Overview of the sensor simulation session at the LHC inter-experiment workshop

BERKELEY LAB

BERKELEY EXPERIMENTAL PARTICLE PHYSICS

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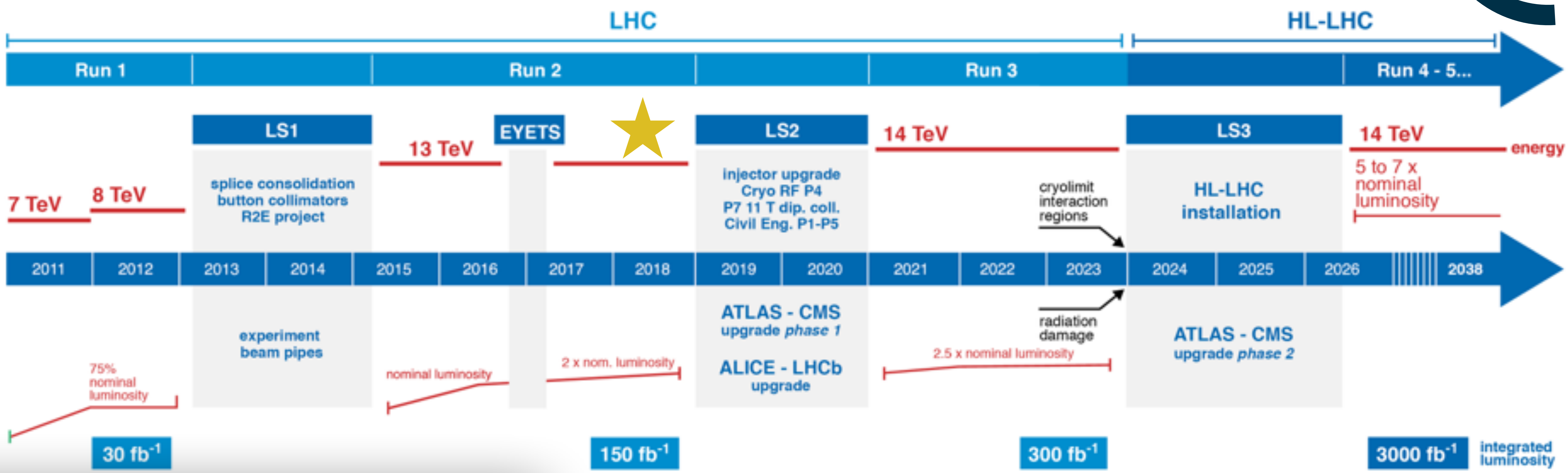
Lawrence Berkeley National Laboratory

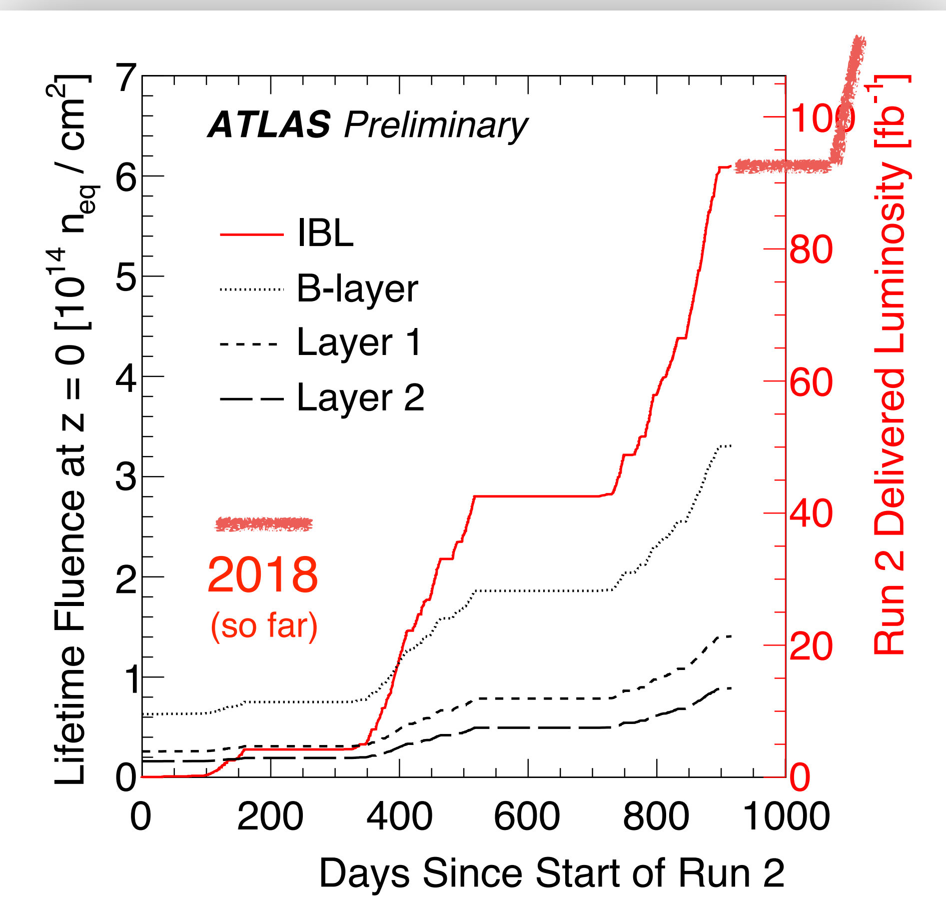
June 2018 RD50 Workshop

on behalf of the recent LHC workshop participants

ALICE ATLAS EXPERIMENT CMS LHCb RD50

Motivation





We are quickly approaching 10^{15} 1 MeV n_{eq}/cm^2

Radiation damage already impacting LHC operations & performance

Need to model in our simulations; **let's compare notes!**

Workshop Session Overview

			6-2-024 - BE Auditorium Meyrin, CERN	12:30 - 14:00
14:00	**Introduction**	*Marco Bomben*	*6-2-024 - BE Auditorium Meyrin, CERN*	14:00 - 14:10
	Silicon Sensor Simulation in the ATLAS Monte Carlo Framework (20'+10')	*Ben Nachman*	*6-2-024 - BE Auditorium Meyrin, CERN*	14:10 - 14:40
	Silicon Sensor Simulation in the LHCb Monte Carlo Framework (15'+5')	*Tomasz Szumlak*	*6-2-024 - BE Auditorium Meyrin, CERN*	14:40 - 15:00
15:00	**Silicon Sensor Simulation in the CMS Monte Carlo Framework (15'+5')**	*Morris Swartz et al.*	*6-2-024 - BE Auditorium Meyrin, CERN*	15:00 - 15:20
	Coffee break		*6-2-024 - BE Auditorium Meyrin, CERN*	15:20 - 15:50
	Cluster and Track Property Data/MC in ATLAS (20'+5')	*Lorenzo Rossini*	*6-2-024 - BE Auditorium Meyrin, CERN*	15:50 - 16:15
17:00	**Discussion and Closeout**		*6-2-024 - BE Auditorium Meyrin, CERN*	16:15 - 17:15

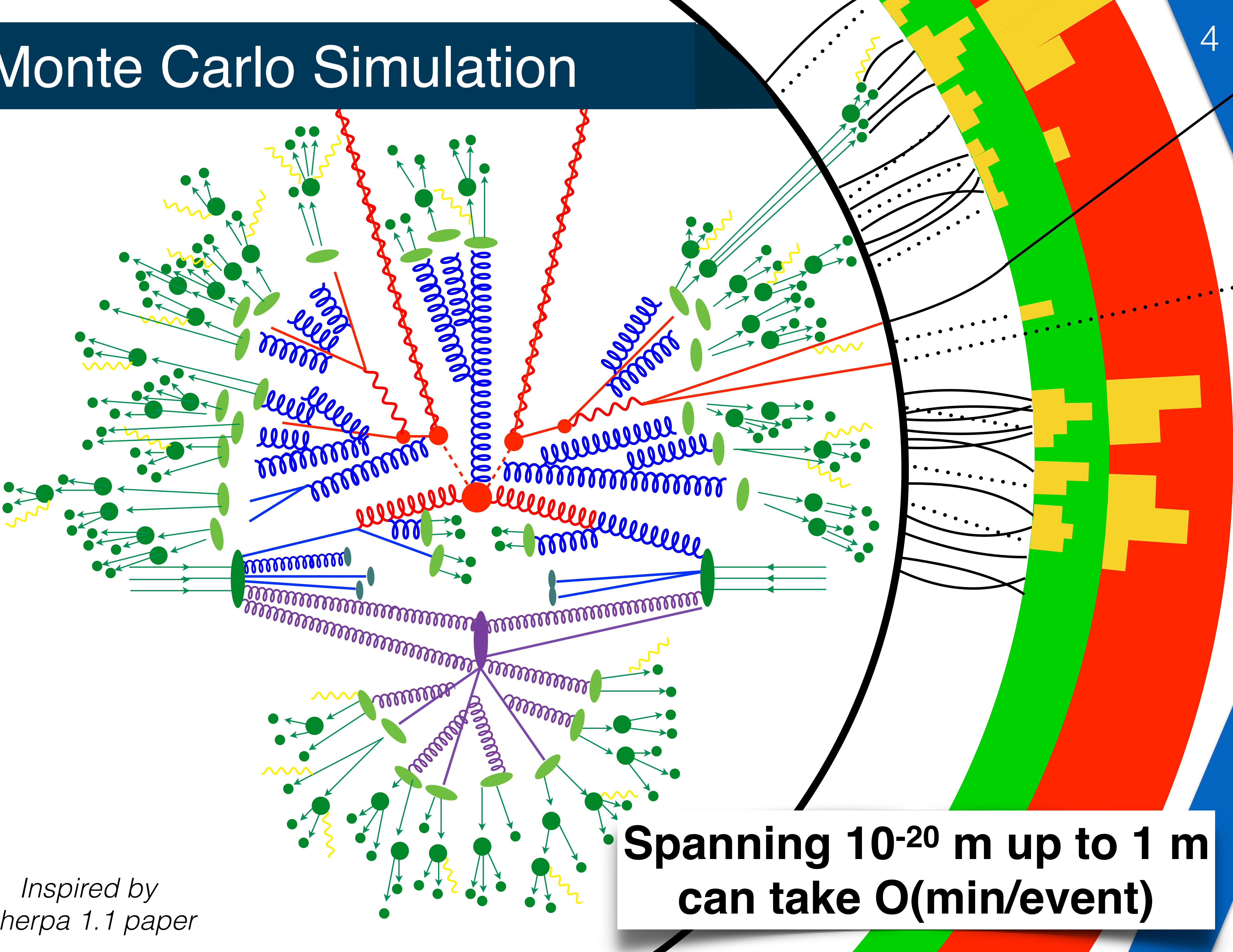
Ben Nachman

Tomasz Szumlak

Morris Swartz

Lorenzo Rossini

Monte Carlo Simulation



Inspired by Sherpa 1.1 paper

Spanning 10^{-20} m up to 1 m can take O(min/event)

