

Update on u -channel
Benchmarks

Zachary Sweger
University of California, Davis



CALIFORNIA EIC
CONSORTIUM



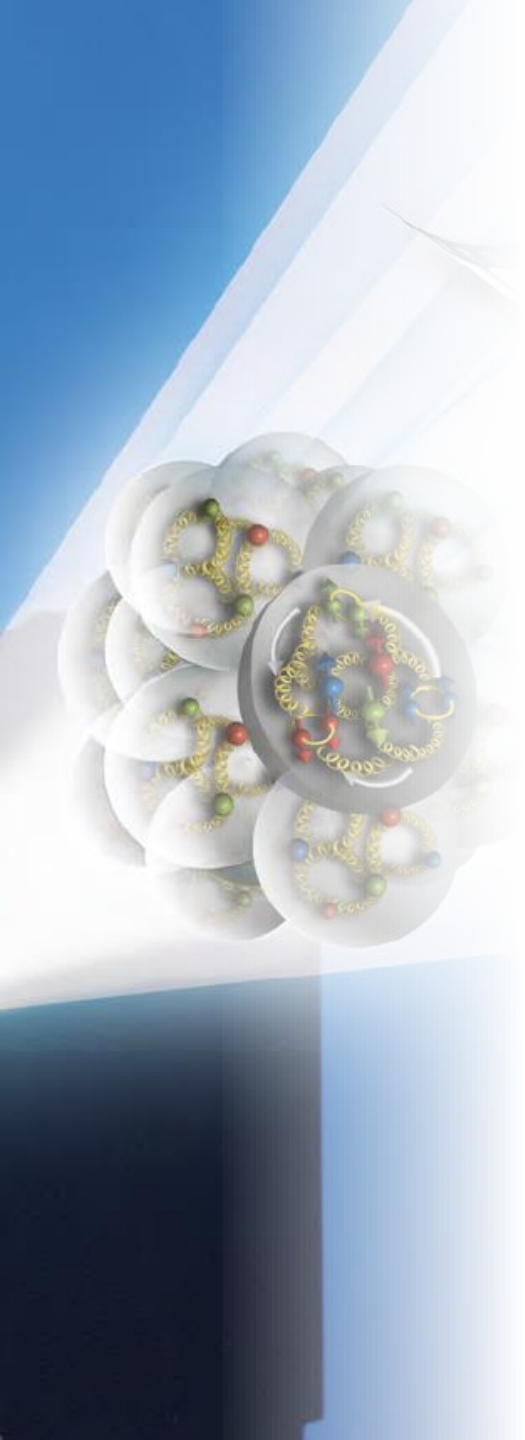
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The Physics

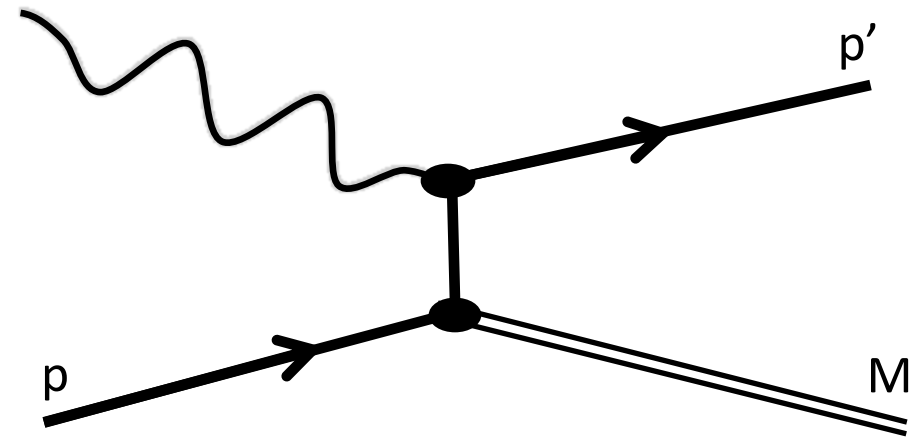
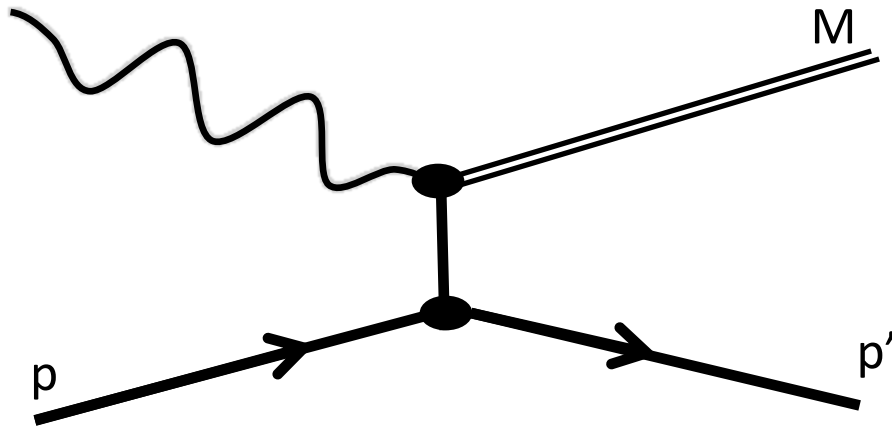


Contributions to Meson Production

t-channel

vs

u-channel



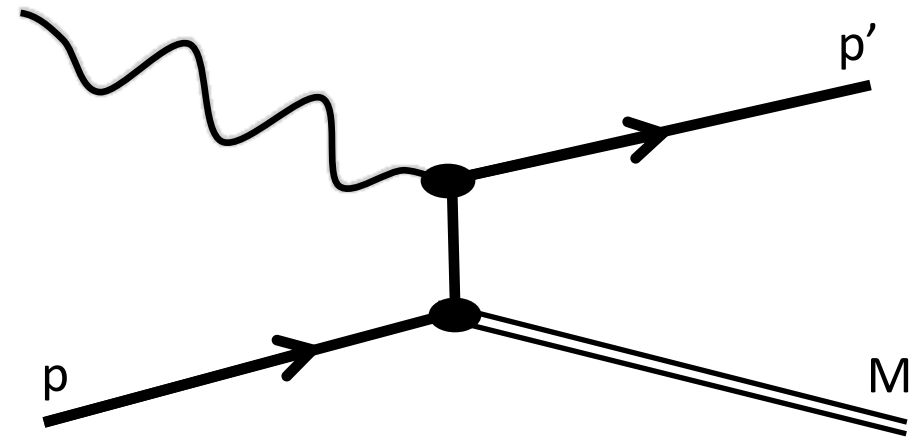
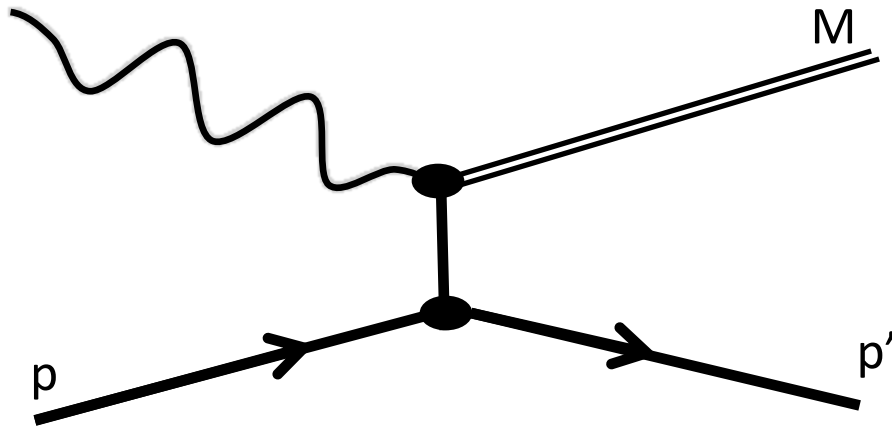
Contributions to Meson Production

t-channel

vs

u-channel

- proton momentum slightly modified



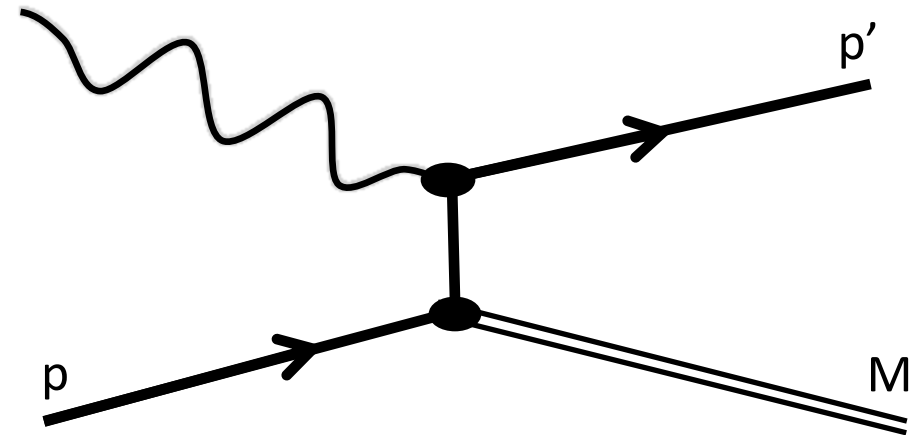
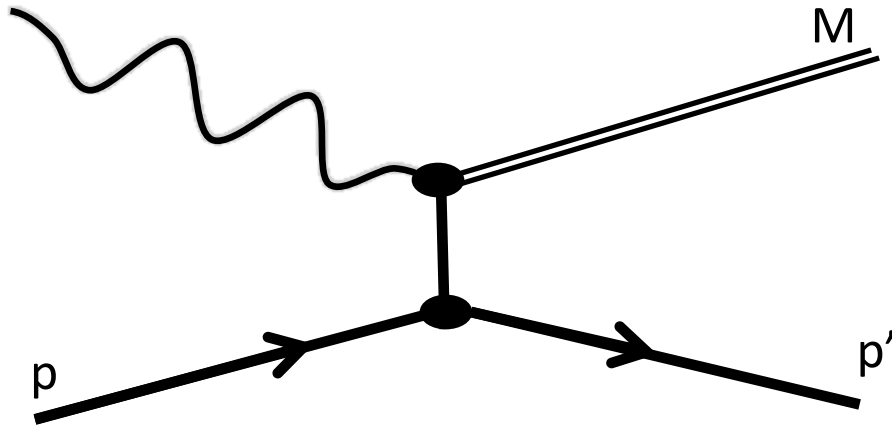
Contributions to Meson Production

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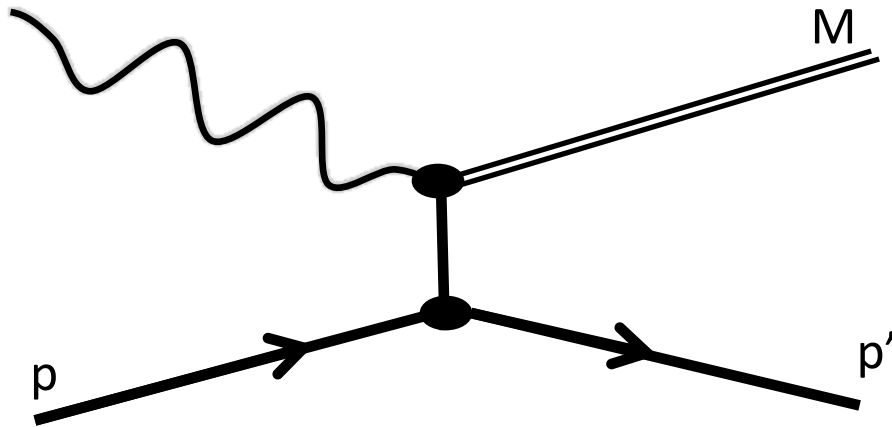
- proton momentum slightly modified
- meson produced near midrapidity



Contributions to Meson Production

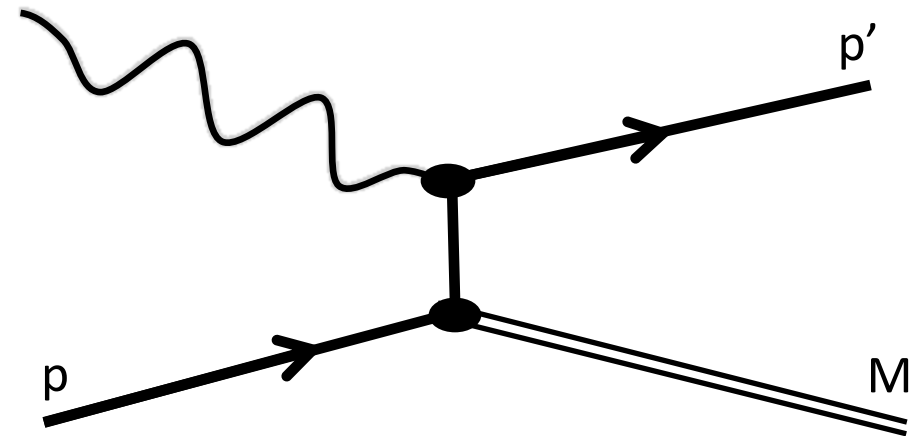
t-channel

- proton momentum slightly modified
- meson produced near midrapidity
- relatively large cross section



vs

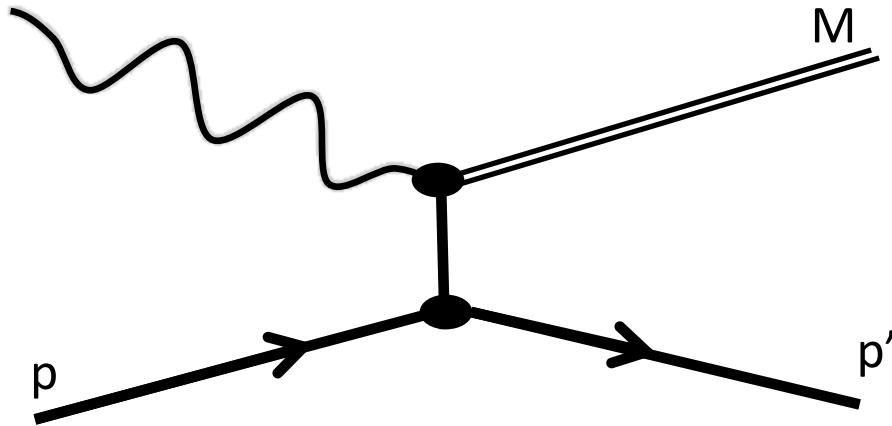
u-channel



Contributions to Meson Production

t-channel

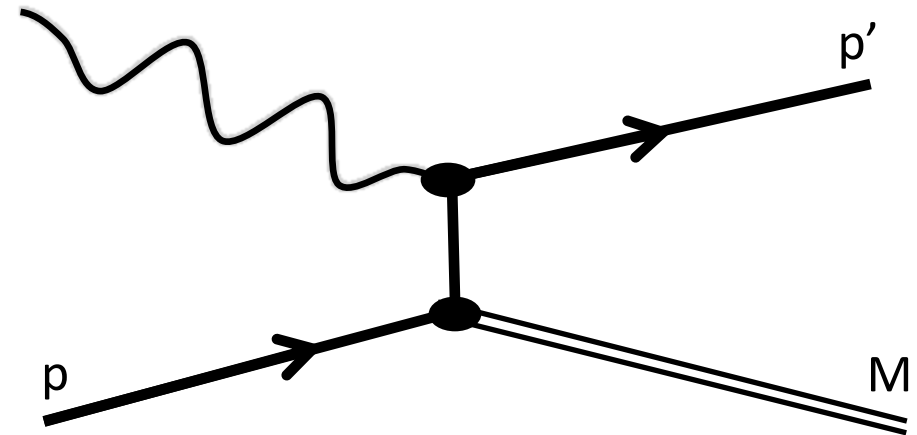
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vs

