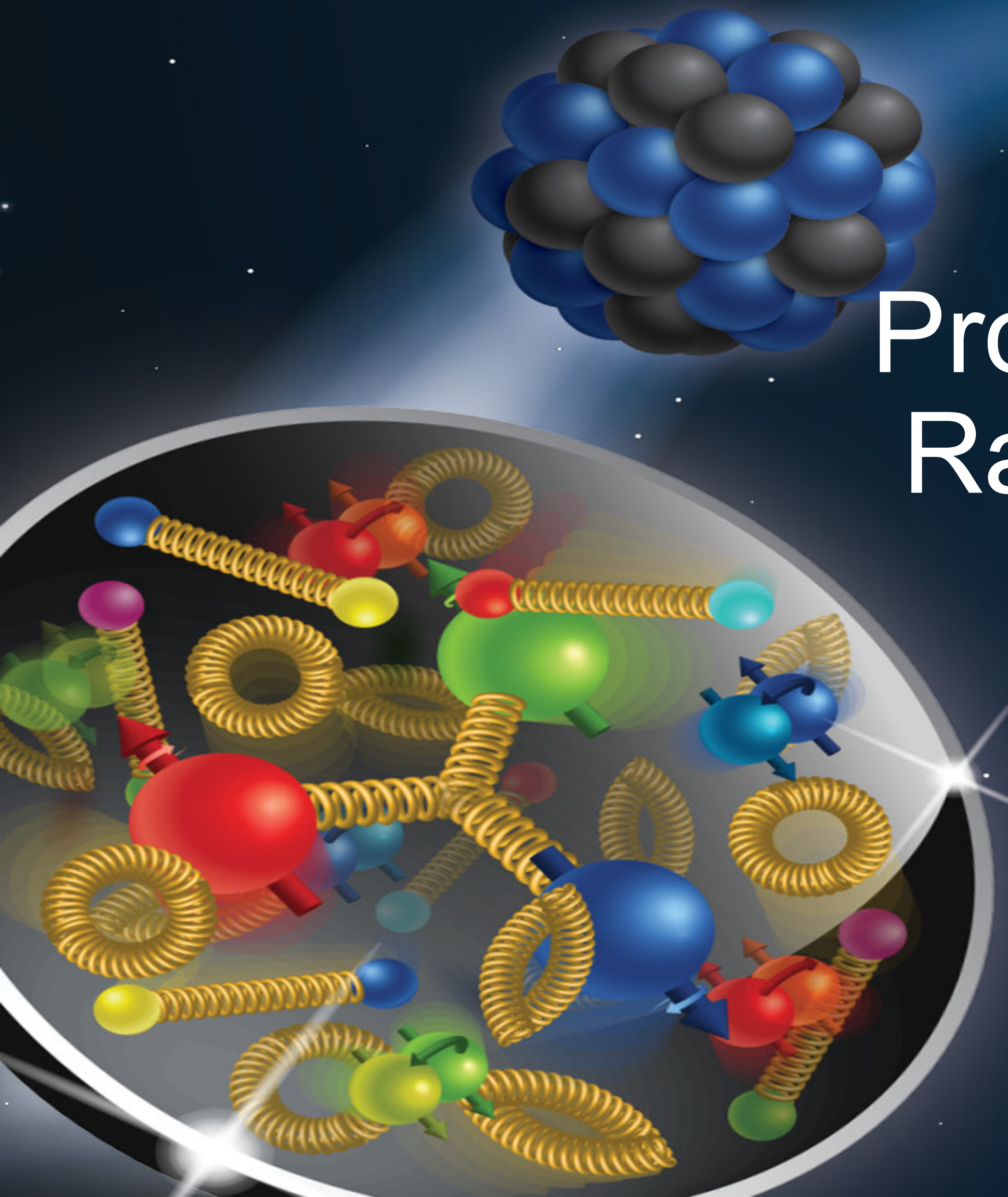

Prospects for Studies of Short-Range Correlations at the EIC

APS DNP Fall Meeting, New Orleans, LA (remote)
October 31st, 2020

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Based on work in arXiv:2005.14706
(accepted for publication in PLB)

Electron Ion Collider

BROOKHAVEN NATIONAL LABORATORY

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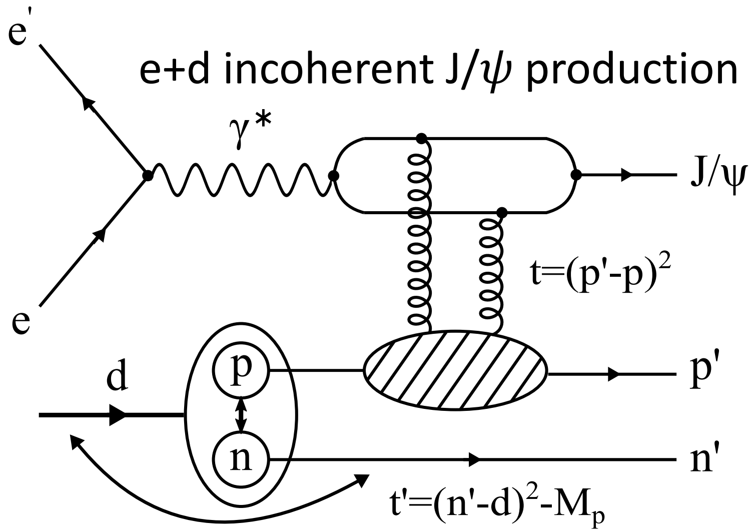
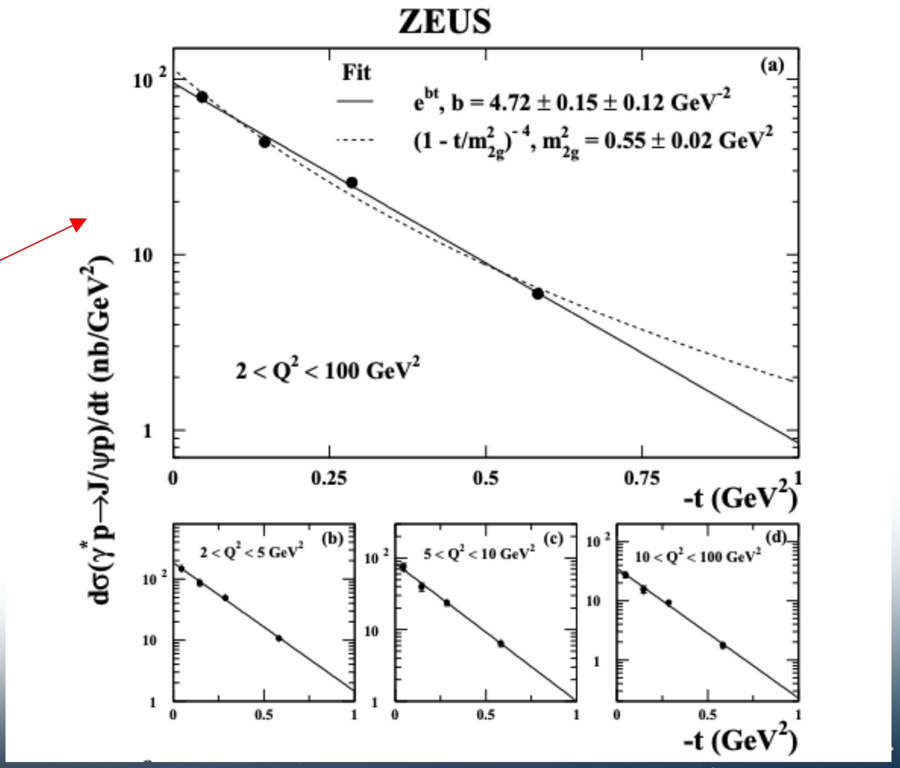
Why Short-Range Correlations?

