t reconstruction studies for DEMP events with LYSO+SiPM-on-tile ZDC

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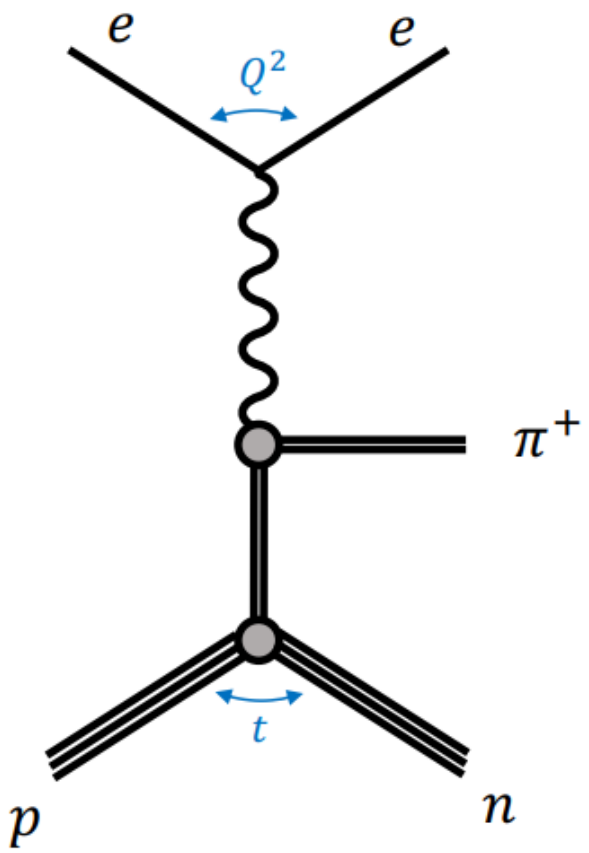
Motivation

- We want to identify some physics processes which we can use to study the performance of the SiPM-on-tile ZDC.
- We then would like to put the performance studies into the official ePIC physics benchmarks repository: https://github.com/eic/physics_benchmarks. This will allow the results to be easily reproducible for the TDR, as well as allow them to be run as part of the monthly simulation campaign.

Deep Exclusive Meson Production (DEMP)

$e^- + p^+ \rightarrow e^- + pi^+ + n$

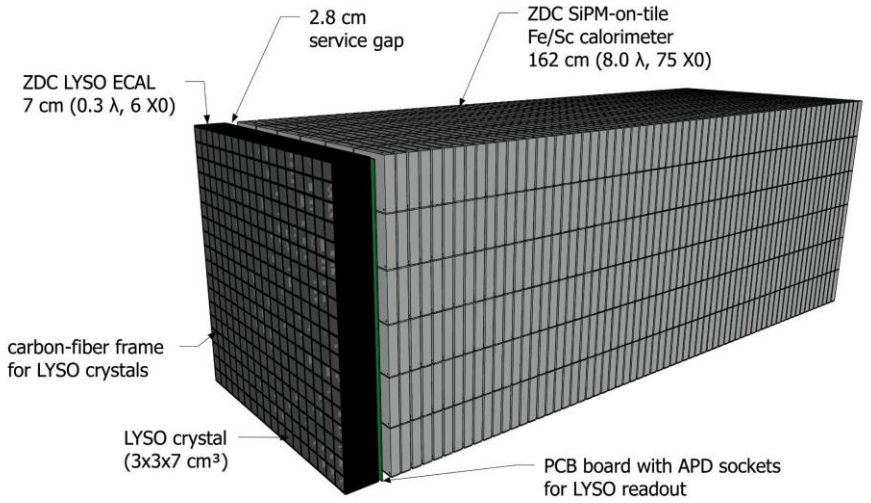


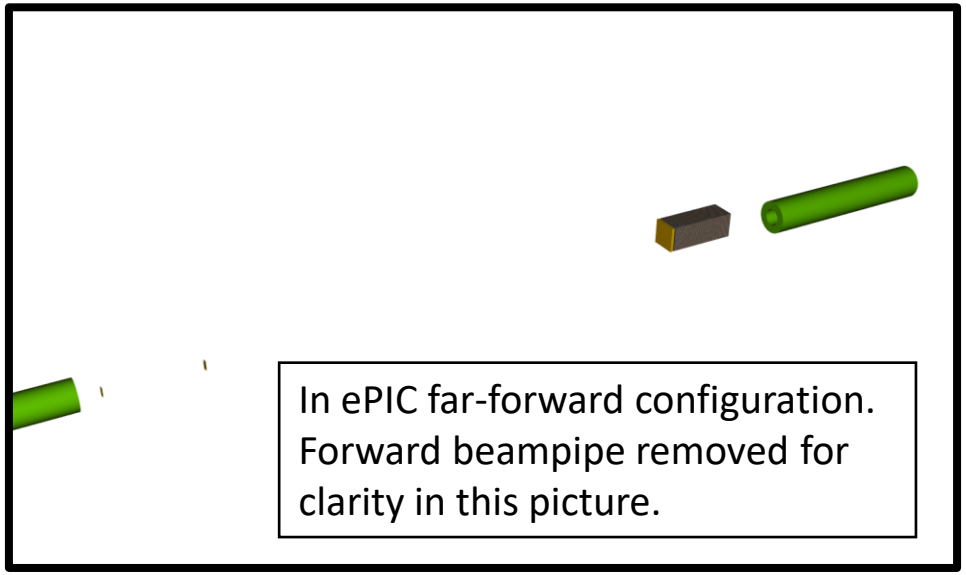
There are some good reasons to use this process for the first set of physics studies:

1. Simple 3-particle final state. Electron and positive pion go into the main detector. The neutron goes into the ZDC.
2. Good reconstruction of the neutron angle may be needed for accurate **t** reconstruction.
3. Generated events from the *DEMPgen* event generator exist on S3 in HepMC3 format. These events have the IP6 crossing angle and beam smearing effects already applied

LYSO+SiPM-on-tile ZDC in the ePIC geometry

- The SiPM-on-tile ZDC detector geometry exists in the ePIC repository and is now the default ZDC configuration. ePIC PR #610, #611.
- Reconstruction has been implemented in an EICRecon branch. Pull request is under review.

