Diffractive ϕ in eAu Collisions at ePIC

Exclusive, Diffractive, Tagging PWG

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ePIC Physics Forum

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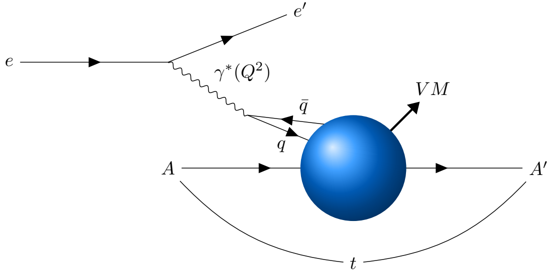
Overview

1. Background
   - Link to analysis note: Zenodo link
2. Results
3. Status Update

Introduction

Critical measurement: exclusive vector meson (VM) production in scattering

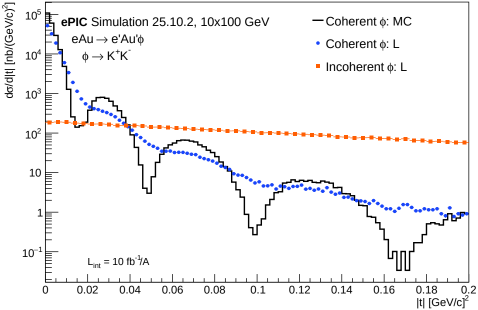
- Probe to gluon density $\rightarrow$ precisely see structure $\rightarrow$ saturation
- Deflection of VM measures spatial distribution of gluons



- Distribution of momentum transfer ($|t|$):
  - Fourier conjugate to impact parameter
  - Reflects the spatial profile
- Gluon imaging

Challenges

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



1. **Limited resolution in measuring $|t|$**
   - Mainly momentum resolution of e'
     - Scattered very far backward → emerges at small angle
     - Tiny angular error → large p_T error
2. **Overwhelming incoherent background**
   - Orange squares
   - Detector cannot suppress all incoherent production

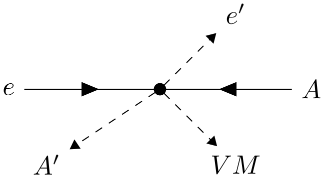
Yellow Report: best method of $|t|$ reconstruction → blue circles

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

Reconstruct from exclusive VM production

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

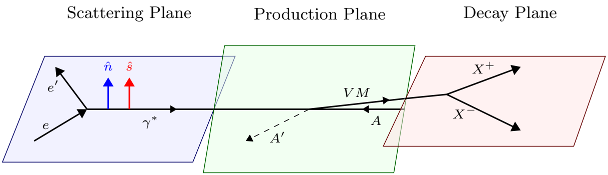
To access $|t|$: need complete final state



- Cannot measure $P_{A'}$
  - For heavy nuclei $\rightarrow$ stays within beam envelope
  - Tiny momentum change + tiny angular deflection

- $|t|_{BABE}$ (Method E): $|t| = (P_A - P_{A'})^2$
  - Small error/inaccuracy has large effect on $|t|$
- $|t|_{eX}$ (Method A): $|t| = [\mathbf{p}_T(e') + \mathbf{p}_T(VM)]^2$
  - Underestimates true t, valid only for small $|t|$ and small Q^2
- $|t|_{eXBE}$ (Method L): $|t|_{\mathrm{corr}} = (P_A - P_{A'}^{\mathrm{corr}})^2$
  - Only applies to coherent events

Projection Technique: $|t| = (P_A - P'_A)^2$



- Measure $|t|$ component along normal direction ($\hat{n}$) of e scattering plane
- $|t|_{\hat{n}}$ unaffected by momentum resolution $\rightarrow$ eliminate momentum resolution contribution from e'

Method L:

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

Method E:

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

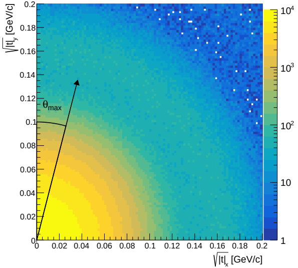
Define $\hat{n}$:

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

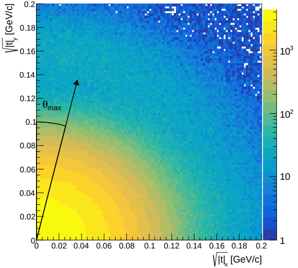
$$\begin{aligned} |t|_{\hat{n}} &= [(P_{VM} + P_{e'} - P_e) \cdot \hat{n}]^2 \\ |t|_{\hat{n}} &= (P_{VM} \cdot \hat{n})^2 \\ |t| &= (|t|_x, |t|_{\hat{n}}, |t|_z, |t|_E) \end{aligned}$$

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

2D MC Distribution



2D Reco Distribution

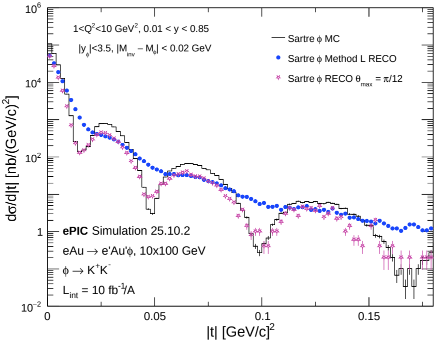


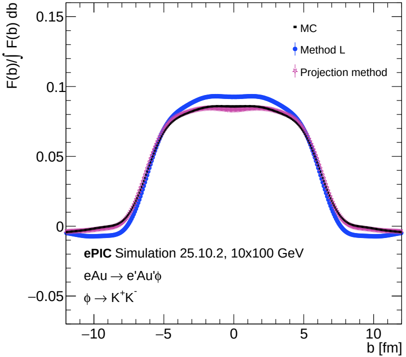
- Define $q_x = \sqrt{|t_x|}$ to be in $\hat{x} = \hat{n} \times \hat{p}_e$ direction (e' direction)
- Cut wedge of angle $\theta_{\max}$ from $\hat{n}$-direction ($q_y = \sqrt{|t|_{\hat{n}}}$)
- Eliminates most of the q_x component (e' direction)

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

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

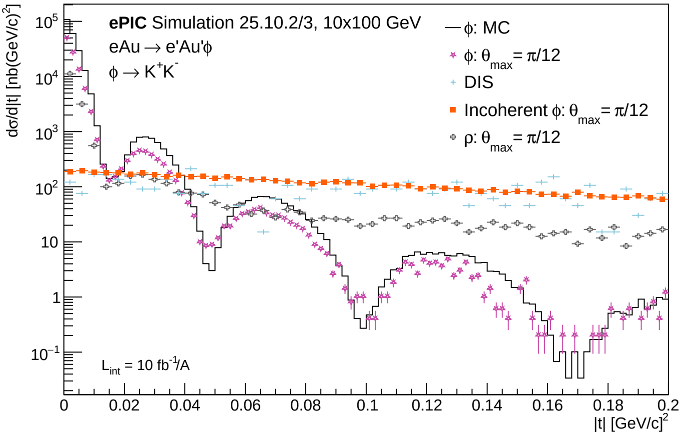
Results





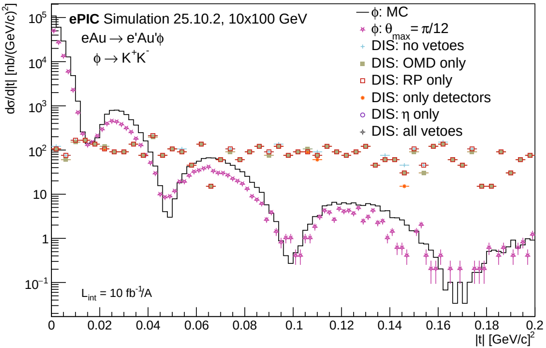
Significant improvement in both distributions

