The electron-ion collider

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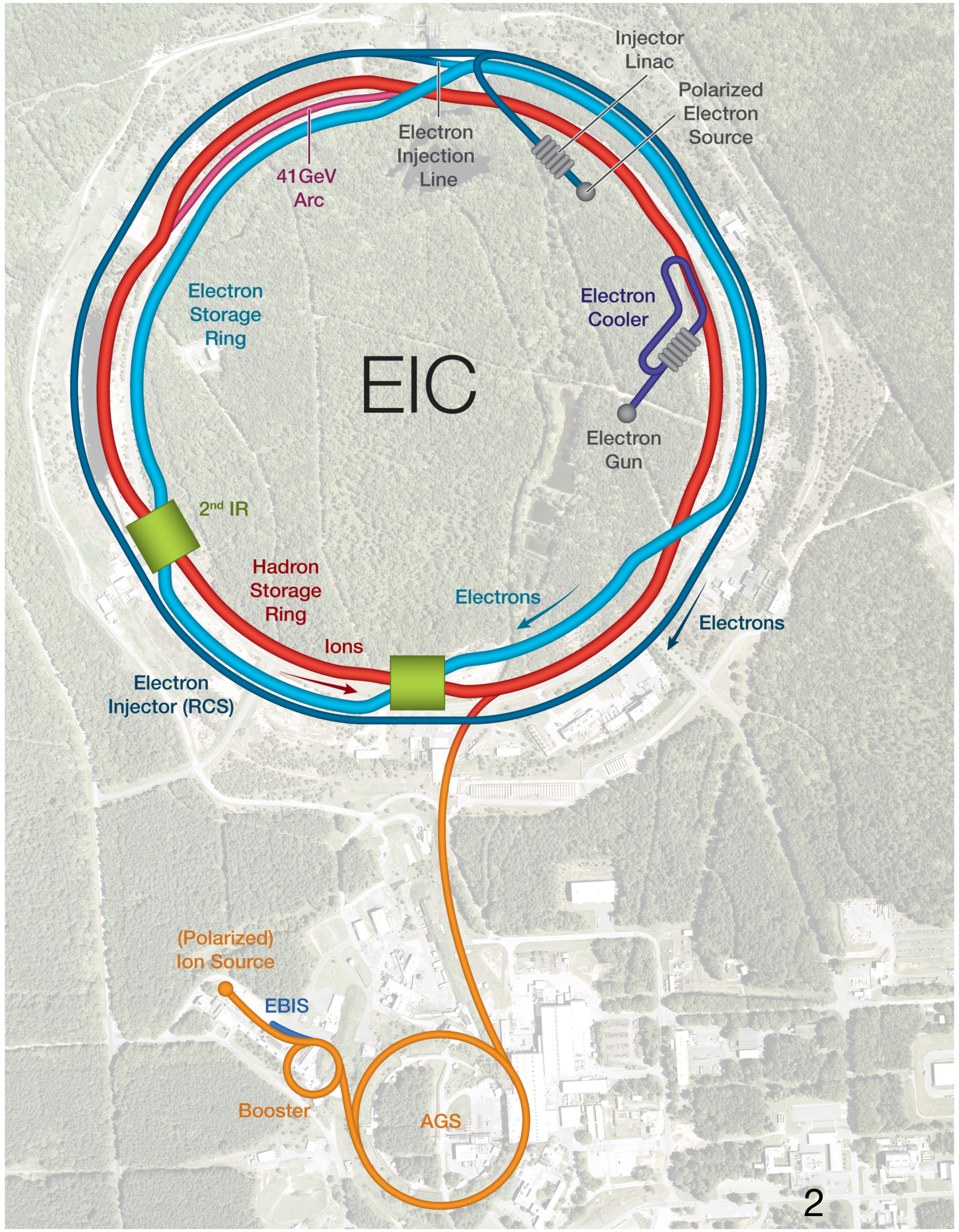
Comunidad de Madrid

Towards improved hadron femtography with hard exclusive reactions 2024
ECT*, Trento, Italy
August 5–9, 2024

The electron-ion collider (EIC)



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

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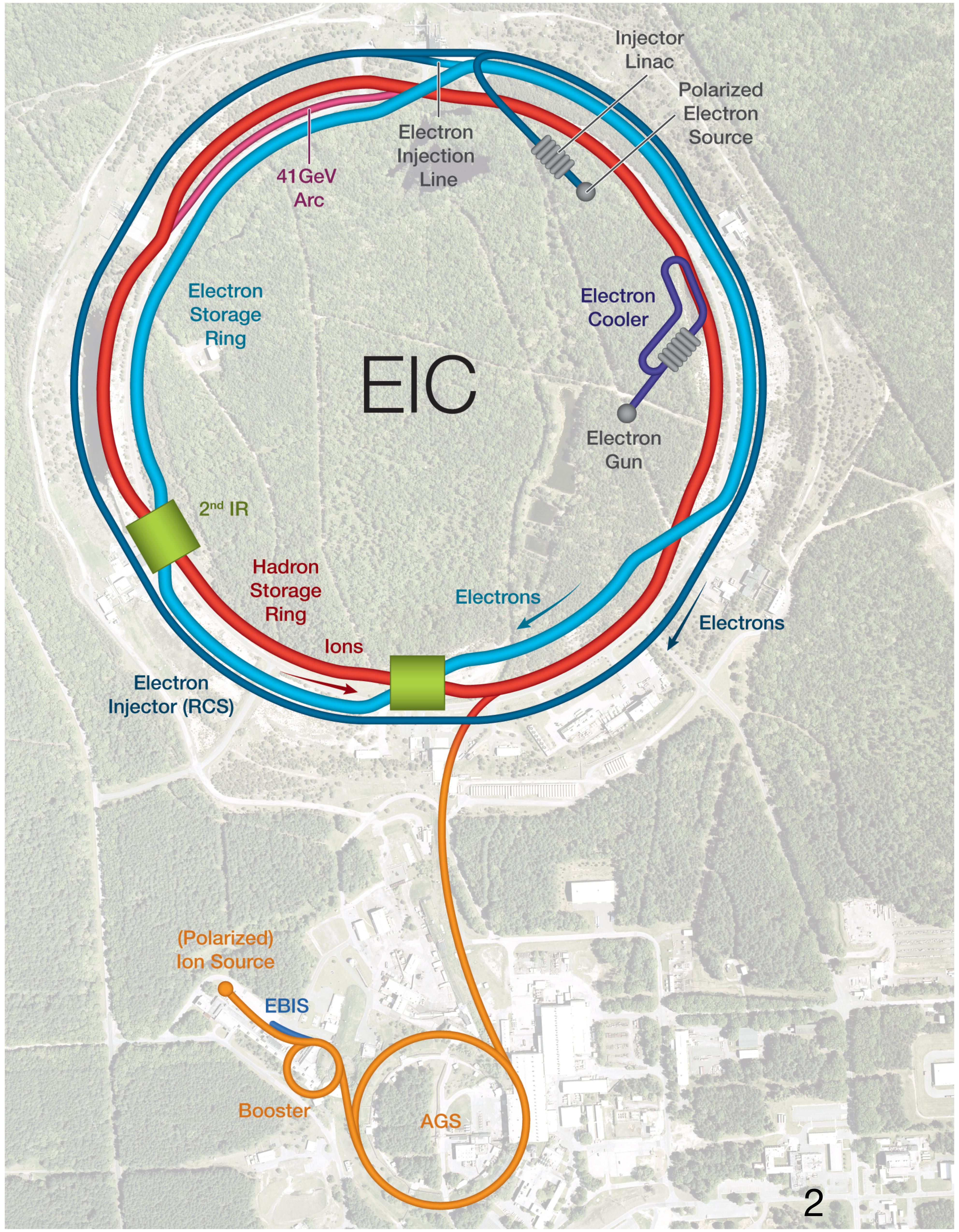

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~ 70% polarisation

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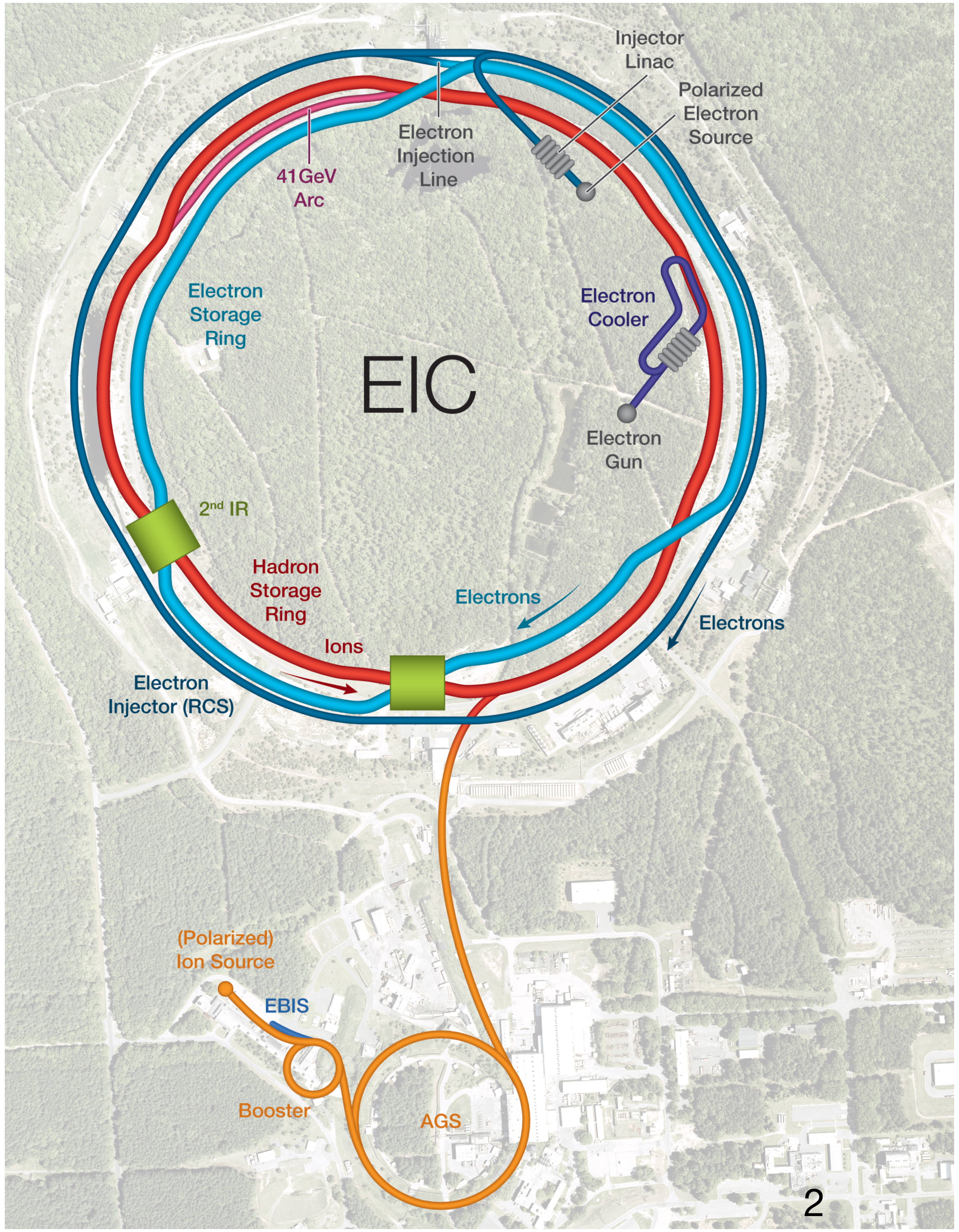

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  $\leftrightarrow \mathscr{L}_{\text{int}} = 10 - 100$ fb^{-1}/year

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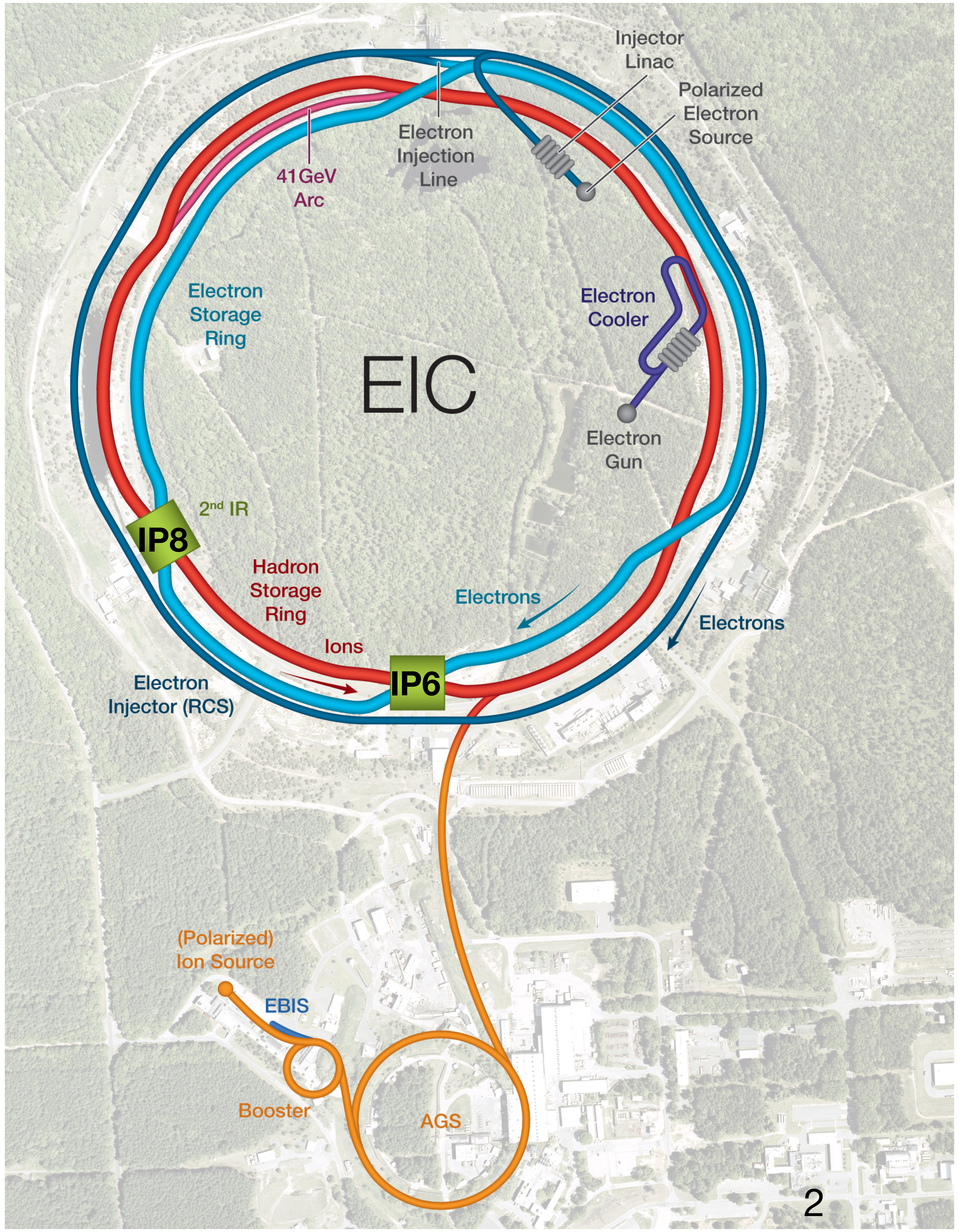

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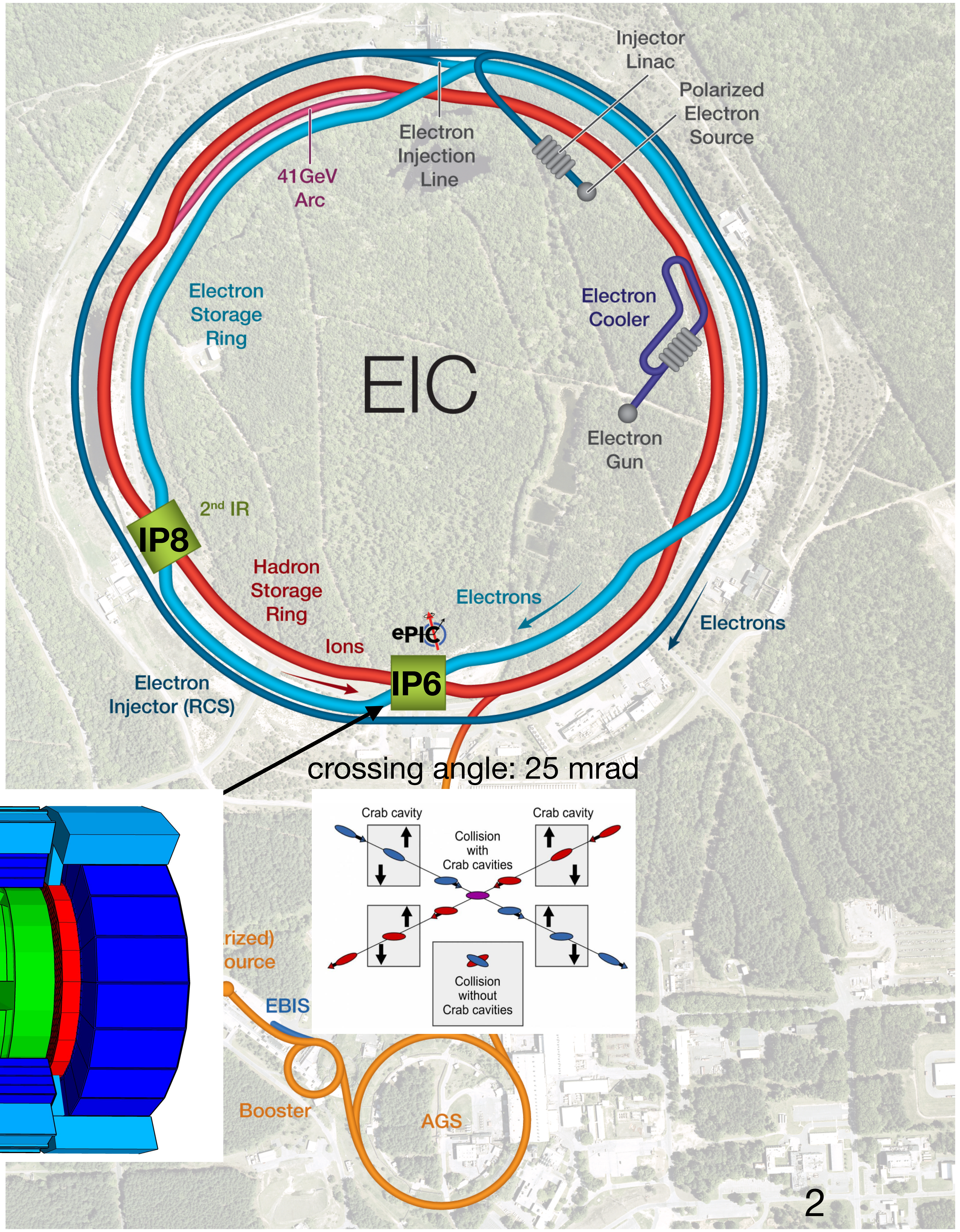

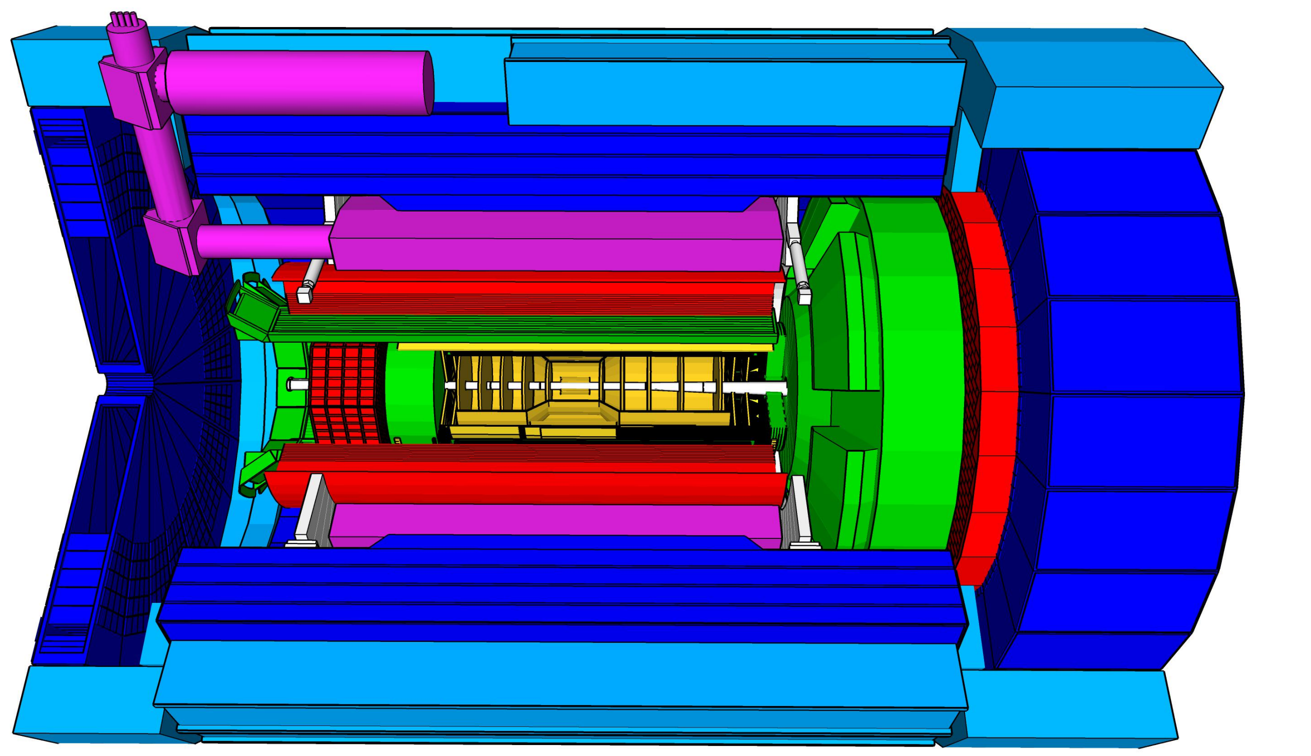

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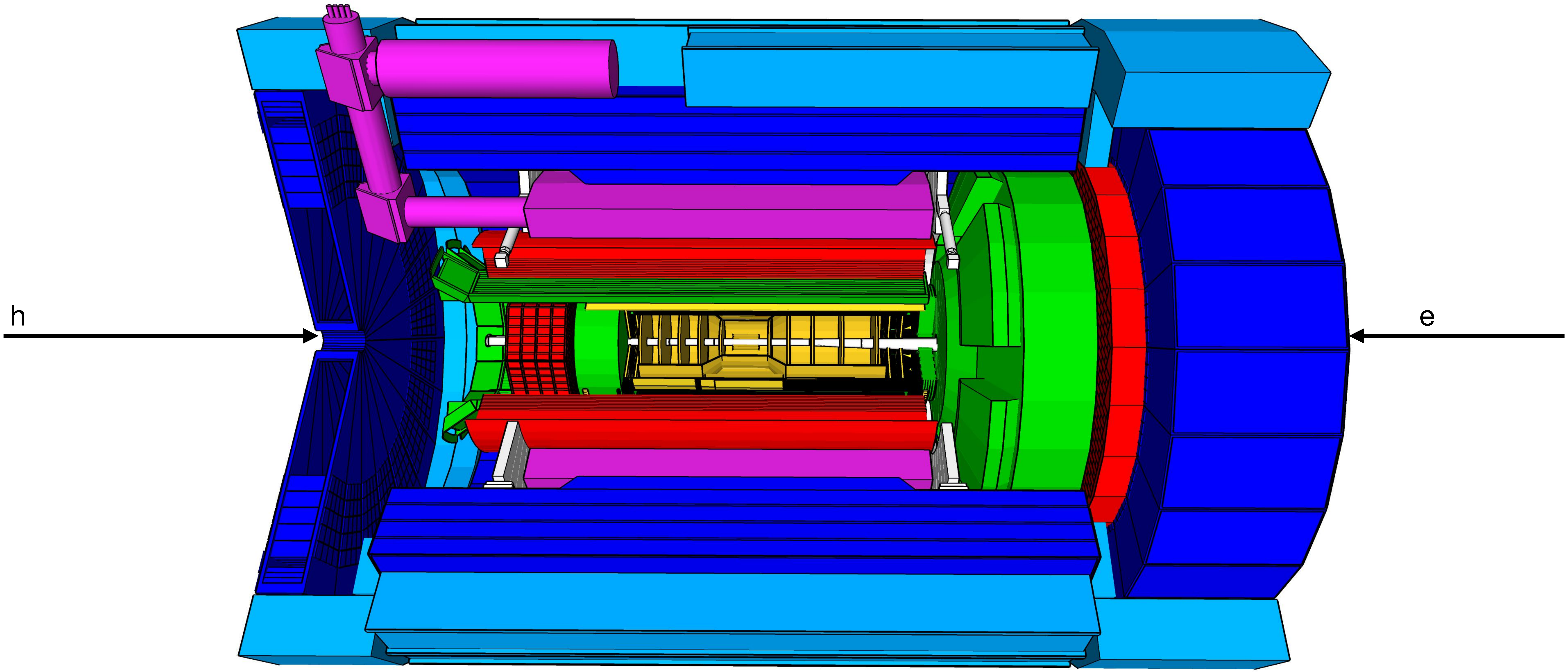
The electron-proton/ion collider (ePIC) detector



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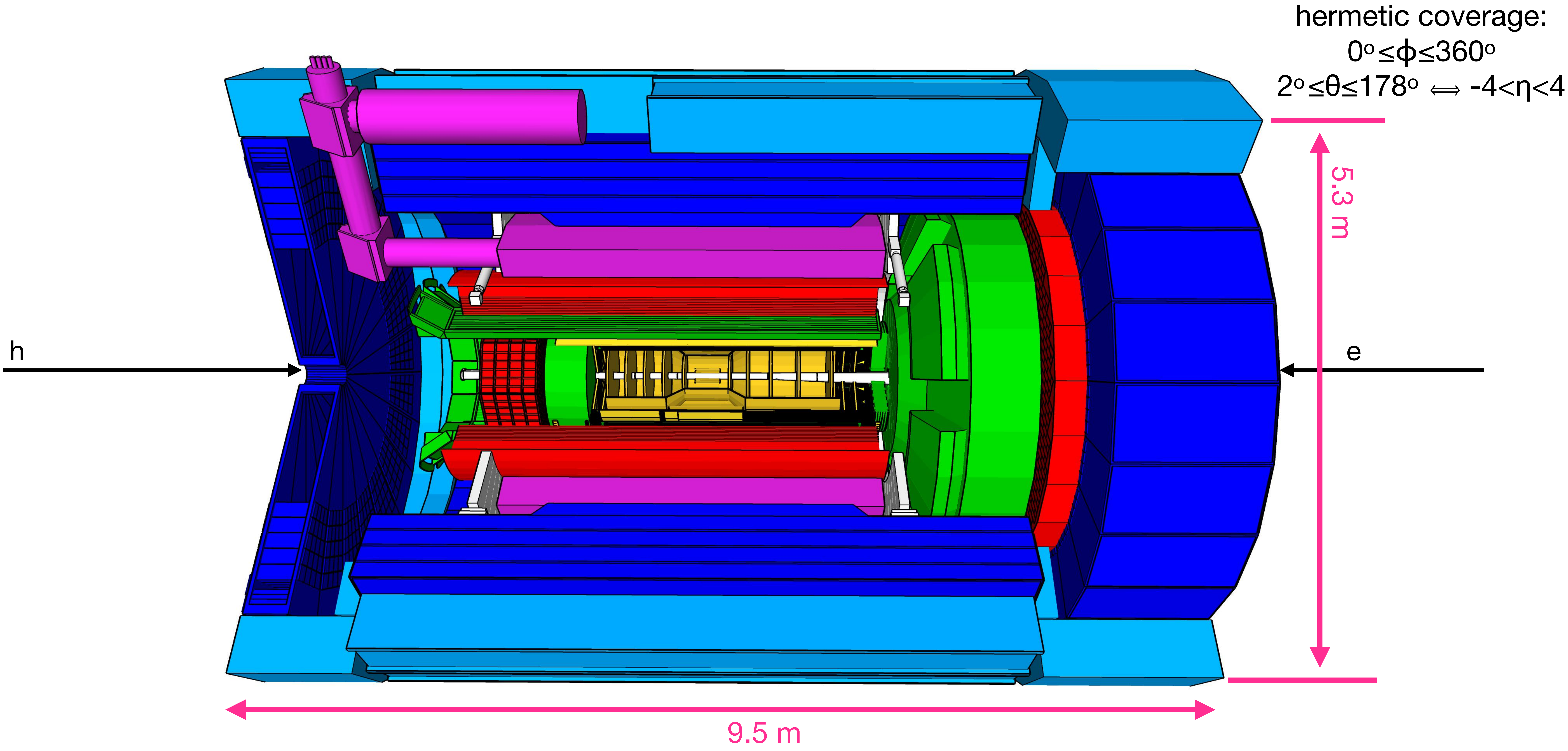
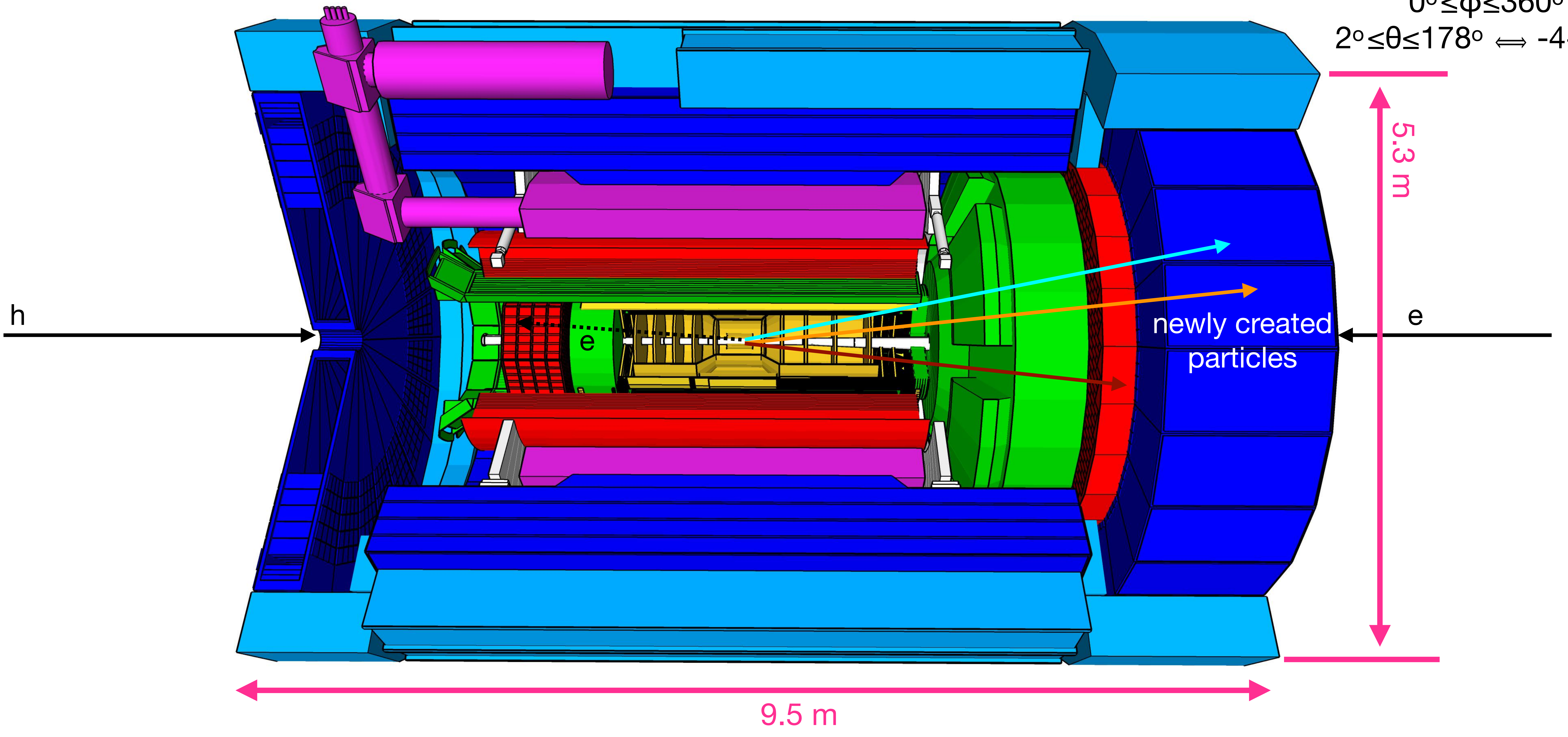


