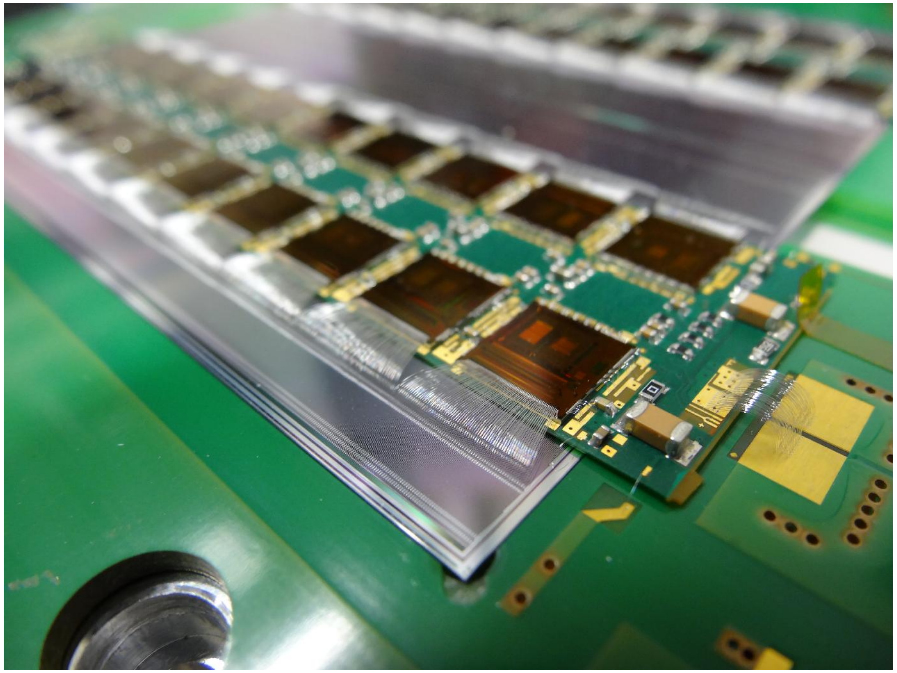
Preparations for the High Luminosity Upgrade of the LHC in ATLAS



Ingo Bloch

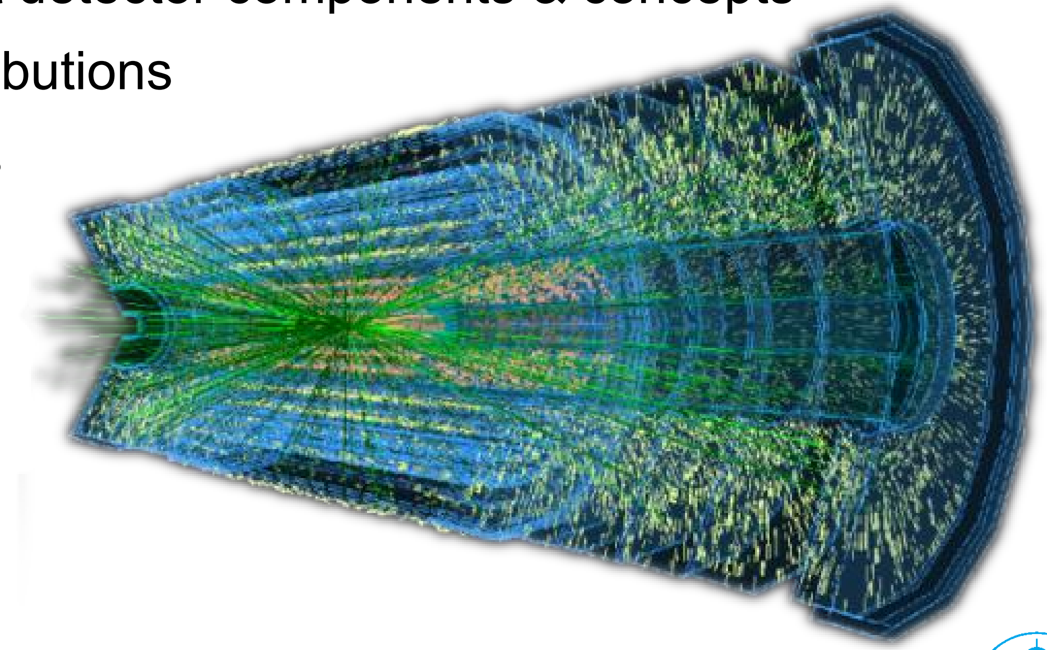
DESY Physics Seminar
Hamburg, 04 March 2014

HELMHOLTZ GEMEINSCHAFT

DESY

Topics

- Motivation for the LHC Luminosity Upgrade in ~2023
  - HL-LHC
- Brief overview of LHC and ATLAS Upgrades
- ATLAS Silicon Strip Detector upgrade
  - Brief recap on relevant detector components & concepts
  - DESY's role and contributions
  - Recent R&D highlights



LHC - Intro

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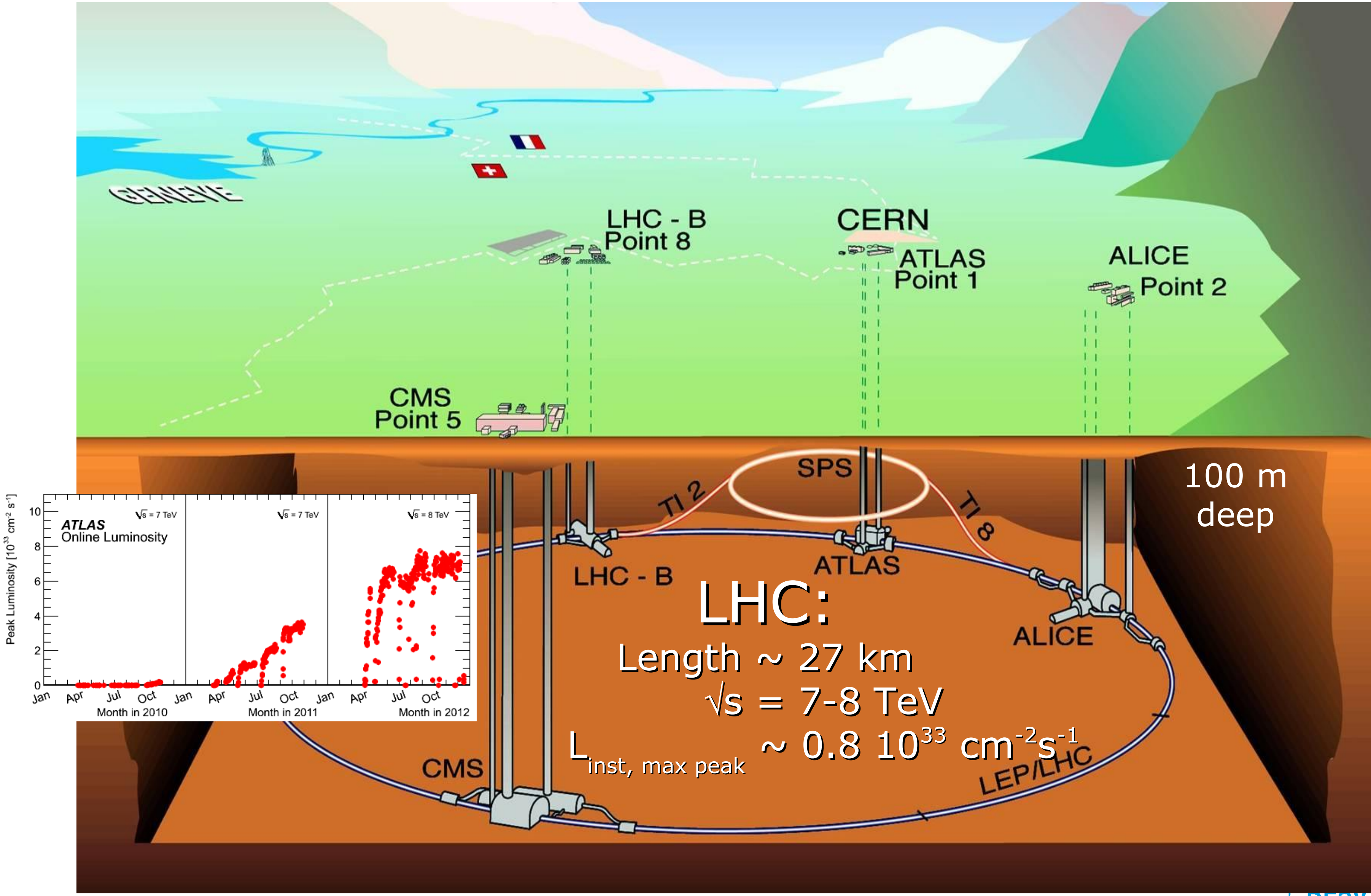


LHC:

Length ~ 27 km

$\sqrt{s}$ = 7-8 TeV

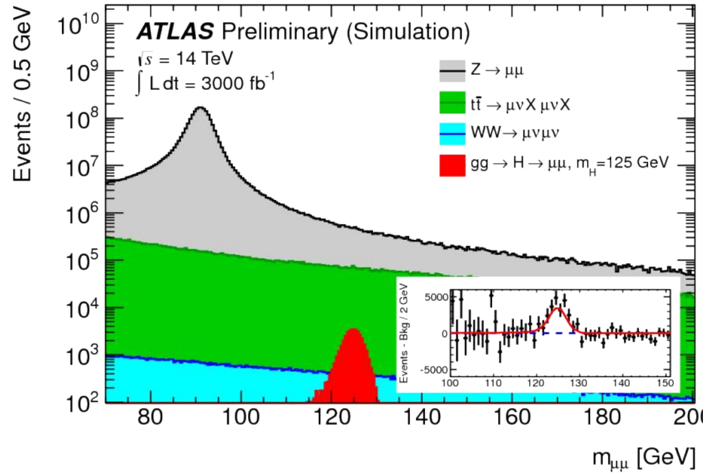
$L_{inst,\ max\ peak} \sim 0.8\ 10^{33}\ cm^{-2}s^{-1}$

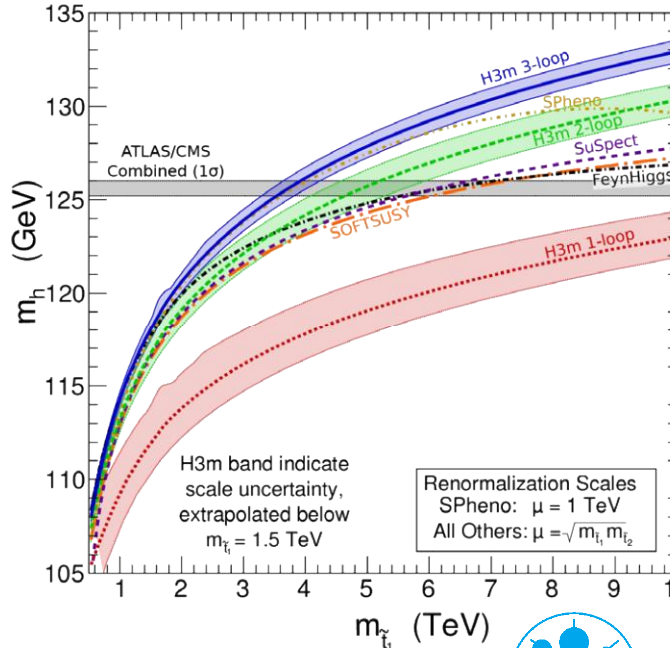
HL-LHC Upgrade – Motivation

- Higgs as one example
- H $\rightarrow$ $\gamma\gamma$

HL-LHC Upgrade – Motivation

- Initial 300 fb^{-1} of LHC data will suffice for some Higgs measurements (e.g. $H\rightarrow\gamma\gamma$, $H\rightarrow ZZ$)
- Others (e.g. $VH\rightarrow H\rightarrow\gamma\gamma$, $H\rightarrow\mu\mu$) remain statistically limited, obtain predictive quality from the HL-LHC dataset
- States with even higher mass particles also require large amounts of data (at fixed energy).
  Current Higgs Mass measurements plus theory improvements imply e.g. Stop at ~3-5 TeV





Feng, Kant, Profumo, Sanford (2013)

HL-LHC Upgrade – Target

European Strategy for Particle Physics

The European Strategy for Particle Physics
Update 2013

c) *Europe's top priority should be the* ***exploitation of the full potential of the 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.*

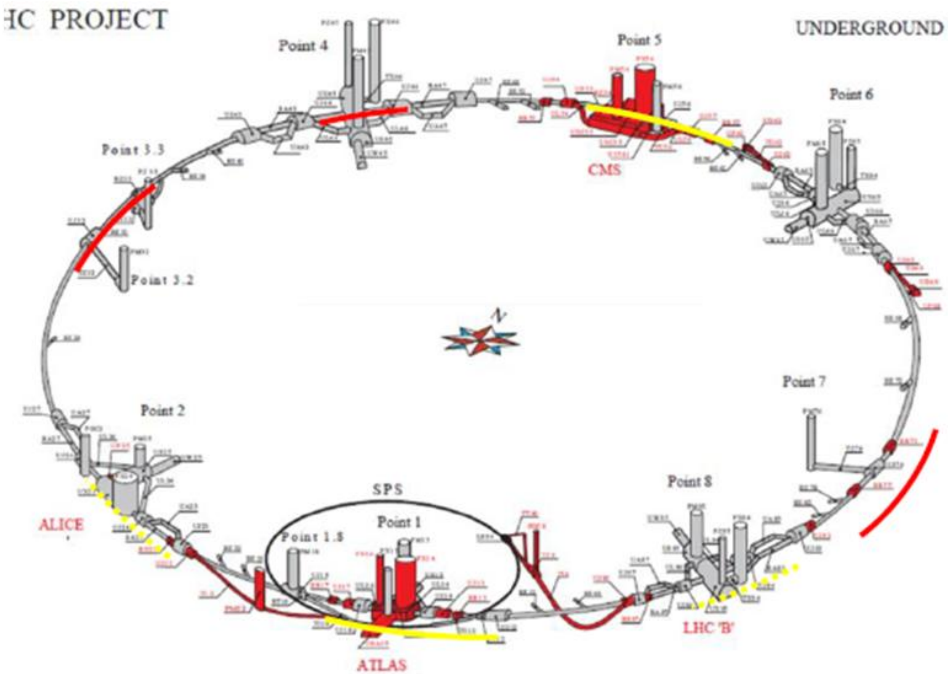
HL-LHC from a study to a PROJECT
300 fb^{-1} → 3000 fb^{-1}
including LHC injectors upgrade **LIU**
(Linac 4, Booster 2GeV, PS and SPS upgrade)

CERN
The High Luminosity LHC
Frédérick Bordry
ECFA High Luminosity LHC Experiments Workshop – 1st October 2013

