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FOR FUNDAMENTAL PHYSICS

Preliminary results of muon-track calibrated Siren (FSD)

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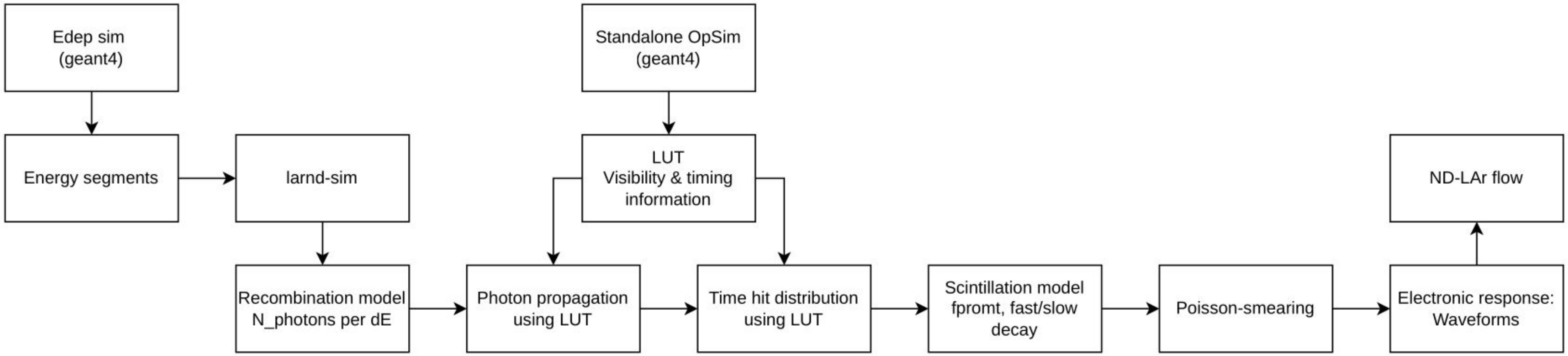
Motivation: Simulation chain for light



Comparison previous to current new best

Siren Model:

$$\boxed{\mathbf{x}} = (x, y, z) \longrightarrow \underbrace{\mathbf{h}_1 = \sin[\omega_0\,(W_1\mathbf{x} + \mathbf{b}_1)]}_{\text{first layer}} \longrightarrow \underbrace{\mathbf{h}_i = \sin[\omega_0\,(W_i\mathbf{h}_{i-1} + \mathbf{b}_i)]}_{\text{hidden layers}} \longrightarrow \begin{cases} \boxed{\hat{\mathbf{y}}} = \sin[\omega_0\,(W_{\text{out}}\mathbf{h}_L + \mathbf{b}_{\text{out}})]\,, & \texttt{linear=False} \\ \boxed{\hat{\mathbf{y}}} = W_{\text{out}}\mathbf{h}_L + \mathbf{b}_{\text{out}}\,, & \texttt{linear=True} \end{cases}$$

LUT voxel position

Transformed visibility

New Siren SIREN model:

$$\boxed{\mathbf{x}} = (x, y, z) \longrightarrow \underbrace{\mathbf{h}_1 = \sin[\omega_0\,(W_1\mathbf{x} + \mathbf{b}_1)]}_{\text{first layer}} \longrightarrow \underbrace{\mathbf{h}_i = \sin[\omega_0\,(W_i\mathbf{h}_{i-1} + \mathbf{b}_i)]}_{\text{hidden layers}} \longrightarrow \underbrace{\boxed{\hat{\mathbf{y}}} = \text{Hardsigmoid}(W_{\text{out}}\mathbf{h}_L + \mathbf{b}_{\text{out}})}_{\text{output layer}} \longrightarrow 120 \text{ channels}$$

- Tested different loss functions:
  - weighted MSE loss: uses visibilities
  - Chi²- loss: uses count-space
- Poisson loss function with additional Gauss uncertainty?

Poisson loss with gaussian nuisance parameter

$$\mathcal{L}(k, \lambda, \mu) = 2\left[\mu - k + k\ln\left(\frac{k}{\mu}\right)\right] + \frac{(\mu - \lambda)^2}{\sigma_0^2}$$

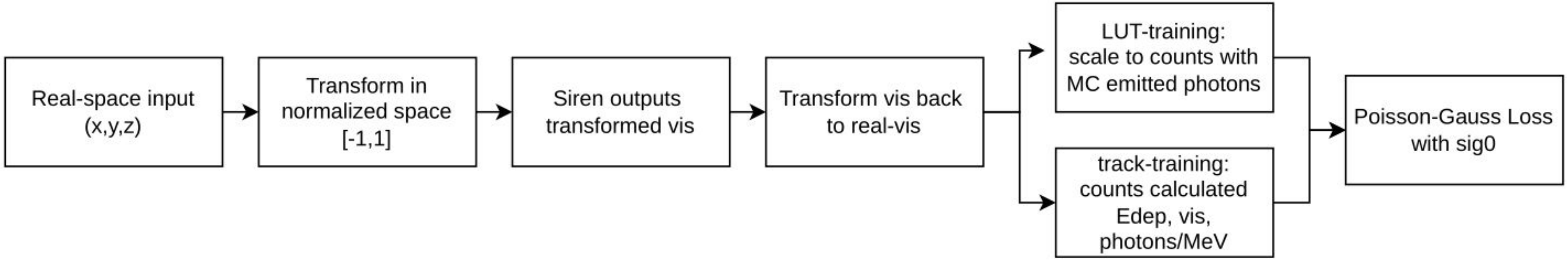
$$\mu^* = \underset{\mu \geq 0}{\arg\min}\, \mathcal{L}(k, \lambda, \mu)$$

$$\mu^* = \frac{\lambda - \sigma_0^2 + \sqrt{(\lambda - \sigma_0^2)^2 + 4k\sigma_0^2}}{2}$$

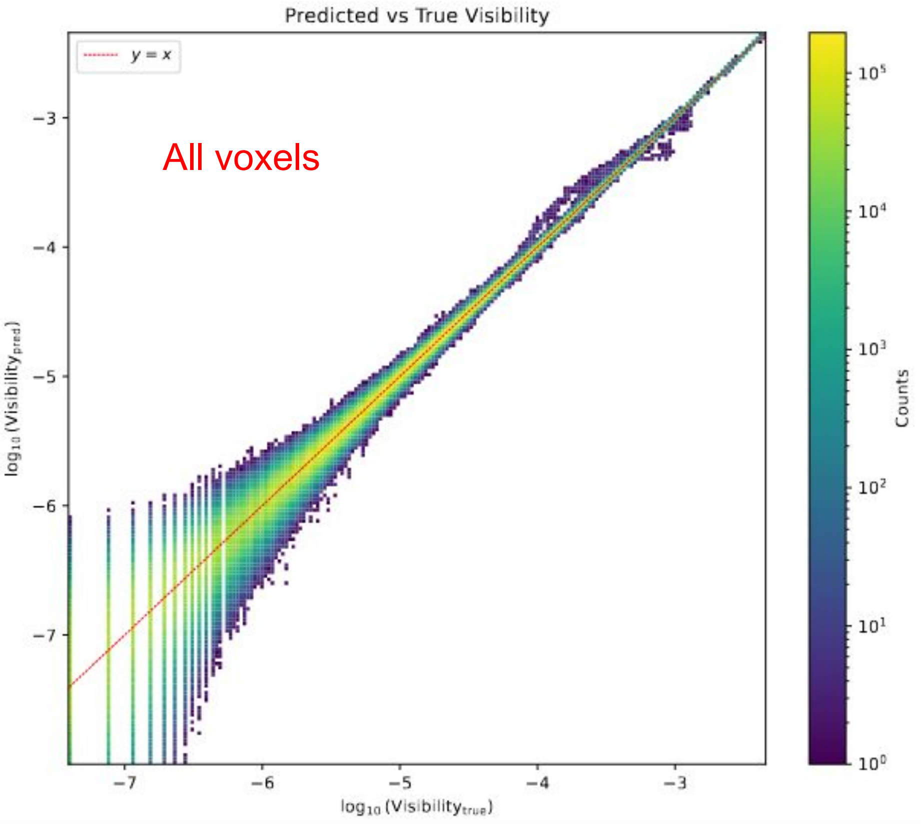
$$\mathcal{L}_{\text{profiled}}(k, \lambda) = 2\left[\mu^* - k + k\ln\left(\frac{k}{\mu^*}\right)\right] + \frac{(\mu^* - \lambda)^2}{\sigma_0^2}$$