u-channel

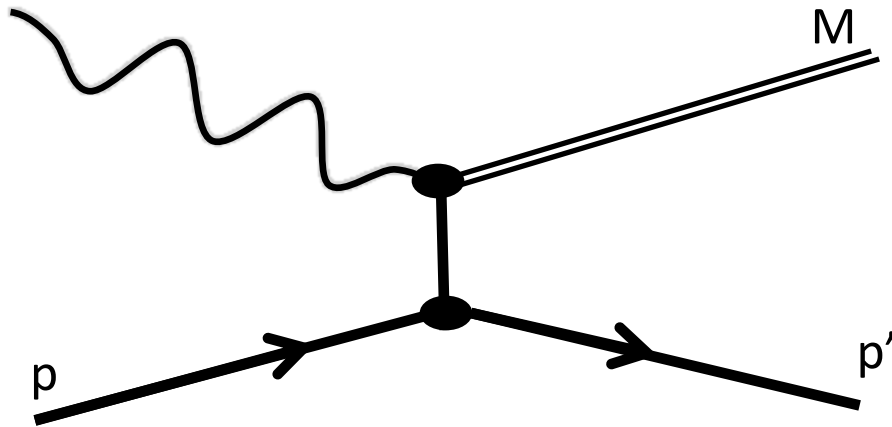
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Contributions to Meson Production

t-channel

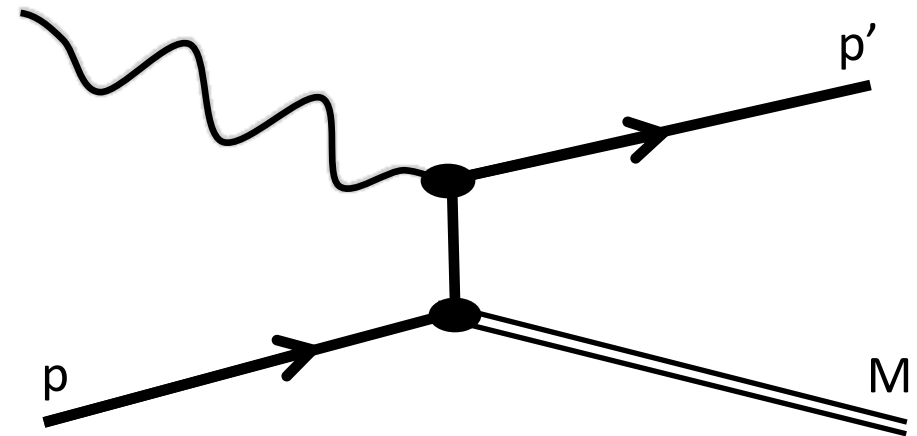
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vs

u-channel

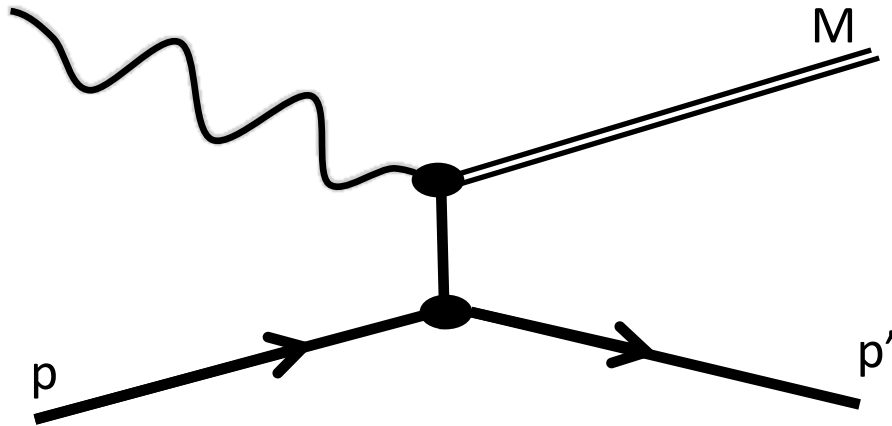
- proton momentum largely modified
- meson produced near beam proton's momentum



Contributions to Meson Production

t-channel

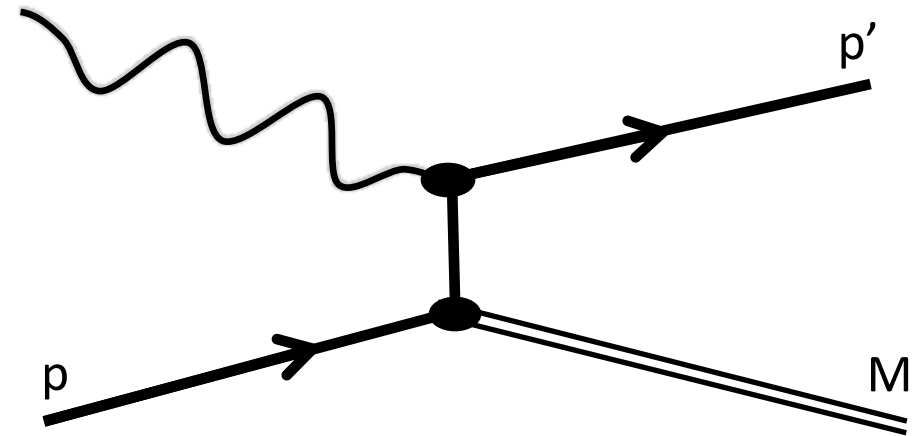
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vs

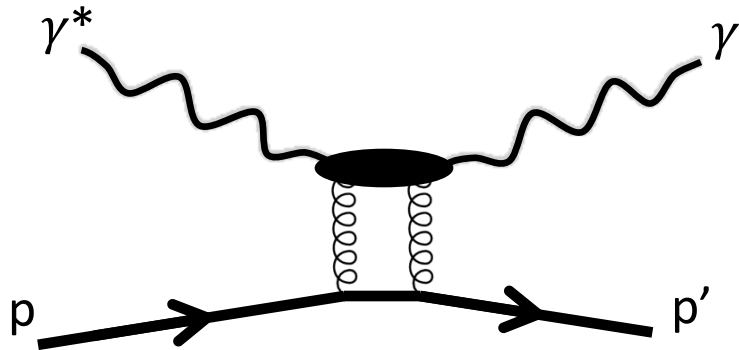
u-channel

- proton momentum largely modified
- meson produced near beam proton's momentum
- suppressed cross section (1/10-1/100 of t-channel)



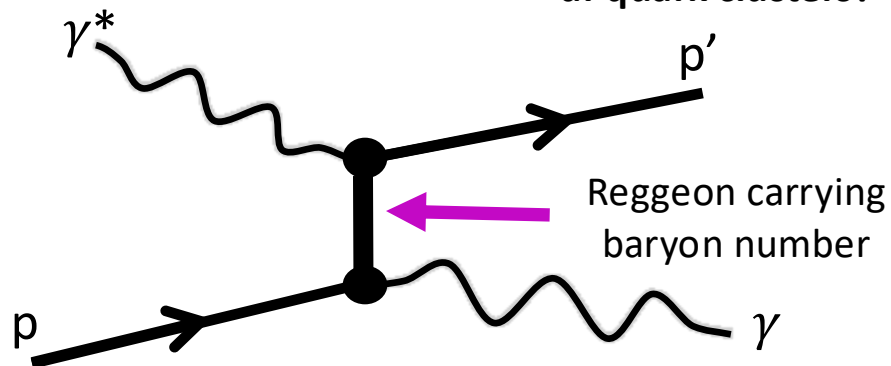
Why u-Channel Production?

Forward scattering off proton's gluon field



Backward scattering off proton's... baryon number?

gluon junction?
di-quark clusters?



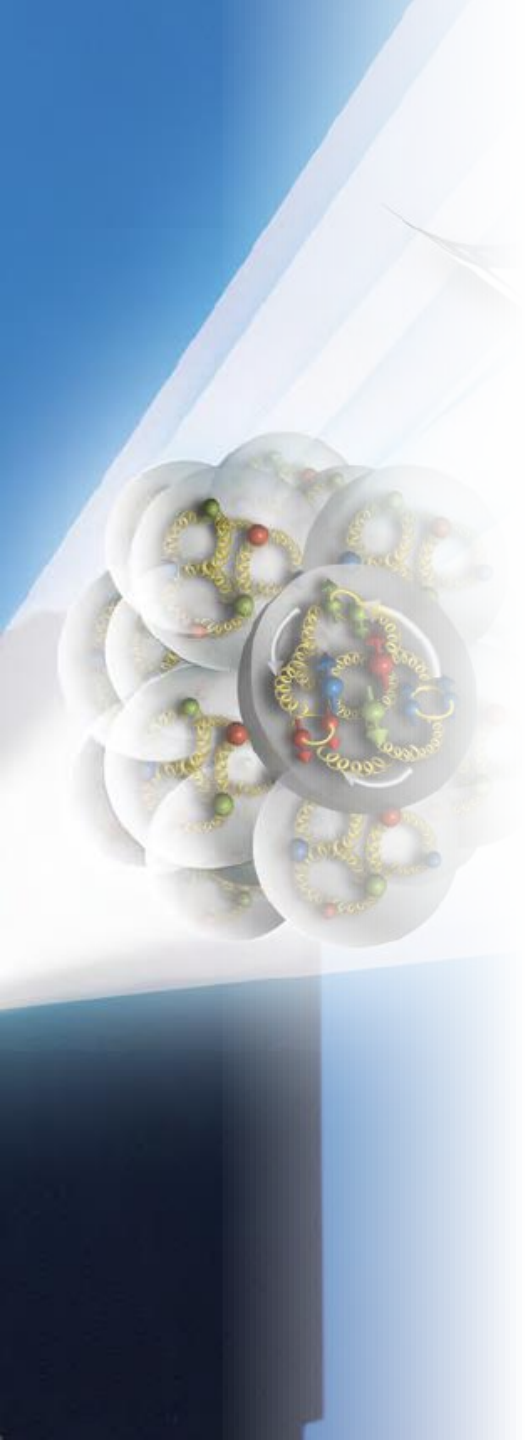
Backward Xsecs $\rightarrow$ partonic correlations and baryon number?

- In our recent PRC 106, 015204 (2022), Spencer discusses a connection between backward production and baryon stopping
- Spencer argues that u-channel processes may probe baryon junctions within the proton

Our question now:

- can we transform u-channel cross sections to tomographically "image" baryon junction? Or baryon-number carrier?

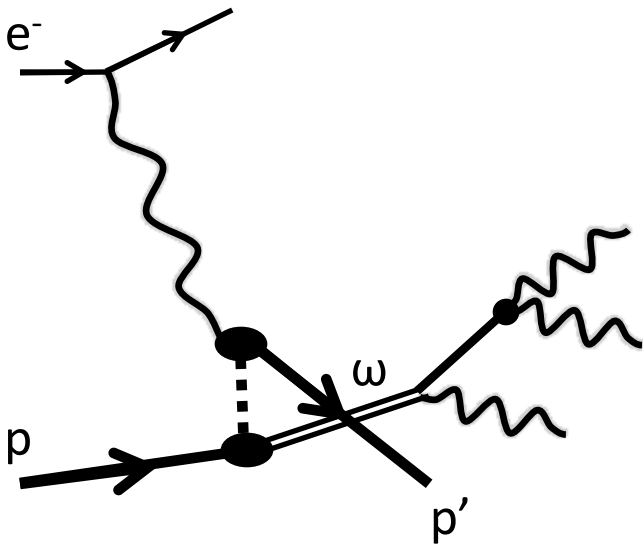
The Physics ↓ The Models



u-channel Processes We've Simulated

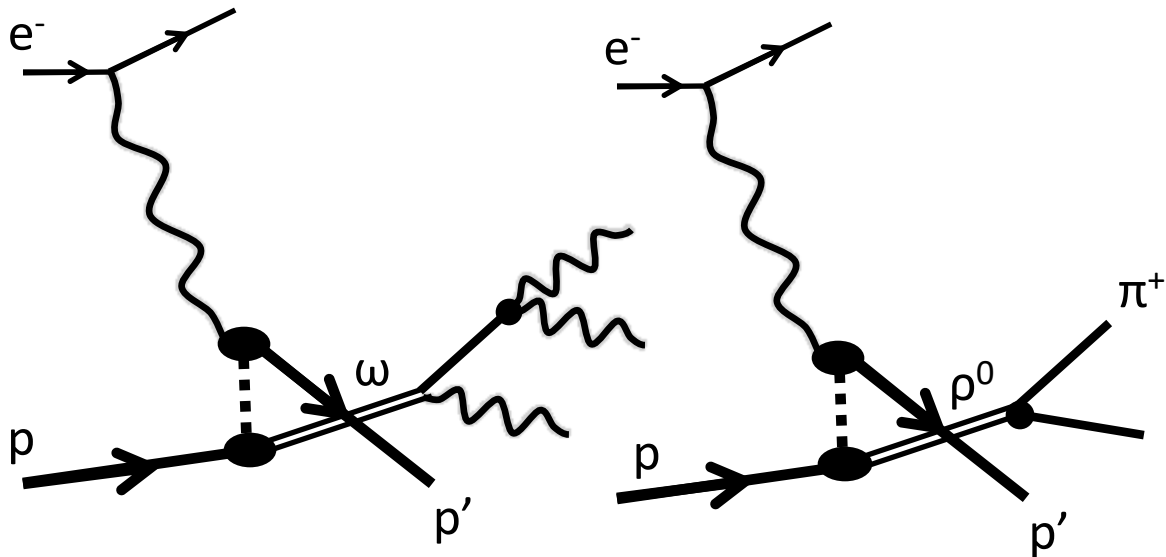
u -channel Processes We've Simulated

- Omega meson production: $\omega \rightarrow \gamma\gamma\gamma$ } Phys. Rev. C 106, 015204 (2022)



