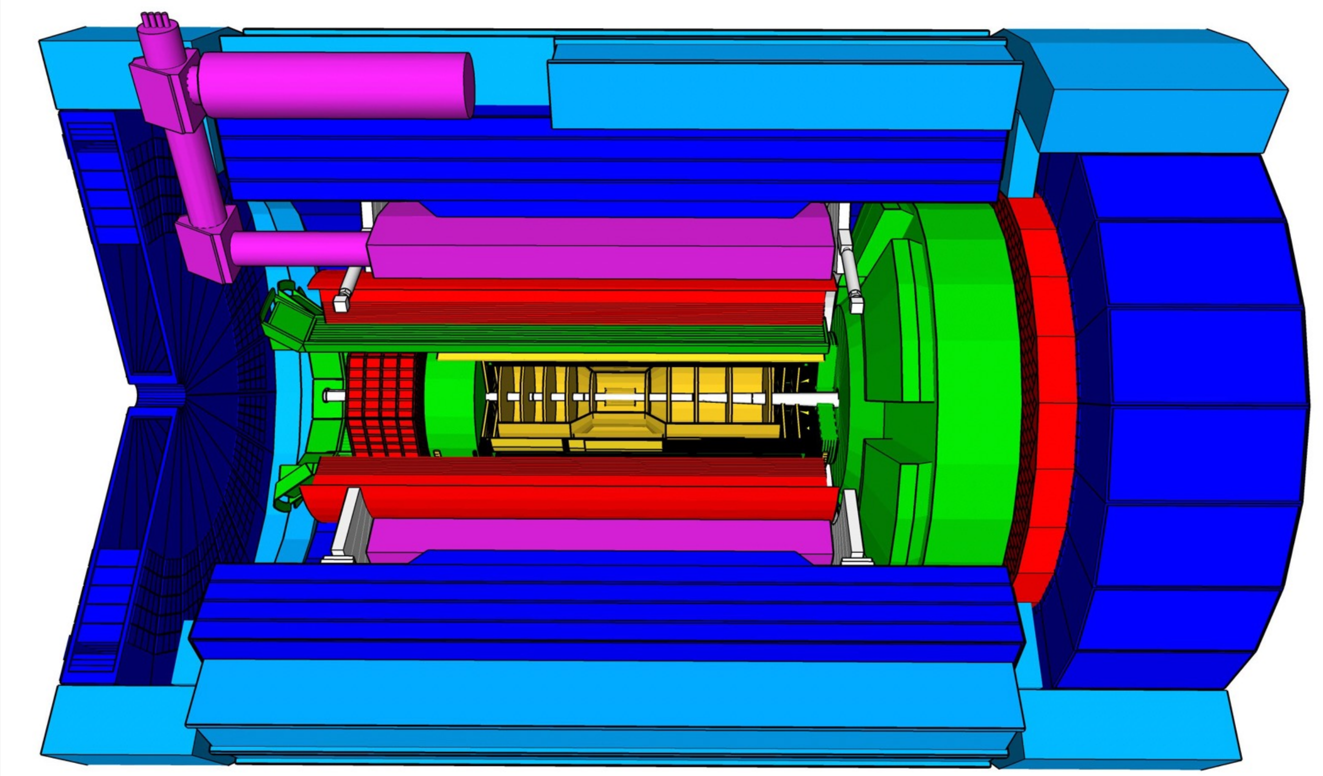
Vector Meson (Photo)production at the EIC

ePIC detector



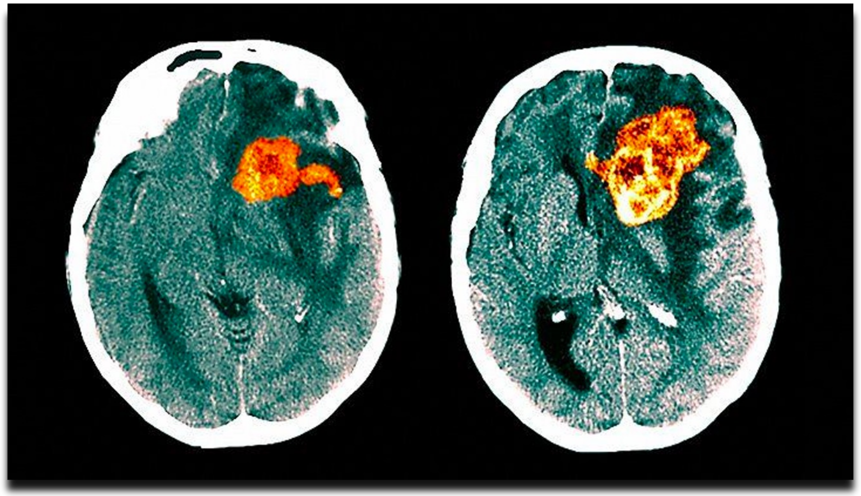
- Kong Tu, BNL

Seeing is believing - the power of *imaging*

38 billion km (~10^{12}m)

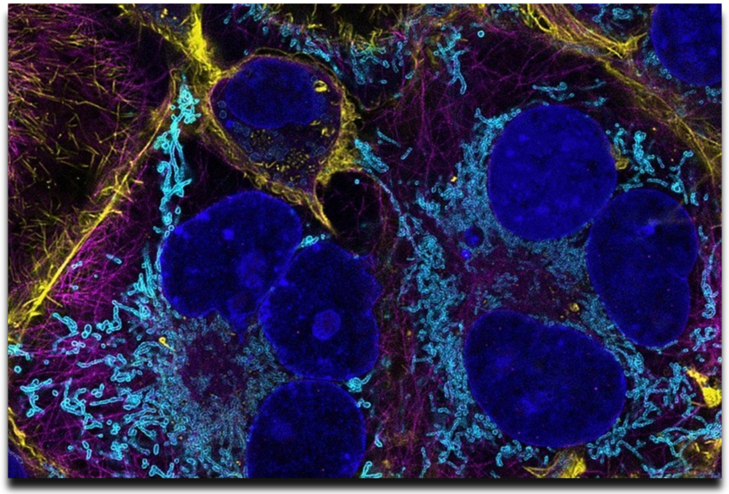
First-ever image of a black hole - *Event Horizon Telescope*

a few centimeter (~10^{-2} m)



CT scan sequence of a patient with a *glioblastoma*.

10-100 nanometer (~10^{-9} m)



3D images of myelin - the insulation coating our nerve fibres

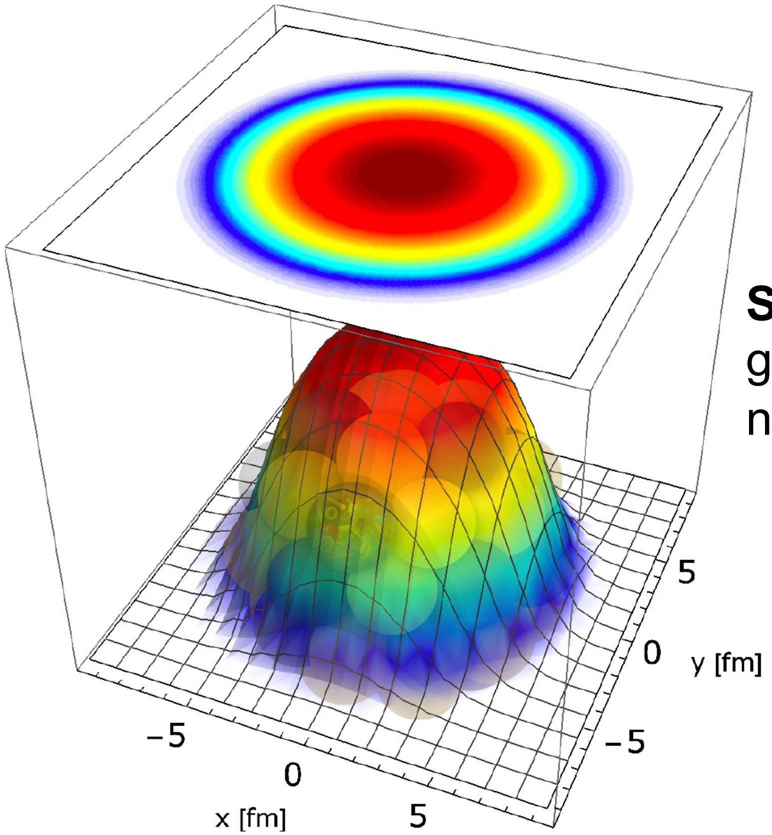
Astronomical scale → microscopic scale

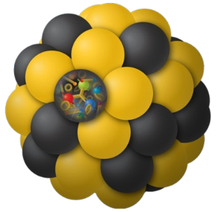
Imaging: one of the most convincing scientific methods to understand our nature!

