Helen Hayward
University of Liverpool

ATLAS ITK Requirements and Layout

The Future Phase II ATLAS Tracker Requirements

General ITk Requirements

Guided by the physics requirements
Maintain and improve performance of existing ATLAS - ID to 3,000fb^{-1}

- ✓ Tracking to <μ> ~ 160−200, expect 1000 tracks per unit of rapidity
- ✓ Measure P_T and direction of isolated particles (e and μ),
- ✓ reconstruct vertices of pile-up events
- ✓ identify vertex of hard scatter
- ✓ Identify secondary vertices in b-jets with high efficiency and purity
- ✓ Measure tracks in the core of dense jets with good resolution
- ✓ Identify the decays of τ leptons, including impact parameter resolution
- ✓ Reconstruct tracks associated with converted photons
- ✓ The tracking must be robust against minor losses of acceptance

Pixel

ITk Pixels.

- ✓ Fluences up to 2x10^{16} 1MeV neq/cm^2
- ✓ Low mass to reduce multiple scattering (<1.5%X_o Inner, < 2.0%X_o Outer)
- ✓ Inner layers removable/replaceable in a short LHC stop (clam shell)
- ✓ Approximately 10m^2 of pixels

Strip Detector

ITk Strips.

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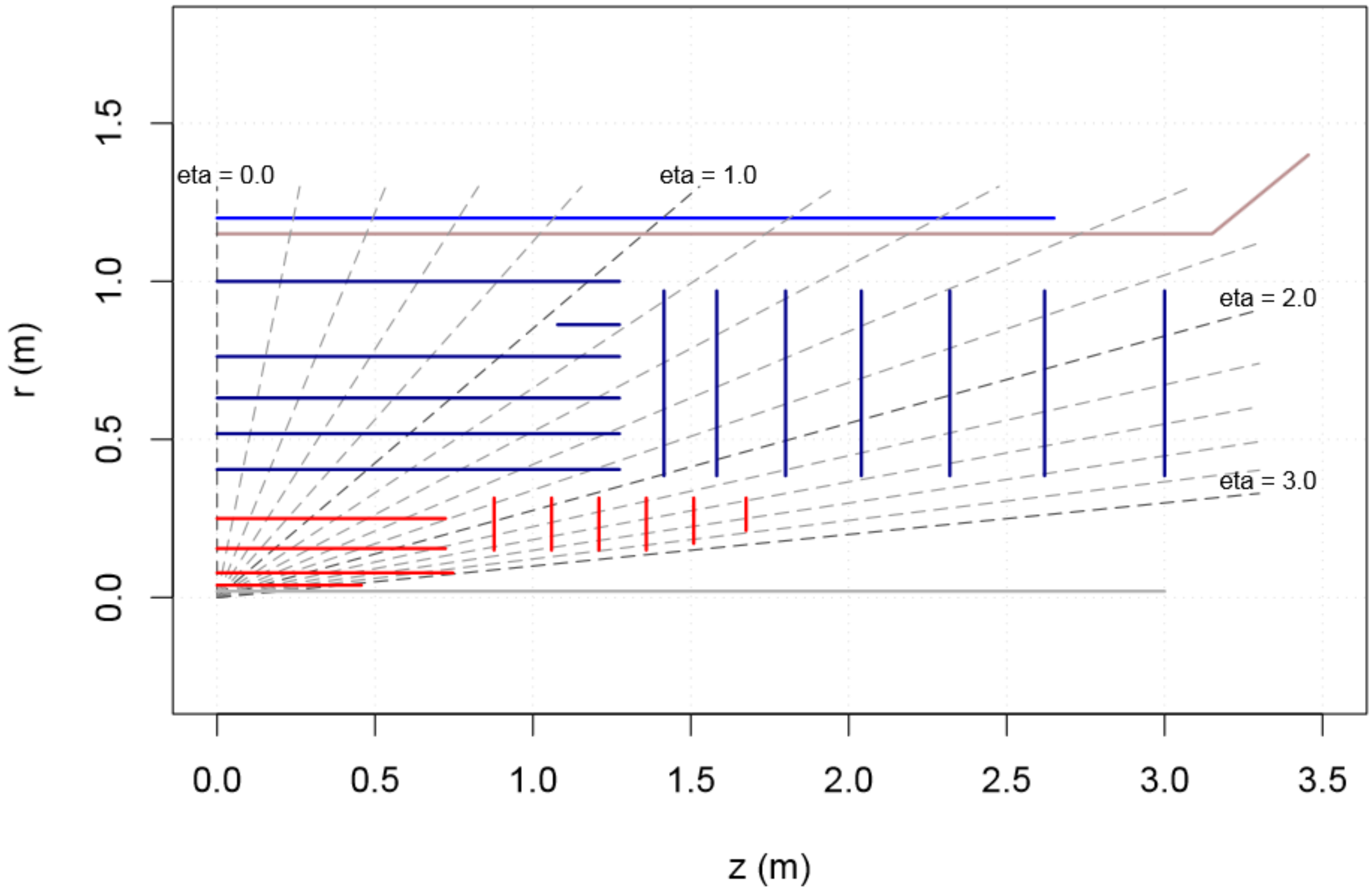
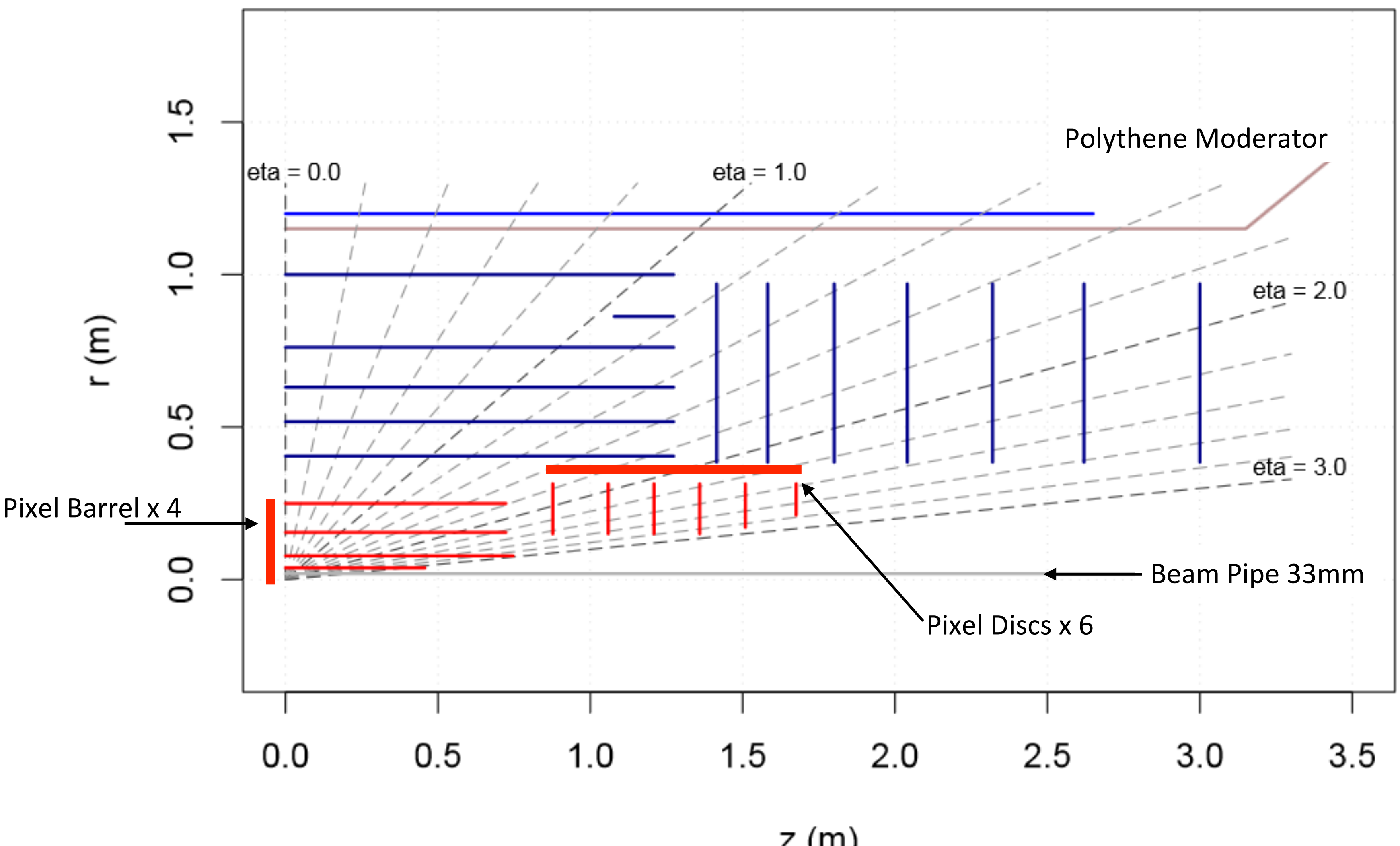
Baseline Layout