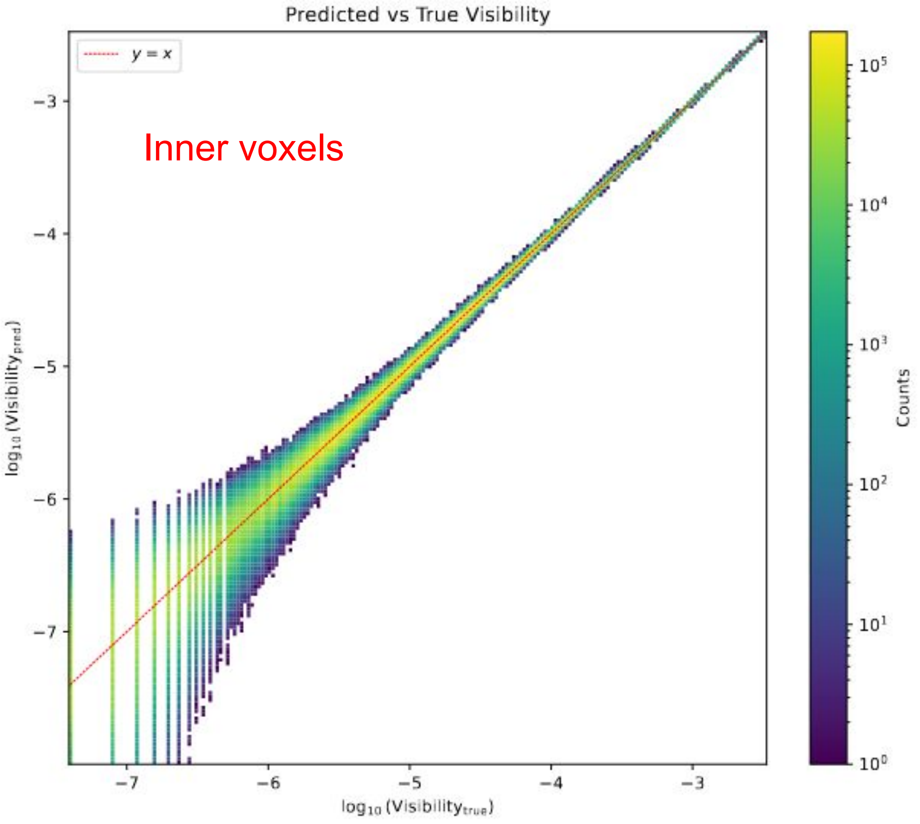
- Found two papers (Conway-2011, Dembinski-2022) who described this poisson loss with a nuisance parameter.