Gluon spatial distribution of heavy nuclei

Understanding how the **gluons are distributed in nuclei** will significantly advance our understanding:

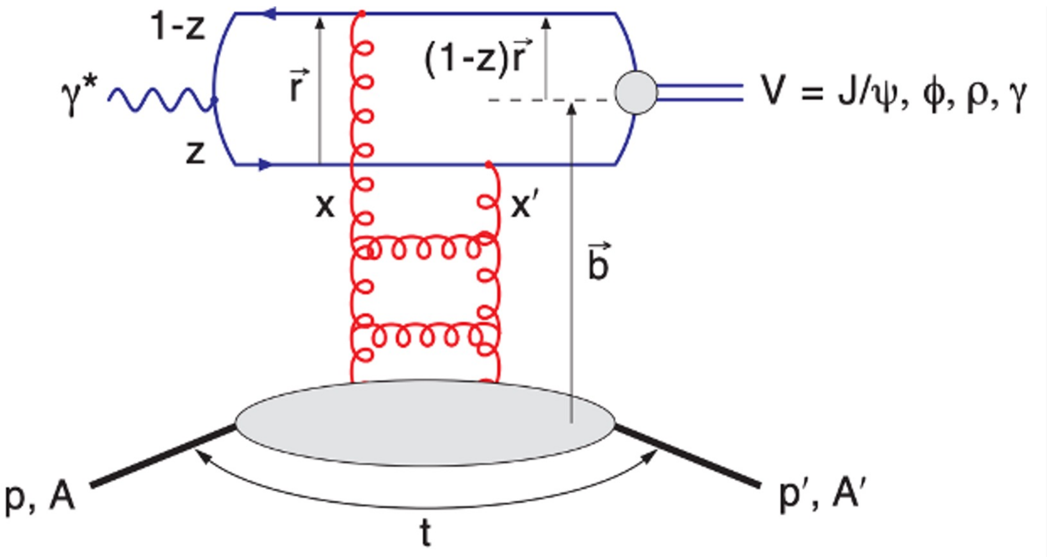
- Nuclear `binding` in high energy where gluons are dominated.
- Probing gluon **saturation dynamics** in terms of gluon spatial distribution.
- Nuclear matter radius vs charge radius.





Sartre model:
gluon density profile in gold nucleus (made by A. Kumar)

Exclusive and diffractive vector meson production



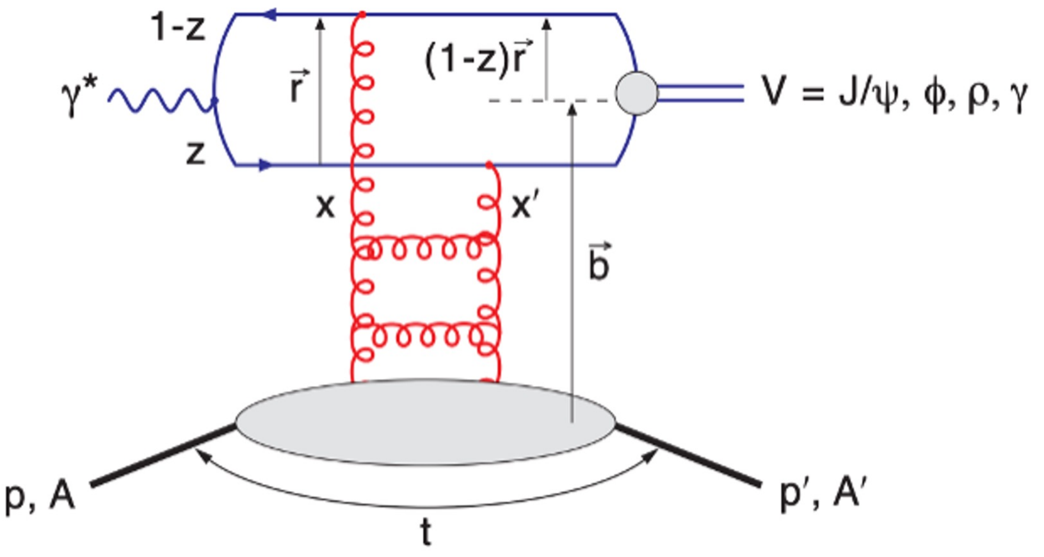
At NLO, things may look differently [arXiv:2203.11613]

Momentum (*t*) and position (*b*) are conjugate variable, and can be related by Fourier Transform:

$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\Delta \Delta J_0(\Delta b)\sqrt{\frac{\mathrm{d}\sigma_{\mathrm{coherent}}}{\mathrm{d}t}(\Delta)}\Bigg|_{\mathrm{mod}}$$

$$\Delta = \sqrt{-t}$$

Exclusive and diffractive vector meson production



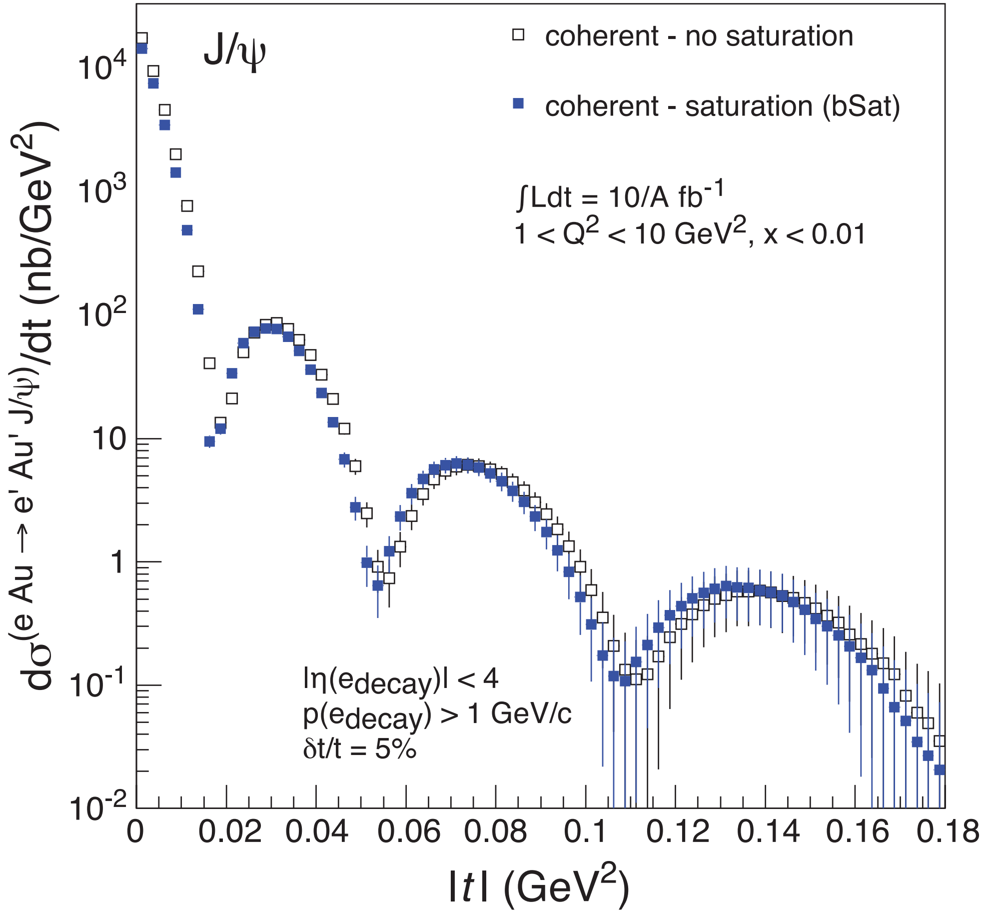
At NLO, things may look differently [arXiv:2203.11613]

Coherent (target stays intact)	Incoherent (target breaks up)
Average nuclear parton density	Event-by-Event parton density fluctuations
Momentum transfer (t) and transverse spatial position (b) are Fourier transforms of each other;	

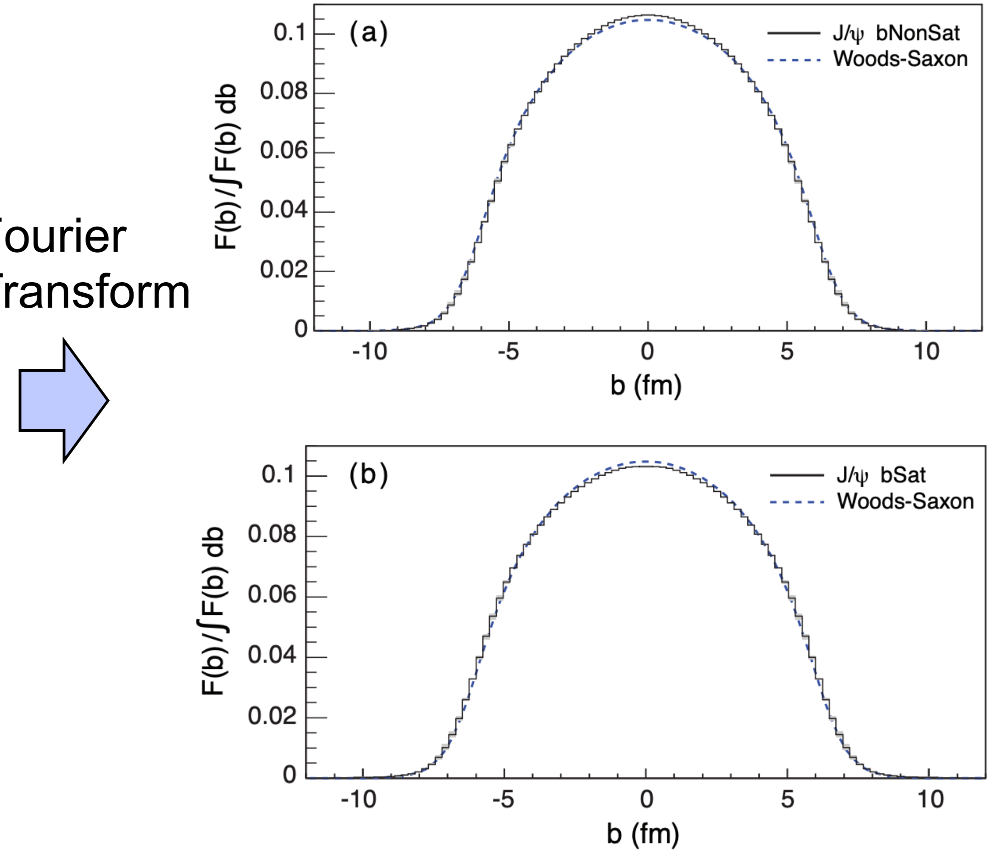
A sensitive probe to the gluon density, spatial distributions, and their fluctuations.

