Improving $|t|$ measurement through exclusive coherent VM production

Exclusive/Diffraction/Tagging PWG Meeting

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Outline

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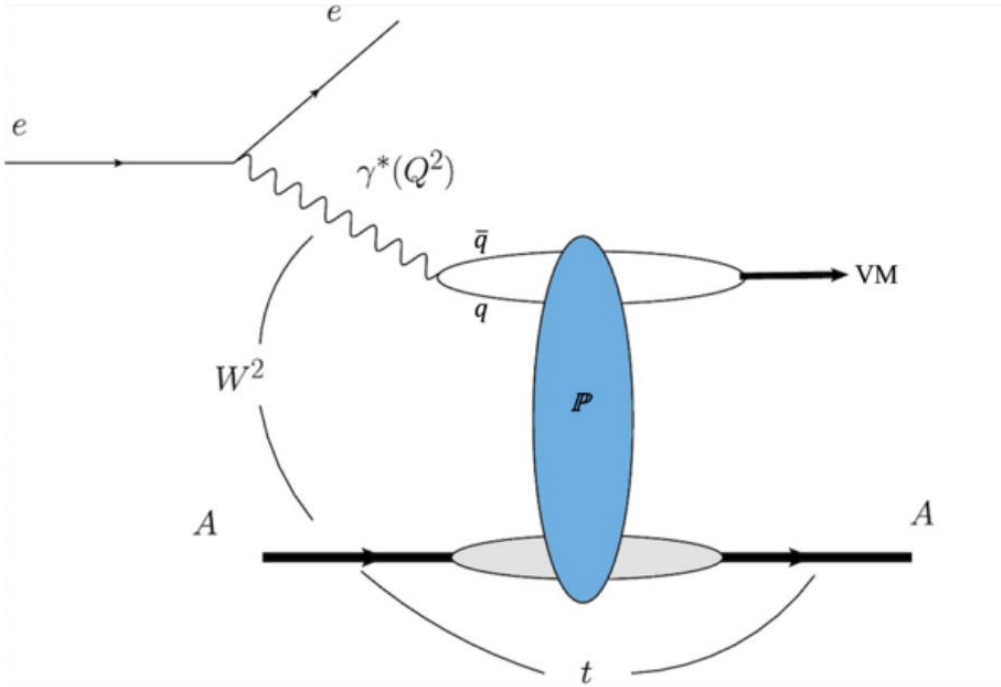
Motivation

Map out gluon structure in nuclei $\rightarrow$ gluon saturation

Critical measurement: exclusive VM production in scattering

- Measures intensity and spatial distribution of gluons
  - Probe to gluon density $\rightarrow$ precisely see structure

