

Angular Conditioning of Generative Models for Fast Calorimeter Shower Simulation

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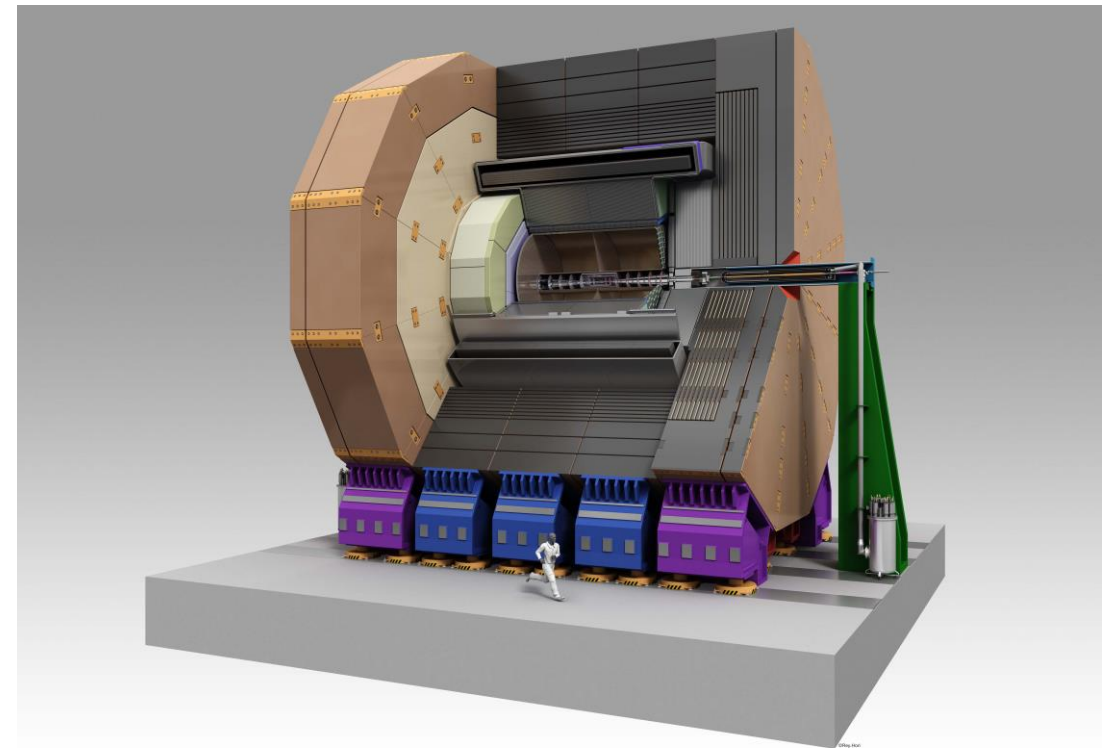
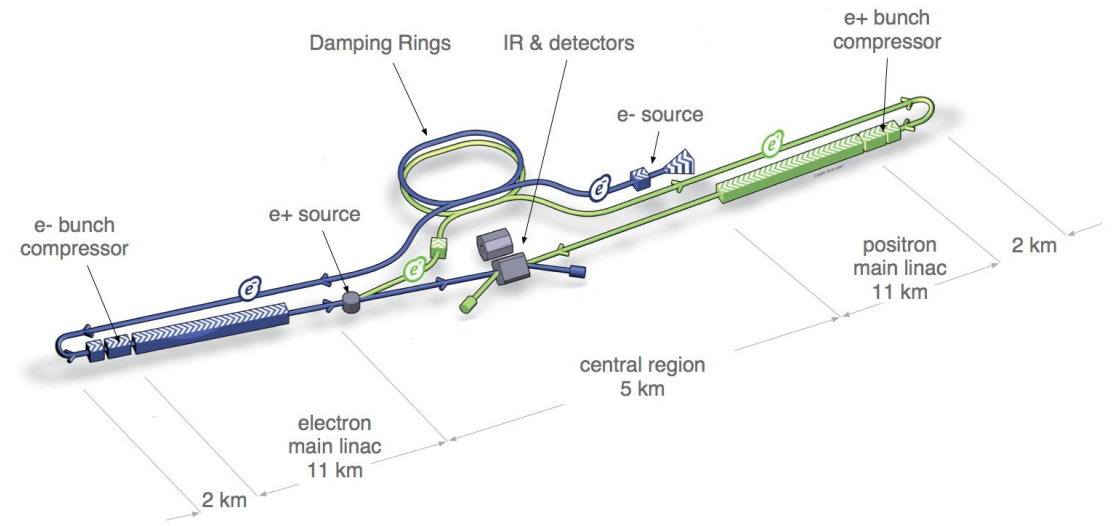


CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE



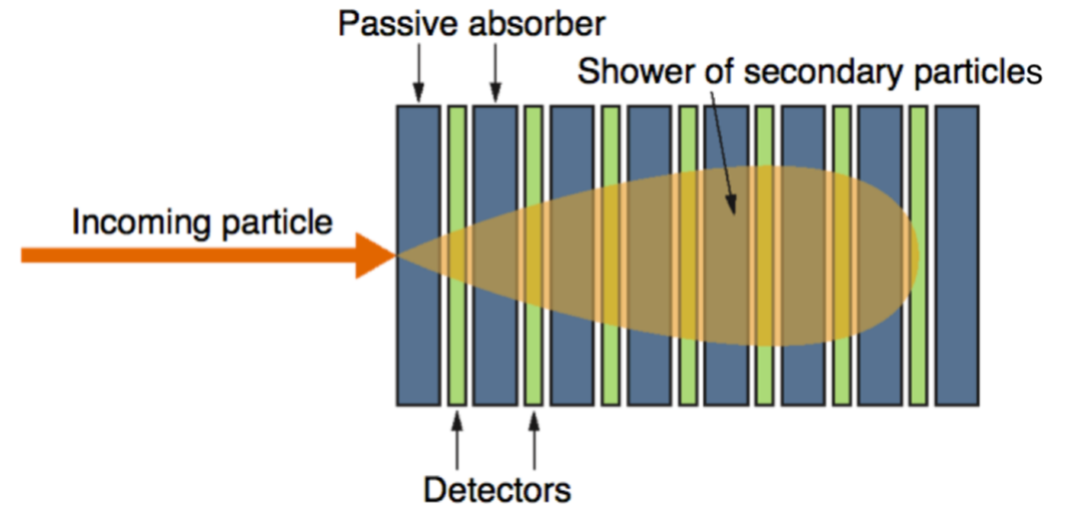
The ILD Concept

- Context: Future Higgs Factories
- Case Study: International Large Detector (ILD) concept for the International Linear Collider (ILC)
- Optimized for Particle Flow
 - Reconstruct each individual particle in subdetector
 - Obtain optimal detector resolution
- Key features:
 - Precise tracking and vertexing
 - Excellent hermeticity
 - **High granularity calorimeters**



The ILD Electromagnetic Calorimeter

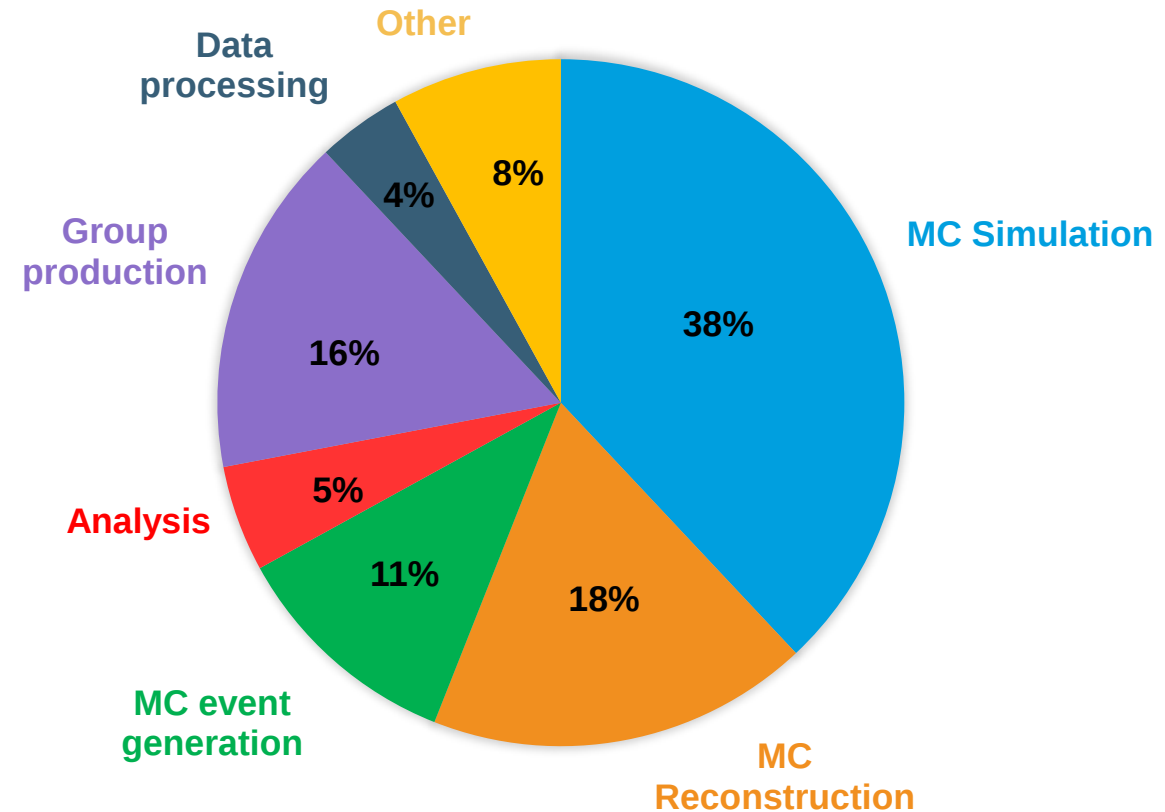
- Destructively measure particle's energy
 - Produce shower of secondary particles until totally absorbed
- Sampling calorimeter- measure fraction of energy
- ILD proposal: Si-W ECAL
 - 30 layers of alternating active (Si) and passive (W) material
 - 5x5 mm² silicon cells
 - ~ 80 million channels for barrel
- High granularity → **High fidelity**



The Strain on HEP Computing Resources

- Ever increasing demand for computing resources
 - MC simulation largest fraction
 - Calorimeters most intensive part of detector simulation
- Projected computing resources required far outstrip what will be available
 - E.g HL-LHC
- Future lepton colliders also benefit from much faster MC
- **Generative models** potentially offer orders of magnitude speed up

