ATLAS Inner TracKer Upgrade

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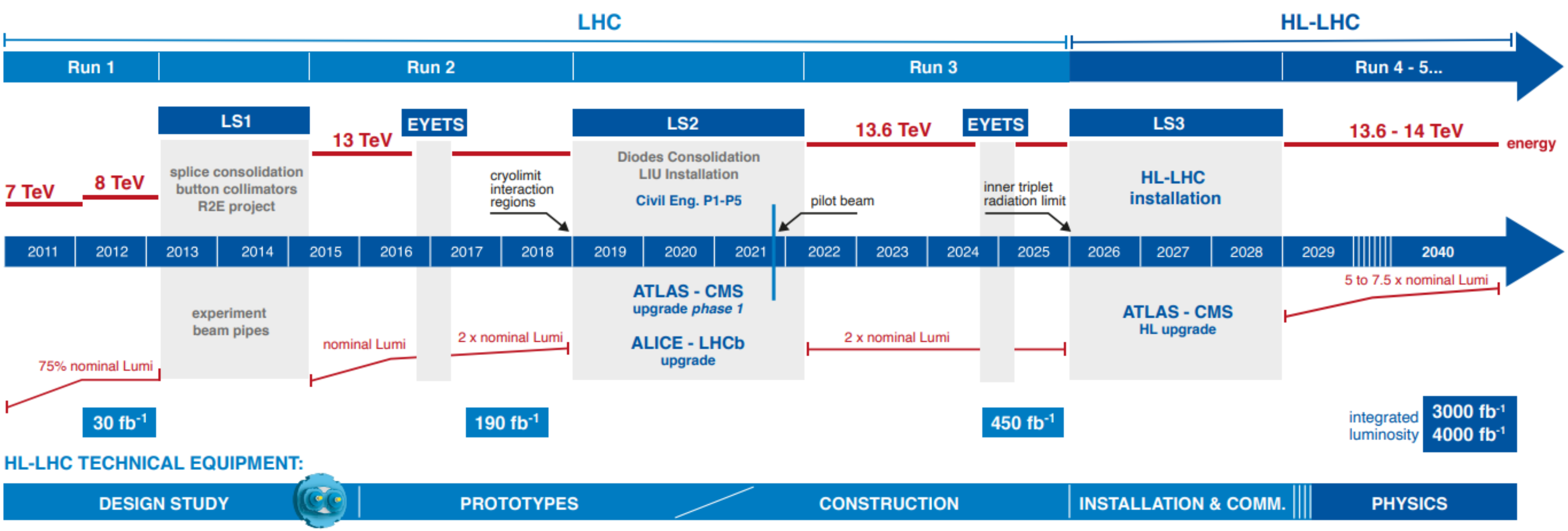
ATLAS ITk

Overview

- LHC upgrade timeline
- Motivation for the ITk upgrade
- Designed improvements of the ITk
- Description of the ITk detector
  - See poster by Dengfeng Zhang for more details on Strips (indico link)
  - See poster by Anna Raquel Petri for more details on Pixels (indico link)
- Description of the ITk readout
- Recent highlights from strips and pixels progress

LHC Upgrade Timeline



ITk Motivation

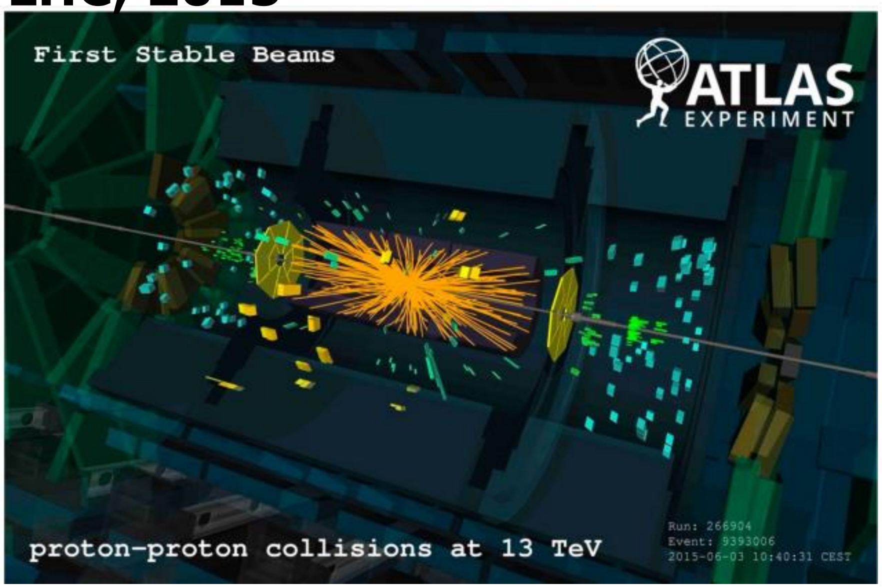
ATLAS running conditions with HL-LHC

Instantaneous luminosity will increase by a factor of 7

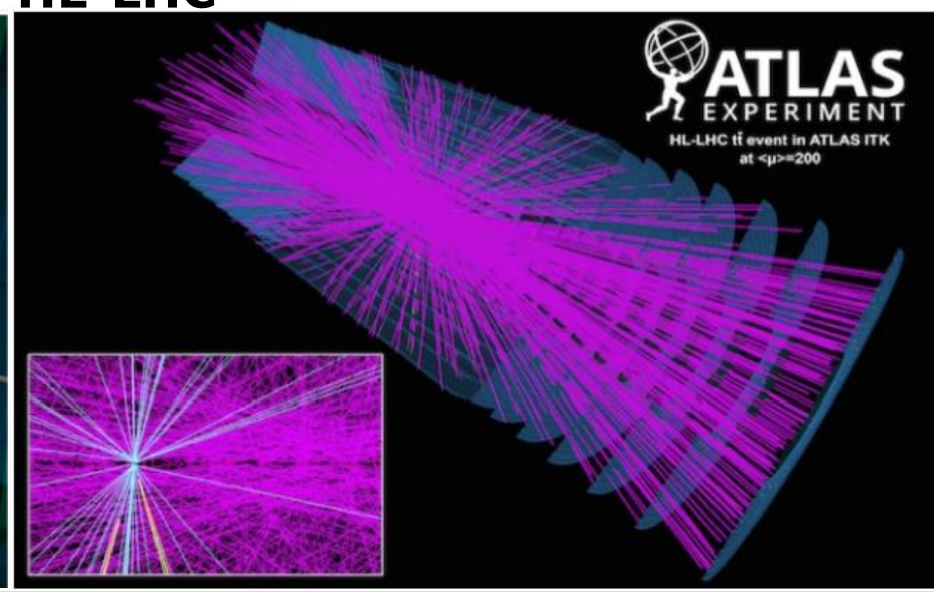
Particle density and radiation levels increase by an order of magnitude

Average interactions per bunch crossing will increase from 50 to 200

LHC, 2015



HL-LHC



ITk Motivation

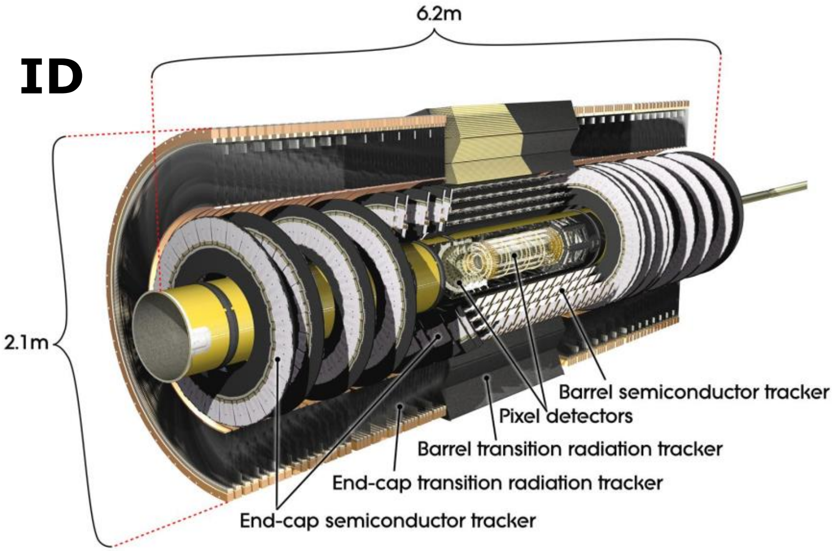
New running condition → Required upgrade

Increased radiation → Higher radiation tolerance

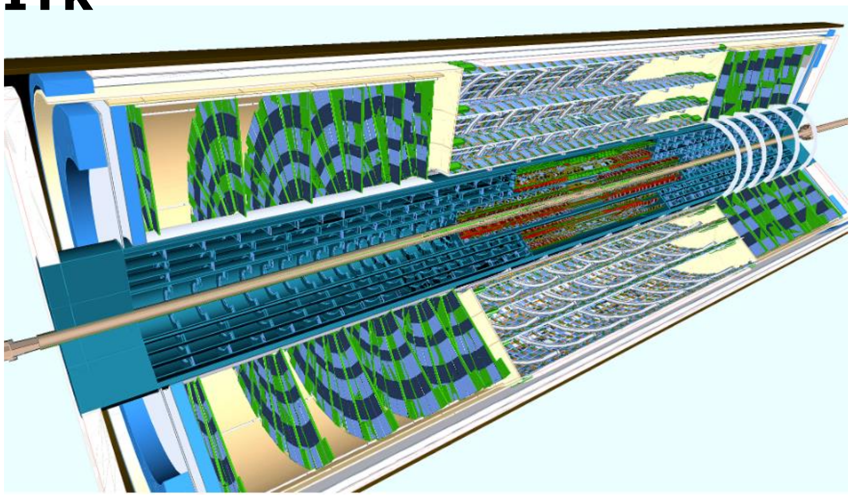
Increased track density → Improved granularity and response

