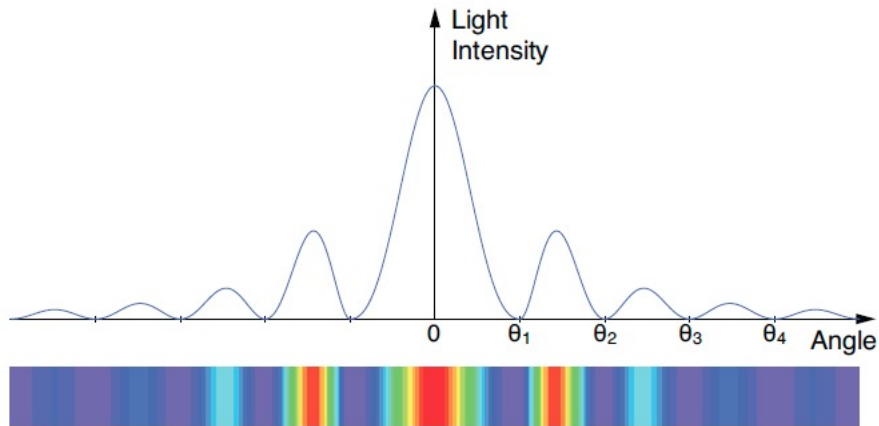


Diffractive Vector Meson production at the Electron-Ion Collider



Kong Tu
BNL

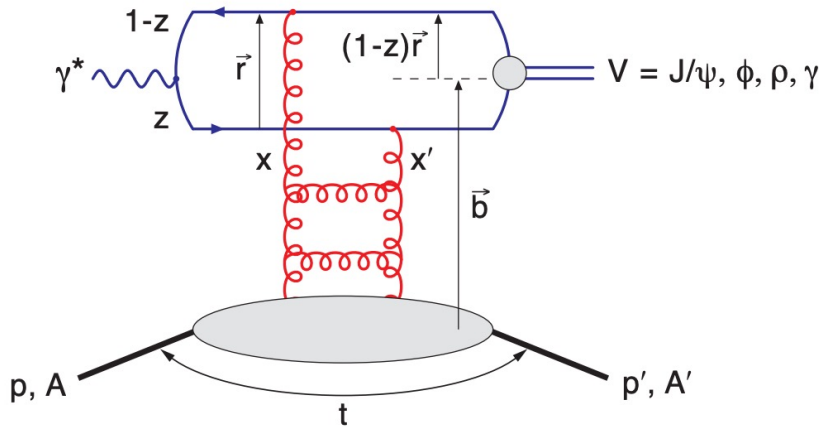
05.04.2022

On behalf of ATHENA

Motivation

Diffraction Vector Meson (VM) production

- a sensitive probe to gluon density, spatial distributions, and their fluctuations.



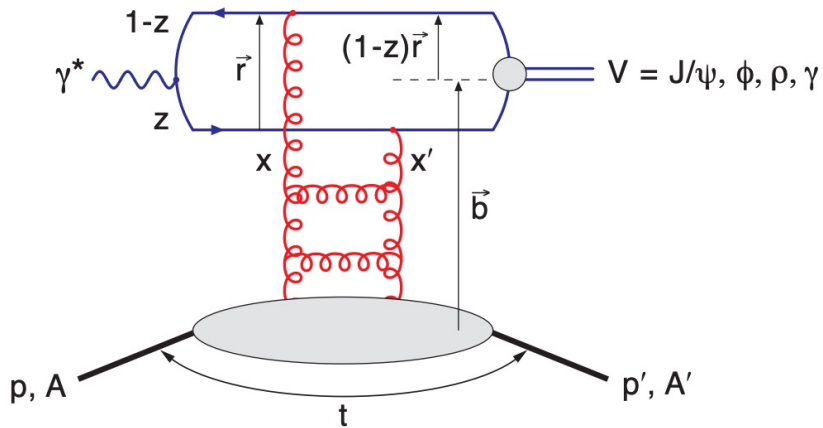
$t \sim$ momentum transfer (kicks)

A dipole picture of diffractive VM in LO;
NLO has recently become available.
(arXiv:2203.11613)

Motivation

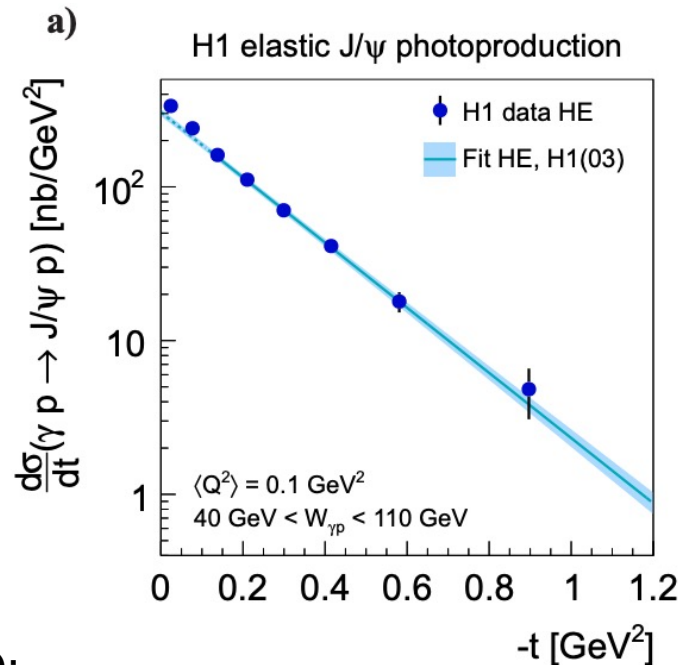
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J/psi from HERA measurements