Background Sources



Note: will implement more sources of uncertainty in future

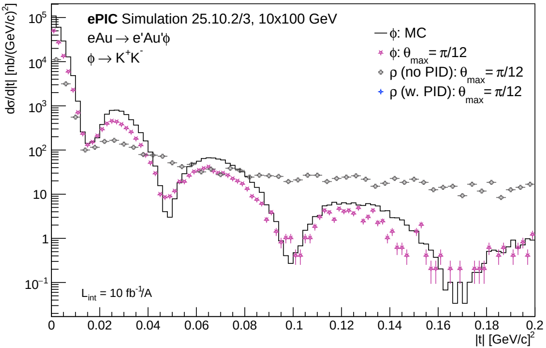
DIS Background



- Vetos: RP and OMD
- Cut: $|\eta| < 3.5$
- Selection: HFS $\phi \to K^+K^-$

Applying all vetoes and cuts *removes all DIS background*

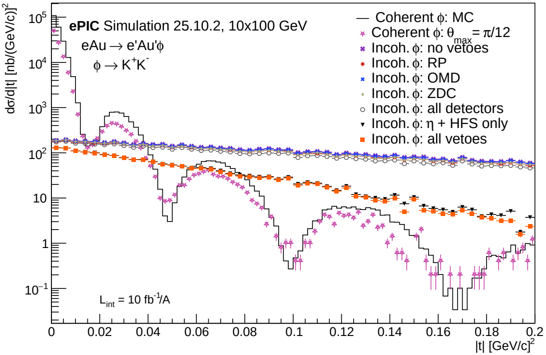
ρ Contamination



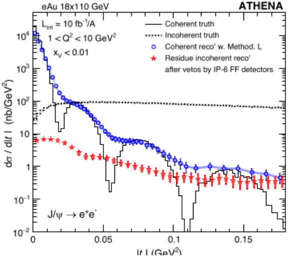
- With PID: reconstructed kaons using *"ReconstructedCharged-Particles"* PDG branch

Implementing PID *removes all ρ misidentification*

Incoherent Production



From analysis note



- ZDC should have more effect
- Expect more suppression at low $|t|$

Updates From Previous Results

Fixed ZDC Issue

```cpp
bool has_ECAL_cluster_energy = (Ecal_total > 0.0);
bool has_HCAL_cluster_energy = (Hcal_total > 0.0);

double veto_energy = 0.0;
if (has_ECAL_cluster_energy)
{
    veto_energy = Ecal_total;
}
else if (has_HCAL_cluster_energy)
{
    veto_energy = Hcal_total;
}

double threshold = 21.0; // GeV
if (veto_energy > threshold)
{
    Cluster_ZDC cluster;
    cluster.energy = veto_energy;
    if (has_ECAL_cluster_energy)
    {
        cluster.x = Ecal_zdc_x_array[0];
        cluster.y = Ecal_zdc_y_array[0];
        cluster.z = Ecal_zdc_z_array[0];
    }
    else if (has_HCAL_cluster_energy)
    {
        cluster.x = Hcal_zdc_x_array[0];
        cluster.y = Hcal_zdc_y_array[0];
        cluster.z = Hcal_zdc_z_array[0];
    }
    event.clusters_zdc.push_back(cluster);
    hZDC_energy->Fill(cluster.energy);
    hZDC_xy->Fill(cluster.x, cluster.y);
}
```