DESY

HL-LHC Upgrade – a lot to achieve

The HL-LHC Project



- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- …

Major intervention on more than 1.2 km of the LHC

Project leadership: L. Rossi and O. Brüning

The High Luminosity LHC
Frédérick Bordry
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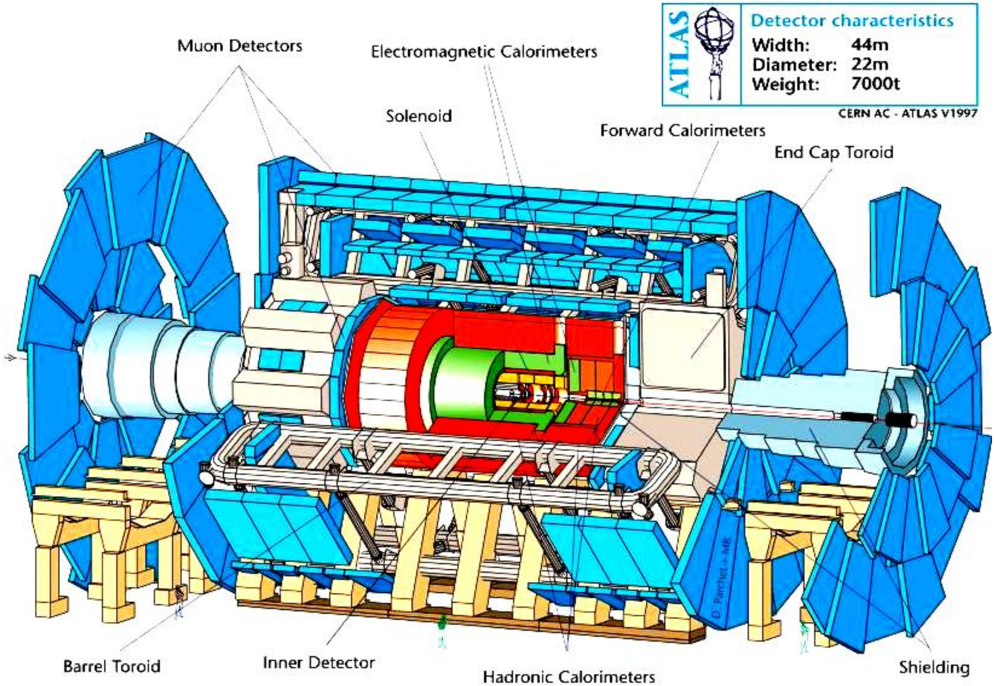
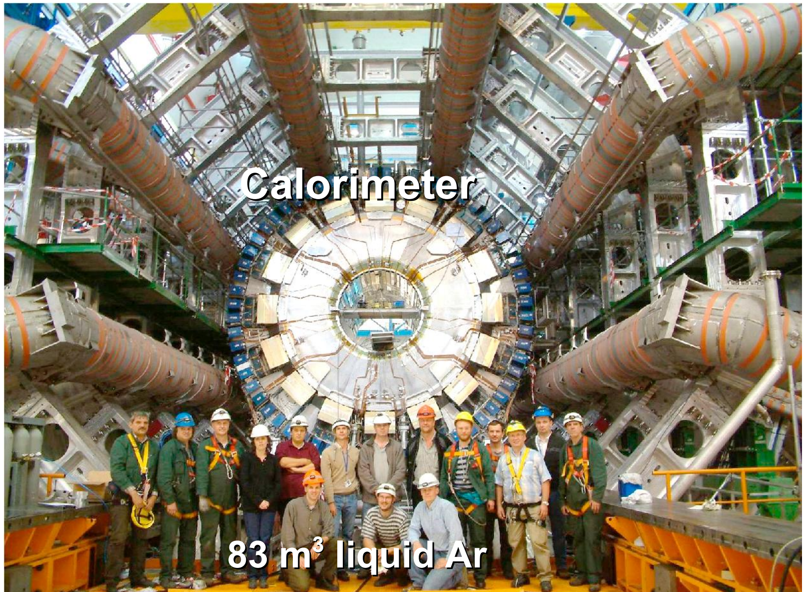
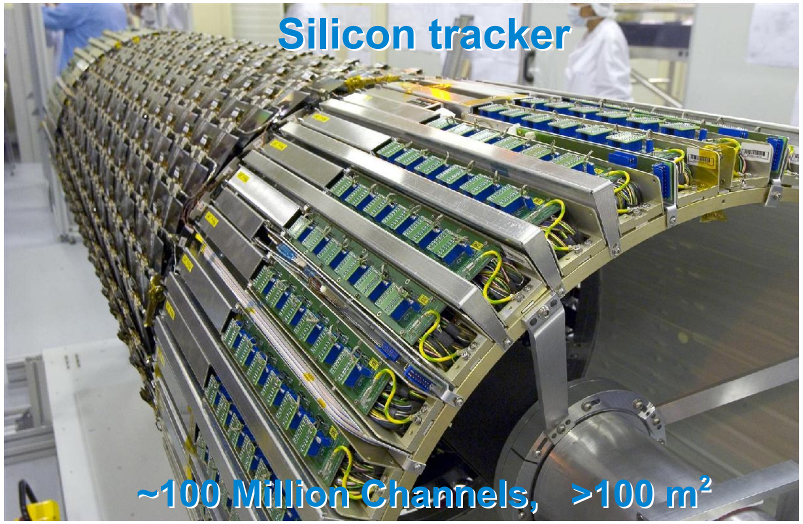
ATLAS - Intro

ATLAS

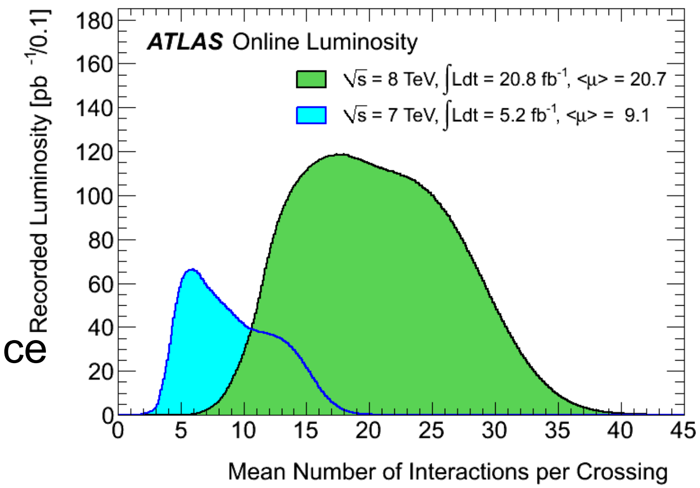




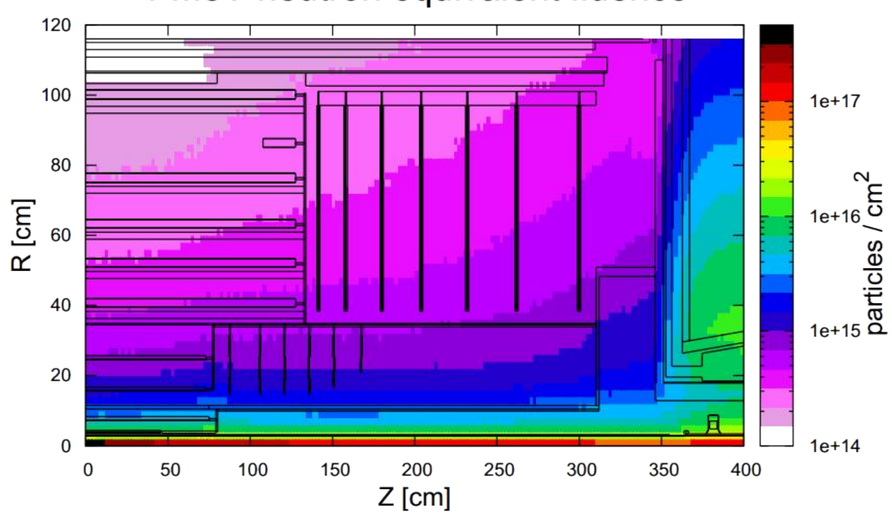


HL-LHC Upgrade – Consequences for ATLAS

- High Luminosity delivered by the HL-LHC results in
  - an average of 140 secondary collisions accompanying the main collision
  - unprecedented levels of radiation exposure
    - Total fluence of the order of 10^{16} cm² 1 MeV neutron equivalence
  - Quite challenging trigger scenarios



Current ATLAS pileup



- ATLAS to be upgraded to meet requirements

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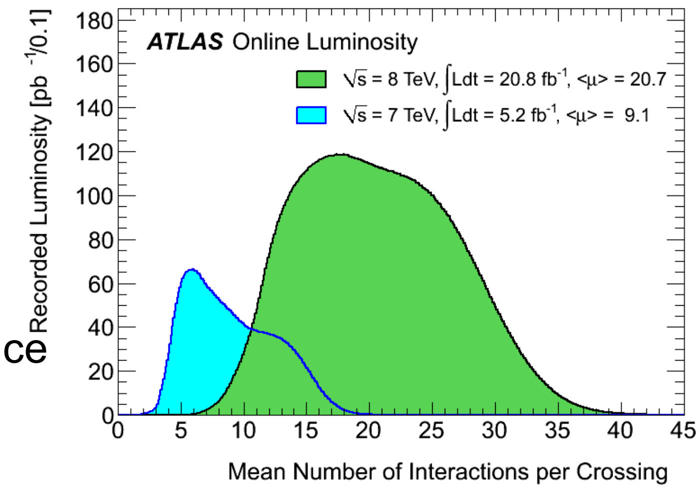

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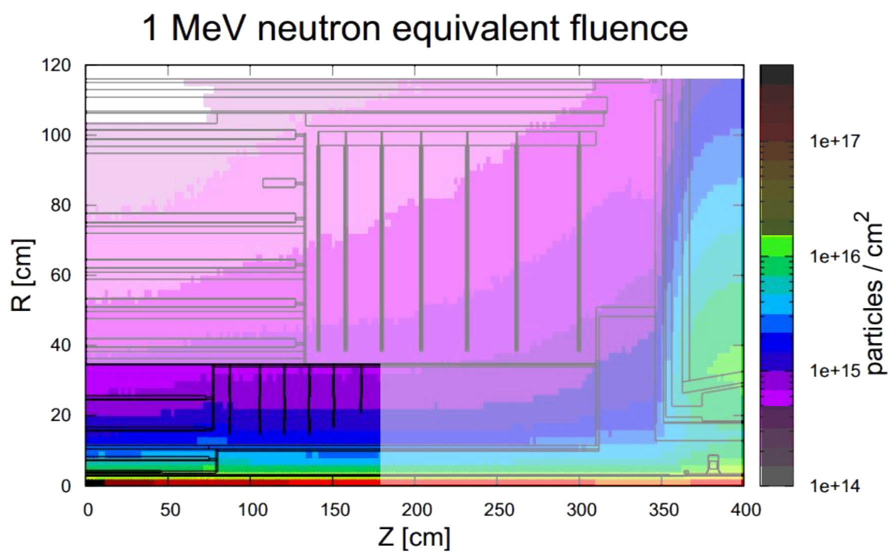

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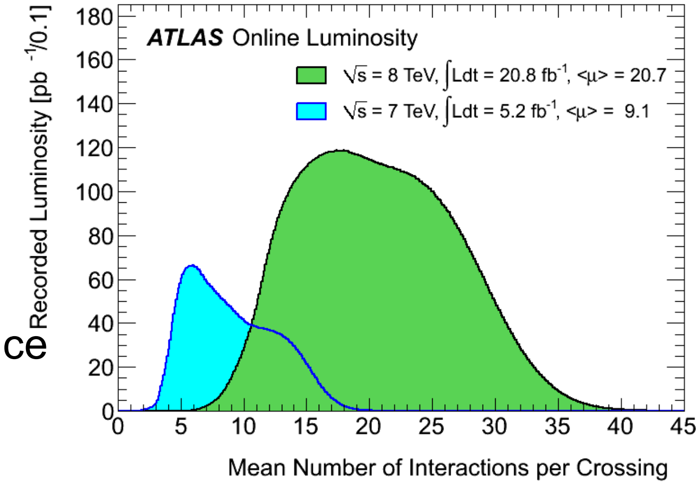

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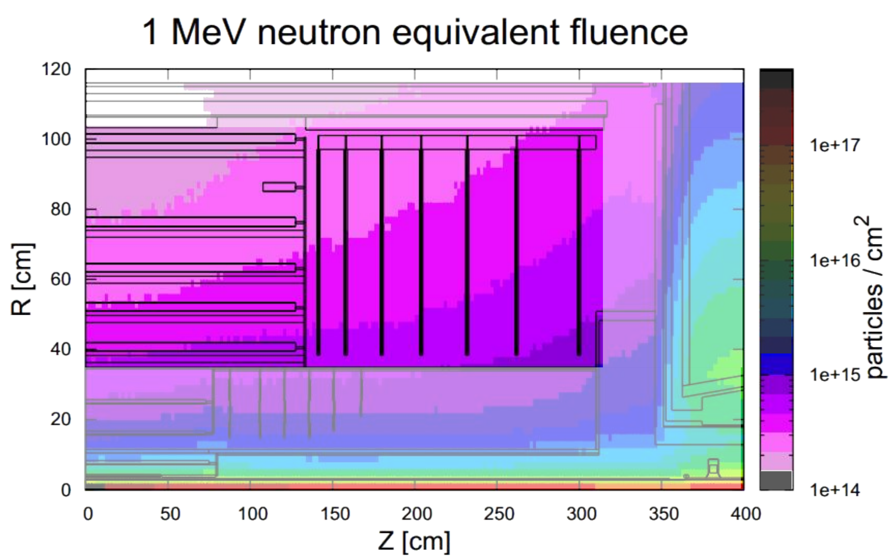
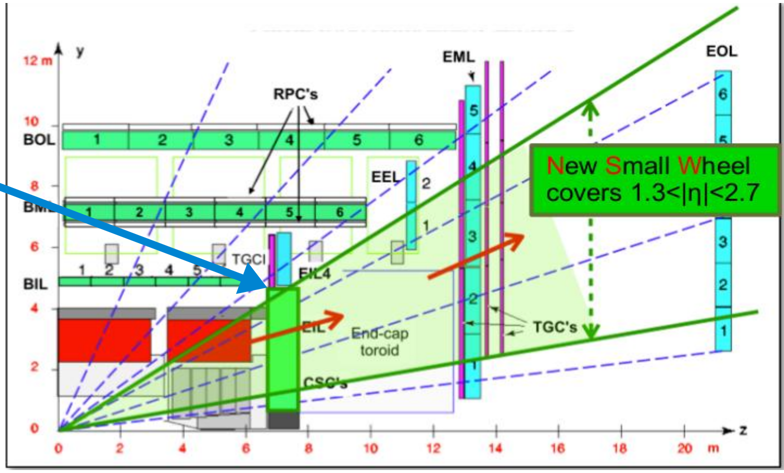


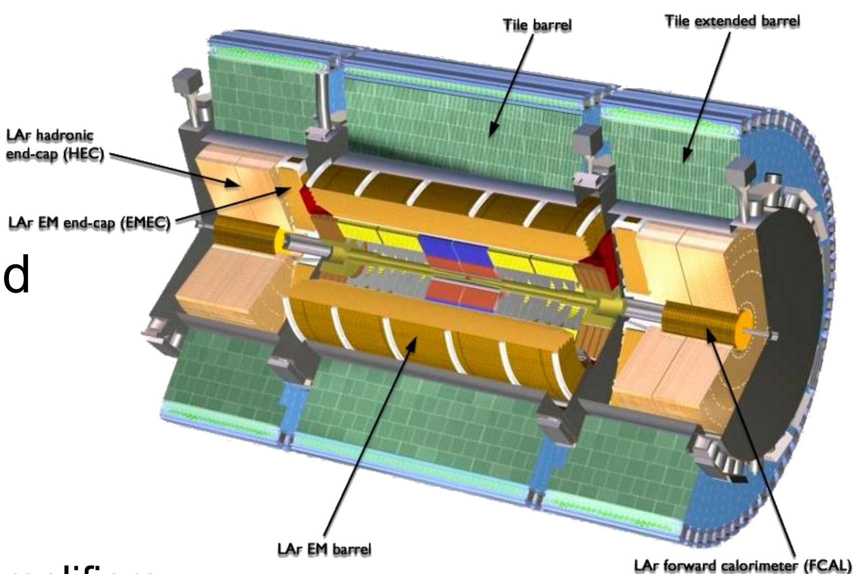
- ATLAS to be upgraded to meet requirements

Upgrade Landscape

- New Small Muon Wheel
  - Improved tracking and triggering
  - Resolution < 100 µm
  - Upgrade before HL-LHC already meets HL-LHC requirements
  - Technology: MicroMegas and small Thin Gap Chambers



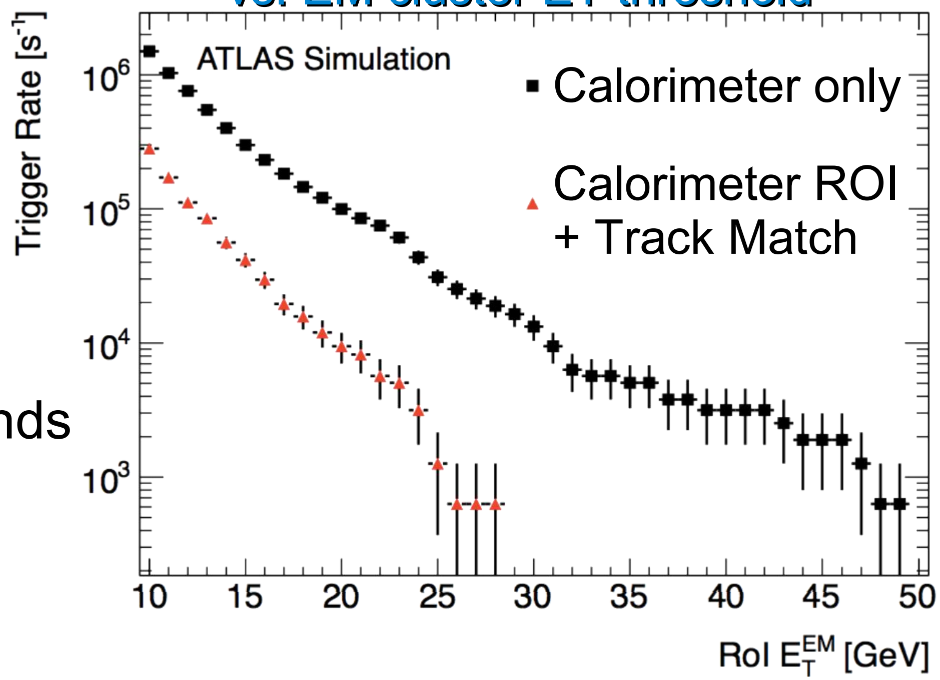
- Calorimeters
  - No change of Tile Calorimeter needed
    - Electronics upgrade to handle higher rate
  - Liquid Argon Calorimeter
    - Also Electronics upgrade
    - Potentially HEC cold preamplifiers
    - Potentially additional FCal