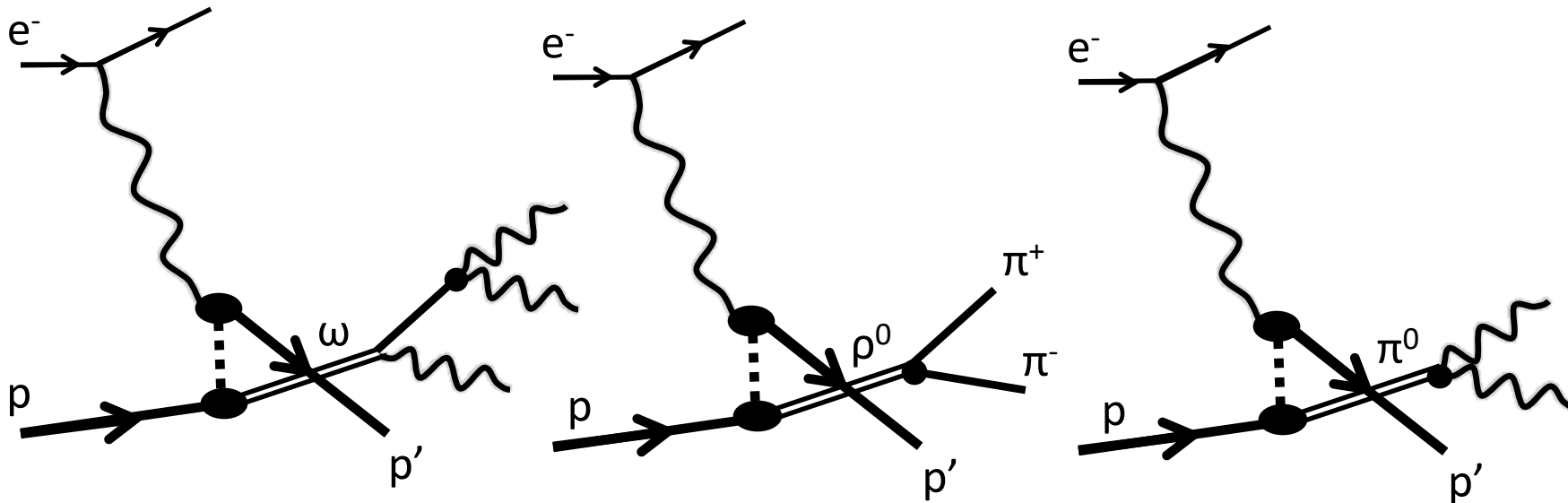
u -channel Processes We've Simulated

- Omega meson production: $\omega \rightarrow \gamma\gamma\gamma$
 - Rho meson production: $\rho^0 \rightarrow \pi^+\pi^-$
- } Phys. Rev. C 106, 015204 (2022)



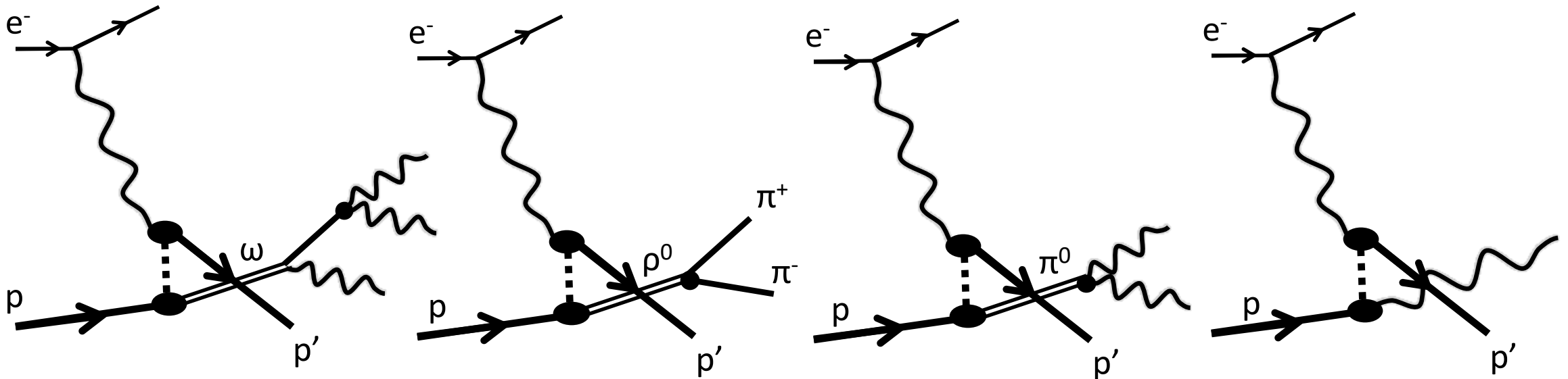
u -channel Processes We've Simulated

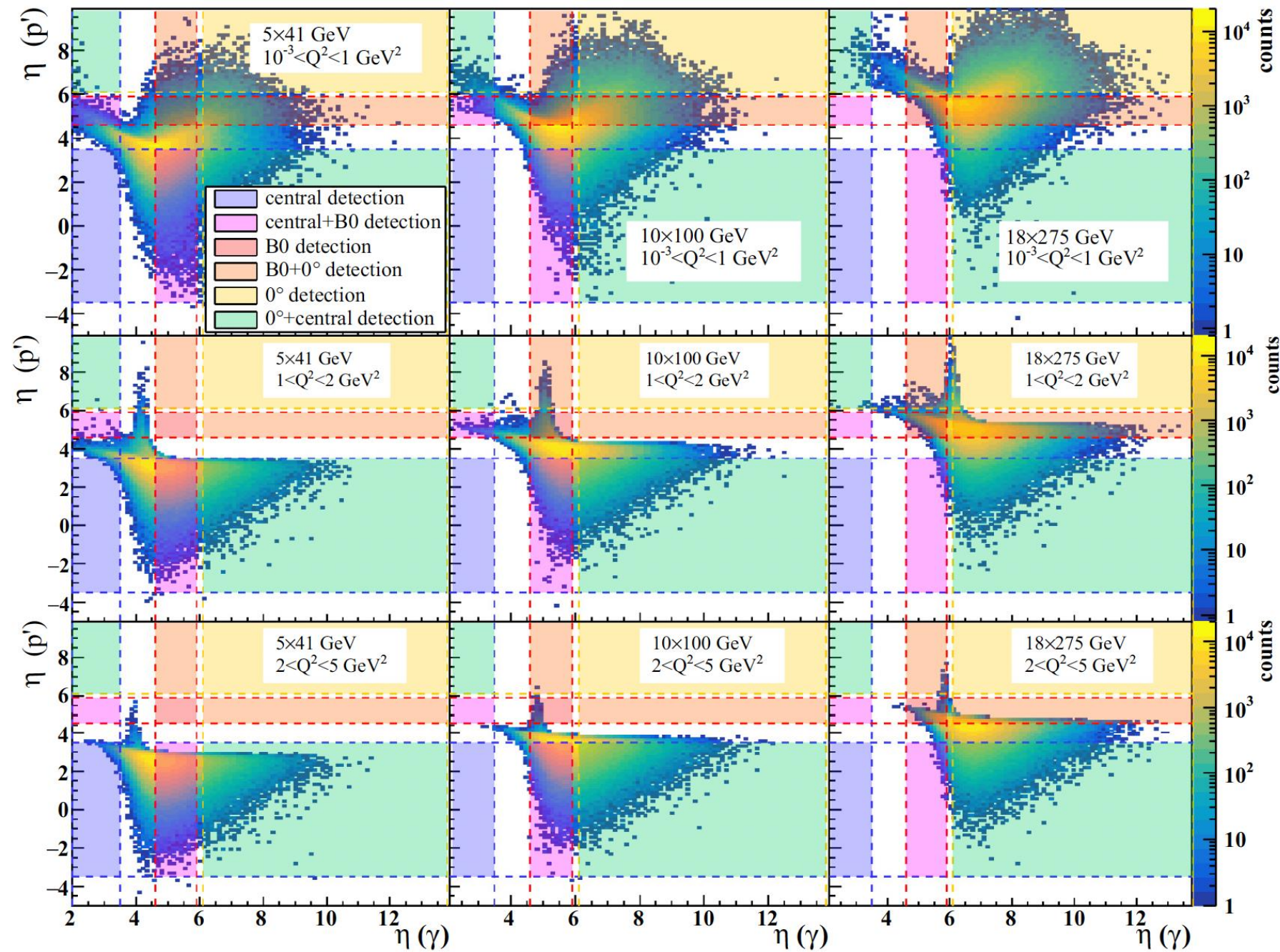
- Omega meson production: $\omega \rightarrow \gamma\gamma\gamma$
 - Rho meson production: $\rho^0 \rightarrow \pi^+\pi^-$
 - Pion production: $\pi^0 \rightarrow \gamma\gamma$
- } Phys. Rev. C 106, 015204 (2022)
- } Phys. Rev. C 108, 055205 (2023)



u -channel Processes We've Simulated

- Omega meson production: $\omega \rightarrow \gamma\gamma\gamma$
 - Rho meson production: $\rho^0 \rightarrow \pi^+\pi^-$
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 - DVCS: γ
- } Phys. Rev. C 106, 015204 (2022)
- } Phys. Rev. C 108, 055205 (2023)



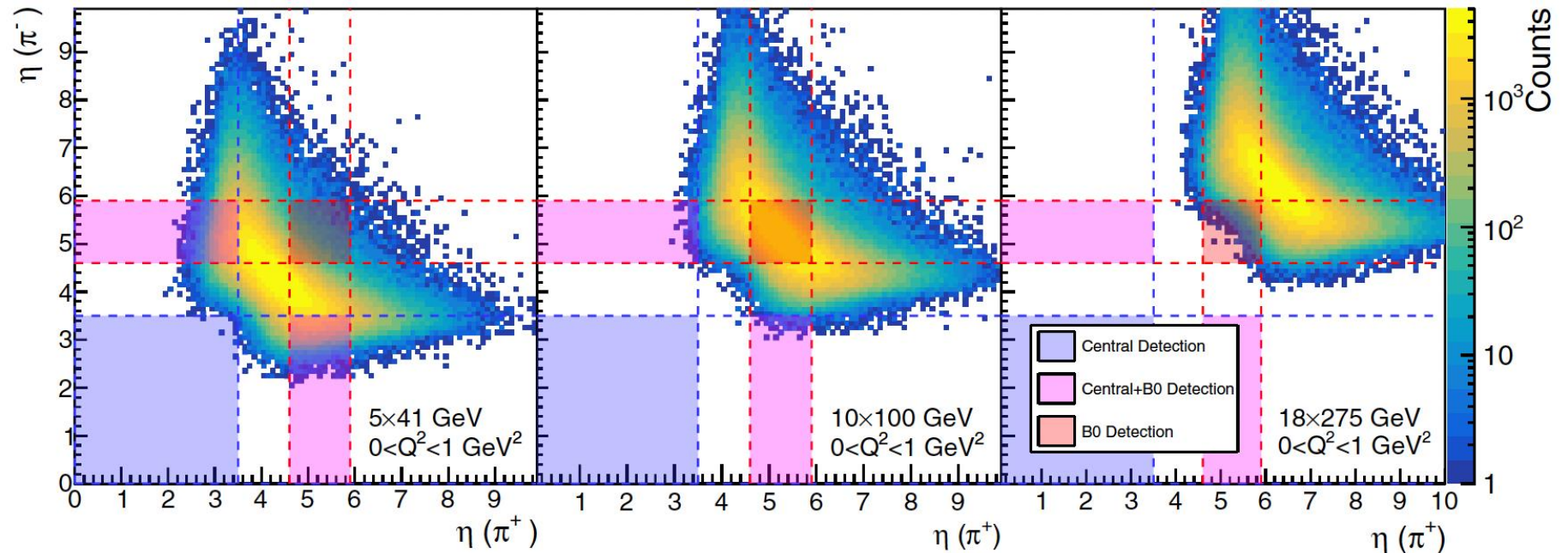


Example Studies:

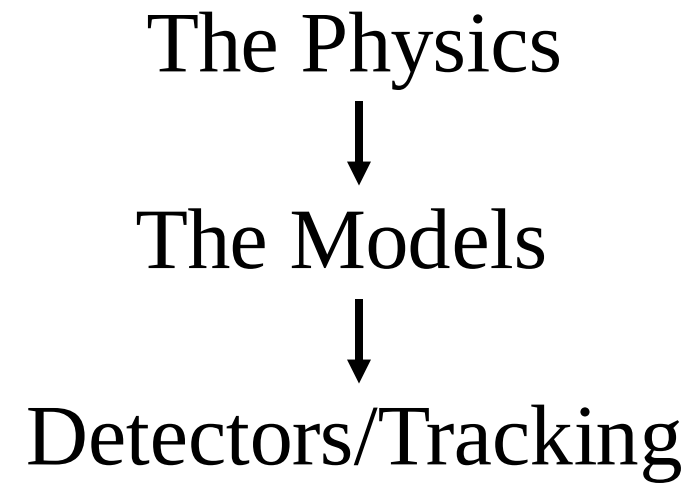
- acceptance with EIC kinematics
- u-channel virtual Compton scattering shown here

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

- 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:eictest/EPIC/RECO/24.07.0/epic_craterlake/EXCLUSIVE/UC HANNEL_RHO/10x100](#)

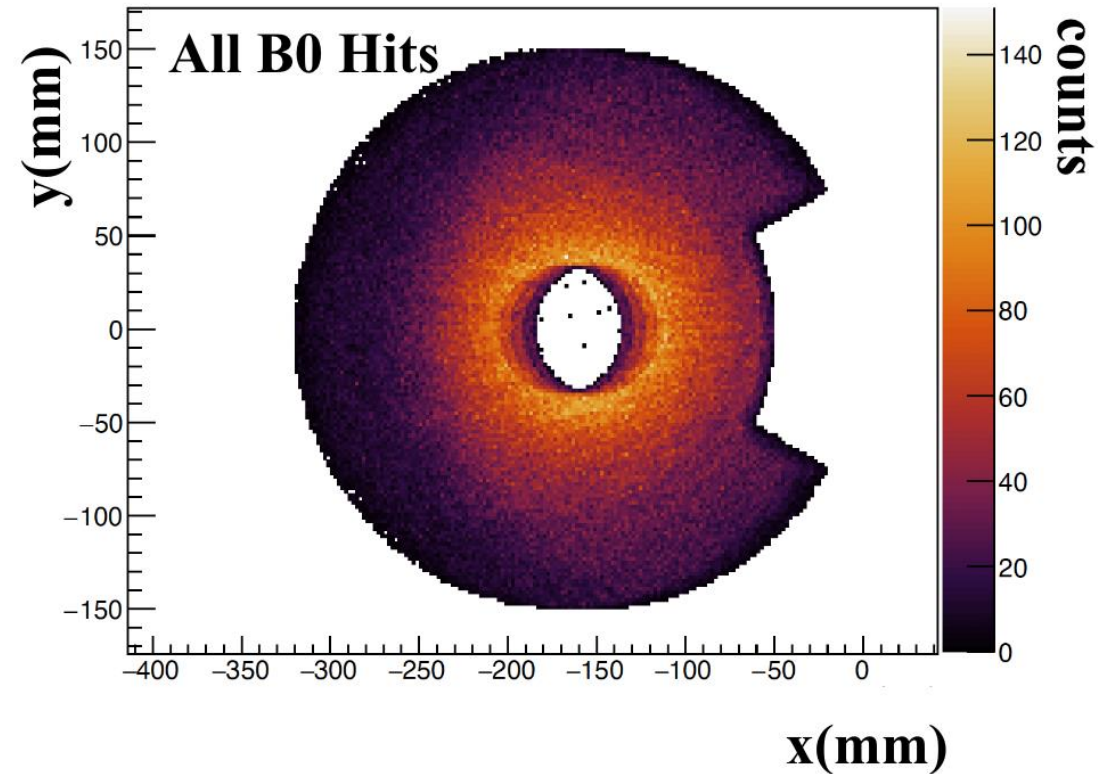
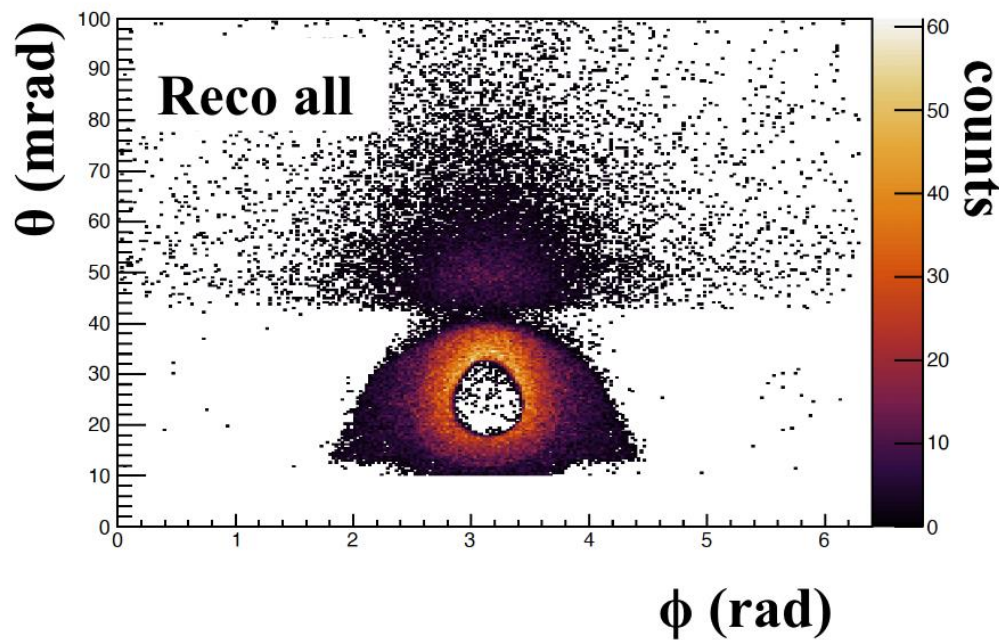


