

Differentiable Surrogate for WCTE

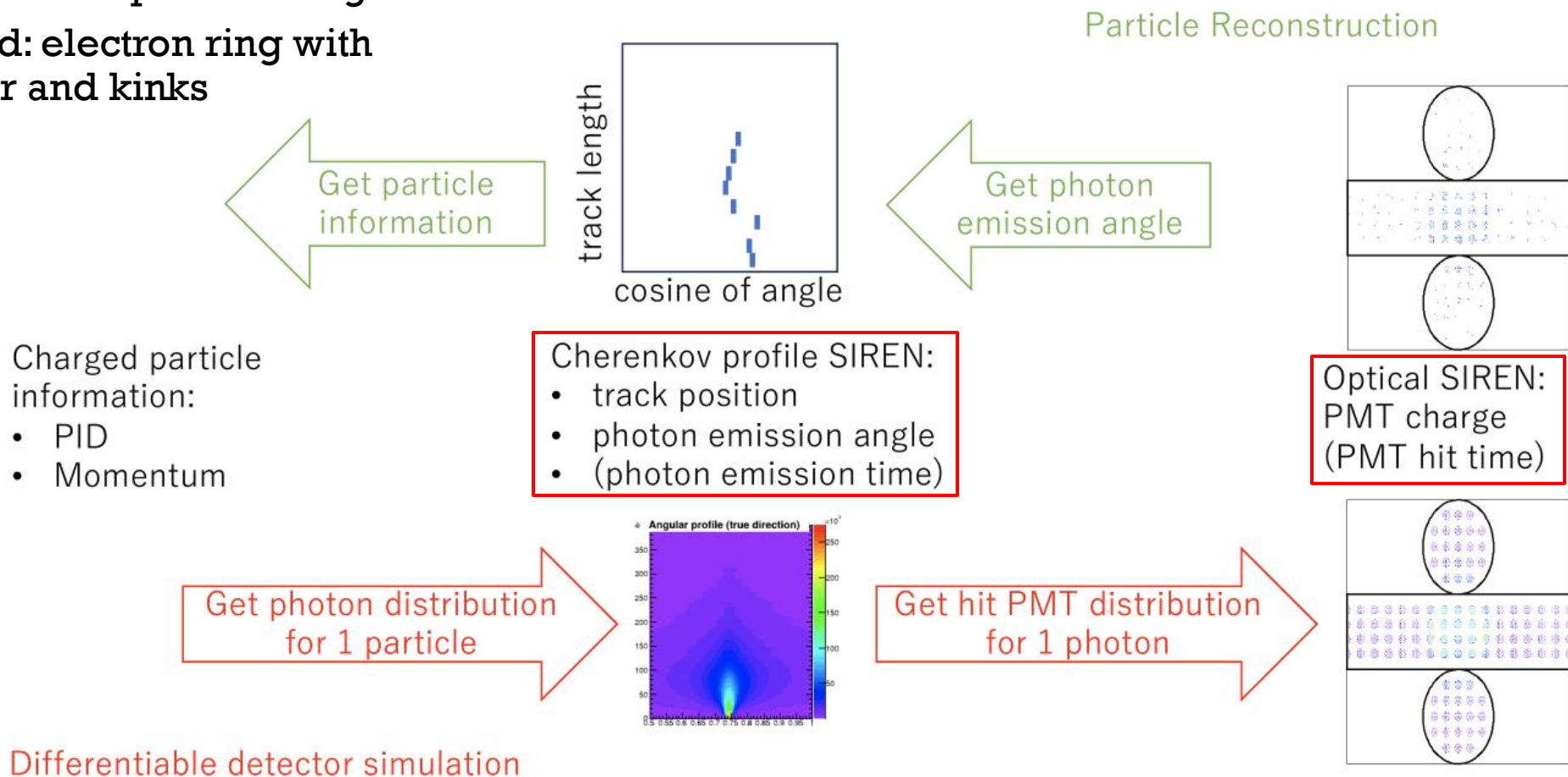
Ka Ming Tsui
Ryo Matsumoto
Ryotaro Tsuchii



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Project goals

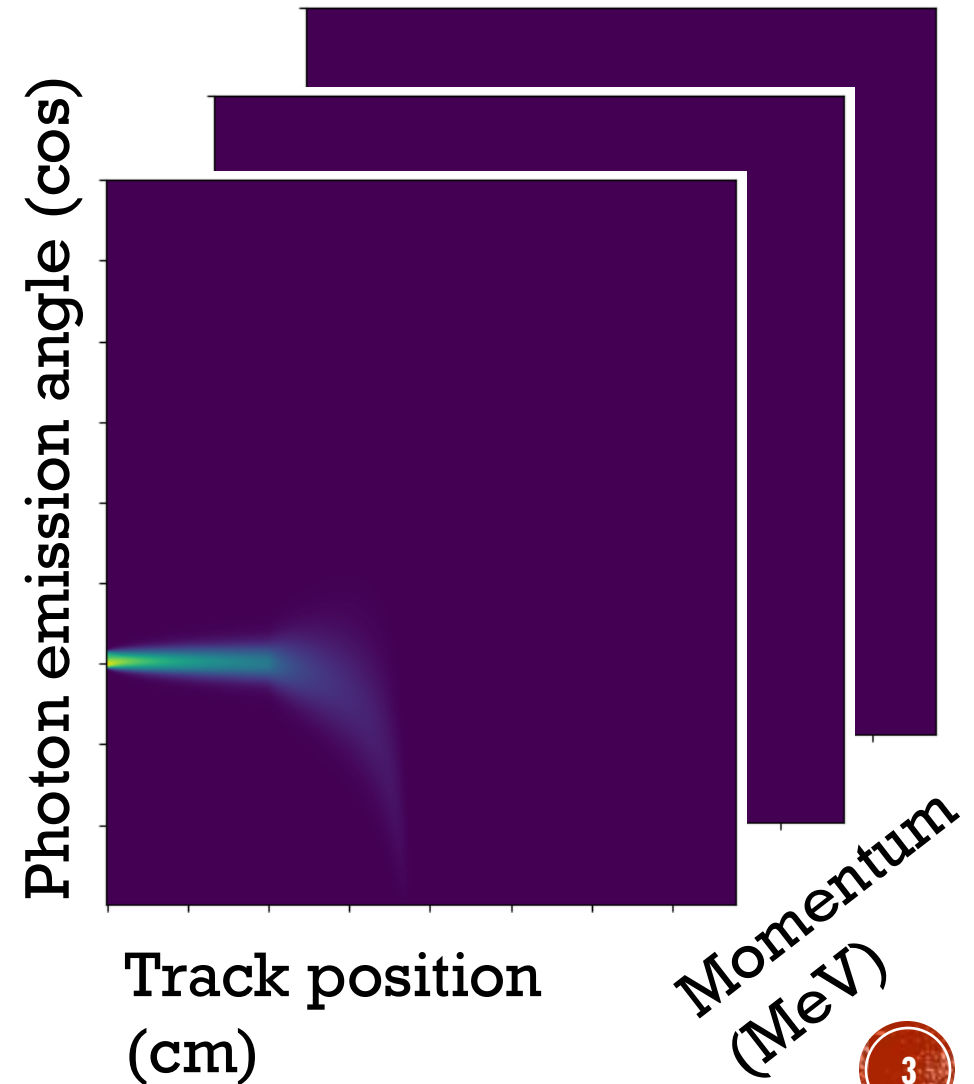
- Track reconstruction and classification
 - This workshop: Muon ring
 - Beyond: electron ring with shower and kinks