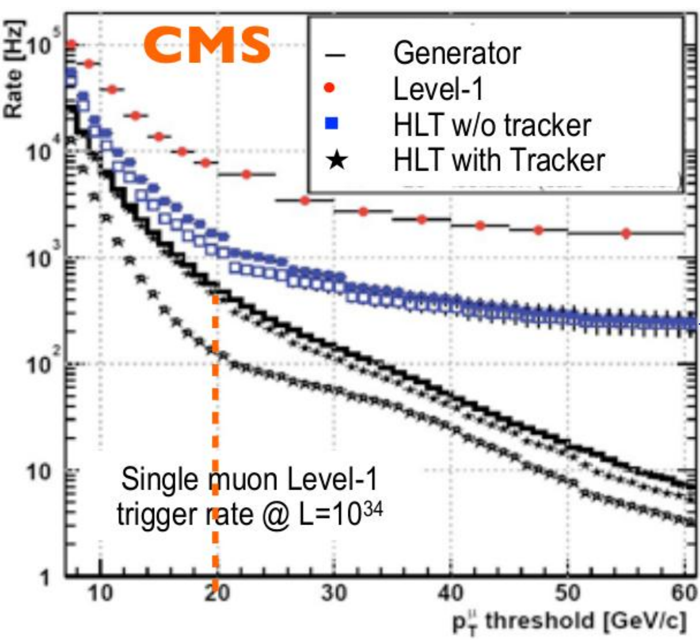


New Track Trigger Schemes

- For HL-LHC, Track triggers central to control trigger rates
- ATLAS and CMS will add tracking information to the first level triggers
  - Challenge: extract sufficient data from trackers in a few microseconds

ATLAS L1 electron trigger rate vs. EM cluster ET threshold



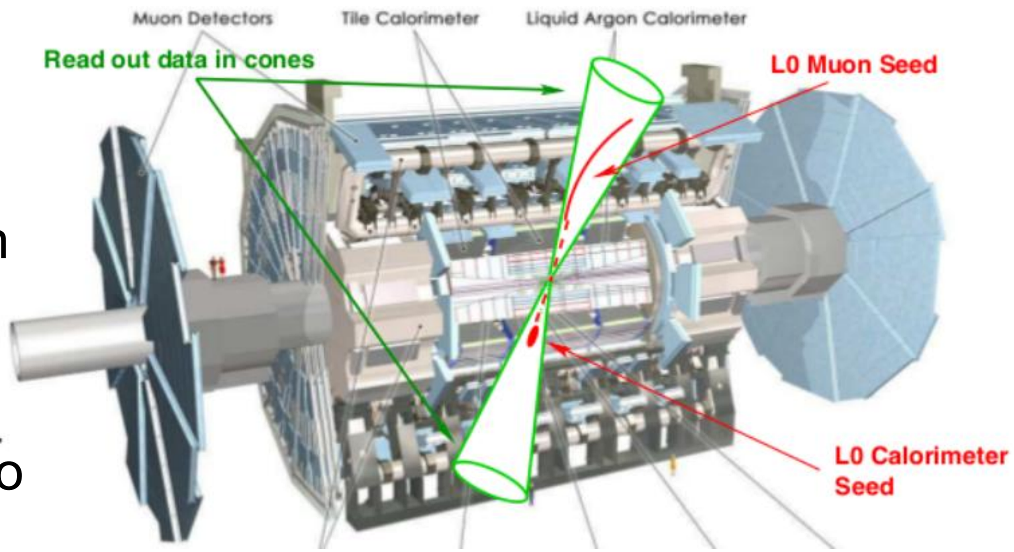


No Track Trigger

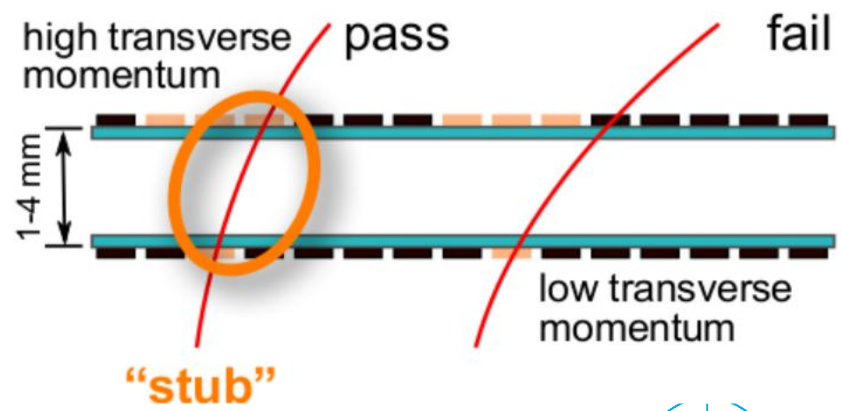
With Track Trigger, p_T sensitive, ~50 times lower rate

Different New Track Trigger Schemes

- **>** ATLAS – Region of Interest (ROI)
  - Improve calorimeter and muon trigger granularity
  - Define ROI from mu/calo
  - Use data from ROI in tracker to find high p_T tracks
  - Little impact on tracker layout

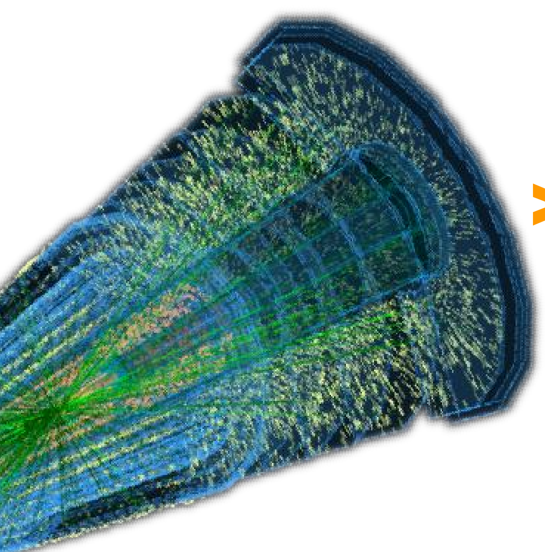


- **>** CMS – Self Seeded Trigger
  - Exploit high magnetic field
  - Reconstruct tracks >2 GeV on trigger level
  - Large impact on tracker layout



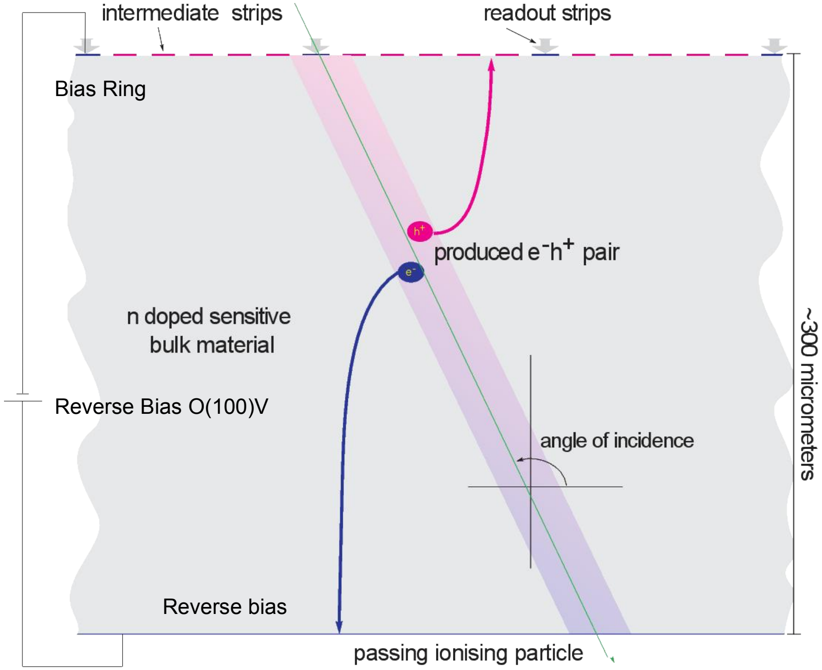
Tracker Upgrade – Environment

- ATLAS tracker for the HL-LHC Upgrade:
  - **Extreme level of radiation exposure** to a total of 10^{16} neq/1MeV
    - current sensors good for 10^{14}-10^{15} neq/1MeV
      →**solution e.g. n-in-p Strip-Sensors, 3D Pixels**
  - **~140 PileUp Events** accompany events of interest
    - With current granularity, several hits per pixel/strip likely
      →**finer granularity: smaller pixels, shorter strips**
    - Higher track density leads to more false hits
      →**Lower material budget e.g. to reduce confusion by multiple scattering**

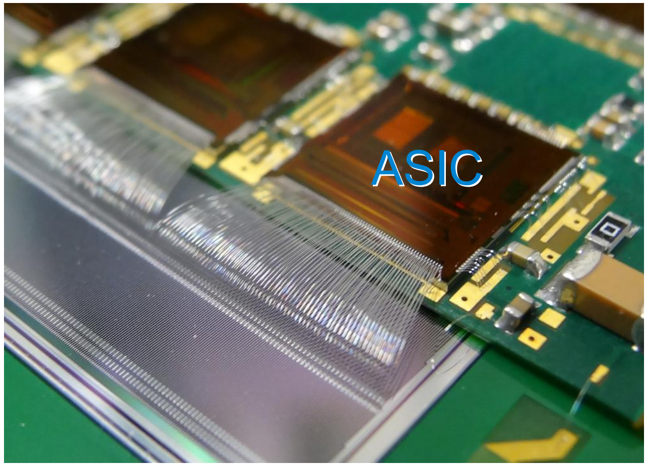


Silicon Trackers – Main Ingredients

- Particle detection with silicon
  - Silicon pn junction (diode) in reverse bias (ideally no current, no free charge carriers)
  - Passing ionising particle excites electrons to conduction band, frees up holes in valence band
  - Charge (~25k e^-) drifts to readout strips

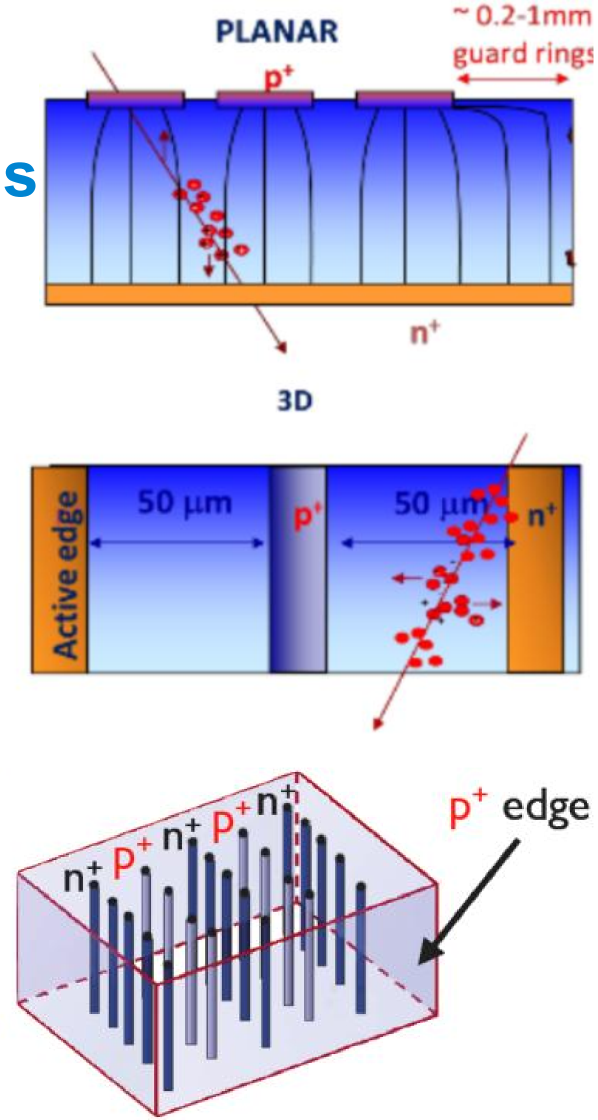


- Frontend readout chips: ASICs
  - Electrically connected to readout strips
  - Collect charge from strips, amplify and store in buffer corresponding to bunch crossing for later readout after external trigger



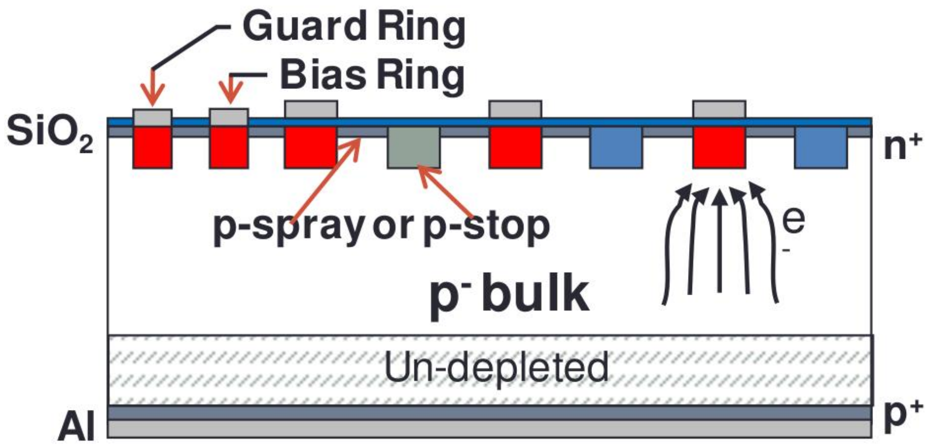
Upgrade Pixel Sensors

- Inner Pixel layers get highest fluence
- ATLAS explores both **Planar and 3D pixels**
- 3D
  - Pro: Small electrode distances allow low depletion voltage and fast charge collection
  - Pro: Good performance at high fluence
  - Contra: newer, less experience
  - To be tested in new innermost pixel layer (Insertable B Layer) currently being installed in ATLAS

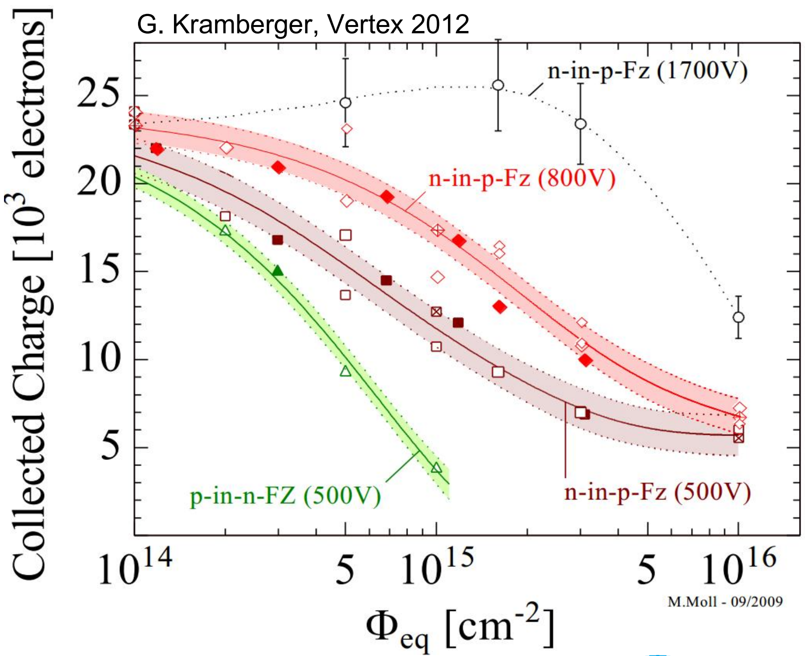


Upgrade Strip Sensors

- **n-in-p Sensors**
- Single sided process
  → less expensive than double sided process
- Can be operated partially depleted, as depletion zone is always on readout side
  → More radiation tolerant
- Collects electrons (not holes as for p-in-n)
  → Faster signal with less charge trapping