The electron-proton/ion collider (ePIC) detector

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



The electron-proton/ion collider (ePIC) detector

- **Tracking**
- **PID**
- **Electromagnetic calorimeter**
- **Hadronic calorimeter**

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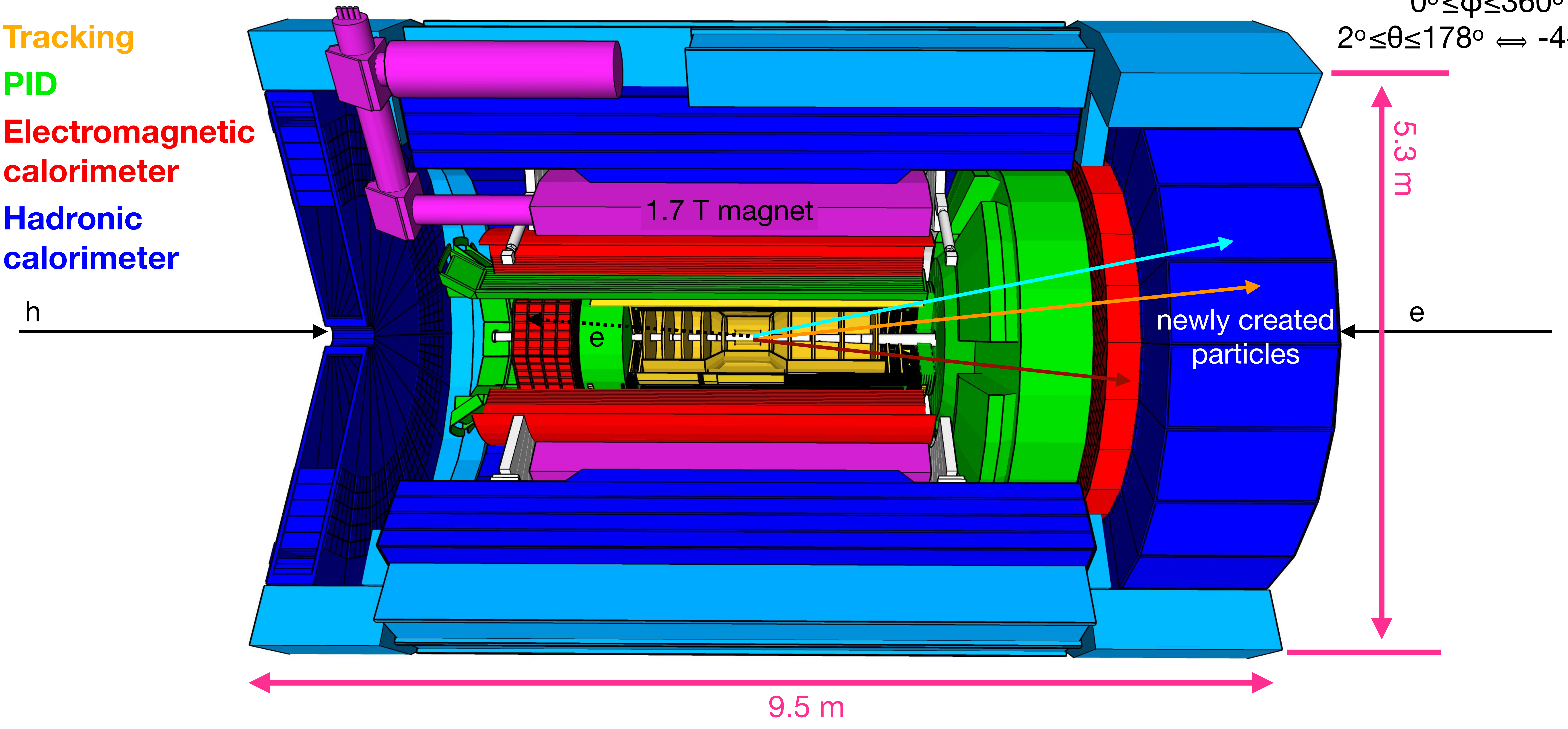

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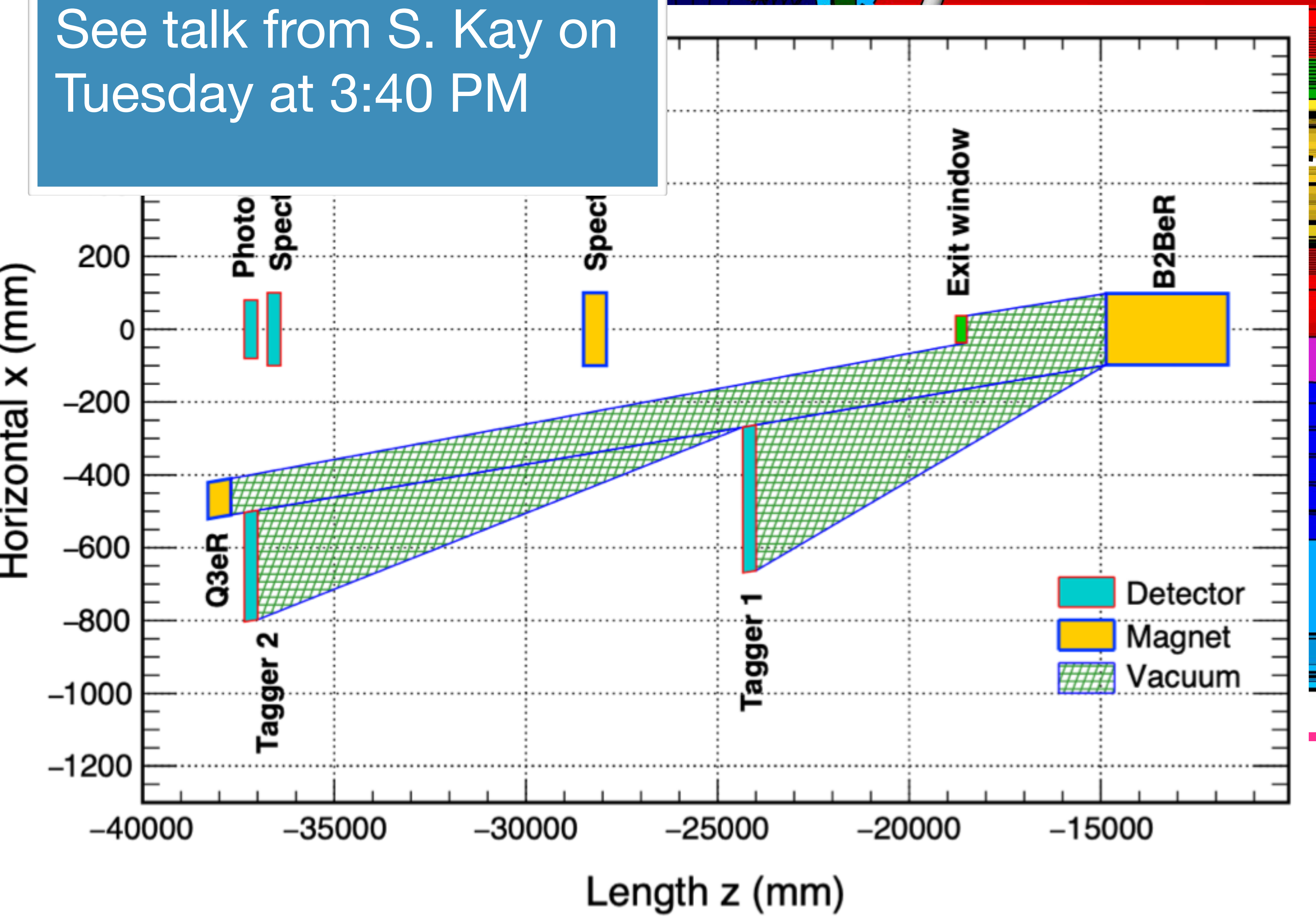
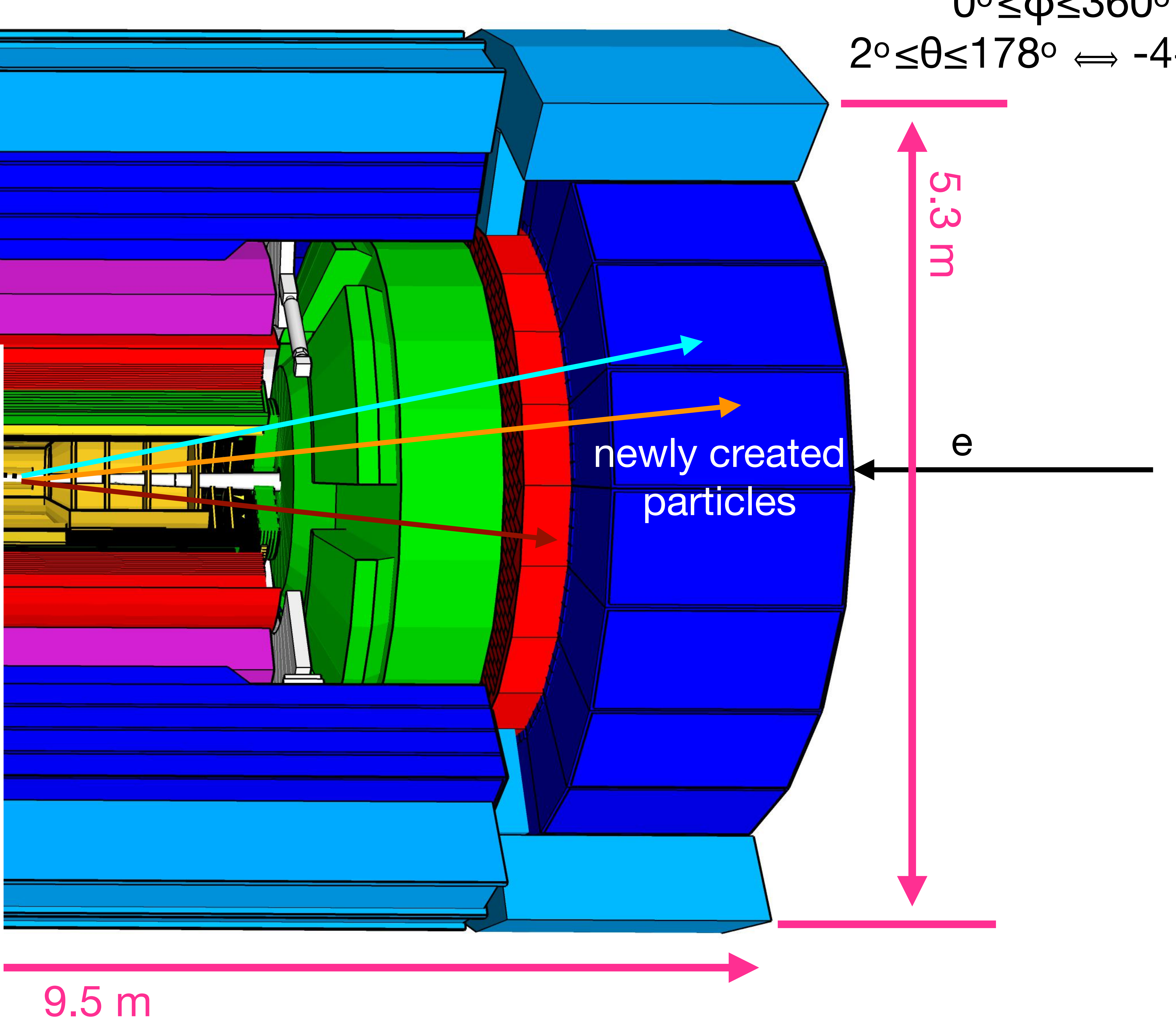
+ far backward

See talk from S. Kay on Tuesday at 3:40 PM





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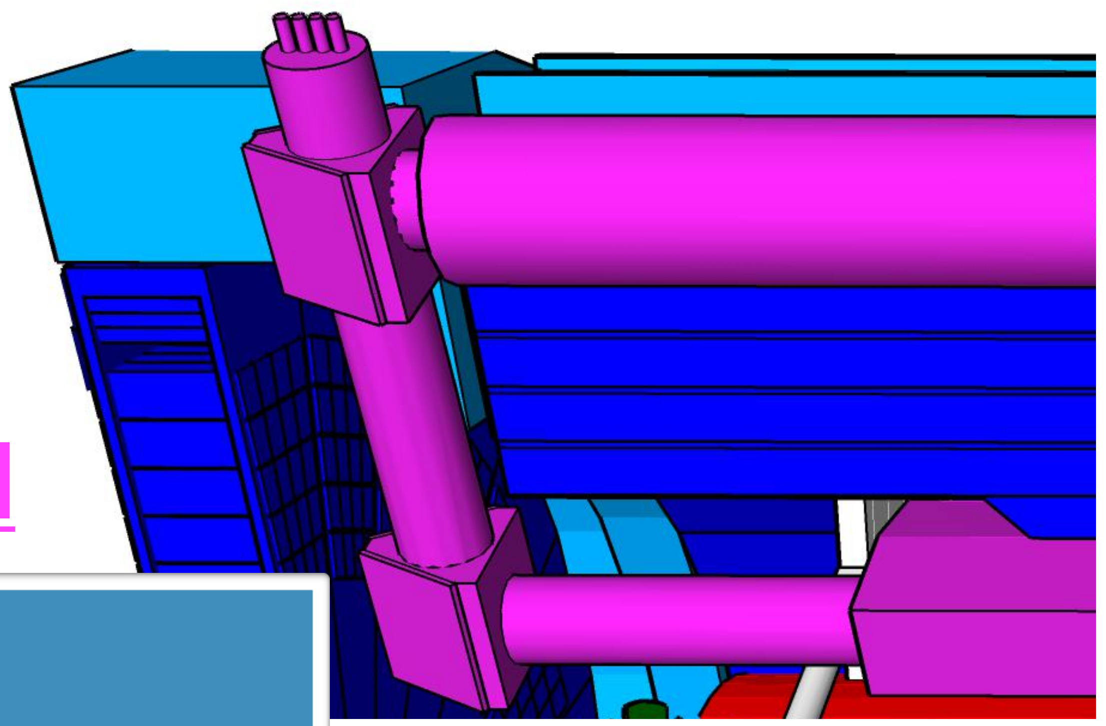

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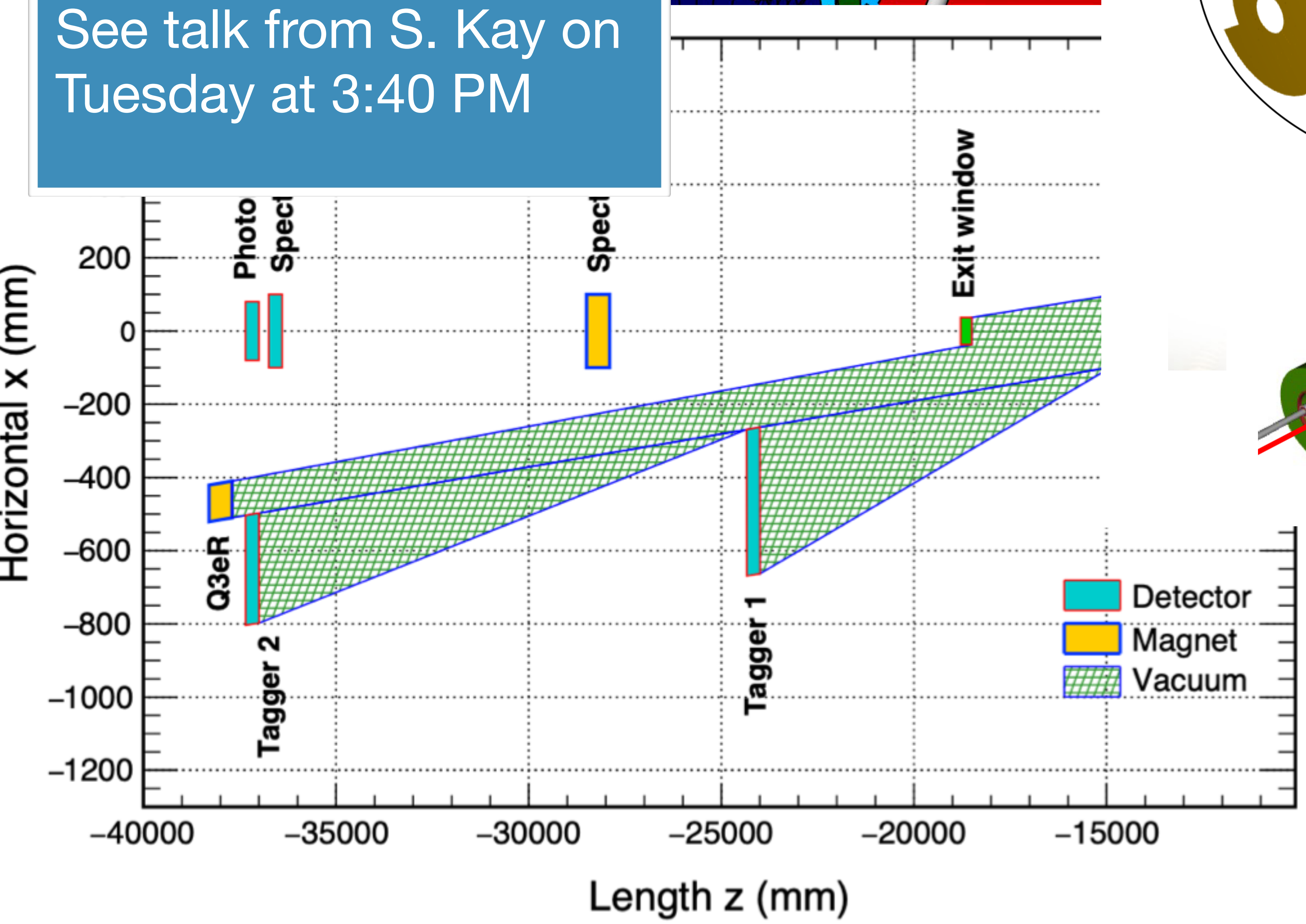

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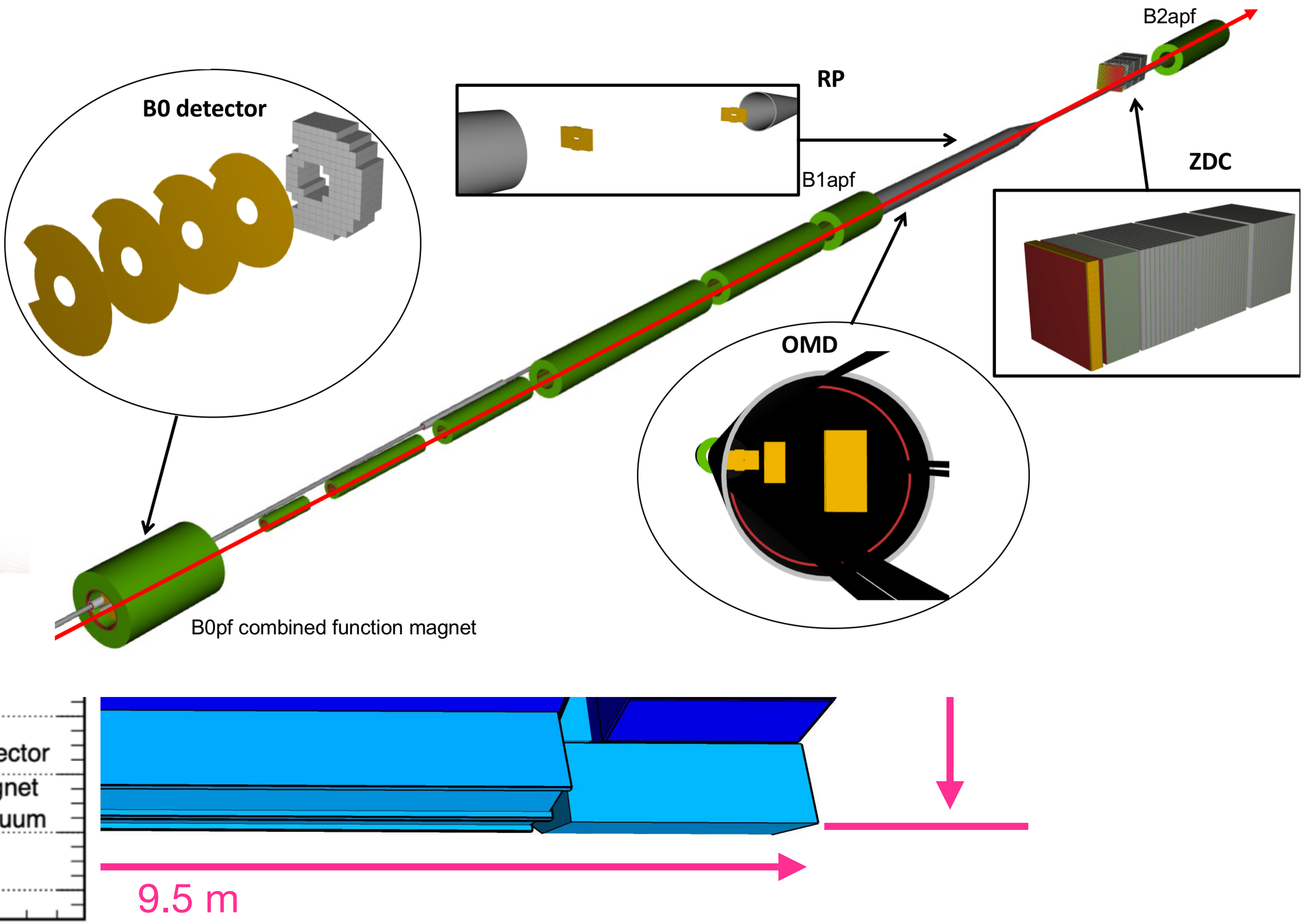

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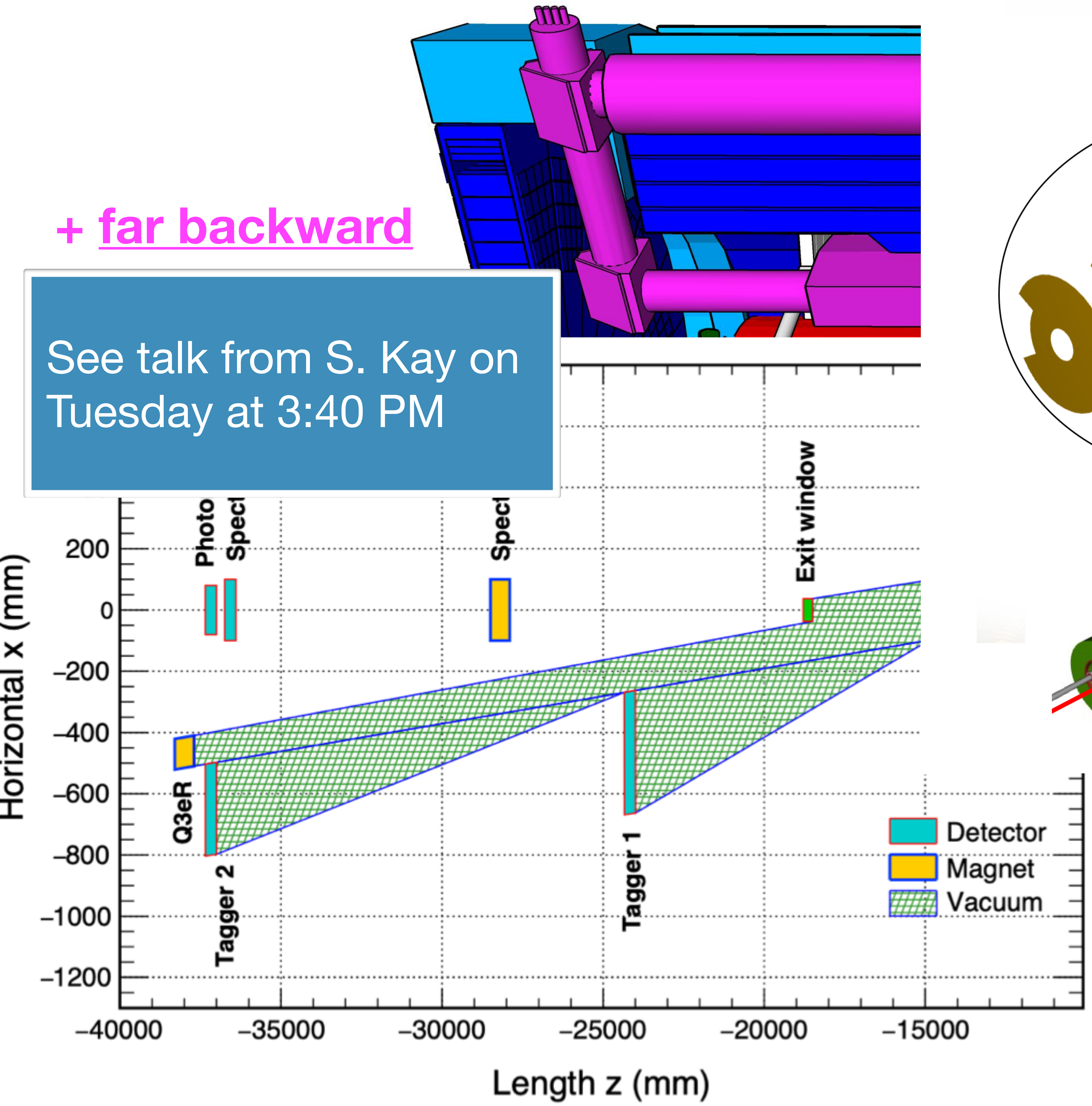

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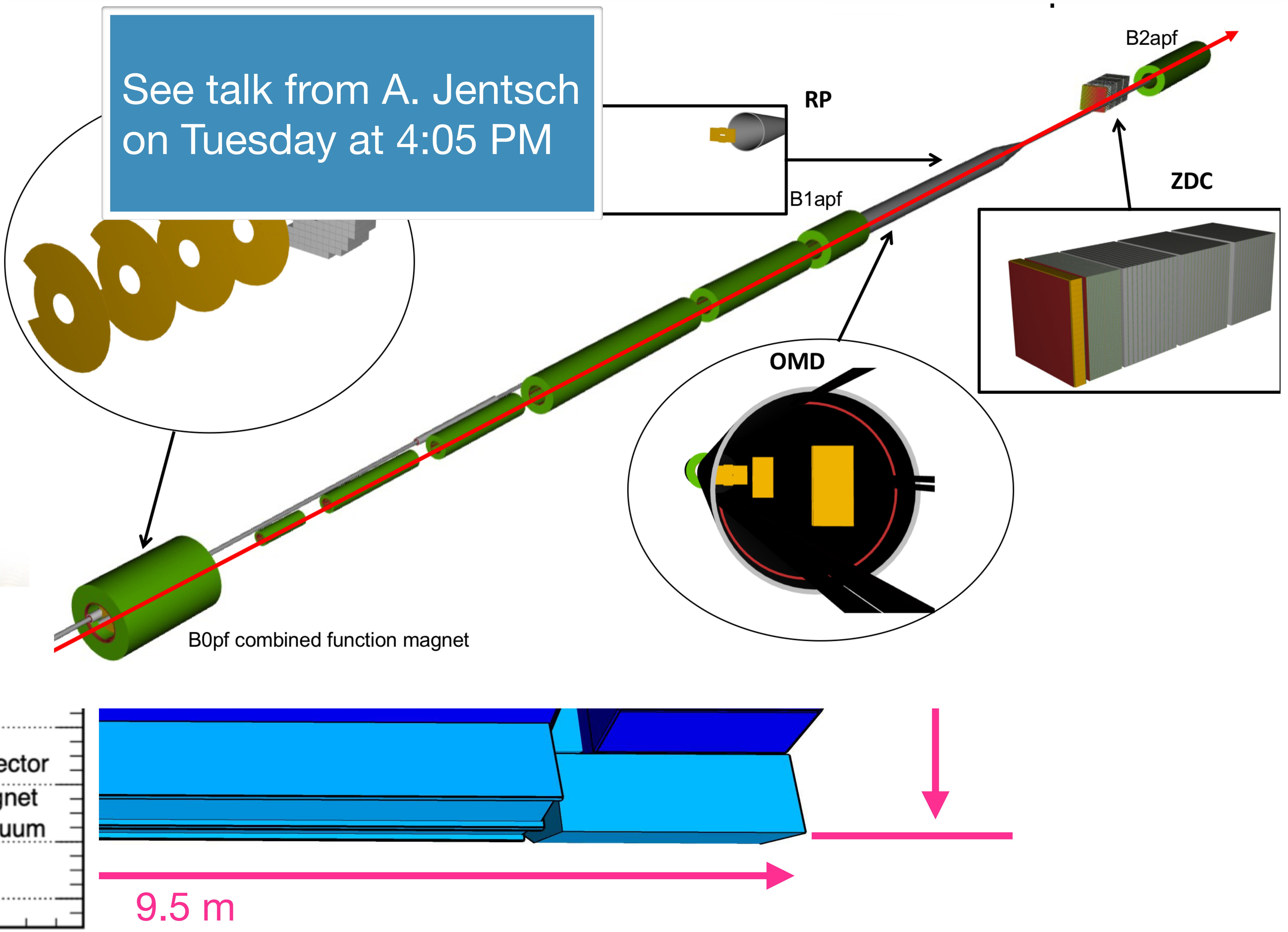

