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SVT Simulation Status and Plan

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SVT Working Meeting @ LBNL

Oct 8, 2026

<https://indico.bnl.gov/event/33887/sessions/9341/#20261008>





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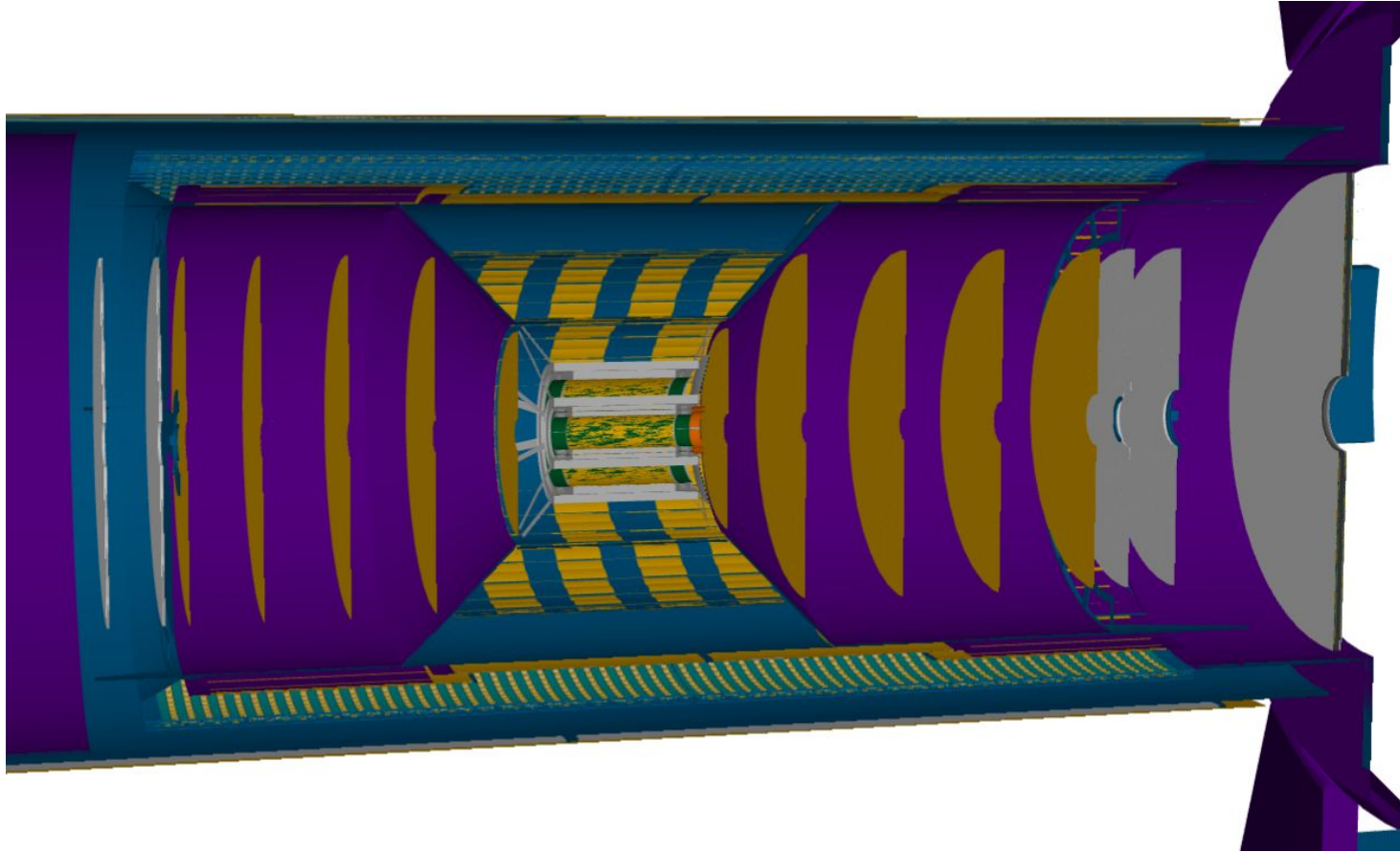


SVT Simulation Status and Plan

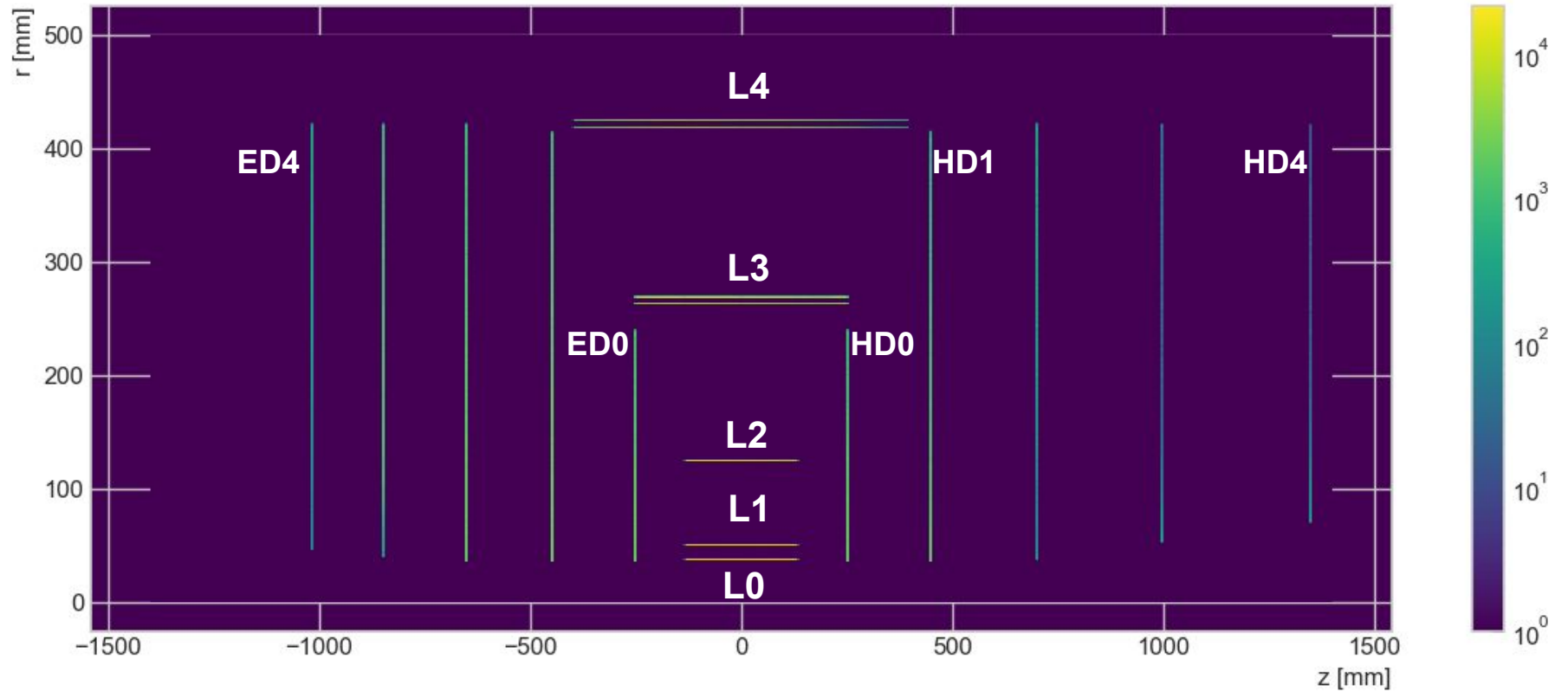
- SVT geometry
- Sensor structure and response
- Tracking performance studies
- Software development and computing

* items labeled as “**TODO**” = contributions are welcome

ePIC Central Tracker in DD4hep



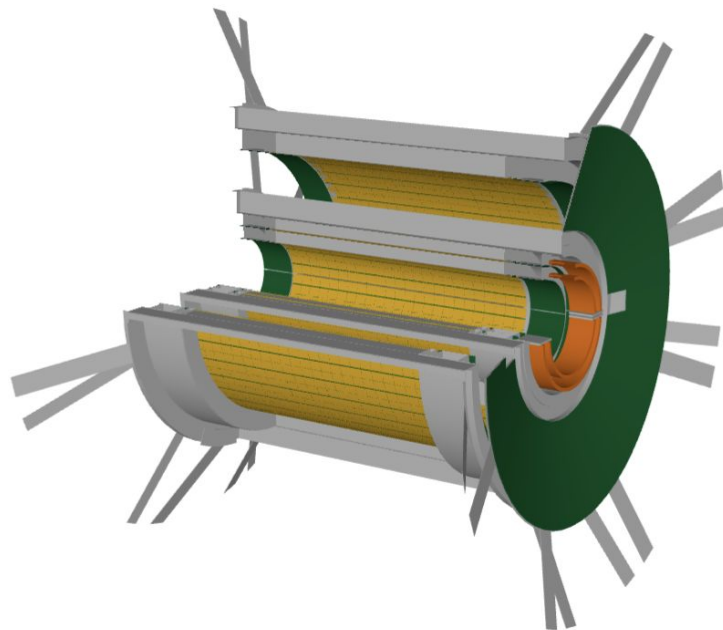
SVT Hit Map



SVT Geometry in DD4hep

Inner Barrel (SL implemented based on step file from Rosario 08.2025, see [talk](#)):

