LUXE · FCAL · DRD Calo · AITANA · IFIC, CSIC-UV

Progress on LUXE ECAL analysis

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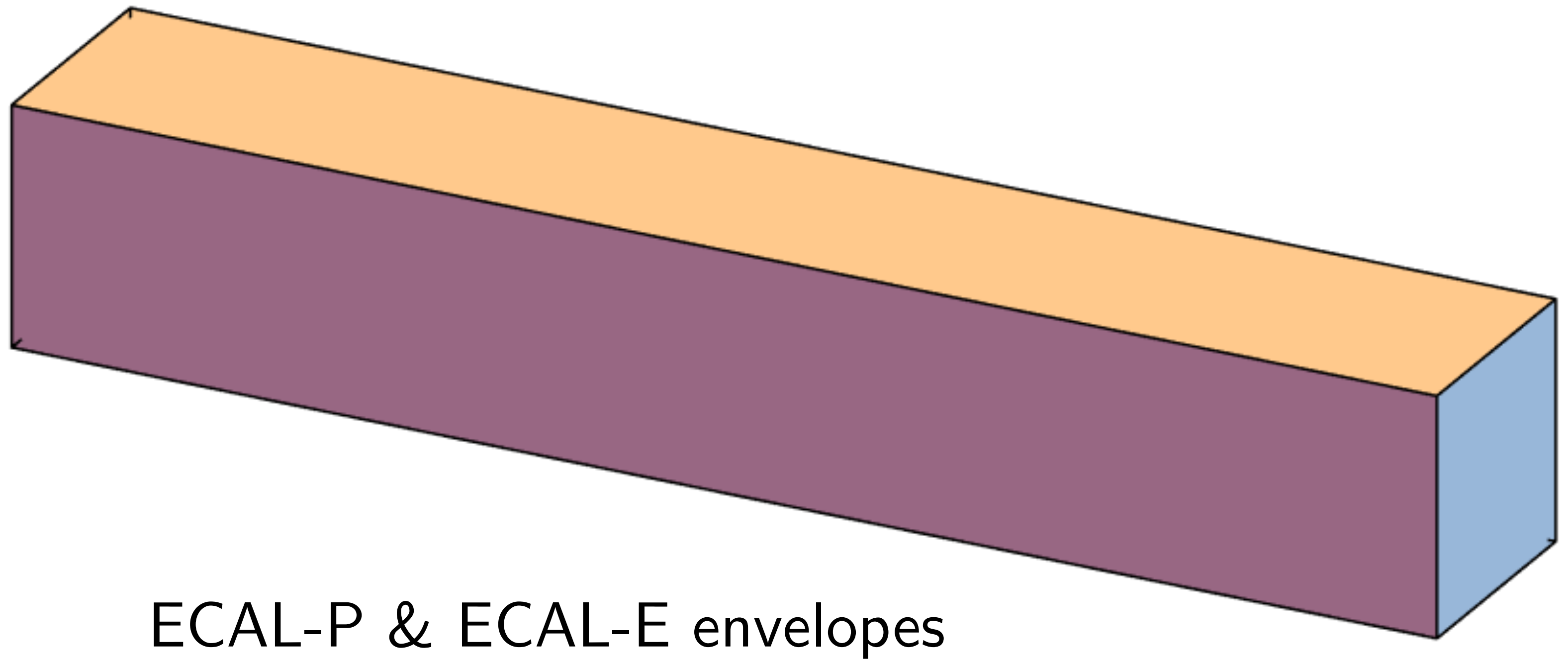
2026-01-26

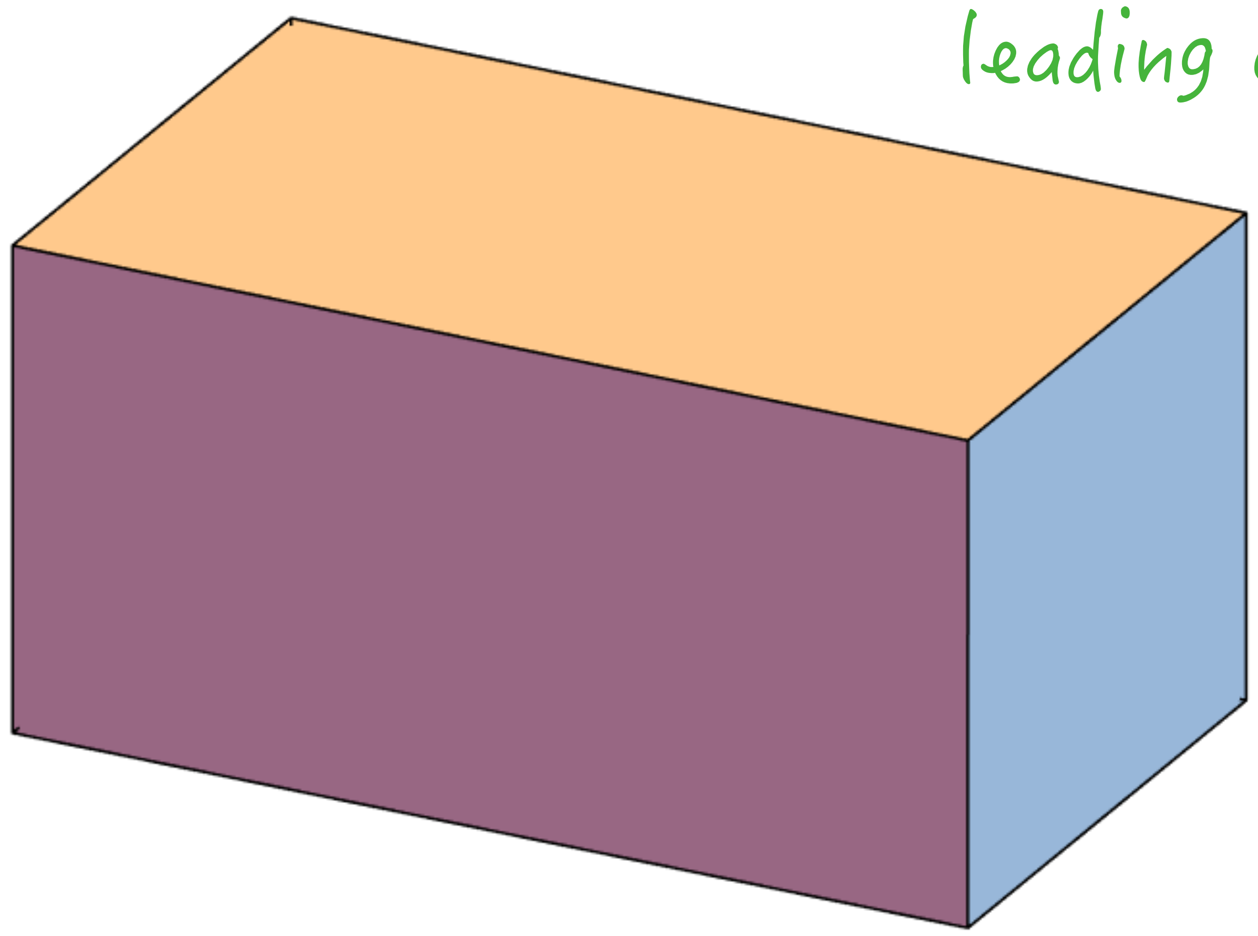
LUXE ECALs



ECAL-P & ECAL-E envelopes

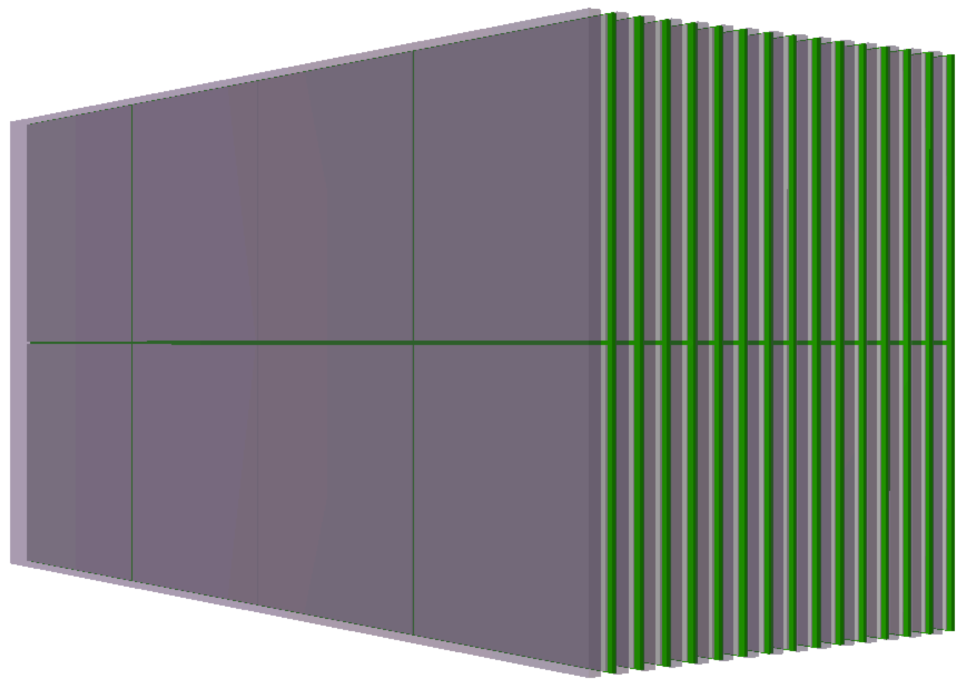
ECAL-E => ECAL-NPOD

leading candidate!



- ECAL-P:
  - 540 x 90 x 90 mm^3
  - 96 x 16 x 20
- ECAL-E:
  - 360 x 180 x 225 mm^3
  - 64 x 32 x 15

- Sandwich sampling calorimeters
- CALICE prototype in beam test campaigns
- Thicker tungsten
- Thicker silicon



ECAL-P group (FCAL-LUXE)

AGH

UNIVERSITY OF WARSAW

TEL AVIV UNIVERSITY

DESY.

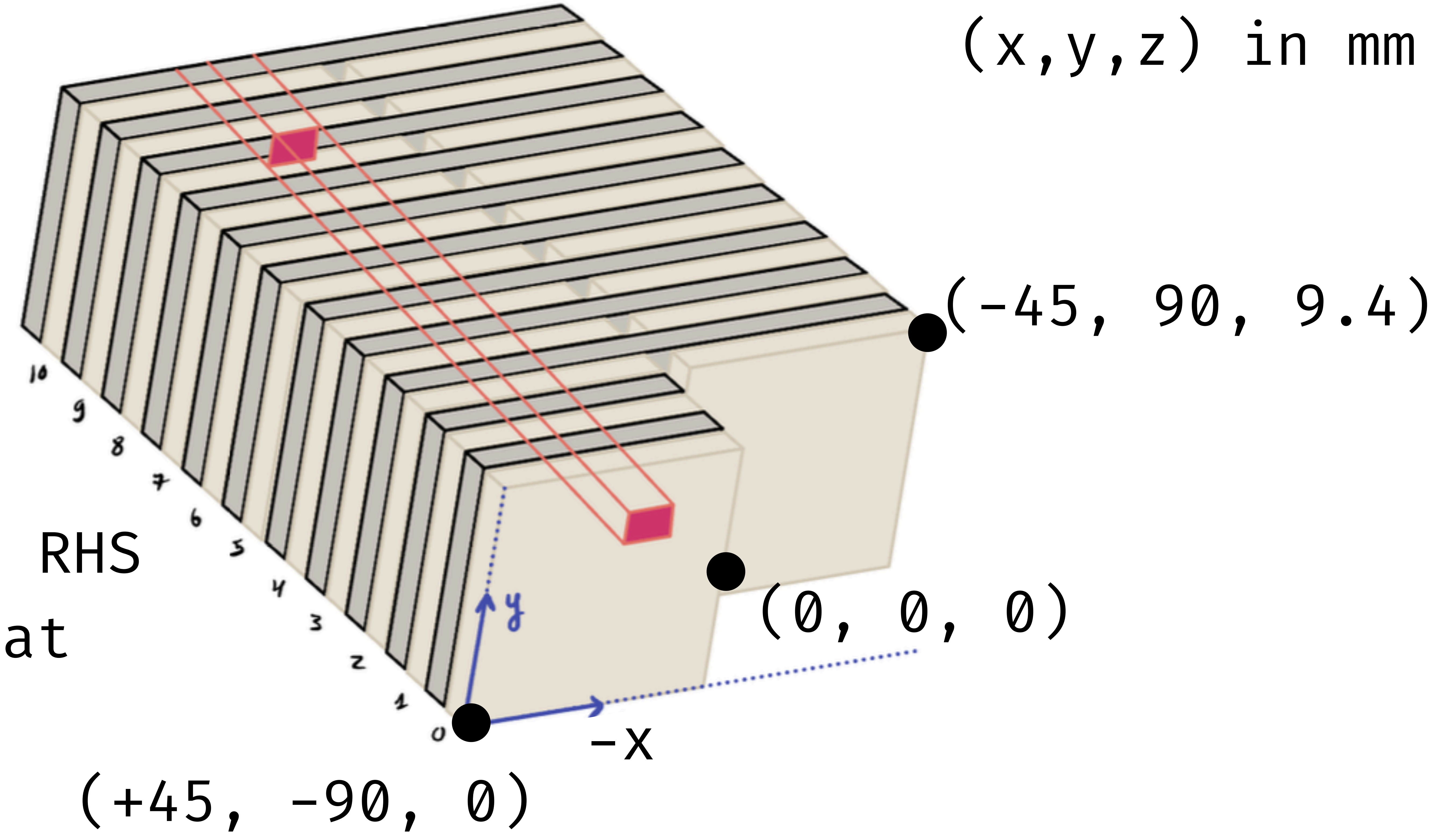
INSTITUTE OF SPACE SCIENCE INFLPR SUBSIDIARY

IFIC

ALL RESULTS ARE PRELIMINARY!

<u>Coordinate system in mm</u>

(x,y,z) in mm

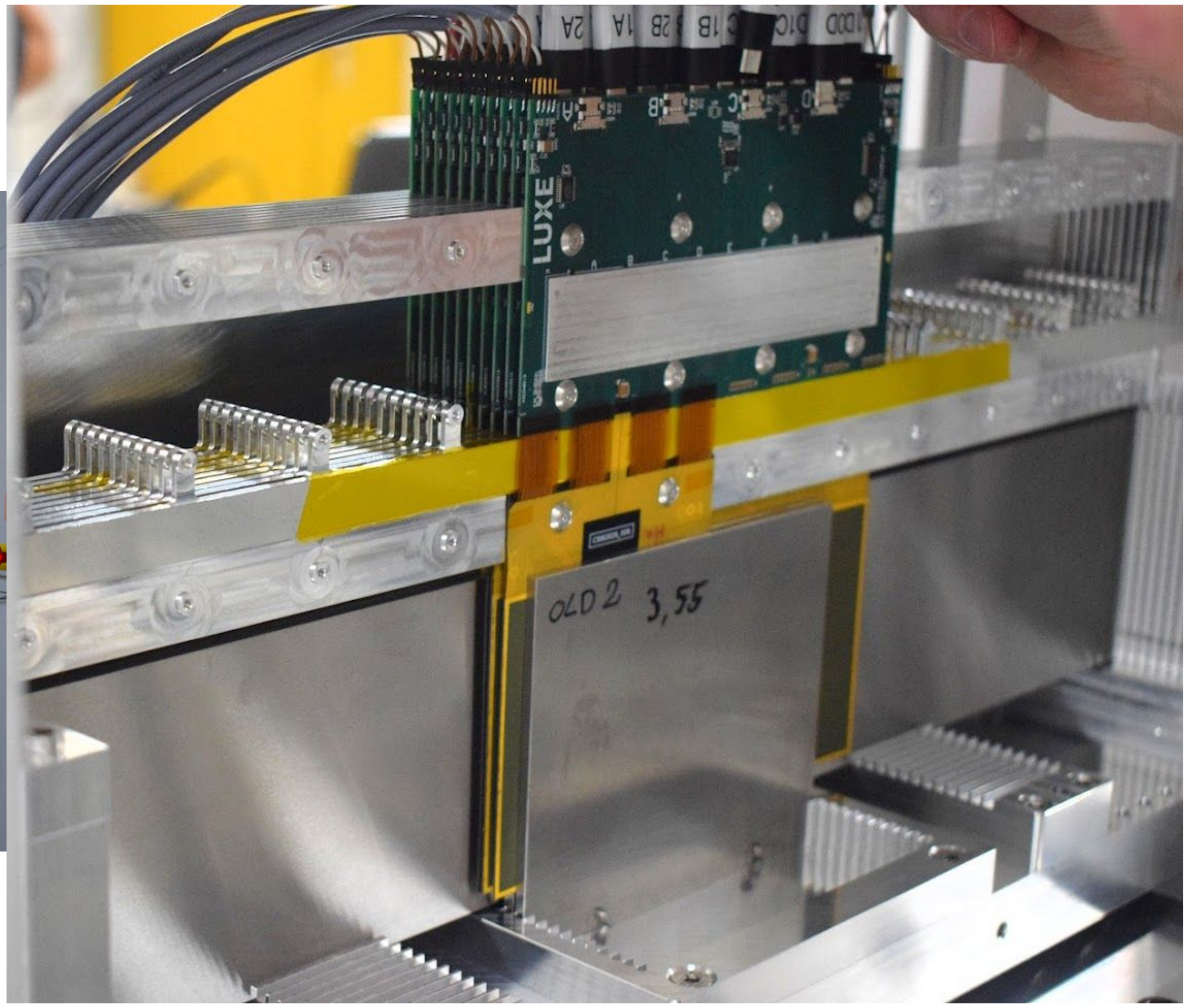


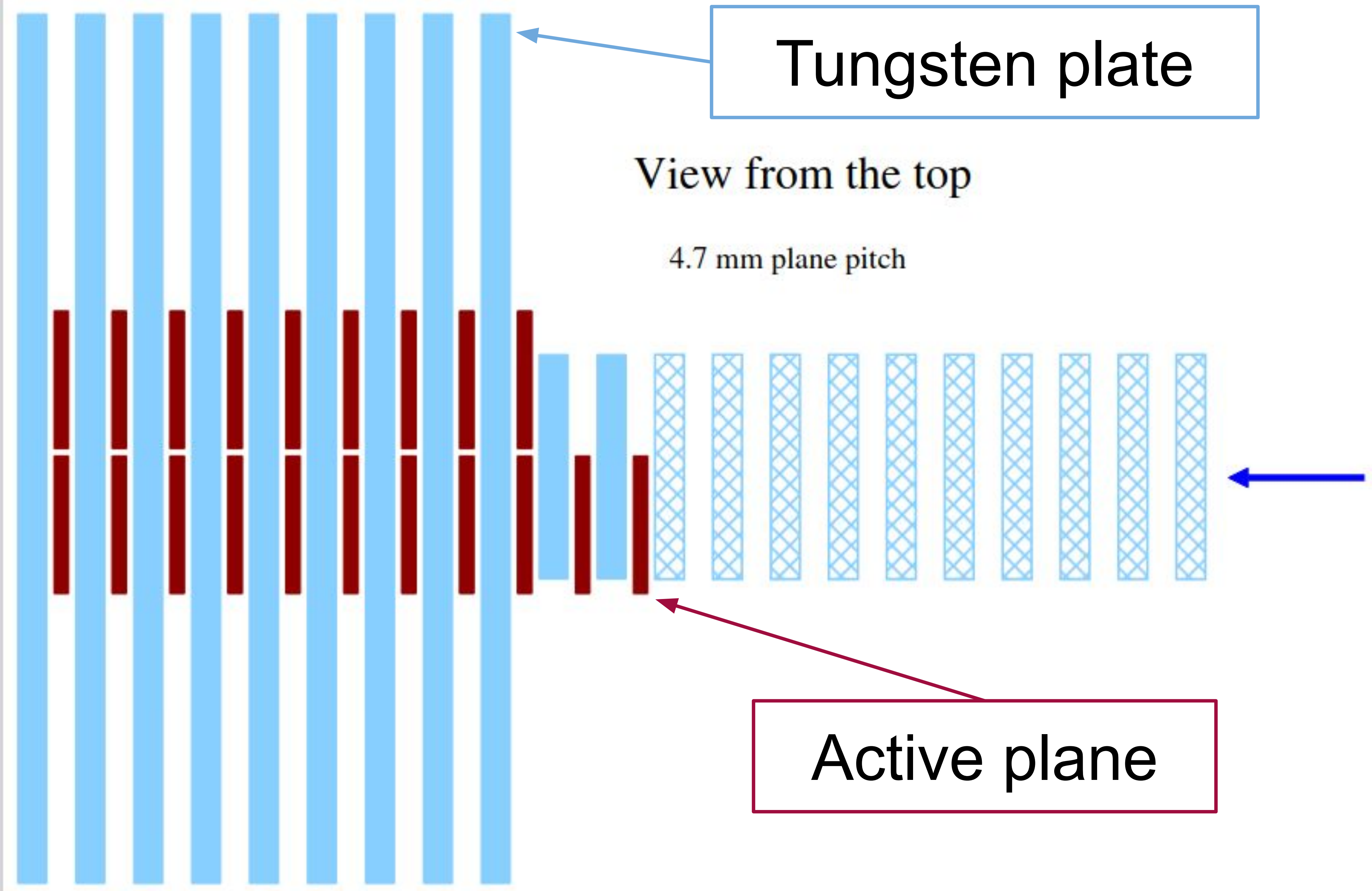
- Revert x-axis to keep RHS
- Keep z = 0 plane afloat