Bigger event size → Improved triggering

ID



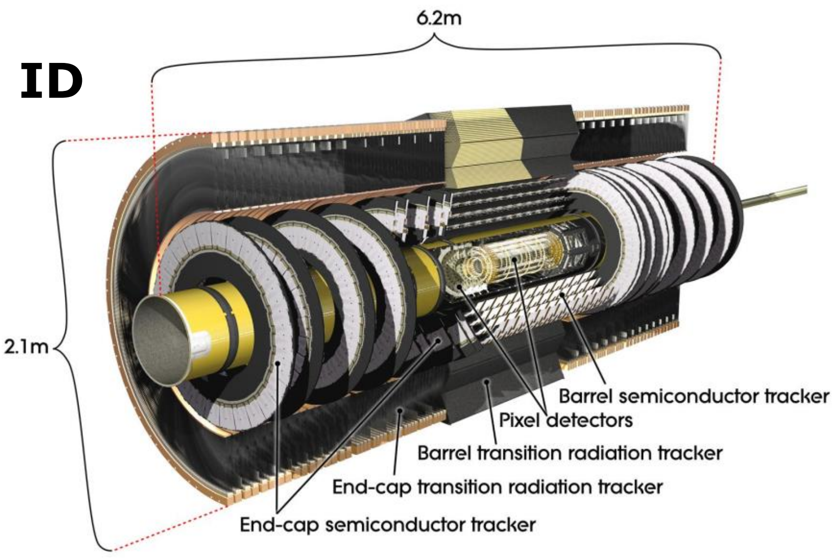
ITk



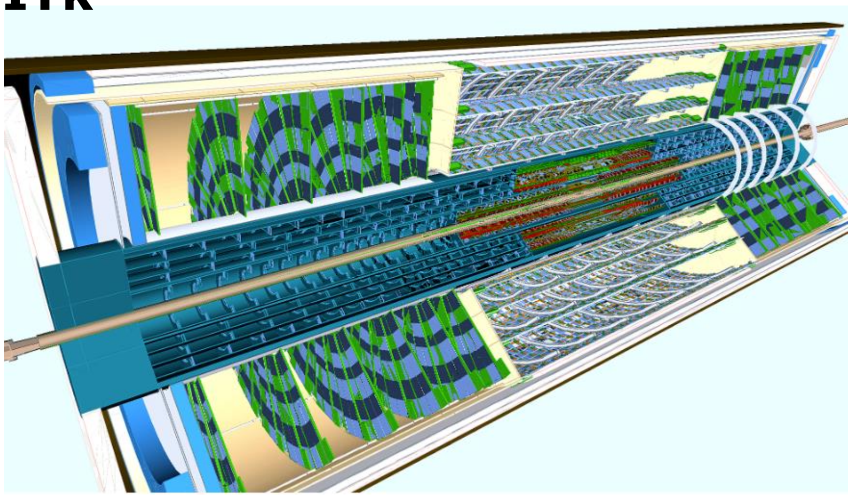
ITk Motivation

Performance increase → Required improvement
Cover larger area → Reduced sensor cost
Improved high p_T performance → Reduced pitch
Reduce particle-material interactions → Reduce material in tracking volume

ID



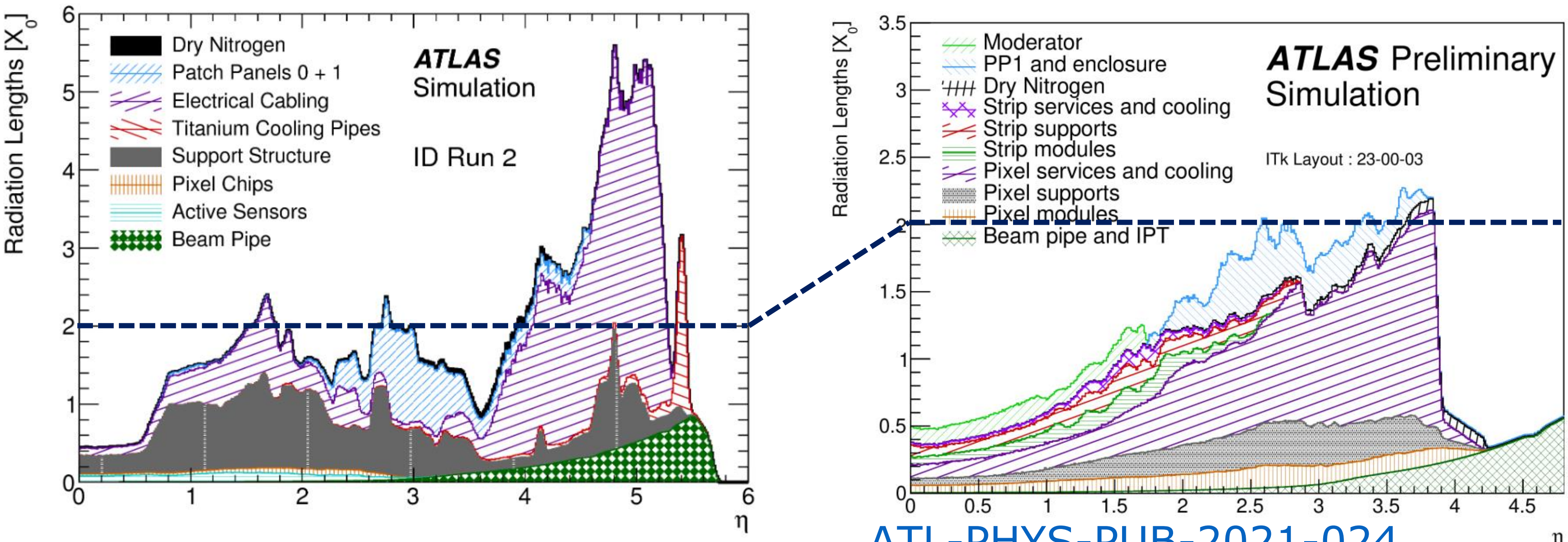
ITk



Material budget

Lower material budget than ID achieved with:

- CO_2 cooling with thin titanium pipes
- Serial powering for pixels, fewer cables
- Carbon structures for mechanical stability and mounting
- Optimized number of readout cables using data link sharing



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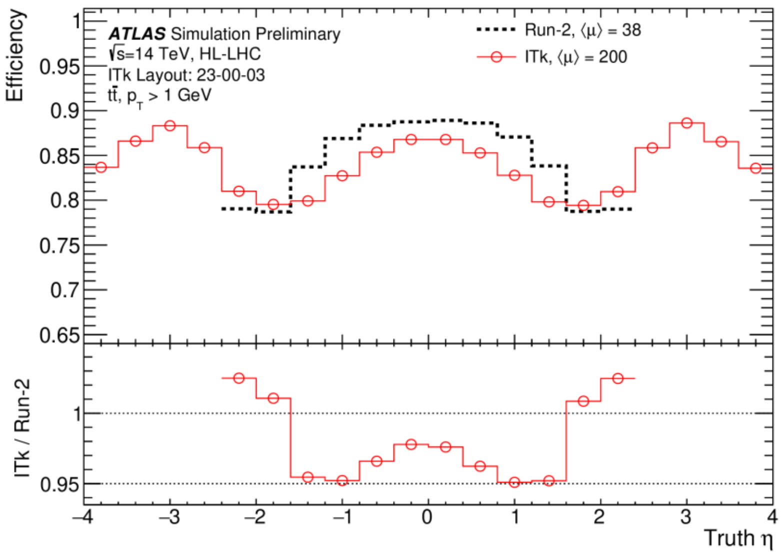
ITk expected performance

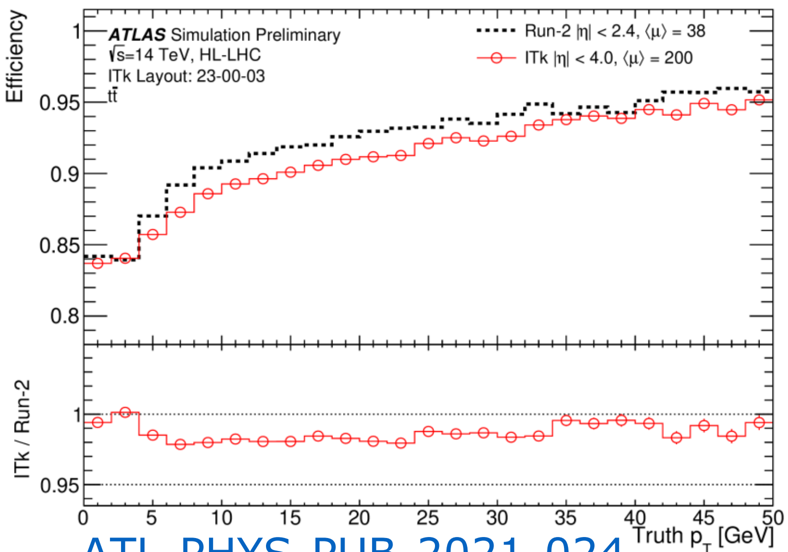
The ITk will experience 4-5 times the number of pileup interactions as the ID in run 2