At 10X100 GeV charged pions land in the B0



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

- I plotted angular acceptance of reconstructed tracks

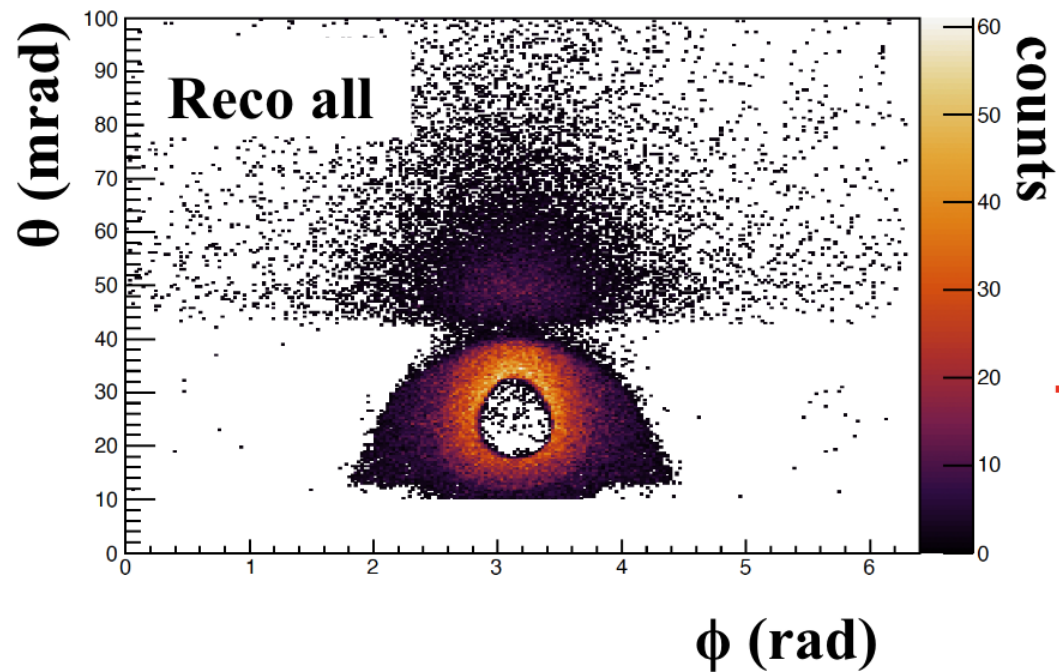


u -channel $\rho^0 \rightarrow \pi^+\pi^-$ in B0

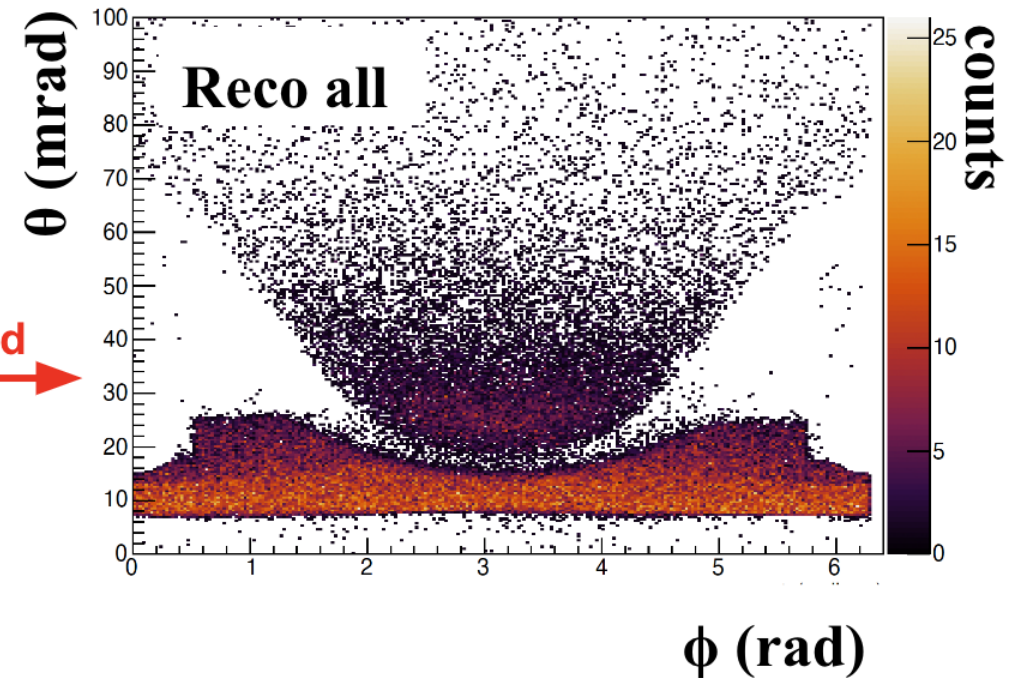
- eicrecon uses coordinate system wrt electron beam pipe
- Far-forward tracks should be rotated by crossing angle

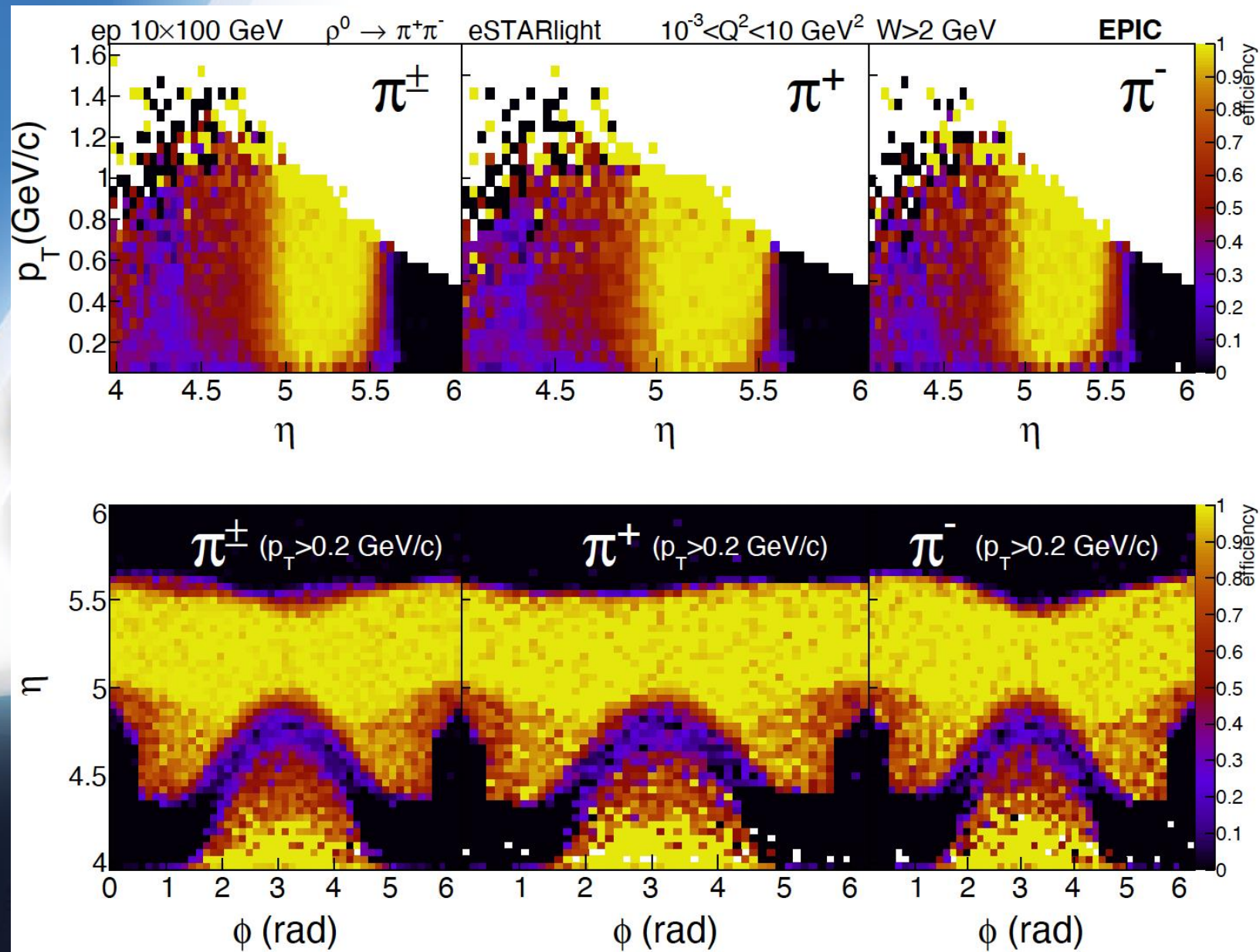
To analyze B0 reco tracks wrt the hadron beam:

```
track.RotateY(0.025);
```