Measure:
Exclusive $ep \rightarrow e'p' + J/\psi$



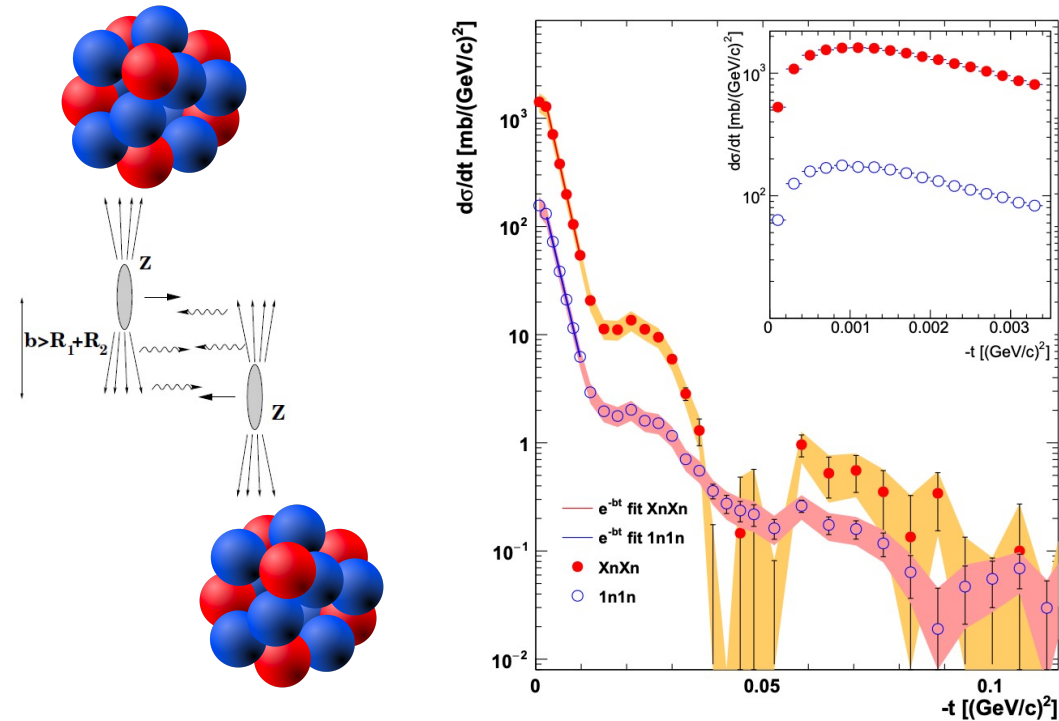
Momentum transfer ($-t$) distribution
is a *Fourier Transform* to the
spatial distribution of the source.



Physics goal:
Fundamental understanding of
nucleon structure at high energy

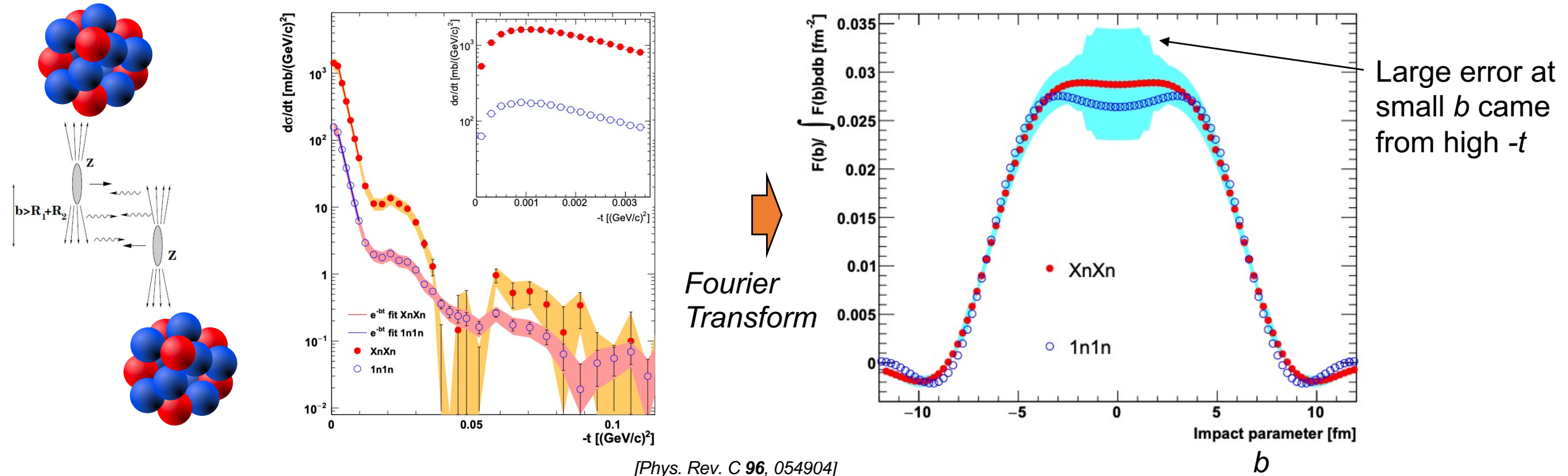
Nucleus – even more unknown

- Gluon spatial distribution in nuclei only has been measured with ρ^0 in Ultra-Peripheral Collisions
- Uncertainty is large at high $-t$, scale is soft ($Q^2+M^2 < 1$), many questions remained!



Nucleus – even more unknown

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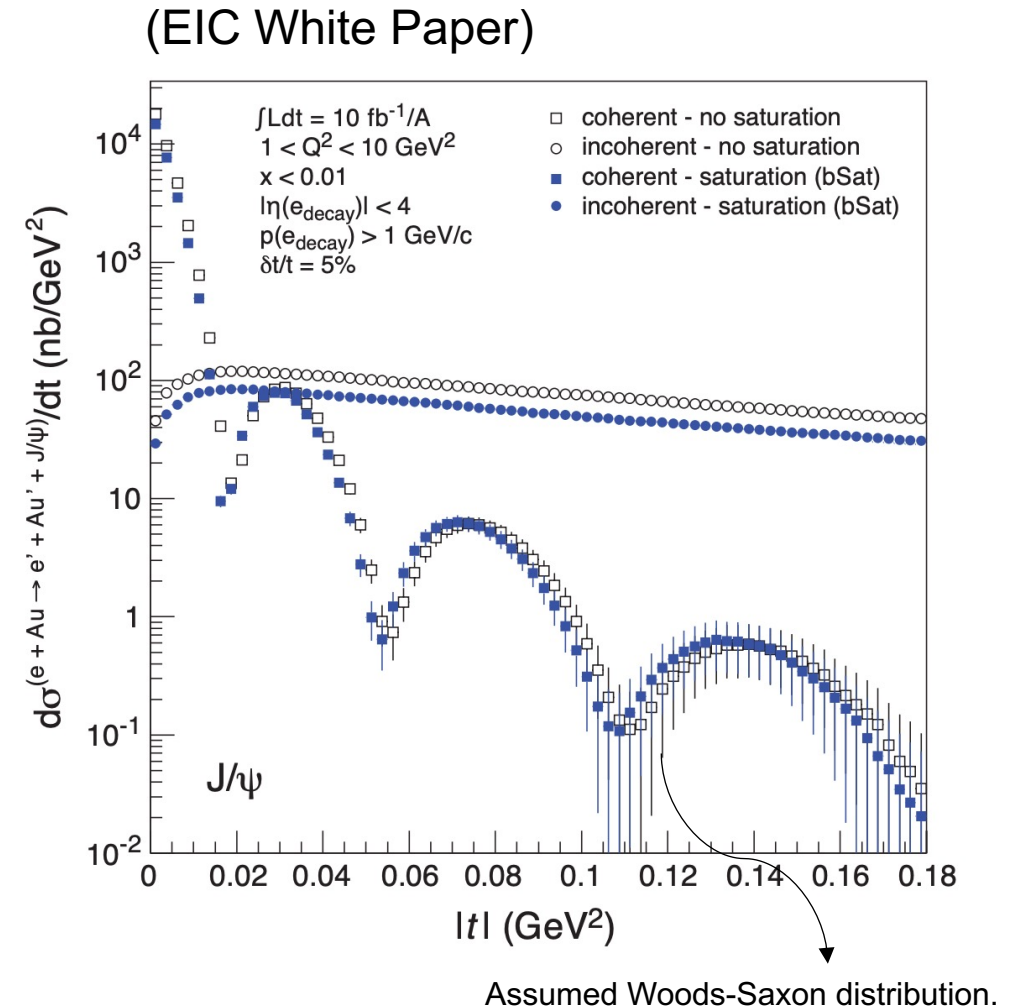


Important first results but not good enough. Why is it so difficult?

