

# Modeling Radiation Damage to Pixel Sensors in the *ATLAS* Detector



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on behalf of the ATLAS Collaboration

*Lawrence Berkeley National Laboratory*

LHC-experiment radiation damage workshop

(31 RD50 Meeting)

November 20, 2017

4 pixel layers

Outer three layers

$50 \times 400 \times 250 \mu\text{m}^3$

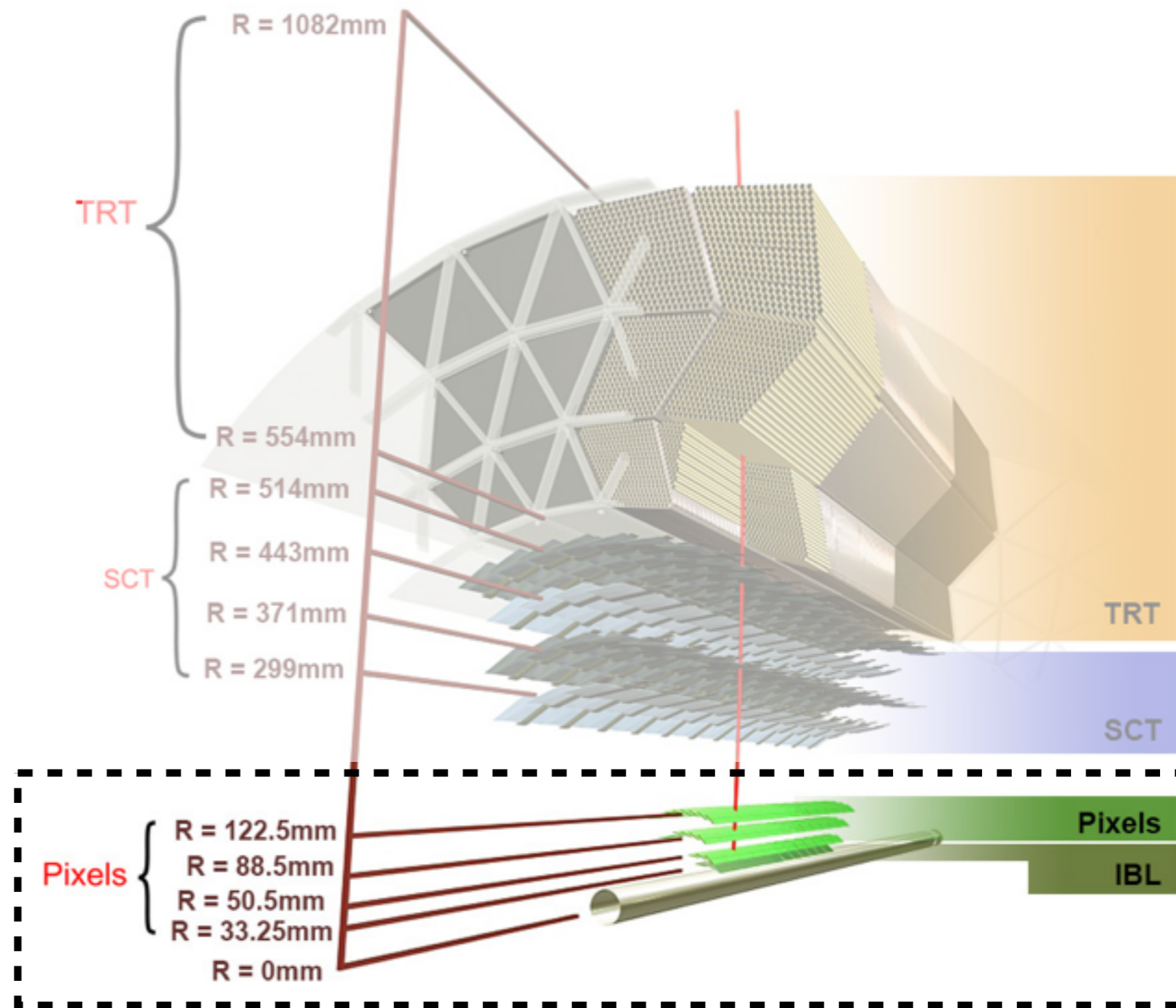
FEI3 readout  
chip (8 bit ToT)

Innermost layer

$50 \times 250 \times 200 \mu\text{m}^3$

FEI4 readout  
chip (4 bit ToT)

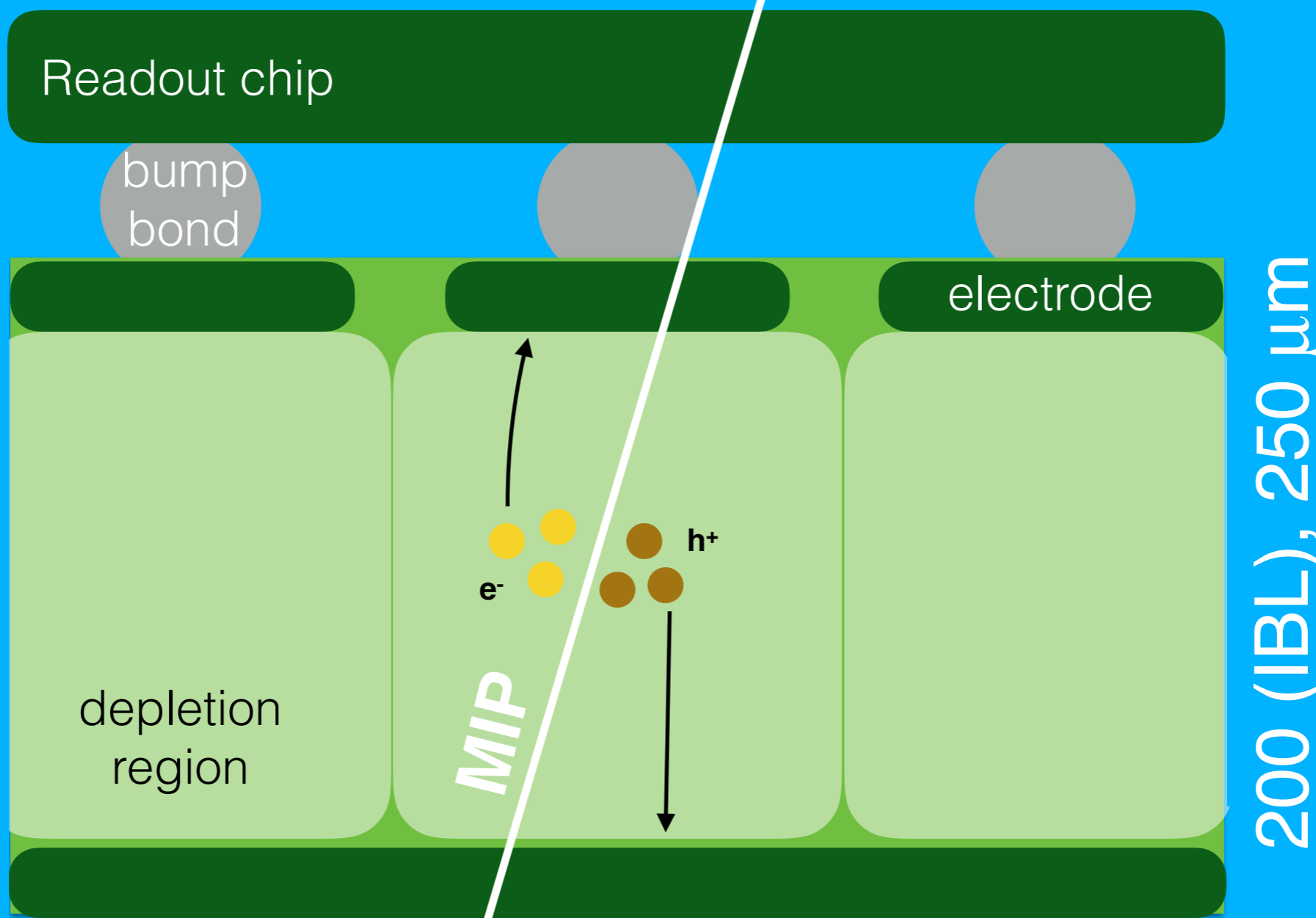
3.3 cm from interaction point; includes 3D sensors at high  $|z|$ .



# Pixel Radiation Damage

Focus on planar; 3D in backup

pitch:  
50 x [250 (IBL), 400]  $\mu\text{m}^2$



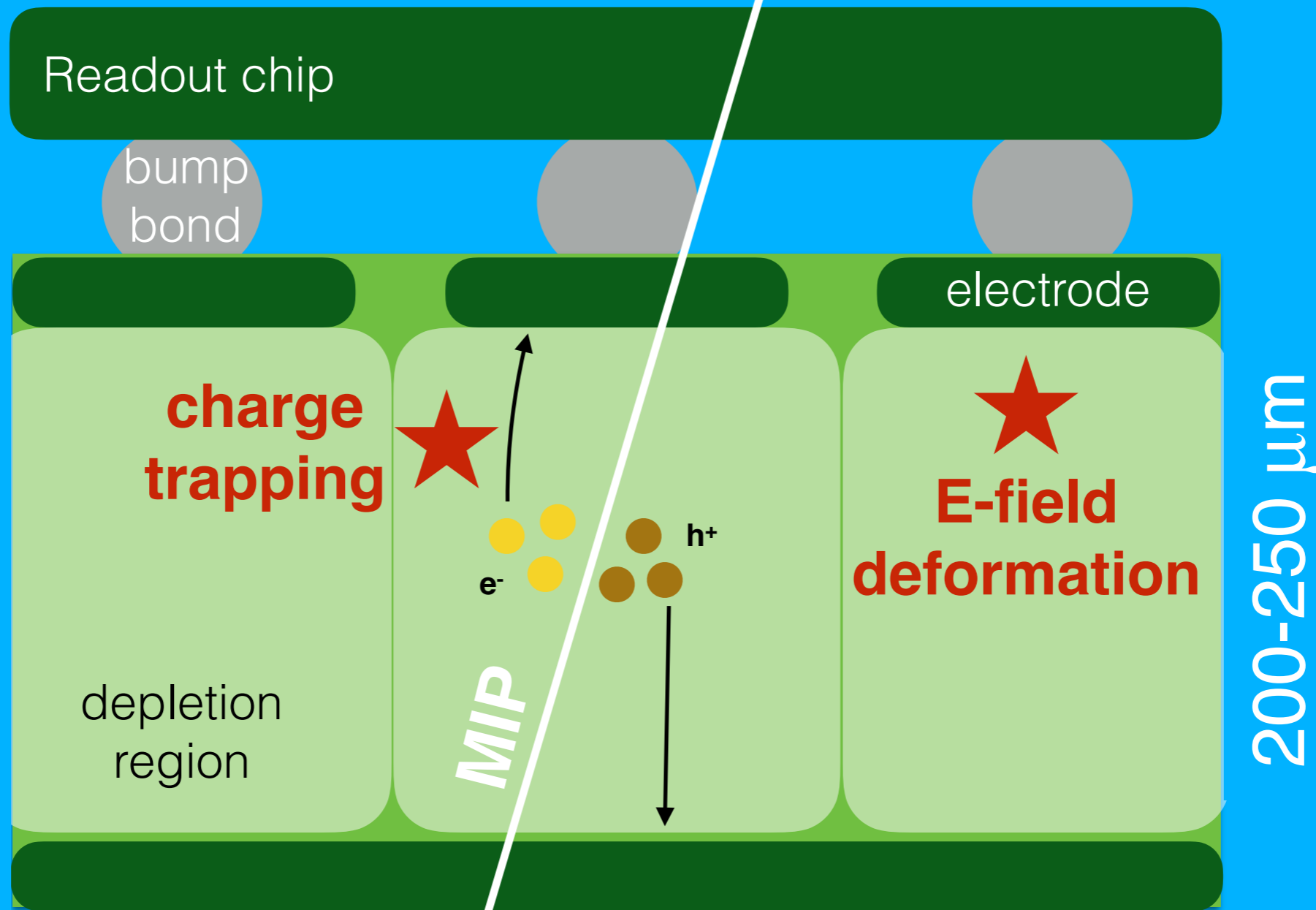
*not to scale*

innermost layer (IBL):  
3.3 cm from the interaction point

# Pixel Radiation Damage → **Defects** in the crystal!

Focus on planar; 3D in backup

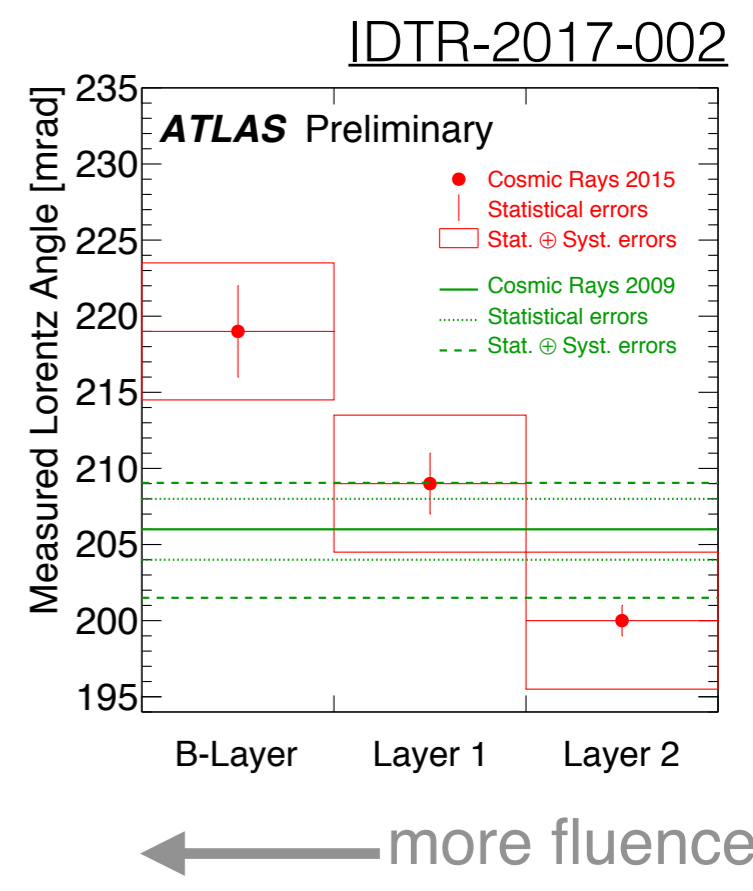
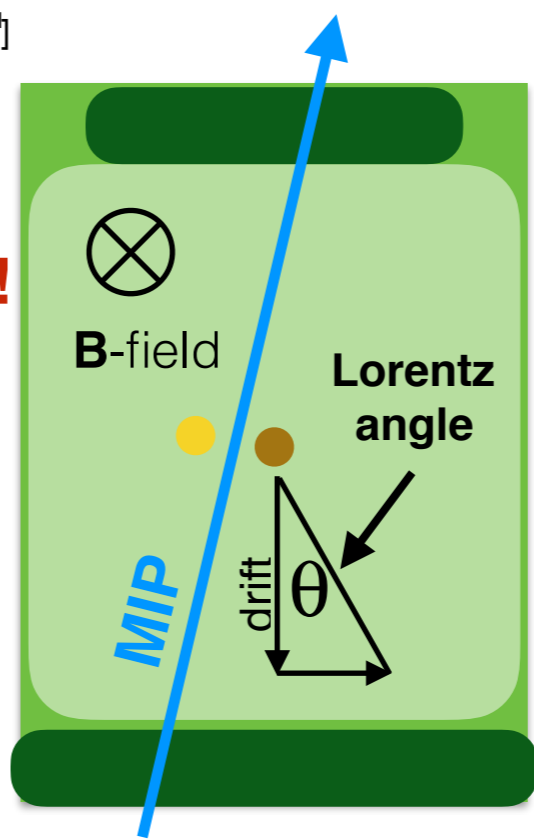
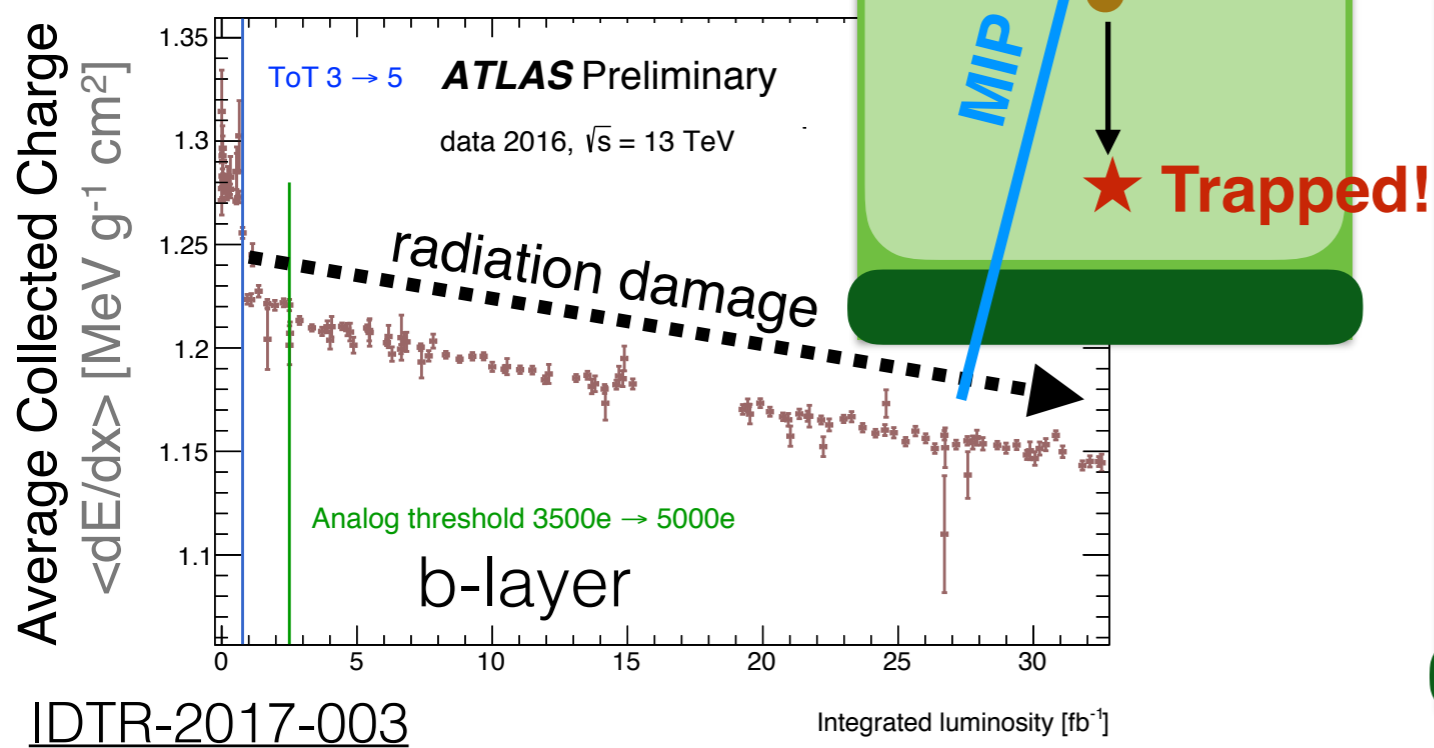
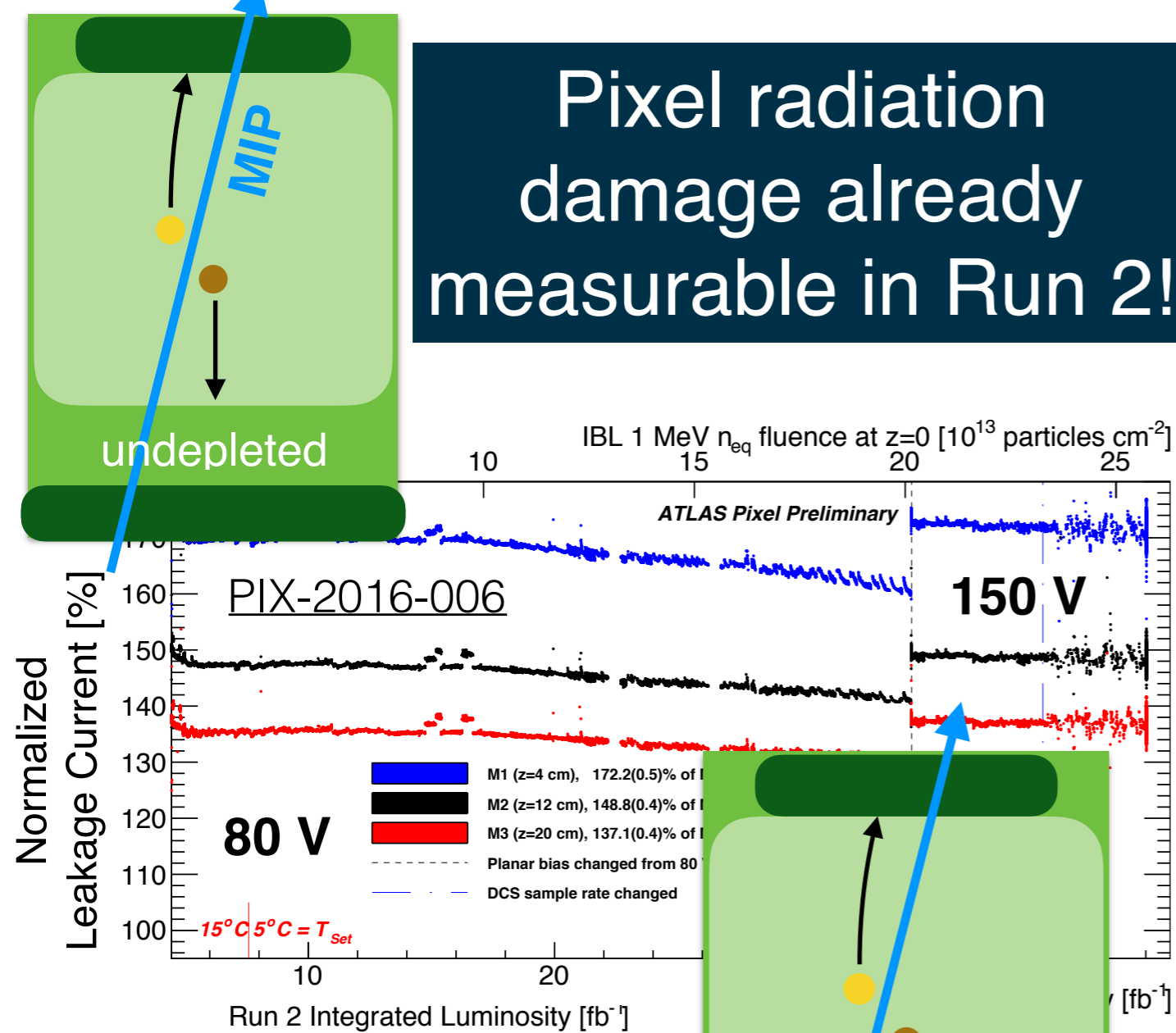
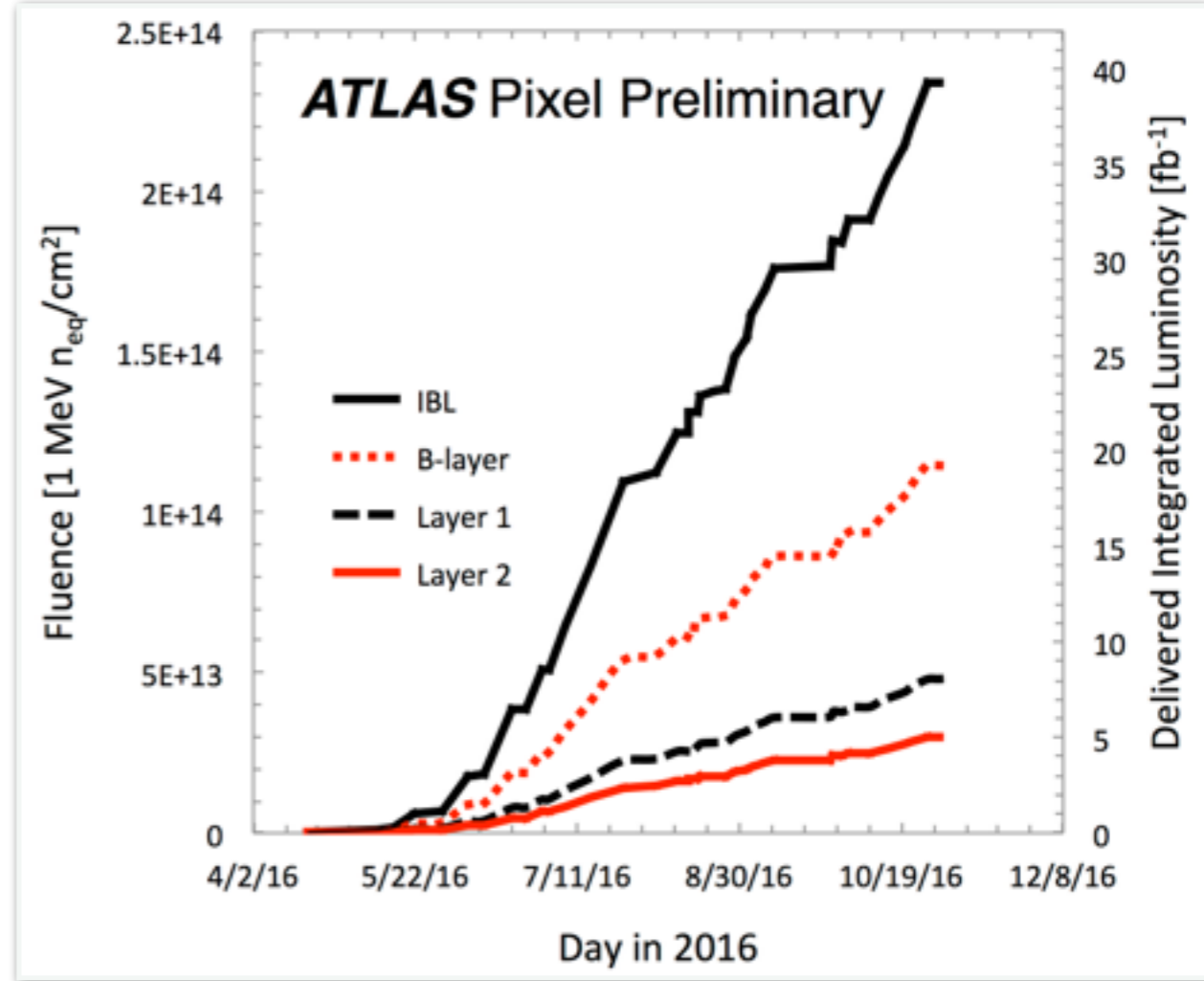
pitch:  $50 \times (200 - 400) \mu\text{m}^2$