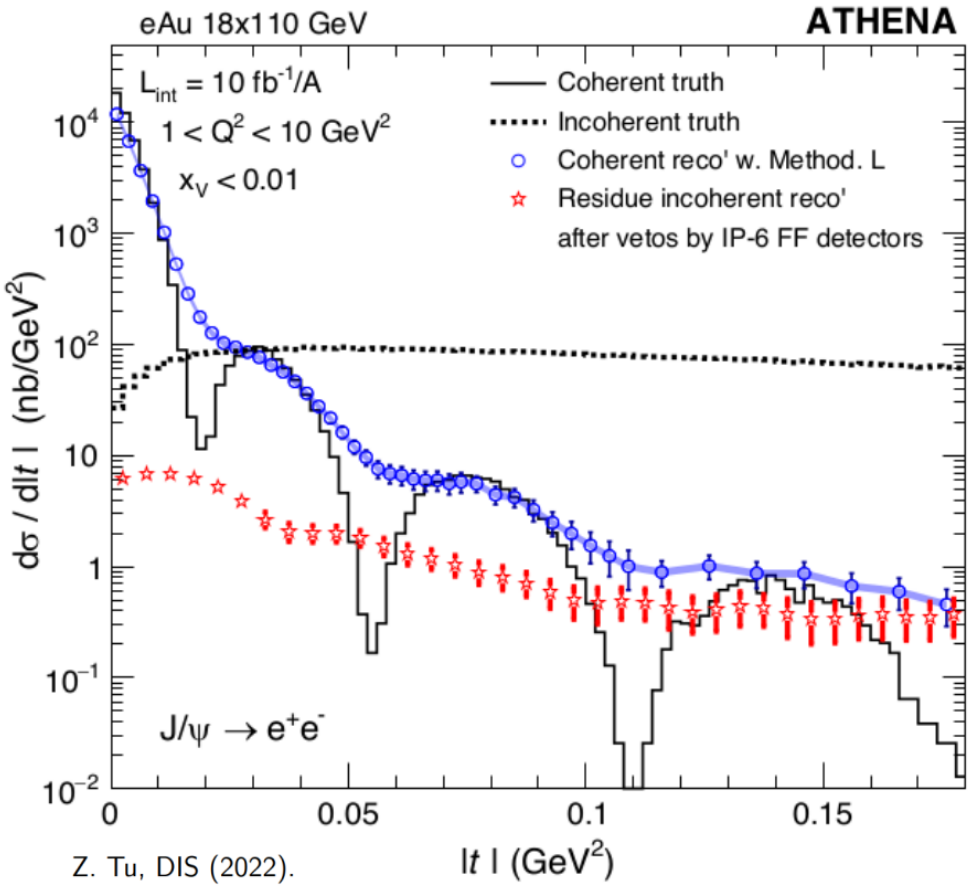


M. Krelina et al., NPA **989**, 187(2019)

- Distribution of nuclear momentum transfer ($|t|$) reflects the spatial distribution of gluons inside nucleus
  - $|t|$ conjugate to impact parameter
  - Fourier transform

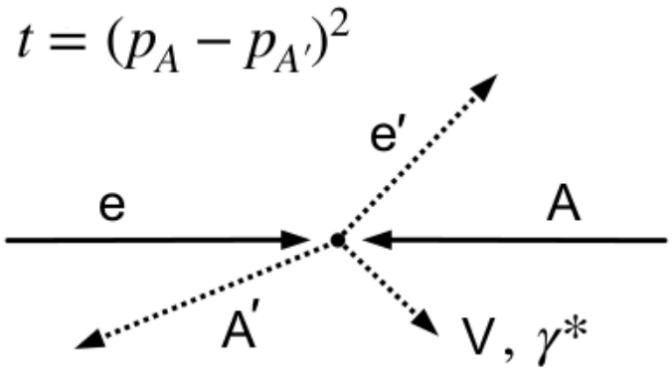
Challenges

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



1. **Limited resolution in measuring $|t|$**
   - Peaks and valleys washed out
   - Mainly momentum resolution of outgoing electron (blue circles)
2. **Overwhelming incoherent background**
   - Black dashed curve
   - Detector can suppress some incoherent production (red stars)

Extracting t: $e + A \rightarrow e' + A' + V$



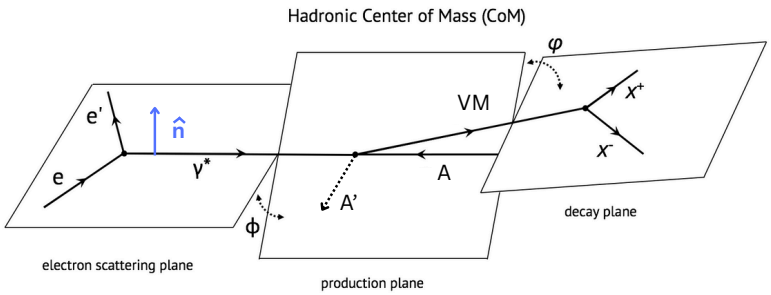
- To access t: need complete final state
  - Cannot measure $p_{A'}$
- Know 4-momenta of e, A, e', and V
- Different methods to do this

