

Beam-dynamics-aware detectors

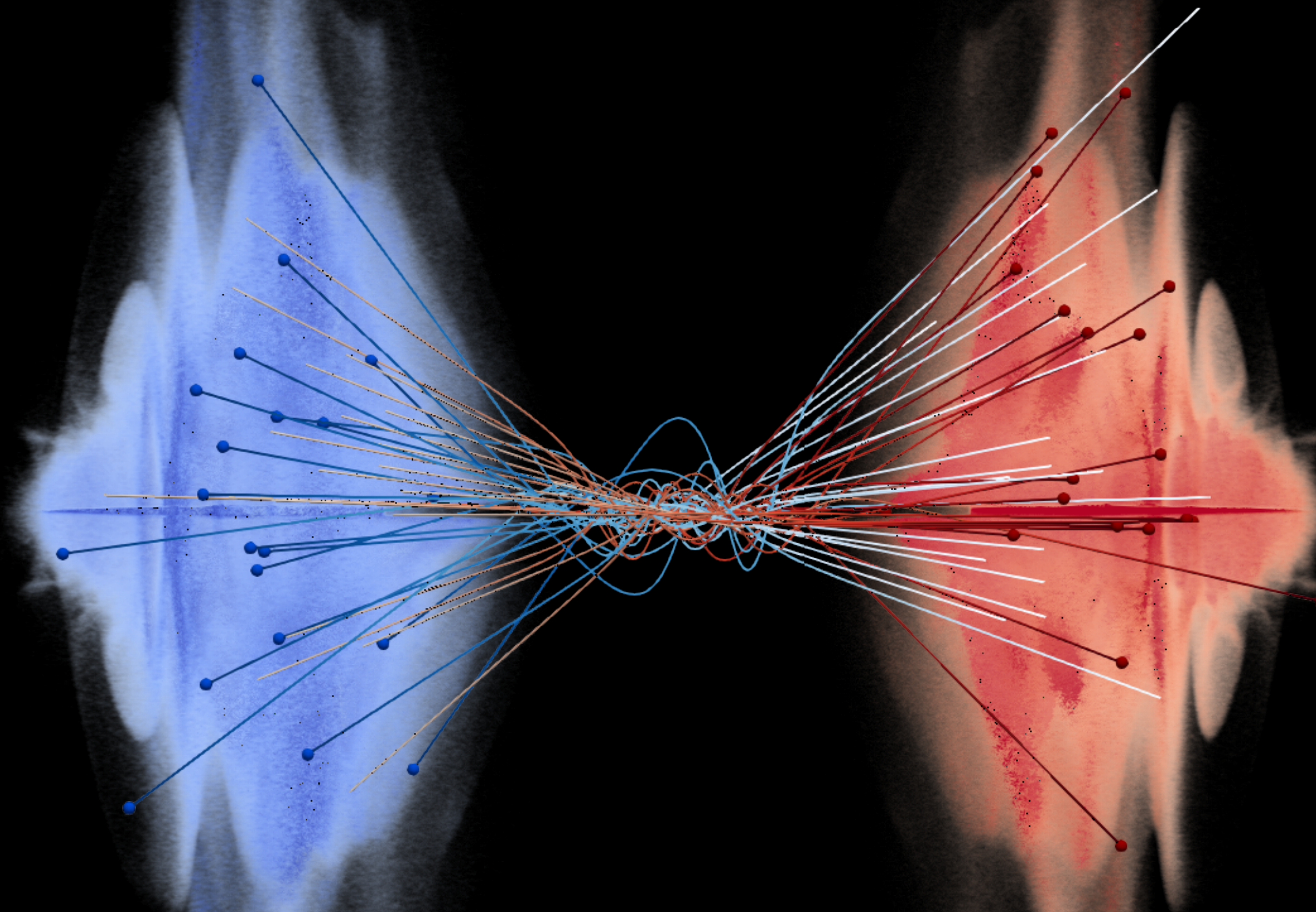


SMU

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Detector Optimization Weekly

Beam Dynamics

WarpX simulates the evolution of **particle species** (e.g., electrons, ions, etc.) in the presence of **electric and magnetic fields**.



