



Tracking with ML



12th February 2025



Jeremy Couthures



Dataset update

Selections:

- $n_{\text{hits}} \geq 3$
- $0.5 \leq p_T \leq 10$ [GeV]
- $|v_x| < 1 \ \&\& \ |v_y| < 1$ [mm]
- $|\eta| \leq 1$

TrackML Kaggle:

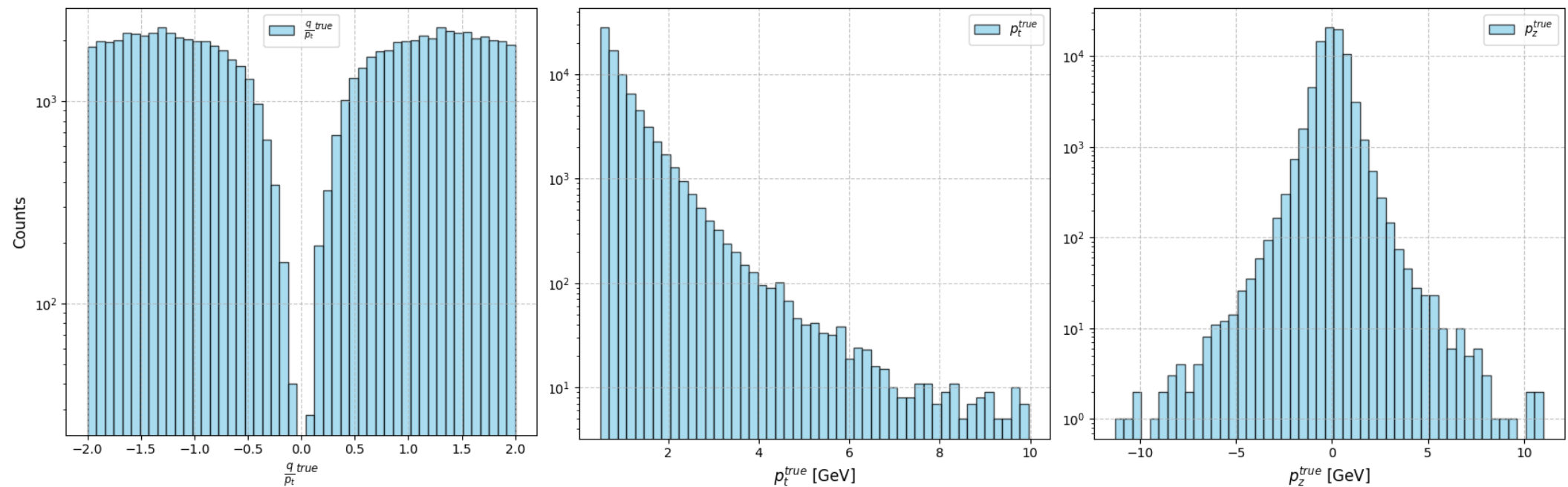
Training: 1 232 896 particles
Validation: 154 082 particles
Testing: 153 788 particles



TrackML Zenodo: (first file)

Training: 629 265 particles
Validation: 78 107 particles
Testing: ~78 656 particles

Target variables



Masking issue

- **Code issue: Padding mask was not used in calculations**
- **Padding per batch: hits with input value of 0 are added to match the highest number of hits in the batch**

Padding:

```
x x x 0 0 0
x x x x x x
x x 0 0 0 0
```



Attention Mask:
(first row: x x x 0 0 0)

	h1	h2	h3	h4	h5	h6
h1	1	1	1	0	0	0
h2	1	1	1	0	0	0
h3	1	1	1	0	0	0
h4	0	0	0	0	0	0
h5	0	0	0	0	0	0
h6	0	0	0	0	0	0

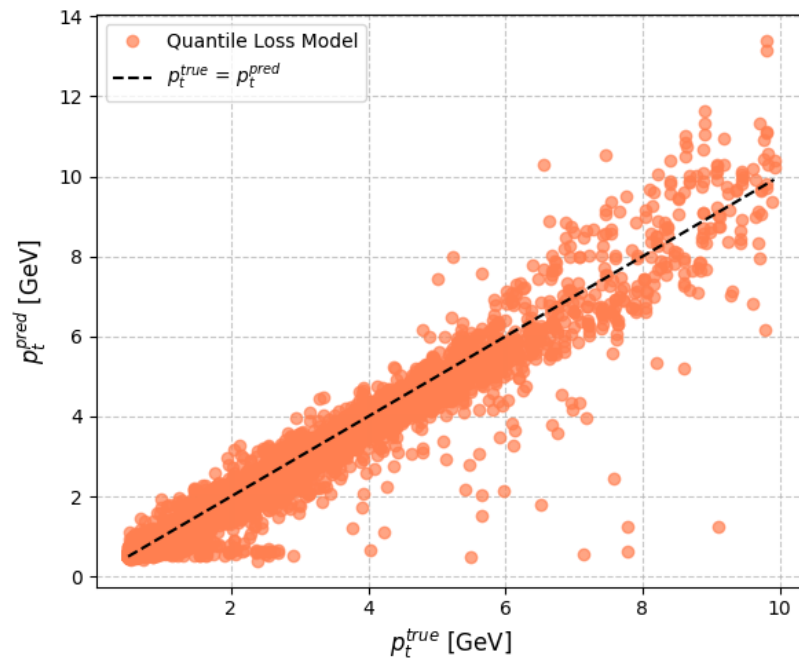
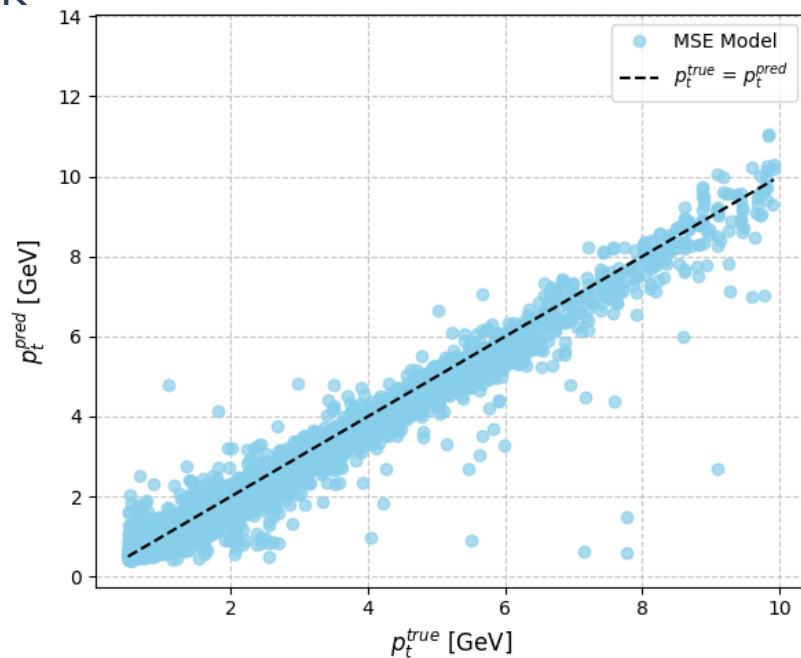
More results

x y z

No mask

p_t^{true} vs p_t^{pred}

TrackML Kaggle



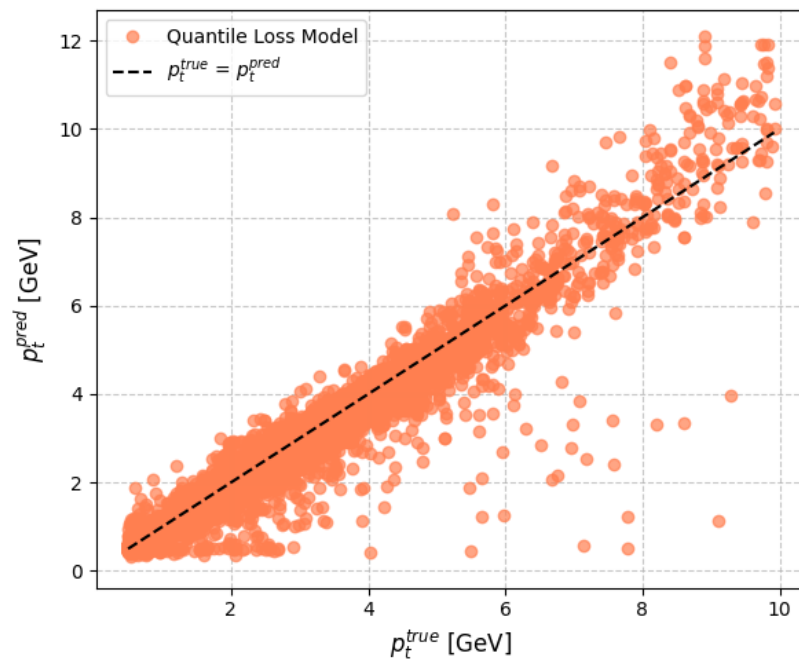
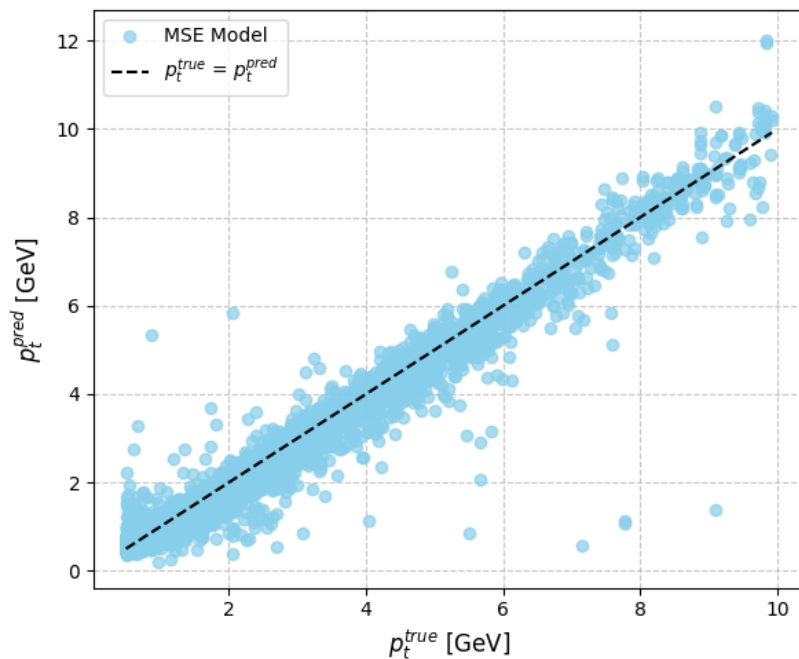
More results