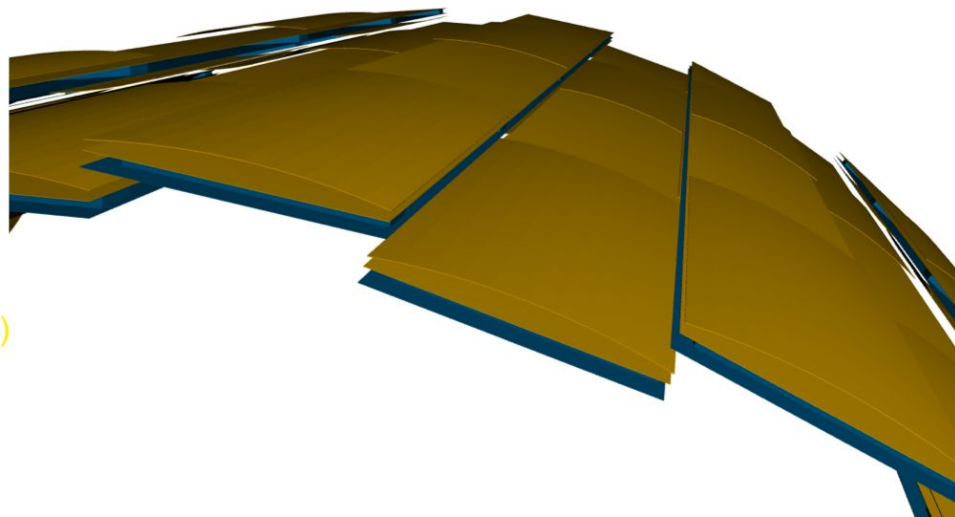
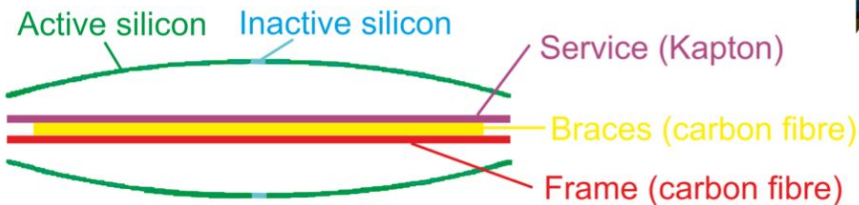
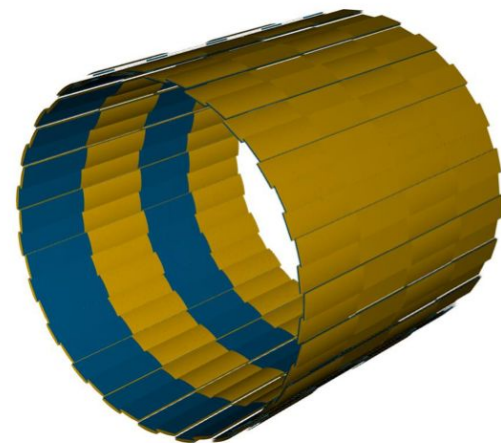
3 barrel layers with RSU structure + mechanical support + simplified cable and readout description to match the material budget



SVT Geometry in DD4hep

Outer Barrel (see Sam Henry's [talk](#) 04.2026):

- Constellated staves
- Curved modules are approximated by thin staves.
- **Work in progress:** fully curved RSU/tile and mechanical structure imported from CAD [[PR](#)].



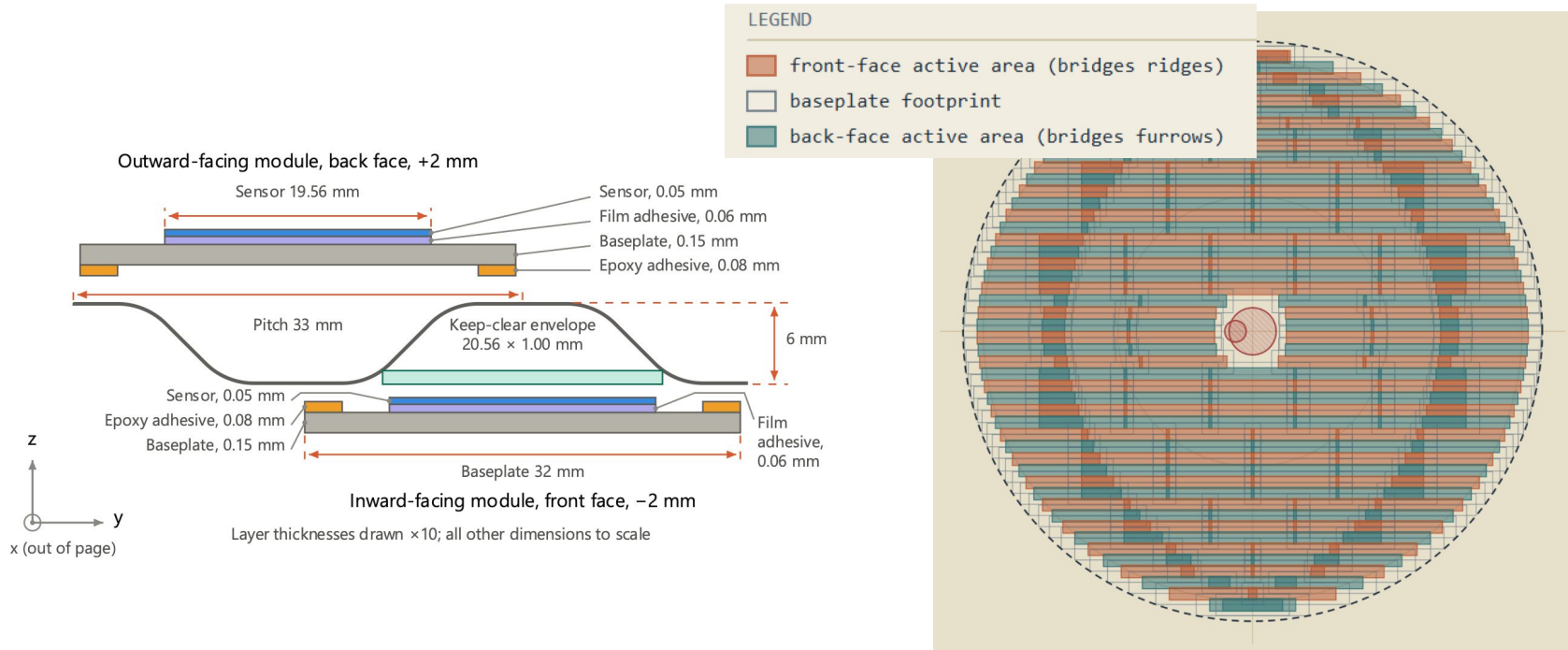
courtesy of Sam Henry

SVT Geometry in DD4hep

Disks (ongoing work [PR](#)):