Cherenkov Siren

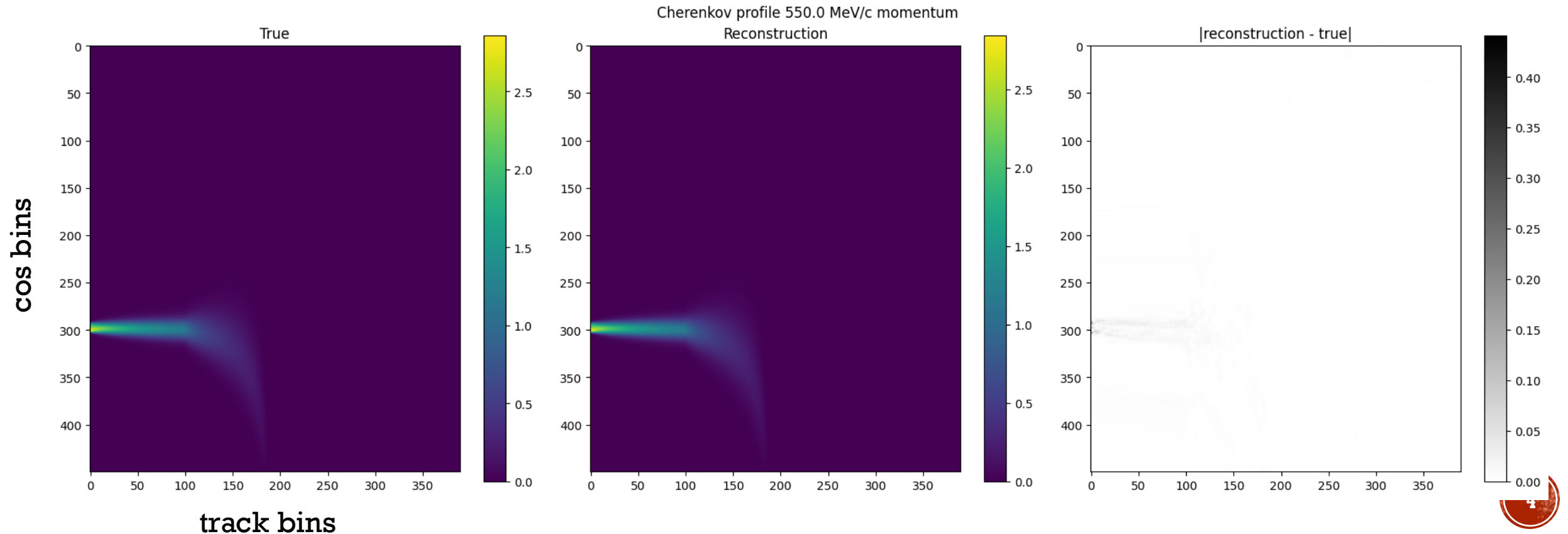
- Generate photon yield table from MC simulation (WCSim)
 - Muon, electron, pion
- Siren training
 - Inputs: photon emission angle (cos), track position (s), initial momentum
 - Smaller bins around peak to capture more details
 - Output: photon yield/cos/s
 - MSE loss

Example: μ profile
(550MeV/c, non-linear bins)

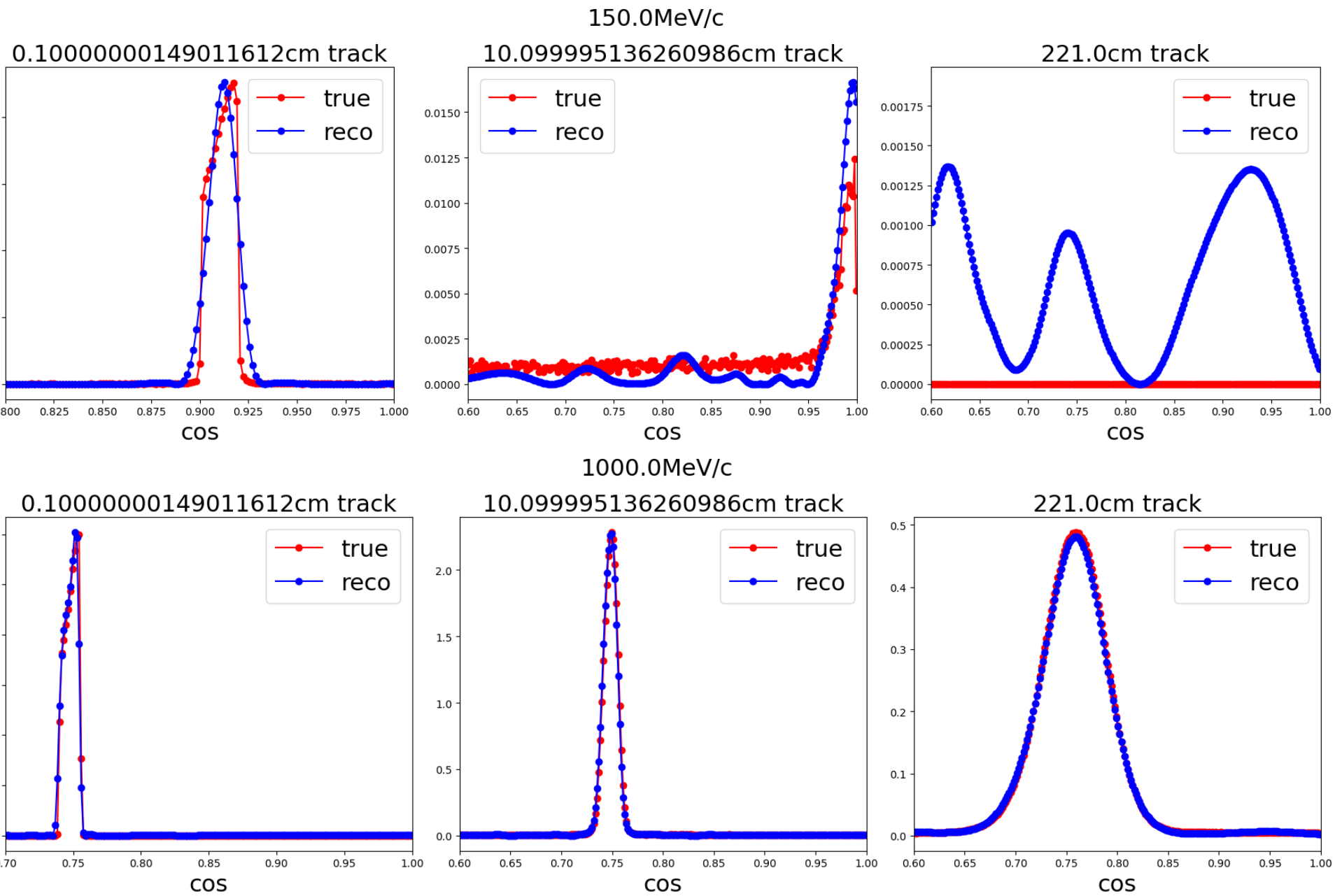


An example of μ profile (550MeV/c)

- Color shows the number of photons / event (normalized by 10^4 to make training efficient)