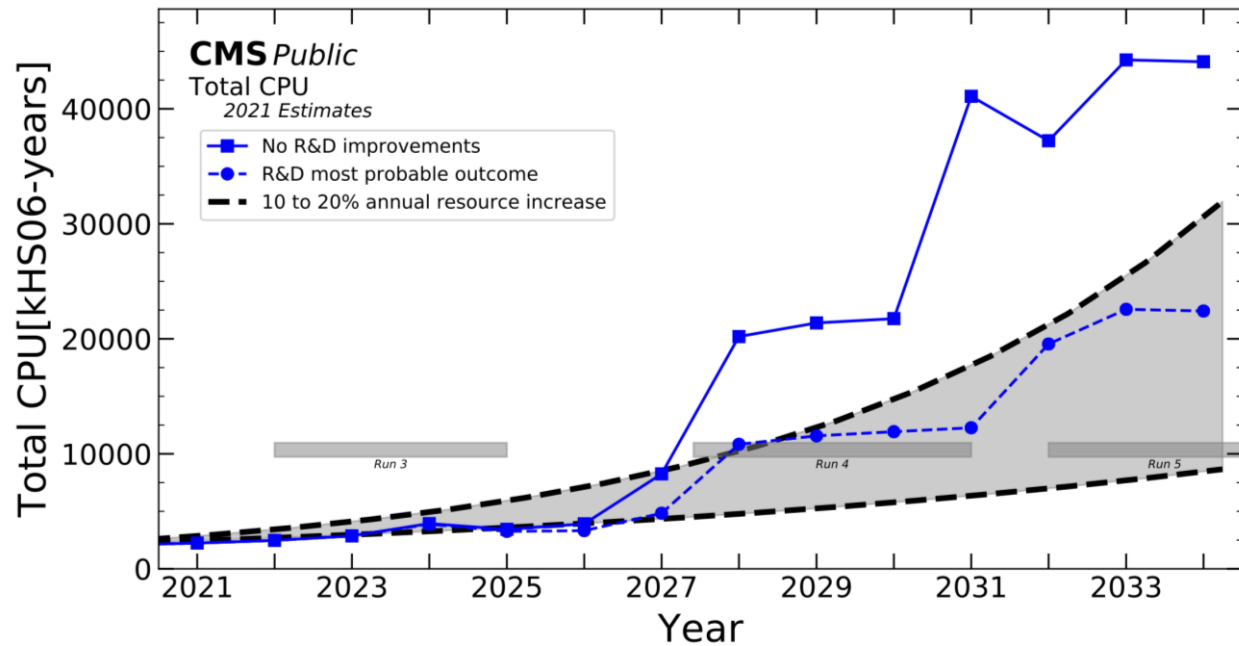
WALL CLOCK CONSUMPTION PER WORKFLOW



D. Costanzo, J. Catmore, ATLAS
Computing update, LHCC meeting , 2019

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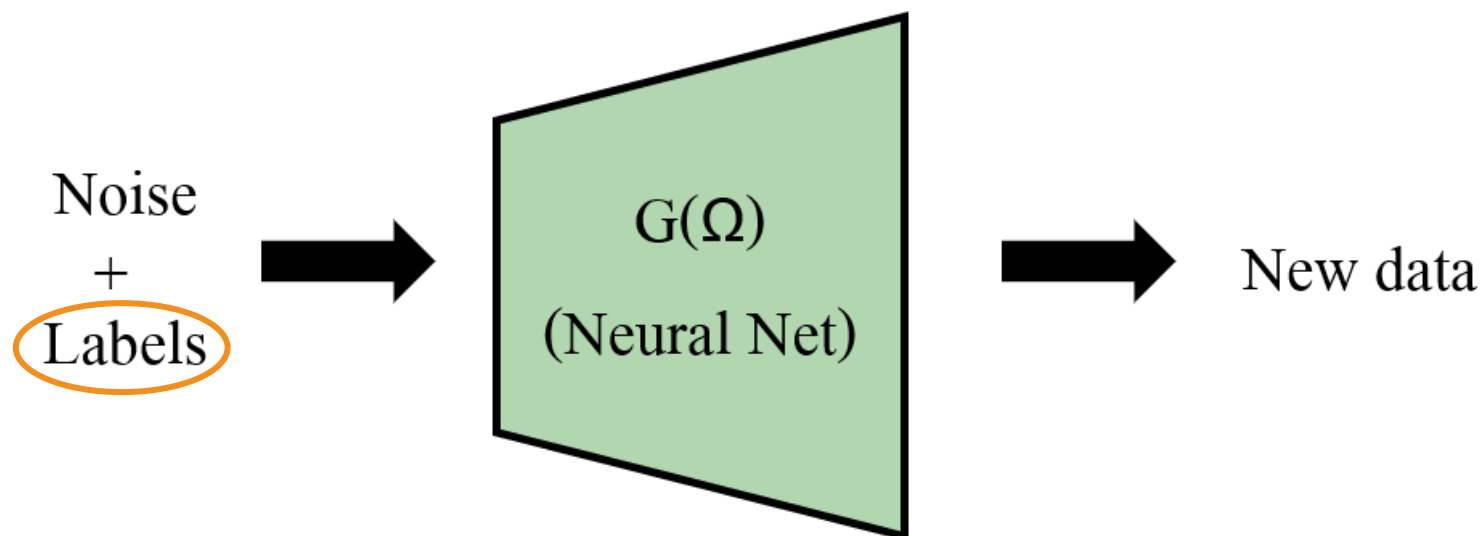
CMS Collaboration, Offline and Computing Public Results (2021),
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSOfflineComputingResults>

Generative Models

- Approach to fast simulation- **amplify statistics**
- Aim: augment full physics-based GEANT4 simulation by learning a transfer function
- Promising solution: **generative models**
 - Generate new samples following the distribution of original data
 - Map random noise to data
 - Highly parallelizable
 - **Conditioning**

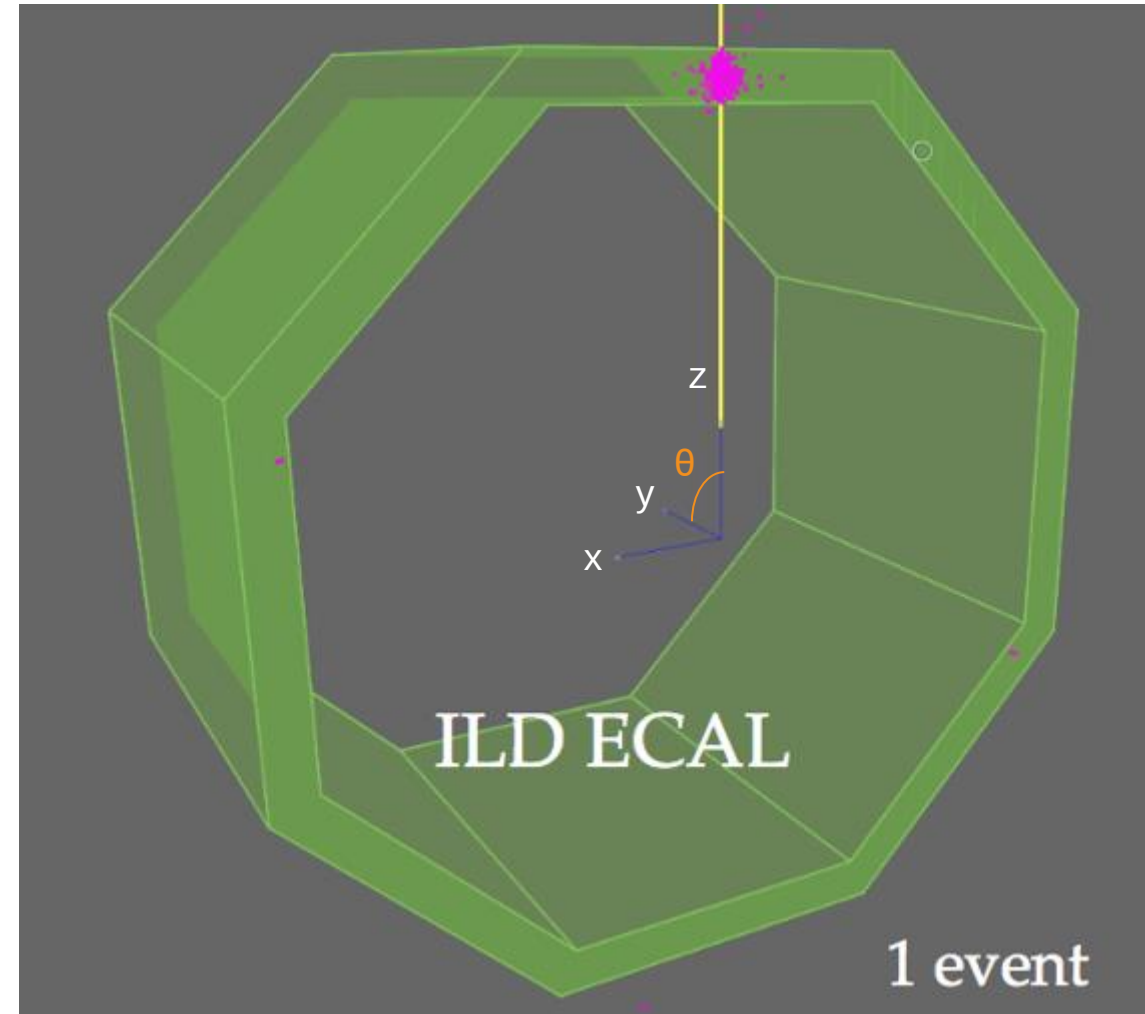
SciPost Phys. 10, 139 (2021)

[doi:10.21468/SciPostPhys.10.6.139](https://doi.org/10.21468/SciPostPhys.10.6.139)



Conditioning Requirements for a General Simulation

- Conditioning for a general calorimeter simulation:
 - Energy
 - Incidence point
 - Two angles
 - Polar angle: θ
 - Azimuthal angle: ϕ



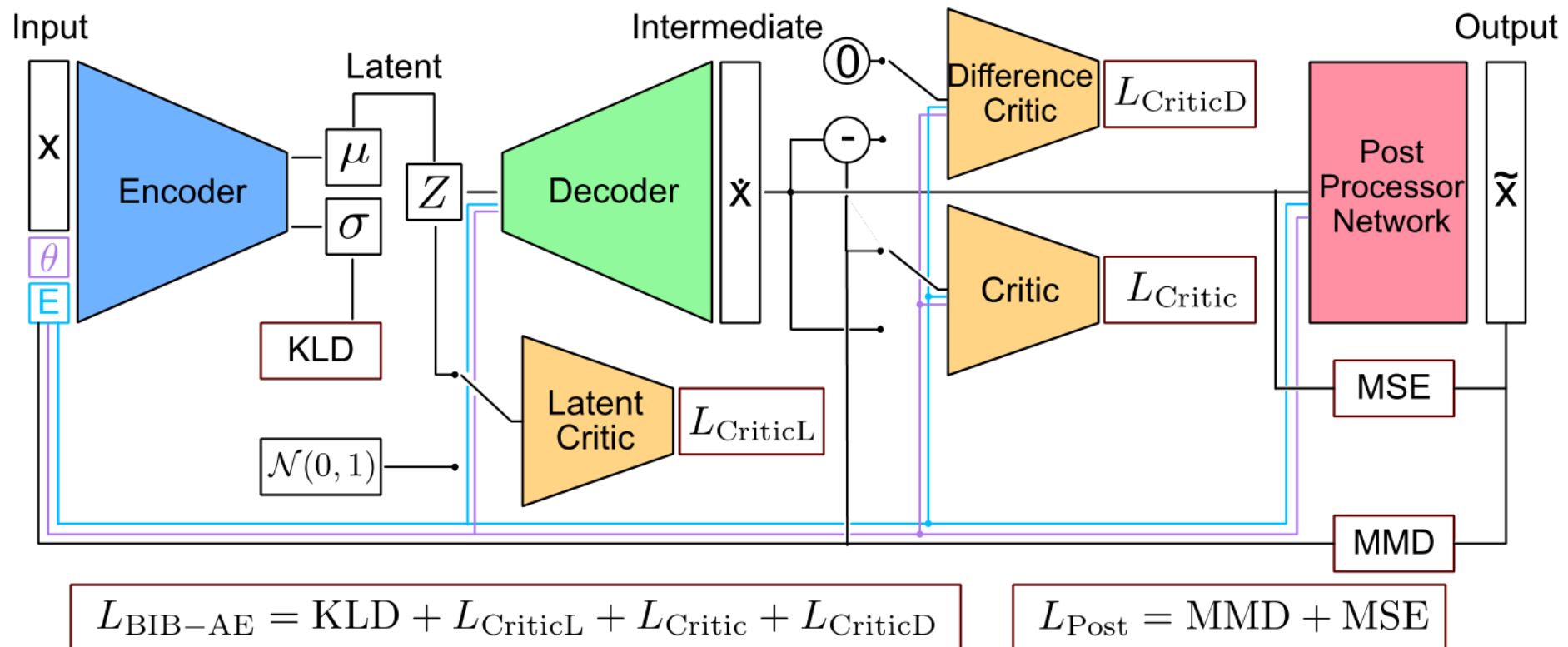
Generative Model: BIB-AE

Bounded-Information Bottleneck Autoencoder

- Unifies features of both GANs and VAEs
- Post-Processor network: Improve per-pixel energies; second training

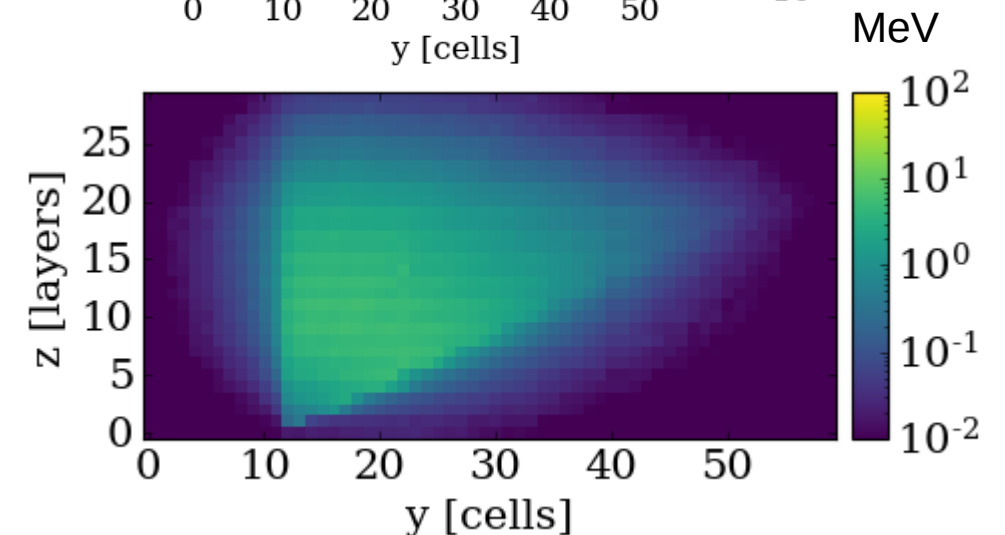
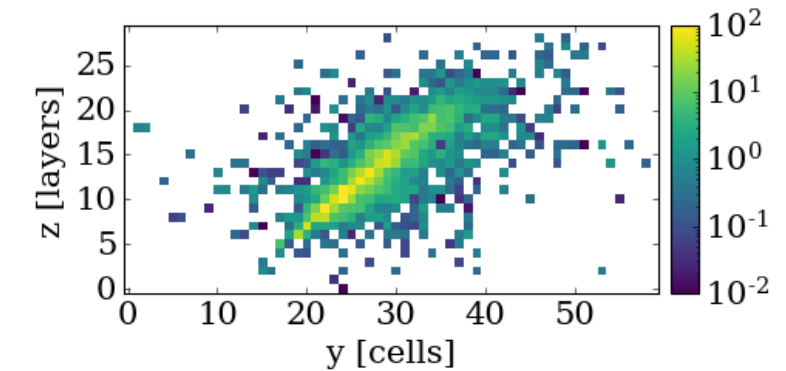
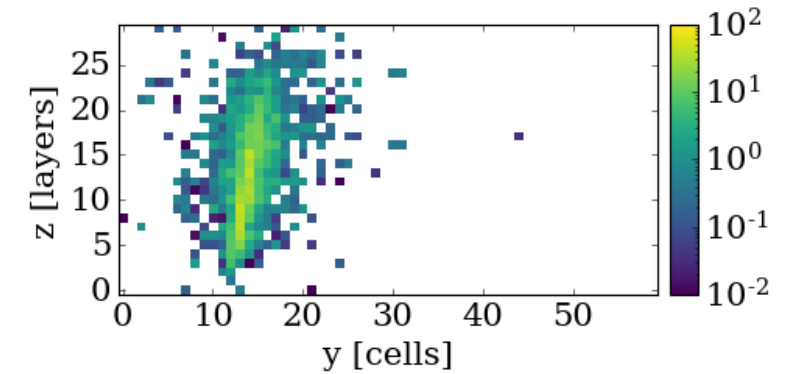
Voloshynovskiy et. al: **Information bottleneck through variational glasses**, arXiv:1912.00830