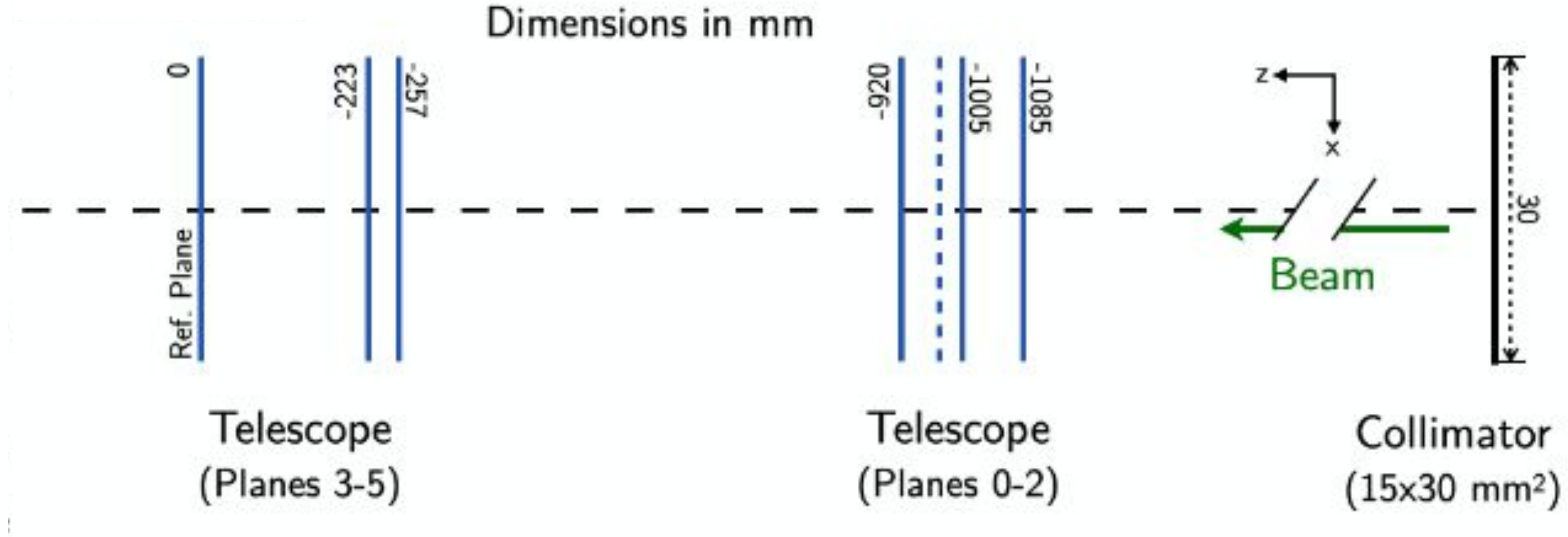
(3D model by Nofar)

Testbeam 2025 at DESY

- 270M Events in total with energies from 1 to 5.6 GeV
  - Tracker mode (no absorber)
  - 9 X_0
  - 11 X_0
    - XY Scan
    - -15 to 15 degrees runs
  - Shower tail study runs
    - 15 X_0, 18 X_0, and 21 X_0







TB data readiness

- Telescope
  - First user of the "new ALPIDE" telescope
  - Tracking & alignment with Corryvreckan (tested in 2022)
- Detector
  - Online zero-suppression data (tested in 2022)
  - Offline debug data (tested with 3 methods)
- Telescope-detector alignment
  - Hough transform
  - Unbinned likelihood
  - Alignment inside the detector