EIC White Paper: golden channel

EIC WP, Toll & Ullrich (2012)



Fourier Transform

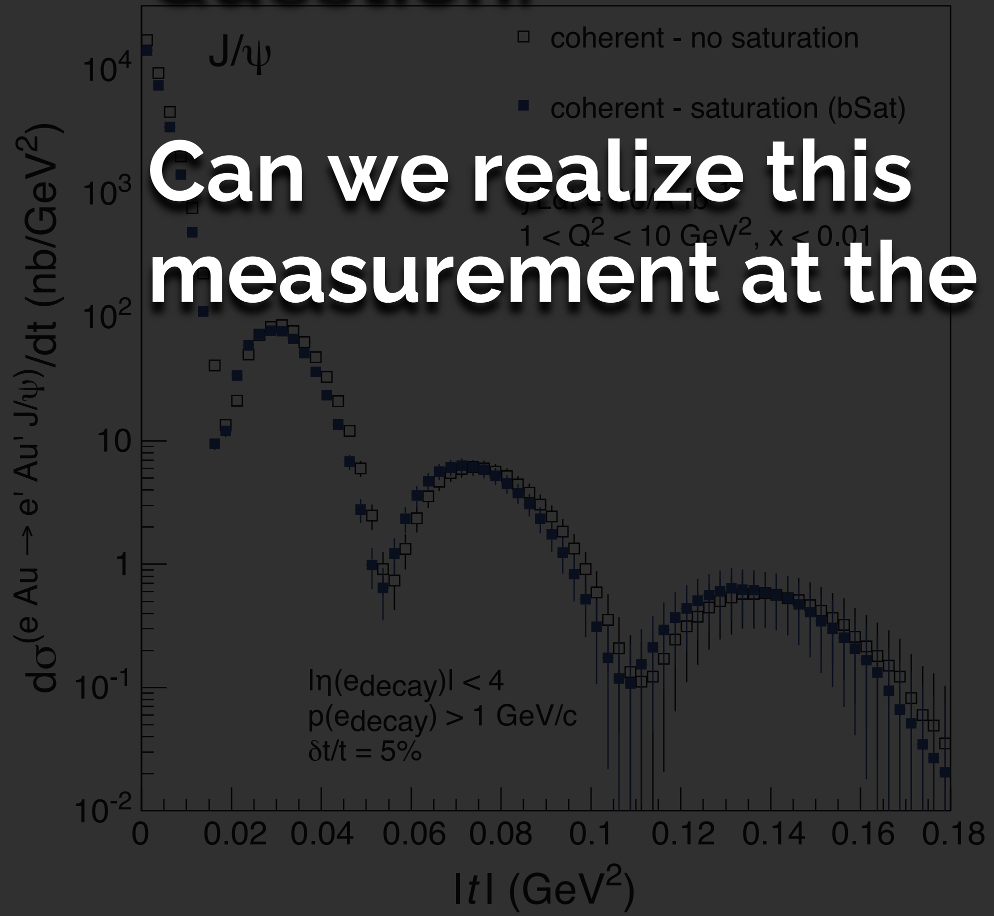


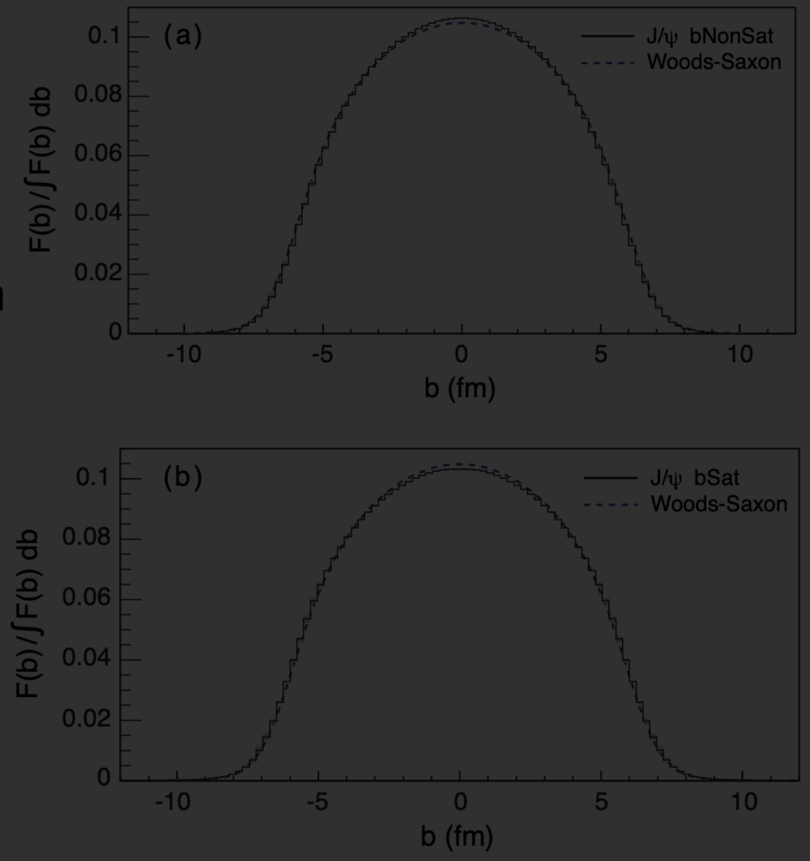
EIC White Paper: golden channel

EIC WP, Toll & Ullrich (2012)

Question:

Can we realize this measurement at the EIC?

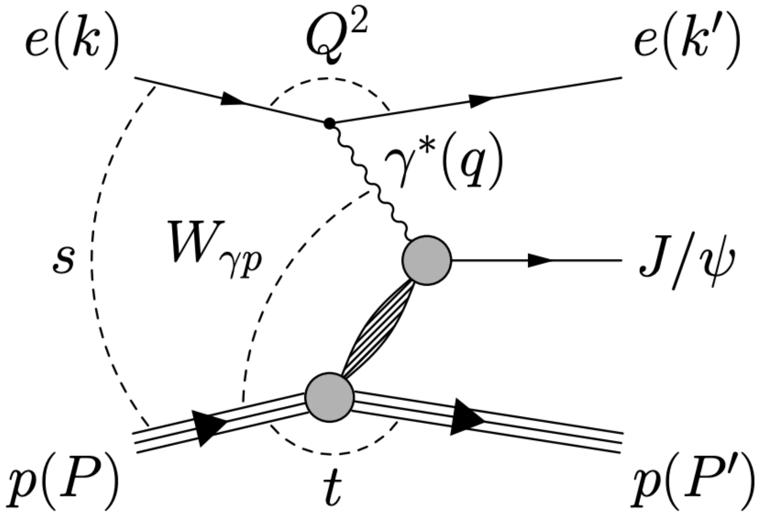




Reconstruction method of *-t*

- 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.