*not to scale*

innermost layer (IBL):  
3.3 cm from the interaction point

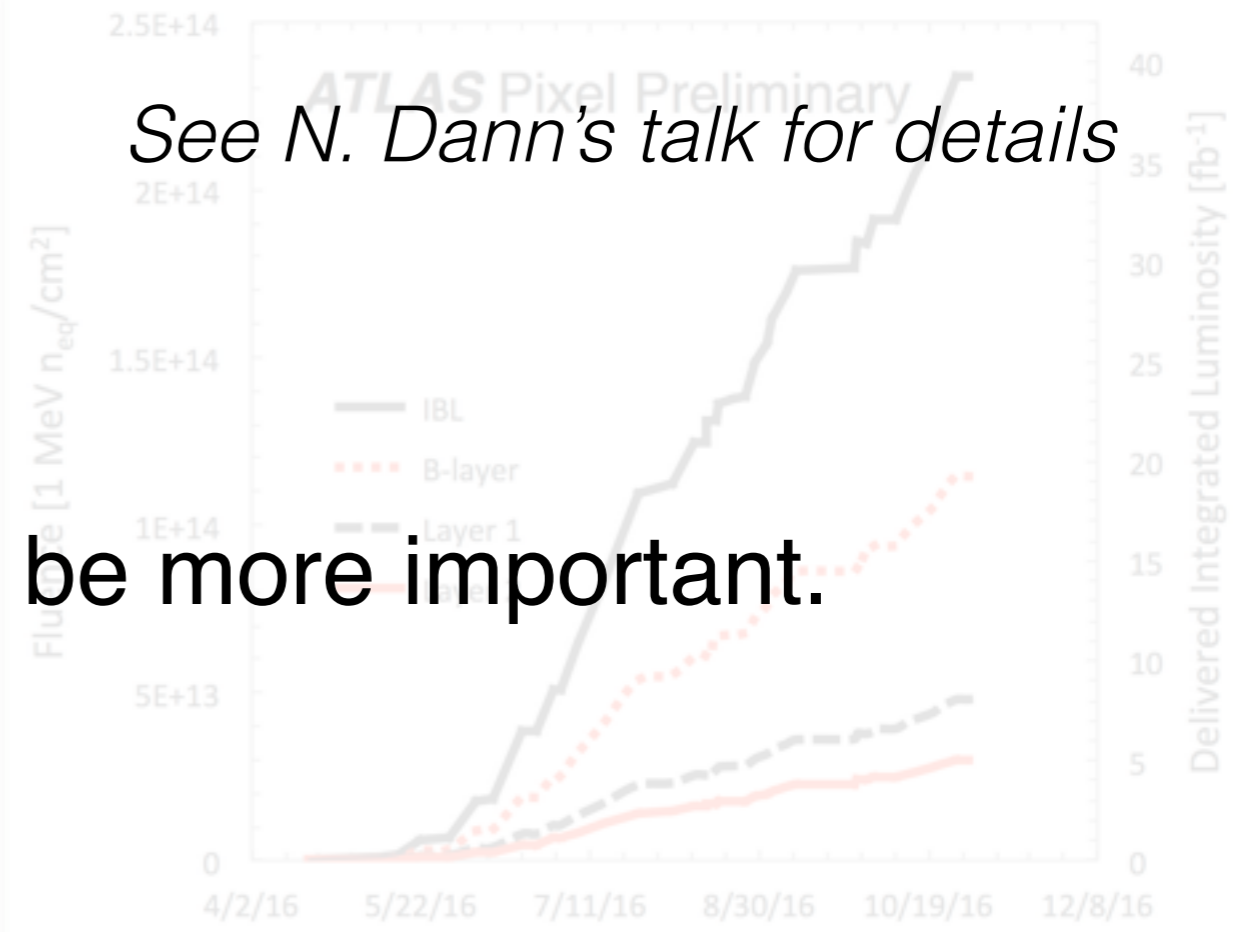
**Pixel radiation damage already measurable in Run 2!**



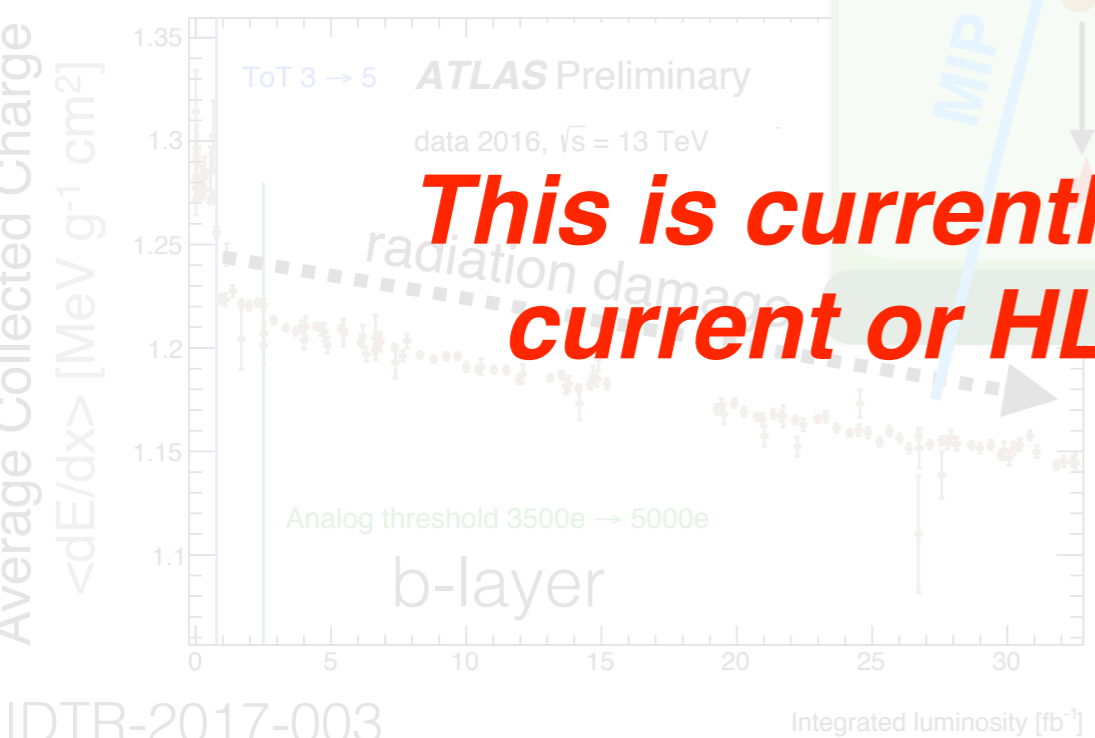
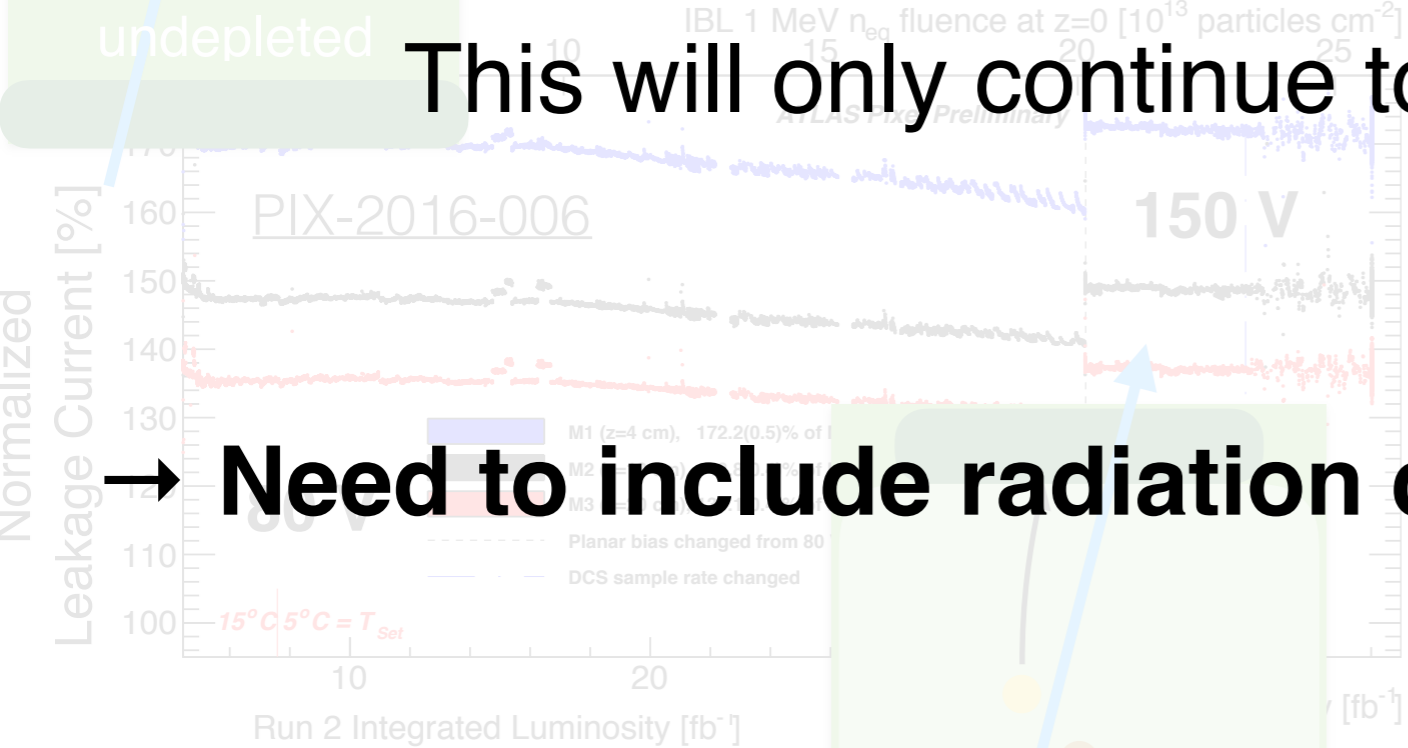
Pixel radiation damage already measurable in Run 2!

See N. Dann's talk for details

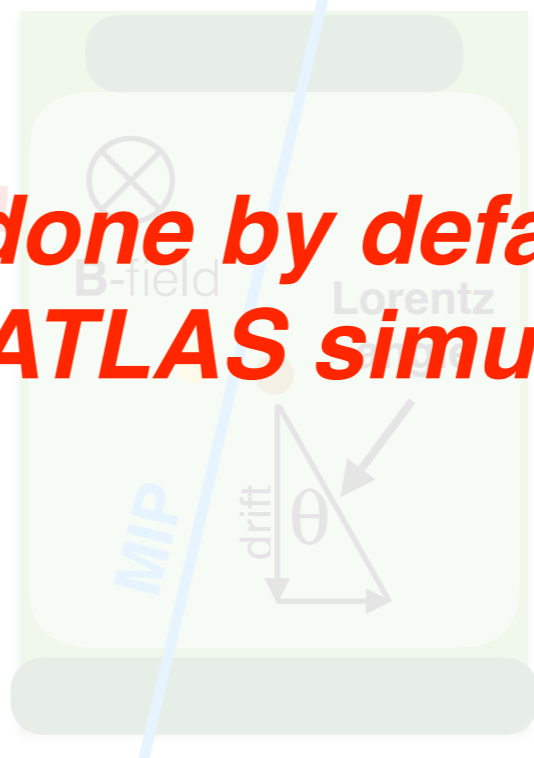
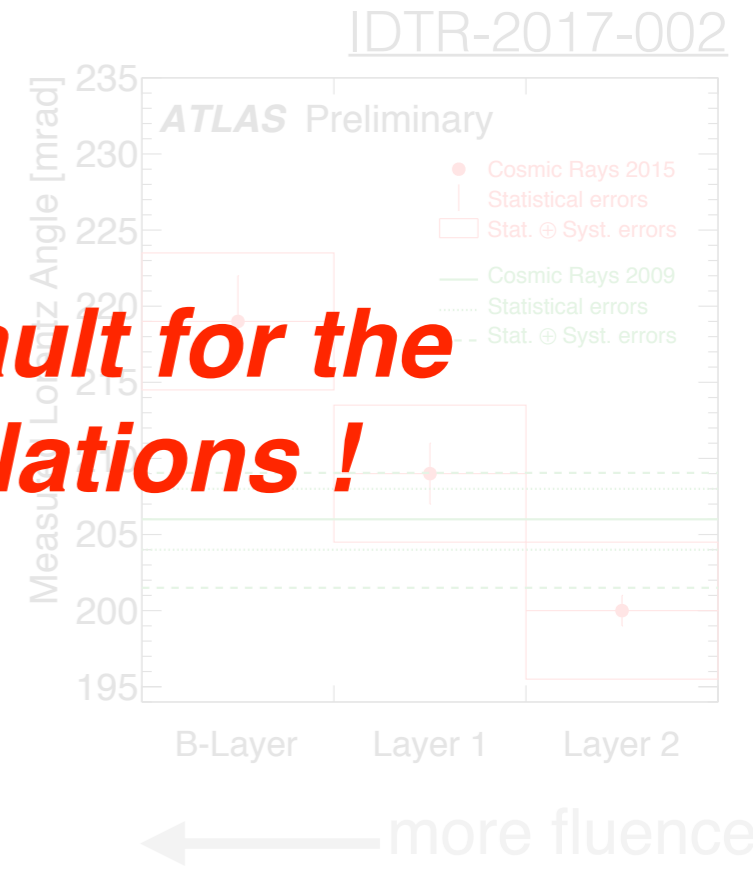
This will only continue to be more important.

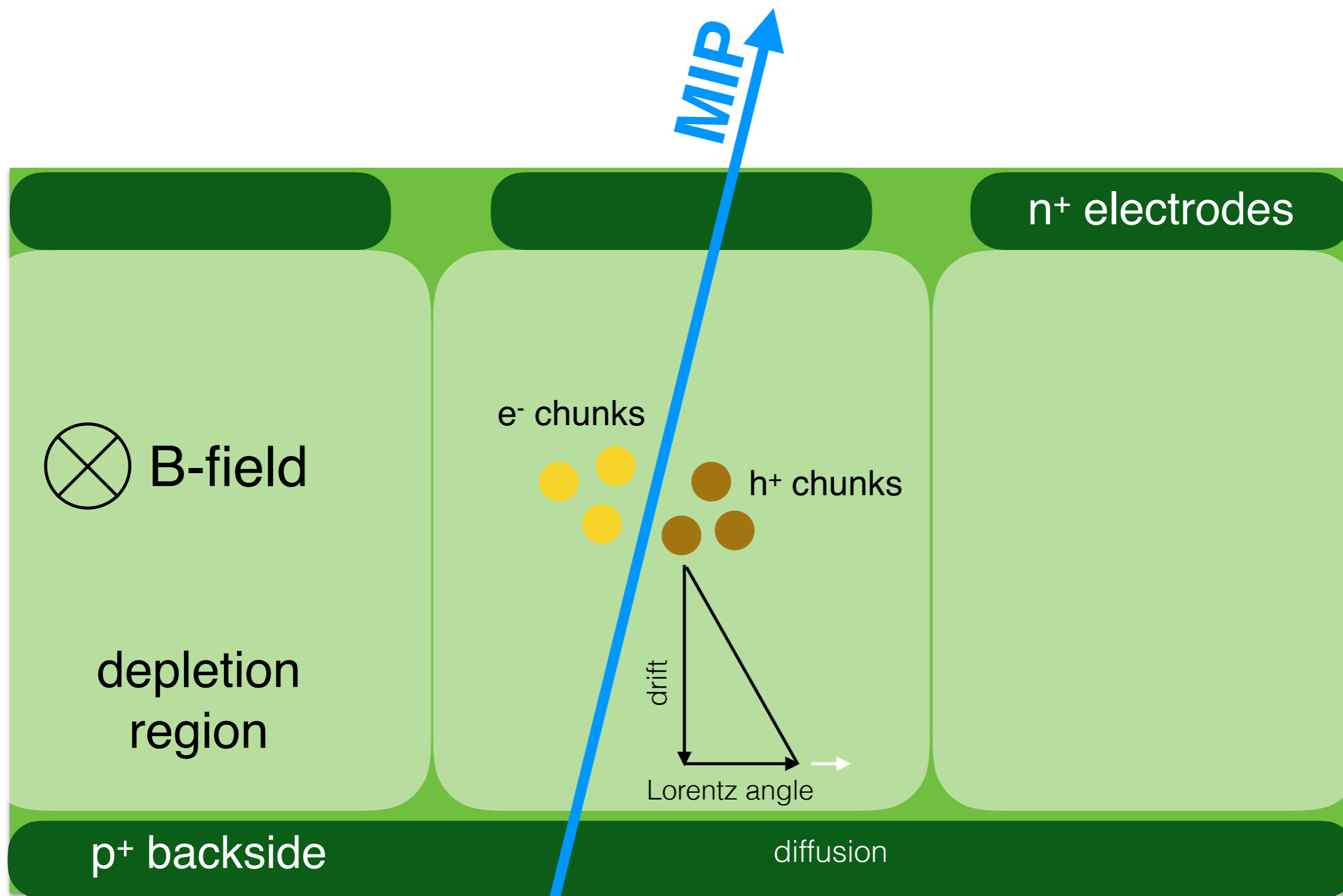


Need to include radiation damage in our simulation!

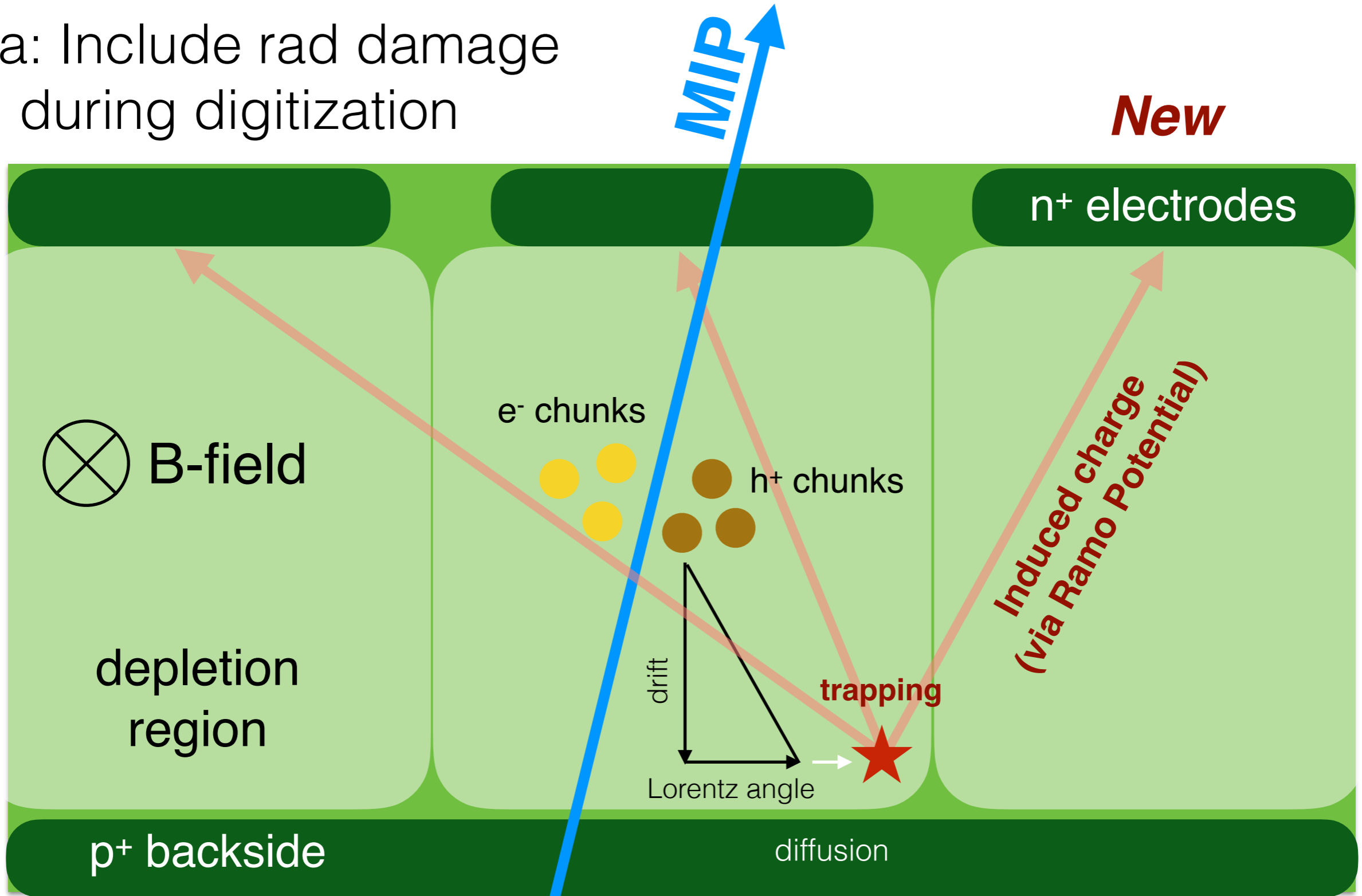


This is currently not done by default for the current or HL-LHC ATLAS simulations!

