LHC and Detector Upgrades

8th Annual Meeting of the Helmholtz Alliance “Physics at the Terascale”
2.12.2014

Susanne Kühn, Albert-Ludwigs-University Freiburg

8th Annual Workshop
1-3 December 2014
DESY, Hamburg

Albert-Ludwigs-Universität Freiburg

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ESF
Chancen fördern
EUROPÄISCHER SOZIALFONDS
IN BADEN-WÜRTTEMBERG

Baden-Württemberg
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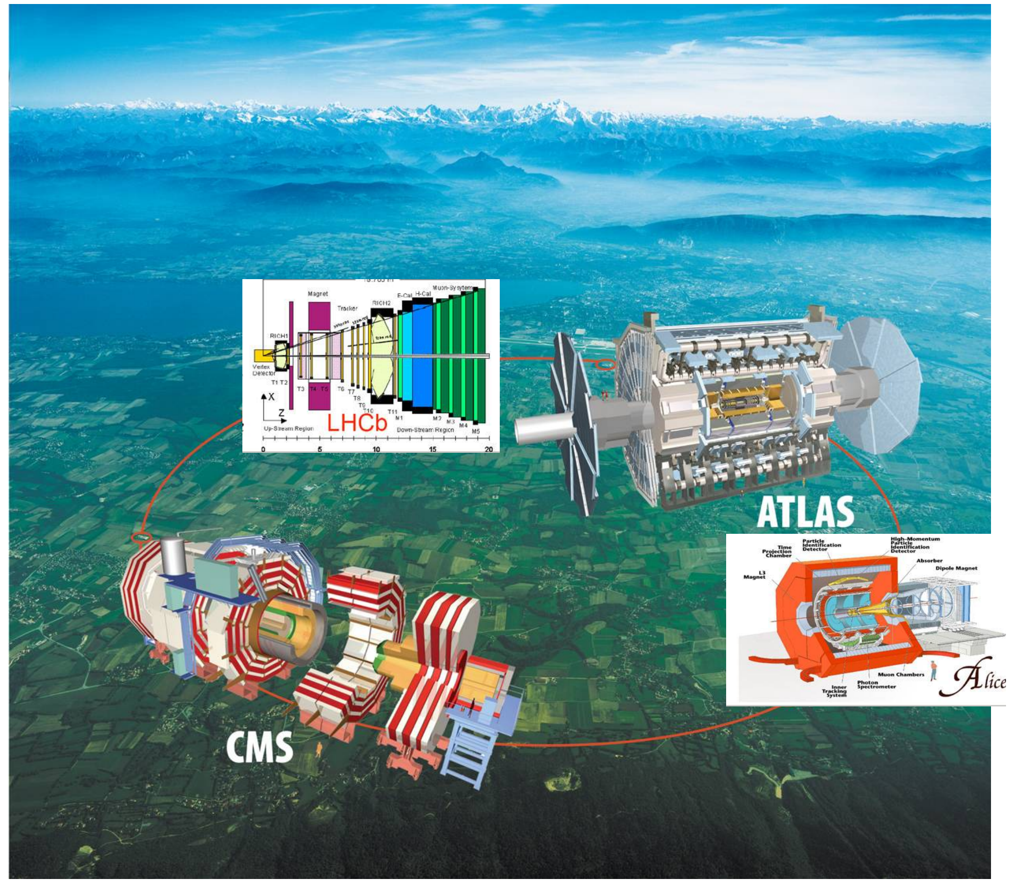
Outline

- Introduction and Motivation for Upgrades
- Schedule and different phases of the Upgrade of the LHC
- Detector Upgrades Phases 0,1,2
- Summary



Selection from broad variety of ongoing developments

Introduction

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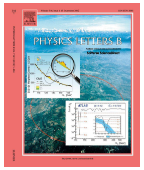
- Successful Run 1: Higgs discovery and plenty of results
- LHC and experiments have an excellent performance
- Recorded data of 5.3 fb^{-1} (7 TeV) and 21.7 fb^{-1} (8 TeV) (CMS, ATLAS), LHCb 3.4 fb^{-1} and ALICE 175 μb^{-1}
- But there is more...



→ **Exploit the physics potential of the LHC and HL-LHC**

- Probing the Higgs sector
- Extending the reach for new physics beyond the Standard Model

The European Strategy for Particle Physics Update 2013

High-priority large-scale scientific

After careful analysis of ... scale scientific activities requiring significant resources, sizeable ... ...med commitment, the following four activities have been identified ... priority.

c) ... iggs boson is the start of a major programme of work to measure this ... with the highest possible precision for testing the validity of the Stand... ...search for further new physics at the energy frontier. The LHC is in a unique posi... ... this programme. *Europe's top priority should be the exploitation of the full potential of ... LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

Report of the Particle Physics Project Prioritization Panel

May 2014

...endation 10: Complete the LHC phase-1 upgrades ... continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project.

From LHC to HL-LHC

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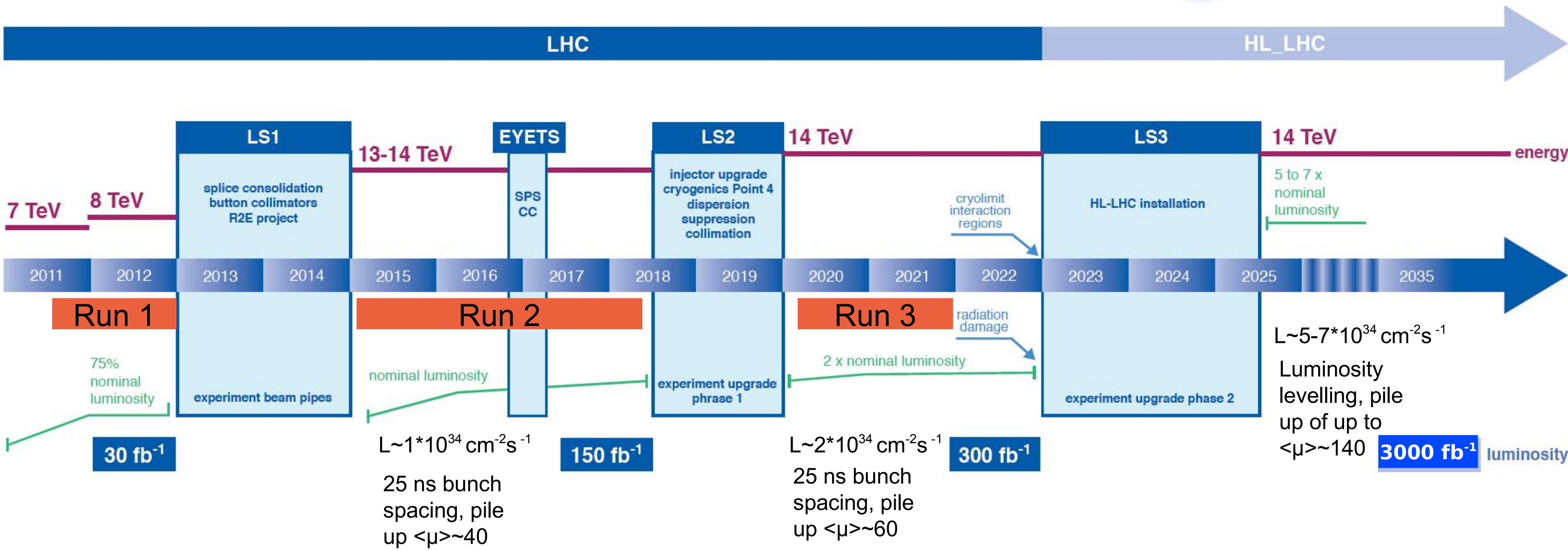
LHC/ HL-LHC Plan (last update 24.09.2014)



From LHC to HL-LHC

Instantaneous luminosity x5 (for ATLAS, CMS, LHCb) → Particle densities x5-10

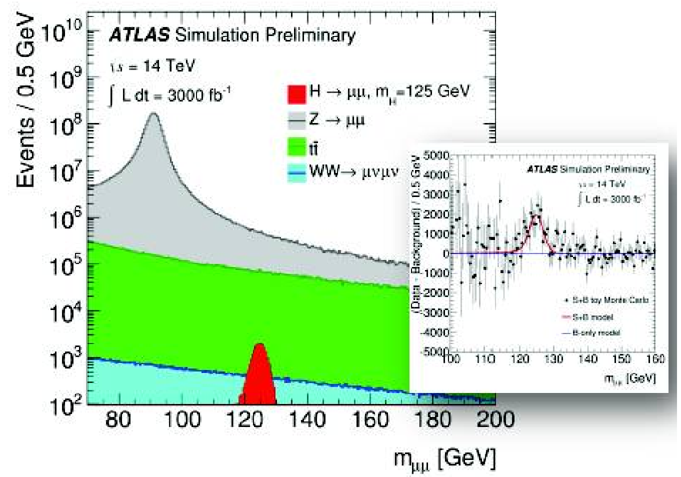
Integrated luminosity x10 (for ATLAS, CMS, LHCb) → Radiation damage x10

Increase of overlap of pp events (pile up x3-5)

Physics of the Higgs Boson

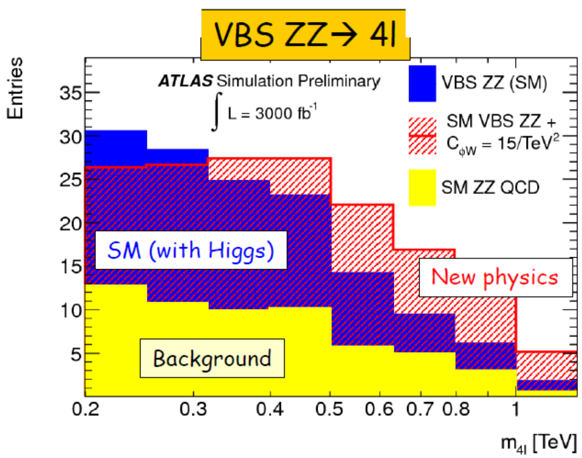
- **Measure as many Higgs couplings** to fermions and bosons as precisely as possible, with 3000 fb^{-1} typical precision 2-10% per experiment (except rare modes), ~1.5-2x better than with 300 fb^{-1}
- **Di-Higgs production** with 3000 fb^{-1} about 1.3 σ significance per experiment (ATLAS,CMS)
- **Measure Higgs self-coupling** (give access to λ)

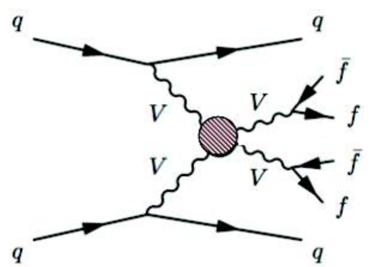
- **Study vector boson scattering (VBS)** with W and Z scattering at high energy (e.g.pp → ZZjj → 4ljj)
Some BSM modules predict enhanced VBS cross-section



With 3000 fb^{-1}:
- H → μμ: > 7 σ significance expected
- Gives access to direct coupling to top quark (mainly ttH → ttγγ)

F. Gianotti, RLIUP, Archamps Oct. 2013





arXiv: 1307.7135
arXiv: 1307.7292

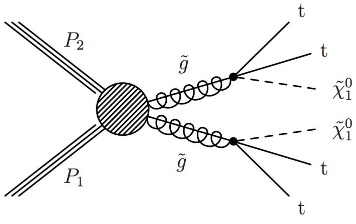
Searches for New Physics

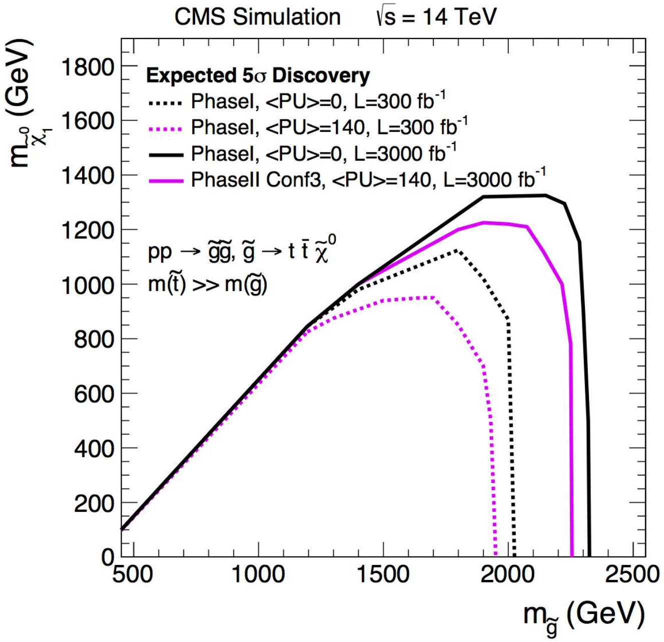
- **Sensitivity to physics beyond the Standard Model:** With 3000 fb^{-1} mass reach can be extended compared to 300 fb^{-1}, depending on scenario.
- Stop mass: Mass reach extends by ~ 200 GeV → most of interesting stop mass range will be covered
- Search for heavy gauge bosons: W', Z': Discovery up to ~6.4 TeV (300 fb^{-1}) and ~ 7.8 TeV (3000 fb^{-1})

arXiv:1307.7135, ATL-PHYS-PUB-2013-003

5σ discovery Simplified model	Run 3 @ 14 TeV (300 fb^{-1})	HL-LHC @ 14 TeV (3000 fb^{-1})
stop mass from direct production [ATLAS]	Up to 1.0 TeV	Up to 1.2 TeV
gluino mass with decay to stop [CMS]	Up to 1.9 TeV	Up to 2.2 TeV

Search for gluinos decaying to top quarks and neutralinos in the single lepton final state CMS PAS FTR-13-2014





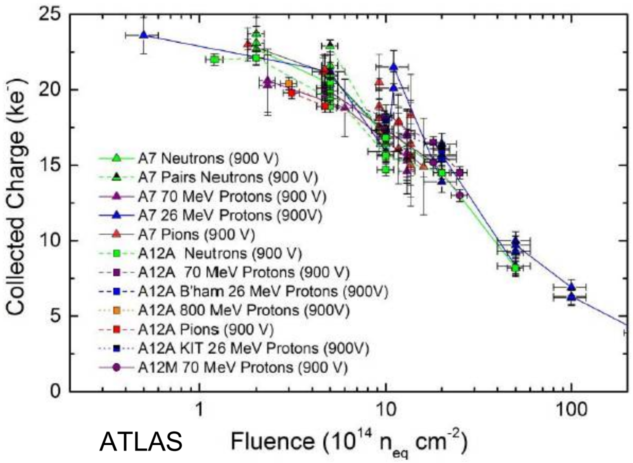
CMS PAS FTR-13-2014

Motivation for Detector Upgrades

Physics aims and HL-LHC environment **challenging for detectors**

- Precise measurement of physics objects: leptons (e, μ, τ-lepton), photons, missing transverse energy, jets, b-(c-)quarks over full p_T range
- Accurate reconstruction of complex event topologies: W/Z, top, VBF
- Keep low-p_T lepton triggers despite high rate
- Radiation damage and high occupancy and pile up

Collected charge of MIP in silicon strip sensors (300 μm thick)



→ Improve, at least maintain performance of present detectors at LHC and HL-LHC

From LHC to HL-LHC

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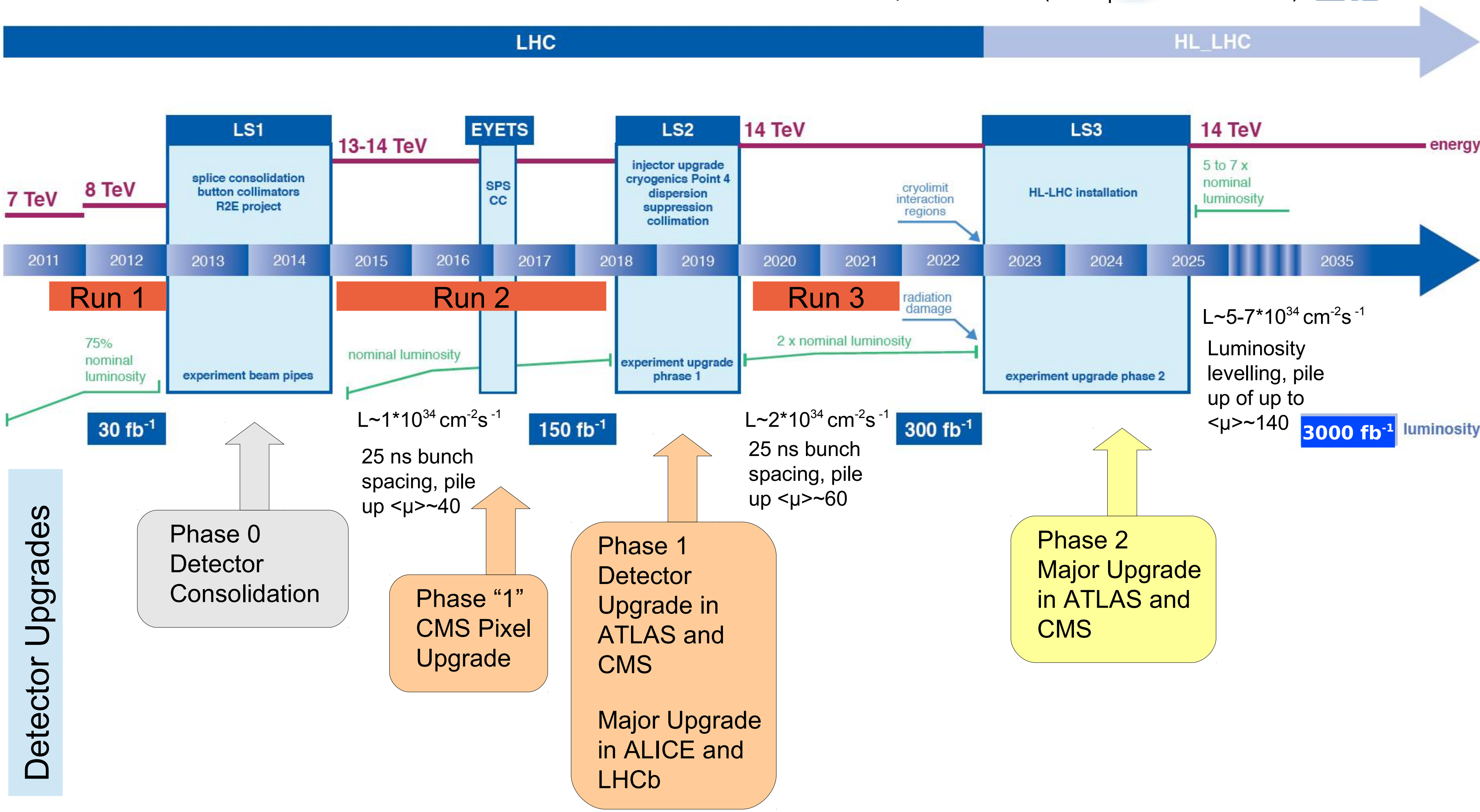
LHC/ HL-LHC Plan (last update 24.09.2014)



Requires right balance between revolutionary approaches and technology evolution, based on physics potential and cost-effectiveness.

LHC Preparation for Run 2

- Preparing for $\sqrt{s}$ = 13 TeV (after 2015 14 TeV) and nominal luminosity ($L \sim 1 \cdot 10^{34}\ cm^{-2}s^{-1}$) with average pile up <μ> ~ 40
- Several optimizations, e.g. consolidation of splices (magnet interconnects), ...

→ Aim for 10 fb^{-1} in 2015

→ PS already running and commissioning with first LHC beam in March 2015

Repair of splices

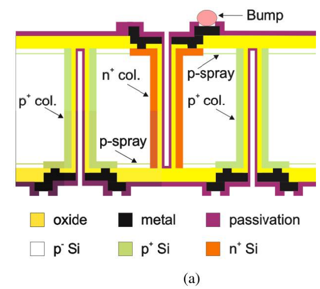
Copper Stabilizer Continuity Measurement (CSCM) to qualify magnet bypass
Status of cooling and test as of 19.11.14

Sector 12	1.9 K	CSCM OK
Sector 23	5 K	CSCM OK
Sector 34	26 K	
Sector 45	20 K	CSCM OK
Sector 56	1.9 K	CSCM OK
Sector 67	1.9 K	CSCM OK
Sector 78	5 K	CSCM OK
Sector 81	1.9 K	CSCM OK

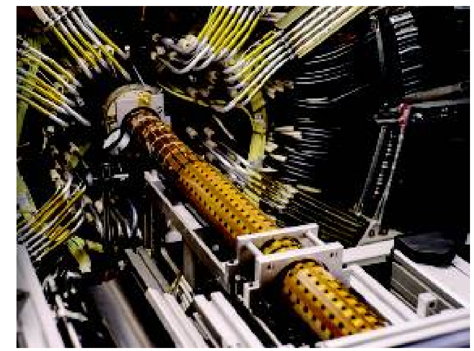
M. Lamont

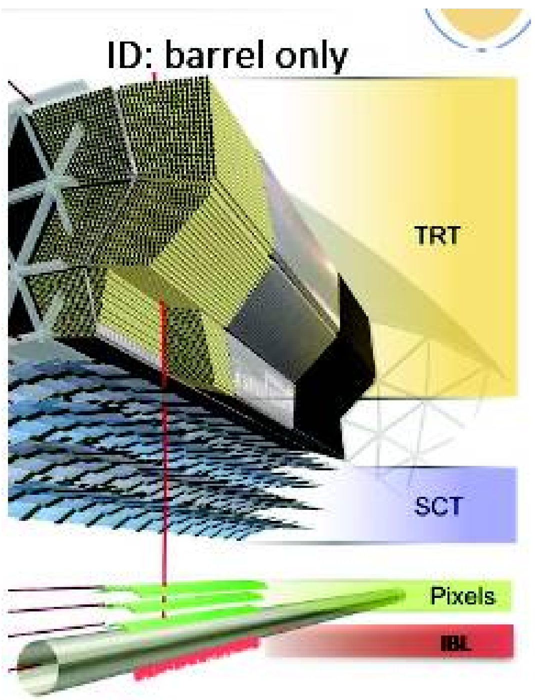
ATLAS Insertable b-layer for Run 2

- Additional 4th pixel layer
- Close to interaction point (33 mm)
- 75% planar n-in-n sensors and 25% 3D sensors, radiation tolerance $\Phi \sim 5 \cdot 10^{15}$ Neq cm^{-2}
- Significant improvement of tracking, impact parameter resolution, vertexing object-ID



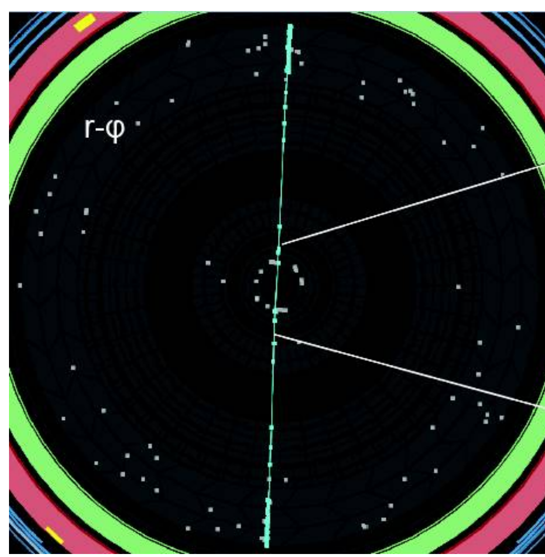
3D sensor

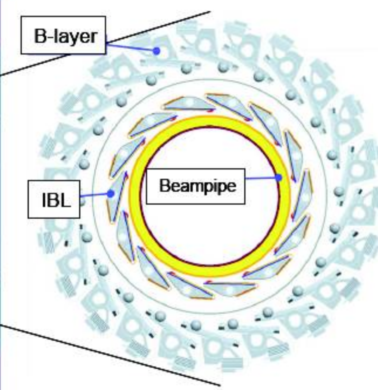




CERN-LHCC-2010-013

Cosmics data taking shows track reconstruction working





Commissioning ongoing

CMS Detector Preparation for Run 2

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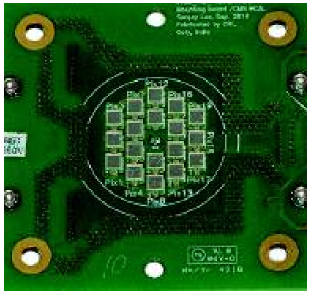
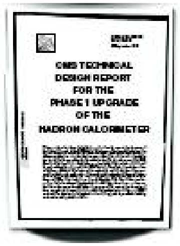
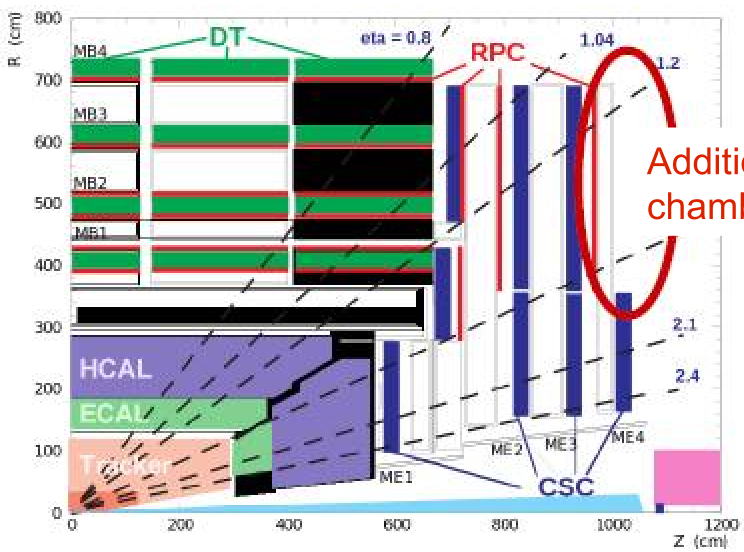
- Started to replace calorimeter readout, planned to finish in 2016
  - Photo-detectors in HCAL
  - New PMTs in forward calorimeter
  - Change HPD with SiPMs in outer calo.



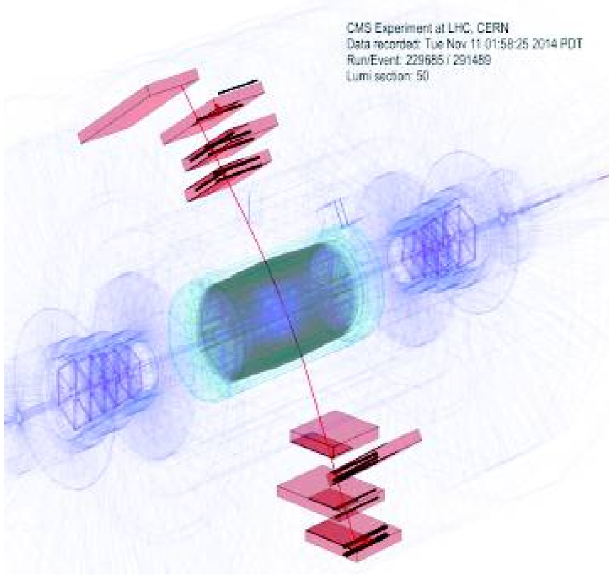
SiPM board with 3x3 mm² SiPMs



- Completion of forward muon system
  → 2% increase in ID efficiency



Successful system test with magnet on in Nov. '14



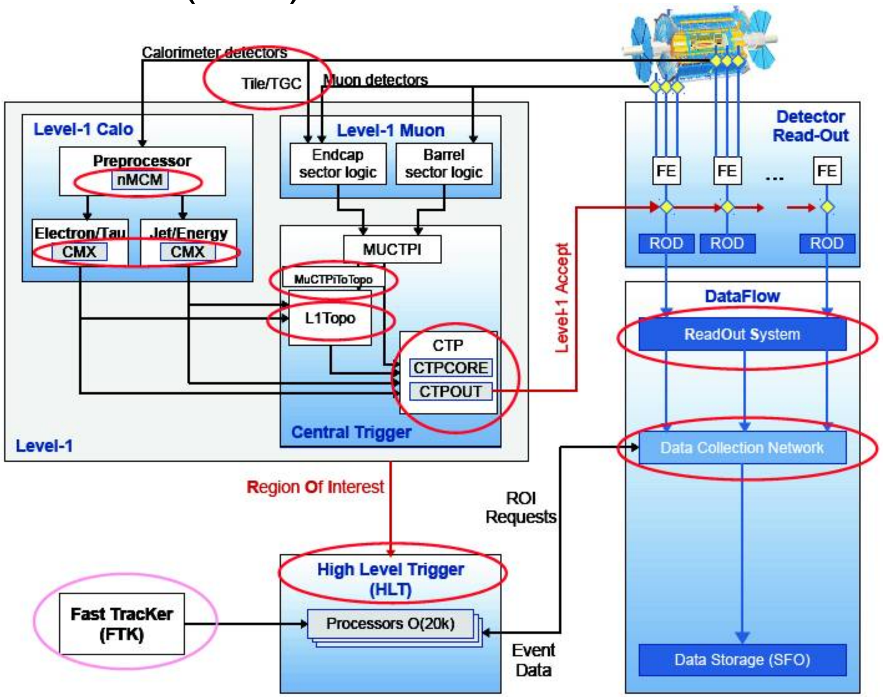
Triggering in ATLAS and CMS in Run 2

Triggering is modified in ATLAS and CMS for Run 2

- Additional flexibility and more selectivity

ATLAS

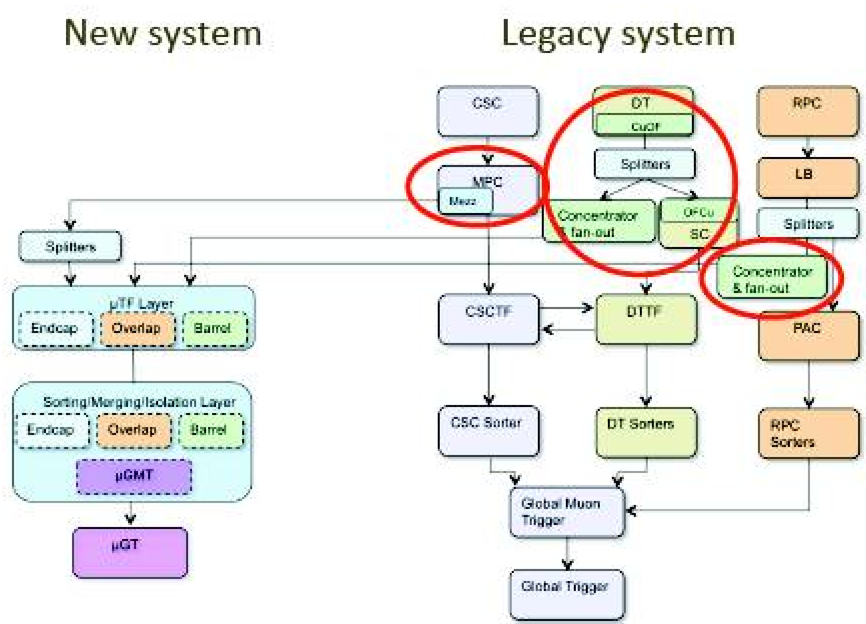
- Many hardware and software improvements
- Rates increased to 100 kHz (L1), 1 kHz (HLT)



O. Igonkina 120th LHCC meeting

CMS

- New structure for L1 calo and L1 muon, replacement until 2016
- HLT new iterative tracking, rate 1 kHz
- Build and commissioning in parallel with current system



