Analysis and Reconstruction Strategies for Exclusive Diffractive eA Physics at ePIC

Exclusive, Diffraction, & Tagging Physics Working Group

Maci Kesler
(on behalf of the ePIC Collaboration)

Towards Improved Hadron Femtography, Edition V
University of Virginia

July 20 - 24, 2026

Exclusive, Diffractive, and Tagging (EDT) Physics Program in *eA*

Why is *eA* different from *ep*?

- **Nuclear breakup:** spectators, forward nucleons, veto logic
- **Coherent vs incoherent diffraction:** imaging vs breakup background
- **Amplification of gluon density:** access to saturation dynamics
- **Allows 3D imaging:** momentum transfer distribution (t) dependent structure

Exclusive, Diffractive, and Tagging (EDT) Physics Program in *eA*

Why is *eA* different from *ep*?

- **Nuclear breakup:** spectators, forward nucleons, veto logic
- **Coherent vs incoherent diffraction:** imaging vs breakup background
- **Amplification of gluon density:** access to saturation dynamics
- **Allows 3D imaging:** momentum transfer distribution (t) dependent structure

Toolbox of reconstruction methods developed to study these processes

- Multiple analysis channels (neutron structure function, diffractive VM production, etc.)
- Strategy depends on **nucleus, final state, and physics goal**

Analysis Strategies and Reconstruction

Exclusivity

- Detect full final state
- Scattered nucleus often escapes through beam pipe
- t reconstructed from combinations of final state 4-momenta

Analysis Strategies and Reconstruction

Exclusivity

- Detect full final state
- Scattered nucleus often escapes through beam pipe
- t reconstructed from combinations of final state 4-momenta

Far-Forward Detector Systems

- **B0:**
  - Forward particles (protons, photons)
- **Roman Pots (RP)/Off-Momentum Detectors (OMD):**
  - **Tag & reconstruct forward protons**
- **Zero Degree Calorimeter (ZDC):**
  - **Tag neutral forward particles**

Analyses in EDT

Will focus on 2 analyses

Neutron SF extraction
Tagged Deep Inelastic Scattering (TDIS)

- Spectator tagging
- Scattered electron reconstruction
- Pole extrapolation
- Obtaining SF

Diffractive ϕ production

- t reconstruction
- Resolving diffractive minima
- Transform to obtain spatial distribution
- Incoherent suppression

Both demonstrate strategies for **extracting nuclear structure** and rely on **exclusive reconstruction & tagging**

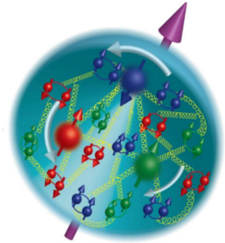
Tagged DIS in *eD* Collisions

Physics Motivation

Understanding structure of neutrons & light nuclei

Neutron Structure Functions (SF):

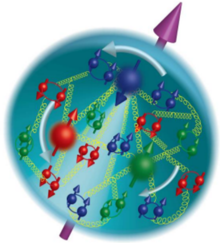
- Vital for full **understanding of nucleon structure & QCD**



- Probability distributions of quarks and gluons
- Tells us **how quarks are distributed** inside a nucleon
- Complementary to traditional DIS measurements of proton structure

Neutron Structure Functions (SF):

- Vital for full **understanding of nucleon structure & QCD**



- Probability distributions of quarks and gluons
- Tells us **how quarks are distributed** inside a nucleon
- Complementary to traditional DIS measurements of proton structure

Main challenges

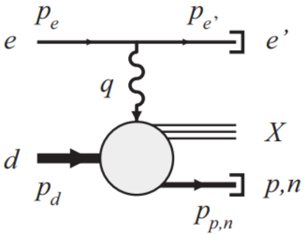
- Neutrons are neutral and cannot be easily accelerated
- Difficult to handle free neutrons

Possible Experimental Solution

Tagged DIS (TDIS) in *eD* Collisions

$$e + d \rightarrow e' + X + p(n)$$

- DIS on deuteron (d)
- Measure e' and spectator p or n
- Detecting spectator allows us to reconstruct struck nucleons kinematics



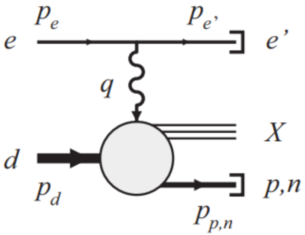
A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205

Possible Experimental Solution

Tagged DIS (TDIS) in *eD* Collisions

$$\boldsymbol{e + d \rightarrow e' + X + p(n)}$$

- DIS on deuteron (d)
- Measure e' and spectator p or n
- Detecting spectator allows us to reconstruct struck nucleons kinematics



Advantages:

- Straightforward when spectators are successfully detected
- Possible to measure p
- Cross check with standard methods

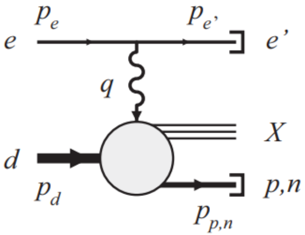
A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205

Possible Experimental Solution

Tagged DIS (TDIS) in *eD* Collisions

$$e + d \rightarrow e' + X + p(n)$$

- DIS on deuteron (d)
- Measure e' and spectator p or n
- Detecting spectator allows us to reconstruct struck nucleons kinematics



A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205

Advantages:

- Straightforward when spectators are successfully detected
- Possible to measure p
- Cross check with standard methods

Challenges:

- Neutron is bound (not free) $\rightarrow$ **we are interested in free *n* SF**
- Detection of the spectator p or n

How Do We Overcome The Challenges?

Solution: Pole extrapolation for extraction of free neutron/proton structure

Nucleon reduced cross section obtained by removing pole of deuteron spectral function

$$\bar{\sigma}_{\mathrm{red},n} = \frac{\bar{\sigma}_{\mathrm{red},d}(x, Q^2)}{[2(2\pi)^2]\ \underbrace{S_d(p_{p,T}, \alpha_p)[\mathrm{pole}]}_{\text{deuteron spectral function}}}$$

- We can measure/calculate this
- External input from model/experiment

Deuteron spectral function

$$S_d(p_{pT,\alpha_p})[\mathrm{pole}] = \frac{R}{(p_{pT}^2 + \alpha_T^2)}$$

- Position of pole:
  $\alpha_T^2 = m_N^2 - \alpha_p(2 - \alpha_p)\frac{M_d^2}{4}$
- Residue of spectral function:
  $R = 2\alpha_p^2 m_N \Gamma^2 (2 - \alpha_p)$
  $\Gamma = 0.007885\ \mathrm{GeV}$

A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205
M. Strikman and C. Weiss: Phys. Rev. C 97, 035209
W. Cosyn and C. Weiss: Phys. Rev. C 102, 065204

How Do We Overcome The Challenges?