Challenges and Opportunities

Two major challenges:

1. Incoherent background dominates most of the $-t$ regime. *How to veto/suppress this background?*
2. Excellent momentum resolution to resolve the structure of the coherent diffractive peaks/dips.



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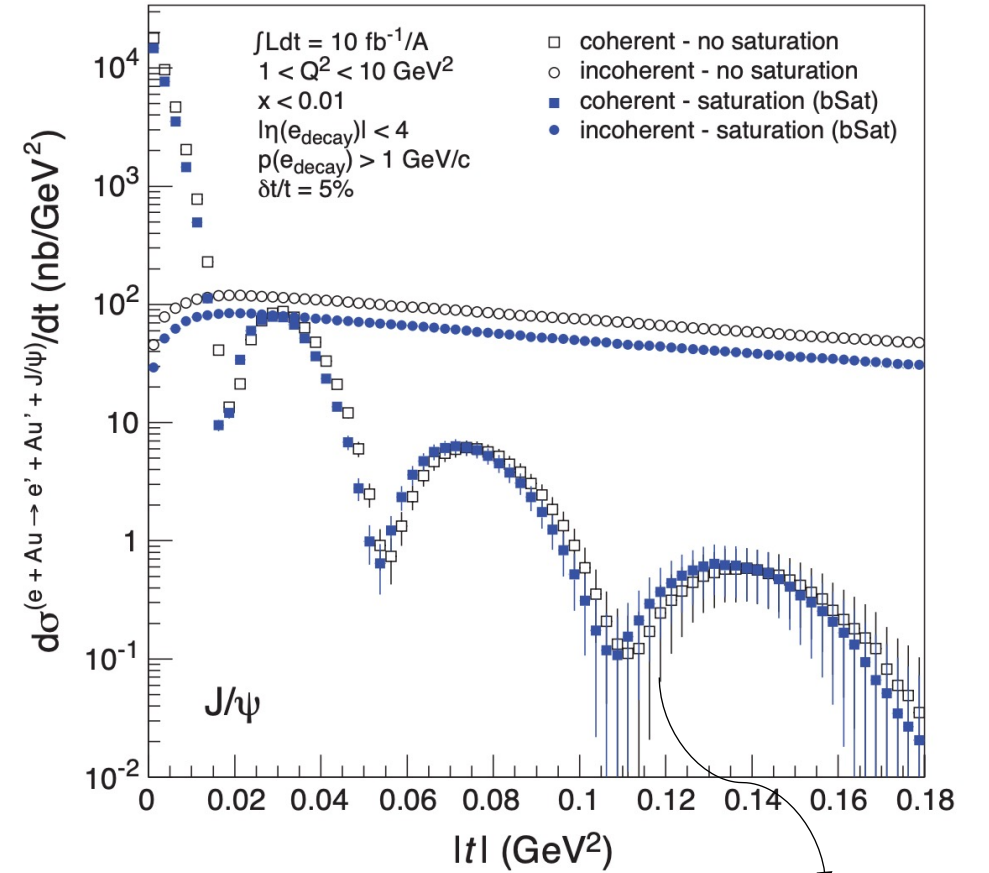
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Electron-Ion Collider: a high-energy high-luminosity electron-nucleus collider.

Advantages:

- Excellent detectors (tracking, calorimetry, etc.)
- Forward detectors to suppress incoherent backgrounds.
- Wide range of Q^2 instead of only photoproductions

(EIC White Paper)



Assumed Woods-Saxon distribution.

ATHENA proposal

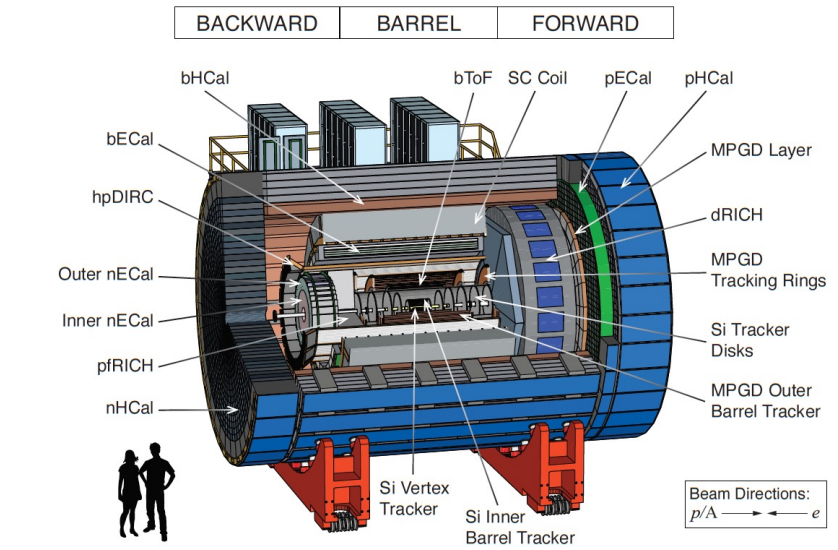
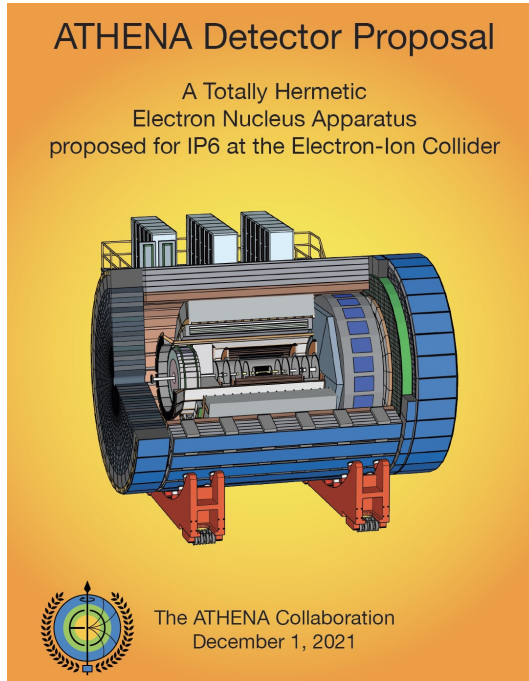
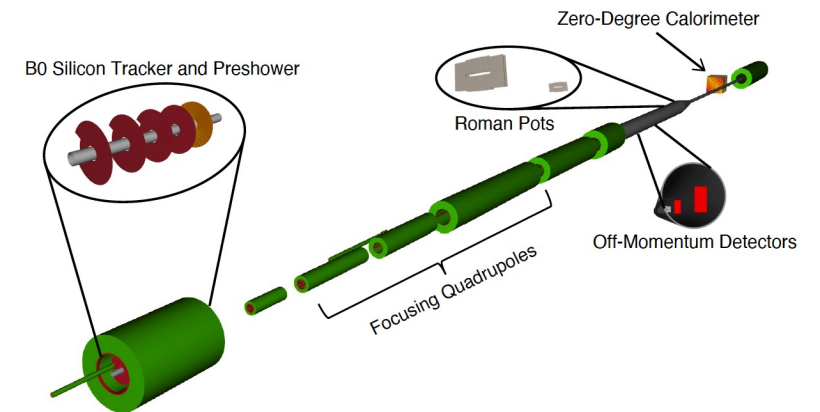


Figure 1.1: Crosscut view of the ATHENA central detector. The detector acronyms are defined in the text and are summarised in the Glossary.

