

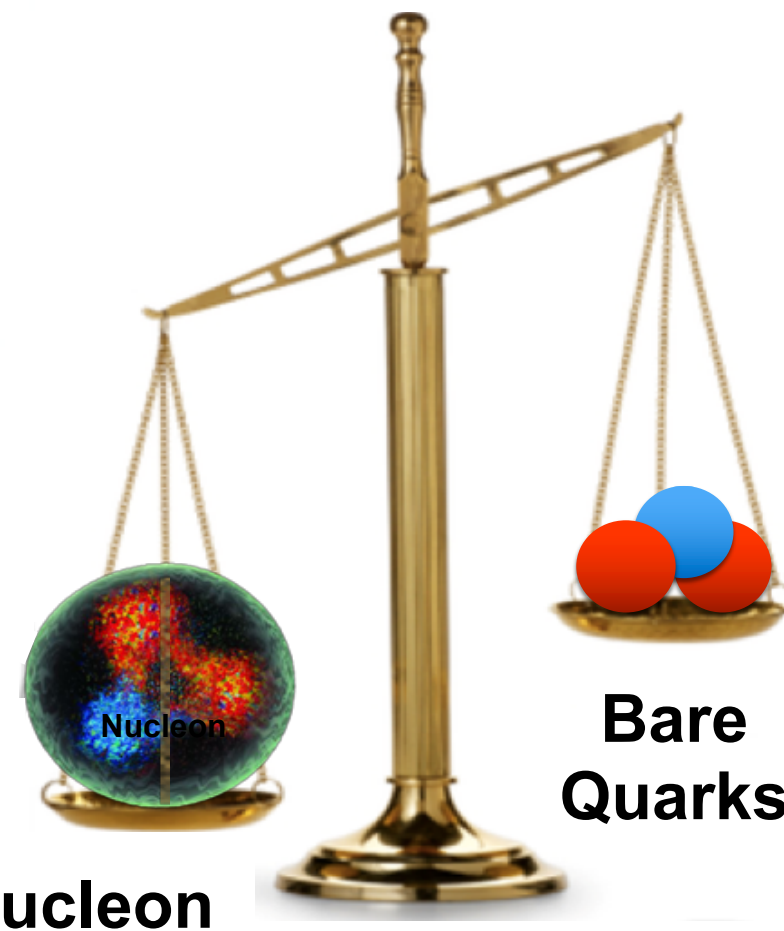
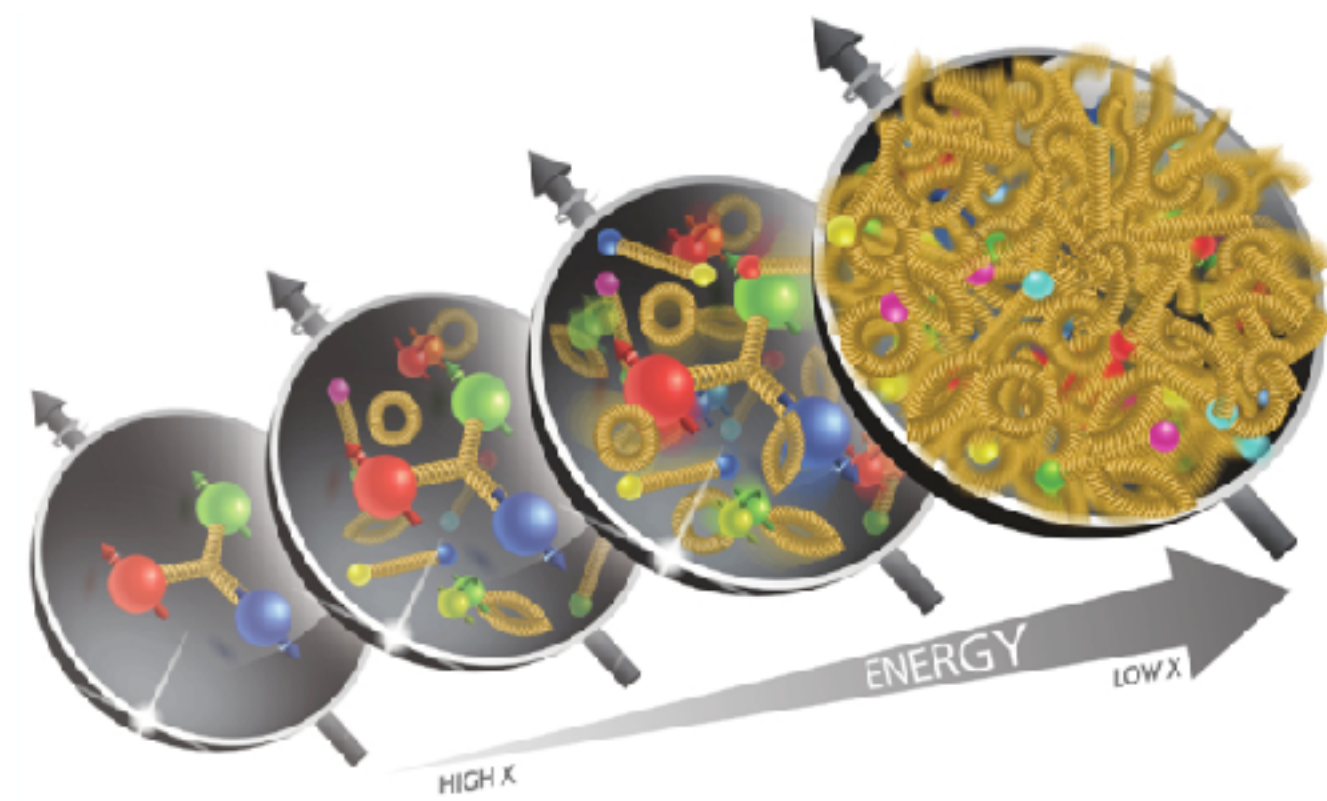
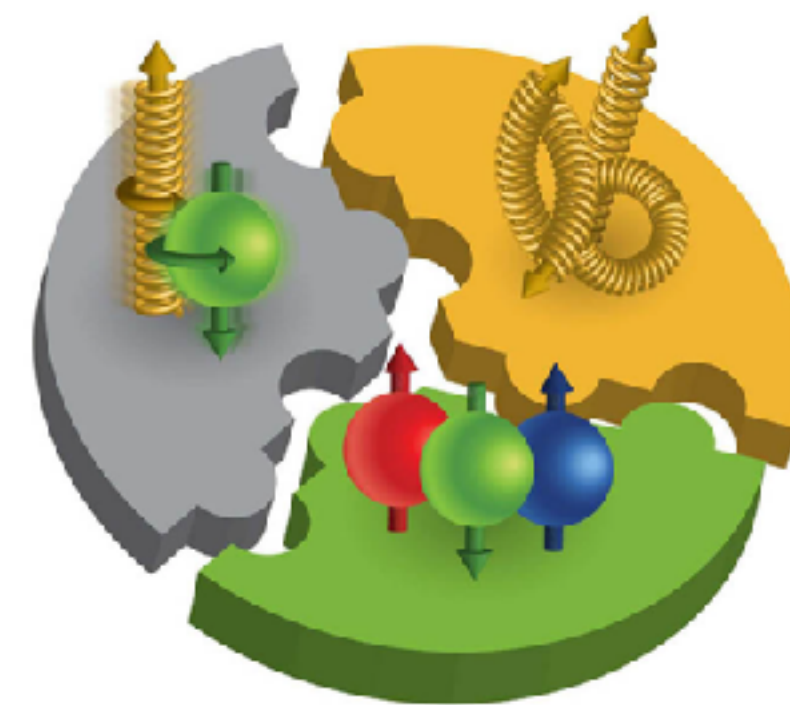
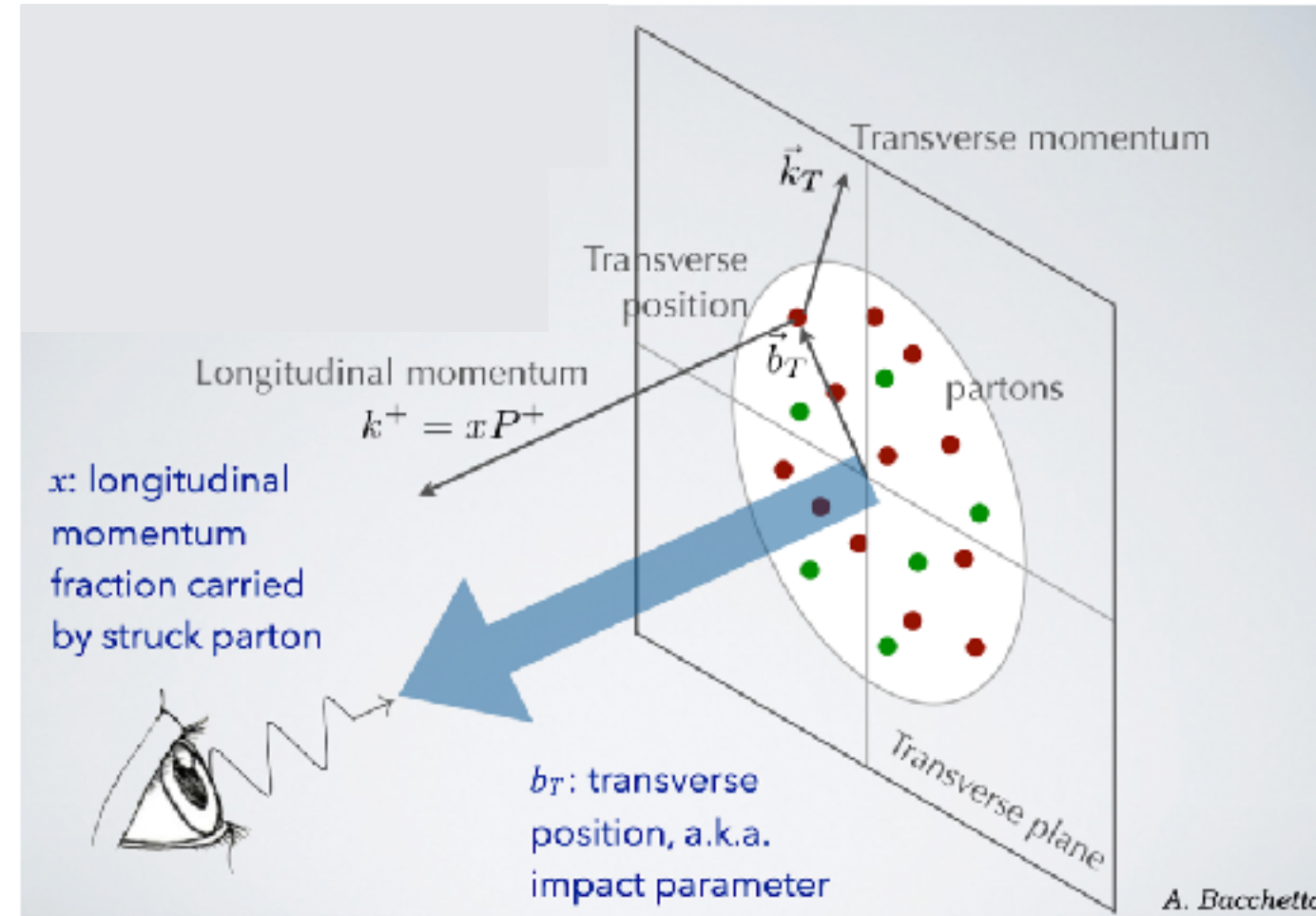
Some Recent Topics from On-Going Analyses in Exclusive, Diffractive and  
Tagging Physics Working Group

Rachel Montgomery (University of Glasgow), Raphael Dupree (IJCLab)

On behalf of *MANY* from the working group

26/6/24, Joint ePIC Software-Physics Meeting

# Reminder on Scope of the Group



- Group encompasses **numerous** different reactions
  - Many on-going and planned studies
- Different NAS topics linked to on-going EDT PWG activities:
  - Origin of nucleon spin
  - 3D structure of nucleons and nuclei (tomography)
  - Gluon structure of nucleon/nuclei
  - Origin of hadron mass
- Open to any science beyond this and to extending the scope to more topics...!



# Update On Monthly Production Requests and Active Channels

Physics Process	Q2 Range	Physics Generator	Settings – e.g. No. Events, beam configs, channels, other generator settings/cuts
DVCS ep	$Q^2 > 1$	EPIC	18x275, 10x100 (or 110), 5x41 currently ?M, need ?M We might want to add a $t_{min}$ as well.
DVMP pi0	$Q^2 > 1$	EPIC ?	Same as DVCS ep
TCS	$Q^2 > 1$	EPIC	Nobody is actively working on it, could be paused until we have an analyser as it takes a lot of computing right now
Elastic ep	$6 < Q^2 < 40$	ROOT-based generator (QED off) Djangoh 4.6.21 (QED ON)	5x41, 10x110 and 18x275. Building on the work done here: <a href="https://arxiv.org/pdf/2207.04378.pdf">https://arxiv.org/pdf/2207.04378.pdf</a>
Tagged DIS (eD)		BeAGLE	10x110 (nb of events ?) 5x110 request coming
VM production eAu coh phi	$Q^2 > 1$	Sartre	Already in monthly production
VM production eAu coh J/Psi	$Q^2 \sim 0$	Sartre	In progress
VM production ePb/Au incoh J/Psi	$Q^2 > 1$	BeAGLE	In progress. Addition of a low Q2 config possible
Pion/kaon FF		DEMPgen	pi+n: 5x41, 5x100, 10x100 K+Lambda: 5x41, and as a test 5x100 K+Sigma0: 5x41
U-channel DVMP/DVCS	$Q^2 > 10^{-3}$	eSTARlight	$\rho_0$ (10x100) and $\pi_0$ (18x275) are already in monthly production. Possible addition of $\omega$ (18x275) and DVCS (18x275) to monthly simulations, 100k events each.
DVCS en	$Q^2 > 1$	TOPEG	TOPEG is in process of upgrading
DVCS He4	$Q^2 > 1$	TOPEG	TOPEG is in process of upgrading We might want to add a $t_{min}$ as well.
J/Psi ep	$Q^2 > 1$	IAger	18x275, 10x100 in progress. Need some upgrade to get in the train. We hope to get both ee and $\mu\mu$ decays
Pion SF		EIC_mesonMC	Match previous ECCE settings for pion : 5x41, 5x100, 10x100, 18x275 (would be good to update generator for kaon SF too at later date. Start with pi. Would be good to get pi in monthly.)
Threshold J/Psi		IAger	Need a run in near future to prepare analysis scripts and makes sense to run monthly. Plan to use same event samples as before.
Upsilon	?	eSTARLIGHT	Propose to run what they need at NERSC@LBL
XYZ		elSpectro	Not in regular trains. (Maybe eventually? Would be good for low Q2 benchmark?)
Diffractive PDF			(e-mailed Anna, waiting for response, in Parallel Thomas finding out more info)
Tagged DIS He			He3, D2 targets for all beam energy configs. But not sure if will be do-able in time frame yet.
Tagged DIS light nuclei			Propose to run simulations themselves
...			?

- Monthly production (MP)
- MP,
- Not Active
- Self-run, but will request MP soon
- Self-run
- MP and already a benchmark
- Self-run
- Self-run
- MP - and would like to request a special run of 5x100 setting
- MP and now a benchmark
- In development - generator being upgraded
- In development - He ion in FF region needs reconstruction
- Self-run
- Self-run, but will request MP soon
- Self-run
- Self-run, but we have an outstanding request for MP
- Self-run
- In development - generator checks underway
- Not Active
- Self-run - needs FF region work

“MP” and “self-run” analyses are underway and developing

Today only show some recent examples

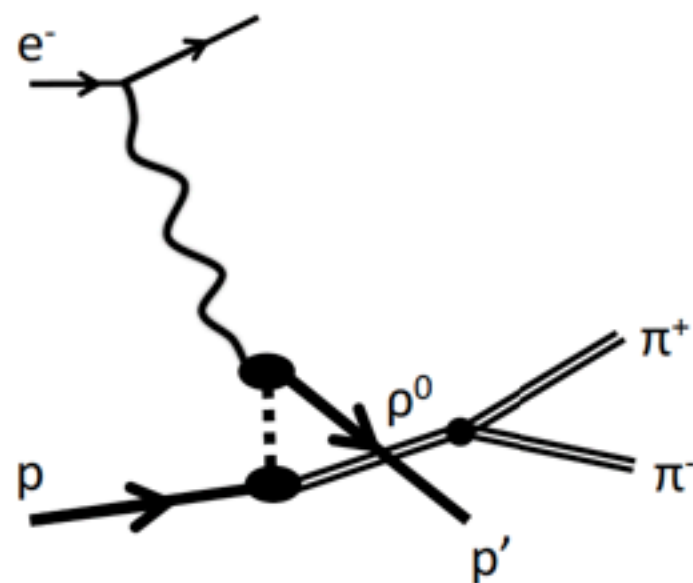
Either ReconstructedParticles or ReconstructedChargedParticles used in analyses

# u-Channel $\rho^0$ Benchmark for B0

- Backwards (u-channel) physics → nucleon/nuclear tomography
- Forward (t-channel) cross-sections → parton distributions in transverse plane via GPDs
- Backwards cross-sections → quark clusters and baryon number distributions in transverse plane via TDAs
- Connections with baryon stopping
- See paper: <https://journals.aps.org/prc/abstract/10.1103/PhysRevC.106.015204>

## RECAP: $u$ -channel $\rho^0 \rightarrow \pi^+\pi^-$ in B0

UC DAVIS  
UNIVERSITY OF CALIFORNIA

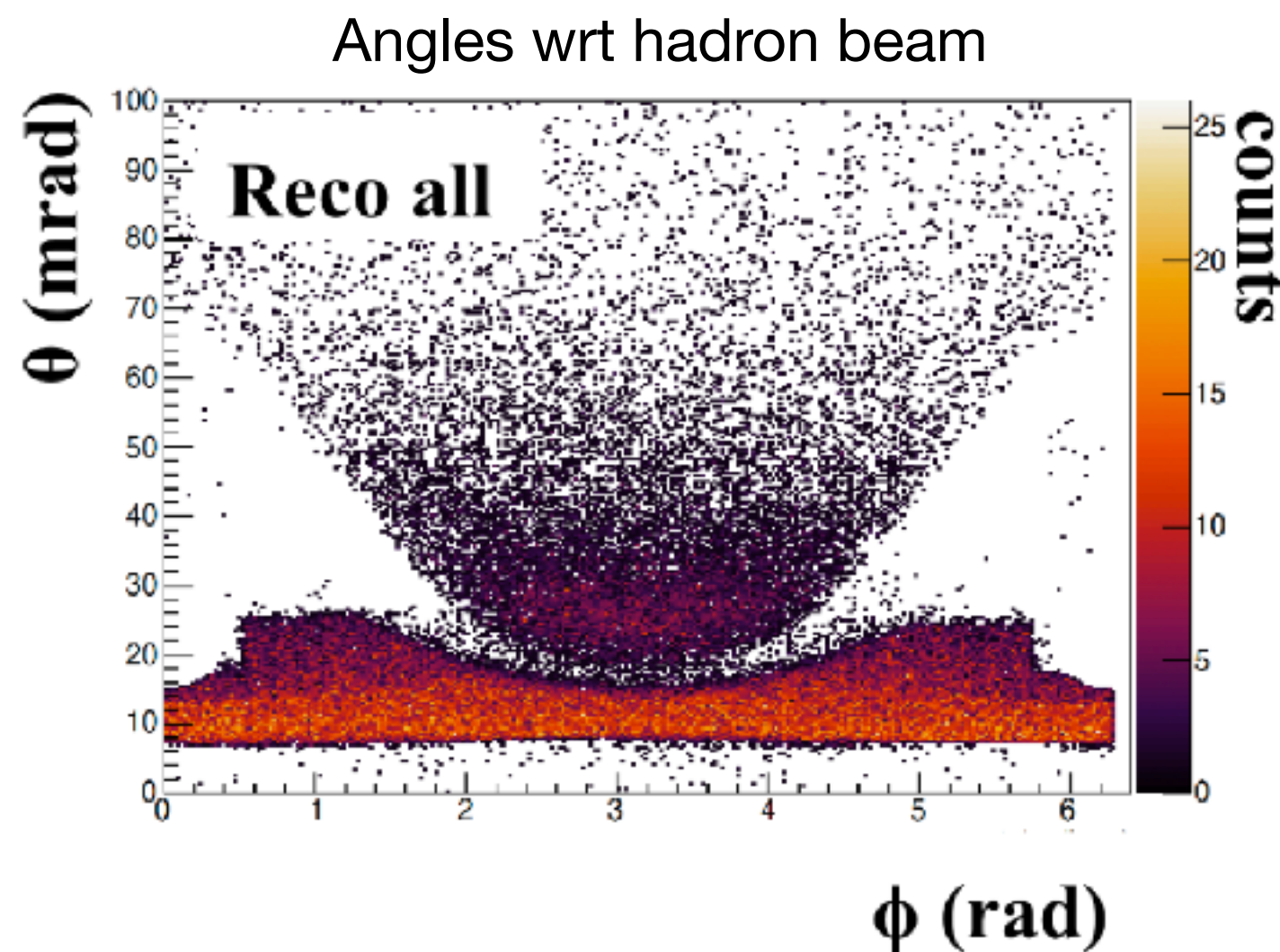
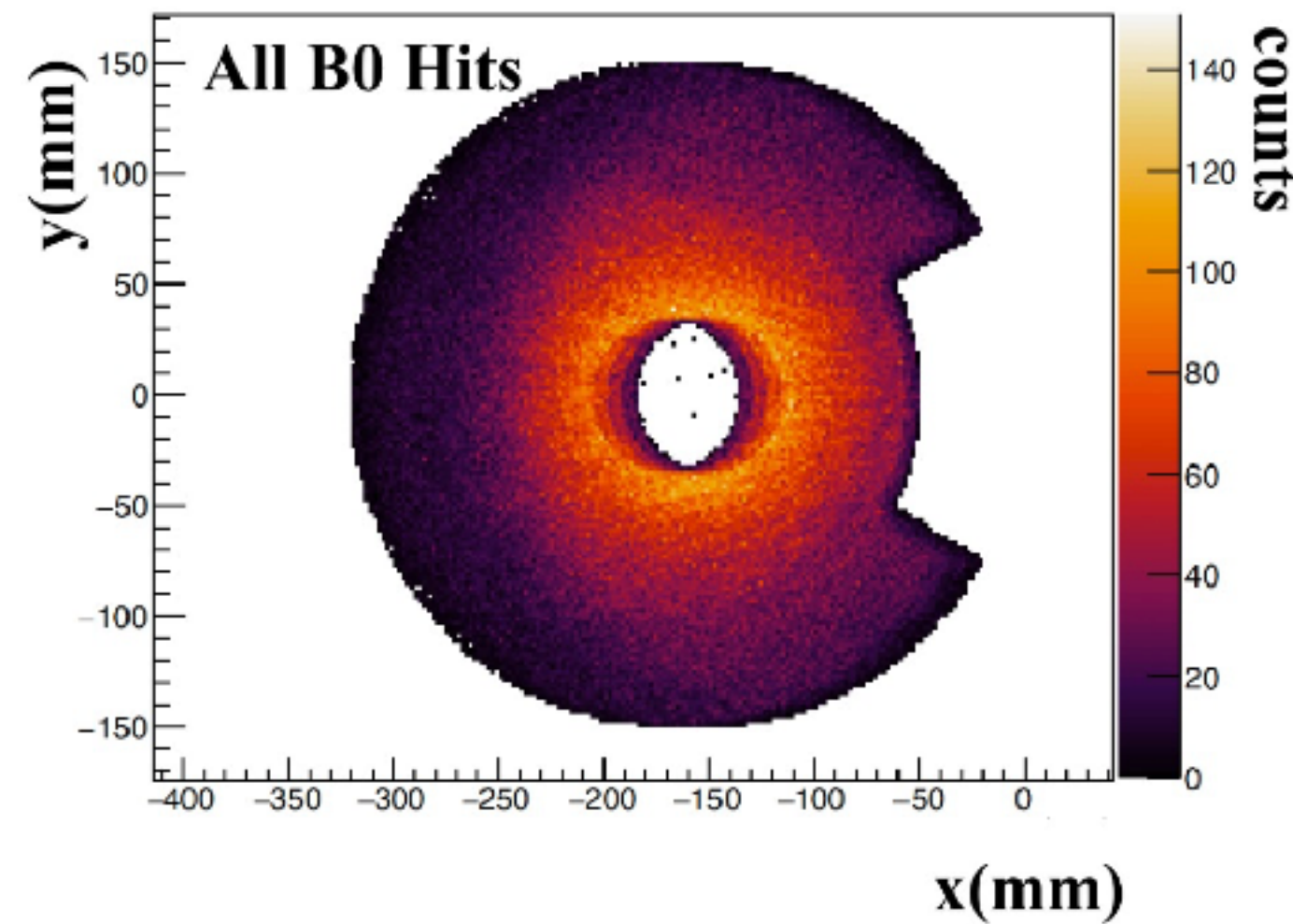


- We developed model for backward  $\rho$  production
- Edited eSTARlight to produce this channel
- Made event samples for the simulation campaigns
- These samples are now run in each campaign and can be found on S3:
  - [eic-test/EPIC/RECO/24.03.1/epic\\_craterlake/EXCLUSIVE/UCHANNEL\\_RHO/10x100](https://eic-test/EPIC/RECO/24.03.1/epic_craterlake/EXCLUSIVE/UCHANNEL_RHO/10x100)
- These charged pions land in the B0

- In ePIC:
  - Produced vector meson takes most of momentum of struck nucleon → ends up in FF region
  - Nucleon shifts by several units in rapidity to mid-rapidity
- **Zachary Sweger (UCDavis) et al**
- Backwards  $\rho^0$  meson production
  - Low Mandelstam  $u$ , high  $t$
- **Benchmark for B0 developed**
  - **B0 is critical for pions in  $\rho^0 \rightarrow \pi^+\pi^-$**