x y z

masked

p_t^{true} vs p_t^{pred}

TrackML Kaggle

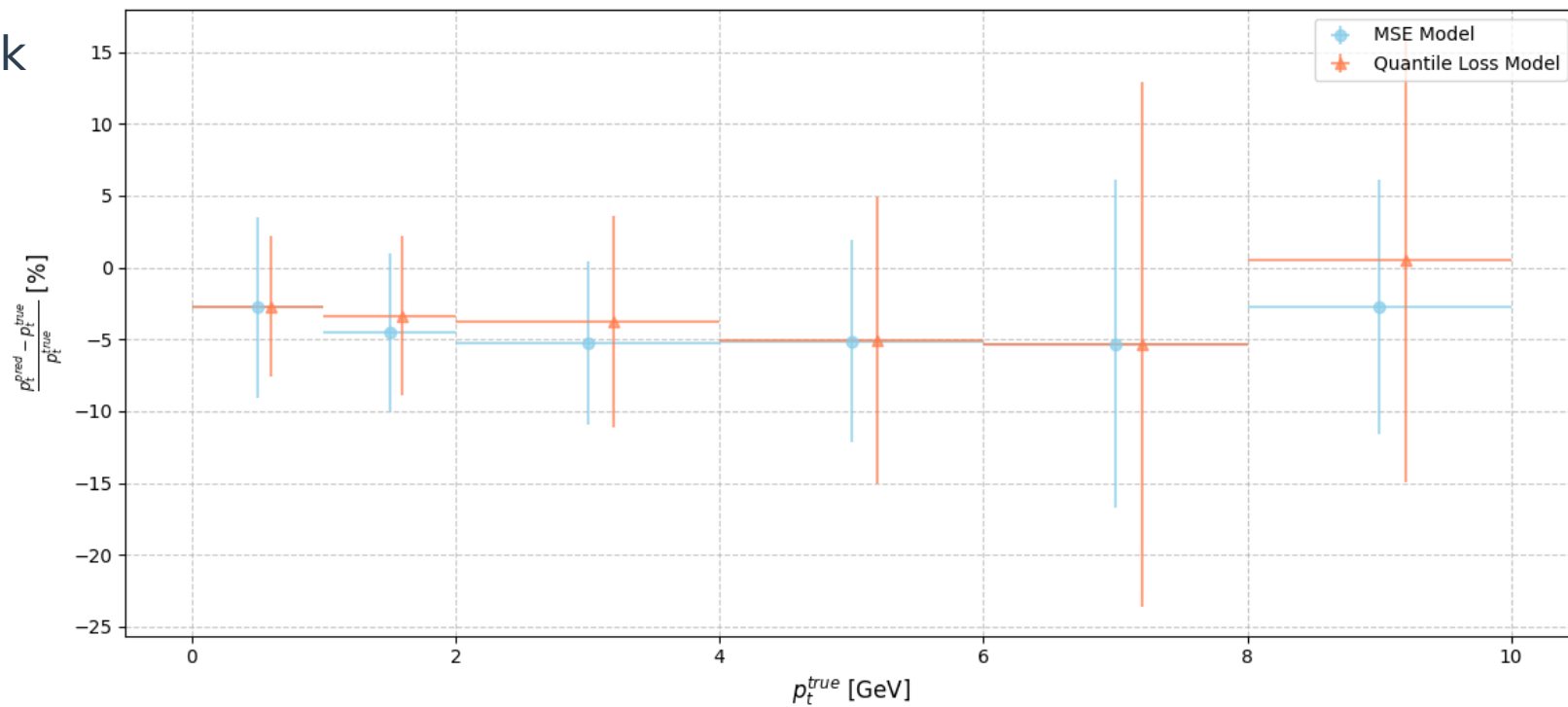


Resolution

x y z

No mask

TrackML Kaggle

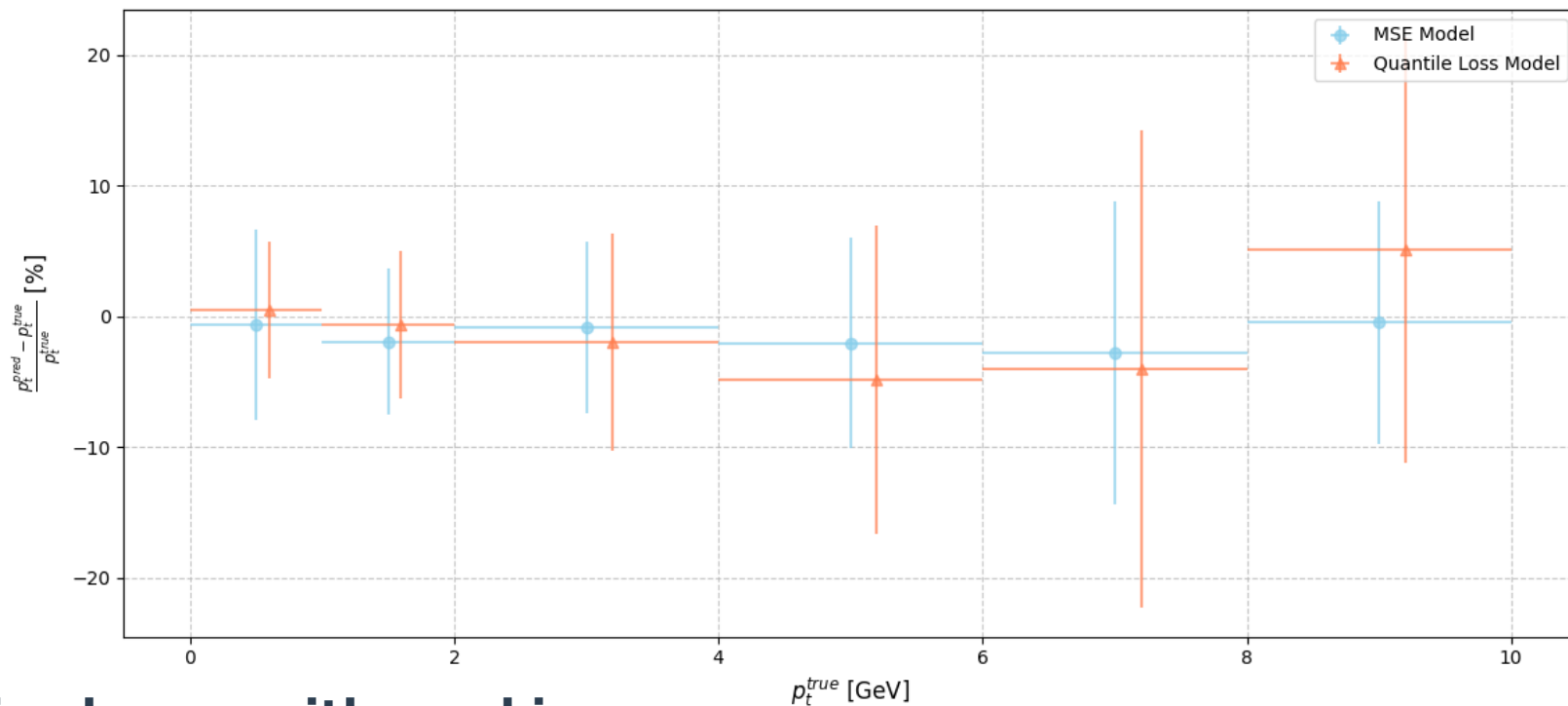


Resolution

x y z

masked

TrackML Kaggle



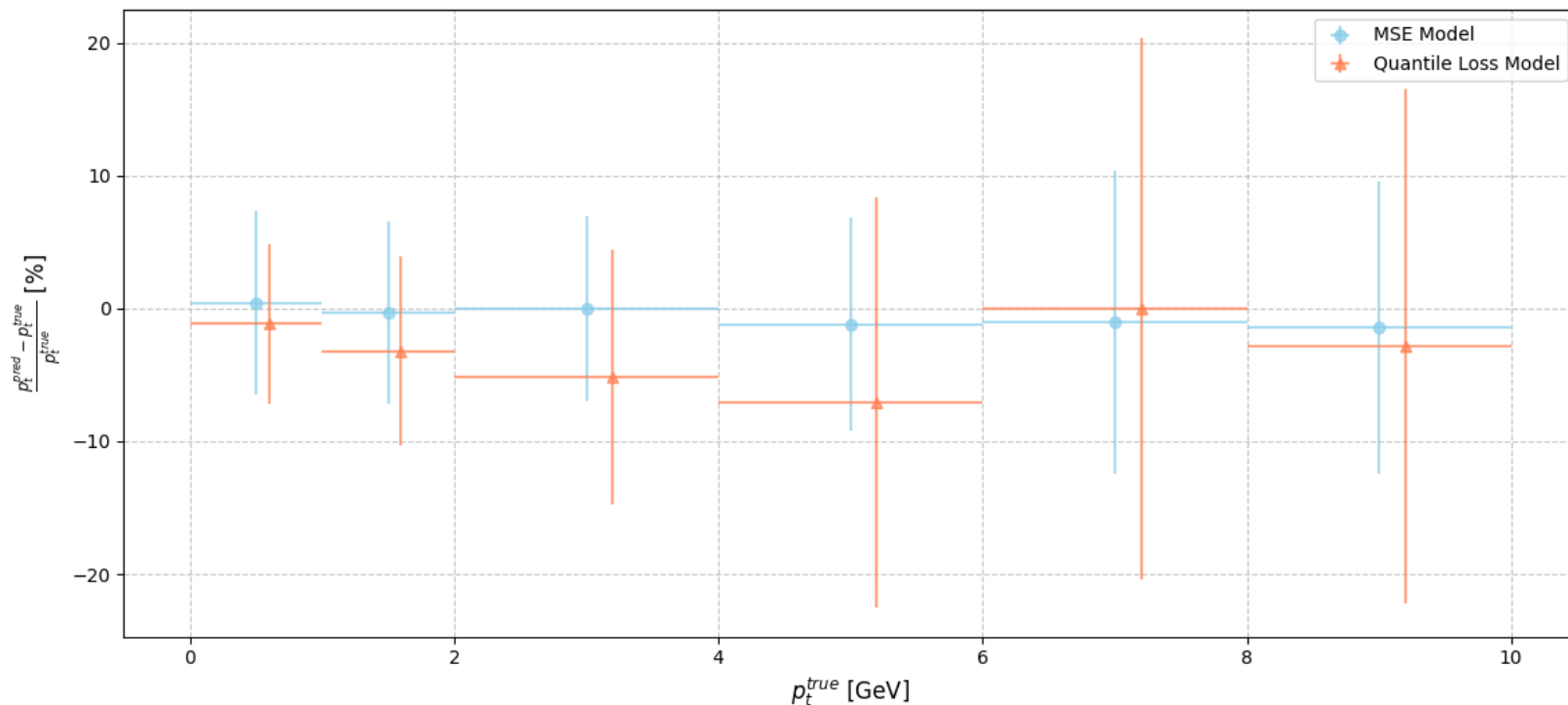
No big change with masking

Resolution

x y z

masked

TrackML Zenodo



Quantile loss drops a bit with dataset change

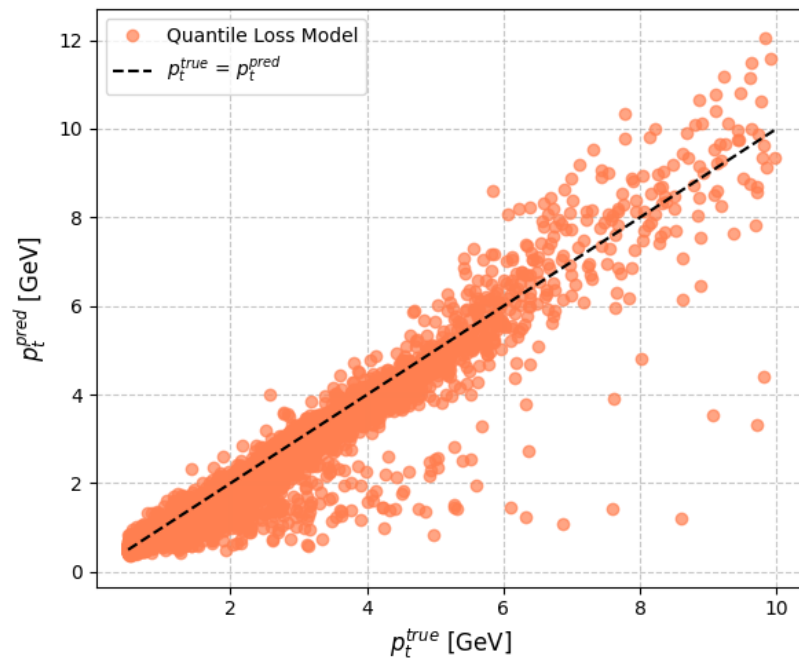
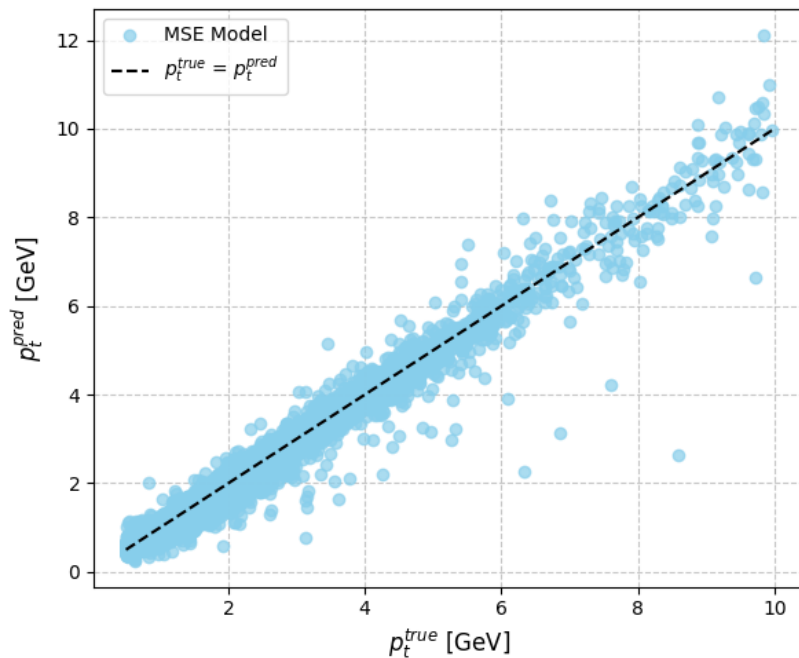
More results

x y z

masked

p_t^{true} vs p_t^{pred} (('tx', 'ty', 'tz') -> ('pT', 'pz'))

