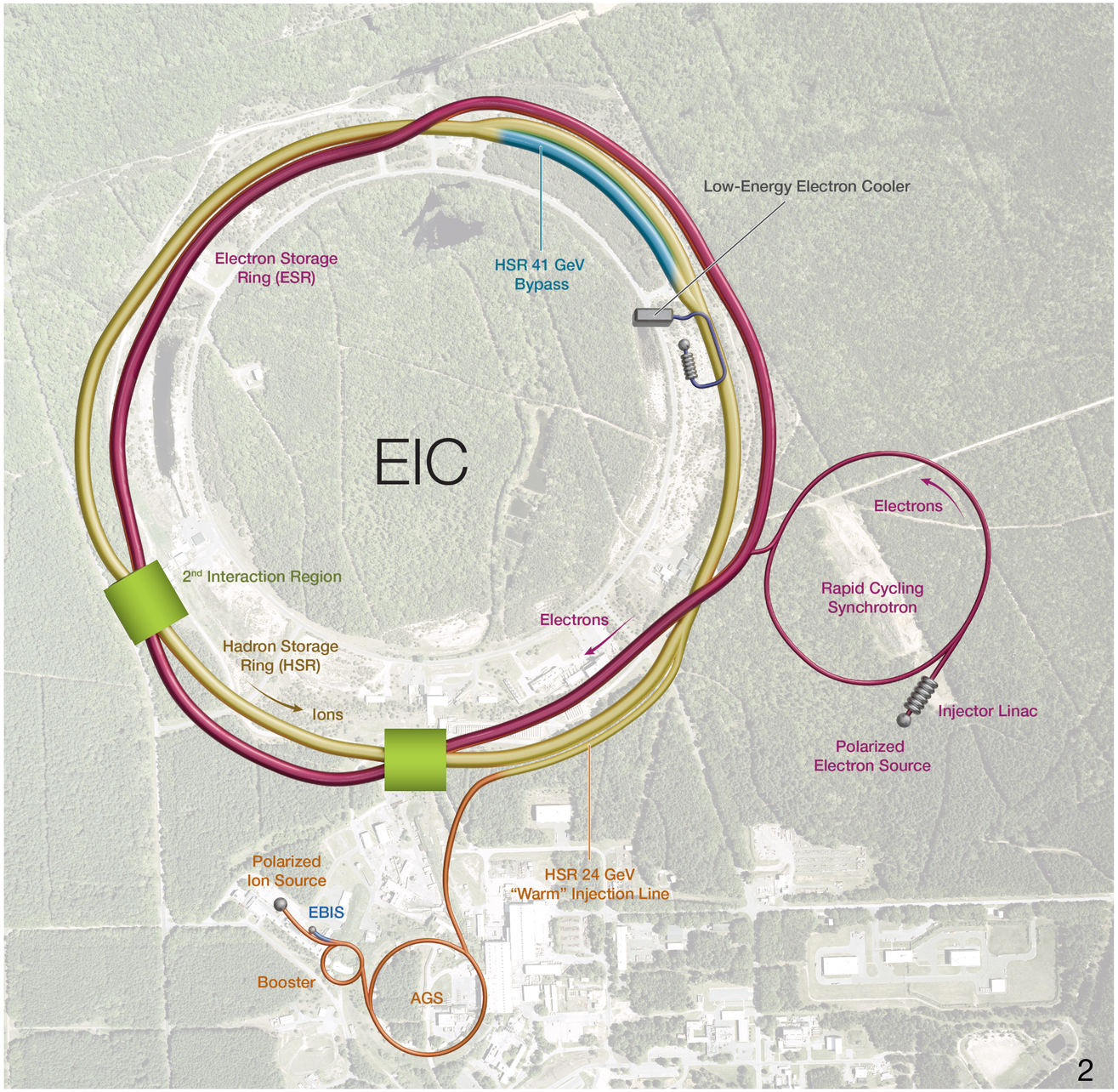
Exclusive physics at the EIC

AdT

Charlotte Van Hulse
University of Alcalá

EuNPC Workshop
Caen, France
September 22–26, 2025

The electron-ion collider



- Based on RHIC:
  - use exiting hadron storage ring
    energy: 41–275 GeV
  - add electron storage ring in RHIC tunnel
    energy: 5–18 GeV

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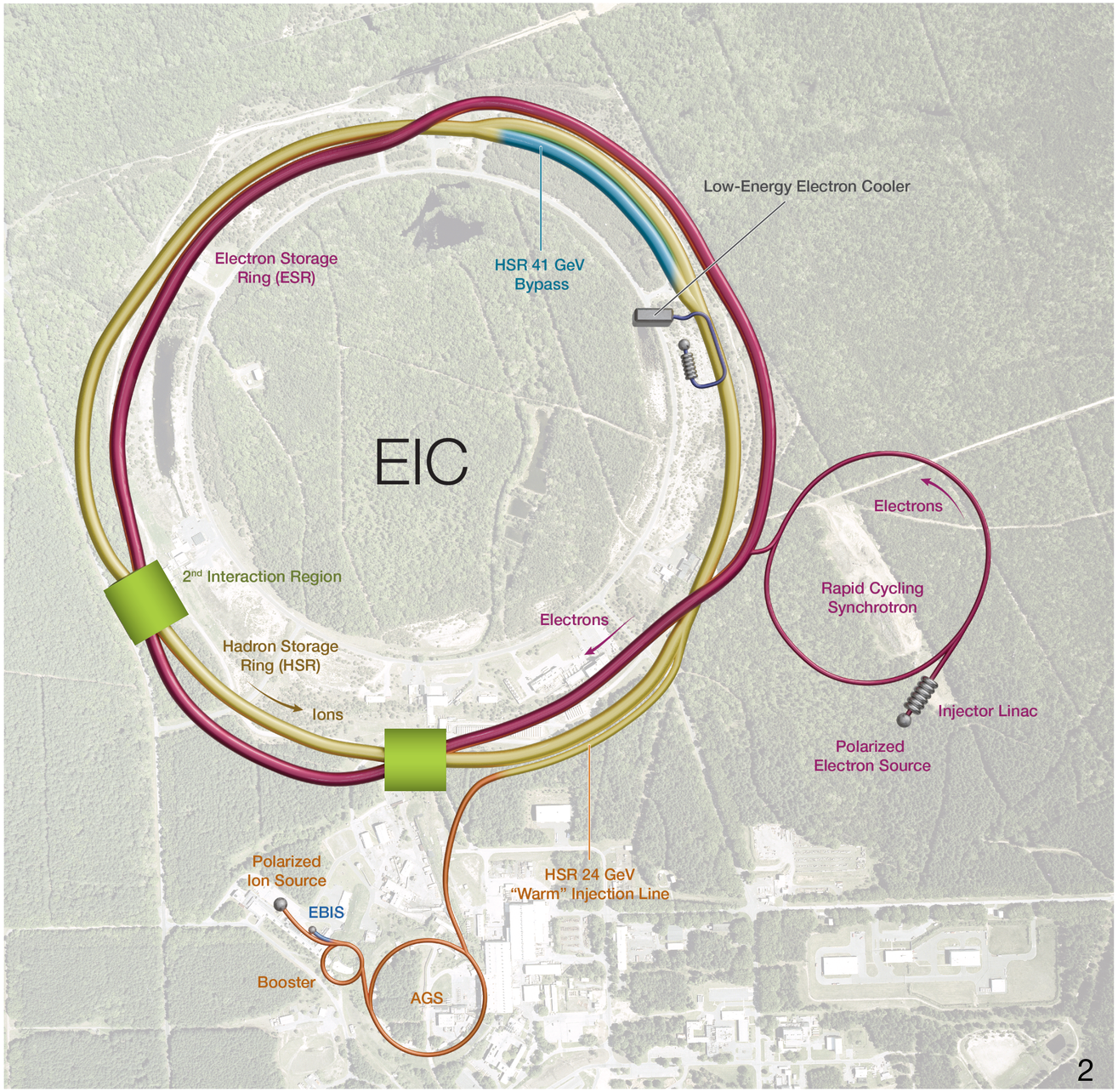

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$\rightarrow \sqrt{s} = 29 - 141$ GeV (per nucleon)

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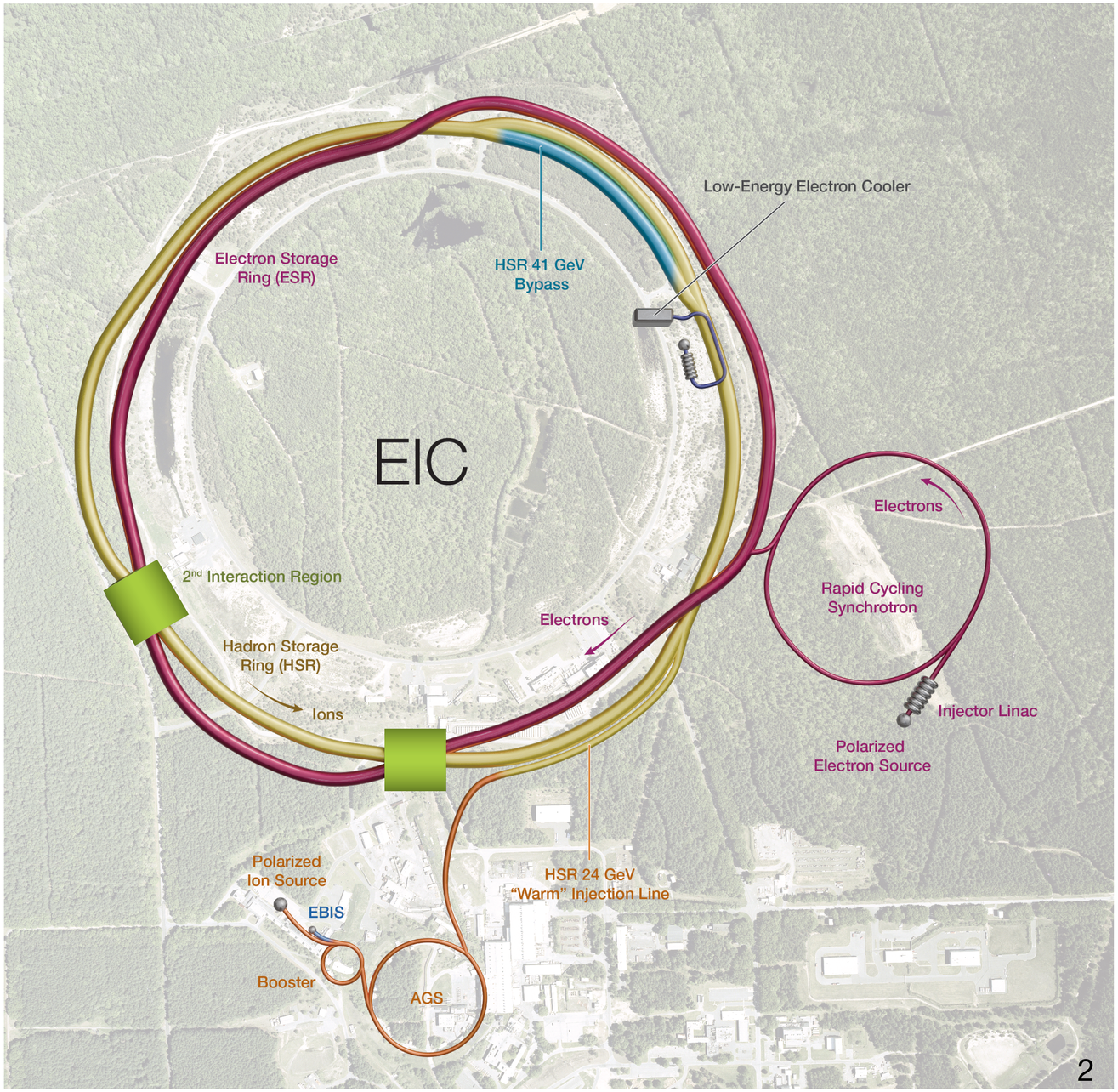

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- $\vec{e} + \vec{p}^{\uparrow}, \overrightarrow{He}^{\uparrow}$

  ~ 70% polarisation

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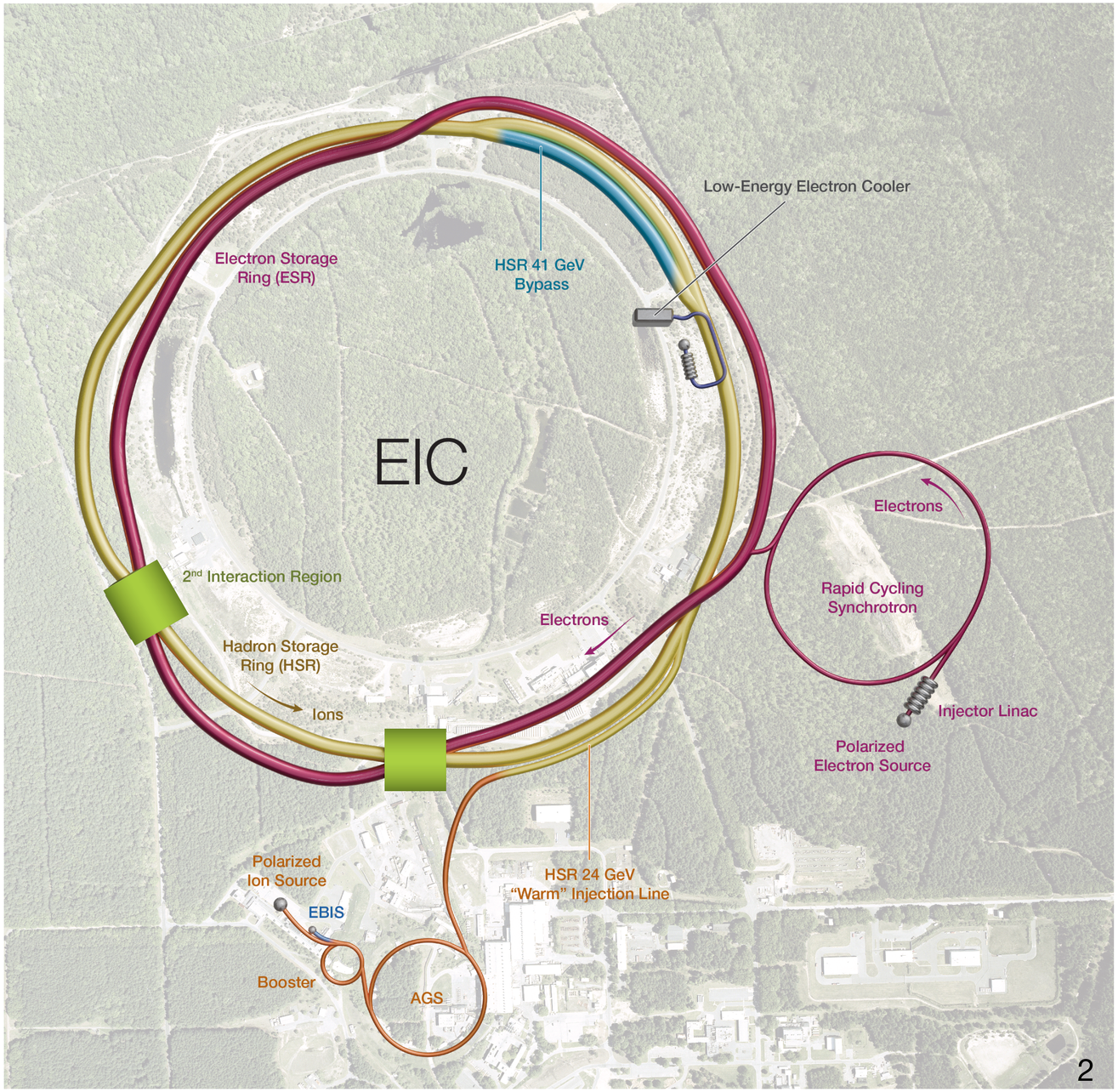

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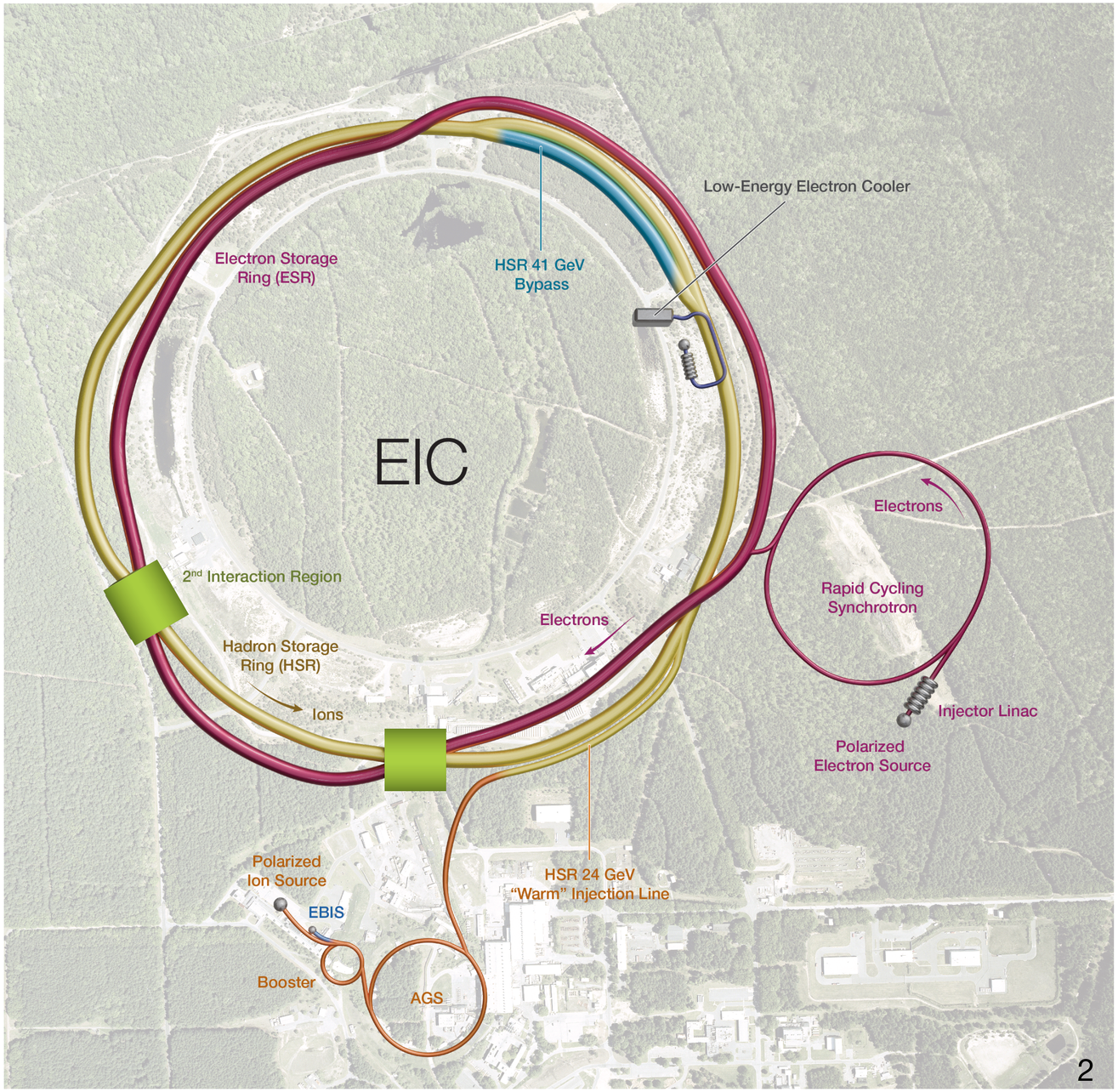

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  $\leftrightarrow \mathscr{L}_{\text{int}} = 10 - 100$ fb^{-1}/year

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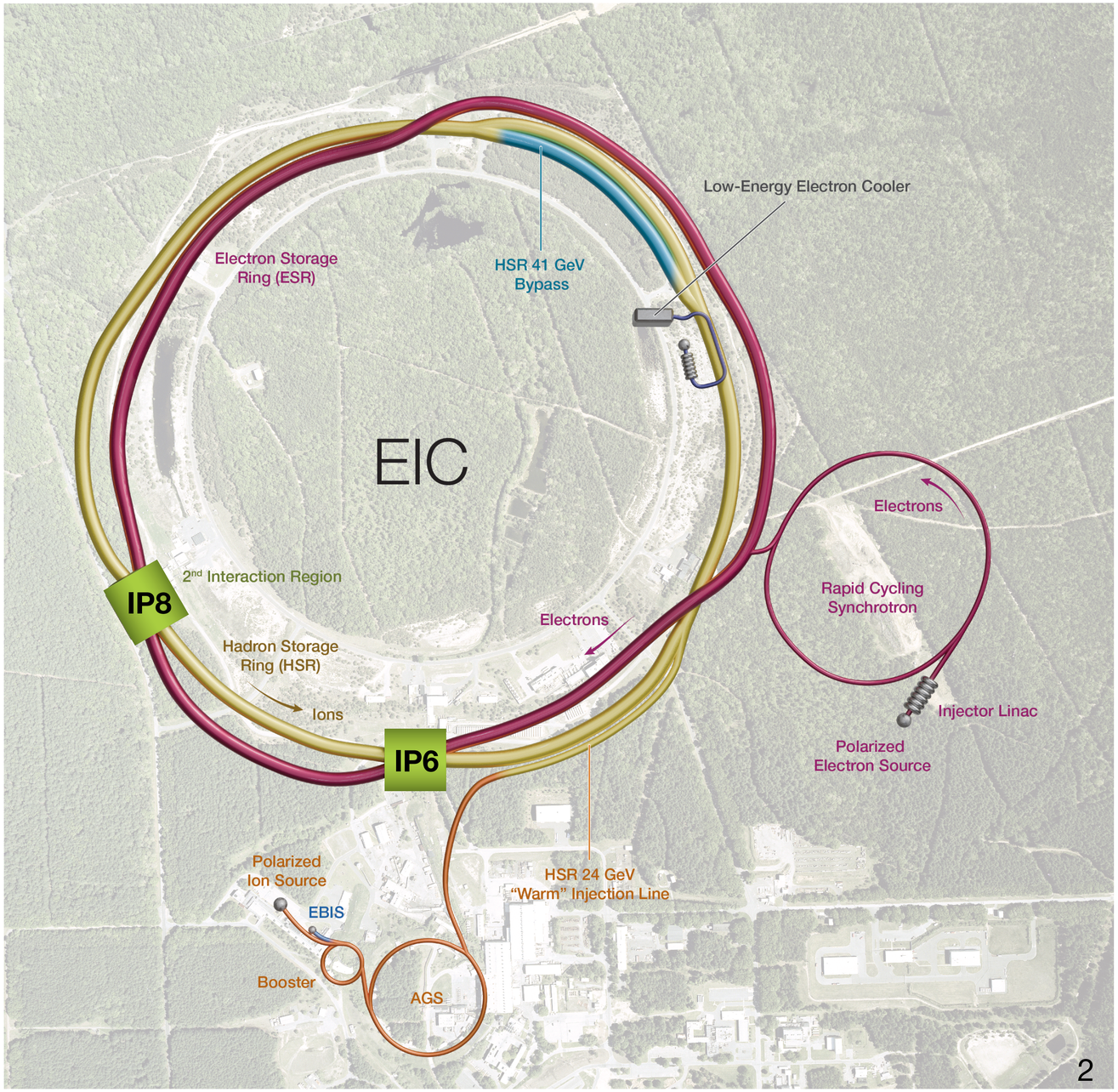

