Design of the new ATLAS Inner Tracker (ITk) for the High Luminosity LHC

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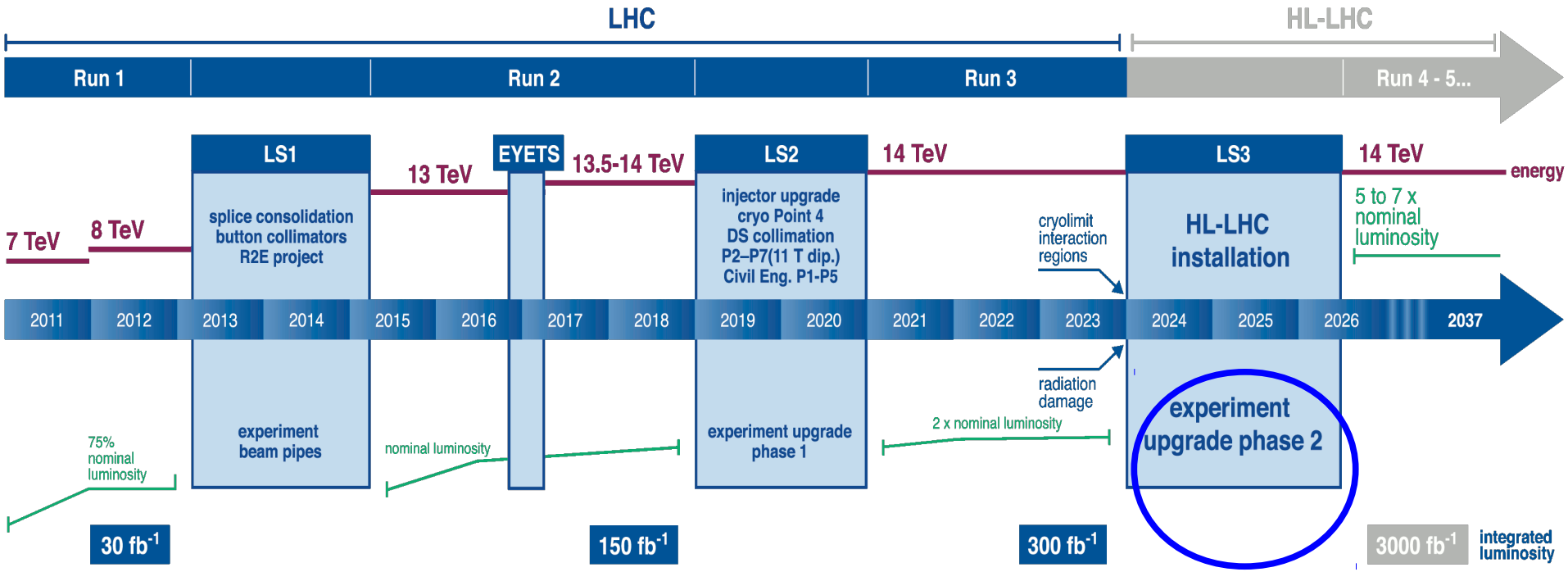
for the ATLAS Collaboration

May/2017, TIPP 2017

HELMHOLTZ ASSOCIATION

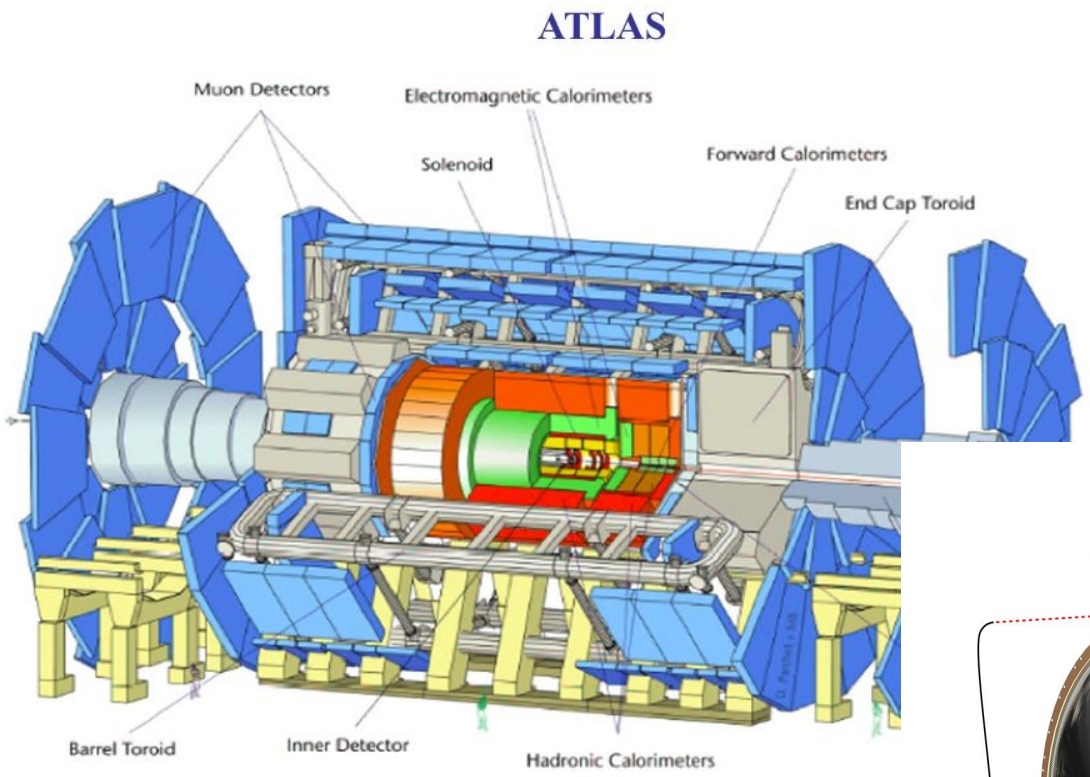
DESY

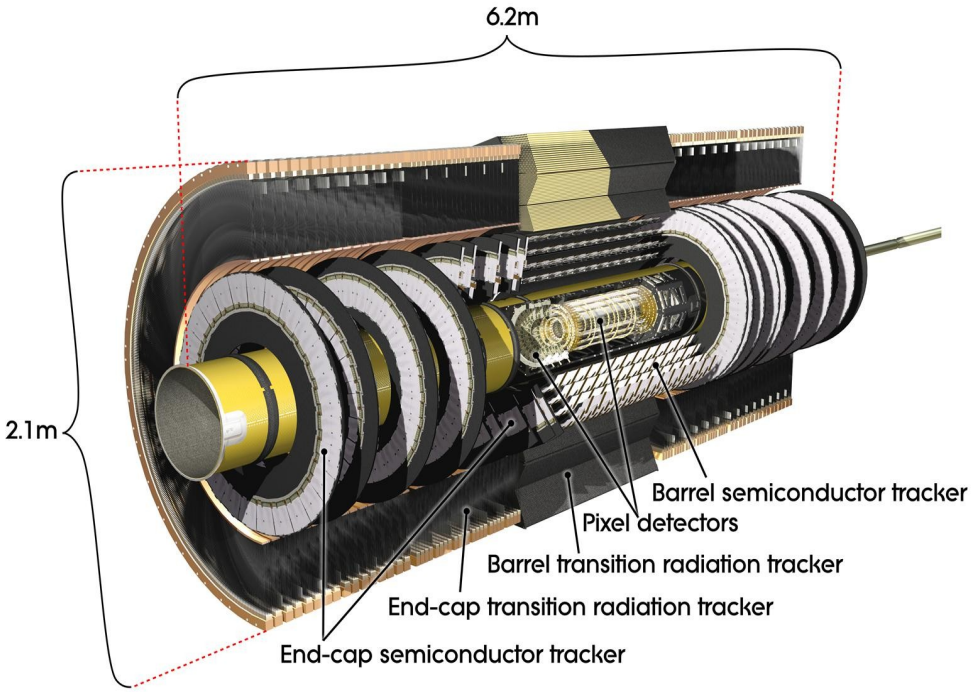
LHC Machine Schedule



- In year 2015, ATLAS and CMS went into Run2
- Till now have already collected up to ~40 fb^{-1} *pp* collision data at 13 TeV.
- Detector will be upgraded after ~10 years (phase 2), then go to the HL-LHC running