Overview Siren training

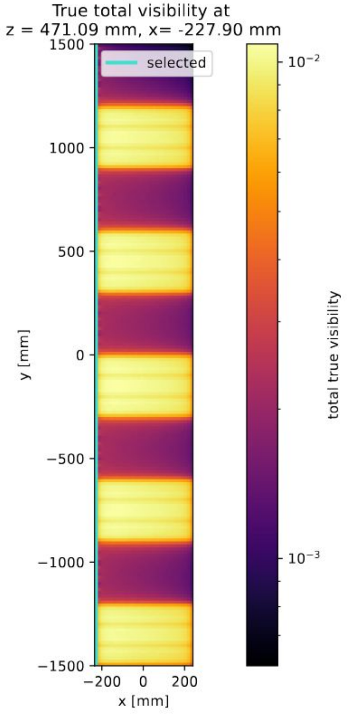


LUT training with Poisson-Gauss loss

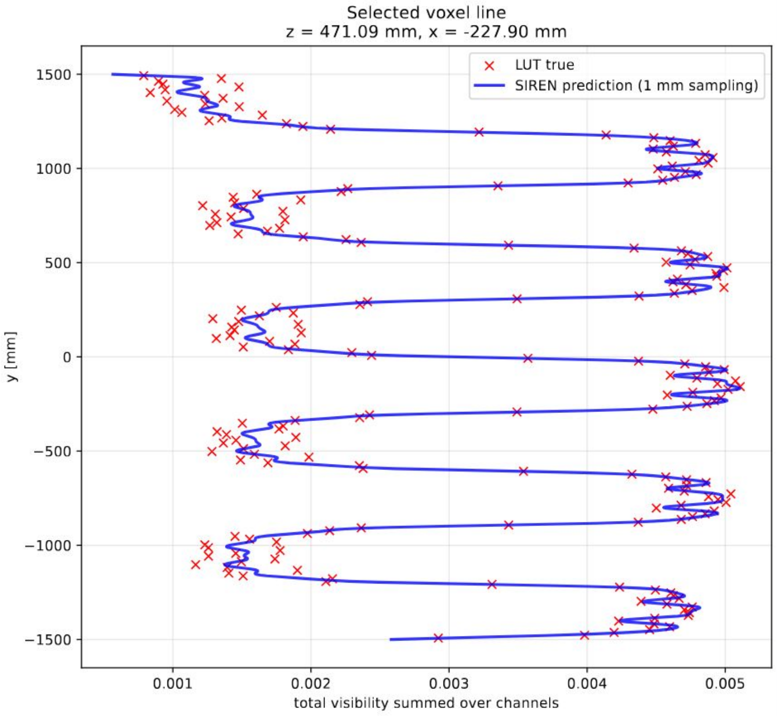




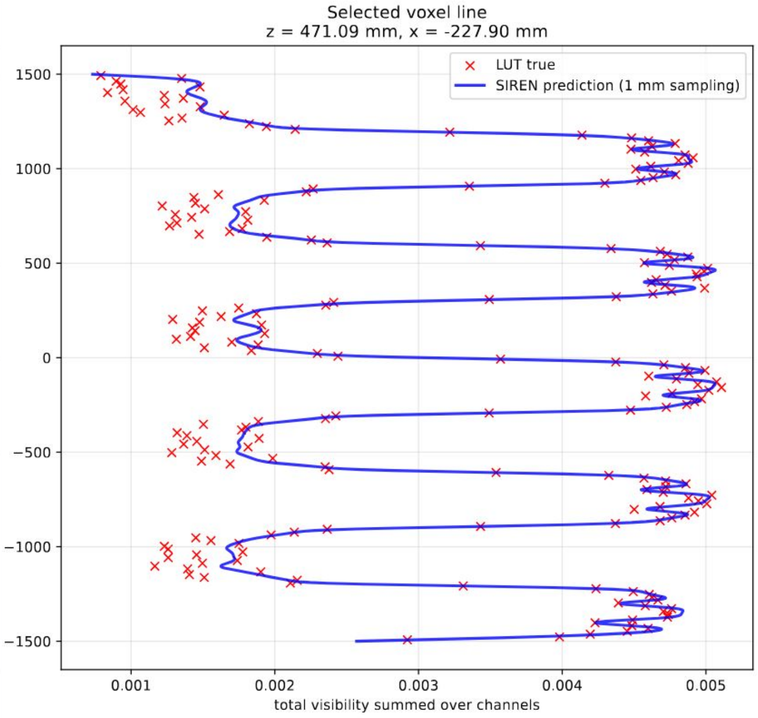
LUT training



Poisson

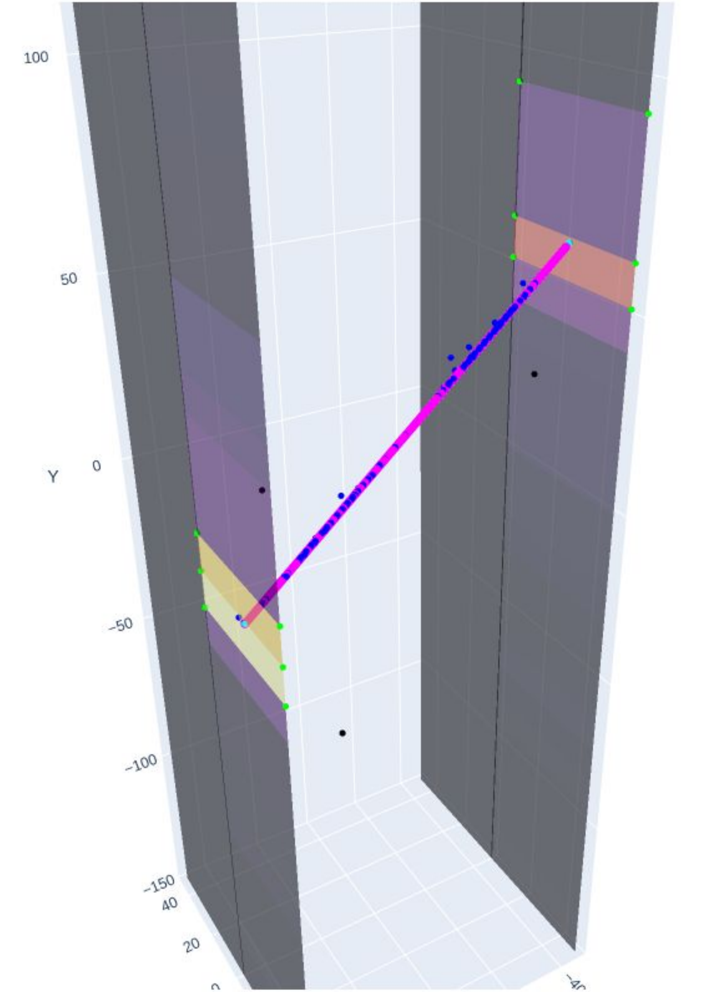


MSE



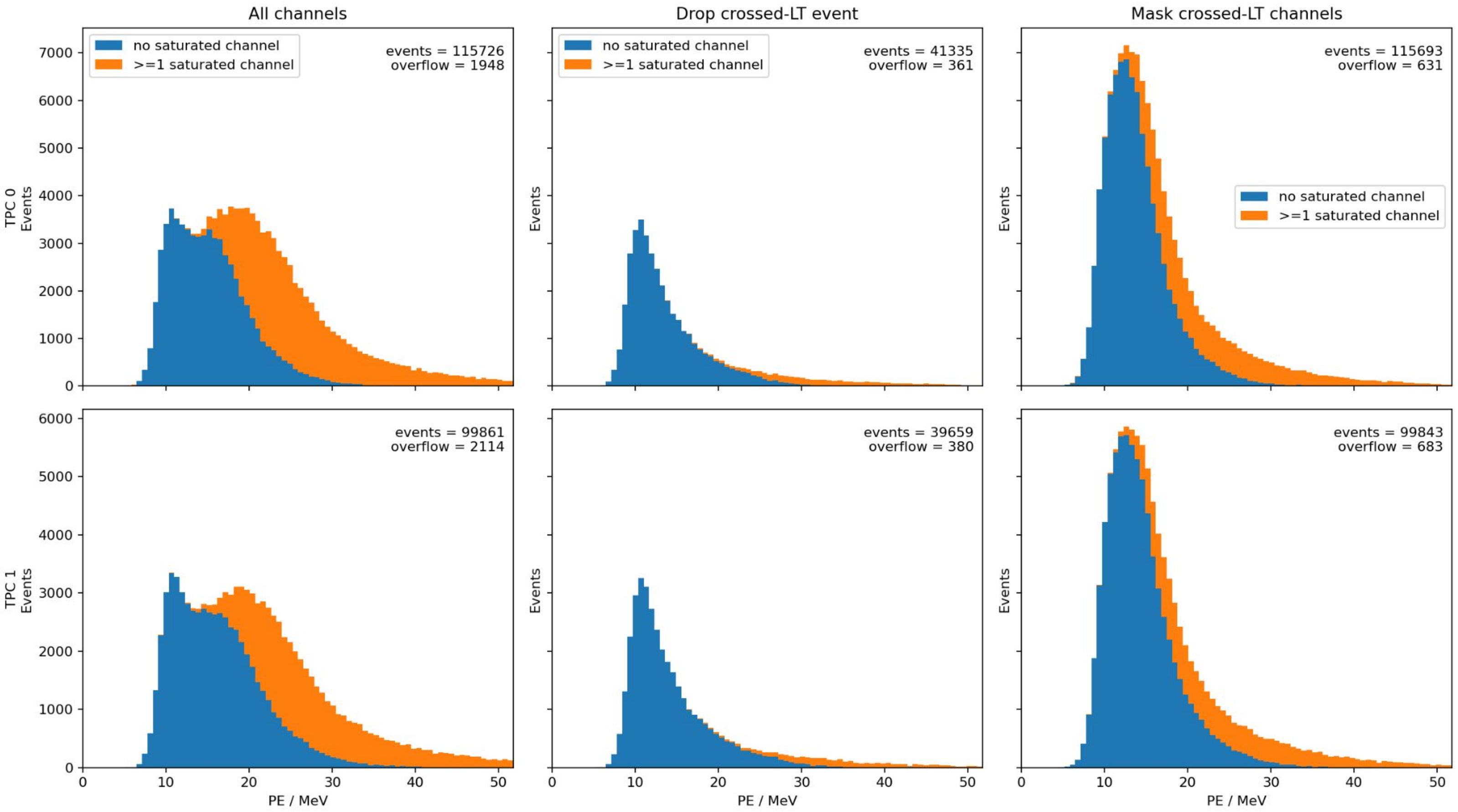
FSD muon selection

- Straight muon tracks, initially on light selected (must only have a single light peak in tpc)
- Needs to be a straight muon track
- Needs to cross the TPC
- Fitted 3D line through charge hits (blue)-> 1mm sampled points (pink) to estimate emitted amount of photons (FSD charge <-> energy calibration problem)
- Needs to have > 5 PE/MeV (flow mismatch)



Crossed light traps and saturated channels

Applied cuts: needs to have > 5 PE/MeV



Track loss

Model prediction:

$$\lambda_{e,c} = Y_\gamma \frac{dE}{dx} \sum_{i \in e} \Delta s_{e,i} \hat{v}_{e,i,c}.$$

$$Y_\gamma = 24000 \text{ photons/MeV}. \qquad \frac{dE}{dx} = 2.1 \text{ MeV/cm},$$

