Diffractive ϕ Analysis Update

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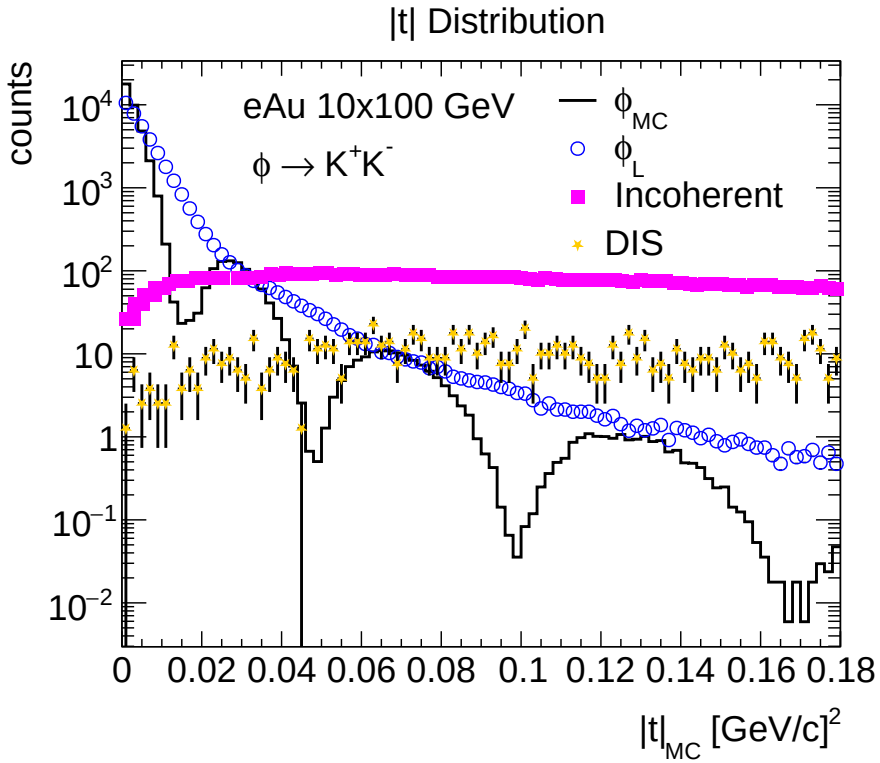
Introduction

Crucial aspect of program → ability to study gluons

Critical measurement: exclusive vector meson (VM) production

- Probe to gluon density → precisely see structure → saturation
- Distribution of momentum transfer (t):
  - Fourier conjugate to impact parameter
  - Gluon imaging



- **Limited resolution in measuring t**
  - Mainly momentum resolution of outgoing electron (blue circles)
- **Overwhelming background**
  - Incoherent (magenta squares)
  - DIS (orange stars)

Status

Kinematic reconstructions	quantity	Reco	Truth	Response (2D)	Purity/bin migration	detector acceptance-only corrected	Unfolding/full correction
(electron,JB, DA,sigma, e-sigma)	Q2	☐	☐	☐	☐	☐	☐
	x	☐	☐	☐	☐	☐	☐
	y	☐	☐	☐	☐	☐	☐
	dQ2/Q2	☐	☐	☐	☐	☐	☐
	dx/x	☐	☐	☐	☐	☐	☐
	dy/y	☐	☐	☐	☐	☐	☐
	e' energy	☐	☐	☐	☐	☐	☐
	e' theta	☐	☐	☐	☐	☐	☐
	HFS (E-pz)	☐	☐	☐	☐	☐	☐
	HFS (pT)	☐	☐	☐	☐	☐	☐
Event level		☐	☐	☐	☐	☐	☐
	E-pz (e'+HFS)	☐	☐	☐	☐	☐	☐
	E/p for calorimeter	☐	☐	☐	☐	☐	☐
	Calo clusters	☐	☐	☐	☐	☐	☐
Observable of interest		☐	☐	☐	☐	☐	☐
	e.g., t,u,etc.	☐	☐	☐	☐	☐	☐
Detector specific variables	Depends	☐	☐	☐	☐	☐	☐
PID quantities:	Add when it comes	☐	☐	☐	☐	☐	☐

- Finalized analysis with QA plots
- Implement AI (PyTorch) for unfolding

Simulation Overview

eAu 10x100 GeV Diffractive ϕ Production

- Sartre1.39-1.0:
  - Coherent exclusive ϕ production
  - CraterLake 25.06.1
- BeAGLE1.03.02-1.0:
  - DIS (background study)
  - CraterLake 25.06.1

Branches Used:

- "MCParticles" $\rightarrow$ MC truth particles
- "EcalEndcapNClusters" and "EcalEndcapNRecHits" $\rightarrow$ EMcal cluster info
- "EcalEndcapNClusterAssociations" $\rightarrow$ rec and sim ID mapping
- "_CalorimeterTrackProjections_points" $\rightarrow$ calorimeter tracks
- "ReconstructedChargedParticles" $\rightarrow$ charged particles
- "ReconstructedFarForwardZDCNeutrals" $\rightarrow$ ZDC hits
- "ForwardRomanPotRecHits $\rightarrow$ RP hits
- "ForwardOffMTrackerRecHits" $\rightarrow$ OMD hits

Code Logic

Remove incoherent events:

- Reject hits in: OMD, RP, ZDC
- Cut on $|\eta| > 3.5$

Indentify e':