- Short-Range Correlations (SRC) are the overlapping of pairs of nucleons in a nucleus that lead to repulsion between the correlated nucleons.
  - Provides large transverse momentum to final-state nucleons acting as spectators in a collision.
- SRC between pairs of nucleons bound in nuclei are one possible explanation for the *EMC Effect* $(0.3 < x < 0.7)$.
- Topic of interest here: how are gluon densities at low-x $(x < 10^{-2})$ affected by SRC in *nuclei*?
  - Look at diffractive vector meson production.
  - Studied at HERA for e+p collisions.
  - Use light nuclei (e.g. deuteron) where the full final-state can be reconstructed → can measure the effect of SRC on the low-x gluon densities!

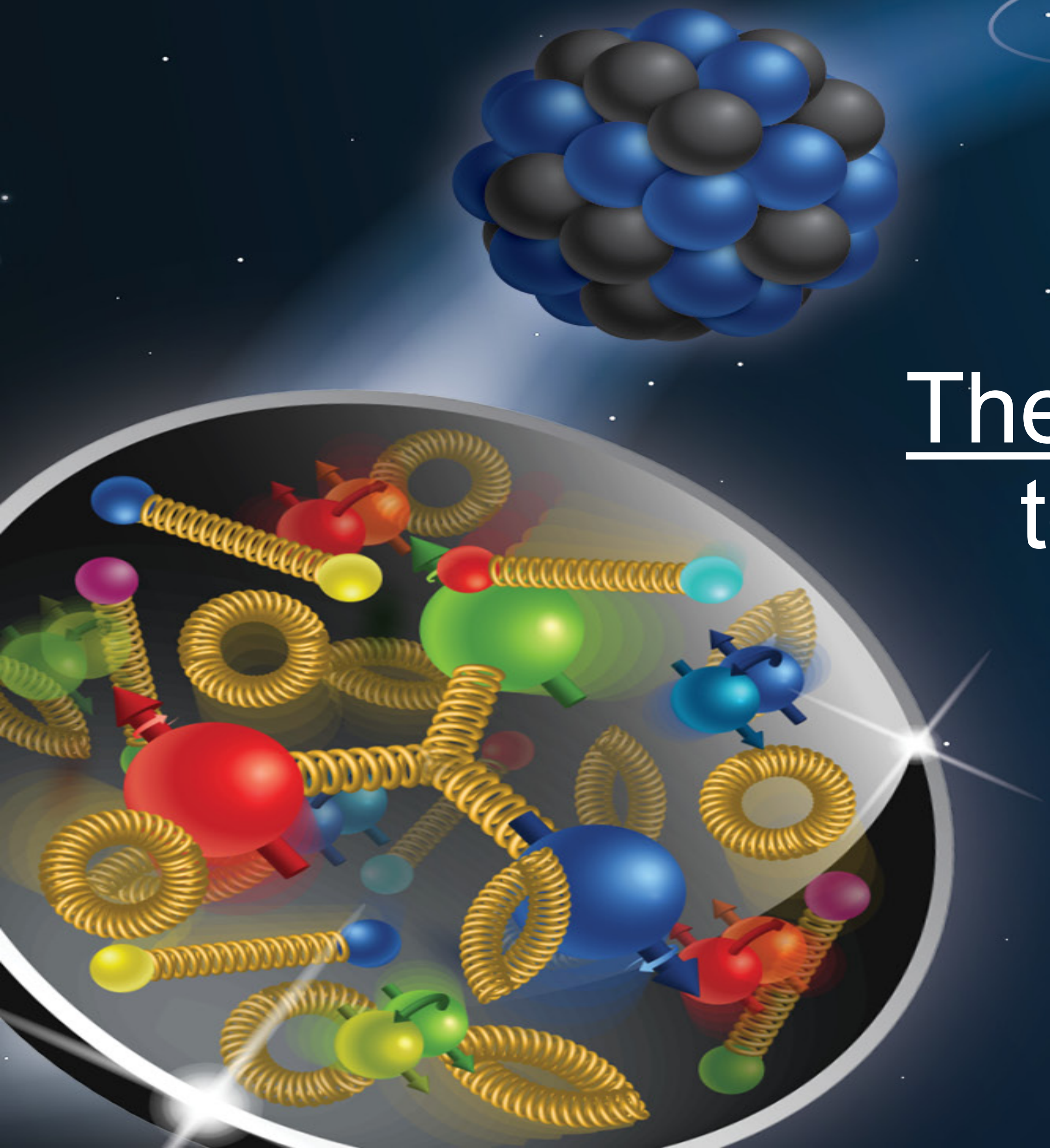


S. Chekanov *et al.* (ZEUS Collab.), Nucl. Phys. B, **695** Iss. 1-2 (2004)



