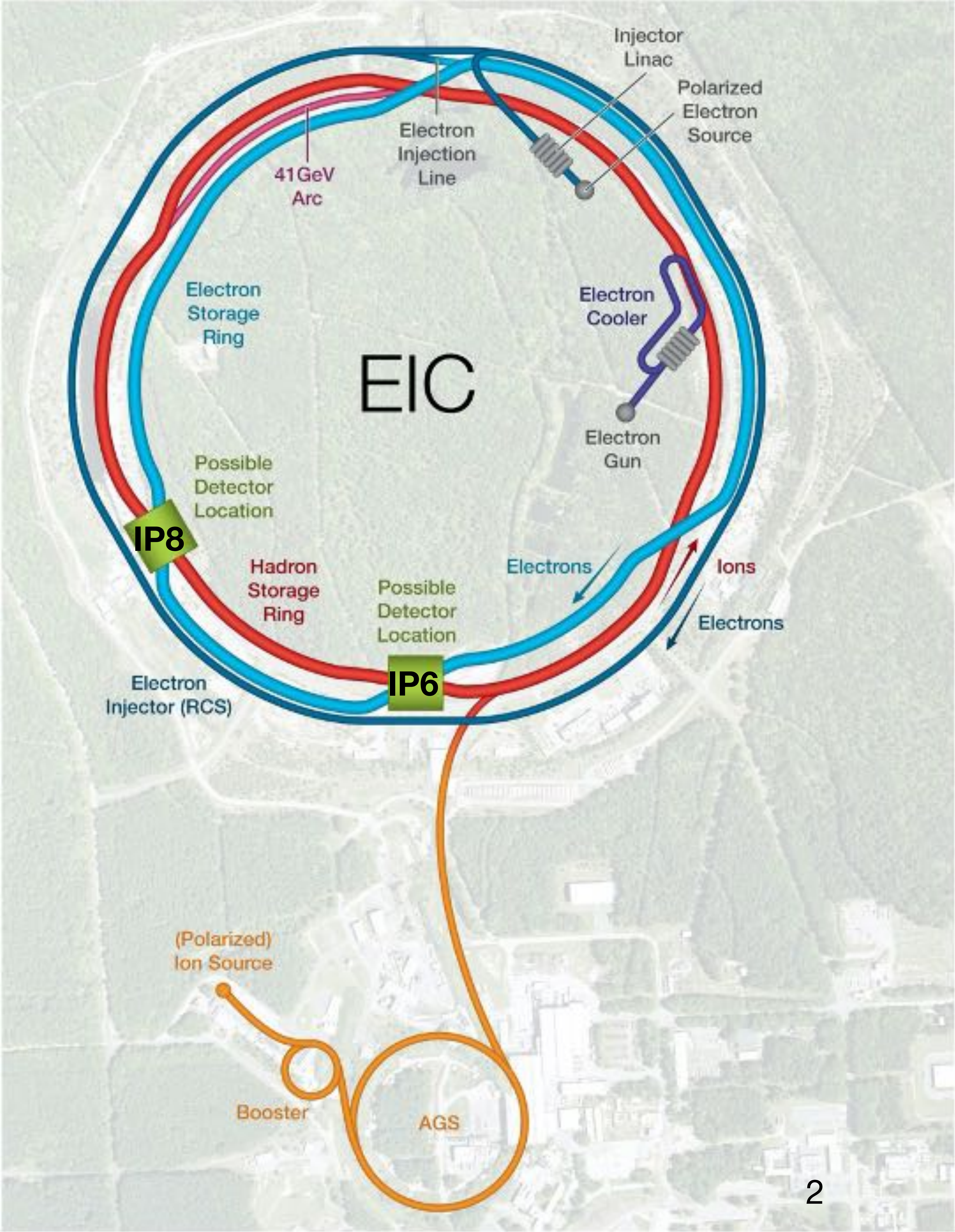
Possible measurements to access low-x physics at the EIC

Charlotte Van Hulse
Alcalá University

Color-Glass Condensate at the electron-ion collider
ECT* Trento, Italy
May 15–19, 2023

AdT CM

The electron-ion collider



$\vec{e} + \vec{p}^{\uparrow}/A$, with A=D, ..., Au, Pb

~ 70% polarisation

$\mathcal{L} = 10^{33-34}\mathrm{cm}^{-2}\mathrm{s}^{-1} \leftrightarrow \mathcal{L}_{\mathrm{int}} = 10 - 100\ \mathrm{fb}^{-1}/\mathrm{year}$

$\sqrt{s} = 30 - 141$ GeV

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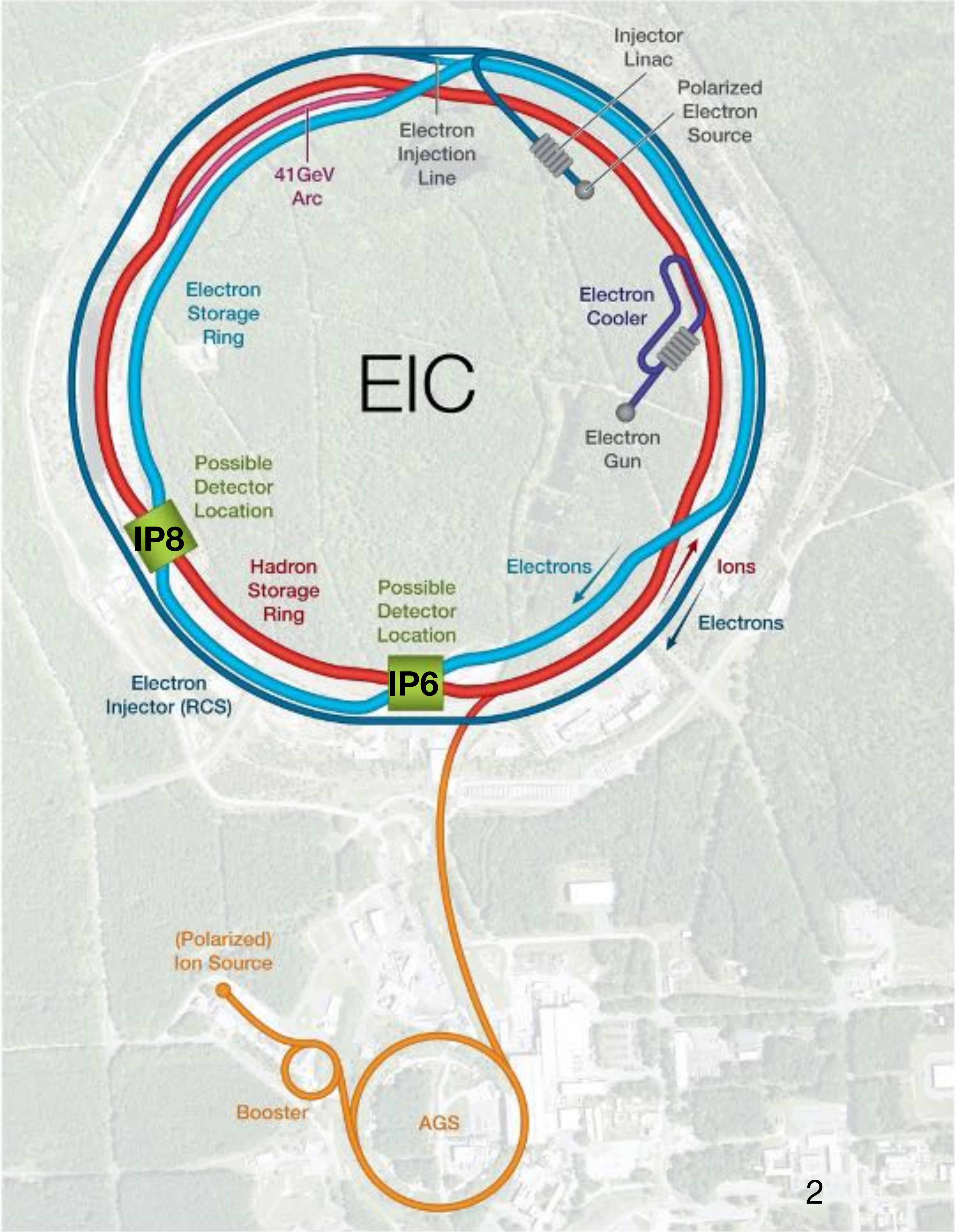

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Selection of possible beam energy modes

e beam E [GeV]	p beam E [GeV]	$\sqrt{s}$ [GeV]
18	275	141
10	275	105
10	100	63
5	100	45
5	41	29

e beam E [GeV]	A beam E [GeV]	$\sqrt{s}$ [GeV]
18	110	89
10	110	66
5	110	47
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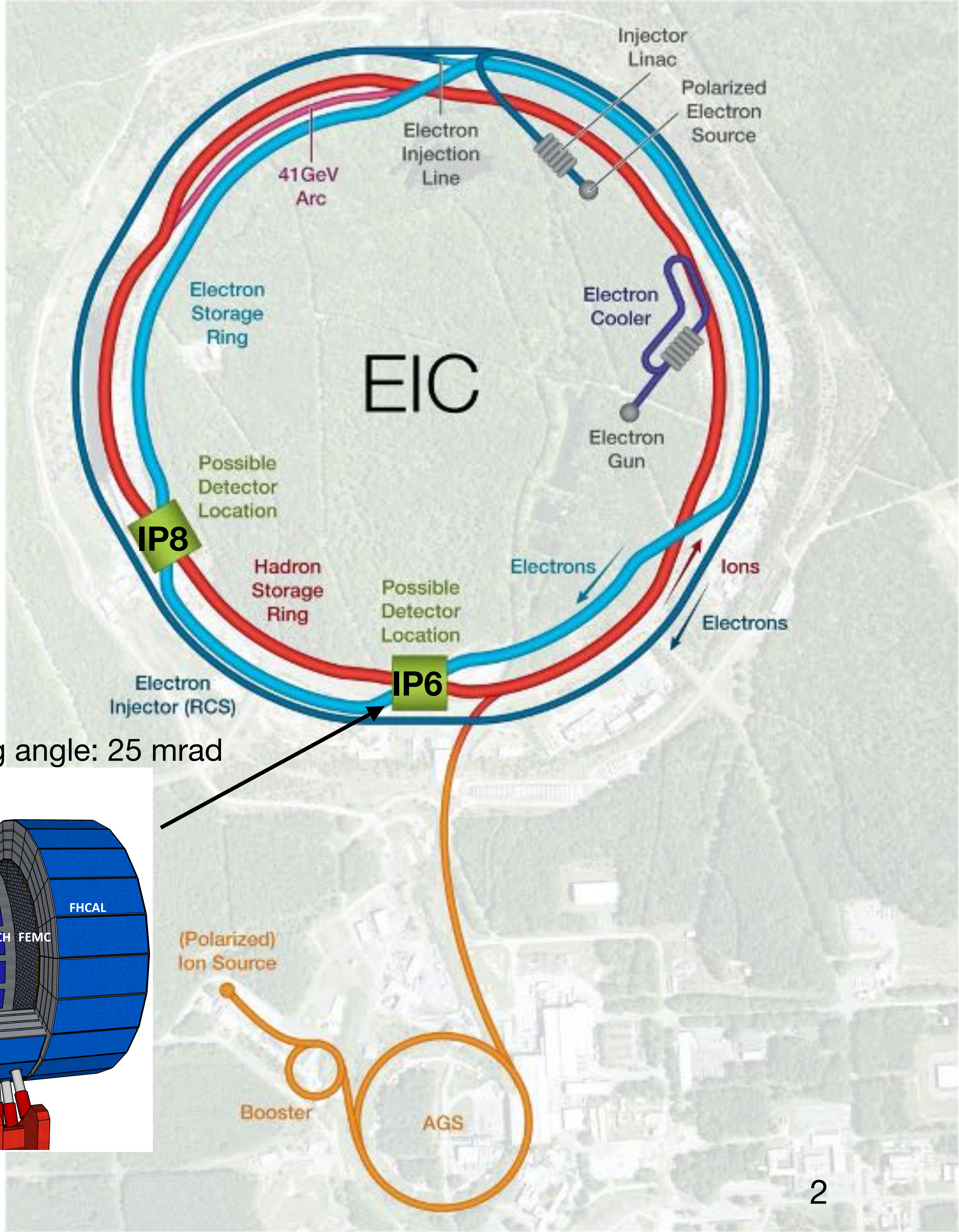
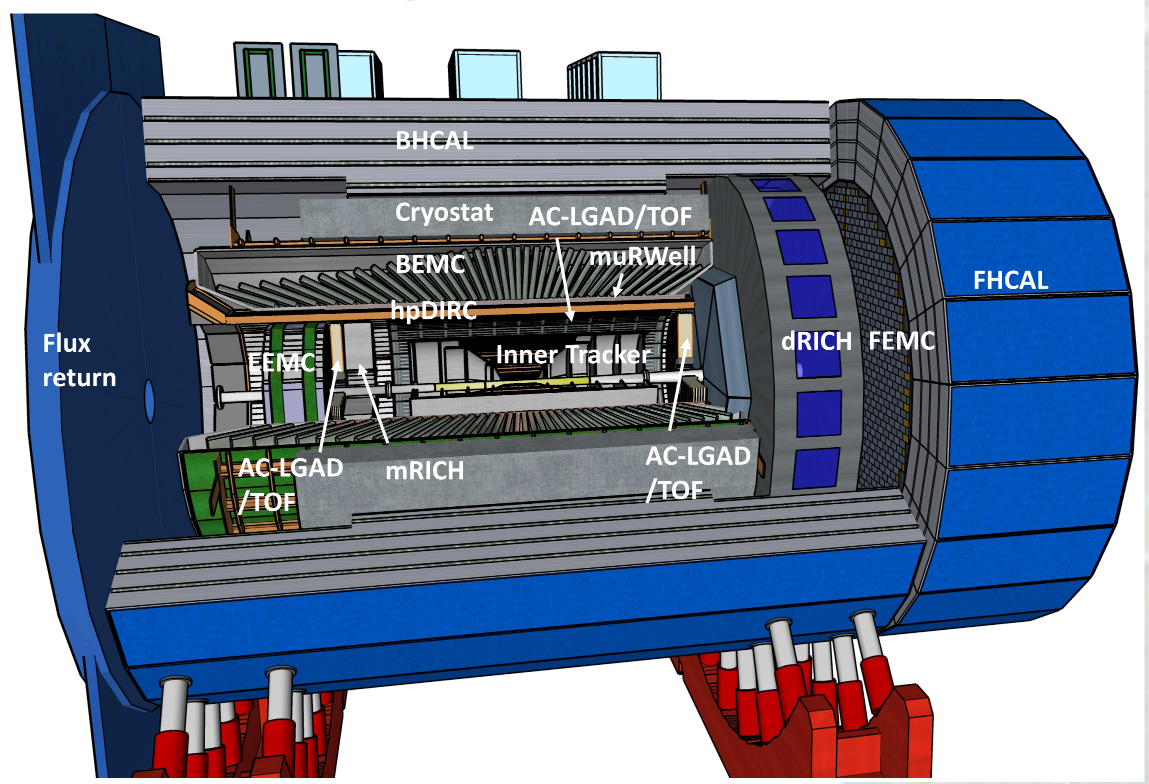


crossing angle: 25 mrad



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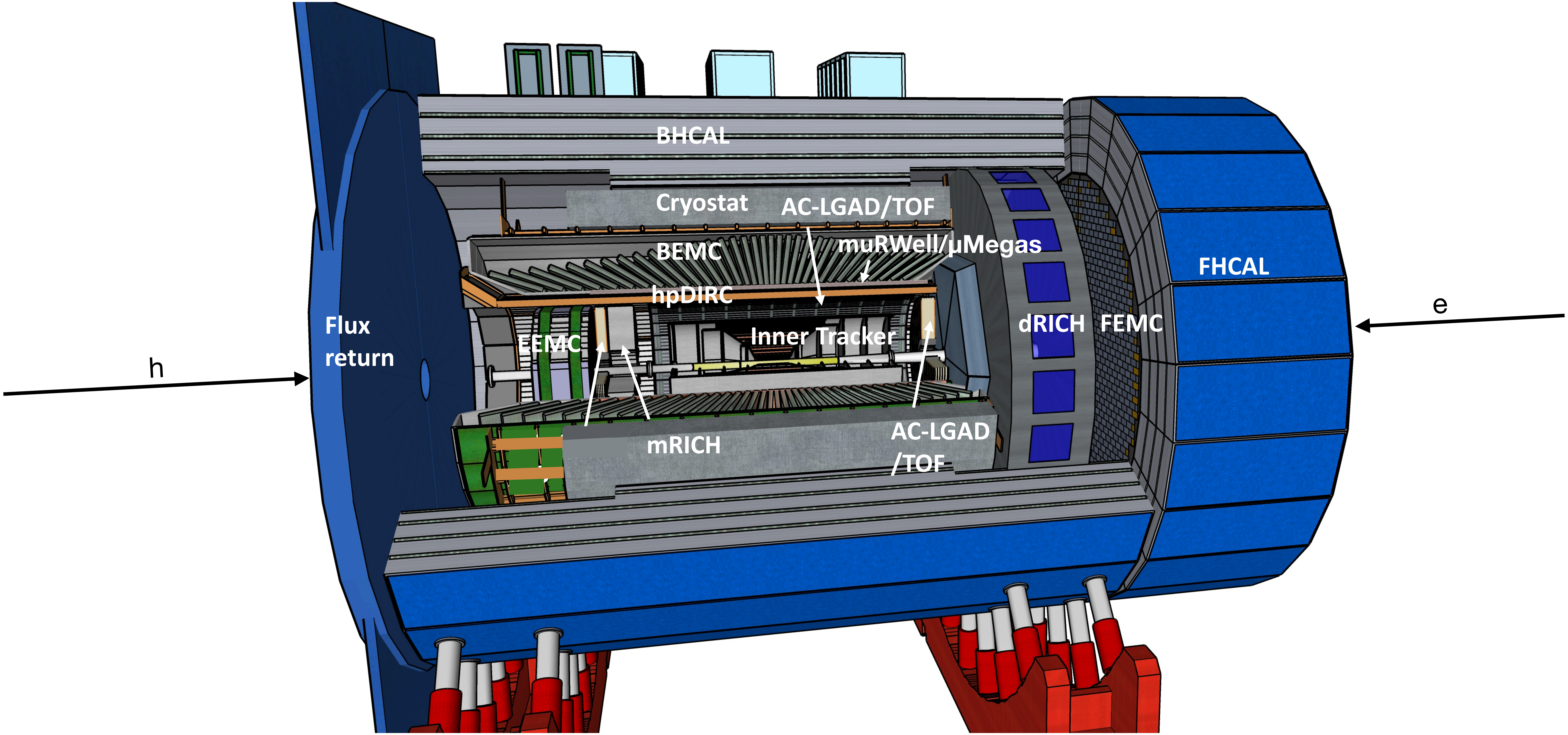
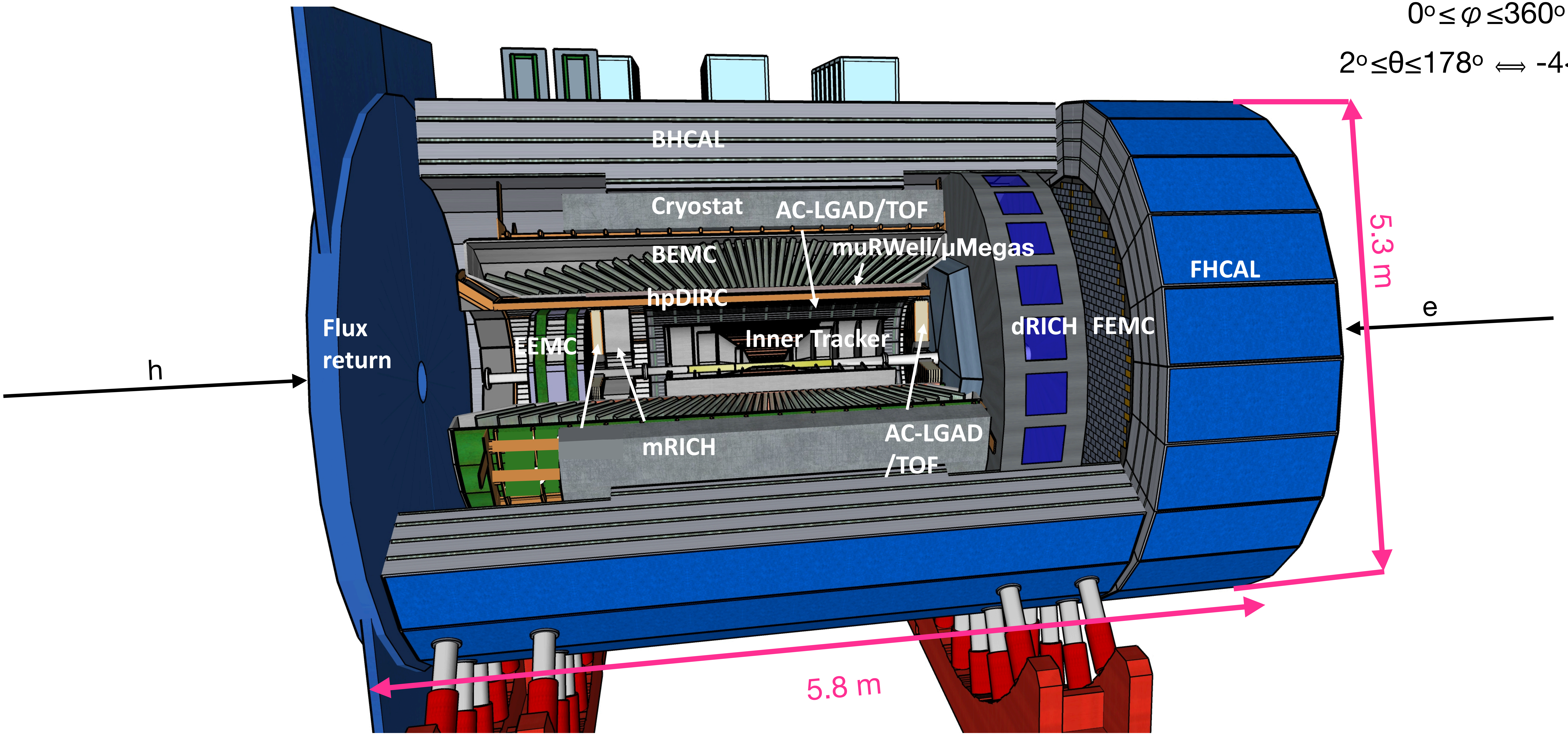
The electron-proton/ion collider (ePIC) detector (current status)



The electron-proton/ion collider (ePIC) detector (current status)

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



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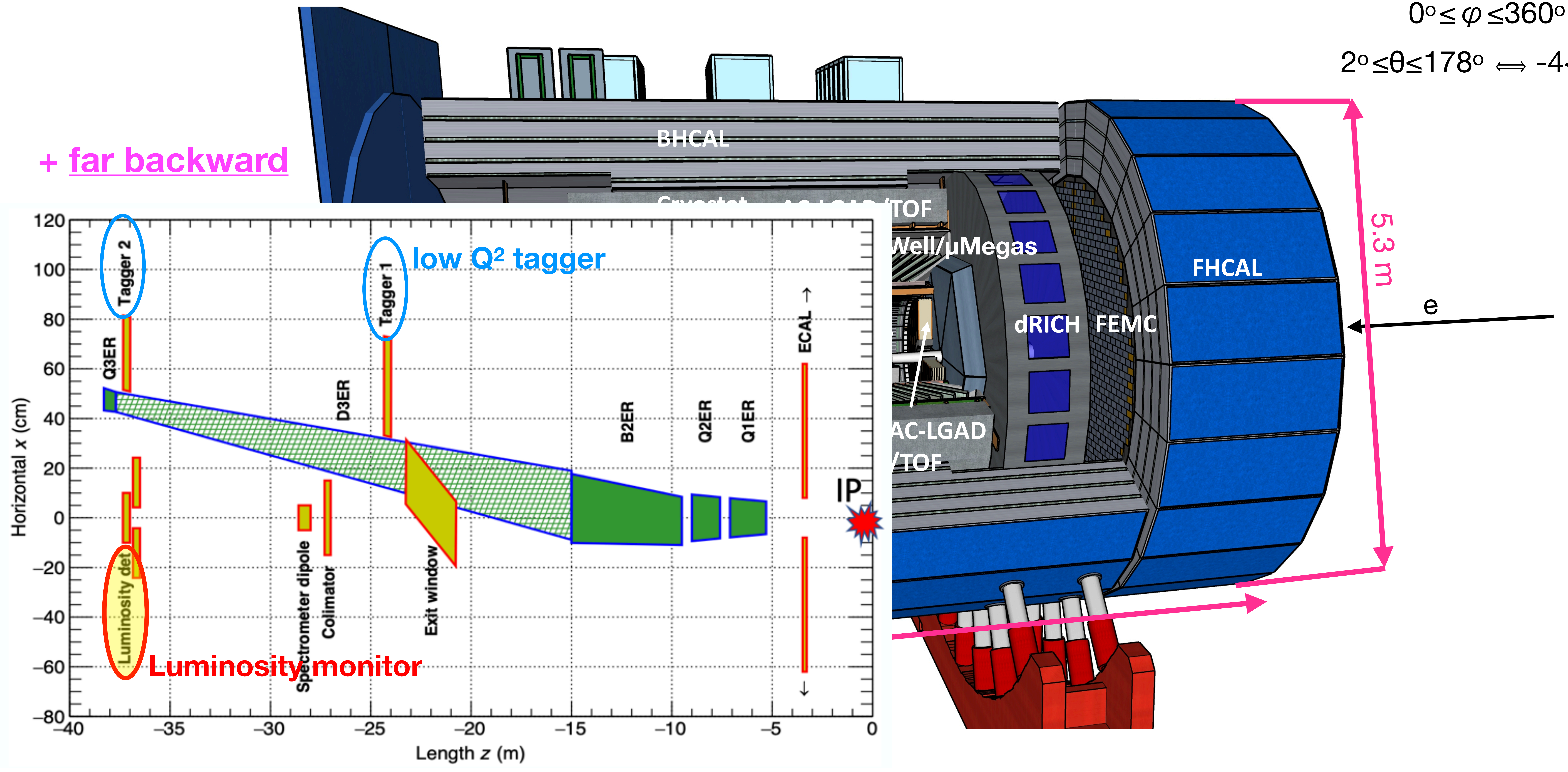

The electron-proton/ion collider (ePIC) detector (current status)