Far-Forward region (A-going direction)



(See A. Jentsch's talk for details, 5/4/22, 11:50 AM, WG6)

Highlights:

1. 3T magnetic field for tracking, great momentum resolution for VM decays.
2. nECal with excellent energy resolution for low Q^2 scattered electron.
3. Wide coverage of far-forward detectors for incoherent background suppression.

Reconstruction method of $-t$

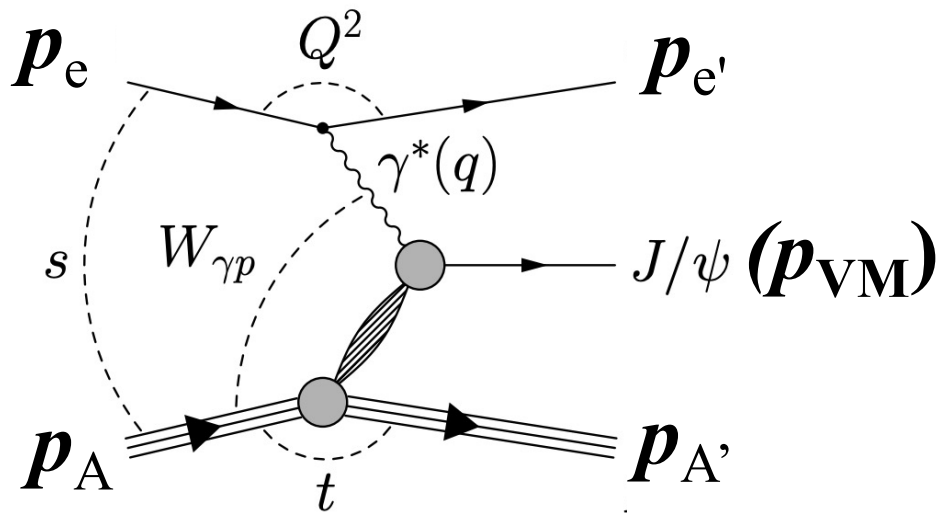
- Method Exact (E):
- Method Approximate (A) (UPCs)
- Improved Method E: **Method L**

$$-t = -(\mathbf{p}_e - \mathbf{p}_{e'} - \mathbf{p}_{\text{VM}})^2 = -(\mathbf{p}_{A'} - \mathbf{p}_A)^2$$

$$-t = (\vec{p}_{T,e} + \vec{p}_{T,\text{VM}})^2$$

$$-t = -(\mathbf{p}_{A',\text{corr}} - \mathbf{p}_A)^2,$$

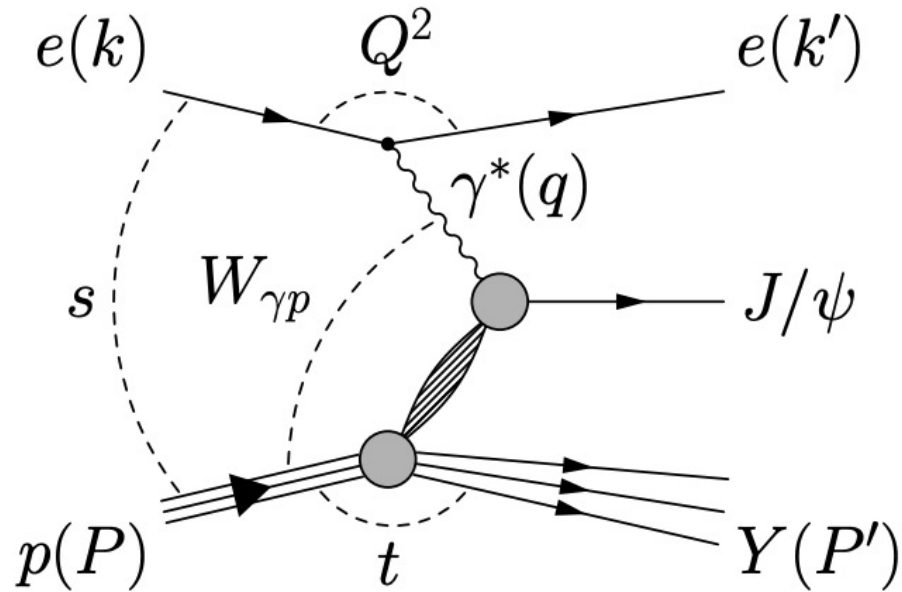
where $\mathbf{p}_{A',\text{corr}}$ is constrained by exclusive reaction.