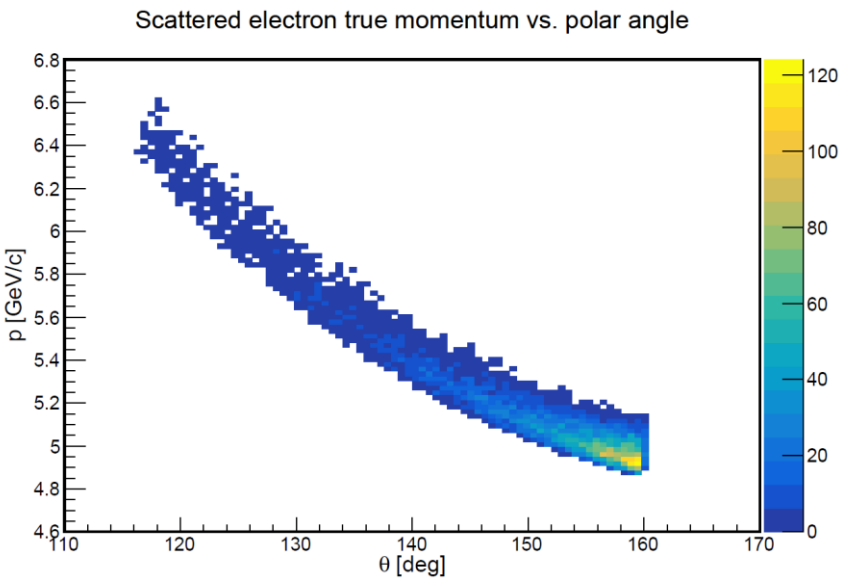


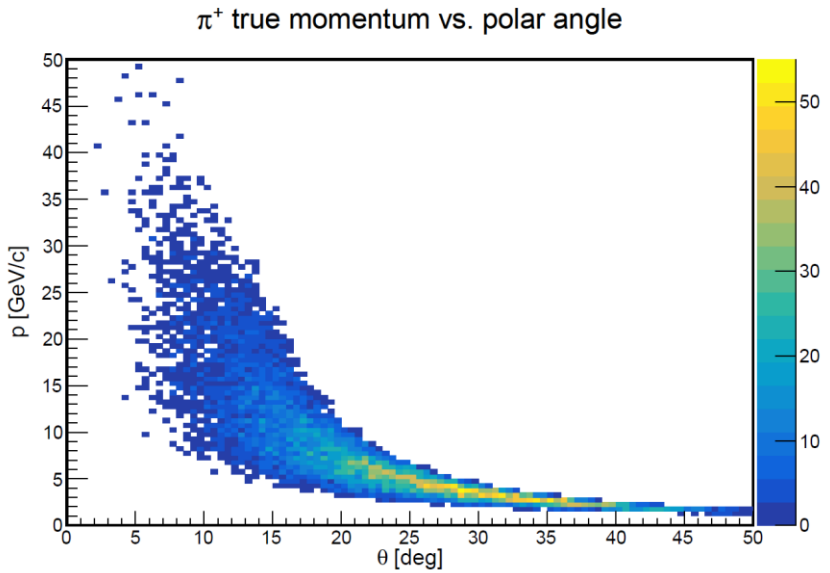


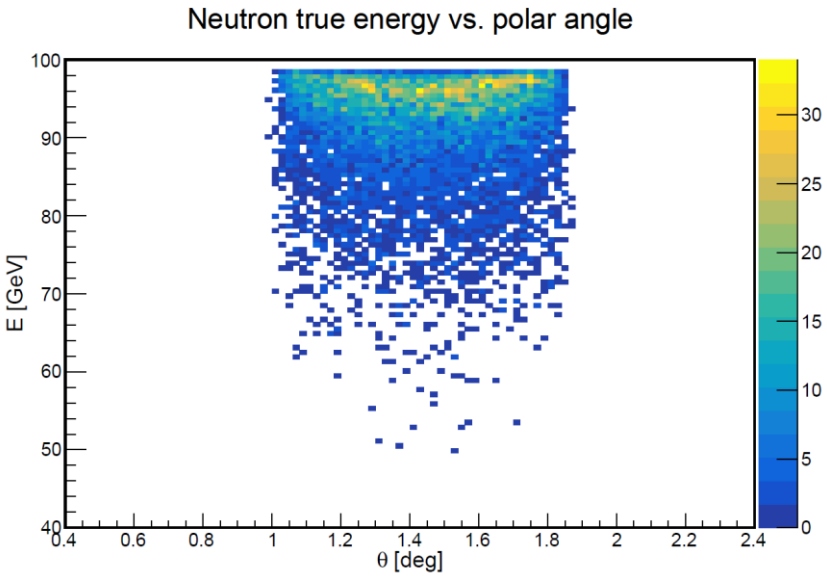
In ePIC far-forward configuration. Forward beampipe removed for clarity in this picture.