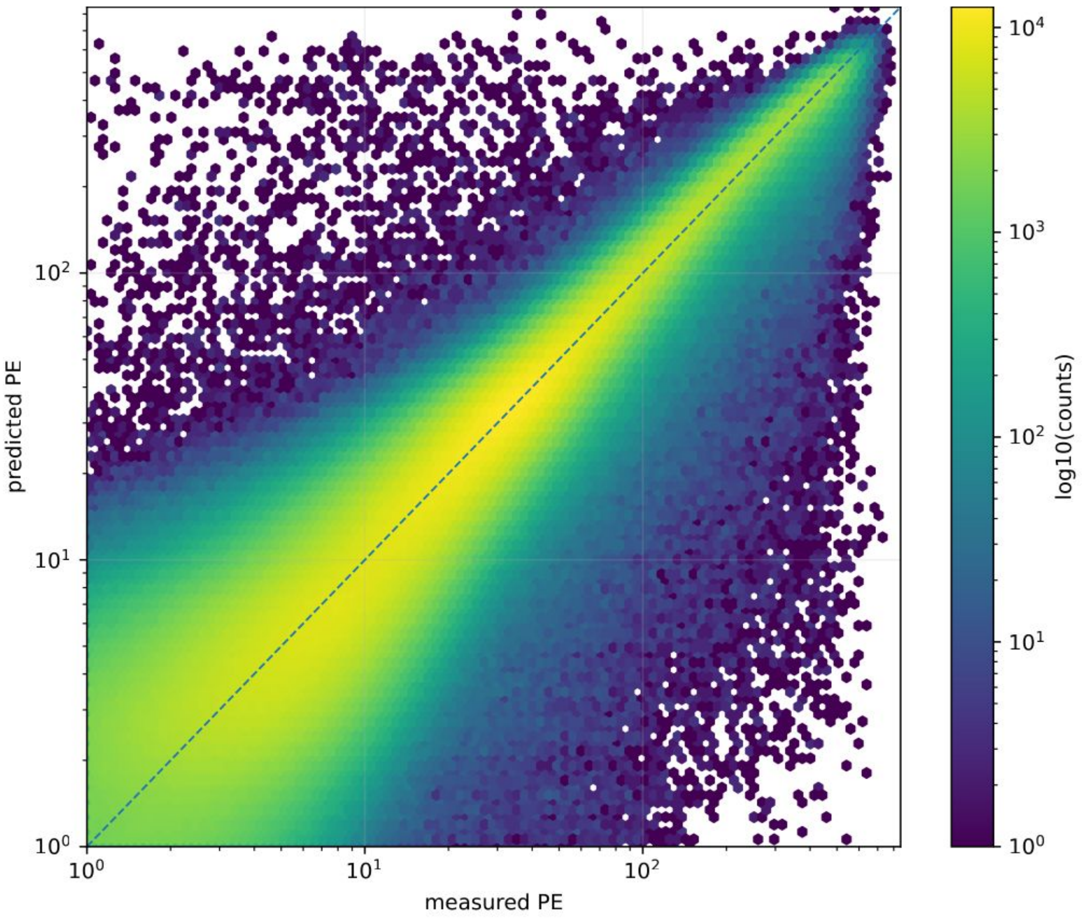
Measurement:

$$k_{e,c} = PE^{\text{meas}}_{e,c}$$

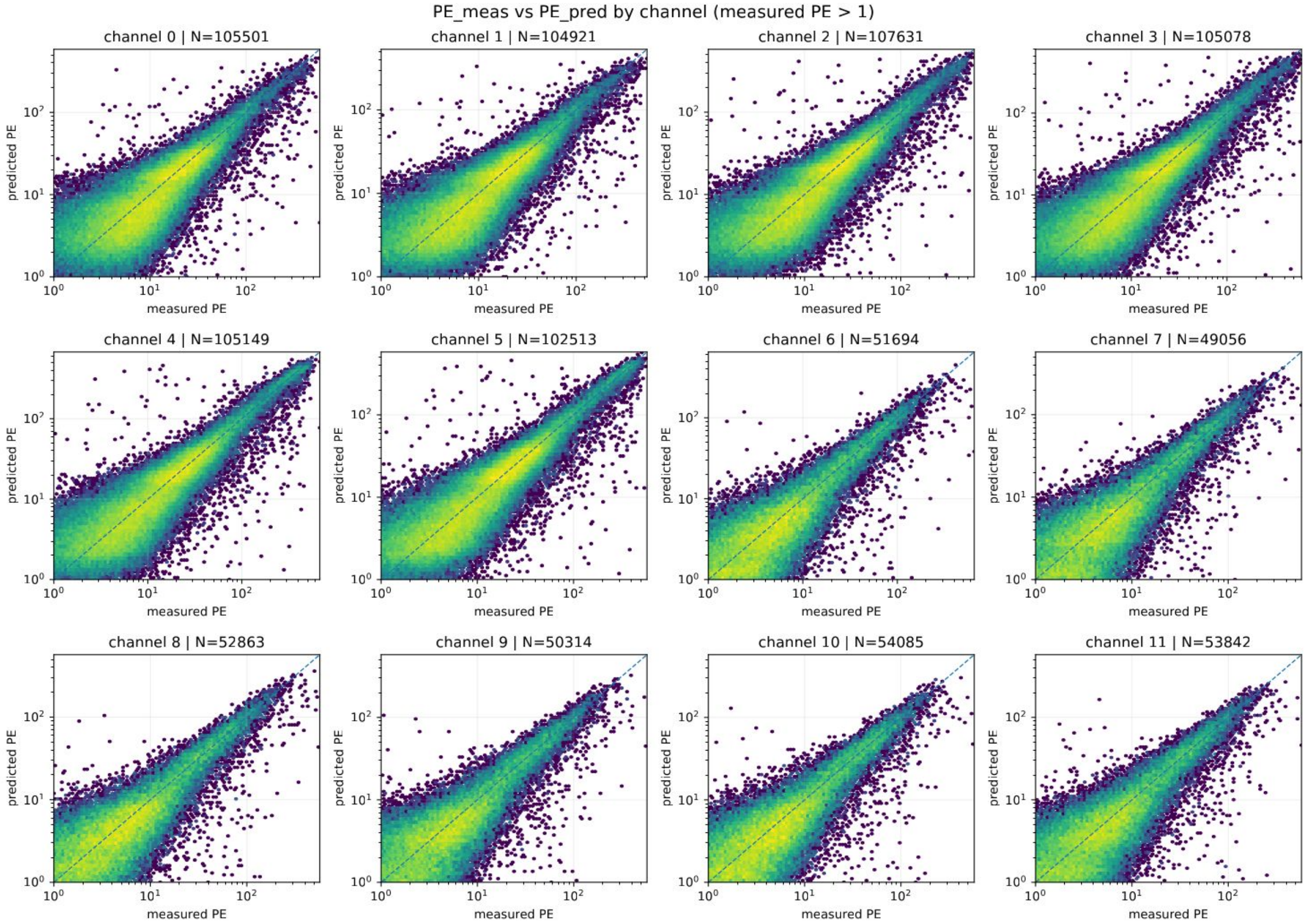
Masked Loss:

$$\boxed{\mathcal{L}_{\text{track}} = \frac{\sum_{e} \sum_{c=1}^{120} m_{e,c} \mathcal{L}^{\text{profiled}}_{e,c}}{\sum_{e} \sum_{c=1}^{120} m_{e,c}}.}$$