Monte Carlo Simulation

Hard-scatter

MadGraph 5 / aMC@NLO
POWHEG-BOX

↓

Fragmentation

Pythia, Herwig, Sherpa

↓

Material Interactions

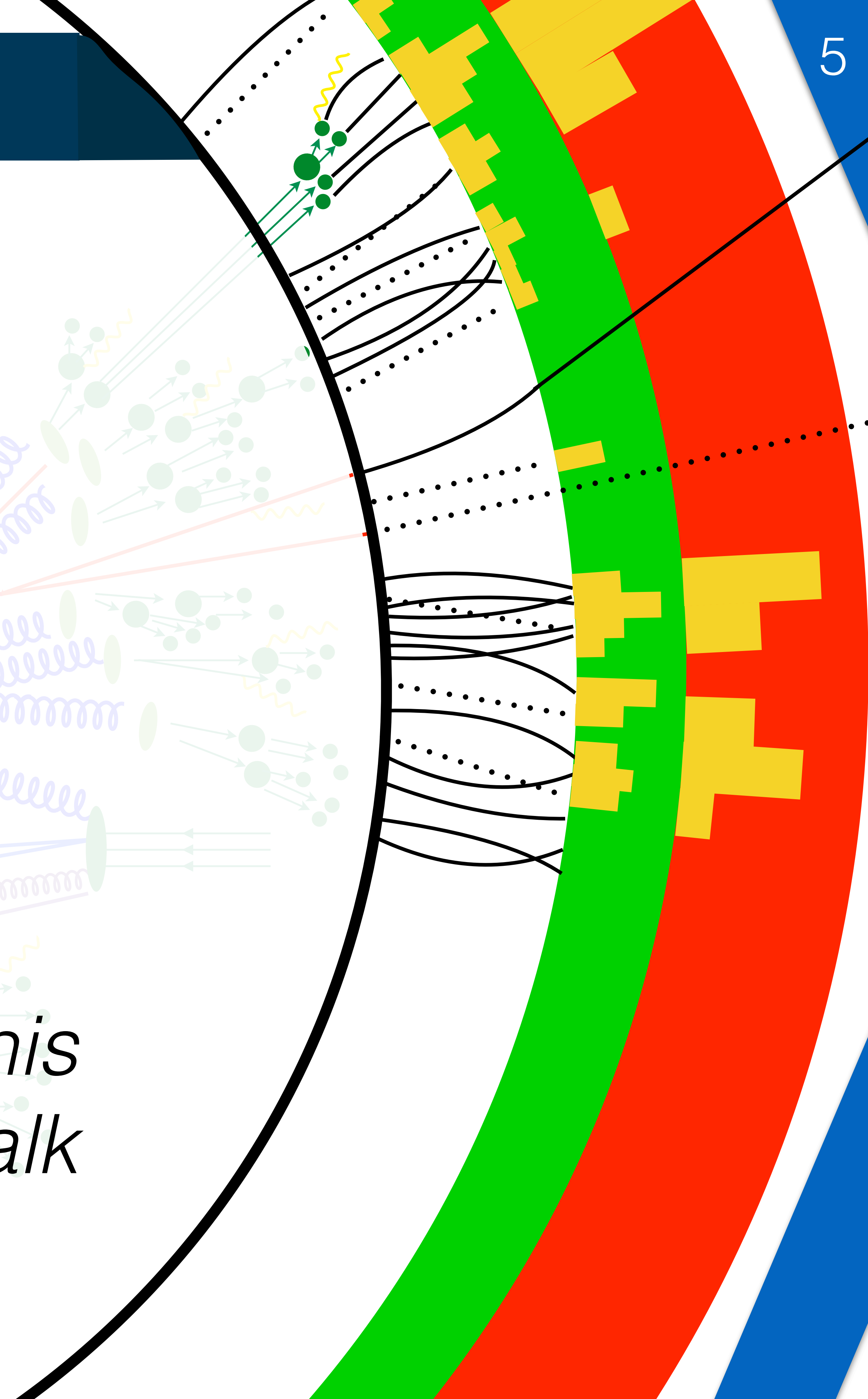
Geant 4

↓

Digitization

Custom code

this talk



Inspired by Sherpa 1.1 paper

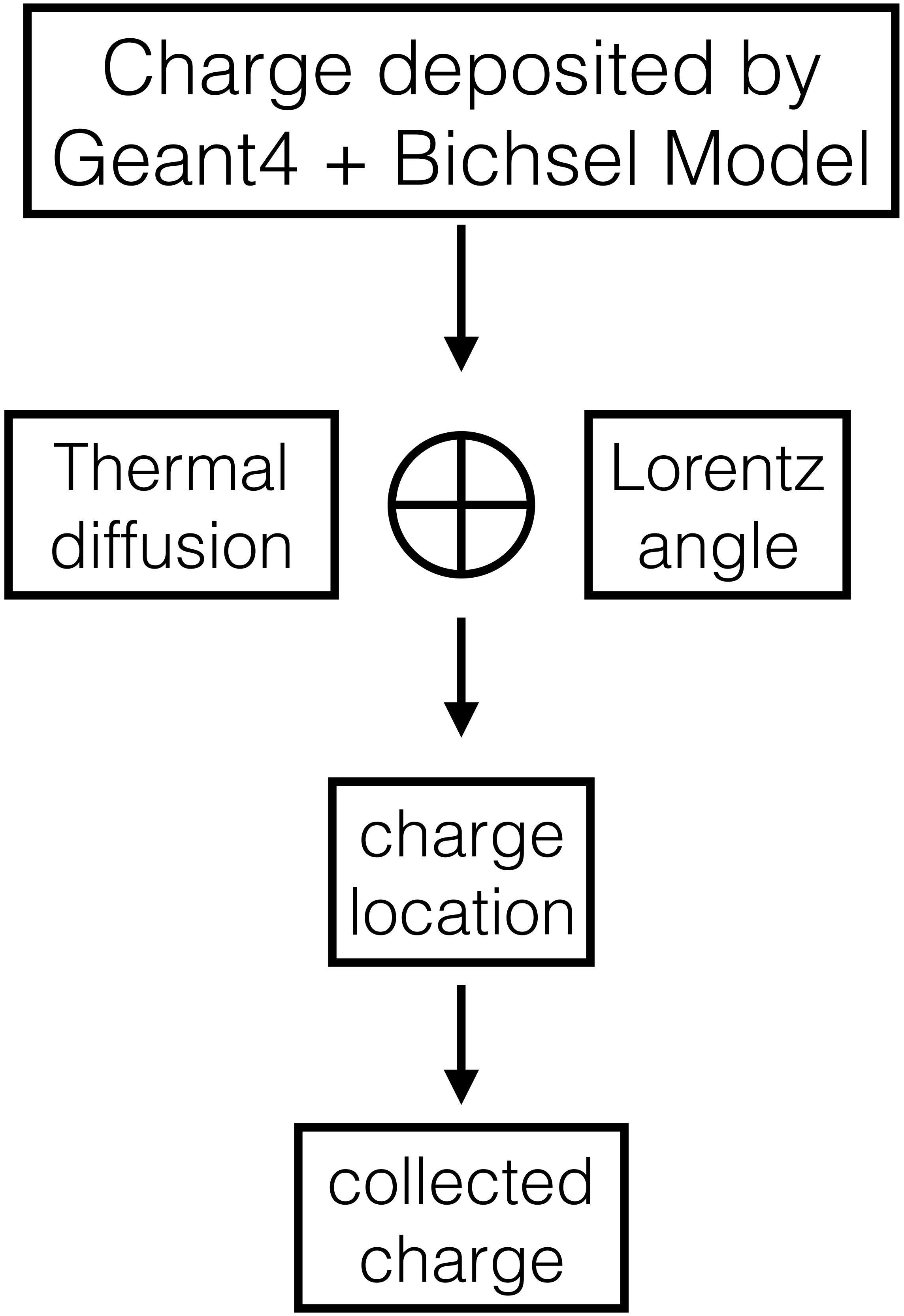
Current Run 2 (Si) Simulation

	ATLAS EXPERIMENT	CMS	LHCb
Energy Deposition	Bichsel Model + G4 (δ-rays)	Geant4	Geant4
Energy spreading	from Bichsel + chunking	from Geant4	Uniform (space) + uniform/Gauss (E)
E-field/ Lorentz angle	uniform	uniform	N/A
Diffusion	Einstein	Einstein	tuned
Noise	capacitive coupling + noise	not discussed	capacitive coupling + noise
Radiation damage	**none**	**none**	**none**