Buhmann et. al: **Getting High: High Fidelity Simulation of High Granularity Calorimeters with High Speed**, CSBS 5, 13 (2021)



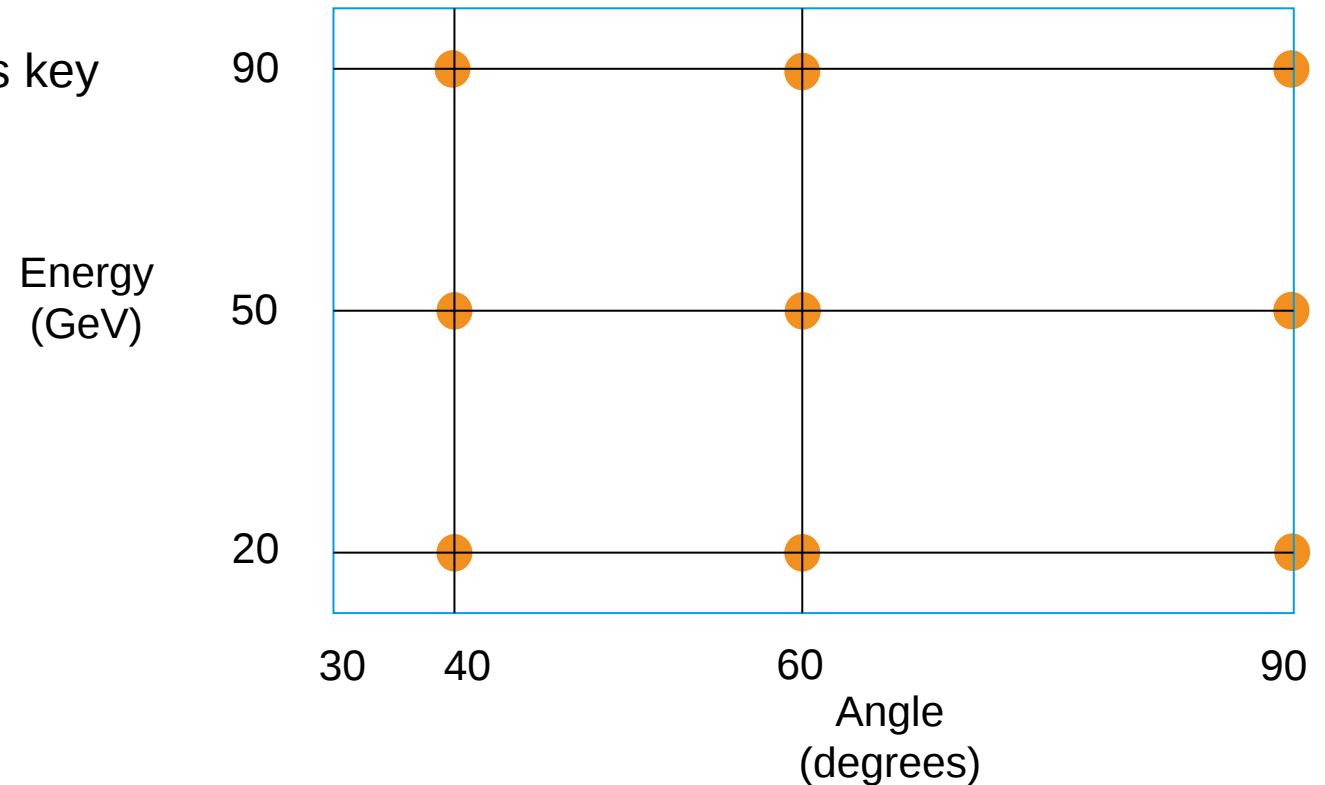
Angular and Energy conditioning- Training data

- In Progress: condition generative networks on particle's angle of incidence and energy
- Vary energy: 10-100 GeV
- Only vary polar angle in one direction: from 90° - 30°
- Photons with fixed incident point
- Project to regular grid
 - Shape (30,30,60) (z,x,y)
- 136,500 showers for training base BIBAE
- 500,000 for Post Processing

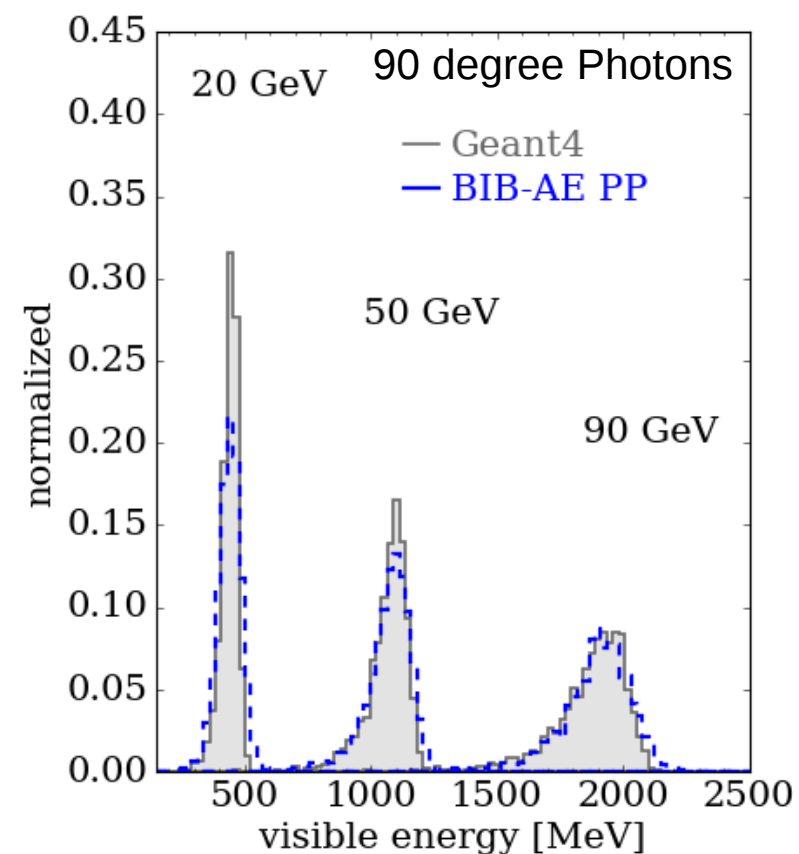
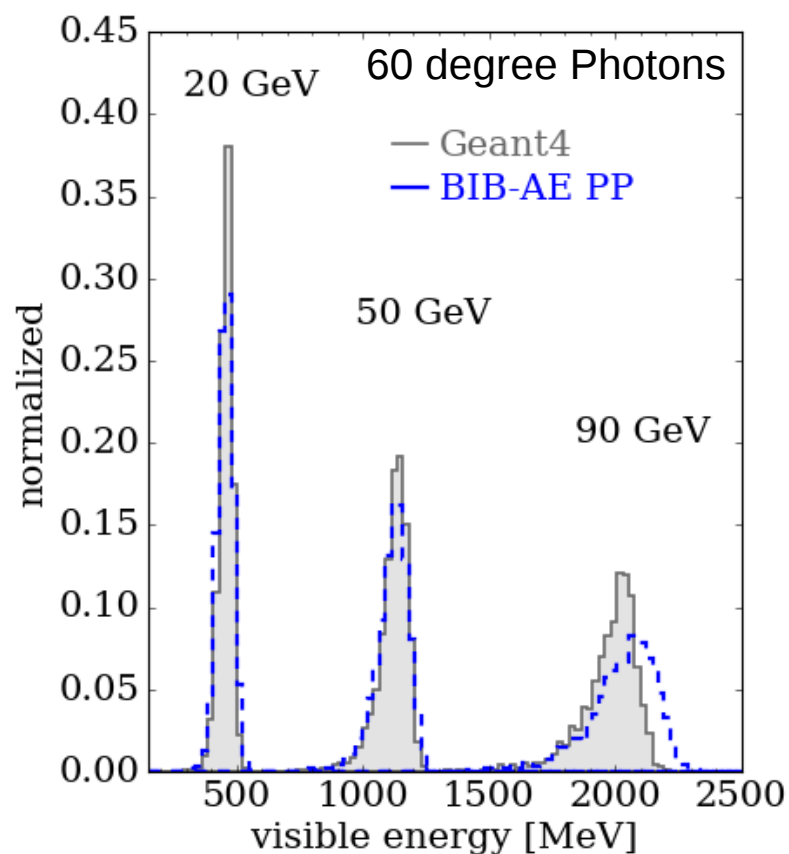
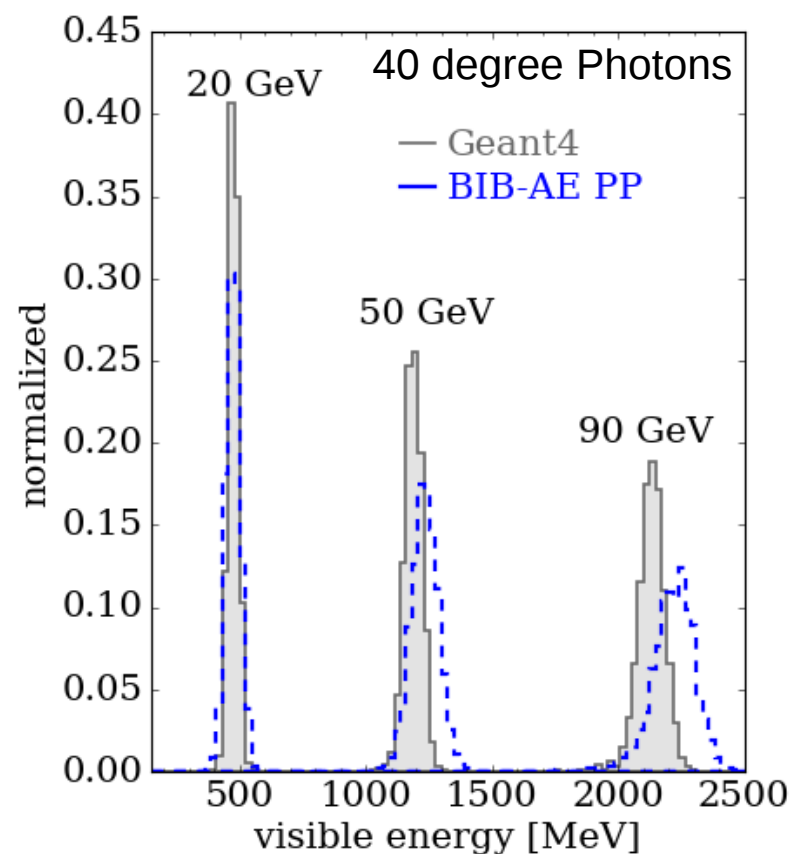


Angular and Energy conditioning- Validation data

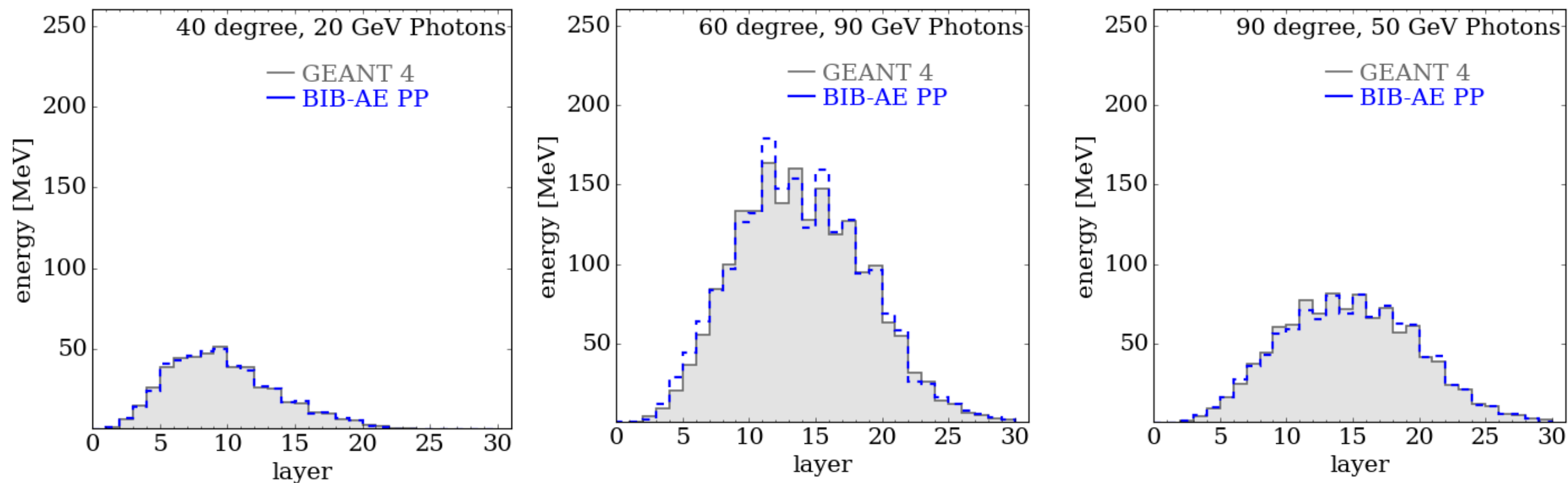
- Choose fixed combinations of energies and angles
- 9 points in the phase space in total
- Investigate how well generative model learns key physics properties of showers:
 - Visible energy sum
 - Number of hits and Hit energy spectrum
 - Shower profiles
 - Angular response