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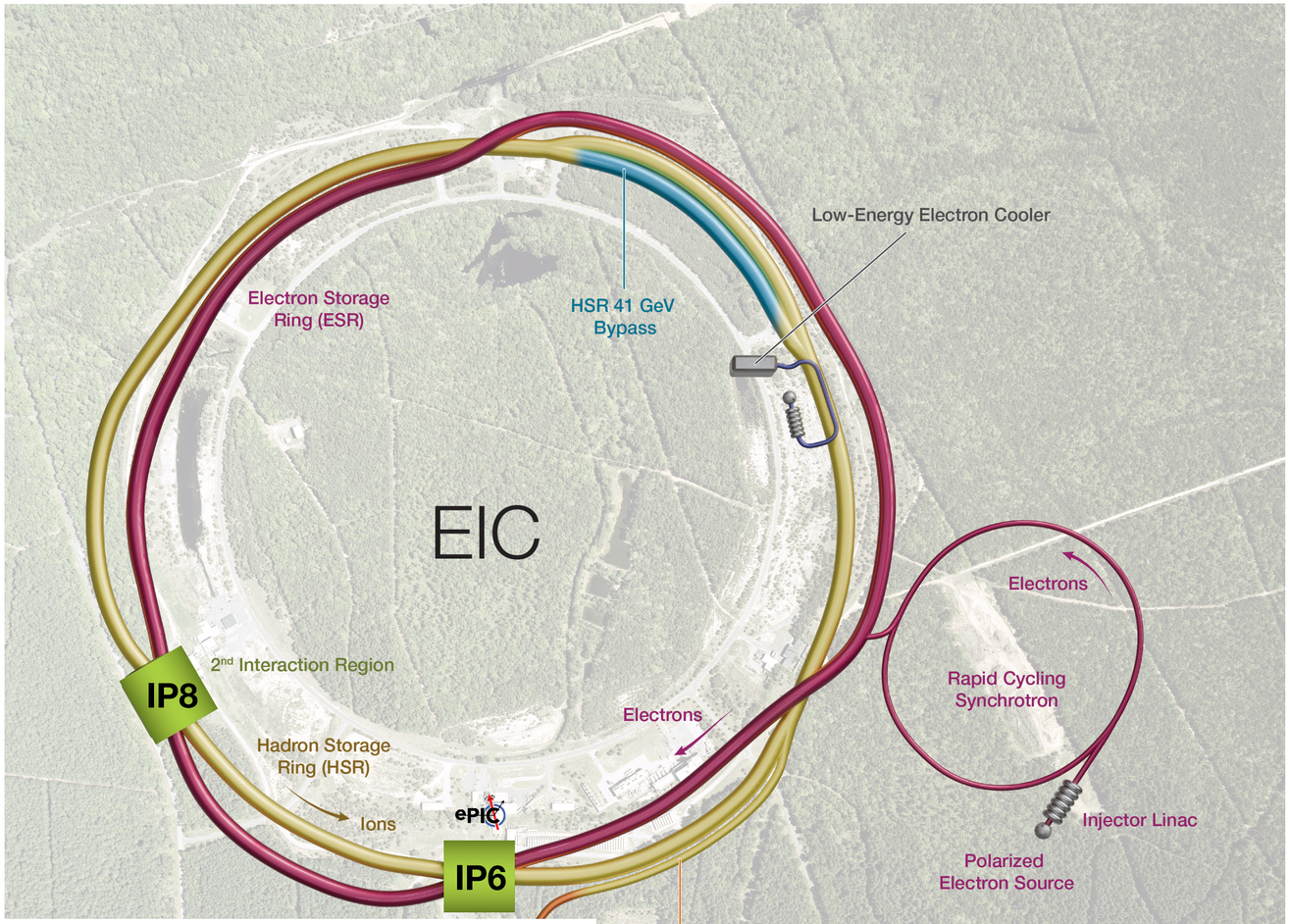

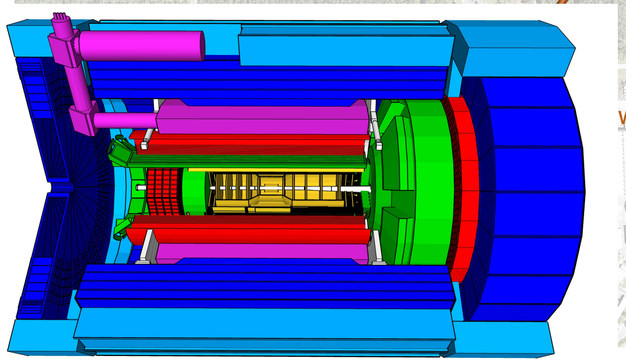

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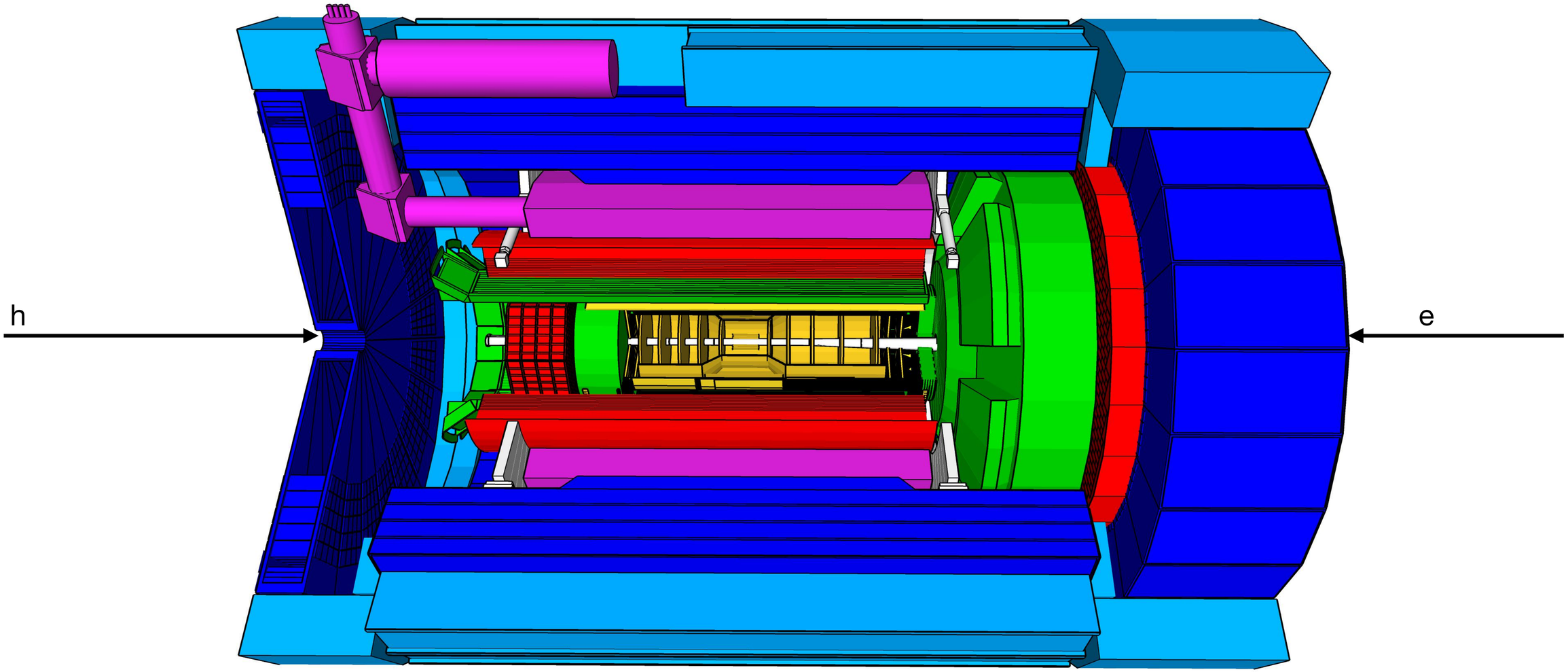
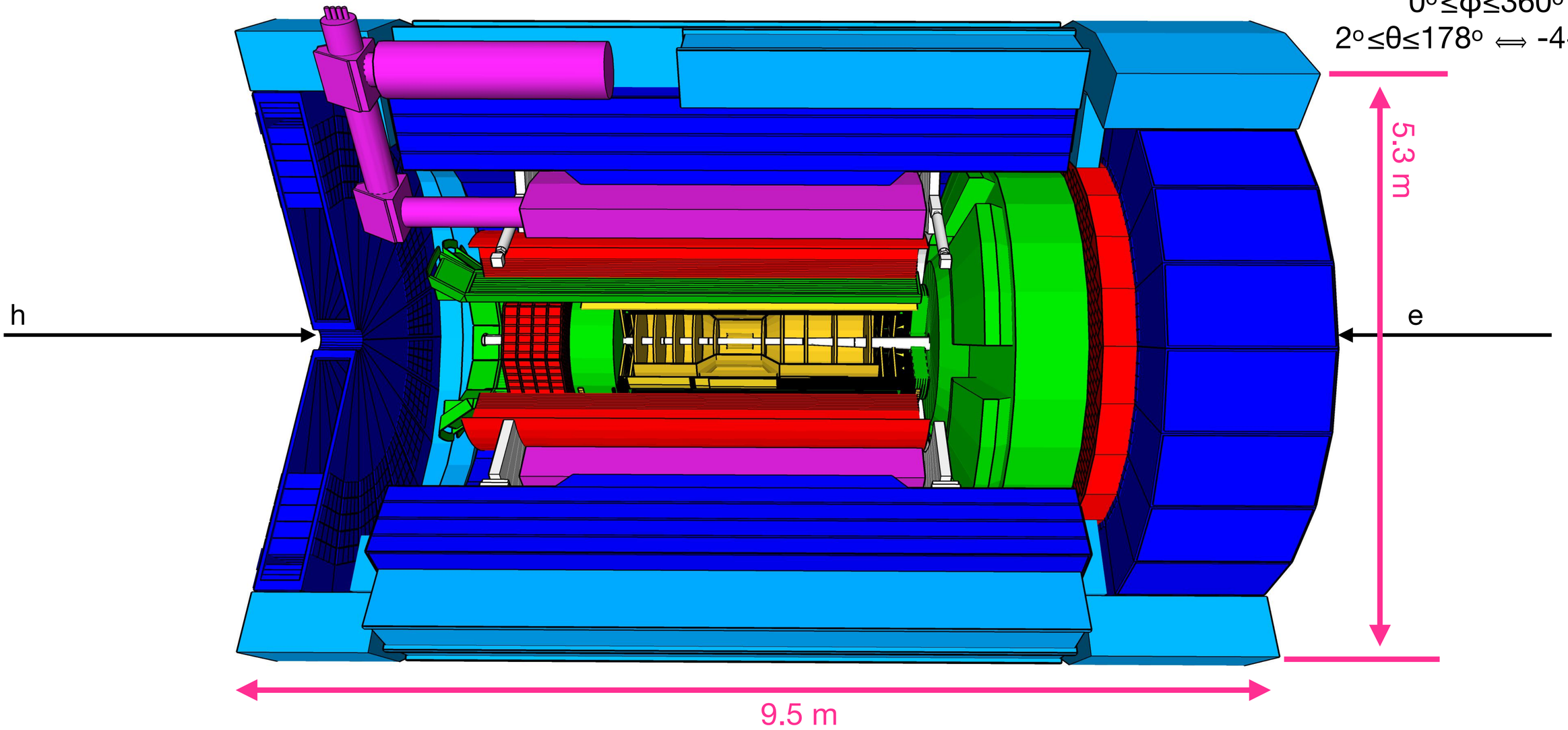
The electron-proton/ion collider (ePIC) detector



The electron-proton/ion collider (ePIC) detector

hermetic coverage:
$0^o \leq \phi \leq 360^o$
$2^o \leq \theta \leq 178^o \iff -4 < \eta < 4$



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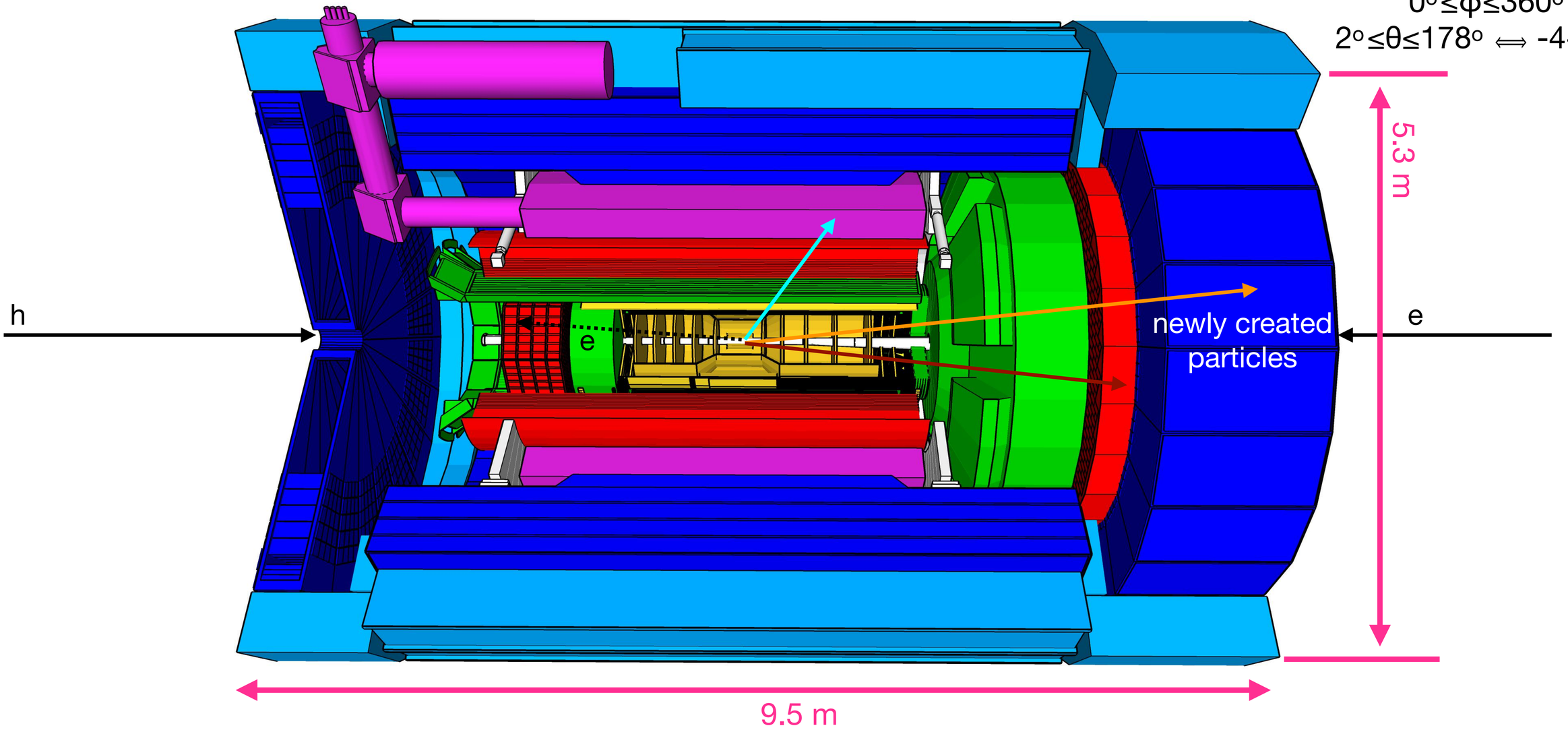

The electron-proton/ion collider (ePIC) detector

- Tracking
- PID
- Electromagnetic calorimeter
- Hadronic calorimeter

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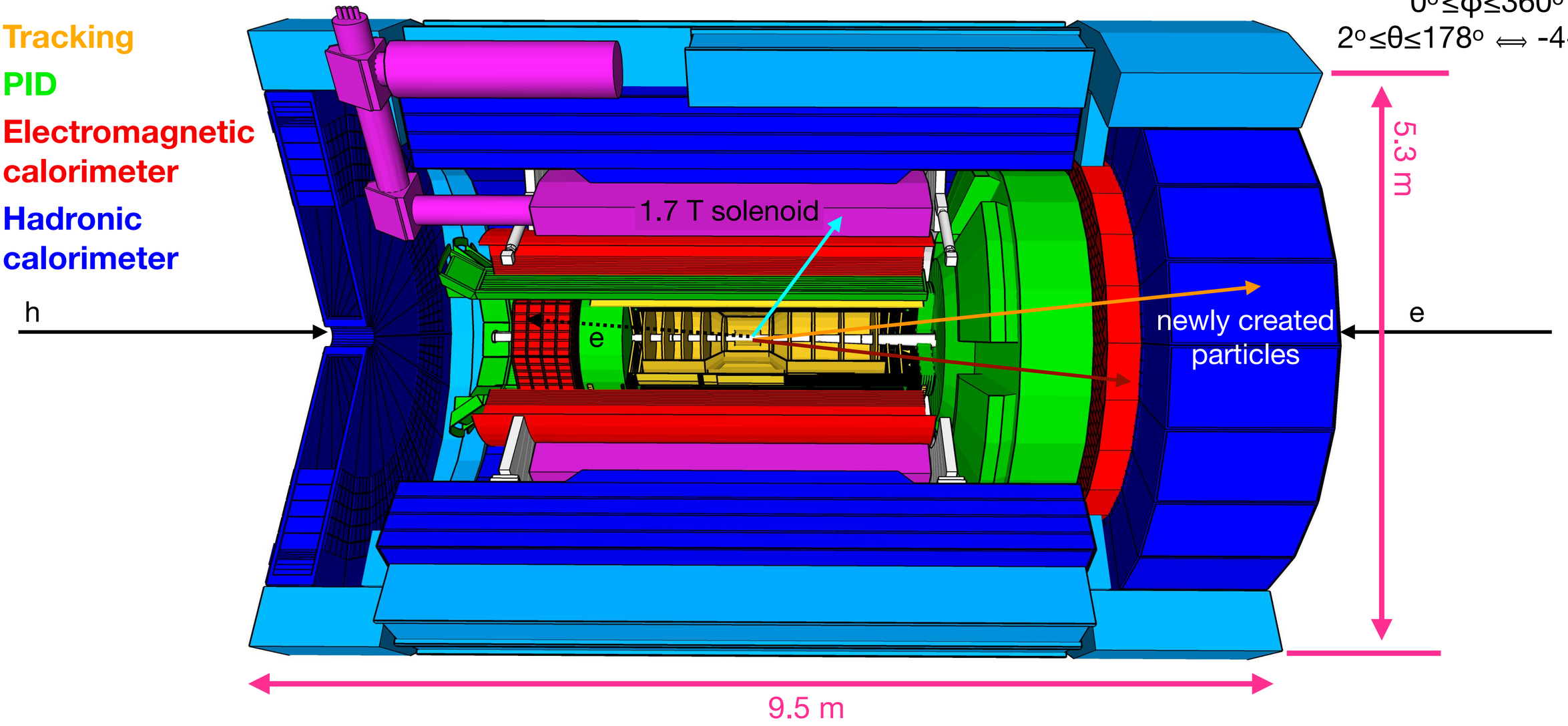

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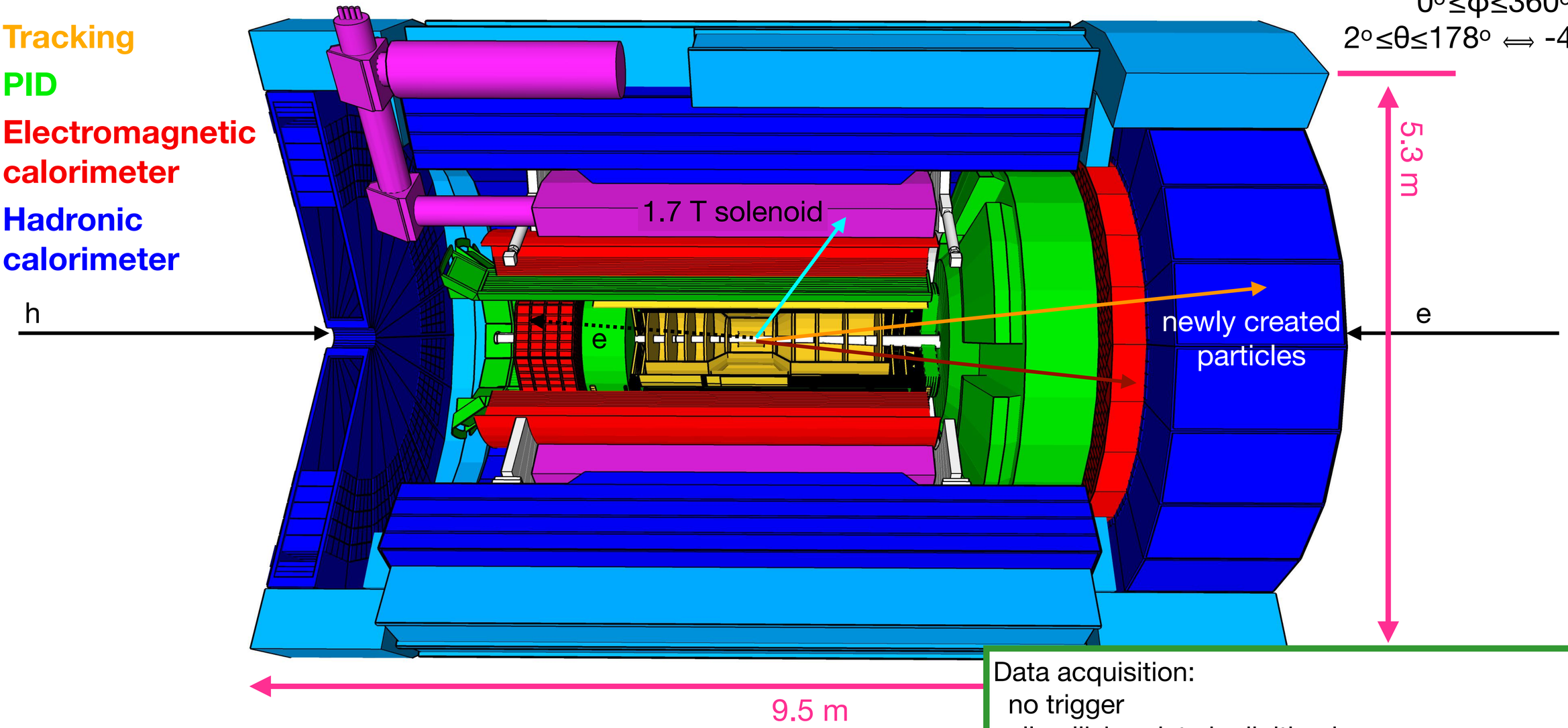
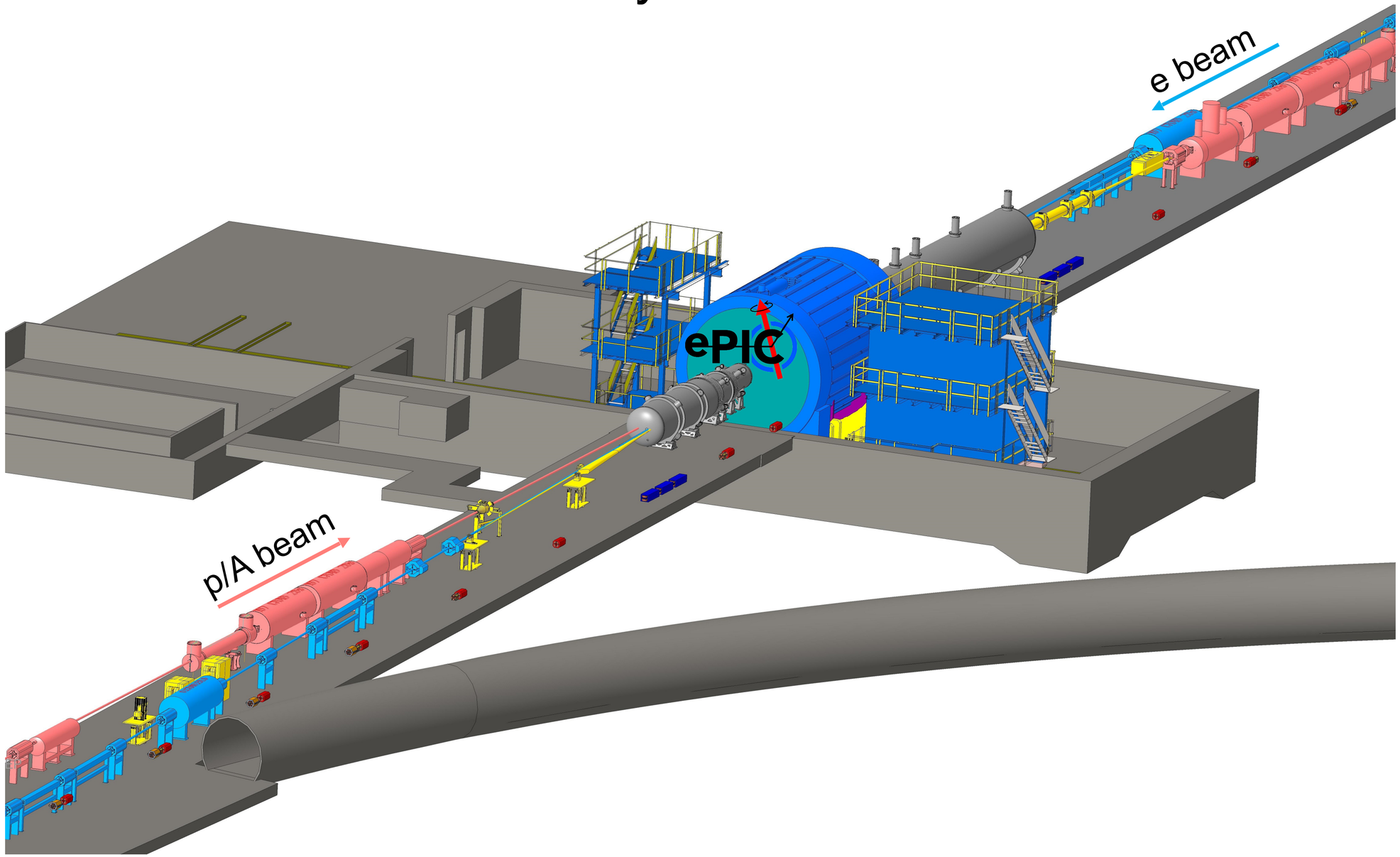