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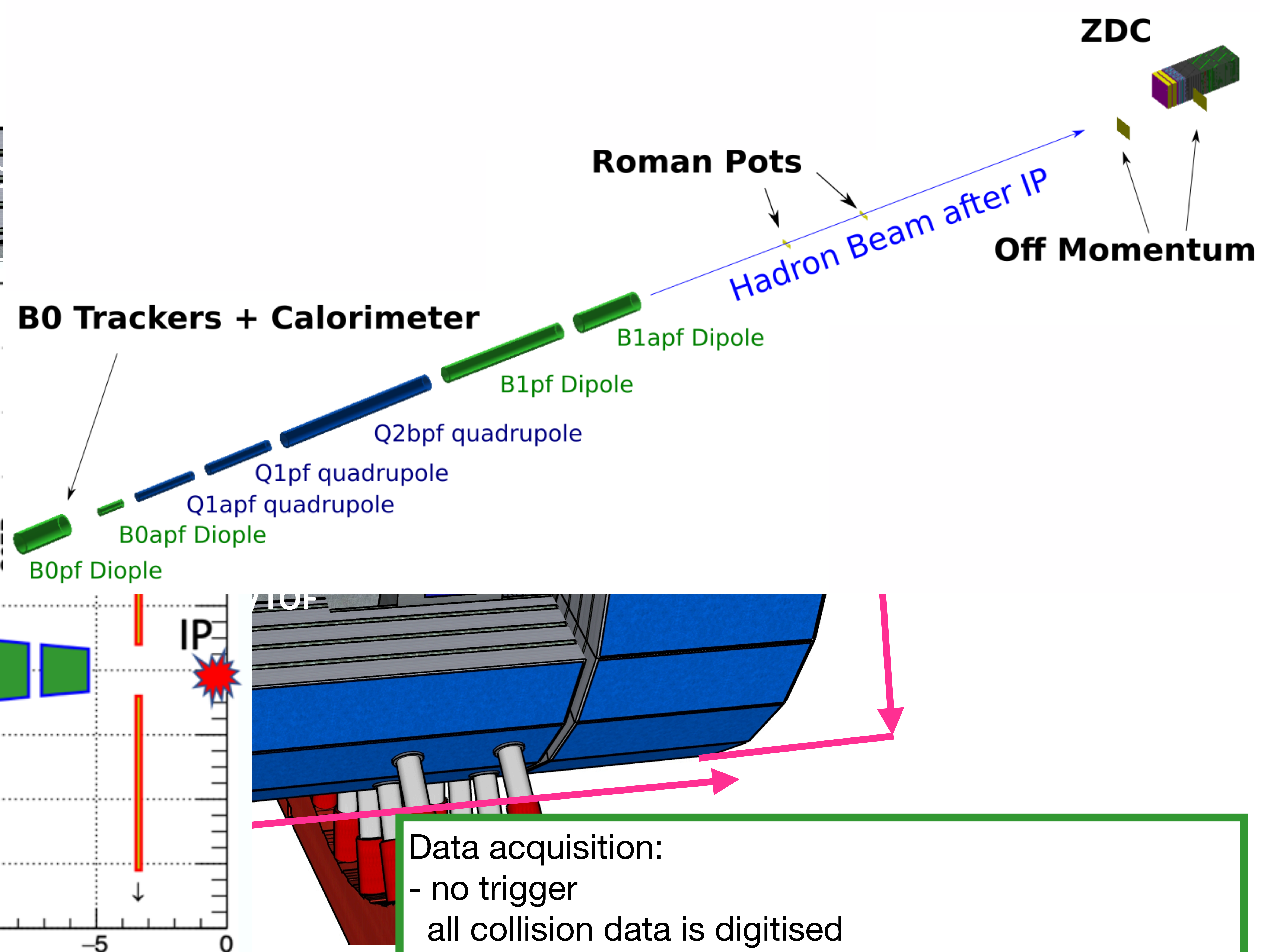
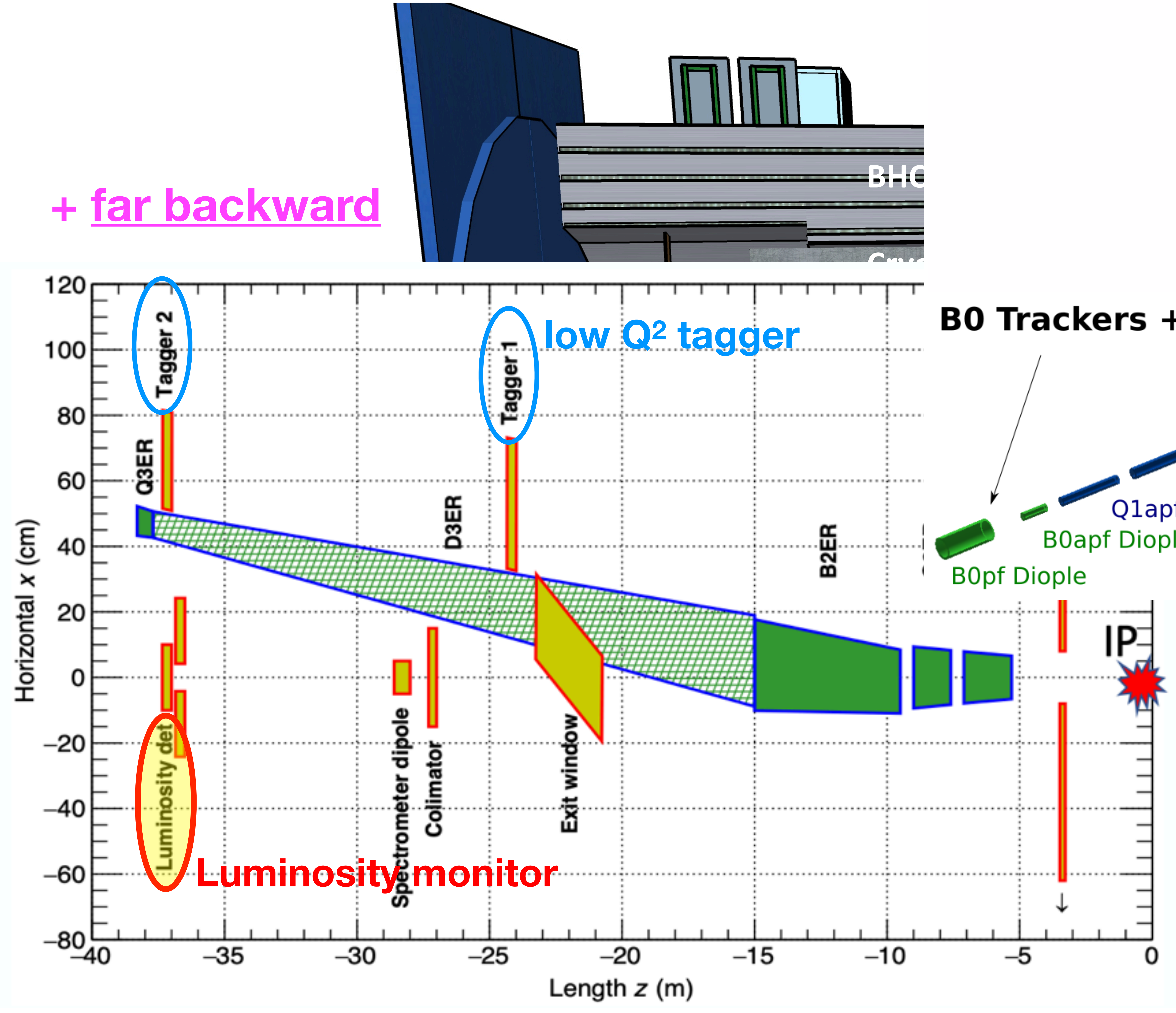
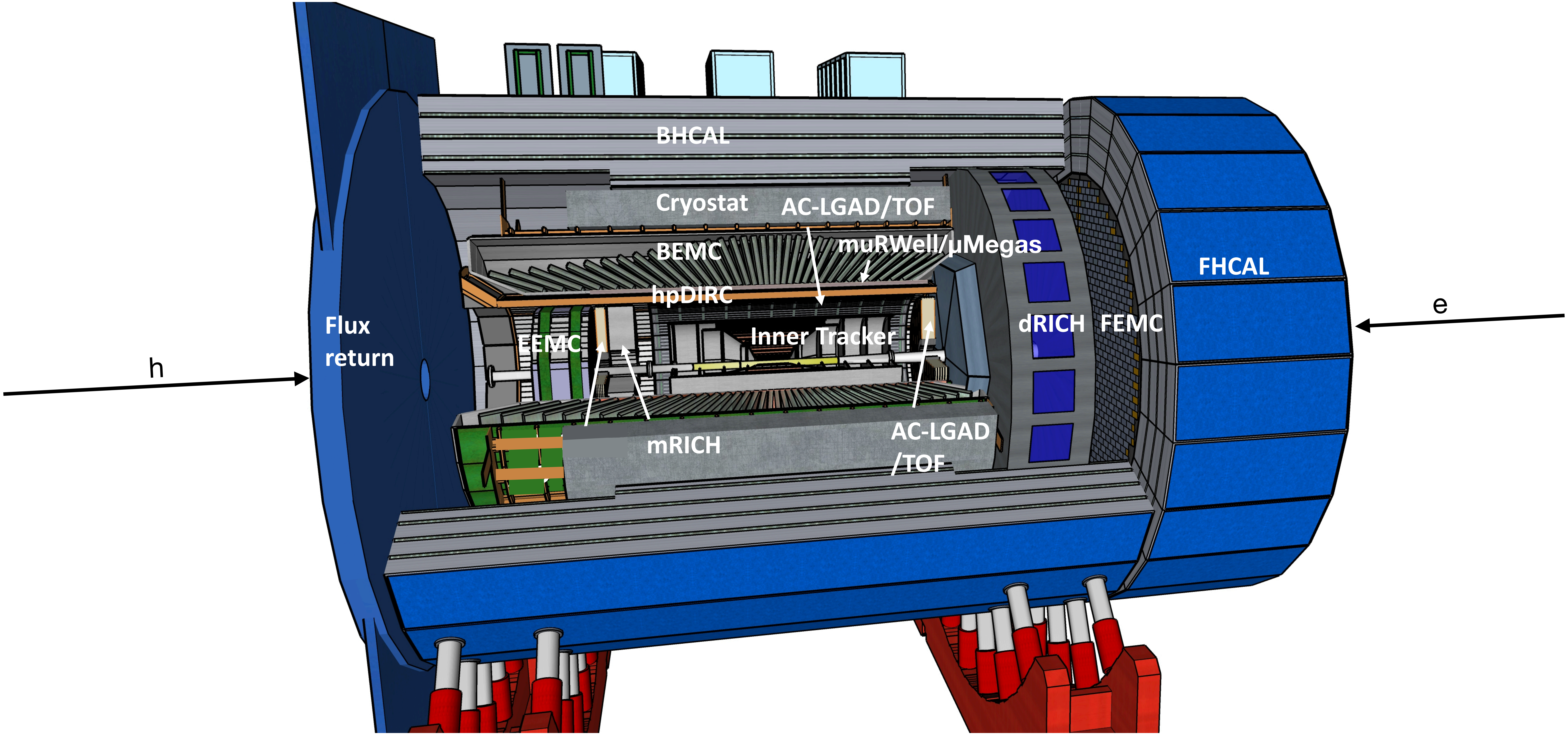


+ far backward



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

The ePIC central detector (current status)



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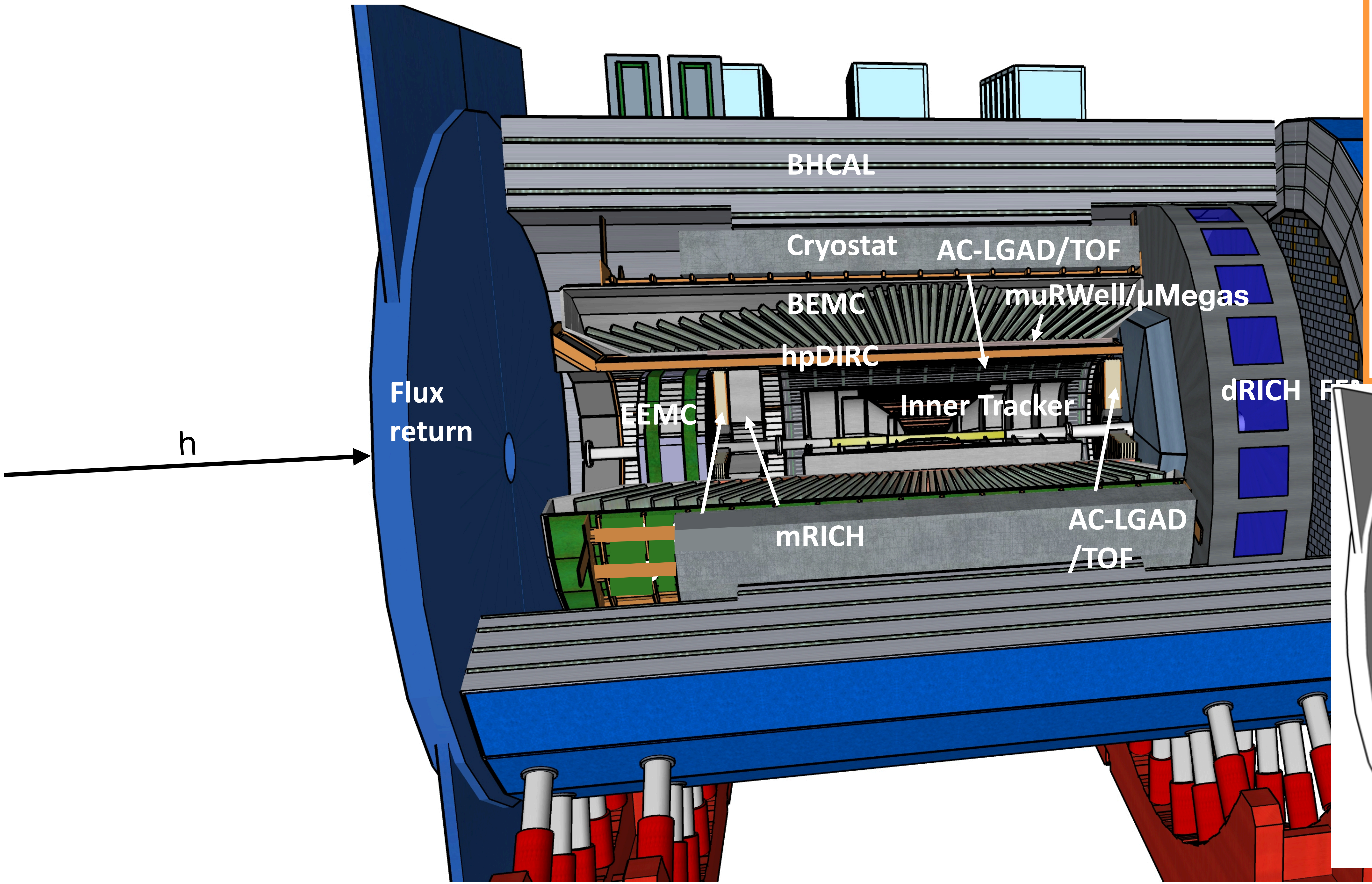
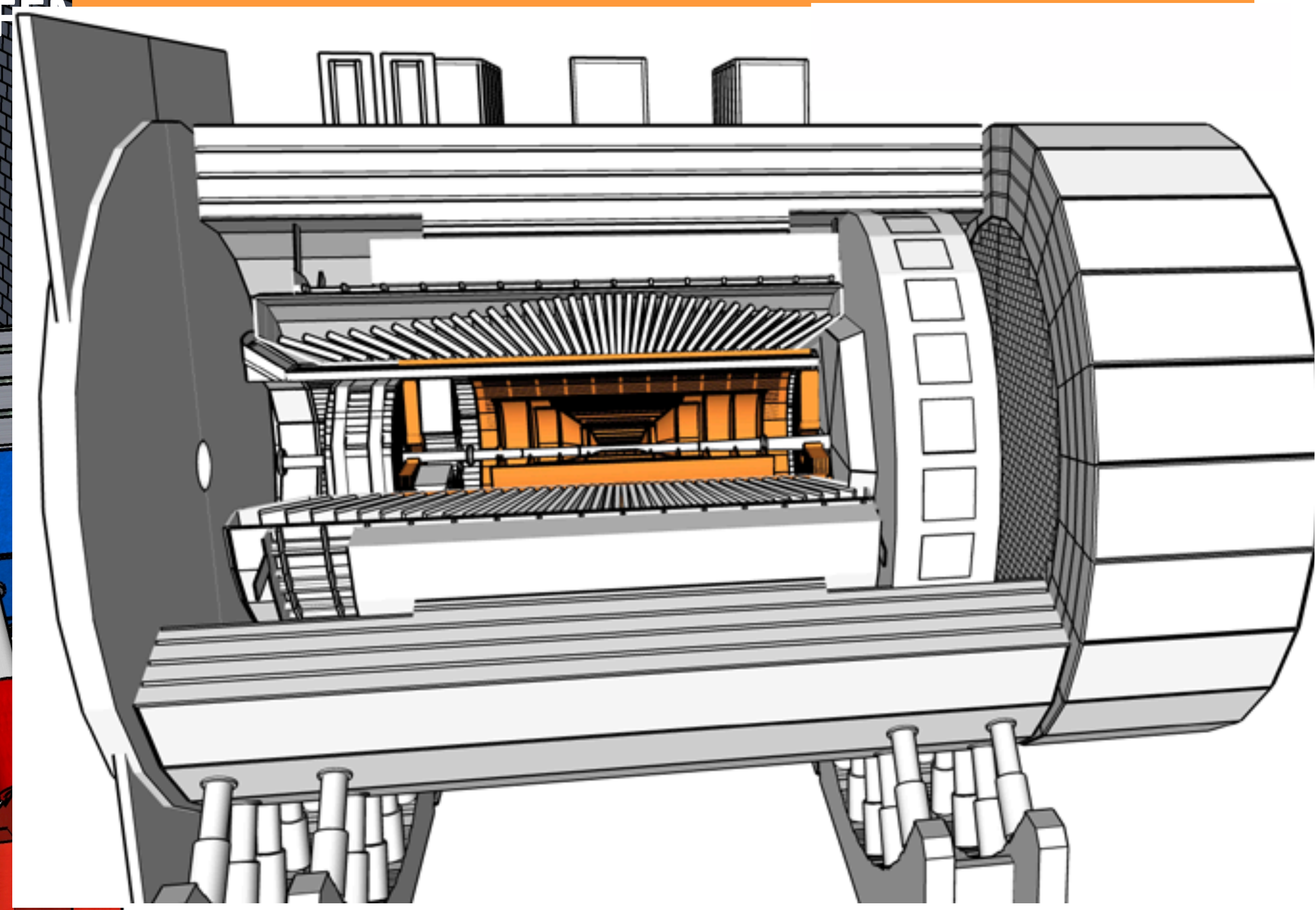


Tracking

- 1.7 T magnet
- Monolithic Active Pixel Sensor (MAPS) Silicon vertexing/inner tracker
- µRWell/microMegas
- AC-LGAD/TOF



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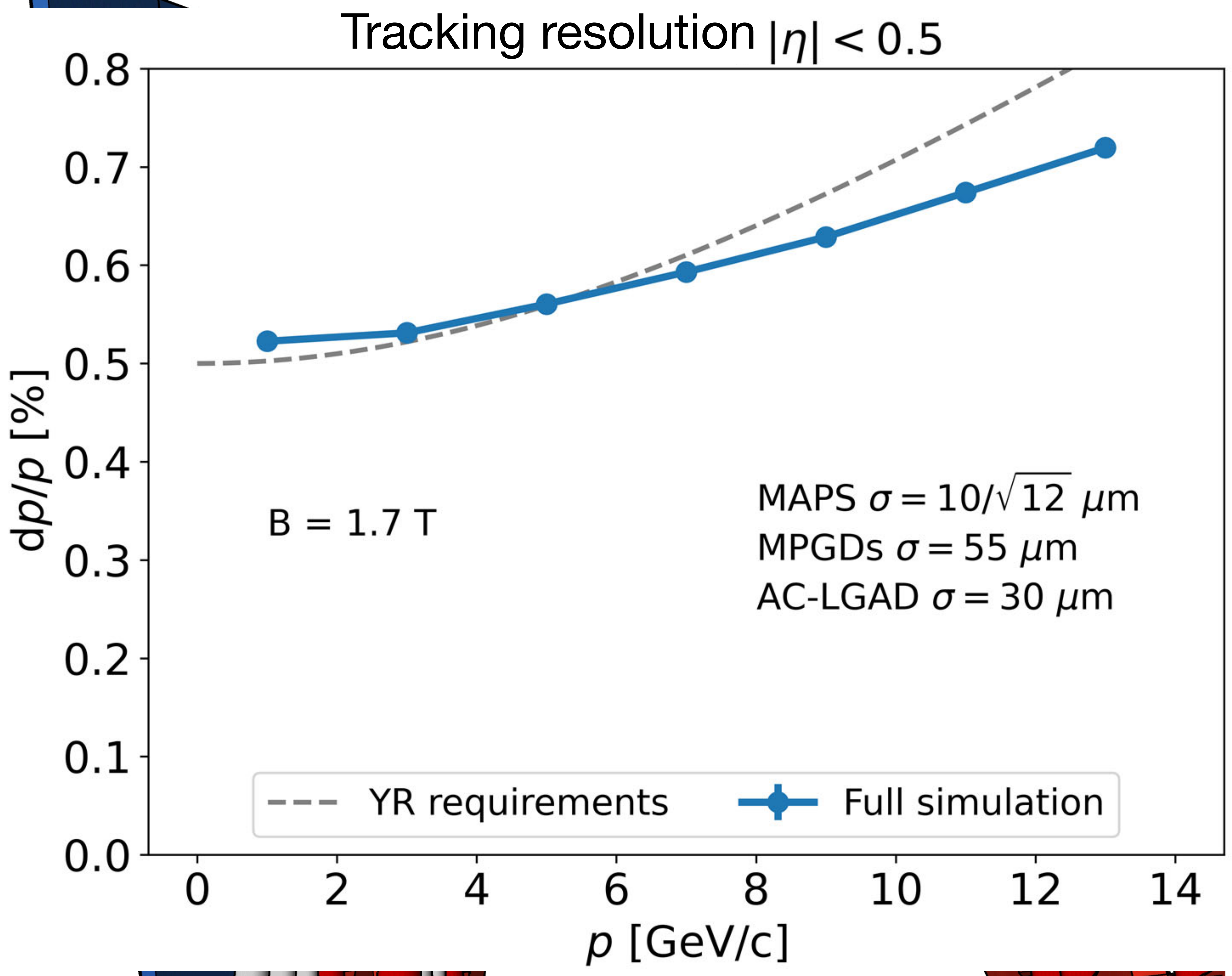

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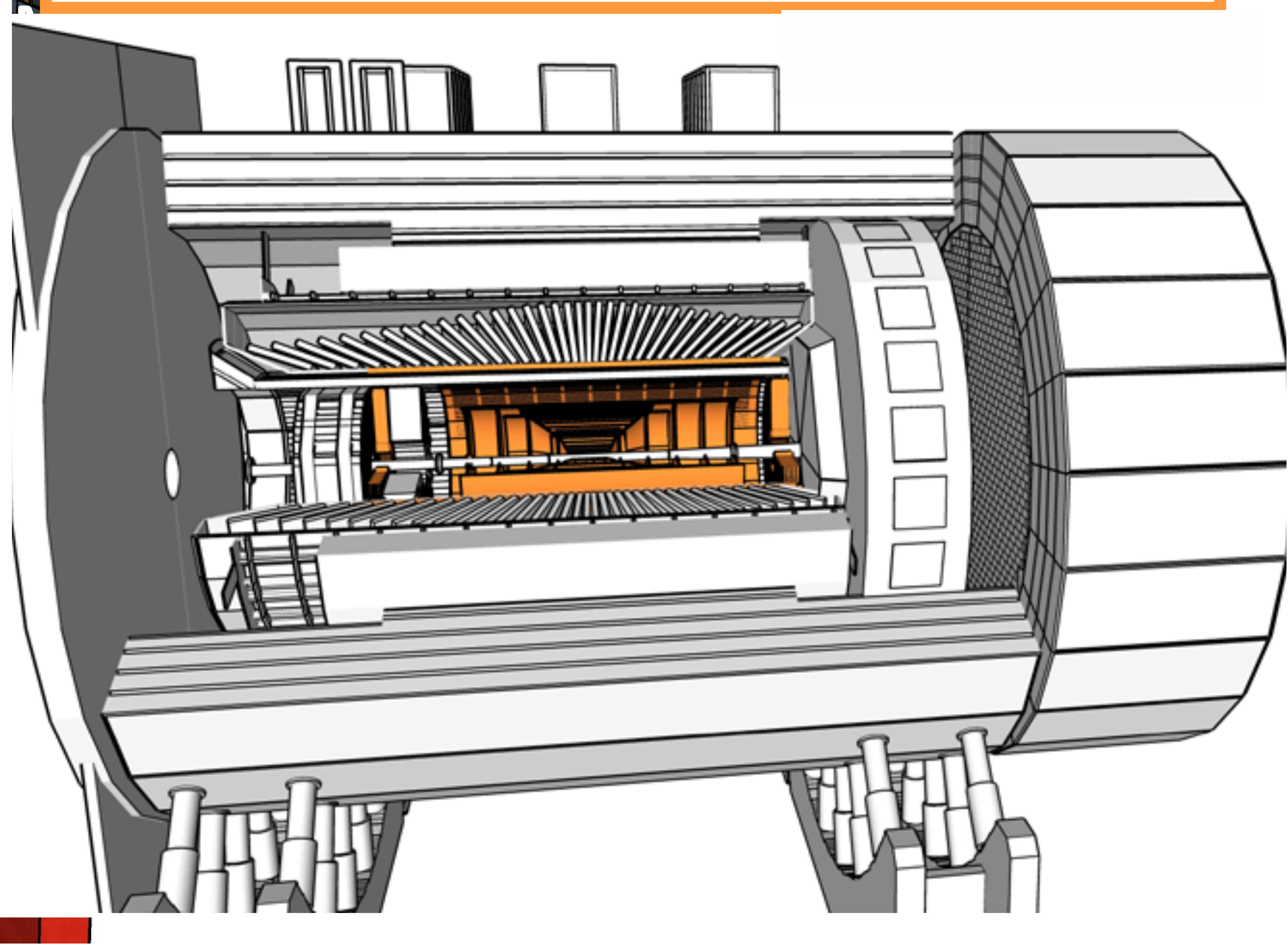
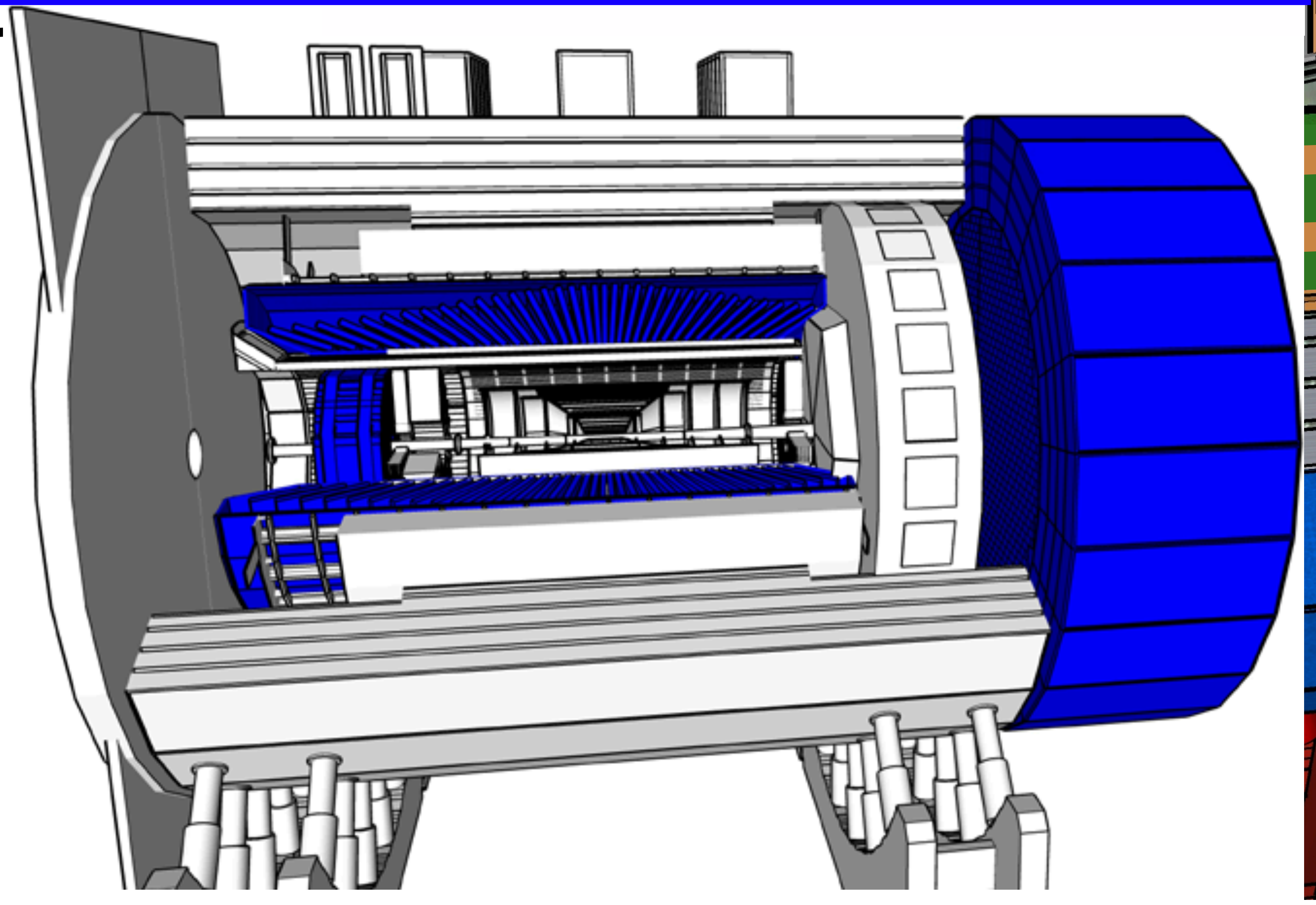
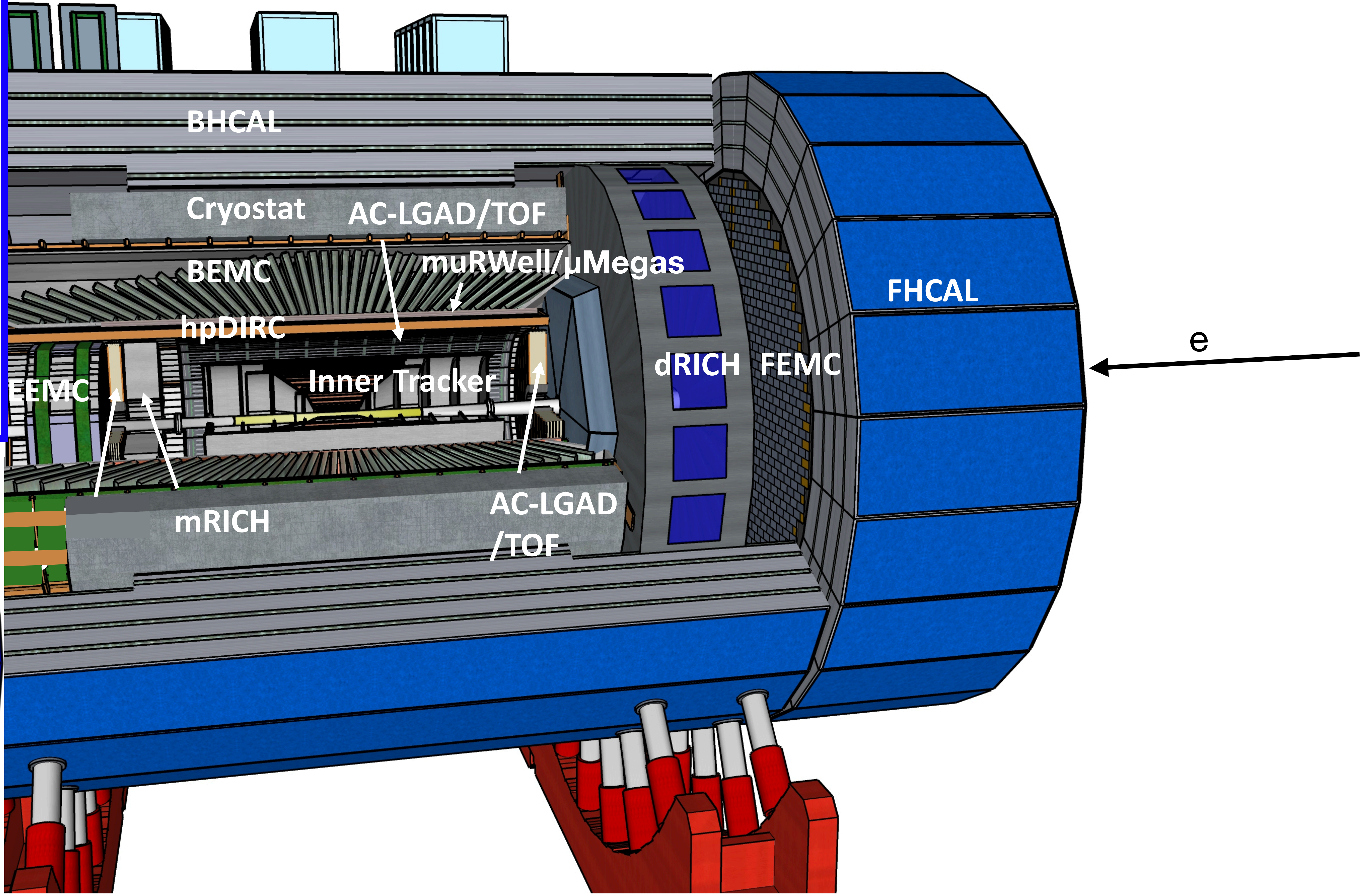


