Pixel Simulation in the ATLAS Monte Carlo Framework

BERKELEY LAB

Benjamin Nachman

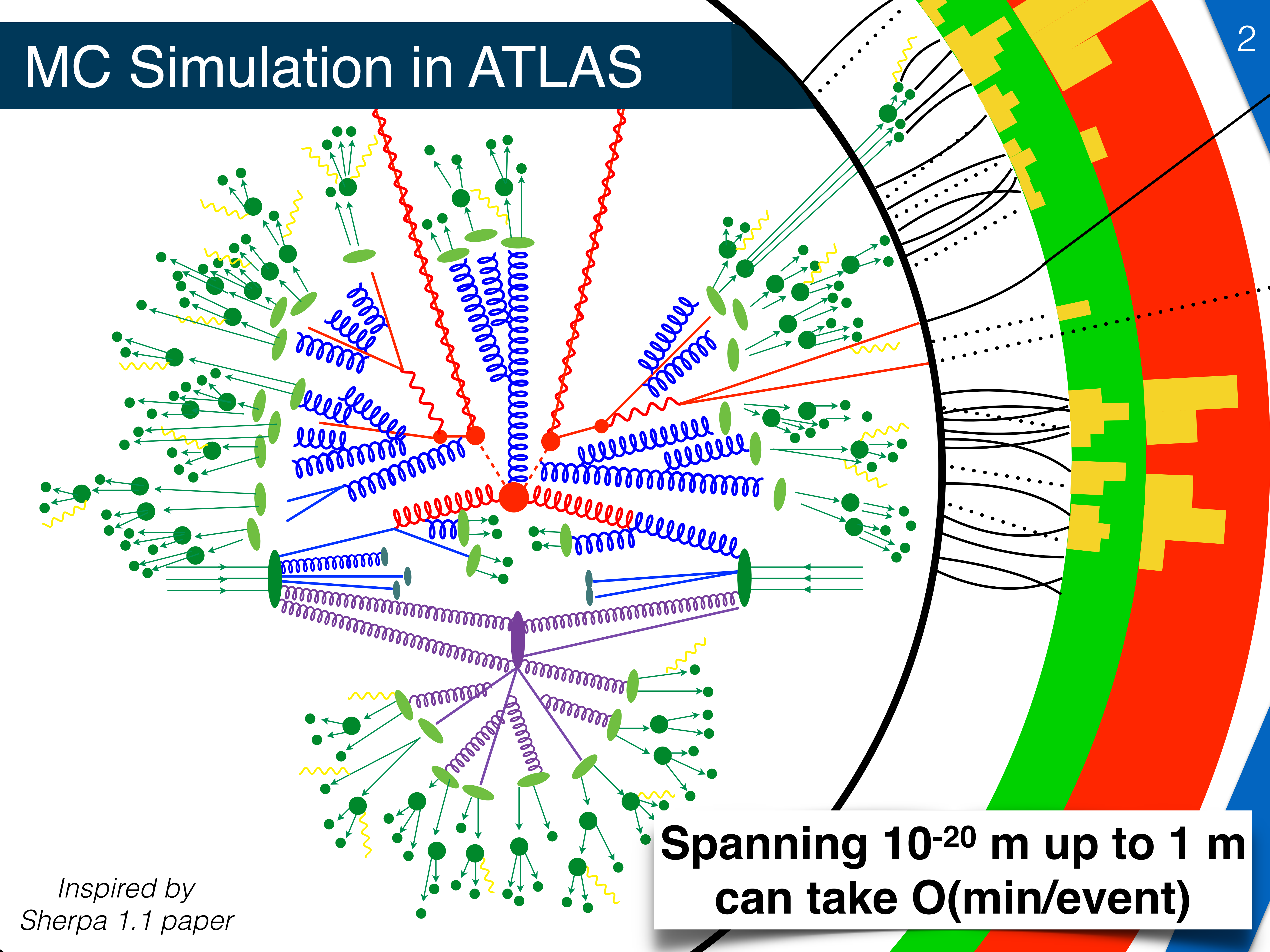
on behalf of the ATLAS Collaboration

Lawrence Berkeley National Laboratory

Radiation effects at the LHC experiments

April 24, 2018

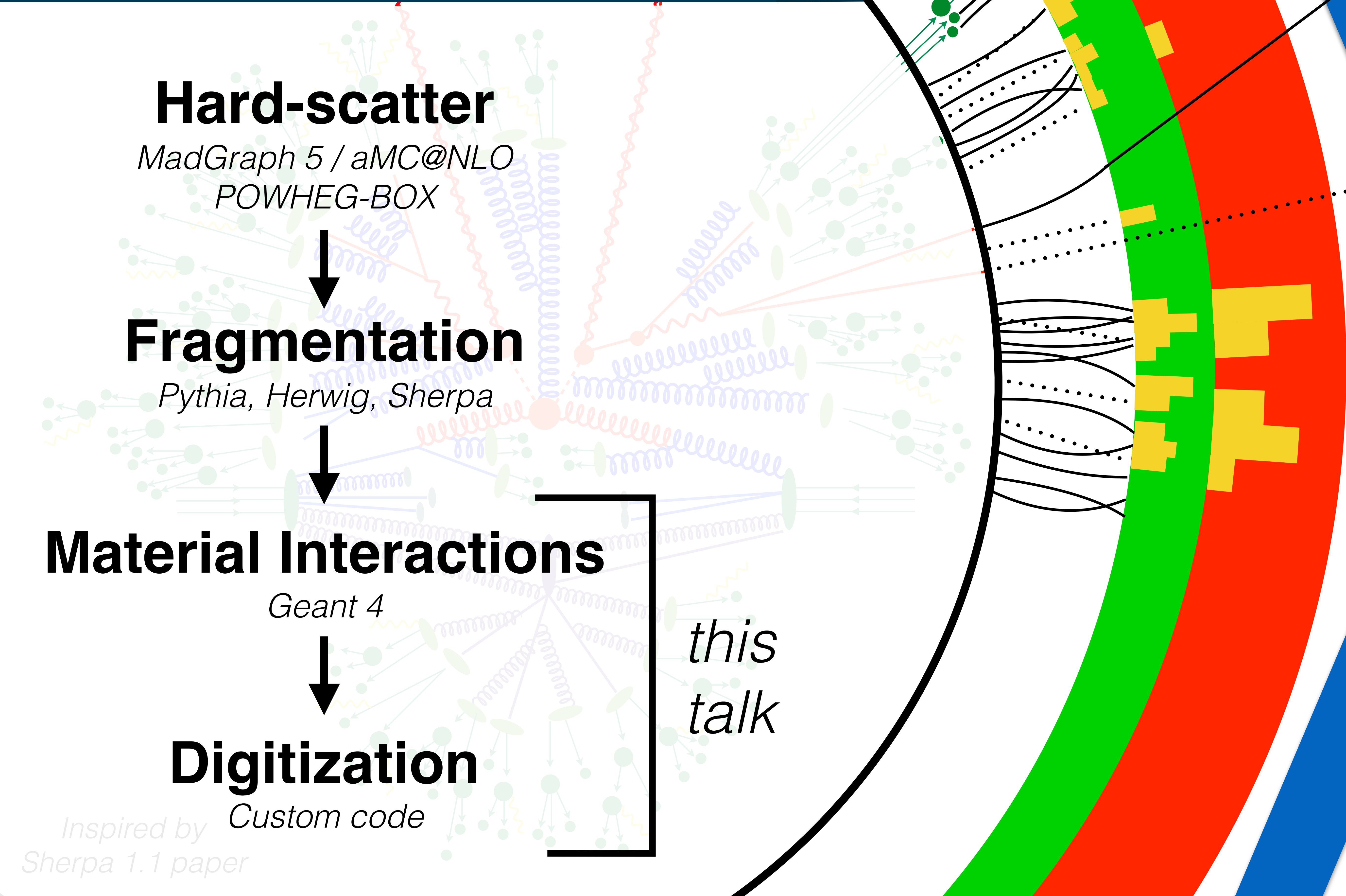
MC Simulation in ATLAS



Inspired by Sherpa 1.1 paper

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

MC Simulation in ATLAS



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

Brief reminder - ATLAS Pixel Detector

4 pixel layers

Outer three layers

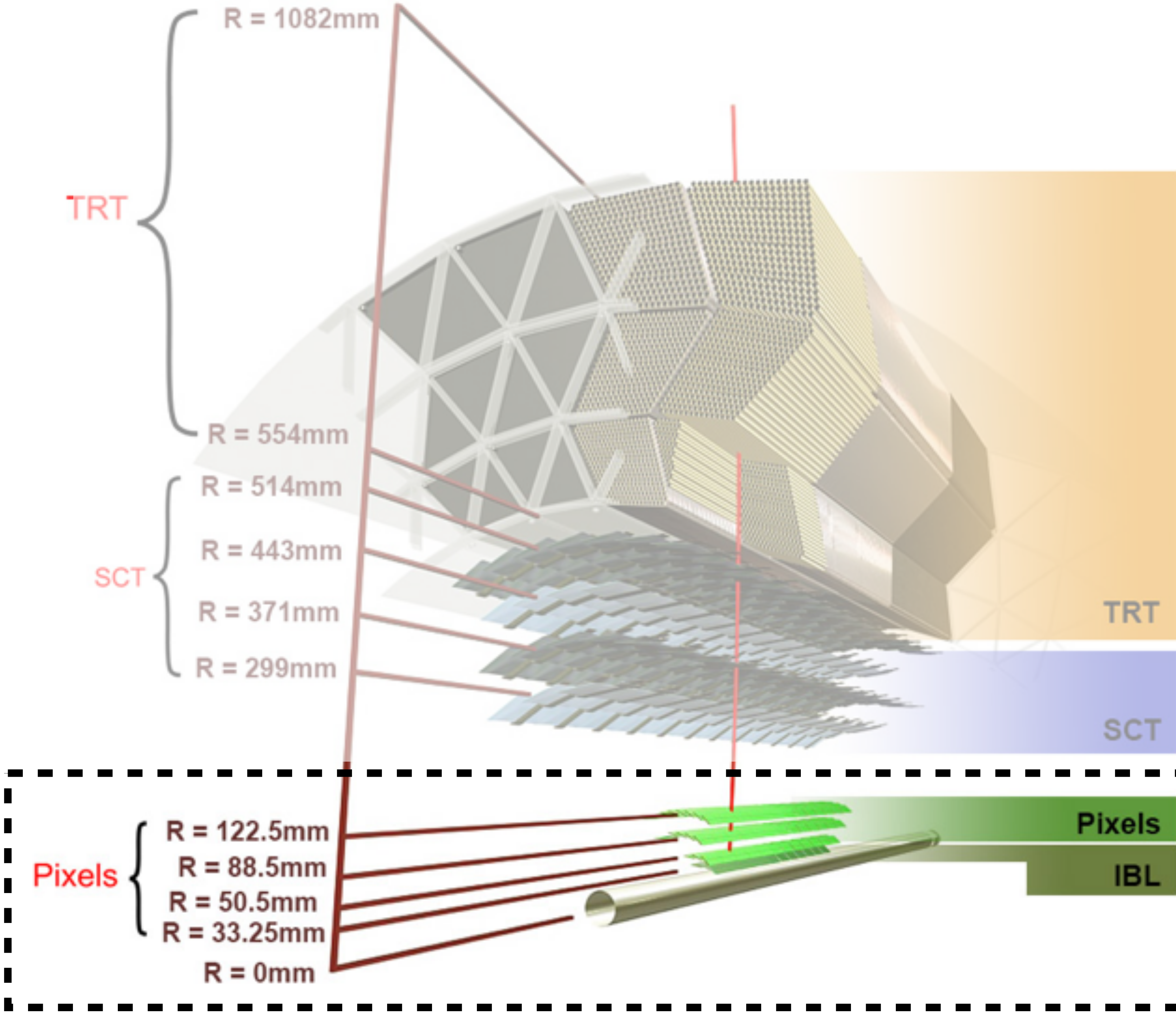
50 x 400 x 250 μm³

FEI3 readout chip (8 bit ToT)