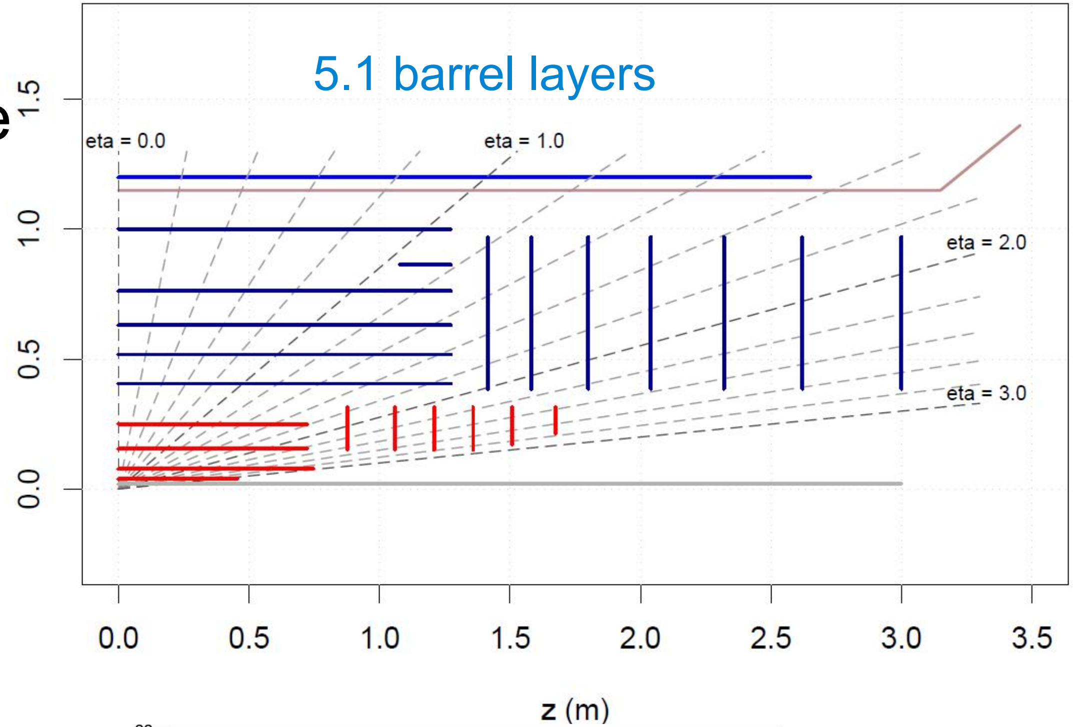


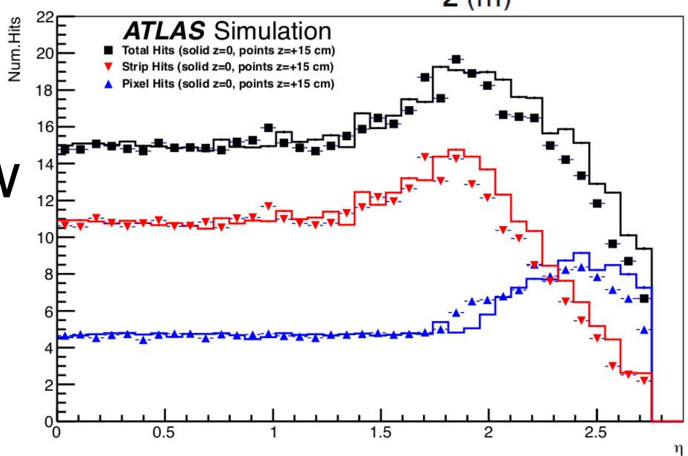
N. Unno, Trento 2012



Tracker Upgrade Layout – Features

- Current baseline layout optimised for performance
  - Full simulation of Letter of Intent layout incl. services
- Sensors at large radii give long lever arm to improve momentum resolution
- Small pixels and short strips increase granularity by more than a factor of 4 to now



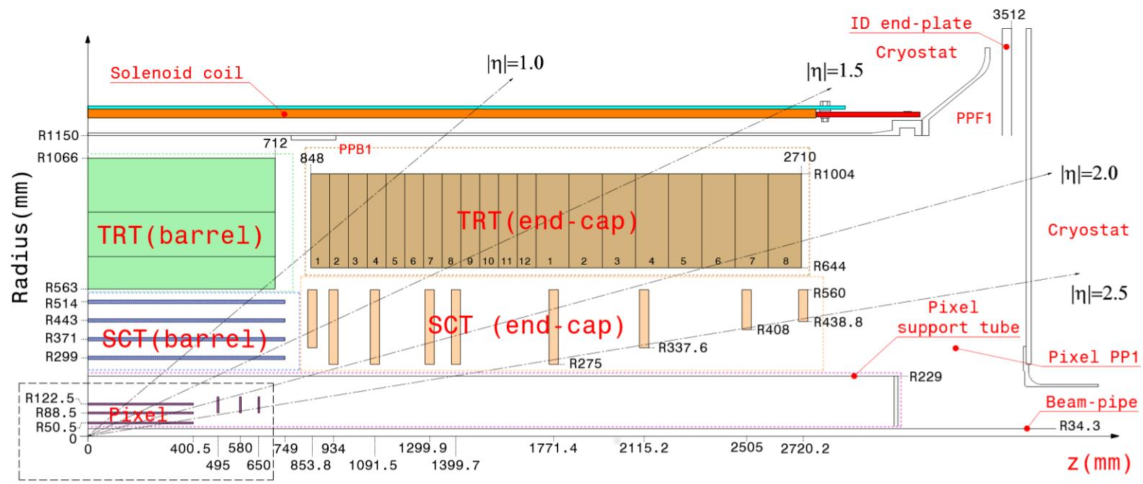


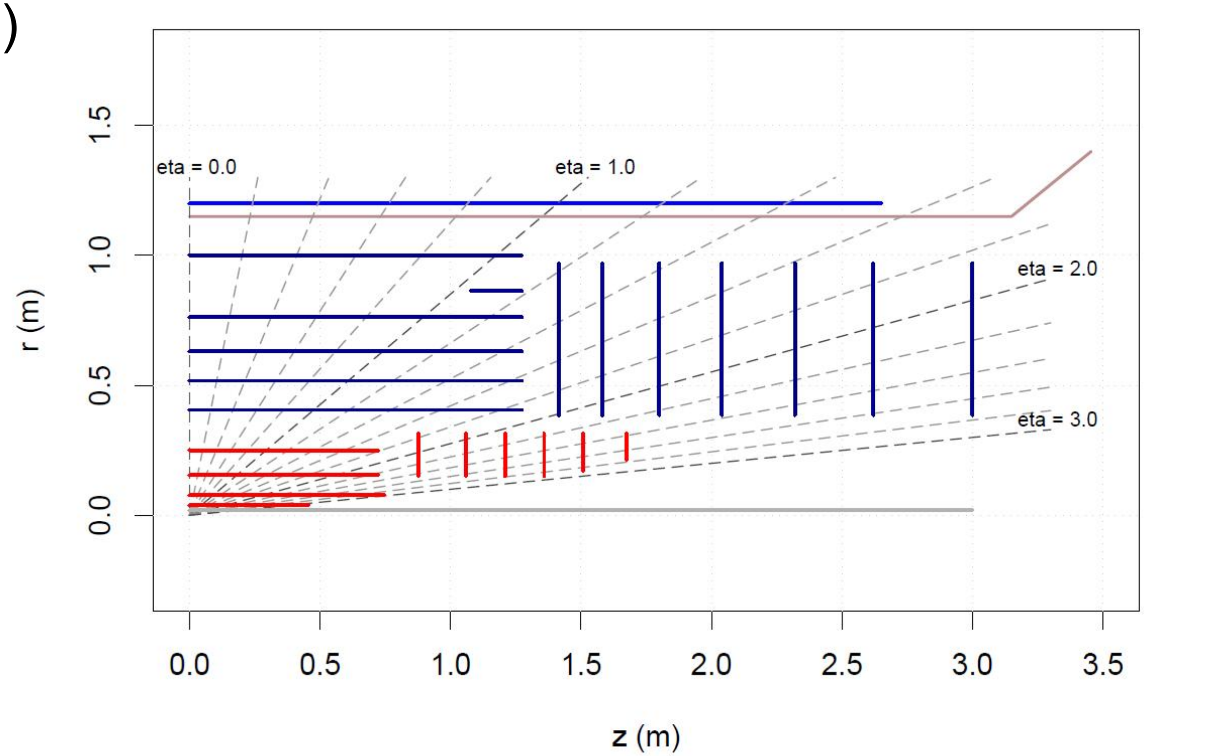
Ensure hits per track are sufficient.

	Silicon Area	Channels [10^6]
Pixel	$8.2m^2$	638
Strip	$193m^2$	74

Tracker Upgrade Layout – Current vs. New

- All silicon
  - TRT removed
  - Space for silicon
- Pixels
  - To larger radii
  - To larger eta (2.5 → 3)
  - Smaller pixel sizes
- Strips
  - To larger radii (x2)
  - More layers
  - Shorter strips





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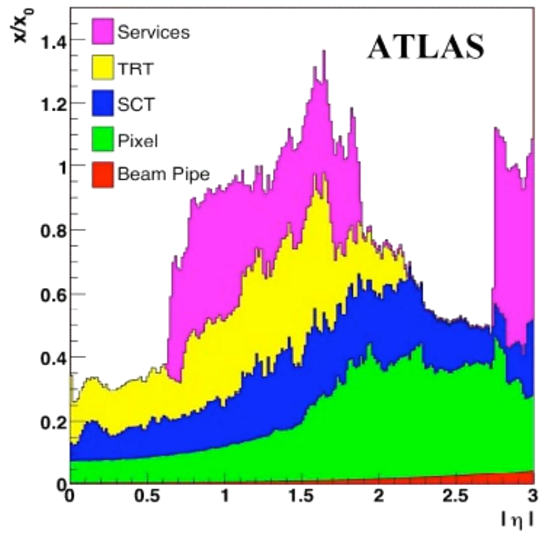
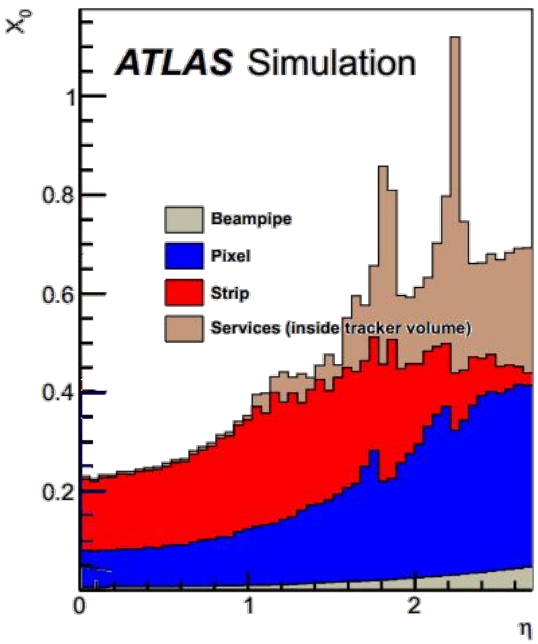


Material budget current tracker



Material budget upgrade tracker

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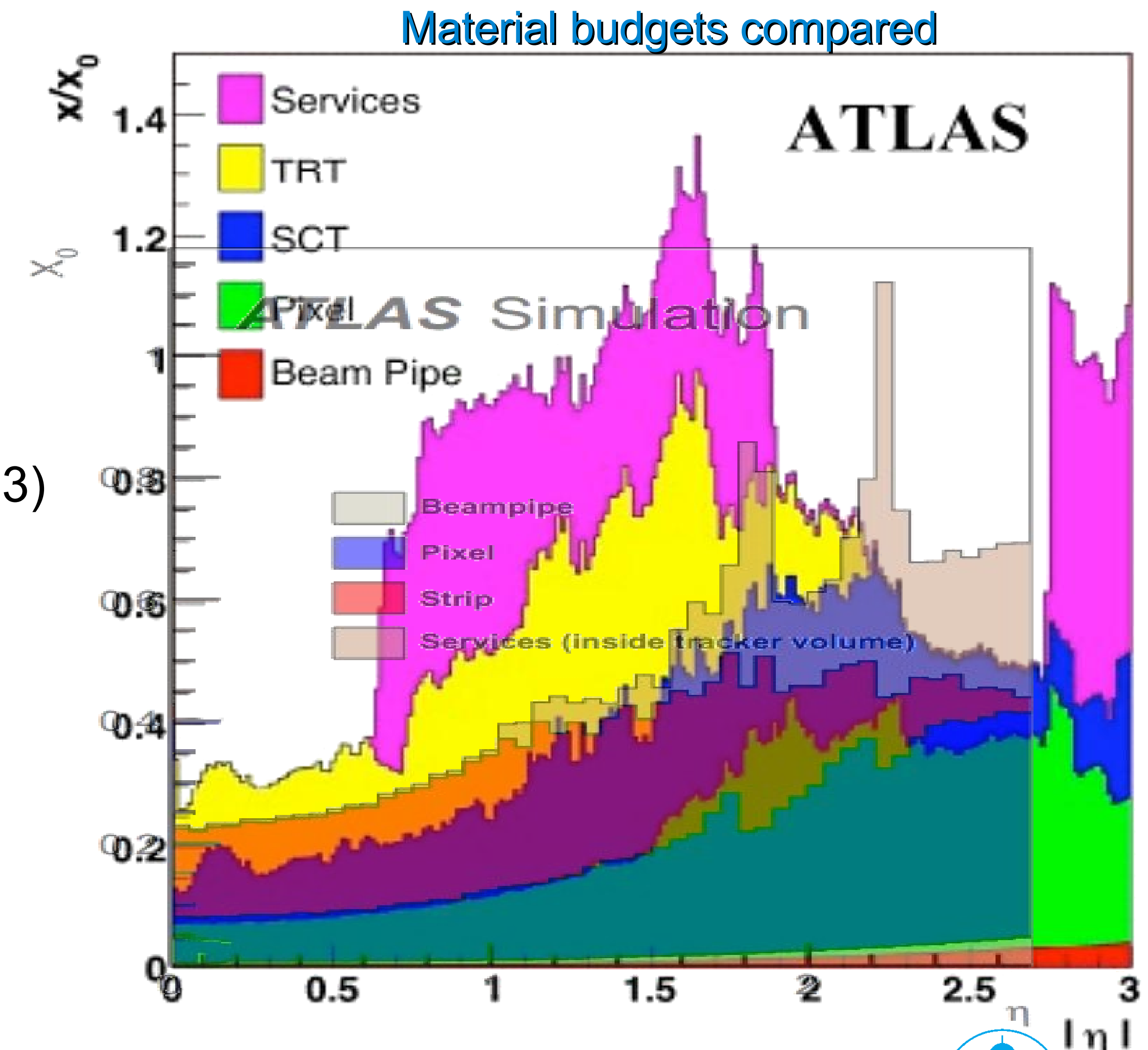
Material budgets compared