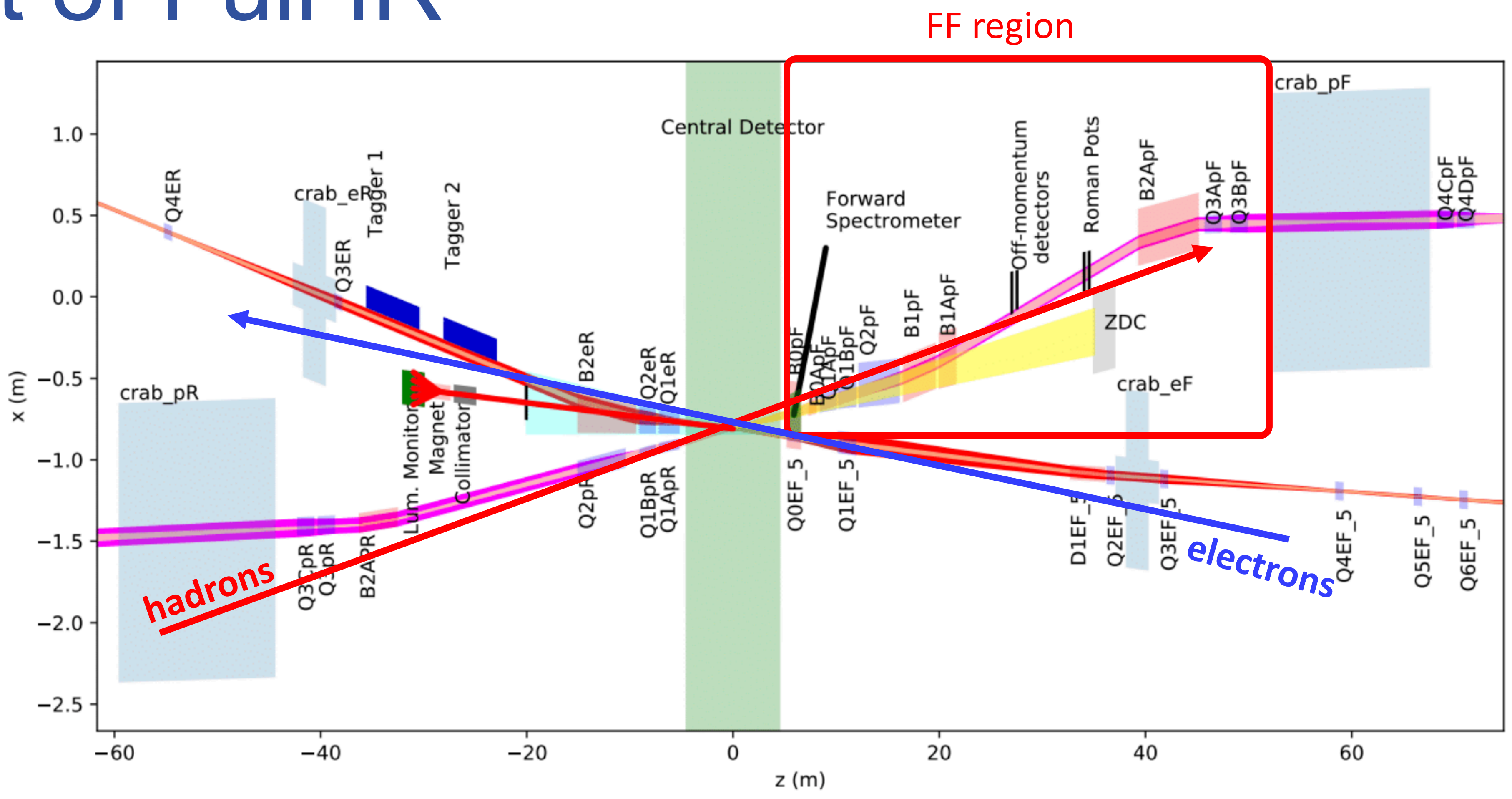
How can the EIC help?

- Using e+d collisions, final state of interest includes only the J/ψ, the proton, and the neutron.
- Experimentally, the goal is to tag the *spectator nucleon* in the final state.
  - Spectator nucleon is used to identify the kinematic region for SRC.
  - Using *both* active and spectator nucleon, can extract gluon densities in the SRC region.
- The spectator nucleons land in a very high pseudorapidity region ($\eta > 4.5$) kinematically.
  - This is outside the main collider detector acceptance -> requires special detectors for this "far-forward" (FF) region.
- Part of the EIC design is aimed at covering this FF region – there are many things to consider that can impact measurements!



