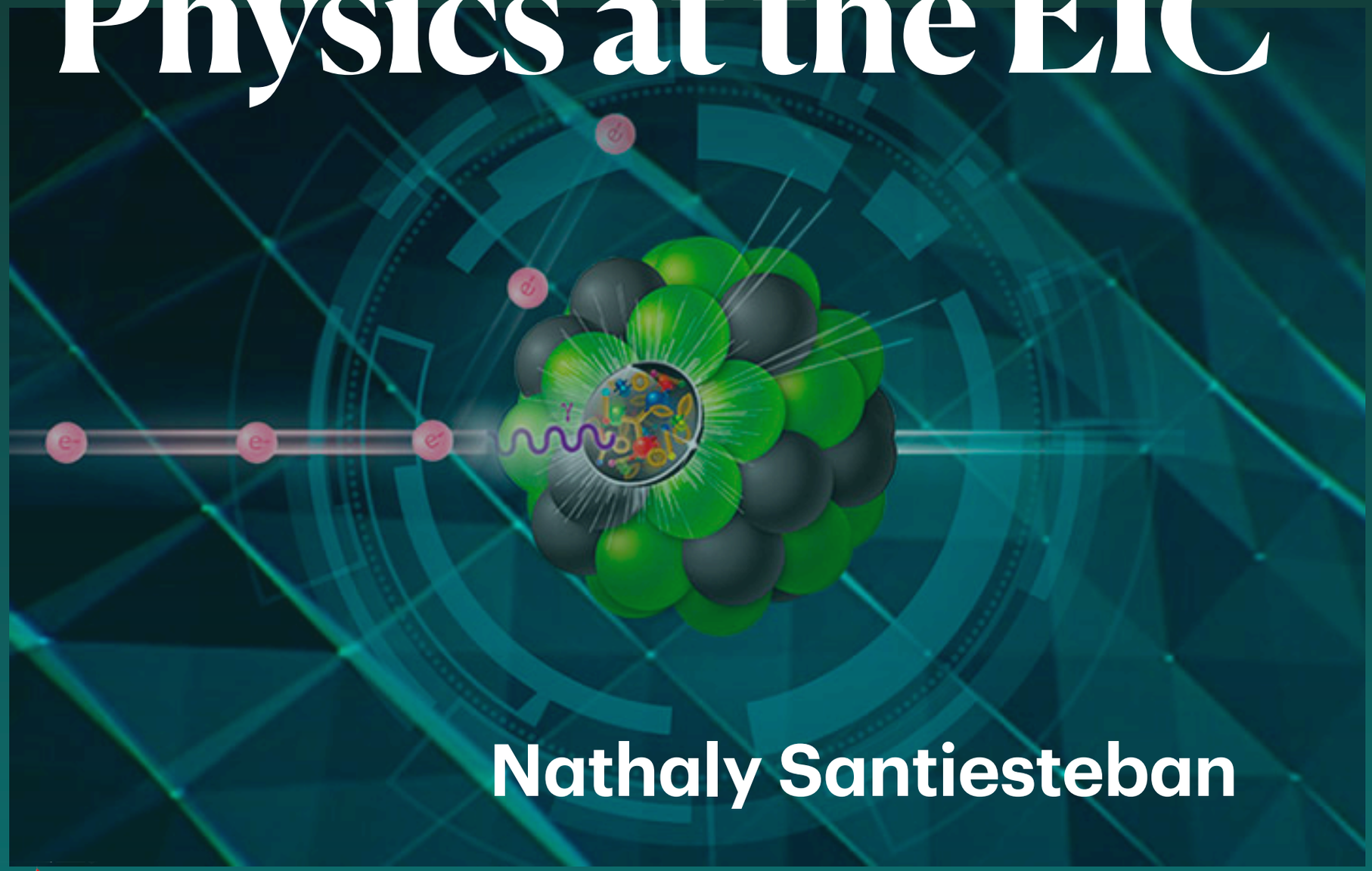
Exclusive Vector Meson Physics at the EIC



Nathaly Santiesteban

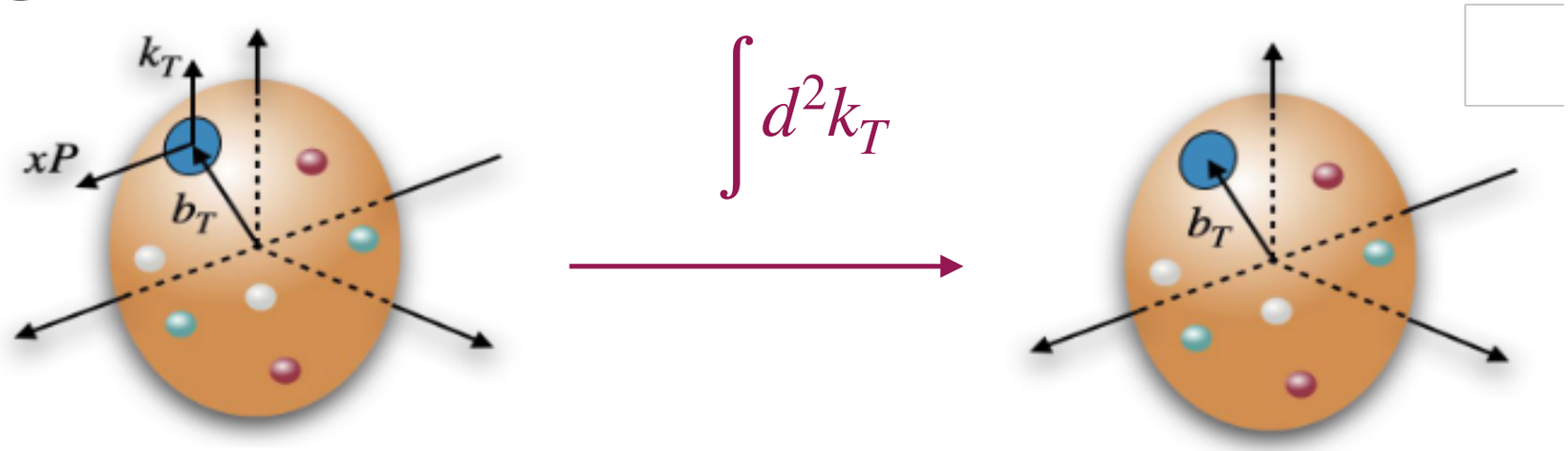
First International Workshop on the Physics of Ultra Peripheral Collisions

2023

University of New Hampshire

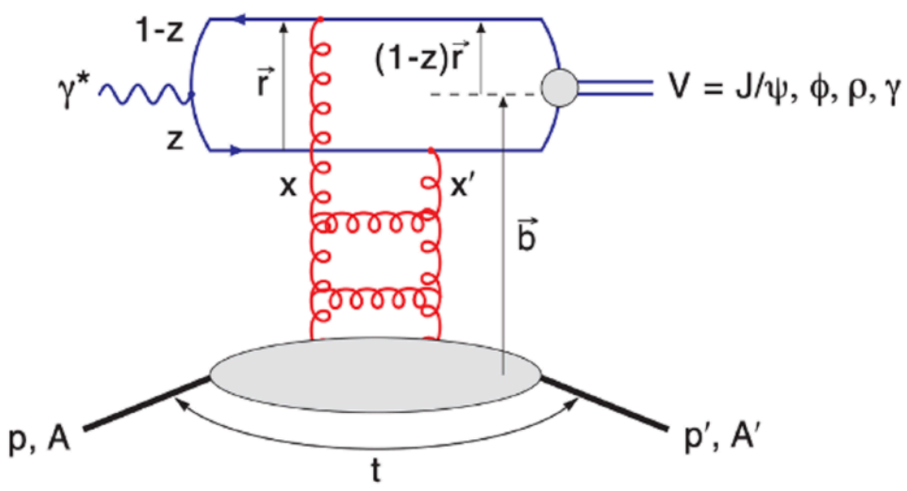
MOTIVATION

Wigner Function



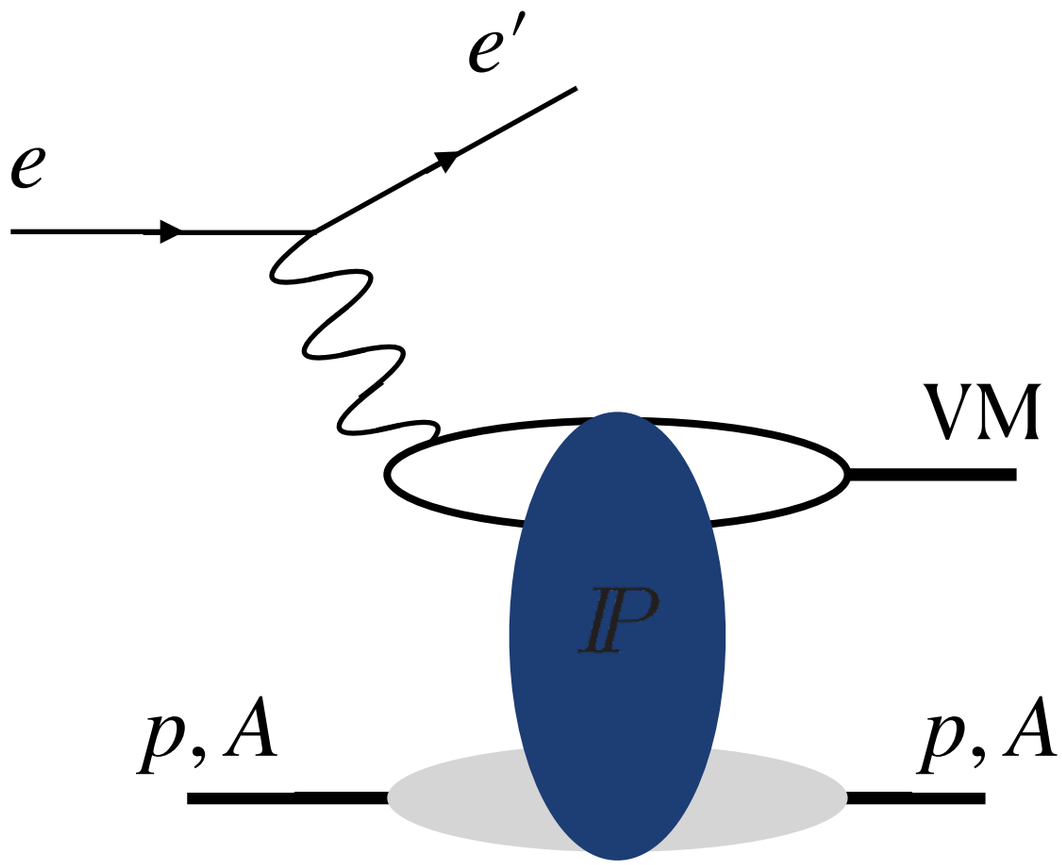
Generalized
Parton
Distributions

- 3D imaging of the nucleon and nuclei: GPDs
- Origin of nucleon mass
- Wigner functions