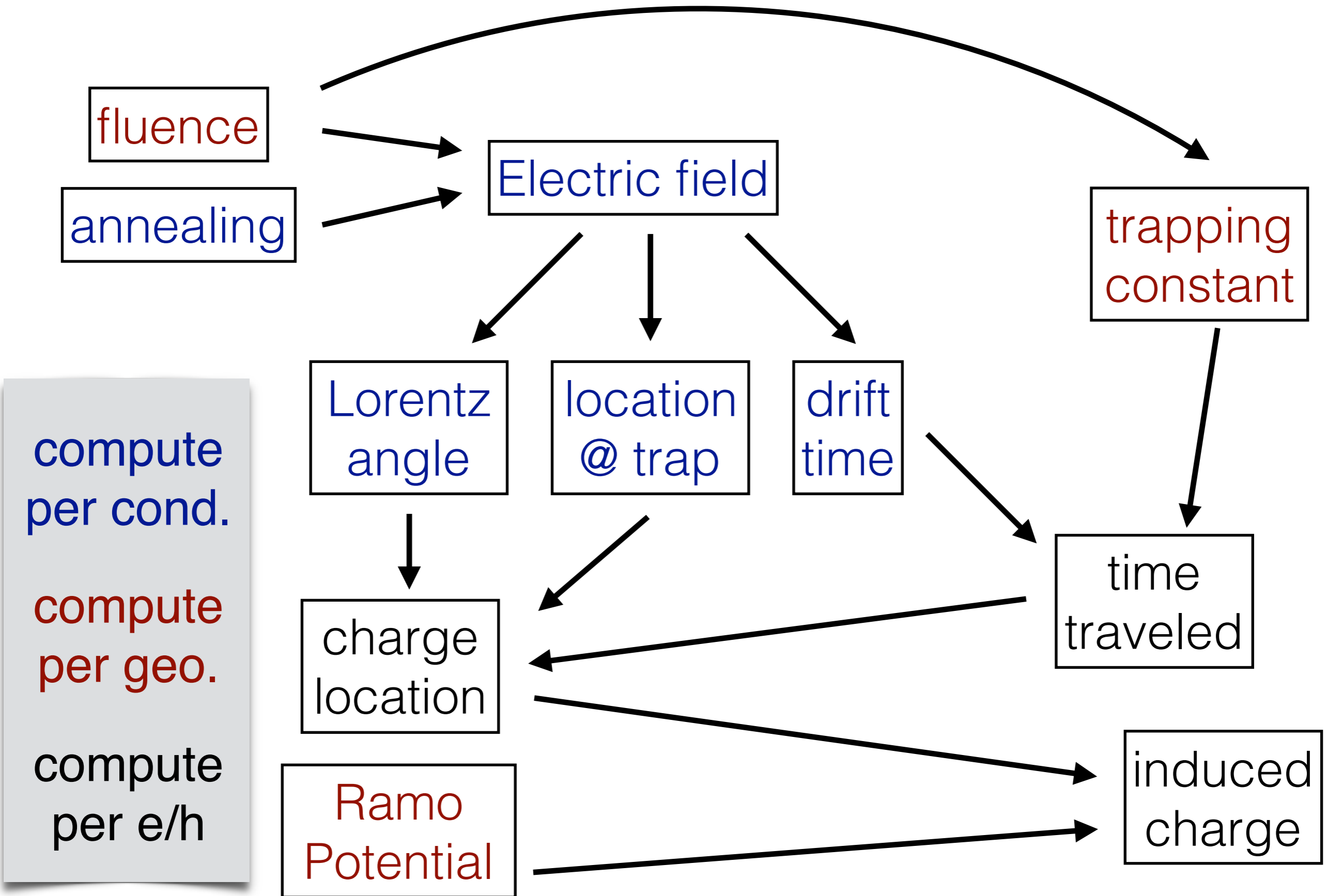


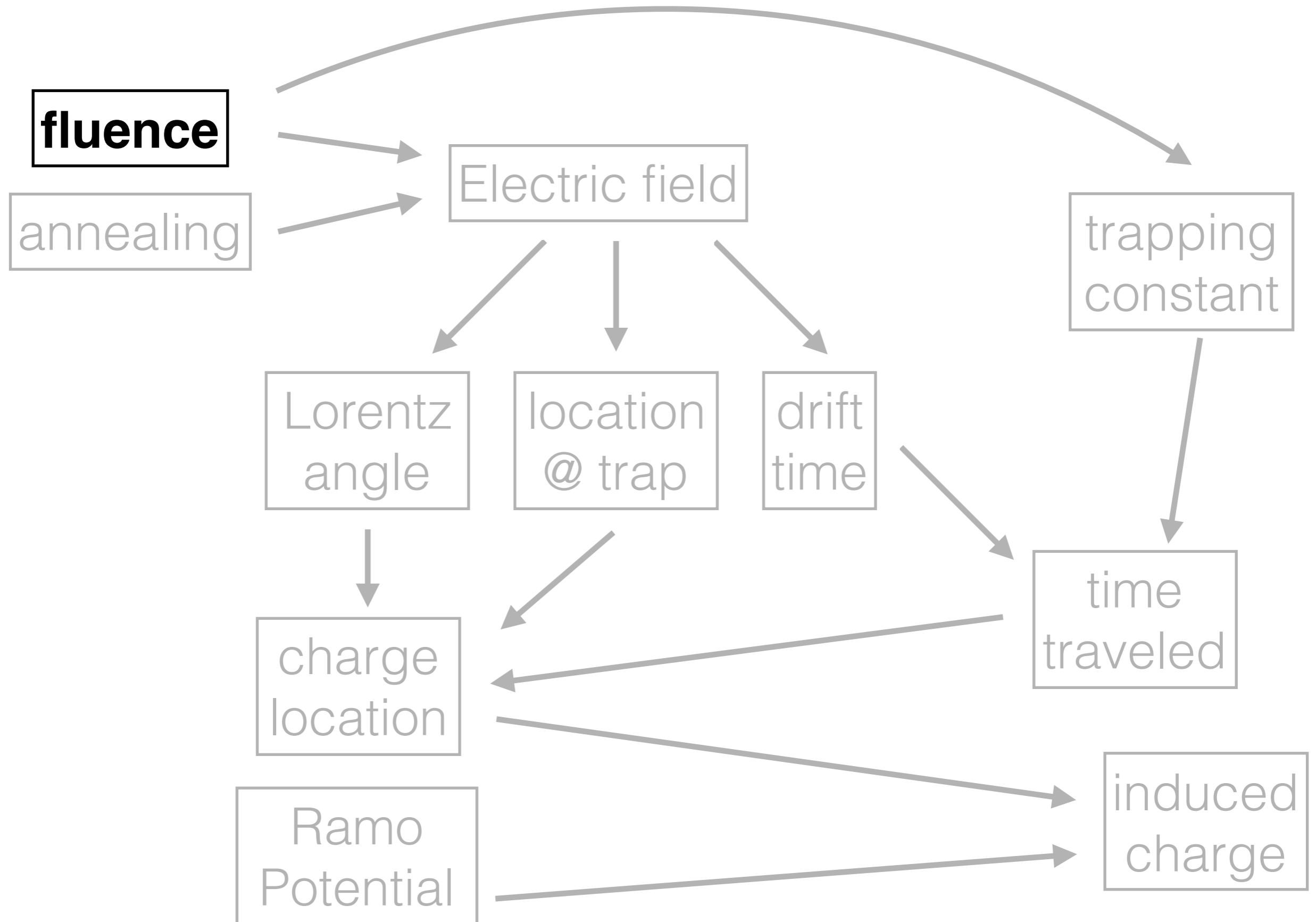


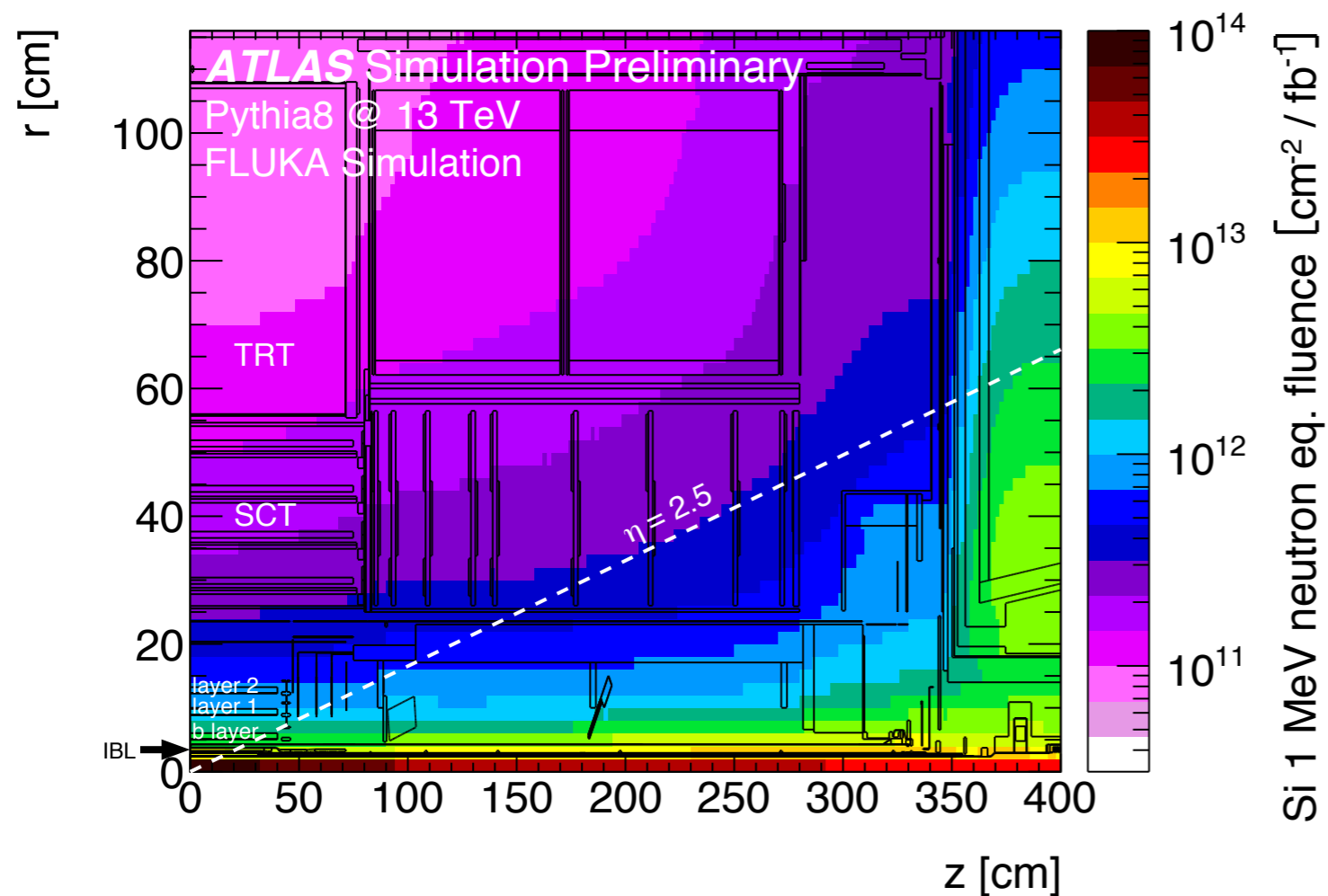
Idea: Include rad damage during digitization