Models beamstrahlung photons and incoherent e^+e^- pairs that strike the detector every bunch crossing

<https://blast-warpX.github.io/warpX-tutorials/install.html>

Goals of the project

- Machine detector interface in bilevel detector optimization
 - Coupling WarpX beam-beam simulation into the ddsim signal chain
- Code has been set up on NERSC



MDI stage

WarpX

Beam-beam at the IP:
beamstrahlung
+ pair production



Outer loop

ddsim

Geometry sweep
MDI overlaid



Inner loop

reco opt

Per-cell optimum
of reco parameters
Score: signal vs.
background

Warp-X pipeline: complete chain runs

- WarpX pipeline in place at Perlmutter@NERSC
- Can run pipeline on A100s
- Pipeline validation at Z-pole: 29,345 beamstrahlung γ generated
- Checked angular distributions and verified “soft” kinematics



- SLURM fan-out for production sweeps
- Per-event 5k bremstrahlung photons overlaid
- Warp-X run parameters adjusted so convergence time is faster

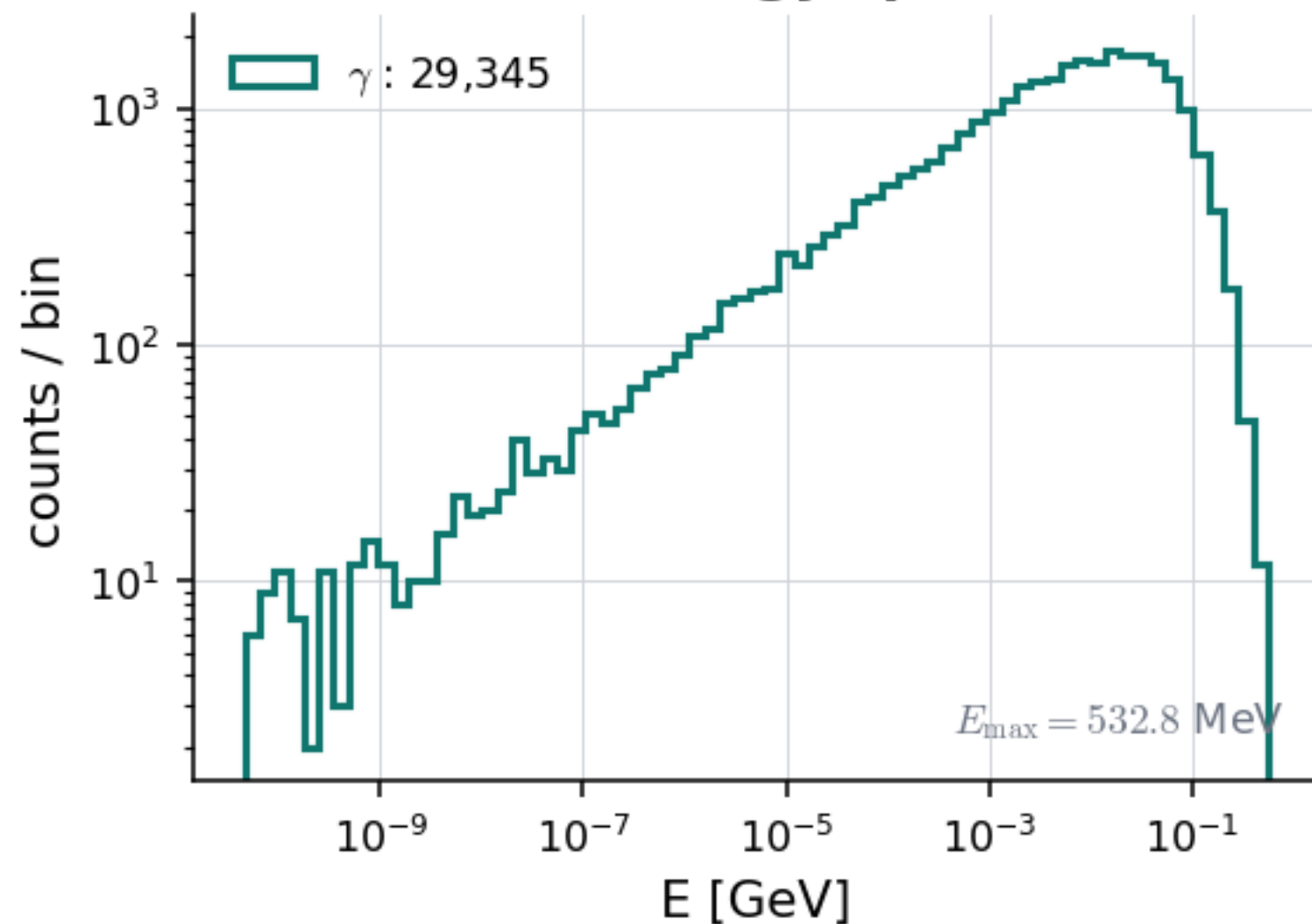
Visualization

- CLD: https://saptaparnabhattacharya.com/cld_o2_v08_explorer.html
- IDEA: https://saptaparnabhattacharya.com/idea_o1_v03_explorer.html
- Allegro: https://saptaparnabhattacharya.com/allegro_o1_v03_explorer.html
- I have included beam dynamics as well, but it is with a Gaussian assumption (not from Warp-X)

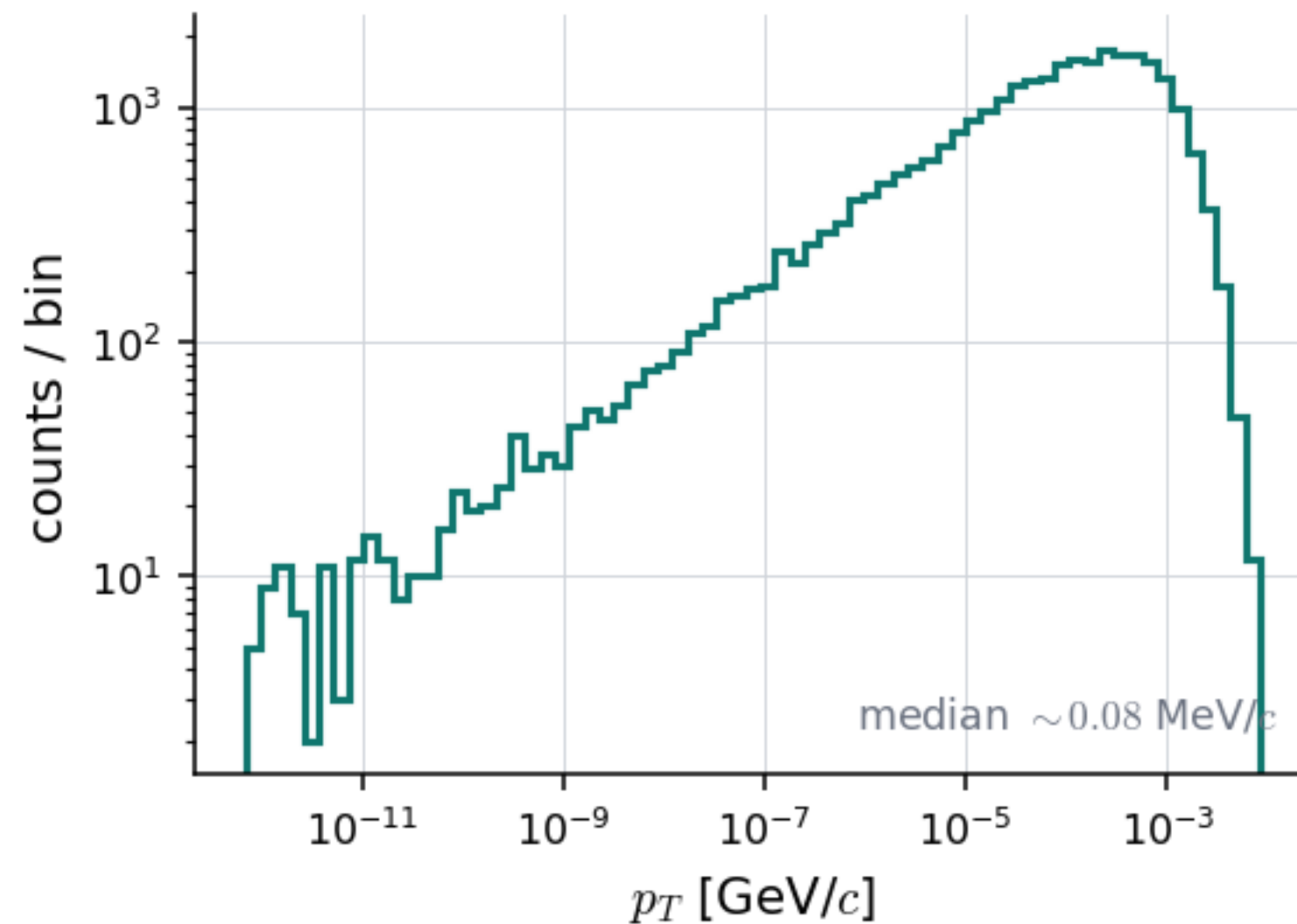
FCC-ee MDI smoke test — Z-pole, 29k photons