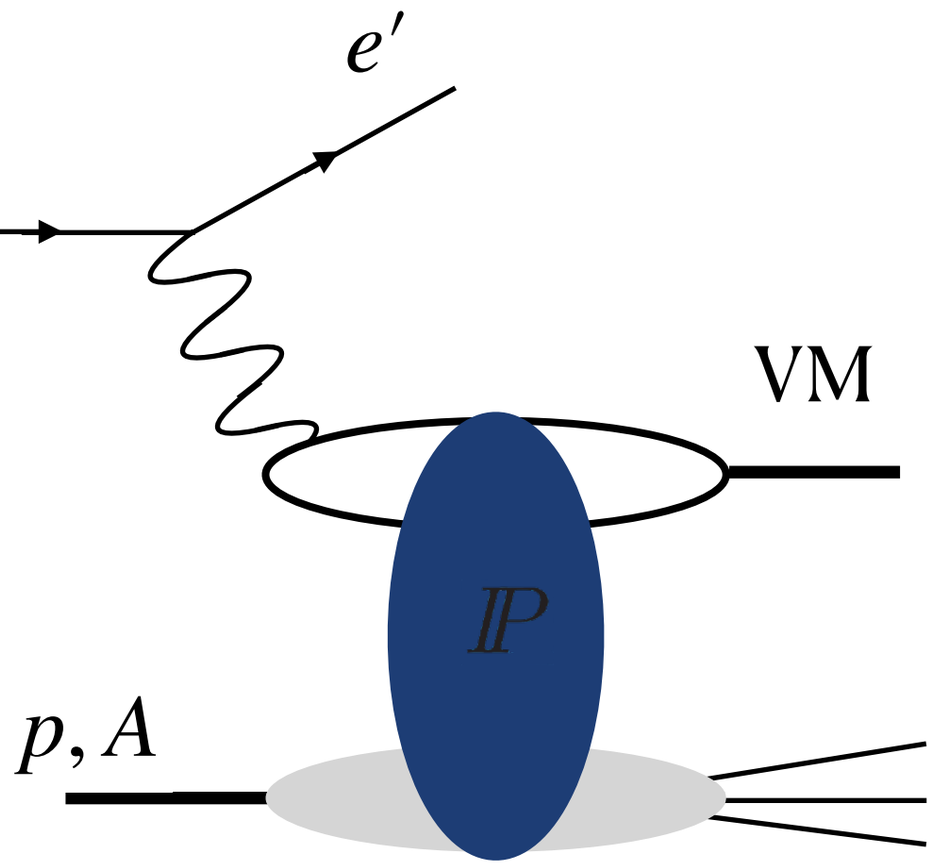
Vector Meson Production

Vector meson production



Coherent

Target stays intact

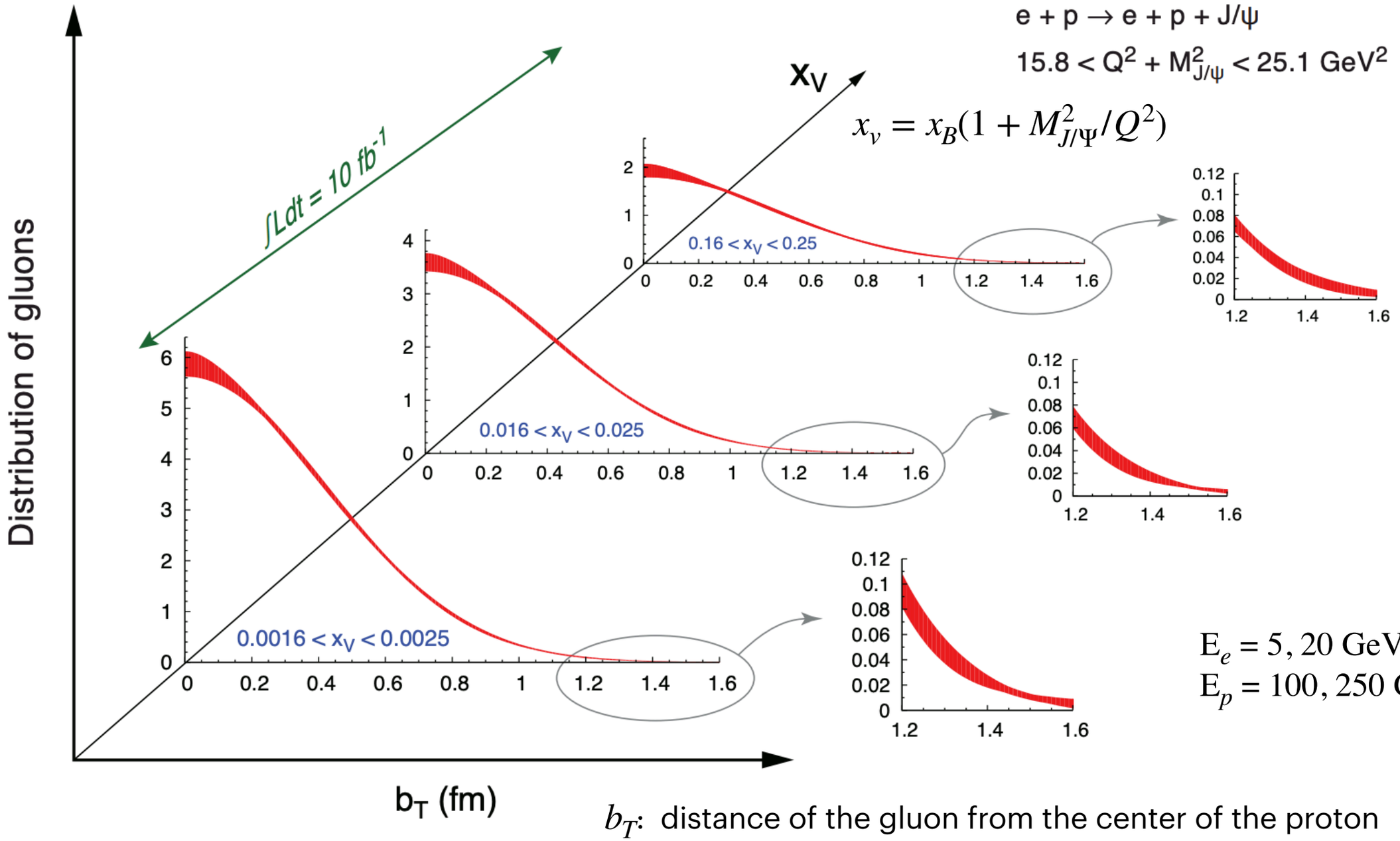


Incoherent

Target breaks up

In electron-ion collisions

MOTIVATION



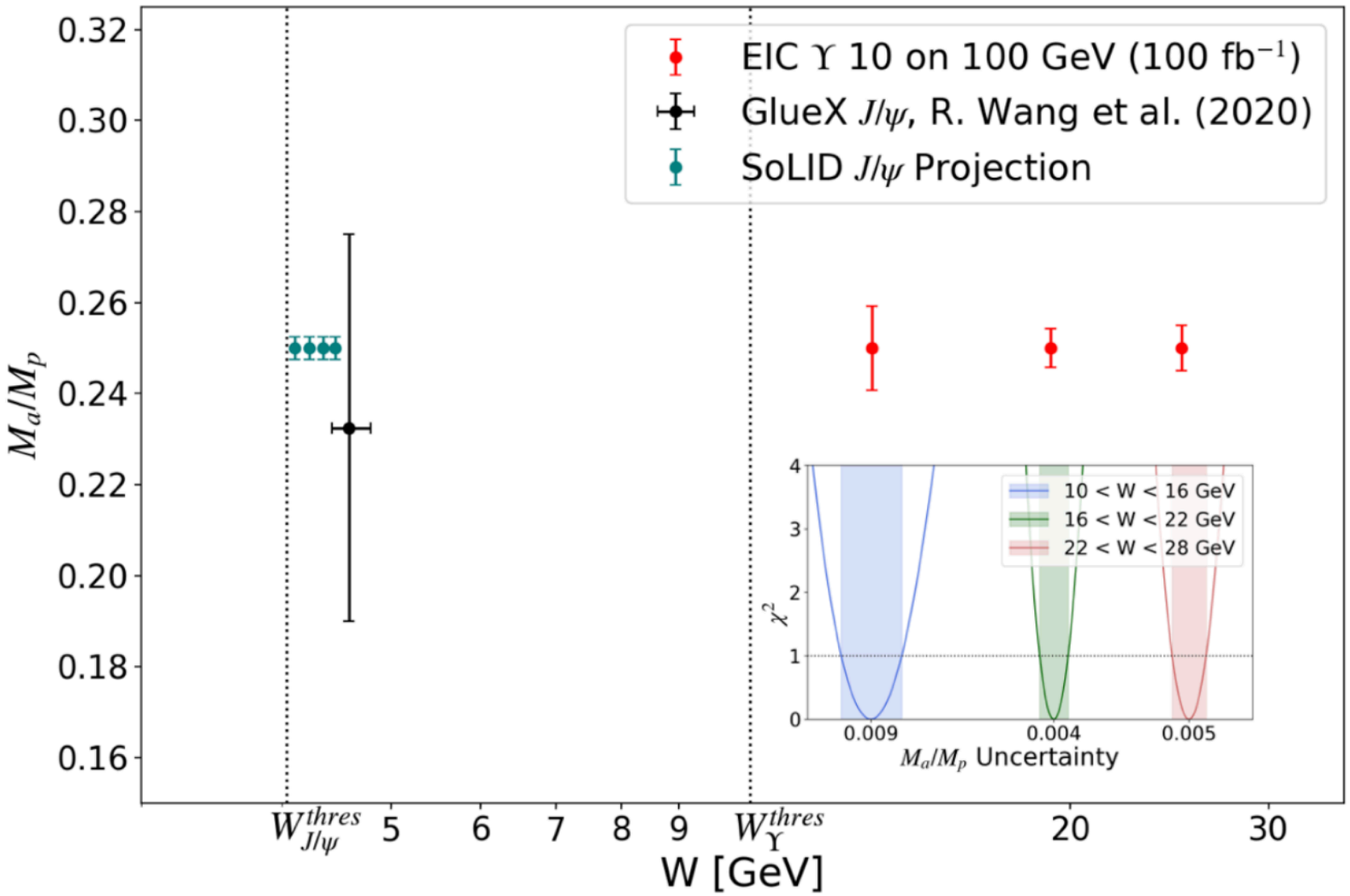
$E_e = 5, 20$ GeV
$E_p = 100, 250$ GeV

b_T: distance of the gluon from the center of the proton

J/Ψ production: transverse spatial distribution of gluons

Eur. Phys. J., 6 vol. A52 (2016)

MOTIVATION

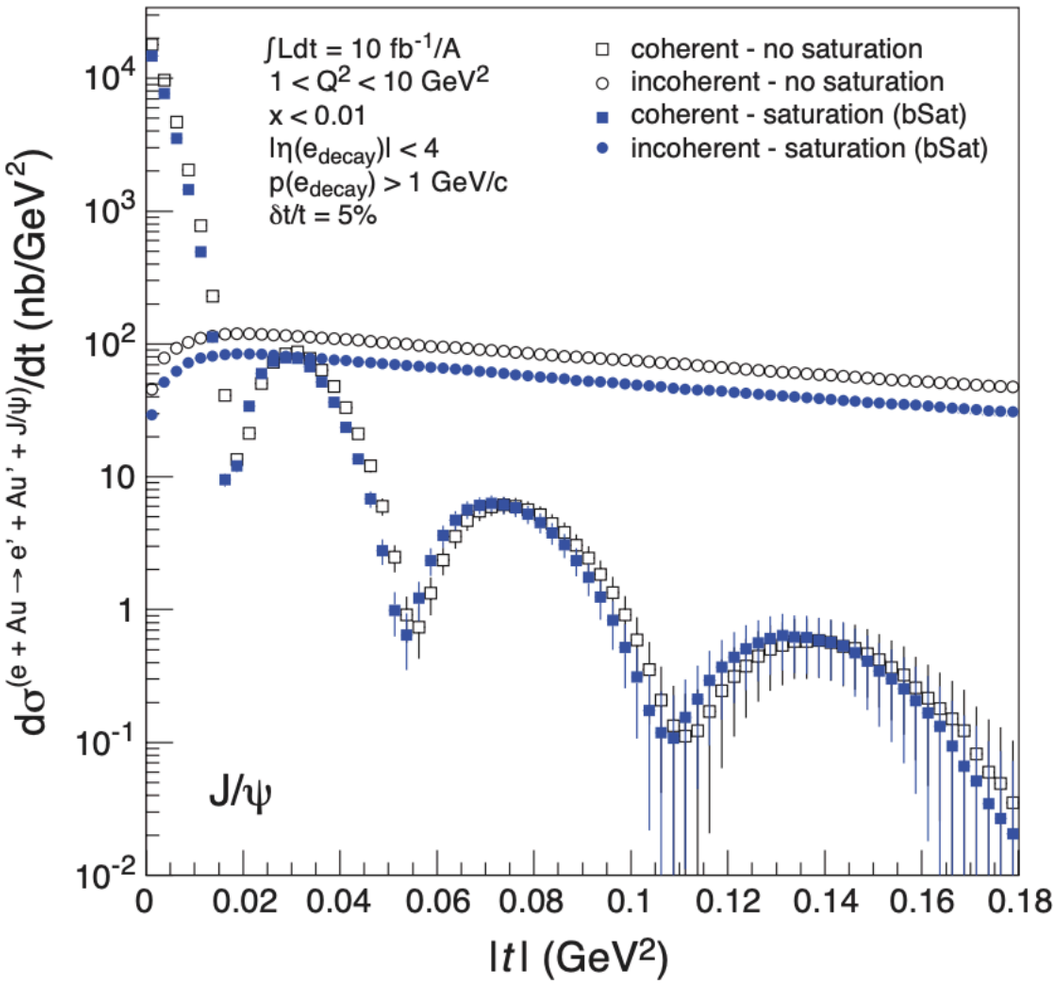


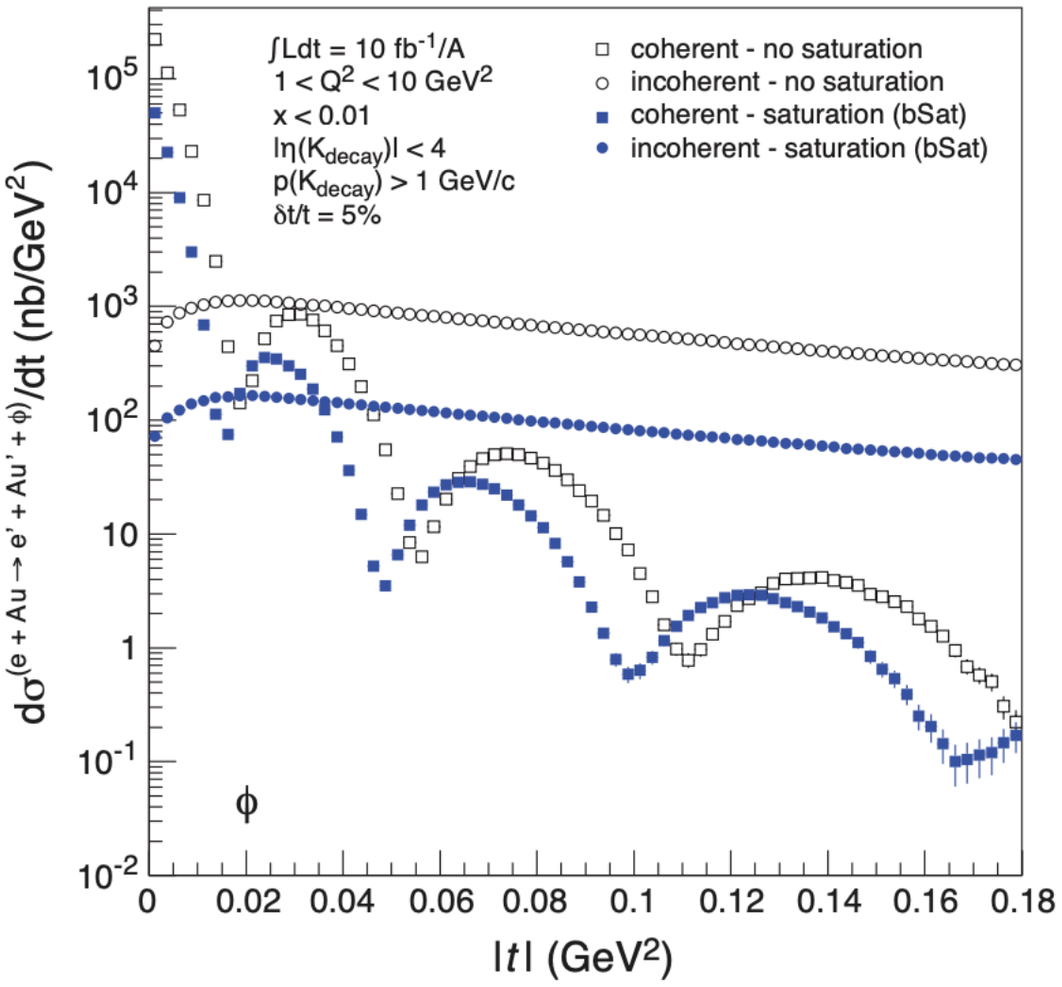
E_e = 10 GeV
E_p = 100 GeV

Trace anomaly contribution to the proton mass.

Nucl. Phys. A 1026 (2022)

Exclusive Vector Meson Production as a Probe of Saturation





J/Ψ is smaller, less sensitive to saturation effects

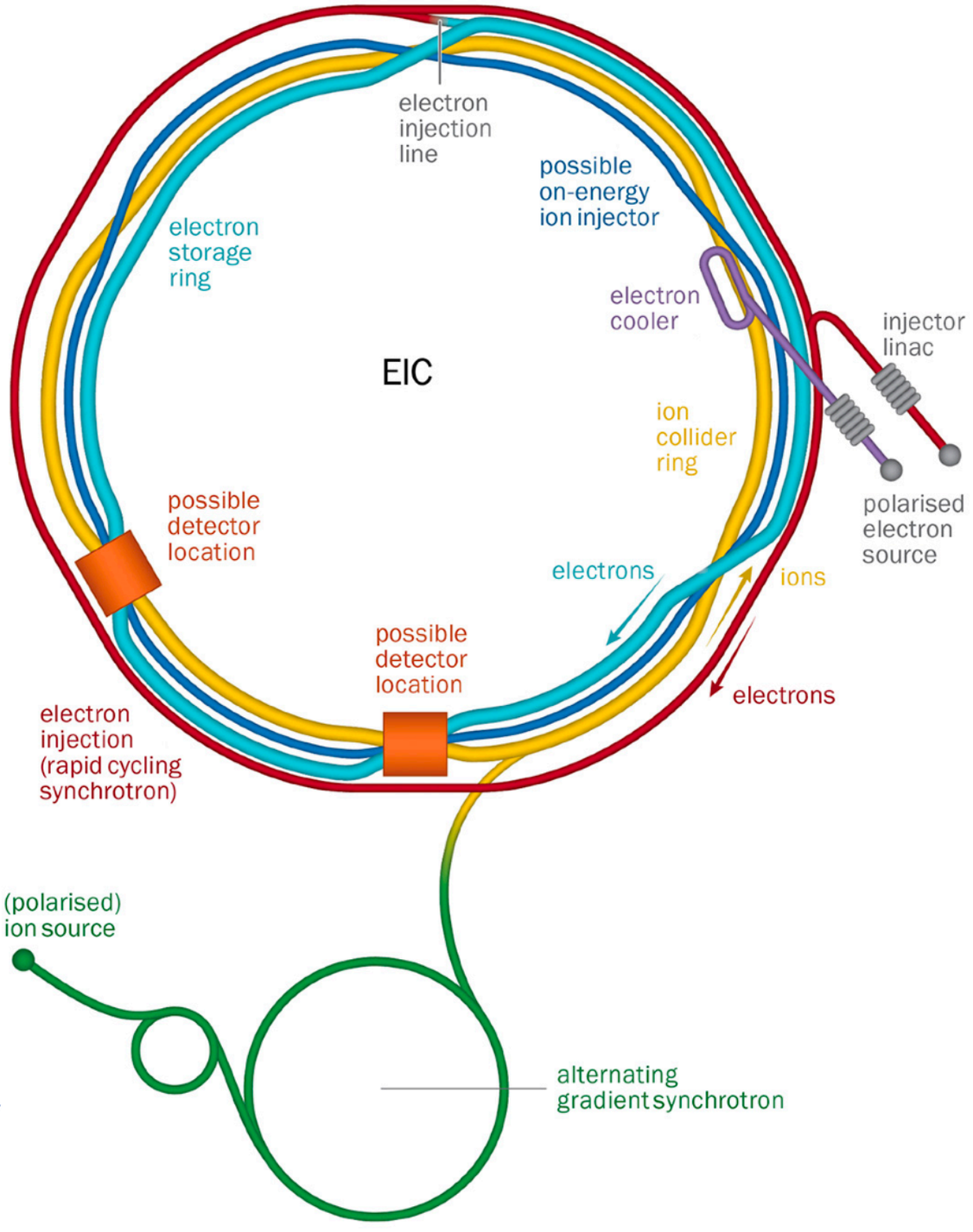
ϕ meson is larger, more sensitive to saturation effects

T. Toll and T. Ullrich
Sartre event generator

Where to perform such studies?