S. Goy Lopez 120th LHCC meeting

LHCb Detector Preparation for Run 2

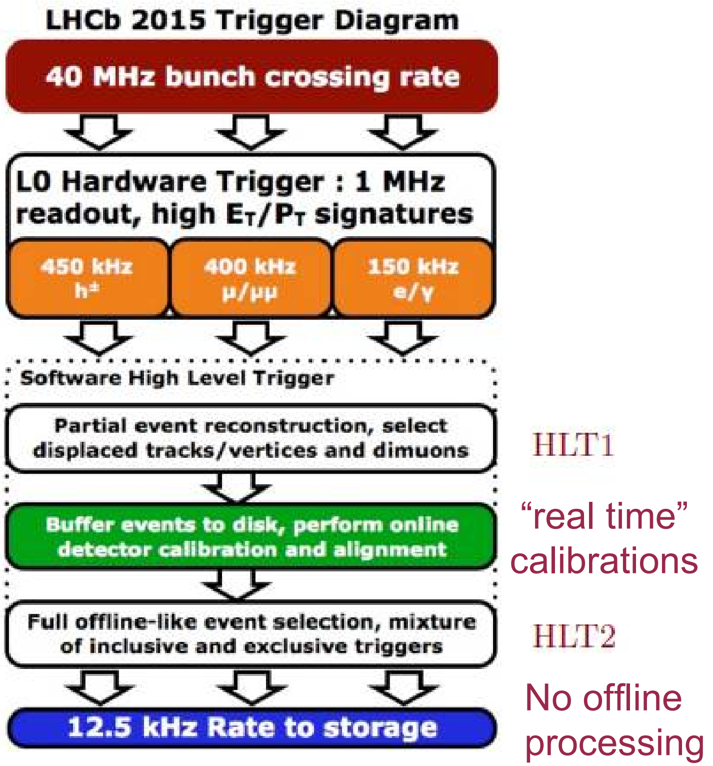
Physics:

- Study CP violation and rare decays in b- and c-quark sector
- Search for deviations of SM due to virtual contributions of new heavy particles

→ Complementary approach to search for New Physics

→ Requires high precision measurements and high statistics

- New control room
- Maintenance of photo-detectors of RICH
- Trigger upgrade: defer trigger to HLT instead of L0



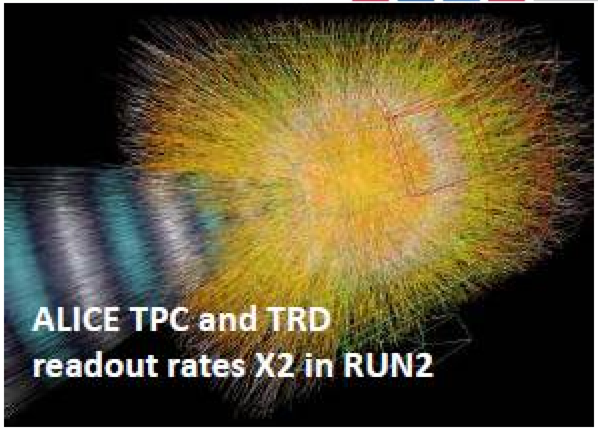
In Run 2 many more results expected: $L \sim 4 \cdot 10^{33}\ cm^{-2}s^{-1}$ about 4 times design lumi, collect ~8 fb^{-1}

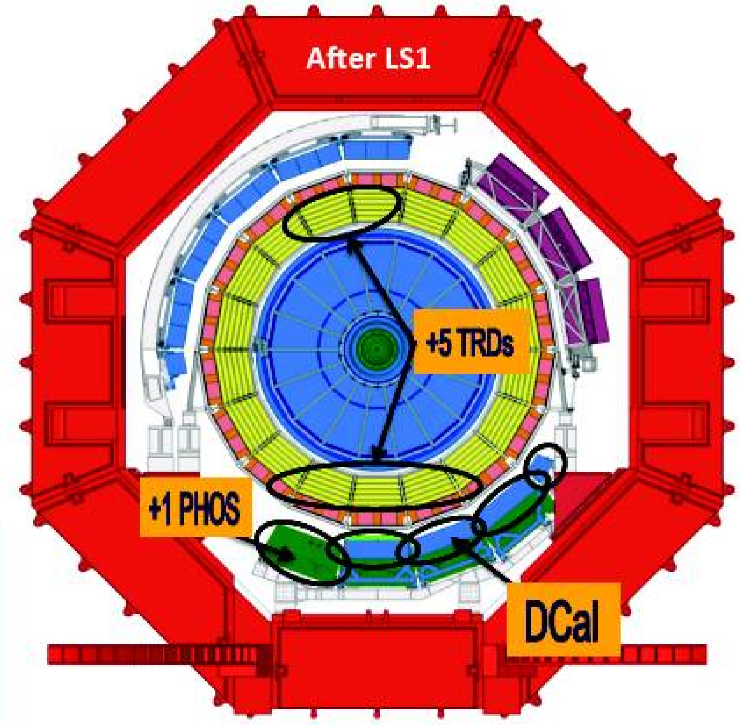
ALICE Detector Preparation for Run 2

Phase 0 Upgrade – Run 2

Physics:

- Heavy ion collisions produce a complex system of strongly interacting matter → Quark Gluon Plasma
- Study its properties using light hadrons, heavy-flavor, jets, photons, …





- Increase of trigger capability: upgrade detectors' readout firmware and software
- Di-Jet Calorimeter (DCAL) installed to allow back-to-back calorimetry

In Run 2:
$\sqrt{s}$ =5.1 TeV
L~10^{29}-10^{32} $cm^{-2}s^{-1}$
collect ~0.5 nb^{-1}

Phase 0 – Run 2

All experiments in LS 1:

- Detector consolidation performed
- Last installations and re-commissioning ongoing
- Preparing for challenge of triggering all interesting events in Run 2

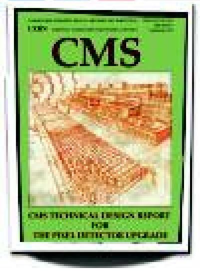
Looking forward to new results at $\sqrt{s}$ = 13 TeV (14 TeV)

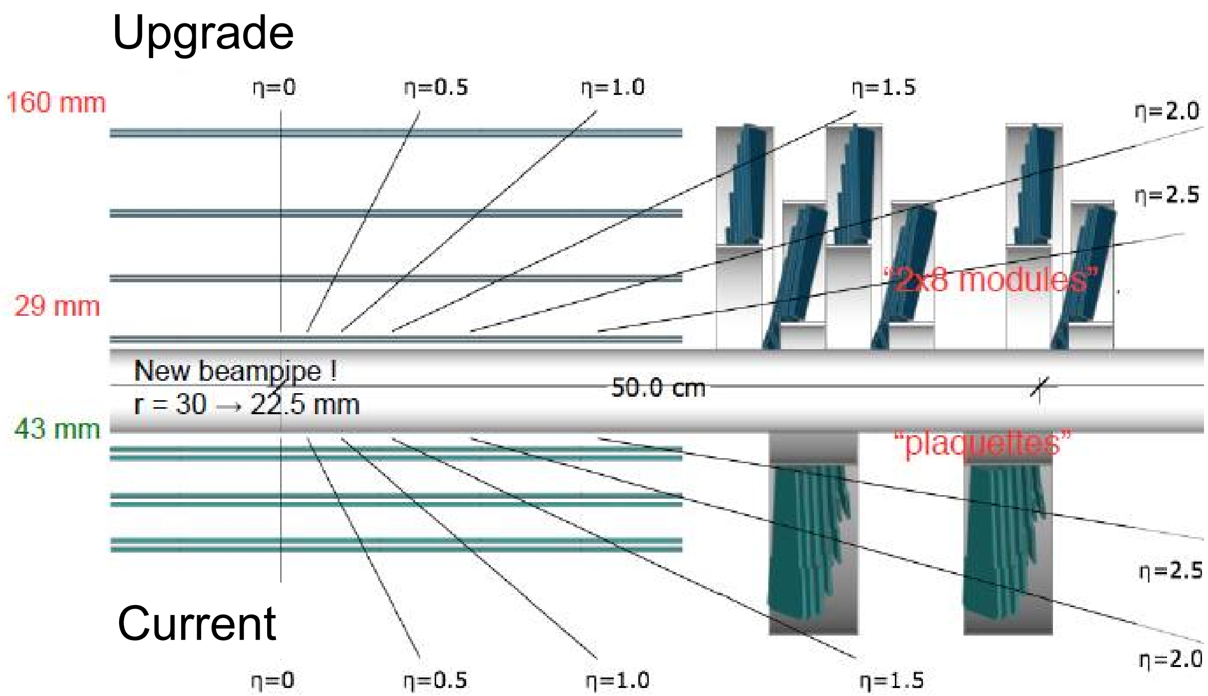
In parallel preparation for Phase 1 and Phase 2 also in full swing

CMS Upgrade in Run 2

During Run 2

- New **pixel detector** in extended end-of-year technical stop 2016

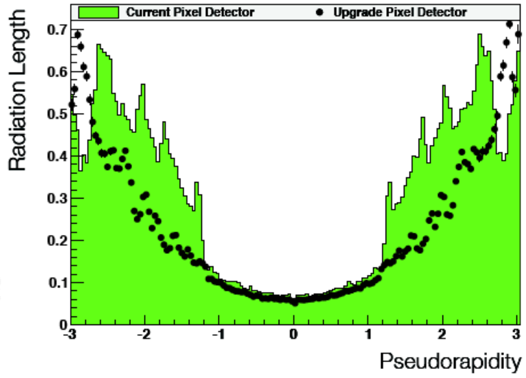




- 4 layers, 3 disks
- N^+-in-n 100x150 μm² pixel
- New readout chip
- DC-DC powering
- To survive $L_{int} = 500\ fb^{-1}$

  <μ> ~ 100
- CO_2 cooling

Expected material



16 ROCs, 66'560 pixel, 10 cm², 0.7% X_0
BPIX: 1184 Modules
FPIX: 672
PIX 1856 = 1.95 m²

CERN-LHCC-2012-015

From LHC to HL-LHC

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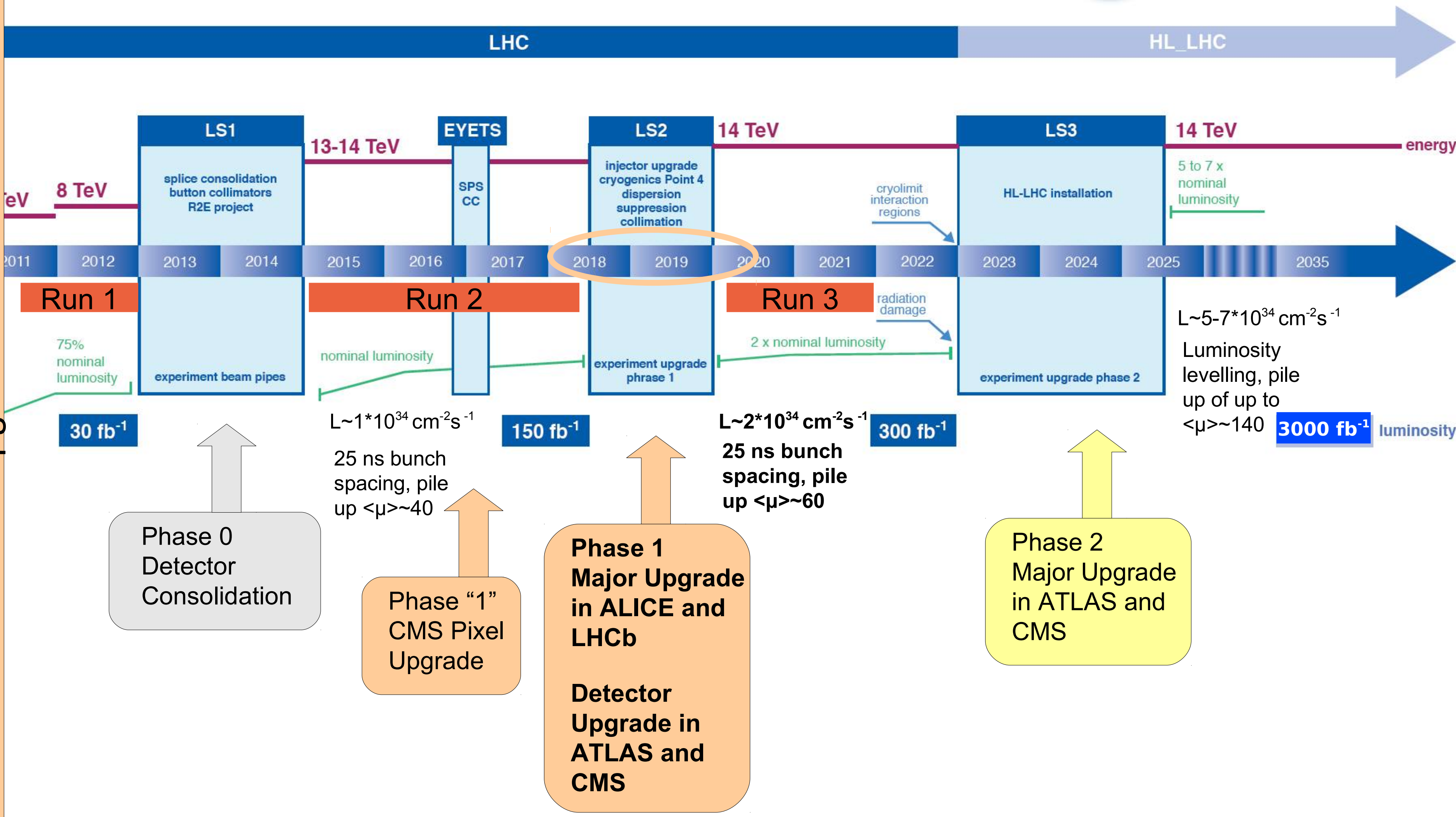
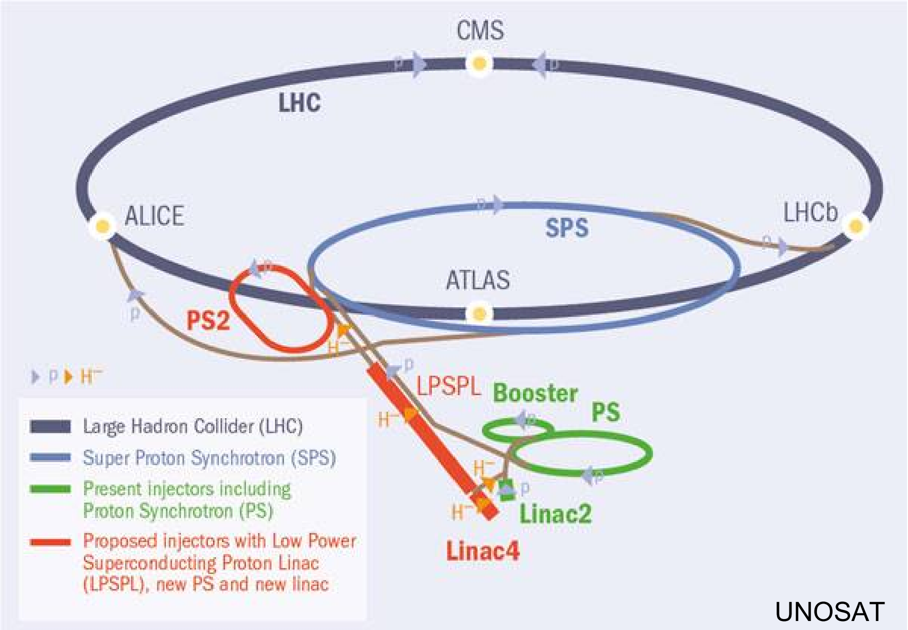
Phase 1 Upgrade – Run 3

LHC/ HL-LHC Plan (last update 24.09.2014)



LHC Phase 1 Upgrade for Run 3

- Shutdown for 18 months
- $L \sim 2 \cdot 10^{34}\ cm^{-2}s^{-1}$, 25 ns bunch spacing, pile up <μ>~60
- LHC Injector Upgrade (LIU) Project
  - LINAC4 H^- injection
  - Increase of PS Booster injection energy from 50 MeV to 160 MeV by new power converters and new cavities
  - Increase of PS injection energy from 1.4 GeV to 2 GeV and new RF collimation and system
  - SPS: modification to main RF system, electron cloud reduction



UNOSAT

ALICE Phase 1 Upgrade

Phase 1 Upgrade – Run 3

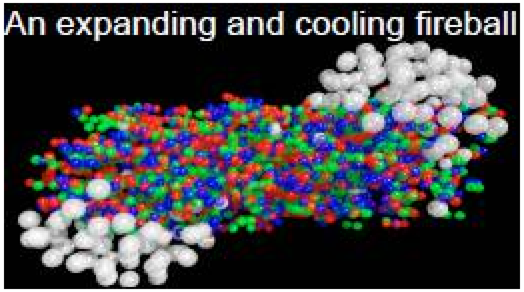
LHC heavy ion programme extended to Run 3 and 4

→ Gain factor 100 over statistics of approved programme, target L ≥10 nb^{-1} Pb-Pb minimum bias + pp data

→ Several processes can't be triggered, a lot of data needed

→ Operate ALICE at a high rate: from 3 kHz → 50 kHz Pb-Pb continuous

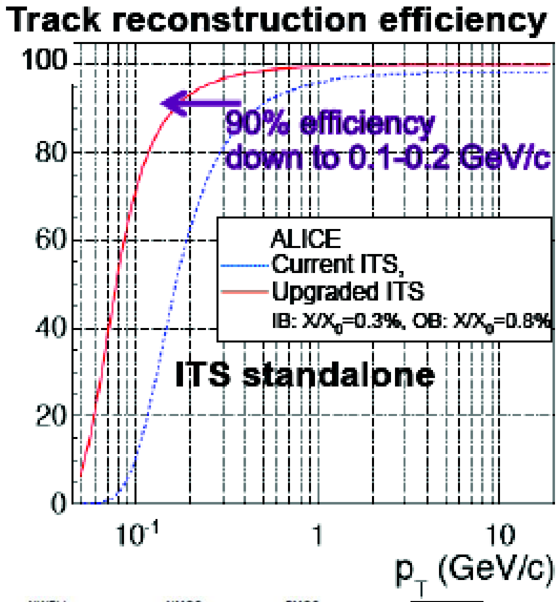
→ New pixel detector, new readout for TPC, TOF, TRD, new muon forward detectors, DAQ/HLT

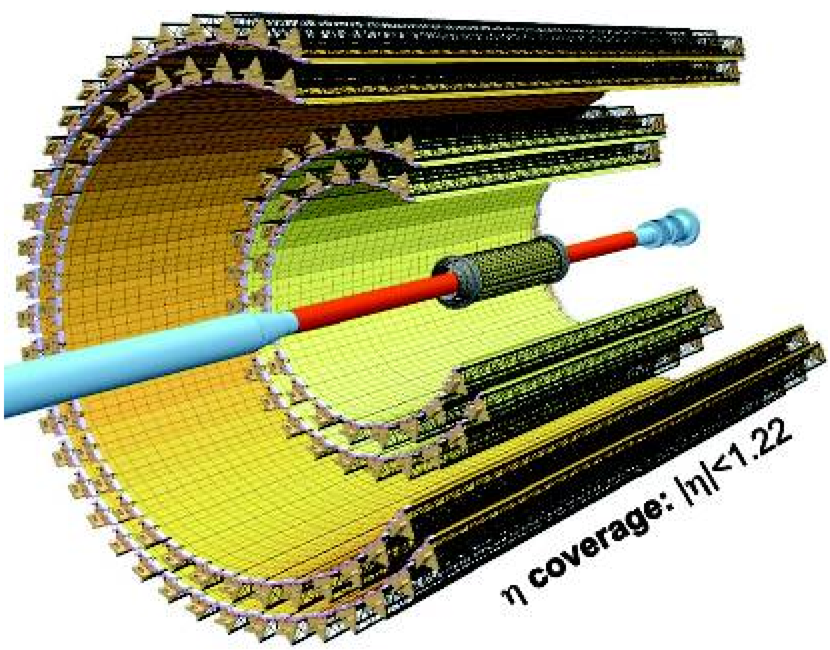


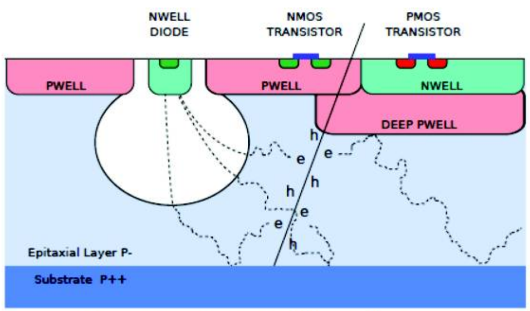
TPC, TRD, HLT

ALICE Phase 1 Upgrade: ITS

- 3 inner (0.3%X_0), 4 outer layers (0.8%X_0)
- Use 50 µm thick monolithic pixel sensors (MAPS)
- Faster readout (x50)
- Increased granularity → improved impact parameter resolution by a factor ~3 (5) in rφ (z)







Schematic cross-section of CMOS pixel sensor
(ALICE ITS Upgrade TDR)

Large CMOS detector

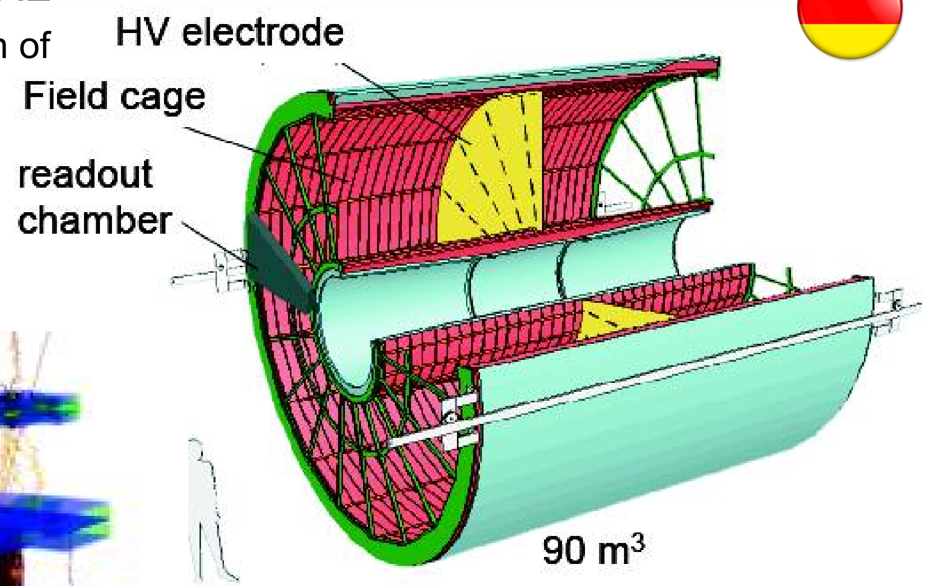
MAPS: integrated sensor & electronics using standard CMOS process (180nm 6-layer TowerJazz), 10.3 m² and 25 G-pixel 25x25 µm² size, 50 µm thick, max. dose $\Phi \sim 1*10^{13}$ Neq cm^{-2}

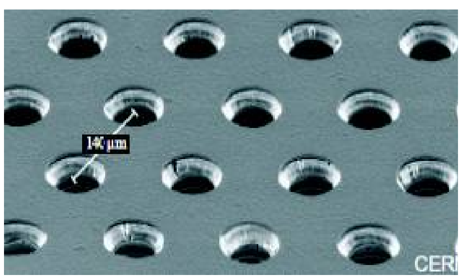
Same technology for muon tracker upgrade

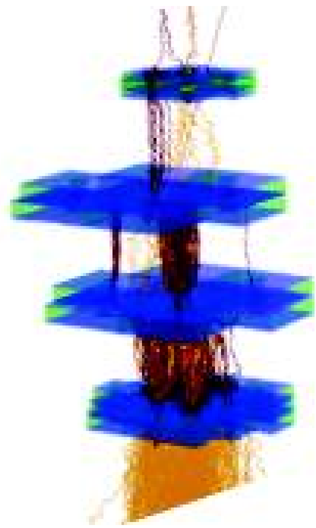
ALICE Phase 1 Upgrade: TPC

Current readout (MWPC) limit rate to 3.5 kHz (ungated readout leads to ion cumulation and distortion of electron drift) but 50 kHz wanted

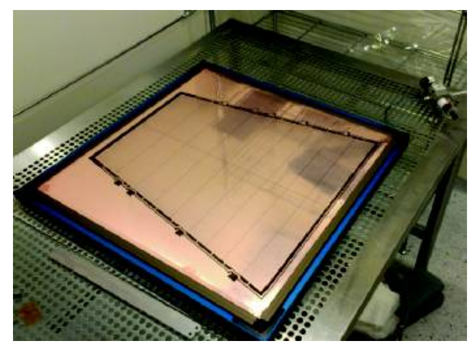
→ Replace readout with **GEMs Gas Electron Multipliers** and new electronics, same field cage





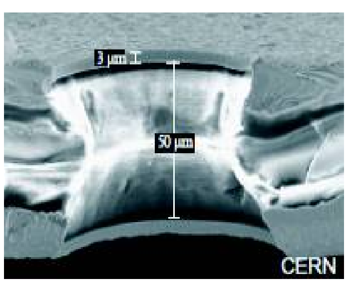


Stack of 4 foils



Foil prototype

GEM holes:
Diam: 70 µm
Distance:
90-280 µm

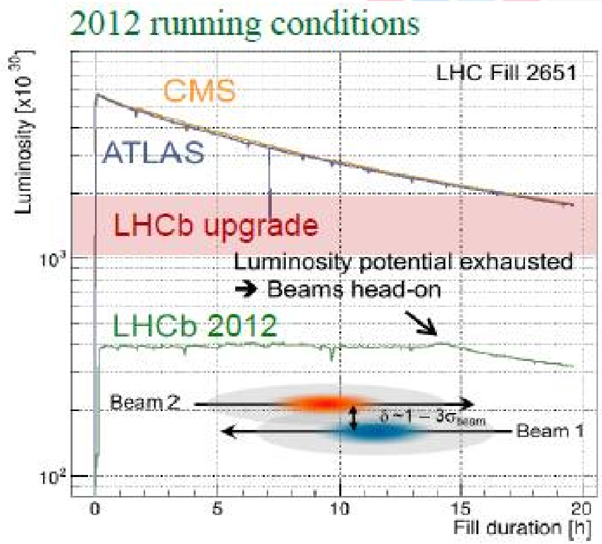


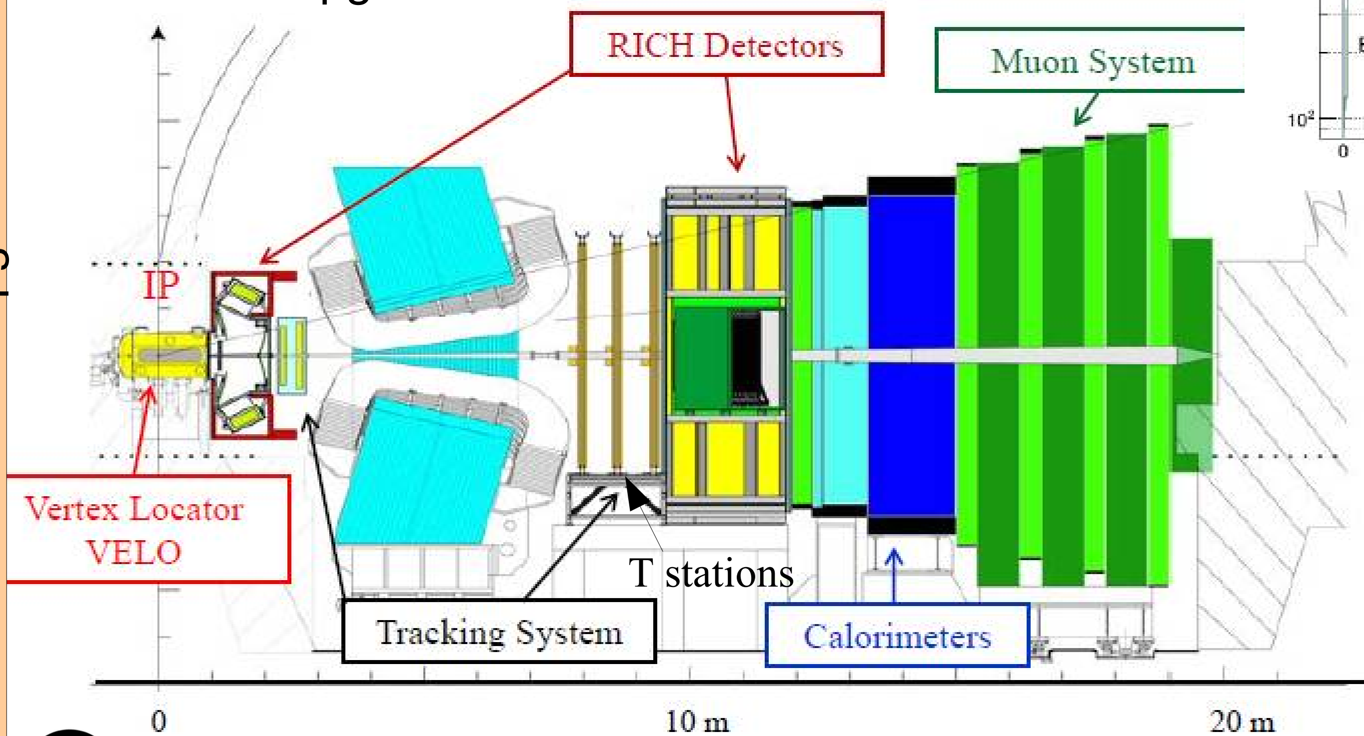
GEM foil

First time large area foils

LHCb Phase 1 Upgrade

- Increase levelled luminosity up to $L \sim 2 \cdot 10^{33}\,cm^{-2}s^{-1}$ to reach 8 fb^{-1}/year
- Trigger up to 40 MHz, record 20-100 kHz
  → full software trigger, upgrade TDAQ and replacement of all front-end electronics and tracker upgrade





→ general purpose detector in forward region

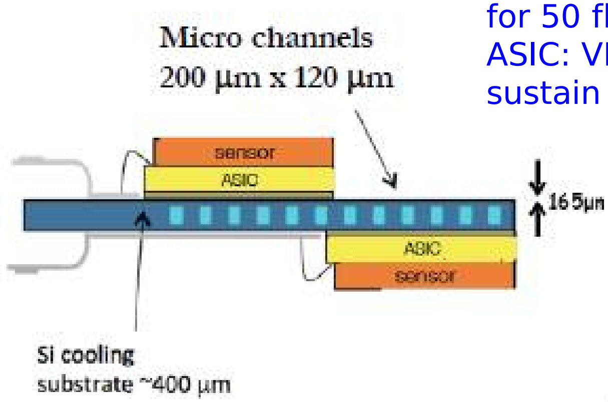
Fibre Tracker

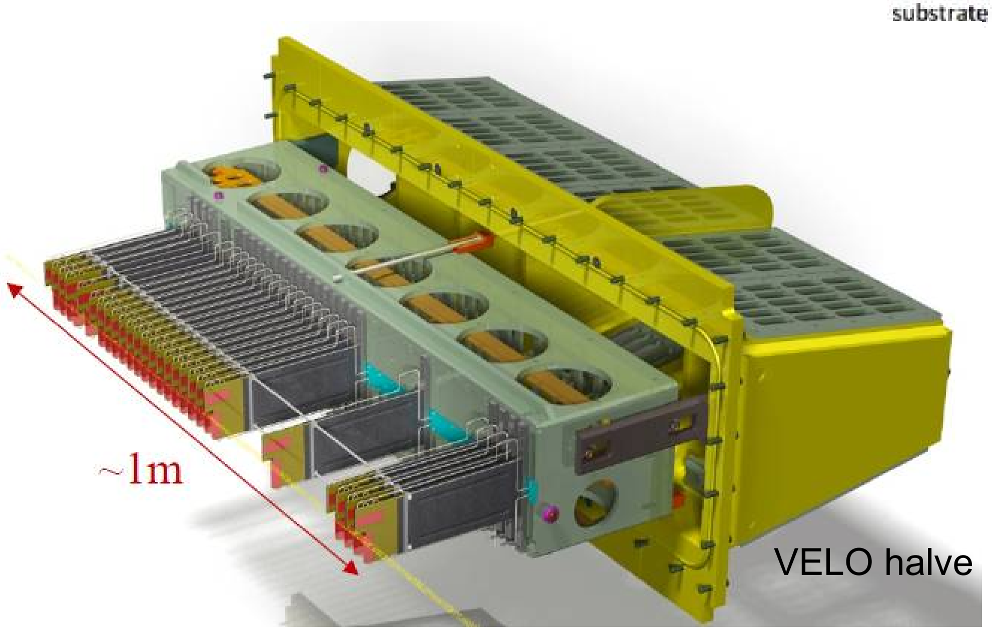
CERN-LHCC-2011-001, CERN-LHCC-2012-007, CERN-LHCC-2013-021, CERN-LHCC-2014-001