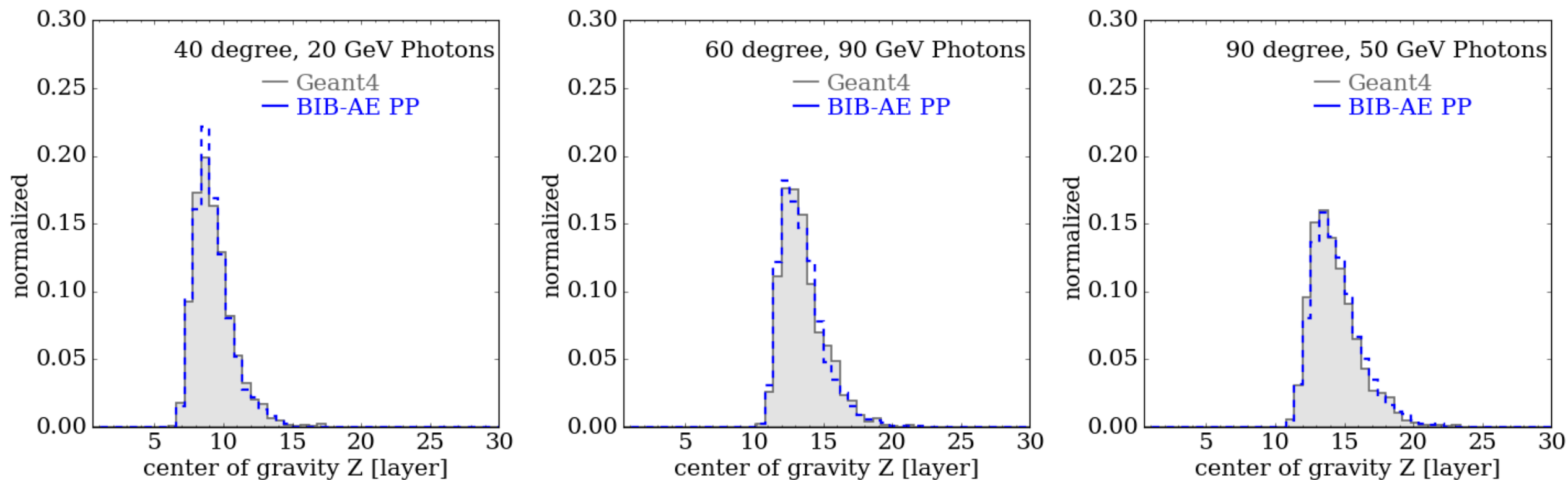
Results: Visible Energy Sum



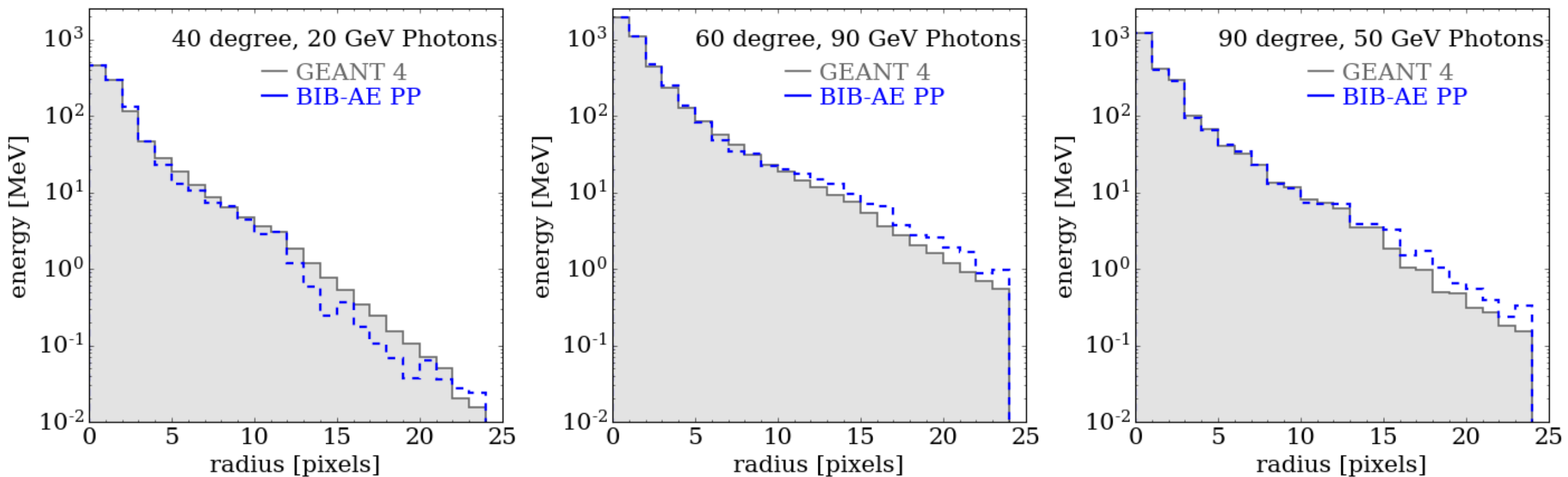
Results: Longitudinal Profile



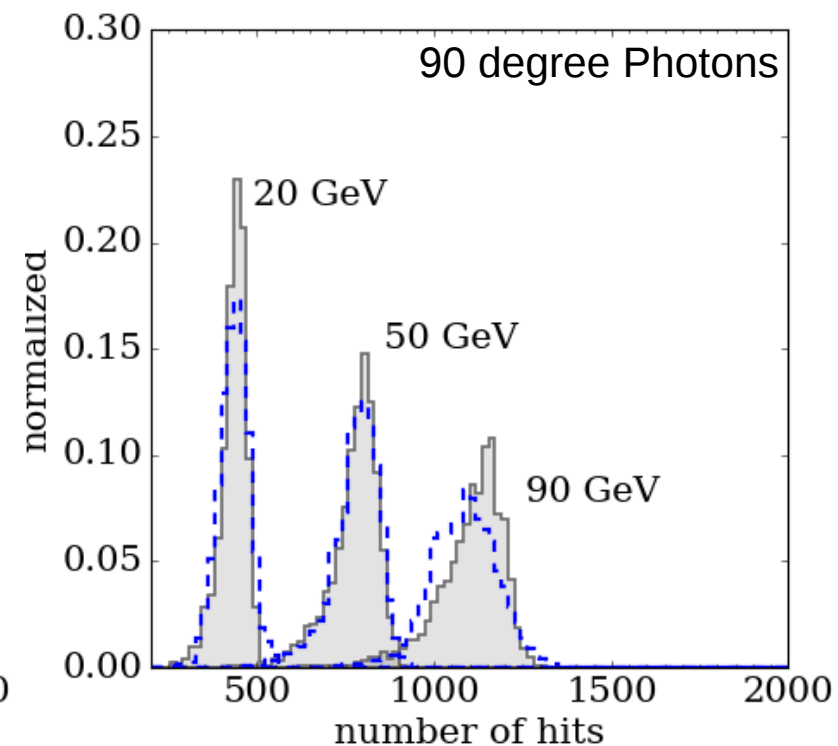
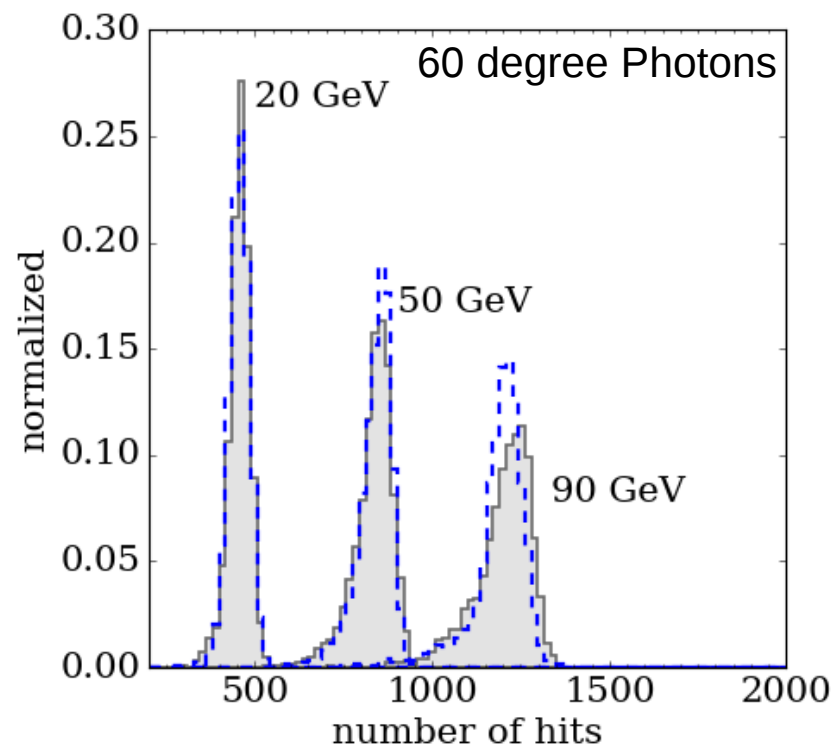
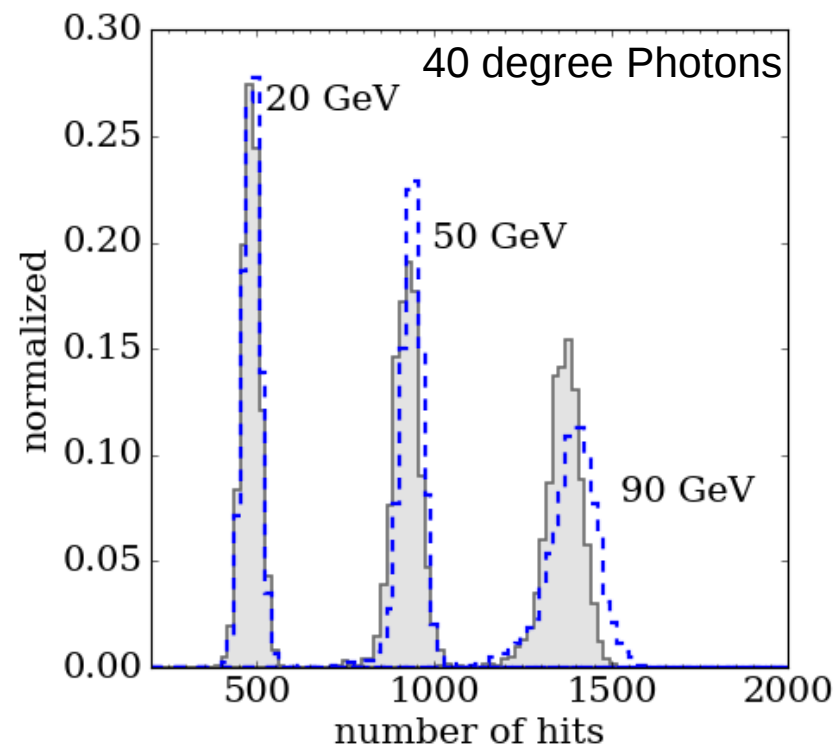
Results: Center of Gravity



