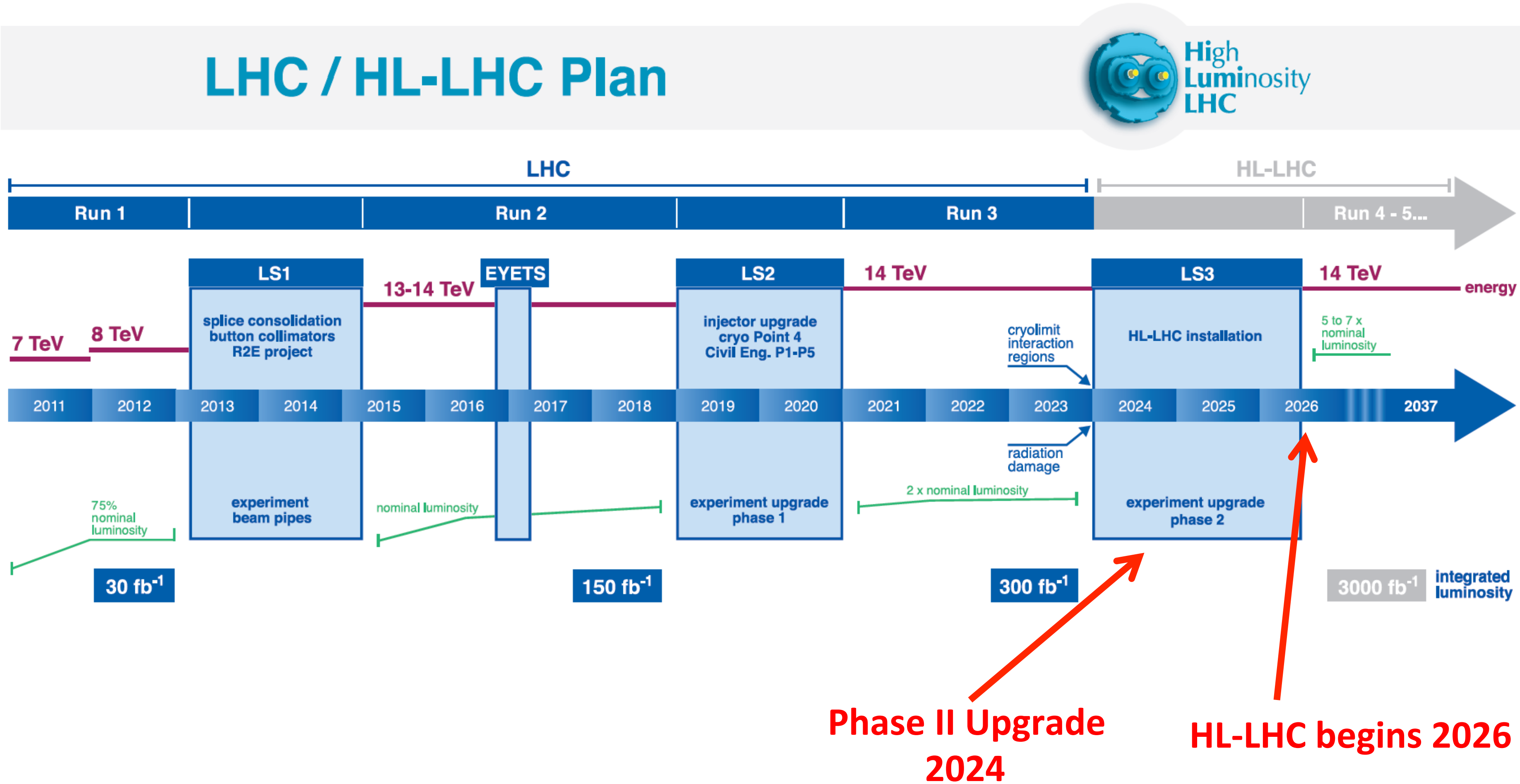
Upgrade of the ATLAS Pixel Detector

Jessica Metcalfe
Argonne National Laboratory

On Behalf of the ATLAS Collaboration

LHC Schedule

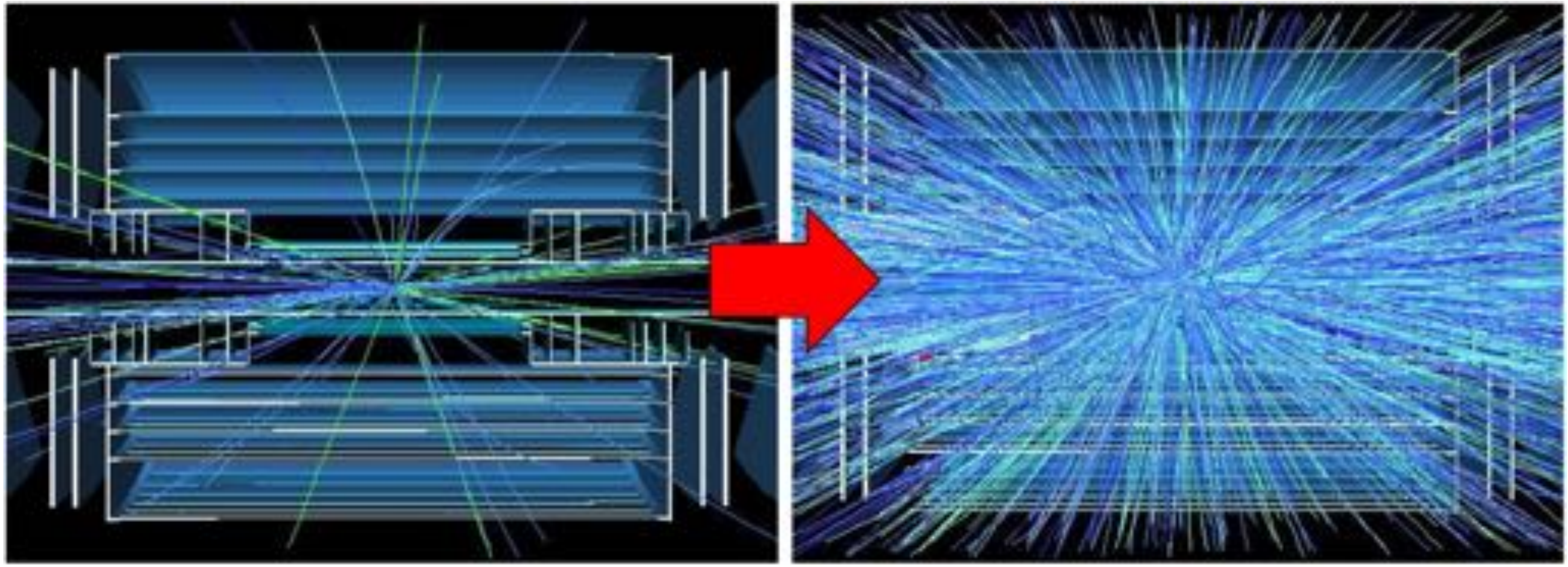
CERN-LHCC-2015-020 ; LHCC-G-166



HL-LHC

The high luminosity LHC (HL-LHC) presents a challenging scenario due to increased instantaneous luminosity:

$7.5\text{x}10^{34}\ \text{cm}^{-2}\text{s}^{-1}$ -> $\langle\mu\rangle \geq 200$ => $3000\ \text{fb}^{-1}$



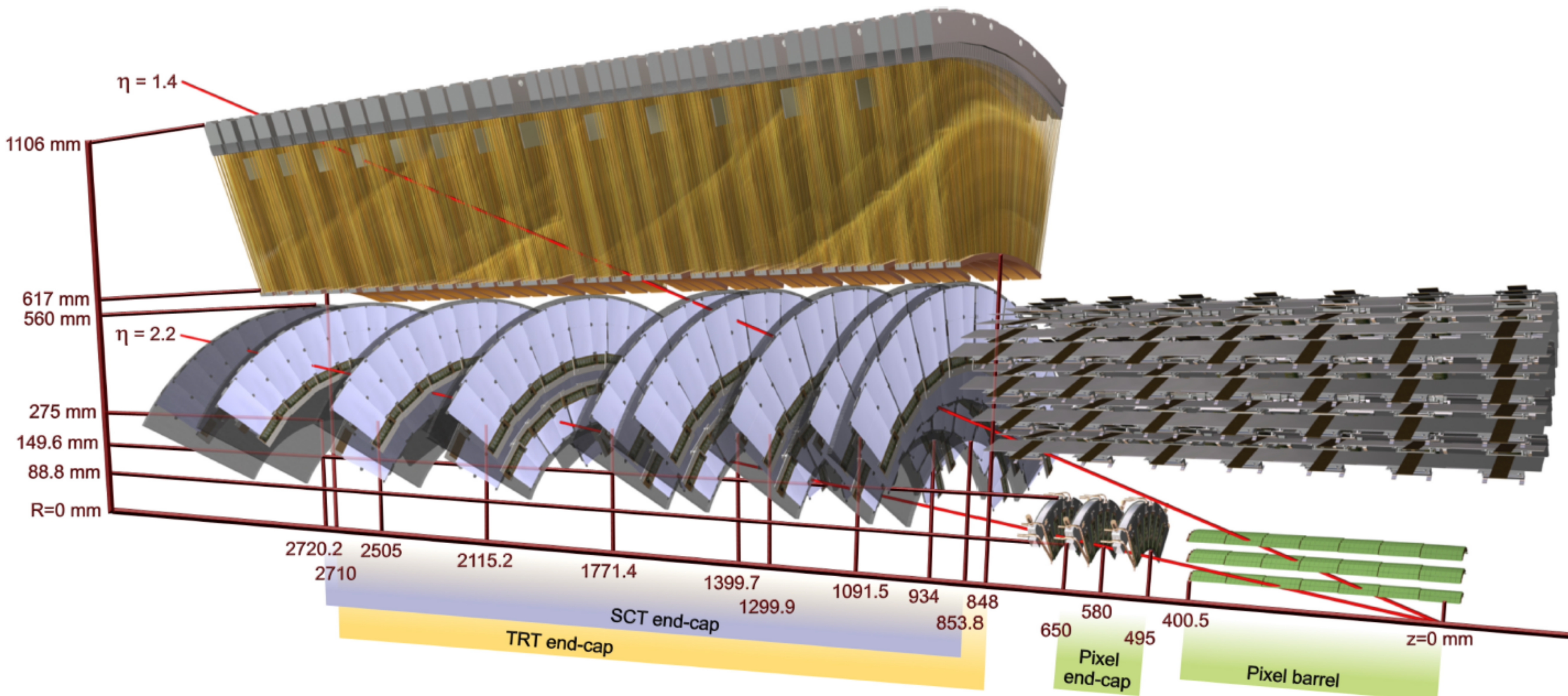
Detector challenges for the HL-LHC

- Pileup
- Trigger
- Forward calorimeters

Inner Detector: Run 1

Inner Tracker Upgrade (ITK) will replace Inner Detector envelope with all silicon trackers.

ATLAS Run 1 ID:



ITK Upgrade Scenarios (Last Year)

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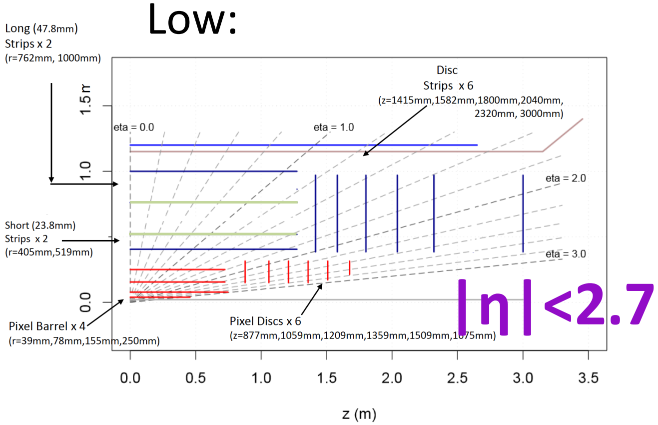
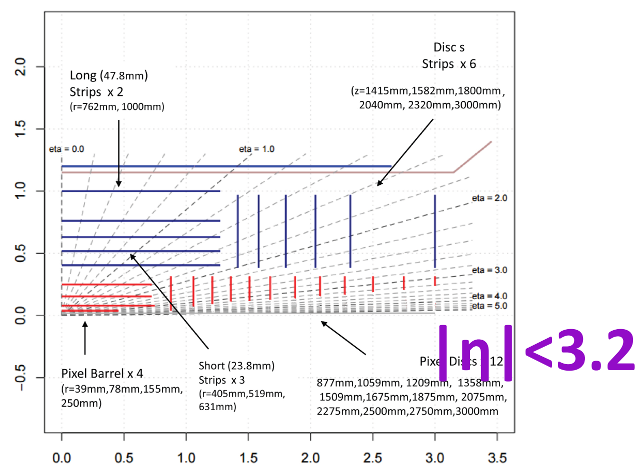
ITK Tracker Options:

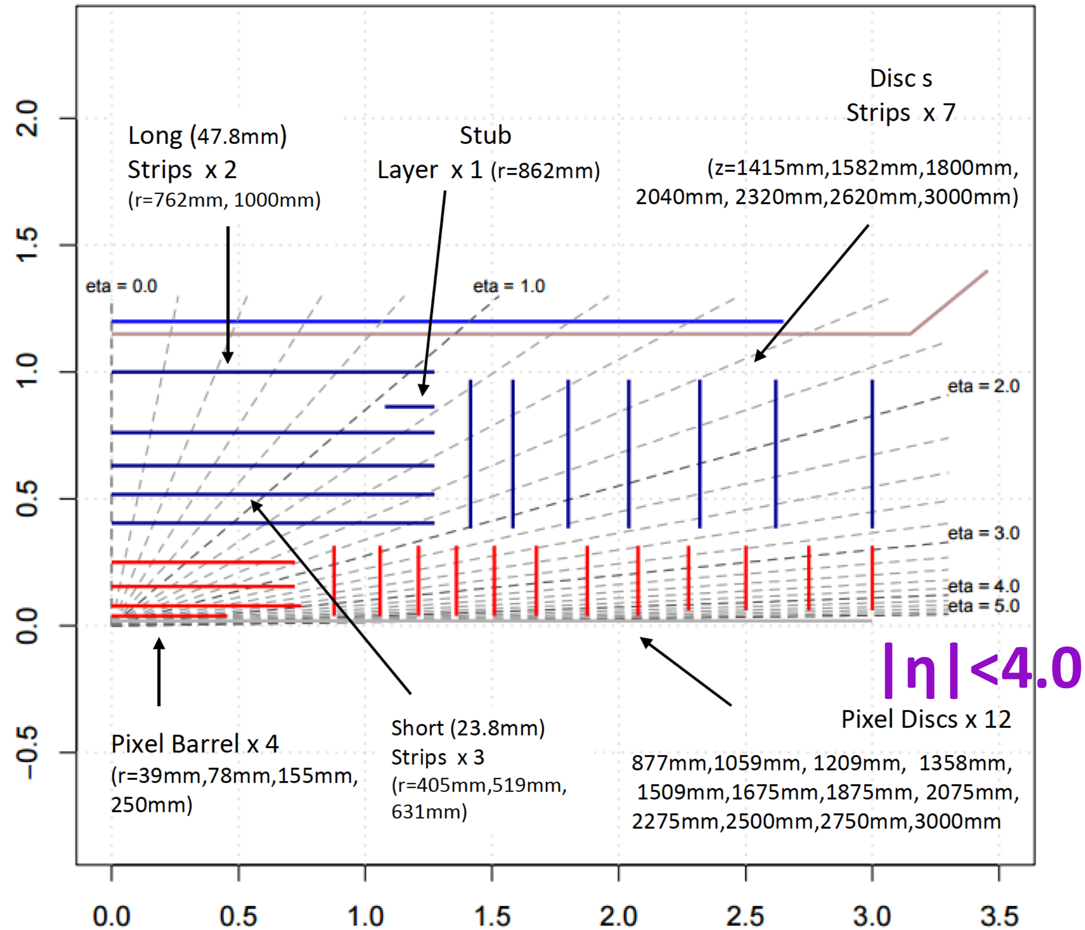
Low:



Middle:



Reference:



ITK Tracking

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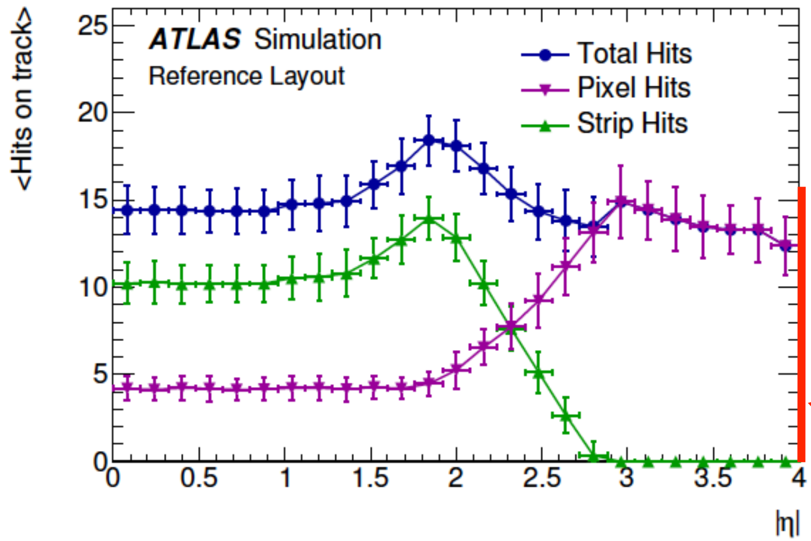
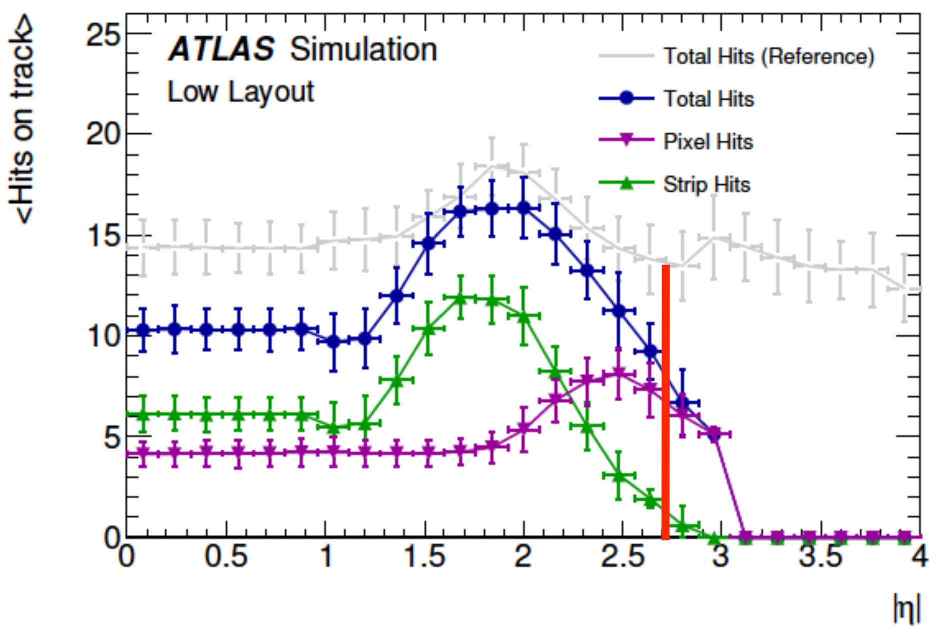
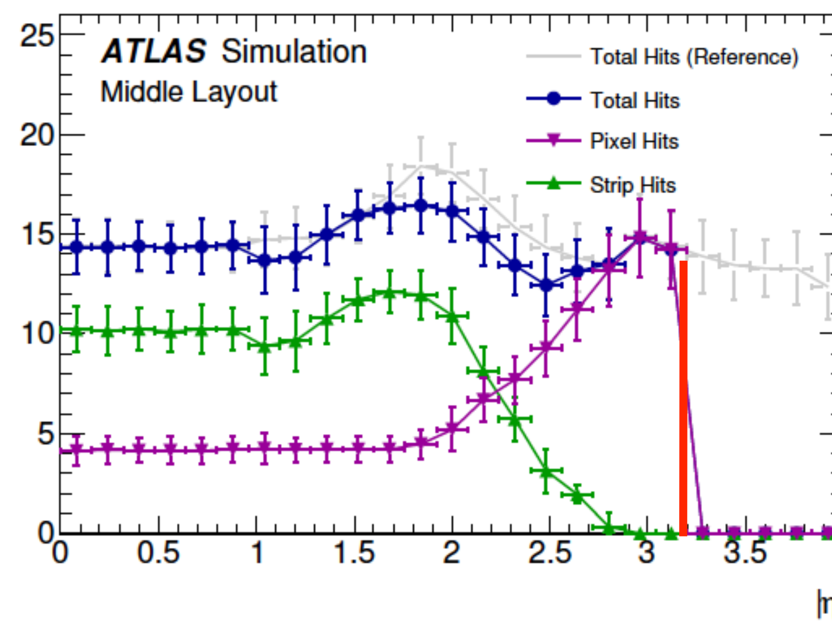
Track Hits:



Tracker coverage

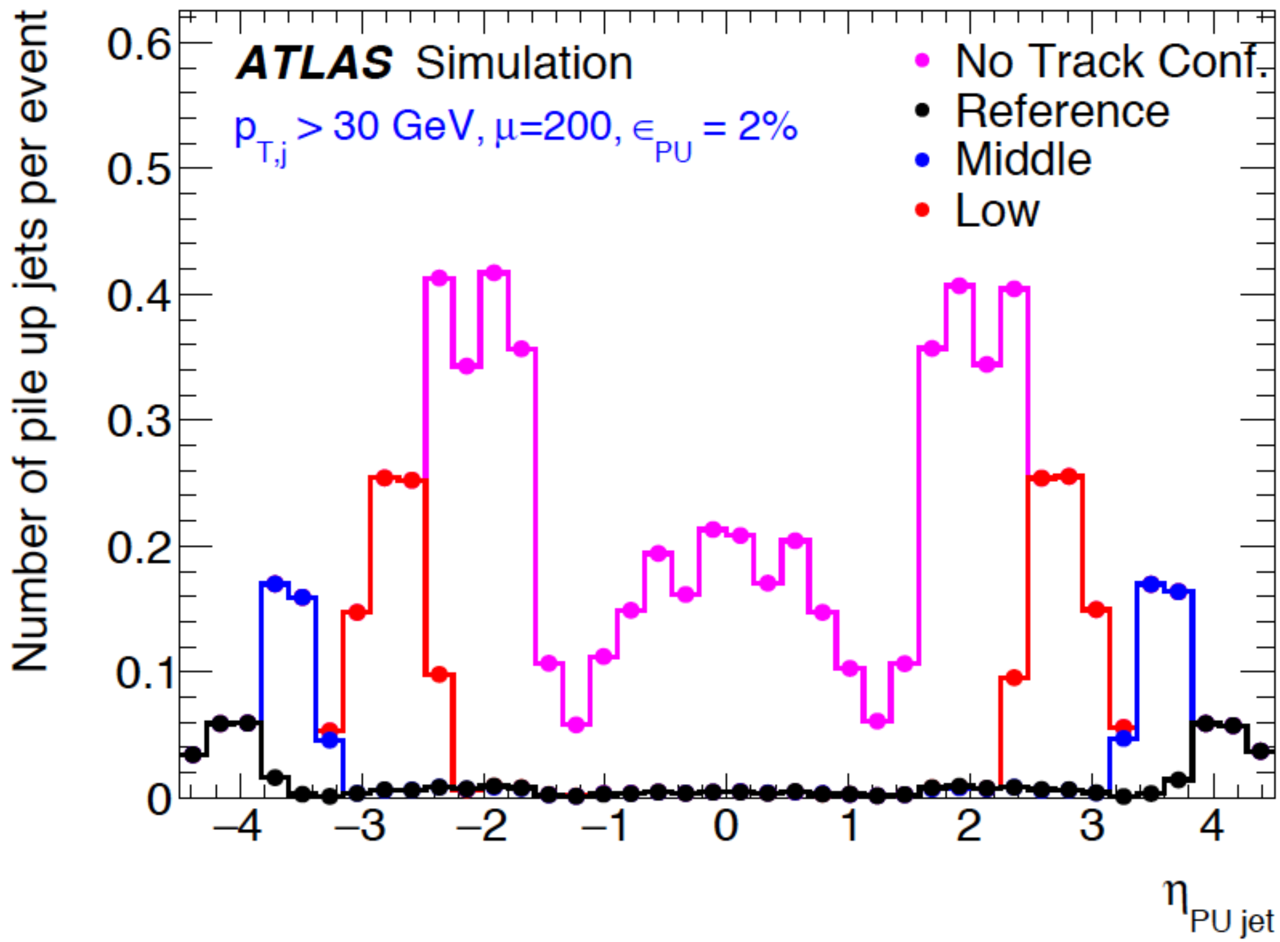




ITK Pileup

CERN-LHCC-2015-020 ; LHCC-G-166

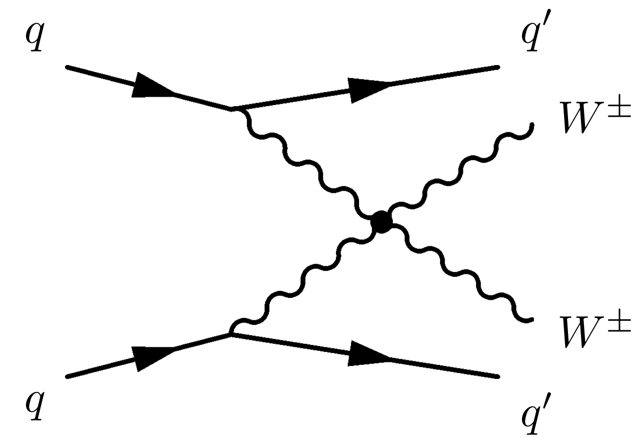
Pileup jets left after track information is used to subtract pileup jets:



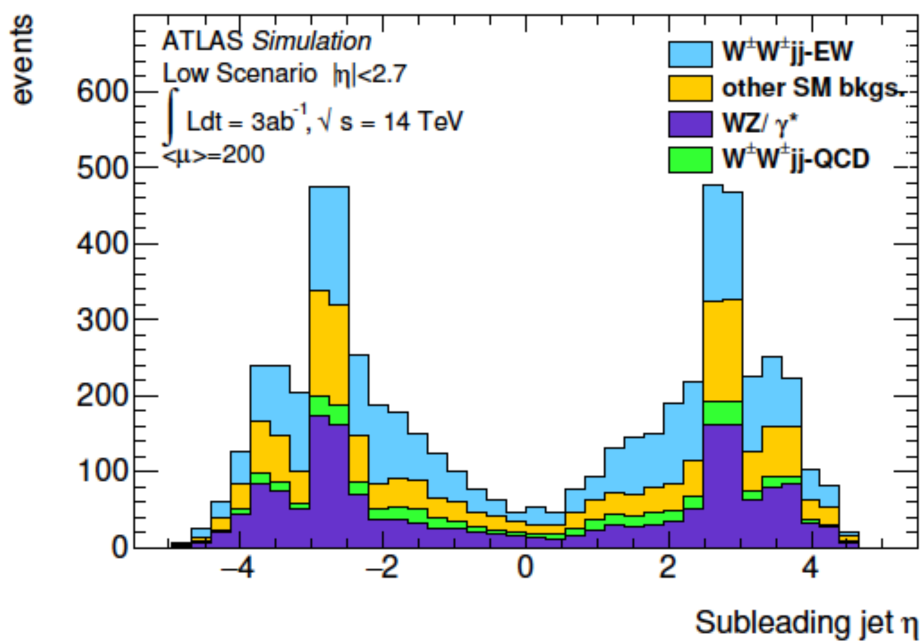
ITK $W^{\pm}W^{\pm}$

$W^{\pm}W^{\pm}$ Electroweak Vector Boson Scattering

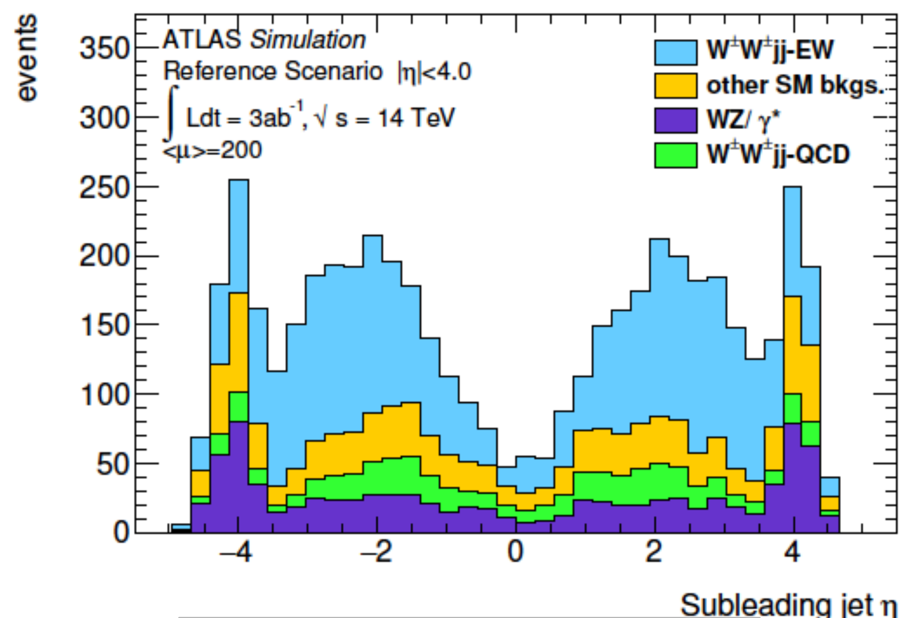
- Reference Scenario, tracker with $|\eta| < 4.0$
- pileup jets are subtracted to $|\eta| < 3.8$
- excess of events are observed in the area without pileup subtraction



Low Scenario $|\eta| < 2.7$



Reference Scenario $|\eta| < 4.0$



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ITK Physics Results

The ITK can improve select vector boson scattering/fusion events by a factor of 2 !!