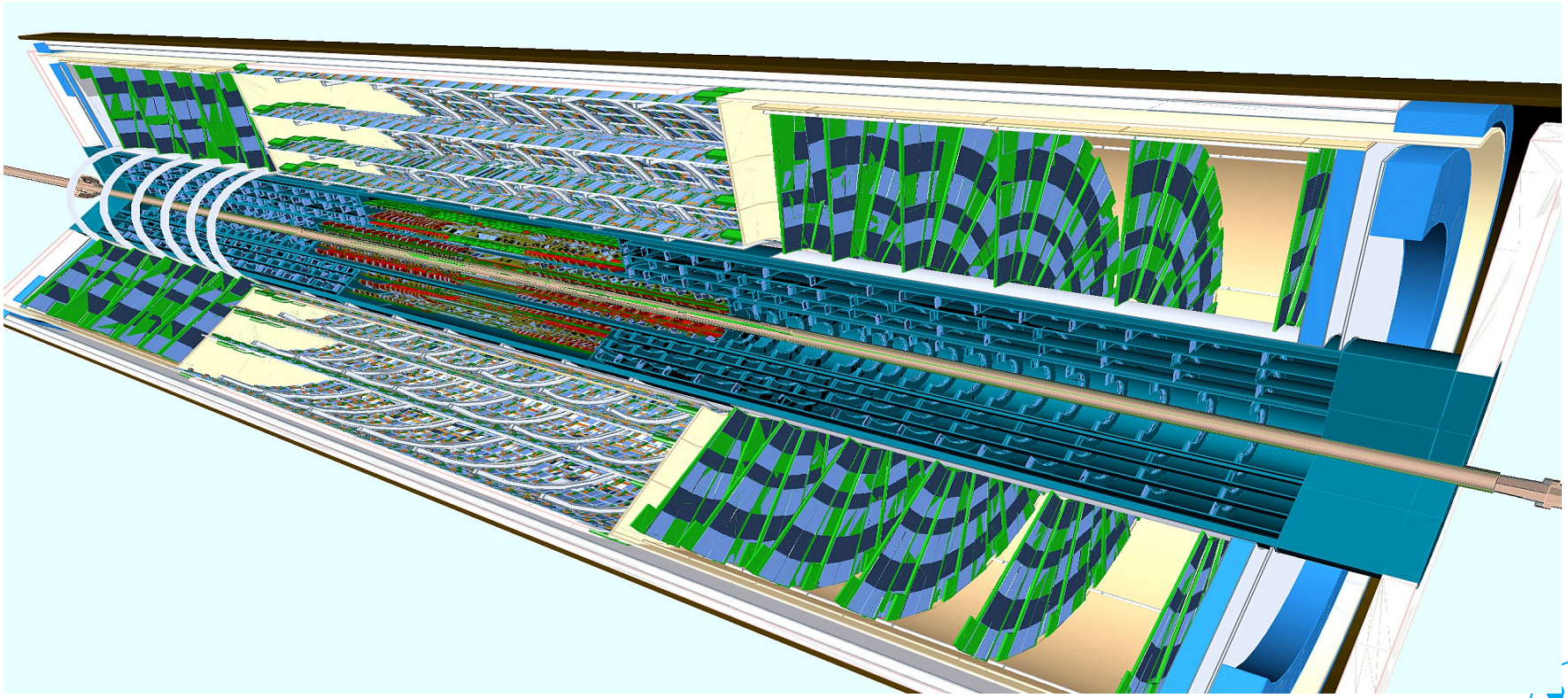
Current ATLAS





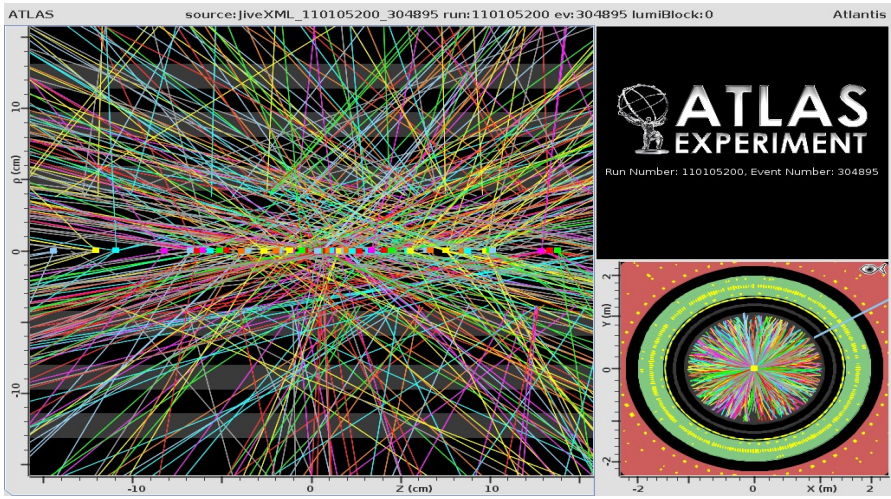
HL-LHC Tracker of ATLAS: ITk

- **ITk** is a full upgrade of the current ATLAS Inner Detector (ID) as part of the Phase-II upgrade
- consists of a **new Pixel and Strip** detectors, "**all-silicon**" detector
  - ID can't survive with 3000 fb^{-1} (radiation damage), has to be replaced
  - remove the TRT (Transition Radiation Tracker). It can't work under HL-LHC multiplicity

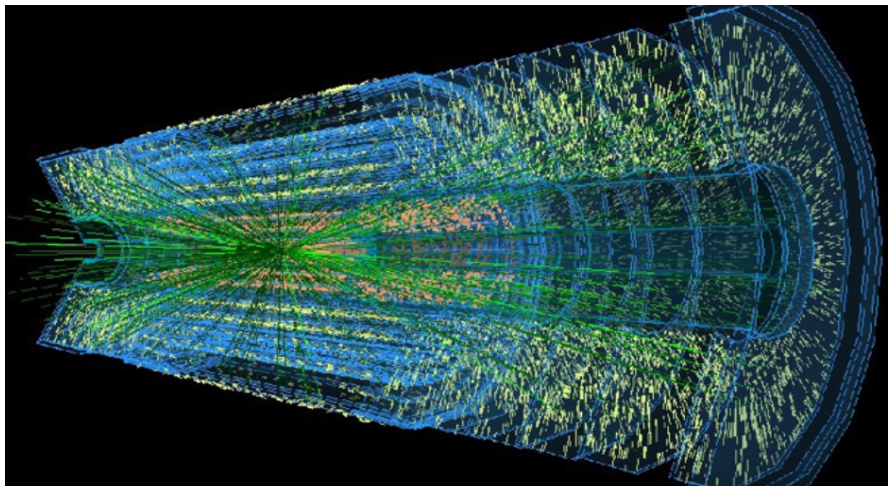


HL-LHC Tracker of ATLAS: ITk

- HL-LHC upgrade would unlock much larger physics potential:
  - VBF h➔ZZ➔4l, BSM hh➔4b, higgs self-coupling, etc
- The ITk would be the most important detector component, will be crucial for:
  - lepton measurements, b-tagging
  - pileup jet rejection in wide kinematic and pseudo-rapidity range, etc.
- There will also be huge challenge: enormous pileup of up to μ = 200
  - Vital to optimize the layout to maximize tracking and vertexing
- **Need to carefully re-design the Tracker**



mu = 200 displays



Pileup: the additional pp collisions except the hard-scattering one

How to Design the ITk

- The basic idea is to build the whole detector, mimic the HL-LHC collision situation, implement the particle-detector interaction etc., using simulation; and use the simulated samples to look and compare the performances

- **Only detecting technique/sensor is good doesn't mean the built detector is good**
  - the shape of the sensor may not optimized; the sensor may not survive the radiation in HL-LHC; need to optimize how to arrange the sensors to minimize the material amounts; need to ensure the 4π coverage etc.