The ePIC central detector (current status)

EM CAL

- Electron-endcap EM cal (EEMC): high-precision $PbWO_4$+SiPMs
- Barrel EM cal (BEMC): Imaging EM cal
- Forward EM cal (FEMC): Finely segmented W-SciFi

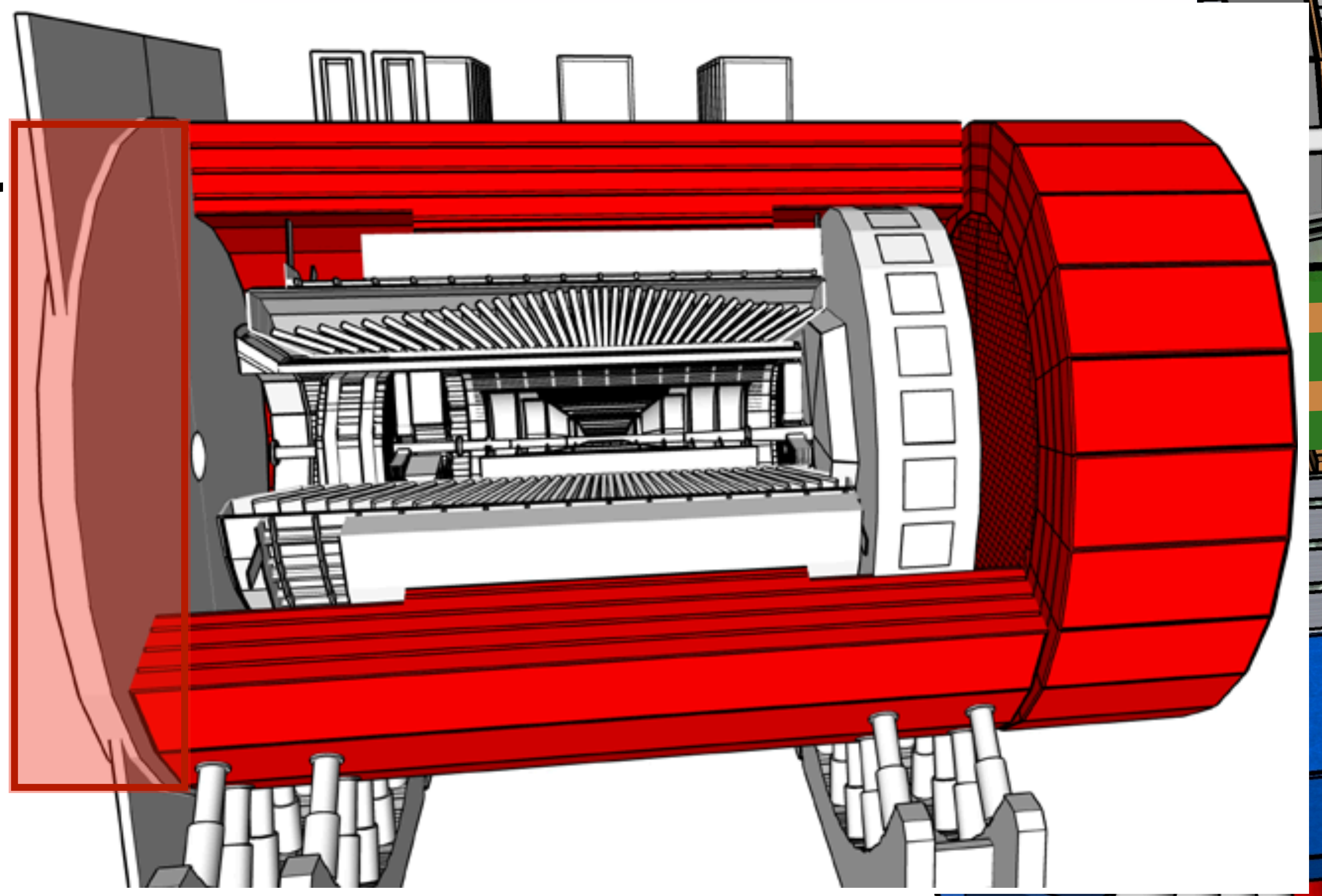


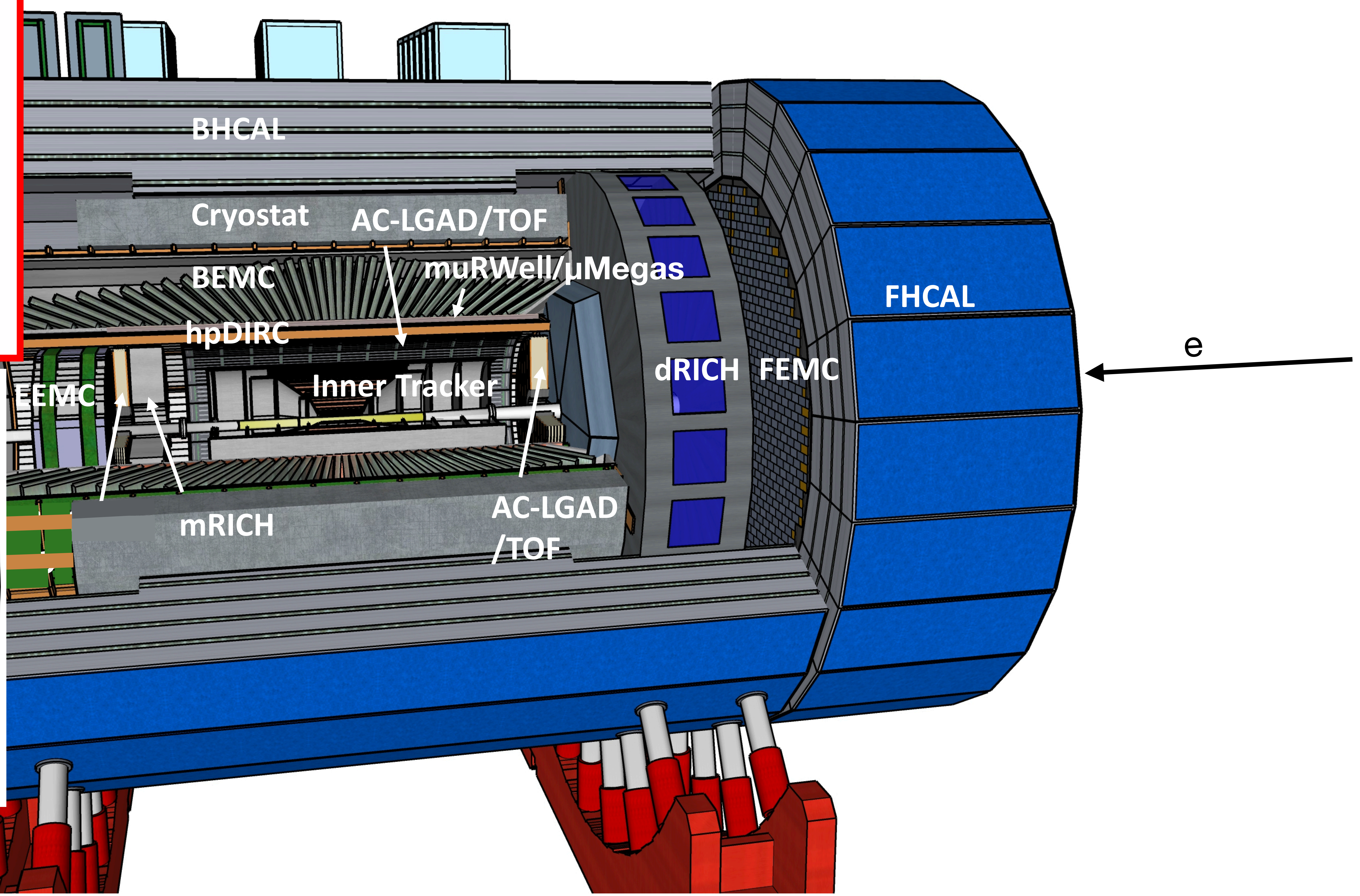


detector (current status)

HCAL

- Inner+outer HCAL: steel+Sci: control shower leakage (inner) and detection of neutrals
- FHCAL: finally segmented steel+tungsten+Sci for good energy resolution
- Backward HCal: steel+Sci sandwich: tail catcher





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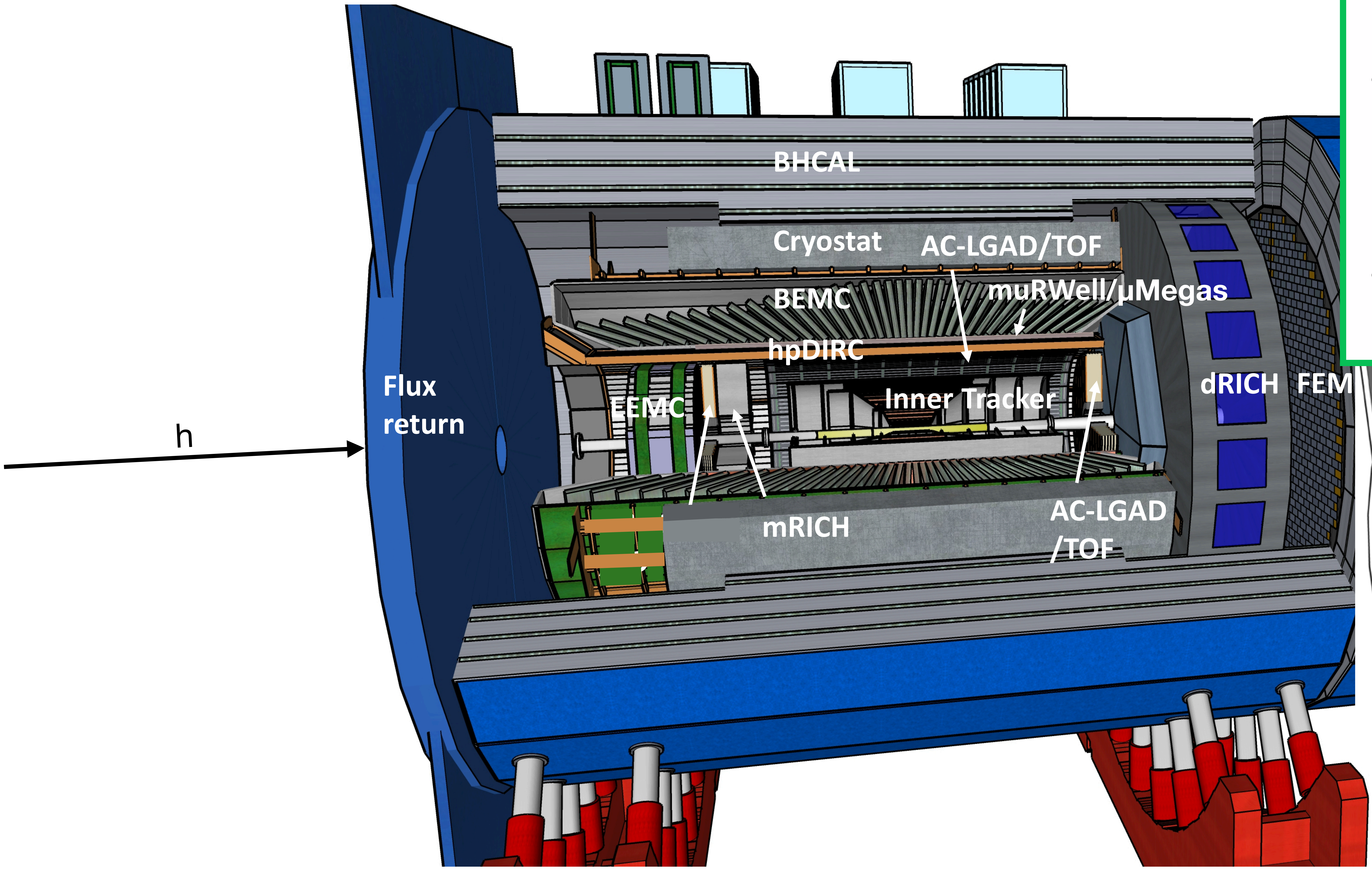
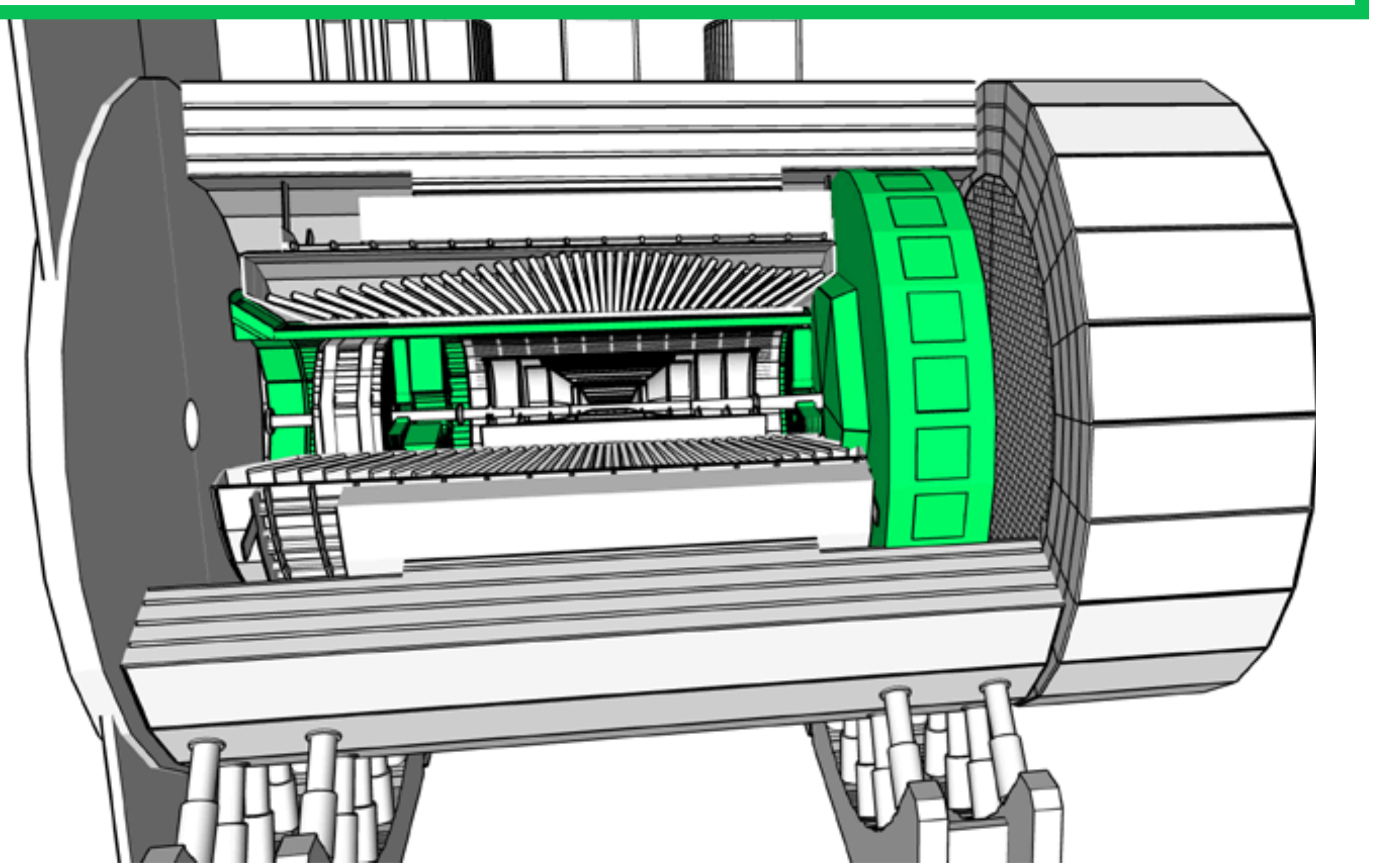


PID

- Cherenkov detectors: pfRICH, hpDIRC, dRICH
  ~ 1 GeV/c<p<50 GeV/c
- AC-LGAD/TOF:
  ~ p < 0.5 – 3 GeV/c



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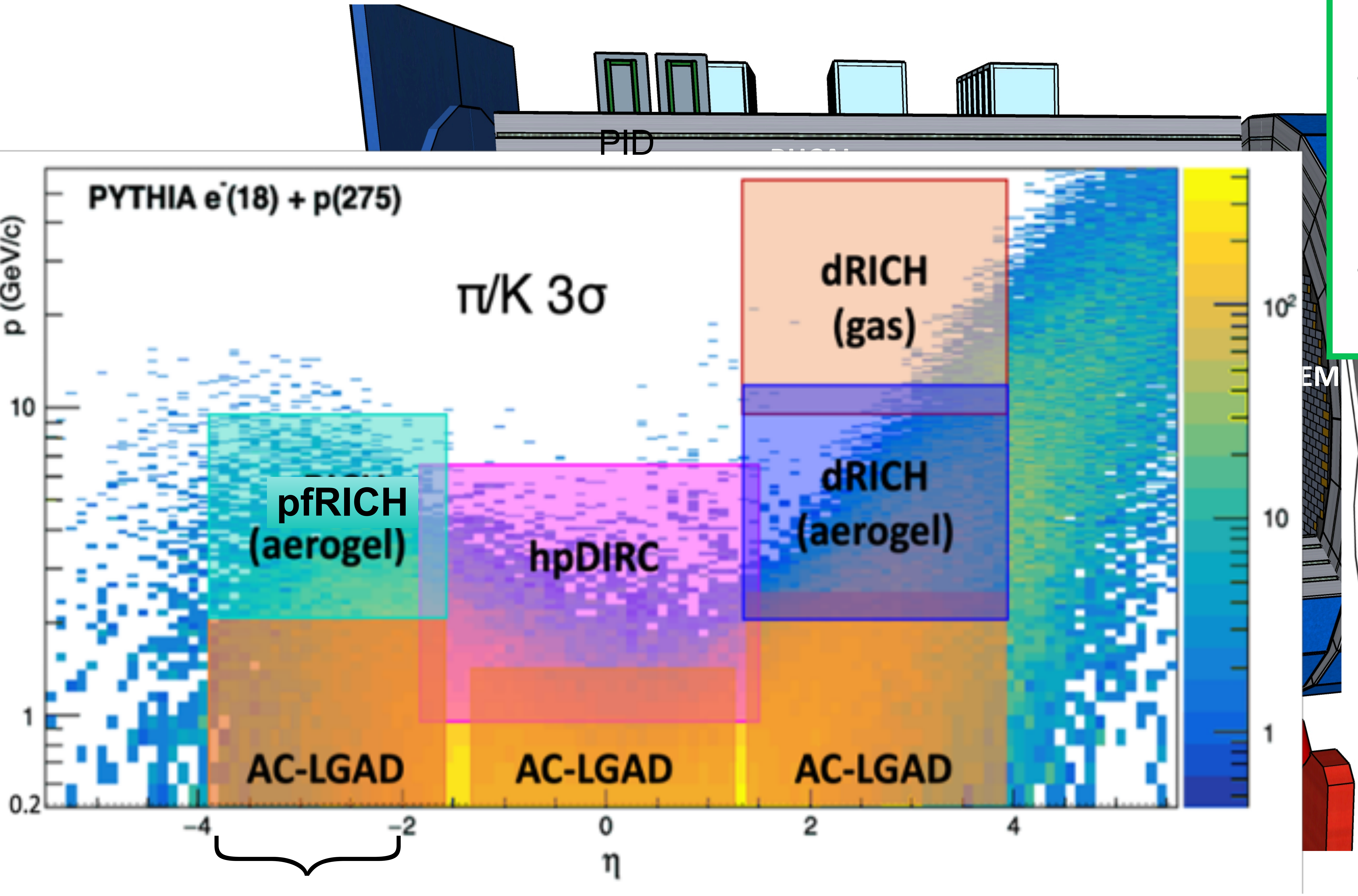