Telescope: data error

```
huangsha@glui02:~/flc/LUXE/TB2025/telescope/v1_0
log/Run_1515/stderr_runcorry_1515.log:[2026-01-09 12:45:50.978] (ERROR) [unknown sender]Unknown data package142
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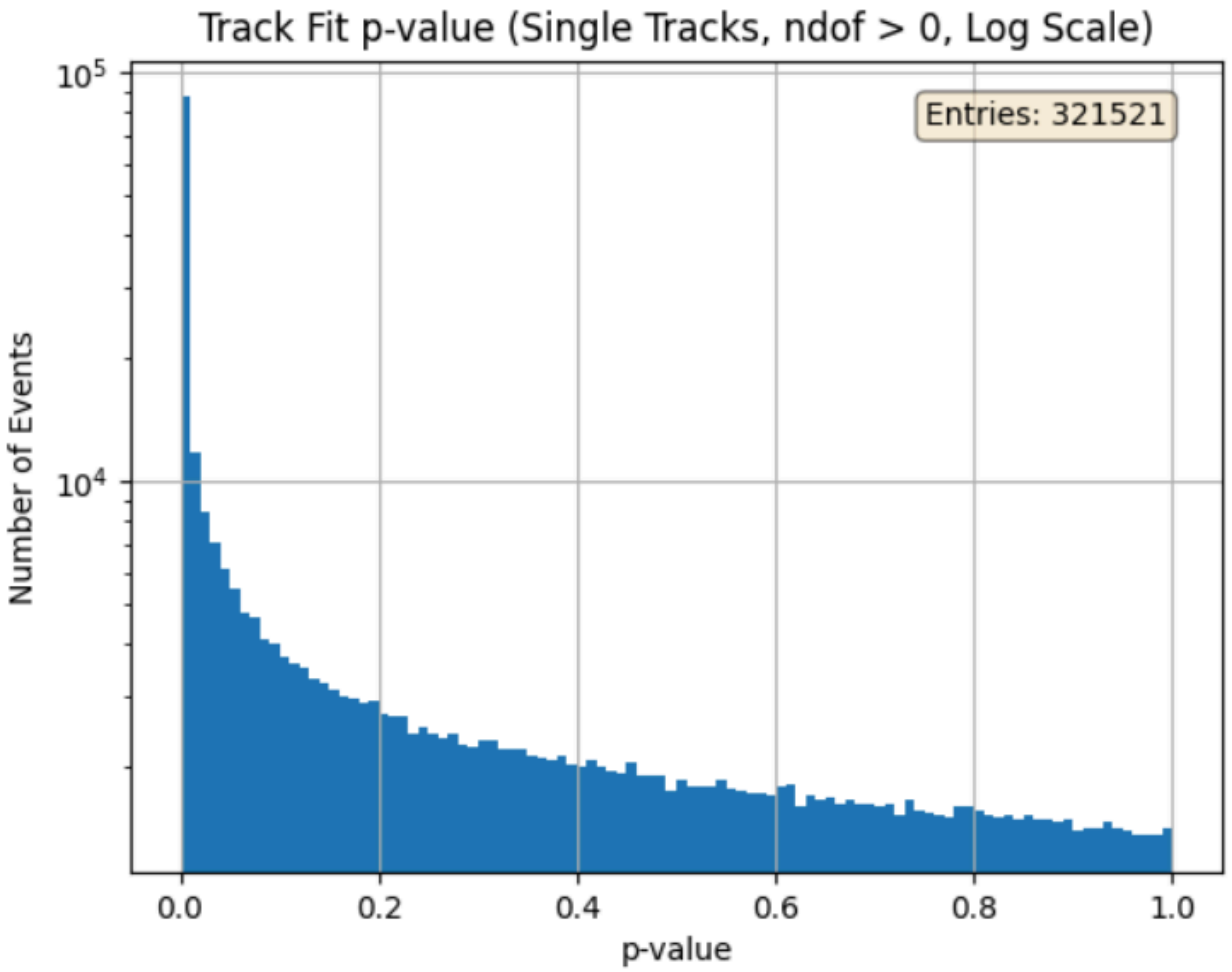
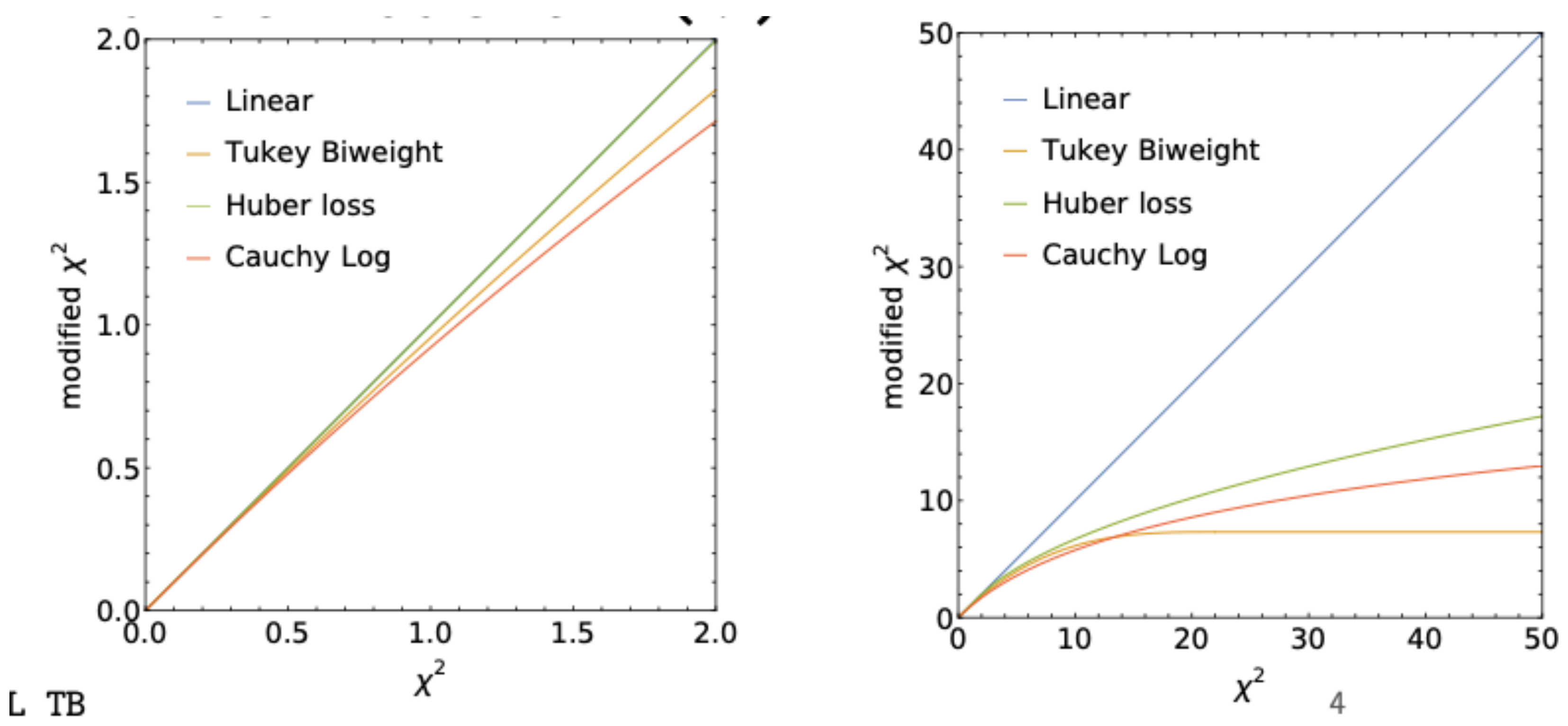
Caribu error (fixed after TB)

Telescope: quality

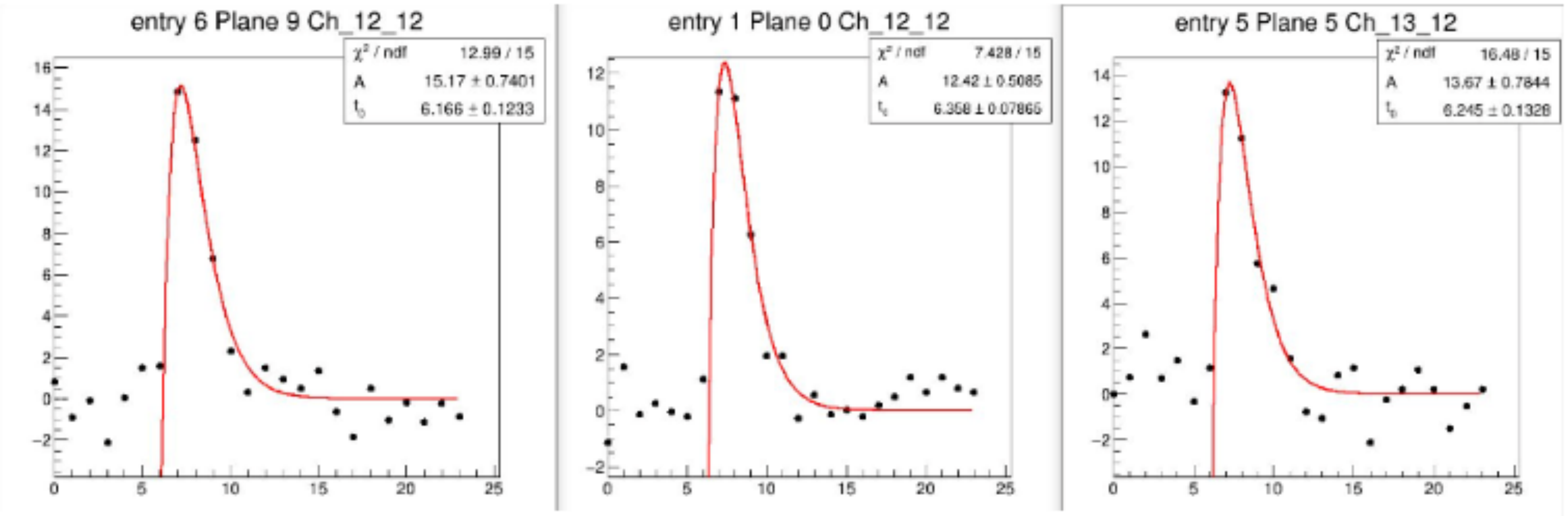


Strange p-value distribution of tracking (related to different statistics)



Detector: amplitude/ToA finding

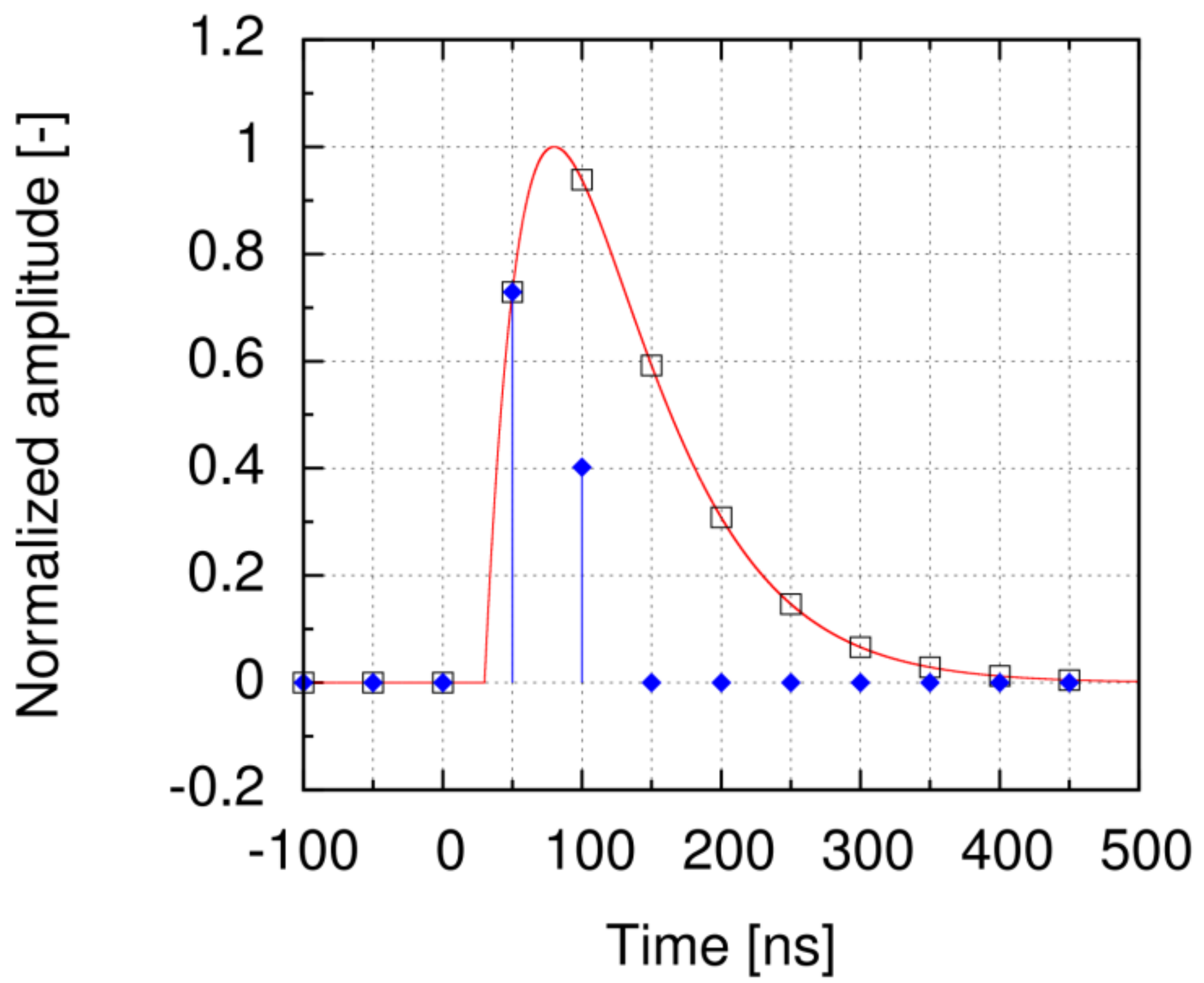
- Offline debug data analysis
  - **Dawid: Deconvolution (used in production)**
  - Melissa: CR-RC curve fitting
  - Arkadiusz's method (WIP)
- All three methods seem to agree



CRRC curve fitting implemented by Melissa

Deconvolution

Without beam clock (e.g. cosmic muons) ADC sampling is asynchronous with FE pulse



FE pulse

$$|\mathrm{V}_{\mathrm{front-end}}(t)| = \frac{\mathrm{q}_{\mathrm{in}}}{\mathrm{C}_{\mathrm{feed}}} \left(\frac{t}{\tau_{\mathrm{sh}}}\right) e^{-\frac{t}{\tau_{\mathrm{sh}}}}$$

- □ ADC samples
- ◆ Digital filter (FIR) samples d_i

$$d_i = v_i - 2e^{-\frac{T_{smp}}{\tau_{\mathrm{sh}}}} v_{i-1} + e^{-\frac{2T_{smp}}{\tau_{\mathrm{sh}}}} v_{i-2}$$

Amplitude A and time of arrival (TOA) t_0 reconstructed as, respectively, weighted sum and ratio of two non-zero d_i samples, output from FIR digital filter

