The (upcoming) dawn of CMS and LHC

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CERN and Univ of Athens
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Outline

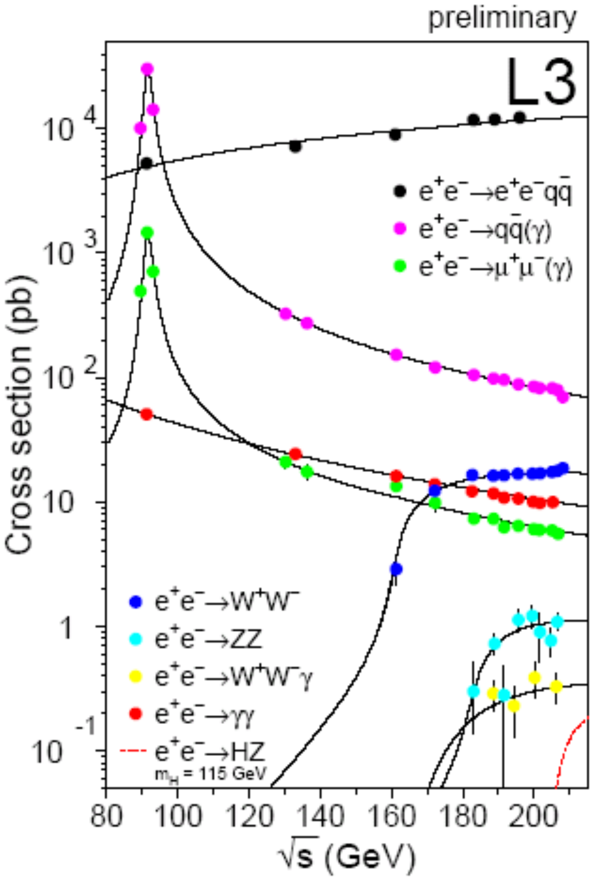
- **Introduction (why all this…)**
- **The LHC and its (high-P_T) pp experiments**
  - **The machine, designing an experiment for it: CMS**
  - **Evolution, construction, installation**
- **Quick look at (asymptotic) physics reach**
- **The LHC (and CMS) startup**
- **"Physics commissioning" and early (2010-2011) physics**
- **Summary…**

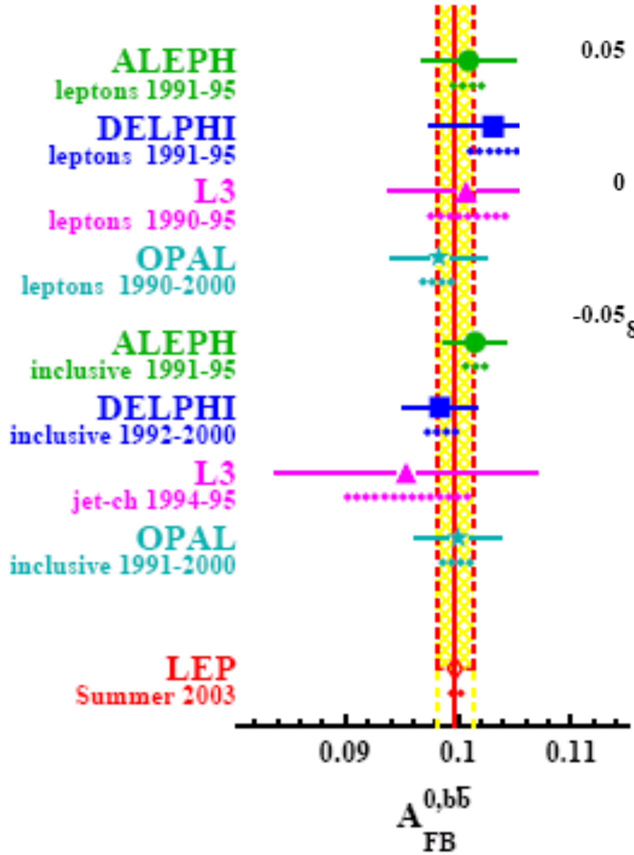
The state (of the Standard Model) of Particle Physics

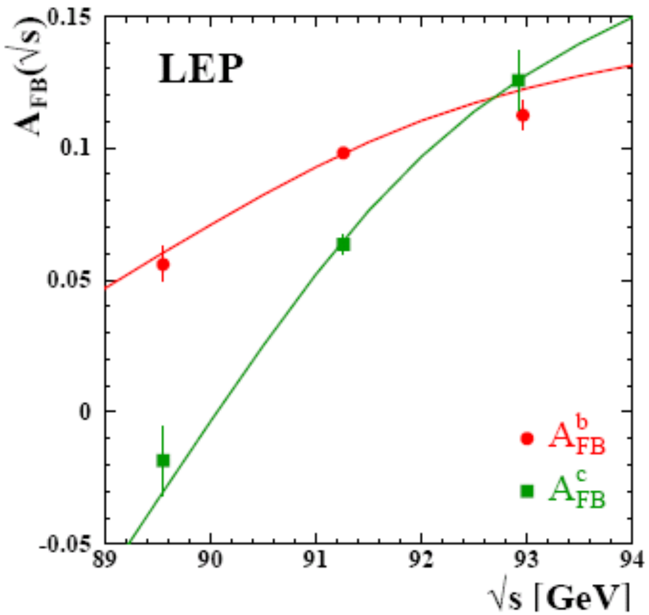
“What we know about the missing Higgs boson”

Standard Model (successes)

- **A true success story: "only" missing piece: the Higgs boson…**







$0.0984 \pm 0.0030 \pm 0.0015$

$0.0954 \pm 0.0101 \pm 0.0056$

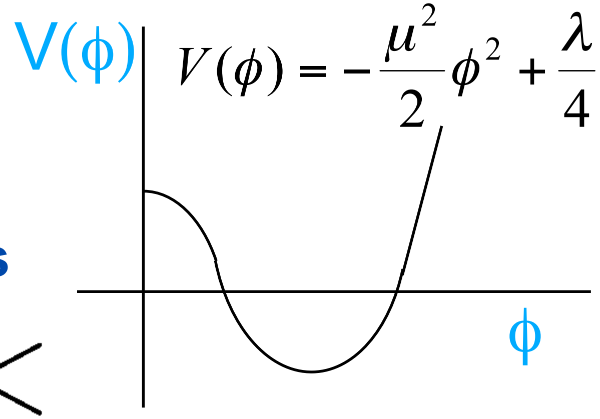
$0.1000 \pm 0.0034 \pm 0.0018$

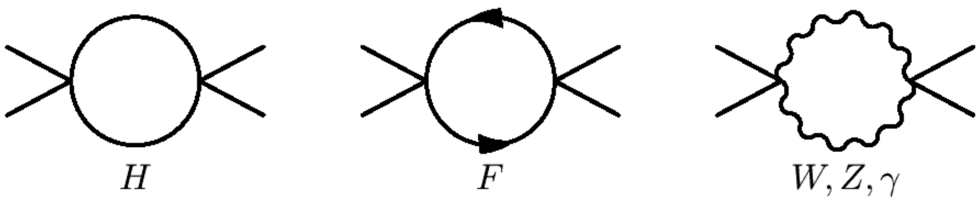
$\langle A_{FB}^{0,b\bar{b}} \rangle = 0.0997 \pm 0.0016$

Limits on M_H (I): EWK vaccum stability

- **Central to the Higgs mechanism: that point with vev≠0 is stable (genuine minimum)**
  - **Radiative corrections can change this**

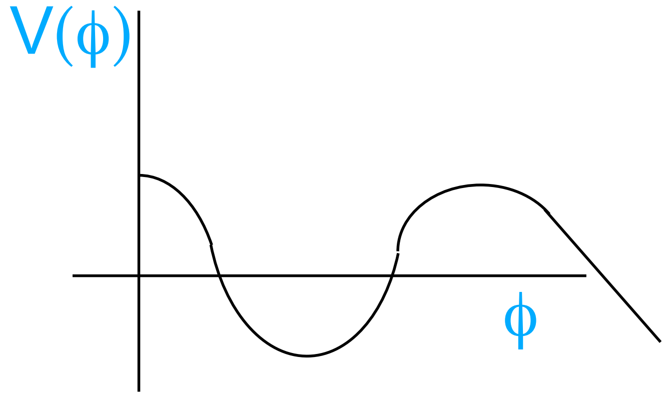
$$V(\phi) = -\frac{\mu^2}{2}\phi^2 + \frac{\lambda}{4}\phi^4$$





$$\Delta V \sim \frac{1}{v^4}\left(M_H^4 + 6M_W^4 + 3M_Z^4 - 12m_t^4\right)H^4 \log\left(H^2 / v^2\right)$$

- For large top masses, potential can curve back down; two terms fighting:
- $\lambda\phi^4$ vs ~ - $(m_t/v)^4$
- And since $M_H^2 \sim \lambda v^2$, get a lower bound on M_H (~ 130 GeV)



Limits on M_H (II): triviality bound

- **From previous discussion: need a high value of λ (i.e. self-coupling) to protect the vacuum**
  - However, the running of the coupling results in an increase with Q^2:

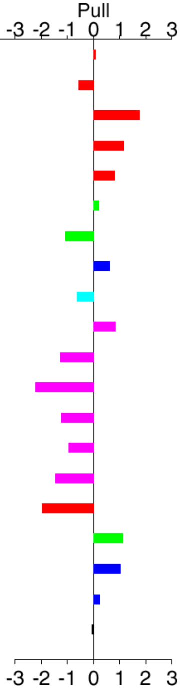
$$\lambda\left(Q^2\right) = \frac{\lambda\left(Q_0^2\right)}{1 - \lambda(Q_0^2)/16\pi^2 \log\left(Q^2/Q_0^2\right)}$$

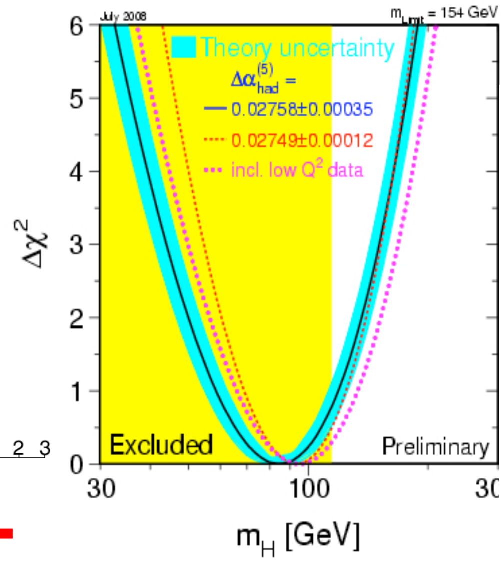
  - So, as $Q^2 \rightarrow \infty$, $\lambda \rightarrow \infty$
  - Alternative: if λ is normalized to a finite value at the pole then it must vanish at low Q^2. Theory is non-interacting → “trivial”
  - Way out: assume that analysis breaks down at some scale Λ (clearly, when gravity gets added, things will change)

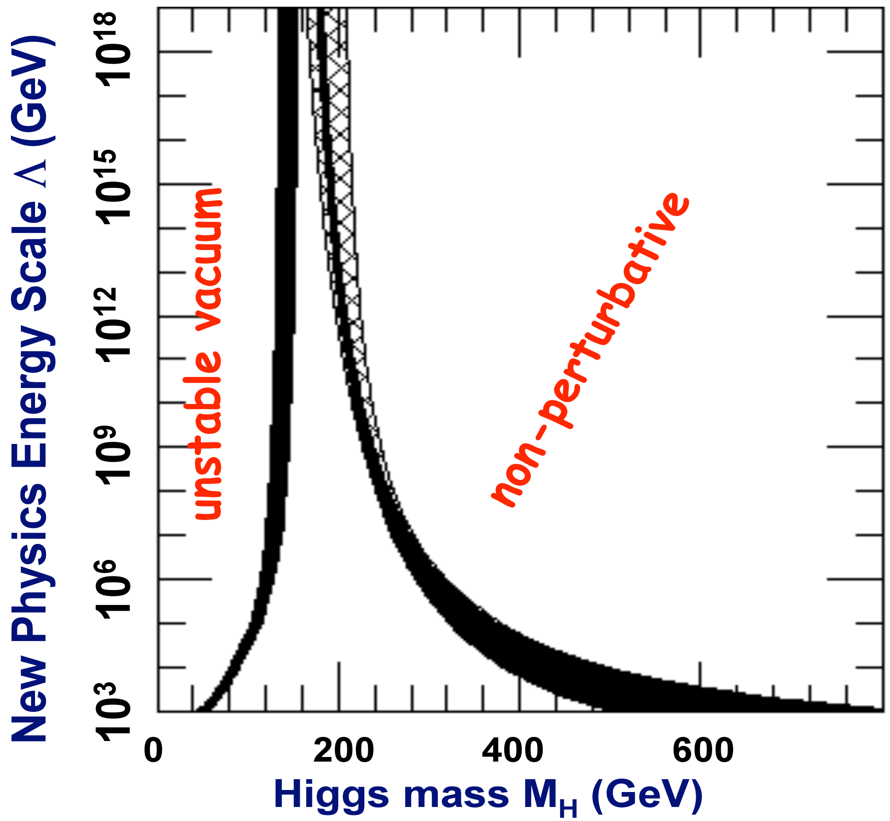
$$\Lambda \le M_H \exp\left(\frac{4\pi^2 v^2}{3M_H^2}\right)$$

Information on M_H: summary

	Measurement	Pull
m_Z [GeV]	91.1871 ± 0.0021	.08
Γ_Z [GeV]	2.4944 ± 0.0024	-.56
σ^0_{hadr} [nb]	41.544 ± 0.037	1.75
R_e	20.768 ± 0.024	1.16
$A^{0,e}_{fb}$	0.01701 ± 0.00095	.80
A_e	0.1483 ± 0.0051	.21
A_τ	0.1425 ± 0.0044	-1.07
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.60
m_W [GeV]	80.350 ± 0.056	-.62
R_b	0.21642 ± 0.00073	.81
R_c	0.1674 ± 0.0038	-1.27
$A^{0,b}_{fb}$	0.0988 ± 0.0020	-2.20
$A^{0,c}_{fb}$	0.0692 ± 0.0037	-1.23
A_b	0.911 ± 0.025	-.95
A_c	0.630 ± 0.026	-1.46
$\sin^2\theta^{lept}_{eff}$	0.23099 ± 0.00026	-1.95
$\sin^2\theta_W$	0.2255 ± 0.0021	1.13
m_W [GeV]	80.448 ± 0.062	1.02
m_t [GeV]	174.3 ± 5.1	.22
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.05



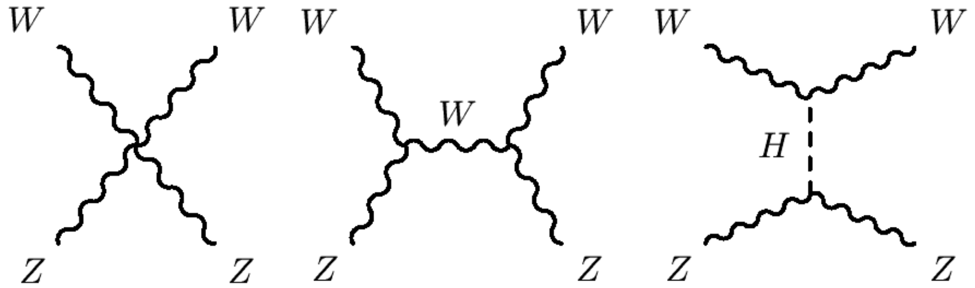




We do not know the Higgs mass

Strong boson-boson scattering

- **Example: $W_L Z_L$ scattering**
  - W, Z polarization vector ε^μ satisfies: $\varepsilon^\mu p_\mu=0$;
    - for $p_\mu=(E,0,0,p)$, $\varepsilon^\mu=1/M_V(p,0,0,E) \approx P^\mu/M_V+O(M_V/E)$
  - Scattering amplitude ~ $(p_1/M_W)\,(p_2/M_Z)\,(p_3/M_W)\,(p_4/M_Z)$, i.e. $\sigma \sim s^2/M_W^2 M_Z^2$



  - Taking $M_H \to \infty$ the H diagram goes to zero (~ $1/M_H^2$)
  - Technicalities: diagrams are gauge invariant, can take out one factor of s
    - but the second always remains (non-abelian group)
  - Conclusion: to preserve unitarity, one must switch on the H at some mass
    - Currently: $M_H \leq 800$ GeV

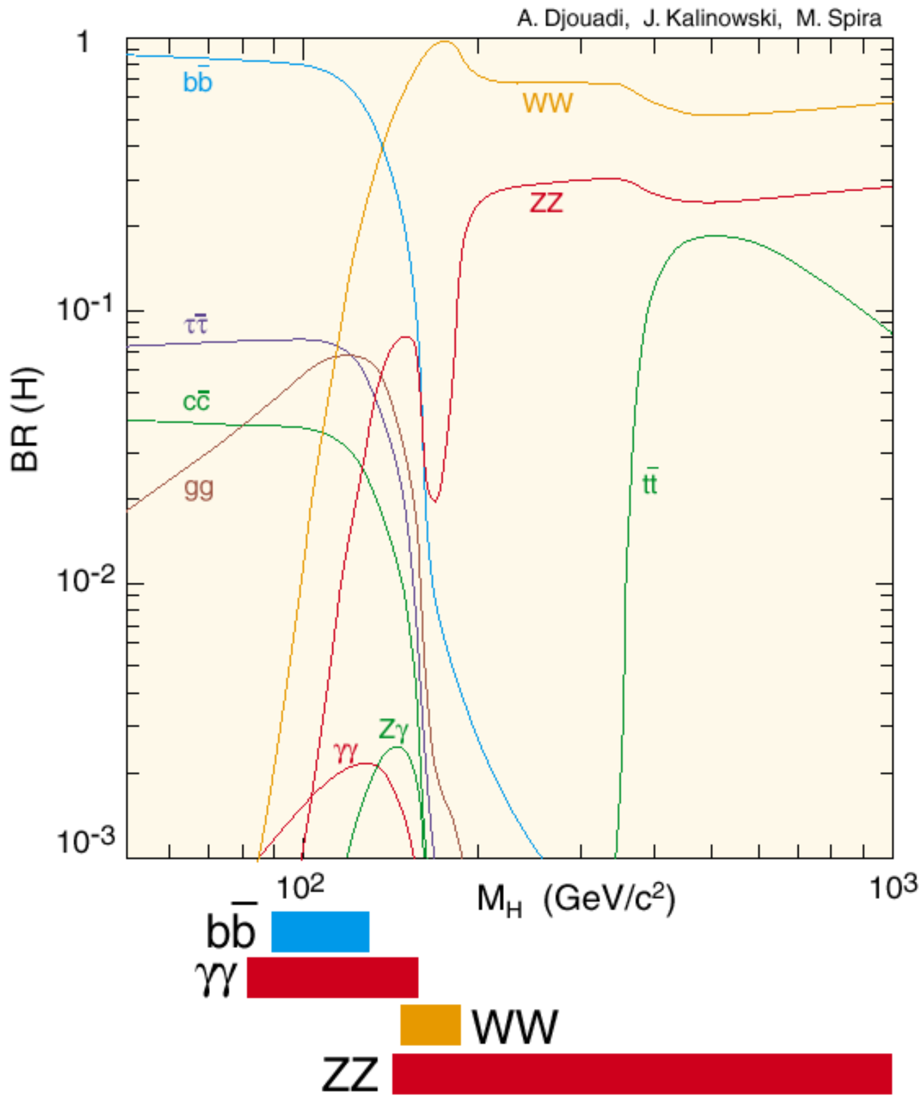
Summary: the TeV scale

- LEP, SLC and the Tevatron: established that we really understand the physics at energies up to 100 GeV
  - And any new particles have masses above 200-300 GeV and in some cases TeV
- The Higgs itself can have a mass up to ~700-800 GeV;
  - if it's not there, something must be added by ~1.2 TeV, or WW scattering exceeds unitarity
- Even if the Higgs exists, all is not 100% well with the Standard Model alone: next question is why is the (Higgs) mass so low?
  - The same mechanism that gives all masses would drive the Higgs to the Planck scale. If SUSY is the answer, it must show up at O(TeV)
  - Recent: extra dimensions. Again, something must happen in the O(1-10) TeV scale if the above issues are to be addressed
- Conclusion: we need to study the TeV region

SM Higgs, New Physics and Detectors

- **Two basic requirements:**
  - an accelerator (energy…)
  - (since we don't know how New Physics will manifest itself):
    - "general-purpose" experiments covering as much of the solid angle as possible ("4π")

    → detectors must be able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….



Going after the Higgs: the Large Hadron Collider (LHC)

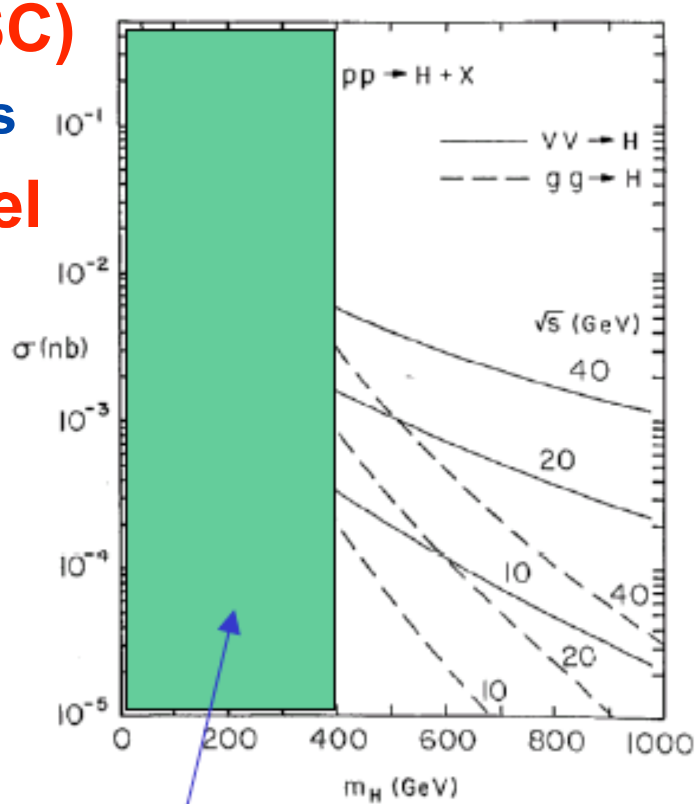
The accelerator

Designing an experiment for the LHC

Some challenges

A machine for EWSB

- **Superconducting Supercollider (SSC)**
  - **By now: would have had 3rd-gen results**
- **Next option: use existing LEP tunnel at CERN**
  - **Large Hadron Collider**

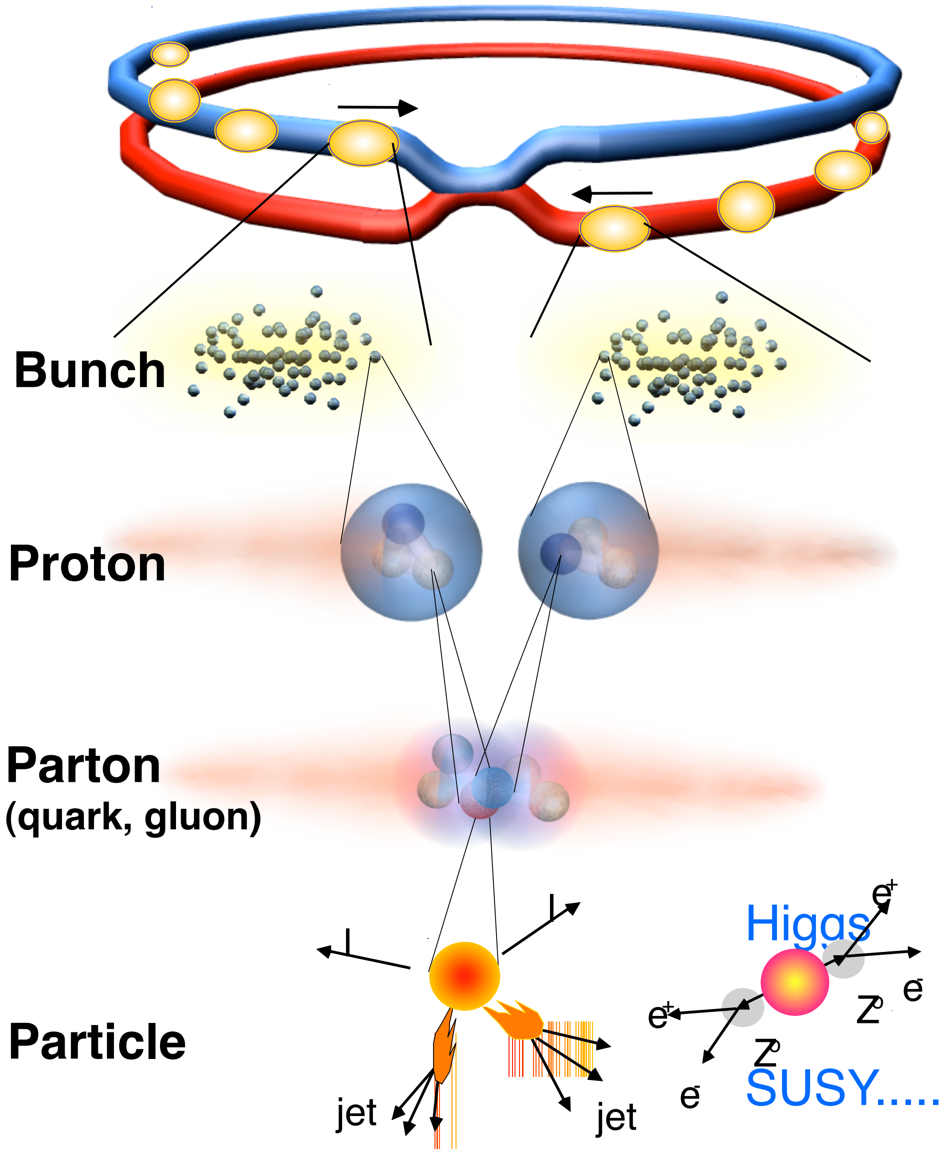


D.Dicus, S. Willenbrock

Phys.Rev.D32:1642,1985

Not true any more (M_T=175 GeV)

Collisions at the LHC: summary



Proton - Proton	2804 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	$10^{34} cm^{-2}s^{-1}$
Crossing rate	40 MHz
Collision rate ≈	10^7-10^9

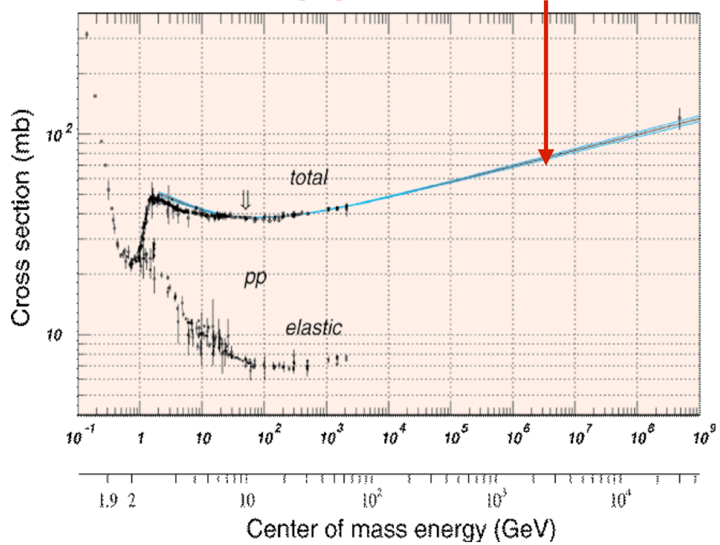
New physics rate ≈ .00001 Hz

Event selection:
1 in 10,000,000,000,000

pp cross section and min. bias

- **# of interactions/crossing:**
  - **Interactions/s:**
    - Lum = 10^{34} $cm^{-2}s^{-1}$=$10^7 mb^{-1}Hz$
    - $\sigma(pp)$ = 70 mb
    - Interaction Rate, R = $7x10^8$ Hz
  - **Events/beam crossing:**
    - Δt = 25 ns = $2.5x10^{-8}$ s
    - Interactions/crossing=17.5
  - **Not all p bunches are full**
    - 2835 out of 3564 only
    - Interactions/"active" crossing = 17.5 x 3564/2835 = 23

