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ATLAS EXPERIMENT

Pixel Radiation Damage Measurements with ATLAS

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on behalf of ATLAS Pixel Group

LHC Pixel Radiation Damage Workshop
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Bundesministerium für Bildung und Forschung

BMBF-Forschungsschwerpunkt ATLAS-EXPERIMENT

Physik bei höchsten Energien mit dem ATLAS-Experiment am LHC

FSP 103 ATLAS

Outline

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ATLAS Insertable B-Layer modules and front-ends (FE-I4)

Properties evolution with radiation fluence

Studies of property vs. time/luminosity/fluence

- Depletion voltage
  - Collision data (vs luminosity)
  - Beam test (before/after irradiation)
- Charge collection efficiency
- Lorentz angle

Depletion voltage vs. longitudinal position

Absorbed radiation fluence changes along the detector

- Cross-check against leakage-current behaviour

Depletion voltage measurement

Signal from FE such as:

Charge ~ Amplitude ~ ToT

with ToT = Time over Threshold

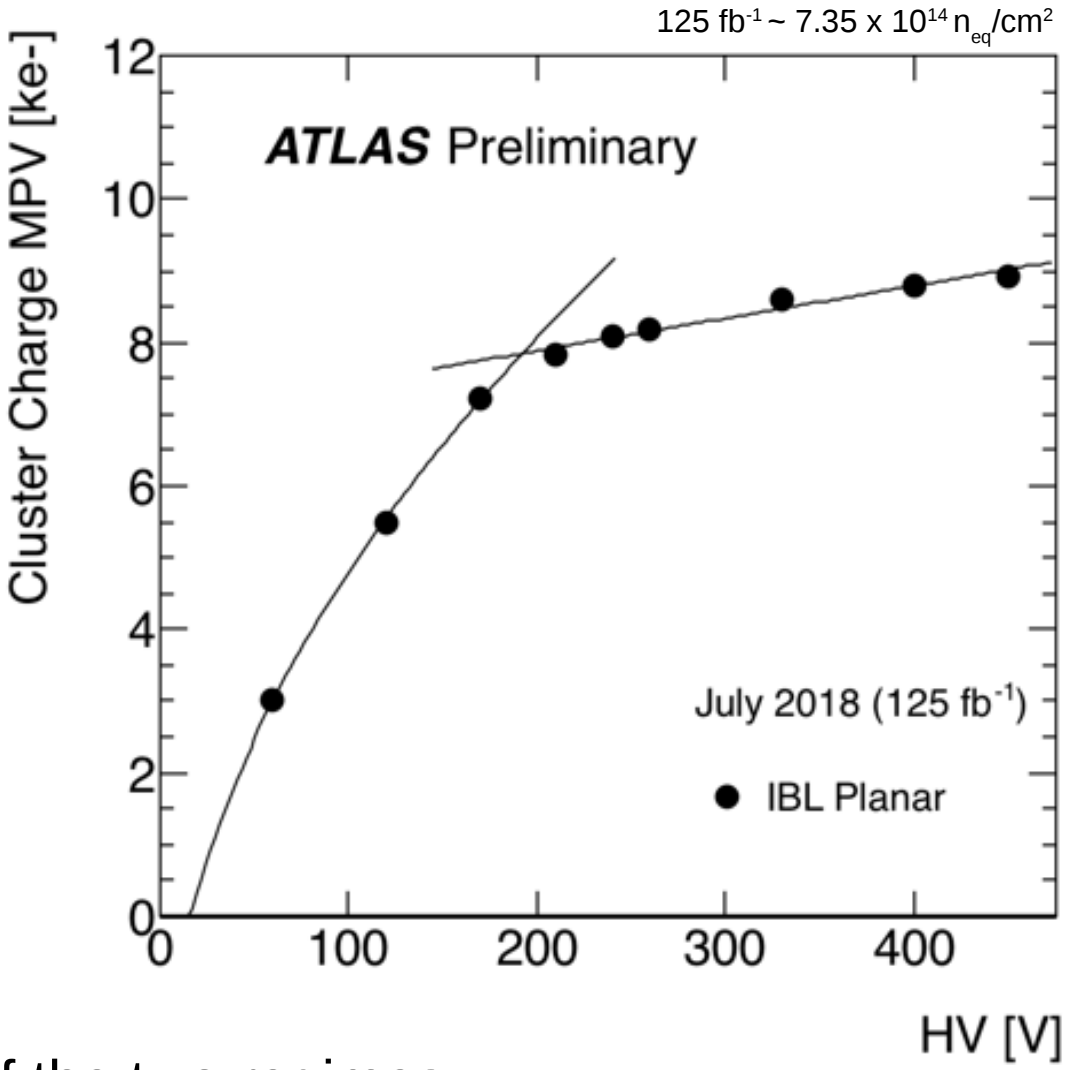
Measure Charge vs. Module Bias Voltage (V)