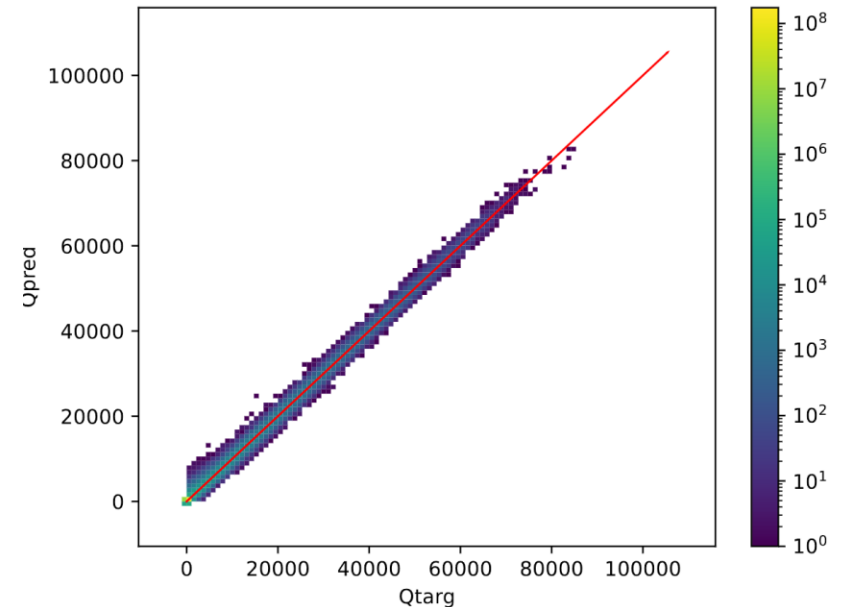
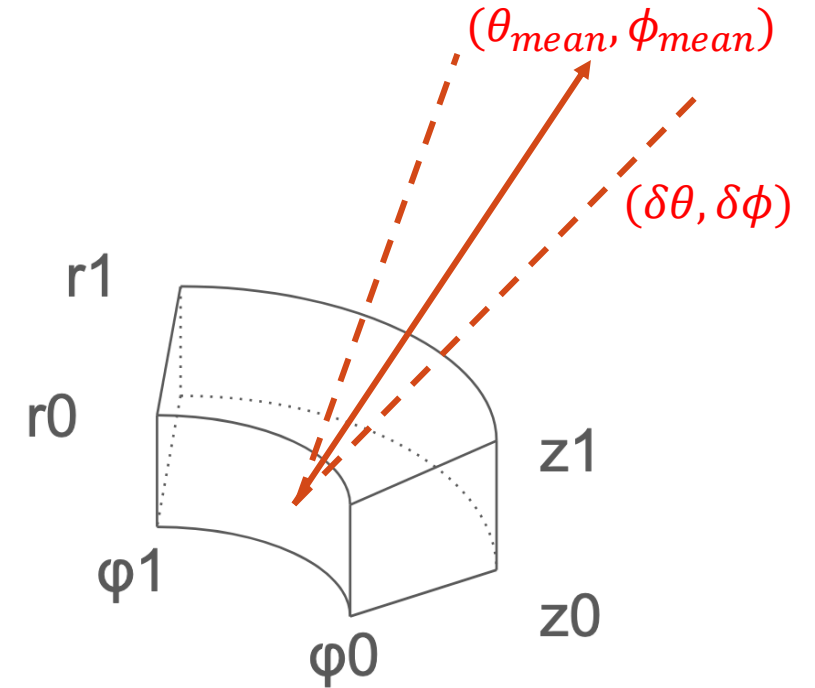
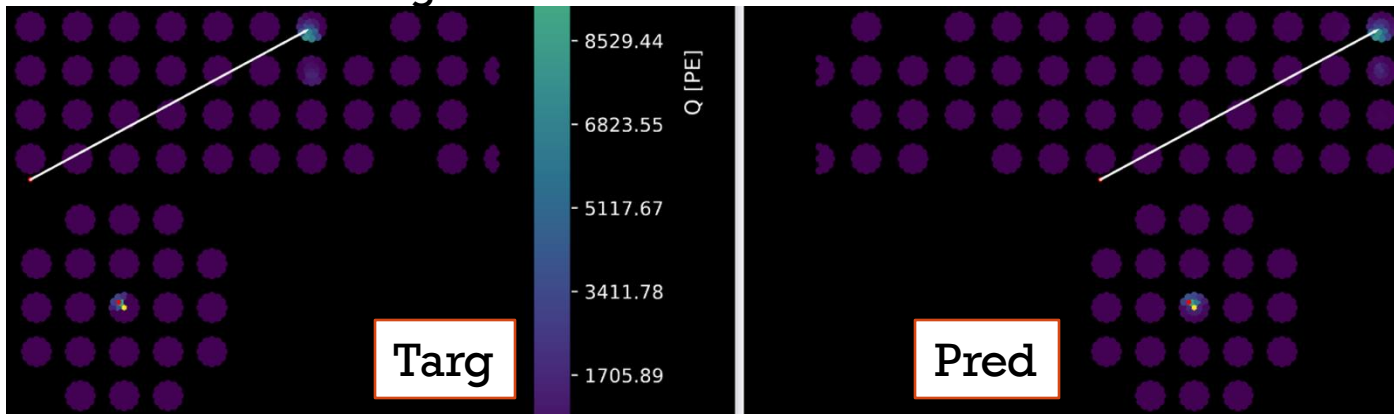


A projection to cos distribution

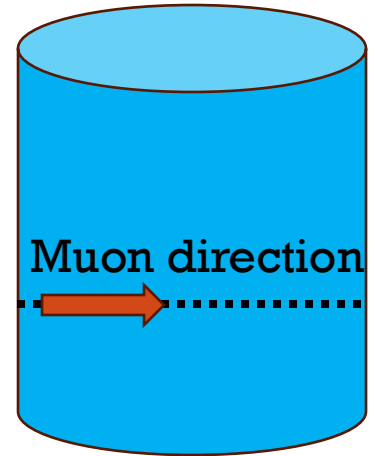


Optic Siren

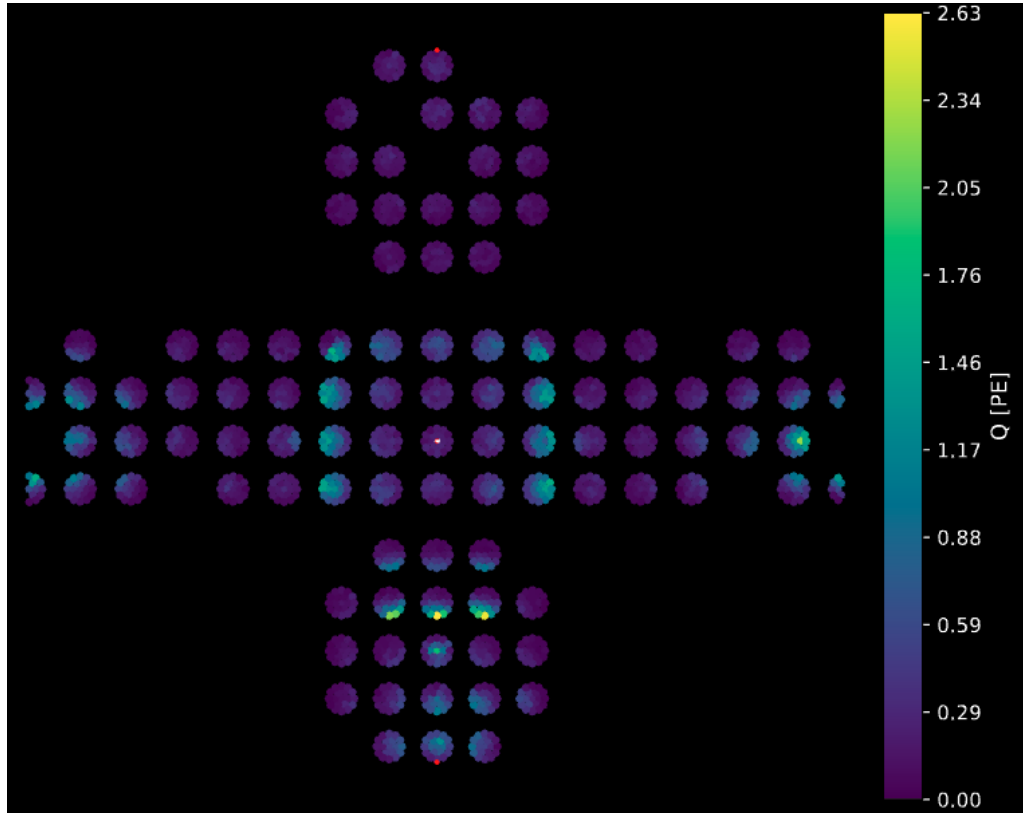
- Training data for WCTE
 - Uniform vertex and isotropic emission within voxel
 - 20 cm bin size in r and z: 2268 sampling positions
 - 10 deg bin in direction: 684 sampling directions (solid angle not conserved)
 - Photons per voxel : $0.5M * 2$
- Inputs: photon starting position and direction
- Outputs: charge prediction per PMT (1843 in total)
- Loss: $\text{Poisson}(Q_{\text{targ}}, Q_{\text{pred}}) * Q_{\text{targ}}$
- Worst performance at low charge region
 - Back scattering/reflection is not modelled well