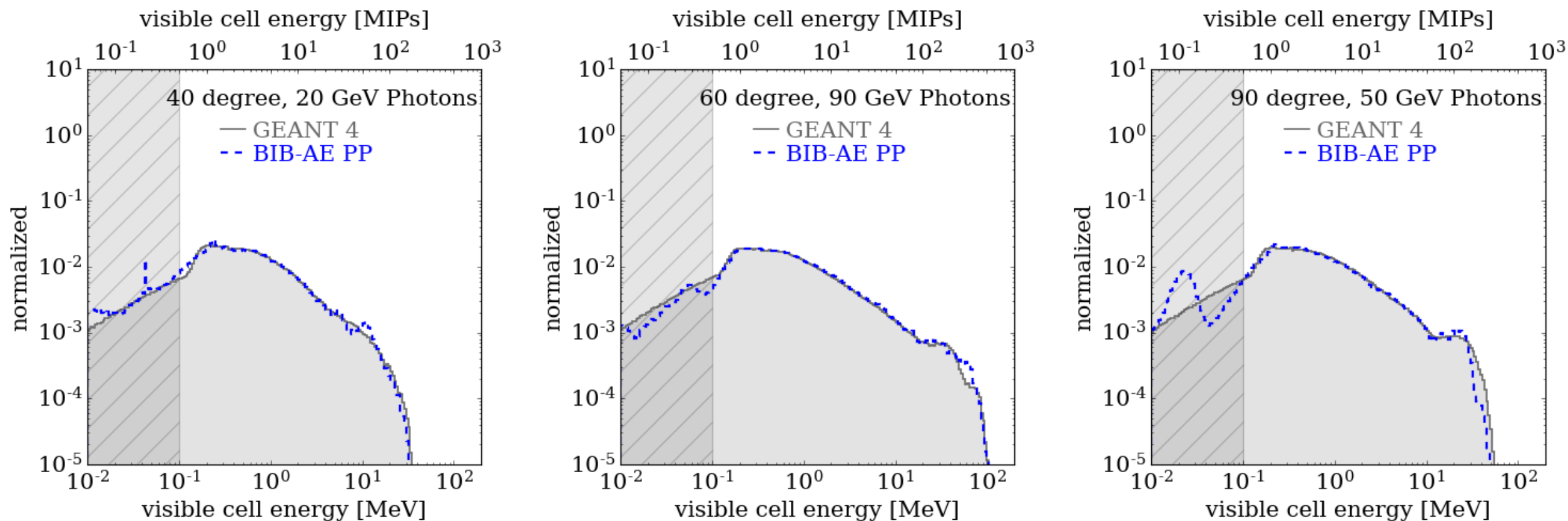
Results: Radial Profile



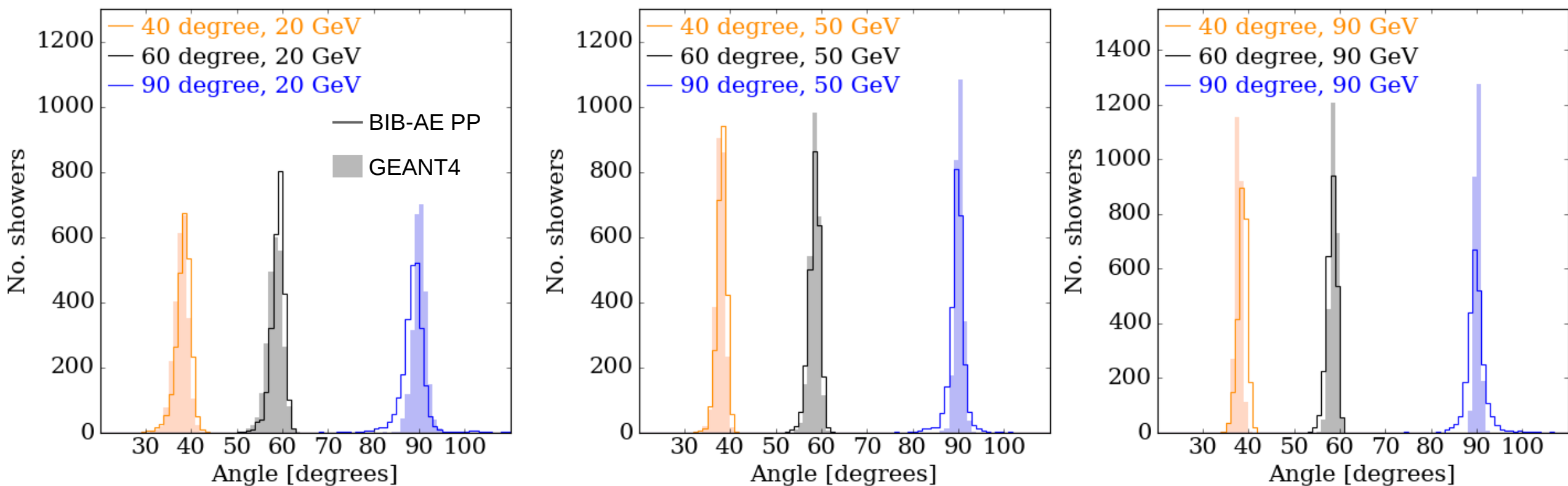
Results: Number of Hits



Results: Cell Energy Spectrum



Results: Angular Reconstruction Distributions



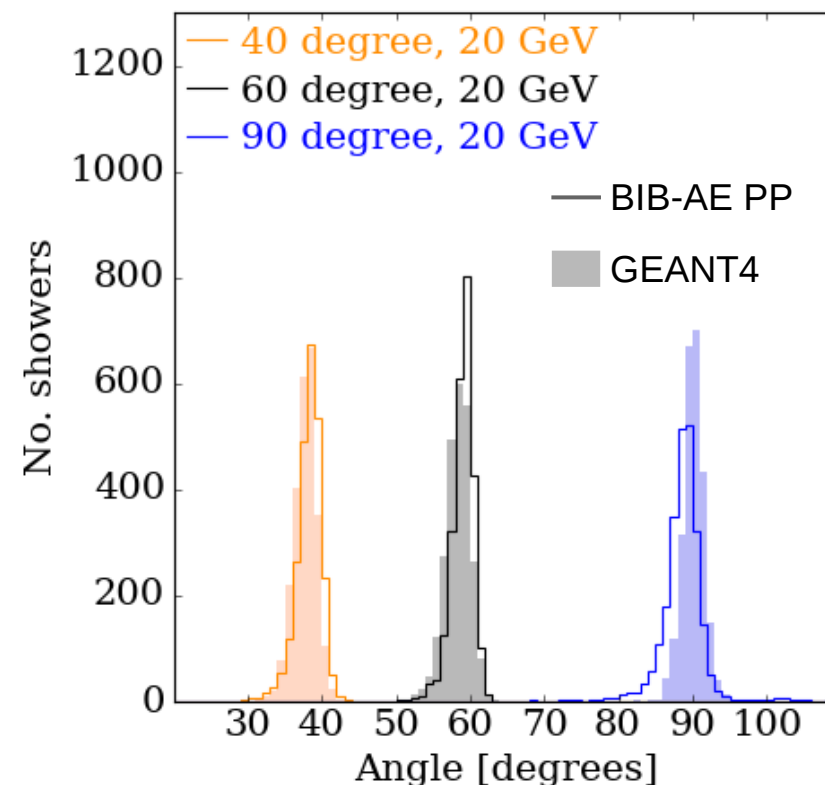
Conclusion

Achieved

- Generative models hold promise for fast simulation of calorimeter showers with high fidelity
- Demonstrated angular and energy conditioning using BIB-AE network architecture

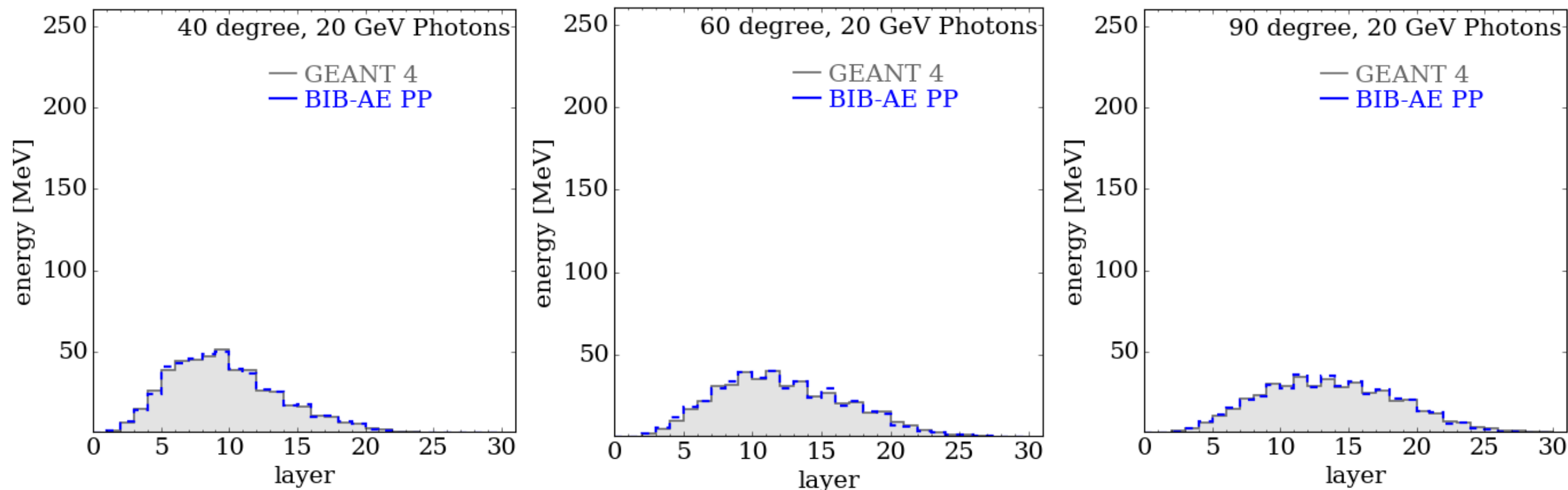
Next Steps

- Train the base BIB-AE with the complete data set
- Improve visible energy sum performance of the network
- Improve current Post-Processing setup
- Benchmark speed-up
- Start considering incidence point