http://cds.cern.ch/record/1502664?ln=en



Baseline (LoI) Layout

http://cds.cern.ch/record/1502664?ln=en

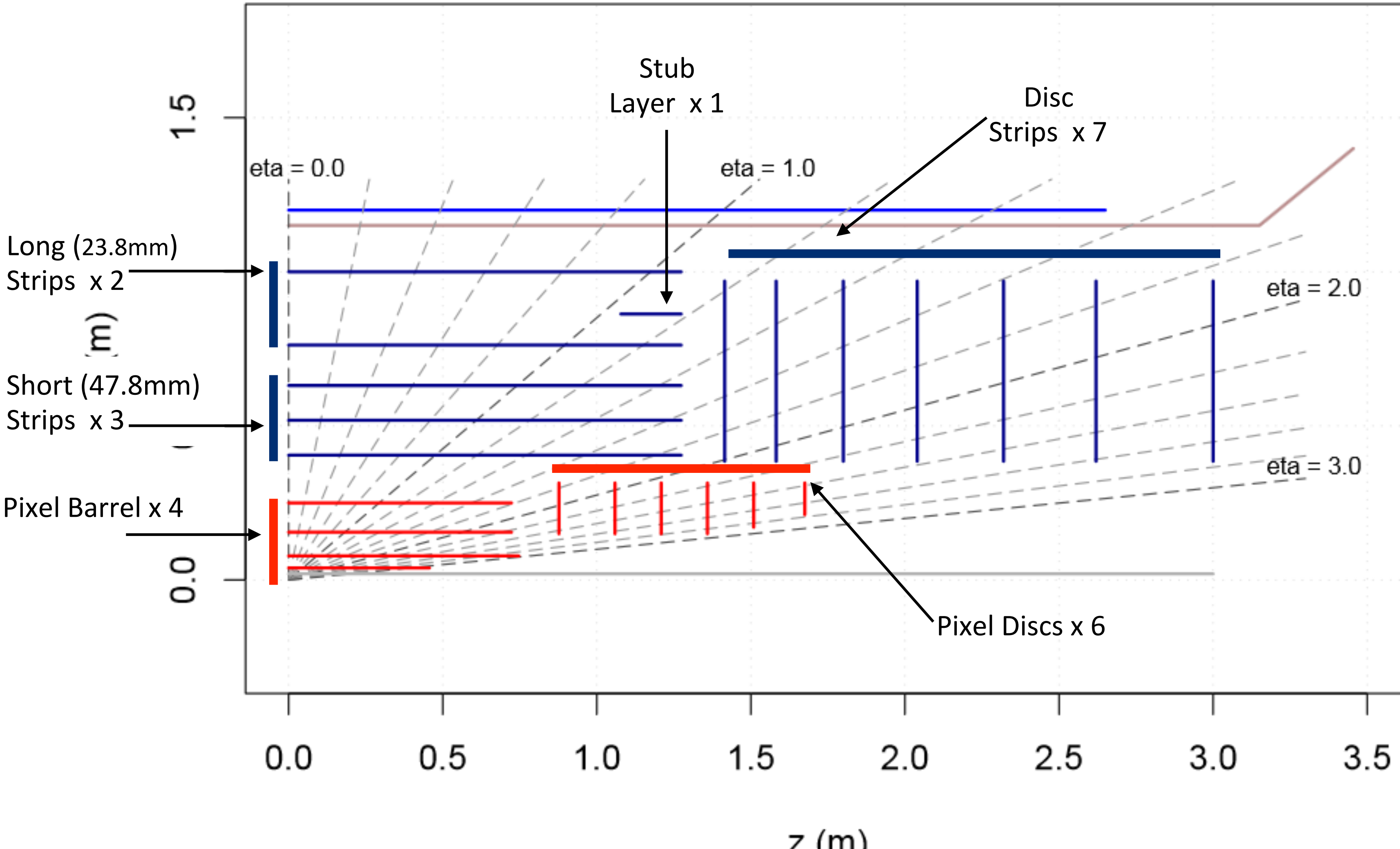


PIXELS
8.2 m^2
638x10^6 channels

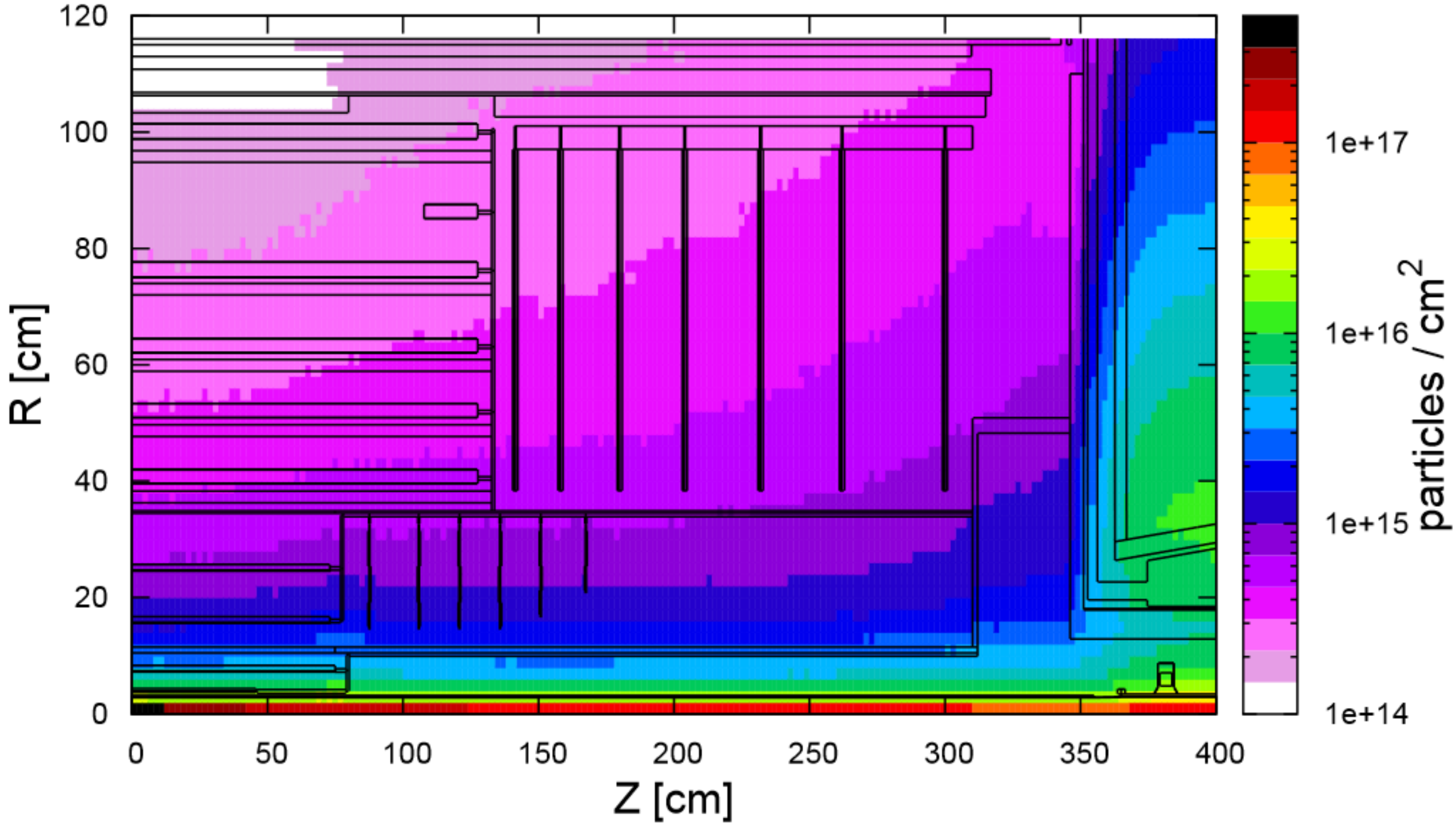
Baseline (LoI) Layout

http://cds.cern.ch/record/1502664?ln=en

STRIPS
193 m^2
74x10^6 channels



ITk - Radiation Fluences : 1 MeV $n_{eq}.cm^{-2}$



Simulations with FLUKA

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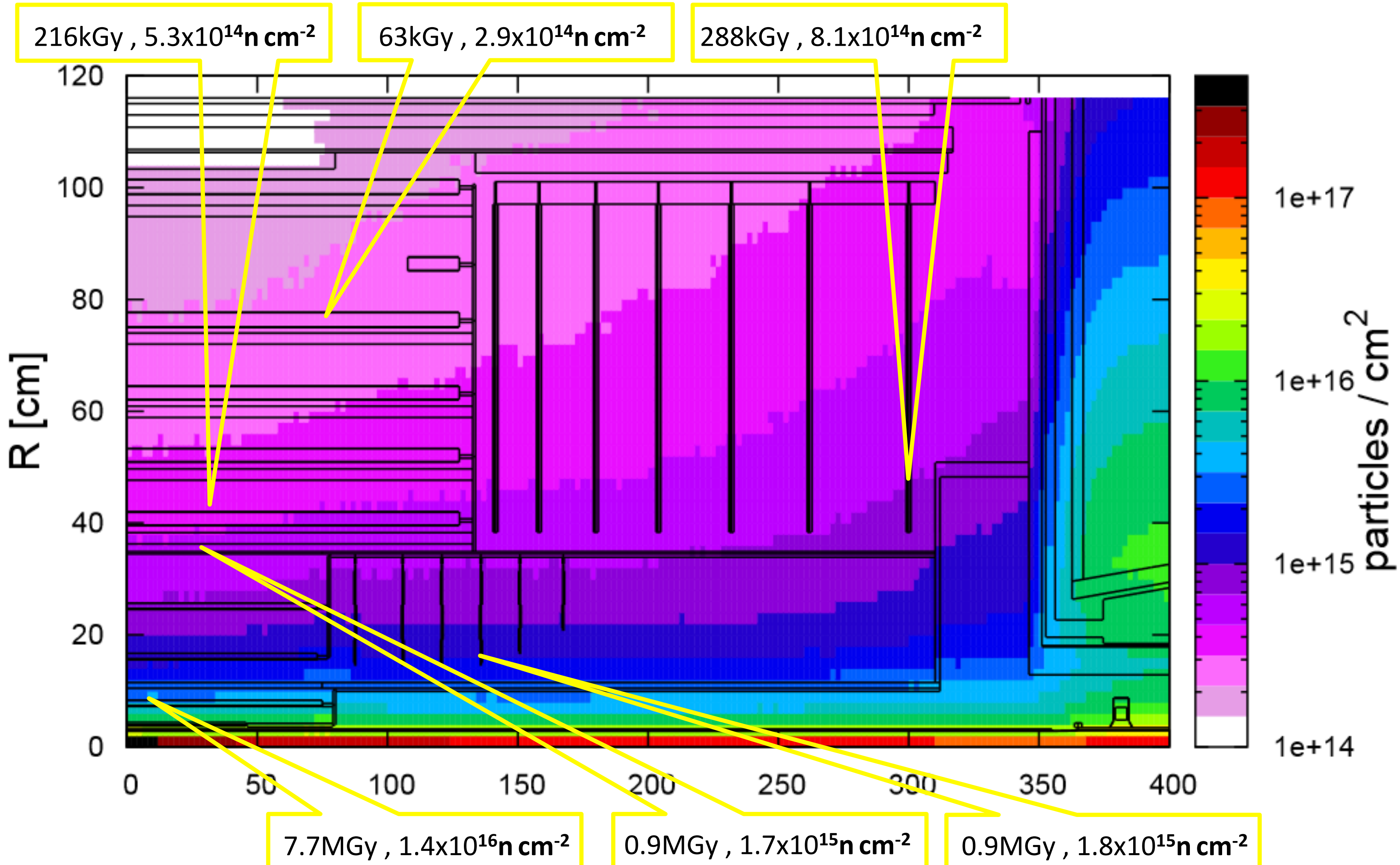
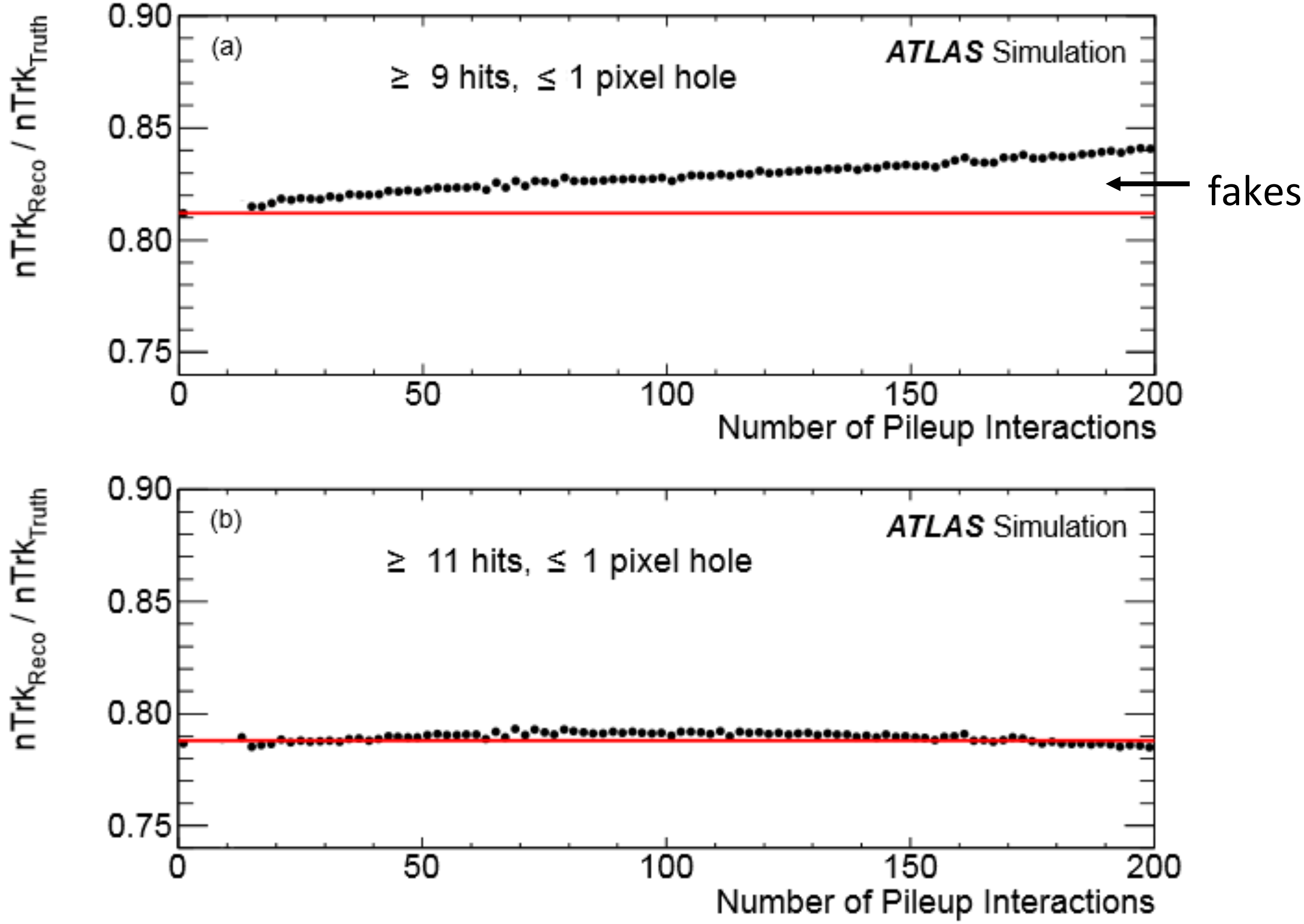


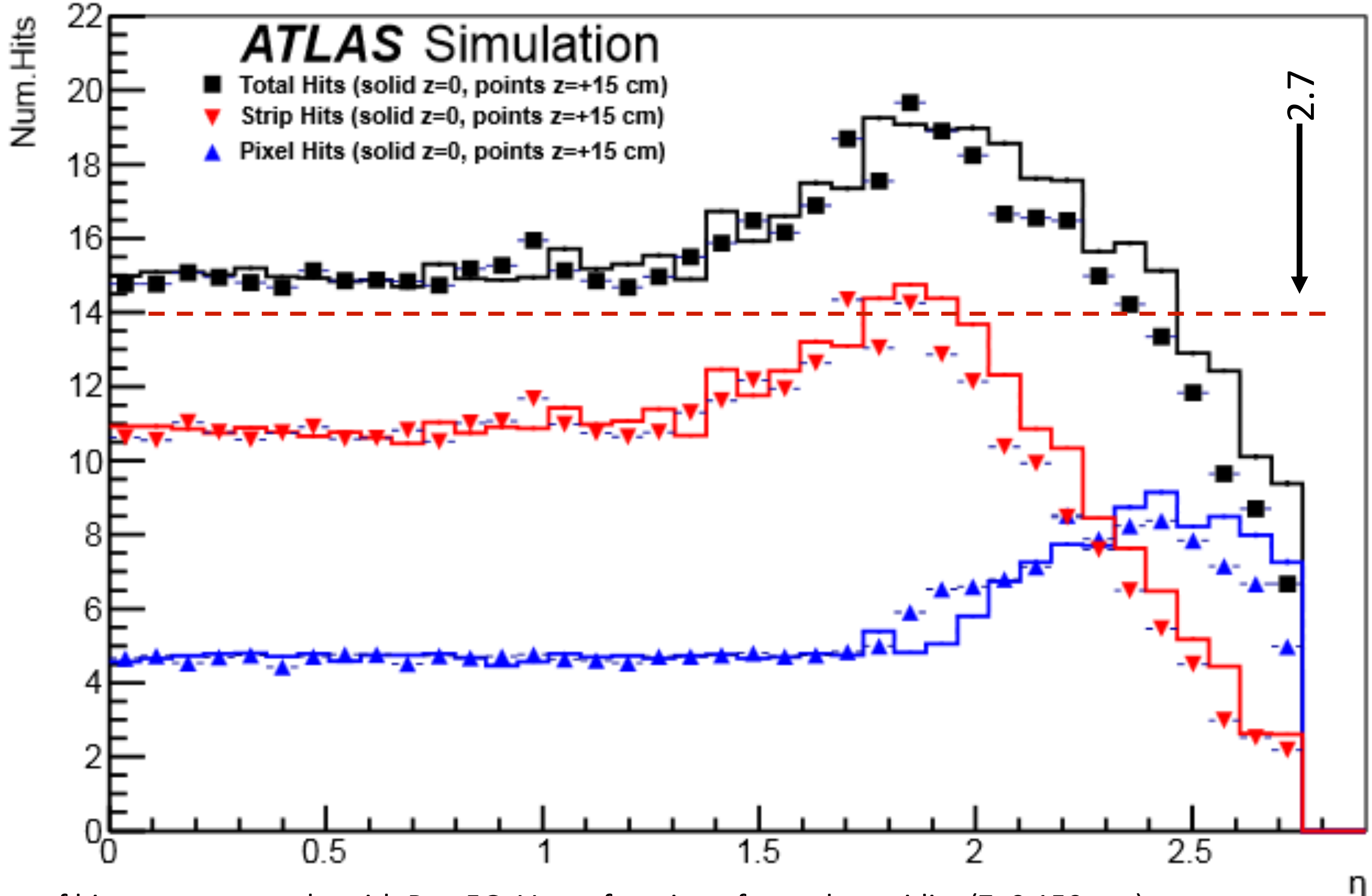
Simulations with FLUKA to 3,000 fb^{-1}

Performance of the ATLAS Phase II Tracker
Number of hits on Track



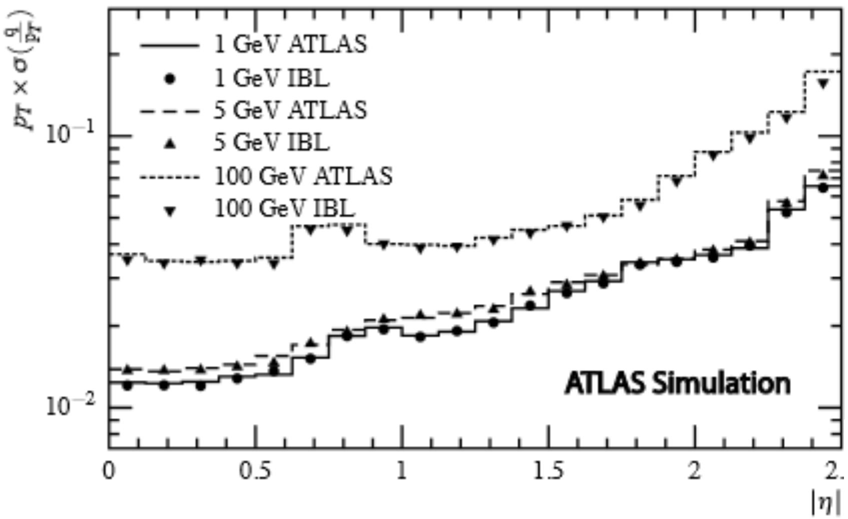
Sample of $t\bar{t}$ events

Performance of the ATLAS Phase II Tracker
Number of hits on Track



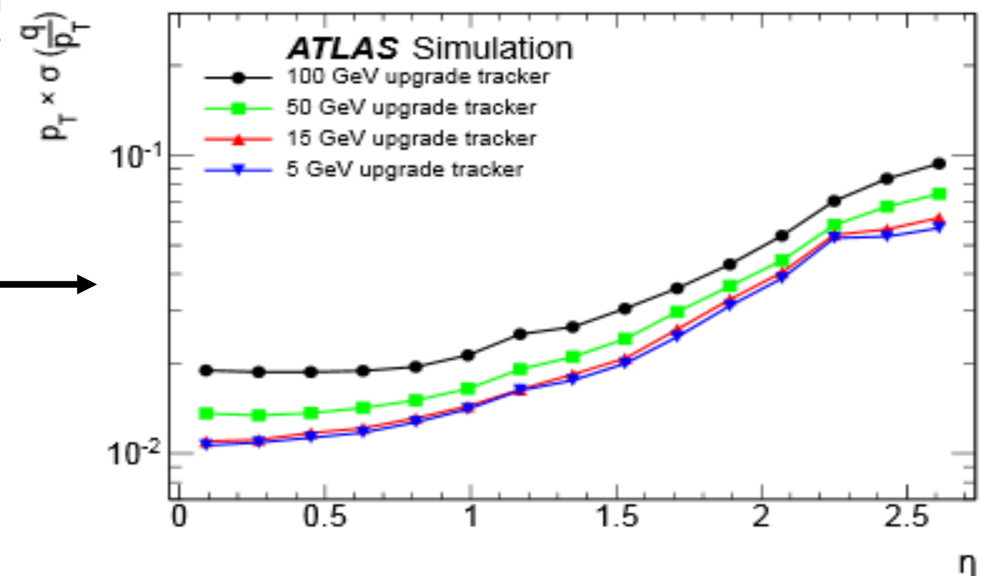
Number of hits on muon tracks with P_T > 5GeV as a function of pseudo-rapidity (Z=0,150mm)