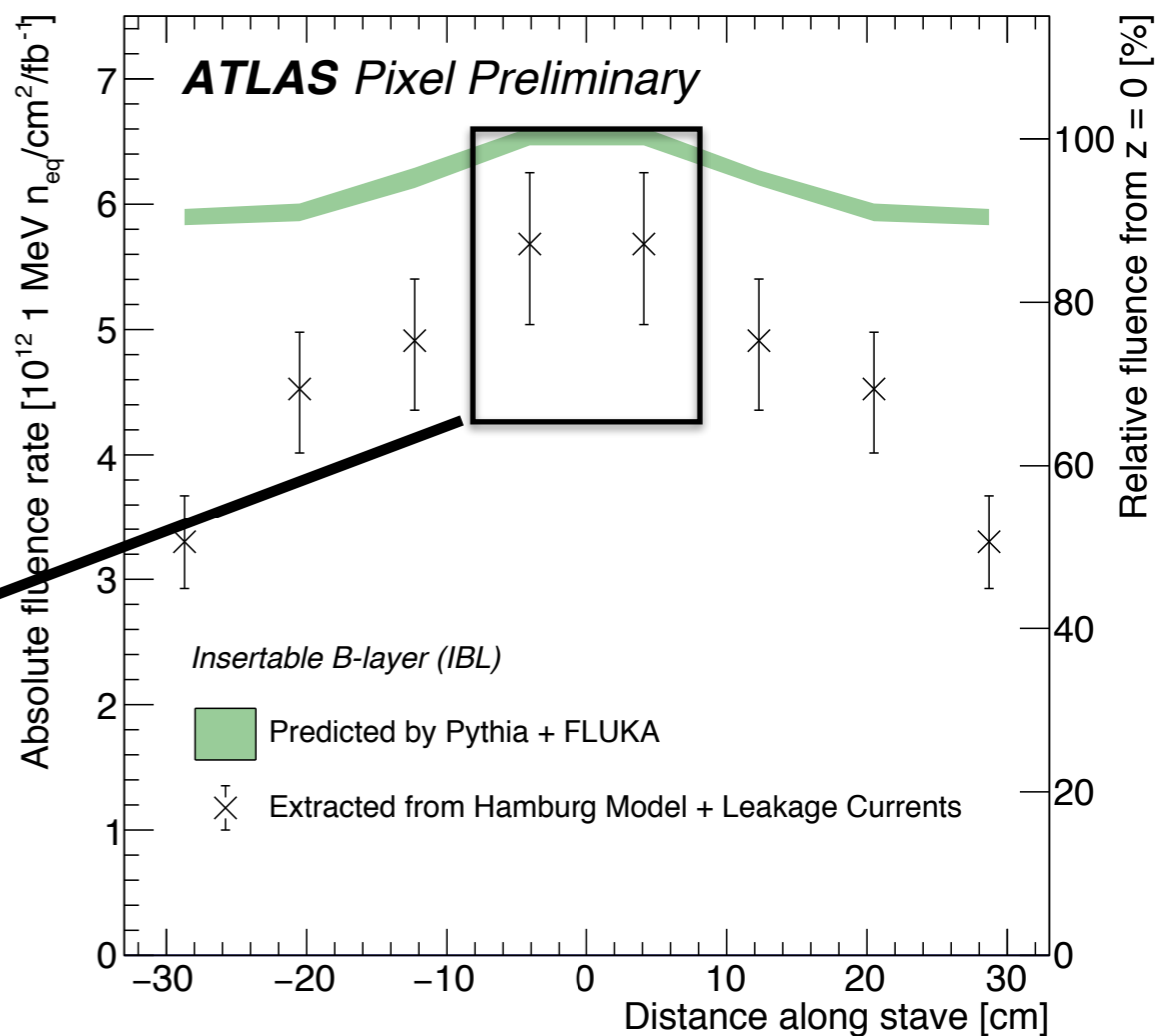






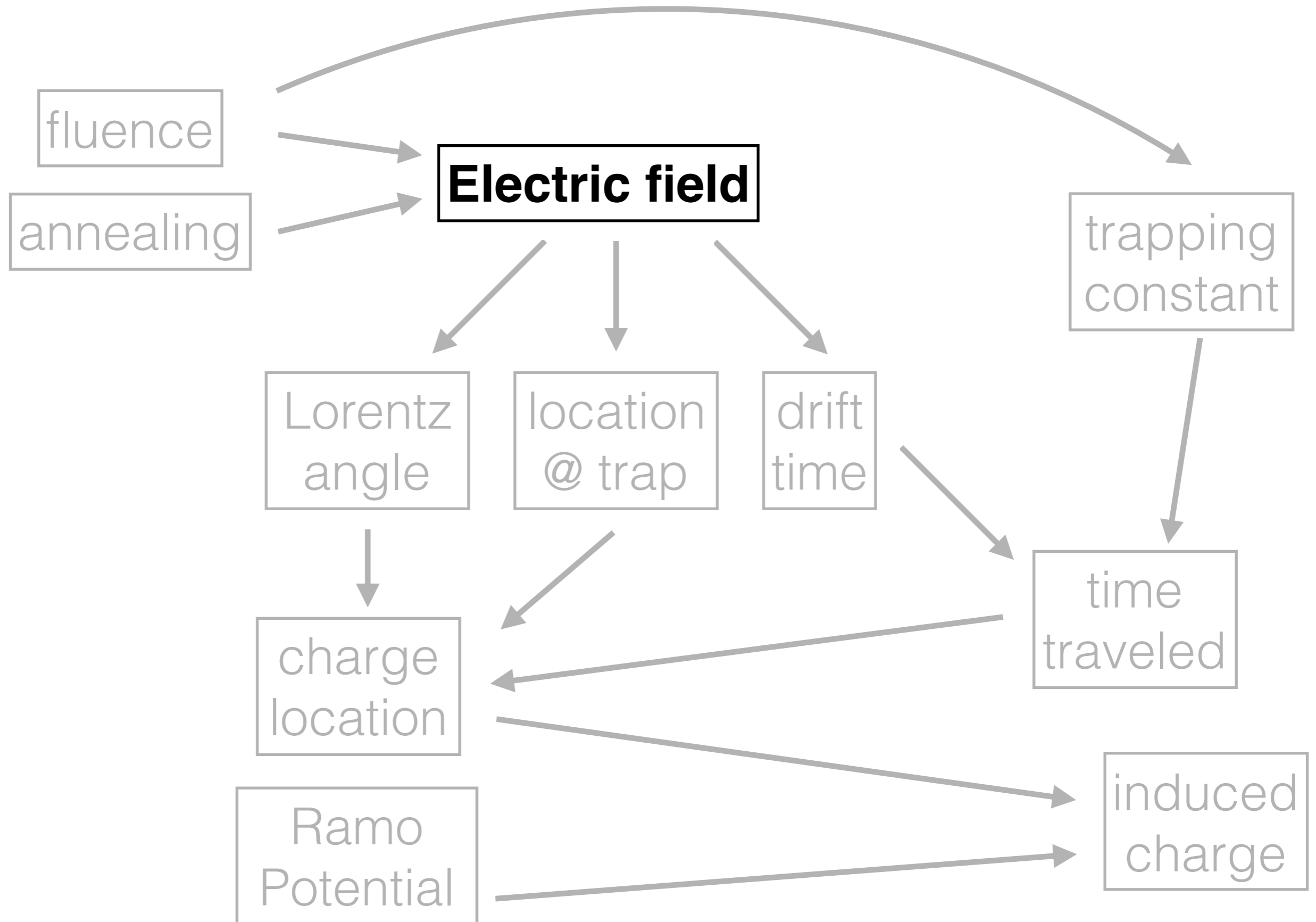
## Lumi-to-fluence from Pythia + FLUKA

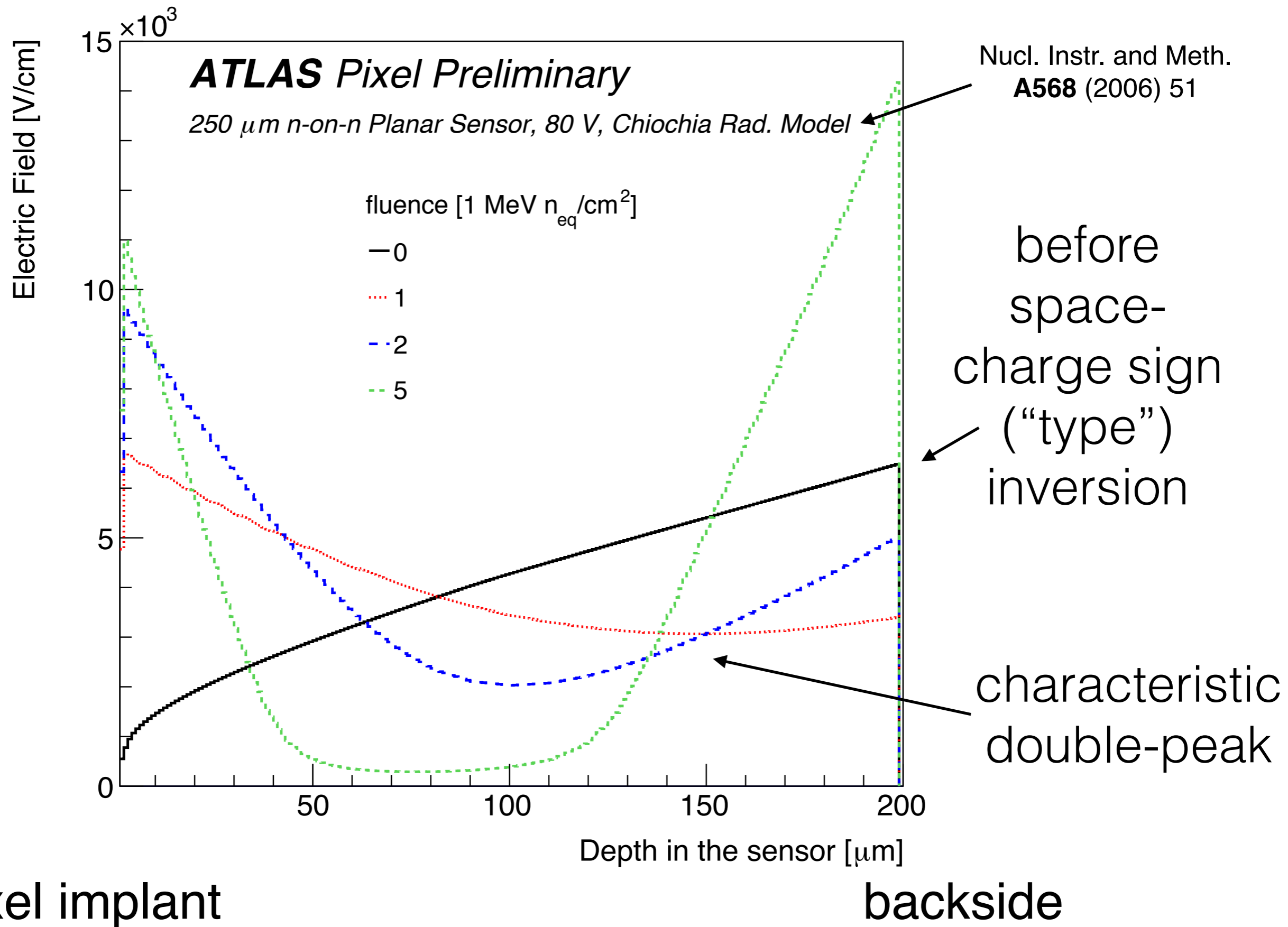
See P. Miagaya's talk for details

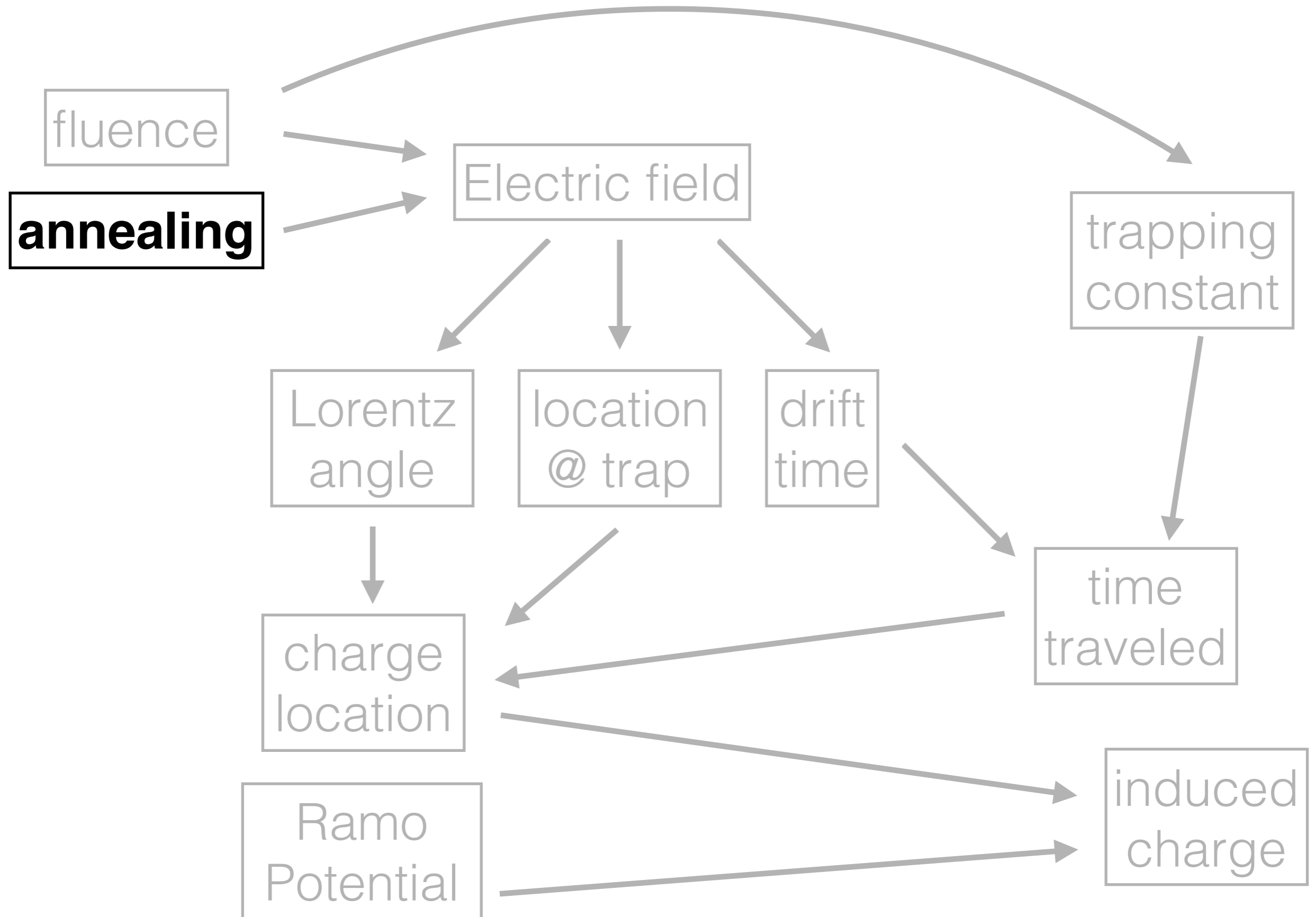


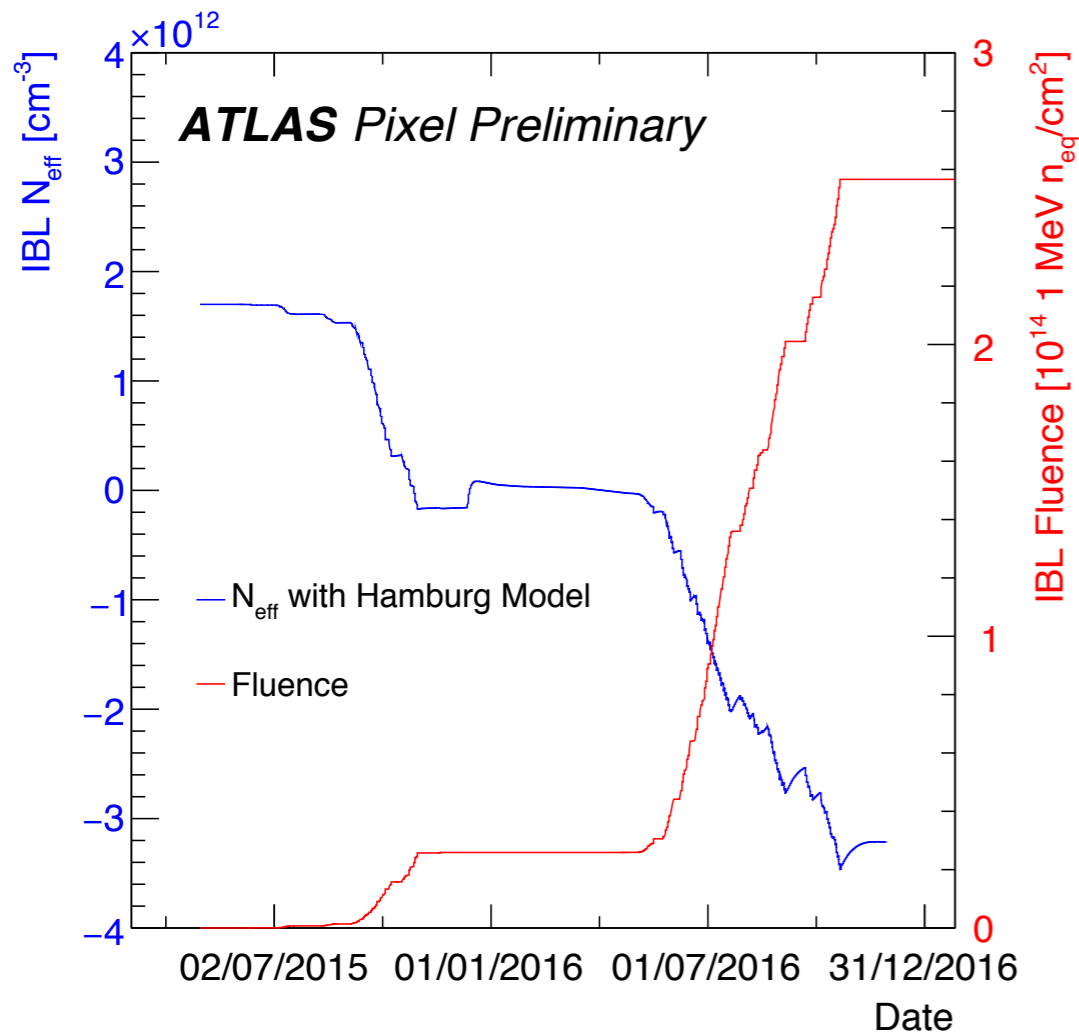
Validate with leakage current + Hamburg model

Assign 15% uncertainty at  $|z| \sim 0$







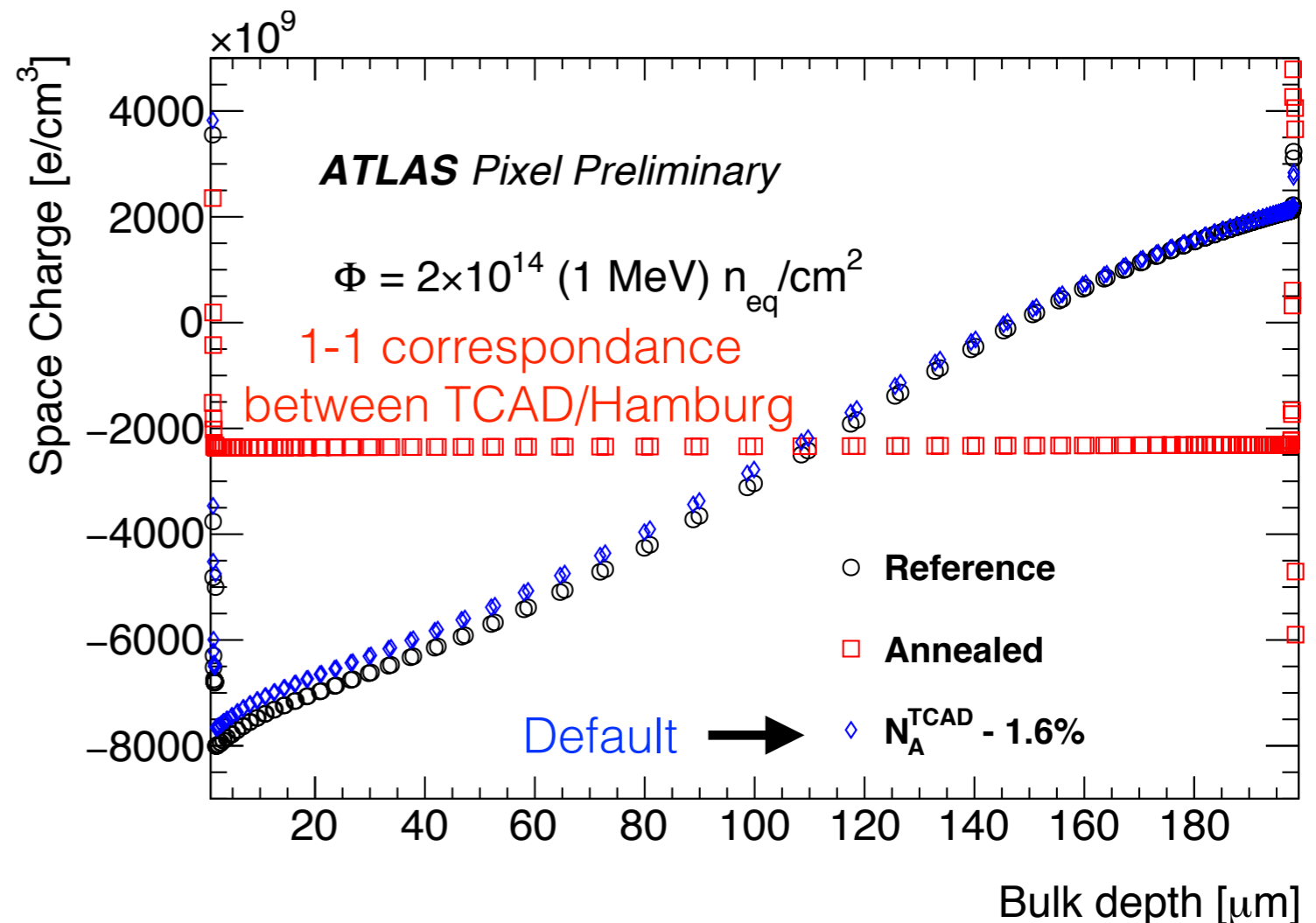


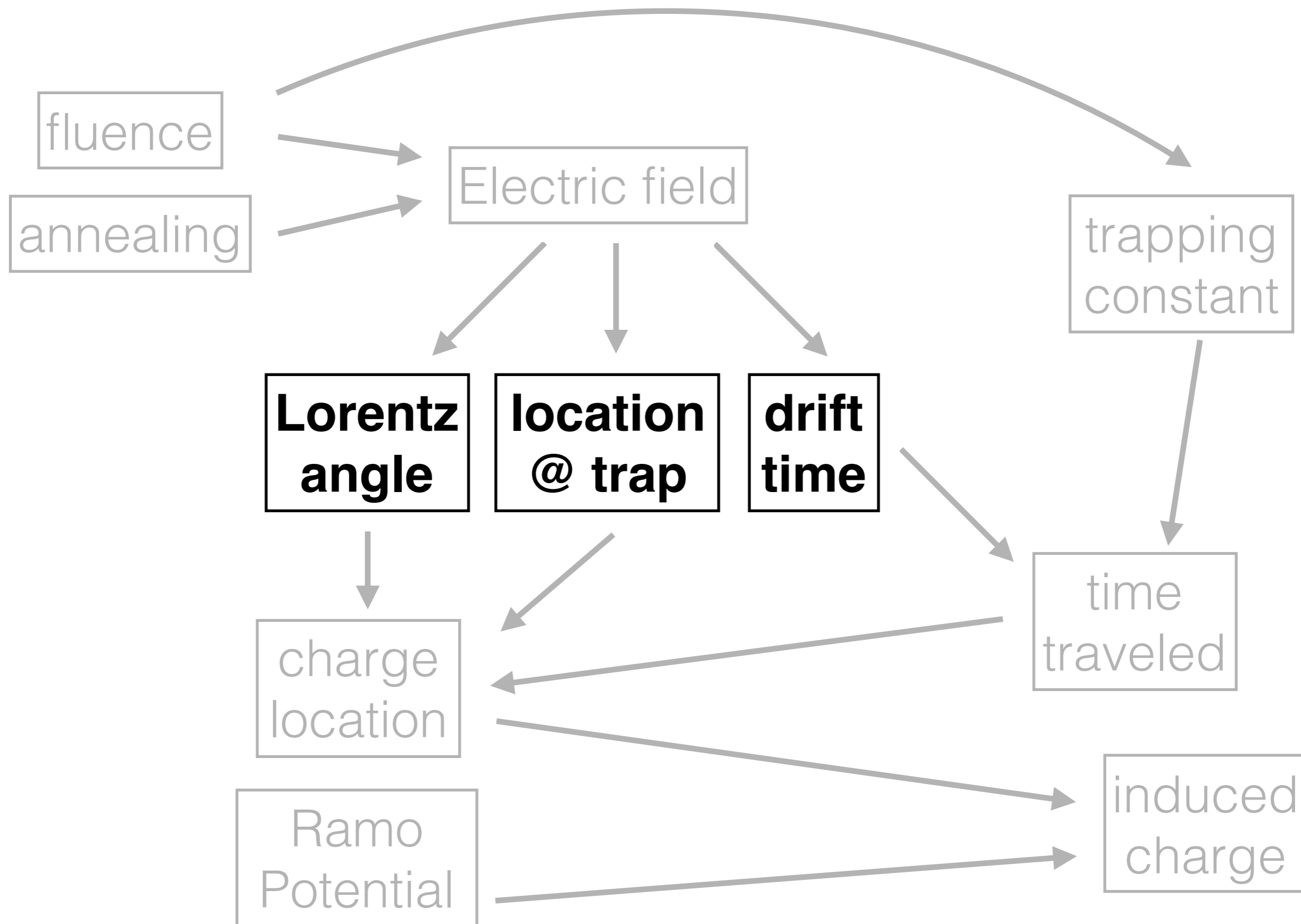
TCAD model does not include thermal / irradiation history

Idea: Use Hamburg model prediction for  $N_{\text{eff}}$  and tune TCAD

Some freedom: effective acceptor, donors for both TCAD and Hamburg.

$$\langle \rho/e \rangle_{\text{TCAD}} = (N_{\text{eff}})_{\text{Hamburg}}$$

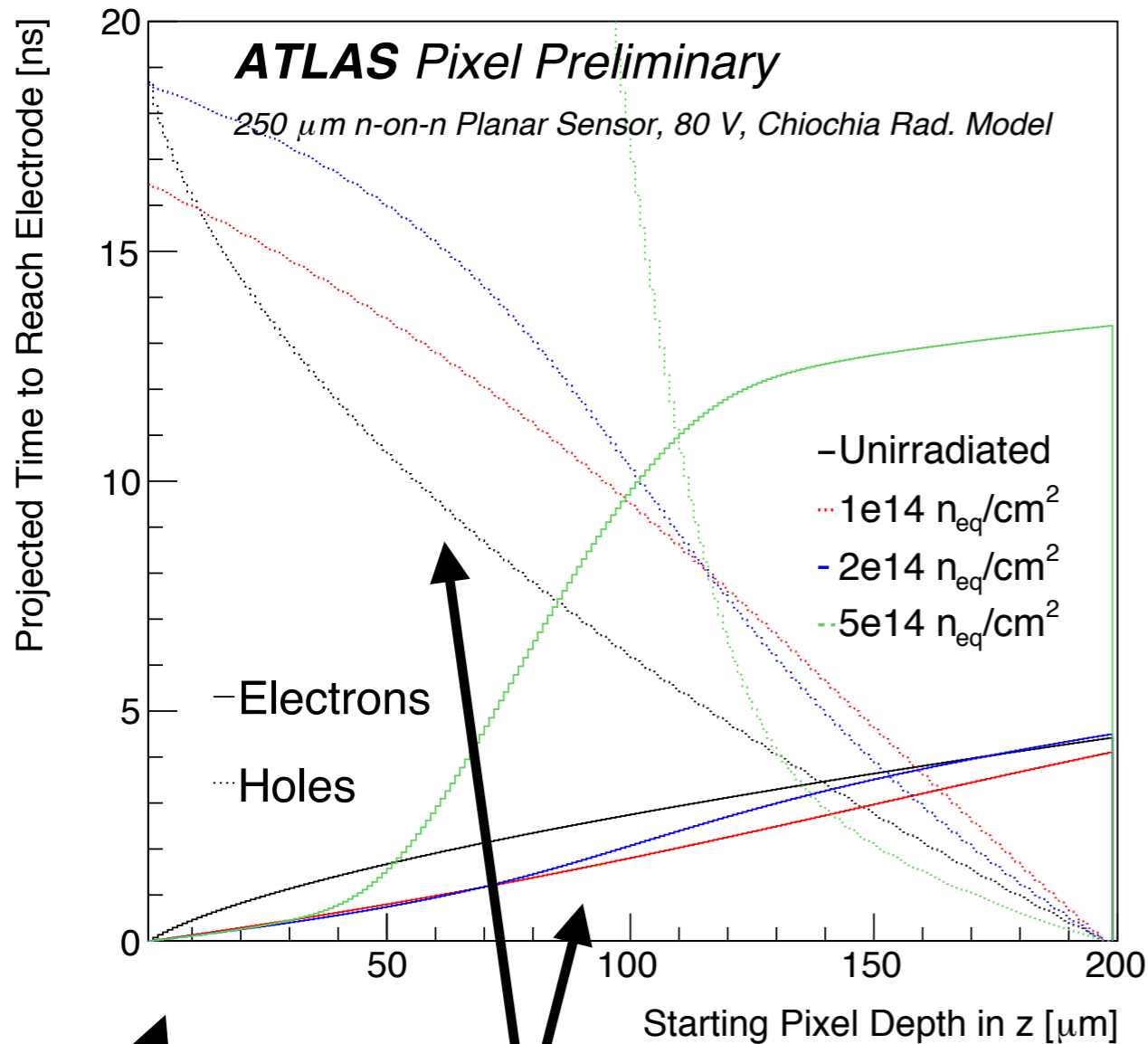






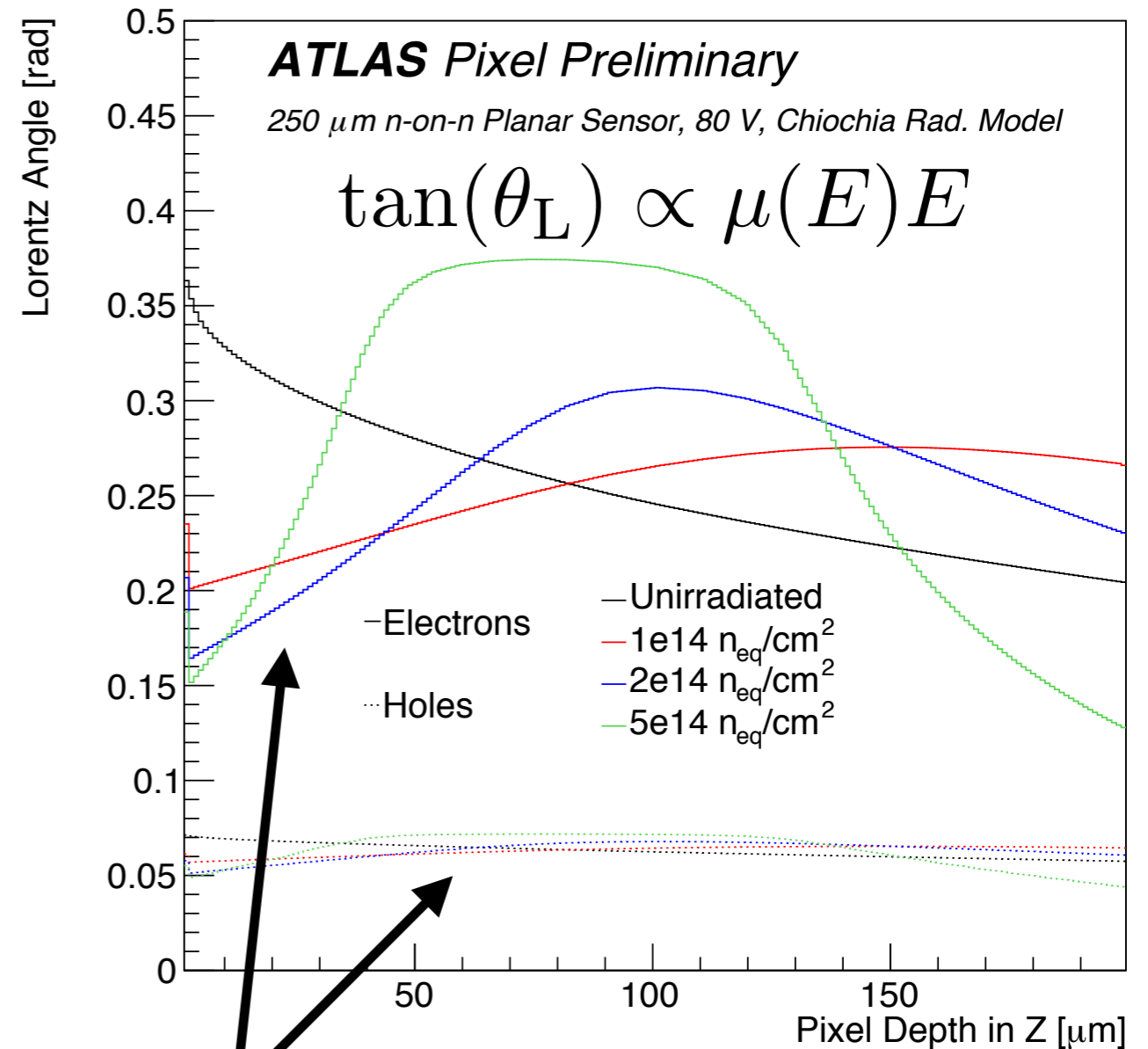
To save time, we pre-compute ('maps') all the quantities derived from the E-field.