significant integration issues

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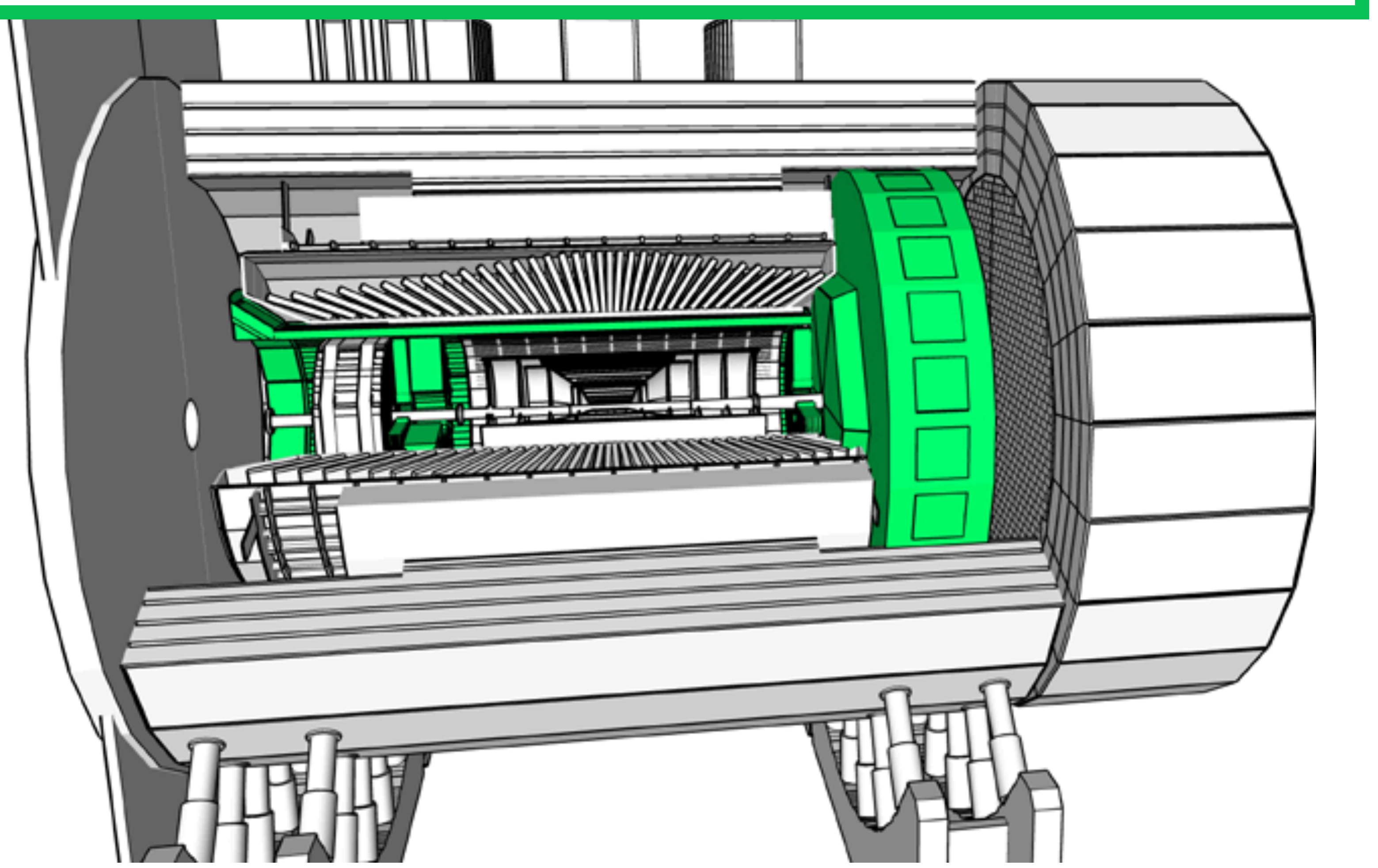
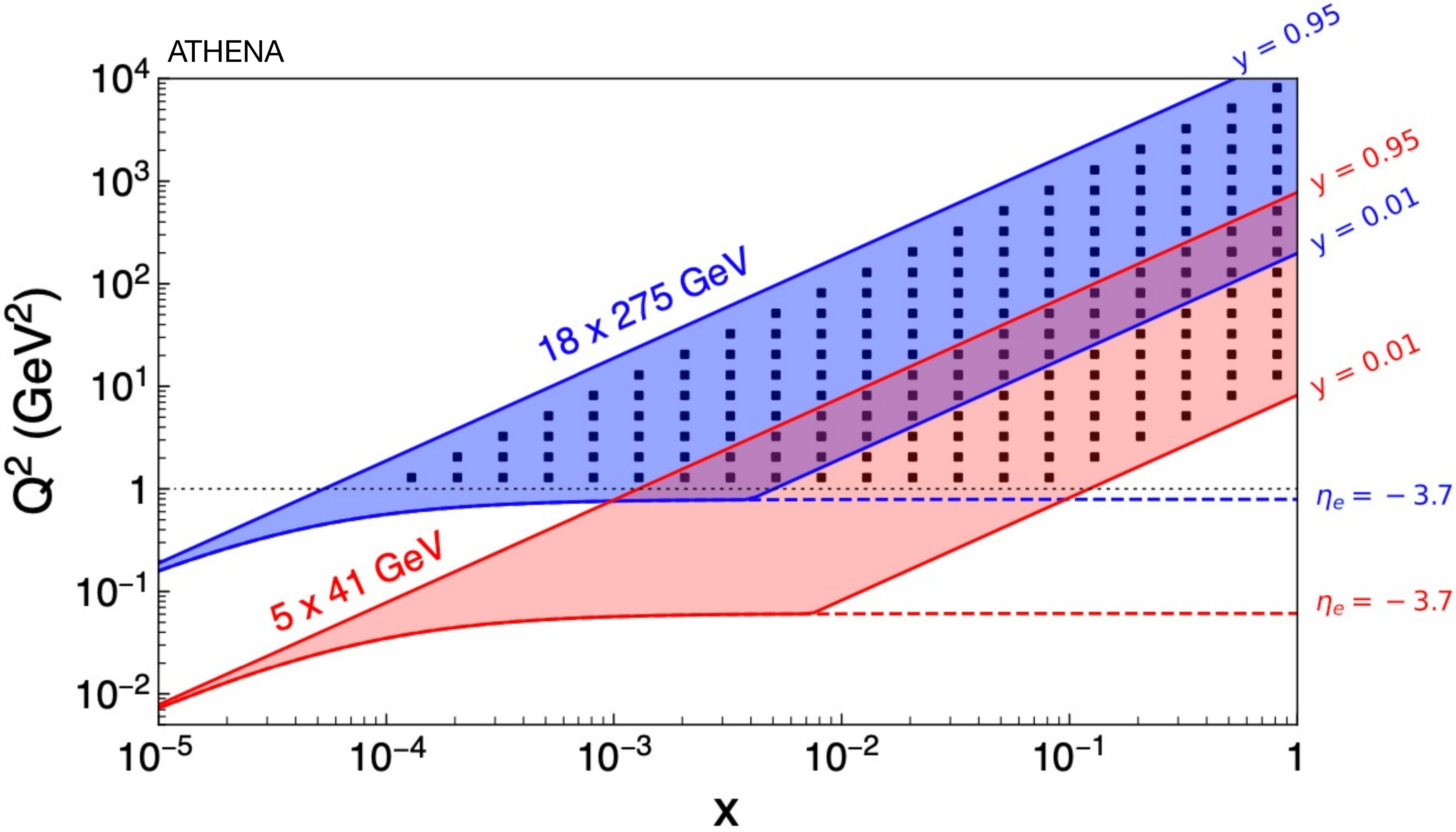
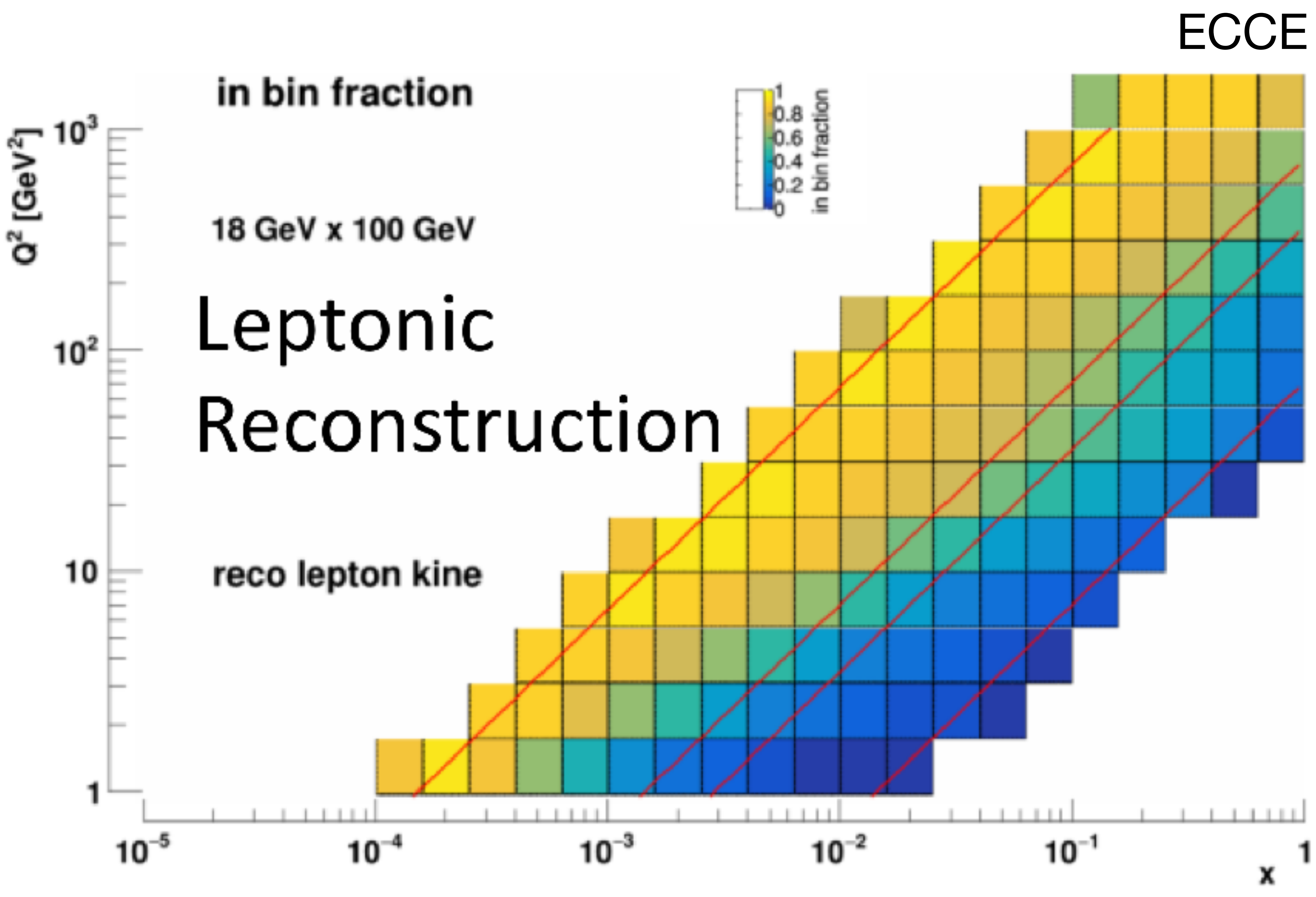
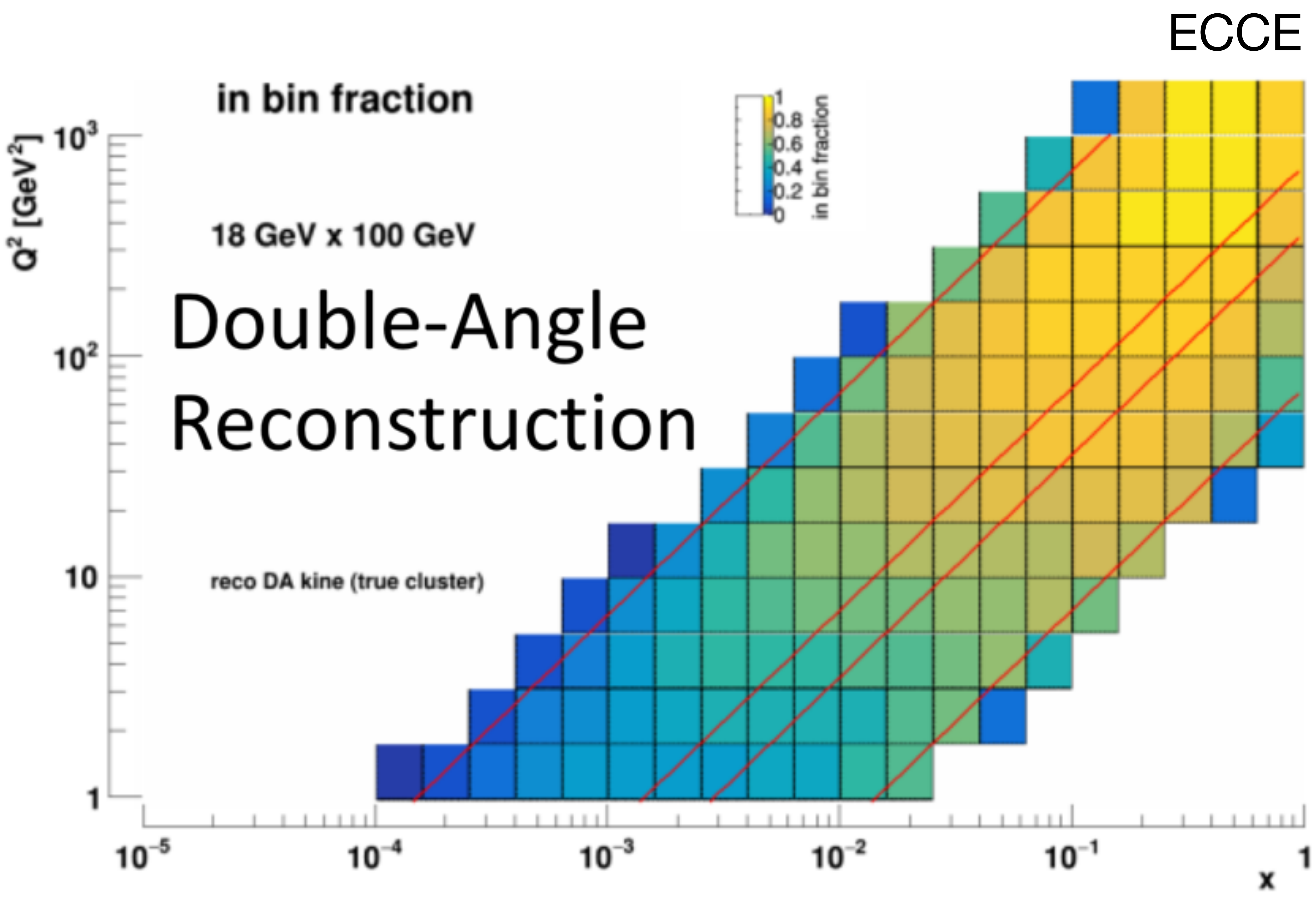


Kinematic coverage for DIS

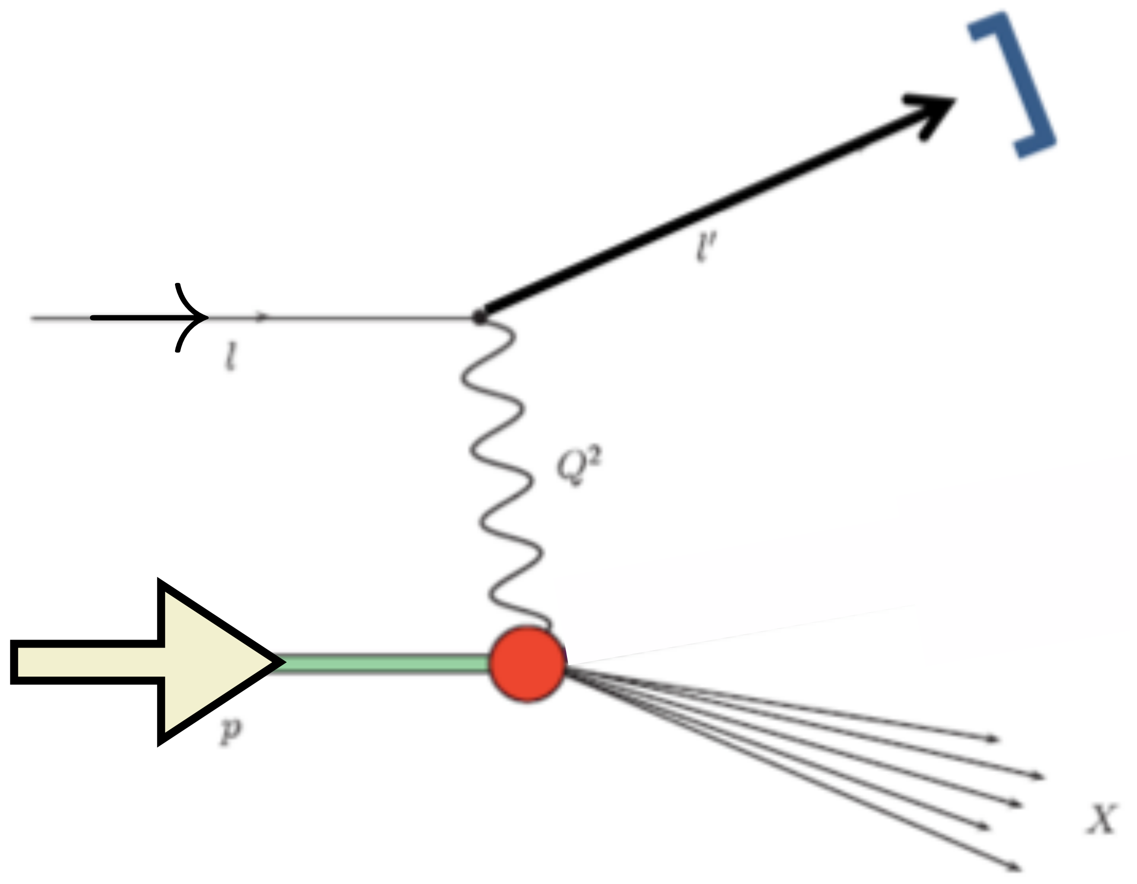


Reconstruction of DIS variables

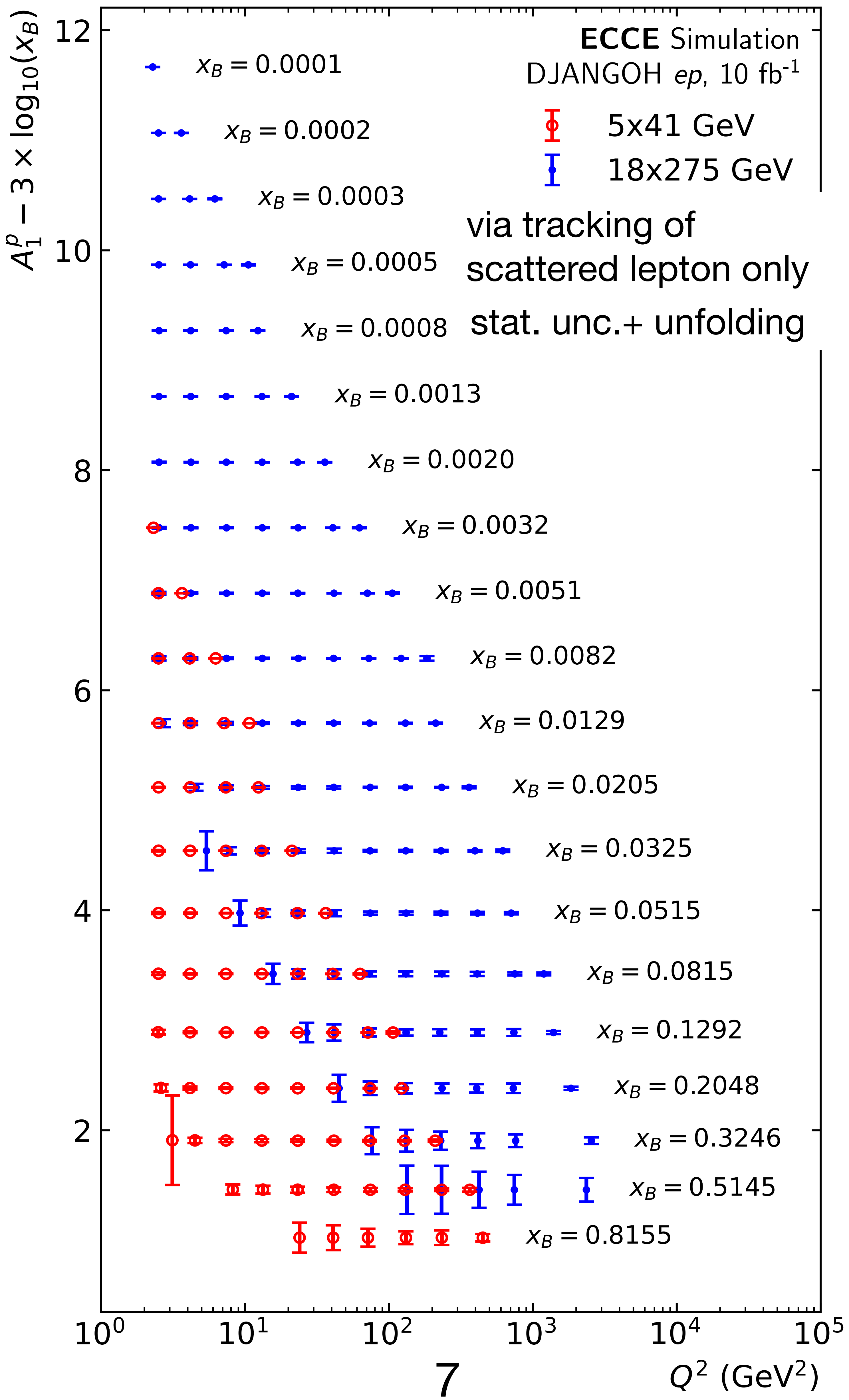




Helicity structure of the nucleon: gluons



Inclusive measurements
→ access to gluon spin



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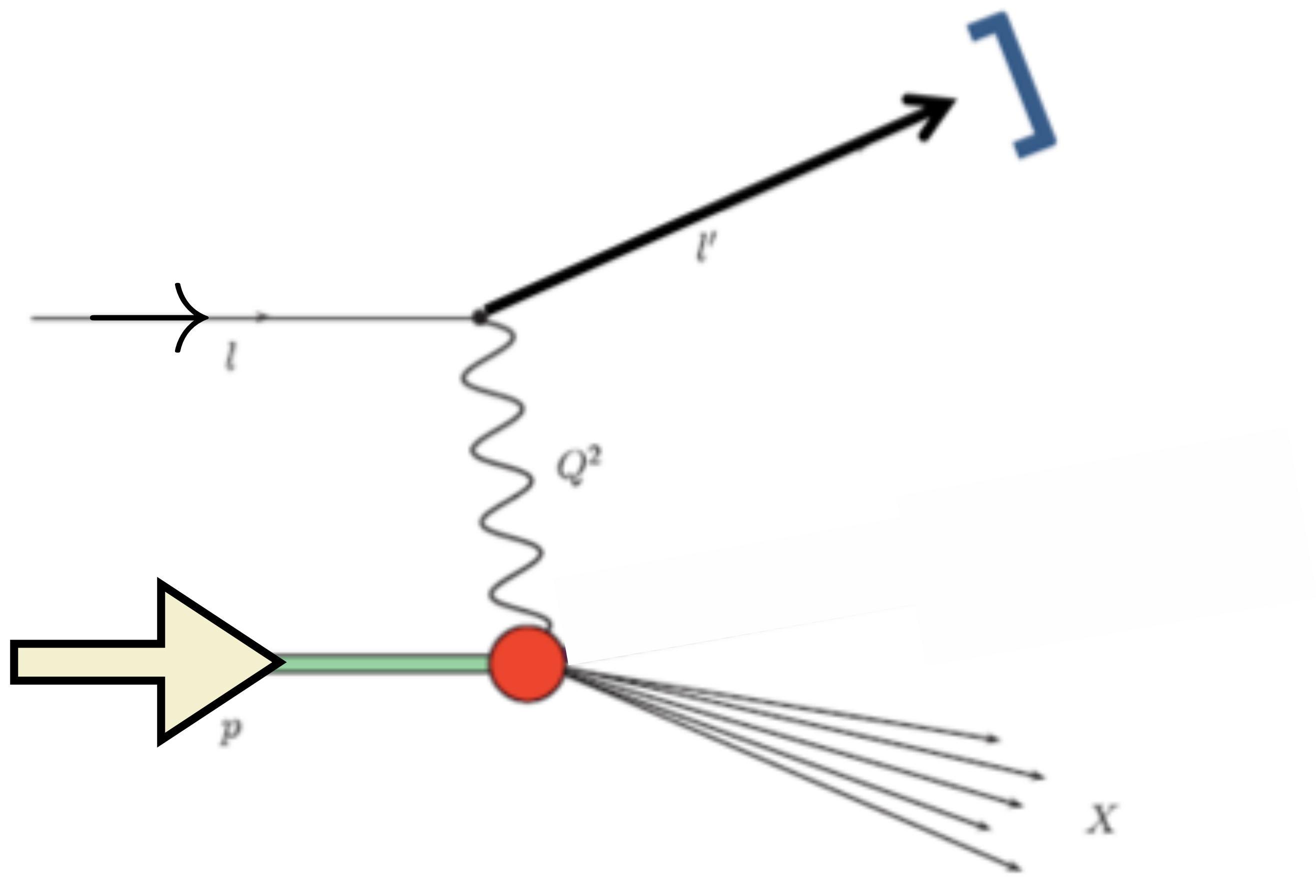

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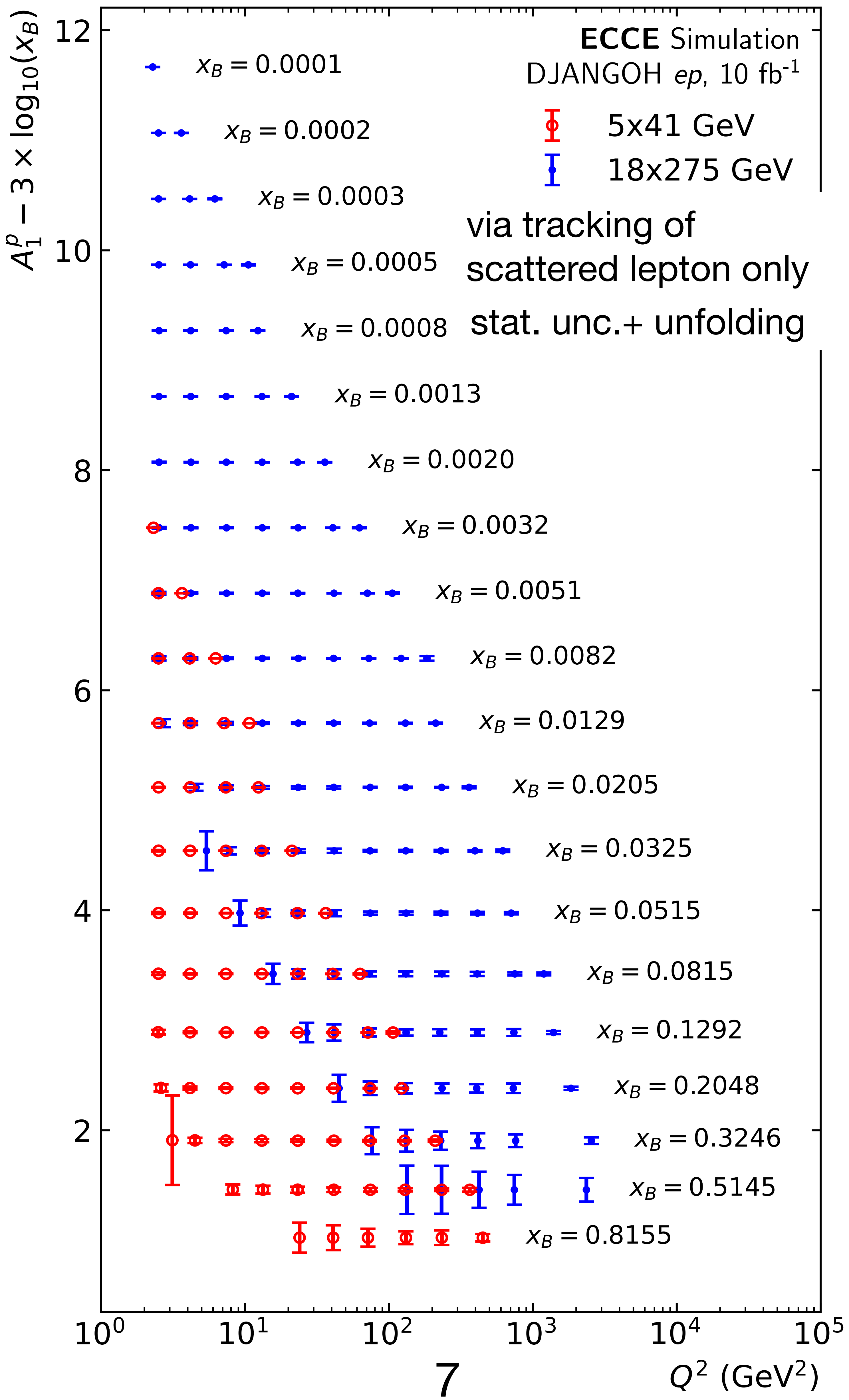

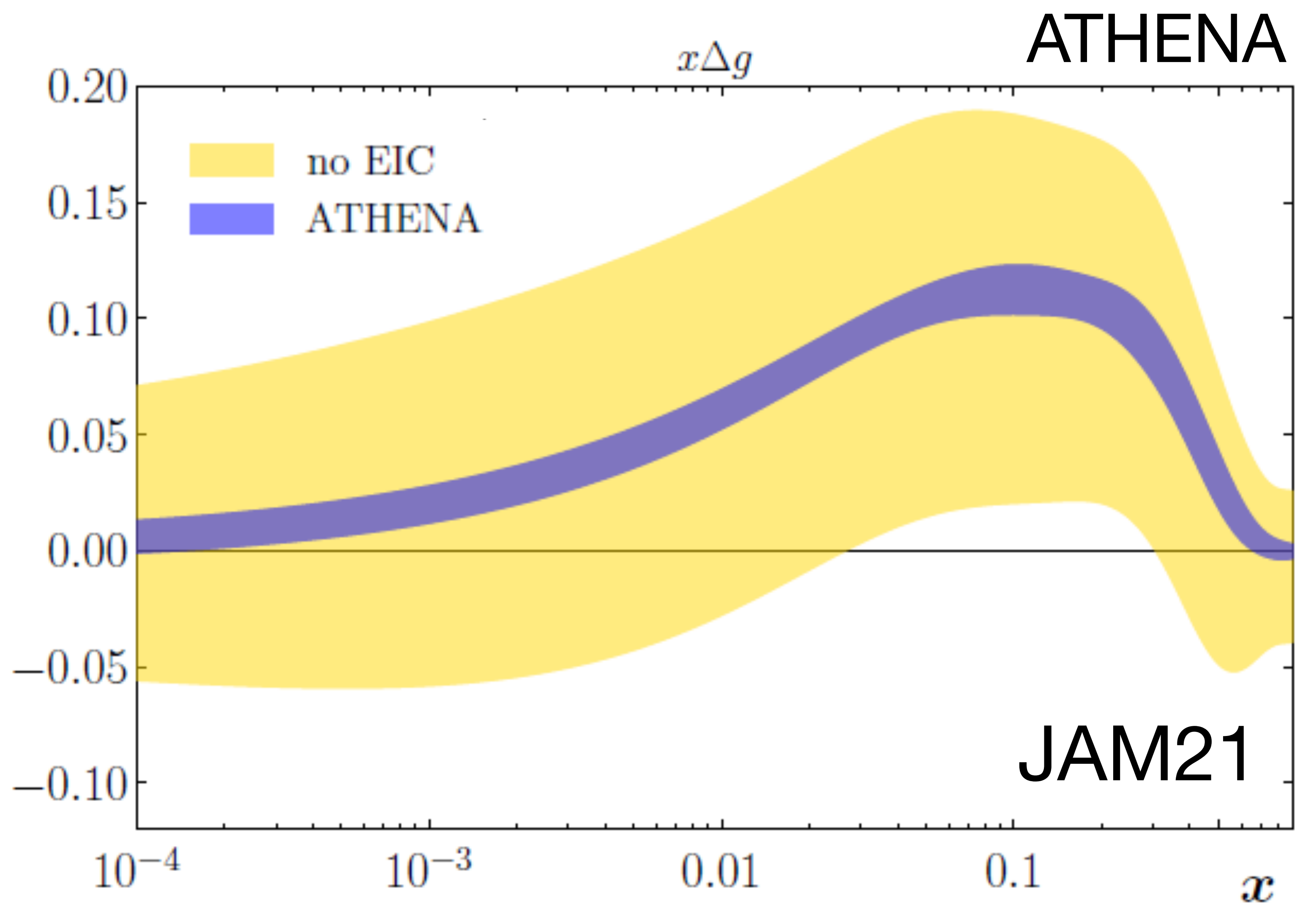

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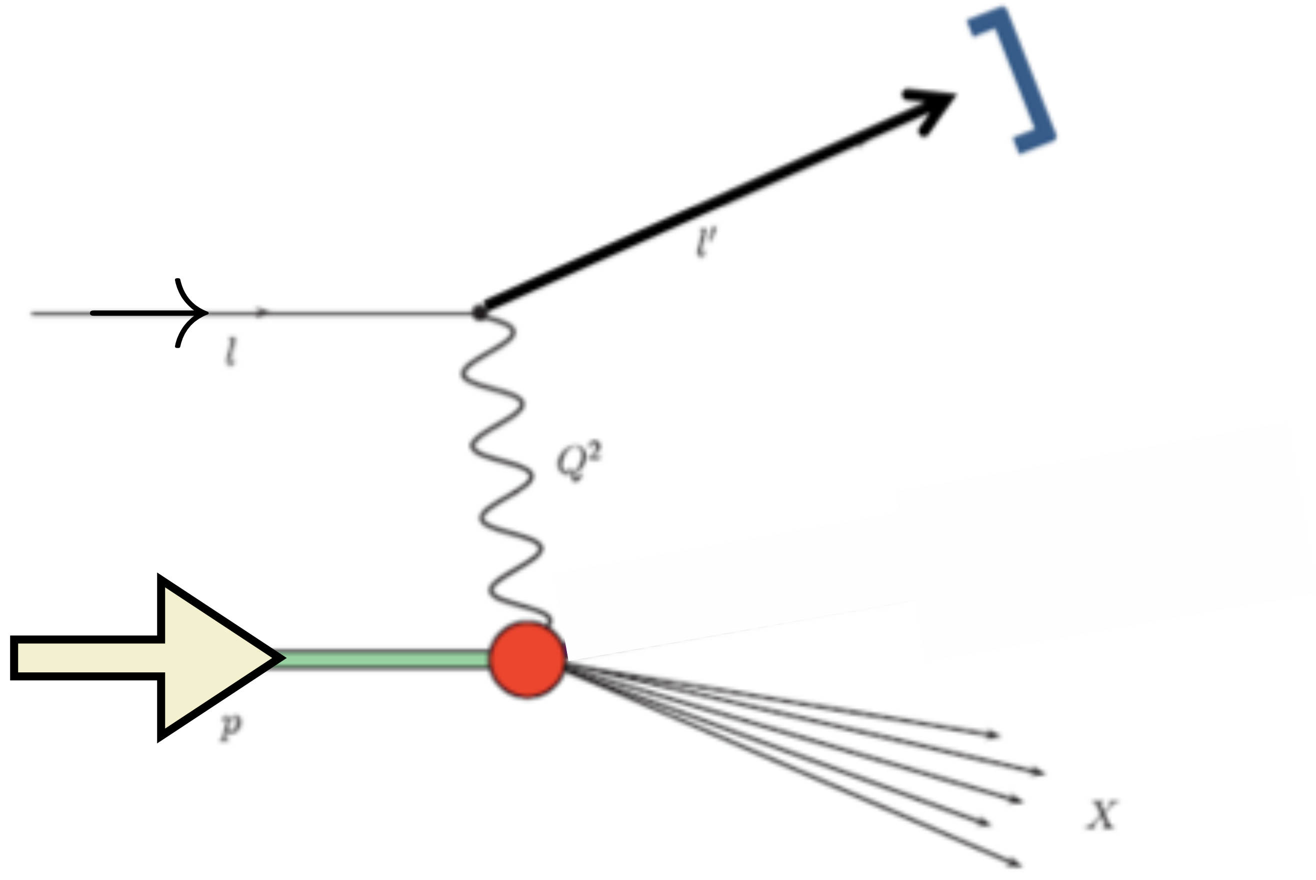