Underdepleted module:

$$\mathrm{Charge} \sim \mathrm{Width}_{\mathrm{depl}} \sim \sqrt{V}$$

Over-depleted module:

$$\mathrm{Charge} \sim V$$



Depletion voltage: interception of the two regimes

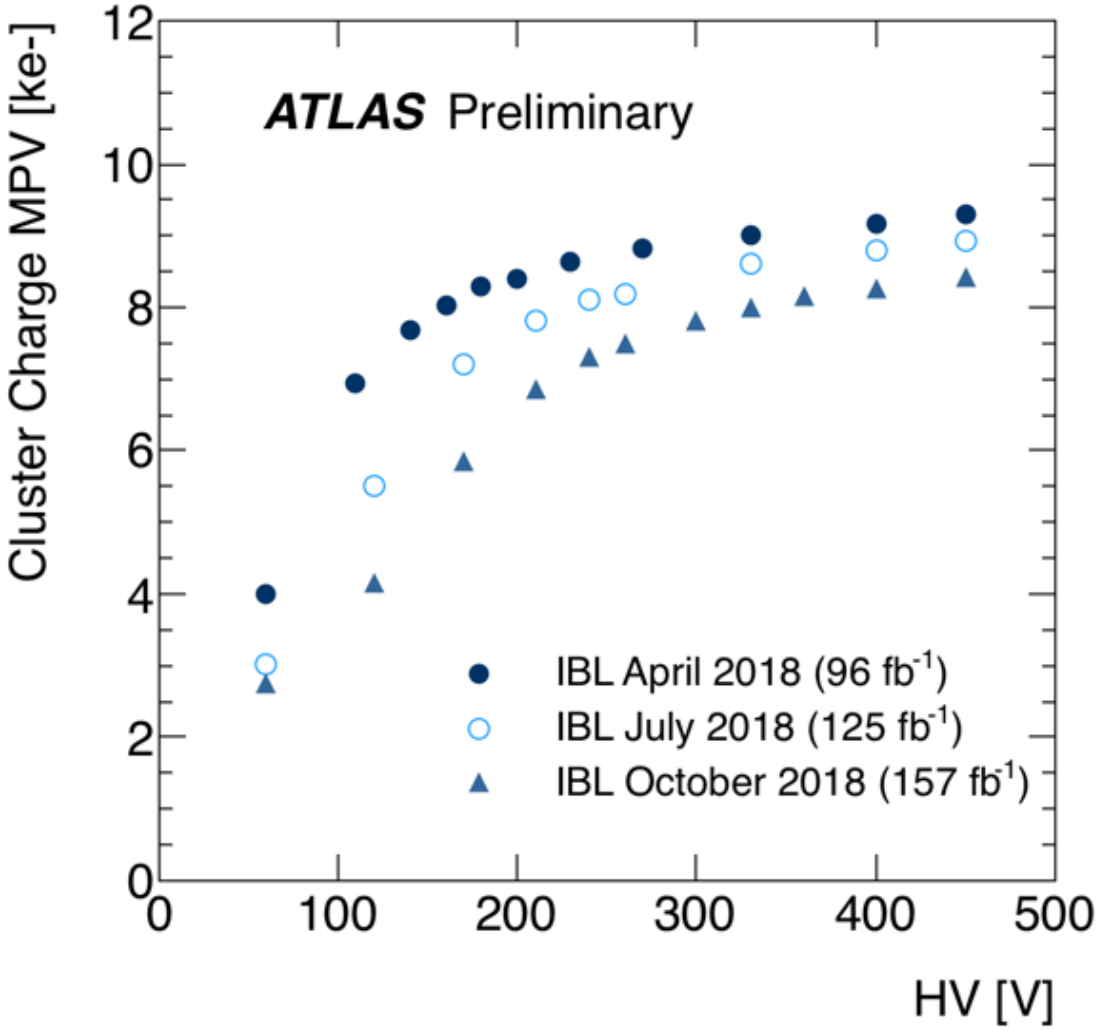
Collision data

96 fb^{-1} ~ 5.6 x 10^{14} n_{eq}/cm^2
125 fb^{-1} ~ 7.6 x 10^{14} n_{eq}/cm^2
157 fb^{-1} ~ 9.2 x 10^{14} n_{eq}/cm^2

