Pandora Performance for Atmospherics

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FD Simulation and Reconstruction Group Meeting

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Framework

Special thanks to Maria B. Brunetti and Pierre Granger

Atm Sample:
`fardet-hd:atmnu_max_weighted_randompolicy_dune10kt_1x2x6_50231162_498_20231118T222014Z_gen_g4_detsim_hitreco__20240503T060840Z_reco2.root`

Reco2 fcl:
`reco2_atmos_dune10kt_1x2x6_geov5.fcl`

Number of events: ~1.3M

Beam Sample:
`fardet-hd:fardet-hd__fd_mc_2023a_reco2__full-reconstructed__v09_81_00d02__standard_reco2_dune10kt_nu_1x2x6__prodgenie_nu_dune10kt_1x2x6__out1__v1_official` + other flavors

Reco2 fcl:
`standard_reco2_dune10kt_nu_1x2x6.fcl`

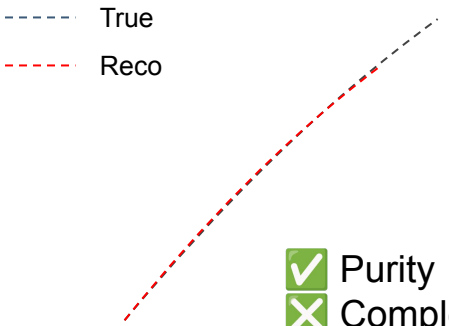
Number of events: ~1.3M

Performance Metrics

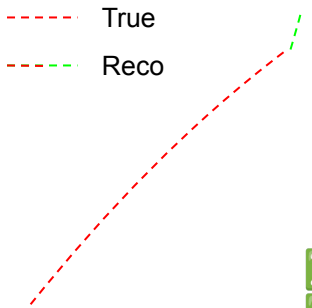
Efficiency: For a given type of MC particle, the fraction of particles that are matched to at least one reconstructed particle.

Purity: The fraction of hits in the reconstructed particle that are shared with the MC particle.

Completeness: The fraction of hits in the MC particle that are shared with the reconstructed particle.



✅ Purity
❌ Completeness



❌ Purity
✅ Completeness

Implementations

Pandora Validation Algorithm stage:

- Save nu flavor, momentum and interaction (CC/NC) in Validation output.

Metrics stage:

- Fiducial Cuts implemented: (X, Y: +-50cm; Z:+50 -150 cm).
- Atm sample reweighted with the Beam energy spectrum.
- Angular Cuts implemented to limit atmospherics in the +z direction.

Samples

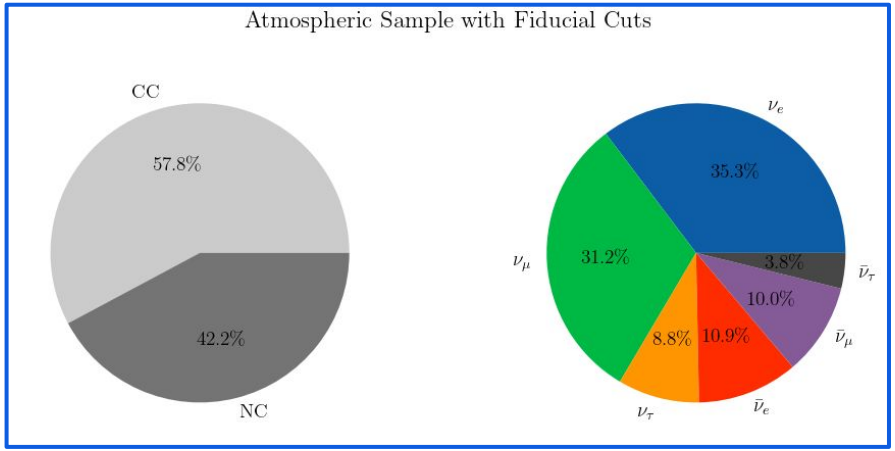
- **Similar statistics** for both samples.

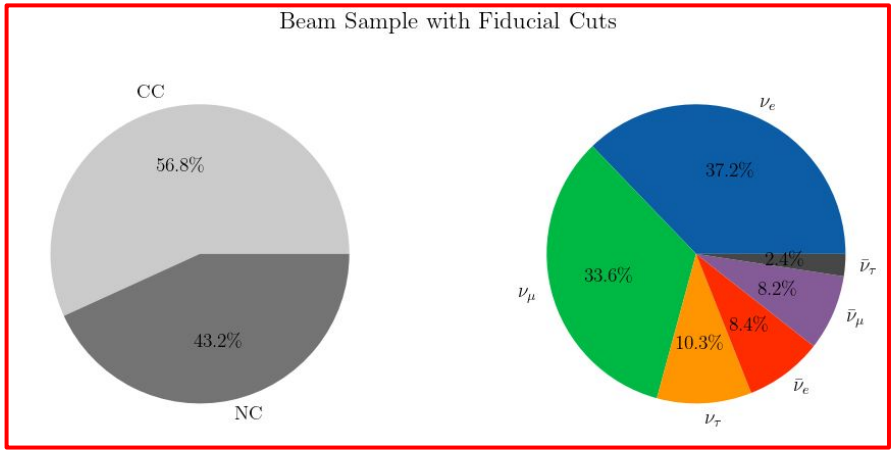
Breakdown after Fiducial Cuts:

	ν_e	ν_μ	ν_τ	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$	Total ν	Total $\bar{\nu}$	Total $\nu + \bar{\nu}$
CC	224,094	189,948	13,543	46,015	39,833	4,801	427,585	90,649	518,234
NC	92,618	89,483	65,582	51,573	49,506	29,605	247,683	130,684	378,367
Total	316,712	279,431	79,125	97,588	89,339	34,406	675,268	221,333	896,601

	ν_e	ν_μ	ν_τ	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$	Total ν	Total $\bar{\nu}$	Total $\nu + \bar{\nu}$
CC	211,641	184,819	18,883	29,065	28,083	2,616	415,343	59,764	475,107
NC	99,569	95,880	66,873	41,140	40,358	17,492	262,322	98,990	361,312
Total	311,210	280,699	85,756	70,205	68,441	20,108	677,665	158,754	836,419

(Vertex Inside FV) / All = 68% for atm, 63% for beam





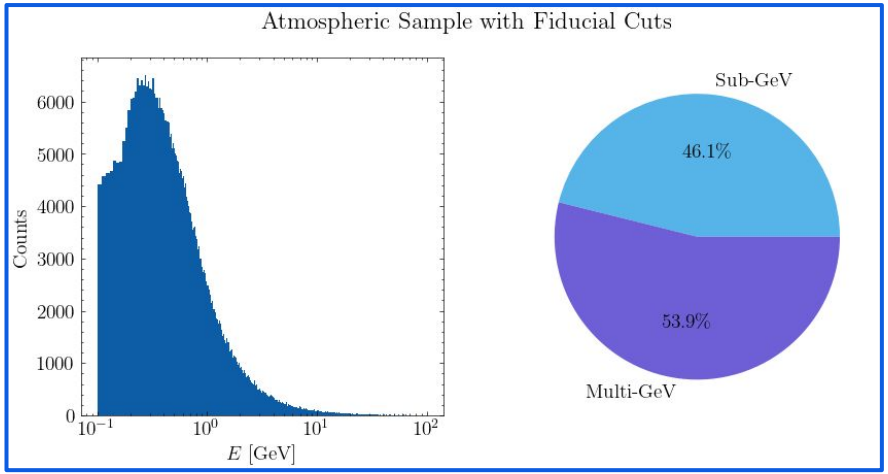
Samples

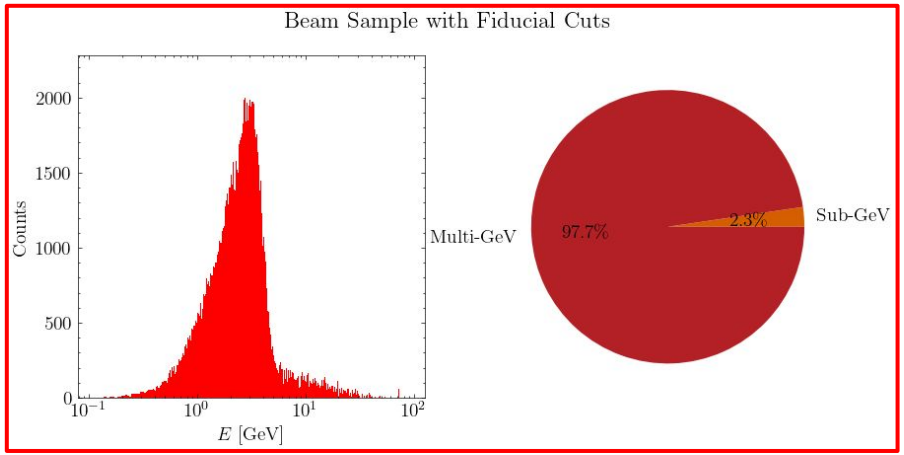
Energy distributions for the samples.

- ~ 50/50 split in atm for Sub-GeV and Multi-GeV events
- Only ~2% of beam events are Sub-GeV

Sub-GeV: True $E_\nu < 1$ GeV

Multi-GeV: True $E_\nu \geq 1$ GeV





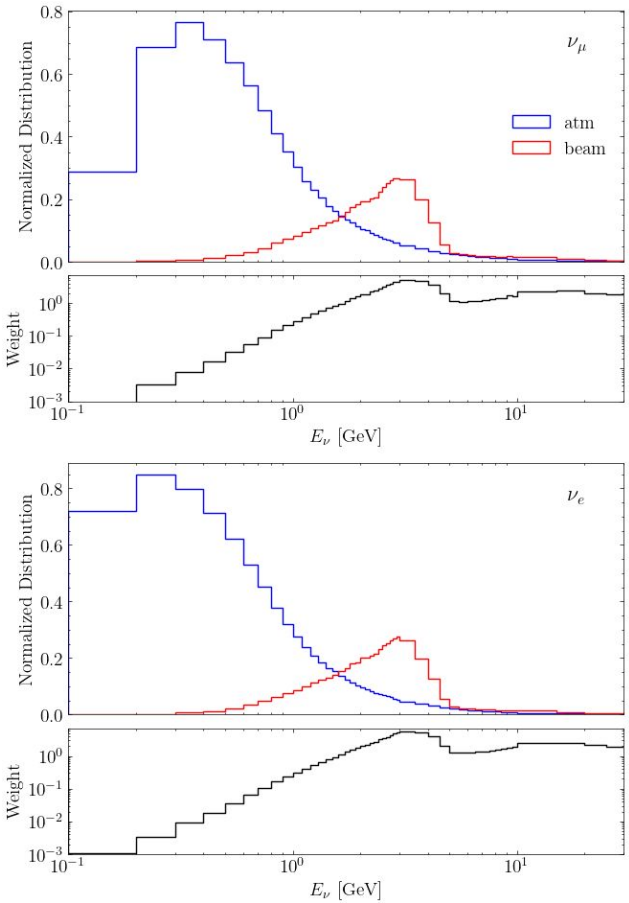
Weights

- **Atm and Beam:** very different flux shapes.

- **Strategy:**
  - Divide samples in flavor and energy bins;
  - To each event in atm sample, assign a weight *w* given by:

$$w = h_b/h_a \ ,$$

where *h* is the height of the bin corresponding to the event's energy.