Performance of the ATLAS Phase II Tracker
Number of hits on Track

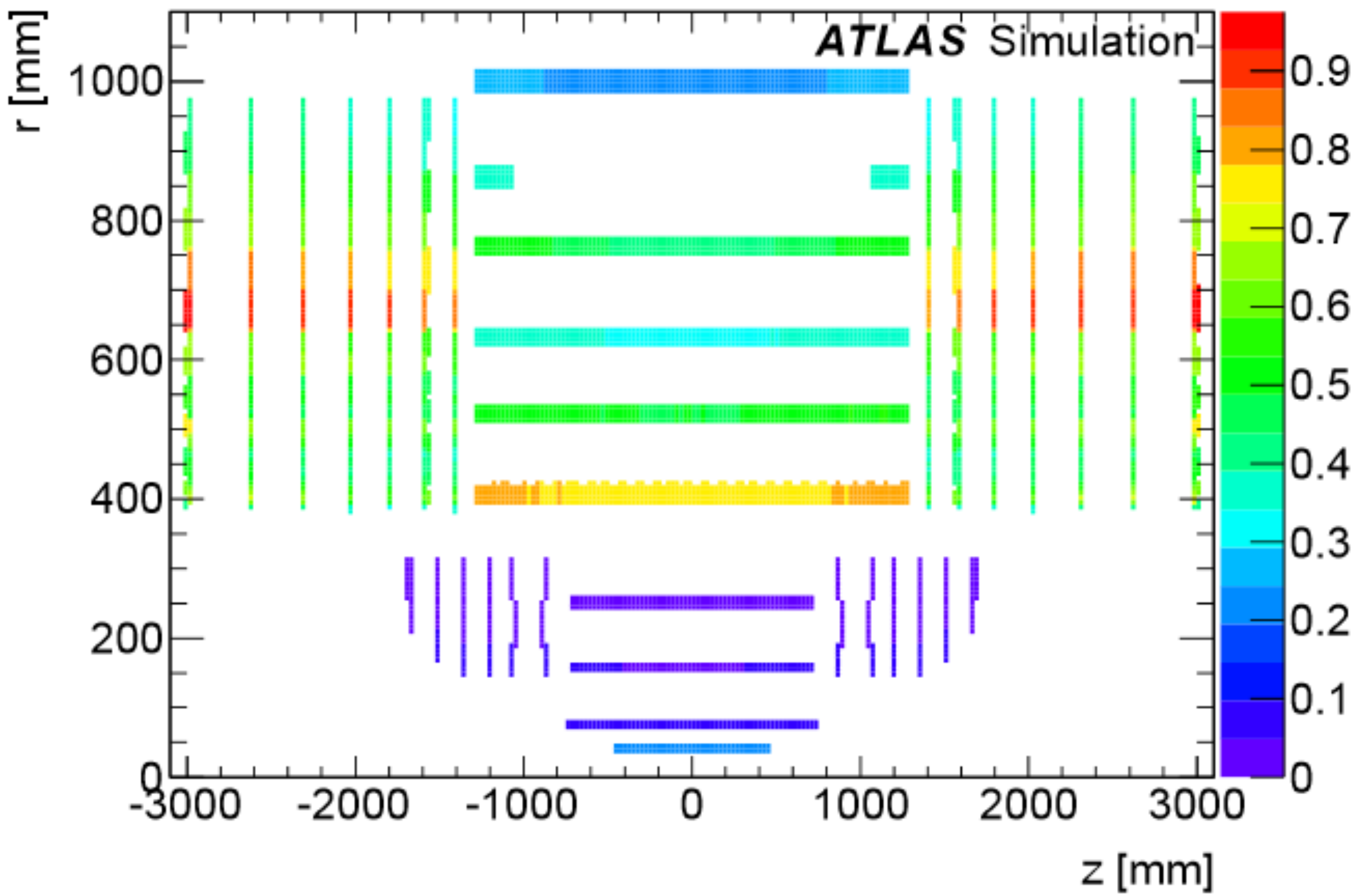


P_T resolution as a function of η
Comparison of current ID with & without the IBL

P_T resolution as a function of η
For Upgrade tracker for different momenta

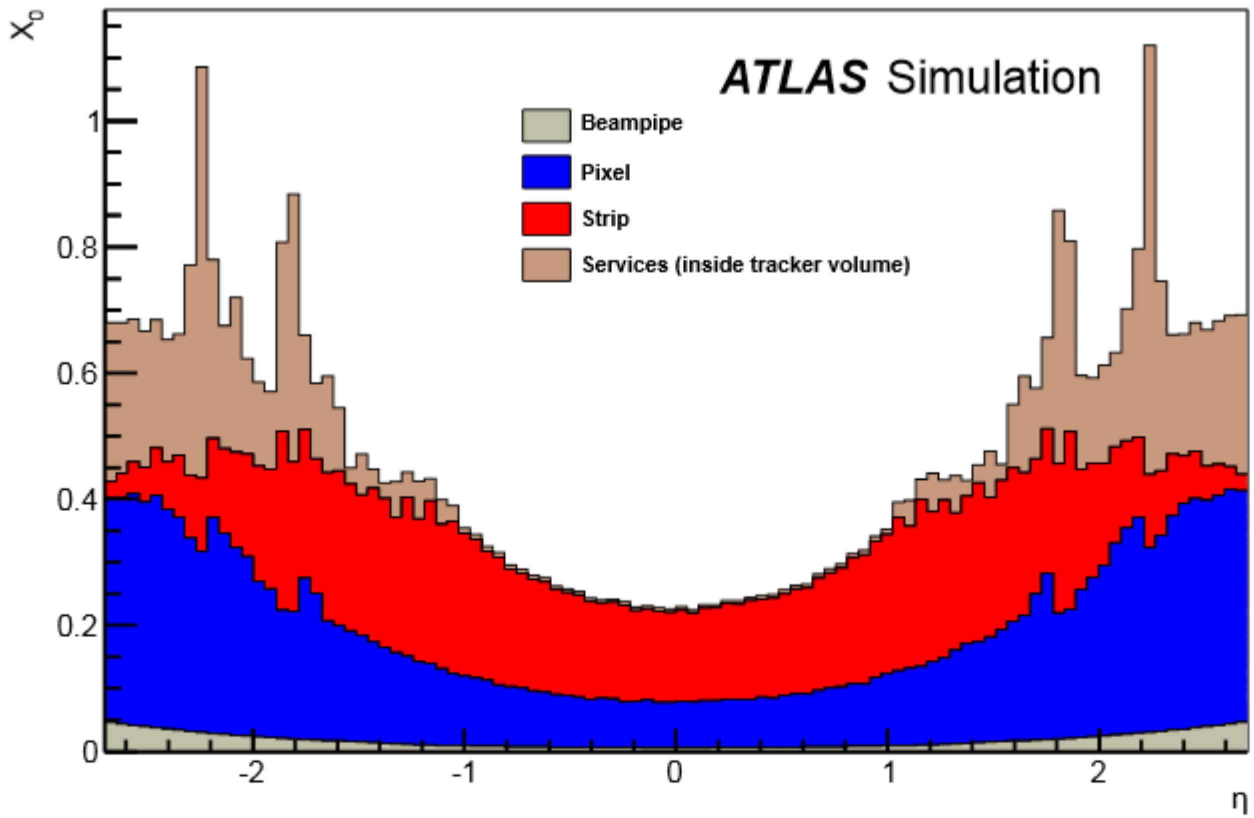


Construction of the ATLAS Phase II Tracker
Detector Occupancies



Hit occupancies in different sub-detectors in the presence of 200 pile up events (peak around 0.9)

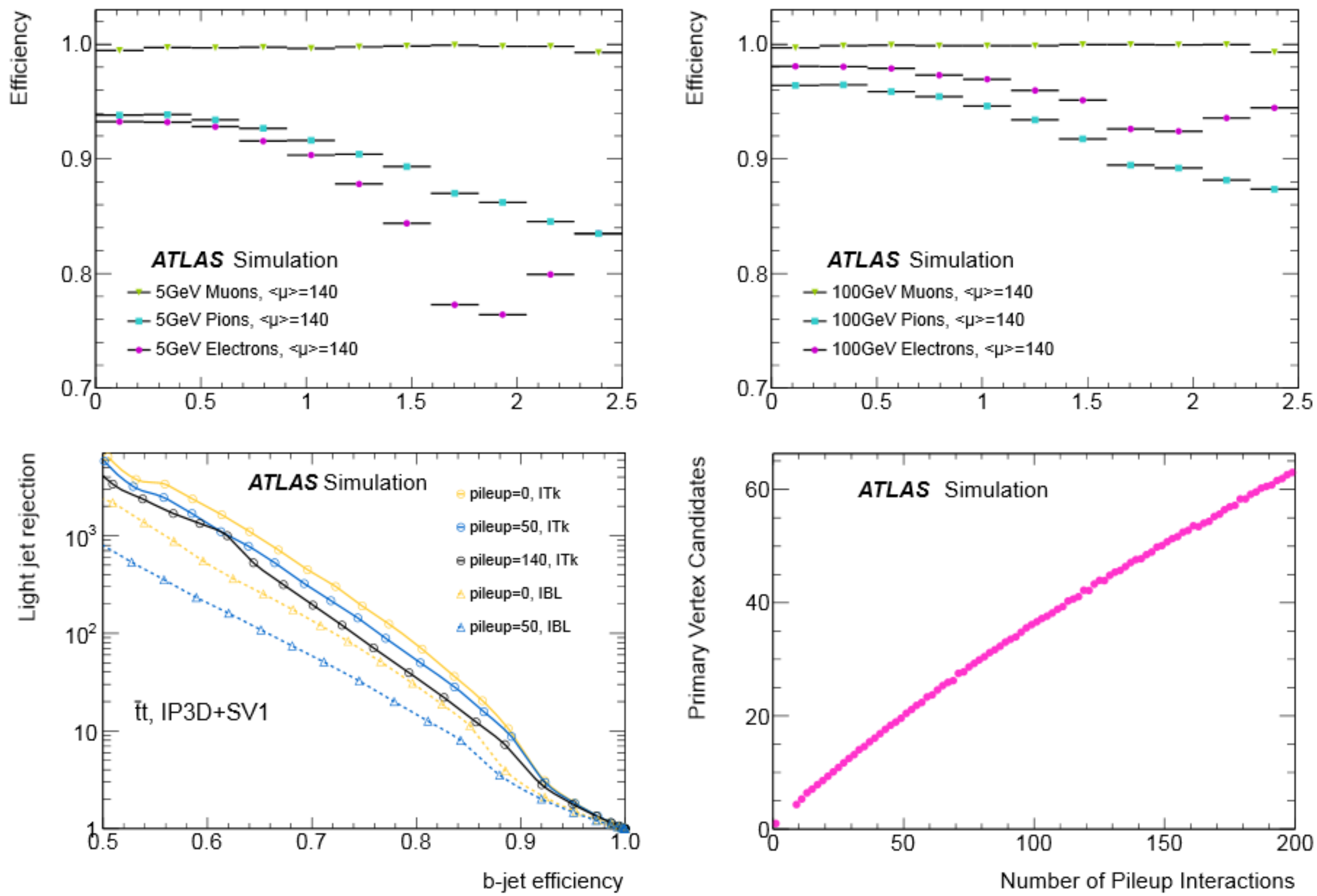
Construction of the ATLAS Phase II Tracker Material



Particular attention put into reducing the material in the tracker volume
Note that everywhere less than 0.7Xo while in ID (+IBL) ~1.2%
Achieved through careful choice of materials, service routing etc

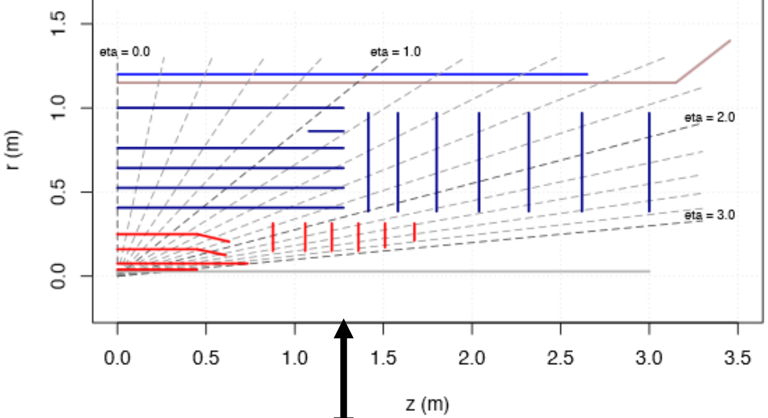
Performance of ATLAS Phase II Tracker Efficiencies

NB Brem recovery used

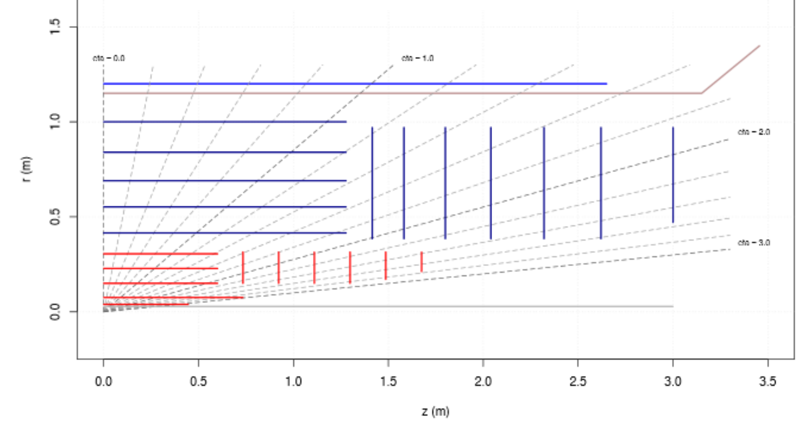


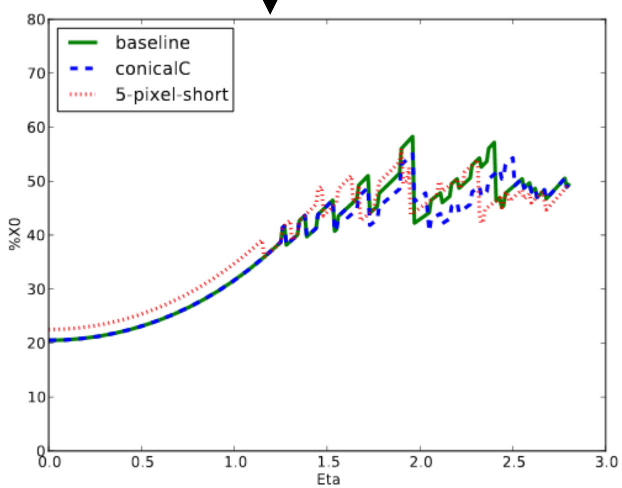
Alternate Layouts of Phase II Pixels

Conical (Barrel area 5.1 → 4.6 m²)

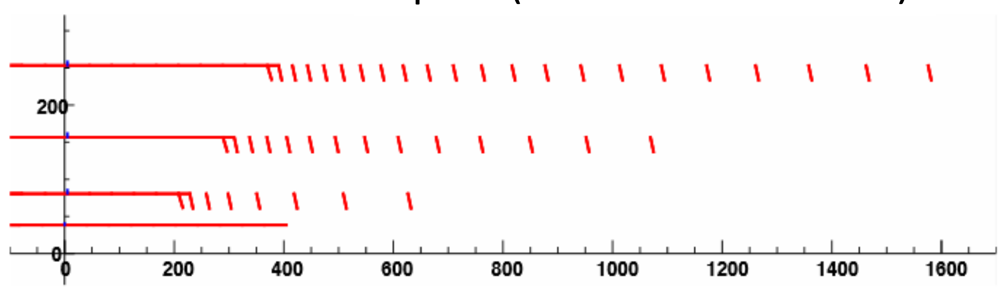


Fifth Pixel (optimized pattern rec)





Alpine (reduced area ∟ modules)