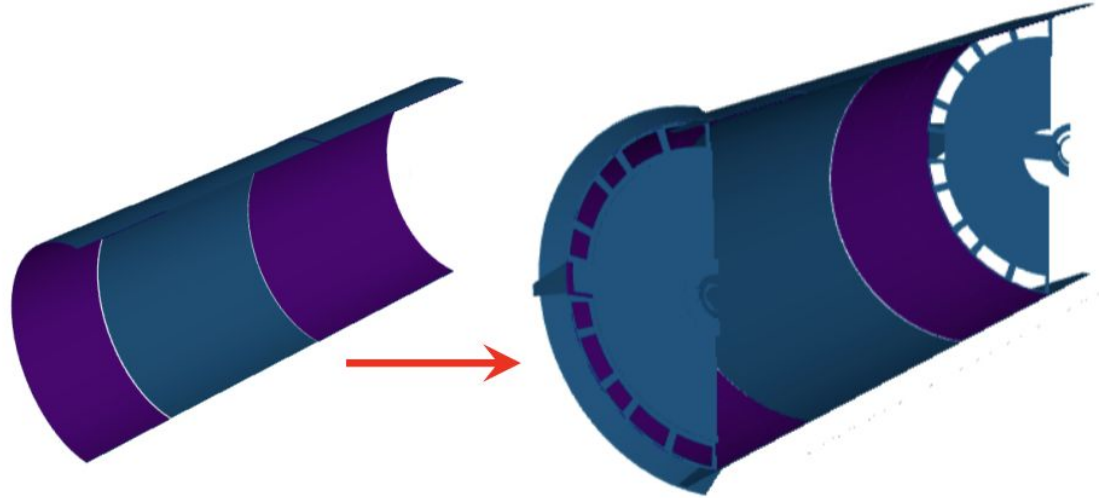
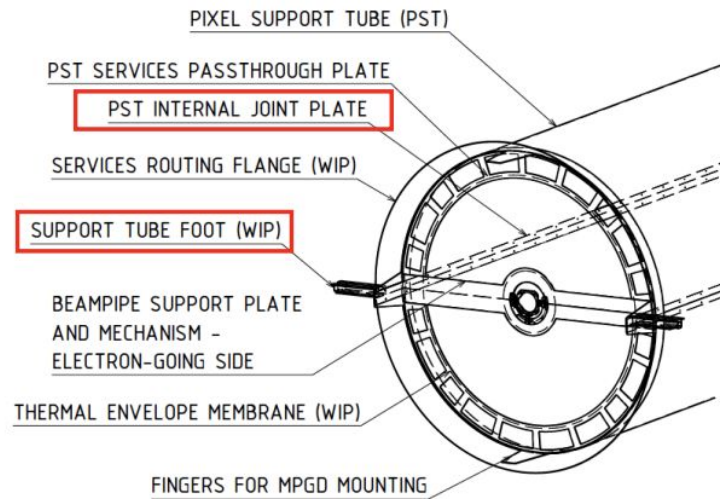
work by Ernst Sichtermann, Nicole Apadula, Provakar Datta (LBNL)

- smooth trapezoid surface $\Rightarrow$ disk assembled with overlapped modules (inward/outward-facing) on two sides of the corrugated carbon frame.
- module type and location are provided to simulation through a separate spreadsheet.



SVT Geometry in DD4hep

PST: implemented by Provakar Datta (LBNL)



❑ Yet to be implemented.

Services and cables:

approximated by layers of aluminum along the projective cone and PST

Sensor Structure

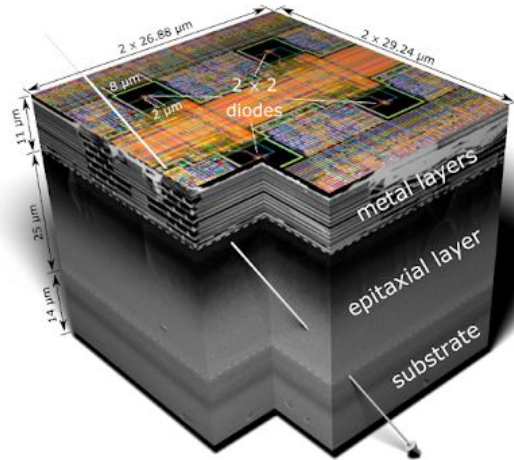
Previously in DD4hep: 1 layer of 40um of sensitive Si



Match sensor response between stand-alone **Geant4** and **TCAD+Allpix2** simulation, and validate against beam test data

- Months of effort led by Zhenyu Ye and Yu Hu (LBNL) [[link](#)]
- Tune effective thickness in Geant4 to match the **interaction probability** for incident particles from both directions:
2.5um Cu (metal layer) + 14um active Si (epitaxial) + 36um inactive Si (substrate)
- DD4hep / Geant4 benchmarked

Sensor Design:

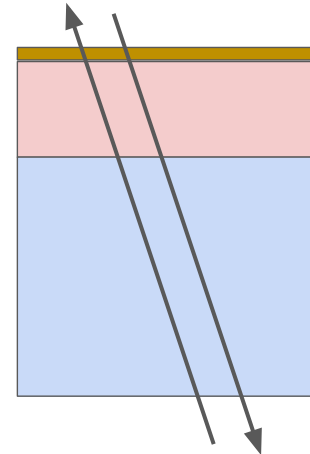


Updated sensor structure in Simulation

Cu ~ 2.5 um

Epitaxial (Si)
~ 14 um

Substrate (Si)
~ 36 um

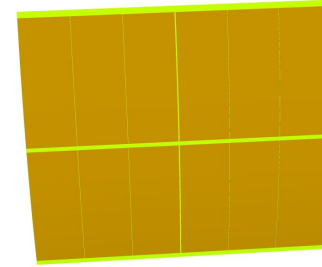


Sensor Structure

Updated in 26.08 [\[PR\]](#):

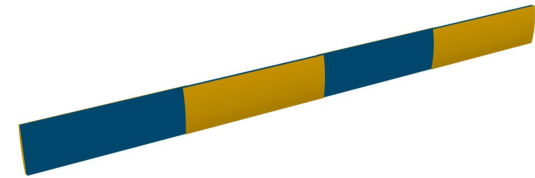
IB: Each **RSU** contains

- One Cu layer always facing outward (larger R)
- One Si layer with 12 active tiles + insensitive areas (shown on the right)
- One Inactive Si layer



OB: each **module** (representing 5 or 6 RSU) contains:

- a Cu layer always facing the external side i.e. away from the support stave, followed by active and inactive Si layers.



Work in progress:

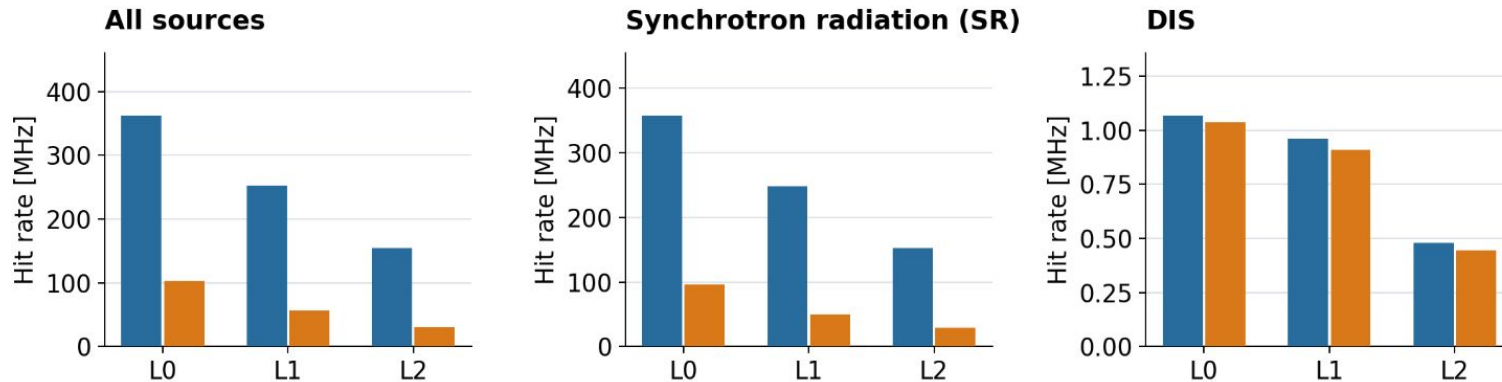
Disks: add RSU structure and sensor layer description

Sensor Structure

Impact on hit rate (example with IB, no noise):

- SR (low energy photons) are sensitive to material thickness.
- Observed a factor of >3 reduction in **total rate per layer** driven by the reduced SR rate as expected.
- **TODO**: re-evaluate the **data rate** estimation after OB and disks geometry updates.
- **ePIC 26.04**: 40um-thick active silicon. used in the recent data rate estimation [\[link\]](#)
- **ePIC 26.08**: updated three-layer (Cu/Si/Si) structure.
- **event sample**: forced DIS ($Q^2 > 1$) +all background, 10x275. 1 event = 2us, rates are averaged over 1.9k and 9.9k event samples.