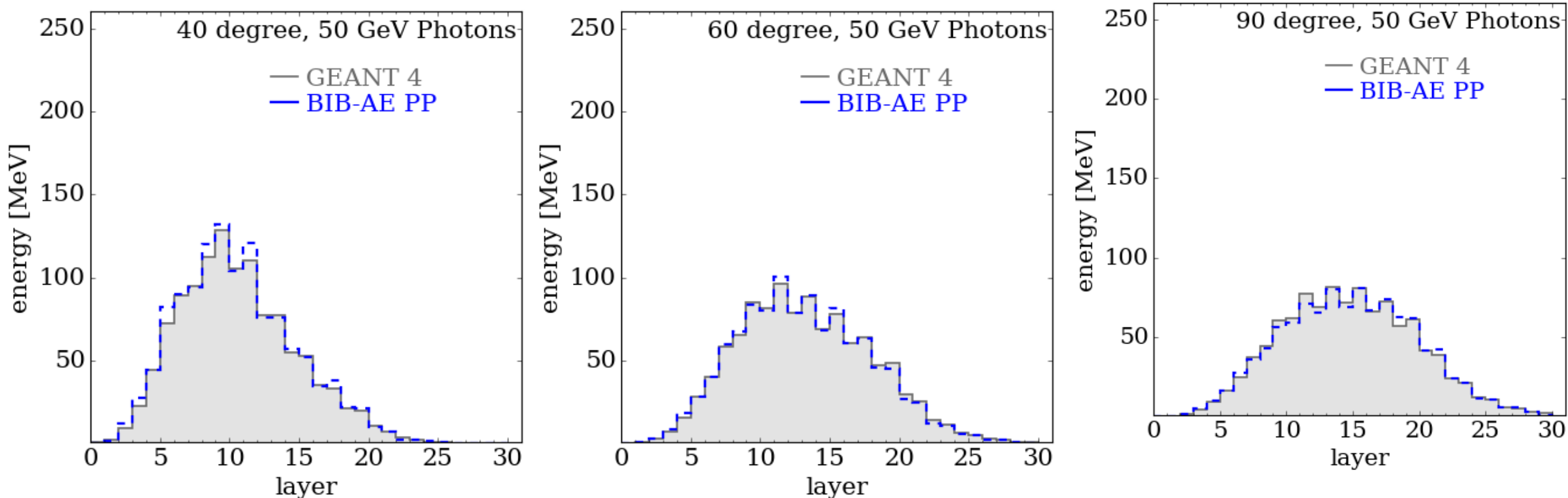


Backup

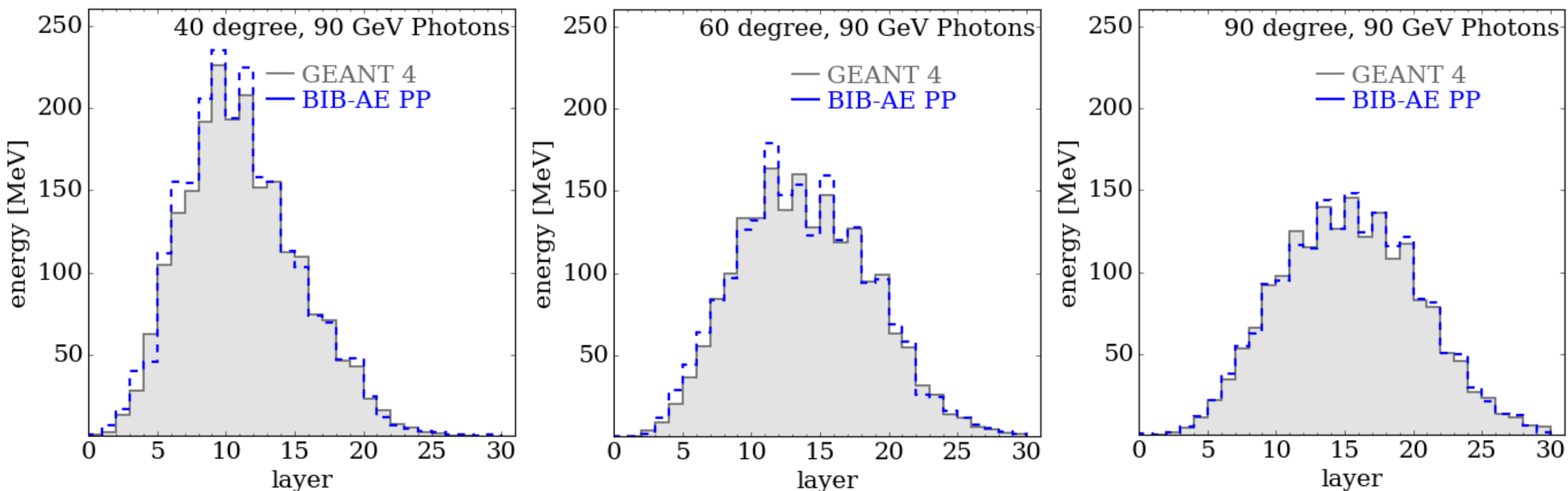
Results: Longitudinal Profile



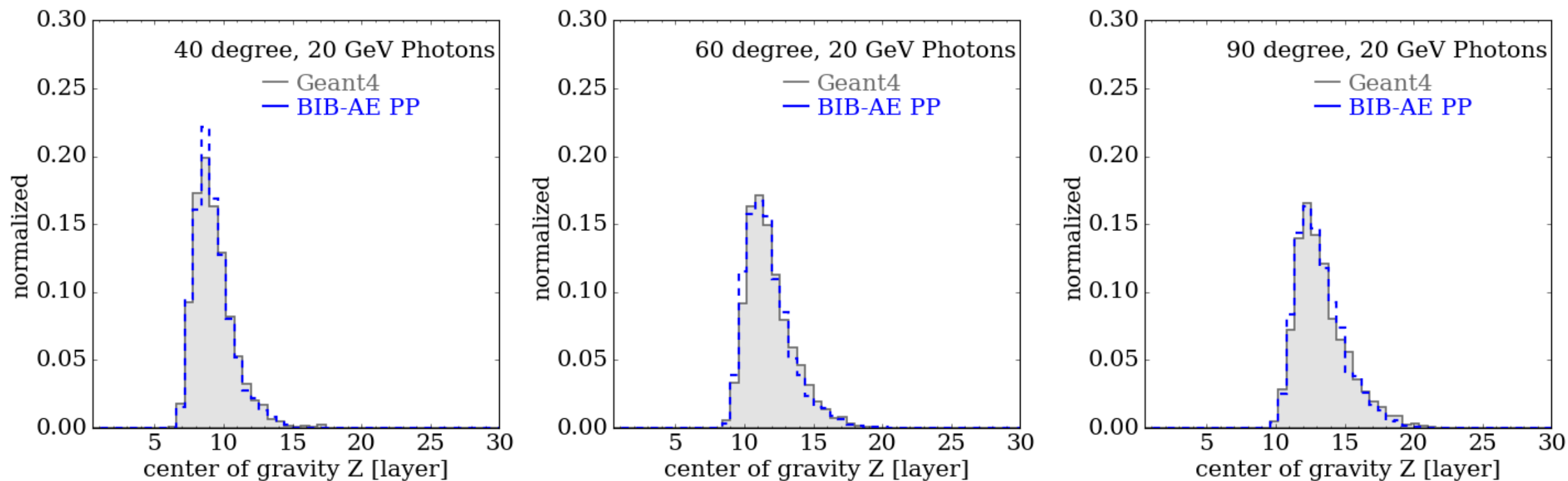
Results: Longitudinal Profile



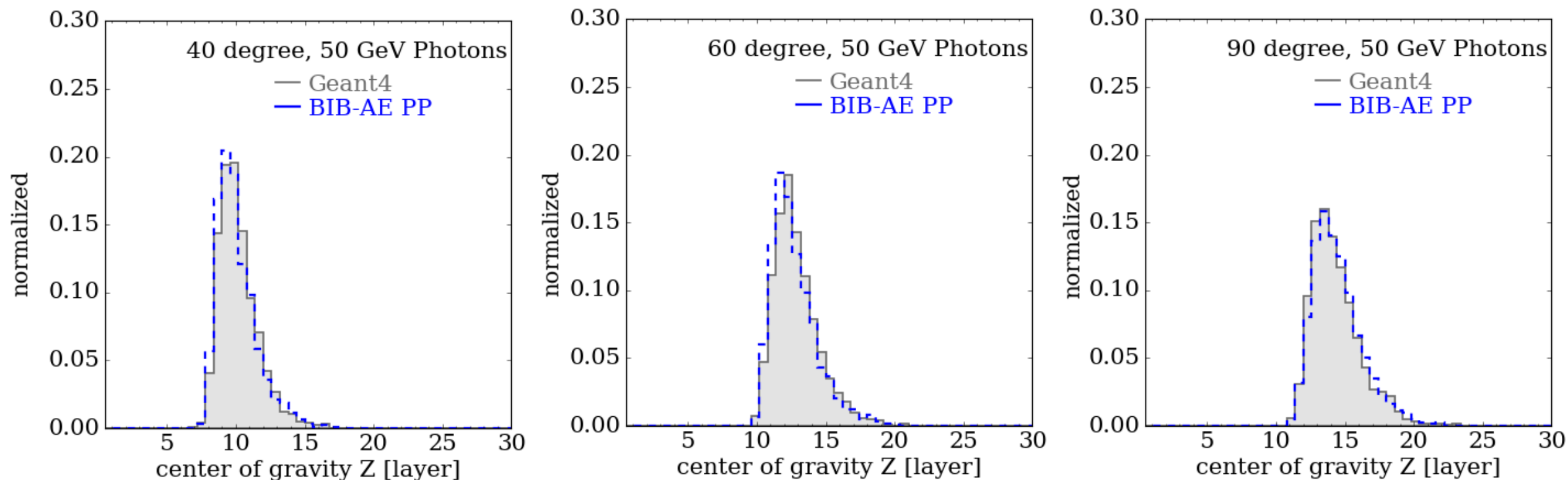
Results: Longitudinal Profile



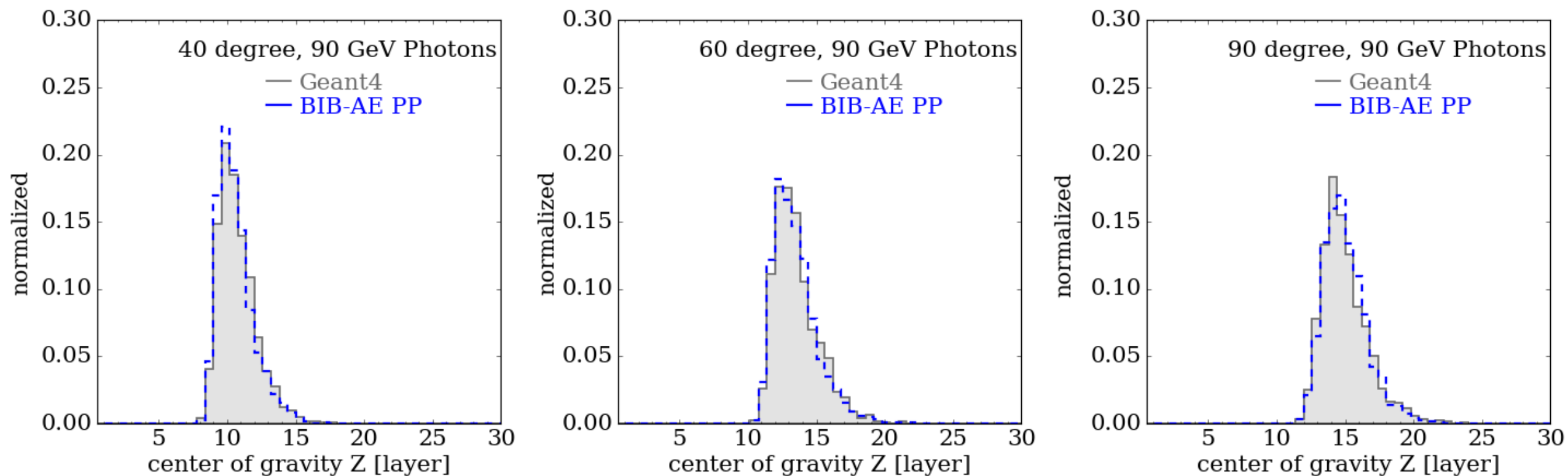
Results: Center of Gravity