Results with DEMP simulation – truth level

5x100 GeV – 10k events simulated



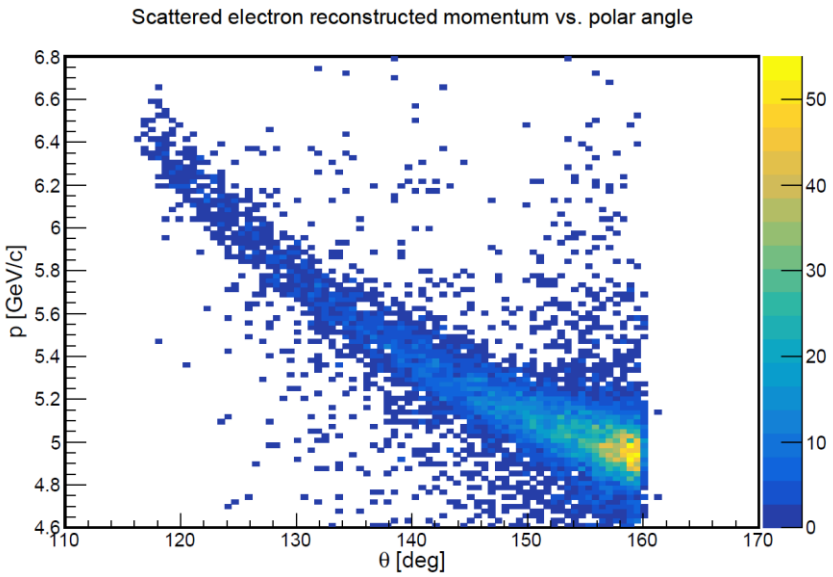


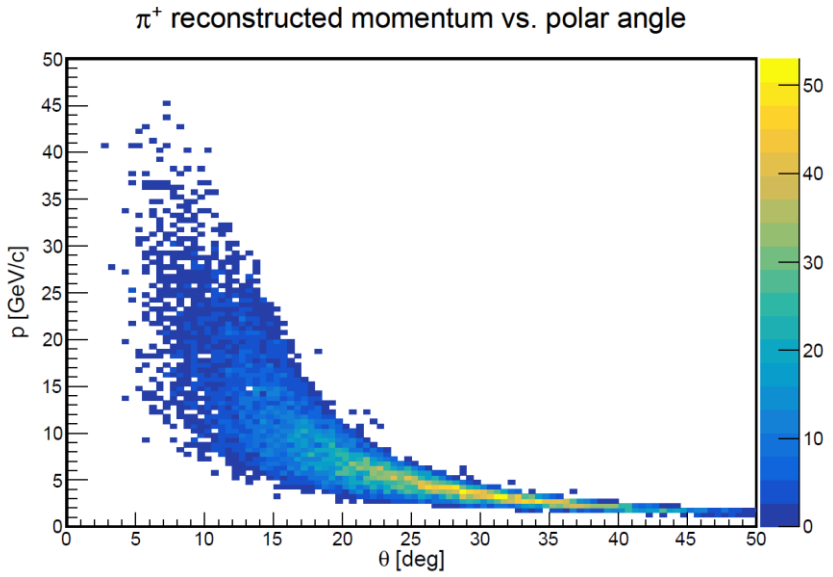


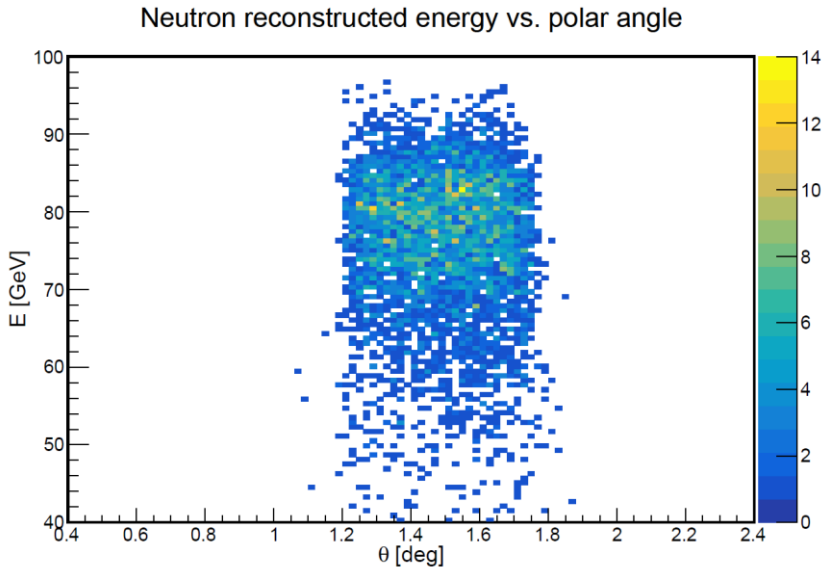
Neutron centered around 25 mRad (1.4 degrees), which is the proton beam direction