- **Need to tightly coordinate with engineering electrically and mechanically**
  - e.g. get information from them about which sensor/layouts are interested, then look; our optimized layouts may impossible in terms of engineering or cost too much …
  - write conclusions into reports/documents, to guide the building

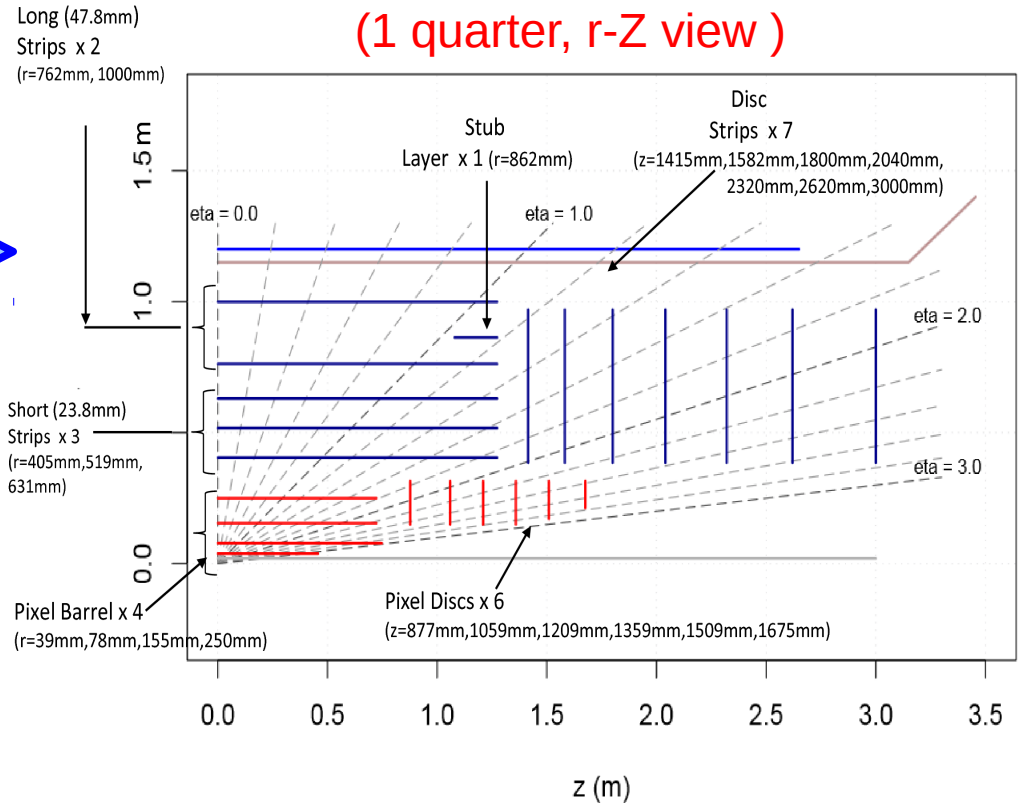
- **A very important component towards building ITk**

The ITk Layout Evolution

There are the following important steps:

- LoI, ~2012
- LoI-VF, ~2013-2014
- Inclined vs. Extended, ~2015-2016
- Decided on Inclined, achieved the Strip TDR layout, used for Strip TDR results. ~2016
- Now: converging on Pixel TDR layout, will be used for releasing the Pixel TDR.

(1 quarter, r-Z view)

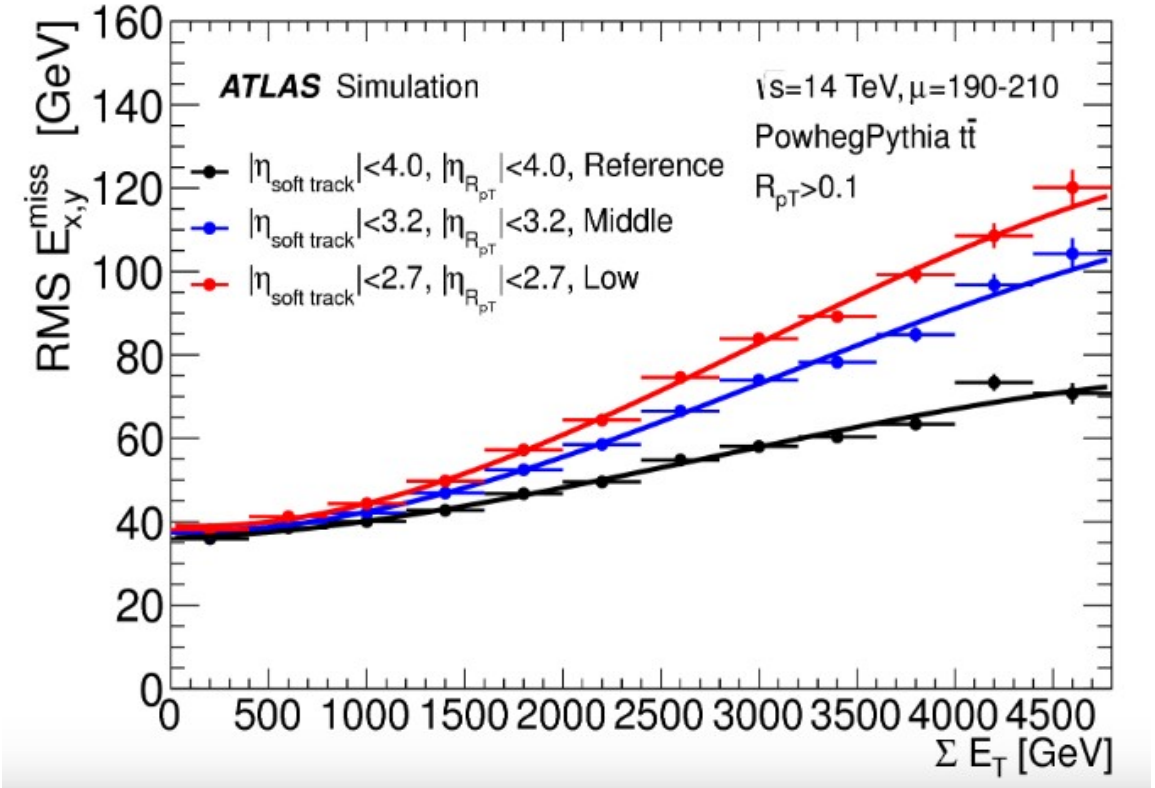


- Features a so-called "**stub**" layer, a short barrel layer between the 4th/5th layer of the Strip, to give robustness in the barrel to end-cap transition region
- **|η|~2.7; 4 pixel + 5 strip**