Under these increased pileup conditions:

- The ITk has a comparable tracking efficiency for $t\bar{t}$ events with respect to η when compared to the ID in run 2, within ~5%
- The ITk has a comparable tracking efficiency for $t\bar{t}$ events with respect to p_T when compared to the ID in run 2, within ~2%

Without pileup, the resolution of the ITk is comparable to significantly improved when compared to the ID performance in run 2 (see backup)





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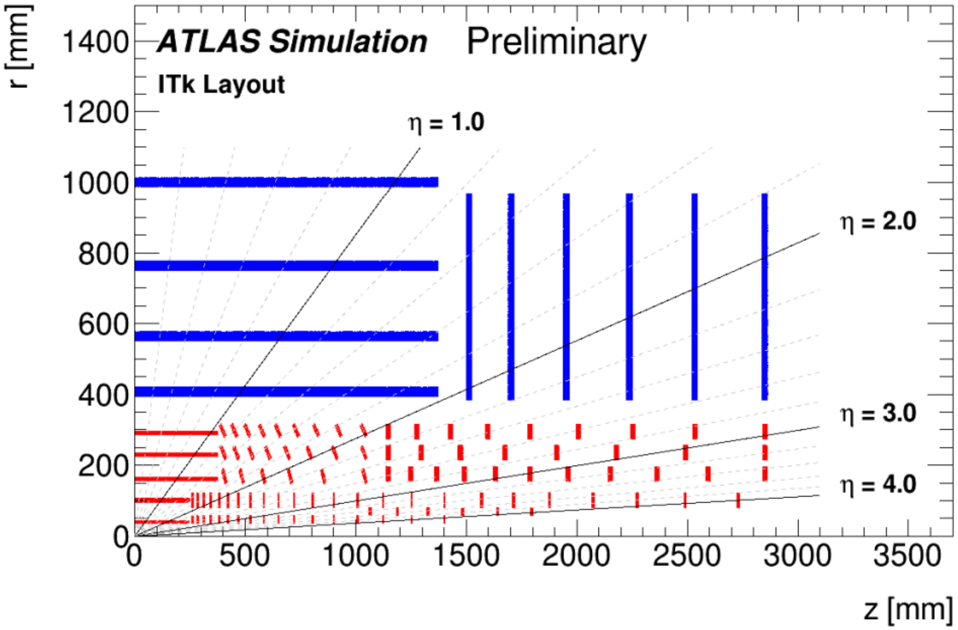
ITk Setup

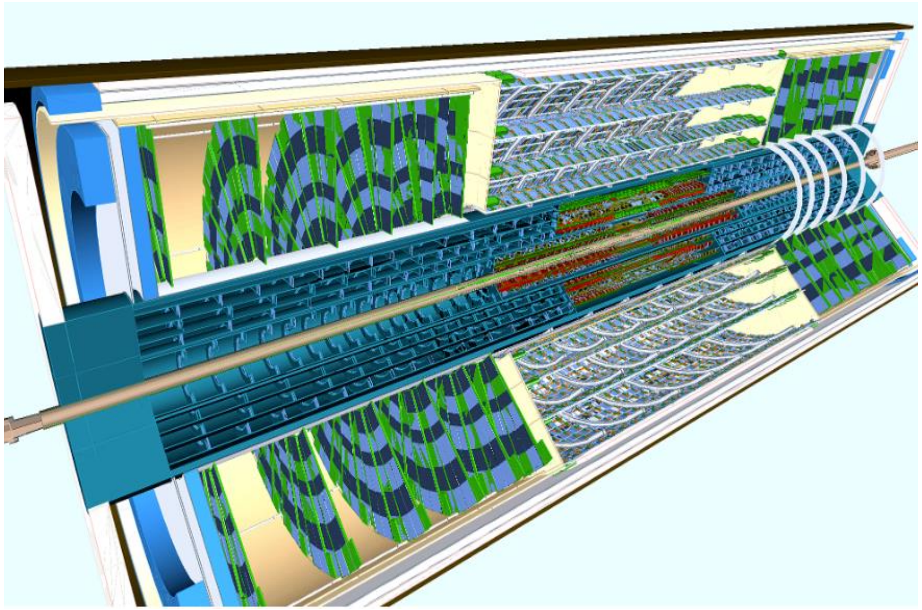
Setup

Fully silicon detector made of strips and pixels

It is divided into a central region (Barrel) and two forward regions (End Cap)

Improved coverage up to $\eta = 4$

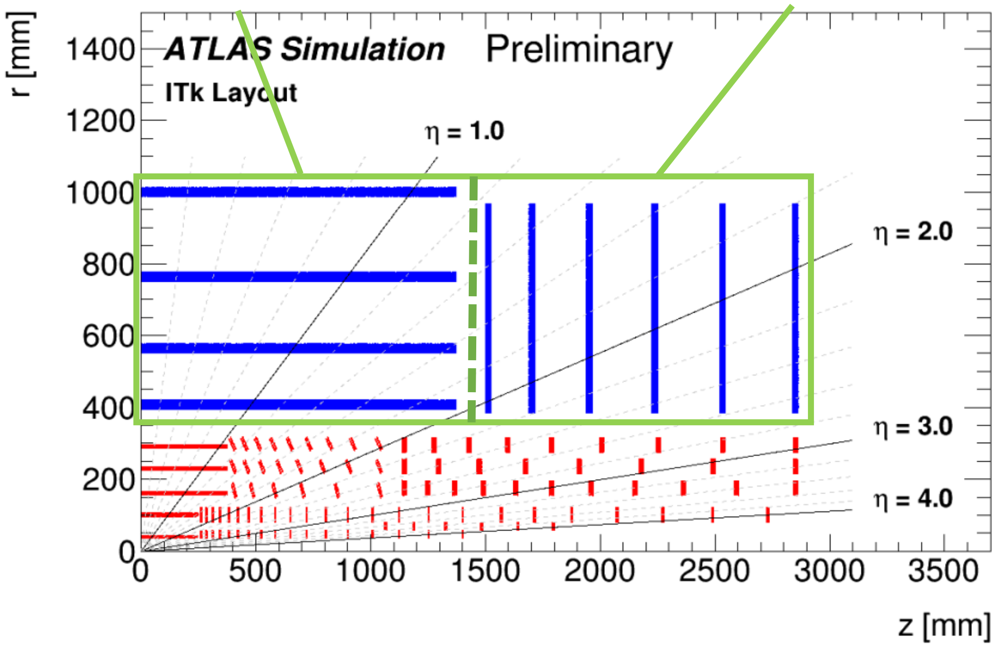


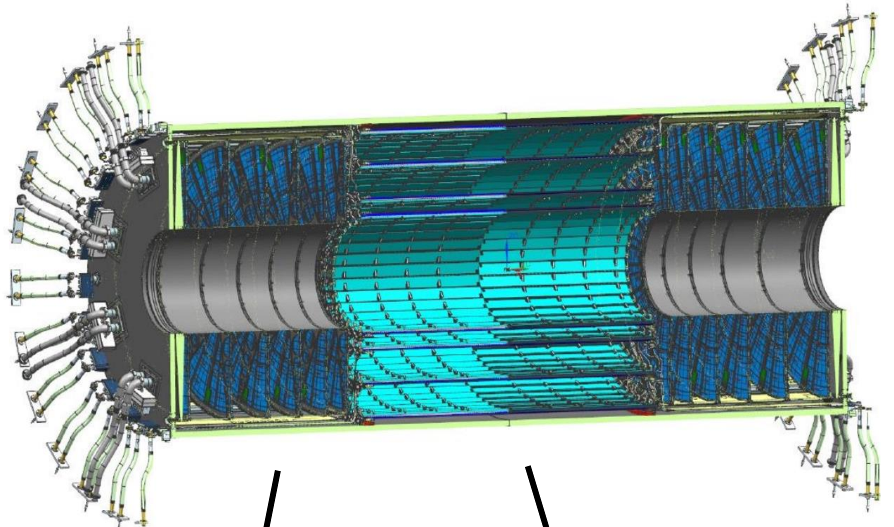


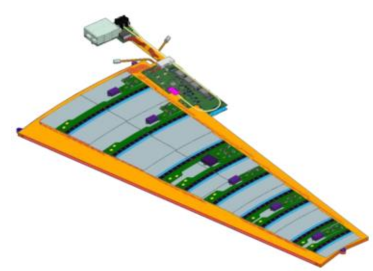
ITk strip detector design

Strips
4 layers of flat staves (Barrel)
12 total disks (End-Cap)