Work also ongoing with coverage out to a pseudorapidity of 4

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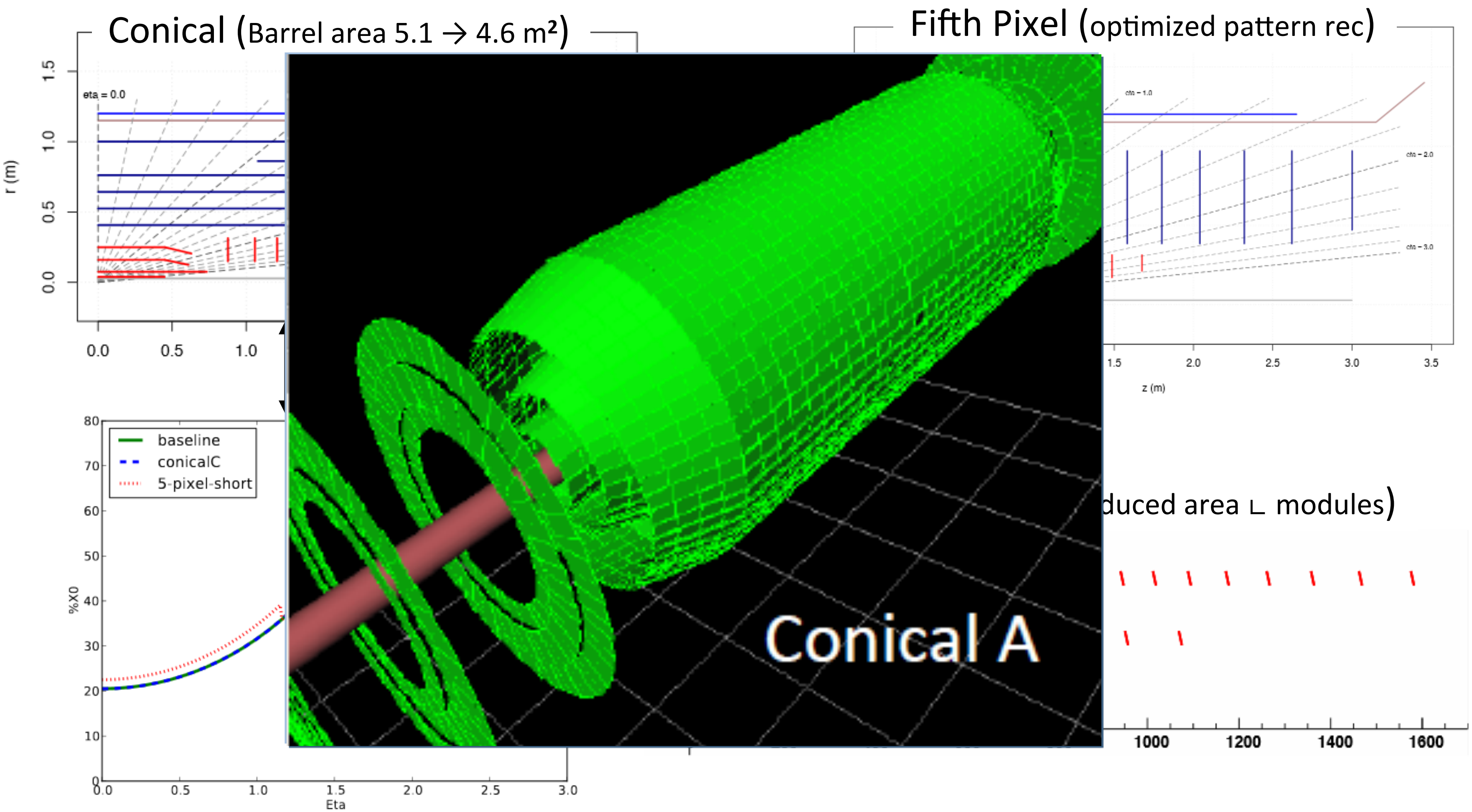

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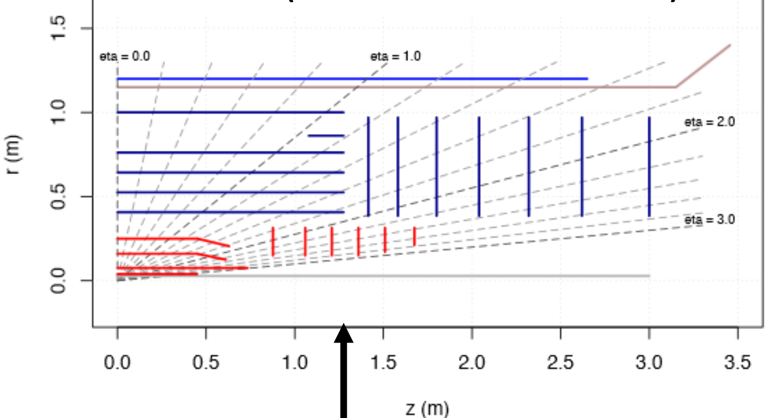

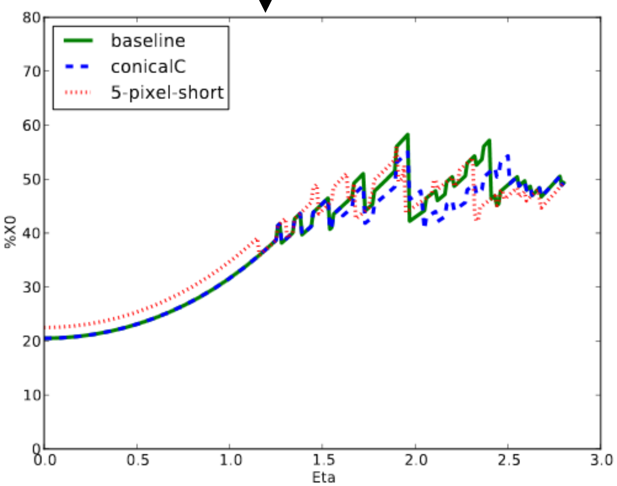

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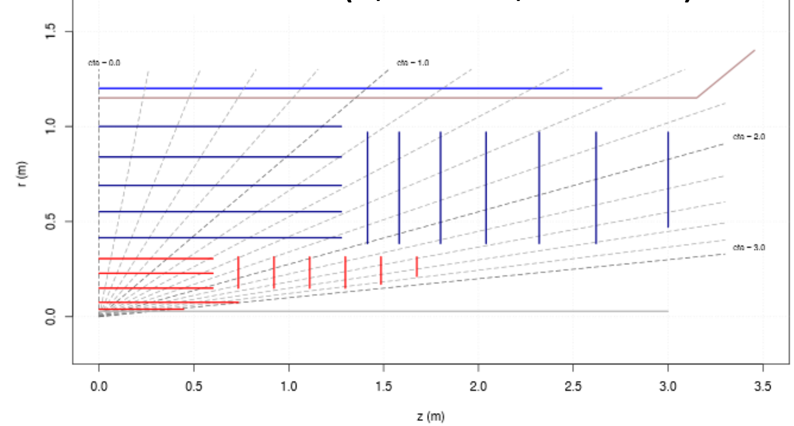

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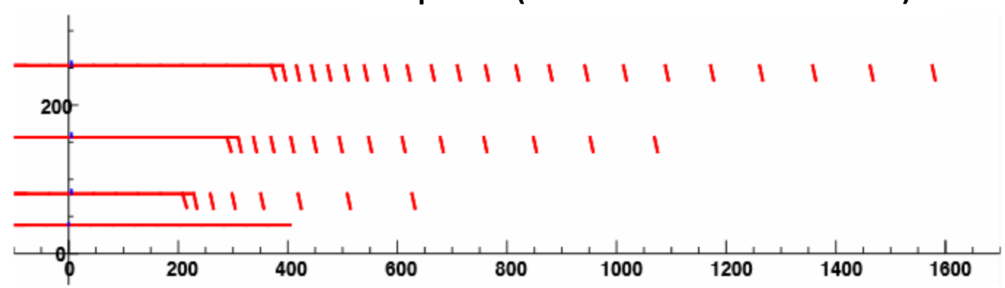

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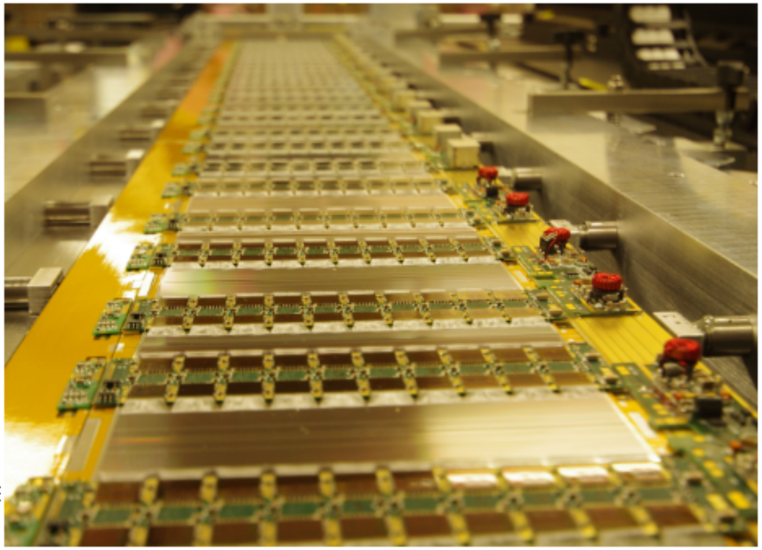
ATLAS Phase II Pixels

- **Candidate Sensor Technologies**
  - **Choices largely driven by radiation tolerance requirements.**
    - *Standard Planar Sensors*
      - Thin (150μm) High Resistivity Silicon [n-in-n (*inner layers*) or n-in-p (outer)]
      - Demonstrated to HL-LHC fluxes, Lots of experience and known vendors, mass production understood.
    - *3D sensors*
      - *Used in the IBL, Low depletion voltage after irradiation, radiation tolerant*
    - *Diamond Sensors*
      - *Good radiation tolerance , Low capacitance (noise), no cooling, BUT expensive*
      - *Used in ATLAS beam monitoring, current and replacement in 2014*
    - *CMOS*
      - *Emergent technology (used on STAR and baseline for ALICE ITS), low power, varying degrees of sensor-hybrid integration (move away from standard implementation) to a more MAPS like approach, <u>Cheap,</u> Need to demonstrate radiation tolerance and readout speed.*
  - **Choices**
    - *Extensive R&D in progress, wait for appropriate time to make decisions*

ATLAS Phase II Strips

- **Sensors**
  - Need to withstand 8.1×10^{14} neq **cm**$^{-2}$ (no safety factor) and operate up to 500V. Including a safety factor takes us to 2×10^{15} neq **cm**$^{-2}$
  - Current baseline is n-in-p FZ , 320 μm thick, 97.54 x 97.54mm^2
  - 1280 strips, AC coupled to FE chip, pitch 74.5μm
  - On stave/petal, sensors axial on one side, small angle stereo on the other
  - 2 lengths of strips: short = 23.82mm, long=47.75 (match track density)
  - The petal sensors use pointing strips (to beam-line) and so sensors are wedge shaped. Ideally sizes would minimize number of wafers (currently assuming 6")

Fully populated DC-DC powered 250nm stave in December 2013



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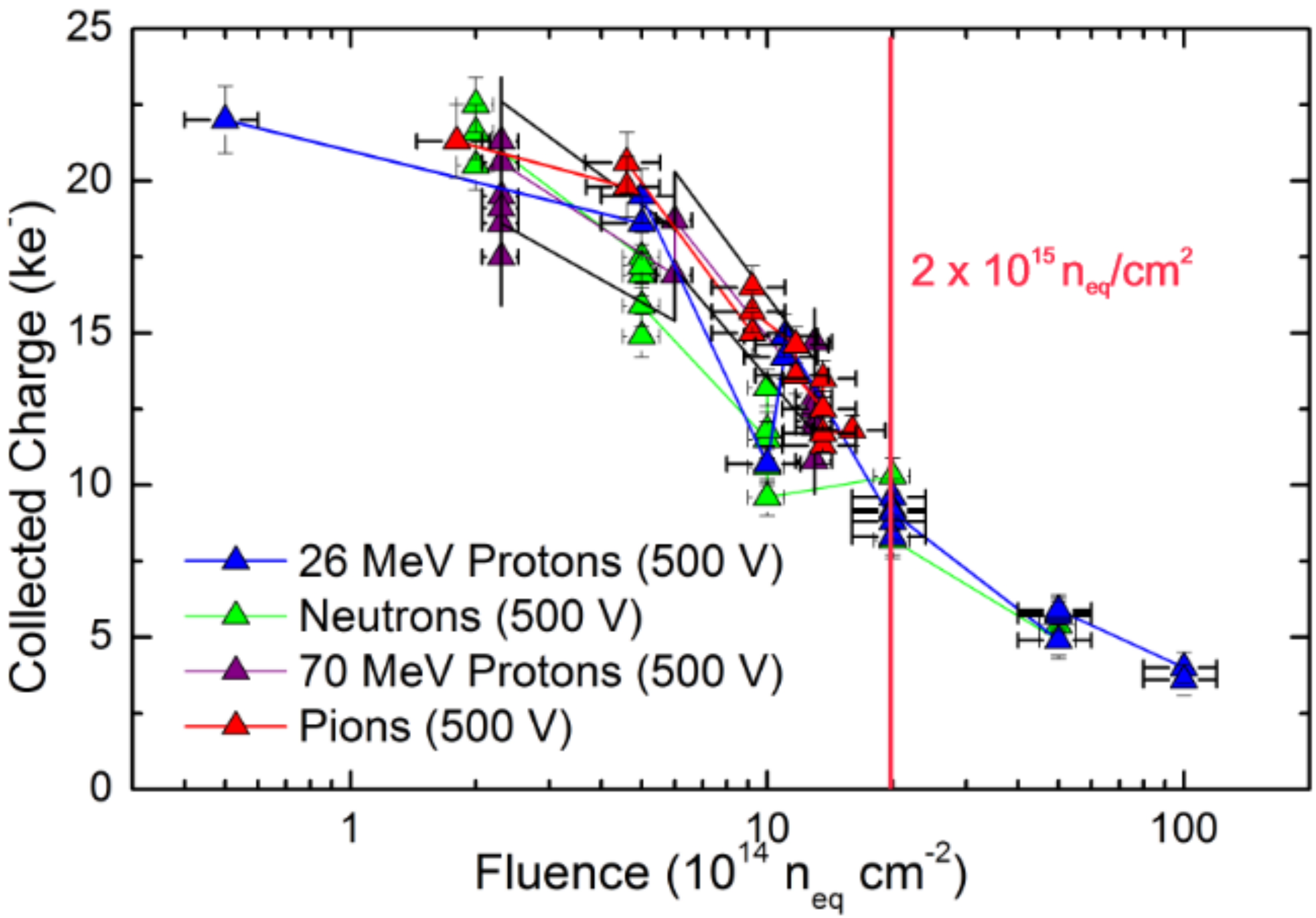
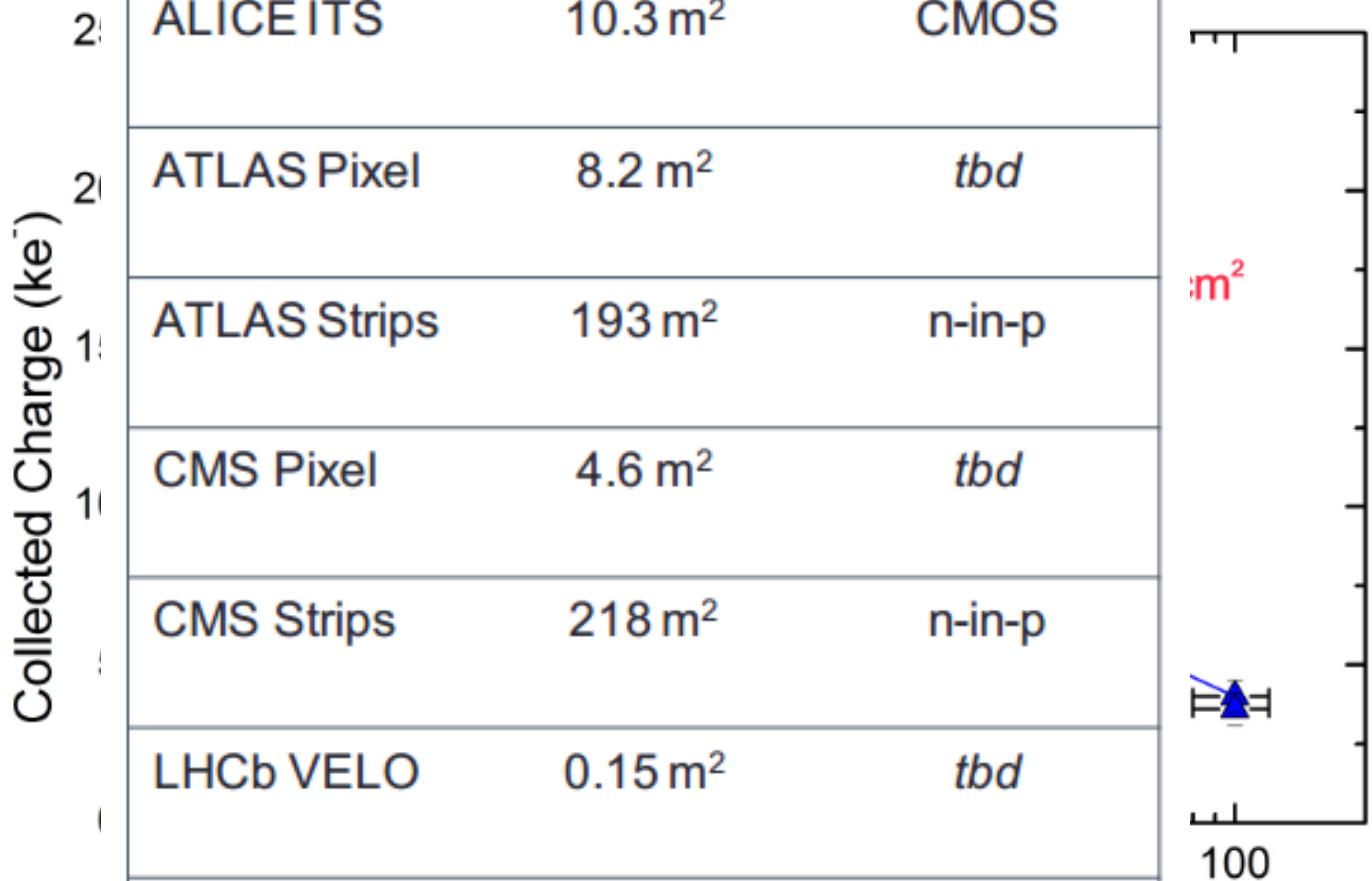