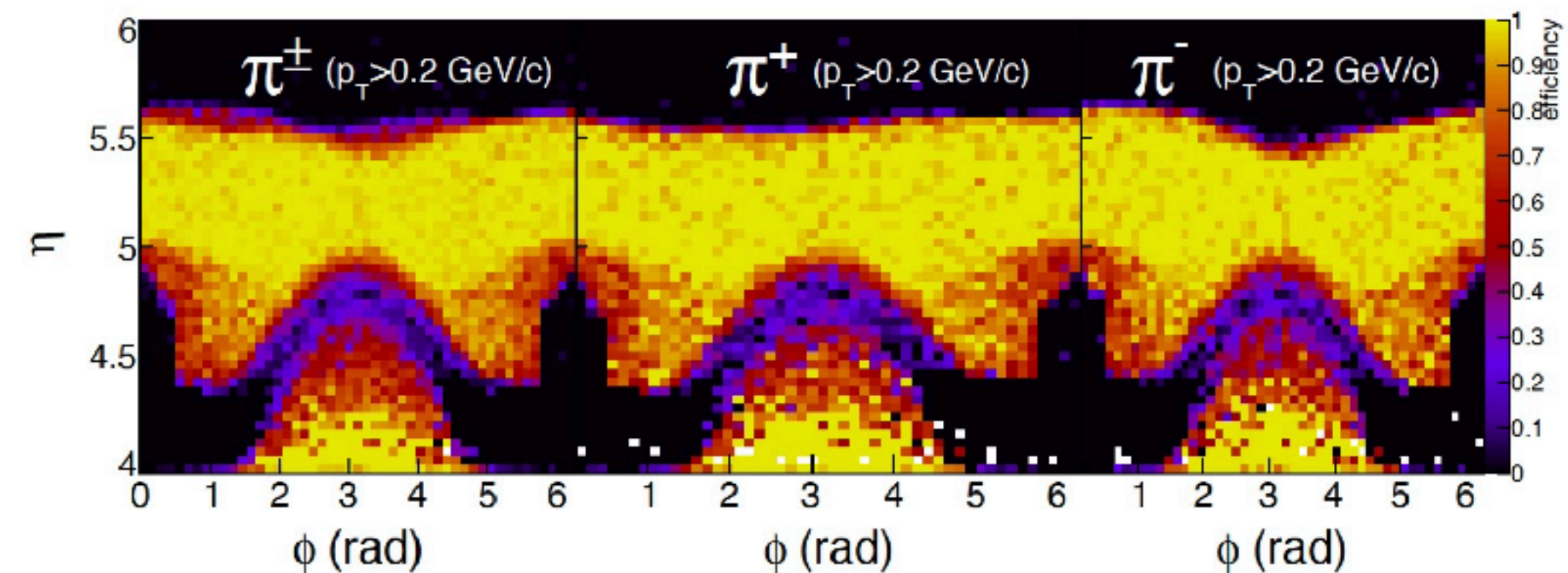
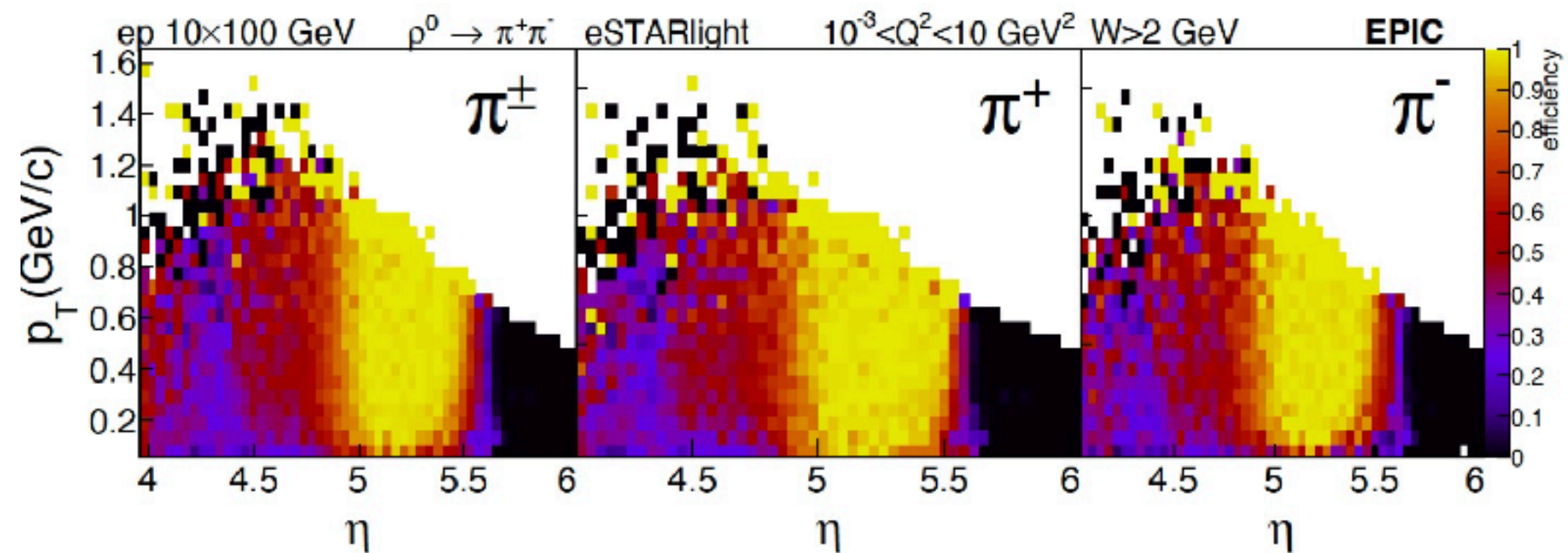
# u-Channel $\rho^0$ Benchmark for B0



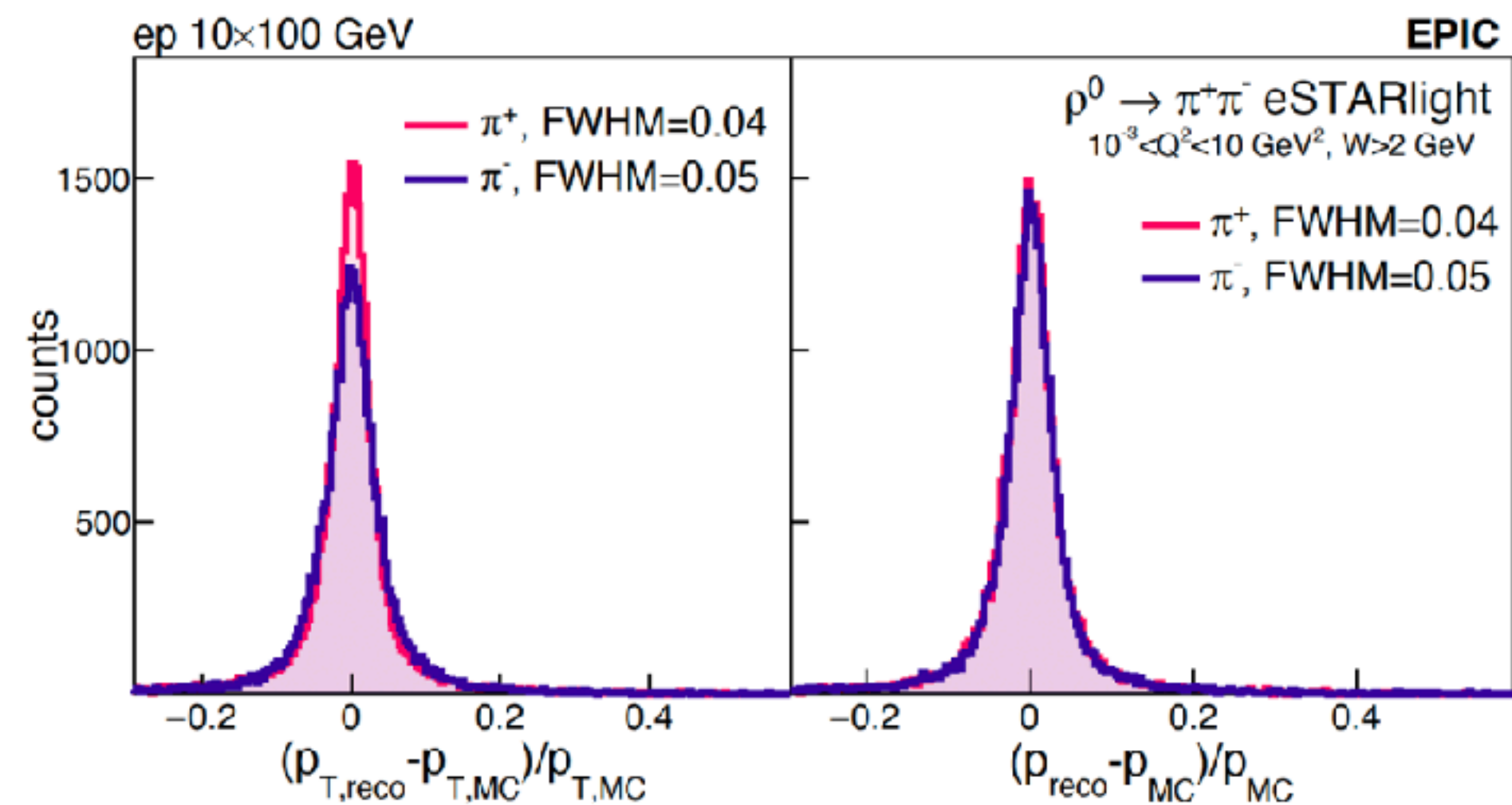
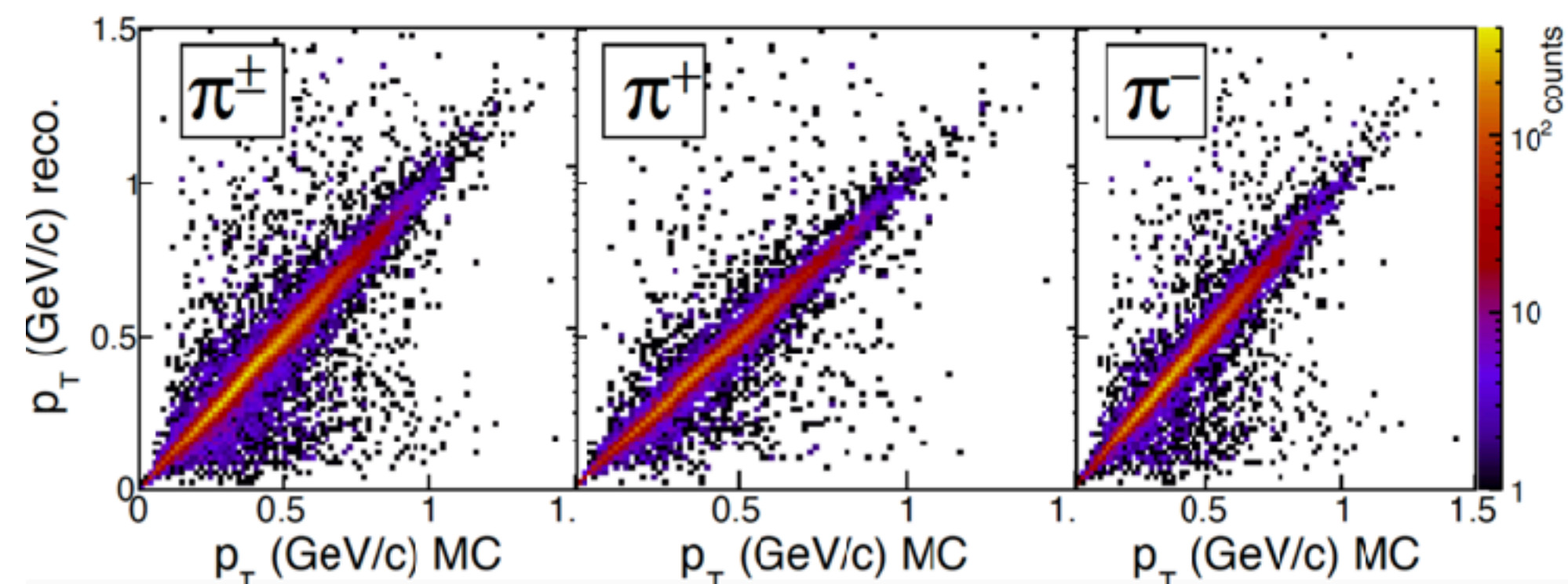
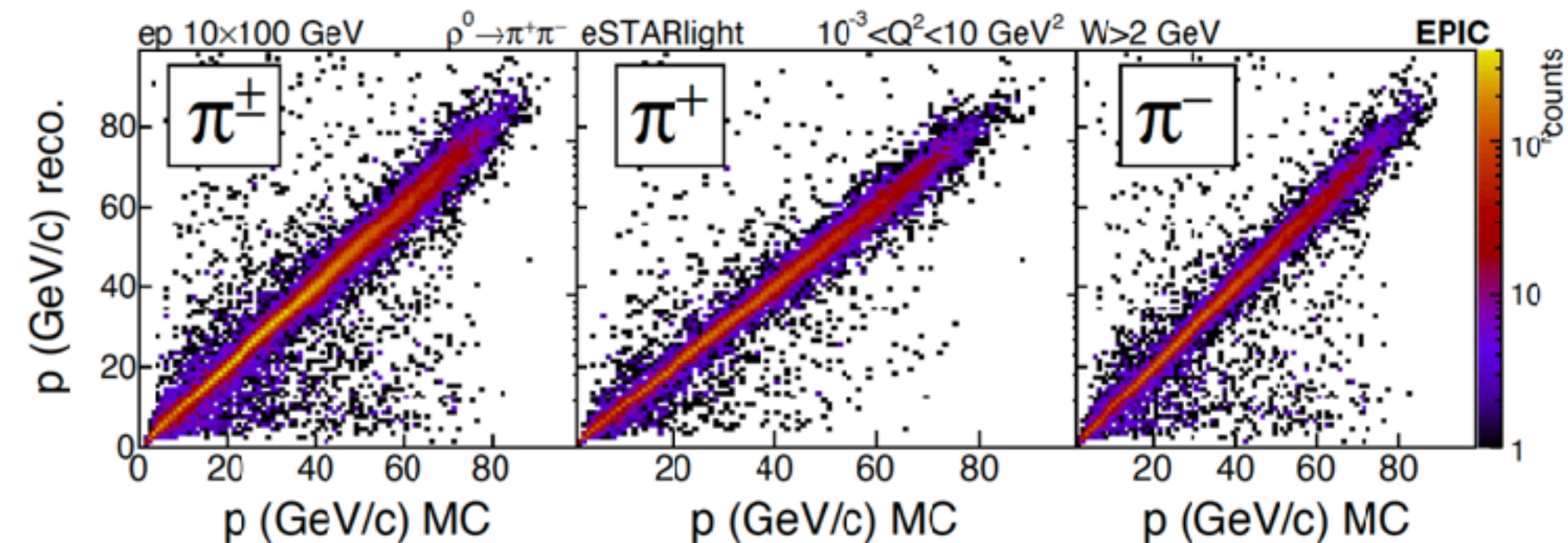
- For plots shown:
  - More details: <https://indico.bnl.gov/event/23350/contributions/91523/attachments/54487/93237/Sweger.pdf>
  - April simulation campaign
  - S3: [eictest/EPIC/RECO/24.04.0/epic\\_craterlake/EXCLUSIVE/UCHANNEL\\_RHO/10x100](https://indico.bnl.gov/event/23350/contributions/91523/attachments/54487/93237/Sweger.pdf)
  - ReconstructedChargedParticles branch
- Benchmark currently works correctly for simulation campaign files
- In progress: fix to allow GitLab CI tool to re-simulate detector response every time
- Benchmark located in
  - physics\_benchmarks repository under u\_channel\_sweger branch
  - [https://github.com/eic/physics\\_benchmarks/tree/pr/u\\_channel\\_sweger/benchmarks/u\\_rho](https://github.com/eic/physics_benchmarks/tree/pr/u_channel_sweger/benchmarks/u_rho)
  - Pull request: [https://github.com/eic/physics\\_benchmarks/pull/3](https://github.com/eic/physics_benchmarks/pull/3)



# u-Channel $\rho^0$ Benchmark for B0



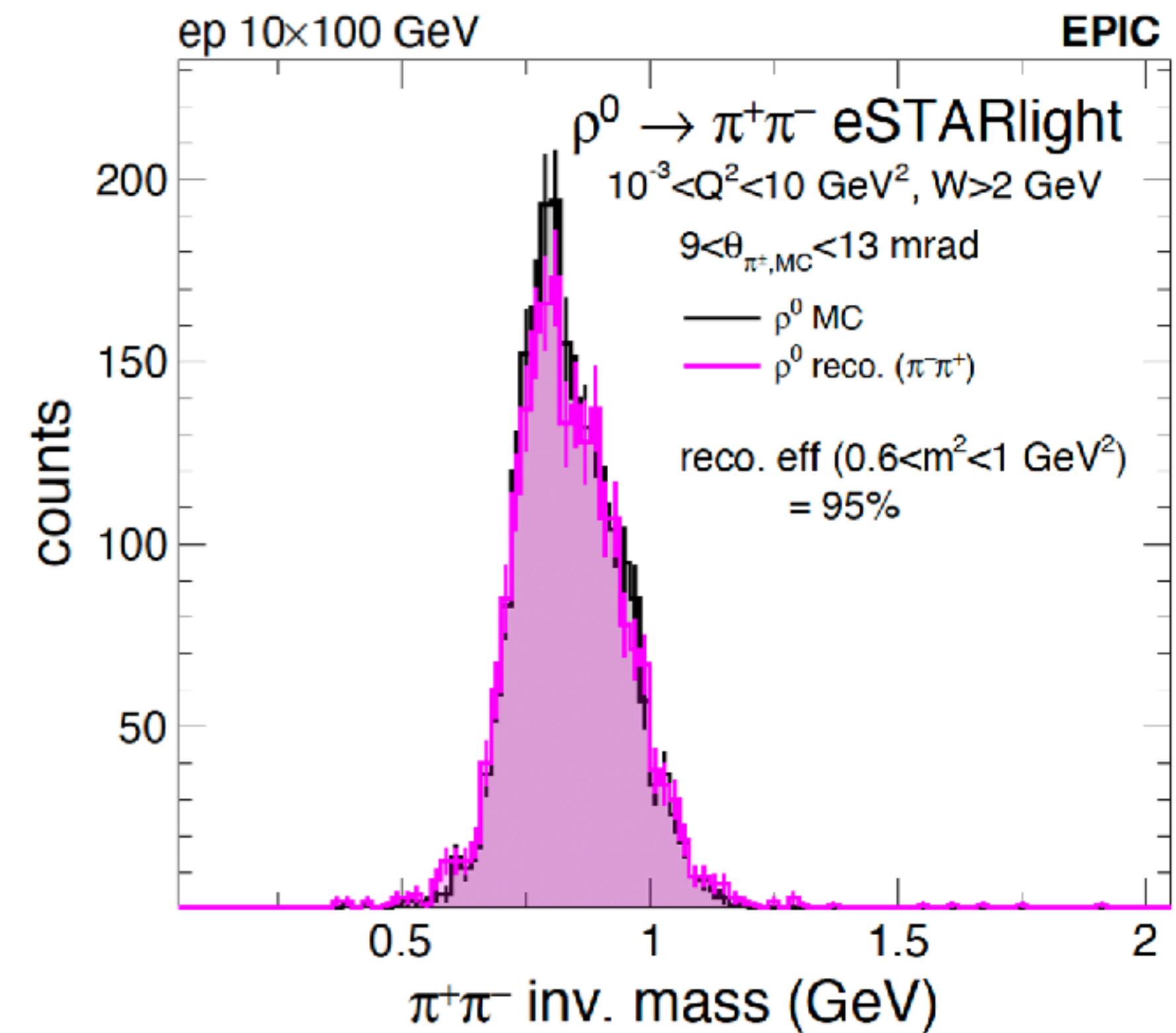
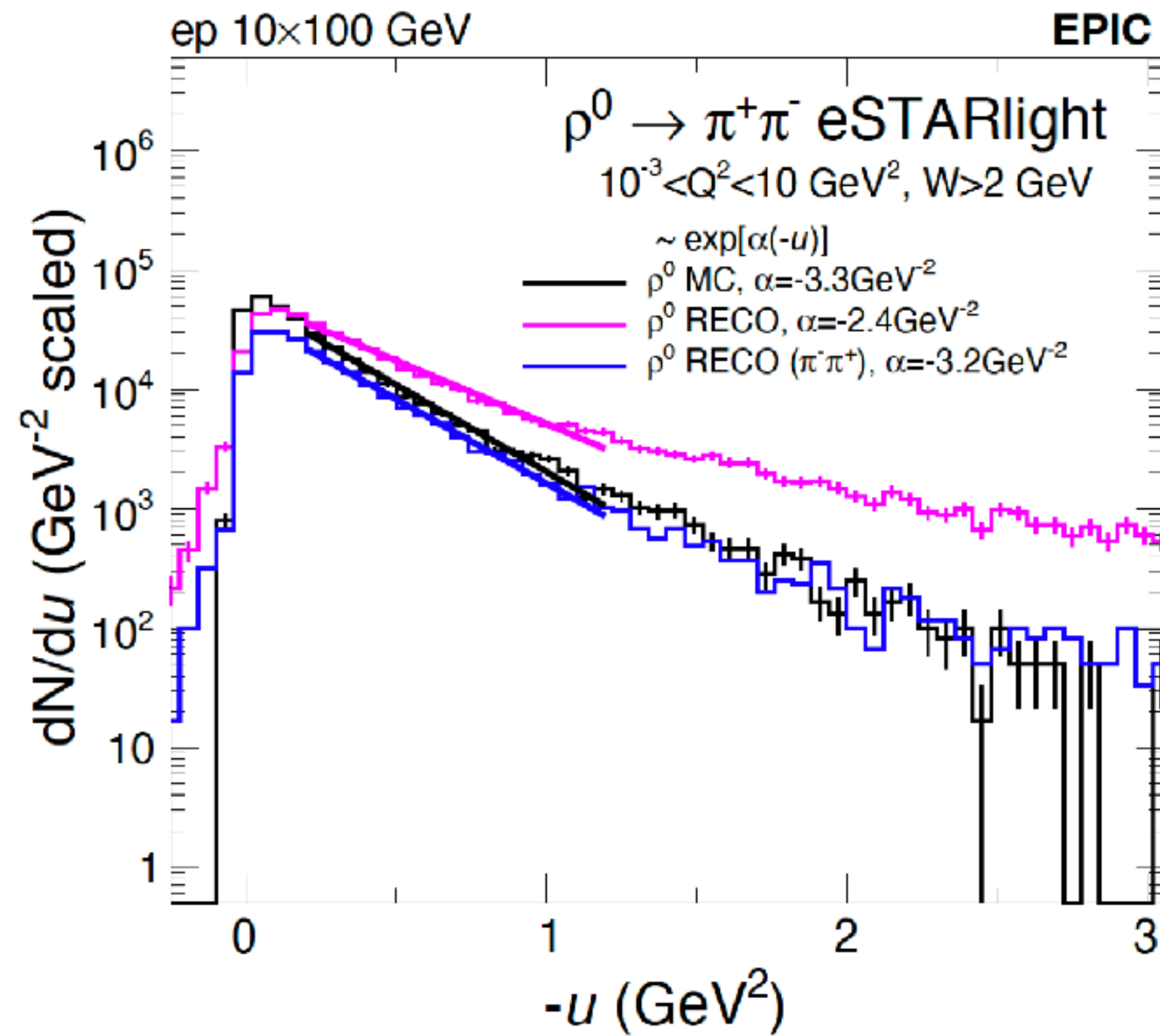
$\pi^+\pi^-$  reconstruction efficiency