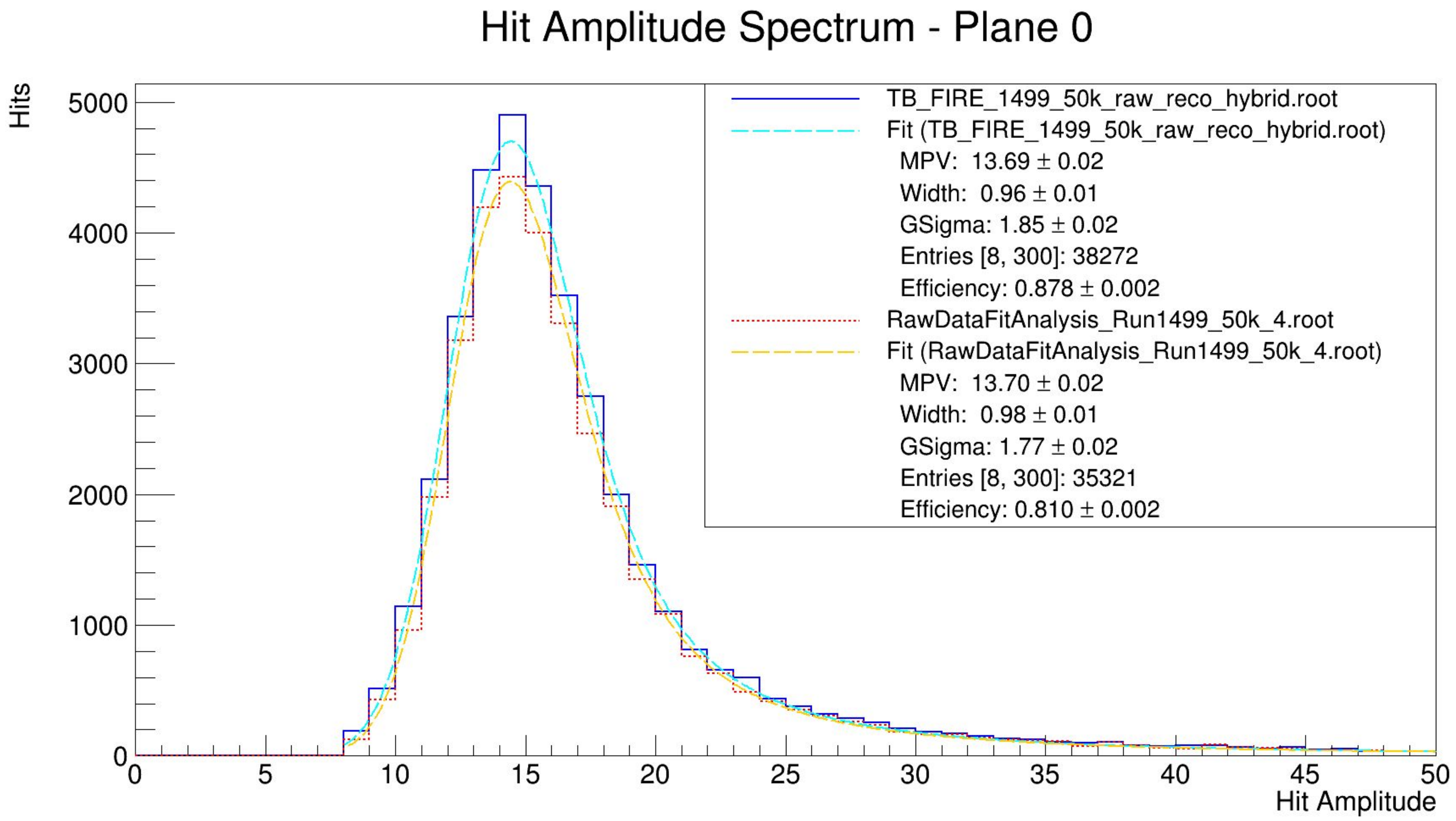
Amplitude

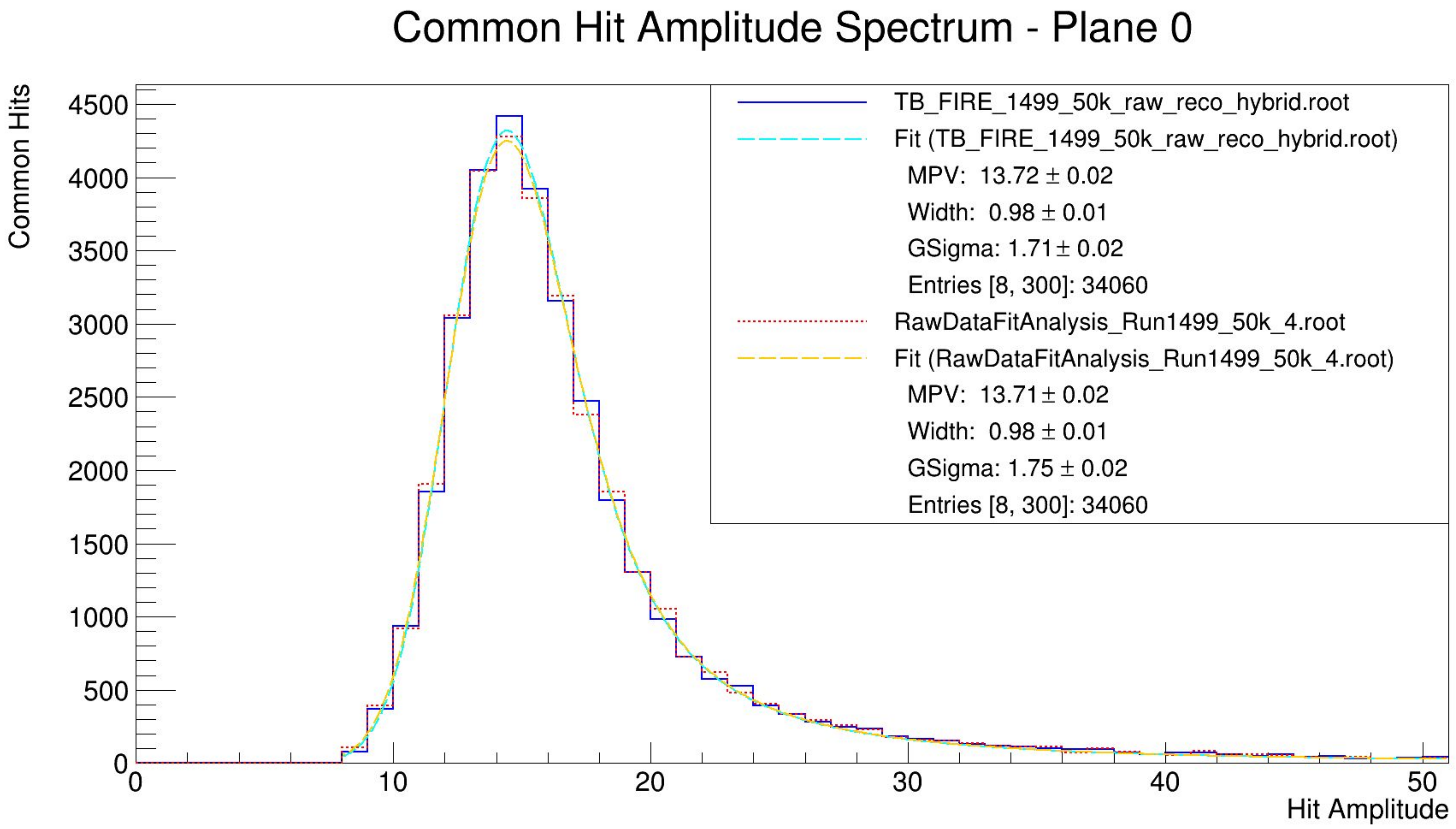
$$A = (d_1 + d_2) \frac{\tau_{\mathrm{sh}} e^{\frac{T_{smp} - t_0 - \tau_{\mathrm{sh}}}{\tau_{\mathrm{sh}}}}}{T_{smp} - t_0 \left(1 - e^{-\frac{T_{smp}}{\tau_{\mathrm{sh}}}}\right)}$$

TOA

$$t_0 = \frac{\frac{d_2}{d_1} T_{smp}}{\frac{d_2}{d_1} + e^{-\frac{T_{smp}}{\tau_{\mathrm{sh}}}}}$$

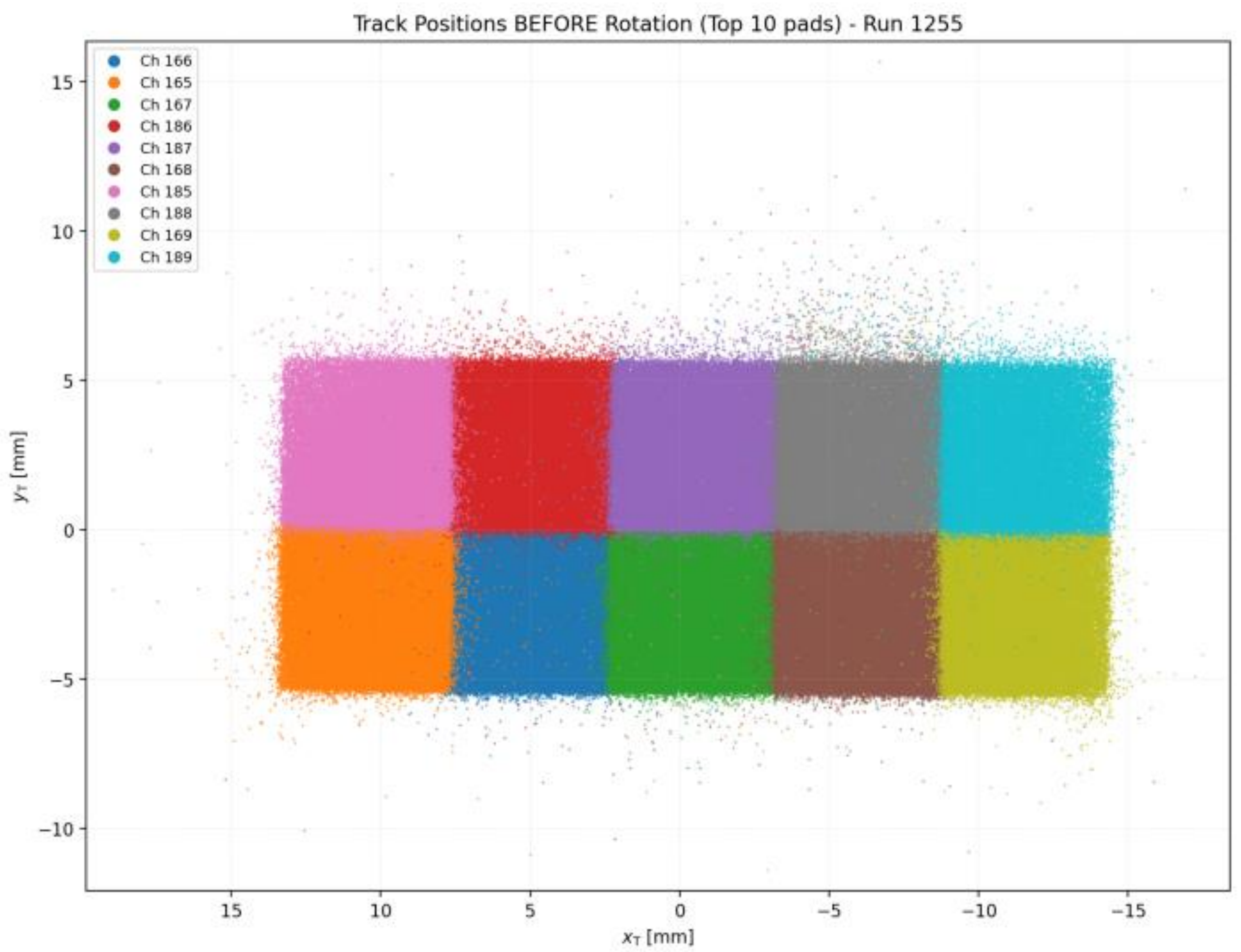
Deconvolution vs Fit

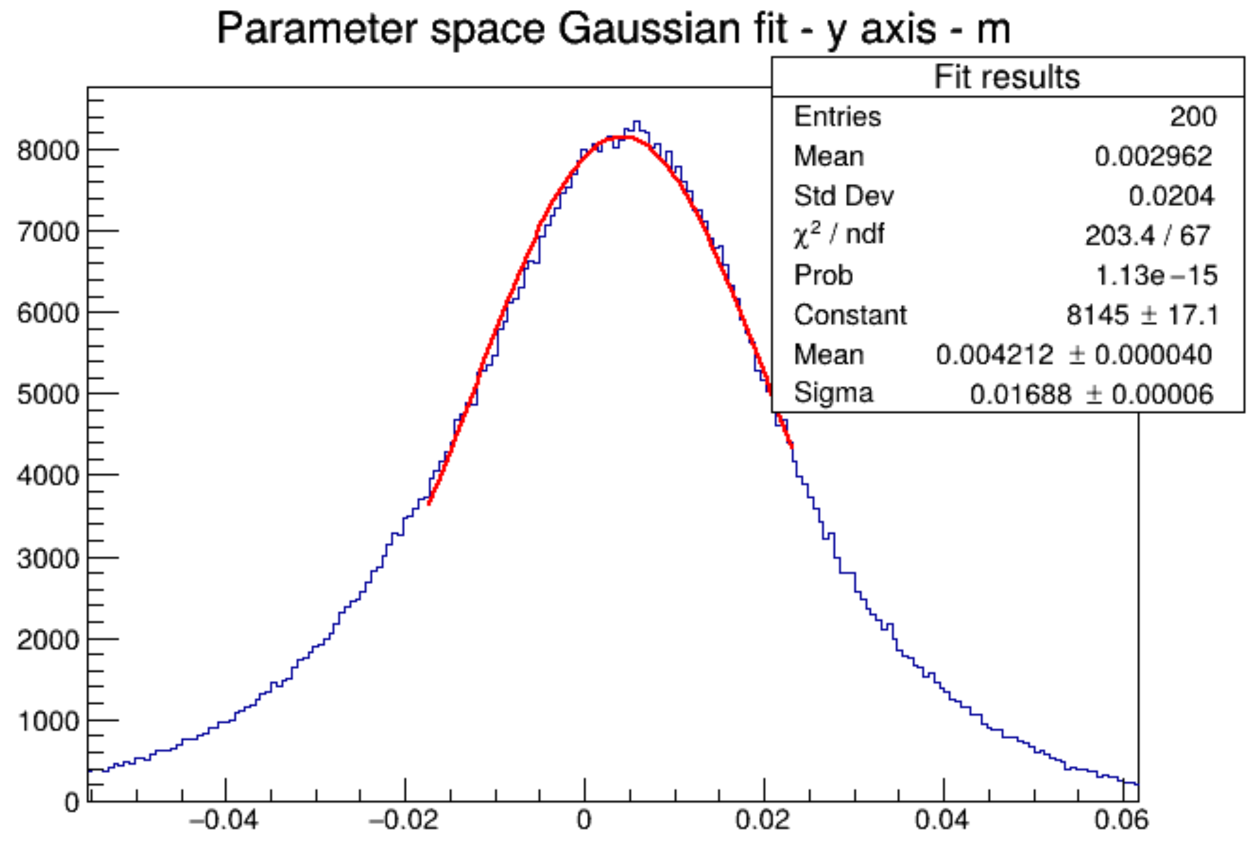


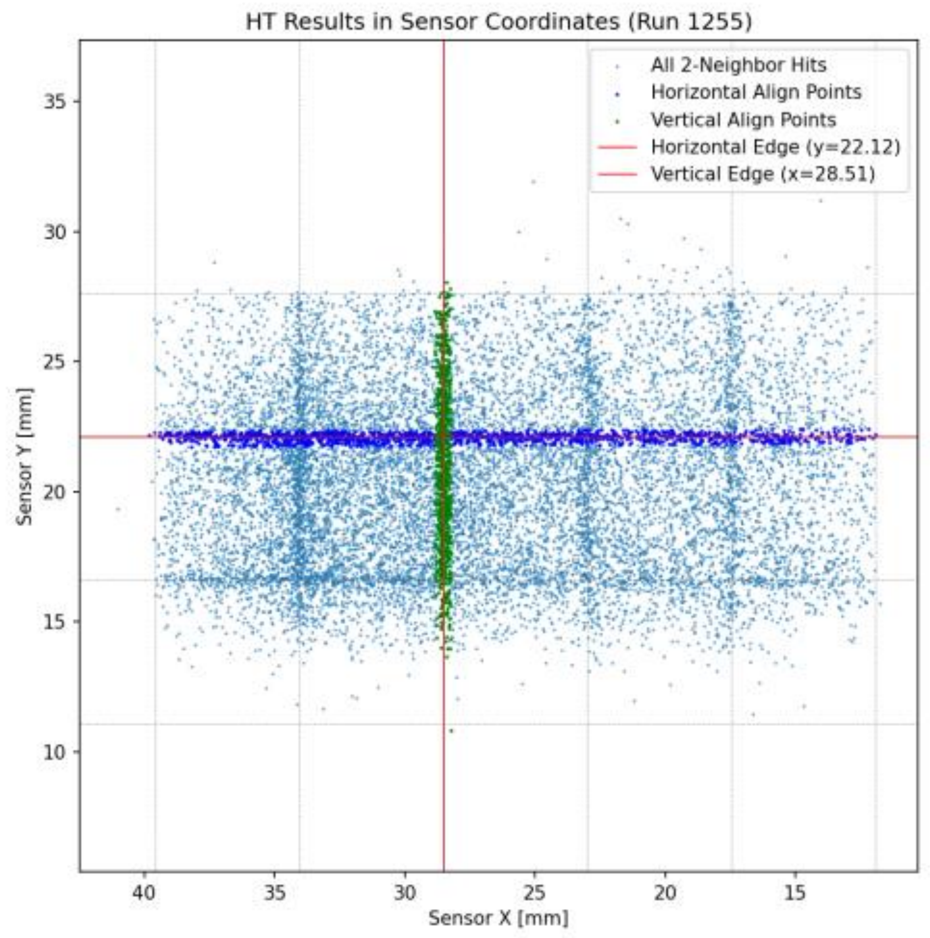


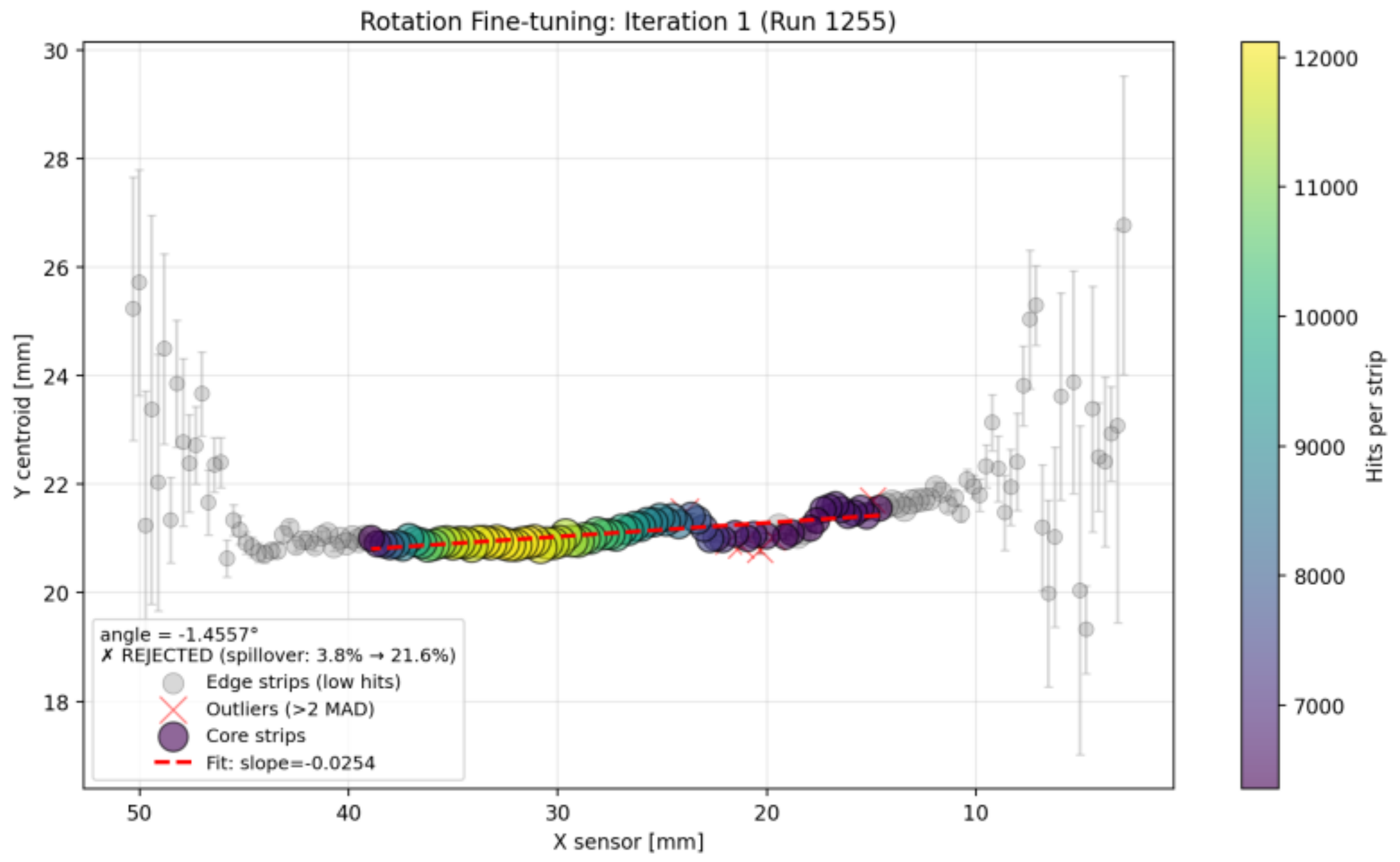
Example for plots

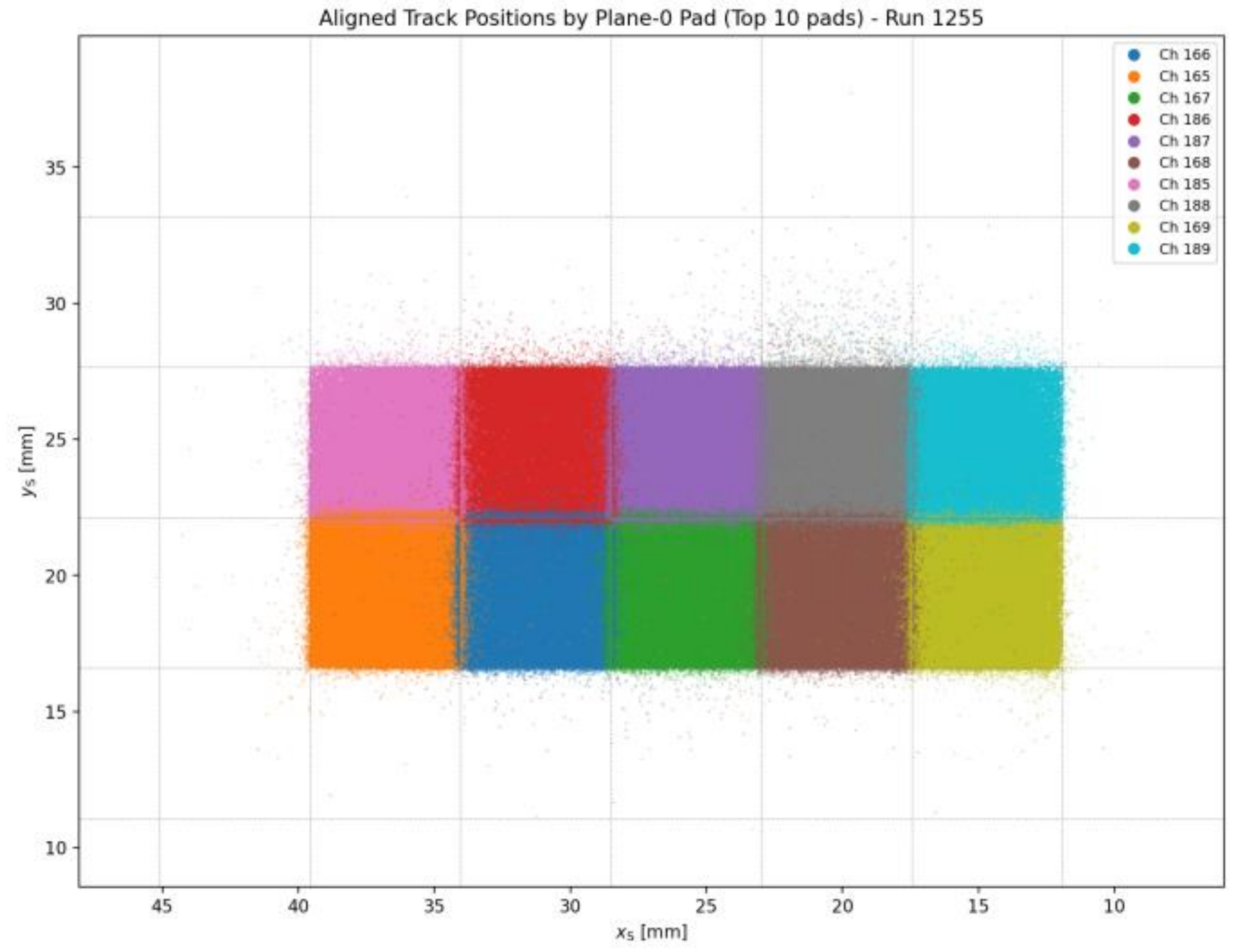
Work by Michal



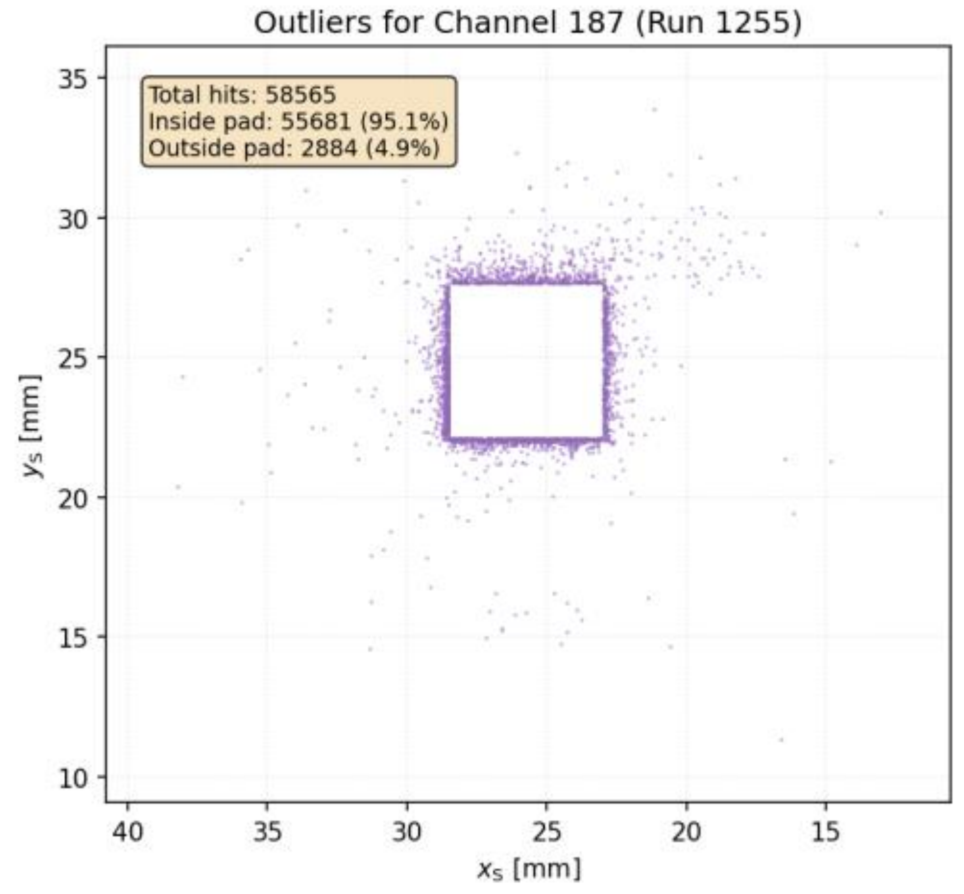








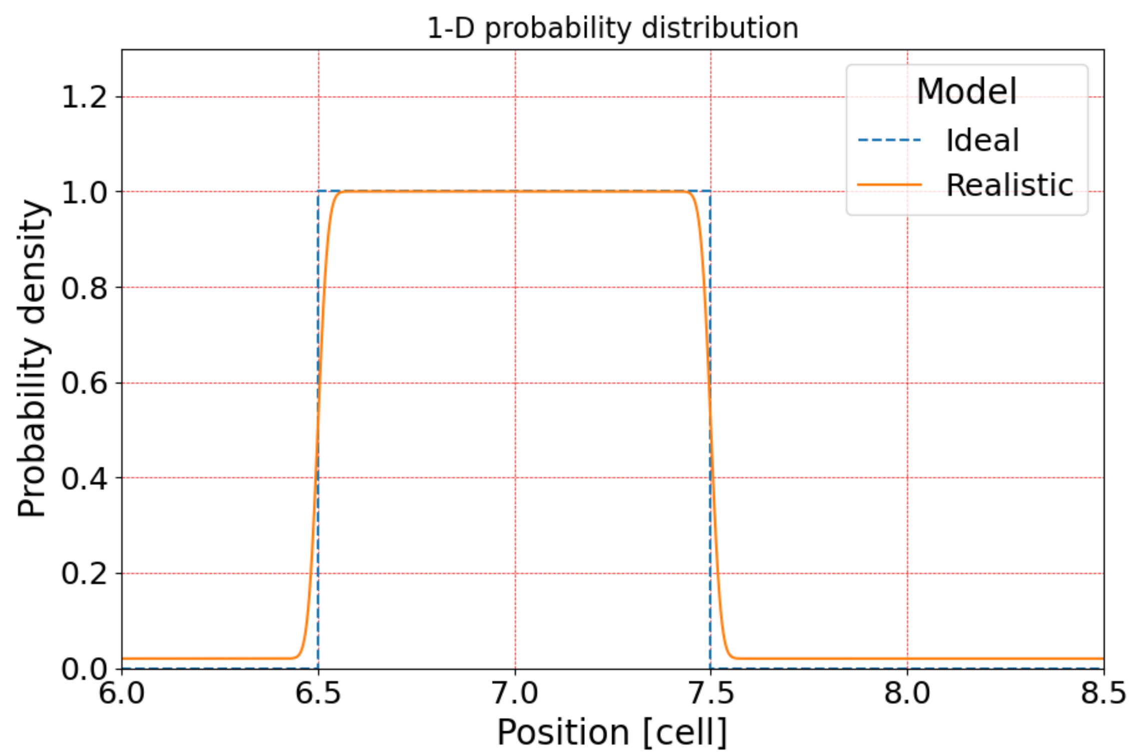
&



Work by Bartłomiej

Concept

Likelihood definition



example plot for $i = 7$

1-D probability density model

Realistic detector, assuming finite telescope position resolution (σ) and noise (p_0):

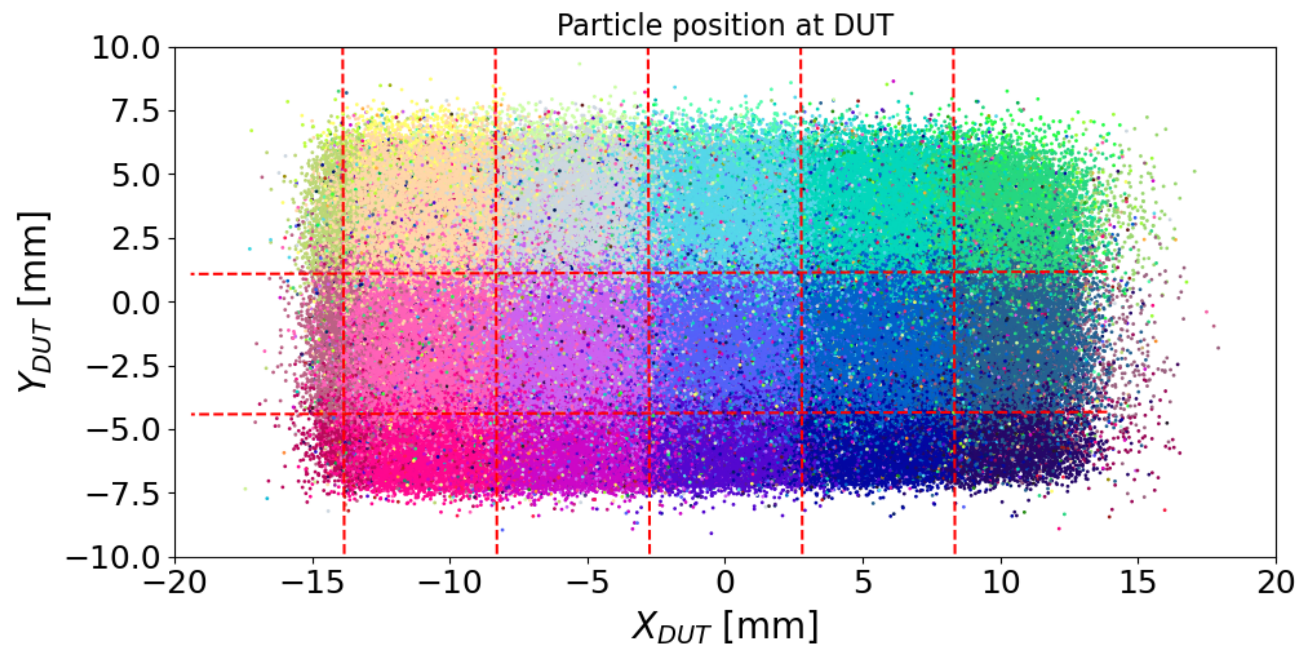
$$p(v) \quad = \quad p_1 \cdot SF\left(\frac{|u-i| - \frac{1}{2}}{\sigma}\right) + p_0$$

where $SF()$ is the "survival function" of the normal distribution (from SciPy library)

σ can be an additional model parameter

p_1 and p_0 should rather be fixed

Fit run 1165 plane 9 Gauss PDF



$u_0 = 10.99997 \pm 0.00116$