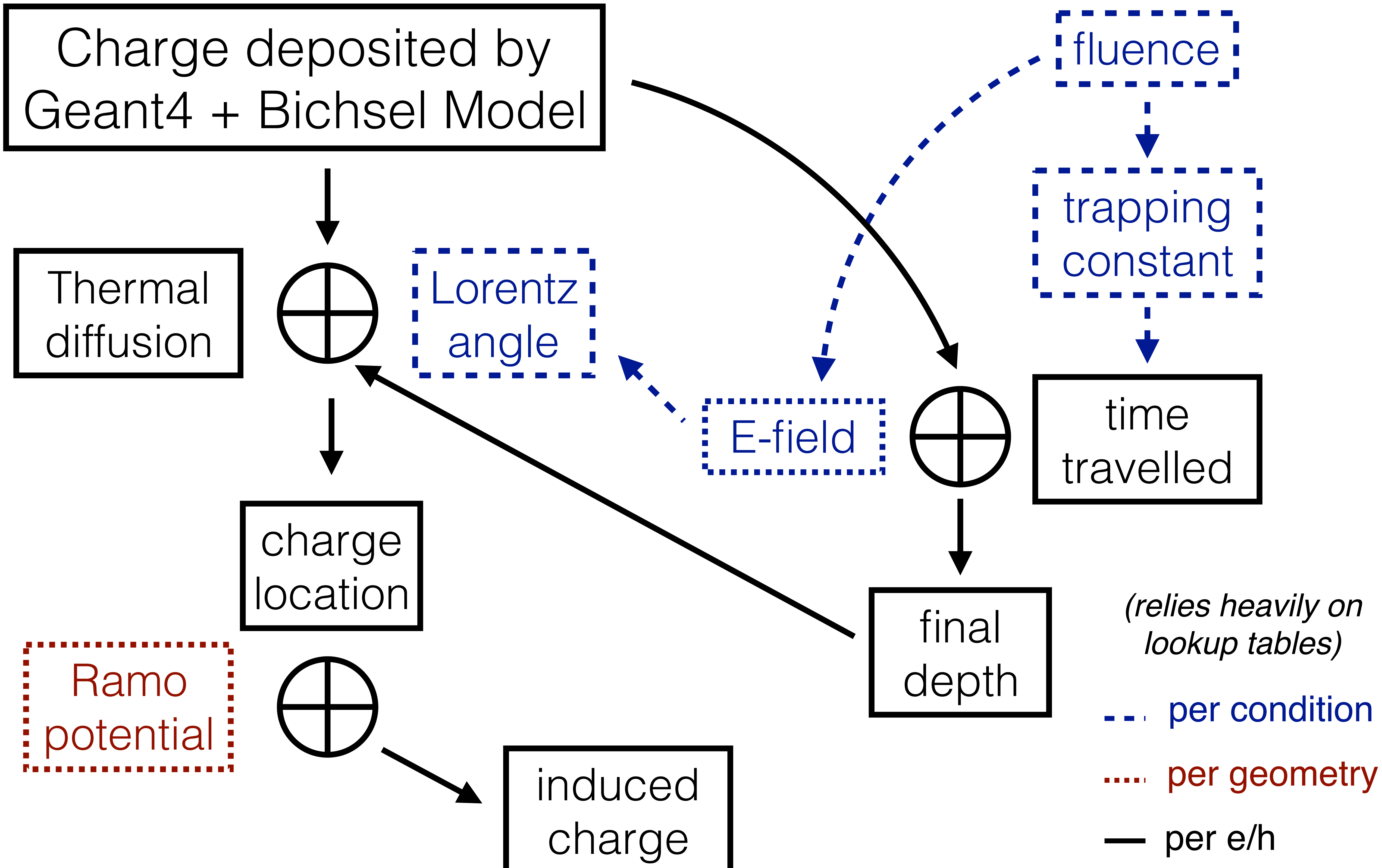
Next Generation (Si) Simulation

	ATLAS EXPERIMENT	CMS	LHCb
Energy Deposition	Bichsel Model + G4 (δ-rays)	Pixelav (applied as correction to G4)	Geant4
Energy spreading	from Bichsel + chunking	from Bichsel + chunking	Uniform (space) + uniform/Gauss (E)
E-field/ Lorentz angle	TCAD (Chiochia et al.)	TCAD (tuned to data)	N/A
Diffusion	Einstein	Einstein	tuned
Noise	capacitive coupling + noise	not discussed	capacitive coupling + noise
Radiation damage	**trapping + charge induction**	**trapping + charge induction**	**charge & 'diffusion' corrections**

Current ATLAS Pixel Simulation

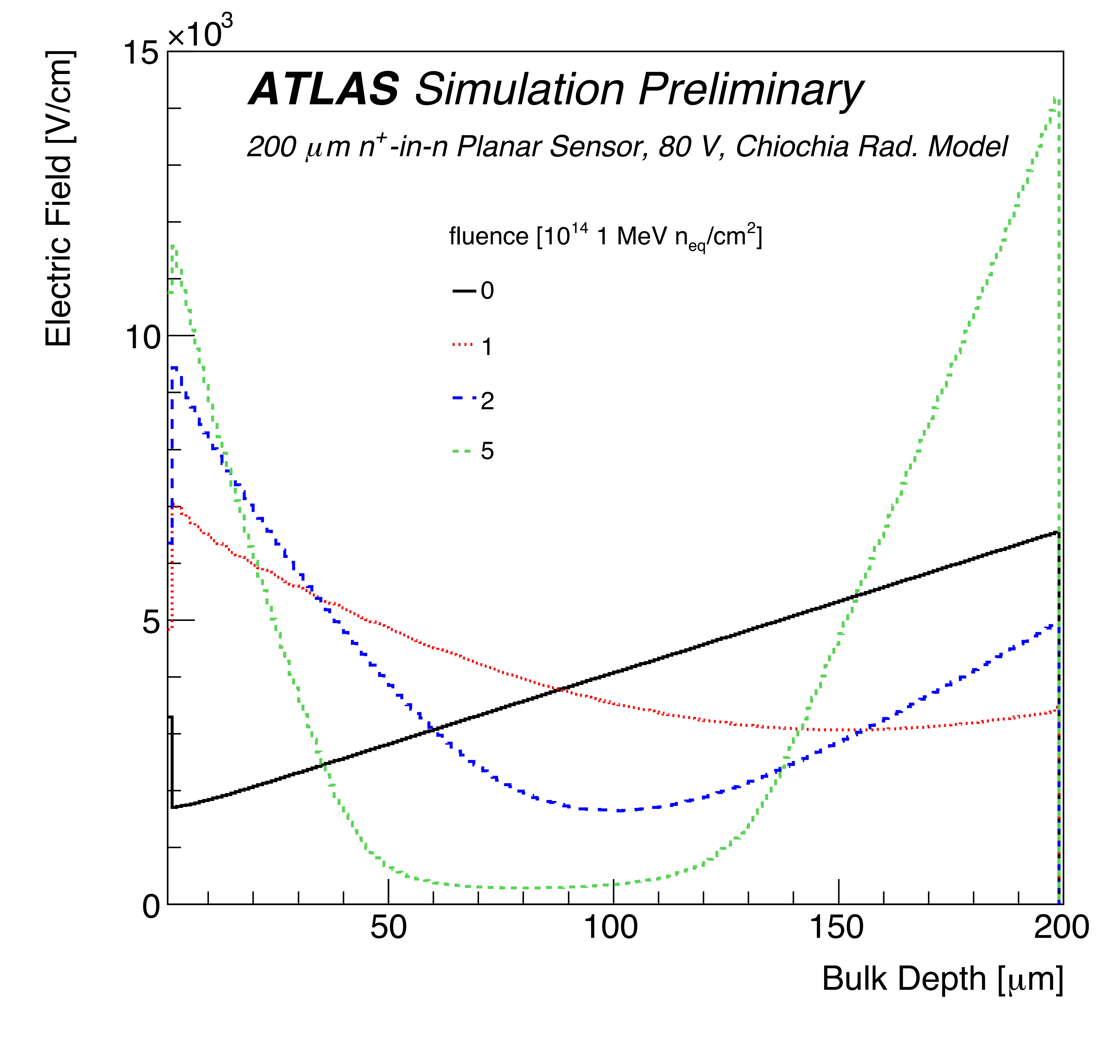


New ATLAS Pixel Simulation



See talk at last RD50 meeting

TCAD in ATLAS

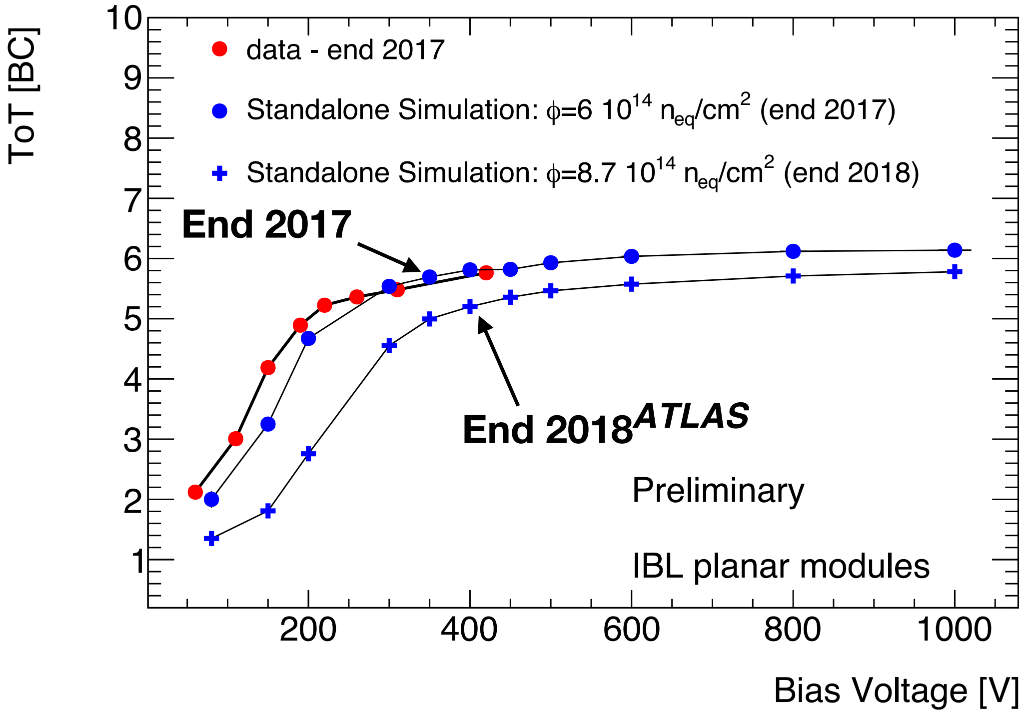


Silvaco TCAD with the radiation damage model from Chiochia et al.