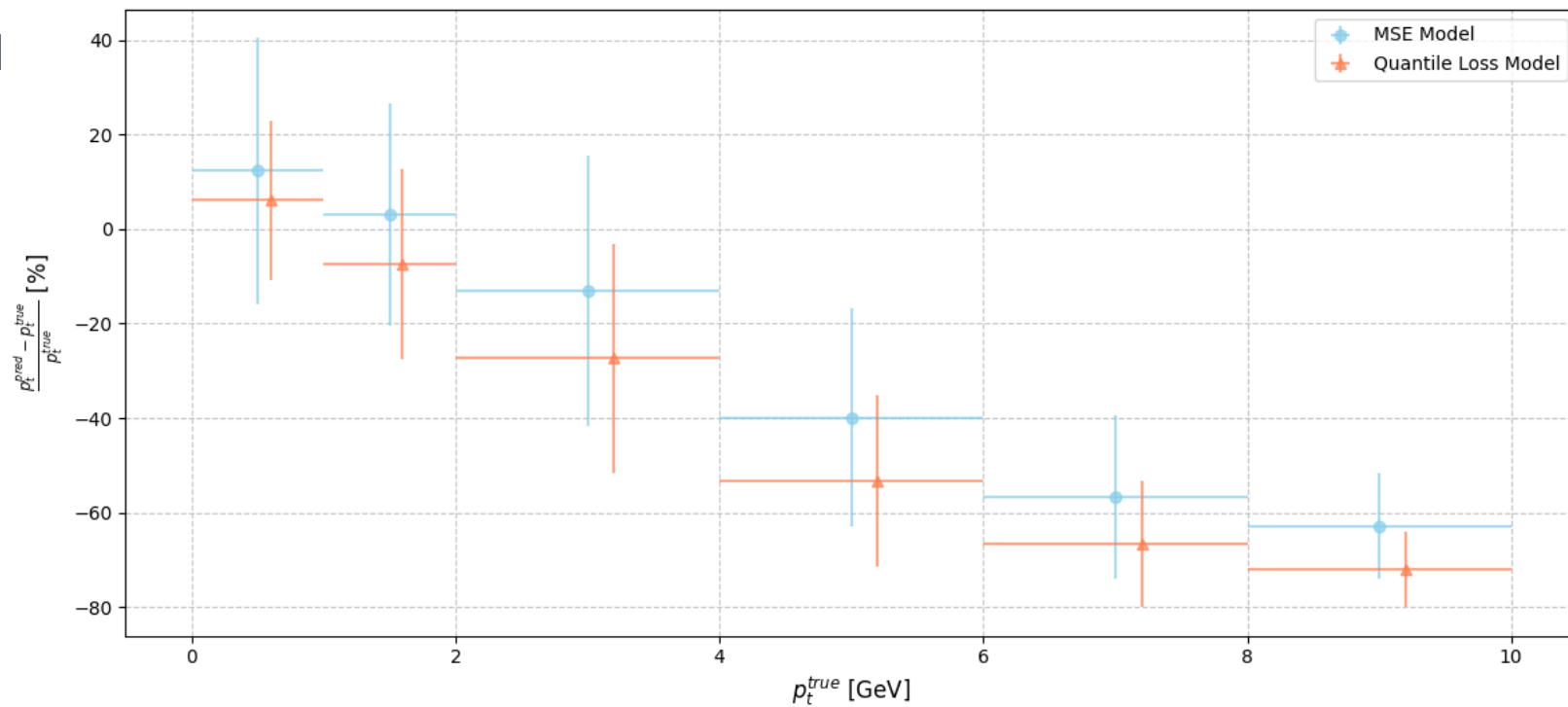
TrackML Zenodo



Resolution

r phi z
masked

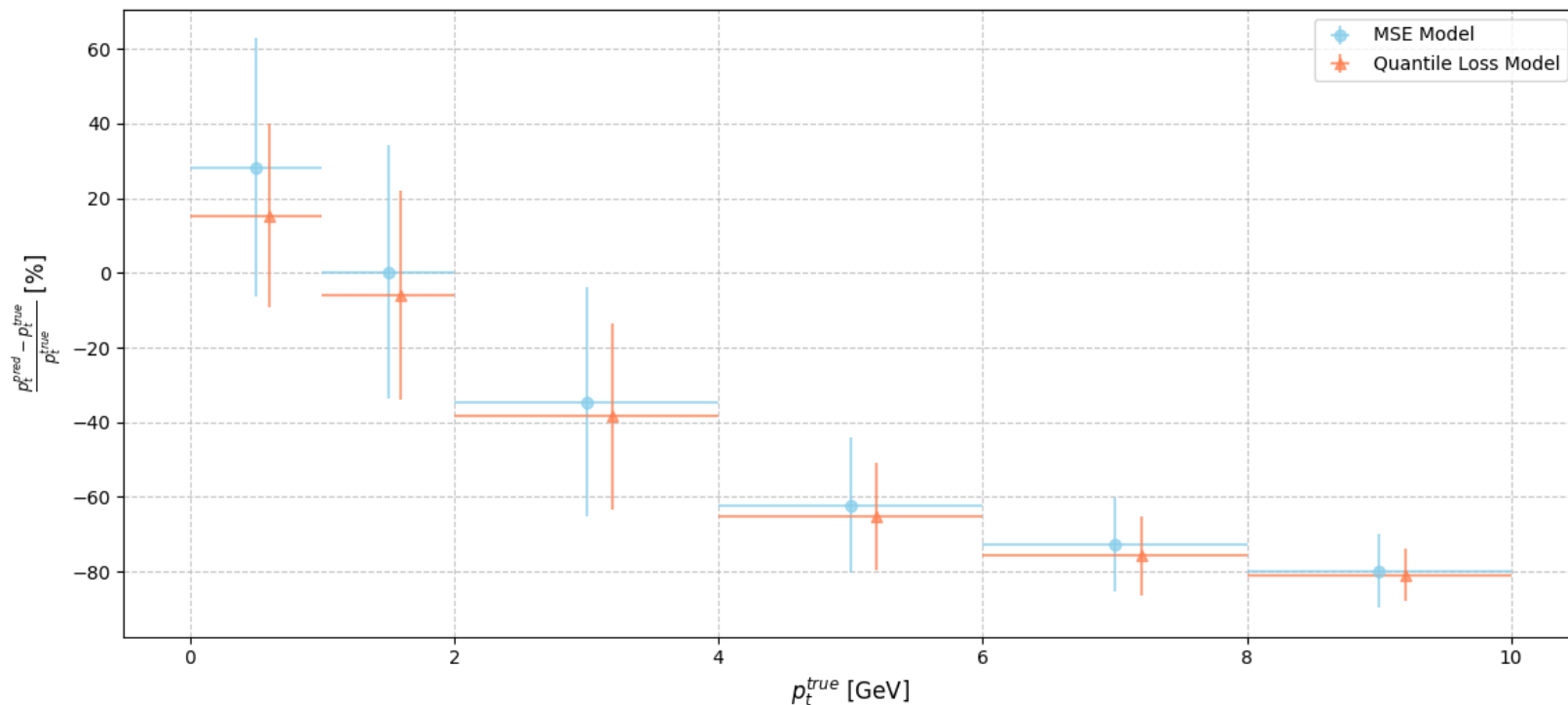
TrackML Kaggle



Resolution

r phi z
masked

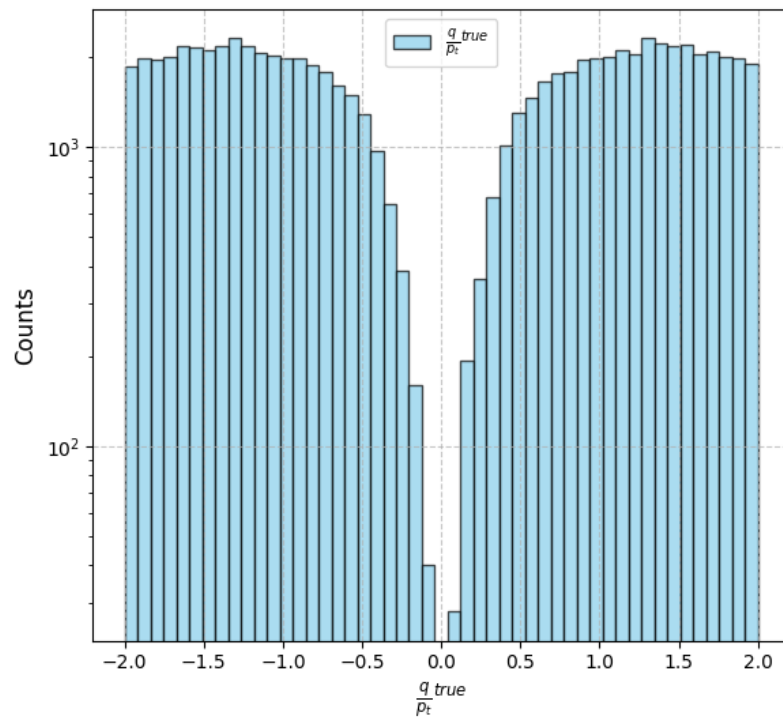
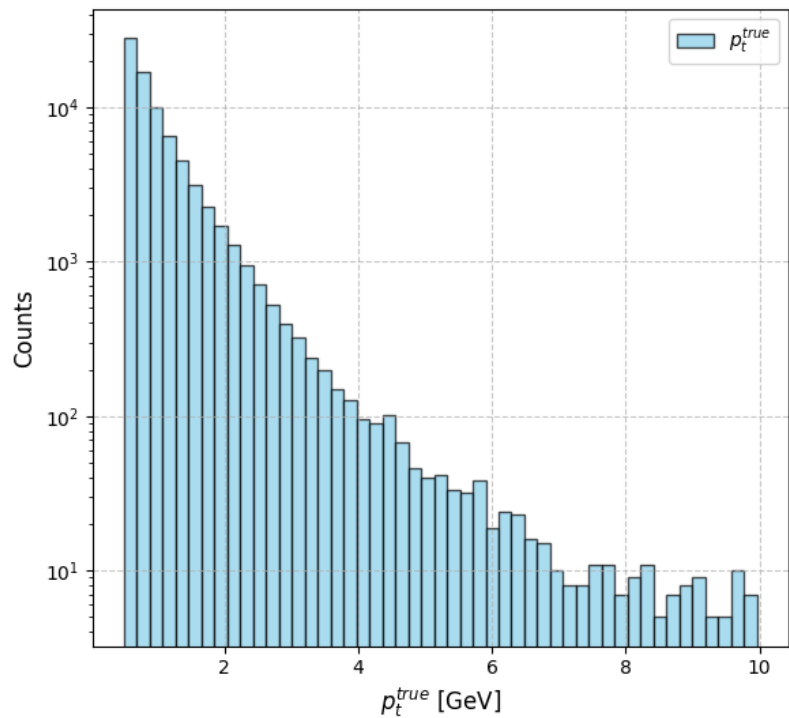
TrackML Kaggle



Both loss drops a bit with dataset change

q/pT

Target variable:

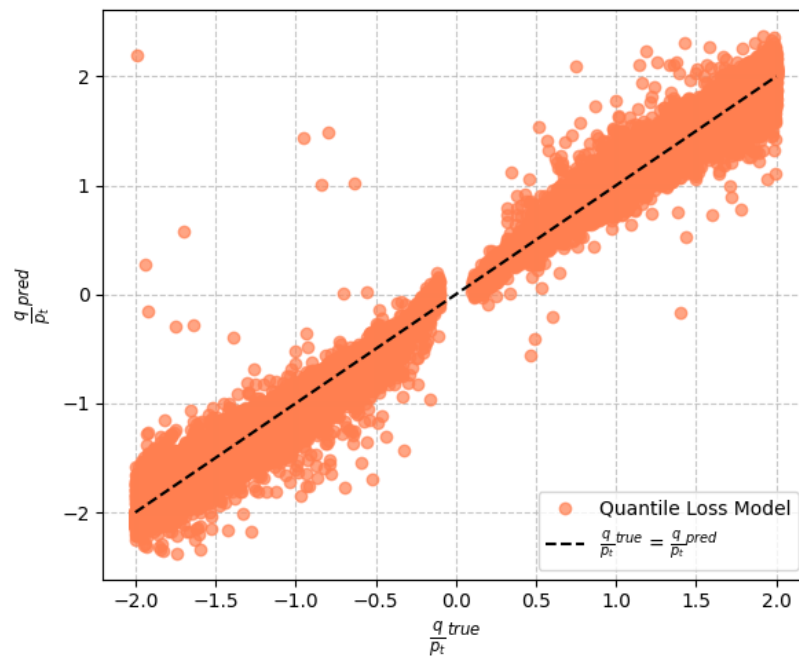
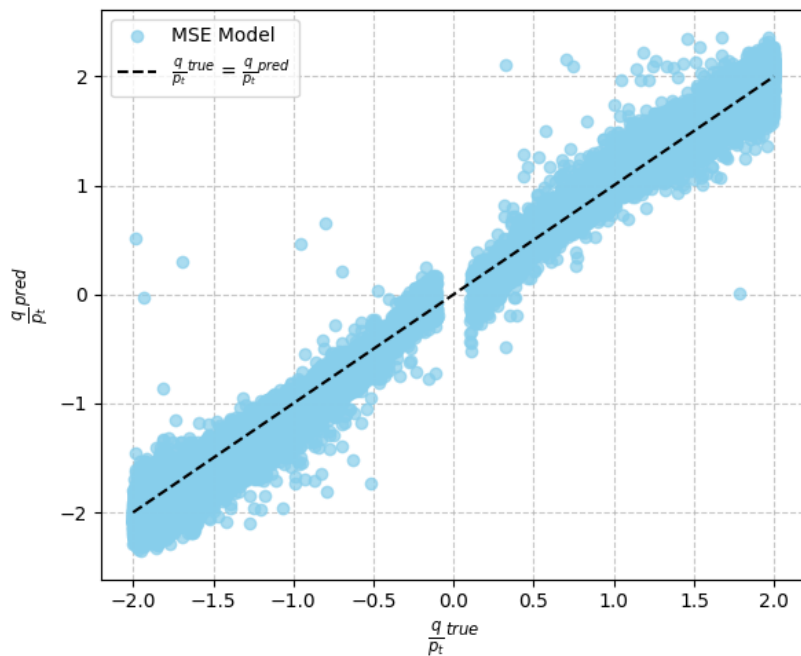


More results

x y z

$\frac{q_{true}}{\bar{p}_t}$ vs $\frac{q_{pred}}{\bar{p}_t}$ (('tx', 'ty', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