Solution: Pole extrapolation for extraction of free neutron/proton structure

Nucleon reduced cross section obtained by removing pole of deuteron spectral function

$$\bar{\sigma}_{\mathrm{red},n} = \frac{\bar{\sigma}_{\mathrm{red},d}(x, Q^2)}{[2(2\pi)^2]\ \underbrace{S_d(p_{p,T}, \alpha_p)[\mathrm{pole}]}_{\text{deuteron spectral function}}}$$

- We can measure/calculate this
- External input from model/experiment

Deuteron spectral function

$$S_d(p_{pT,\alpha_p})[\mathrm{pole}] = \frac{R}{(p_{pT}^2 + \alpha_T^2)}$$

- Position of pole:
  $\alpha_T^2 = m_N^2 - \alpha_p(2 - \alpha_p)\frac{M_d^2}{4}$
- Residue of spectral function:
  $R = 2\alpha_p^2 m_N \Gamma^2 (2 - \alpha_p)$
  $\Gamma = 0.007885\ \mathrm{GeV}$

- **$\bar{\sigma}_{\mathrm{red},n}$ at pole corresponds to a free n**
  - $p_{pT}^2 \to -\alpha_T^2$ which means negative (unphysical) p_{pT}^2

A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205
M. Strikman and C. Weiss: Phys. Rev. C 97, 035209
W. Cosyn and C. Weiss: Phys. Rev. C 102, 065204

How Do We Overcome The Challenges?

Solution: Pole extrapolation for extraction of free neutron/proton structure

Nucleon reduced cross section obtained by removing pole of deuteron spectral function

$$\bar{\sigma}_{\mathrm{red},n} = \frac{\bar{\sigma}_{\mathrm{red},d}(x, Q^2)}{[2(2\pi)^2]\ \underbrace{S_d(p_{p,T}, \alpha_p)[\mathrm{pole}]}_{\text{deuteron spectral function}}}$$

- $\bar{\sigma}_{\mathrm{red},n}$ **at pole corresponds to a free** n
  - $p_{pT}^2 \rightarrow -\alpha_T^2$ which means negative (unphysical) p_{pT}^2
- Same measurement can be done for p
  - Cross check with proton F_2 extracted with traditional method
  - Can be used to select optimal deuteron spectral function

- We can measure/calculate this
- External input from model/experiment

Deuteron spectral function

$$S_d(p_{pT,\alpha_p})[\mathrm{pole}] = \frac{R}{(p_{pT}^2 + \alpha_T^2)}$$

- Position of pole:

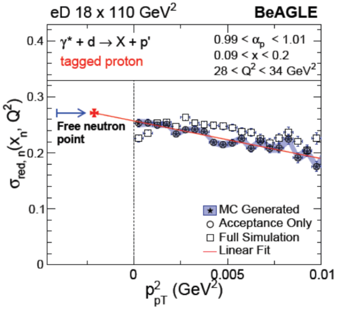
  $\alpha_T^2 = m_N^2 - \alpha_p(2 - \alpha_p)\frac{M_d^2}{4}$

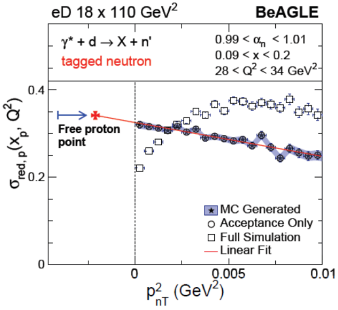
- Residue of spectral function:
  $R = 2\alpha_p^2 m_N \Gamma^2 (2 - \alpha_p)$
  $\Gamma = 0.007885$ GeV

A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205
M. Strikman and C. Weiss: Phys. Rev. C 97, 035209
W. Cosyn and C. Weiss: Phys. Rev. C 102, 065204

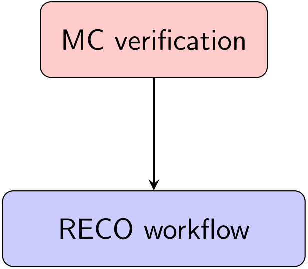
Experimental Method: MC Truth Validation

- Method verified in publication by A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205
  - Used only MC truth information
  - Manual smearing applied (no EICRecon)
  - RECO not yet incorporated





Experimental Method: This Analysis



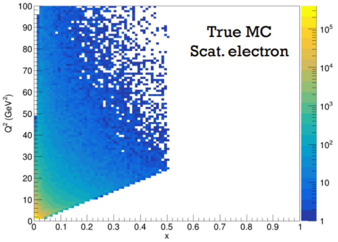
Implement complete TDIS framework:

- **Using RECO info from EICRecon**
- Full efficiency and acceptance corrections
- More realistic estimate of systematic uncertainties
- Projection of stat. uncertainties to early year EIC luminosity

Scattered Electron Finding

MC

- Find electron with beam electron as parent



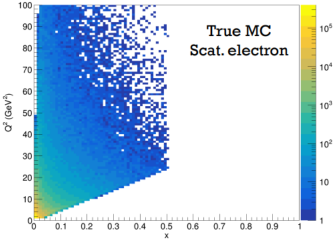
Scattered Electron Finding

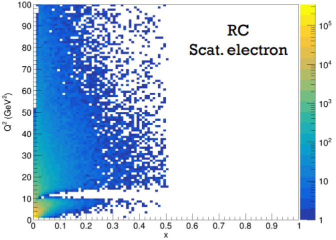
MC

- Find electron with beam electron as parent

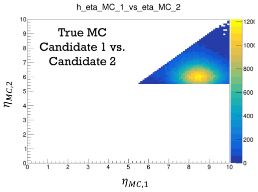
RECO (RC)

- Find negative track with well matched nECAL or bECAL cluster with $0.8 < E/p < 1.2$
- Select one with highest momentum
- Correct momentum magnitude using energy deposition in ECAL
- **Main source of efficiency drop in final cross sections**





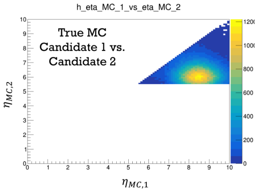
Spectator Selection

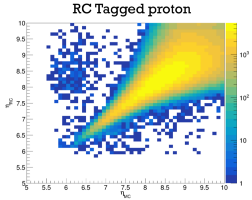


MC

- Select final state p, n with $\eta > 5.5$
- If two candidates, take the one with larger η