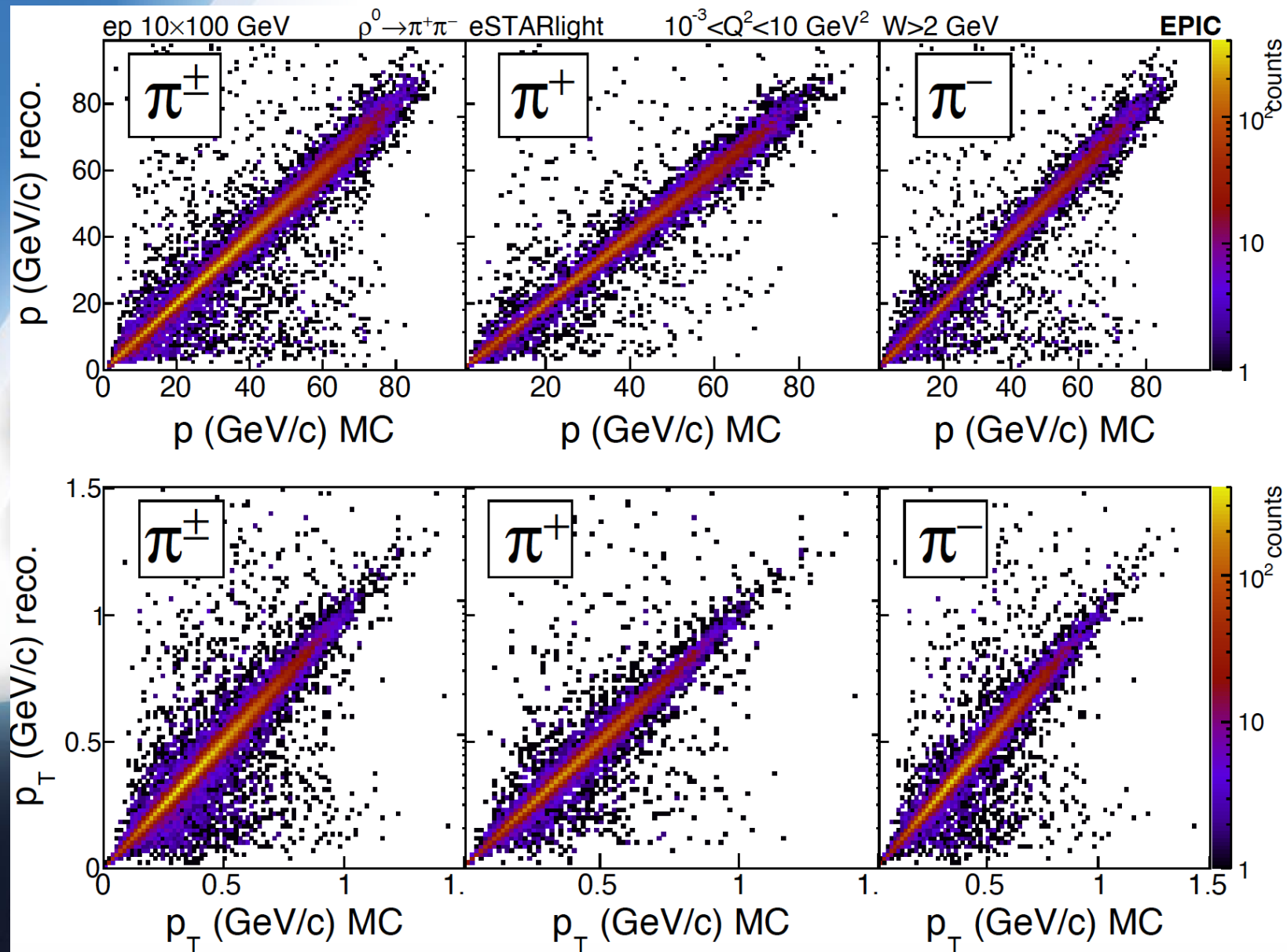


25 mrad



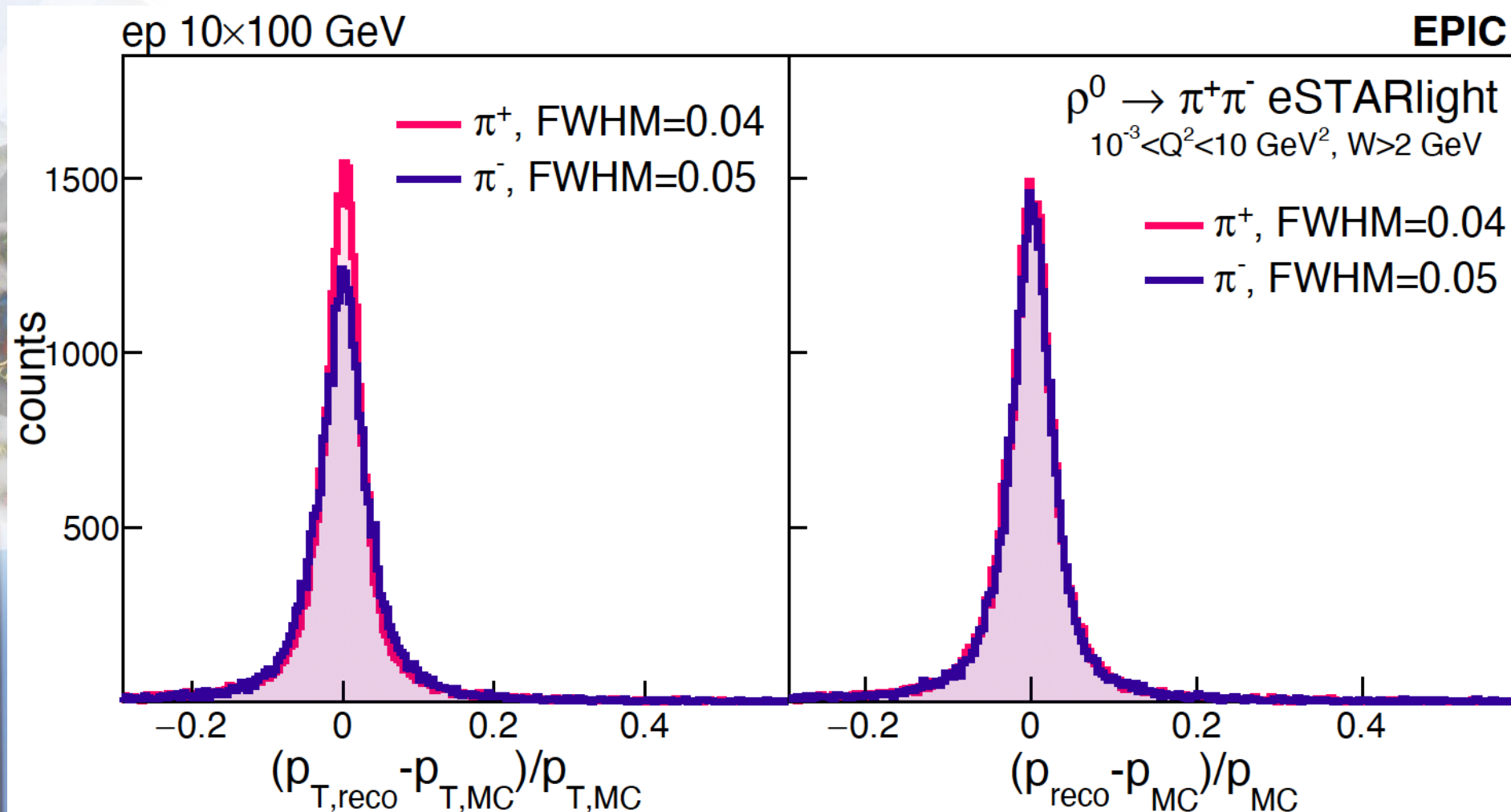


Benchmark plot:
 $\pi^+\pi^-$ reconstruction
efficiency

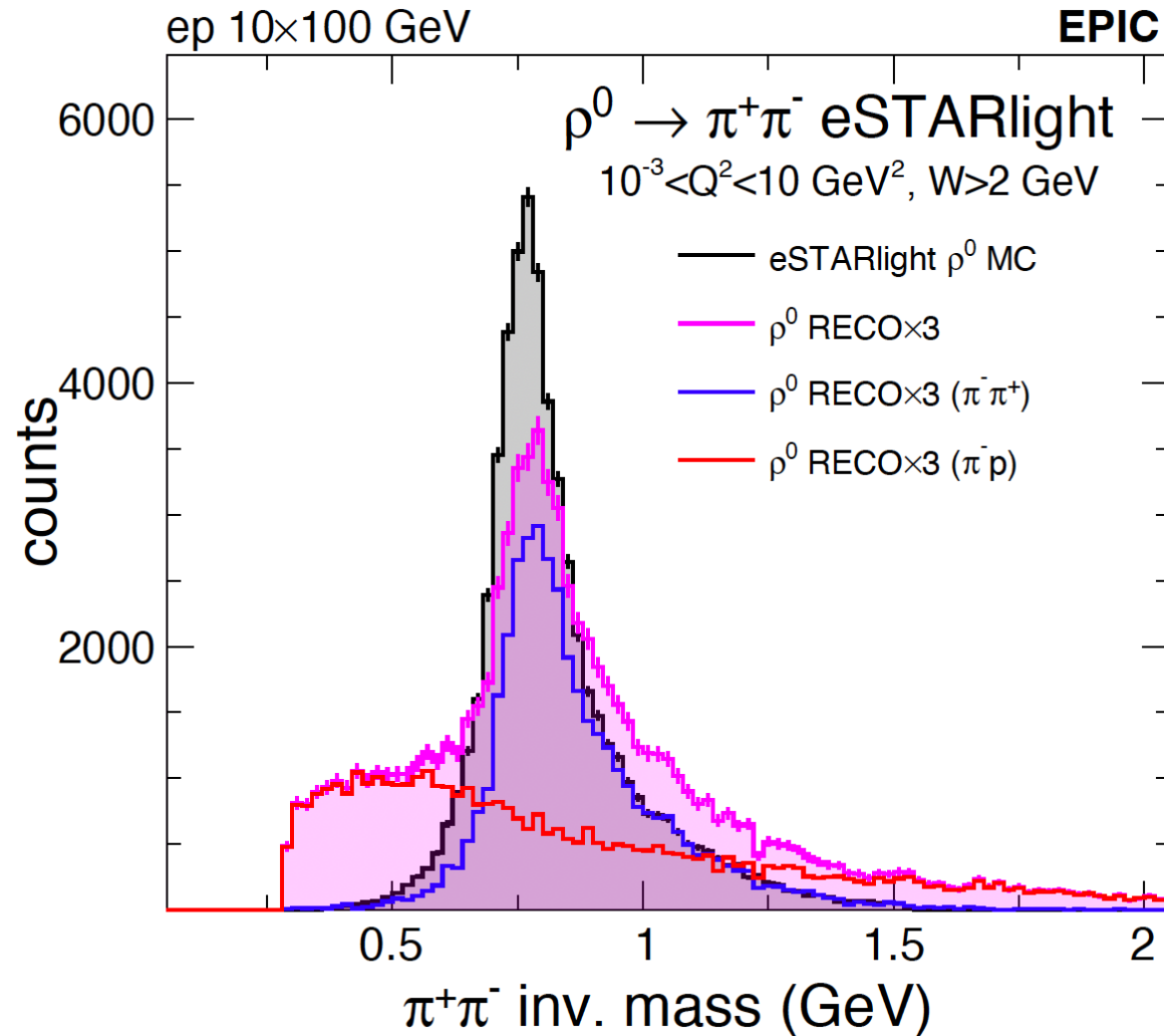


Benchmark plot:
 $\pi^+\pi^-$ reconstruction
quality

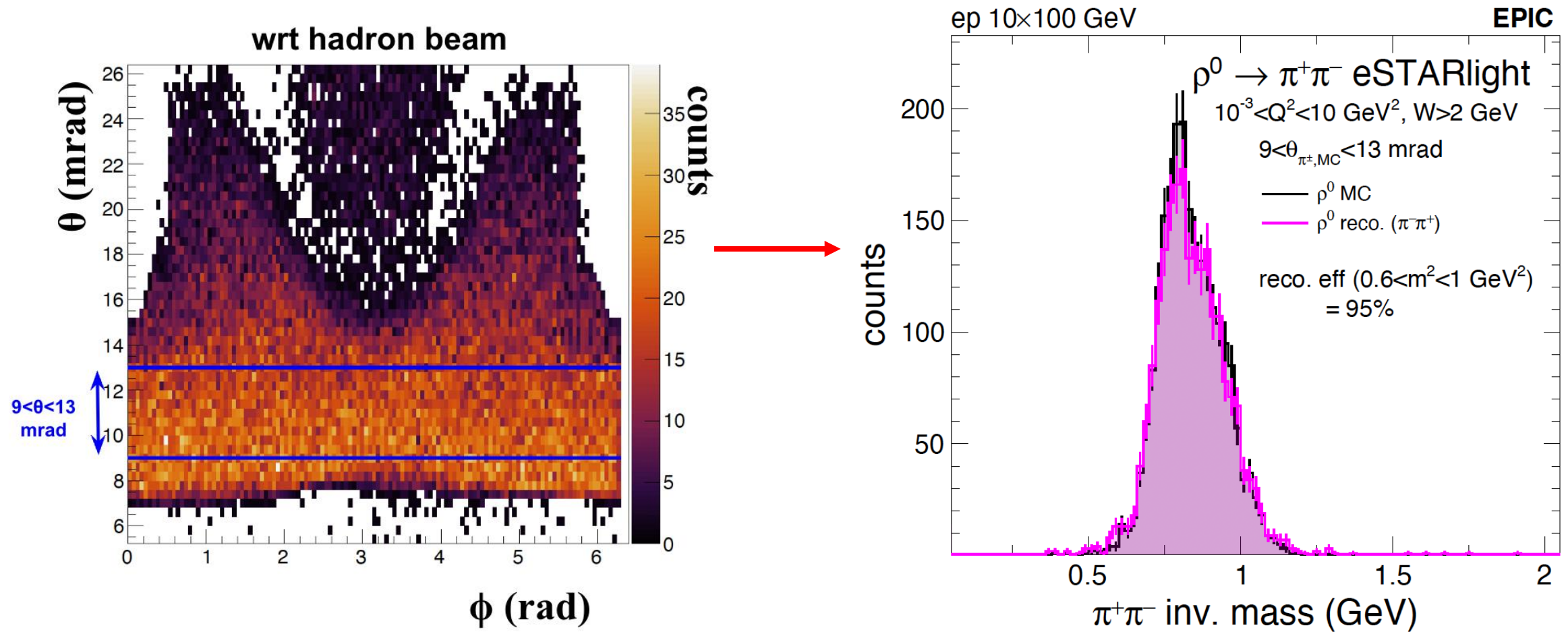
Benchmark plot: $\pi^+\pi^-$ reconstruction quality (percent)