T. Ullrich, (2020).

- **Method E:** gives true $t = (\mathrm{p}_V + p_{e'} - p_e)^2$
  - **Cons:** Subtract large incoming/outgoing momenta to get longitudinal component of $t \rightarrow$ small error/inaccuracy has large effect on t
- **Method A:** ignores longitudinal momenta $t = [\mathbf{p}_T(e') + \mathbf{p}_T(V)]^2$
  - **Cons:** underestimates true t, valid only for small t and small Q^2
- **Method L:** improvement to Method E, corrects $p_{A'}$ and uses true invariant mass to compensate the smearing $t_{\mathrm{corr}} = |p_A - p_{A'}^{\mathrm{corr}}|^2$
  - **Cons:** only applies to coherent events

Reconstruct t from exclusive VM production

- Measure *projection of* $|t|_\perp$ along the normal direction ($\hat{n}$) of the electron scattering plane
  - Eliminate momentum resolution contribution from the outgoing e
  - **Potential issue:** loss of information on gluon structure



$$\begin{aligned} |t|_\perp &= (p_V \cdot \hat{n} + p_{e'} \cdot \hat{n} - p_e \cdot \hat{n})^2 \\ &= (p_V \cdot \hat{n})^2 \end{aligned}$$

Decompose t:

$$t = t_\perp + t_\parallel \longrightarrow t_\perp = t_x + t_y$$
$$t_\perp = q_\perp^2 = q_x^2 + q_y^2$$

t in terms of q:

$$\begin{aligned} q_x &= \pm\sqrt{t_x} = (p_V + p_{e'} - p_e) \cdot (\hat{n} \times \hat{z}) \\ q_y &= \pm\sqrt{t_y} = p_V \cdot \hat{n} \end{aligned}$$

Projection technique

Add detector resolution to the form factor:

$$F(t = q^2) = \frac{4\pi\rho_0}{Aq^3}\left[\sin(tR) - tR\cos(tR)\right]\left(\frac{1}{1+a^2t^2}\right)$$

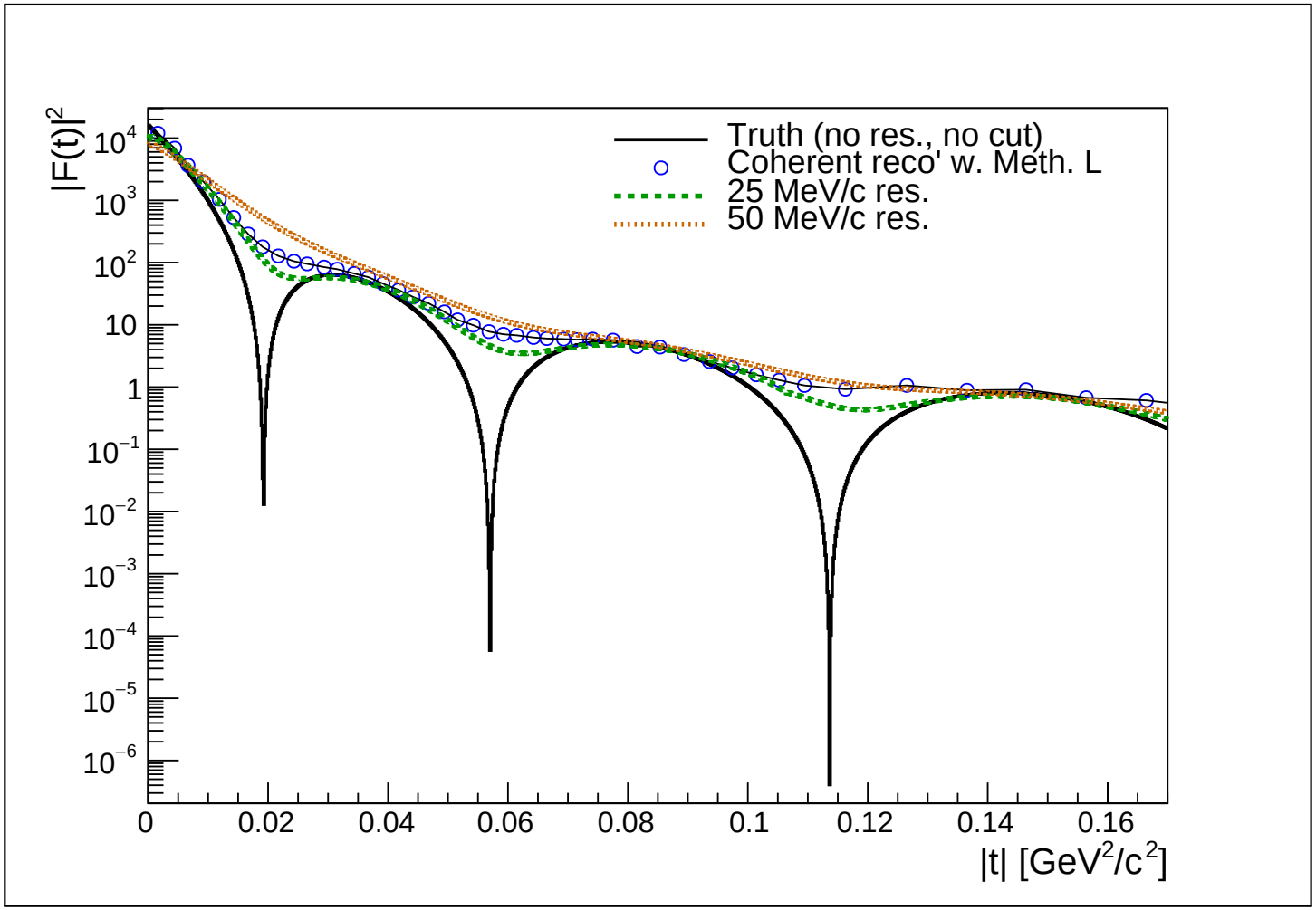
ρ_o: nuclear density, A: atomic number, R: nuclear radius, a: range of Yukawa potential