Data acquisition:
no trigger
all collision data is digitised
with strong zero-suppression at front-end electronics

Far-backward and far-forward systems



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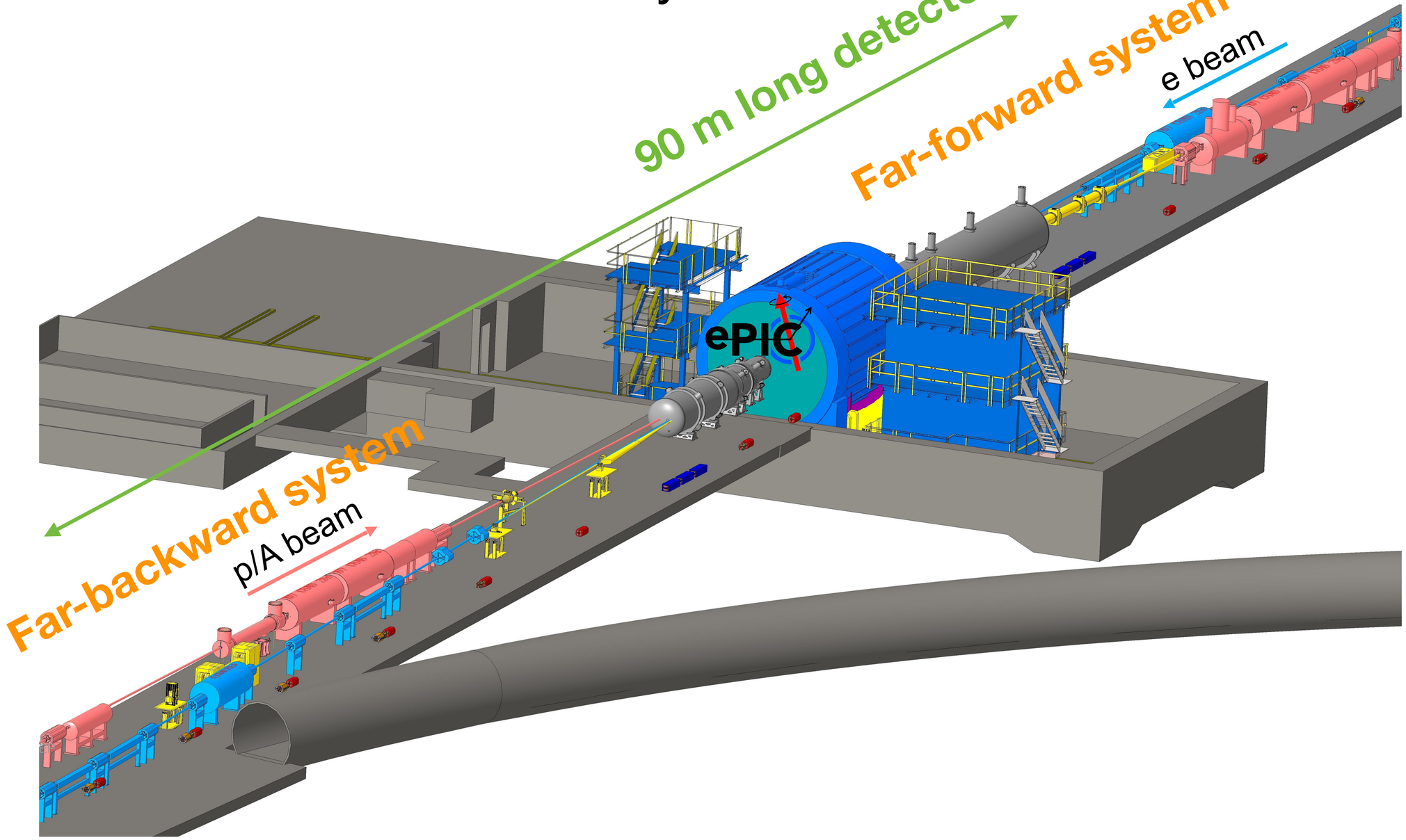

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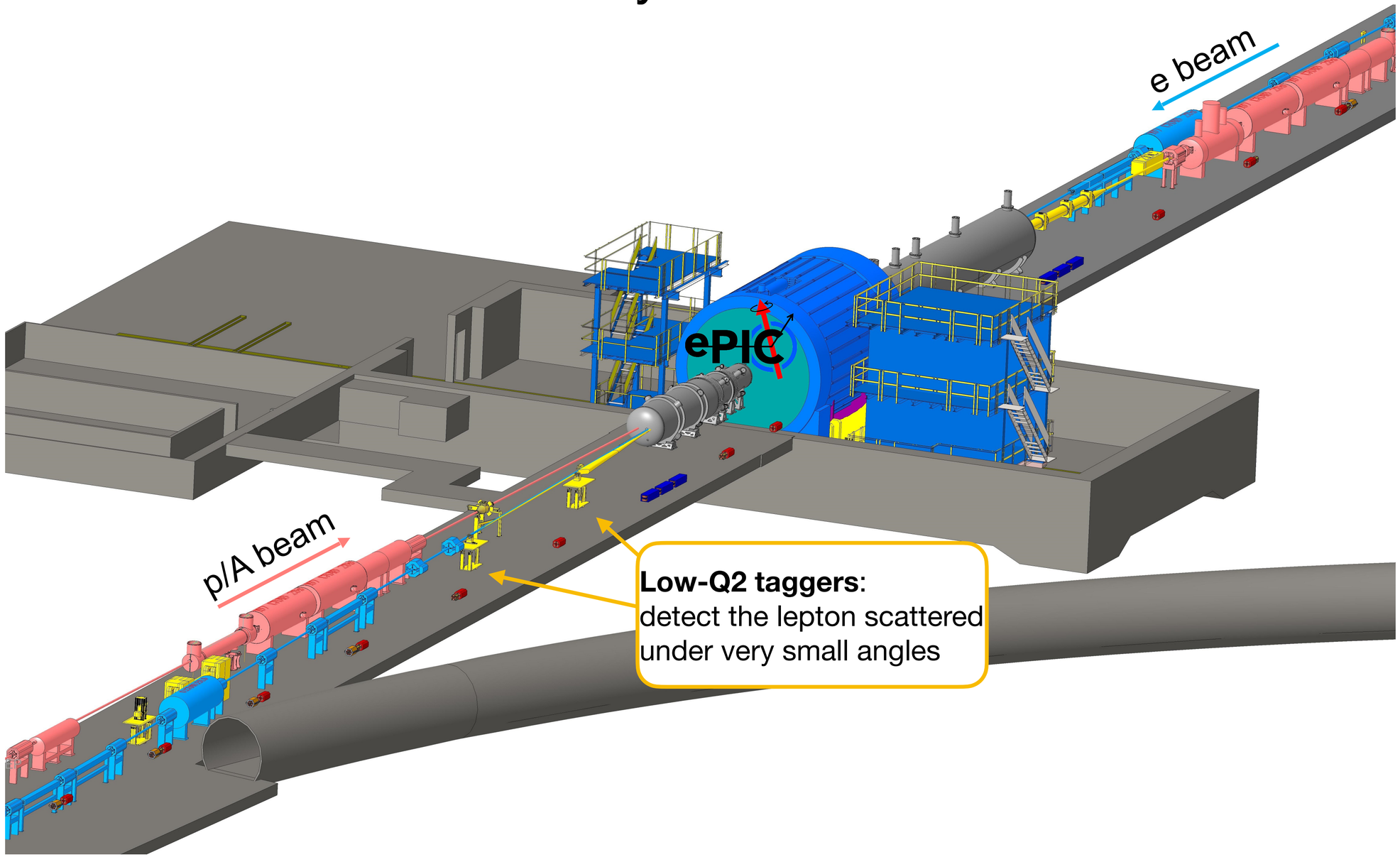

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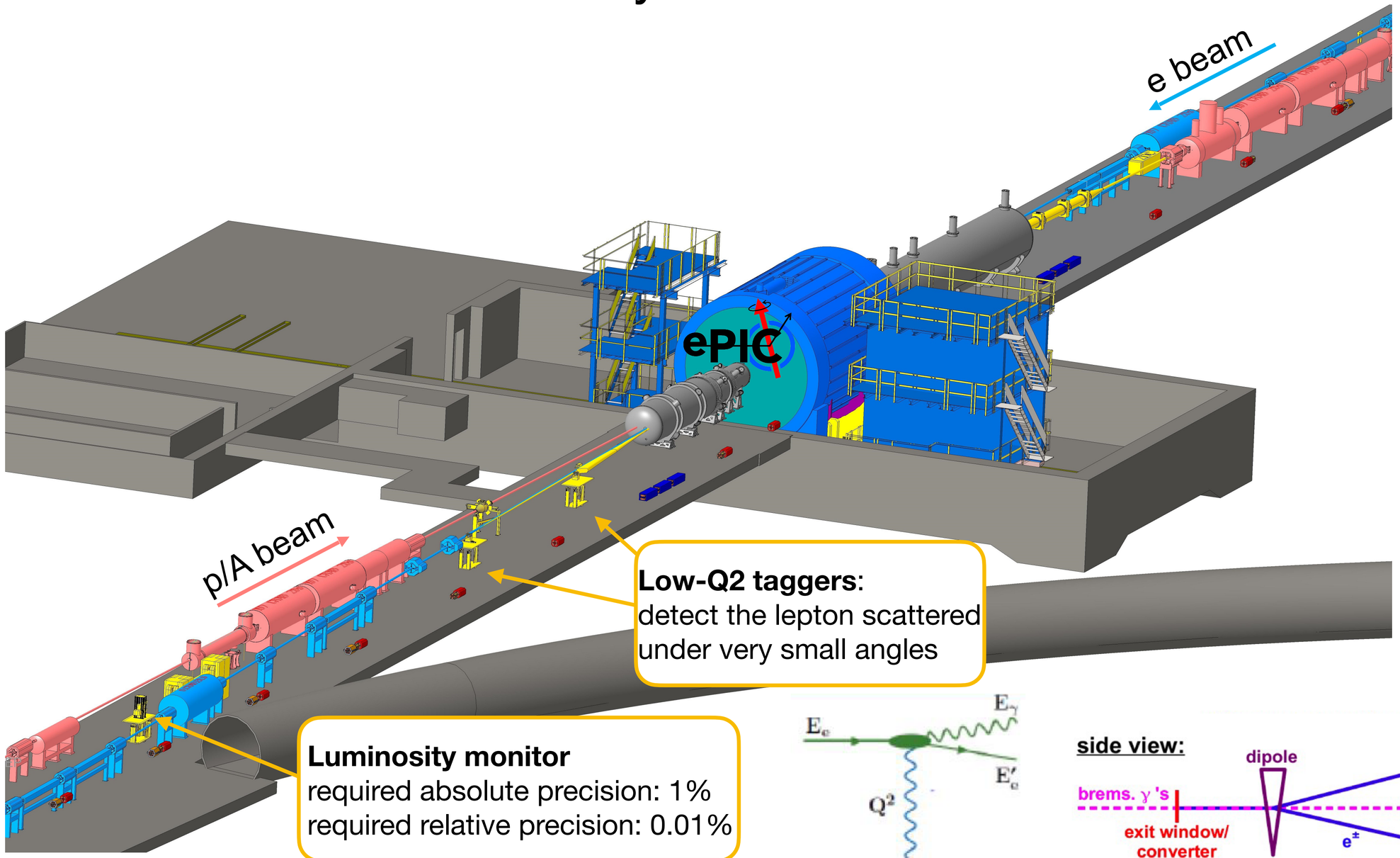
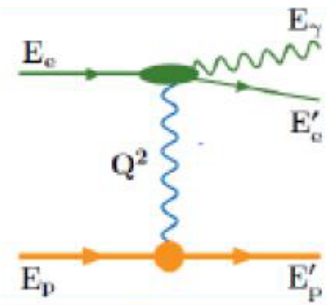
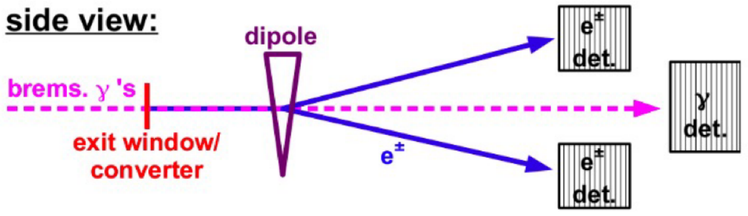


Low-Q2 taggers:
detect the lepton scattered under very small angles

Luminosity monitor
required absolute precision: 1%
required relative precision: 0.01%





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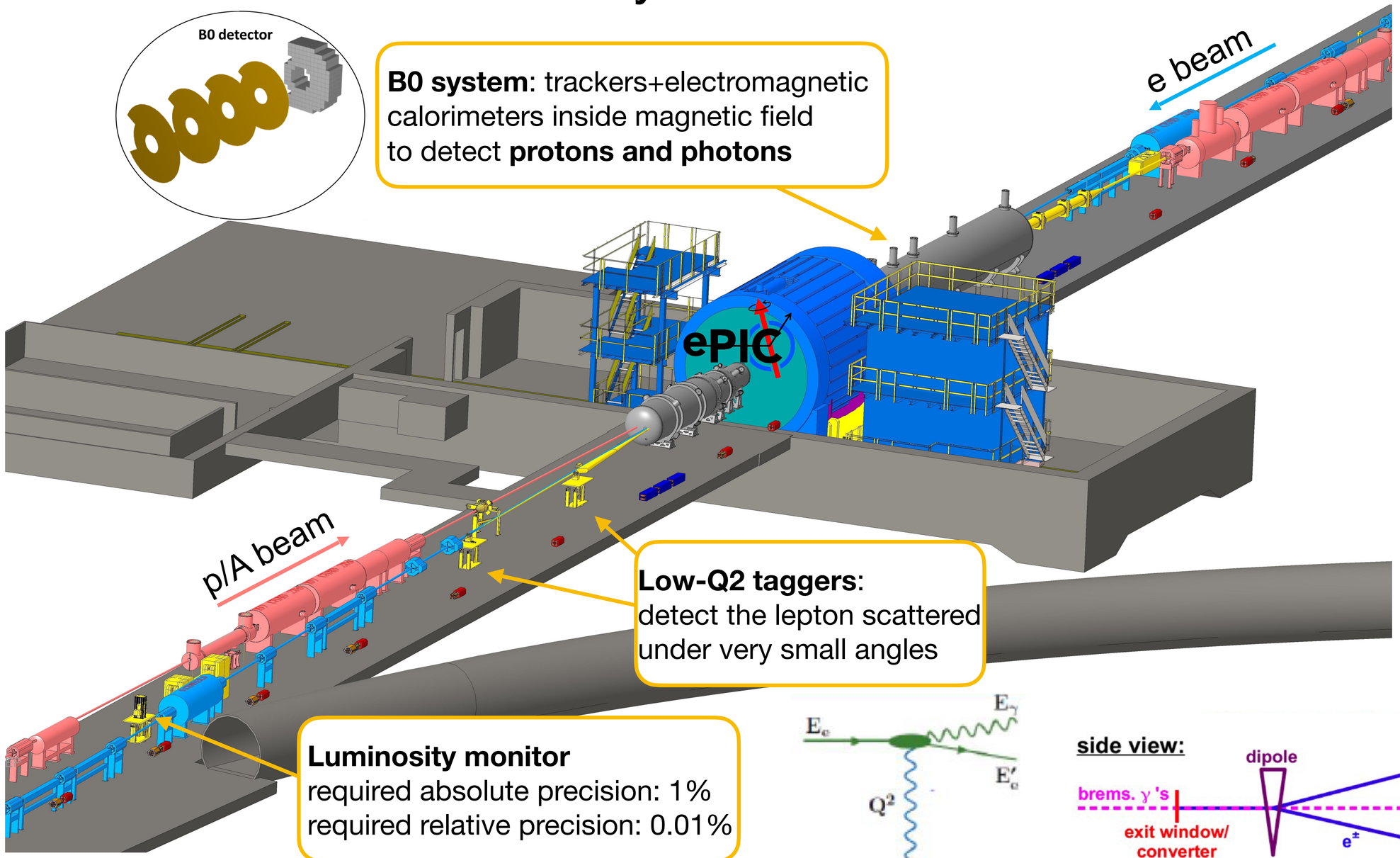

B0 system: trackers+electromagnetic calorimeters inside magnetic field to detect **protons and photons**

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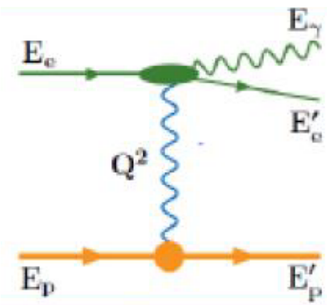

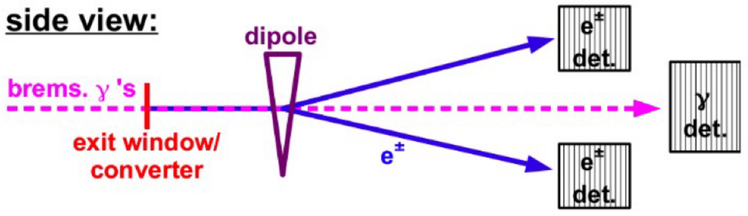

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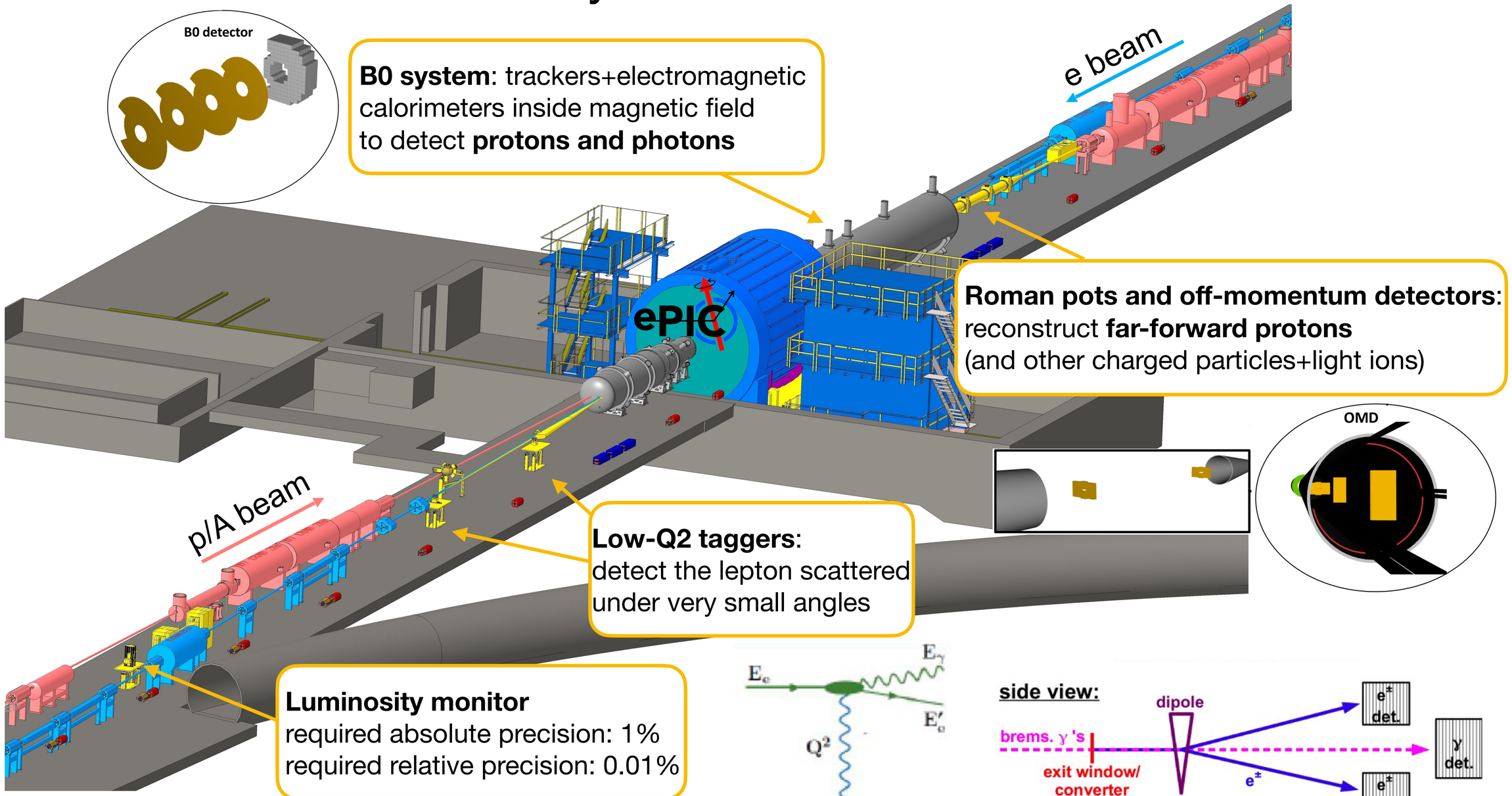