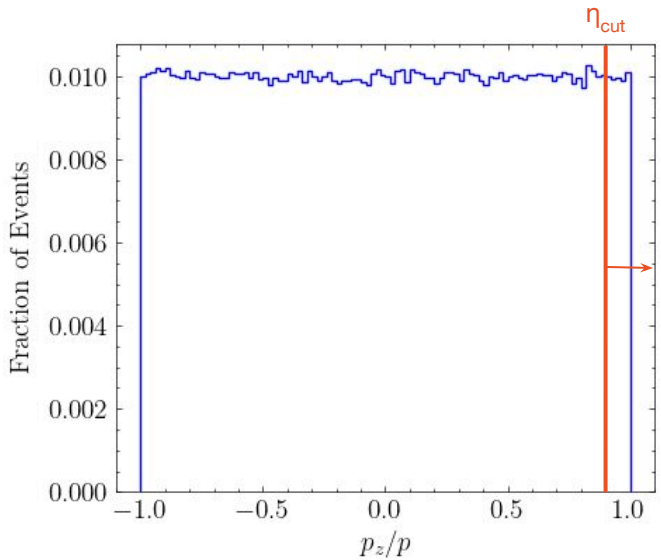


Angular Cuts

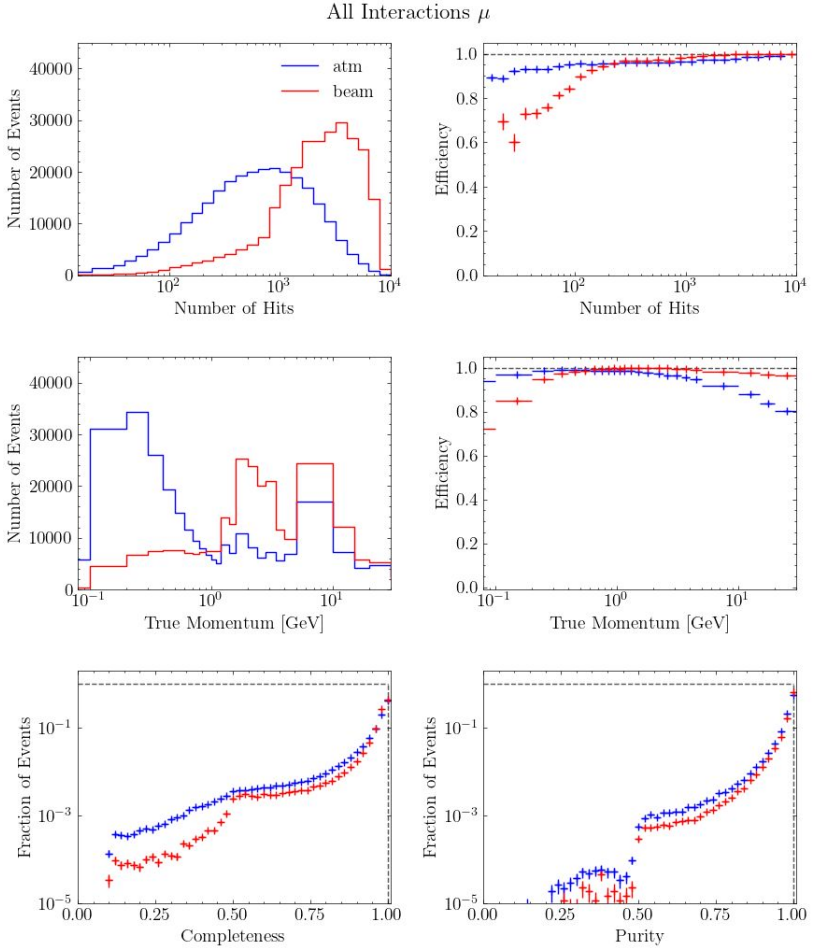
- **Atmospheric sample:** isotropic.
- **Strategy:** only use events where

$$p_z/p > \eta_{cut}$$

For this presentation: $\eta_{cut} = 0.9$



All Interactions

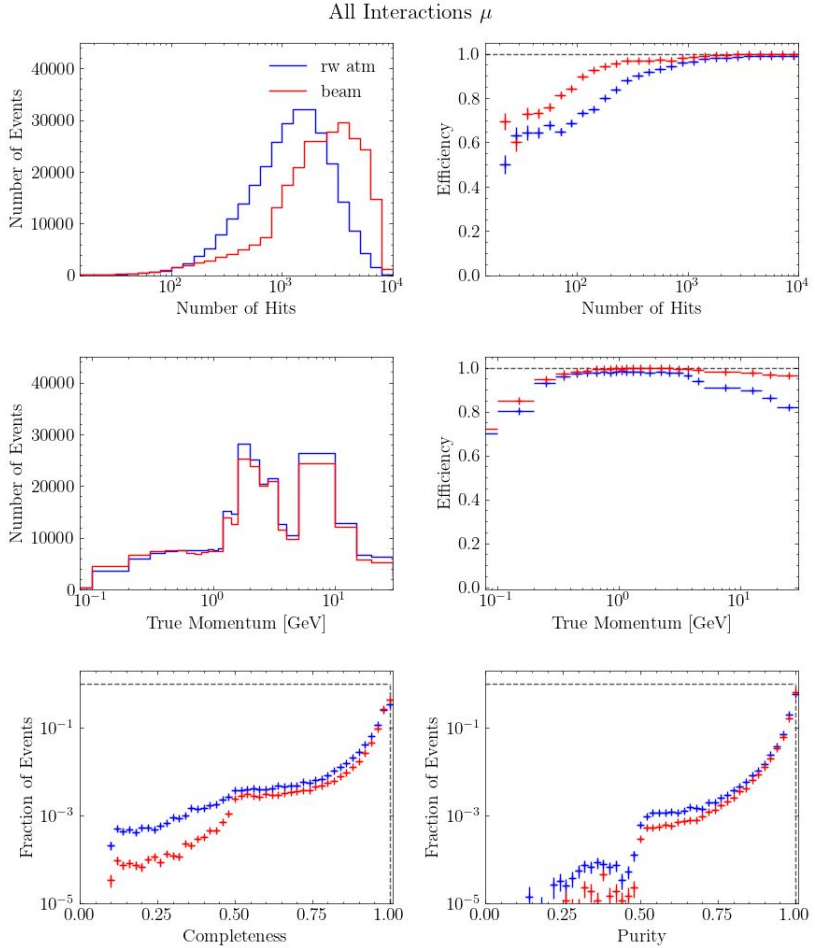


Muons

Simple Comparison

- ➔ No Reweighting.
- ➔ No angular cut.

- Notable performance differences for low and high energies.

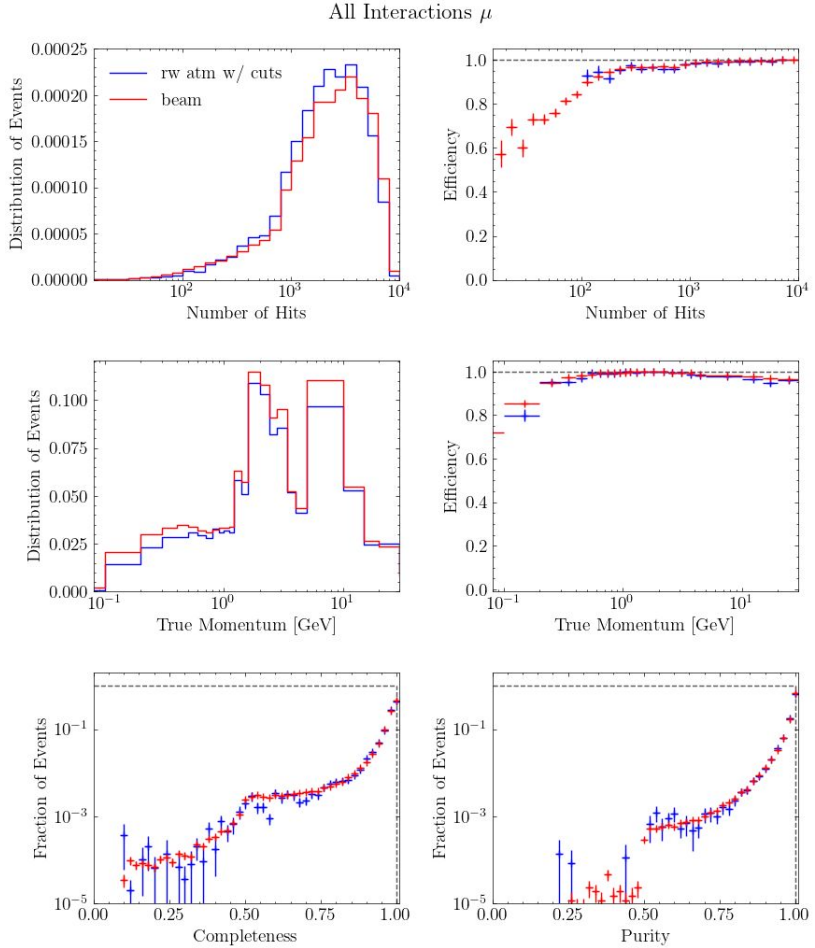


Muons

Reweighted Comparison

➔ No angular cut.

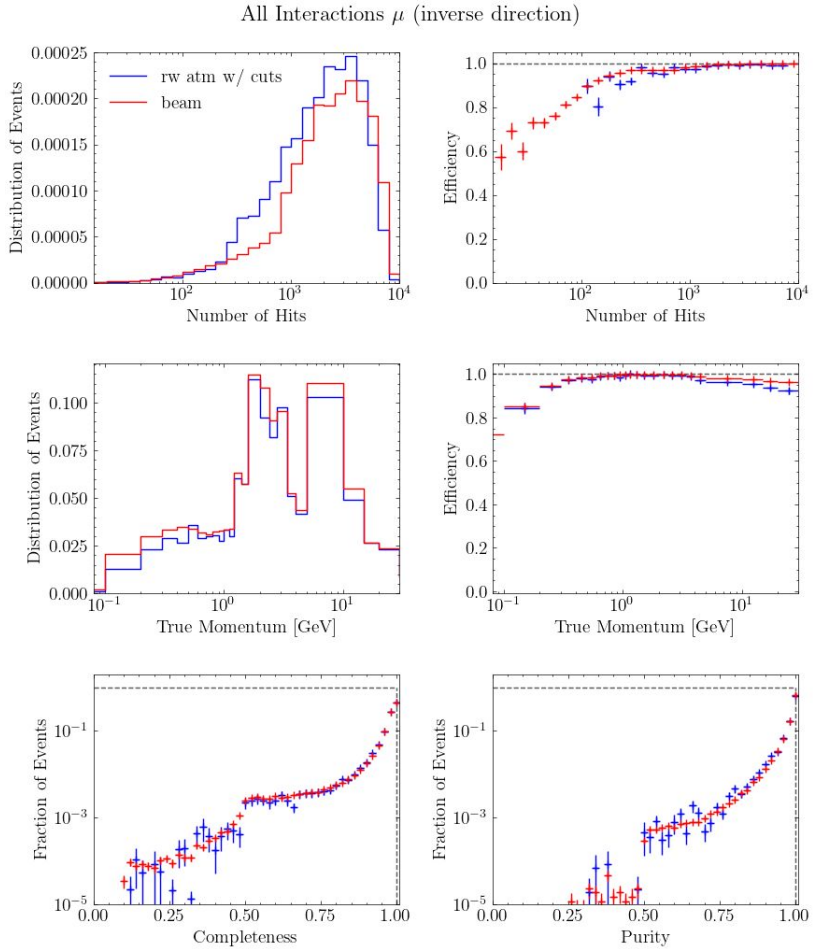
- Atm NHits distribution shifted to the left: geometrical effect.
- Low E: differences mitigated.
- High E: differences persist.



Muons

Reweighted, Angular Cut Comparison

- NHits distributions almost identical.
- High E: differences mitigated.
- Atm Low NHits: very few events per bin (drastic cut in stats).



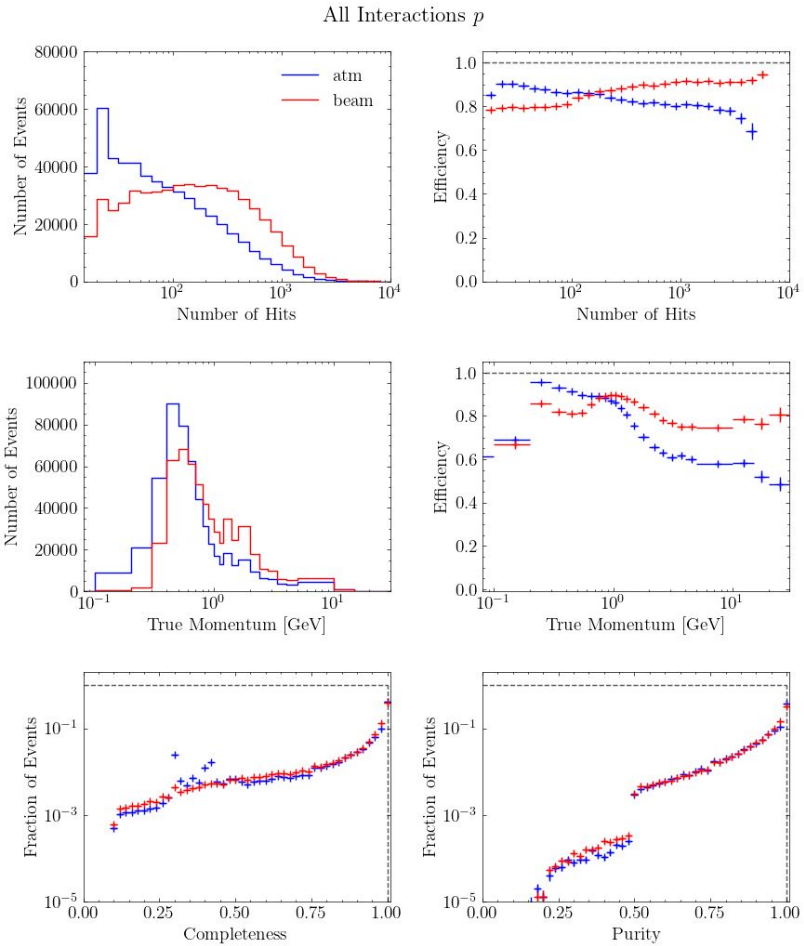
Muons

Reweighted, Angular Cut* Comparison

- *Using cut in the opposite direction:

  $p_z/p < -0.9$

- Slight bias (?) in High E.