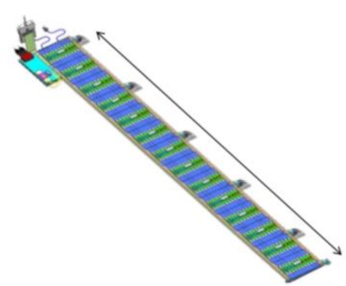
Strip Barrel **Strip End-Cap**







Strip End-Cap Petal

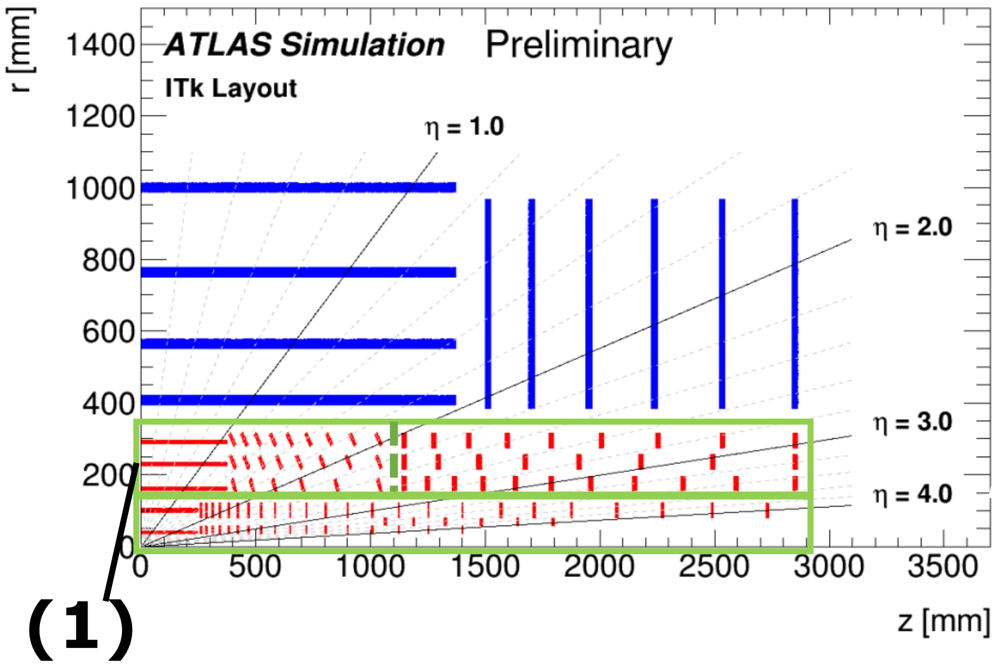


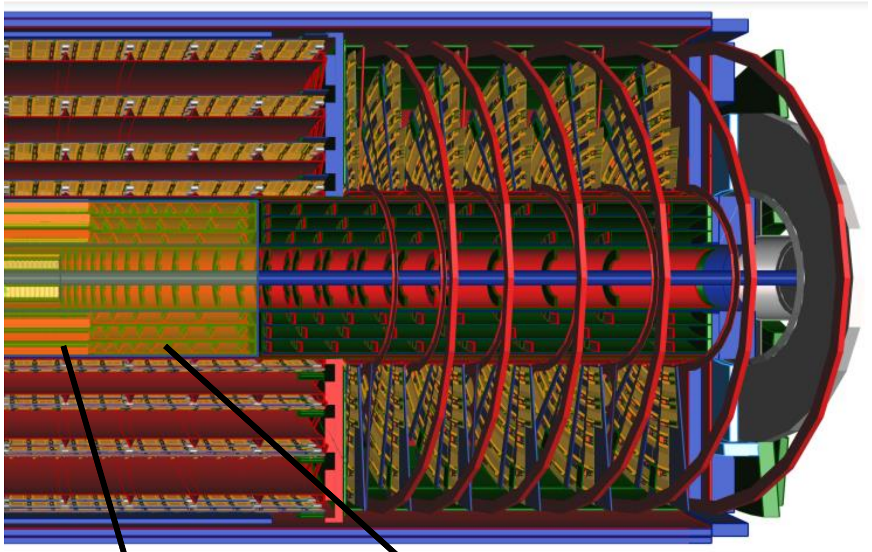
Strip Barrel Stave

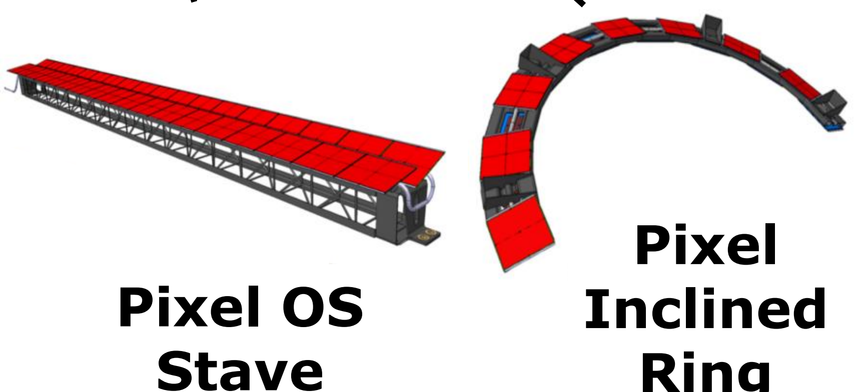
ITk pixel detector design

(1) Pixel OS barrel

3 layers of flat staves
3 layers of inclined rings
50x50 μm^2 planar sensors





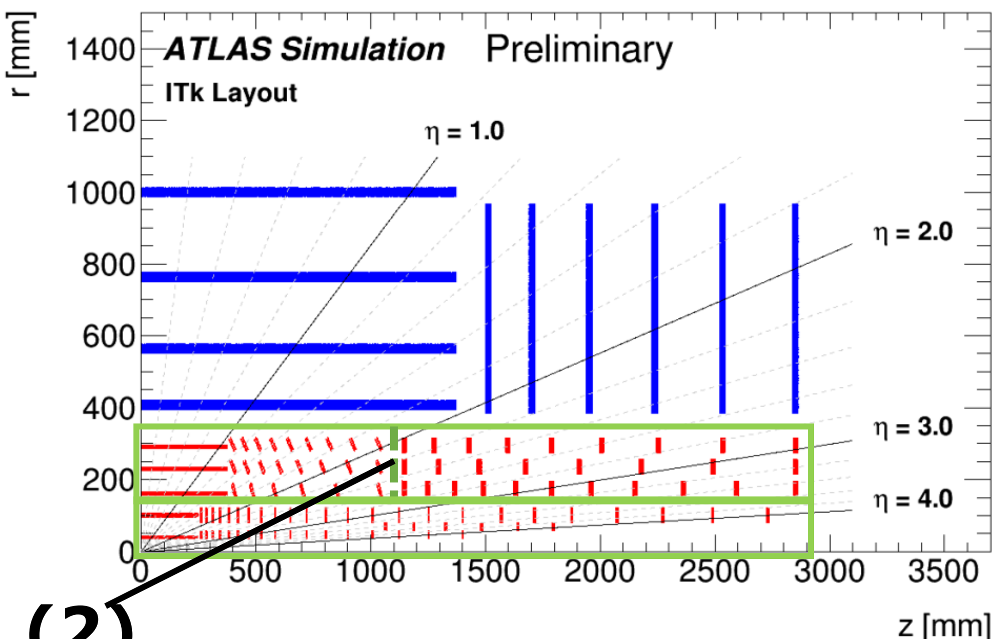


ITk pixel detector design

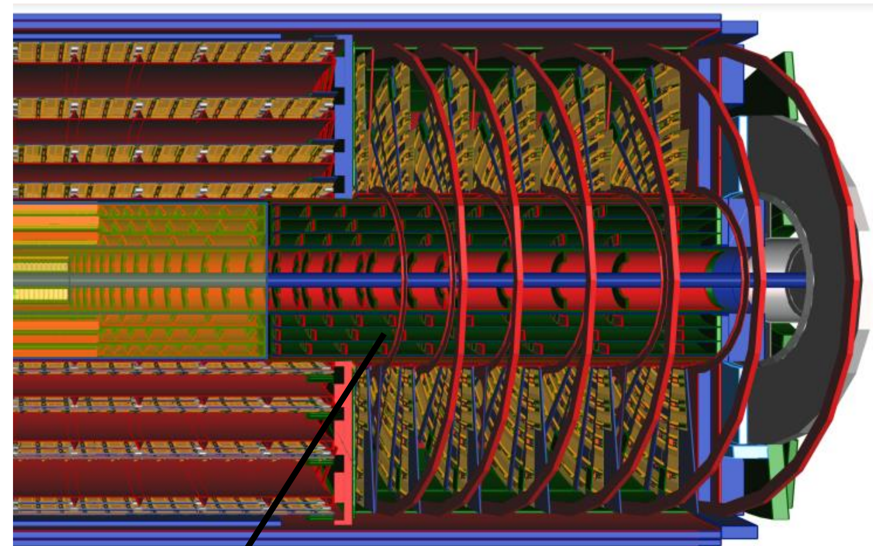
(2) Pixel OS end-cap

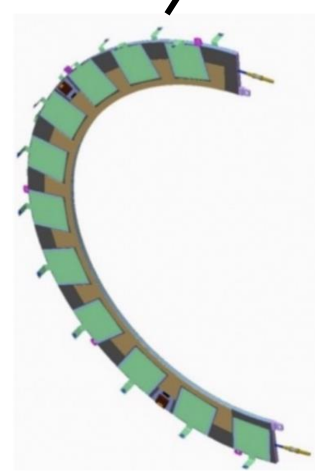
3 layers of rings

50x50 μm^2 planar sensors



(2)