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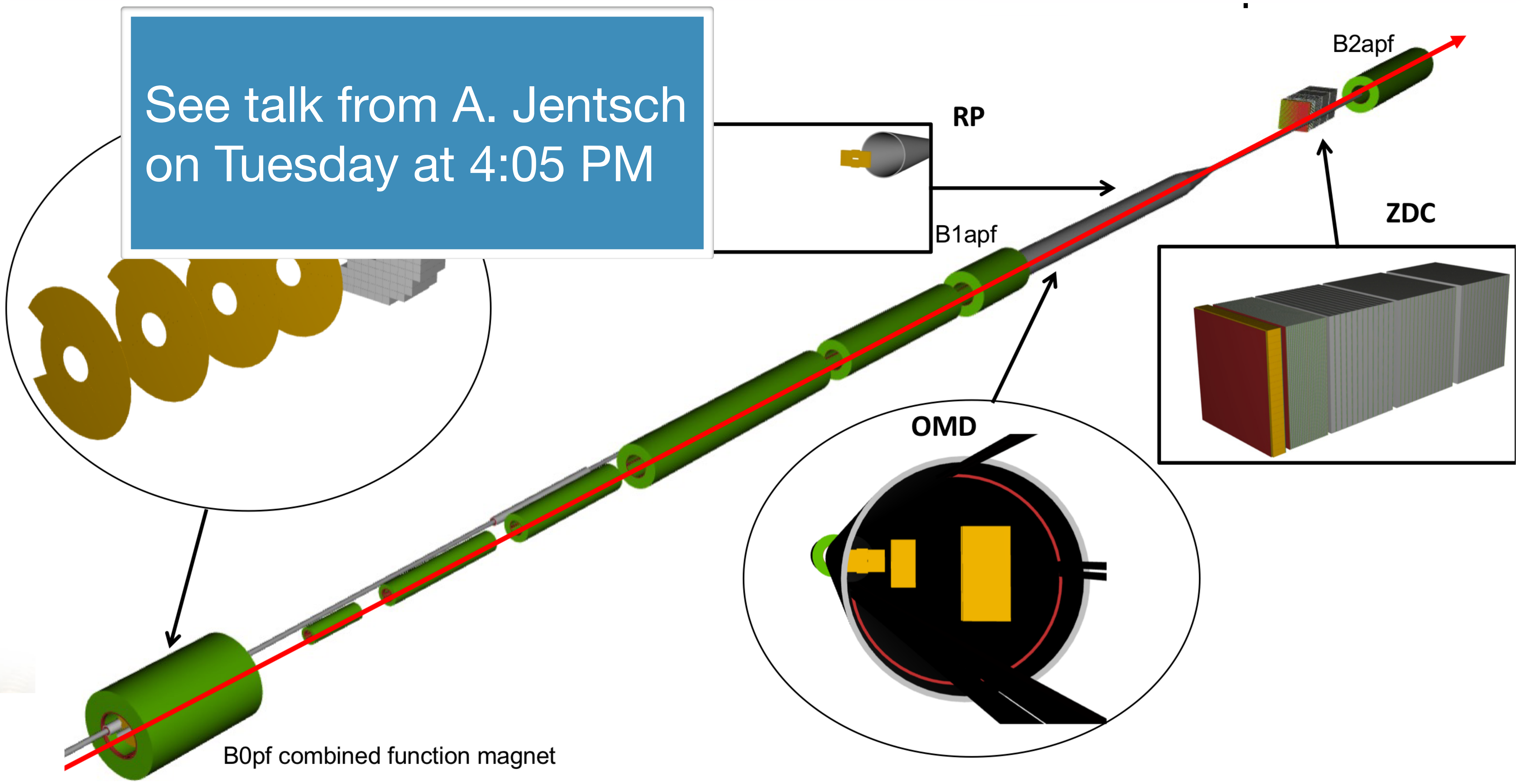

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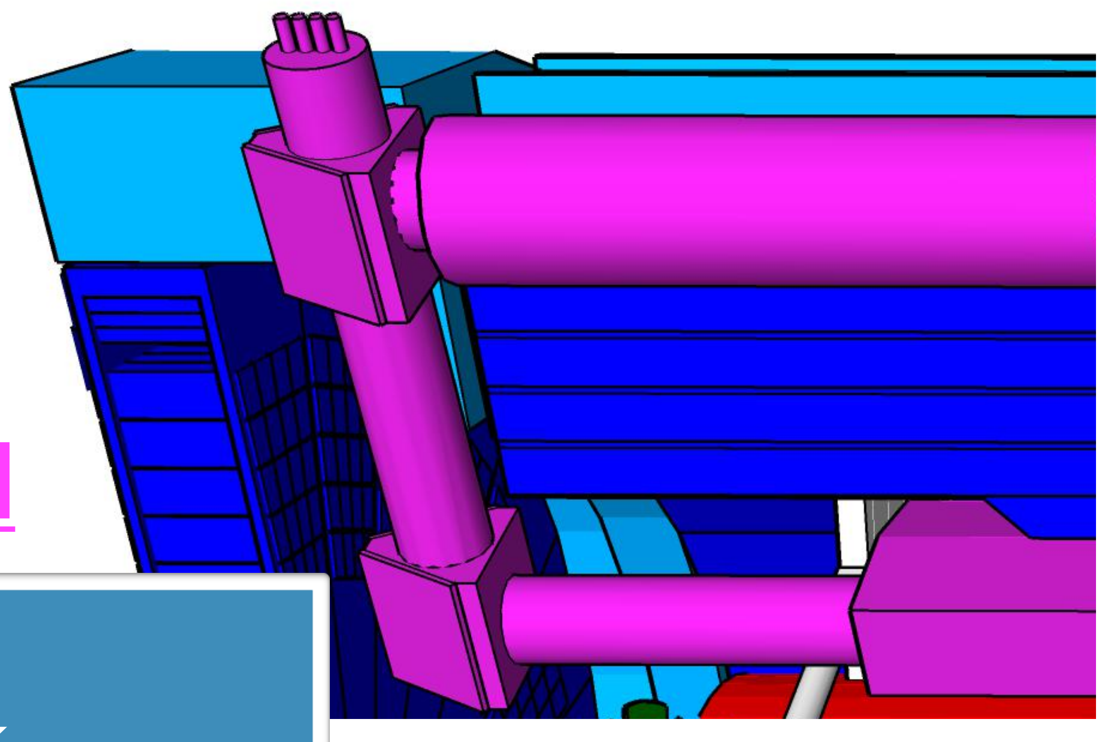

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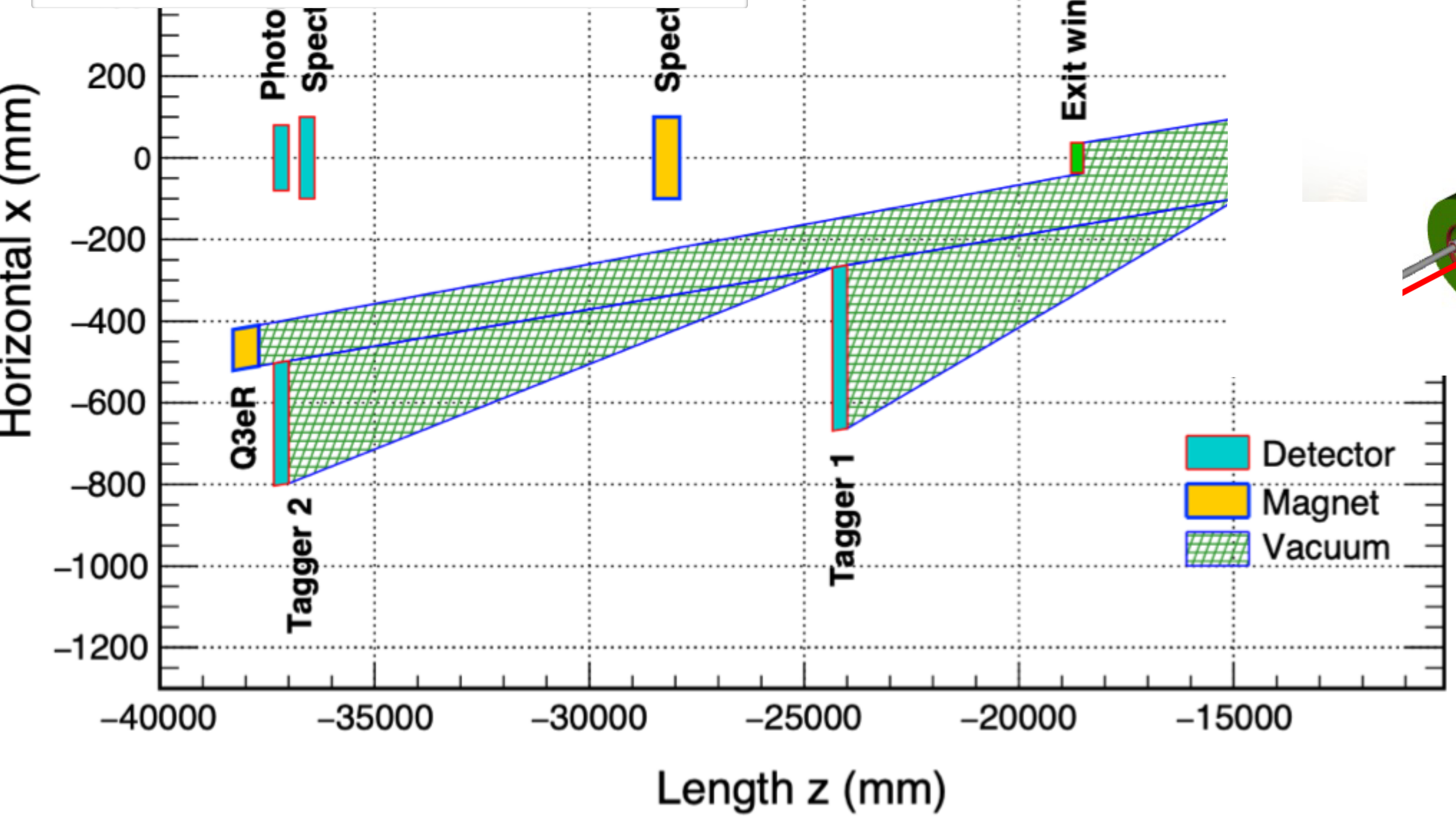


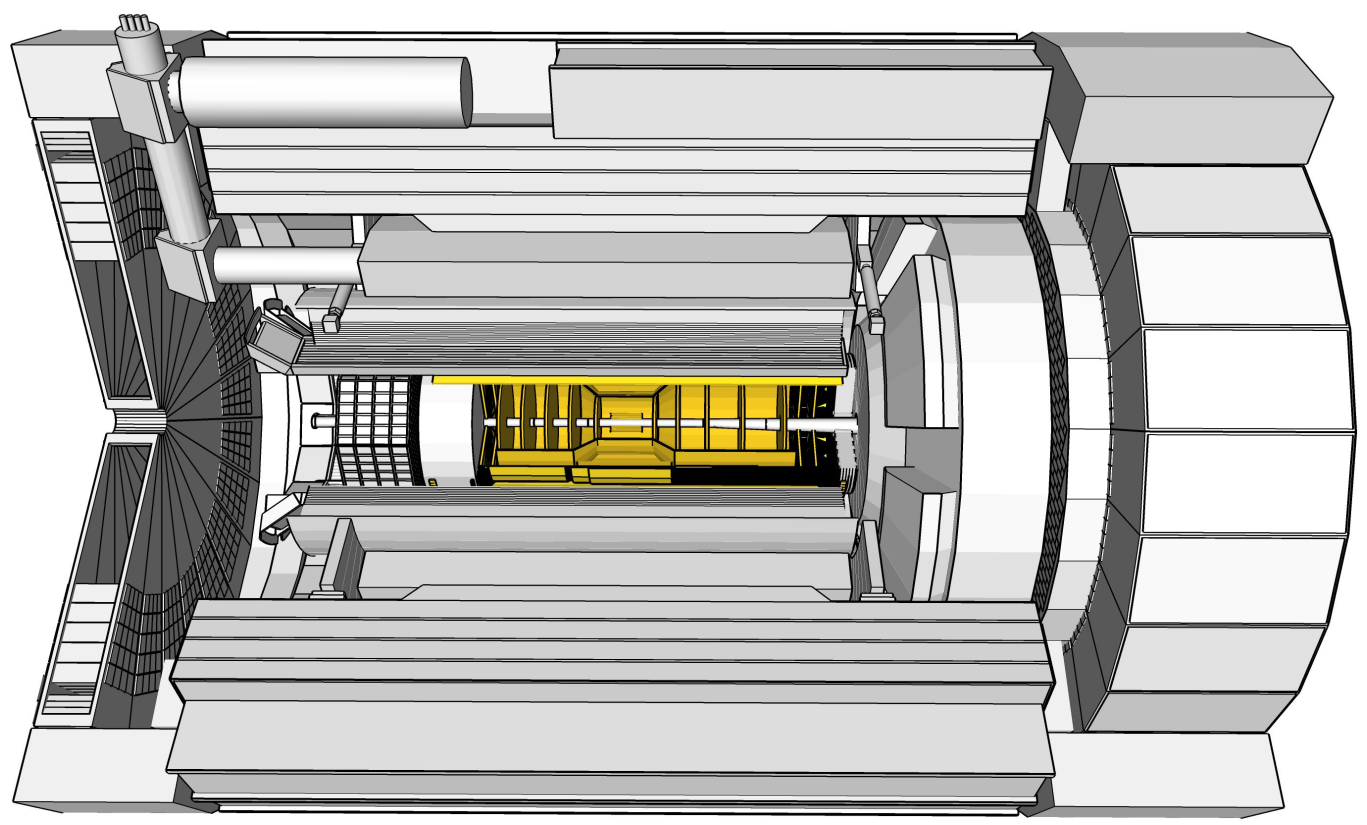
9.5 m

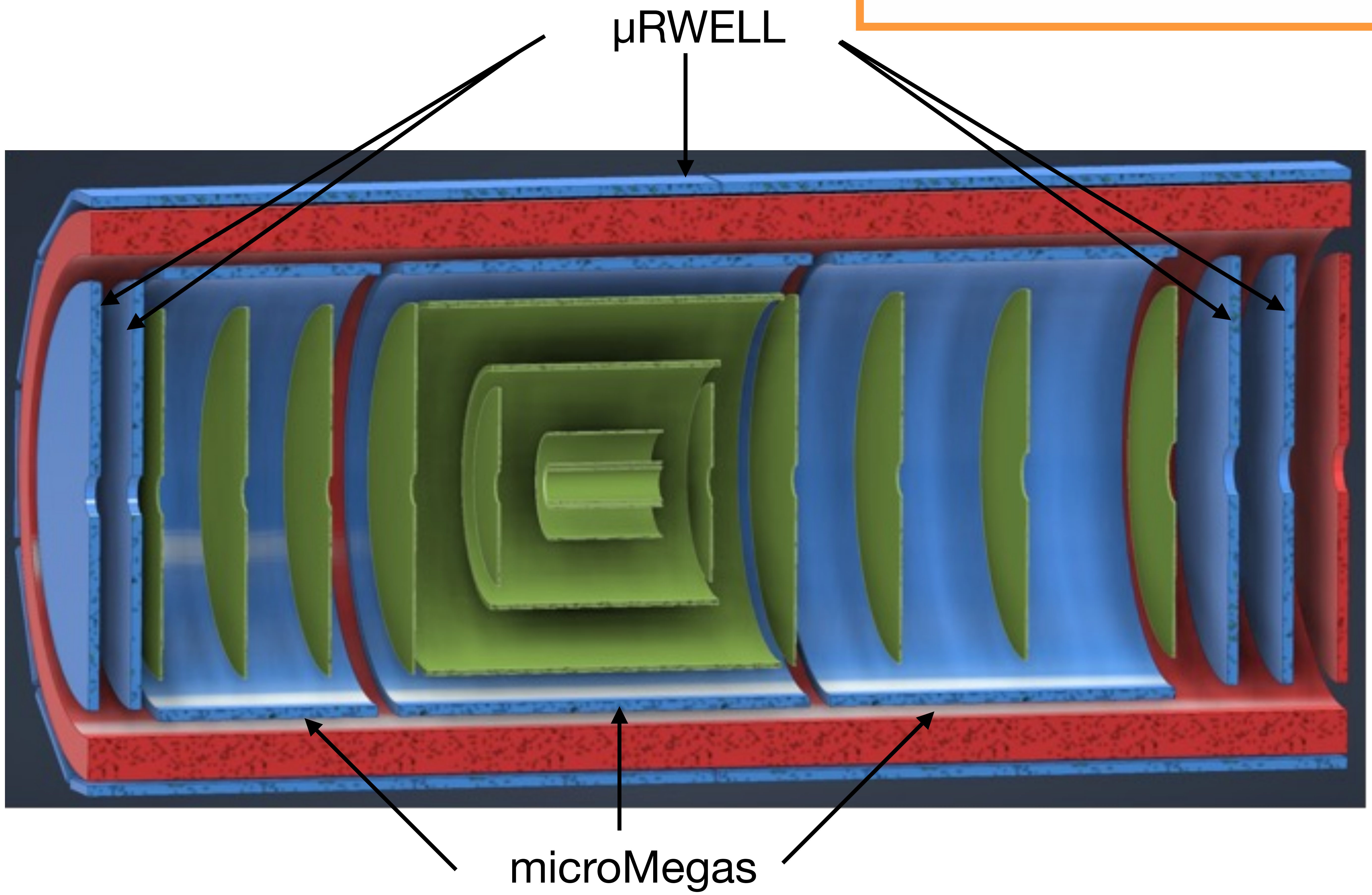
Data acquisition:
- no trigger
- all collision data is digitised
- with strong zero-suppression at front-end electronics

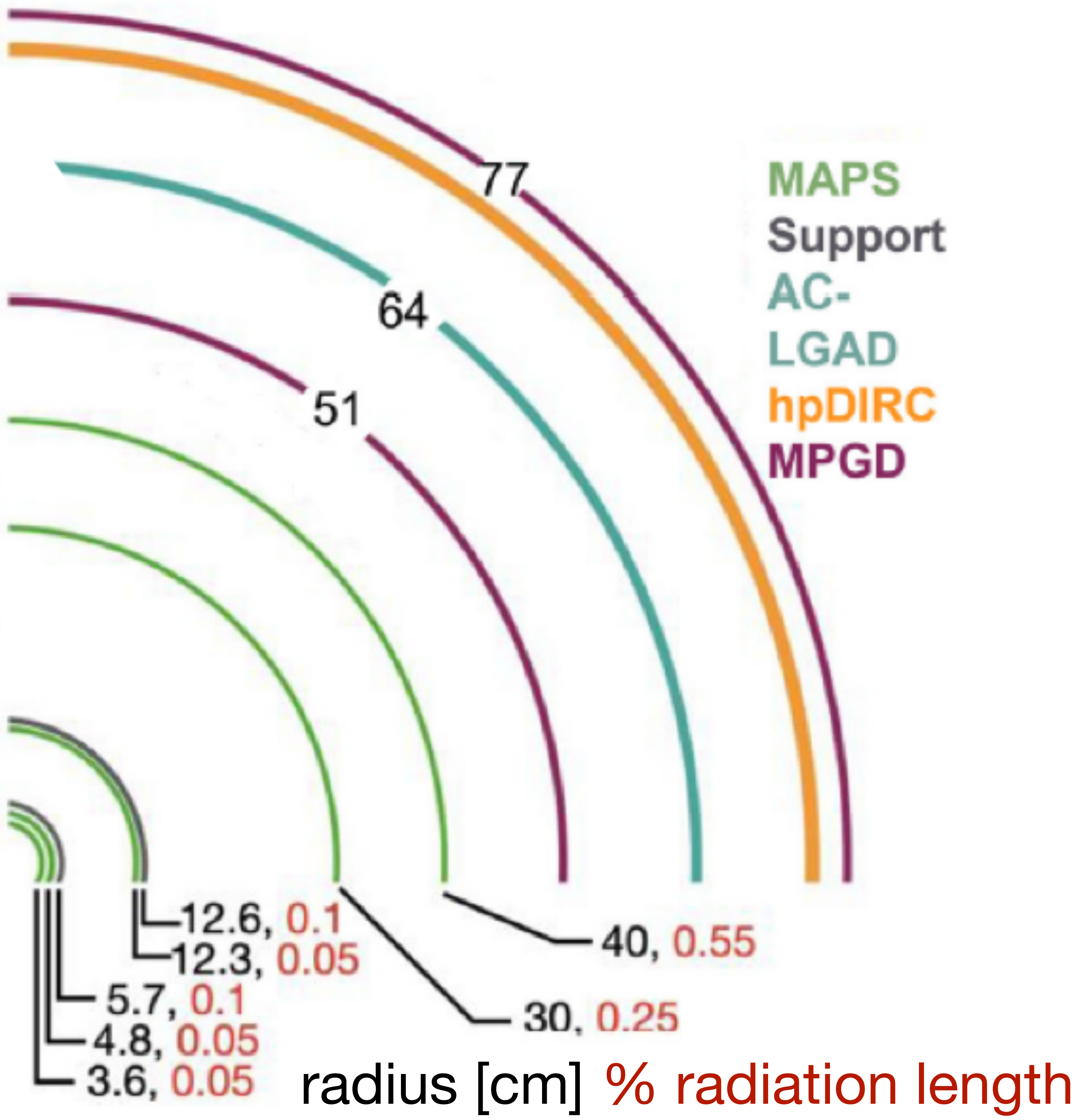
Tracking system

1.7 T magnet

- Monolithic Active Pixel Sensor (MAPS)
  Silicon vertexing/inner tracker
- Micro-pattern gaseous detectors
  μRWELL/microMegas:
  timing & pattern recognition
- AC-LGAD based TOF:
  PID & additional tracking point







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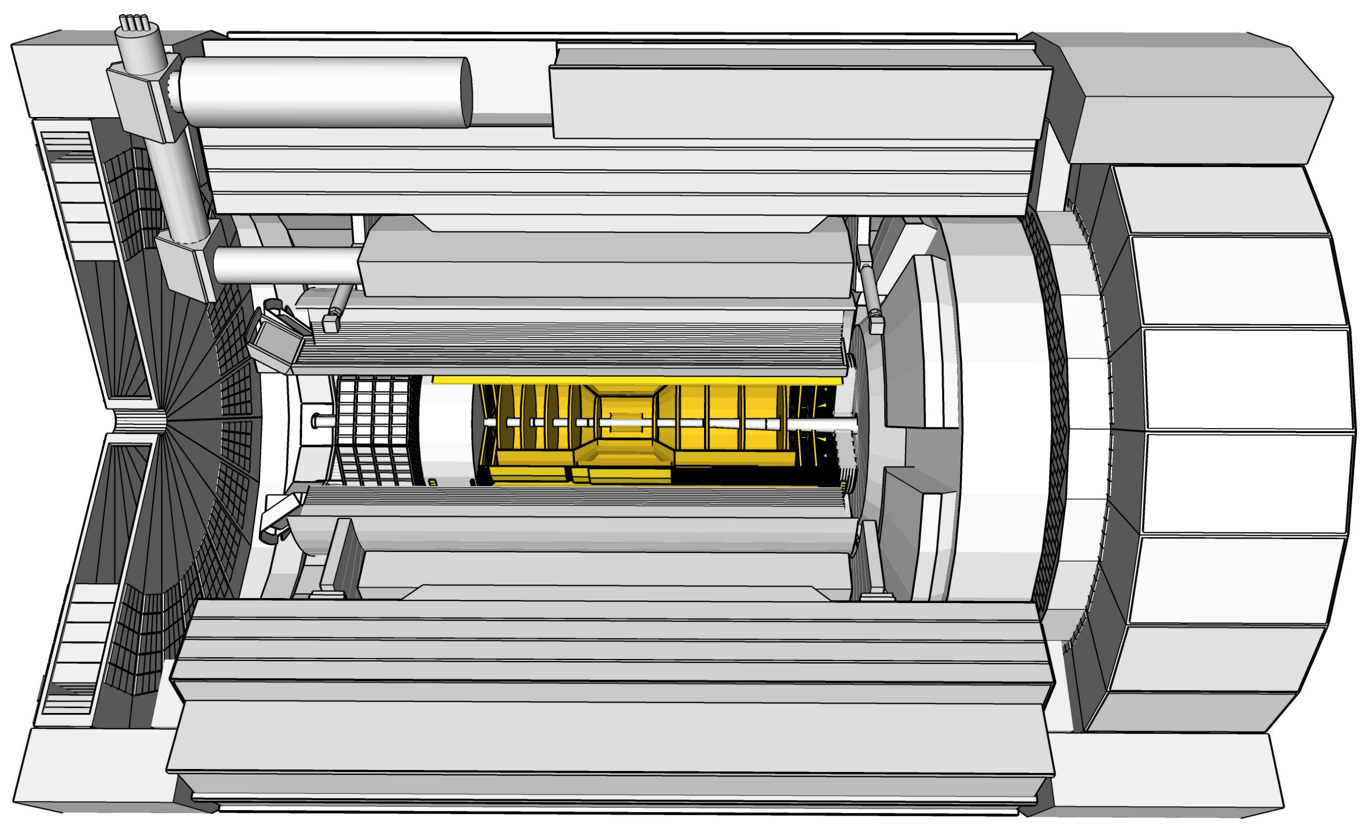
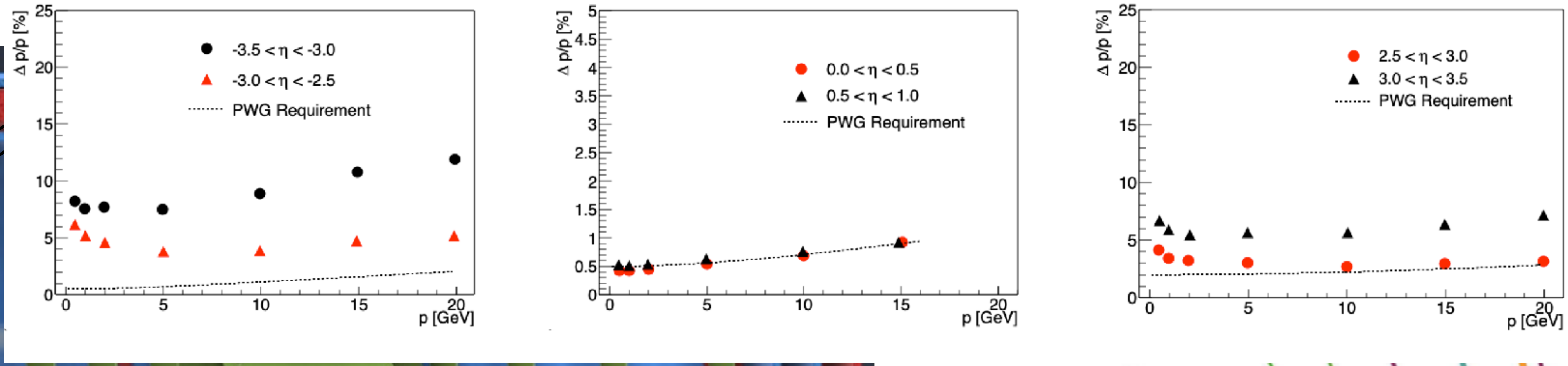
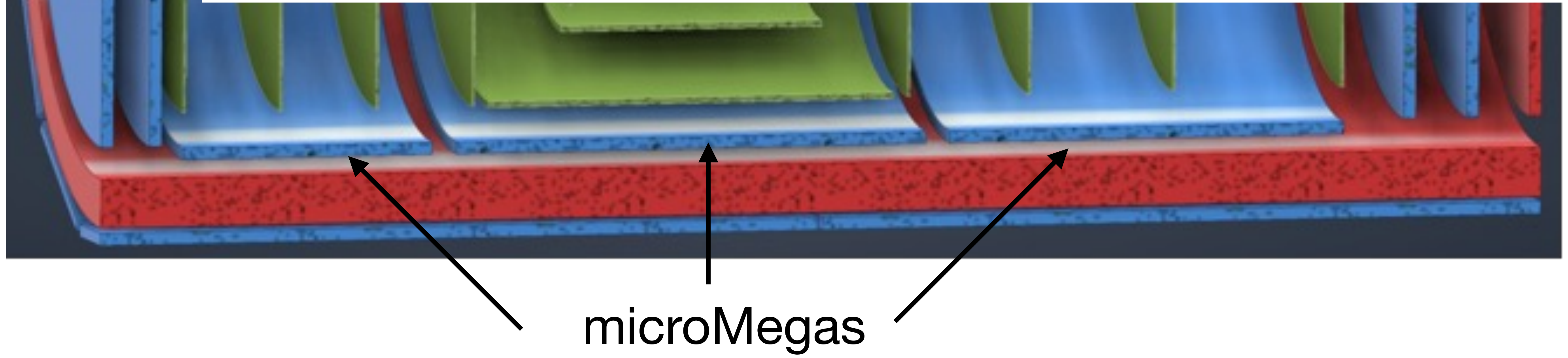
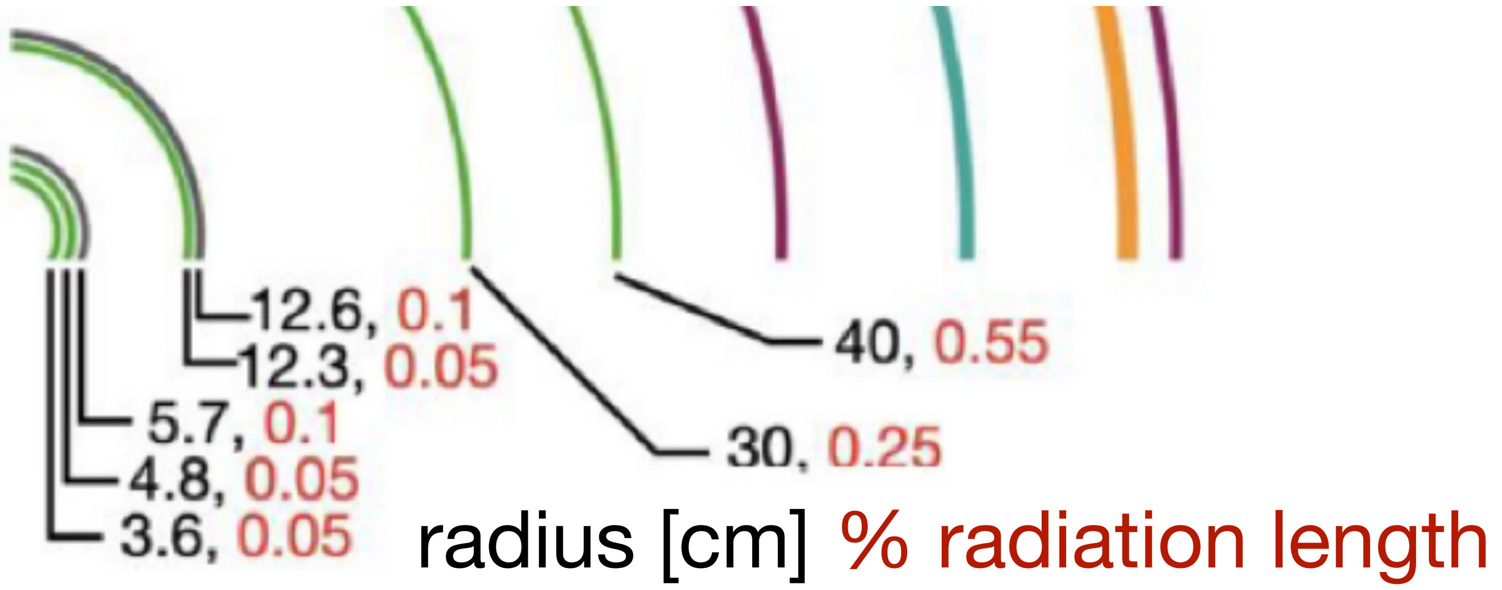


momentum resolution







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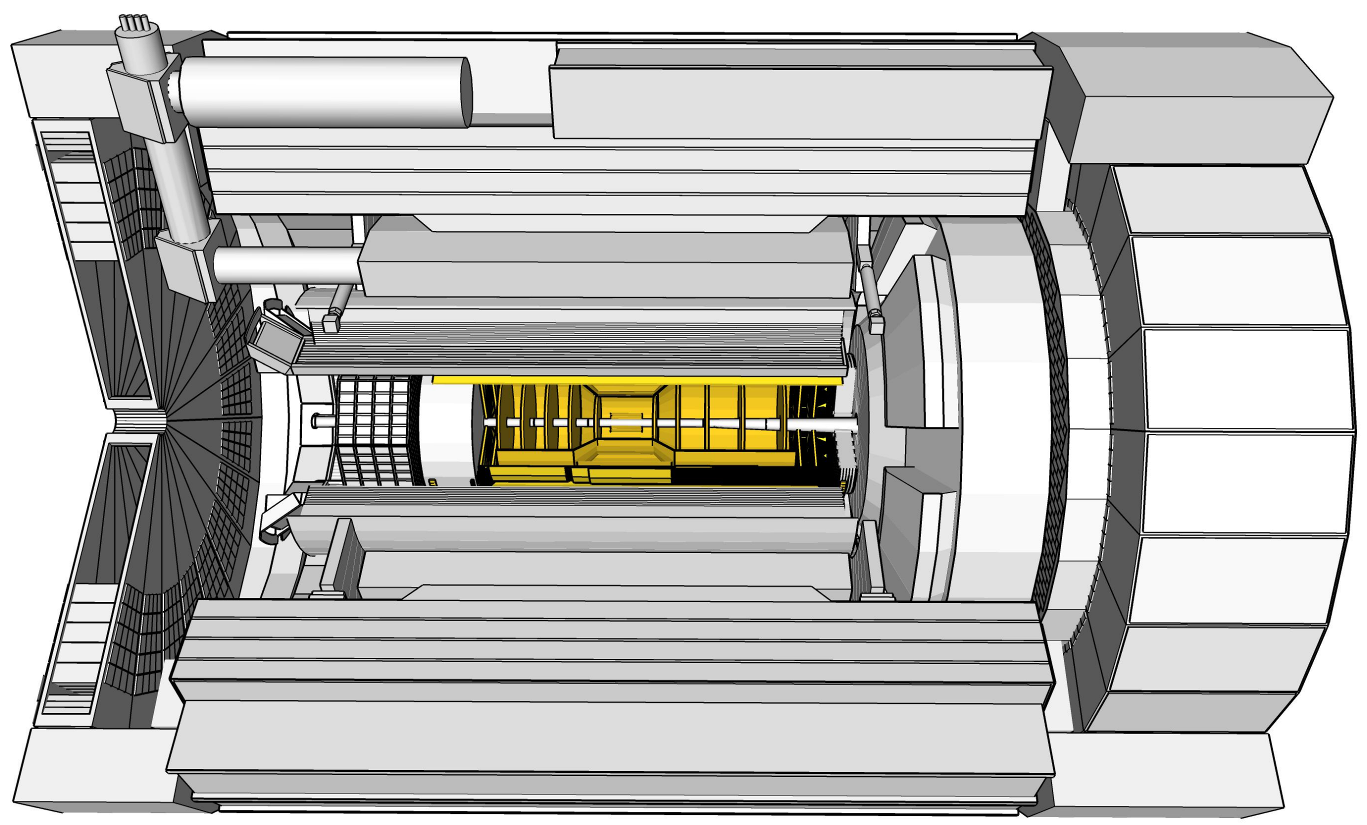