We can parameterize $t_\perp$ in terms of $q_\perp$:

$$q_x = q_\perp \sin(\theta_{\max}), \quad q_y = q_\perp \cos(\theta_{\max}).$$

- Cut wedge of angle $\theta_{\max}$ from the $\hat{n}$-direction (q_y)
- Eliminates most of the q_x component

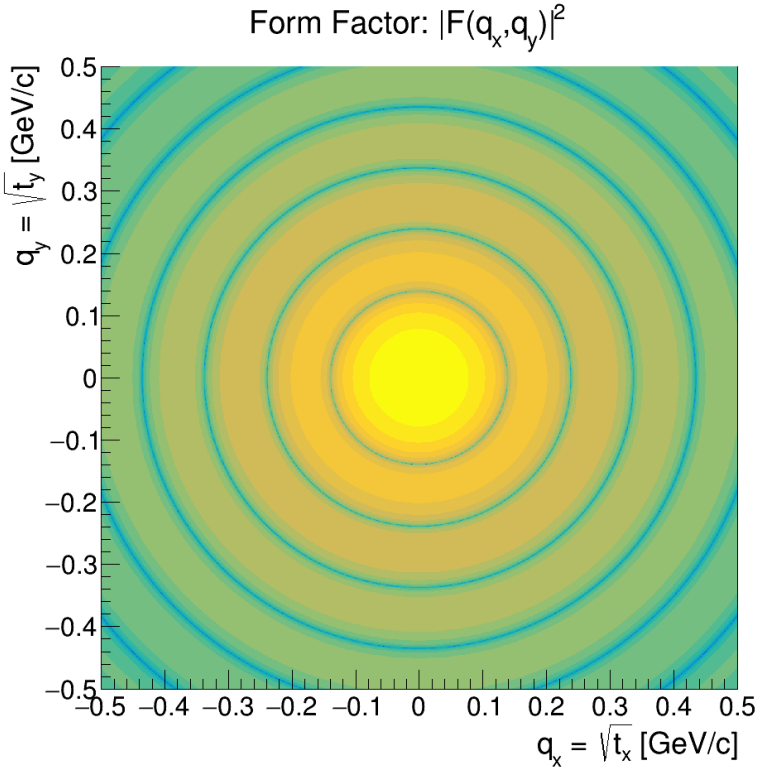
Compare with different resolution

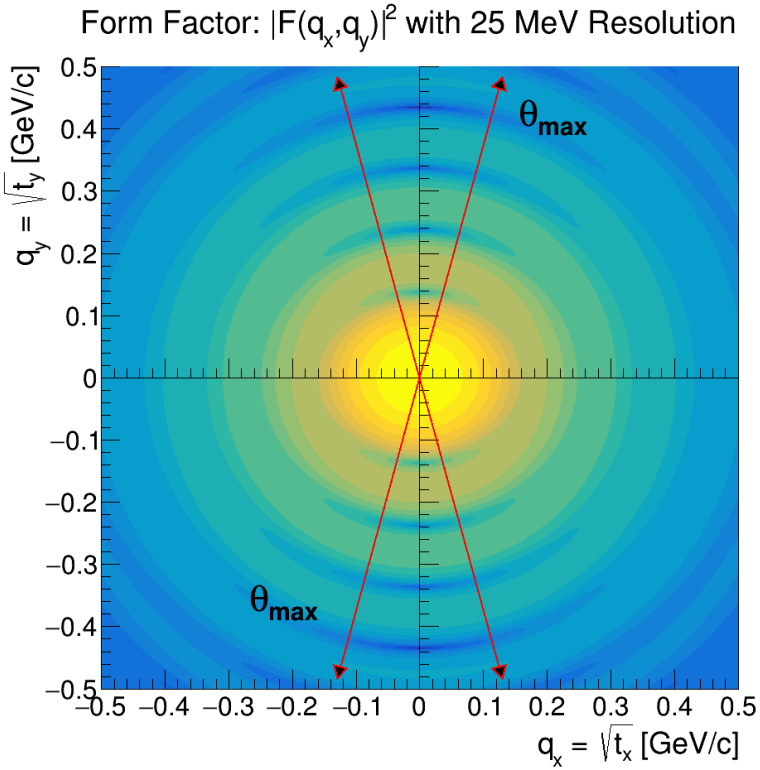


- Seems like we can reproduce the ATHENA data with resolution between 25-50 MeV $\rightarrow$ we use 25 MeV for our results