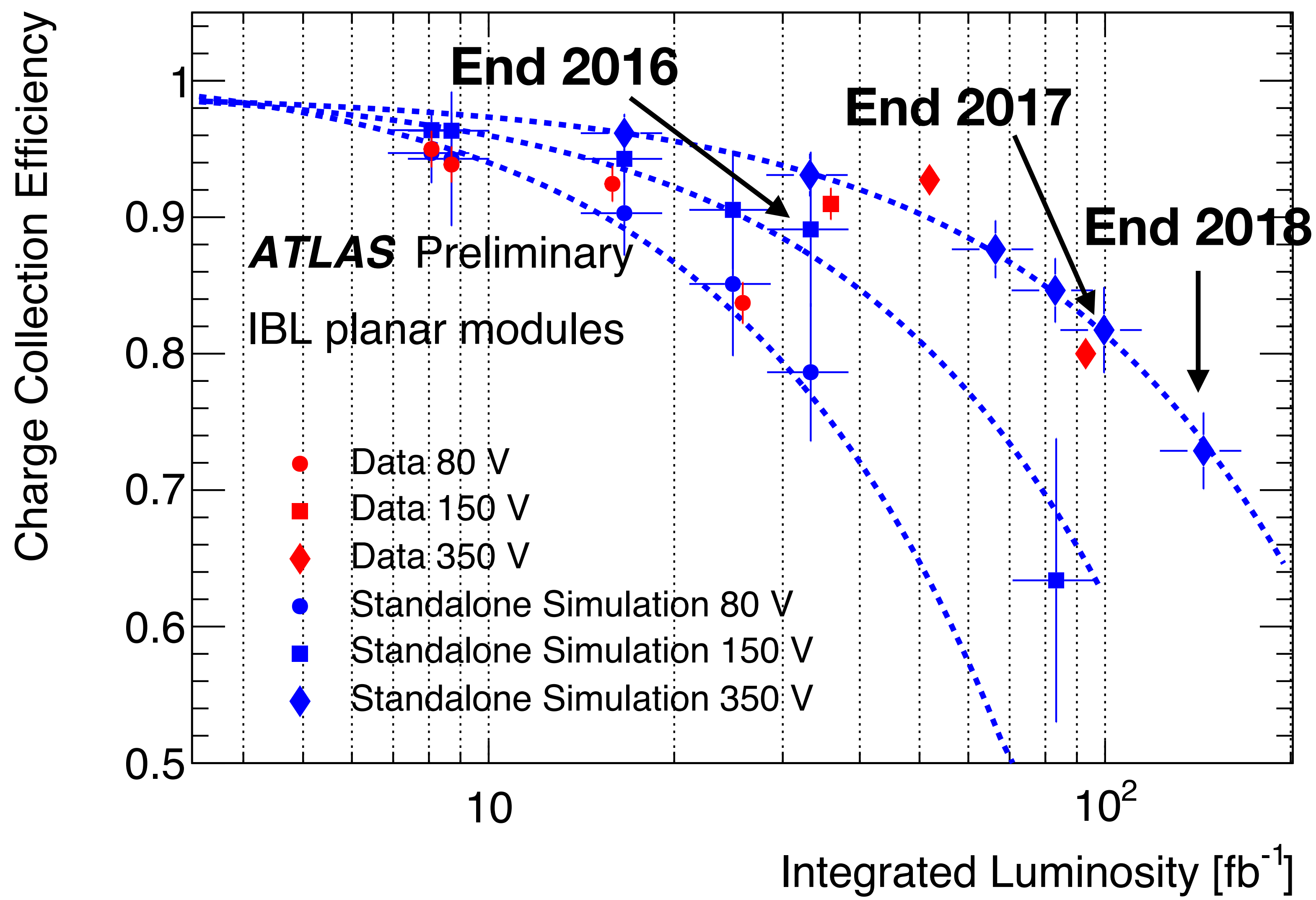
Parameters linearly interpolated when applicable.

Systematic uncertainty from varying parameters by ~10%; plan to tune/ constrain with data in the near future.

Validation with data



Measure and predict the charge as a function of fluence / bias voltage



Nice agreement thus far, but large uncertainties - need to bring these down to make precise predictions!

New CMS Pixel Simulation

The TCAD+Pixelav simulations are tuned to measured distributions

Measure E_z vs z profile → **TCAD** model E-field with 2-traps → **Pixelav** (detailed sim) T, r_H, Φ → electronic response (6 params) → **Simulated Data:**
- charge distribution
- size distributions
- shape probabilities
- Lorentz angle cals
  - *clust size vs cot(α)
  - *grazing angle
- extracted E-field profiles

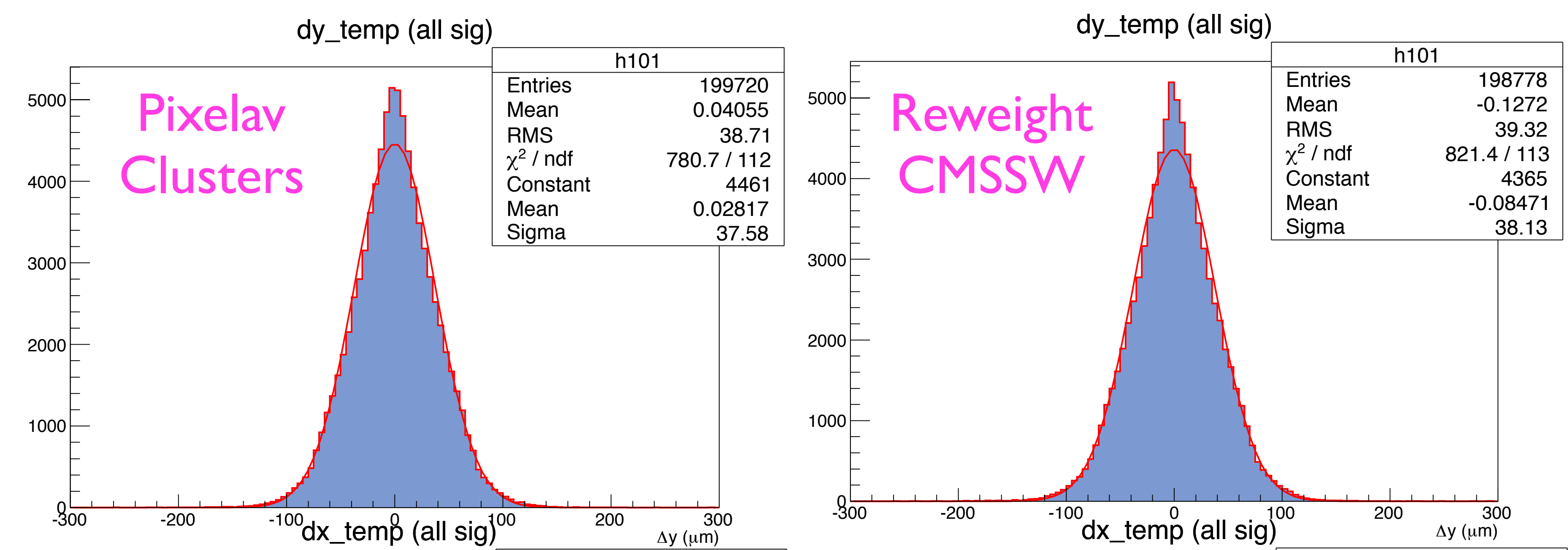
→ **Calibrations:**
- Standard Reco
  - * Lorentz corrs
  - * error estimates
- Template Reco
  - *1D cluster shapes
  - *error estimates
  - *probability info
  - *2D cluster shapes

Adjust these to match simulated data to measurements

Different approach:

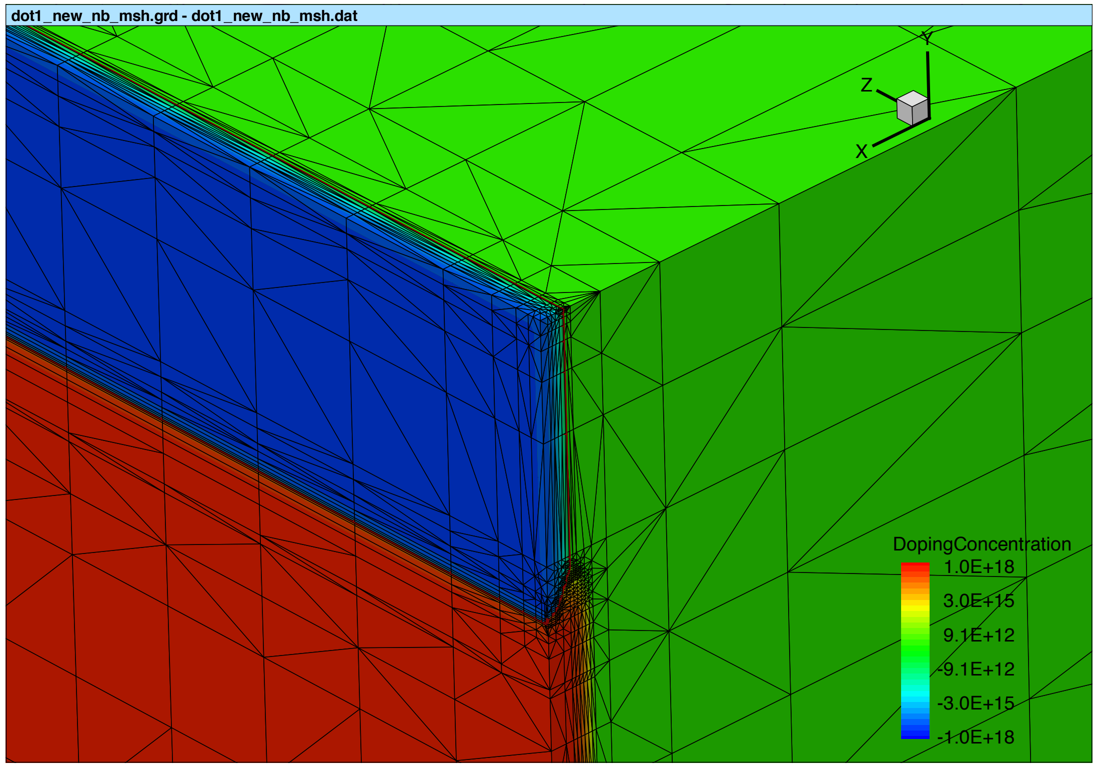
instead of modifying primary simulation, perform detailed independent simulation and apply correction factors.

Fully simulated $\Phi = 1.2\times10^{15}\ n_{eq}/cm^2$ clust vs reweighted CMSSW-like clust