$\sigma(pp) \approx 70$ mb



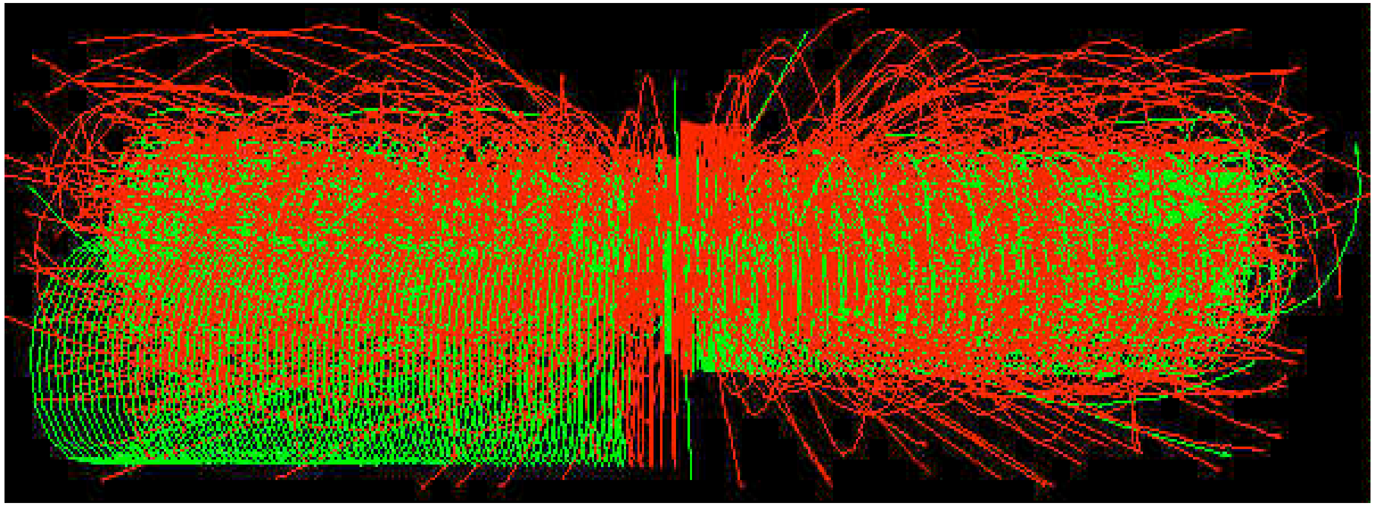
Operating conditions (summary):
1) A "good" event containing a Higgs decay +
2) $\approx$ 20 extra "bad" (minimum bias) interactions

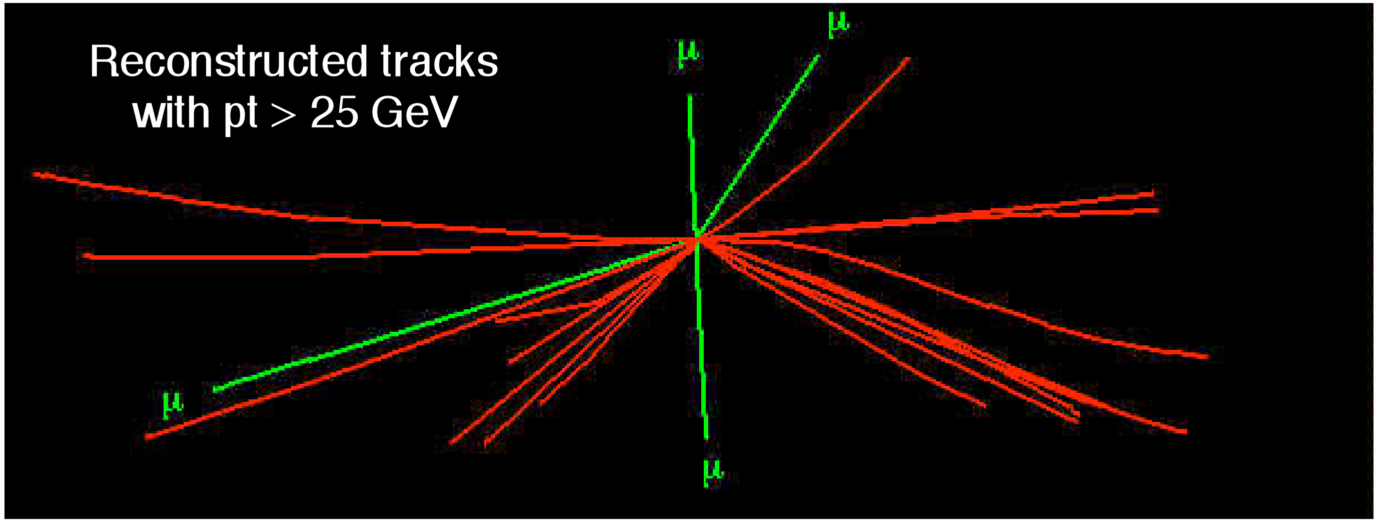
pp collisions at 14 TeV at 10^{34} $cm^{-2}s^{-1}$

- 20 min bias events overlap
- H→ZZ

Z →μμ

H→ 4 muons: the cleanest ("golden") signature





And this (not the H though…) repeats every 25 ns…

LHC challenges: detector design

- **LHC detectors must have fast response**
  - Otherwise will integrate over many bunch crossings → large "pile-up"
  - Typical response time : 20-50 ns

    → integrate over 1-2 bunch crossings → pile-up of 25-50 min-bias

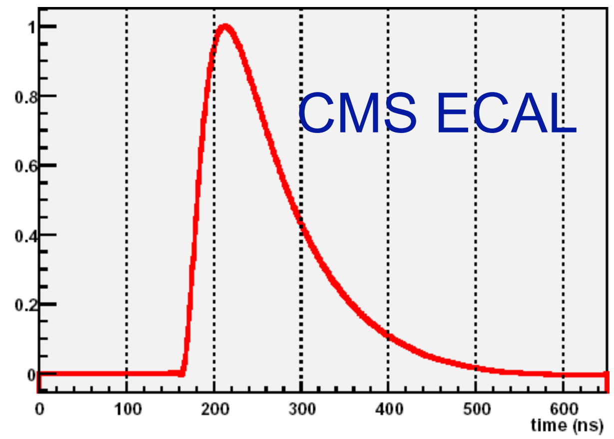
    → very challenging readout electronics
- **LHC detectors must be highly granular**
  - Minimize probability that pile-up particles be in the same detector element as interesting object (e.g. γ from $H \to \gamma\gamma$ decays)

    → large number of electronic channels

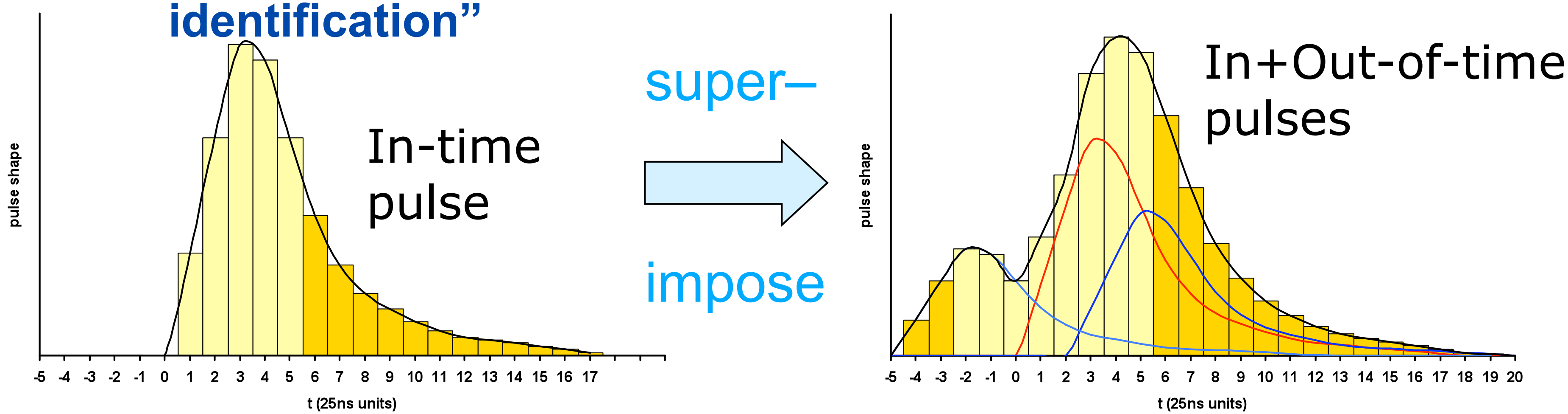
    → high cost
- **LHC detectors must be radiation resistant:**
  - high flux of particles from pp collisions → high radiation environment e.g. in forward calorimeters:
    - up to 10^{17} n/cm^2 in 10 years of LHC operation
    - up to 10^7 Gy (1 Gy = unit of absorbed energy = 1 Joule/Kg)

Pile-up & Electronics; BCID

"In-time" pile-up: particles from the same crossing but from a different pp interaction

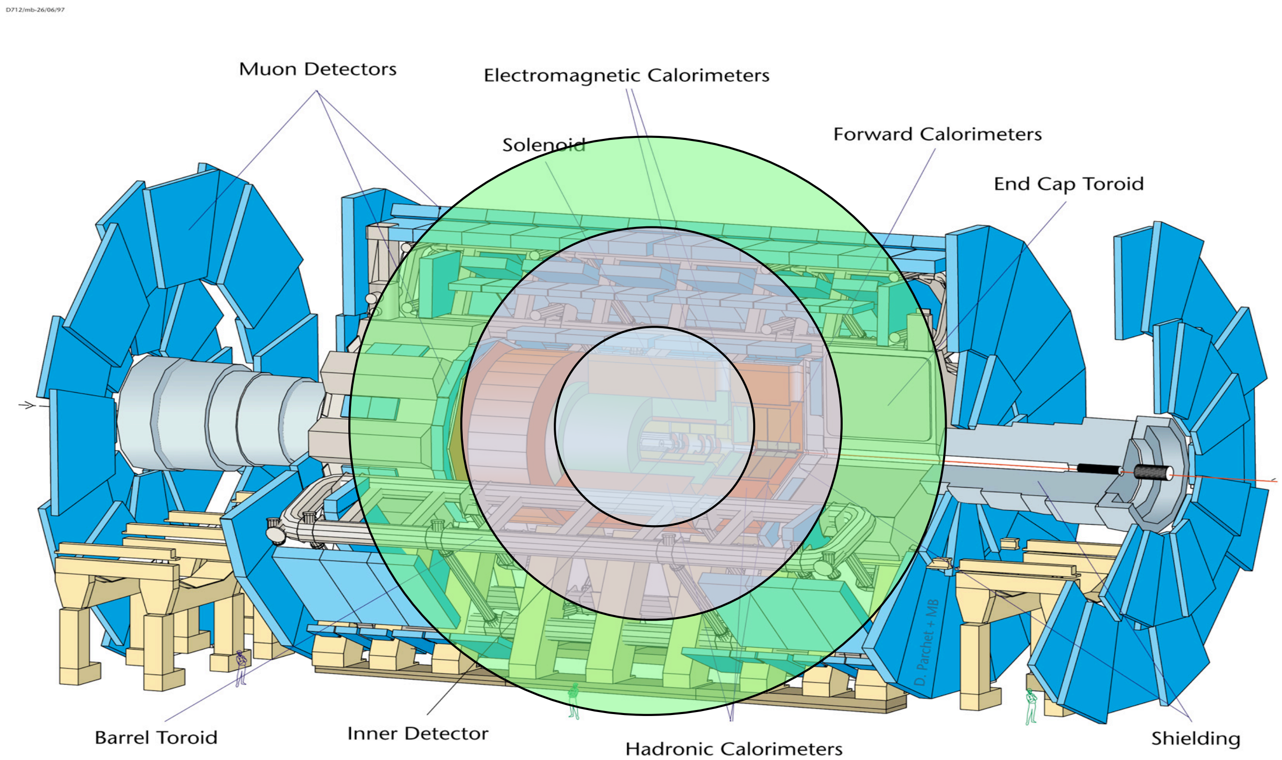


- **Long detector response/ pulse shapes:**
  - **"Out-of-time" pile-up: left-over signals from interactions in previous crossings**
  - **Need "bunch-crossing identification"**



Synchronization

- Time-of-flight (25 ns = 7.5 m < detector size)
  - Plus intra-channel synchronization
  - Plus inter-detector synchronization
- http://cmsdoc.cern.ch/cms/TRIDAS/html/WELL2.html



Detector design at hadron colliders

- **At high luminosity hadron colliders: need to measure muon momenta online – with sufficient accuracy for triggering**

Solenoid	BR^2	Tm^2	Tm	Δr(Fe) (m)
1.GEM	$0.8*9^2$	65	7	-
2.CMS	$4*3^2$	36	12	~1.5
3.ALEPH'	$3*2.5^2$	19	7.5	<1
4.ATLAS	$2*1.2^2$	3	2.4	-

1: low-field inner tracking

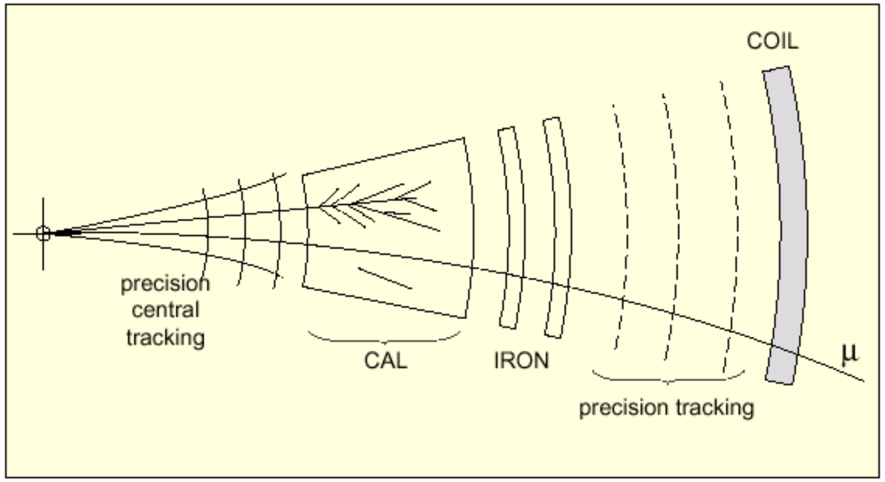
2: bending power at high eta

3: Coil at hadron shower max, saturated iron for muons too thin

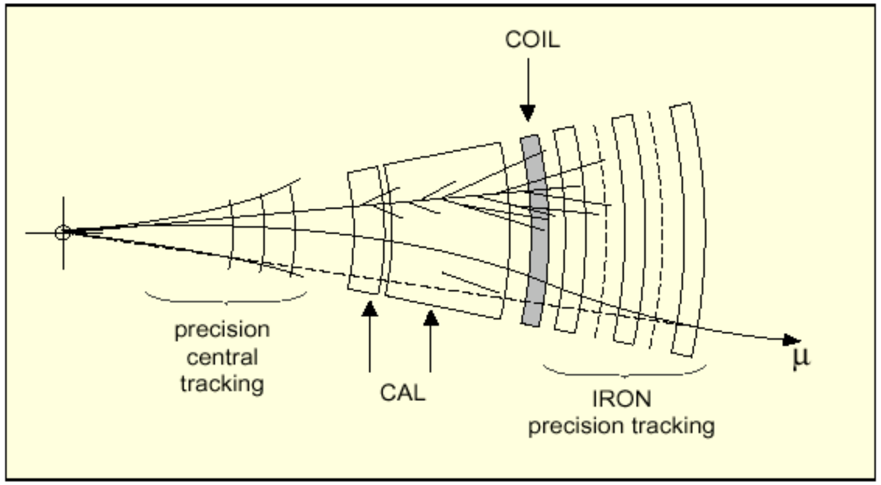
4: need toroid magnets, coil-ECAL interface

Designing an LHC experiment

- **THE issue: measure momenta of charged particles (e.g. muons); so which measurement "architecture"?**



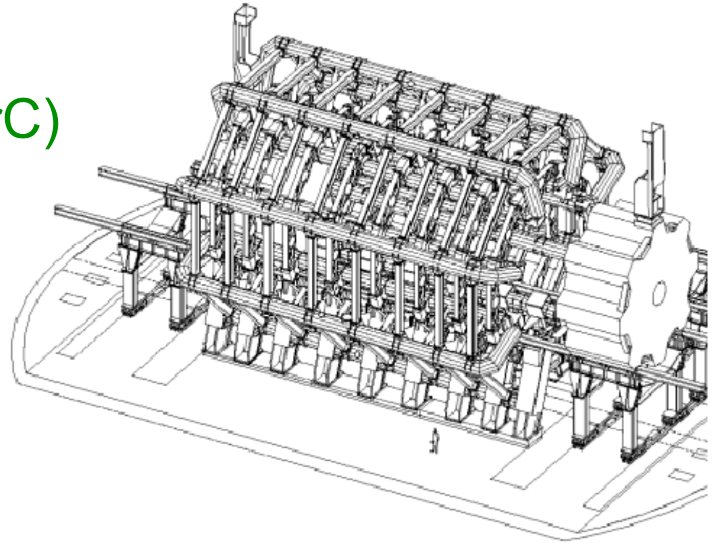
ATLAS
Standalone p measurement;
safe for high multiplicities;
Air-core torroid
Property: σ flat with η



CMS
Measurement of p in
tracker and B return flux;
Iron-core solenoid
Property: muon tracks
point back to vertex

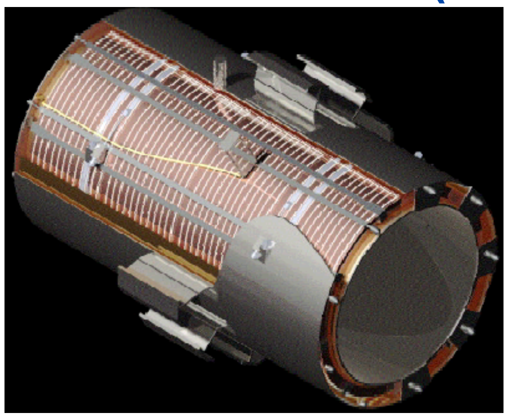
Choice of magnet (I)

- **Basic goal: measure 1 TeV muons with 10% resolution**
  - **ATLAS: <B>~0.6T over 4.5 m → s=0.5mm → need σ_s=50μm**

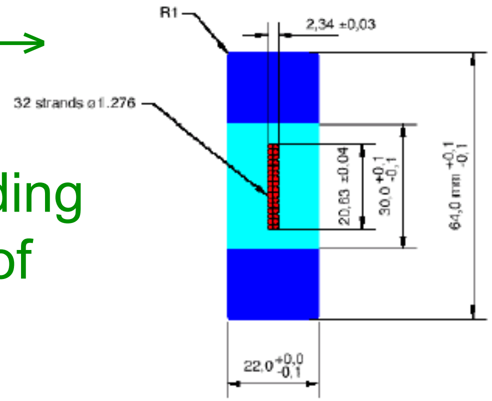


- Ampere's thm: $2\pi RB=\mu_0 nI \rightarrow nI=2\text{x}10^7$ At
- With 8 coils, 2x2x30 turns: I=20kA (superC)
- Challenges: mechanics, 1.5GJ if quench, spatial & alignment precision over large surface area

  - **CMS: B=4T (E=2.7 GJ!)**

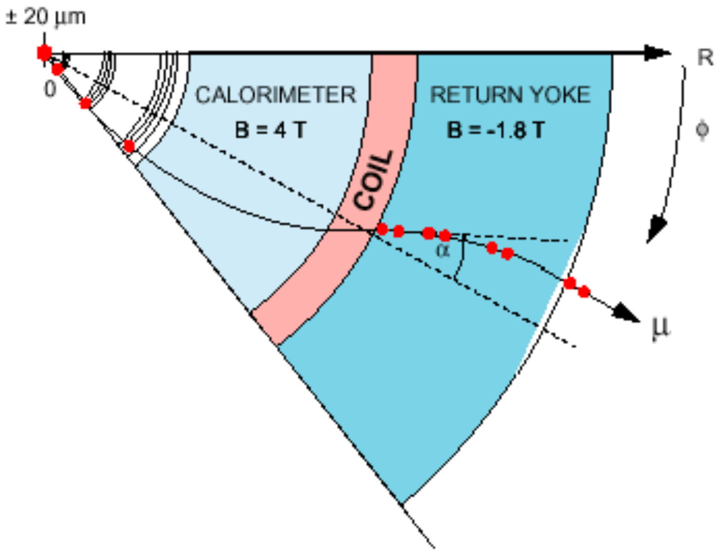


- $B=\mu_0 nI$; @2168 turns/m→ I=20kA (SuperC)
- Challenges: 4-layer winding to carry enough I, design of reinforced superC cable



Choice of magnet (III)

- **Solenoid:**

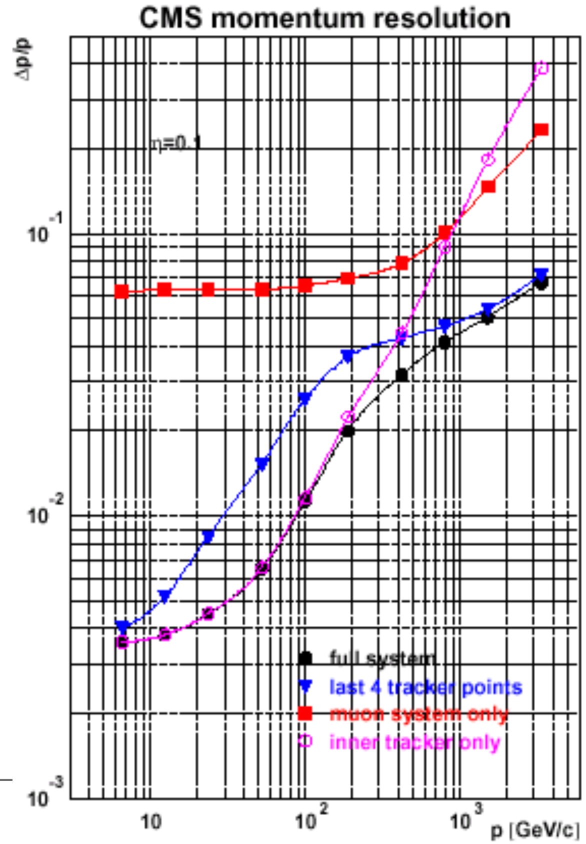


Bending in transverse plane

Use 20μm beam spot

BUT: 4T brings problems

(e.g. cannot use PM tubes)



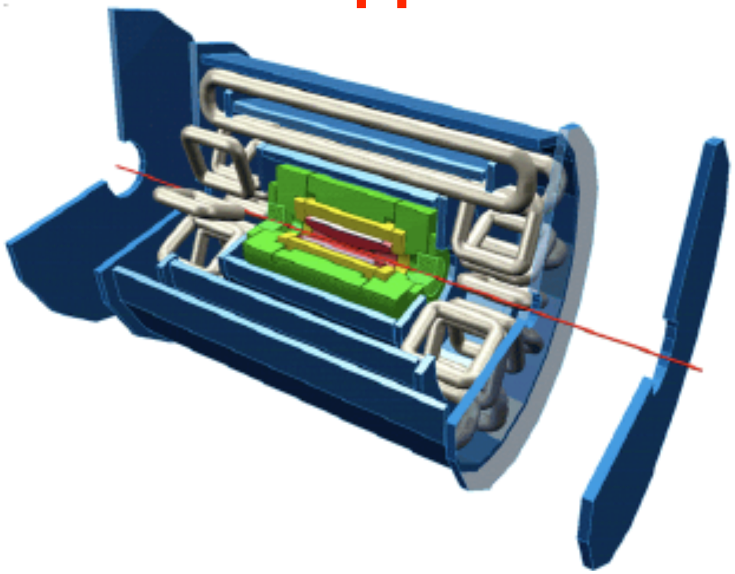
- **Iron-core → multiple scattering**
  - **Tracking in magnetized iron:**

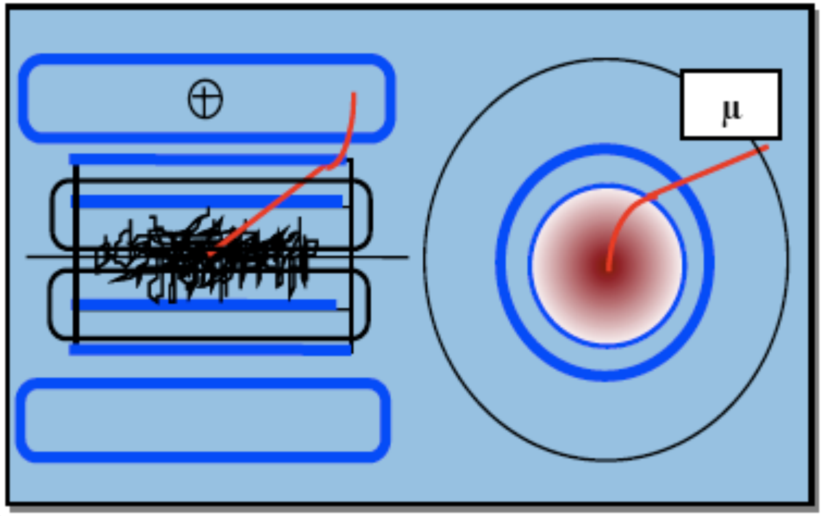
$$\frac{\Delta p}{p} = \frac{40\%}{B\sqrt{L}}$$

  - **BUT measurement much better when combined with the tracker**

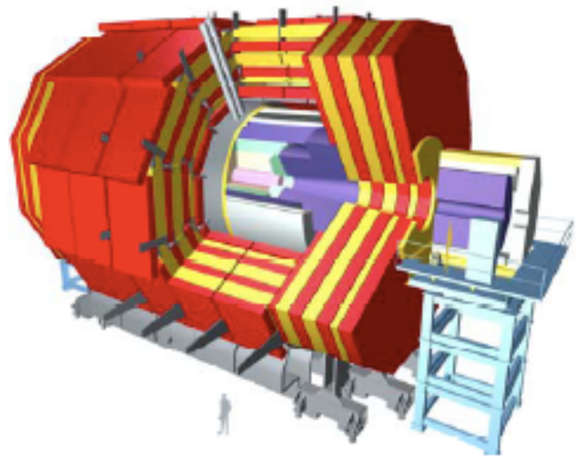
The general-purpose detectors @ LHC

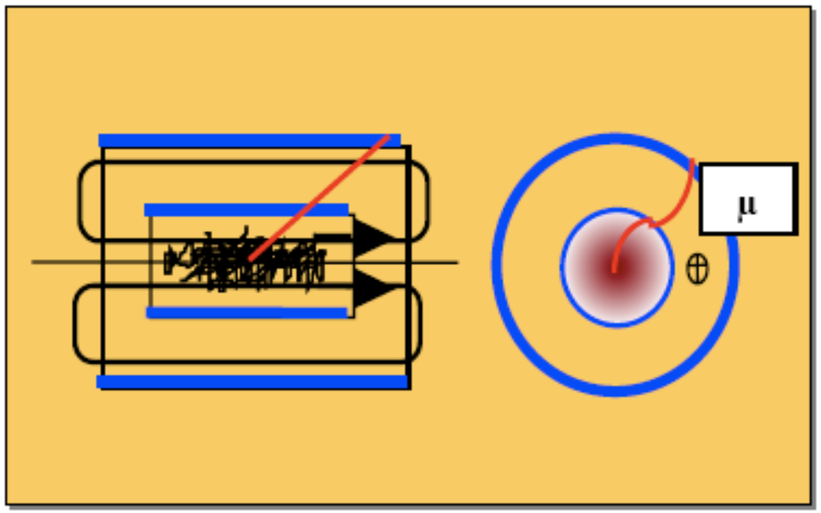
A Toroidal LHC ApparatuS





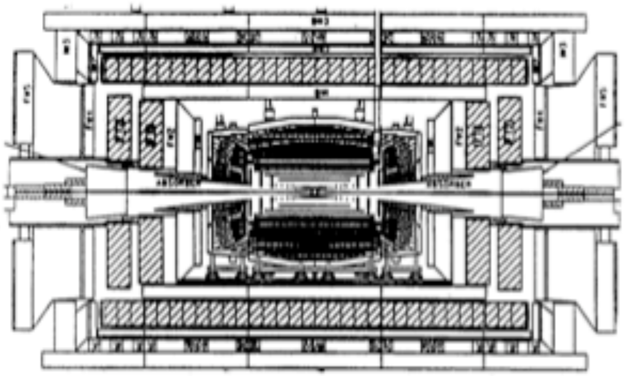
Compact Muon Solenoid





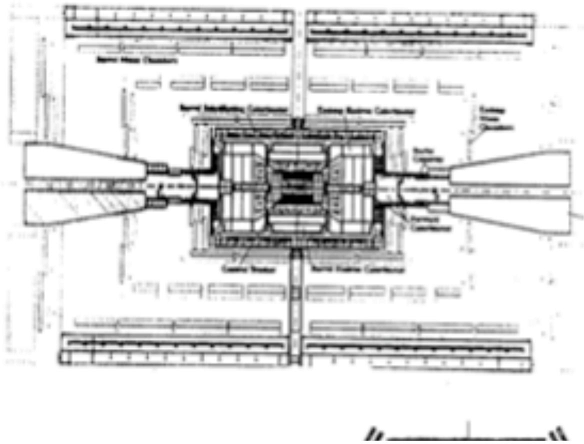
Designs of Various Detectors

SDC



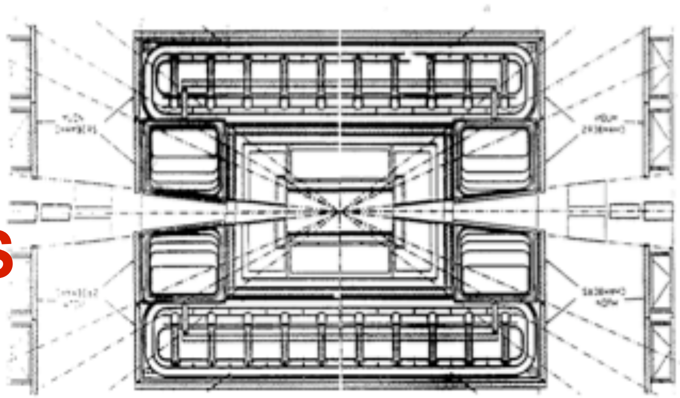
L=40m, ϕ=22m, Solenoid R=1.7m, B=2T
Fe Toroid 6.75m < R < 8.25 m, B=1.8T