Collected signal charge at 500Vbias voltage for minimum ionising particles as a function of 1MeV neq/cm2 fluence for different particle species. S/N at end of life > 23 (17) for barrel (EndCap)
Need S/N >10 for efficient tracking.



Upgrades	Area	Baseline sensor type
ALICE ITS	10.3 m^2	CMOS
ATLAS Pixel	8.2 m^2	*tbd*
ATLAS Strips	193 m^2	n-in-p
CMS Pixel	4.6 m^2	*tbd*
CMS Strips	218 m^2	n-in-p
LHCb VELO	0.15 m^2	*tbd*
LHCb UT	5 m^2	n-in-p

Taken from talk of P. Rieder in Aix Les Bain (Oct 2013)

Collected signa ... function
of 1MeV neq/c ... (17) for barrel (EndCap)
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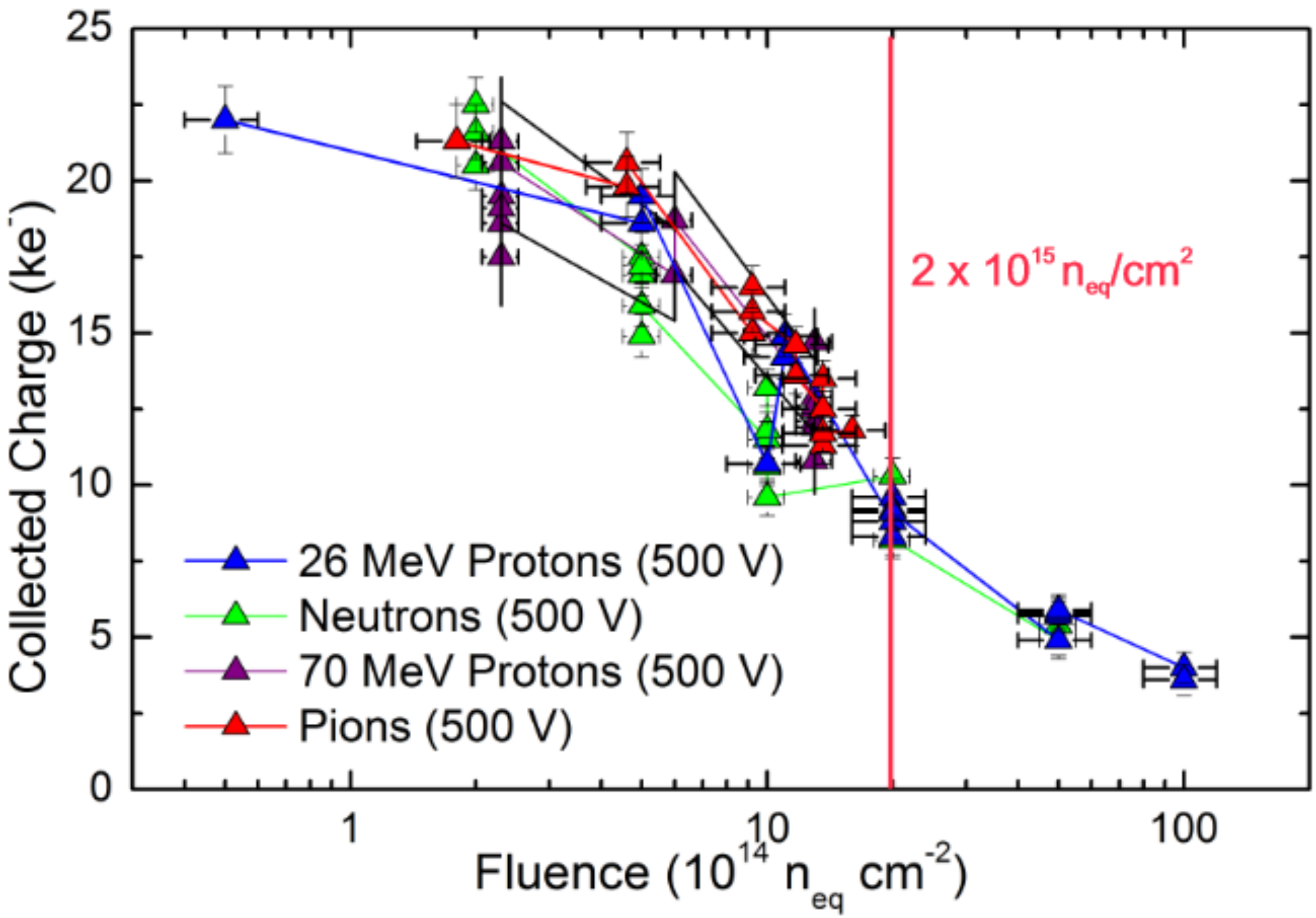

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Conclusions

- Designing a new Inner Tracker detector to maintain and improve on the existing ID performance
- The ITK will be a pixel plus strip based tracker which can perform
  - At higher pile up conditions
  - At higher radiation environment

The End

Bonus Material

The Current ATLAS Inner Detector (ID)
Initial Specifications & Limitations

Current Inner Detector

3 layers of Pixels (PIX), 4 layers of Si micro-strips (SCT), straw tracker (TRT)
Additional PIX-layer (IBL) to be inserted in Long Shut-Down 1 (LS1 - 2014)
ID designed for **10 years** of operation, peak luminosity of **1 x 10^{34} cm^{-2}s^{-1}**
The assumed pile up (μ) was **23**, bunch crossing frequency **25ns**
and the L1 trigger rate of **100kHz. 2 Tesla Magnetic field**

Radiation Damage

PIX: desi
IBL: desi
SCT: desi
1
)fb^{-1}

Bandwidth Limitation

Both SCT
This is be
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FE chip a
up to 50
^{1} **@ 25ns)**
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Occupancy limits

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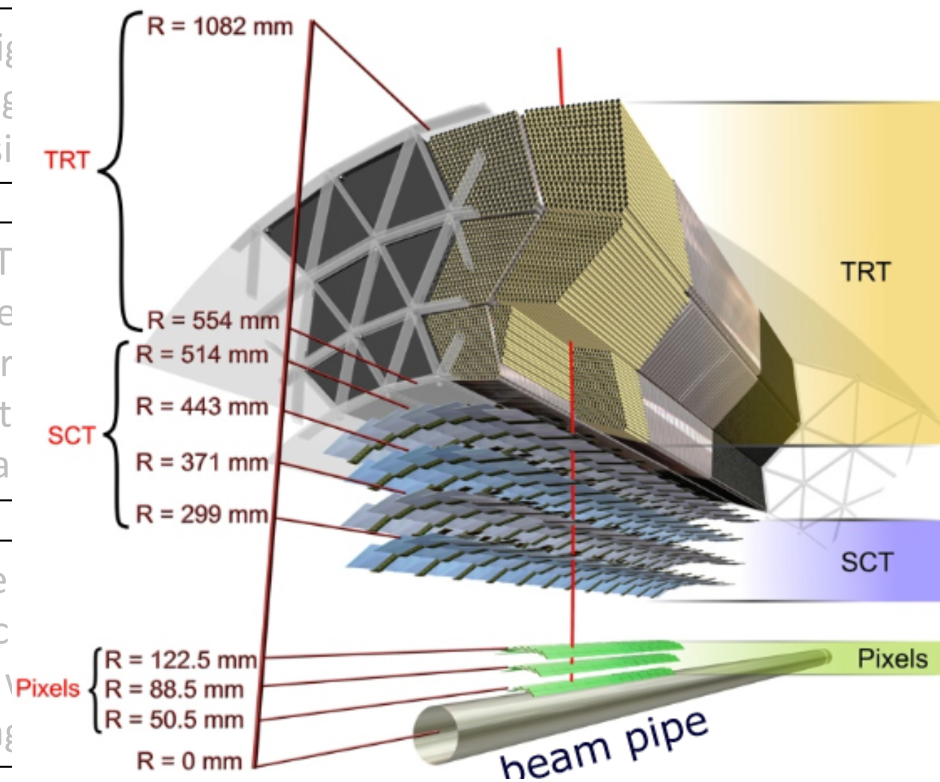

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Radiation Damage

PIX: designed to withstand 10^{15} 1MeV neq/cm² or about 400fb^{-1}
IBL: designed to about 850fb^{-1}
SCT: designed to withstand 2x10^{14} 1MeV neq/cm² or about 700fb^{-1}

Bandwidth Limitation

Both SCT and PIX apply zero suppression to accommodate <μ> up to 50
This is being expanded in LS1 to get bveyond 75 (**3 x 10^{34} $cm^{-2}s^{-1}$ @ 25ns)**
However, there are "hard wired" limitations which mean one cannot go beyond this. PIX-Limits 0.2-0.4 pixels per 25ns. For SCT data rate between FE chip and ReadOut Driver (ROD) limit us to **3 x 10^{34} $cm^{-2}s^{-1}$**

Occupancy limits

With the occupancy expected at the HL-LHC the SCT would not be able to resolve close-by tracks in the core of High P_T jets
The TRT will approach 100% occupancy and tracking efficiency will suffer accordingly

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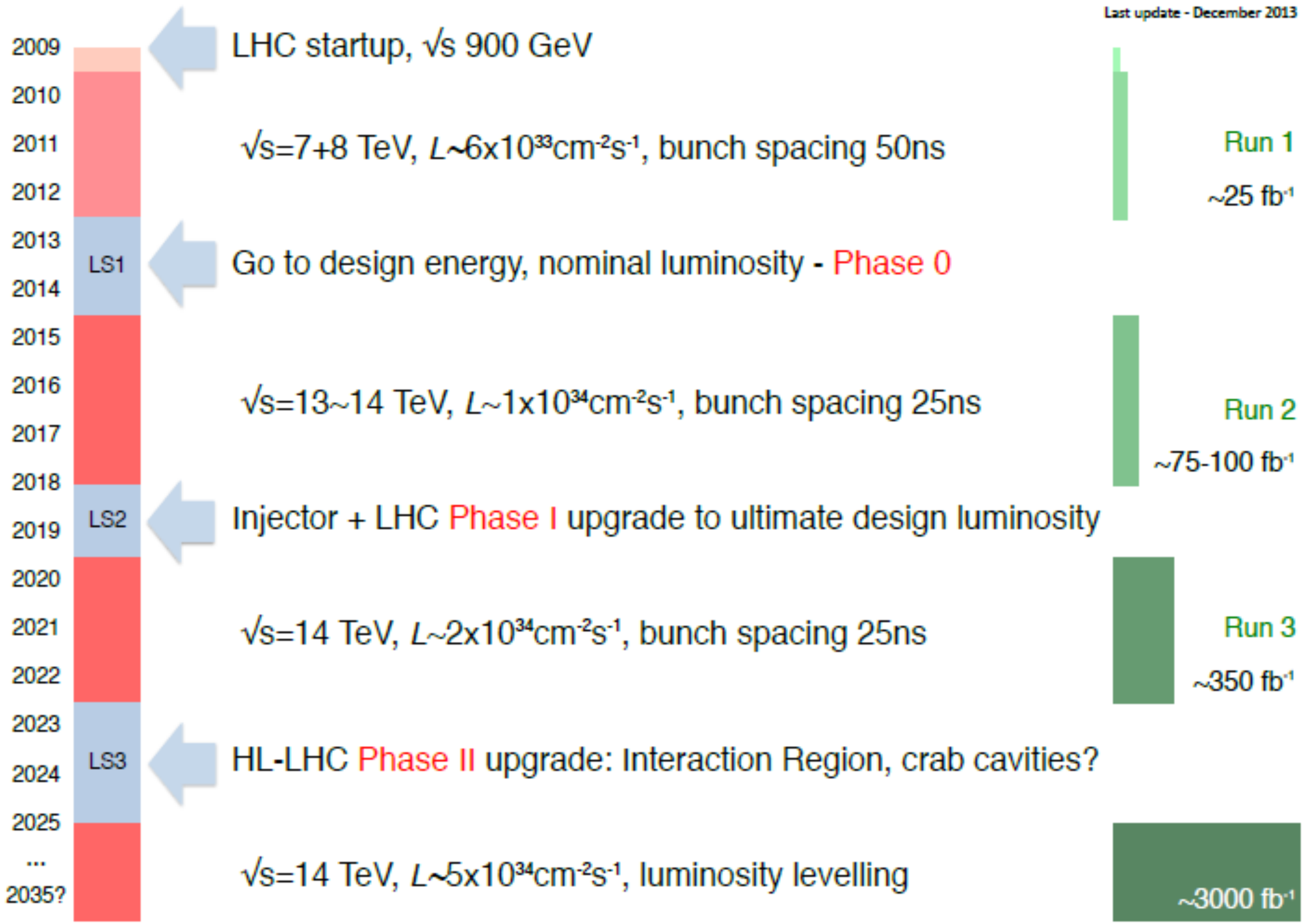
The LHC roadmap (updated december 2013)