ATLAS performed dedicated voltage scans during data-taking

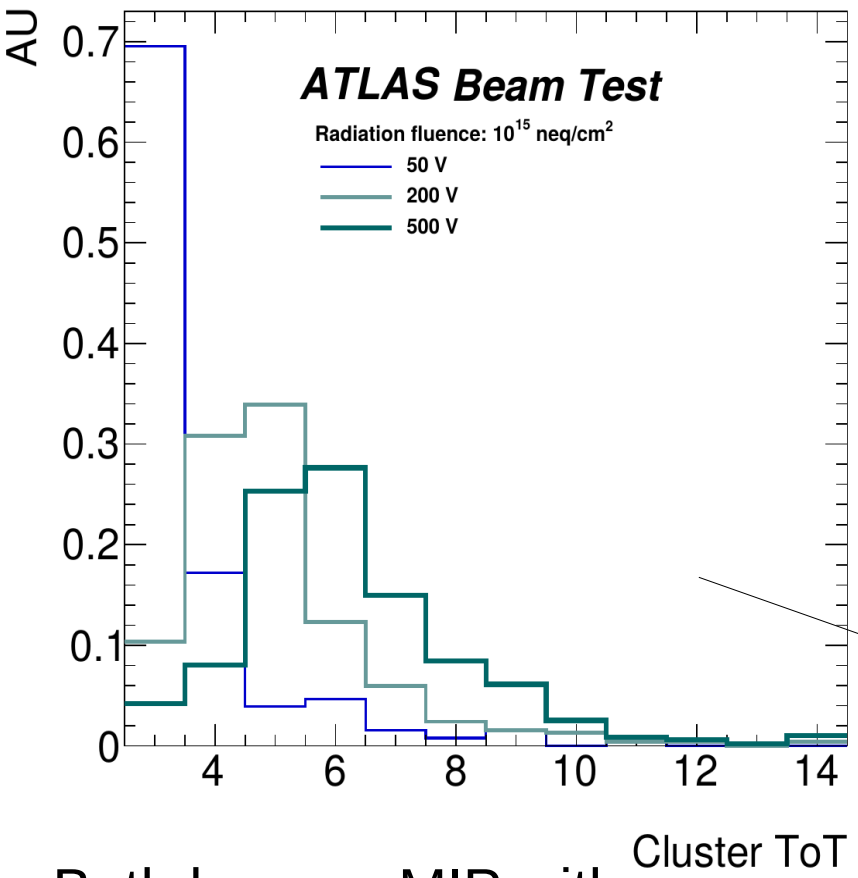
Track selection:
- p_T > 1 GeV
- No shared clusters
- Pixels multiplicity in clusters:
  - N_X < 4 – pitch = 50 μm
  - N_Y = 1 – pitch = 200 μm

Charge (ToT) distribution corrected by cos (inc. angle)
→ Landau distribution on Minimum Ionisation Point (MIP)



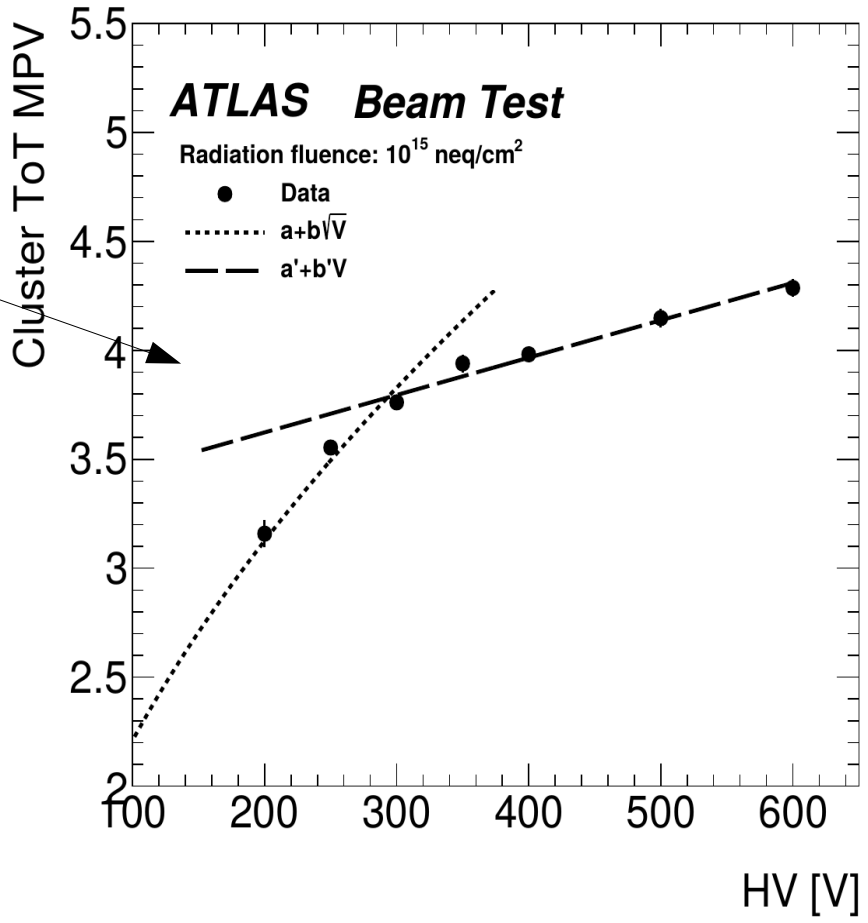
Fit of charge distribution → Most Probable Value (MPV) vs bias voltage