GEM



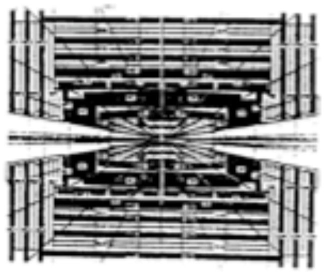
L=38m, ϕ=24m, Solenoid R=9m, B=0.8T

ATLAS



L=40m, ϕ=20m, Solenoid R=1.1.5m, B=2T
Air Toroid 5m < R < 10 m, B=0.6T

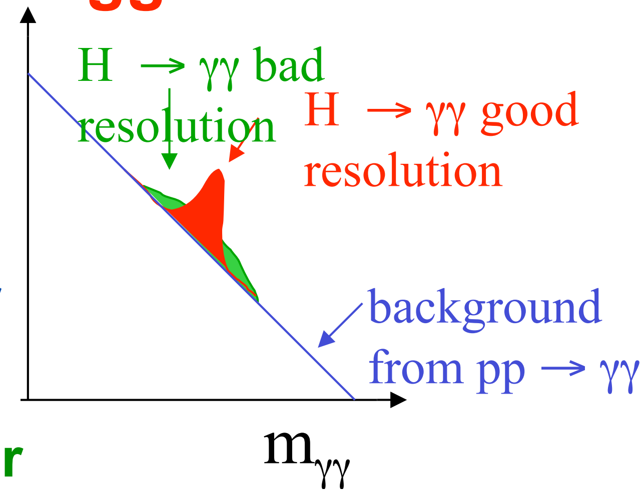
CMS



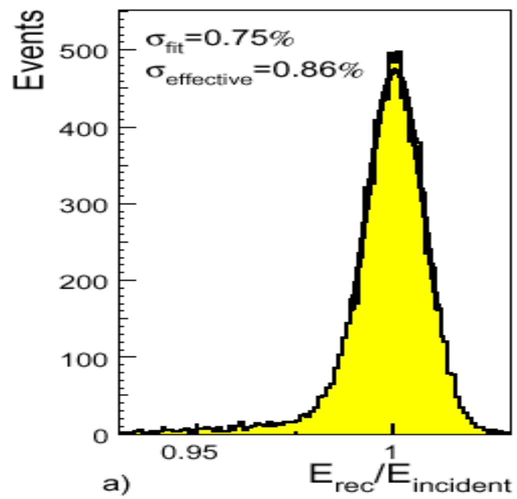
L=20m, ϕ=13m, Solenoid R=3, B=4T

One example: calorimetry

- **Need excellent energy resolution of EM calorimeters for e/γ; Example: H $\rightarrow \gamma\gamma$ for low mass Higgs**
  - **Higgs width is very narrow, so S/N directly $\propto$ to signal resolution**
  - **Moreover, initial background: x100 larger**
    - **π^0 rejection: strips (ATLAS), crystal size (isolation) (CMS); preshower in the endcap**



Tracker vs ECAL resolution match: at ~50 GeV (spot on for Higgs)



Electromagnetic Calorimetry

- **Electromagnetic calorimeter**
  - Liquid argon by ATLAS. Not enough space in CMS for cryogenics. Need something more compact. Crystal ECAL

Properties of some crystals

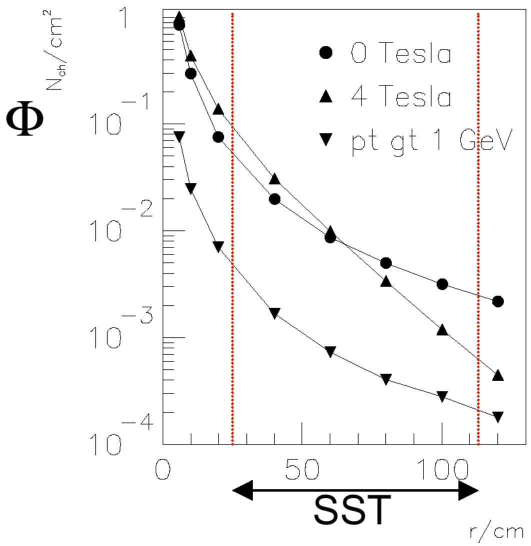
Crystal	X_0 (cm)	R_M (cm)	Light Yield Gammas/MeV	Peak (nm)	Decay (ns)
BaF_2	2.06	3.4	2000	210	0.6
			6500	310	620
CeF_3	1.68	2.6	2000	300	5
				340	20

  - CeF_3 best choice. Good light yield; short X_0; short τ; good radiation resistance
  - Post LoI: PbWO4

$PbWO_4$	0.89	2.2	250	440	5-15

Example: Tracking Requirements

- **Efficiency: need low, ~few % occupancy; Resolution**



Twelve hits; 4T field
spatial resolution: (pitch/ √12)
Radius: 110 cm
→momentum resolution:

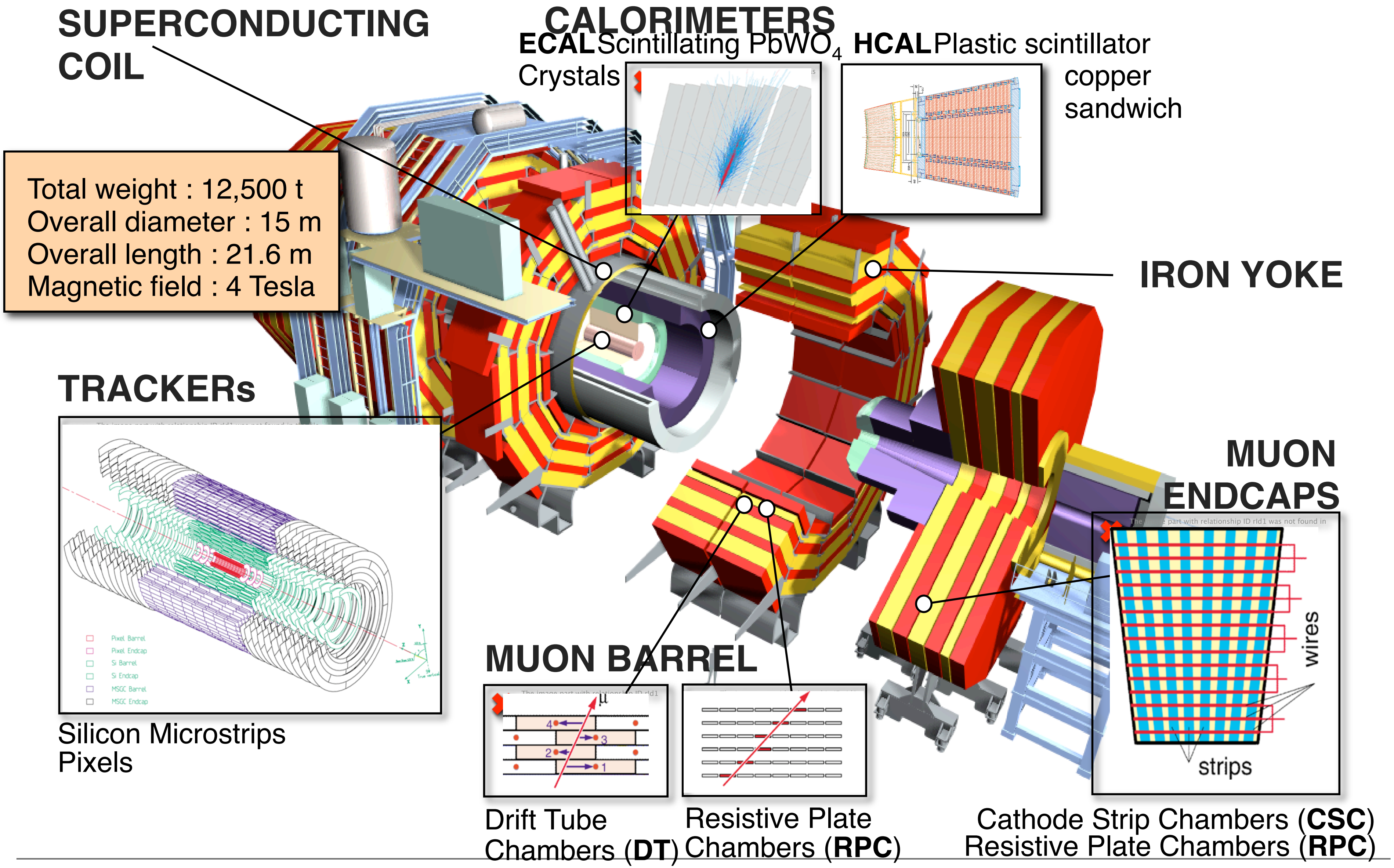
$$\frac{\Delta p}{p} \approx 0.12 \left(\frac{pitch}{100\mu m}\right)^{1} \left(\frac{1.1m}{L}\right)^{2} \left(\frac{4T}{B}\right)^{1} \left(\frac{p}{1Tev}\right)$$

→Need pitch ~100μm.

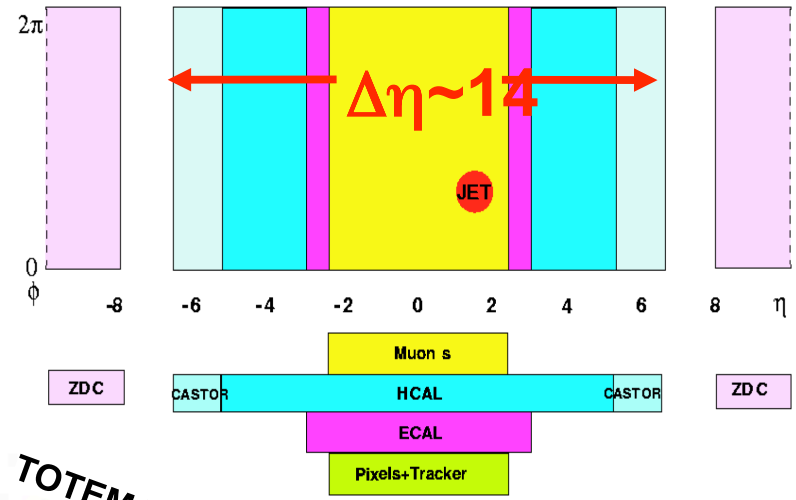
small radii: need cell size < 1cm²
+ fast (~25ns) shaping time
condition is relaxed at large radii

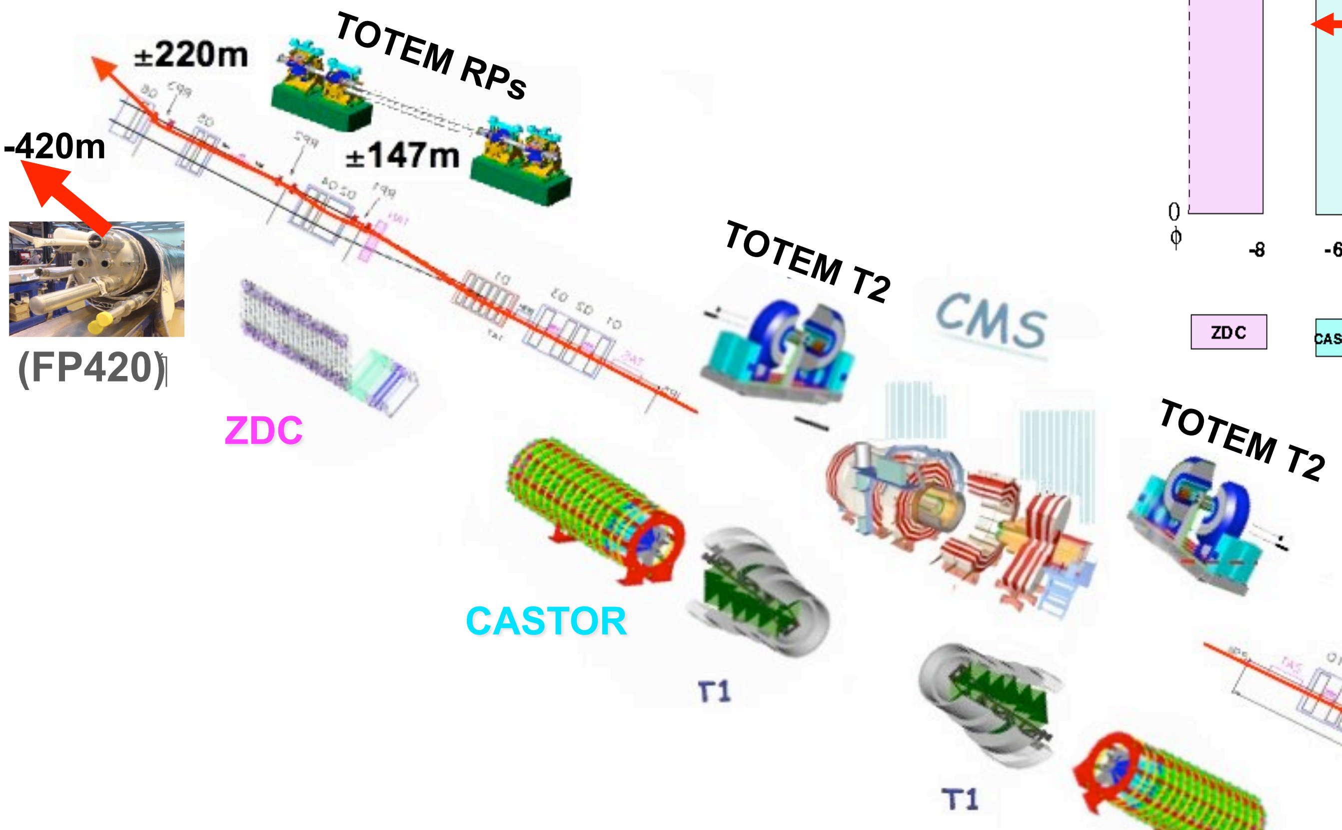
- **Strip size**
  - **Strip length: 10cm (inner layers) to 20cm (outer layers).**
  - **Pitch: 80μm (inner layers) to 200μm (outer layers)**

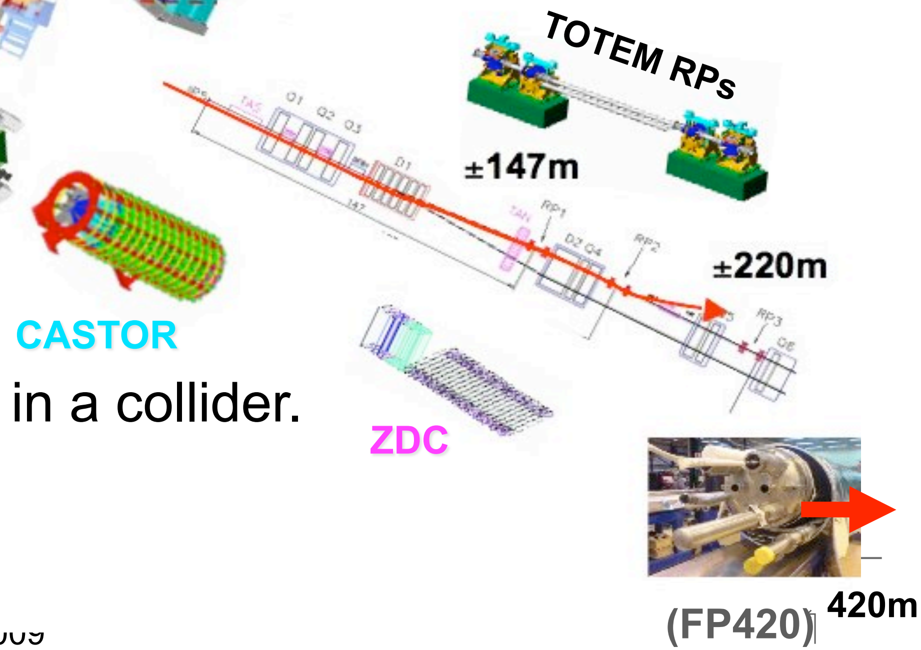
The Compact Muon Solenoid (CMS)



Including forward detectors







- CMS (+TOTEM):

Largest phase-space coverage ever in a collider.

Timeline (e.g. CMS)

- LHC Workshop, Aachen 1990
  - Concept of a compact detector based on a 4T superconducting solenoid
- Expression of Interest, Evian 1992
  - Conceptual Design
- Letter of Intent, October 1992
  - CERN/LHCC 92-3
- Technical Proposal, Dec 1994
  - CERN/LHCC 94-38
- Interim Memorandum of Understanding (IMoU) 1995
- Memorandum of Understanding (MoU) 1998
- Detector Technical Design Reports: 1997-98; Lvl-1 Trigger: 2000; DAQ/HLT: 2002.
- Computing & Physics TDR: end 2005; mid 2006.

“Asymptotic” physics reach

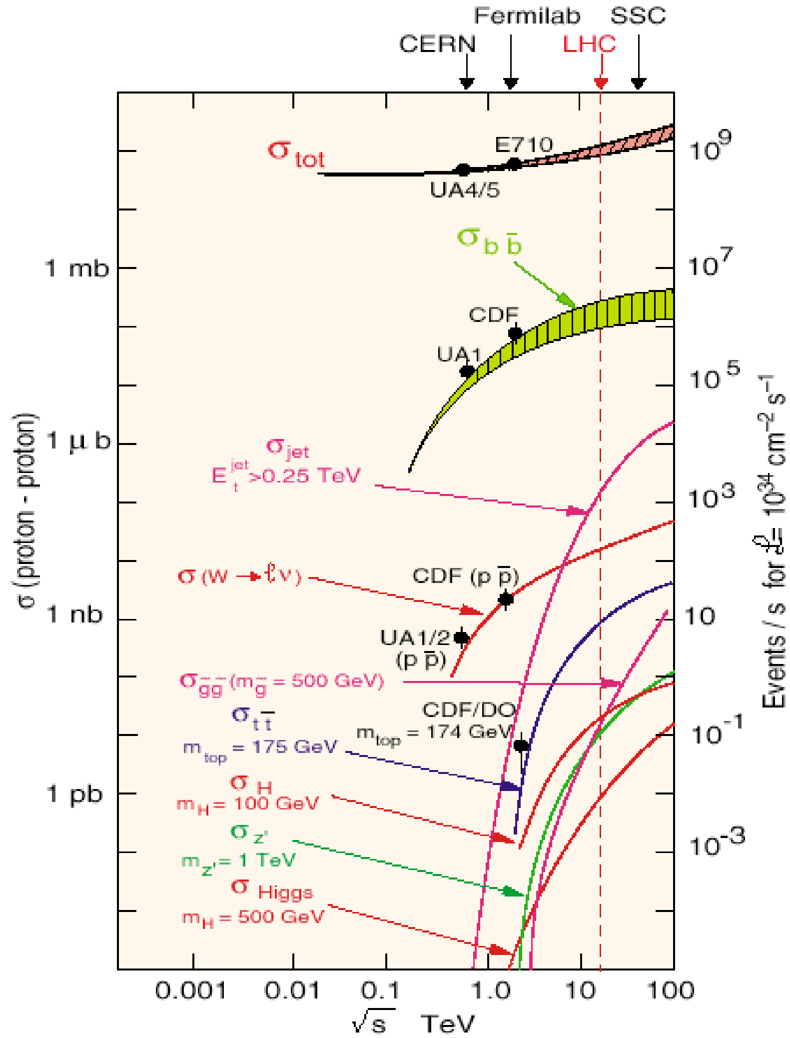
Standard Model Higgs search

SUSY Higgs search

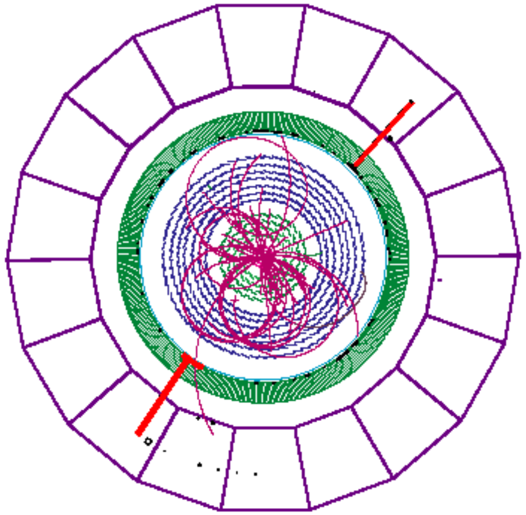
General Supersymmetry (sparticles) search

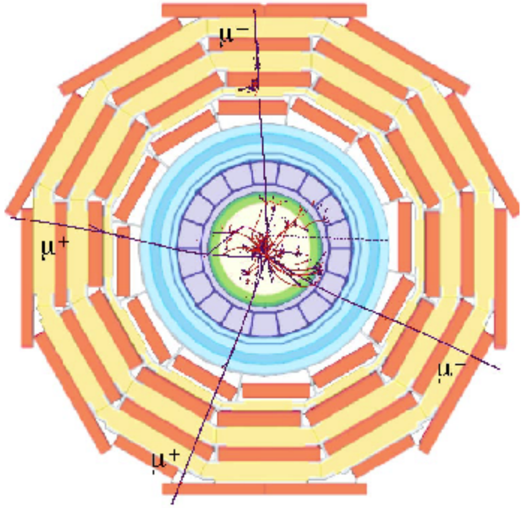
Selectivity: the physics

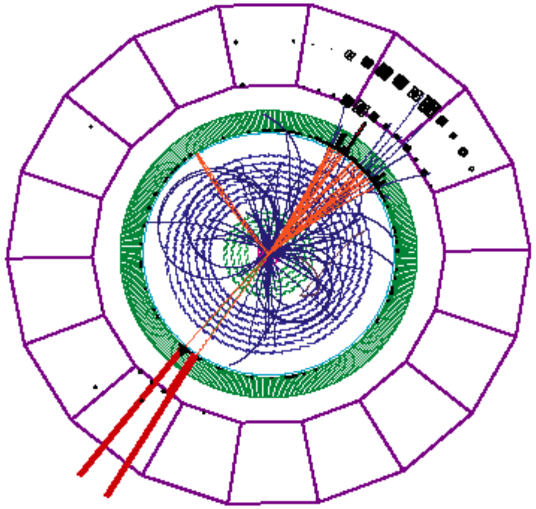
- **Cross sections for various physics processes vary over many orders of magnitude**
  - Inelastic: 10^9 Hz
  - $W \rightarrow \ell\,\nu$: 10^2 Hz
  - t t production: 10 Hz
  - Higgs (100 GeV/c^2): 0.1 Hz
  - Higgs (600 GeV/c^2): 10^{-2} Hz
- **Selection needed: 1:10^{10-11}**
  - Before branching fractions...

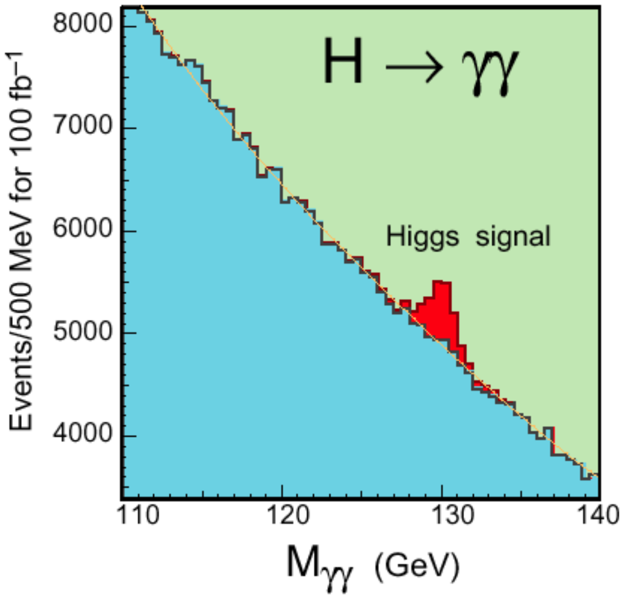


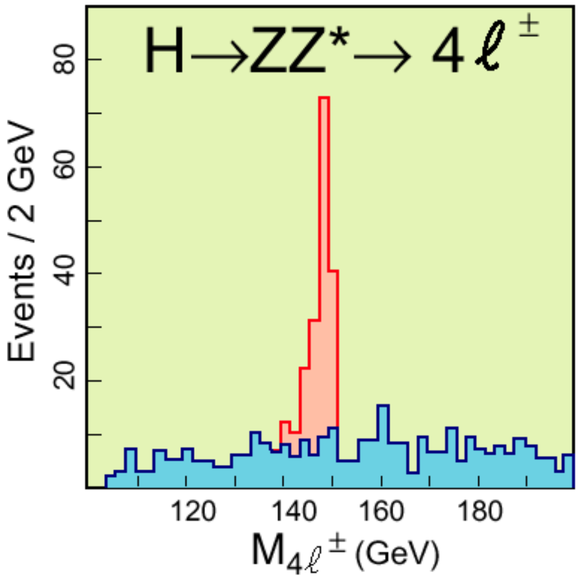
The (SM) Higgs in the detector

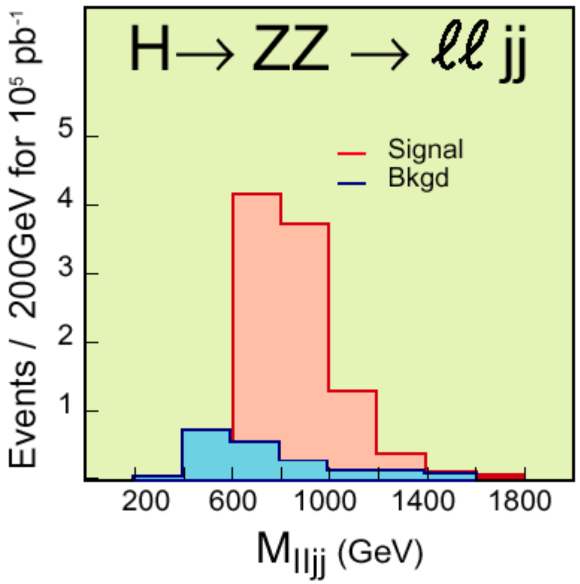






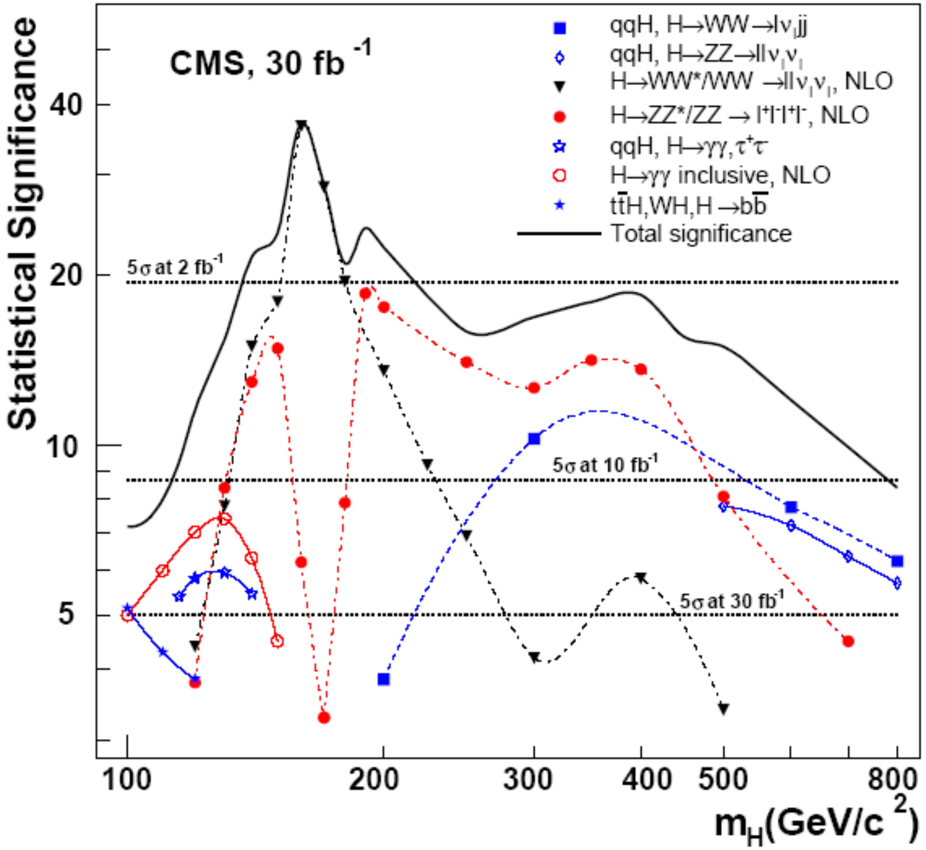






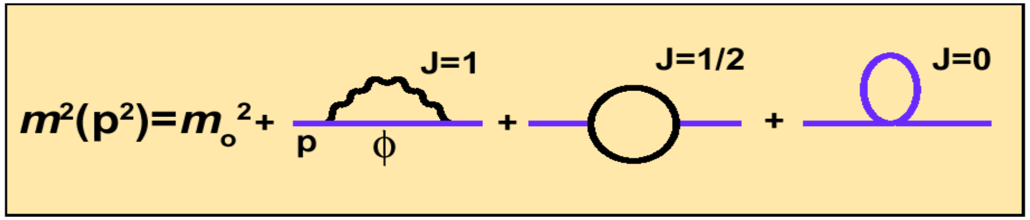
Higgs reach

- **The LHC can probe the entire set of "allowed" Higgs mass values;**
  - **in most cases a few months at $10^{33}cm^{-2}s^{-1}$ are adequate for a 5σ observation**



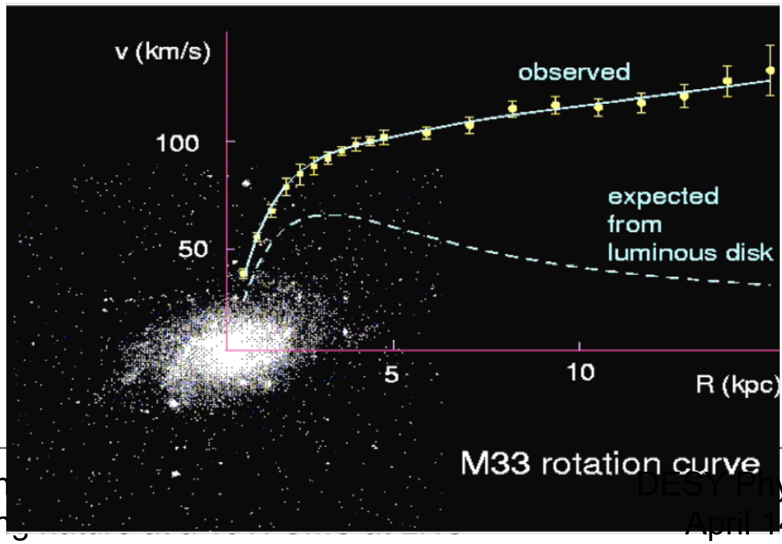
Problems with the Higgs and the Standard Model

- **Quadratic divergence in its mass**

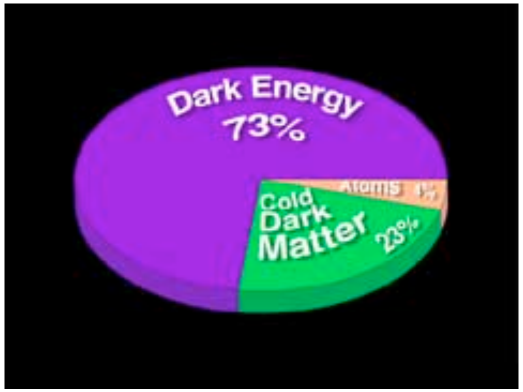


$$m^2(p^2) = m^2(\Lambda^2) + Cg^2 \int_{p^2}^{\Lambda^2} dk^2$$

  - Or: why is the Higgs mass so low? What is the mechanism?
- **Where is all this vacuum energy?**
  - We would expect a tremendous energy density (>10^{100} times larger than observed! Cosmological constant "too small")
- **What about the missing mass (dark matter)? What is it?**

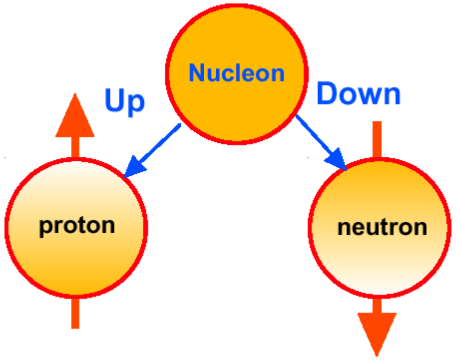


Dark (invisible) matter!