Electron Ion Collider

- High luminosity: L = 10^{33} to 10^{34} $cm^{-2}sec^{-1}$
- Center-of-mass energies: E_{cm} = 29 to 141 GeV
- Polarized beams
  World's first:
  polarized-electron + polarized-proton/light-ion
  polarized-electron + Nucleus collider
- Hadron species: Protons …. Uranium
- Two superconducting storage rings
  3.8km circumference

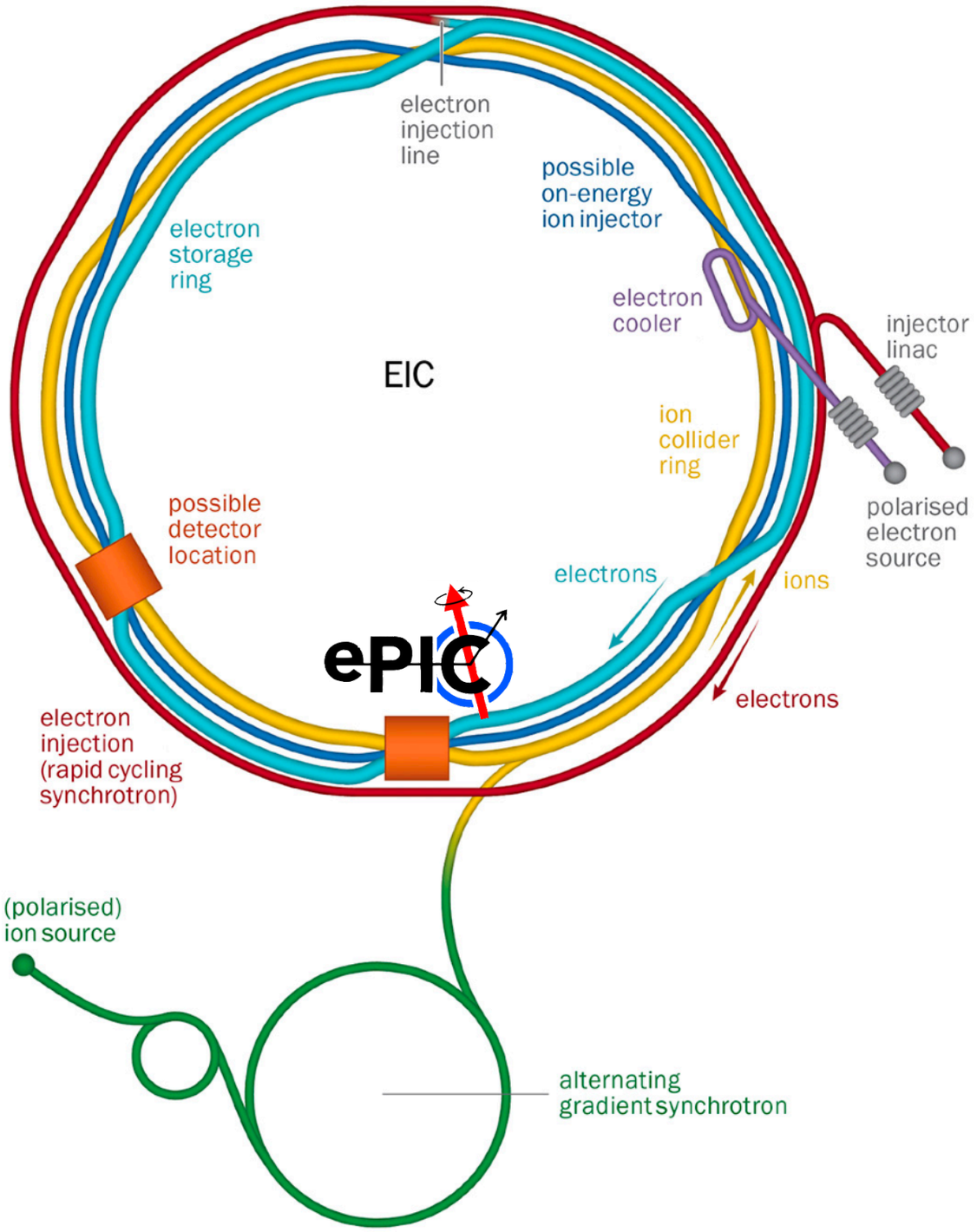


EIC is based on existing RHIC facility

Electron Ion Collider

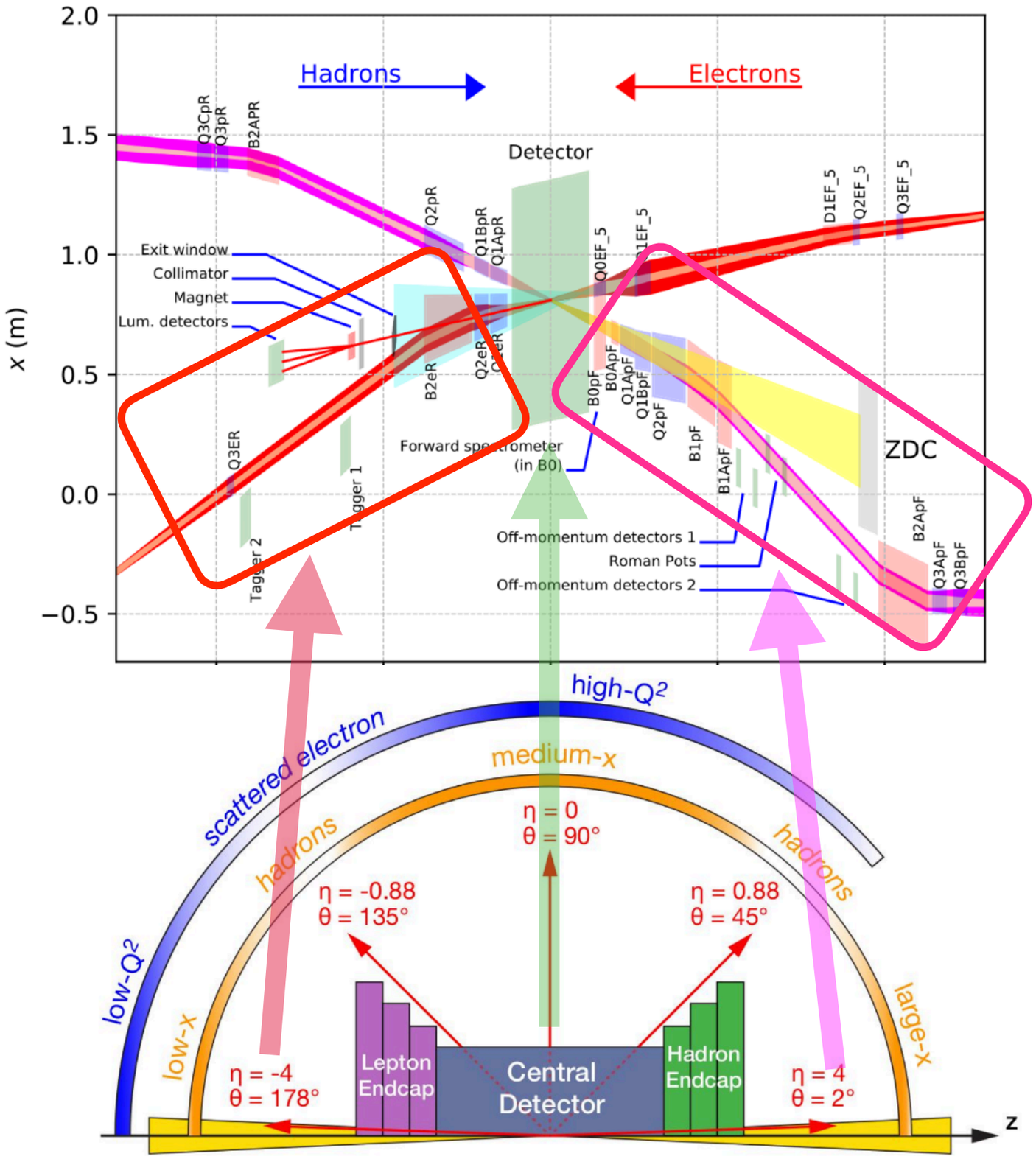
- *(Existing)* Hadron Storage Ring (HSR):

  injectors, ion sources, infrastructure; needs only relatively few modifications and upgrades
- *(In progress)* Add a 5 to 18 GeV electron storage ring and its injector complex to the RHIC facility
- *(In progress)* Design and built a suitable interaction region (**ePIC**)



EIC is based on existing RHIC facility

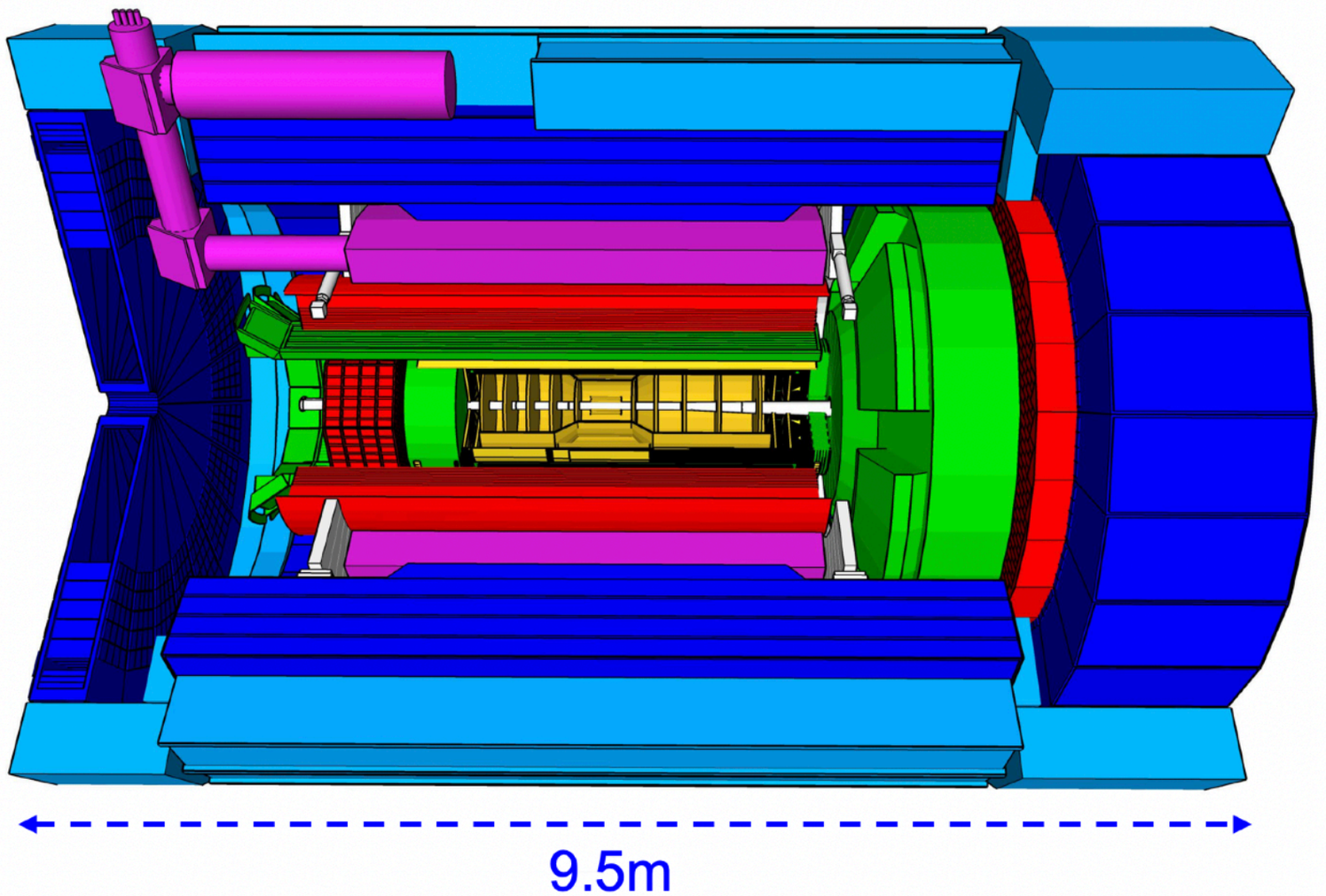
Interaction Region Layout



Large detector acceptance

- Total size of the detector: ~75 m
- Central detector (~10 m)
- Far Backward (electron detection) ~35 m
- Far Forward (hadron detection) ~40m