PE_{meas} vs PE_{pred} (channel-wise, over all events), only > 1 PE



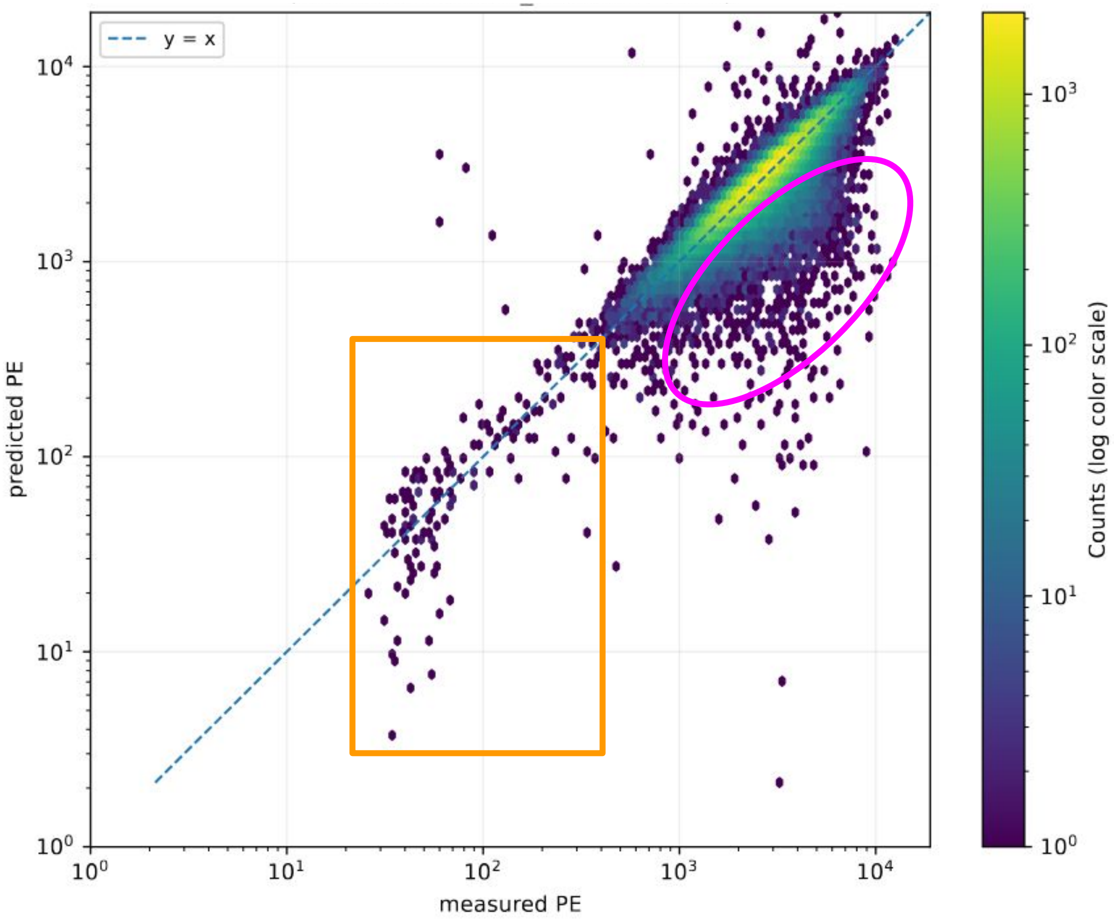
PE_{meas} vs PE_{pred} (channel-wise, over all events), only > 1 PE



Ch 0-5: LCM

Ch 6-11: ACL

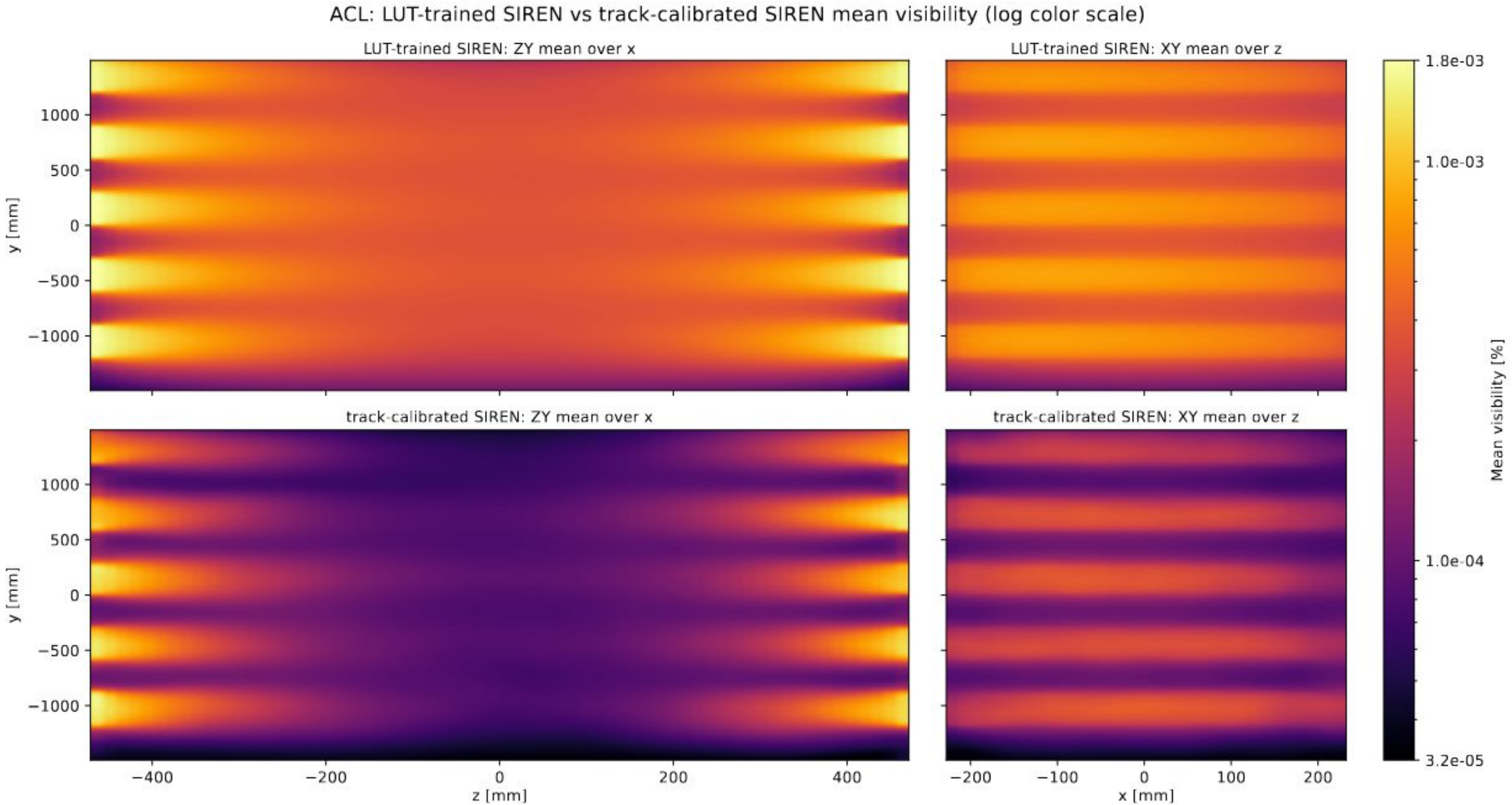
PE_{meas} vs PE_{pred} (sum over channels per events)