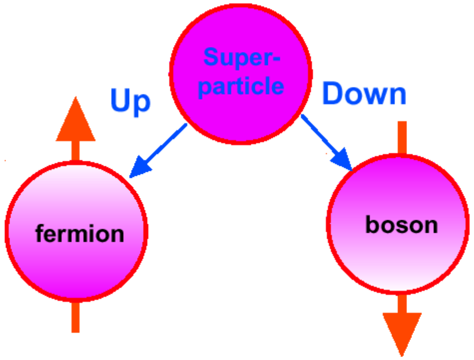
Supersymmetry (SUSY), effect on Higgs and dark matter (?)

- **SUSY (super-symmetry) solution: for every particle in the SM, there is a super-partner with spin-½ difference**



Isotopic symmetry

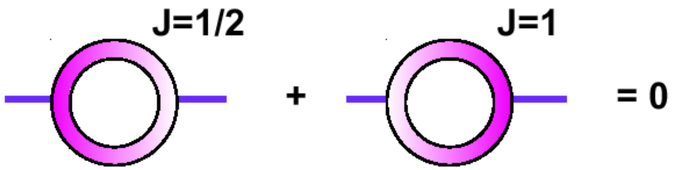
Proton and Neutron:
different states of a
generalized particle (Nucleon)

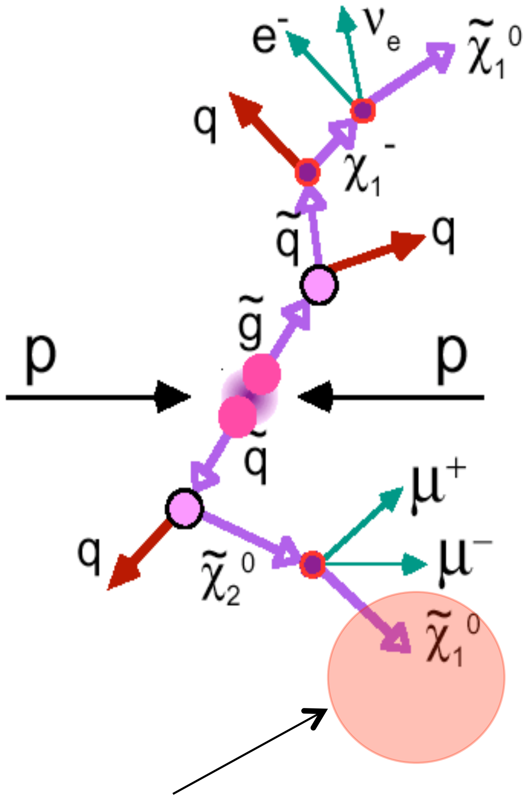


Supersymmetry :

Fermion and Boson:
different states of a
generalized entity (Superparticle)

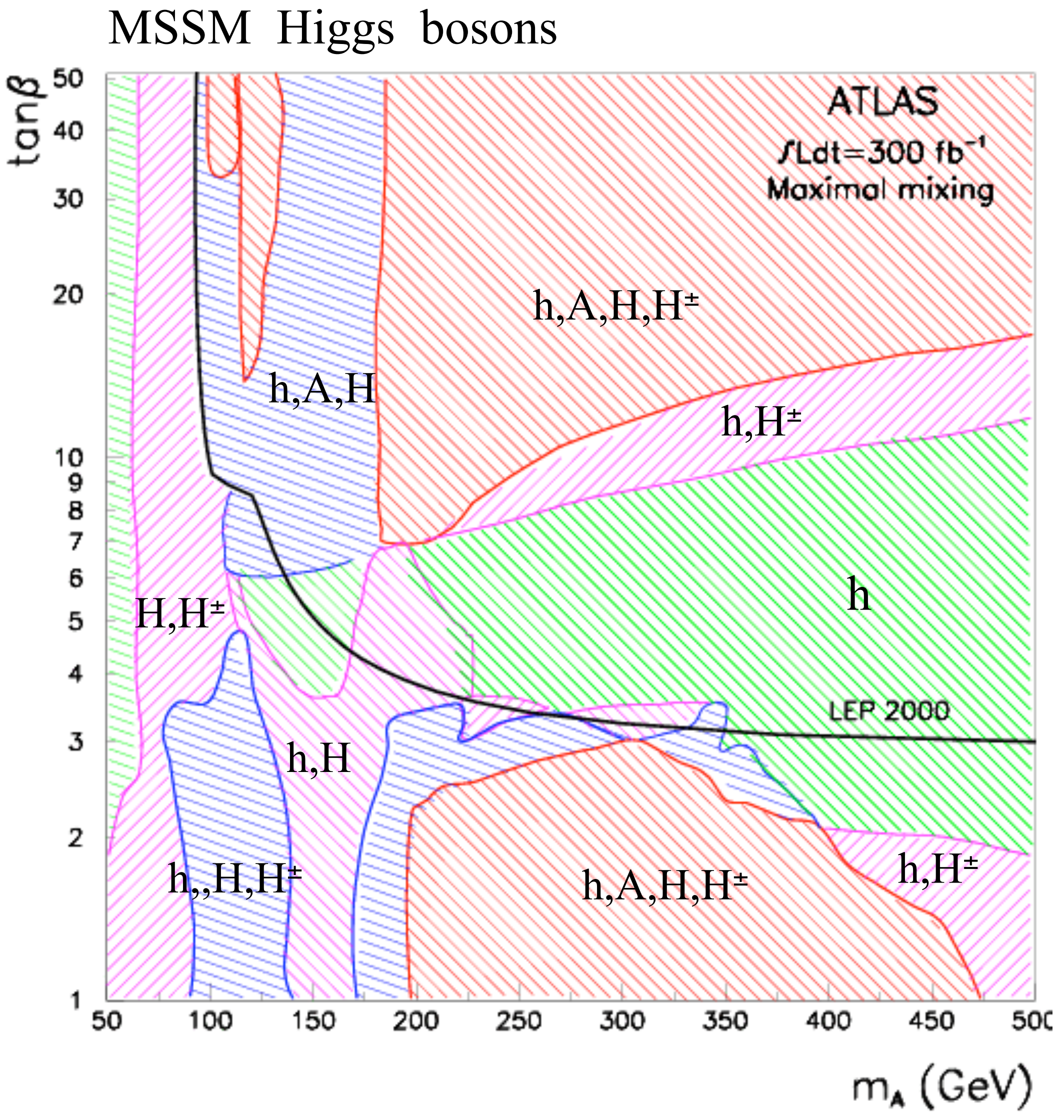
In SUSY, the loops cancel naturally:





Candidate for dark matter!

Observability of MSSM Higgses



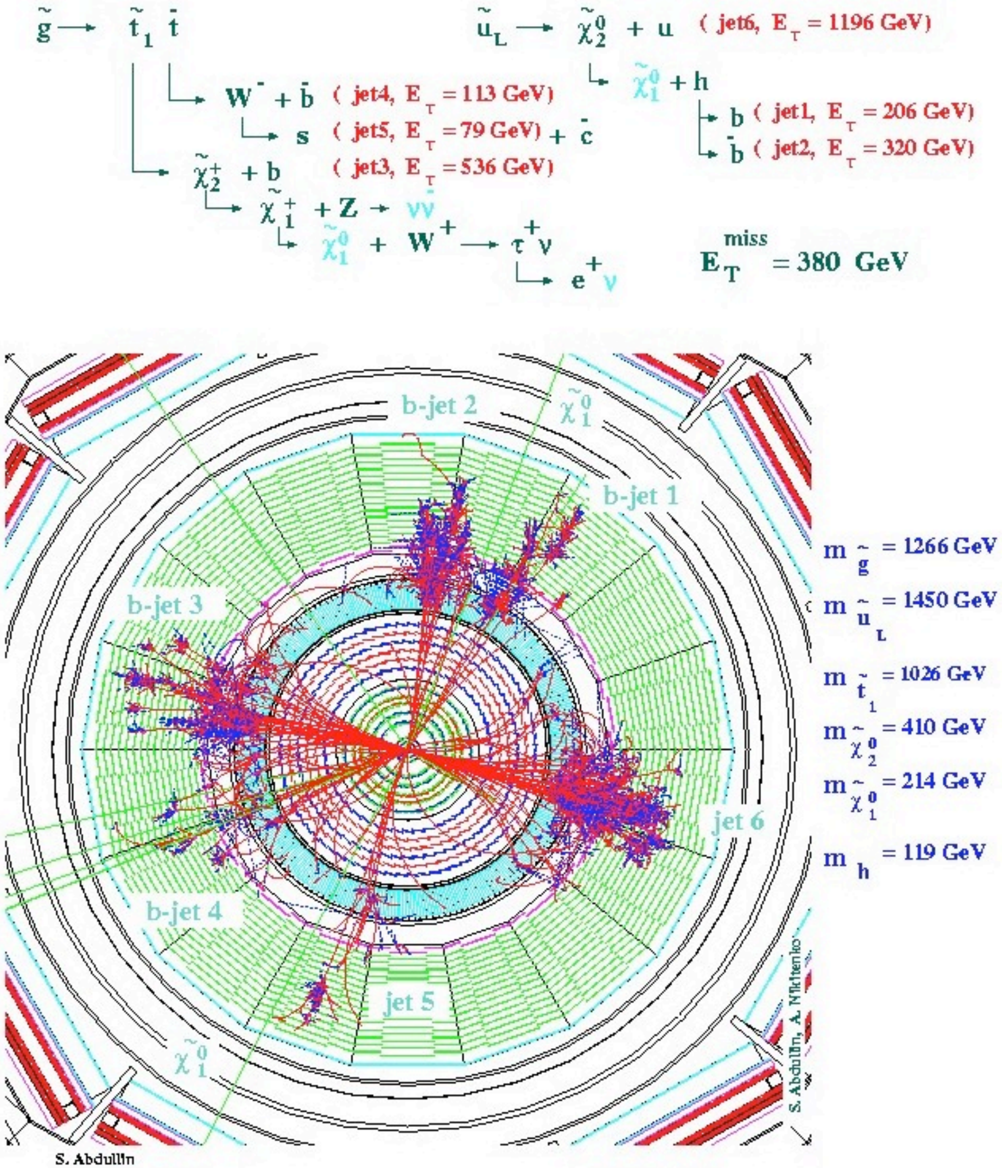
- 4 Higgs observable
- 3 Higgs observable
- 2 Higgs observable
- 1 Higgs observable

5σ contours

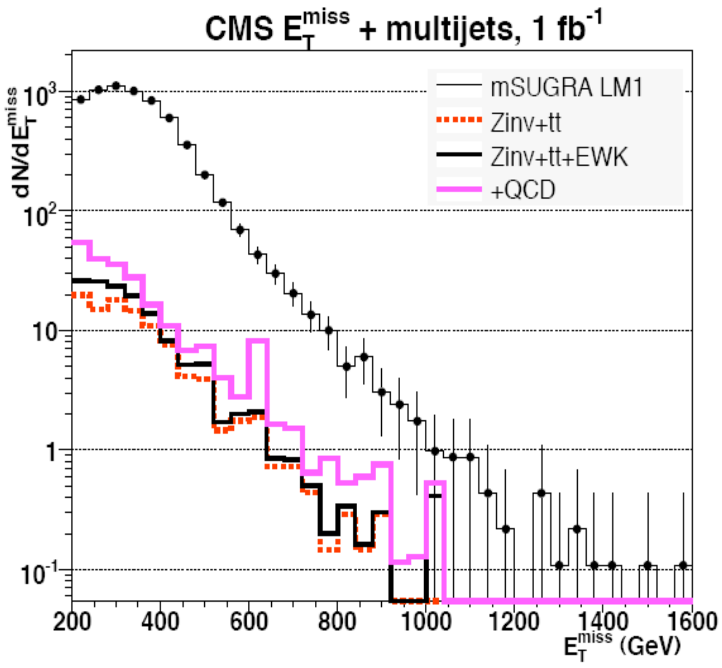
Assuming decays to SM particles only

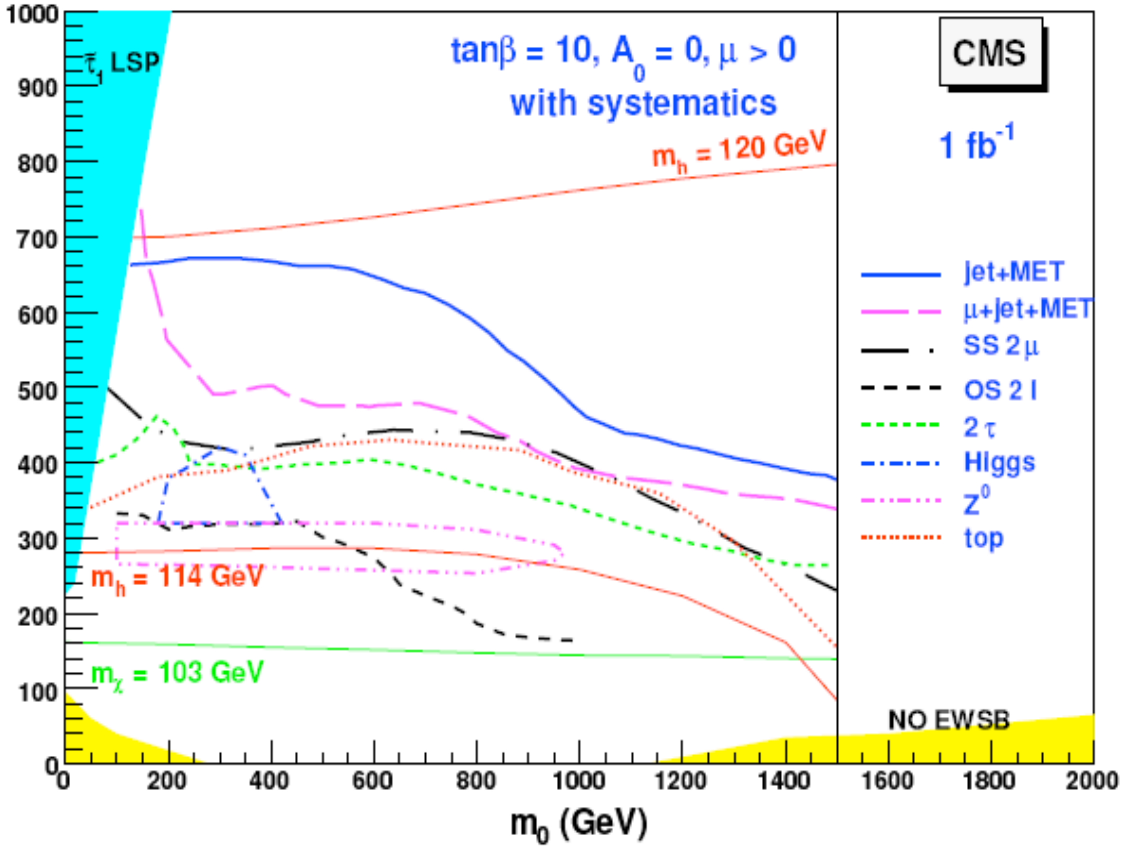
SUSY signatures in CMS

- **Many hard Jets**
- **Large missing energy**
  - **2 LSPs**
  - **Many neutrinos**
- **Many leptons**
- **In a word Spectacular!**



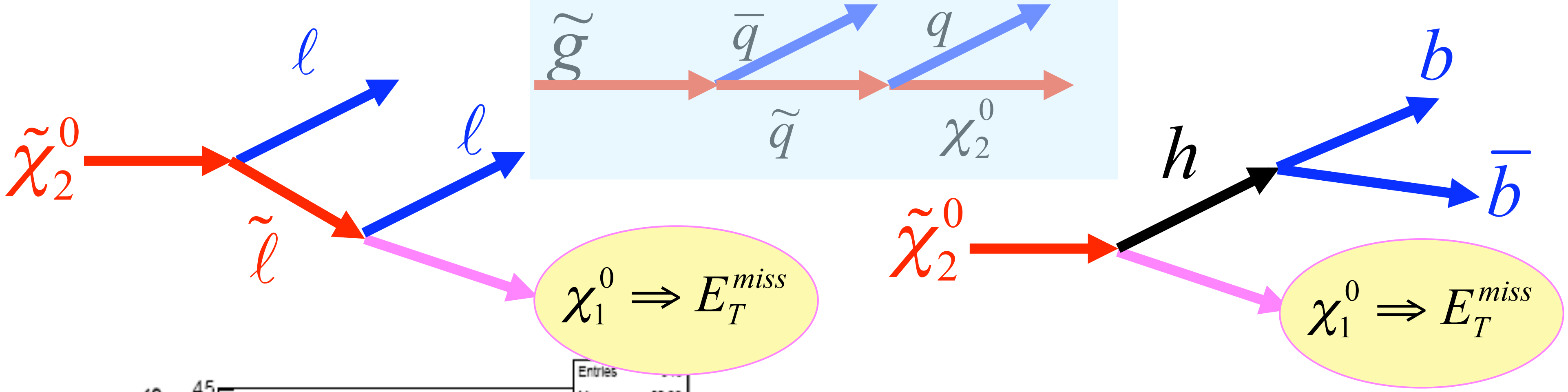
Inclusive SUSY searches

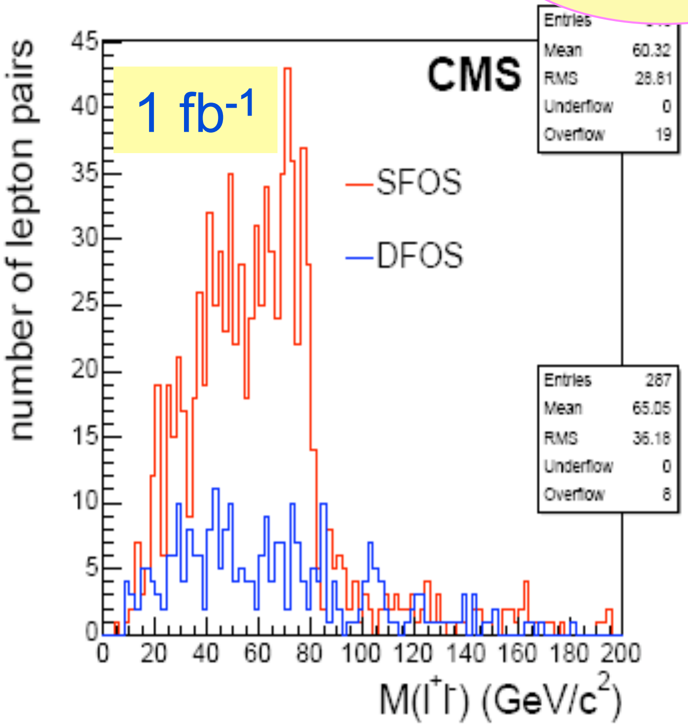


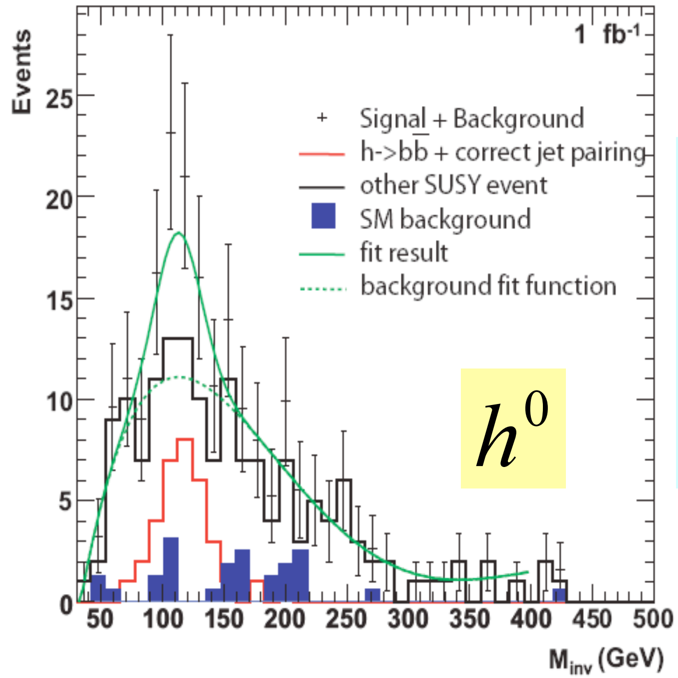


E_T^{miss} @ LM1

SUSY signals (cascades)