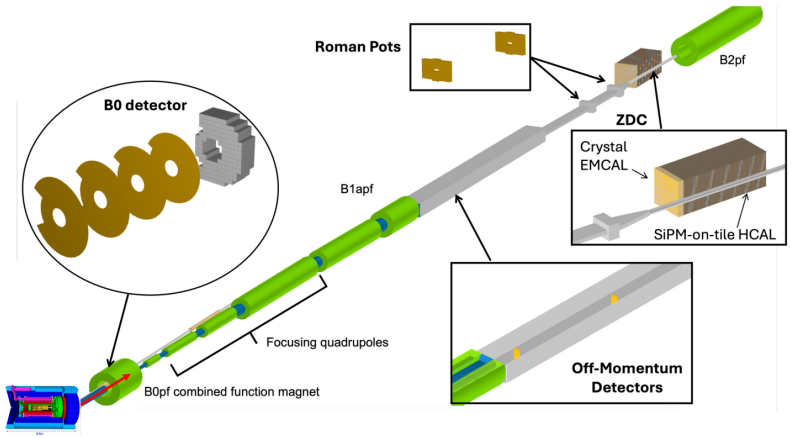
- Find highest energy cluster
- Build 3x3 cluster within 70 mm
- Weighted average of position
- Match cluster to track

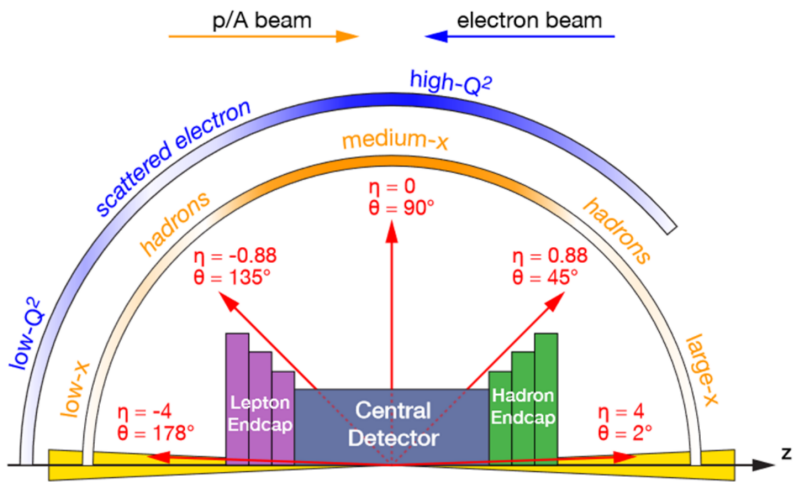
Build HFS:

- Use all tracks except e'
- $\phi \to K^+K^-$
- Veto if HFS >2

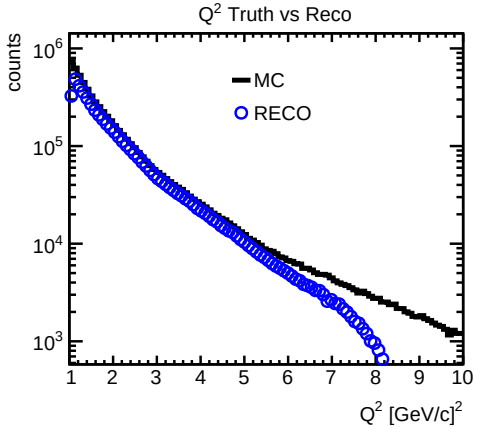
Calculate $|t|$:

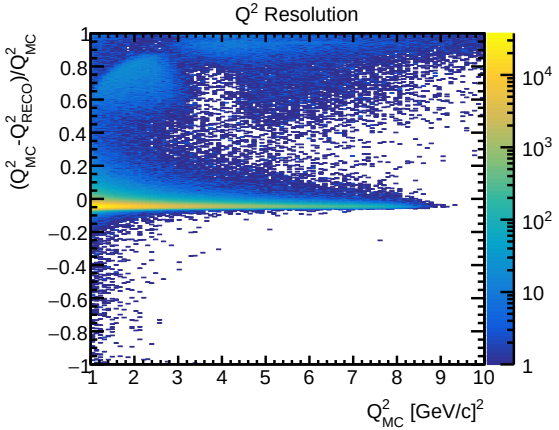
- Extract $|t|$ from ϕ kinematics

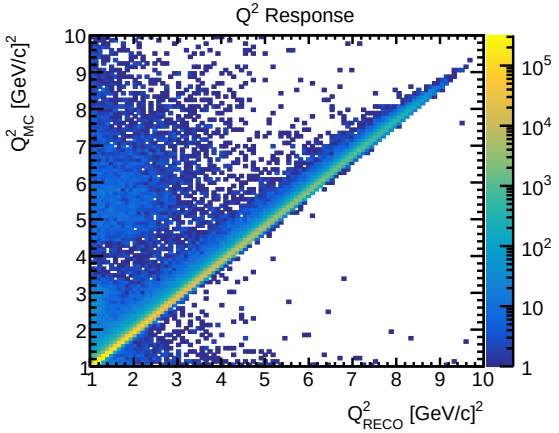


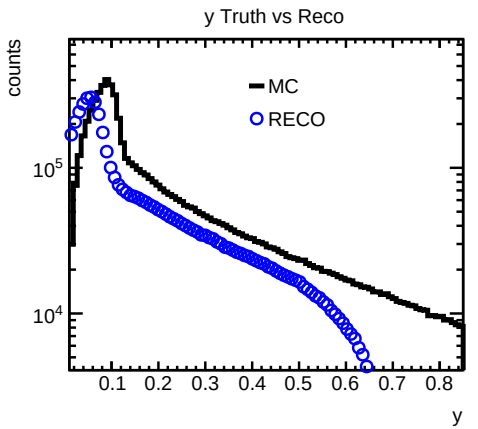


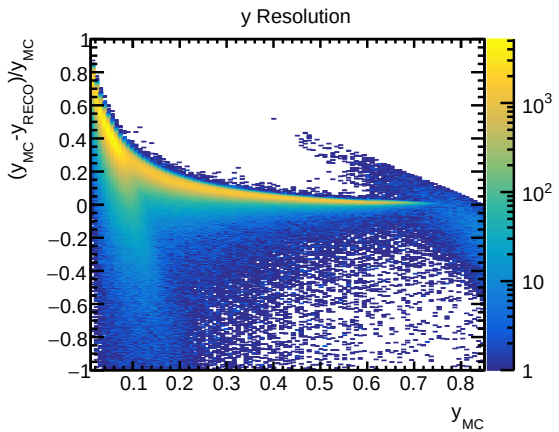
Cuts: Q^2 and y

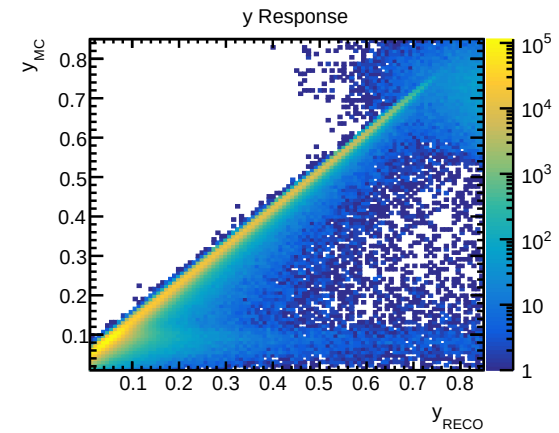












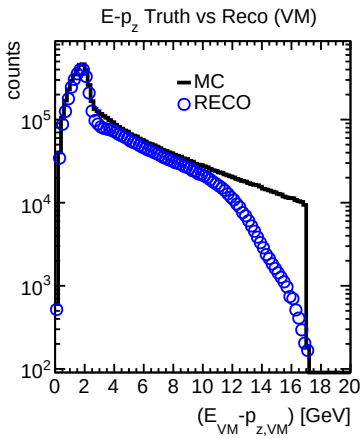
$1 < Q^2 < 10\ (\mathrm{GeV}/c)^2$

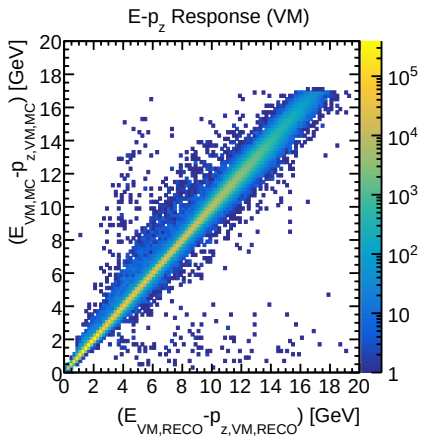
- Ensure photon hard enough
- Avoid poor resolution

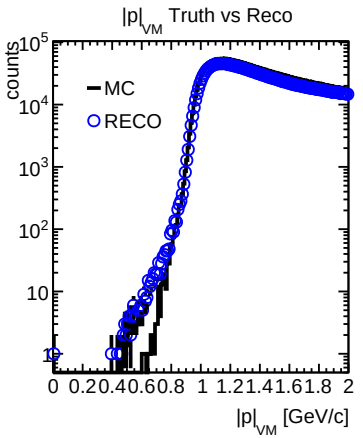
$0.01 < y < 0.85$

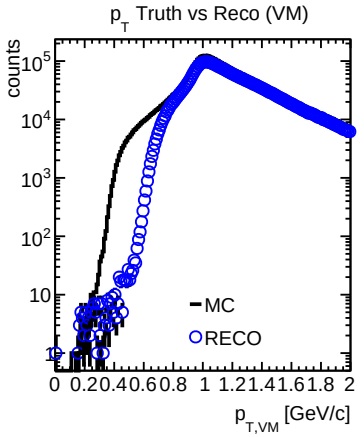
- Avoid where e barely interacts
- Avoid where e loses almost all energy