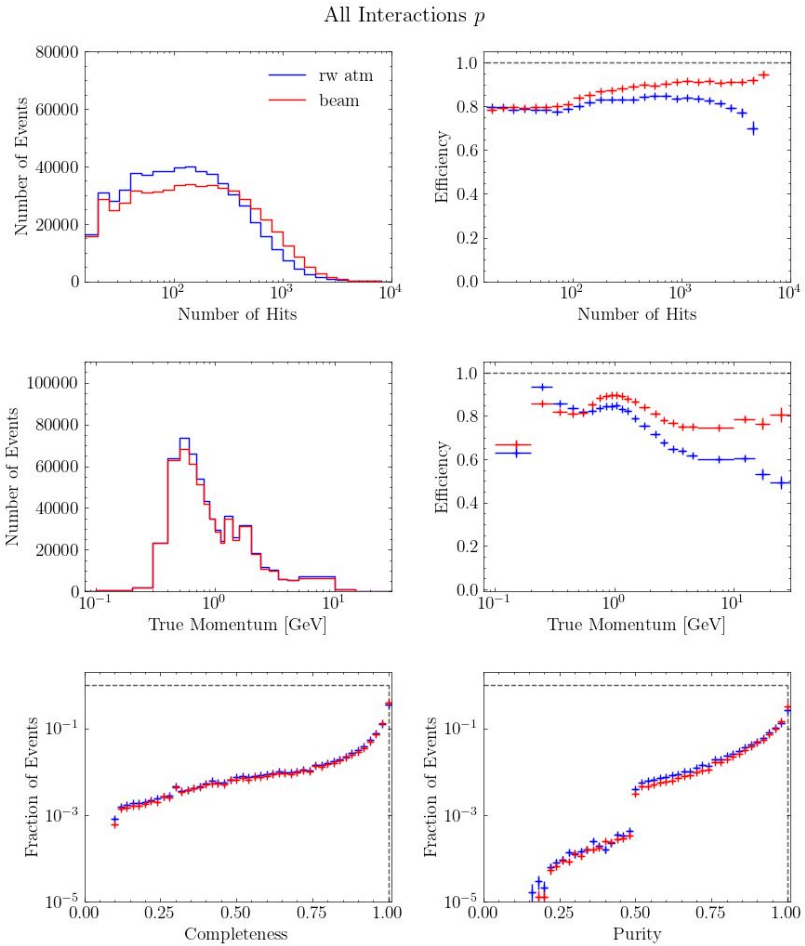


Protons

Simple Comparison

- ➔ No Reweighting.
- ➔ No angular cut.

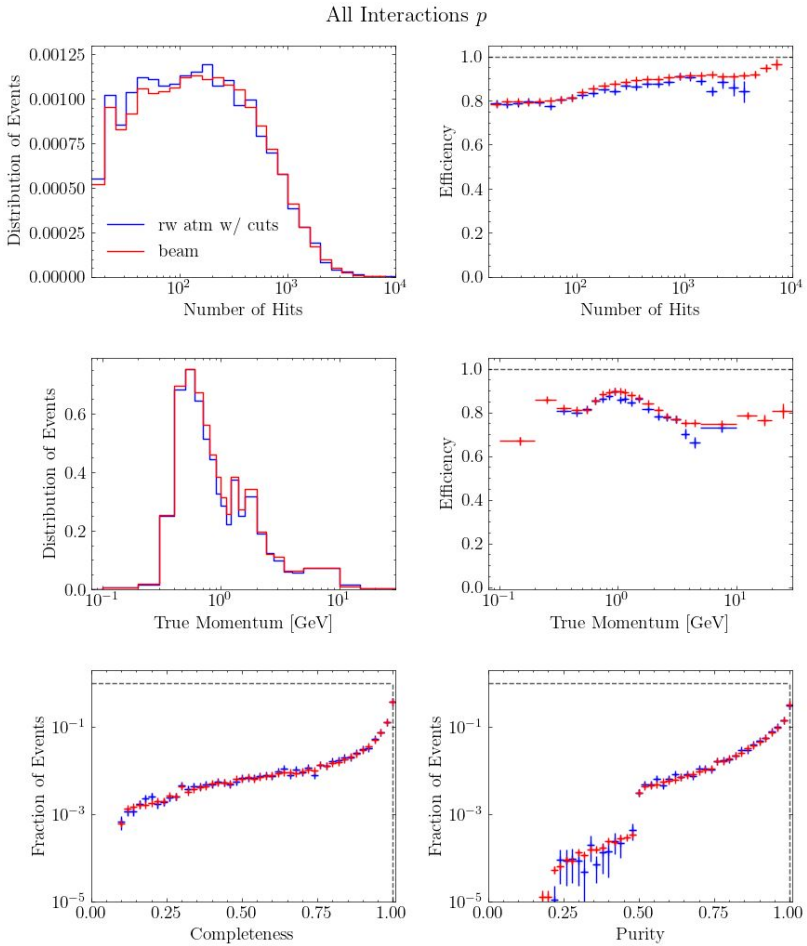
- Notable performance differences for low and high energies.
- Beam: efficiency starts to increase for high p.
- Atm: weird structure in completeness (NCQEL?).



Protons

Reweighting

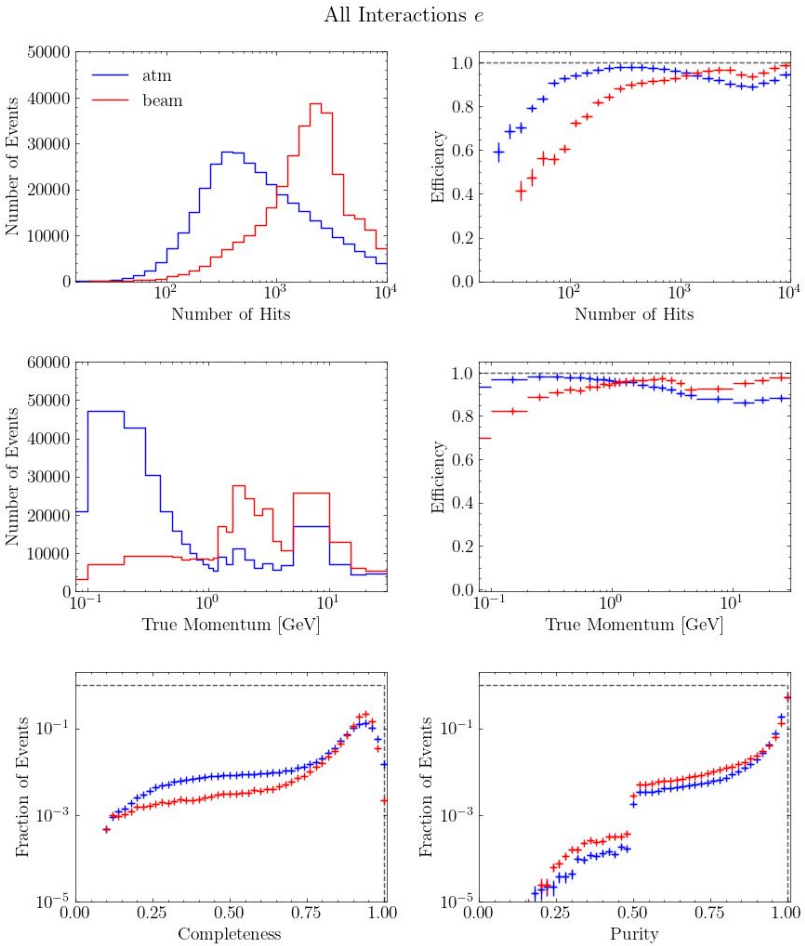
- ➔ No angular cut.
- Hits efficiency dropped for low E.
- Slightly lower Purity.
- Better behavior for Completeness.
- Differences in high E persist.



Protons

Reweighting, Angular Cut

- Very similar efficiencies.
- Purity and Completeness almost identical.

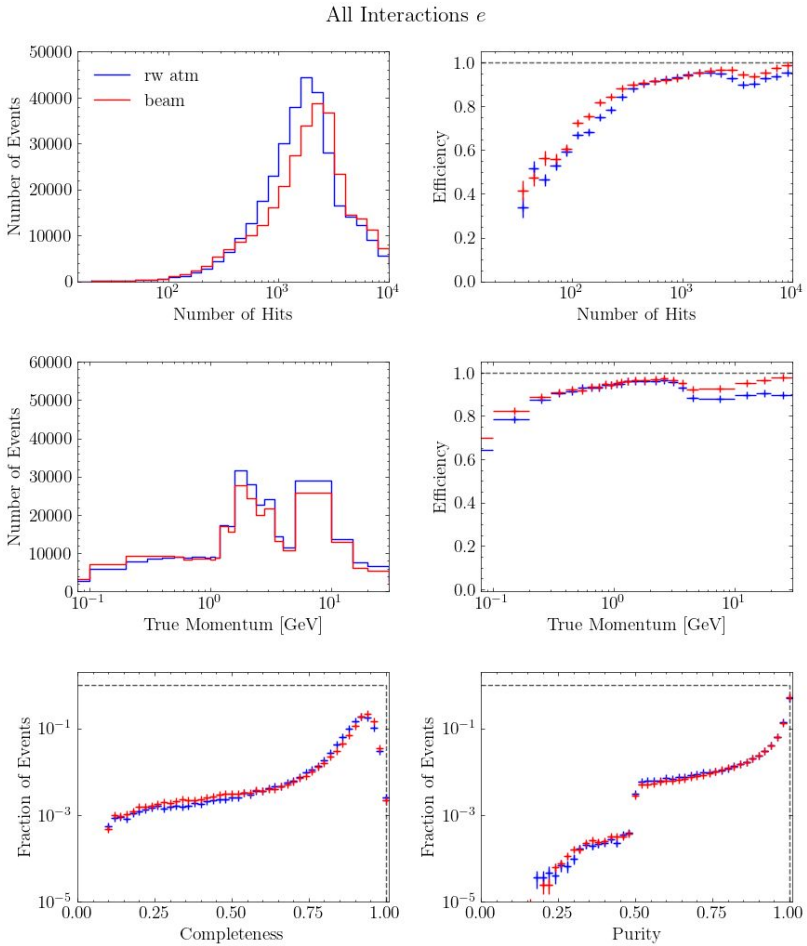


Electrons

Simple Comparison

- ➔ No Reweighting.
- ➔ No angular cut.

- Very different behavior for low and high E.
- Efficiency also grows in the end.
- Completeness: higher for Beam.
- Purity: higher for Atm.