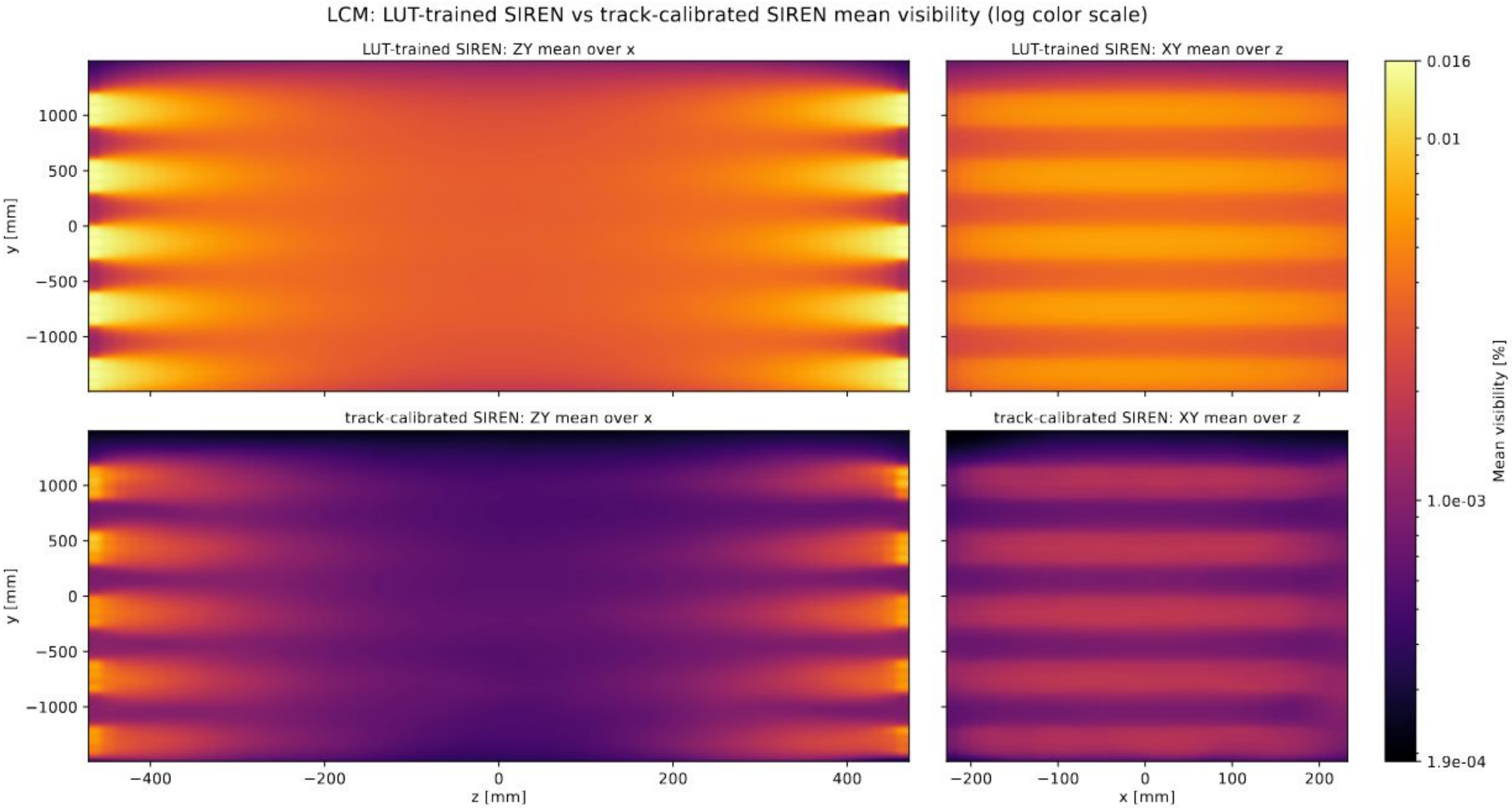
Light saturated events generally have high measured PE. Masking those events in Loss might train the model to predict lower PE?

Currently only cuts on PE/MeV & crossing, allows short tracks, which are crossing LT's? (and they are excluded)

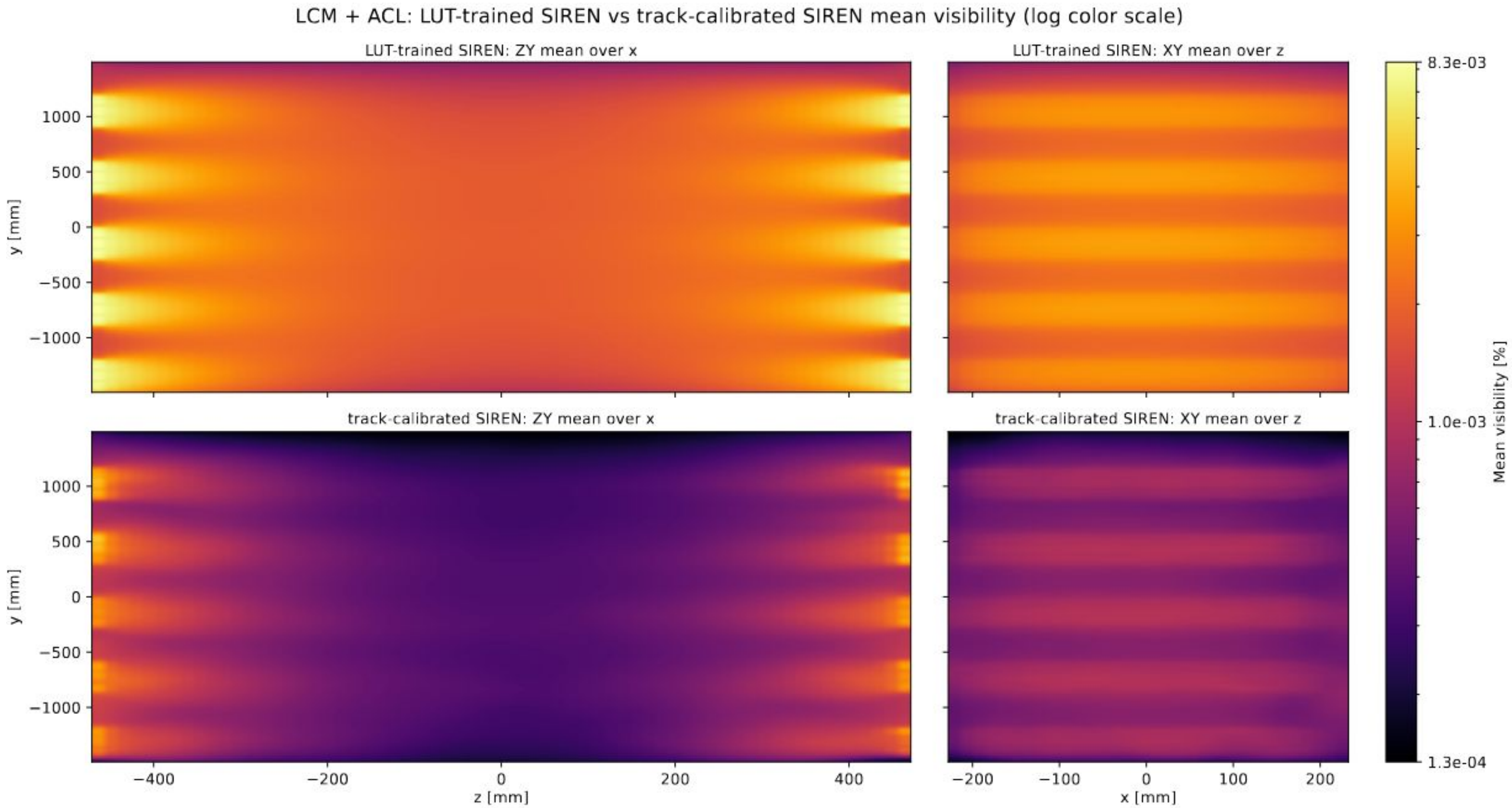
ACL: LUT-trained vs track-tuned SIREN visibility map