Results with DEMP simulation – reconstructed level

5x100 GeV – 10k events simulated





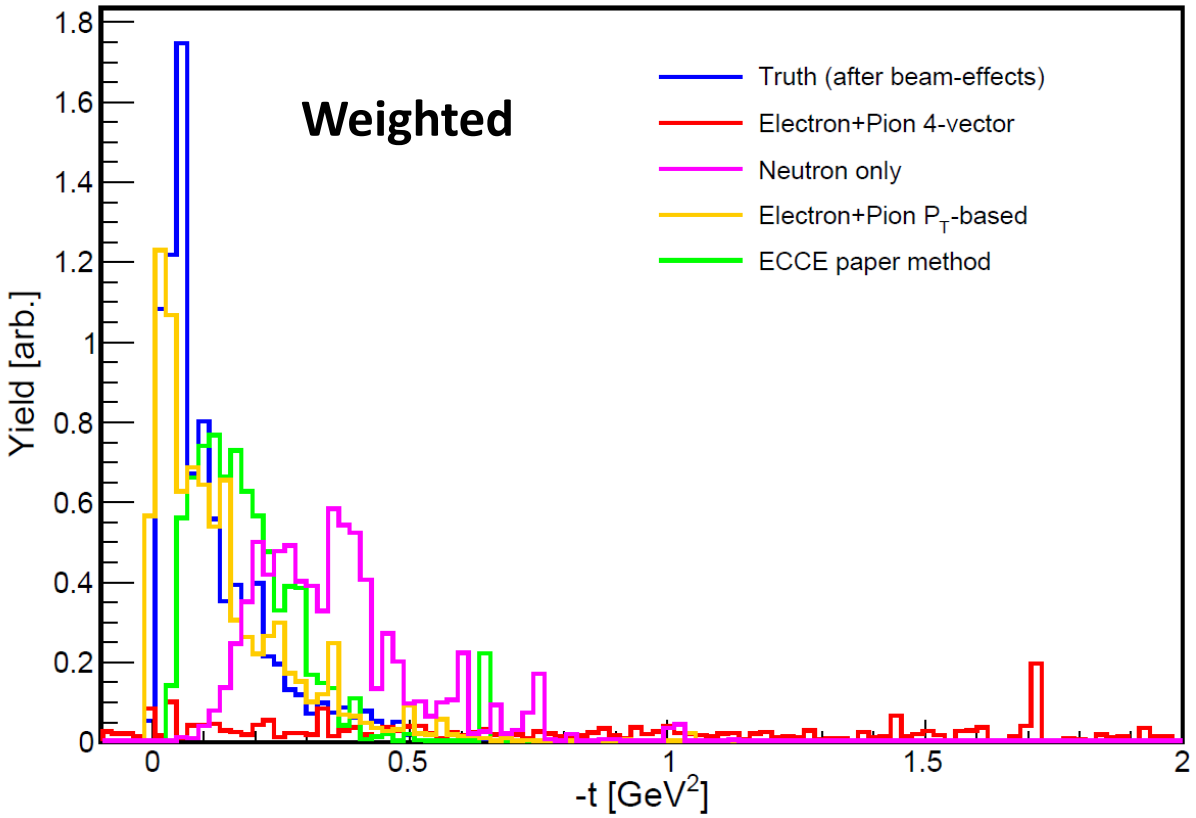


Electron and pion are reconstructed using the central detector tracker (i.e. ReconstructedChargedParticles)

The neutron is reconstructed in the ZDC using the HEXPLIT algorithm: https://arxiv.org/pdf/2308.06939.pdf

t reconstruction

5x100 GeV – 10k events simulated



Electron+Pion 4-vector:

$$t = (p_e - p_{e\prime} - p_\pi)^2$$

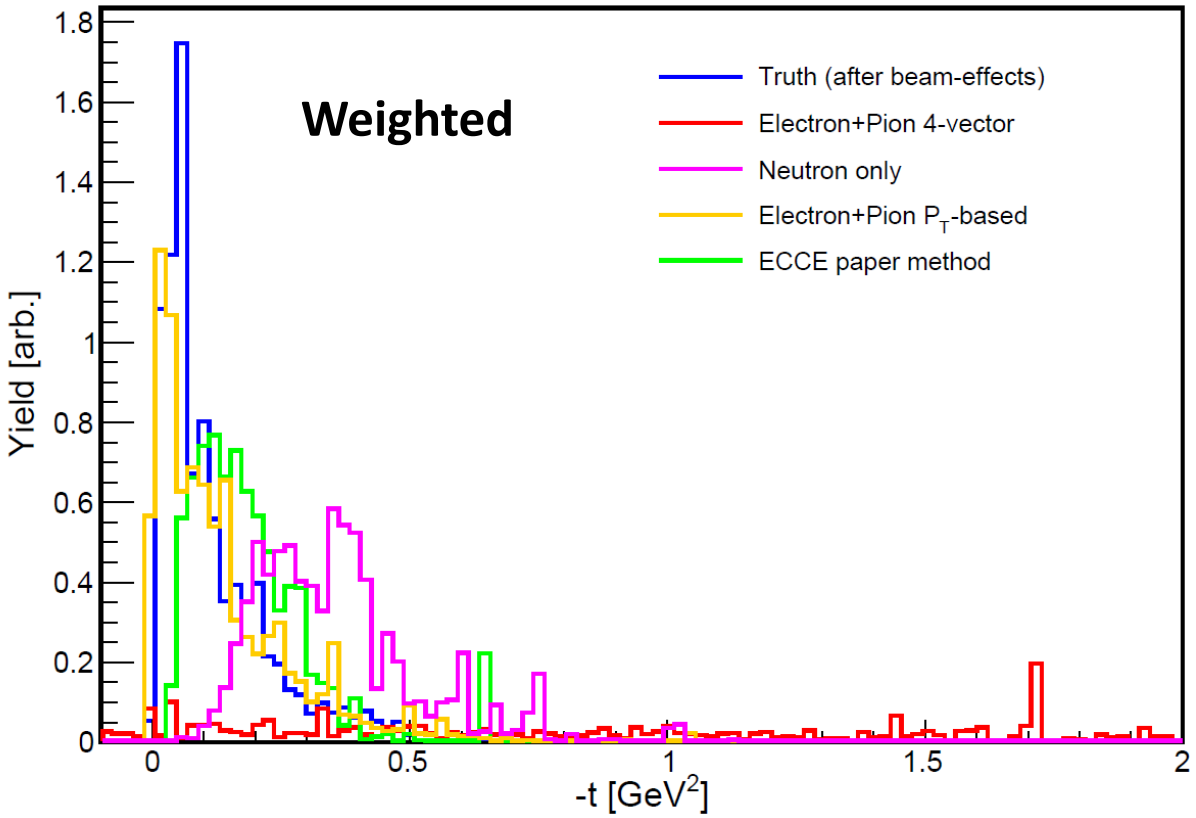
$$p_e = (0{,}0, -5{,}5)\ \text{GeV/c}$$

Method 2 in Probing short-range correlations in the deuteron via incoherent diffractive J/ψ production with spectator tagging at the EIC