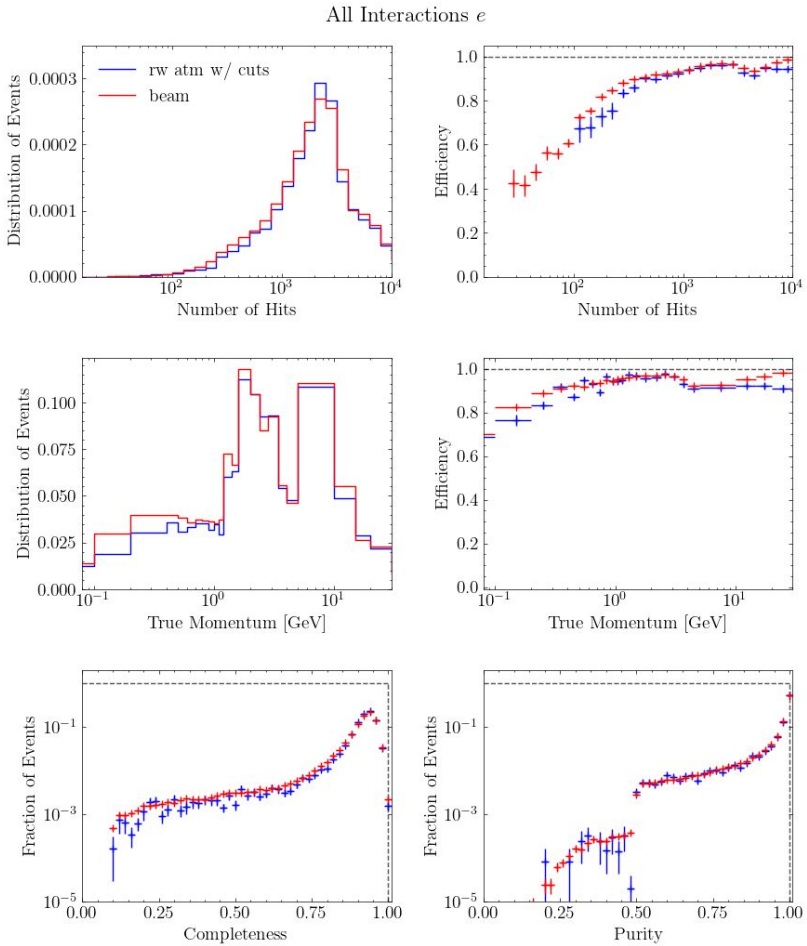


Electrons

Reweighting

➔ No angular cut.

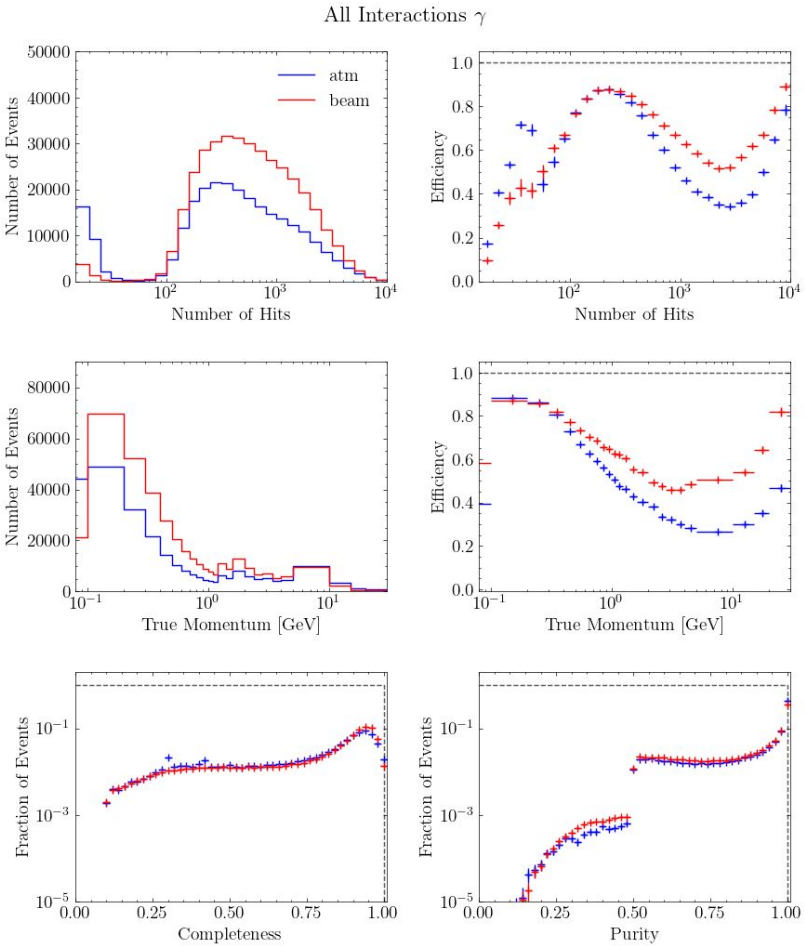
- Hits and momentum efficiency dropped significantly for low E.
- Atm: Increased in Completeness but decreased in Purity.



Electrons

Reweighting, Angular Cut

- Still see some differences for high E.

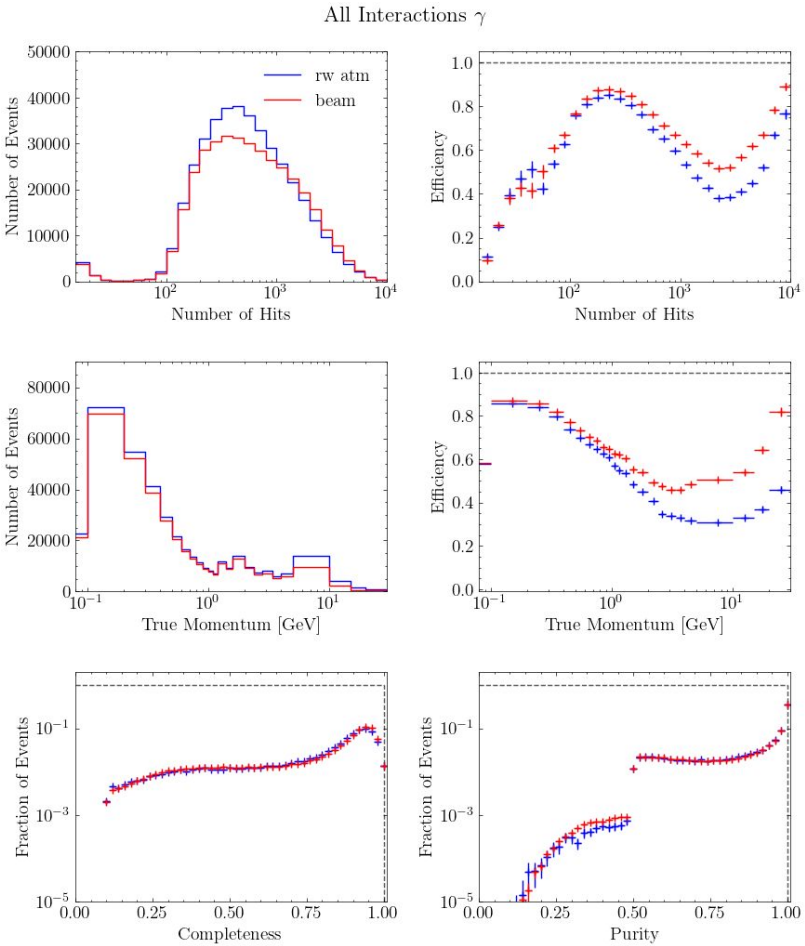


Photons

Simple Comparison

- ➔ No Reweighting.
- ➔ No angular cut.

- Low hits: better efficiency for Atm.
- Similar hit and momentum distributions, different efficiencies at high E.

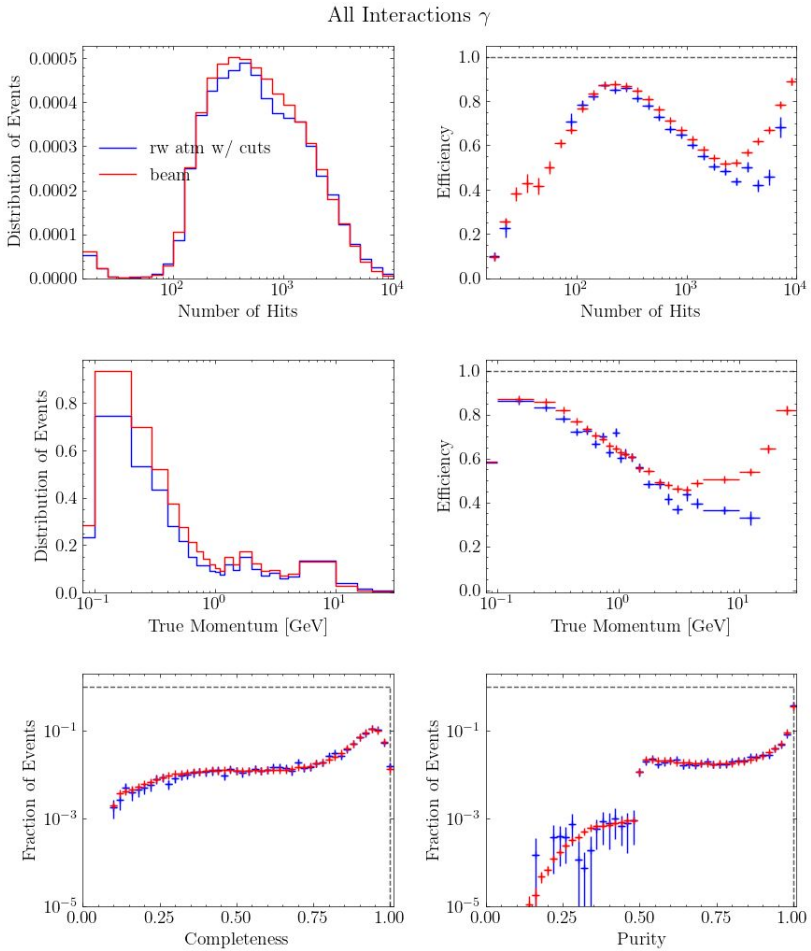


Photons

Reweighting

➔ No angular cut.

- Hits efficiency dropped.
- Momentum efficiency increased a little for high E
- About the same Purity.
- Better behavior for Completeness.

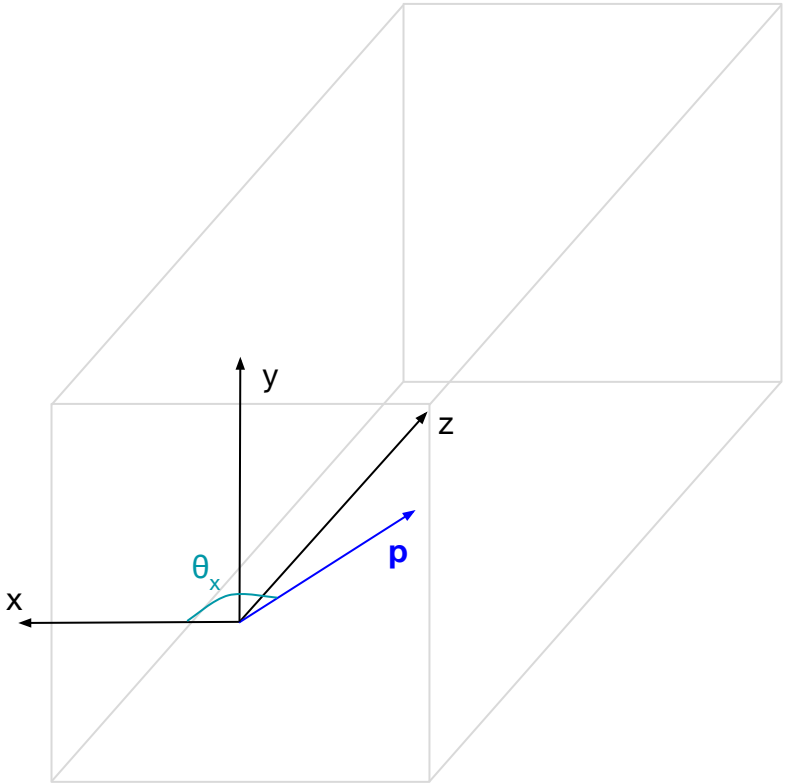


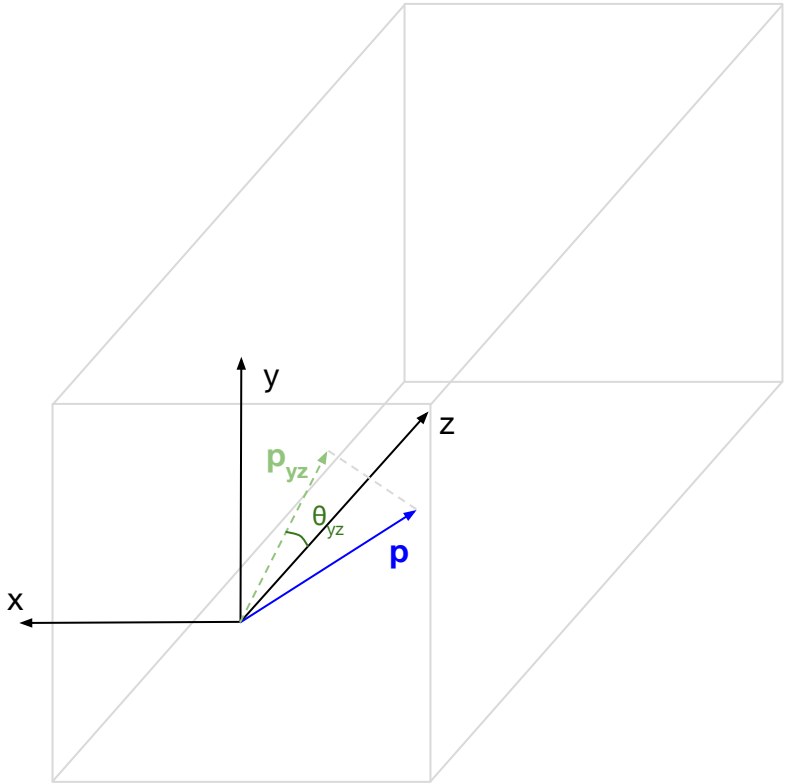
Photons

Reweighting, Angular Cut

- Still see differences at high E.