$v_0 = 8.29401 \pm 0.00129$

$\phi = 0.00279 \pm 0.00119$

Old parametrization results:

$u_0 = 10.99511 \pm 0.00058$

$v_0 = 8.29201 \pm 0.00088$

$\phi = 0.00196 \pm 0.00017$

$$p(u,v) = p_1 \cdot \mathrm{PDF}\left(\frac{|u-i|}{\sigma_x}\right) \cdot \mathrm{PDF}\left(\frac{|v-j|}{\sigma_y}\right) + p_0.$$

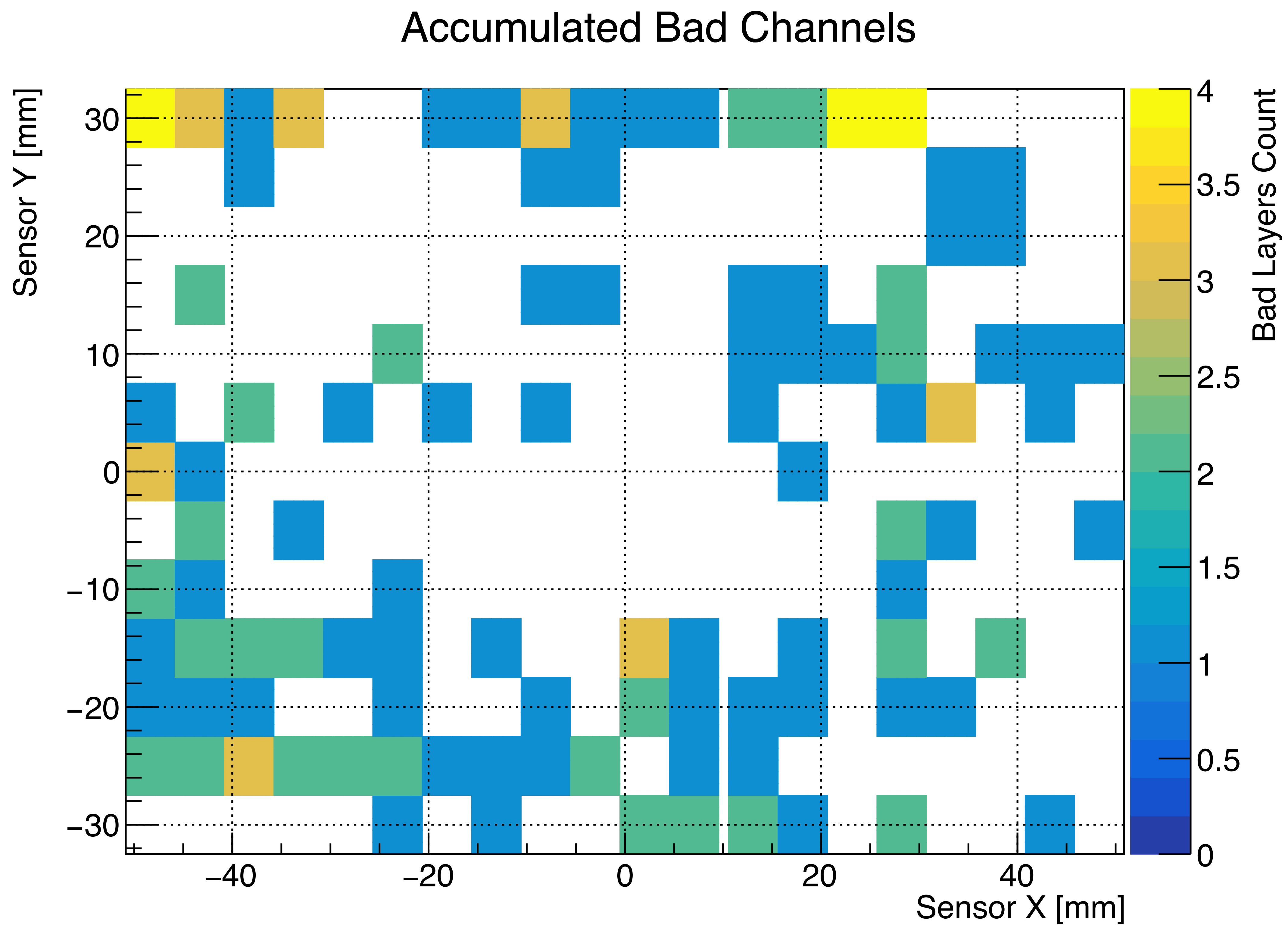
Punch list

- Basic calorimetry
  [ ] Longitudinal shower profile (leakage)
  [ ] Moliere radius (transverse profile)
  [ ] Preliminary energy resolution and linearity
- Specific topics
  [ ] Position resolution
  [ ] Angular resolution
  [ ] Effects from hardware (gap, glue, precision, …)
- [ ] Monte Carlo simulation for TB layouts
- [ ] …

The Reality: Our detector has a lot of dead area

1. **Inter-sensor Gap:** $\sim$ 1.72mm spaces between wafers.
2. **Dead Channels:** Masked noisy or not working pads.

The Effect: When a shower crosses a gap or dead area, artificially decrees measured energy. This creates "dips" in the radial profile and lowers the total energy.



Map of Dead Channels & Gaps

Work by Dawid

Assumption: Electromagnetic showers are **Radially Symmetric**.

The Algorithm - per Radial Ring (width = dr):

1. Calculate the **Theoretical** number of sub pads within the ring (N_{total}).
2. Calculate the number of **Active** sub pads (excluding number of dead sub pads within the ring) (N_{good}).