*Small field = long time at **high fluence***



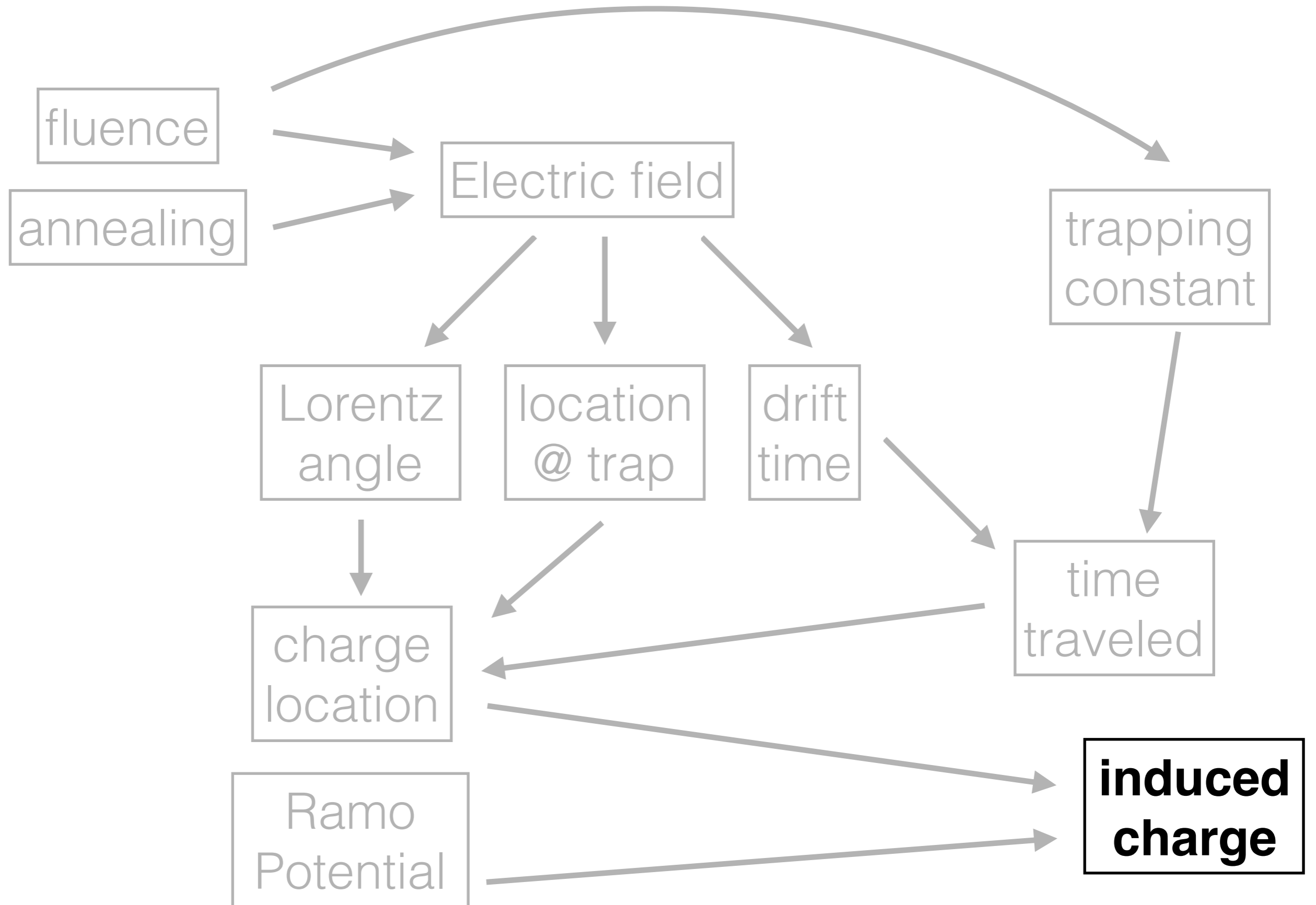
pixel  
implant

*Electrons move  
faster than holes*



*Electrons are deflected  
more than holes*

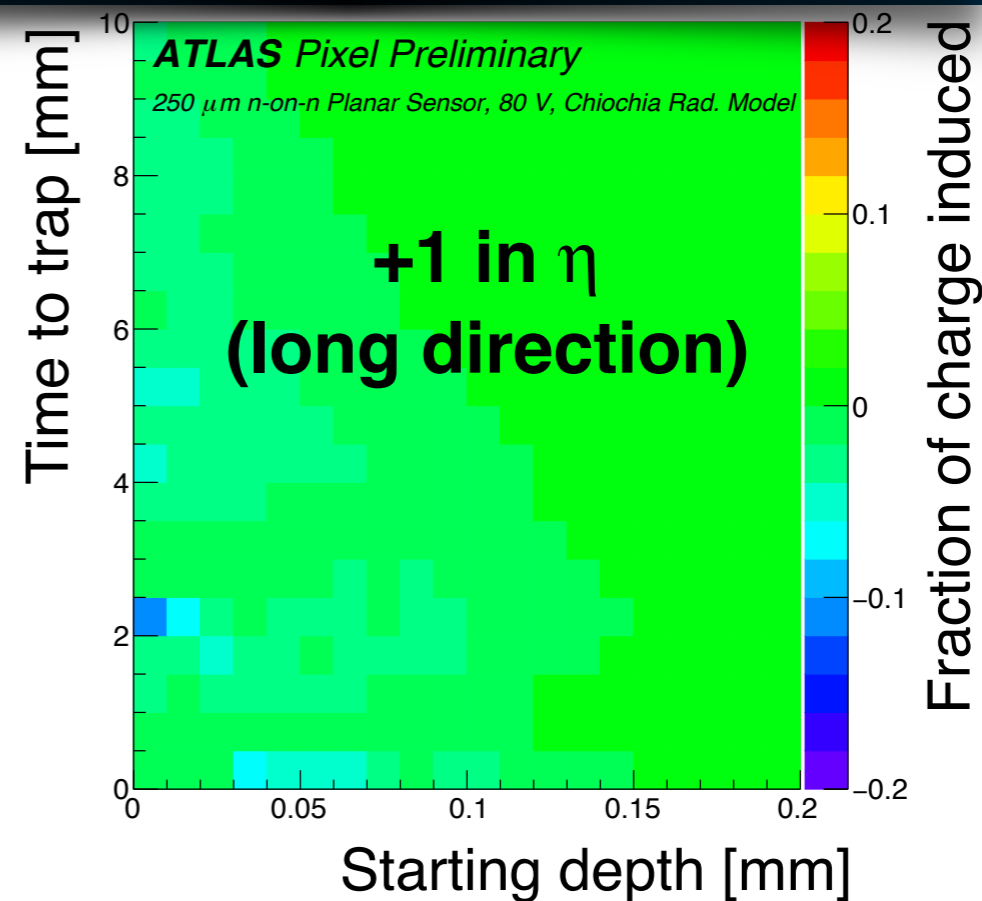
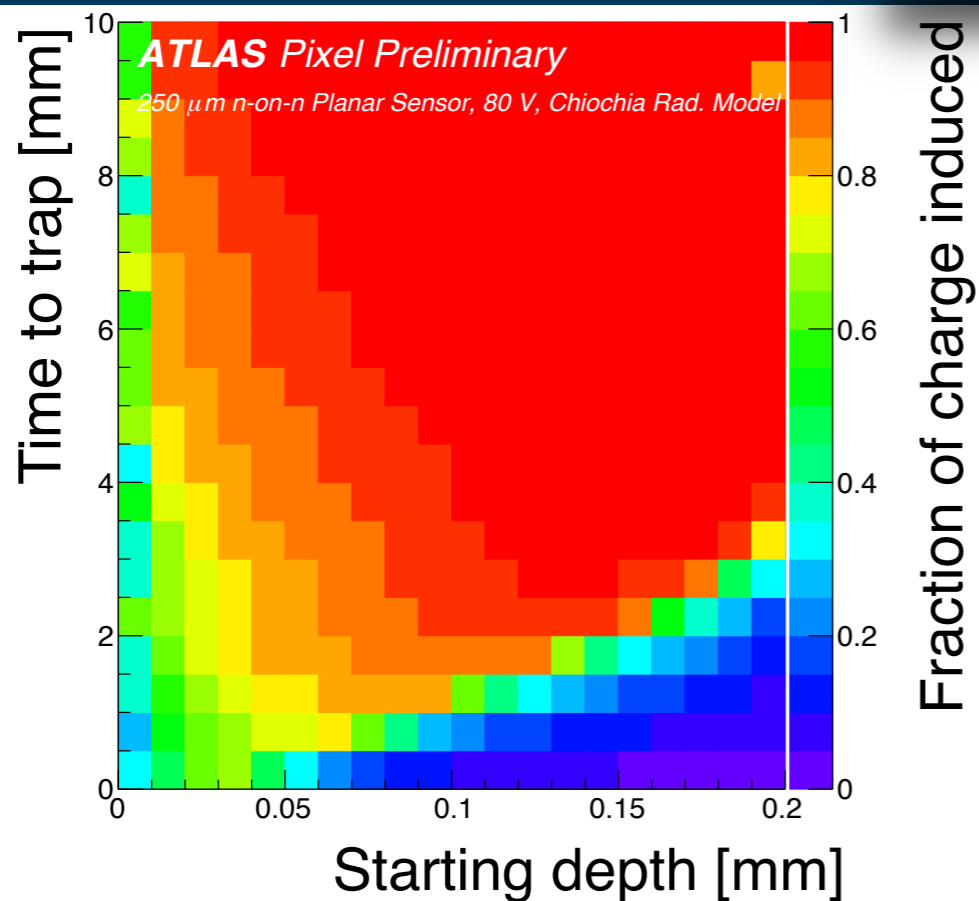
backside



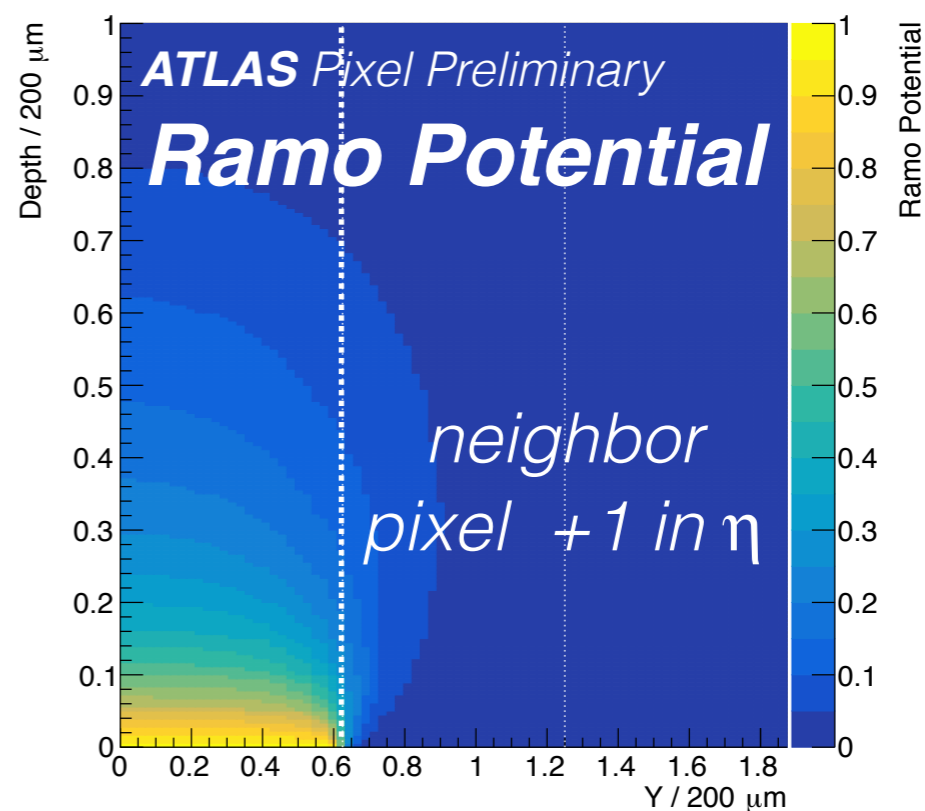
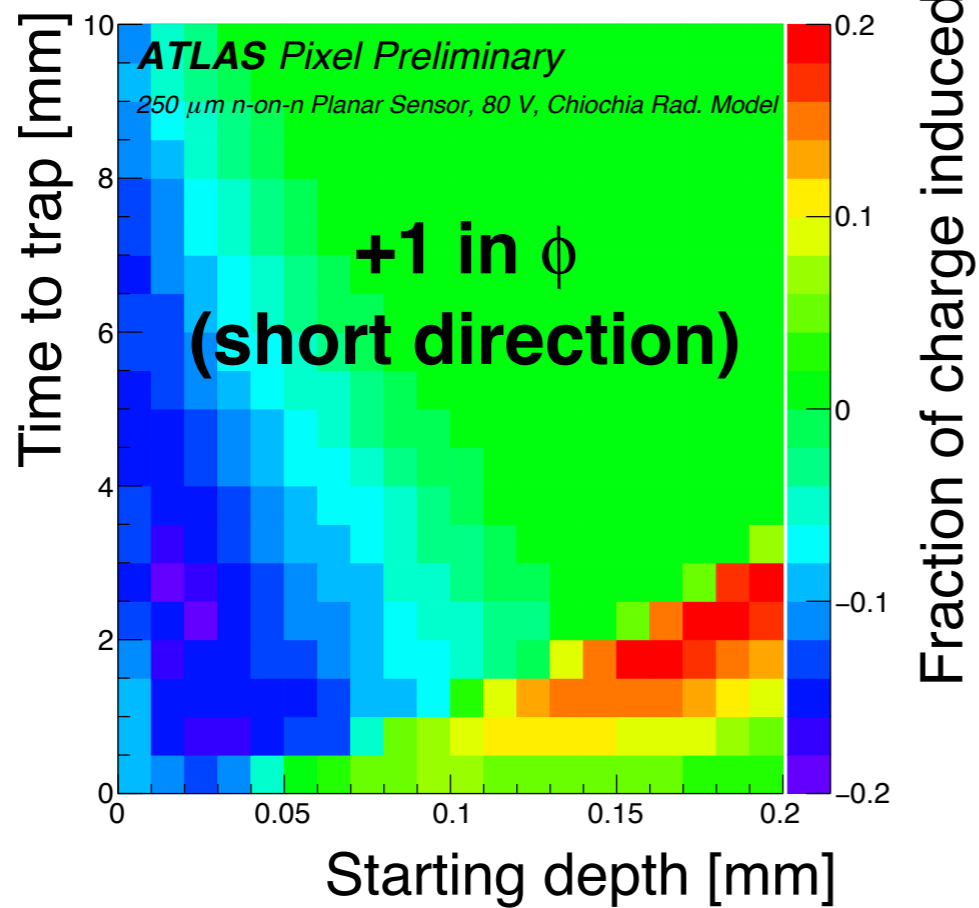
# Induced Charge

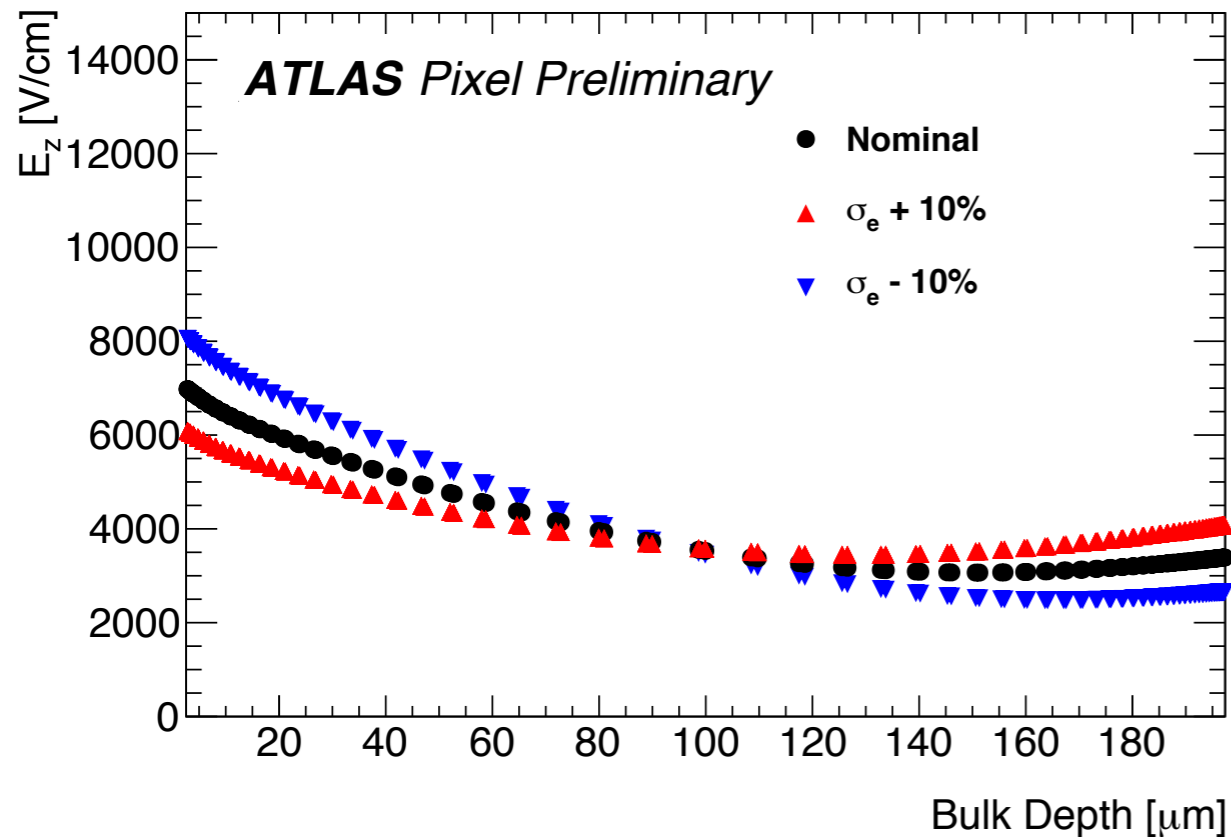
$$Q_{\text{induced}} = -Q[\phi(\vec{x}_{\text{end}}) - \phi(\vec{x}_{\text{start}})]$$