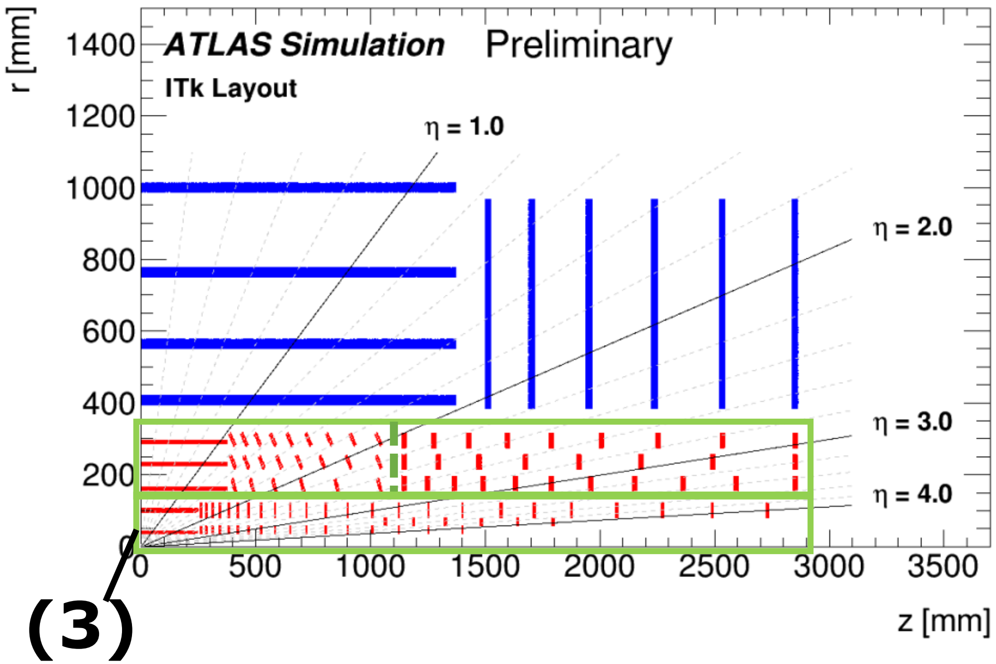


Pixel OS Ring

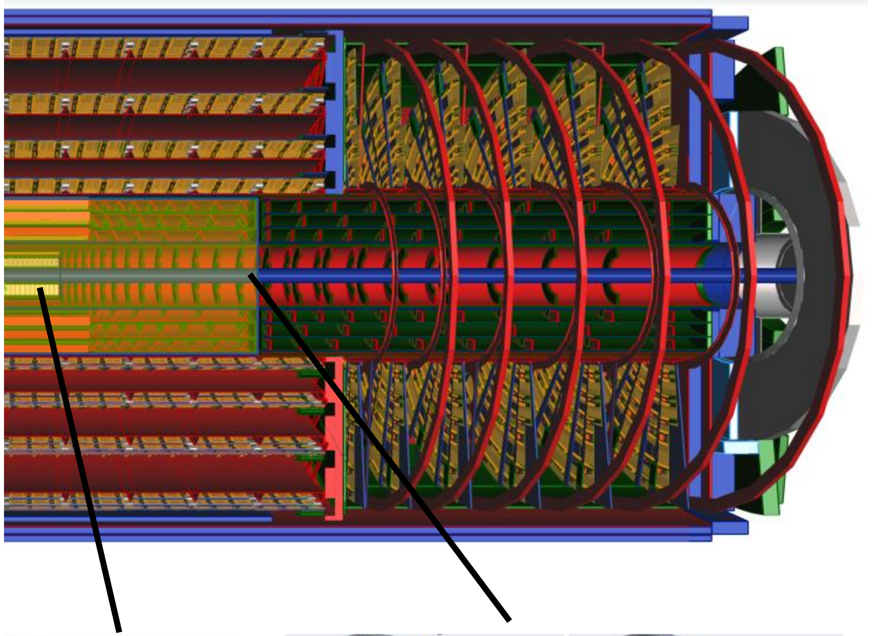
ITk pixel detector design

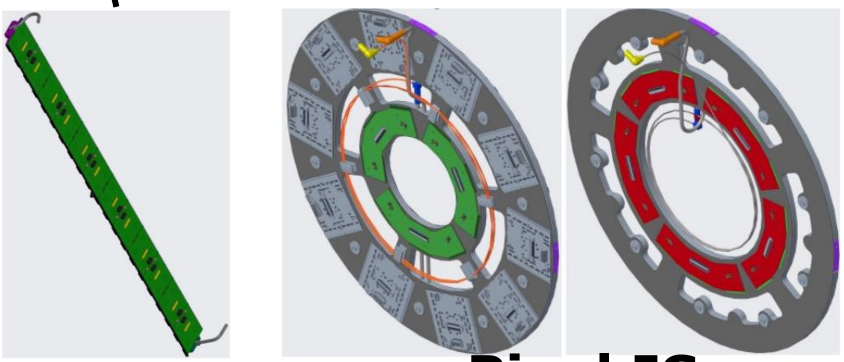
(3) Pixel IS

2 layers of flat staves and rings
L0 B: 3D 25x100 μm^2 sensors, triplet
L0 EC: 3D 50x50 μm^2 sensors, triplet
L1: 50x50 μm^2 planar sensors, quad



(3)





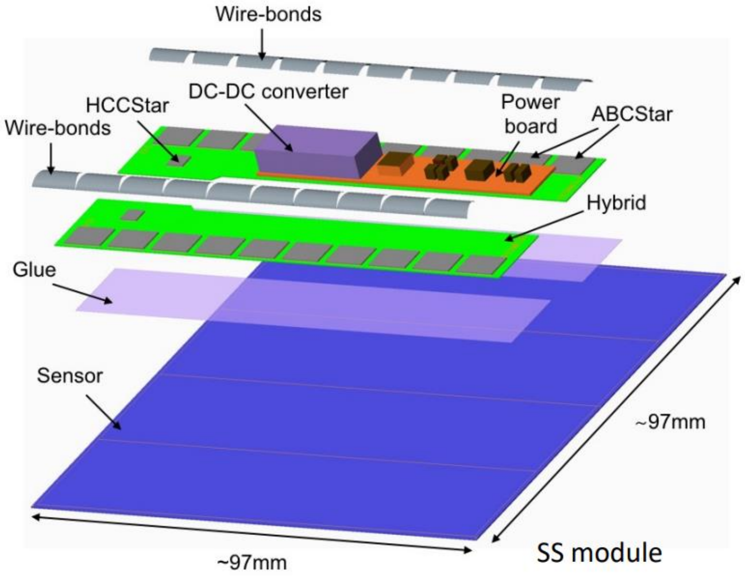
Pixel IS Stave

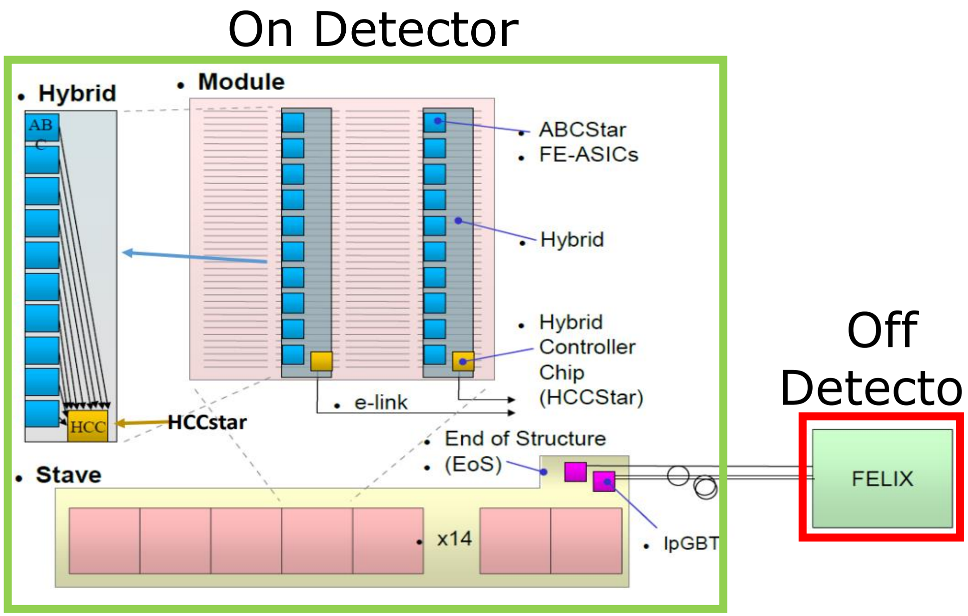
Pixel IS Ring

ITk strip readout software

Challenges of ITk software design

- Processing L0 triggers at an increased data rate
- Detect missing/broken packets at high rates
- Increase radiation (bit-flips): chips must be reconfigured at high rates
- Efficient calibration: 1 hour between runs for maintenance and calibration of entire ITk