3. Scale the measured energy:

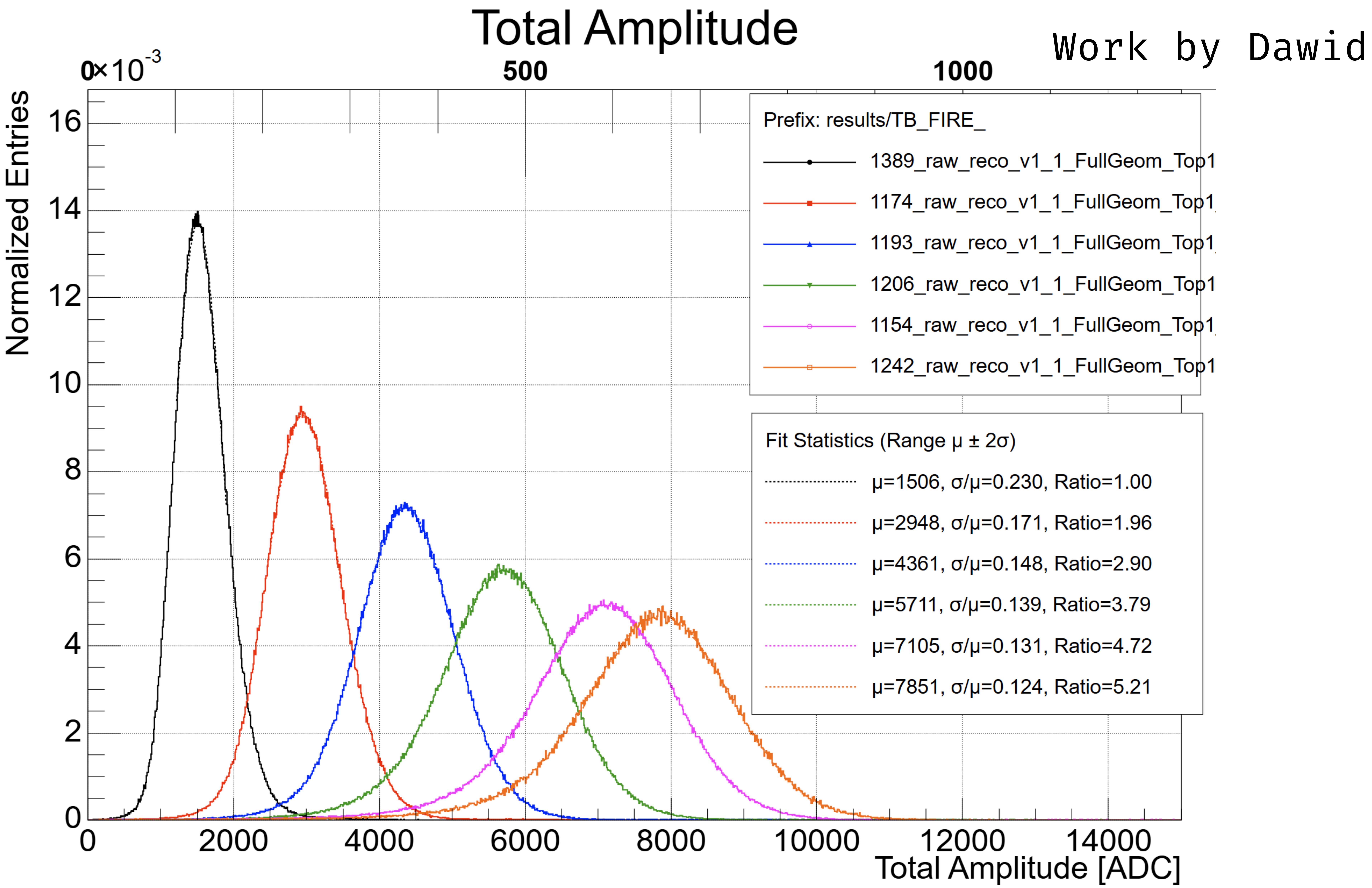
$$E_{corrected} = E_{measured} \times \frac{N_{total}}{N_{good}}$$

Example

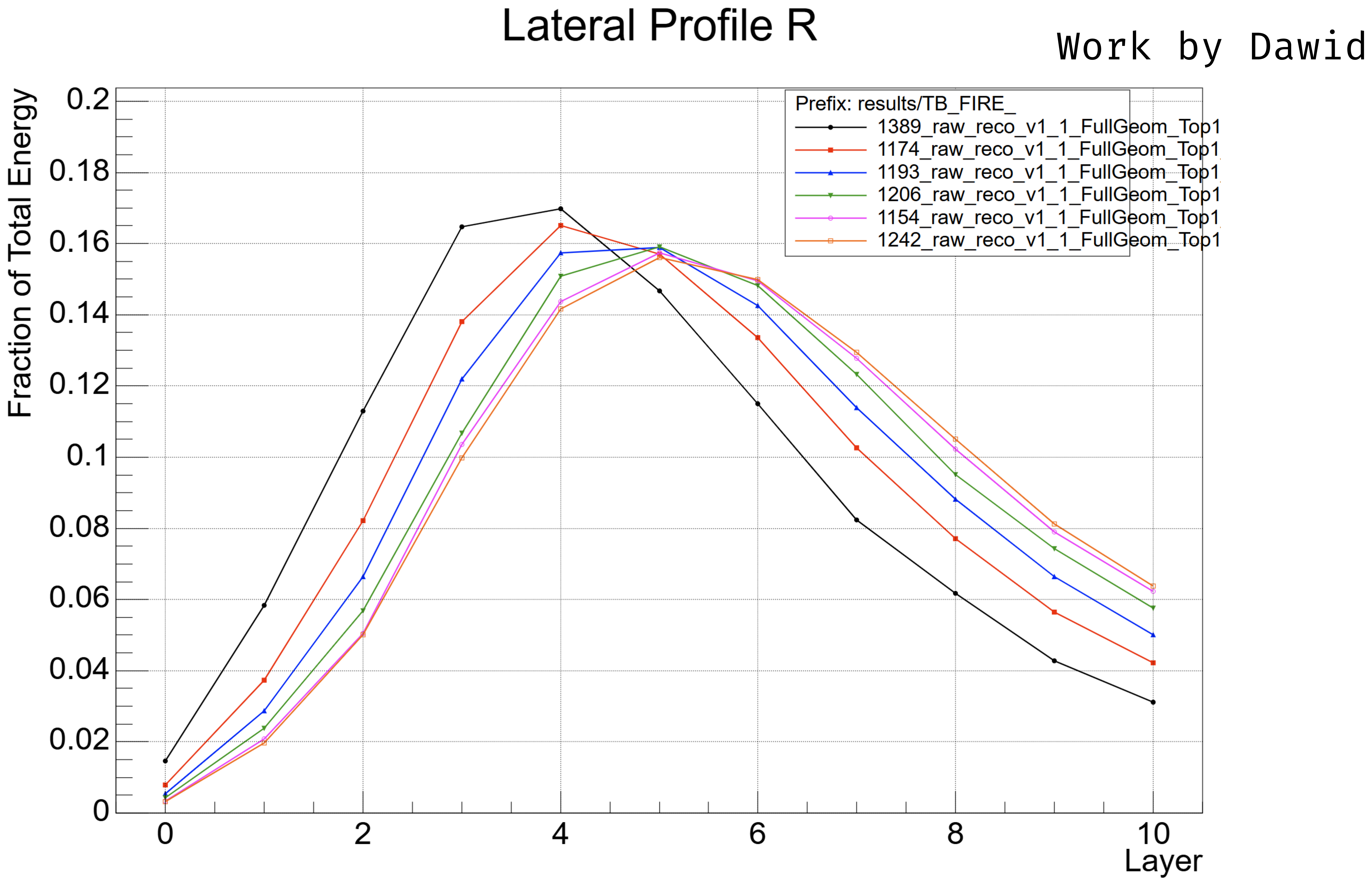
If a ring falls 25% into a dead area:

- We only see 75% of the energy.
- We multiply by $1/0.75 = 1.33$.

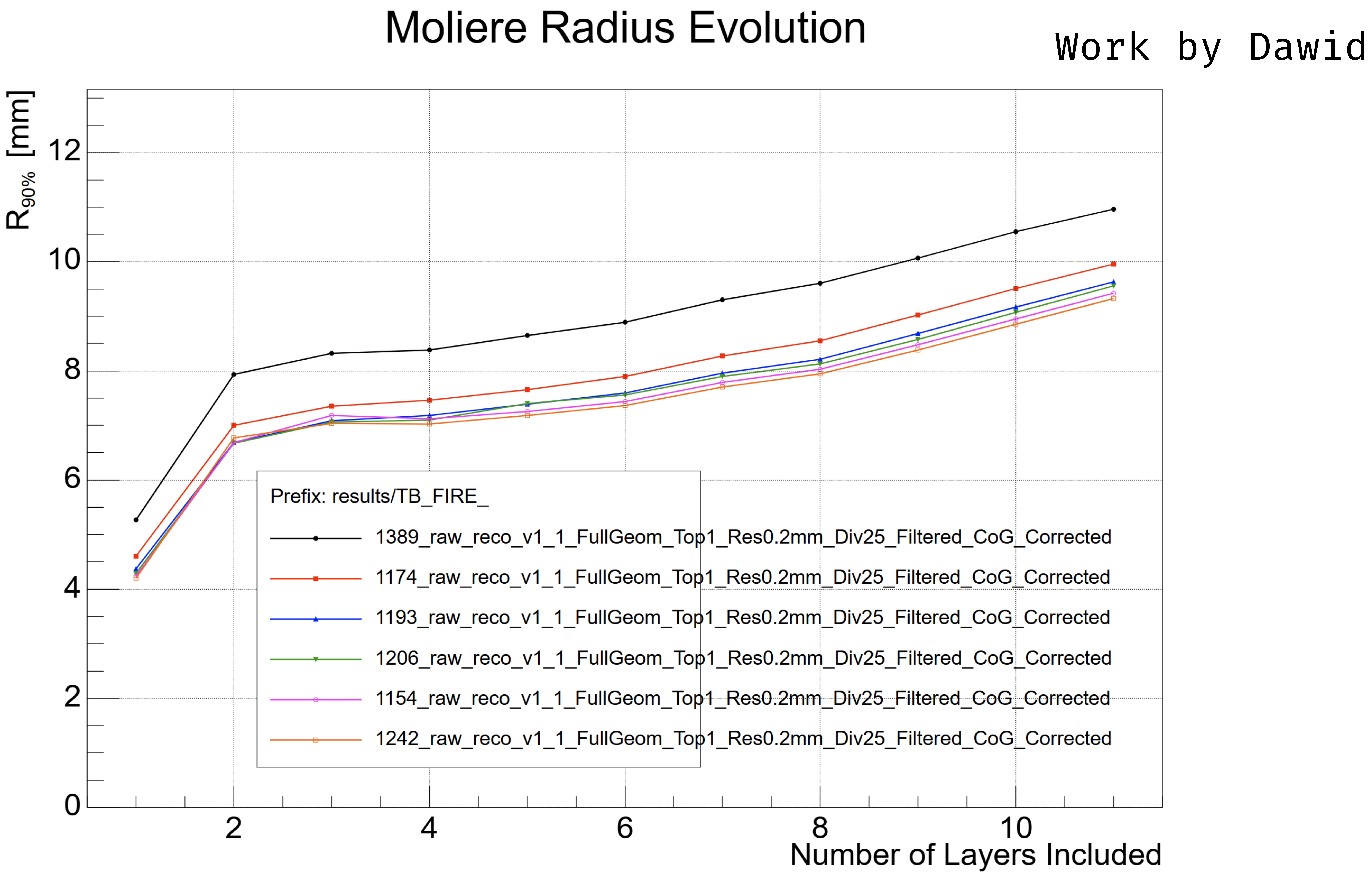
Result: Comparison for different beam energy



Result: Comparison for different beam energy

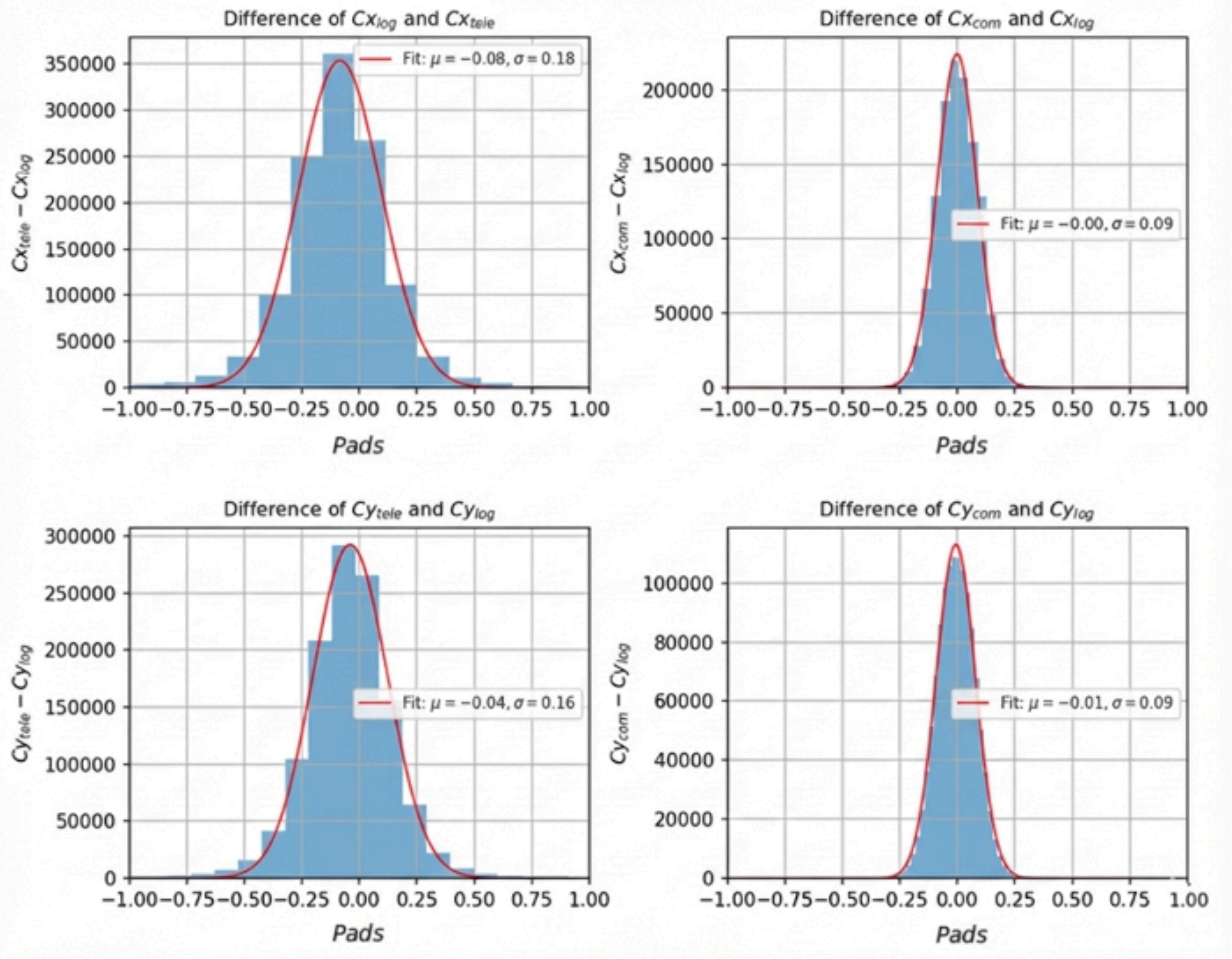


Result: Comparison for different beam energy



Position Resolution

Work by Gal



- The center found by logarithmic weighting is calculated by:

$$W_n = \max\left\{0, W_0 + \ln\frac{E_n}{\sum_n E_n}\right\}$$

$$C_x = \frac{\sum_n W_n x_n}{\sum_n W_n}$$

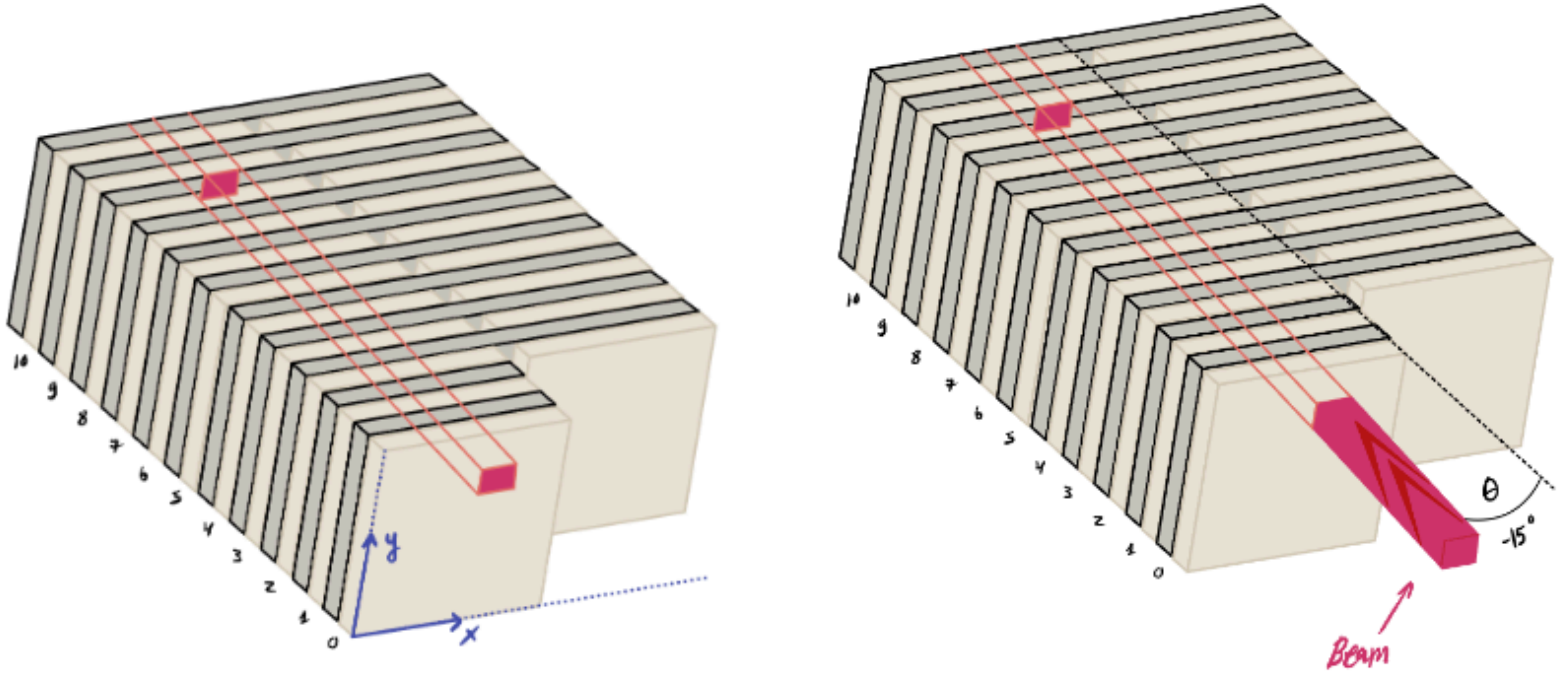
- Optimal value for W_0 was found by **minimizing the variance and the mean of the gaussian fit** to differences from telescope:

$$W_{0_{opt}} = 3$$

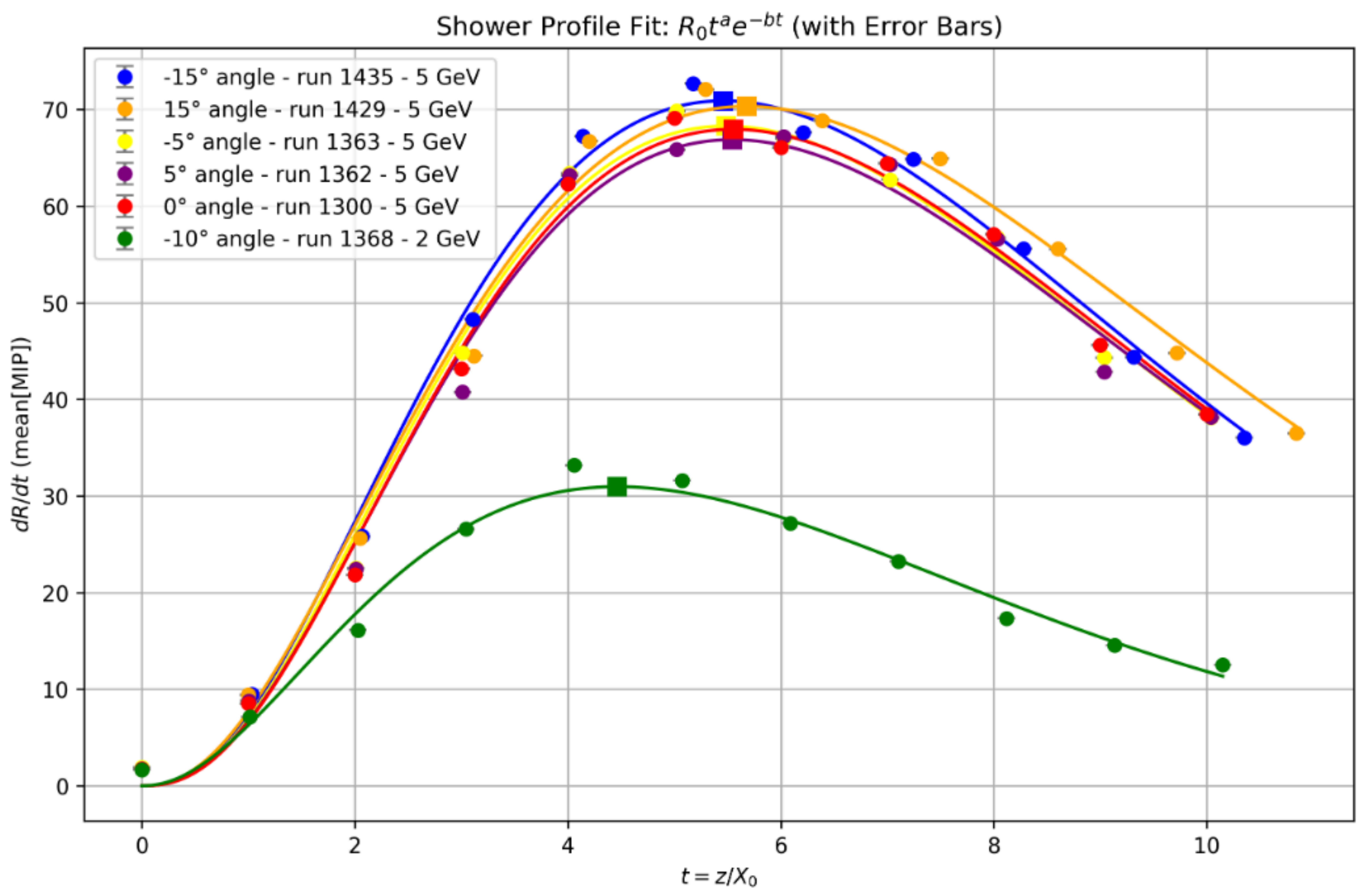
Tested for 3 runs (1154: 5 GeV, 1280: 4 GeV, 1255: 2 GeV)

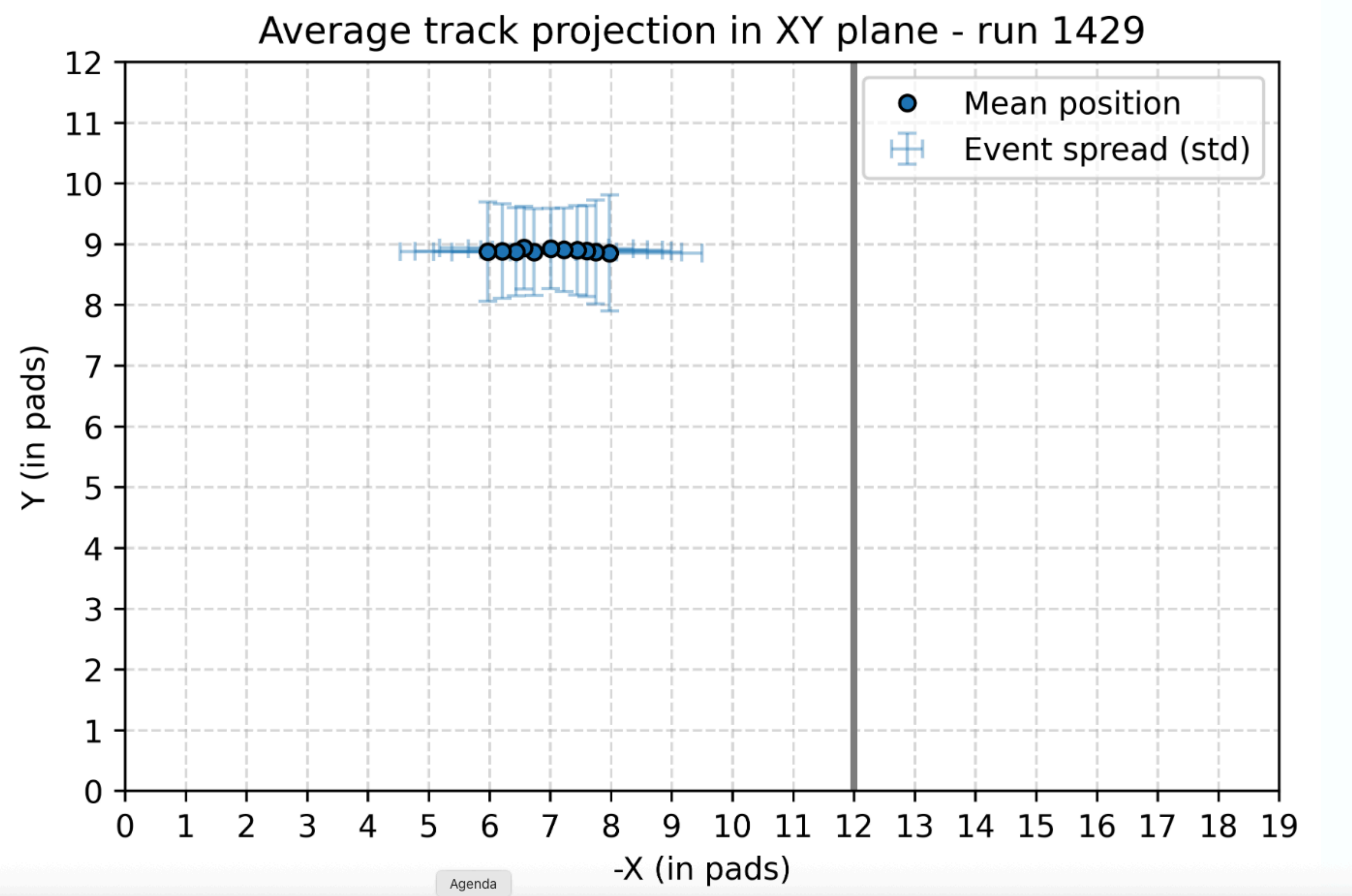
Angle reconstruction

VISUALISATION



Work by Nofar

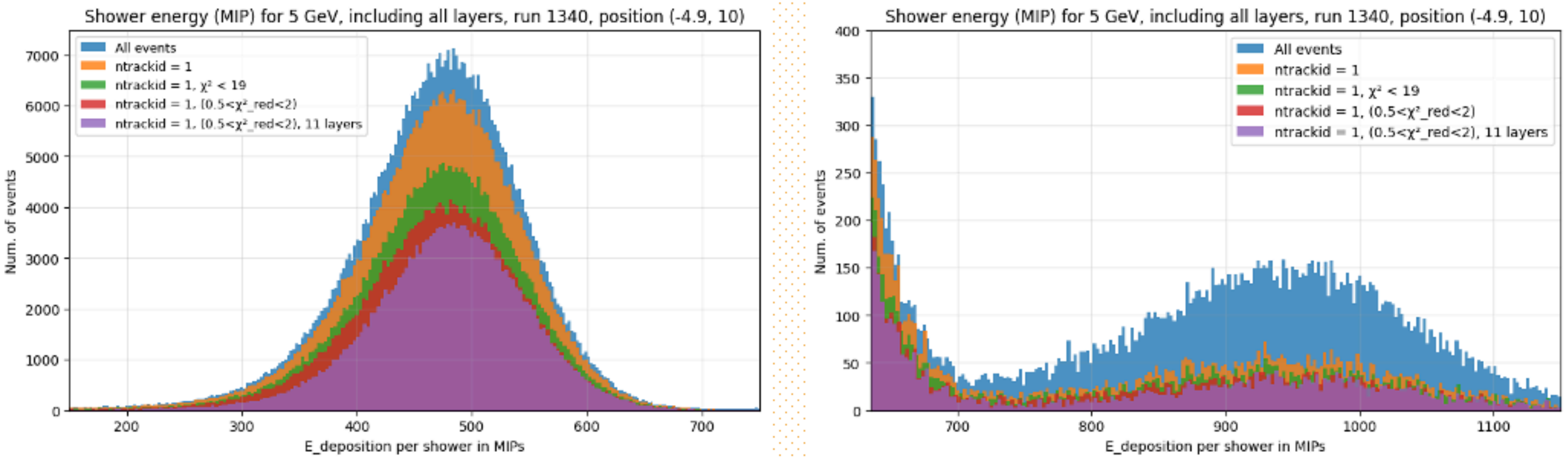




As expected, here the peaks of 5 GeV have nearly the same location.

Work by Roni

Reconstructed data



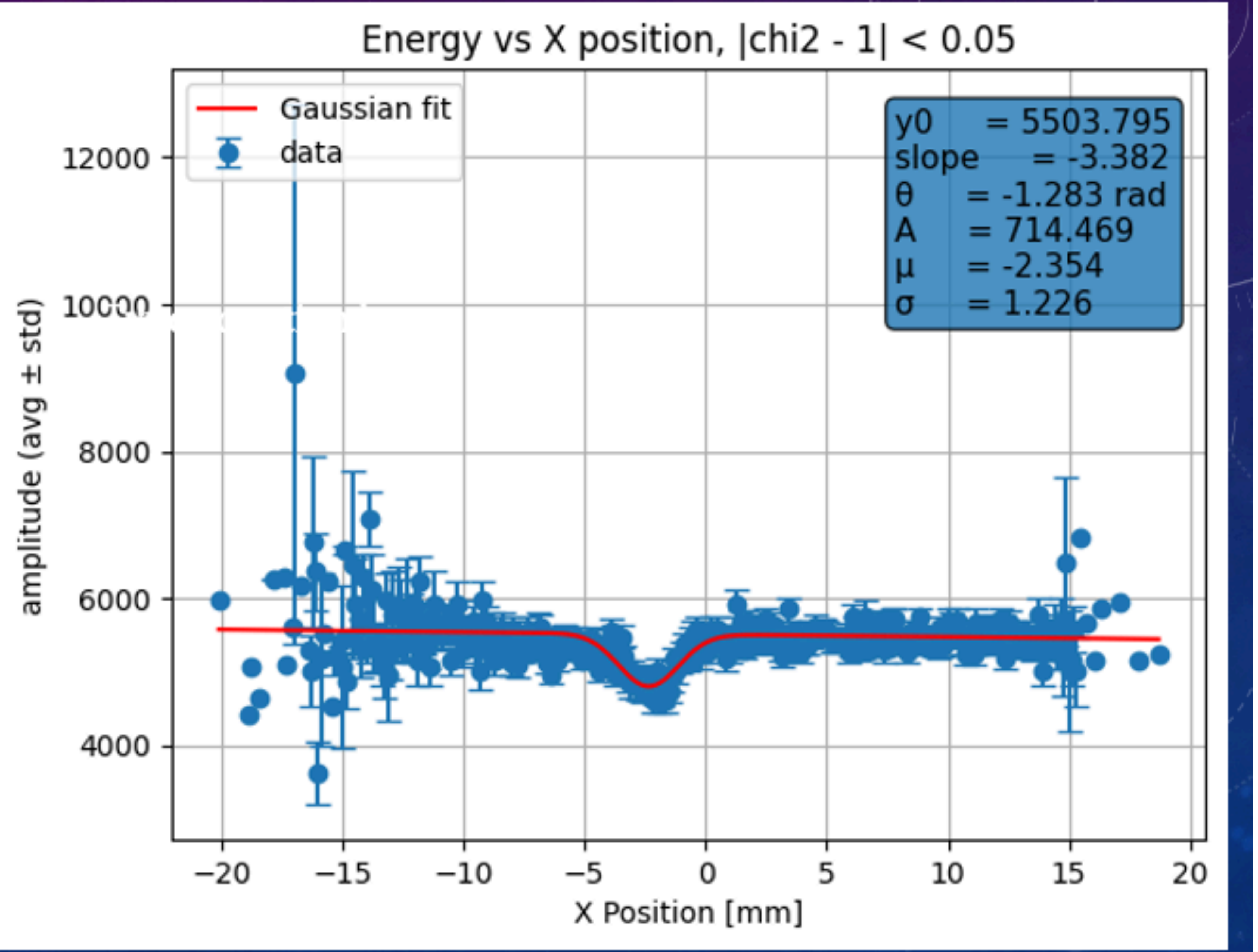
- Lower energies tail duo (probably) to dead channels.