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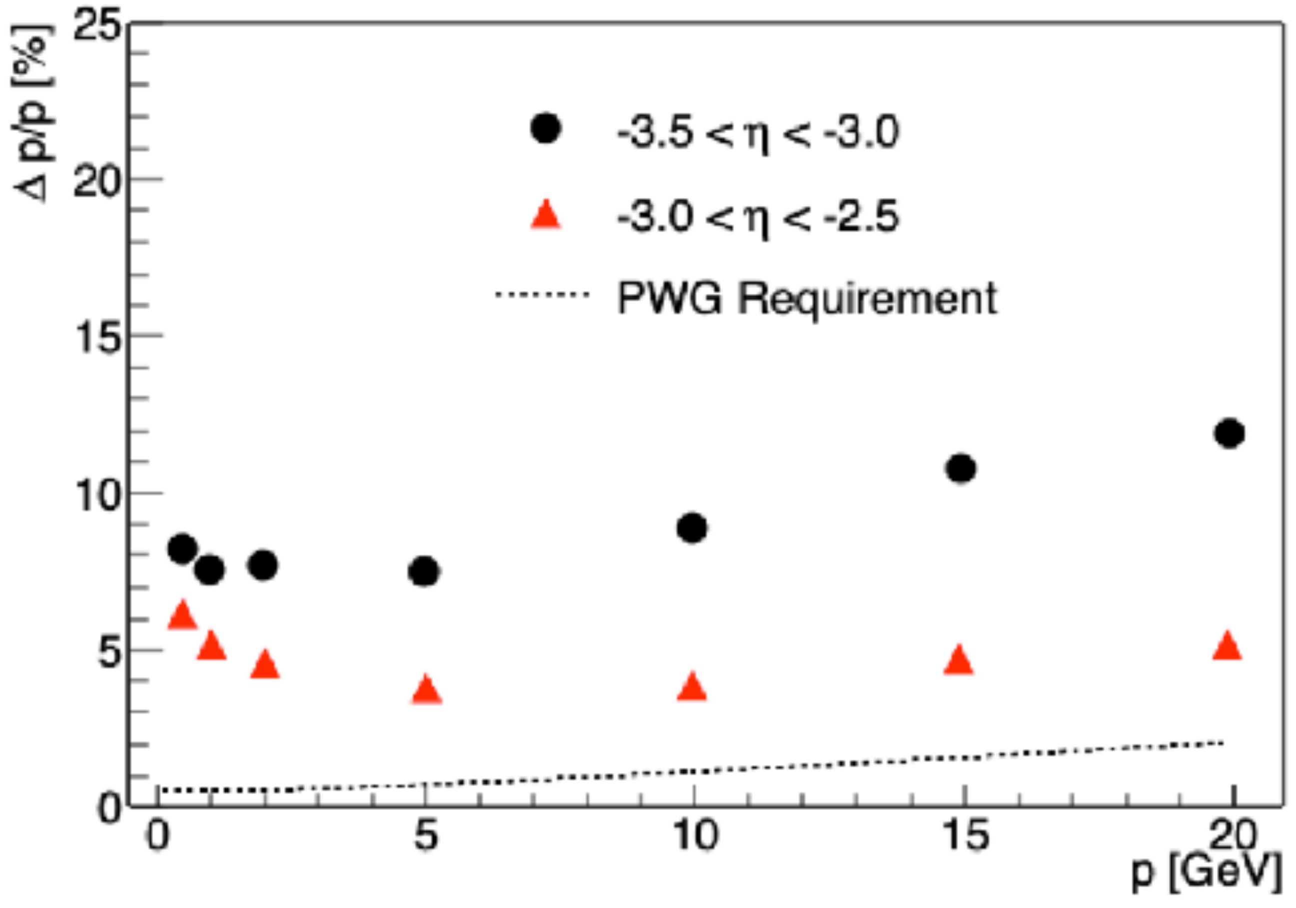
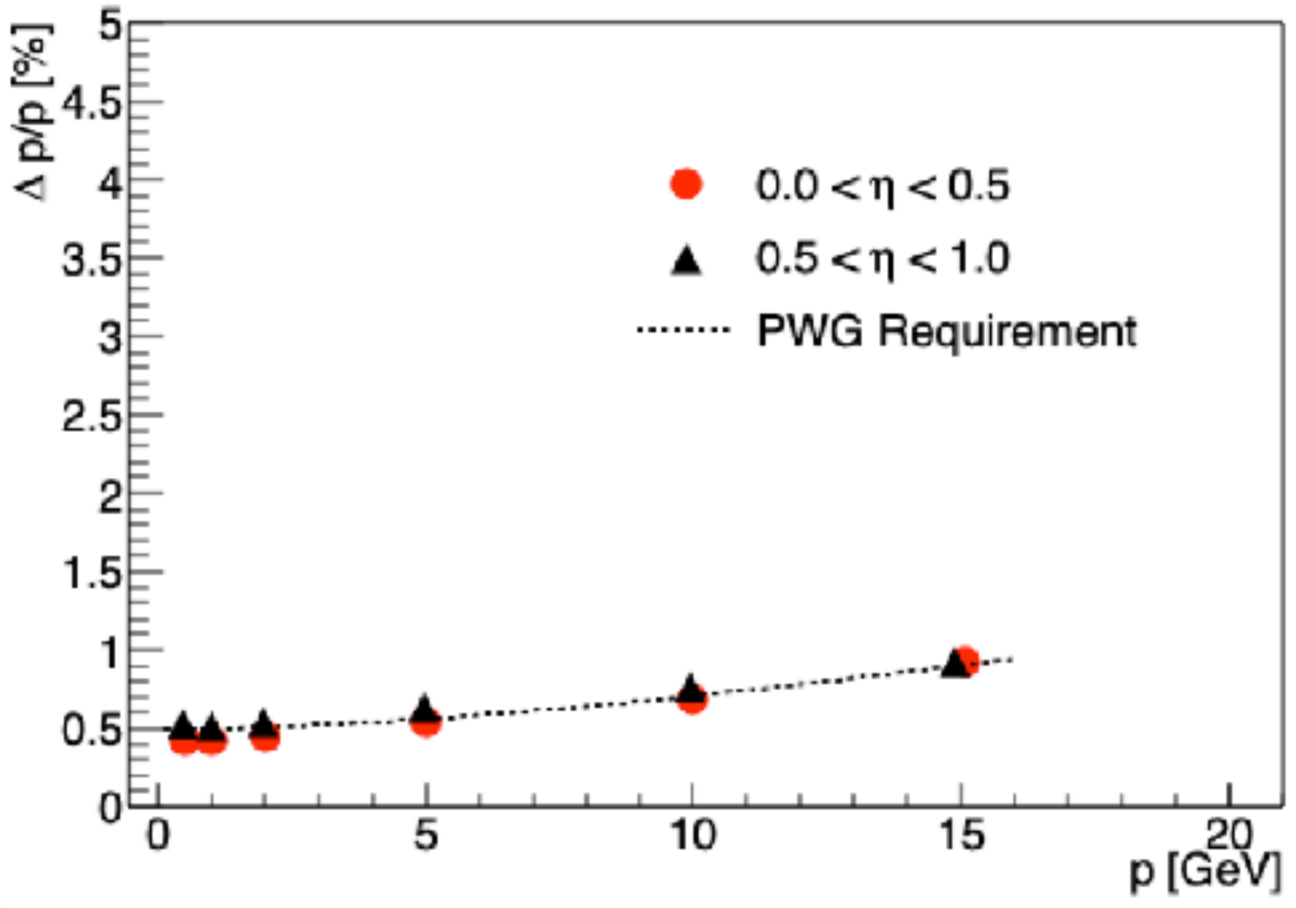
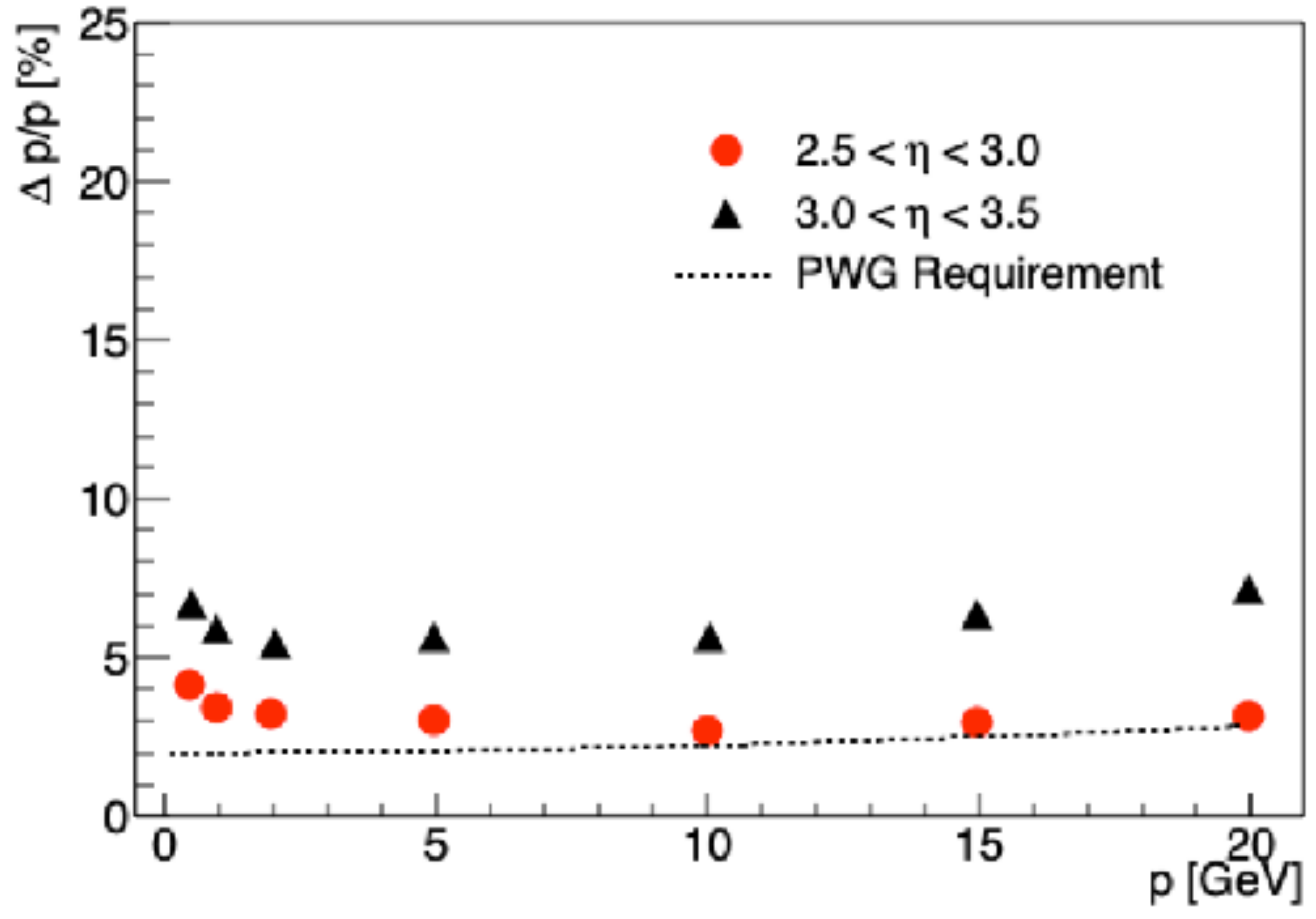
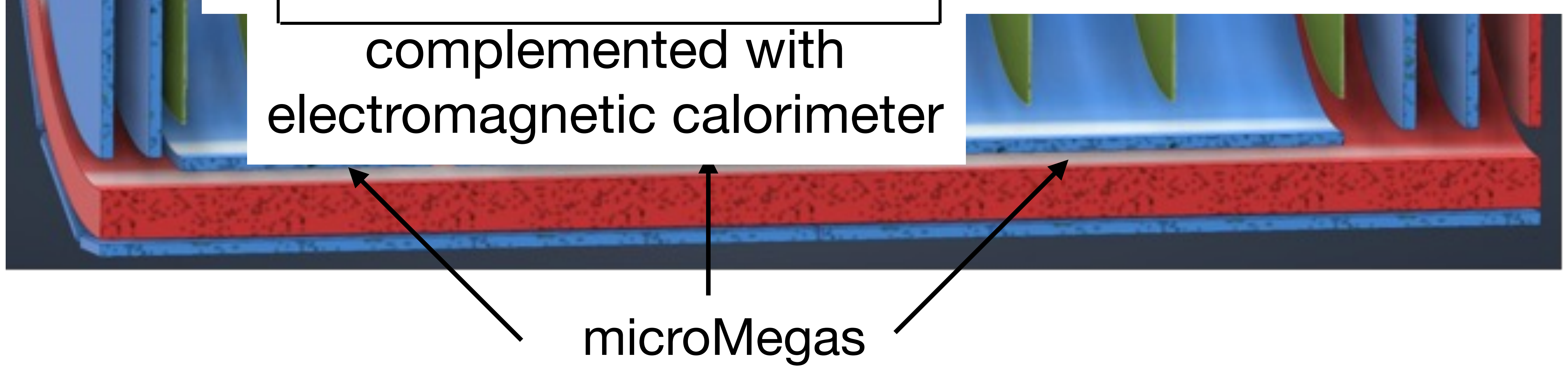
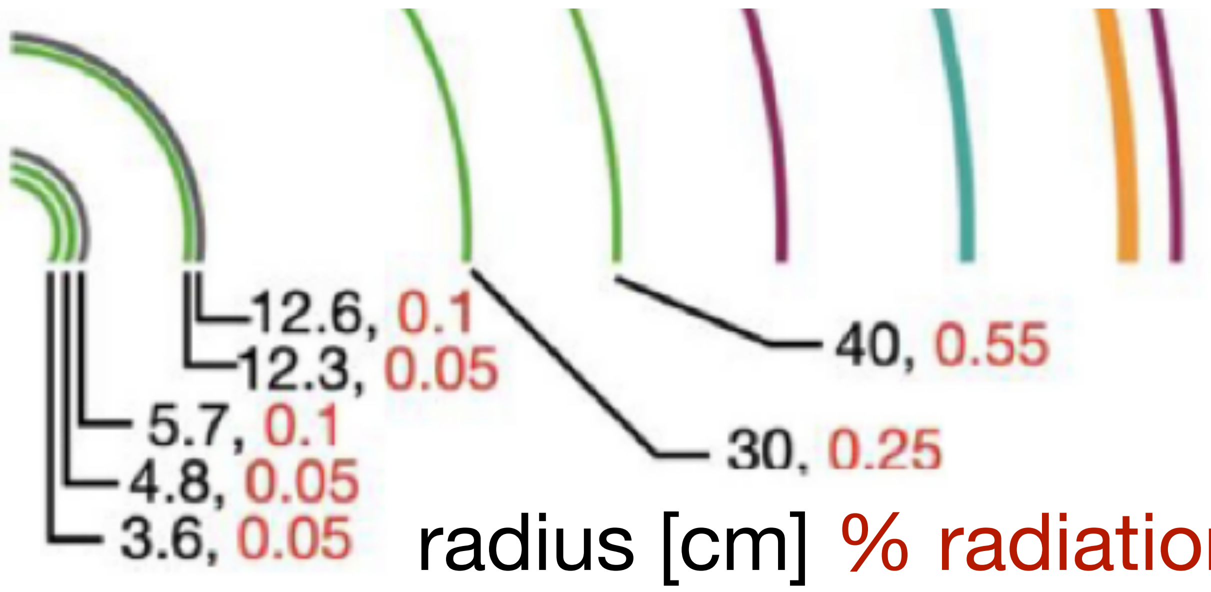






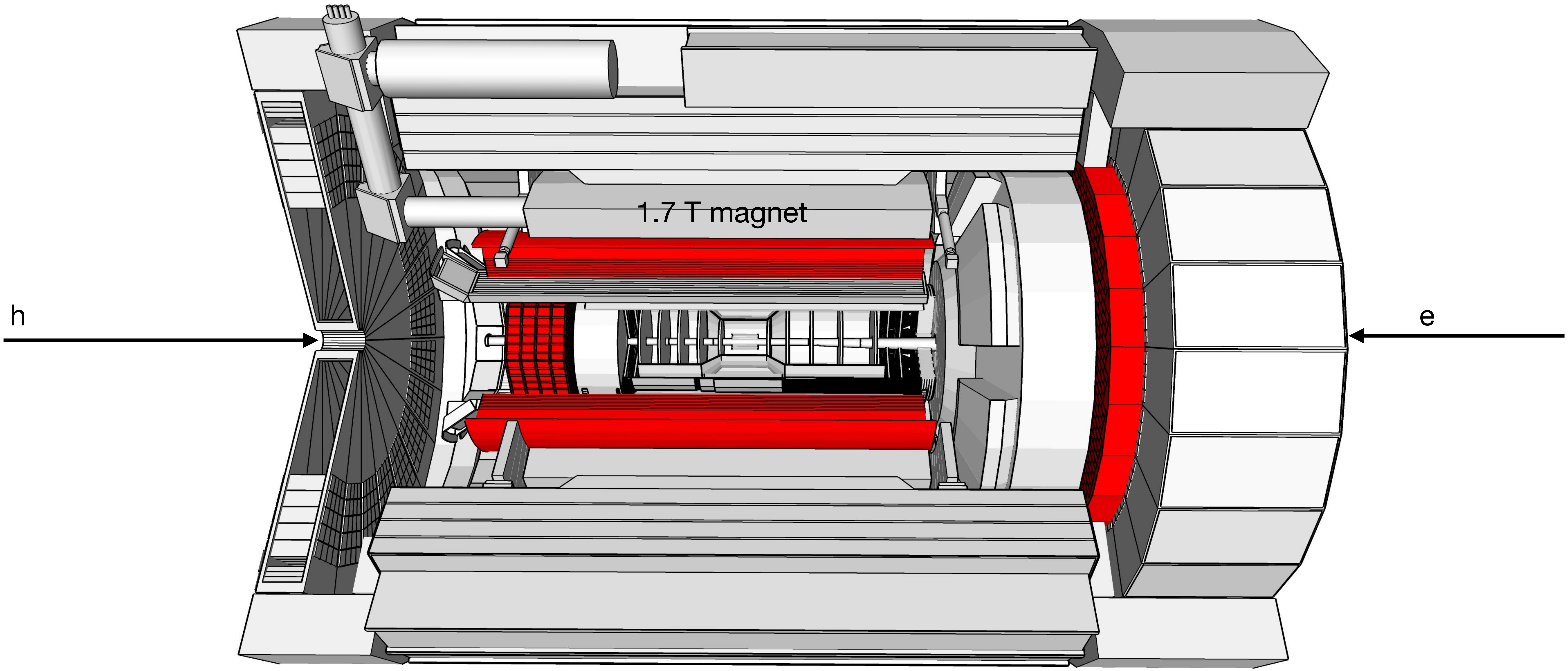
complemented with electromagnetic calorimeter





radius [cm] % radiation length

Electromagnetic calorimeter



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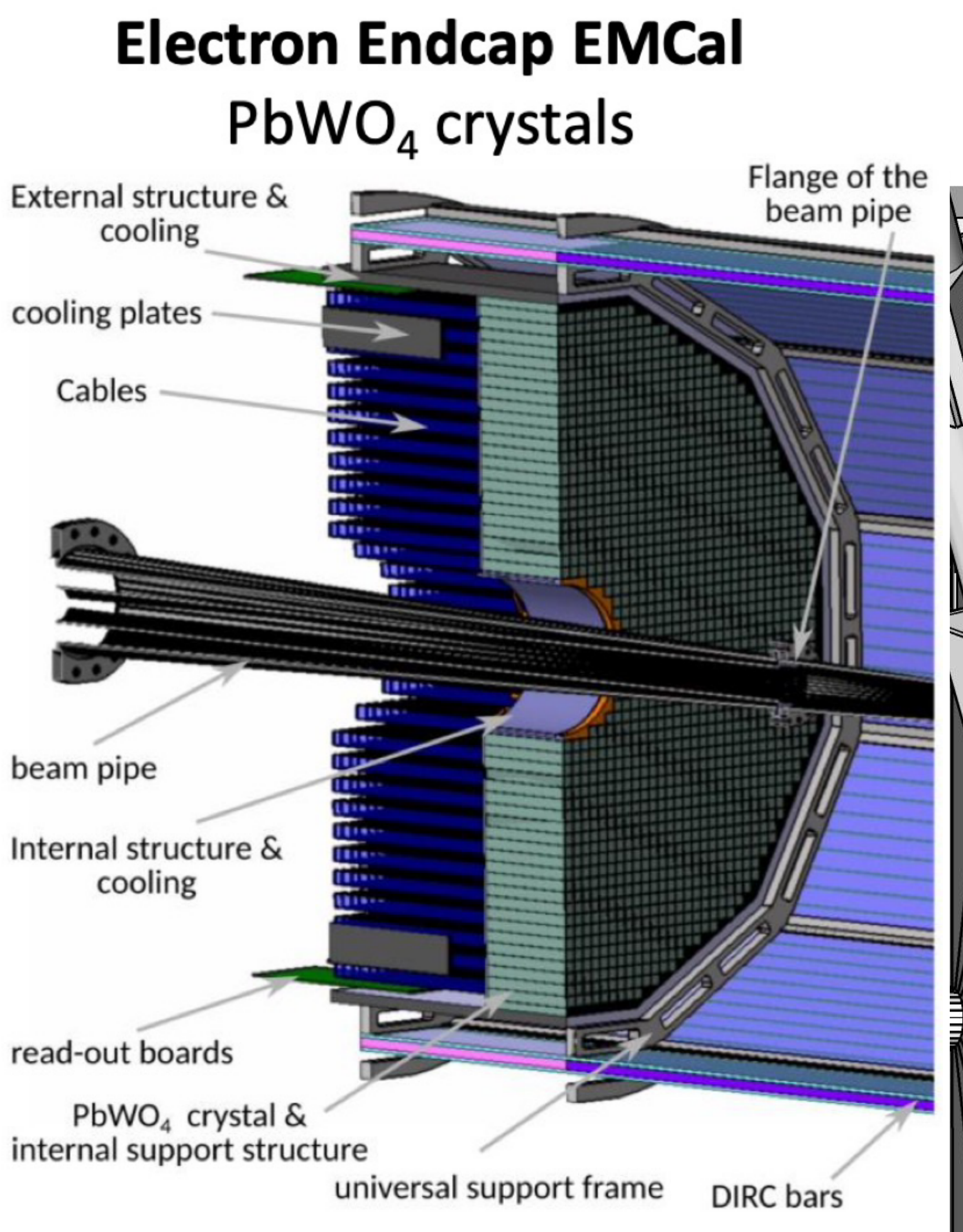
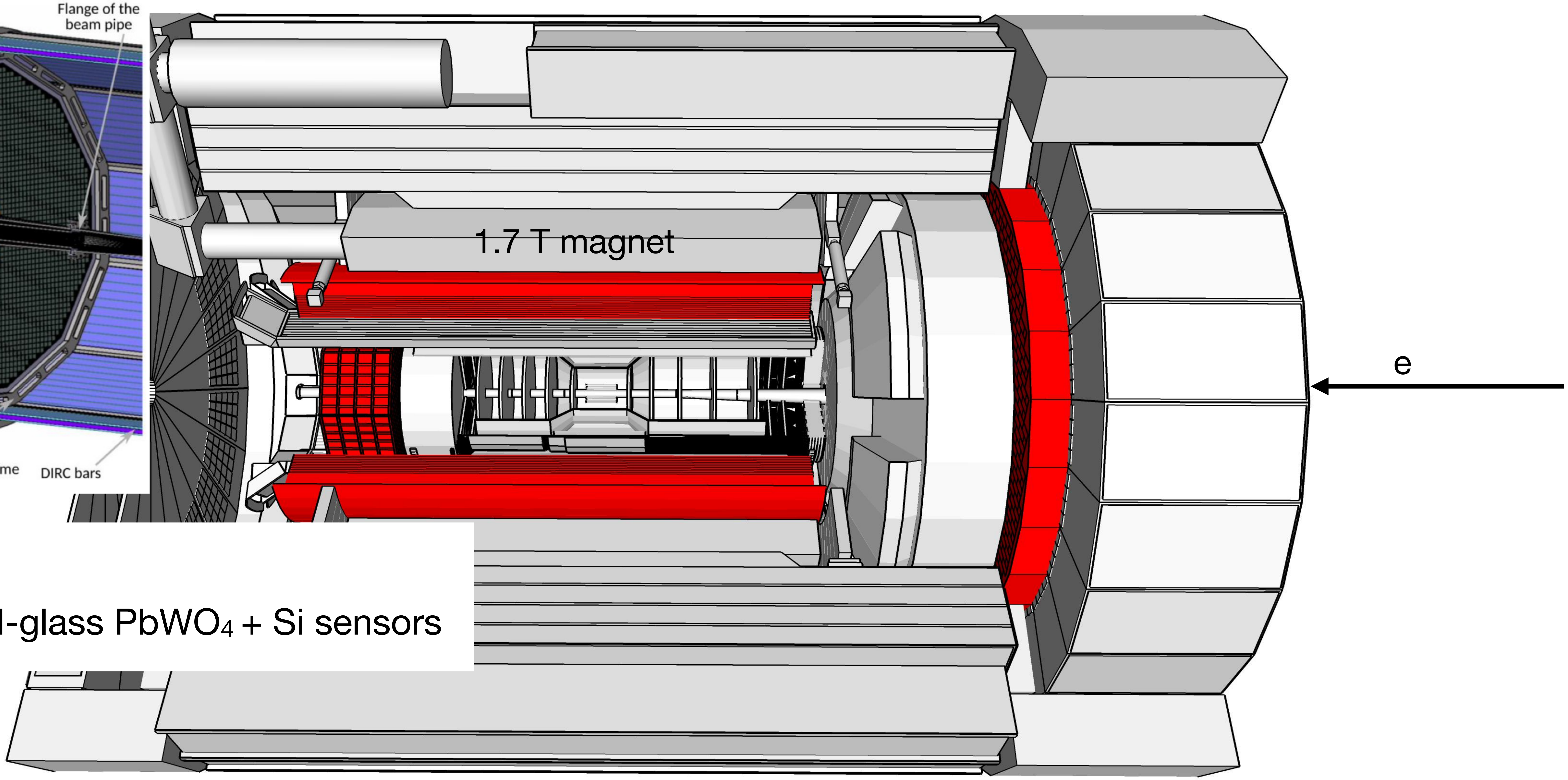
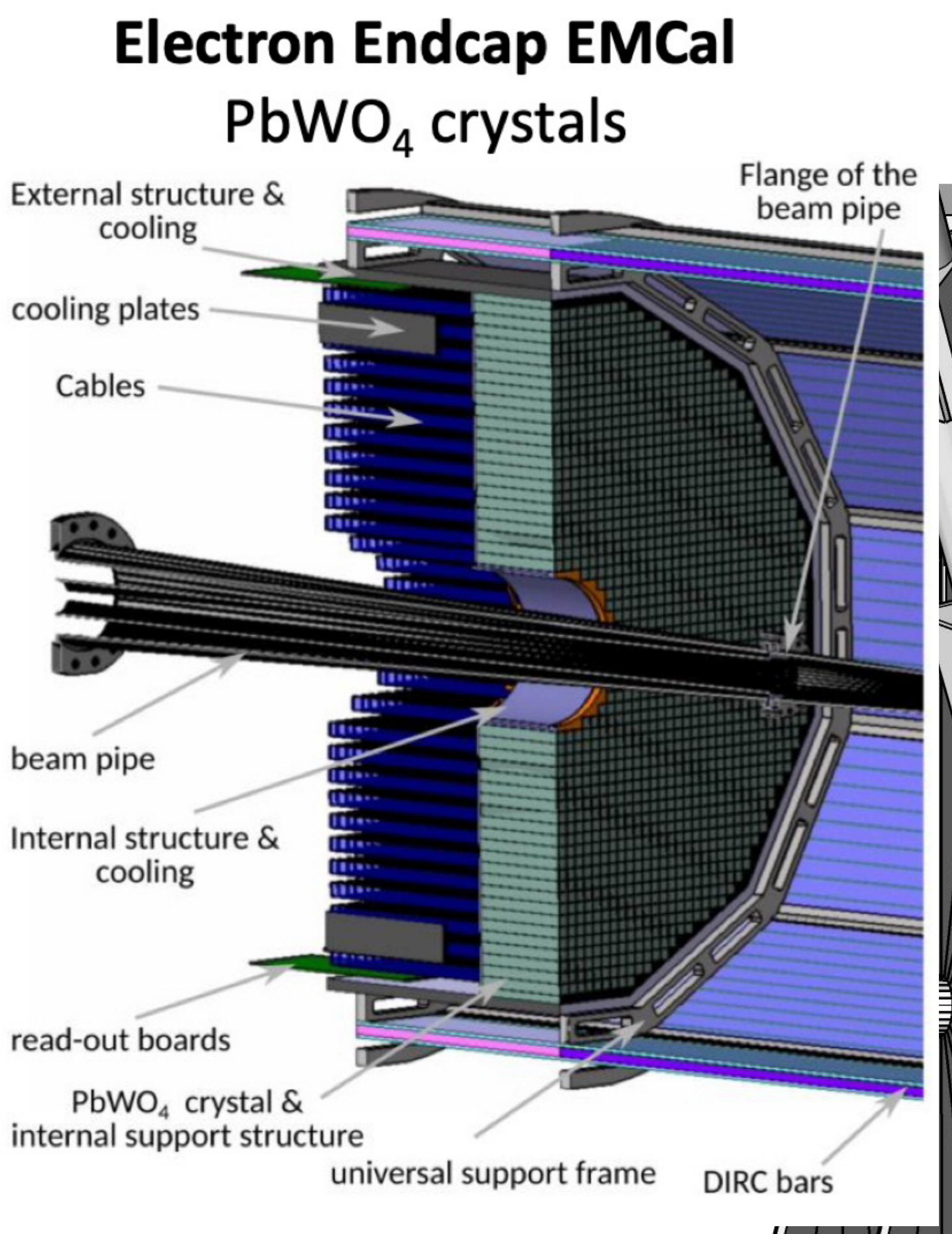
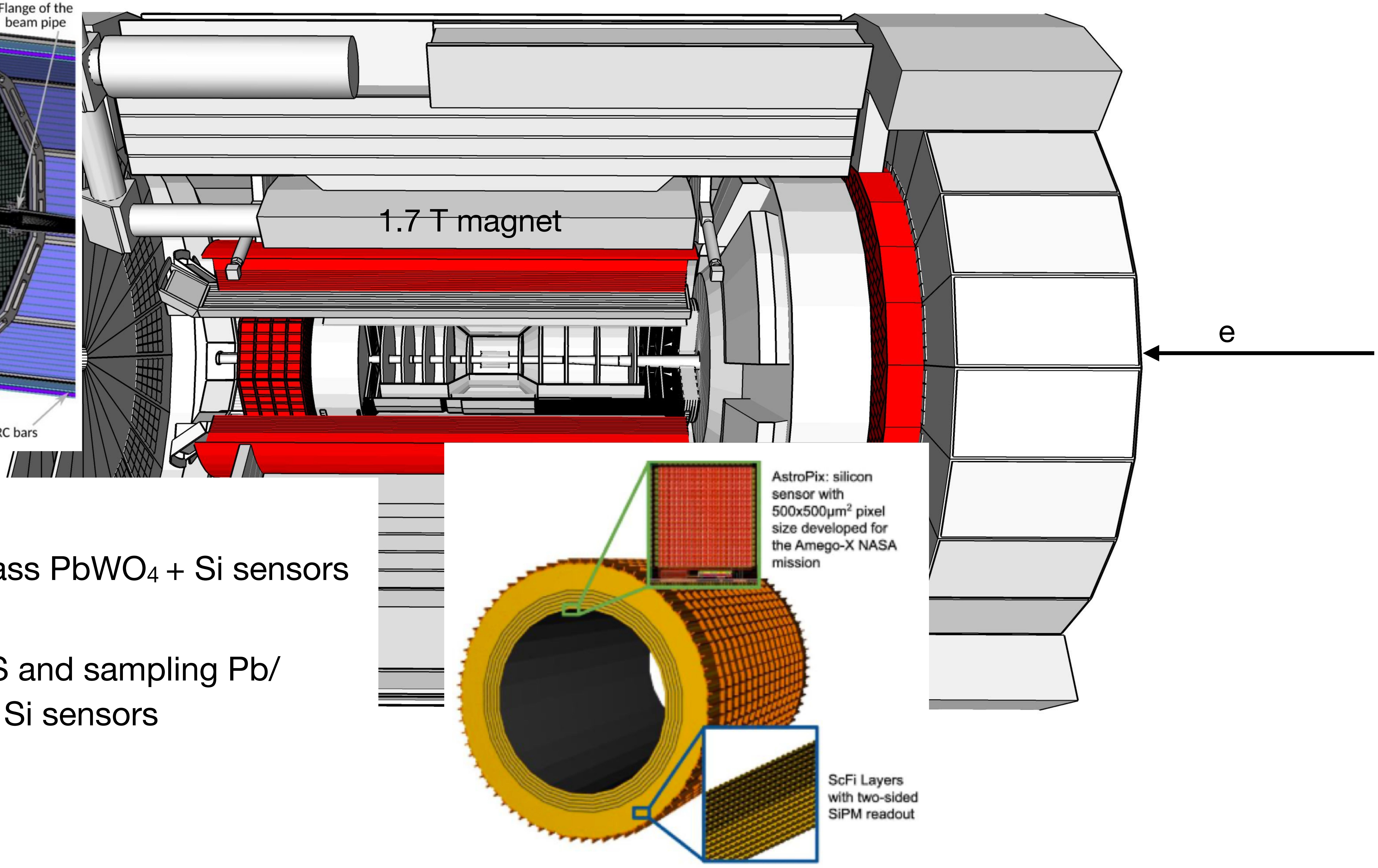