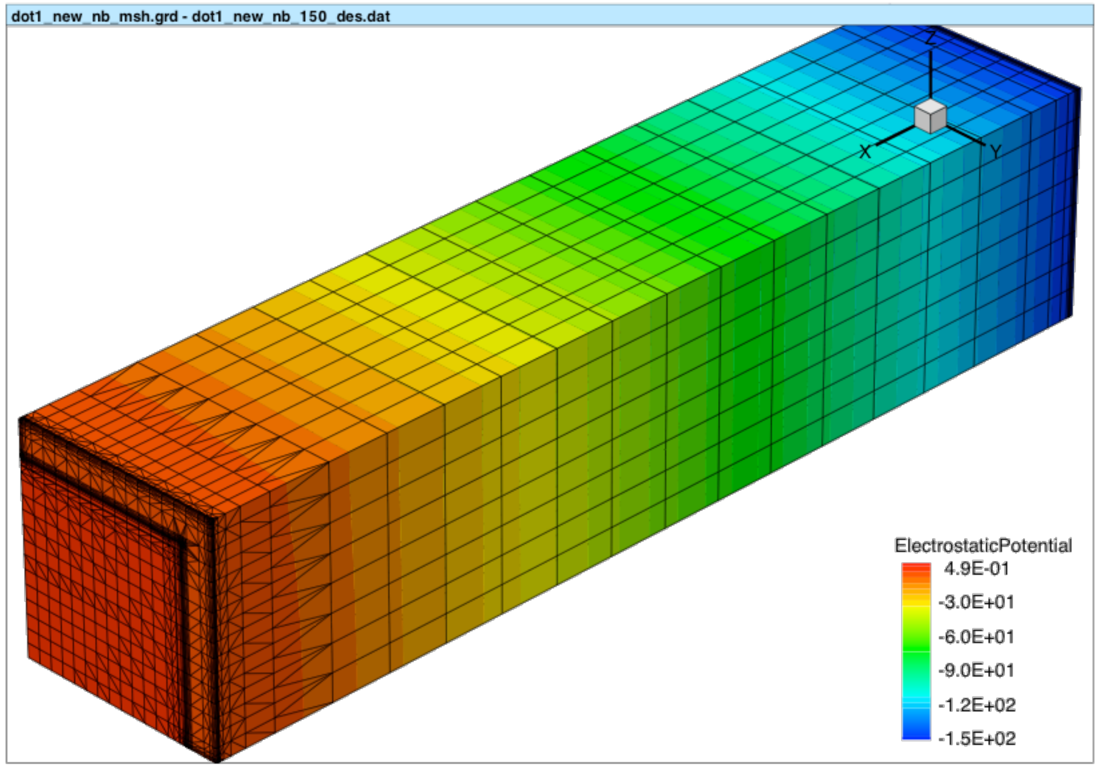


TCAD in CMS

- Electric field calculation: uses TCAD 9.0 software
  - simultaneously solves Poisson and carrier continuity eqs
  - includes lots of semiconductor physics (including SRH)
  - simulate 1/4 (1/2) pixel cell to keep mesh size ~17000 (25000) nodes. This requires 4-fold (2-fold) symmetry.
  - no process simulation, use MESH w/ analytic doping profiles to generate grid and doping files



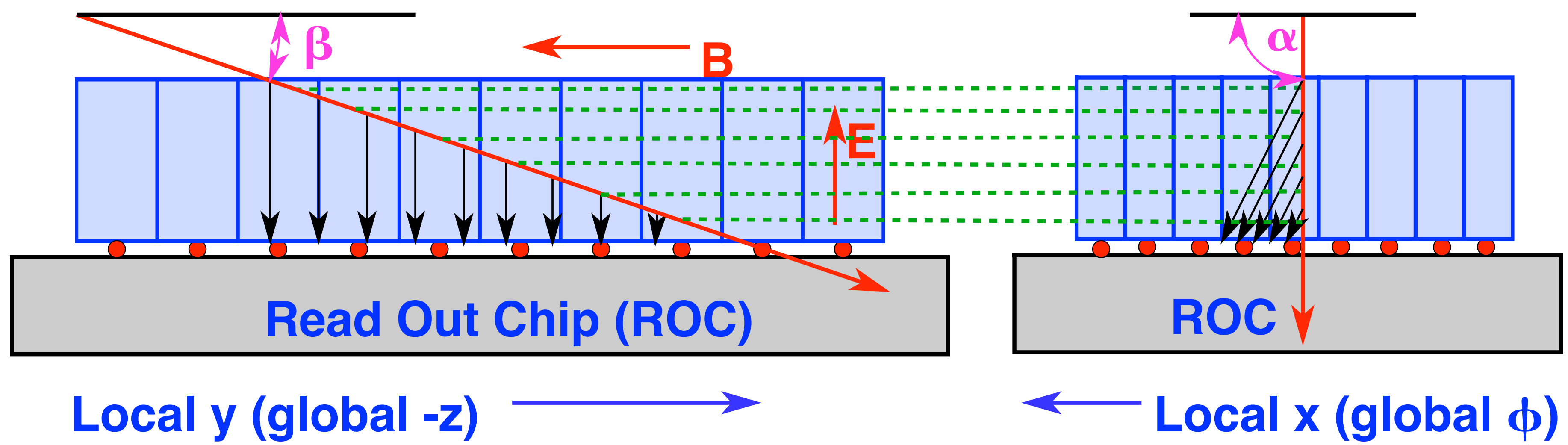
doping profiles

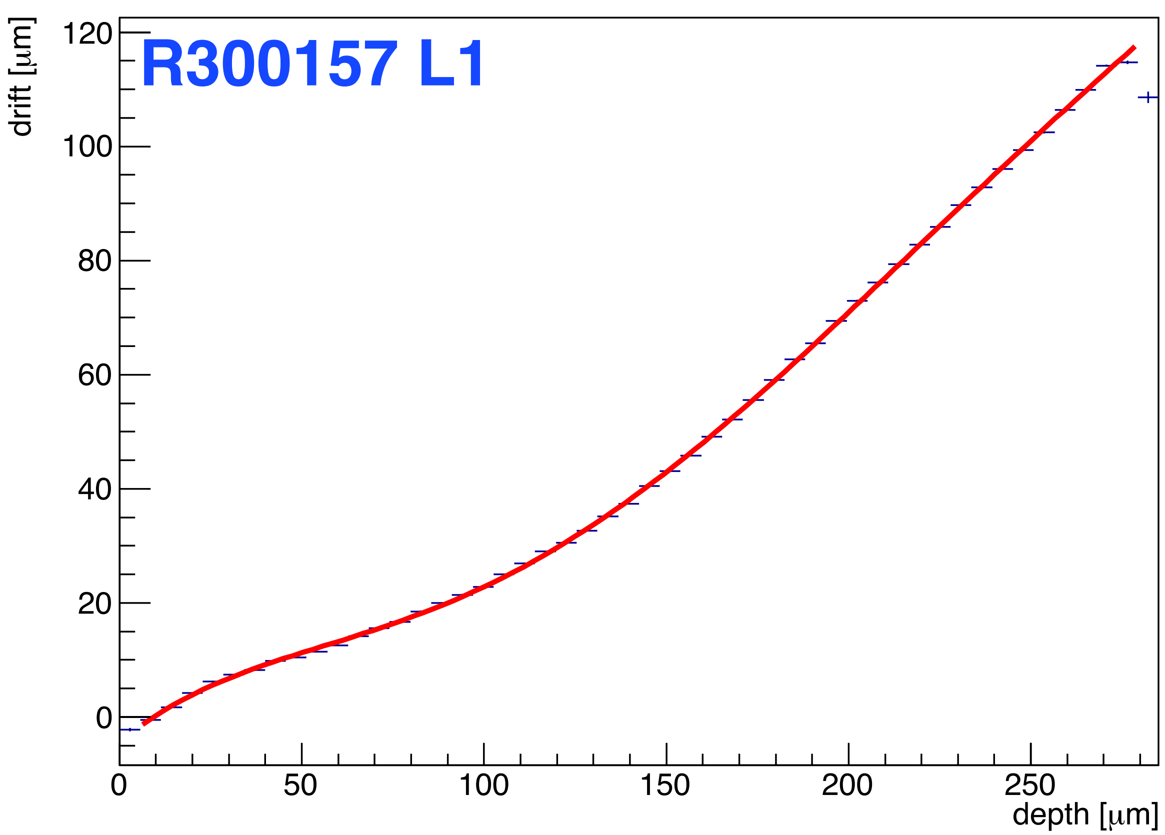


potential distribution

E-field Calibration in CMS

Clever in situ scheme for modifying the E-field based on data





Measure Lorentz angle as a function of length inside long cluster (probes depth)

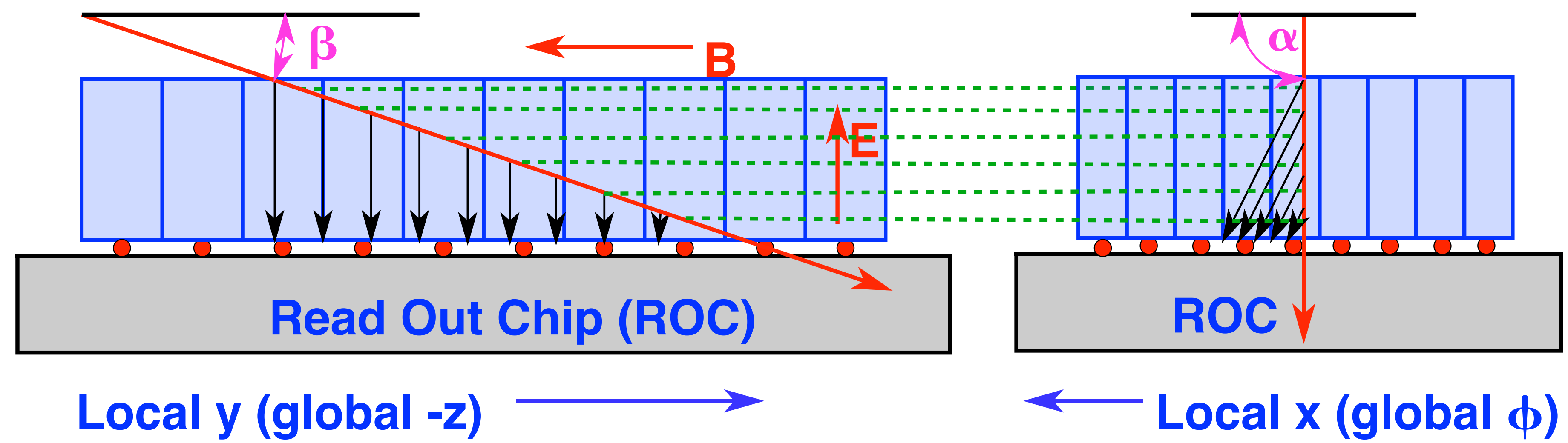
$$\tan\theta_L = \frac{dx}{dD} = r_H \mu(E) B_y$$