Wedge Cut

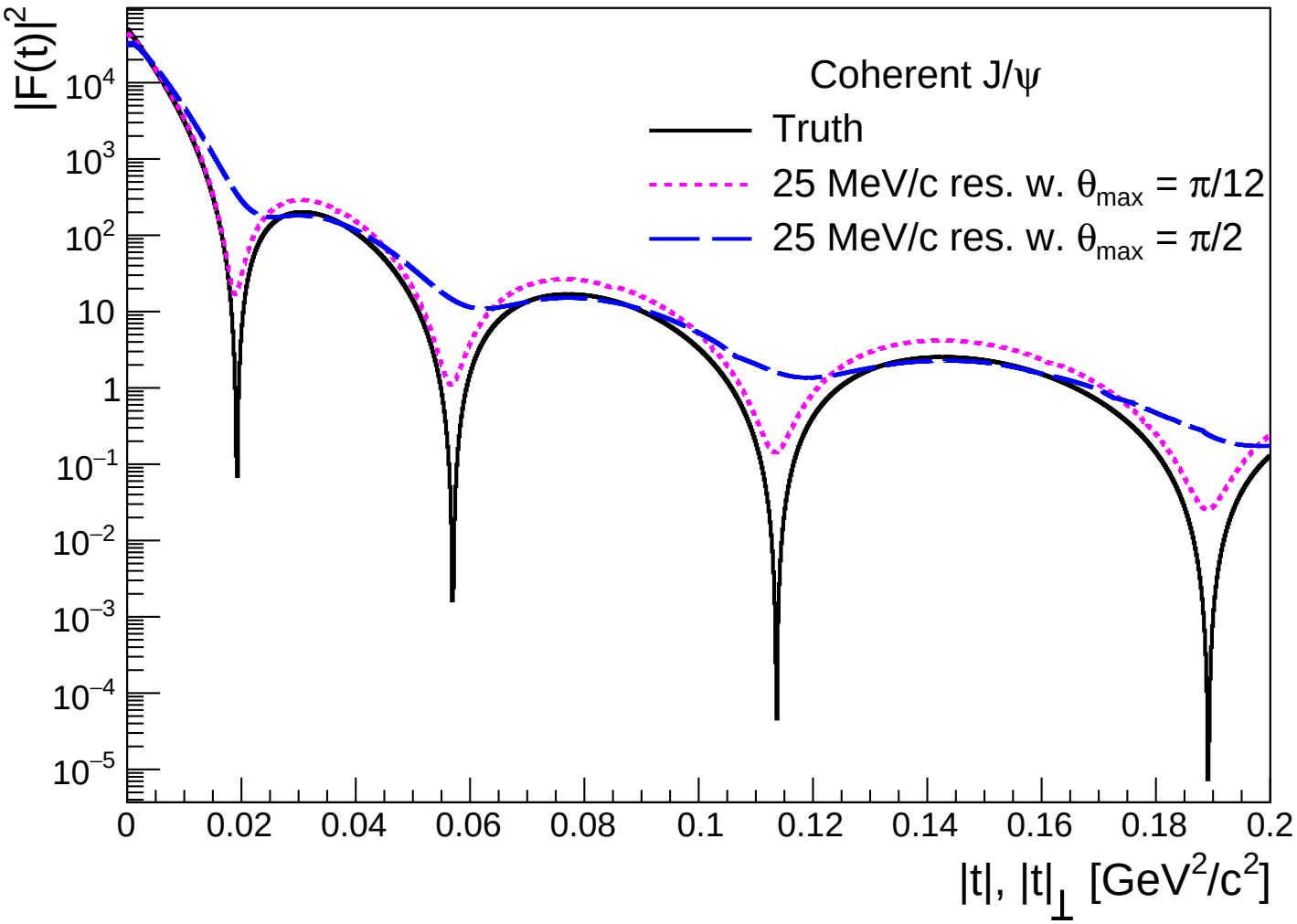
$$|F(t=q^2)|^2 \rightarrow \int_0^{\theta_{\max}} |F'(t,\theta)|^2 d\theta \rightarrow |F_{\hat{n}}(t)|^2(1)$$





- Resolution and $\theta_{\max}$ parameters can be adjusted accordingly

Result on $|t|$ distribution



- We see a significant improvement!

Next steps...

- Analyze on ePIC software
- Correcting/Unfolding
- Fourier Transform to spatial distribution
- Separate coherent and incoherent events
  - Determine the fraction of coherently produced VMs by utilizing the transversely polarized electron beams $\rightarrow$ spin projection

Paper is on arxiv! $\longrightarrow$

Thank You :)

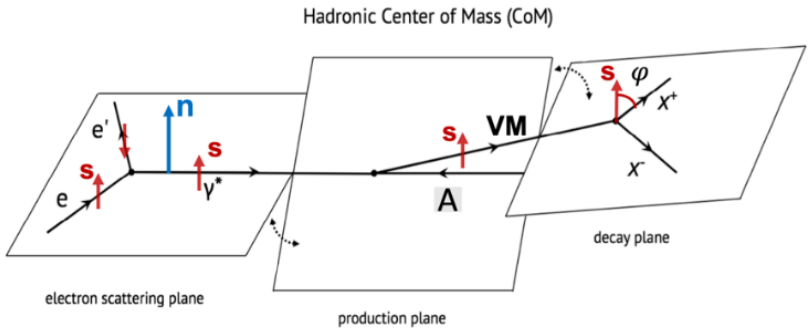
Backup Slides

Future Plan

- 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 $|t|_n$ distributions for coherent VM production
  - Extract spatial distribution of gluons in nucleus

Goal:

- Provide a solution for the measurement of $|t|$ at the EIC for imaging gluon structure in nuclei
  - Through exclusive VM production
  - Electron beam polarization
  - Separate coherent and incoherent VM production