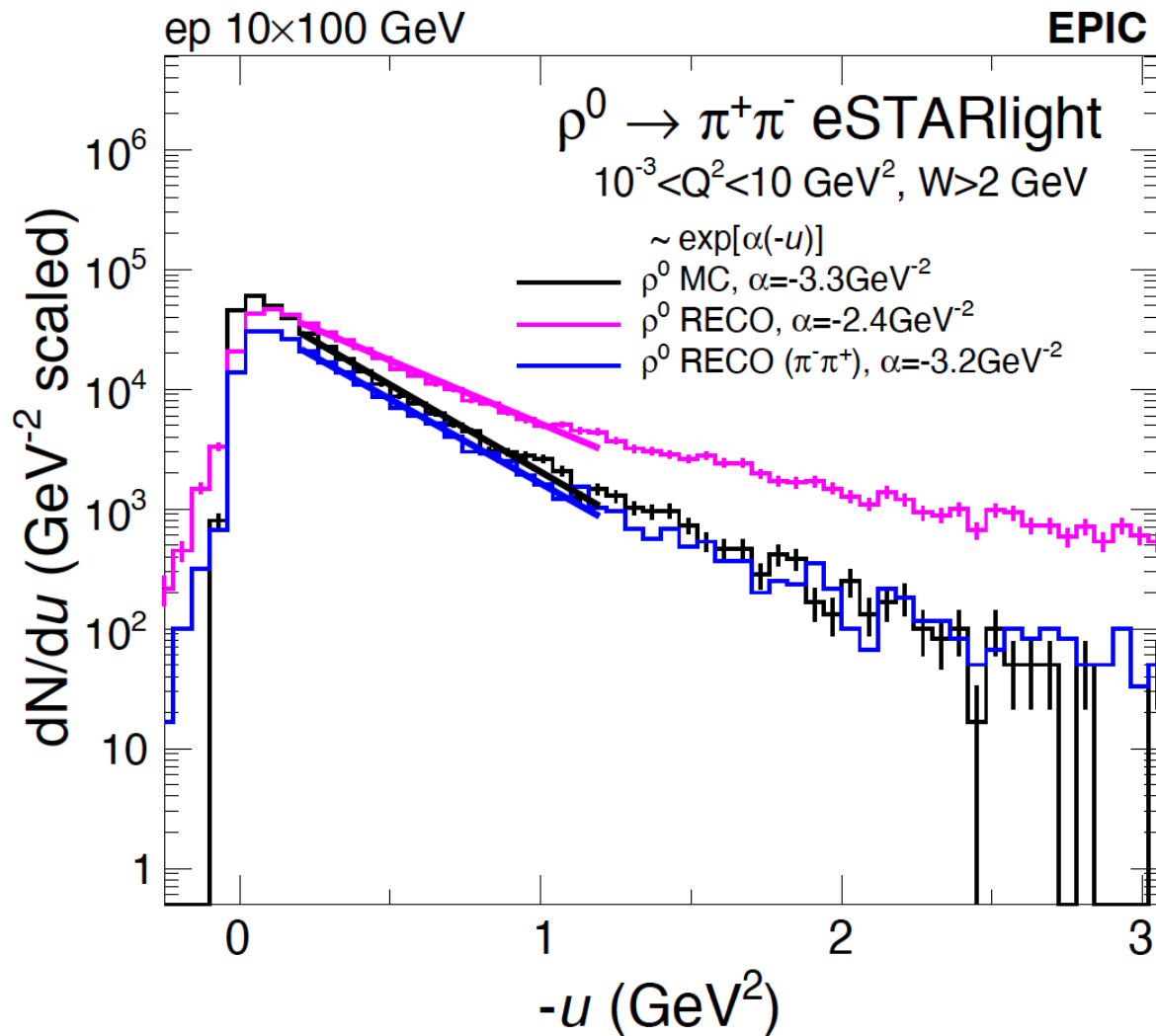
Benchmark plot: ρ^0 mass reconstruction



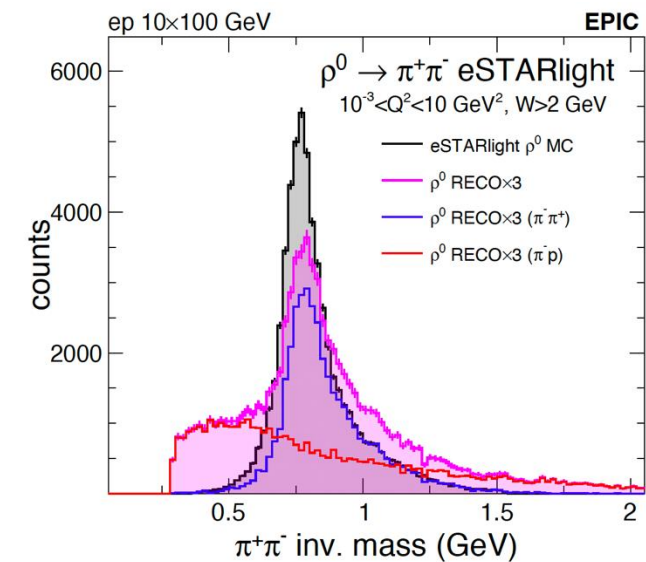
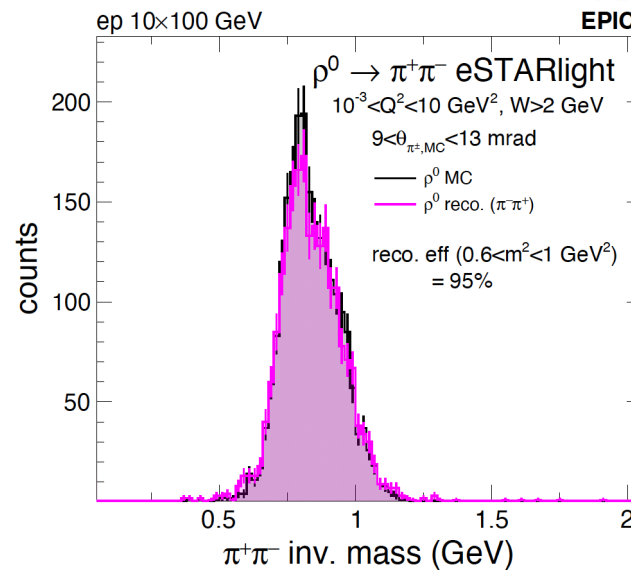
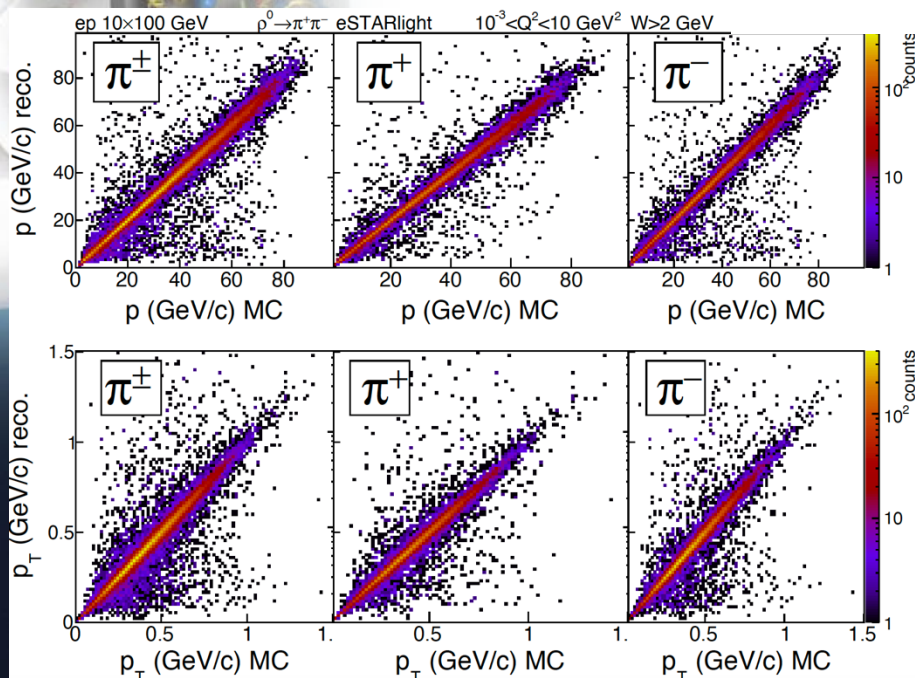
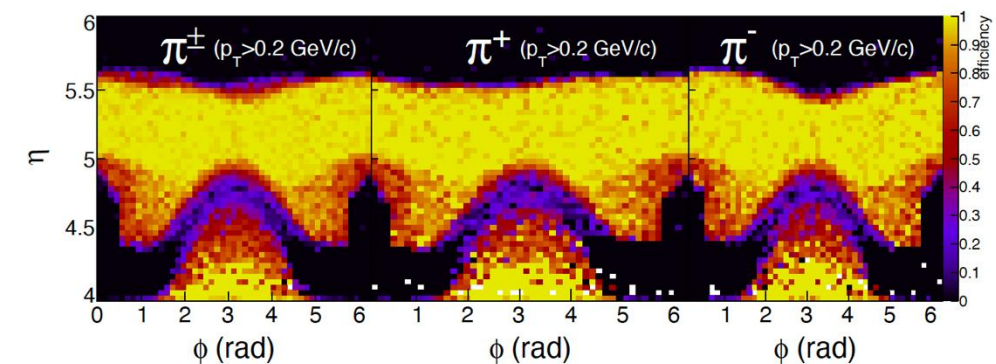
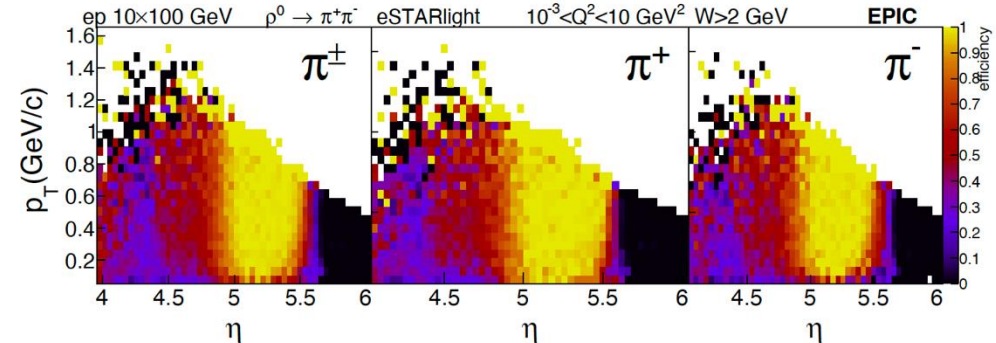
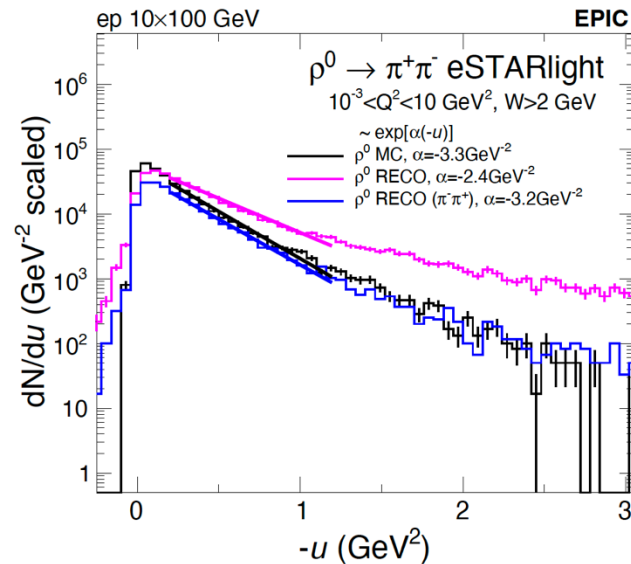
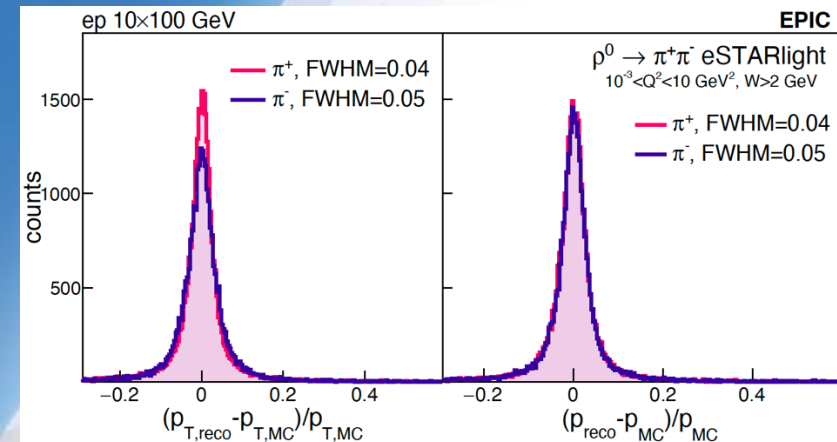
Benchmark plot: ρ^0 mass reconstruction within B0

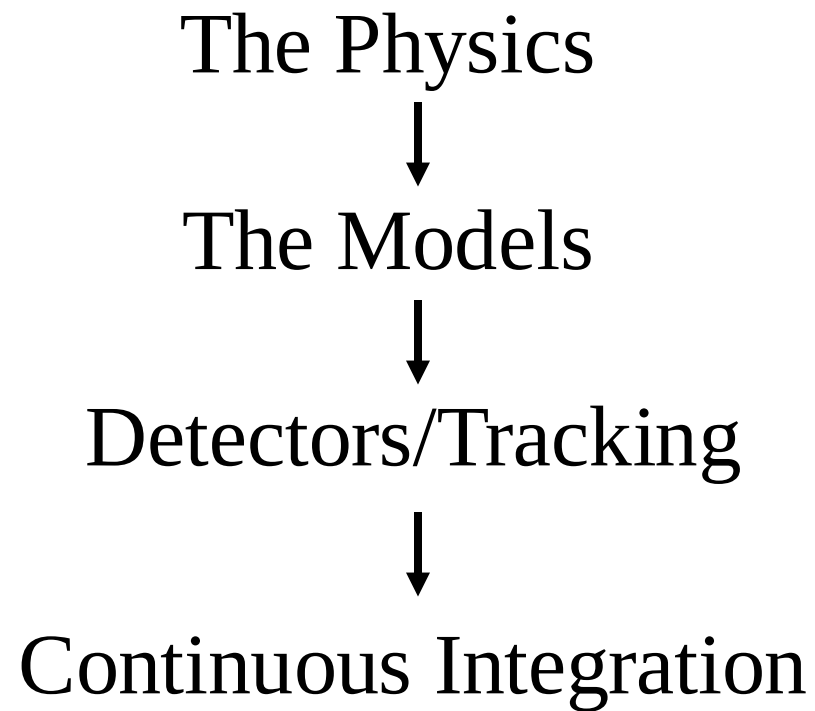


Benchmark plot: u -channel slope reconstruction



Benchmark Figures





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All1,000+FinishedBranchesTags

Filter pipelines

CI lint

Run pipeline

Show Pipeline ID

Status	Pipeline	Created by	Stages	
Running	Hello California! (and John!) #99894 pr/u_channel_sweger 4cd11cd8 trigger token latest		✓ ✓ 🔄 🔄 ⌚ ⌚ ⌚ ⌚ ⌚ ⌚	🛑 📄
» Skipped	Hello California! (and John!) #99893 pr/u_channel_sweger 4cd11cd8 latest			📄
Running	eic/EICrecon: Add Track-Based Cluster Mergin... #99890 master 7df12ae2		🔄 → ✓ ✓ ✓ ✓ 🔄 ✓ ✓ 🔄 ⌚ ⌚	📄
Running	eic/EICrecon: Add Track-Based Cluster Mergin... #99889 master 7df12ae2		🔄 → ✓ ✓ ✓ ✓ 🔄 ✓ ✓ 🔄 ⌚ ⌚	📄
Passed 🕒 02:49:58 📅 1 hour ago	Lambda zdc (#19) #99884 master 7df12ae2		✓ → ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓	📄
Passed 🕒 02:44:52 📅 5 hours ago	eic/EICrecon: MatrixTransferStatic only initializ... #99879 master 7df12ae2		✓ → ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓	📄
Passed 🕒 03:30:19	eic/EICrecon: MatrixTransferStatic only initializ... #99878 master 7df12ae2		✓ → ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓	📄

How the Benchmark Works

- The pipeline walks through 11 steps including Geant simulations of detector response, tracking and reco, and the analysis script

EIC / benchmarks / physics_benchmarks / Pipelines / #99894

Hello California! (and John!)

Running Dmitry Kalinkin created pipeline for commit 4cd11cd8 just now

For pr/u_channel_sweger

trigger token latest 56 jobs In progress, queued for 3 seconds

Pipeline Needs Jobs 56 Tests 0

Group jobs by Stage Job dependencies

status-pending	config	initialize	compile	generate
✓ benchmarks:physics:pending	✓ common:setup	✓ common:detector	dis:compile	dis:gene
			✓ single:compile	u_chann
			✓ u_channel_rho:compile	

How the Benchmark Works

- The pipeline walks through 11 steps including Geant simulations of detector response, tracking and reco, and the analysis script
- Explore at: https://eicweb.phy.anl.gov/EIC/benchmarks/physics_benchmarks/-/pipelines/99894

The screenshot displays the EIC Benchmarks Pipeline interface. On the left is a sidebar with navigation options: Project (physics_benchmarks), Pinned, Issues (16), Merge requests (7), Manage, Plan, Code, Build, Pipelines (selected), Jobs, Pipeline editor, Pipeline schedules, Artifacts, Secure, Deploy, Operate, Monitor, Analyze, and Help. The main content area shows the pipeline details for 'Hello California! (and John!)'. It indicates the pipeline is 'Running' and was created by Dmitry Kalinkin for commit 4cd11cd8. The pipeline is for the 'pr/u_channel_swager' branch and is triggered by a 'trigger token' at the 'latest' version. It shows 56 jobs in progress, queued for 3 seconds. The pipeline is grouped by 'Stage' and 'Job dependencies'. The stages and their jobs are: 'status-pending' (benchmark:physics:pending), 'config' (common:setup), 'initialize' (common:detector), 'compile' (dis:compile, single:compile, u_channel_rho:compile), and 'generate' (dis:gene, u_chann). A red box highlights the 'compile' and 'generate' stages.

EIC / benchmarks / physics_benchmarks / Pipelines / #99894

Hello California! (and John!)