DESY

LoI-VF (Very Forward) Layout

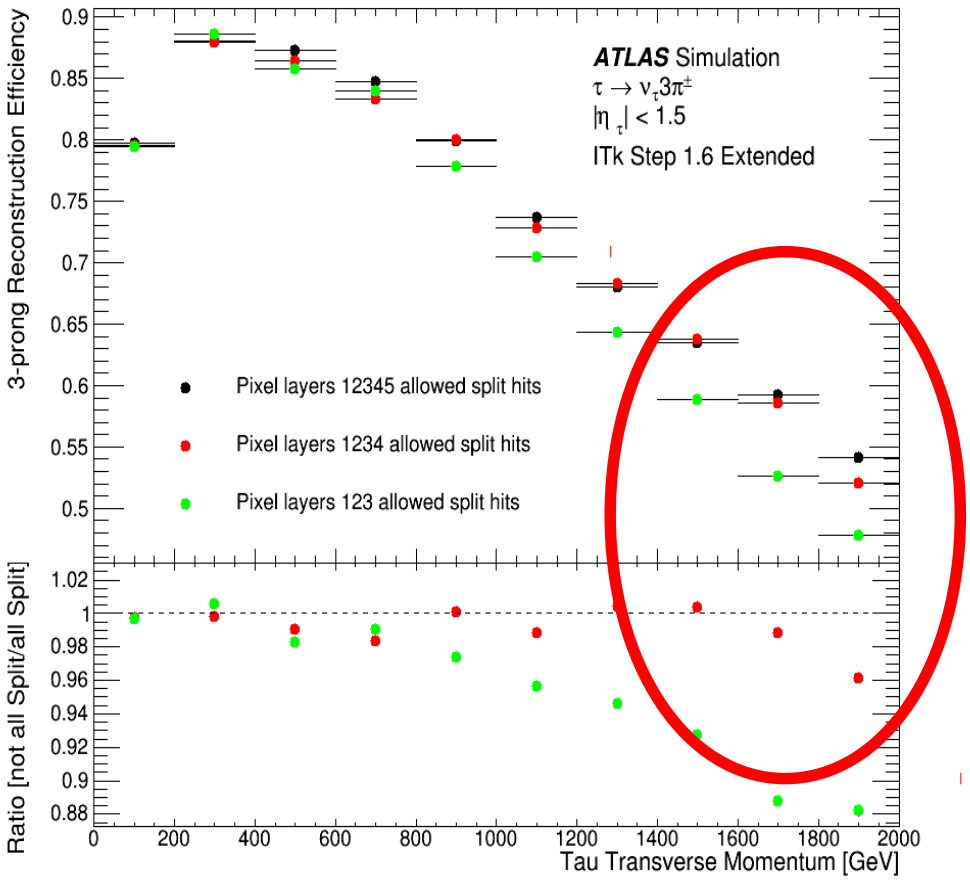
- Studies showed that many performances and physics at HL-LHC can benefit from larger Tracker coverage. One e.g.:



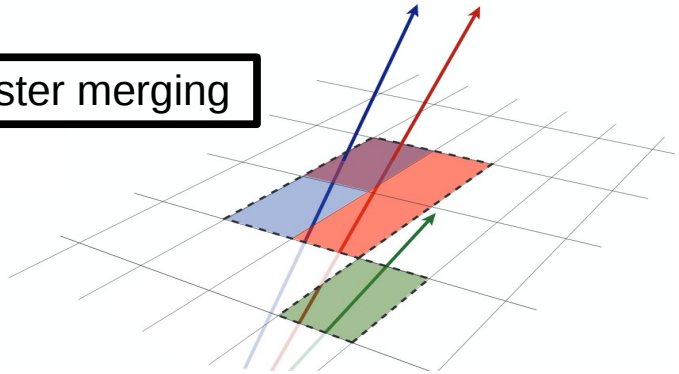
- **LoI-VF:**
  - simple extension, |η|~4
  - was not optimized in terms of mechanical construction and maximum performance for a given silicon area.

Have 5 Pixel Layers

- There were strong motivations to change from 4 pixel + 5 strip ⇒ 5 pixel + 4 strip
  - better efficiency/fake balance at μ = 200
  - improve the performance of tracking in dense environment, etc



Cluster merging

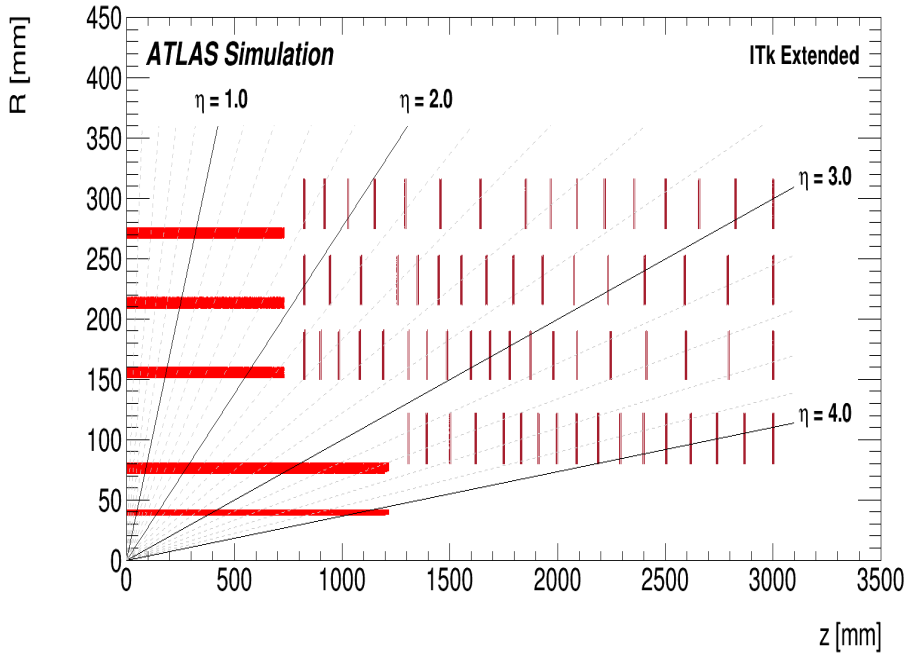


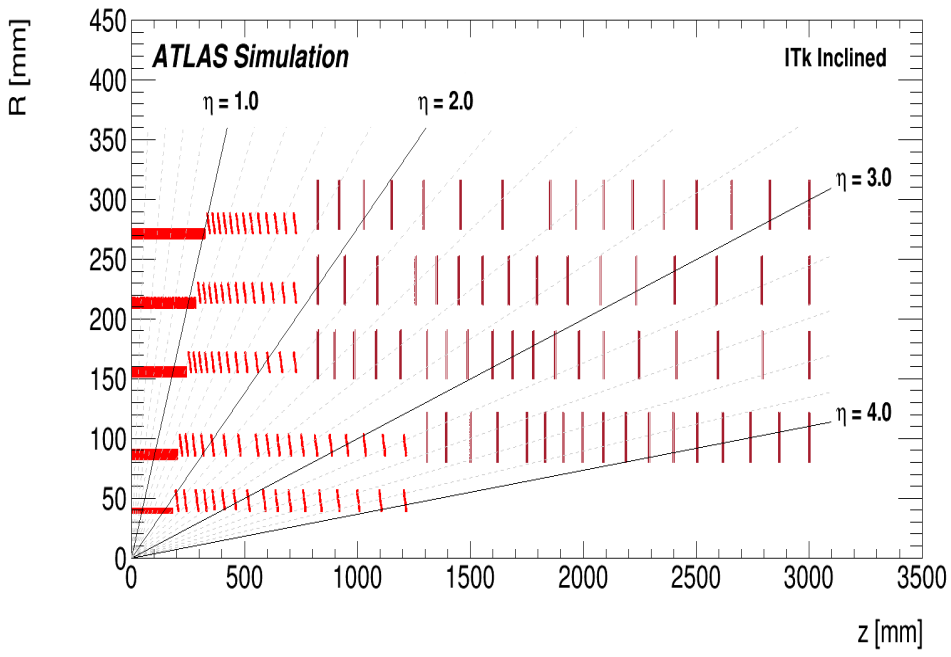
- For example, left plot shows τ reconstruction performance vs. pT in the 3-prong decay channel
- Better efficiency with more pixel information, especially for highly boosted case

Pixel Optimizations

• **Extended vs. Inclined,** both push the material of the end of barrel services and support region to **large Z**.