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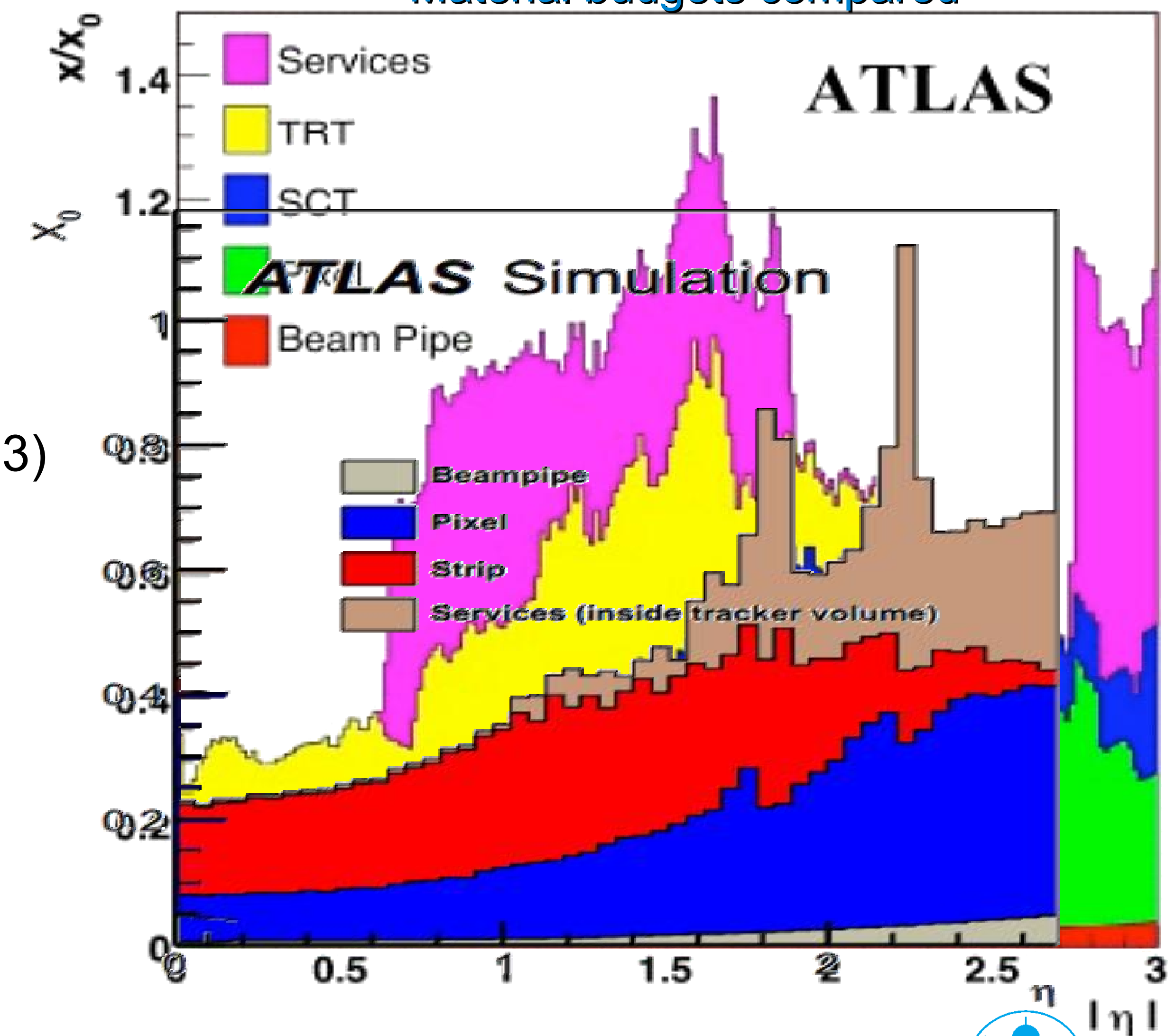
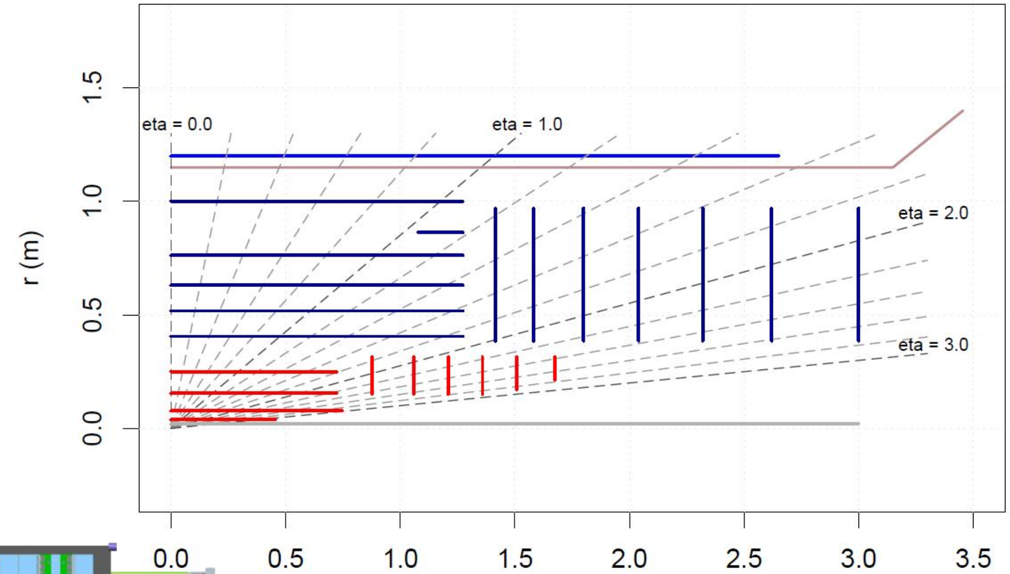
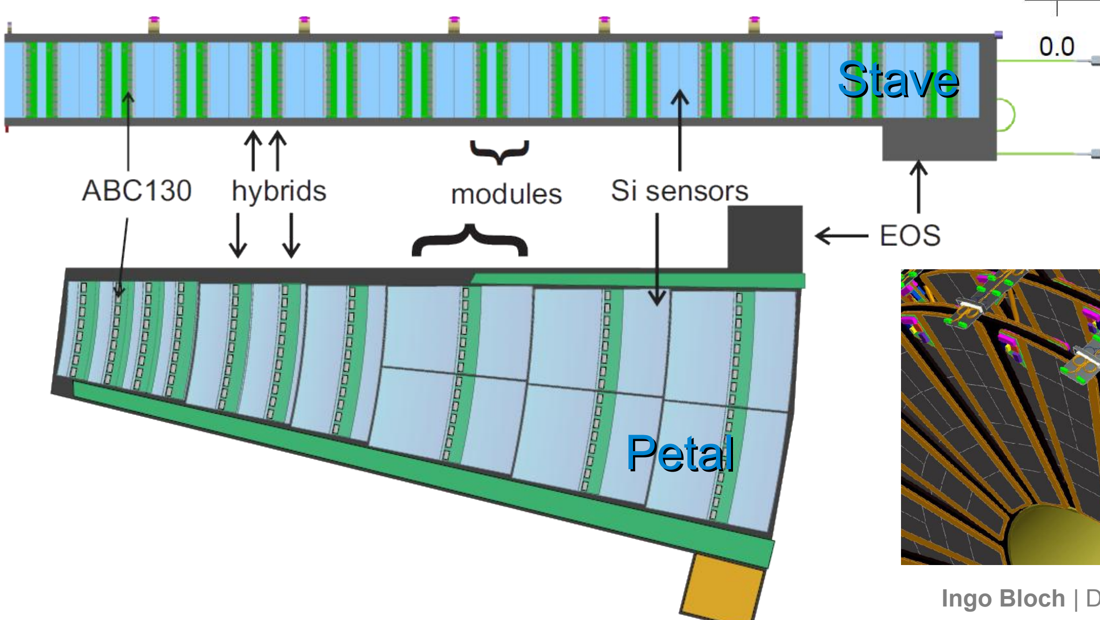
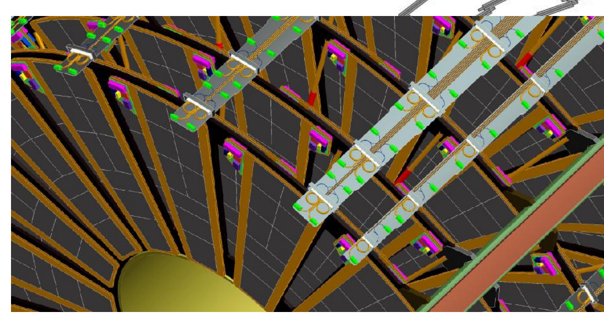


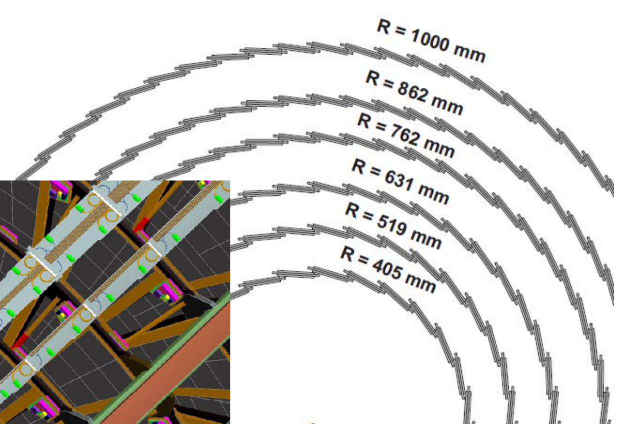
Strip Tracker Layout

- **Phase II upgrade: new all Si tracker**
- Planned strip layout
  - 5.1 barrel layers
  - 7 endcap layers
- Barrel built from **Staves**
- Endcap (EC) from **Petals**



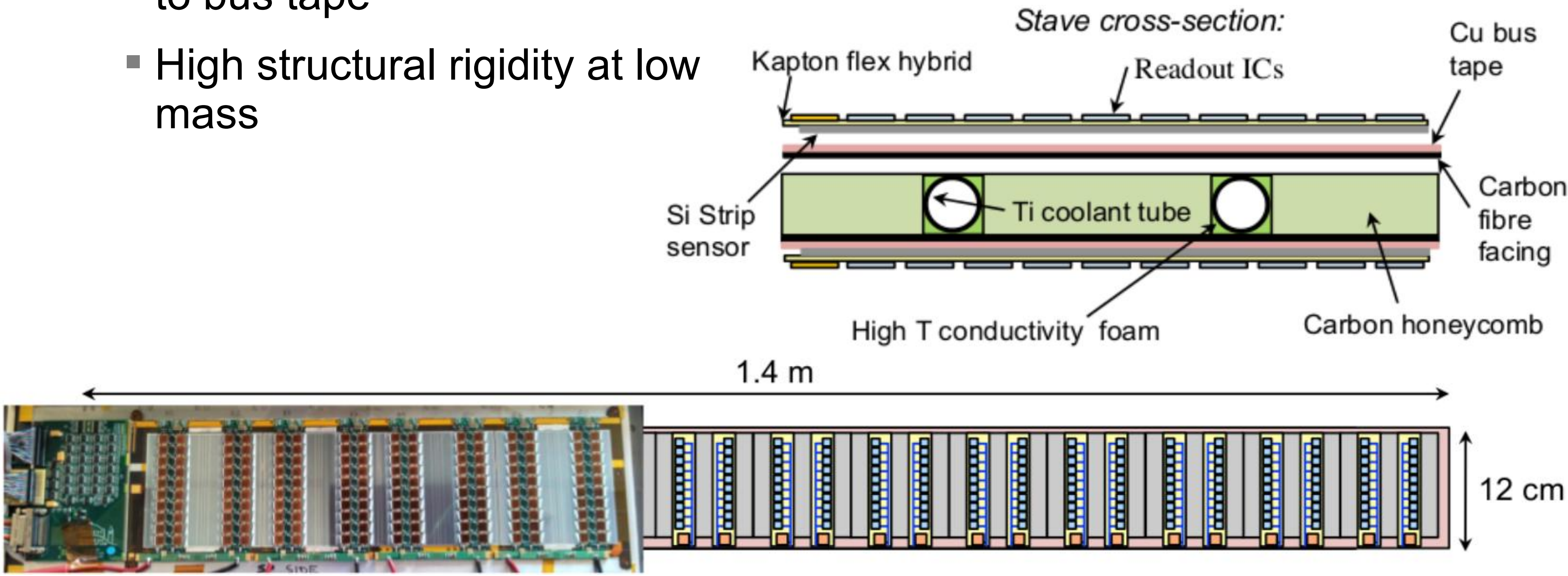






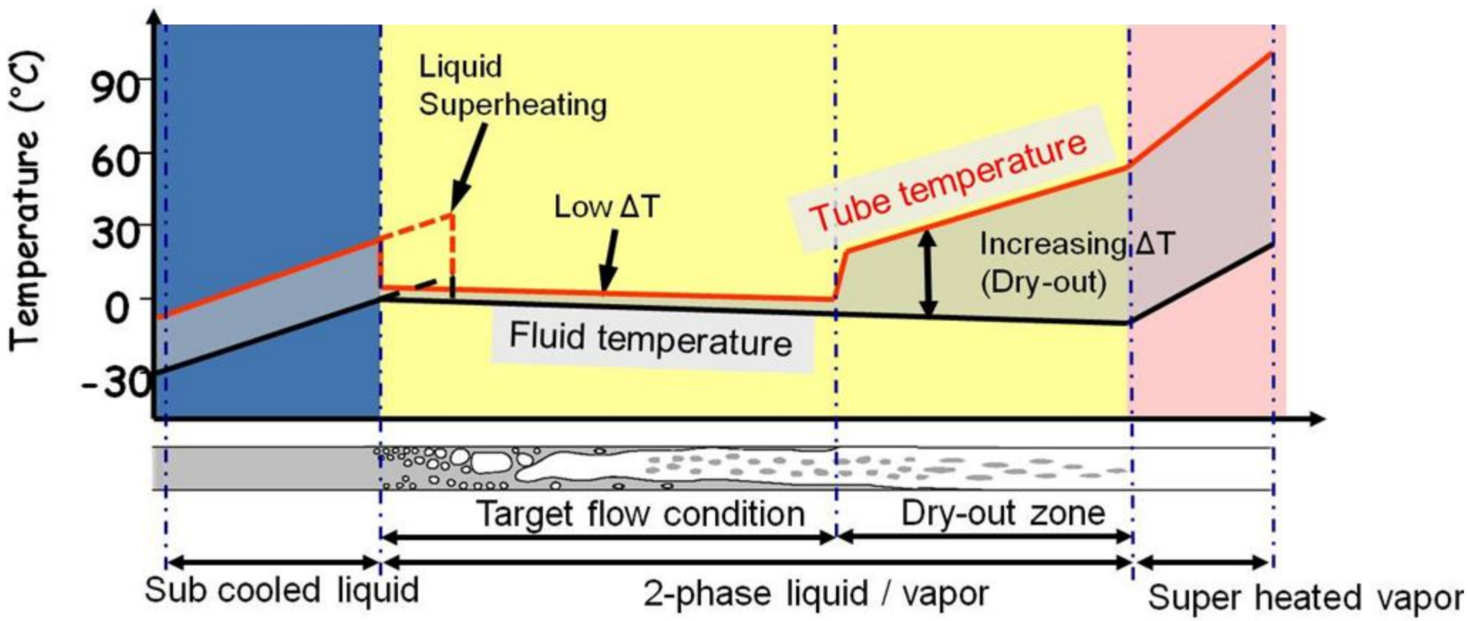
Strip Tracker Layout

- Mechanical / electrical structure of Staves / Petals
  - Titanium cooling tubes embedded in carbon fibre core
  - Readout bus tape co-cured to carbon fibre facing
  - Strip modules with 10x10 cm^2 n-in-p sensors connected to bus tape
  - High structural rigidity at low mass



Brief aside: CO_2 Cooling

- Efficient and low mass cooling is essential for HL-LHC
  - Detectors need to be kept at ~-20°C to limit radiation damage
  - Coolant and cooling system mass and Z needs to be minimal to limit multiple scattering in detector
- Liquid CO_2 is the current coolant of choice



Brief aside: CO_2 Cooling

Why is evaporative CO_2 cooling good for HEP detectors?

CO_2 allows small tubing

Currently using „Ozone-killer“ C_3F_8

Why?