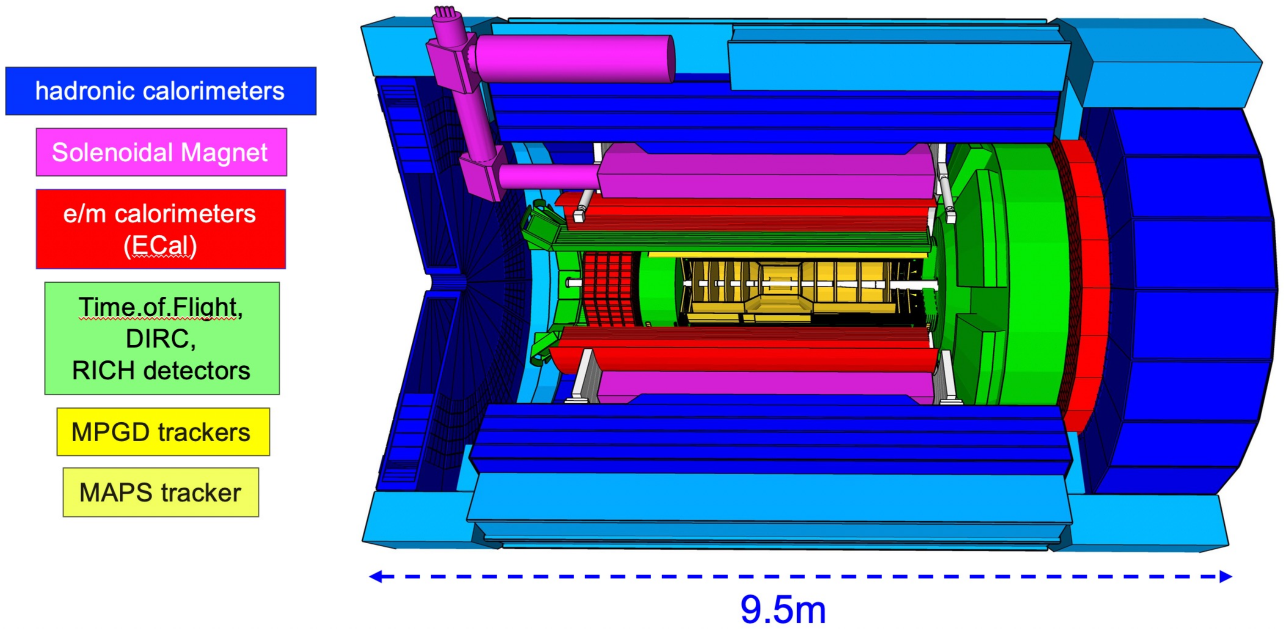


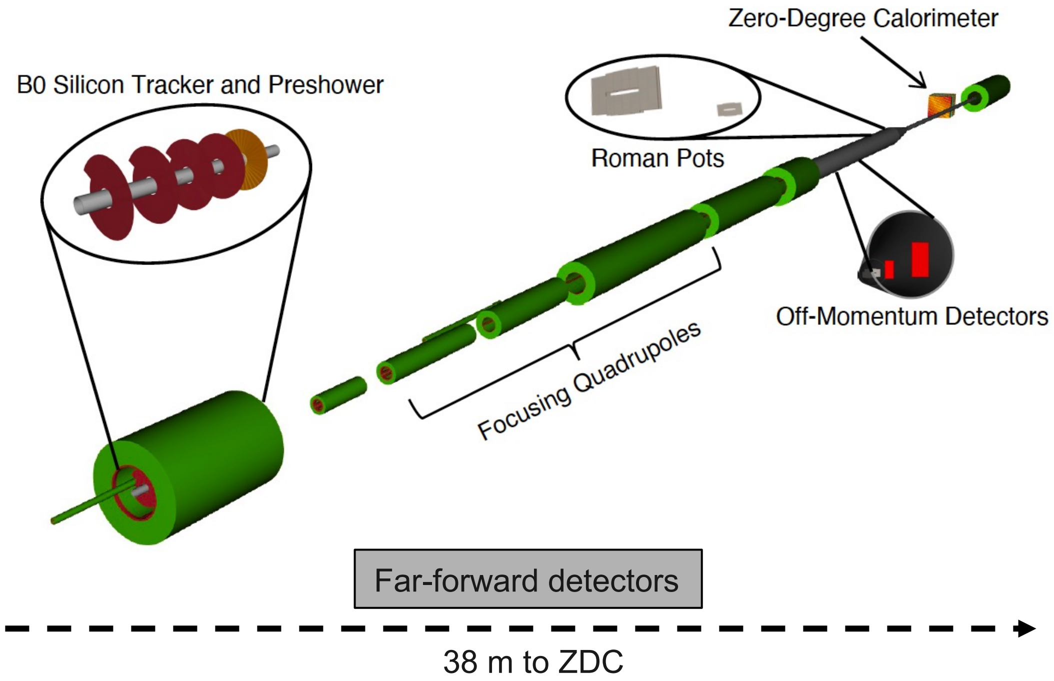
Best method concluded from the EIC Yellow Report* is with **exclusivity corrected**:

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

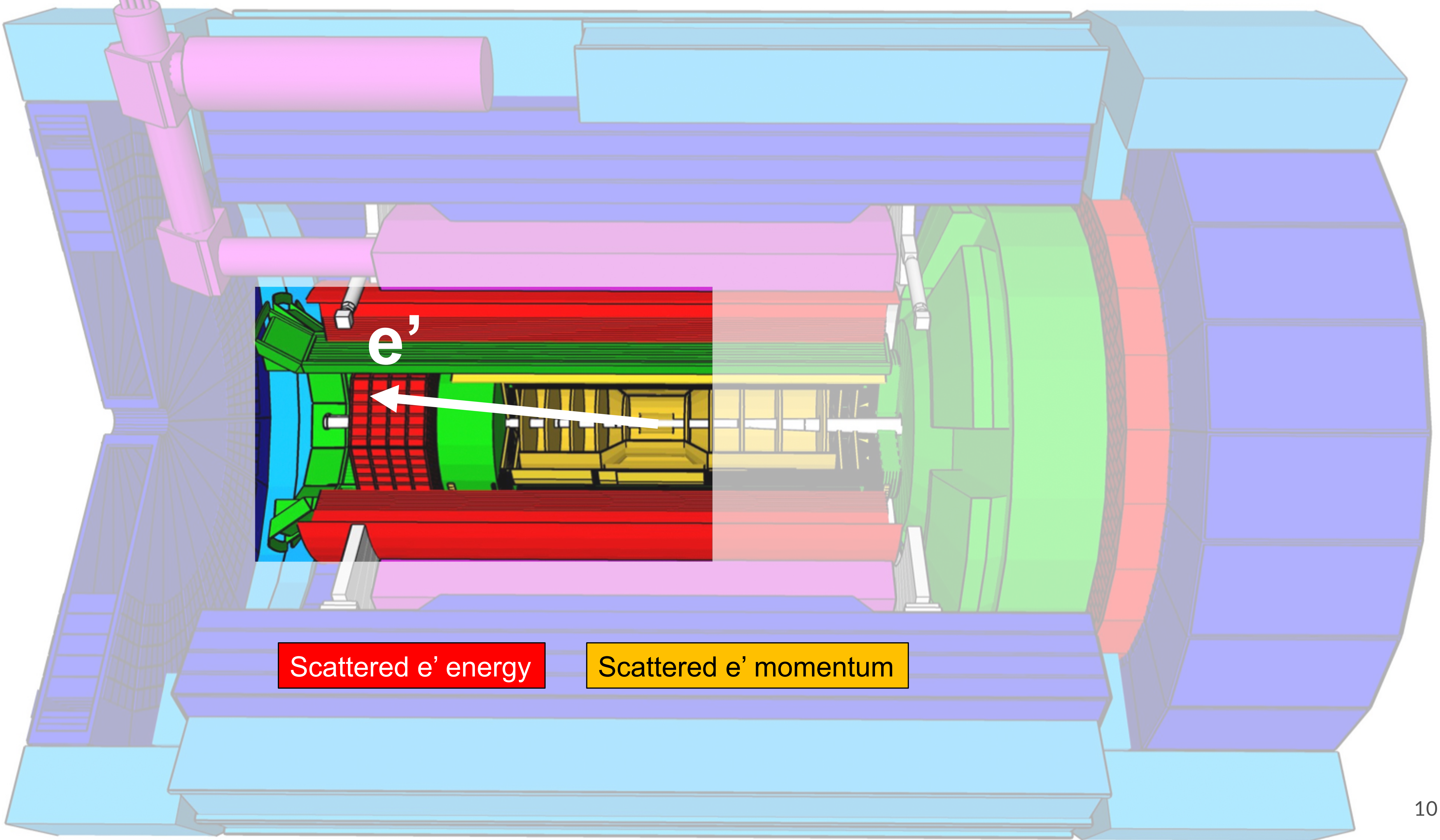
** also known as `**Method L**` in the Yellow Report*