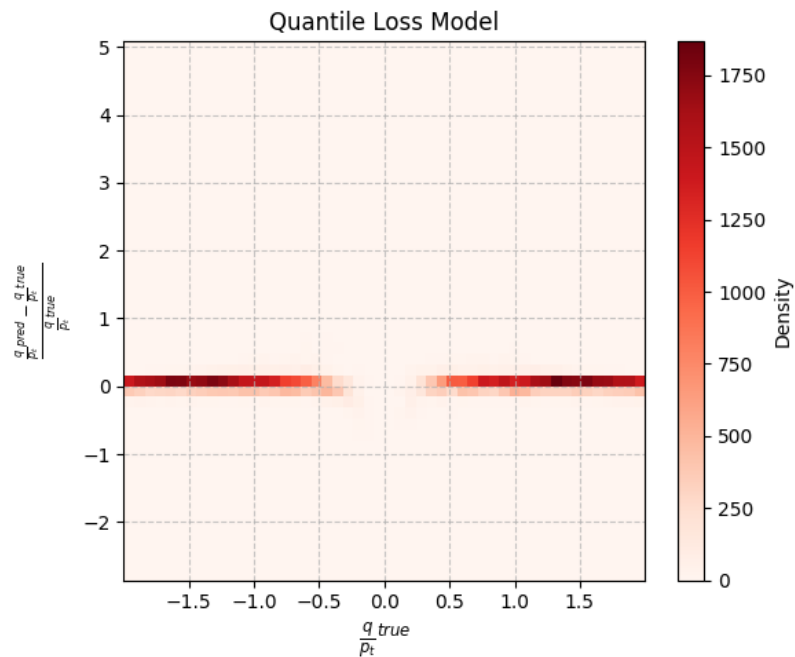
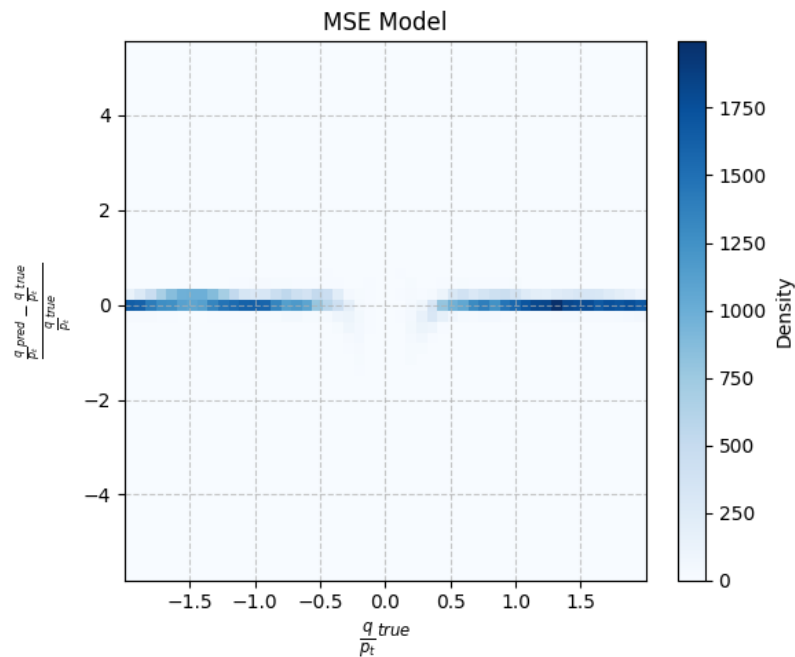


Resolution

x y z

Relative error resolution for $\frac{q}{p_t}$ (('tx', 'ty', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

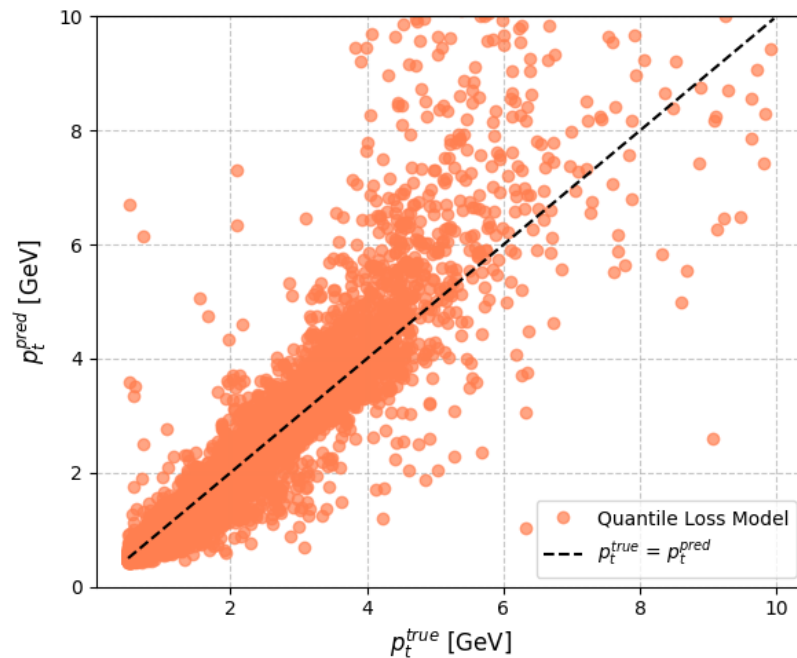
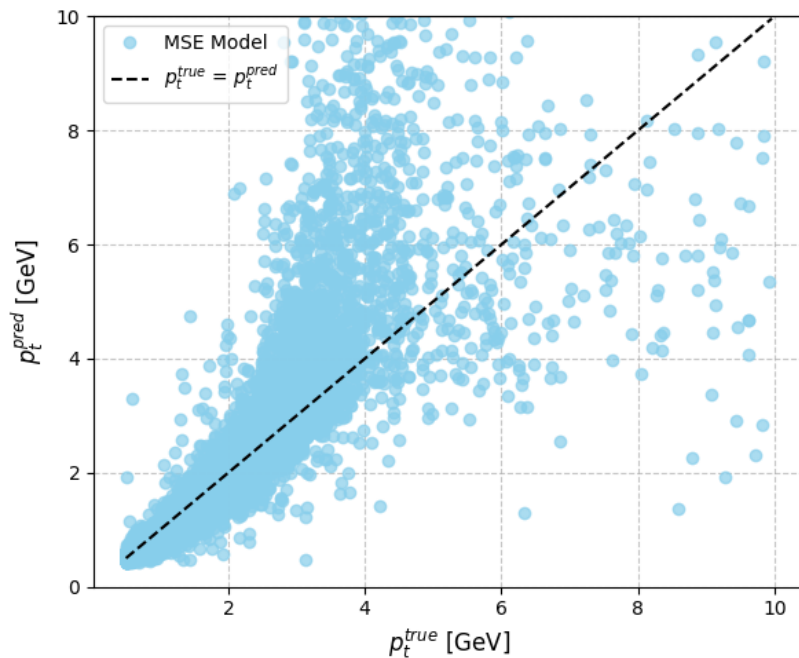


More results

x y z

p_t^{true} vs p_t^{pred} (('tx', 'ty', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

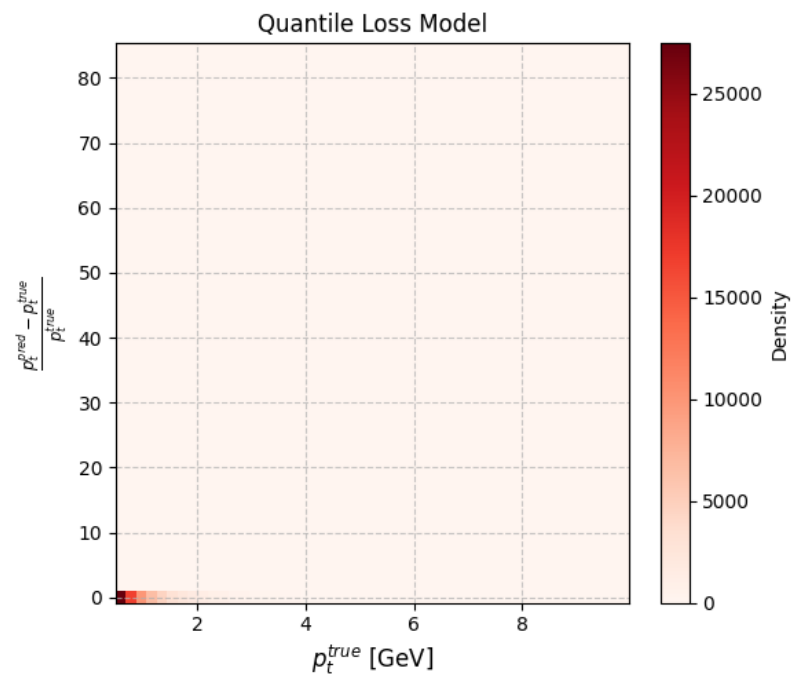
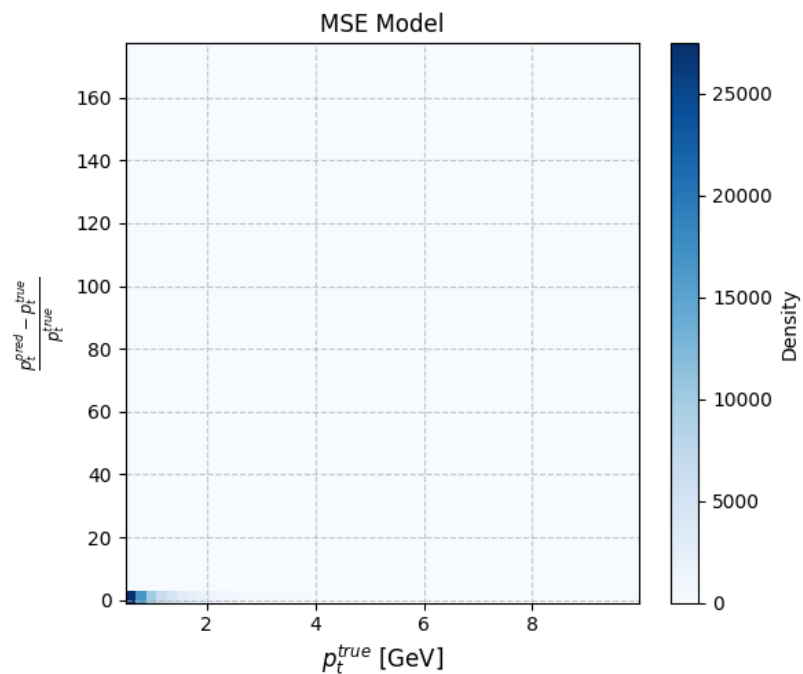


Resolution

x y z

Relative error resolution for p_t (('tx', 'ty', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

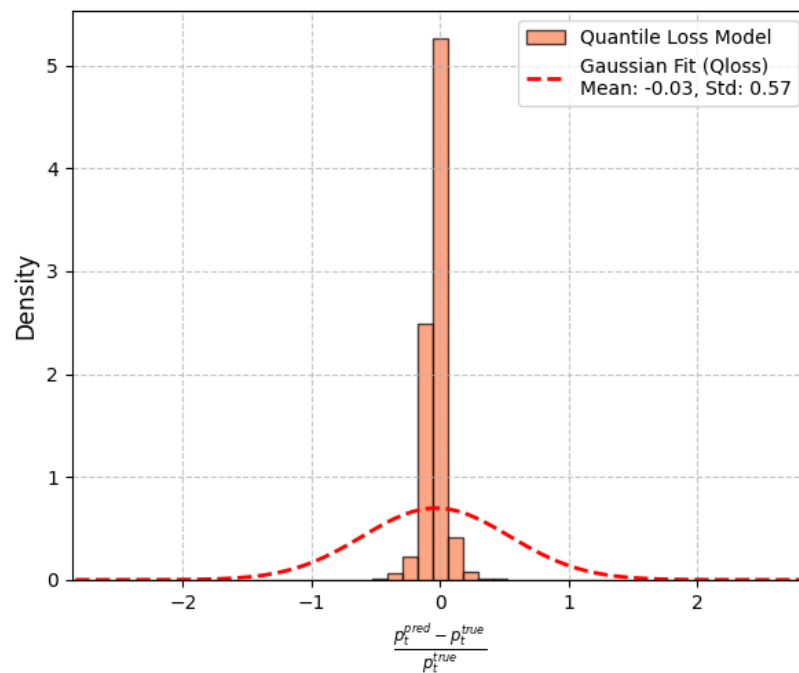
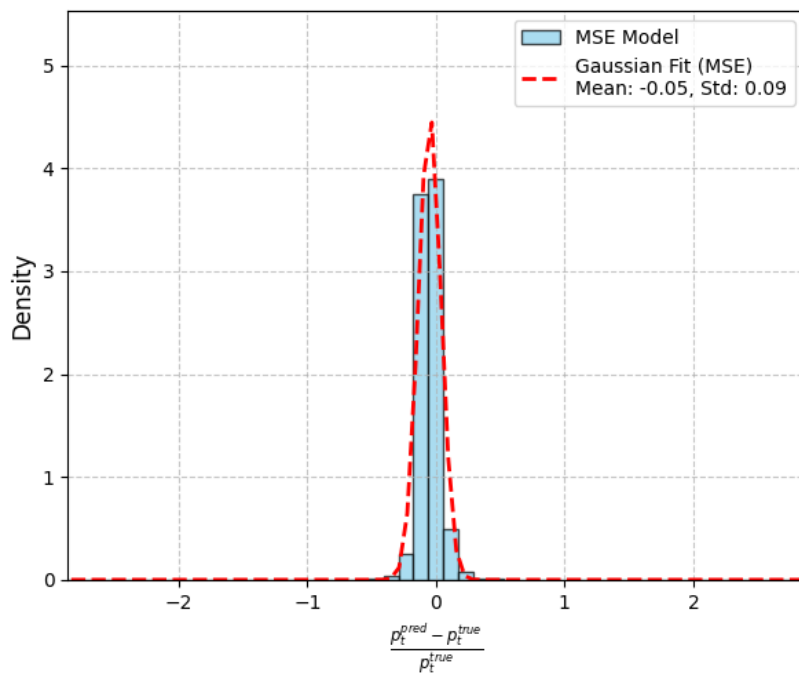