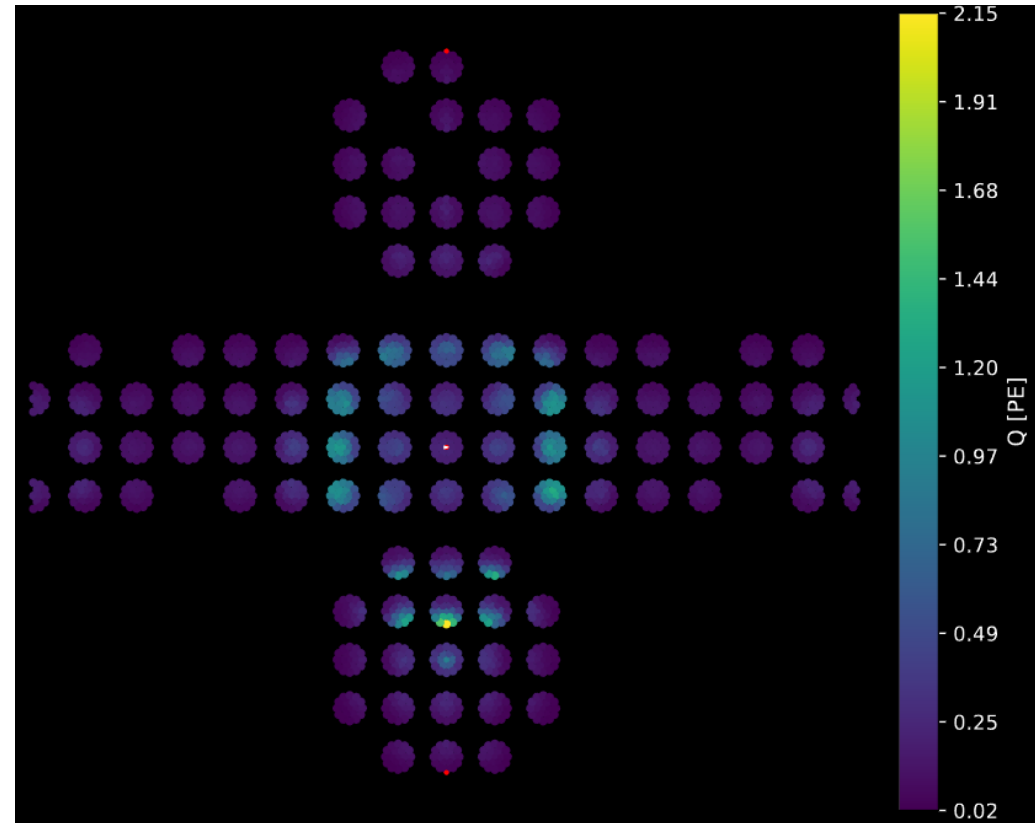
A simple demo of forward simulation



- 200 MeV/c muon
 - Ring edge not sharp enough
 - Missing backward hits

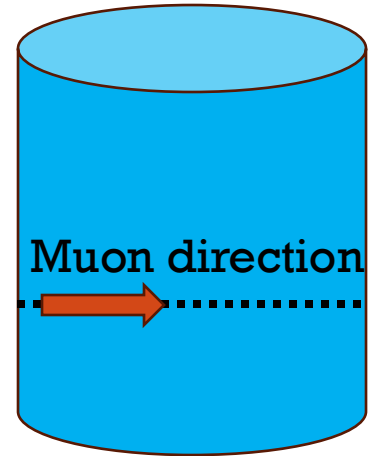


MC simulation

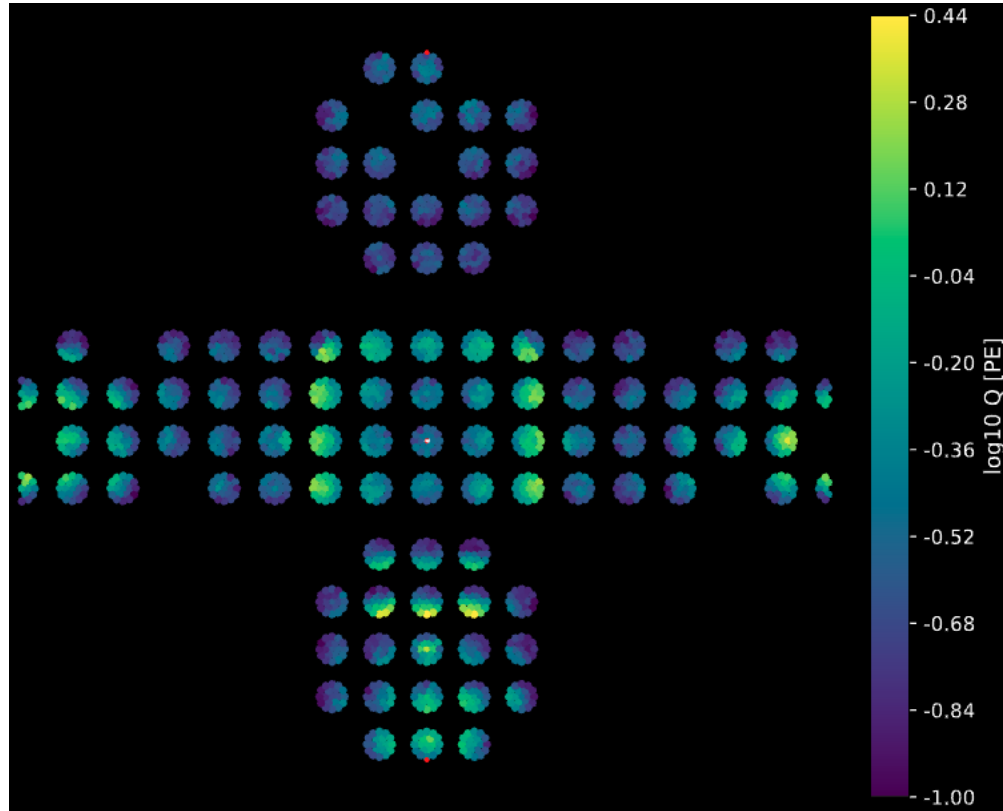


Siren

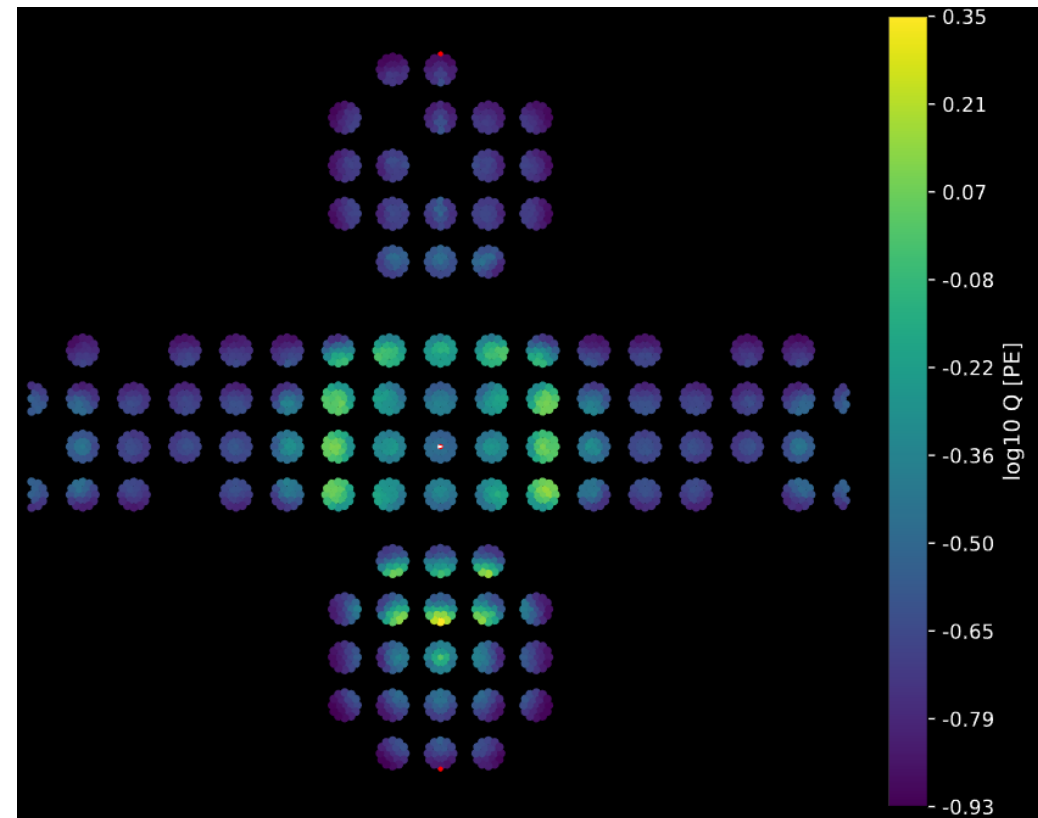
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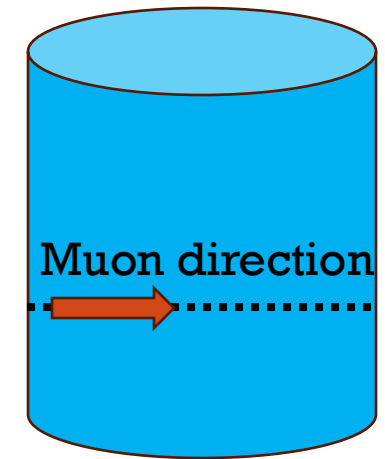