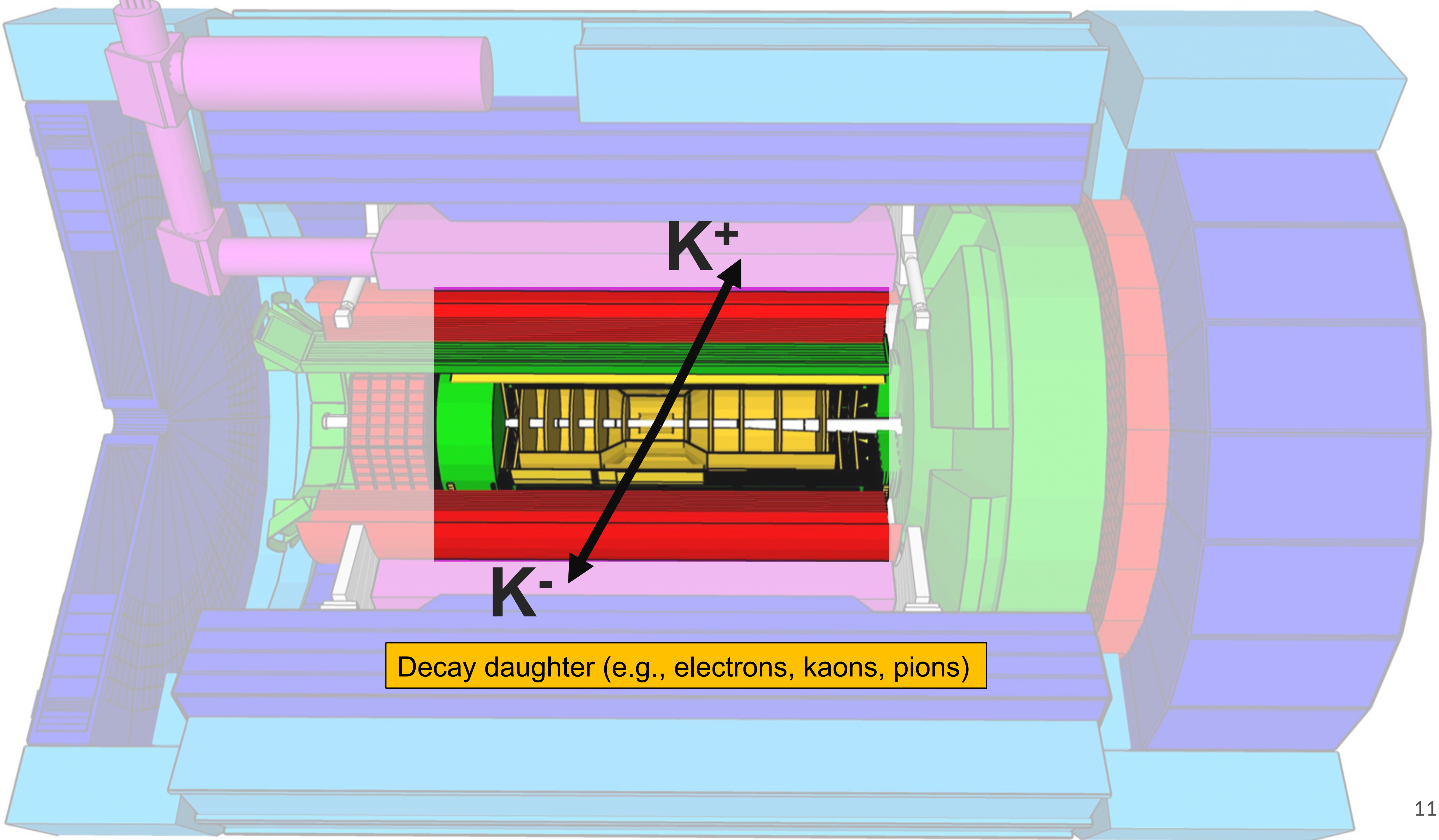
How to measure exclusive VMs in ePIC?



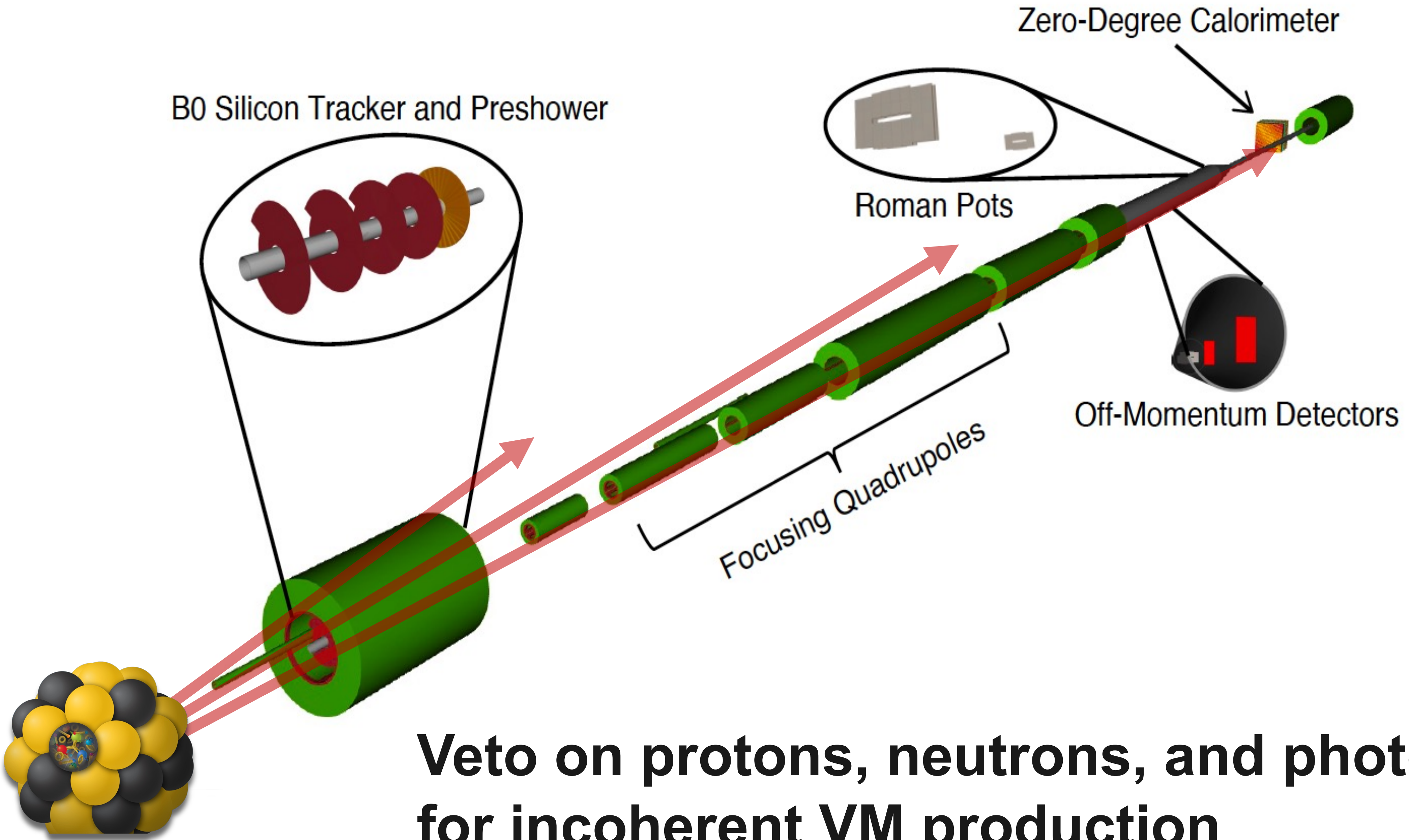


See Yulia Furletova's talk earlier for details


e’
Scattered e’ energy
Scattered e’ momentum



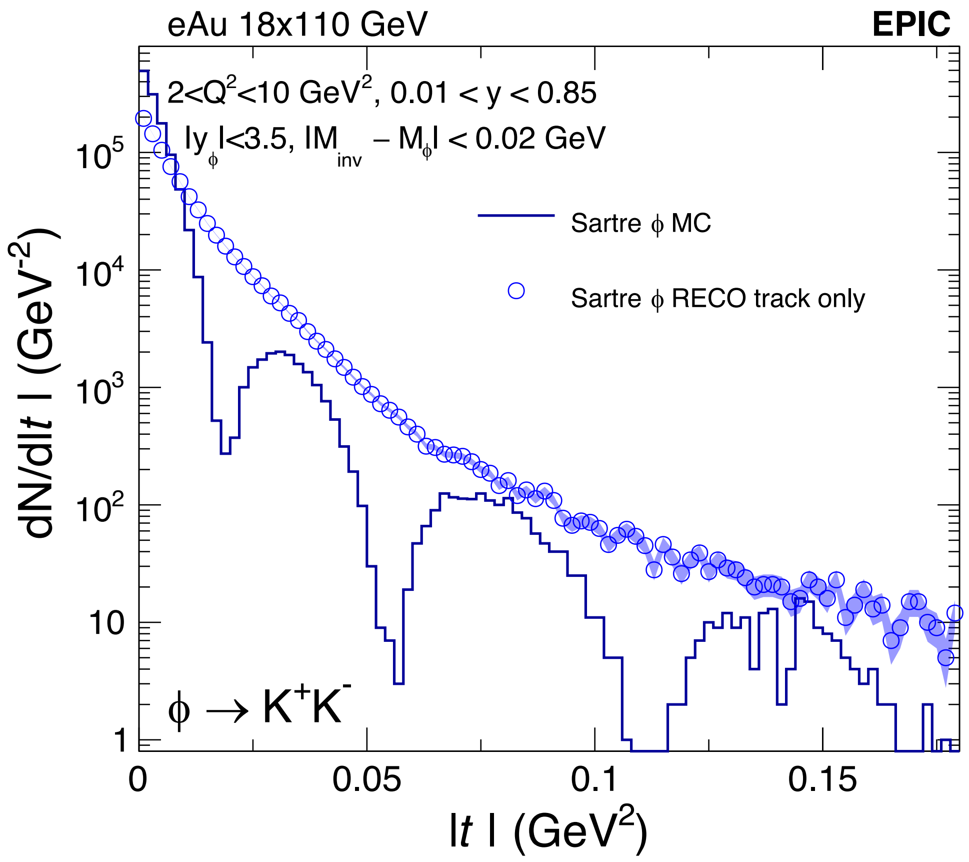
K+
K-
Decay daughter (e.g., electrons, kaons, pions)