Beam test



Same IBL module (D31-18-01) tested in two different beam tests:

- Fluence = 0 n_{eq}/cm^2
  Fermilab, March 2018
- Fluence = 10^{15} n_{eq}/cm^2
  CERN H8, September 2018



Both beams: MIP with perpendicular incidence

Fit of ToT distribution (~ charge)
→ MPV vs. Bias voltage

n_{eq} = Silicon 1 MeV neutron equivalent dose

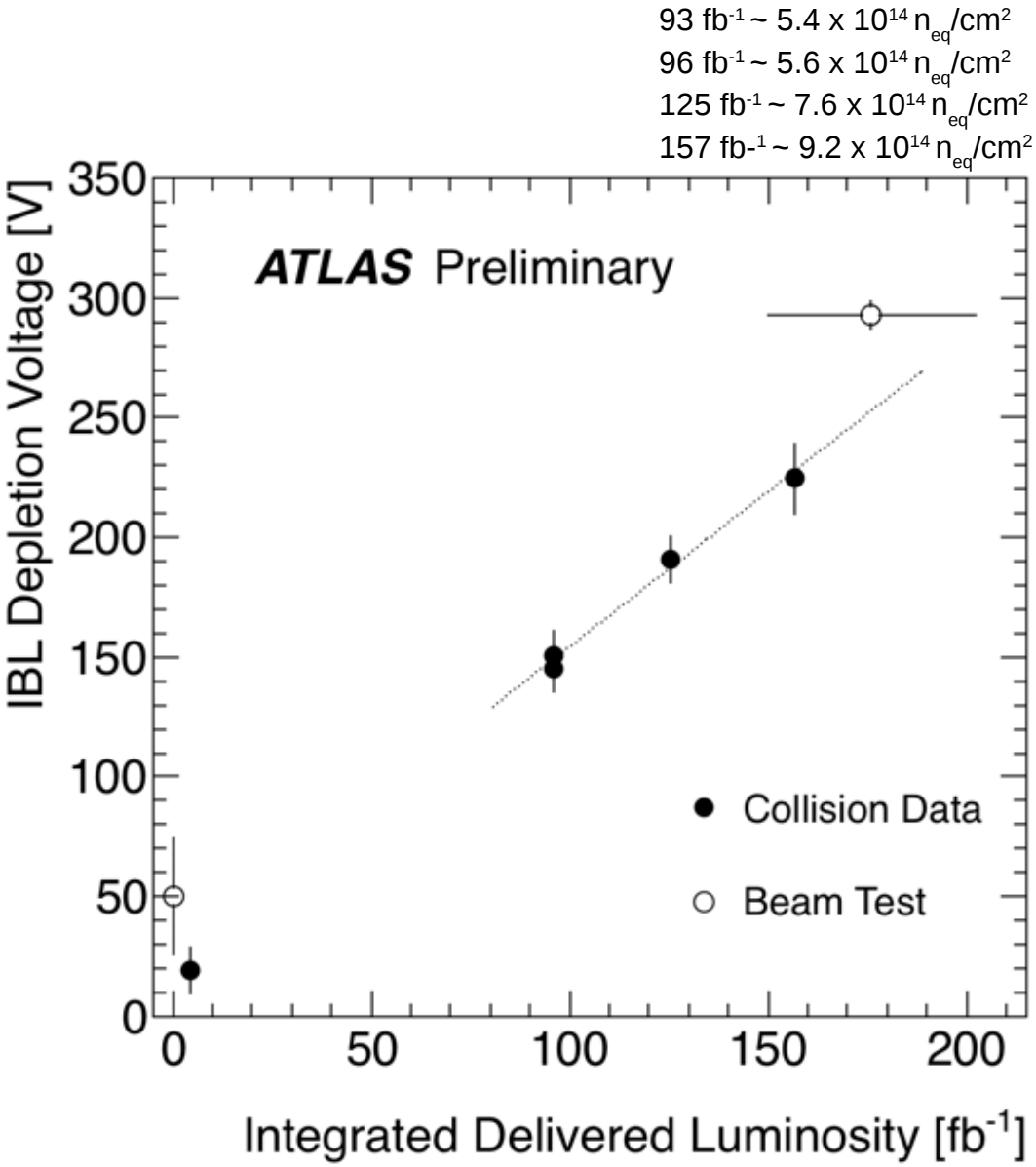
Results on depletion voltage