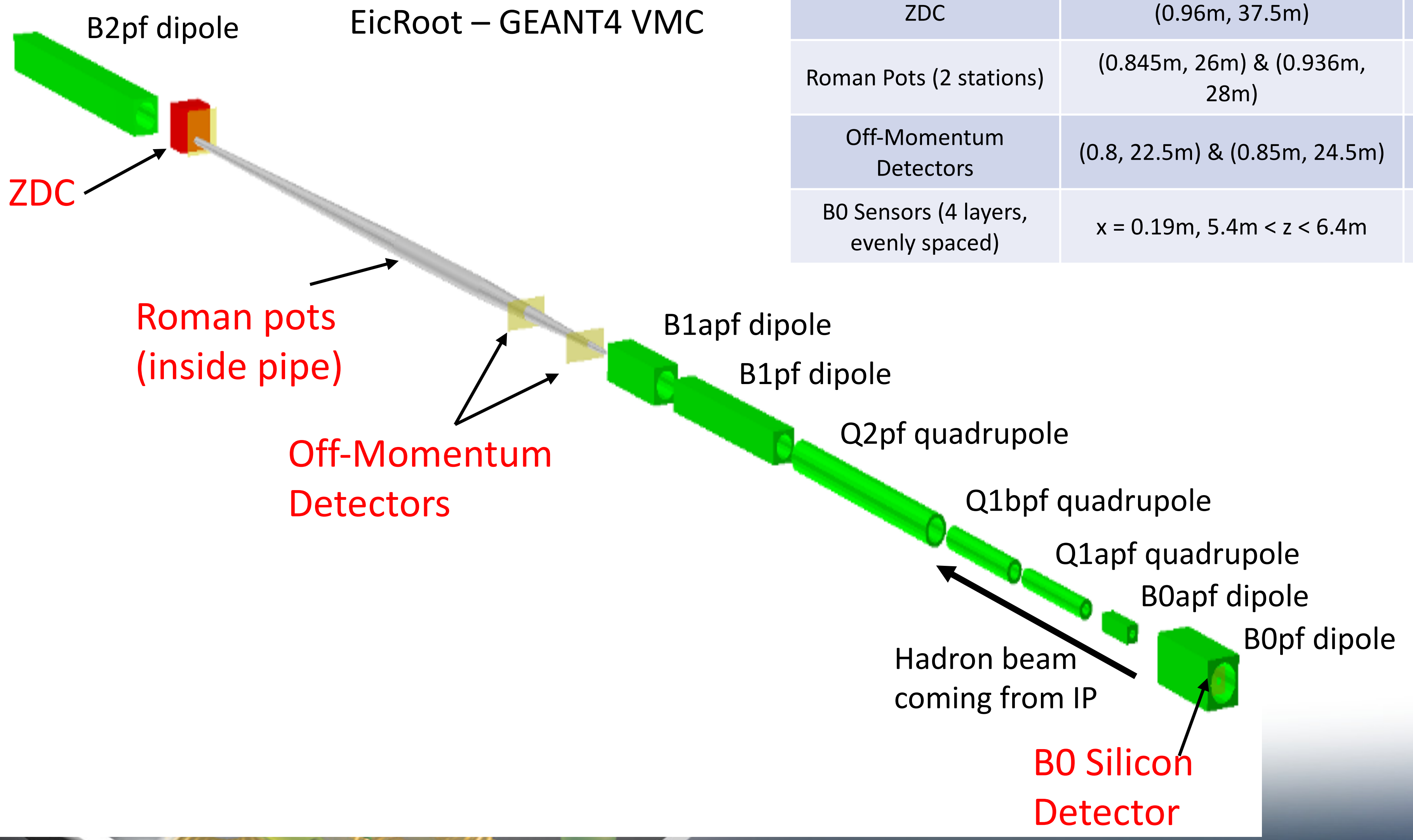
The "How": Full EIC Simulations to Assess SRC Measurement Capabilities

Layout of Full IR



- ~9 m around the IP is reserved for the *central* detector
- But the *far forward* and *far backward* detector components are distributed along the beam line within ±35 m
- FF detectors constrained by machine design.

Layout of Far-Forward Region

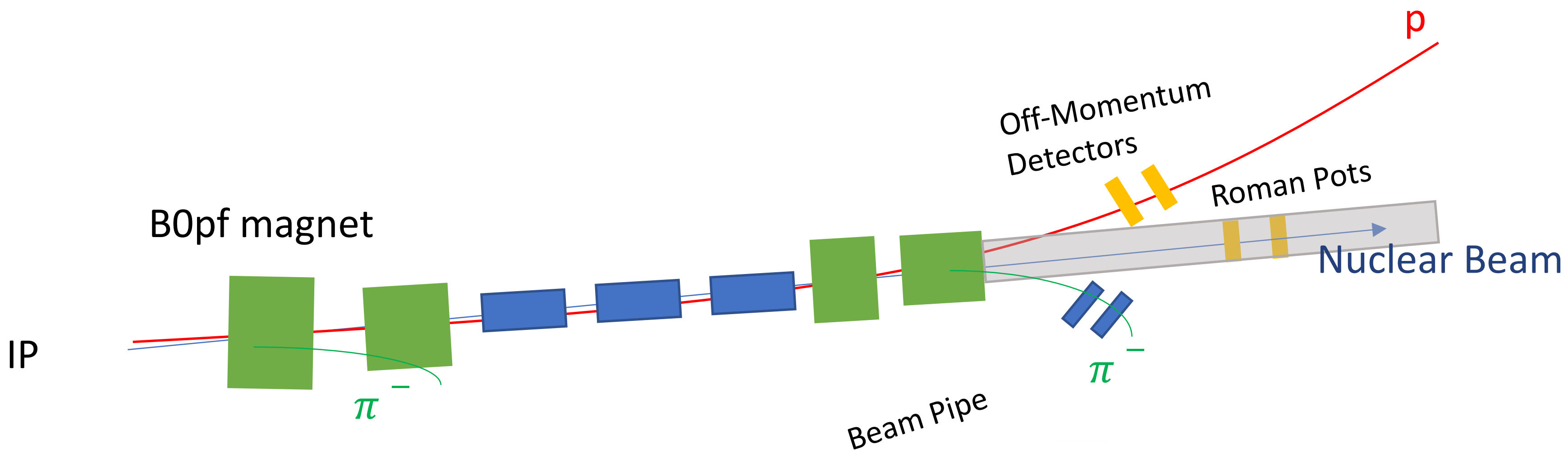


Detector	Detector Position (x,z)	Angular Acceptance	Notes
ZDC	(0.96m, 37.5m)	$\boldsymbol{\theta}$ < 5.5 mrad	About 4.0 mrad at φ ~ π
Roman Pots (2 stations)	(0.845m, 26m) & (0.936m, 28m)	0.0* < $\boldsymbol{\theta}$ < 5.0 mrad	0.65 < x_L < 1.0 10σ cut
Off-Momentum Detectors	(0.8, 22.5m) & (0.85m, 24.5m)	0.0 < $\boldsymbol{\theta}$ < 5.0 mrad	Roughly 0.4 < x_L < 0.6
B0 Sensors (4 layers, evenly spaced)	x = 0.19m, 5.4m < z < 6.4m	5.5 < $\boldsymbol{\theta}$ < 20.0 mrad	Could change a bit depending on pipe and electron quad.