■ ePIC 26.04 · 1,900 events ■ ePIC 26.08 · 9,900 events



Clustering

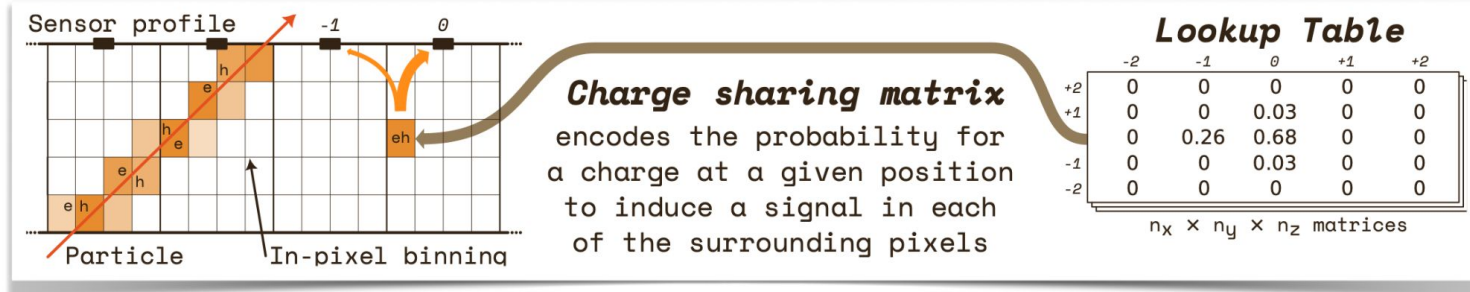
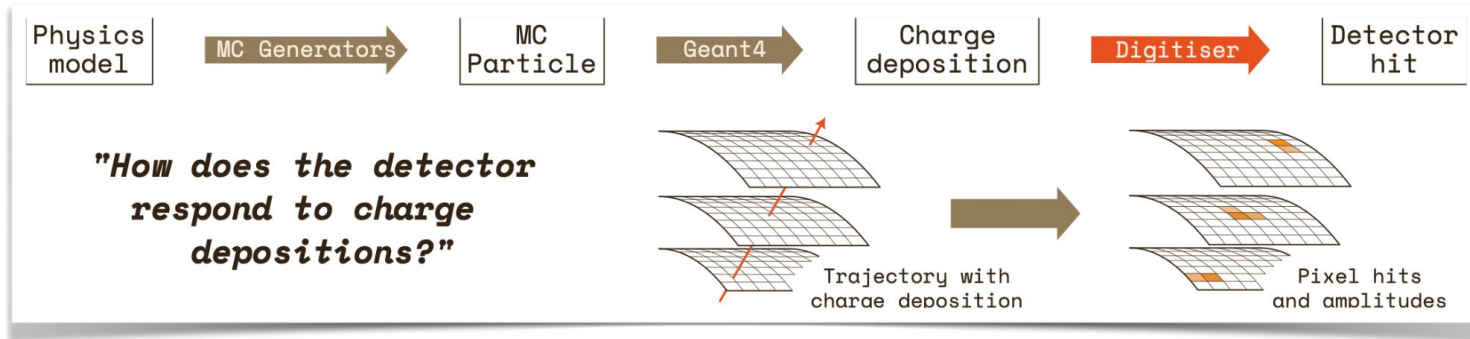
DD4hep simulation:

- No explicit clustering mechanism. 1 hit $\rightarrow$ 1 fired pixel
- **diffusion/charge-sharing** is not modeled in dd4hep but expect to be relatively small
- **Geometry** effect is missing because npsim is configured to record only one hit (weighted sum) per sensitive surface per particle. Recording intermediate steps is computationally expensive.

Clustering

In EICrecon:

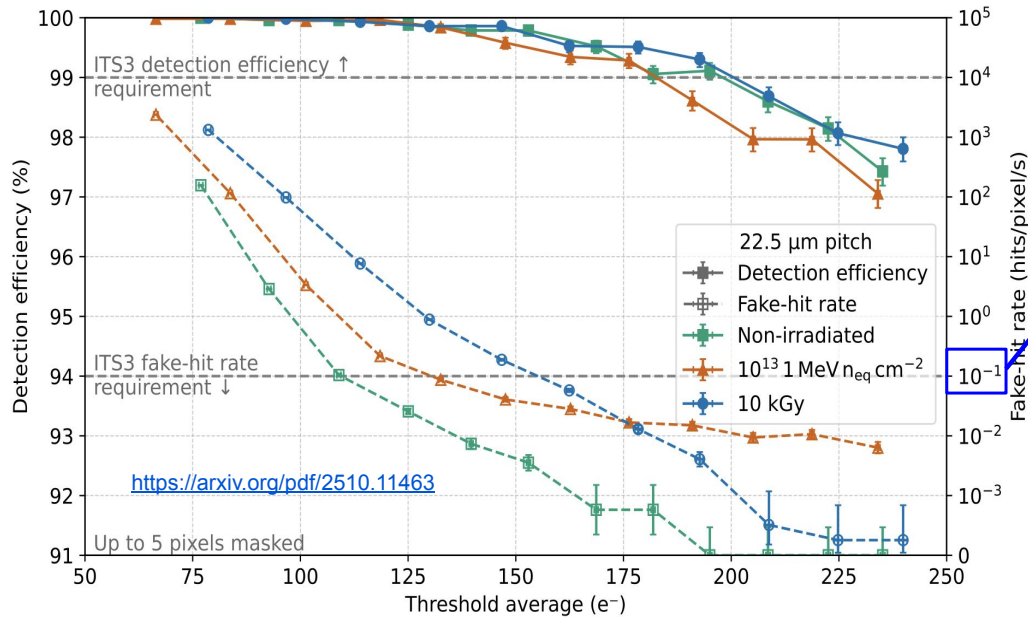
- **Now:** no clustering algorithm. Assume **1 hit = 3 pixels** (upper limit from ITS3) in data rate estimation.
- **TODO:** TCAD+Allpix2 lookup table for clustering (see [example](#) from OCTOPUS below) in EICrecon, followed by a proper clustering algorithm to form the measurement for tracking.



Sensor Noise

Fake hit rate:

Implemented by Joshua Sobajic (UCB), Beatrice Liang-Gilman (UCB), Minjung Kim (UCB), Barak Schmookler (Houston), SL. See [\[link\]](#)



Use the ITS3 upper limit of 0.1/second:

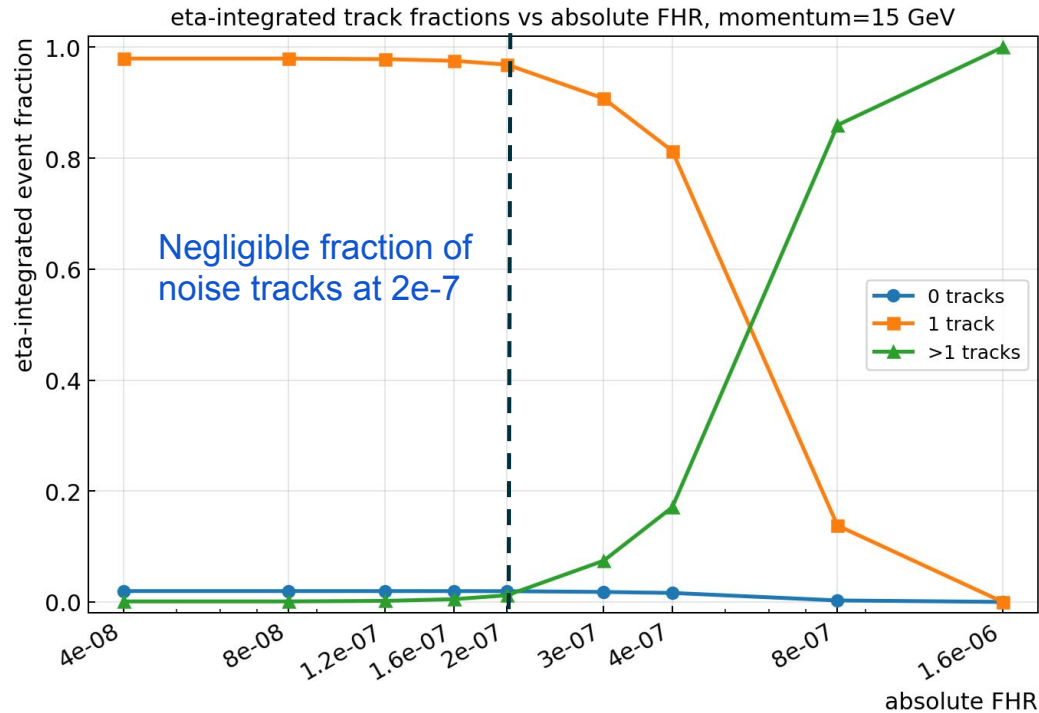
- $2e-7 \text{ hit/pixel/2us} \Rightarrow 0.08\text{MHz / RSU}$
- Assume randomly distributed on all RSU surfaces

(a) Pixel matrix with pitch 22.5 μm irradiated to different levels.