Spectator Selection





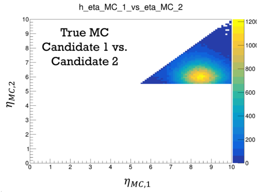
MC

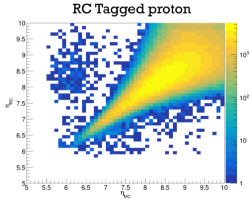
- Select final state p, n with $\eta > 5.5$
- If two candidates, take the one with larger η

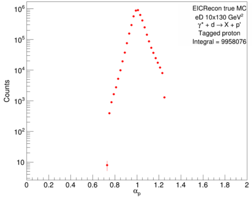
RECO

- Accept events with candidate in OMD or ZDC
- If two candidates, take the one with larger η

Spectator Selection







MC

- Select final state p, n with $\eta > 5.5$
- If two candidates, take the one with larger η

RECO

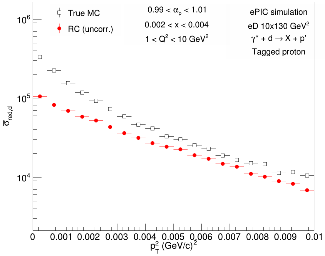
- Accept events with candidate in OMD or ZDC
- If two candidates, take the one with larger η
- Require $0.99 < \alpha_p < 1.01$

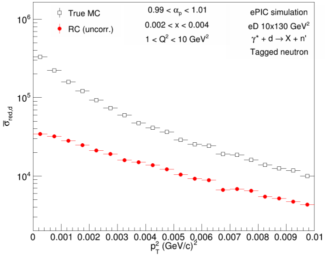
$$\alpha_p \equiv \frac{2p_p^+}{p_d^+} = \frac{2(E_p + p_{z,p})}{E_d + p_{z,d}}$$

Deuteron Reduced Cross Section

Campaign 26.03.1

Top: Calculated using **tagged protons**
Bottom: Calculated using **tagged neutrons**

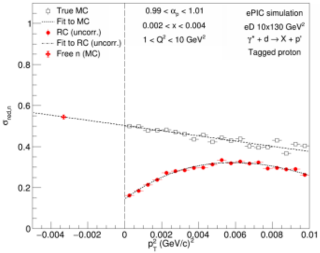


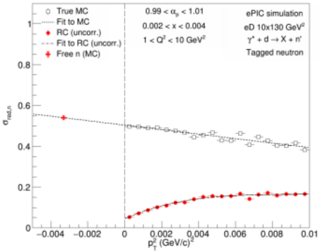


- Drop in counts due to efficiency loss by electron finding algorithm
- Change in shape of p_T^2 due to spectator resolution

Nucleon Reduced Cross Section - Uncorrected

Campaign 26.03.1





Top: **Neutron** reduced cross section
Bottom: **Proton** reduced cross section

MC:

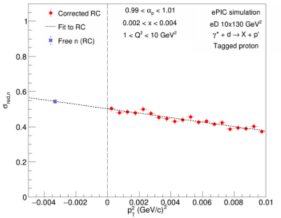
- Fitted with linear function
- Extrapolation uncertainty from 1σ confidence interval of the fit

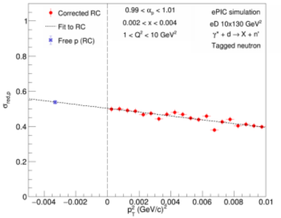
RECO (RC):

- Fitted with 3^{rd} order polynomial

Nucleon Reduced Cross Section - Corrected

Campaign 26.03.1





Top: Fully corrected **neutron** reduced cross section in EICRecon

Bottom: Fully corrected **proton** reduced cross section in EICRecon

Sources of systematic uncertainties

- Luminosity: $\sigma_{\mathrm{lumi}} = 1.5\%$
- Theory/extrapolation: $\sigma_{\mathrm{th}} = 2\%$
- Beam effects: $\sigma_{\mathrm{beam}} = 1.5\%$
- Proton reconstruction: $\sigma_p = 2\%$
- Neutron reconstruction: $\sigma_n = 1\%$

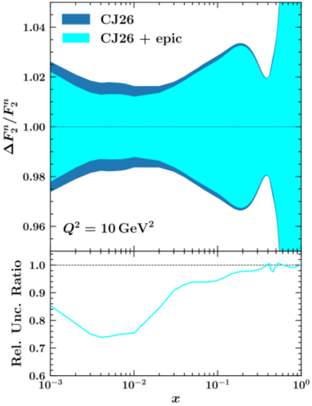
$$\sigma_{\mathrm{sys}} = \sqrt{\sigma_{\mathrm{lumi}}^2 + \sigma_{\mathrm{th}}^2 + \sigma_{\mathrm{beam}}^2 + \sigma_{p/n}^2}$$

$$\sigma_{\mathrm{tot}} = \sqrt{\sigma_{\mathrm{stat}}^2 + \sigma_{\mathrm{sys}}^2}$$

- Error bars are total systematic uncertainties
- Extrapolation uncertainty from 1σ confidence interval of fit to dist. with combined uncertainties

Neutron SF Results

- Results clearly **demonstrate feasibility of measurement of TDIS in *eD* collisions** in early years of the EIC
- Expected luminosity more than sufficient to have **small or negligible statistical uncertainties**
- Final uncertainty will be dominated by systematic uncertainty
- This **measurement will have significant impact**, even with luminosity in the early EIC years



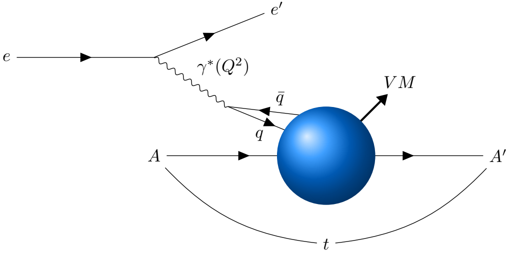
Caculated by Matteo Cerutti & Alberto Accardi
Analysis by Jan Vanek & Alex Jentsch

Momentum Transfer from Diffractive ϕ in *eAu*

Critical Measurement:

Exclusive Vector Meson (VM) Production

- Probe to gluon density → precisely see structure → **saturation**
- Deflection of VM measures **spatial distribution** of gluons