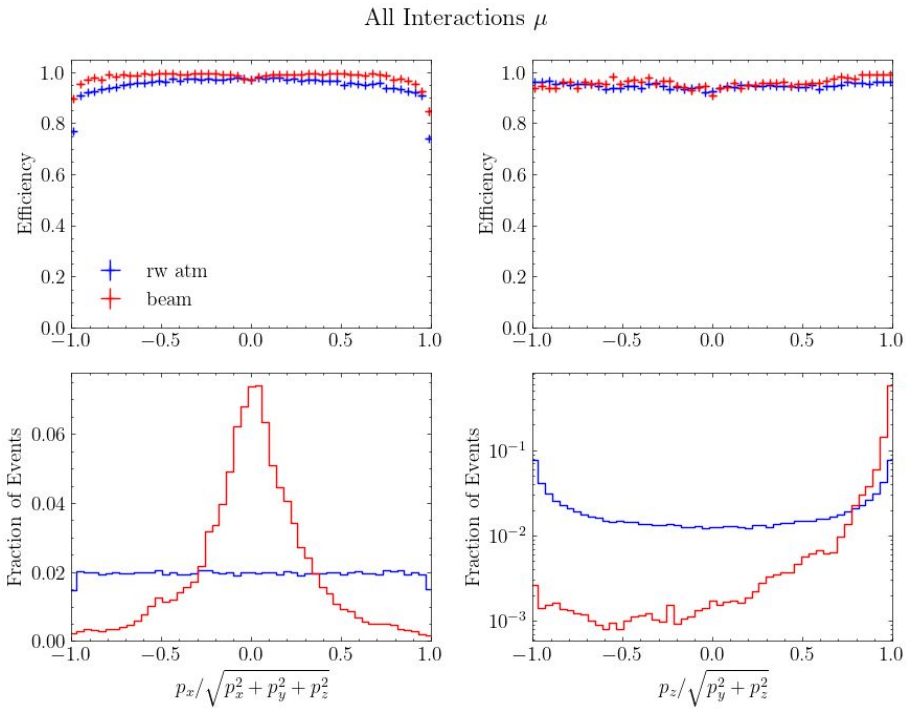
Track Direction Efficiency


y
z
x
θx
p

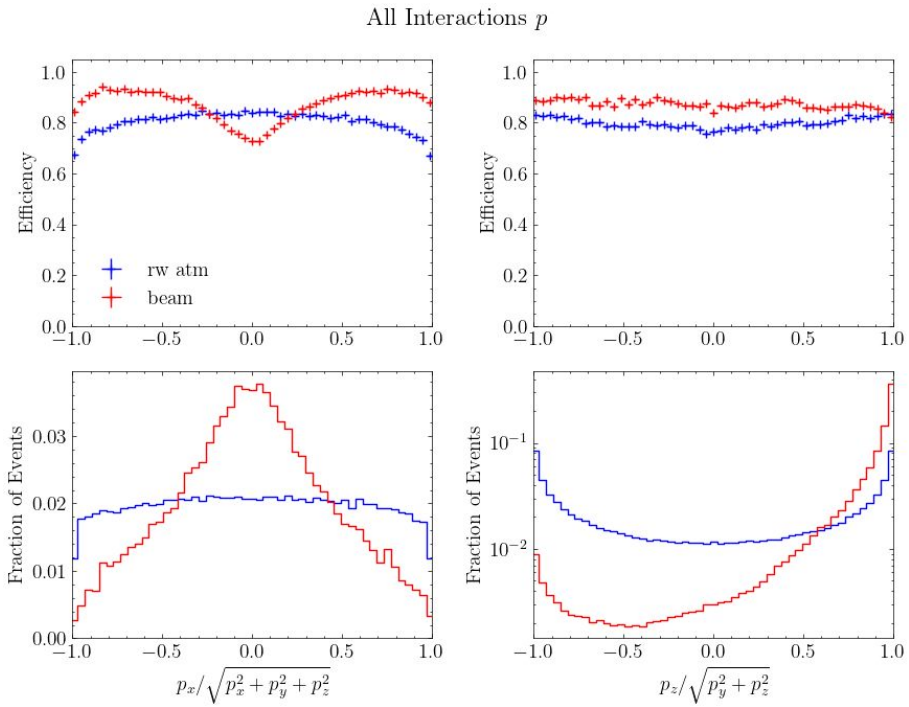

y
z
x
pyz
θyz
p

Reweighted Comparison

Muons

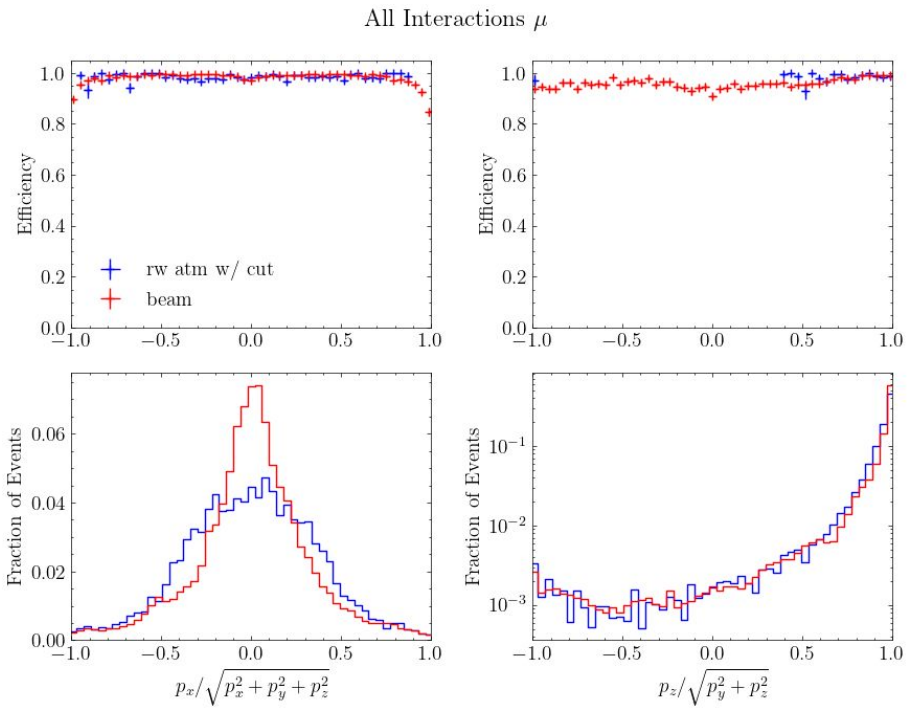


Protons

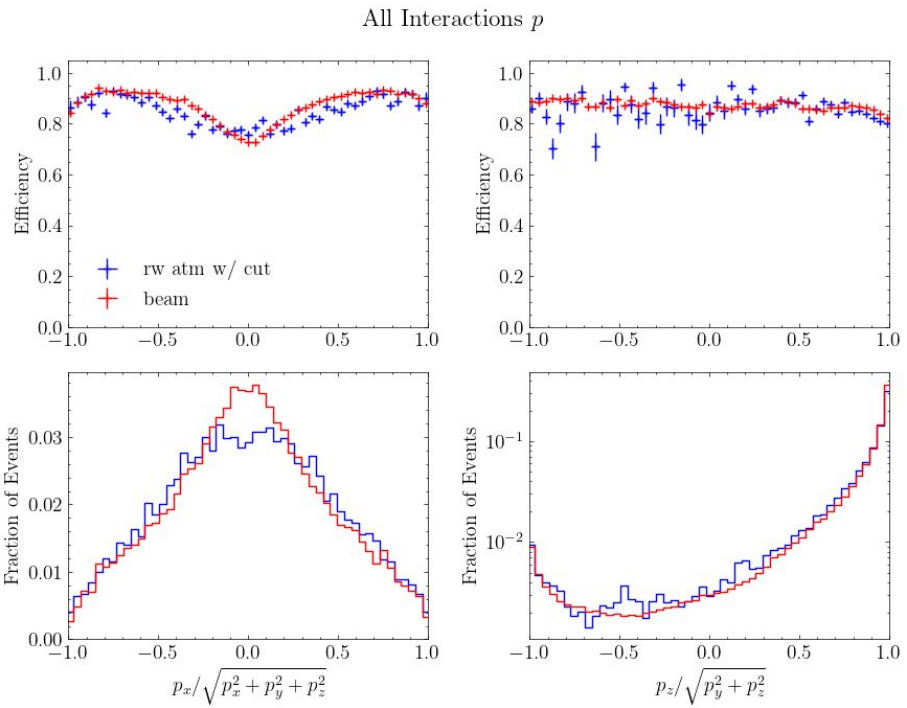


Reweighted, Angular Cut Comparison

Muons



Protons



Summary and Next Steps

- Robust samples **(high stats, all flavors in beam).**
- Fiducial cuts applied **(same for both samples).**
- Reweighting and angular cuts implemented **(performance differences mitigated).**
- Better understand performance differences;
  - Breakdown in momentum slices to check for track direction dependencies.
- Choose best variables to plot;

Please send feedback! **(question, comments, suggestions…)**

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Marcelo Oliveira @ Slack

Thank you!

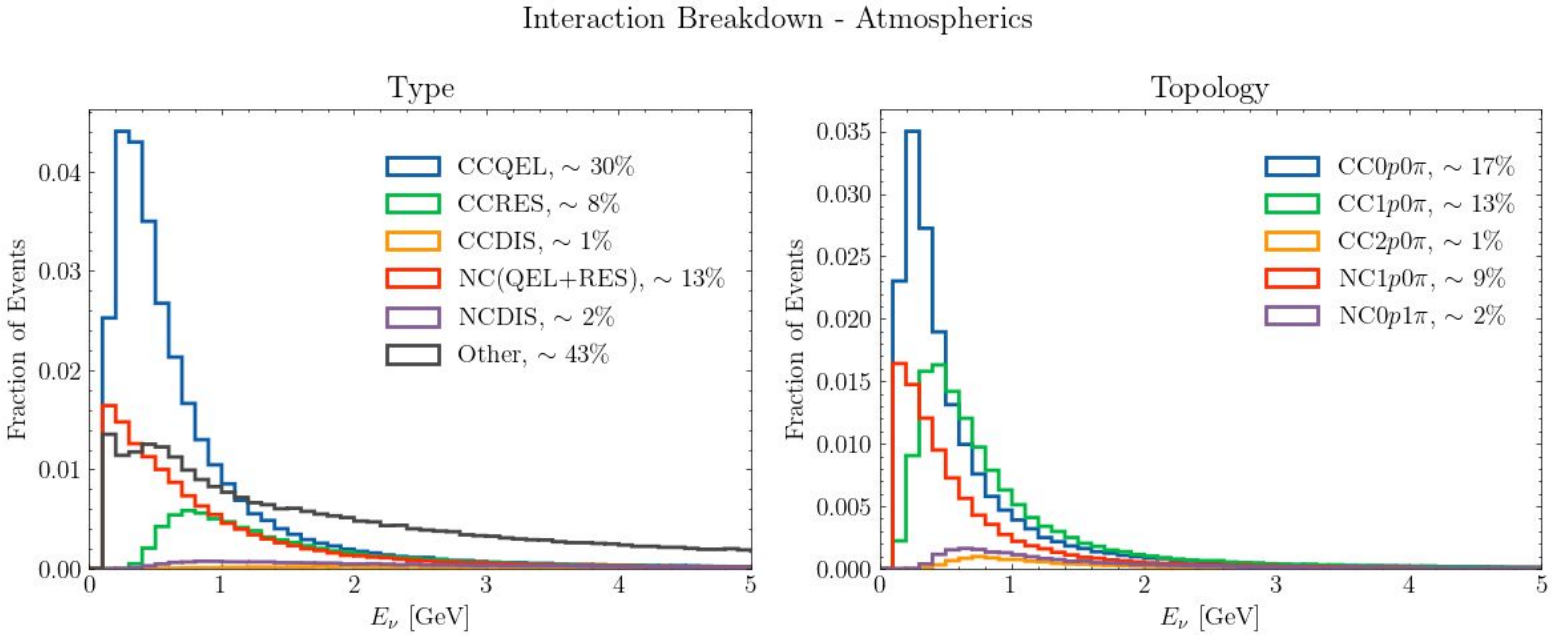
Backup

Events are classified according to true interaction:

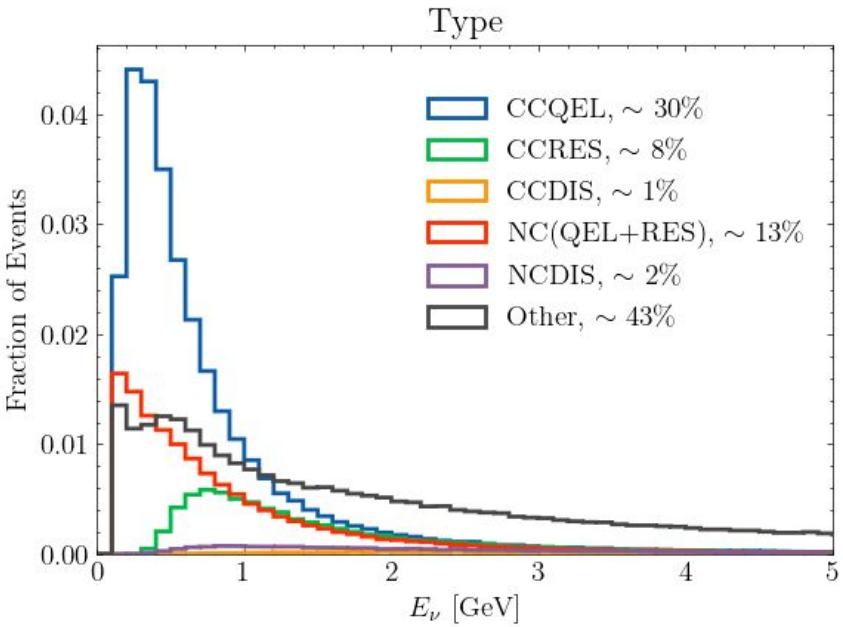
- CC/NC: QEL, RES, DIS, COH, other

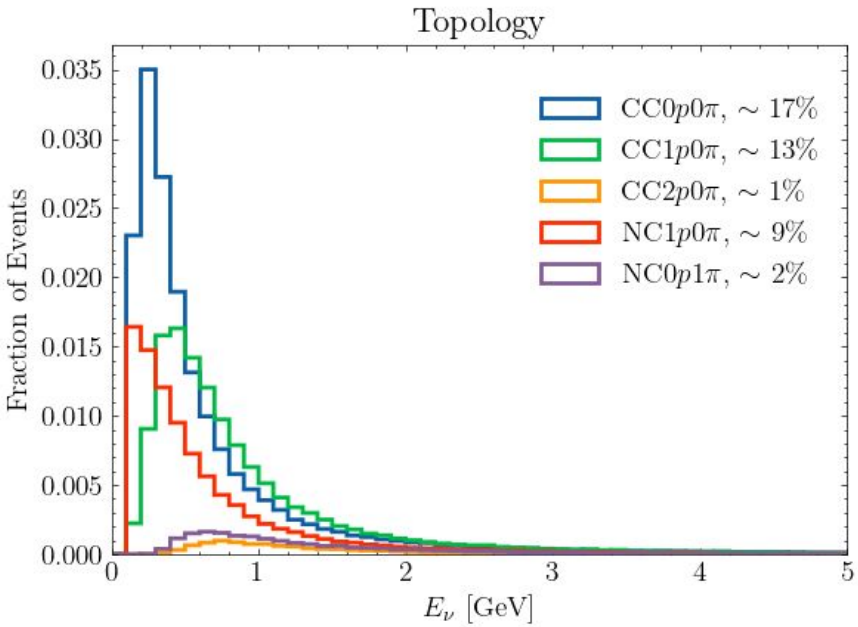
and topology:

- n*p*mπ
- n*p*mγ
- other

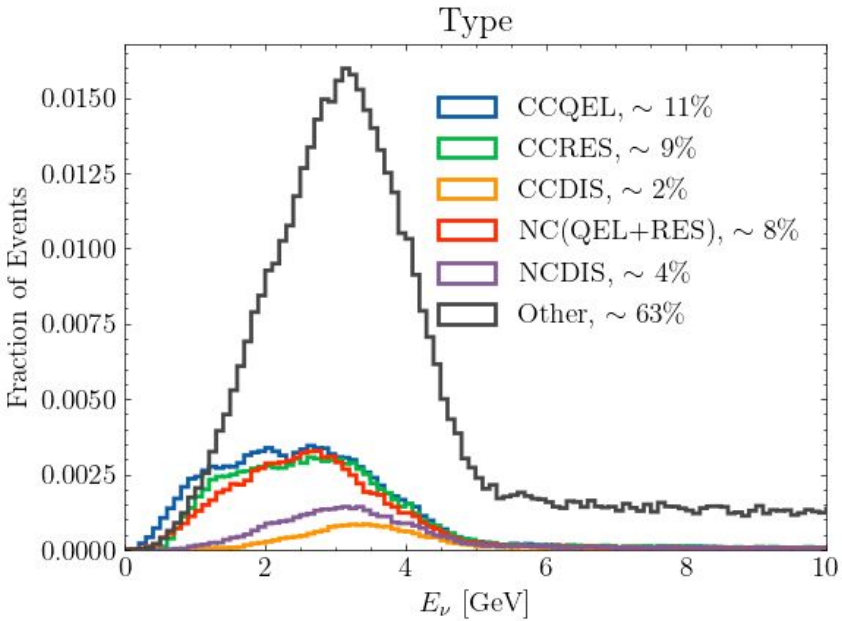


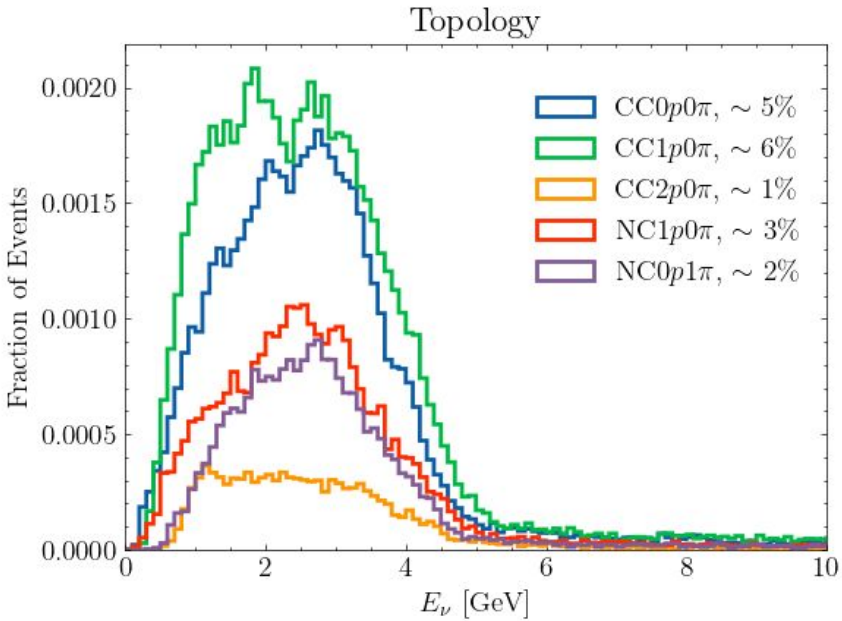
Interaction Breakdown - Atmospherics

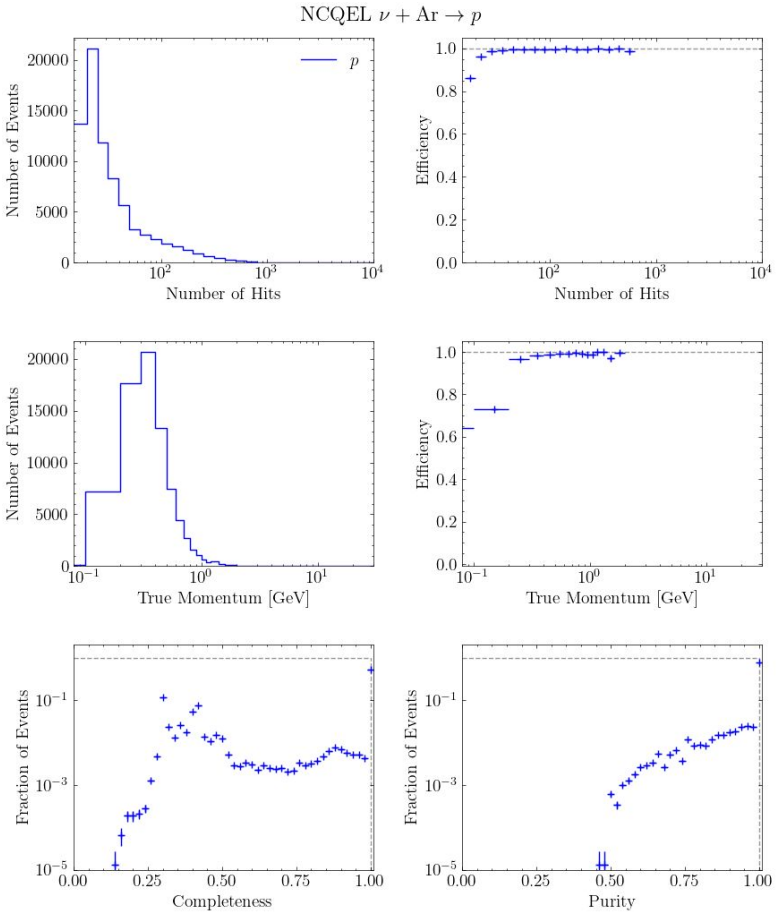




Interaction Breakdown - Beam





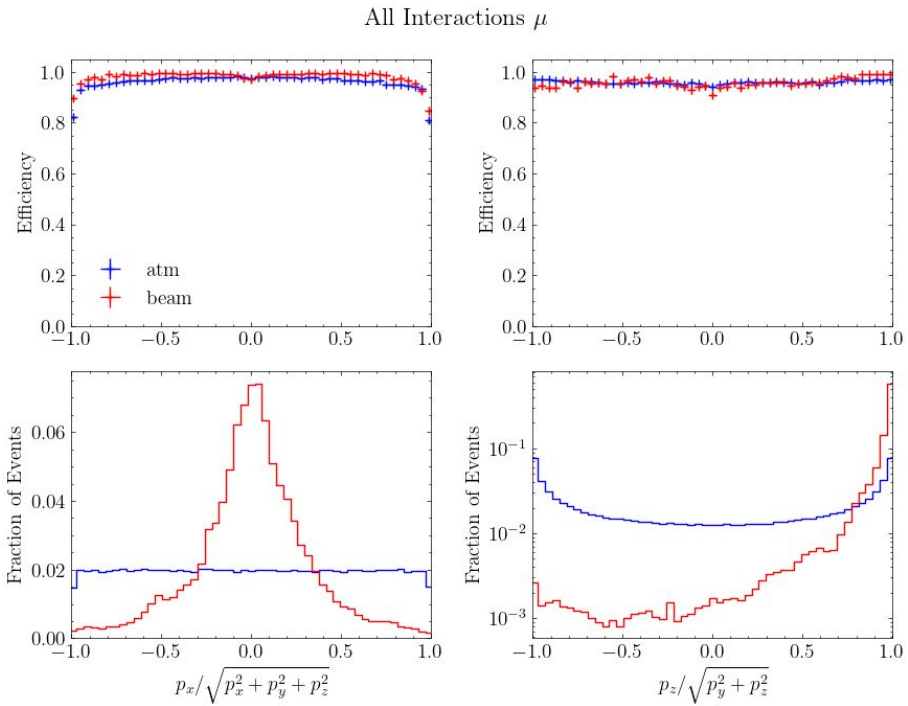

NCQEL $\nu + \mathrm{Ar} \to p$
Number of Events
Number of Hits
p
Efficiency
Number of Hits
Number of Events
True Momentum [GeV]
Efficiency
True Momentum [GeV]
Fraction of Events
Completeness
Fraction of Events
Purity