B0 system: trackers+electromagnetic calorimeters inside magnetic field to detect **protons and photons**

Roman pots and off-momentum detectors: reconstruct **far-forward protons** (and other charged particles+light ions)

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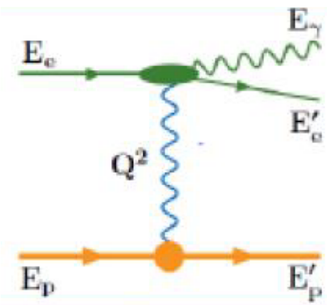

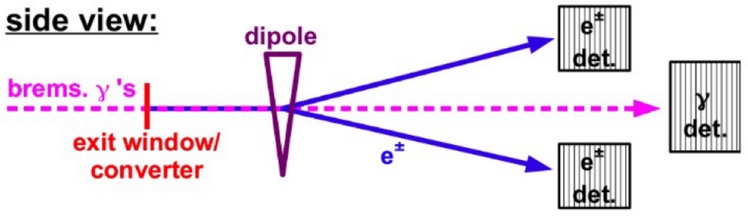

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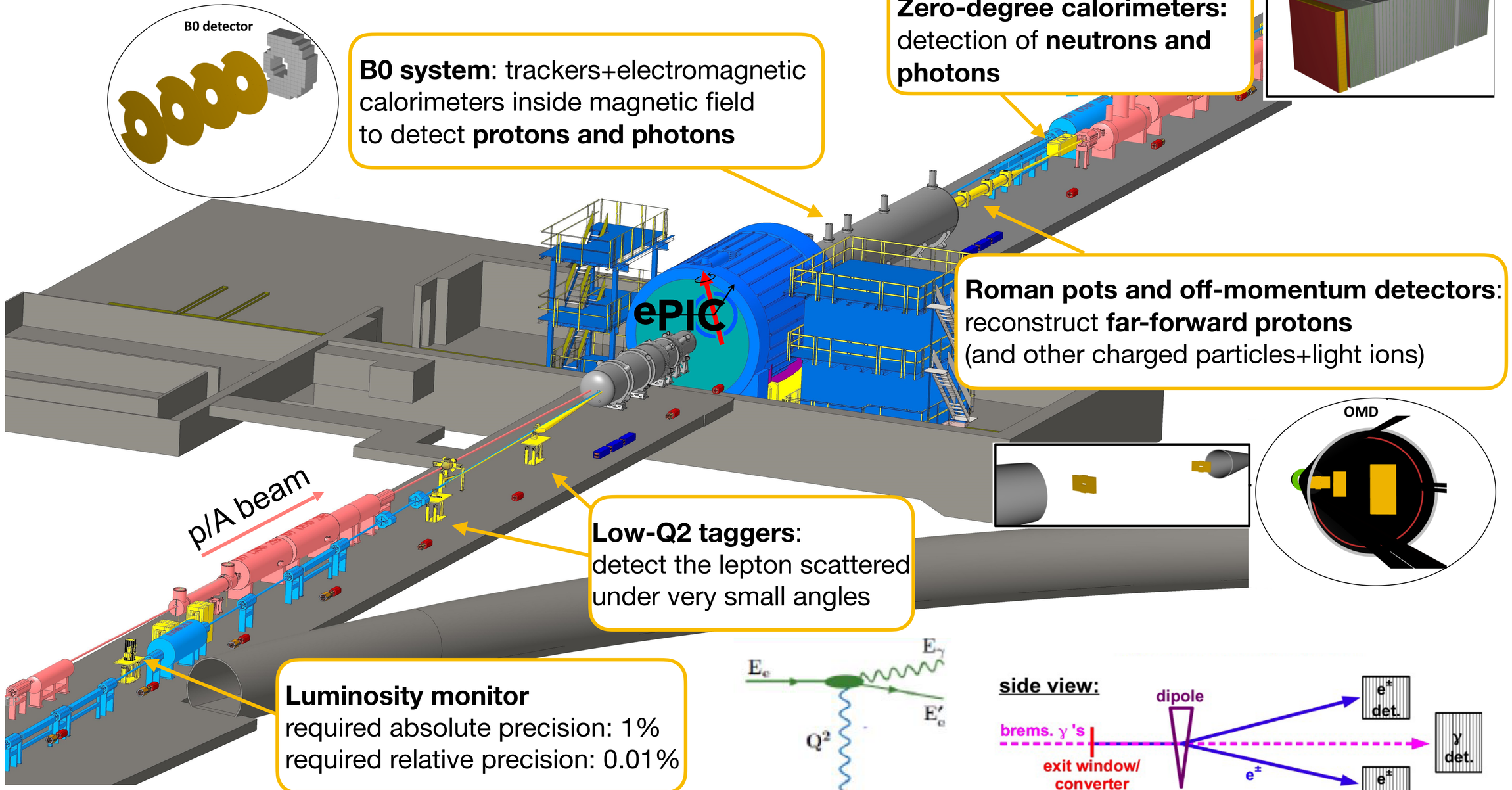

B0 system: trackers+electromagnetic calorimeters inside magnetic field to detect **protons and photons**

Zero-degree calorimeters: detection of **neutrons and photons**

Roman pots and off-momentum detectors: reconstruct **far-forward protons** (and other charged particles+light ions)

Low-Q2 taggers: detect the lepton scattered under very small angles

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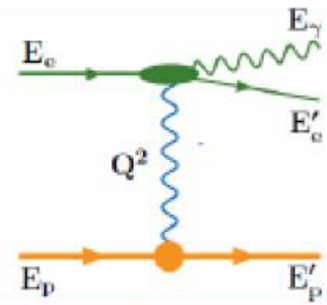
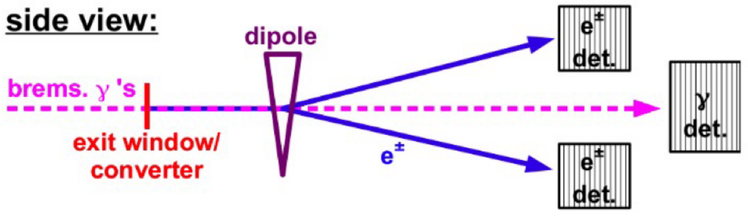
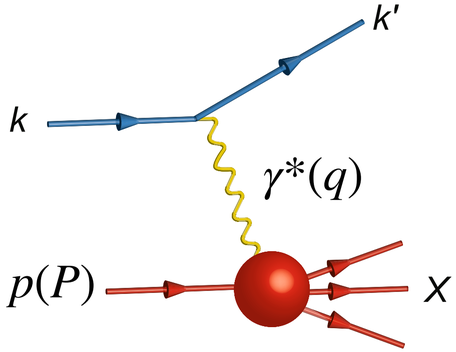
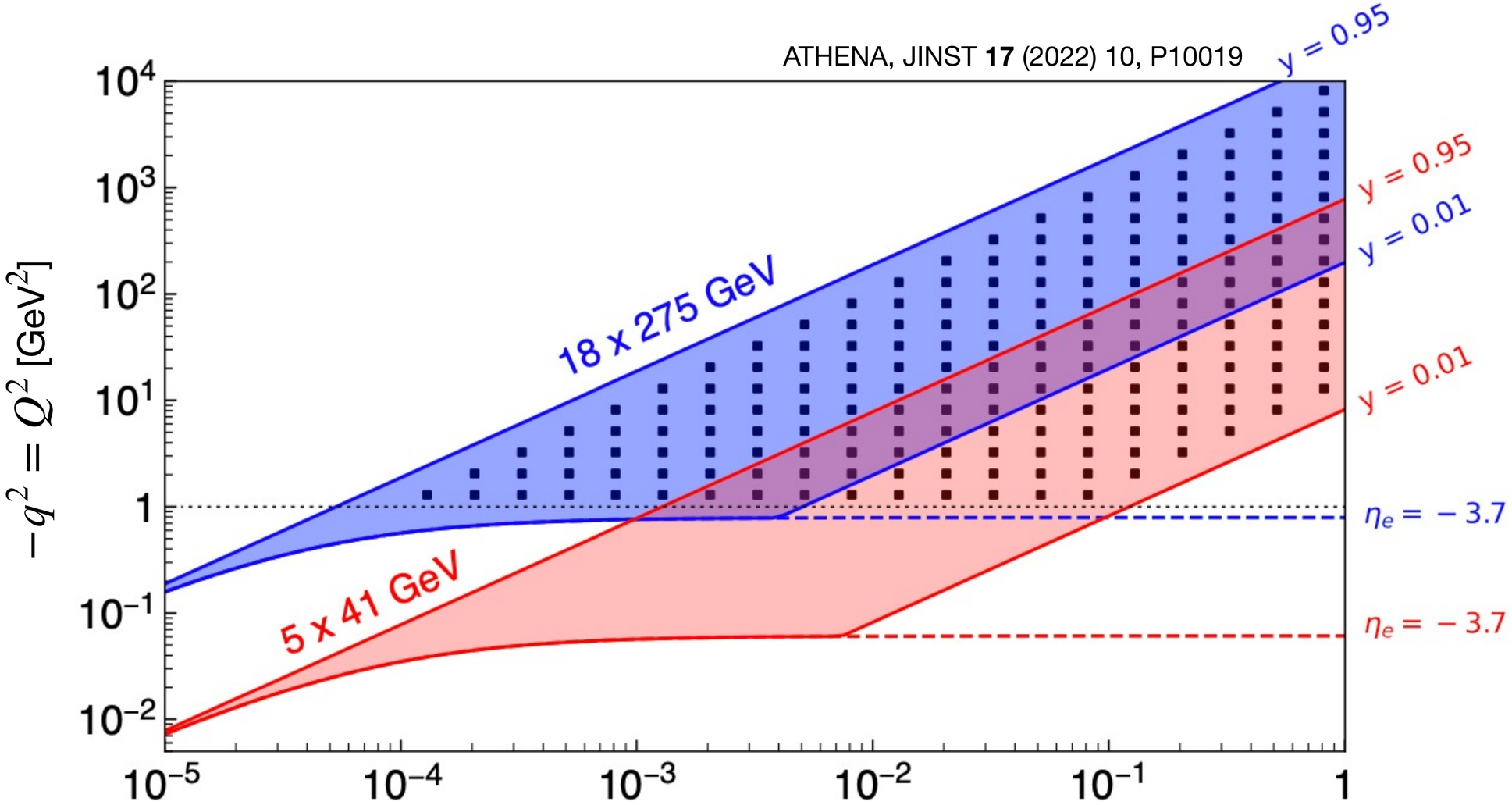




Kinematic coverage at the EIC

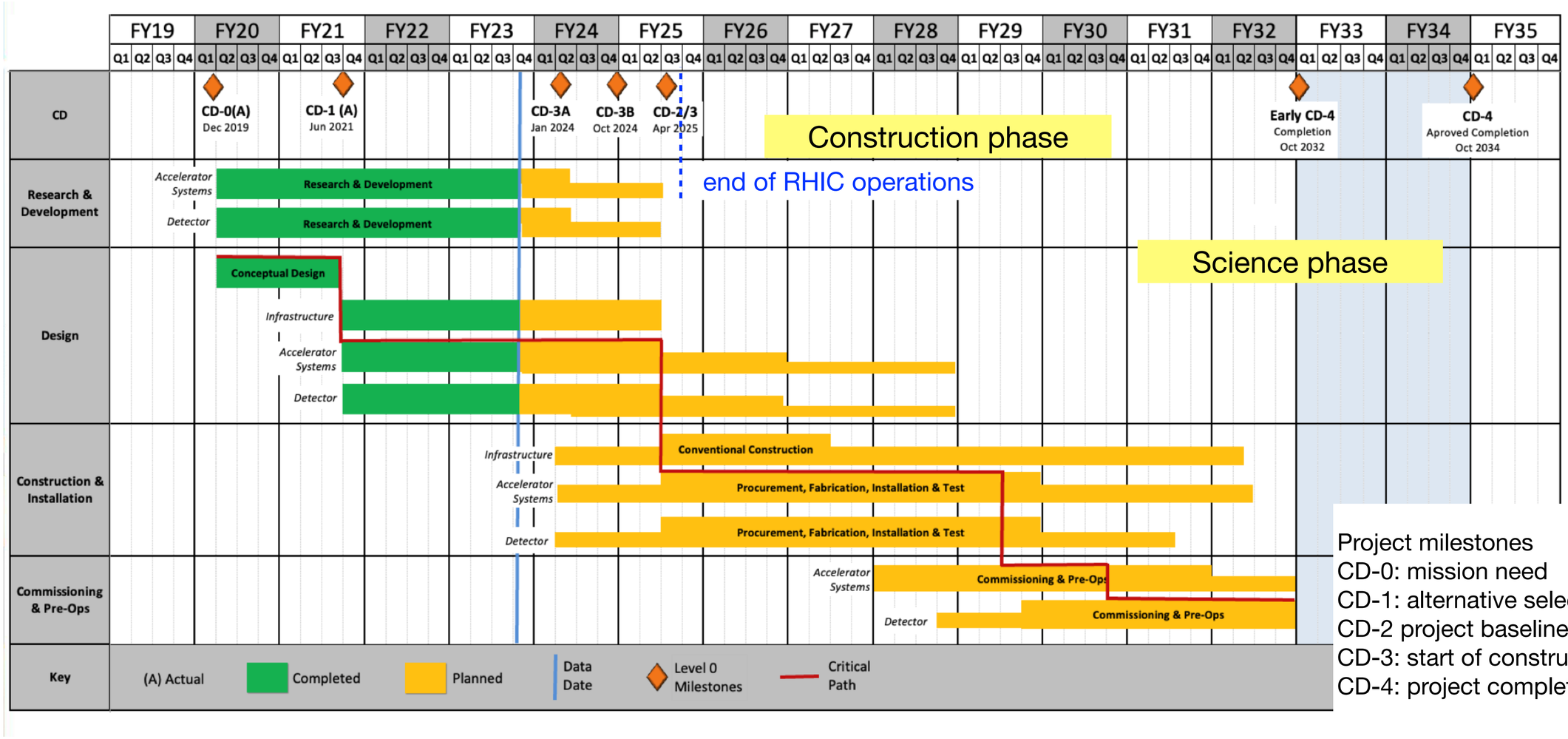


ATHENA, JINST **17** (2022) 10, P10019



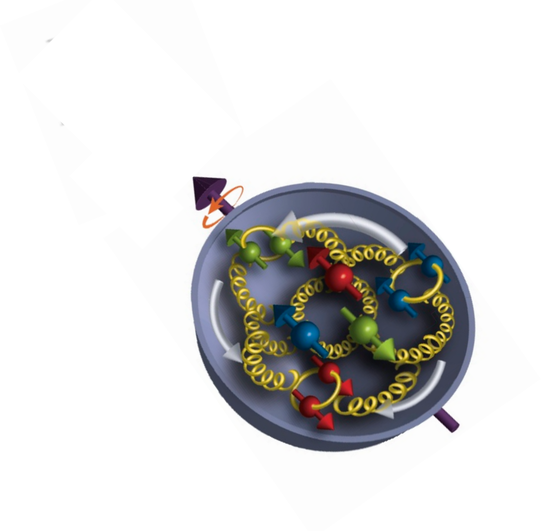
$$x_B = \frac{Q^2}{2P \cdot q}$$

Timeline

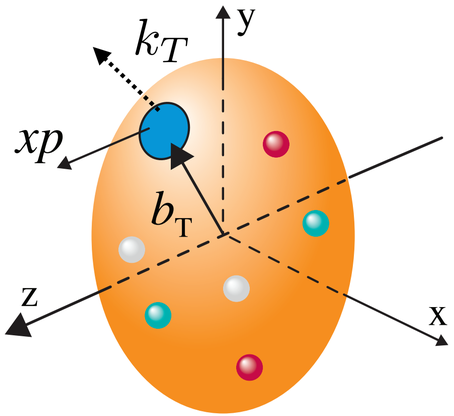


Project milestones
CD-0: mission need
CD-1: alternative selection, cost range
CD-2 project baseline
CD-3: start of construction
CD-4: project completion, start of operation

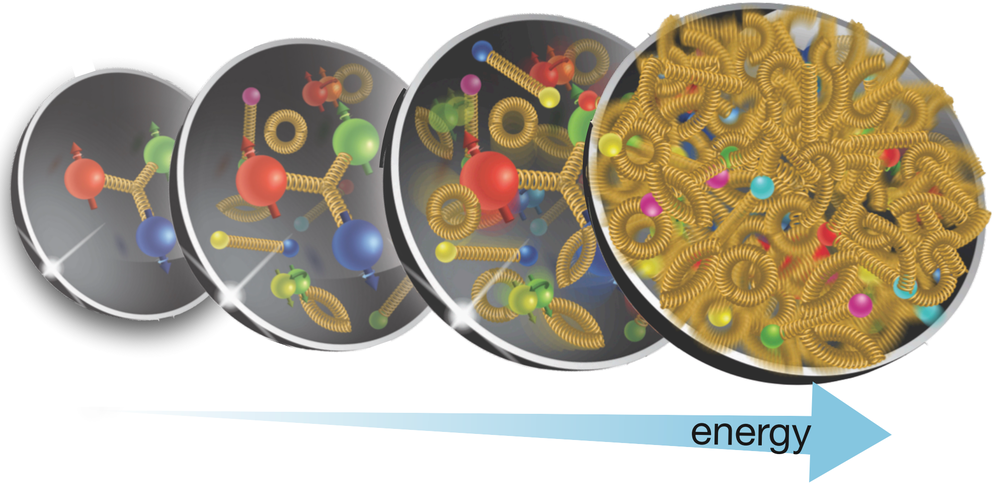
Research at the EIC



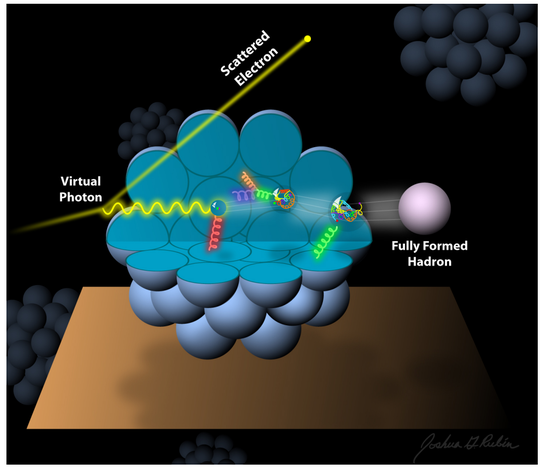
nucleon spin structure



nucleon multi-dimensional structure



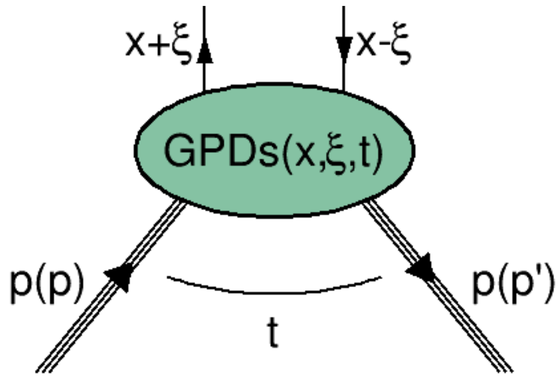
gluon saturation



hadron formation

Exclusive physics at the EIC: study of the proton

Generalised parton distributions (GPDs)



- x=average longitudinal momentum fraction
- 2ξ=longitudinal momentum transfer
- t=squared momentum transfer to hadron

- experimental access to t and ξ
- in general: no experimental access to x

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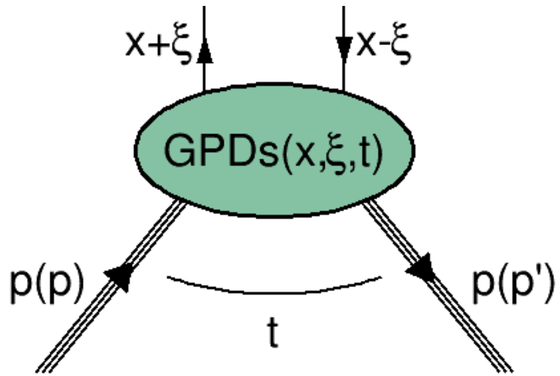

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for spin-1/2 hadron:

Four parton helicity-conserving twist-2 GPDs

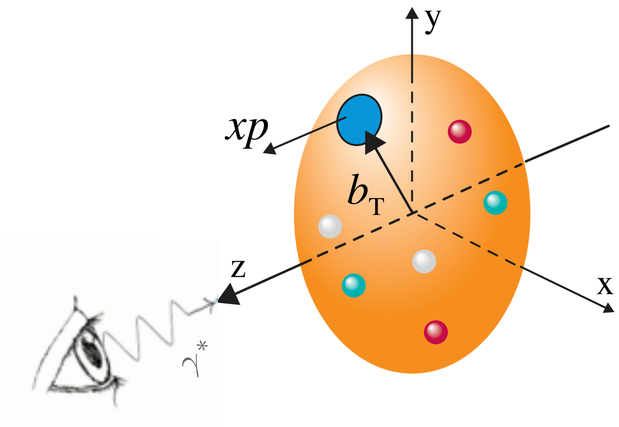
$H(x,\xi,t)$	$E(x,\xi,t)$	parton-spin independent
$\tilde{H}(x,\xi,t)$	$\tilde{E}(x,\xi,t)$	parton-spin dependent
proton helicity non flip	proton helicity flip	

Four parton helicity-flip twist-2 GPDs

$H_T(x,\xi,t)$	$E_T(x,\xi,t)$
$\tilde{H}_T(x,\xi,t)$	$\tilde{E}_T(x,\xi,t)$

GPDs and the nucleon structure

3D parton distributions



impact-parameter dependent distributions:
probability to find parton (x, b_T)

Fourier transform (ξ=0)

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JMP A **18** ('03) 173

GPDs

GPDs and the nucleon structure

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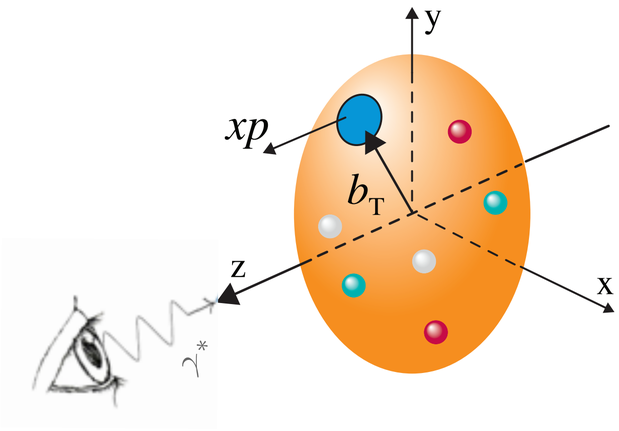