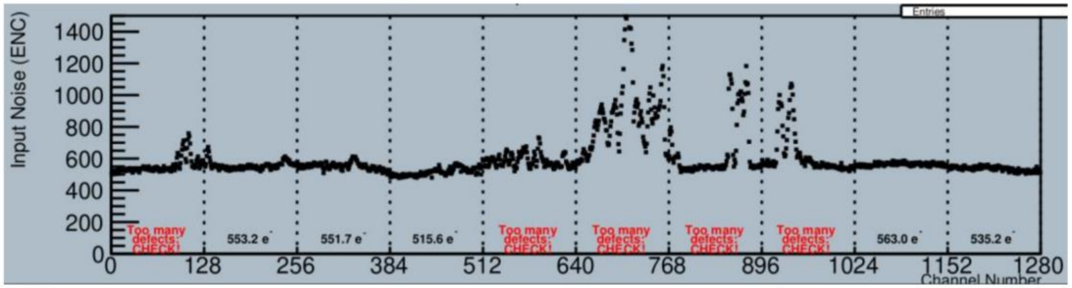




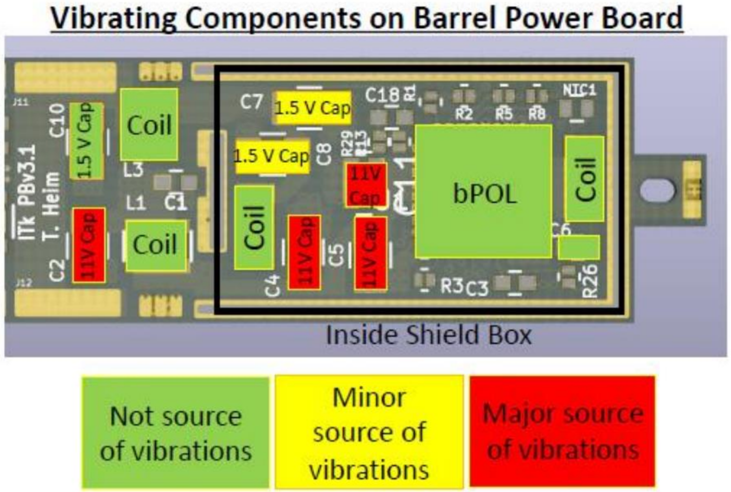
Strip status update

What is cold noise?

- Noise first observed in SS modules when thermal cycling



LBNL SS PPA 0001 -26C



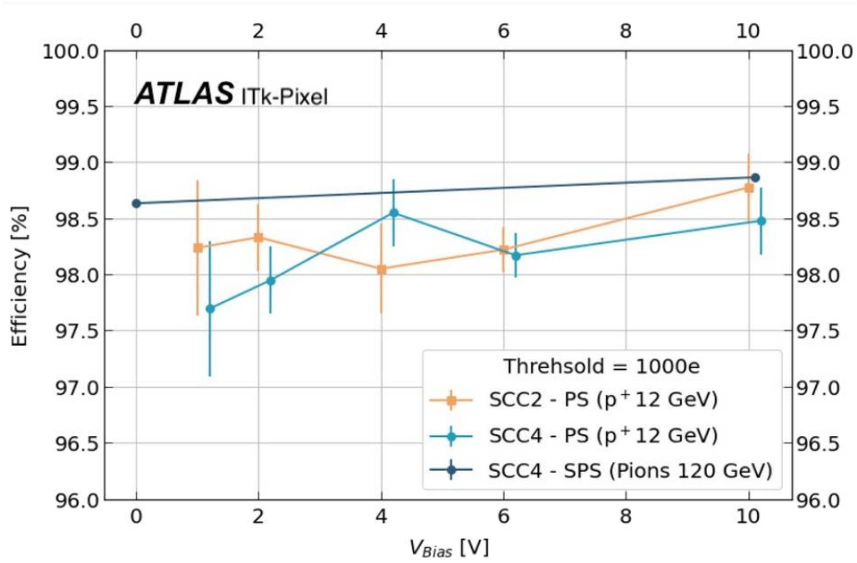
Status:

- 11V Capacitors found as source of CN
- Tests have shown that for LS modules True Blue (Eccobond F112) mitigates CN in normal operation conditions. For SS modules work continues to look into mitigation strategies.

Pixel status update

Module efficiency tests

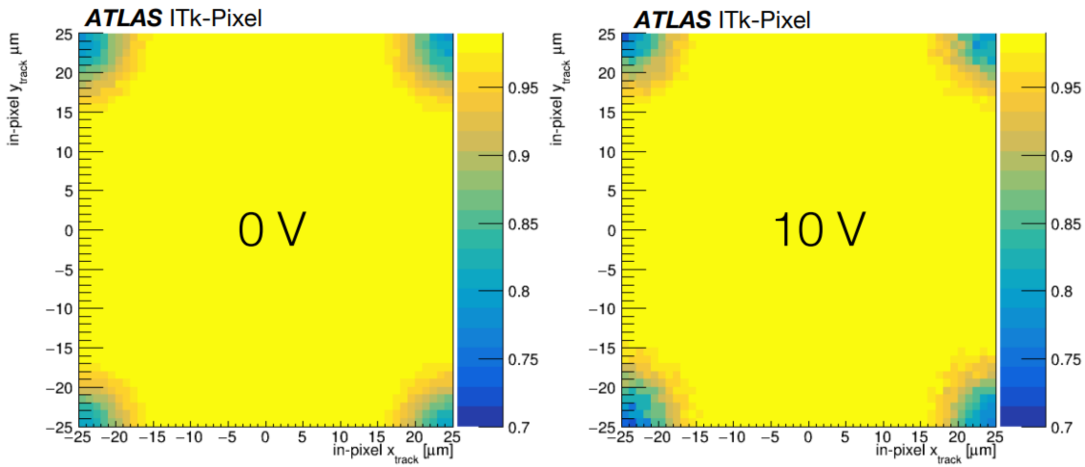
Single Chip Modules made with ITkPixV1.1 chips and 3D 50x50 μm^2 pixel sensors made by FBK



Pre-irradation
Test 1: 12 GeV proton beam @ PS
Test 2: 120 GeV pion beam @ SPS

Sensor efficiency:
- 98.7 ± 0.1% at 0 V bias
- 98.9 ± 0.1% at 10 V bias

Local efficiency
- Central area has efficiency over 99%
- Corners have efficiency of ~75% due to p^+ columns



PLOT-ITKD-2022-05

Pixel status update

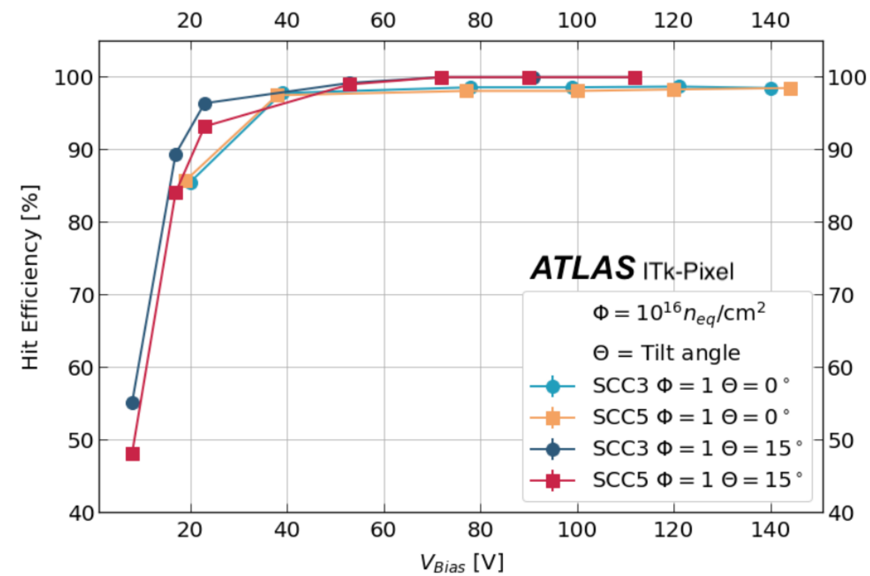
Module efficiency tests

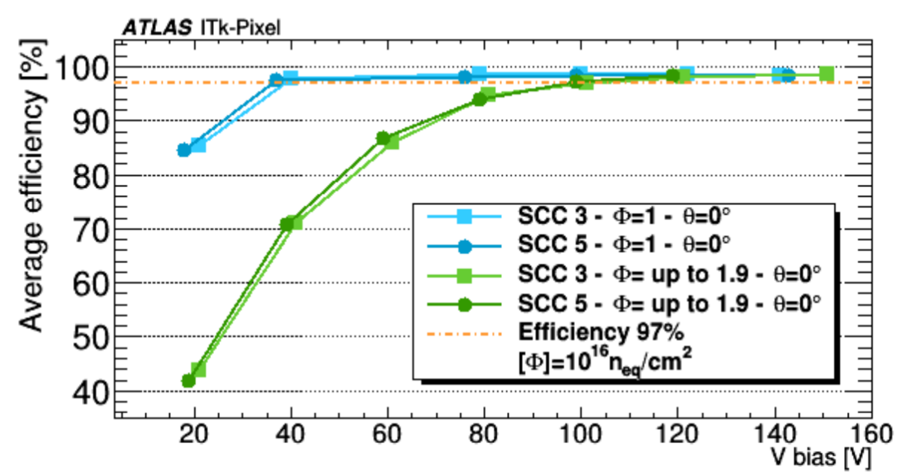
Irradation

1) 14 MeV protons for
   $\Phi = 1\text{x}10^{16}\text{n}_{\text{eq}}/\text{cm}^2$ @ Bonn
2) 24 GeV protons for
   $\Phi = 0.5\text{x}10^{16}\text{n}_{\text{eq}}/\text{cm}^2$ @ IRRAD