- Backward EMCAL:
  high-precision lead-glass $PbWO_4$ + Si sensors

Electromagnetic calorimeter

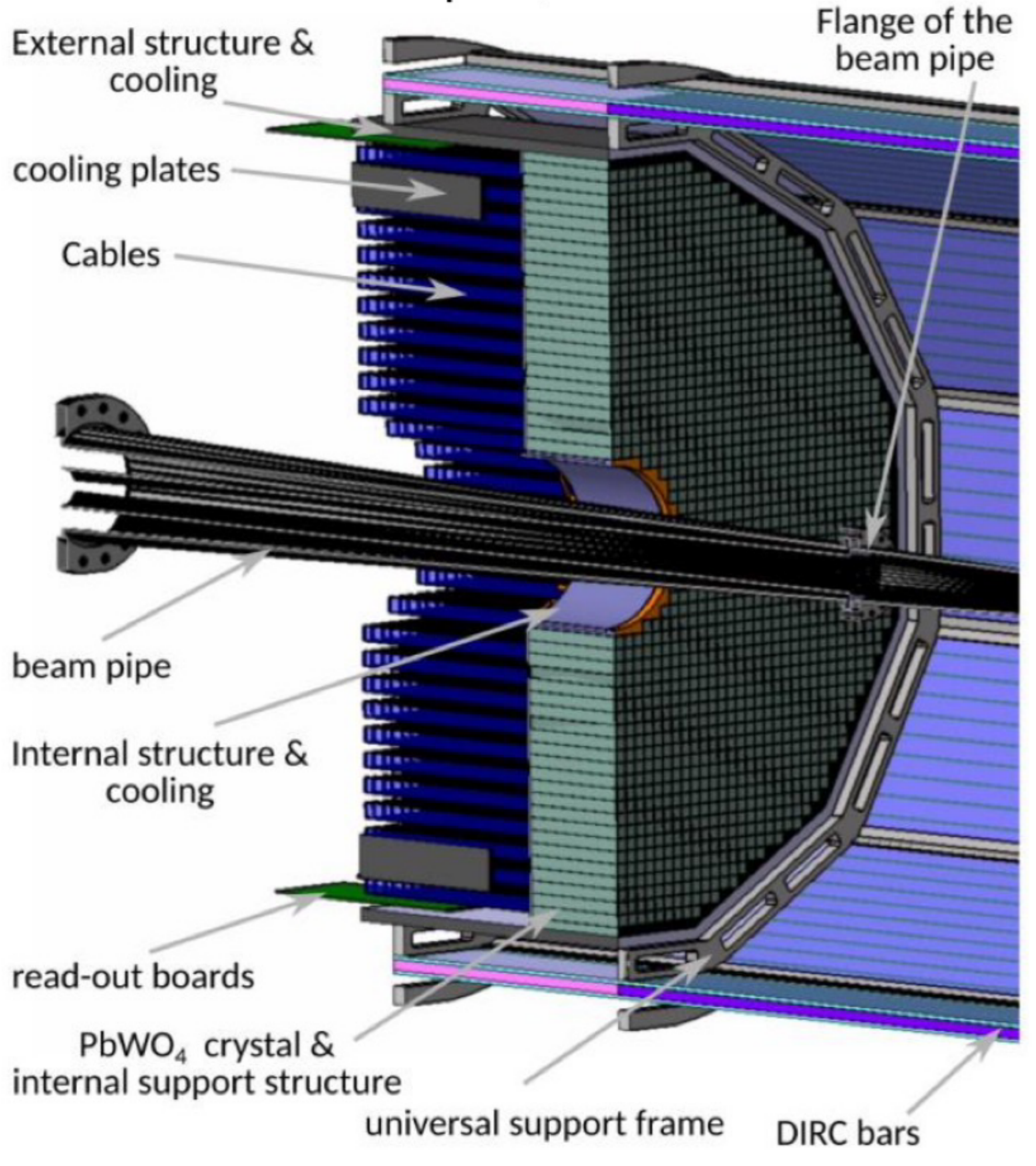


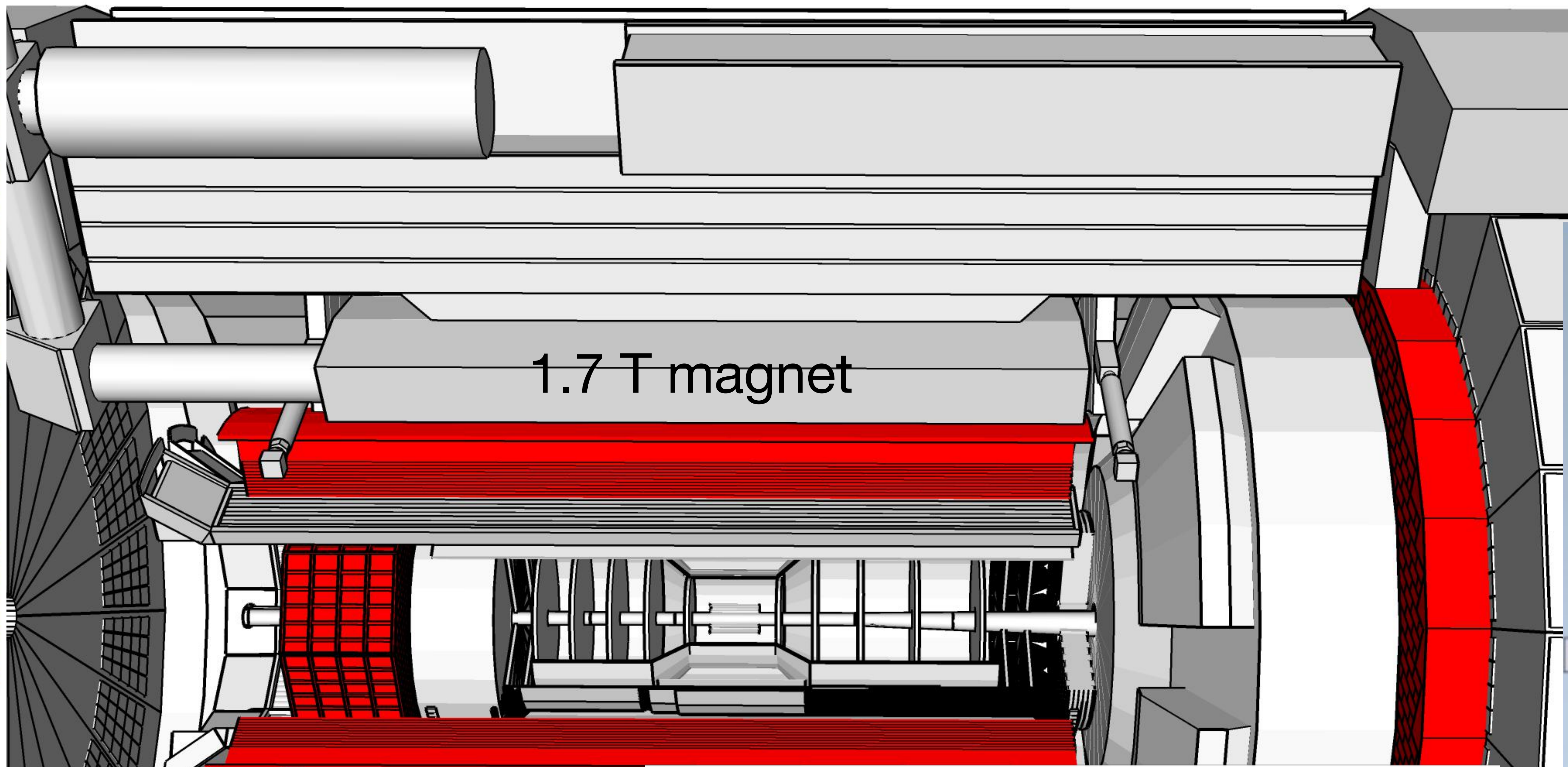


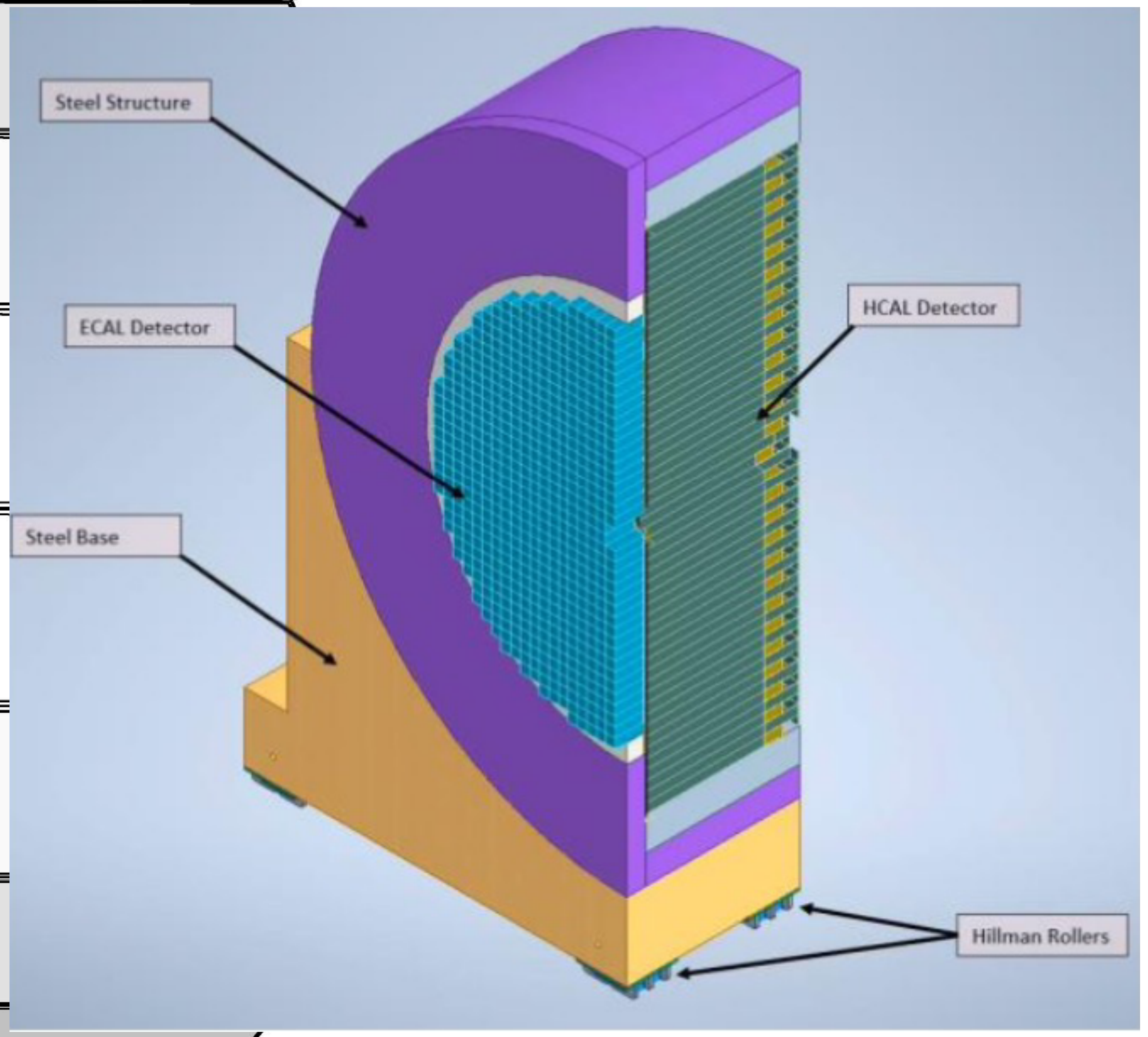
- Backward EMCAL:
  high-precision lead-glass $PbWO_4$ + Si sensors
- Barrel EMCAL:
  3D imaging with MAPS and sampling Pb/ scintillating fibres with Si sensors

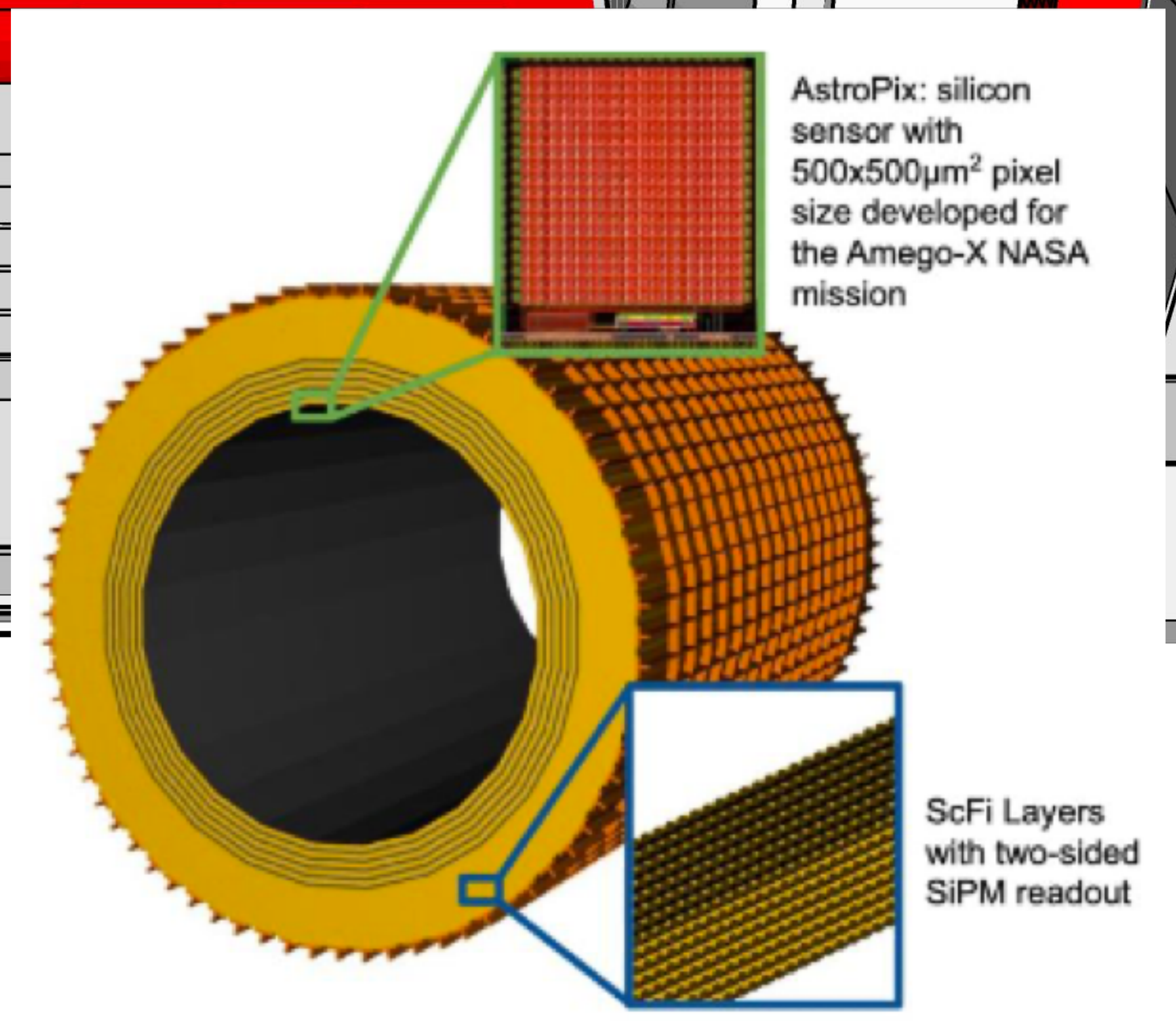
Electromagnetic calorimeter

Electron Endcap EMCal
$PbWO_4$ crystals



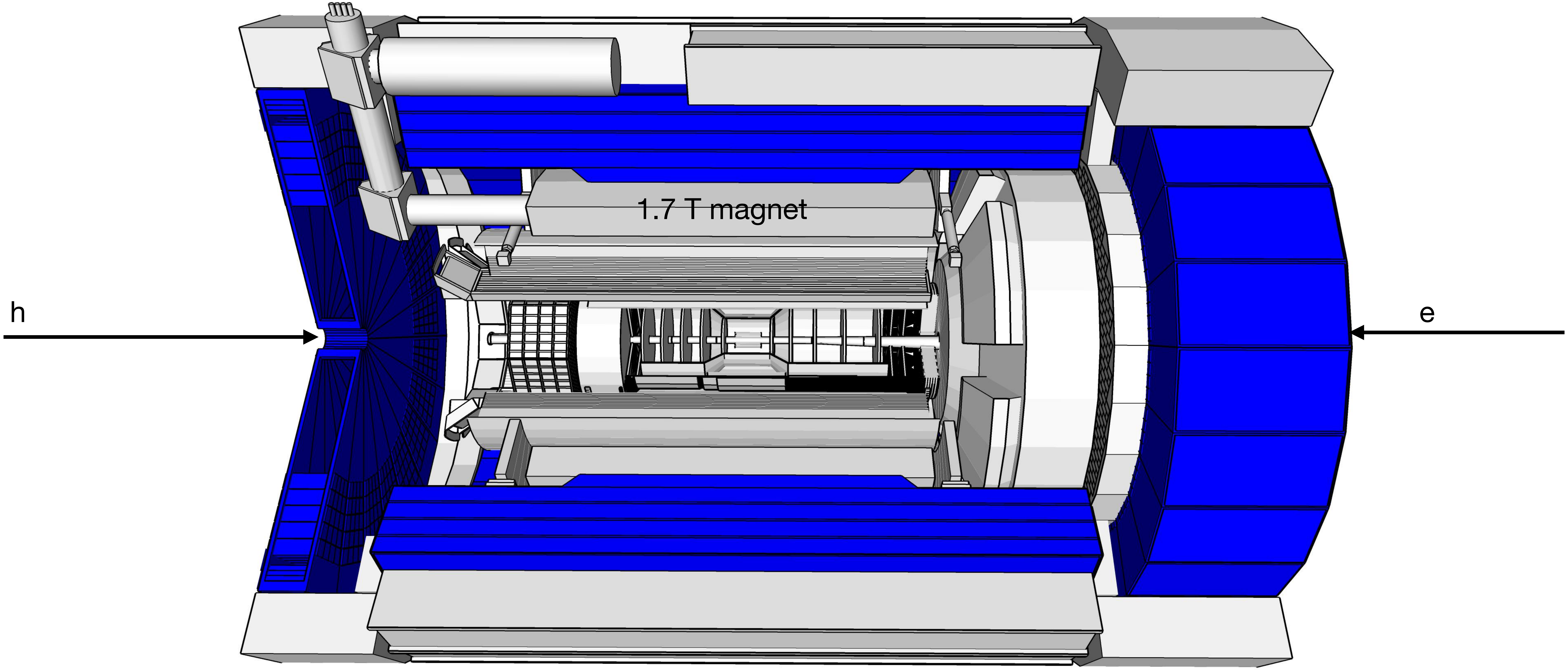






- Backward EMCAL:
  high-precision $PbWO_4$ + Si sensors
- Barrel EMCAL:
  3D imaging with MAPS and sampling Pb/scintillating fibres with Si sensors
- Forward EMCAL:
  finely segmented W powder/scintillating fibres

Hadronic calorimeter



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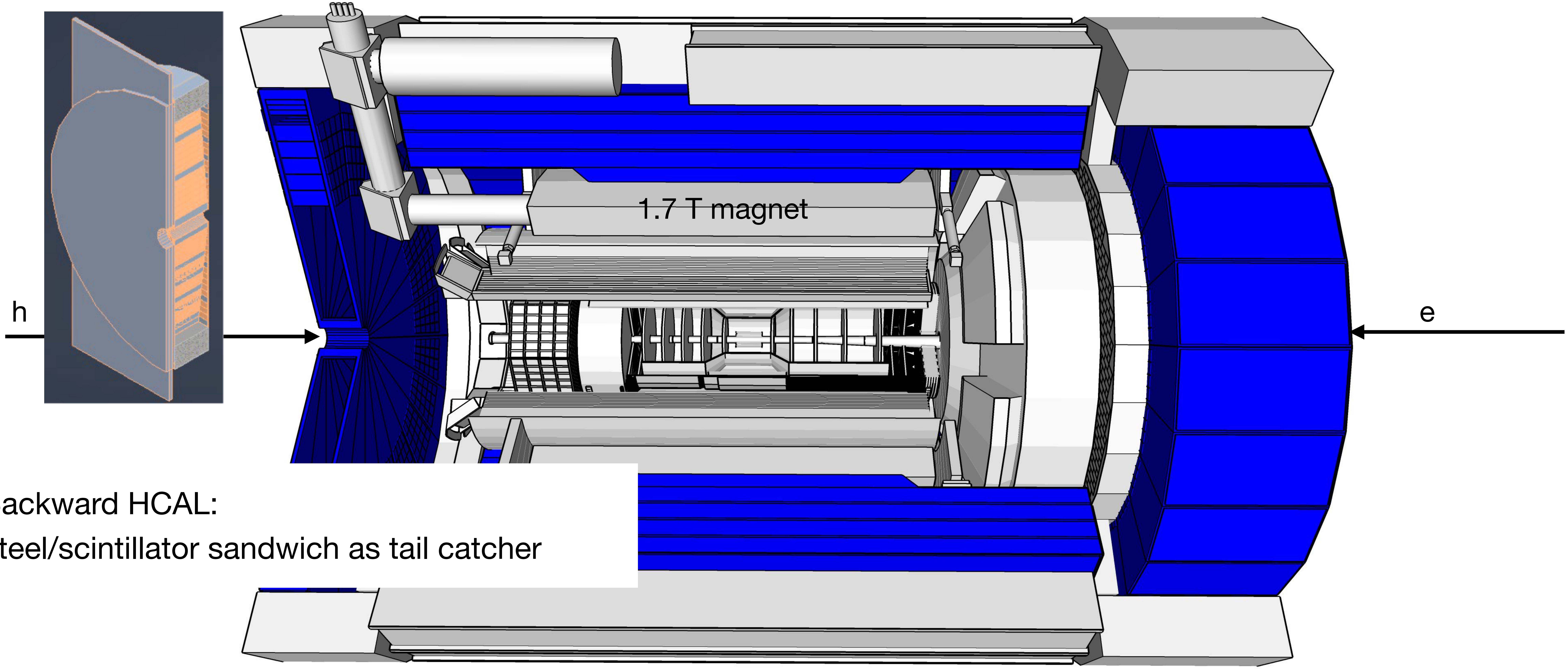
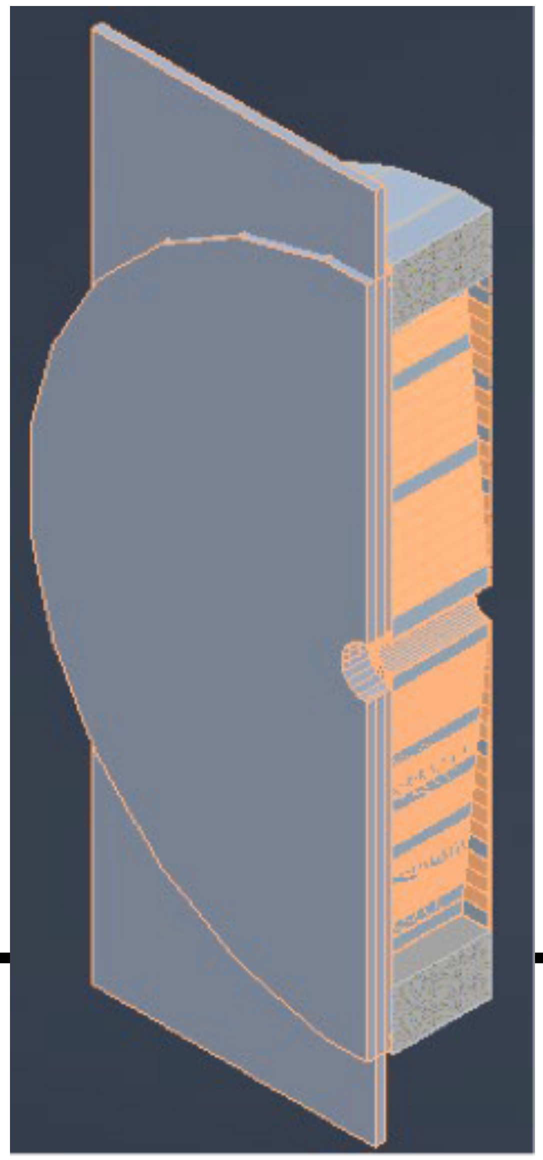
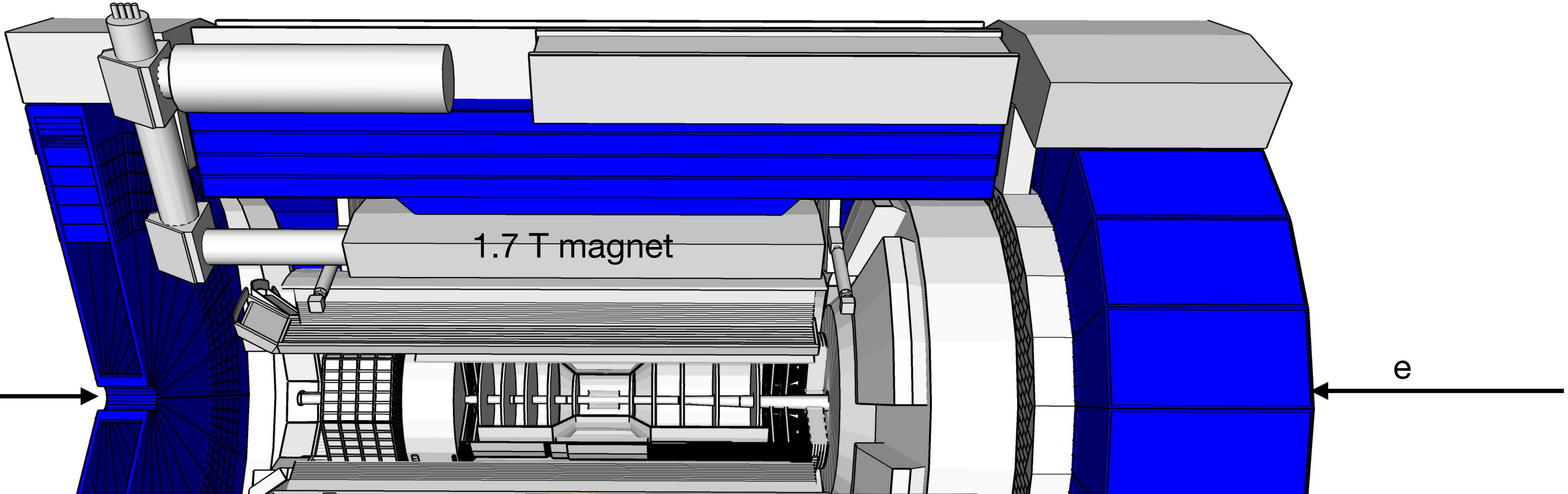