LCM: LUT-trained vs track-tuned SIREN visibility map

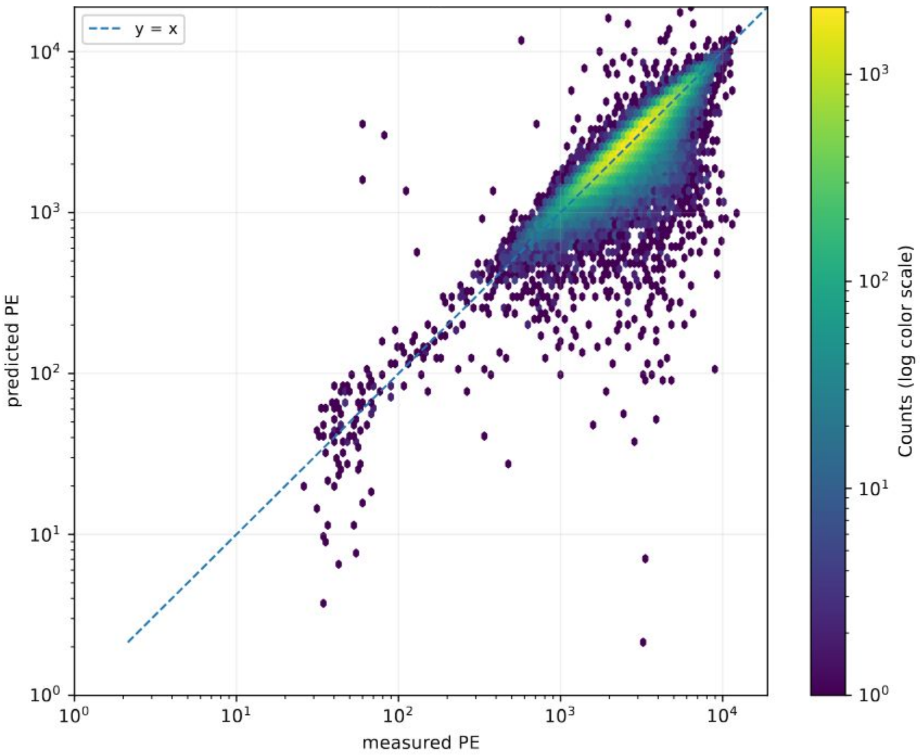


LCM & ACL: LUT-trained vs track-tuned SIREN visibility map

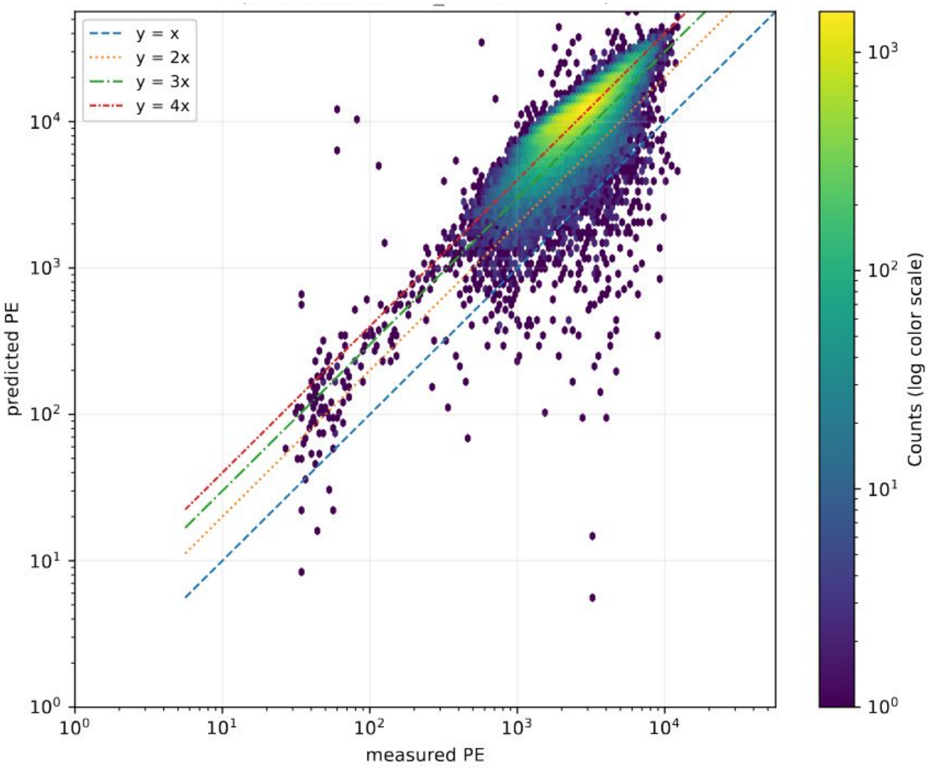


PE_{meas} vs PE_{pred}: track-fine-tuned vs LUT trained

Track fine tuned

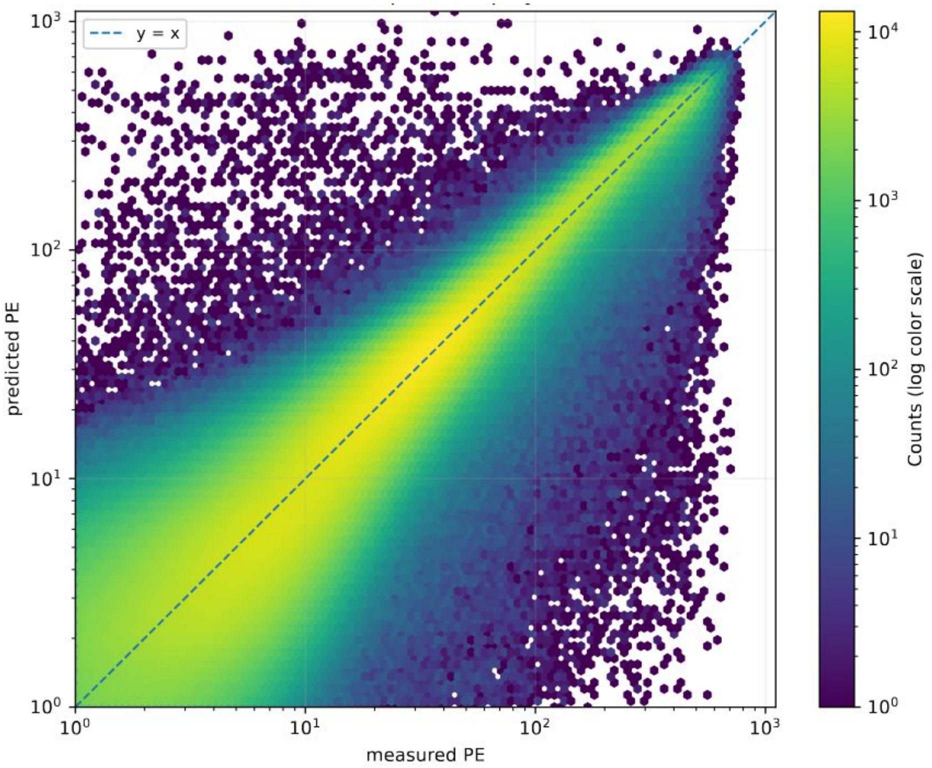


LUT trained only

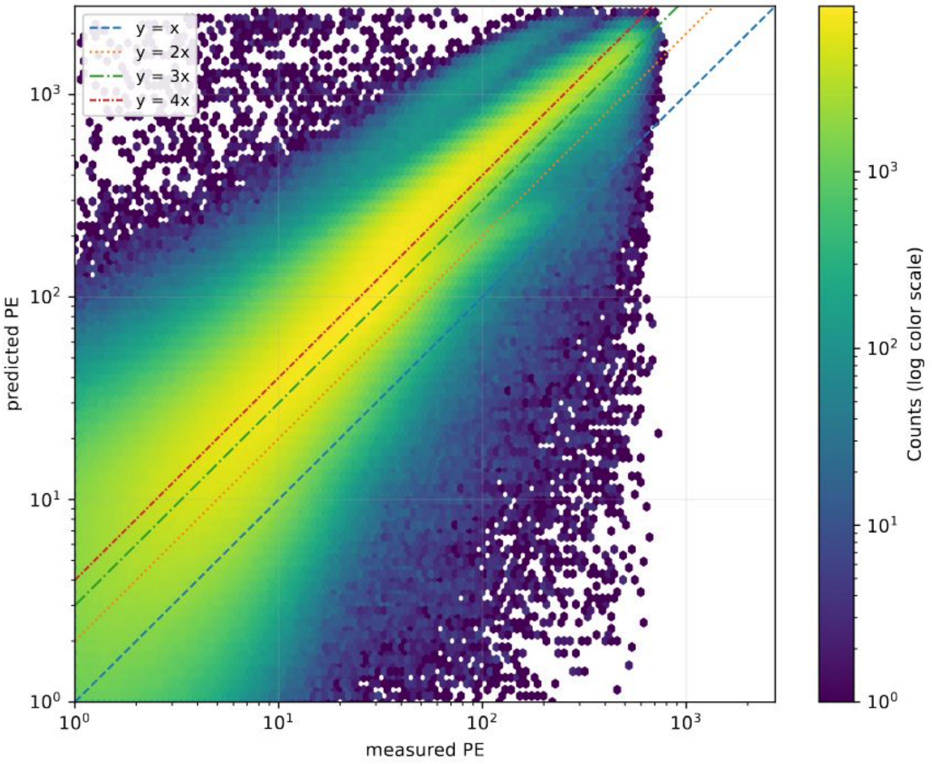


PE_{meas} vs PE_{pred}: track-fine-tuned vs LUT trained

Track fine tuned

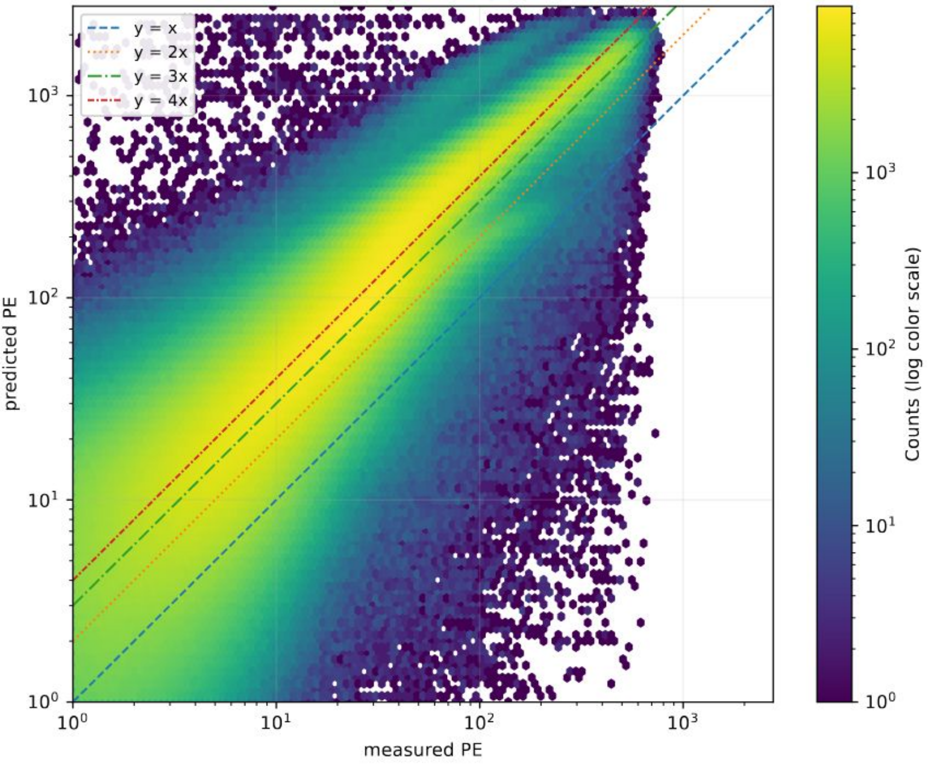