- pileup jet identification
- *lepton acceptance -> background reduction*
- *b-tagging efficiency*

Cross-section precision:

Scenario	VBF $H \to WW^{(*)}$	VBS ss$W^{\pm}W^{\pm}$
Reference	0.14	0.059
Middle	0.20	0.11
Low	0.30	0.13

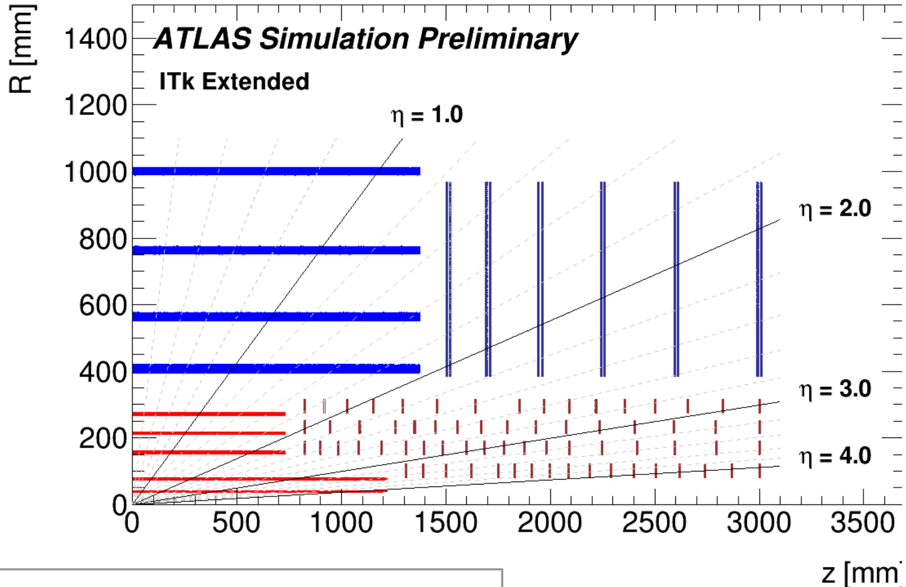
Scenario	SUSY $\chi_1^{\pm}\chi_2^{o} \to \ell b\bar{b}+X$		BSM $HH \to b\bar{b}b\bar{b}(M_{G^*_{KK}}$=2.0 TeV)	
	Mass (GeV)	$\mathcal{L}^{\text{int}}_{\text{equiv.}}$ [fb^{-1}]	Significance	$\mathcal{L}^{\text{int}}_{\text{equiv.}}$ [fb^{-1}]
Reference	850	3000	4.4	3000
Middle	770	6000	4.5	
Low	675	12000	3.1	7200

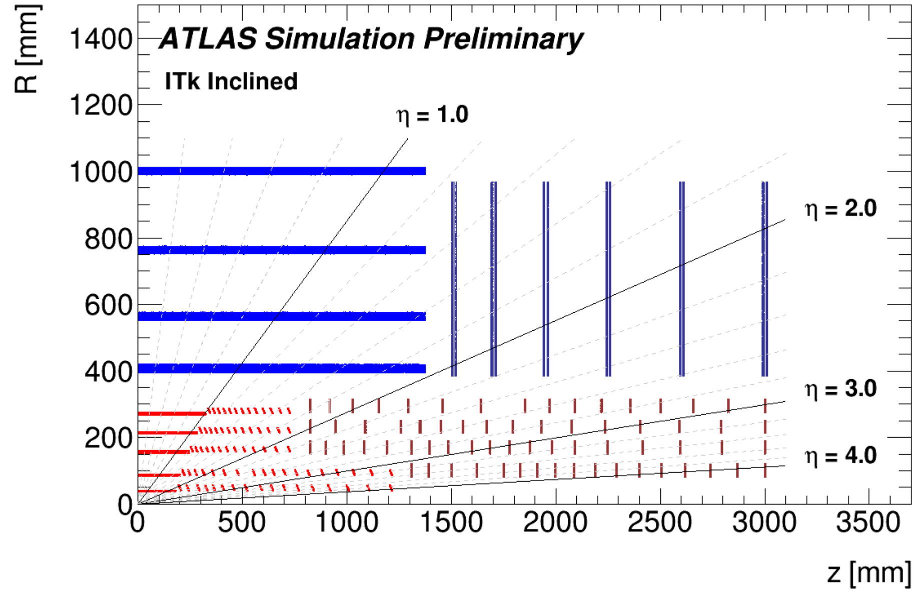
CERN-LHCC-2015-020 ; LHCC-G-166

Inner Detector Upgrade

Extended Inner Barrel

Inclined Inner Barrel





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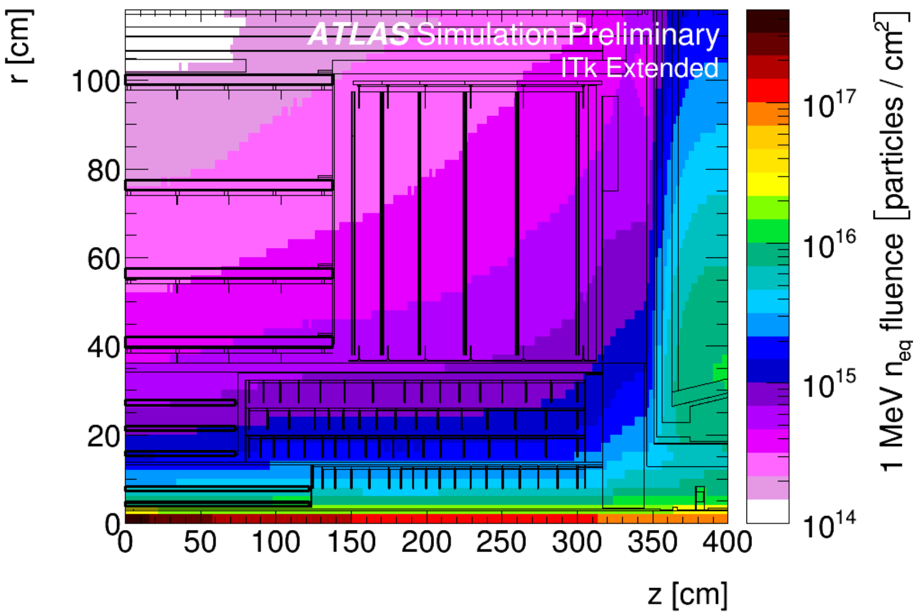
Extended (Inclined) layout

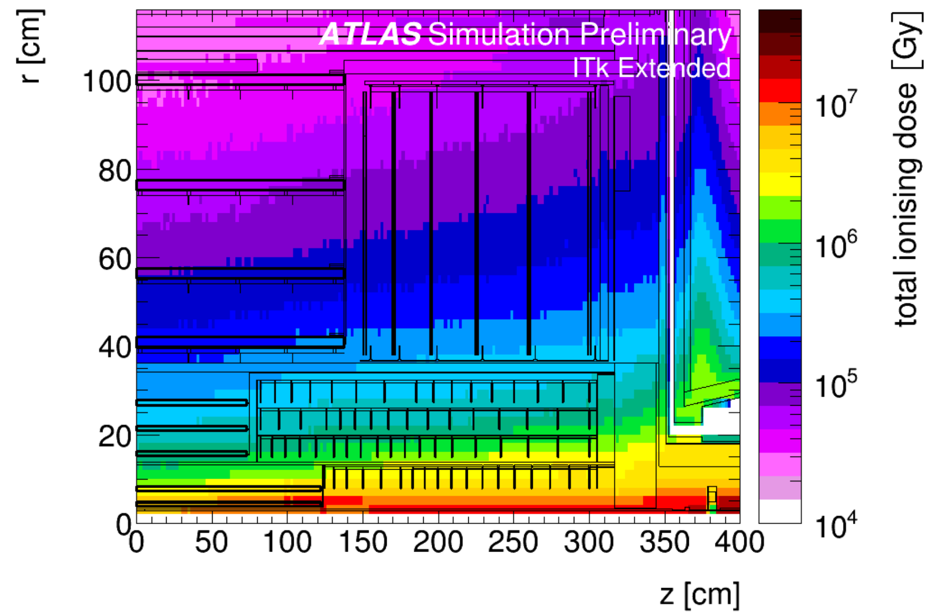
Layer	Module type	Half Stave Length [mm]	Radius [mm]	Inclined module $\|z\|$ positions [mm] (Inclined layout only)
0	2×1	1218 (1250)	39	193.8 – 1206.9
1	2×2	1218 (1250)	75 (85)	210.4 – 1206.5
2	2×2	731 (780)	155	250.1 – 719.6
3	2×2	731 (780)	213	291.7 – 719.5
4	2×2	731 (780)	271	332.7 – 719.4

ITK Pixel Detector Requirements

Neutron Fluence



Ionizing Dose



Requirements for the HL-LHC:

- Radiation tolerant ~$2x10^{16}$ 1 MeV n_{eq}/cm^2
- High granularity ~50 x 50 μm^2 pixel size
- Data transmission up to 5 Gb/s

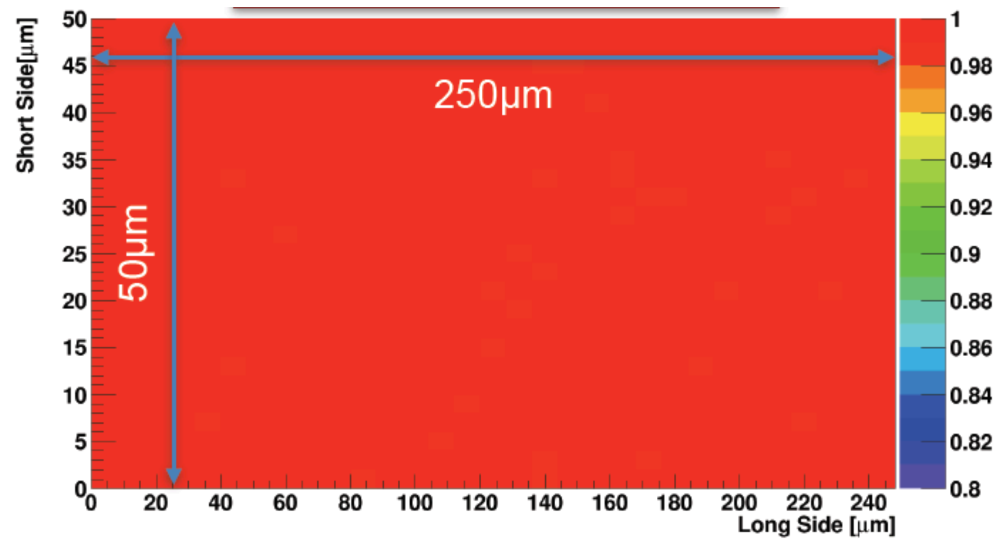
ITK Pixel: Planar Sensors

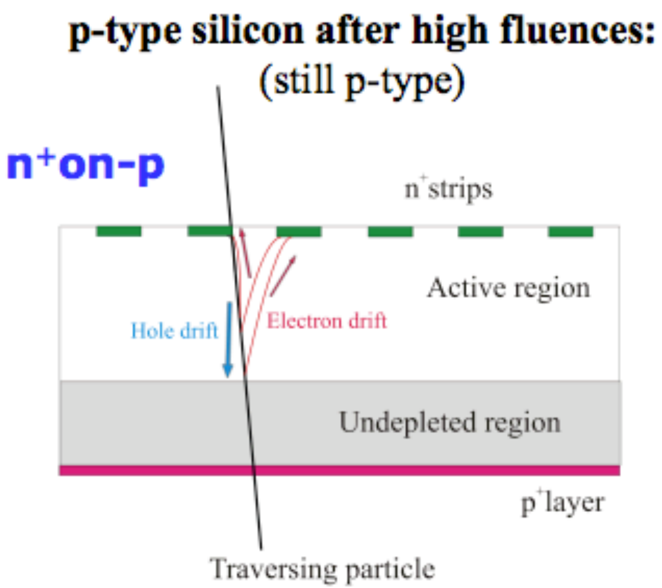
Planar Sensors

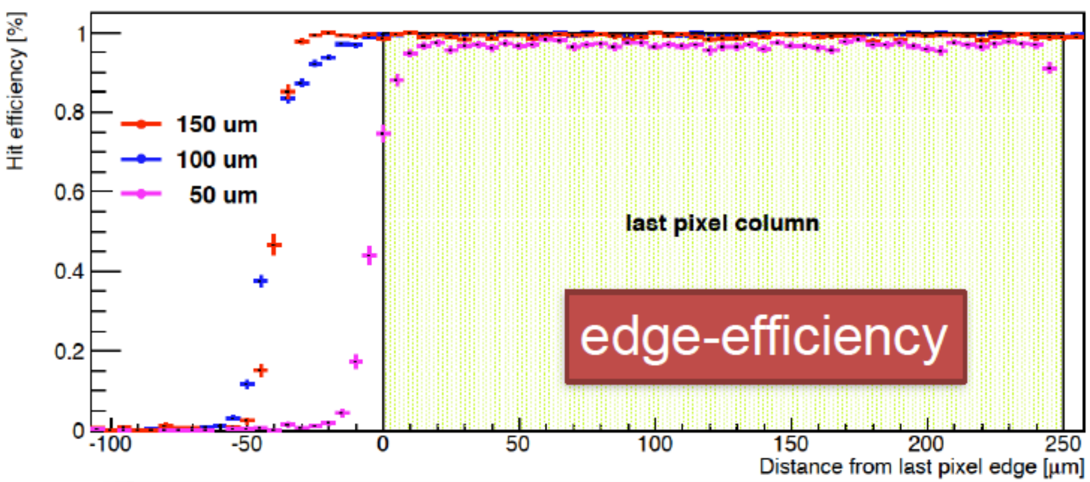
Improvements:

- Single sided processing
- Thinned 100-150 µm to reduce material
- Slim or Active edges to reduce dead space

=> very good, well known behavior

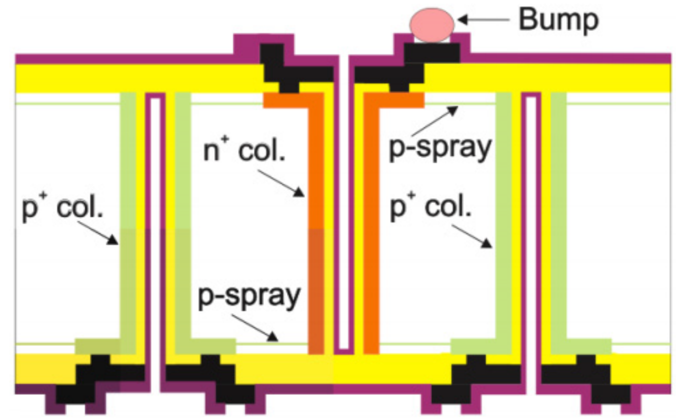


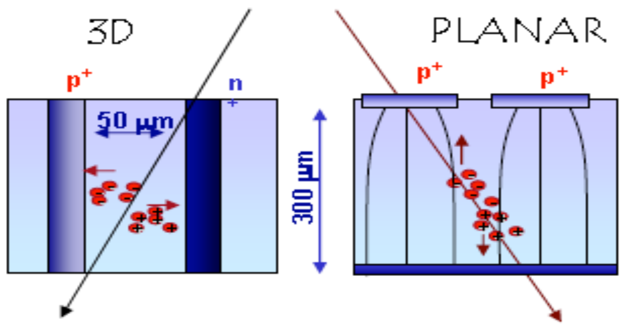


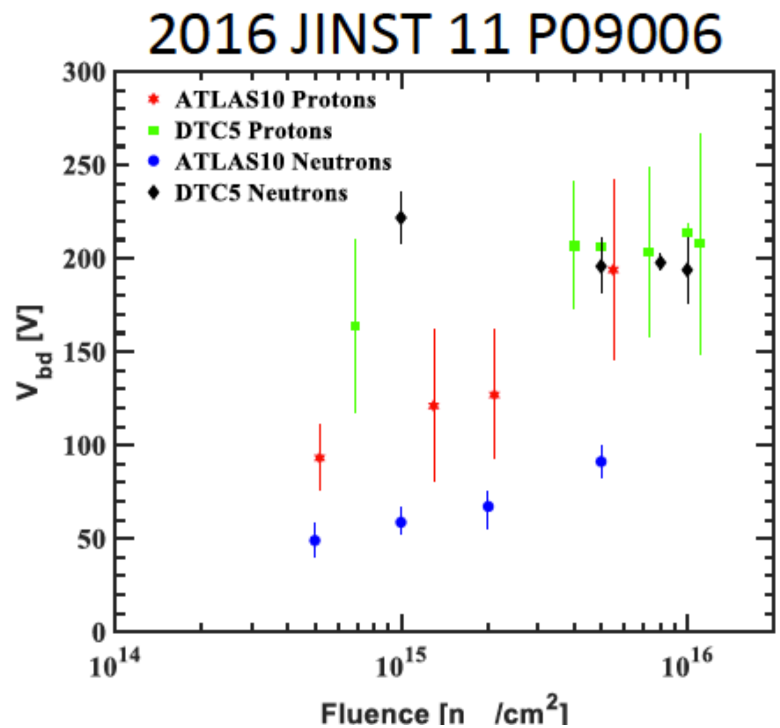


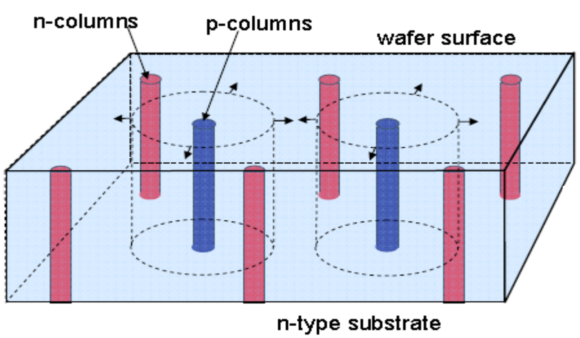
3D Sensors:

- Radiation hard to $1\text{x}10^{16}$ n_{eq}/cm^2
- Double or single sided geometries
- Closer electrodes
- Thinner sensors
- Slim or active edges







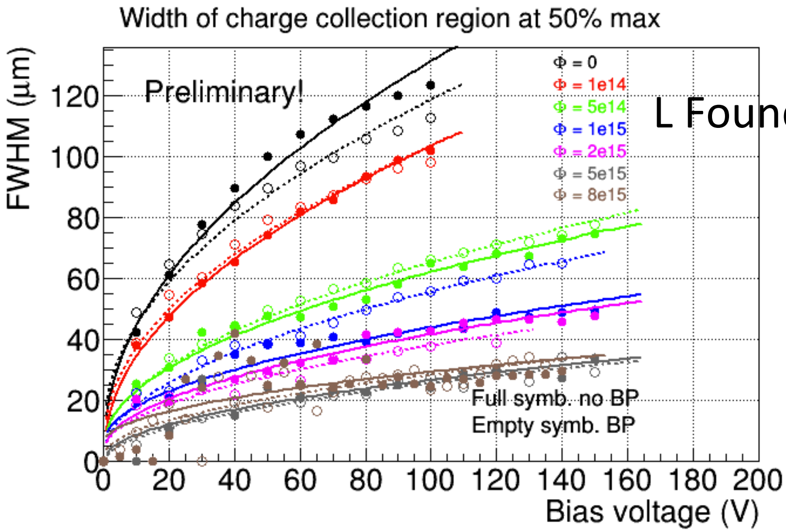


HVCMOS

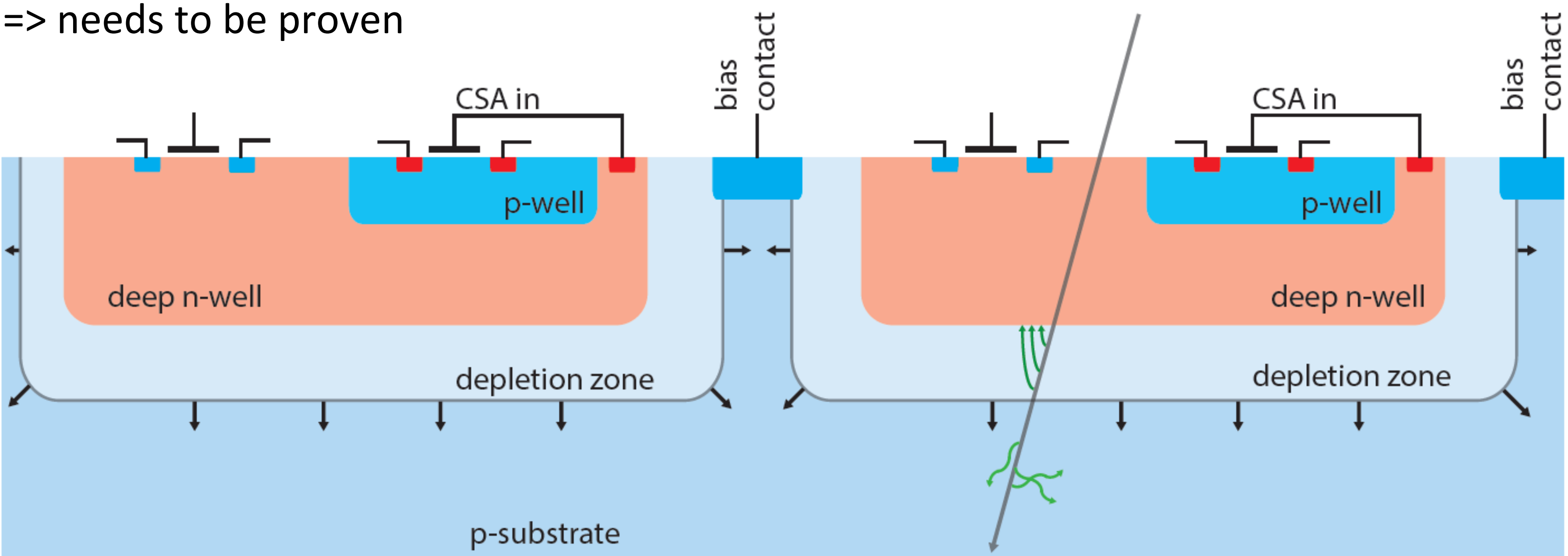
HVCMOS

- Integrated sensor + signal amplification
- Use commercially available CMOS processing with a few modifications
- Deep n-well to isolate on-pixel electronics
- high resistivity substrates for high voltage without breakdown
- designing for fully monolithic -> no bump bonding

=> needs to be proven



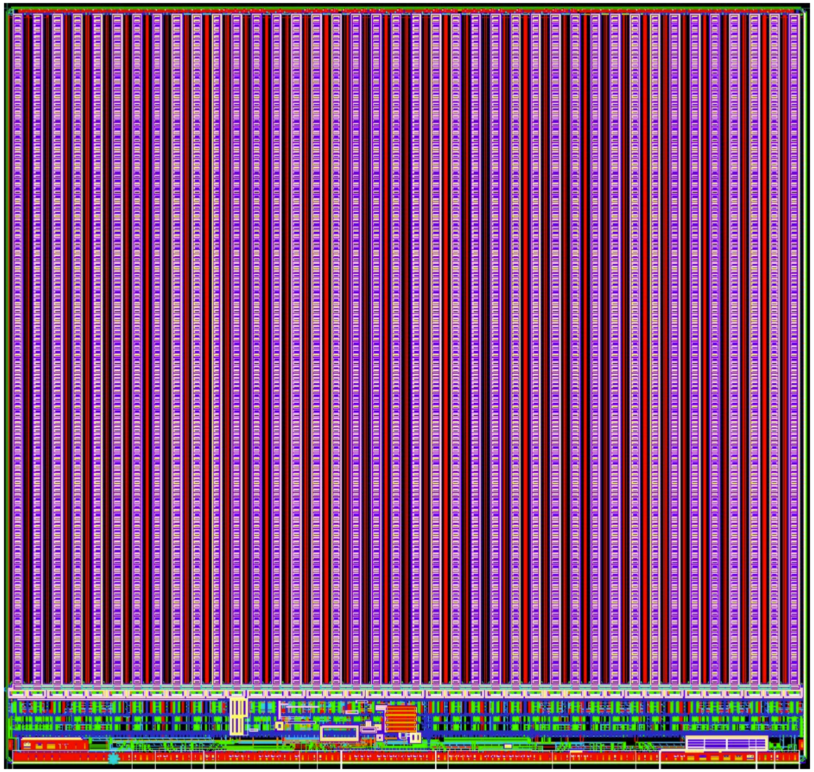
L Foundry



Pixel Detector Phase II Upgrade

FEI4 (Insertable B-Layer installed LS1)

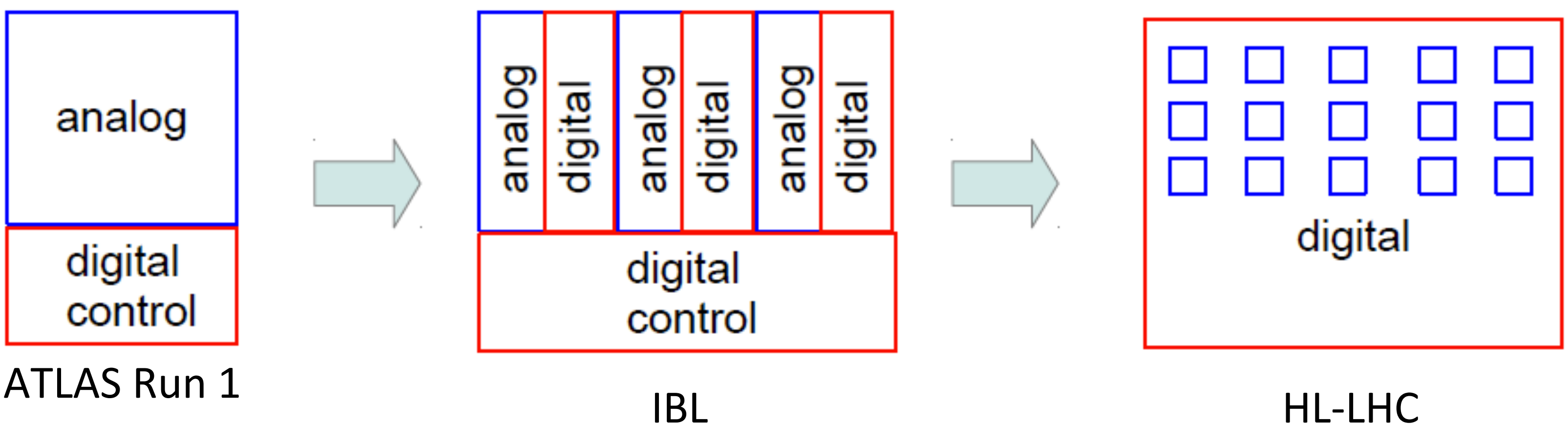
- 130 nm CMOS
- Pixel size 50 x 250 μm^2
- 80 x 336 pixels = 26,880 channels
- Overall size 19 x 20 mm^2
  - 2 mm periphery
- Data transmission 160 Mb/s
- 100 e^- noise (400 fF capacitance)
- 160 e^- untuned threshold dispersion
- 200 Mrad radiation tolerance
- 1.2 V
- 7 µW/pixel for digital



ITK Pixel: ATLAS FE Chip (RD53)

	RD53	*FE-I4*
technology	65 nm	*130 nm*
Pixel dimension	50 µm x 50 µm	*50 µm x 250 µm*
# of pixels	~140 000	*26880*
chip dimension	18 mm x 20 mm	*19 mm x 20 mm*
hit rate	3 GHz/cm^2	0.4 GHz/cm^2
in-time threshold	< 1000 e	*< 4000 e*
typ. noise (ENC)	< 100 e	*< 300 e*
bandwidth	5 Gb/s	*160 Mb/s*
rad. hardness	> 5 MGy	*> 2.5 MGy*

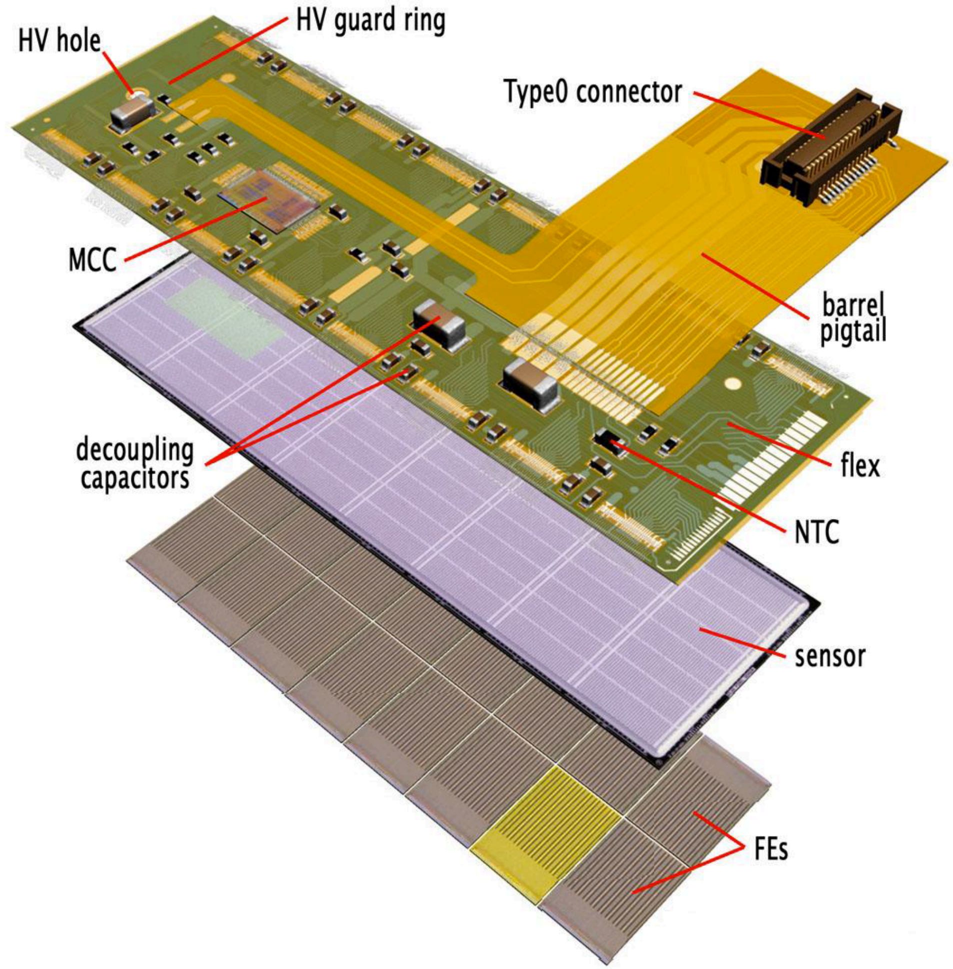
- Design is in collaboration with CMS through RD53
- RD53A submitted next spring
- See talk by Farah Fahim this afternoon

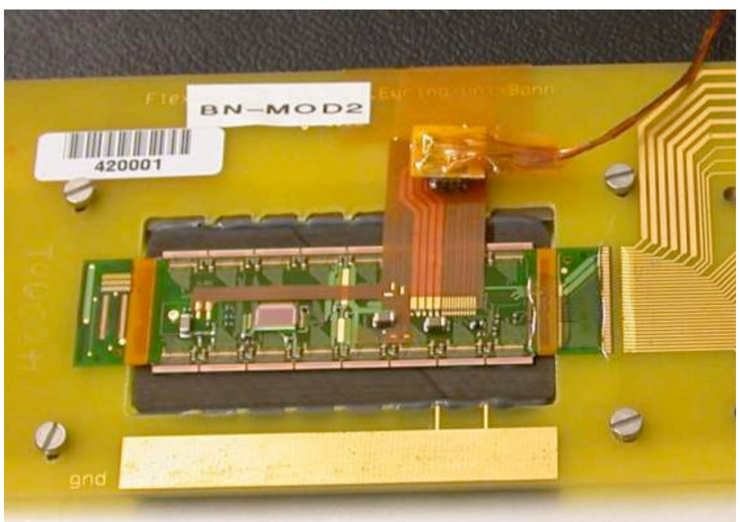


ATLAS Pixel: Original

Pixel Sensors for ATLAS

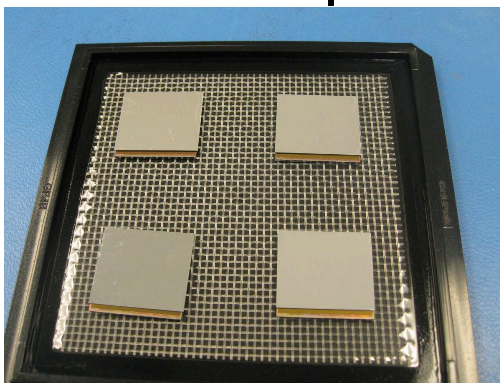
- 16 FE’s per module
- 250 µm tick n-type Float Zone (FZ)
- 80 million read-out channels
- 1.7 m^2
- Pixel size: 50 µm x 400 µm
- resolution: 10 µm in r-ϕ, 115 µm in z