Central Detector



Magnet
1.7 T Solenoid
2.8 m bore diameter

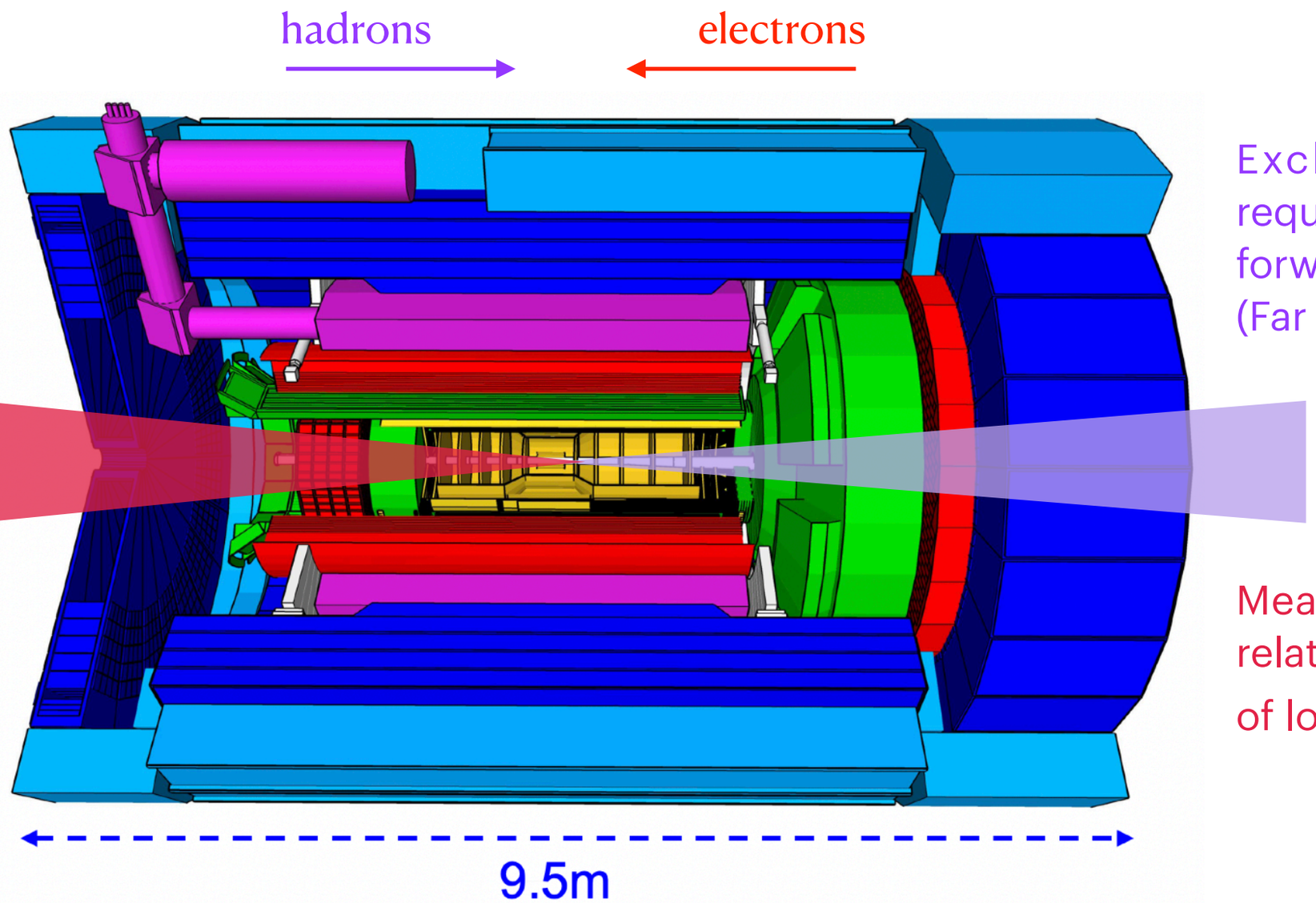
Tracking
Si Vertex Tracker MAPS wafer-level stitched sensors
Si Tracker MAPS barrel an disks
Gaseous tracker: MPGDS (μRWELL, MMG) cylindrical and planar

PID
High performance DIRC (hpDIRC)
Dual RICH (aerogel + gas) (forward)
Proximity focussing RICH (backward)
ToF using AC-LGAD (barrel + forward)

EM Calorimetry
Imaging EMCAL (barrel)
W-powder/SciFi (forward)
$PbWO_4$ crystals (backward)

Hadron calorimetry
FeSc (barrel, re-used from sPHENIX)
Steel/Scint - W/Scint (backward/forward)

Central Detector

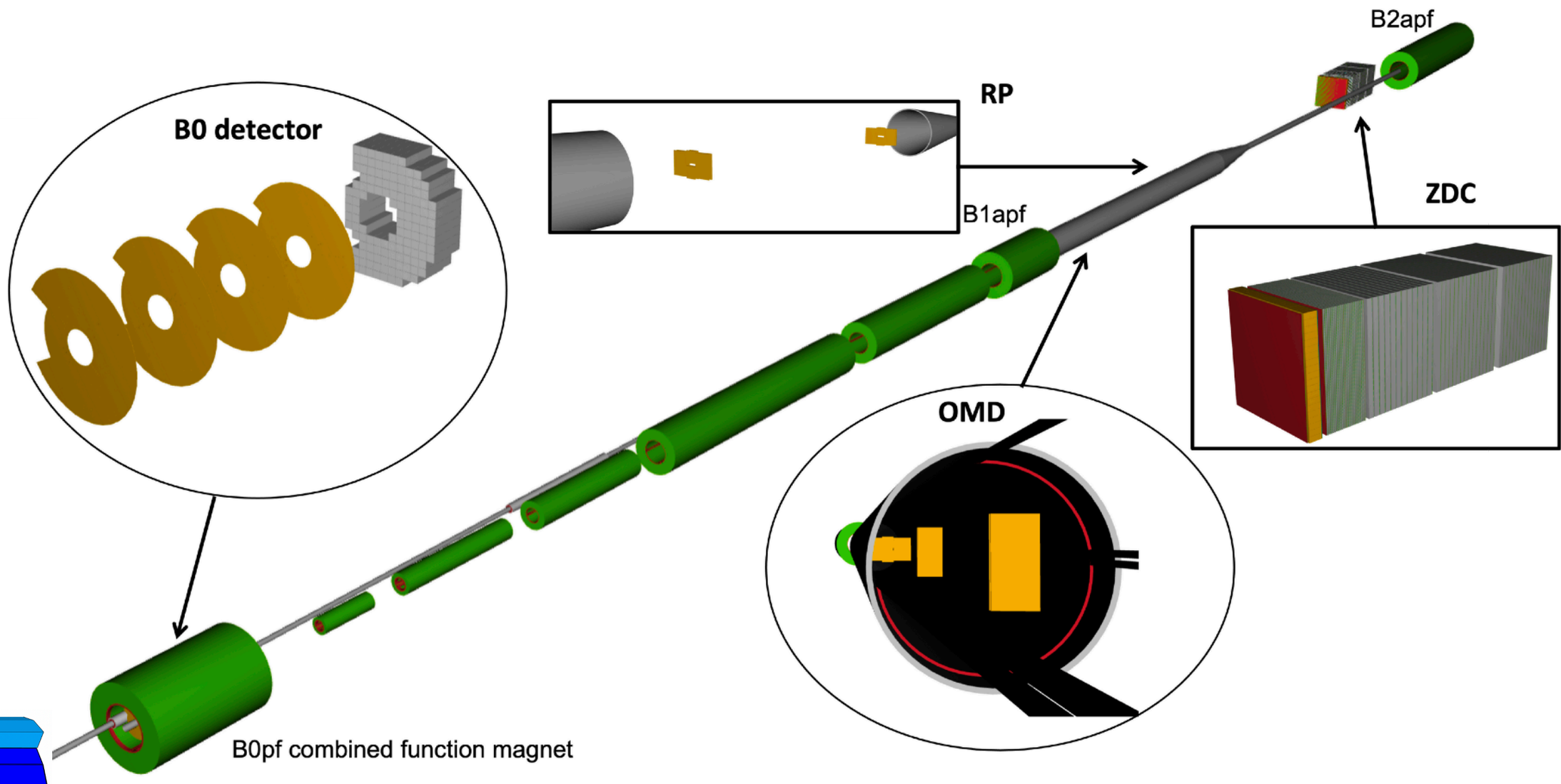


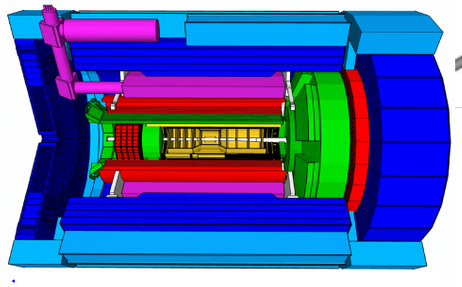
Exclusive vector meson physics requires tagging charged hadrons or forward particles at large rapidities. (Far Forward)

Measurement of the absolute and relative luminosity, as well as tagging of low-Q^2 electrons (Far backward)

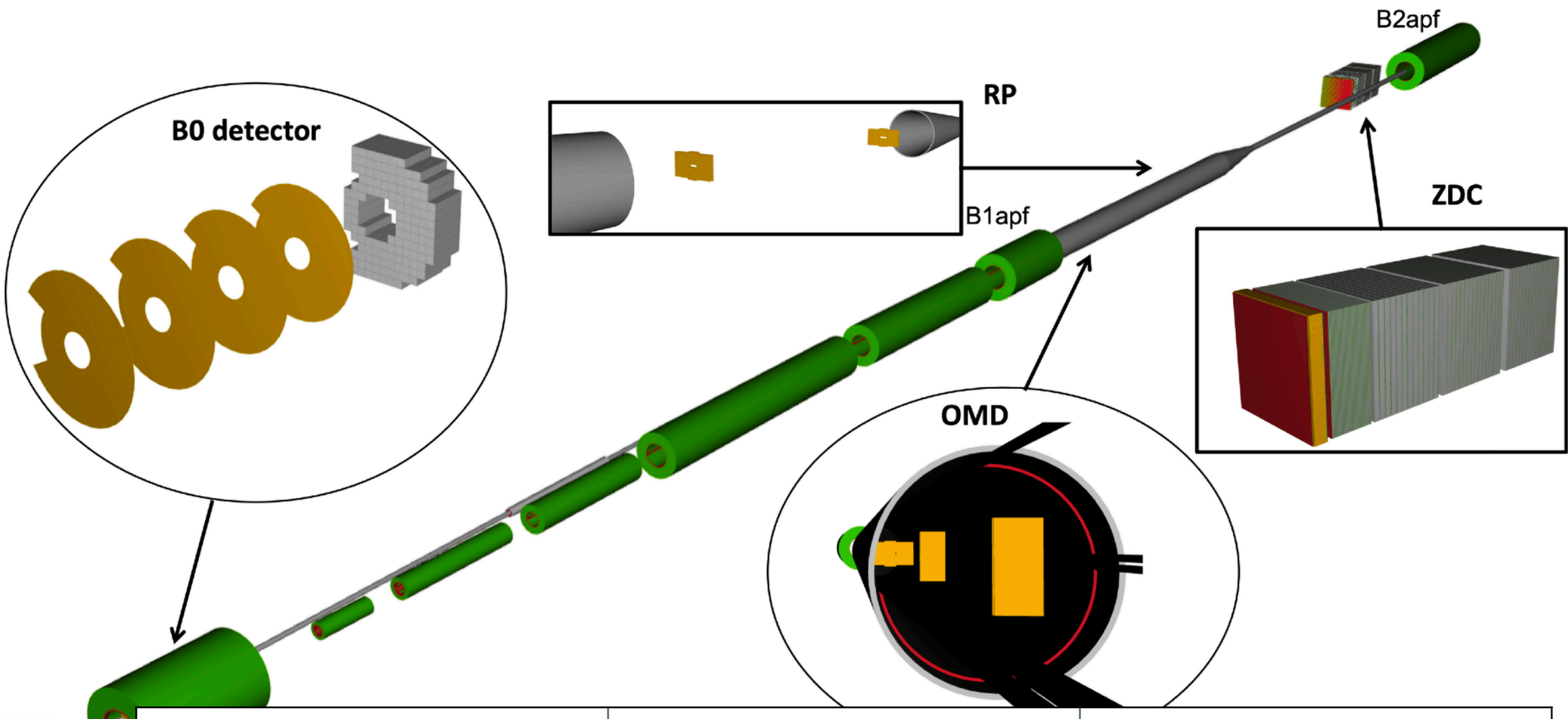
rapidity coverage ($-4 < \eta < 4$)
coverage

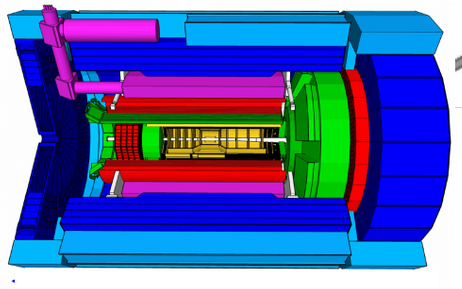
Far-Forward Detectors





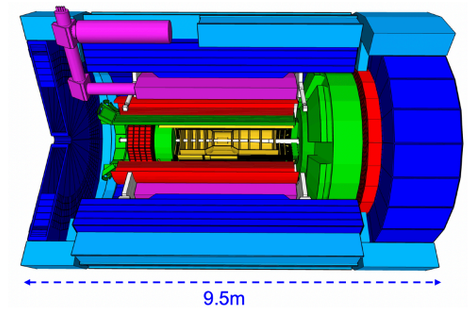
Far-Forward Detectors

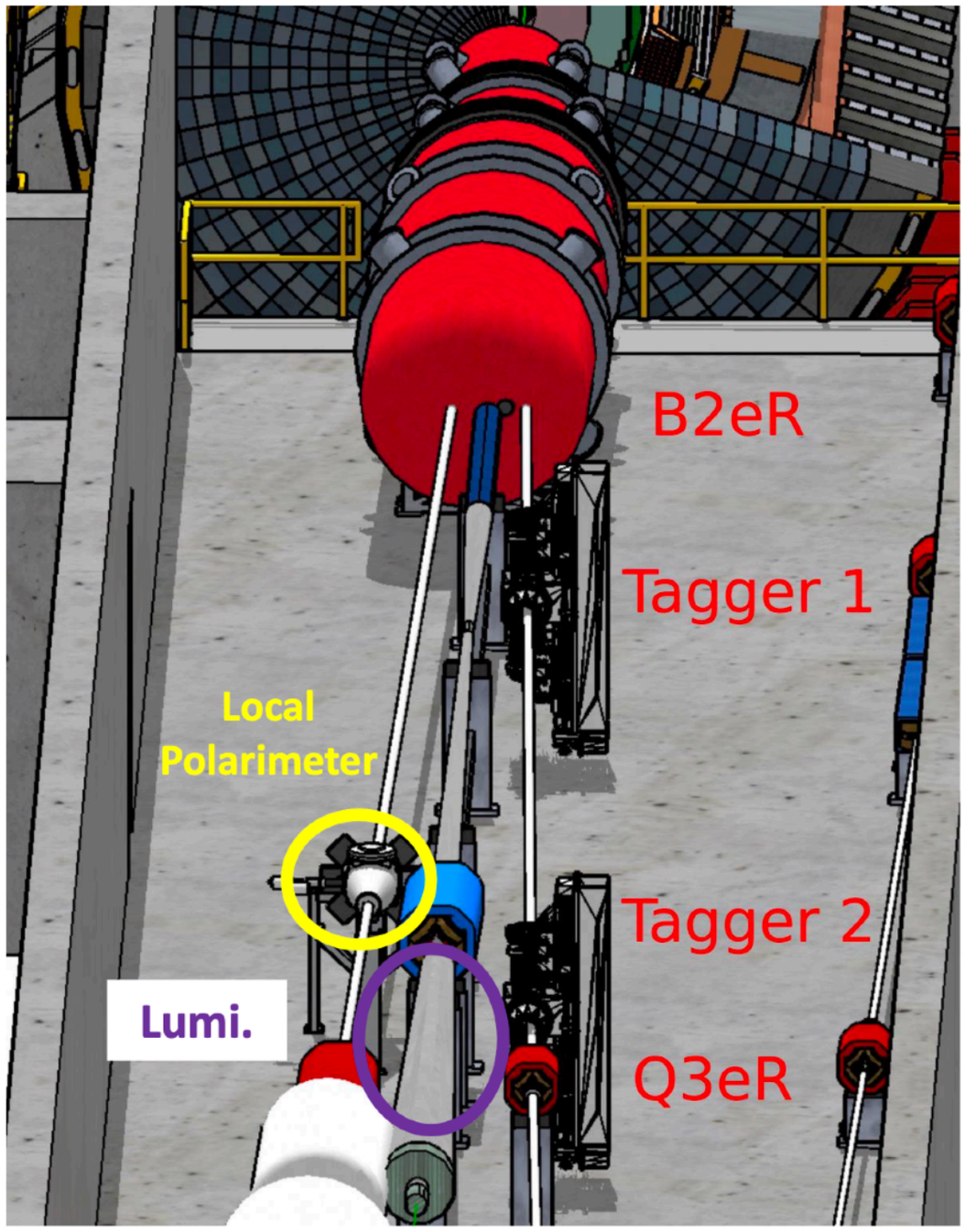




Detector	Acceptance	Particles
Zero-Degree Calorimeter	$\theta < 5.5\ mrad$	Neutrons, photons
Roman Pots (2 stations)	$0^* < \theta < 5.0 mrad$	Protons, light nuclei
Off-Momentum Detectors	$0 < \theta < 5.0\ mrad$	Charged particles
B0 Detector	$5.5 < \theta < 20\ mrad$	Charged particles, tagged