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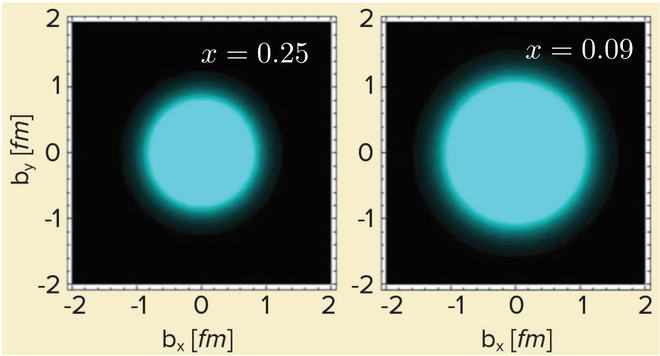

GPDs and the nucleon structure

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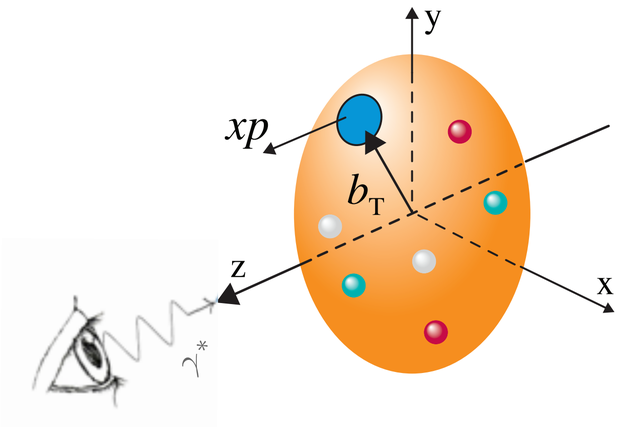

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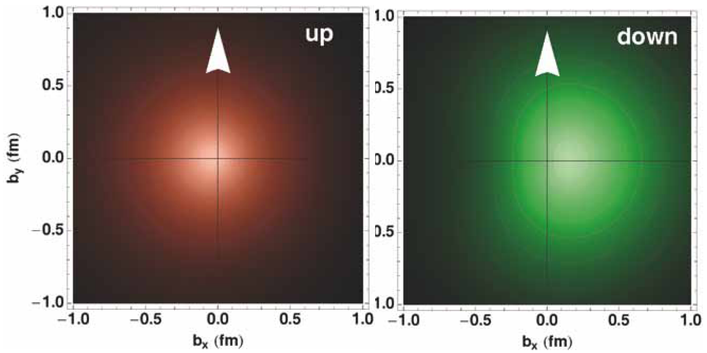

GPDs and the nucleon structure

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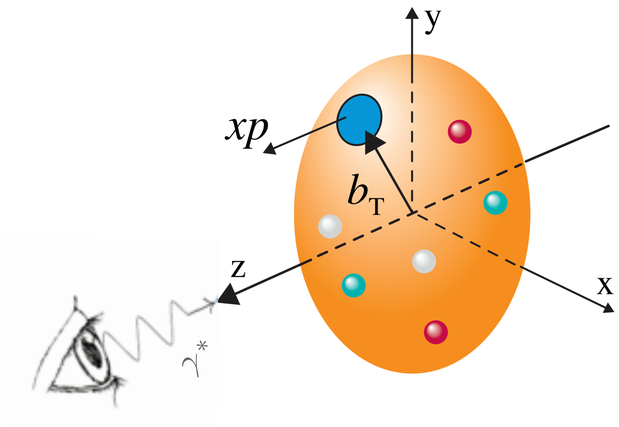

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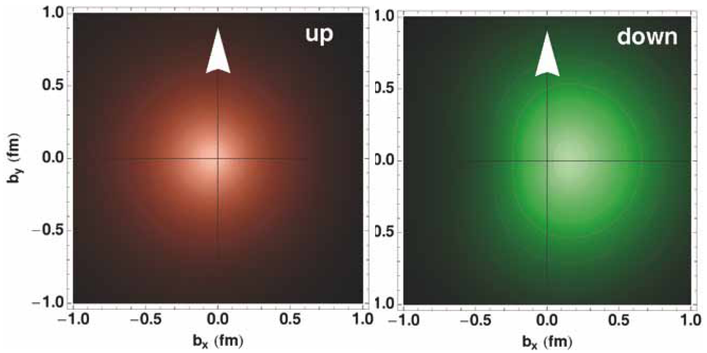


pressure distributions

GPDs

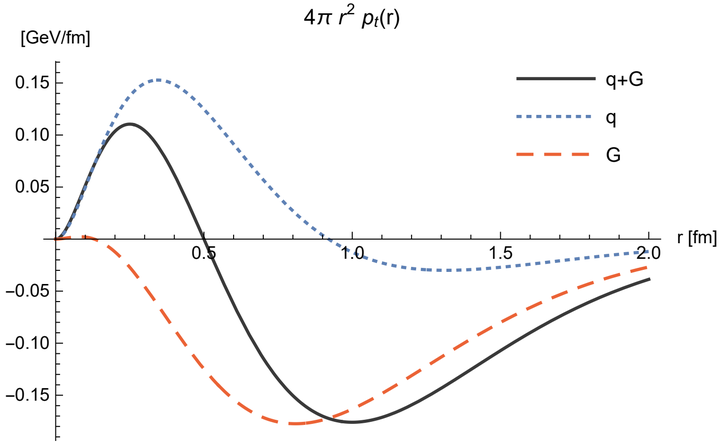
↓

gravitational form factors

↓ Fourier transform

pressure distributions

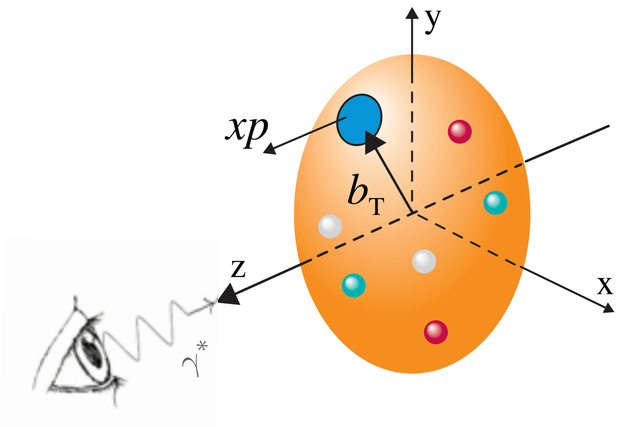
tangential pressure



C. Lorcé, H. Moutarde, A. P. Trawiński EPJ. C **79** ('19) 89

GPDs and the nucleon structure

3D parton distributions

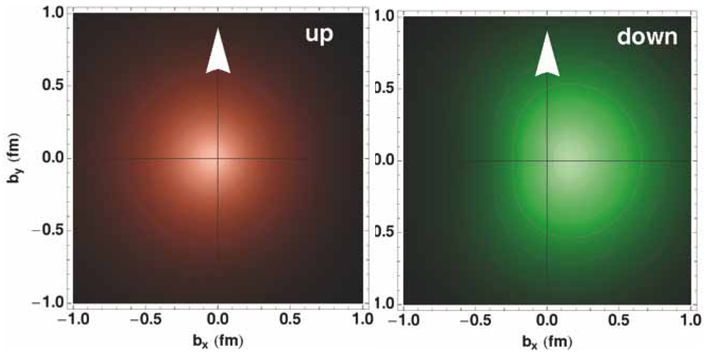


impact-parameter dependent distributions.
probability to find parton (x, b_T)

Fourier transform (ξ=0)

M. Burkardt,
PRD **92** ('00) 071503
JMP A **18** ('03) 173

GPDs



pressure distributions

GPDs

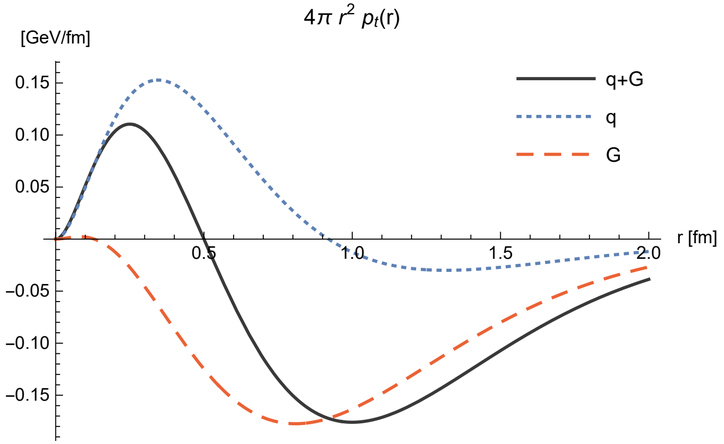
↓

gravitational form factors

↓ Fourier transform

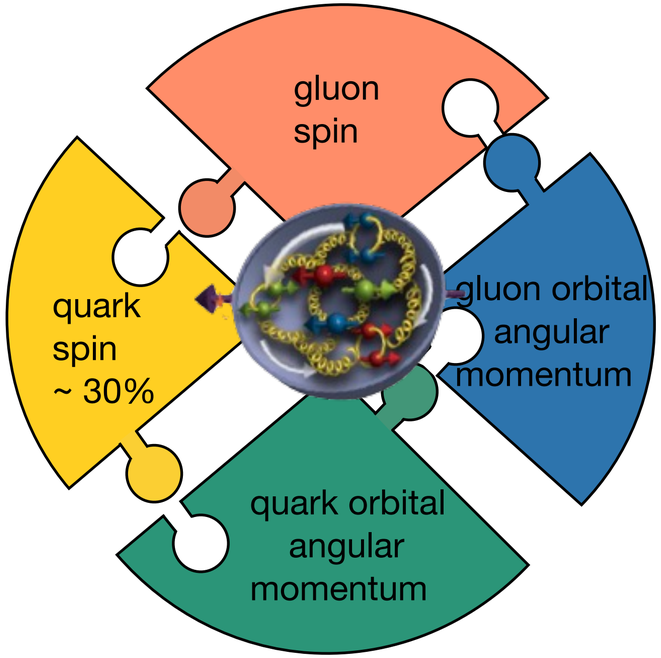
pressure distributions

tangential pressure



C. Lorcé, H. Moutarde, A. P. Trawiński EPJ. C **79** ('19) 89

angular momentum

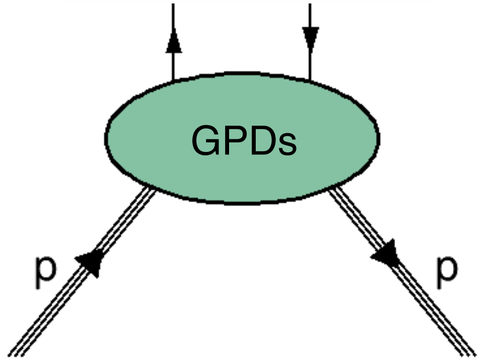


Ji relation:

$$J^{q,g} = \lim_{t\to 0} \frac{1}{2} \int_{-1}^{1} dx\, (x)[H^{q,g}(x,\xi,t) + E^{q,g}(x,\xi,t)]$$

X. Ji, PRL **78** (1997) 610

Experimental access to GPDs



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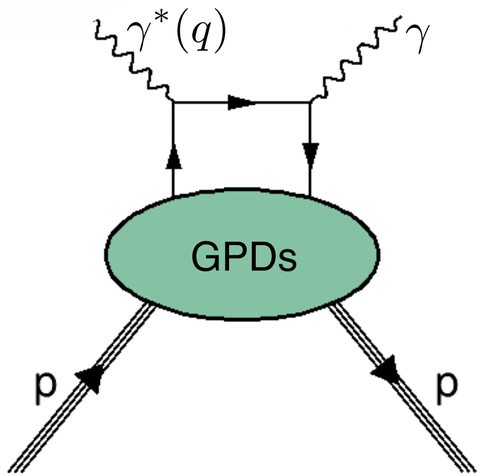
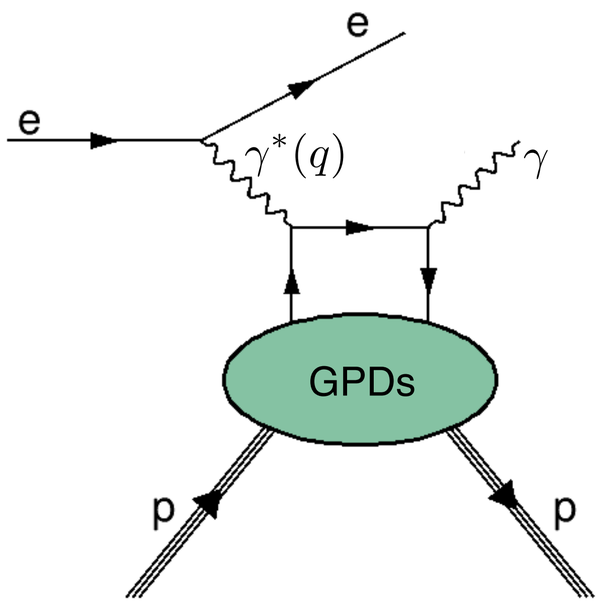


Deeply virtual Compton scattering (DVCS)
Hard scale=large $Q^2=-q^2$

Experimental access to GPDs



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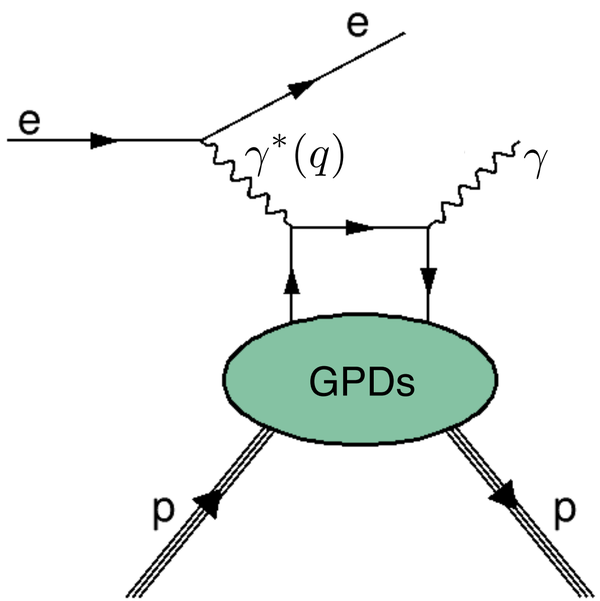

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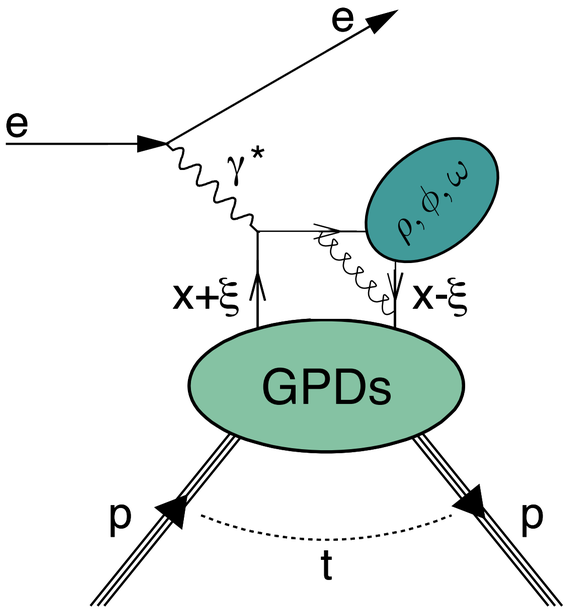
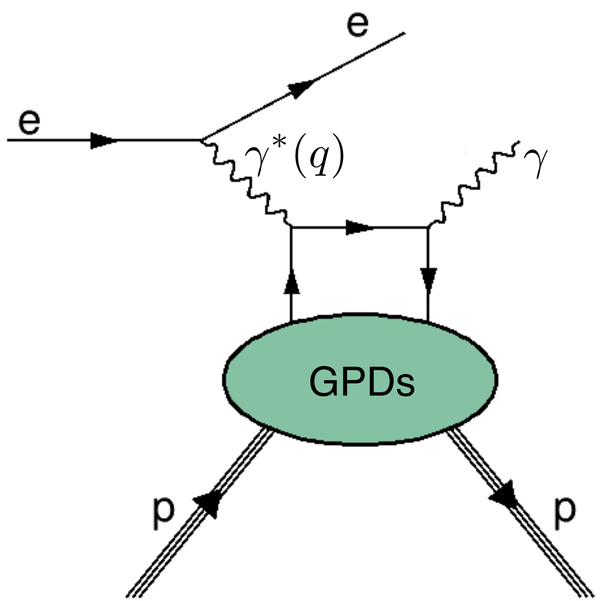


Hard exclusive meson production
Hard scale=large Q^2

Experimental access to GPDs



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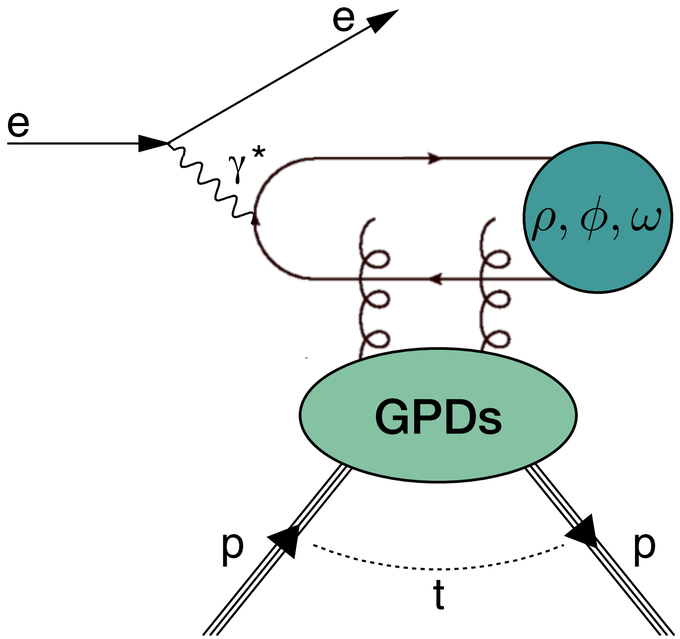

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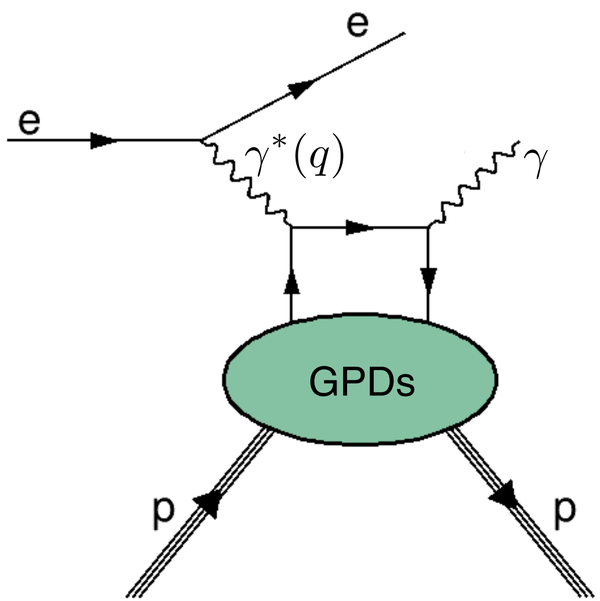

Deeply virtual Compton scattering (DVCS)
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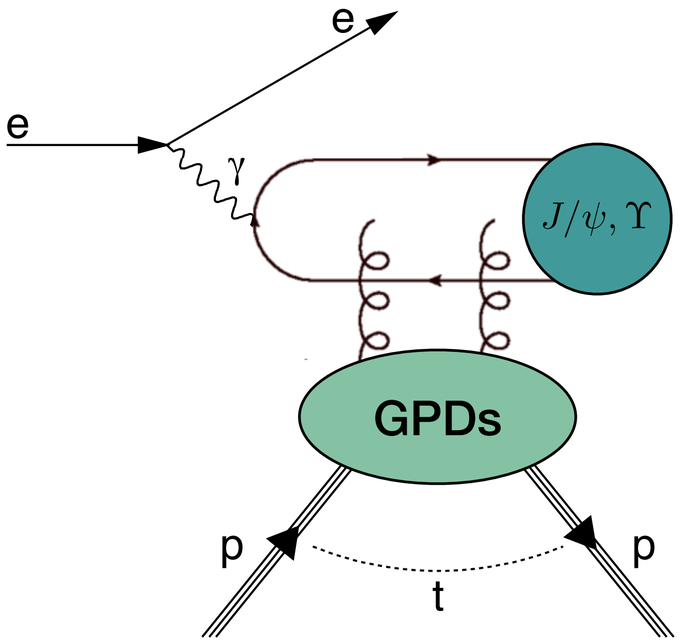
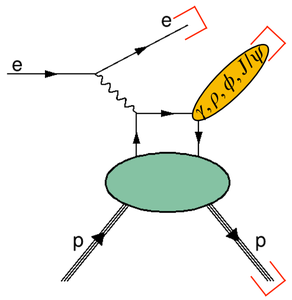


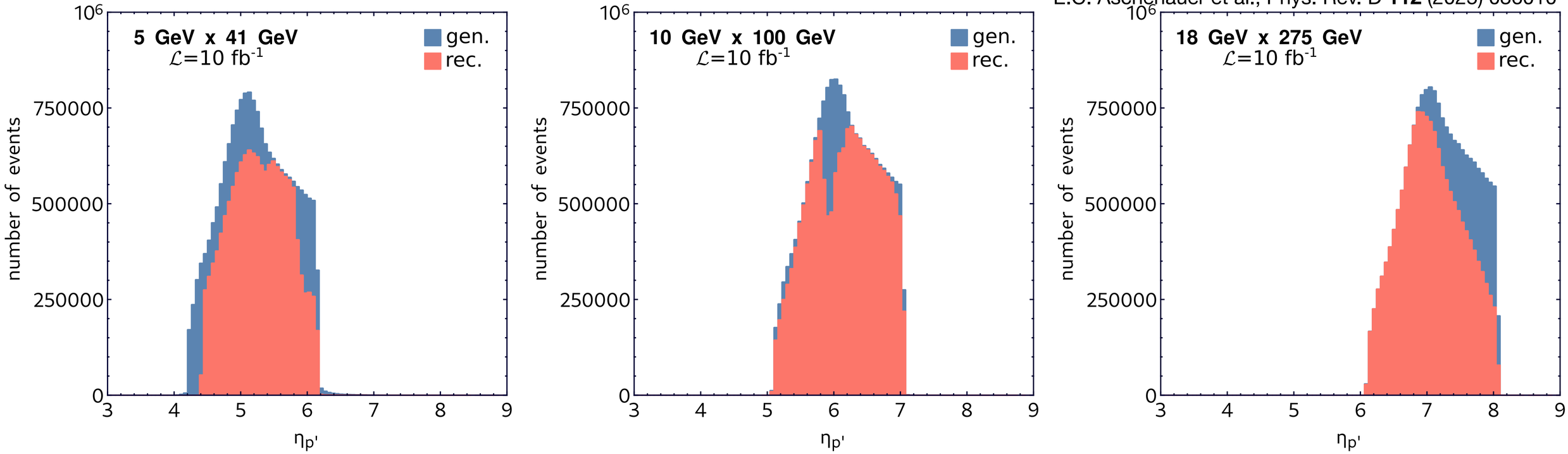
Exclusive meson photoproduction
Hard scale = large charm/bottom-quark mass

Reconstruction of the scattered proton in DVCS



Complementarity of far-forward B0 and roman pots

E.C. Aschenauer et al., Phys. Rev. D **112** (2025) 036010

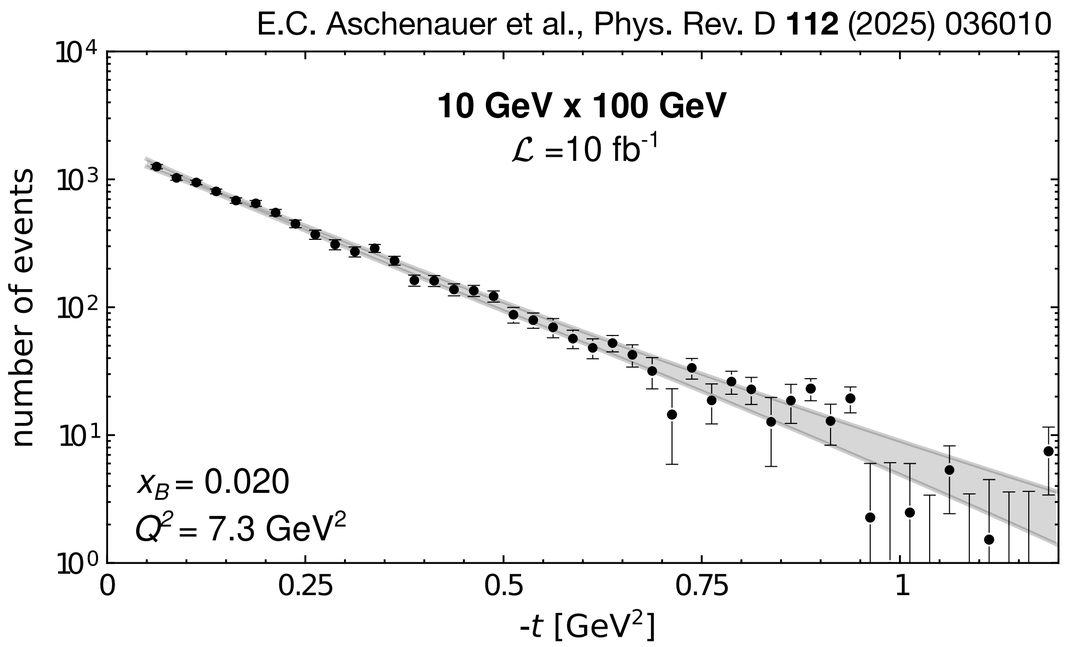


B0 | Roman pots

Figures do not include momentum smearing; only acceptance effects are shown.