Veto on protons, neutrons, and photons for incoherent VM production

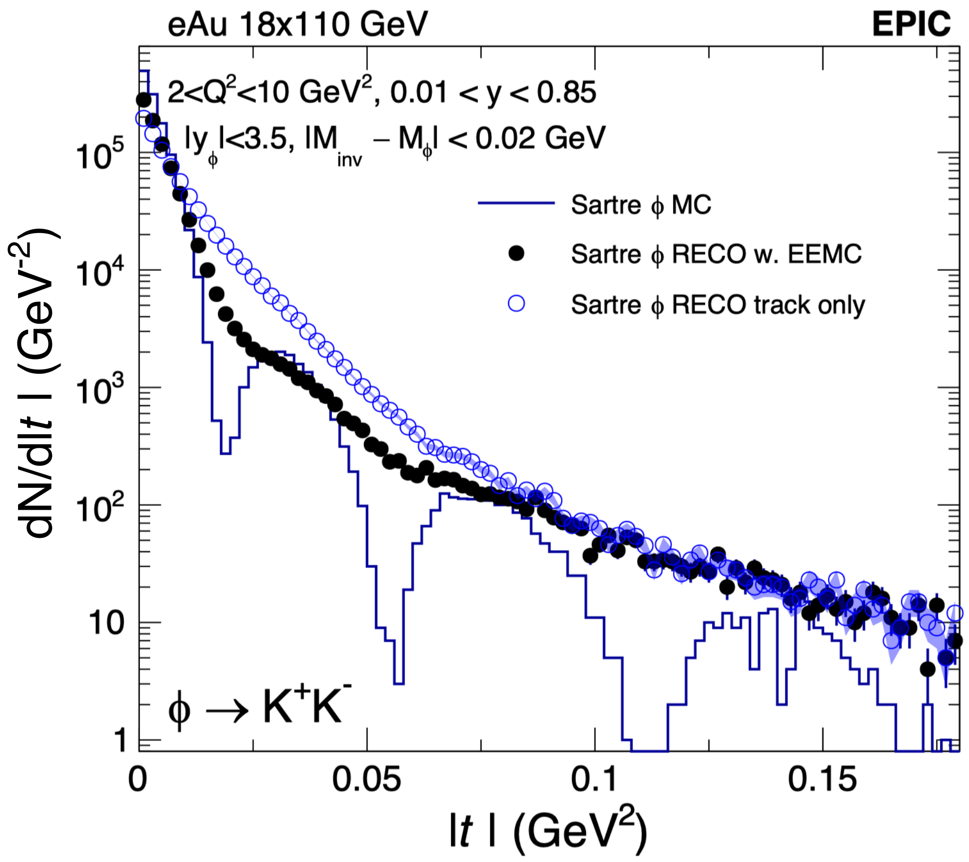
Result – with tracking only

Legend details:
- Track only: e', φ→KK, all from tracking



Result – tracking + calorimetry

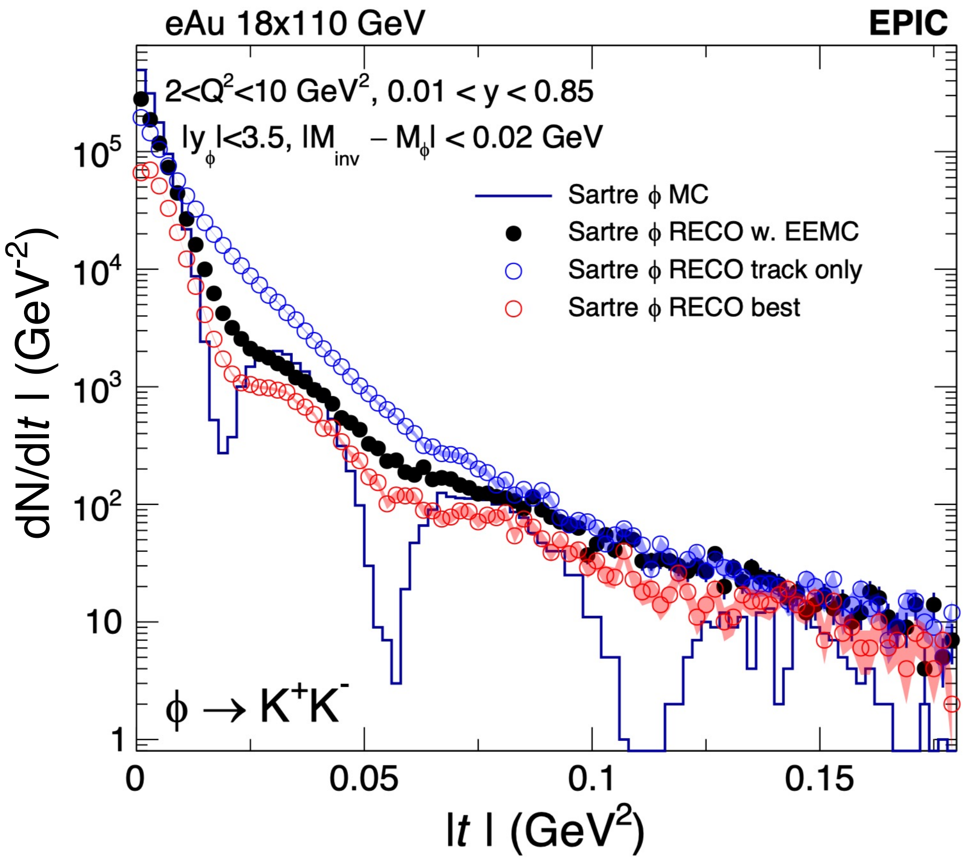
Legend details:
- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking

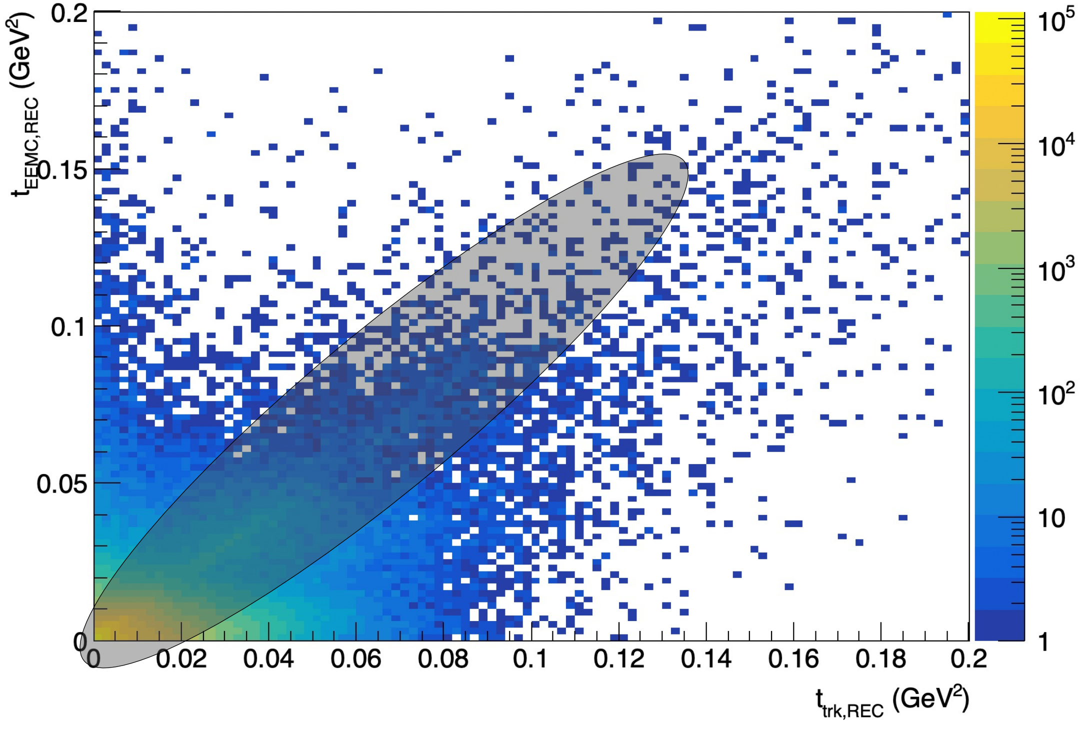


Result – combination of two

Legend details:

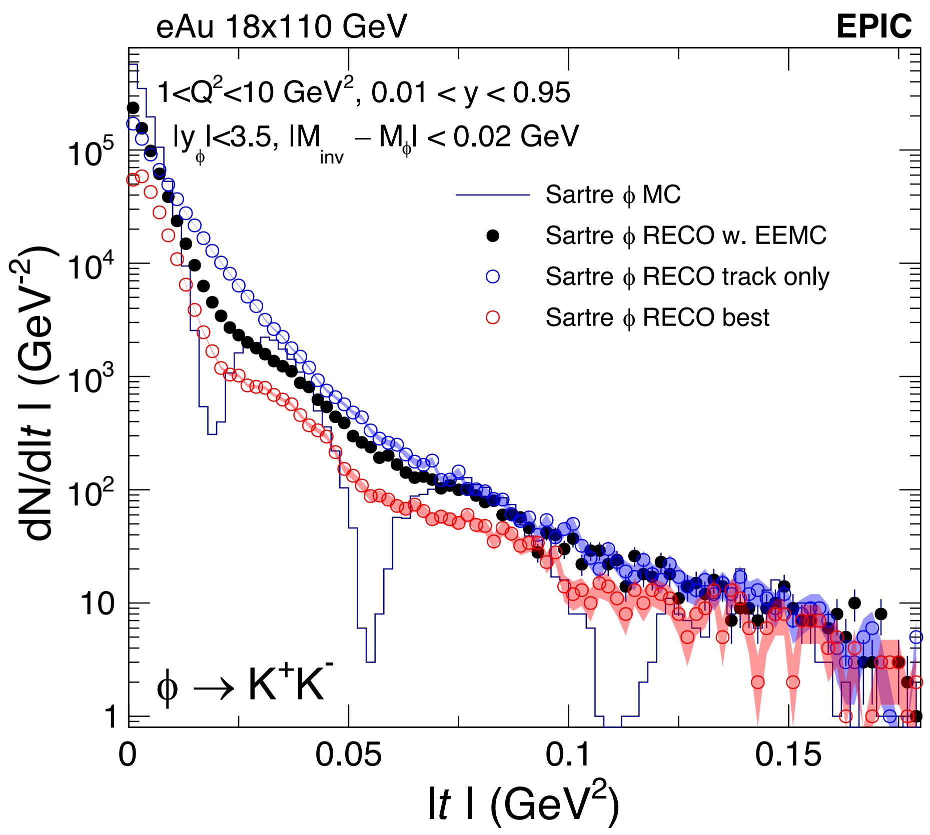
- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking
- Best: average of the above 2 E-by-E.

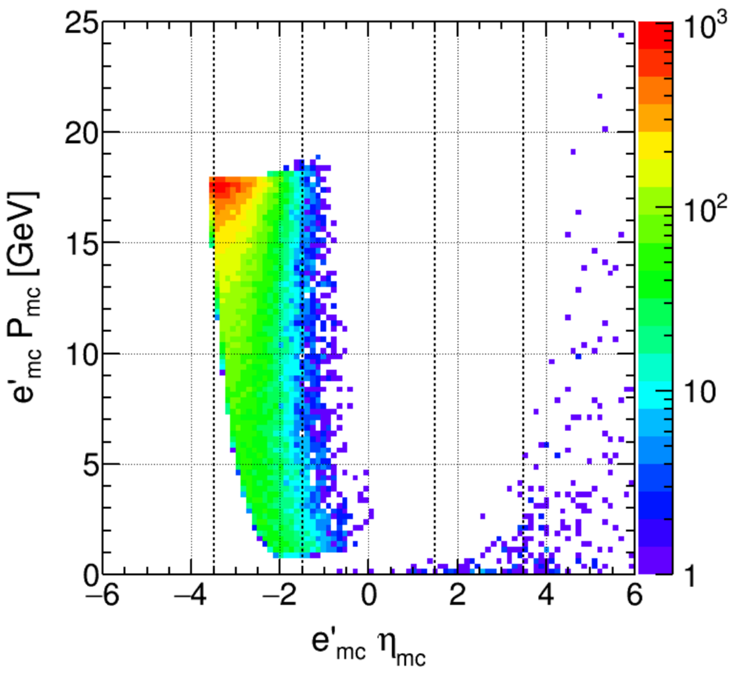




Result - at the lowest Q^2

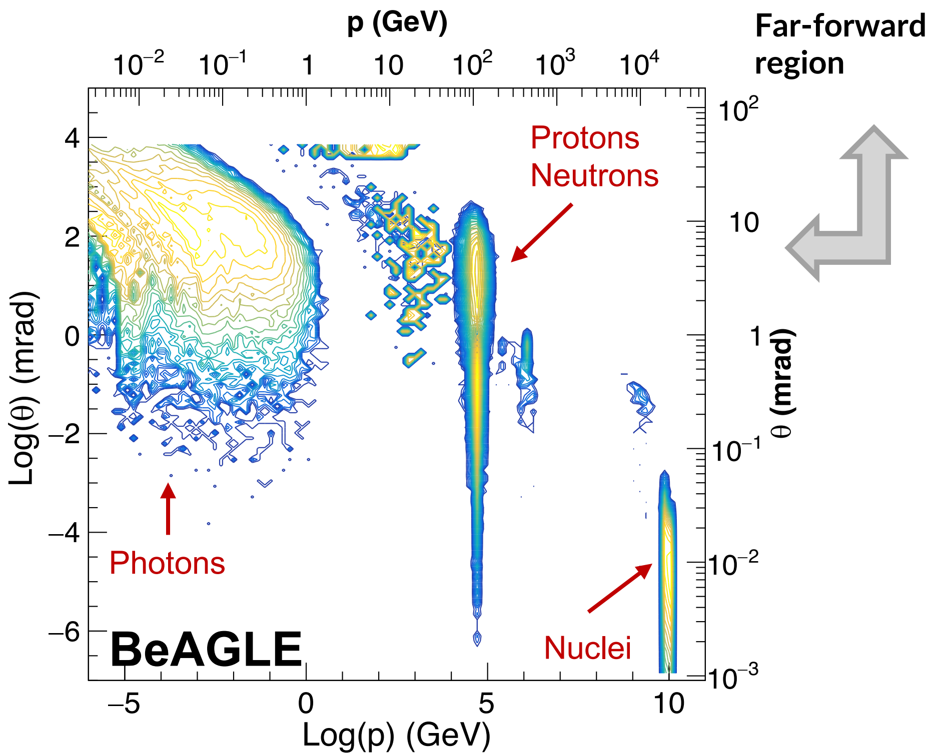
Legend details:
- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking
- Best: average of the above 2 E-by-E.



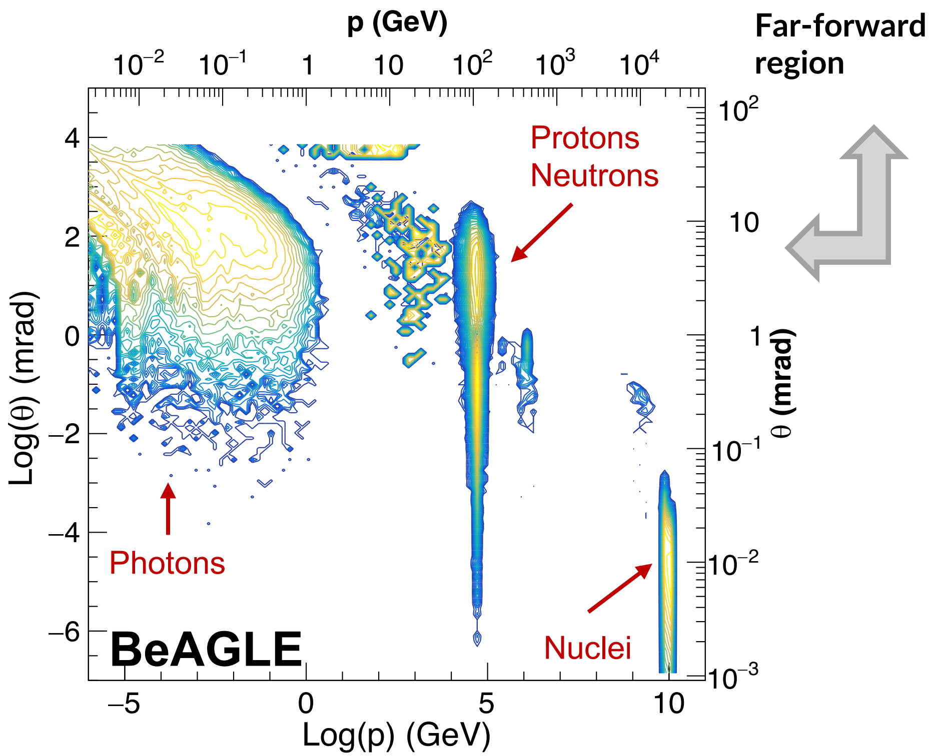


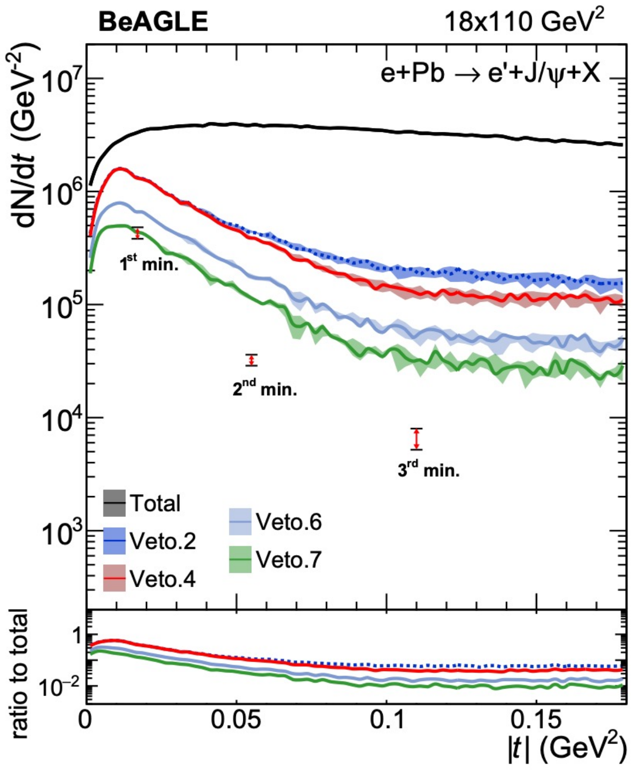
This is at the limit of low Q^2 by using the endcap EMCal – **Q^2 > 1 GeV²**