ITK Pixel: Quad Module

4 FE Chips



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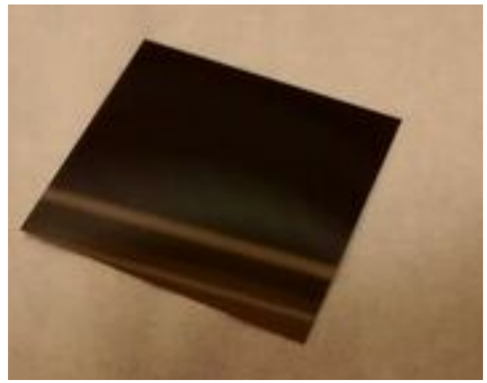
Sensor



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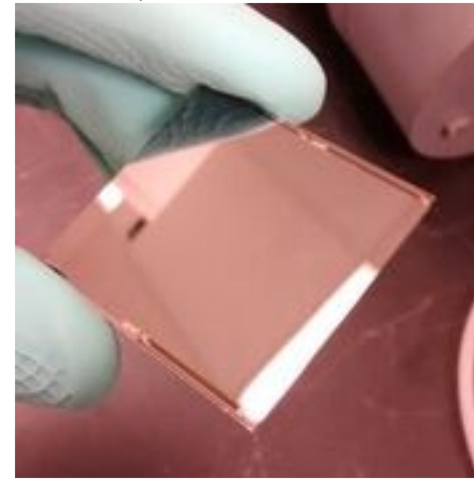
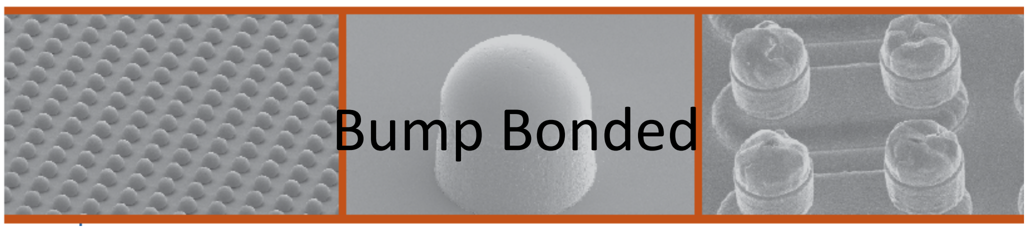
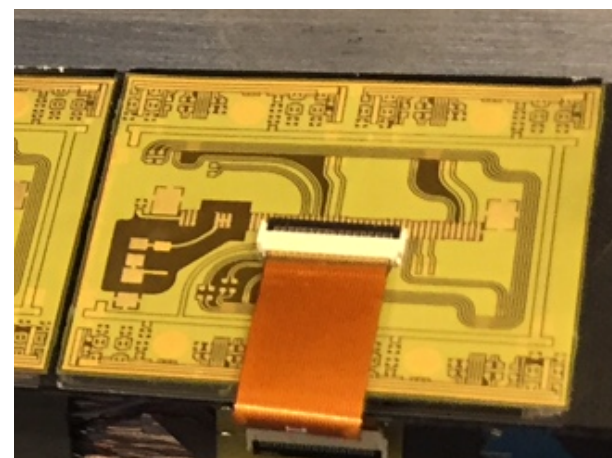
Quad Module



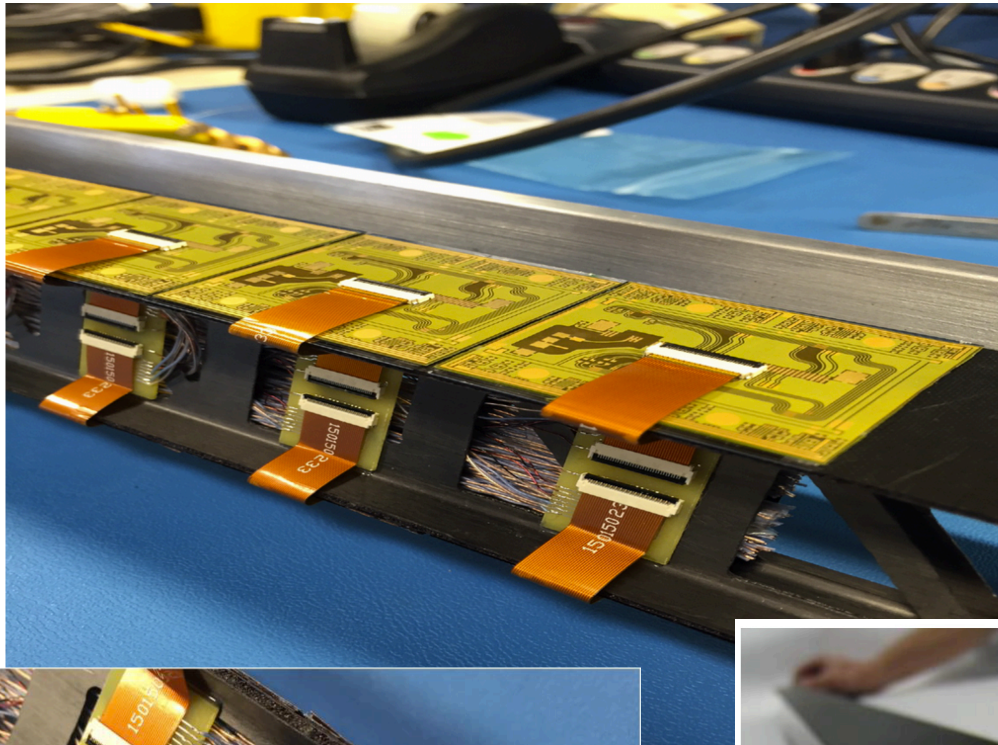


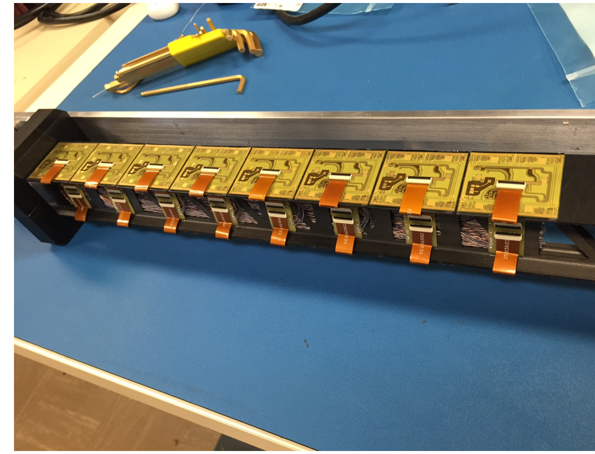
Quad Module Flex Cable

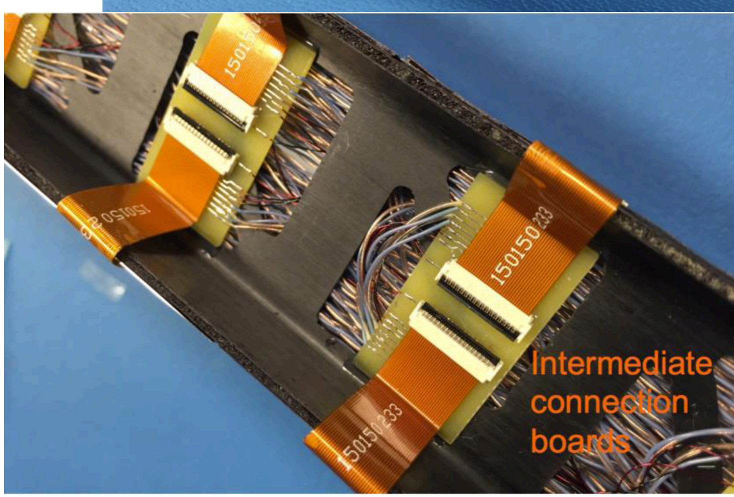


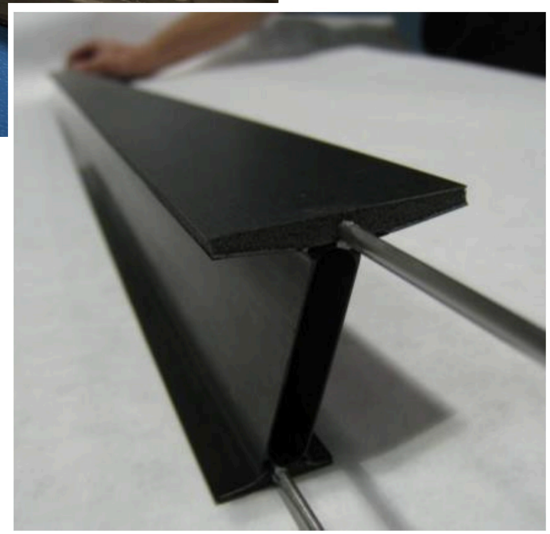
- ~10,000 pixel modules
- Up to 16 m^2
- Pixels: 50 µm x 50 µm (25 µm x 100 µm)

ITK Pixel I-beam



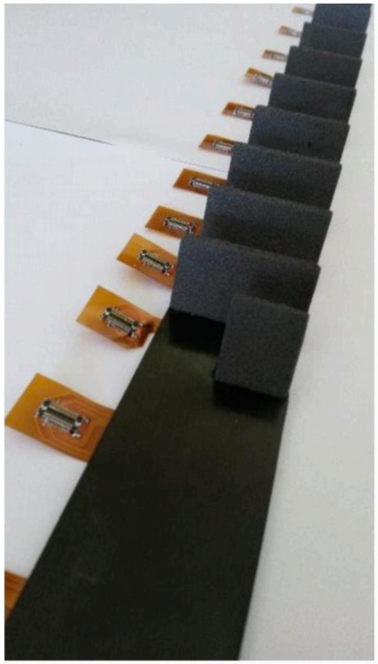


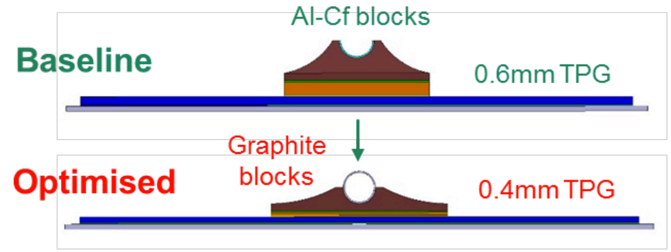


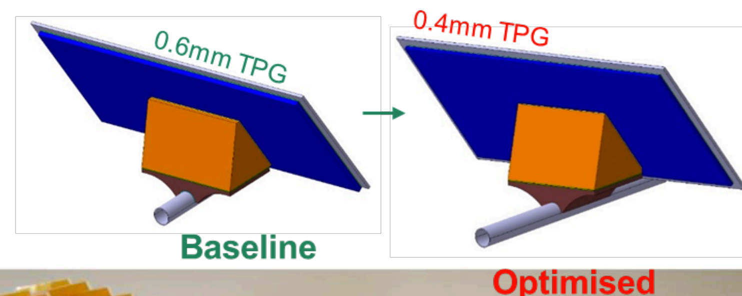


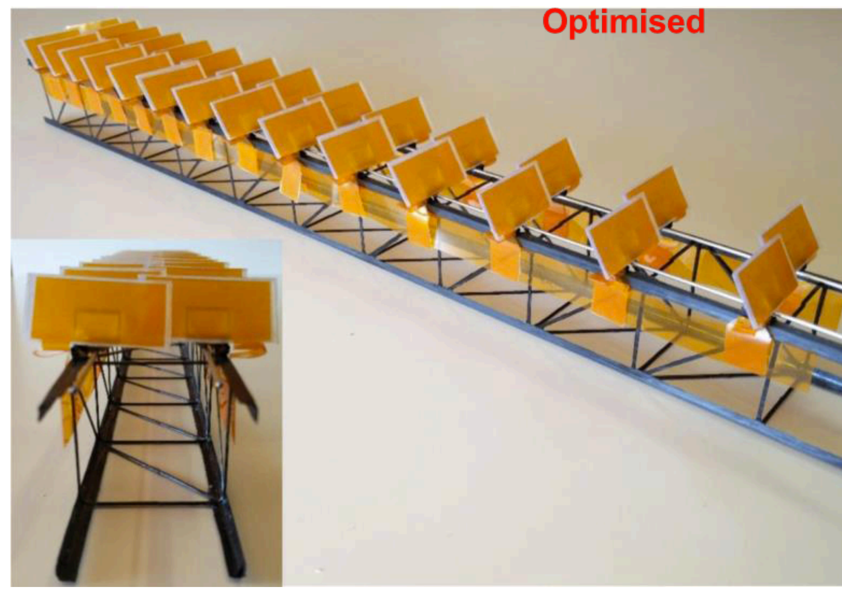
- Simple efficient design
- Low material budget

ITK Pixel Alpine/Slim



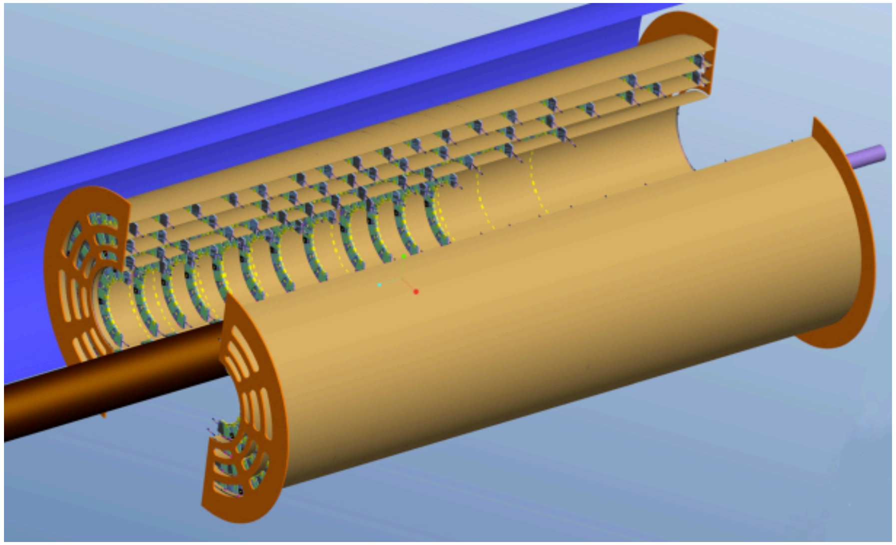


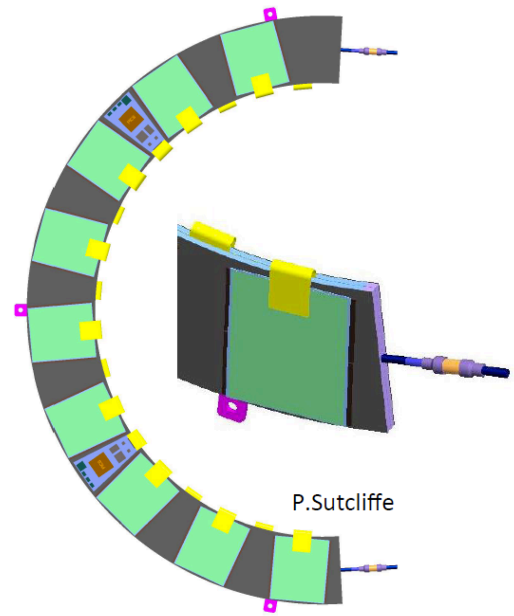


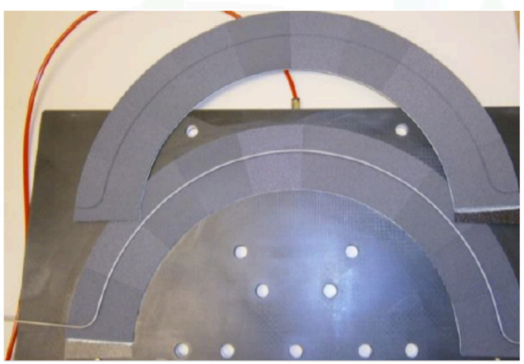


- Optimized for track efficiency
- Fewer modules needed
- More complex assembly

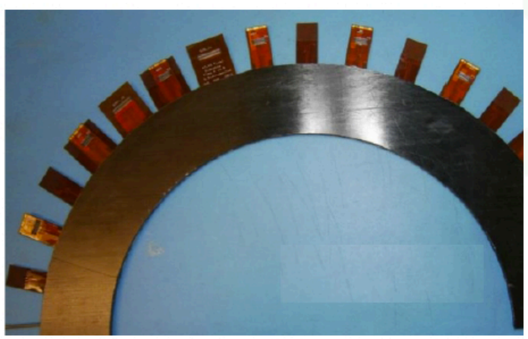
ITK Pixel EndCaps



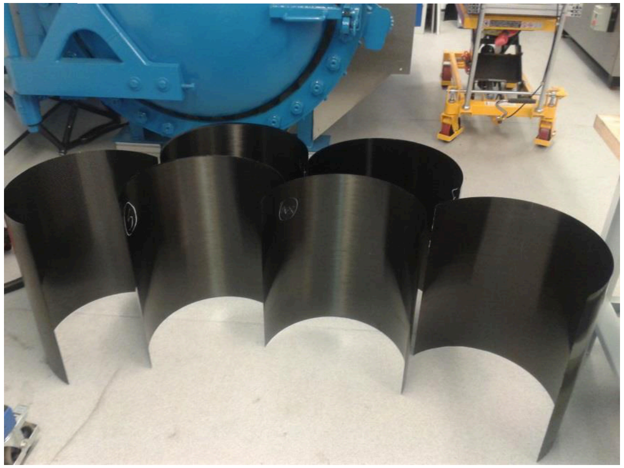




Titanium CO_2 cooling pipe embedded in ring.