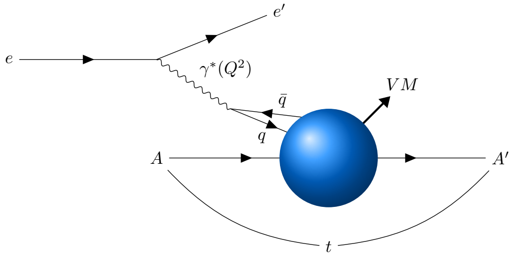


Motivation

Critical Measurement:

Exclusive Vector Meson (VM) Production

- Probe to gluon density → precisely see structure → **saturation**
- Deflection of VM measures **spatial distribution** of gluons



Distribution of momentum transfer (t)

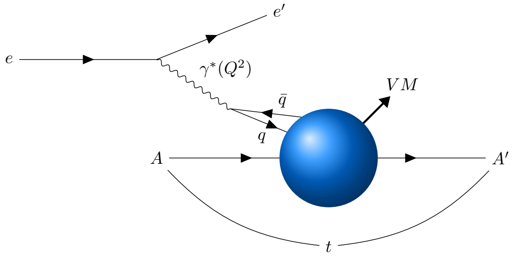
- **Fourier conjugate to impact parameter**
- Reflects the spatial profile
- **Gluon imaging**

Motivation

Critical Measurement:

Exclusive Vector Meson (VM) Production

- Probe to gluon density $\rightarrow$ precisely see structure $\rightarrow$ **saturation**
- Deflection of VM measures **spatial distribution** of gluons



Distribution of momentum transfer (t)

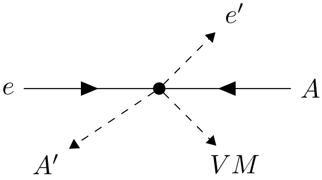
- **Fourier conjugate to impact parameter**
- Reflects the spatial profile
- **Gluon imaging**

Saturation models predict at EIC **more than 20% of the cross-section will be diffractive**

EIC YR: https://doi.org/10.1016/j.nuclphysa.2022.122447

Extracting $|t|$

Reconstruct from exclusive VM production



$$\boxed{|t| = (P_A - P_{A'})^2}$$

To access $|t|$: **need complete final state**

We know 4-momenta of $\boldsymbol{e}$, $\boldsymbol{A}$, $\boldsymbol{e'}$, and $\boldsymbol{VM}$

$$e + A \rightarrow e' + A' + VM$$

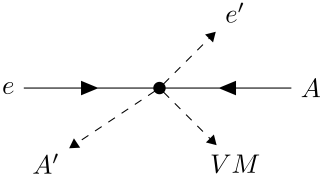
$$P_{A'} = P_e + P_A - P_{e'} - P_{VM}$$

Cannot measure $P_{A'}$

- For heavy nuclei → **stays within beam envelope**
- Tiny momentum change + tiny angular deflection

Different Methods

Reconstruct from exclusive VM production



$$\boxed{|t| = (P_A - P_{A'})^2}$$

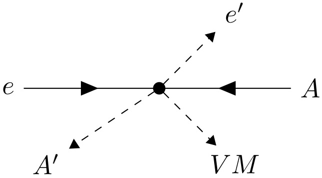
To access $|t|$: **need complete final state**

- $|\boldsymbol{t}|_{\mathbf{BABE}}$ (method E) MC: $|t| = (P_{VM} + P_{e'} - P_e)^2$
  - Small error/inaccuracy has large effect on $|t| \rightarrow \frac{\sigma_t}{t}$
  - Beam momentum spread

EIC YR: https://doi.org/10.1016/j.nuclphysa.2022.122447

Different Methods

Reconstruct from exclusive VM production



$$\boxed{|t| = (P_A - P_{A'})^2}$$

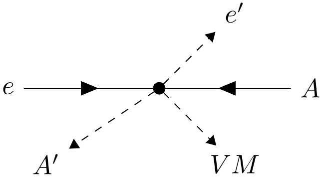
To access $|t|$: **need complete final state**

- $|\boldsymbol{t}|_{\mathbf{BABE}}$ (method E) MC: $|t| = (P_{VM} + P_{e'} - P_e)^2$
  - Small error/inaccuracy has large effect on $|t| \rightarrow \frac{\sigma_t}{t}$
  - Beam momentum spread
- $|\boldsymbol{t}|_{\mathbf{eX}}$ (method A) default: $|t| = [\mathbf{p}_T(e') + \mathbf{p}_T(VM)]^2$
  - Underestimates true t
  - Valid only for small $|t|$ and small Q^2

EIC YR: https://doi.org/10.1016/j.nuclphysa.2022.122447

Different Methods

Reconstruct from exclusive VM production



$$\boxed{|t| = (P_A - P_{A'})^2}$$

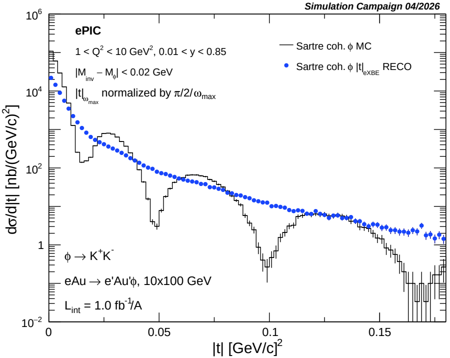
To access $|t|$: **need complete final state**

- $|\boldsymbol{t}|_{\mathbf{BABE}}$ (method E) MC: $|t| = (P_{VM} + P_{e'} - P_e)^2$
  - Small error/inaccuracy has large effect on $|t| \rightarrow \frac{\sigma_t}{t}$
  - Beam momentum spread
- $|\boldsymbol{t}|_{\mathbf{eX}}$ (method A) default: $|t| = [\mathbf{p}_T(e') + \mathbf{p}_T(VM)]^2$
  - Underestimates true t
  - Valid only for small $|t|$ and small Q^2
- $|\boldsymbol{t}|_{\mathbf{eXBE}}$ (method L): $|t| = (P_A - P_{A'}^{\mathrm{corr}})^2$
  - Improvement to $|t|_{\mathrm{eX}}$
  - Only applies to coherent events