Far-Backward Detectors





Selected Previous Study (2021)

$$e + p \rightarrow e' + p' + J/\Psi$$

N. Santiesteban, S. Fegan

Generator

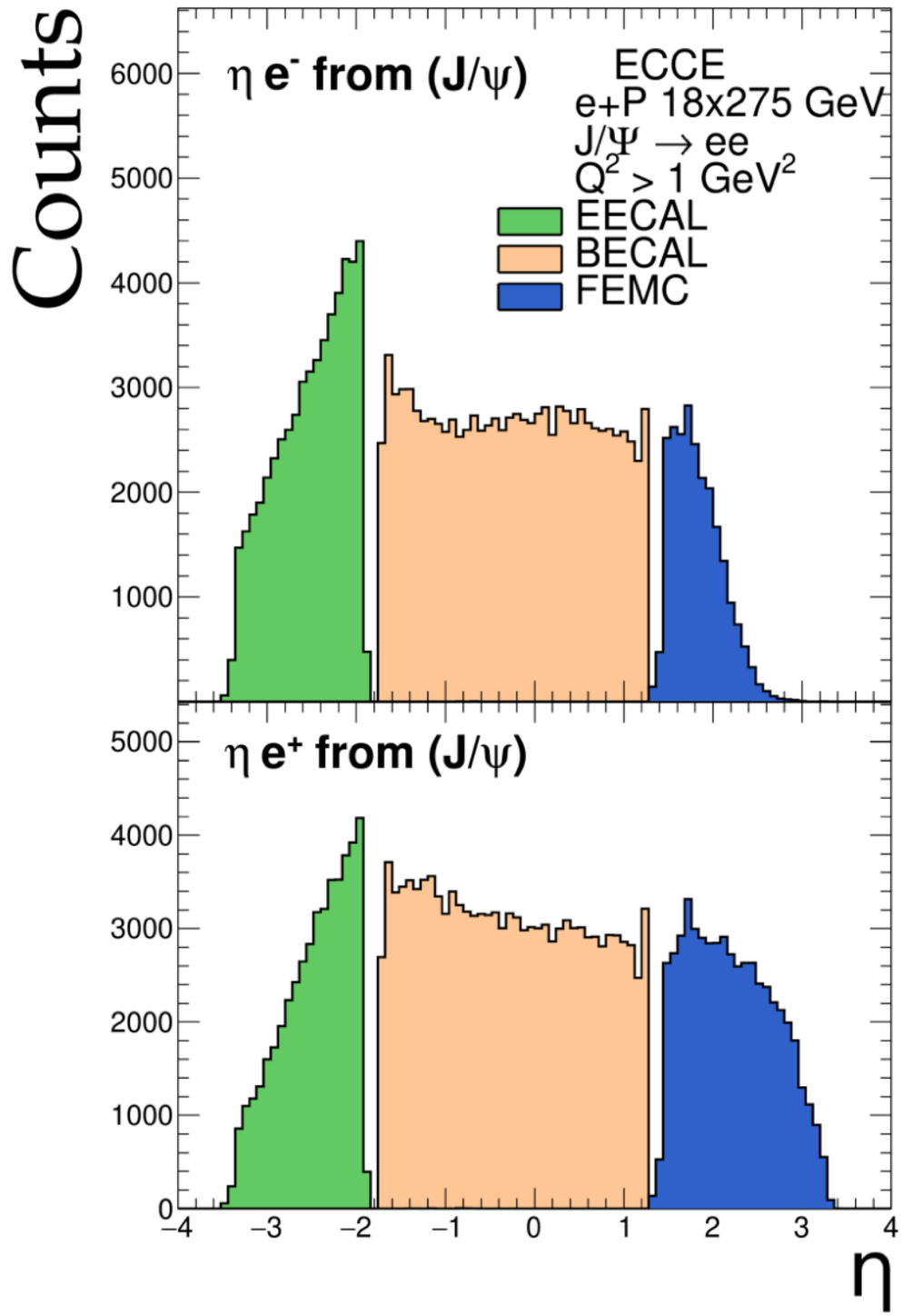
lAger - Argonne generic l/A-event generator (S. Joosten)

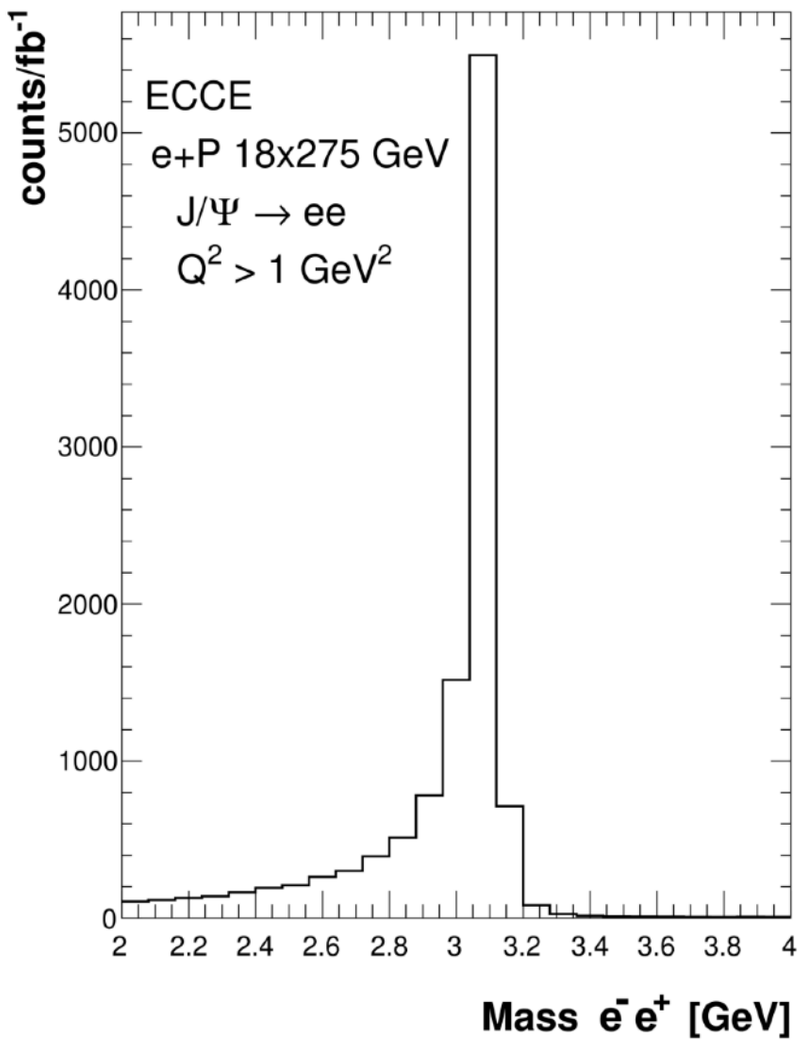
- The LAGER generator **was used to produce** event samples for the studies presented.
- Modular accept-reject generator, capable of simulating both fixed target and collider kinematics

Variable	**Definition**	**Range**
Q^2 [GeV]	$Q^2 = -q^2 = -(k_e - ke')$	0 - 50 GeV^2
x_B	$x_B = \frac{Q^2}{2 \cdot k_p \cdot q}$	0 - 0.15