Reconstruction of DVCS at the EIC and impact on GPD determination

DVCS after efficiency and acceptance corrections



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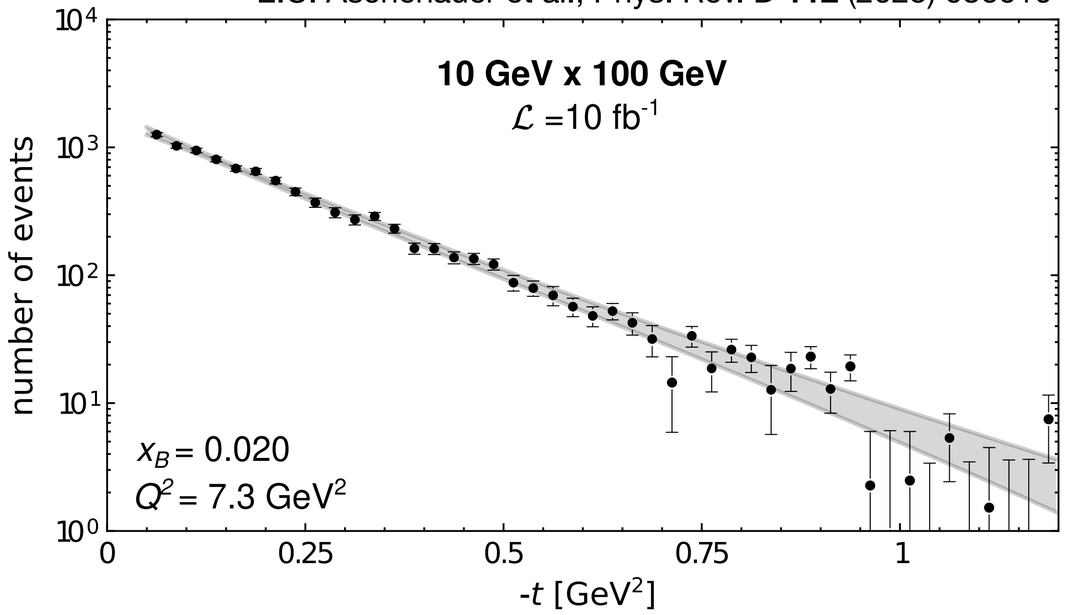
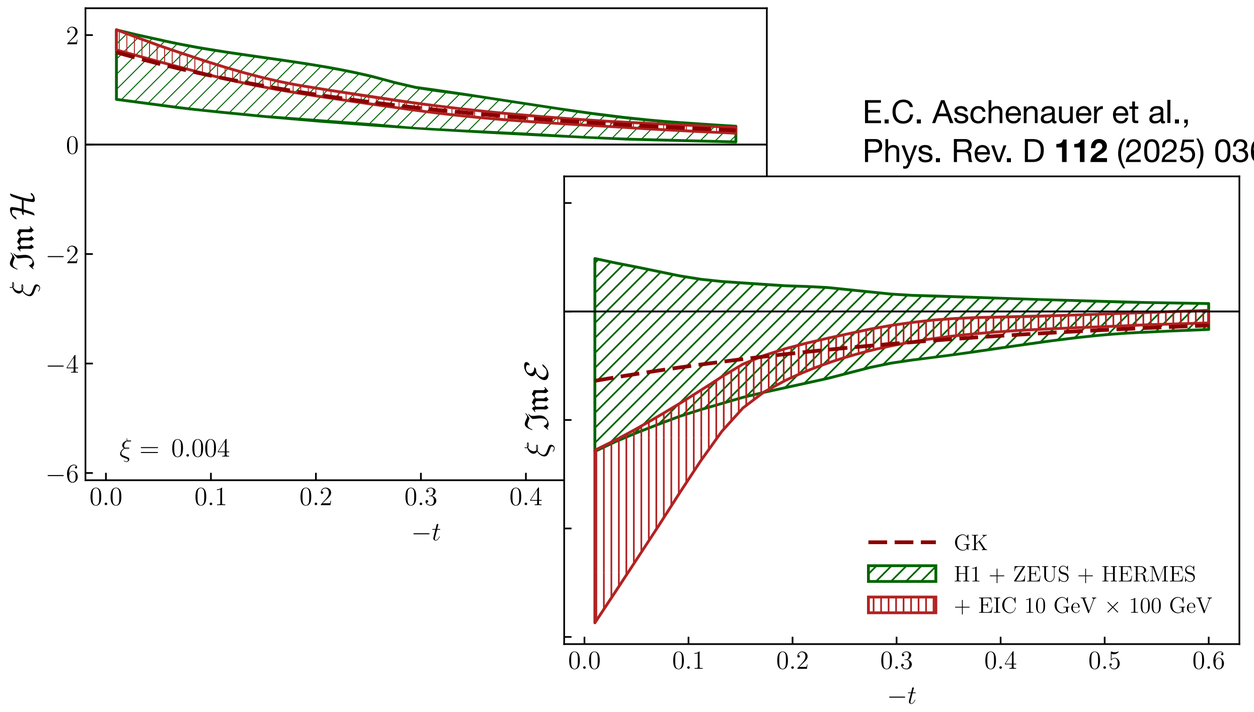
E.C. Aschenauer et al., Phys. Rev. D **112** (2025) 036010



Lepton-beam helicity asymmetry

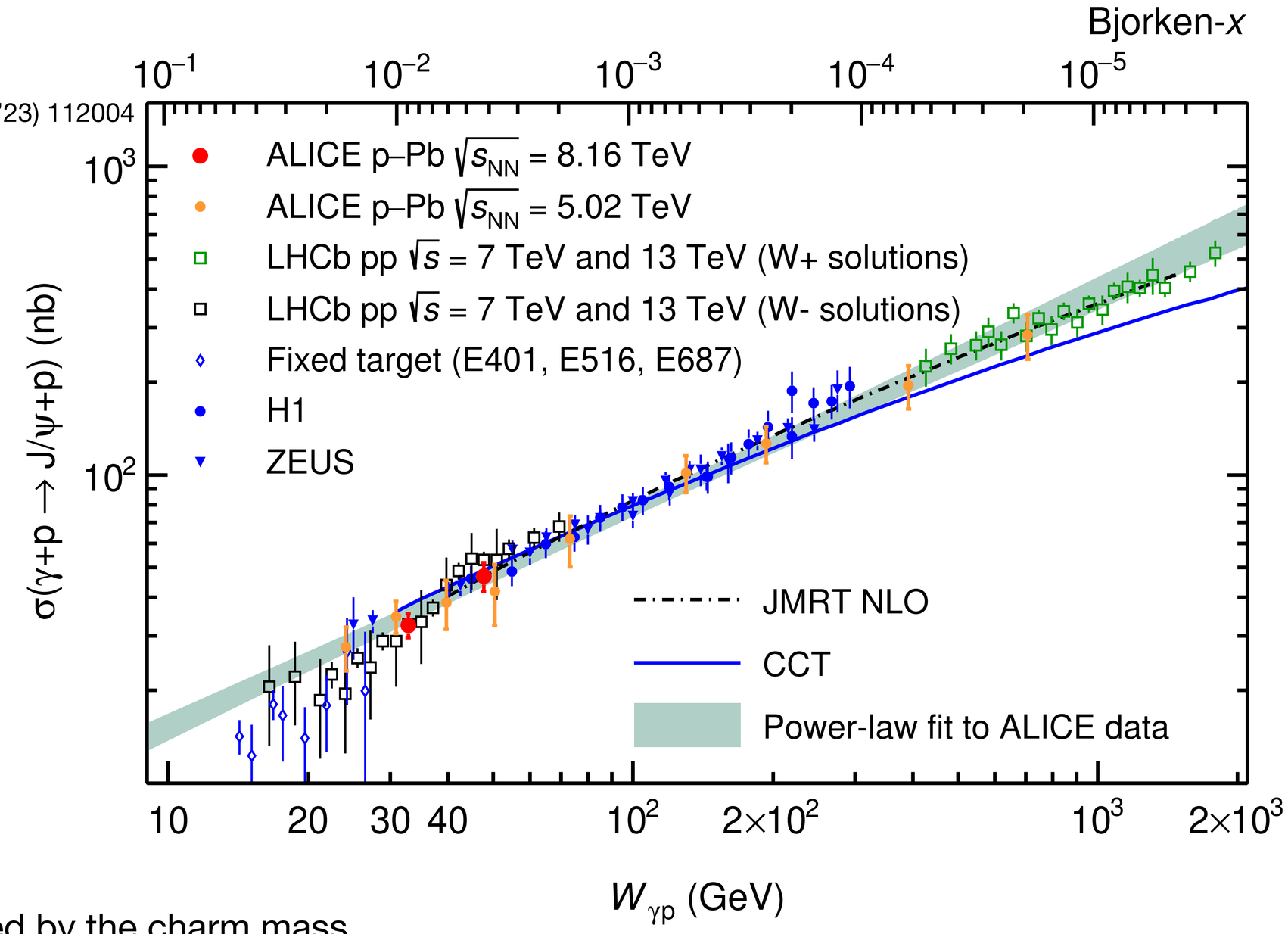
$$\rightarrow \mathrm{Im}\left(F_1 \mathcal{H} + -\frac{t}{4m^2} F_2 \mathcal{E} + \ldots \right)$$

E.C. Aschenauer et al.,
Phys. Rev. D **112** (2025) 036010



Complementarity with the LHC: kinematic coverage

Phys. Rev. D **108** ('23) 112004

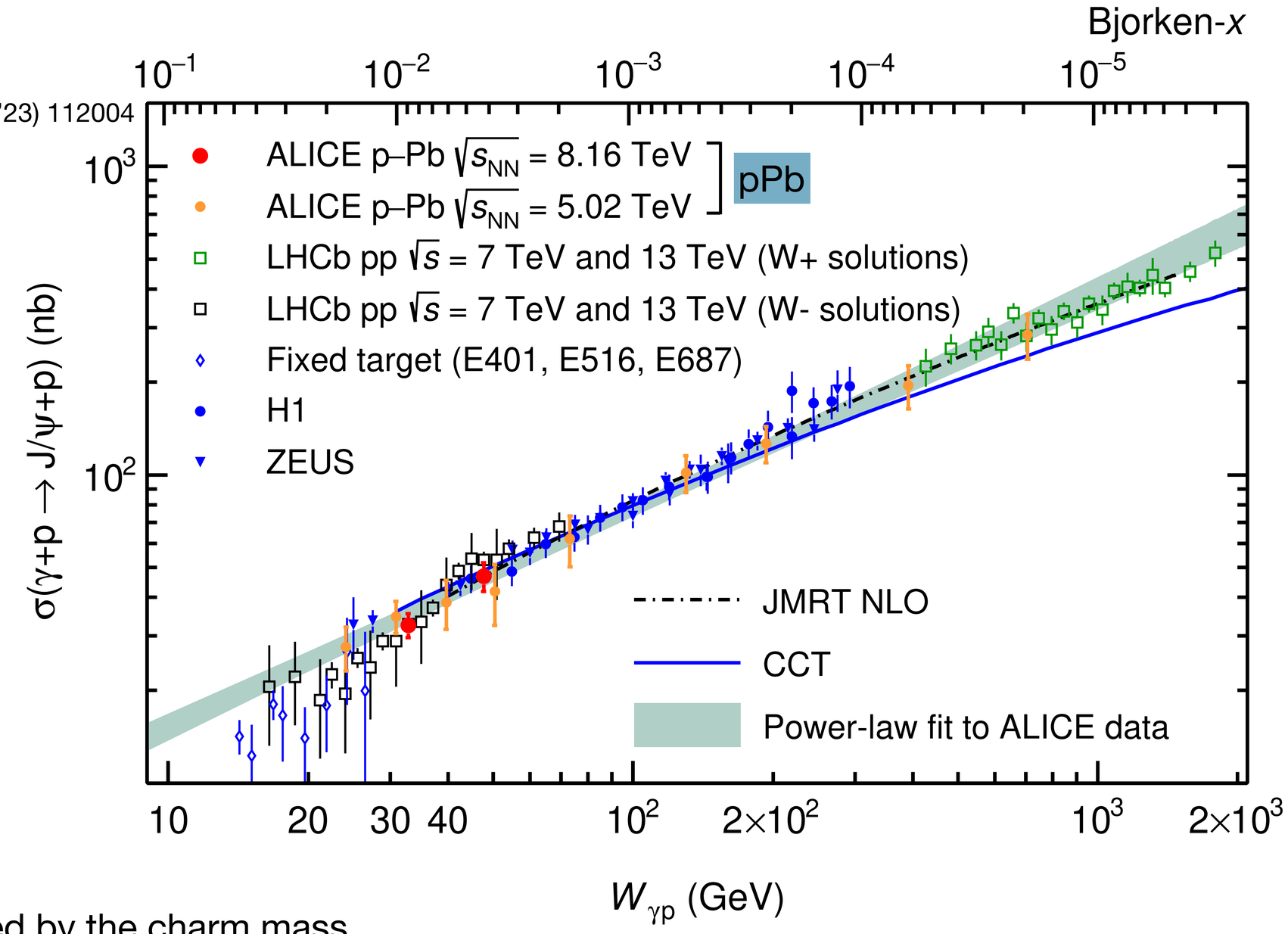


GPD H

Hard scale: fixed by the charm mass

Complementarity with the LHC: kinematic coverage

Phys. Rev. D **108** ('23) 112004



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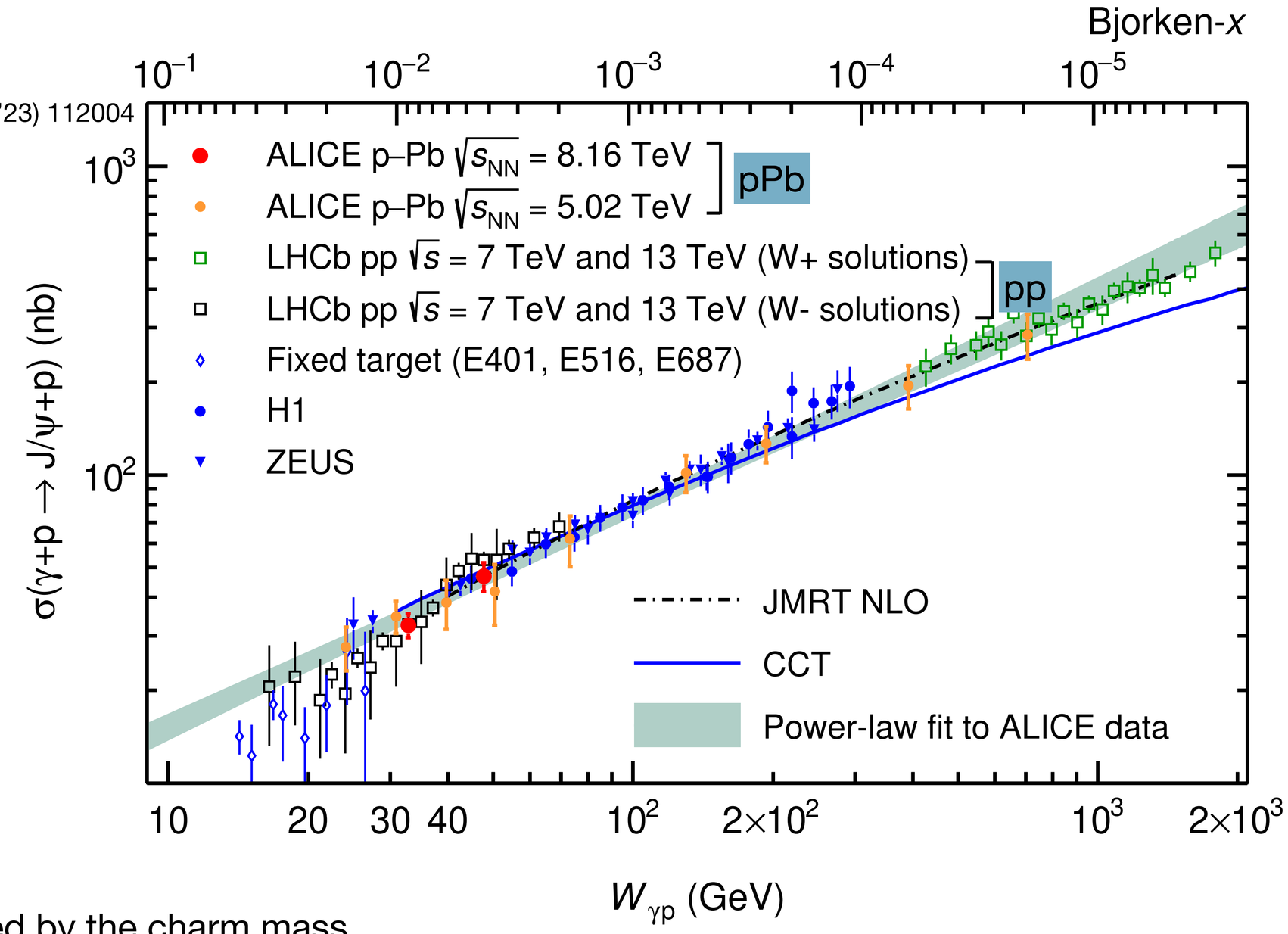
Phys. Rev. D **108** ('23) 112004



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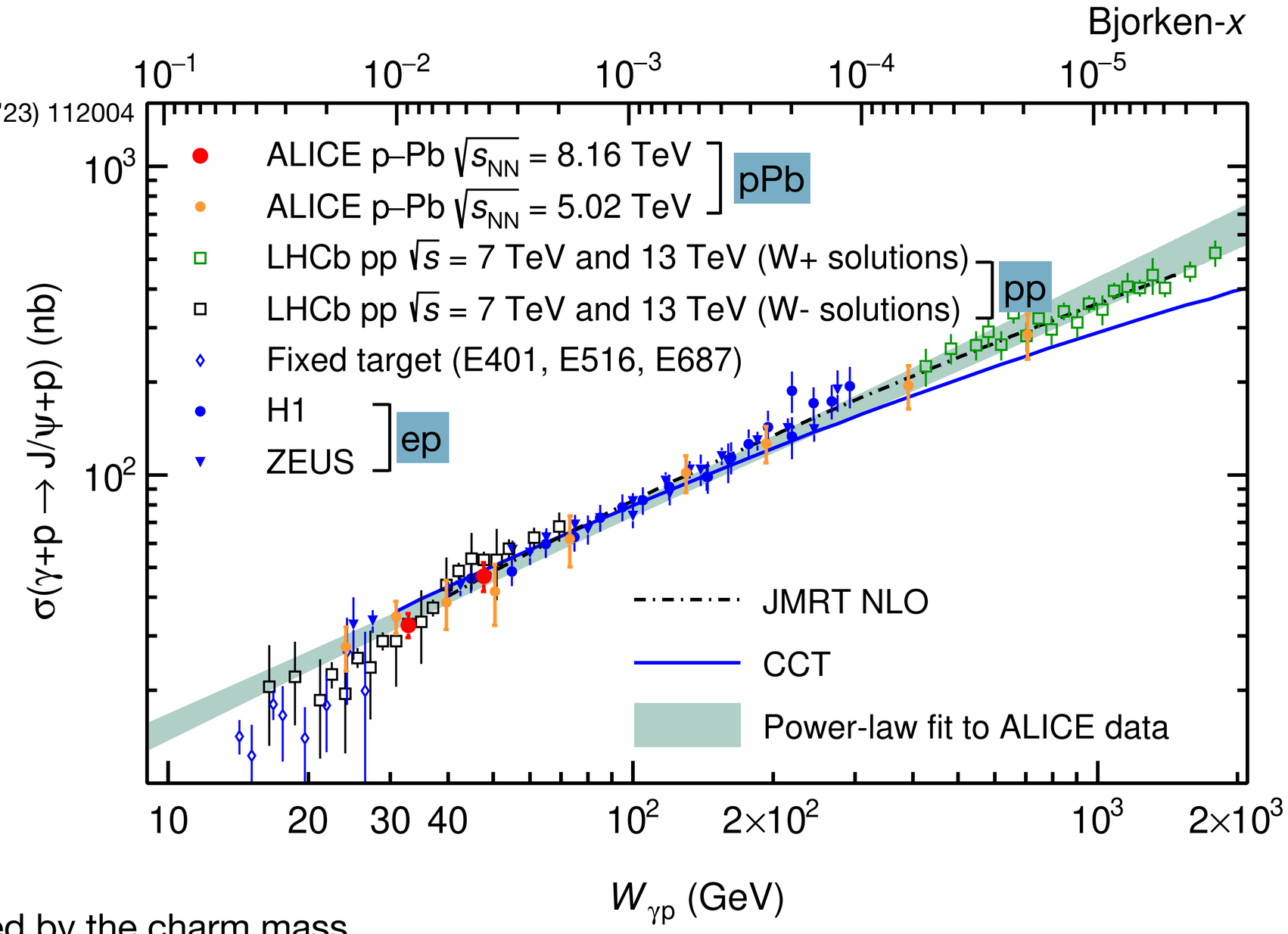
Phys. Rev. D **108** ('23) 112004



GPD H

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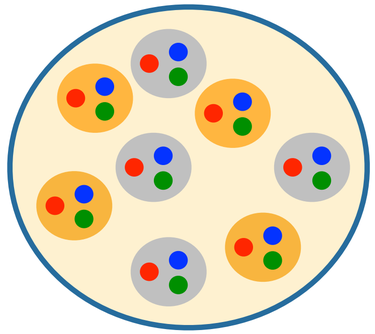
Exclusive physics at the EIC: study of nuclei

What object are we probing?