Innermost layer

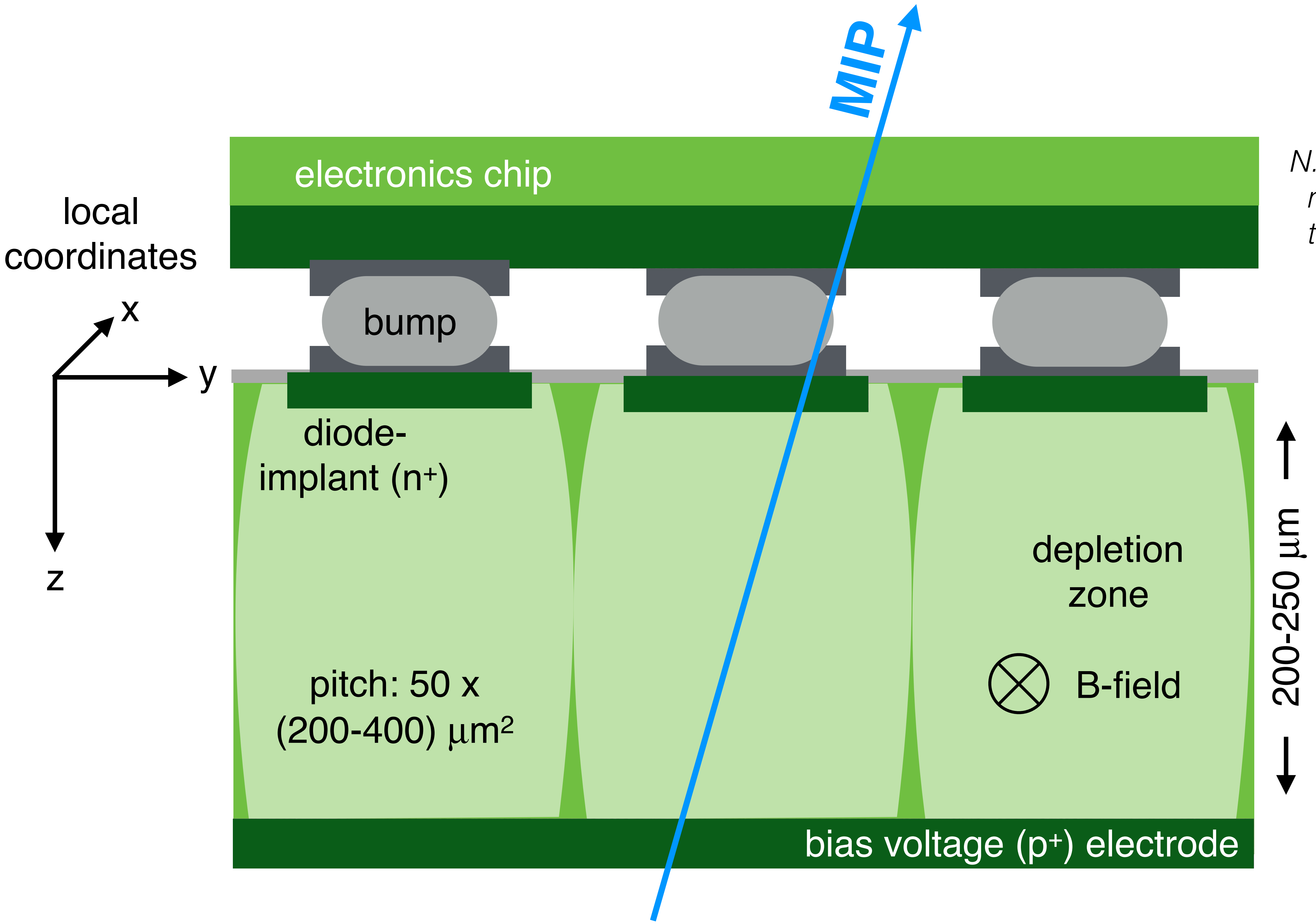
50 x 250 x 200 μm³

FEI4 readout chip (4 bit ToT)