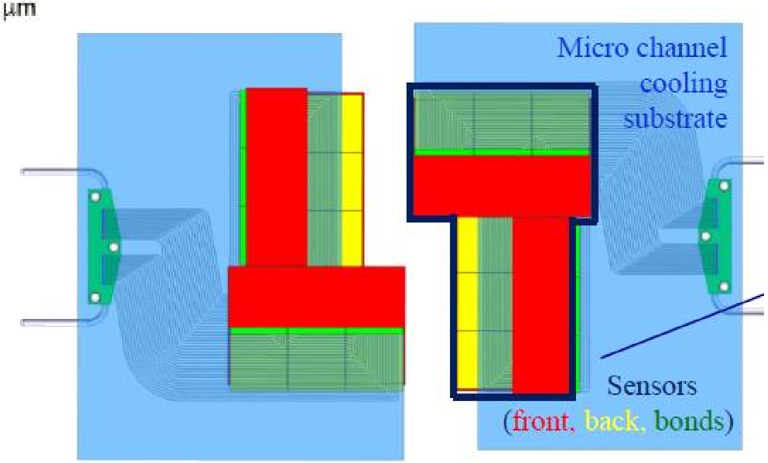
LHCb Phase 1 Upgrade: VELO

- From strips → L-shaped modules of hybrid silicon pixel detectors
- Micro channel CO_2 cooling
- Thinner RF-foil between sensor and LHC vacuum
- Closer to beam (35 mm)

PIXELS: 50x50 µm²
max. dose $\Phi \sim 8*10^{15}$ Neq cm^{-2} for 50 fb^{-1}
ASIC: VELOPIX 130 nm
sustain ~400 Mrad





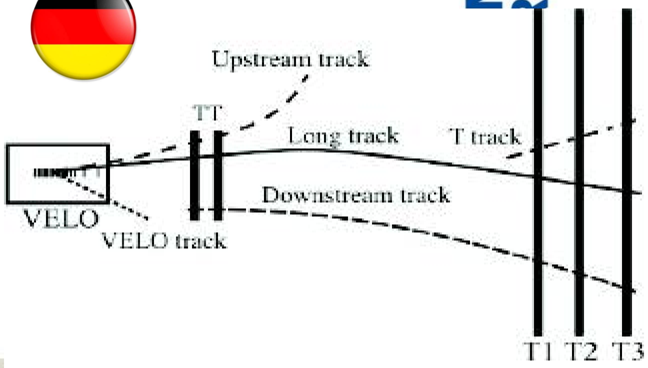


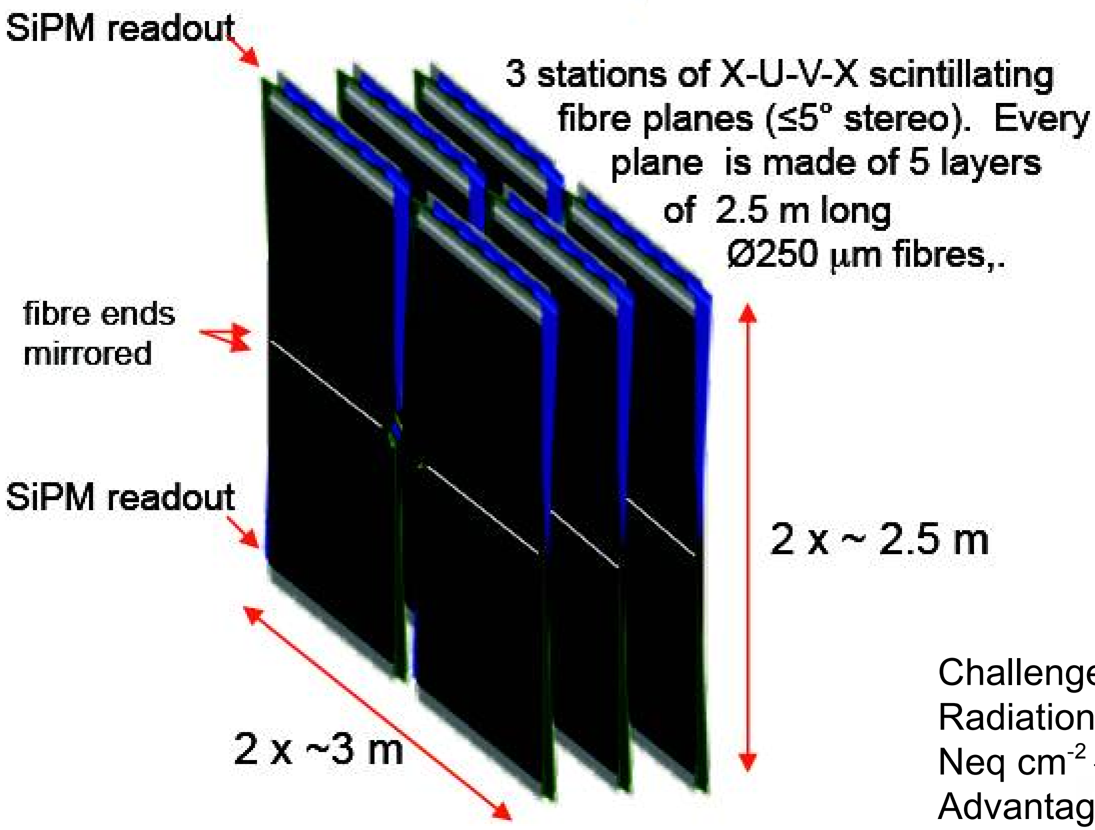
Sketch of two modules

First use of micro channel cooling in experiment

LHCb Phase 1 Upgrade: Tracker

Replacement of downstream tracker (T stations):
straw drift tubes → scintillation fibre tracker





Sci. fibre mat (5 layers),
O(8000 km) fibres

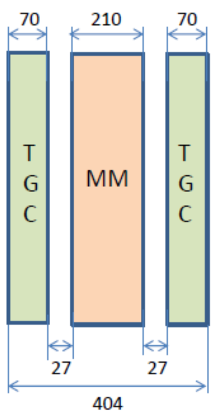
Challenge:
Radiation damage to SiPMs up to dose of $1 \cdot 10^{11}$ Neq cm^{-2} → operated at - 40 °C
Advantages:
- fast, uniform material budget
- fine granularity (50-75 μm resolution in x)

ATLAS Phase 1 Upgrade: Muon System

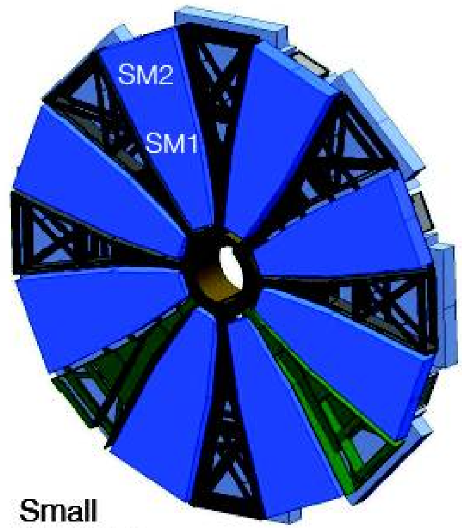
- Improved muon tracking for |η| > 1.3
- Reduce fake rates and keep precision at high rates

→ New Small Wheels

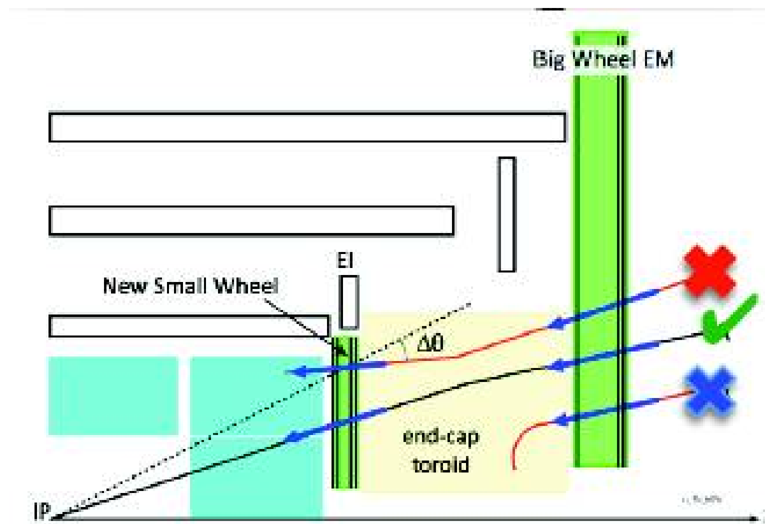
CERN-LHCC-2013-006



Sketch of chamber



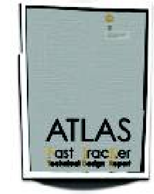
Small Modules



- Micromegas:
  ~1200 m² for precision tracking, high rate capable
- Small-strip thin gap chambers:
  ~1200 m² for triggering, bunch ID will give good timing, proven technology
  - Space resolution < 100 μm

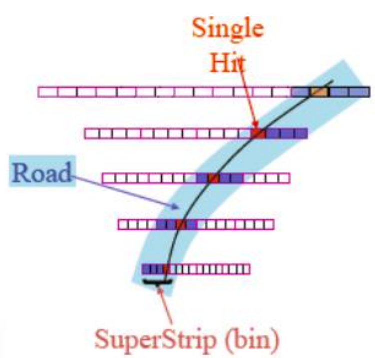
ATLAS Phase 1 Upgrade: FTK

- Fast Track trigger at L1.5
  - Hardware based trigger to allow rapid pattern recognition using inner tracker (FPGA fitting: 1 fit/ns)
  - Input to HLT
  - Installation started, to finish in 2018

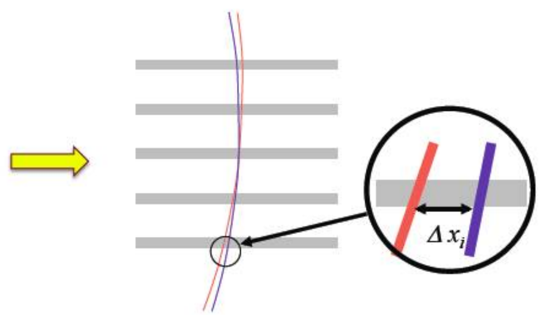


CERN-LHCC-2013-007

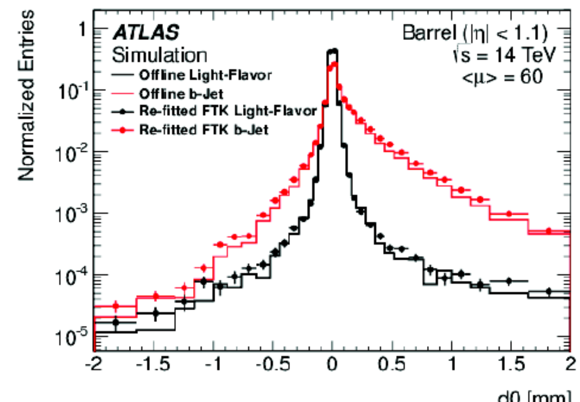
Using associative memory ASIC



Pattern recognition in coarse resolution (superstrip→road)



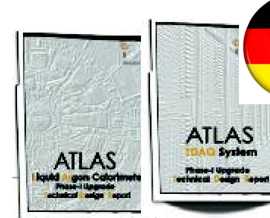
Track fit in full resolution (hits in a road)
$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$



Light jet rejection using FTK compared to offline reconstruction

c-tagging: offline ~ online precision

- Upgrade of trigger back-end electronics & TDAQ
- New front-end in LAr calorimeter + possibly forward physics (AFP)



CERN-LHCC-2013-017, CERN-LHCC-2013-018

Phase 1 – Run 3

Experiments in LS 2:

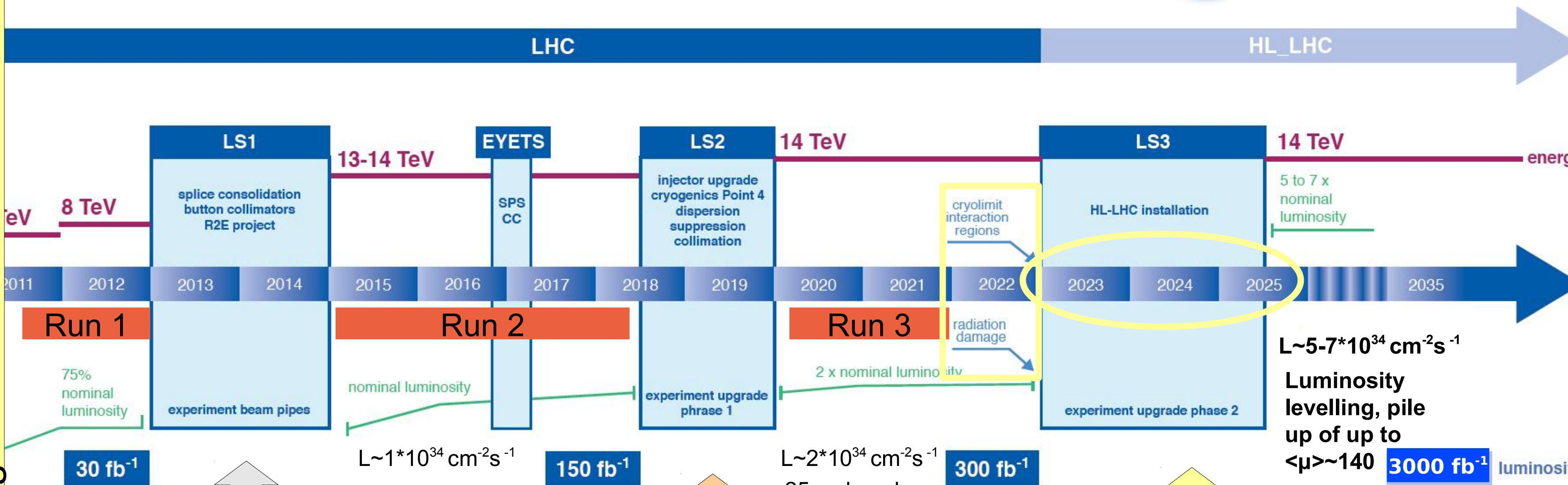
- Major upgrade of LHCb and ALICE: new tracking systems (+ CMS Pixel tracker)
- ATLAS + CMS (all upgrades compatible with Phase 2 upgrades)
  - Increase granularity for calorimeters: new electronics
  - Partial upgrade of muon systems
- All experiments improve bandwidth and processing for triggering
  - Data handling and computing not to forget!

From LHC to HL-LHC

Albert-Ludwigs-Universität Freiburg

Phase 2 Upgrade – Run 4+

LHC/ HL-LHC Plan (last update 24.09.2014)



$L \sim 1*10^{34}\ cm^{-2}s^{-1}$

25 ns bunch spacing, pile up <μ>~40

$L \sim 2*10^{34}\ cm^{-2}s^{-1}$

25 ns bunch spacing, pile up <μ>~60

$L \sim 5\text{-}7*10^{34}\ cm^{-2}s^{-1}$

Luminosity levelling, pile up of up to <μ>~140

Phase 0 Detector Consolidation

Phase "1" CMS Pixel Upgrade

Phase 1 Detector Upgrade in ATLAS and CMS

Major Upgrade in ALICE and LHCb

Phase 2 Major Upgrade in ATLAS and CMS

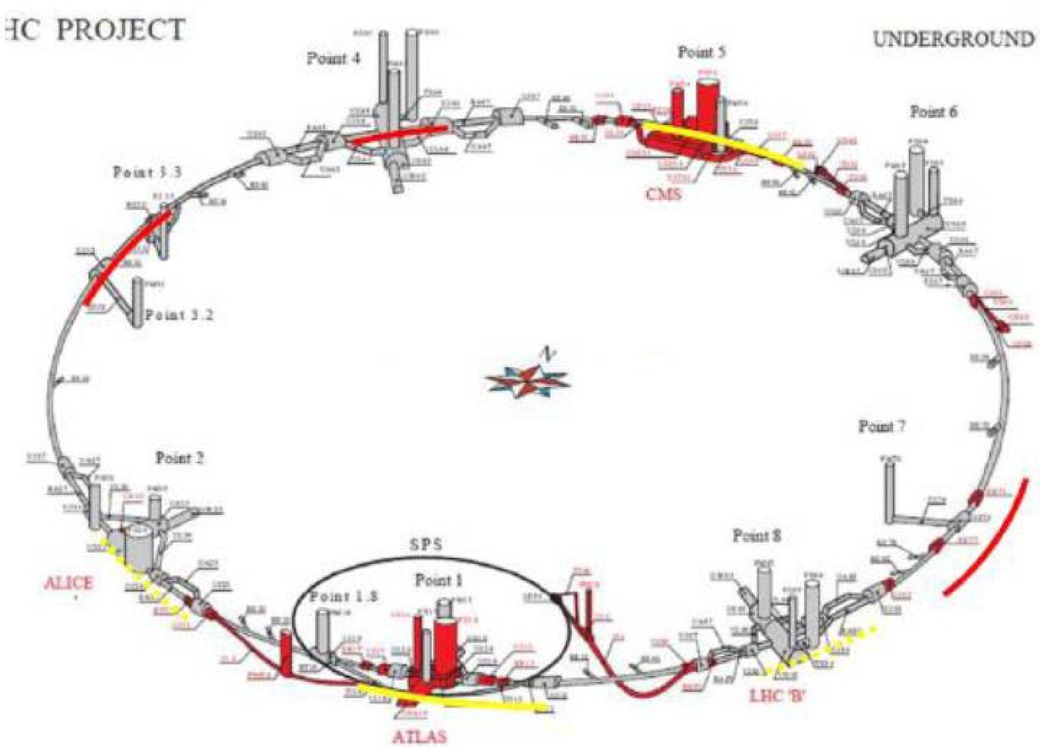
ALICE and LHCb run already in Run 2 with all data collection rate LHCb at twice its design luminosity

HL-LHC for Run 4+

O. Brüning, ECFA HL-LHC Aix-les-Bains Oct. 2014

- Shutdown of 30 months
- Aim for maximal luminosity of 3000 fb $^{-1}$

$$L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \epsilon_n \beta^*} F \qquad F = 1/\sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

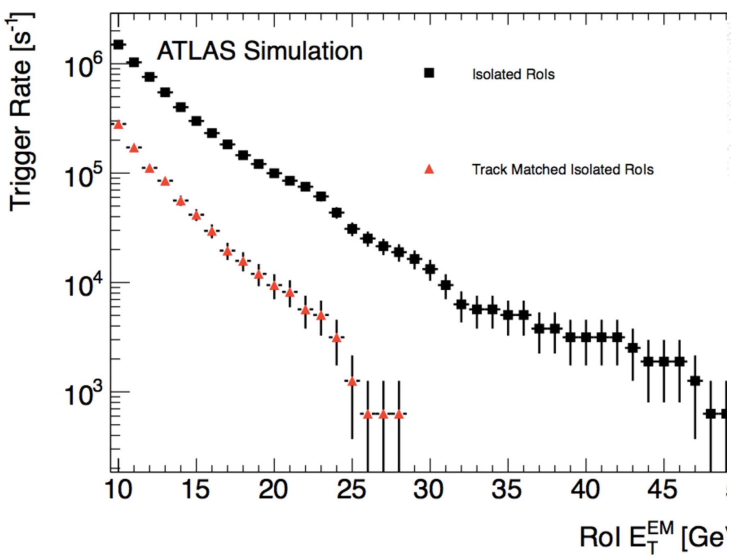


- Cryogenic system upgrade
- New large aperture triplet magnets (Nb_3Sn)
- New 11 T insertion magnets (NbTi)
- Crab Cavities
- Collimation upgrade
- Machine protection
- ...

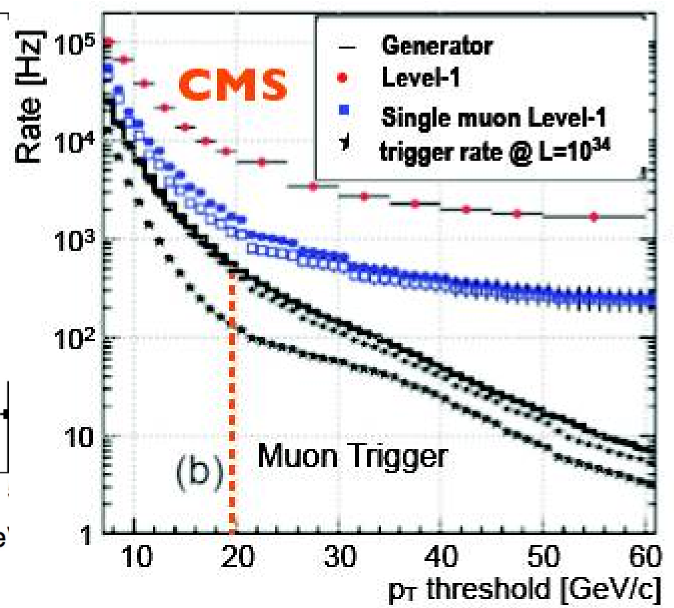
Major intervention on more than 1.2 km of the LHC

Triggering at the HL-LHC

- High luminosity → many interesting events
- High pile up and occupancy lead to decrease in resolution at trigger level
- Aim to keep low-p_T lepton triggers (~20-25 GeV)
  - → Matching tracking information to muon and calorimeter information
  - → Exploiting isolation for electron and tau identification and veto for photons



Single electron trigger rate @ 1E34 for <μ> ~ 140



Single muon trigger rate @ 1E34 for <μ> ~ 140

No track trigger

With track trigger

Phase 2 Detector Upgrade: ATLAS + CMS

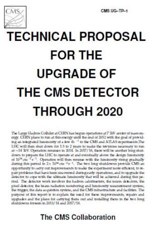
Tracking detector:
New all silicon tracking detectors
ATLAS: Possibly extended coverage in forward region
CMS: Extended coverage to $|\eta| < 4$

Calorimetry:
ATLAS: New FE electronics for Tile and LAr calorimeter and potential replacement of forward calorimeter
CMS: Replace endcaps and replace electronics

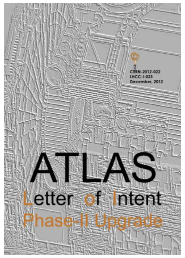
Muon system:
ATLAS: New FE electronics and possible upgrade of muon spectrometer
CMS: Extend forward chambers and replace electronics

Trigger/DAQ:
Upgrades, add tracking at L1, partially new electronics

CMS: Shielding/beampipe for higher aperture


TECHNICAL PROPOSAL
FOR THE
UPGRADE OF
THE CMS DETECTOR
THROUGH 2020

The CMS Collaboration



ATLAS: LHCC-I-023, CERN-LHCC-2012-022

CMS: Technical preparation in preparation, LHCC-2011-006, LHCC-P-004

Upgrade Phase 2 Tracker

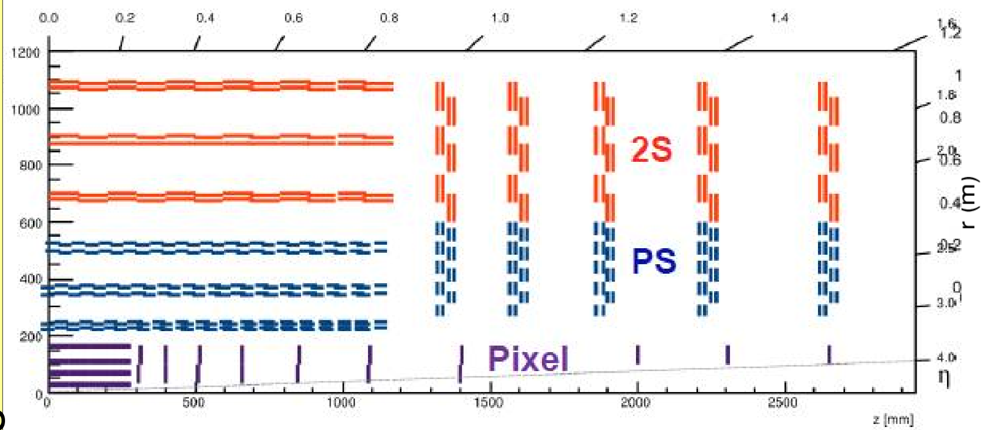
Albert-Ludwigs-Universität Freiburg

Phase 2 Upgrade – Run 4+

Installation of new trackers due to radiation damage of current ones

Fluences of up to $2*10^{16}$ Neq/cm^2

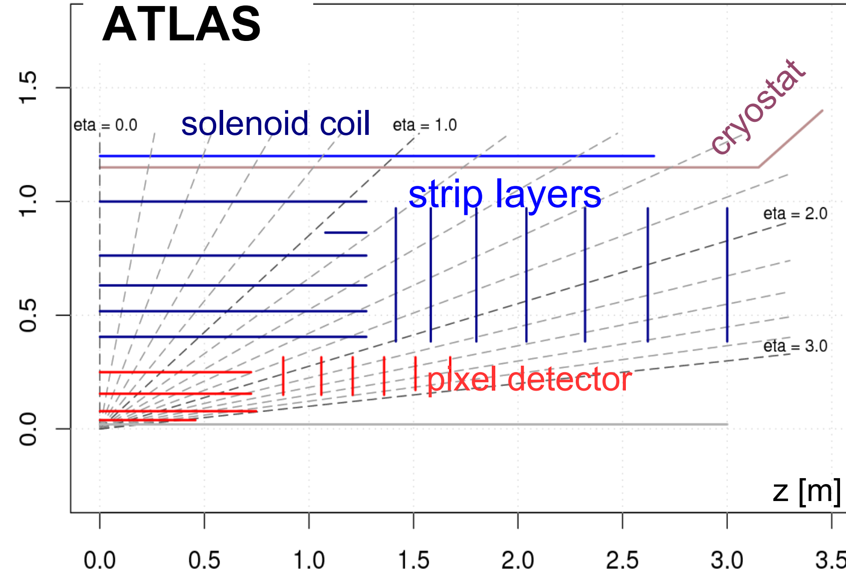
CMS



Detector	Area [m²]	Layers (B+EC)
CMS Pixel	4.6	4 + 10
CMS Outer	218	6 + 5

- Keep occupancy at %-level and resolve vertices → high granularity, many channels, power consumption to concern
- Improve performance at high p_T → smaller pitch
- Improve low-p_T tracking → reduce material budget

ATLAS



Detector	Area [m²]	Layers (B+EC)
ATLAS Pixel	8.2	4 + 6
ATLAS Strip	193	5.1 + 7

Deploy

- Fast data transmission with low power giga-bit transmitter
- CO_2 cooling (thinner pipes)

Phase 2 Outer Tracker CMS

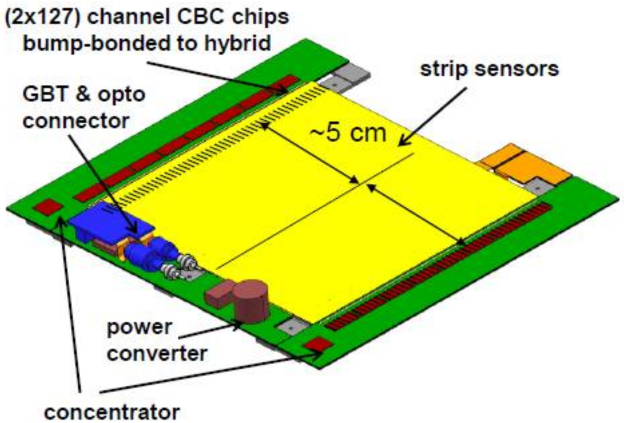
- 2 types of 200 µm thick n-in-p silicon modules, p_T-discriminating

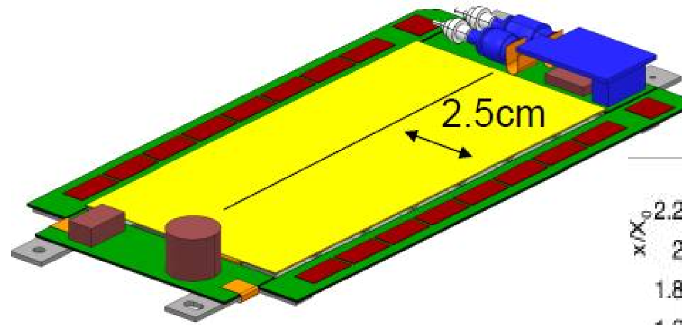
2S modules

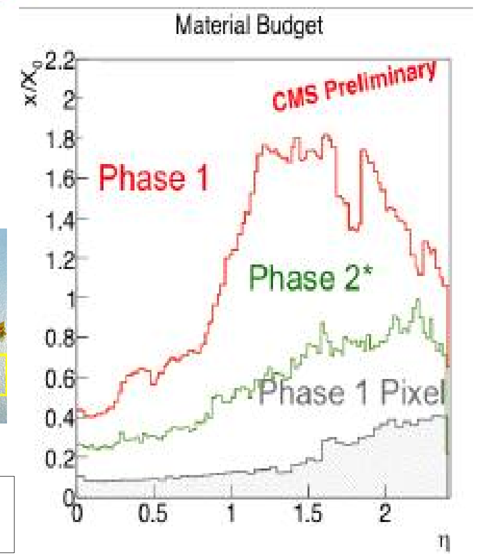
- 2 strip sensor mounted back-to-back
- Sensors wire-bonded to hybrid from top and bottom
- Strip dimensions: 5 cm x 90 µm

PS modules

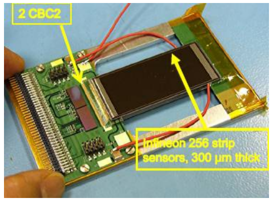
- Measures z
- 1 strip sensor (2.5 cm x 100 µm) 1 pixel sensor (1.5 mm x 100 µm) mounted back-to-back with a separating bridge







- Hybrid with binary readout electronics connecting data from two sides
- Module single entity, uses DC-DC powering
- Modules mounted on support structure



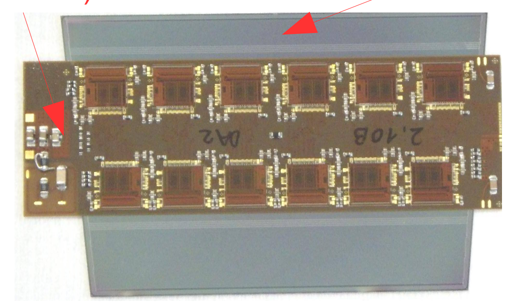
Small prototype

TDR in 2016

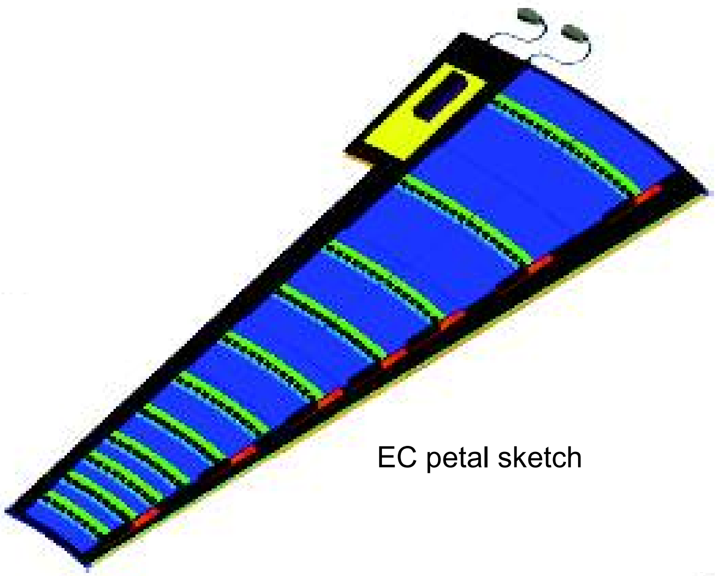
Phase 2 Strip Tracker in ATLAS

- Silicon strip detector consists of n-in-p FZ sensors 320 µm thick
  - Strip length 1.8 – 4.8 cm and ~74.5 µm pitch
- Modularity for easier final assembly, multiple site production, early system tests
- Modules: Sensors with binary readout electronics (130 nm CMOS) glued on top
- Stave/Petals: Modules glued double-sided with 40 mrad stereo on carbon and cooling structure
- Stave/Petals mounted on support structure including services in panels integrated → Mass reduction
- DC-DC conversion or serial powering → Increase power efficiency

TDR in 2016



EC prototype module



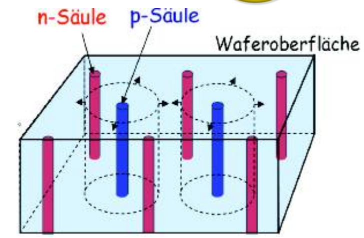
EC petal sketch

Upgrade Phase 2 Pixel Detectors

Requirements: Radiation tolerance up to $2*10^{16}$ Neq/cm^2
Very high particle rates (1-2 GHz/cm²)
Need for higher resolution than current ones

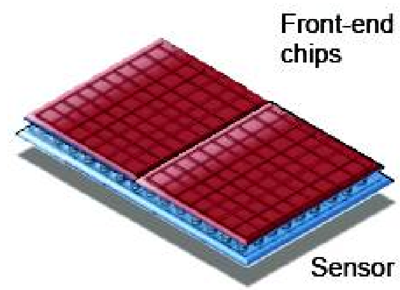
→ For CMS and ATLAS new 4 layer pixel detector

→ For CMS coverage up to |η|~ 4, in ATLAS under investigation



3D sensor

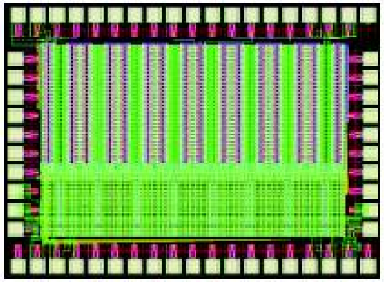
- Sensor type options:
  - Hybrid pixel detectors with planar or 3D sensors
  - Thin sensors with active edges and both n-in-n and n-in-p under study
  - CMOS monolithic technologies emerging (for larger radii?)