travel longer, induce more



travel longer, induce less



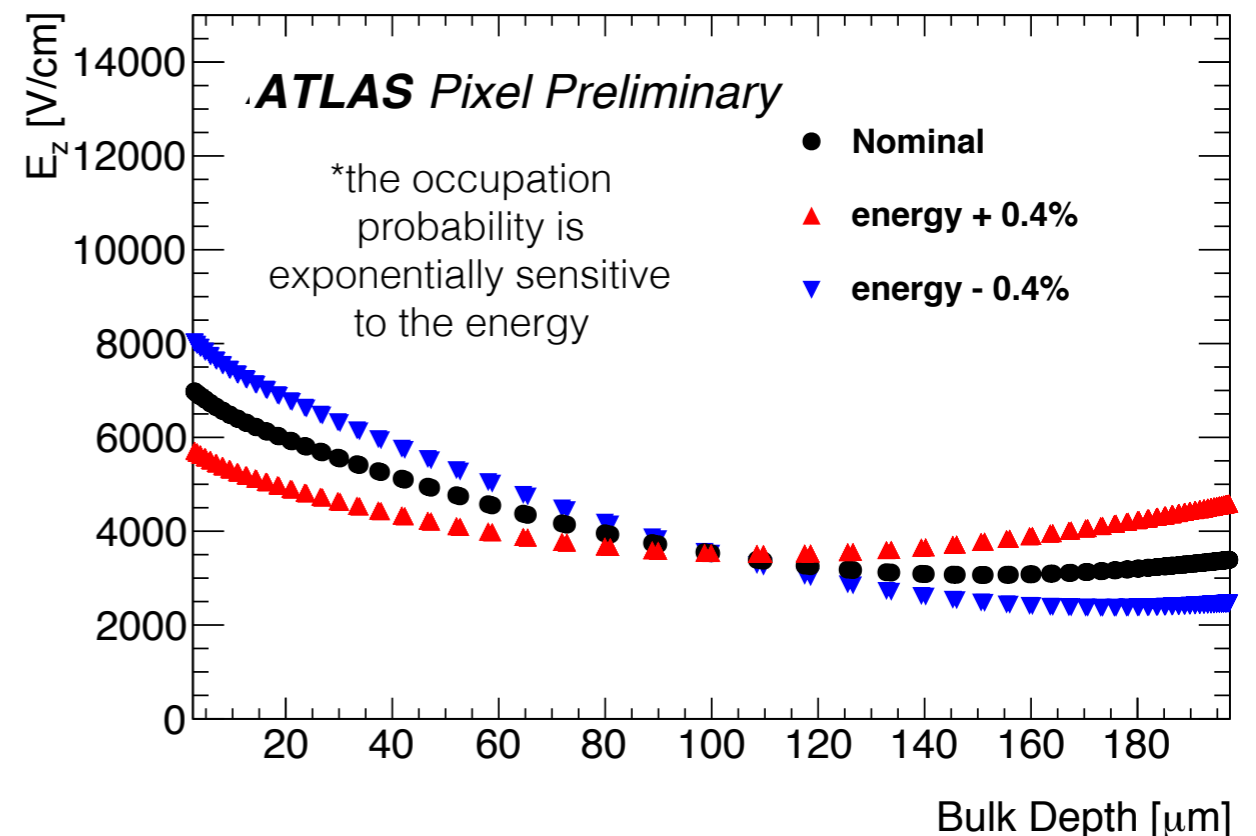


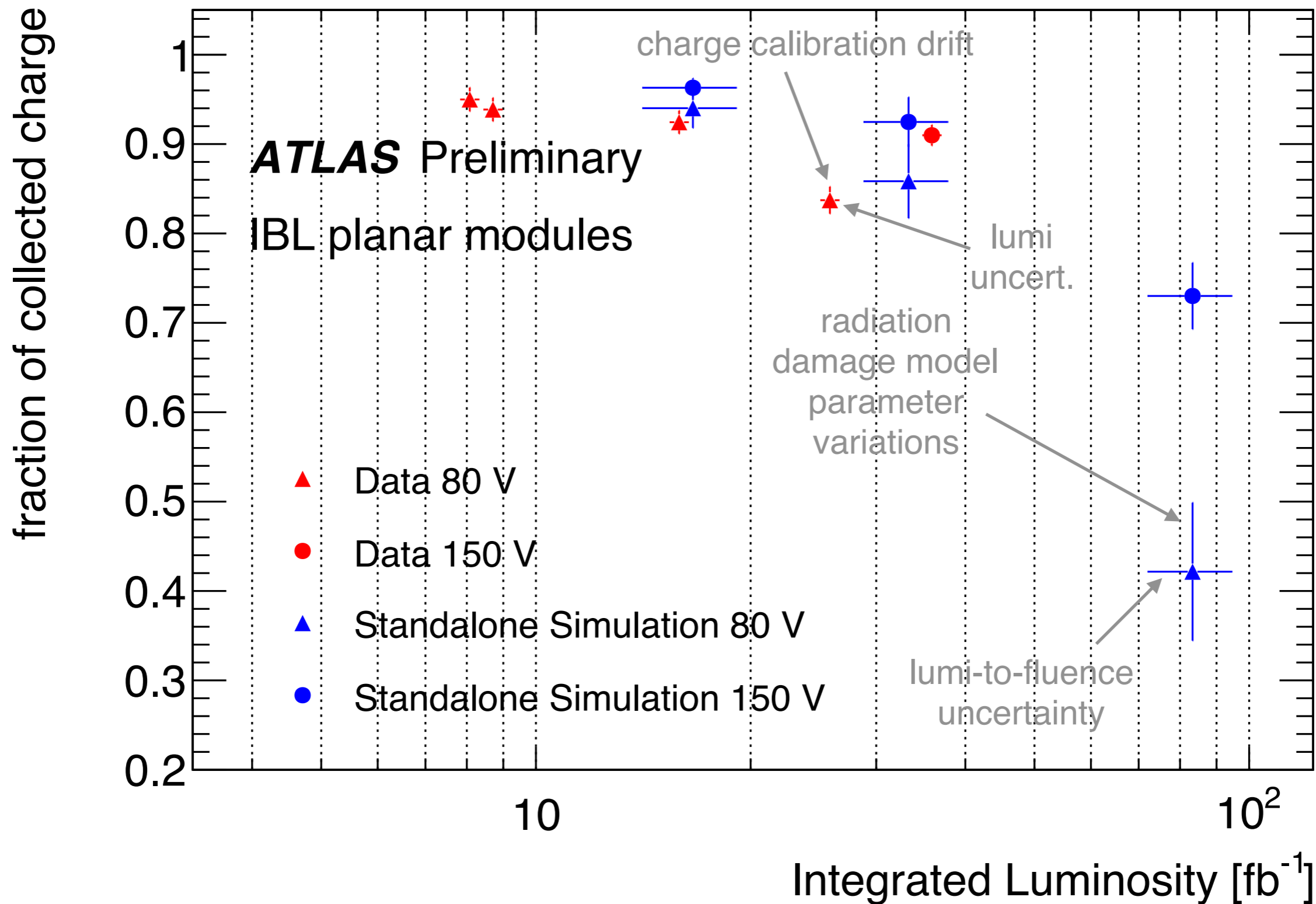
The existing rad damage models only have central values in the effective traps

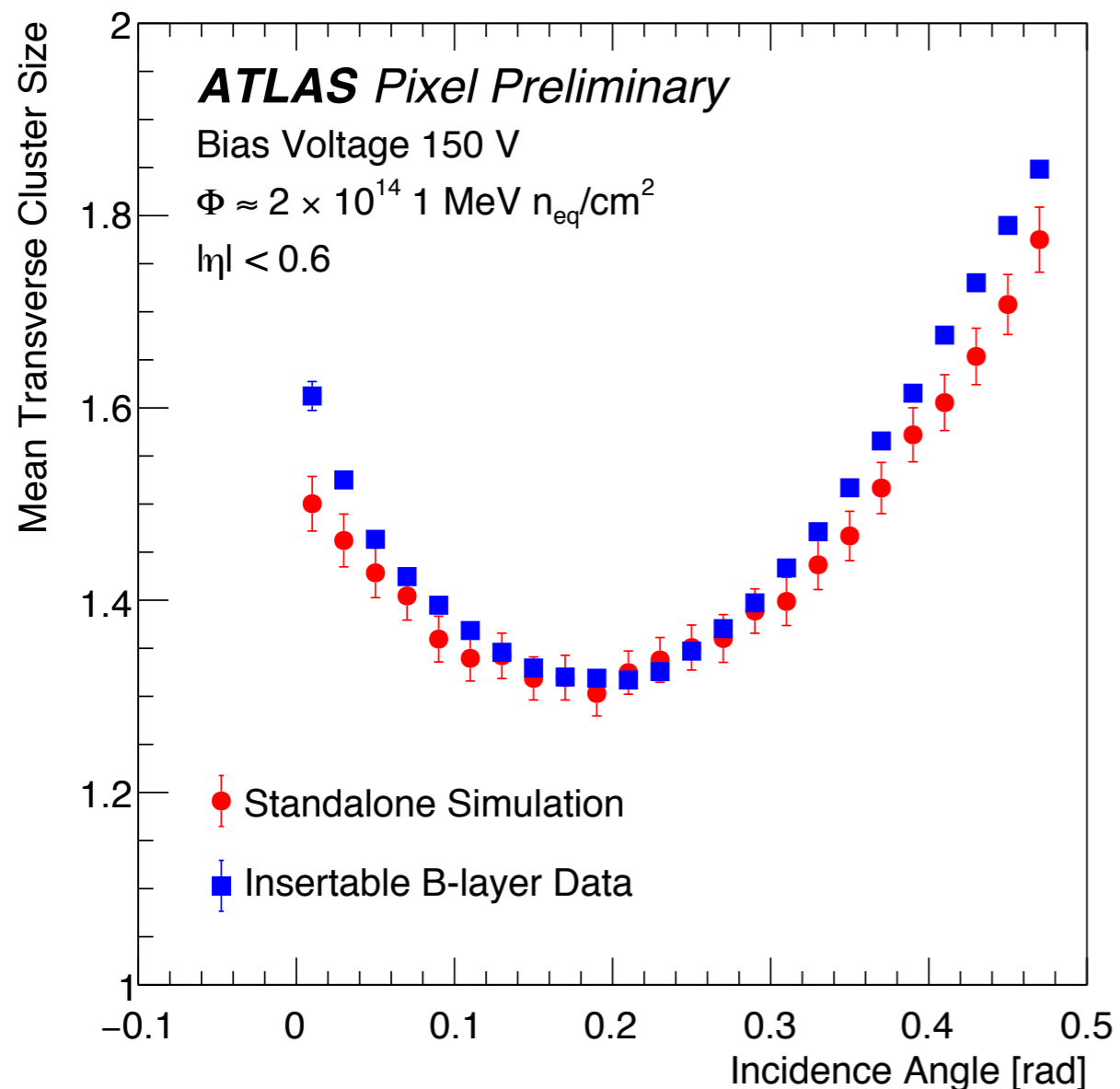
We vary the model parameters by 10%\* to assess the sensitivity

In the future, we will try to profile these uncertainties with collision data

Would also be great to provide fit uncertainties from TB data for new models!

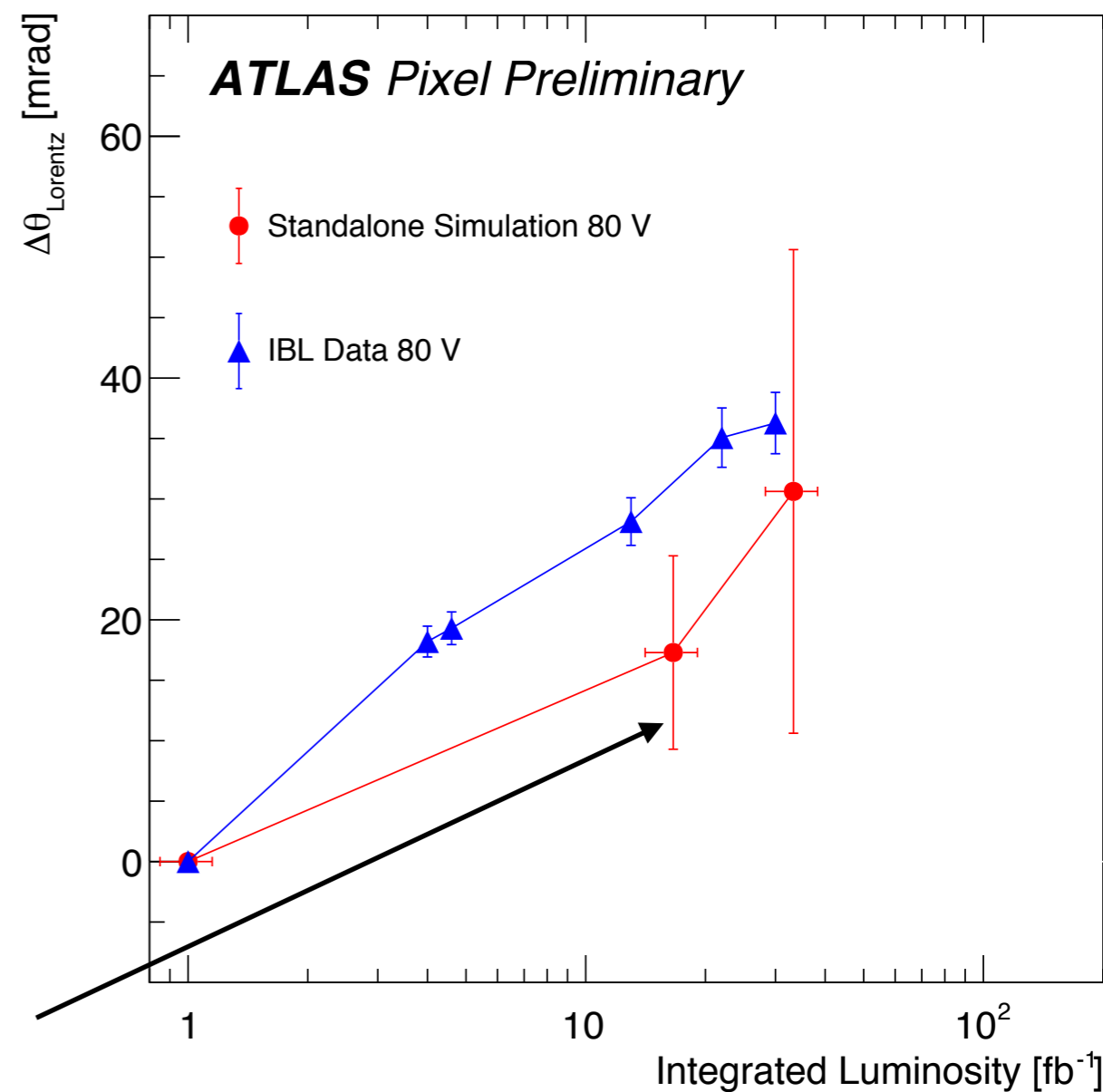






large correlation;  
 increase is robust

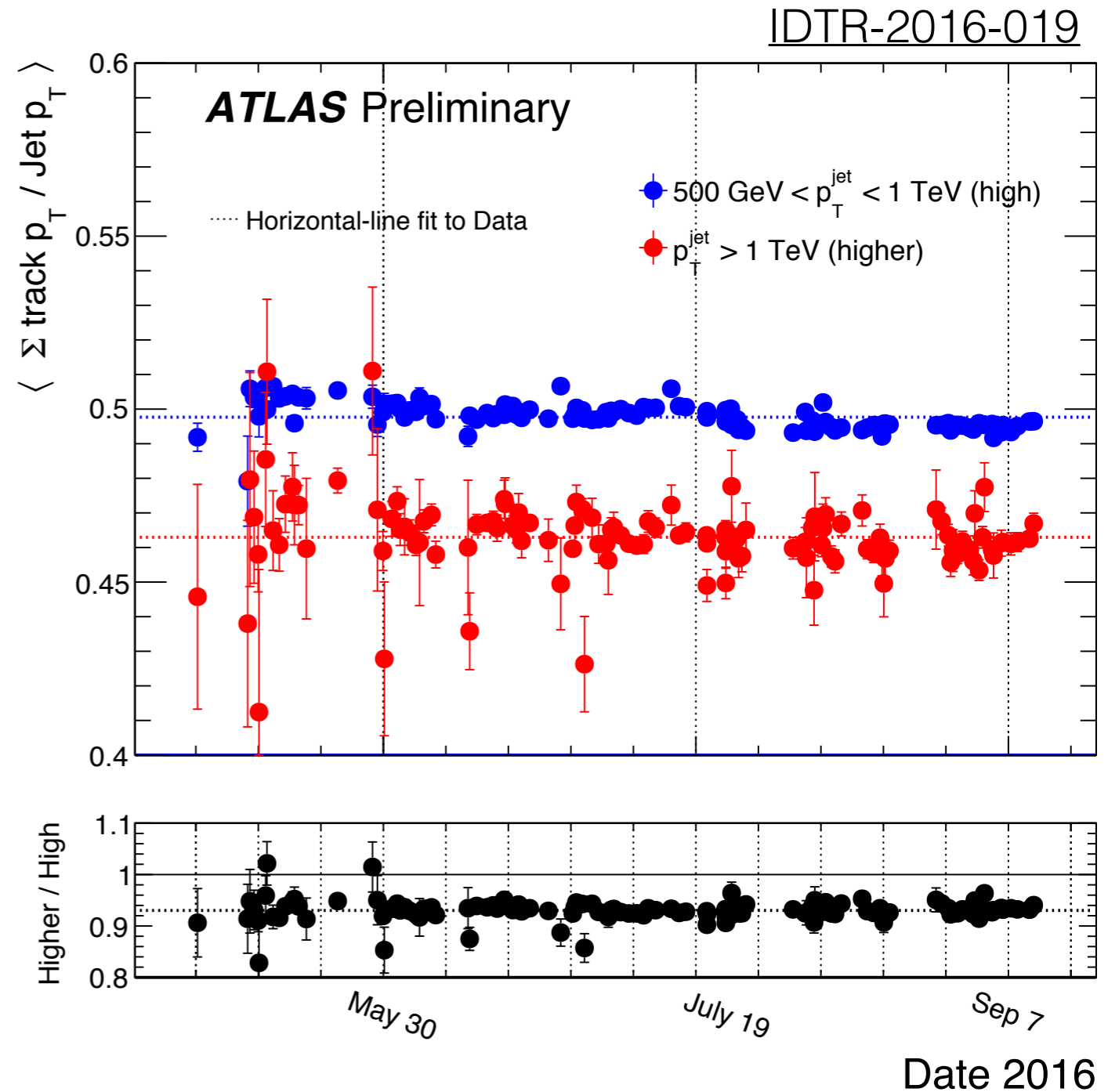
The Lorentz angle is also sensitive via the E-field (not from trapping)



We have developed pixel digitization model with radiation damage effects.

Tracking performance seems insensitive to the present fluence levels, but **degradation is inevitable**

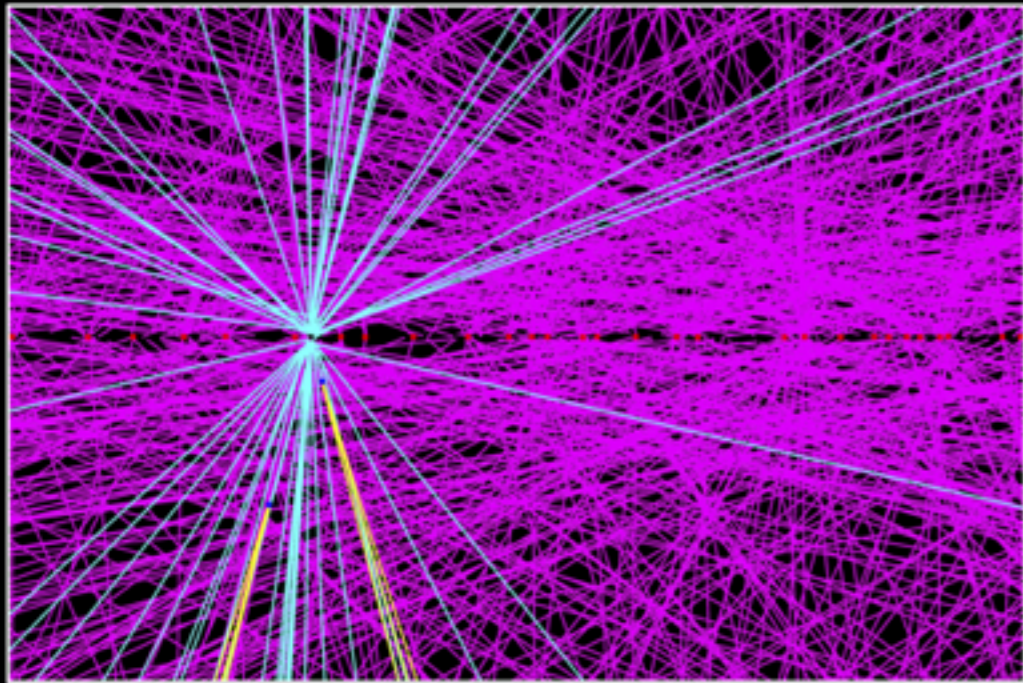
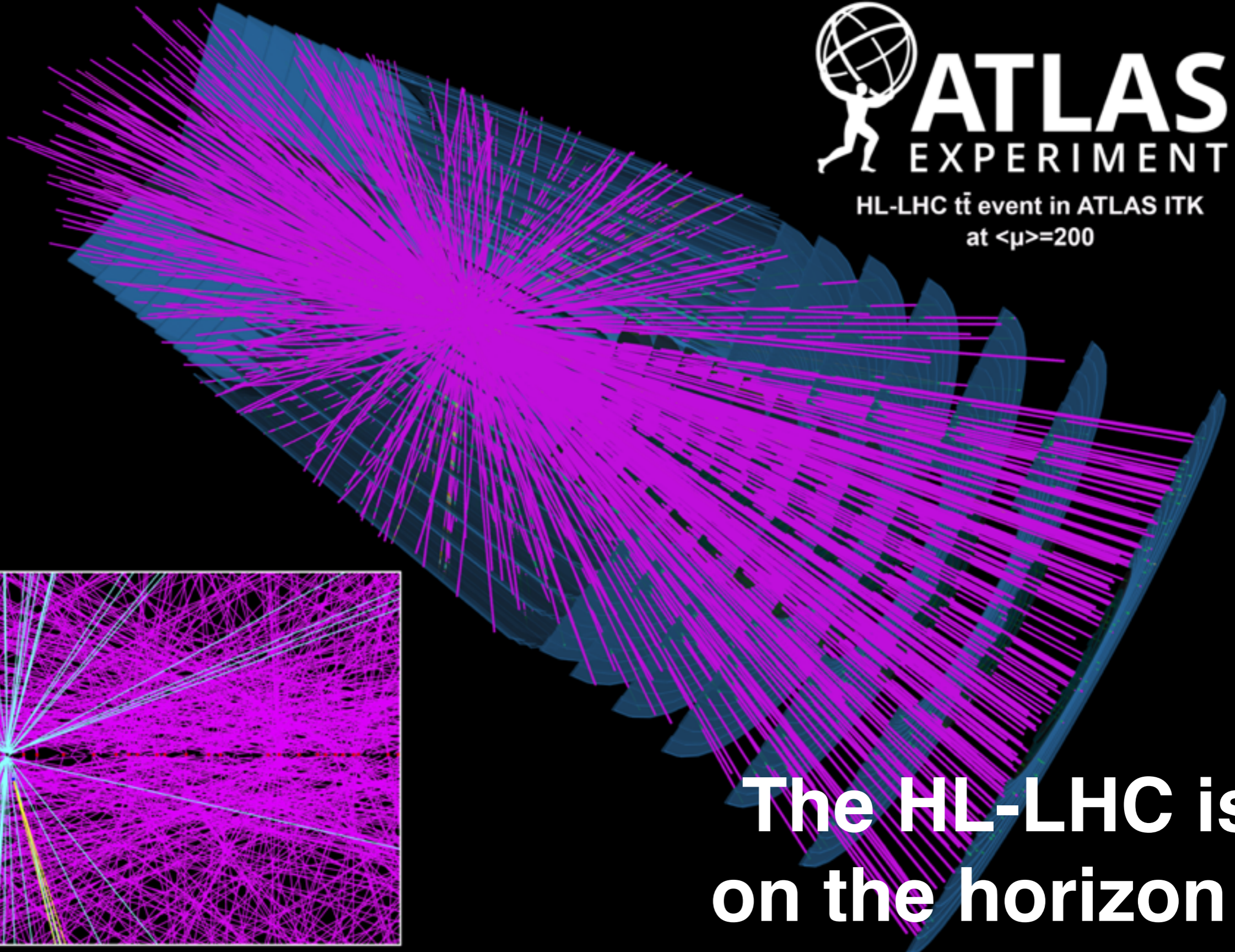
We are now prepared to model the degradation for Run 2+3 and for the HL-LHC