Pixel Noise Injection

Fake hit → noise track:

- single particle event: 1 event = 1 track
- single particle + noise scan: check when the noise hit will introduce ambiguity in tracking



Beam background + Noise Impact

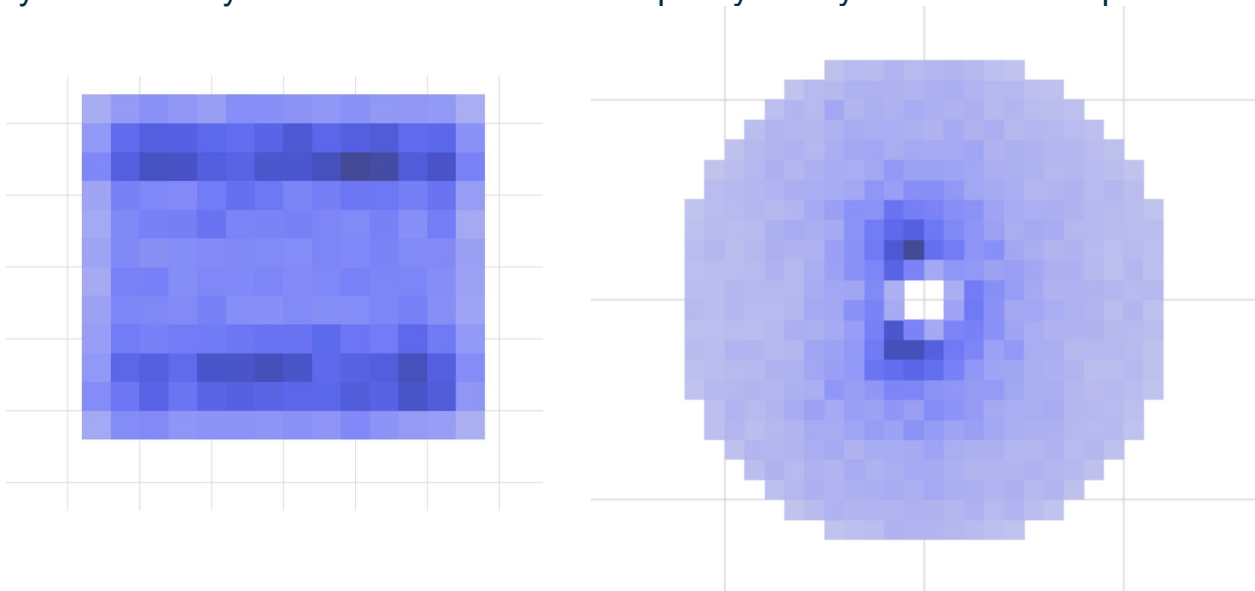
Noise hit: uniform distribution, proportional to SVT surface area ($<0.08\text{MHz/RSU}$)

Beam background: strong geometry dependence and source dependence

Their impact on [track reconstruction](#) varies on each surface, e.g. at larger R: noise hit density unchanged, background hit density drops sharply. See recent [TIC](#) update

Hit distribution example: DIS+background hits on L0 (left) and ED0 (right). 1 bin = $2\text{cm} \times 2\text{cm}$ square (roughly size of one RSU). See more at [\[link\]](#)

TODO: extract hit rate from the actual sensitive module structure instead of geometry binning. Study the frame-by-frame fluctuation and occupancy. Study the radiation exposure.



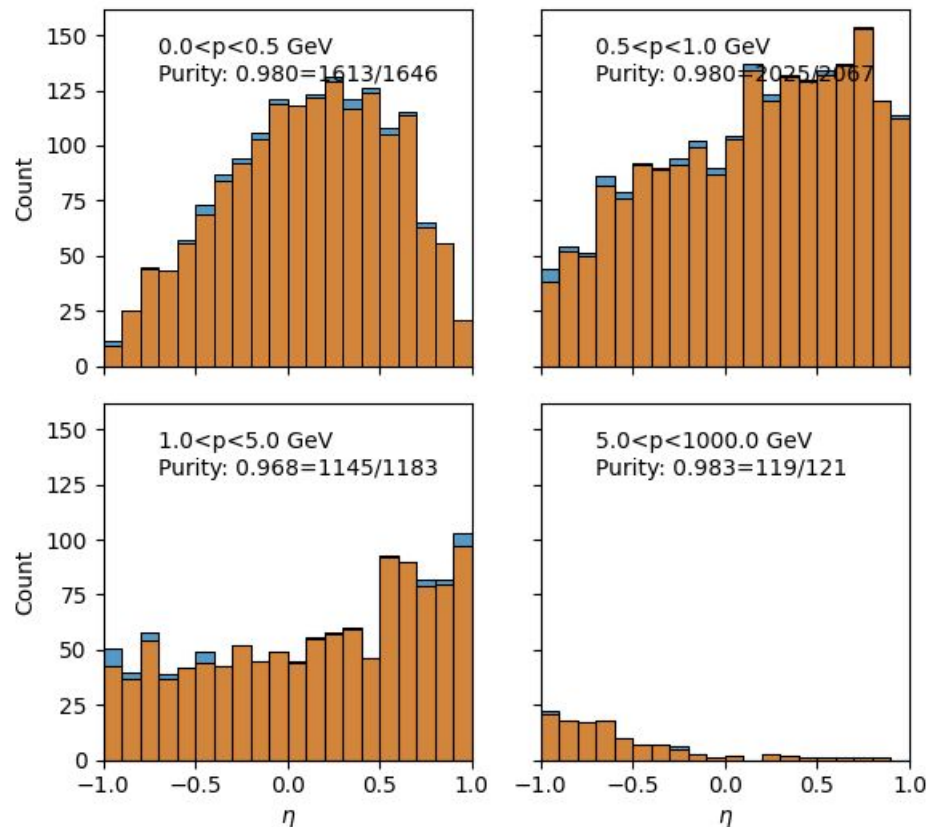
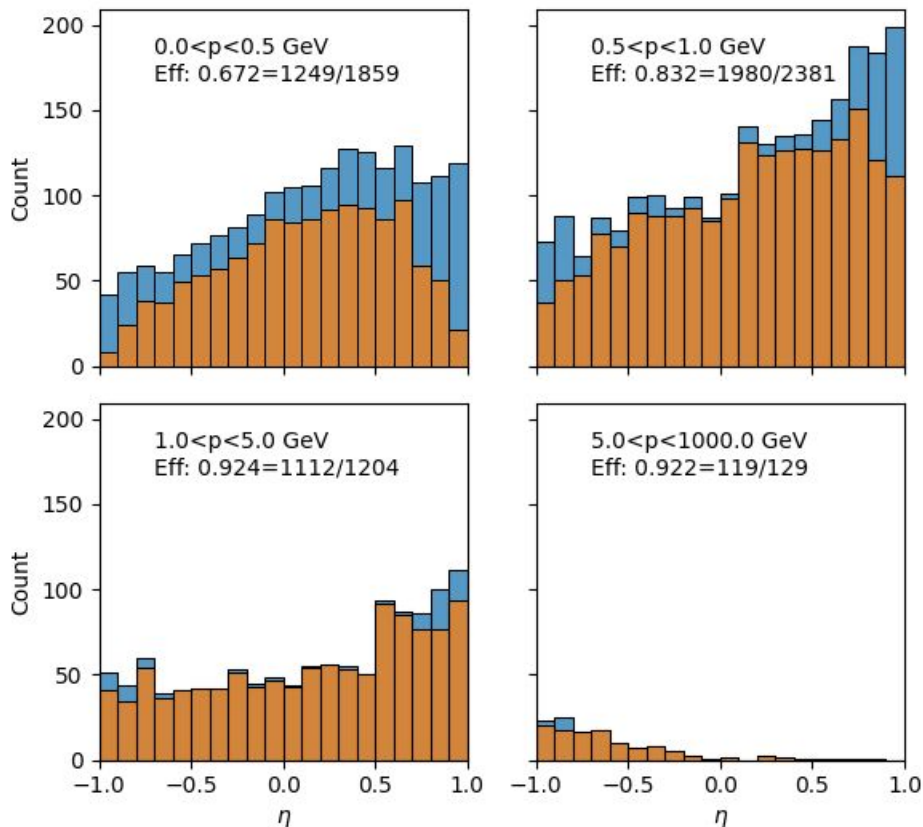
Beam background + Noise Impact

- Barrel region ($-1 < \eta < 1$), DIS+background, no noise

Efficiency (4 hits) | 10x275, epic | total=0.800 (4460/5573)

blue: generated; orange: reconstructed

Purity (4 hits) | 10x275, epic | total=0.977 (4902/5017)