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

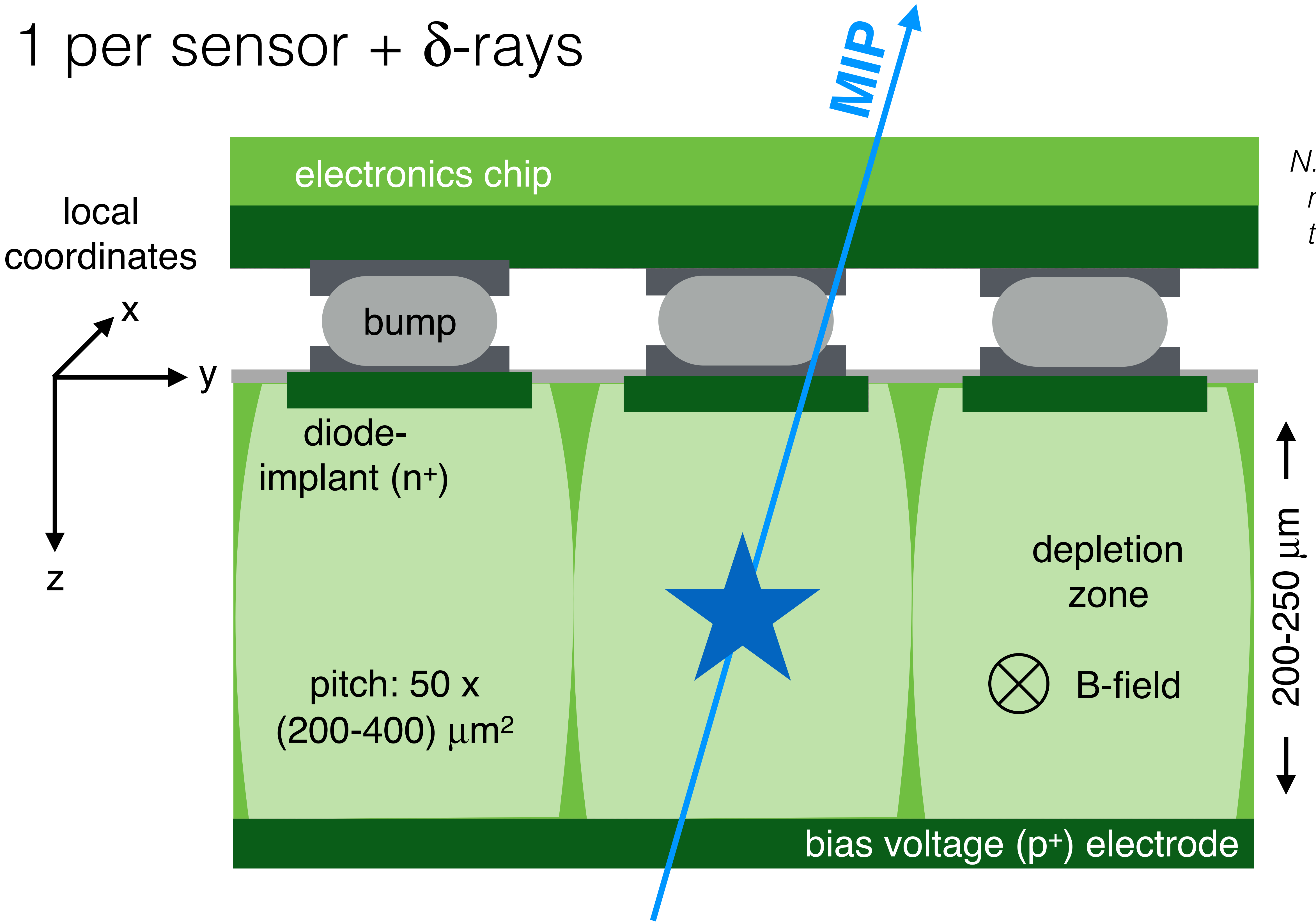
(Current) Simulation Model



N.B. Geometry model is not this detailed

Step 1: energy deposit from G4

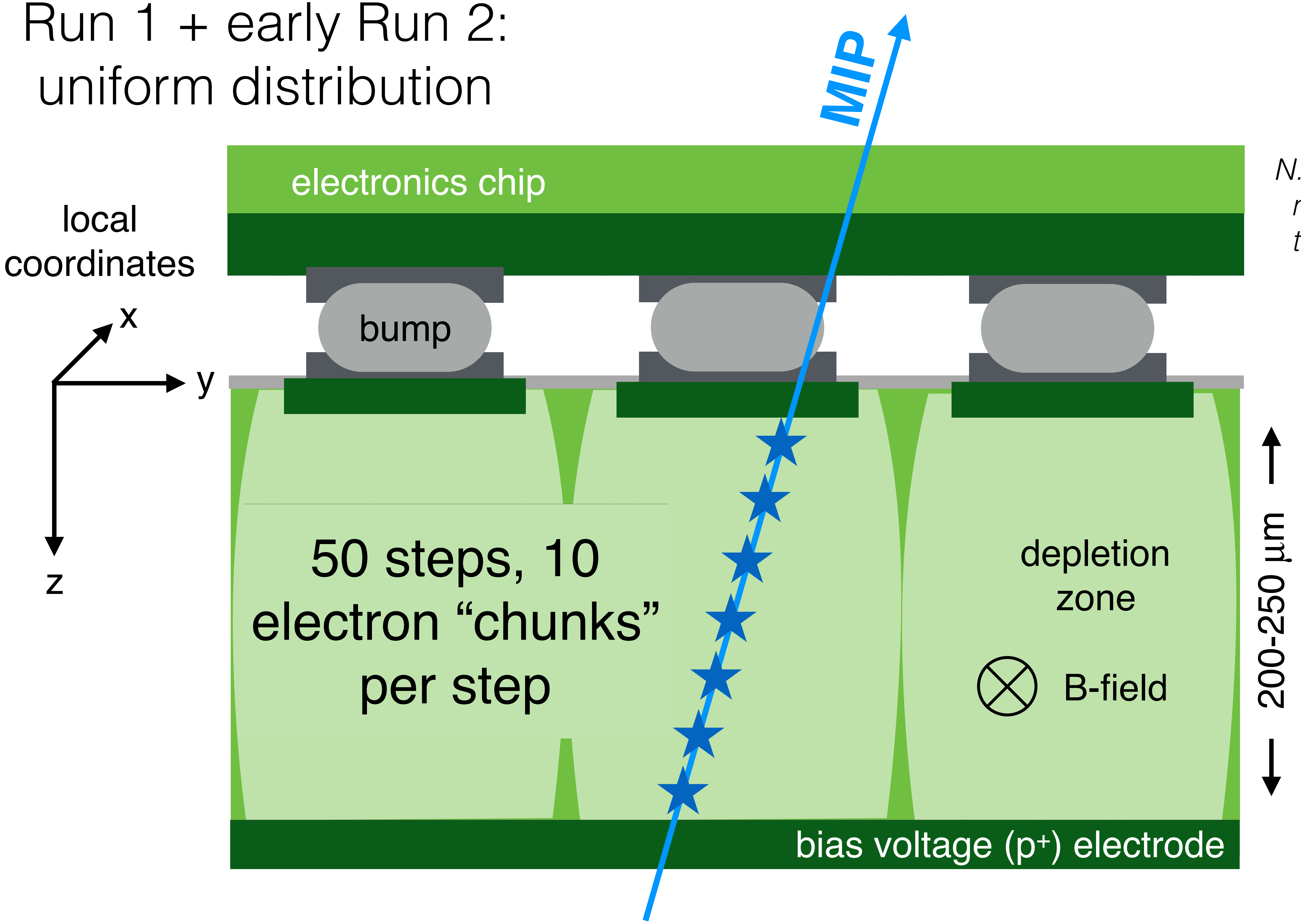
1 per sensor + δ-rays



N.B. Geometry model is not this detailed

Step 2: spread charge in sensor

Run 1 + early Run 2:
uniform distribution

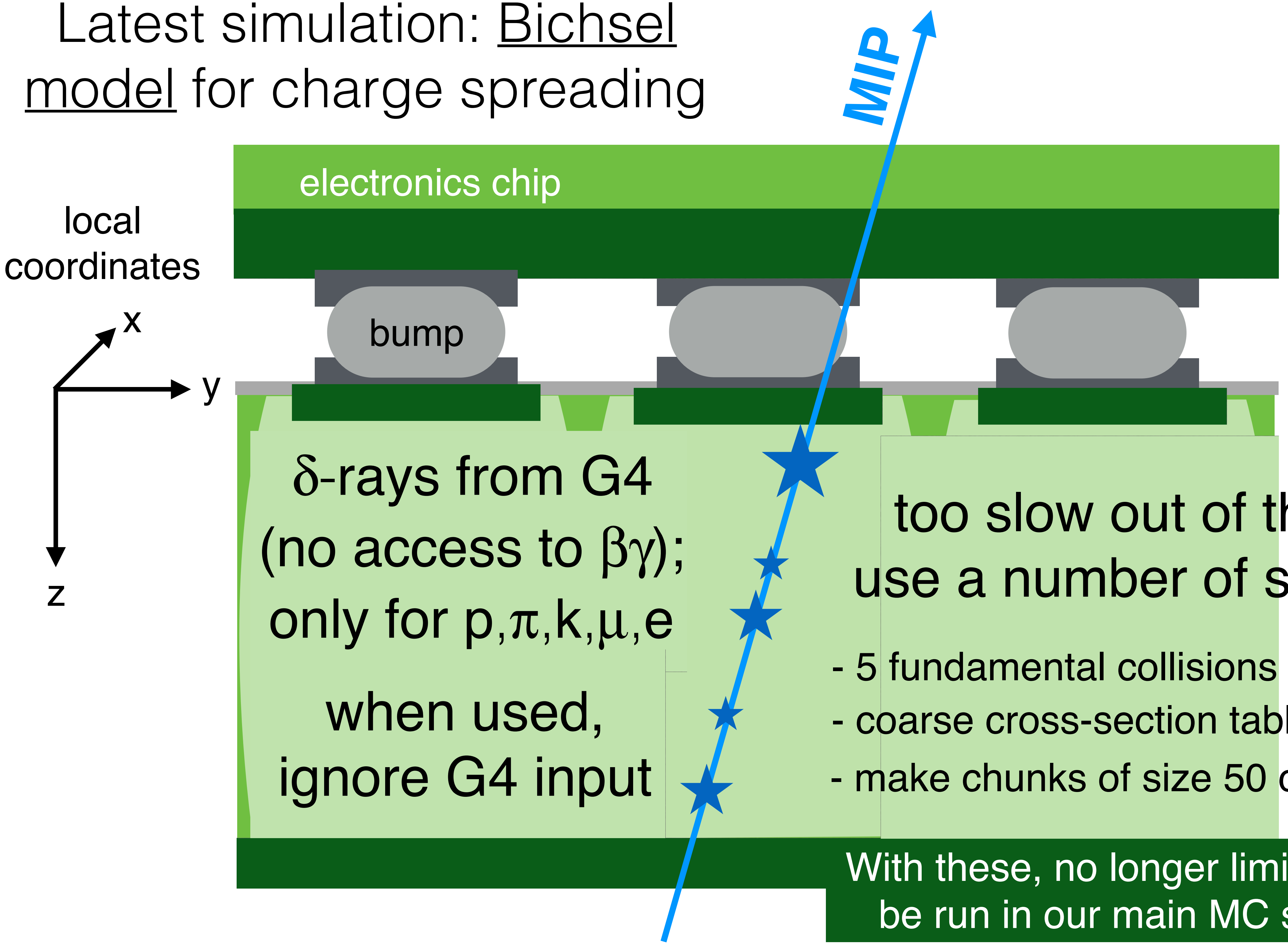


50 steps, 10 electron “chunks” per step

N.B. Geometry model is not this detailed

Step 2: spread charge in sensor

Latest simulation: Bichsel model for charge spreading



N.B. Geometry model is not this detailed

δ-rays from G4 (no access to $\beta\gamma$); only for p,π,k,μ,e

when used, ignore G4 input

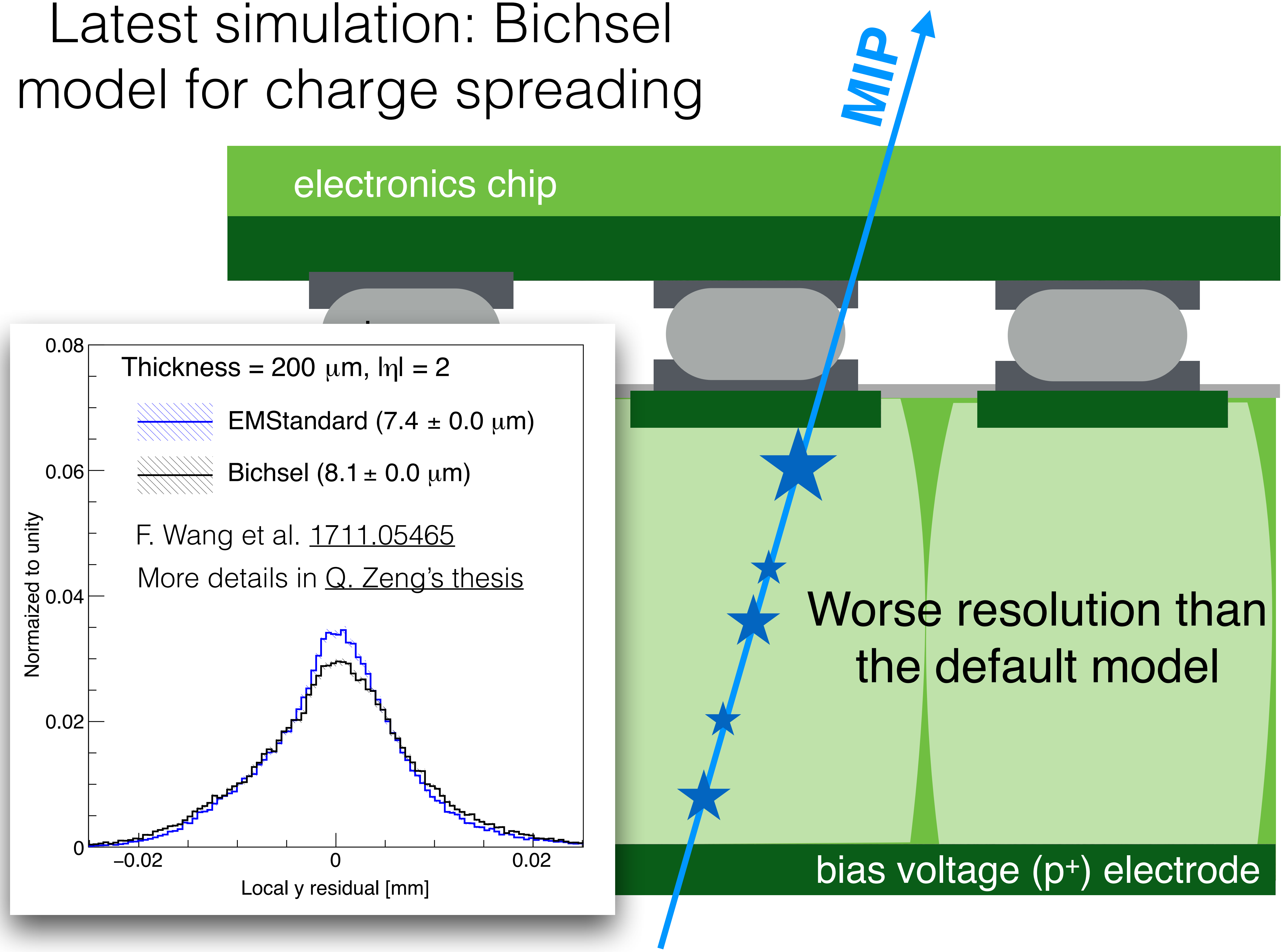
too slow out of the box - use a number of speedups:

- 5 fundamental collisions / sampling
- coarse cross-section tables
- make chunks of size 50 charges

With these, no longer limiting and can be run in our main MC simulation!