Post-irradiation
Test: 120 GeV pion beam @ SPS

Sensor efficiency:
After 1): 97% at 40 V bias
After 1) and 2): 97% at 100 V bias





PLOT-ITKD-2022-05

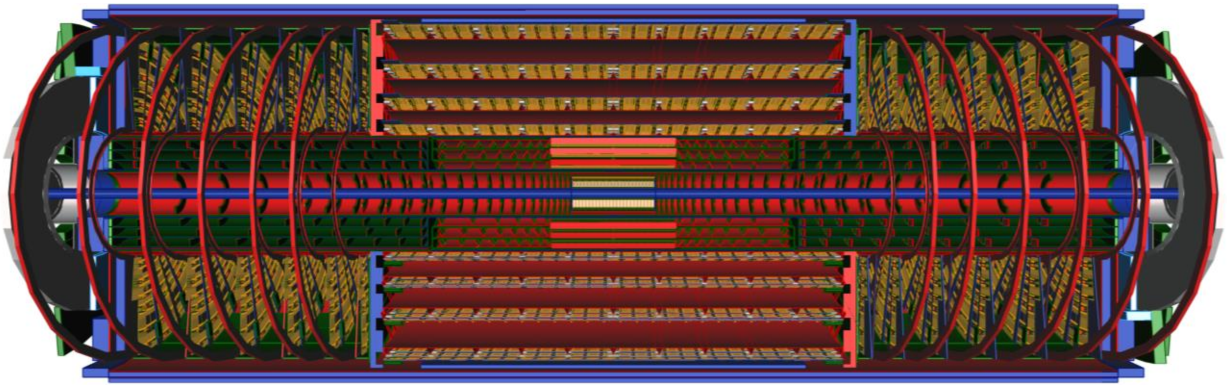
Conclusion

HL-LHC will create high radiation and particle dense running conditions

The ITk is designed specifically to meet, if not exceed, the performance of the ID in run 2 within this new environment

- Performance up to η=4
- Reduced material budget
- Reduced sensor pitch

Both pixel and strip detectors are progressing well through preliminary stages of production



Backup

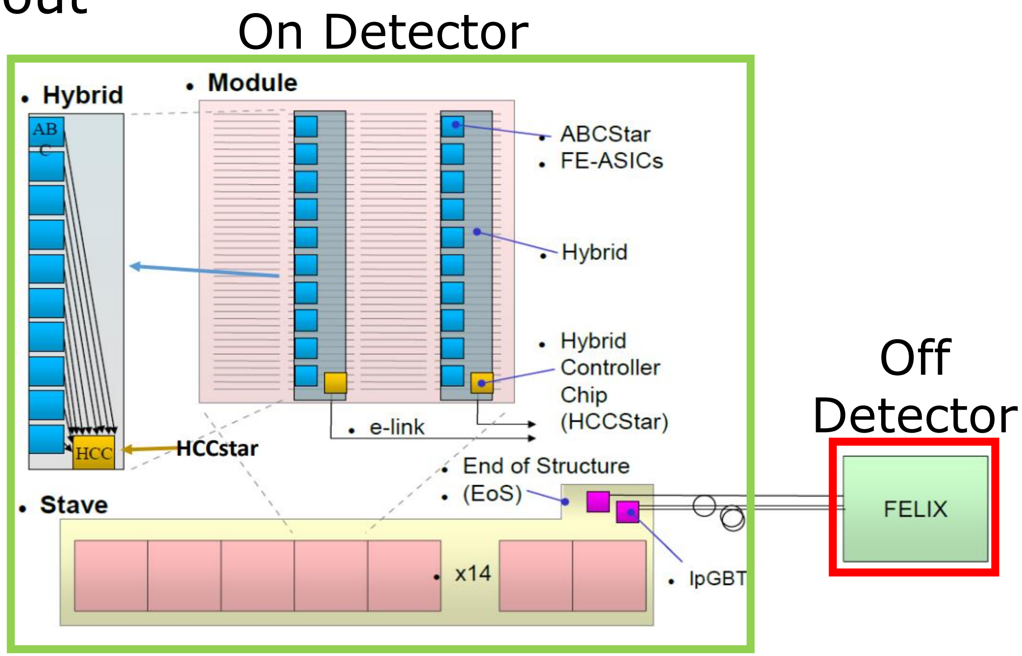
ITk strip readout hardware

ABCStar
Reads data from 256 strip channels
Capable of 1 MHz L0 trigger readout

HCCStar
Communicates with 10 ABCStars
Interprets TTC for ABCStars
Readout data up to 640 Mb/s

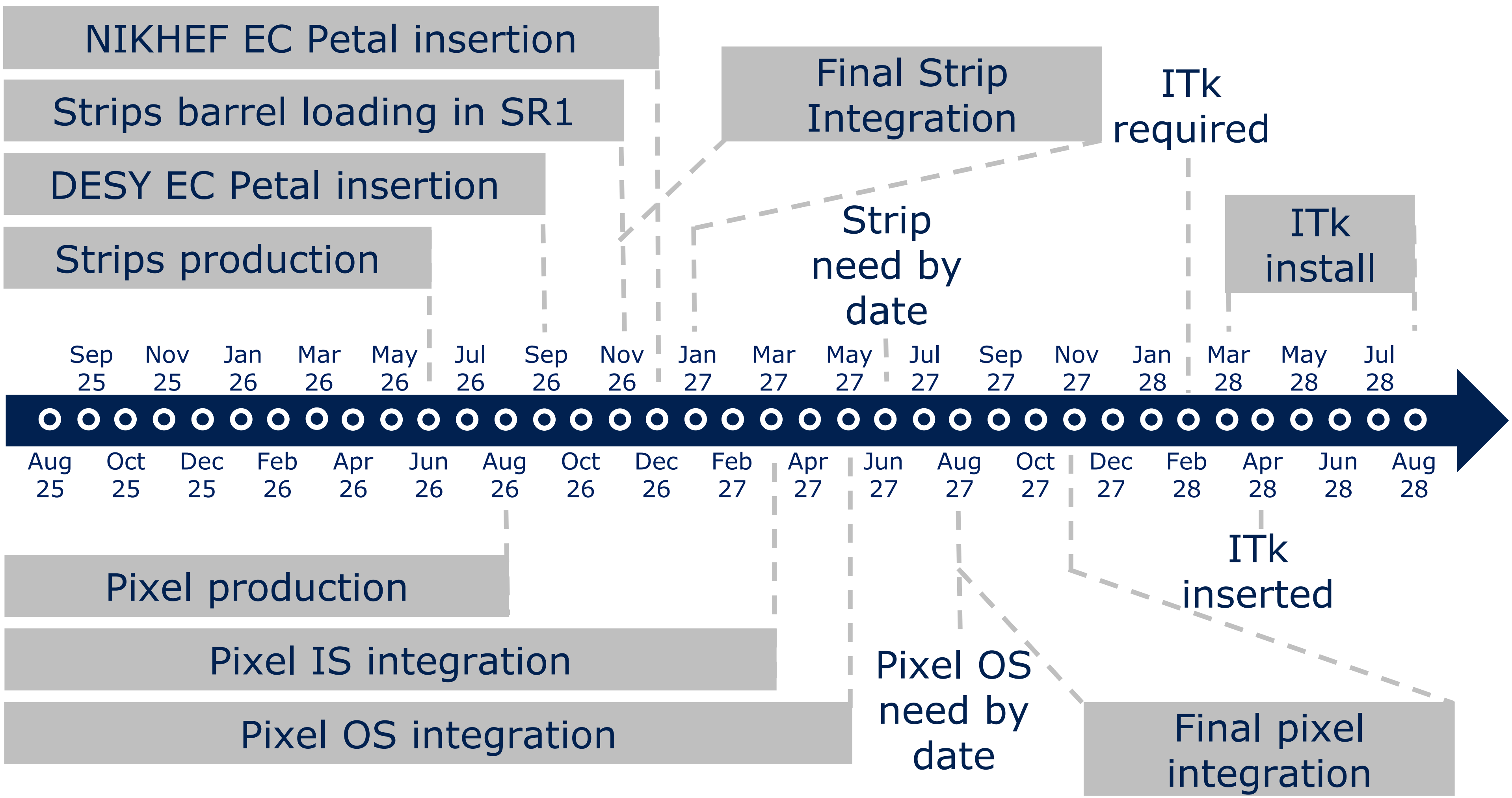
LpGBT
Communicates to 14 HCCStars
Distributes TTC to HCCStars
Downlink speed of 2.56 Gb/s
Uplink speed of 5.12 Gb/s