$\sigma_y = 3 \mu\text{m}$, 2×10^6 macros, $256 \times 128 \times 256$ cells

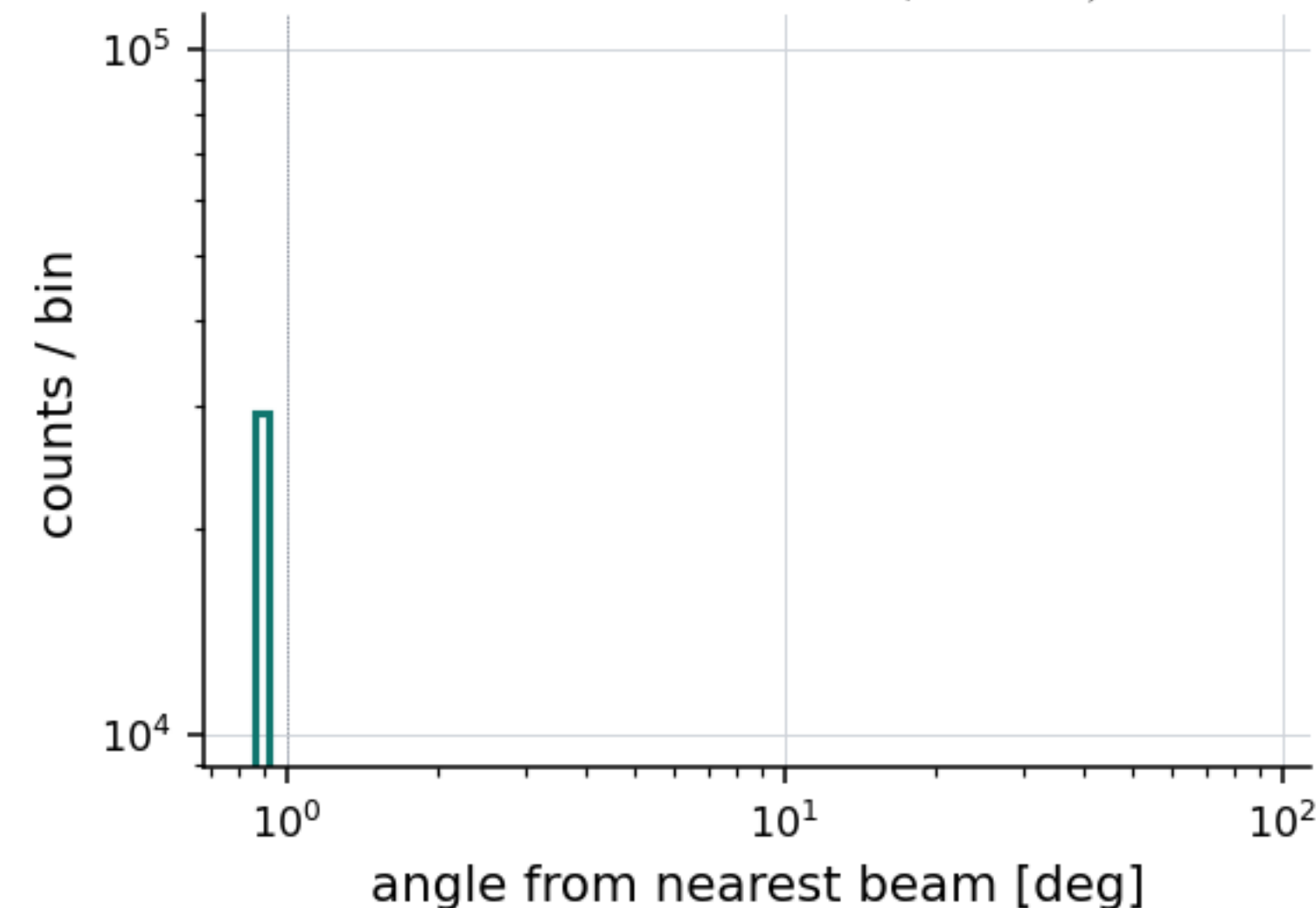