Step 2: spread charge in sensor

Latest simulation: Bichsel model for charge spreading



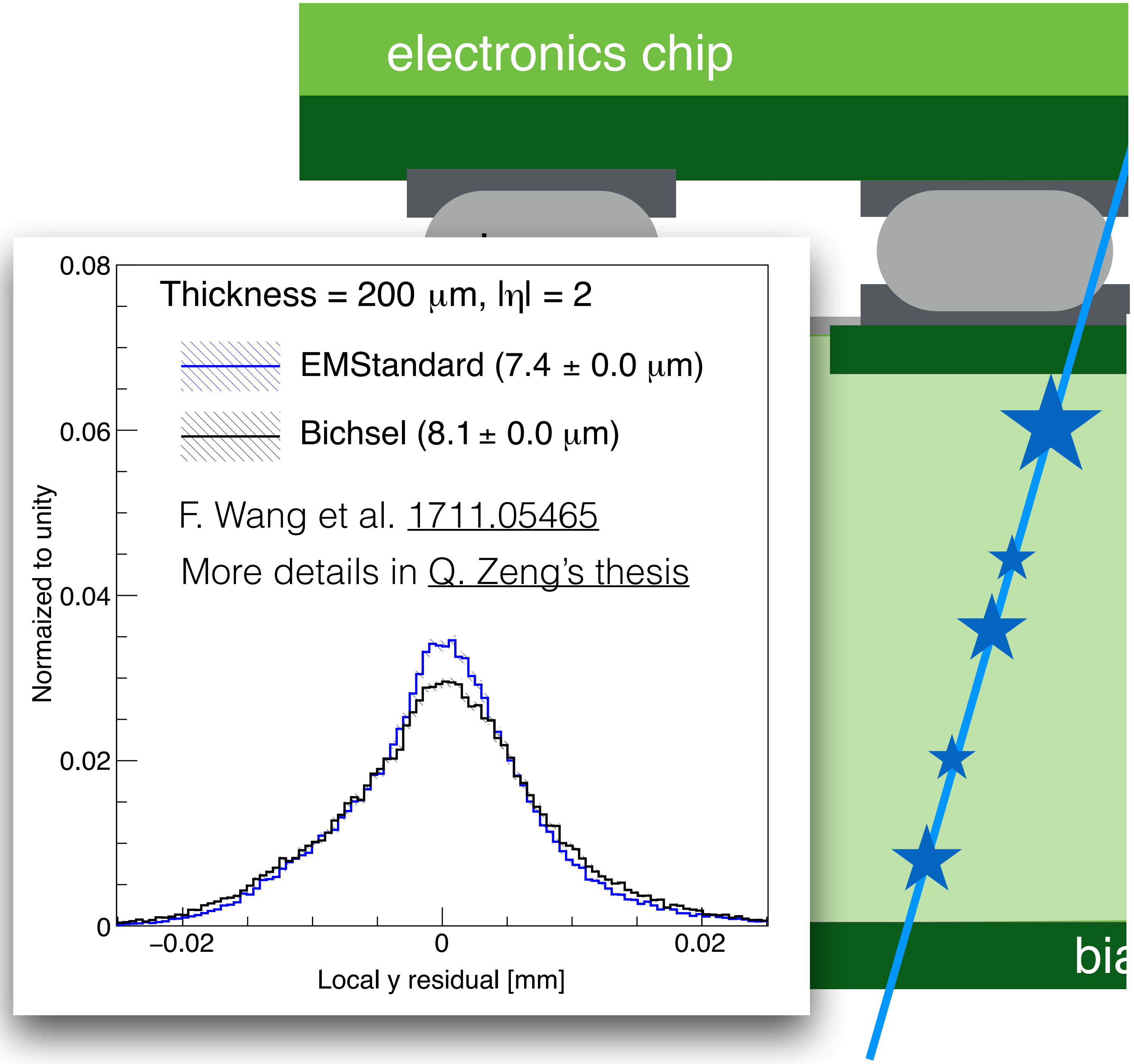
F. Wang et al. 1711.05465

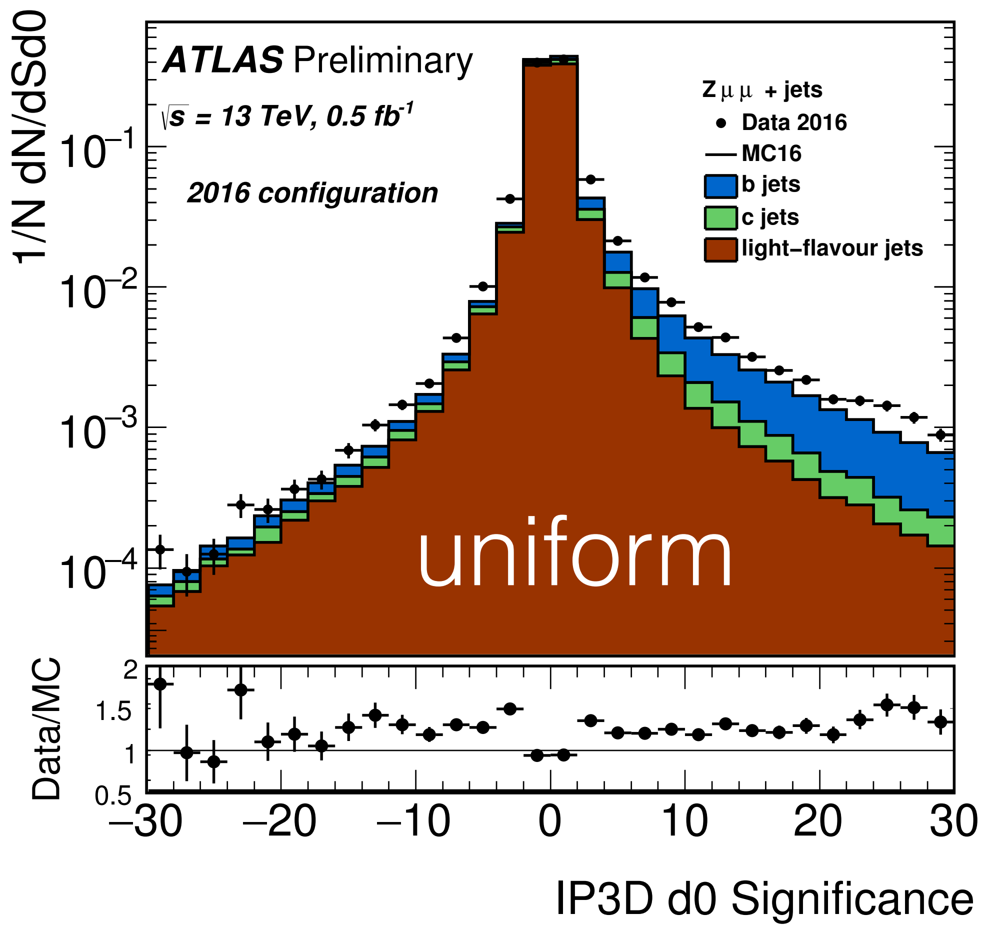
More details in Q. Zeng's thesis

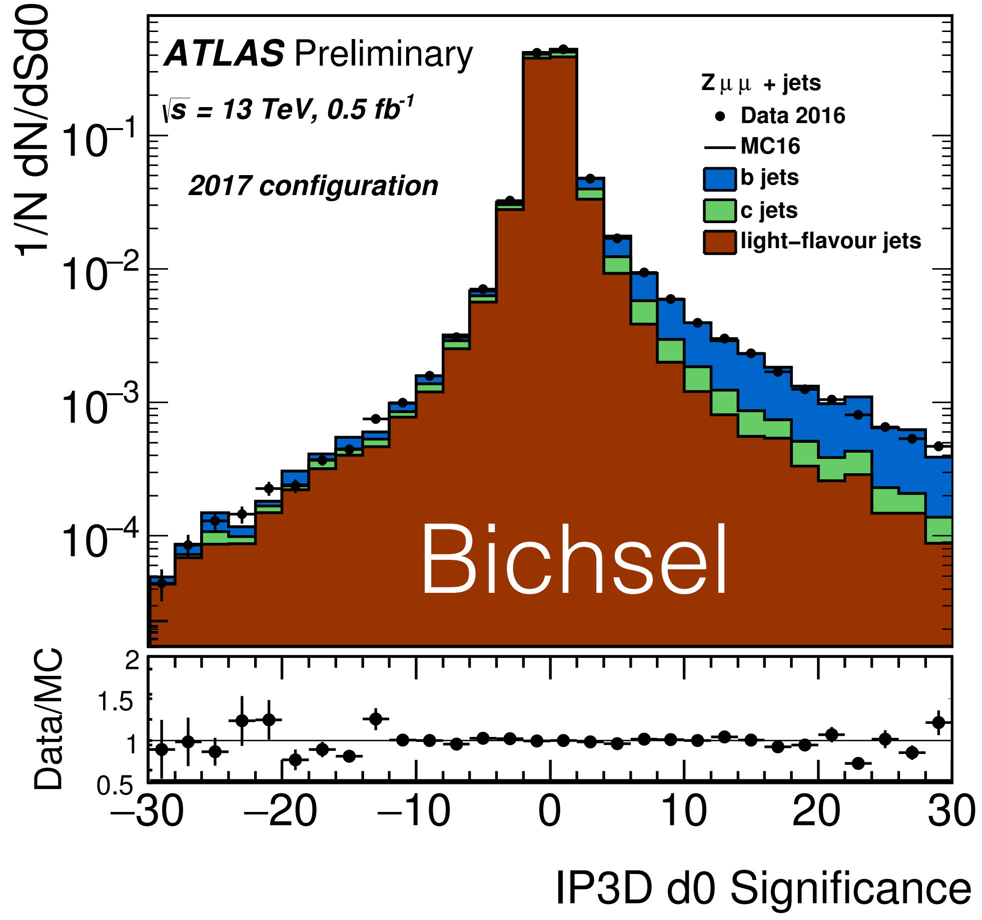
Worse resolution than the default model

Step 2: spread charge in s

But better data/MC agreement







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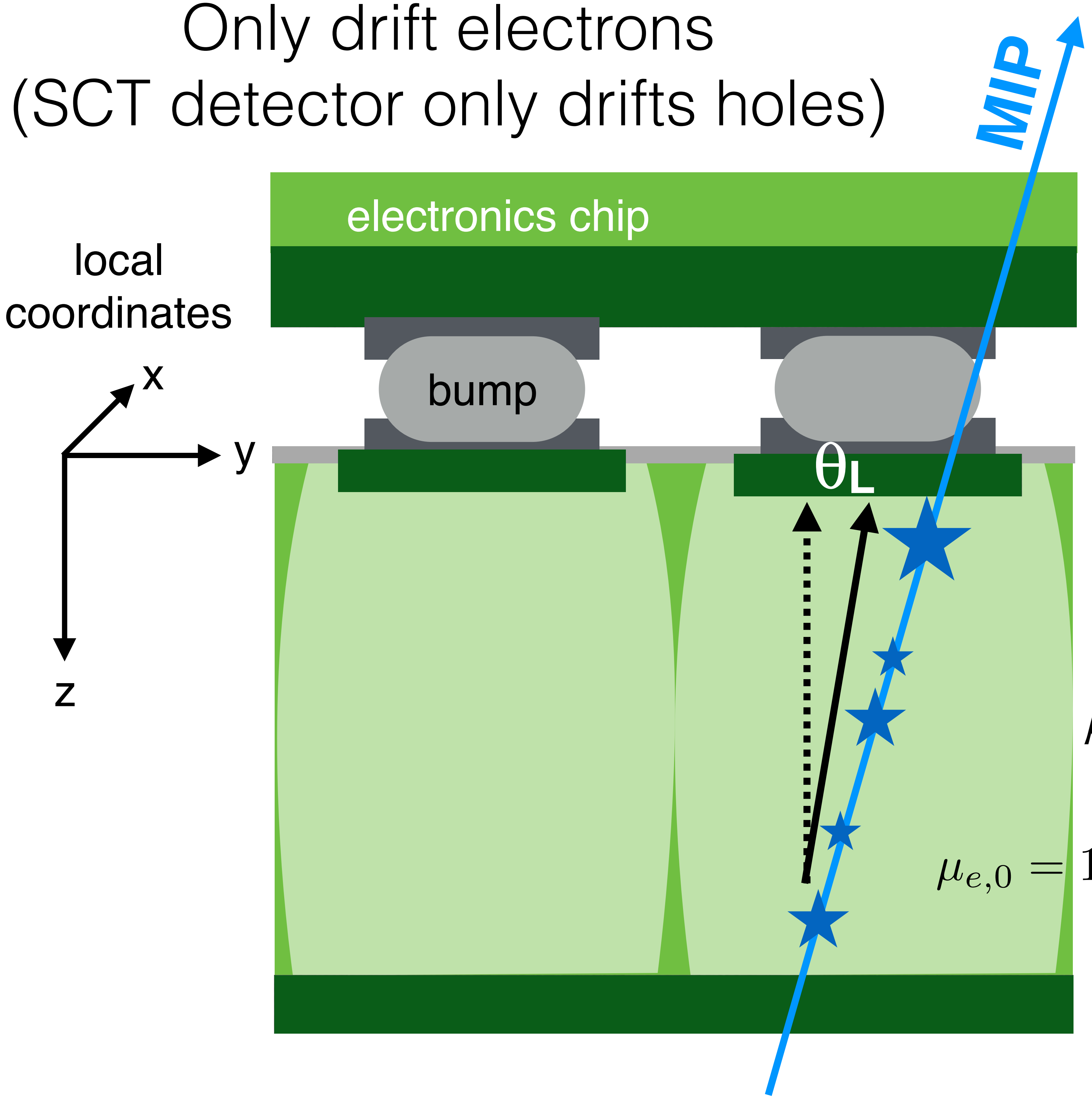
Step 3: Drift + diffusion

Only drift electrons
(SCT detector only drifts holes)



Hall scattering factor

local field

$$\tan \theta_L = r\,\mu\,\hat{z} \times \vec{B}$$

depth direction

$$\mu(T,E) = \mu_0(T)\left[1 + \left(\frac{E}{E_c(T)}\right)^{\beta}\right]^{-1/\beta}$$

$$\mu_{e,0} = 1533.7\ \mathrm{cm}^2/(\mathrm{V}\cdot\mathrm{s}) \times (T/300)^{-2.42}$$

values from
Jacoboni et al.
review article

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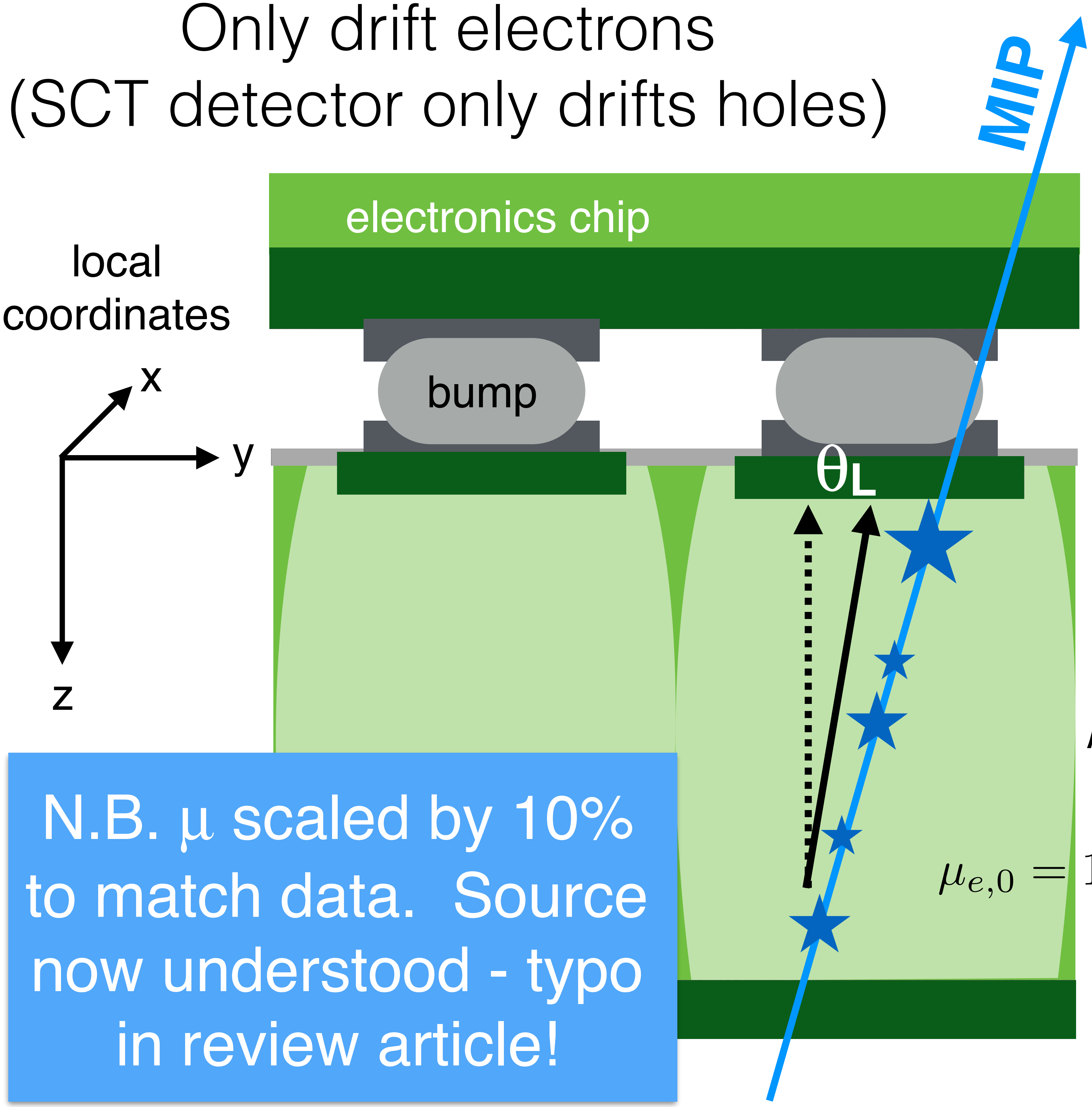