Running Dmitry Kalinkin created pipeline for commit 4cd11cd8 just now

For pr/u_channel_swager

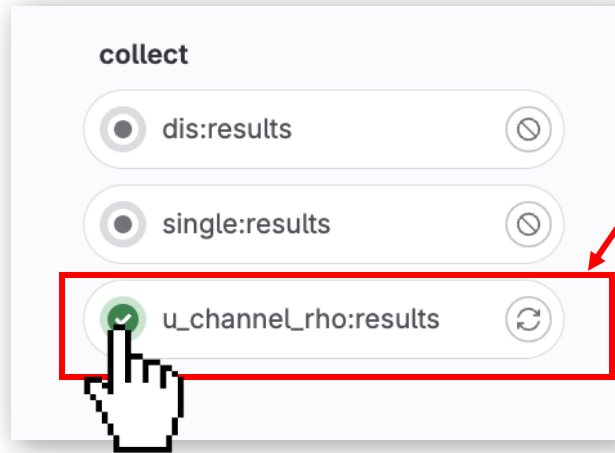
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✓ benchmark:physics:pending	✓ common:setup	✓ common:detector	dis:compile	dis:gene
			✓ single:compile	u_chann
			✓ u_channel_rho:compile	

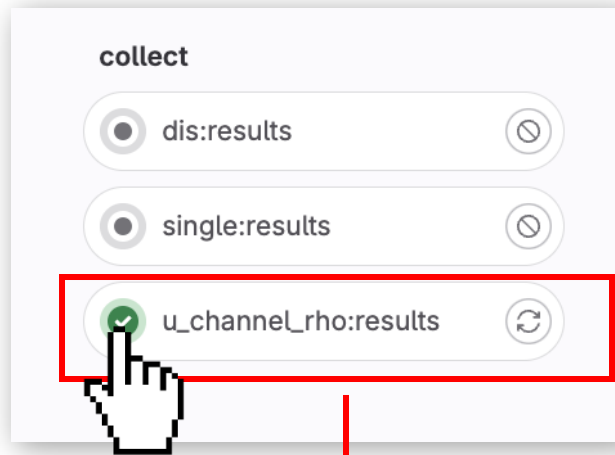
How the Benchmark Works



- By clicking on the “collect” stage, you can view a log of the analysis script

How the Benchmark Works

- By clicking on the “collect” stage, you can view a log of the analysis script



EIC / benchmarks / physics_benchmarks / Jobs / #3641318

Search job log

```
37 --> Loading benchmark definition from: benchmarks/u_rho/benchmark.json
38 --> Collecting all test results
39 --> Loading file: results/u_rho/u_rho_eff.json ... done
40 --> Aggregating benchmark statistics
41 --> Saving benchmark results to: results/u_rho.json
42 =====
43 Summary for: u-Channel Rho Benchmarks
44 Pass: 1, Fail: 0, Error: 0 out of 1 total tests
45 Weighted sum: 1.0 / 1.0
46 Benchmark value: 1.0 (target: 0.9)
47 ==> status: pass
48 =====
49 $ echo "Finished collecting!"
50 Finished collecting!
51 Uploading artifacts for successful job
52 Uploading artifacts...
```

00:03

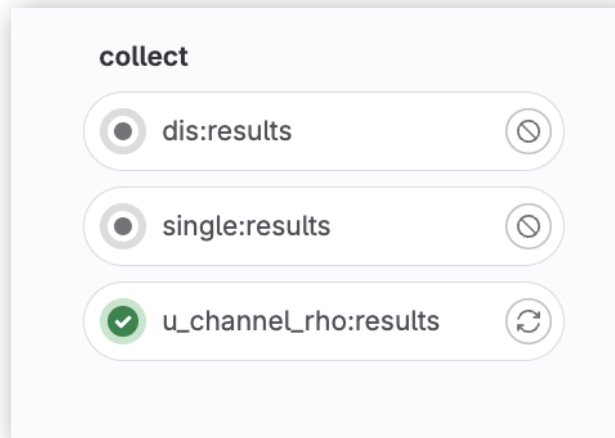
Duration: 10 seconds
Finished: 17 minutes ago
Queued: 2 seconds
Timeout: 6h (from project) ⓘ
Runner: #71 (Twsw3h3hWs) Runner on eic-n0 with write access to scratch
Tags: phy-scratch

Job artifacts ⓘ
These artifacts are the latest. They will not be deleted (even if expired) until newer artifacts are available.

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How the Benchmark Works

- By clicking on the “collect” stage, you can view a log of the analysis script
- The pipeline creates “artifacts” which are just the plots and files from the analysis script



EIC / benchmarks / physics_benchmarks / Jobs / #3641318

Search job log

```
37 --> Loading benchmark definition from: benchmarks/u_rho/benchmark.json
38 --> Collecting all test results
39 --> Loading file: results/u_rho/u_rho_eff.json ... done
40 --> Aggregating benchmark statistics
41 --> Saving benchmark results to: results/u_rho.json
42 =====
43 Summary for: u-Channel Rho Benchmarks
44 Pass: 1, Fail: 0, Error: 0 out of 1 total tests
45 Weighted sum: 1.0 / 1.0
46 Benchmark value: 1.0 (target: 0.9)
47 ==> status: pass
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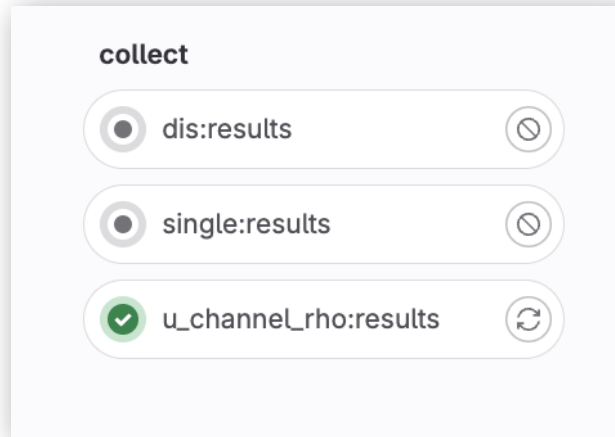
00:03

Duration: 10 seconds
Finished: 17 minutes ago
Queued: 2 seconds
Timeout: 6h (from project) ⓘ
Runner: #7 (Twsw3hWs) Runner on eic-n0 with write access to scratch
Tags: phy-scratch

Job artifacts ⓘ
These artifacts are the latest. They will not be deleted (even if expired) until newer artifacts are available.

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How the Benchmark Works



- By clicking on the “collect” stage, you can view a log of the analysis script
- The pipeline creates “artifacts” which are just the plots and files from the analysis script
- You can browse these by clicking here

EIC / benchmarks / physics_benchmarks / Jobs / #3641318

Search job log

```
37 --> Loading benchmark definition from: benchmarks/u_rho/benchmark.json
38 --> Collecting all test results
39 --> Loading file: results/u_rho/u_rho_eff.json ... done
40 --> Aggregating benchmark statistics
41 --> Saving benchmark results to: results/u_rho.json
42 =====
43 Summary for: u-Channel Rho Benchmarks
44 Pass: 1, Fail: 0, Error: 0 out of 1 total tests
45 Weighted sum: 1.0 / 1.0
46 Benchmark value: 1.0 (target: 0.9)
47 ==> status: pass
48 =====
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```

00:03

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Tags: phy-scratch

Job artifacts ⓘ
These artifacts are the latest. They will not be deleted (even if expired) until newer artifacts are available

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How the Benchmark Works

- [Hot and ready plots](#) to evaluate detector performance!

Job artifacts ?

These artifacts are the latest. They will not be deleted (even if expired) until newer artifacts are available.

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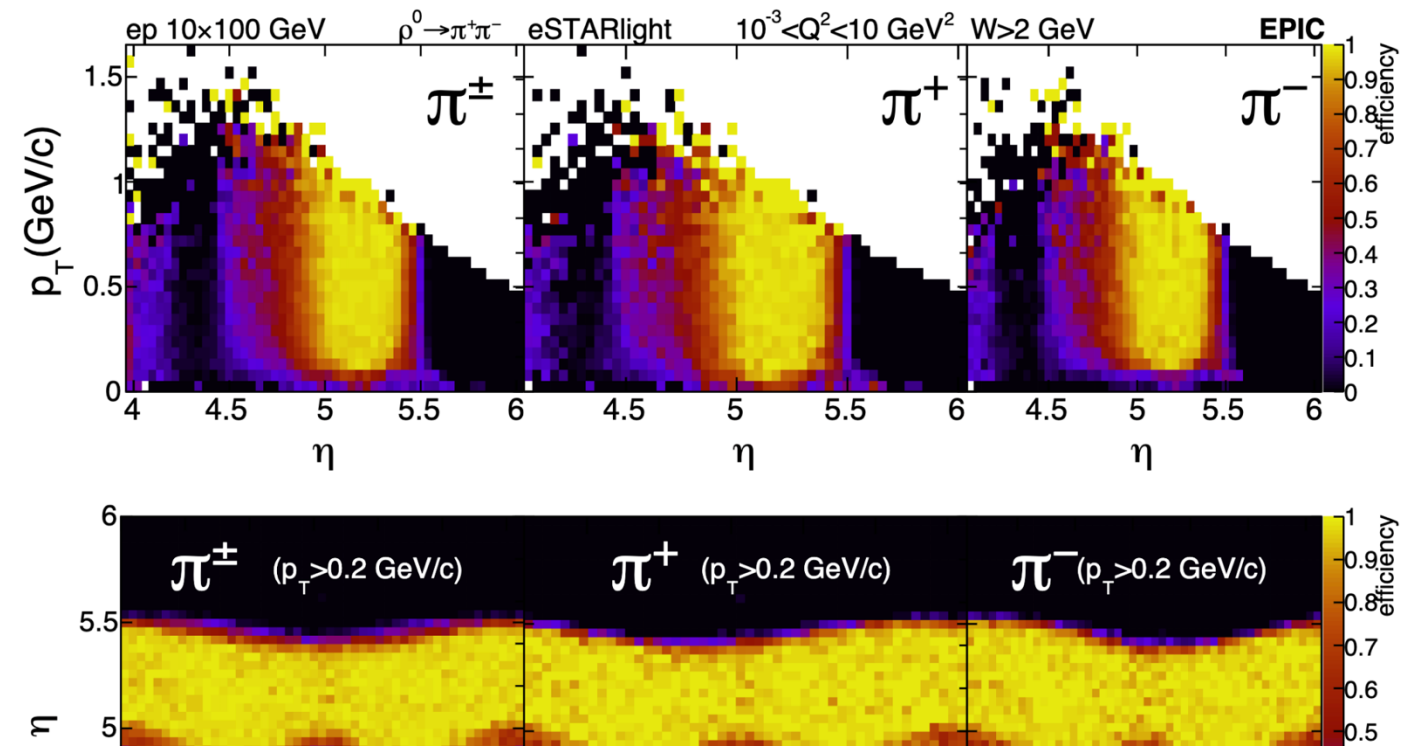
Help

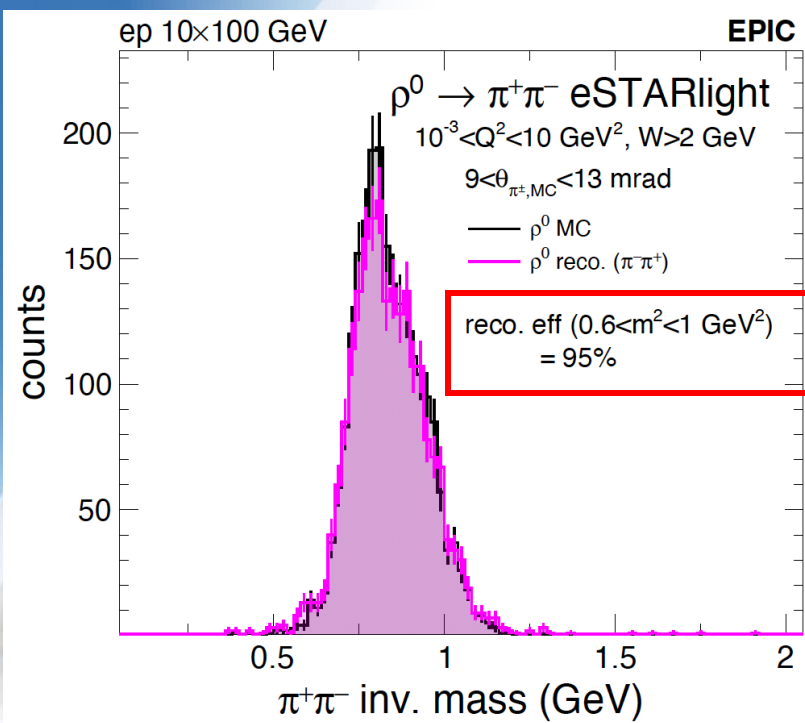
EIC / benchmarks / physics_benchmarks / Jobs

passed Job #3641318 in pipeline #99894 for 4cd11cd8 from pr/u_channel_sweger by Dmitry Kalinkin 50 minutes ago

Artifacts

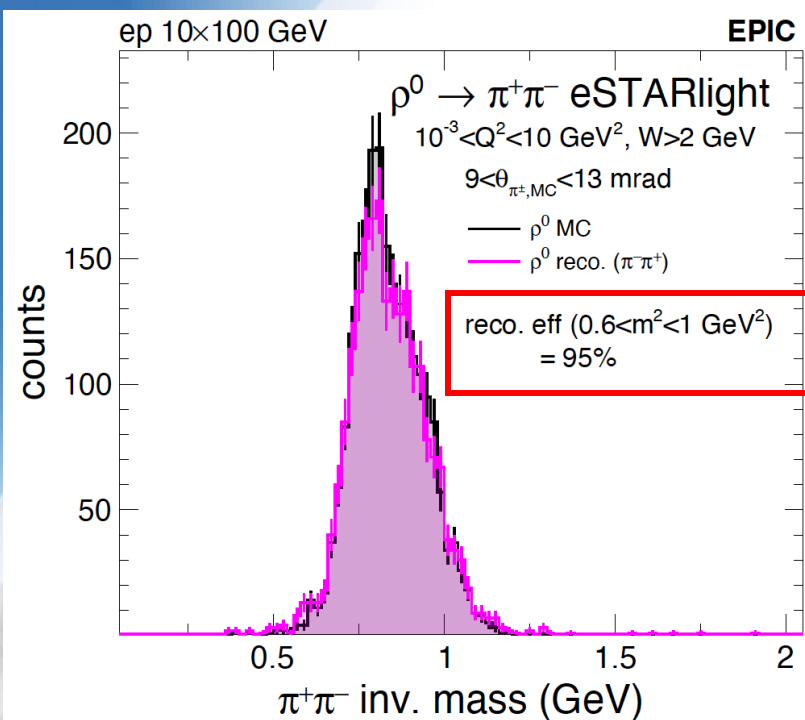
benchmark_rho_efficiencies.pdf 88.6 KiB





Benchmark Status Flag: ρ^0 Reconstruction Efficiency

- Raise a bad status flag if this eff. drops below 90%
- Status procedure detailed in [common_bench](#) repo



Benchmark Status Flag:

ρ^0 Reconstruction Efficiency

- Raise a bad status flag if this eff. drops below 90%
- Status procedure detailed in [common_bench](#) repo
- The benchmark status flag seems to have worked

Explore

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Project

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- Plan
- Code
- Build
- Pipelines
- Jobs
- Pipeline schedules
- Artifacts
- Deploy