Incoherent nuclear breakup in the Far-Forward region



Incoherent veto based on the final-states



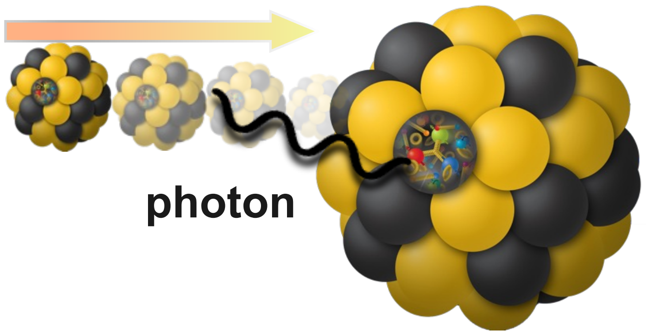


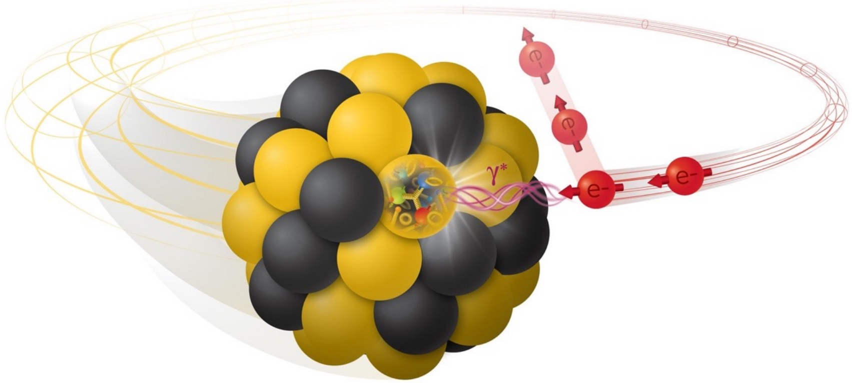
Phys. Rev. D ***104****, 114030*

- 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.

Beampipe design was found to be important to this performance - still being developed.

Complementarity: UPC and EIC





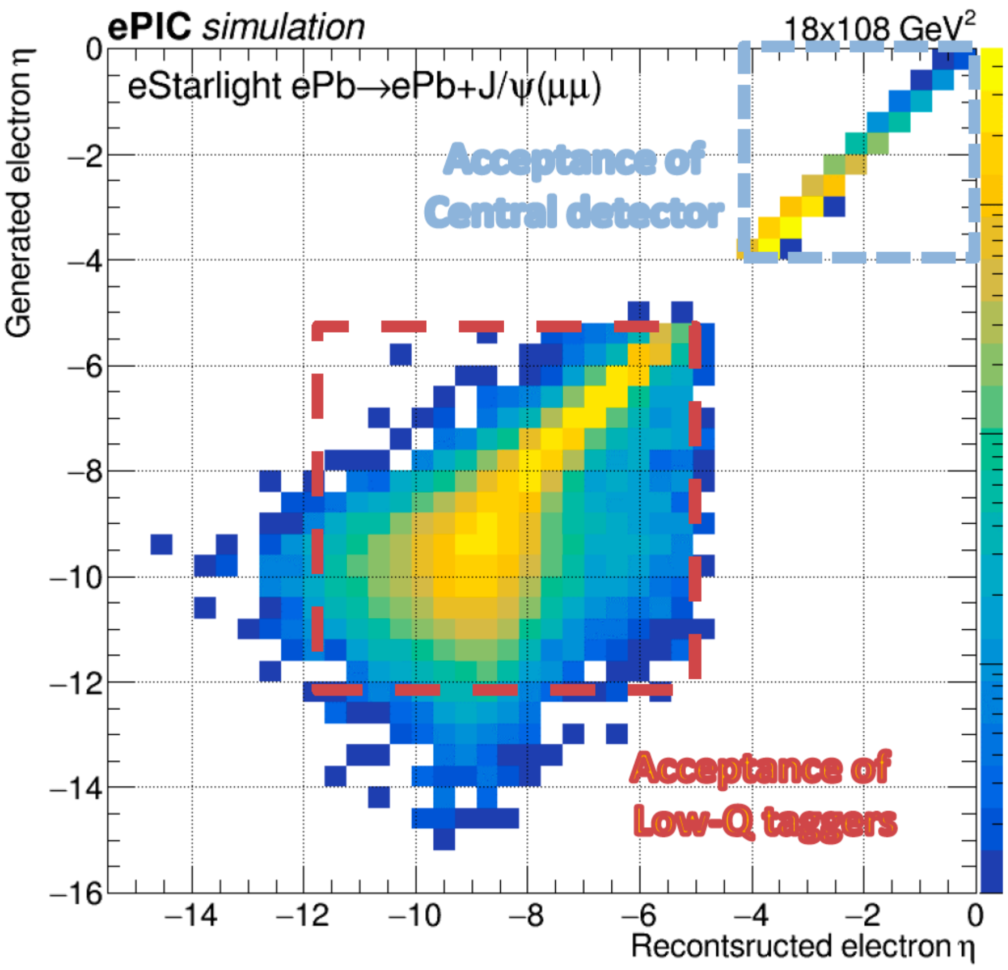
UPC RHIC & LHC	EIC
Photoproduction only (real photons)	Electroproduction (virtual photons)
Mass or p_T – hard scales	Q^2 – an independent hard scale
CM energy, W ~ [4, 400-1000] GeV, x ~ 10^{-5} - 10^{-1}	CM energy, W ~ [9, 86] GeV, x ~ 10^{-4} - 10^{-2}
mostly Pb^{208}, Au^{197}.	Deuterium to Uranium
Limited far-forward coverage for breakup products	Large far-forward coverage, esp. for nuclear breakup.

Can EIC measure photoproduction of VM?

Low-Q^2, photoproduction, and beyond

Acceptance in the low-Q^2 tagger ~ 10^{-4} -10^{-2} .

- Very low-Q^2 (like UPCs), *-t* reco becomes easier, because the scattered e' contributes little in *-t*.
- In ePIC, $Q^2 \sim 10^{-2} – 1.0$ is the most challenging region in terms of i) *e' acceptance ii) -t reconstruction.*



This is actively being developed, including EIC 2nd detector

(M. Pitt, BGU)

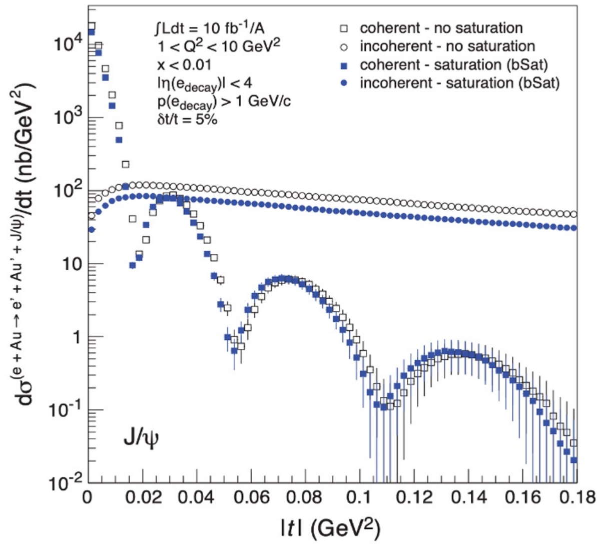
Summary - a dream came true

- Diffractive Vector-Meson is a powerful experimental tool to study the nucleon and nuclear structure, e.g., **gluon spatial distributions**.

- Since the formation of collaboration:
  - **We achieved:** First full **ePIC simulation** in an unified and modern software framework.
  - **Next in ePIC:** Incoherent background, where the nucleus breaks up. Veto on far-forward particles.

- **Photoproduction of VMs** are being actively developed and intermediate Q^2 (10^{-2} – 1.0) is most challenging.

2012



2023