- Backward HCAL:
  steel/scintillator sandwich as tail catcher

Hadronic calorimeter





- Backward HCAL:
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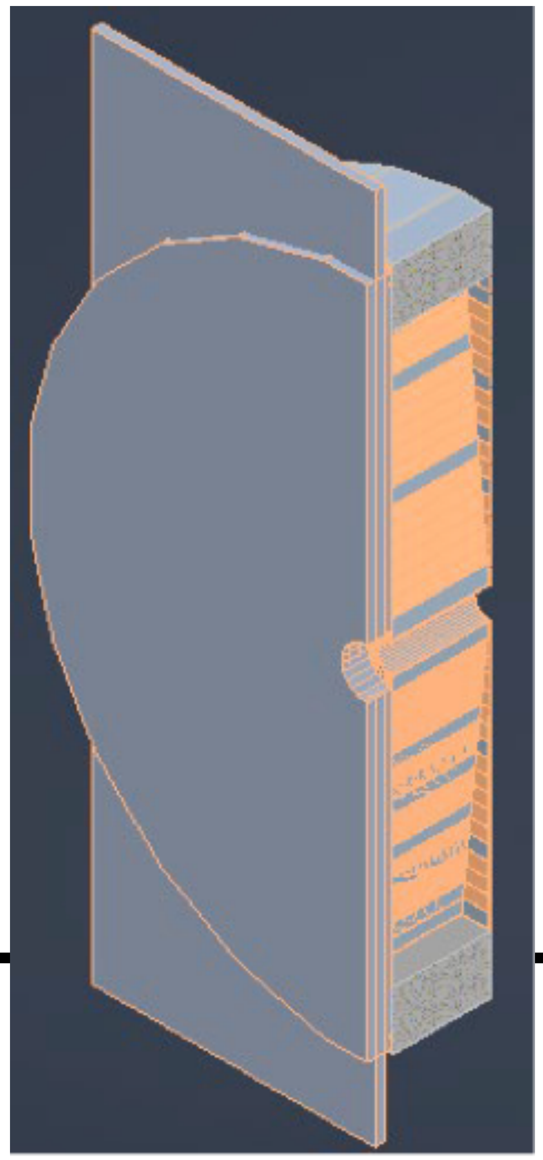
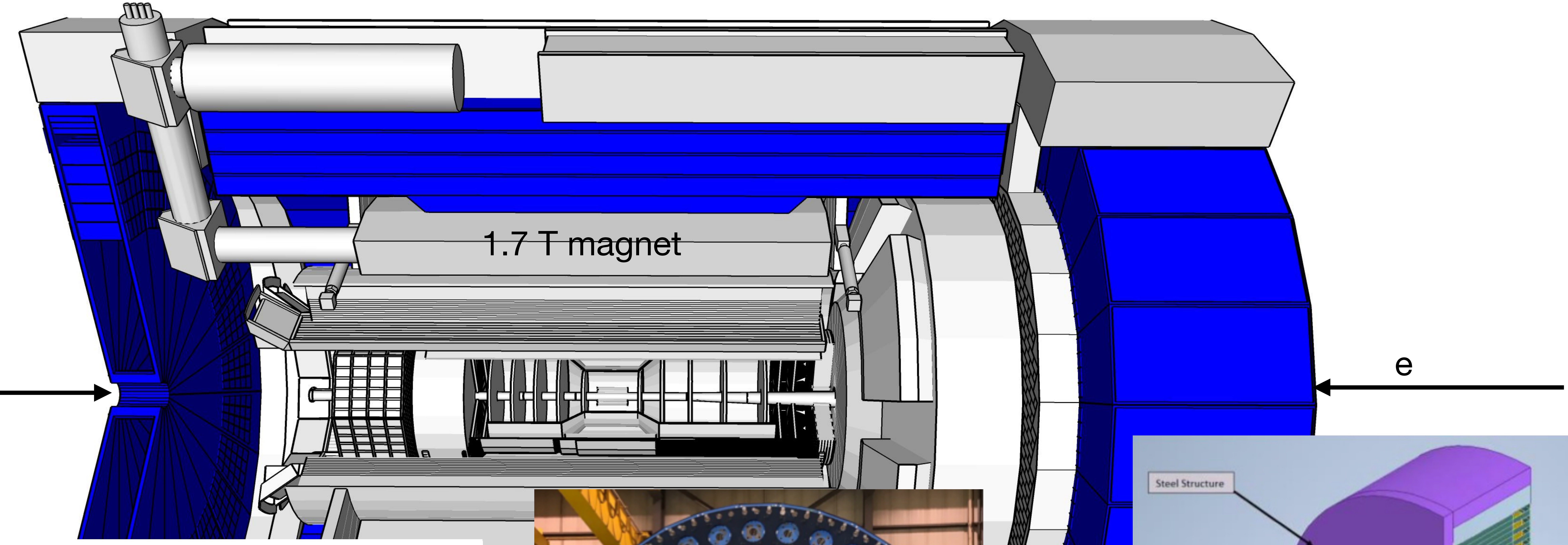
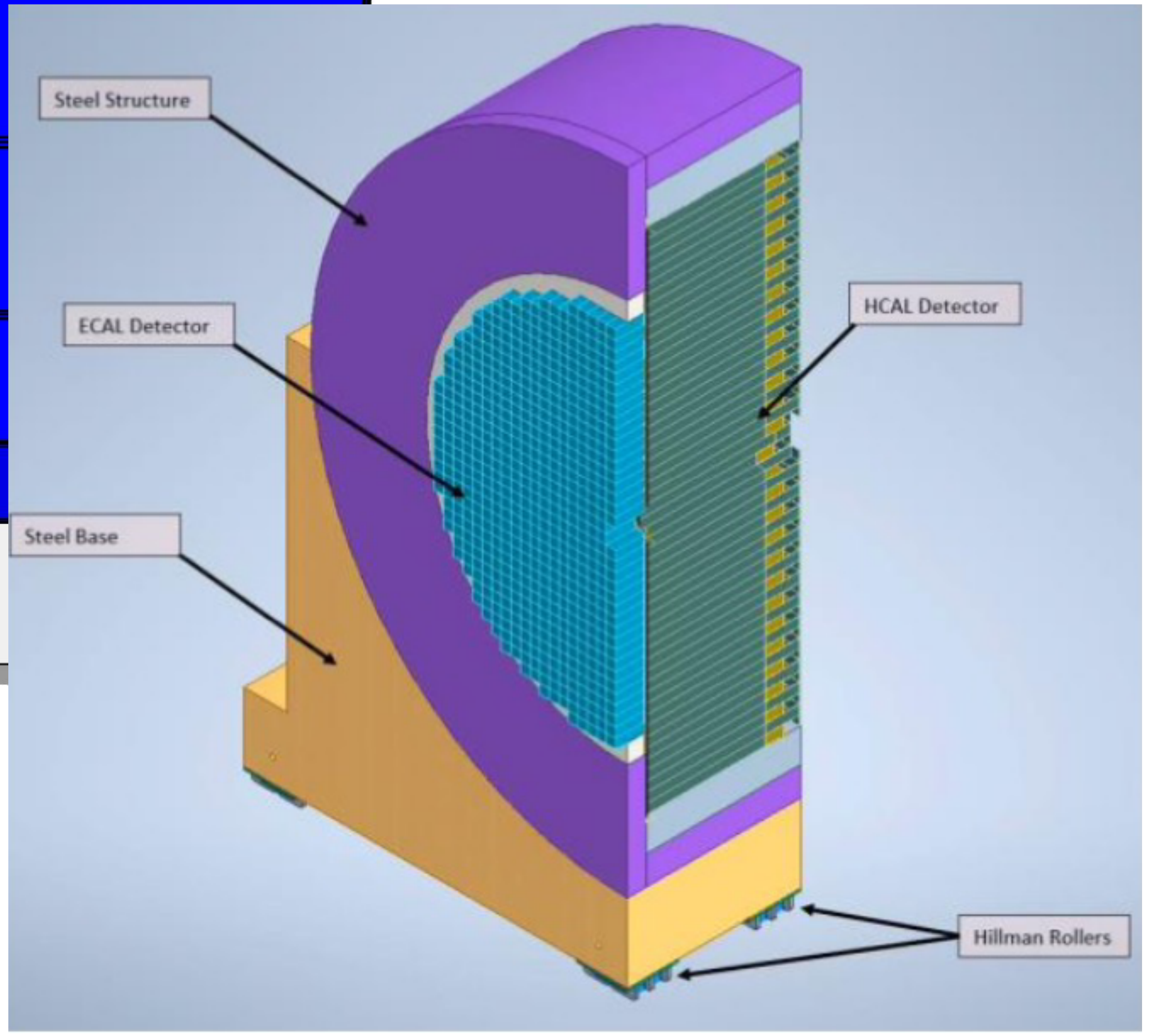
- Barrel HCAL:
  Fe/scintillator sandwich: detection of neutrals

Hadronic calorimeter

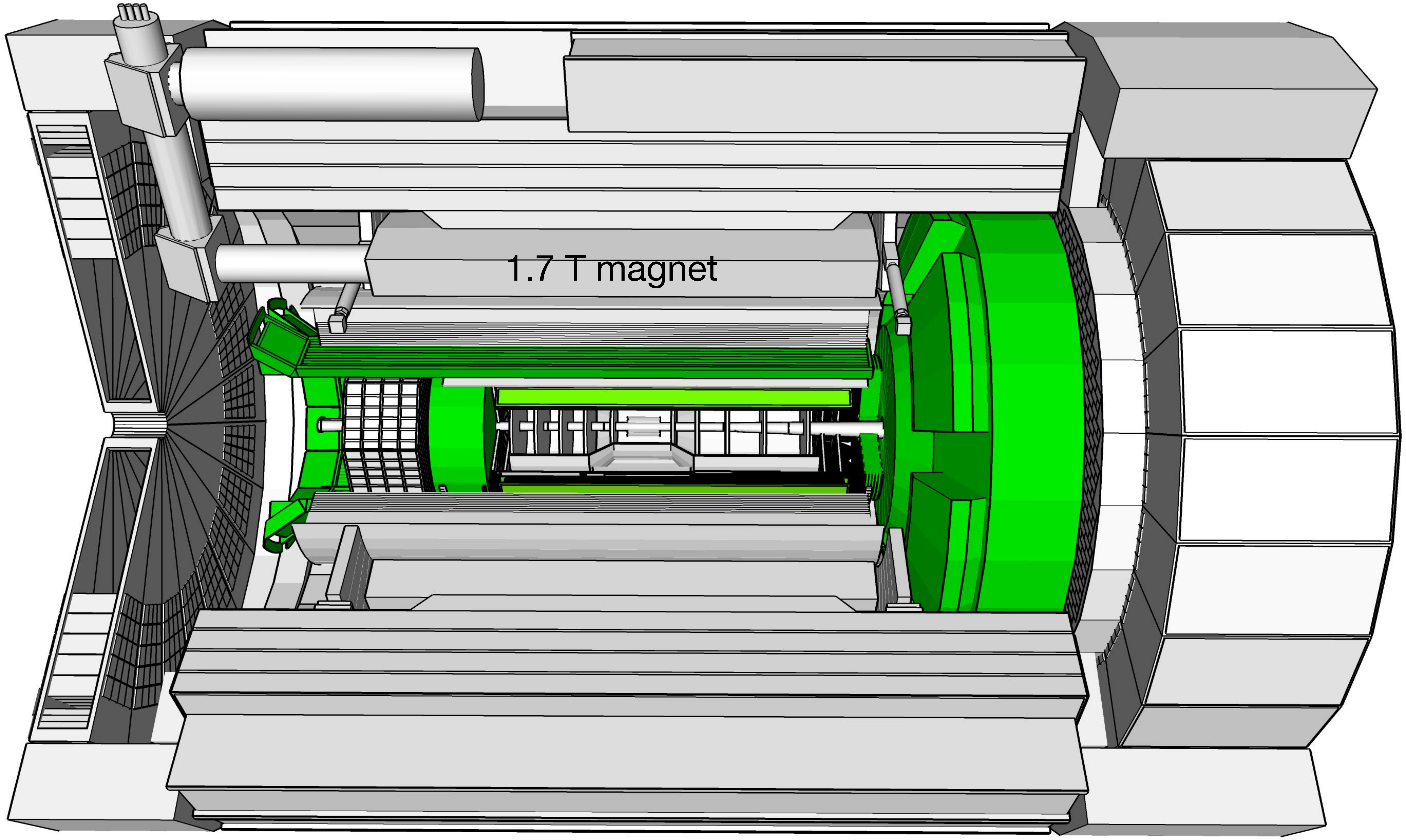




- Backward HCAL:
  steel/scintillator sandwich as tail catcher
- Barrel HCAL:
  Fe/scintillator sandwich: detection of neutrals
- Forward HCAL:
  W/scintillator sandwich longitudinally segmented, high granularity: good E resolution

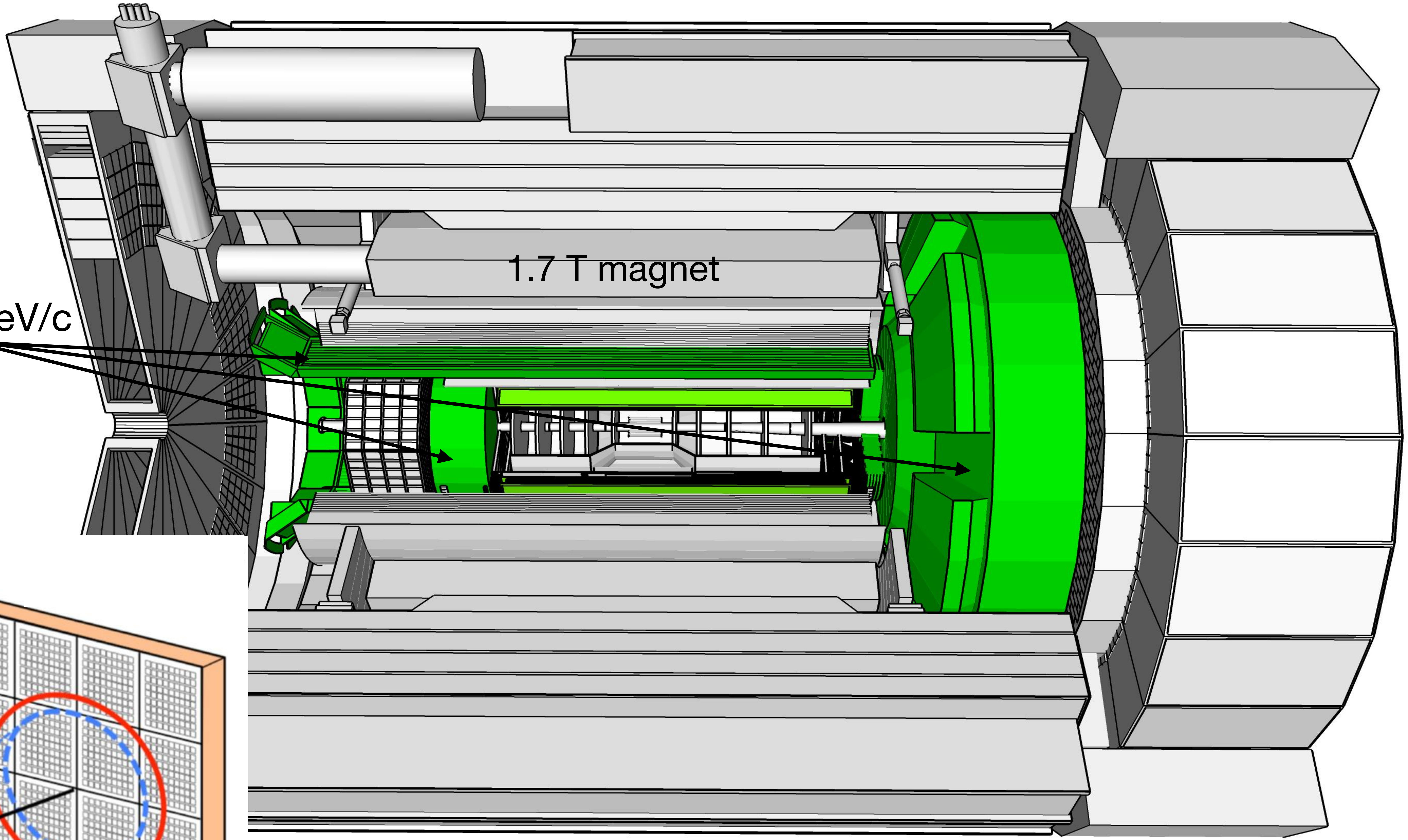


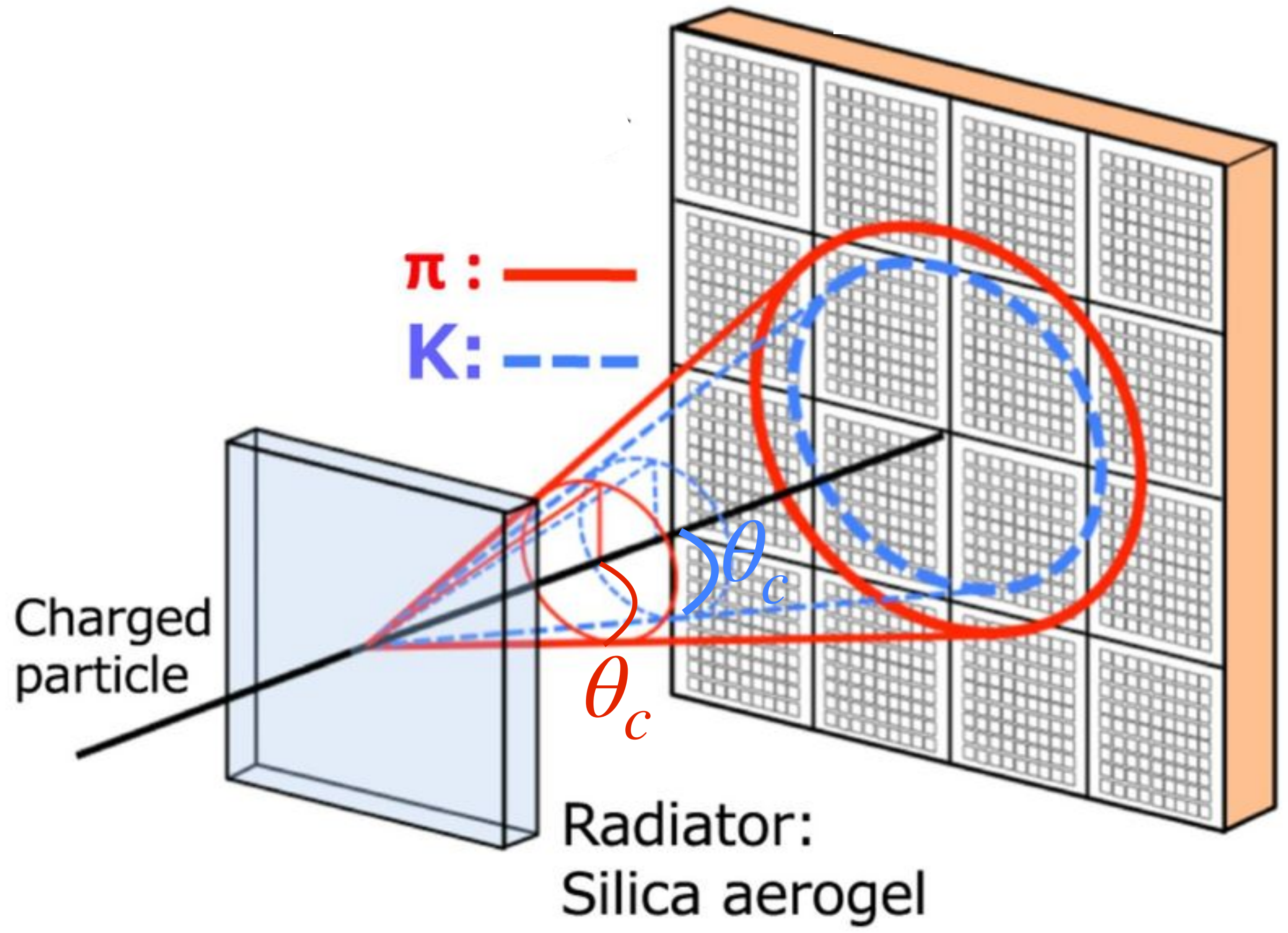
Particle identification



Particle identification

detectors based on
Cherenkov radiation
for 1 GeV/c<p<50 GeV/c





$$\cos\theta_c \propto \frac{1}{v}$$

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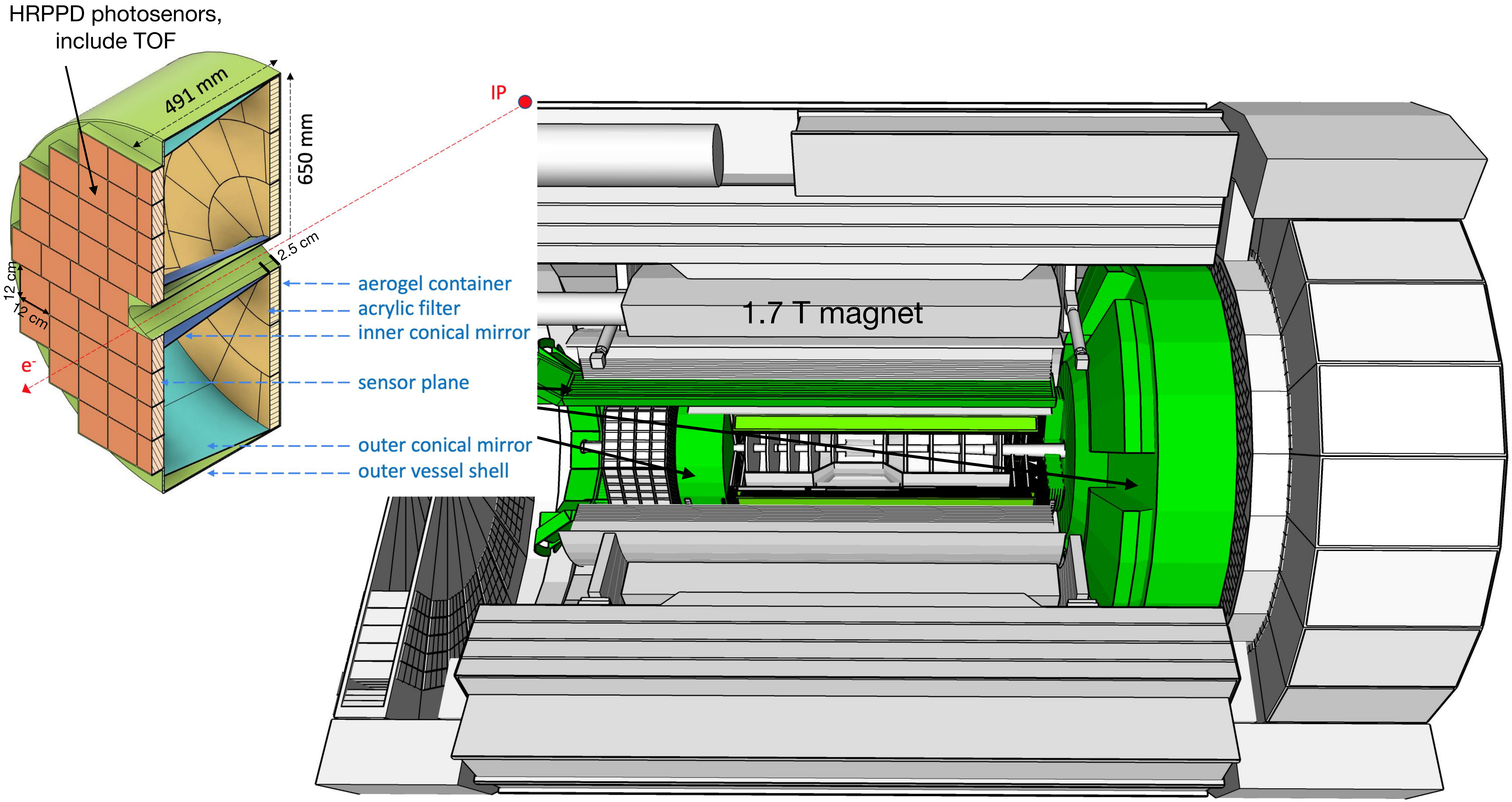

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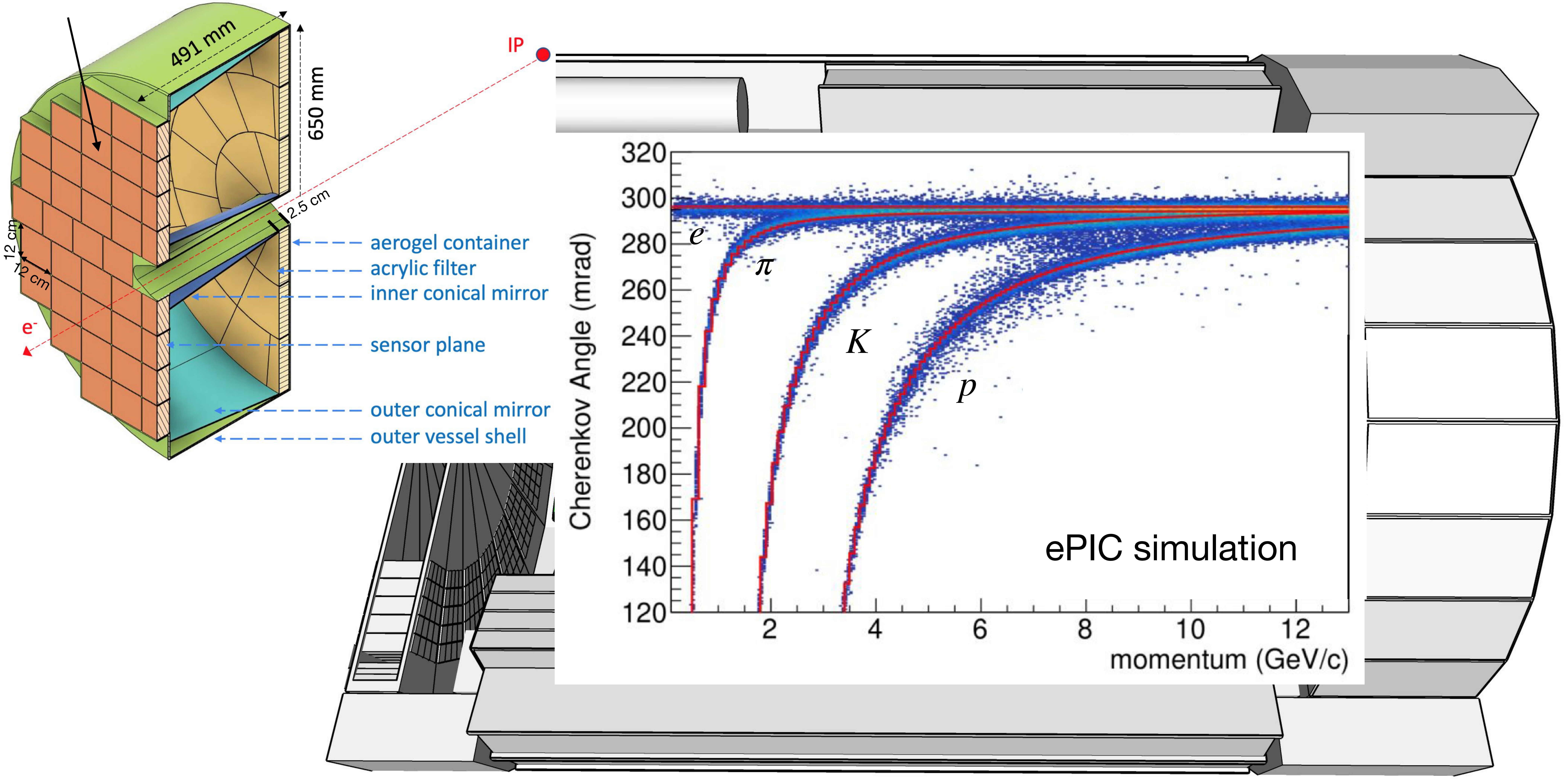