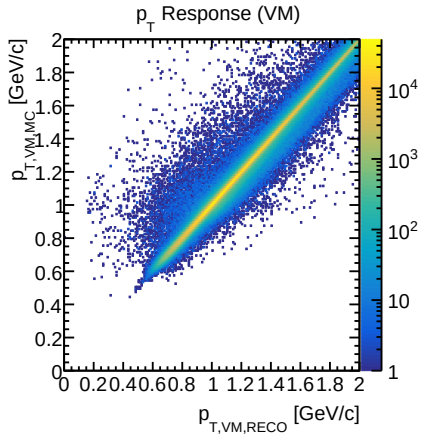
Cuts: VM

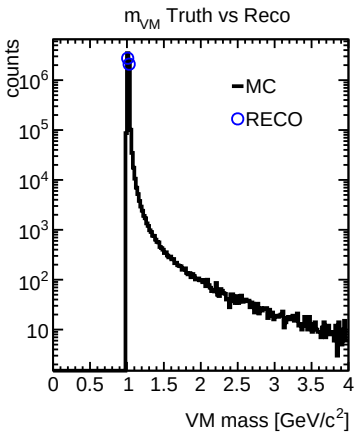












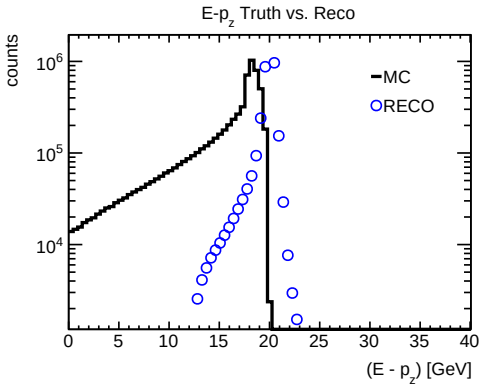
$|\text{Rapidity}| < 3.5$

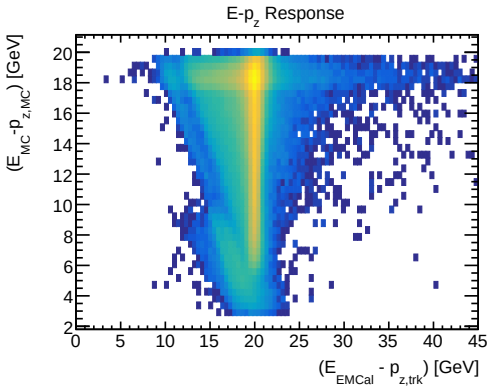
- Centrally produced
- Distinct diffractive event

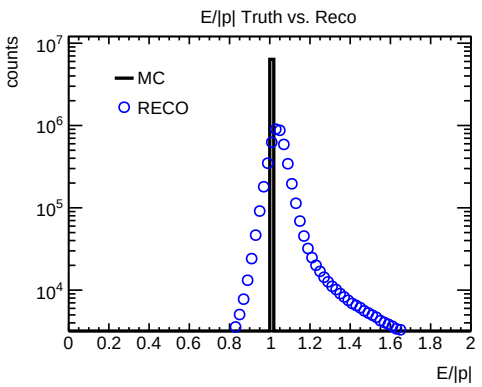
$|m_{\text{VM}} - 1.02| < 0.02$ (GeV/c^2)

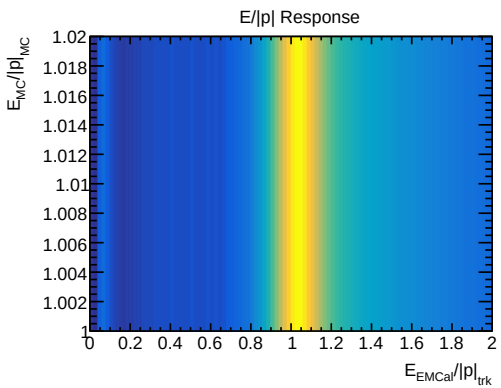
- Ensure ϕ selection

Cuts: $E - p_z$, E/p









e'_{RECO}:

- Use EMcal cluster energy $\rightarrow$ get p
- Use reco track $\rightarrow$ get η, ϕ, θ

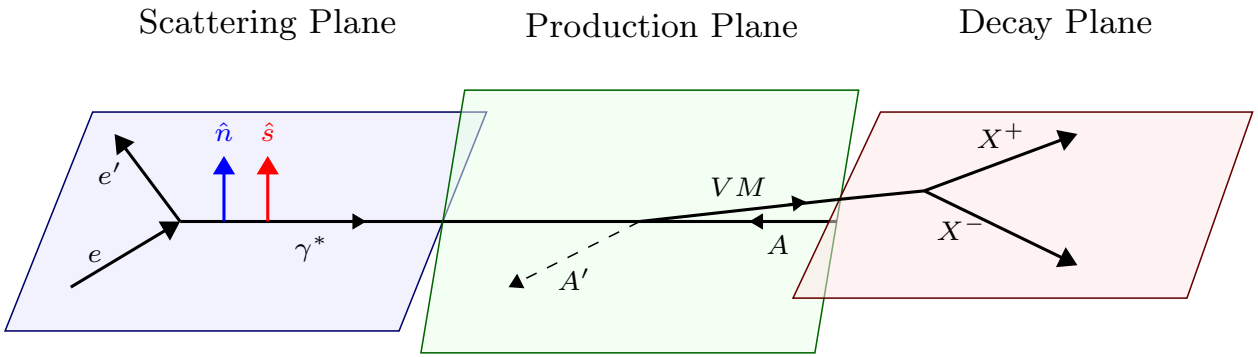
$15 < E - p_z < 25$ (GeV)