$$x_L = \frac{p_{z,nucleon}}{p_{z,beam}}$$

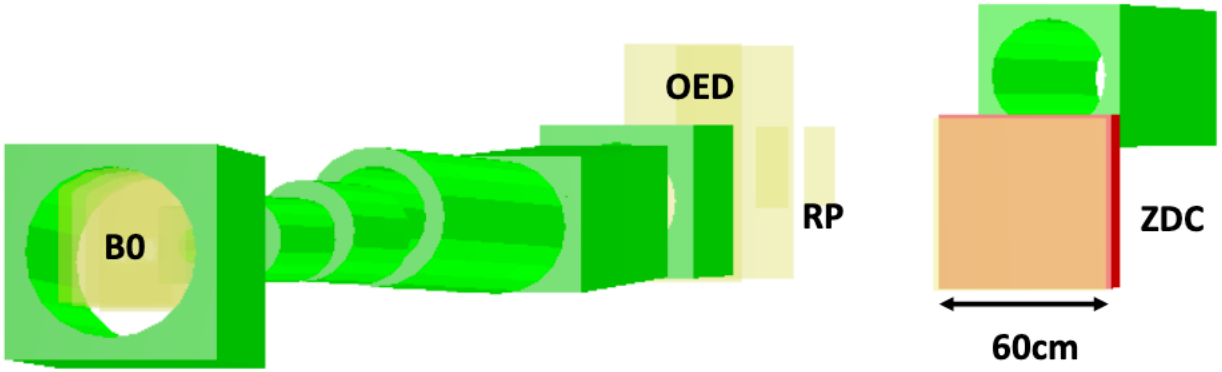
Aside: Off-Momentum Detectors (protons)

- Needed for measuring protons from nuclear breakup.
- Another set of sensors on the other side can be used to detect negative pions from lambda decay.

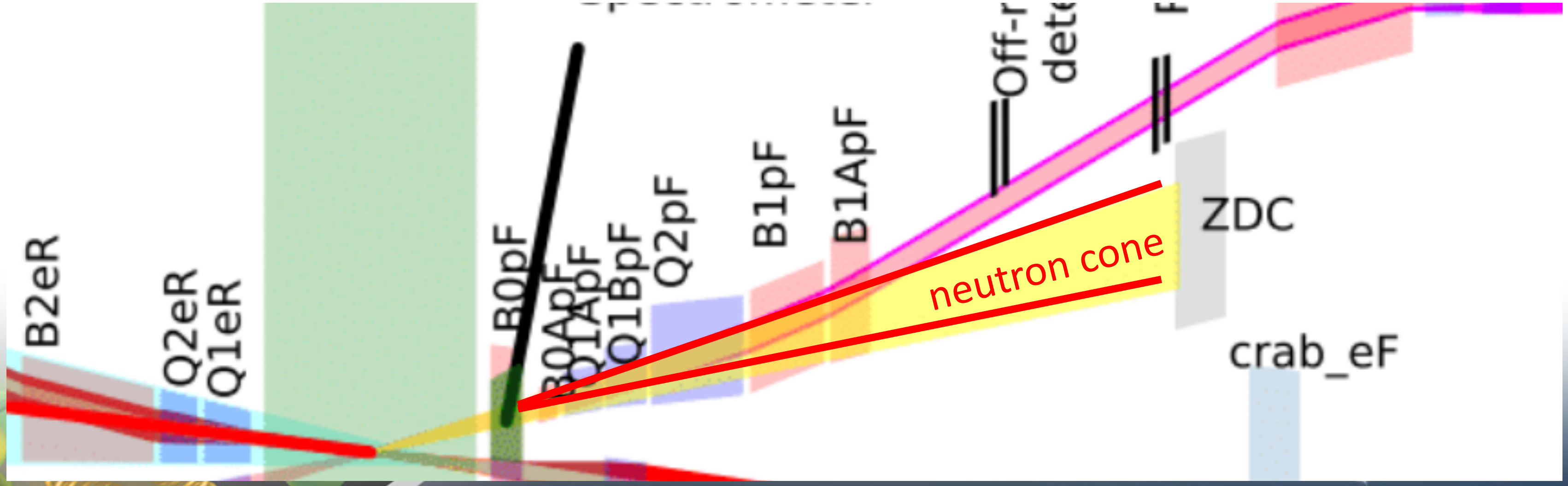


- Very off-momentum particles can be lost in the magnets.

Zero-Degree Calorimeter (neutrons)

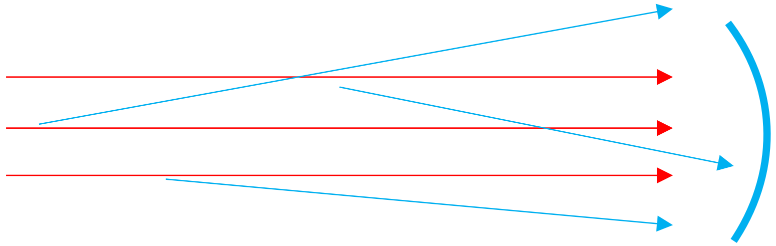


- For detecting neutral forward-going particles (neutrons and photons)
- Acceptance limited by bore of magnet where the neutron/photon cone exits.