Method E in On the Calculation of t in Diffractive VM production and DVCS

t reconstruction

5x100 GeV – 10k events simulated



Neutron only:

$$t = (\, p_p - p_n \,)^2$$

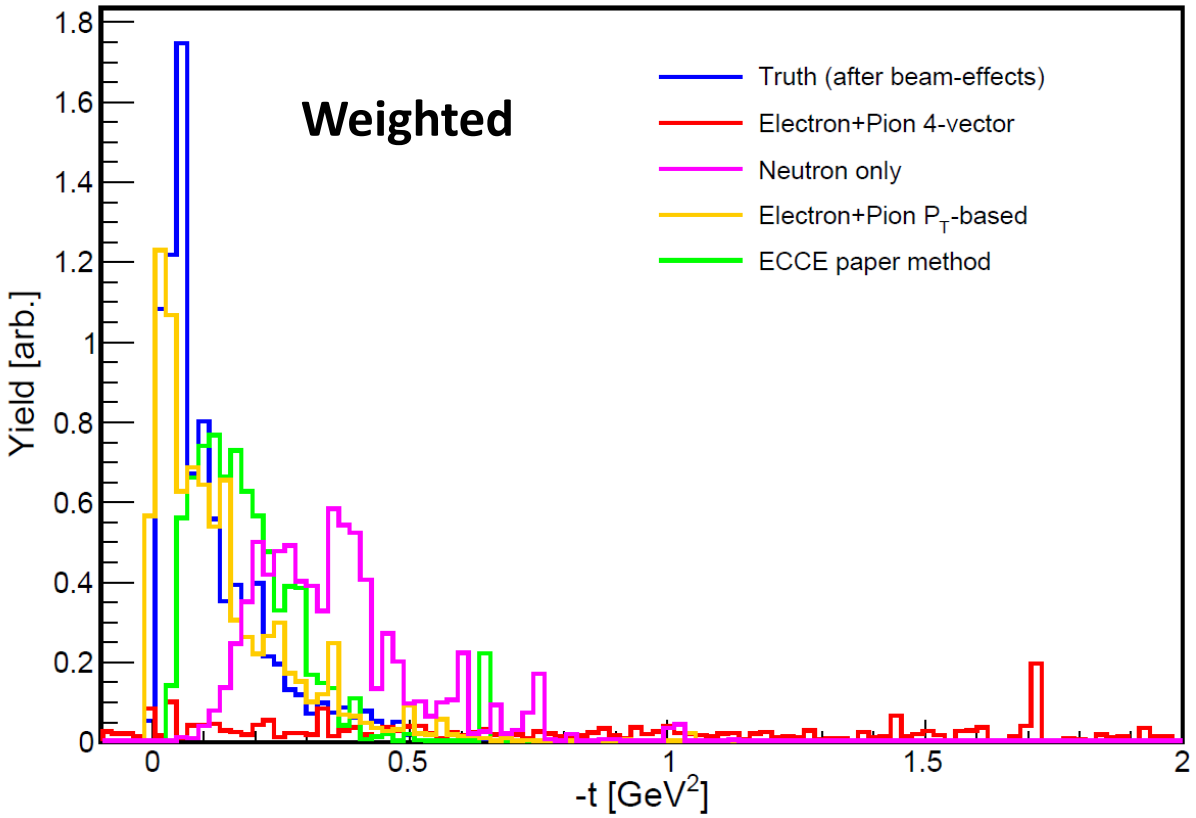
$$p_p = 100 \times (\sin(\theta), 0, \cos(\theta), 1) \text{ GeV/c}$$

Method 1 in Probing short-range correlations in the deuteron via incoherent diffractive J/ψ production with spectator tagging at the EIC

Method shown on slide 3 in On the Calculation of t in Diffractive VM production and DVCS

t reconstruction

5x100 GeV – 10k events simulated



Electron+Pion P_T-based:

$$t = -(\overrightarrow{p_{T,e'}} + \overrightarrow{p_{T,\pi}})^2$$

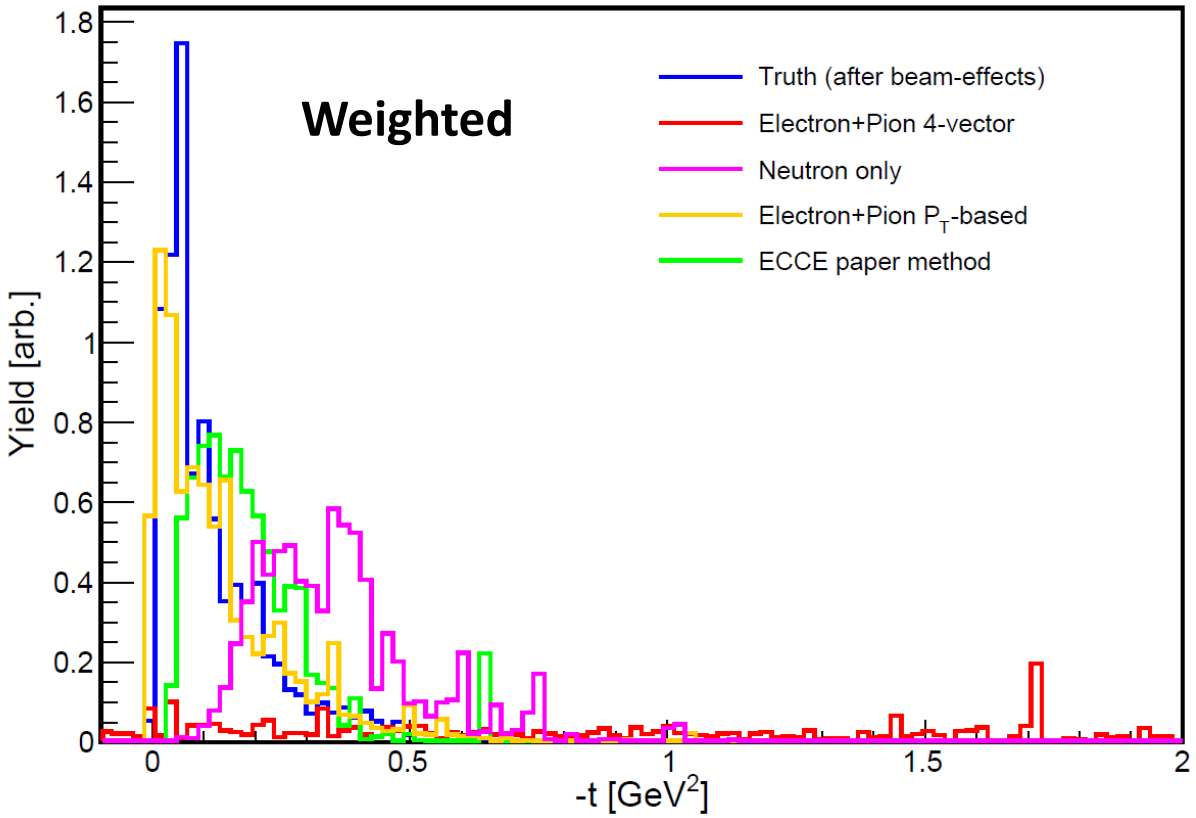
We use transverse momenta defined in lab frame with respect to proton beam direction. Is this correct?