$\pi^+\pi^-$  reconstruction quality



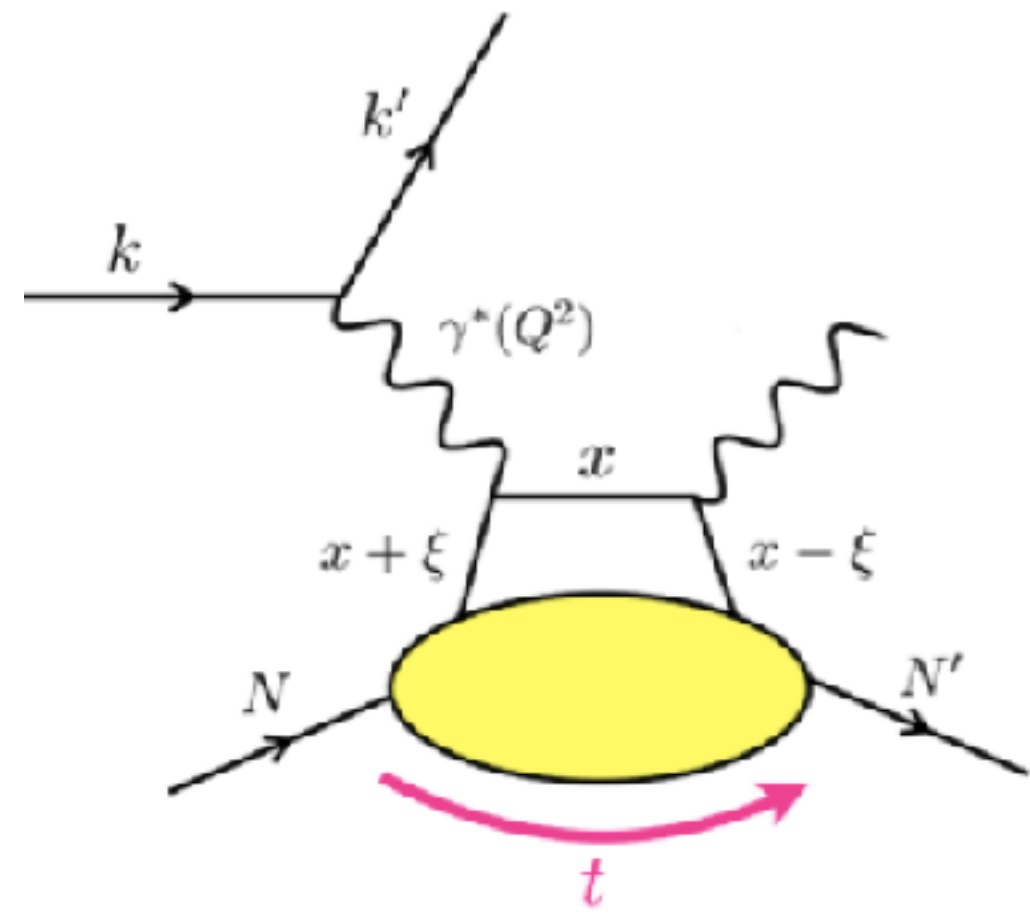
# u-Channel $\rho^0$ Benchmark for B0



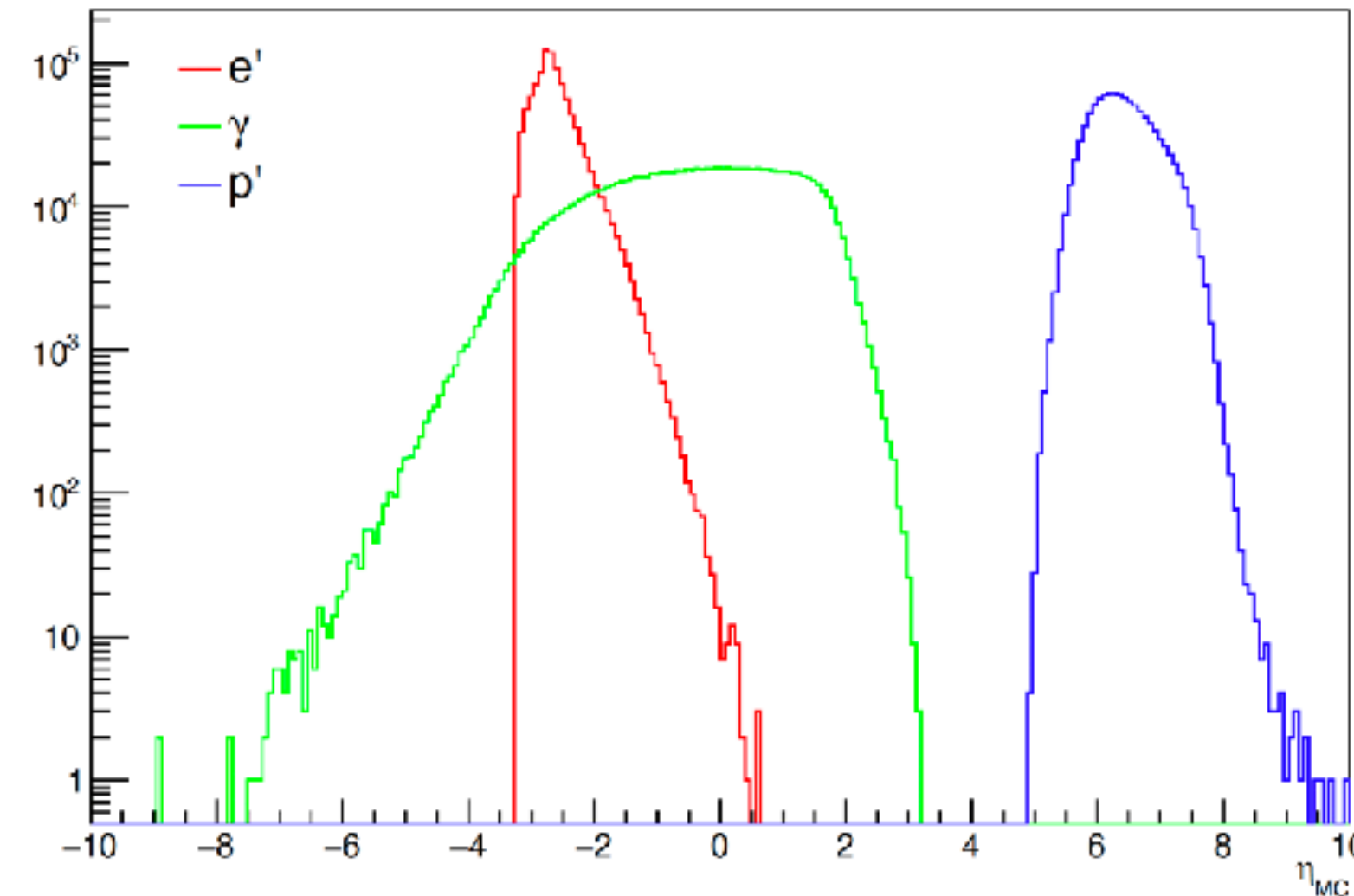
- u-channel cross-section slope reconstruction

- Status flag for  $\rho^0$  reconstruction efficiency
- Bad status flag raised if efficiency drops to  $< 90\%$
- Status procedure detailed in [common\\_bench](#) repo
- Benchmark status flag works and is propagated to last pipeline step

# DVCS ep



10 x 100 Generated



- Nucleon tomography, origin of mass and spin
- Electron PID crucial and FF region critical for p'

- Development of analysis underway

• **Oliver Jevons (University of Glasgow)**

- ReconstructedParticles collection

- High acceptance and 10x100 ep setting shown

- Nb 24.04.0 was missing RP (restored in 24.05.0)

- 24.05.0 and 24.06.0 analysis originally missing p' in B0 due to new PID implementation

- No particles with PDG 2212 in B0 due to lack of PID system

- RP still uses truth PID

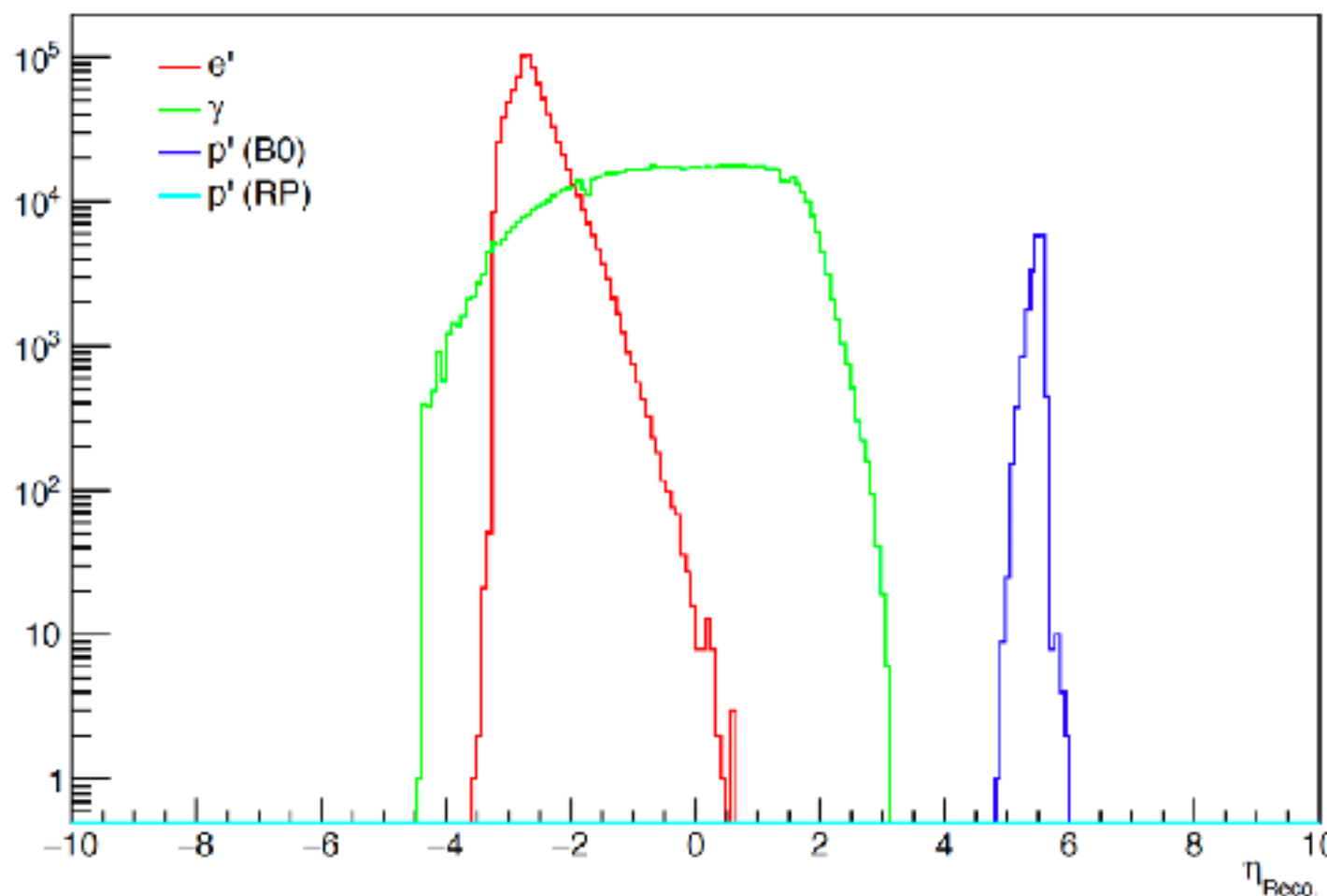
- Need to figure out how to overcome this for analysis

- Initial look at lower stats sample from 24.06.0 shown

- Reconstructed p' in B0 identified by recorded mass and charge of track

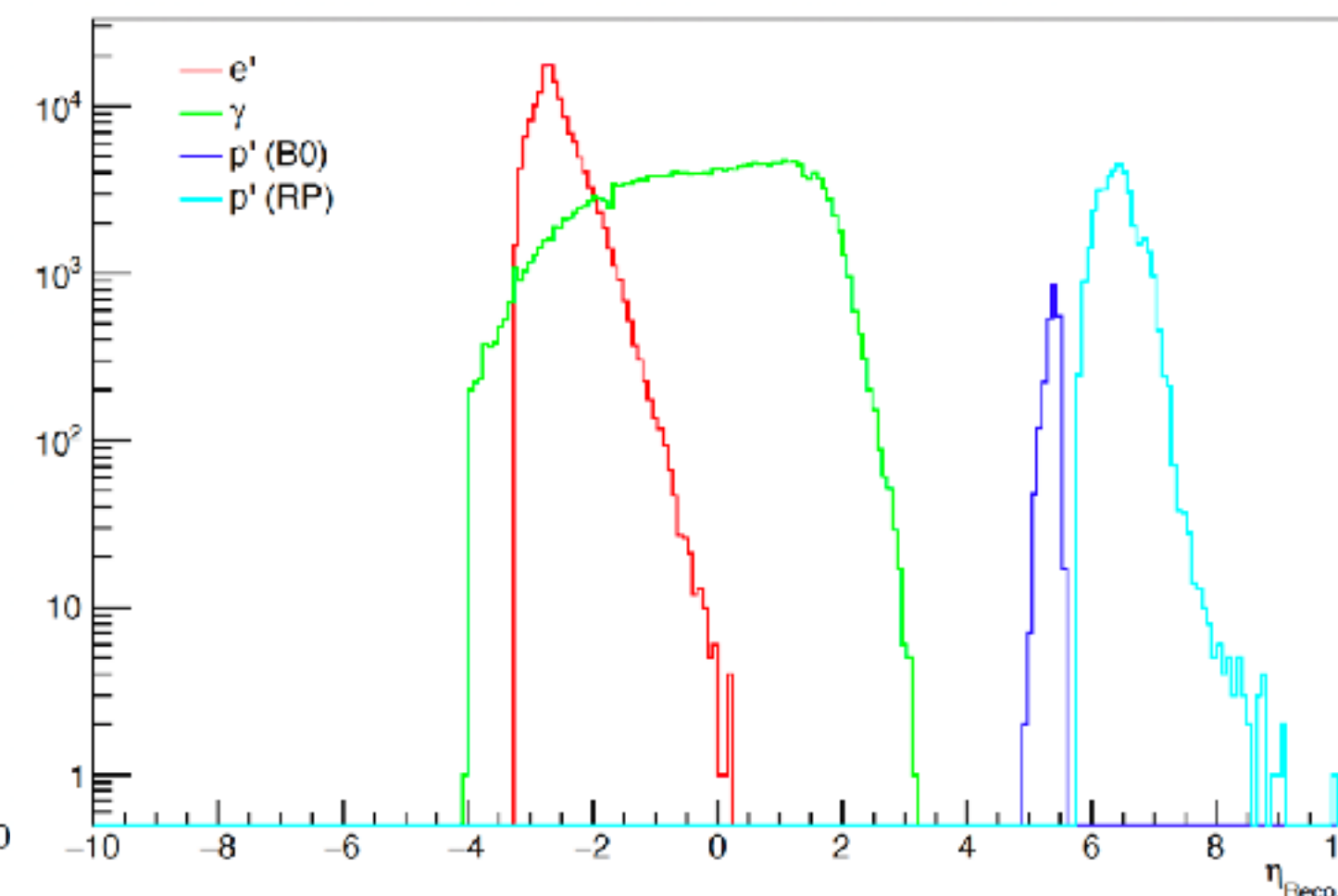
- Electrons/photons use identified PID value

- Can compare with 24.04.0 for electron finder/PID



10 x 100, monthly production 24.04.0

(Truth PID)

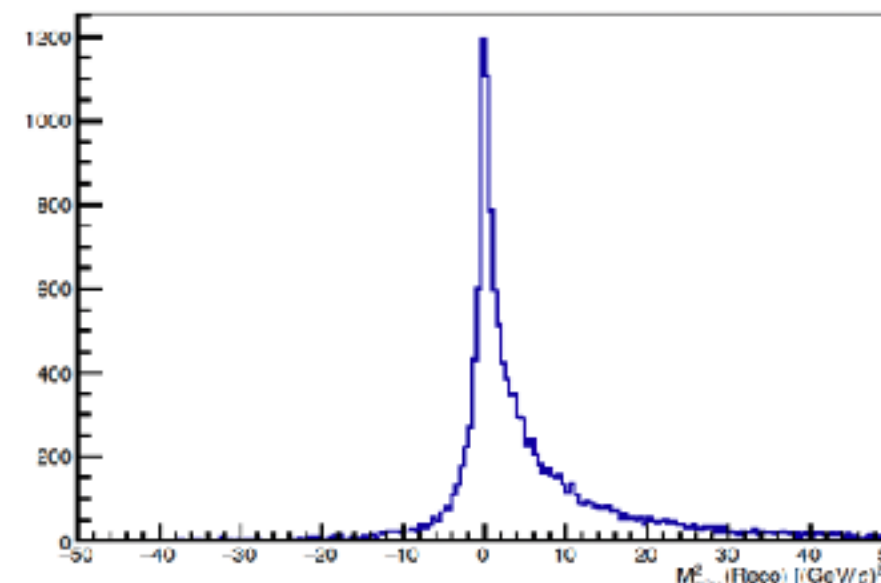
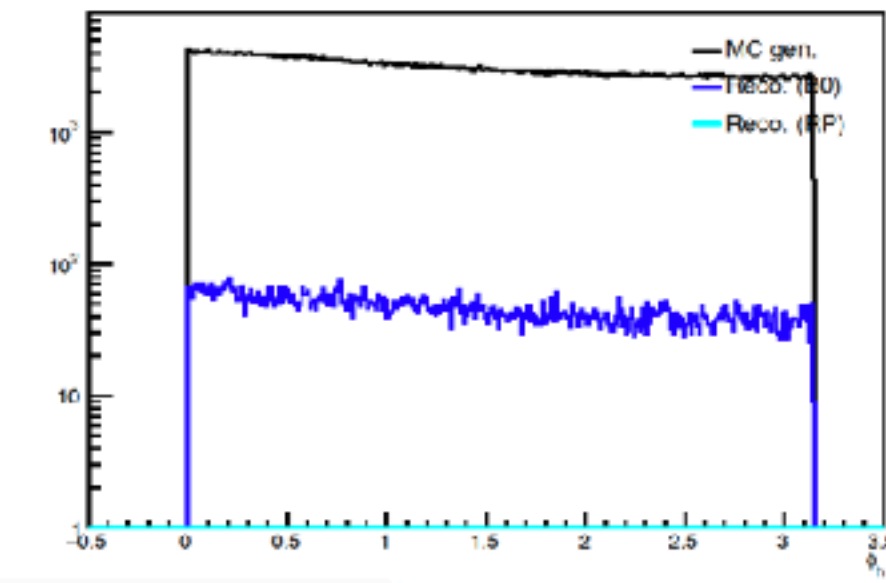
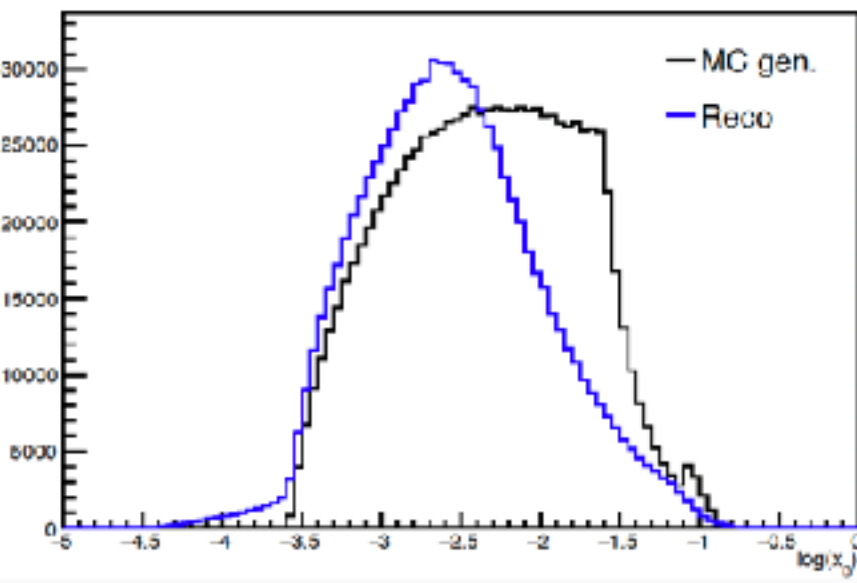
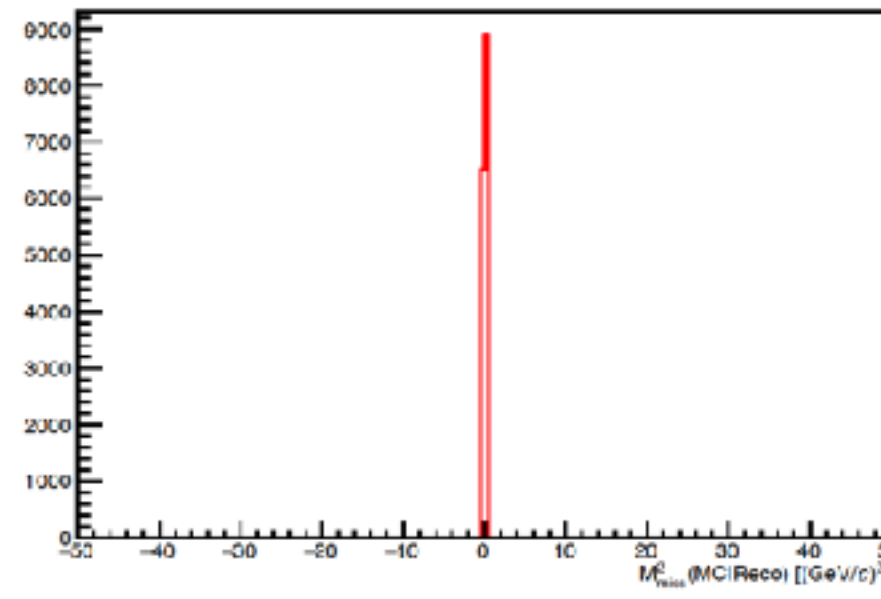
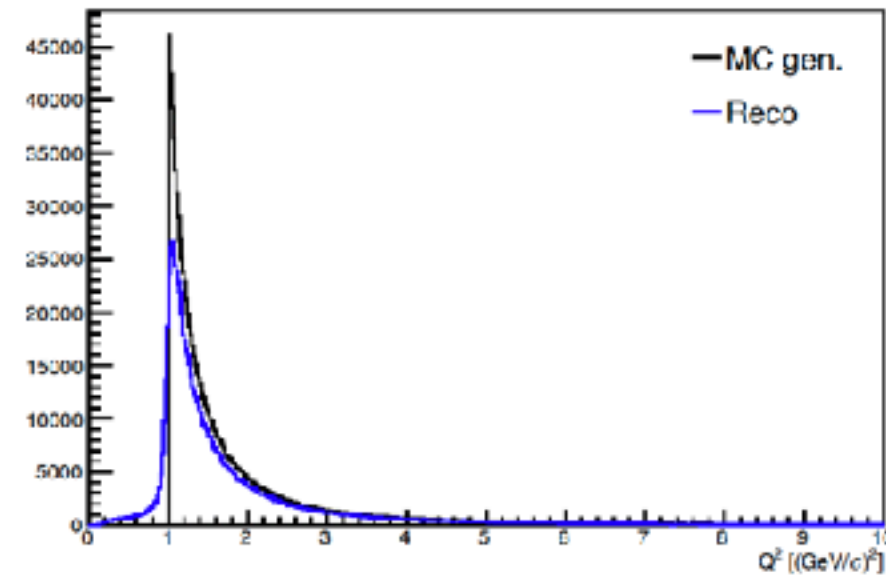
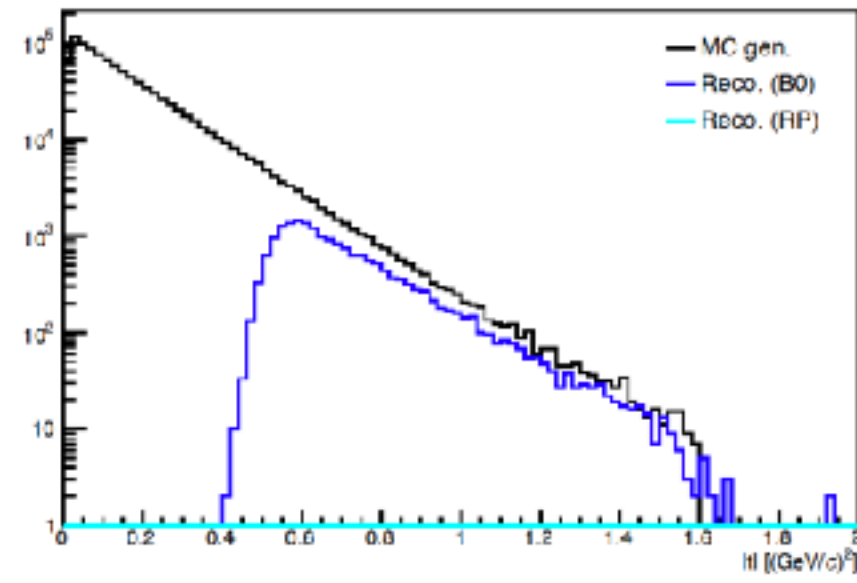