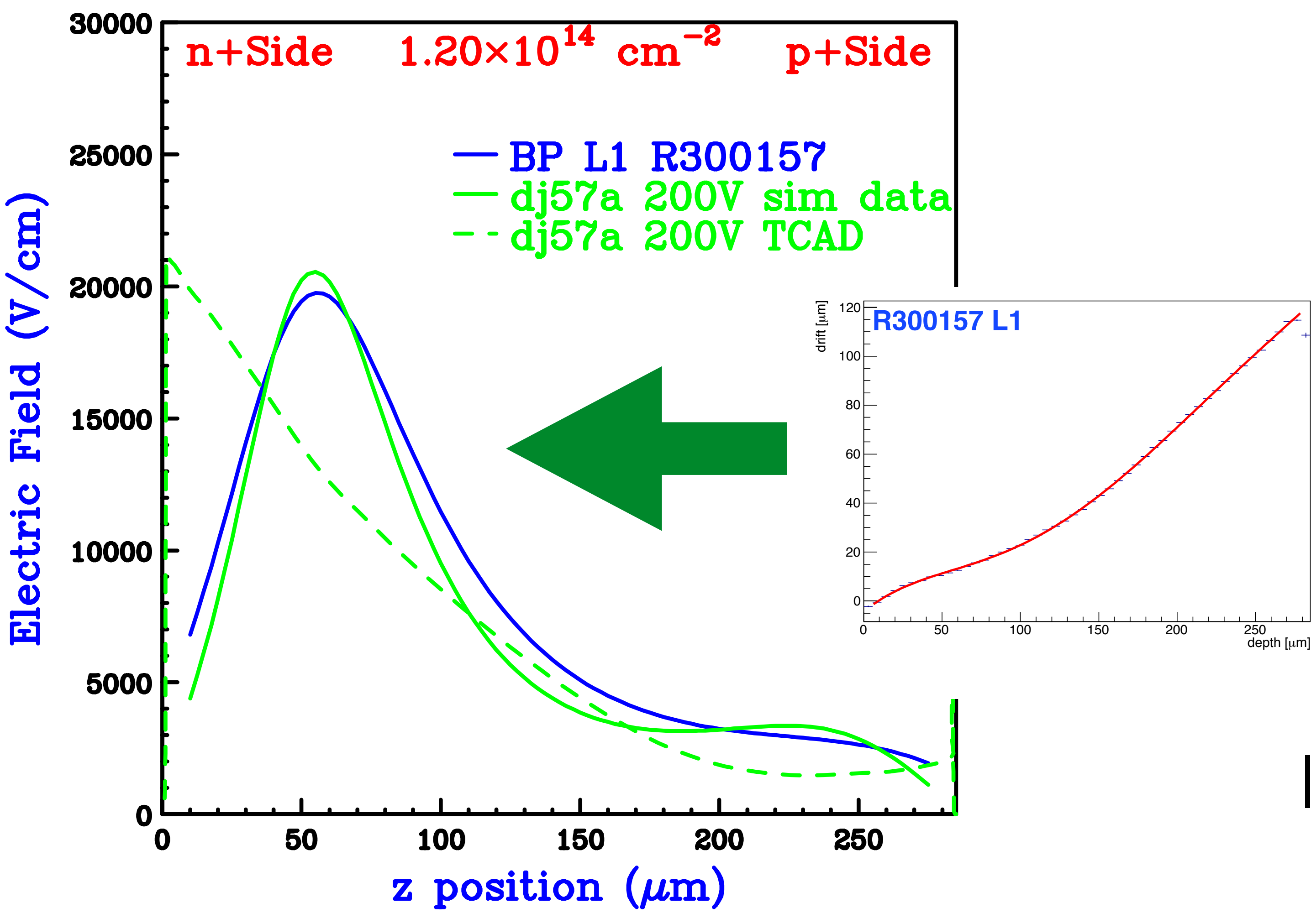
$$\rightarrow E = \mu^{-1}\left(\frac{1}{r_H B_y}\frac{dx}{dD}\right)$$

Independent of trapping; tune the trap densities to match data.

E-field Calibration in CMS

Clever in situ scheme for modifying the E-field based on data





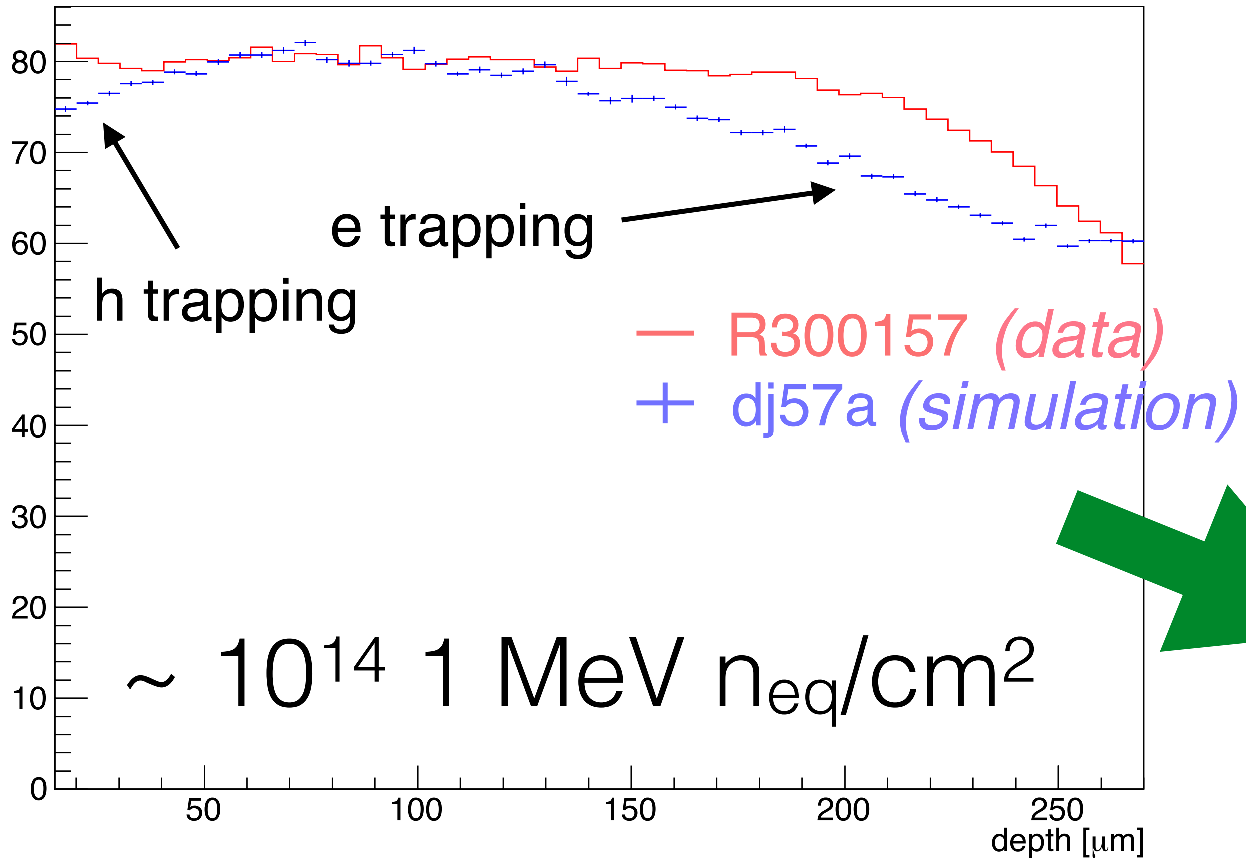
Measure Lorentz angle as a function of length inside long cluster (probes depth)

$$\tan\theta_L = \frac{dx}{dD} = r_H \mu(E) B_y$$

$$\rightarrow E = \mu^{-1}\left(\frac{1}{r_H B_y}\frac{dx}{dD}\right)$$

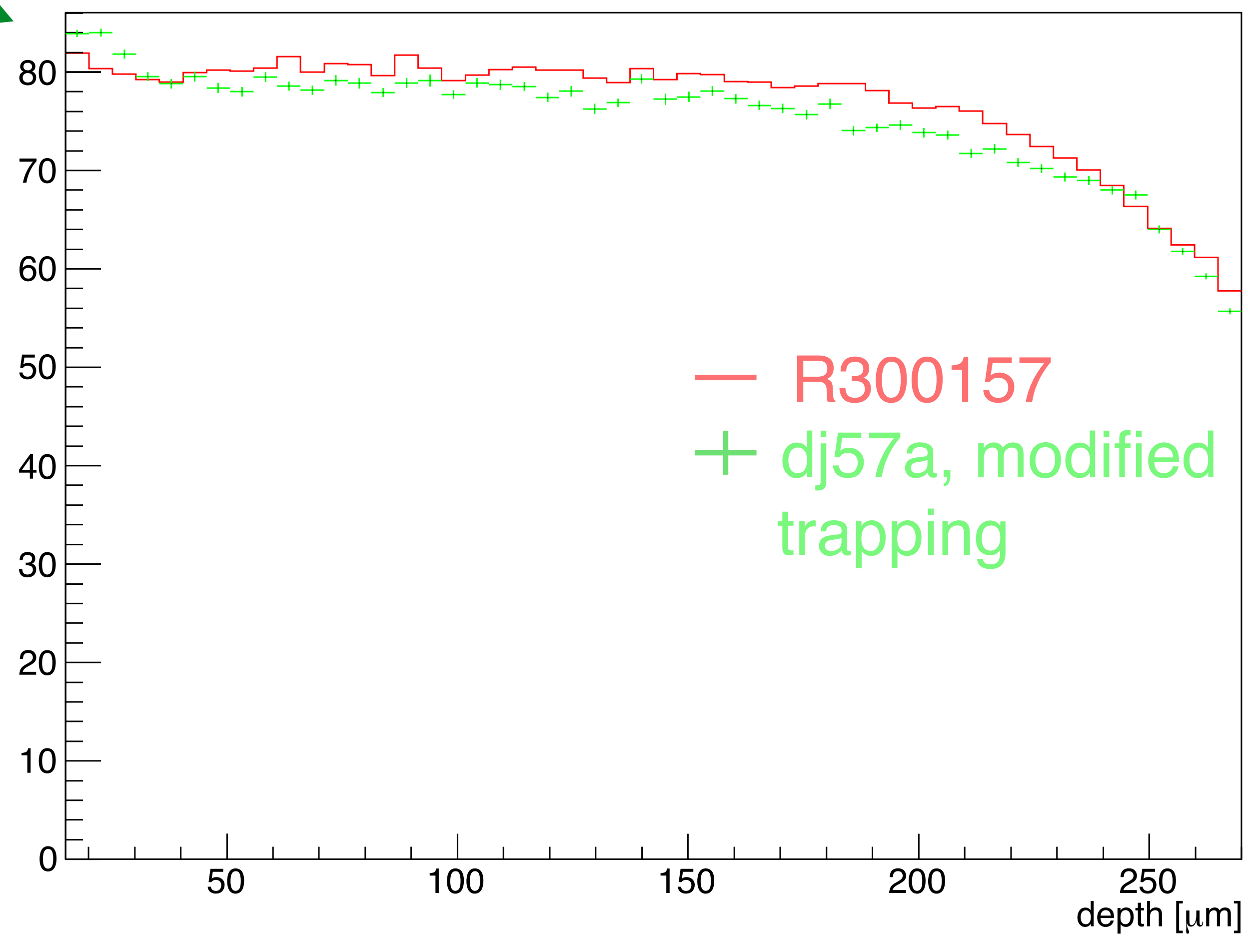
Independent of trapping; tune the trap densities to match data.