EIC YR: https://doi.org/10.1016/j.nuclphysa.2022.122447

Challenges

Measurements of the $|t|$ distribution encounter **2 primary challenges:**



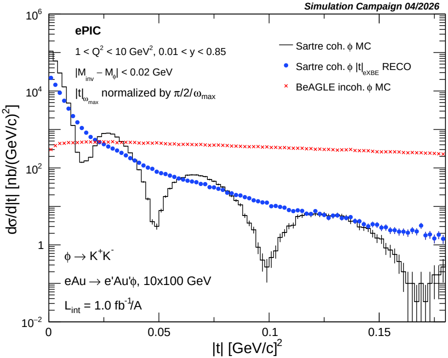
1. **Limited resolution in measuring $|t|$:**
   - **Mainly momentum resolution of e'**
     - Tiny angular error $\rightarrow$ large p_T error

Best method of $|t|$ reconstruction $\rightarrow |t|_{\mathrm{eXBE}}$ **(blue circles)**

EIC YR: https://doi.org/10.1016/j.nuclphysa.2022.122447

Challenges

Measurements of the $|t|$ distribution encounter **2 primary challenges:**

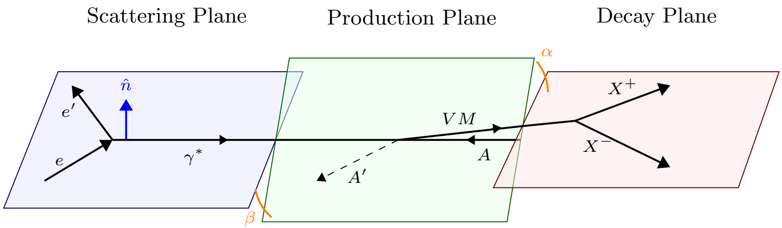


1. **Limited resolution in measuring $|t|$:**
   - **Mainly momentum resolution of e'**
     - Tiny angular error $\to$ large p_T error
2. **Overwhelming incoherent background:**
   - **Red x's**
   - Detector **cannot** suppress all incoherent production

Best method of $|t|$ reconstruction $\to$ $|t|_{\mathrm{eXBE}}$ **(blue circles)**

EIC YR: https://doi.org/10.1016/j.nuclphysa.2022.122447

Projected-$|t|$ Method



- Measure **$|t|$ component along normal direction ($\hat{n}$)** of electron scattering plane
- **$|t|_{\hat{n}}$ unaffected by momentum resolution** $\rightarrow$ eliminate momentum resolution contribution from scattered electron

M. Kesler, A. I. Sheikh, et. al., 10.1016/j.physletb.2026.140585

Projection + Wedge Cut

Calculate $\hat{n}$

$$\hat{n} = \hat{p}_e \times \hat{p}_{e'}$$

$|t|_{\mathrm{eXBE}}$

$$|t| = (P_A - P_{A'}^{\mathrm{corr}})^2$$

$|t|_{\mathrm{BABE}}$

$$|t| = (P_{VM} + P_{e'} - P_e)^2$$

$$|t|_{\hat{n}} = [(P_{VM} + P_{e'} - P_e) \cdot \hat{n}]^2$$

$$\boxed{|t|_{\hat{n}} = (P_{VM} \cdot \hat{n})^2}$$

$$|t| = (|t|_x, |t|_{\hat{n}}, |t|_z, |t|_E)$$

Want phase space where $|t|_{\hat{n}}$ dominates

Projection + Wedge Cut

Calculate $\hat{n}$

$\hat{n} = \hat{p}_e \times \hat{p}_{e'}$

$|t|_{\text{eXBE}}$

$|t| = (P_A - P_{A'}^{\text{corr}})^2$

$|t|_{\text{BABE}}$

$|t| = (P_{VM} + P_{e'} - P_e)^2$

$$|t|_{\hat{n}} = [(P_{VM} + P_{e'} - P_e) \cdot \hat{n}]^2$$

$$\boxed{|t|_{\hat{n}} = (P_{VM} \cdot \hat{n})^2}$$

$$|t| = (|t|_x, |t|_{\hat{n}}, |t|_z, |t|_E)$$

Want phase space where $|t|_{\hat{n}}$ dominates

- **e' direction ($\hat{x} = \hat{n} \times \hat{p}_e$)**
  $\rightarrow \Delta_x = \sqrt{|t_x|}$
- **$\hat{n}$ direction**
  $\rightarrow \Delta_y = \sqrt{|t|_{\hat{n}}}$

Projection + Wedge Cut

Calculate $\hat{n}$

$\hat{n} = \hat{p}_e \times \hat{p}_{e'}$

$|t|_{\mathrm{eXBE}}$

$|t| = (P_A - P_{A'}^{\mathrm{corr}})^2$

$|t|_{\mathrm{BABE}}$

$|t| = (P_{VM} + P_{e'} - P_e)^2$

$$|t|_{\hat{n}} = [(P_{VM} + P_{e'} - P_e) \cdot \hat{n}]^2$$

$$\boxed{|t|_{\hat{n}} = (P_{VM} \cdot \hat{n})^2}$$

$$|t| = (|t|_x, |t|_{\hat{n}}, |t|_z, |t|_E)$$

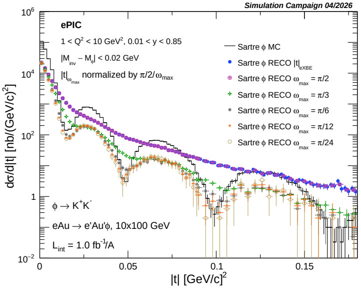
Want phase space where $|t|_{\hat{n}}$ dominates

- **e' direction ($\hat{x} = \hat{n} \times \hat{p}_e$)**
  $\rightarrow \Delta_x = \sqrt{|t_x|}$
- **$\hat{n}$ direction**
  $\rightarrow \Delta_y = \sqrt{|t|_{\hat{n}}}$

Parameterize $\Delta_\perp = \pm\sqrt{|t_\perp|}$

$$\begin{aligned} \Delta_x &= \Delta_\perp \sin(\omega) \\ \Delta_y &= \Delta_\perp \cos(\omega) \\ \omega_{\mathrm{max}} &= \tan^{-1}\left(\frac{\Delta_x}{\Delta_y}\right) \end{aligned}$$

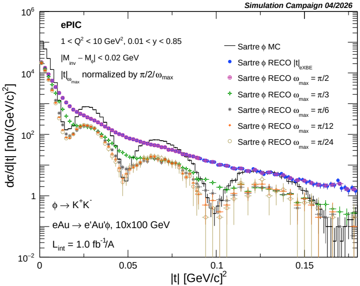
Resulting $|t|$ Distribution and Transformation

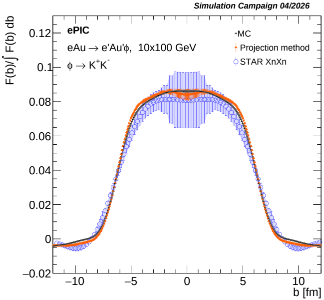


- Increase $\omega_{\max}$:
  - **Ability to resolve dips**
  - Lose statistics
- Need **precise location of minima**

Resulting $|t|$ Distribution and Transformation

Significant improvement in both distributions!