MC simulation

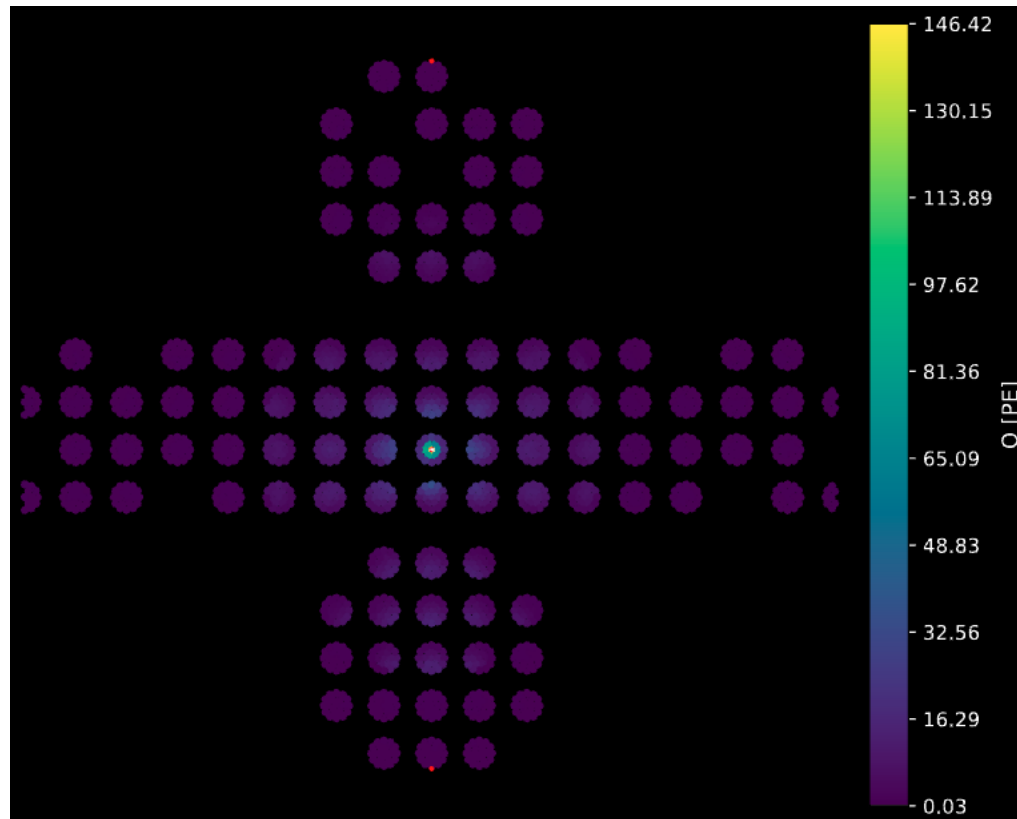


Siren

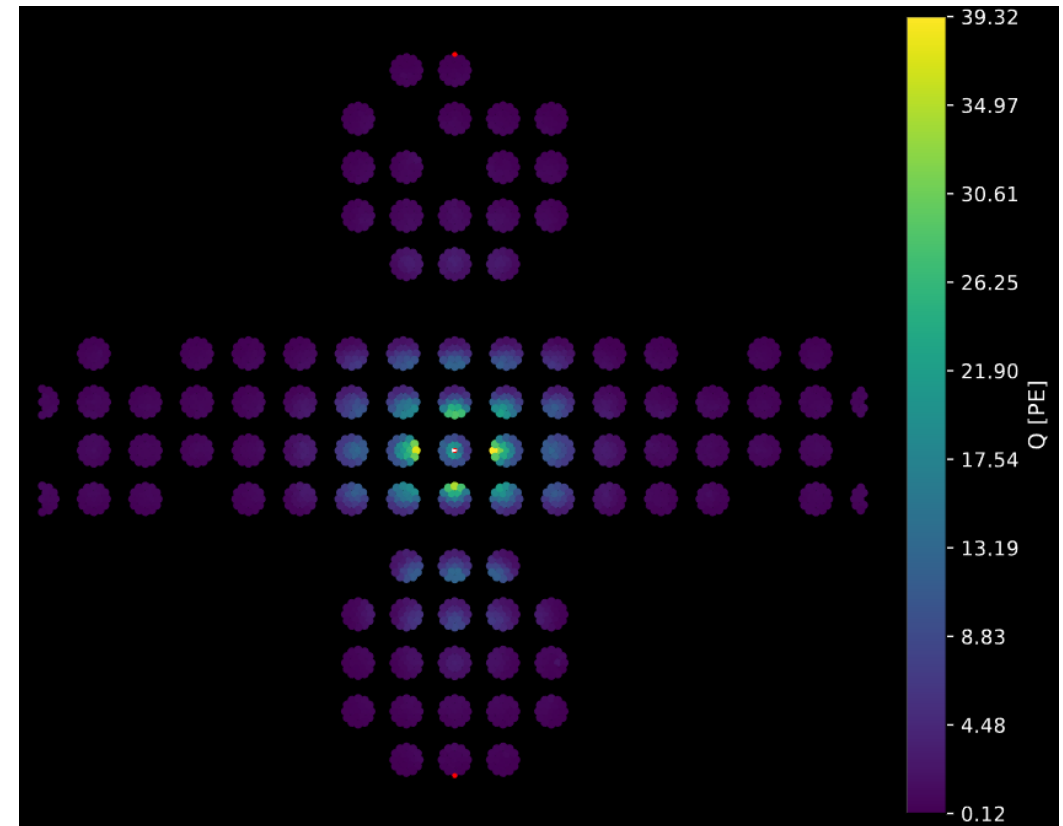
A simple demo of forward simulation



- 1000 MeV/c muon
 - mPMT prediction on beam axis is way off

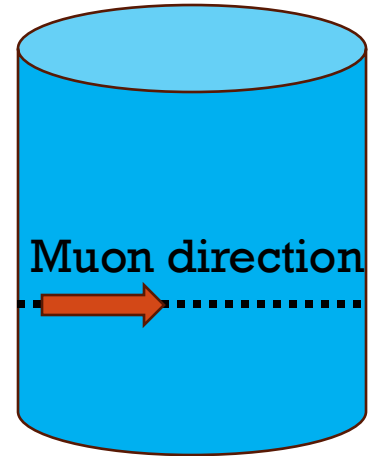


MC simulation

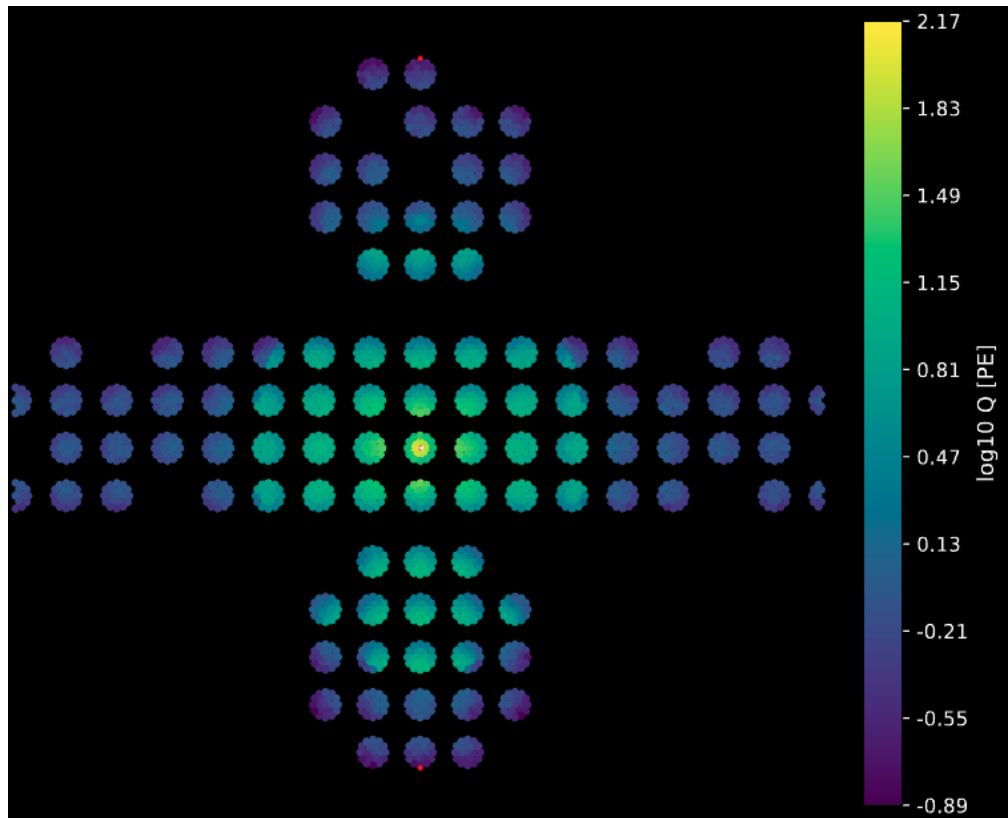


Siren

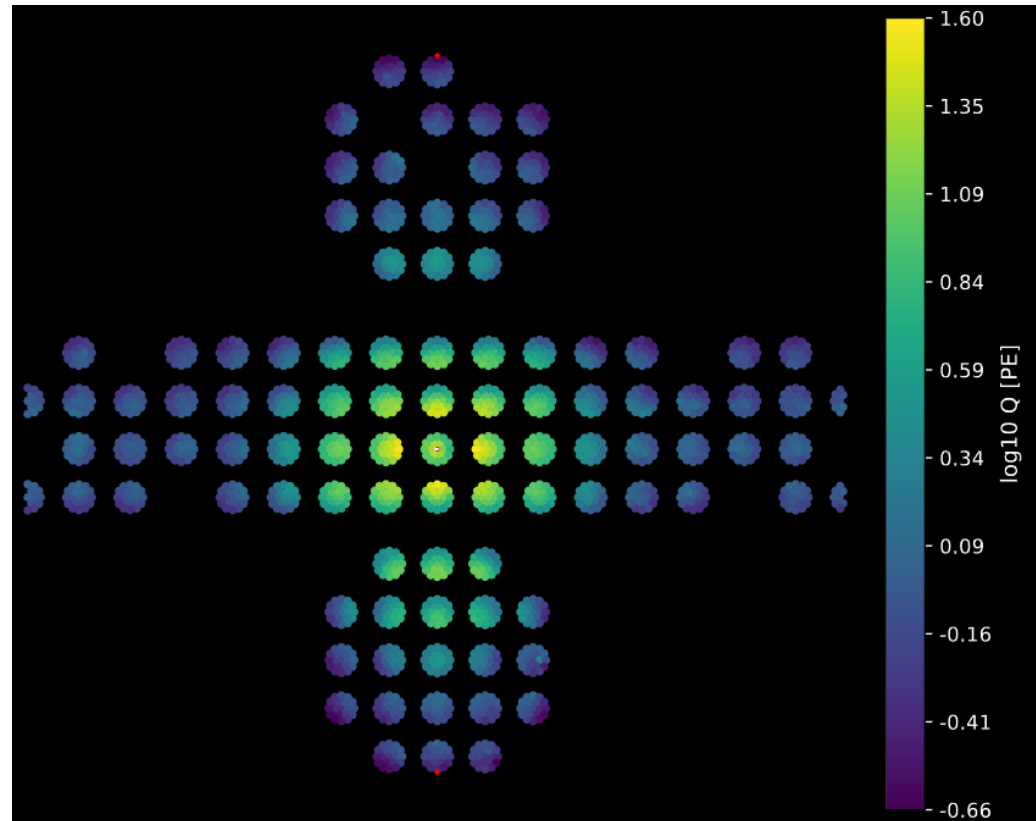
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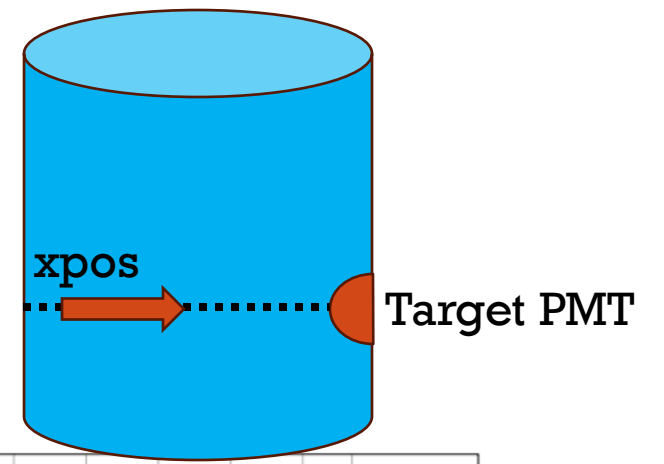