LUT trained only

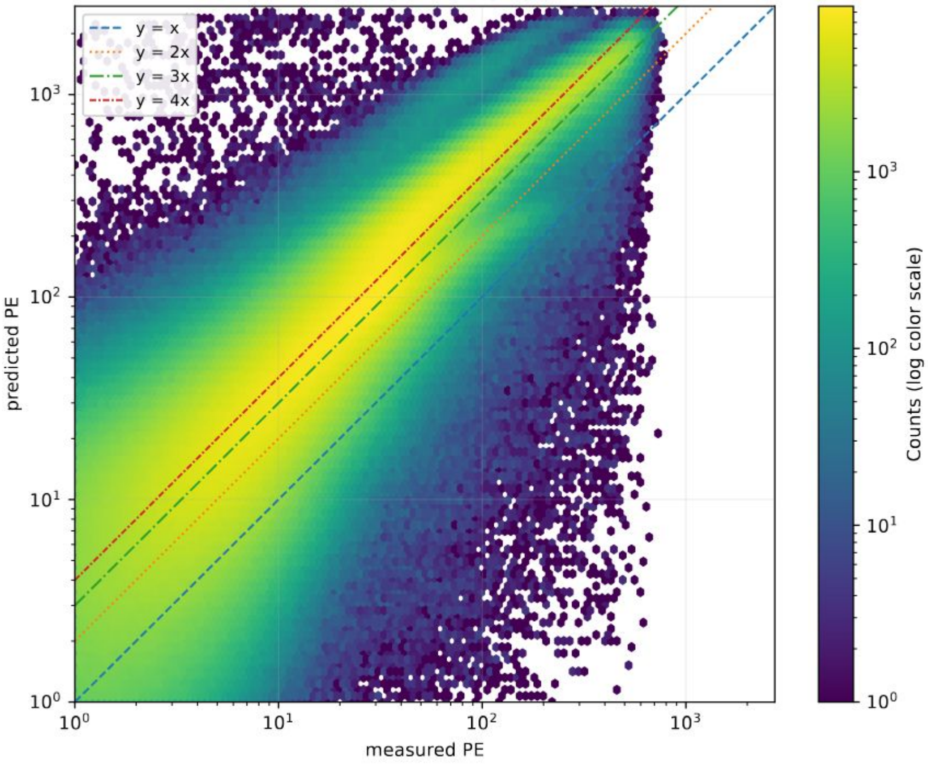


PE_{meas} vs PE_{pred}: track-fine-tuned vs LUT trained

LUT direct



LUT trained only



Next steps

- Investigate with different muon-track cuts (include min track length)
- Feed train with saturated channels (include time-over-threshold as cut?)
- Investigate training on LUT vs training on simulated tracks (generated with LUT) -> would have truth information
- Investigate behaviour of sigma0 in the loss function