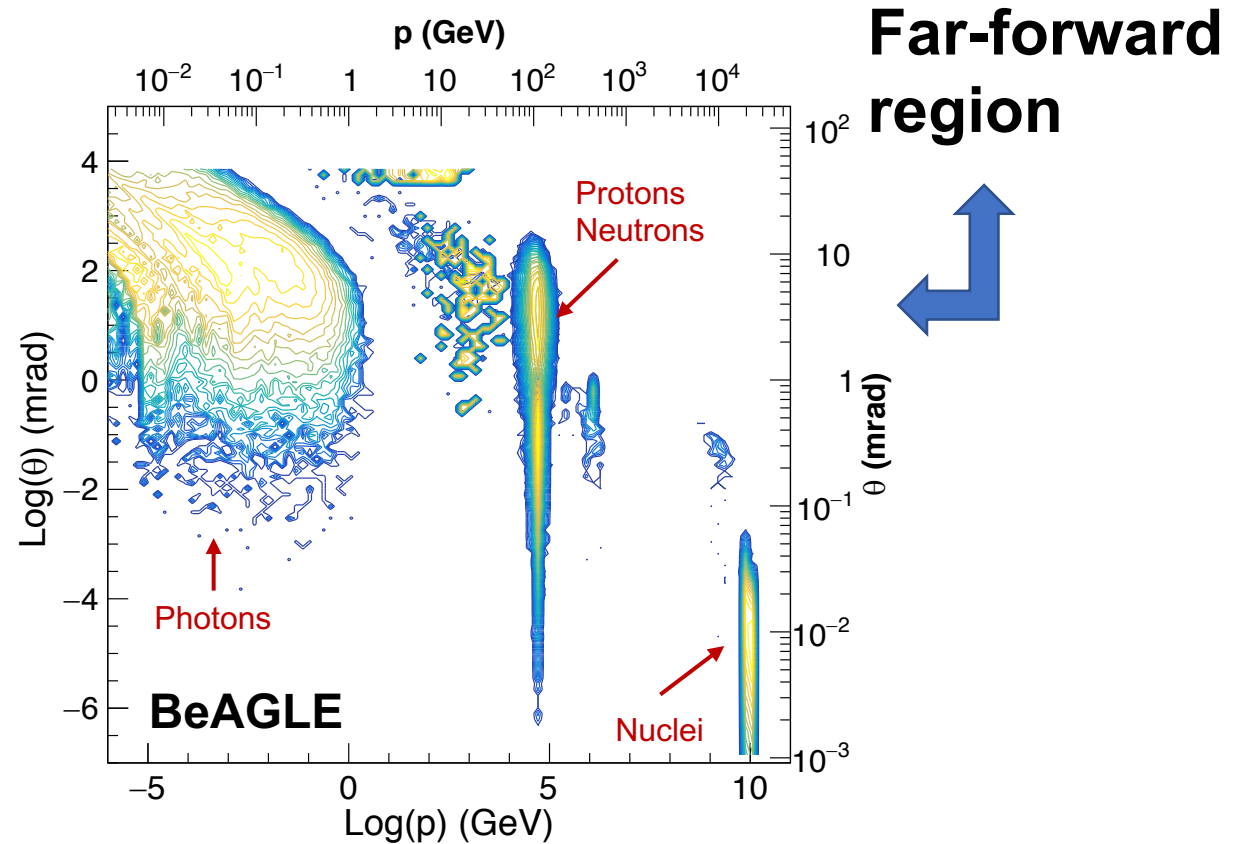
Best method concluded from the EIC Yellow Report – **Method L**

- Insensitive to beam effects, e.g., angular divergence and momentum spread.
- More precise than Method A for electroproduction

Incoherent background



Proton or nucleus dissociation



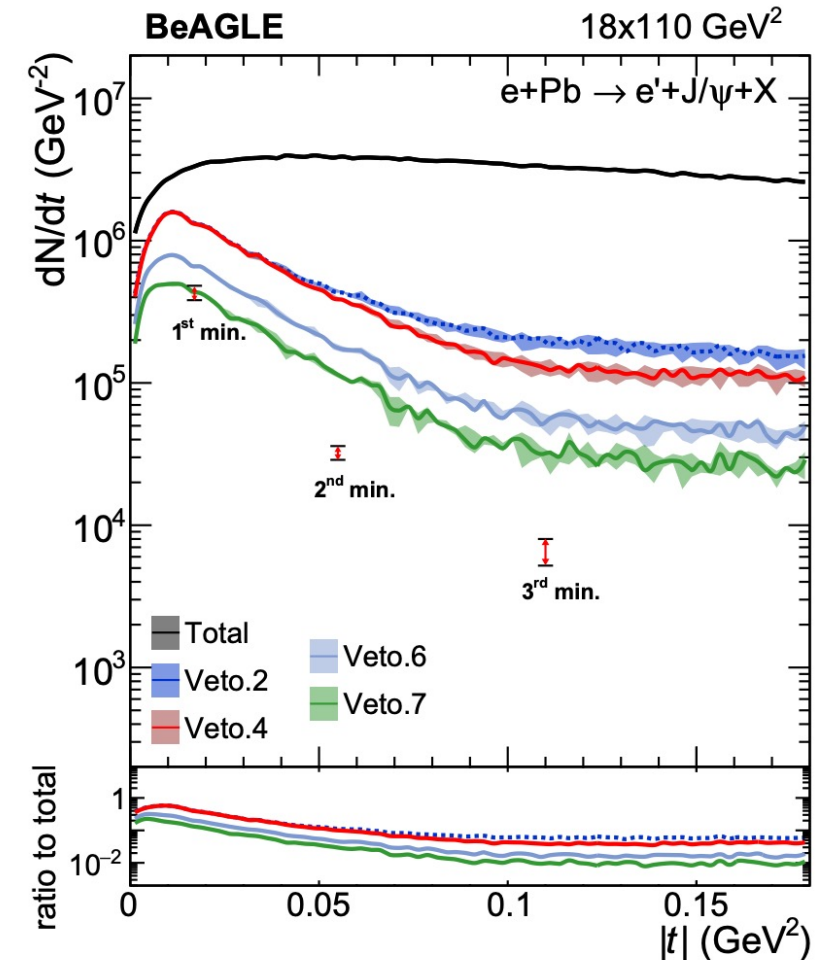
- *Incoherent itself is a great interest*, but it is the major background to the coherent case.
- Far-forward region is busy! Many breakup particles, e.g., protons, neutrons, photons, and nuclei
- BeAGLE – general-purpose eA MC, see <https://eic.github.io/software/beagle.html>

Performance of background suppressions

- No neutrons in ZDC (veto 2)
- No proton in any forward detectors (veto 3-5)
- No photon > 50 MeV in B0 or ZDC (veto 6-7)
- Minima (1st min. 2nd min. 3rd min.) are from *Sartre* MC generator (slide 4-5). Only 5% resolution assumed.

➤ Vetoing all of them is impossible. The question is how much is needed.