Electrical services (flex) embedded in ring.



ITK Pixel: Radiation Length

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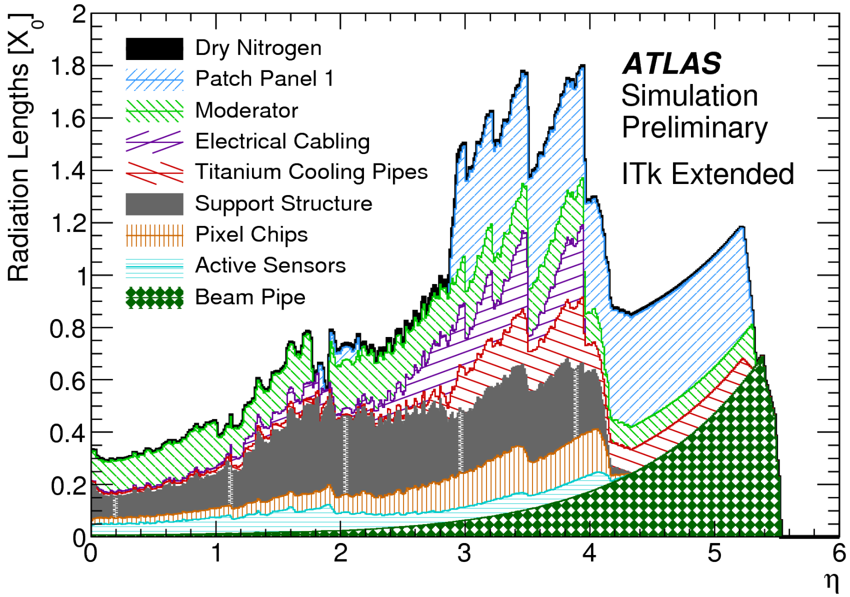
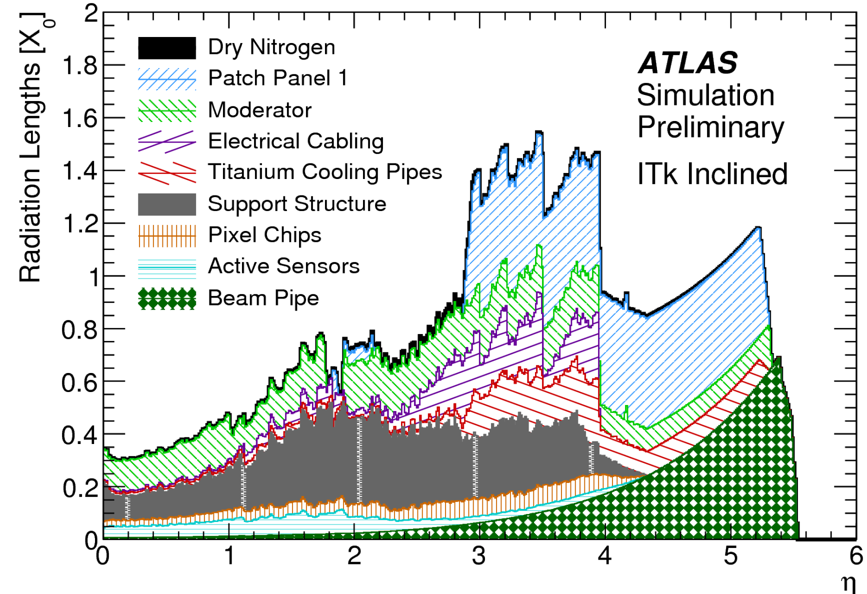
Extended



Inclined



- Material distribution similar for both layouts
- Work in progress

ITK Pixel: Cluster Performance

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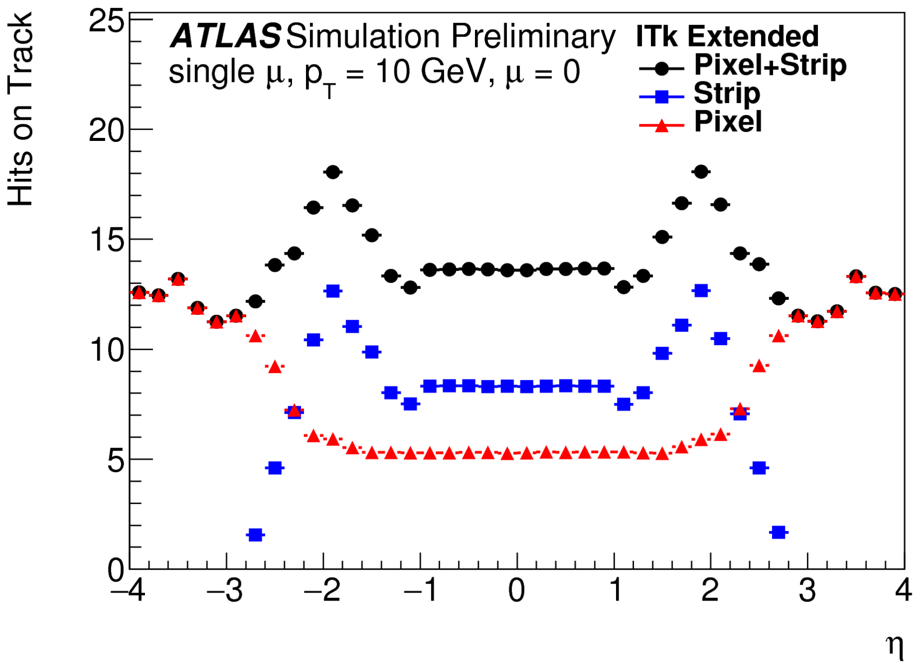

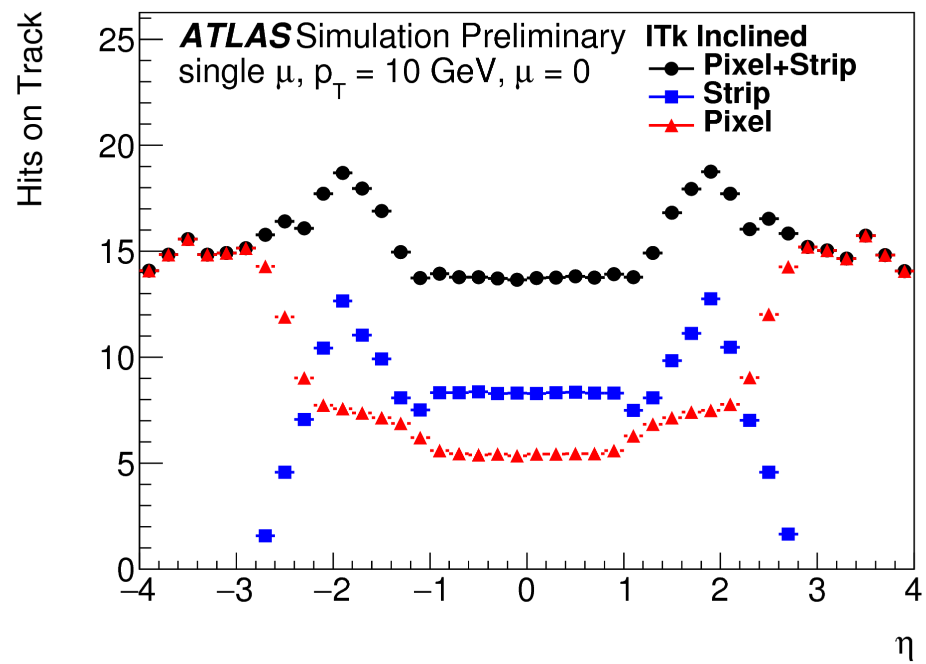

- Full tracking coverage out to $|\eta| < 4$
- More hits on average for inclined layout especially in forward regions

ITK Pixel: Tracking Efficiency

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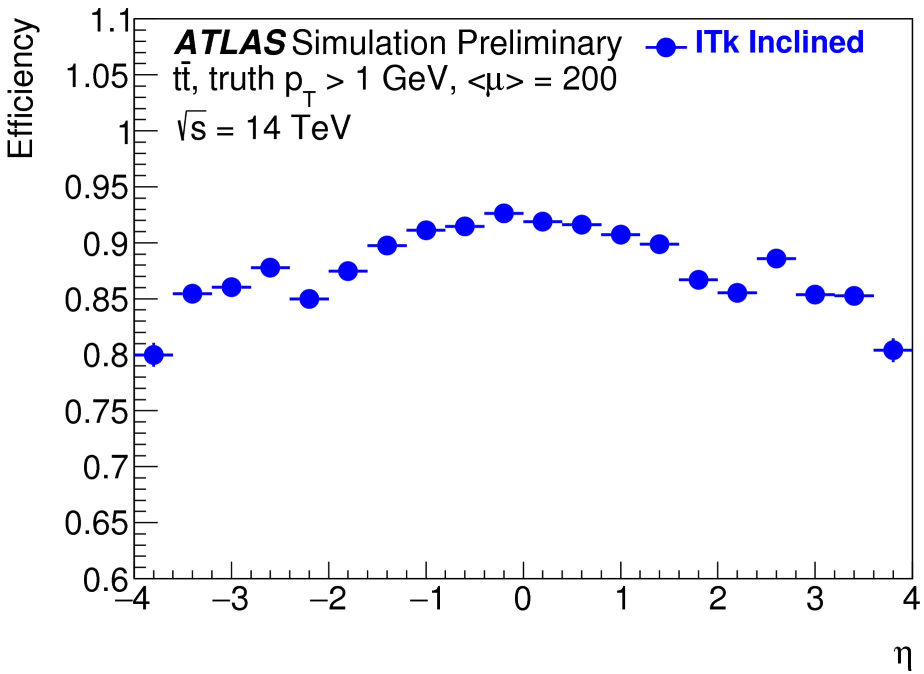
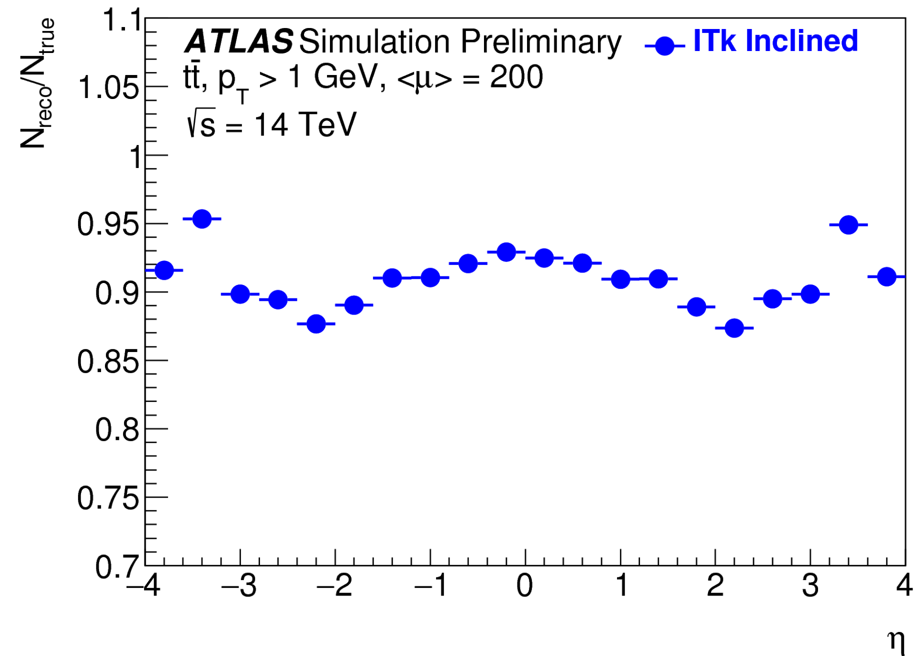
Reconstruction efficiency



Fakes: N_Reconstructed/N_Truth



- Good tracking efficiency across the full detector acceptance
- Secondary and fake tracks are well under control
- Inclined layout is representative of expected ITK performance

IT Pixel: Impact Parameter Resolution

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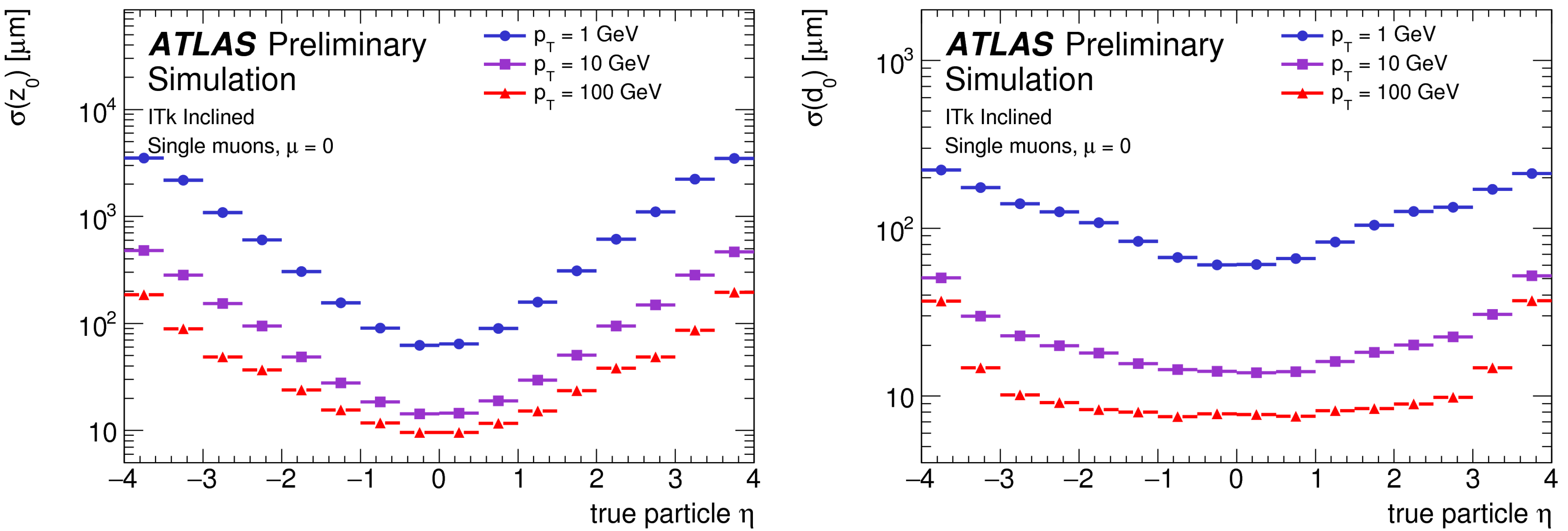