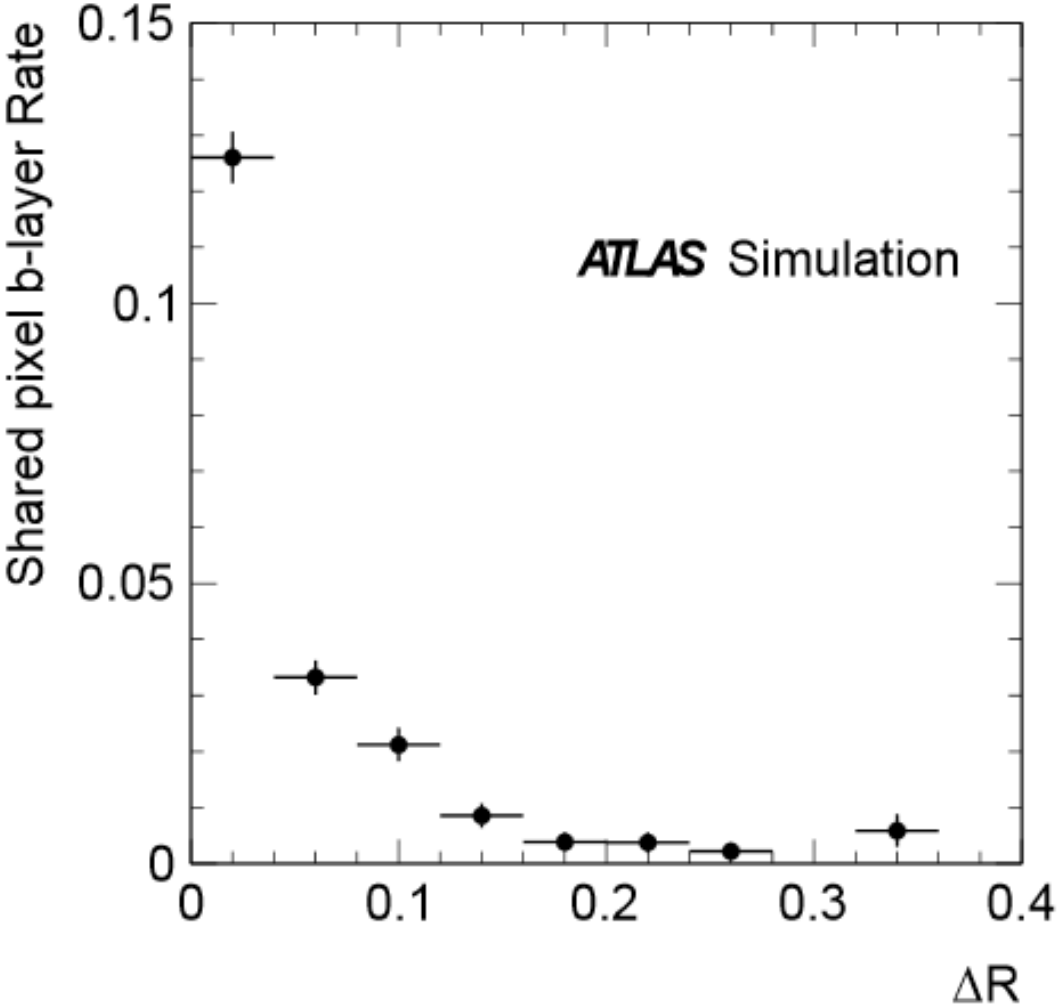
Performance of the ATLAS Phase II Tracker Compared with the existing ID + IBL

Track parameter $|\eta| < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum (q/p_T) [/TeV]	0.3	0.2
Transverse impact parameter (d_0) [μm]	8	8
Longitudinal impact parameter (z_0) [μm]	65	50

The expected performance of the ATLAS Phase II tracker compared to the performance of the existing ID with the addition of the IBL.
$\sigma x(\infty)$ refers to σx for $P_T \to \infty$ which allows one to remove the effect of material.

Performance parameters extracted from full ATLAS simulation including realistic service routing and appropriate engineering considerations.

Performance of the ATLAS Phase II Tracker
Number of hits on Track

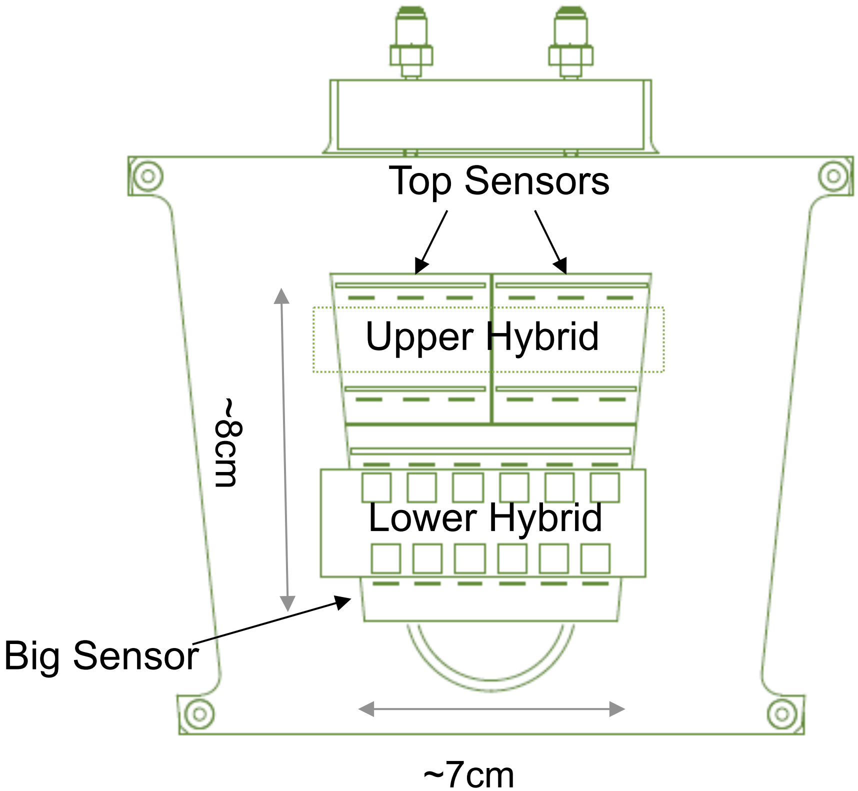


Good particle separation
Inside jets achieved with
Small pixel size
2 innermost pixels: 25x 150μm²
2 outer pixels: 50 x 250μm²

ATLAS Phase II : Strips Material

Barrel		End-Cap	
Element	% Radiation Length	Element	% Radiation Length
Stave Core	0.55	Petal Core	0.47
Bus Cable	0.30	Bus cables	0.03
Short-Strip Modules	1.07	Modules	1.04
Module Adhesive	0.06	module adhesive	0.06
Total	1.98	Total	1.60

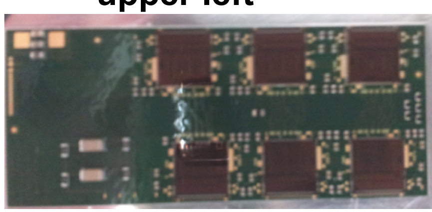
Petalet layout



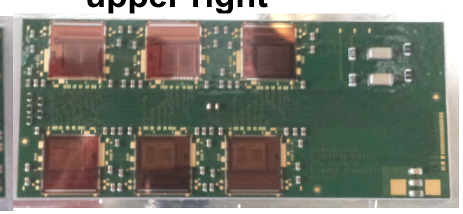
Lamb&Flag upper hybrids

- 1 lower and 2 upper hybrids designed and produced
- Population with passive components
- ASIC assembly with flip-chip bonder
- Tested with low noise of ~380ENC

upper left

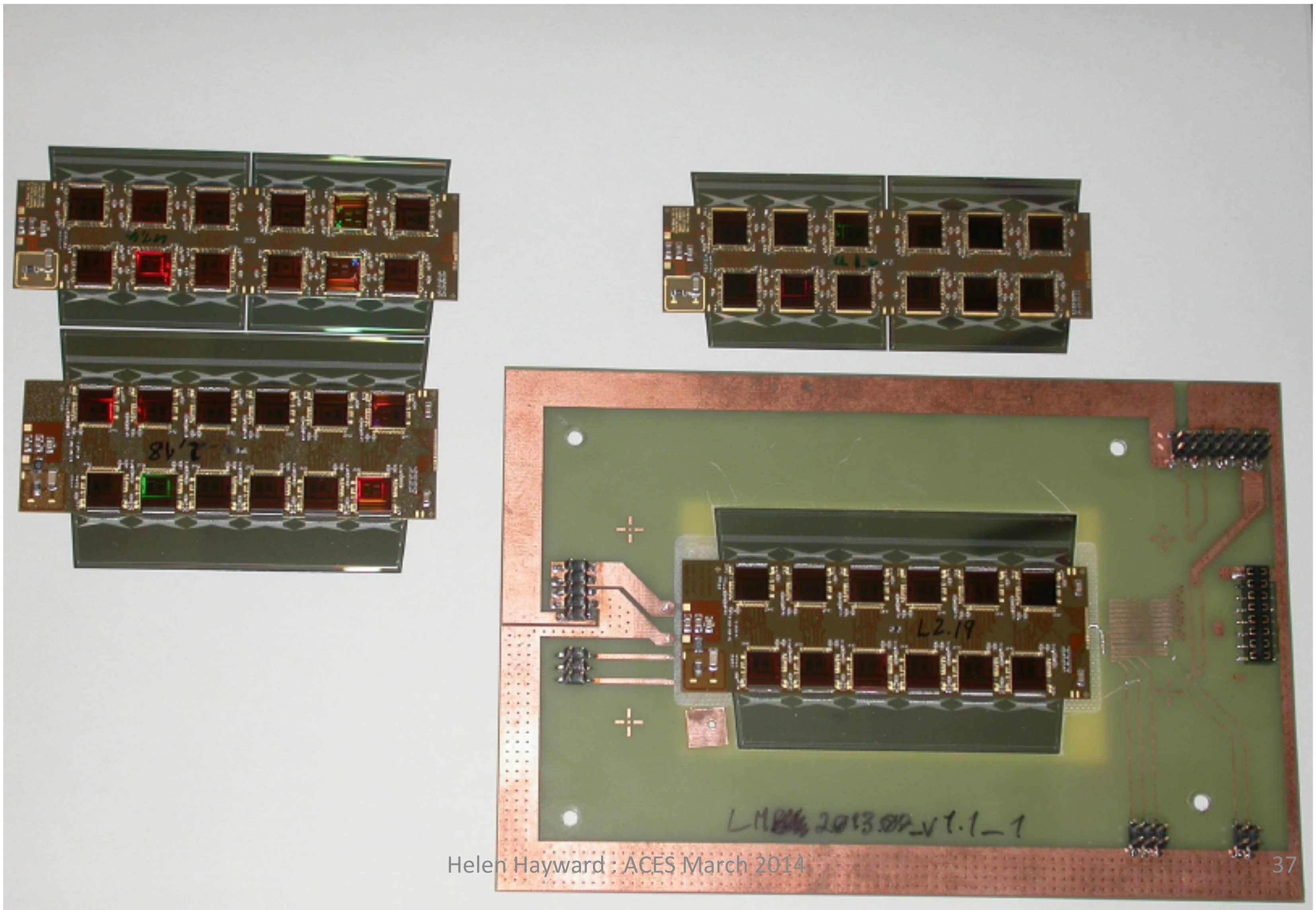


upper right



Bear modules for petalet in embedded (straight bonding due to double metal layer on sensor) configuration

lower modules have noise of ~660 ENC upper module to be tested, upper and lower hybrids have noise of ~380ENC



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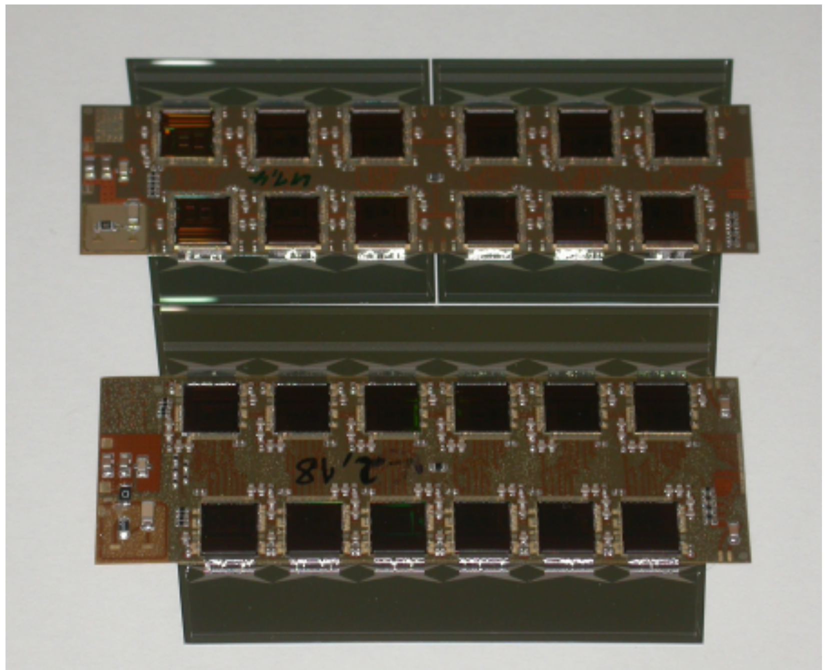
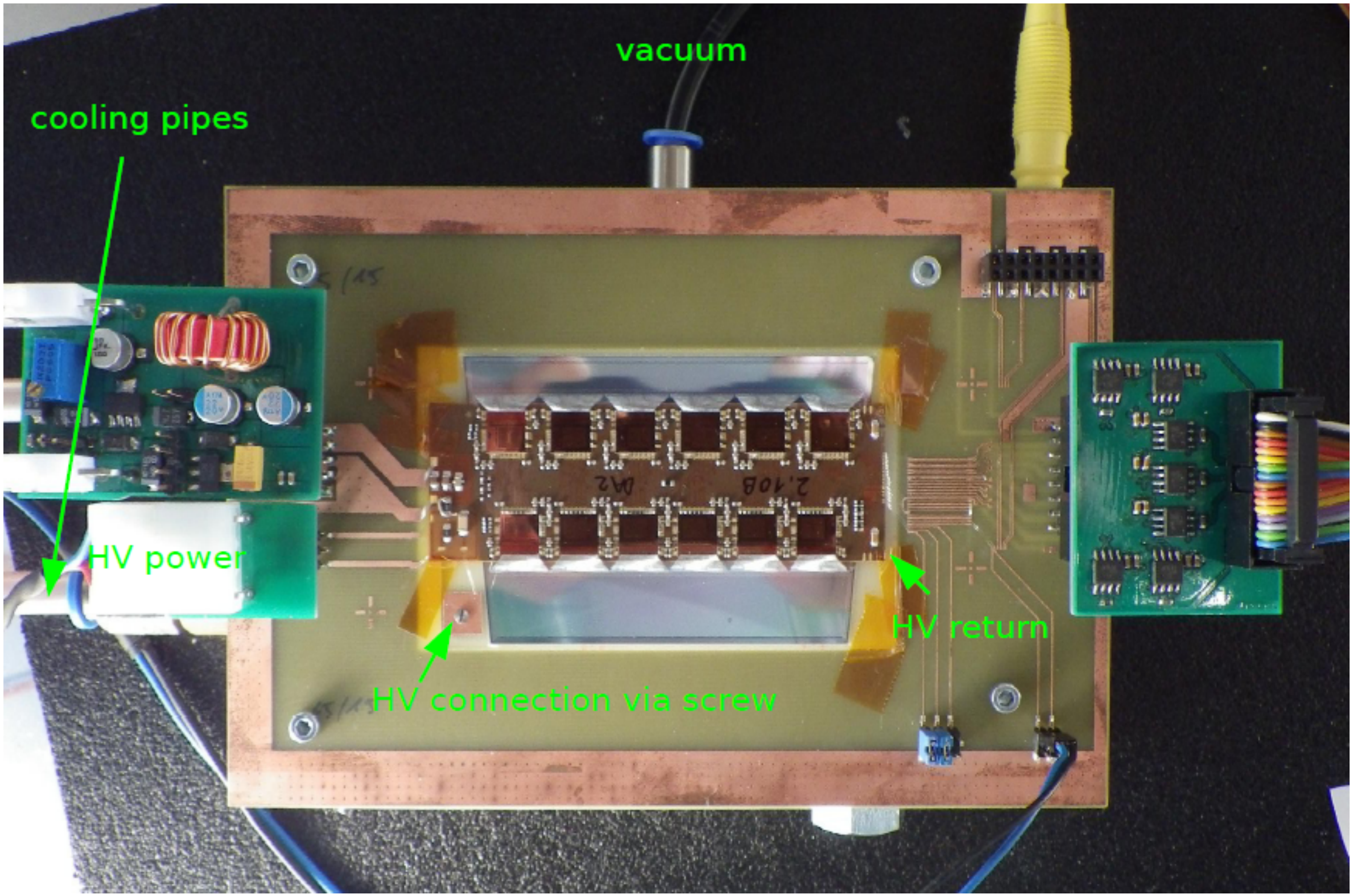
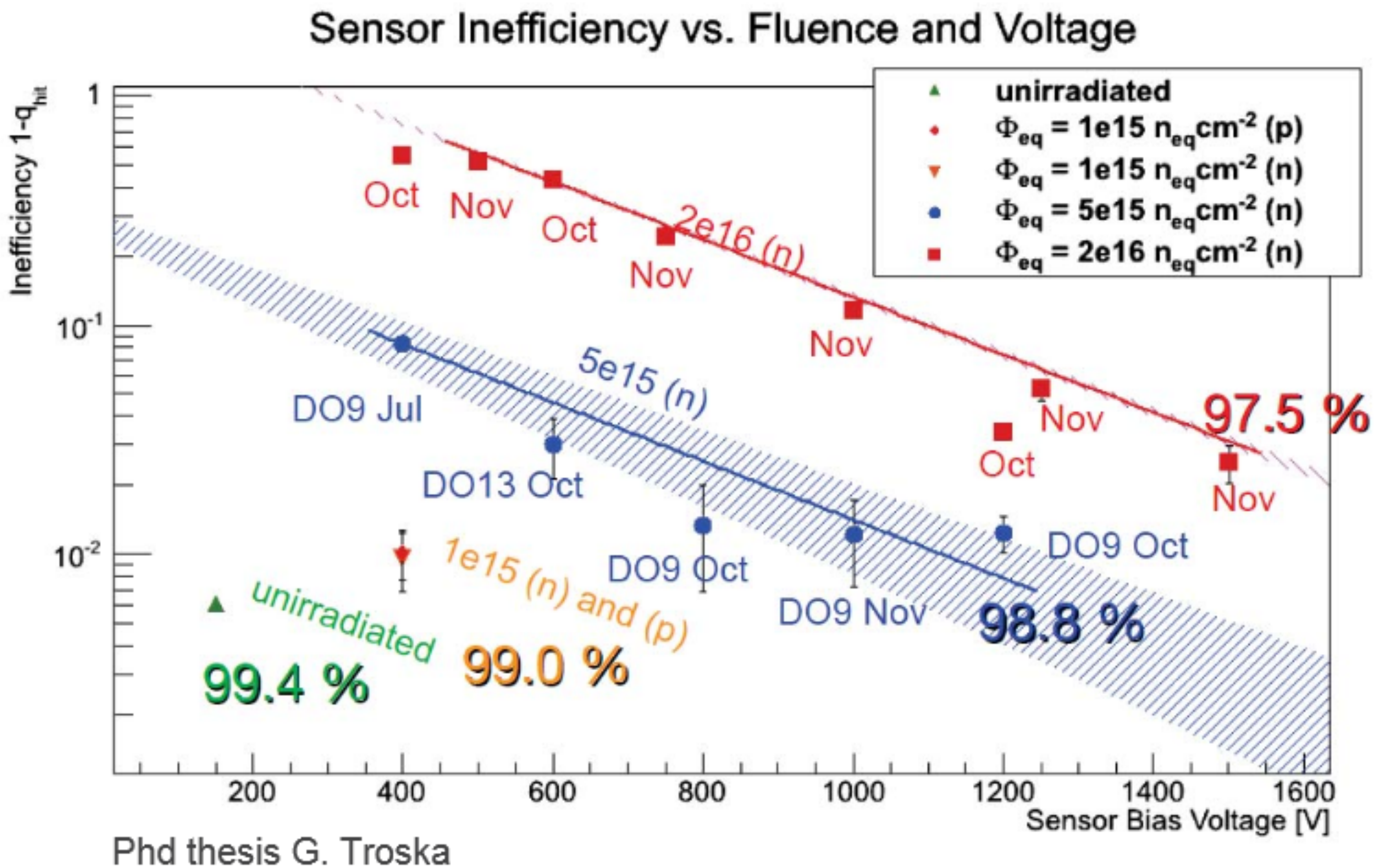