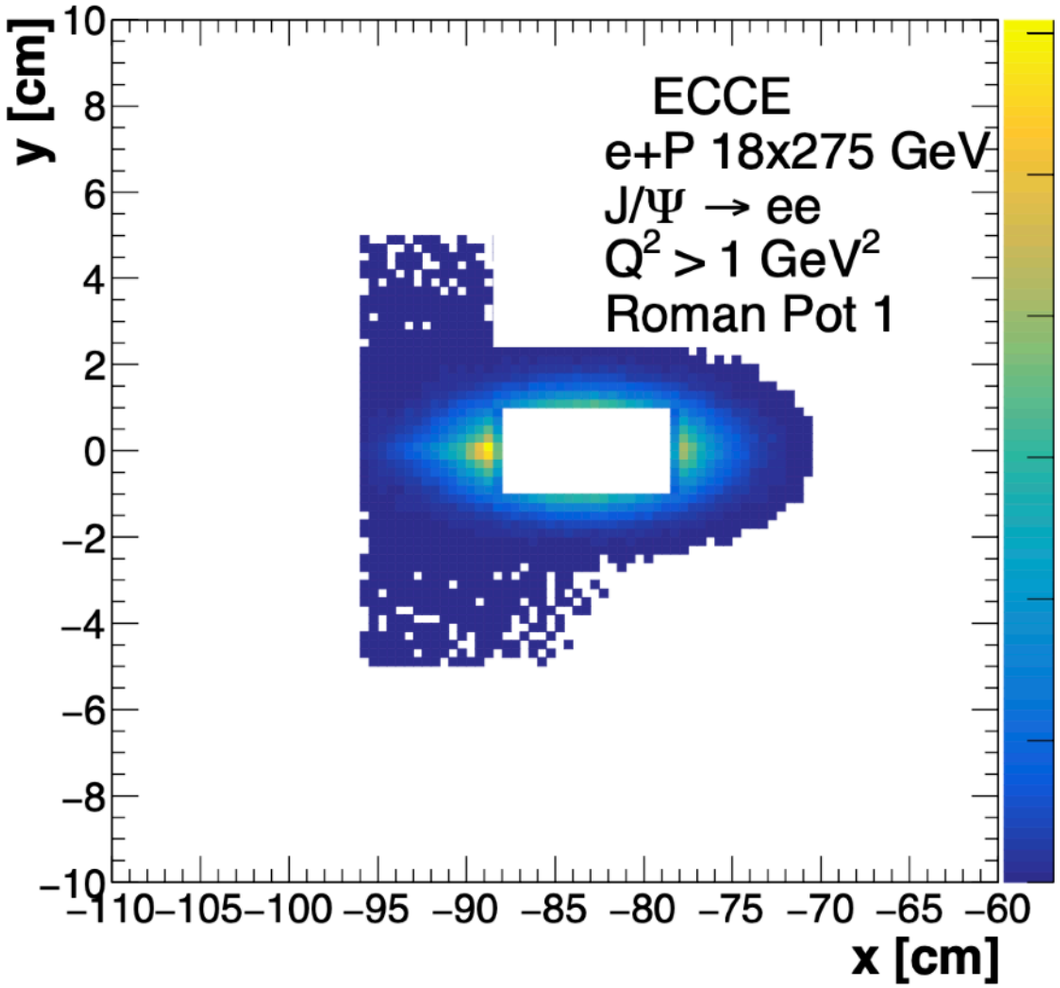
J/ψ reconstruction

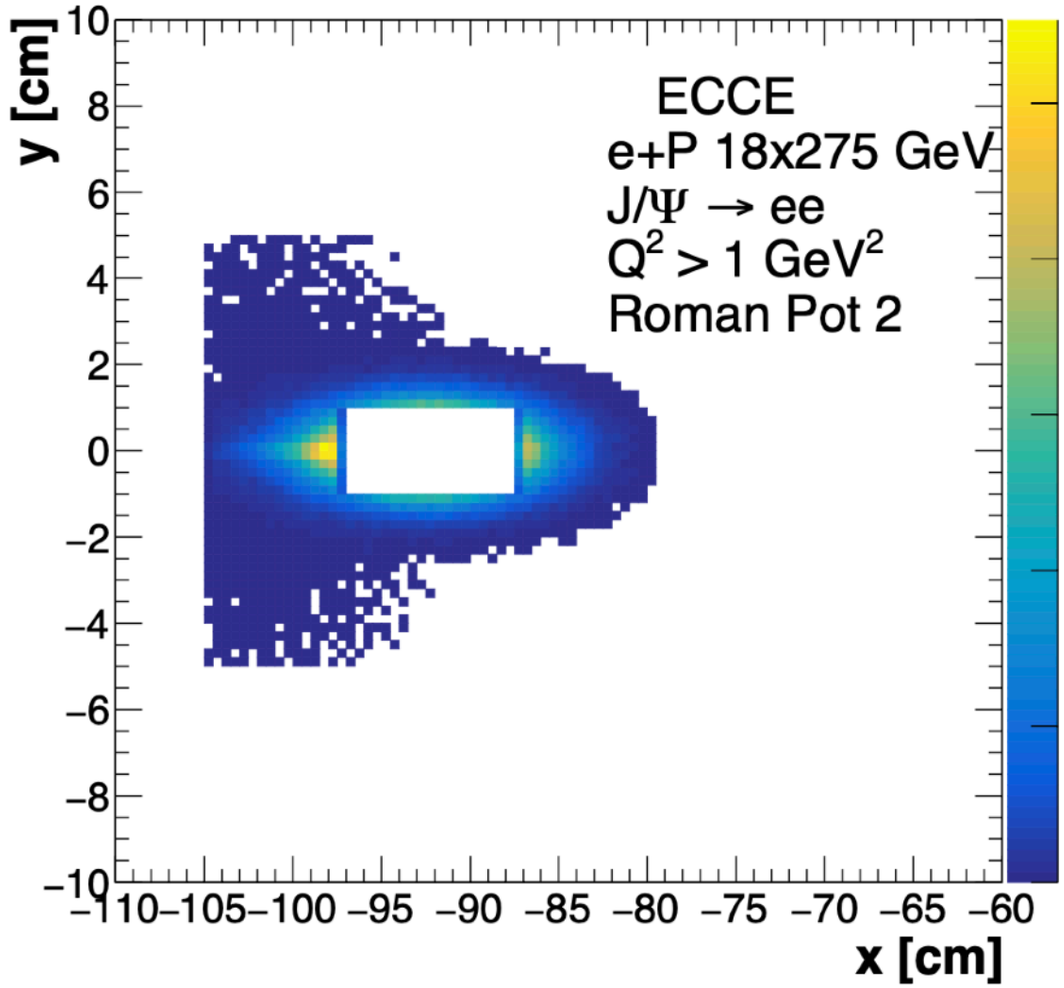
$$J/\psi \rightarrow e^+e^-$$





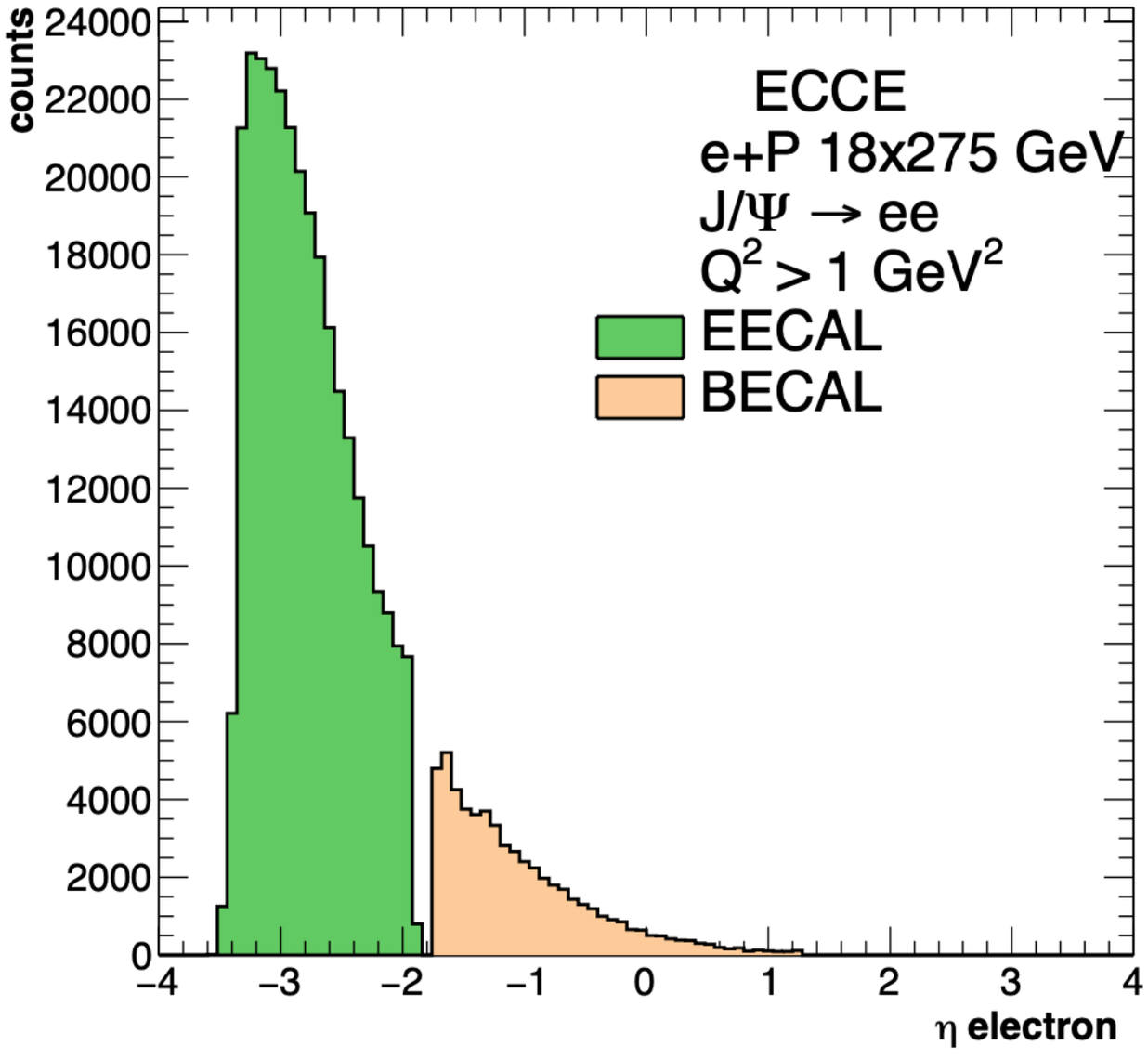
Scattered proton detection





B_0 outside acceptance of kinematics studied

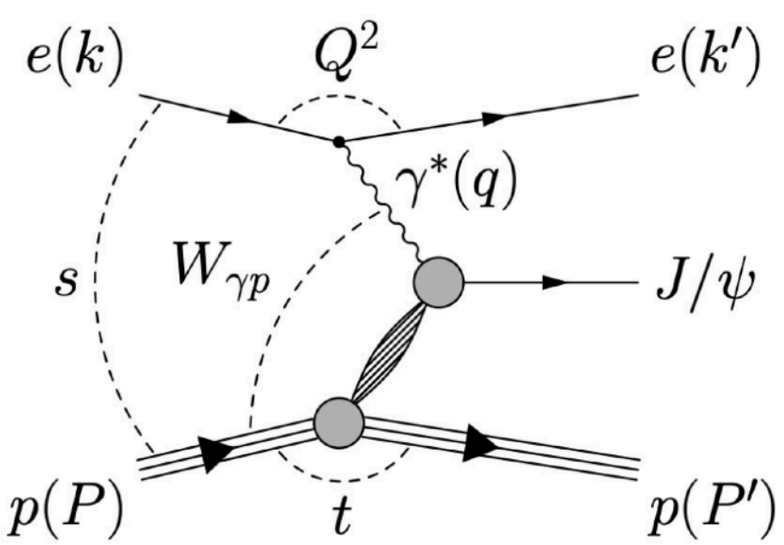
Scattered electron reconstruction



Reconstruction method of $-t$

- Method Exact (E): $-t = -(\boldsymbol{p}_e - \boldsymbol{p}_{e'} - \boldsymbol{p}_{VM})^2 = -(\boldsymbol{p}_{A'} - \boldsymbol{p}_A)^2$
- Method Approximate (A) (UPCs) $-t = (p_{T,e'} + p_{T,VM})^2$
- Method with **exclusivity corrected** (L): $-t = -(\boldsymbol{p}_{A',corr} - \boldsymbol{p}_A)^2$,

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



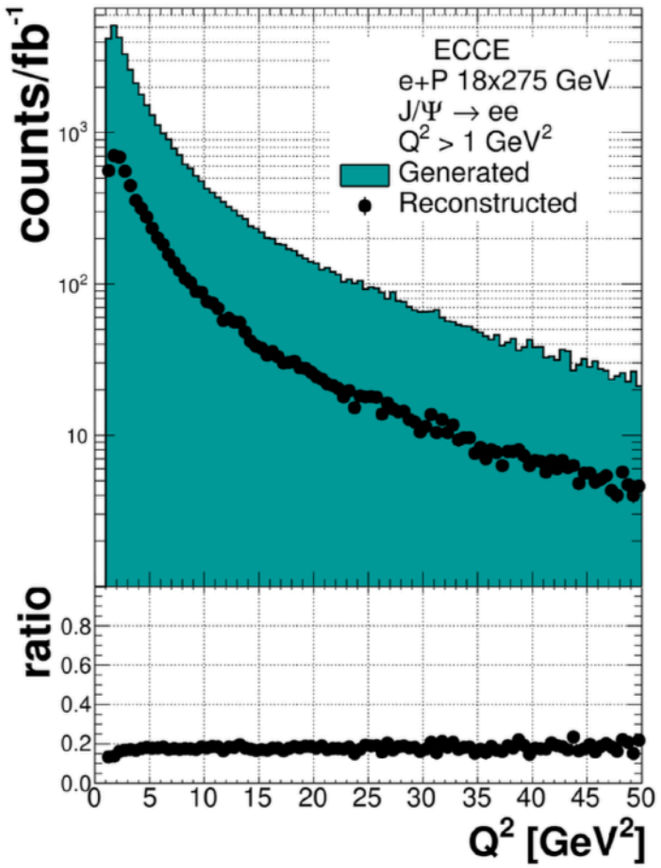
Best method concluded from the EIC Yellow Report* is with **exclusivity corrected**:

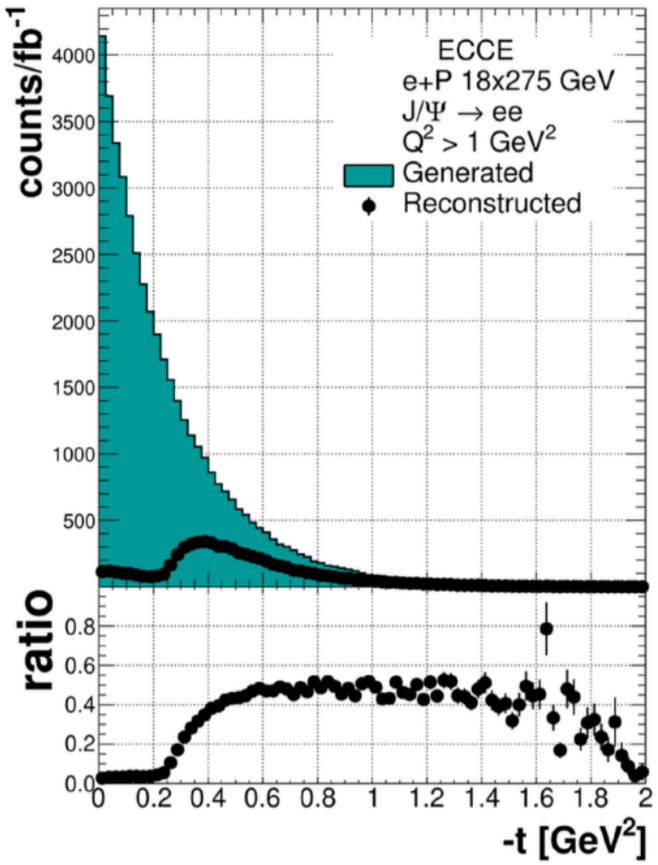
- Insensitive to beam effects, e.g., angular divergence and momentum spread.
- More precise than Method A for electroproduction

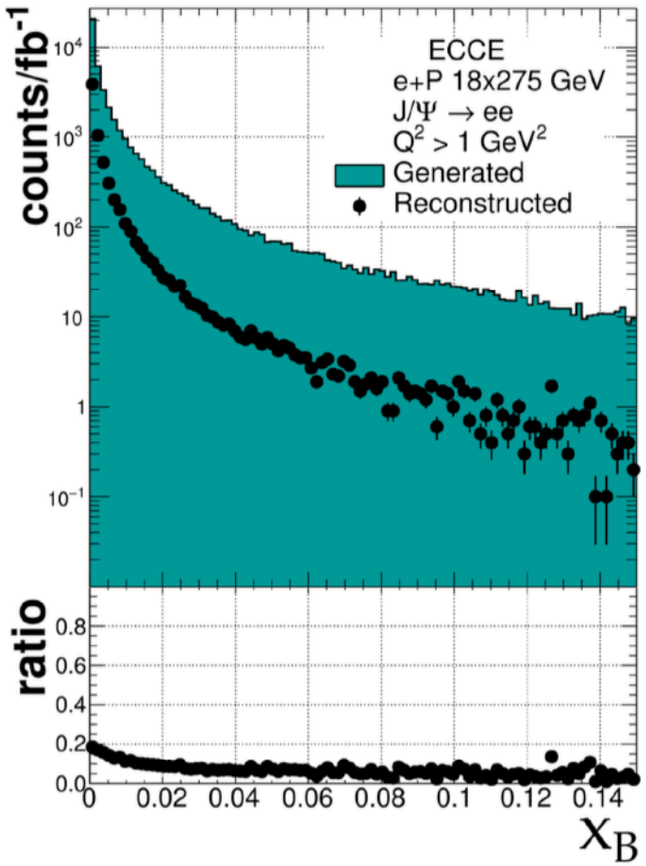
** also known as `**Method L**` in the Yellow Report*