Resolution

x y z

TrackML Zenodo

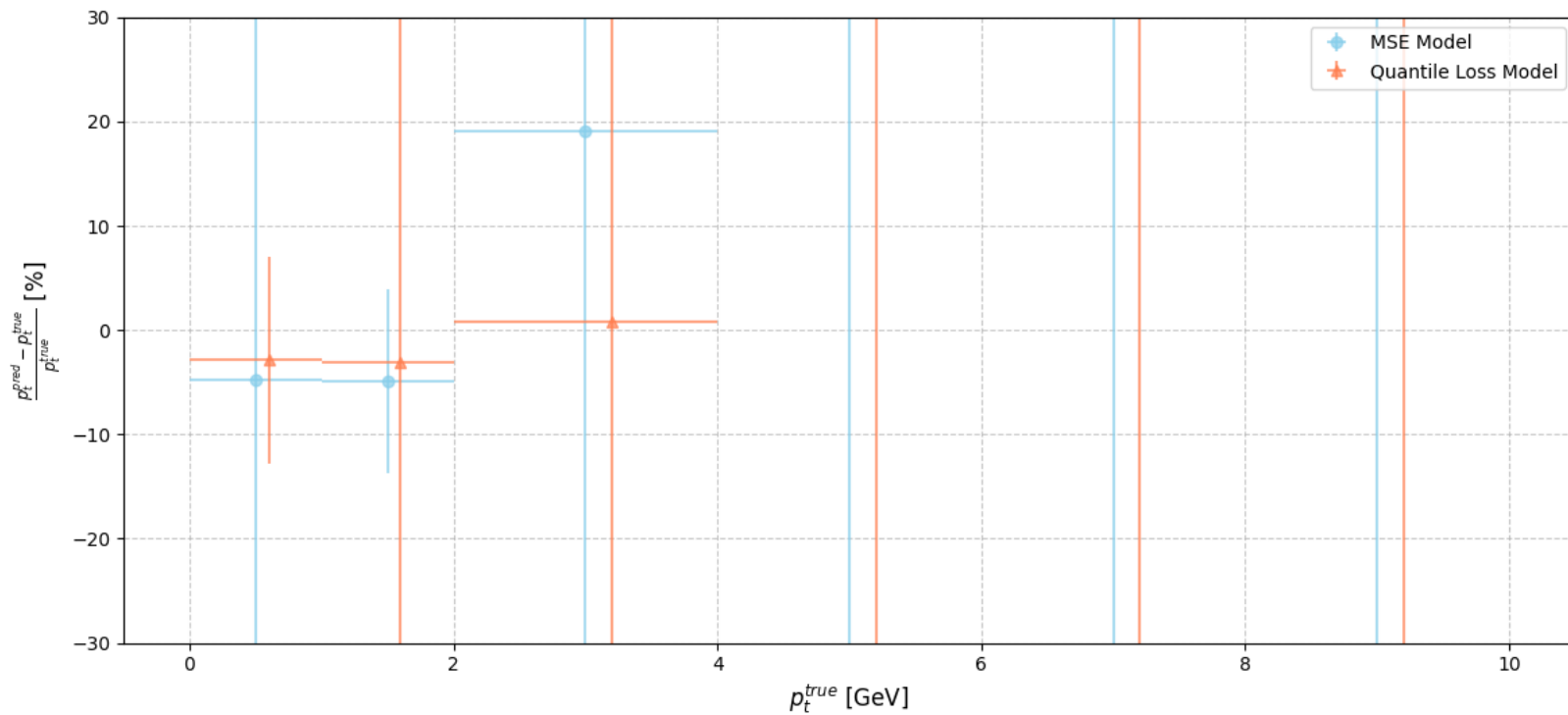
Relative Error Distributions for p_t ($1 \text{ GeV} < p_t < 2 \text{ GeV}$) (('tx', 'ty', 'tz') -> ('qopT', 'pz'))



Resolution

x y z

TrackML Zenodo

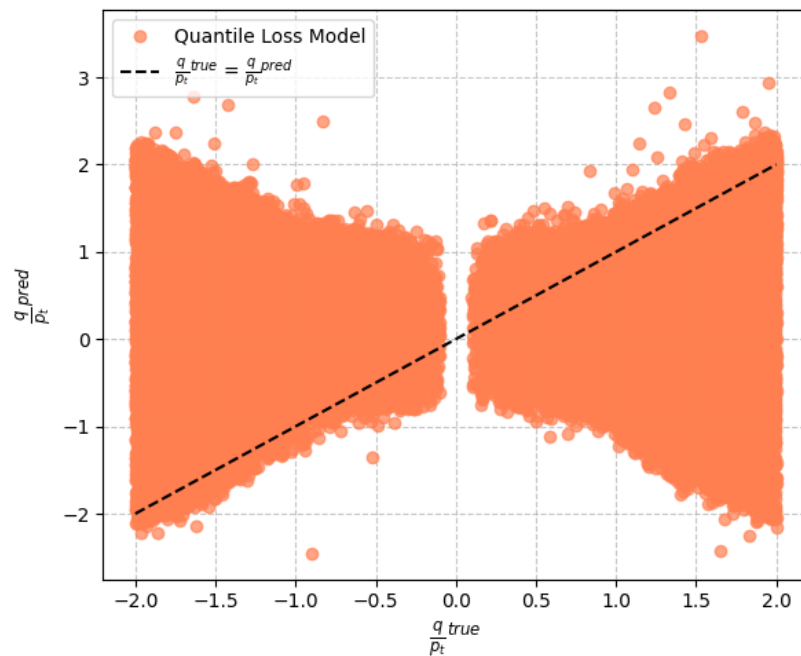
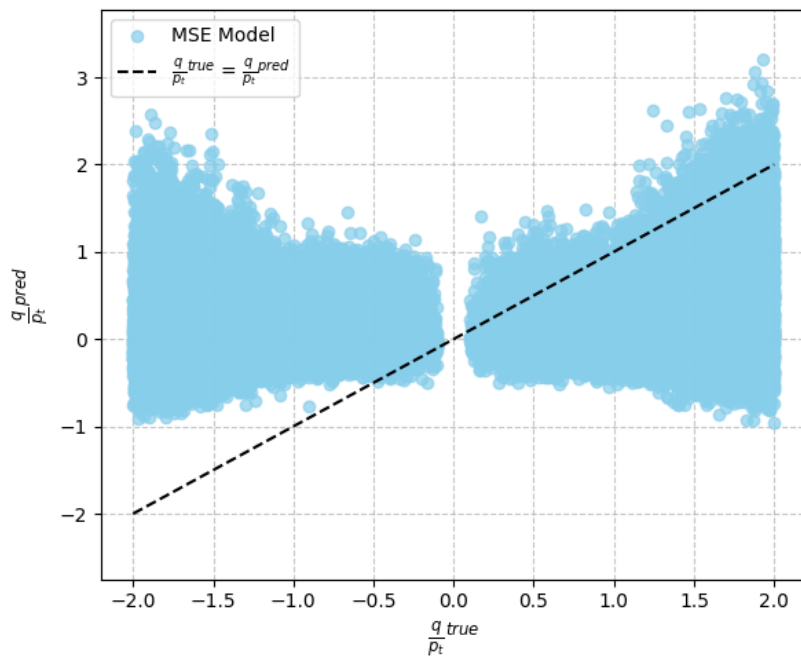


More results

r phi z

$\frac{q}{p_T}^{true}$ vs $\frac{q}{p_T}^{pred}$ ($\frac{q}{p_T} < 10$ GeV) (('tr', 'tphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

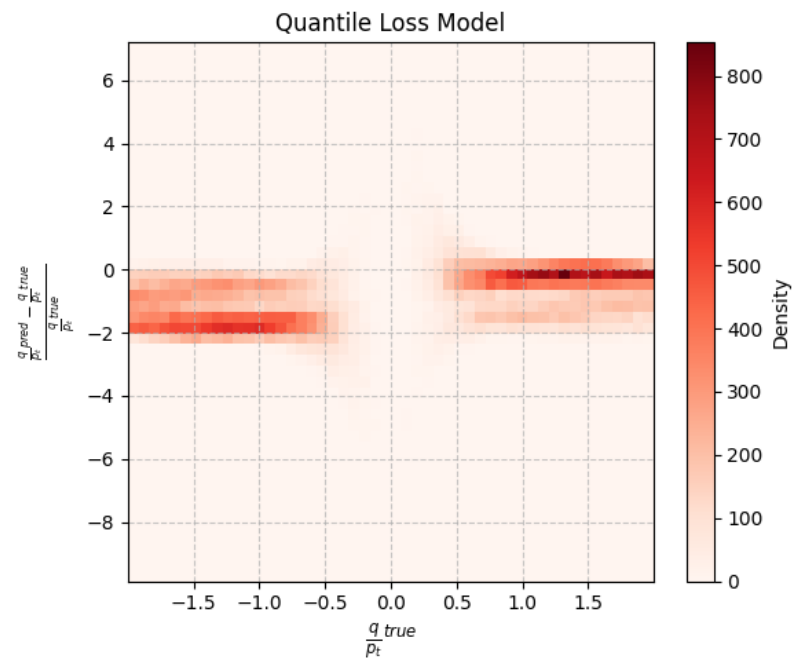
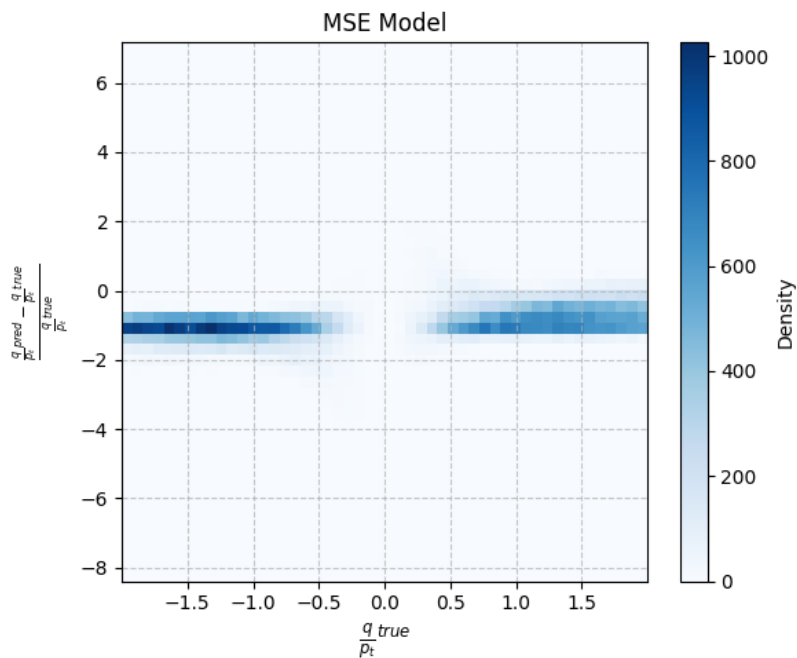


Resolution

r phi z

Relative error resolution for $\frac{q}{p_t}$ (('tr', 'tphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

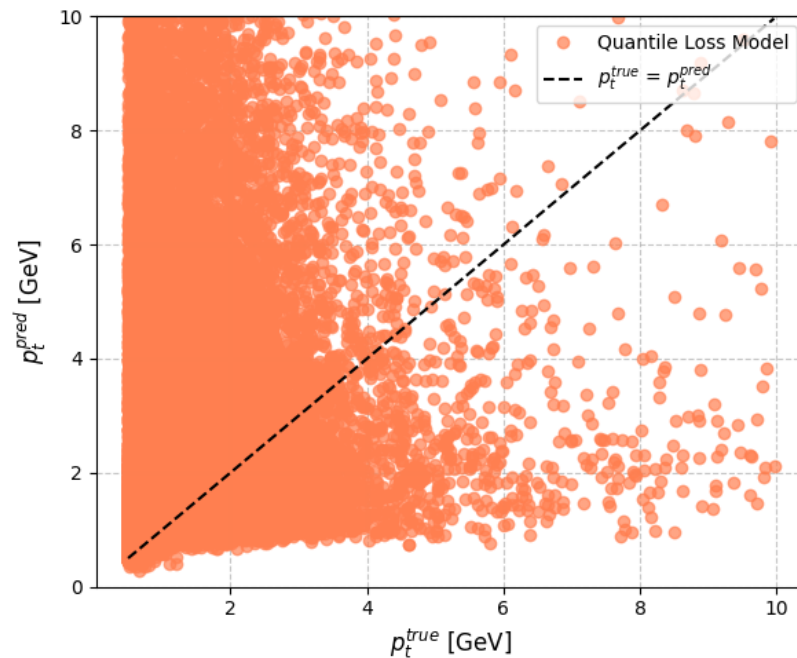
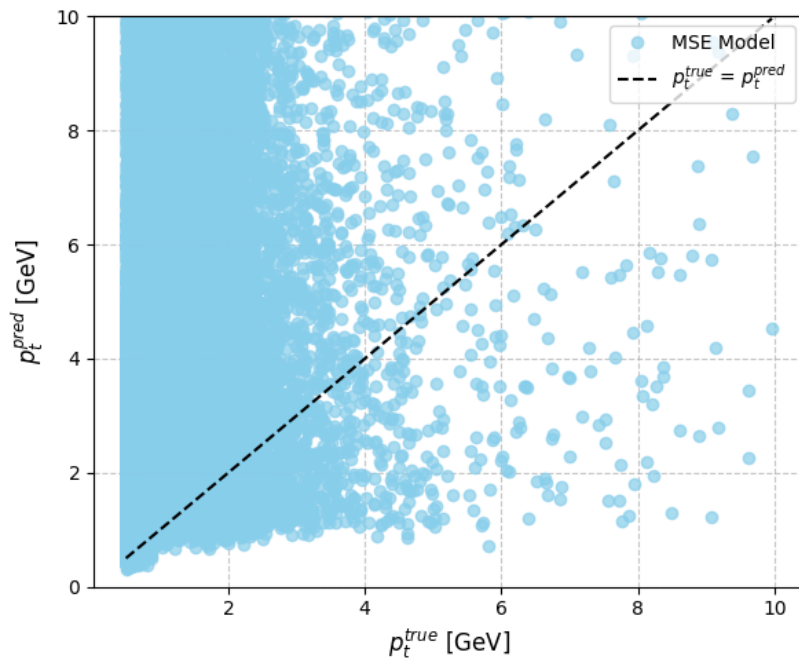


More results

r phi z

p_t^{true} vs p_t^{pred} (('tr', 'tphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