Hybrid pixel detector

- Fast readout needed: R&D in RD53 Collaboration aiming for
  - Readout in 65nm technology
  - With low operating voltage
  - Small sizes like 25 µm x 100 µm

- Several more years for R&D
  (ATLAS TDR planned for 2017)

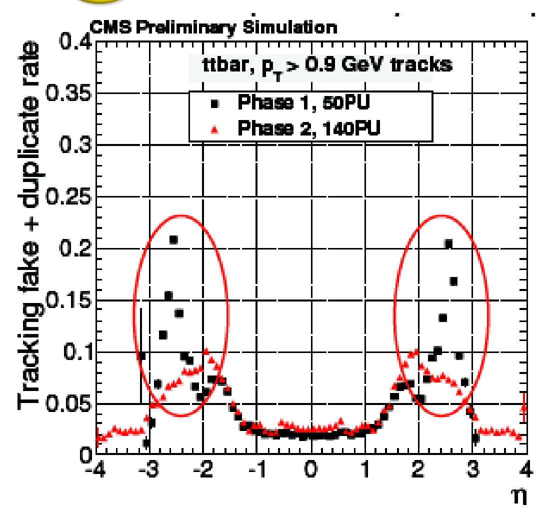


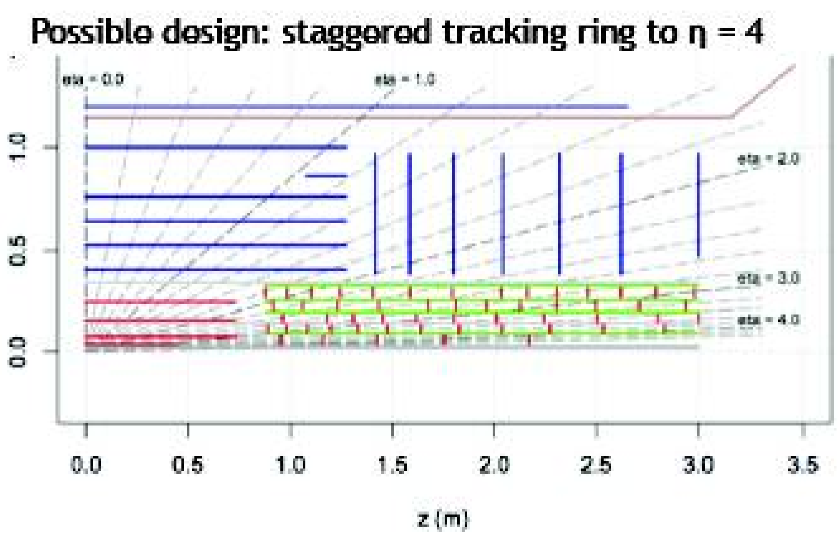
RD53: Test chip in 65nm CMOS technology

Upgrade Phase 2: ATLAS high η extension

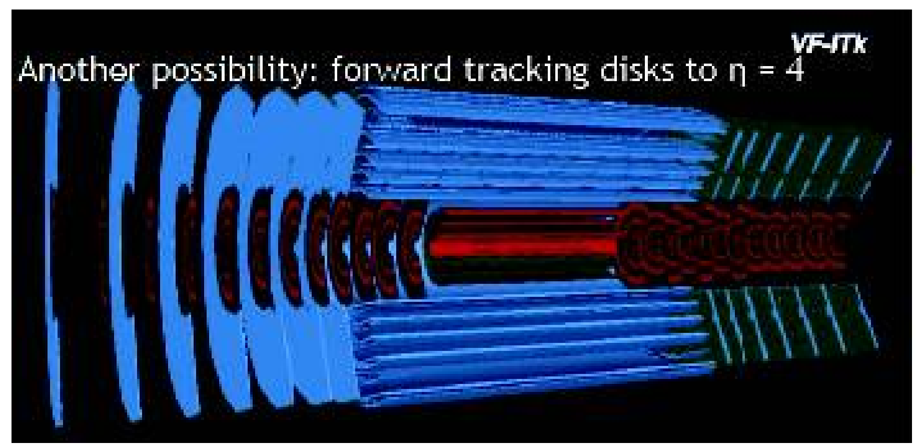
- Acceptance increase to |η|~4 under evaluation to
  - Better associate jets to tracks
  - Reduce fake rate of jets from pile up in VBF and VBS channels
- Possible extension of tracker, FCAL, muon spectrometer
- Different pixel detector layouts → physics impact under evaluation (e.g. for H → ZZ → 4μ: + 35 % acceptance)

L. Gray, ECFA HL-LHC Aix-les-Bains Oct. 2014





ATL-PHYS-PUB-2014-018

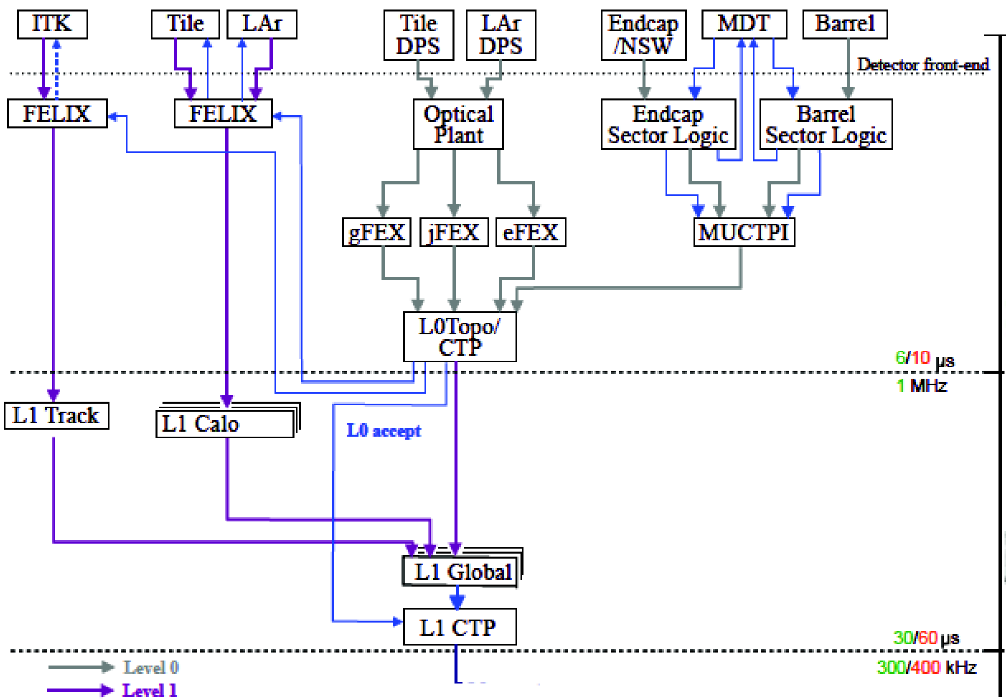


Recommendation in March 2015

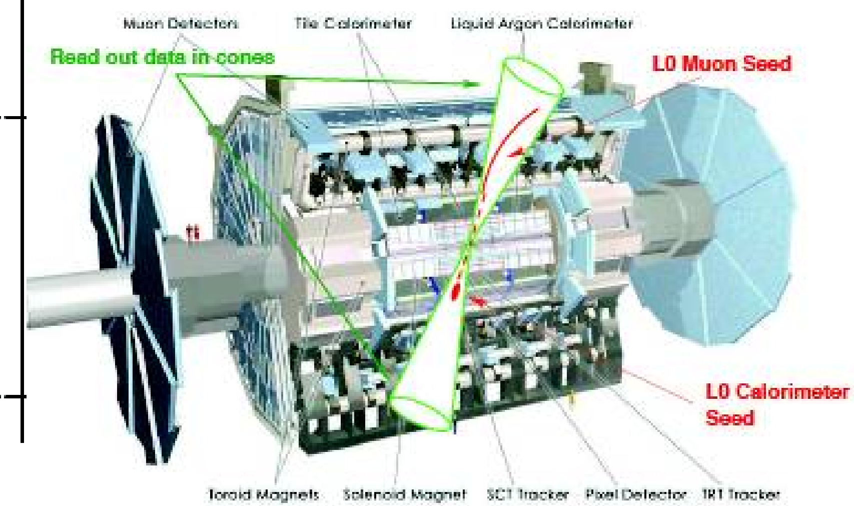
Upgrade Trigger Scheme in ATLAS

Phase 2 Upgrade – Run 4+

- New design foresees Phase1 Level 1 → in Phase2 Level 0
- Precision calo, muon and inner tracker information in L1 (with new electronics)



Triggering sequence: L0 trigger (calo/muon) reduces rate within ~ 6 μs to 1 MHz and defines ROI → L1 track trigger extracts info in ROIs from readout electronics



Level 0	Rate ~ 1 MHz, latency ≤ 6 μs, muon + calo
Level 1	Rate 300-400 kHz, latency ≤ 30 μs, muon + calo + tracks
HLT	Rate 5-10 kHz

- Event building ROI driven

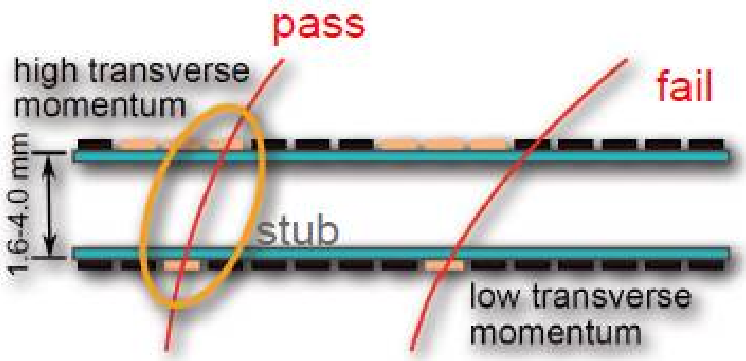
Upgrade Trigger Scheme in CMS

- L1 latency increase (3.2 μs→ 12.5 μs) allows integration of tracking in L1 trigger objects
- L1 track trigger + finer segmented L1 calo, muon and global triggers
- Event building at full L1 rate

Level 1	Rate ~ 1 MHz, muon + calo + tracks
HLT	Rate 10 kHz

Track trigger: silicon strip modules provide time and p_T discrimination → Rate reduction due to sharp thresholds (leptons) and isolation (multijet backround reduction)

p_T discrimination with stacked modules: exploit bending in magnetic field two closely spaced sensors read out by a single readout chip



Sensor spacing optimized
Same geometrical cut corresponds to different p_T

→ Correlation on module level to form stubs is sent out if within p_T cut (down to 2 GeV)

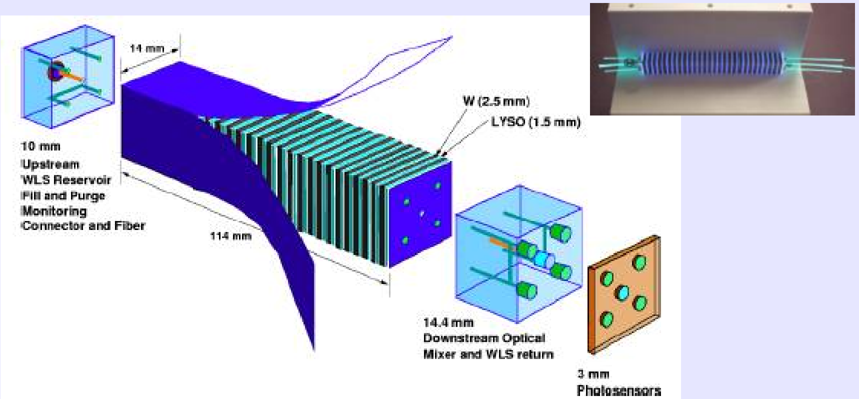
Phase 2 Upgrade: Calorimetry CMS

- Replacement of endcap EM calorimeter and hadronic calorimeter due to radiation induced loss of transparency
  Possible concepts:

- Replacement of barrel electromagnetic calorimeter electronics (for track trigger latency)

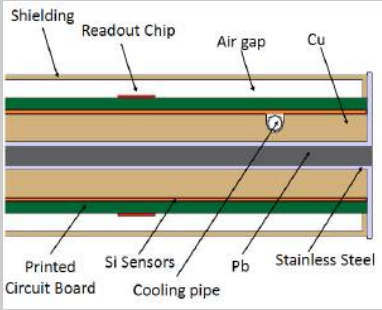
Crystal LYSO Shashlik + Scintillator HE

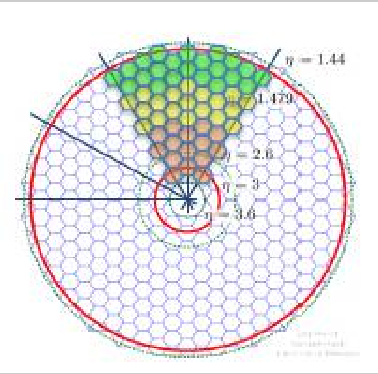
- EM: W/LYSO Shashlik using WLS and SiPM readout
- Hadr: Scintillator-based with 30% of volume tiles + 10% higher rad. tolerance



Silicon + Scintillator backing calorimeter

- EM: Silicon-lead/copper
- Hadr: Silicon-brass
- Scintillator-brass backing calorimeter
- 700 m² silicon pads 0.5-1 cm²



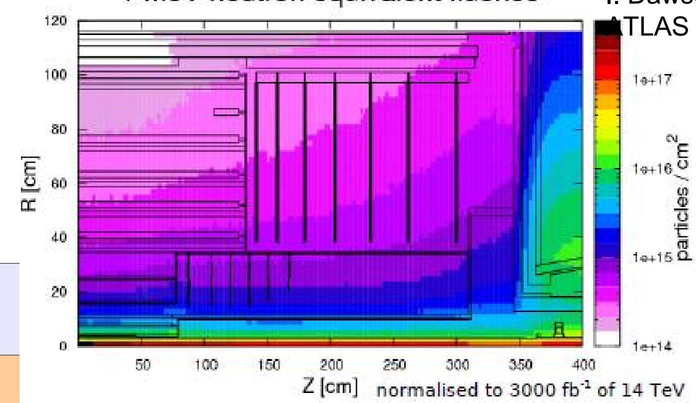


Summary: Silicon detectors

- Several new silicon detectors foreseen in upgrades have to withstand doses of up to
  $\Phi \sim 2 \cdot 10^{16}$ Neq/cm^2, ~1.5 GRad (ATLAS, CMS),
  $\Phi \sim 8 \cdot 10^{15}$ Neq/cm^2 (LHCb)

1 MeV neutron equivalent fluence

I. Dawson, ATLAS



Experiment	Type	Speciality
ATLAS Phase 0	IBL	Planar and 3D (NEW) pixels
CMS Phase 1	Tracker pixels	Planar: n+-in-n
ALICE Phase 1	ITS + Muon forward tracker	NEW: MAPS/CMOS
LHCb Phase 1	Pixel tracker + upstream tracker	NEW: Micro channel cooling, Pixel sensors
ATLAS Phase 2	Tracker strips and pixels	Strip n-in-p, 300 µm, 207 m² + possible high η extension
CMS Phase 2	Tracker strips and pixels	Strip: n-in-p, 200 µm thick 220 m² Pixel: open + high η extension
CMS Phase 2 + Run 2	SiPM or silicon for calorimeter	Si sensors used in calorimetry, 700 m²

- New technologies:
  CMOS
  Micro channel cooling
  Powering
  Si in calorimetry

- Challenge:
  Low material
  Fine granularity
  Integration on large areas

- Common R&D in RD50 Collaboration

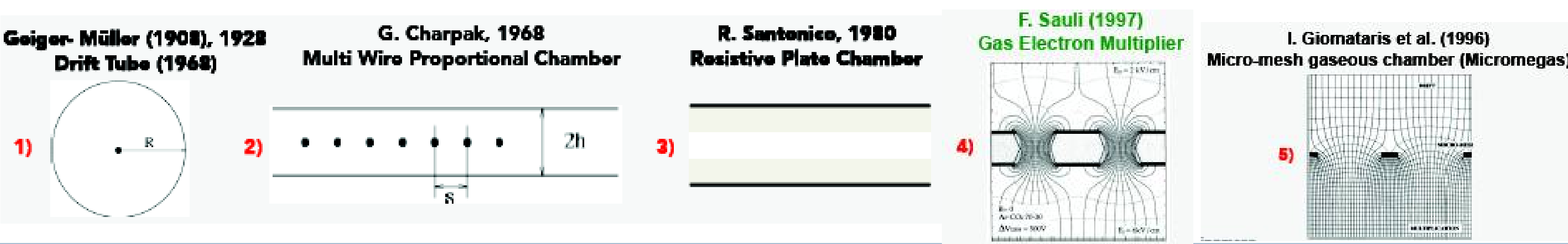
HGF Alliance Project (ATLAS+CMS groups): "Enabling Technologies for Silicon Tracking detectors at HL-LHC" (PETTL)

Summary: Gaseous Detectors

Main use as muon detectors, work very well in all Phases of LHC

1) **Upgrade without changing detectors**
   - Modify electronics (DT CMS, ALICE RPC)
   - Continue (largest part in ATLAS, CMS, LHCb)
2) **Upgrade by scaling standard geometries**
   - Increased acceptance (ATLAS MDTs, TGCs in new small wheel)
   - Increased granularity (CSC CMS)
3) **Upgrade by introducing novel gas detectors**
   - Micromegas (ATLAS new small wheel, 1200 m²)
   - GEMs (TPC ALICE, forward muon system CMS, LHCb 50 kHz readout)

Common R&D in RD51 Collaboration



Summary: Electronics

Philippe Farthouat

- **Large part of upgrades covers replacement**
  - Read-out electronics
  - Power supplies
  - Front-end electronics
  - Trigger electronics

ATLAS (Calo LV,trackers, Lar FE, MDT), CMS (tracker, FE HCAL, trigger), LHCb (VELO), ALICE (Readout)

- **Common issue**
  - Fast, radiation hard (up to 1MGy), low power readout electronics for tracking detectors
    → R&D effort in RD53 Collaboration

- **Common development**
  - Fast data transmission required: common R&D on Gbps optical link
  - Radiation hard and magnetic hard: DC-DC converters
  - Frame contracts for IC technologies
    (65 nm and 130nm TSMC and in use IBM 130 nm, Techno de On-Semi 350 nm)

HGF project on silicon photonics: “Enabling Technologies for Next-Generation Detectors”

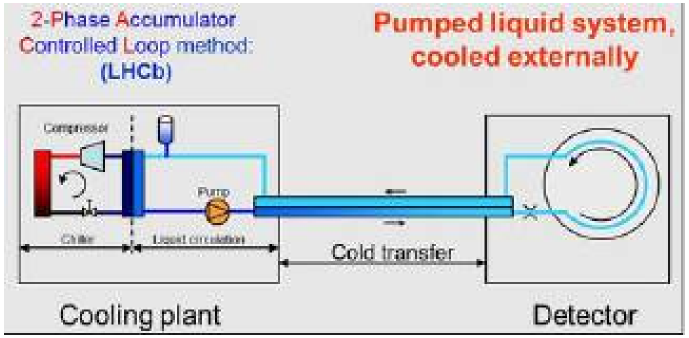
Summary: Calorimetry, Activation, Cooling

- Calorimetry
  - Upgrade of readout and electronics in several calorimeter parts required
  - Part of CMS calorimeter (to be upgraded due to radiation dose in Phase 2)

- Radiation doses in Phase 2 and activation of material to be considered
  → effect shielding and handling

ALARA

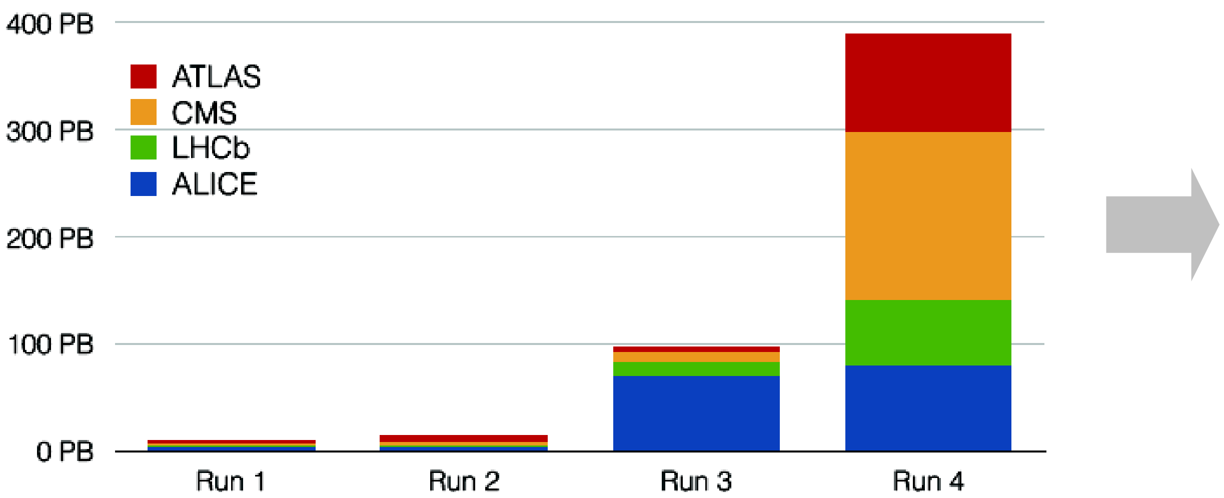
- Detector cooling with evaporative CO_2 cooling:
  - 15...100 bar
  - 200...300 J/g instead of ~2 J/g in mono-phase cooling system
  - Allows thinner and longer pipes
  - New cooling plants LHCb 2*7 kW,
    ATLAS 6*30 kW
    CMS 9*45 kW



Summary: Triggering

Albert-Ludwigs-Universität Freiburg

- Triggering
  - ALICE and LHCb plan to read out all data with upgraded electronics
  - ATLAS and CMS include tracking → control Level 1 rate
    With different approaches similar HLT rate of 5-10 kHz in Phase 2
  - Upgrades by hardware and software modifications (new electronics on various systems, TDAQ infrastructure, Track Trigger)
  - Collecting a lot of data → Imposes challenge for further offline processing



New physics results

M. Krzewicki, ECFA HL-LHC Aix-les-Bains Oct. 2014

Very crude estimate of data per year

Conclusions

- Exciting physics program with $300fb^{-1}$ and $3000fb^{-1}$ possible
- Search for new particles and measurements of Higgs properties in reach

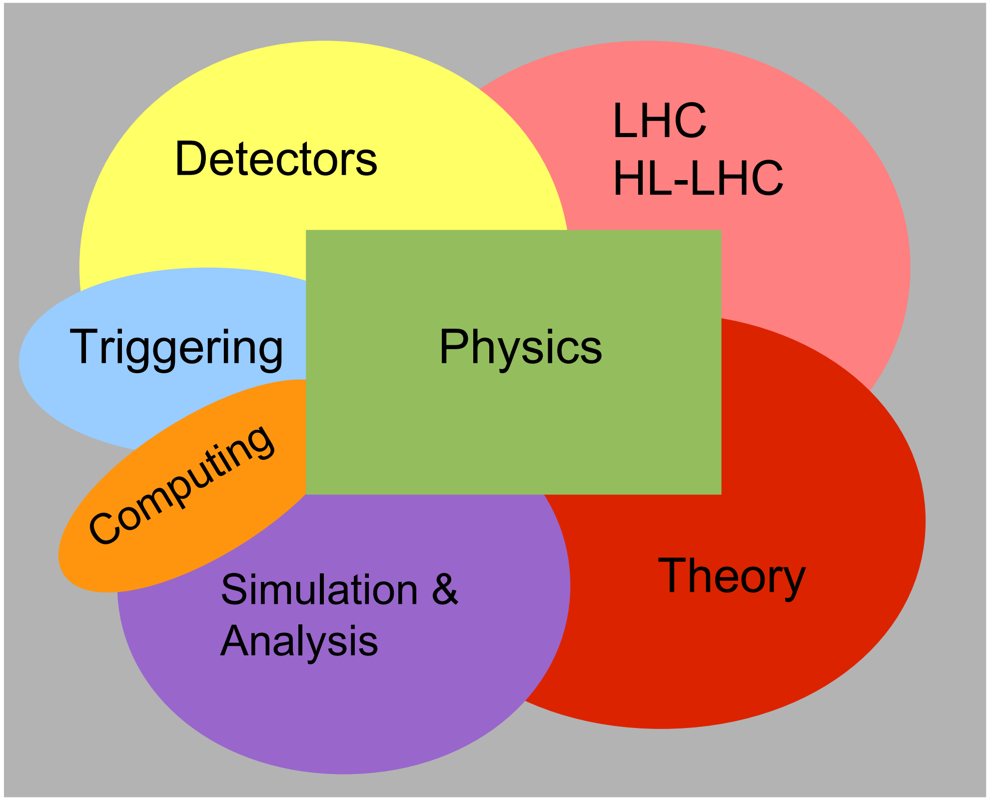
- Technical challenges ahead
  - High radiation environment
  - High rate of pile up and occupancy
  - High trigger rates

- LHC and all 4 experiments have coherent plans to perform upgrade of systems
  - Main issues: Silicon tracking detectors, electronics and trigger strategies
  - Several TDRs for Phase 0 and Phase 1 approved
  - More to be written for Phase 2 in staged upgrade planning

- Collaboration between experiments for upgrades in the context of
  - RD50, RD51 and RD53 R&D Collaborations, Helmholtz Alliance projects
  - More potential overlaps e.g. trigger and software techniques

Exciting program for detector development in parallel with data analysis and data taking

Thank you


Detectors
LHC
HL-LHC
Triggering
Physics
Computing
Simulation &
Analysis
Theory

Spares

References

Much more on ALICE in:
CERN-LHCC-2012-012, LHCC-I-022
CERN-LHCC-2013-014, LHCC-I-022-AOD-1
CERN-LHCC-2012-005, LHCC-G-159, 2012
CERN-LHCC-2013-024, ALICE-TDR-017
CERN-LHCC-2013-020, ALICE-TDR-018
CERN-LHCC-2013-018, ALICE-TDR-015

LHCb
LHCC-2011-001
LHCC-2012-007 CERN-LHCC-2011-001
CERN-LHCC-2012-007
CERN-LHCC-2013-021
CERN-LHCC-2014-001

ATLAS
Phase 1 CERN-LHCC-2011-012, LHC-I-020
CERN-LHCC-2013-006
CERN-LHCC-2013-007
CERN-LHCC-2013-017
CERN-LHCC-2013-018
Phase 2 ATLAS: LHCC-I-023, CERN-LHCC-2012-022

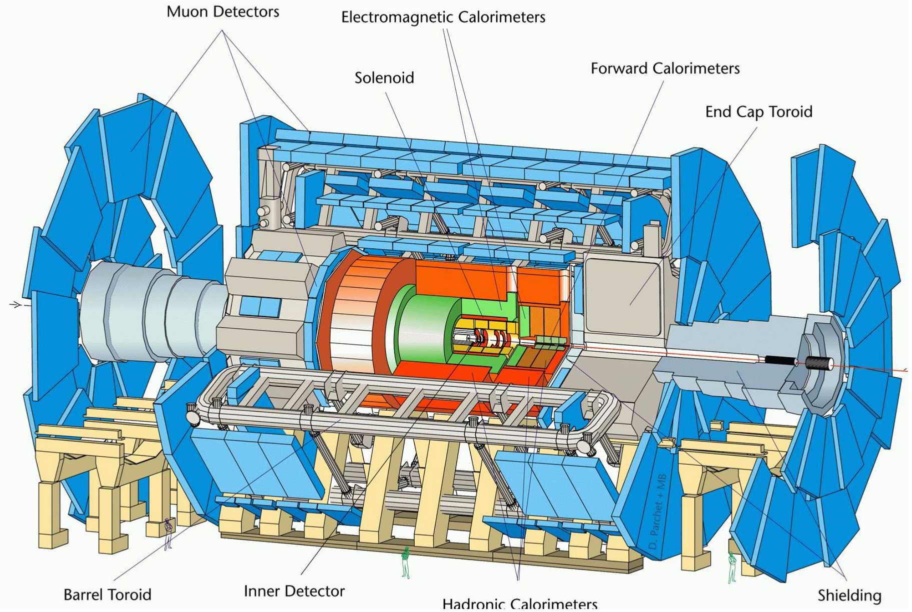
CMS
CERN-LHCC-2012-015
LHCC-2011-006, LHCC-P-004