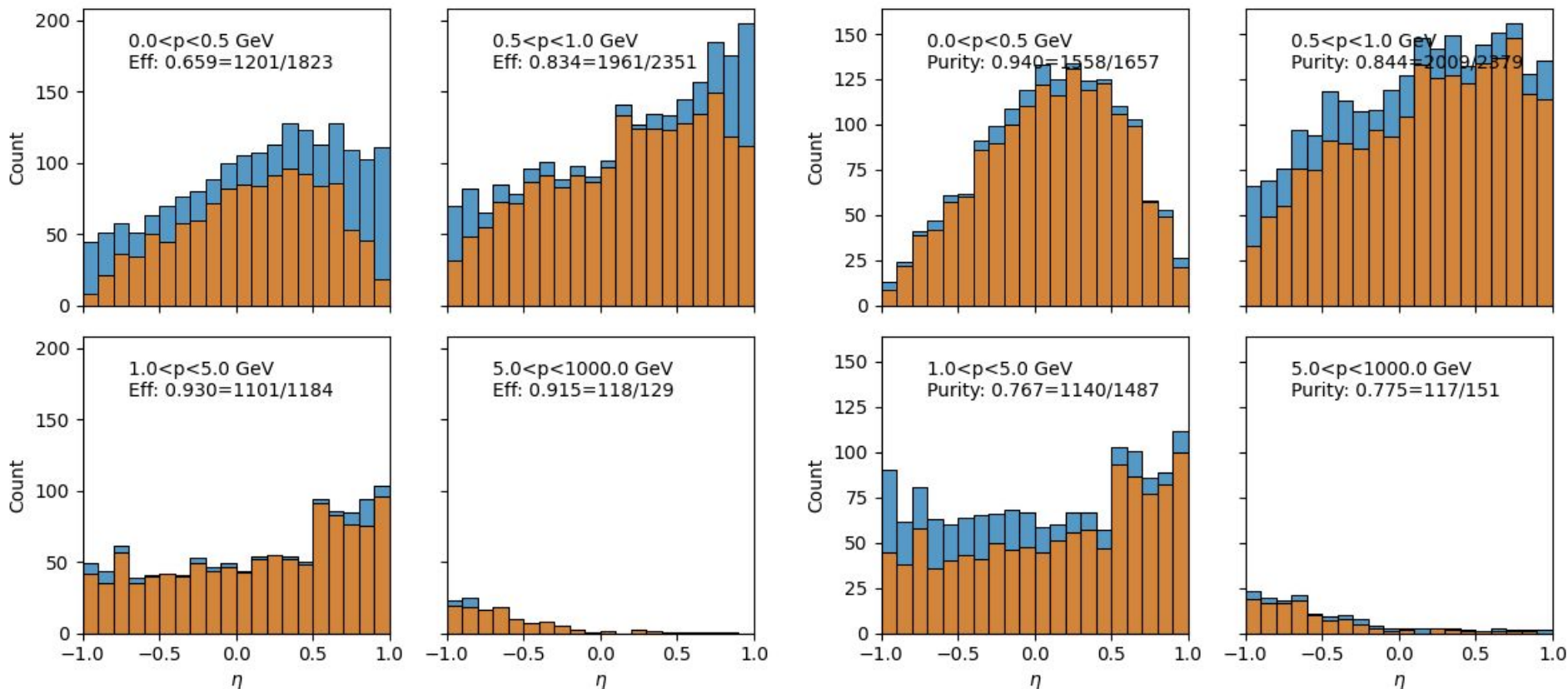
Beam background + Noise Impact

- Barrel region ($-1 < \eta < 1$), DIS+background + noise:
comparable efficiency ($0.8 \rightarrow 0.798$), lower purity ($0.977 \rightarrow 0.85$)

Efficiency (4 hits) | 10x275, epic_noise | total=0.798 (4381/5487)

Purity (4 hits) | 10x275, epic_noise | total=0.850 (4824/5674)

blue: generated; orange: reconstructed



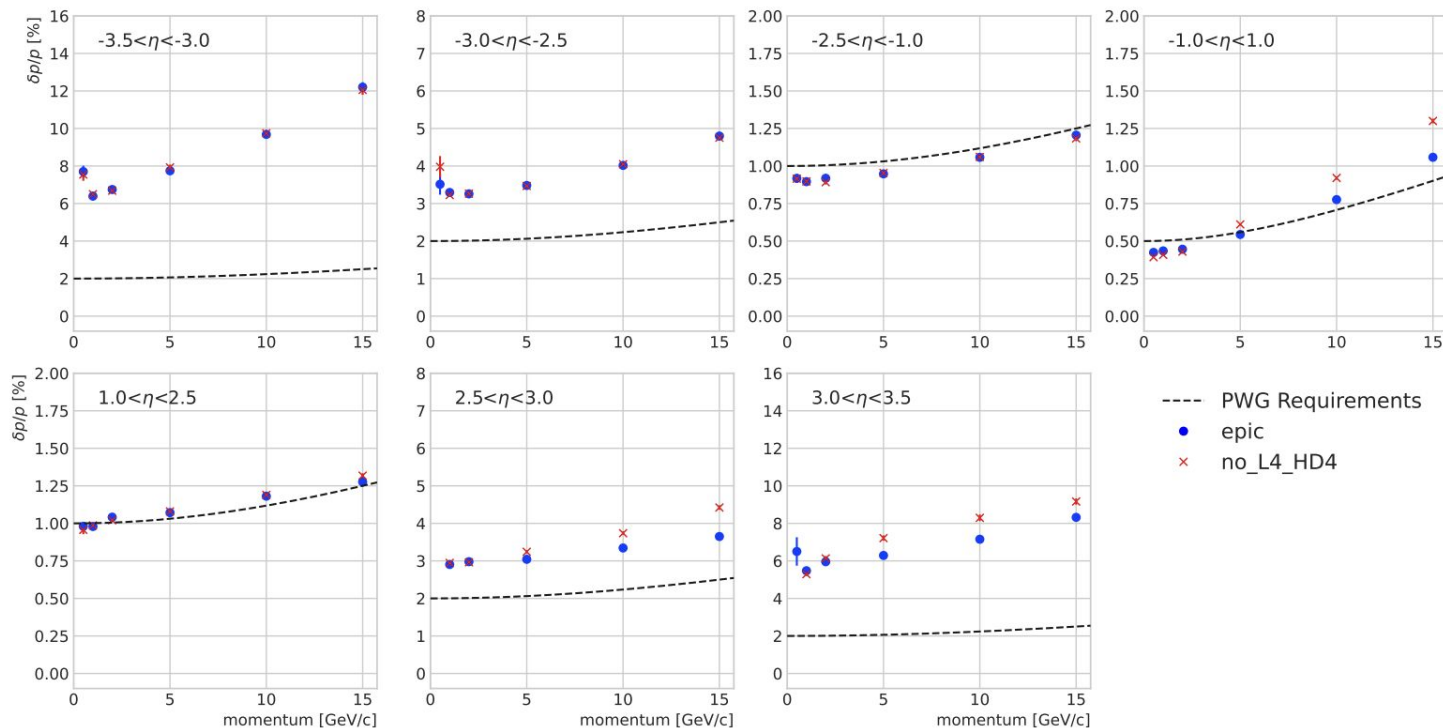
L4 and HD4 Impact

ePIC general meeting talk by Ernst [link](#)
tracking meeting talk by SL [link](#)

more plots available at [\[folder\]](#)

Single pion track resolution with vs. without L4 / HD4:

- **momentum (dp/p) resolution:**
 - **-1<eta<1 (L4):** up to 25% worse at high momentum
 - **eta > 2.5 (HD4):** up to 20% worse at high momentum
- **angular resolution and DCAr:**
 - L4: unchanged, HD4: <10% change