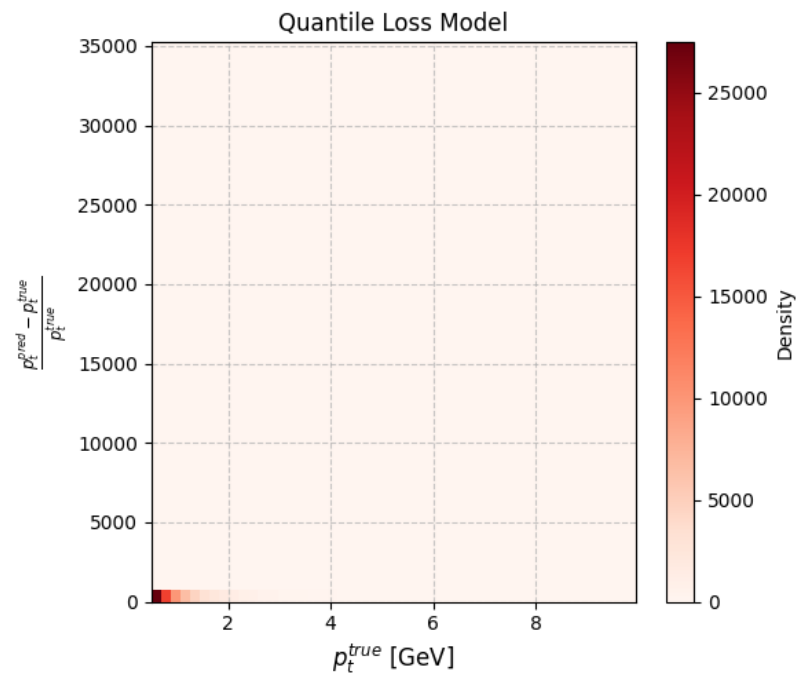
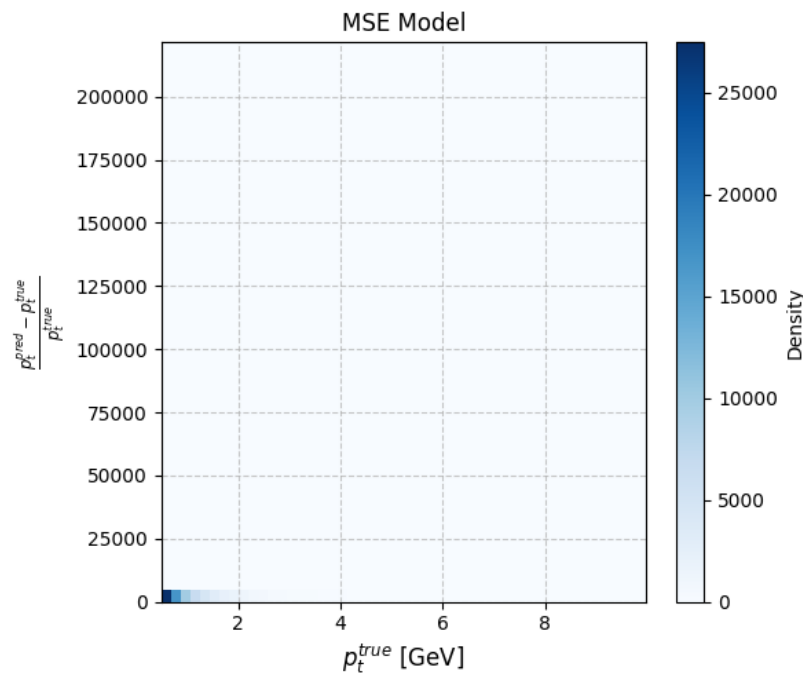


Resolution

r phi z

Relative error resolution for p_t (('tr', 'tphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

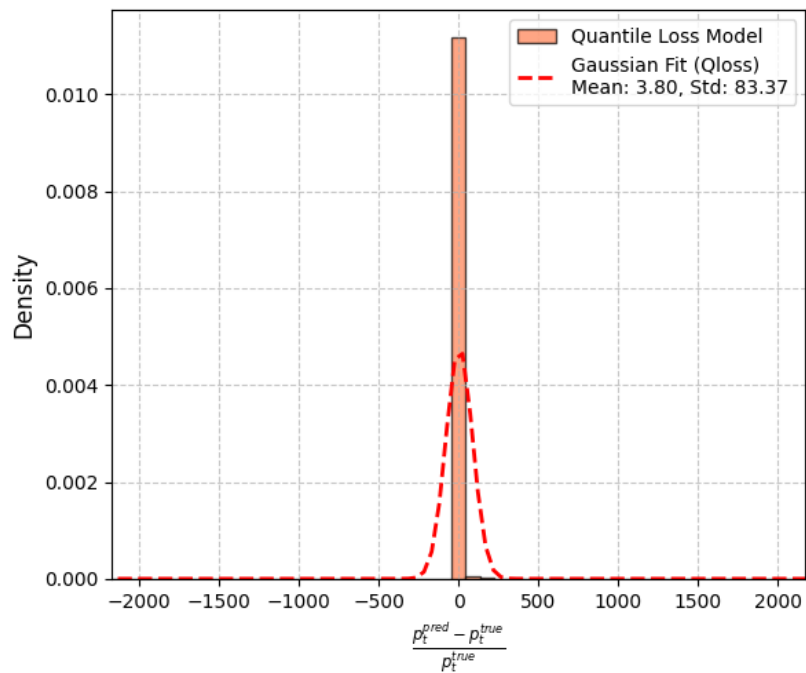
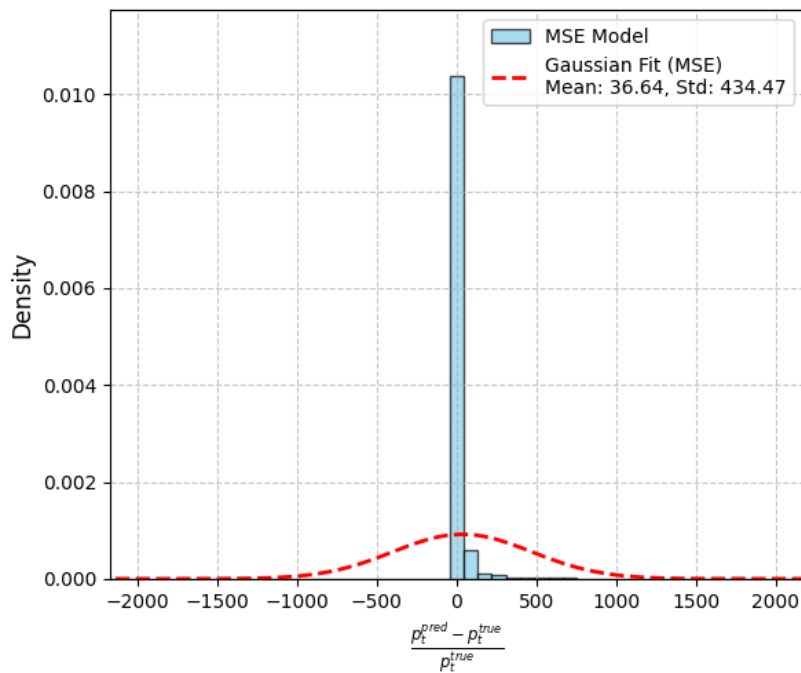


Resolution

r phi z

TrackML Zenodo

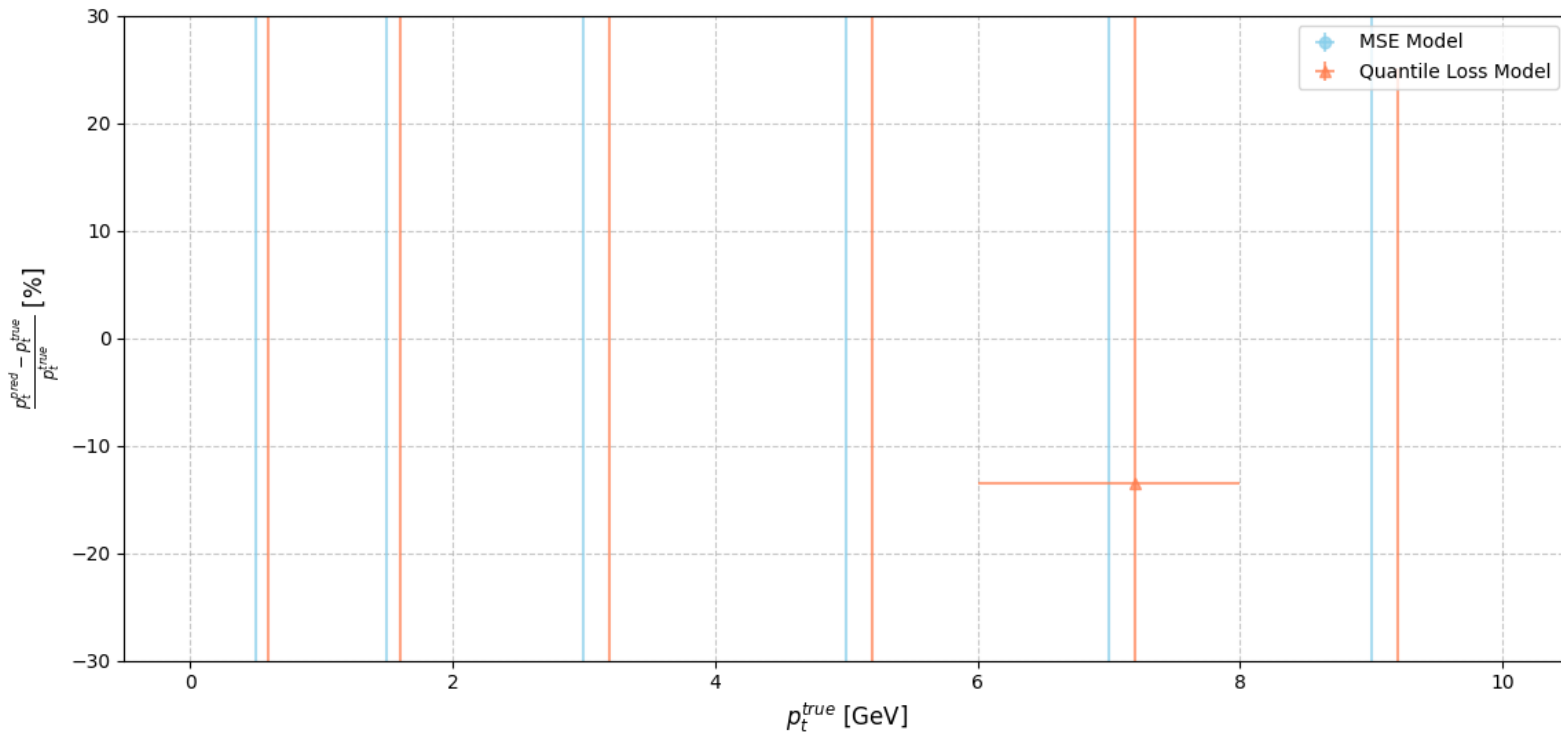
Relative Error Distributions for p_t ($1 \text{ GeV} < p_t < 2 \text{ GeV}$) (('tr', 'tphi', 'tz') -> ('qopT', 'pz'))



Resolution

r phi z

TrackML Zenodo



dPhi

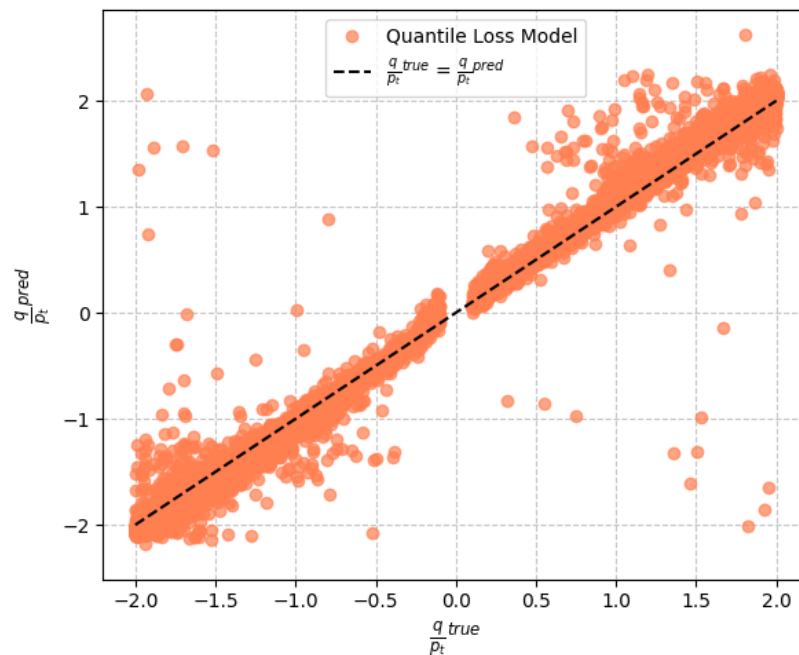
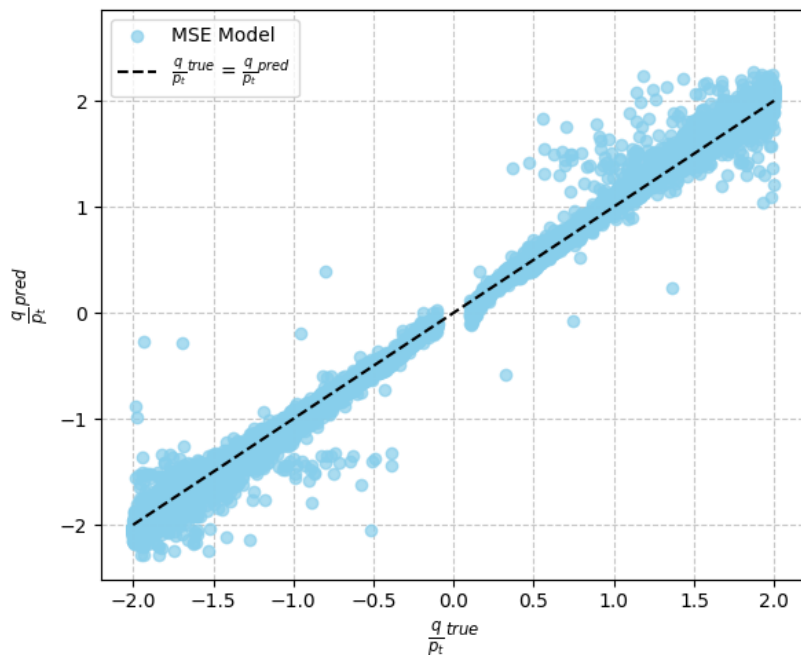
- **Use dphi instead of phi as input**
- **$d\phi = \Phi - \phi_0$ ($\phi_0 = \phi$ of first hit)**
- **Introduces circular symmetry**