Bear modules for petalet in standard (wire-bonds with different angles) configuration have lower noise of about 560ENC.



ATLAS Phase II Pixels : Planar sensors



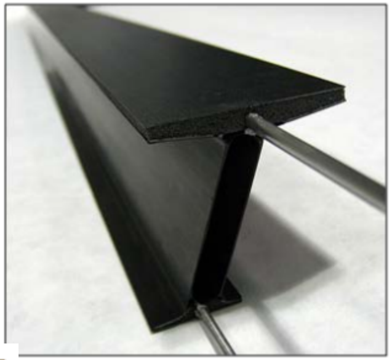
Hit inefficiency for n-in-n sensors (IBL) as a function of bias voltage for different fluences.

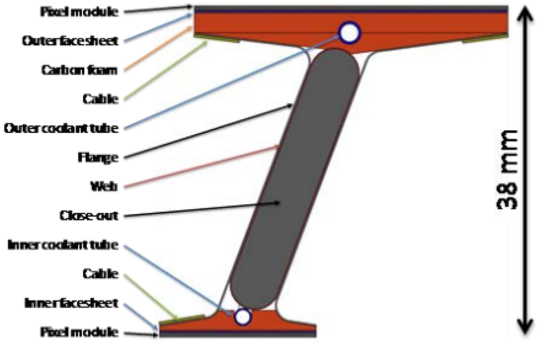
ATLAS Phase II Pixels

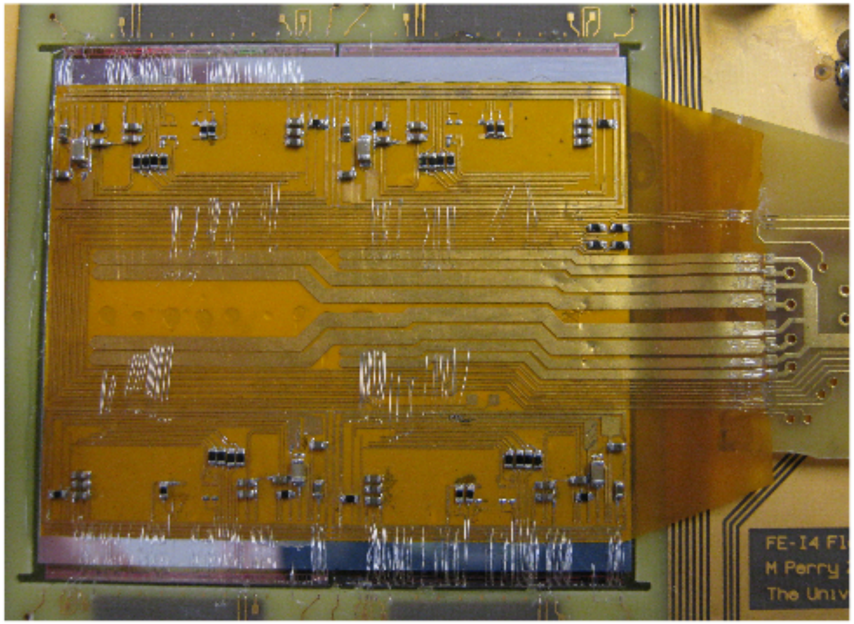
- **Electronics Technologies & Challenges**
  - **Specifications and Challenges.**
    - Radiation tolerance, Low power consumption per channel, Low noise
    - High density of channels -> interconnects (TSV, bump-bonding=cost)
    - Move towards deep(er) sub-micron technologies 65nm. CERN - RD53 now established and operational.
    - On detector power conversion (DC-DC (baseline) and Serial Power under consideration)
  - **FEI4**
    - *Currently being used for IBL, requirement well matched to outer layers of ITk pixel detector. To limit cooling requirements chip power should not exceed 450mW/cm²*.
    - *RD65 to develop the next generation of chips*
  - **Choices**
    - *Extensive R&D in progress, wait for appropriate time to make decisions*

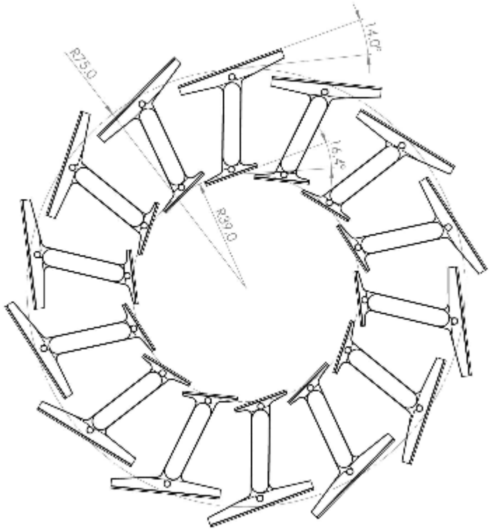
ATLAS Phase II Pixels: Modules and Structures

A prototype of a Quad Module
This has 4 FEI4 chips



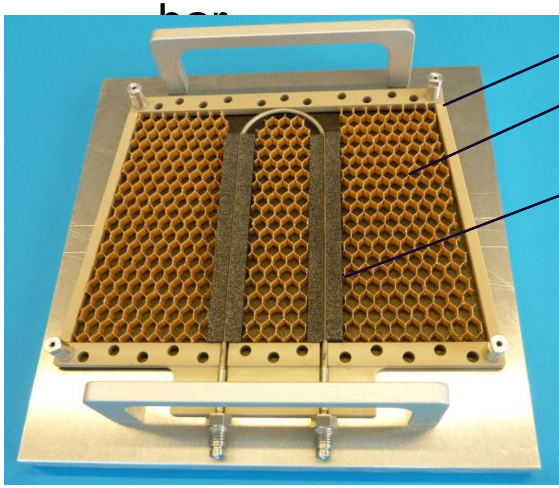






Core and bus tape

- Core:
  - Designed and production ongoing
  - Results:
    - Planarity: still low (~250 um flatness).
    - Ti-pipes resistance: more than 200 bar

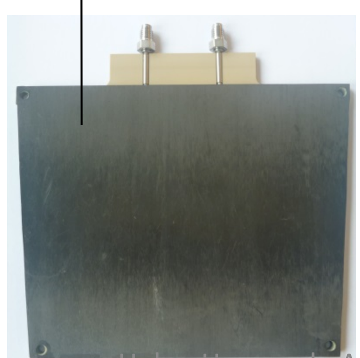


Closeouts (PEEK)

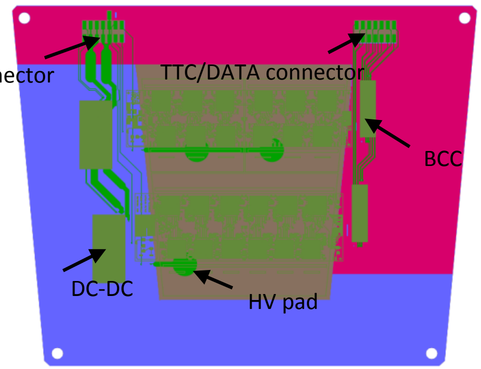
Honeycomb

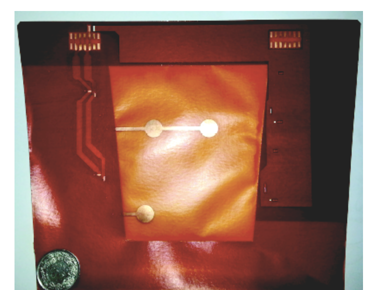
Cooling, Ti-tube / Pocofoam

Facing

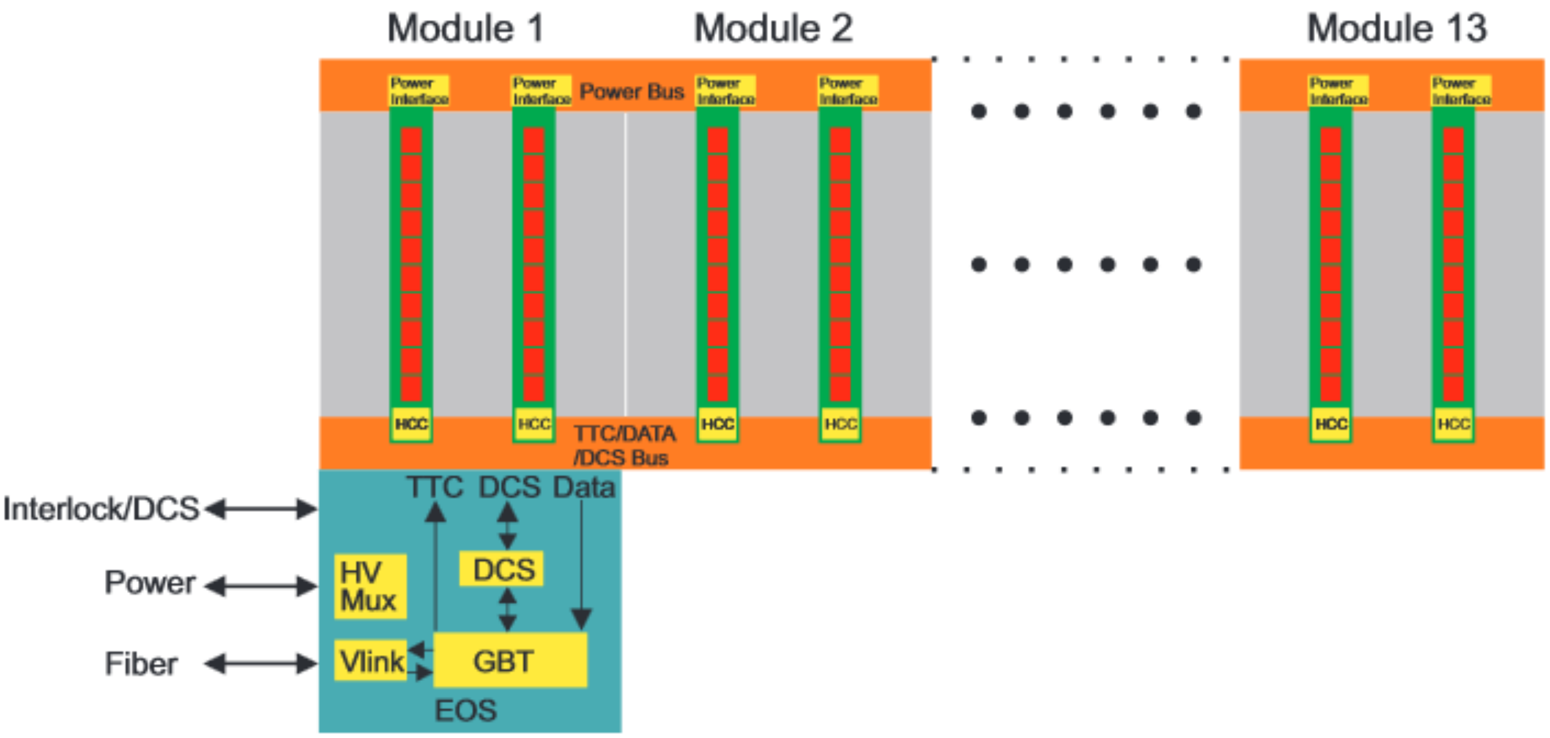


- Bustape:
  - First designed and produced.