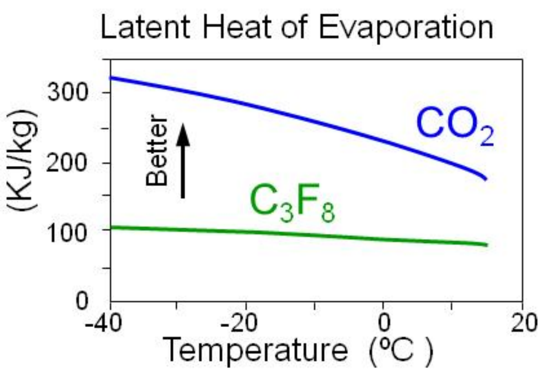
Large latent heat & Low viscosity & High pressure

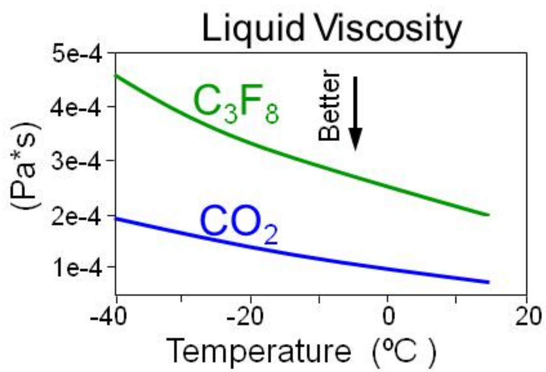
Large latent heat → Allow low flow → Low pressure drop → Lower pressure drop

Low viscosity → Low pressure drop → Lower pressure drop

High pressure → Allow high pressure drop → Allow very small tubing

Lower pressure drop → Allow very small tubing



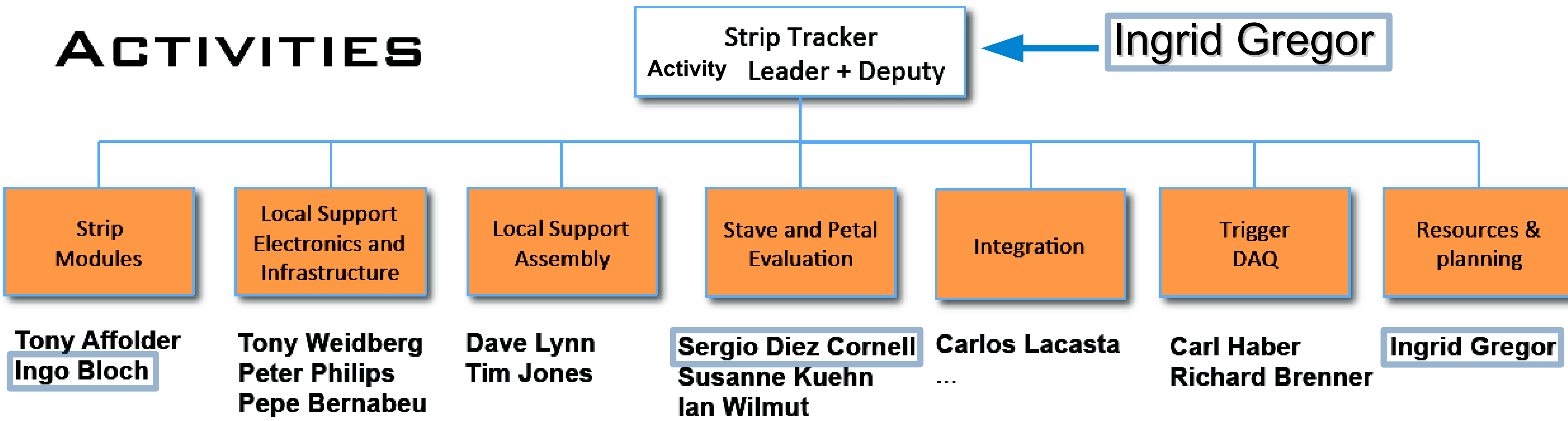


Allow very small tubing

But with very high heat transfer capability!

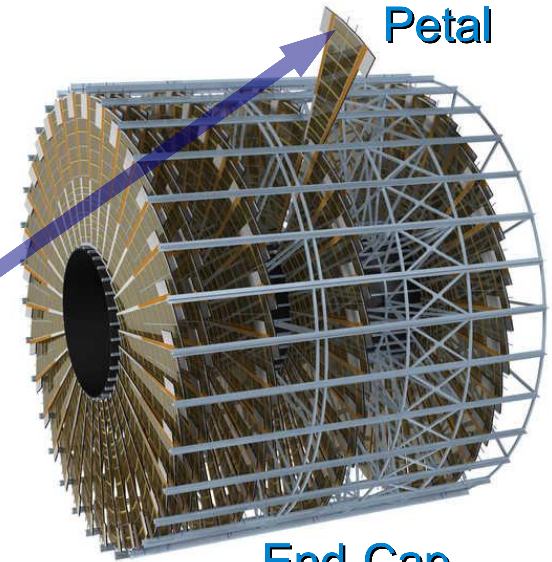
Strip Tracker Upgrade – Organisational Structure

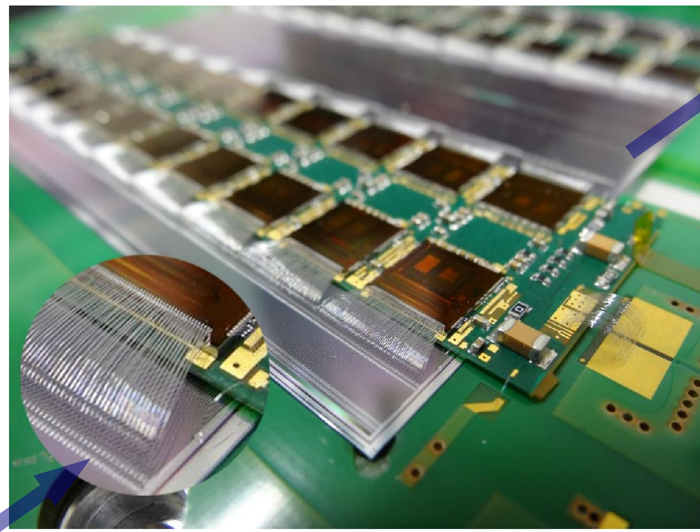
- New Strip Project Structure with significant DESY contribution

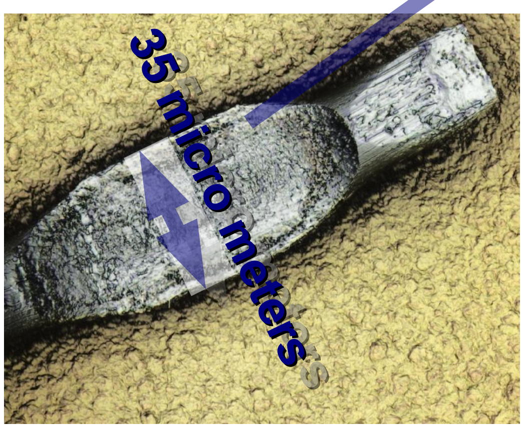


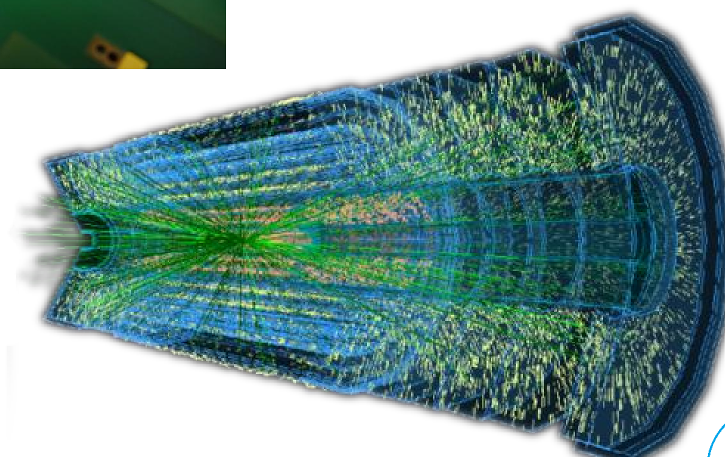
Strip Tracker Upgrade @ DESY

> Towards an End-Cap



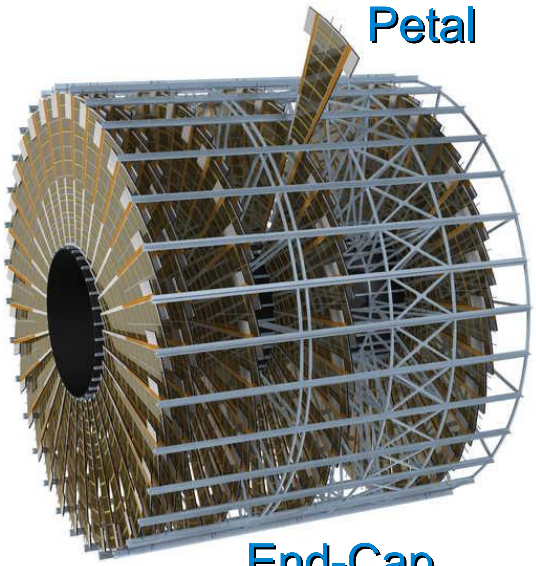






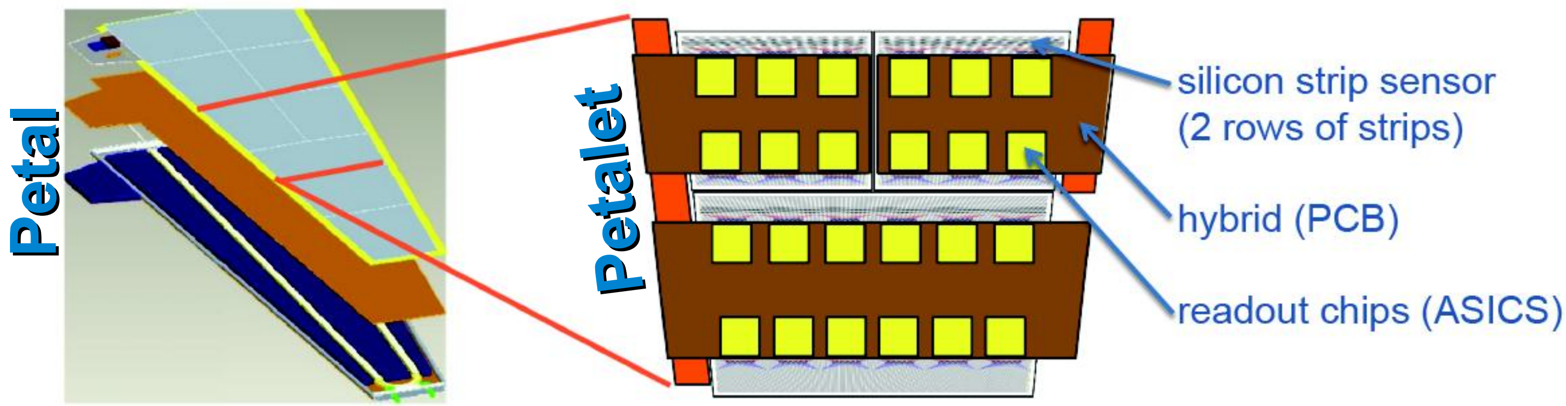
Strip Tracker Upgrade @ DESY

- **Towards an End-Cap**
  - **Goal:**
    - one full end-cap assembled in Hamburg
  - **Intermittent milestones:**
    - Petalet
    - Petal
  - **Ingredients:**
    - Mechanical construction
    - Electronics & electronic construction
    - Readout
    - Testing
    - Improvements / re-design: R&D



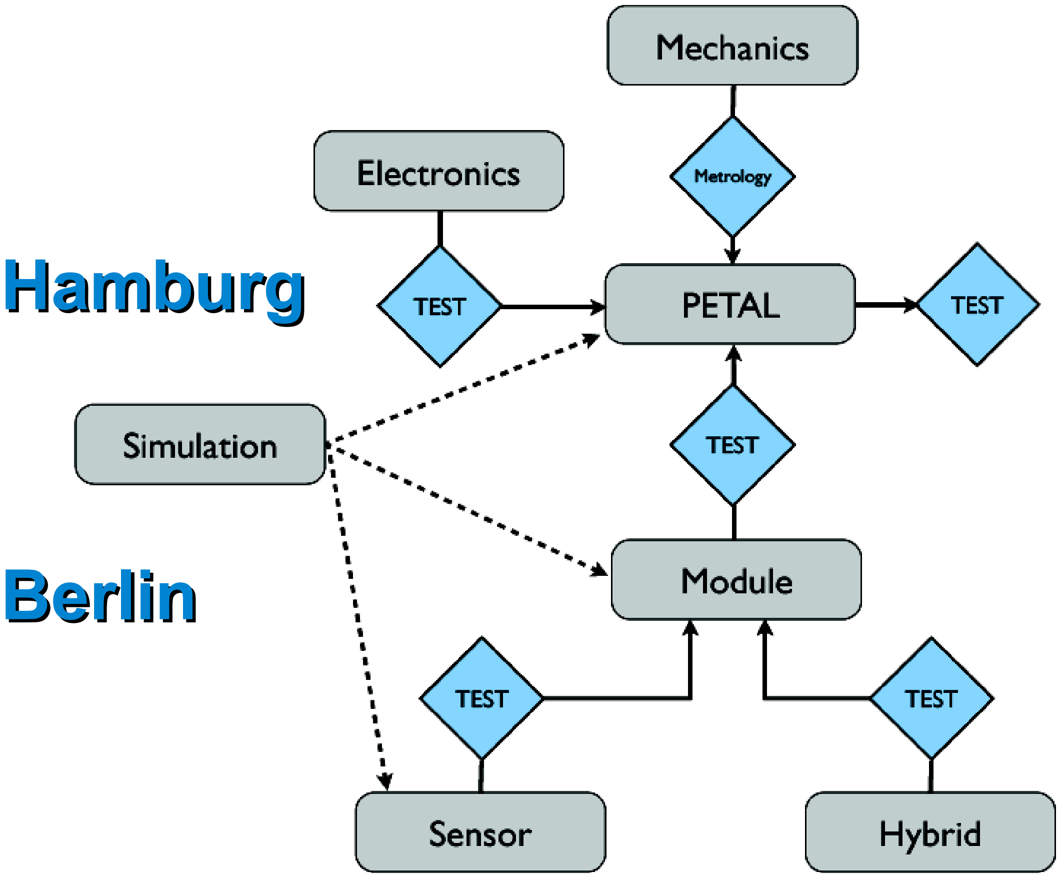
Strip Tracker Prototyping – Petalet → Petal → EC

- With Petalet address specific challenges posed by the Petal design, e.g.
  - Local high strip density → high readout density
  - Sensors too large to fit on one wafer → have to be split



Strip Tracker Upgrade Flowchart @ DESY

- Both DESY sites work on the Endcap Strip Upgrade

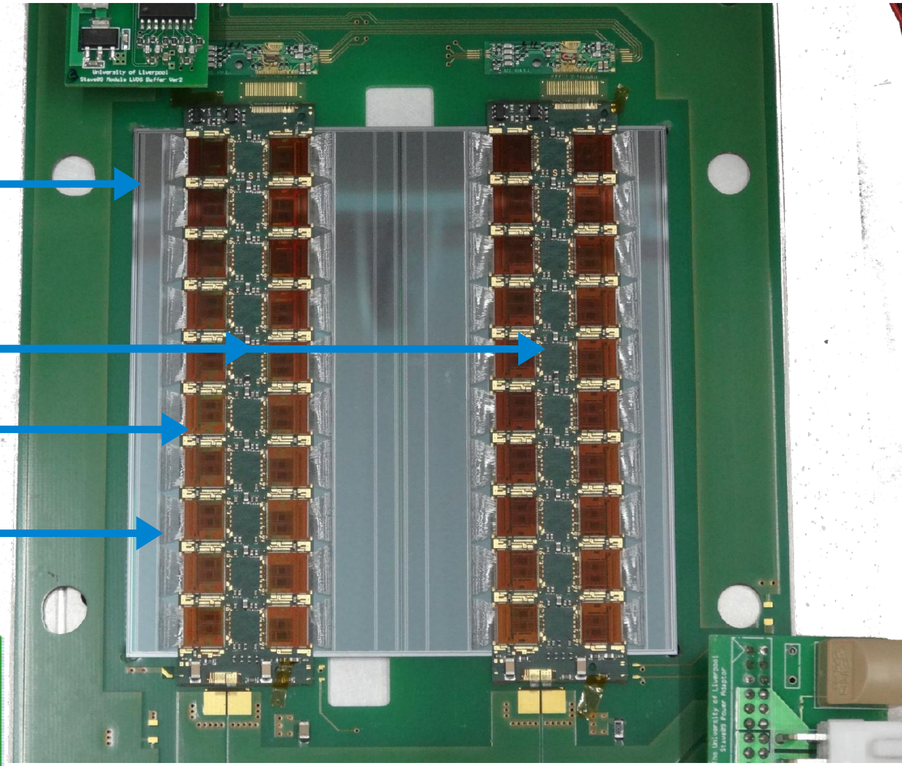


- Distribution according to local infrastructure and expertise:
  - Petals in Hamburg
  - Modules in Berlin (Zeuthen + HU)
- Use identical setups to ease knowledge transfer, avoid duplicate work

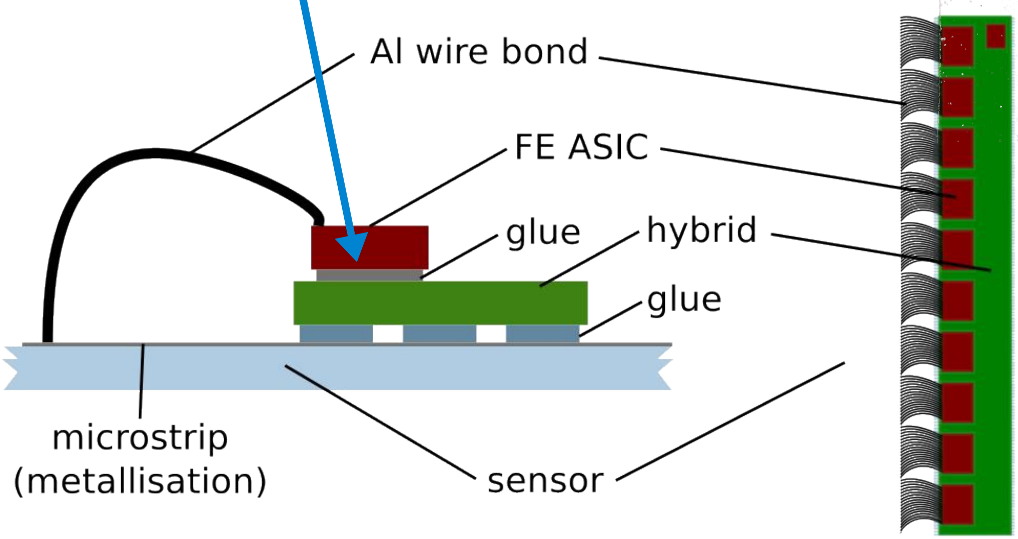
Prototype Upgrade Strip Module

- Components of a strip module
  - Silicon n-in-p sensor with 4 rows of 1280 strips
  - 2 circuit boards (hybrid)
  - Readout chips on hybrids
  - Glue and wire bonds