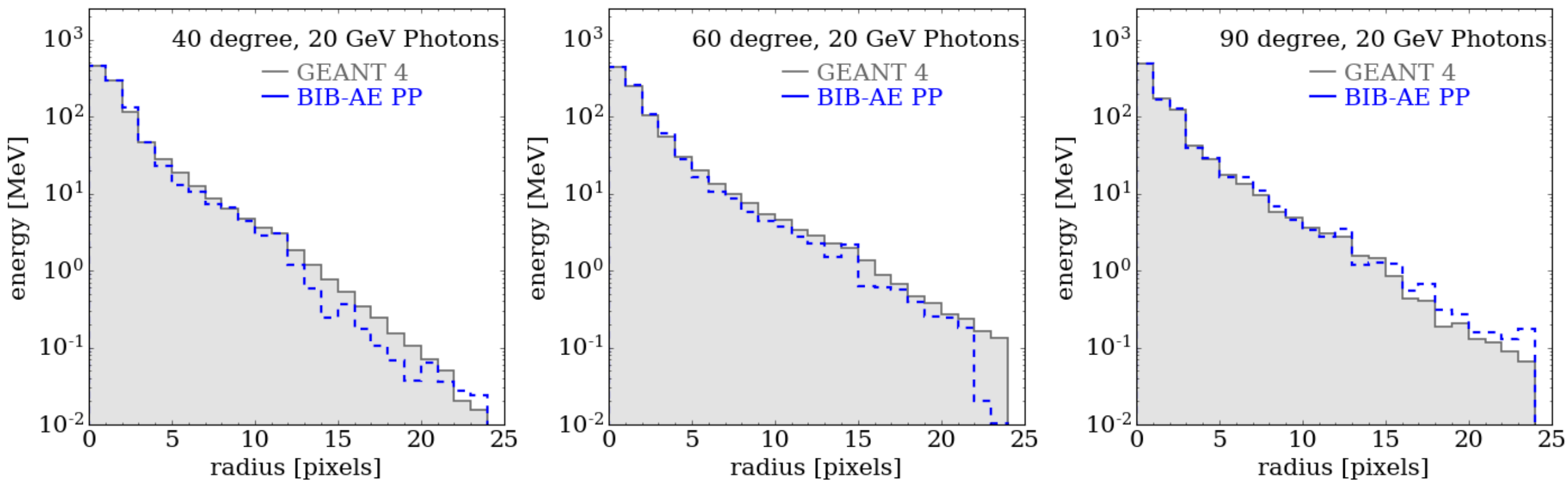
Results: Center of Gravity



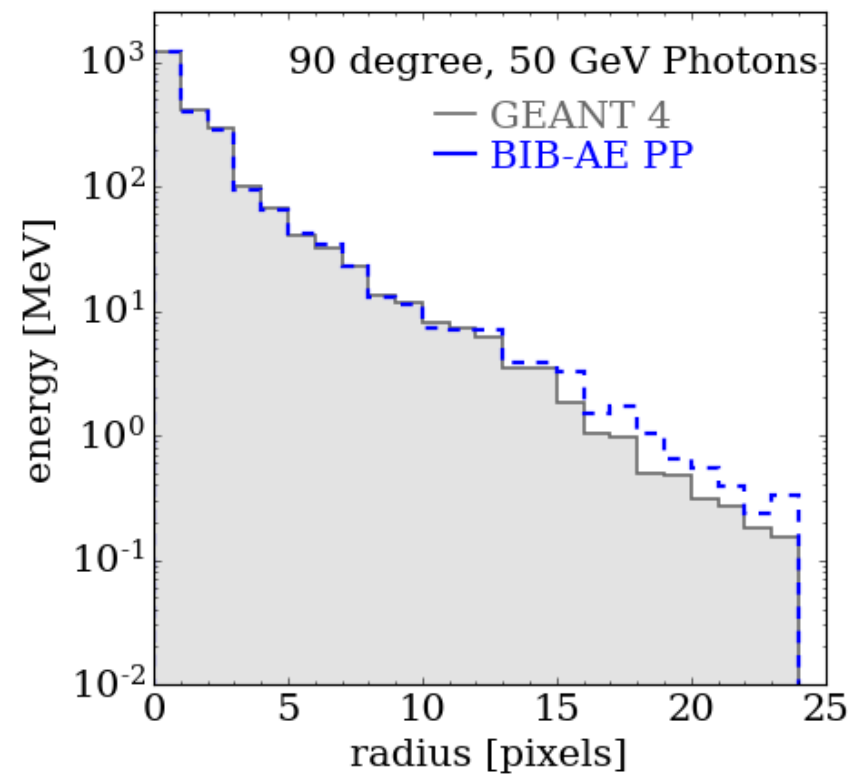
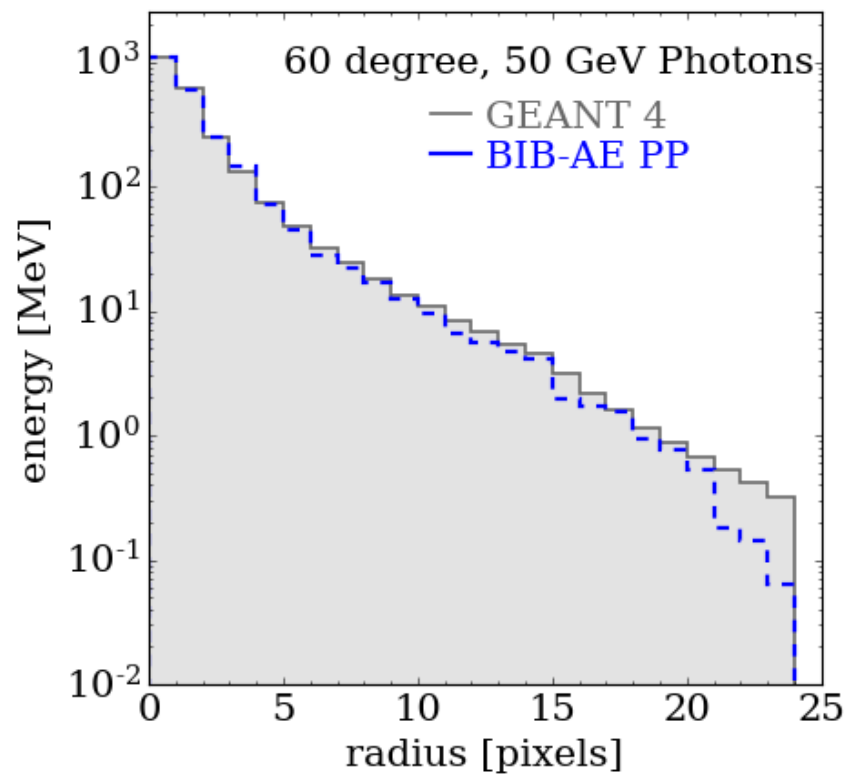
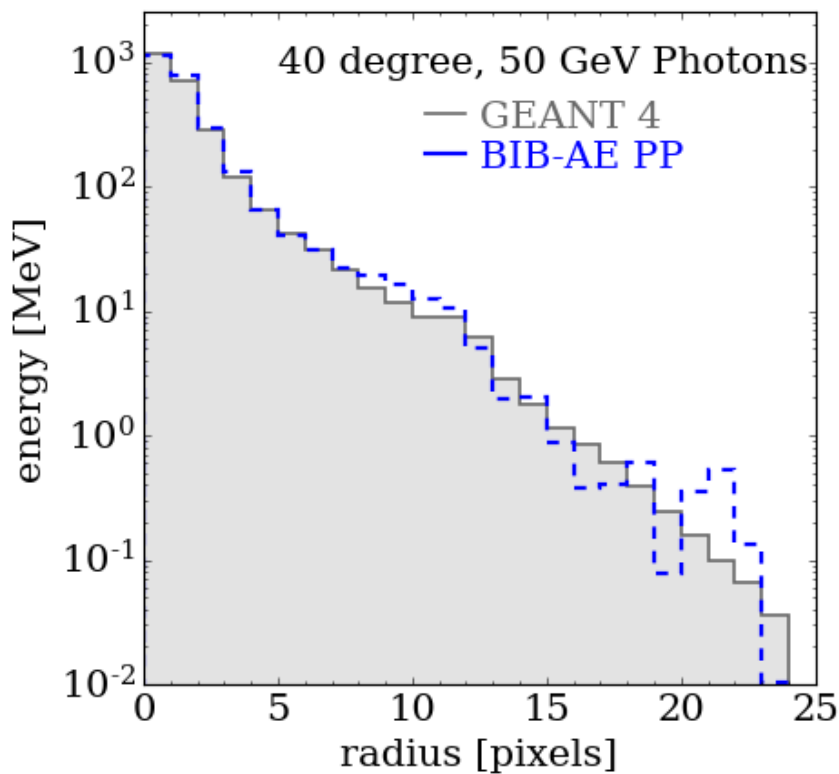
Results: Center of Gravity



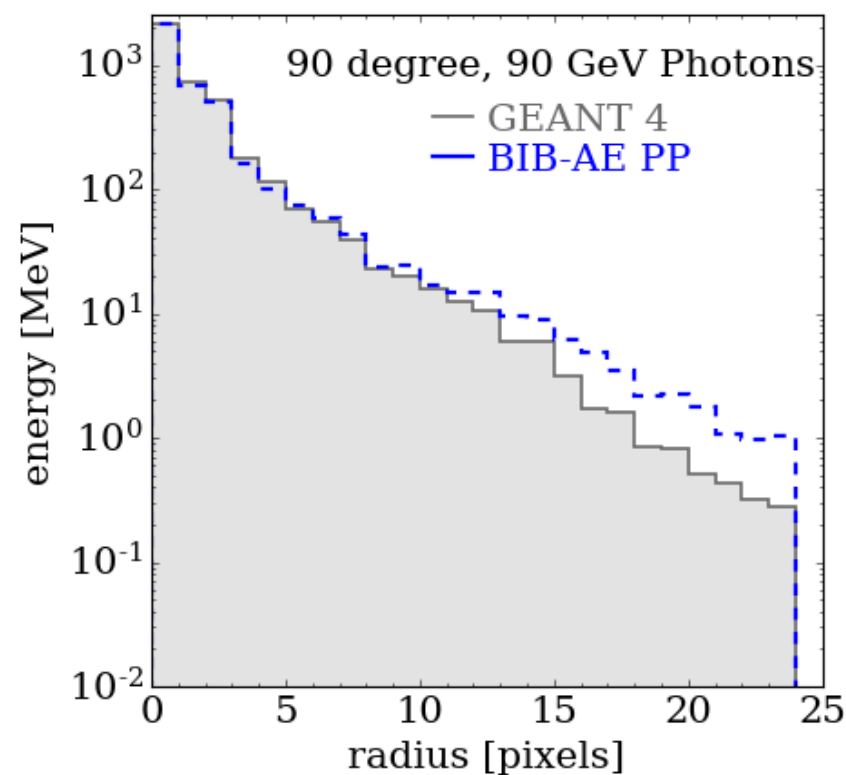
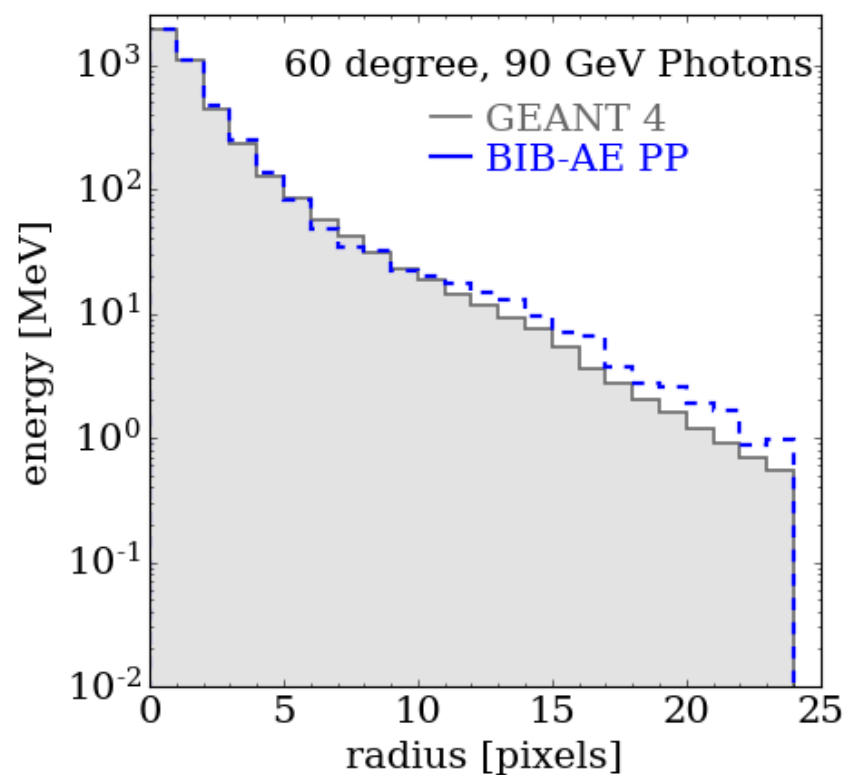
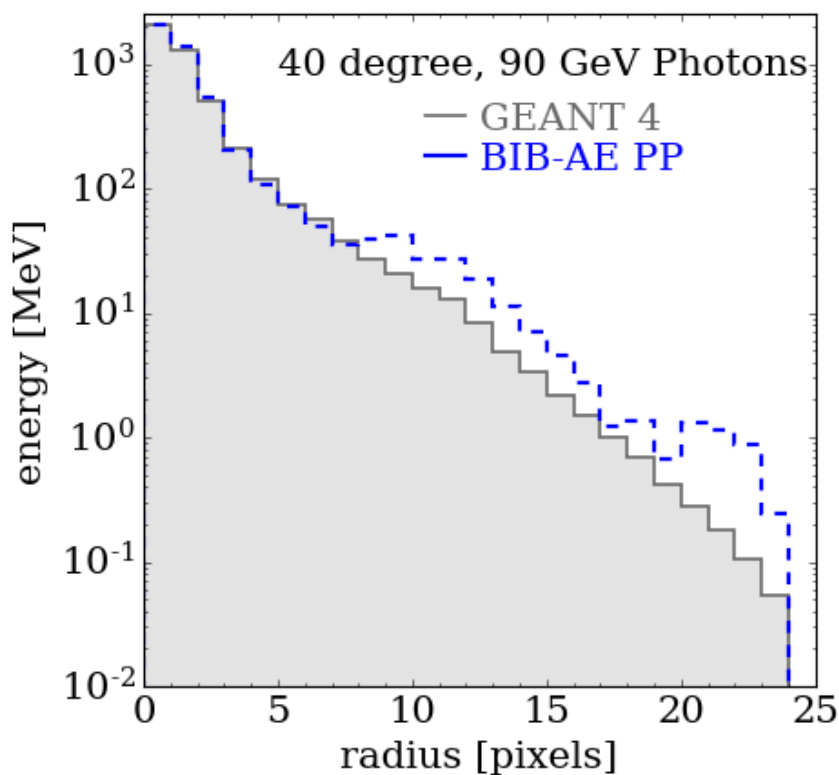
Results: Radial Profile