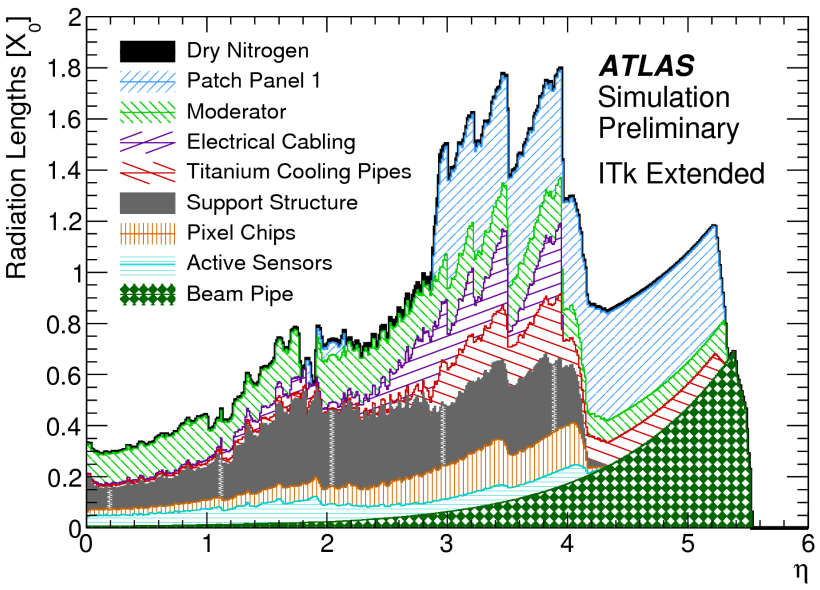
- the difference between the two are in the treatment of the forward part of the barrel layers.
- Extended use long barrel; Inclined uses rings

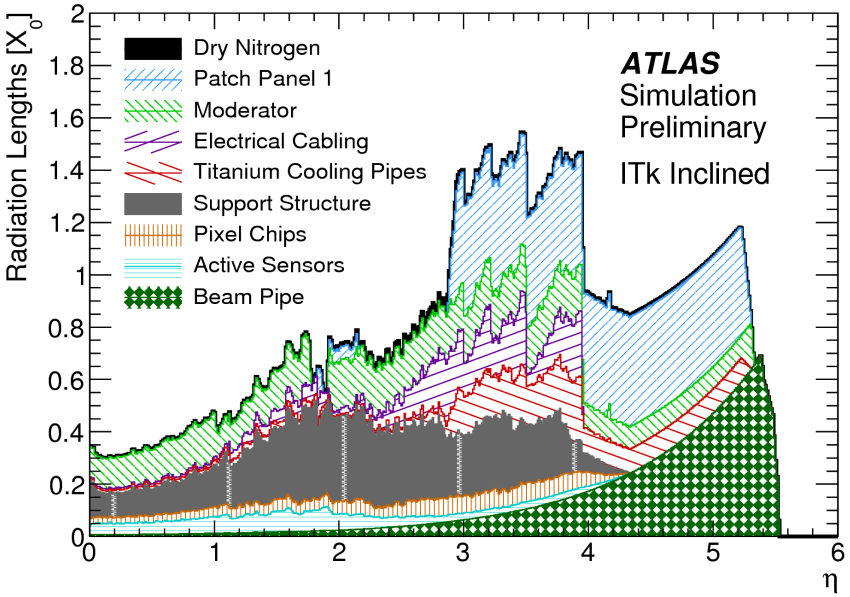




Pixel Optimizations

- **Preliminary estimation of the material budget for the two layouts**
  - as expected inclined has less material: the tracks are more perpendicular to the sensor

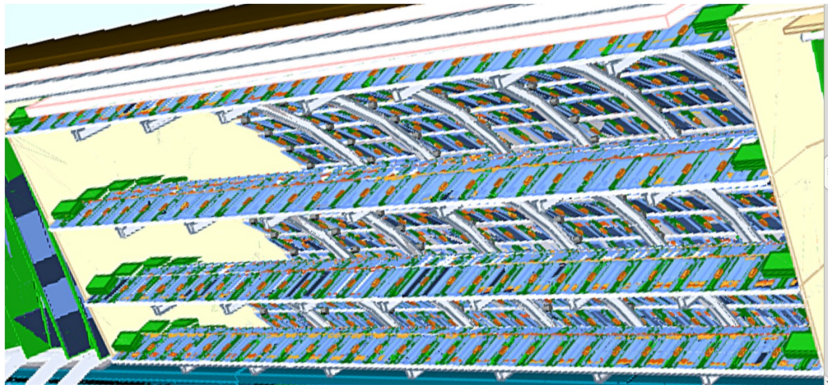


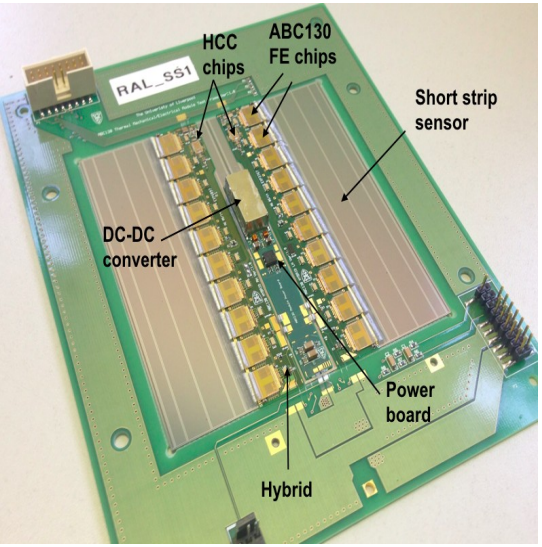


- Extended has another intrinsic problem: the long clusters and the corresponding bad quality space points, make the seeding problematic.
- **Inclined** is preferred.