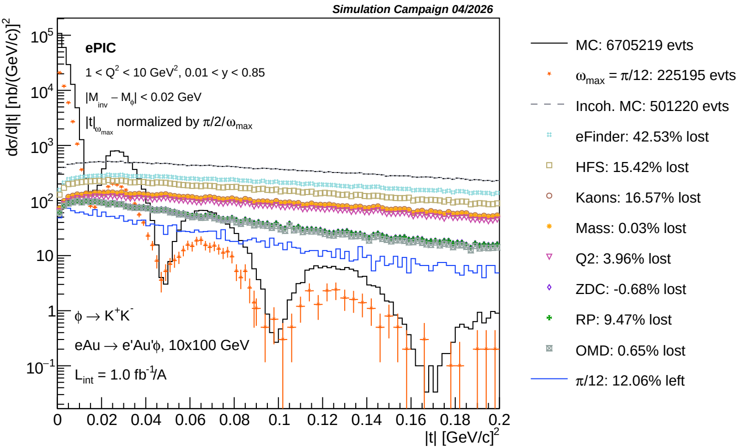


STAR Collaboration, 10.1103/PhysRevC.96.054904

- Increase $\omega_{\max}$:
  - **Ability to resolve dips**
  - Lose statistics
- Need **precise location of minima**

- Small **errors in minima** = large **errors in density**
- Smaller $|b|$ determined by larger $|t|$

Incoherent Production



- **Dominant source of background** → can **only resolve first minima**
- Also studied DIS and ρ background sources and they are found to be negligible

Summary

TDIS: Neutron SF

- Uncertainty reduction on neutron SF
- Outlook: Polarized structure of deuterons

Diffractive ϕ: Gluon Imaging

- Recovery of diffractive minima & transformation
- Outlook: Incoherent suppression

EDT program is delivering early EIC physics!

Backup Slides

Analysis Strategies:

Calculating the distribution of momentum transfer, t

Several methods

- Each with distinct advantages
- Depends on specific reaction under study

t can be calculated using combinations of 4 momenta of final states:

- p^{μ}_{BA}: outgoing **BA**ryon 4-momentum
- p^{μ}_{BE}: incoming proton **BE**am momentum
- $p^{\mu}_{\gamma^*}$: difference between incoming & scattered electron 4-momenta (i.e. information relating to e & e')
- p^{μ}_{X}: 4-momentum of the rest of final state, **X**

Tagged DIS in *eD* Collisions at 10x130 GeV^2

Variables Used in Analysis

Scattered electron:

- $Q^2 = -q^2 = -(p_{e,\mathrm{beam}} - p_{e,\mathrm{scat}})^2$
- $x = \frac{Q^2}{P \cdot q}$
- $x_{\mathrm{nucleon}} = \frac{Q^2}{2P_{\mathrm{nucleon}} \cdot q} = \frac{x}{2-\alpha_p}$

Kinematic variables:

- $y = \frac{p_d \cdot q}{p_d \cdot p_{e,\mathrm{beam}}}$
- $1 - \epsilon = \frac{y}{1+(1-y)^2}$

Light cone momentum fraction:

$$\boxed{\alpha_p \equiv \frac{2p_p^+}{p_d^+} = \frac{2(E_p + p_{z,p})}{E_d + p_{z,d}}}$$

Proton transfer momentum:

- $p_{T,p} = \sqrt{p_{x,p}^2 + p_{y,p}^2}$

Fine structure constant:

- $\alpha_{\mathrm{em}} = \frac{1}{137}$

Luminosity and cross section:

- $L_{\mathrm{int}} = \frac{N_{\mathrm{events}}}{\sigma_{\mathrm{tot}}}$
  - mb $= 2.568$ GeV^{-2}
  - $\sigma_{\mathrm{tot}} = 3.538 \cdot 10^{-4}$ mb (en)
  - $\sigma_{\mathrm{tot}} = 3.707 \cdot 10^{-4}$ mb (ep)

Tagged DIS in *eD* Collisions at 10x130 GeV^2

Deuteron Reduced Cross Section

- Differential cross section on d can be written in terms of deuteron reduced cross section ($\sigma_{\mathrm{red},d}$) and photon flux A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205
  M. Strikman and C. Weiss: Phys. Rev. C 97, 035209
  W. Cosyn and C. Weiss: Phys. Rev. C 102, 065204

$$\mathrm{d}\sigma_d = \underbrace{\frac{2\pi\alpha_{\mathrm{em}}^2[1+(1-y)^2]}{Q^4 x}}_{\text{photon flux}} \times \sigma_{\mathrm{red},d} \times \underbrace{\mathrm{d}x\,\mathrm{d}Q^2 \frac{\mathrm{d}\phi_{e'}}{2\pi}}_{\text{scat. electron}} \underbrace{[2(2\pi)^3]^{-1} \frac{\mathrm{d}\alpha_p}{\alpha_p} \frac{\mathrm{d}p_{T,p}^2}{2} \mathrm{d}\phi_p}_{\text{spectator}}$$

- Measured reduced cross section (integrated over $\mathrm{d}\phi_p$)

$$\boxed{\bar{\sigma}_{\mathrm{red},d} = \underbrace{\left(\frac{2.568}{L_{\mathrm{int}}}\right)}_{\text{lumi + unit conversion}} \frac{Q^4 x}{2\pi\alpha_{\mathrm{em}}^2[1+(1-y)^2]} \frac{[4(2\pi)^3]\alpha_p}{\Delta\alpha_p} \frac{\mathrm{d}N}{\Delta x \Delta Q^2 \Delta p_{T,p}^2 2\pi}}$$

Full azimuthal coverage for electron: $\Delta\phi_{e'}/2\pi = 2\pi/2\pi = 1$
Full azimuthal coverage for spectator: $\Delta\phi_p = 2\pi$

Tagged DIS in *eD* Collisions at 10x130 GeV^2

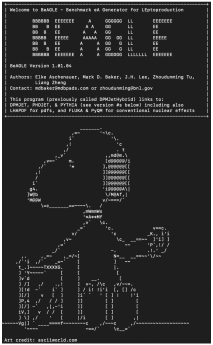
Simulation: BeAGLE

Overview:

- Campaign 26.03.1
- 20M events of *eD* 10x130 GeV^2
  - 10M *en* and 10M *ep*

Luminosity and cross section:

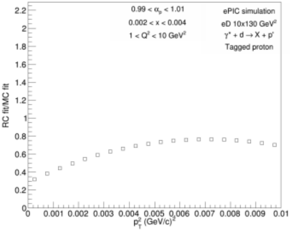
- Total integrated luminosity (EICRecon): $\boldsymbol{L_{\text{int}} = 0.056\ \text{fb}^{-1}}$
- Expected luminosity for year 2: $\boldsymbol{L_{\text{int}} = 1.5\ \text{fb}^{-1}}$
  - **All statistical uncertainties projected to expected luminosity**

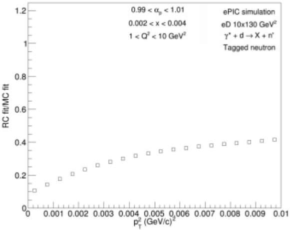


https://eic.github.io/software/beagle.html

- *en* : $\boldsymbol{\sigma_{\text{tot}} = 3.538 \cdot 10^{-4}\ \text{mb}}$, $L_{\text{int}} = N_{\text{evt}}/\sigma_{\text{tot}} = 10\text{M}/(3.538 \cdot 10^{-4}\ \text{mb}) = 10\text{M}/(3.538 \cdot 10^{8}\text{fb}) = \boldsymbol{L_{\text{int}} = 0.028\ \text{fb}^{-1}}$
- *ep* : $\boldsymbol{\sigma_{\text{tot}} = 3.707 \cdot 10^{-4}\ \text{mb}}$, $\boldsymbol{L_{\text{int}} = 0.028\ \text{fb}^{-1}}$

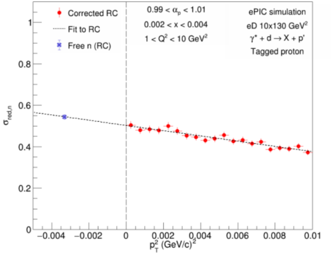
- Efficiency and bin migration correction done using ratio of MC and RC fit functions to nucleon reduced cross section
    - Eff. = RC fit/MC fit
    - Functions evaluated at histogram bin centers
- Efficiency then applied back to RC reduced cross section point by point

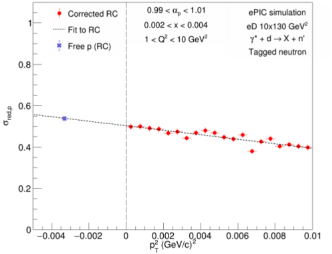




Tagged DIS in *eD* Collisions at 10x130 GeV^2

Systematic Uncertainties (1/2)





Luminosity: $\sigma_{\text{lumi}} = 1.5\%$

- From YR and current discussion

Theory/extapolation: $\sigma_{\text{th}} = 2\%$

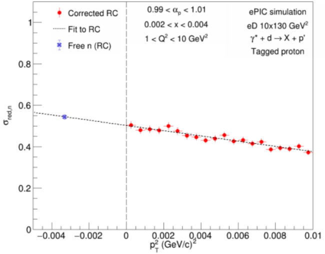
- From original paper
- A. Jentsch, Z. Tu, C. Weiss: Phys. Rev. C 104, 065205

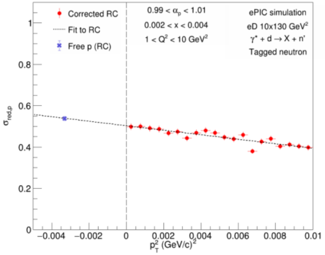
Beam effects: $\sigma_{\text{beam}} = 1.5\%$

- Crossing angle, angular divergence, beam momentum spread
- Based on values cited by ATLAS or HERA
- ATLAS Collaboration: The European Physical Journal C 83 (2023)
- HERA Collaboration: Nuclear Physics B 816, 1–61 (2009)

Tagged DIS in *eD* Collisions at 10x130 GeV^2

Systematic Uncertainties (2/2)





Proton reconstruction: $\sigma_p = 2\%$

- Uncertainty of transport matrix
- Based on values cited by ATLAS
- ATLAS Collaboration, The European Physical Journal C 83 (2023)

Neutron reconstruction: $\sigma_n = 1\%$

- Uncertainty of the primary vertex resolution
- Based on values cited by HERA and ePIC Roman Pot studies
- HERA Collaboration, Nuclear Physics B 816, 1–61 (2009)

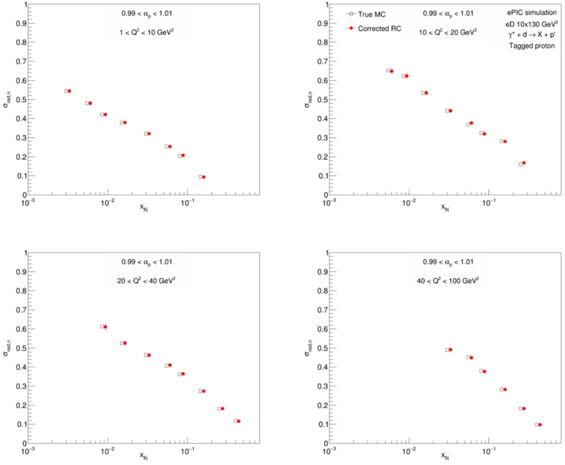
Total systematic uncertainty:

$$\sigma_{\rm sys} = \sqrt{\sigma^2_{\rm lumi} + \sigma^2_{\rm th} + \sigma^2_{\rm beam} + \sigma^2_{n/p}}$$

Tagged DIS in *eD* Collisions at 10x130 GeV^2

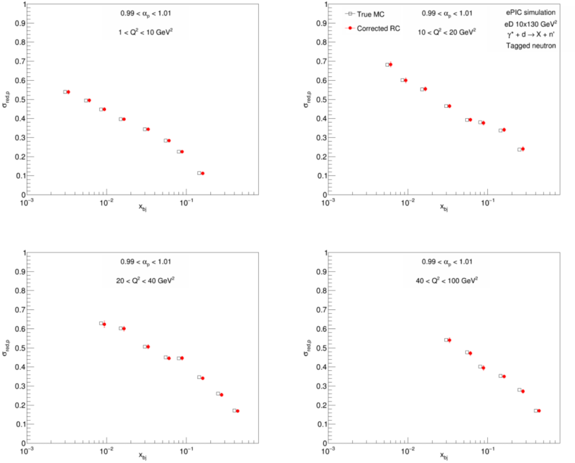
Neutron Reduced Cross Section vs x_{bj}

- Comparison of **MC and RECO neutron reduced cross sections** in bins of (x_{bj}, Q^2)
- Uncertainties dominated by systematics
- **Statistical uncertatinties negligible** even in early years of running the EIC