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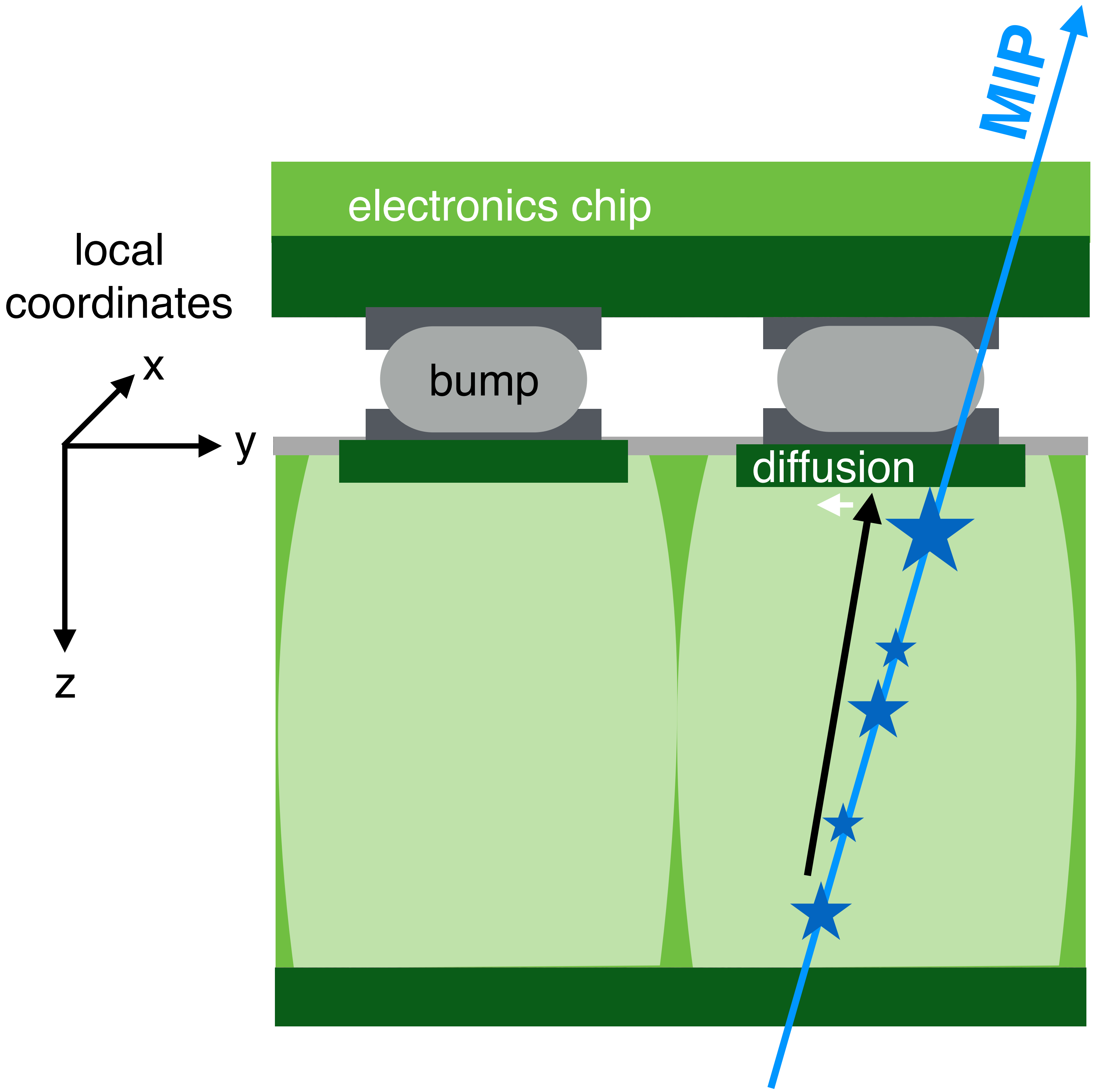
N.B. μ scaled by 10% to match data. Source now understood - typo in review article!

Step 3: Drift + diffusion



One random transverse smearing per electron chunk.

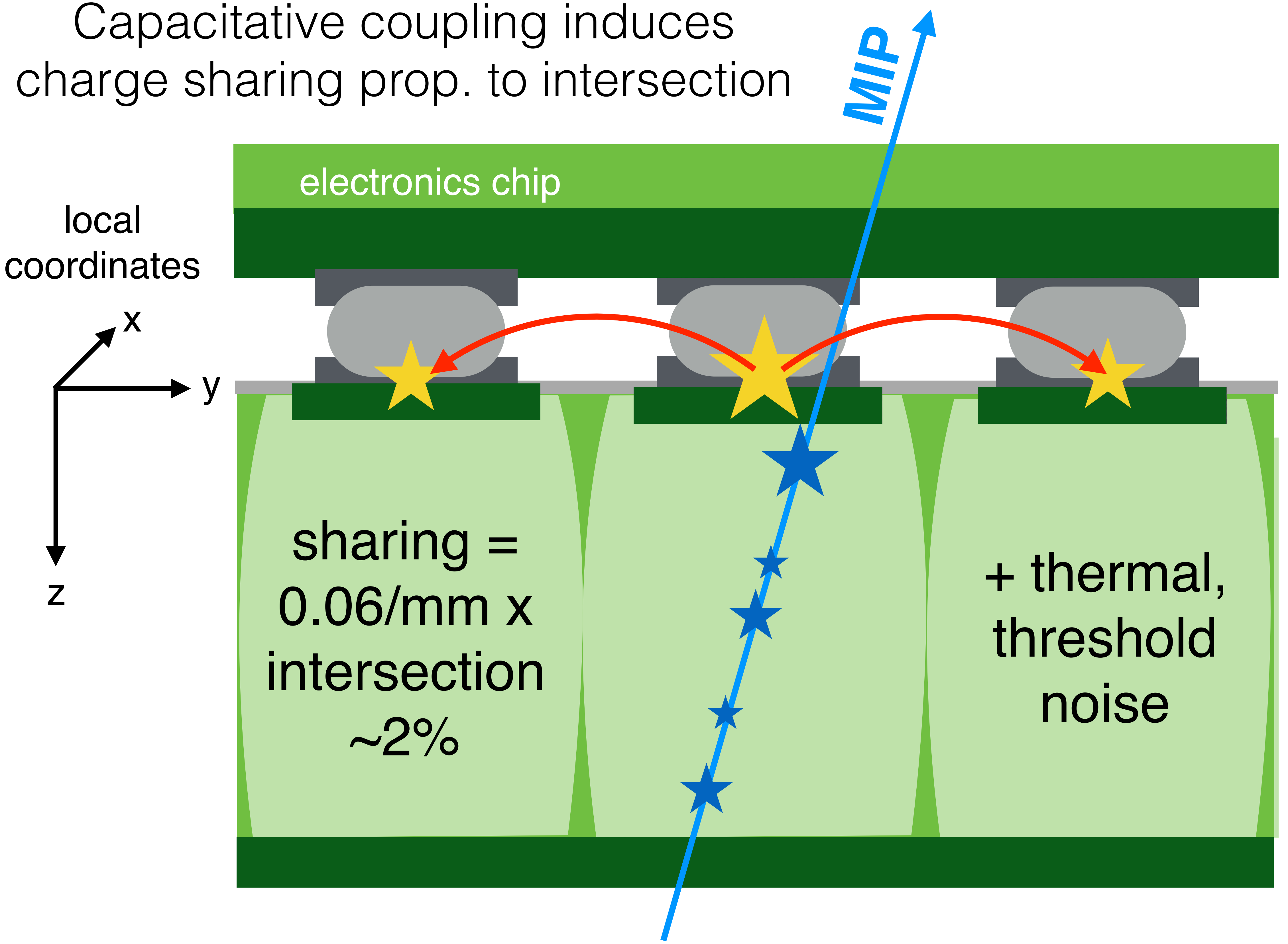
diffusion length is fixed at 7 µm / 300 µm