Measured depletion voltage as function of luminosity.

End Run II fluence ~ 10^{15} n_{eq}/cm^2

Similar results observed in beam test and collsition data (2015 + 2018)

	Slope [V / fb^{-1}]
Collision Data 2018	1.39 ± 0.10



Charge collection efficiency

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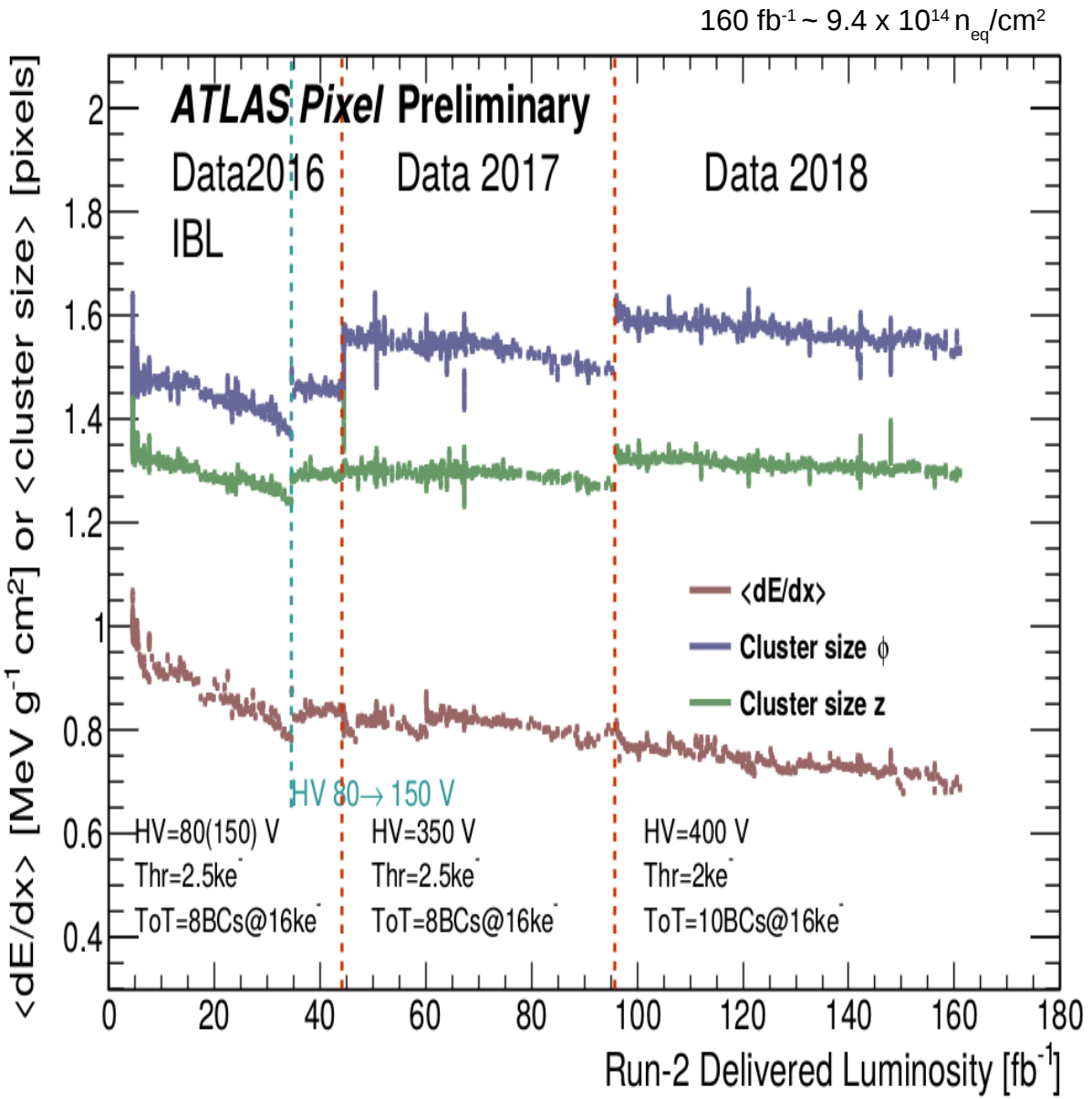
Studied as function of luminosity:

- Fit of charge distribution (corrected by incidence angle)
- Normalised for the sensor thickness (dE/dx)

Clear trend in luminosity, that is absorbed fluence.

Trend also in cluster shapes indicating a loss of collected charge.



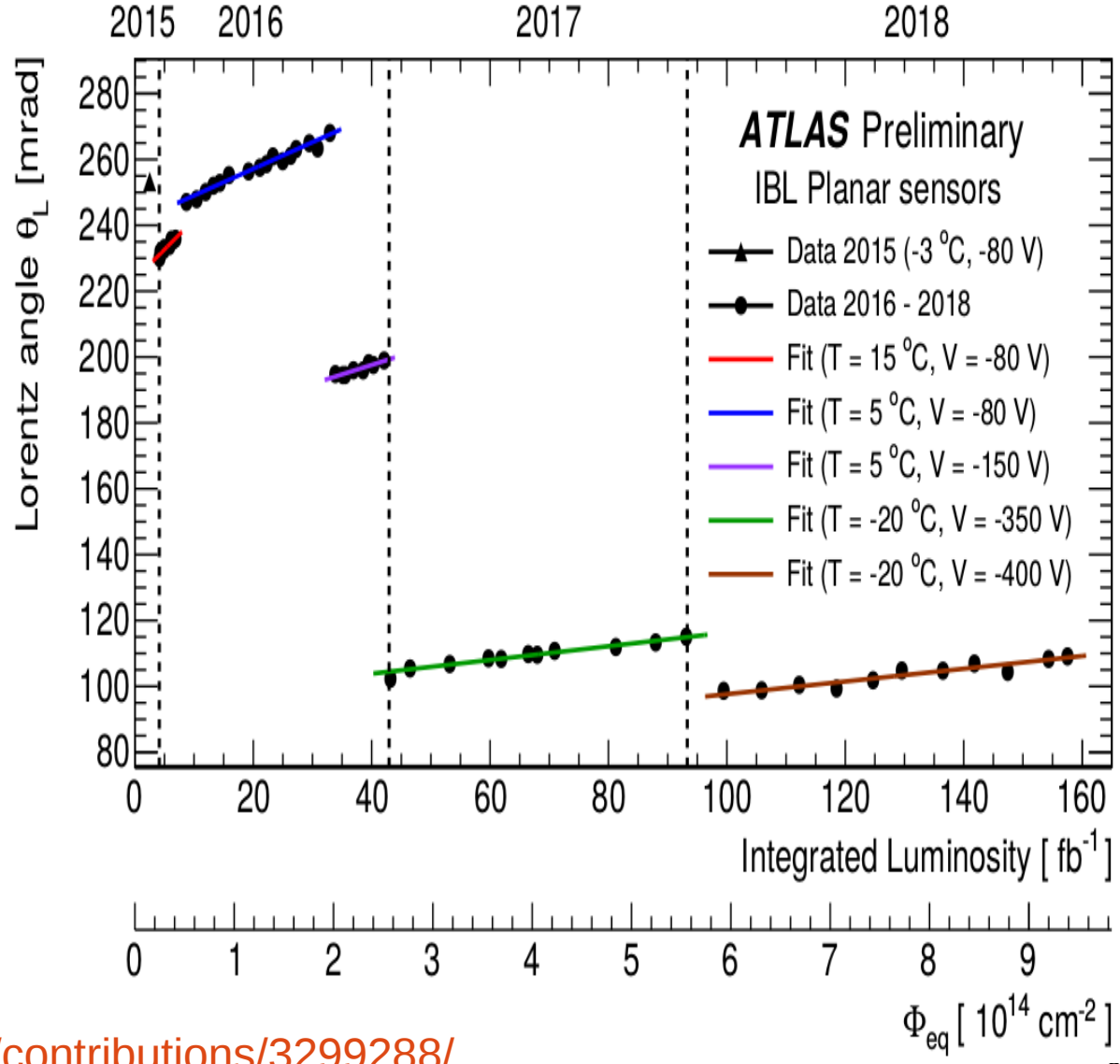
Lorentz angle

Ionisation charge drift azimuthal angle due to external magnetic field and bias electric field

Sensor bulk defects change electric field
→ Lorentz angle change

Defined as track incidence angle on the module that minimises the pixel multiplicity in cluster!