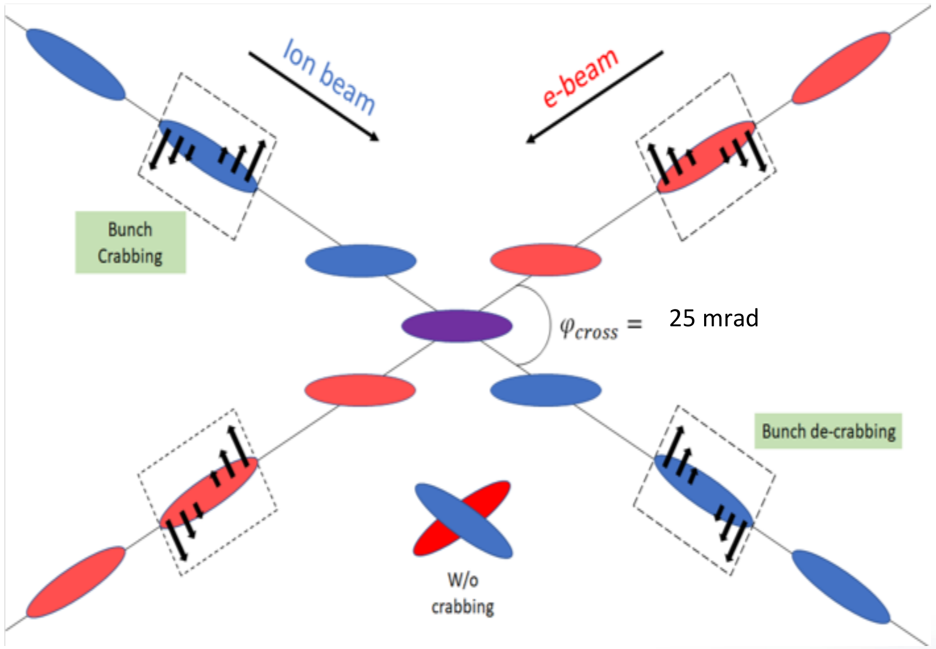


Resolution: Smearing Contributions

- Angular divergence
  - Angular "spread" of the beam away from the central trajectory.
  - Gives some small initial transverse momentum to the beam particles.



- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.



- Detector Choices
  - Pixel size, transfer matrix, etc.

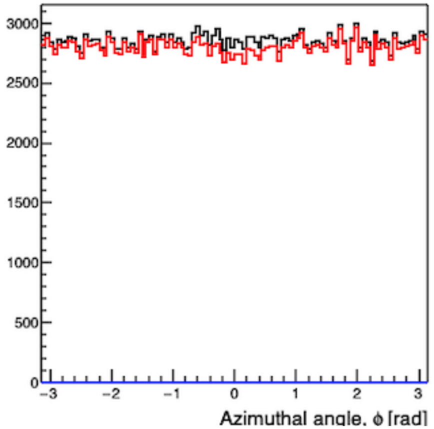
These effects introduce smearing in our momentum reconstruction.

e+d -> p + n + J/ψ

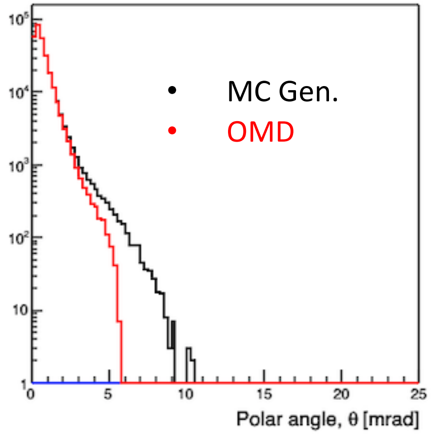
Particular process in BeAGLE: incoherent diffractive J/psi production off bounded nucleons.

[arXiv:2005.14706](https://arxiv.org/abs/2005.14706)

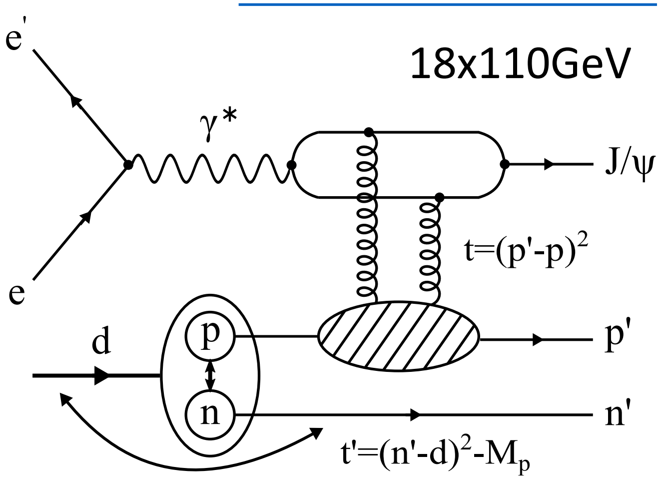
Protons

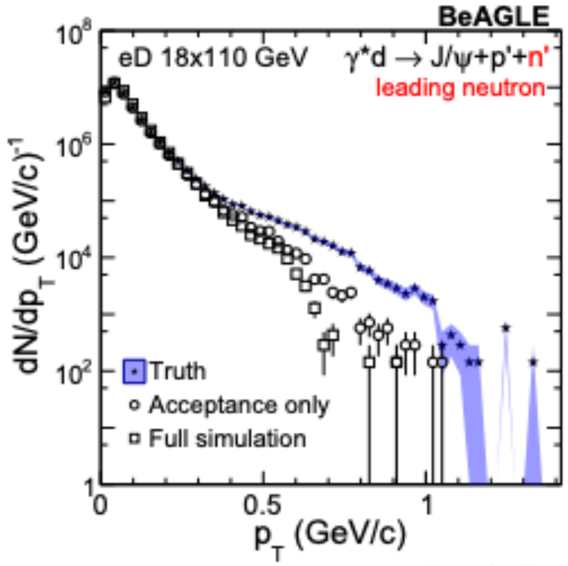


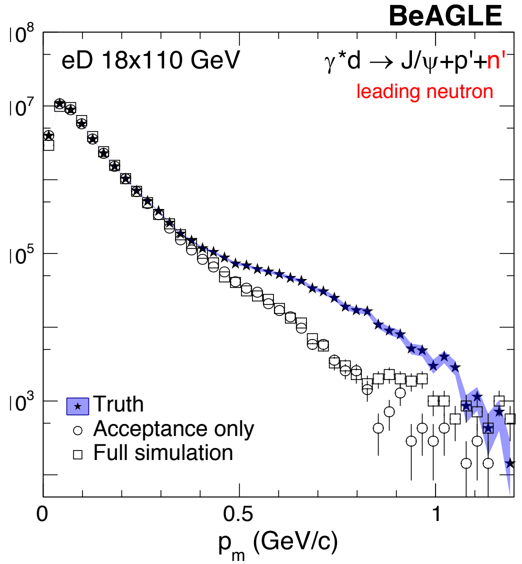
Protons

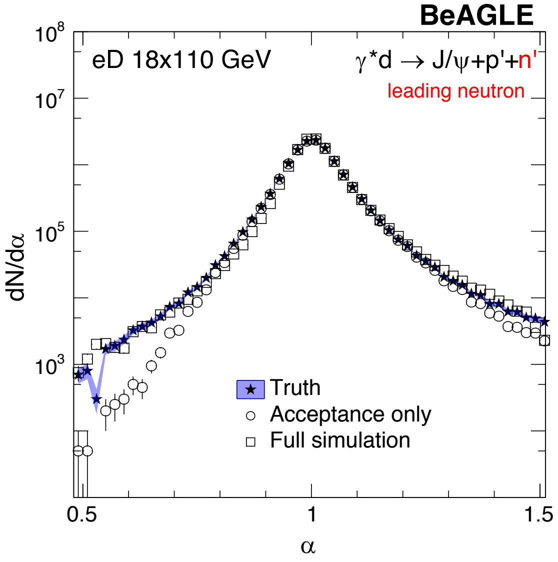


Proton spectator case.