Trapping Calibration in CMS



Using same long-cluster data, study the charge as a function of depth

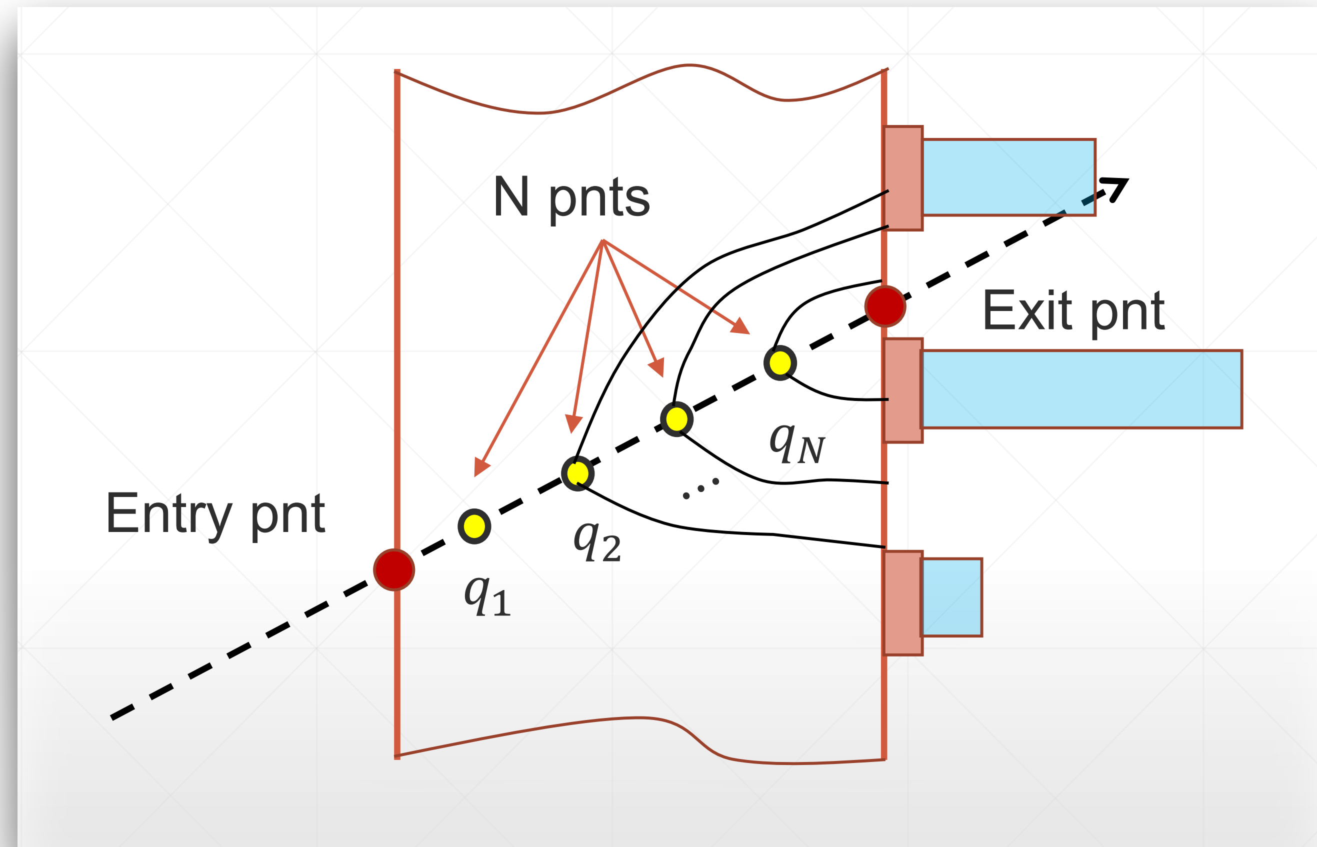
← too much e and h trapping!



E-field evolving faster than predicted; trapping rates evolving slower than expected (~60% fluence)

Important implications for longevity!

New LHCb Pixel Simulation



Different than both ATLAS/CMS: reduce charge and increase “diffusion length” to match data.

Tuned once/year.

Preliminary results look promising and validation with bigger simulations is ongoing.

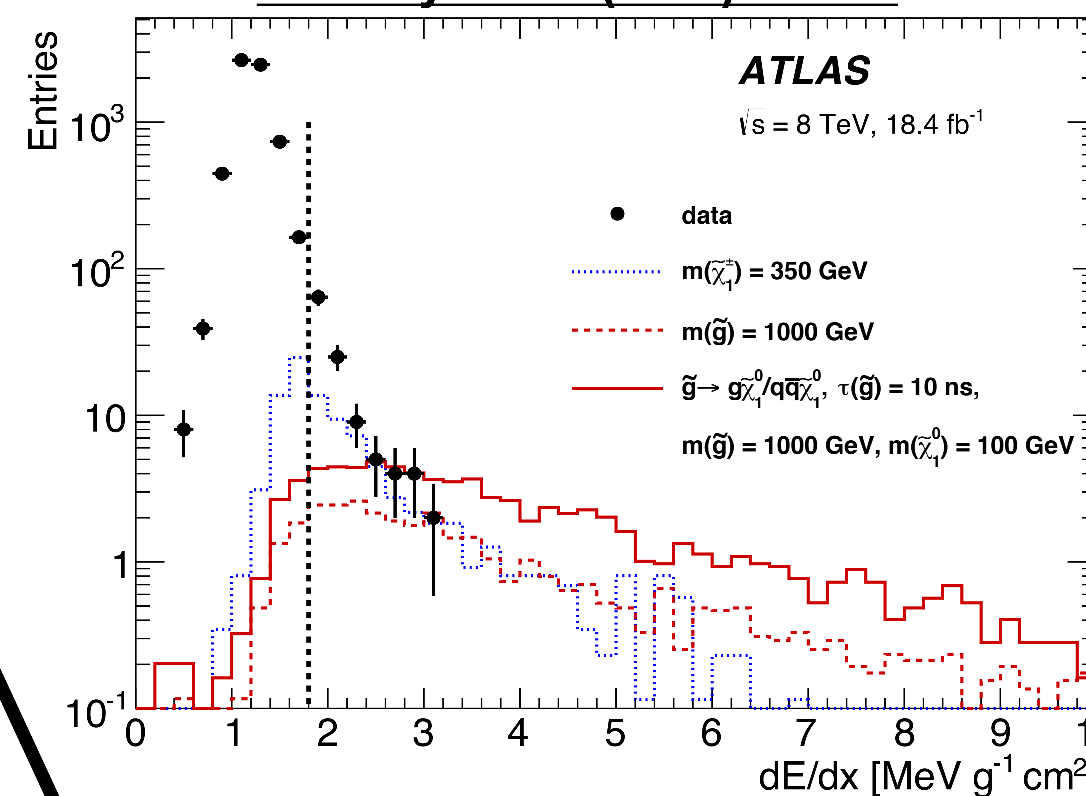
Impact on Physics and Performance

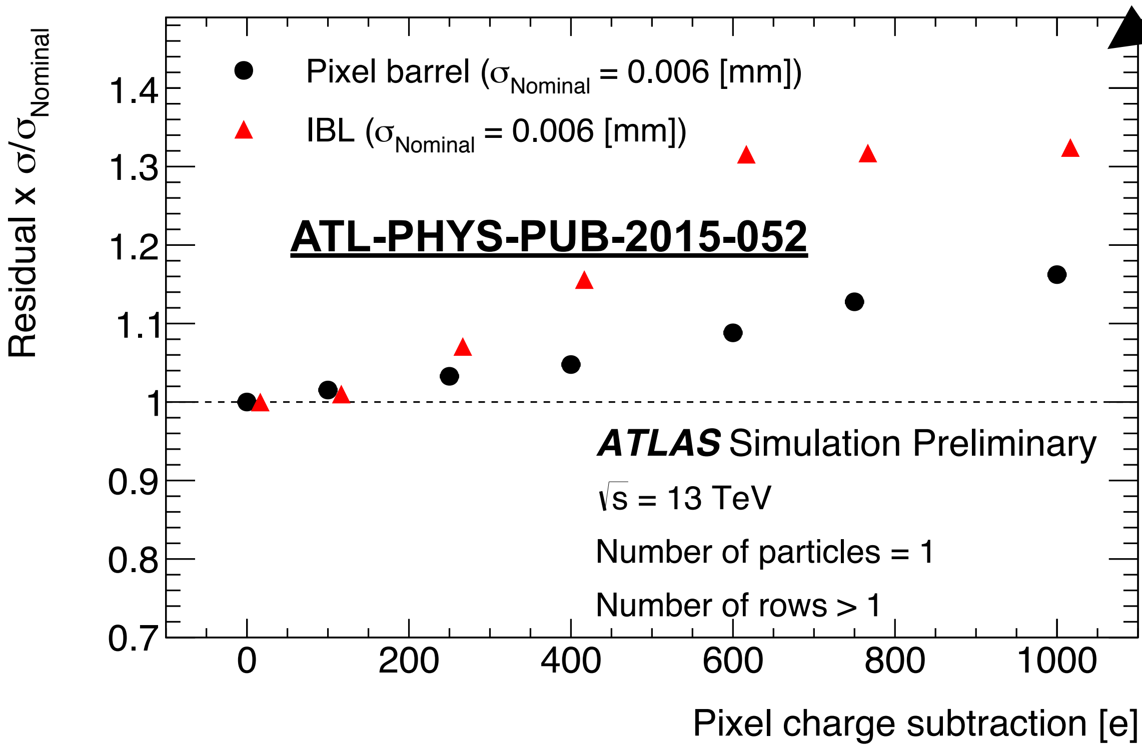
Charge loss directly effects searches for new highly ionizing particles →