NCQEL 1p

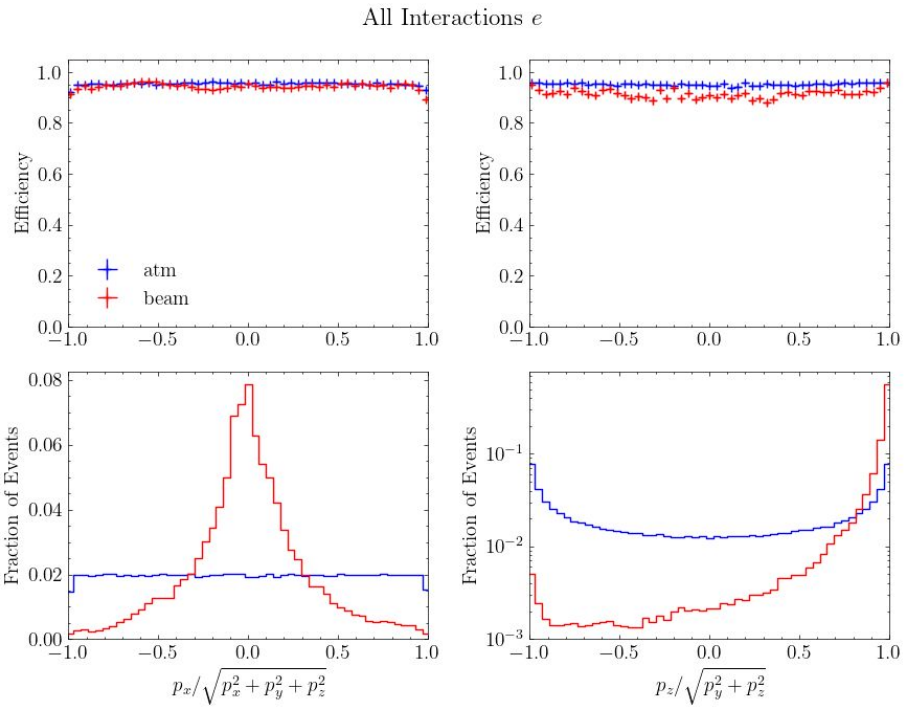
Track Direction Efficiency

Simple Comparison

Muons

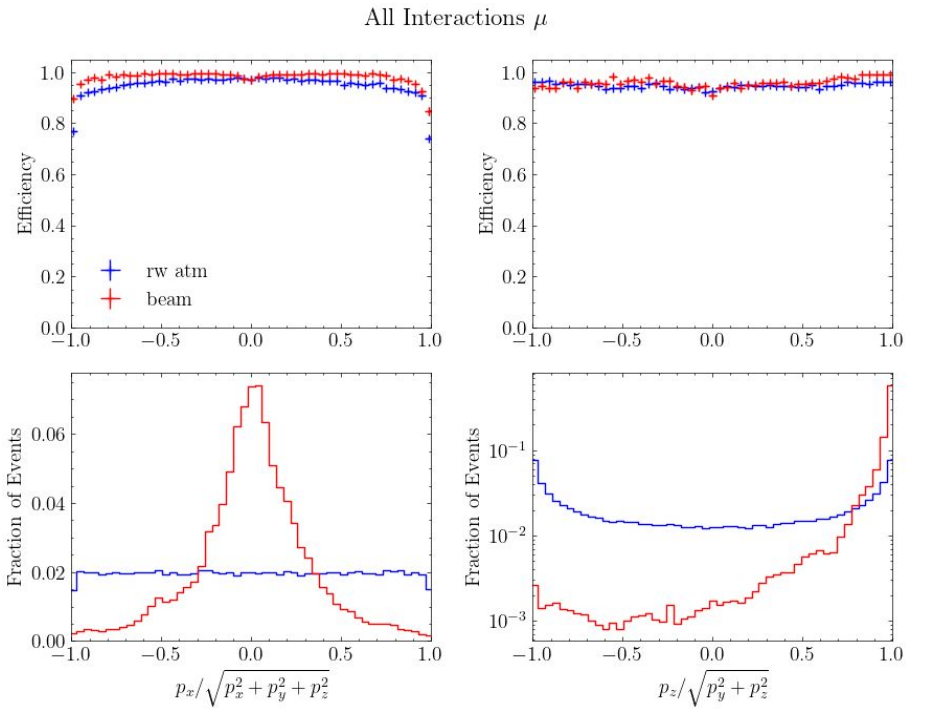


Electrons

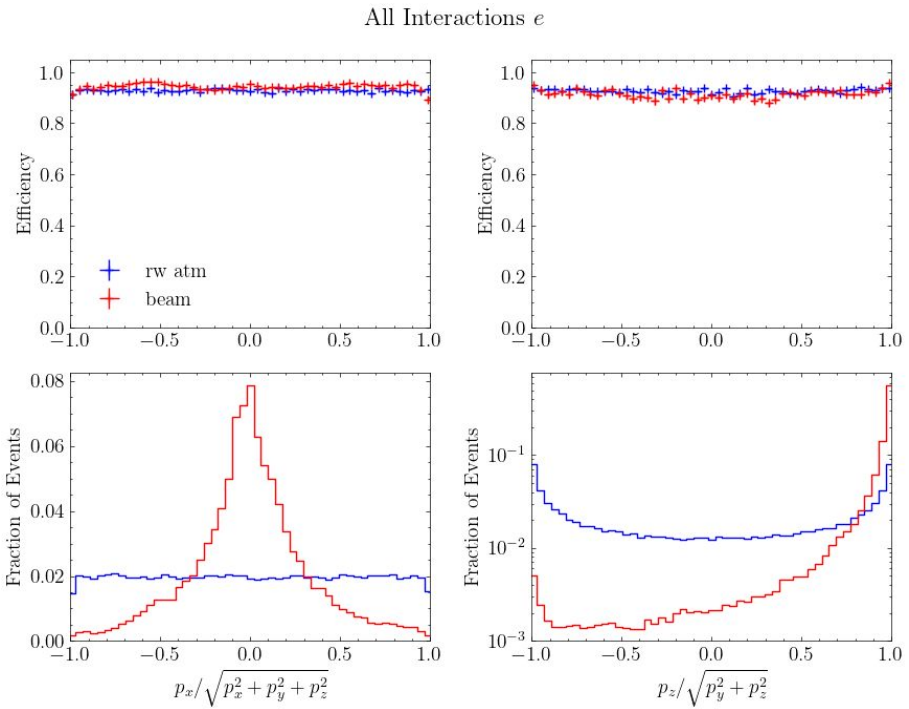


Reweighting

Muons

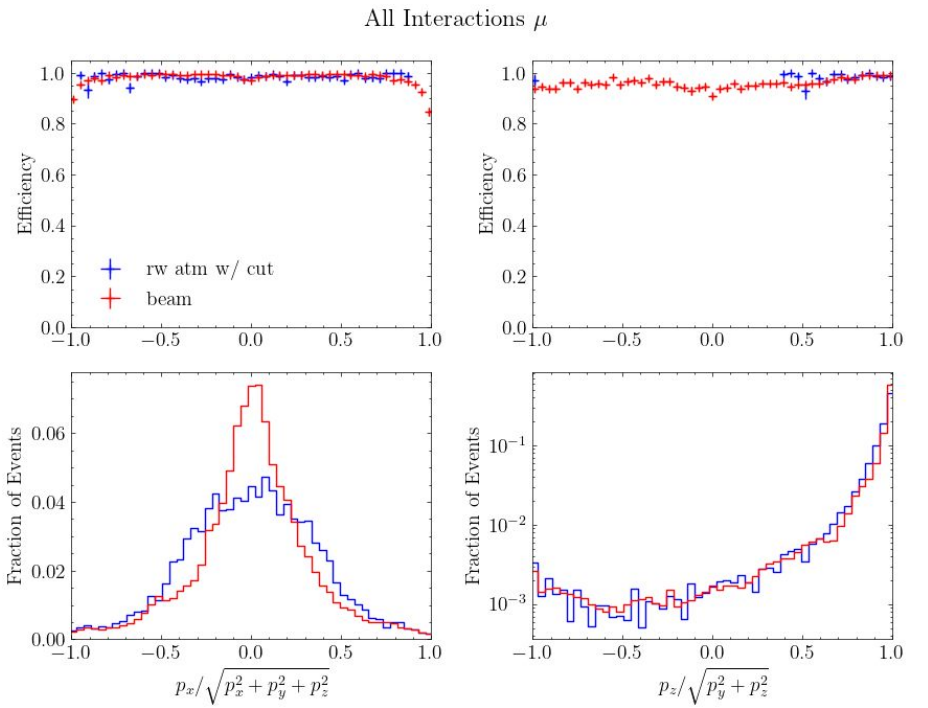


Electrons

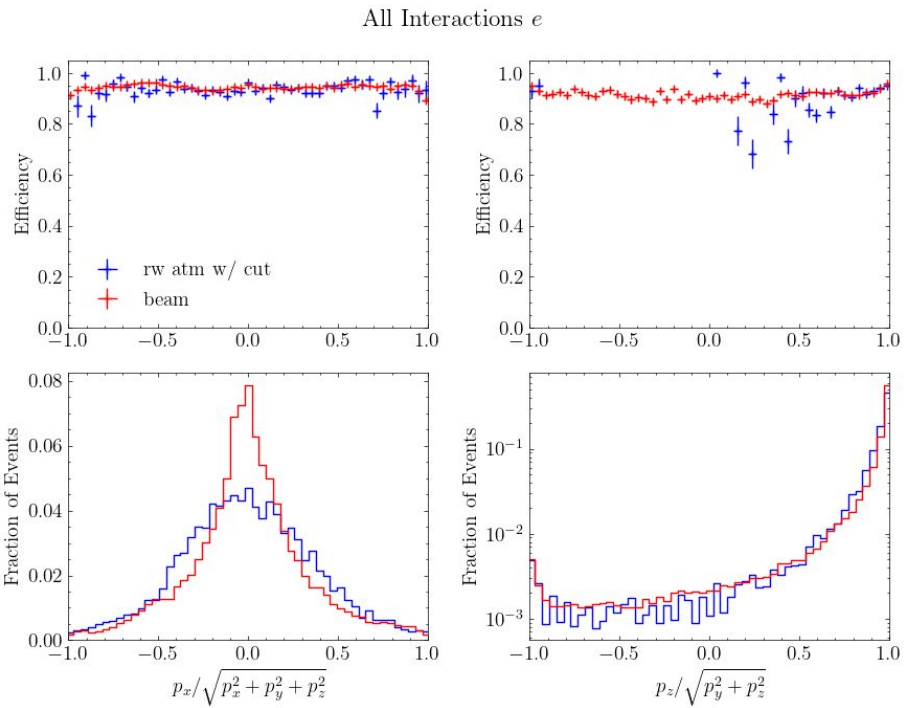


Reweighting, Angular Cut

Muons



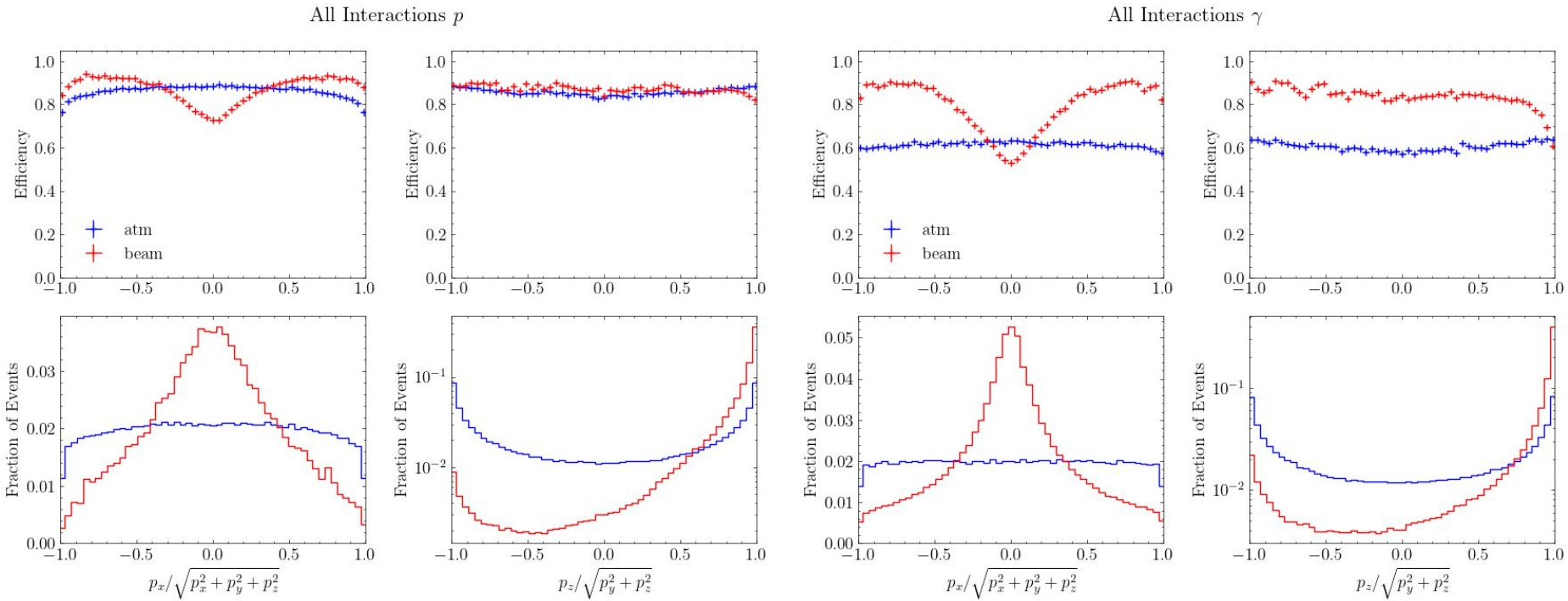
Electrons



Simple Comparison

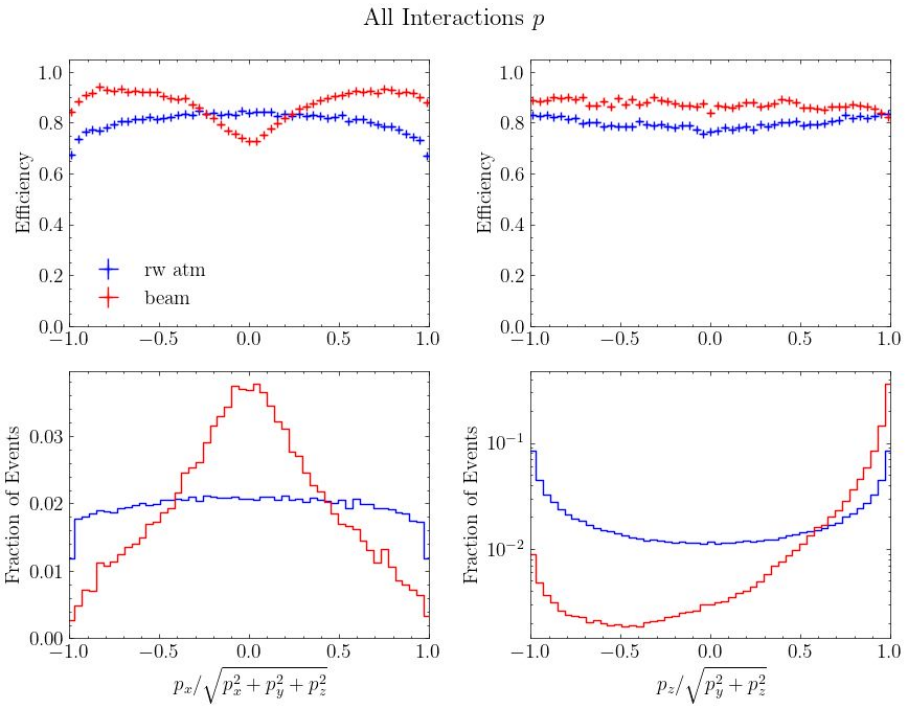