Method 3 in Probing short-range correlations in the deuteron via incoherent diffractive J/ψ production with spectator tagging at the EIC

Method A in On the Calculation of t in Diffractive VM production and DVCS

t reconstruction

5x100 GeV – 10k events simulated



ECCE paper (here) method:

$$p_{miss} = p_e + p_p - p_{e'} - p_\pi$$

$$p_e = (0,0,-5,5)\ \text{GeV/c}$$

$$p_p = 100\ \times (\sin(\theta), 0, \cos(\theta), 1)\ \text{GeV/c}$$

Replace the angles in p_{miss} by the reconstructed neutron angles and set the mass of the 4-momentum to the neutron mass → p_{neut}^{opt}

$$t = (\ p_p - p_{neut}^{opt})^2$$

Some conceptual similarity to method L in On the Calculation of t in Diffractive VM production and DVCS

HepMC files on S3

S3/eictest/EPIC/EVGEN/EXCLUSIVE/DEMP/5on100/eic_DEMPGen_5on100_ip6_pi+_1B_1.hepmc

```
A ab_afterburner_is_used 1
A ab_crossing_angle 0.025
A ab_hadron_beta_crab_hor 500000
A ab_hadron_beta_star_hor 610
A ab_hadron_beta_star_ver 55
A ab_hadron_divergence_hor 0.000206
A ab_hadron_divergence_ver 0.000206
A ab_hadron_rms_bunch_length 70
A ab_hadron_rms_emittance_hor 2.6e-05
A ab_hadron_rms_emittance_ver 2.3e-06
A ab_lepton_beta_crab_hor 150000
A ab_lepton_beta_star_hor 780
A ab_lepton_beta_star_ver 71
A ab_lepton_divergence_hor 0.00016
A ab_lepton_divergence_ver 0.00016
A ab_lepton_rms_bunch_length 7
A ab_lepton_rms_emittance_hor 2e-05
A ab_lepton_rms_emittance_ver 1.8e-06
A ab_use_beam_bunch_sim 1
E 0 1 5 @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
U GEV MM
A 0 weight 0.000495402
P 1 0 11 9.3822153510404738e-04 -1.3923773484238392e-03 -4.9995943299398453e+00 4.9995946118601431e+00 5.1099999999999995e-04 4
P 2 0 2212 -2.5286097026826884e+00 2.3338502715787763e-02 9.9991886598796910e+01 1.0002785518694716e+02 9.3827000000000005e-01 4
V -1 0 [1,2] @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
P 3 -1 11 -2.3352746752187579e+00 5.4161533649472282e-01 -4.5546191010509229e+00 5.1469778437014160e+00 5.1099999999999995e-04 1
P 4 -1 211 1.8670699700915940e+00 -4.1359670537440302e-01 5.8428628263162263e+00 6.1494253309933304e+00 1.3957000000000000e-01 1
P 5 -1 2112 -2.0594704286934160e+00 -1.0607250754029605e-01 9.3704078566628965e+01 9.3731466636879958e+01 9.3957000000000002e-01 1
```

HepMC files on S3

S3/eictest/EPIC/EVGEN/EXCLUSIVE/DEMP/5on100/eic_DEMPGen_5on100_ip6_pi+_1B_1.hepmc

```
A ab_afterburner_is_used 1
A ab_crossing_angle 0.025
A ab_hadron_beta_crab_hor 500000
A ab_hadron_beta_star_hor 610
A ab_hadron_beta_star_ver 55
A ab_hadron_divergence_hor 0.000206
A ab_hadron_divergence_ver 0.000206
A ab_hadron_rms_bunch_length 70
A ab_hadron_rms_emittance_hor 2.6e-05
A ab_hadron_rms_emittance_ver 2.3e-06
A ab_lepton_beta_crab_hor 150000
A ab_lepton_beta_star_hor 780
A ab_lepton_beta_star_ver 71
A ab_lepton_divergence_hor 0.00016
A ab_lepton_divergence_ver 0.00016
A ab_lepton_rms_bunch_length 7
A ab_lepton_rms_emittance_hor 2e-05
A ab_lepton_rms_emittance_ver 1.8e-06
A ab_use_beam_bunch_sim 1
E 0 1 5 @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
U GEV MM
A 0 weight 0.000495402
P 1 0 11 9.3822153510404738e-04 -1.3923773484238392e-03 -4.9995943299398453e+00 4.9995946118601431e+00 5.1099999999999995e-04 4
P 2 0 2212 -2.5286097026826884e+00 2.3338502715787763e-02 9.9991886598796910e+01 1.0002785518694716e+02 9.3827000000000005e-01 4
V -1 0 [1,2] @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
P 3 -1 11 -2.3352746752187579e+00 5.4161533649472282e-01 -4.5546191010509229e+00 5.1469778437014160e+00 5.1099999999999995e-04 1
P 4 -1 211 1.8670699700915940e+00 -4.1359670537440302e-01 5.8428628263162263e+00 6.1494253309933304e+00 1.3957000000000000e-01 1
P 5 -1 2112 -2.0594704286934160e+00 -1.0607250754029605e-01 9.3704078566628965e+01 9.3731466636879958e+01 9.3957000000000002e-01 1
```

Incoming electron and proton beam with crossing angle plus energy and angle smearing applied.