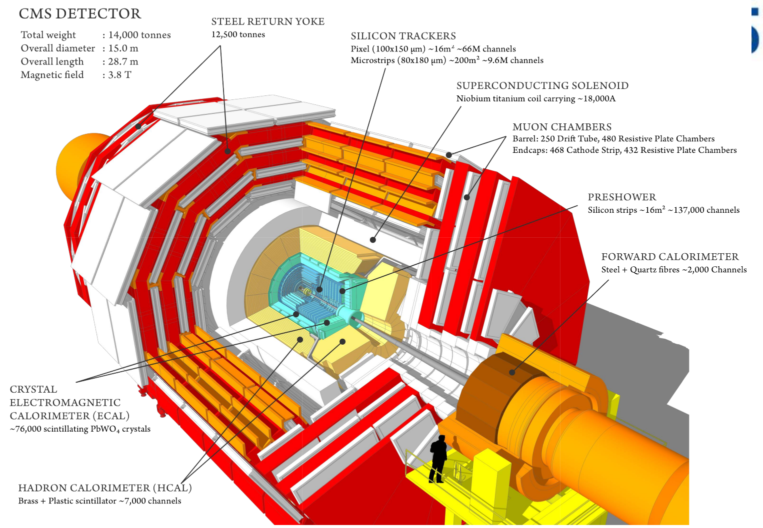
Acknowledgment

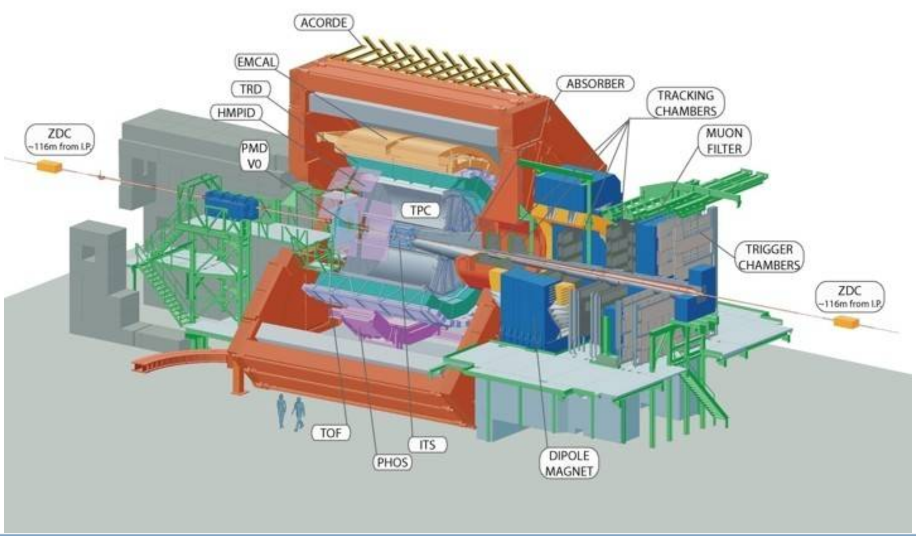
Hans-Christian Schulz-Coulon, Ingrid Maria Gregor, Karl Jakobs, Ulrich Parzefall, Lutz Feld, Peter Jenni, Anadi Canepa, Olga Igonkina, Mike Lamont, Frederic Bordry, Letizia Lunqaro Mendez, M. Cagliari, Phil Allport, Francesco Dattori, Jay Hauser, Quy Nohne, Claudia Gemme, Marcello Mannelli, Andreas Schopper, A. Rossi, Isabel Bejar Alonso, Gaelle Boudoul, Alexander Dierlamm, Georg Steinbrueck, Wei-Ming Yao, Benedikt Hegner, Benedetto Gorini, Christian Lippmann, Paula Collins, Mirco Dorigo, Mikolaj Krezwicki

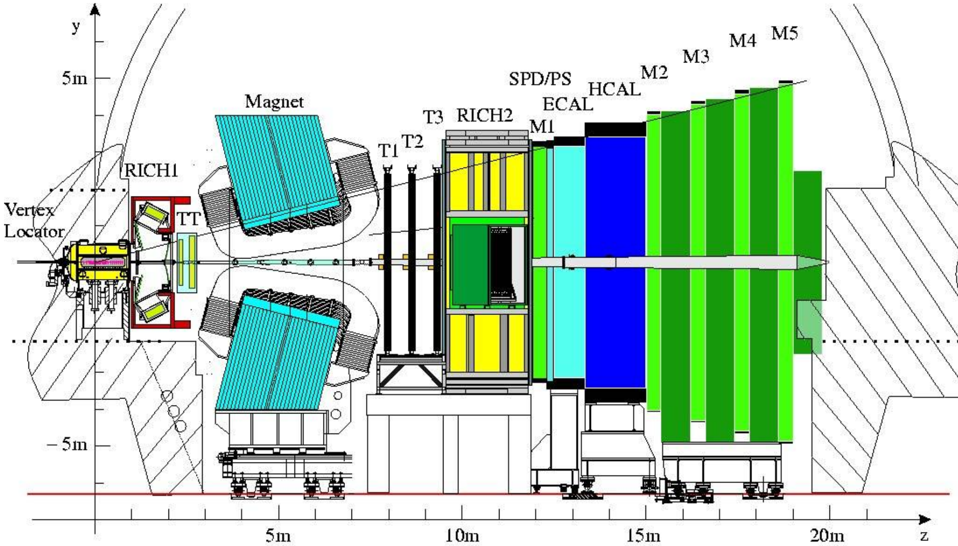
Spares

Experiments









S

Frédérick Bordry, LHCP 2014

To measure Higgs boson properties

A Apyan, ECFA HL-LHC Aix-les-Bains Oct. 2014

- **Measure as many Higgs couplings** to fermions and bosons as precisely as possible, with 3000 fb^{-1} typical precision 2-10% per experiment (except rare modes), ~1.5-2x better than with 300 fb^{-1}

Assumptions:

- Single resonance of mass 125 GeV
- Zero width approximation
- Tensor structure of Langrangian assumed to be the same of SM

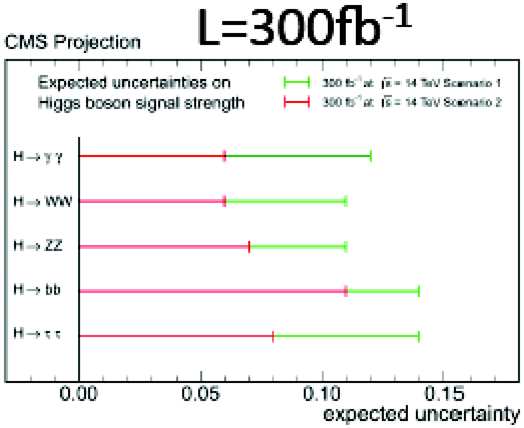
		κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	κ_μ
300fb^{-1}	ATLAS	[9,9]	[9,9]	[8,8]	[11,14]	[22,23]	[20,22]	[13,14]	[24,24]	[21,21]
300fb^{-1}	CMS	[5,7]	[4,6]	[4,6]	[6,8]	[10,13]	[14,15]	[6,8]	[41,41]	[23,23]
3000fb^{-1}	ATLAS	[4,5]	[4,5]	[4,4]	[5,9]	[10,12]	[8,11]	[9,10]	[14,14]	[7,8]
3000fb^{-1}	CMS	[2,5]	[2,5]	[2,4]	[3,5]	[4,7]	[7,10]	[2,5]	[10,12]	[8,8]

Uncertainties on coupling measurements

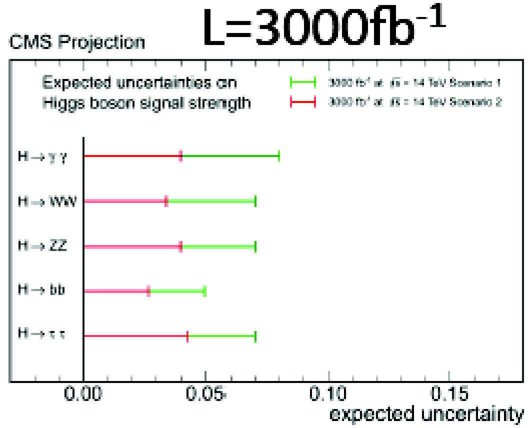
arXiv: 1307.7135
arXiv: 1307.7292

- **Reduced uncertainty on Higgs signal strength**

L=300fb^{-1}



L=3000fb^{-1}



- ATLAS: [no theory uncert., full theory uncert.]
- CMS: [Scenario 2, Scenario1]
- Scenario 1: Systematic uncertainties remain the same
- Scenario 2: Theoretical uncertainties scaled by ½, other systematic uncertainties scaled by 1/ √L

Detector preparation for Run 2

ATLAS

- Insertable B-layer (pixel layer) cooled with CO_2
- New cooling plant for pixel + SCT
- New Al/Be beam pipe
- Replaced all LV power supplies of calorimeter
- Increased acceptance in muon spectrometer
- Upgrade of L1 Calo (L1 trigger)
- Add neutron shielding
- ...

CMS

- Upgrade HCAL photo detectors
- Increased acceptance in muon system
- Thinner and centered beam pipe
- Repair of shorts in pixel detector barrel
- Installed pilot system for future upgrades
- Consolidation work to complete original detector
- Start upgrade for high pile-up
- ...

LHCb

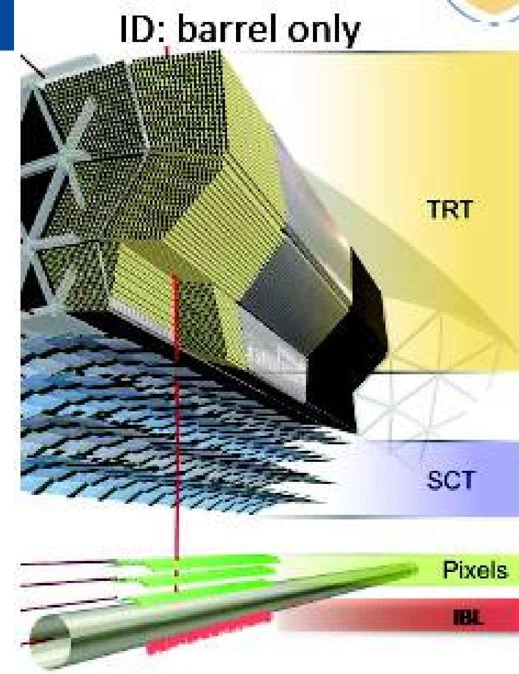
- New Forward shower detector
- RICH detector
- Trigger system to allow offline analysis at 12.5kHz
- ...

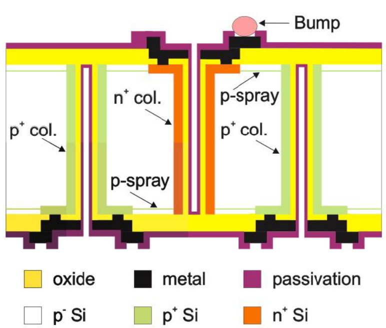
ALICE

- DCAL installation
- Additional TRD modules
- Augmented trigger hardware and software
- ...

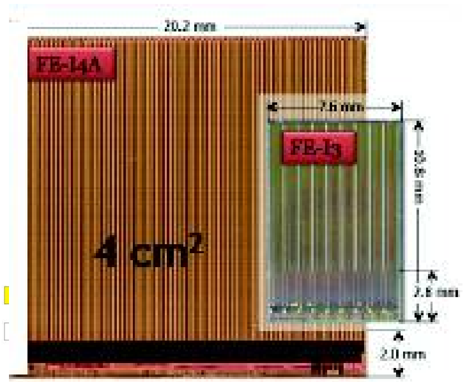
ATLAS Insertable b-layer

- Additional 4th pixel layer
- Close to interaction point (33 mm)
- 75% planar n-in-n sensors and 25% 3D-detectors (radiation tolerance $\Phi \sim 5*10^{15}$ Neq cm^{-2})
- Will improve tracking, have better impact parameter resolution, vertexing and b-tagging performance

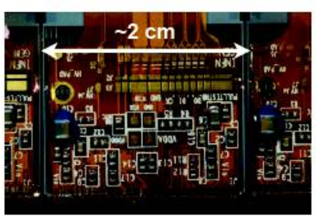




(a)

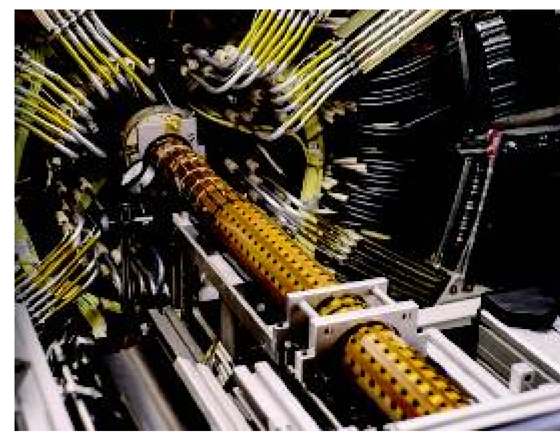


FEI4 electronics



ATLAS IBL pixel module

Smaller pixel cell
50x250μm², FEI4 130nm
CMOS electronics

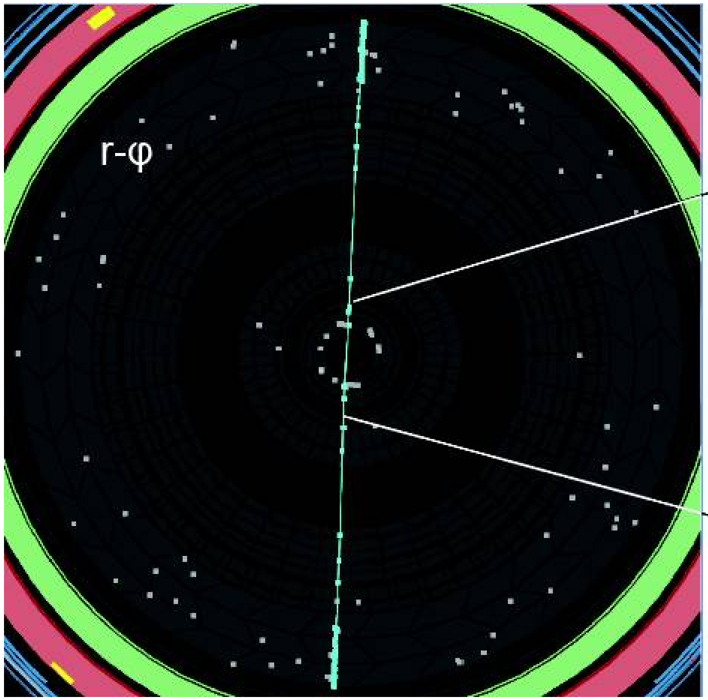


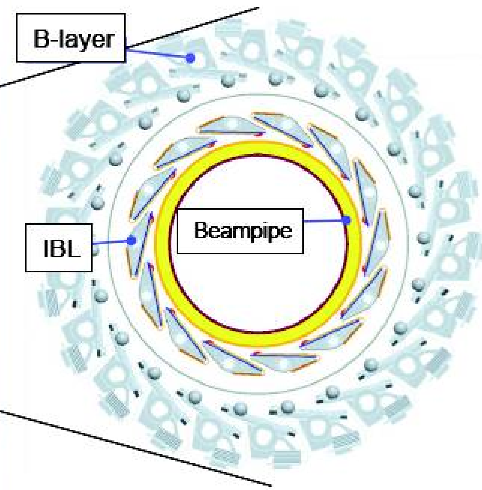
- Successfully inserted in detector and 99.9% working

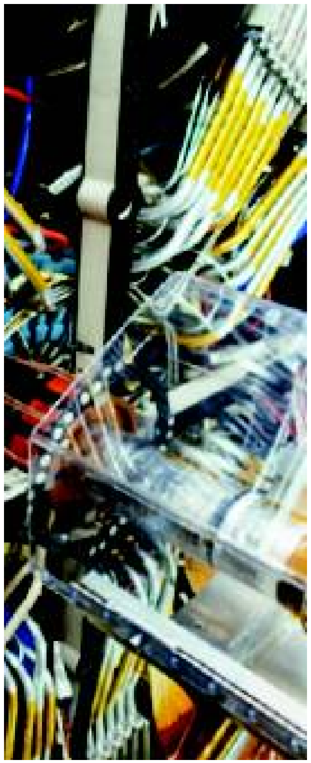
CERN-LHCC-2010-013

ATLAS Inner detector for Run 2

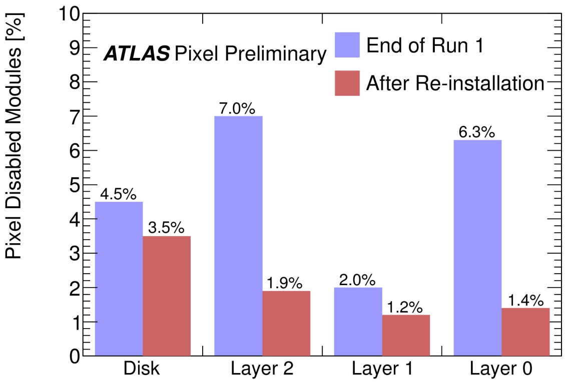
- Beam pipe backout done







- Cosmics data taking of all parts of inner detector
- Track reconstruction working

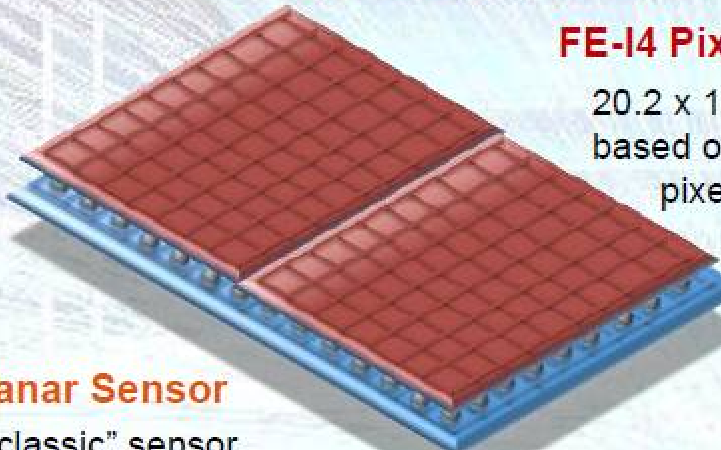


Pixel detector after the re-insertion

All installation in pit finished and commissioning ongoing!

Phase 0 – Run 2

Insertable B-Layer



FE-I4 Pixel Chip (26880 channels)

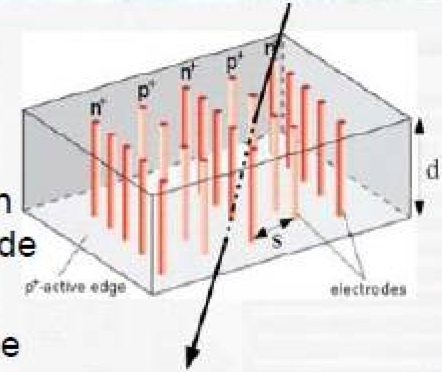
20.2 x 18.8 mm^2 130 nm CMOS process, based on an array of 80 by 336 pixels (each 250 x 50 μm^2)

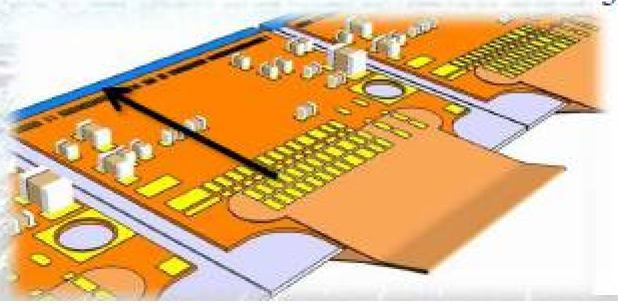
Planar Sensor

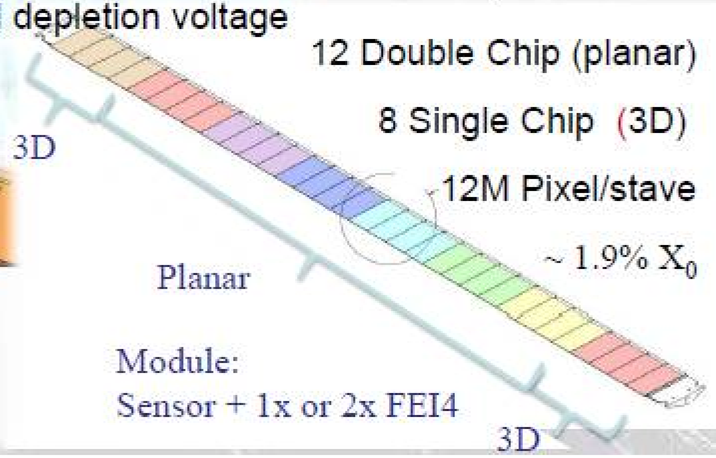
- “classic” sensor design
- oxygenated n-in-n
- 200µm thick
- Minimize inactive edge by shifting guard-ring under pixels (215 µm)
- Radiation hardness proven up to 2.4×10^{16} p/cm^2

3D Sensor

- Both electrode types are processed inside the detector bulk
- Max. drift and depletion distance set by electrode spacing
- Reduced collection time and depletion voltage





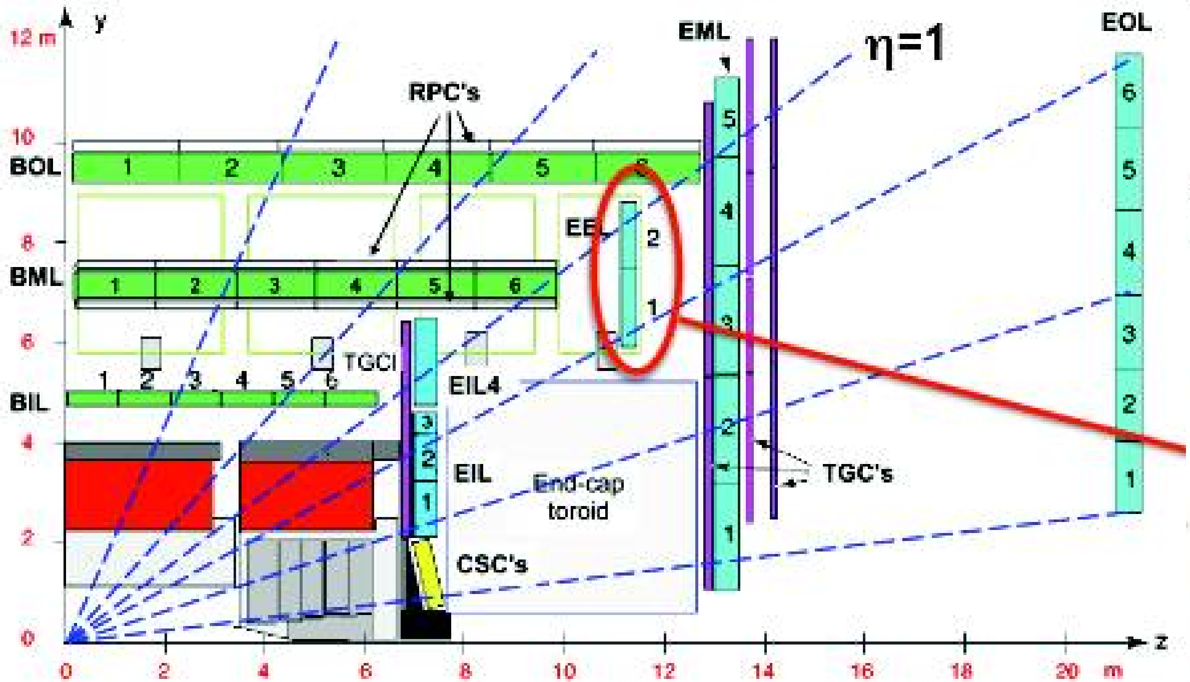


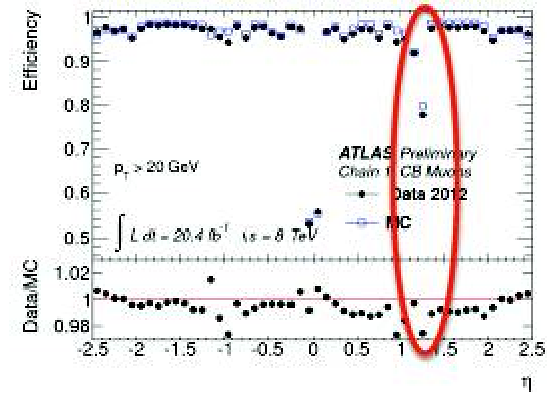
P. Allport

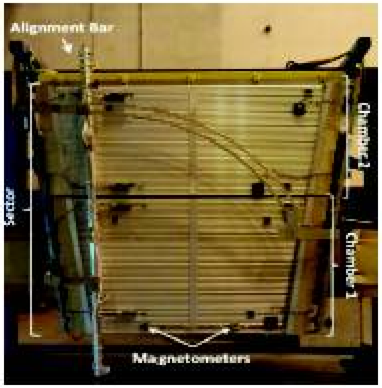
14

ATLAS muon spectrometer

- Consolidation for low efficiency on barrel-end cap transition region





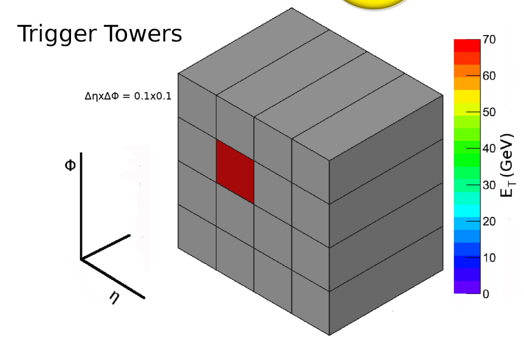


ATLAS Phase 1 Upgrade: L1 calo trigger

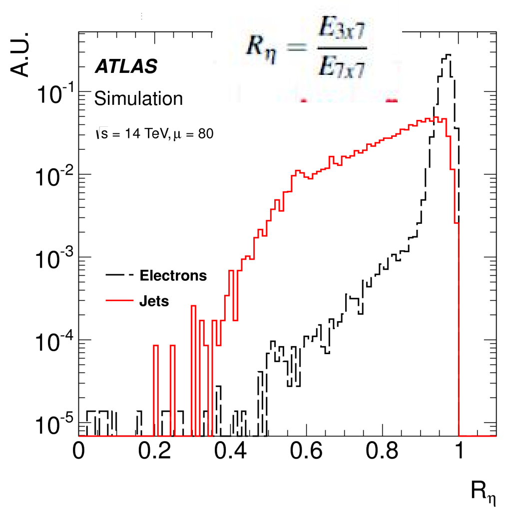
Phase 1 Upgrade – Run 3

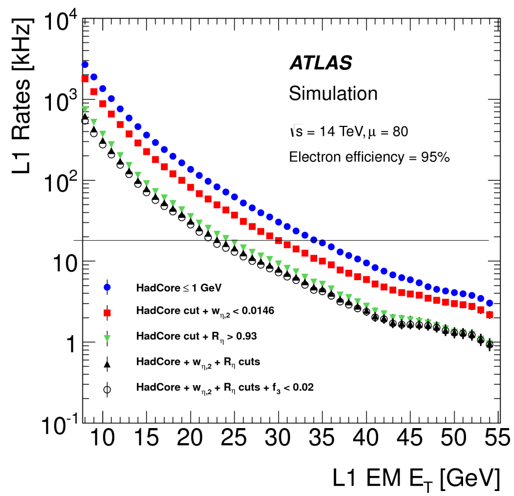
Improve granularity of L1 calorimeter readout to improve electron/jet discrimination and maintain low p_T electron and photon triggering

- Upgrade of calorimeter front-end electronics
- New shower shape algorithms at L1

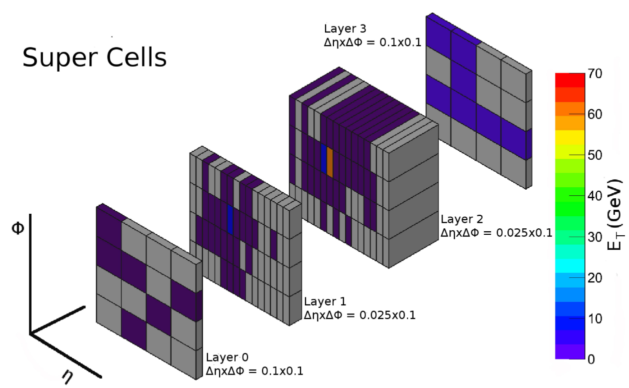


At 20 kHz pT ~23 GeV possible





From one trigger tower 0.1x0.1 to 1+4+4+1 supercells on 4 layers

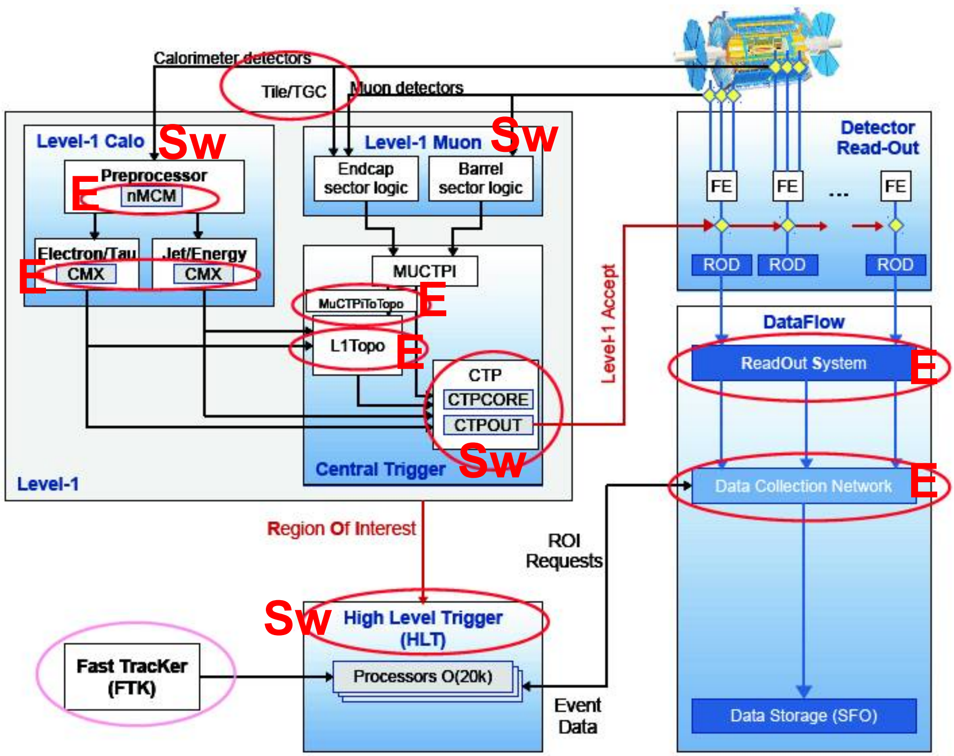


CERN-LHCC-2013-017, CERN-LHCC-2013-018

Triggering in ATLAS in Run 2

- Triggering is modified in ATLAS for Run 2
  - Additional flexibility and more selectivity