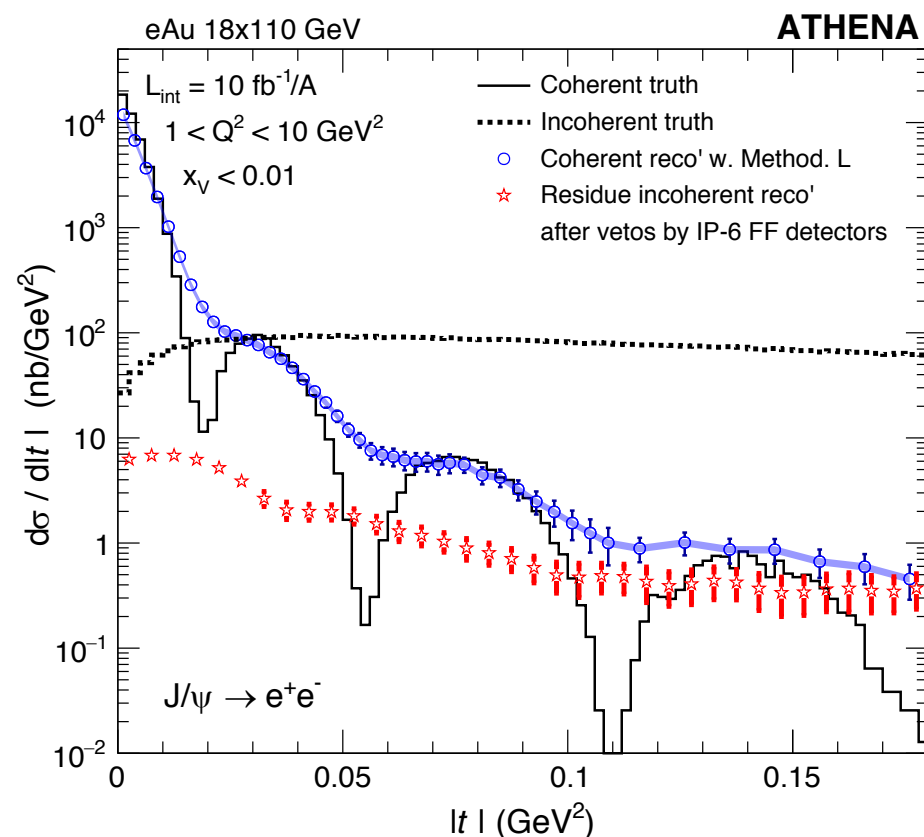
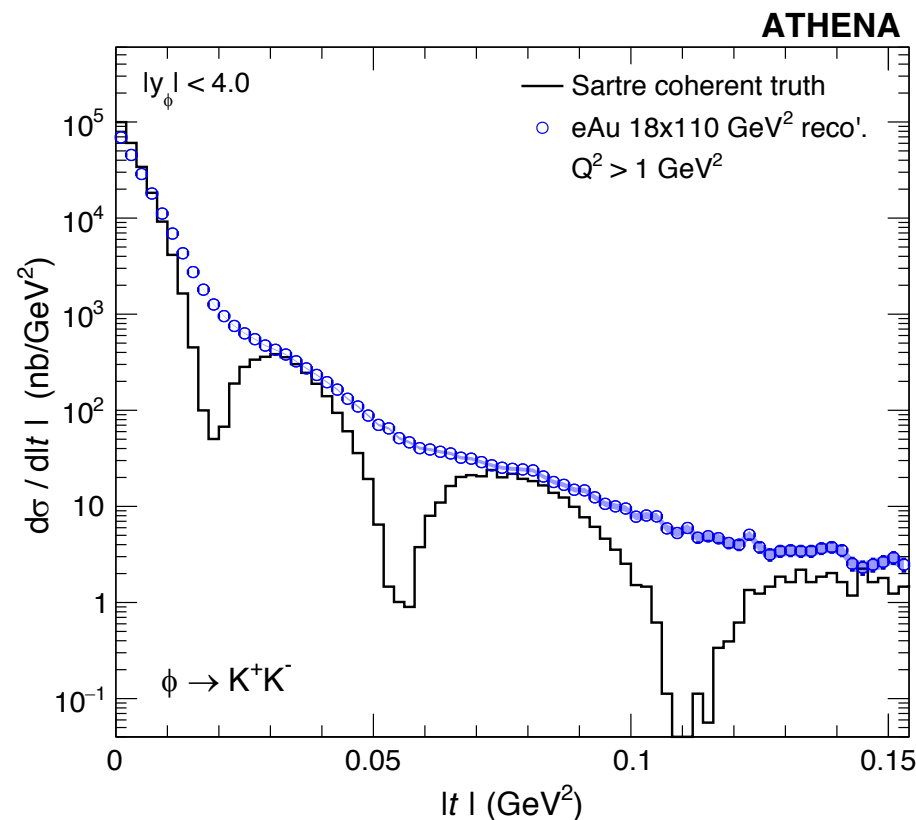
➤ This result was used in ATHENA proposal



Phys. Rev. D **104**, 114030

Result – ATHENA Tracker only

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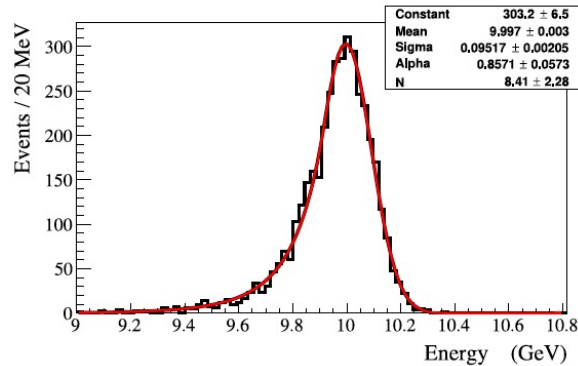
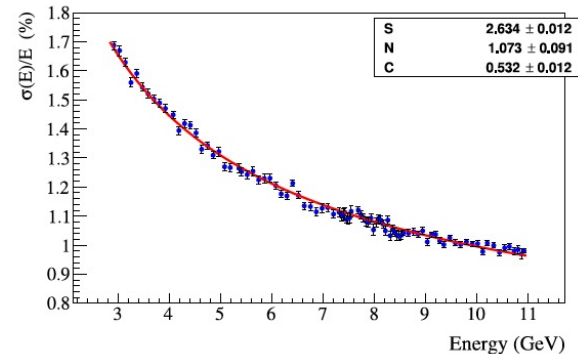
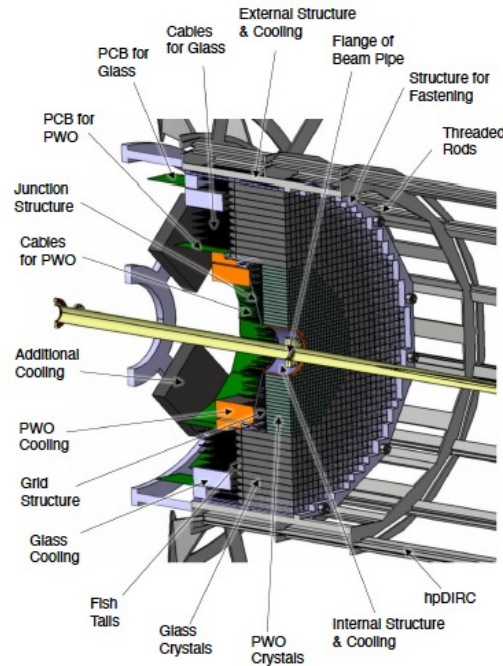


J/ψ

- Challenge 1: Incoherent background, but it only becomes an issue at high $-t$;
- Challenge 2: *Momentum resolution is not enough. Bottleneck - p_T resolution of the scattered electron.*