- Complete final state
- Ensure exclusivity

$0.8 < E/p < 1.18$

- Confirm EMcal matches track
- Select true electrons

Cuts: $\theta_{\max}$



- Find region where P_{VM} dominates

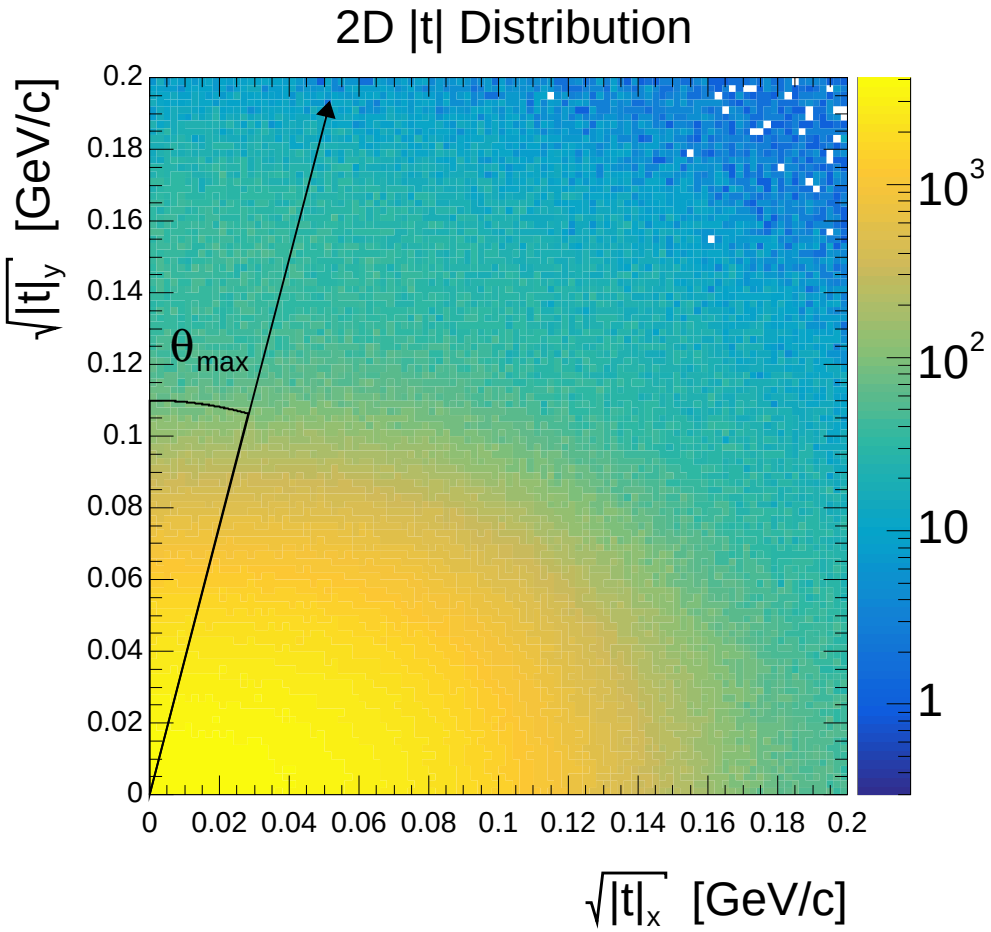
Decompose t:

$$\begin{aligned} t &= t_\perp + t_{//} \\ t_\perp &= t_x + t_y \\ &= q_x^2 + q_y^2 \\ t_\perp &= q_\perp^2 \end{aligned}$$

Parameterize $q_\perp = \pm\sqrt{|t_\perp|}$:

$$\begin{aligned} q_x &= q_\perp \sin(\theta) \\ q_y &= q_\perp \cos(\theta) \\ \theta_{\max} &= \tan^{-1}\left(\frac{q_x}{q_y}\right) \end{aligned}$$

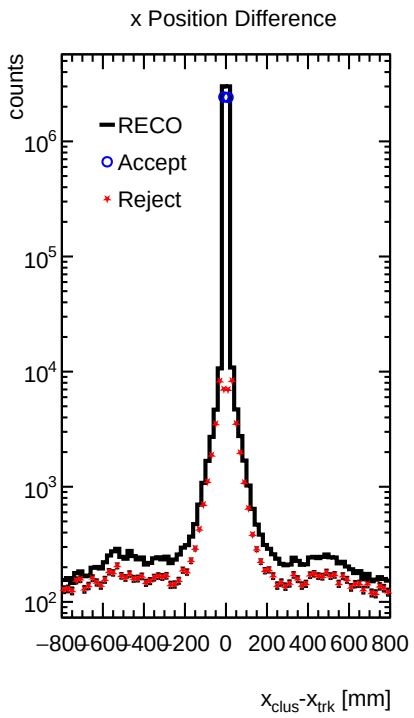
Cuts: $\theta_{\max}$

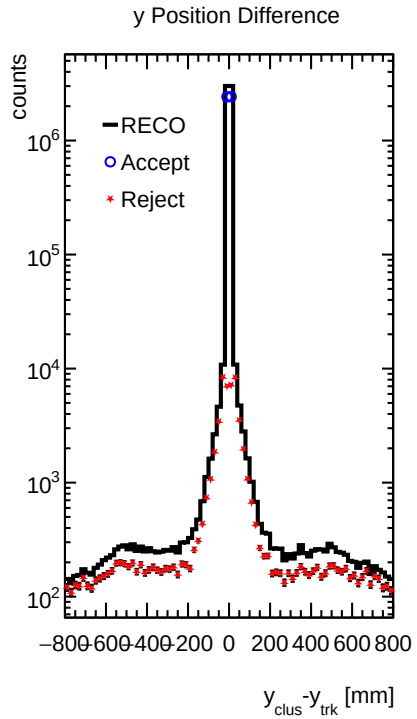


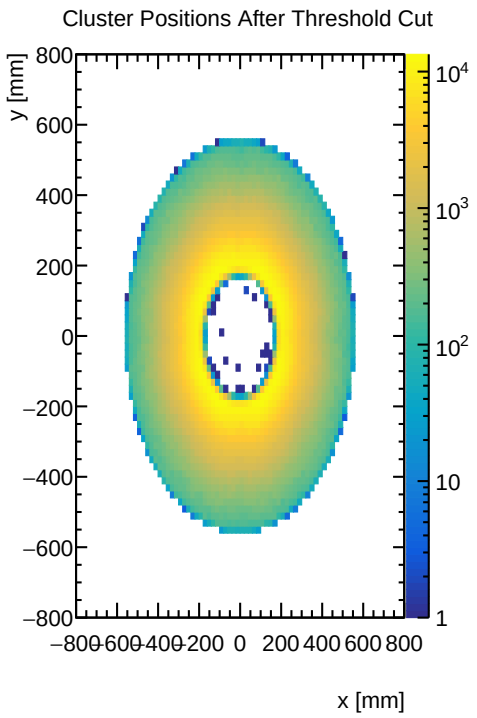
- **Define $q_x = \sqrt{|t_x|}$ to be in $\hat{x} = \hat{n} \times \hat{p}_e$ direction**
- Cut wedge of angle $\theta_{\max}$ from $\hat{n}$-direction
  - $q_y \rightarrow$ projected VM
- Eliminates most of the q_x component