Readout connections



LV and HV power

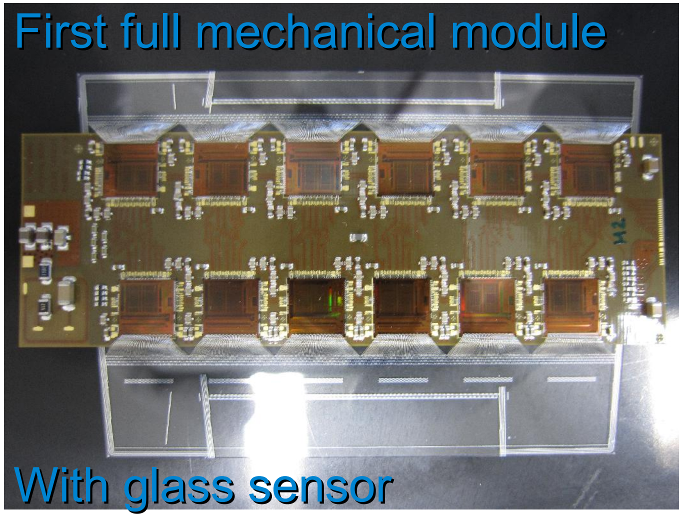


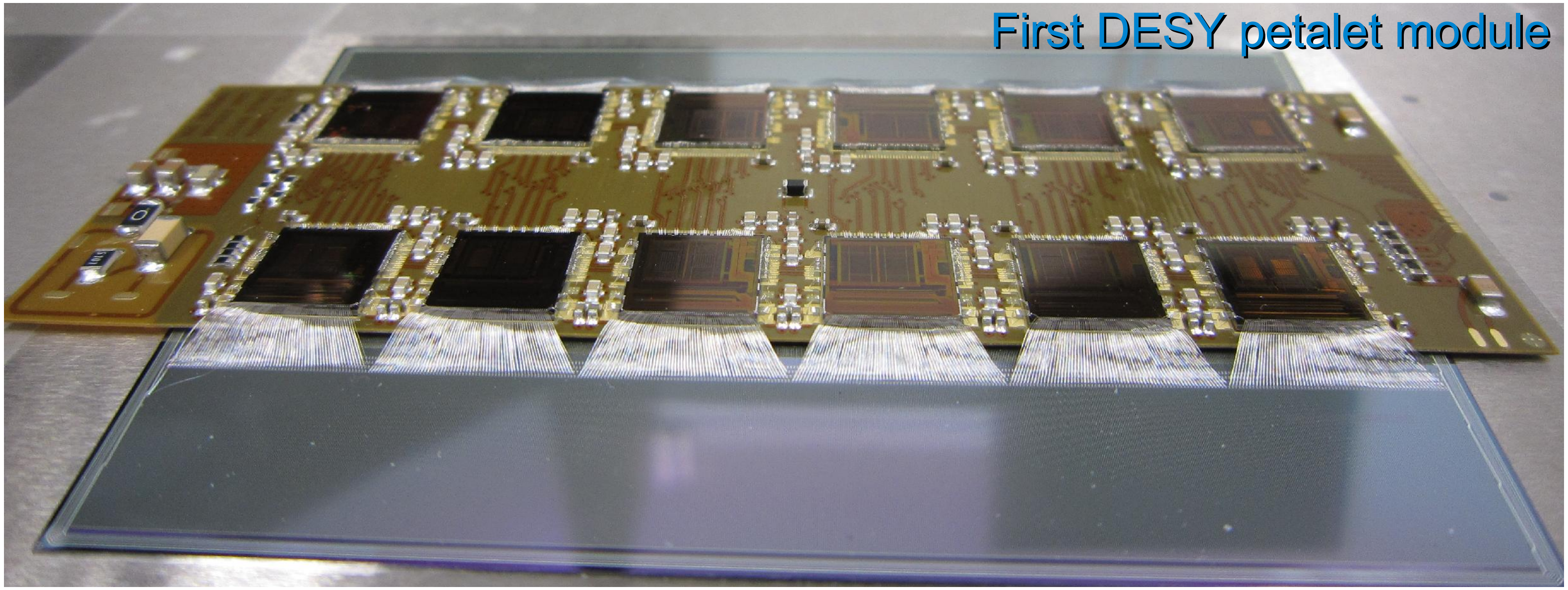
Side-view

Top-view

Petalet Modules @ DESY

- Building Petalet strip modules
  - Initially **mechanicals** on glass dummy sensors
  - Then electrical hybrids
  - First **electrical modules**
- No show stoppers





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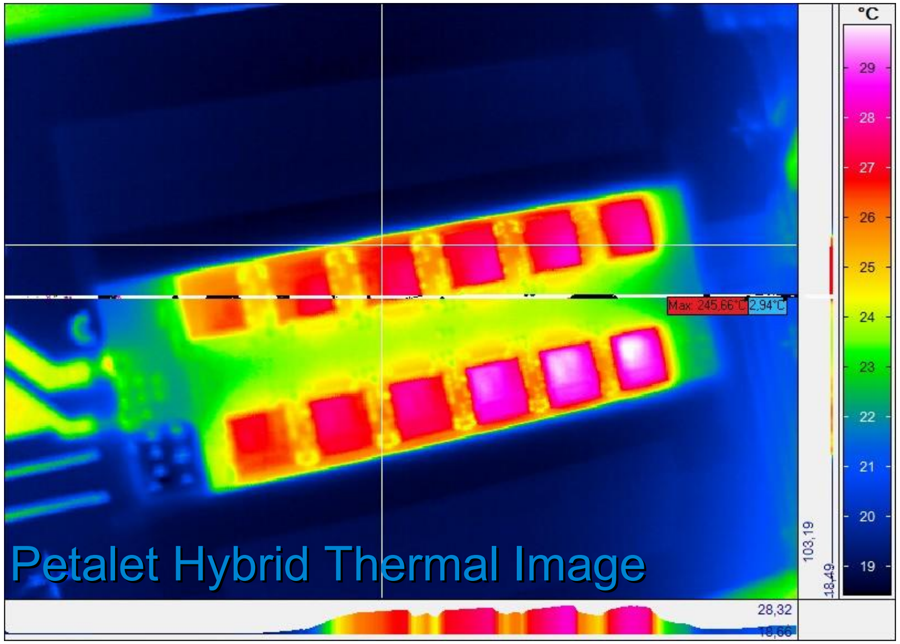
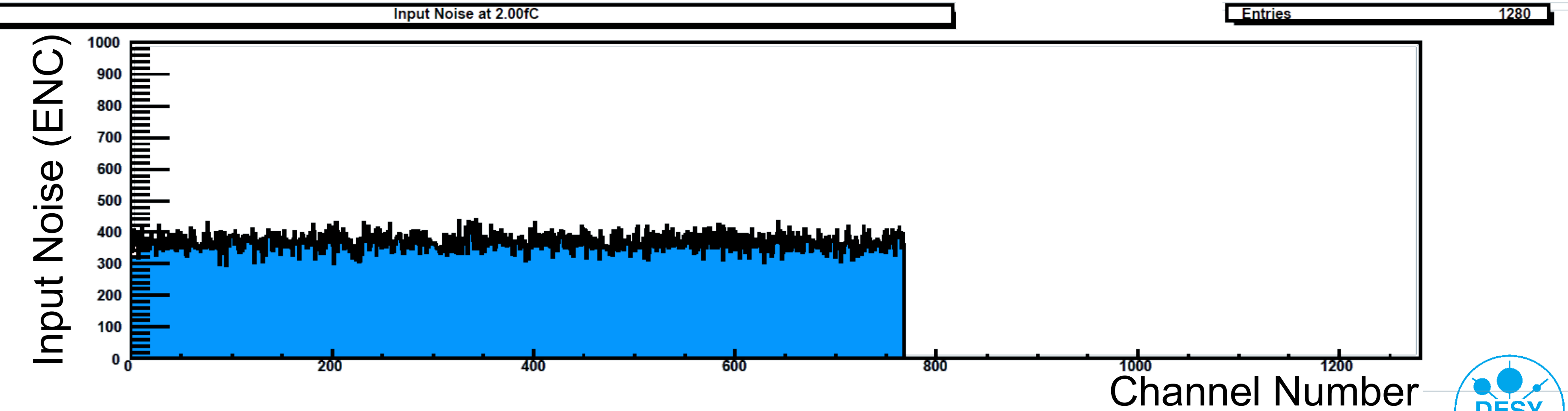
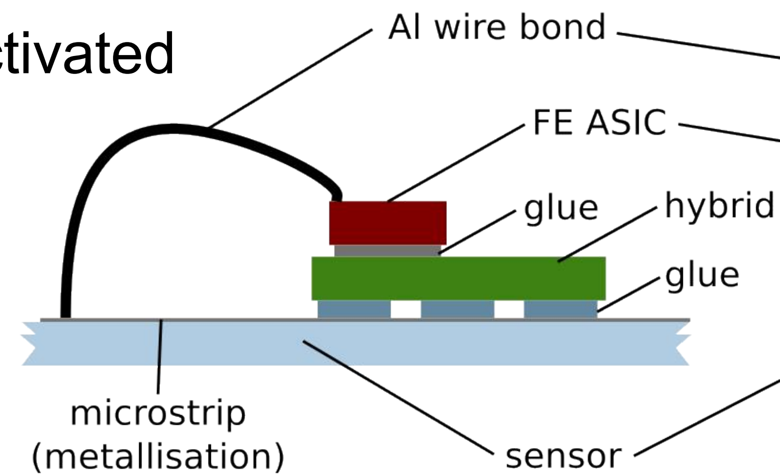


Petalet Hybrid Input Noise, lower row of ASICs



R&D Adhesives

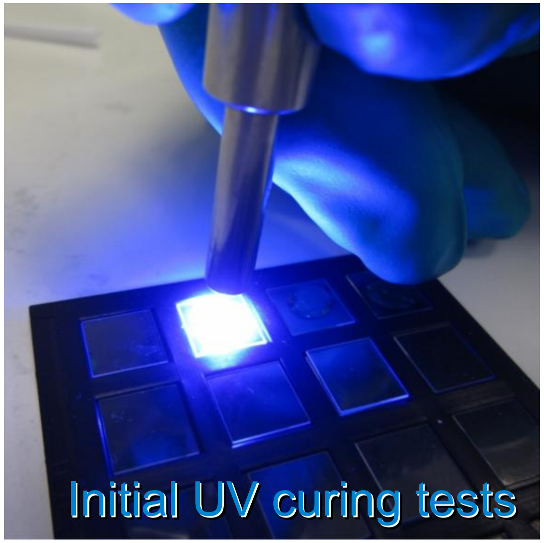
- Started out a seemingly boring task: Find an new glue, which turned out as interesting project with many facets
- Current standard for ASIC fixation: Silver Epoxy Glue
  - 24 hour curing time
  - >70% of silver → short X_0, can be activated
  - Could corrode aluminium
  - Potentially carcinogen
  - Alternative needed

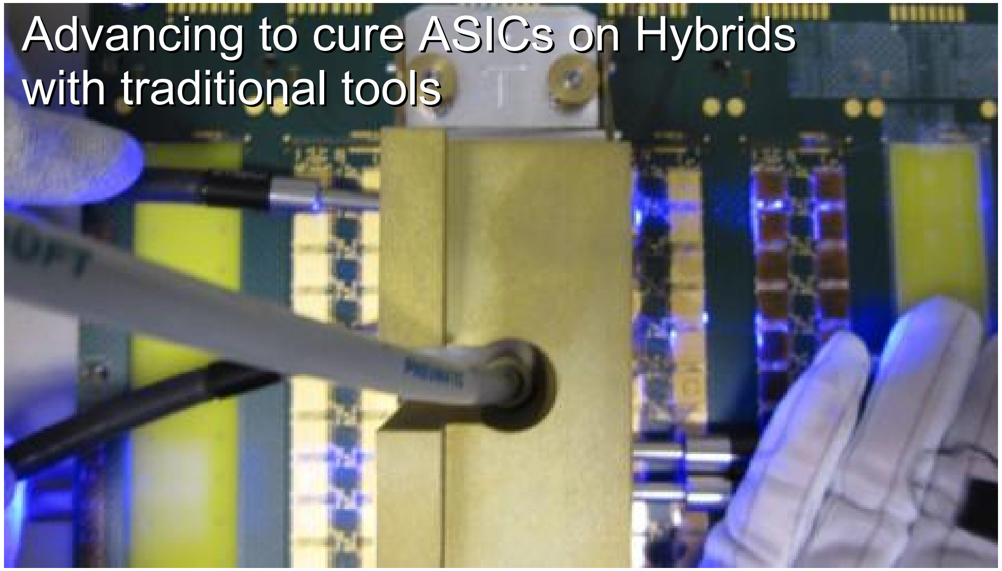


- Requirements, e.g.
  - Radiation hard
  - Sufficiently thermally conductive
  - Sticks on Gold and Aluminium
  - Non-toxic
  - Low price
  - Fast curing

R&D Adhesives

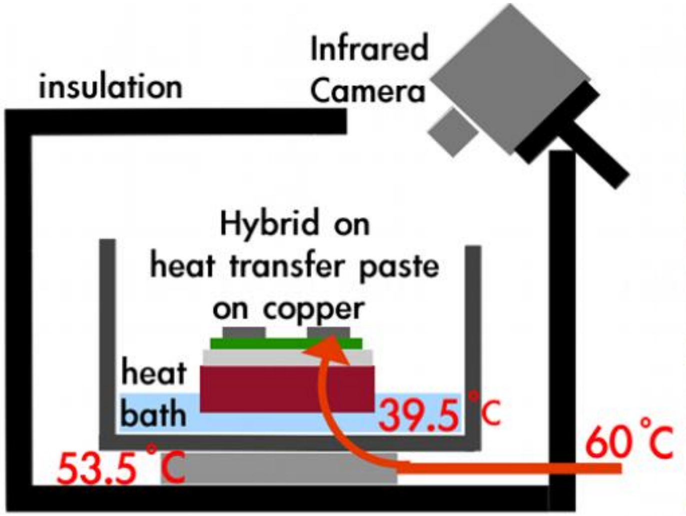
- Search for alternative led to 7 candidates
  - UV curable glues
  - Glueing film
- Many parameters unknown, need to determine e.g.
  - Wire-Bondability
  - Thermal conductivity
  - Radiation tolerance
  - Usability in module geometry

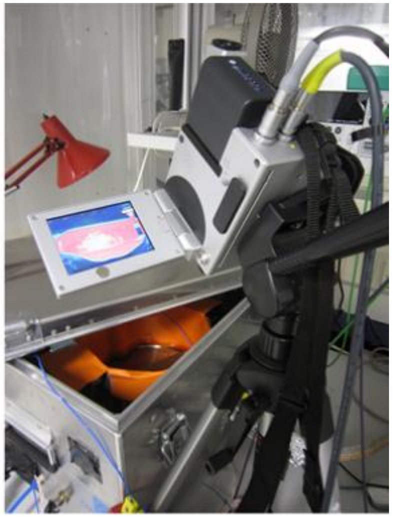




R&D Adhesives

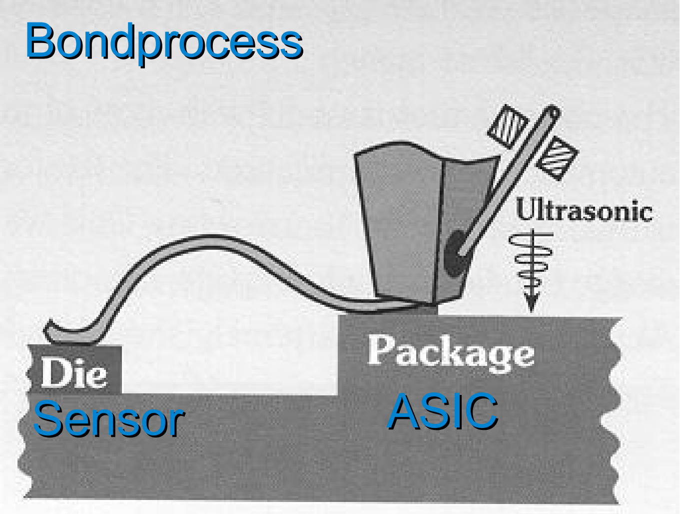
- 7 candidate glues
  - thermally cycled
  - Irradiated ($2*10^{15}$ neq)
- Compared with current
  - Thermal properties
  - Mechanical shear force
- Some results:
  - **3 UV glues remain candidates**
  - All 3 good thermal and mechanical properties, also after aging/irradiation. UV glues actually adhere better after irradiation
  - Next: construct full hybrid with UV glue