Result – ATHENA nECal+Tracker

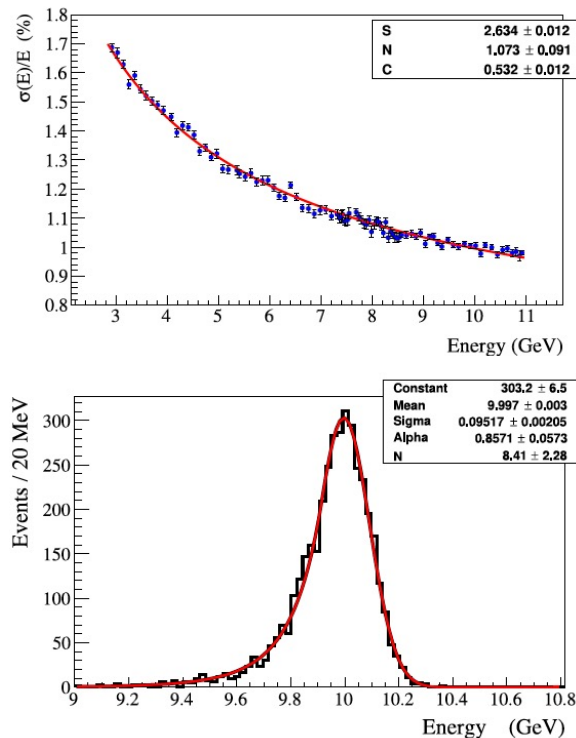
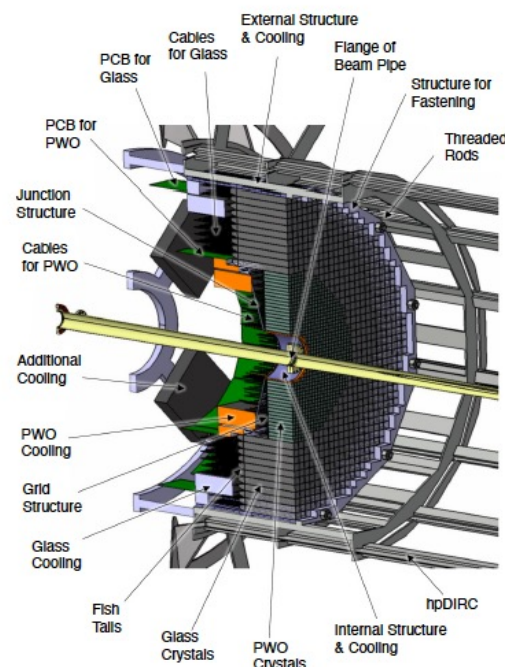
ATHENA backward nECal *Nucl.Instrum.Meth.A* 1013 (2021) 165683
($-4 < \eta < -1.5$)



Results on PbWO_4 scintillating crystals for Jlab experiments. $\sim 1\%$ energy resolution

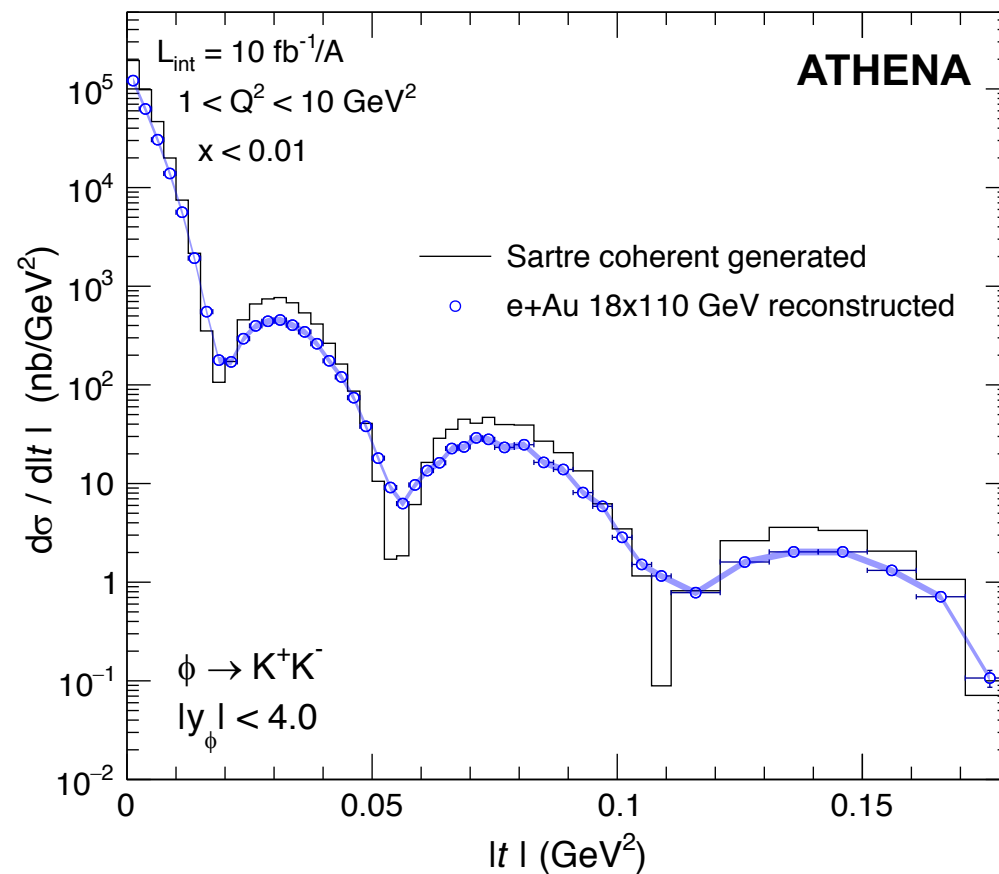
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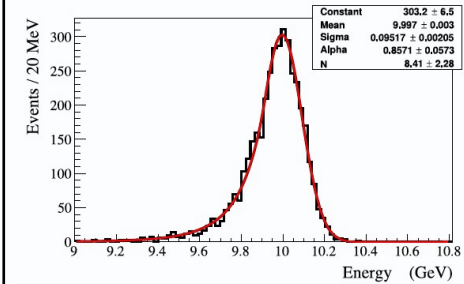
Gaussian smearing = 1% energy resolution



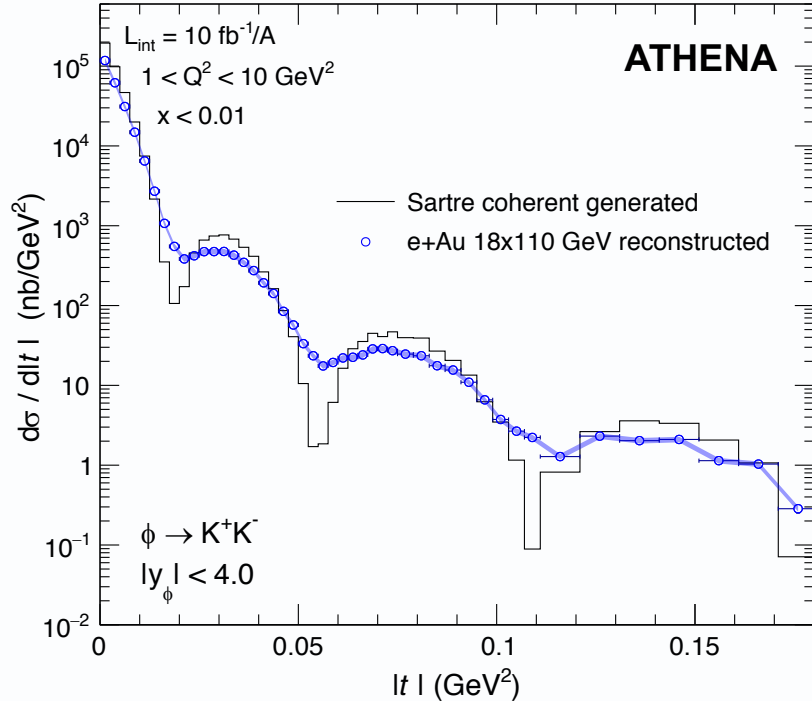
Huge improvement. Resolution of scattered electron dominated by nECal energy resolution