**ATLAS**  
EXPERIMENT

HL-LHC  $t\bar{t}$  event in ATLAS ITK  
at  $\langle\mu\rangle=200$



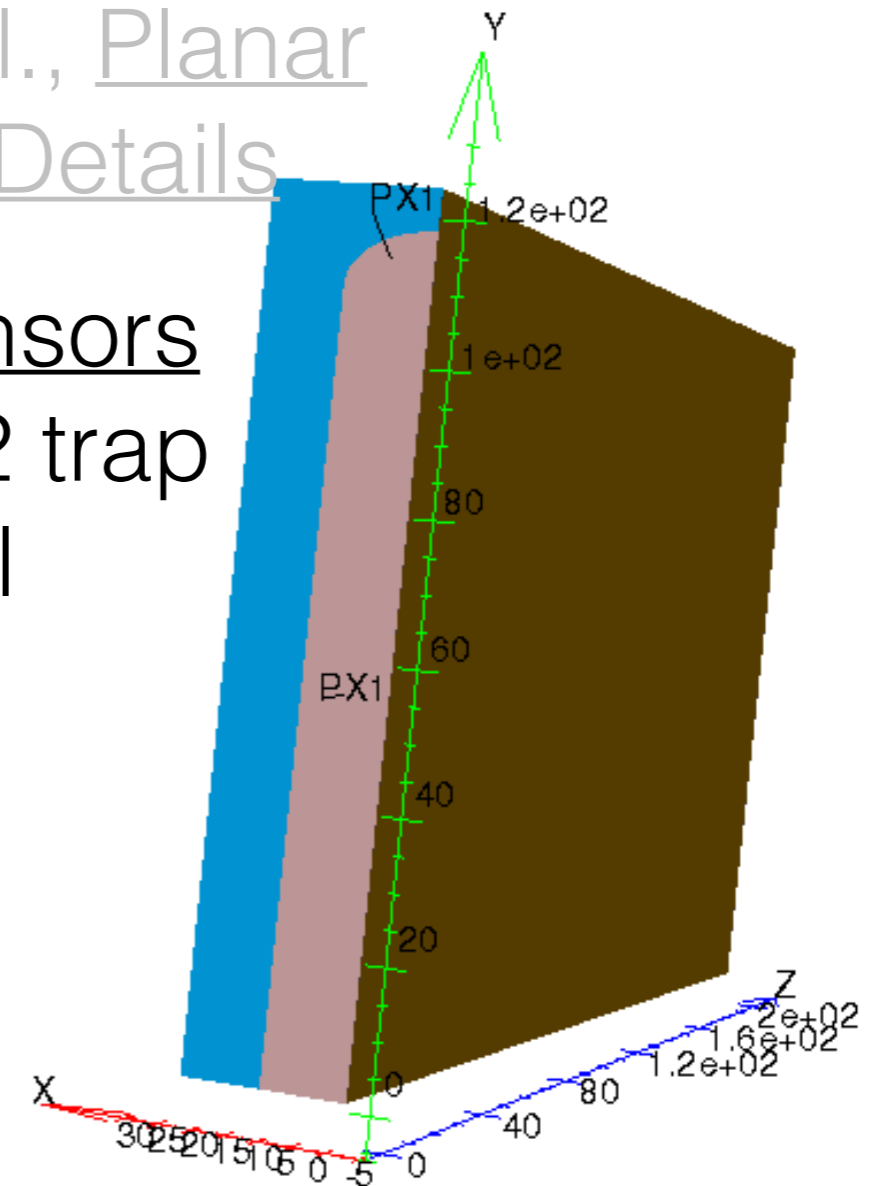
**The HL-LHC is  
on the horizon ..  
are you ready?**



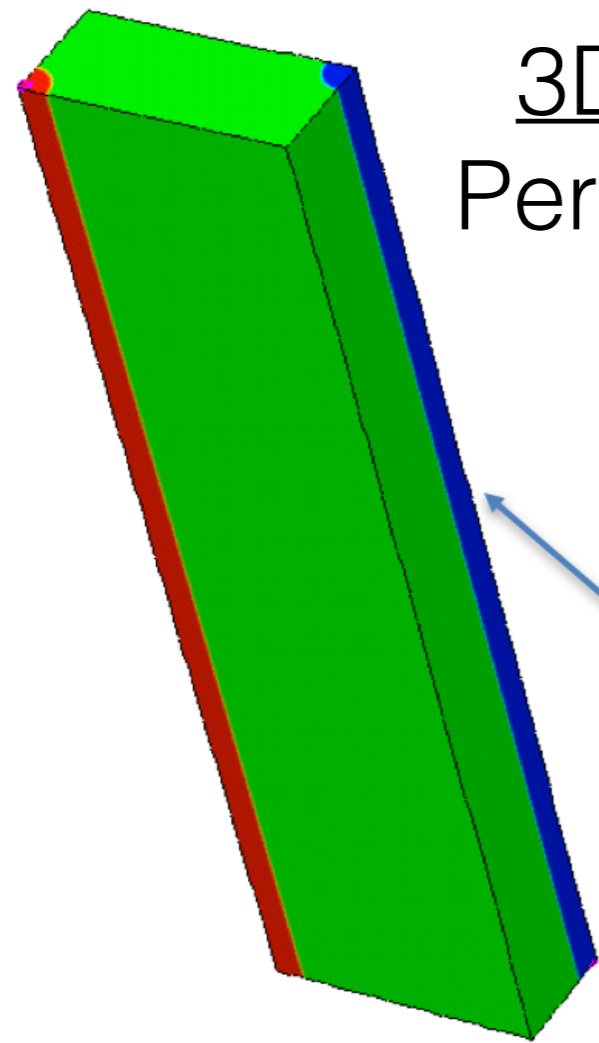
# Backup

Marco Bomben et al., Planar TCAD Simulation Details

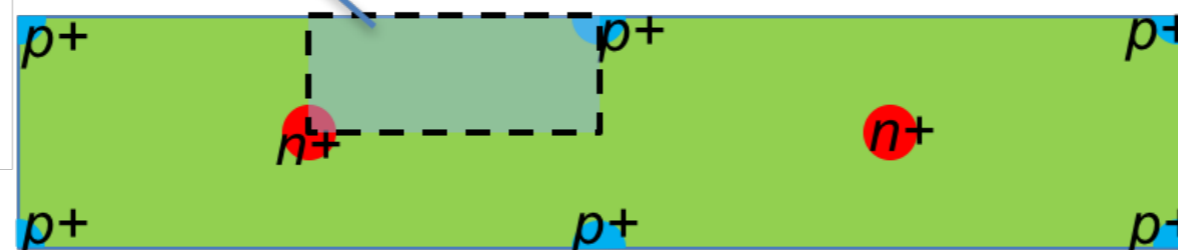
planar sensors  
Chiochia 2 trap  
model



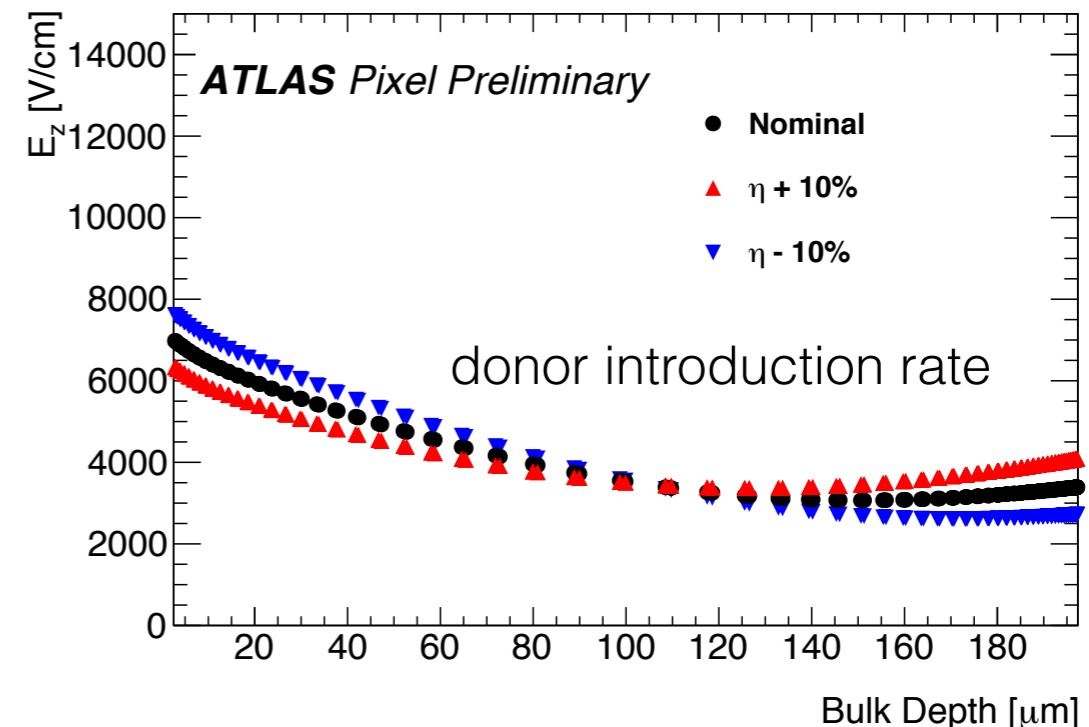
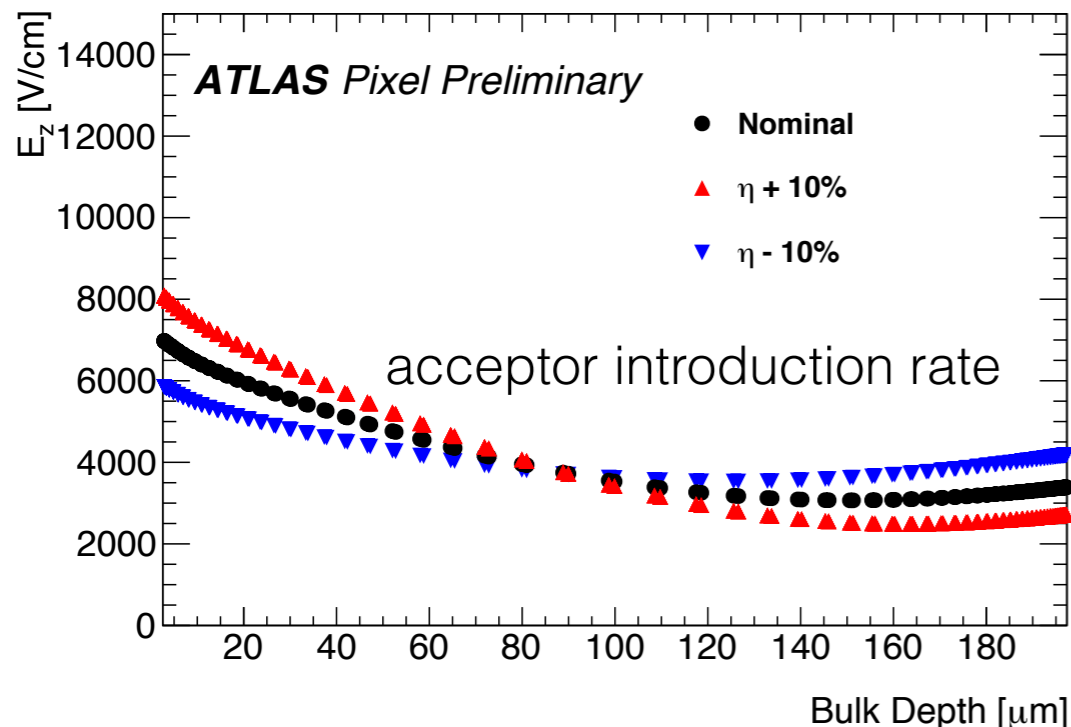
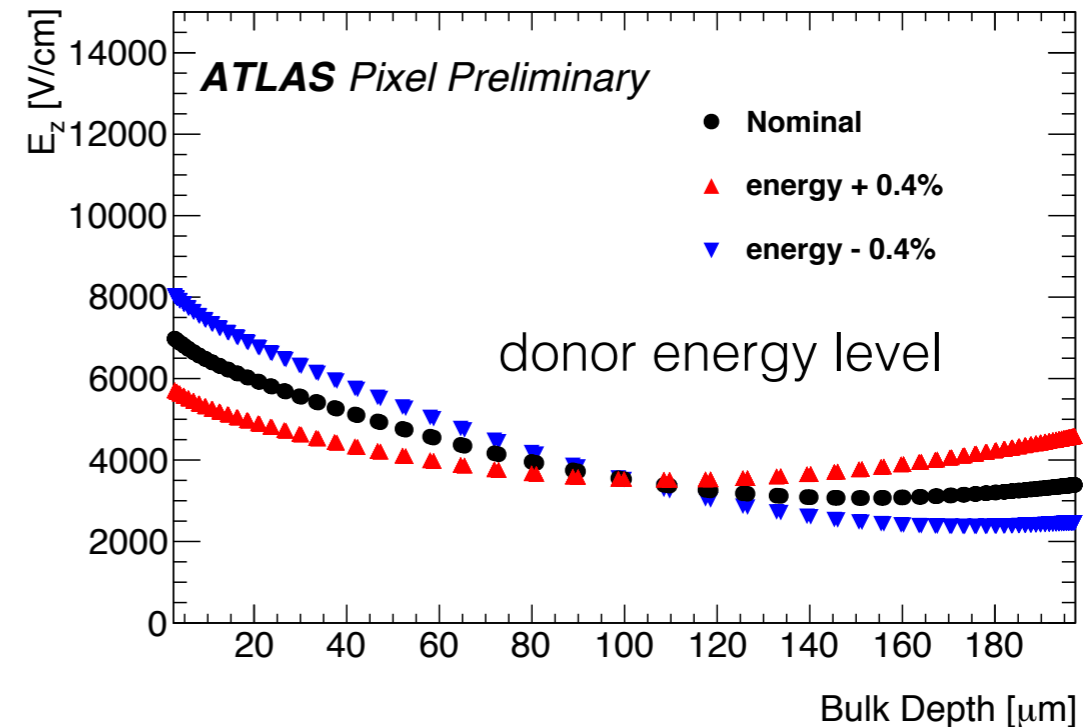
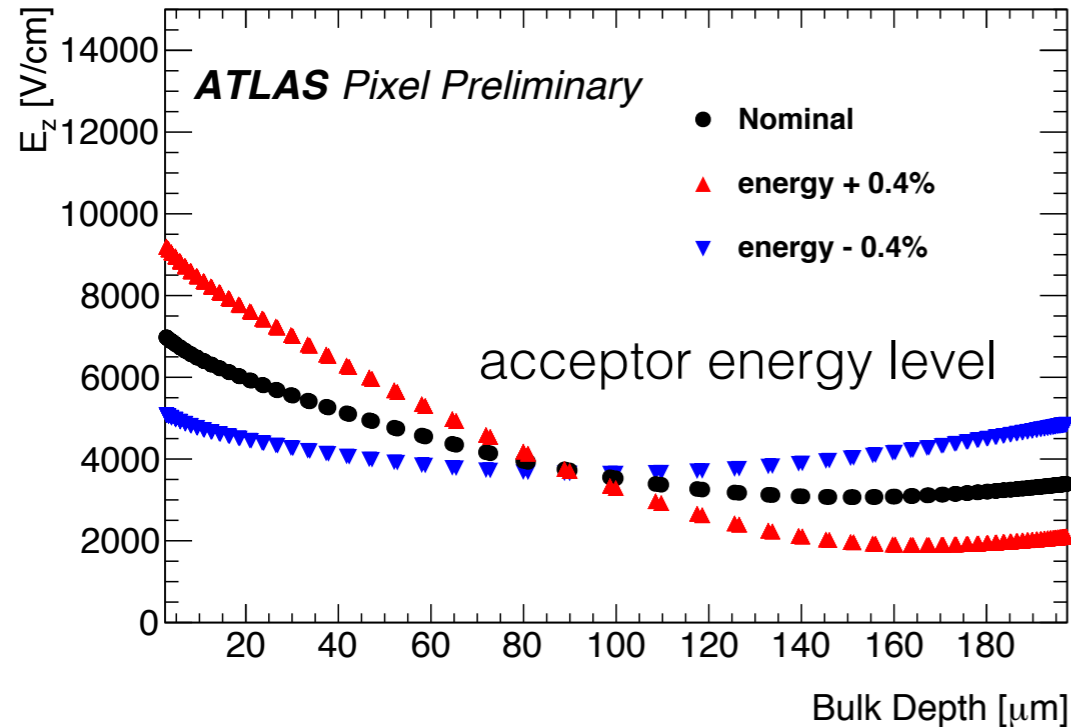
3D sensors  
Perugia 3 trap  
model



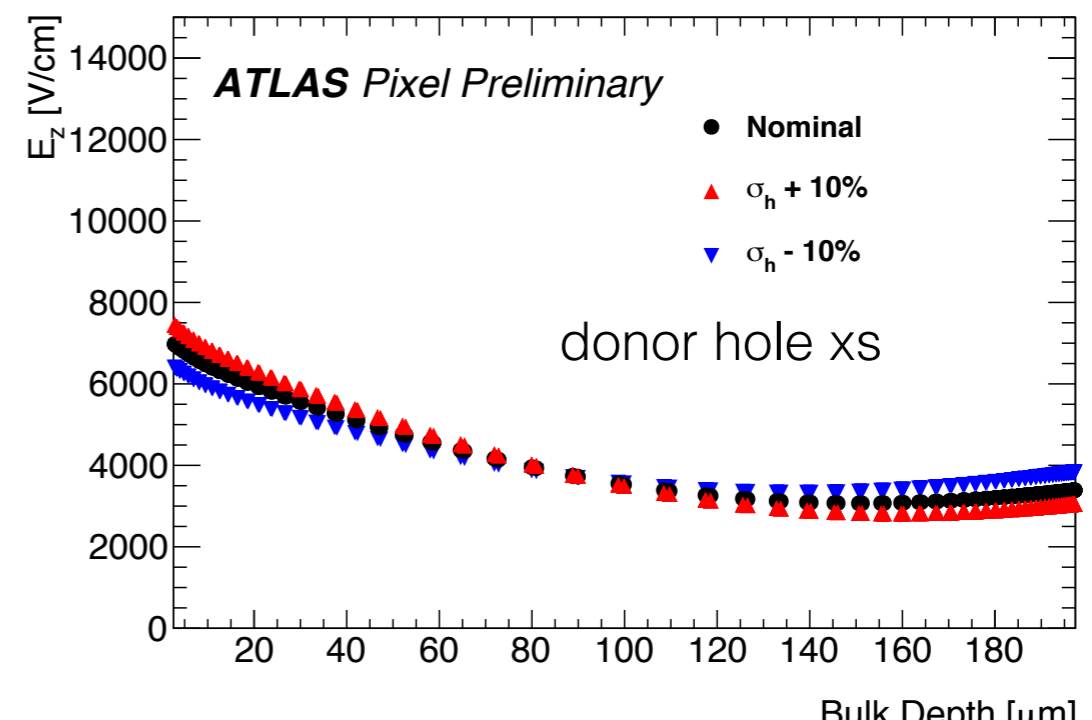
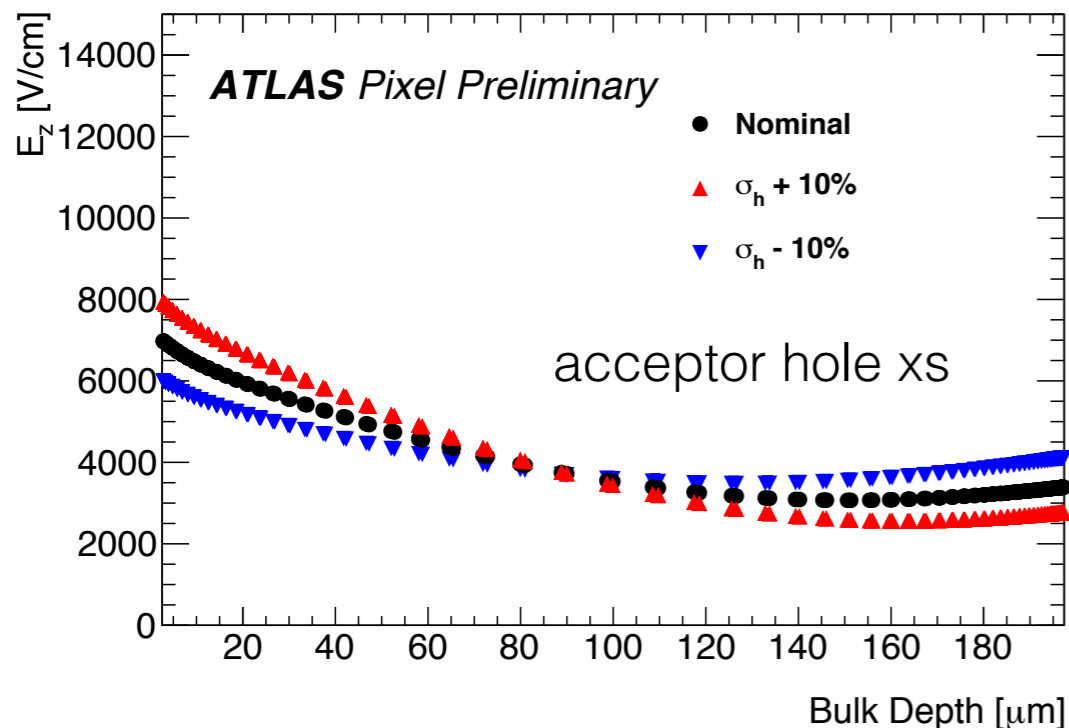
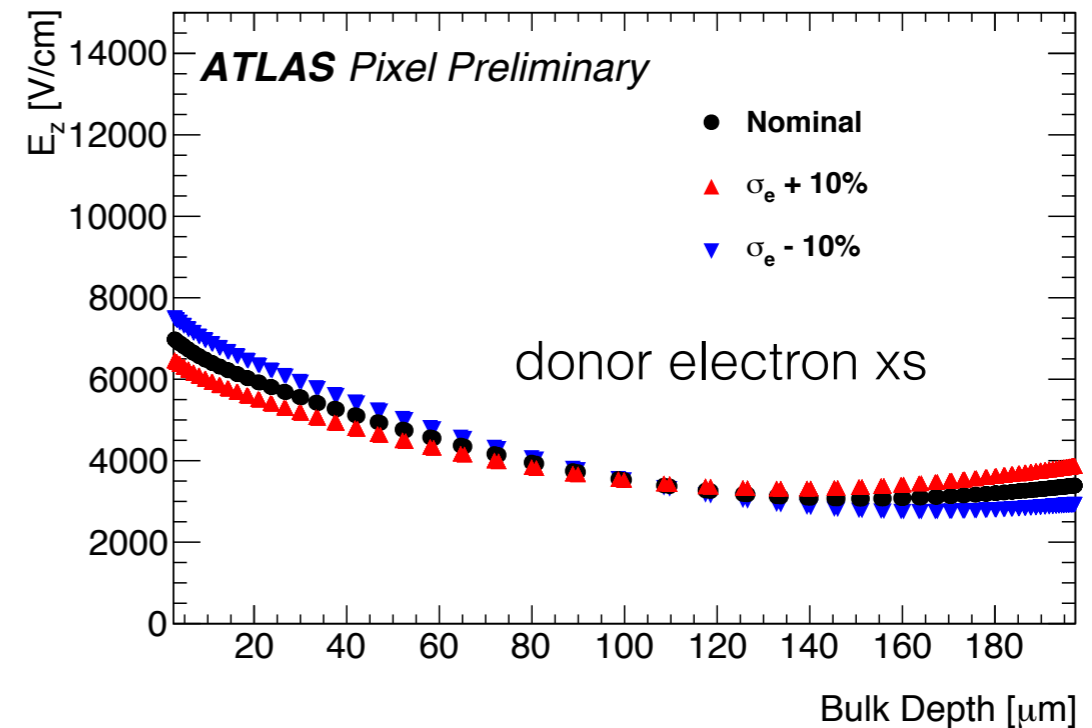
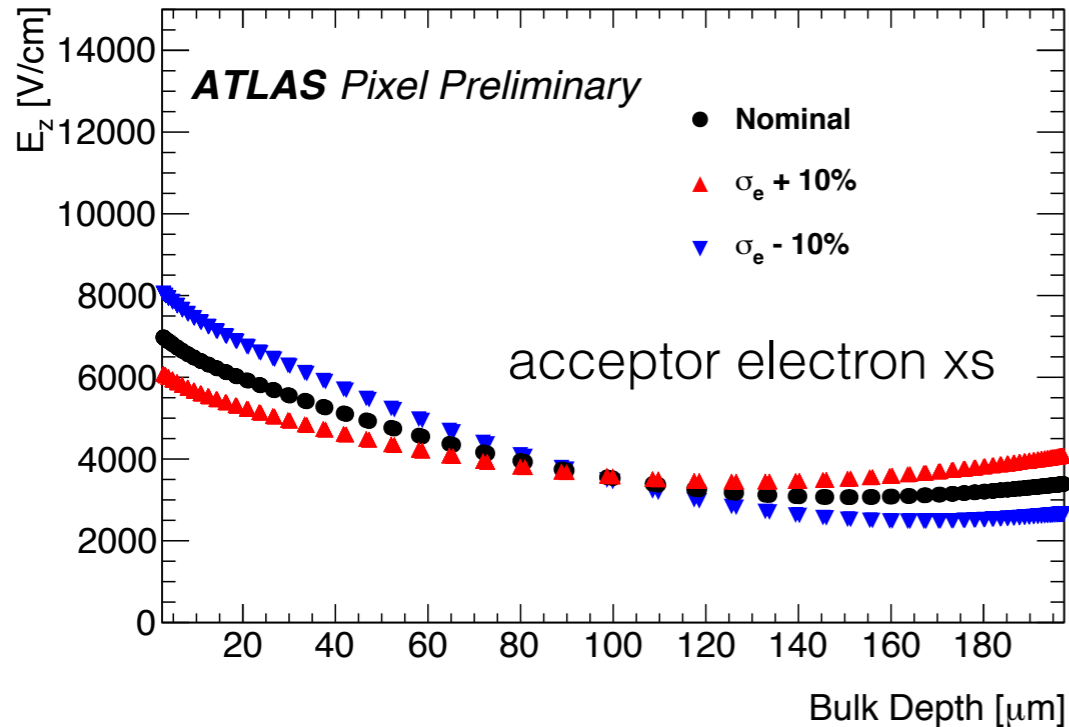
Calculation  
box