- Peak has shifted to the right, from ~ 440 (ZS) to ~480 (Recons.) MIP.
- Percentage of events with all 11 layers (taken from all the data) : 85.93%.
- Percentage of events with all 11 layers (taken from only ntrakckid = 1 data sample) : 86.25%.
- Further investigation required about the 2 particles peak. (appear even after filtering)

ENERGY LOST AROUND THE GAP

Work by Ben

$$F_{fit}(x) = c + mx + A \cdot e^{\frac{-(x-mu)^2}{(2\sigma^2)}}$$

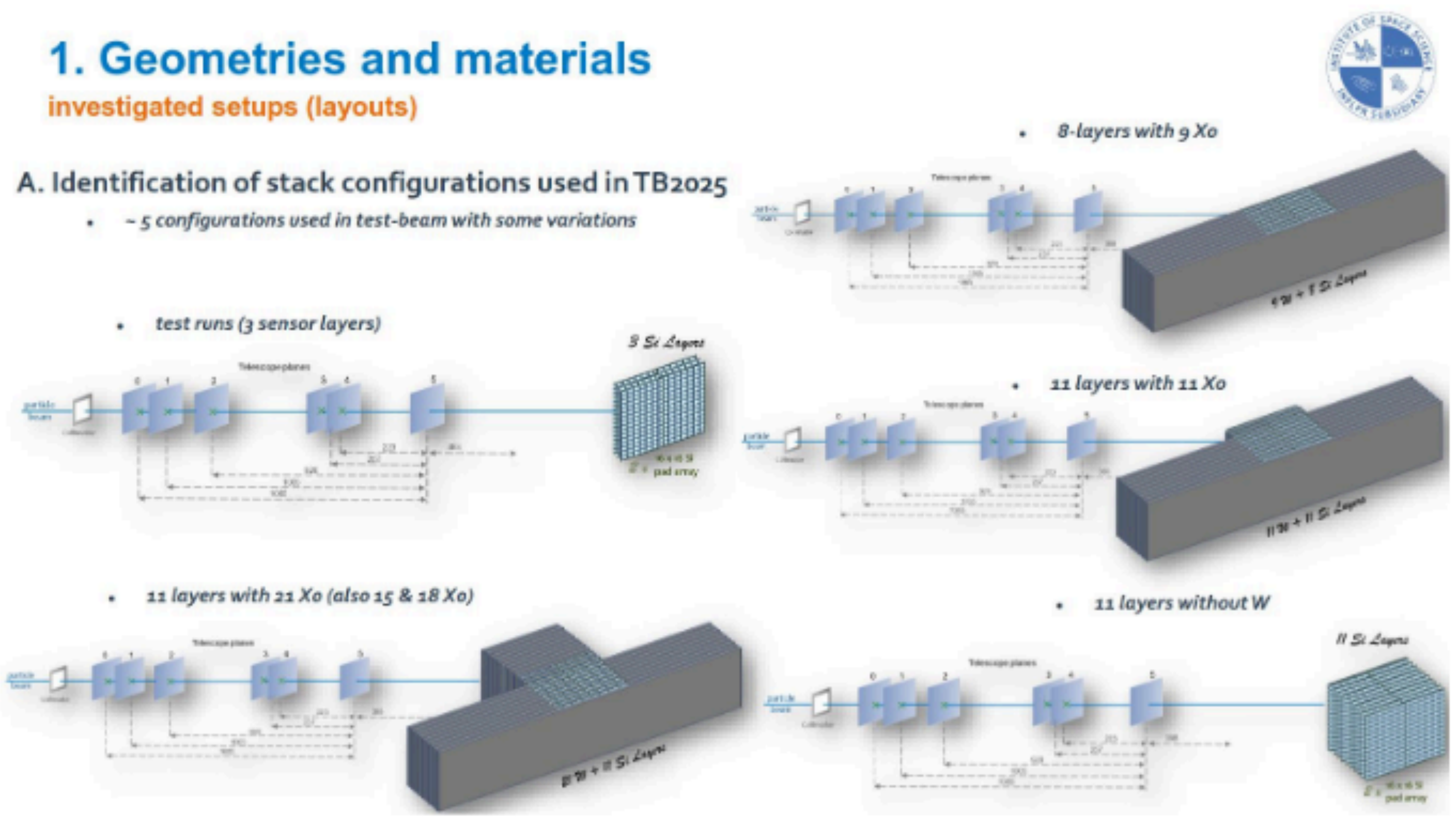
$$\theta = arctan(m)$$

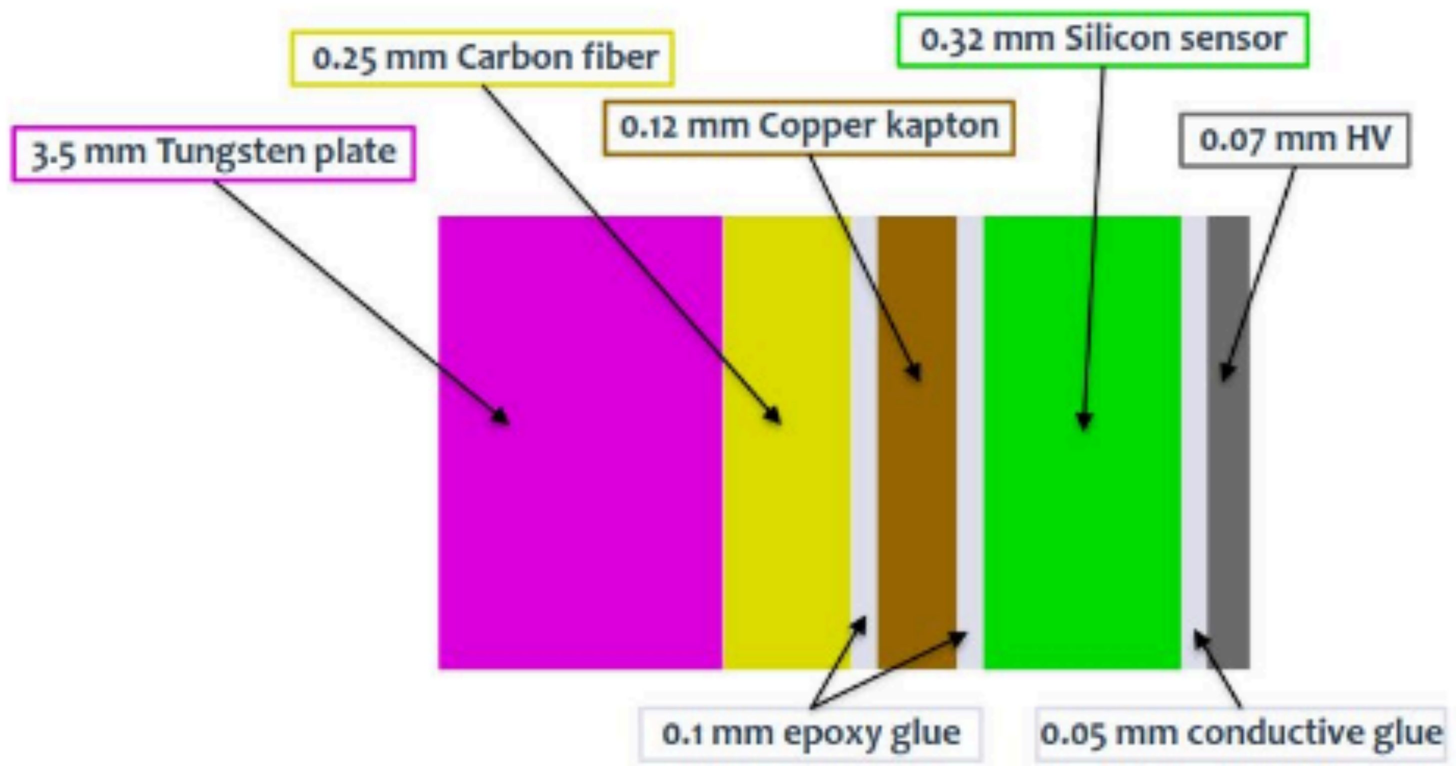


Standalone simulation

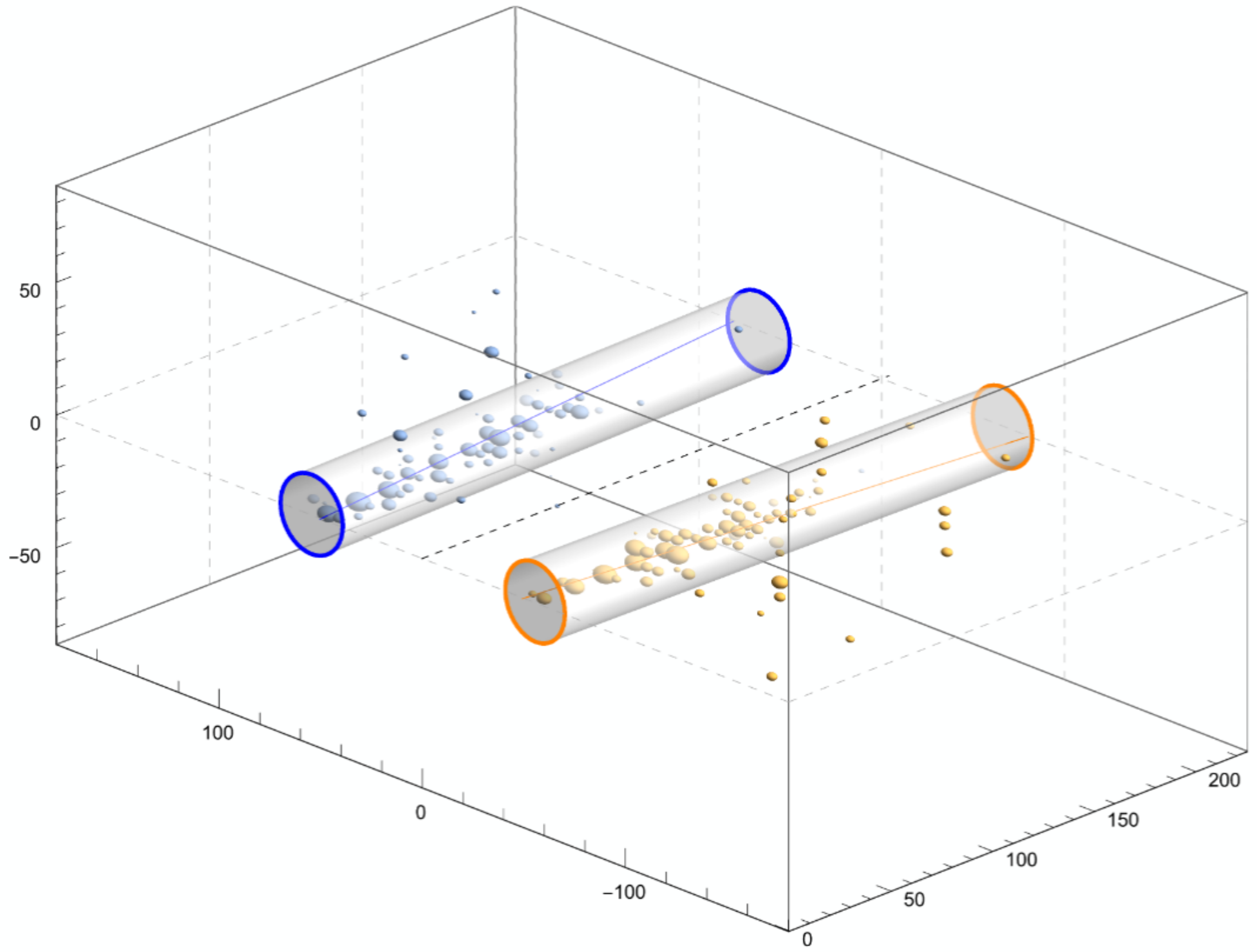
Work by Mihai

- Simulations with Geant4
  - TB 2025 Configurations identified
  - Active plane geometry and sub-layer materials will be applied to Geant4 geometry



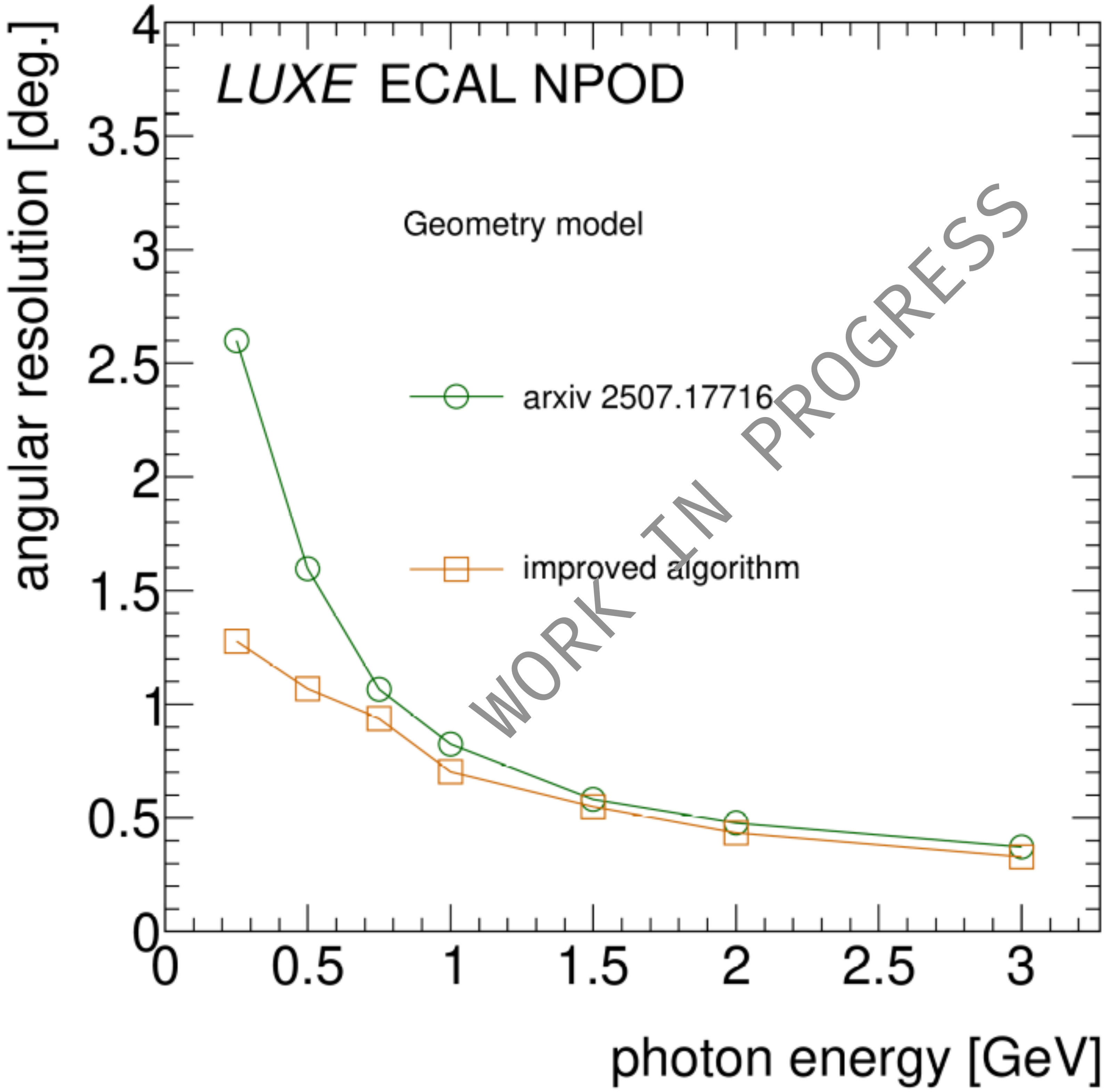


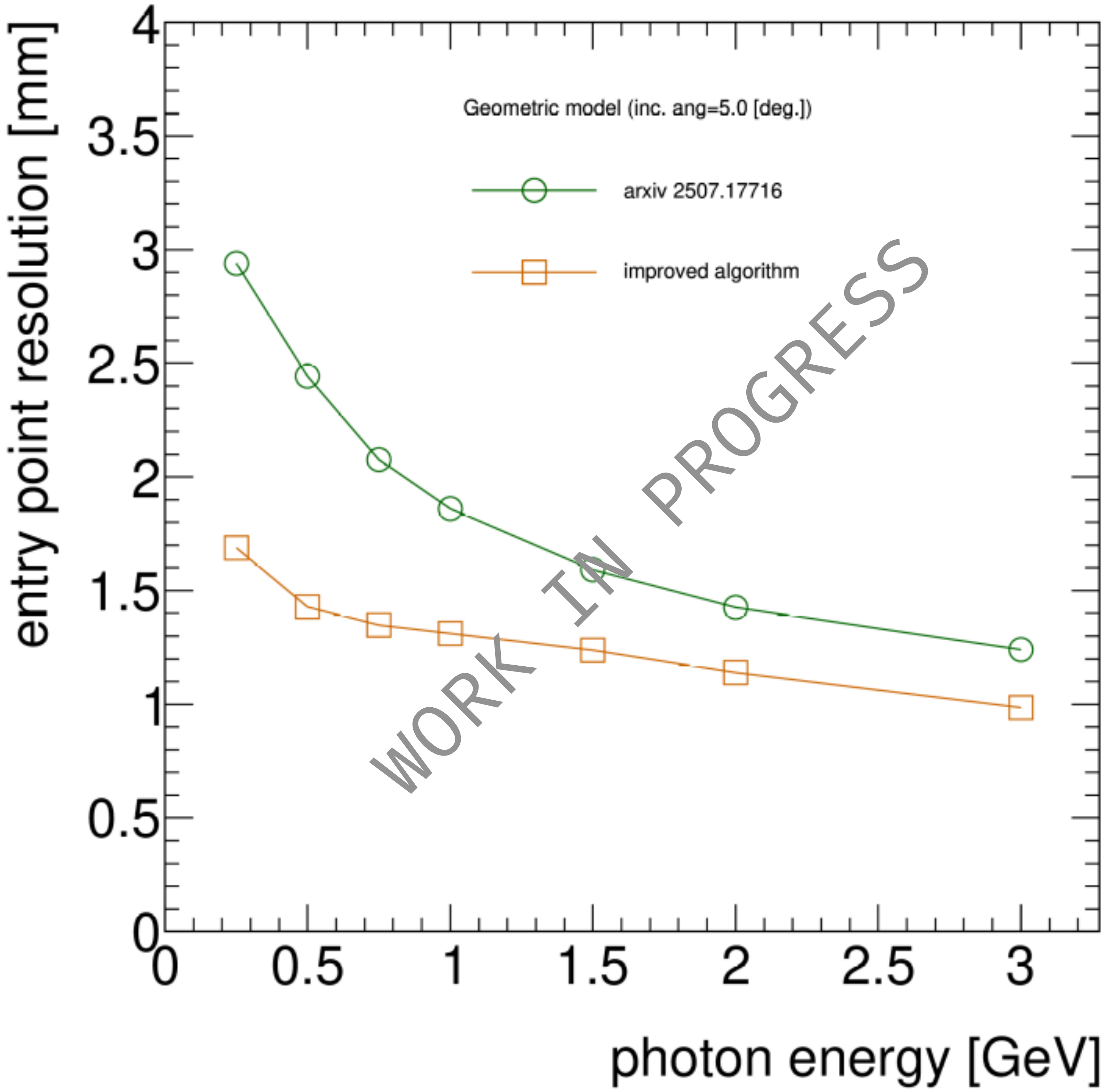
20

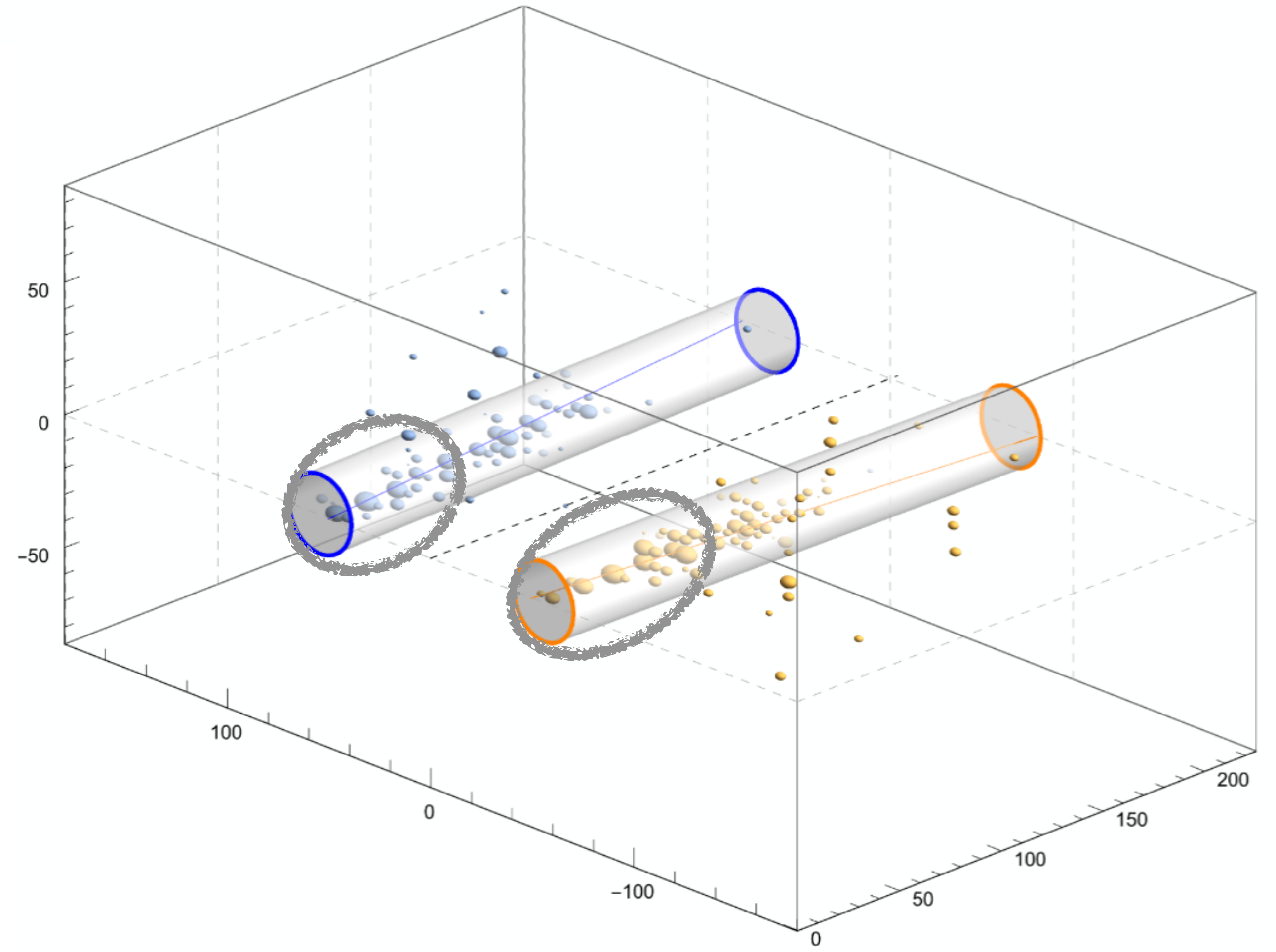

50
0
-50
100
0
-100
0
50
100
150
200

Angular and entry-point resolutions

- Furthermore, we focused on the **beginning part** of the cluster core (hits before the barycentre) to improve the resolution.



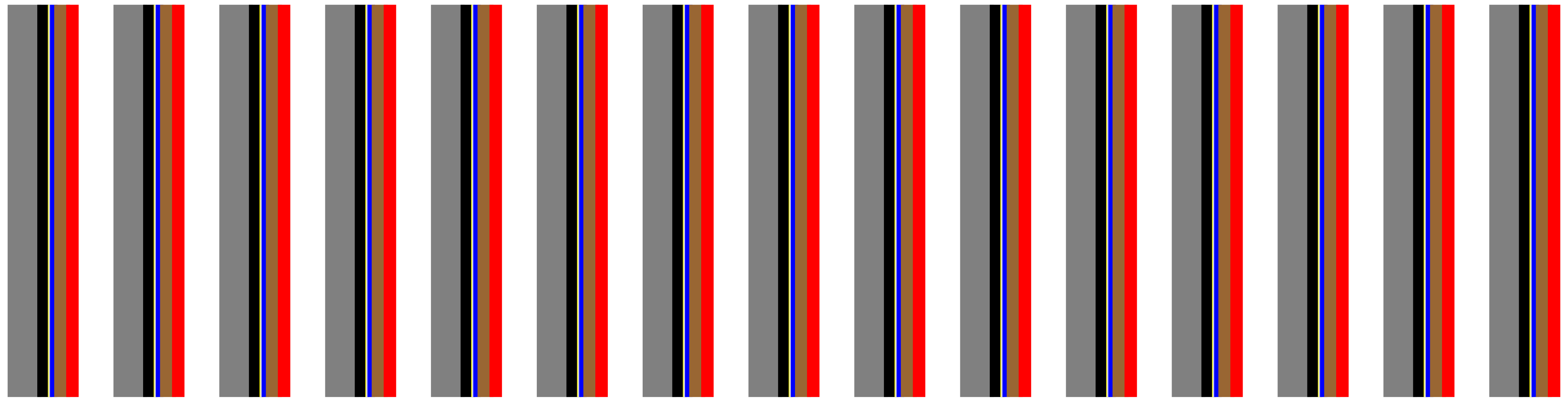


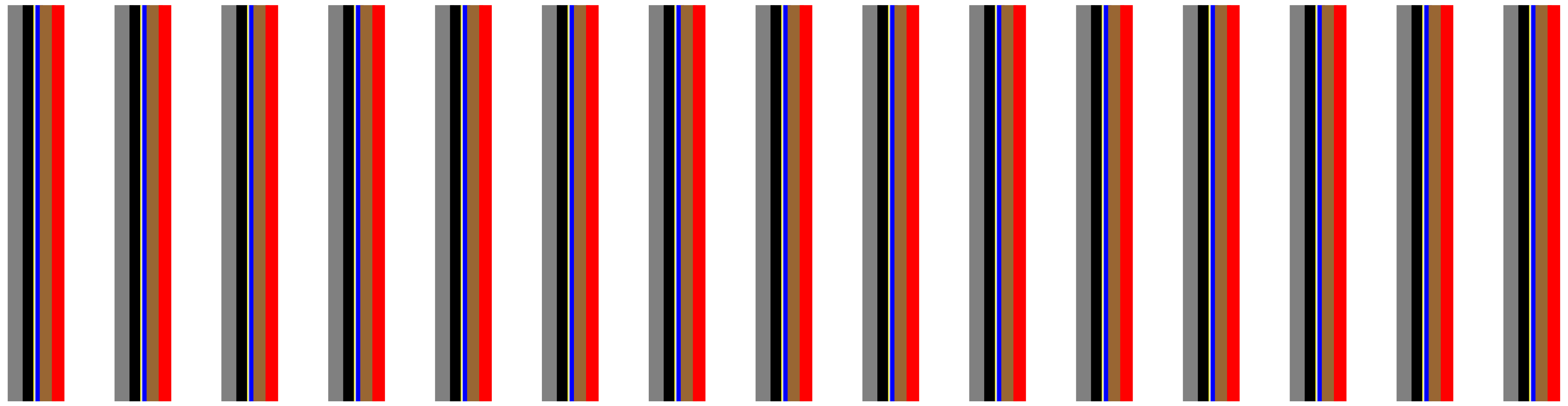


More geometries

- SiW-ECAL prototype is highly modular and relatively easy to modify its geometry, such as total X_0 and repartition ratio.