Result – ATHENA's further “*improvement*”

After discussion with ECCE in our first joint meeting

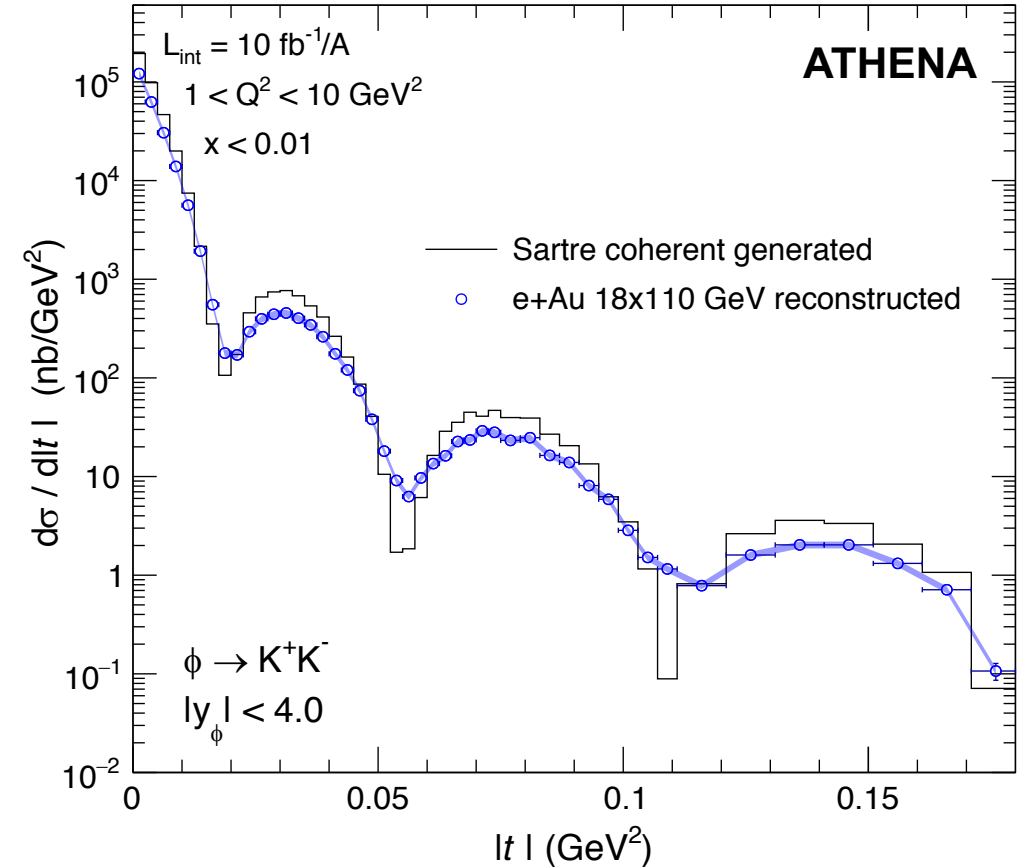


Non-Gaussian tail
~ Crystal Ball



The reconstructed $-t$ distribution has an impact from Non-Gaussian tail

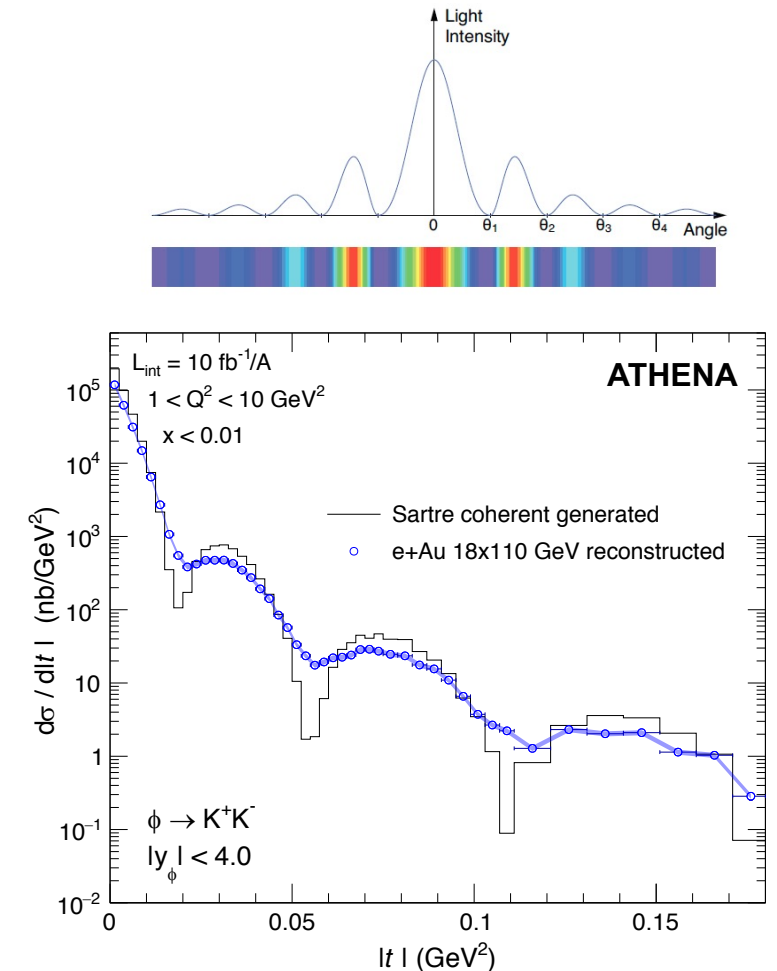
Gaussian smearing = 1% energy resolution



ATHENA and ECCE are working together in benchmarking this process with the EIC “Detector 1”

Summary

- Diffractive Vector-Meson is a powerful experimental tool to study the nucleon and nuclear structure, e.g., gluon spatial distributions.
- One of the most difficult, if not the most, measurements at the EIC.
- In order to achieve this measurement, we need to overcome:
 - 1) Incoherent background, where the nucleus breaks up. Veto on far-forward particles.
 - 2) Excellent energy resolution ($\sim 1\%$) to reconstruct the scattered electron.
- Will be working jointly from now on between the two proto-collaborations.



Back up

Crystal Ball smearing