Clear trend in luminosity!



Detailed discussion in Javier's talk (later):
https://indico.cern.ch/event/769192/contributions/3299288/

Fluence and longitudinal position

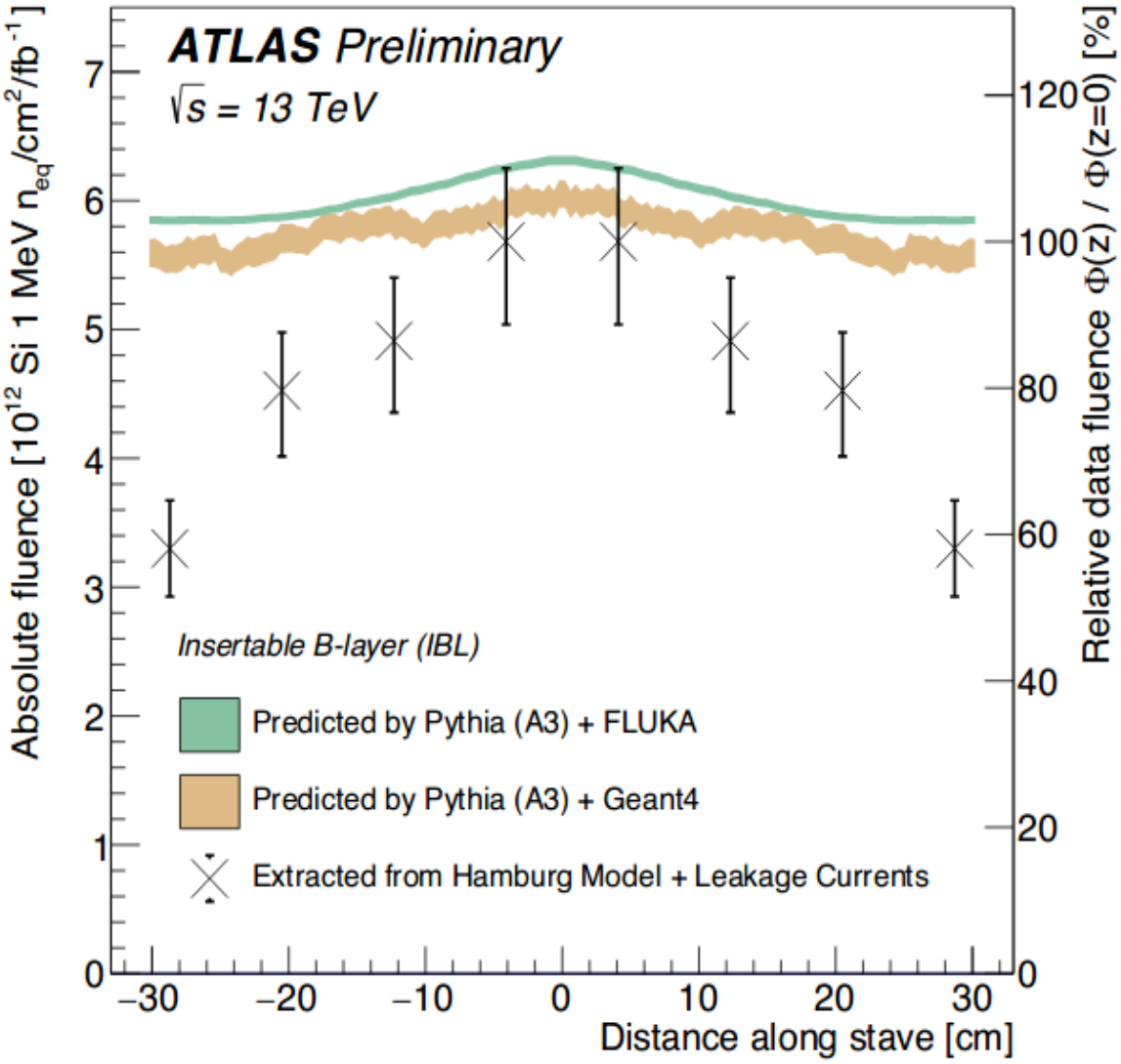
Module along the pipe axis get different radiation fluence.