- New firmware and boards in central trigger system
- L1 rate increased to 100 kHz
- Improve L1 triggers by e.g. selection by topological signatures (L1 topo), ROI match to muon track (L1 muon), pile-up suppression (L1 MET)
- HLT rate increase to average 1kHz
- Better algorithms and use of resources for HLT to keep lepton triggers for W, Z

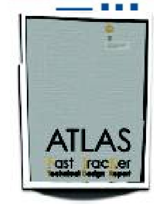


Topological board

E - Electronic boards
Sw - Software

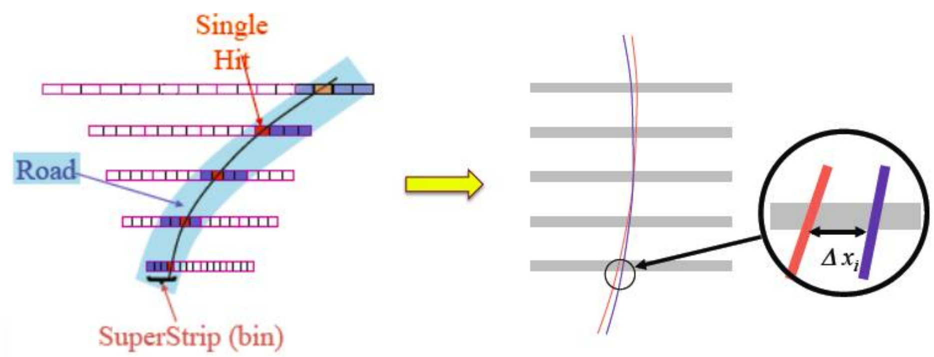
ATLAS Phase 1 Upgrade: FTK

- Fast Track trigger at L1.5
  - Hardware based trigger to allow rapid pattern recognition using inner tracker (FPGA fitting: 1 fit/ns)
  - Input to HLT
  - Improves b-tagging and τ-lepton triggers by combining tracking and calorimeter information
  - Installation started, to finish in 2018



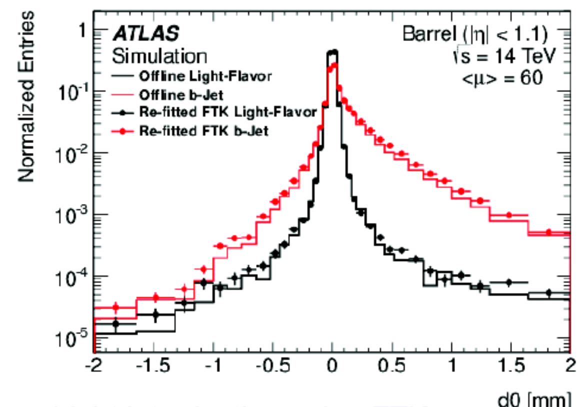
CERN-LHCC-2013-007

Using associative memory ASIC



Pattern recognition in coarse resolution (superstrip→road)

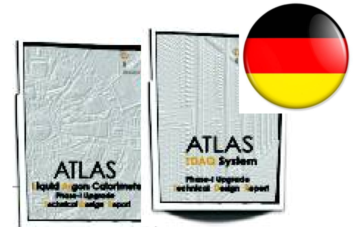
Track fit in full resolution (hits in a road)
$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$



Light jet rejection using FTK compared to offline reconstruction

→ offline ~ online precision

- Upgrade of trigger back-end electronics & TDAQ
- New front-end in LAr calorimeter + possibly forward physics (AFP)



CERN-LHCC-2013-017, CERN-LHCC-2013-018

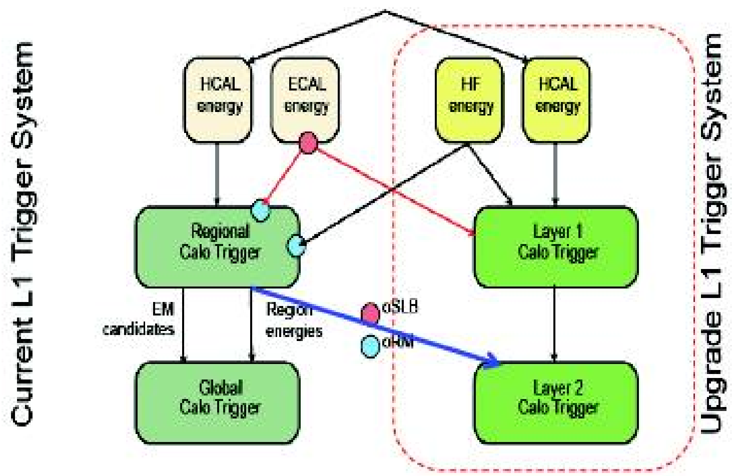
Triggering in CMS in Run 2 + Phase 1

Phase 0 Upgrade – Run 2

S. Lopez LHCC Nov. 2014

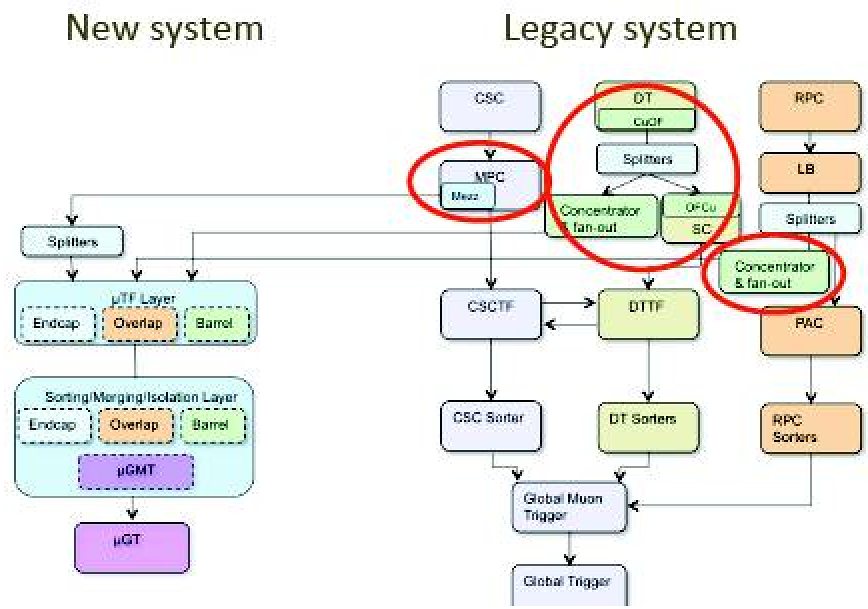
Triggering is modified in CMS for Run 2

L1 Calo trigger scheme



- Two-layer calorimeter trigger with
  - calorimeter tower-level precision
  - improved taus and electron isolation
  - pile-up subtraction
- Replacement of copper cable connections with optical connections.
  - Splitting from ECAL to Regional Calo Trigger and Layer 1 ✔
  - Splitting from Regional Calo Trigger to Global Calorimeter Trigger and Layer 2 ✔
  - Configurable switching legacy/upgrade

L1 Muon trigger scheme

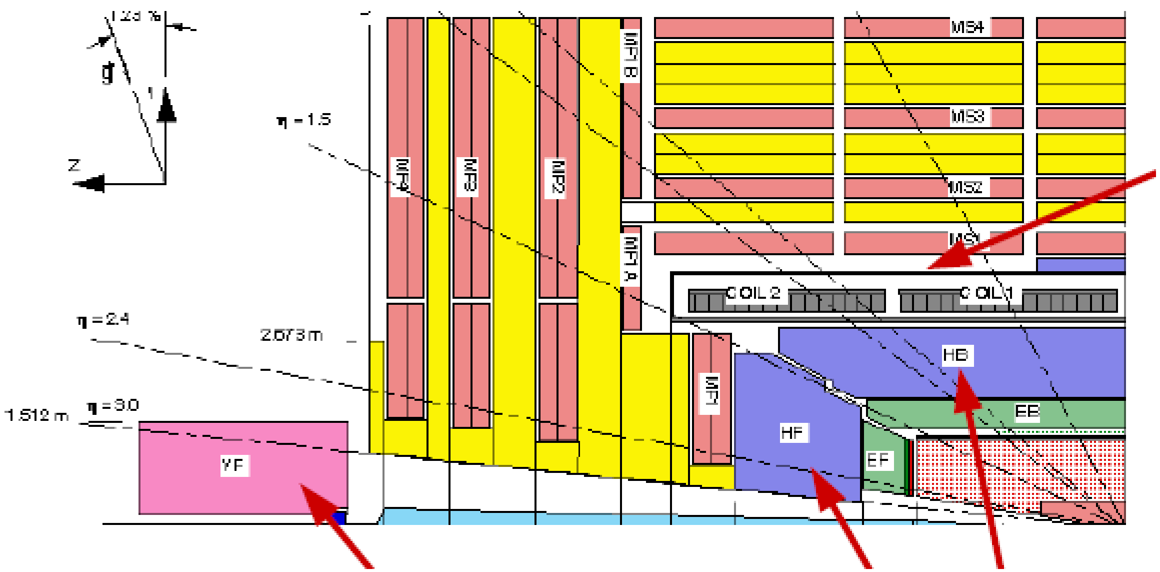


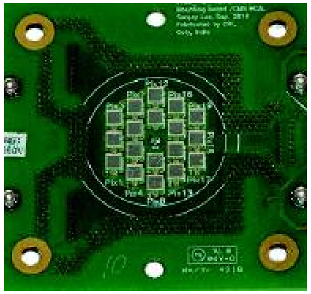
- Integrated muon trigger combining all 3 muon systems in 'early' track-finding
  - higher robustness and efficiency
  - more sophisticated p_T measurement
- Build up new Muon Track Finders in 2015 and commission in parallel (ready for physics by 2016)
- Full Full split of CSC signals installed and tested ✔
- Split a slice of the DT ✔and RPC signals to commission the new trigger

CMS detector preparation for Run 2 ctd'

Replacements

- Photo-detectors in HCAL
- New PMTs in forward calorimeter
- Change HPD with SiPMs in outer calo.
  → lower pedestals





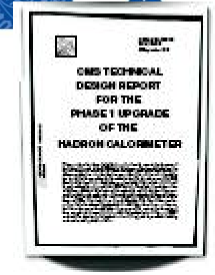
HPD → SiPMs
(due to magnet field)

Switch to
multi-anode PMTs
and fast electronics

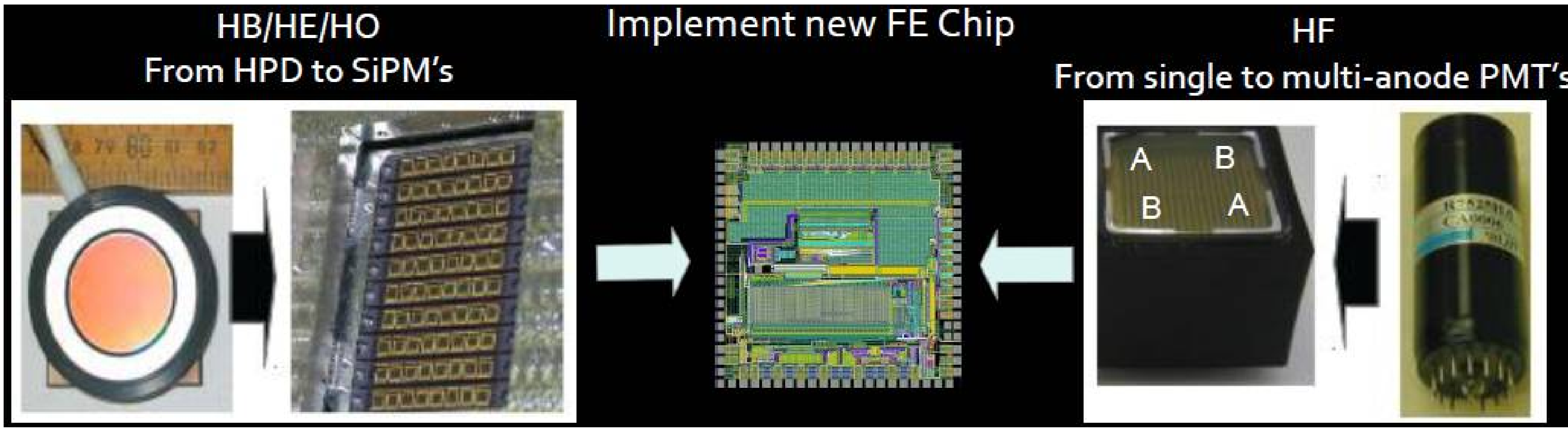
Replacement of
control modules

CMS Upgrade in Run 2

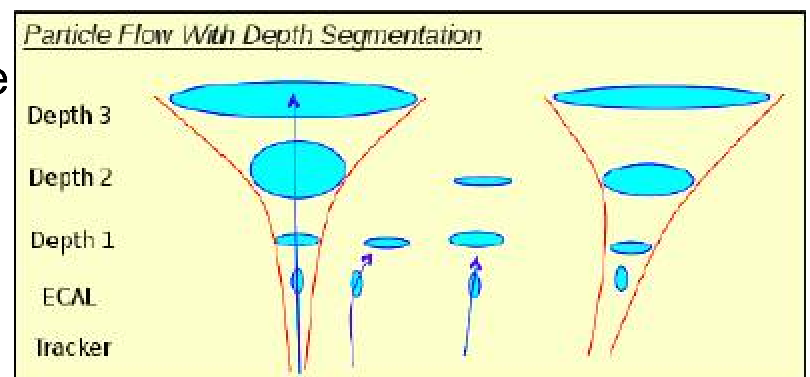
During Run 2



- Upgrade trigger system until 2016, already started in LS 1
- Replace photo-transducers to reduce noise and improve performance
  - New FE chip for HCAL

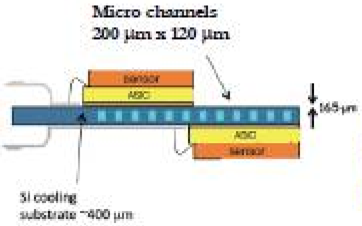


- SiPMs increase depth segmentation → Improved particle flow hadronic shower localization
- Readout upgrade to μTCA

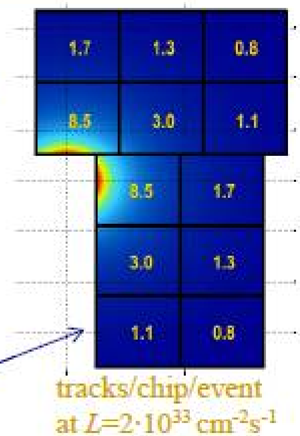


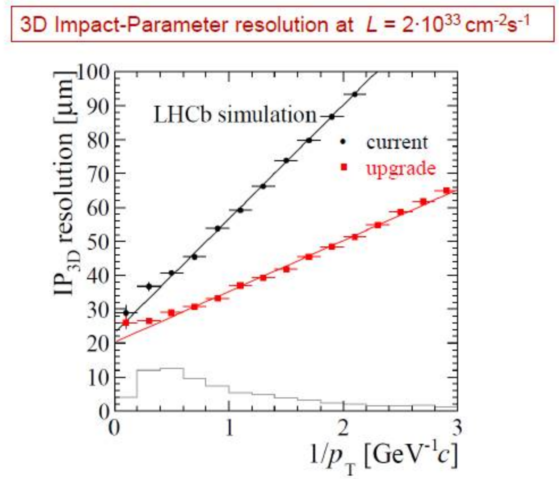
LHCb VELO upgrade Phase 1

VELO upgrade

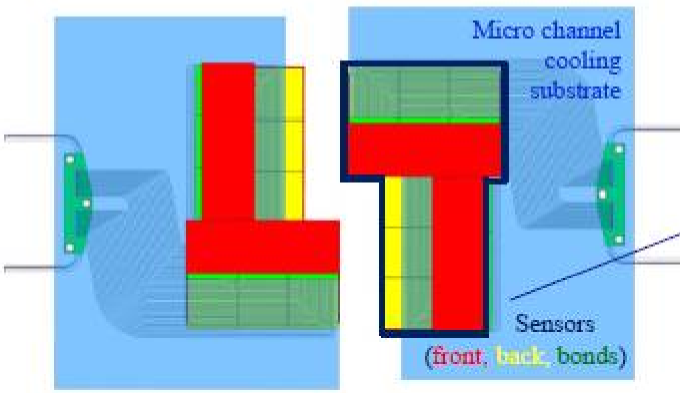


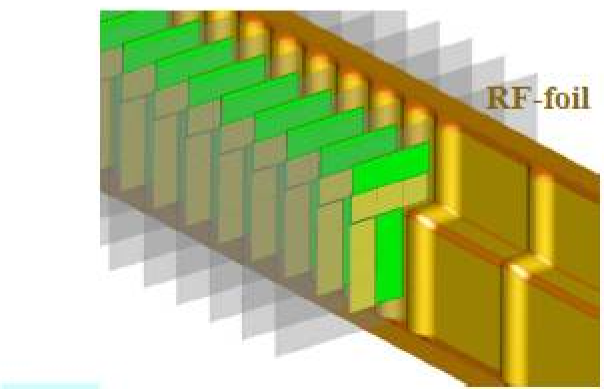
pixel detector with
micro channel cooling

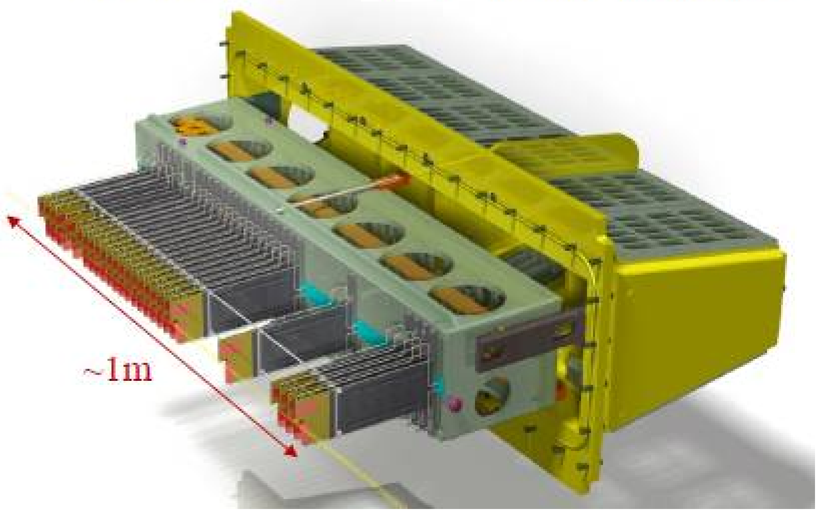




note: full GEANT Monte Carlo with standard LHCb simulation framework





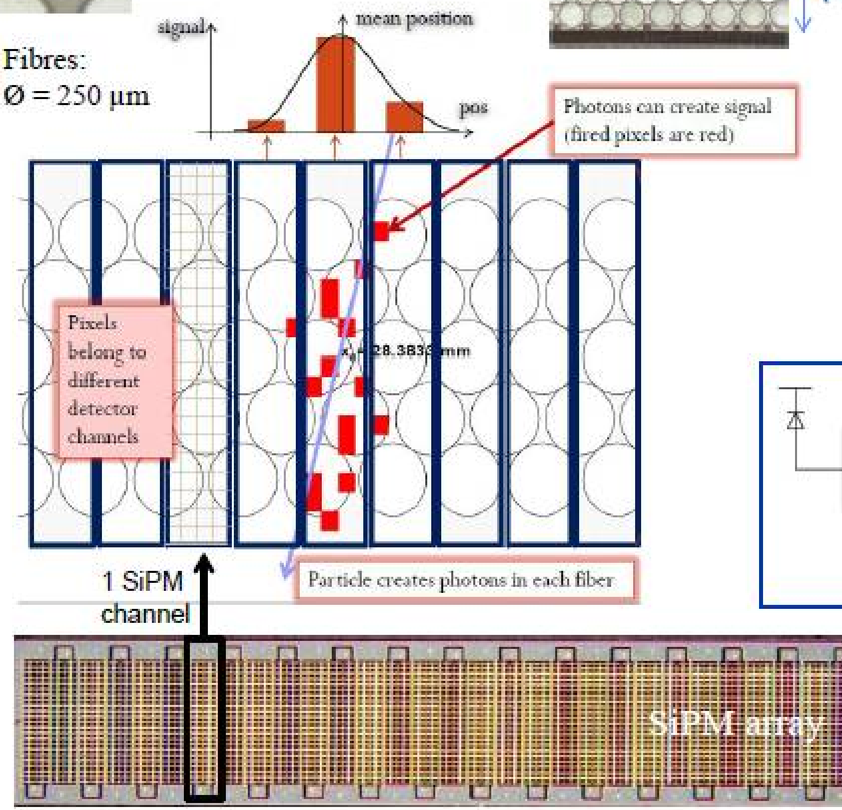


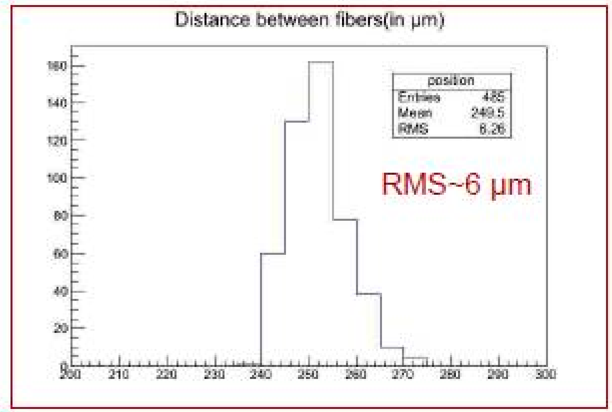
Andreas Schopper

T-stations upgrade: Fibre Tracker (FT)

scintillating-fibre mat (5-6 layers)

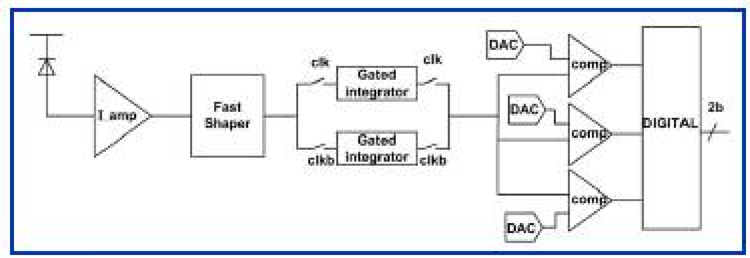
Fibres:
Ø = 250 µm





2s-1

framework



Readout by dedicated 128 ch.
40 MHz PACIFIC chip

- 3 thresholds (2 bits)
- sum threshold (FPGA)

Andreas Schopper

ALICE Phase 1 Upgrade

New Inner Tracking System (ITS)
- improved pointing precision
- less material -> thinnest tracker at the LHC

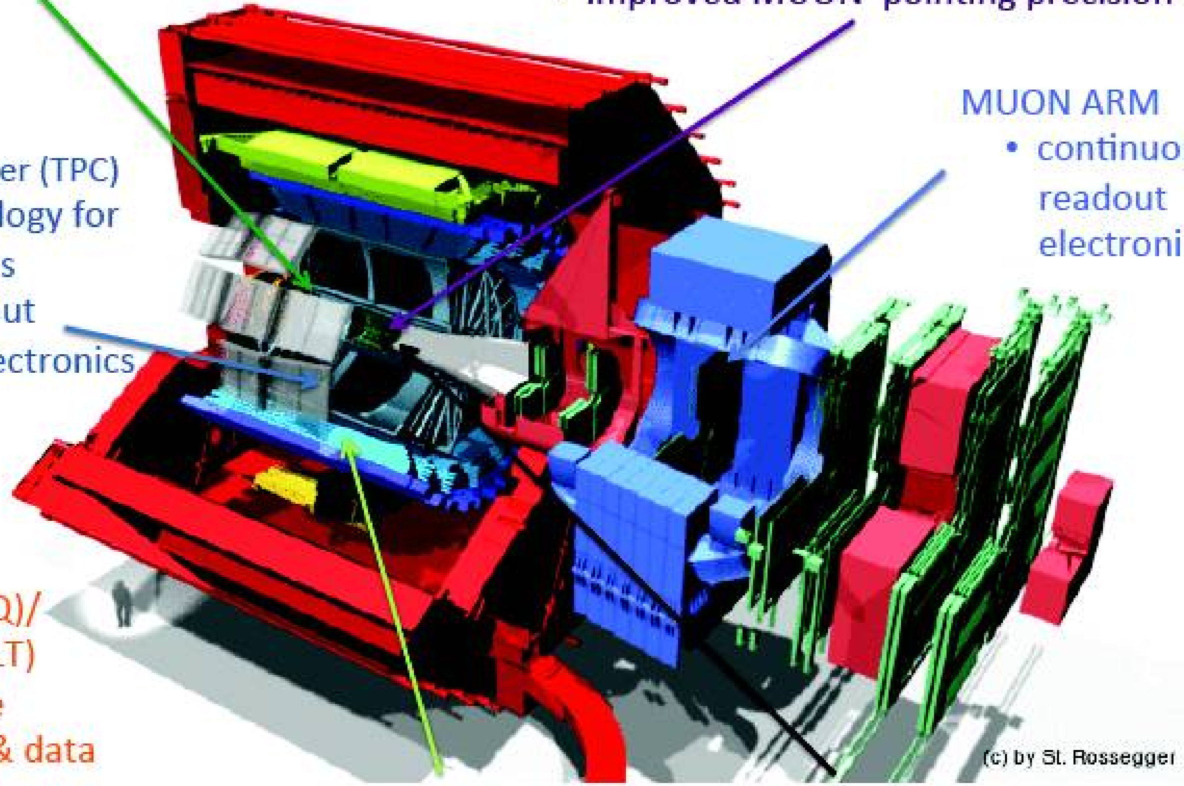
Muon Forward Tracker (MFT)
- new Si tracker
- Improved MUON pointing precision

MUON ARM
- continuous readout electronics

Time Projection Chamber (TPC)
- new GEM technology for readout chambers
- continuous readout
- faster readout electronics

New Central Trigger Processor

Data Acquisition (DAQ)/ High Level Trigger (HLT)
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate



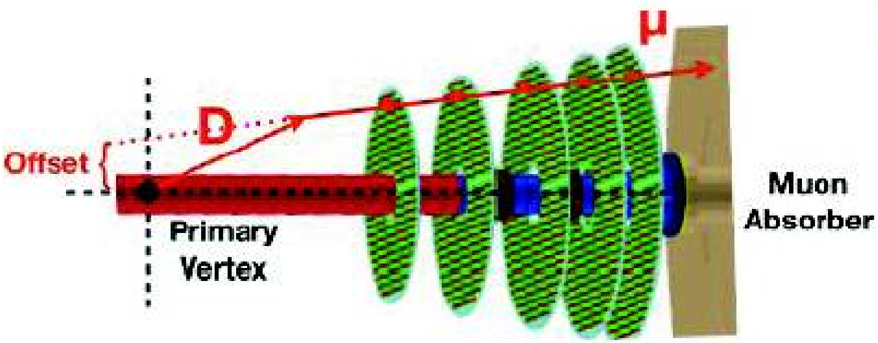
TOF, TRD
- Faster readout

New Trigger Detectors (FIT)

Phase 1 Upgrade – Run 3

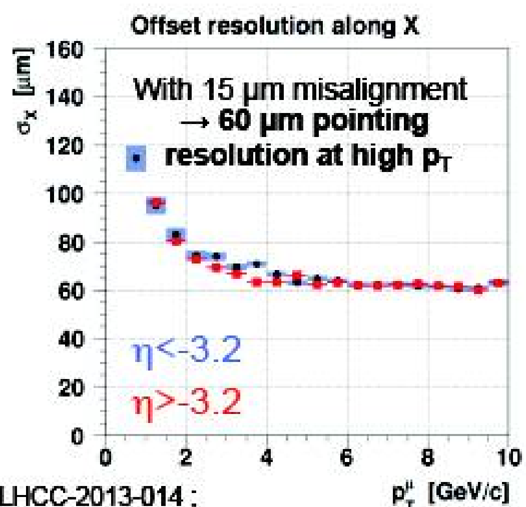
ALICE

Muon Forward Tracker



5-6 planes of CMOS silicon pixel sensors (same technology as ITS):

- $50 < z < 80$ cm
- $R_{min} \approx 2.5$ cm (beam pipe constraint)
- $11 < R_{max} < 16$ cm
- Area ≈ 2700 cm^2
- $X/X_0 = 0.4\%$ per plane
- Current pixel size scenario: ~25 x 25 μm^2



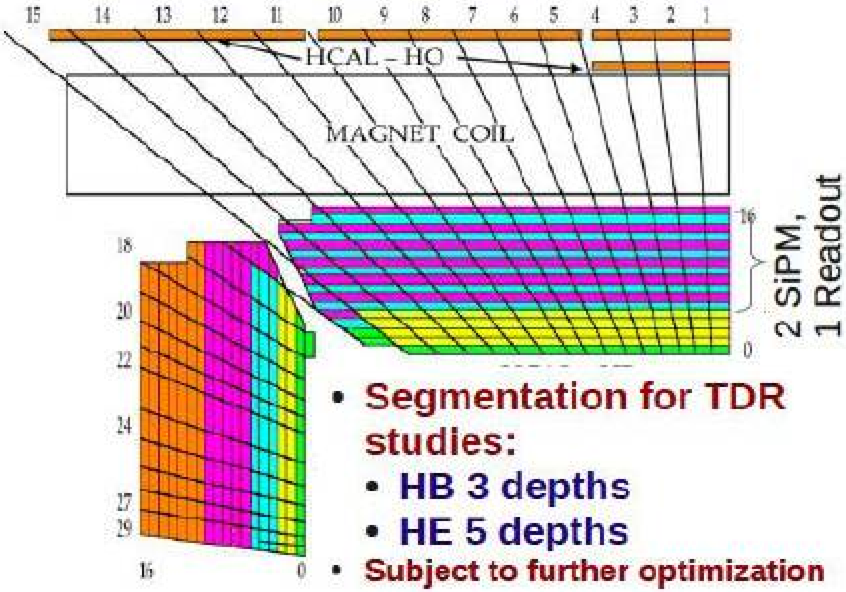
CERN-LHCC-2013-014 ;
LHCC-I-022-ADD-1

Technical Design Report in preparation

16

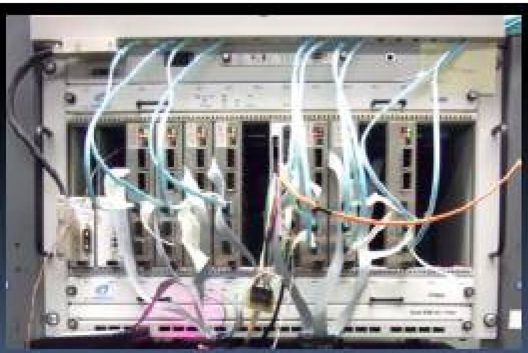
CMS Phase 1 Upgrade

- Finish implementation of new photo-detectors for hadron calorimeter
- Complete coverage of muon read-out chambers, increased granularity (CSC)
- New trigger back-end electronics:
  - Modern FPGAs and muTCA backplane technology for high bandwidth and processing power
  - Allows earlier combination of calorimeter info and muon system



- Segmentation for TDR studies:
  - HB 3 depths
  - HE 5 depths
- Subject to further optimization