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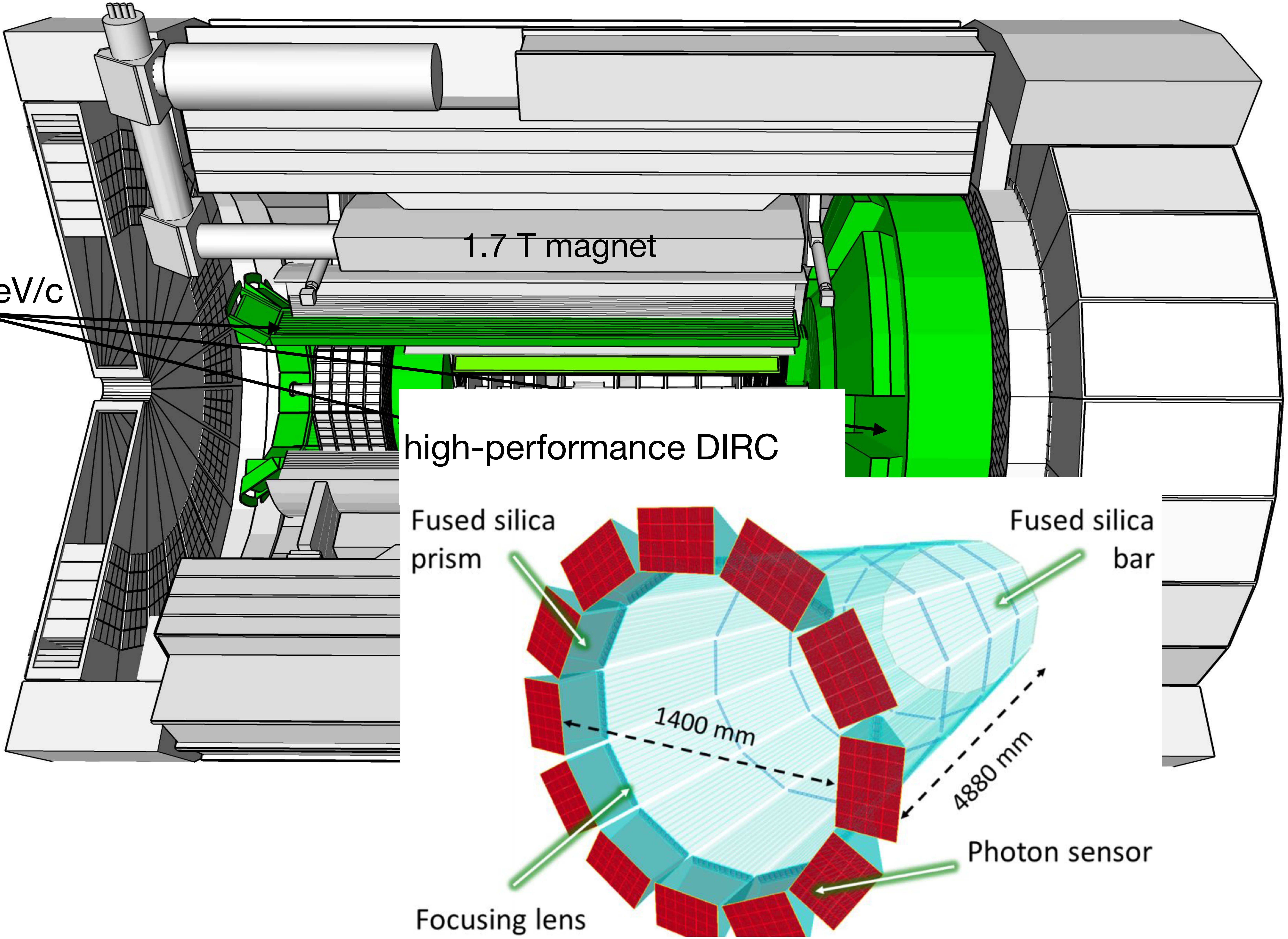

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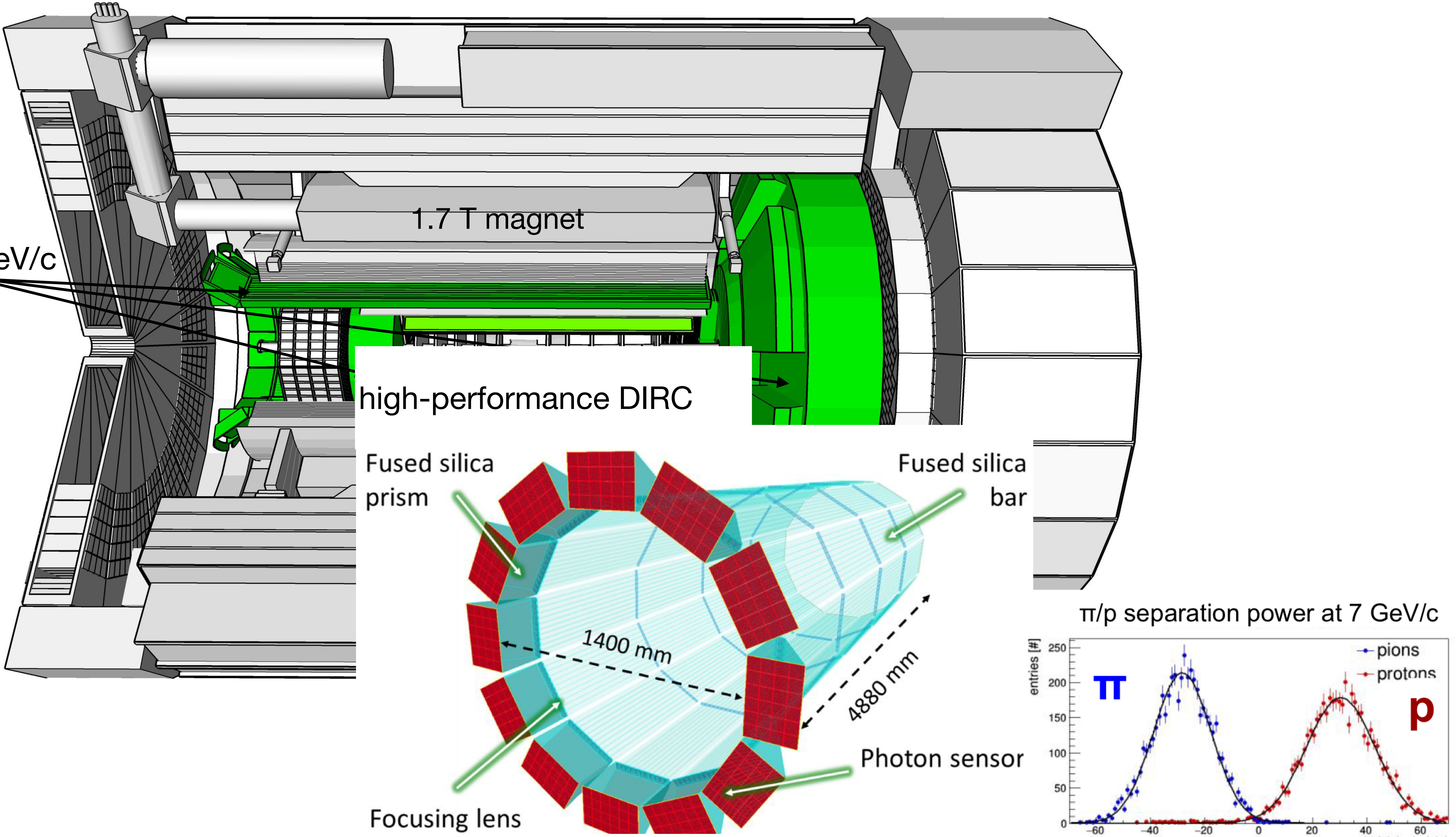

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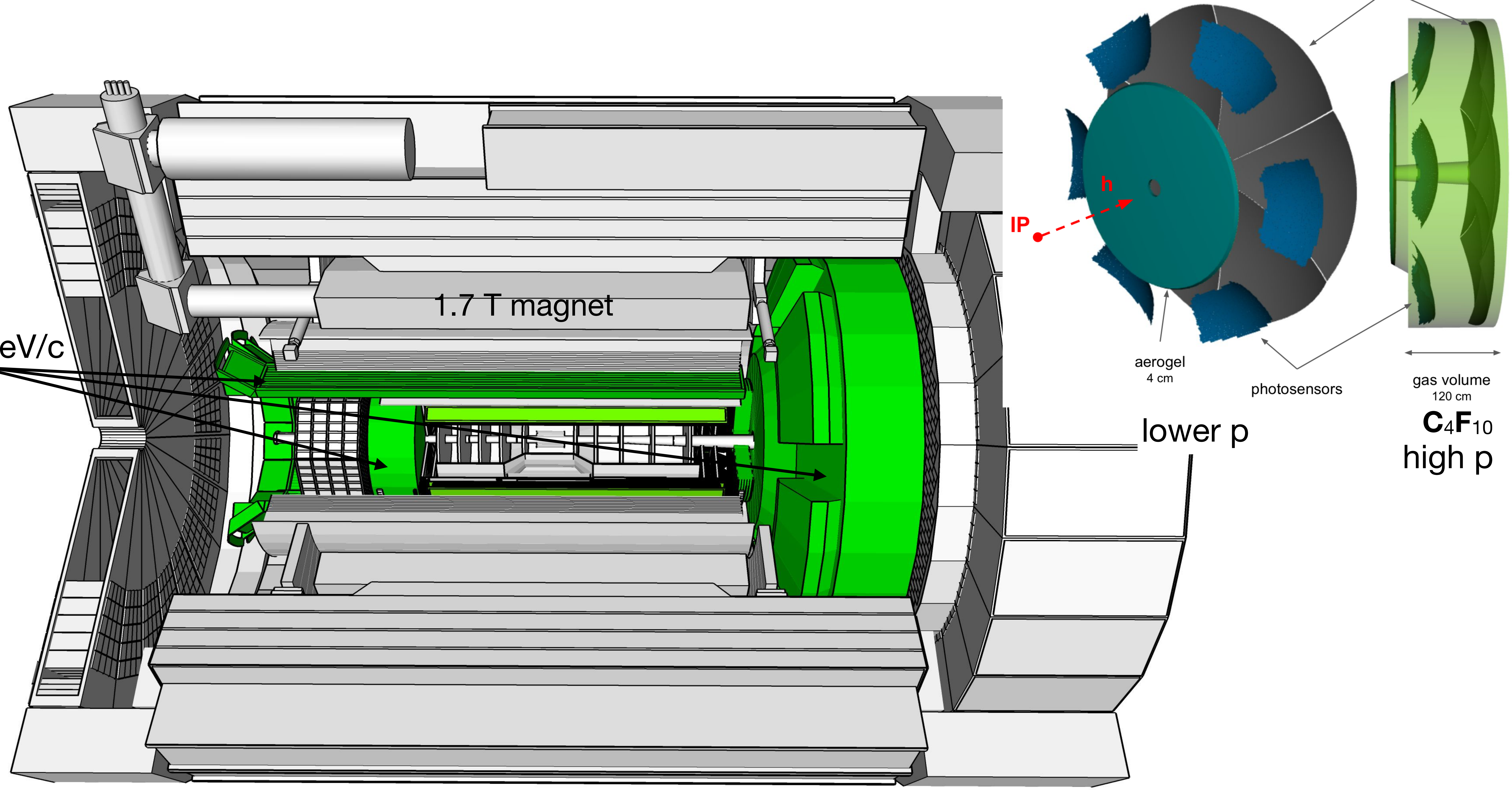

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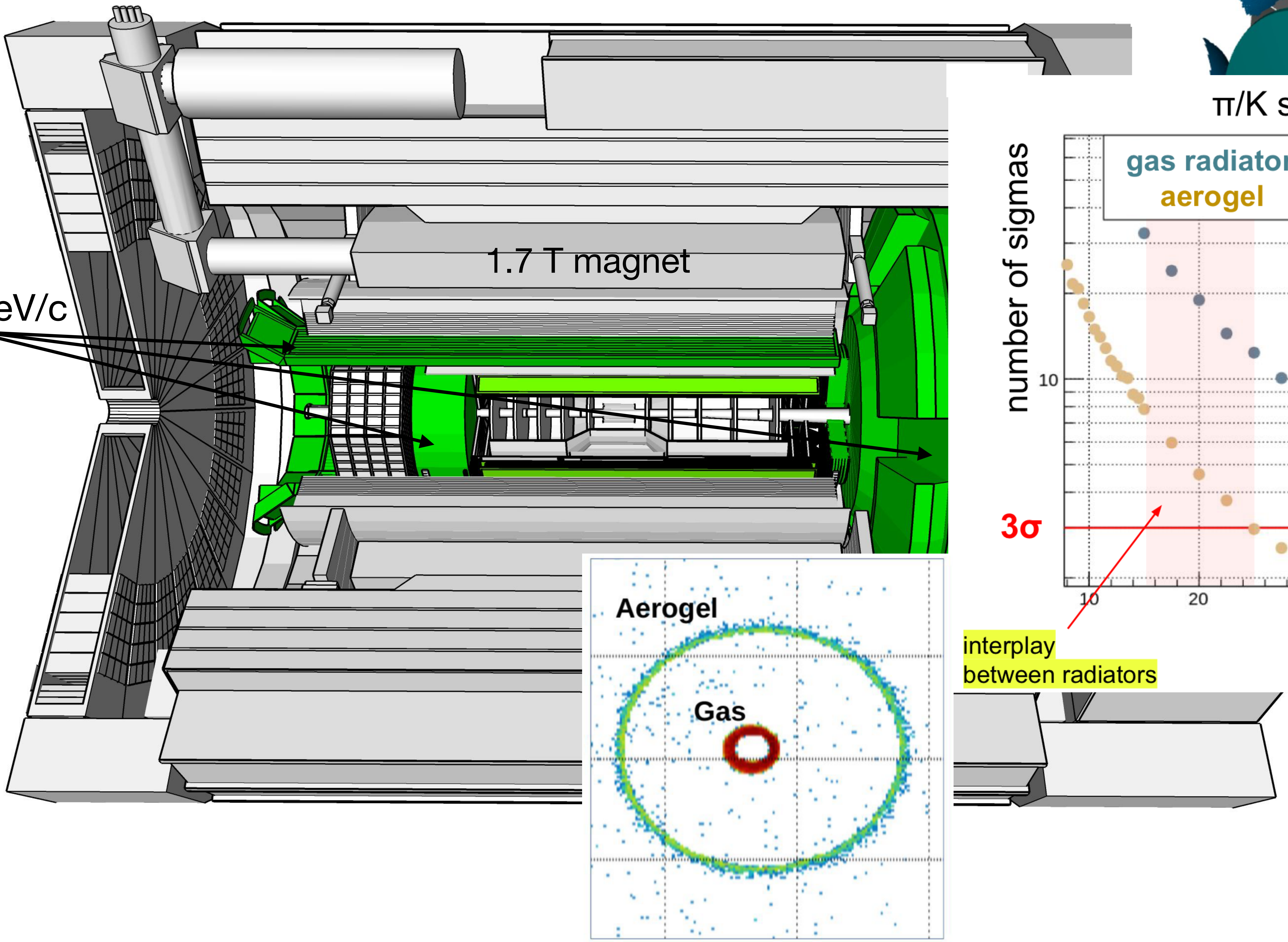
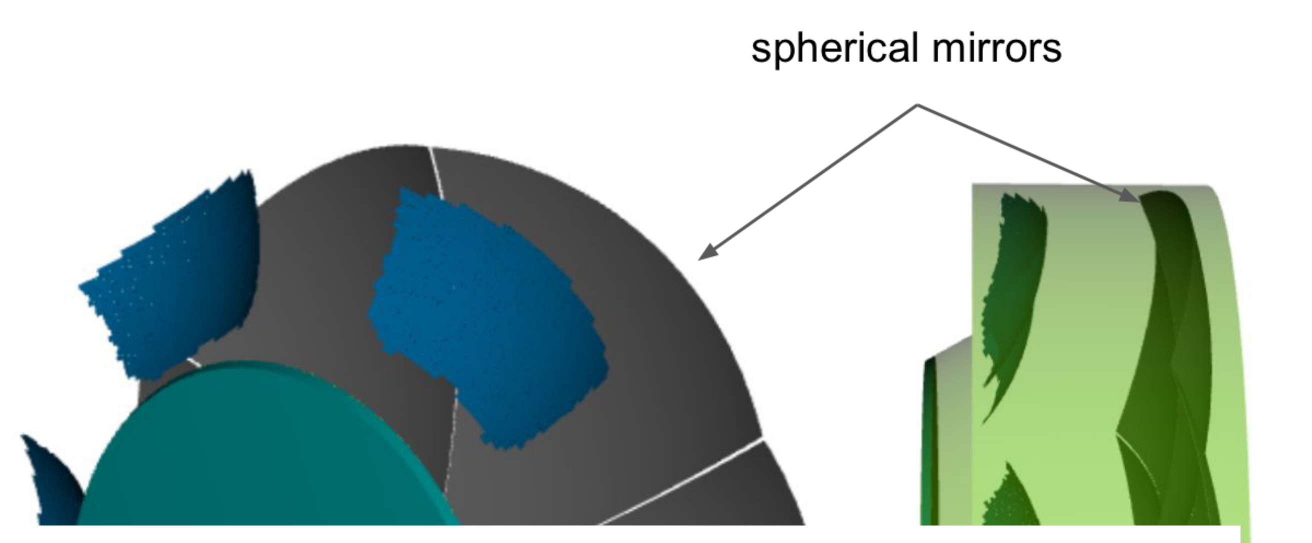
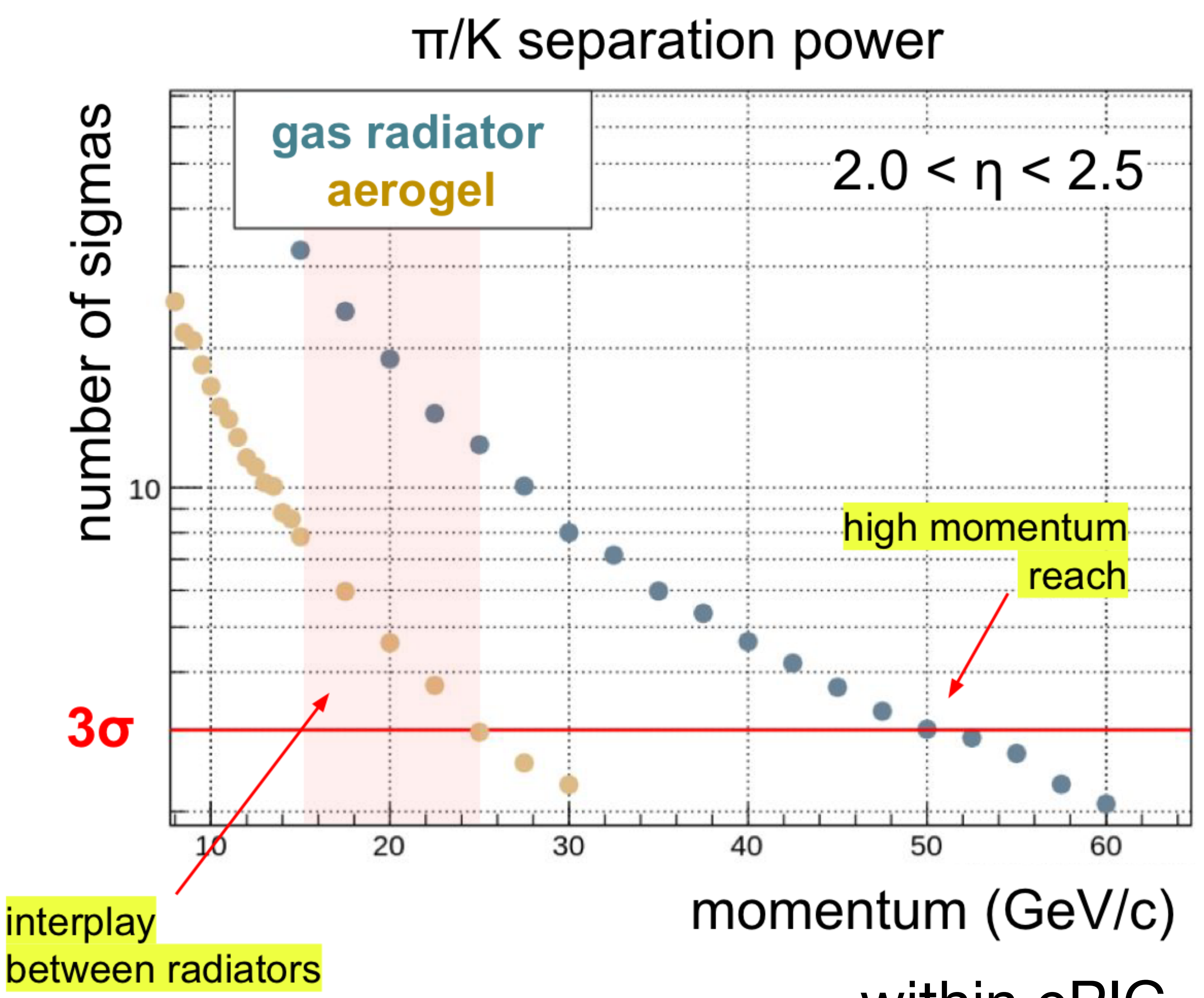