$$\theta_{\max} = tan^{-1}\left(\frac{q_x}{q_y}\right)$$

Cuts: Geometric







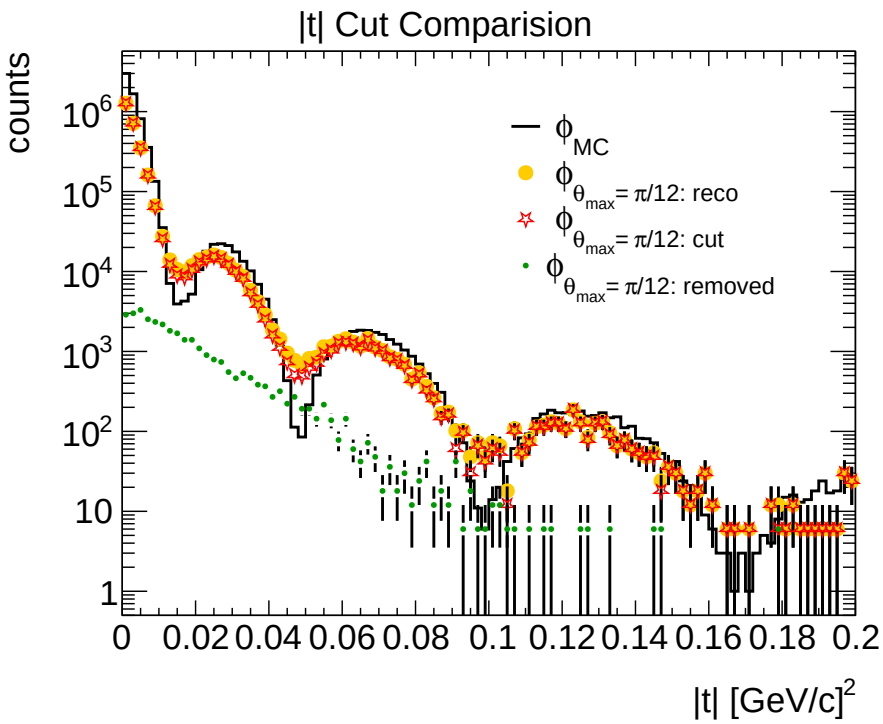
$$|x_{\text{clus}} - x_{\text{trk}}| < 20 \text{ mm}$$
$$|y_{\text{clus}} - y_{\text{trk}}| < 20 \text{ mm}$$