Tagged DIS in *eD* Collisions at 10x130 GeV^2

Proton Reduced Cross Section vs x_{bj}

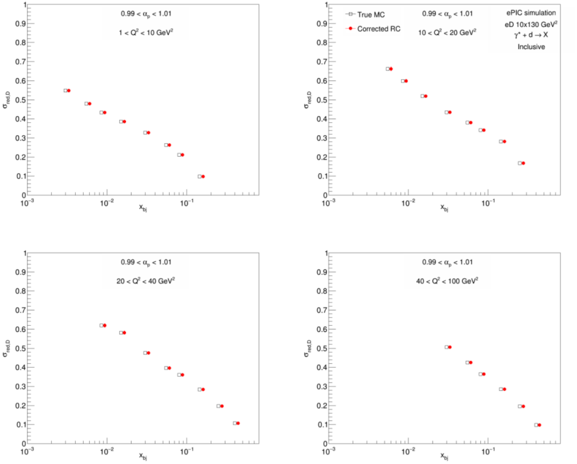


- Comparison of **MC and RECO proton reduced cross sections** in bins of (x_{bj}, Q^2)
- Uncertainties dominated by systematics
- **Statistical uncertatinties negligible** even in early years of running the EIC

Tagged DIS in *eD* Collisions at 10x130 GeV^2

Dueteron Reduced Cross Section vs x_{bj}

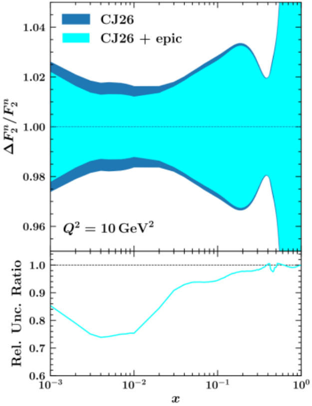
- Comparison of **MC and RECO inclusive deuteron reduced cross sections** in bins of (x_{bj}, Q^2)
- Used primarily for calculations by our theory colleagues for ESR



Tagged DIS in *eD* Collisions at 10x130 GeV^2

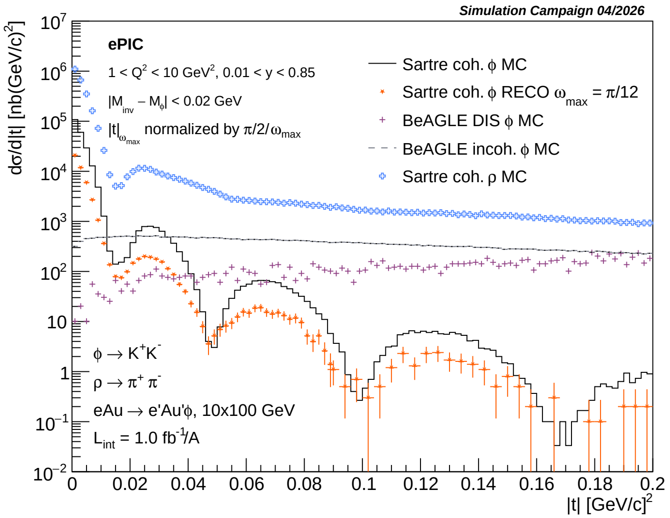
Result for ESR

- Impact study demonstrating uncertainty reduction on neutron SF F_2^n after using TDIS pseudo-data from ePIC
- Expected 20% uncertainty reduction for $10^{-3} < x < 10^{-2}$
- Calculation by Matteo Cerutti and Alberto Accardi



Diffractive ϕ Production

Background Contributions

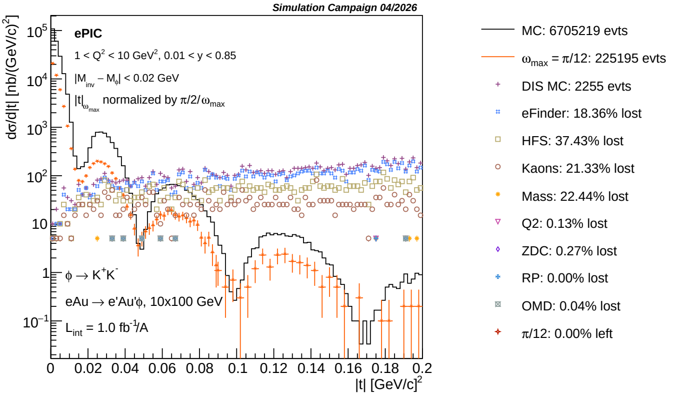


1. DIS background
2. Incoherent production
3. ρ contamination

Note: will implement more sources of uncertainty in future

Diffractive ϕ Production

DIS Background

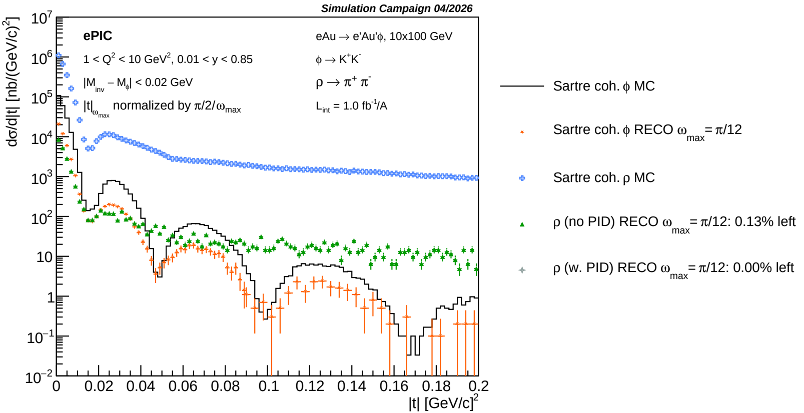


Distribution is dominated by DIS background contributions

Applying all vetoes and cuts **removes DIS background**

Diffractive ϕ Production

ρ Contamination



VM **daughters can be misidentified**

Applying PID **removes ρ contribution**