10 x 100, monthly production 24.06.0

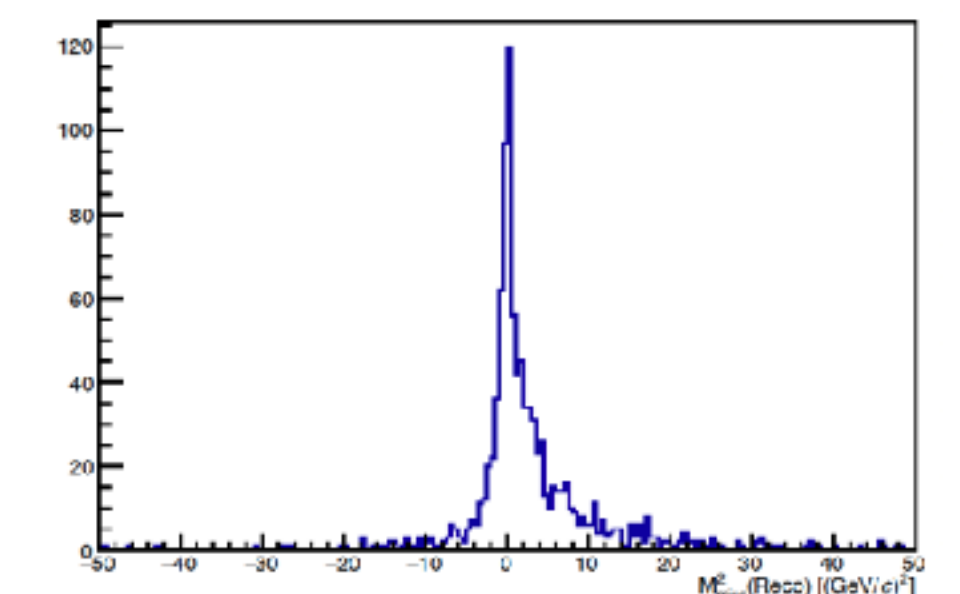
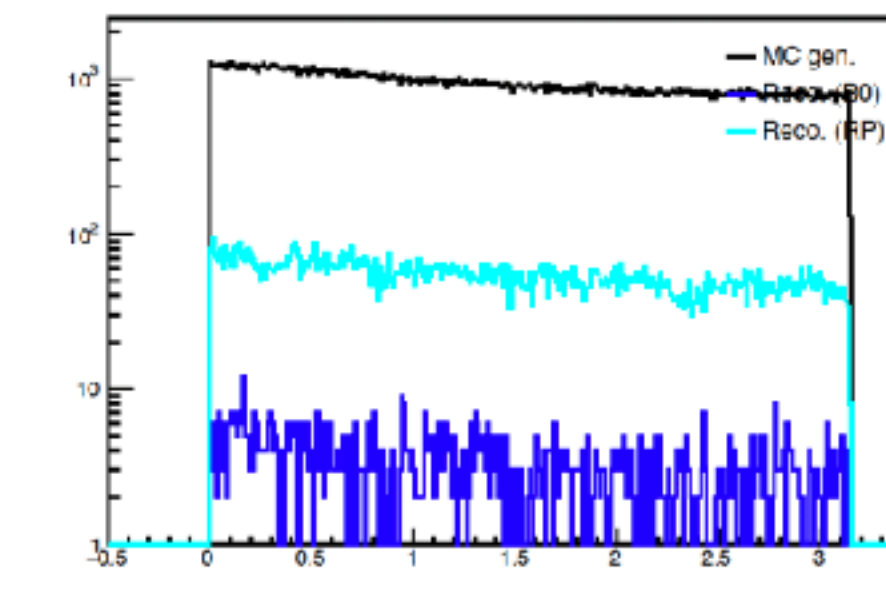
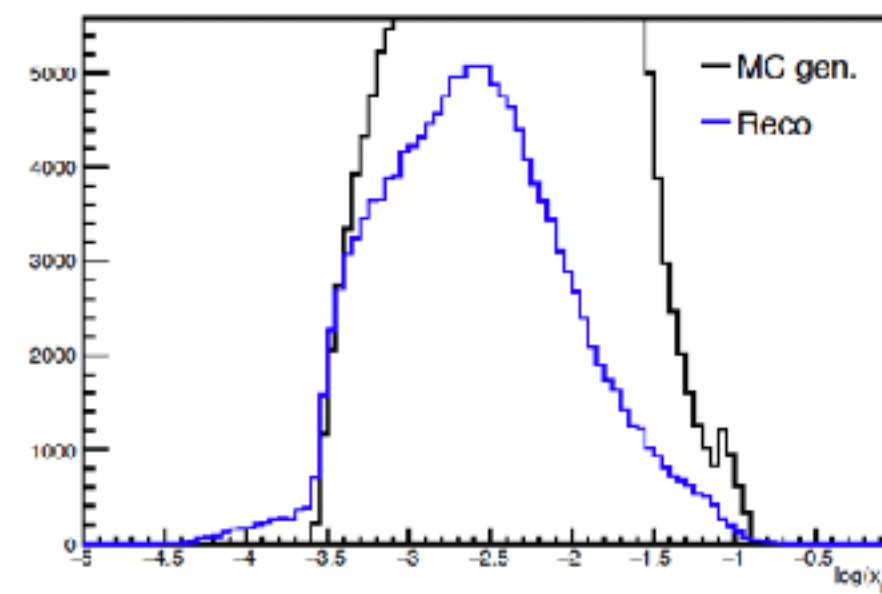
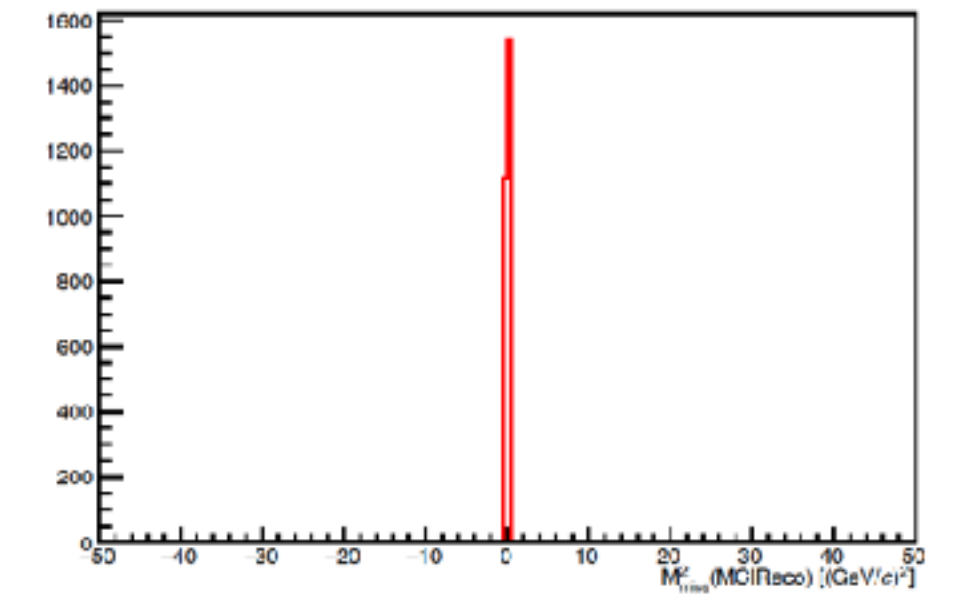
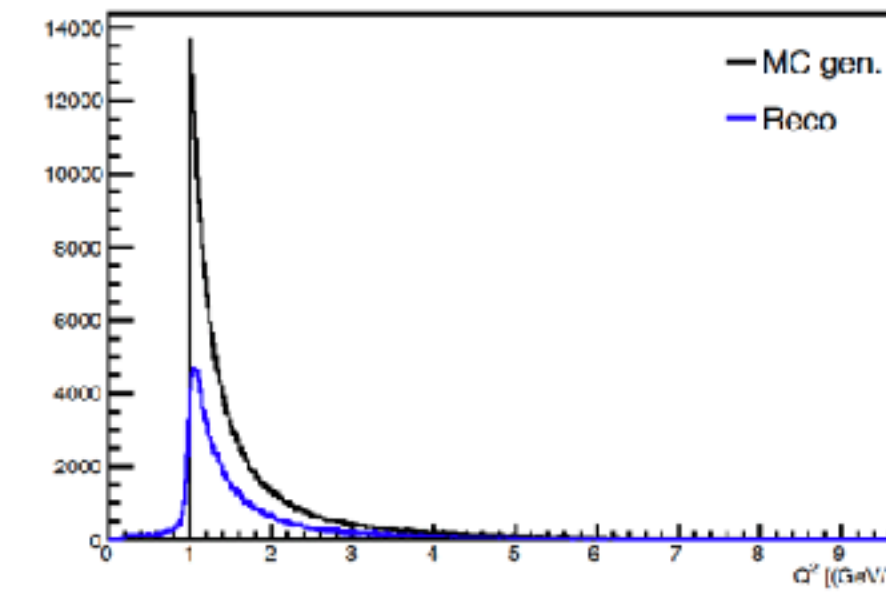
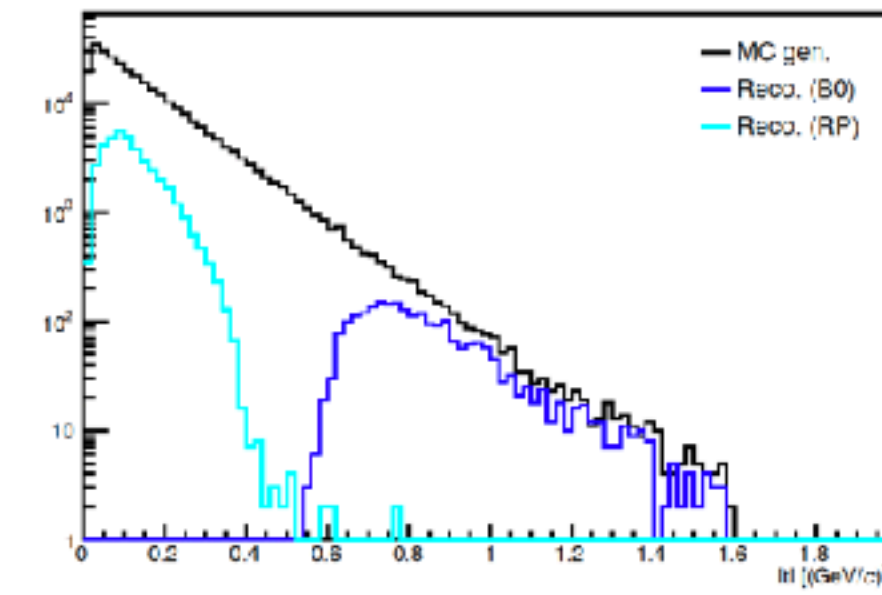


10 x 100, monthly production 24.04.0

# DVCS ep

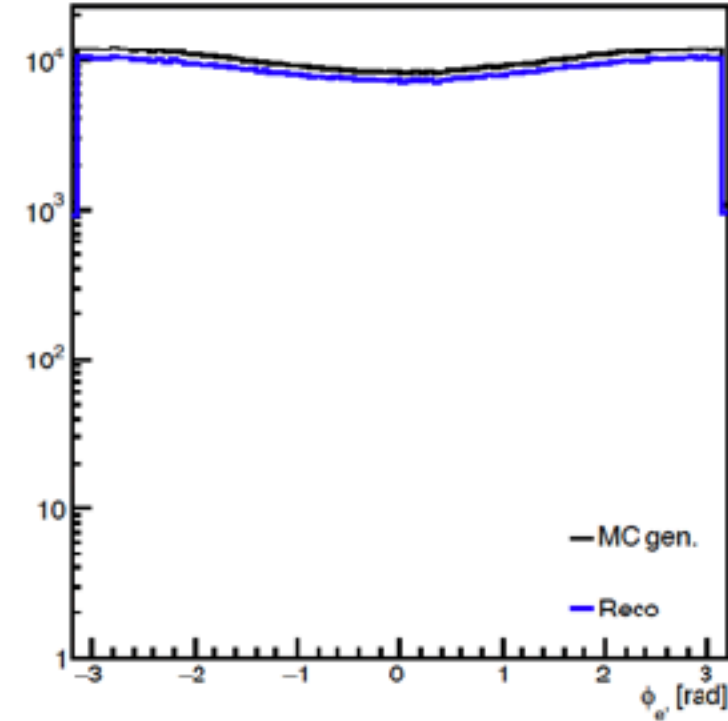
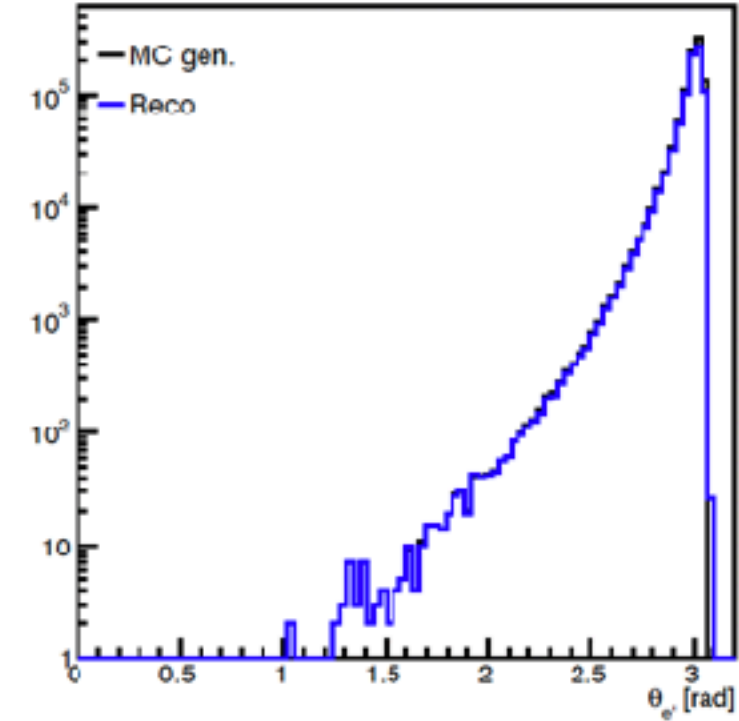
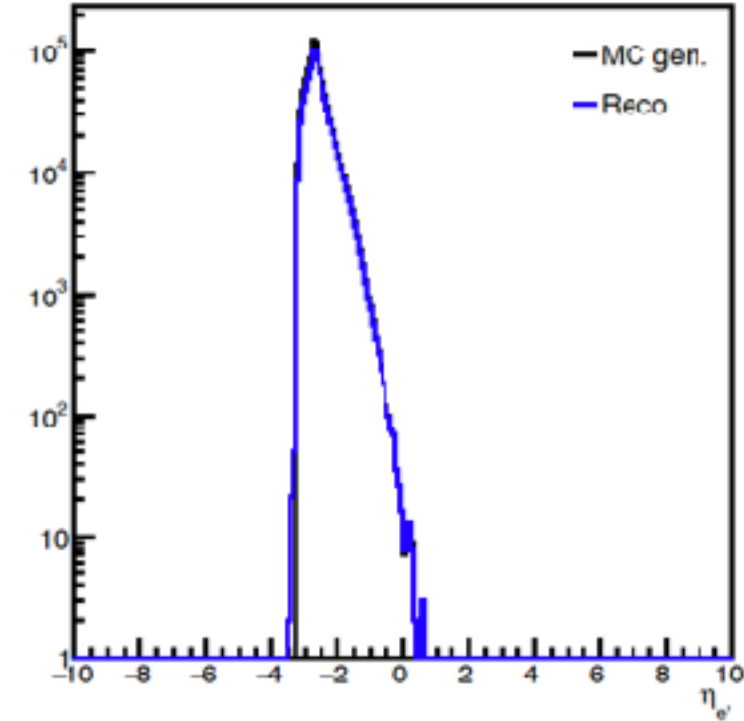


10 x 100, monthly production 24.06.0



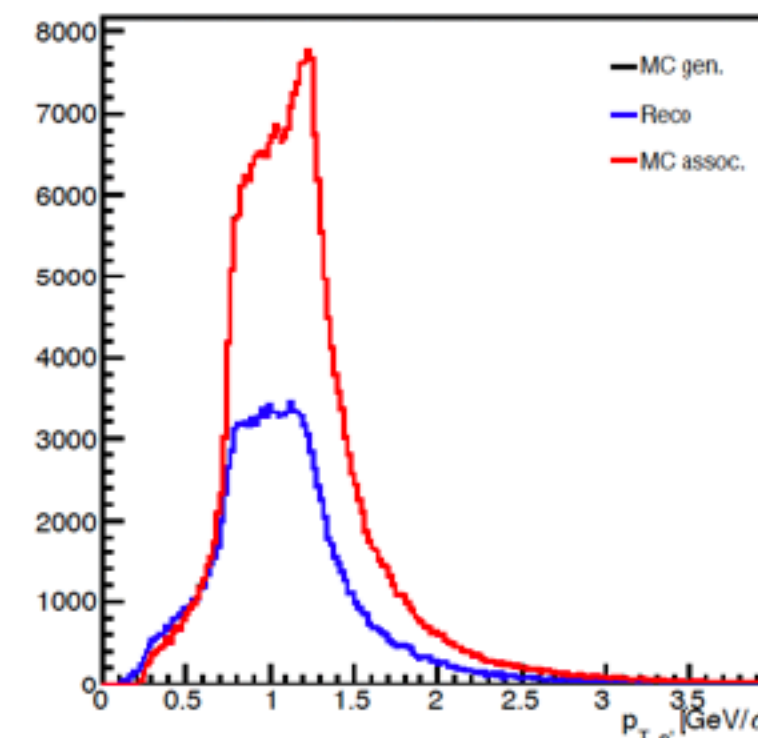
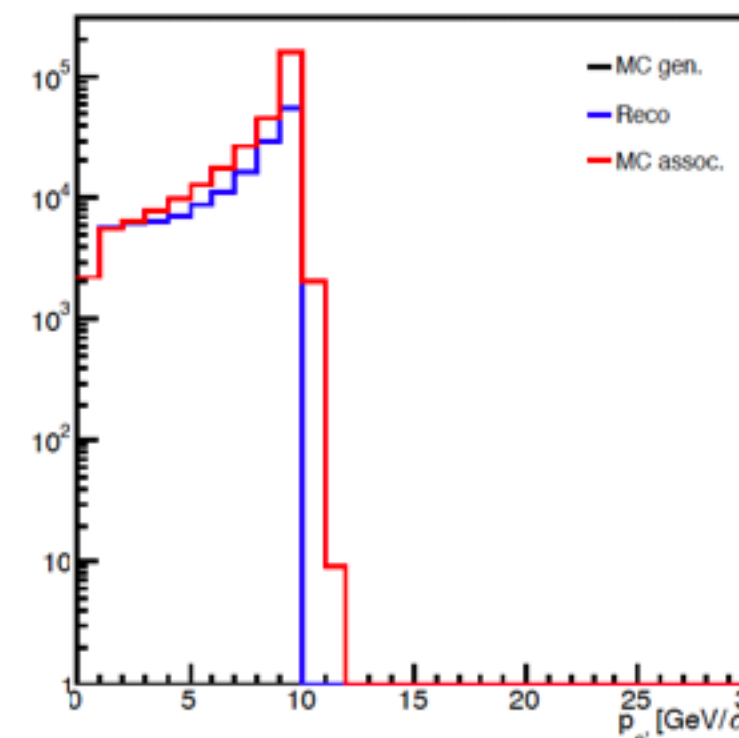
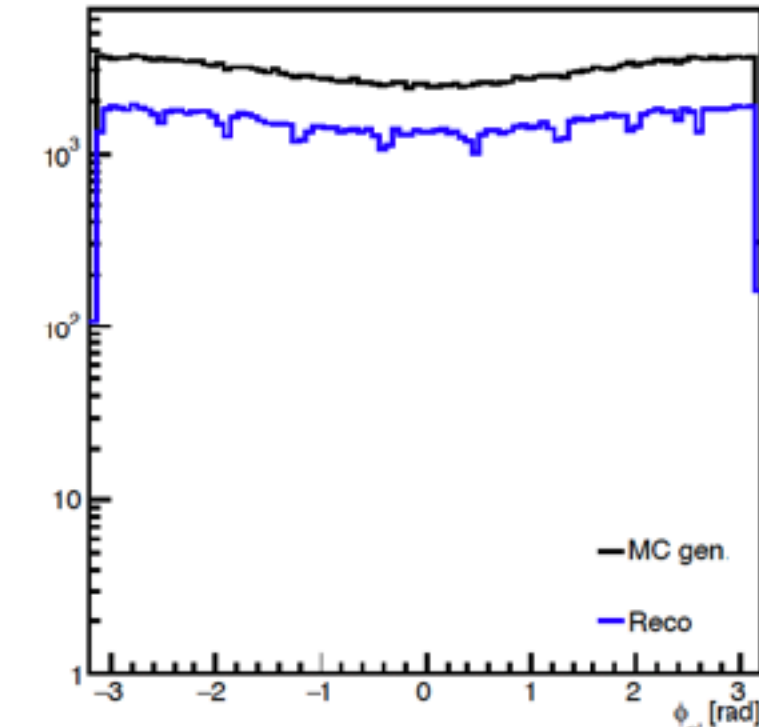
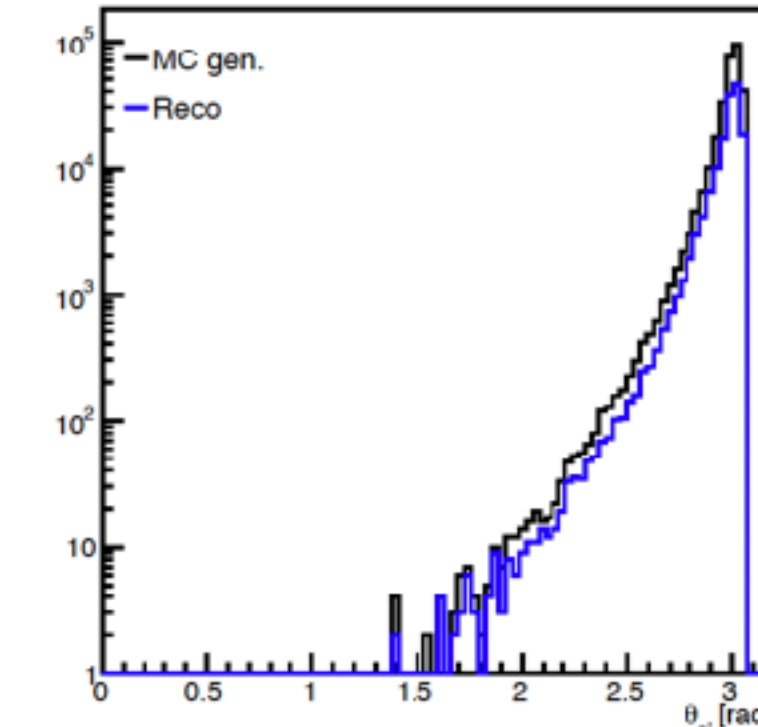
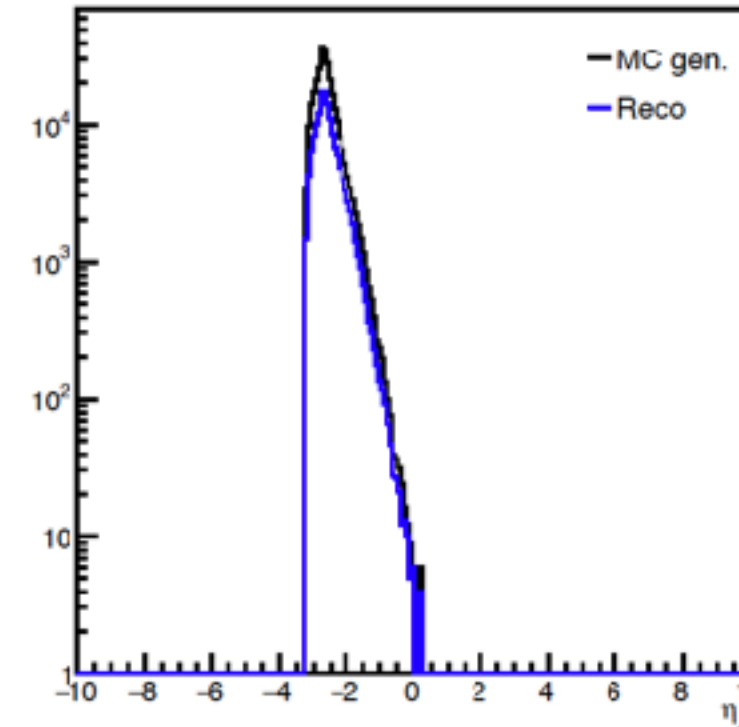
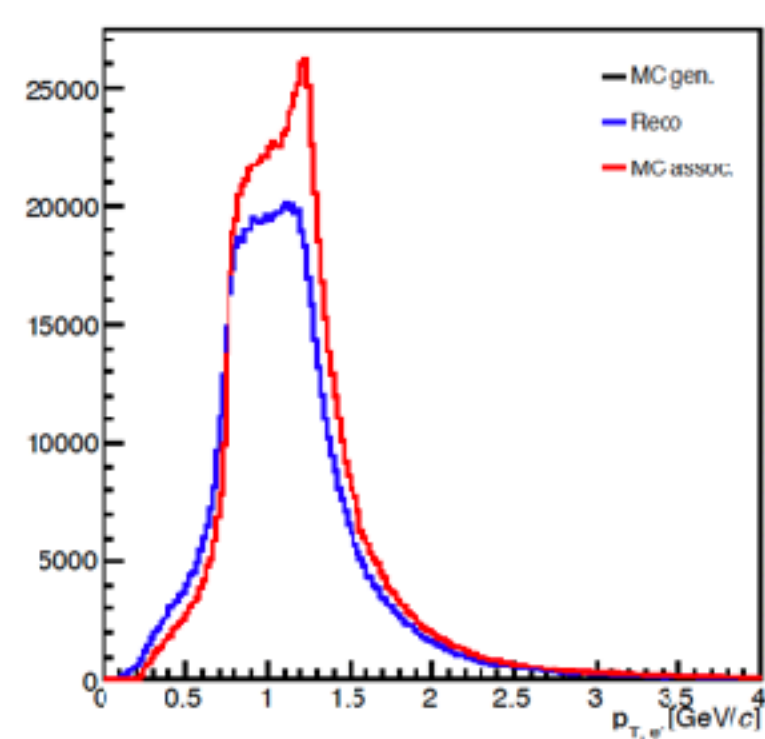
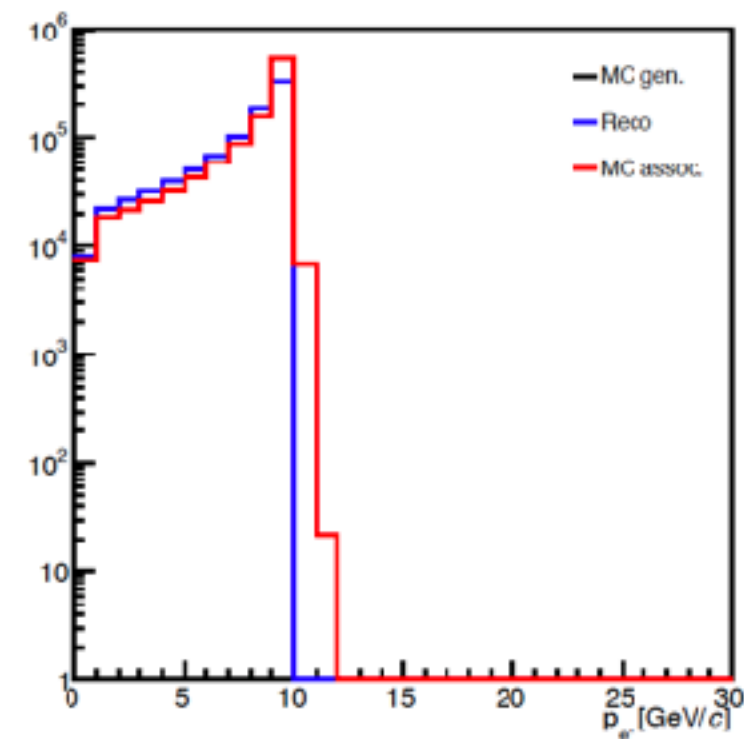
# DVCS ep