Search job log

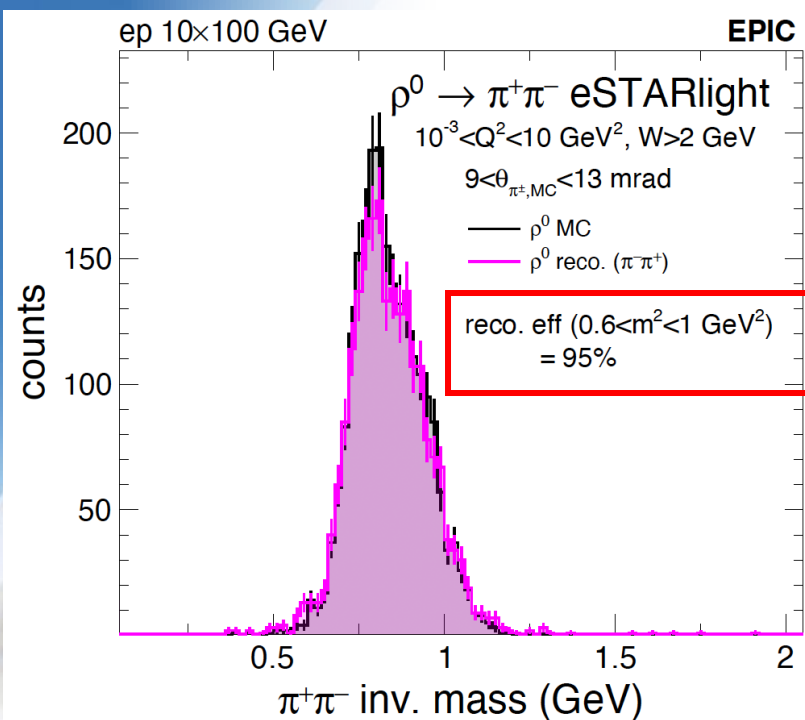
```
2178 Writing test data to rhorecoeff.json
2179 {
2180   "tests": [
2181     {
2182       "description": "u-channel rho->pi+pi- reconstruction efficiency when both pions should be within B0 acceptance",
2183       "name": "rho_reconstruction_efficiency",
2184       "quantity": "efficiency",
2185       "result": "pass",
2186       "target": "0.9",
2187       "title": "rho Reconstruction Efficiency for rho -> pi+pi- in the B0",
2188       "value": 0.9605459586265728,
2189       "weight": 1.0
2190     }
2191   ]
2192 }
```

Duration: 4 minutes 50 seconds
Finished: 14 minutes ago
Queued: 0 seconds
Timeout: 6h (from project)
Runner: #71 (Twsw3hWs) Runner on eic-n0 with write access to scratch
Tags: phy-scratch

Job artifacts
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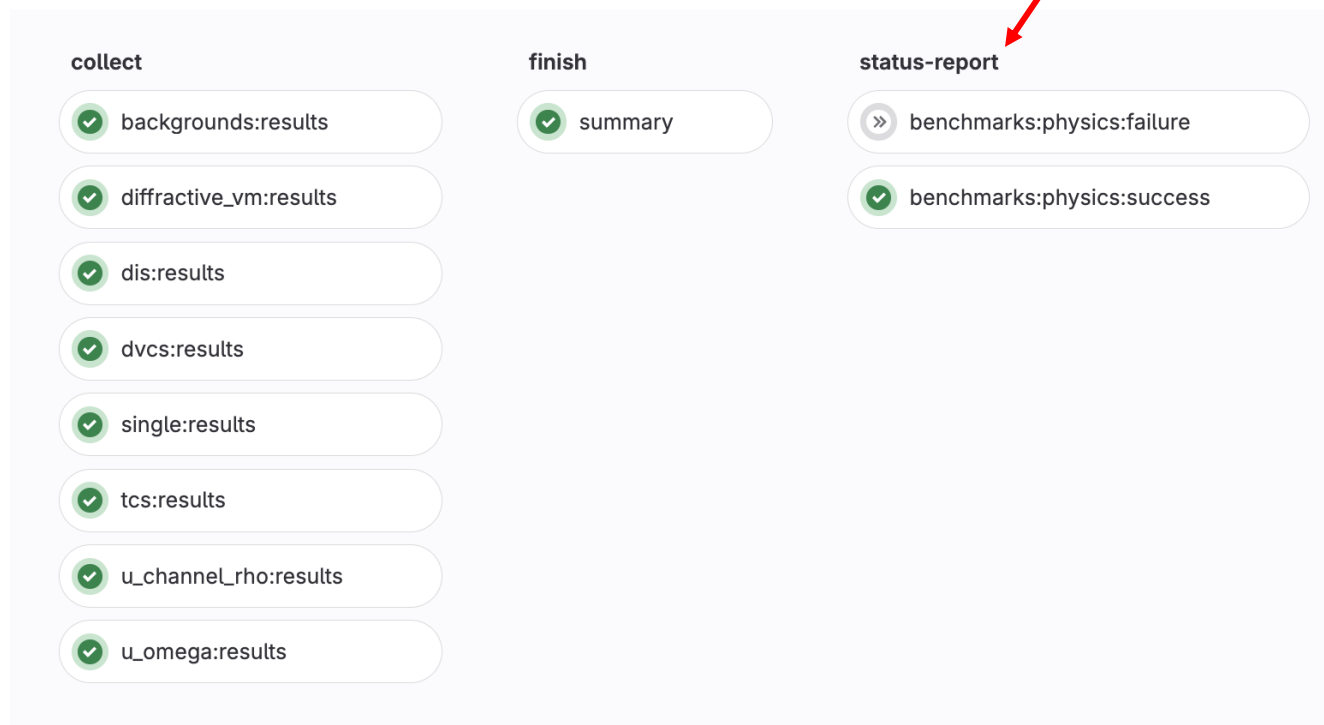
Trigger token: b5c6



Benchmark Status Flag:

ρ^0 Reconstruction Efficiency

- Raise a bad status flag if this eff. drops below 90%
- Status procedure detailed in [common_bench](#) repo
- The benchmark status flag seems to have worked
- Flag is now propagated to last pipeline step!



Benchmark Plots Explained

- The most important artifact created with each pipeline is this [bench.pdf](#) which explains each figure and defines quantities like “efficiency,” kinematic cuts, etc.

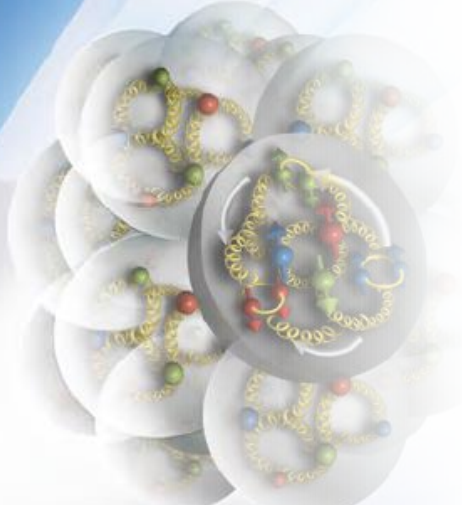
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passed

Job #3641318 in pipeline #99894 for 4cd11cd8 from pr/u_channe`l_sweger by Dmitry Kalinkin 1 day ago

Artifacts

bench.pdf

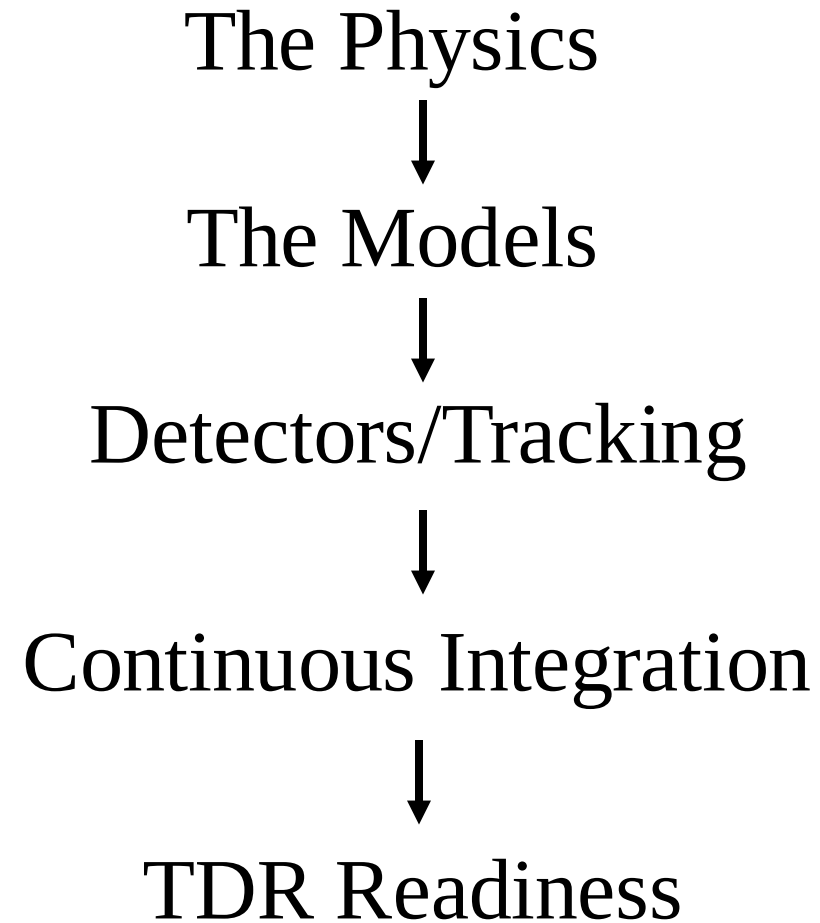
27.6 KiB

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u -channel ρ^0 Benchmark Figures

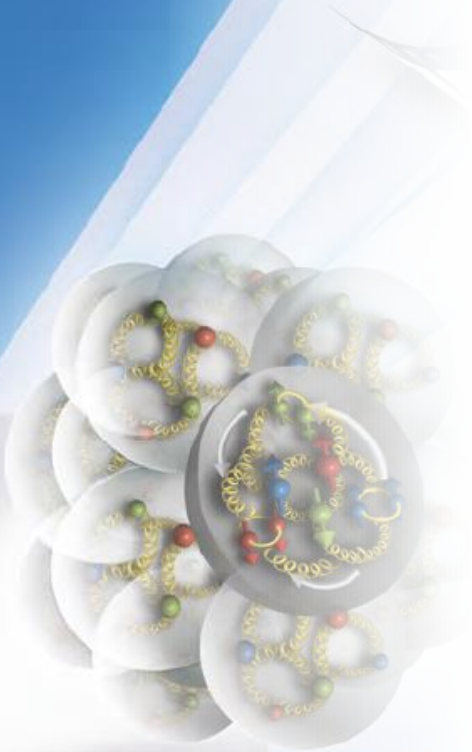
benchmark_rho_mass.pdf: This figure shows the reconstruction of the ρ^0 mass. The **black** histogram is the invariant mass of each MC $\pi^+\pi^-$ pair after being processed by the afterburner. The **blue** histogram is the invariant mass of reconstructed $\pi^+\pi^-$ pairs with no cuts on acceptance. PDG codes were used to select pions, although this PID is unrealistic. In the absence of PID, the ρ^0 will be reconstructed from each oppositely-charged track. The dominant combinatorial background from this approach comes from pairing protons with the π^- . This $m_{p\pi^-}$ background is shown by the red histogram. The sum of the signal and background is shown in **magenta**.

benchmark_rho_mass_cuts.pdf: This figure shows ρ^0 mass reconstruction for events in which both MC-level pions should be within the B0 acceptance ($9 < \theta < 13$ mrad with respect to the hadron beam pipe). The **black** histogram is the invariant mass of each MC $\pi^+\pi^-$ pair which passes this θ cut after being processed by the afterburner. The **magenta** histogram is the invariant mass of reconstructed $\pi^+\pi^-$ pairs for these same events. PDG codes were used to select pions. The **magenta** and **black** distributions were integrated over $0.6 < m < 1$ GeV to calculate the ρ^0 reconstruction efficiency.



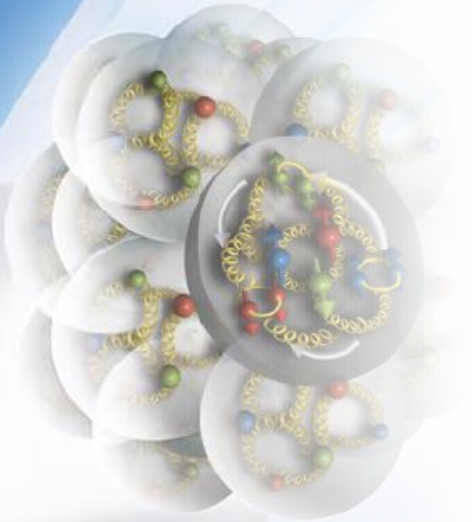
Benchmark Tutorial

- ePIC has been running tutorials for TDR readiness



Benchmark Tutorial

- ePIC has been running tutorials for TDR readiness
- I've been contacted to organize a tutorial on developing benchmarks



Benchmark Tutorial

- ePIC has been running tutorials for TDR readiness
- I've been contacted to organize a tutorial on developing benchmarks
- Tutorial will be October 3rd 1-4pm EST! (It'll be recorded & posted)

This lesson is in the early stages of development (Alpha version)

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Developing Benchmarks

Benchmarks are scripts that run detector simulations and analyze the resulting data to extract quantities related to the detector performance.

☀ Prerequisites

The following tutorial assumes basic knowledge of shell. It may be practical to use eic-shell for benchmark development, as it is the environment that will closely match the one during benchmark execution. It also assumes that you are a member of the [EIC organization](#) on GitHub and belong to the “epic-devs” team. You also need to have your local ssh key added to GitHub so that you can push.

Schedule

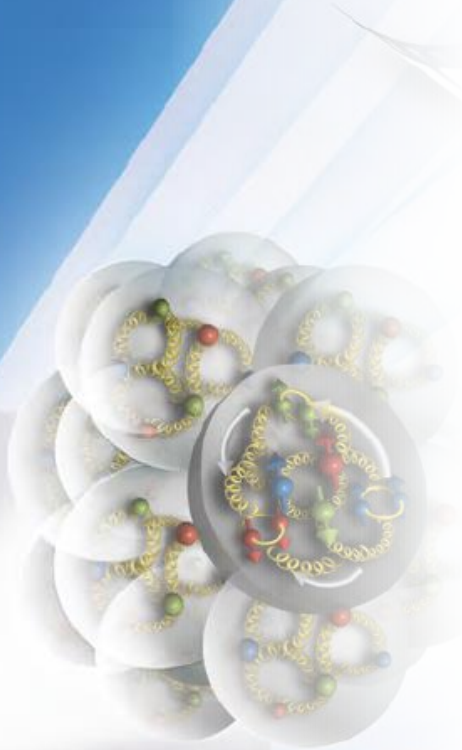
	Setup	Download files required for the lesson
00:00	1. Excercise 1: Setting up your first benchmark	
00:20	2. Excercise 2: Workflow management with Snakemake	How does one share data analysis workflows?
00:40	Finish	

Conclusions

- The backward rho benchmark for the B0 is in good shape
 - ✓ Easily switches between simulation campaign files and dynamically-simulated results (1 hour per 1000 events)
 - ✓ Produces presentation-ready figures
 - ✓ Contains status flag to communicate detrimental changes in B0 performance
- Thanks to Saeahram Yoo for fixing reco. association issue in the code!
- I am now working with ePIC software devs to organize a tutorial on making benchmarks
- Next: Finish the ZDC u -channel π^0 benchmark

**Electron Ion Collider:
The Next QCD Frontier**

Understanding the glue
that binds us all



Thank you for your attention!

zwsweger@ucdavis.edu