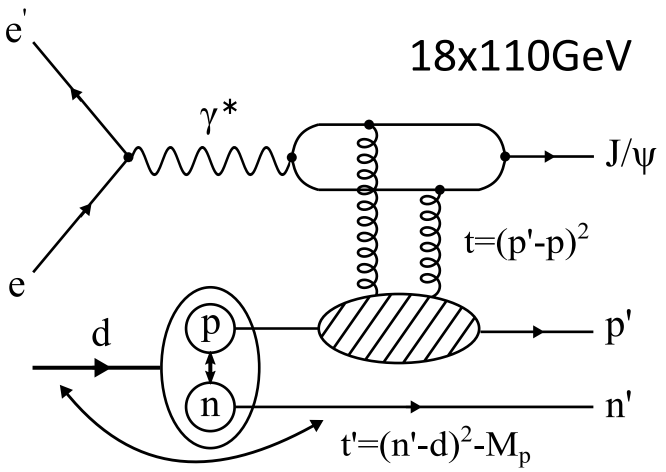
Spectator kinematic variables reconstructed over a broad range. Bin migration is observed due to smearing in the reconstruction. Each plot shows the MC (closed circles), acceptance effects only (open circles), and full reconstruction (open squares).

- **In the proton spectator case, essentially all spectators tagged.**
- **Active neutrons only tagged up to 4.5 mrad.**

e+d -> p + n + J/ψ

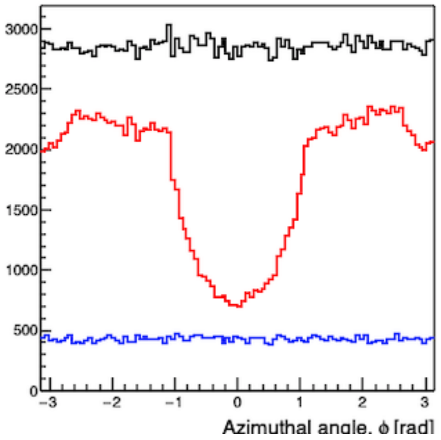
arXiv:2005.14706

Particular process in BeAGLE: incoherent diffractive J/psi production off bounded nucleons.

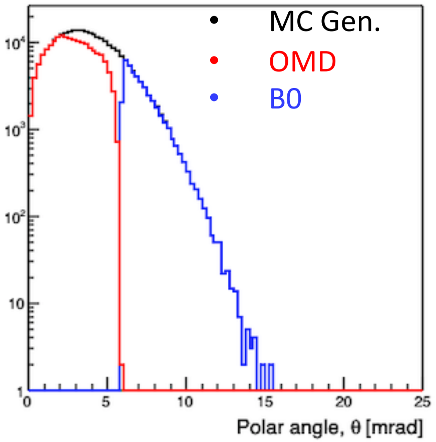


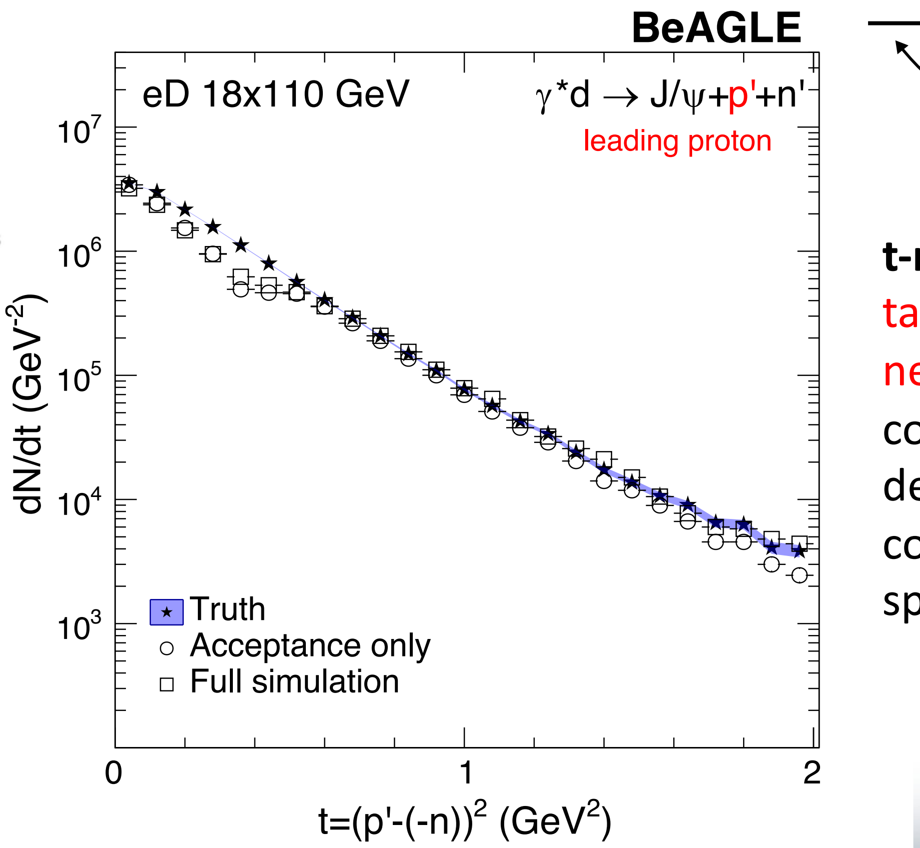
Neutron spectator/leading proton case.