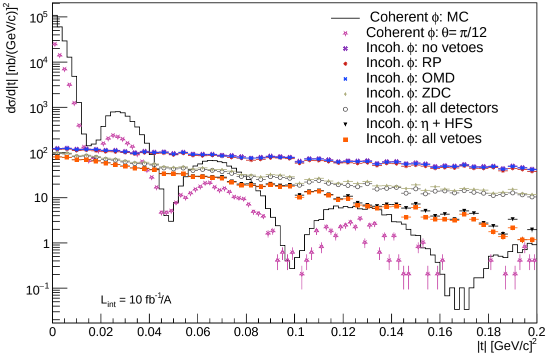
ZDC veto code from analysis note

```cpp
// --- Fill ECal ZDC clusters -------------------------------------------
for (int i = 0; i < Ecal_zdc_energy_array.GetSize(); i++)
{
    Cluster_ZDC cl;
    cl.x = Ecal_zdc_x_array[i];
    cl.y = Ecal_zdc_y_array[i];
    cl.z = Ecal_zdc_z_array[i];
    cl.energy = Ecal_zdc_energy_array[i];
    event.zdc_clusters.push_back(cl);

    TVector3 zdc_Ecal_position(Ecal_zdc_x_array[i], Ecal_zdc_y_array[i], Ecal_zdc_z_array[i]);
    h_zdc_Ecal_eta->Fill(zdc_Ecal_position.Eta());
}

// --- Fill HCal ZDC clusters -------------------------------------------
for (int i = 0; i < Hcal_zdc_energy_array.GetSize(); i++)
{
    Cluster_ZDC cl;
    cl.x = Hcal_zdc_x_array[i];
    cl.y = Hcal_zdc_y_array[i];
    cl.z = Hcal_zdc_z_array[i];
    cl.energy = Hcal_zdc_energy_array[i];
    event.zdc_clusters.push_back(cl);

    TVector3 zdc_Hcal_position(Hcal_zdc_x_array[i], Hcal_zdc_y_array[i], Hcal_zdc_z_array[i]);
    h_zdc_Hcal_eta->Fill(zdc_Hcal_position.Eta());
}
```

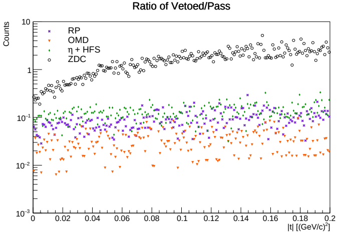
Updated ZDC veto code

- **Before:** veto based on ZDC ECal
- **Now:** veto based on both ZDC ECal and HCal

New ZDC Distribution



- Still expect more suppression at low $|t|$



Code Logic

Reconstruct e':

- Cuts on $E - p_z$ and E/p

HFS:

- Require 2 kaons in same event
- η cut

Event Selection

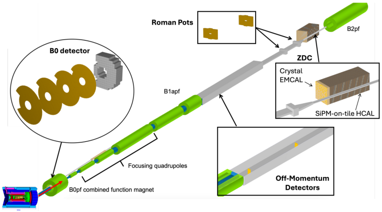
- Q^2, y, and m_{VM}

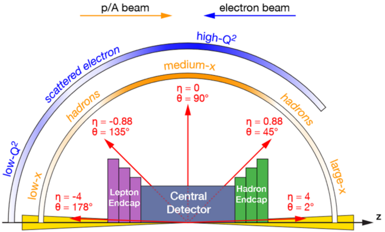
Detector Vetoes

- Reject activity in: OMD, RP, ZDC

Extract $|t|$ from ϕ kinematics:

- $|t|_{\hat{n}}$ projection and $\theta_{\max}$ cut





Events Killed by Cuts/Vetoes

Selection	Events
$e'! = 0$	160
$15 < E - p_z < 25$	4793
$0.8 < E/p < 1.2$	407
HFS $== 2$	5686
Kaons $== 2$	2100
$\eta < 3.5$	0
$(m_{\mathrm{VM}} - 1.02) >= 0.02$	6
$1 < Q^2 < 10$	7
$0.01 < y < 0.85$	922
ZDC	765
RP	36
OMD	12