Two balancing effects going towards detector edges:

- Elastic pp XS increases
- Covered solid angle decreases

Absorbed fluence **decreases** towards detector edges.

Radiation effects on detector properties investigated wrt the center of the detector



Look at Sven's talk (tomorrow)
https://indico.cern.ch/event/769192/contributions/3287299/

Depletion voltage

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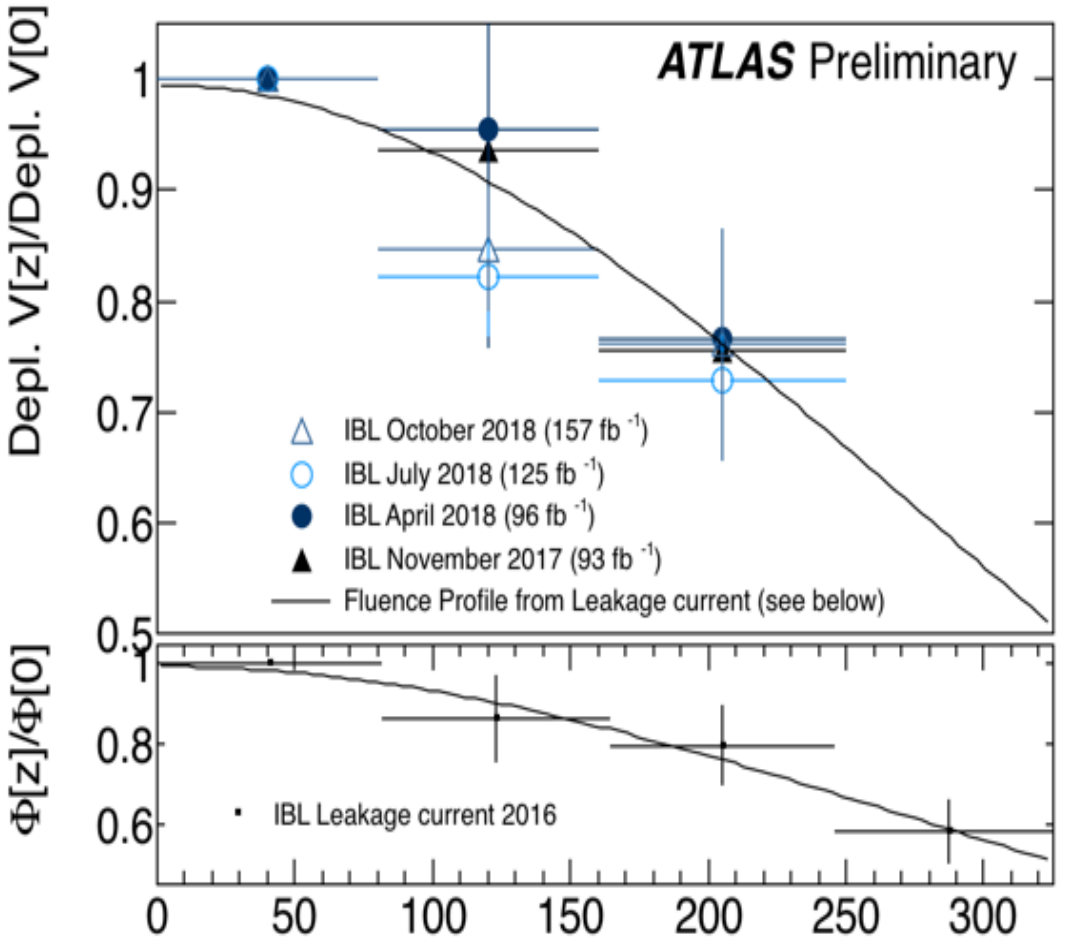
Different prediction from simulations → how to know the relative fluence?

Relative fluence: **Φ(z)/Φ(0)**

- Leakage current very sensitive to radiation
- Model = fit on leakage current behaviour vs. z

Relative depletion voltage:

- Same trends for different periods
- Consistent with the expectations from the leakage current



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Summary

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Properties evolution with fluence

Depletion voltage

- Beam test and collision data comparison at similar absorbed fluences
- Similar results from both observations

Charge Collection Efficiency

- Trends in dE/dx and cluster shapes indicate a loss of charge as expected

Lorentz angle

- Clear evolution with luminosity due to electric field change

Depletion voltage vs. longitudinal position

Different absorbed fluence along the detector

- Clear trend observed
- Consistent with leakage current evolution along the stave

Many thanks for your attention!