Protons

Photons

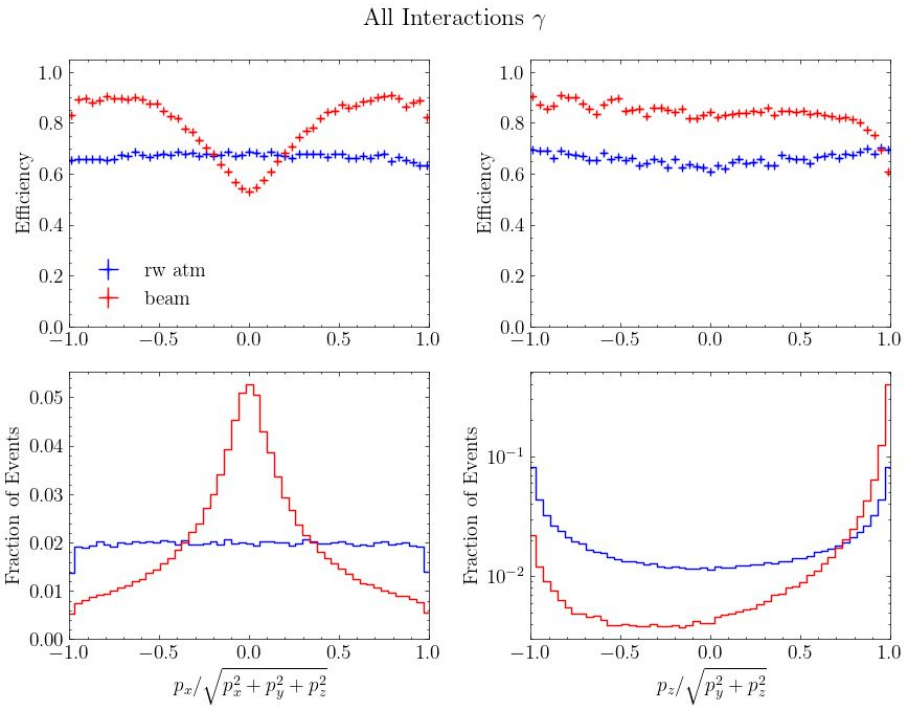


Reweighting

Protons



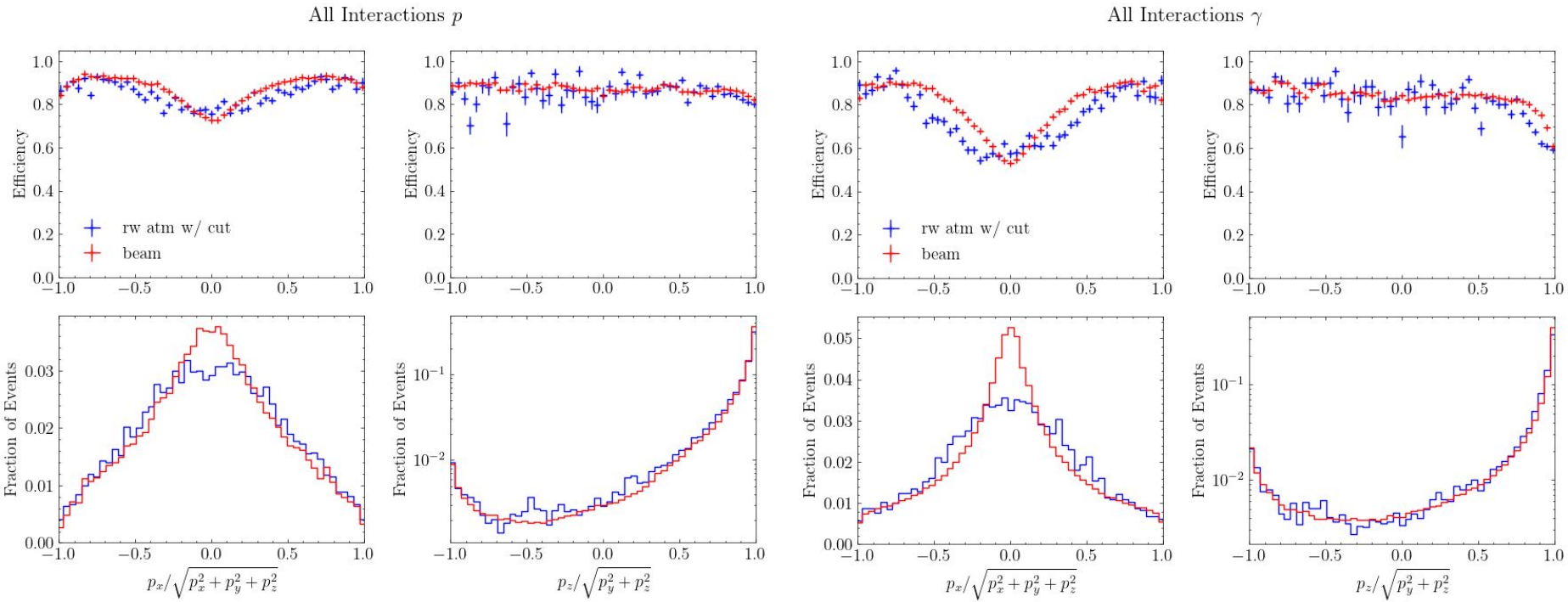
Photons

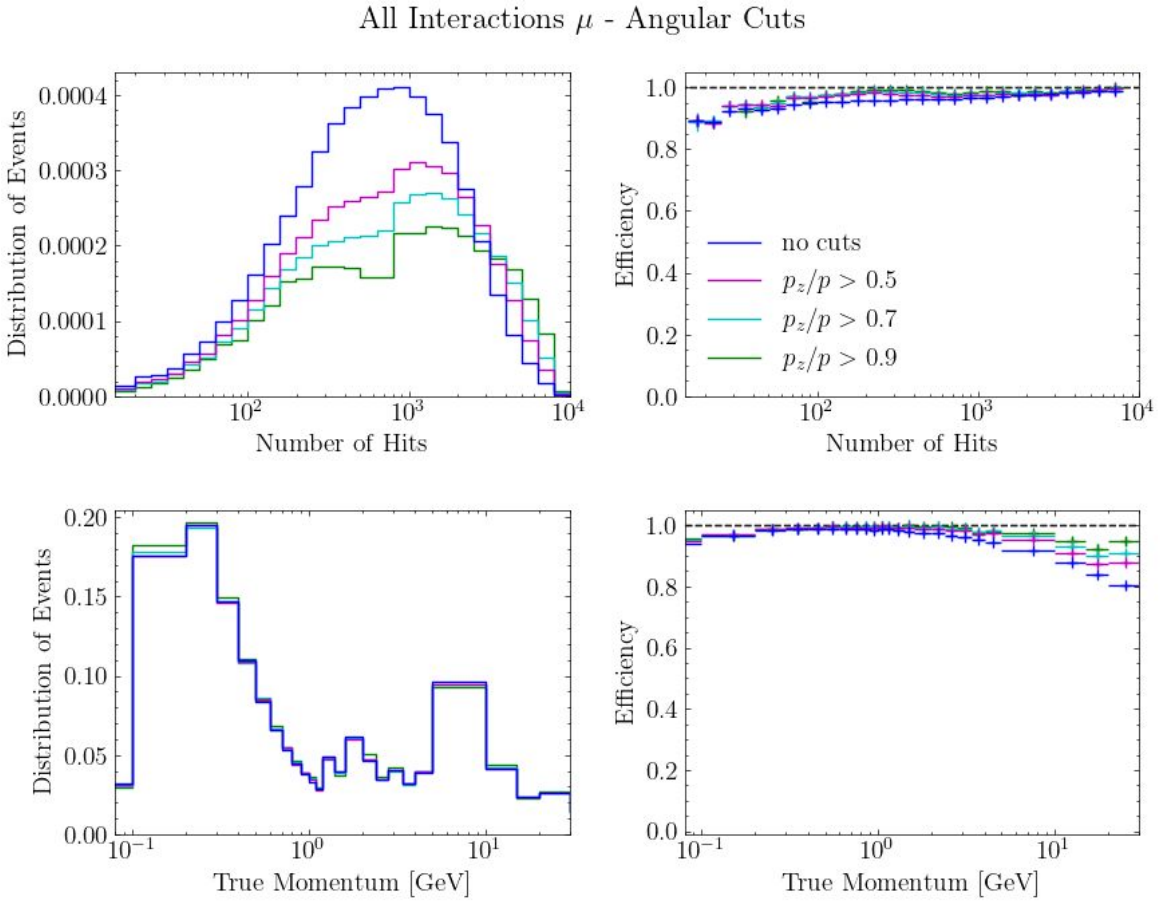


Reweighting, Angular Cut

Protons

Photons




All Interactions μ - Angular Cuts
Distribution of Events
Number of Hits
Efficiency
Number of Hits
no cuts
$p_z/p > 0.5$
$p_z/p > 0.7$
$p_z/p > 0.9$
Distribution of Events
True Momentum [GeV]
Efficiency
True Momentum [GeV]