Slide courtesy of K. Tu

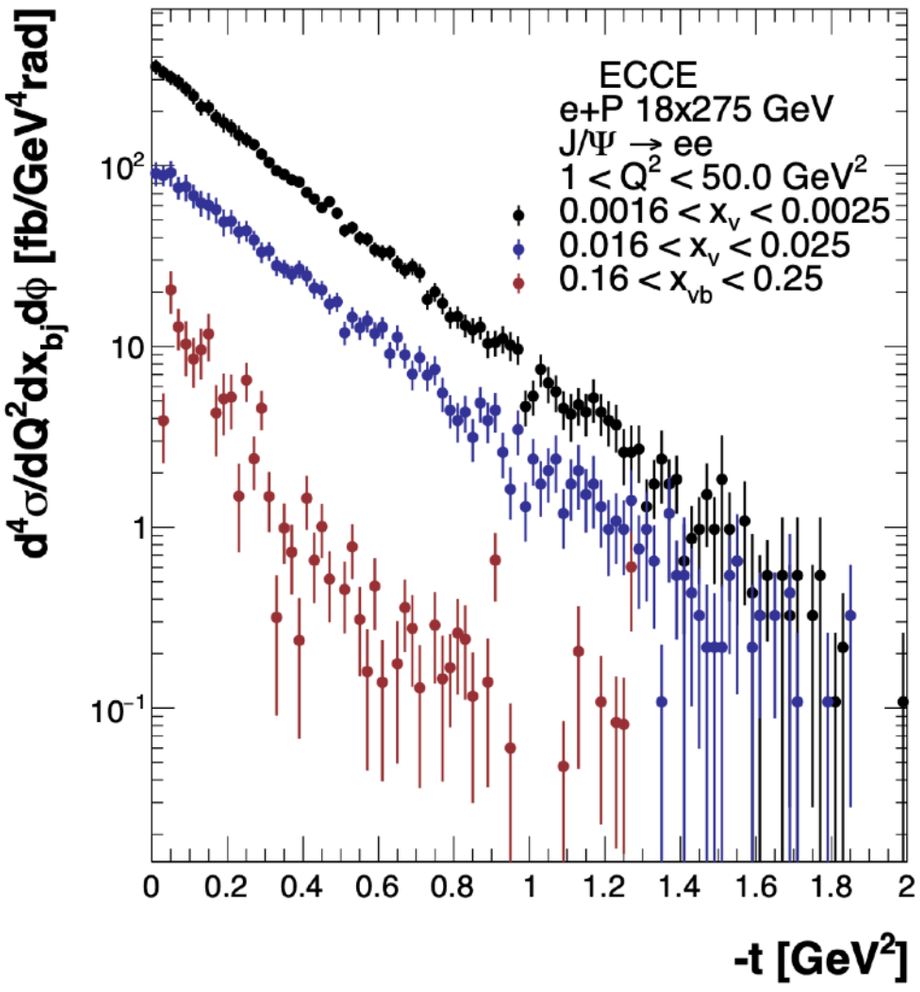
Kinematics and Resolutions







Study results



J/ψ differential cross section interest will come from the evolution over $-t$

Q^2 dependence will be useful for multi-dimensional binning

Selected Current Studies

Generator

Simulation with **eStarlight**: $e + A \rightarrow e' + A' + VM$

A: ^{16}O, ^{63}Cu, ^{90}Zr and ^{208}Pb

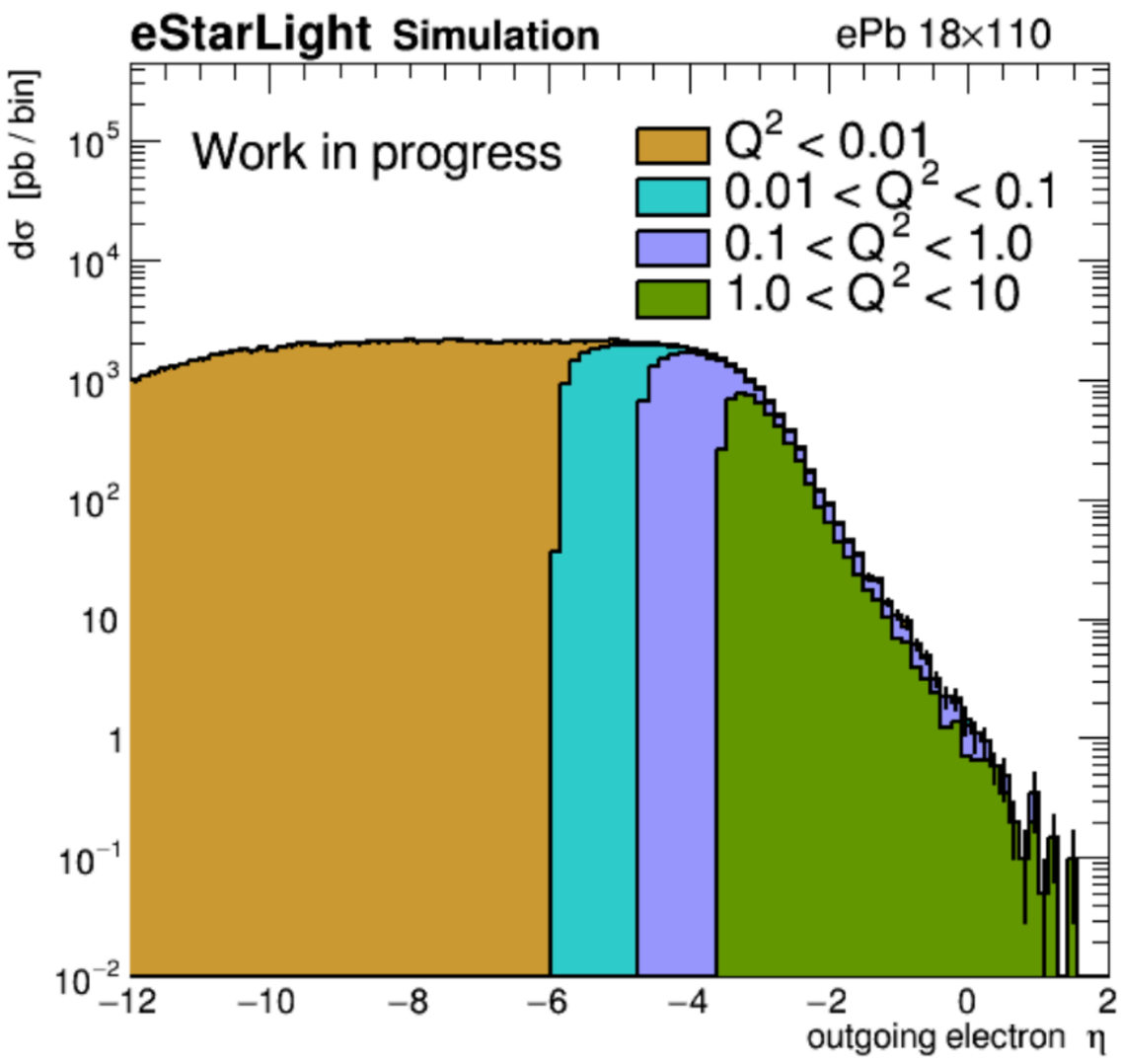
Vector mesons: ρ, J/Ψ, ϕ, ...

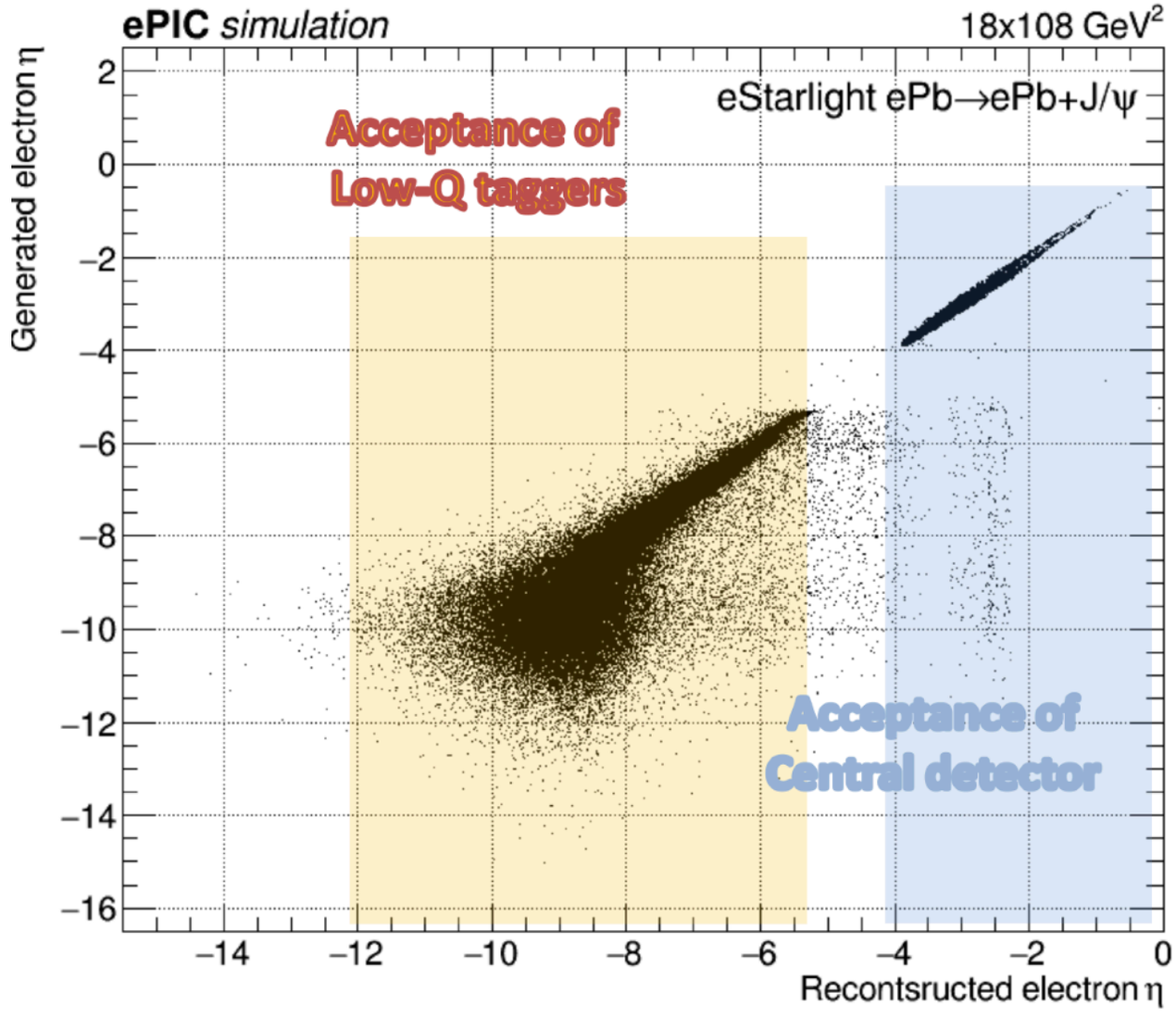
Energies: 5x100 GeV^2 and 18 x 275 GeV^2 (electron x proton)

arXiv:1803.06420
arXiv:1805.08586

Z. Citron , E. Mautner , M. Pitt

$$e + Pb \rightarrow e' + Pb' + J/\Psi$$



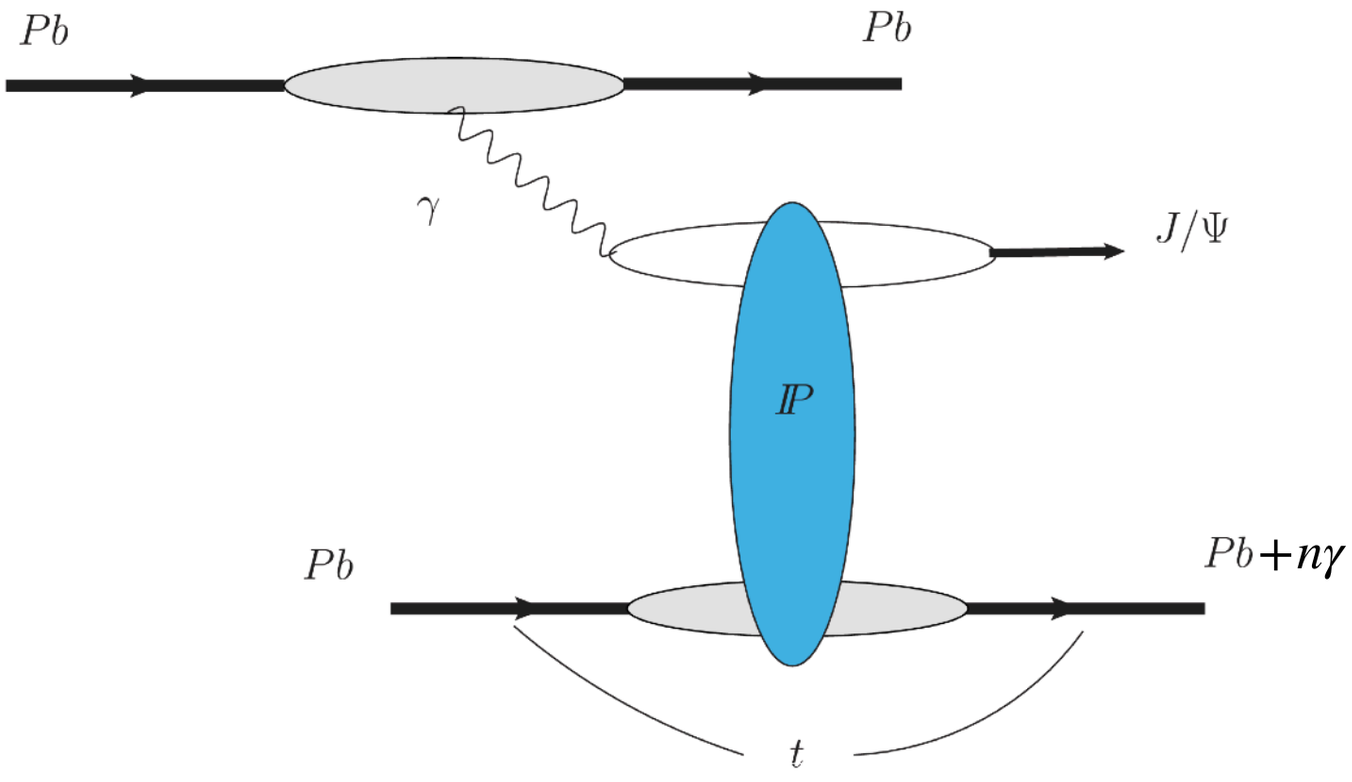


Q2 is correlated with outgoing electron rapidity.