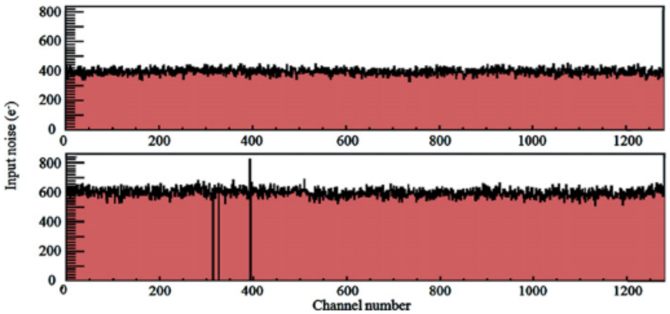




ATLAS Phase II Strips



ATLAS Phase II Strips : Staves/Petals



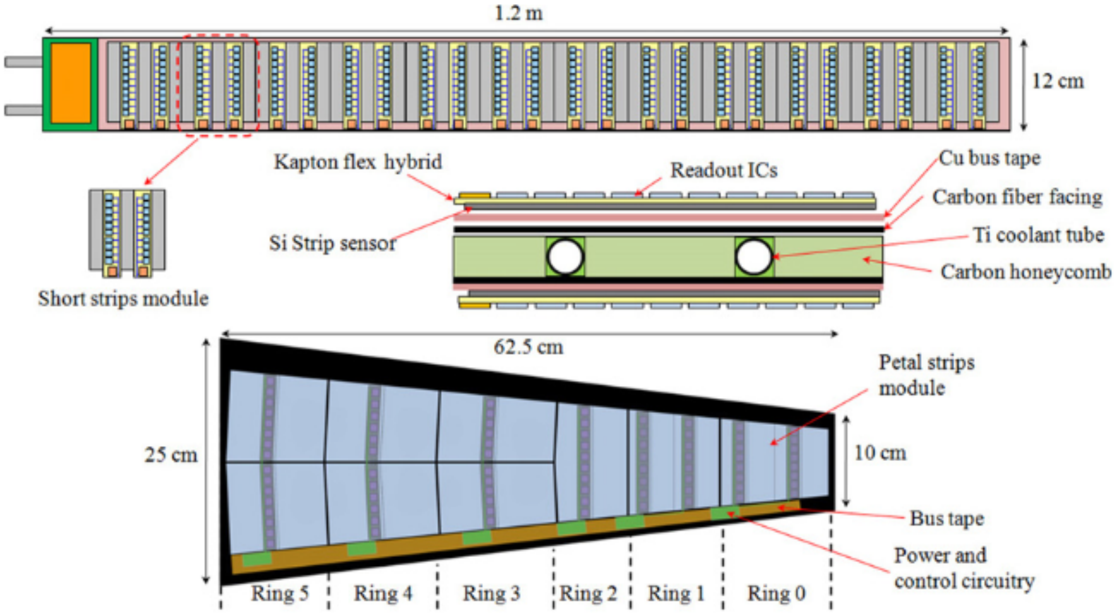
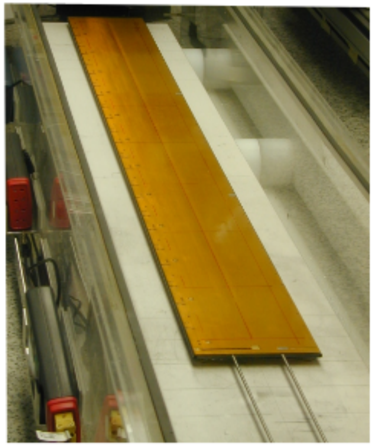
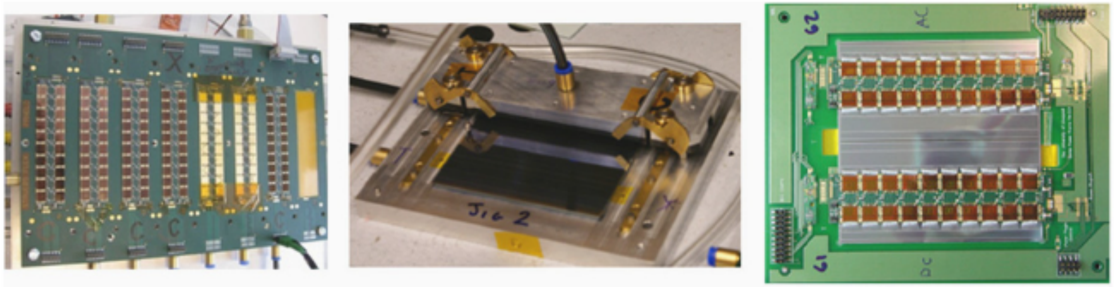


Fig. 1. Sketch of a barrel short strip stave and its cross-section (top); sketch of an end-cap petal (bottom).





ATLAS Phase II Strips : End-Caps

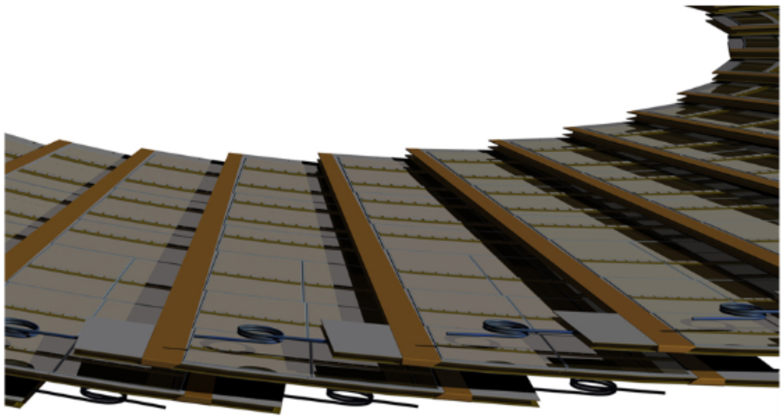
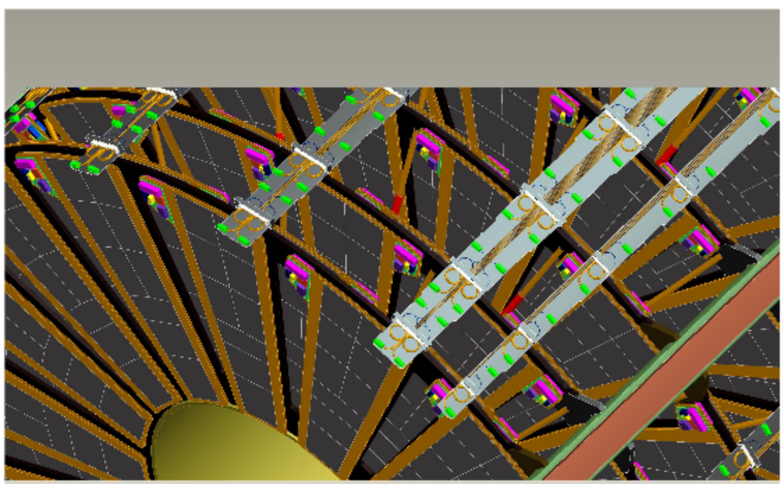
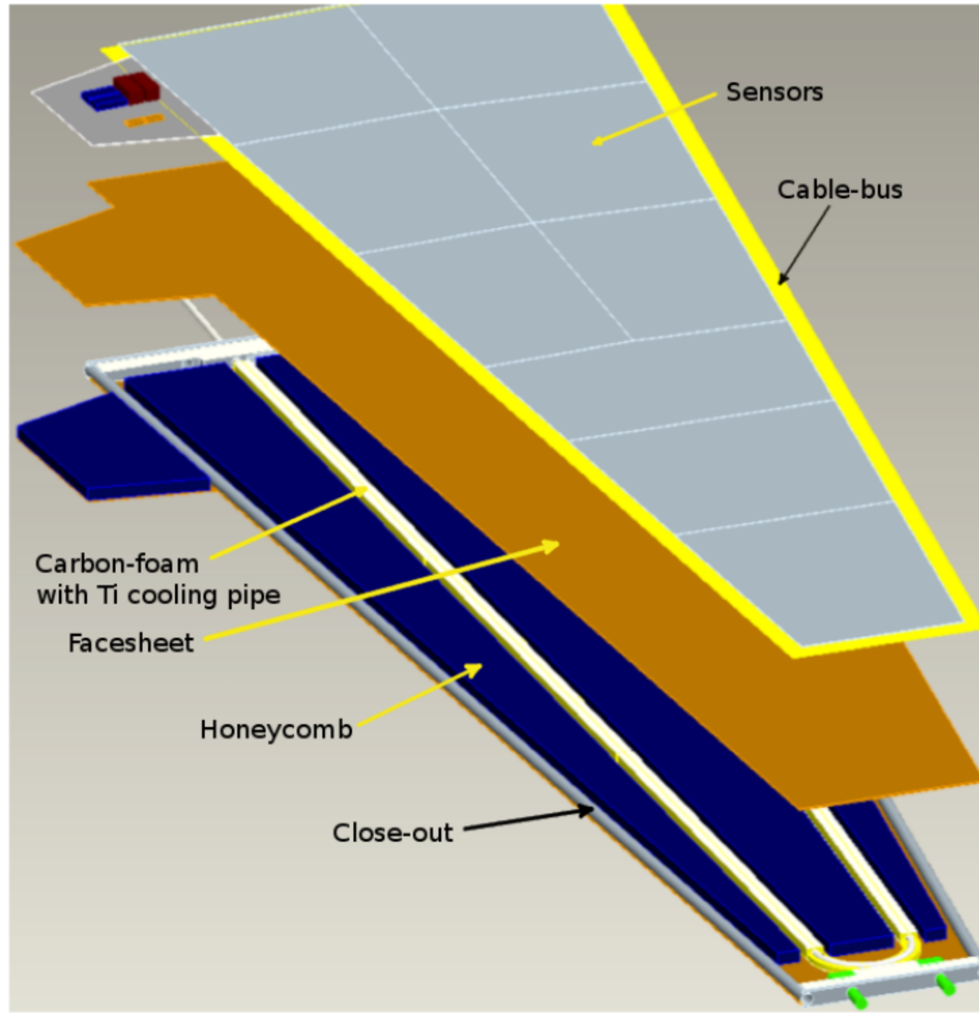


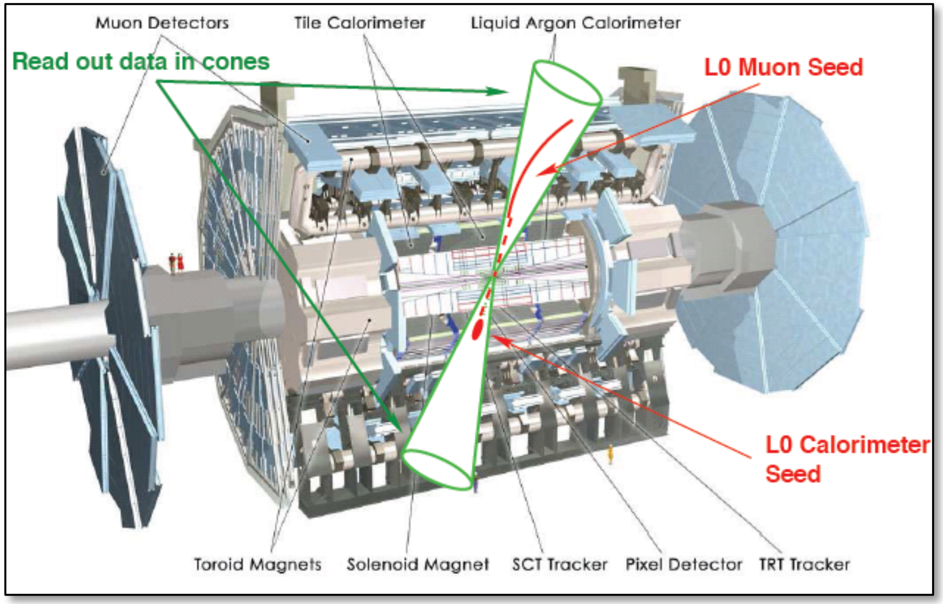
Figure 6.37: Turbofan arrangement of petals.





ATLAS Phase II : Track Trigger

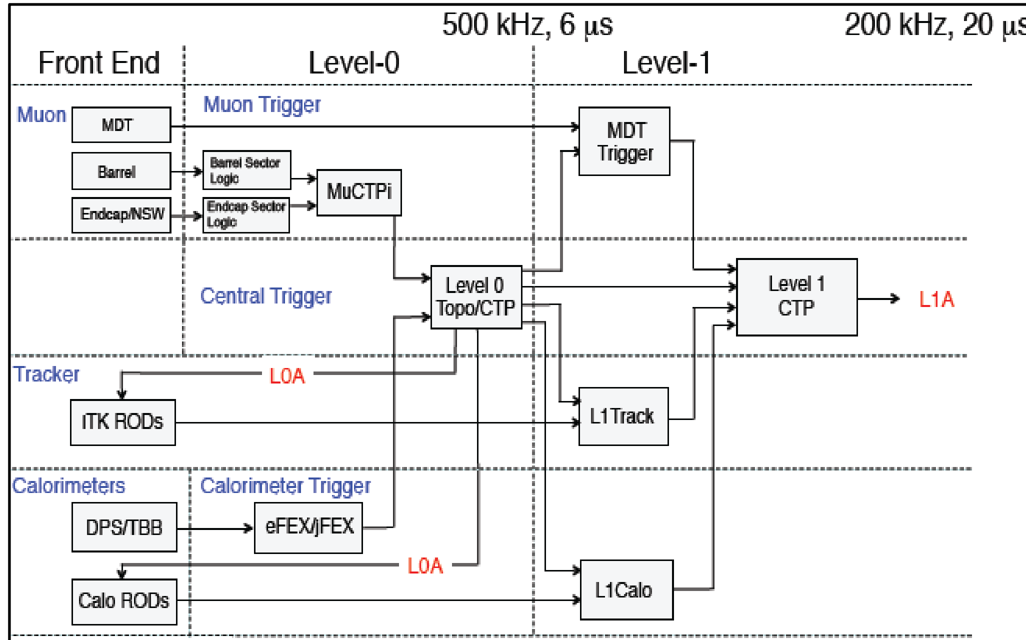
- **L1 Track Trigger**
  - ✓ Aim to keep p_T thresholds and trigger rates low at L1
  - ✓ Part of High Level Trigger reconstruction moved to L1
- **Triggering sequence**
  - **Based on Regions of Interest (RoI)**
  - ✓ L0 trigger (Calorimeter/Muons) reduces rate within 6 μs to ≳ 500 kHz and defines RoIs
  - ✓ L1 track trigger extracts tracking info inside RoIs from detector FEs



Alternate self seeded (a la CMS) approach also being studied.

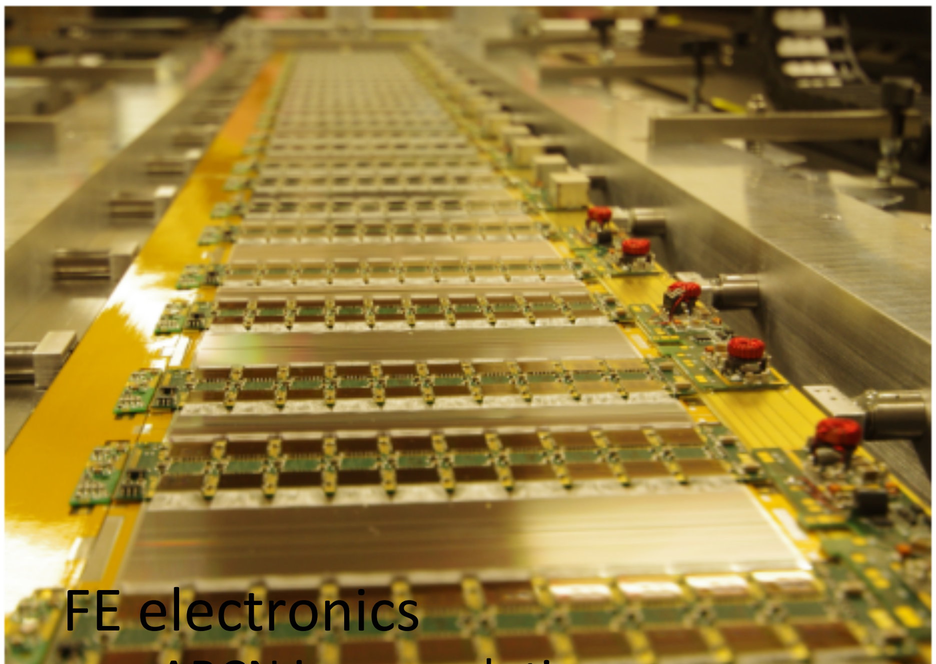
ATLAS Phase II : Changes to trigger architecture

- New design in time for Phase II
  - 2-level system at Phase II
  - Phase-I L1 becomes Phase-II L0, new L1 includes tracking
  - Make use of improvements made in Phase 1 (NSW, L1Calo) in L0
  - Introduce precision muon and inner tracking information in L1
    - Better muon pT resolution
    - Track matching for electrons,…
  - Requires changes to detector FE electronics feeding trigger system



Level-0
Rate ~ 500 kHz, Lat. ~6 μs
Muon + Calo
Level-1
Rate ~200 kHz, Lat. ~20 μs
Muon + Calo + Tracks

Fully populated DC-DC powered 250nm stave in December 2013



FE electronics

ABCN is an evolution of the binary chip used for the SCT