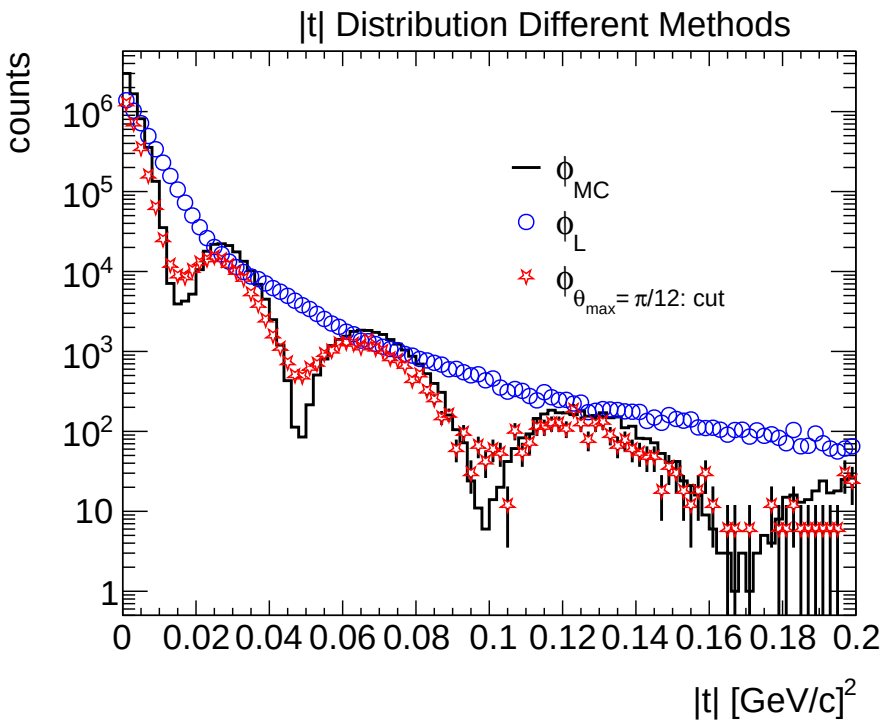
- Improve e' reconstruction

$$r < 550 \text{ mm}$$

- Ensure electron is within detectors sensitive region

Reconstruction Methods: $|t|$

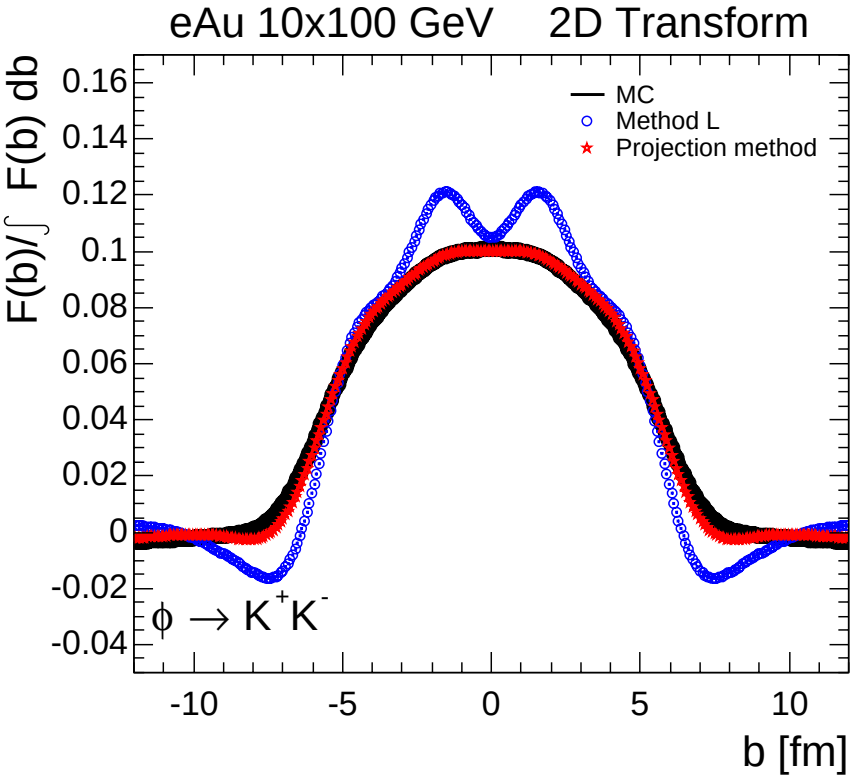




$|t|$ Distribution:

- **Method E:** $|t|_{MC} = (P_{VM} + P_{e'} - P_e)^2$
- **Method L:** $|t|_{\mathrm{L}} = (P_{\mathrm{A}} - P_{\mathrm{A}'}^{\mathrm{corr}})^2$
- **Projection method:** $t_{\mathrm{proj}} = (t_x, t_{\hat{n}}, t_z, t_E)$, $|t|_{\hat{n}} = (P_{\mathrm{VM}} \cdot \hat{n})^2$

The Transformation



Import $|t|$ distribution:

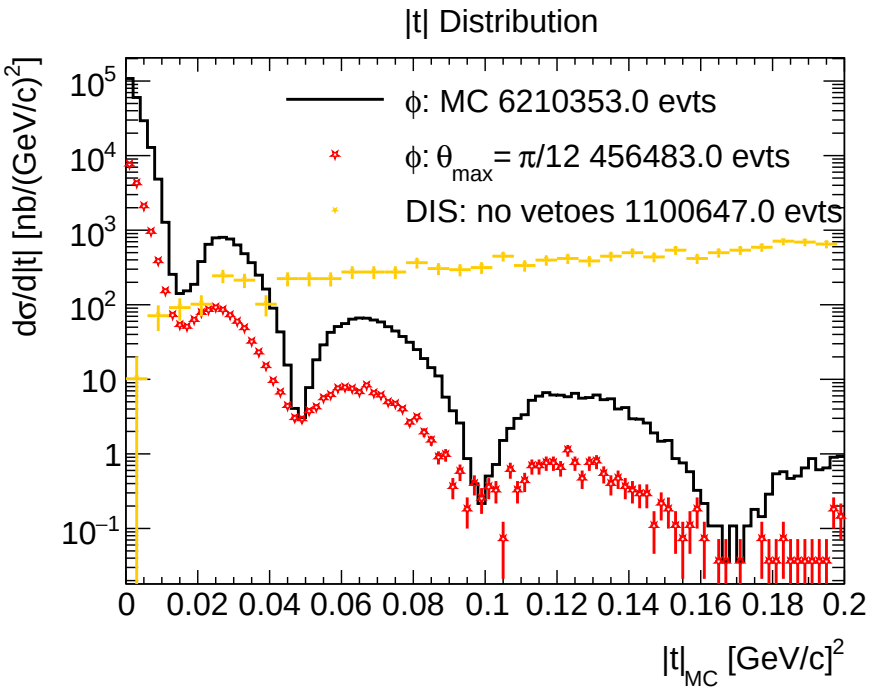
- Based on diffractive minima of $|t| \to$ apply sign flips
  - Maintain osillatory structure

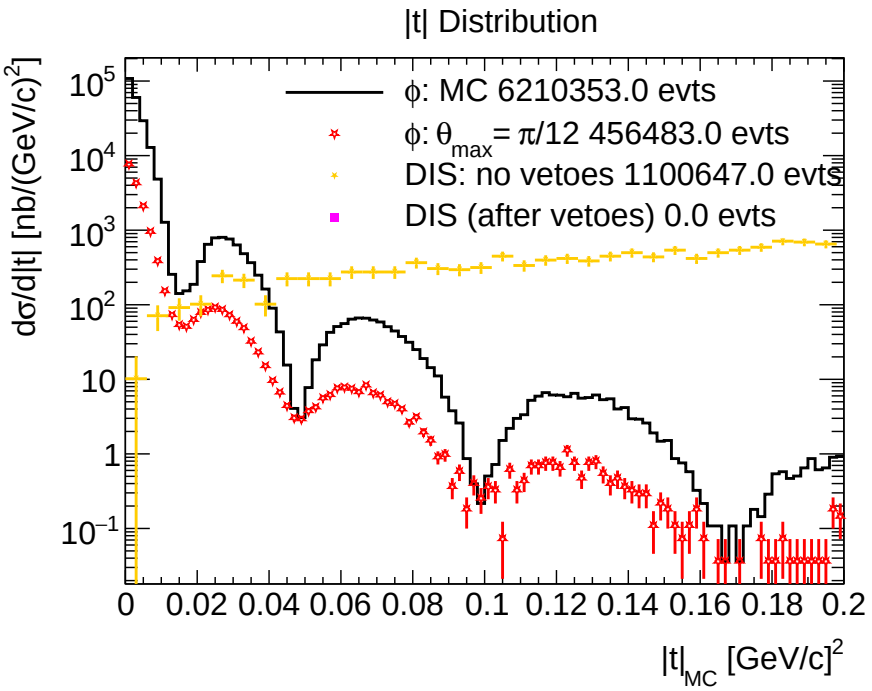
Fourier-Bessel Transformation

$$F(b) \propto \frac{1}{2\pi} \int_0^\infty \sqrt{\frac{d\sigma}{dt}} J_0(bq_T) q_T dq_T$$