HepMC files on S3

S3/eictest/EPIC/EVGEN/EXCLUSIVE/DEMP/5on100/eic_DEMPGen_5on100_ip6_pi+_1B_1.hepmc

```
A ab_afterburner_is_used 1
A ab_crossing_angle 0.025
A ab_hadron_beta_crab_hor 500000
A ab_hadron_beta_star_hor 610
A ab_hadron_beta_star_ver 55
A ab_hadron_divergence_hor 0.000206
A ab_hadron_divergence_ver 0.000206
A ab_hadron_rms_bunch_length 70
A ab_hadron_rms_emittance_hor 2.6e-05
A ab_hadron_rms_emittance_ver 2.3e-06
A ab_lepton_beta_crab_hor 150000
A ab_lepton_beta_star_hor 780
A ab_lepton_beta_star_ver 71
A ab_lepton_divergence_hor 0.00016
A ab_lepton_divergence_ver 0.00016
A ab_lepton_rms_bunch_length 7
A ab_lepton_rms_emittance_hor 2e-05
A ab_lepton_rms_emittance_ver 1.8e-06
A ab_use_beam_bunch_sim 1
E 0 1 5 @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
U GEV MM
A 0 weight 0.000495402
P 1 0 11 9.3822153510404738e-04 -1.3923773484238392e-03 -4.9995943299398453e+00 4.9995946118601431e+00 5.1099999999999995e-04 4
P 2 0 2212 -2.5286097026826884e+00 2.3338502715787763e-02 9.9991886598796910e+01 1.0002785518694716e+02 9.3827000000000005e-01 4
V -1 0 [1,2] @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
P 3 -1 11 -2.3352746752187579e+00 5.4161533649472282e-01 -4.5546191010509229e+00 5.1469778437014160e+00 5.1099999999999995e-04 1
P 4 -1 211 1.8670699700915940e+00 -4.1359670537440302e-01 5.8428628263162263e+00 6.1494253309933304e+00 1.3957000000000000e-01 1
P 5 -1 2112 -2.0594704286934160e+00 -1.0607250754029605e-01 9.3704078566628965e+01 9.3731466636879958e+01 9.3957000000000002e-01 1
```

Scattered electron, positive pion, and neutron

HepMC files on S3

S3/eictest/EPIC/EVGEN/EXCLUSIVE/DEMP/5on100/eic_DEMPGen_5on100_ip6_pi+_1B_1.hepmc

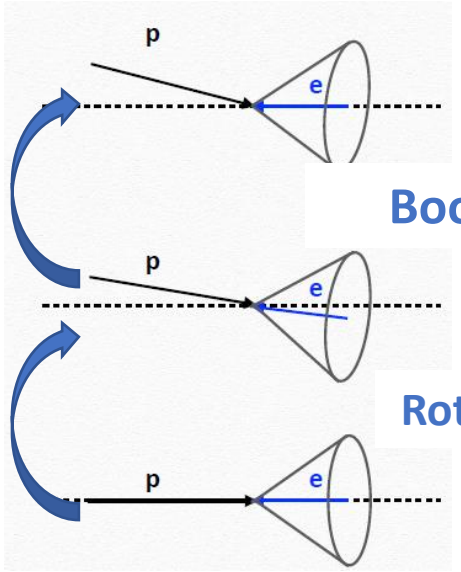
```
A ab_afterburner_is_used 1
A ab_crossing_angle 0.025
A ab_hadron_beta_crab_hor 500000
A ab_hadron_beta_star_hor 610
A ab_hadron_beta_star_ver 55
A ab_hadron_divergence_hor 0.000206
A ab_hadron_divergence_ver 0.000206
A ab_hadron_rms_bunch_length 70
A ab_hadron_rms_emittance_hor 2.6e-05
A ab_hadron_rms_emittance_ver 2.3e-06
A ab_lepton_beta_crab_hor 150000
A ab_lepton_beta_star_hor 780
A ab_lepton_beta_star_ver 71
A ab_lepton_divergence_hor 0.00016
A ab_lepton_divergence_ver 0.00016
A ab_lepton_rms_bunch_length 7
A ab_lepton_rms_emittance_hor 2e-05
A ab_lepton_rms_emittance_ver 1.8e-06
A ab_use_beam_bunch_sim 1
E 0 1 5 @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
U GEV MM
A 0 weight 0.000495402
P 1 0 11 9.3822153510404738e-04 -1.3923773484238392e-03 -4.9995943299398453e+00 4.9995946118601431e+00 5.1099999999999995e-04 4
P 2 0 2212 -2.5286097026826884e+00 2.3338502715787763e-02 9.9991886598796910e+01 1.0002785518694716e+02 9.3827000000000005e-01 4
V -1 0 [1,2] @ -5.5270989698305503e-02 -3.4184489514529101e-03 9.2400434587506002e+00 -1.2210289059169902e+01
P 3 -1 11 -2.3352746752187579e+00 5.4161533649472282e-01 -4.5546191010509229e+00 5.1469778437014160e+00 5.1099999999999995e-04 1
P 4 -1 211 1.8670699700915940e+00 -4.1359670537440302e-01 5.8428628263162263e+00 6.1494253309933304e+00 1.3957000000000000e-01 1
P 5 -1 2112 -2.0594704286934160e+00 -1.0607250754029605e-01 9.3704078566628965e+01 9.3731466636879958e+01 9.3957000000000002e-01 1
```