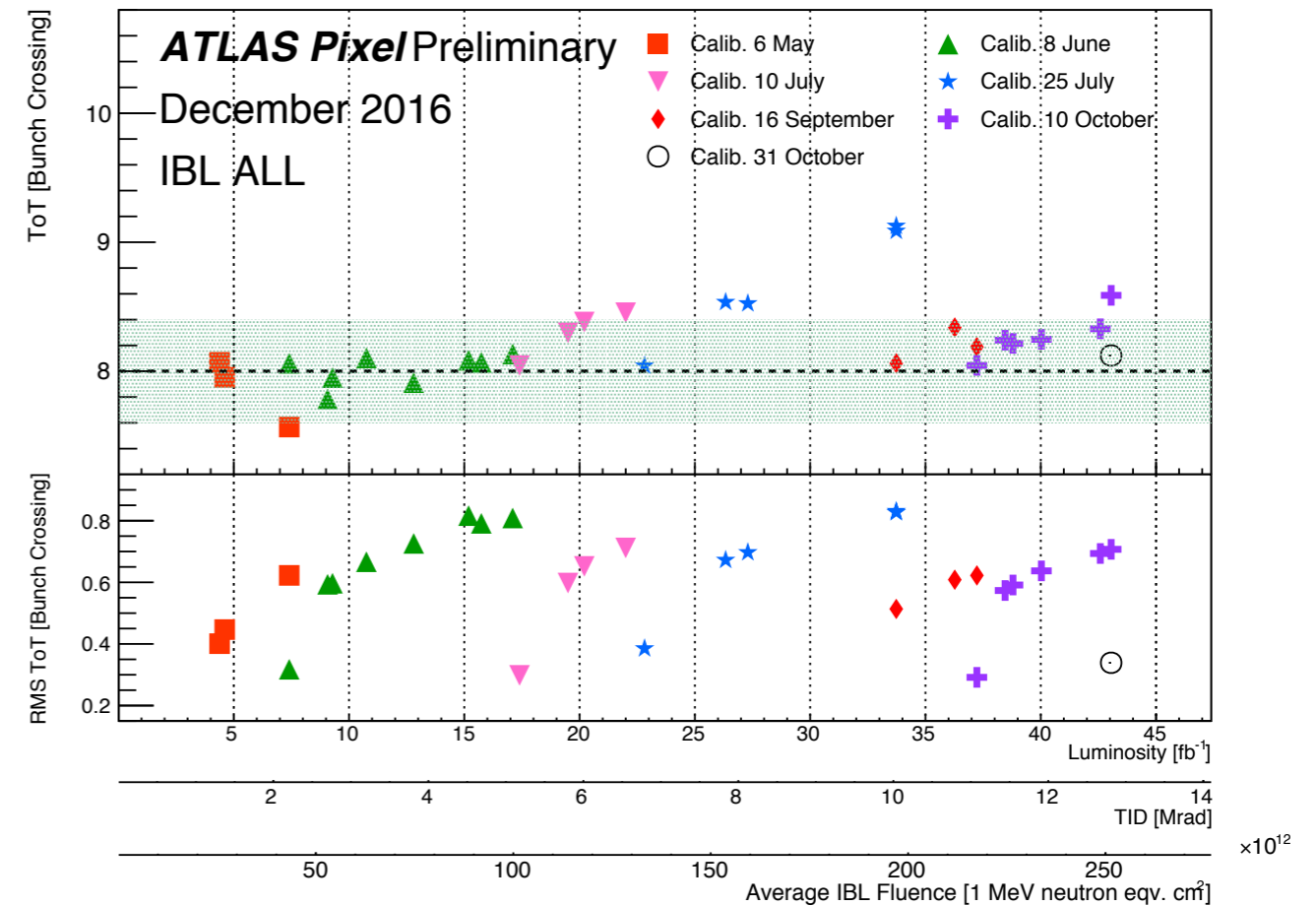
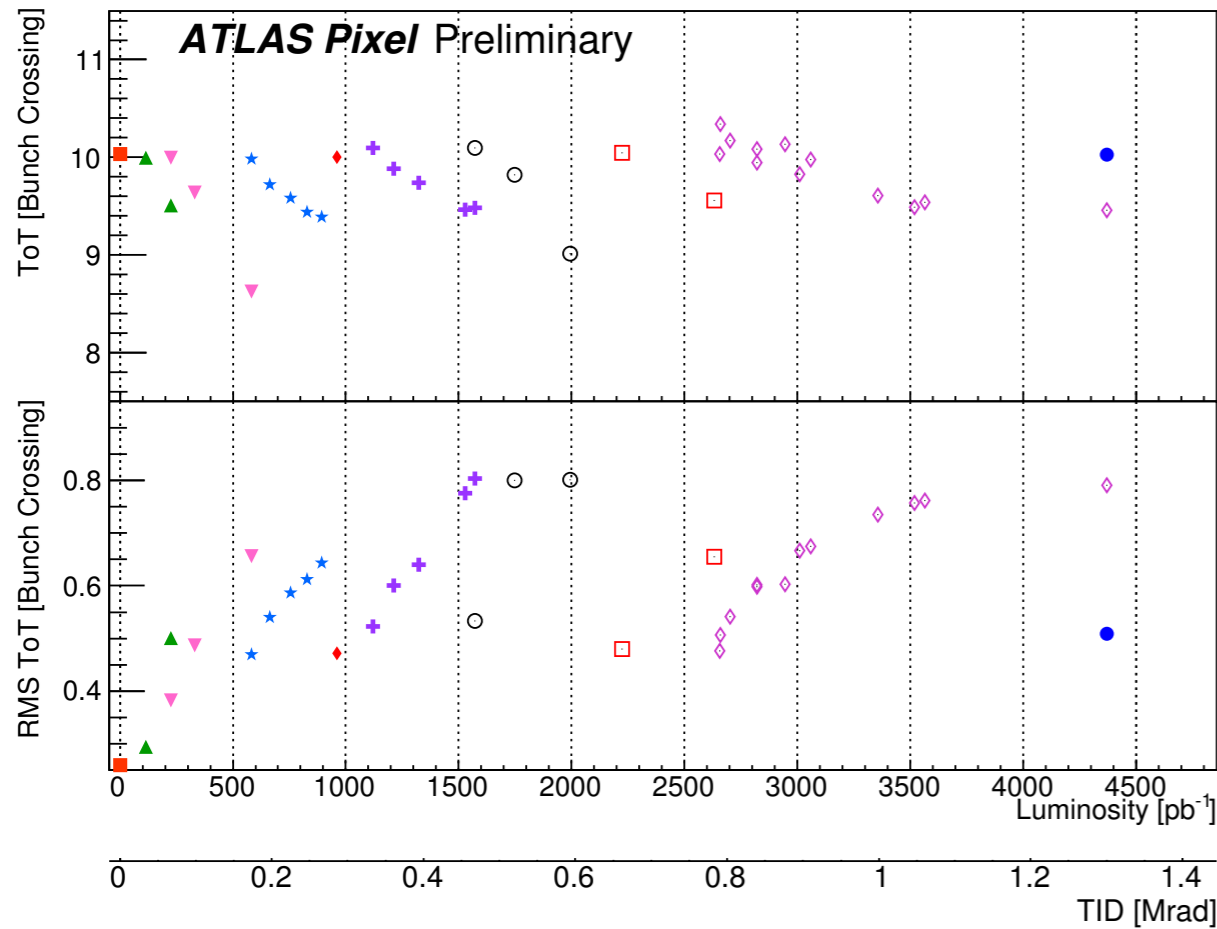


Each trap comes with 4 parameters: capture cross-section for electrons/holes, the introduction rate, and the energy level.



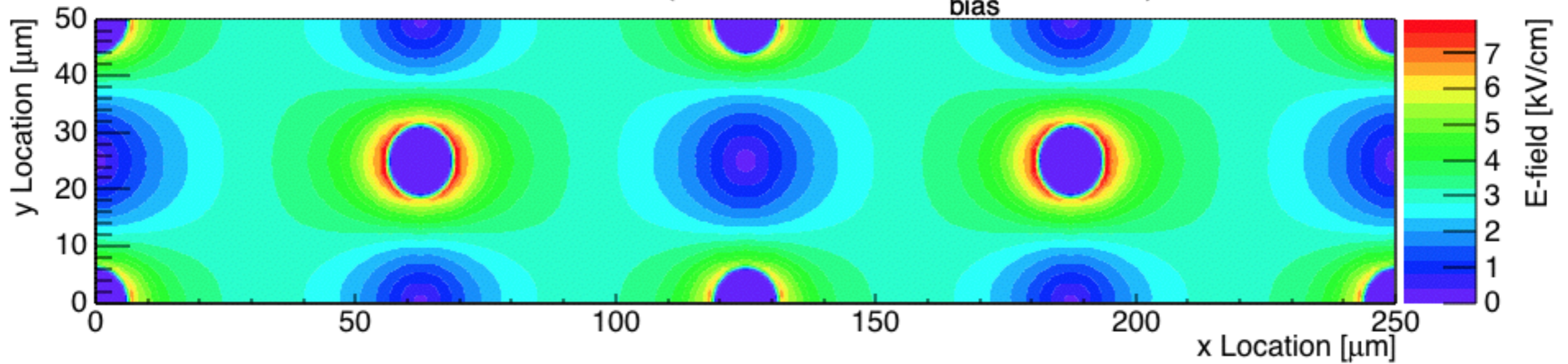
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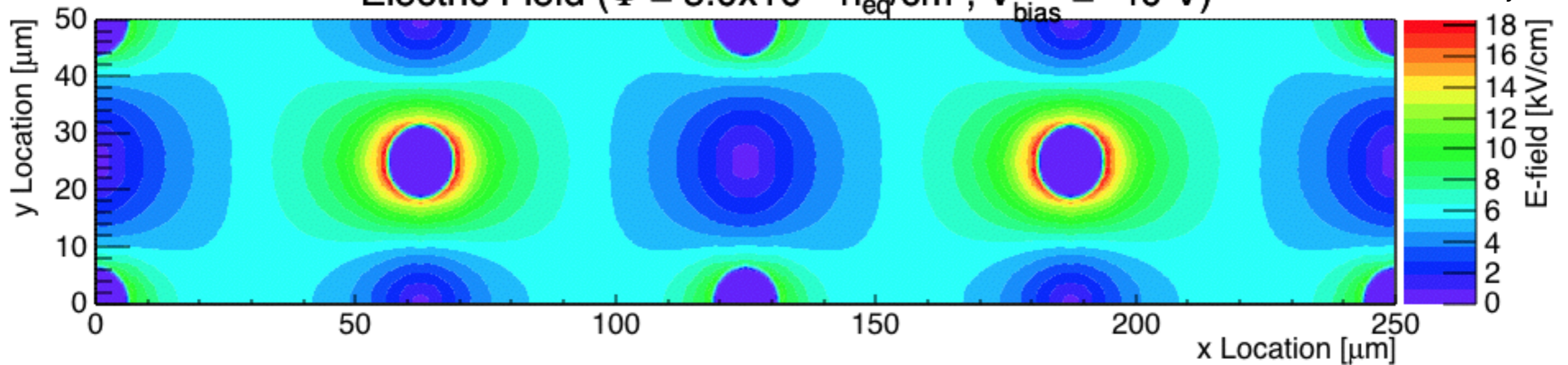


We apply corrections and uncertainties to our data in the CCE plot on p21 based on the observed drift.

Electric Field (Unirradiated,  $V_{\text{bias}} = -20 \text{ V}$ ) *ATLAS Pixel Preliminary*

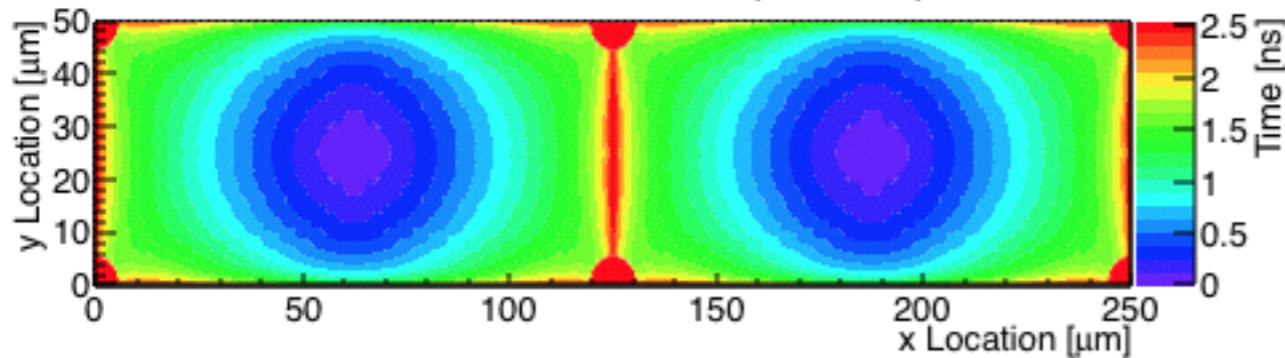


Electric Field ( $\Phi = 5.0 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$ ,  $V_{\text{bias}} = -40 \text{ V}$ ) *ATLAS Pixel Preliminary*



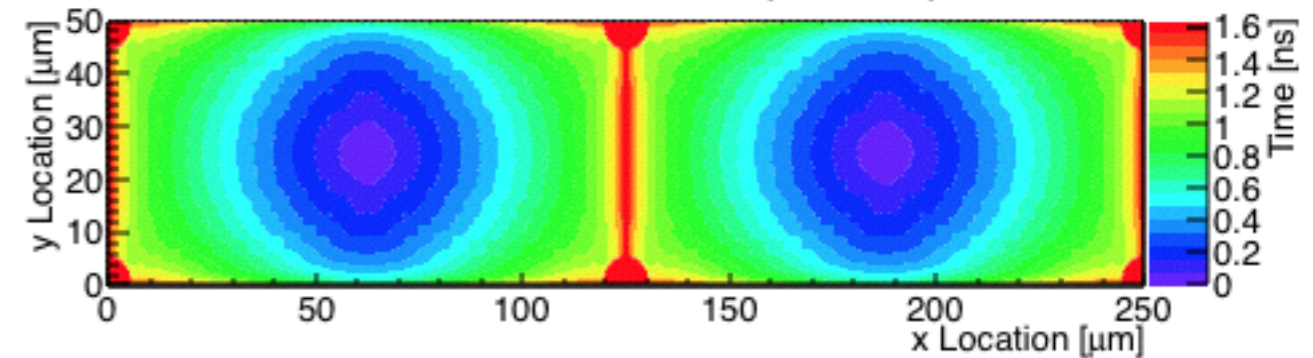
*ATLAS Pixel Preliminary*

**Unirradiated ( $V_{\text{bias}} = -20 \text{ V}$ )**  
Times to electrode (electrons)

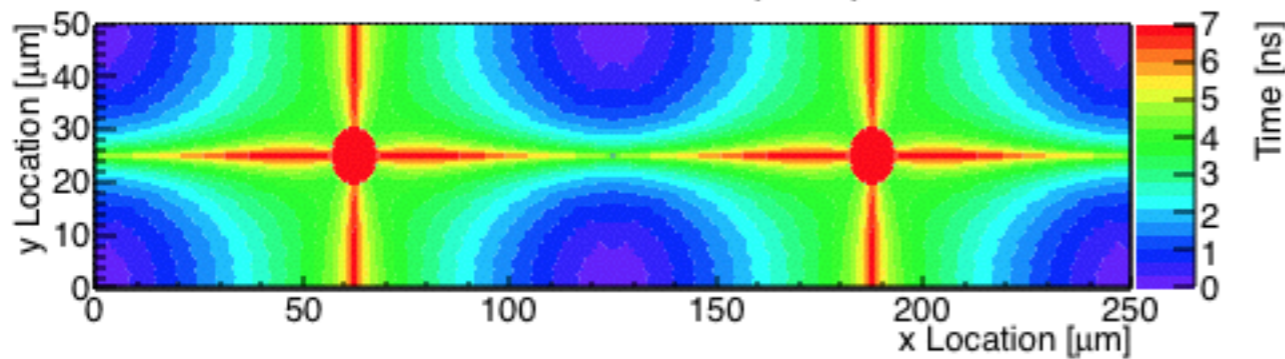


*ATLAS Pixel Preliminary*

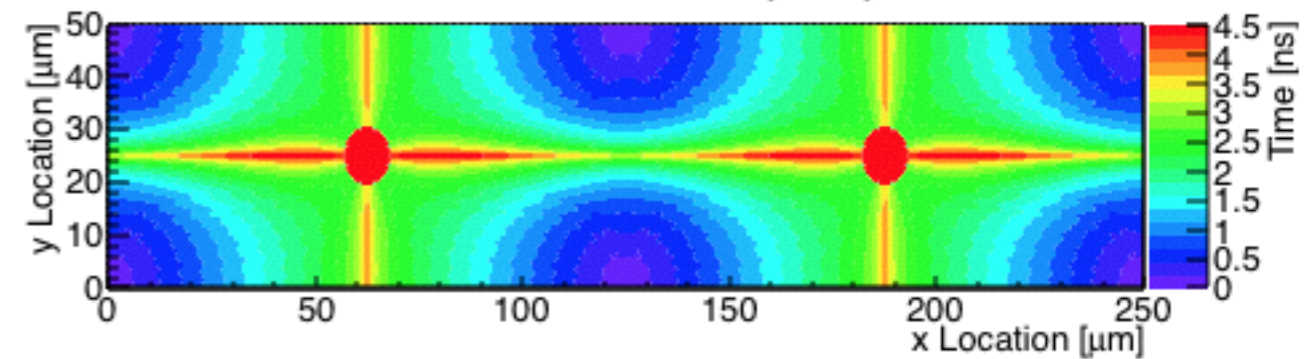
**$\Phi = 5.0 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$  ( $V_{\text{bias}} = -40 \text{ V}$ )**  
Times to electrode (electrons)



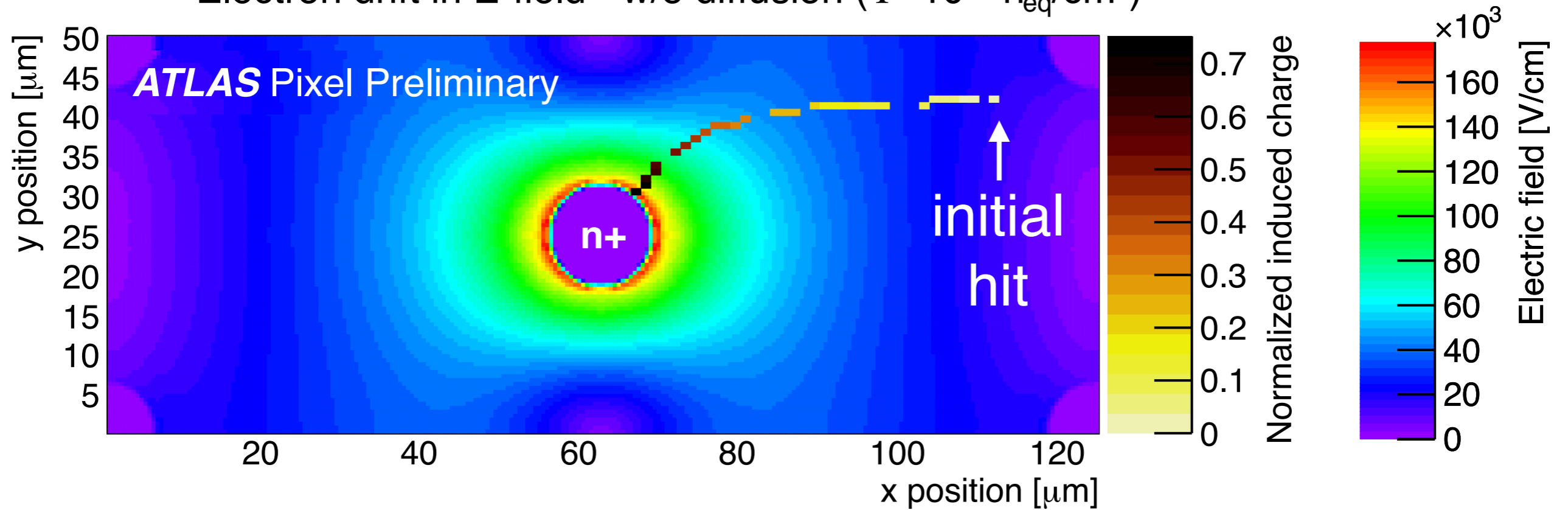
Times to electrode (holes)



Times to electrode (holes)



Electron drift in E-field - w/o diffusion ( $\Phi=10^{16} n_{eq}/cm^2$ )





Maximum fraction of induced charge per pixel