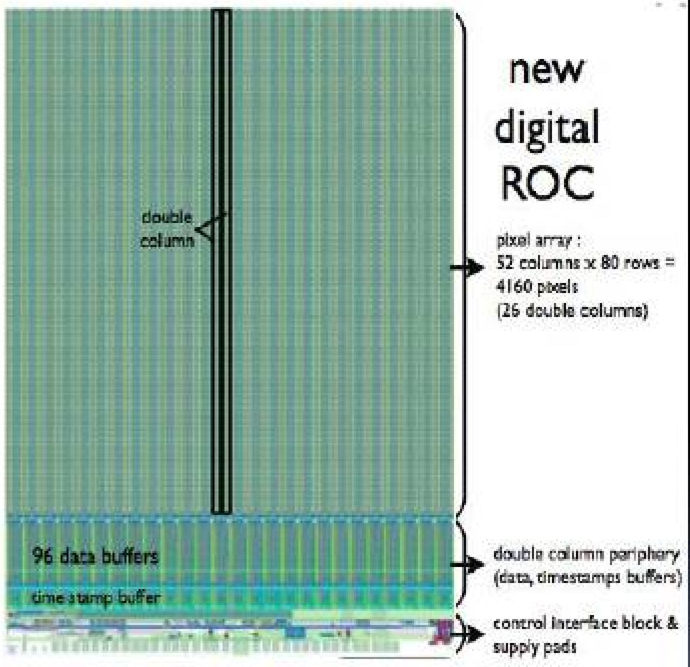
MP7 board Virtex 7 and 72 I/O links at 10Gpbs



Demonstrator of Calorimeter trigger in µTCA crate

CMS Phase 1 pixel detector

- Pixel Size: 100µm x 150µm
- Reduced data loss
  - increased time stamp / data buffers 12/32 → 24/80 to prevent overflow with high occupancy
  - Additional readout buffer (32->96) to reduce readout related data loss
- Increased readout link speed (40 MHz analog→160MHz digital) for pixel address and pulse heights
- Reduced pixel threshold of 1800e from present 3500e



ıtion

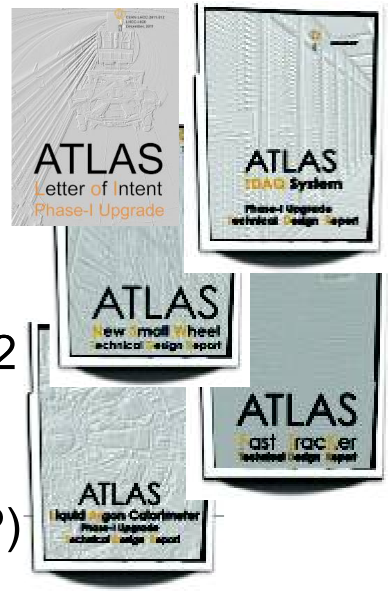
M. Manelli

Phase 1 Upgrade – Run 3

ATLAS

- New trigger back-end electronics & TDAQ
- Adding forward disks in muon spectrometer
- Fast Track Trigger at L2
- New front-end in liquid argon calorimeter

+ Forward physics (AFP)



CMS

- Finish implementation of new photo-detectors for hadron calorimeter
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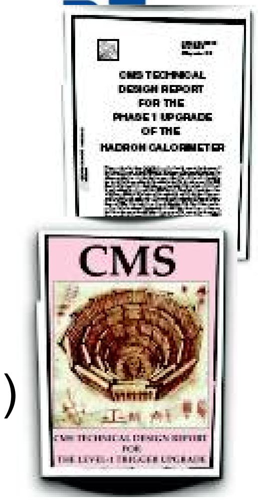
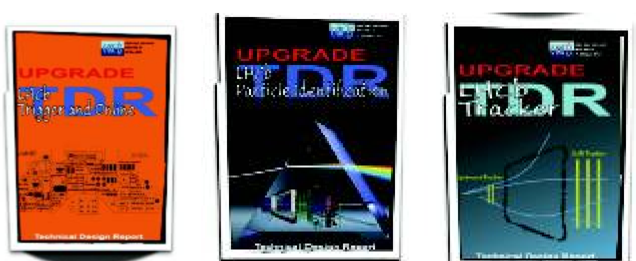


LHCb

- New tracker: pixel + scintillating fibres
- Particle ID: RICH with new MAPMT
- Triggering

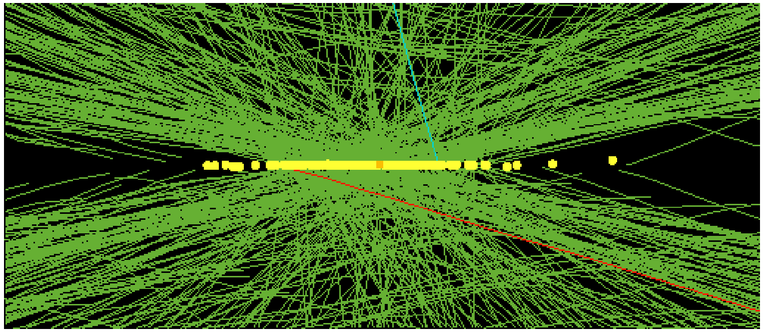


ALICE

- New Pixel detector (ITS)
- TPC with GEM readout
- New Muon Forward Tracker (Pixels)
- New readout for all detectors
- Online offline system

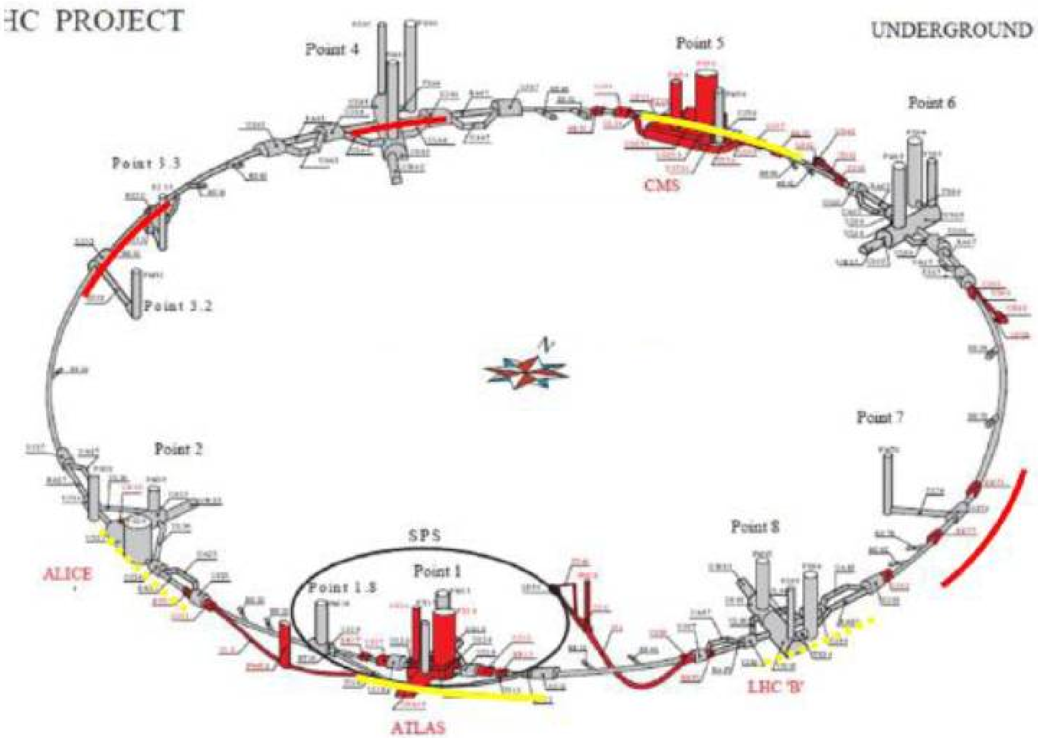
Phase 2 – Run 4+

High luminosity LHC requires major upgrade of ATLAS and CMS

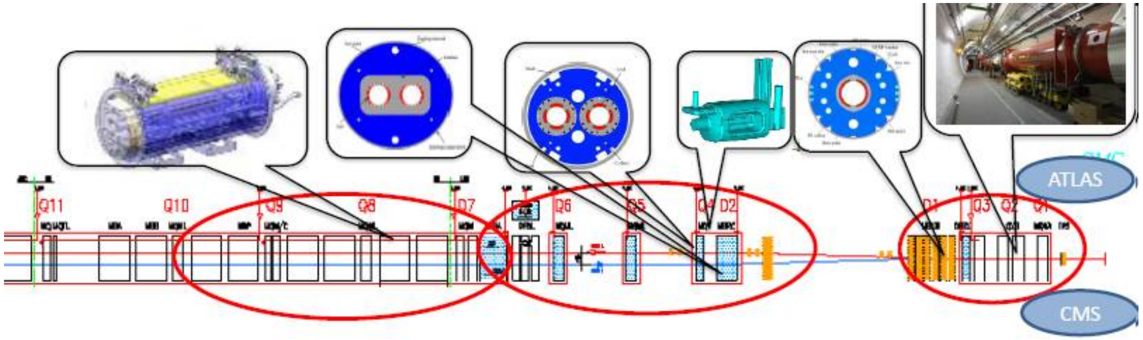


HL-LHC for Run 4+

F. Bordry



- Major intervention on more than 1.2 km of the LHC
- Next project milestone: Cost and schedule review for LIU and HL-LHC in spring 2015



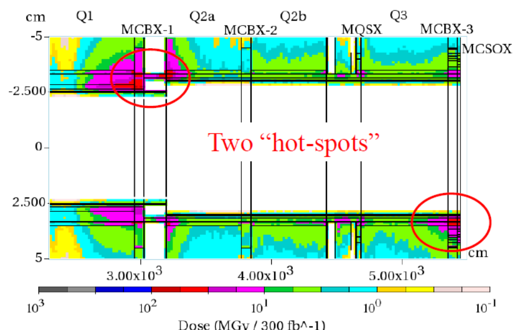
HL-LHC for Run 4+

High Luminosity LHC

F. Bordry

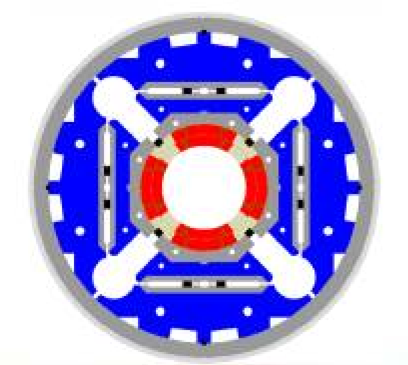
Phase 2 Upgrade – Run 4+

→ New large aperture triplet magnets (Nb_3Sn) due to radiation damage



Expected radiation dose in present triplets after 300 fb^{-1}

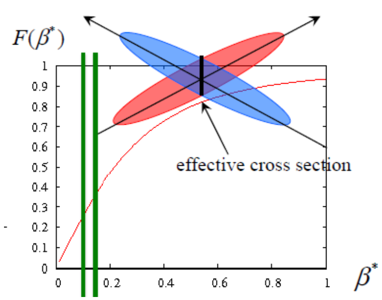
New technology
140 T/m and
150 mm coil aperture

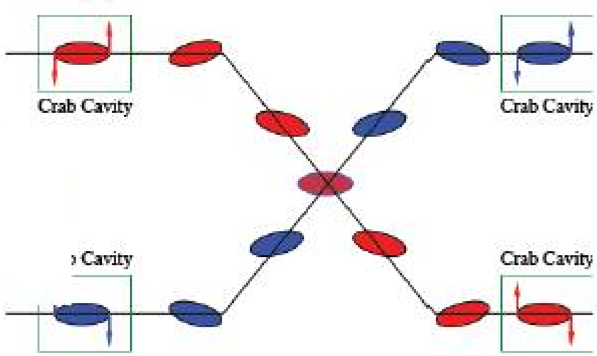


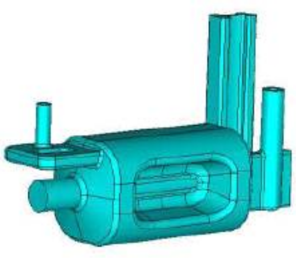
US-LARP MQXF magnet design

→ Crab Cavities for compensation of geometrical reduction
Reduce effect of crossing angle

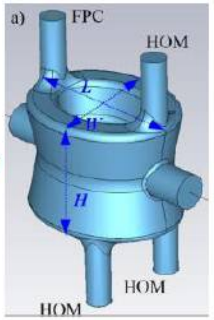
New technology







RF Dipole: Waveguide or waveguide-coax couplers



Double ¼-wave:

Test installation in SPS in 2016/17

Requirements and Challenges for the Phase 2 Detectors (ATLAS + CMS)

Hal Evans

Requirements

SUSY cascades	Triggering & reconstruction of low p_T leptons + identifing heavy flavor
H → ττ	Triggering of τ-leptons
Resonances in top pairs, W, Z, H	Reconstruction of leptons & b-quarks in boosted topologies
High-mass gauge bosons	Good lepton momentum resolution at high p_T
VBF, Missing transverse energy	Allow acceptance in forward region
Efficient tracking with small fake rates	Radiation tolerance and high granularity, low material budget

Challenges

Triggering: compatibility with current trigger system, sustain rates and occupancy

High particle fluences: radiation hardness and activation of material

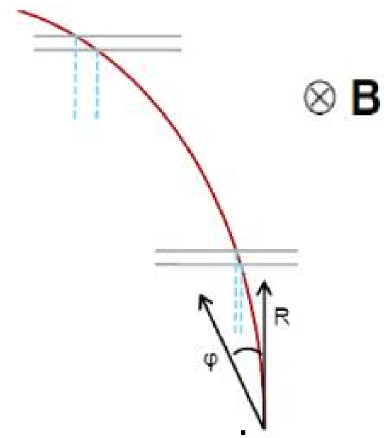
Implementation in existing detector

Improve (at least maintain) at HL-LHC the performance of present detectors

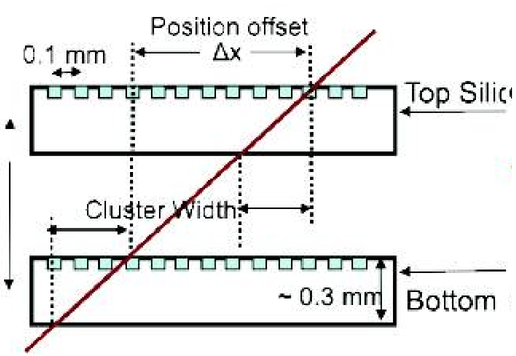
Upgrade Trigger Scheme in CMS

• Track trigger: silicon strip detectors explicitly used for triggering, modules provide time and p_T discrimination → rate reduction due to sharp thresholds (leptons) and isolation (multijet backround reduction)

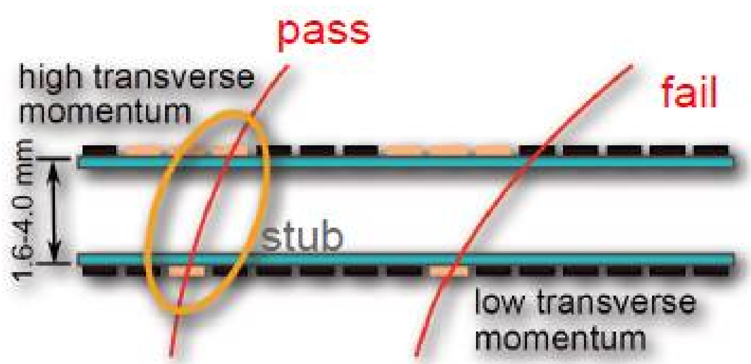
• Aim for p_T to 2 GeV



Preselection of hits due to cluster width
CW ~ radial distance of sensor from interaction point
CW ~ $1/p_T$



p_T discrimination with stacked modules:
exploit bending in magnetic field two closely spaced sensors read out by a single readout chip



sensor spacing and window optimized for best performance
same geometrical cut corresponds to different p_T

→ Correlation on module level to form stubs is sent out via separate trigger path if within p_T cut

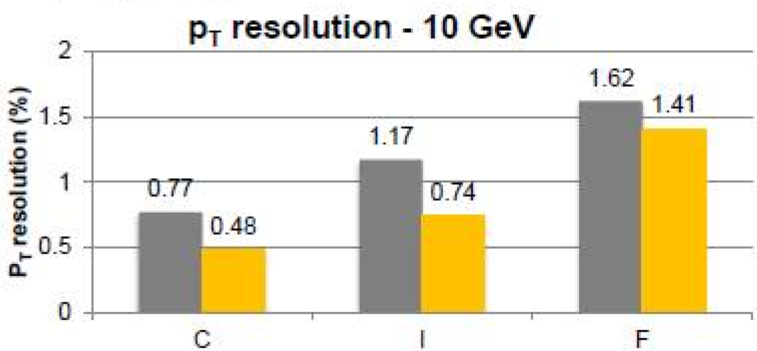
Outer tracker CMS: performance

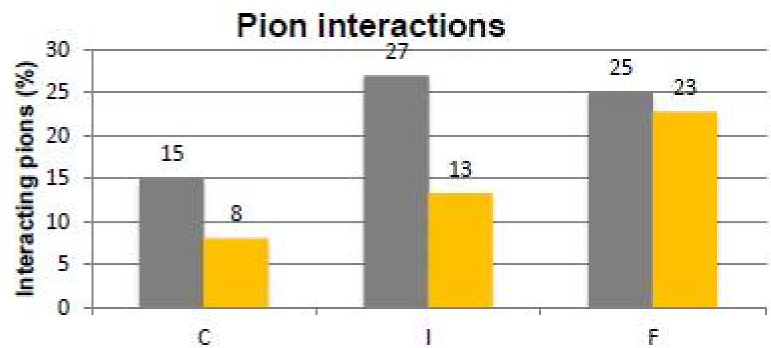
Calculated performance with a "phase-1" pixel detector

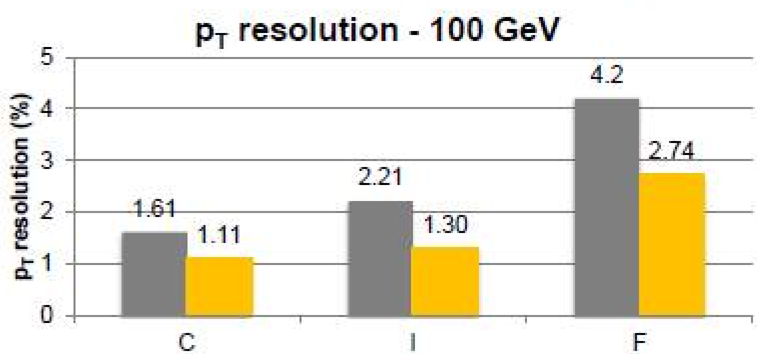
Rapidity regions

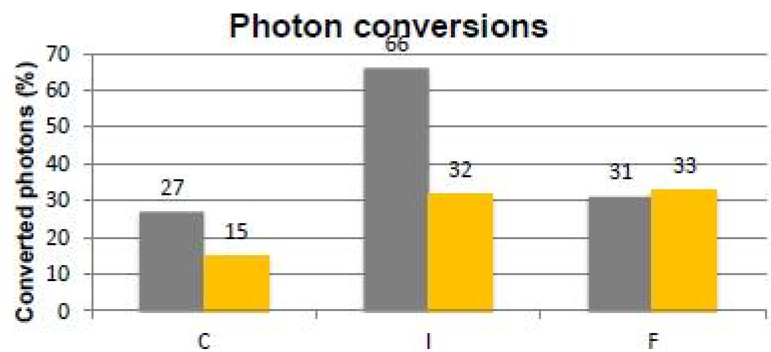
C 0 – 0.8
I 0.8 – 1.6
F 1.6 – 2.4

■ CMS
■ Upgrade









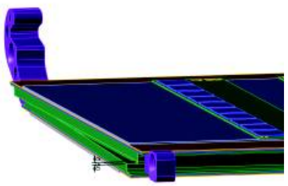
A. Dierlamm, G. Steinbrueck

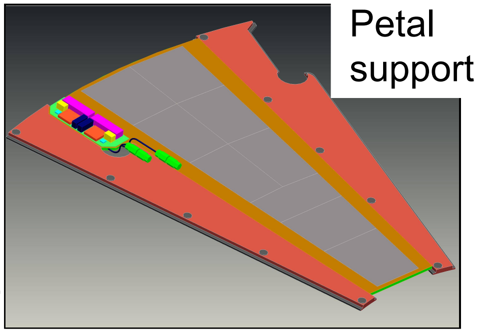
Modularity of ATLAS strip tracker Phase 2

- Staves slid into support cylinders and locked using single edge mounting, afterwards connection of services

- Service modules provide connection between EOS and patch panel: power, TTC, coolant, ground

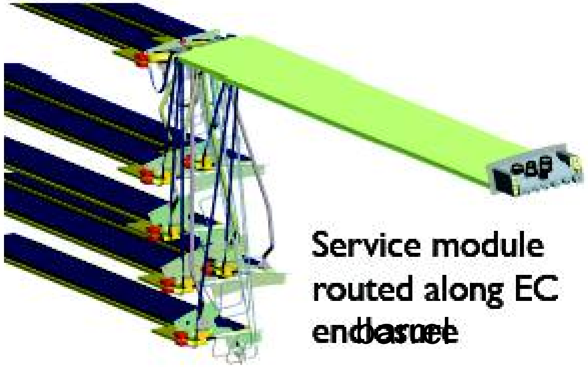
→ Reduce time for installation and material



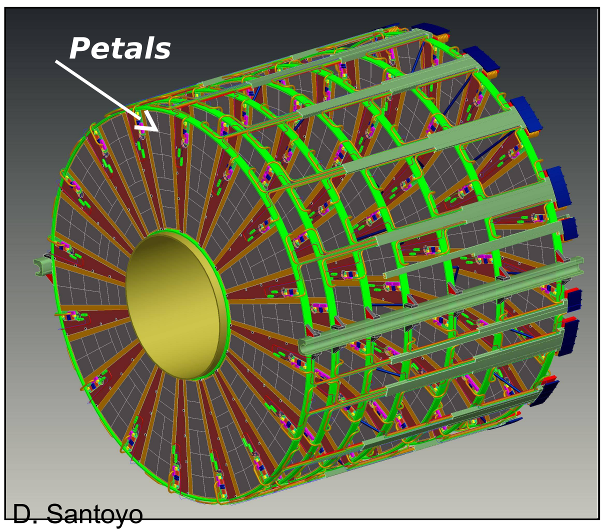


Petal support

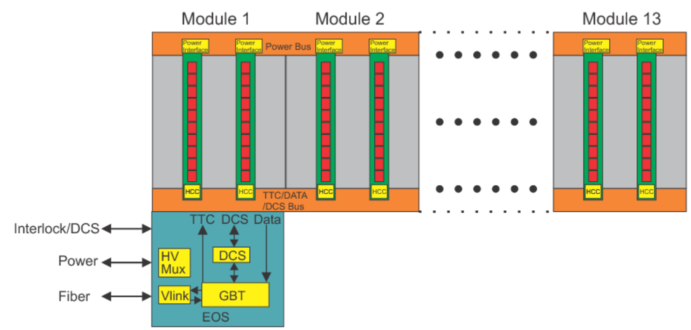
From Ian Wilmut at Forum on Tracking Detector Mechanics, Oxford, 2013 and David Santoyo



Support cylinder for EC where petals are slid in

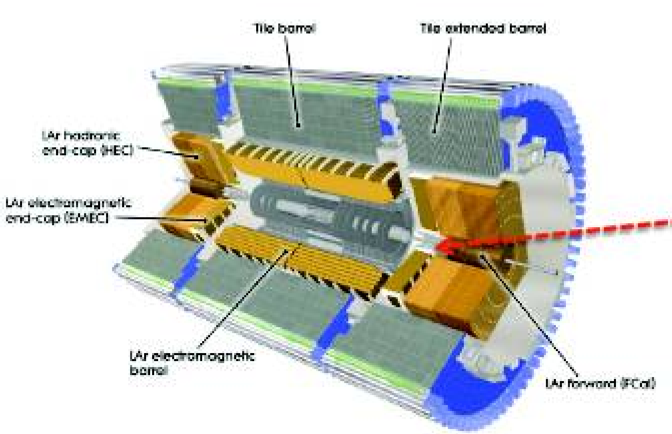


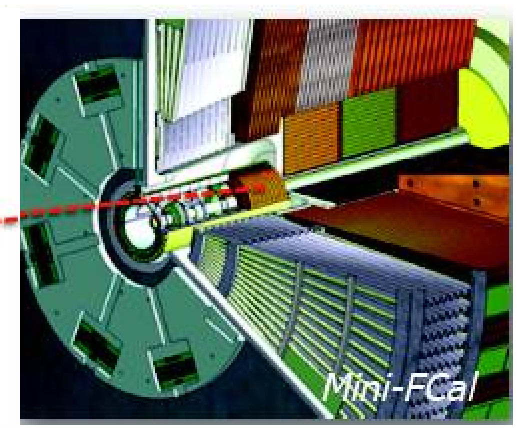
Readout scheme



Phase 2 Upgrade: Calorimetry in ATLAS

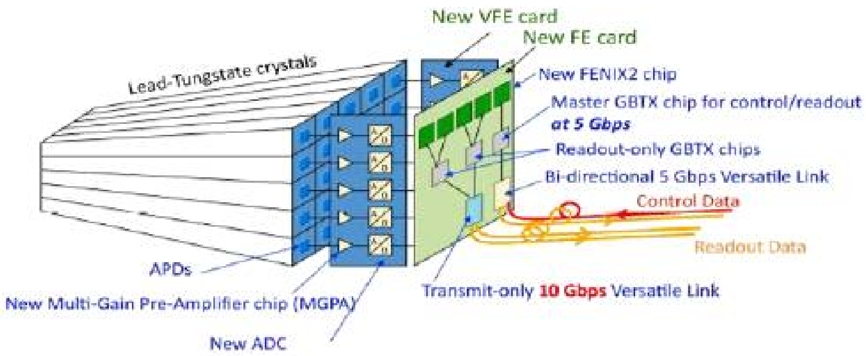
- Replacement of electronics to digitize and move off-detector data for L0/L1 trigger and readout (no on detector buffer)
- EM and hadronic calorimeter don't require upgrade
- Possibly replacement of forward calorimeter with new mini-FCal or sFCal in front of FCAL with greater granularity





Phase 2 Upgrade: Calorimetry CMS

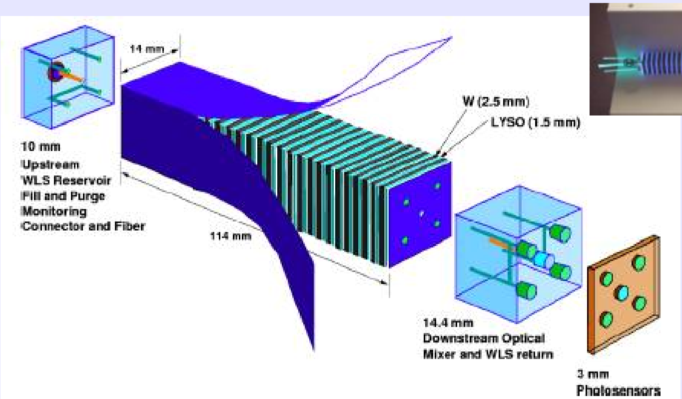
- Replacement of barrel electromagnetic calorimeter electronics (for track trigger latency)



- Replacement of endcap EM calorimeter and hadronic calorimeter due to radiation induced loss of transparency
  Possible concepts:

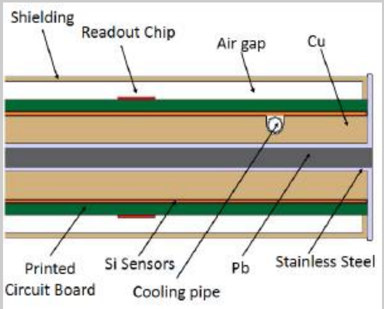
Crystal LYSO Shashlik + Scintillator HE

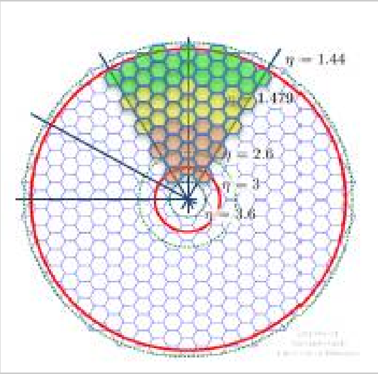
- EM: W/LYSO Shashlik using WLS and SiPM readout
- Hadr: Scintillator-based with 30% of volume tiles + 10% higher rad. tolerance



Silicon + Scintillator backing calorimeter

- EM: Silicon-lead/copper
- Hadr: Silicon-brass
- Scintillator-brass backing calorimeter
- 700 m² silicon pads 0.5-1 cm²

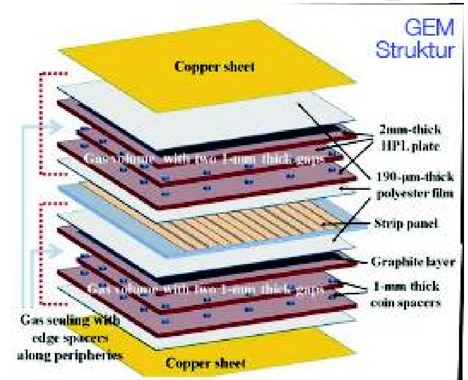


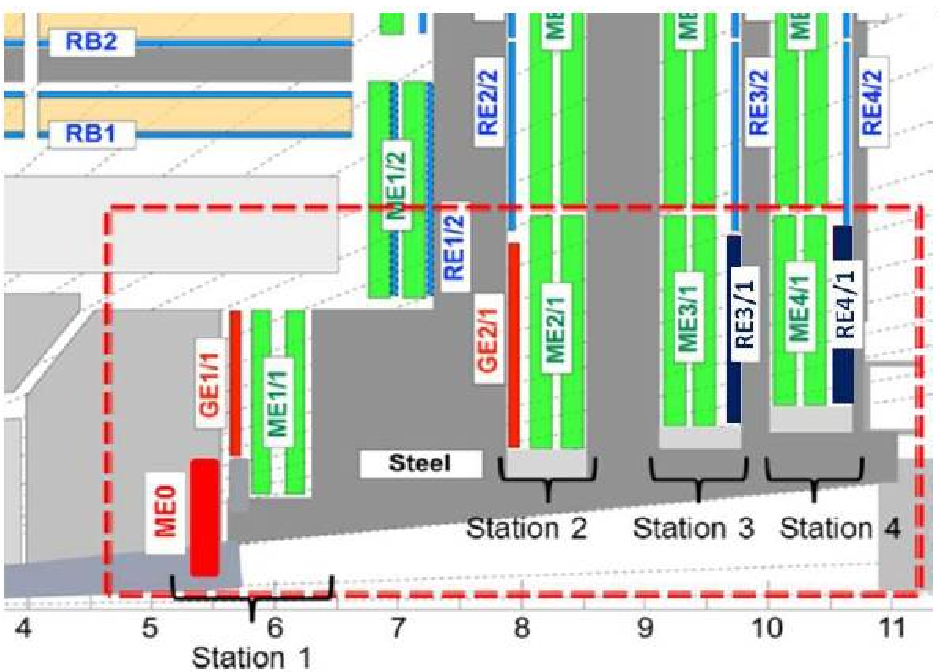


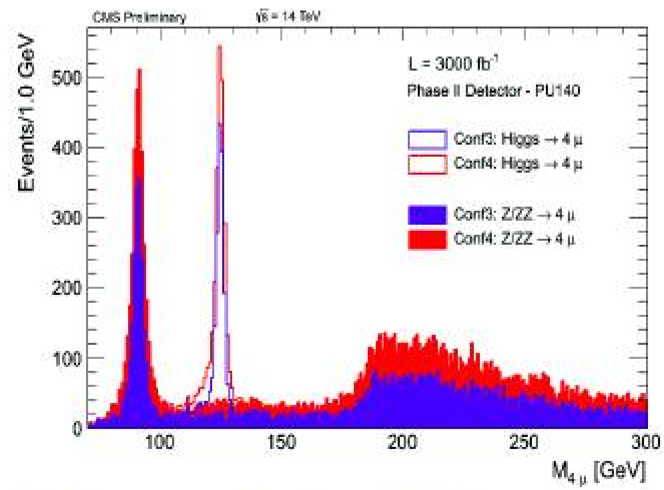
Phase 2 Upgrade: CMS Muon Systems

CMS

- Complete muon stations to $1.6 < |\eta| < 2.4$
  - GEMs in 2 first stations (improved p_T resolution)
  - RPCs in 2 last (timing resolution to reduce background)
- Consider increased coverage to $|\eta| < 4$: ME0 with GEMs
- Replacement of electronics in DT minicrates and CSC inner readout