- $\sqrt{\frac{d\sigma}{dt}}$: Amplitude of scattering
- $J_0(bq_T)$: Bessel function $\to$ radial symmetry in transverse plane
- $q_T = \sqrt{|t|}$

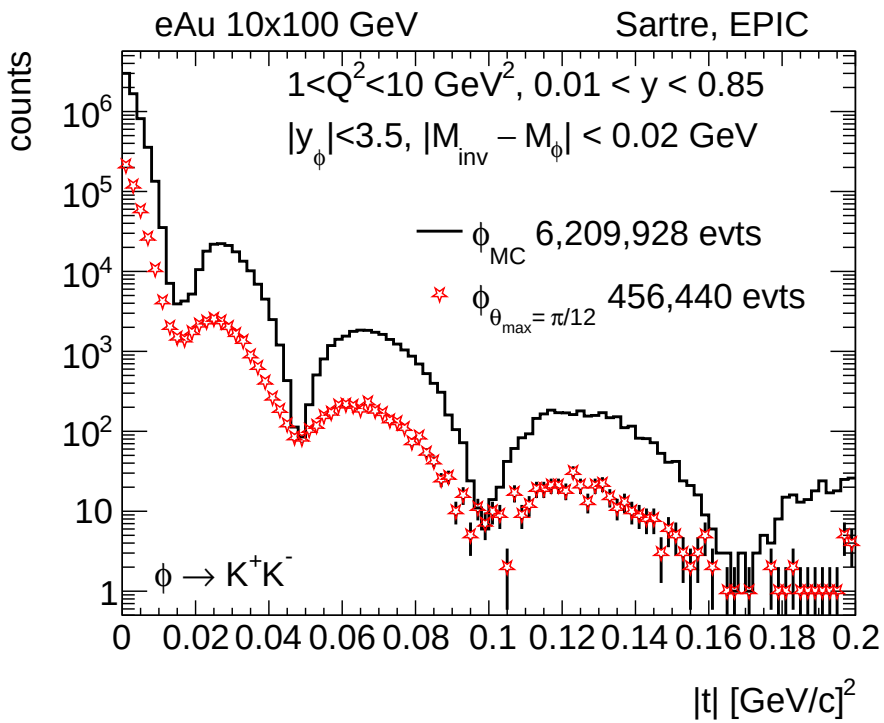
DIS Background

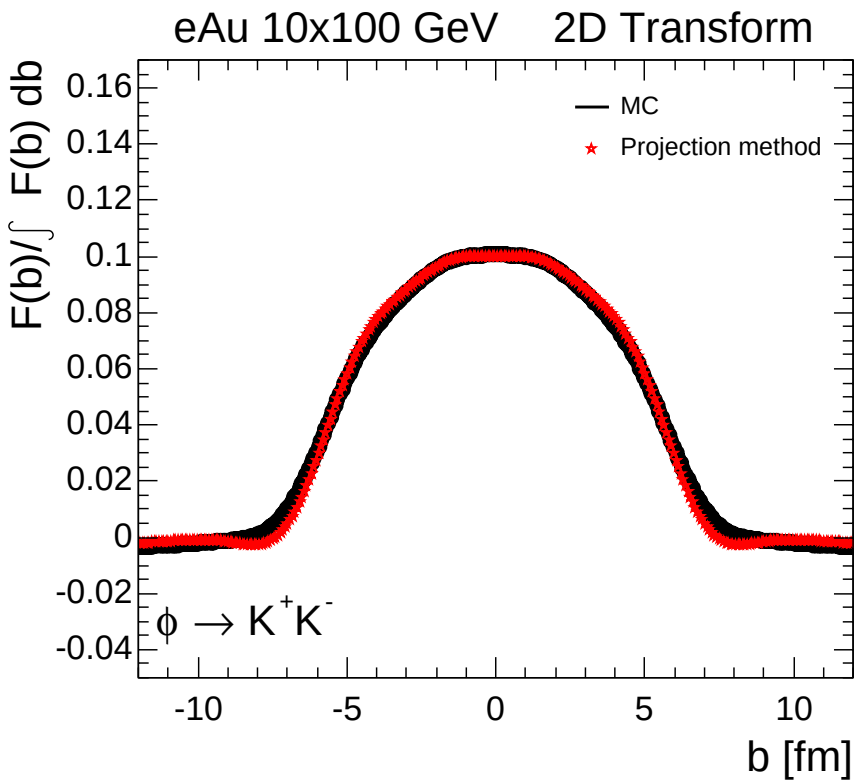




- Combine all cuts → remove all background

Results





Substantial improvement!

- Refined diffractive pattern
- Obtained spatial profile
- **Con:** loss of statistics

Summary

- *What has been done:*
  - DIS background study
  - Recovered diffractive structure
  - Mapped gluon density distribution
- *What still needs to be done:*
  - For preTDR: redo analysis with eAu 18x110
  - **Add incoherent** for both eAu 10x100 and 18x110
  - Statistically remove incoherent, AI unfolding
  - Add ρ background
  - Add DIS and incoherent to analysis note
- *What simulations still need to be ran:*
  - Need eAu 18x110 and 10x100 BeAGLE (exclusive incoherent diffractive ϕ) files
  - Need diffractive ρ coherent/incoherent 10x100 files