Z. Citron , E. Mautner , M. Pitt

$$e + Pb \rightarrow e' + Pb' + J/\Psi + n\gamma$$

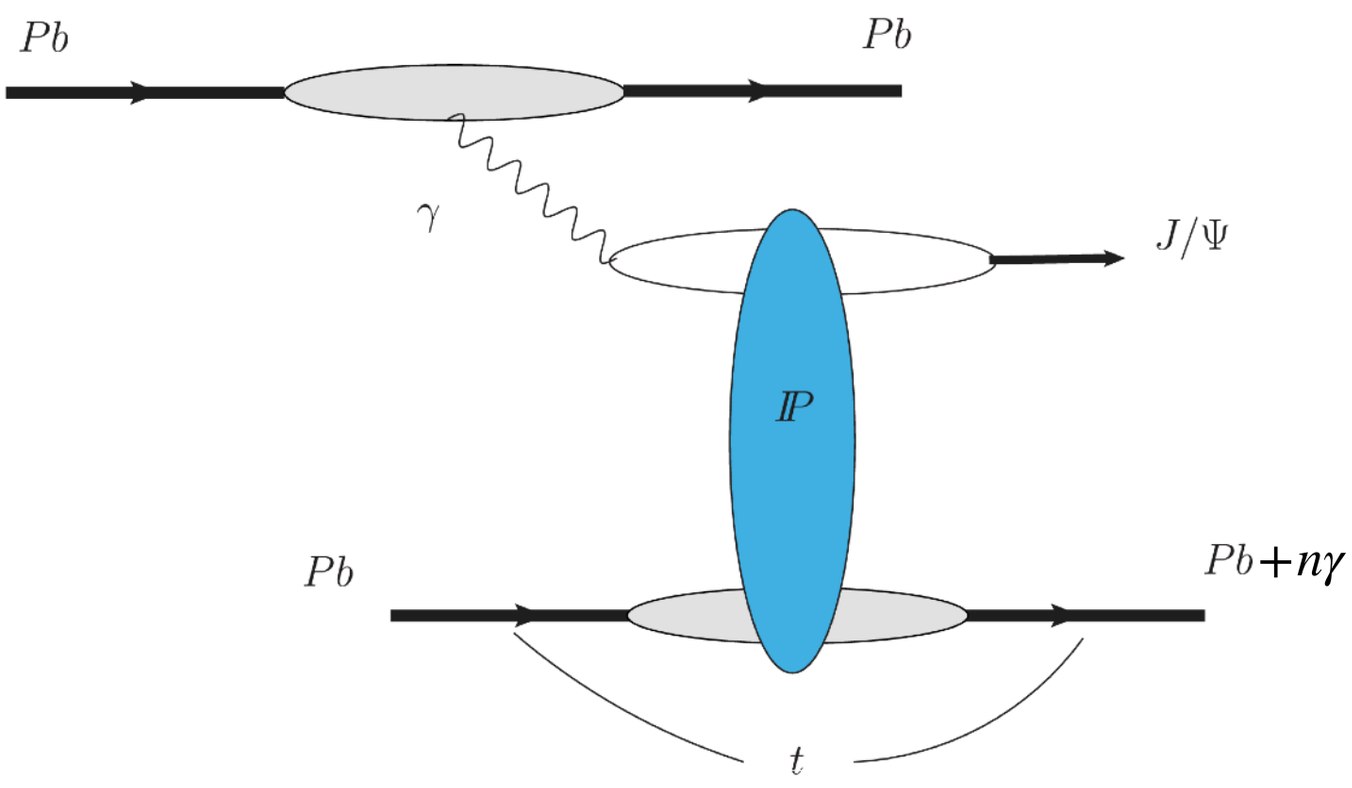
n = 1, 2, ...~6

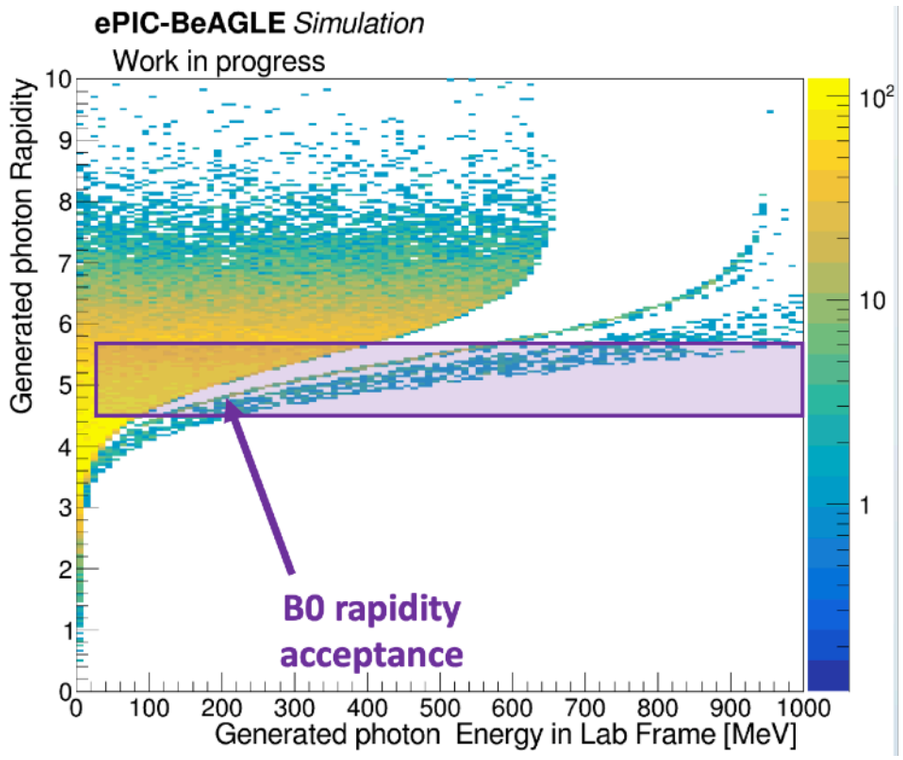


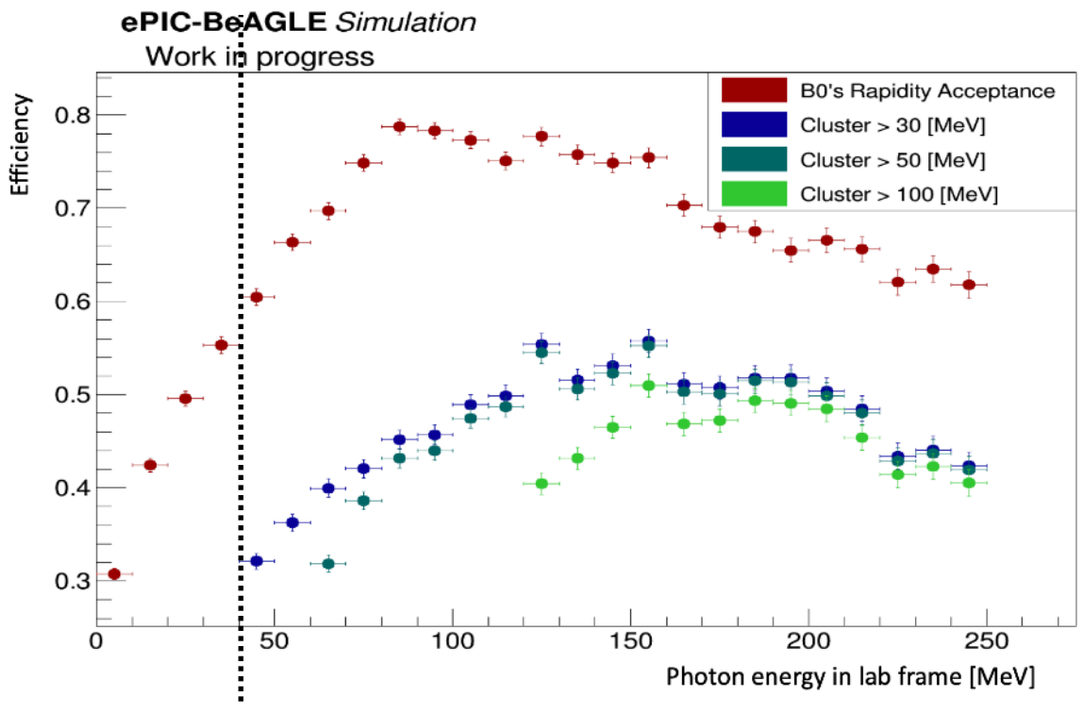
arXiv:2007.13625

Z. Citron , E. Mautner , M. Pitt

$$e + Pb \rightarrow e' + Pb' + J/\Psi + n\gamma$$ n = 1, 2, ...~6





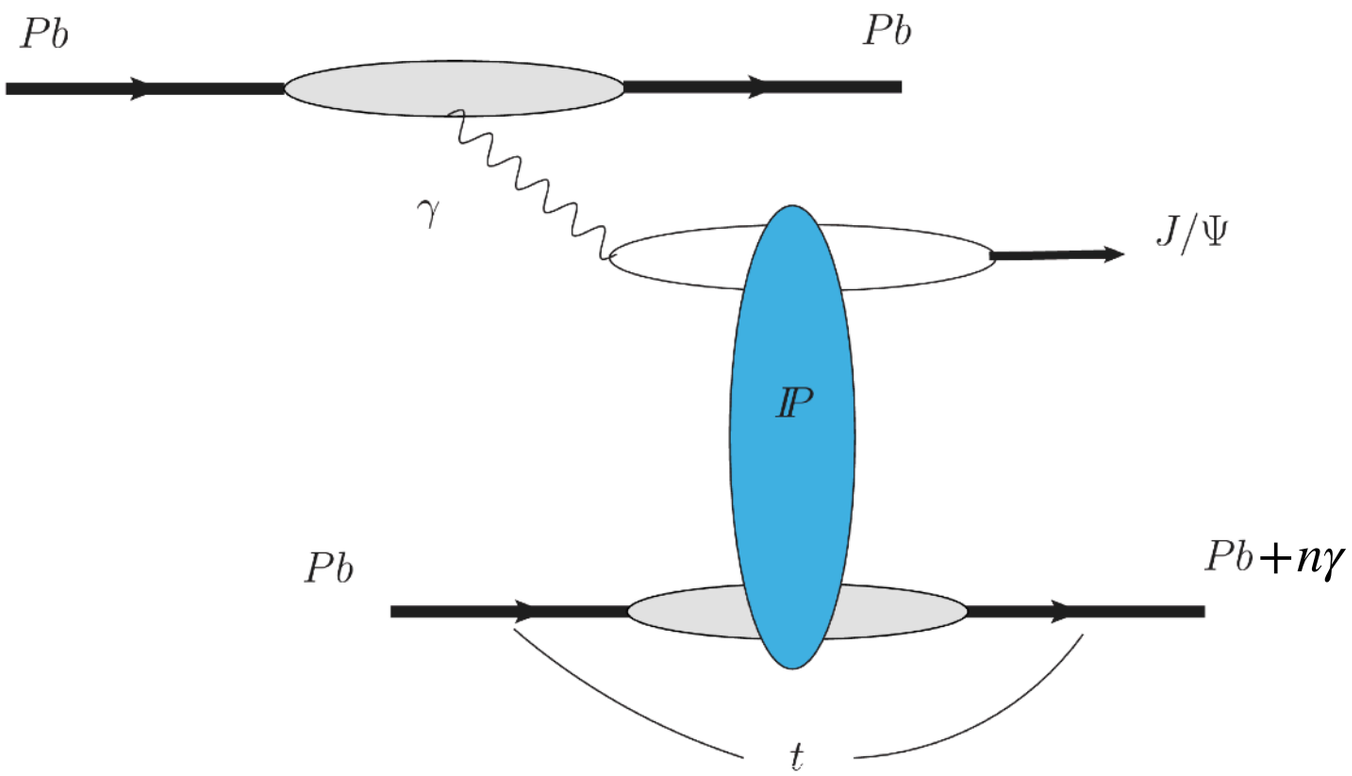


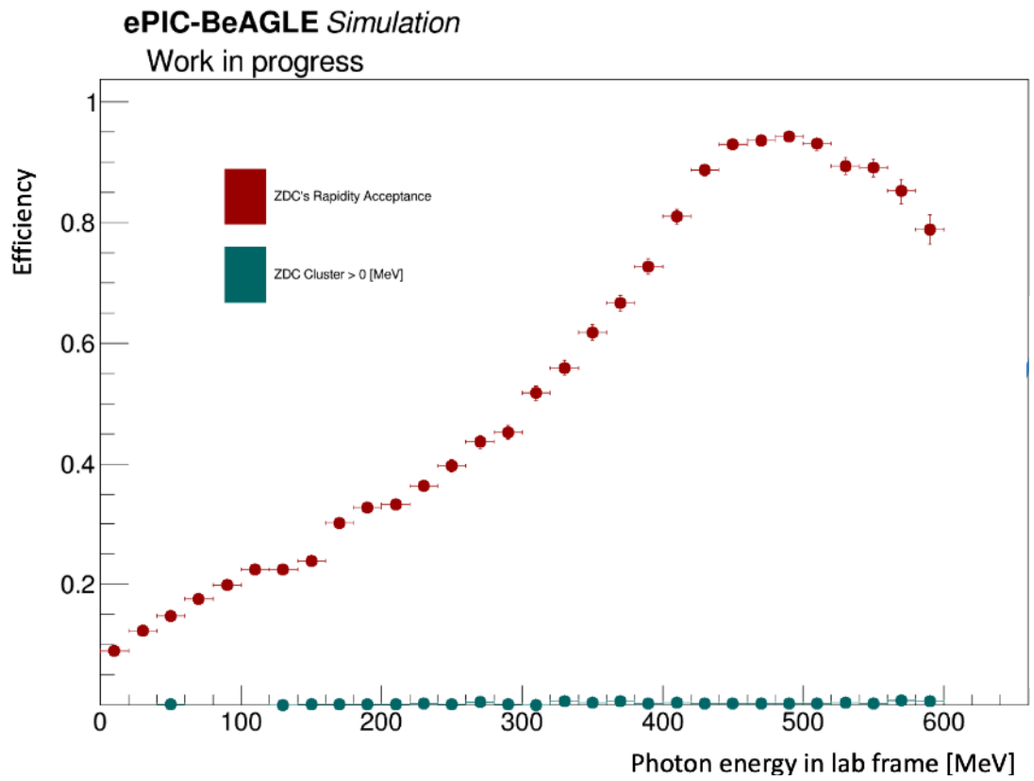
arXiv:2007.13625

Z. Citron , E. Mautner , M. Pitt

$$e + Pb \rightarrow e' + Pb' + J/\Psi + n\gamma$$

n = 1, 2, ...~6

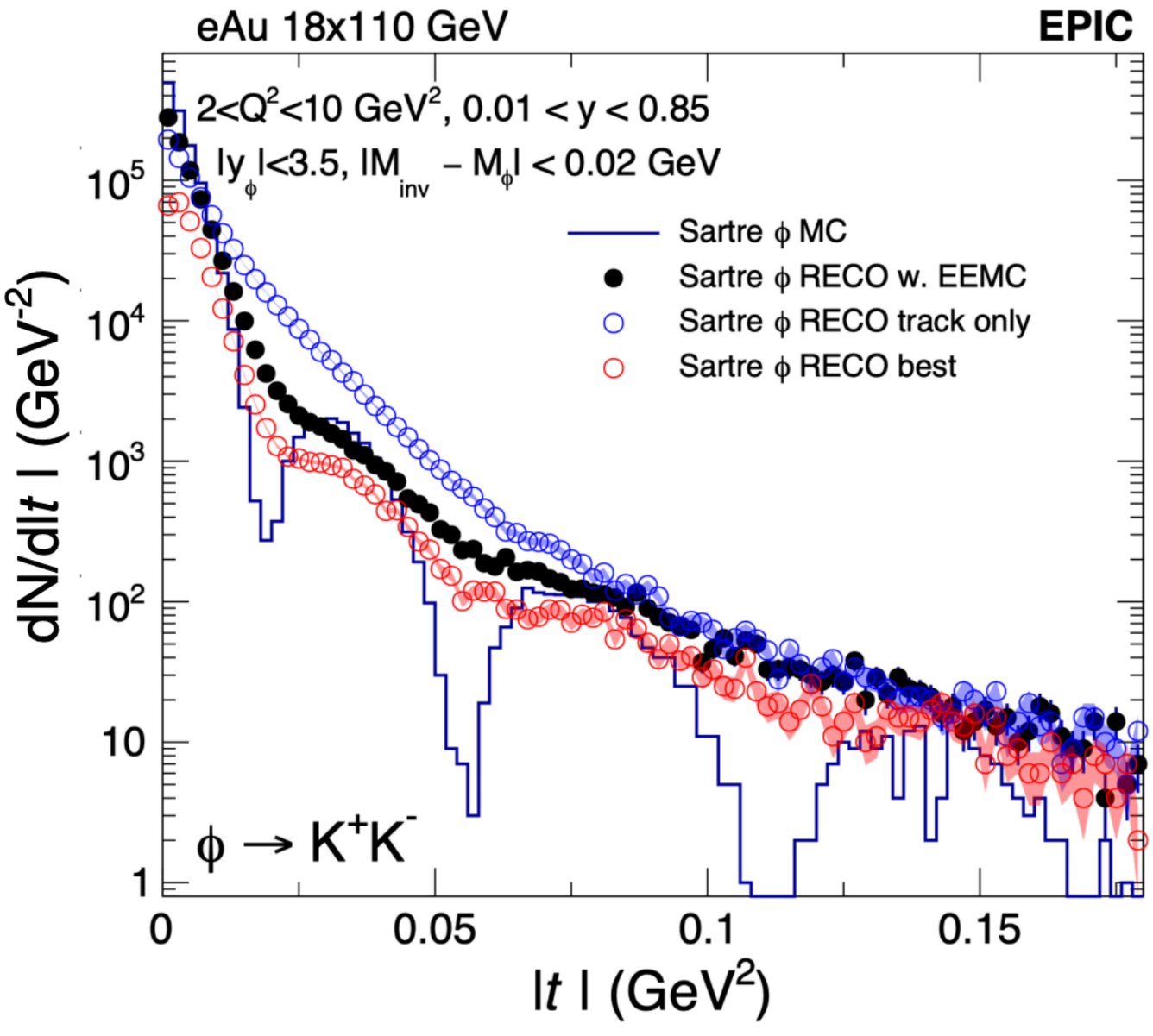




arXiv:2007.13625

Z. Citron , E. Mautner , M. Pitt

Exclusive and diffractive vector meson production



Legend details:

- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking
- Best: average of the above 2 E-by-E.

Z. Tu

Summary

- ePIC is a new collaboration formed last year to build the first EIC detector and realize the science potential of the EIC.
- ePIC simulations are ongoing with unified and modern software framework. Next:
  - Continue exclusive vector meson simulations (ongoing efforts on software and reconstruction)
    - Incoherent background, where the nucleus breaks up. Veto on far-forward particles.
- Far-forward physics characterized by exclusive reactions.
- Far-Backward can help to tag coherent processes at very low Q
- This work is part of the Exclusive, Diffractive and Tagging working group, one of the physics working groups in the ePIC collaboration