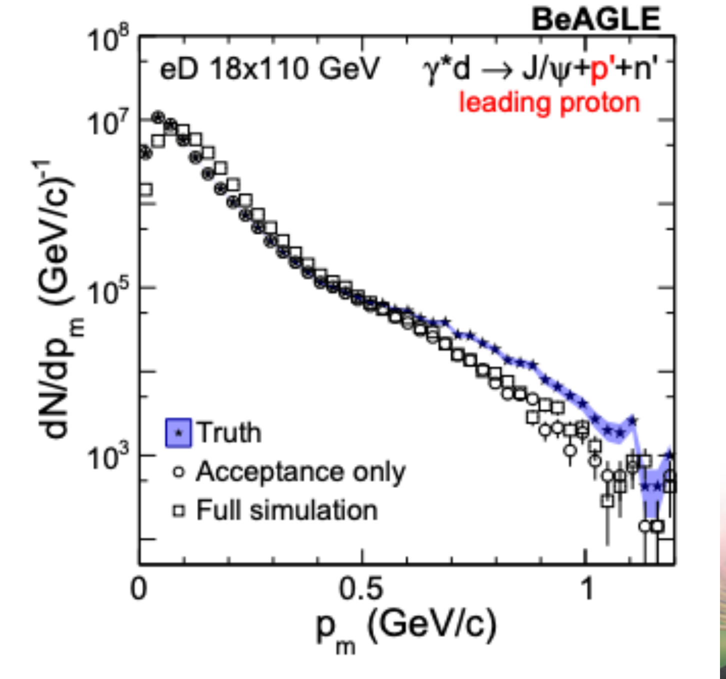
Protons



Protons







t-reconstruction using double-tagging (both proton and neutron). Takes advantage of combined B0 + off-momentum detector coverage. Better coverage in the neutron spectator case.

➢ **Spectator information is the "dial" for the SRC region.**

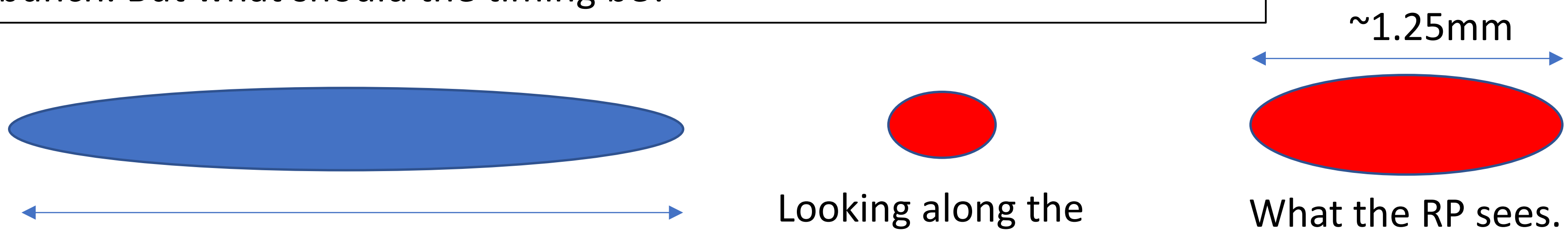
Takeaways

- Acceptances and resolutions in the FF region of the EIC IR are well-understood.
  - Multiple detector sub-systems, lots of engineering considerations affecting acceptance.
  - Major design challenge!
- Impact on SRC studies assessed (detailed in arXiv:2005.14706)
  - Able to comprehensively tag the spectator nucleons from e+d collisions.
  - Double-tagging efficiency better in the neutron spectator case.
- EIC R&D groups studying detector technologies for the FF region.
  - These studies have provided essential feedback the process of refining the EIC IR design, and the choice of detector technologies.

Backup

Reminder: Timing

For exclusive reactions measured with the Roman Pots we need good timing to resolve the position of the interaction within the proton bunch. But what should the timing be?



RMS hadron bunch length ~10cm*.
*based on "ultimate" machine performance.

Looking along the beam with no crabbing.

What the RP sees.

- Because of the rotation, the Roman Pots see the bunch crossing **smeared in x**.
- Vertex smearing = 12.5mrad (half the crossing angle) * 10cm = **1.25 mm**
- If the effective vertex smearing was **for a 1cm bunch**, we would have **0.125mm** vertex smearing.
- The simulations were done with these two extrema and the results compared.

➢ **From these comparisons, reducing the effective vertex smearing to that of the 1cm bunch length reduces the momentum smearing to a negligible amount from this contribution.**
➢ **This can be achieved with timing of ~ 35ps (1cm/speed of light).**

Geometric Acceptances

<u>Neutrons:</u>

- Assume uniform acceptance for $0<\theta<4.5$ mrad
  - Limited by bore of magnet where the neutron cone has to exit.
  - Up to 5.5 mrad on one side of the aperture.
- Resolutions (ZDC)
  - Assume an overall energy resolution of $\sigma_E/E=(50\%)/\sqrt{E} \oplus 5\%$
  - Assume angular resolution of $\sigma_\theta=(3\text{ mrad})/\sqrt{E}$

<u>Protons:</u>

- Assume uniform acceptance for $6 < \theta < 13$ mrad (20mrad on the other side) – “B0 spectrometer”
- For protons with p_z/(beam momentum) > 0.6 – “Roman pots”
  - 275 GeV: Assume uniform acceptance for $0.5<\theta<5.0$ mrad
  - 100 GeV: Assume uniform acceptance for $0.2<\theta<5.0$ mrad
  - 41 GeV: Assume uniform acceptance for $1.0<\theta<4.5$ mrad
- For protons with $0.25<p_z$/(beam momentum)<0.6 – “Off-momentum Detectors”
- Assume uniform acceptance for $0.0<\theta<2.0$ mrad
- for $2.0<\theta<5.0$ mrad, only accepted for $|\varphi|>1$ radian
- Resolutions (silicon reconstruction with transfer matrix or conventional tracking).
    - pt ~ 3% for pt > 550 MeV/c, p ~ 0.5%