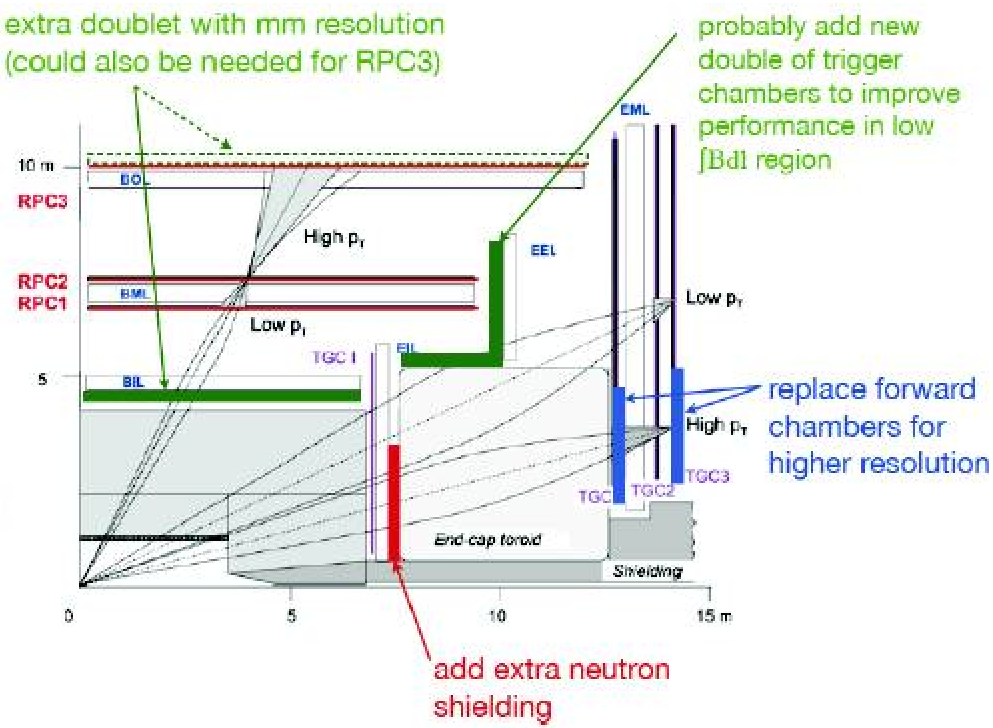


H→ZZ (4μ) without with MEo

Phase 2 Upgrade ATLAS Muon System

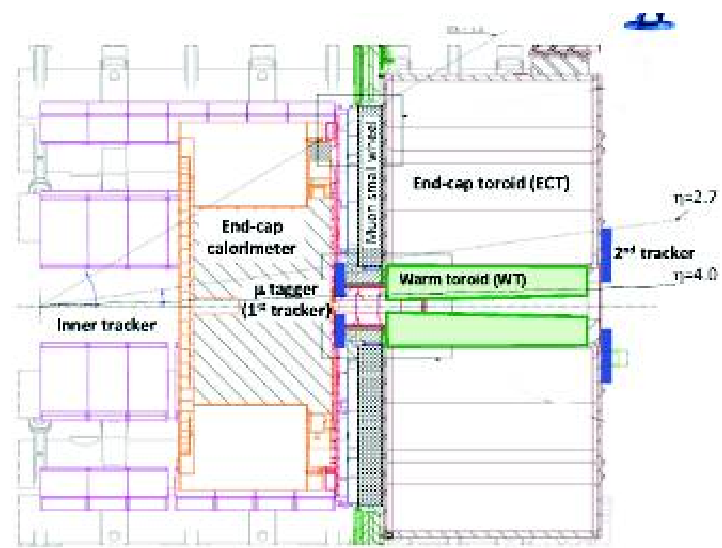
Albert-Ludwigs-Universität Freiburg

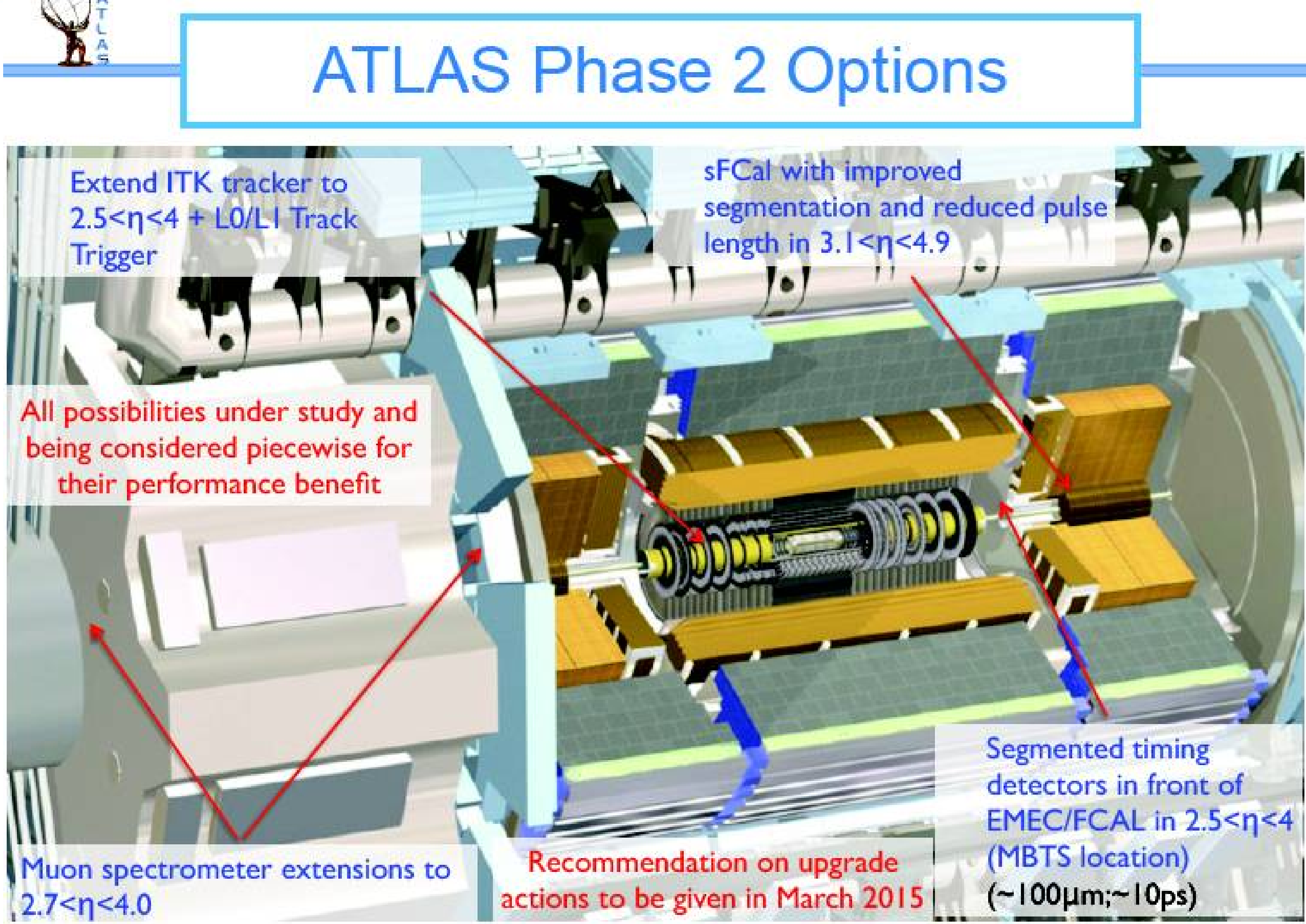
- Muon spectrometer sustains 3000 fb^{-1}: aging studies are ongoing
- Only replace of accessible electronics for more trigger flexibility
- Replacement of precision chambers electronics (MDTs) under investigation to deal with hardware trigger latency



Possible extension to high η under consideration:
- Pixelated chamber before and after EC toroid
- Additional warm EC toroid with 8Tm bending power

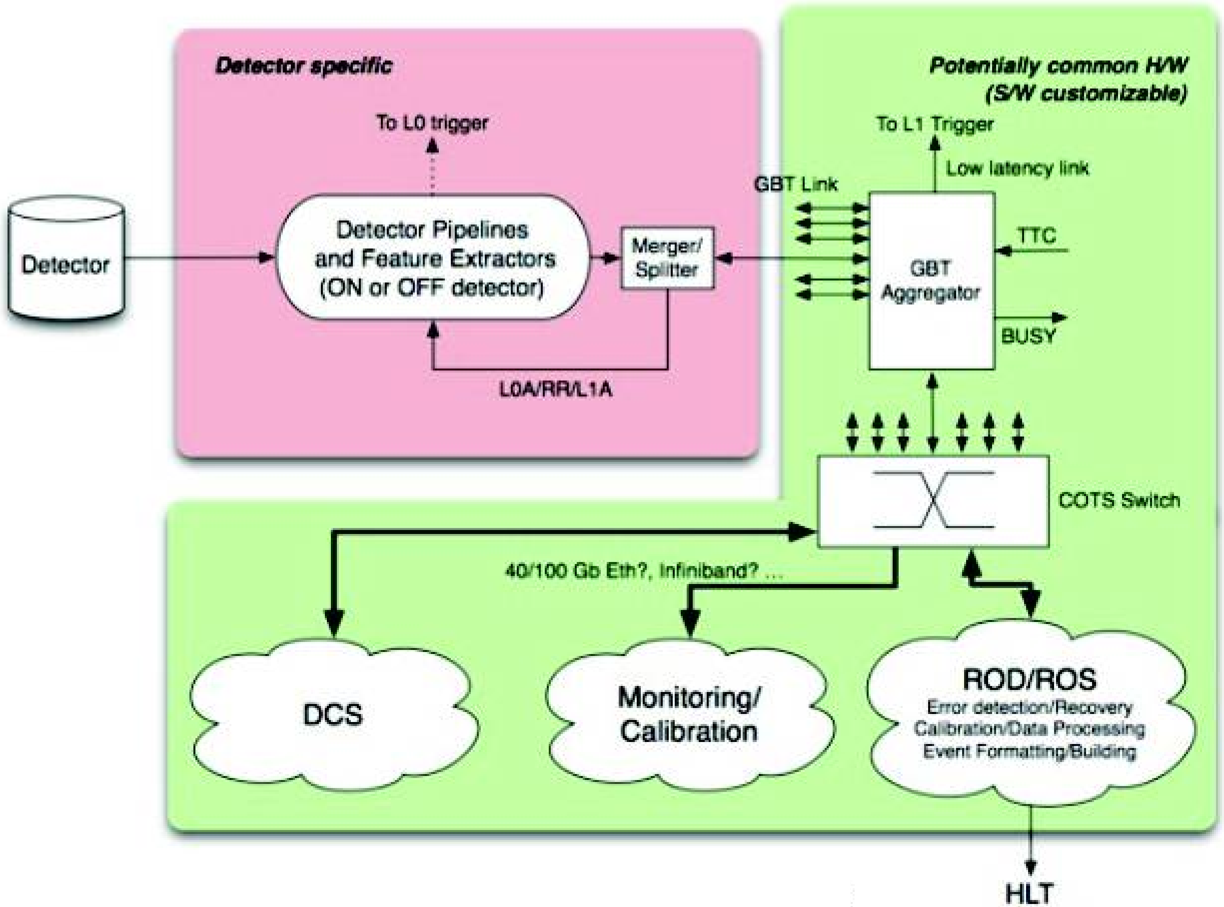
→ resolution better 35% to η = 4





Olga Igonkina, LHCC Nov. 2014

Readout architecture for Phase 2



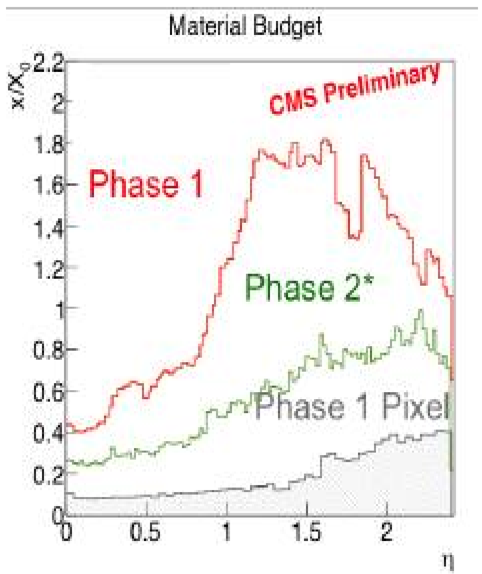
Expected performance: Silicon strip tracker

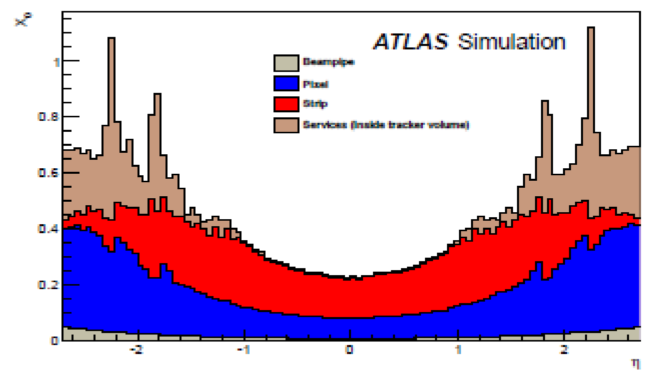
Albert-Ludwigs-Universität Freiburg

Phase 2 Upgrade – Run 4+

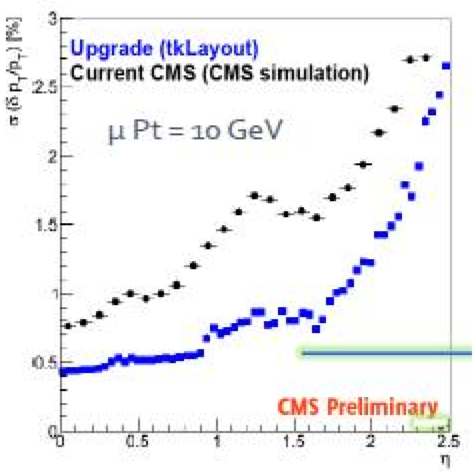
CMS **ATLAS**

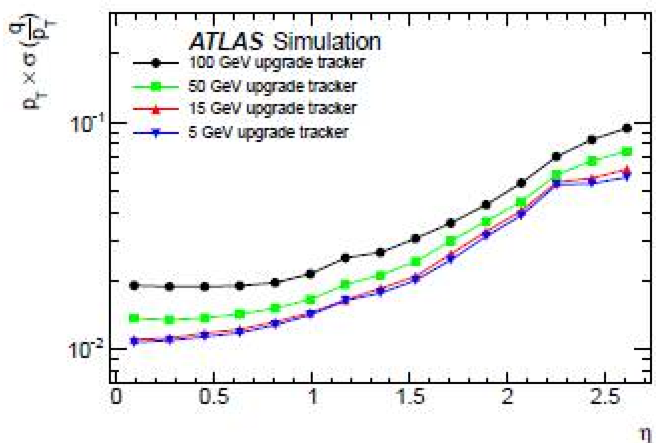
X_0 vs. η:





Muon pT resolution:



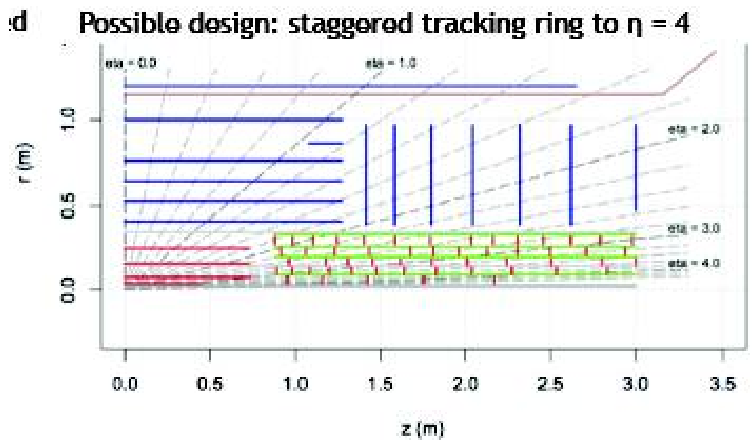


Upgrade Phase 2: ATLAS high η extension

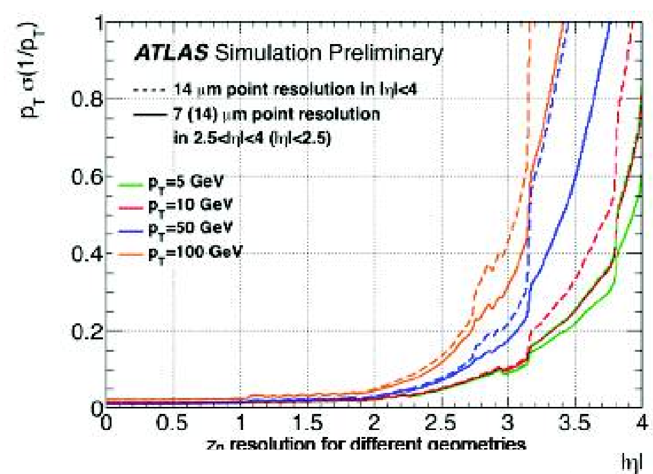
Phase 2 Upgrade – Run 4+

L. Gray, ECFA HL-LHC
Aix-les-Bains Oct. 2014

- Acceptance increase to |η|~4 under evaluation to
  - Better associate jets to tracks
  - Reduce fake rate of jets from pile up in VBF and VBS channels
- Possible extension of tracker, FCAL, muon spectrometer
- Different pixel detector layouts → physics impact under evaluation (for H → ZZ → 4μ: acceptance + 35 %)



Area with 1T magnet field
Finer granularity brings improved p_T resolution



ATL-PHYS-PUB-2014-018

Recommendation in March 2015

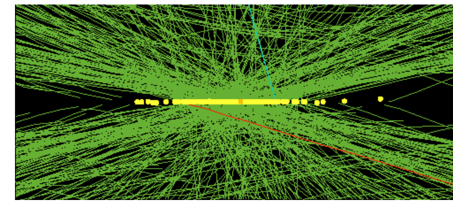
Pile-up at the HL-LHC

Albert-Ludwigs-Universität Freiburg

Phase 2 Upgrade – Run 4+

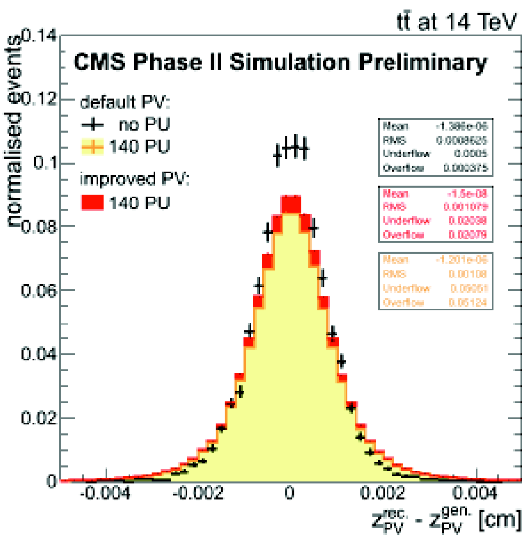
Capabilities to mitigate pile-up assessed in ATLAS and CMS

At L~ $5*10^{34}$ $cm^{-2}s^{-1}$ average pile-up of 140, in-time and out-of-time pile-up occuring

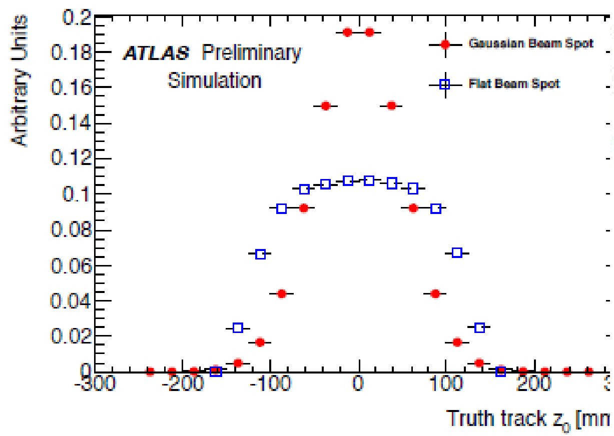


CMS-PHO-GEN-2012-002
78 reconstructed vertices in event from high pile-up

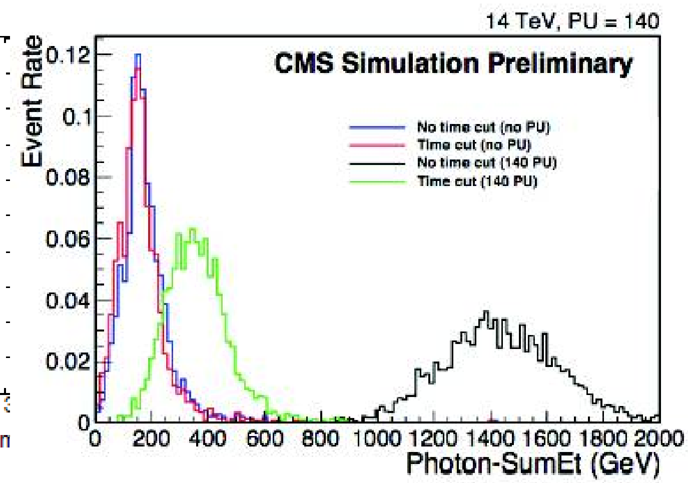
- Drives several detector developments (high eta tracking, muon tagging, timing) and algorithm optimization
- Impact of different beam configurations evaluated in ATLAS



Vertex finding in CMS Phase 2 tracker: new alg. 90% → 96% eff.



Longer beam spot ~flat +- 15cm compared gaussian sigma = 5 cm, ttbar events with 140 pile-up



Precise timing
Sum ET of photons in VBF $H \rightarrow \gamma\gamma$

P. Wells, ECFA HL-LHC Aix-les-Bains Oct. 2014

HL-LHC for Run 4+

O. Brüning, ECFA HL-LHC Aix-les-Bains Oct. 2014

- Baseline for Upgrade of LHC
  - Cryogenic system upgrade (IR1&5 and IR4)
  - Tungsten shielding of triplet
  - New large aperture triplet magnets (Nb_3Sn) due to radiation damage
  - New large aperture insertion magnets (NbTi)
  - Crab Cavities for compensation of geometrical reduction → new technology!
  - Operation with luminosity levelling
  - Collimation upgrade (DS and impedance) to protect magnets
  - Removal of electronics from tunnel region and superconducting link to avoid radiation damage to electronics

HL-LHC for Run 4+

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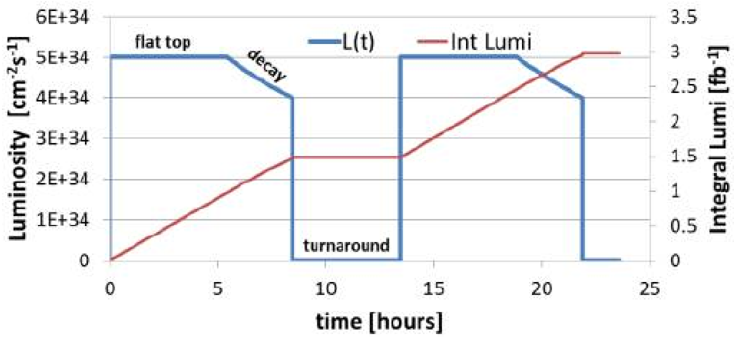
- Shutdown of 30 months
- Aim for maximal luminosity of 3000 fb $^{-1}$

$$L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \epsilon_n \beta^*} F \qquad F = 1/\sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

  - Maximize bunch intensities → Injector complex
  - Minimize beam emittance → LIU
  - Minimize beam size (constant power) → triplet aperture
  - Maximize number of bunches → 25 ns
  - Compensate for "F" (reduce β* (beam focal length at collision point) → flat beam operation or crab kissing scheme
  - Improve machine "efficiency" → minimal unscheduled beam aborts, plan for 160 days/year operation

→ Collider upgrades and operation with levelled peak luminosity L~5-7*10 ^{34} cm $^{-2}$ s $^{-1}$



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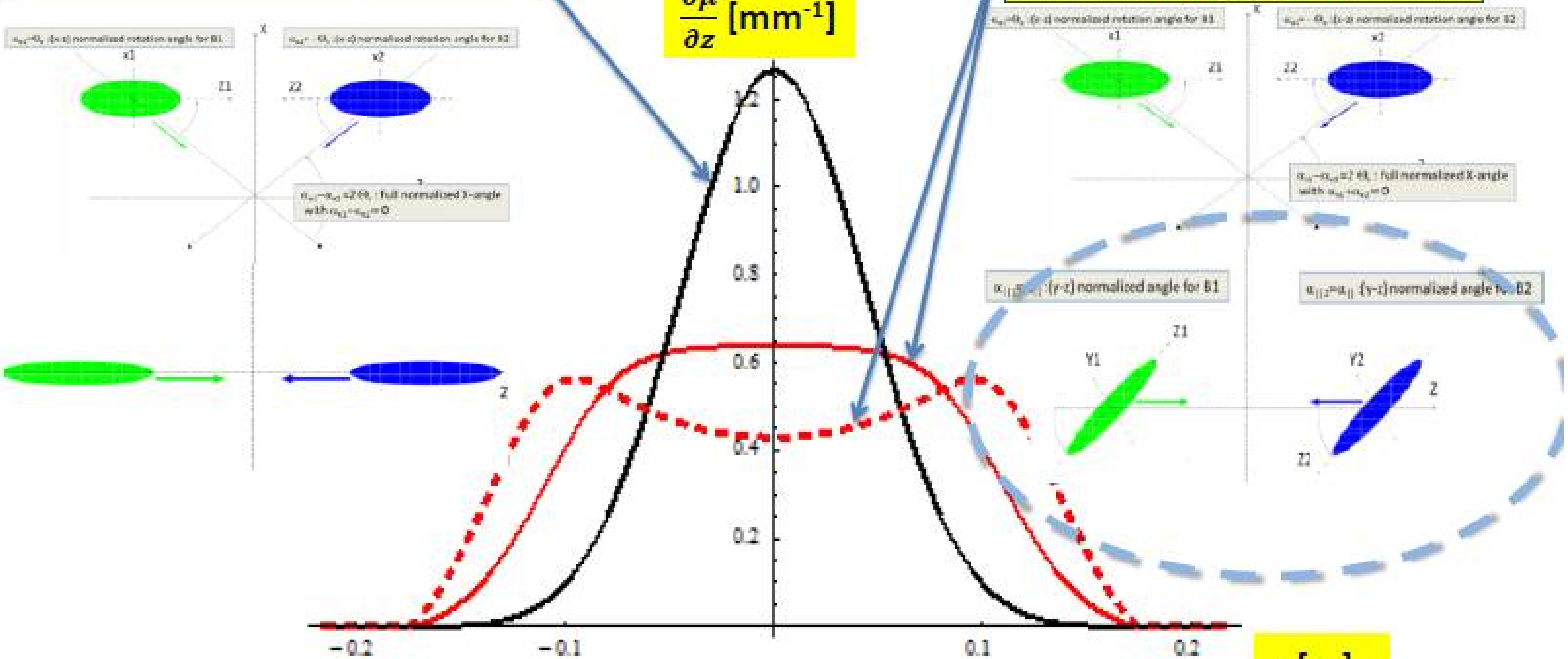
The **Crab-kissing** (CK) scheme for **pile-up density** shaping and leveling (S. Fartoukh)

Baseline: CC in X-plane "only"

Crab-kissing & variants: CC also in ||-plane



... Work on-going together with the machine experiments (S. Fartoukh, A. Valishev, A. Ball, B. Di Girolamo, *et al.*)

Phase 2 Upgrade – Run 4+

HL-LHC Baseline Parameters:

$$L = \gamma \frac{f_{rev}\, n_b\, N_b^{\,2}}{4\pi \varepsilon_n \beta^*} R$$

Parameter	Nominal LHC ([illegible]esign report)	HL-LHC 25ns (standard)	HL-LHC 25 ns (BCMS)	HL-LHC 50ns
Beam energy in collision [TeV]	7	7	7	7
N_b	1.15E+11	2.2E+11	2.2E11	3.5E+11
n_b	2808	2748[1]	2604	1404
Number of collisions at IP1 and IP5	2808	2736	2592	1404
N_{tot}	3.2E+14	6.0E+14	5.7E+14	4.9E+14
beam current [A]	0.58	1.09	1.03	0.89
x-ing angle [μrad]	285	590	590	590
beam separation [σ]	9.4	12.5	12.5	11.4
β^* [m]	0.55	0.15	0.15	0.15
ε_n [μm]	3.75	2.50	2.50	3
ε_L [eVs]	2.50	2.50	2.50	2.50
r.m.s. energy spread	1.13E-04	1.13E-04	1.13E-04	1.13E-04
r.m.s. bunch length [m]	7.55E-02	7.55E-02	7.55E-02	7.55E-02
IBS horizontal [h]	80 -> 106	18.5	18.5	17.2
IBS longitudinal [h]	61 -> 60	20.4	20.4	16.1
Piwinski angle	0.65	3.14	3.14	2.87
Geometric loss factor R0 without crab-cavi[illegible]	0.836	0.305	0.305	0.331
Geometric loss factor R1 with crab-cavity	(0.981)	0.829	0.829	0.838
beam-beam / IP without Crab Cavity	3.1E-03	3.3E-03	3.3E-03	4.7E-03
beam-beam / IP with Crab cavity	3.8E-03	1.1E-02	1.1E-02	1.4E-02
Peak Luminosity without crab-cavity [$cm^{-2} s^{-1}$]	1.00E+34	7.18E+34	6.80E+34	8.44E+34
Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2} s^{-1}$]	(1.18E+34)	19.54E+34	18.52E+34	21.38E+34
Events / crossing without levelling w/o crab-cavity	27	198	198	454
Levelled Luminosity [$cm^{-2} s^{-1}$]		5.00E+34	5.00E34	2.50E+34
Events / crossing (with levelling and crab-cavities for HL[illegible]		138	146	135
Peak line densit[illegible]	[illegible]	1.25	1.31	1.20
Levelling time [h[illegible]	[illegible]	8.3	7.6	18.0

Collision values

LIU required

Impedance, efficiency etc.

ATS required

Crab Cavity required

Leveling required

Efficiency requires long fill times (ca. 10h)!

ECFA High [illegible] Oliver Bruning, CERN