- Excellent impact parameter performance
- d_0 <30 μm for |η| < 3.5 , < 50 μm for |η| < 4 for p_T = 10 GeV muons
- z_0 <300 μm for |η| < 3.5 , < 450 μm for |η| < 4 for p_T = 10 GeV muons

Summary

- ITK Pixel design is well underway
  - Tracker extension out to $|\eta| < 4$ is well motivated by physics
    - VBF, VBS, and other forward jet signatures
    - Extend reach of SUSY
    - Improve precision Higgs measurements
  - In the process of selecting final layout concept
    - Extended or Inclined, some of both?
  - Sensor technology under investigation
    - Planar
    - 3D sensors
    - HVCMOS monolithic sensor
  - FE chip design on critical path
    - via RD53 collaboration
  - First performance results look promising

Backup

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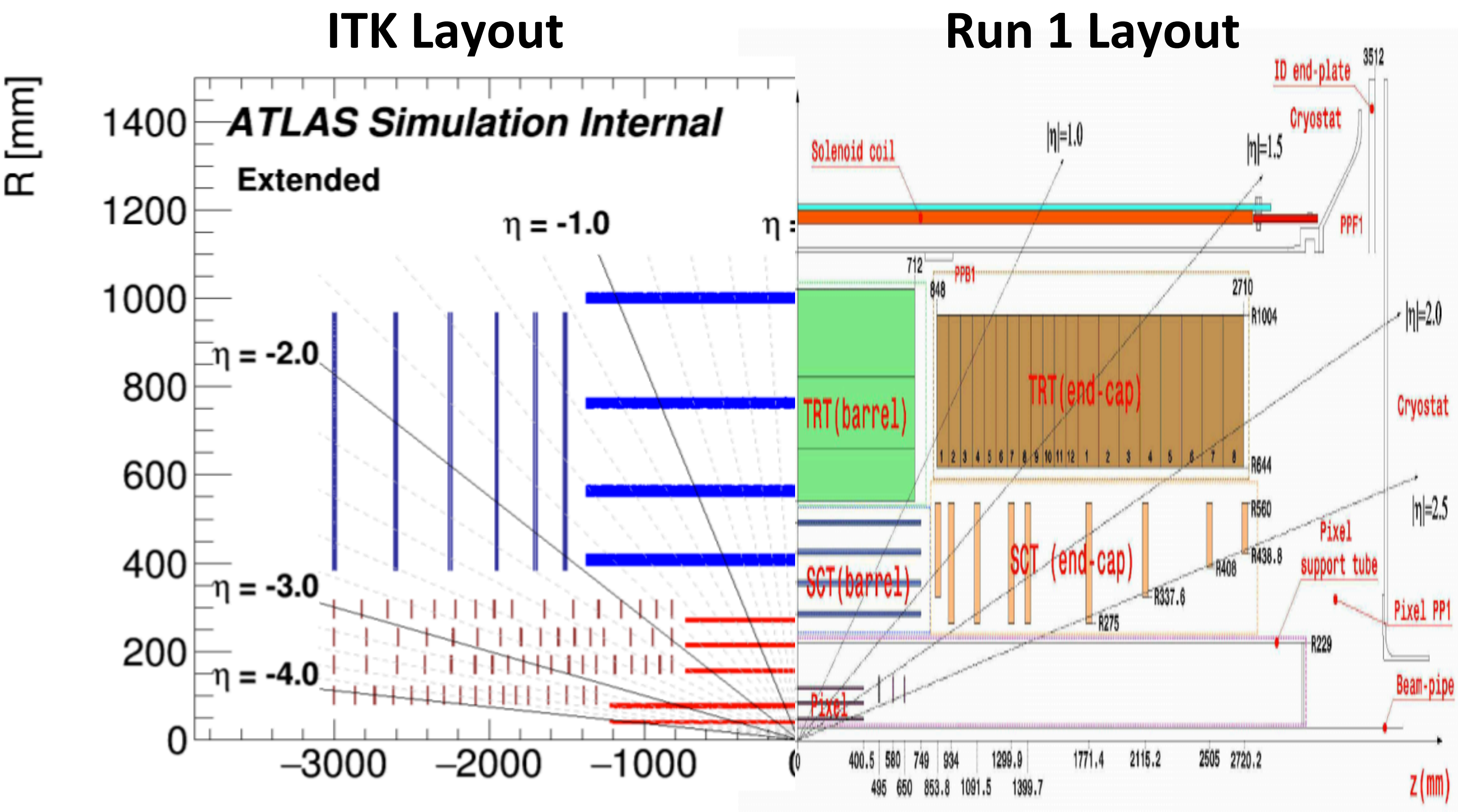
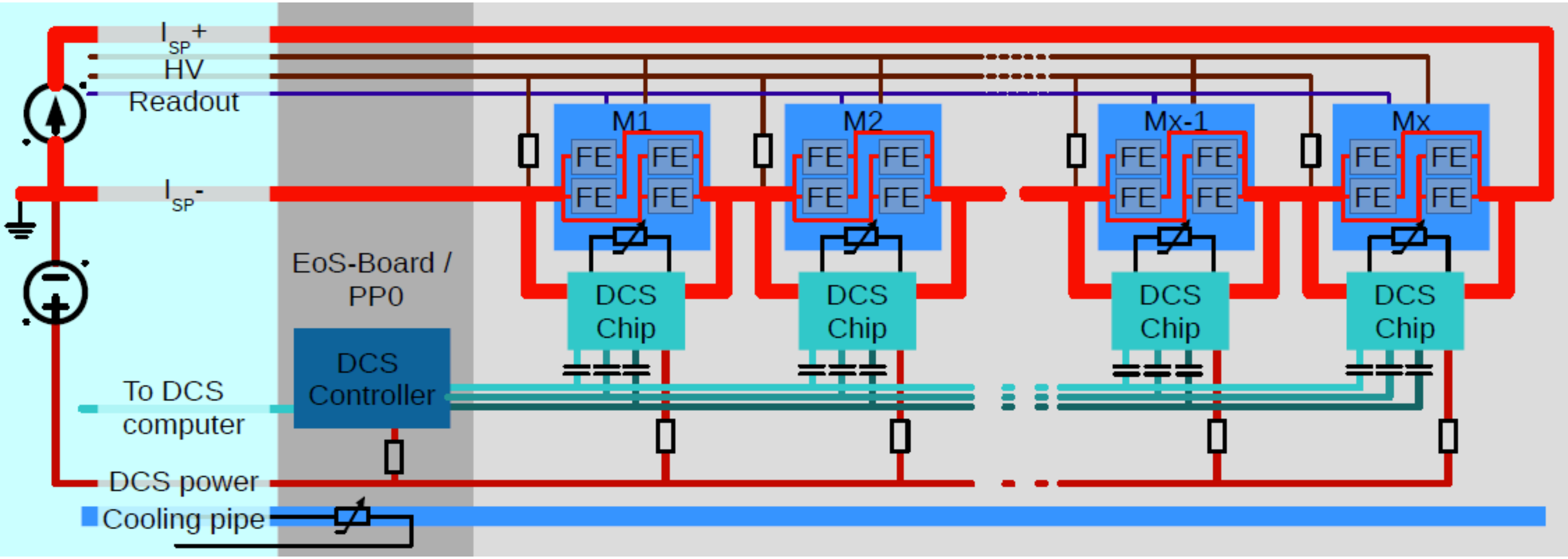


Pixel Detector Phase II Upgrade

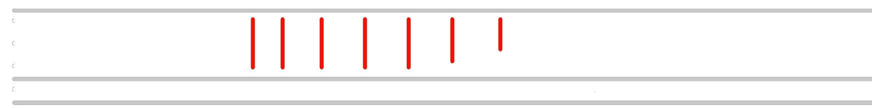
Services: serial powering



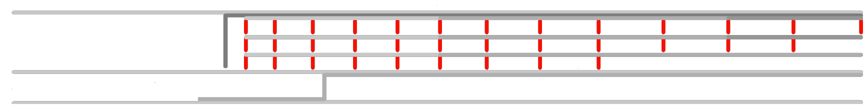
Inner Detector Upgrade

EndCap evolution

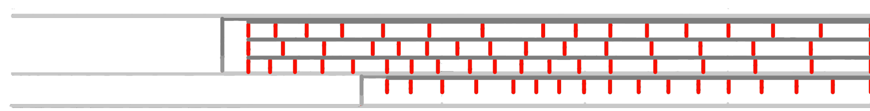
1) LOI EndCap disks



2) Ring system |η|<3.2



3) Optimized rings

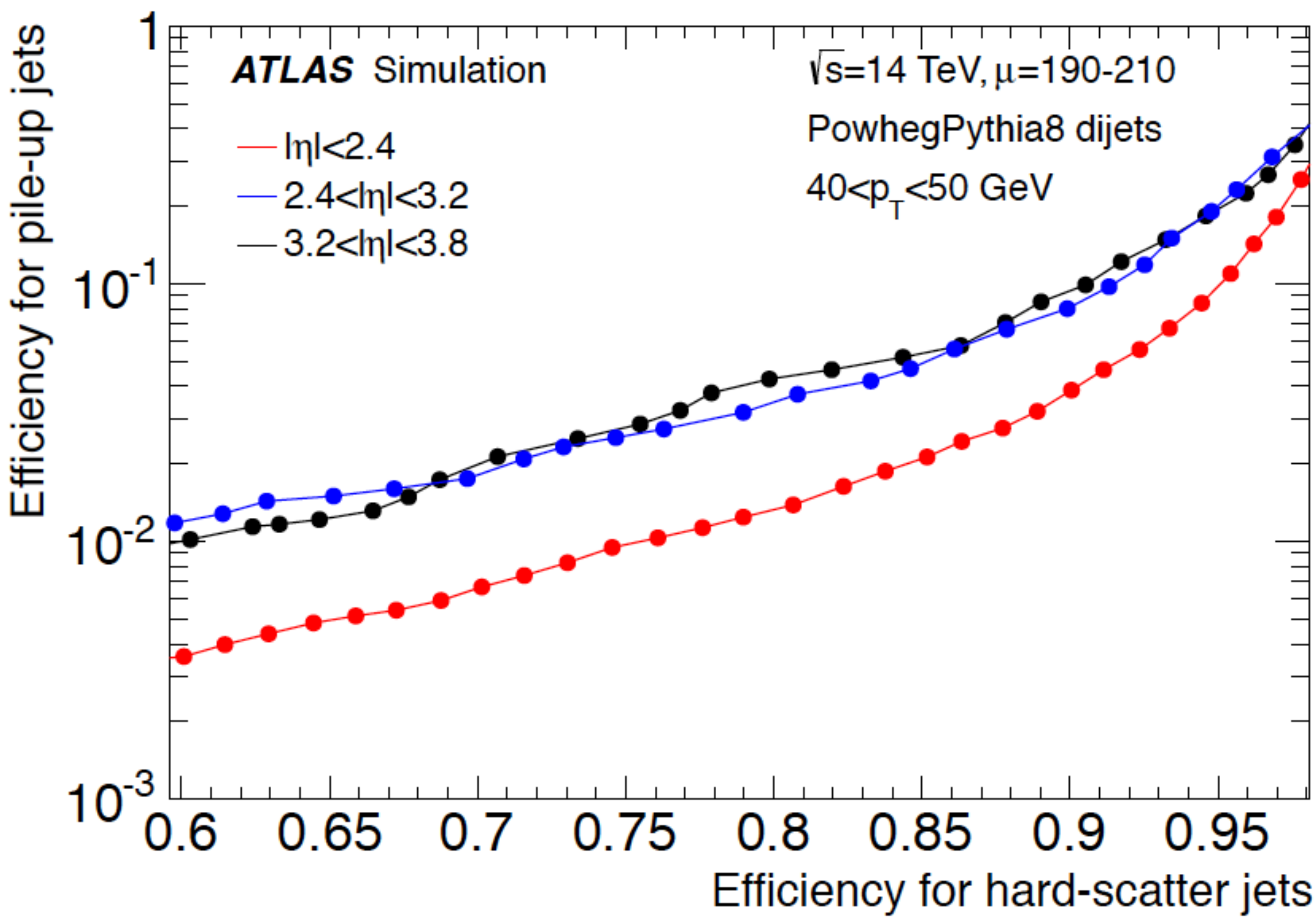


ITK Jets

CERN-LHCC-2015-020 ; LHCC-G-166

Pileup jet versus hard scatter jet efficiency:

- limit is reached for pileup rejection based on calorimeter coverage ECal/HCal -> FCal