10 x 100, monthly production 24.04.0



Final state electron

10 x 100, monthly production 24.06.0



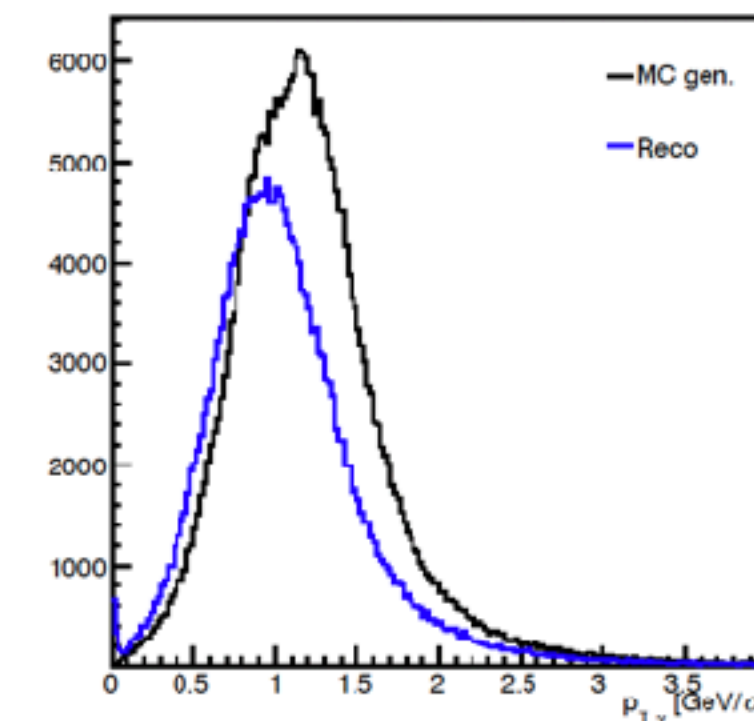
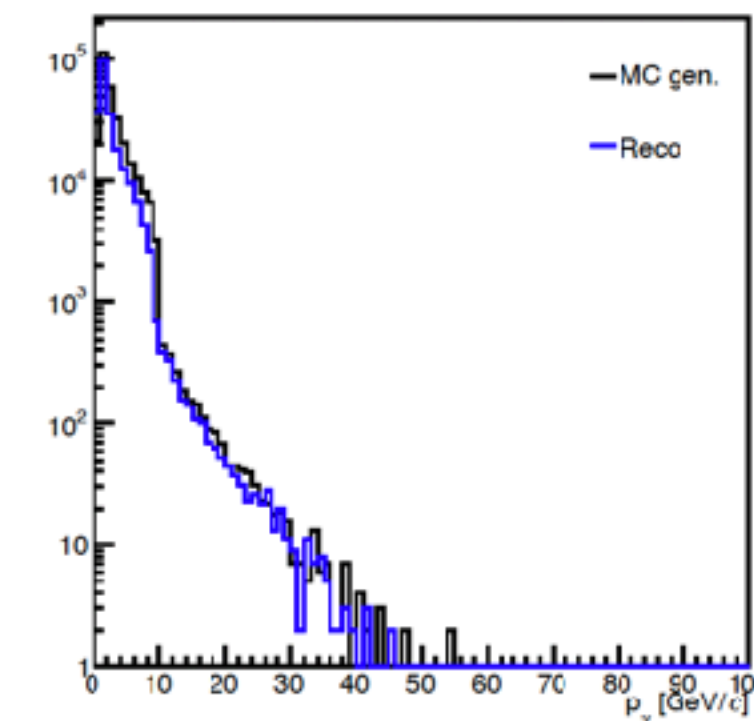
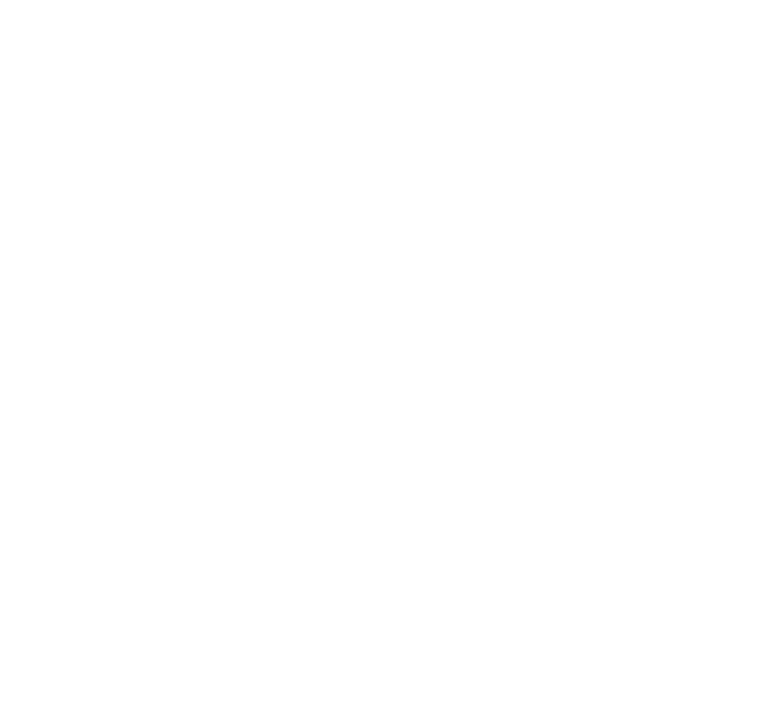
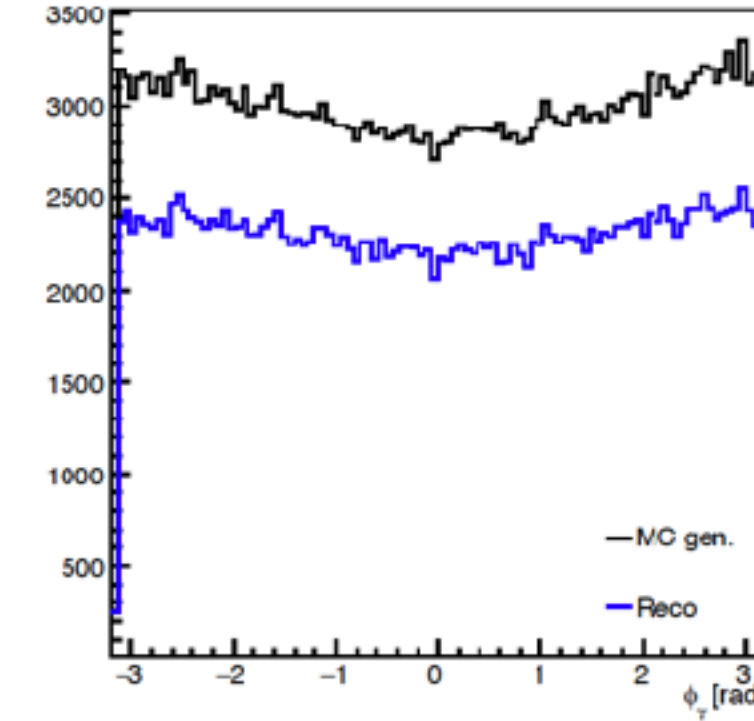
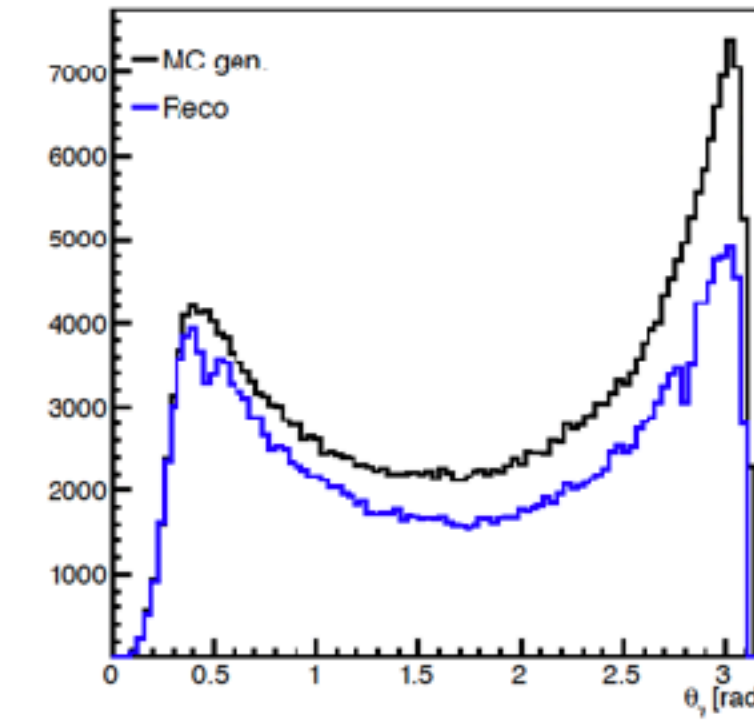
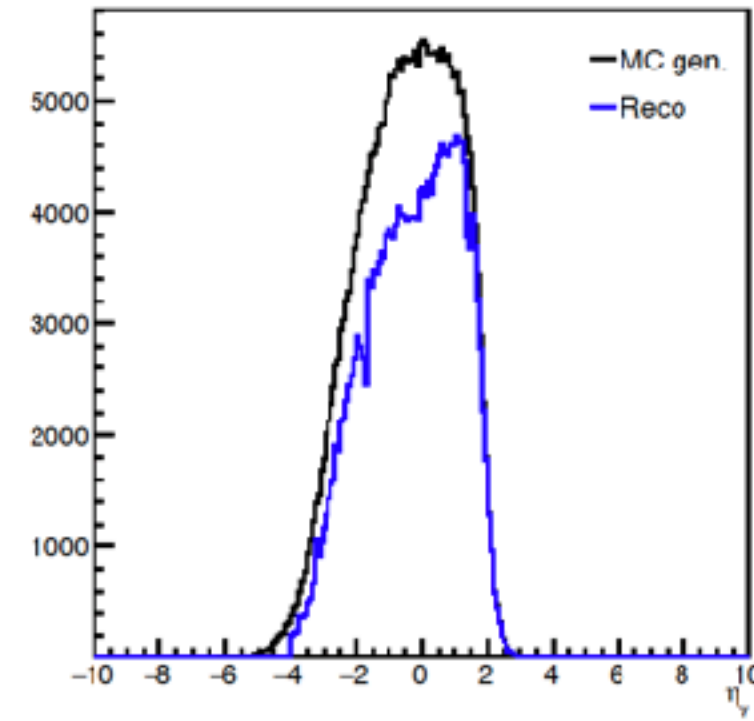
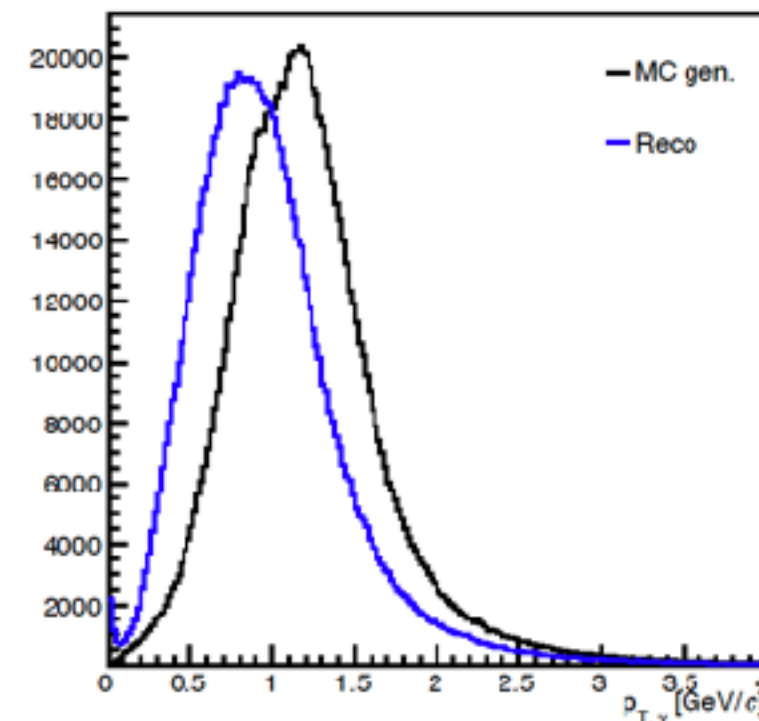
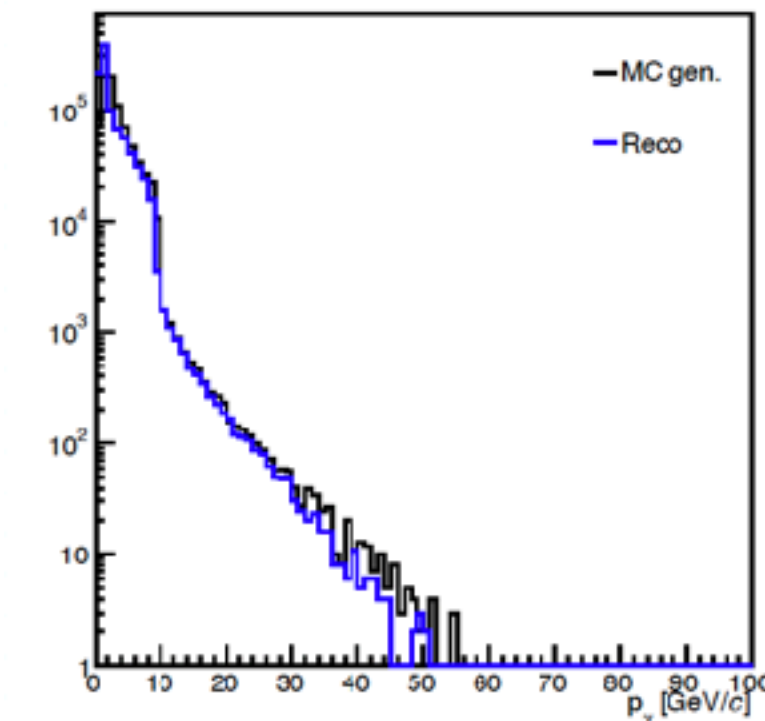
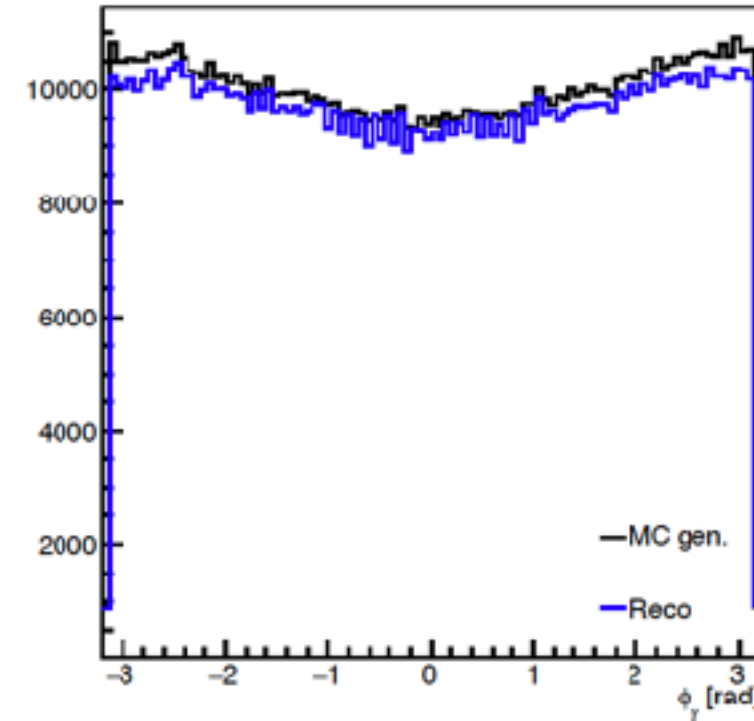
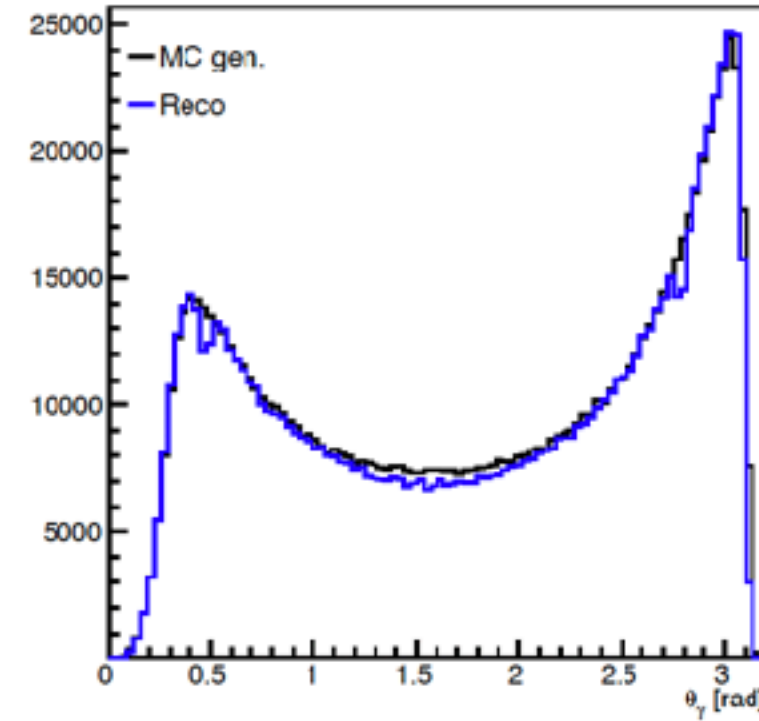
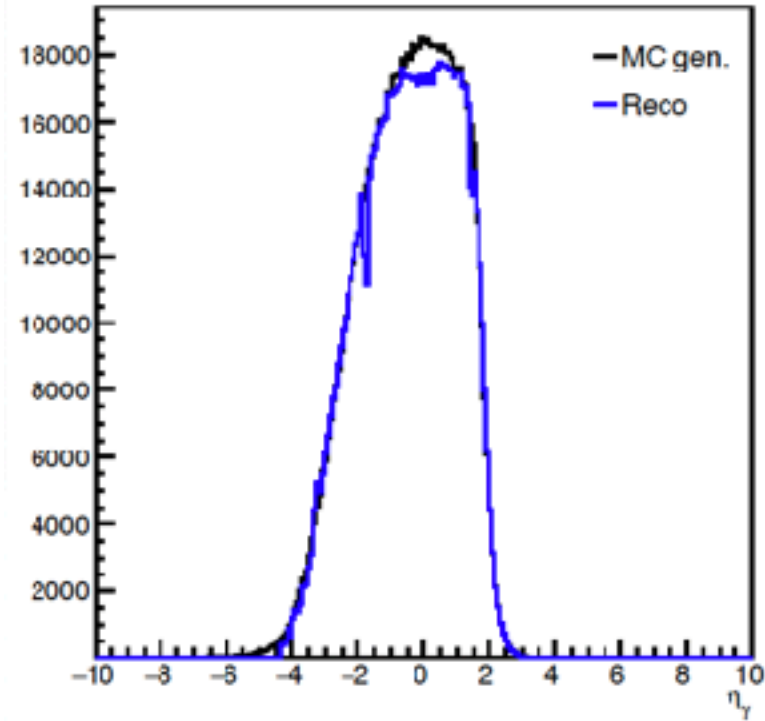


# DVCS ep

10 x 100, monthly production 24.04.0

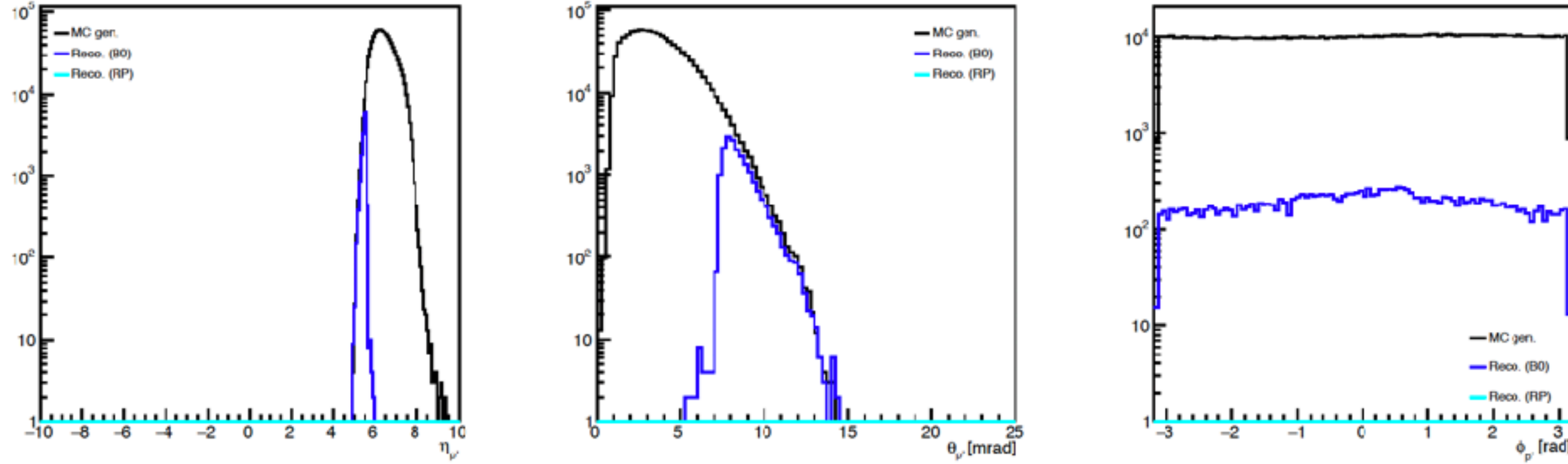
Final state photon

10 x 100, monthly production 24.06.0



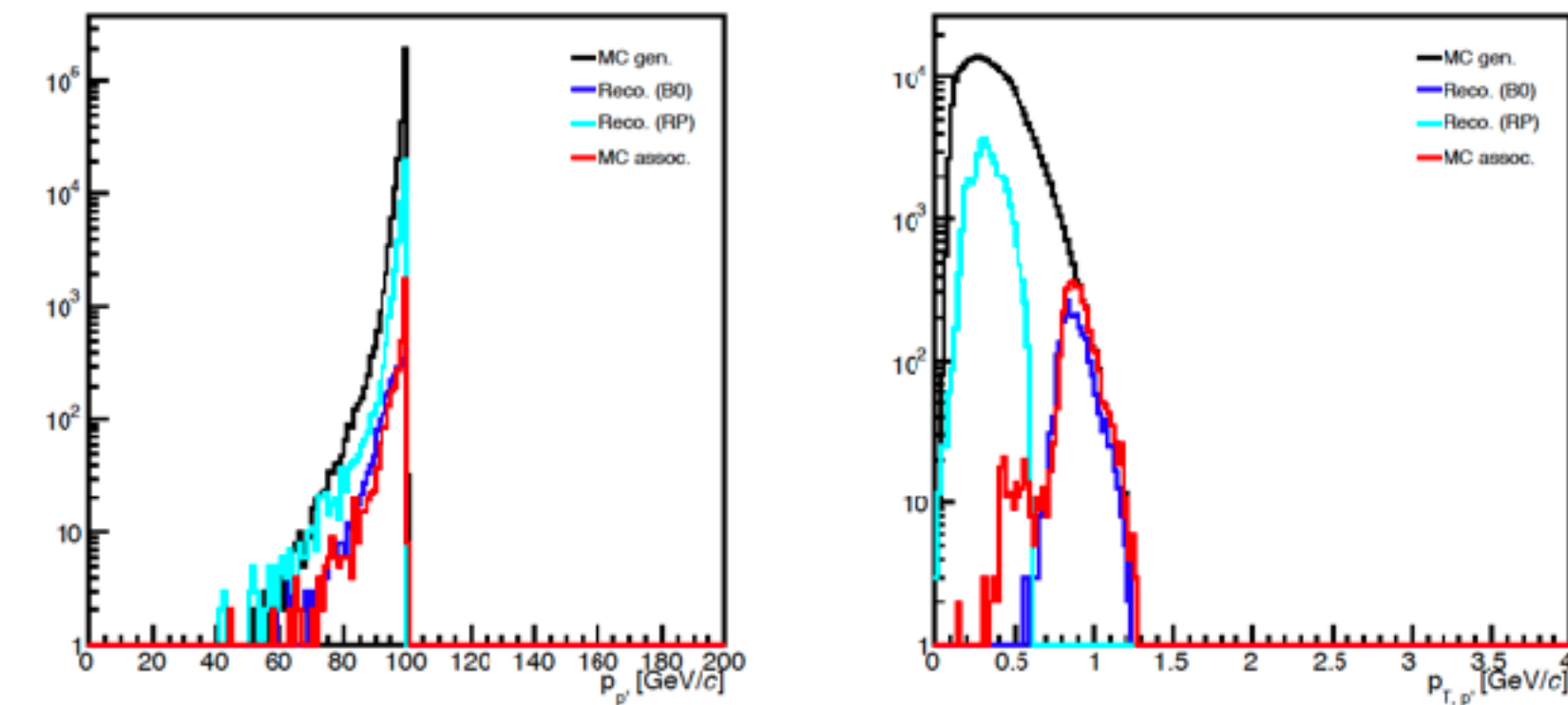
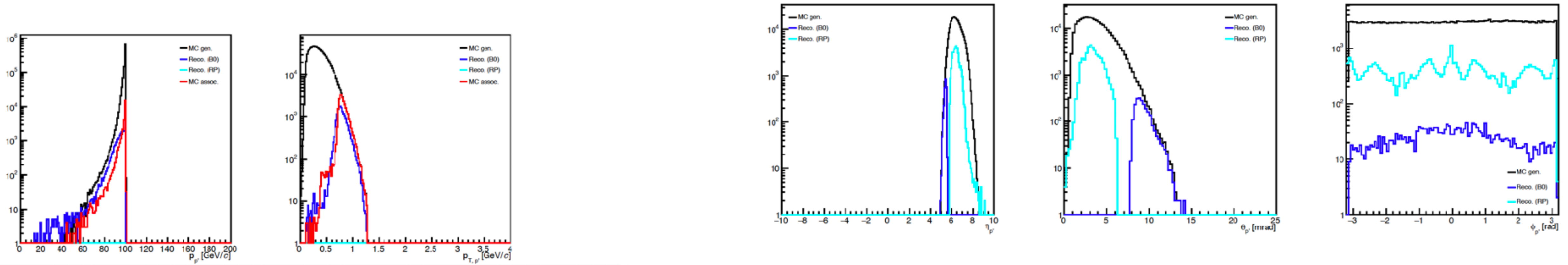
# DVCS ep