scaled by square root of path length

for the future: proper Einstein relation

Step 4: Charge sharing + Noise

Capacitative coupling induces charge sharing prop. to intersection



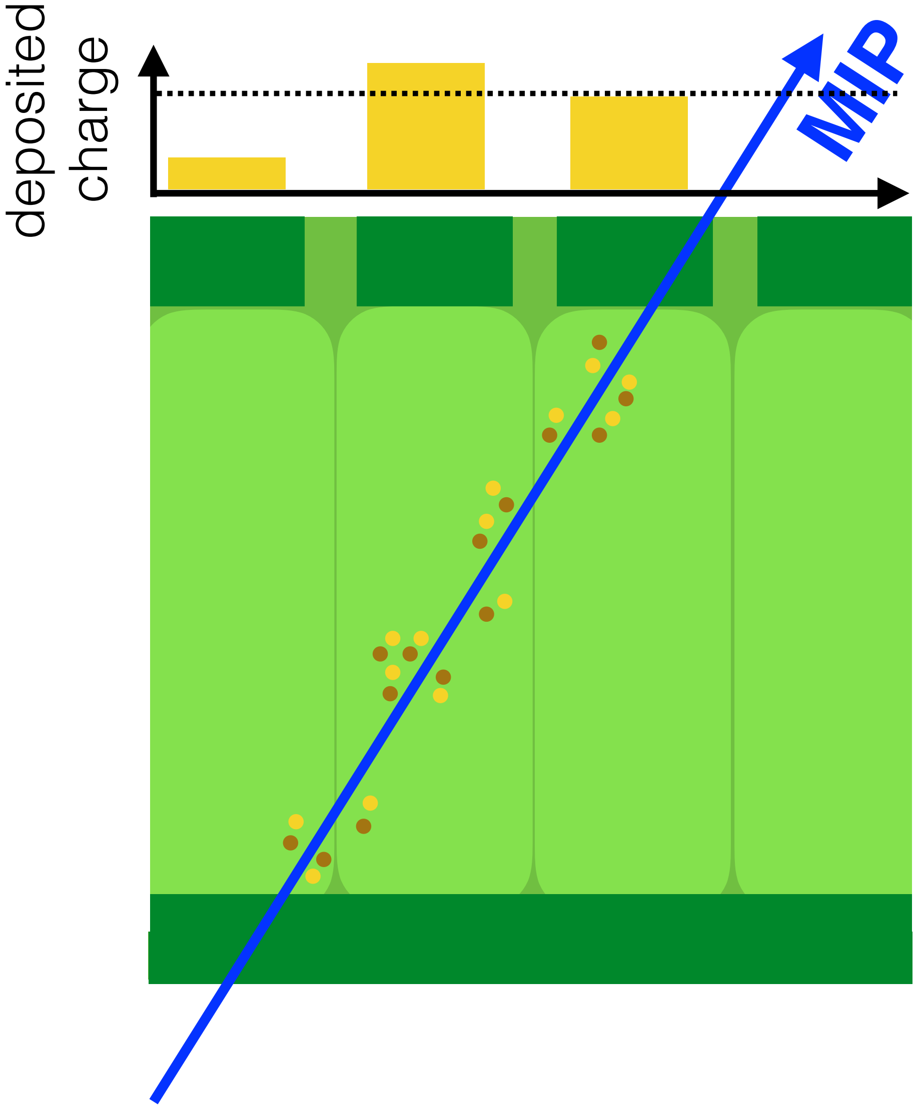
sharing = 0.06/mm x intersection ~2%

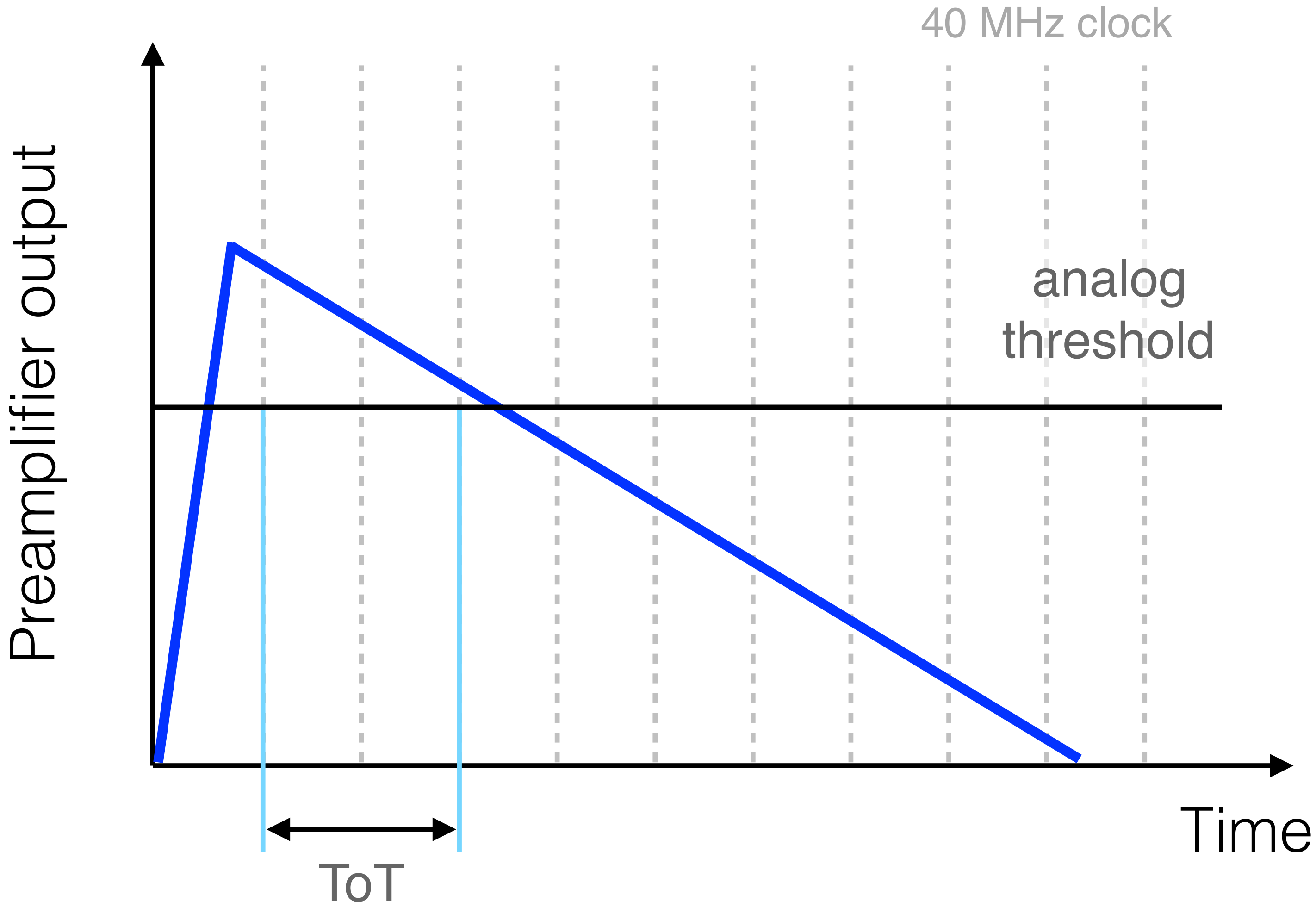
+ thermal, threshold noise

Step 4: Analog - to - digital

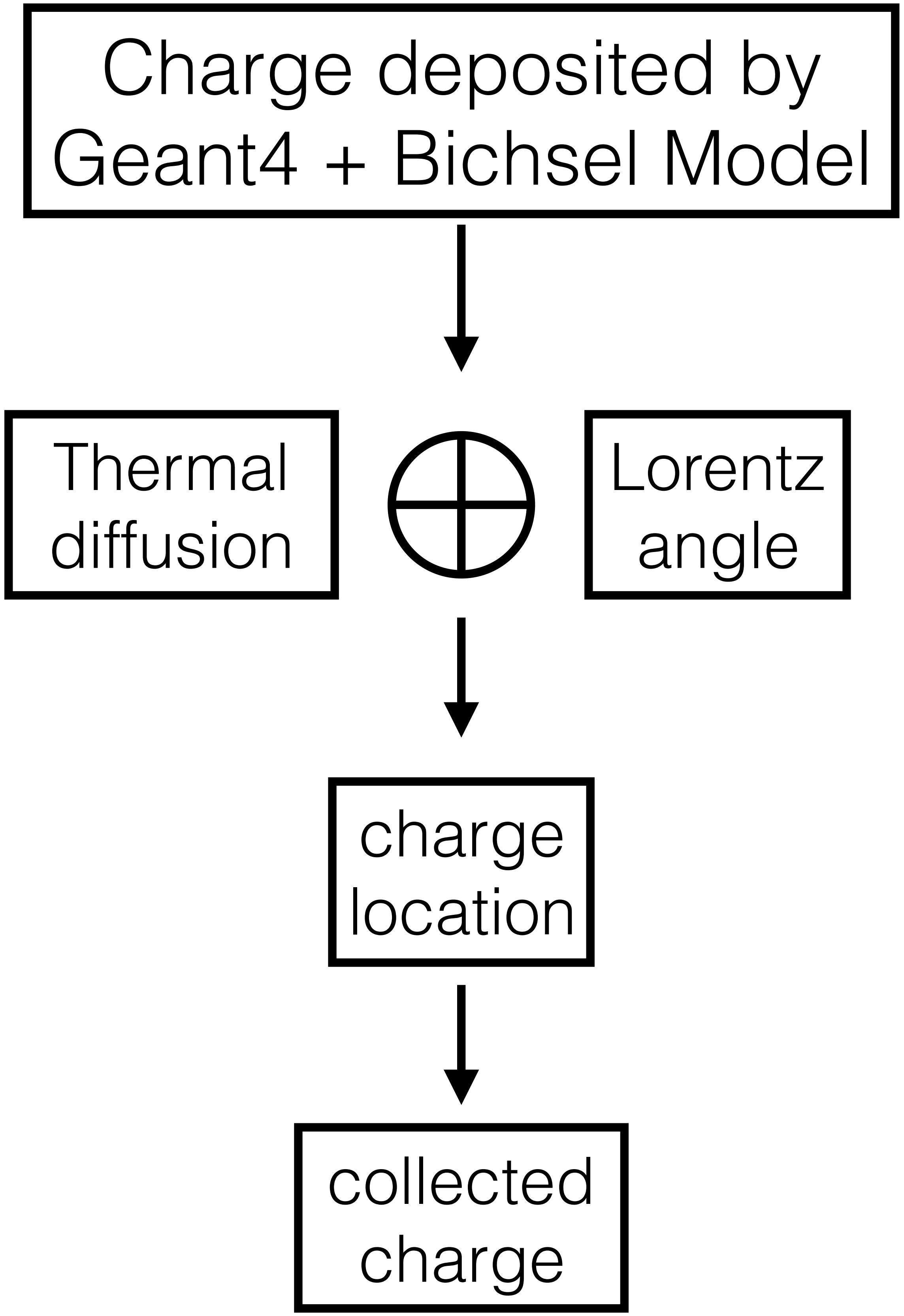
Time-over-threshold (ToT) tuning and threshold set to match detector

+ readout specific such as overflow, small hits, etc.





Pixel Simulation Overview



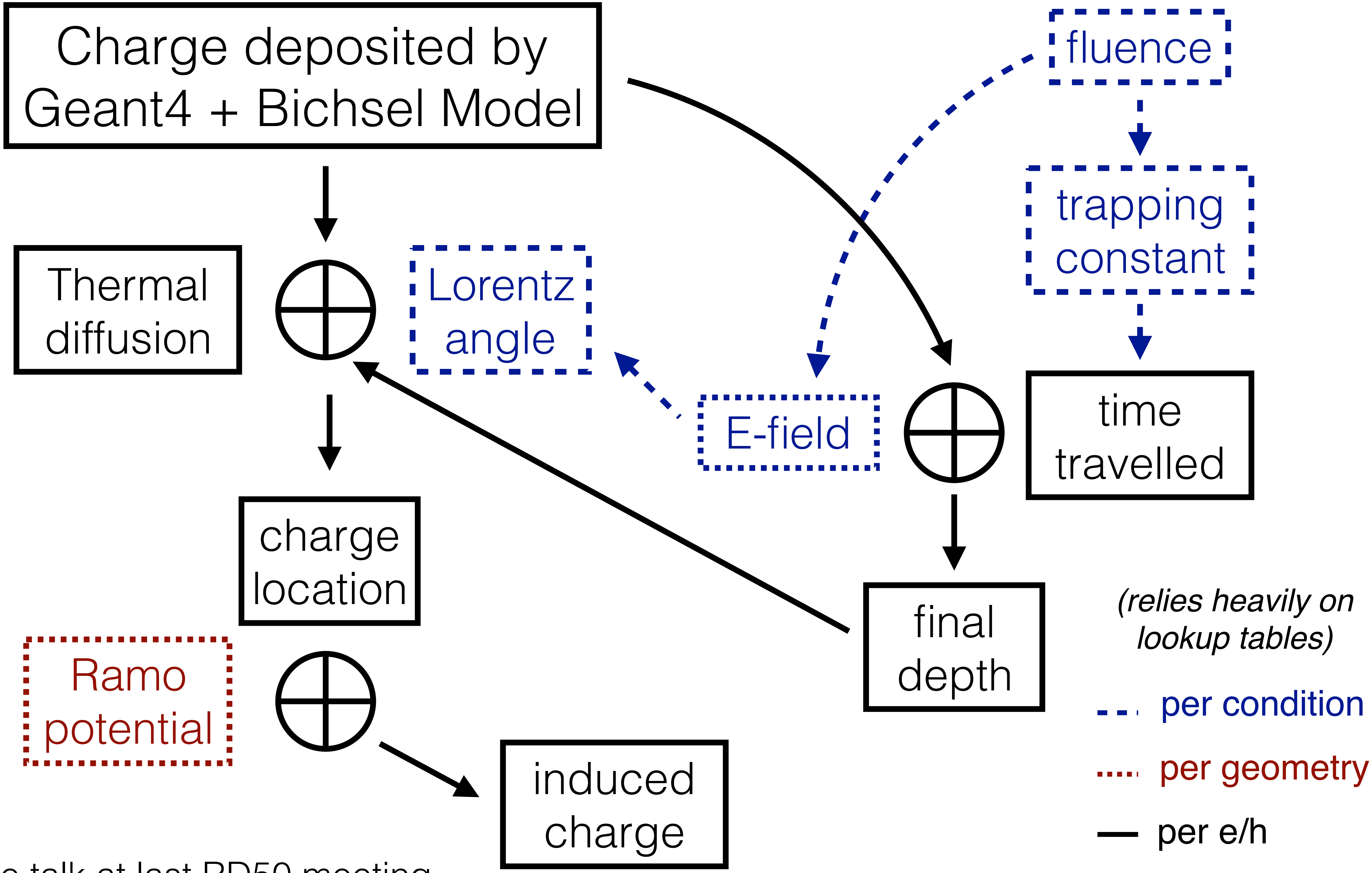
Charge deposited by Geant4 + Bichsel Model