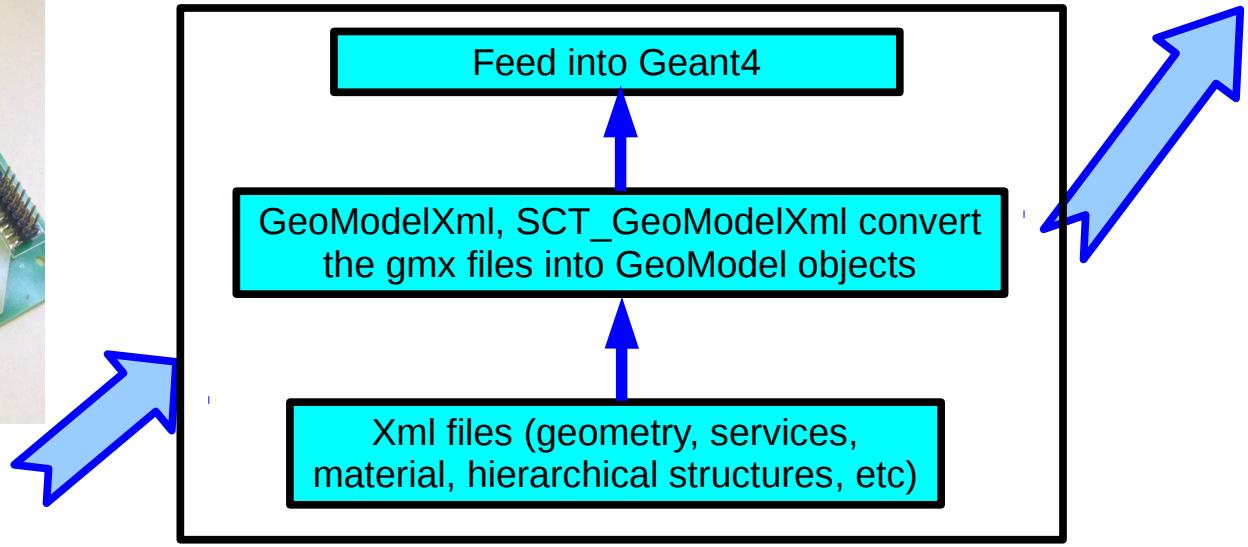
Strip Description: General Idea

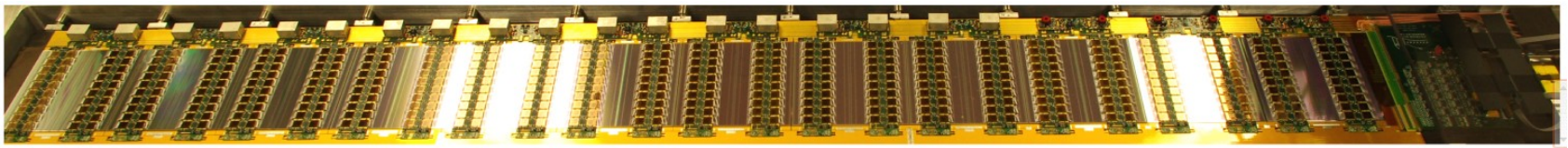
- A new **Xml-based** detector description framework has been developed
  - easy to understand and maintain
  - has highly flexibility geometry building and detector description





(A barrel module)

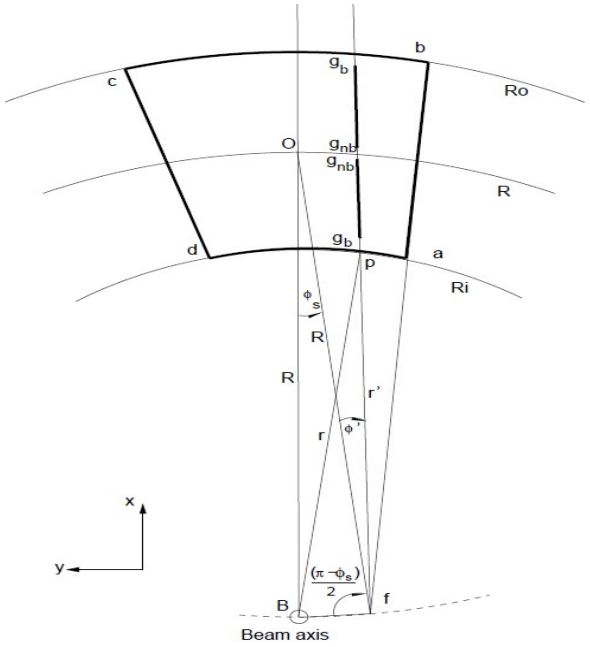


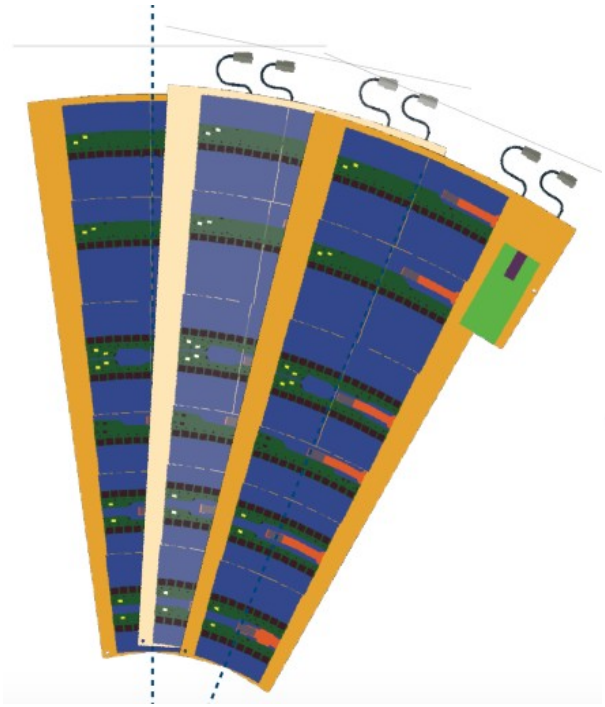


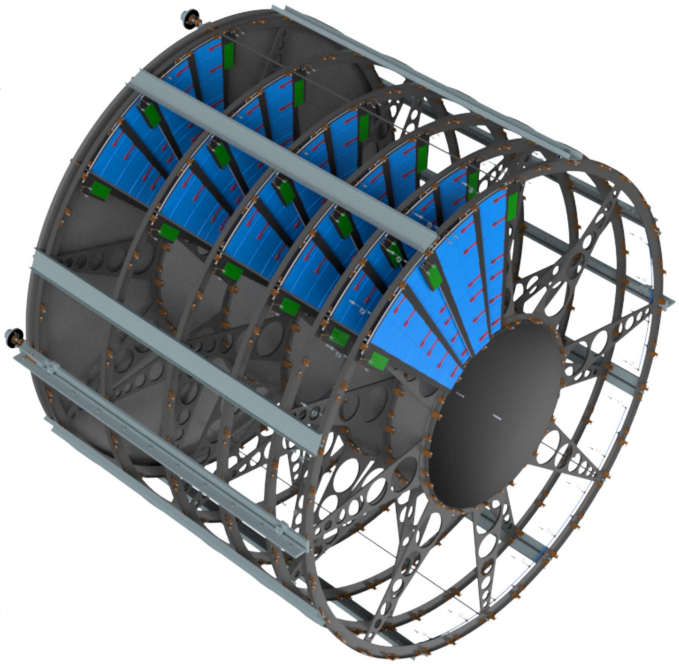
(A barrel stave)