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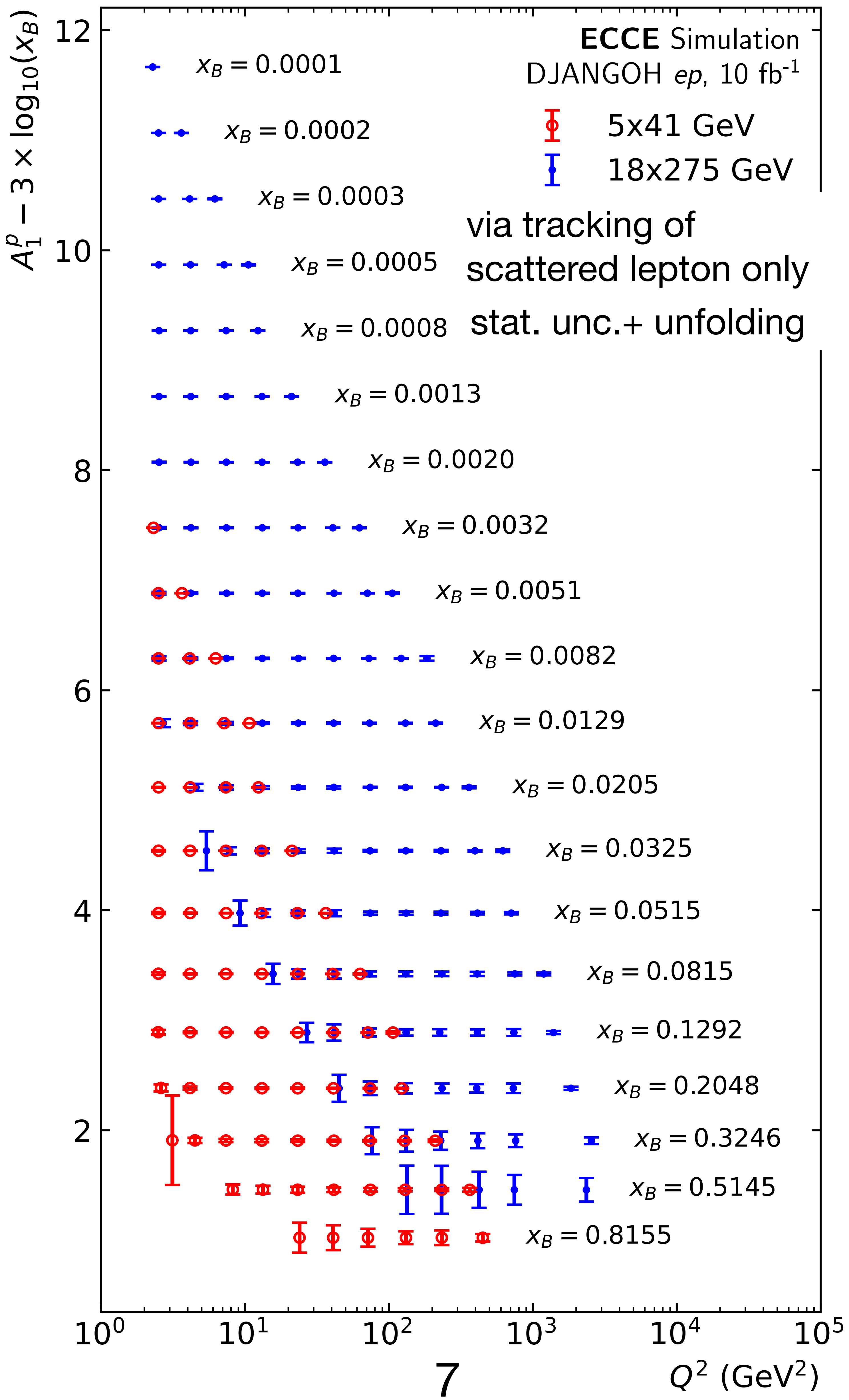
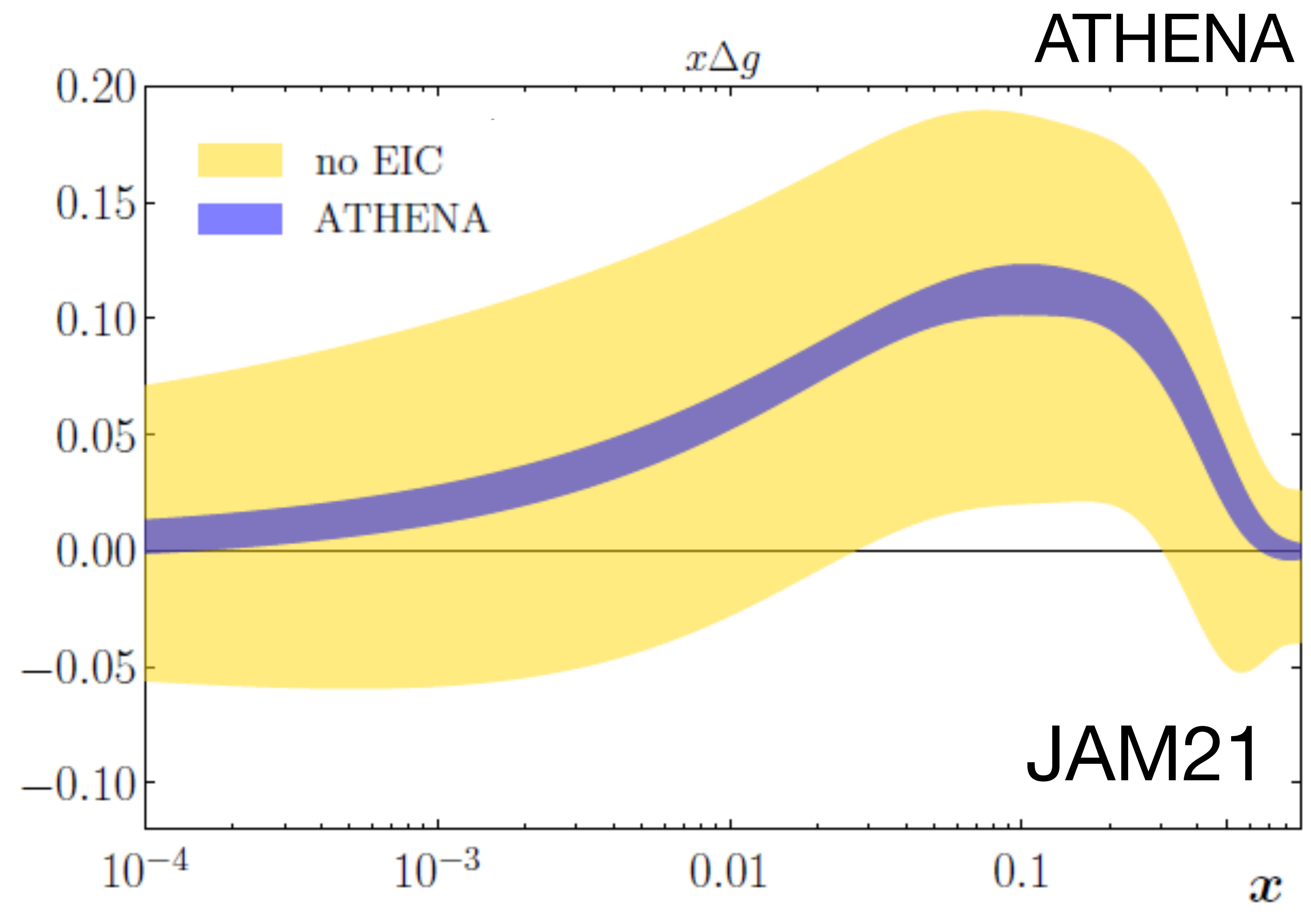
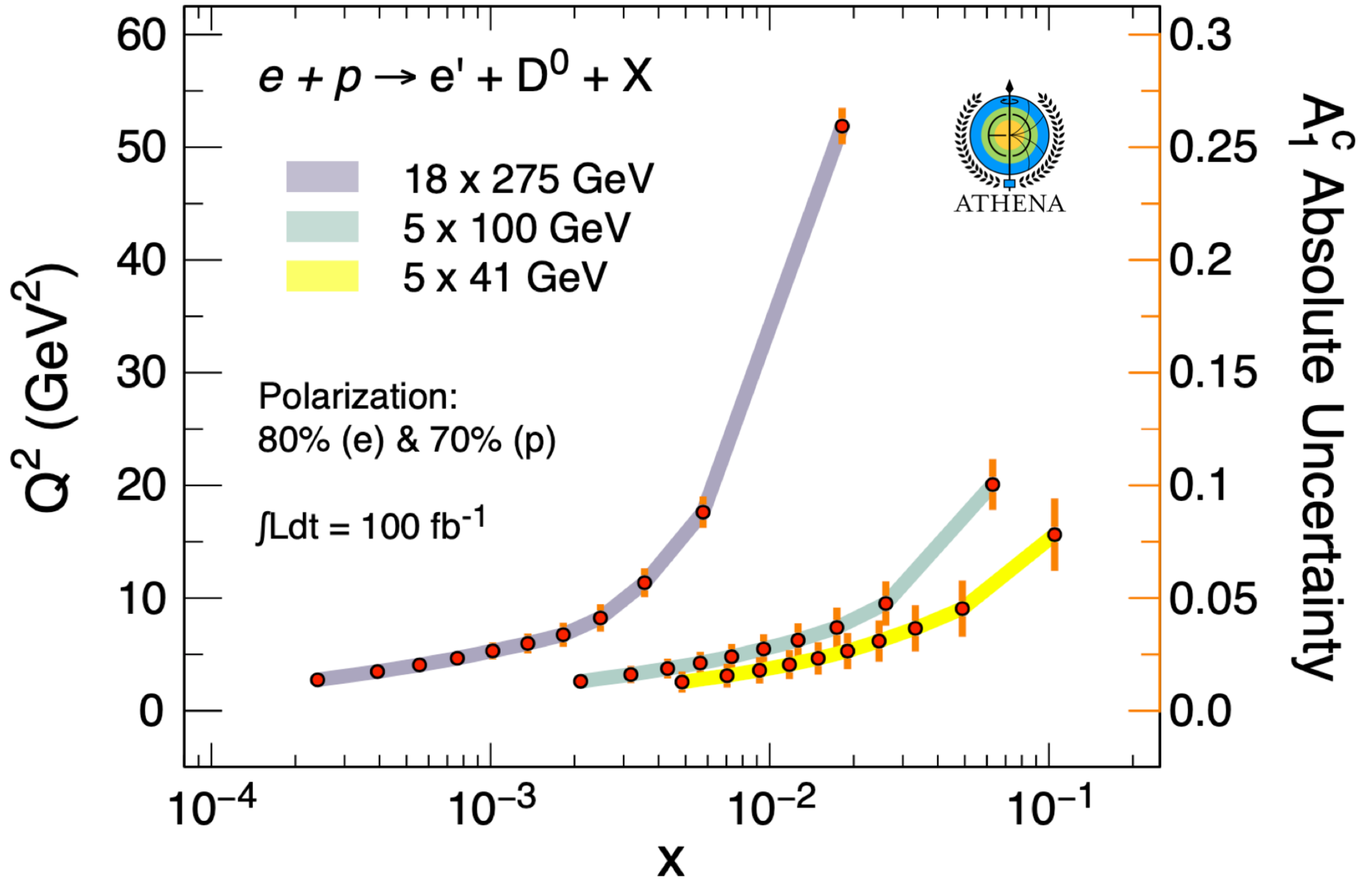
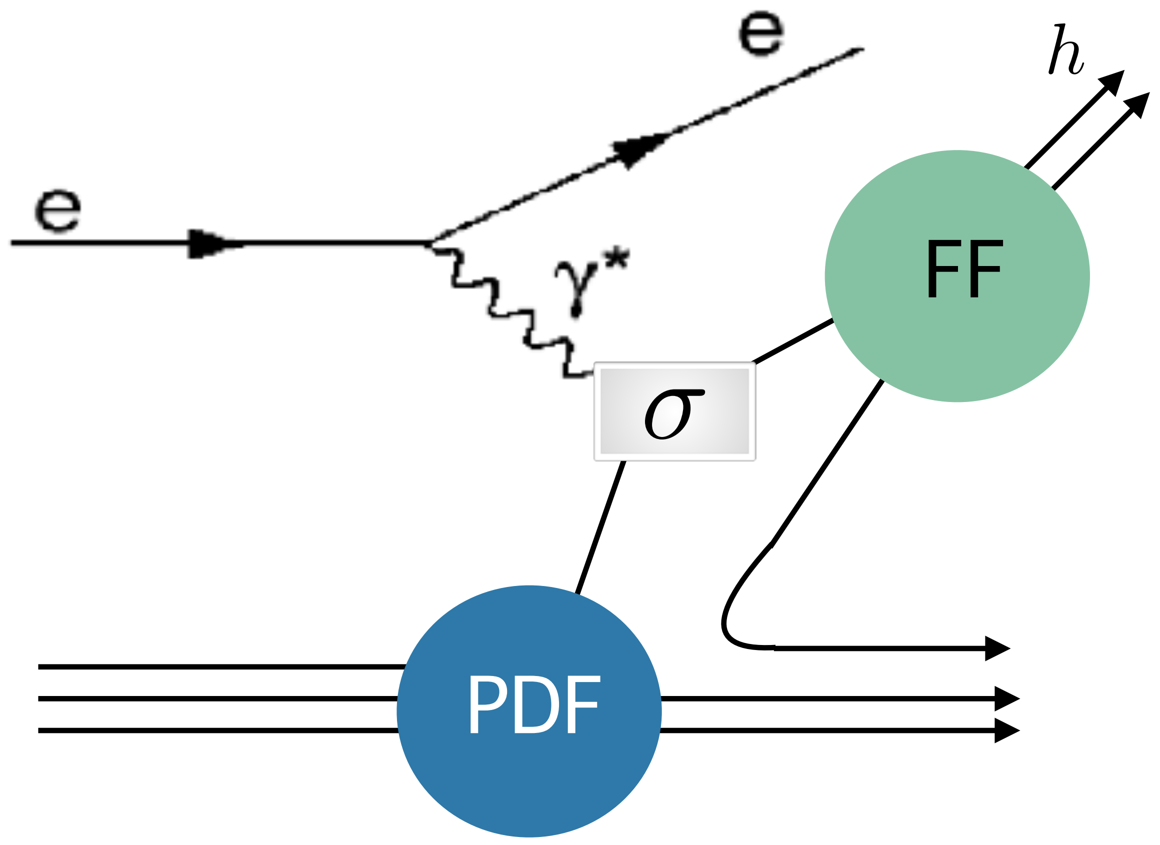




D mesons: $\gamma + g \rightarrow c\bar{c}$

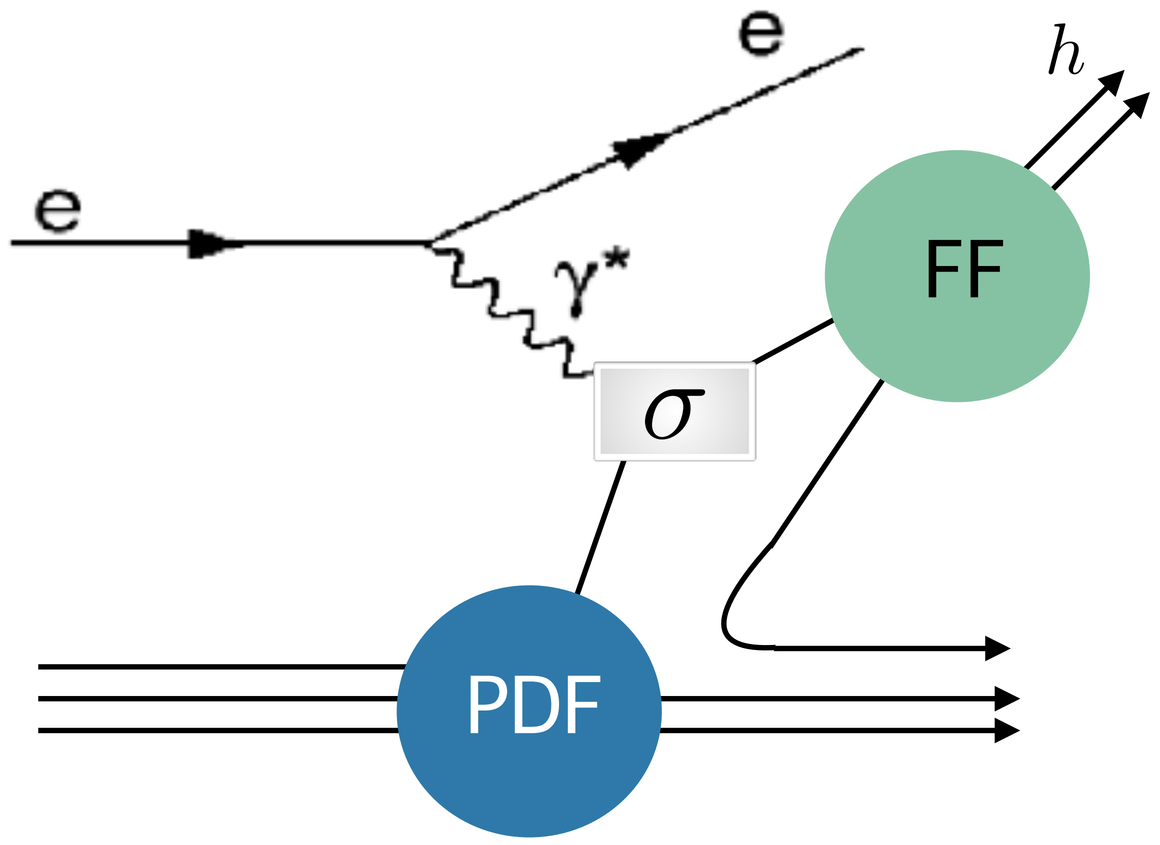


Helicity structure of the nucleon: sea quarks

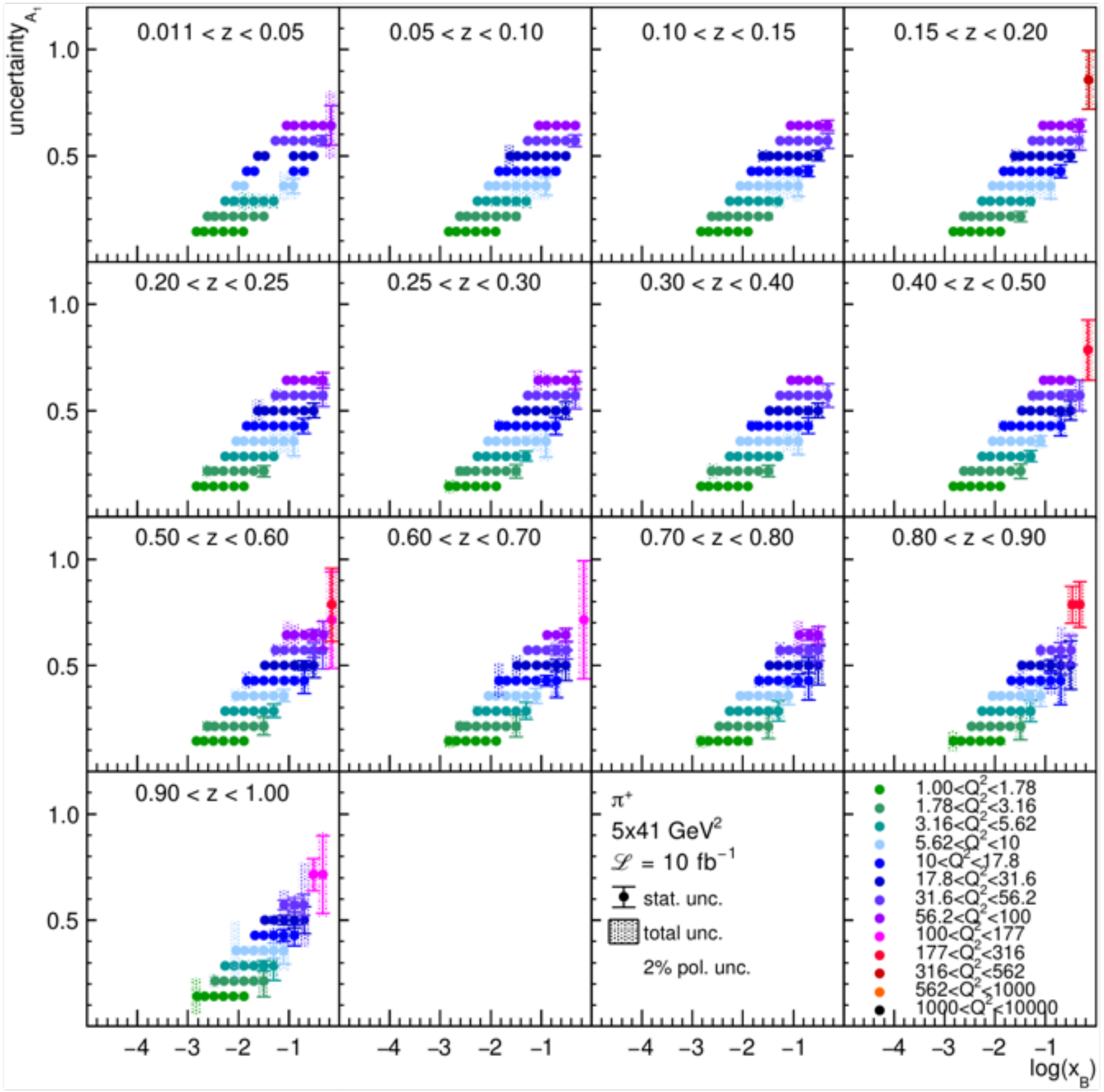


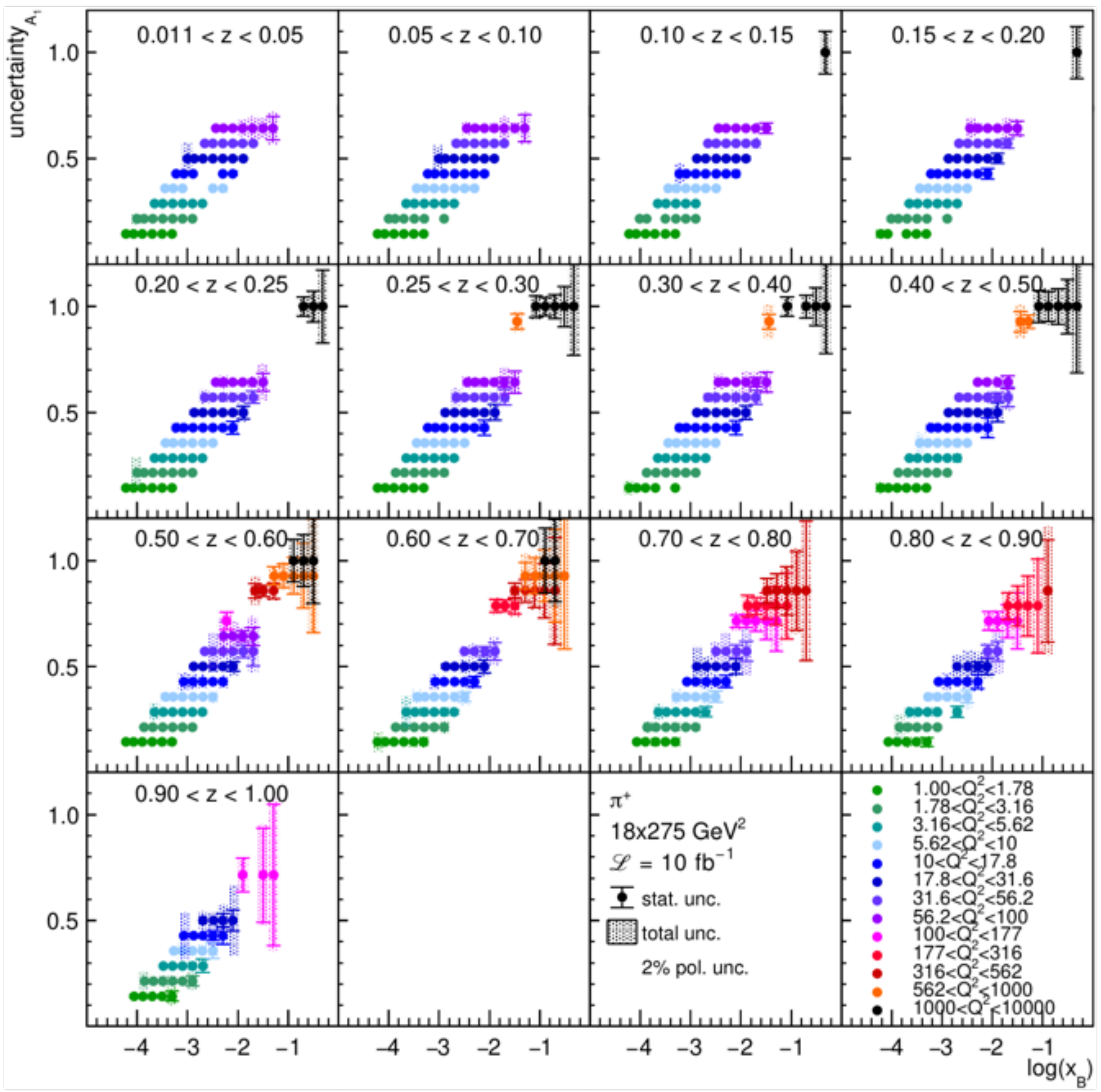
Semi-inclusive measurements, via good hadron PID
→ access to sea-quark spin

Helicity structure of the nucleon: sea quarks



ECCE





Semi-inclusive measurements, via good hadron PID
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systematic uncertainty
=|reconstructed-generated|

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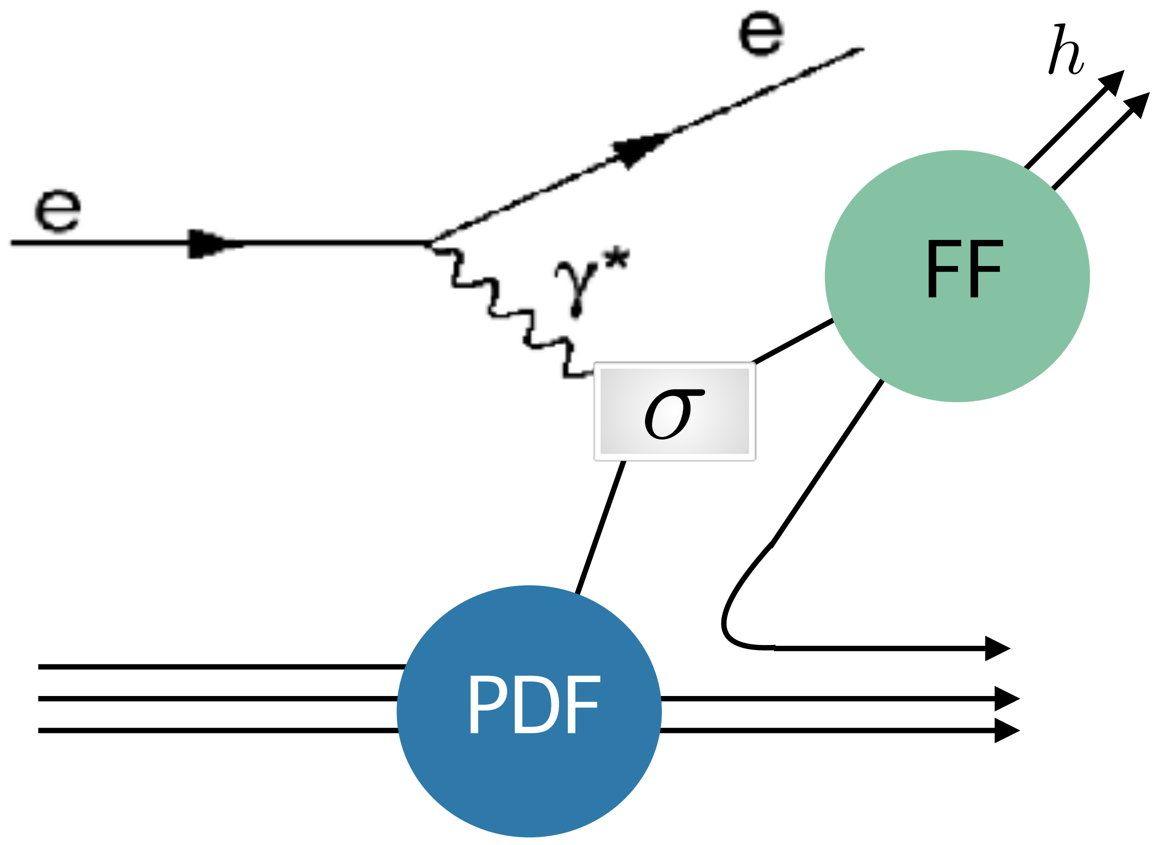