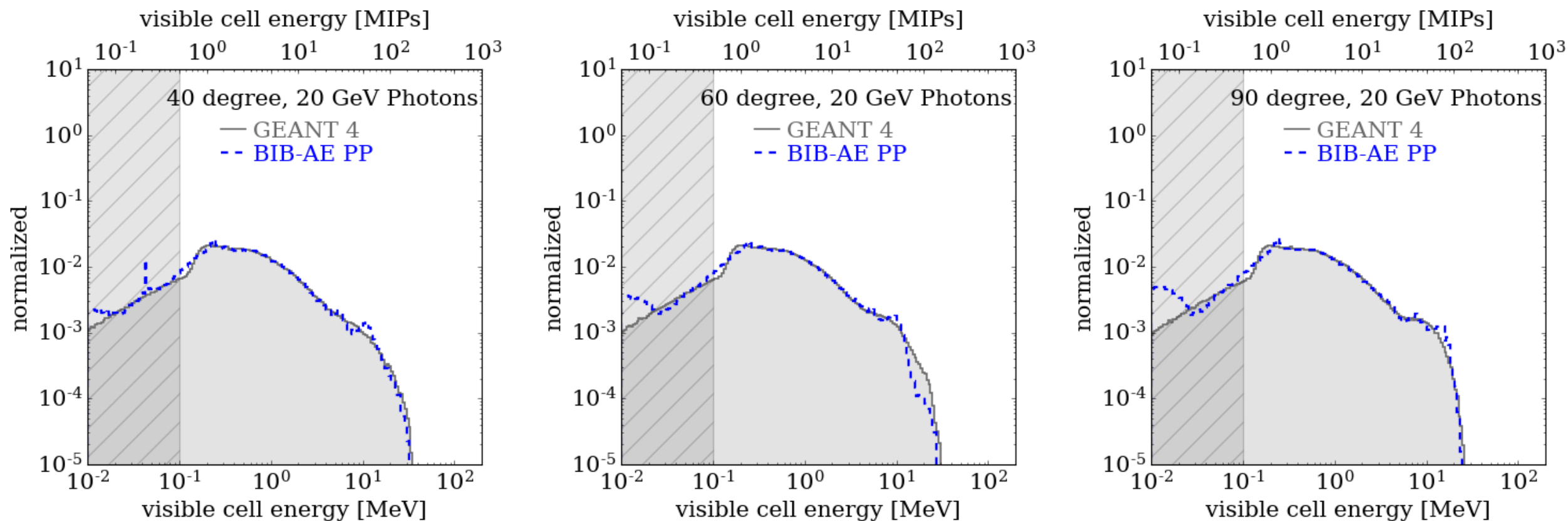
Results: Radial Profile



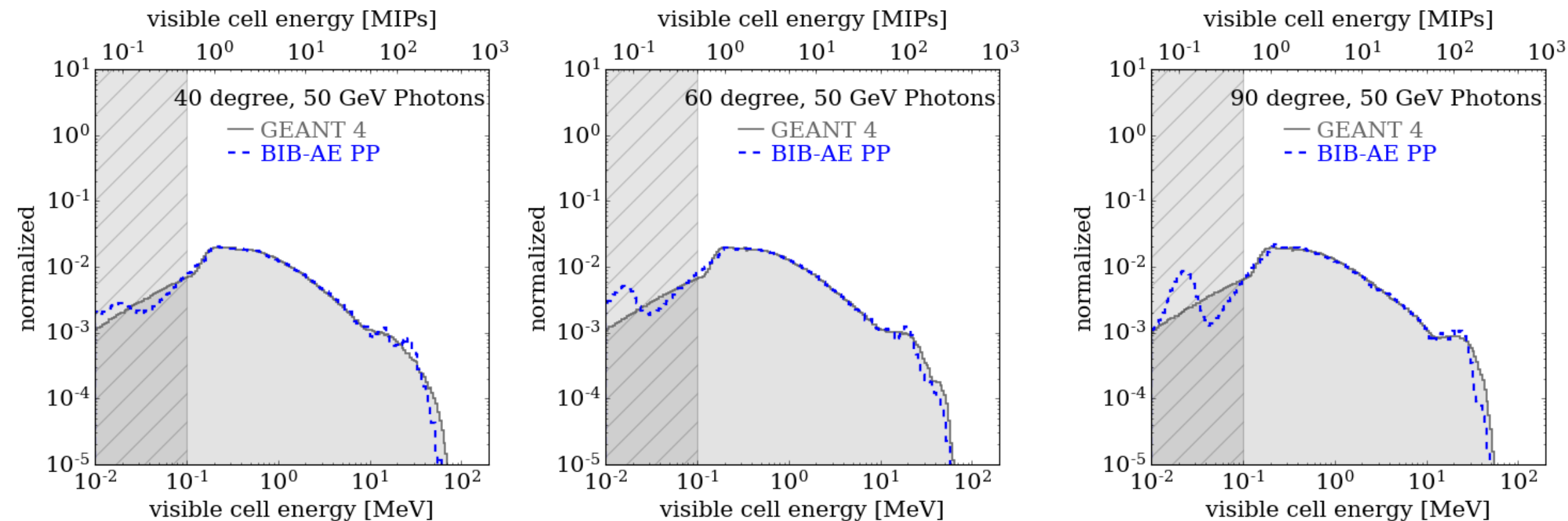
Results: Radial Profile



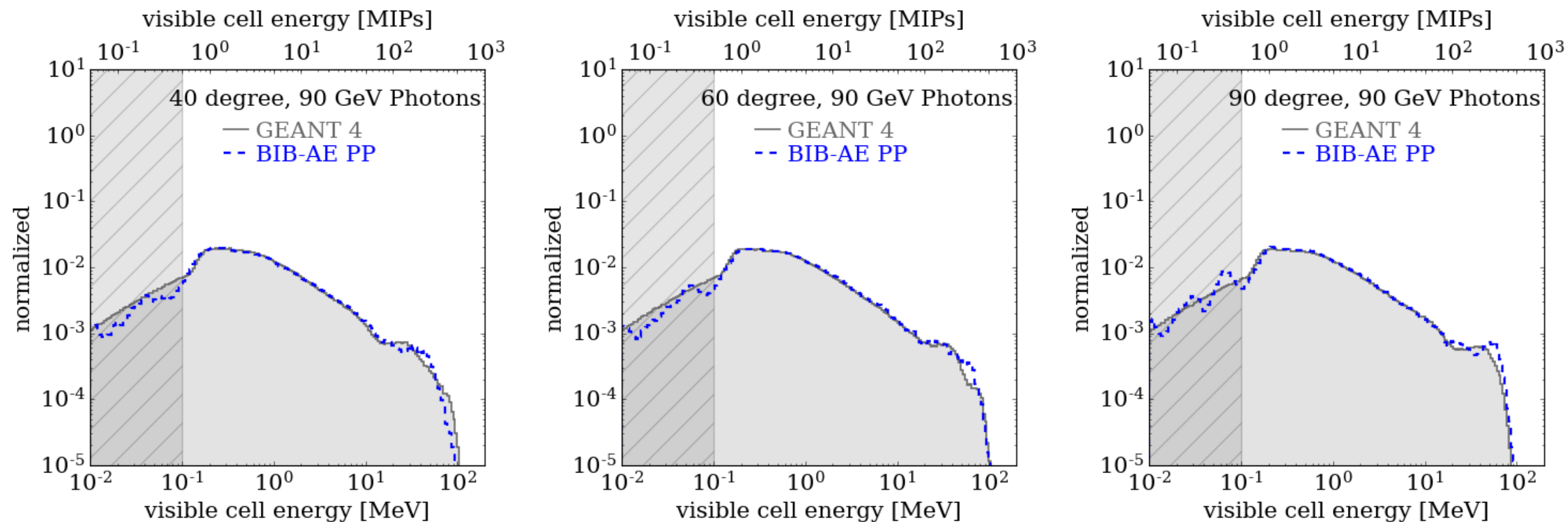
Results: Cell Energy Spectrum



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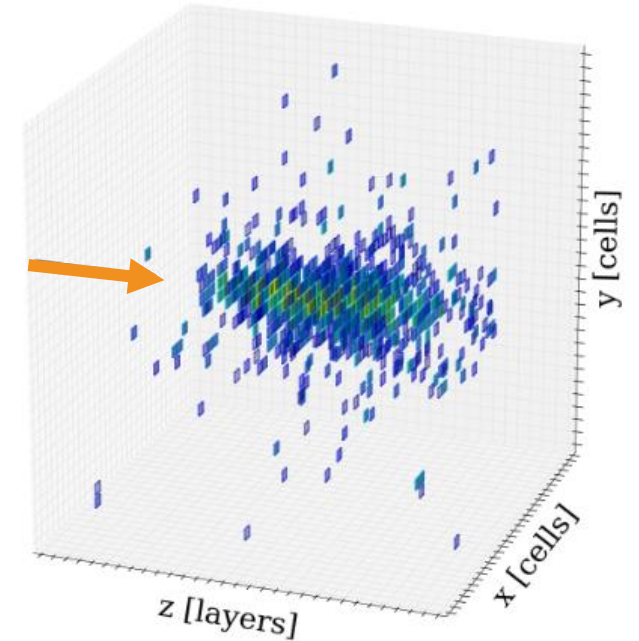


Results: Cell Energy Spectrum



Getting High: Simulating the ILD ECAL with Deep Learning

- Previous work in our group: ILD ECAL simulation with 3 generative models
 - 30x30x30 regular grid of calorimeter cells
 - Projection from irregular geometry
 - 950k photon showers
 - Continuous and uniform range of energies: 10-100 GeV
 - Fixed incident point
 - **Perpendicular to the calorimeter face**



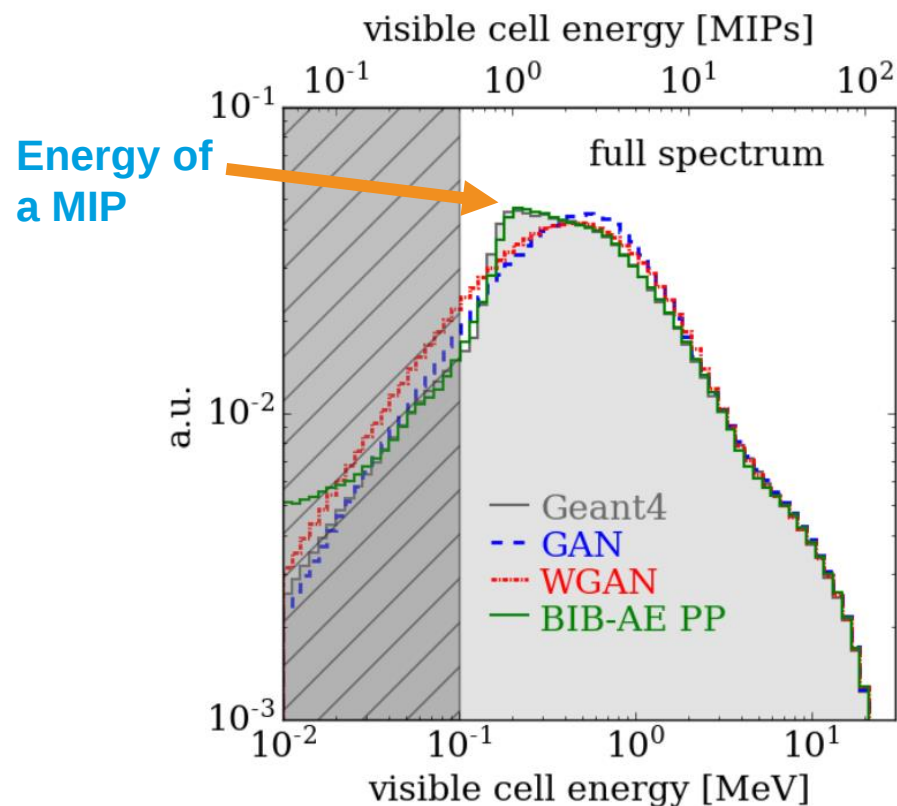
Getting High: High Fidelity Simulation of High Granularity Calorimeters with High Speed

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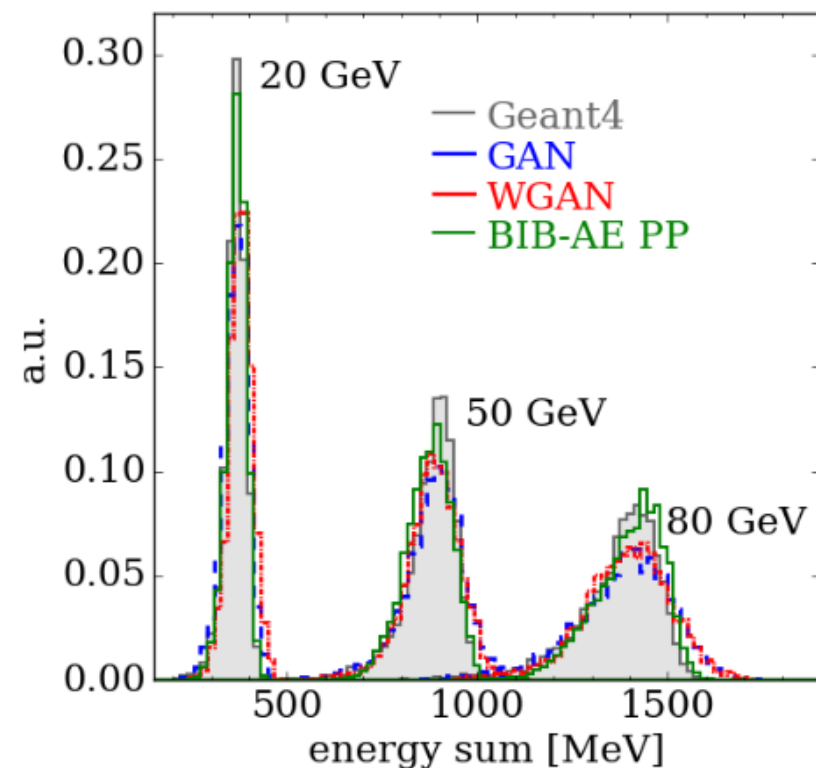
CSBS 5, 13 (2021)

<https://doi.org/10.1007/s41781-021-00056-0>

Getting High: High Fidelity Simulation



- All models reproduce shape well
- More sophisticated BIB-AE* successfully reproduces MIP peak



- Mean and width well reproduced

BIB-AE architecture described in subsequent talk by Engin

(more details: EPJ Web Conf., 251 (2021) 03003

DOI: <https://doi.org/10.1051/epjconf/202125103003>)

Computational performance from Getting High

Simulator	Hardware	Batch Size	15 GeV	Speed-up	10-100 GeV Flat	Speed-up
Geant4	CPU	N/A	1445.05 $\pm$ 19.34 ms	-	4081.53 $\pm$ 169.92 ms	-
WGAN	CPU	1	64.34 $\pm$ 0.58 ms	x23	63.14 $\pm$ 0.34 ms	x65
		10	59.53 $\pm$ 0.45 ms	x24	56.65 $\pm$ 0.33 ms	x72
		100	58.31 $\pm$ 0.93 ms	x25	58.11 $\pm$ 0.13 ms	x70
		1000	57.99 $\pm$ 0.97 ms	x25	57.99 $\pm$ 0.18 ms	x70
BIB-AE	CPU	1	426.60 $\pm$ 3.27 ms	x3	426.32 $\pm$ 3.62 ms	x10
		10	422.60 $\pm$ 0.26 ms	x3	424.71 $\pm$ 3.53 ms	x10
		100	419.64 $\pm$ 0.07 ms	x3	418.04 $\pm$ 0.20 ms	x10
WGAN	GPU	1	3.24 $\pm$ 0.01 ms	x446	3.25 $\pm$ 0.01 ms	x1256
		10	6.13 $\pm$ 0.02 ms	x236	6.13 $\pm$ 0.02 ms	x666
		100	5.43 $\pm$ 0.01 ms	x266	5.43 $\pm$ 0.01 ms	x752
		1000	5.43 $\pm$ 0.01 ms	x266	5.43 $\pm$ 0.01 ms	x752
BIB-AE	GPU	1	3.14 $\pm$ 0.01 ms	x460	3.19 $\pm$ 0.01 ms	x1279
		10	1.56 $\pm$ 0.01 ms	x926	1.57 $\pm$ 0.01 ms	x2600
		100	1.42 $\pm$ 0.01 ms	x1017	1.42 $\pm$ 0.01 ms	x2874

Computational performance from Hadrons, Better, Faster, Stronger

Hardware	Simulator	Time / Shower [ms]		Speed-up
CPU	GEANT4	2684	± 125	$\times 1$
	WGAN	47.923 ± 0.089		$\times 56$
	BIB-AE	350.824 ± 0.574		$\times 8$
GPU	WGAN	0.264 ± 0.002		$\times 10167$
	BIB-AE	2.051 ± 0.005		$\times 1309$