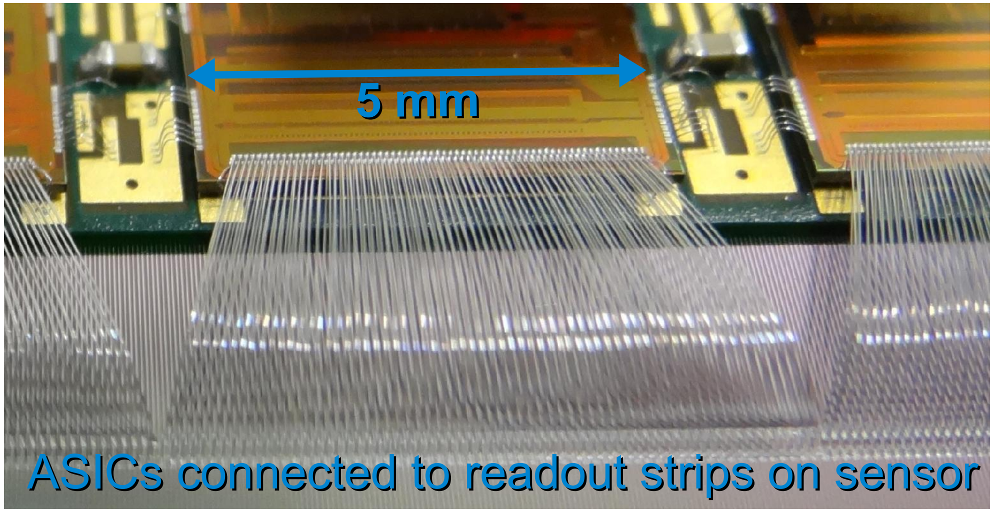


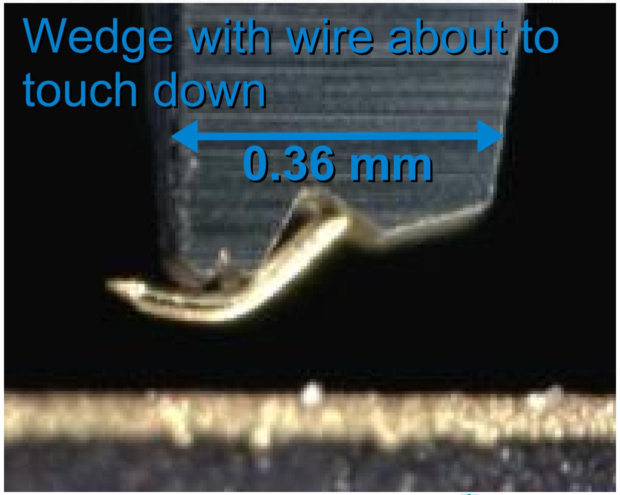


R&D Wirebonding

- Wirebonding used to electrically connect ASICs to readout boards
- Use aluminium wire, diameter: 25 µm
- Tool (wedge) to press wire onto ASIC
  - Tungsten Carbide
  - Typical tip size ~80 x 70 µm^2
- Speed ~1 - 4 wires / sec

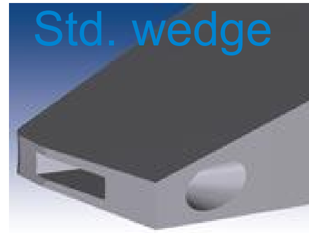


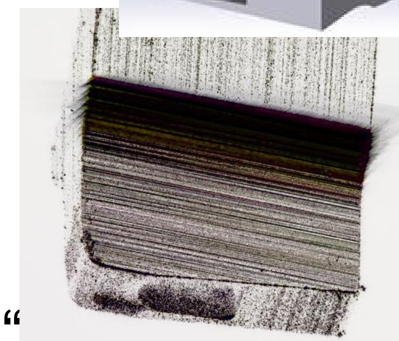


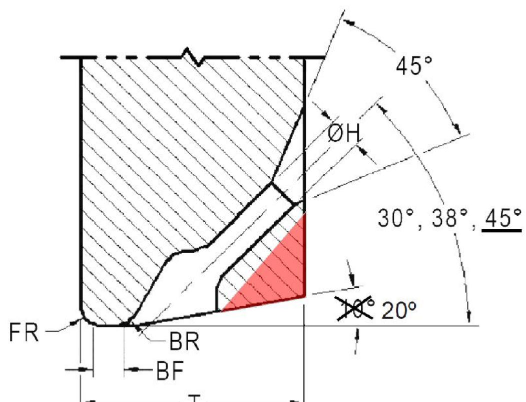


R&D Wirebonding

- Issues with narrow pads and collisions of wedge and wires
- Attempt narrow width wedge
  - Not enough :(
- Attempt narrow width wedge with custom-made „raised heel“
  - **Works :)**

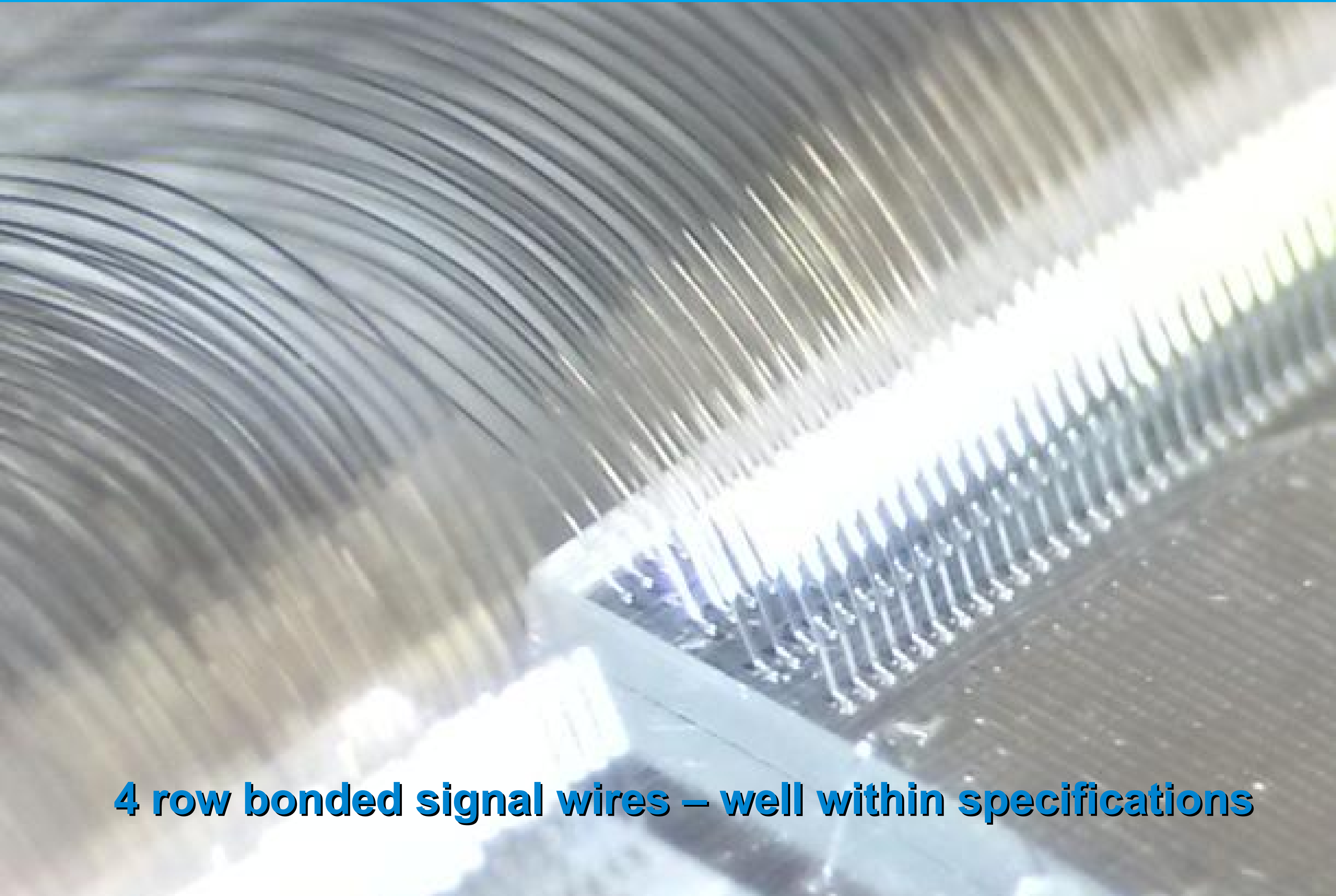






FP45A-W-1520-1.00-C W=VW=003 VR=006
+ Roten Bereich entfernen

R&D Wirebonding Results



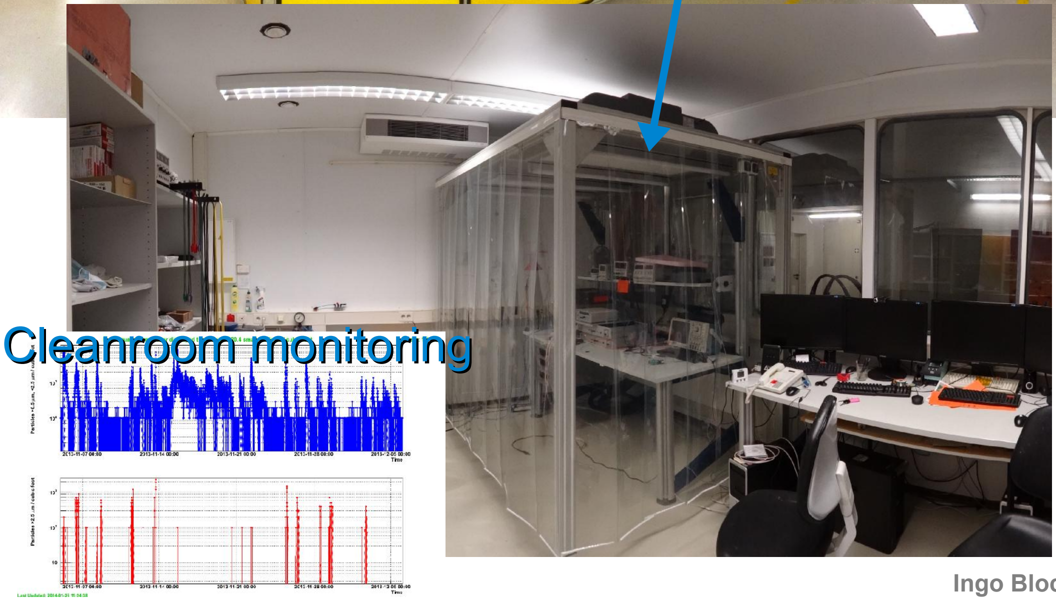
4 row bonded signal wires – well within specifications

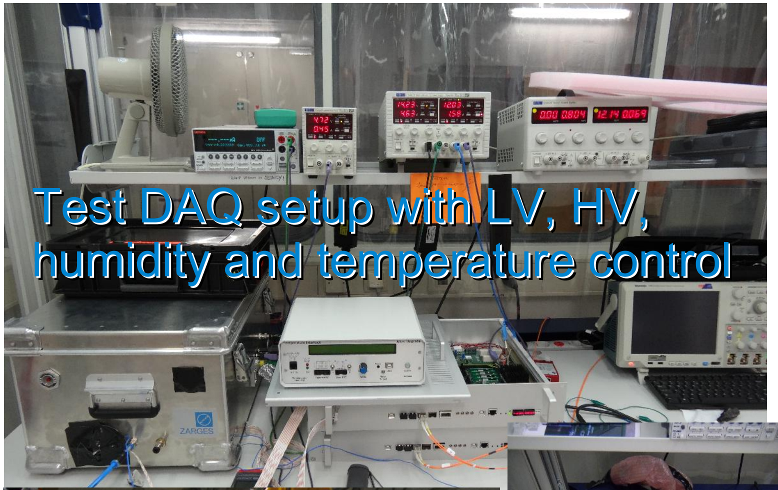
Milestones Infrastructure Zeuthen Labs

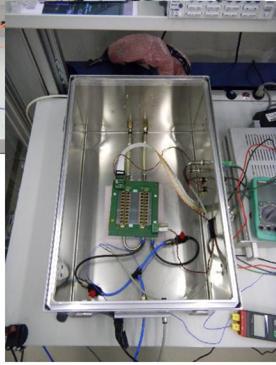
> Tools in Module-Construction Lab: Bond-Lab

Milestones Infrastructure Zeuthen Labs

- Tools in Module-Test Lab: DAQ-Lab

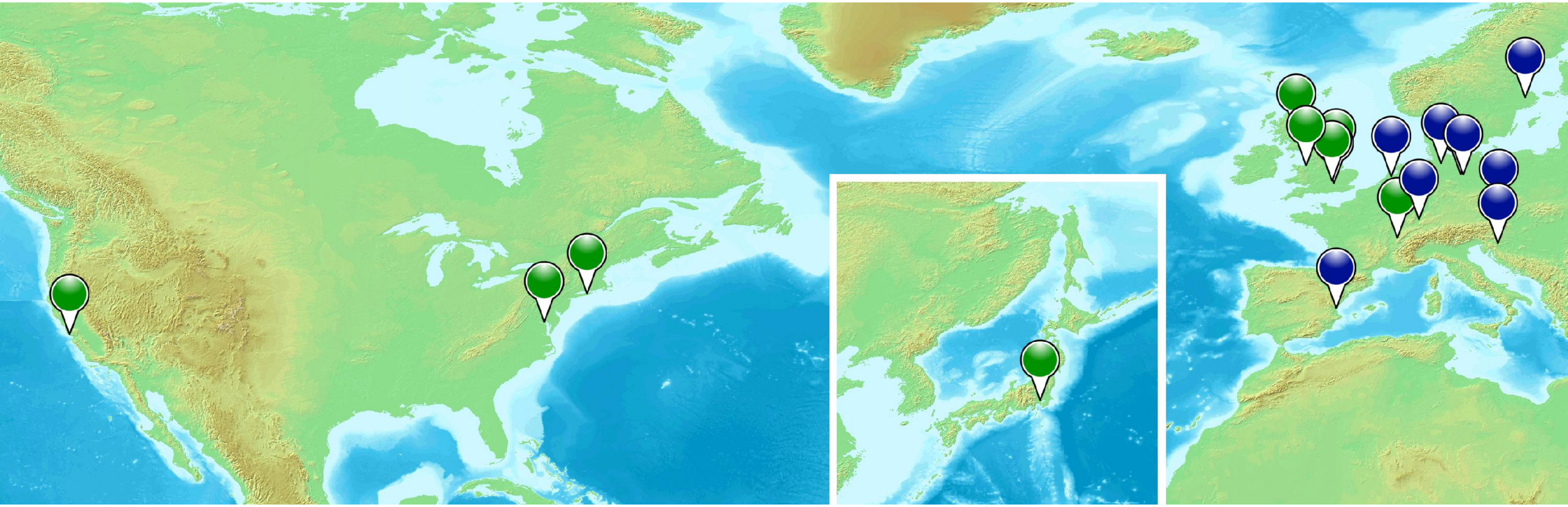






Zoom Out – Upgrade Community

- Institutes across the globe on the strip tracker upgrade



- Very active community preparing all new detector components in great detail
  - Very collaborative work, great opportunity for students
  - On route for technical design report

Summary

- LHC to deliver 3000 fb^{-1} e.g. to enhance sensitivity to rare processes
- LHC and Experiments en route to master challenging High-Luminosity target
- ATLAS will
  - Exchange tracking detector
  - Revamp trigger
  - Upgrade parts of Muon and Calorimeter systems
- DESY taking leading role in strip detector R&D headed for construction
- New technologies and developments make this a very exciting time