Diagnostic run on 20 BeAGLE files

- Total 15380 events
- Event cuts/vetoes in order after found e'
- 77 events remain in $|t|_{\theta_{\mathrm{max}}}$ distribution

New Final Results

...coming soon

Summary

- **We are close to having final plots:**
  - Sanity checks
  - Update everything
- **To do:**
  - Phase II $\rightarrow$ statistically separate coherent and incoherent
  - Unfolding $\rightarrow$ will be ready to show to PWG soon
  - Still working on incorporating ML

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Backup Slides

Simulation Details I

Coherent Diffractive ϕ Production eAu 10x100 GeV

Sartre1.39-1.0, CraterLake 25.10.2, 2352 files

Branches Used:

- *"MCParticles"* $\rightarrow$ MC truth particles: PDG, momentum, mass, gen status
- *"EcalEndcapNClusters"* $\rightarrow$ EMcal cluster reco: position, energy
- *"EcalEndcapNRecHits"* $\rightarrow$ EMcal hit reco: position, energy
- *"EcalEndcapNClusterAssociations"* $\rightarrow$ reco and sim ID mapping
- *"_CalorimeterTrackProjections_points"* $\rightarrow$ calorimeter track reco: position, momentum
- *"ReconstructedChargedParticles"* $\rightarrow$ charged particle reco: momentum, charge

Simulation Details II

Coherent Diffractive ρ Production eAu 10x100 GeV

Sartre1.39-1.1: CraterLake 25.10.3, 2255 files

Additional Branches Used:

- *"ReconstructedChargedParticles"* $\rightarrow$ charged particle reco: PDG

DIS eAu 10x100 GeV

BeAGLE1.03.02-1.0: CraterLake 25.10.2, 4998 files

Additional Branches Used:

- *"ForwardRomanPotRecHits"* $\rightarrow$ RP hits: position
- *"ForwardOffMTrackerRecHits"* $\rightarrow$ OMD hits: position

Inoherent Diffractive ϕ Production eAu 10x100 GeV

BeAGLE1.03.02-1.1: CraterLake 25.10.3, 2599 files

Additional Branches Used:

- *"EcalFarForwardZDCClusters"* $\rightarrow$ ZDC Ecal: position, energy
- *"HcalFarForwardZDCClusters"* $\rightarrow$ ZDC Hcal: position, energy
- *"ReconstructedFarForwardZDCNeutrals"* $\rightarrow$ ZDC reco: position, energy

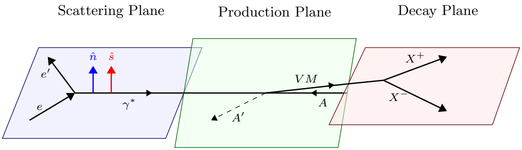
Future Plan

Statistically separate coherent from incoherent events

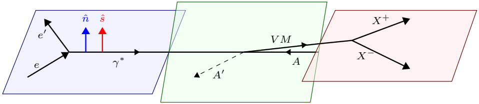
- Utilize transversely polarized e^- beams
  - *e^- spin is perpendicular to its momentum*
- Exploit decay pattern of VM wrt $\hat{n}$
  - Determine the *fraction of coherently produced VMs*

Coherent Events

- If e^- spin flips:
  - Spin of VM aligns with $\hat{n}$
  - Expect $\cos 2\phi$ modulation if we project momentum of VM decay daughter onto VM spin direction



Future Plan



- If e^- spin does not flip:
  - No preferred direction of VM spin
  - Expect a flat ϕ distribution

Incoherent Events

- VM spin expected to be random wrt $\hat{n}$

Result:

- Fraction of coherent events (case when e^- flips spin) is $< \cos 2\phi >$
- Assume probability for e^- to flip spin is C
- Fraction of total coherent events is given by $\frac{<\cos 2\phi>}{C}$
- Can then obtain $|t|_{\hat{n}}$ distributions for coherent VM production
  - Extract spatial distribution of gluons in nucleus