Thermal diffusion ⊕ Lorentz angle

charge location

collected charge

+ Radiation Damage



Charge deposited by Geant4 + Bichsel Model

Thermal diffusion

Lorentz angle

charge location

Ramo potential

induced charge

fluence

trapping constant

time travelled

E-field

final depth

(relies heavily on lookup tables)

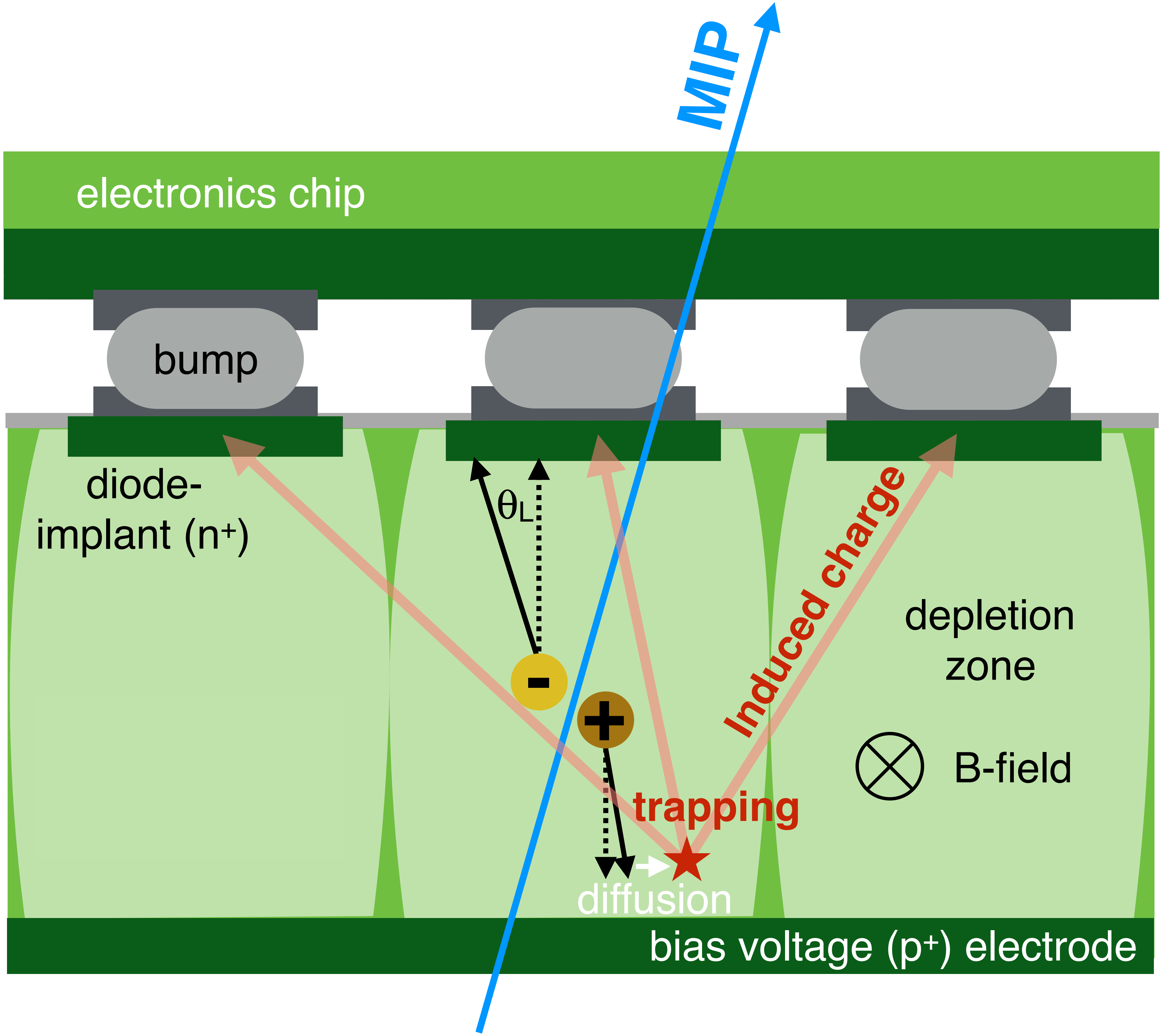
- - - per condition

····· per geometry

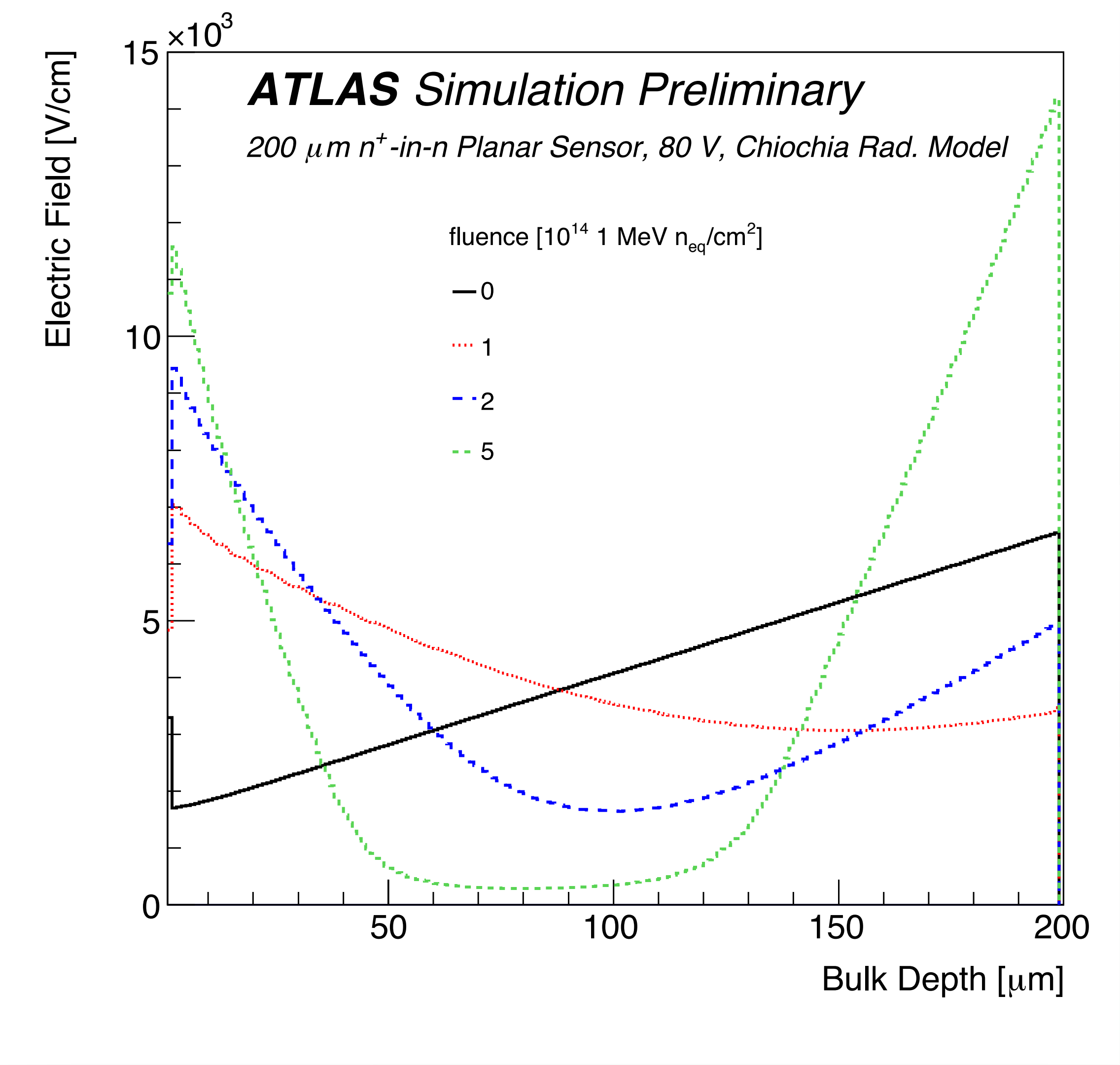
— per e/h

See talk at last RD50 meeting

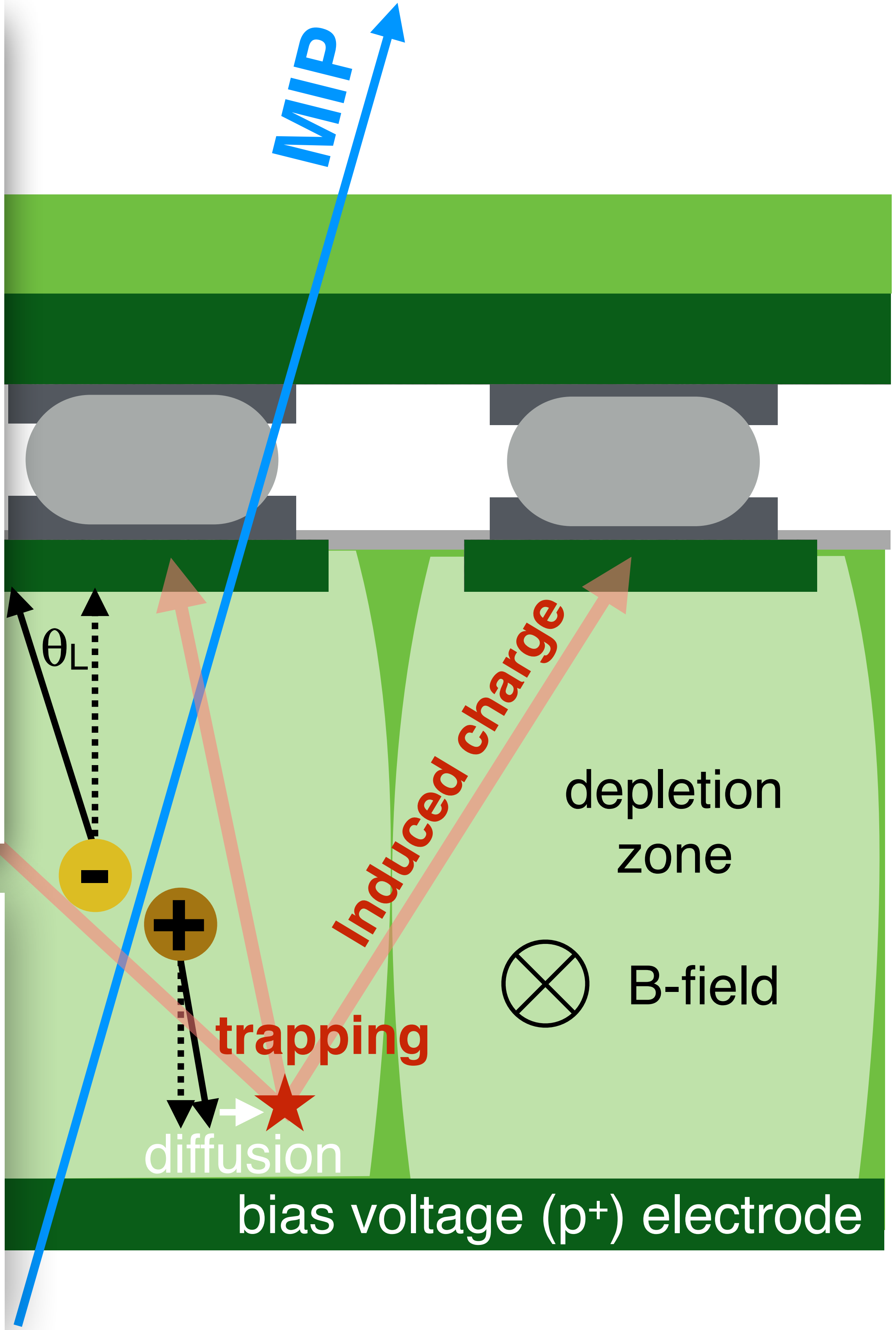
Reminder: (Bulk) Radiation Damage Effects