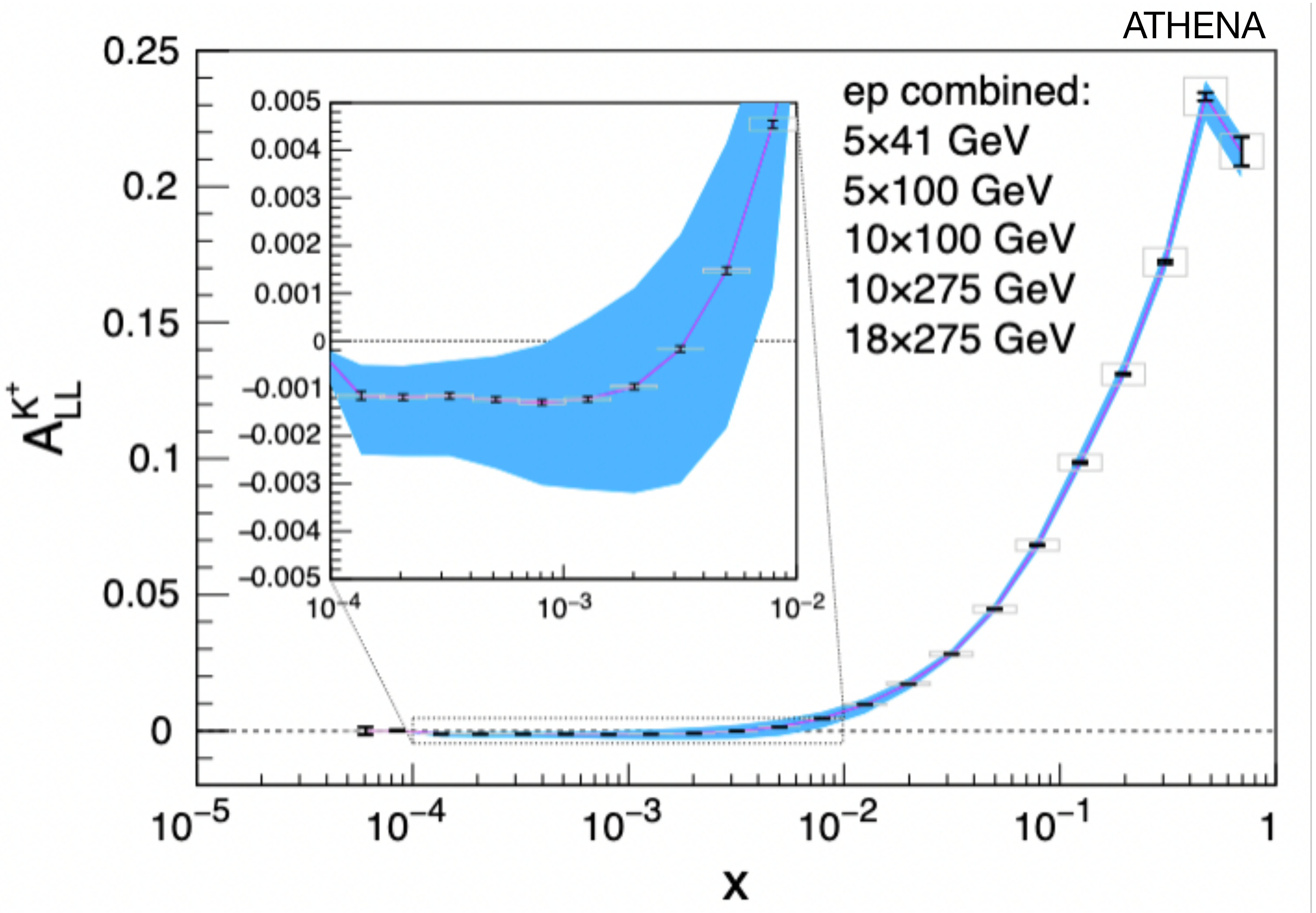

Semi-inclusive measurements, via good hadron PID
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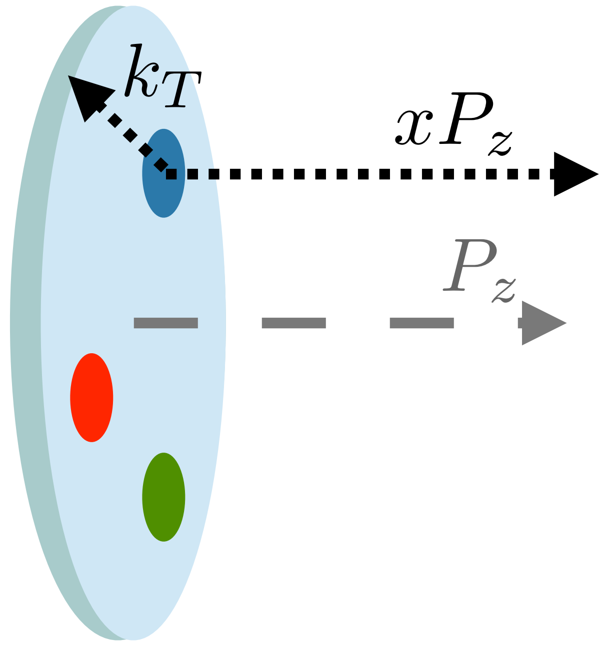
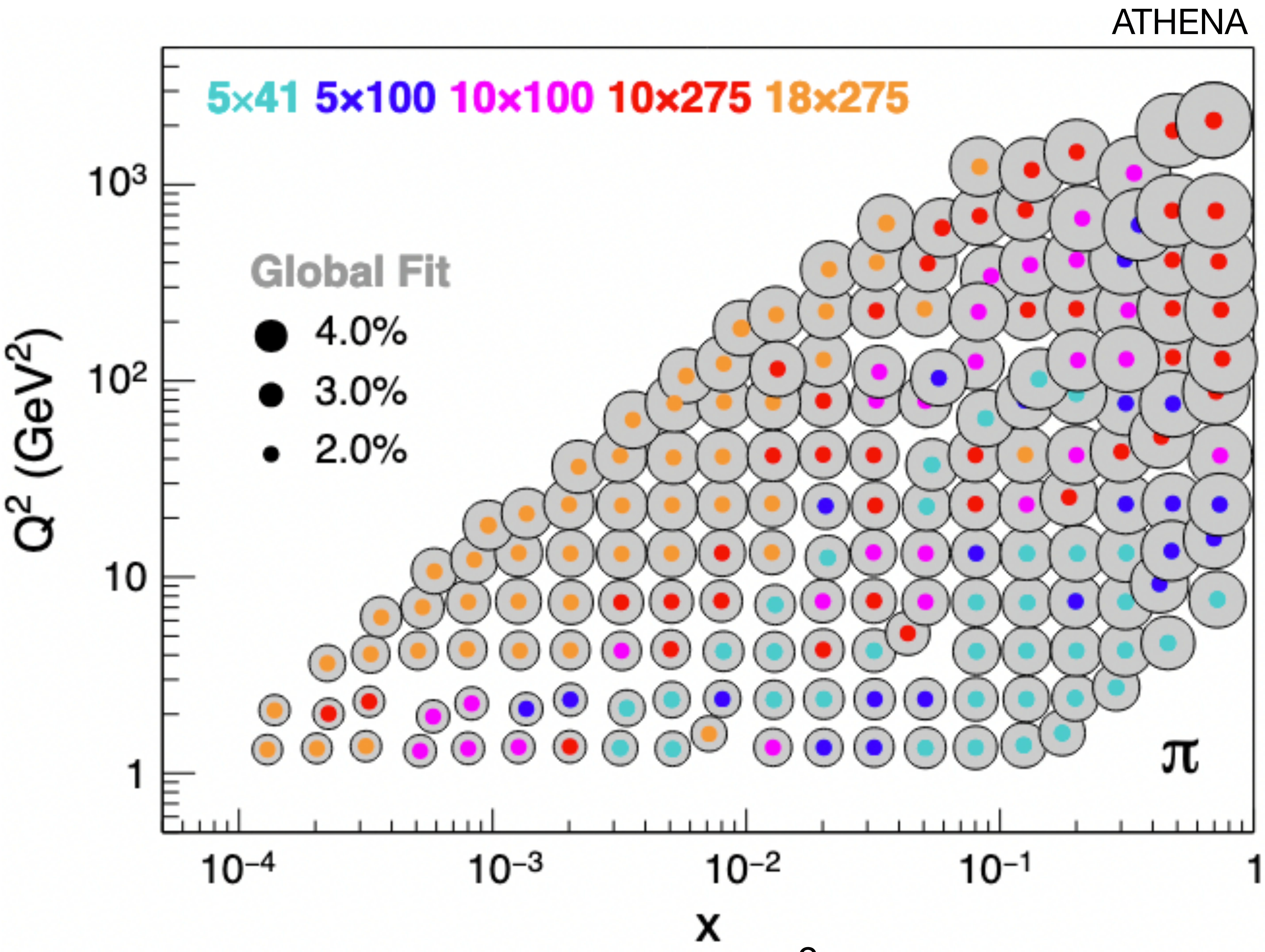
Spin-independent TMD PDF



Large lever-arm in Q^2 over large x range
→ Q^2 evolution of TMD PDF

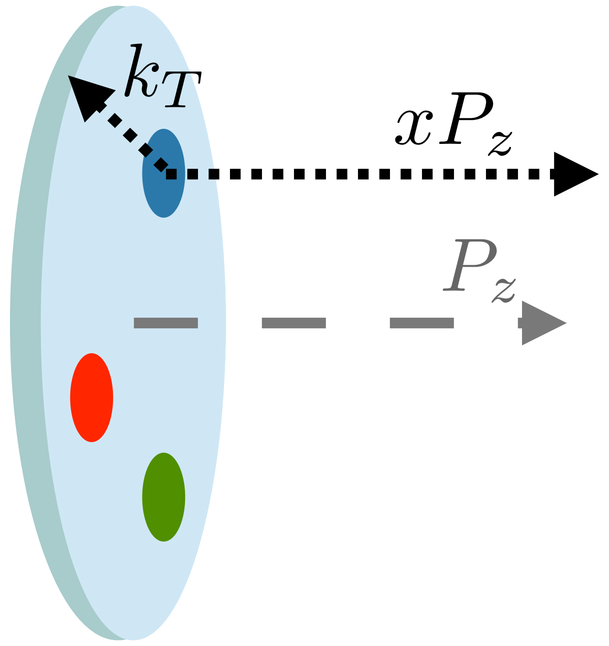


Fit:
A. Bacchetta et al.,
JHEP 06 (2017) 081,
JHEP 06 (2019) 051 (erratum)

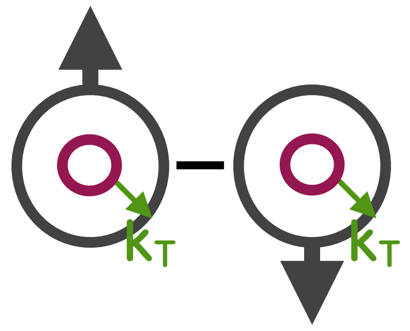
EIC uncertainties dominated by assumed
3% point-to-point uncorrelated uncertainty
3% scale uncertainty

Theory uncertainties dominated by TMD evolution.

3D spin-dependent momentum structure of the nucleon



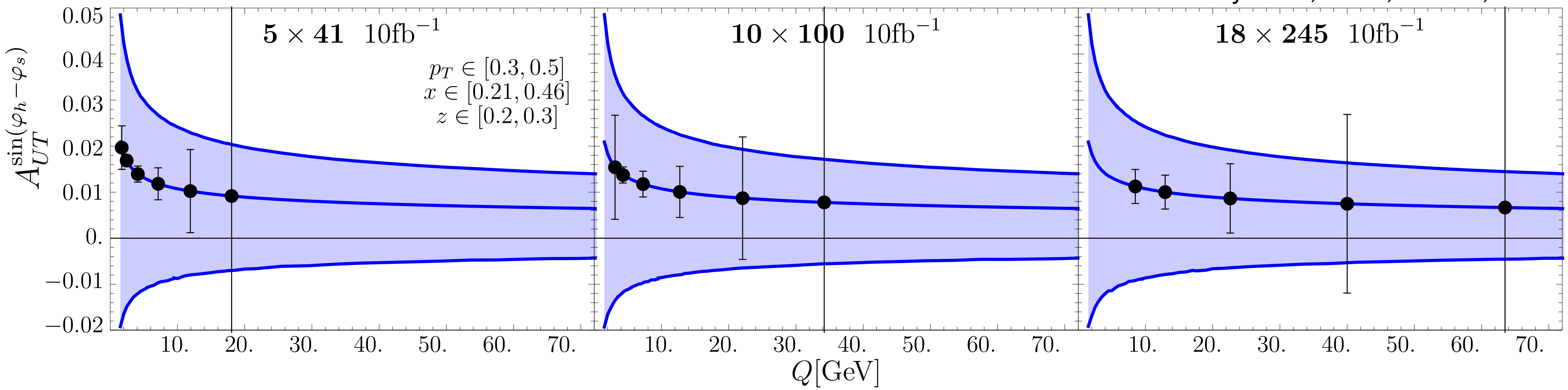
Semi-inclusive measurements, with hadron reconstruction and pid down to low p_T (~100 MeV for π)



Sivers asymmetry

- Low x and Q^2: asymmetry well below 1% → need high precision
- TMD evolution

ECCE
Parametrisation: M. Bury et al., JHEP, 05:151, 2021

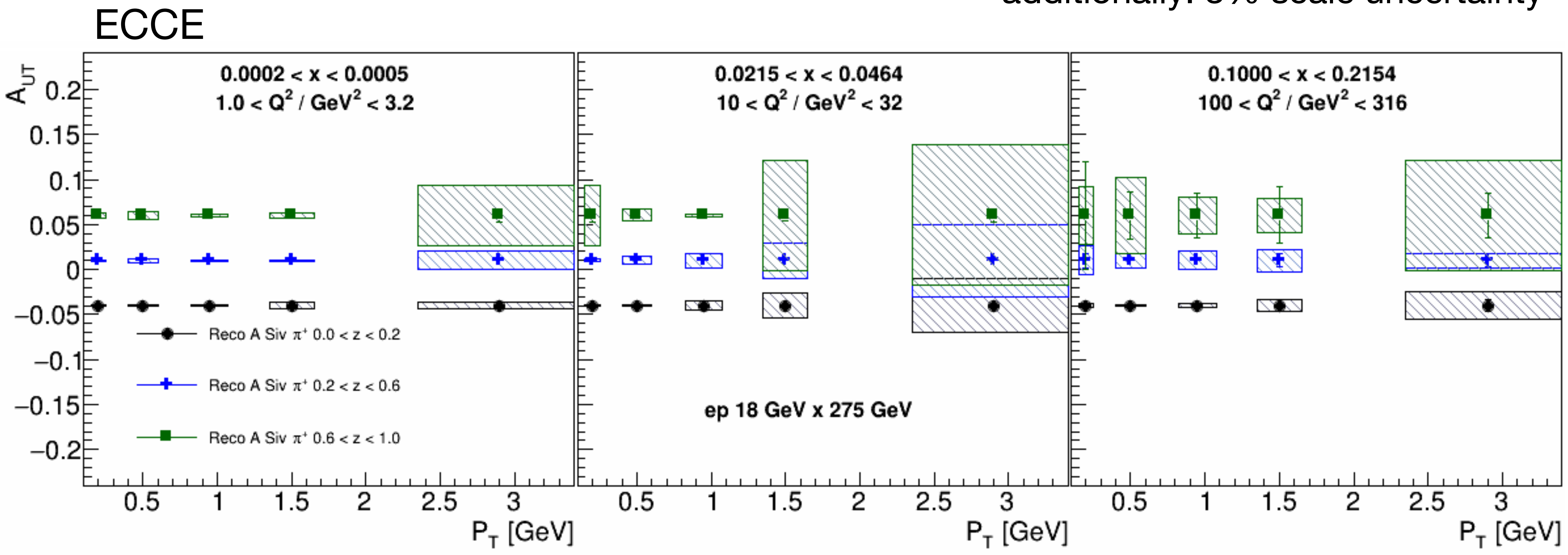


Decrease of asymmetry with increasing Q^2 → need high precision (<1%) to measure asymmetry at high Q^2

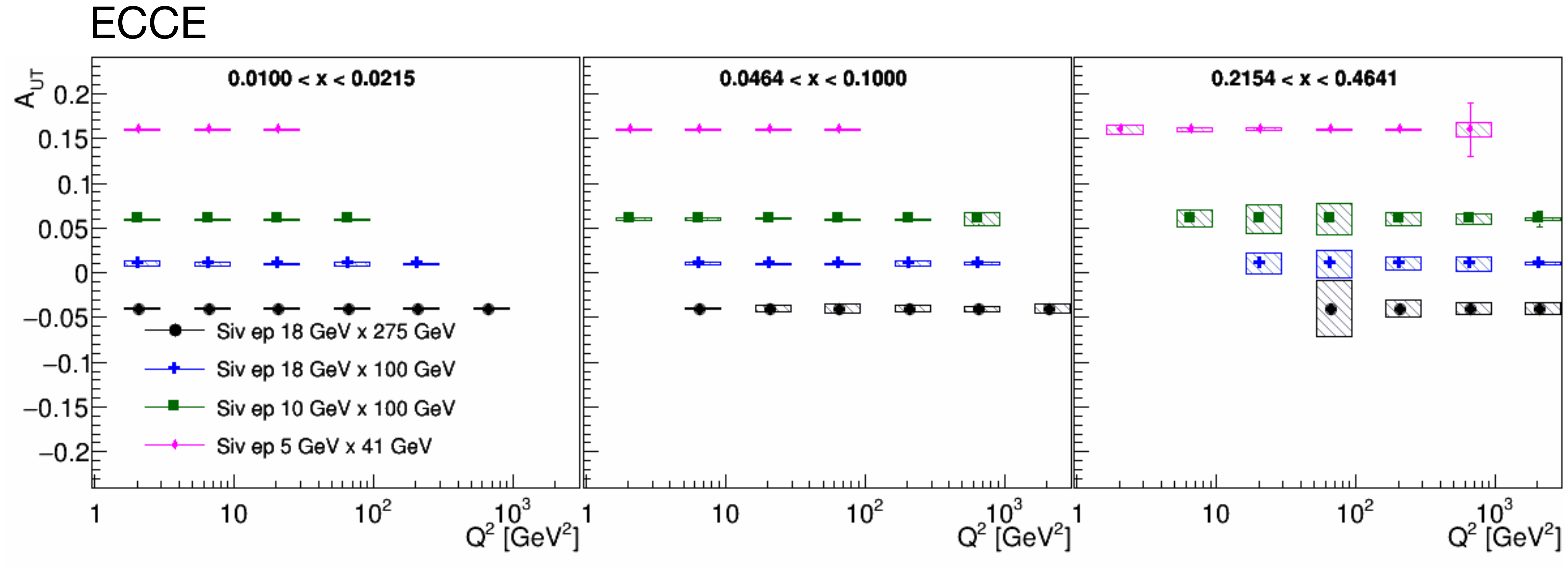
Uncertainties Sivers asymmetry

- Beam polarisations set to 70%.
- systematic uncertainty= |generated - reconstructed|
- additionally: 3% scale uncertainty

- Low x and Q^2: small statistical uncertainty.
- For not too large P_T (and z) statistical uncertainty well below 1%.
- Systematic uncertainties increase with P_T (and z) likely because of higher smearing effects.



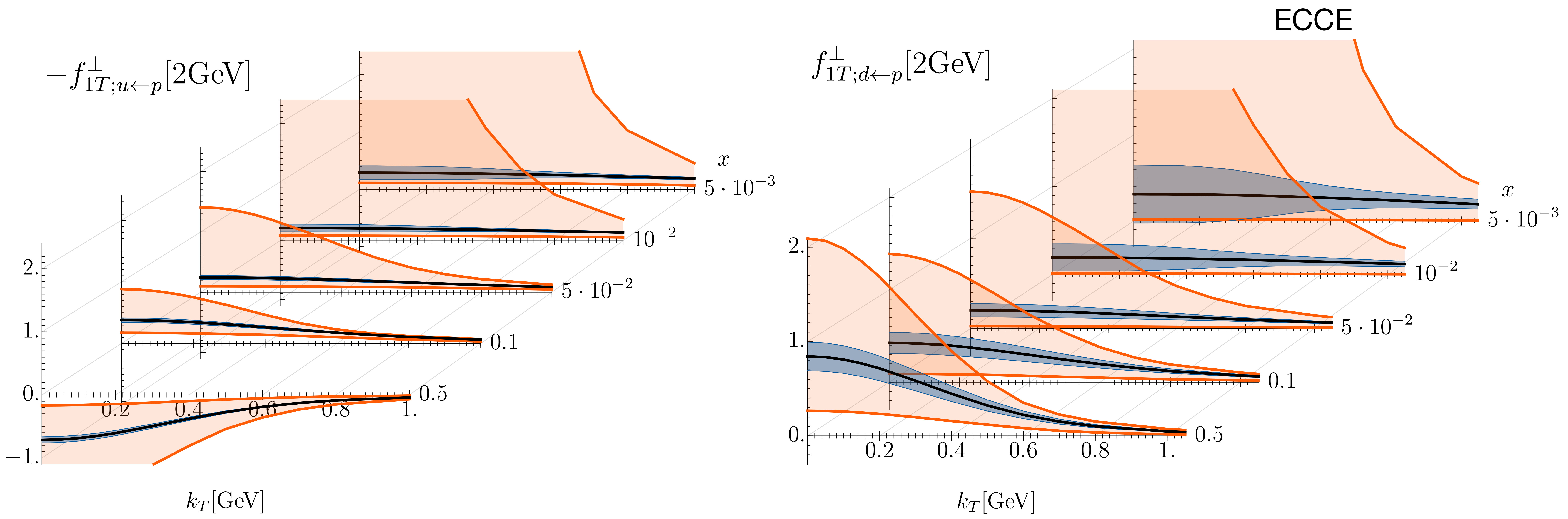
- Intermediate and high x: good coverage in Q^2, complementarity at different COM energies.



Sivers TMD PDF: impact of EIC

Parametrisation from
M. Bury et al., JHEP, 05:151, 2021

Q=2 GeV



DIS variables via scattered lepton

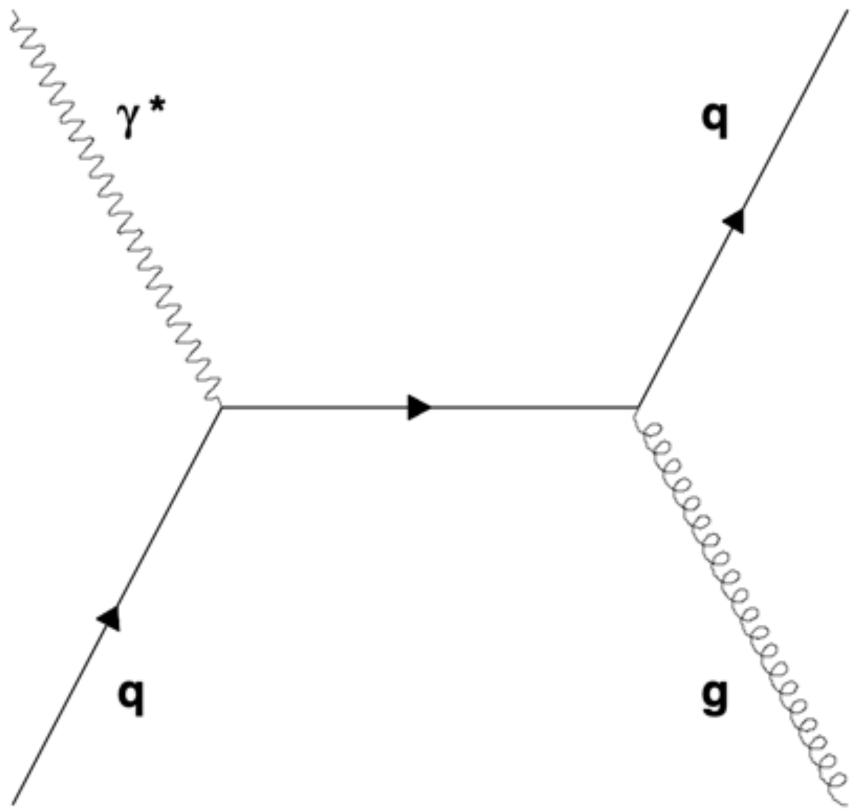
$$Q^2 > 1\ \text{GeV}^2$$
$$0.01 < y < 0.95$$
$$W^2 > 10\ \text{GeV}^2$$

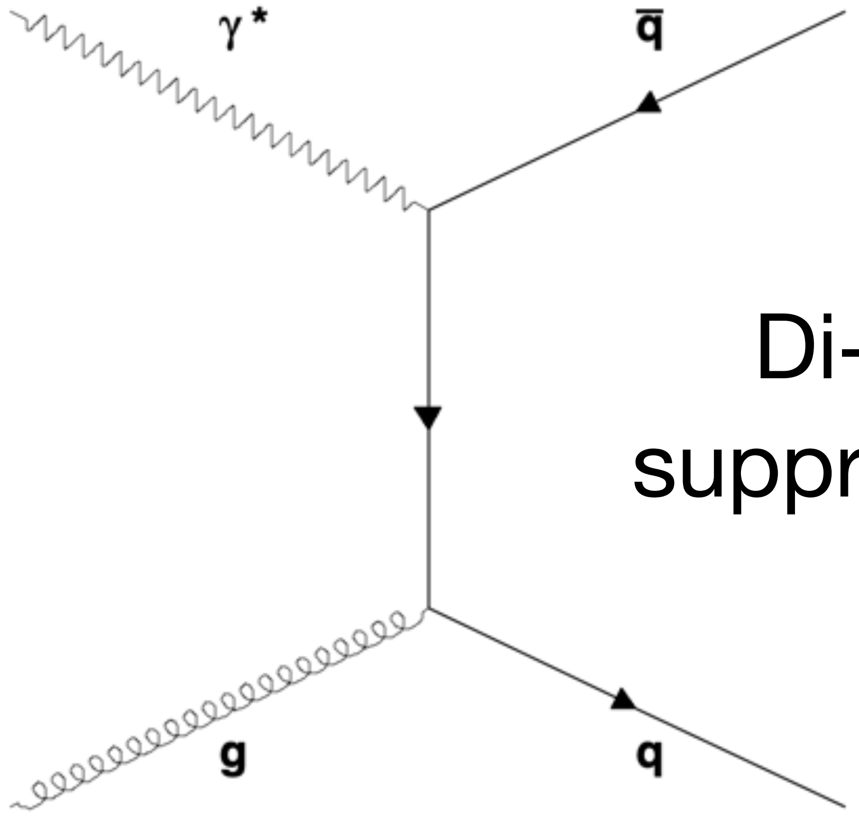
$$5 \times 41\ \text{GeV}^2$$
$$10 \times 100\ \text{GeV}^2$$
$$18 \times 100\ \text{GeV}^2$$
$$18 \times 275\ \text{GeV}^2$$