MC simulation

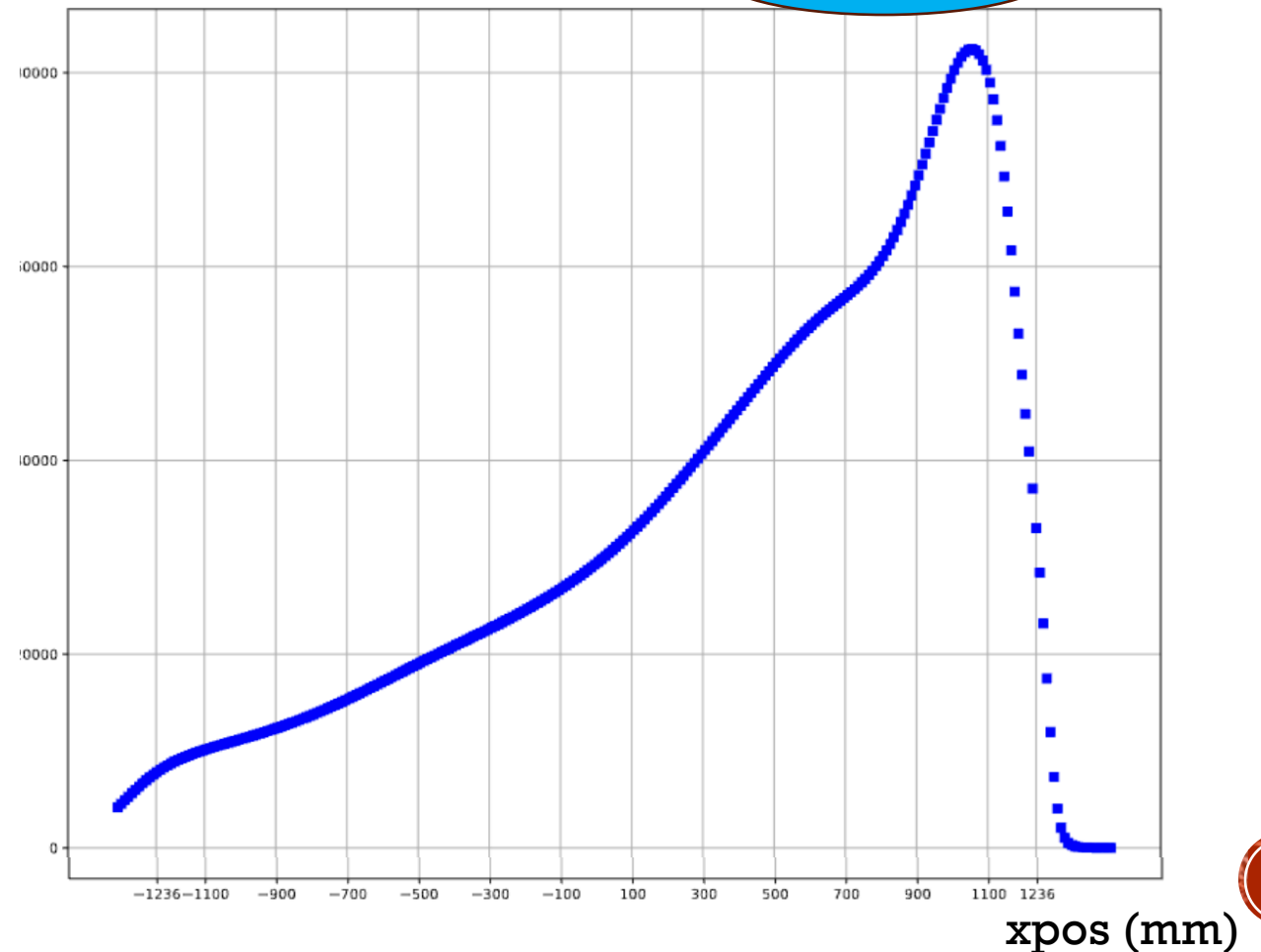


Siren

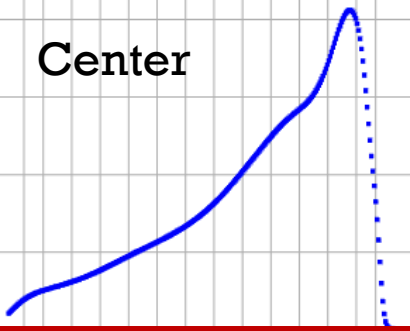
Undesirable OpticSiren response



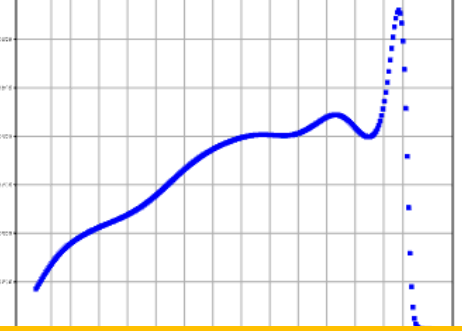
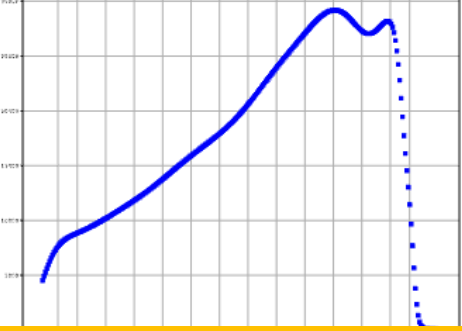
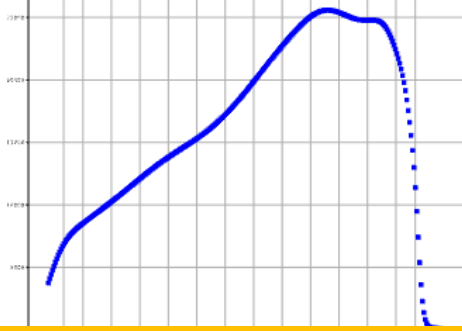
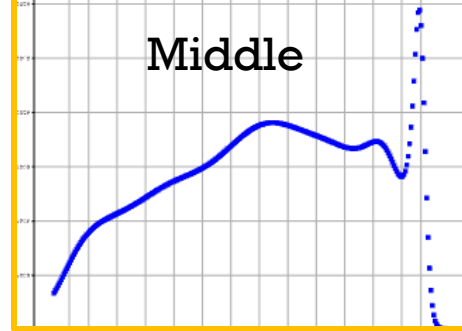
- Bin size in training data (200 mm)
 - Rapid drop in acceptance when starting position is close to target
 - Fuzzy ring edge?
- No voxel position near mPMT



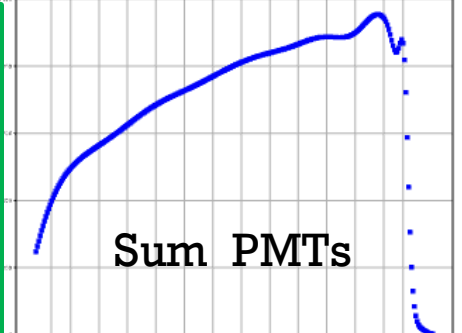