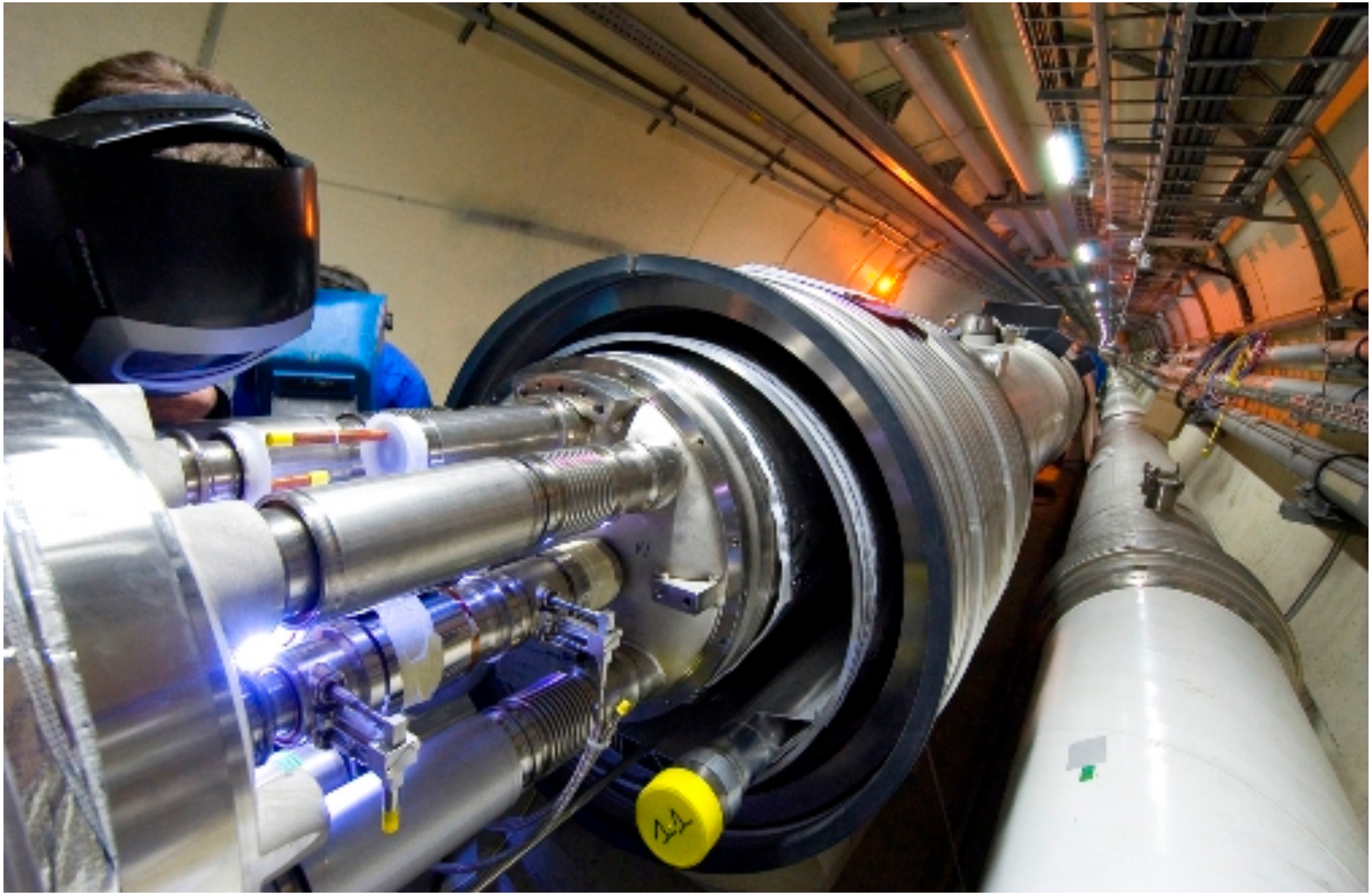




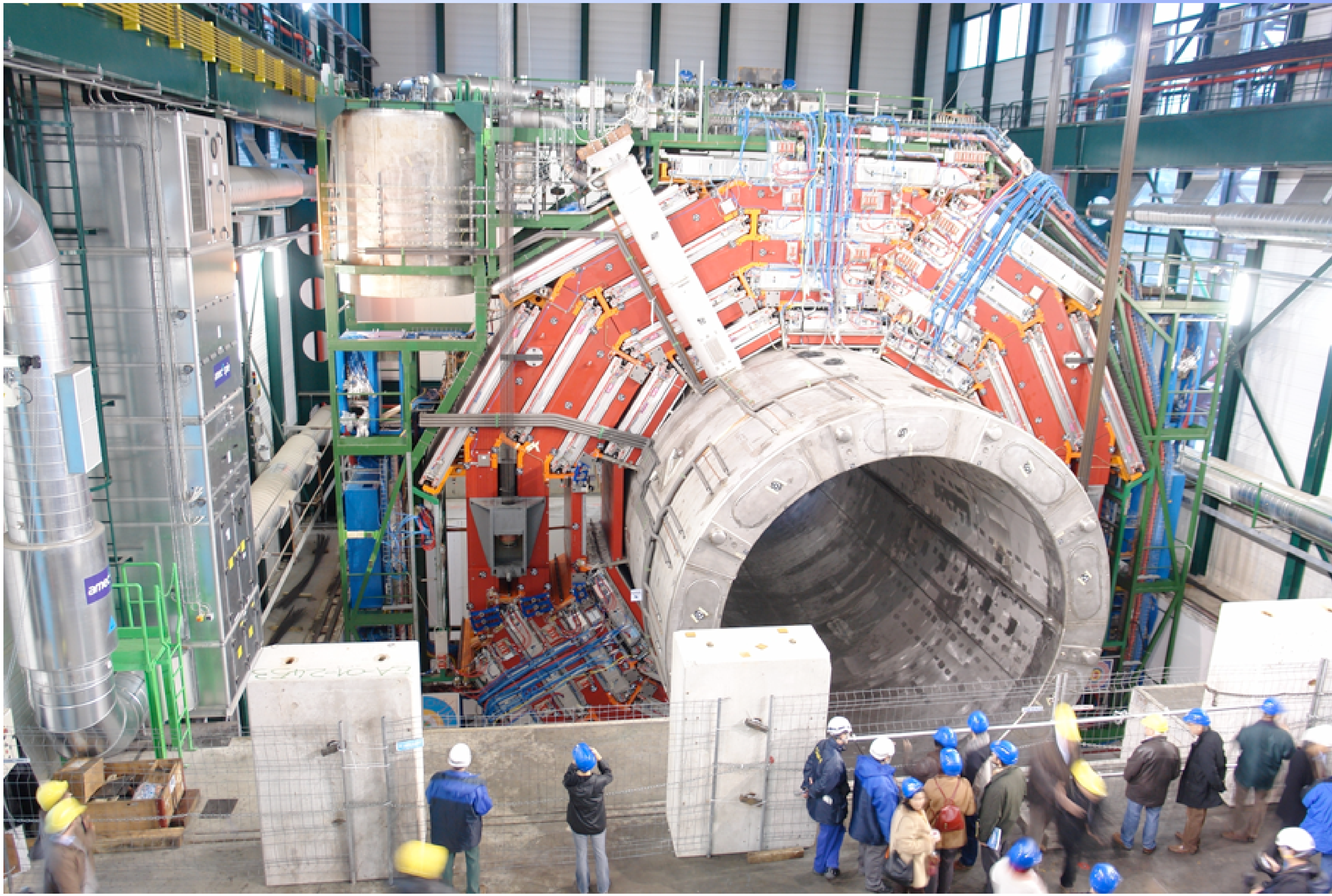
Can be discovery channel for the Higgs

LHC startup, future

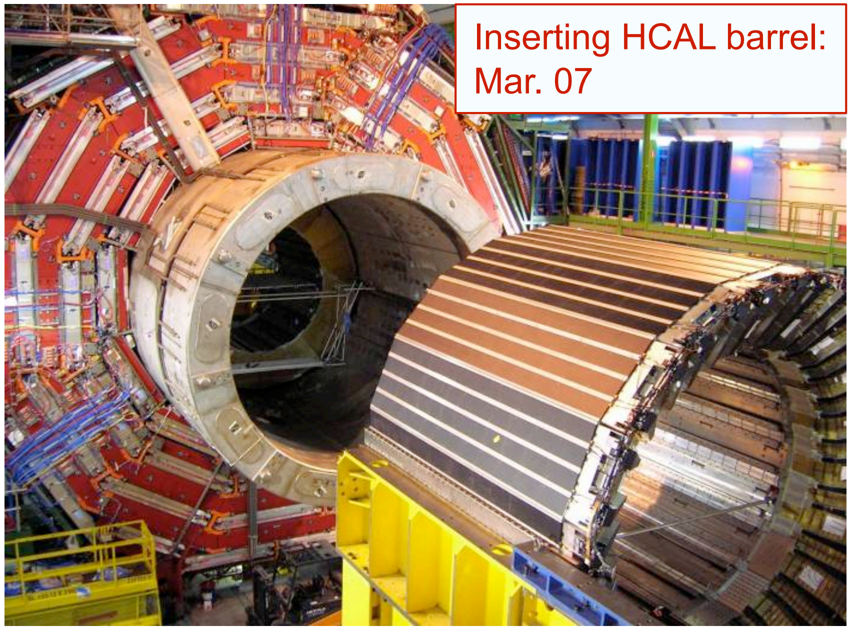
Machine ~ready in Sep 2008

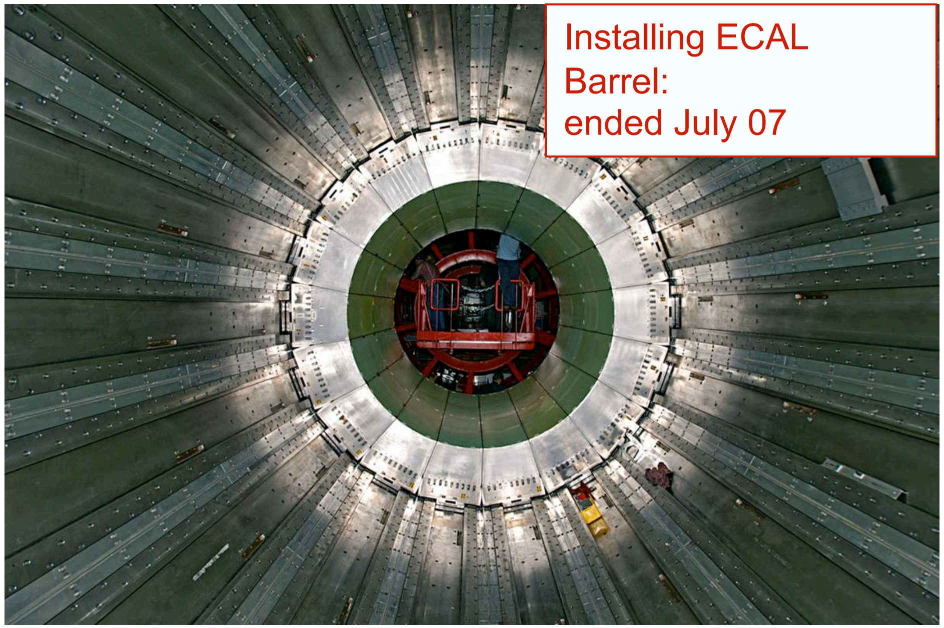


CMS

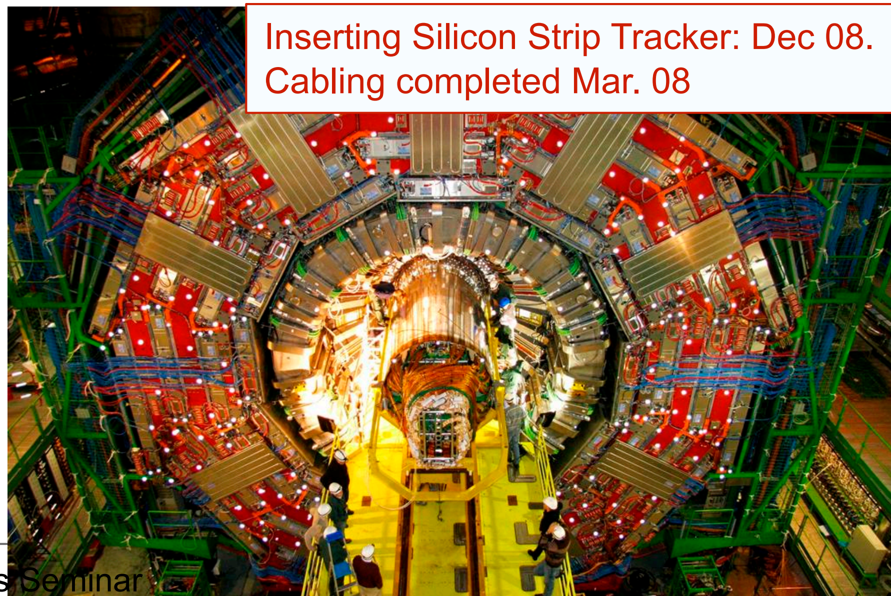


Installing Detectors Inside the Magnet

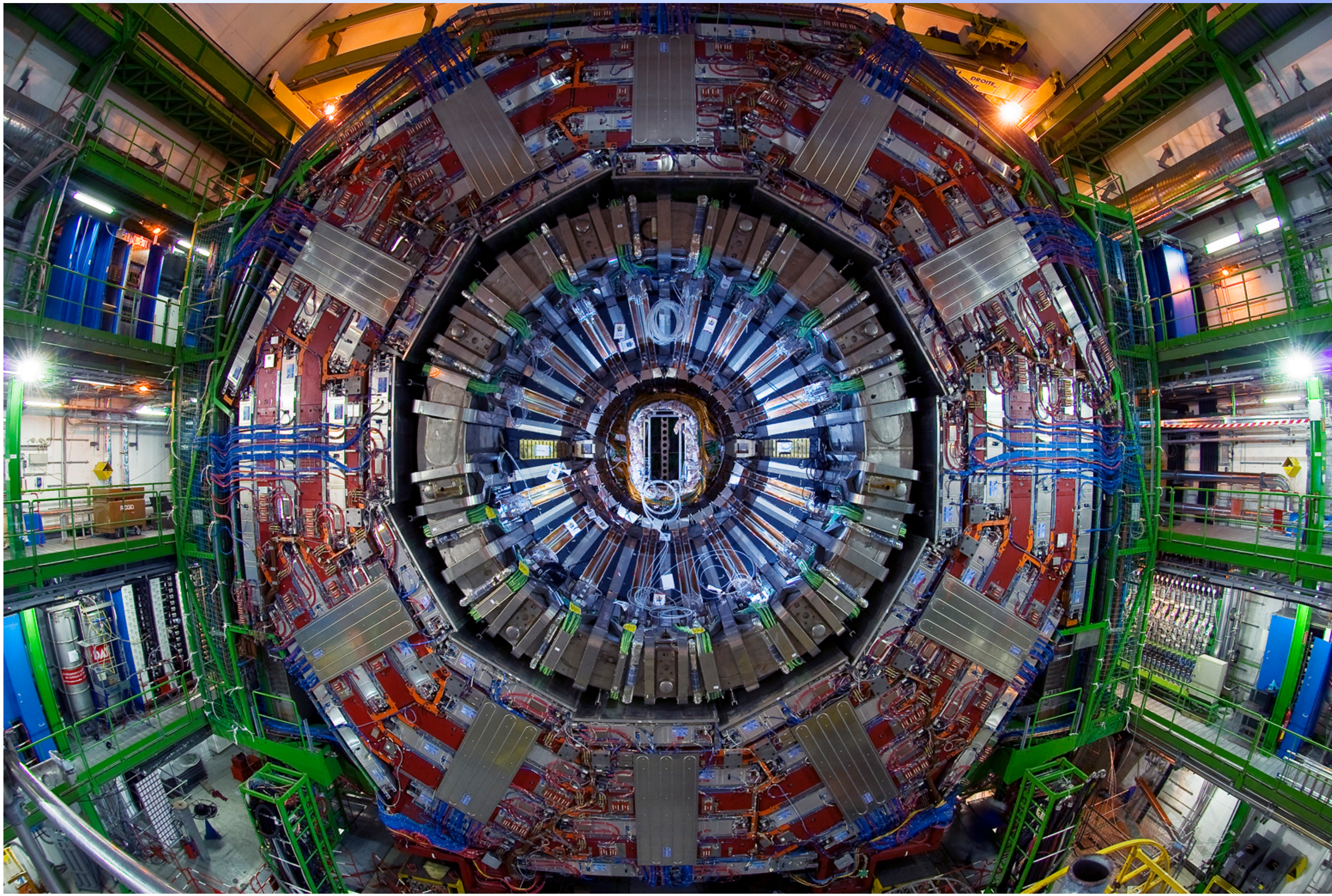

Inserting HCAL barrel: Mar. 07


Installing ECAL Barrel: ended July 07


YB0 After Cabling Dec. 07

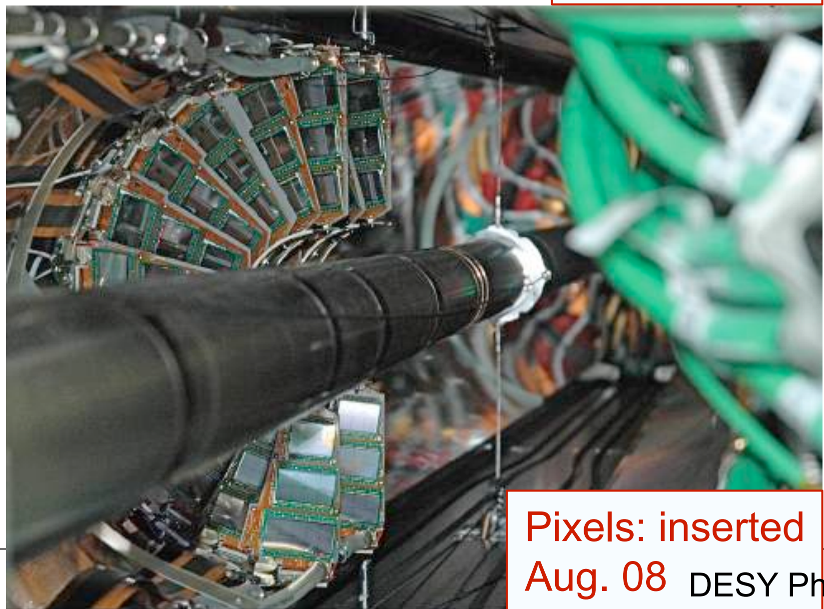

Inserting Silicon Strip Tracker: Dec 08. Cabling completed Mar. 08

Fisheye view of CMS

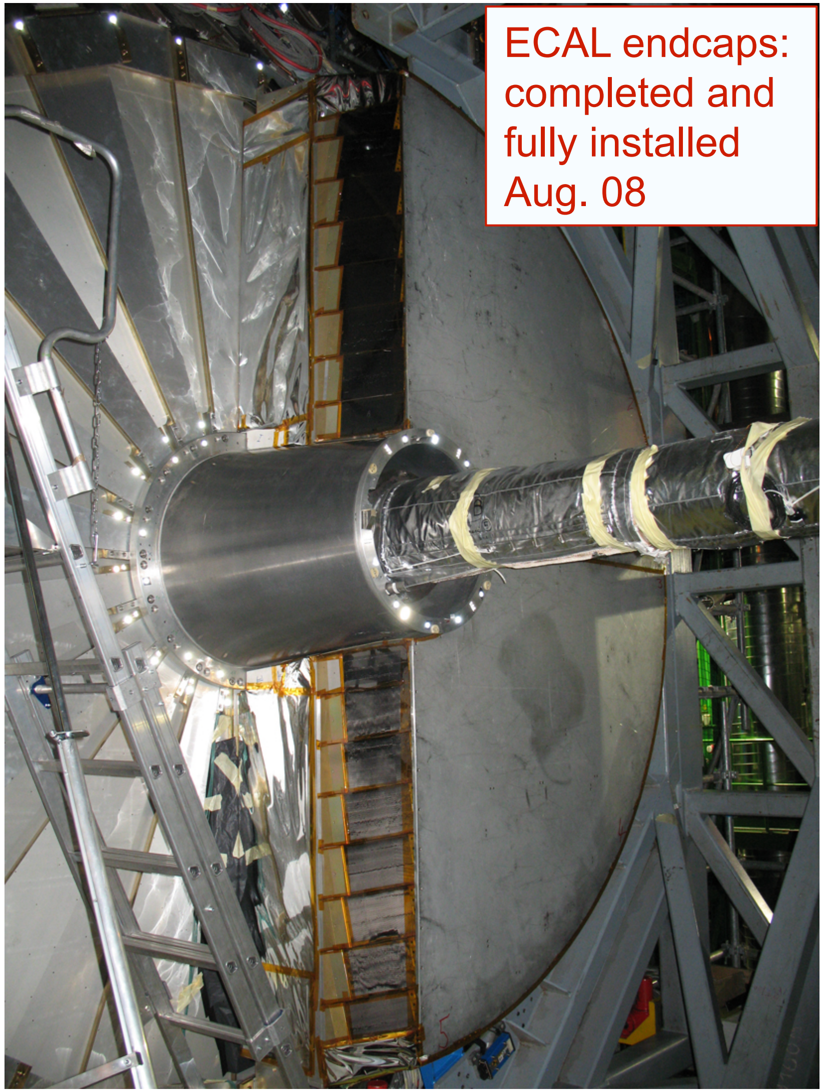


Latest Installed Components

Beam pipe: insertion and bakeout June 08



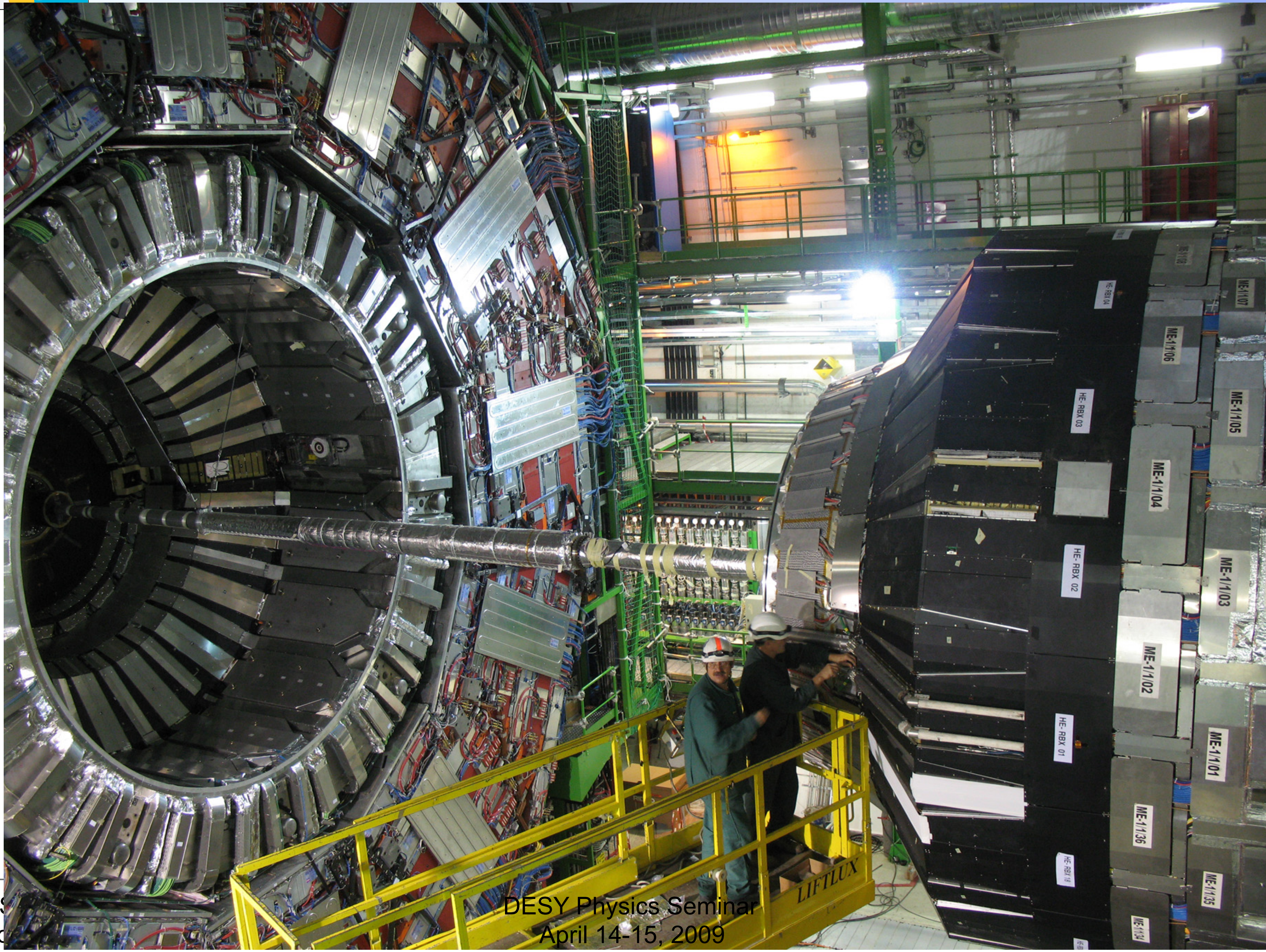
Pixels: inserted Aug. 08



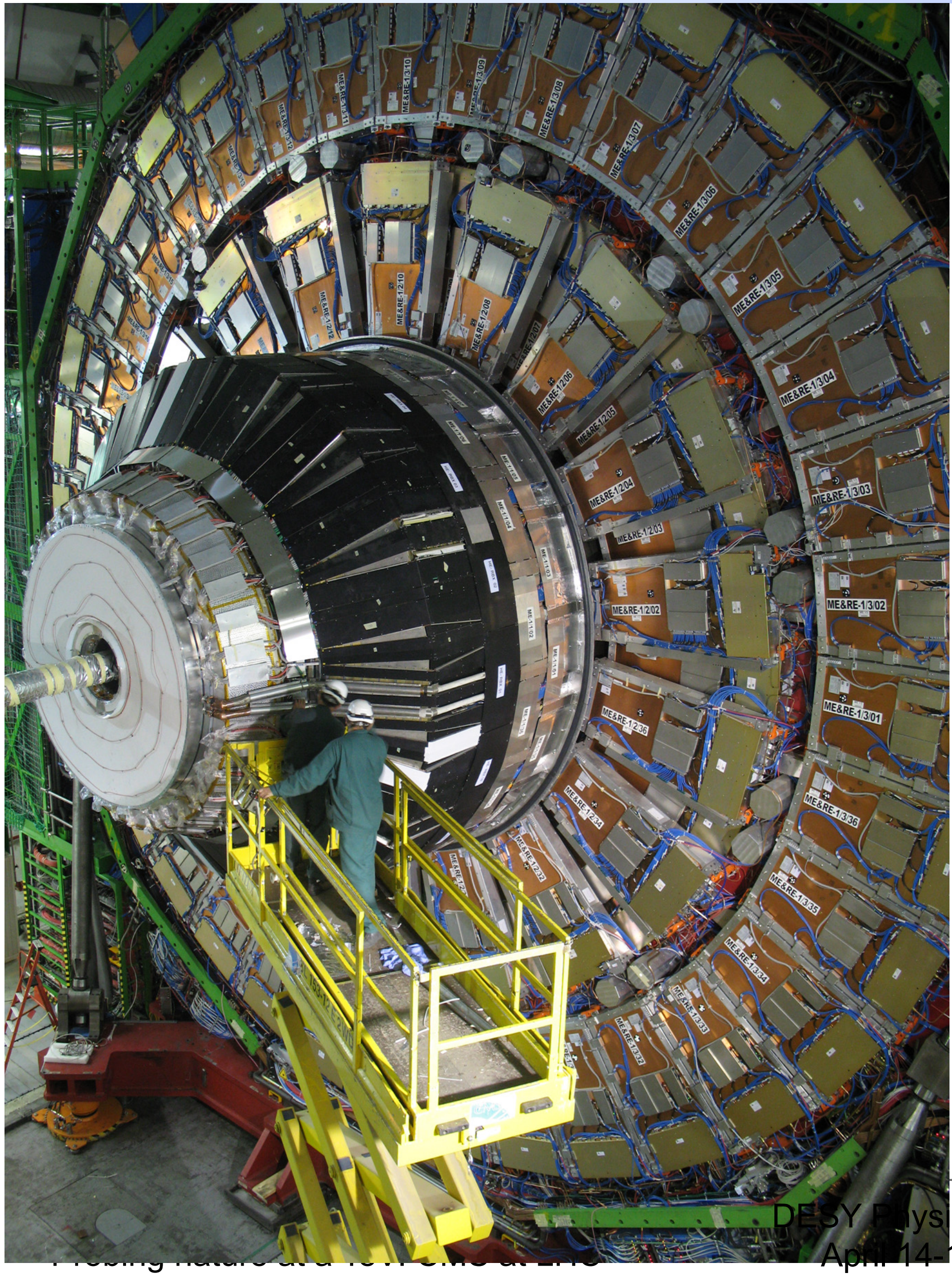
ECAL endcaps: completed and fully installed Aug. 08

- EE and Pixels were installed just before beam and worked quite well very soon

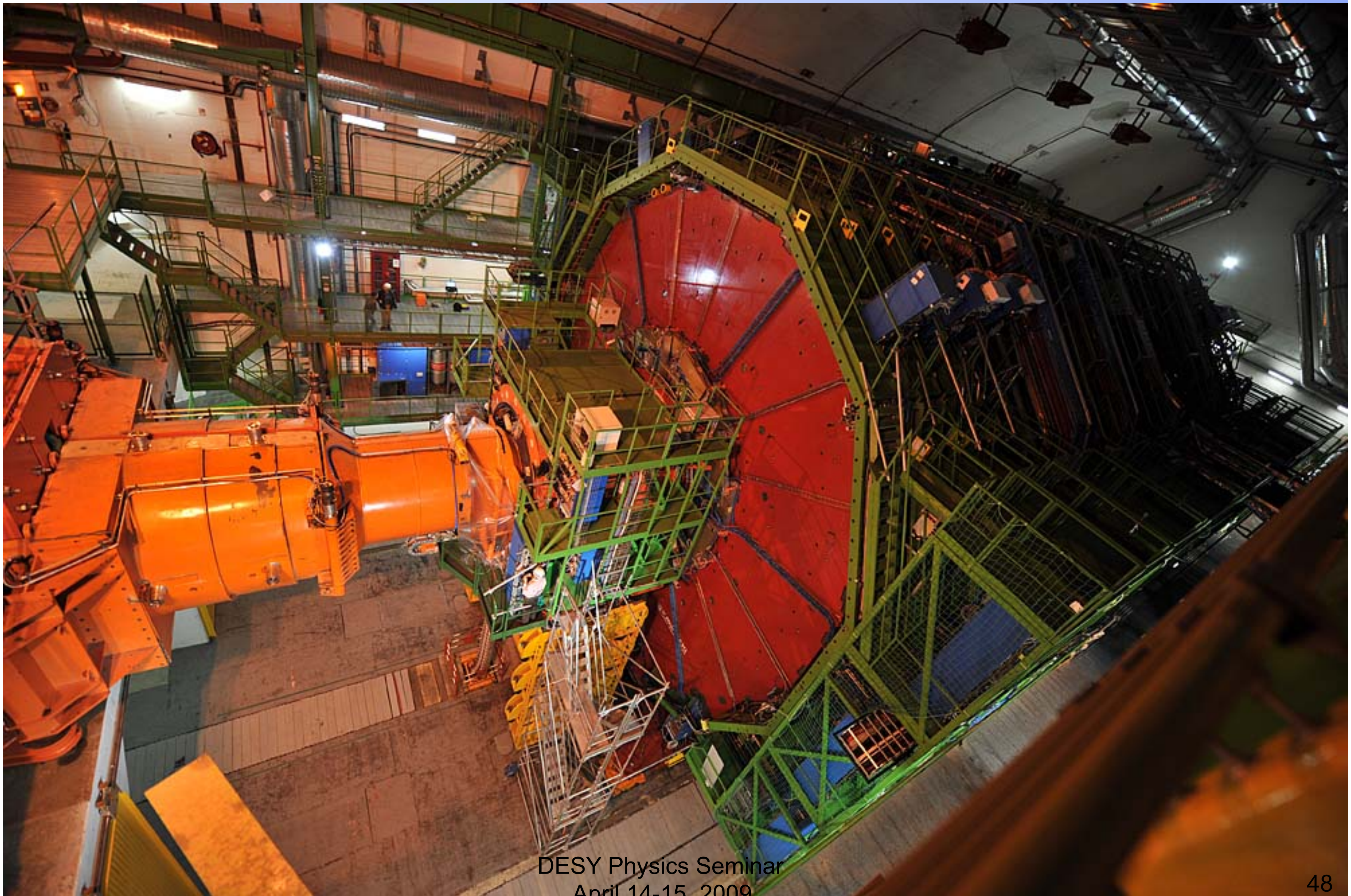
Minus End before Closure



Minus End & Closure



Final Closure



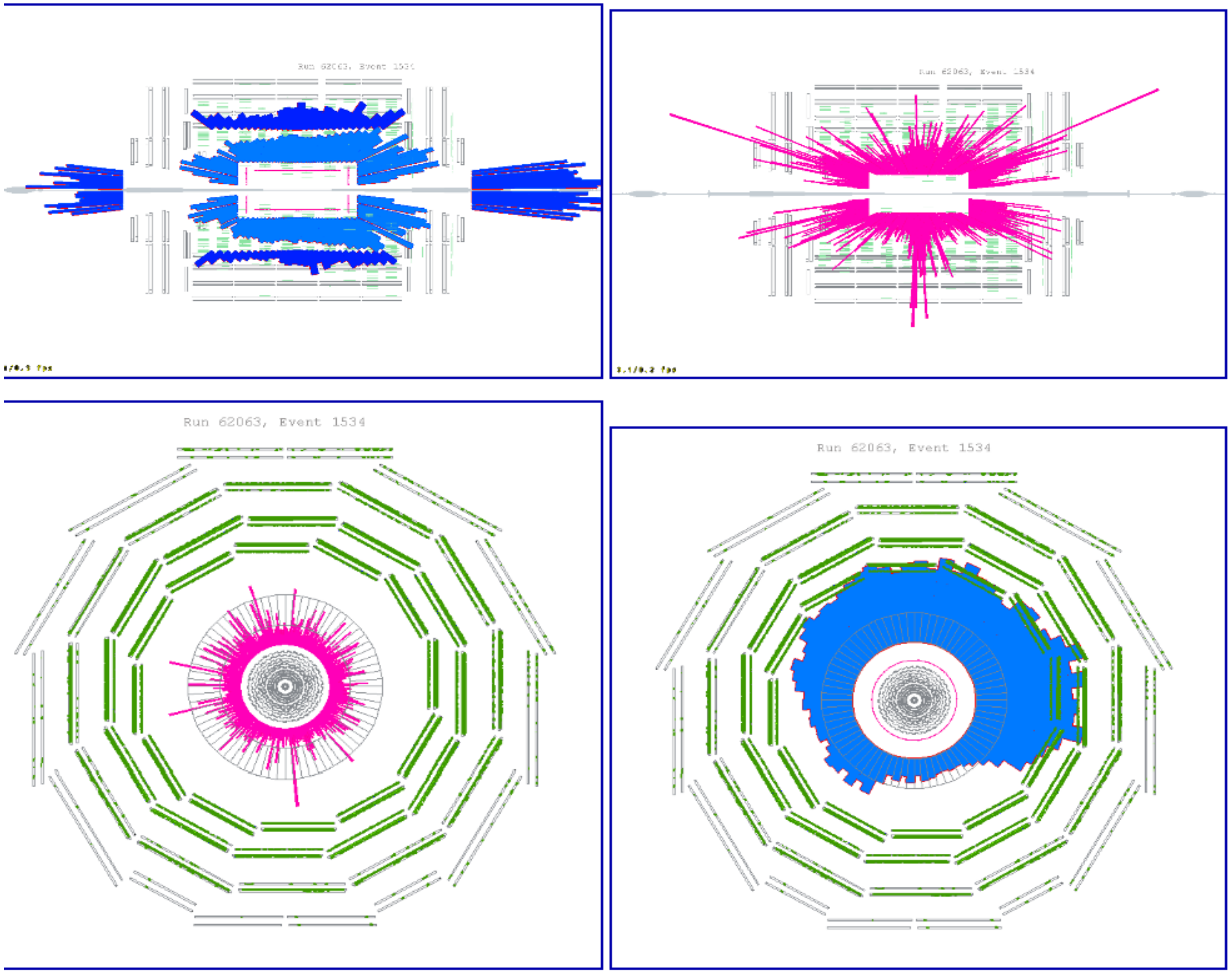
First LHC beam

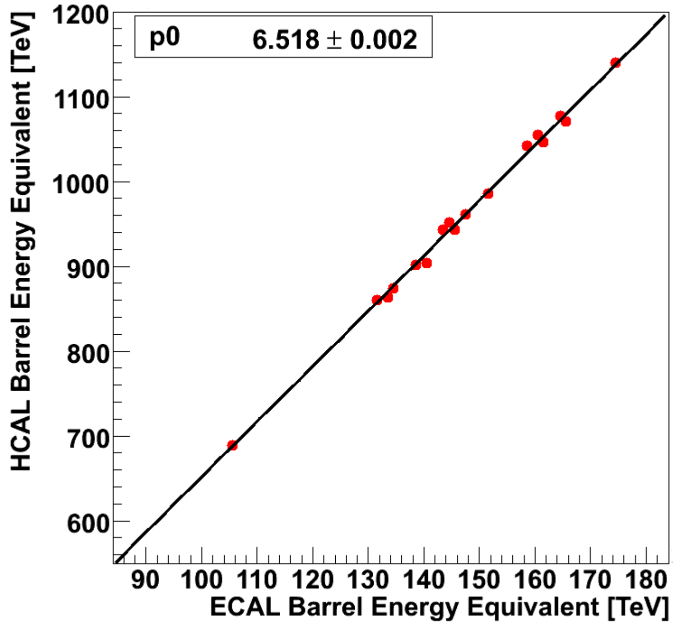
- **In Sep 2008, after almost 20 years of design and construction CMS started taking data with LHC beams.**
  - **(Much appreciation for the work of the accelerator folks)**
- **Sun/Mon, 7-8 Sept.**
  - **Single shots of Beam 1 (clockwise via ALICE) onto collimator 150m upstream of CMS, ~ 1 hour**
  - **Allows synchronization of BPTX trigger (good prep for Wed.)**
- **Tues, 9-Sept**
  - **20 shots of Beam 1 onto collimator 150m upstream of CMS**
- **Wed., 10 Sept.**
  - **Nice splash events observed when beam onto collimators (as before), 100-1000 TeV observed in ECAL-HCAL**
  - **Halo muons observed once beam started passing through CMS**