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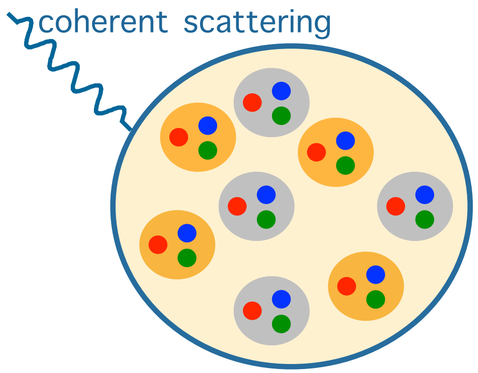

Coherent interaction: interaction with target as a whole.
~ target remains in same quantum state.

Exclusive physics at the EIC: study of nuclei

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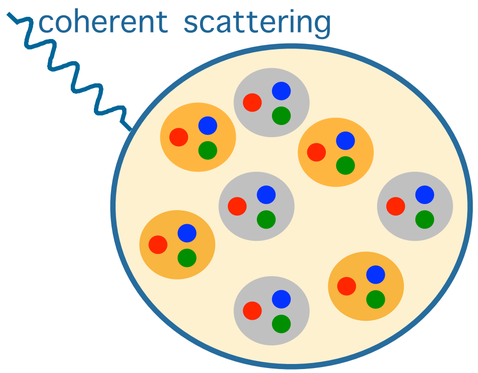
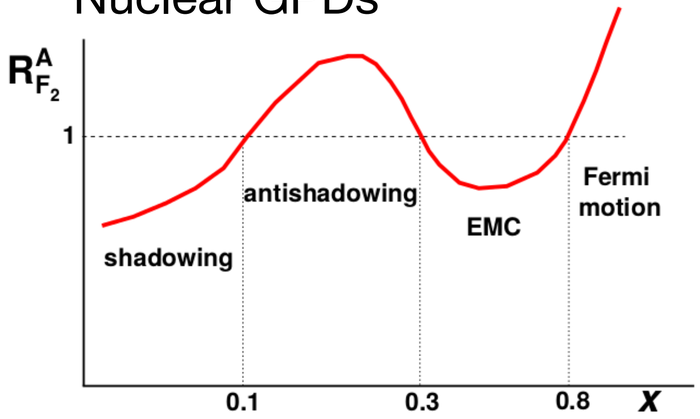


Nuclear GPDs



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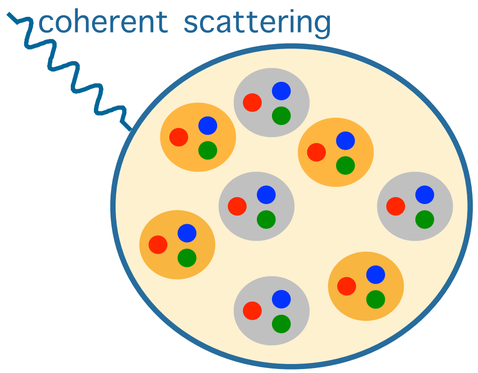

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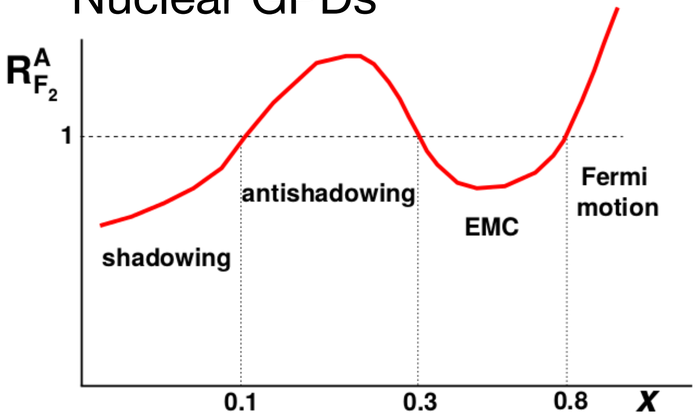
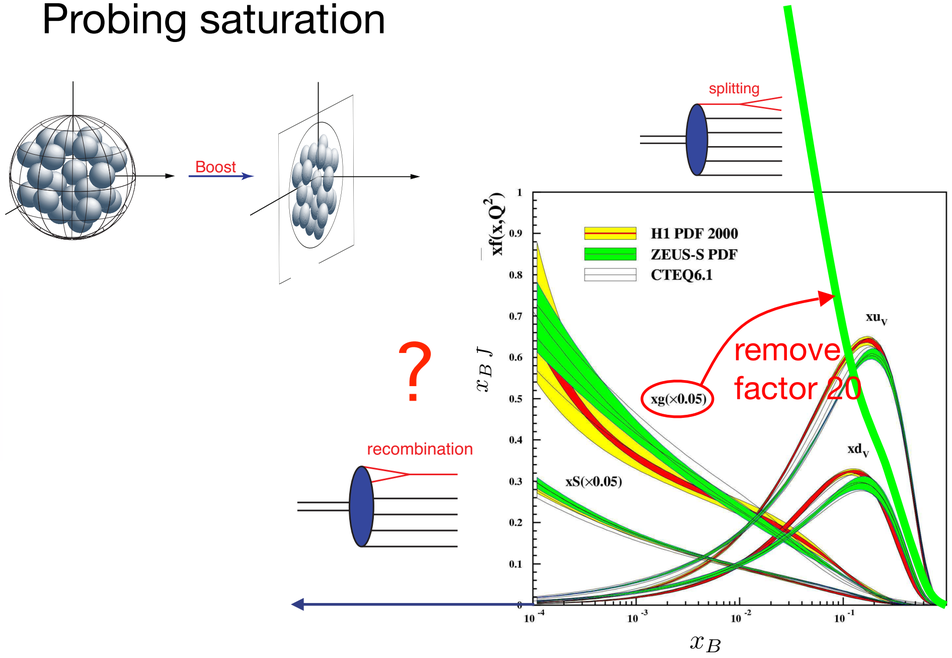


Probing saturation



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Exclusive physics at the EIC: study of nuclei

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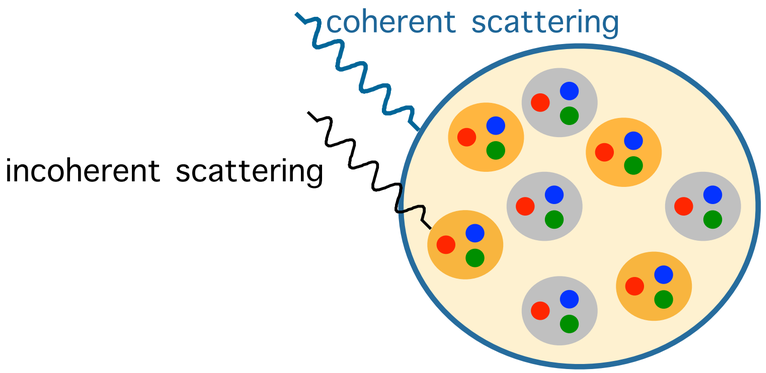

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Incoherent interaction: interaction with constituents inside target.
~ target does not remain in same quantum state.
Ex.: target dissociation, excitation

Exclusive physics at the EIC: study of nuclei

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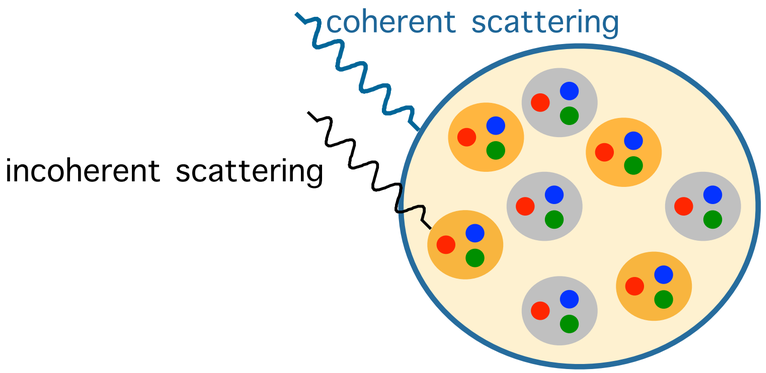

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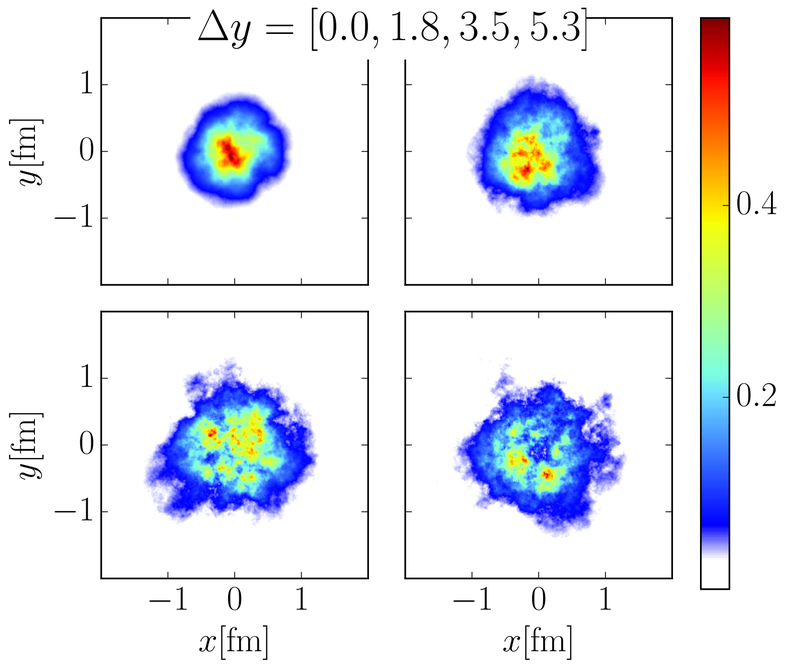
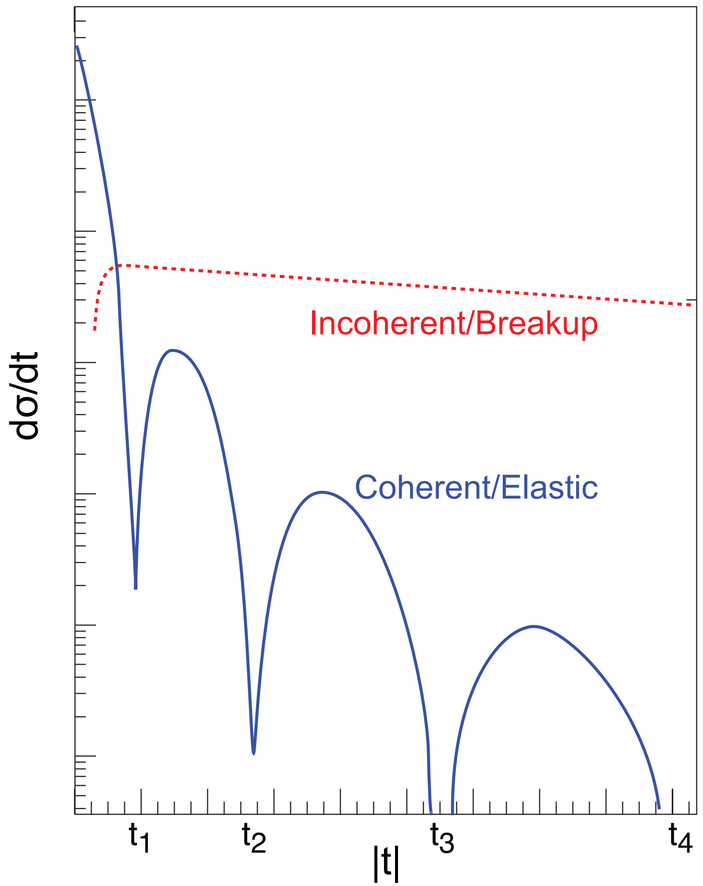


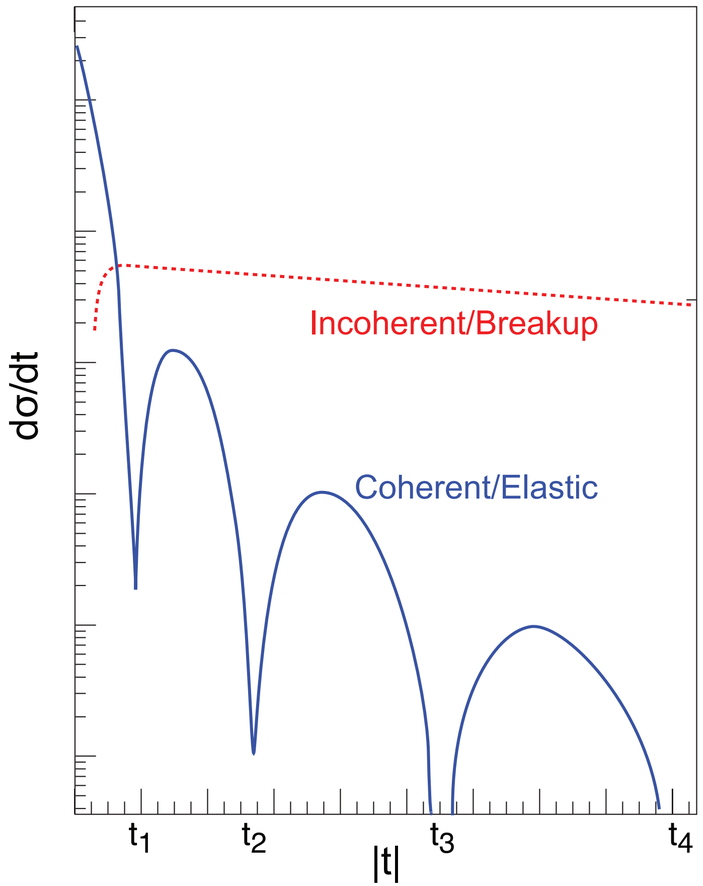
H. Mäntysaari and B. Schenke.
Phys. Rev. D 98, 034013 (2018)

Experimentally important points



Experimentally important points

- Need good separation of coherent and incoherent signal
- Need good reconstruction of t



Experimentally important points

- Need good separation of coherent and incoherent signal
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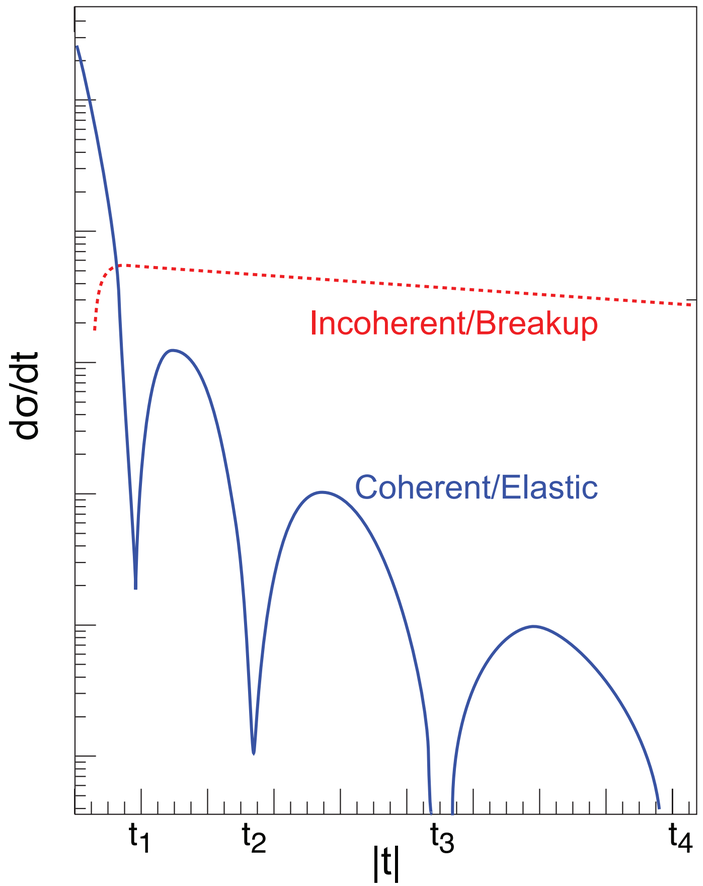
- Coherent production: measurements up to large t:
  - 3D or 2D (x independent) transverse position

$$\int_0^{\infty} d\Delta_\perp \, \mathrm{GPD}(x, 0, \Delta_\perp) \, e^{-ib_\perp \Delta_\perp}$$

Experimentally limited by maximum transverse momentum.
Need to extend p_T range as much as possible in measurement.
~third diffractive minimum.



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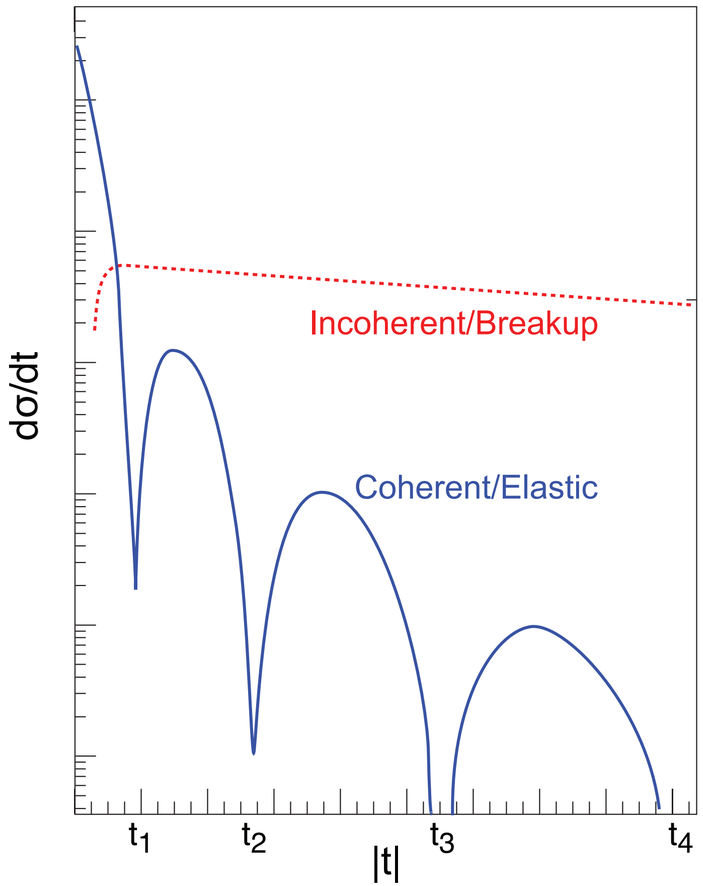
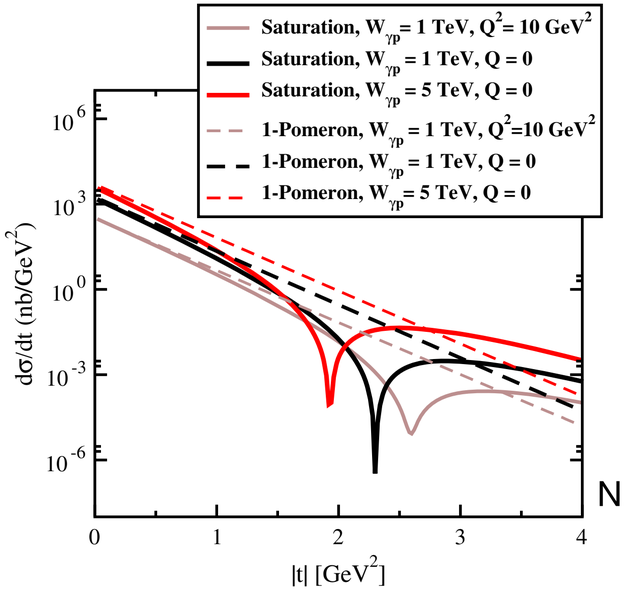


  - Saturation:

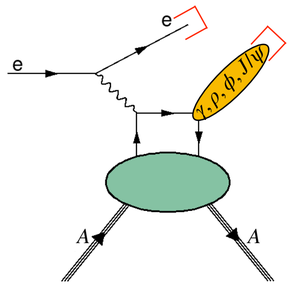
    determine dip position indirectly
    via slope and probe its dependence
    With $W_{\gamma p}$

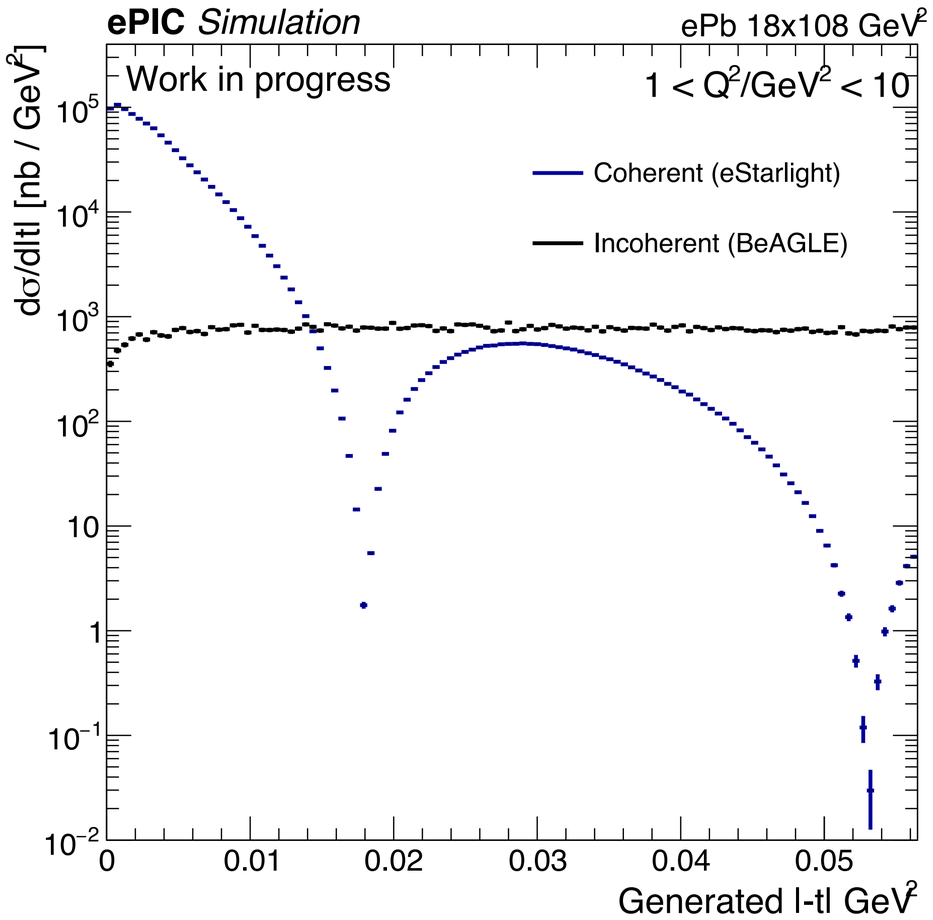


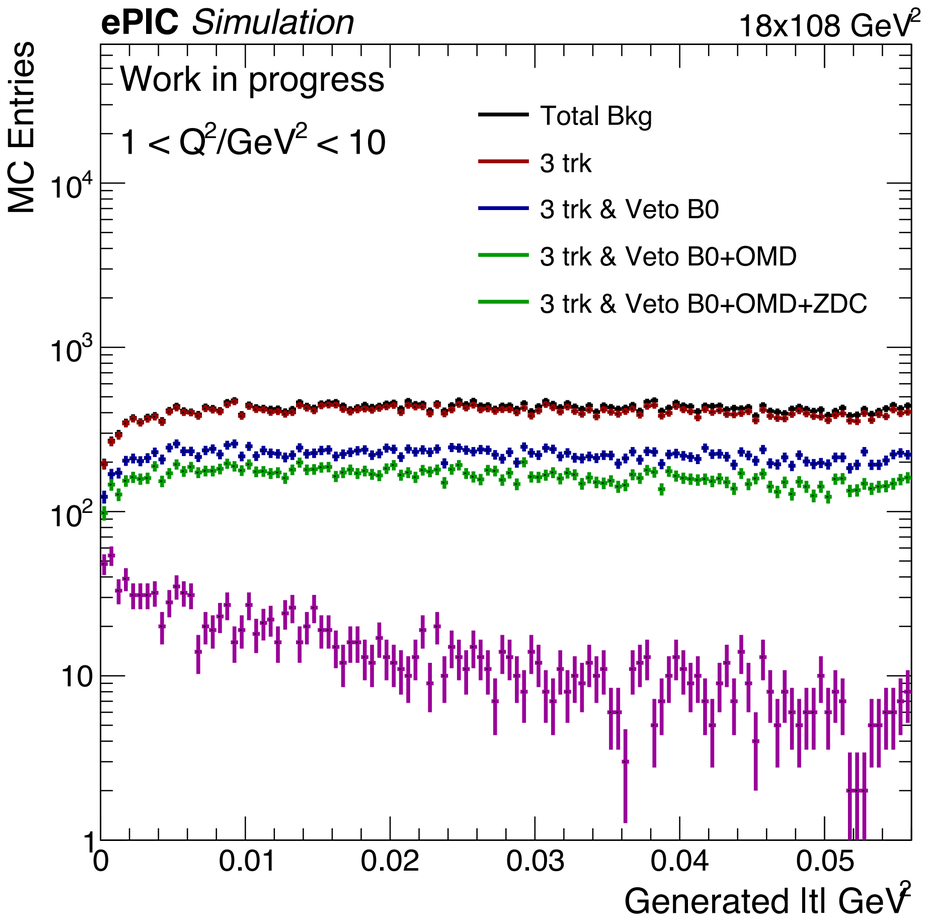
N. Armesto and A. H. Rezaeian, Phys. Rev. D **90** (2014) 054003.