Photon energy spectrum



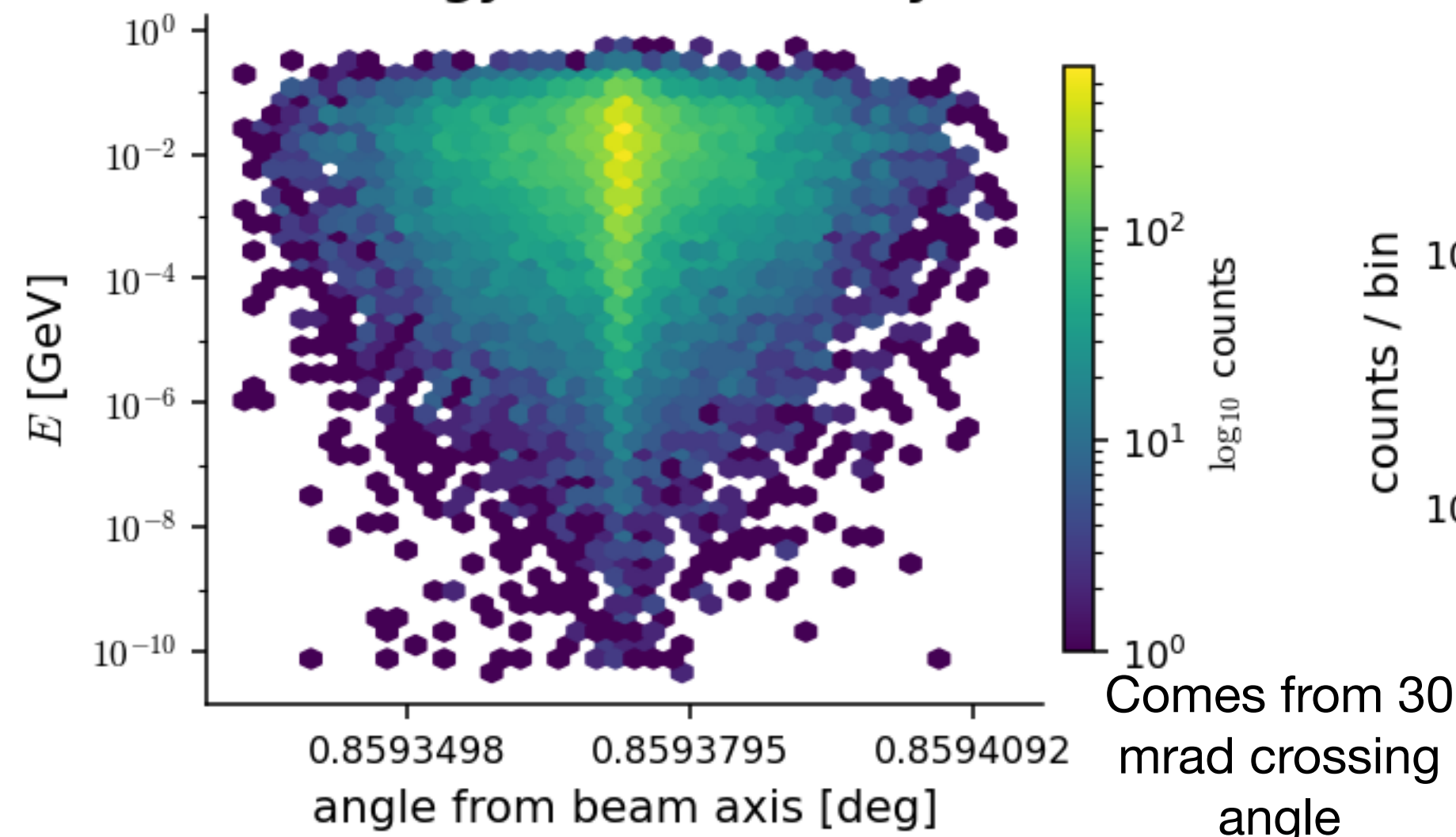