First LHC beams in CMS

~2.10⁹ protons on collimator ~150 m upstream of CMS

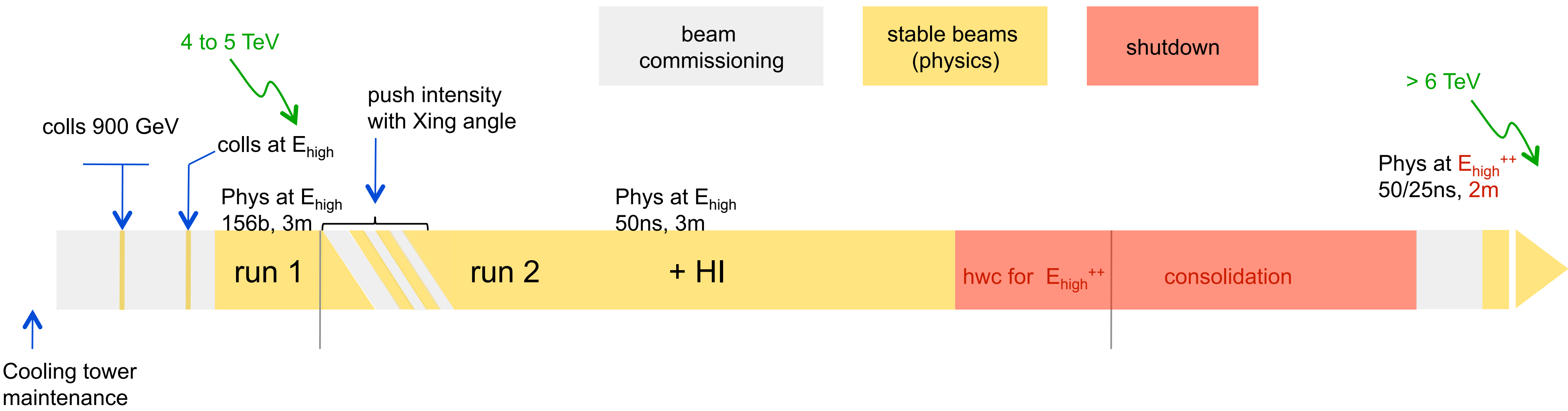
ECAL- pink; HB,HE - light blue; HO,HF - dark blue; Muon DT - green; Tracker Off



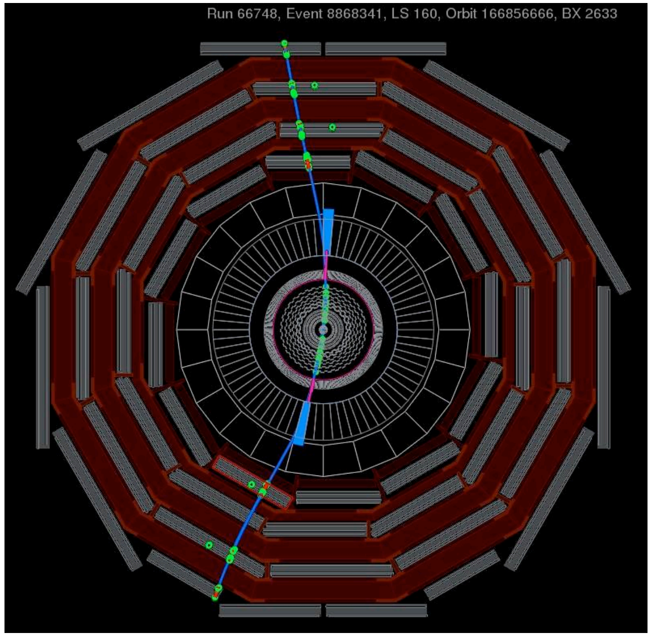


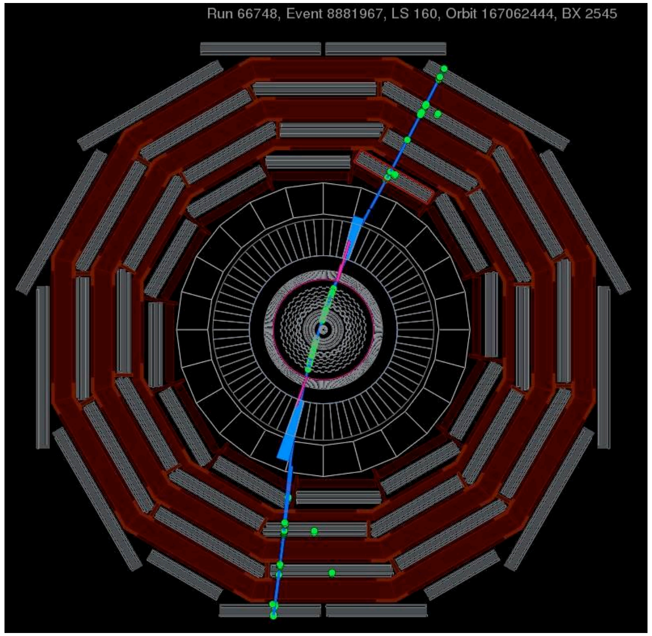
Next…

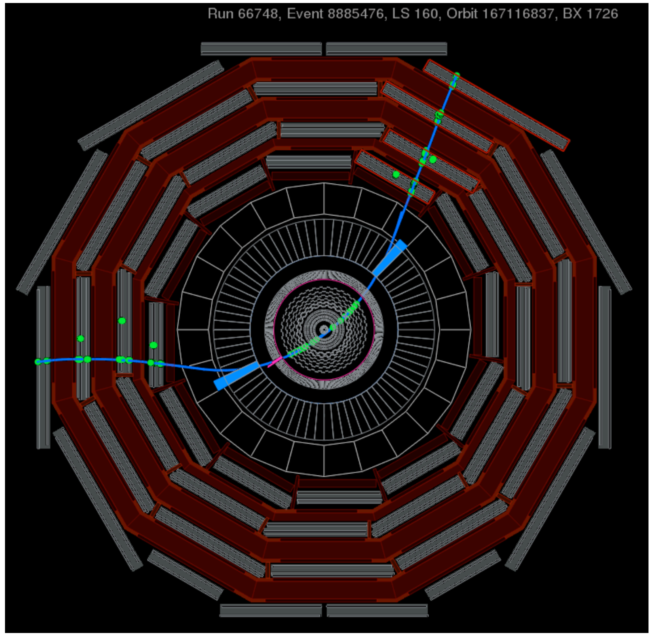
- **Incident on Sep 19 2008: an electrical fault between two magnets resulted in the release of ~1 ton of liquid He**
  - **Repairs under way. Additional protection systems put in place**
  - **Due to restart in September 2009**
  - **First collisions by October 09**
  - **New plan: run through Winter 09-10, to get to ~200 pb-1 (albeit at 10 TeV)**

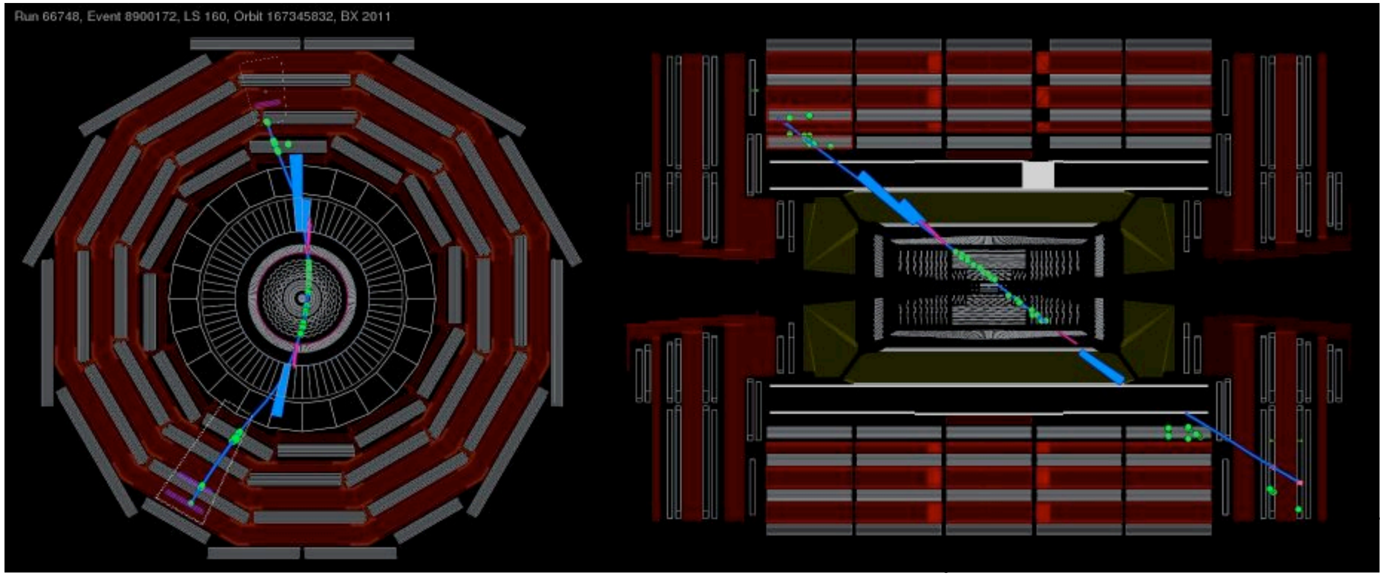


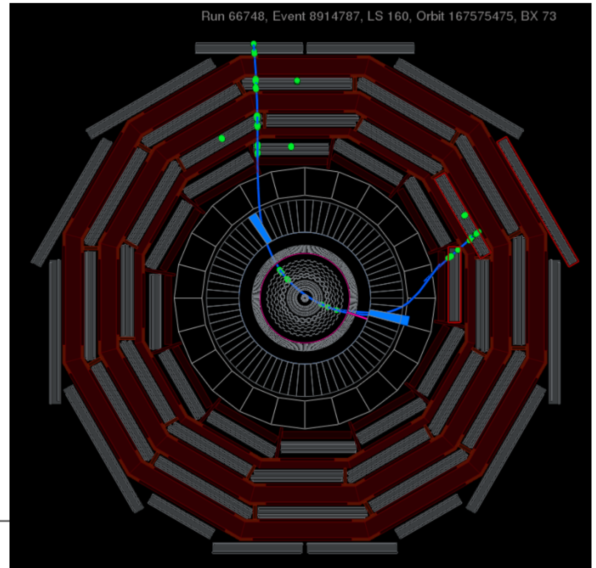
Cosmic Run At Four Tesla - CRAFT







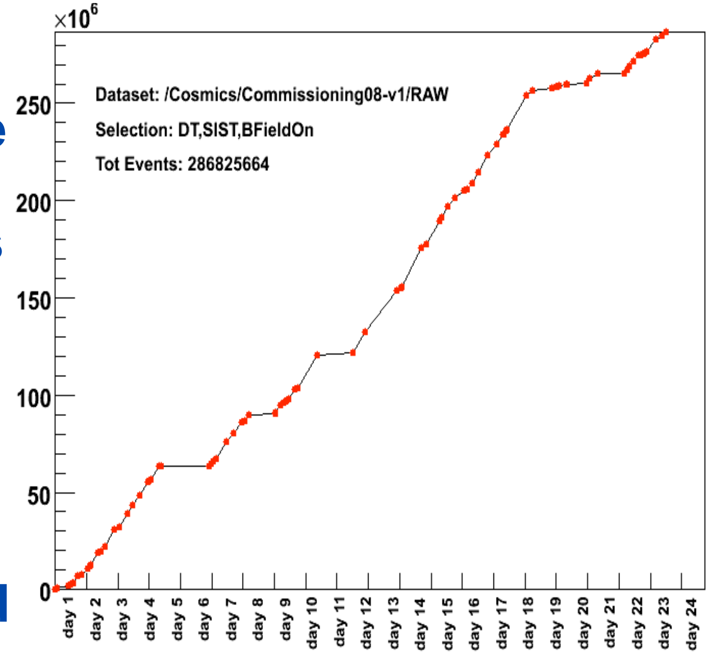




CRAFT

- **Four weeks of continuous running**
  - **19 days with magnet at the operational setting of B=3.8 T**
  - **Gained operational experience and put in evidence sources of inefficiency**
- **Collected 370 M cosmic events; 290 Mevt with B = 3.8 T. Of those with B on:**
  - **87% have muon track reconstructed in the chambers**
  - **3% have muon track with strip tracker hits (~7.5 M tracks)**
  - **3×10^{-4} have a track with pixel hits (~75K tracks)**
- **Data operation performed satisfactorily**
  - **600 TB of data volume transferred**
  - **Prompt reconstruction at Tier 0 completed with typical latency of 6h**
  - **Tier 0 to Tier 1 at average of 240 MB/s**

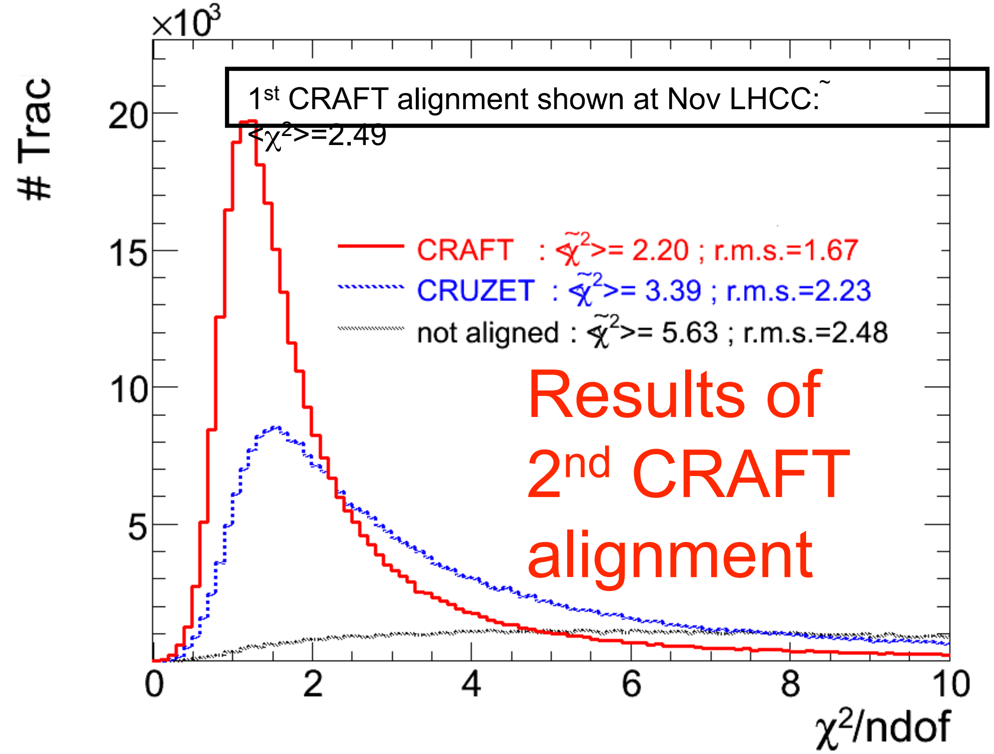
Number of cosmic events vs. time



Tracker Alignment with Cosmics Data

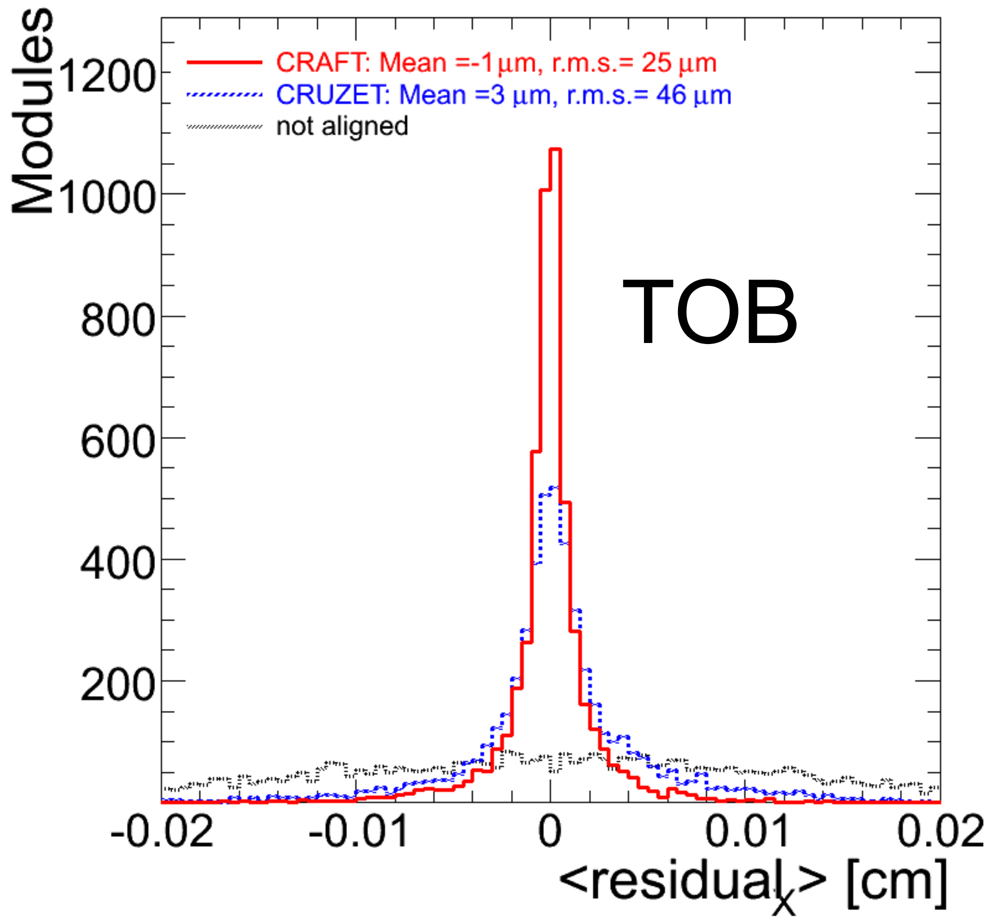
- First reprocessing of the CRAFT data – shortly after the end of the run in November – was already based on a comprehensive set of tracker alignment constants derived from this sample
- The reprocessed data have been used to further improve the alignment
  - synchronous update of Lorentz angle calibration & alignment constants
  - more tracks with pixel hits due to adjusted error object
  - continuous improvements in methodology
  - combining the powers of HIP + MillePede-II alignment algorithms

➔ Steady improvement of track quality (visible in χ^2/ndf) from CRUZET → 1st CRAFT → 2nd CRAFT alignment



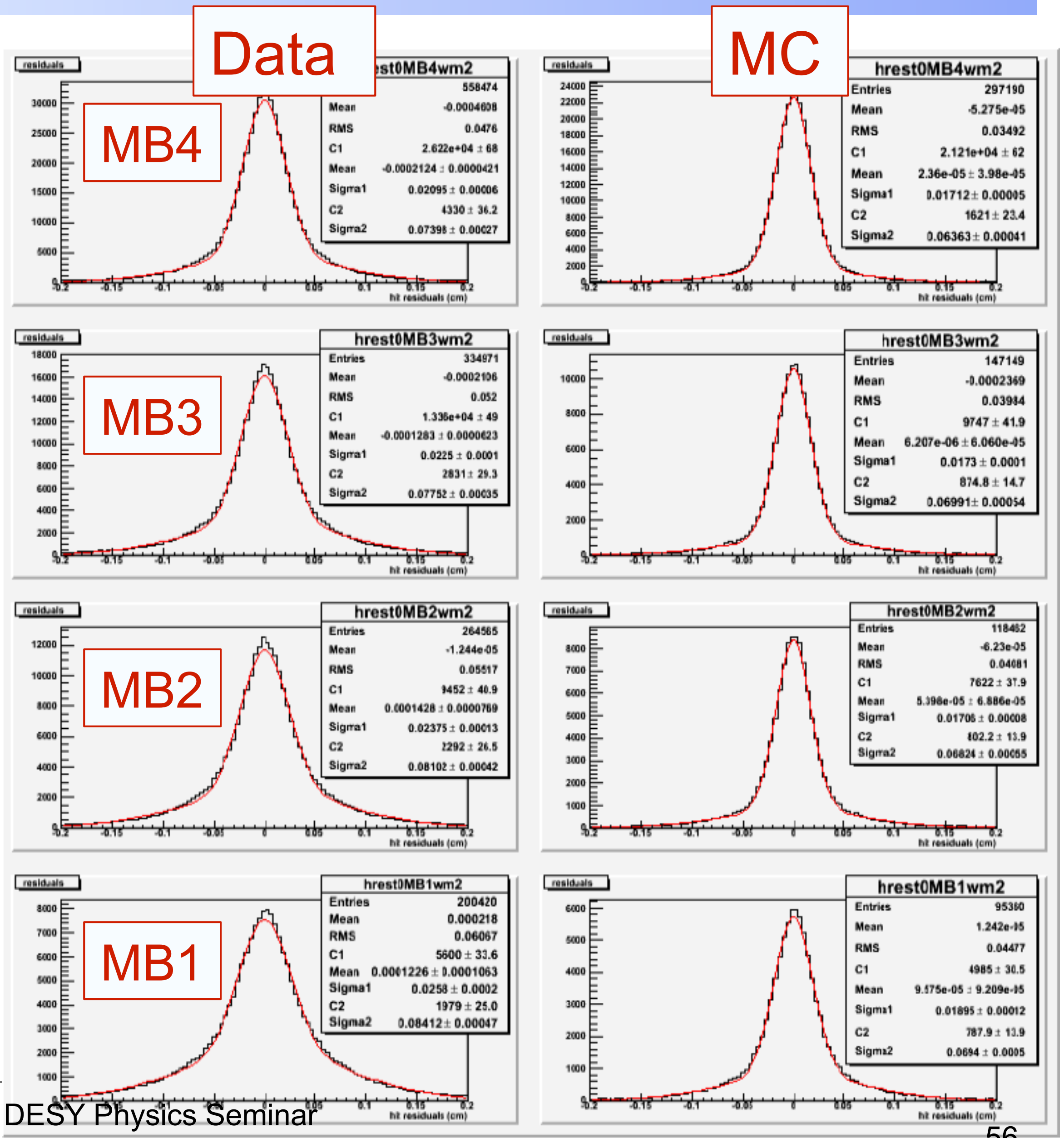
Update of Tracker Alignment (II)

- **Variance of mean values from the individual residual distributions is studied as a measure of alignment quality**
  - ➔ **further improvements of accuracy resulting from alignment performed on reprocessed data are particularly visible in TIB, TOB (tracker inner/outer) and PXB (pixel barrel)**



Drift Tube Muon System

- **Residual Distributions**
  - Reasonable agreement between data and MC after cosmic muon arrival time fit
  - Sigma ~ 200–260 μm
  - Shown here: sector 4 of wheel -2
  - B field degrades MB1 distribution in wheels +/-2

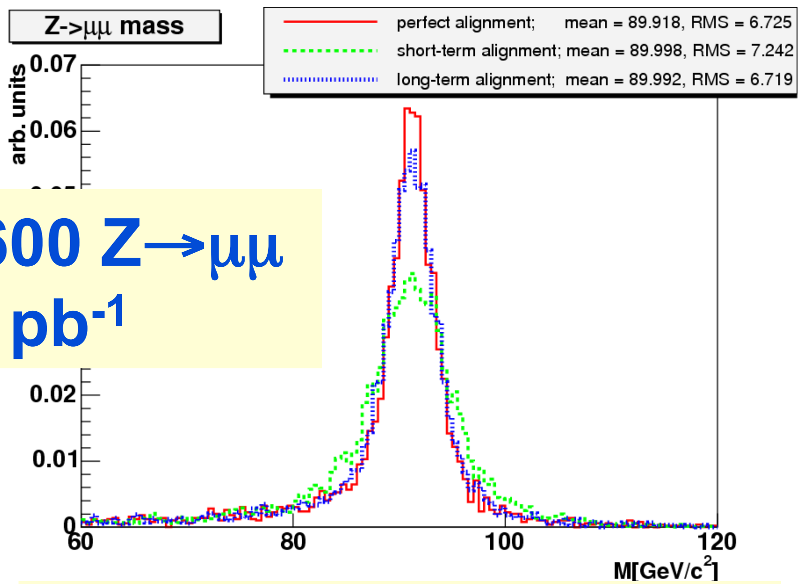


“Physics commissioning” and early (2010-2011) physics

First few pb^{-1}'s: tracker & calorimeters

- **Tracker Alignment**

	Expected Day 0	Goals for Physics
Tracker alignment	20-200 μm in Rϕ	O(10 μm)



600 Z→μμ / pb^{-1}

Z peak visible even with initial (rough) alignment

- **Calorimeter calibration**

	Expected Day 0	Ultimate goals
ECAL uniformity	~4%	< 1%
Lepton energy	0.5-2%	0.1%
HCAL uniformity	2-3%	< 1%
Jet energy	<10%	1%

ECAL, HCAL: intercalibration using azimuthal symmetry (min bias).