10 x 100, monthly production 24.04.0

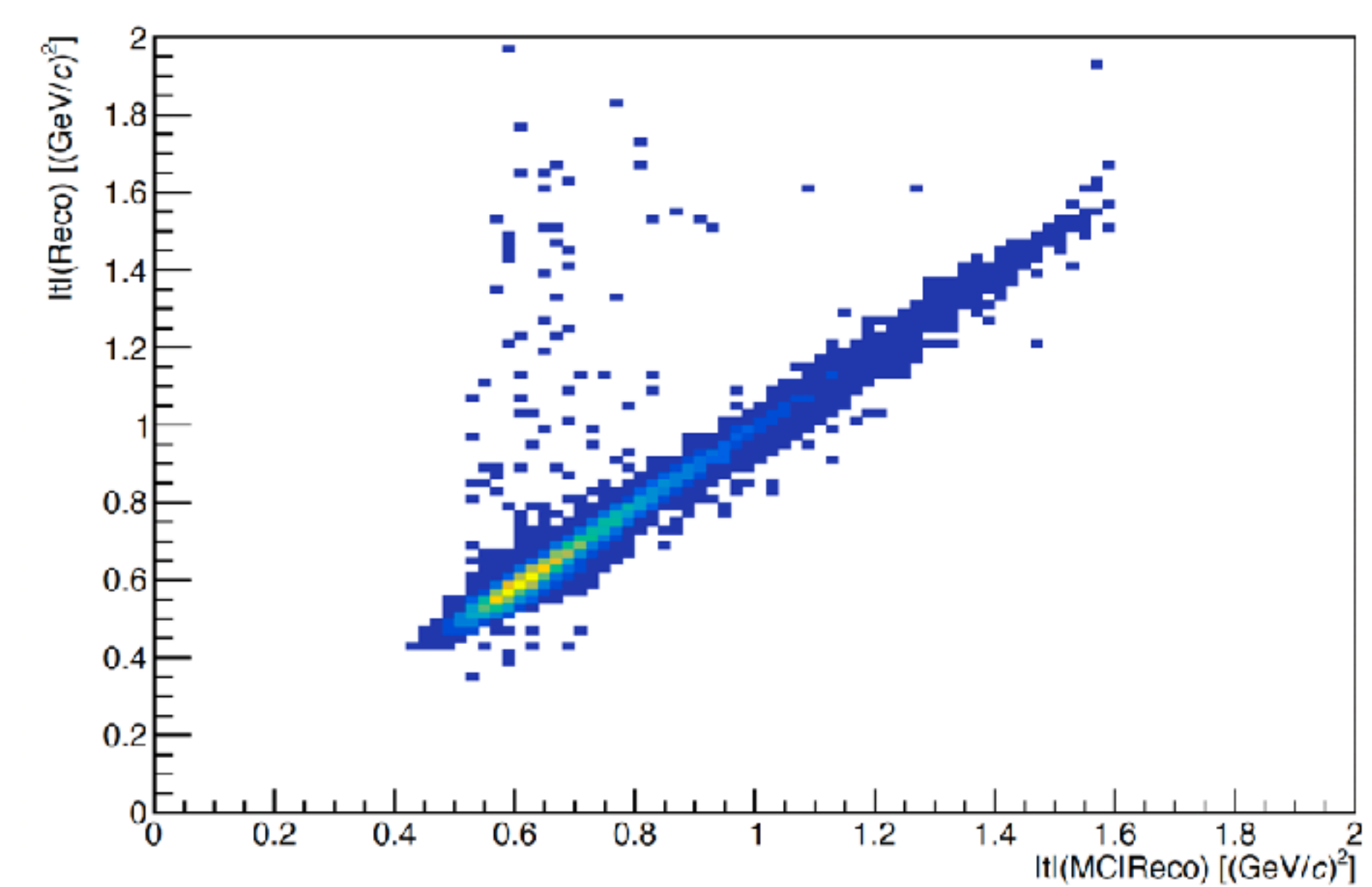
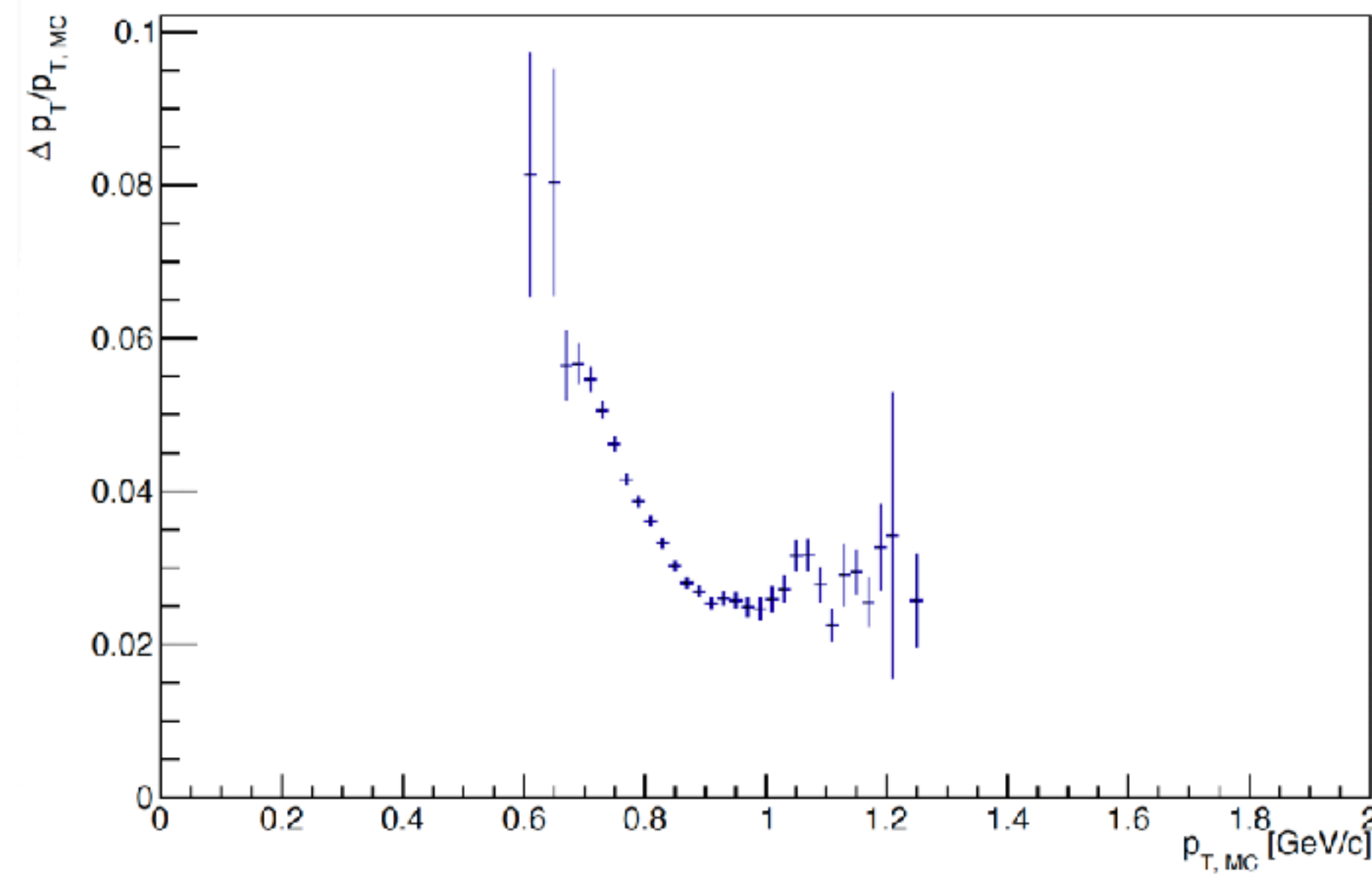
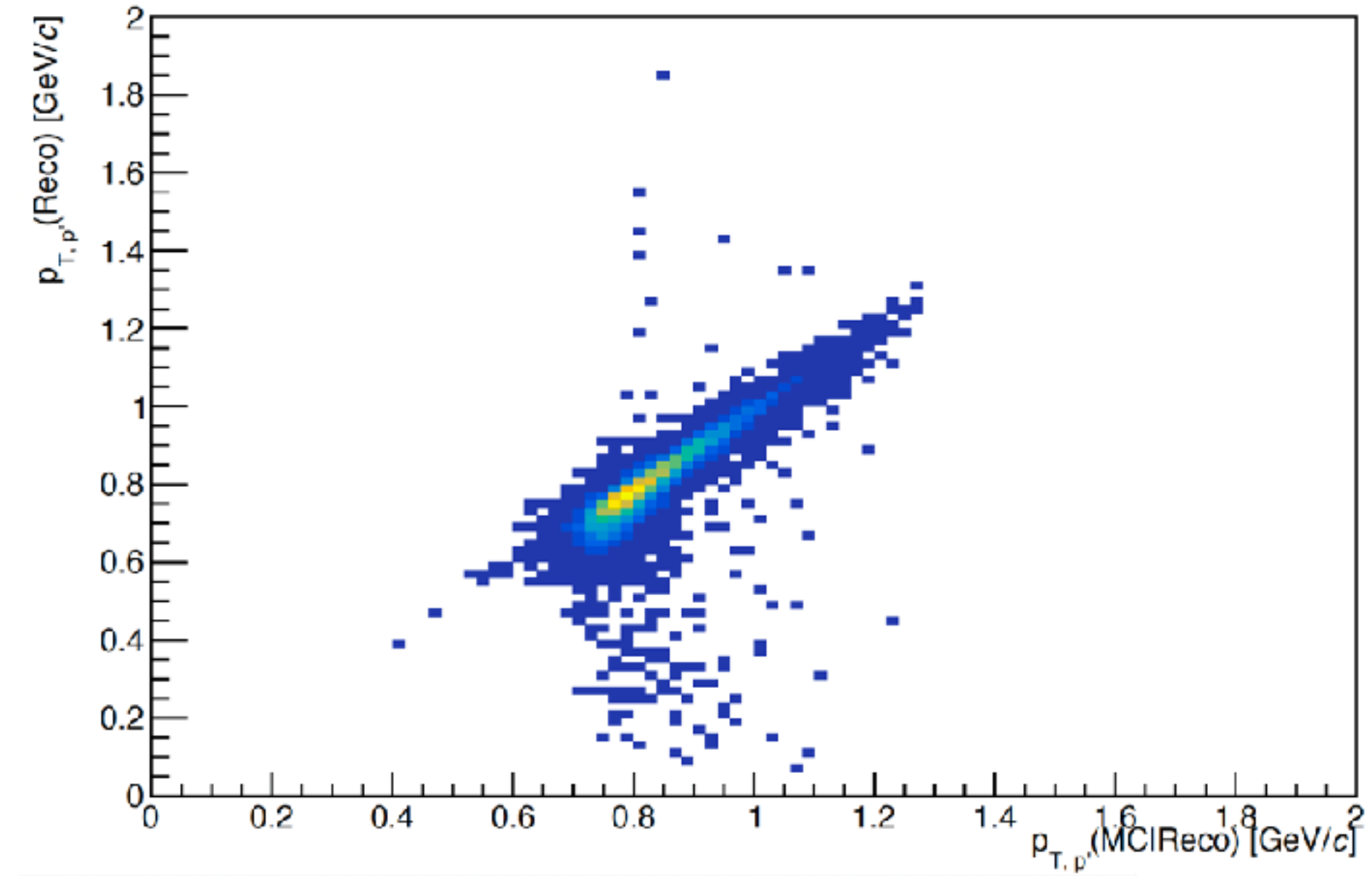
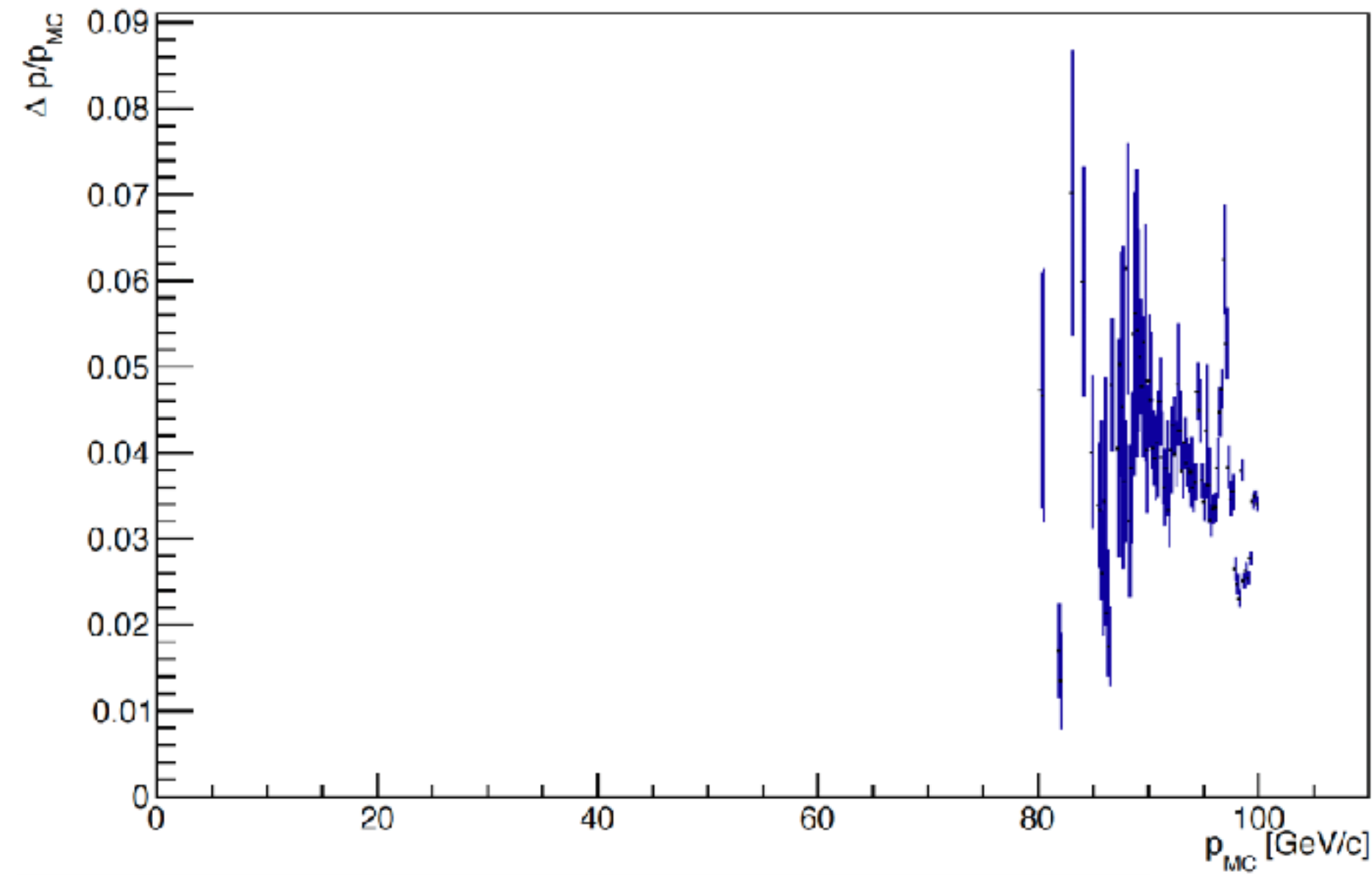


Final state proton

10 x 100, monthly production 24.06.0

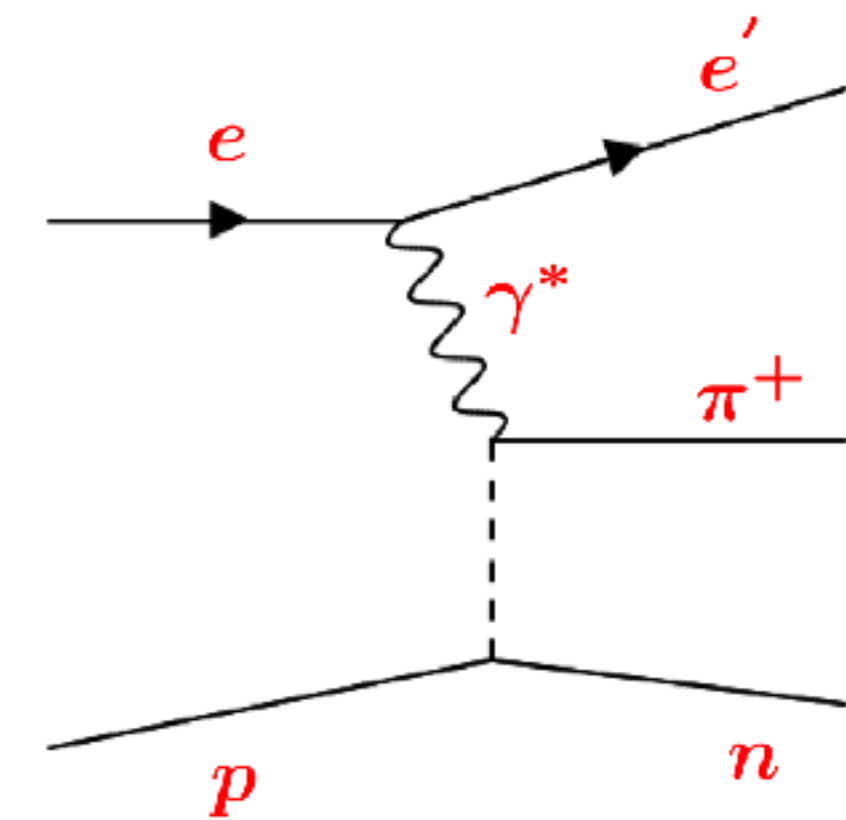




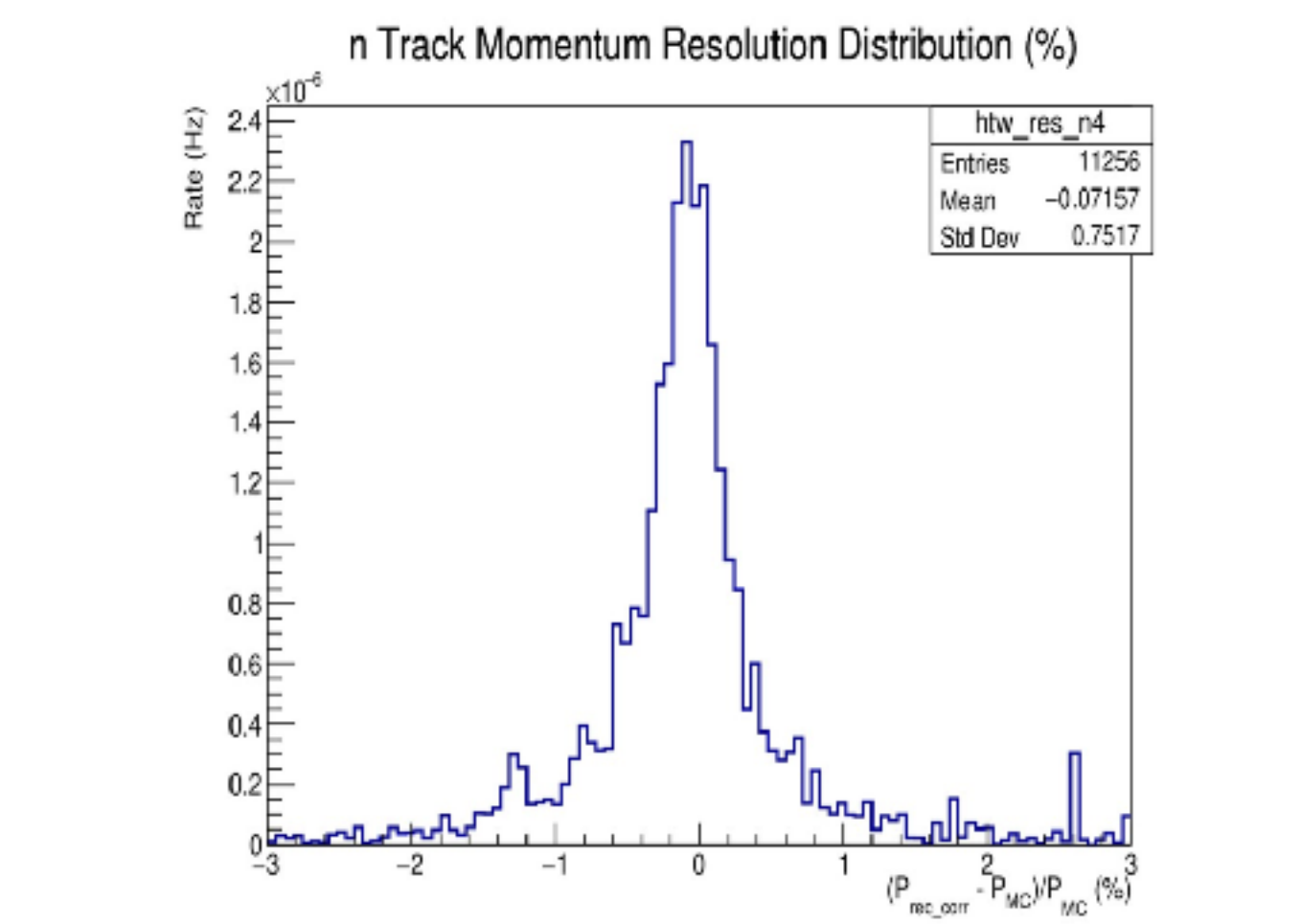
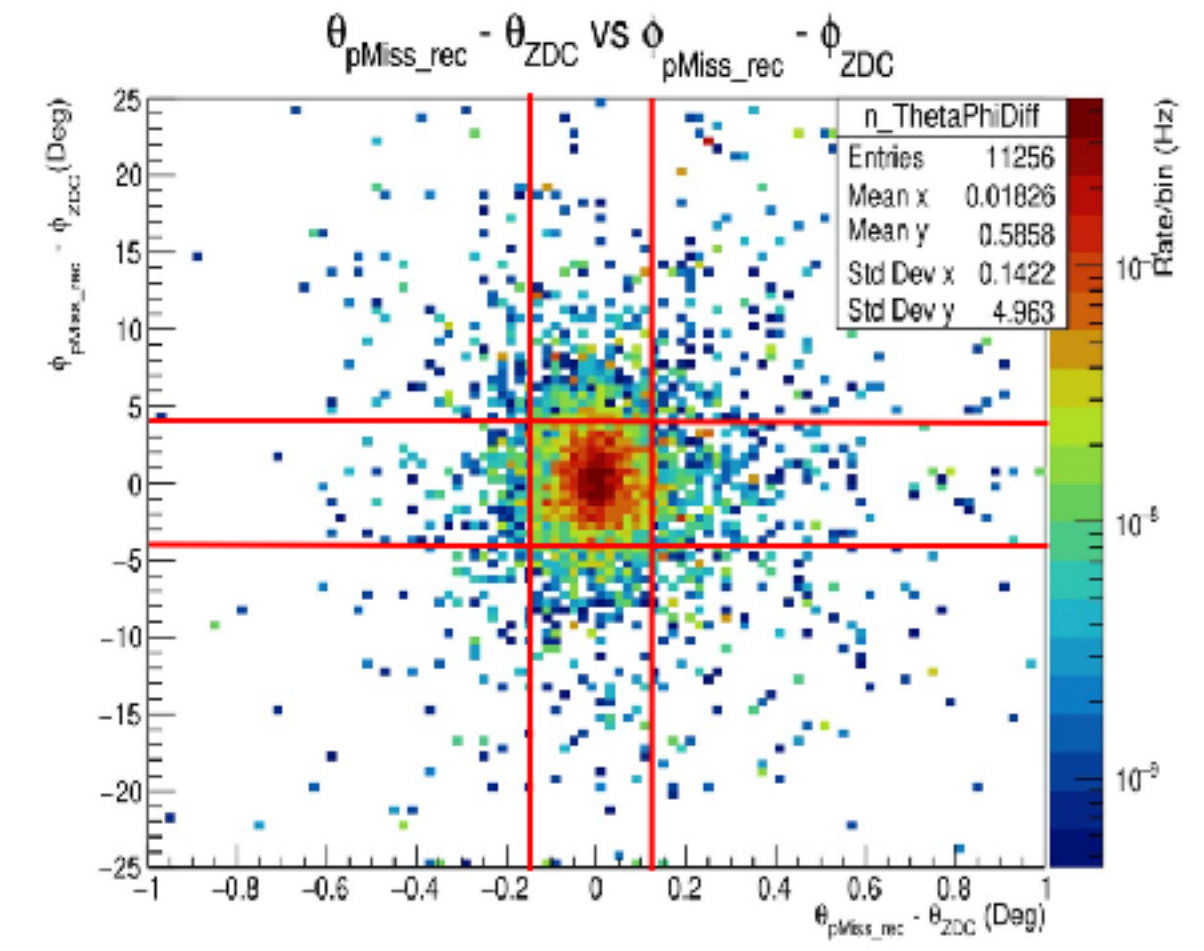
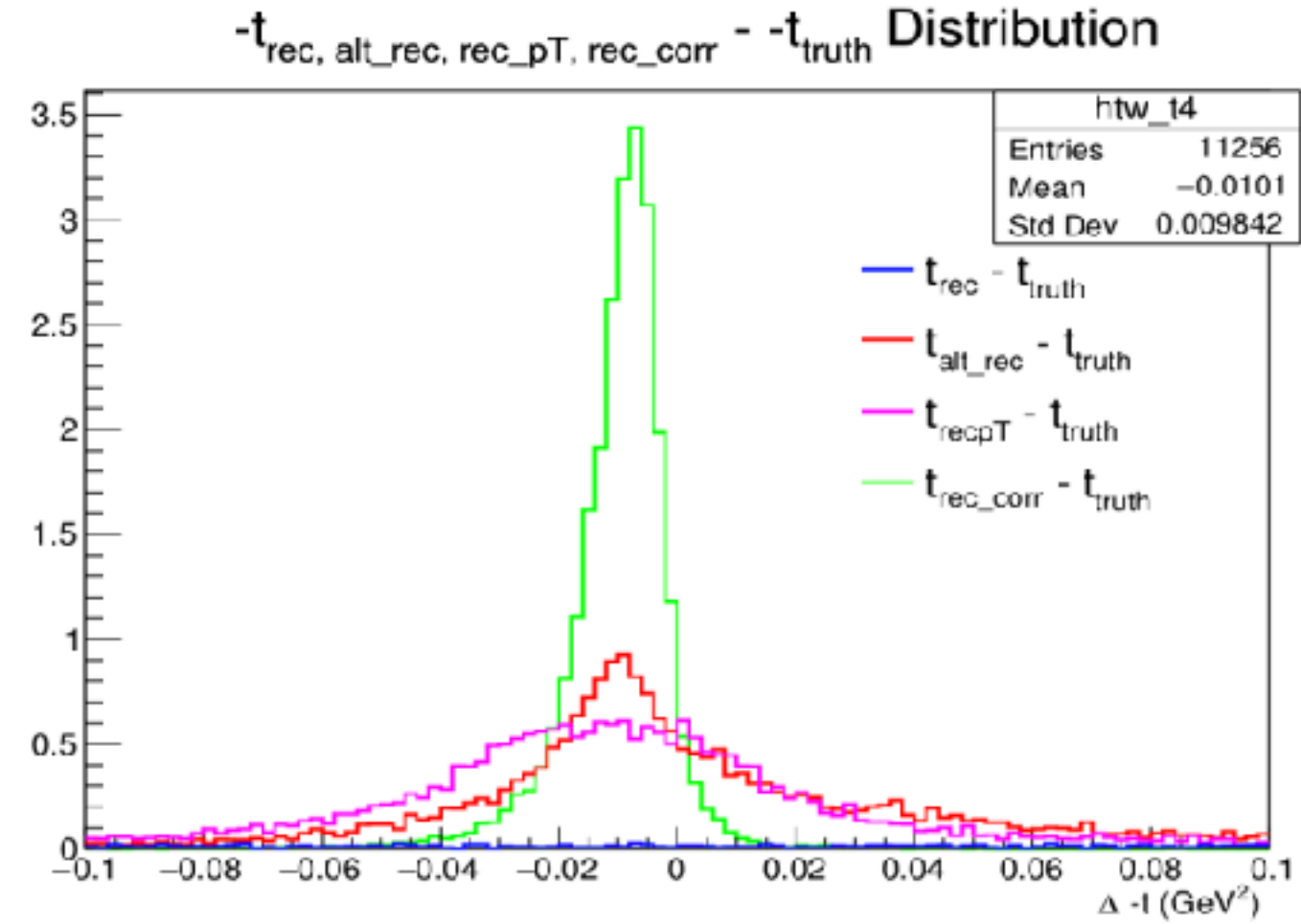
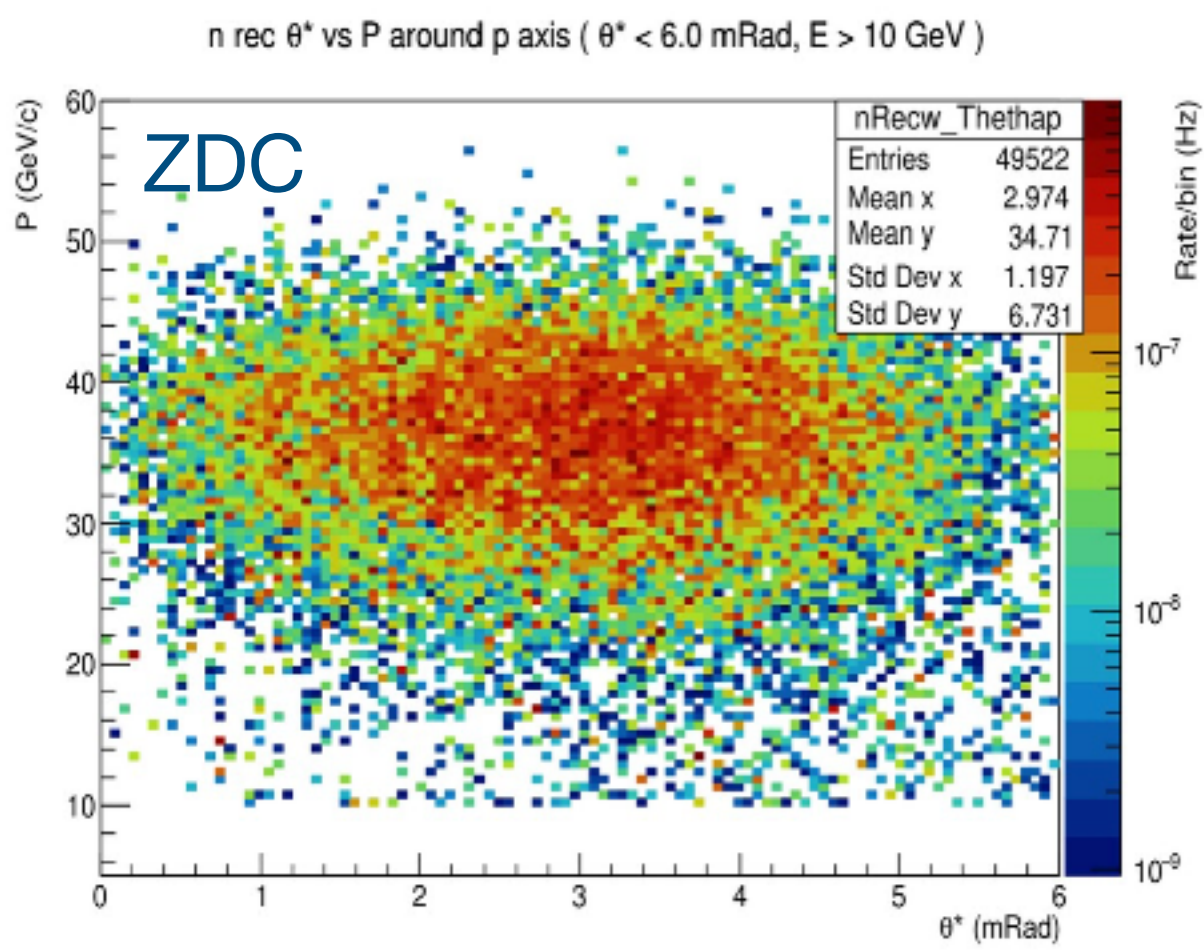