Truth t distribution is above plots calculated using lines below:

$$t_{true} = (p_p - p_n)^2$$

Weight is applied for each event

HepMC files before afterburner



S3/eictest/EPIC/EVGEN/EXCLUSIVE/DEMP/eic_DEMPGen_5on100_1B_1_100.hepmc

```
E 0 1 6
U GEV MM
P 1 0 11 6.1232300000000001e-16 0.0000000000000000e+00 -5.0000000000000000e+00 5.0000000000000000e+00 0.0000000000000000e+00 21
P 2 0 2212 0.0000000000000000e+00 0.0000000000000000e+00 1.0000000000000000e+02 1.0000399780273438e+02 8.9419043234744078e-01 21
P 3 0 22 -1.5014300000000000e+00 -2.9472200000000002e+00 -7.5489600000000001e-01 -3.8157001137733459e-01 -3.3711526323400878e+00 21
P 4 0 11 1.5014300000000000e+00 2.9472200000000002e+00 -4.2450999999999999e+00 5.3815698623657227e+00 4.7328873876336490e-03 1
P 5 0 2112 -7.6801800000000003e-02 -2.4961500000000000e-01 8.6905199999999994e+01 8.6910697937011719e+01 9.4203115329907905e-01 1
P 6 0 211 -1.4246200000000000e+00 -2.6976100000000001e+00 1.2339900000000000e+01 1.2712100028991699e+01 1.3309124911411238e-01 1
E 0 1 6
U GEV MM
P 1 0 11 6.1232300000000001e-16 0.0000000000000000e+00 -5.0000000000000000e+00 5.0000000000000000e+00 0.0000000000000000e+00 21
P 2 0 2212 0.0000000000000000e+00 0.0000000000000000e+00 1.0000000000000000e+02 1.0000399780273438e+02 8.9419043234744078e-01 21
P 3 0 22 2.3812799999999998e+00 1.3961900000000000e+00 -6.6133200000000003e-01 -1.4236100018024445e-01 -2.8349487322263309e+00 21
P 4 0 11 -2.3812799999999998e+00 -1.3961900000000000e+00 -4.3386699999999996e+00 5.1423602104187012e+00 -5.4579943685371573e-03 1
P 5 0 2112 6.4095700000000000e-01 -1.2139400000000000e-01 9.4416200000000003e+01 9.4423103332519531e+01 9.3704755726459565e-01 1
P 6 0 211 1.7403200000000001e+00 1.5175799999999999e+00 4.9225099999999999e+00 5.4389700889587402e+00 1.3974322769940900e-01 1
```

HepMC files before afterburner

Two issues:

1. Events don’t seem to match the events in the post-afterburner file. For example, the scattered electron momentum in event 1 is very different in the two files.
2. Trying to run the beam effects afterburner on this file causes a crash on the first event (due to no defined vertices). Can contact exclusive/diffractive/tagging group about this.

S3/eictest/EPIC/EVGEN/EXCLUSIVE/DEMP/eic_DEMPGen_5on100_1B_1_100.hepmc

```
E 0 1 6
U GEV MM
P 1 0 11 6.1232300000000001e-16 0.0000000000000000e+00 -5.0000000000000000e+00 5.0000000000000000e+00 0.0000000000000000e+00 21
P 2 0 2212 0.0000000000000000e+00 0.0000000000000000e+00 1.0000000000000000e+02 1.0000399780273438e+02 8.9419043234744078e-01 21
P 3 0 22 -1.5014300000000000e+00 -2.9472200000000002e+00 -7.5489600000000001e-01 -3.8157001137733459e-01 -3.3711526323400878e+00 21
P 4 0 11 1.5014300000000000e+00 2.9472200000000002e+00 -4.2450999999999999e+00 5.3815698623657227e+00 4.7328873876336490e-03 1
P 5 0 2112 -7.6801800000000003e-02 -2.4961500000000000e-01 8.6905199999999994e+01 8.6910697937011719e+01 9.4203115329907905e-01 1
P 6 0 211 -1.4246200000000000e+00 -2.6976100000000001e+00 1.2339900000000000e+01 1.2712100028991699e+01 1.3309124911411238e-01 1
E 0 1 6
U GEV MM
P 1 0 11 6.1232300000000001e-16 0.0000000000000000e+00 -5.0000000000000000e+00 5.0000000000000000e+00 0.0000000000000000e+00 21
P 2 0 2212 0.0000000000000000e+00 0.0000000000000000e+00 1.0000000000000000e+02 1.0000399780273438e+02 8.9419043234744078e-01 21
P 3 0 22 2.3812799999999998e+00 1.3961900000000000e+00 -6.6133200000000003e-01 -1.4236100018024445e-01 -2.8349487322263309e+00 21
P 4 0 11 -2.3812799999999998e+00 -1.3961900000000000e+00 -4.3386699999999996e+00 5.1423602104187012e+00 -5.4579943685371573e-03 1
P 5 0 2112 6.4095700000000000e-01 -1.2139400000000000e-01 9.4416200000000003e+01 9.4423103332519531e+01 9.3704755726459565e-01 1
P 6 0 211 1.7403200000000001e+00 1.5175799999999999e+00 4.9225099999999999e+00 5.4389700889587402e+00 1.3974322769940900e-01 1
```

Summary

- Studies of **t** reconstruction for DEMP events with LYSO+SiPM-on-tile ZDC. Studied various reconstruction methods guided by prior work.
- Began comparison of DEMP events before and after application of the beam-effects afterburner. Some thought is needed on how beam effects are applied, and ‘truth’ quantities are calculated.