Reminder: (Bulk) Radiation Damage Effects

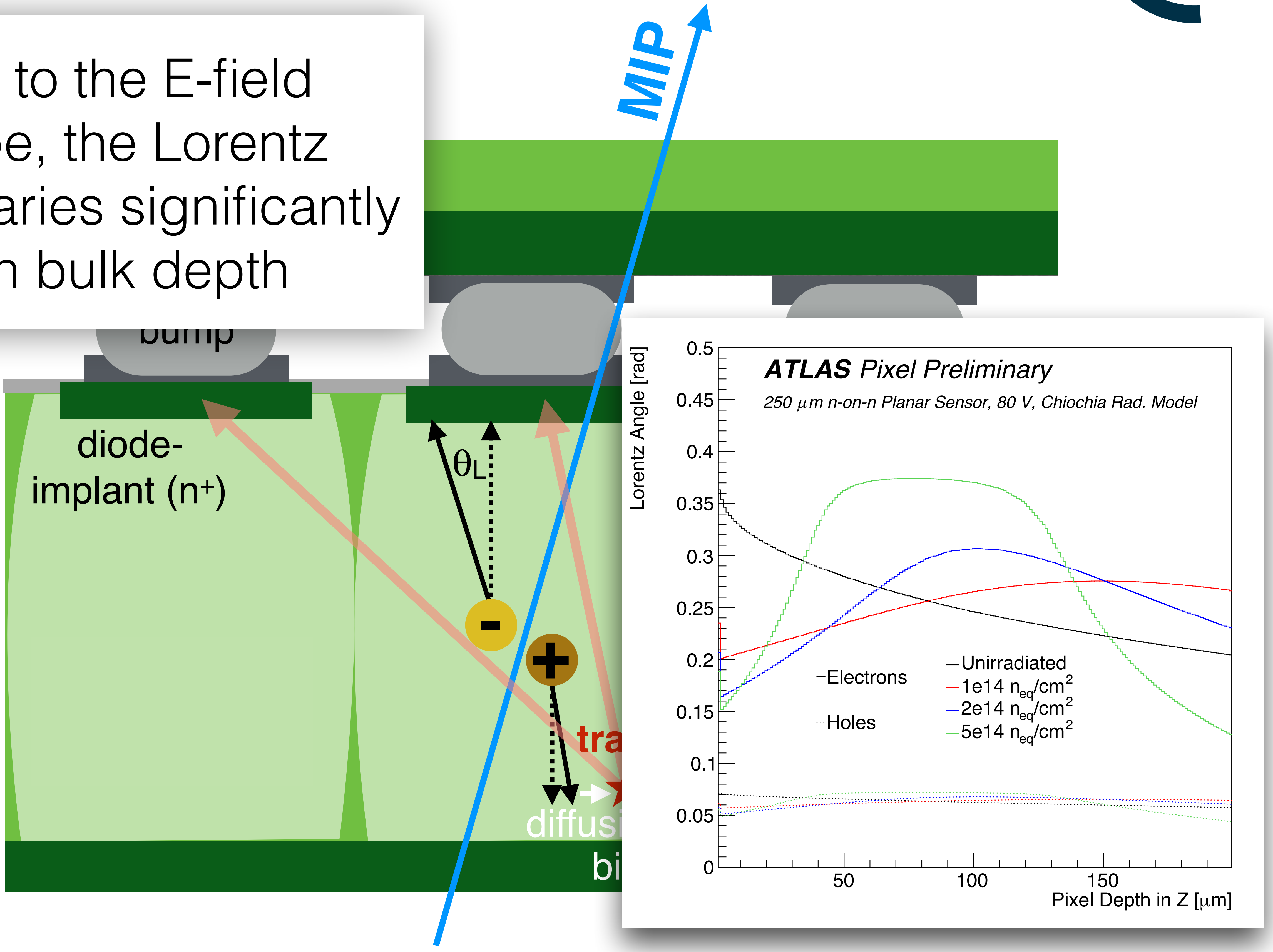


Deformed electric field in the bulk modeled with radiation damage model in TCAD



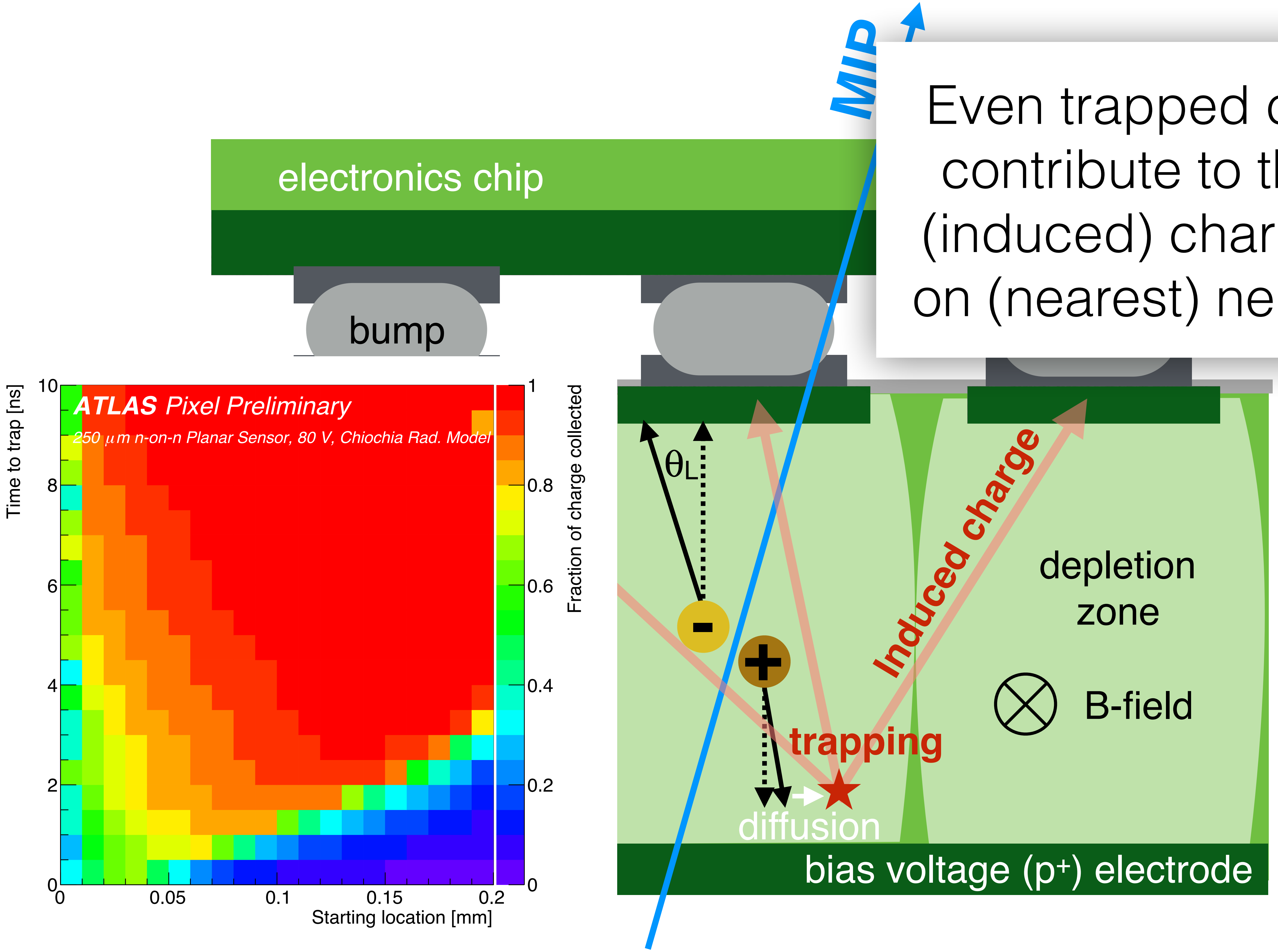
Reminder: (Bulk) Radiation Damage Effects

Due to the E-field shape, the Lorentz angle varies significantly with bulk depth



Reminder: (Bulk) Radiation Damage Effects

Even trapped charges contribute to the total (induced) charge; also on (nearest) neighbors!



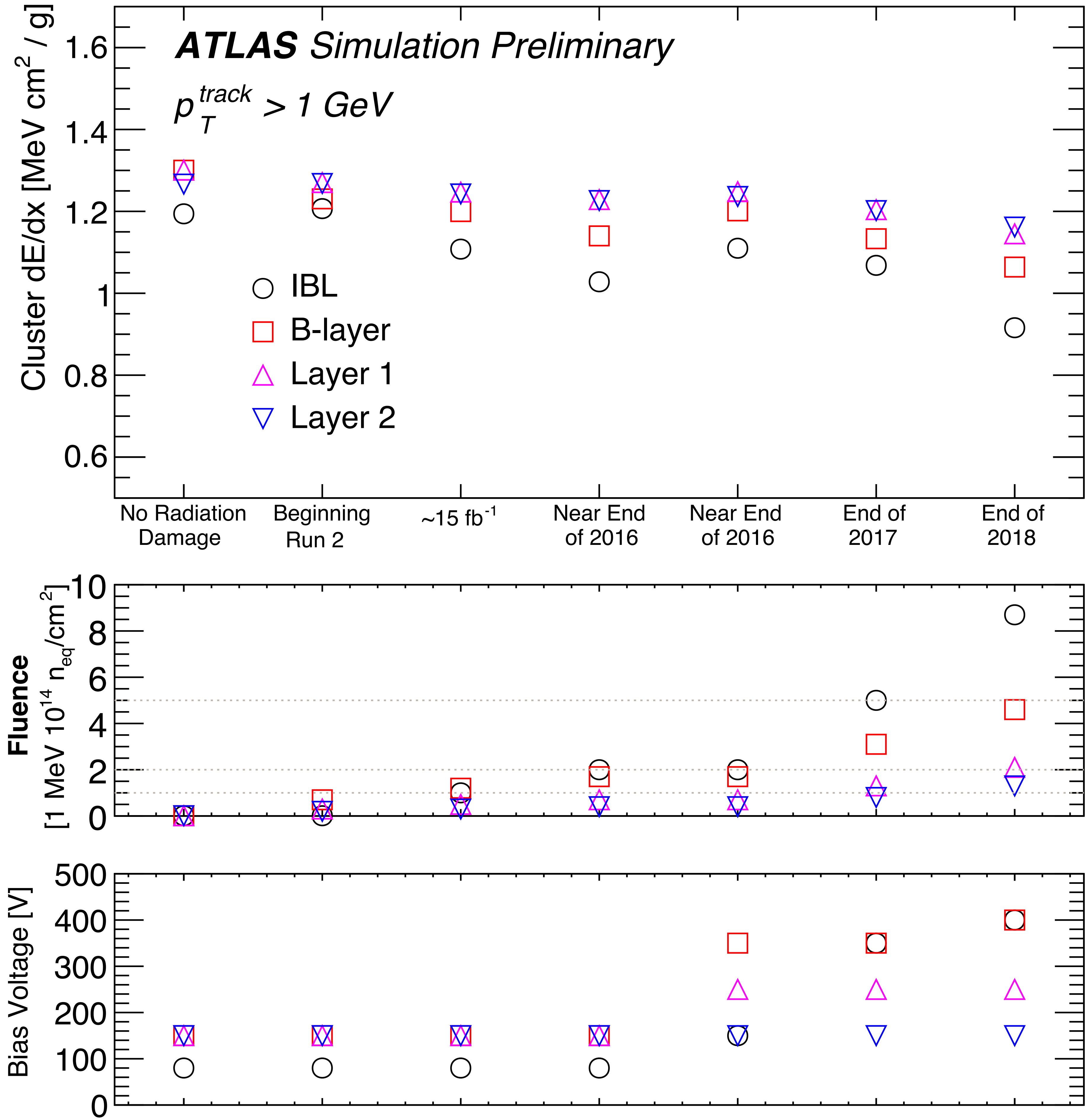
Conclusions and Future Outlook

Geant 4 is workhorse for material interactions, but significant part of ATLAS pixel digitization is custom

Many physical effects to consider, but also a lot of data to constrain models!

We are always trying to improve our models, even in the absence of the new radiation damage digitization

We all have silicon sensors and so it is very useful to compare notes and take the best of all our approaches!



First simulation results with the fully implemented digitizer model in the ATLAS framework!

… more on this in Lorenzo’s talk