More results

r dphi z

$\frac{q_{true}}{p_t}$ vs $\frac{q_{pred}}{p_t}$ (('tr', 'dphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

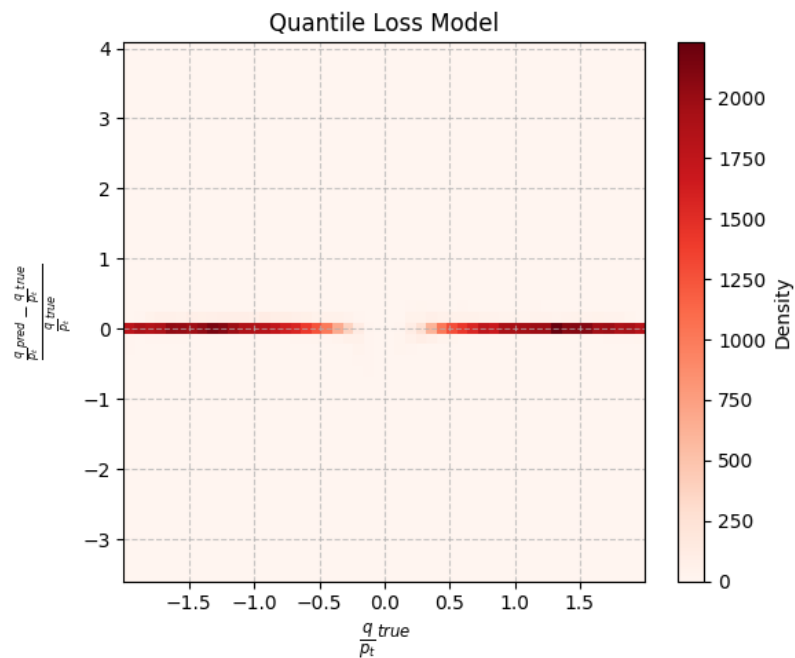
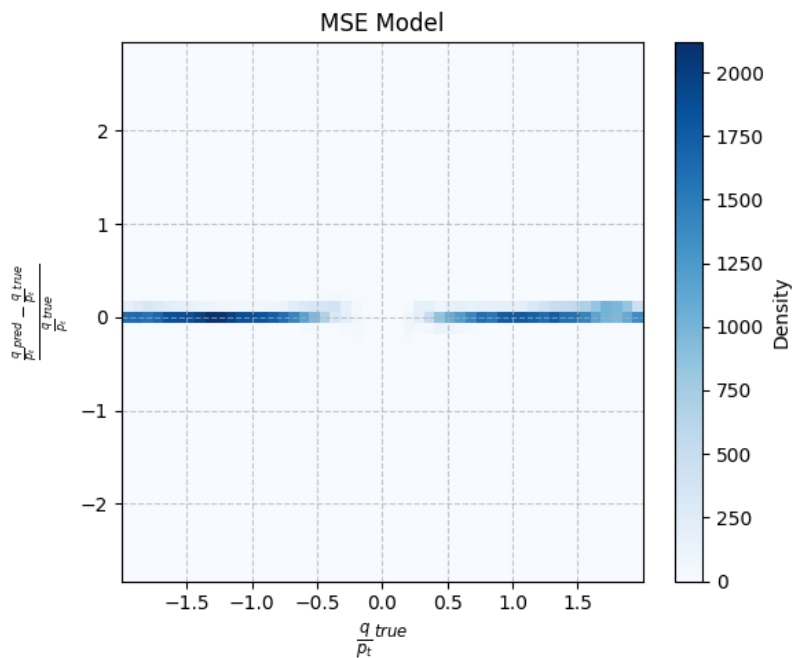


Resolution

r dphi z

Relative error resolution for $\frac{q}{p_t}$ (('tr', 'dphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

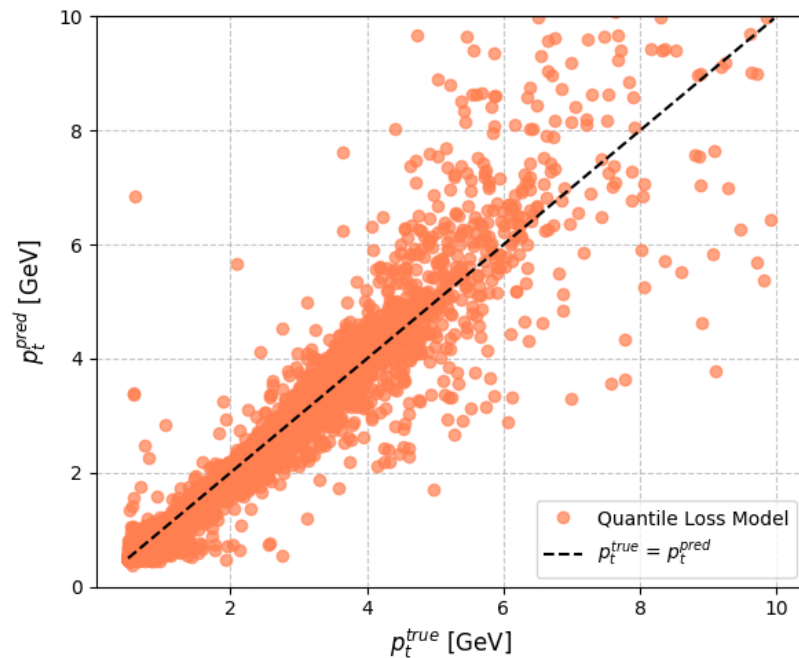
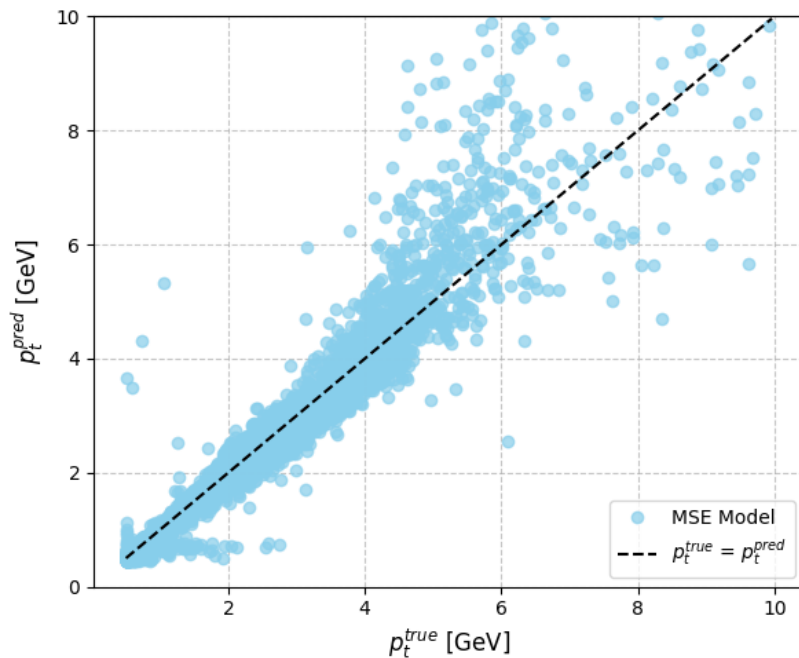


More results

r dphi z

p_t^{true} vs p_t^{pred} (('tr', 'dphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

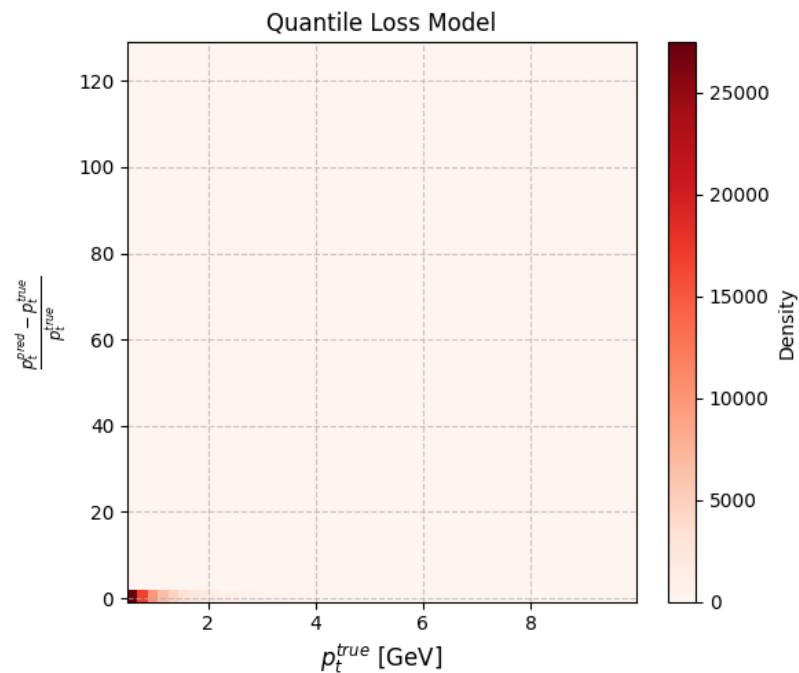
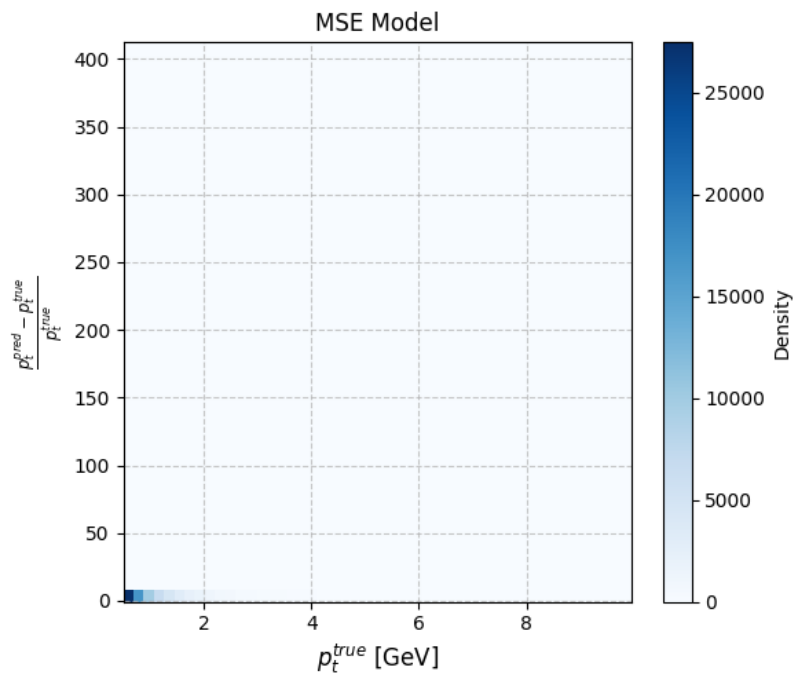


Resolution

r dphi z

Relative error resolution for p_t (('tr', 'dphi', 'tz') -> ('qopT', 'pz'))

TrackML Zenodo

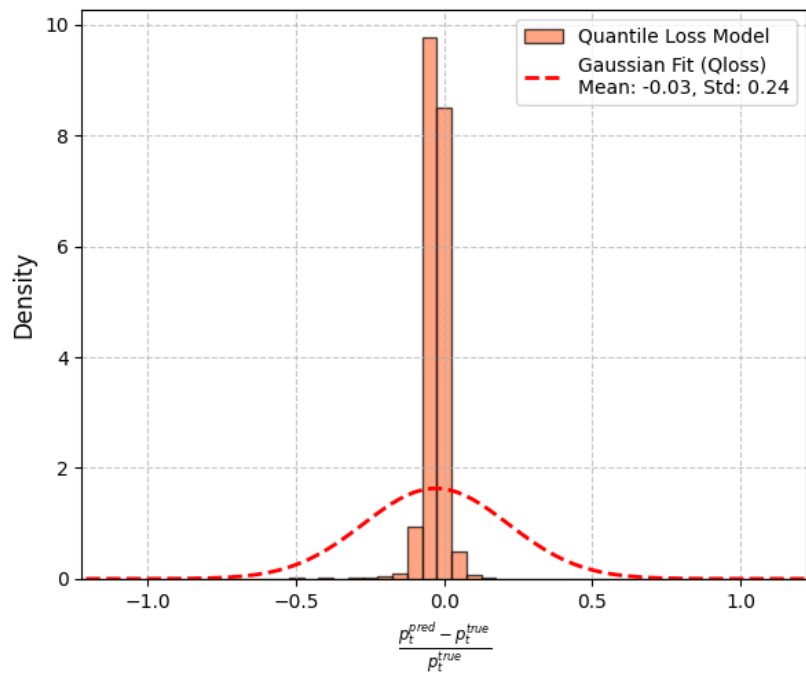
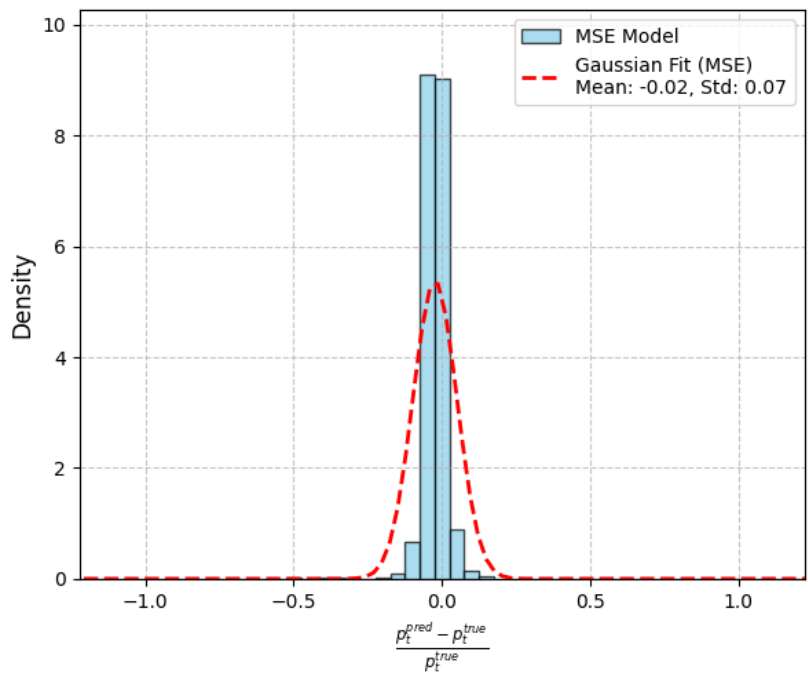