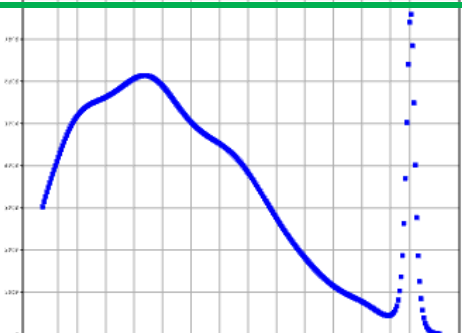
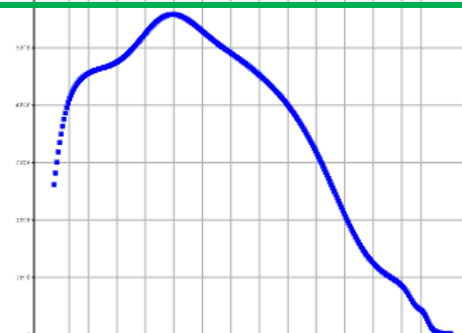
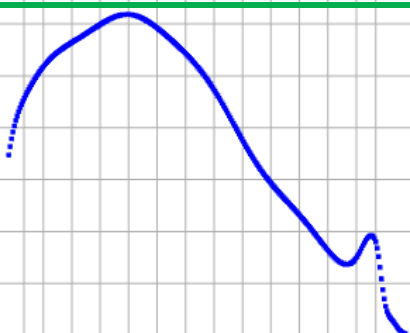
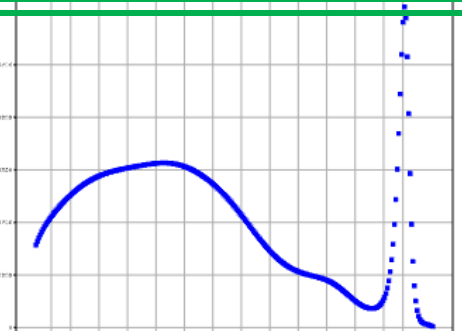
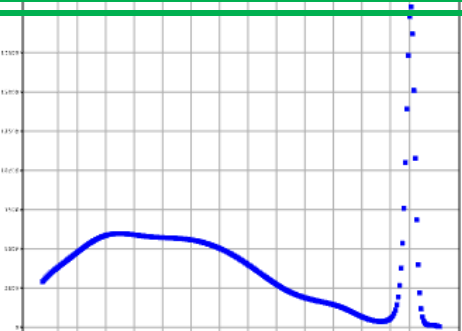
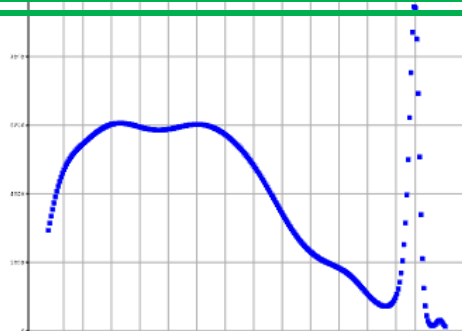
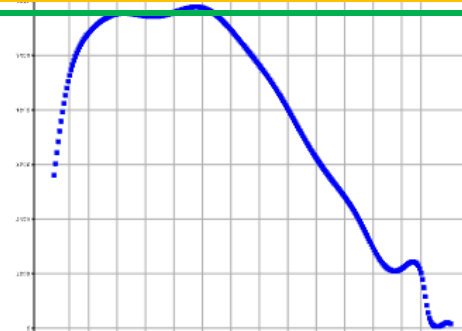
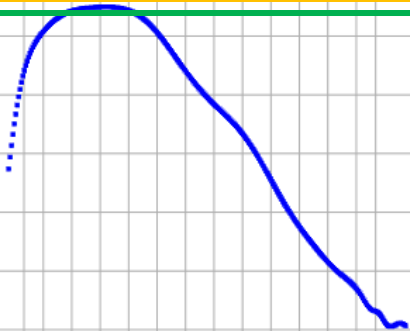
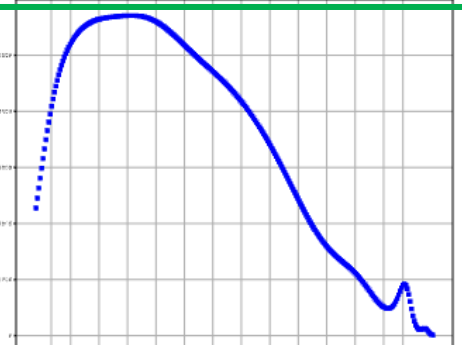
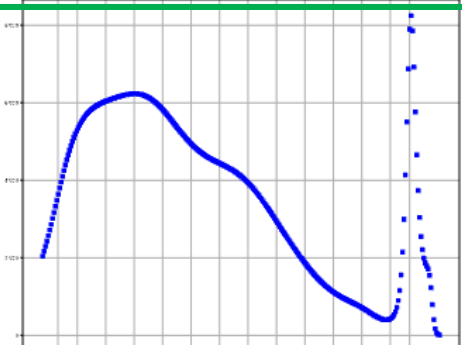
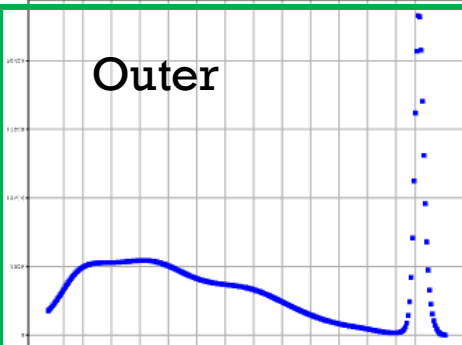
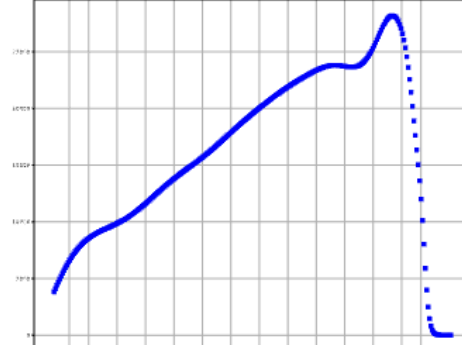
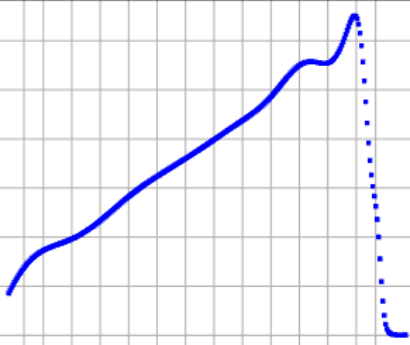
Center