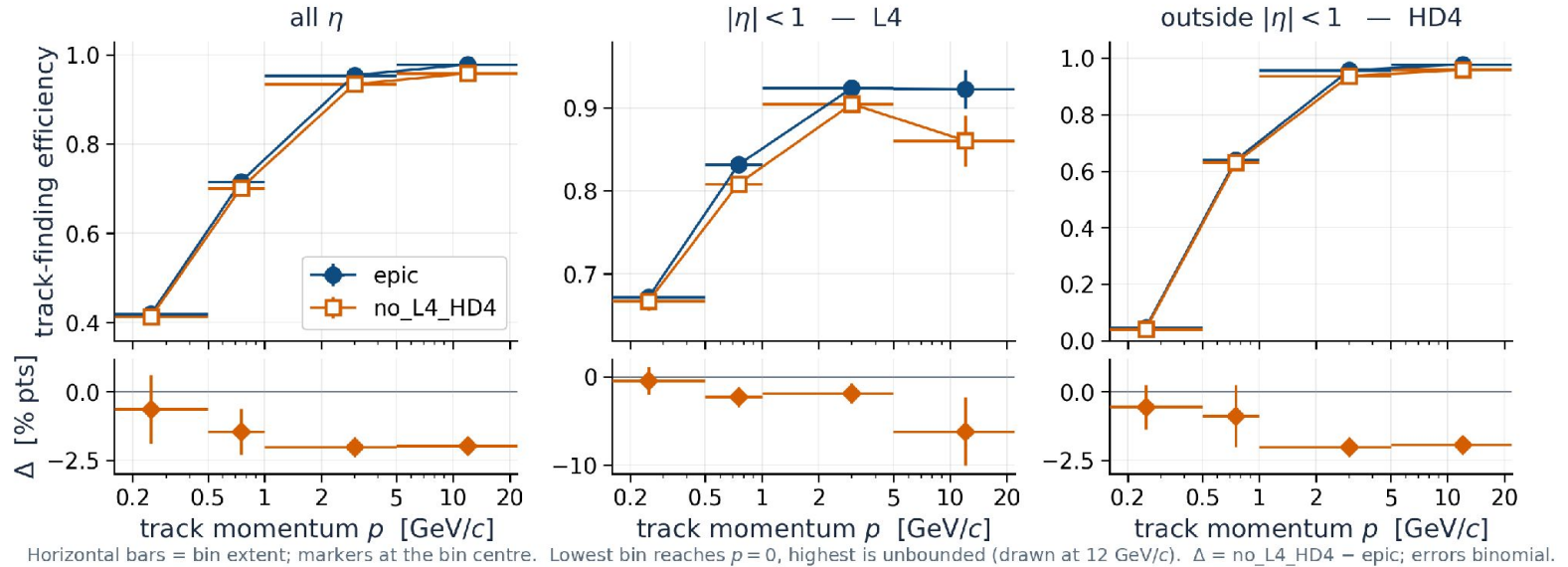
L4 and HD4 Impact

DIS+background with vs. without L4 / HD4:

Simulated efficiency summary by eta region

Courtesy of Ernst

Track-finding efficiency, full simulation — 10×275, forced DIS + background, no noise



Same full simulation. Left: all η . Centre: $|\eta| < 1$, the L4 acceptance. Right: outside $|\eta| < 1$, which contains HD4.

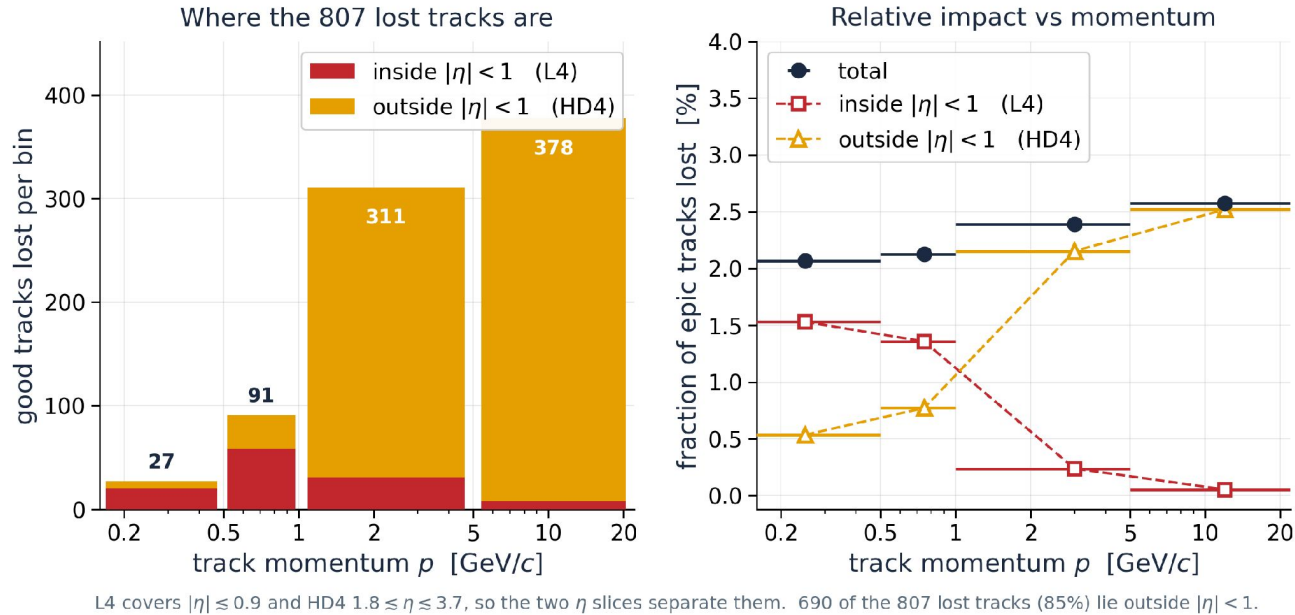
L4 and HD4 Impact

DIS+background with vs. without L4 / HD4:

Simulated track losses – acceptance

Courtesy of Ernst

Decomposition of the efficiency loss by acceptance — full simulation, no noise



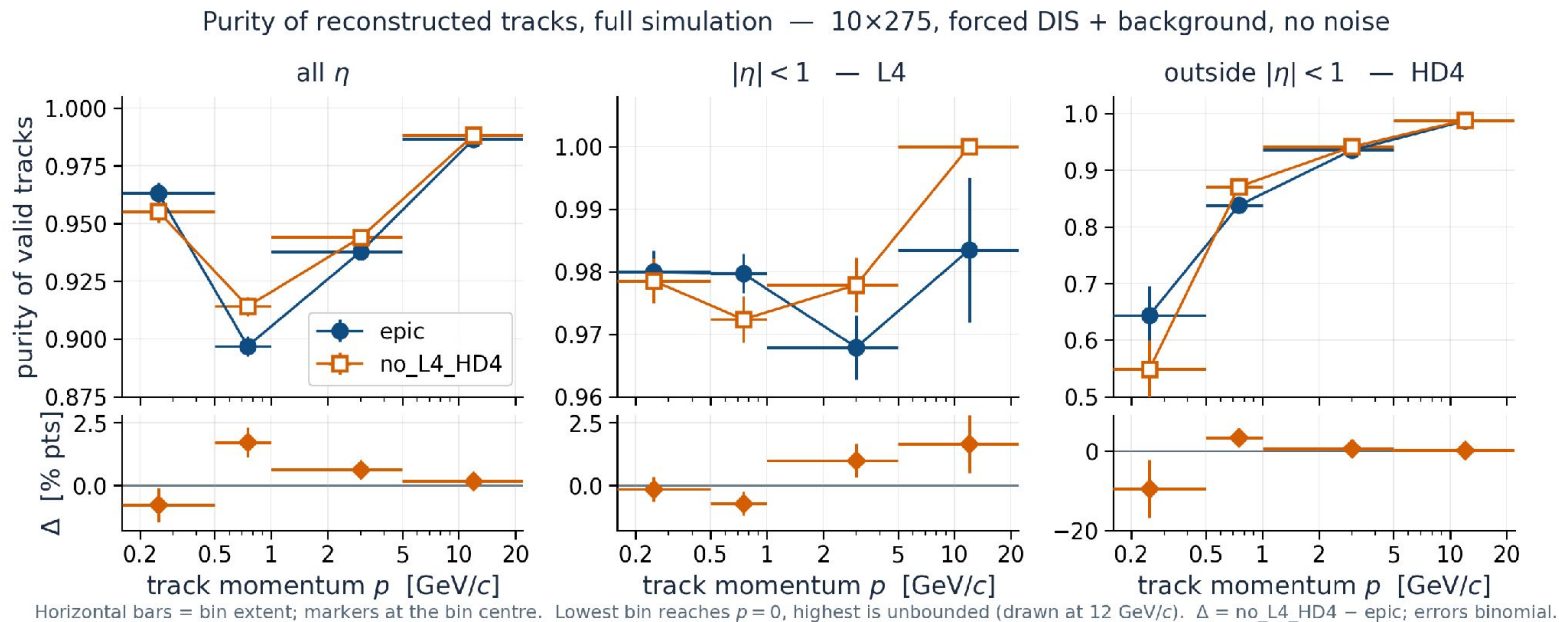
Same full simulation. Loss split by the two disjoint acceptances of slide 4. Counts include both acceptance and reconstruction effects.