Resolution

r dphi z

TrackML Zenodo

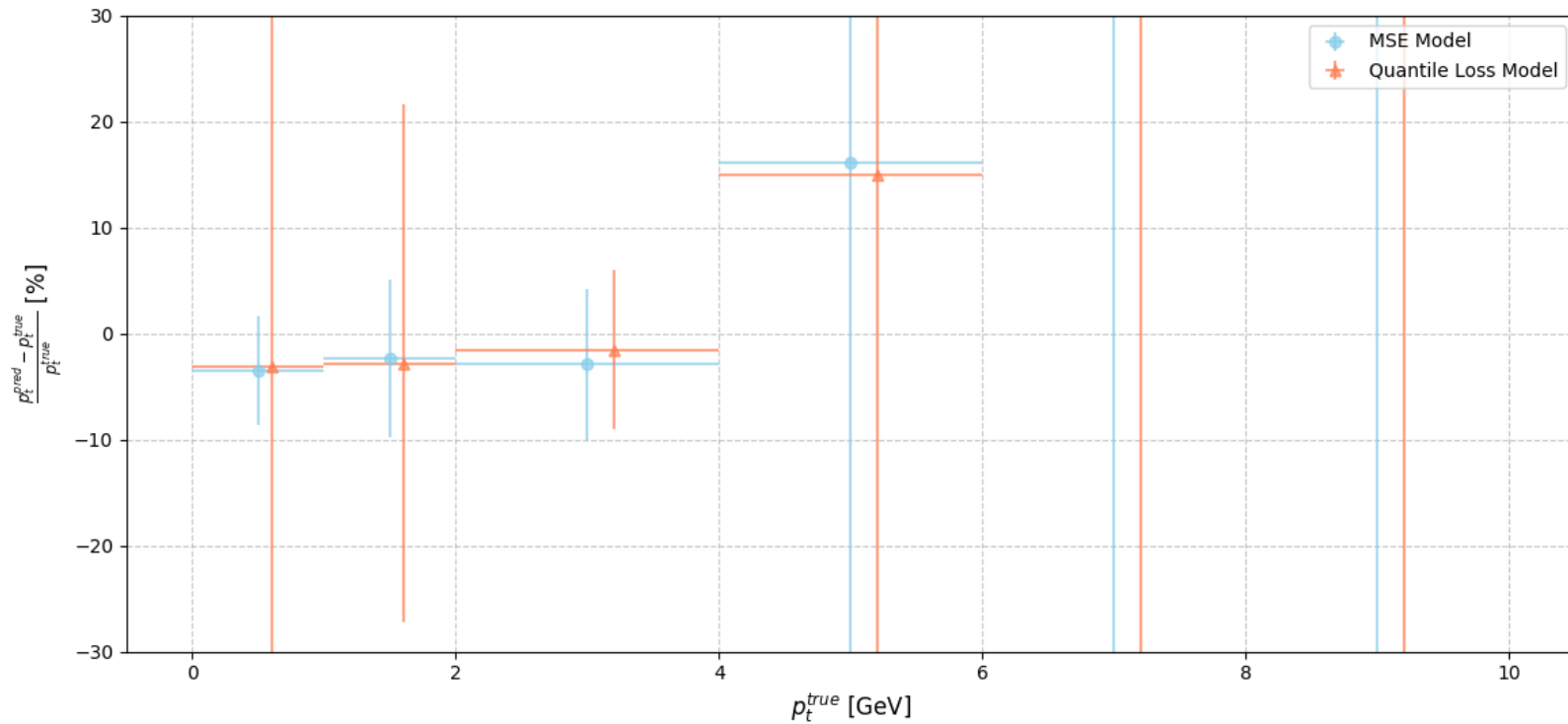
Relative Error Distributions for p_t ($1 \text{ GeV} < p_t < 2 \text{ GeV}$) (('tr', 'dphi', 'tz') -> ('qopT', 'pz'))



Resolution

r dphi z

TrackML Zenodo



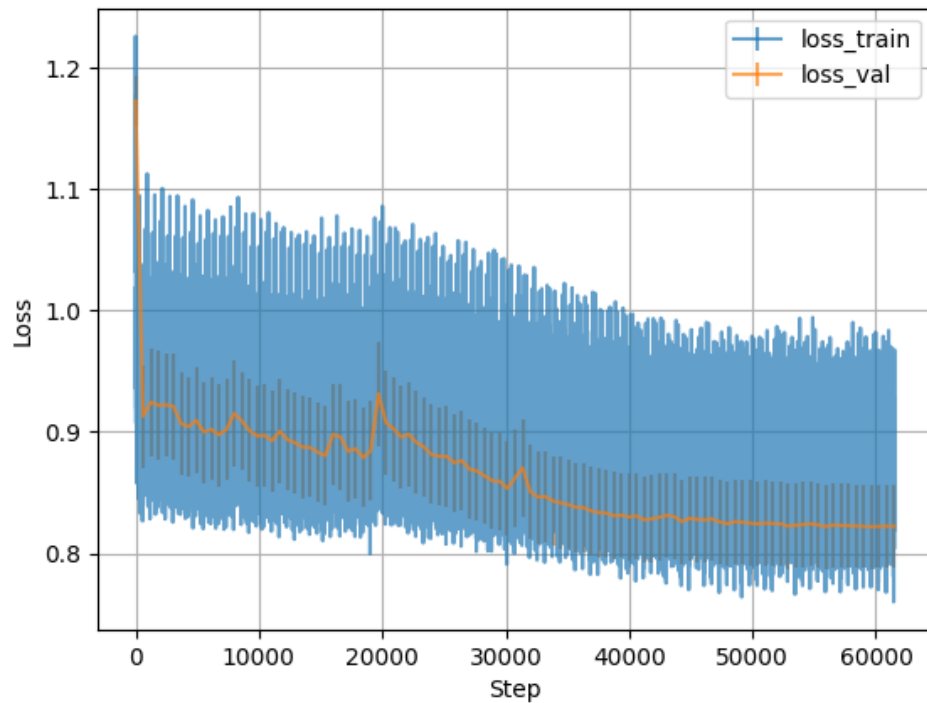
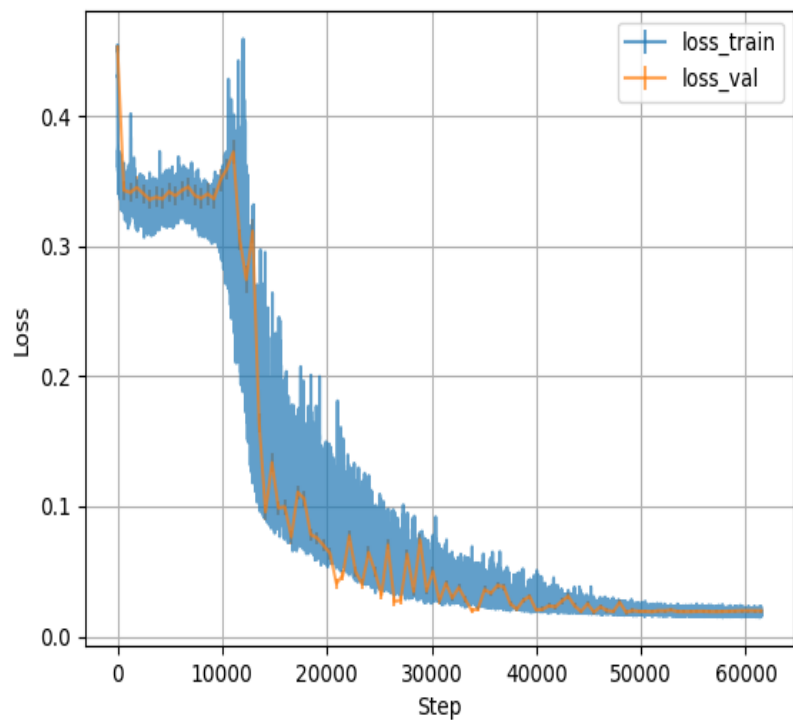
Loss

r dphi z

Target: q/pT

r phi z

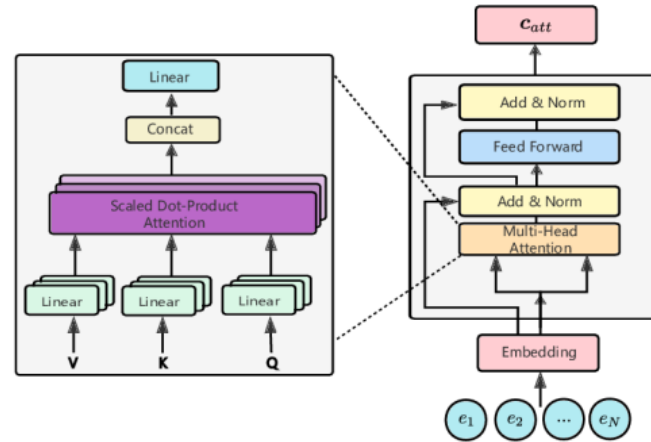
TrackML Zenodo



BACKUP

TrackFormer

- **Transformer for track parameter regression**
- **Tested on several dataset: ToyTracks, Acts, TrackML**
- **Regression in pt and pz**
- **Shown promising results**



Sequences were padded to a fixed length

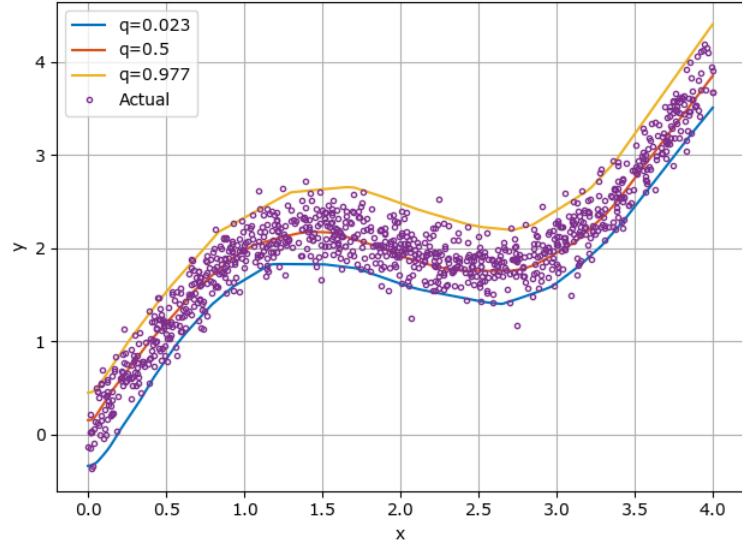
TrackFormer loss functions

Mean squared error:

$$\text{MSE} = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2$$

Quantile loss:

$$\text{QL} = \frac{1}{n} \sum_{i=1}^n (\max(q(y_i - \hat{y}_i), (q - 1)(y_i - \hat{y}_i)))$$



Dataset selection

Selections:

- $n_{\text{hits}} \geq 3$
- $0.5 \leq p_T \leq 10$ [GeV]
- $|v_x| < 1 \ \&\& \ |v_y| < 1$ [mm]
- $|\eta| \leq 1$

Before:

Training: 11 222 273 particles
Validation: 1 334 273 particles
Testing: 1 404 273 particles

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TrackML Kaggle

After:

Training: 1 232 896 particles
Validation: 154 082 particles
Testing: 153 788 particles

Dataset selection details

Selections:

- $n_{\text{hits}} \geq 3$
- $0.5 \leq p_T \leq 10$ [GeV]
- $|v_x| < 1 \ \&\& \ |v_y| < 1$ [mm]
- $|\eta| \leq 1$

Test dataset:

Total: 1643787 particles

621539 particles, $\text{min_pt}=0.5$, $\text{max_pt}=10$

599332 particles, $\text{min_hits}=3$, $\text{min_pt}=0.5$, $\text{max_pt}=10$, $\text{keep_secondaries}=\text{True}$

553606 particles, $\text{min_hits}=3$, $\text{min_pt}=0.5$, $\text{max_pt}=10$, $\text{keep_secondaries}=\text{False}$ (" $|v_x| < 1 \ \&\& \ |v_y| < 1$ " cut)

153788 particles, $\text{min_hits}=3$, $\text{min_pt}=0.5$, $\text{max_pt}=10$, $\text{keep_secondaries}=\text{False}$, $\text{max_abs_eta}=1$

Training

Architecture:

input_dim: 3
model_dim: 128
num_classes: 2
num_heads: 4
num_layers: 2

Training:

warmup: 100
lr: 0.0005
dropout: 0.1
input_dropout: 0.1
batch_size: 1024
max_epochs: 100

Saving:

monitor: val_loss
mode: min

Variables:

input:
tx, ty, tz
input:
tr, tphi, tz
input:
tr, dphi, tz
target:
pt, pz
target:
qopt, pz