Middle



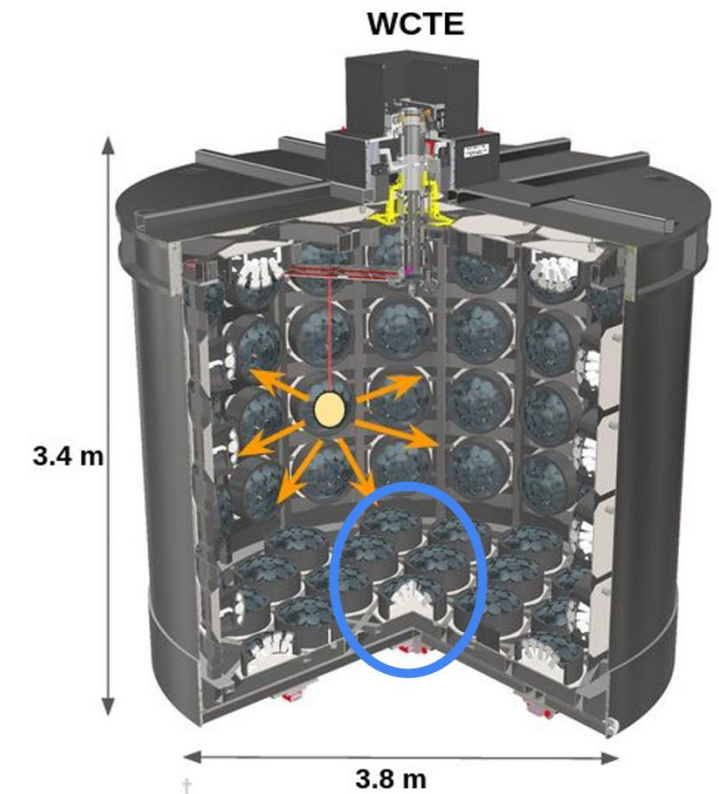
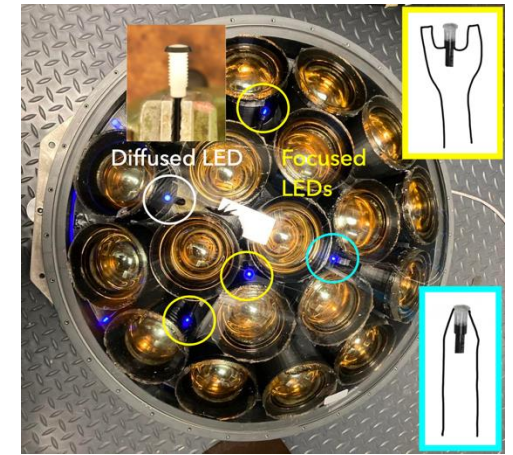
Outer



Sum PMTs

Fine tuning with calibration data

- Available calibration sources in WCTE
 - LED installed inside mPMT: point source with different opening angles; training data does not cover such large r/z positions
 - Diffuser ball: finite volume with isotropic emission
- Training data has finite volume and emission cone
- Technically how to use this data in fine tuning?
 - Train with the training data together?



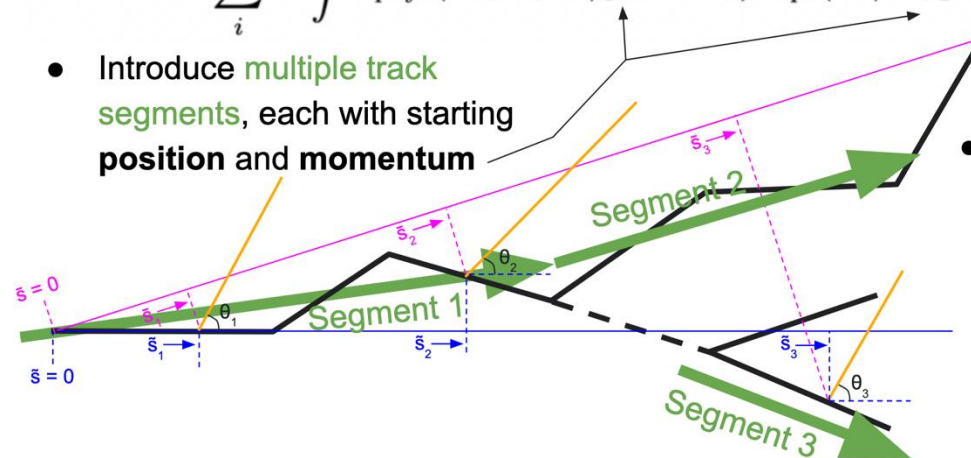
Reconstruction

- Conceptual workflow
 - Define loss function from PMT charges
 - Minimization algorithm
 - Previous work by Ryotaro?
 - Momentum only
 - Should be easy to optimize with Cherenkov Siren (only need to run Optic Siren once for fixed track positions/directions)
 - Momentum + direction (+ position)
 - Need efficient track sampling
- Next step: track segmentation

$$\mathcal{L}(\mathbf{X}) = P(\mathcal{D} | \mathbf{X}) = P(\mathcal{D} | \mathbf{x}, \mathbf{p}, PID)$$

$$= \sum_i^{N_{segments}} \int S_{phys}(\mathcal{N}_i, s_i, \theta_i | p_i, PID_i) S_{opt}(\mathcal{D} | \mathbf{x}_i, \hat{\mathbf{p}}_i, s_i, \theta_i) d\mathcal{N}_i ds_i d\theta_i$$

- Introduce **multiple track segments**, each with starting **position and momentum**



- Can reuse existing Physics SIREN?
 - Ryo says “no” (especially for EM shower), details to come later