Reconstruction at the EIC

Separation of coherent and incoherent signal







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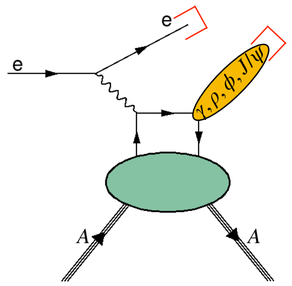
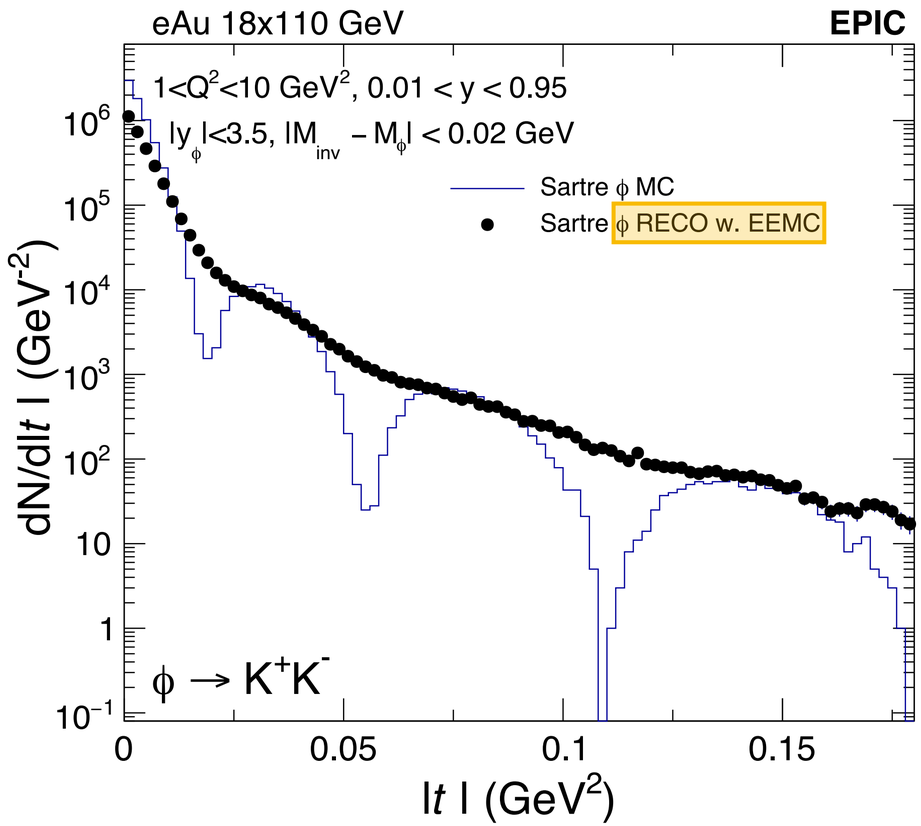
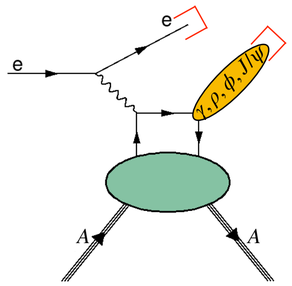


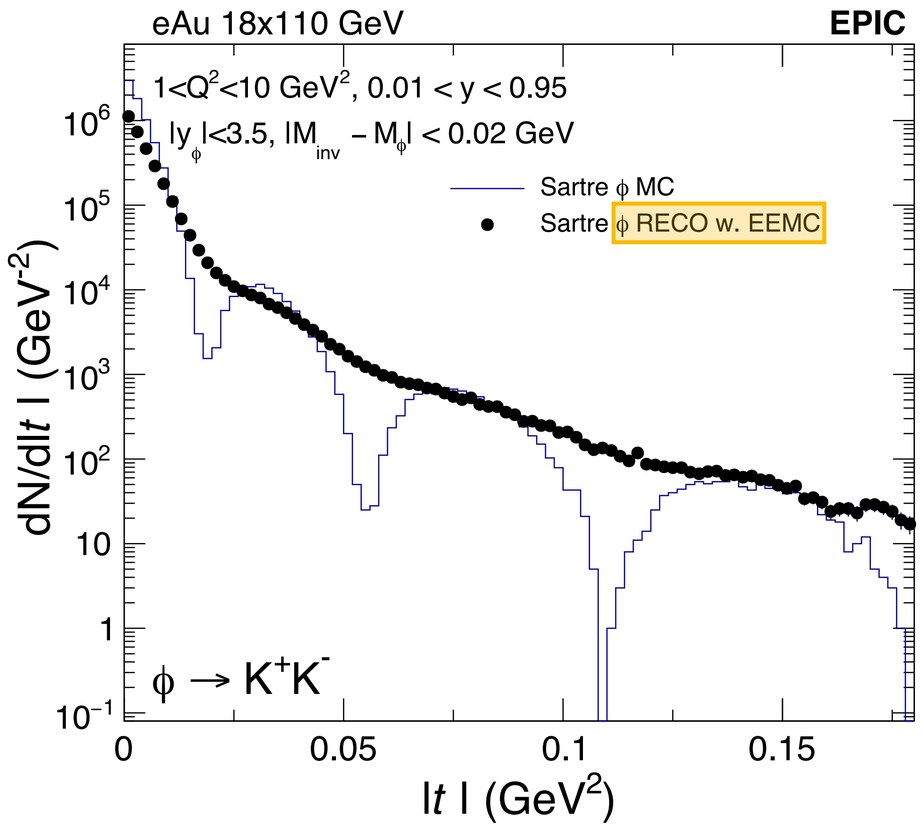
Resolution in t



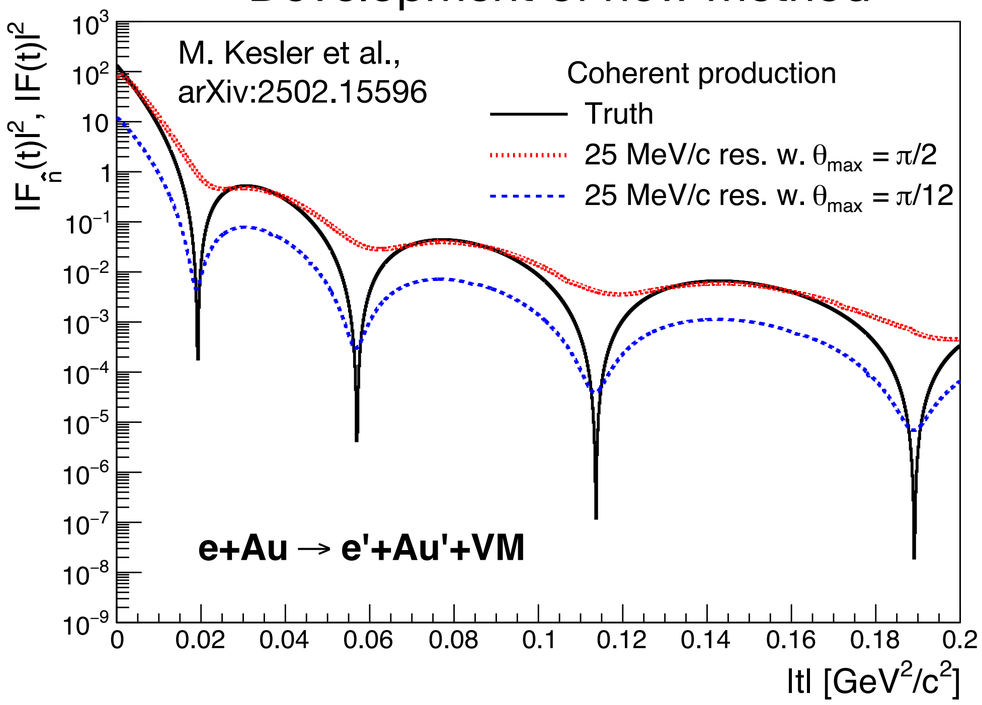
Reconstruction at the EIC

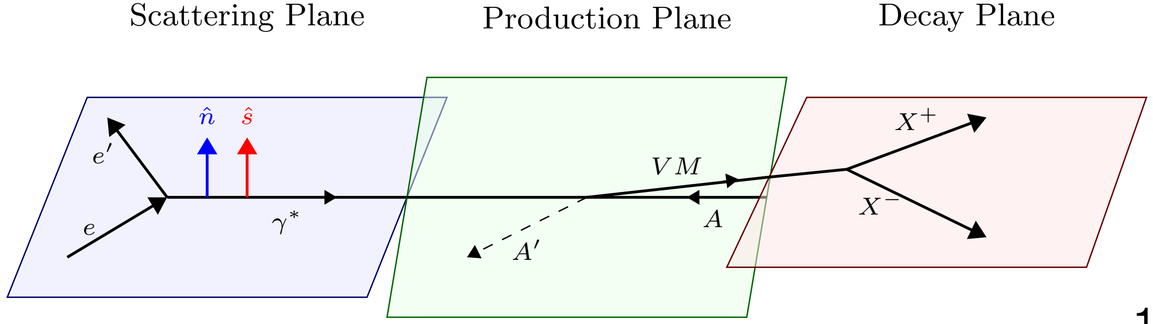


Resolution in t



Development of new method





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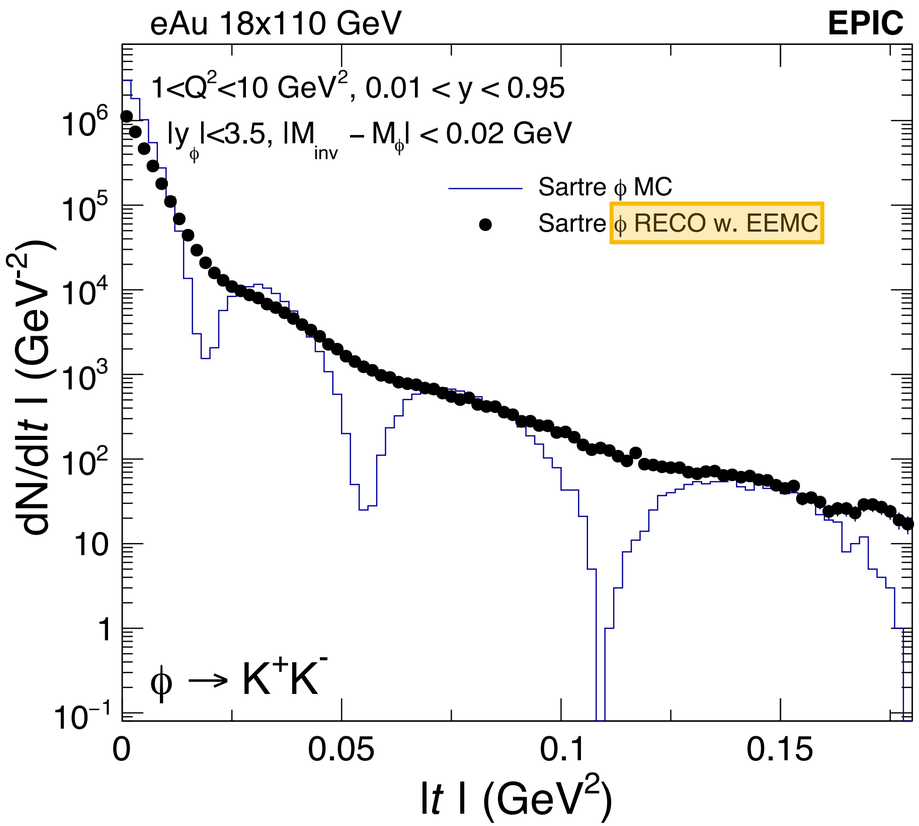
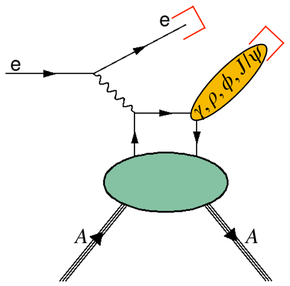
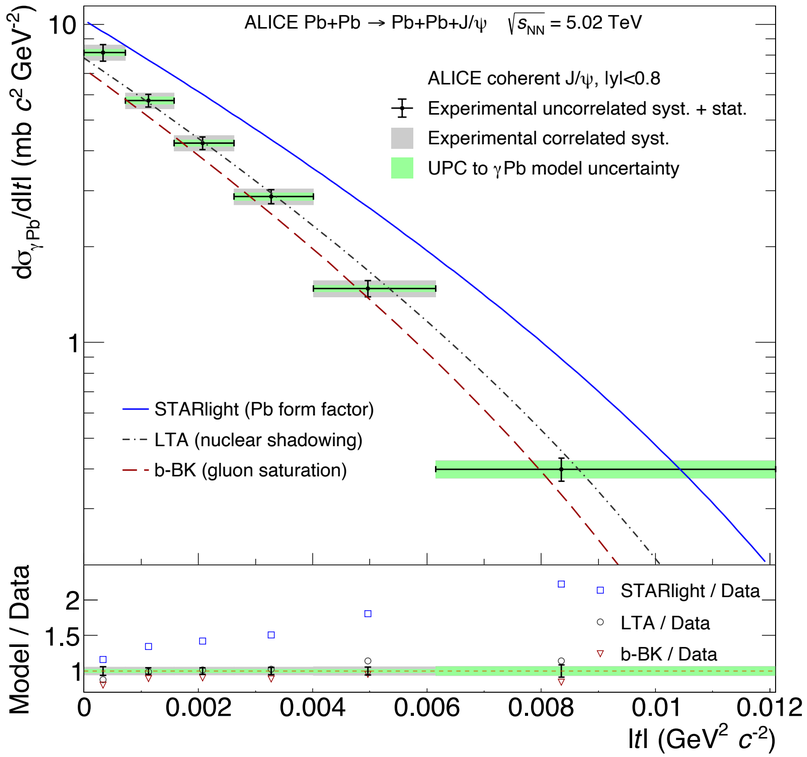
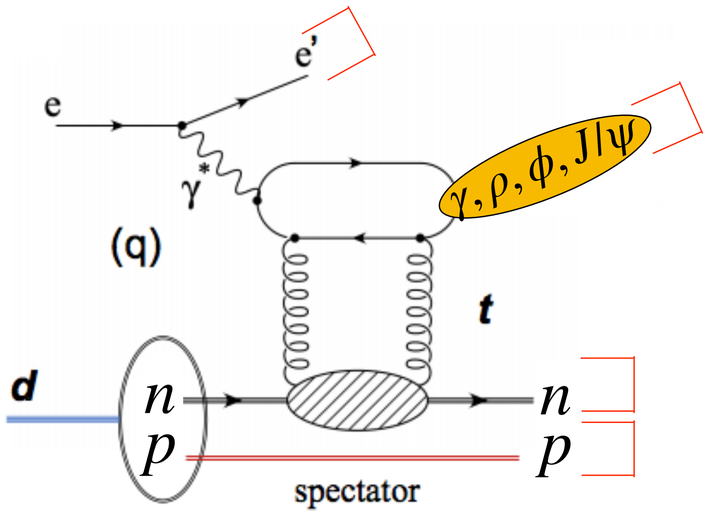




LHC ALICE, Phys. Lett. B **817** (2021) 136280



Tagging of exclusive processes with light nuclei



Access to quasi-free neutron
Different flavour combinations of GPDs

Study of short-range correlations

Z. Tu et al., Phys. Lett. B **811** (2020) 135877

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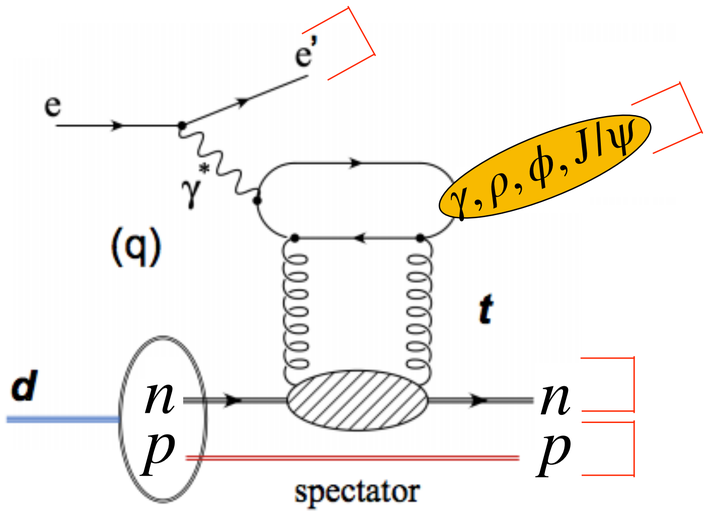

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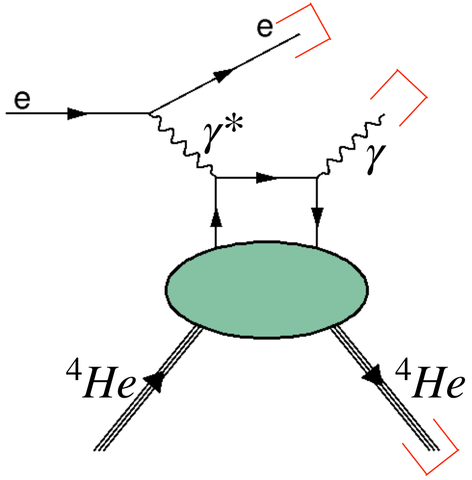

Spin-0 particle:
1 leading-twist GPD

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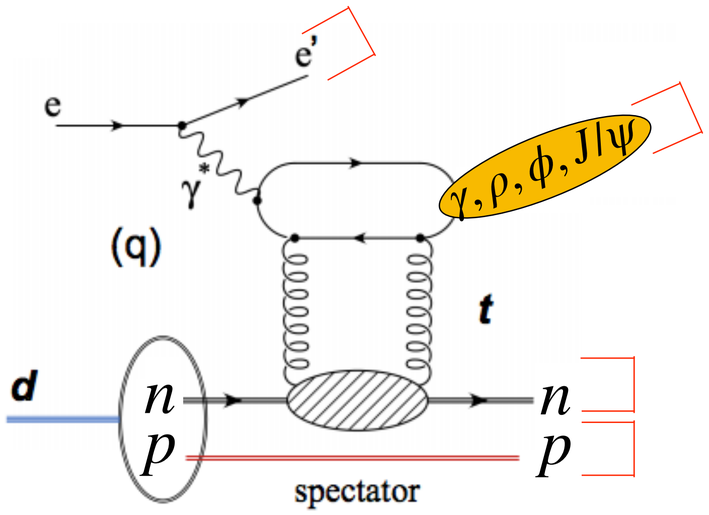

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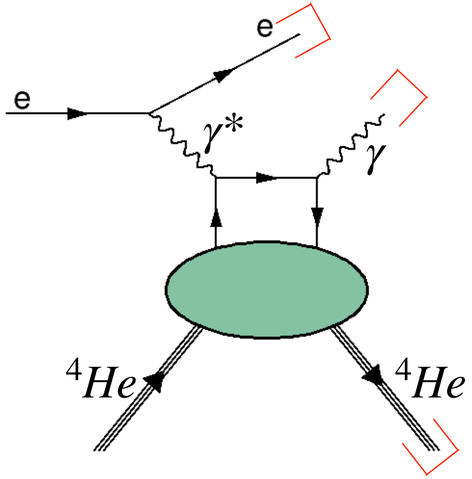

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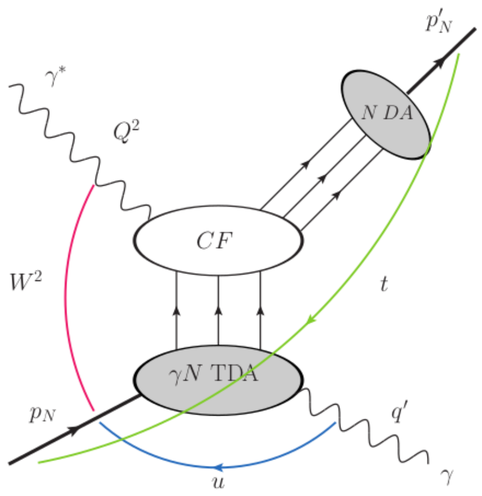

u-channel DVCS

Summary and outlook

- The EIC will provide measurements of exclusive processes of very high precision
- Complementarity of different beam energies: extended kinematic coverage
- Polarisation of electron and proton beam in hard exclusive photon and meson production: access to all, eight leading-twist GPDs
- EIC covers large variety of nuclei
  → valuable for study of nuclear effects and saturation
- Efforts for a second detector at IR8 ongoing:
  - Access to lower t in exclusive processes compared to ePIC
  - Detection of heavier nuclei in exclusive, coherent scattering compared to ePIC