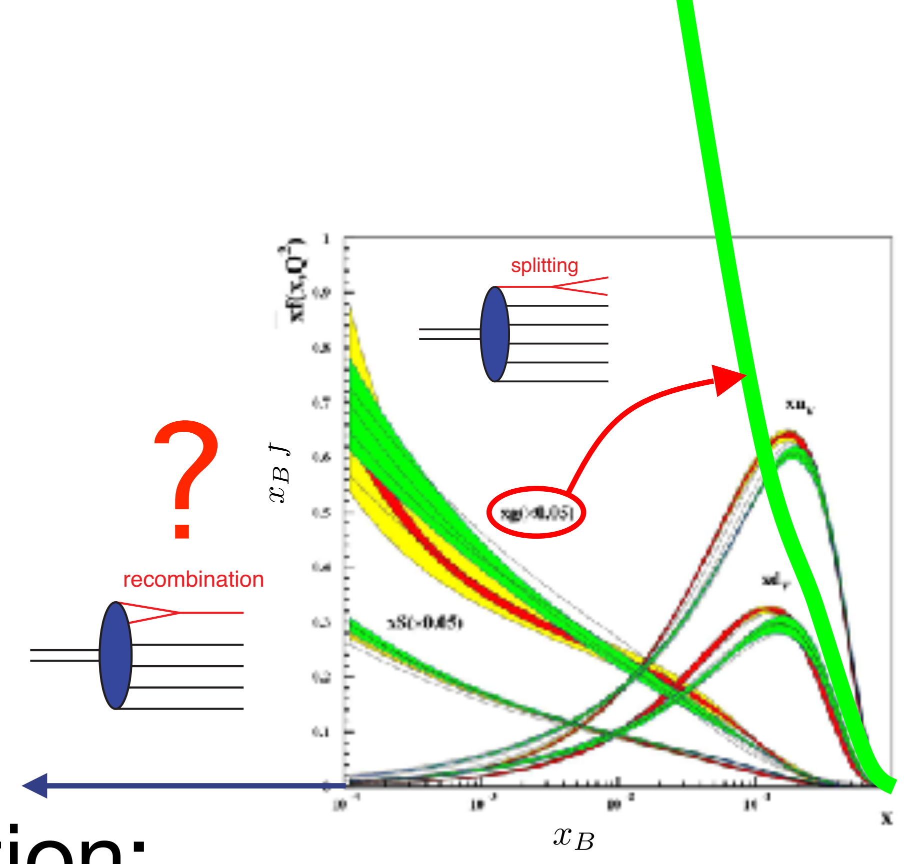
$\mathcal{L} = 10\ \text{fb}^{-1}$ for each collision energy

pion and kaon data

Di-hadron production from in eA

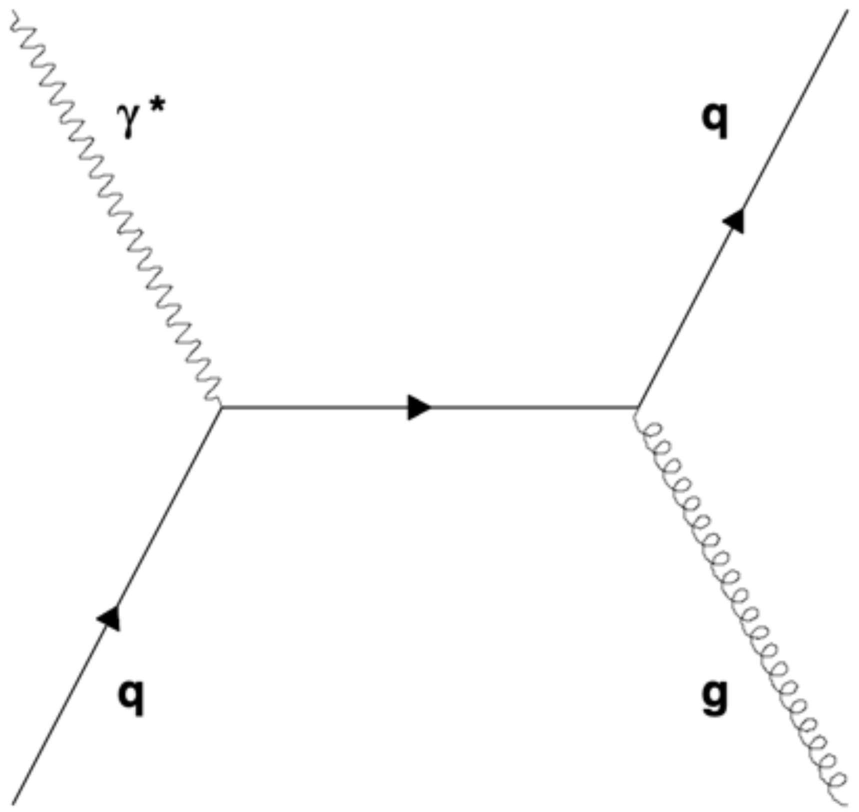


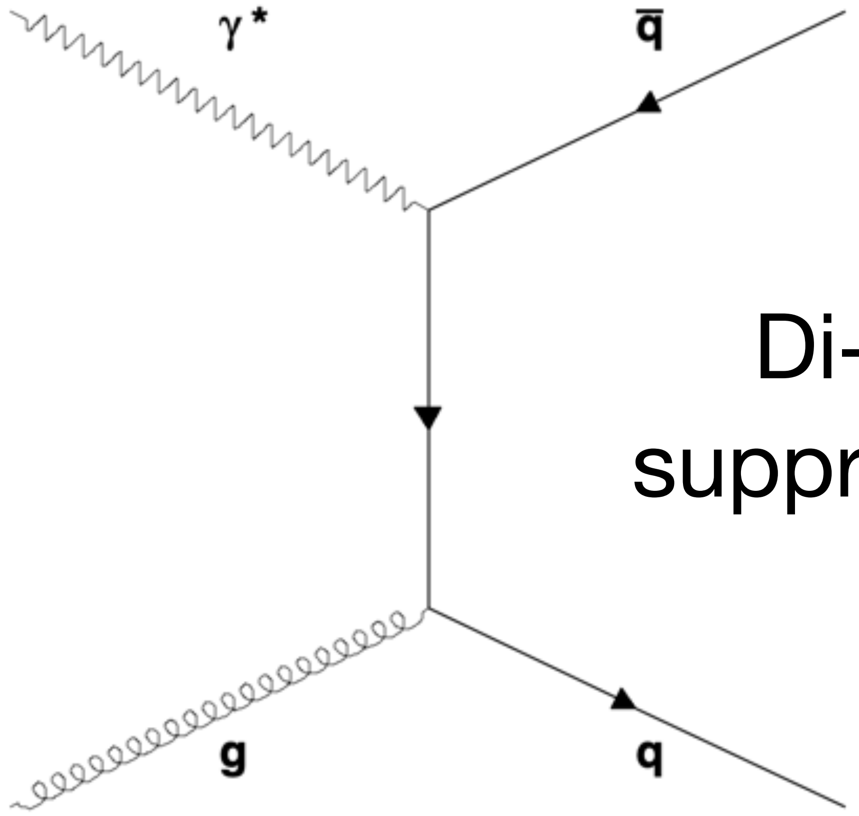


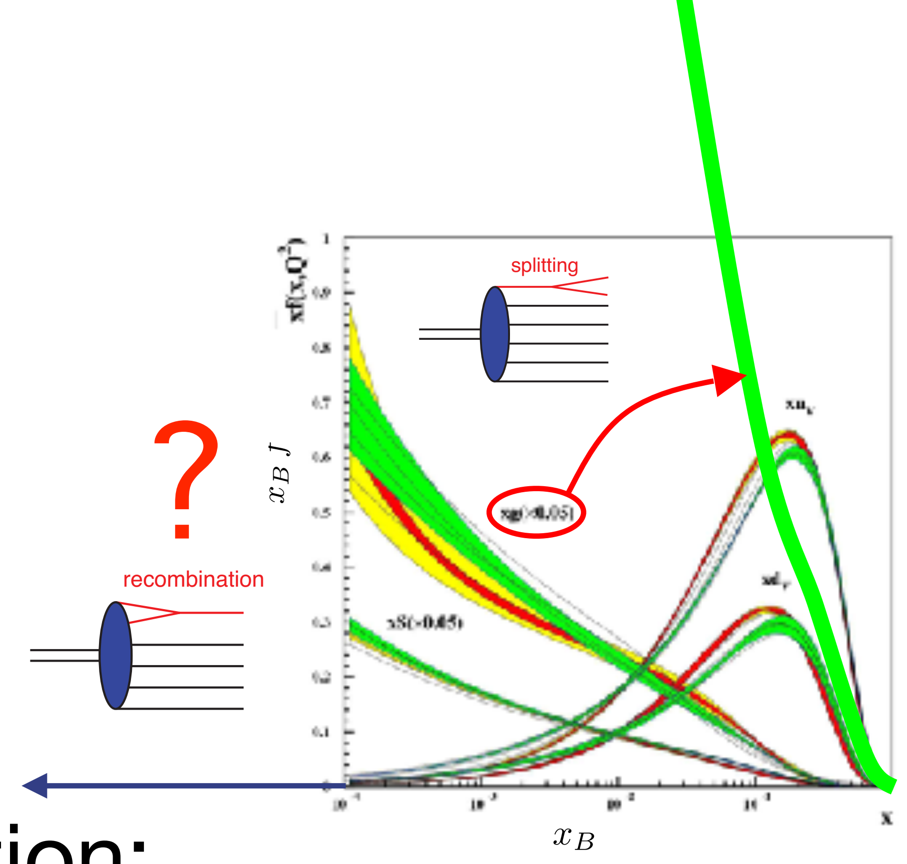


Di-jet correlations → search for signs of saturation:
suppression of back-to-back dijet correlations in nucleus

Di-hadron production from in eA

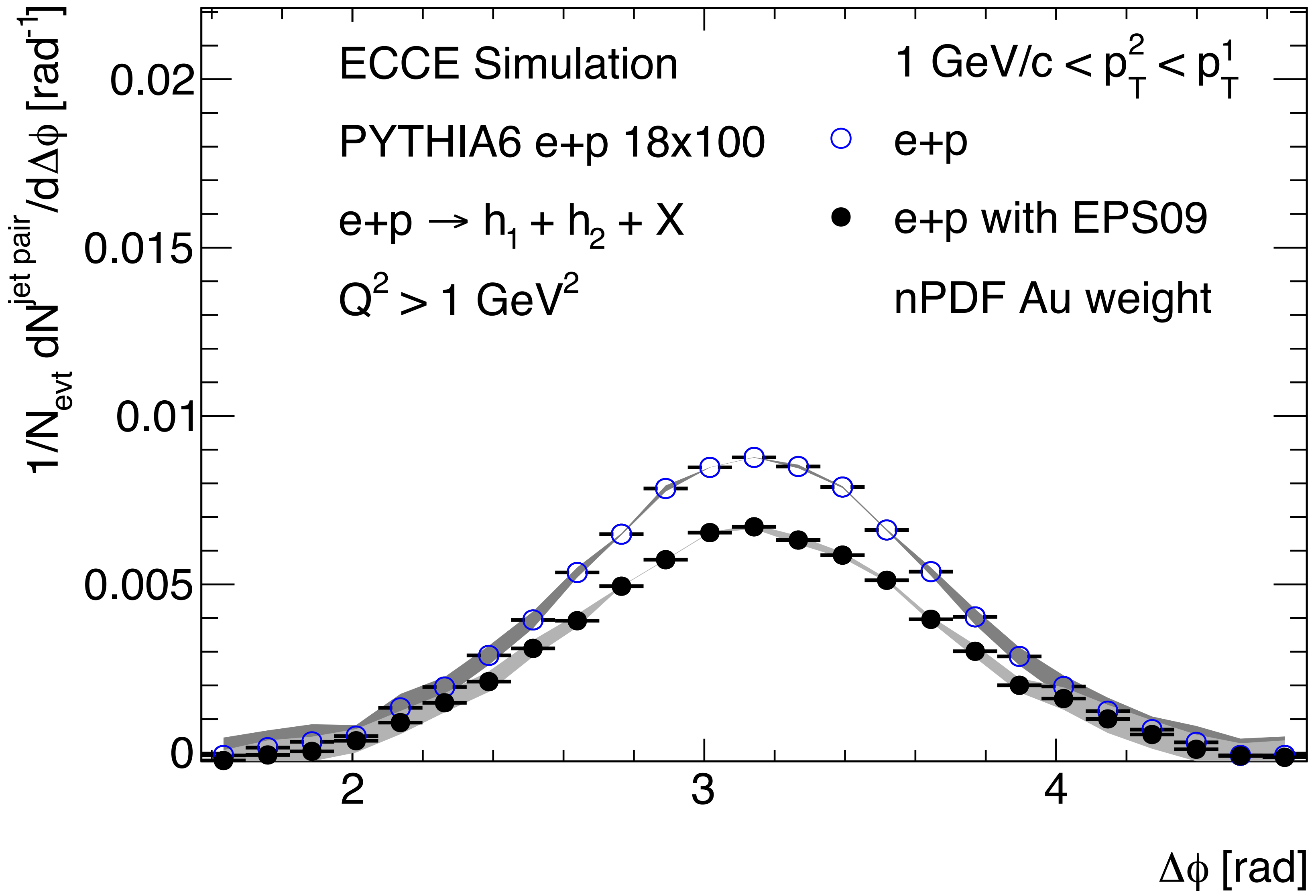






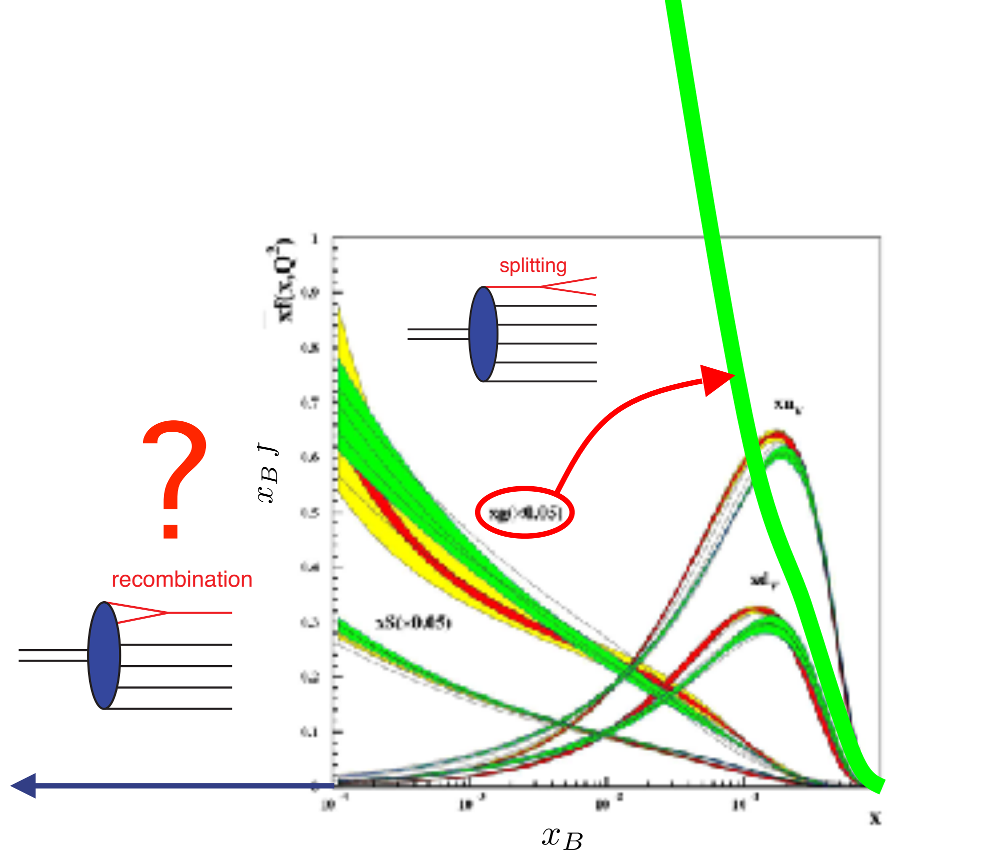
Di-jet correlations → search for signs of saturation:
suppression of back-to-back dijet correlations in nucleus

For π/2<Δϕ<3π/2 difference eA–ep
>
systematic uncertainties (grey band)
systematic=diff. (gen.,rec.)



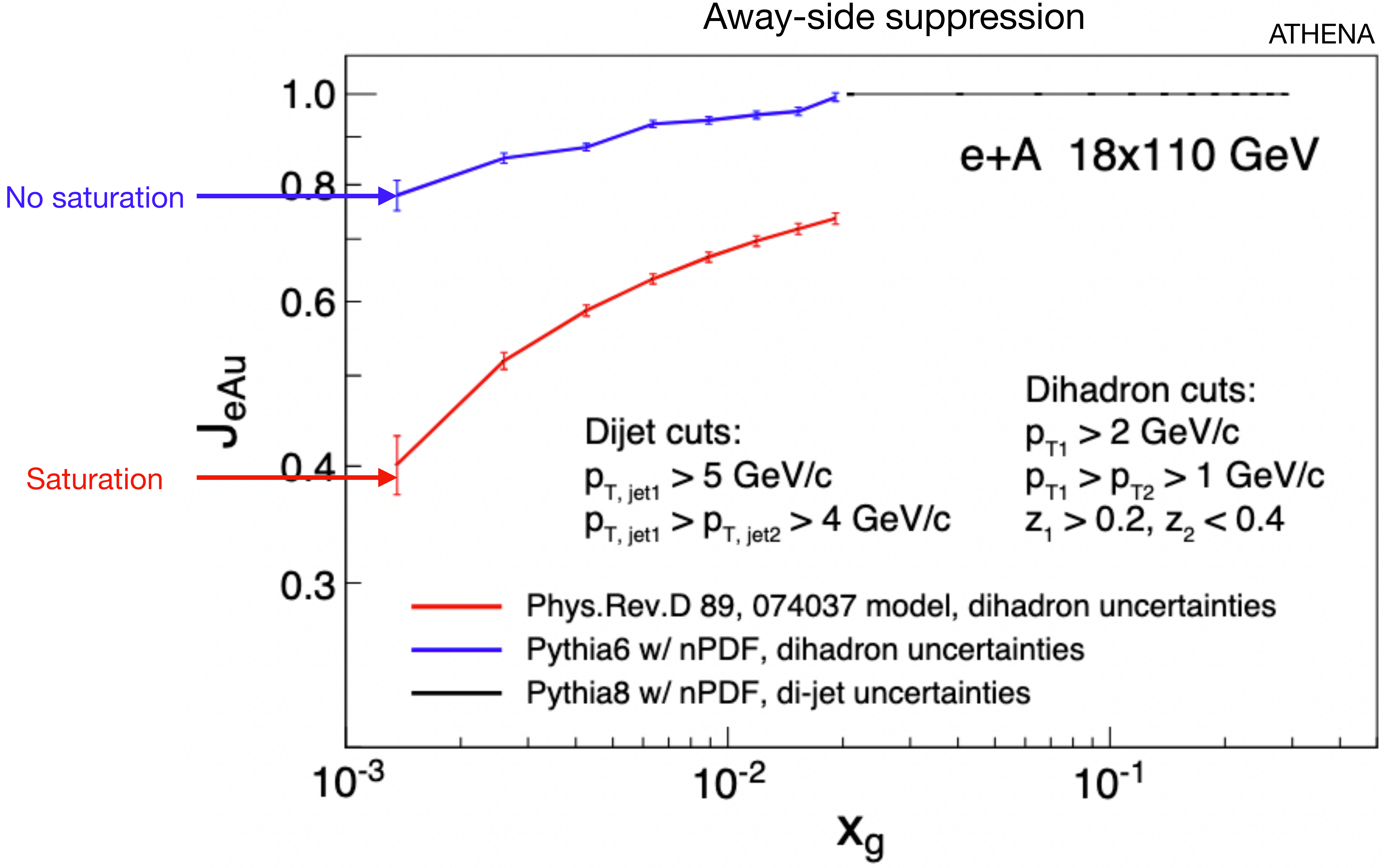
Di-hadron production and jets in eA

- Complementarity region covered by dihadron and jet production



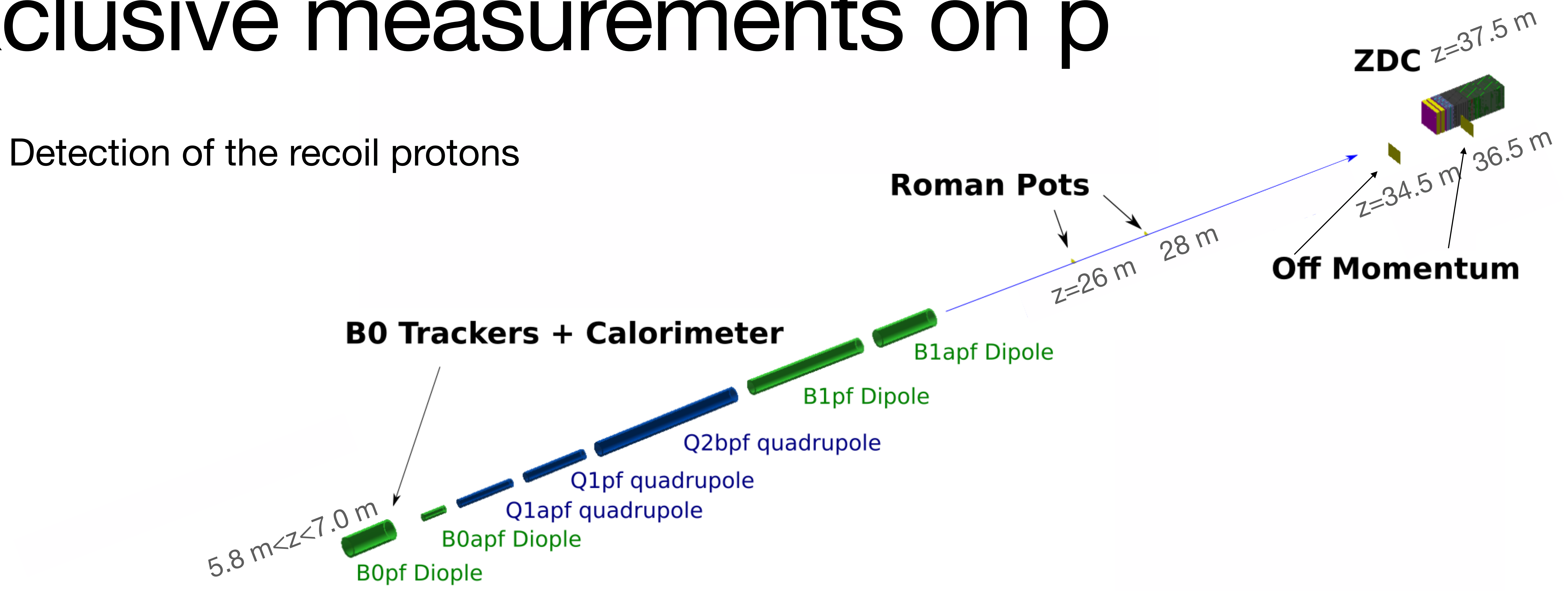
correlated back-to-back hadron pairs in e+Au/e+p scaled by A^{1/3}