Felix
Communicates with up to 24 LpGBTs per optical link
Gets and distributes TTC to LpGBTs
Data transport decoupled from data processing
Detector independent router to FE chips

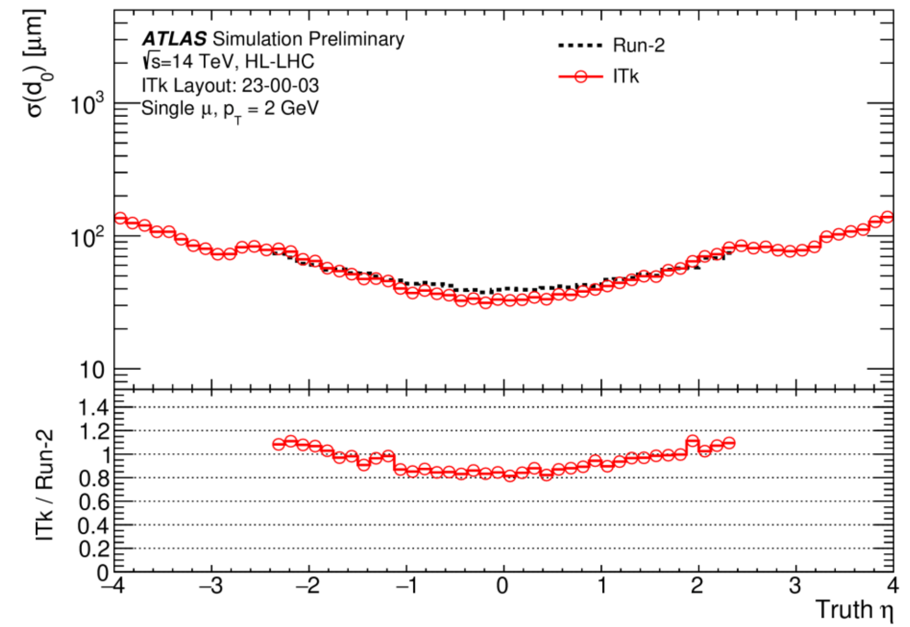


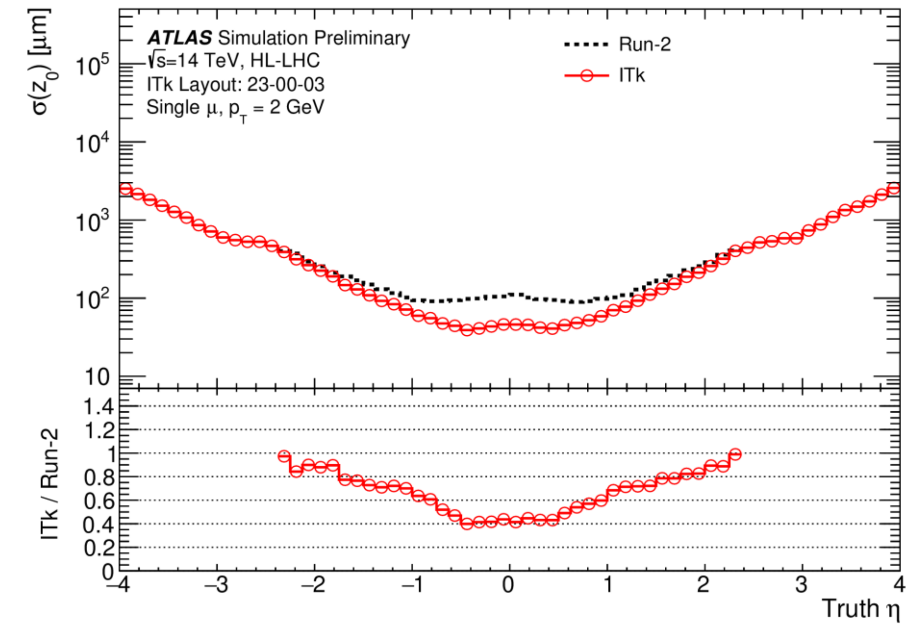
Adapted from:
https://indico.cern.ch/event/688153/

Updated ITk project timeline



ITk expected performance





With no pileup interactions:

- The resolution of the transverse impact parameter for a single muon at low p_T is slightly improved when compared to the ID in run 2.
- The resolution of the longitudinal impact parameter for a single muon at low p_T is improved by a factor of 2 when compared to the ID in run 2. This is in part due to the reduced pitch of the pixel sensors.

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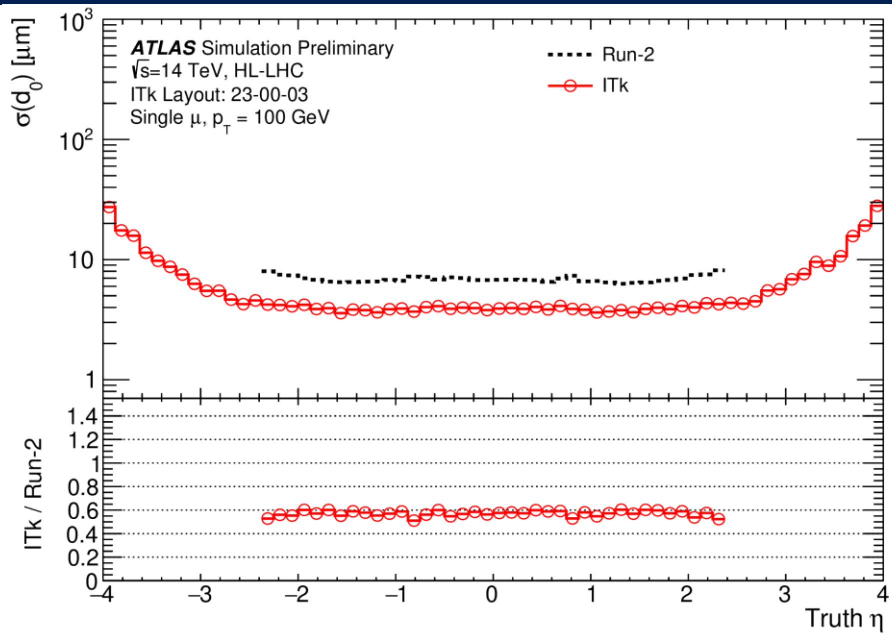
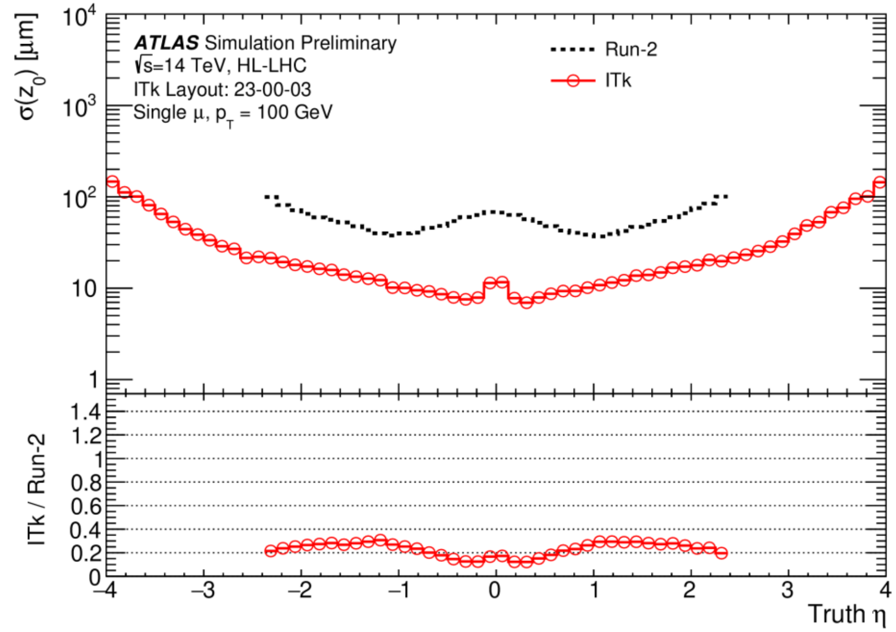
ITk expected performance





With no pileup interactions:

- The resolution of the transverse impact parameter for a single muon at high p_T is significantly improved when compared to the ID in run 2.
- The resolution of the longitudinal impact parameter for a single muon at high p_T significantly improved when compared to the ID in run 2. This is in part due to the reduced pitch of the pixel sensors.

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ITk strip readout software

Role
- Data taking
- Calibrate pixel and strip between runs
- Reconfigure detector configuration during runs at high rates

Structure

Config DB
- Stores chip configuration data

Configure
- Configure chips for calibration scans or data taking

Decoding
- Collect data stream from Felix
- Parse ABCStar/HCCStar packets
- Check for packet errors

Analysis
- Calculates calibrated detector settings from decoded data

Plotting
- Creates plots of data and calibration scans