Strip Design: Endcap

Sensors⇒ Petals ⇒ Endcap



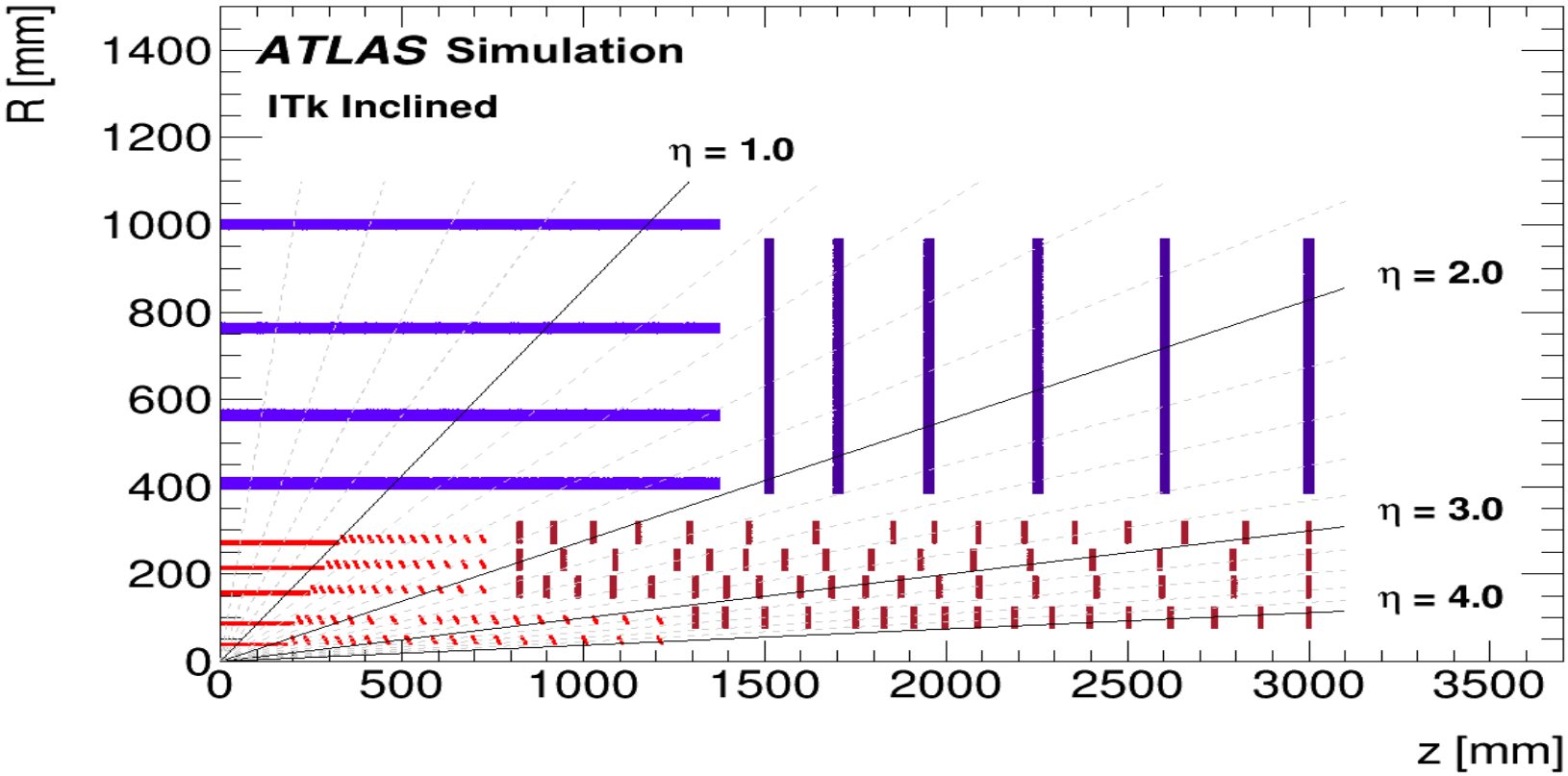




- Completely new endcaps
  - Complicated new sensor shape (stereo annulus).
  - Petals are overlapping like turbo fans. Different sensor geometries for each petal.

The Milestone: Strip TDR Layout

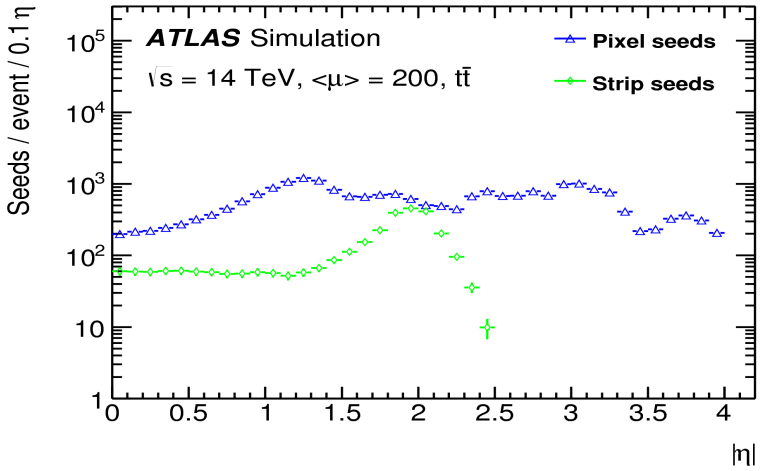
- **4 pixel + 5 strip ⇒ 5 pixel + 4 strip**
- **Remove “stub”**
- **Inclined is picked up for Pixel**

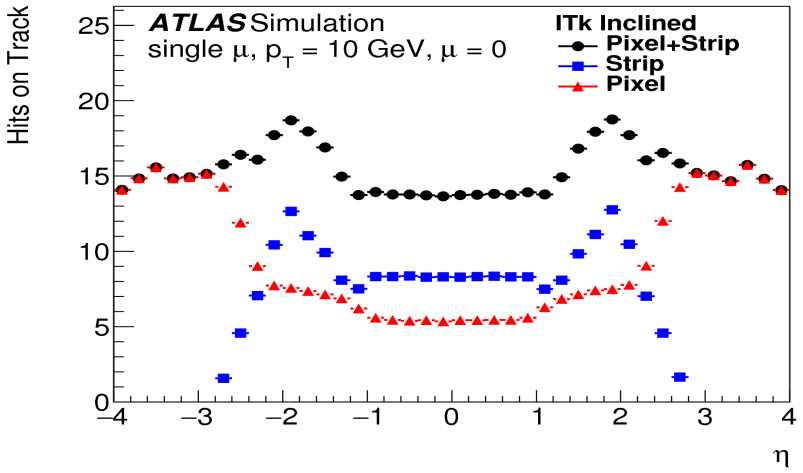


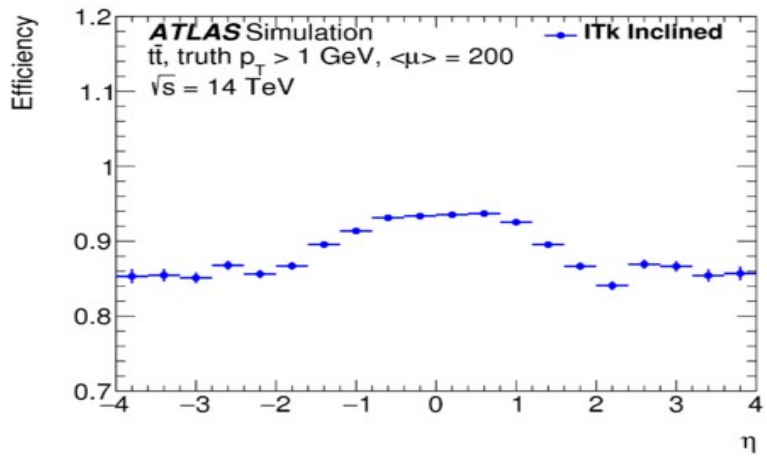
- Baseline used for the recently released Strip TDR (Apr/2017)
  - **CERN-LHCC-2017-005**

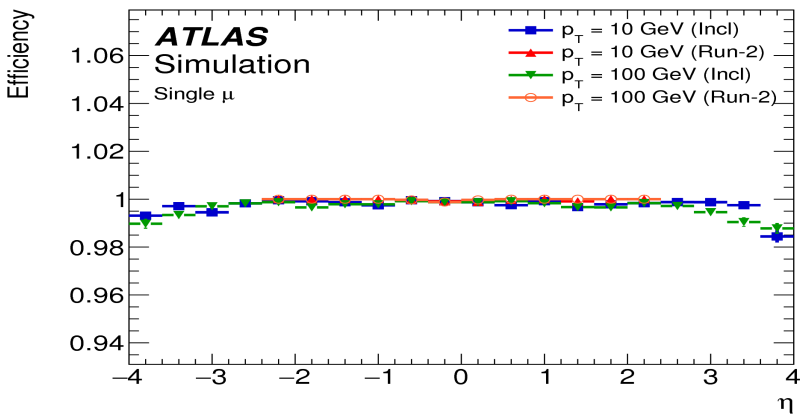
Various Tracking Performance Plots

- Reasonable distributions
- Demonstrate that the layout geometry implementation and the algorithms (simulation, reconstruction) are working well