# Meson Form Factors

- Emergent hadronic mass enigma
- **Love Preet et al. (University of Regina and University of York)**
- More info: [https://indico.bnl.gov/event/23814/contributions/92533/attachments/55095/94308/Love\\_slides.pdf](https://indico.bnl.gov/event/23814/contributions/92533/attachments/55095/94308/Love_slides.pdf)



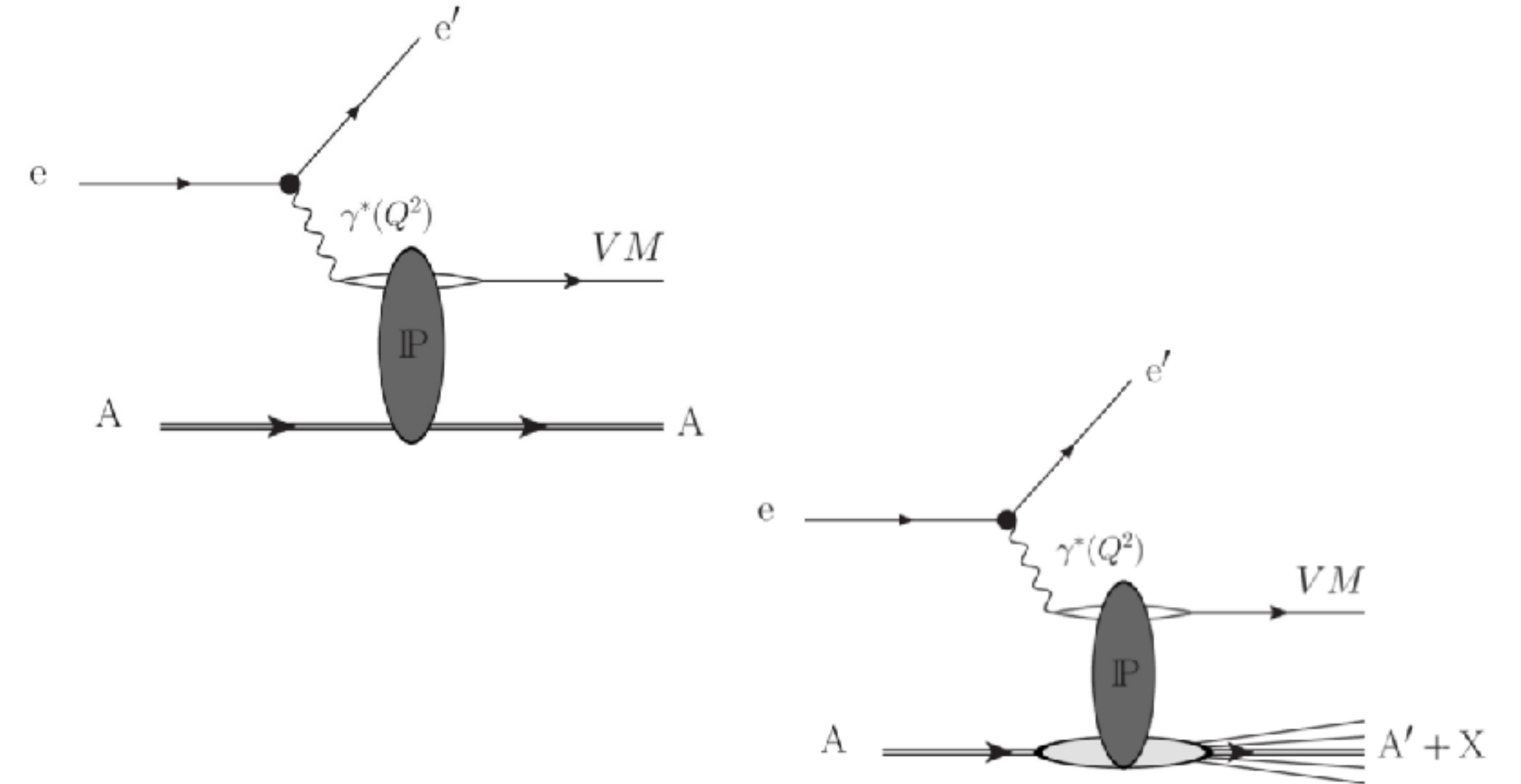
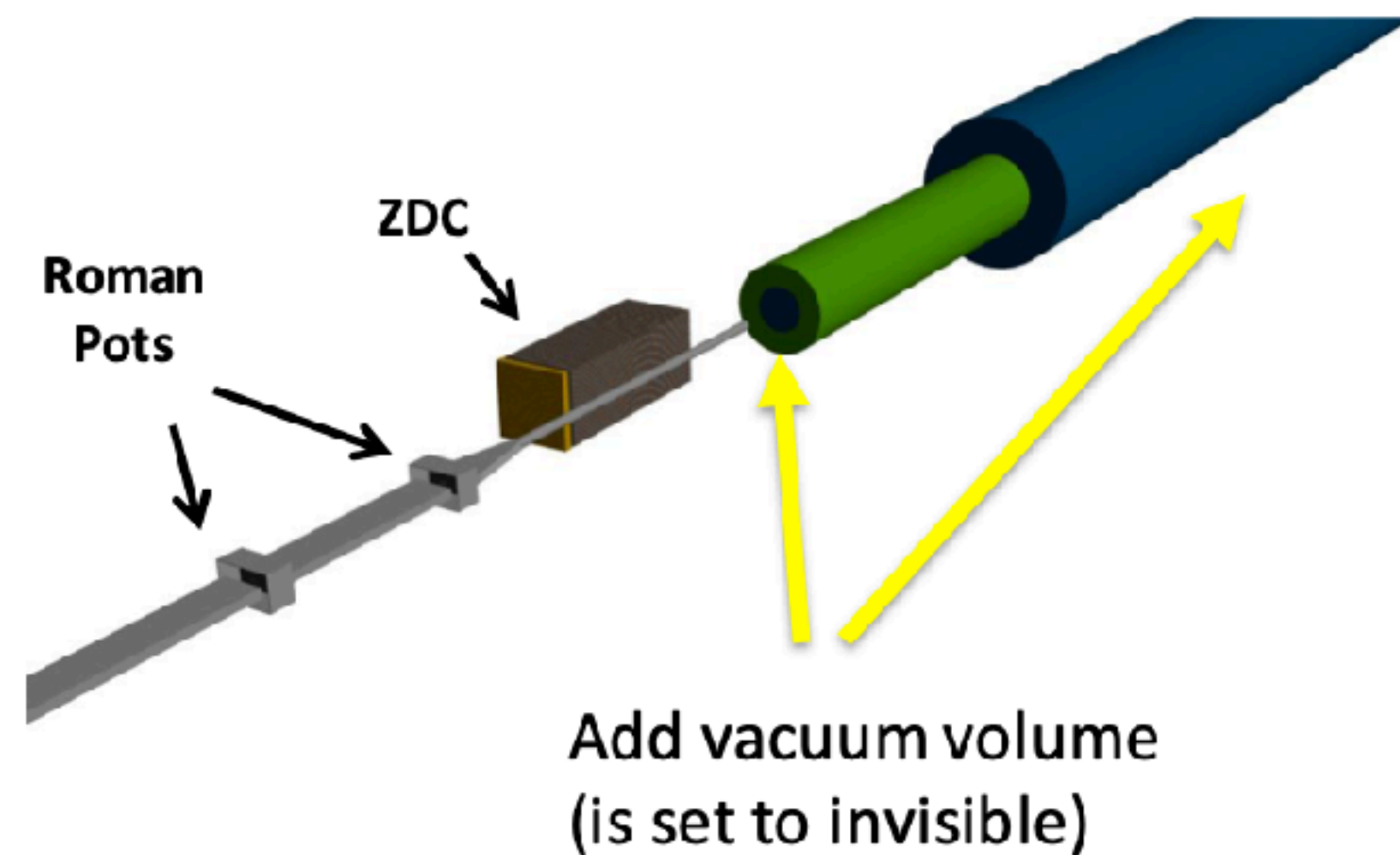
- Pion form factor under study,  $ep \rightarrow e'\pi^+n$ , all final state particles reconstructed
- $e'$  and  $\pi^+$  central detector,  $n$  FF region (mainly ZDC)
- Analysis in recent campaigns also likely affected by new PID implementation in 24.05.0
- **ReconstructedFarForwardZDCNeutrons** branch
- Results promising and comparable to previous resolutions (eg neutron track angle and momentum resolutions)
  - Previous t-reconstruction method still working well
    - Post-burner next month will check offset
- **Request a 5x100 campaign from simulation team for important direct comparison with previous YR results**
- $F_\pi(Q^2)$  projections for TDR expected imminently
- Further plans to extend to kaons (more challenging)





# Diffractive Vector Meson Production

- Probe low-x structure, sensitivity to gluon distributions in nucleon/nuclei, probe spatial parton structure of nuclei
- Challenges: incoherent background, t-reconstruction
- **Michael Pitt et al. (Ben Gurion University of the Negev)**
- More info: [https://indico.bnl.gov/event/23345/contributions/91508/attachments/54637/93485/Jpsi\\_in\\_eA.pdf](https://indico.bnl.gov/event/23345/contributions/91508/attachments/54637/93485/Jpsi_in_eA.pdf)
- Self-run simulation
- On-going study of coherent VM production (J/Psi in ePb) and background veto for TDR
- Planning to make incoherent veto benchmark for FF region
- Coherent events eStarlight, incoherent events BeAGLE



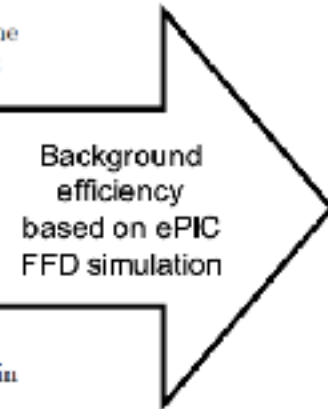
- Using latest merged FF design ([PR-665](#)) from April and April detector geometry
- To speed up reconstruction in FF, vacuum added inside hadron beam pipe (vacuum extended for  $Z > 40$ )
  - Eg coherent  $183.2\text{s/ev} \rightarrow 16.23\text{ s/ev}$
  - Incoherent  $320\text{s/ev} \rightarrow 35\text{s/ev}$
- This is [PR720](#)  $\rightarrow$  now merged to master branch DD4HEP
- Necessary for incoherent study

# Diffractive Vector Meson Production

## Incoherent rejection

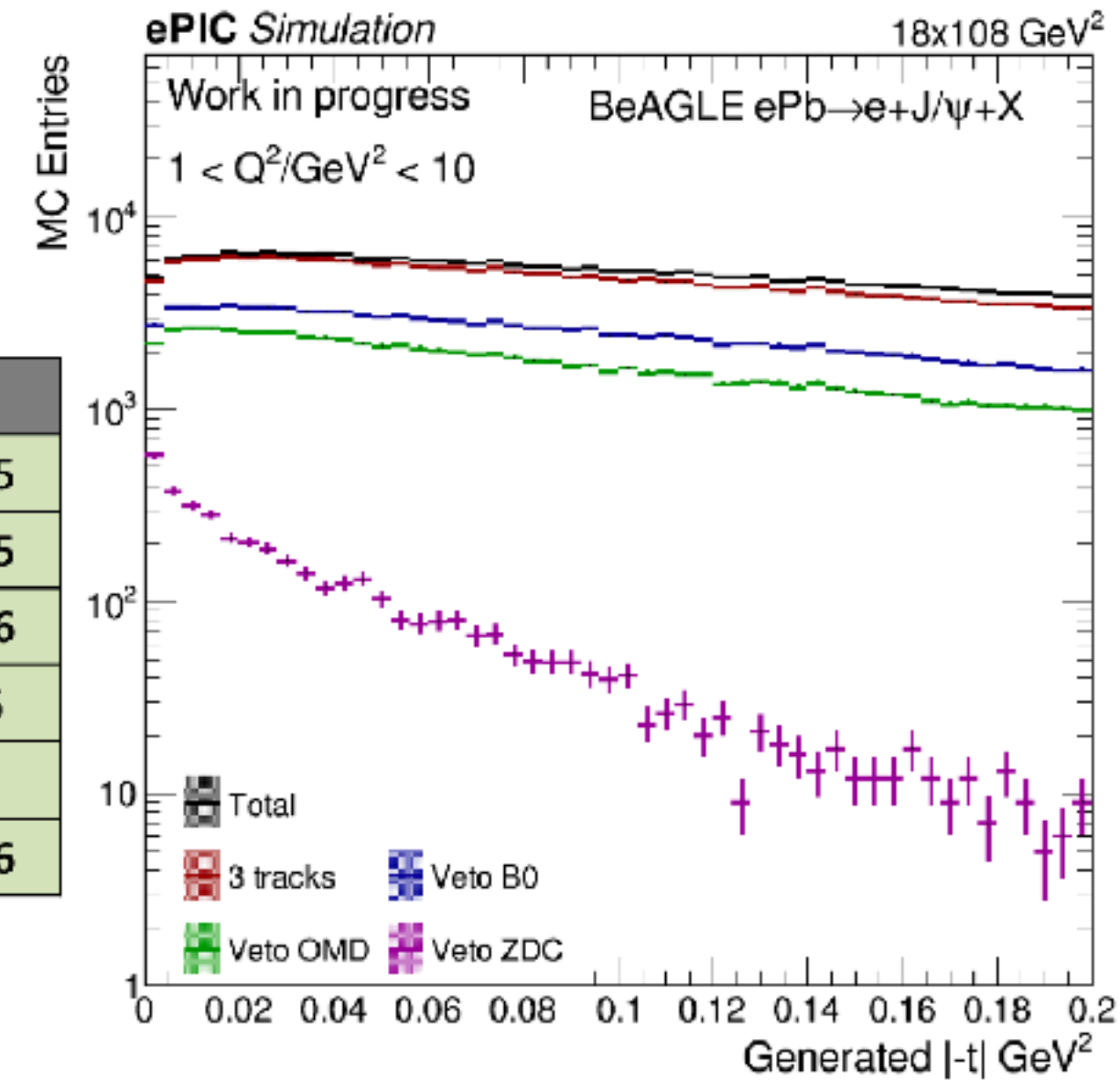
- Modify the strategy of [2108.01694](#) (from object rejection to signal rejection)
- Work by Eden Mautner (in progress)

- Veto.1: no activity other than  $e^-$  and  $J/\psi$  in the main detector ( $|y| < 4.0$  and  $p_T > 100$  MeV/c);
- Veto.2: Veto.1 and no neutron in ZDC;
- Veto.3: Veto.2 and no proton in RP;
- Veto.4: Veto.3 and no proton in OMDs;
- Veto.5: Veto.4 and no proton in B0;
- Veto.6: Veto.5 and no photon in B0;
- Veto.7: Veto.6 and no photon with  $E > 50$  MeV in ZDC.

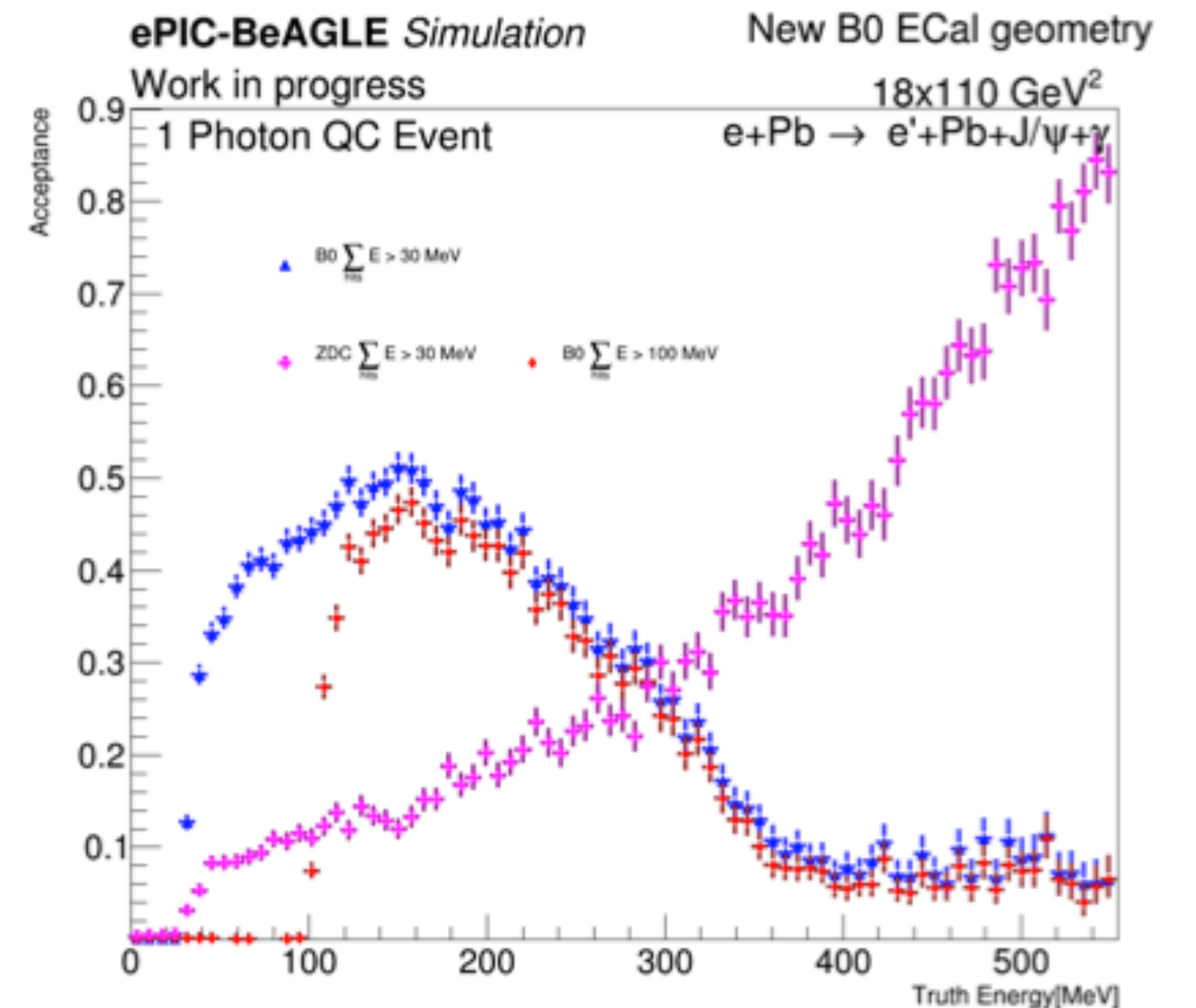
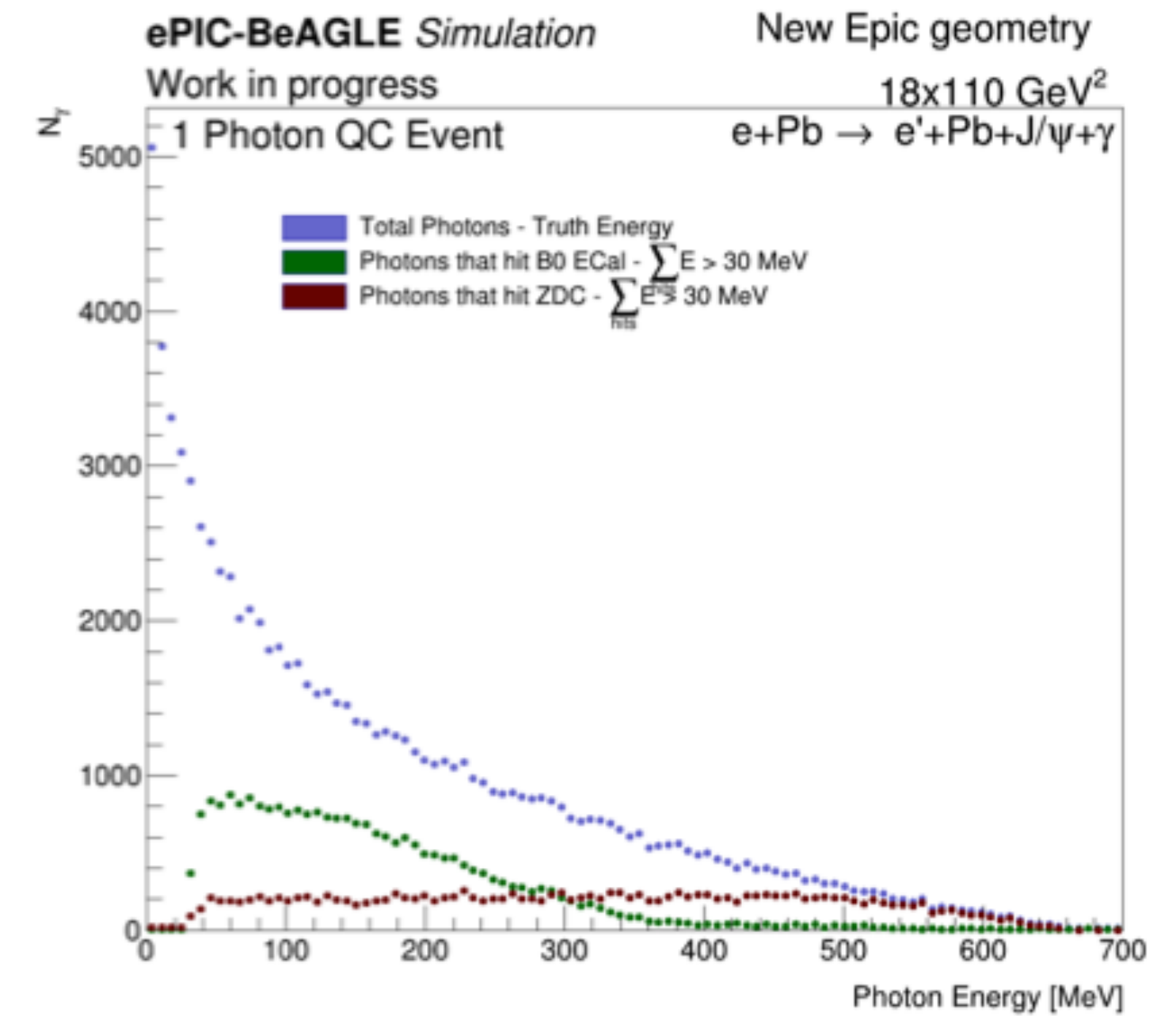


Cut	el+mu
3 tracks	0.914885
VM mass cut	0.827045
Veto B0	0.429656
Veto OMD	0.29286
Veto RP	$\theta$
Veto ZDC	0.013776

RomanPots response is investigated...  
(See backup slide #22)



9



- Incoherent benchmark under development
- Promising veto performance so far following full event selection
- Majority of remaining background after full event selection is photons from quasi-coherent events (J/Psi+Pb+photon)
  - Under study with BeAGLE
  - Good sensitivity to these events in B0/ZDC with current geometry
  - Some work first needed on EICRecon clustering for photons in B0/ZDC to allow check of energy energy resolution