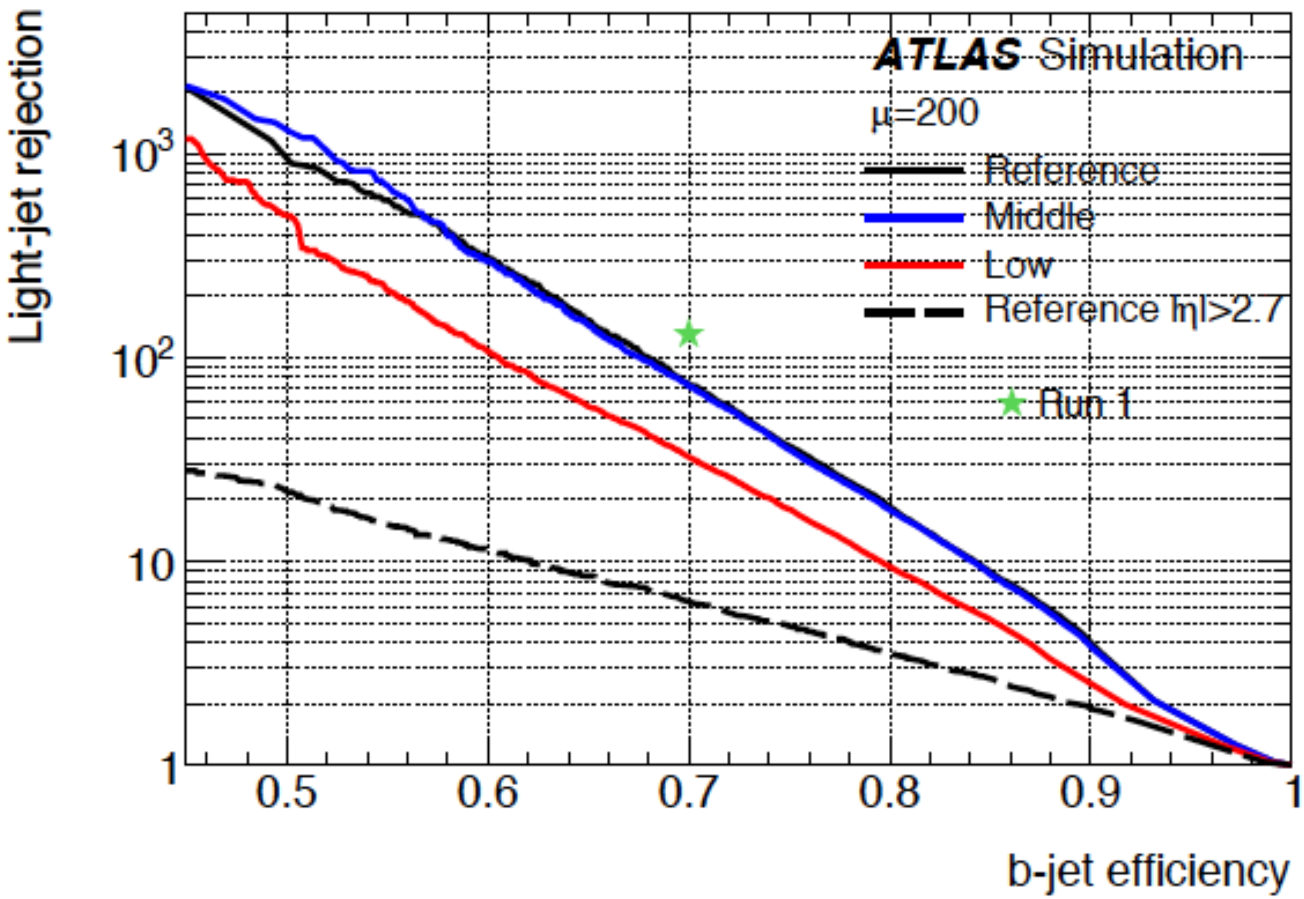


ITK b-tagging

CERN-LHCC-2015-020 ; LHCC-G-166

b-tagging

- increased material negates benefit between middle and reference scenarios

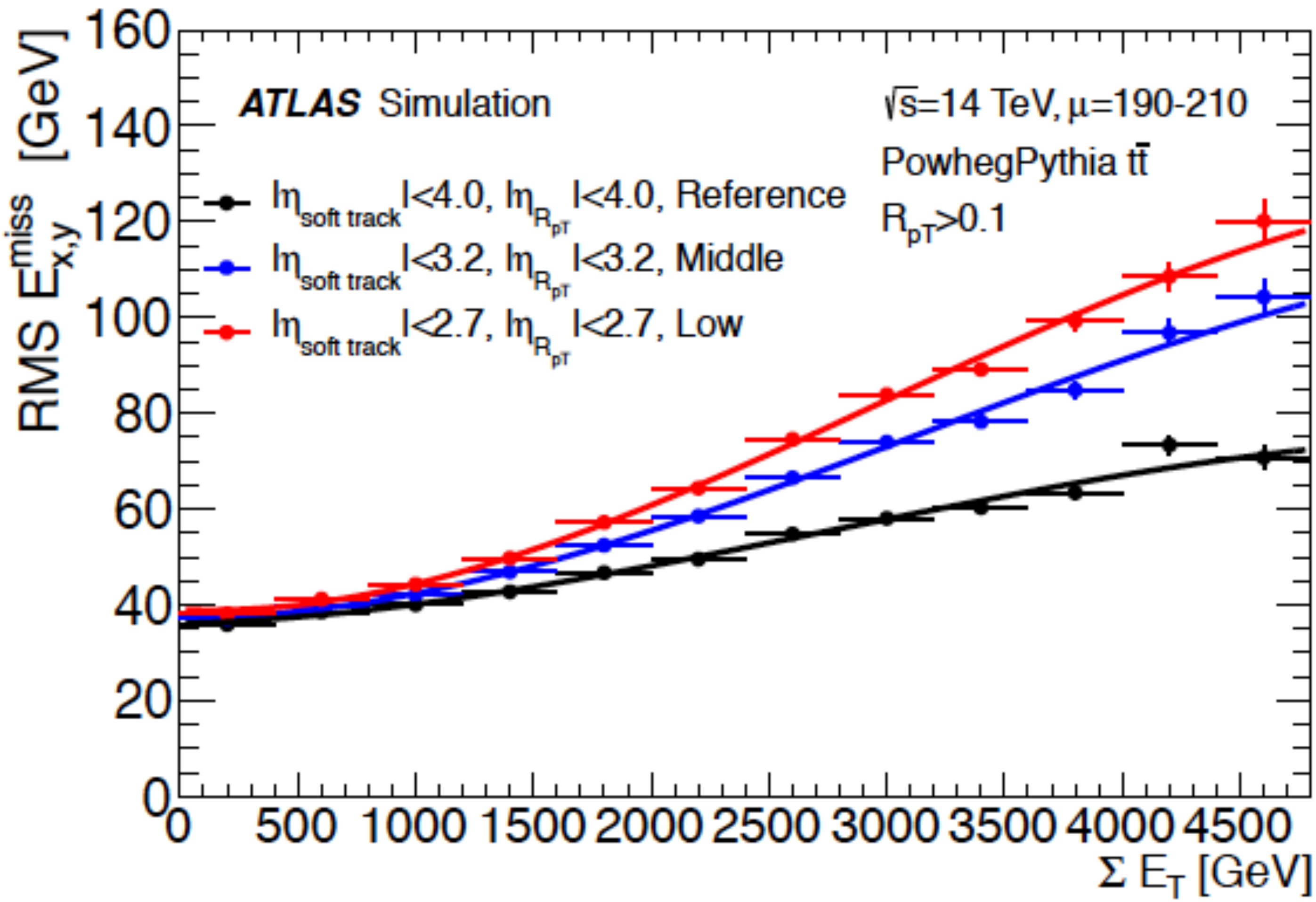


ITK MET

CERN-LHCC-2015-020 ; LHCC-G-166

MET energy resolution:

- definite benefit for large MET, above 1 TeV



ITK Physics

Physics process studies for the Scoping Document, i.e. for the HL-LHC:

- √s = 14 TeV
- $$\int Ldt = 3,000\ fb^{-1}$$
- <μ> = 200 (average number of interactions per event)

Detector system	Trigger–DAQ		Inner Tracker	Inner Tracker + Muon Spectrometer	Inner Tracker + Calorimeter		
Object Performance / Physics Process	Efficiency/ Thresholds						
	$\mu^{\pm}$	$e^{\pm}$	b-tagging	$\mu^{\pm}$ Identification/ Resolution	Pile-up rejection	Jets	E_T^{miss}
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓	✓	✓	✓	✓	✓
SUSY, $\chi_1^{\pm}\chi_2^{0} \rightarrow \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \rightarrow b\bar{b}b\bar{b}$			✓			✓	

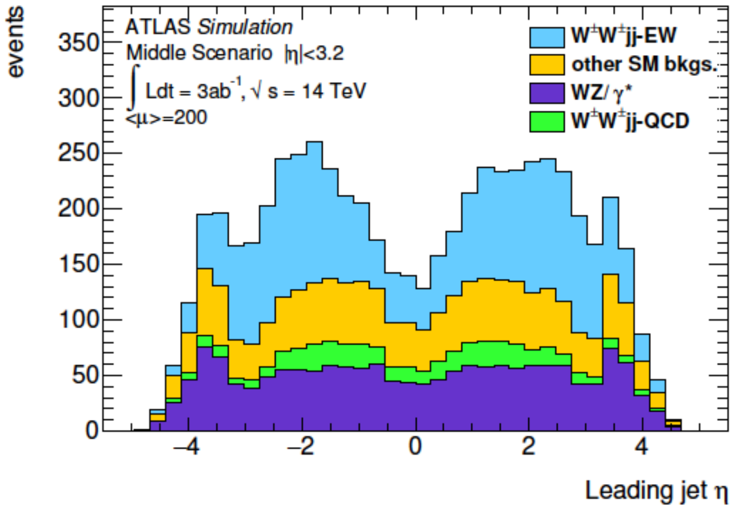
CERN-LHCC-2015-020 ; LHCC-G-166

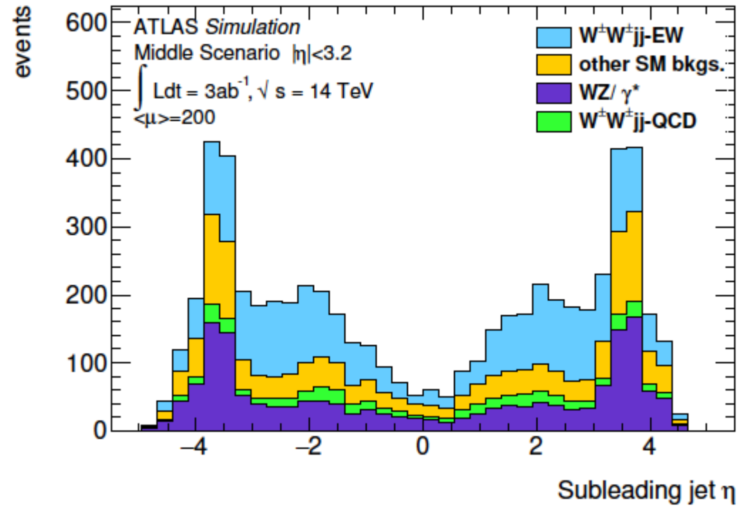
ITK W±W±

Pileup becomes more of an issue with less tracker coverage

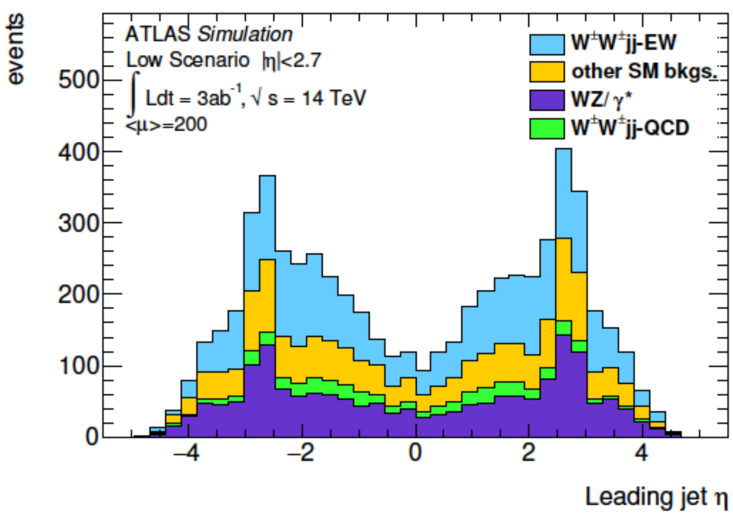
Leading Jet | **Subleading Jet**

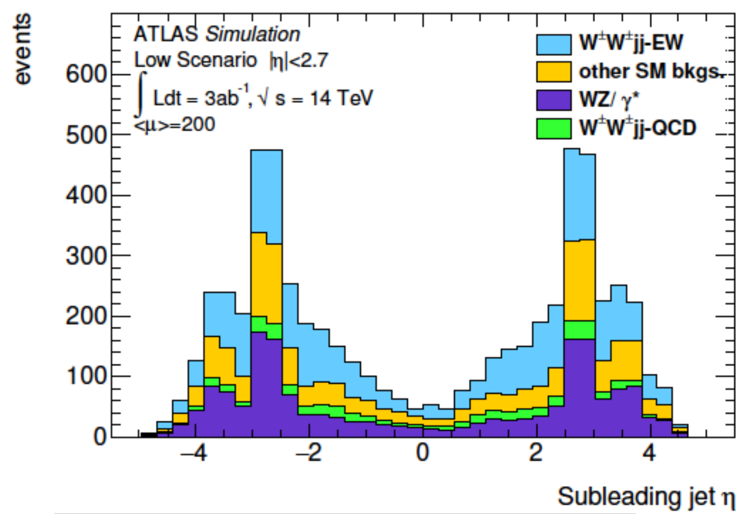
Middle Scenario: |η|<3.2





Low Scenario: |η|<2.7



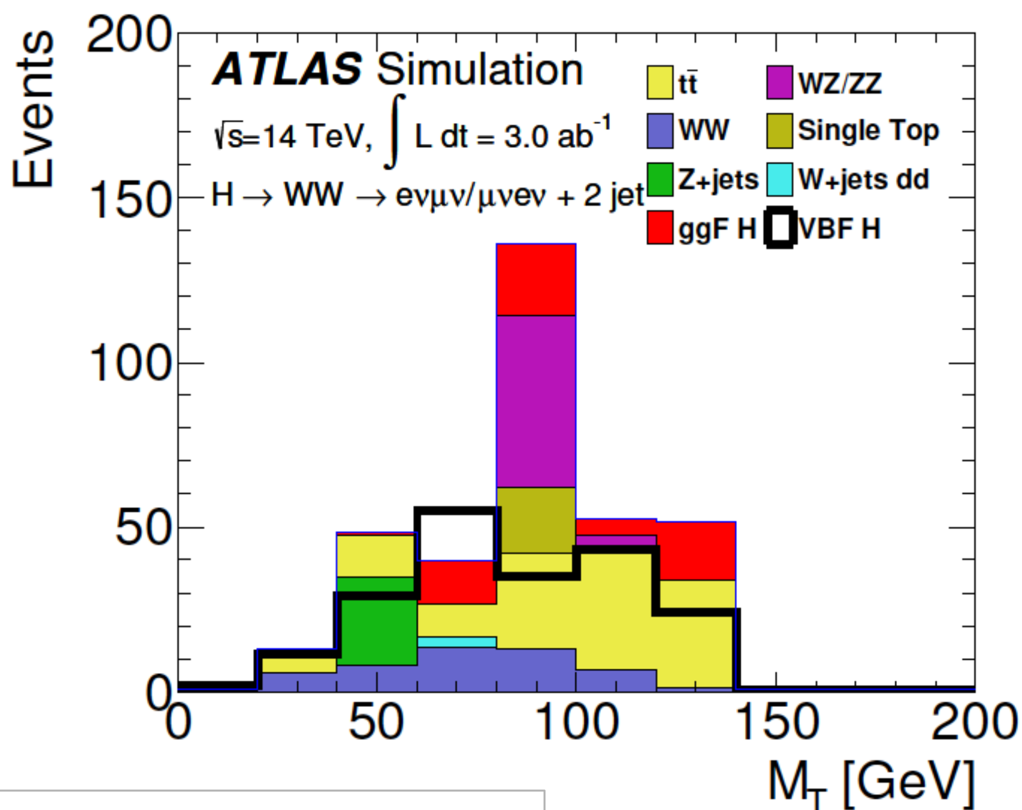


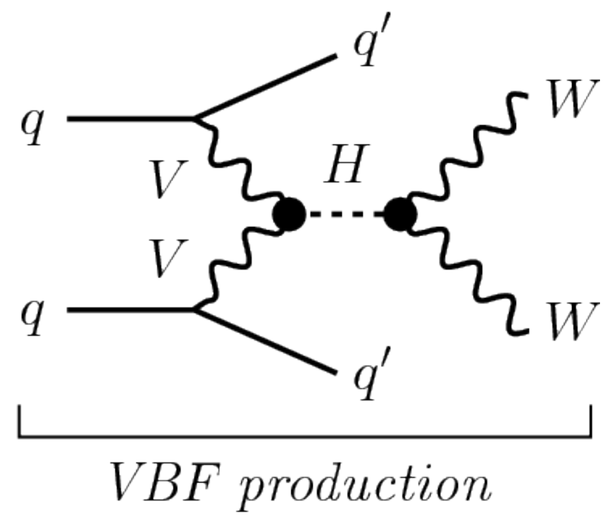
CERN-LHCC-2015-020 ; LHCC-G-166

ITK VBF Higgs

H -> WW* Vector Boson Fusion

- same forward jet signature
- benefits from b-tagging in tracker region





CERN-LHCC-2015-020 ; LHCC-G-166

ITK SUSY

CERN-LHCC-2015-020 ; LHCC-G-166

SUSY: Charginos and Neutralinos
- trigger efficiency
- b-tagging
- E_T^{Miss}