L4 and HD4 Impact

DIS+background with vs. without L4 / HD4:

Simulated purity of reconstructed tracks by eta region

Courtesy of Ernst



Purity is unchanged within the sensitivity of this study. Pure tracks are still found with the deferred or descoped SVT configurations in current simulations including backgrounds.

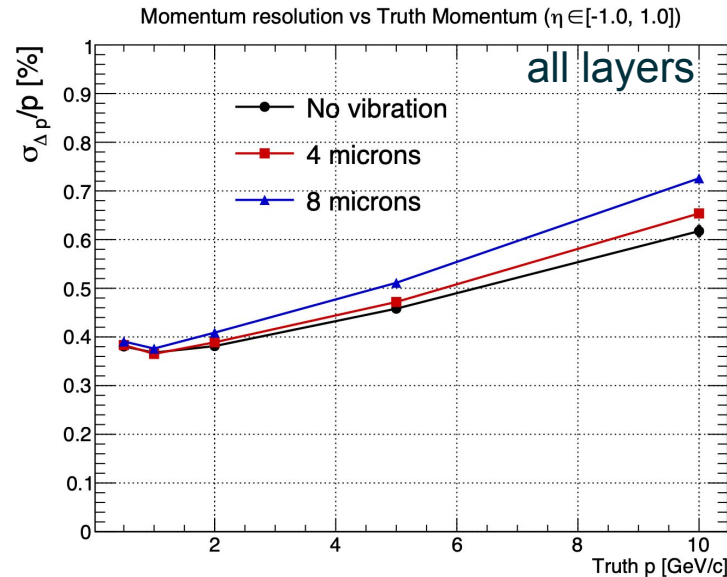
Mechanical Stability (Vibration) Impact

Work by Vassu Doomra (UCB)

- introduce event-by-event in-plane offset of hits on given SVT layer(s).
- inflate the hit resolution accordingly
- Compare single track performance with various levels of vibration amplitude (e.g. 0 vs 4um vs 8um).

TODO:

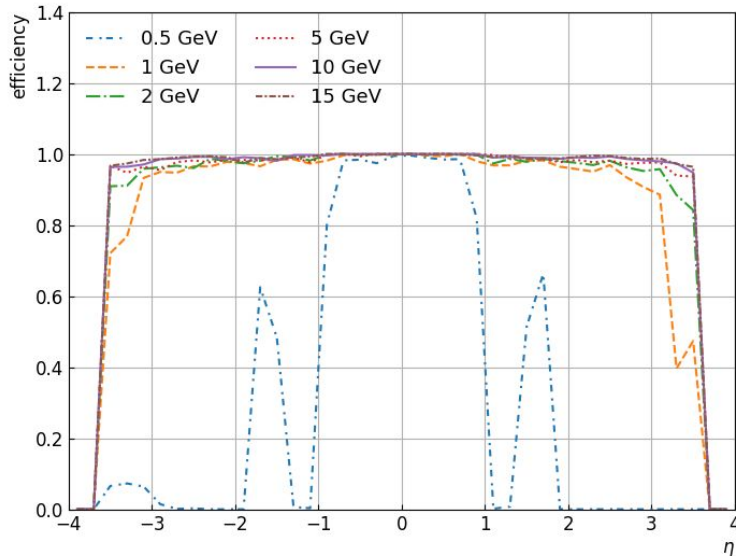
- Out of plane vibration,
- angular resolutions and DCA
- full eta coverage with fine bin size to capture the geometry change.



Software Development

Seed (triplet) finder:

- Known low tracking efficiency at low momentum caused by **low seeding efficiency**, see Barak's [talk](#)



- Work in progress** by Barak, Jeetendra Gupta (UIC), and Wouter Deconinck (U. Manitoba)
- incorporate new seeding framework from ACTS
 - tune seeding parameters to allow seeds with large curvature
 - implement algorithm and parameters by region for more geometry-aware seed finding

Software Development

Use time info in tracking:

Implementation as an option by Wouter Deconinck

- include time in chi2 calculation for Combinatorial Kalman Filter [\[link\]](#)
- update time resolution for tracker hits [\[link\]](#)
 - in the current event-based simulation, 1 event=2us which is set by the SVT integration window. The SVT hits, particle induced or noise, should not provide any additional time constraint within the window⇒ **place sv hits at the center of time window, with 2us/sqrt(12) resolution?** [\[open PR\]](#)

TODO: determine the appropriate timestamp/covariance representation in ACTS; then study timing from MPGD/AC-LGAD for background rejection.

Longer term: how to handle this with **stream readout**?

Second vertexing:

work by Shyam Kumar (Houston), Xin Dong (LNBL), Rongrong Ma (BNL), Bishoy (Stonybrook)

- helix swing method ready
- developing algorithm and [data model](#) for adaptive multi-vertex finder

Software Development

(Mis)alignment

TODO: implement the infrastructure to displace sensors/modules in simulation, and align them in tracking.

- existing ACTS+Millipede2 framework, and local expertise from sPHENIX (Gregory Ottino)
- need inputs on:
 - what is the smallest sensor unit in misalignment?
 - what degrees of freedom, and magnitude to consider?
 - for SVT design, what needs to be validated/demonstrated with simulation?

Longer term: synergy with lab measurements and beamtest. Develop realtime and time-dependent alignment that fits ePIC's trigger design in **stream readout**

Dead channels/inactive regions and sensor acceptance

ongoing work by SL:

- prepare a combination of inactive sensor samples $O(100)$ node hours per set of simulation
- create a SVT layer $\rightarrow$ module $\rightarrow$ RSU $\rightarrow$ tile $\rightarrow$ global position database
- associate track with given sensor
- evaluate tracking performance with certain fraction of dead channels on IB (work in progress), OB and disks (after geometry update)

Computing Resource

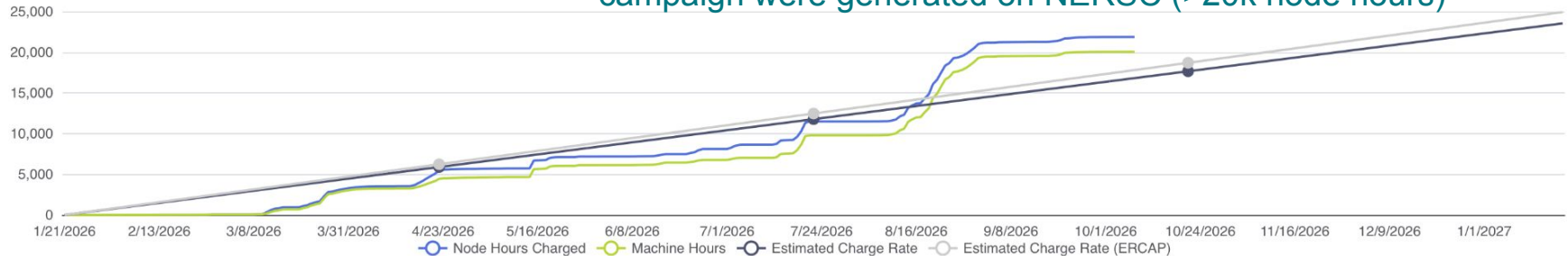
- All local tracking simulation, and a large fraction of ePIC simulation campaign, is supported through the **NERSC ERCAP project** (PI: Irakli Chakaberia (LBNL))
- Growing SVT simulation needs:
 - more realistic event sample and detector description
 - large number of SVT configurations are needed for impact studies e.g. dead channel, vibration...
 - GPU and AI/ML: sensor response study with TCAD+Allpix2, ML-enhanced tracking...

Current Allocation: 23,609 node hrs
Node Hours Charged: 21,883 node hrs
Available Hours: 1,725 node hrs
Remaining %:  7.3%

Machine Hours Used: 20,055 node hrs
Raw Hours Used: 20,055 node hrs
Average Charge Factor: 1.1

ERCAP Request: 25,000 node hrs
ERCAP Award: 25,000 node hrs
Premium Threshold Reached? No
Premium Hours Used? 3,798 node hrs
16.09% of allocation

Over the past six months, 50% of ePIC simulation campaign were generated on NERSC (>20k node hours)



Outlook

Near-term priorities (contributions are welcome)

- complete OB + disk geometry / sensor structure;
- clustering lookup + reconstruction;
- missing layer / misalignment / vibration / dead-sensor impact studies;
- validate timing configuration.

Meanwhile, several identified software developments will help realize the detector's full potential and provide more reliable feedback to the current SVT design

The SVT NIM paper will be updated to reflect this progress.

Please reach out if you think certain task needs to be prioritized, or additional studies are needed to support upcoming reviews.

Thank you!