  - Maintain the 15 mm layer "pitch":

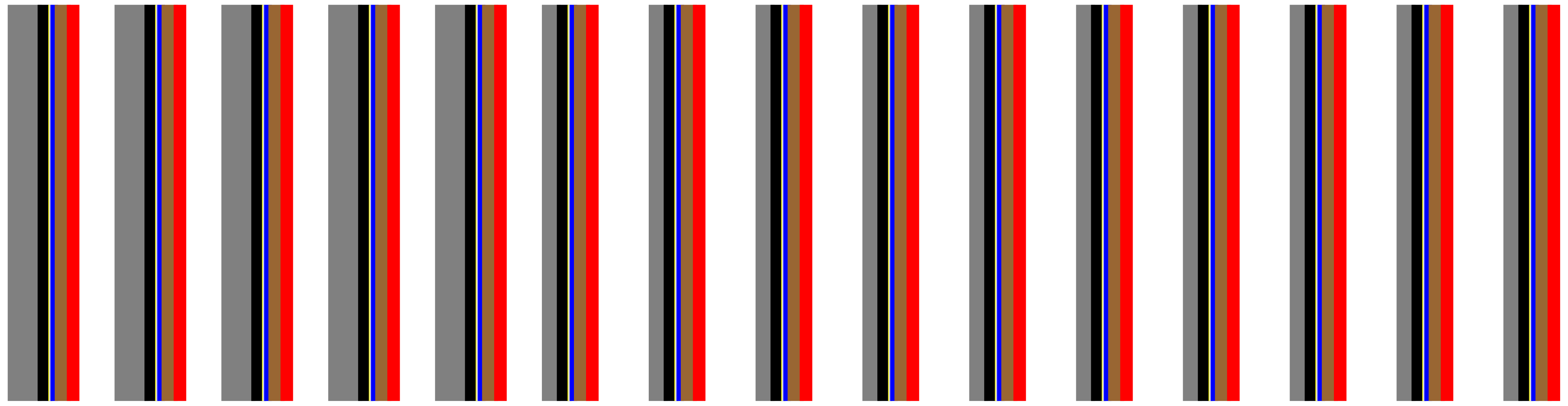
$18X_0$ (15 × 4.2 mm plates)

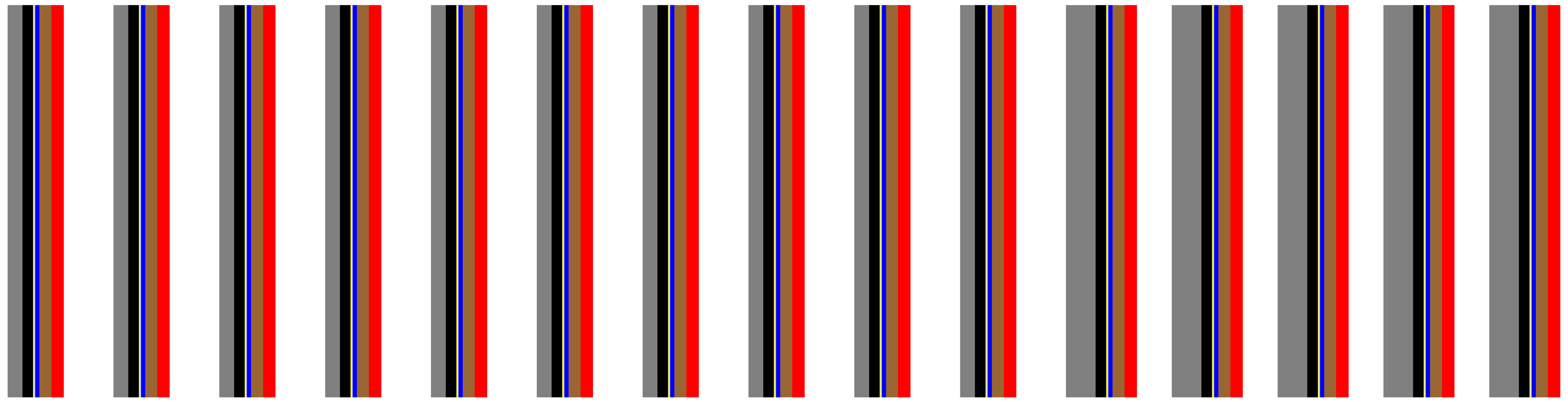




$9X_0$ (15 × 2.1 mm plates)

$12X_0$ (5 × 4.2 mm + 10 × 2.1 mm)

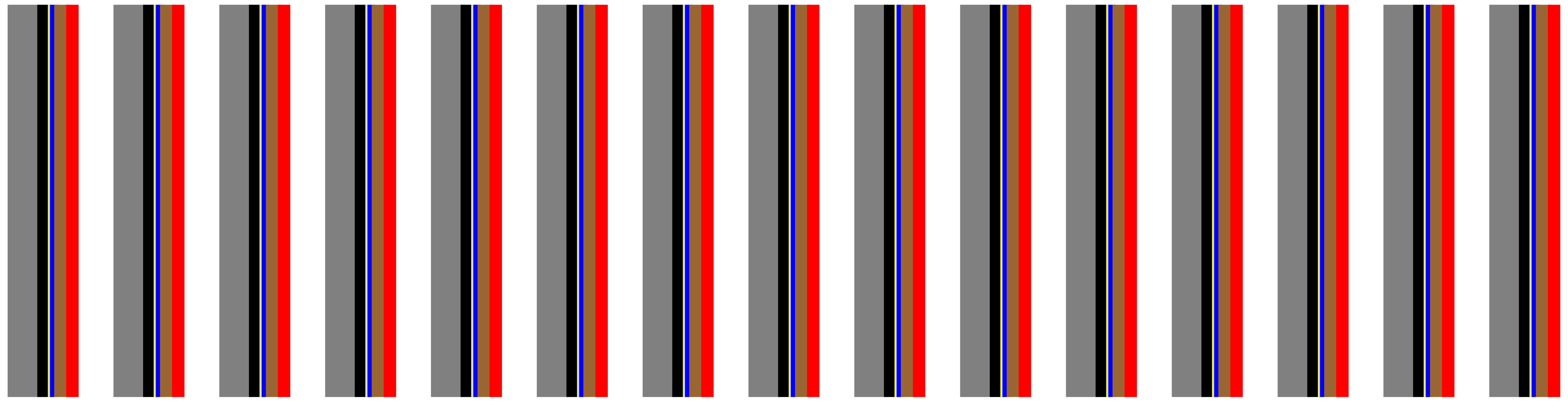




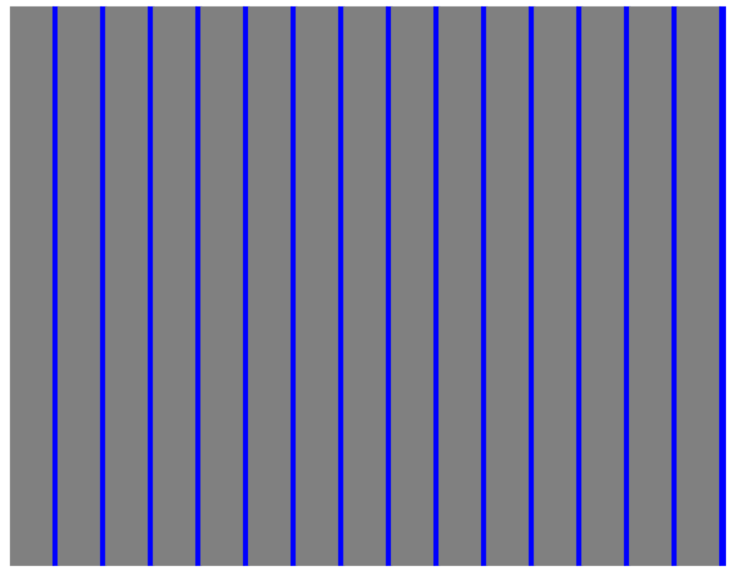
$12X_0$ (10 × 2.1 mm + 5 × 4.2 mm)

More geometries

- SiW-ECAL prototype is highly modular and relatively easy to modify its geometry, such as total X_0 and repartition ratio.
  - "Squeeze" on the air gap (inspired by HighCompactCalo):



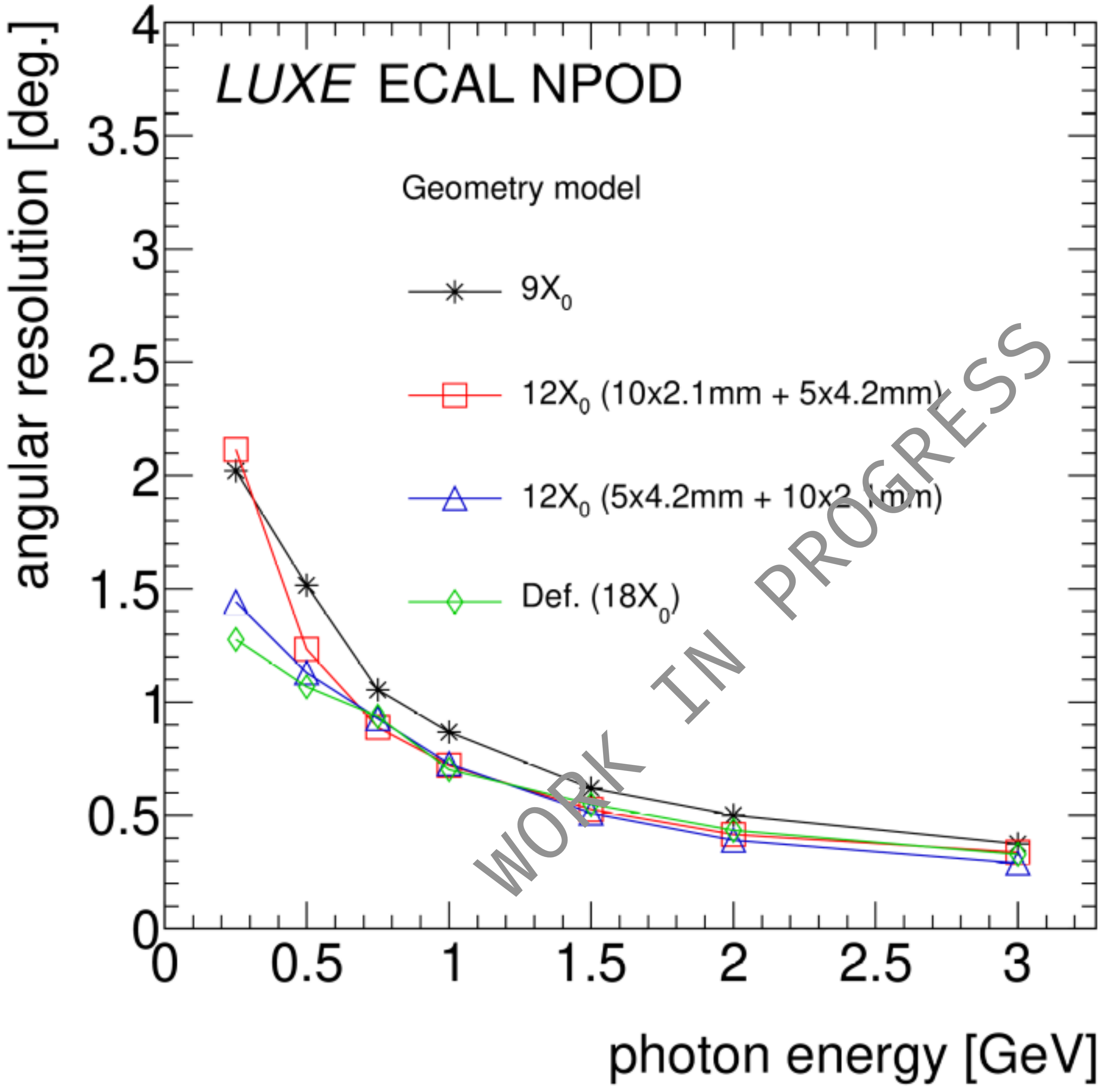
$18X_0$ (15 mm "pitch" between layers)



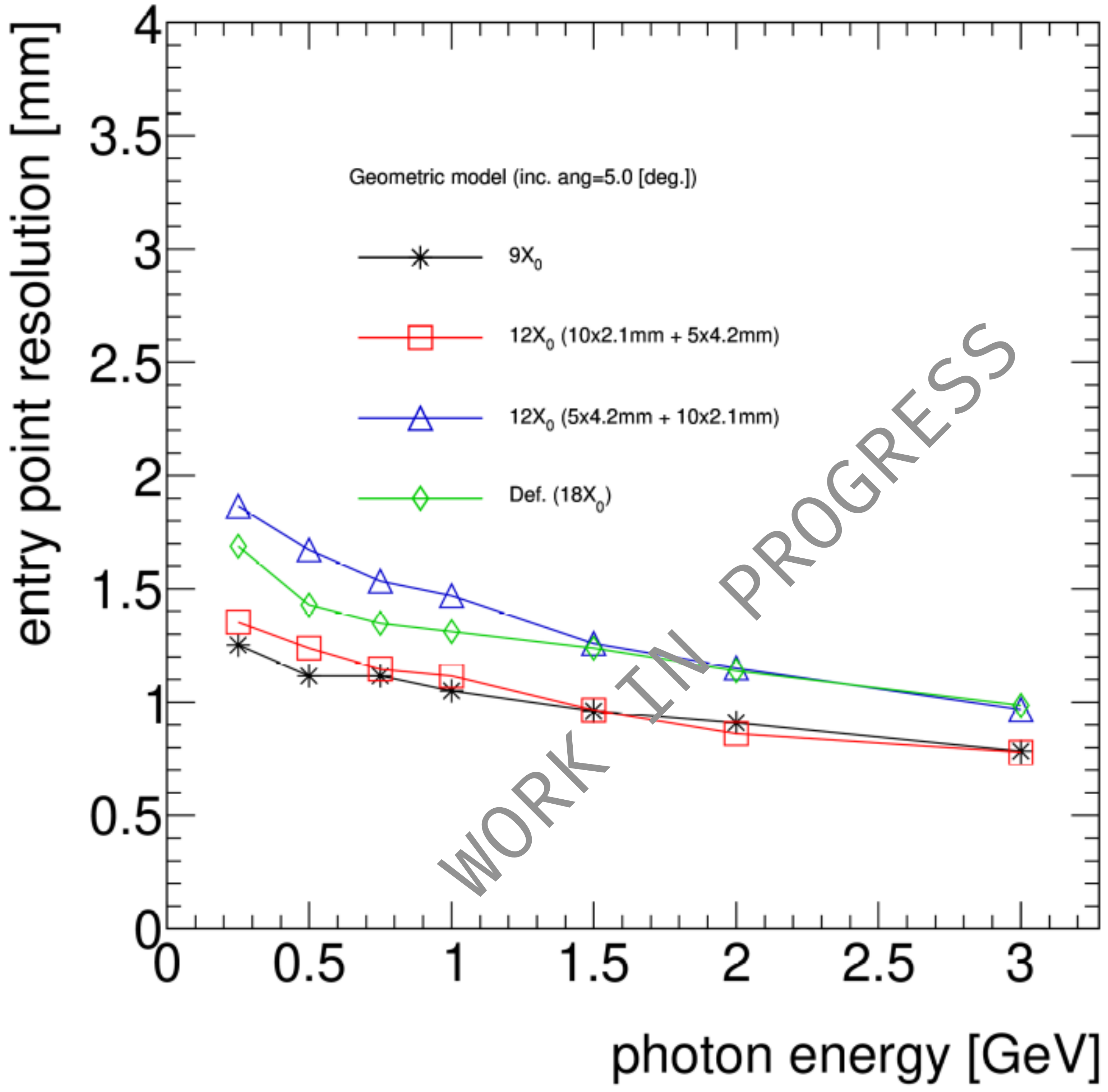
$18X_0$ (no air between layers)

More geometries: Results

- We kept the algorithms unchanged.



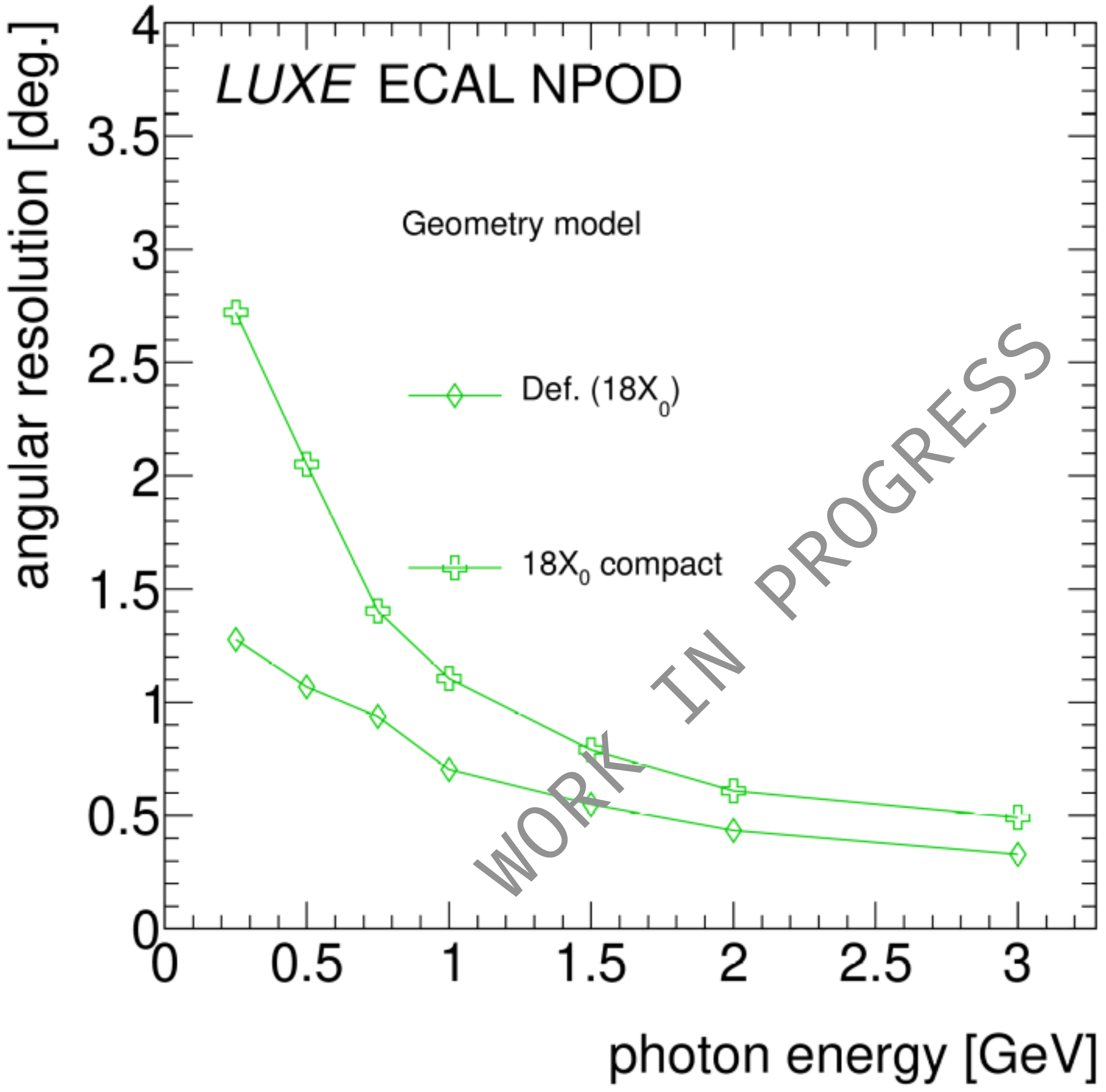
More W improves the angular resolution



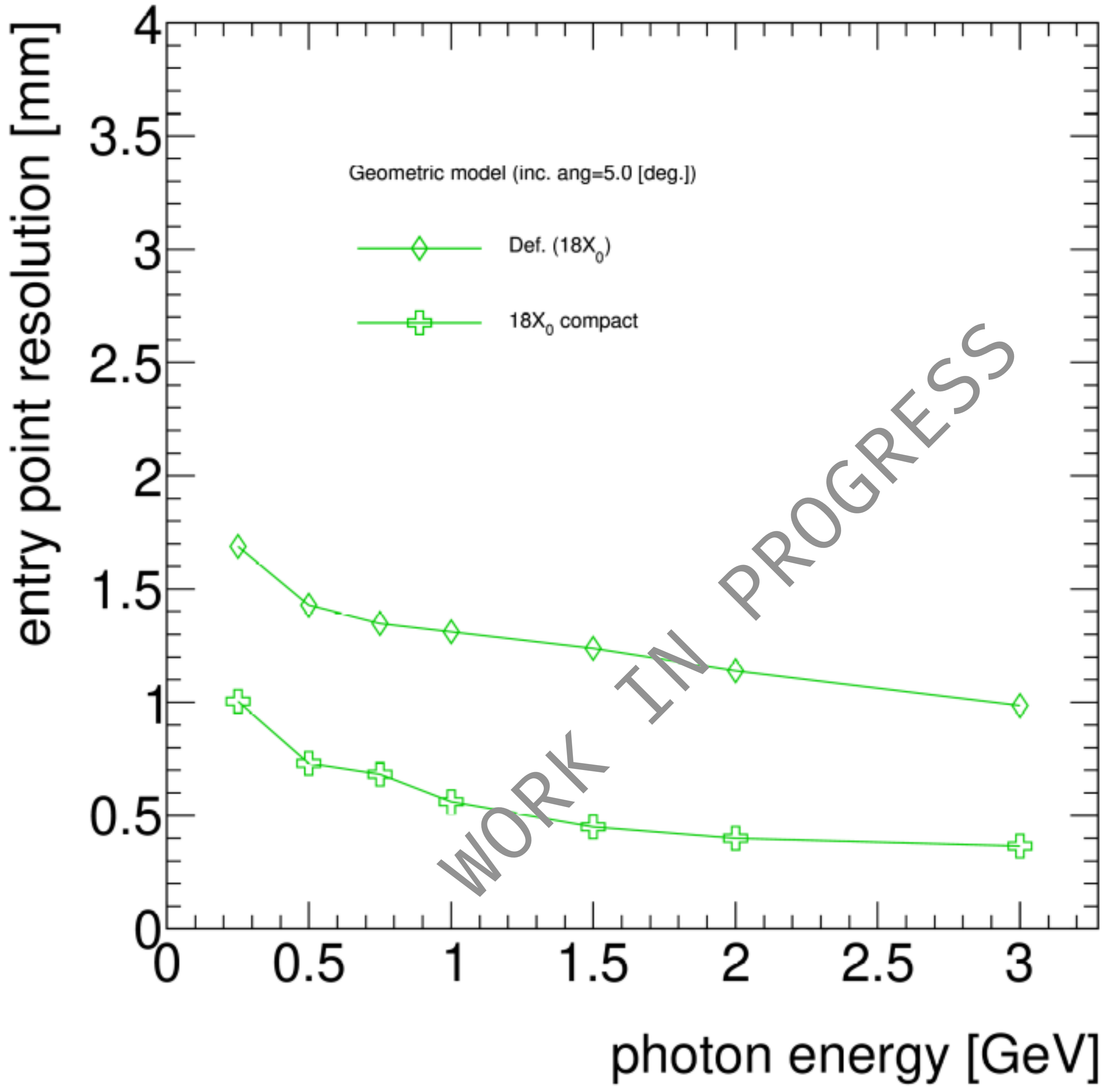
… but seems to worsen the entry point resolution

More geometries: Results

- We kept the algorithms unchanged.



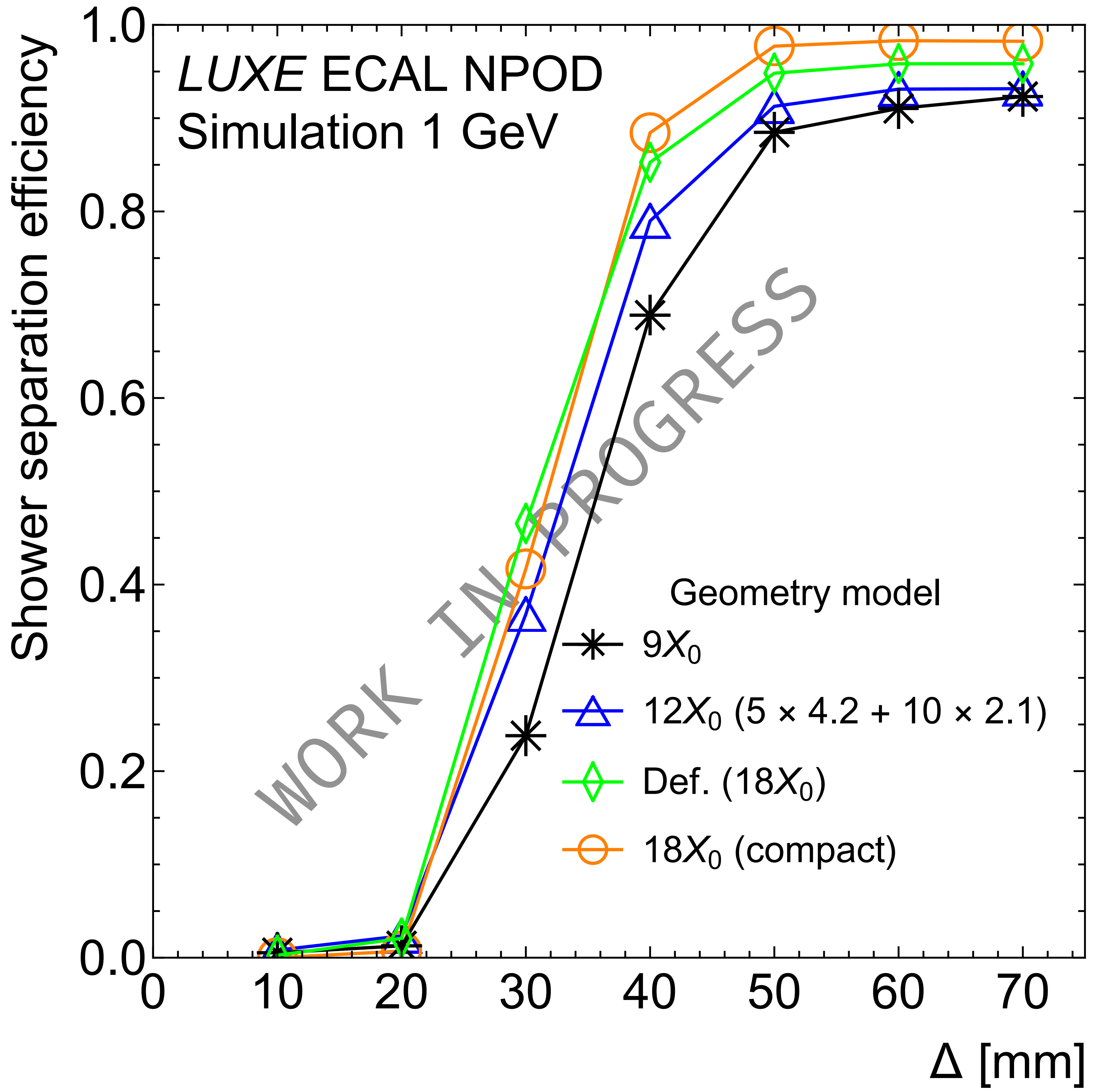
More compactness aggravates the angular resolution

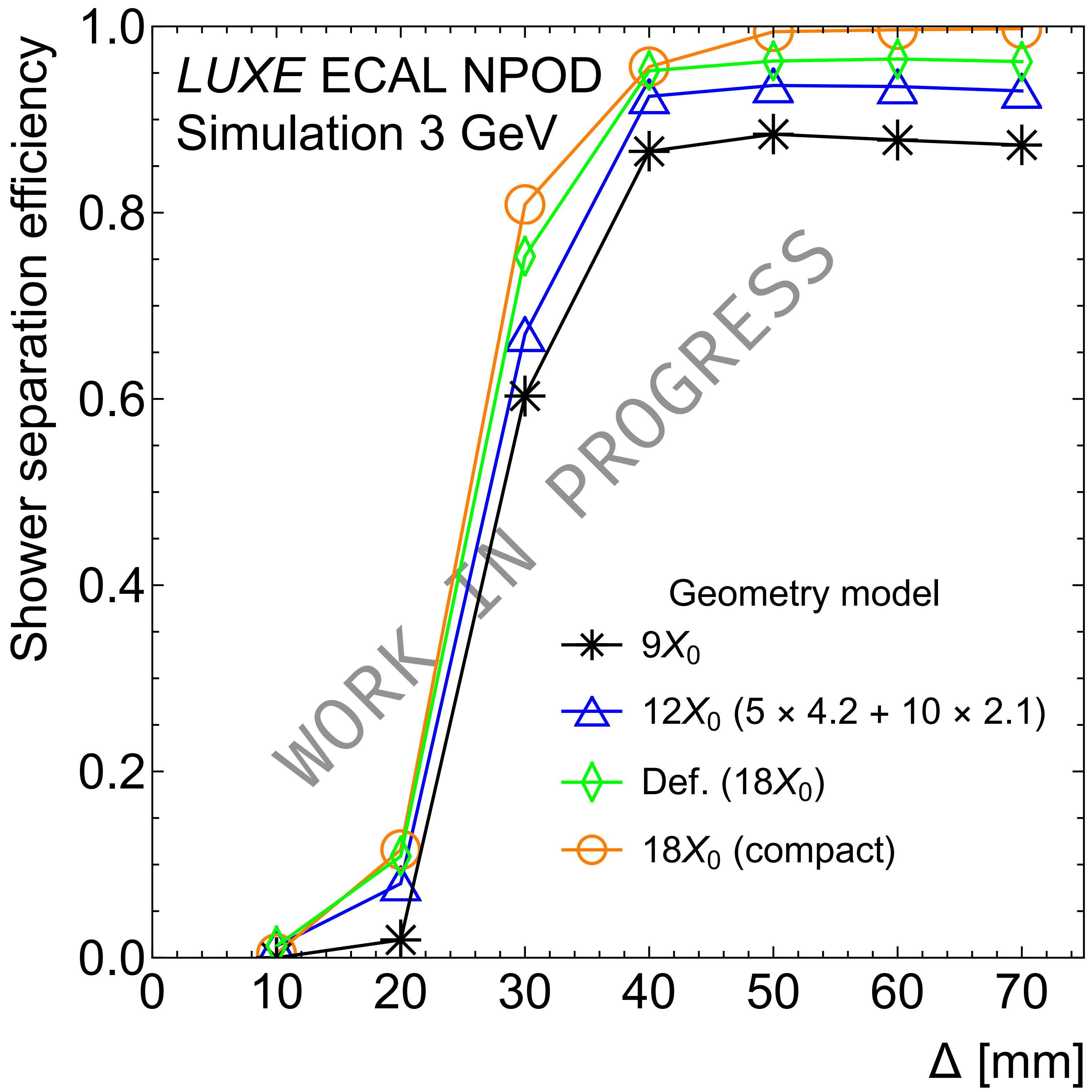


... but benefits the entry point resolution

More geometries: Results

- We kept the algorithms unchanged.





Compactness and more W generally improve the shower separation efficiency, but the critical point for Δ remains at 40-50 mm.