# Diffractive Vector Meson Production

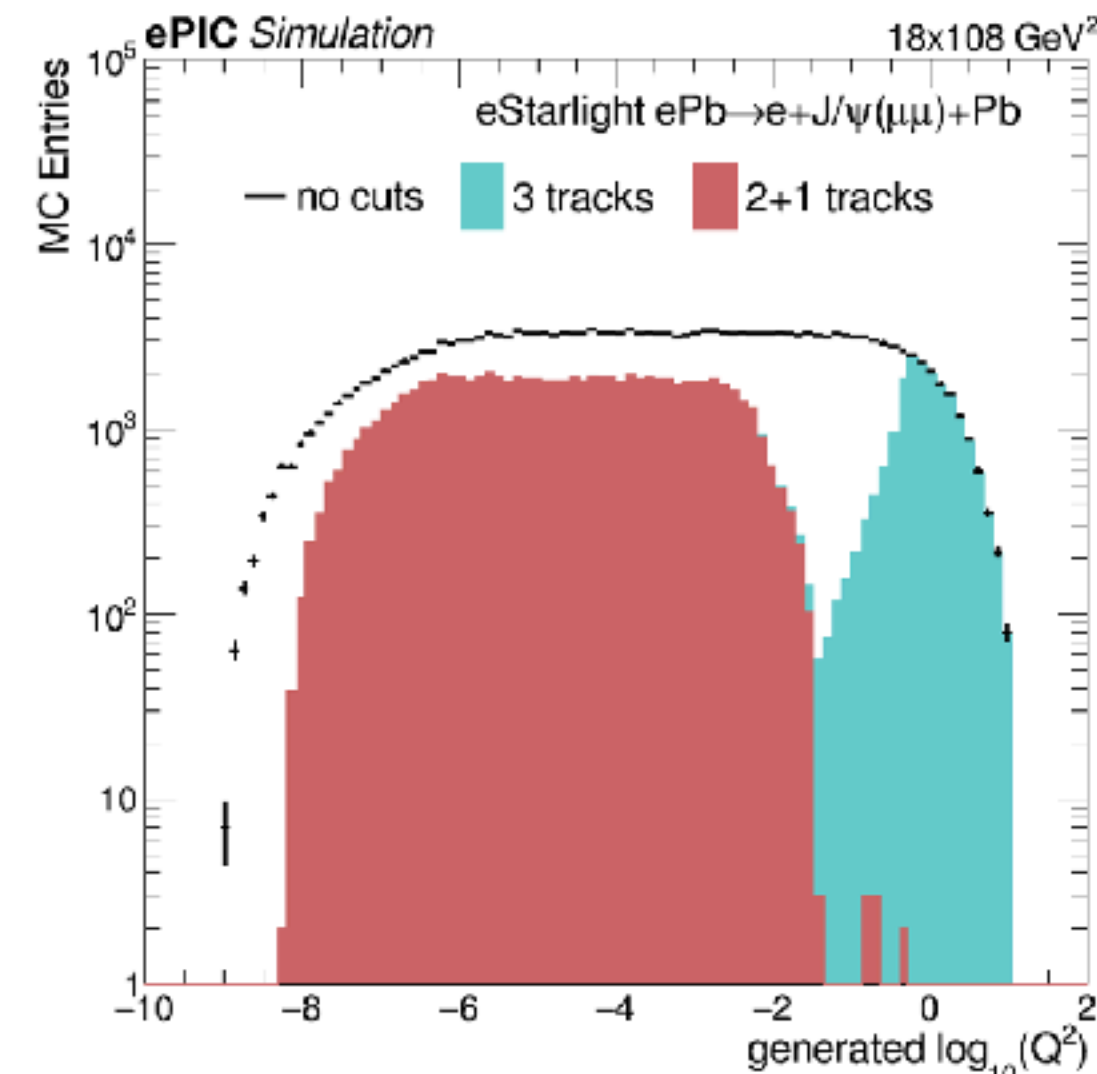
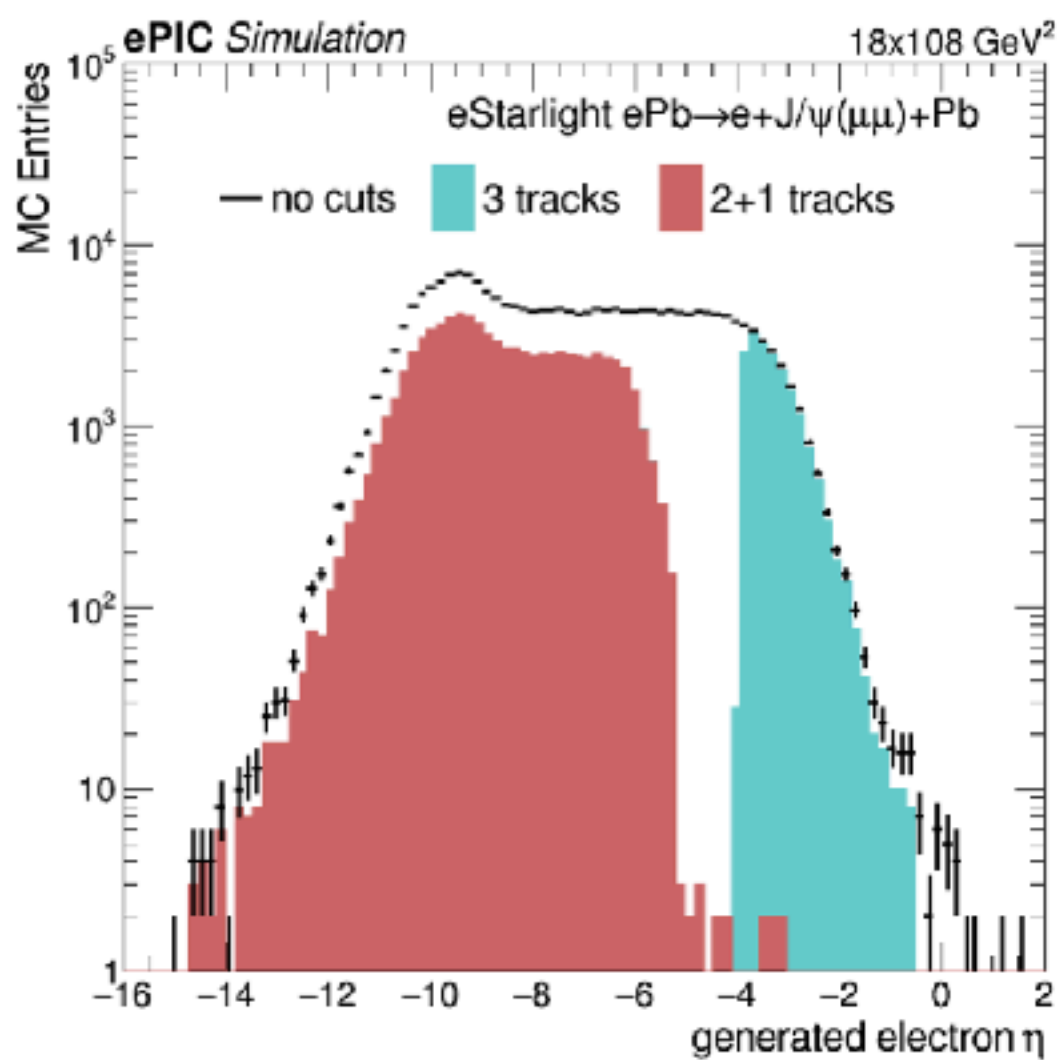
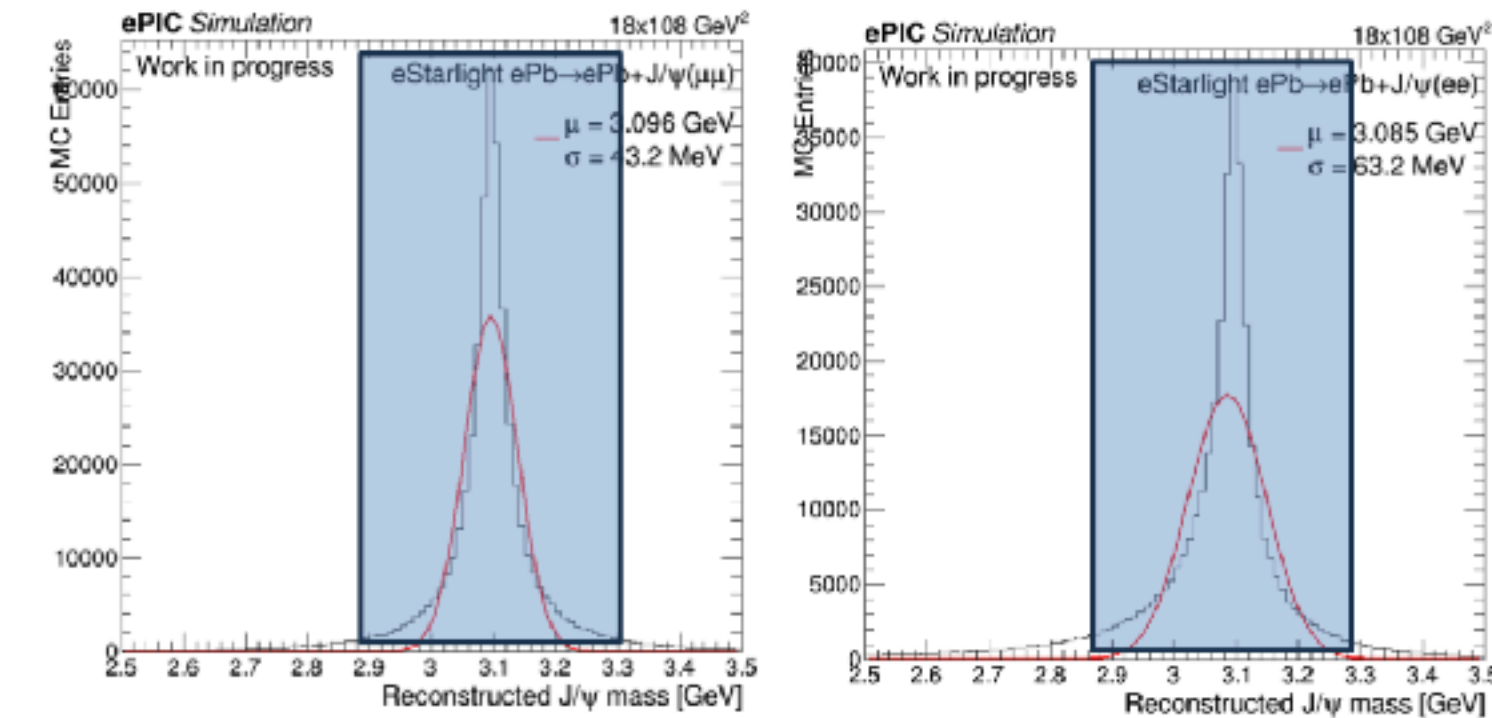
## Analysis

### Coherent event Selection

- 3 track events (with 2 tracks in  $|\eta| < 4$ )
- J/psi mass window of 0.4 GeV (no PID)
- Veto activity in forward region (reco/hits):  
B0 tracks, B0 clusters, Hits in OMD / RP, Ecal and Hcal ZDC Clusters

Signal efficiency for different  $Q^2$  regions:

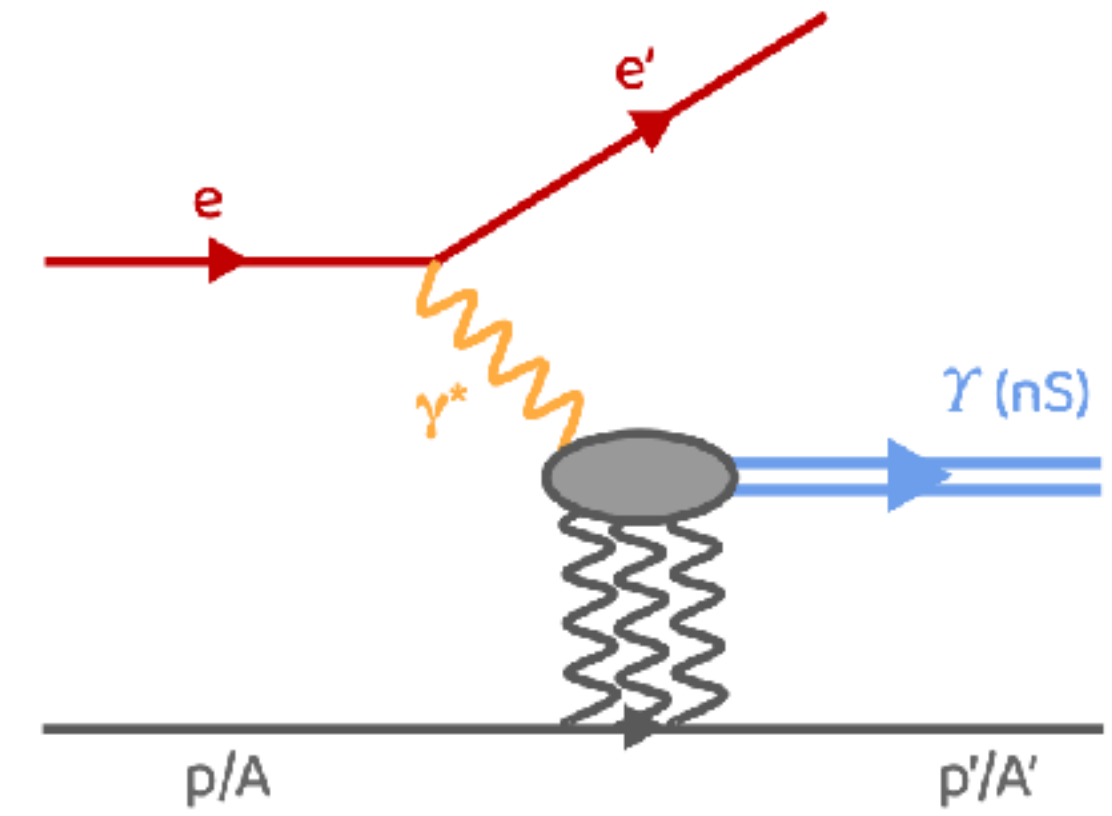
Cut	electrons			Muons		
	$Q^2 < 0.001$	$0.001 < Q^2 < 0.03$	$1 < Q^2 < 10$	$Q^2 < 0.001$	$0.001 < Q^2 < 0.03$	$1 < Q^2 < 10$
3 tracks	0.565585	0.338035	0.973705	0.566175	0.337	0.97383
VM mass cut	0.495305	0.29898	0.838785	0.52959	0.317285	0.898815
Veto FFD	0.495305	0.29897	0.838745	0.52959	0.31727	0.898795



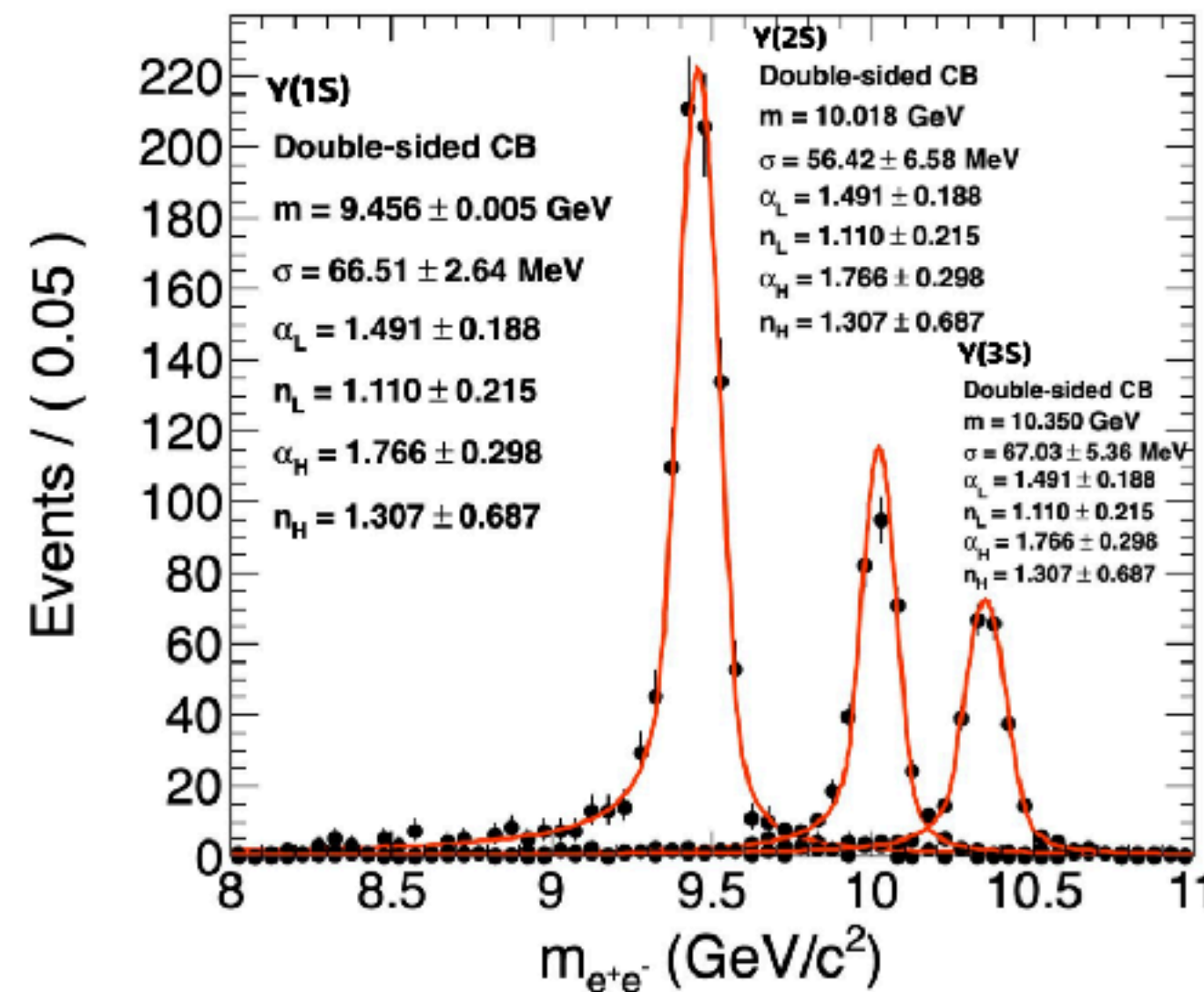
- Phase space can be extended by use of low  $Q^2$  tagger
  - Increases statistics and reduces uncertainty on  $e'$ , can eventually help t-reconstruction
  - (Also looking at afterburner bias in t-reco)
- Coherent analysis divided into acceptance of  $e'$  in **central detector** (main analysis) and **low  $Q^2$  tagger**
- $\log(Q^2) < -3$  not included (due to bremsstrahlung background)
- For study shown used TaggerTrackerTrackParameters branch of EICRecon output
- Now low  $Q^2$  reconstruction is part of EICRecon (Simon Gardner, Glasgow)

# Y Production

- Sensitivity to gluon distributions; near threshold production - mass enigma
- **Saeahram Yoo (Berkeley Lab) et al**
- Resolution study for  $\Upsilon(1S)$ ,  $\Upsilon(2S)$ ,  $\Upsilon(3S) \rightarrow e^+e^-$
- Tracking crucial
- More details: [https://indico.bnl.gov/event/23163/contributions/90798/attachments/54163/92658/EICUpsilon\\_ExcdfTag\\_SaeahramYoo\\_Apr29.pptx.pdf](https://indico.bnl.gov/event/23163/contributions/90798/attachments/54163/92658/EICUpsilon_ExcdfTag_SaeahramYoo_Apr29.pptx.pdf)



## Invariant Mass Fit of Reconstructed $\Upsilon(1S)$ , $\Upsilon(2S)$ , $\Upsilon(3S)$



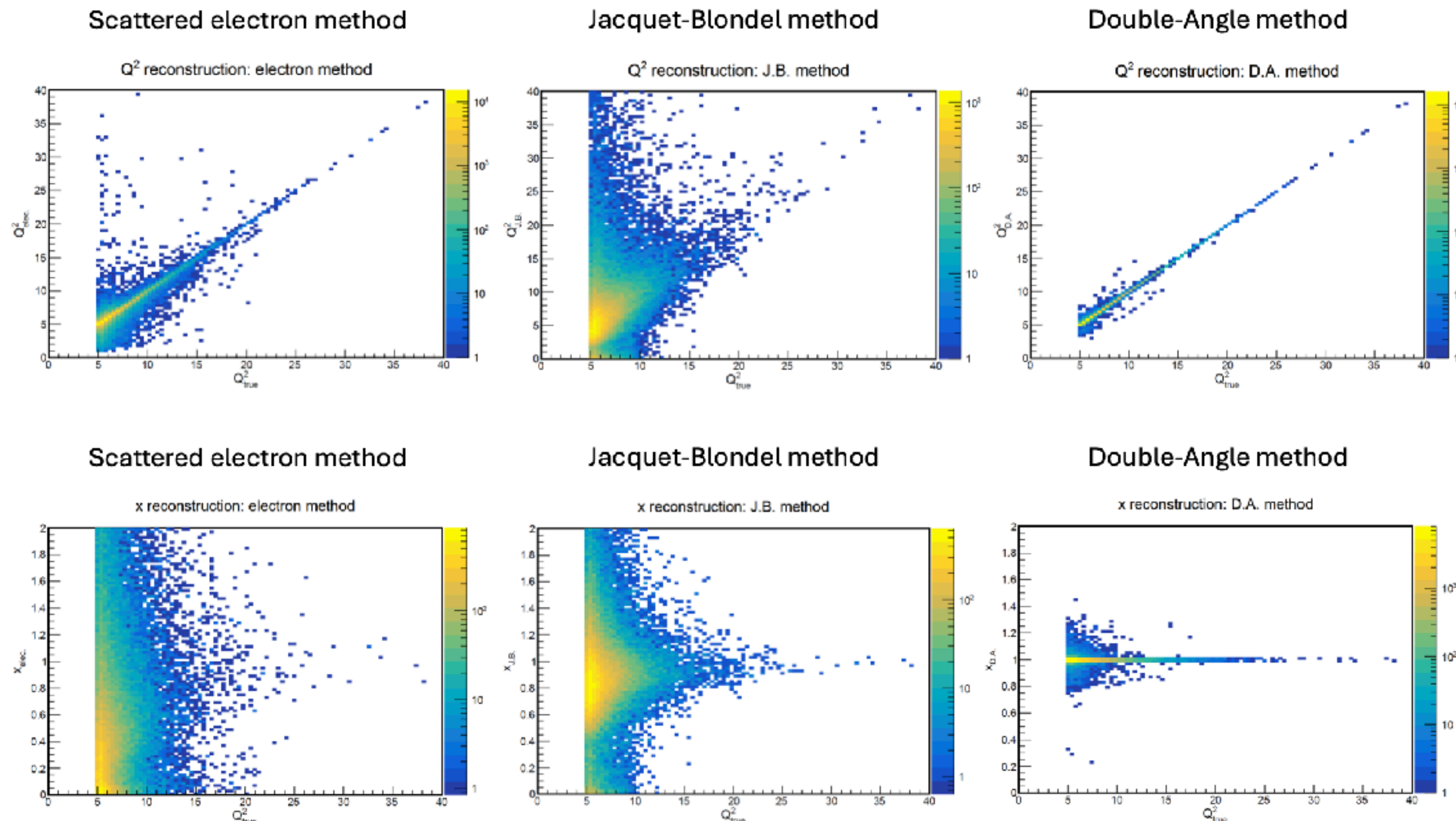
- Used the ratio for the yields  
1 : 0.45 : 0.33  
from [the STARlight paper](#)
- Fitted with the DSCB (Double-Sided Crystal Ball) function with the constraints on the mean and tail parameter values of  $\Upsilon(2S)$  and  $\Upsilon(3S)$ .
- $m_{\Upsilon nS} = m_{\Upsilon 1S} * \frac{\text{PDGmass}_{nS}}{\text{PDGmass}_{1S}}$
- Resolution of each peak:  
 $\sigma_{1S} = 66.52 \pm 2.64$  MeV  
 $\sigma_{2S} = 56.42 \pm 6.58$  MeV  
 $\sigma_{3S} = 67.03 \pm 5.36$  MeV  
 → need to obtain values using a larger sample size

- April 2024, self-run, eAu, 10x100
- $\Upsilon(1S)$ ,  $\Upsilon(2S)$ ,  $\Upsilon(3S)$  generated for  $0 < Q^2 < 0.01 \text{ GeV}^2$  (truth seeding)
- eSTARlight (generate seeds) → afterburner (nb afterburner *not* used here, due to a bug but will be used in future plots) → npsim → EICrecon
- Next:
  - Add afterburner; larger samples
  - realistic seeding and study different regions of detector (barrel vs endcap)
- **Want to develop this into a tracking benchmark**
- **Have requested this to be included in monthly campaigns**



# Elastic e-p

- Nucleon structure, input for multi-dimensional imaging; over-constrained kinematics would make it useful for detector calibrations
- **Barak Schmookler (UC Riverside) et al**
- Reconstruction of elastic e-p for high  $Q^2$  events 5 x 41, self run simulation with April version of ePIC/EICRecon (ie truth PID)
- At 5x41 e' and p are in central detector
- More details: [https://indico.bnl.gov/event/23163/contributions/90802/attachments/54165/92670/epic\\_elastic\\_042924.pdf](https://indico.bnl.gov/event/23163/contributions/90802/attachments/54165/92670/epic_elastic_042924.pdf)



- Good reconstruction of  $x$  and  $Q^2$  possible if detect *both* e' and p'
- Next steps
  - Over next month check PID/ electron finder effects on analysis
  - Check higher energy configuration where p' is in FF
  - Look at low  $Q^2$  events and QED effects
- Develop a benchmark
- We will likely request monthly productions in future

# Summary

- Many exciting studies are underway
  - Many thanks to the working group for their contributions to these studies and these slides!
- Monthly productions
  - Upsilon production has requested to be included in monthly to make a tracking benchmark
  - Meson FF will request a one-off 5x100 run for important benchmarking of results with past studies
  - Pion SF have been tuning ZDC for neutron in analysis, almost done and will request monthly production
  - Elastic ep will be a good benchmark for detector calibrations and will likely request a monthly production
- Our group heavily relies on the FF region
  - For many analyses need to tune the FF region correctly for the analysis
  - We make a lot of requests to far forward group (thank you for their help)
- PID in FF region
  - Since the change of PDG implementation in 24.05.0 we will need to work on new solutions in analysis codes for B0
  - Previously we were matching ReconstructedParticles in B0 with PDG codes, but B0 has no PID system so can not do this anymore
- Thank you also to the software and production team for all the help