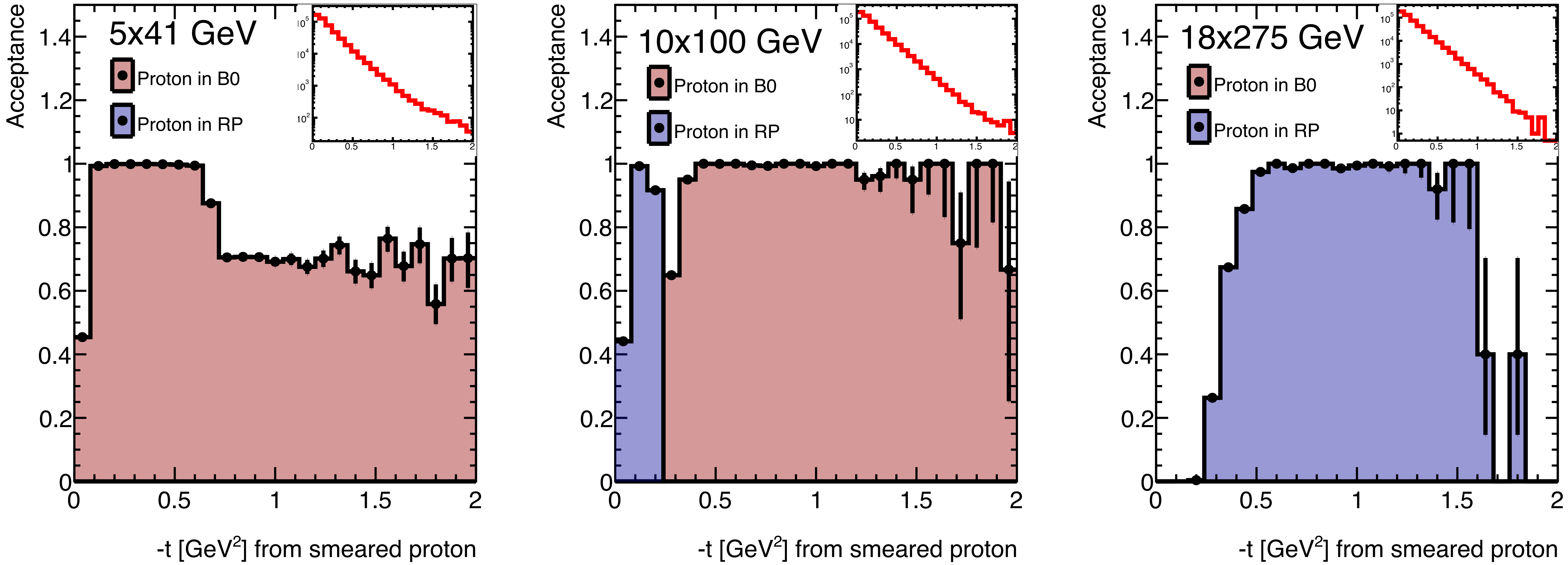
Away-side suppression



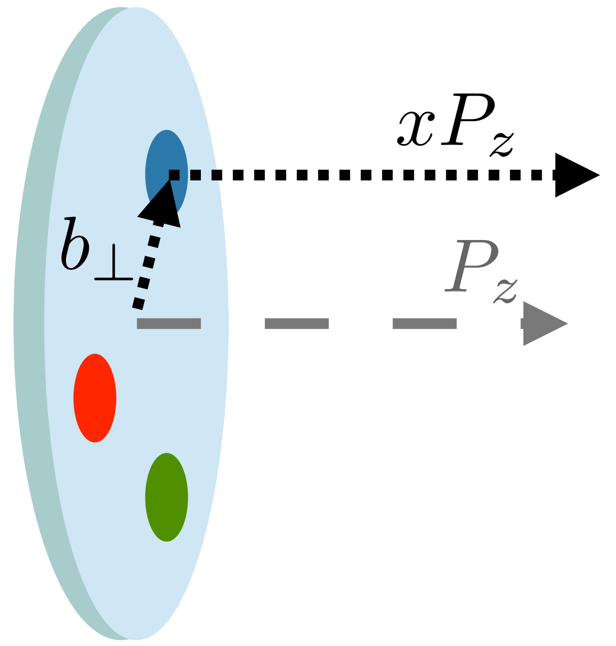
Exclusive measurements on p

Detection of the recoil protons

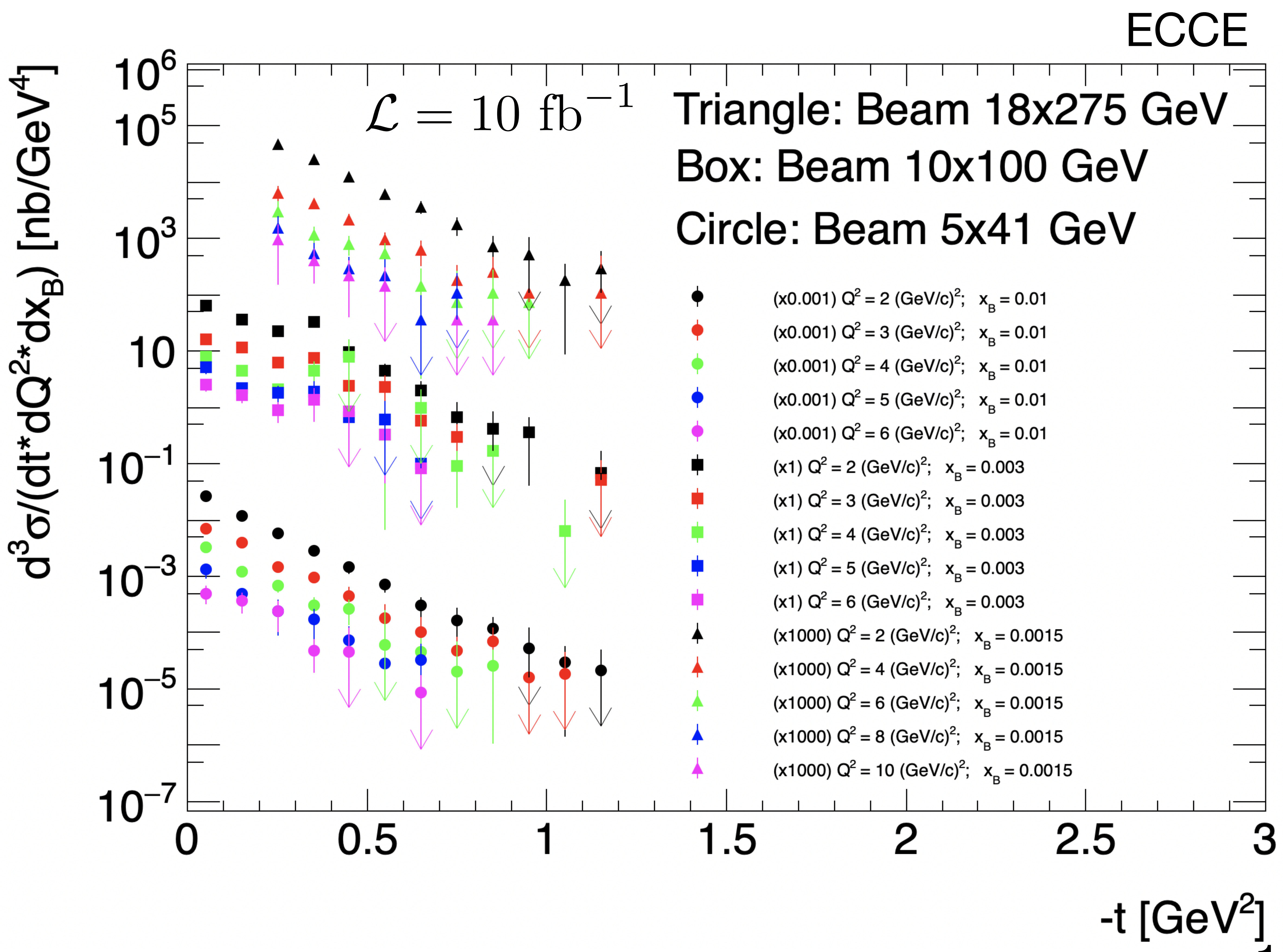




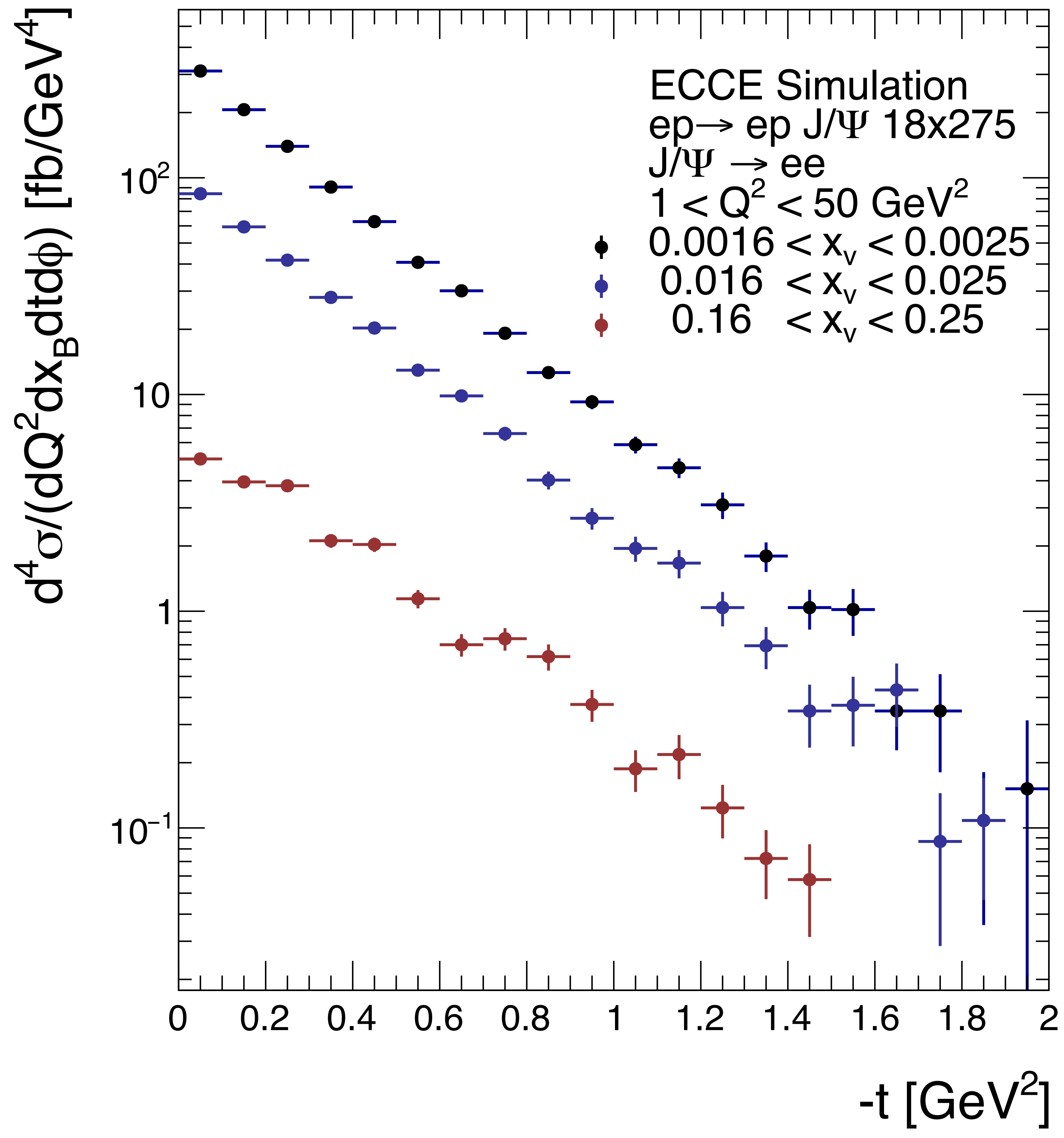
3D position+momentum structure of nucleon: exclusive measurements on p



Deeply virtual Compton scattering
→ sensitive to quarks (and gluons)



Exclusive J/ψ production
→ excellent to probe gluon GPDs



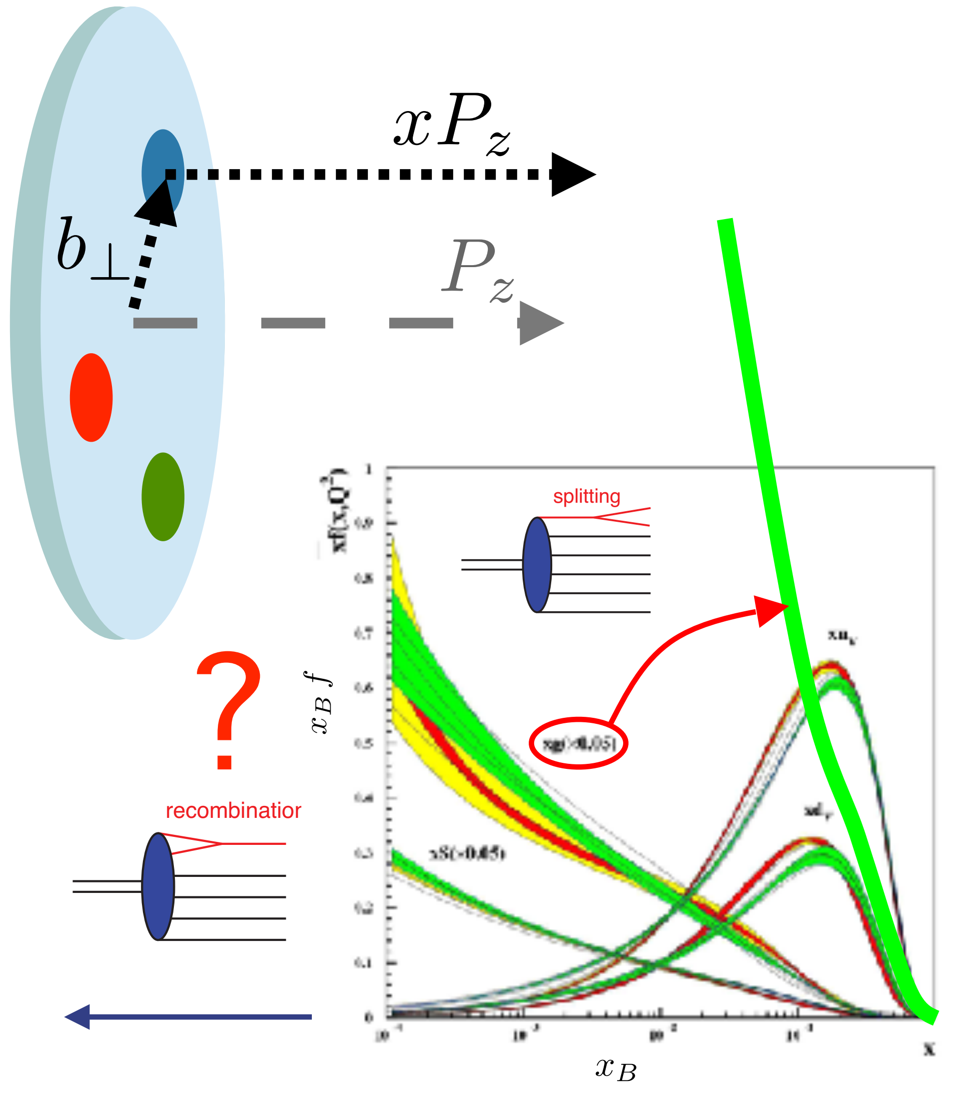
Coherent eA production

→ probe gluon saturation

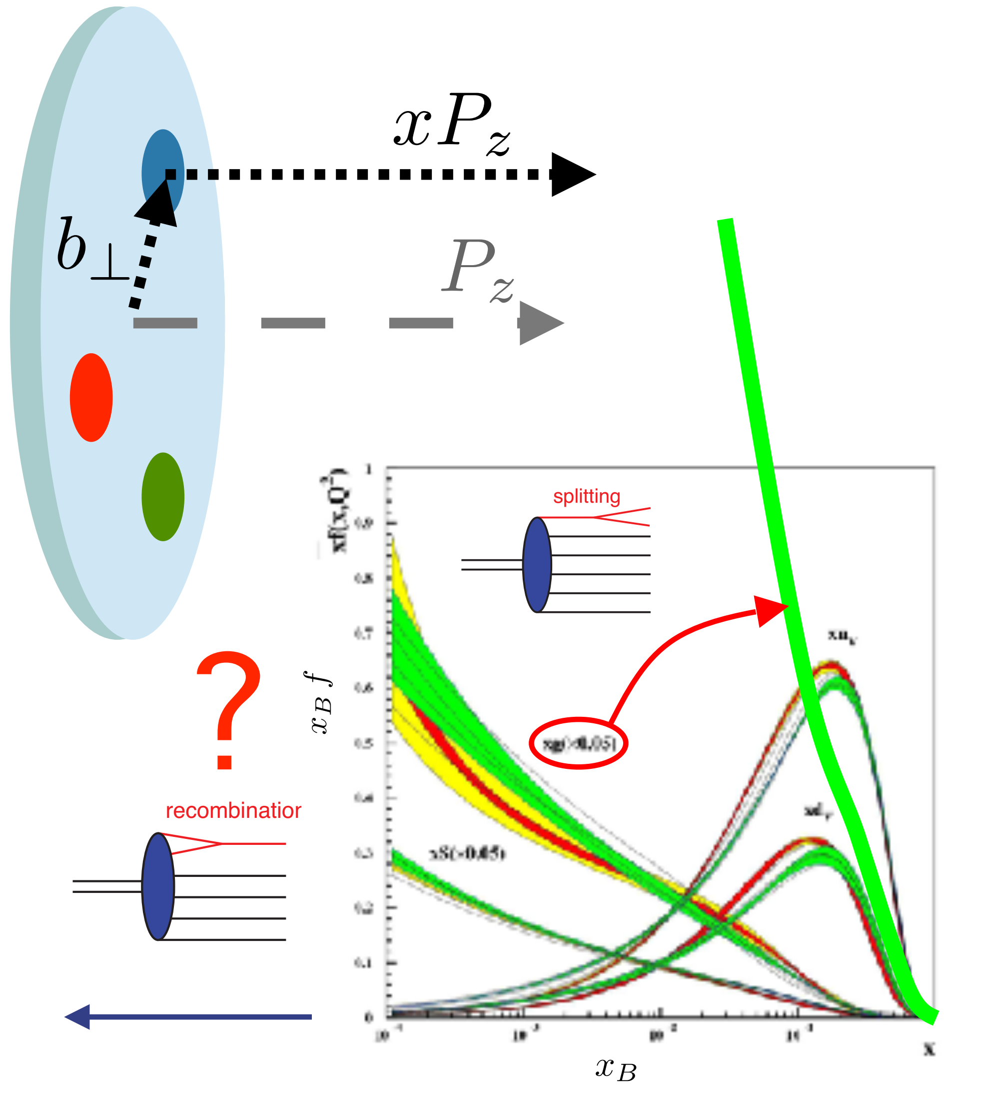
→ nuclear imaging in position space:

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

Experimentally limited by maximum transverse momentum.
Need measured p_T range as extended as possible.
~third diffractive minimum.



Coherent eA production



→ probe gluon saturation

→ nuclear imaging in position space:

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

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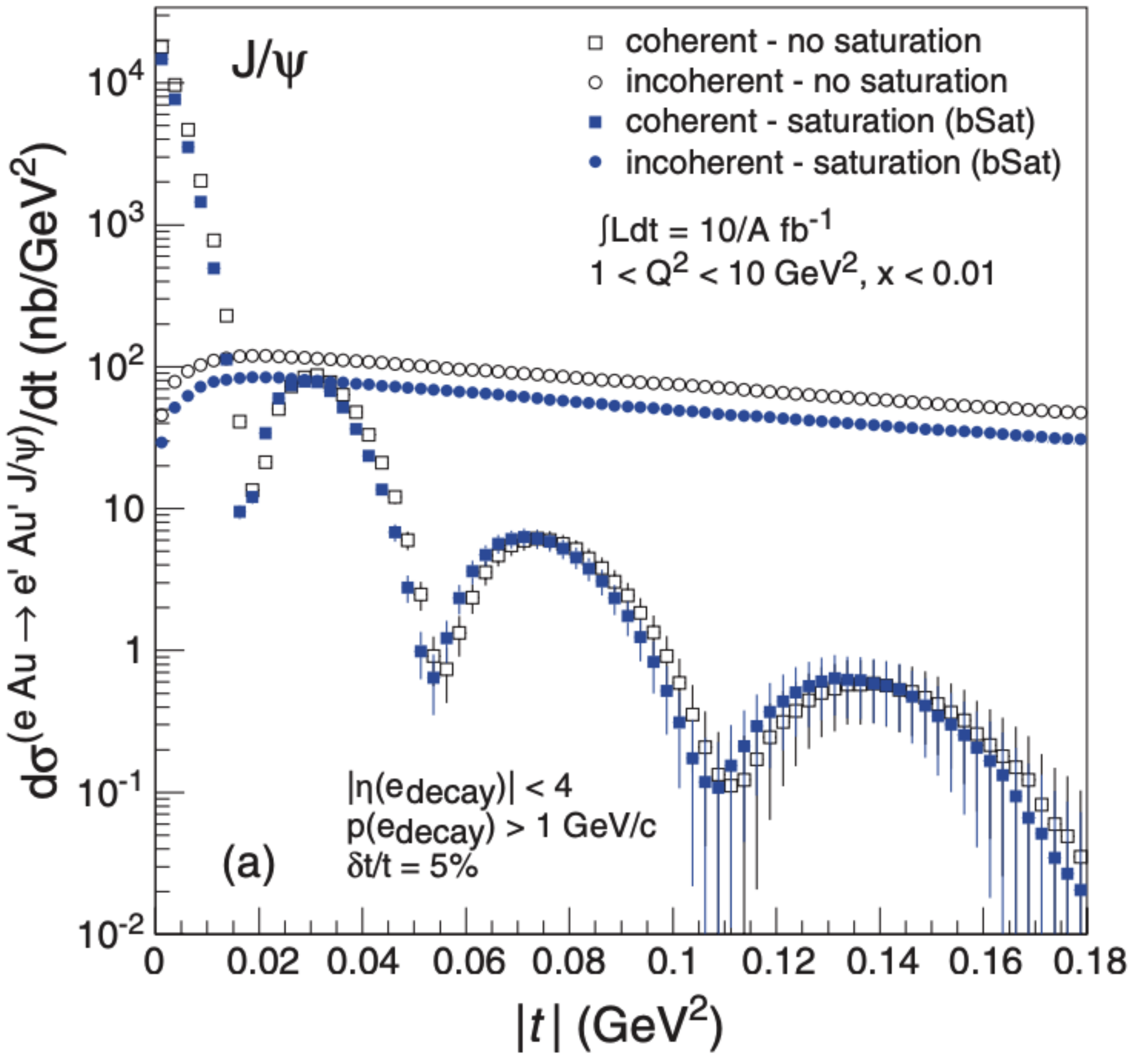


→ resolving minima is crucial

- Need 90%, 99%, and > 99.8% veto efficiency for incoherent production, for the respective minima at increasing t.

- veto of events where nuclei break up

  → use entire far-forward detector systems

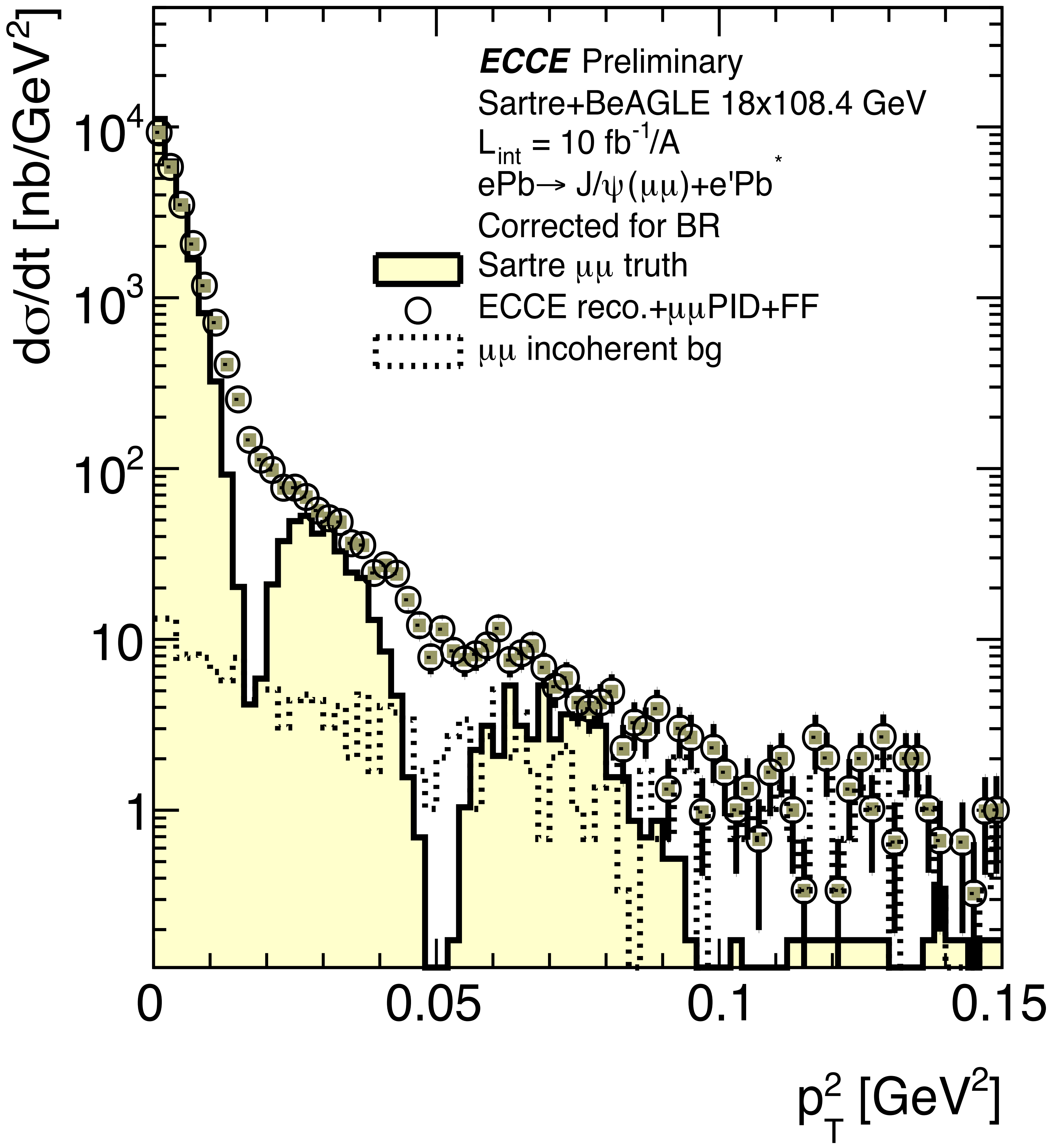
- Need precise determination of t.

- reconstruction via scattered lepton and exclusively produced vector meson/photon

Diffractive eA: study of exclusive J/ψ production in ePb

Extraction of coherent signal from coherent and incoherent production

→ nuclear imaging in position space:

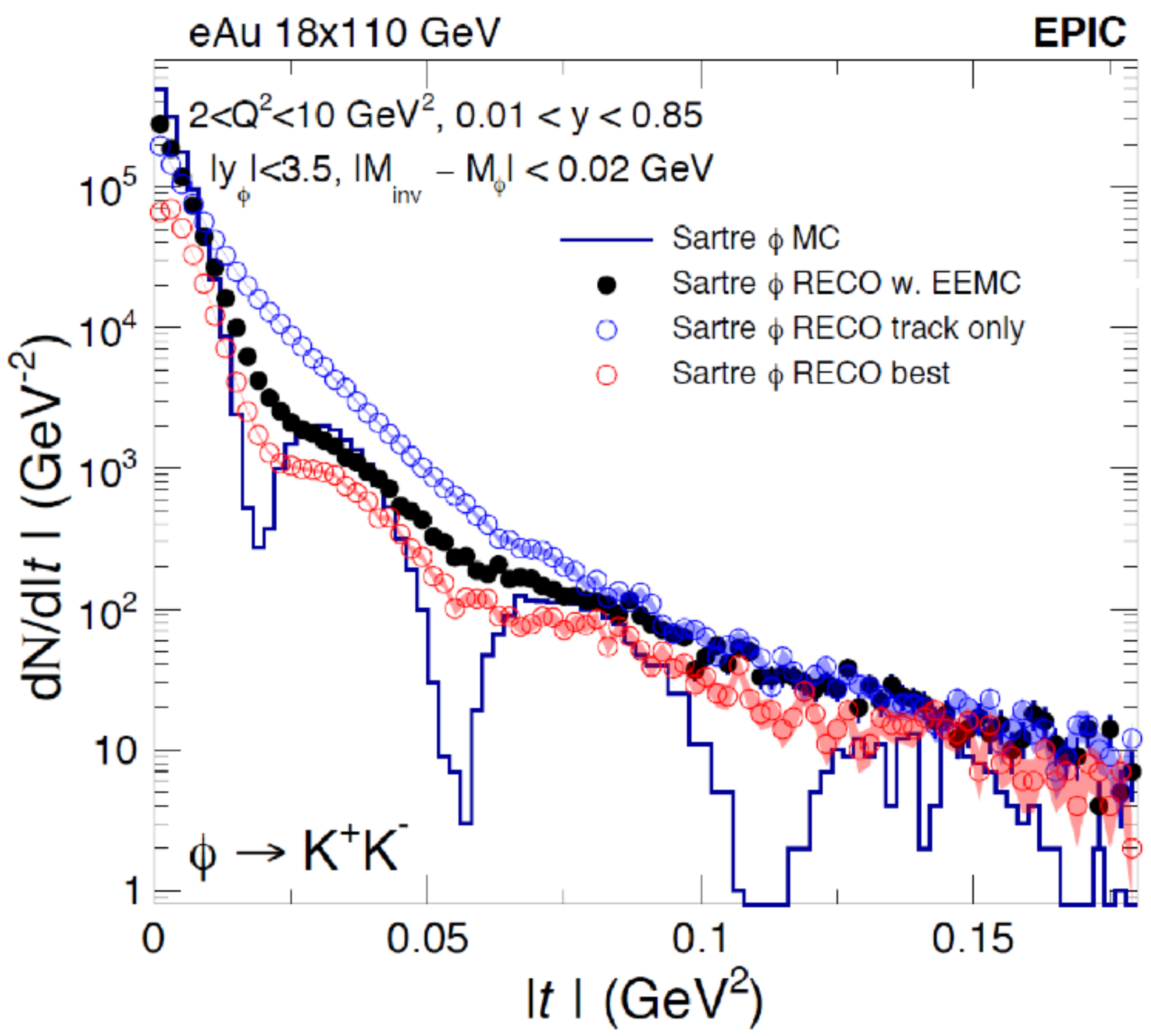


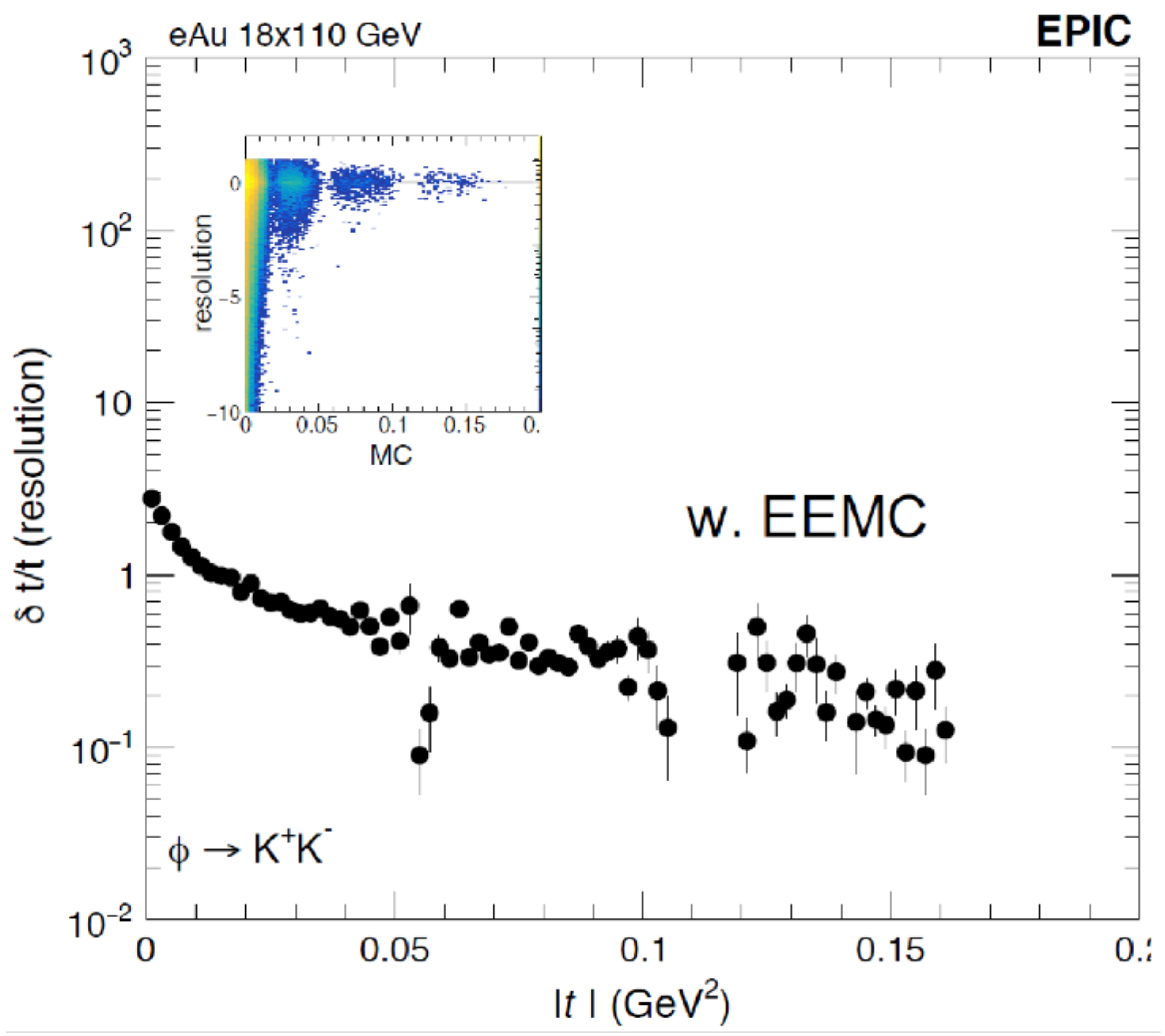
t via scattered lepton and reconstructed vector meson $p_T^2 \approx (\vec{p}_{J/\psi,T} + \vec{p}_{e',T})^2$

- Simulation: coherent (Sartre)+incoherent (Beagle, normalised to Sartre)
- No background simulation
- No simulation of the beam spread

Coherent ϕ production in eA

→ probe gluon saturation





Kong Tu

w. EEMC: E_e from EECAL; m_e from PDG; angles from tracking;
$\phi \rightarrow KK$ from tracking

track only: e and ϕ from tracking only

best: weighted average of above methods after cut on their E ratios (0.5 - 1.5)

Summary

- EIC with ePIC can address various low-x physics topics through:
  - Precise inclusive (spin-dependent) DIS measurements via high-resolution EM calorimeters.
  - Measurements for 3D (spin-dependent) tomography in momentum space provided by good Cherenkov-based and TOF AC-LGAD hadron PID detectors and tracking.
  - Study of nuclear matter via heavy-flavour production (precise vertexing) and di-hadrons.
  - Diffractive and exclusive measurements with coherent/incoherent separation via very precise EM calorimeters and forward detector system.