ECAL: π^0 calibration, then electrons

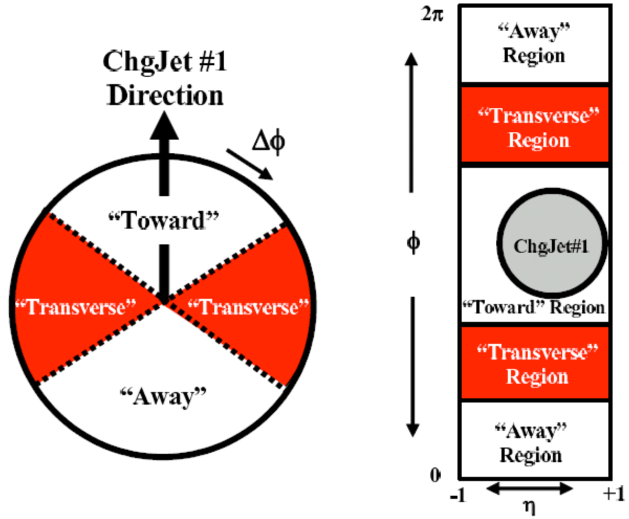
HCAL: di-jet balancing; check with photon+jets; Jet Energy Scale set by W→jj in top events

Event structure

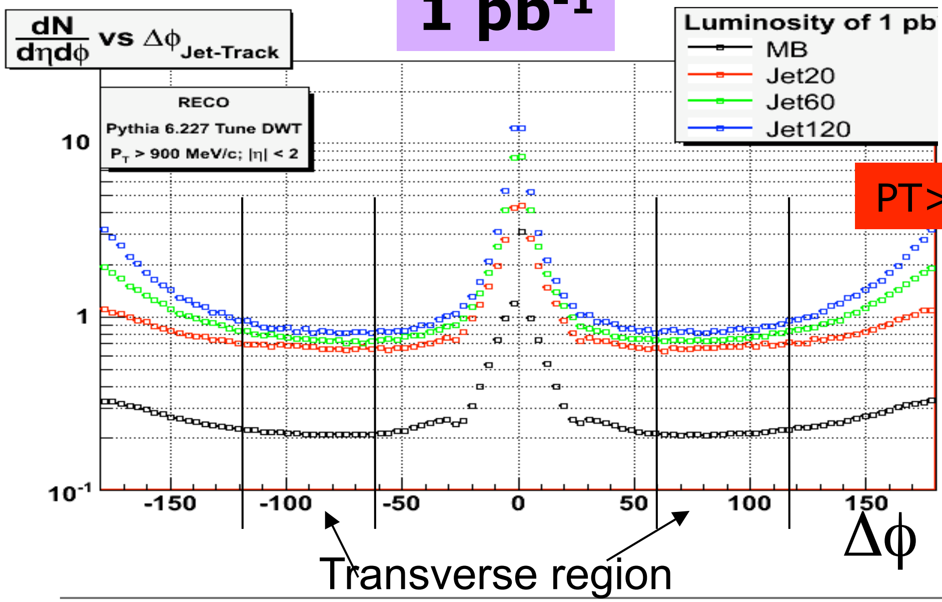
- **Minimum-bias & jet events**
  - **measure underlying event activity**

Main observables:

+ $dN/d\eta d\phi$, charged density
+ $d(P_T^{sum})/d\eta d\phi$, energy density

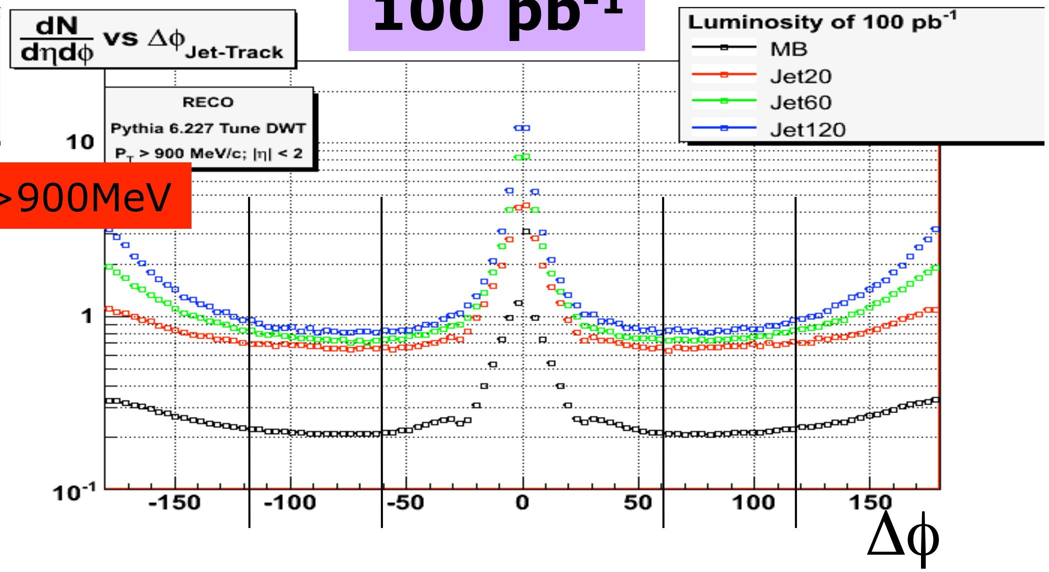


1 pb^{-1}



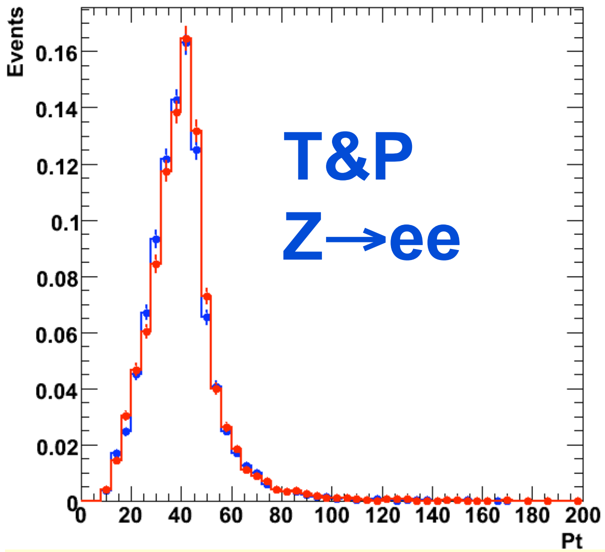
PT>900MeV

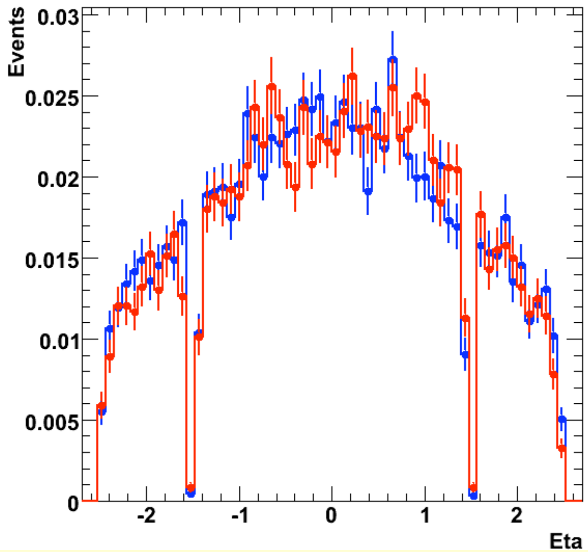
100 pb^{-1}

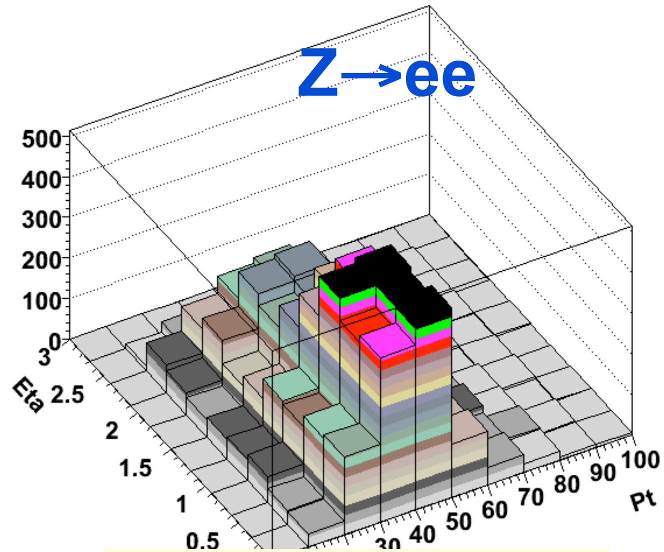


Object-ID/efficiency: data-driven methods

- **Tag and Probe (T&P): identify a physics object in an unbiased way in order to study efficiencies.**
  - **One object (tag) has strict ID criteria imposed on it. Second object (probe) has looser ID criteria. Additional property that links it to the Tag object to ensure a pure sample.**
    - **$Z \rightarrow ee$ events: one tight electron (tag); the other can be a probe, provided the invariant mass of the pair is $\approx M_Z$**



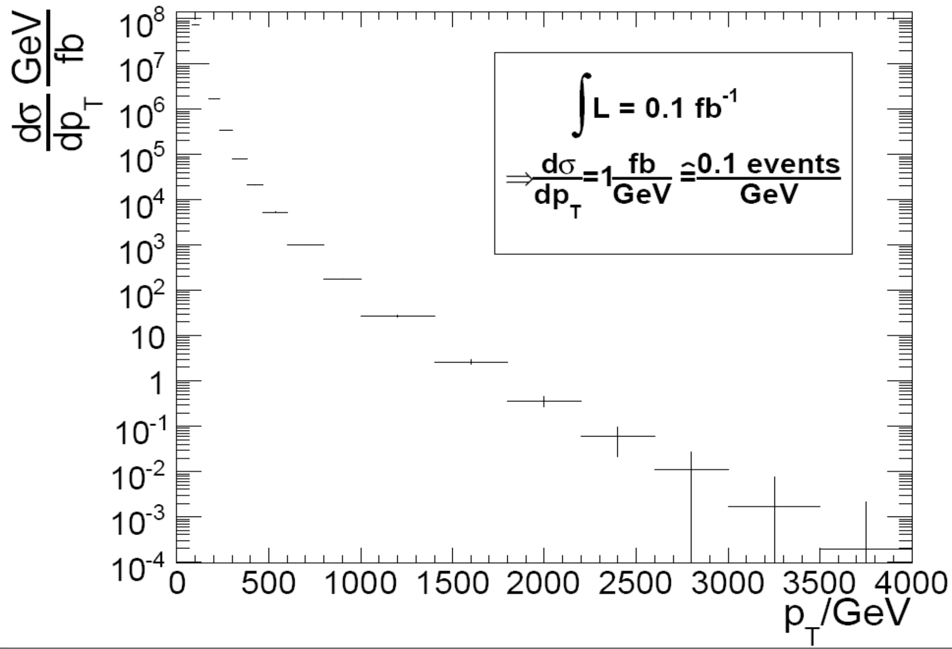


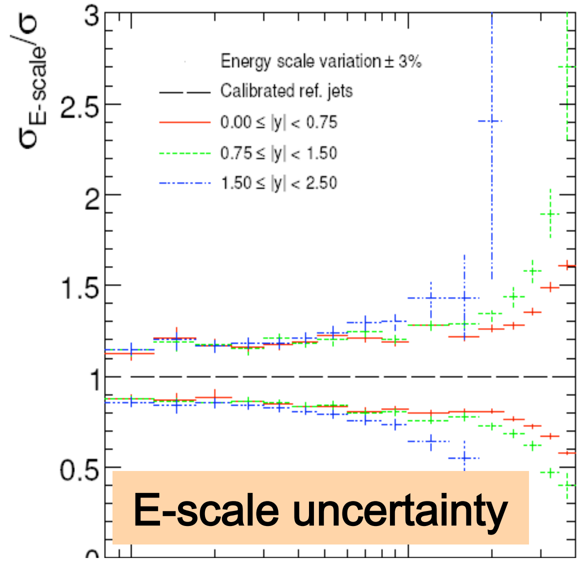


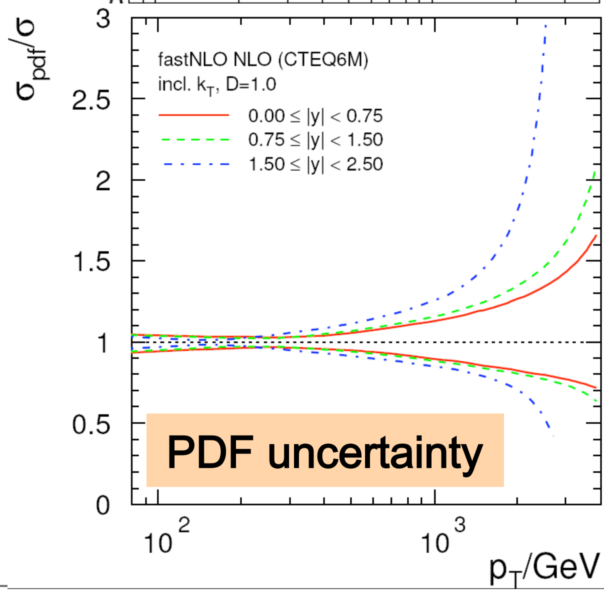
Efficiency from T&P: 94.36±0.24
Efficiency from MC truth: 94.63±0.24
} **(for 10 pb^{-1})**

QCD: jet production

- With 100 pb^{-1}: reach ~2 TeV (E_T)
- With 1fb^{-1}: reach ~3 TeV
  - ~10^4 events with E_T> 1 TeV
- Systematic uncertainties:
  - detector: jet energy scale
  - theory: PDFs







Di-jet resonances

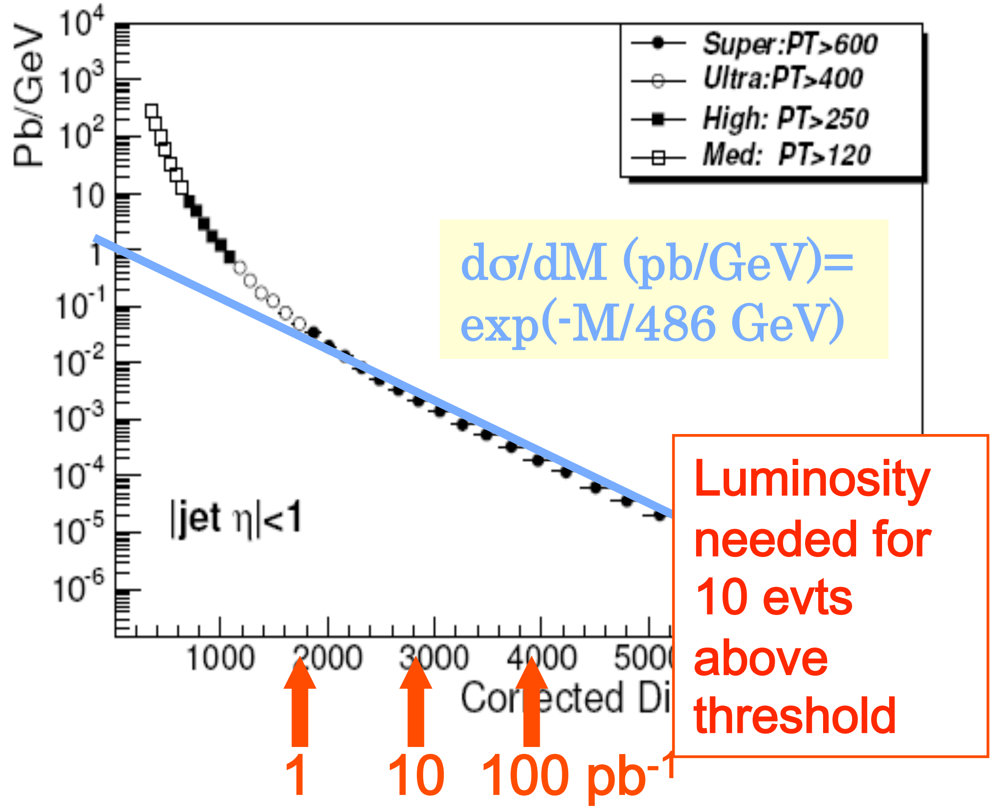
- **Huge hadronic jet rates**
  - Few weeks at 10^{31} cm^{-2}s^{-1} (~1wk at 10^{32}): see E_T (jet) ~ >0.5 TeV
- **Search also starts immediately**
  - Strongly-produced → high rate. Physics in high-mass tail.

• Sensitivity to excited quarks, RS Gravitons, W′, Z′…

• Limits from Tevatron in the range 0.4 - 1 TeV

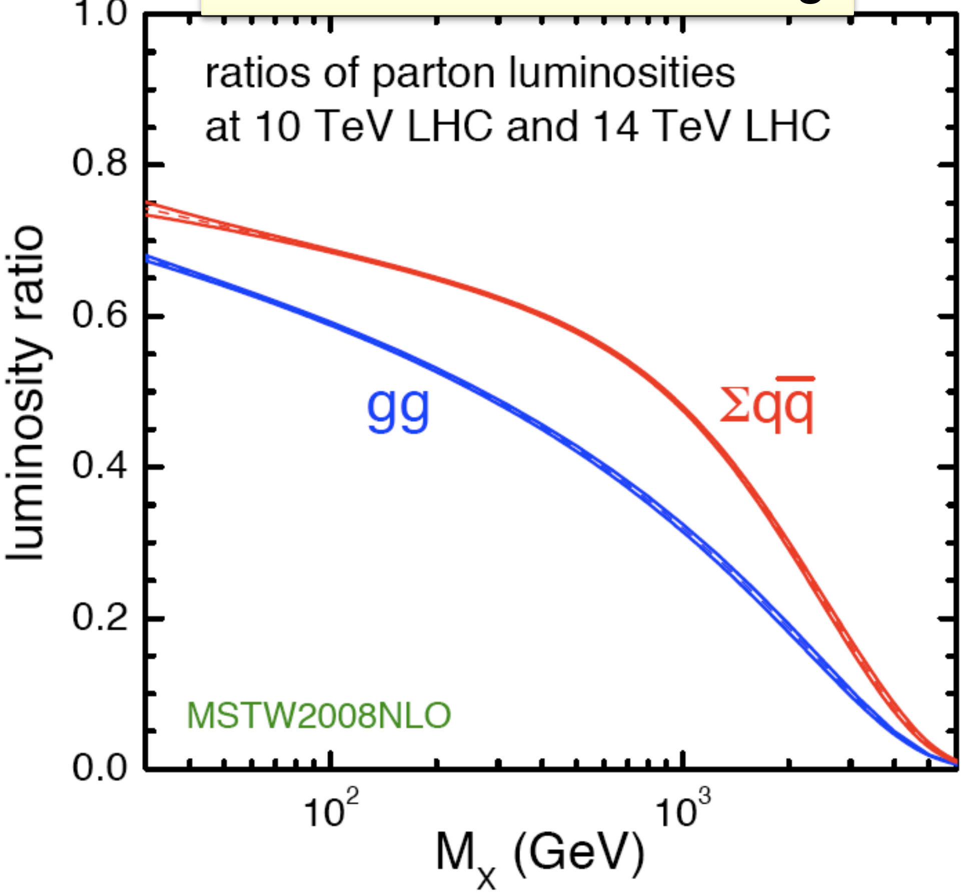
  • Few pb^{-1} at 14 TeV: extend range

• Crucial experimental parameter: energy resolution in measuring jet energy (expect narrow resonances)



Parton luminosities at 10-14 TeV

Thanks to James Stirling



$$\frac{\sigma(t\bar{t})\ \text{at 14 TeV}}{\sigma(t\bar{t})\ \text{at 10 TeV}} = 2.3$$

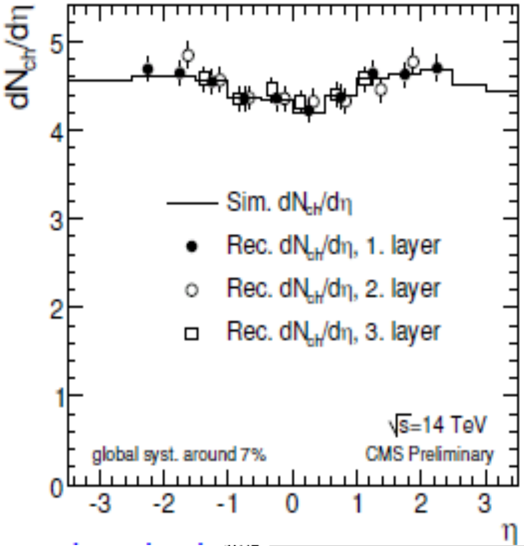
$$\frac{\sigma(W)\ \text{at 14 TeV}}{\sigma(W)\ \text{at 10 TeV}} = 1.4$$

HWW search

NLO MCFM x-sec (14:10TeV):

gg➔H	1 : 0.54
WW and WZ	1 : 0.65
tt	1 : 0.45
W+jets and DY	1 : 0.68

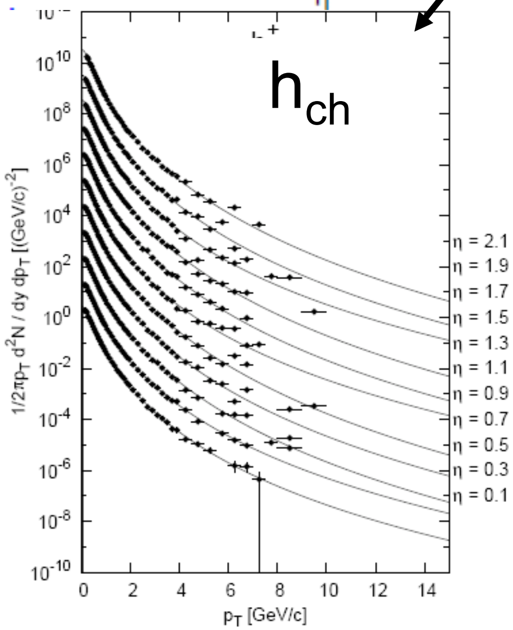
Charged hadron spectra



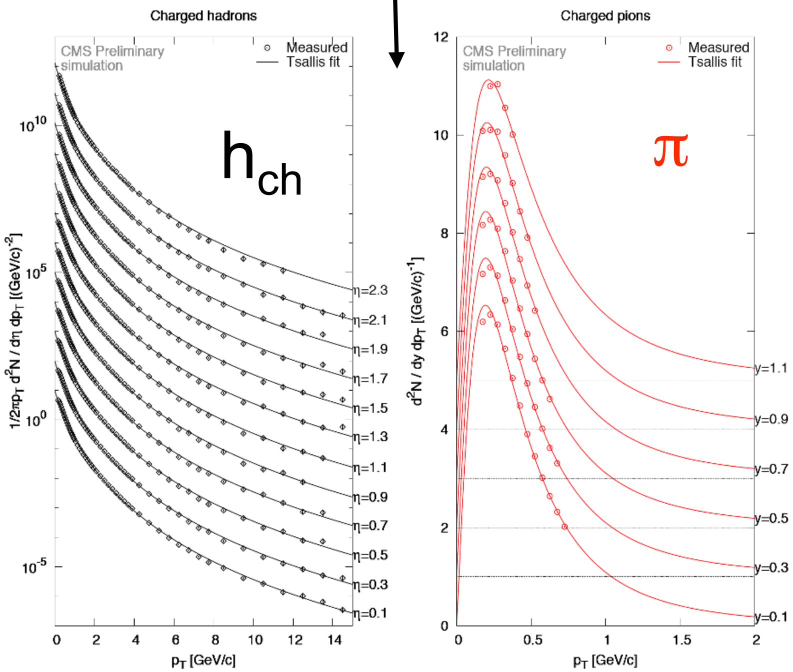
Count clusters in the pixel barrel layers

– No need for tracking, sensitivity down to 30 MeV/c

charged hadron spectra @ 900 GeV



… and at full energy



Important measurement for HI program

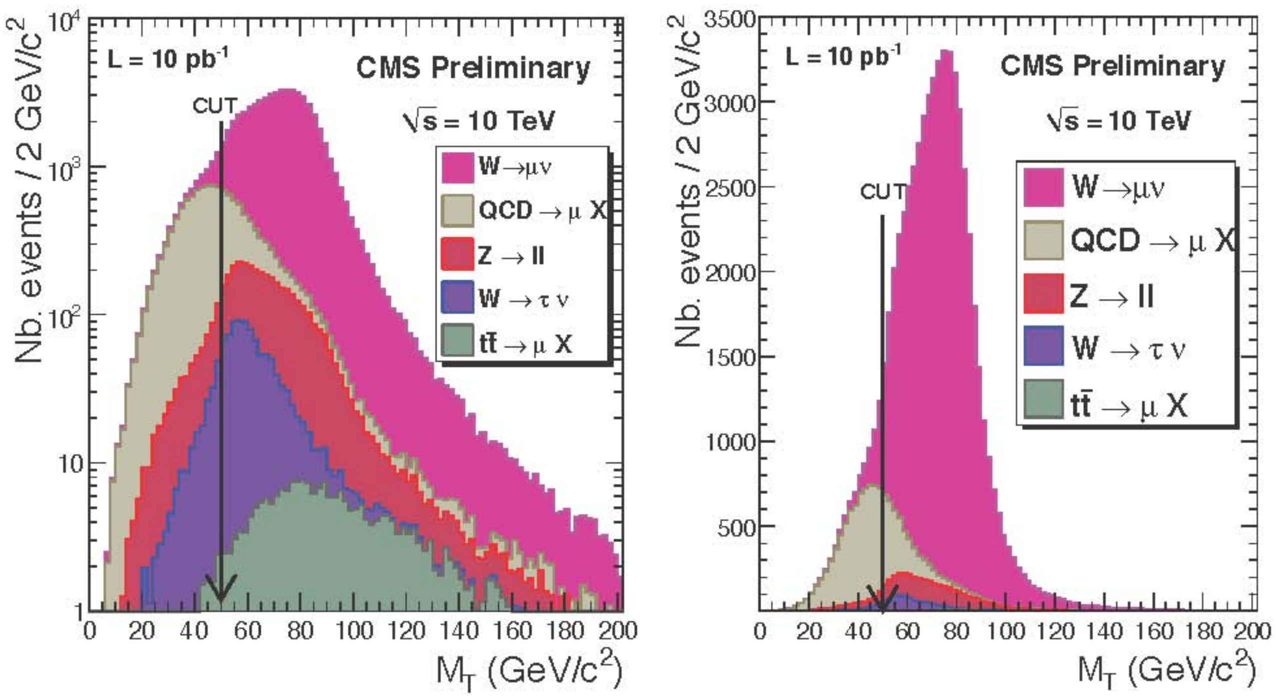
EWK channels

- **Expect thousands of W's and Z's very early on**
  - **Analysis updates at 10 TeV for muons so far**

W selection rerun on 10-TeV samples

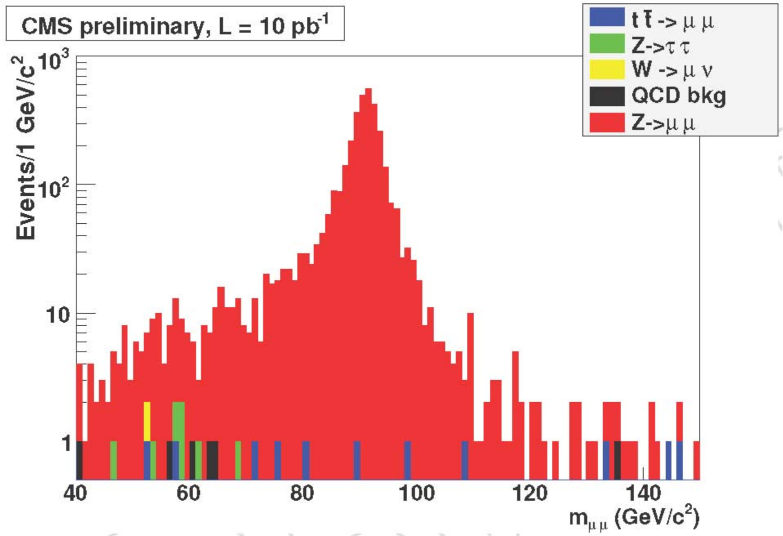
Signal cross section reduced by ~30%

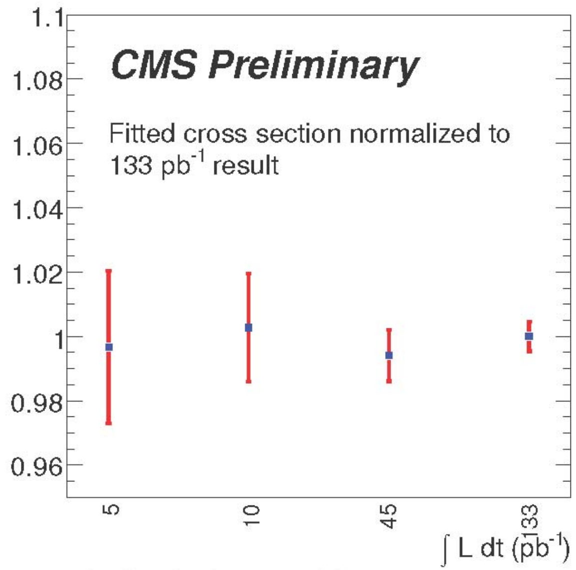
Top background is also reduced compared to 14TeV



Z Analysis @ 10 TeV

- Z backgrounds are small when both muons are globally reconstructed (μ) using tracker and muon systems
- Simultaneous fit with independent samples with standalone muons, tracker-only muons, and non-isolated muons, to obtain efficiencies
- Z cross section measurement as a function of integrated luminosity