Transverse momentum



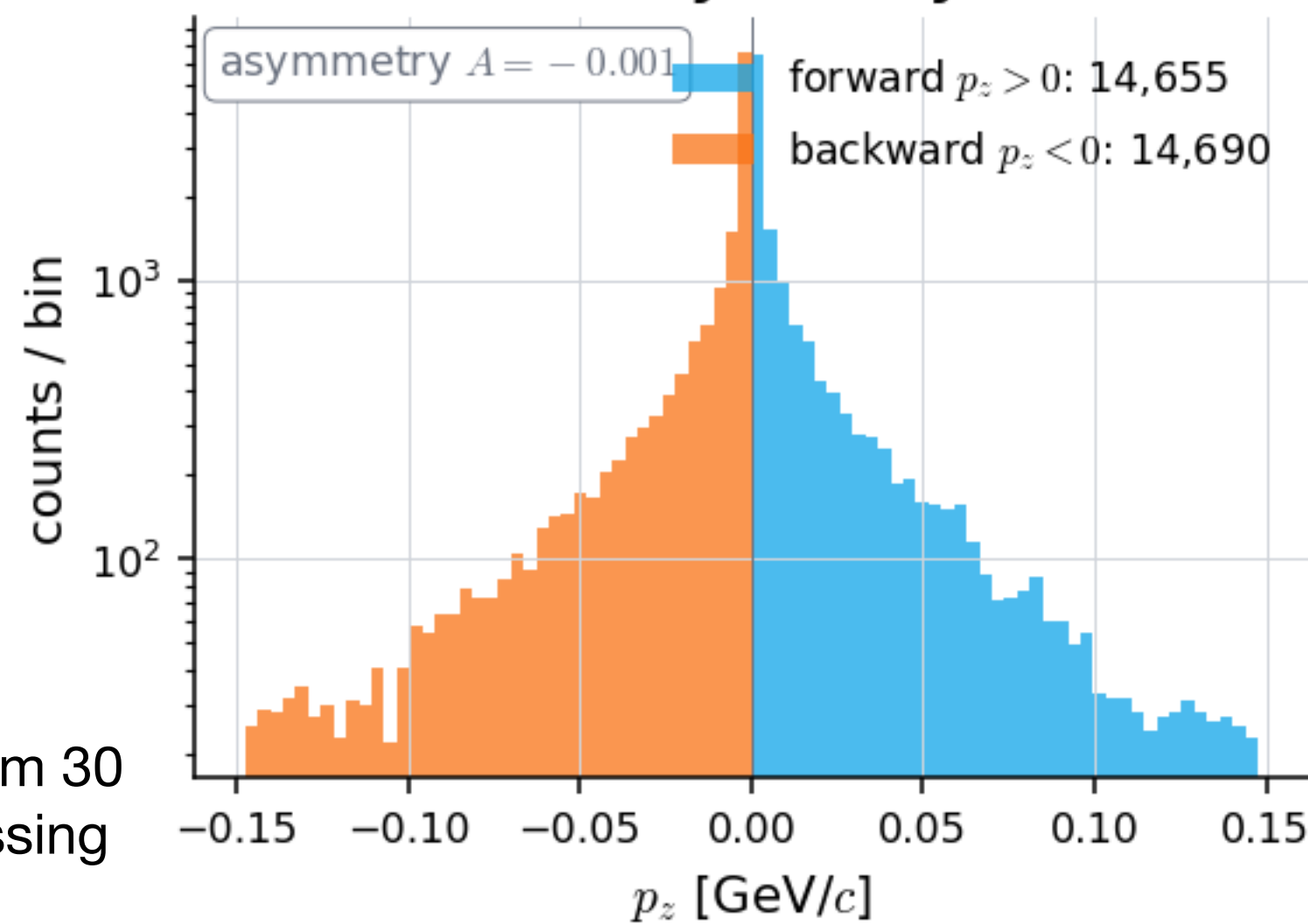
Collinearity, $\min(\theta, \pi - \theta)$