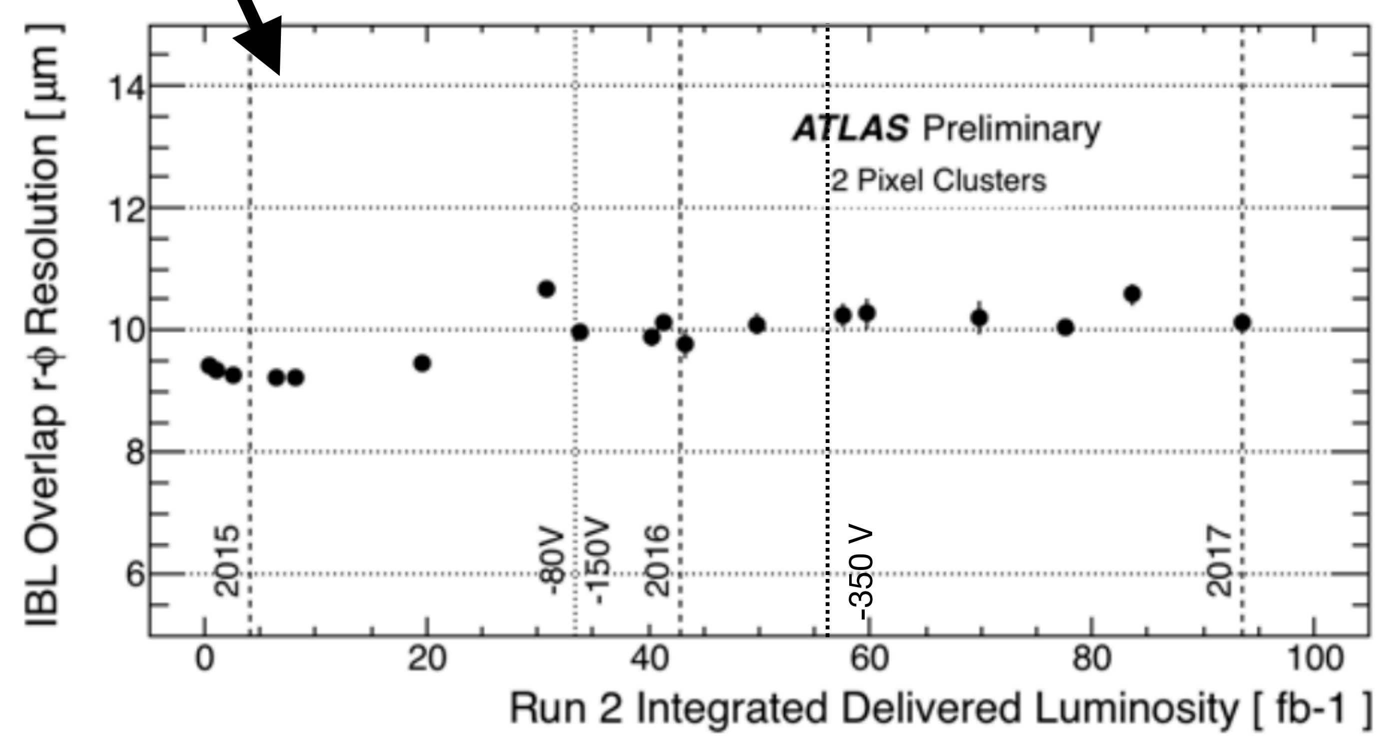
We may be seeing a degradation in position resolution.

Widespread loss in performance not yet, but **inevitable** - we must continue to monitor and model!

Eur. Phys. J. C (2015) 75:407



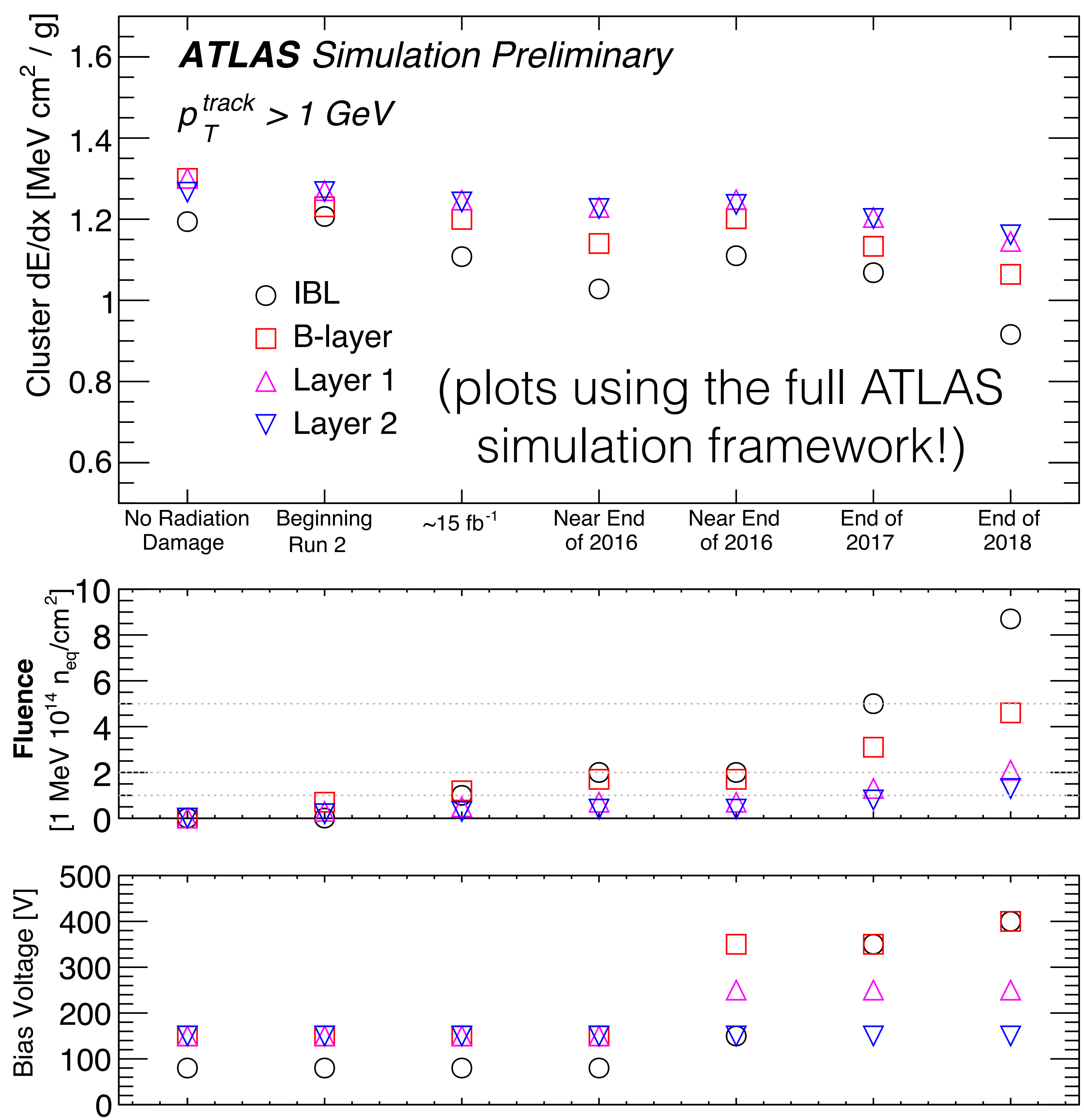




Plans for the future

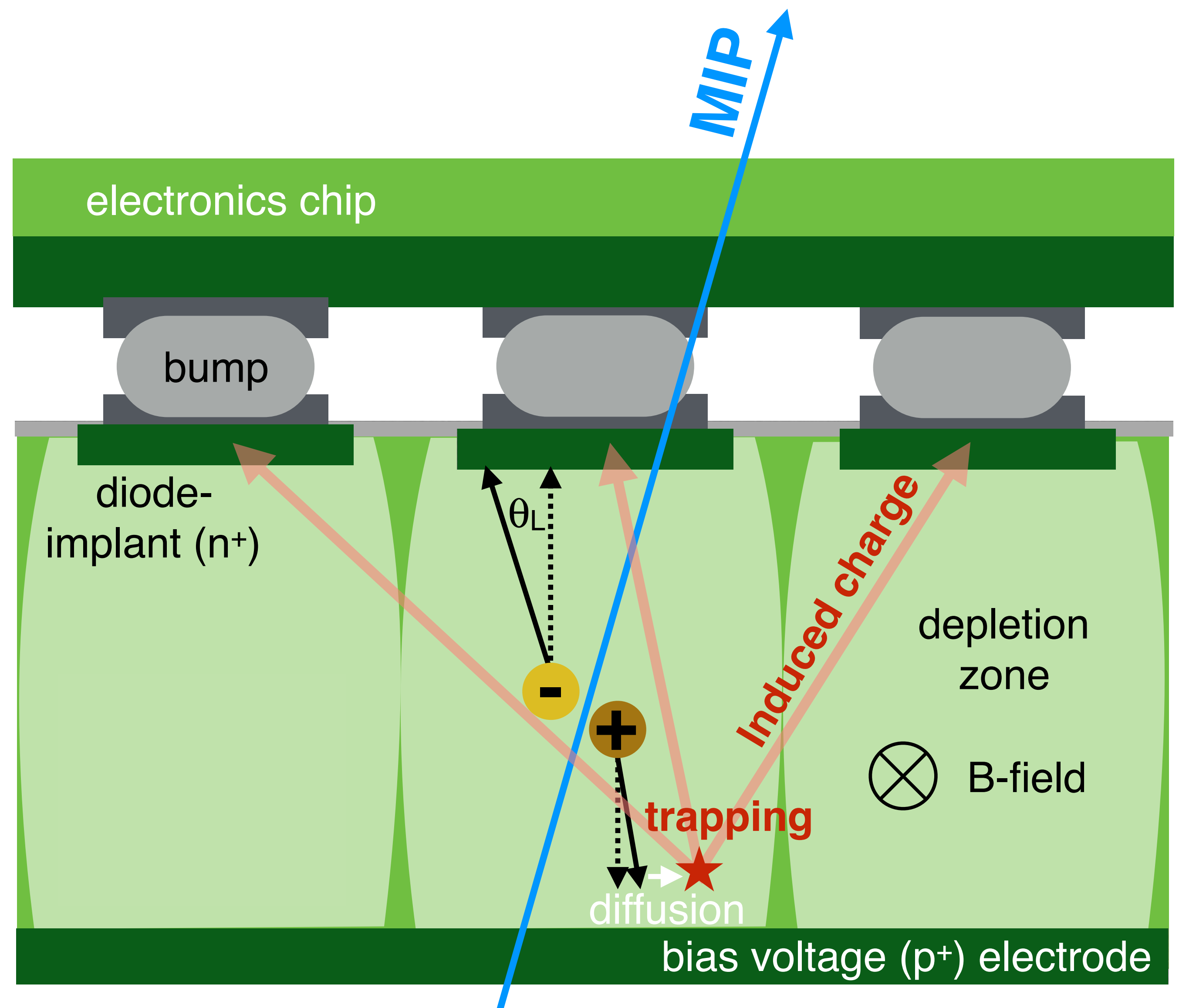
ATLAS, CMS, and LHCb are planning to incorporate radiation damage into their main simulation.

All three approaches are different and it will be very valuable to continue to compare notes as we accurate more experience with more data (=damage)



Conclusions

The inter-experiment workshop was an excellent opportunity to gather experts and exchange our methods and ideas*



Looking forward to the next gathering after we have the full Run 2 dataset!

*for our **default** simulation and for radiation damage