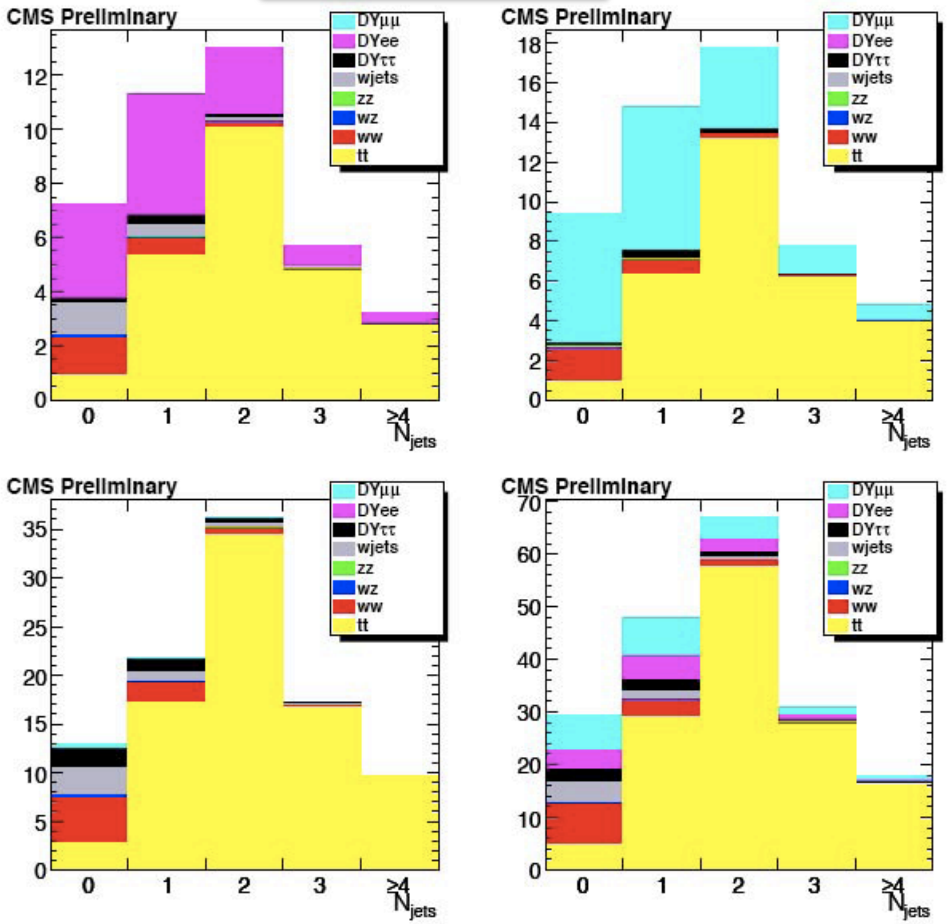




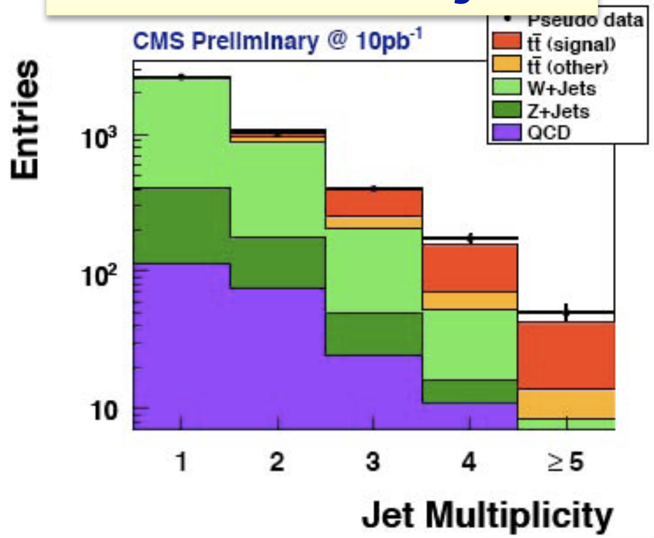
Top physics (at 14 TeV)

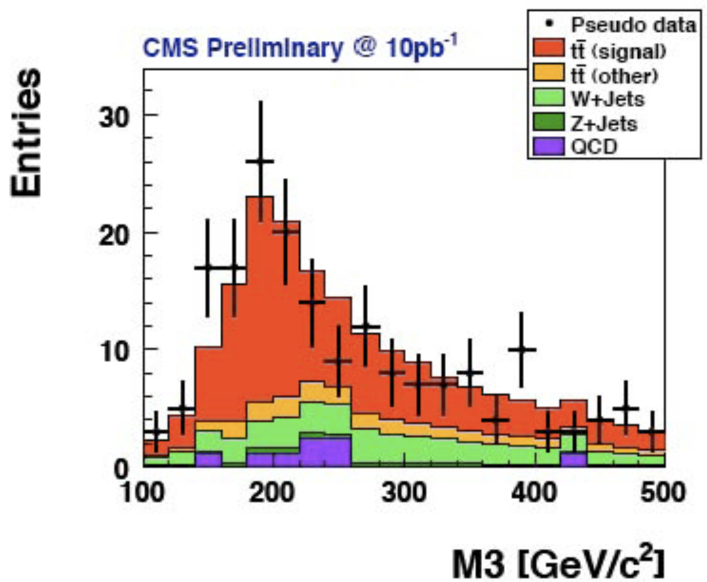
- **At 10 TeV: factor 2 in lumi**

Dileptons



Mu+Etmiss+jets

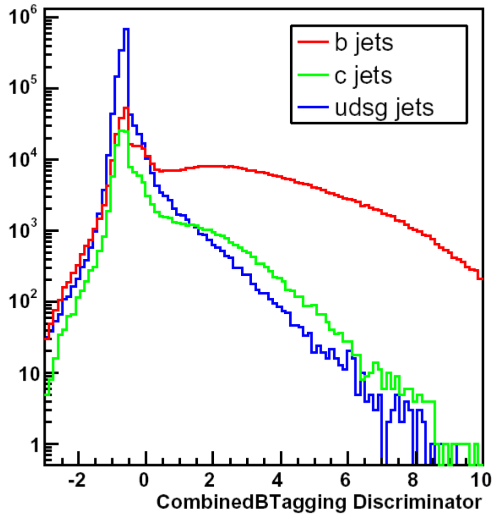


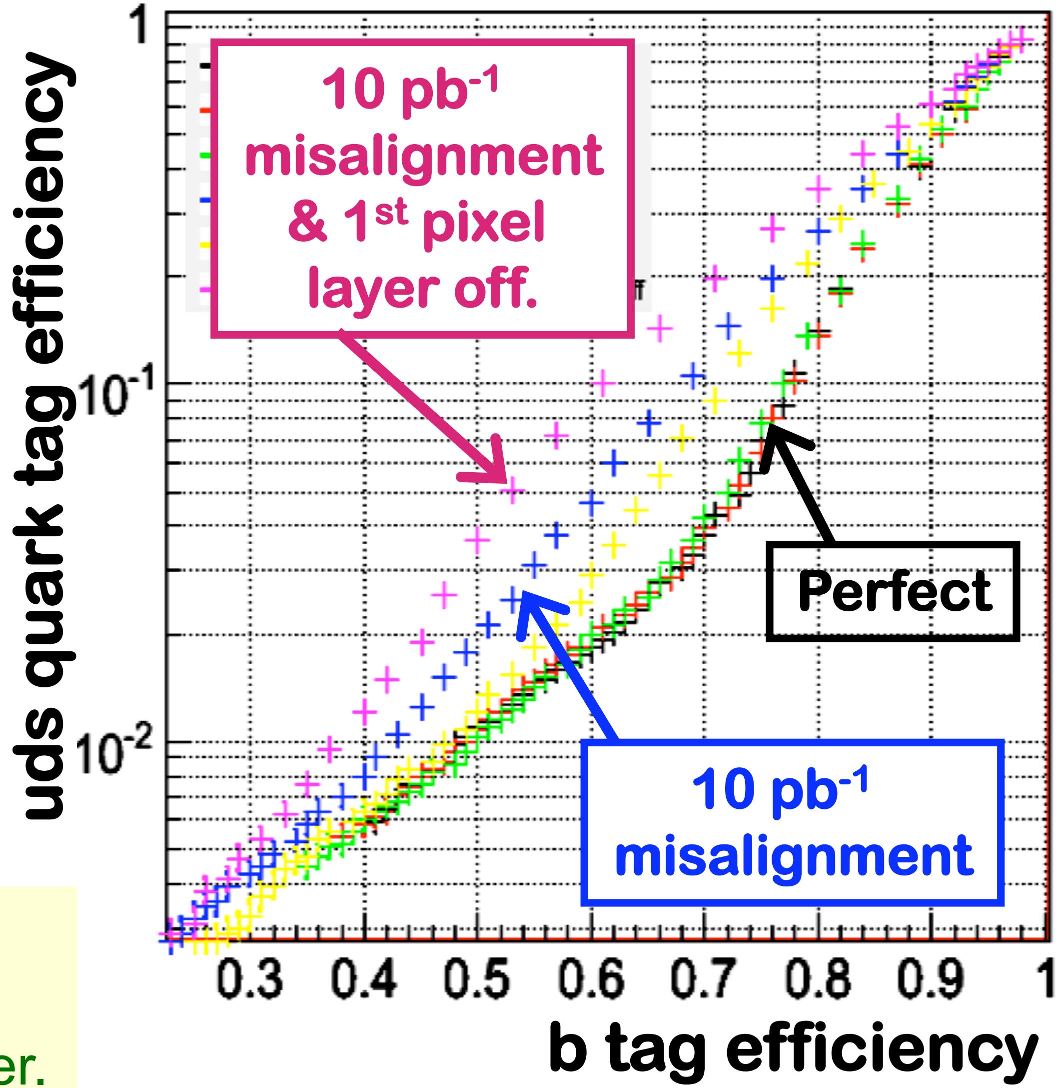


Event reconstruction: b-tagging

- **Combined secondary vertex b-tagging algorithm**
  - combination of several topological and kinemat observables

CMS Note 2006/064

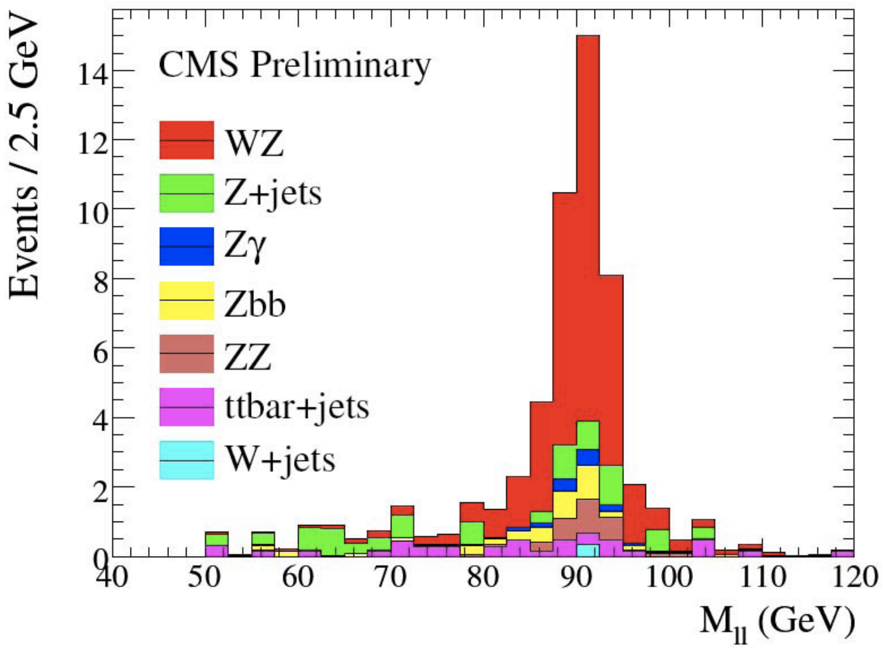


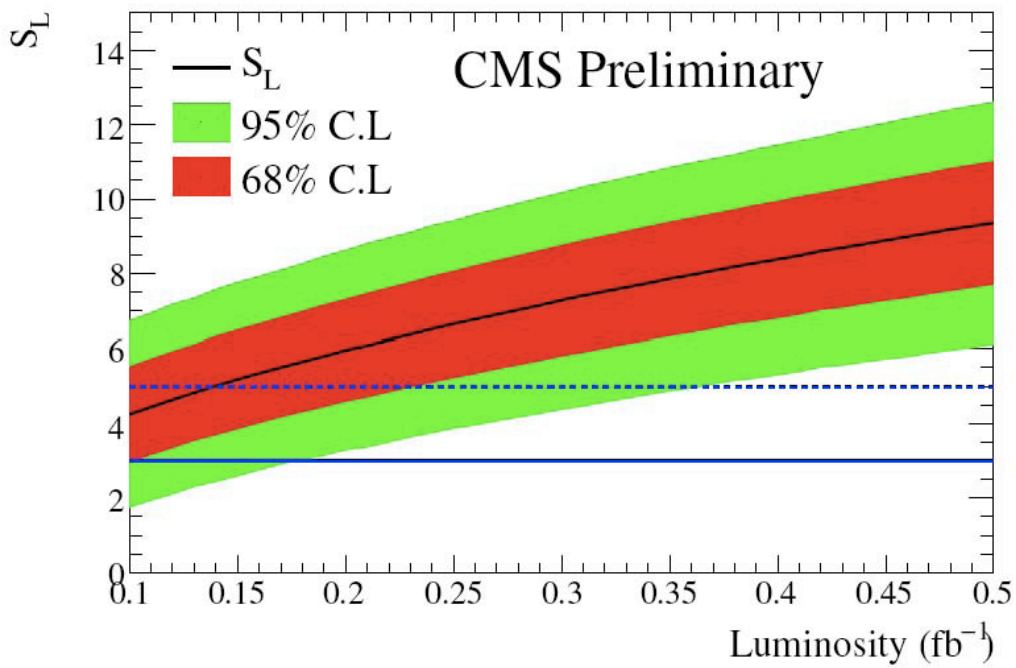


Lifetime-based b tags work OK, even with Tracker misalignment and disabled innermost pixel layer.

Dibosons

- Important measurement for searches (Higgs to WW, but also SUSY, etc)
  - Also for TGCs etc

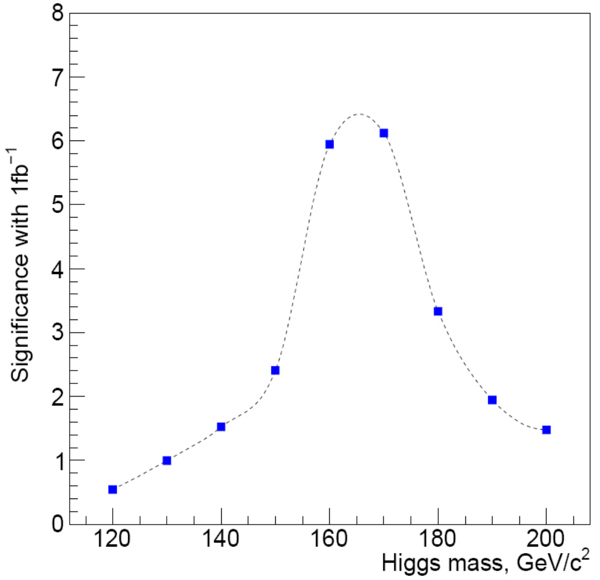




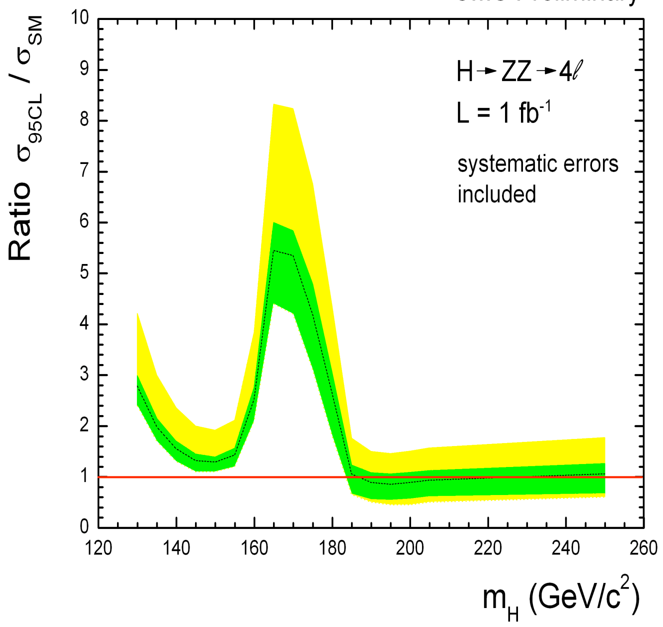
- At 14 TeV, signal with 150 pb^{-1} (for WZ)
  - With 200pb-1 at 10 TeV: should have a signal

Approved full analyses (1 fb^{-1} @ 14 TeV)

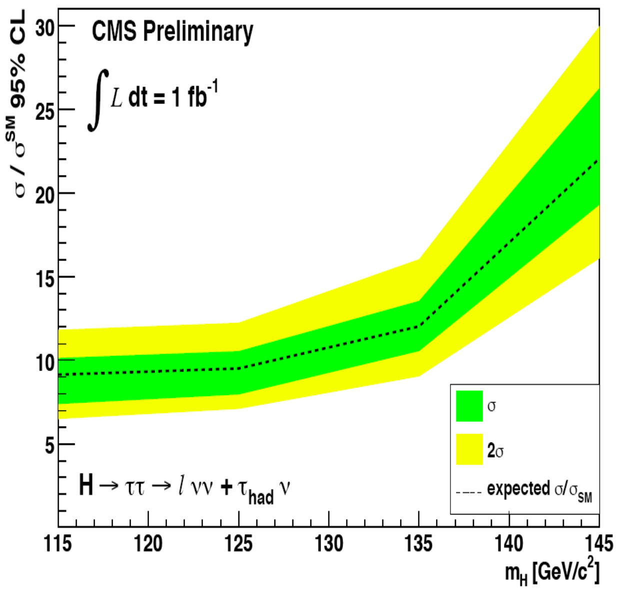
H→WW→2l2ν



H→ZZ→4l



VBF H→ττ→l+τ$_{jet}$+MET



1 fb^{-1} @ 14 TeV

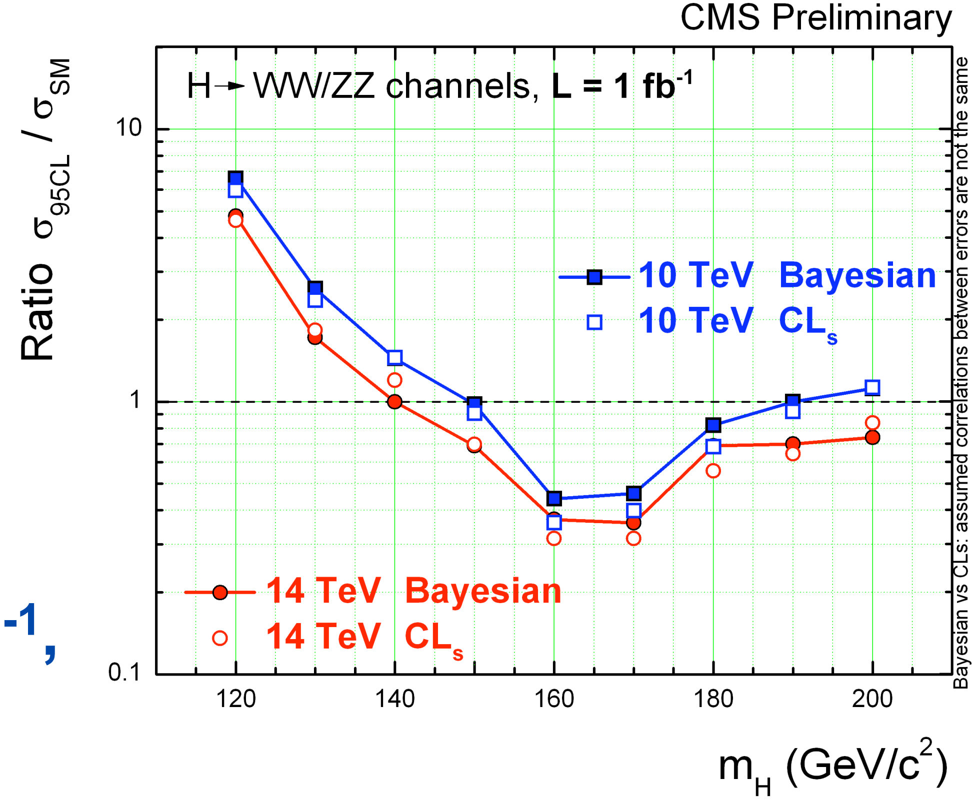
WW: has enough sensitivity for a discovery (160-170 GeV)

ZZ: has enough sensitivity for exclusion (190-230 GeV)

ττ: only high upper limits are possible

Higgs: 14→10 TeV

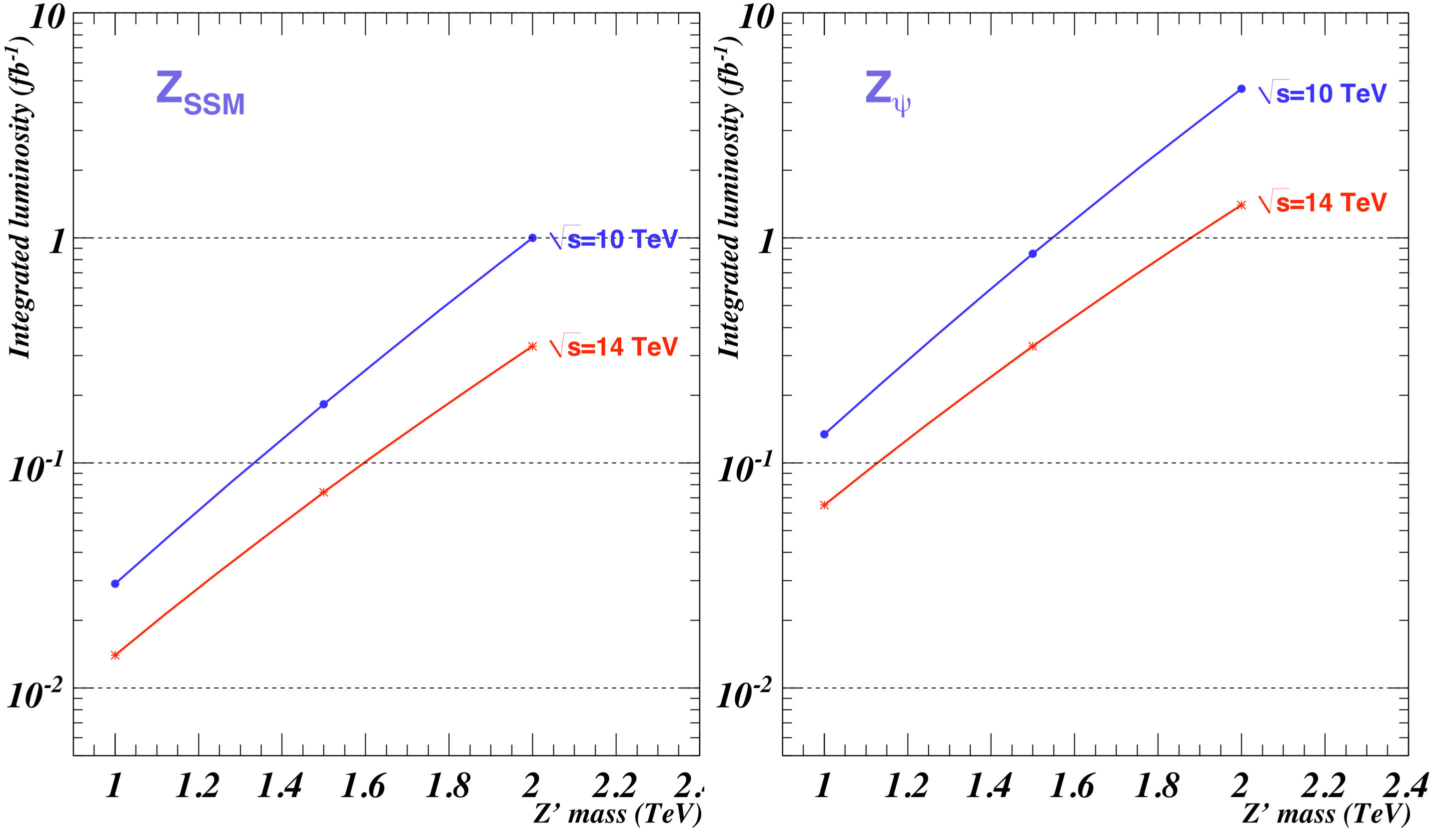
- **signal and bkgd yields re-scaled**
- **14→10 TeV:**
  - **loss of a factor of 1.5 in sensitivity, or a factor of 2 in luminosity**
  - **with roughly ~200 pb^{-1}, reach sensitivity for a SM Higgs with m_H~160-170 GeV** ***(comparable to the current Tevatron sensitivity)***



Z' to mumu

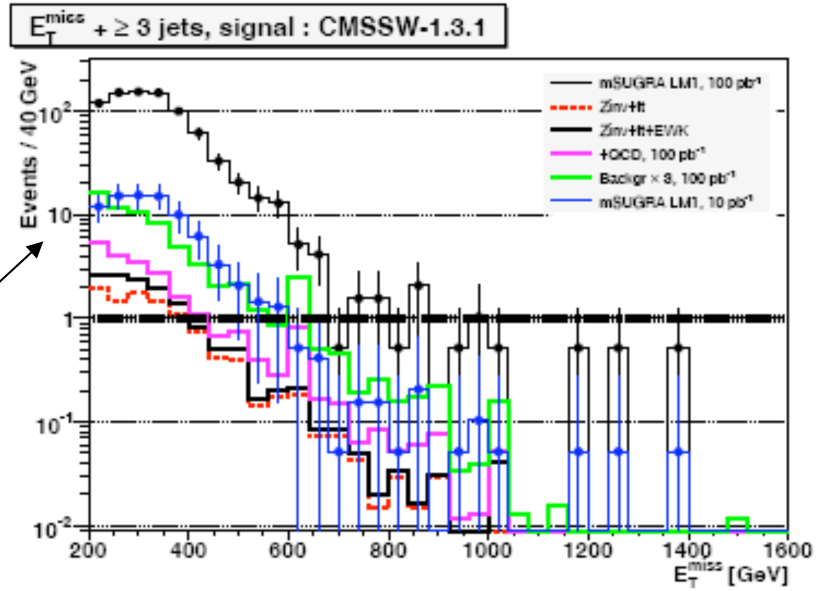
- **14 TeV curves: from full analysis of signals and bkgs**
  - Rescale 14 TeV curves by corresponding cross section ratios for Signal and Drell-Yan bkg → 10 TeV curves
  - Z_ψ and Z_{SSM}: the two extremes in "reach":

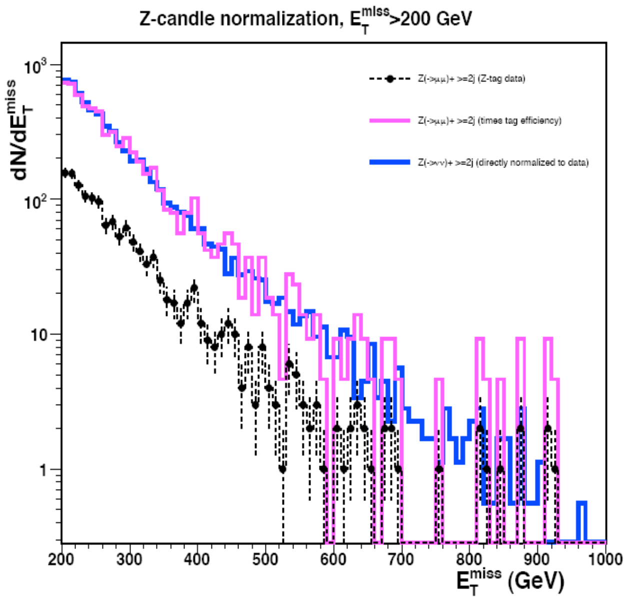
Z' mass (TeV)	σ(14 TeV)/ σ(10TeV)
1	2
2	3



SUSY – early hints

- **100pb^{-1}→ ~600 GeV sparticles, but:**
  - **Need control over backgrounds**
  - **Example from E_T^{miss}+3jet events**
    - **bkg*3 ~ signal @ 10pb^{-1}**





Normalizing Z→νν E_T^{miss} to Z→μμ using data

Quick one-page summary plan

- **With $10pb^{-1}$ we will measure event properties, first jet (and dijet) distributions**
  - **Note that searches start early!**
- **With $100pb^{-1}$ we will measure the Standard Model and establish CMS as a physics-producing engine**
  - **We will also look for hints of new physics**
- **With $1fb^{-1}$ we enter the Higgs discovery era. With a few fb^{-1}: firm discovery**
  - **“SUSY” explorable over very large area with $1fb^{-1}$; possible new resonances**

Summary

Summary

- **Despite its tremendous successes, the Standard Model is still missing its "symmetry breaker"**
- **The LHC and its experiments (CMS…) have been designed to search for the Higgs but also to explore all the possible physics at energies of ~ TeV**
  - **Technological marvels that took ~20 years from concept to scientific intrument**
  - **The LHC should be decisive in revealing the Electro Weak Symmetry Breaking mechanism in the SM (Higgs/no Higgs)**
- **LHC: on track for first collisions in 2009**
  - **Challenge 1: commission machine and detectors of unprecedented complexity, technology and performance**
  - **Challenge 2: "rediscover" the Standard Model**
  - **Challenge 3: probe the physics beyond**