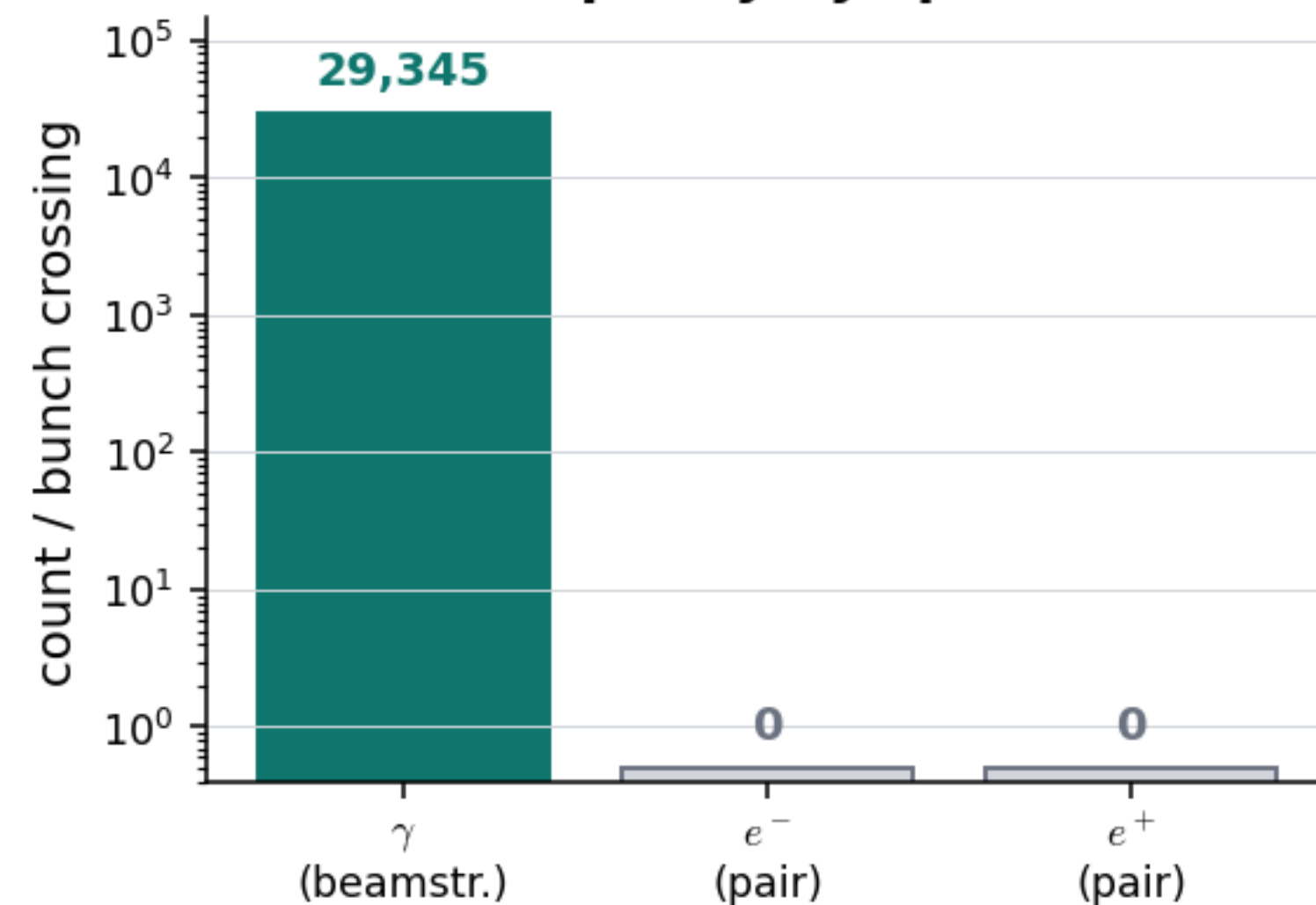
Energy vs. collinearity



F/B symmetry



Multiplicity by species



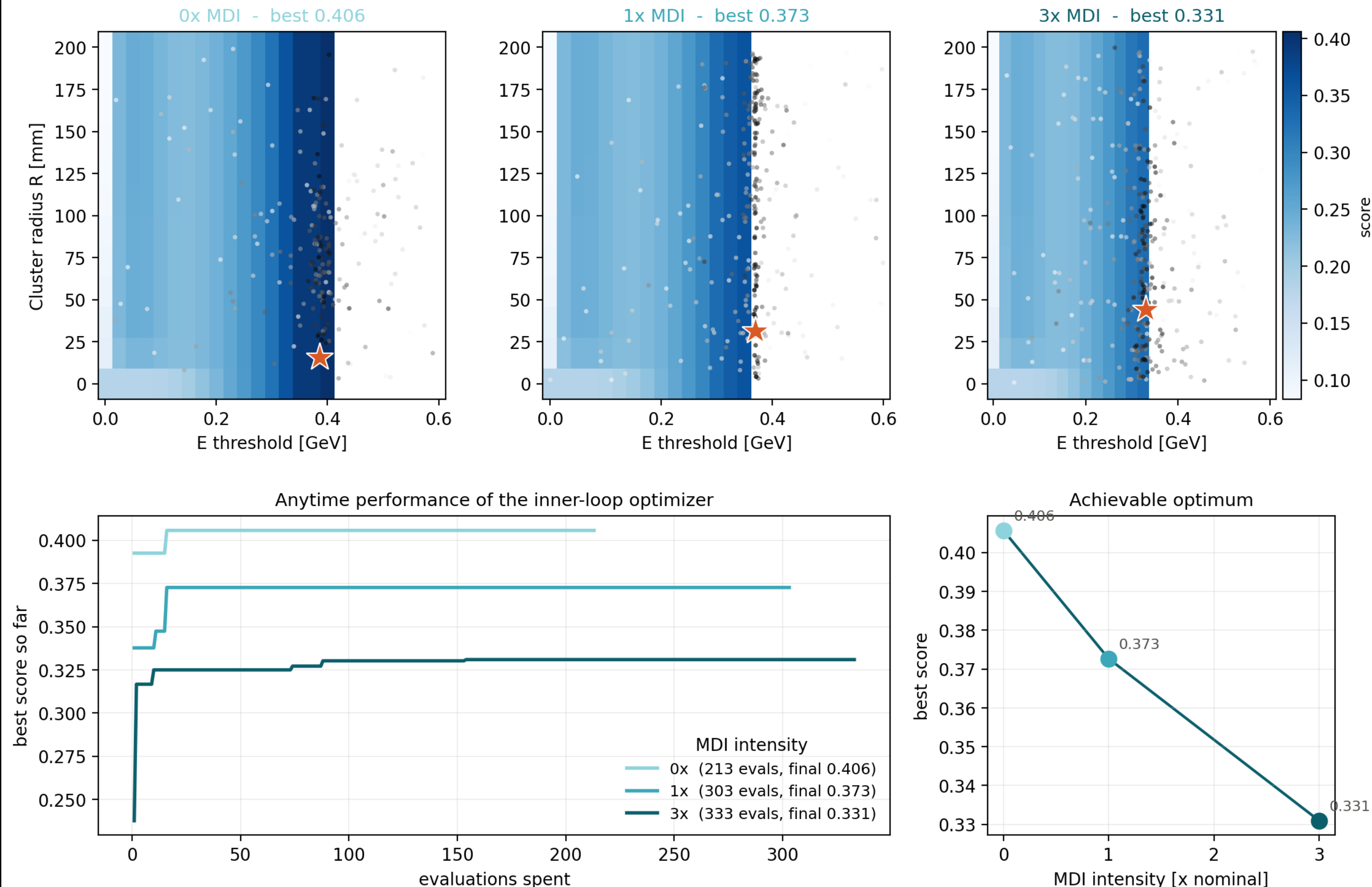
Smoke-test fidelity: $\chi_{\text{min}} = 10^{-5}$ engine threshold lowered to fire at our undersampled χ . Multiplicity and spectrum should NOT be quoted as FCC-ee predictions. pair species suppressed by Breit-Wheeler at $\chi \ll 1$

Visualization

- The re-optimize reconstruction vs background intensity:
 - 0 X overlay (default)
 - 1 X overlay (nominal)
 - 3 X overlay (exaggerated)

Landscape view: the basin slides, fades, and shrinks

Inner-loop optimization vs MDI background intensity — landscapes, trajectories, anytime performance



Ridge slides & dims

optimal-threshold band moves left, peak fades with intensity

Feasible region shrinks

white dead zone (no surviving hits) advances to lower thresholds

Optimization hardens

DE needs 213 → 303 → 333 evaluations; 27→41% land infeasible; convergence ~5× slower at 3×

Score: event-averaged $E_{\text{clus}}/\sigma_0\sqrt{n_{\text{hits}}}$ $\sigma_0 = 1$ GeV (normalization only); events with empty clusters excluded from the mean, score = $-\infty$ if all clusters empty.

Next steps

- Full chain with results ready
- Synchronize with Qibin on optimization target