Summary

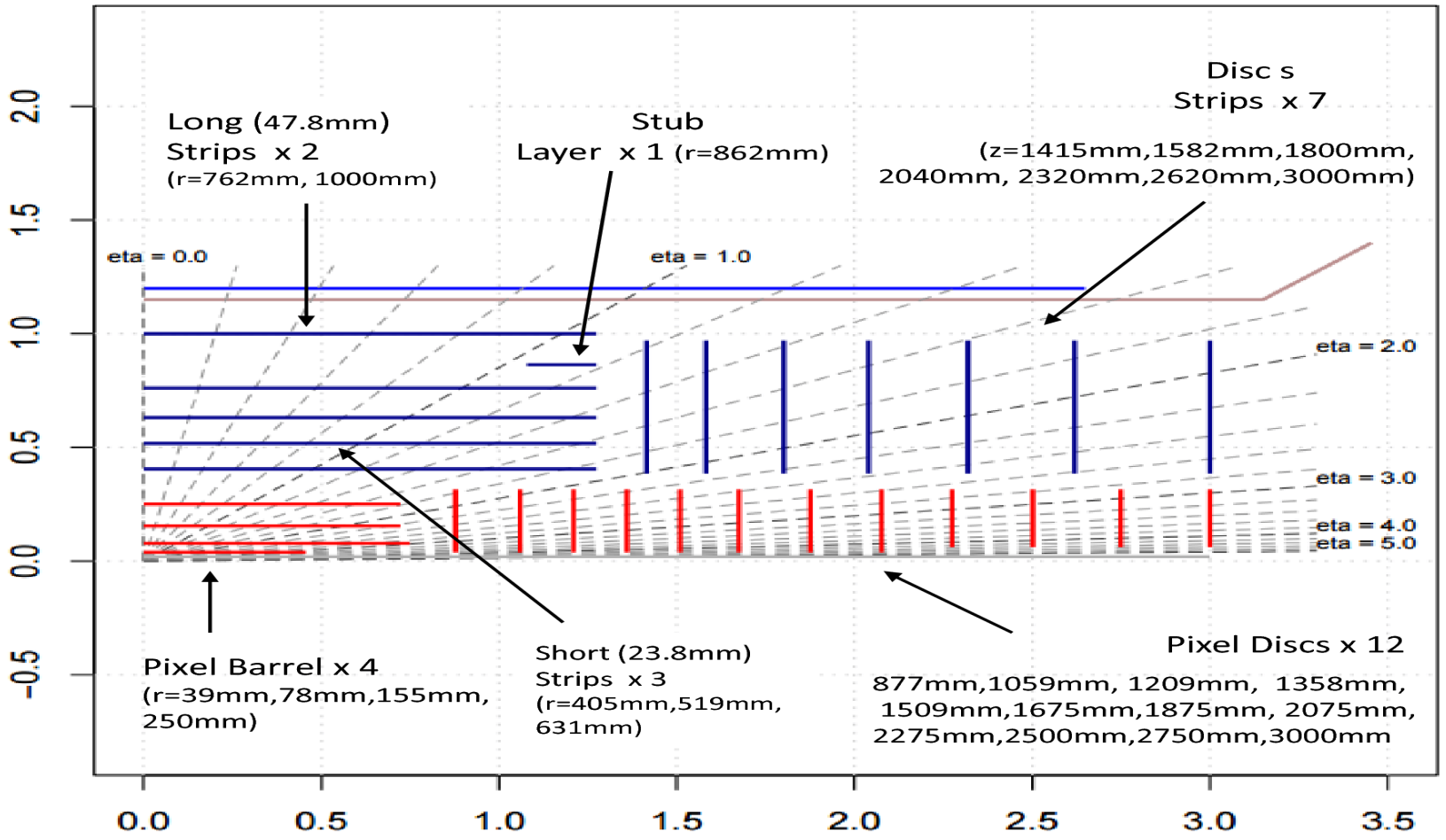
- Extremely challenging situation at HL-LHC makes very hard to design the new Tracker.

- Several years' work successfully converged on the Strip TDR layout, used for the results in the Strip TDR

- Now trying to converge on Pixel TDR layout, then will be used for results for the Pixel TDR

Backup Slides

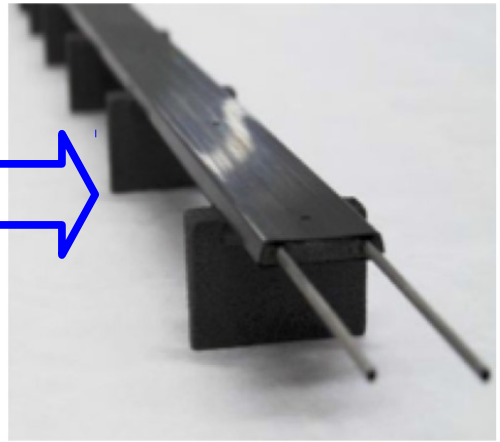
LoI-VF Layout

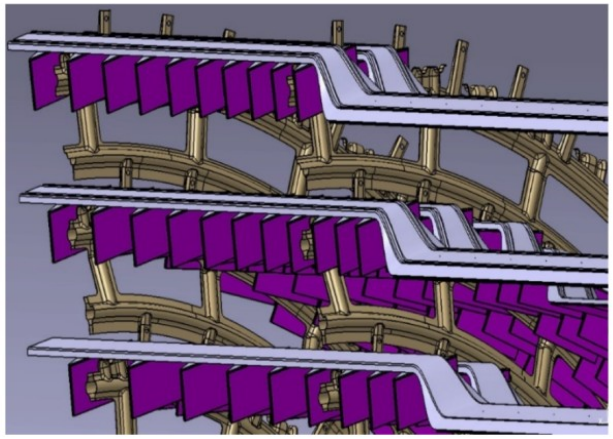


Look Beyond: Pixel and Strip

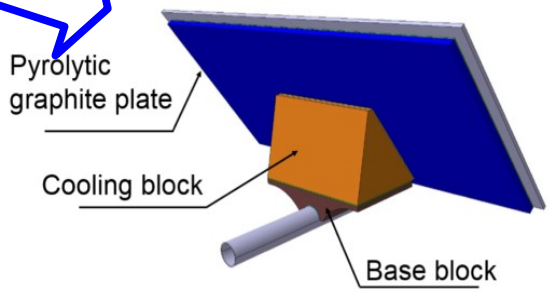
- To build the Inclined, two concepts are under study

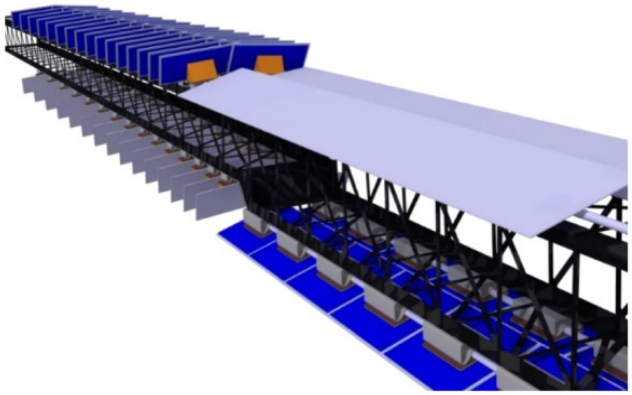
- **Alpine:** builds on the technologies used for the IBL project. Each stave contains two titanium pipes embedded in a carbon foam





- **SLIM**: relies on the module cells. In these cells the silicon module is supported by a pyrolytic graphite plate used as a heat spreader





- Some further studies for the Strip are also ongoing
  - e.g. more investigation about the necessity and feasibility of better coverage in the barrel-endacp transition region