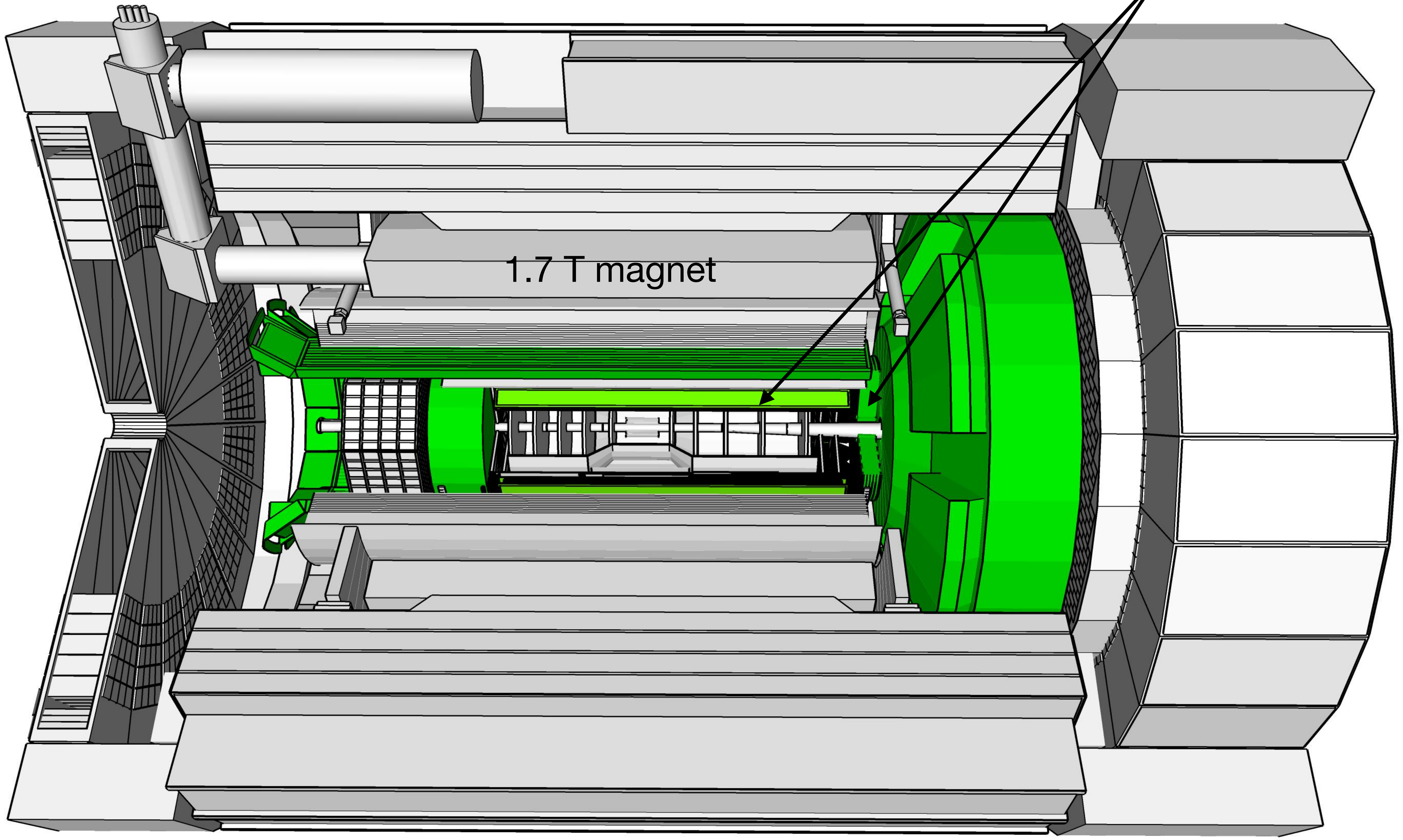


within ePIC simulation framework

Particle identification

AC-LGAD based TOF, for p < 0.5 – 3 GeV/c

$$v = \frac{L}{t_{stop} - t_{start}}$$



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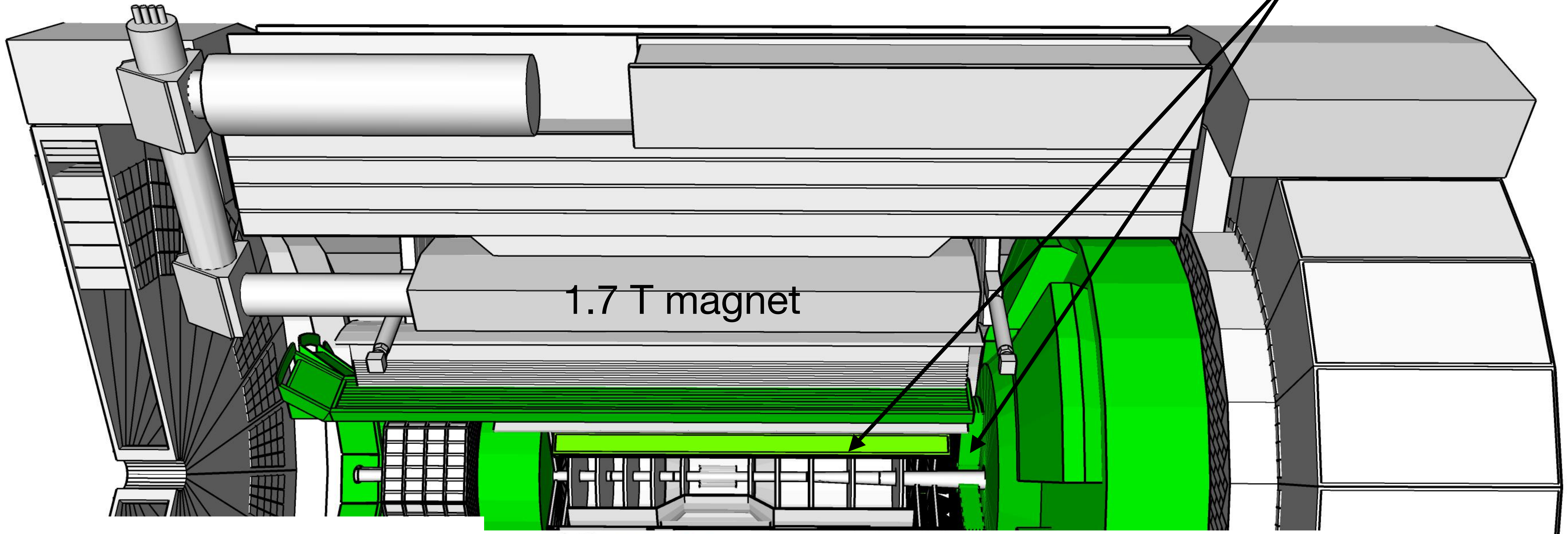
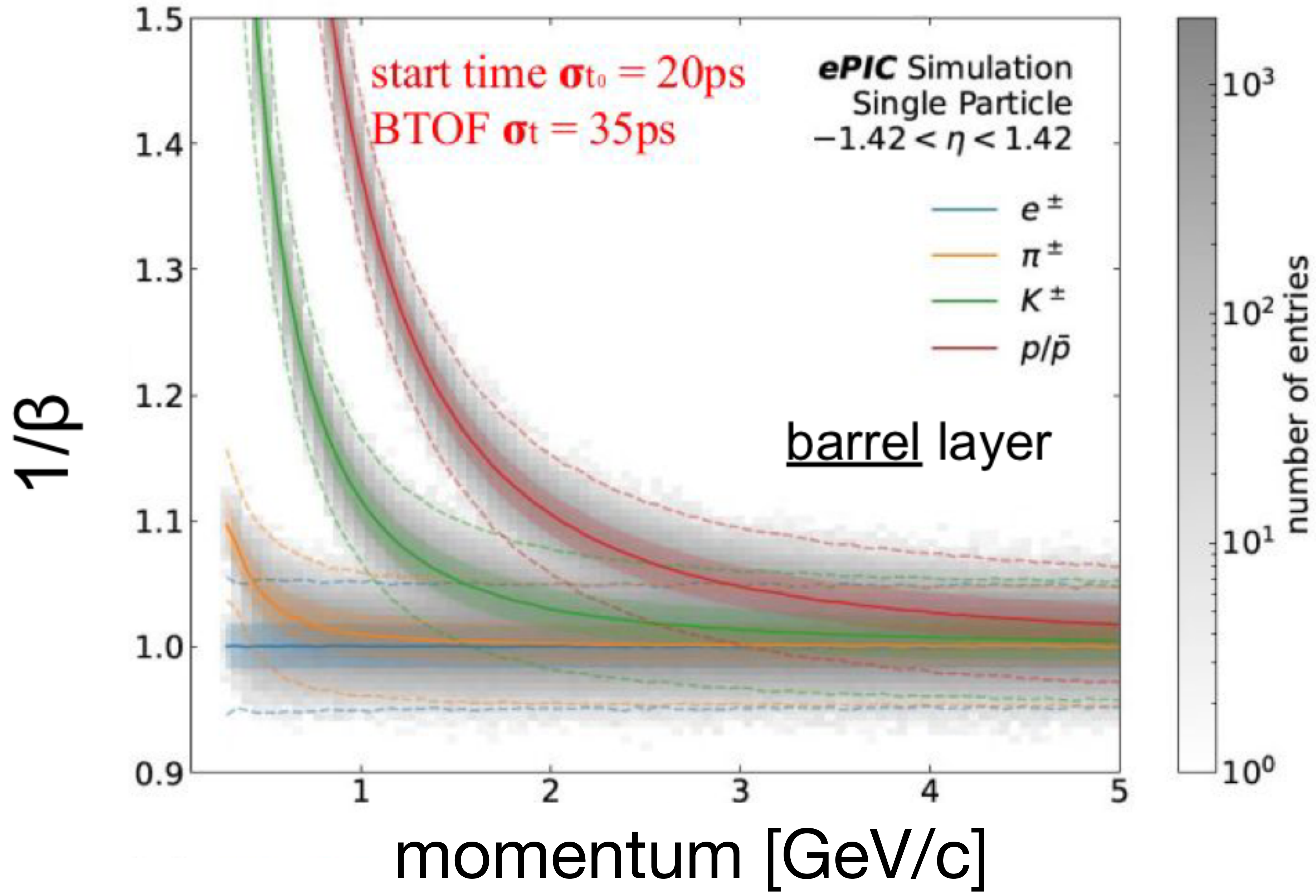
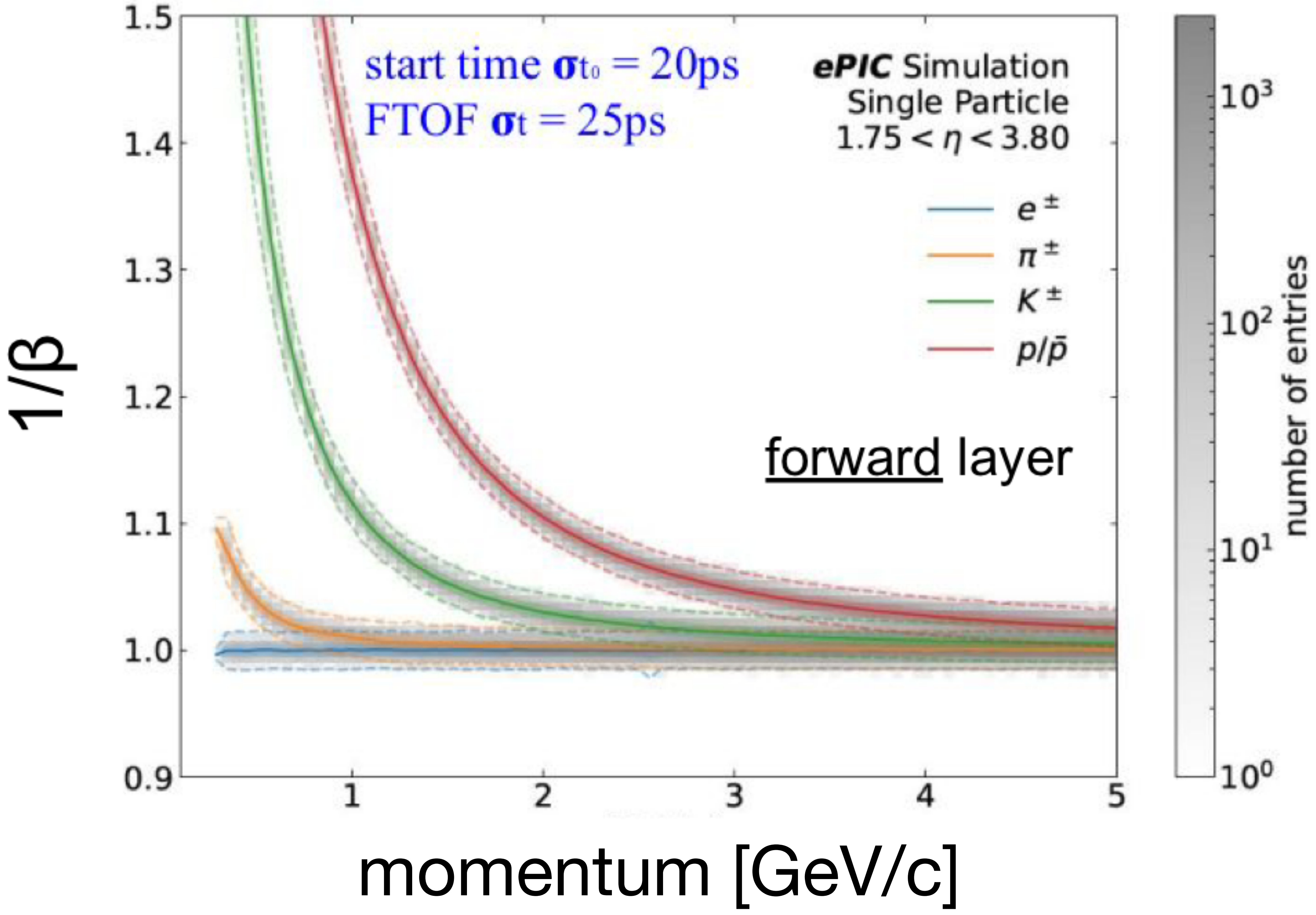
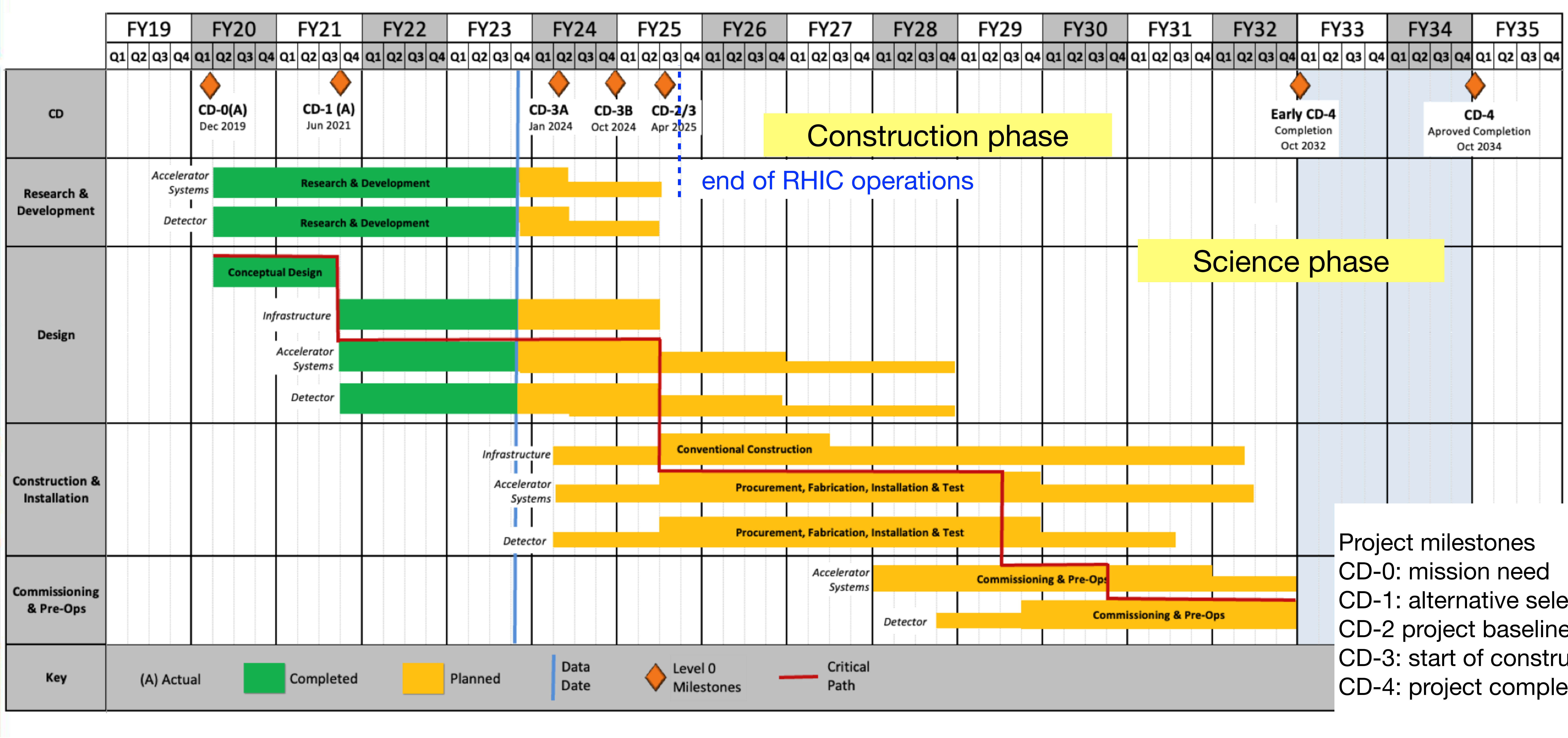






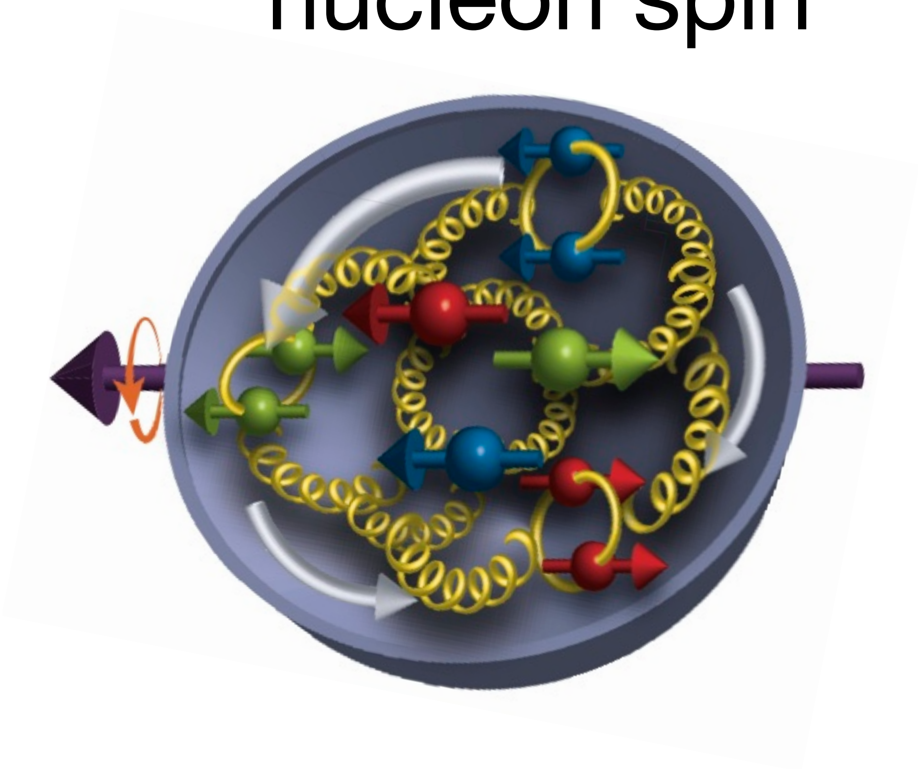
Timeline



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

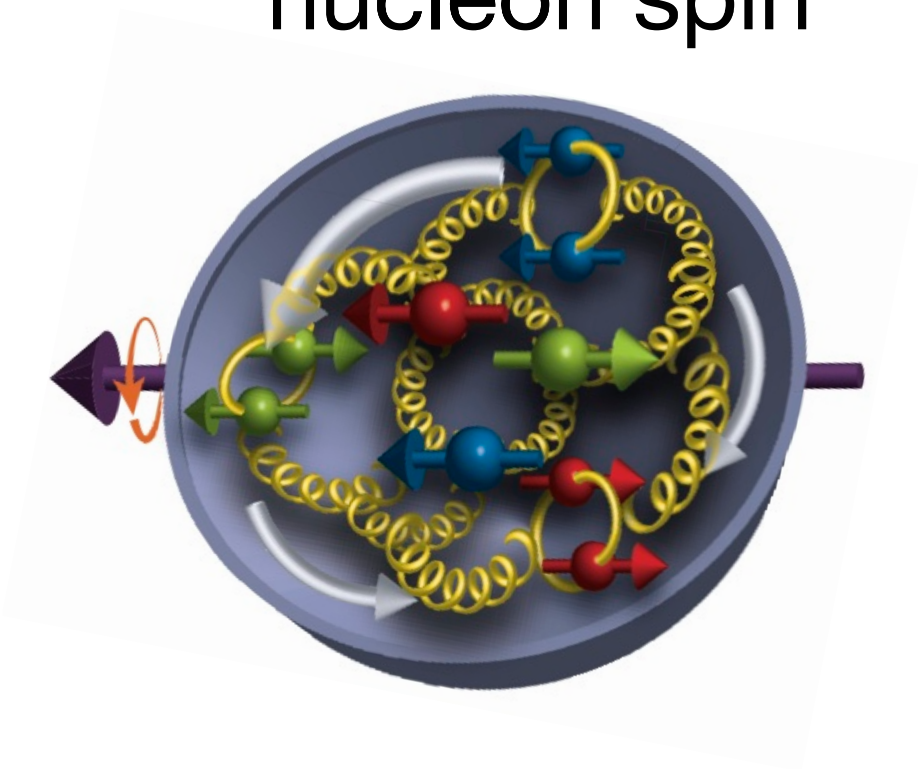
Why an electron-ion collider

nucleon spin

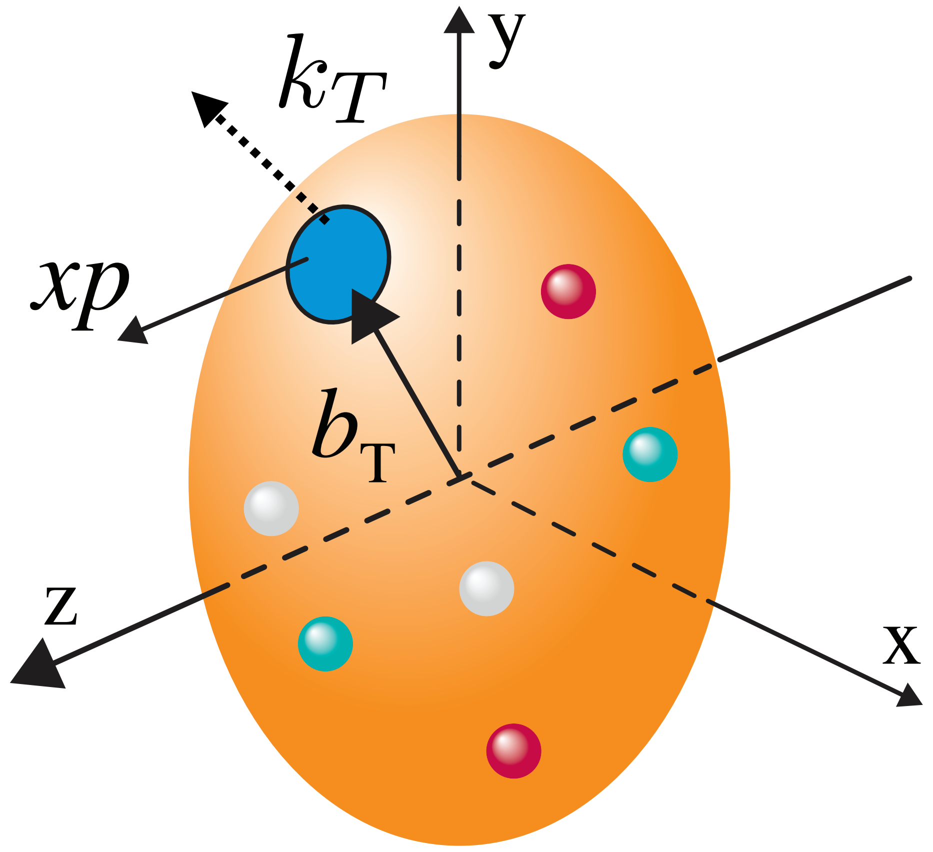


Why an electron-ion collider

nucleon spin



spin-dependent nucleon multi-dimensional structure



Why an electron-ion collider

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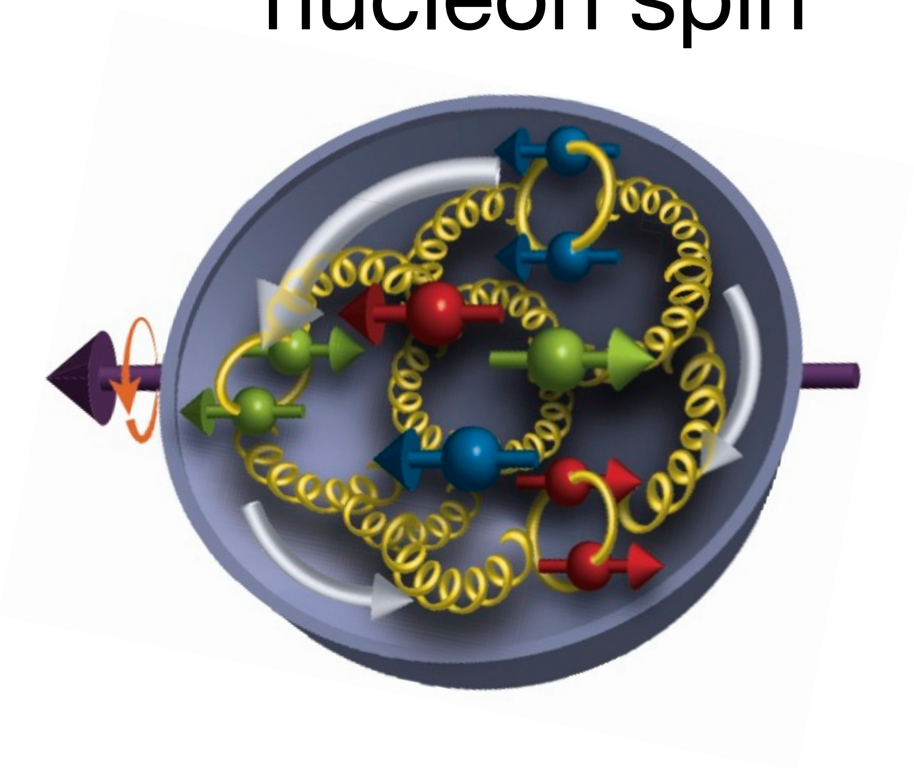
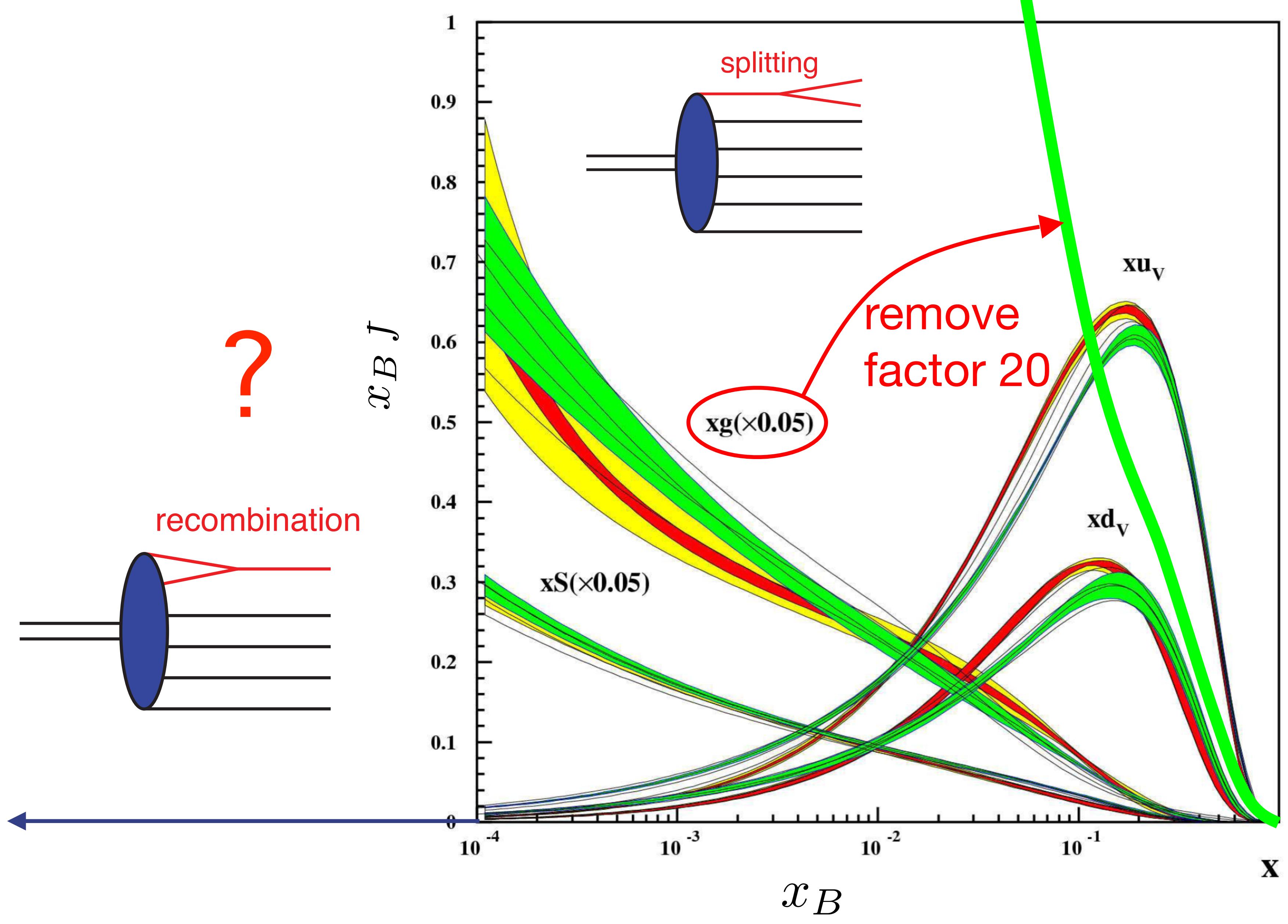


probing saturation



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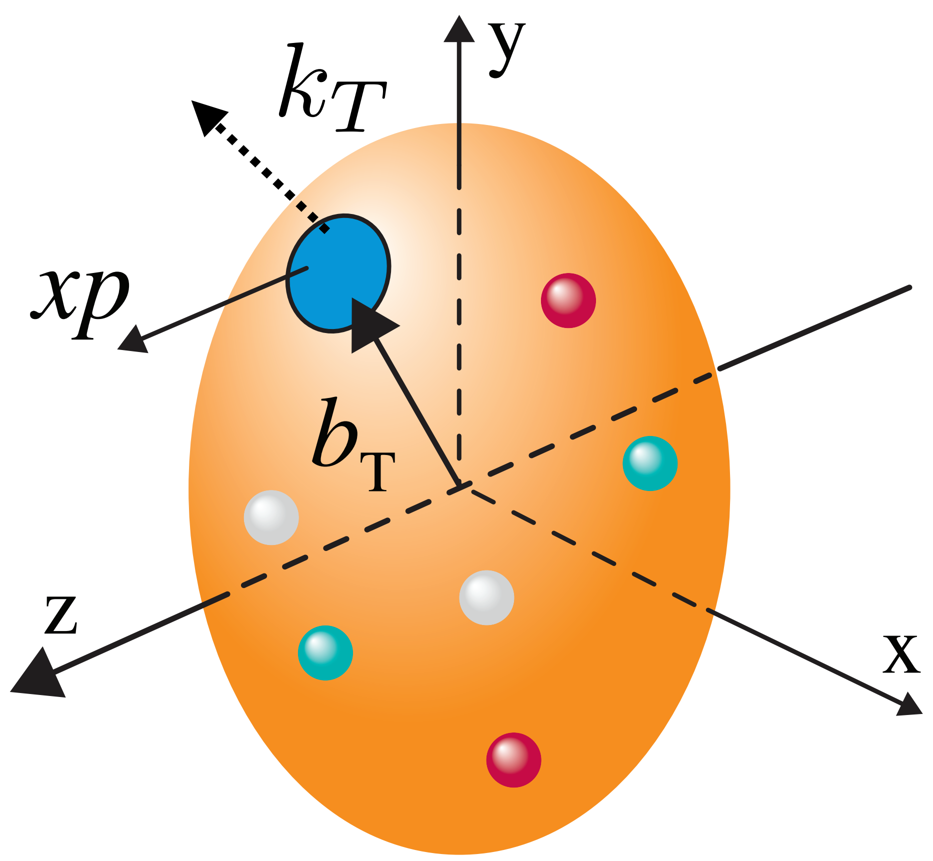
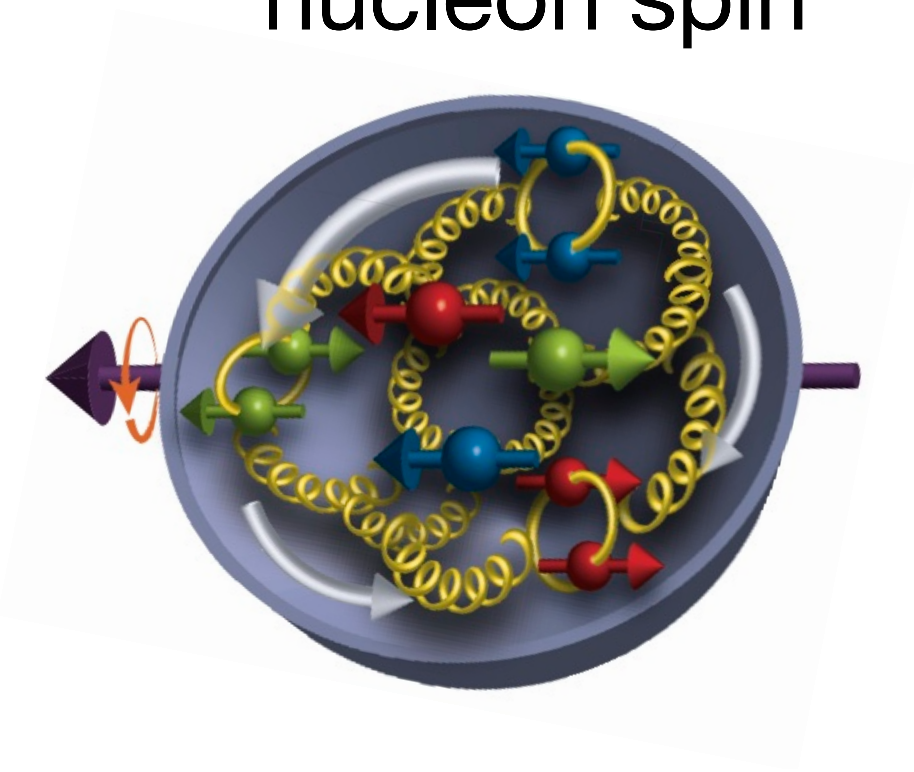
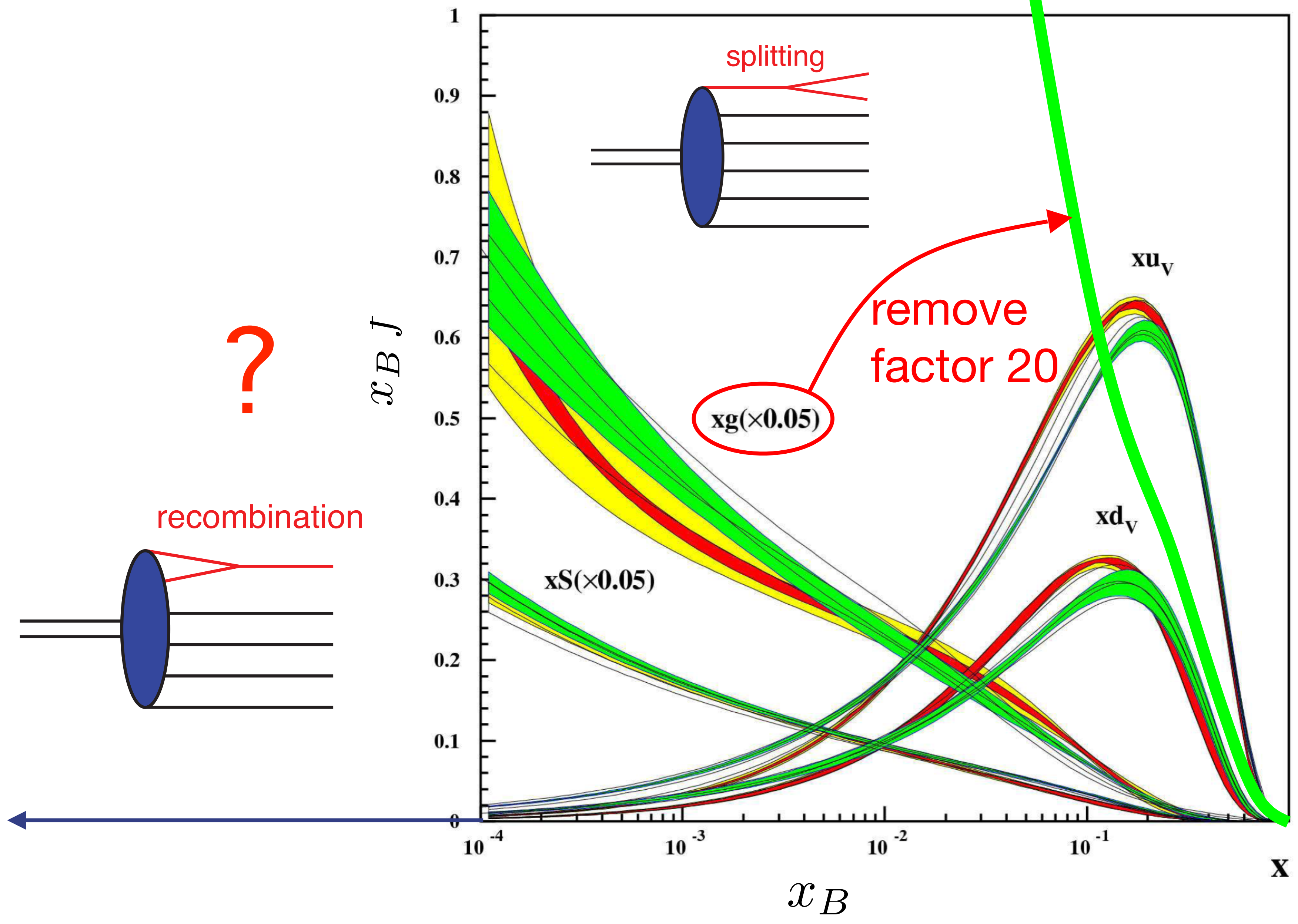


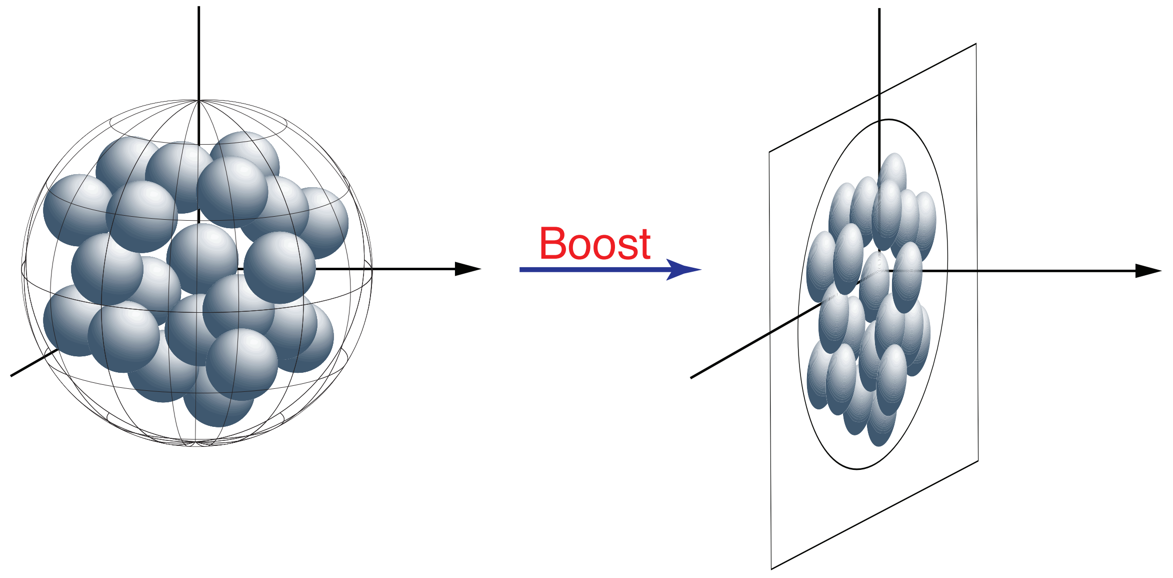
Why an electron-ion collider

nucleon spin



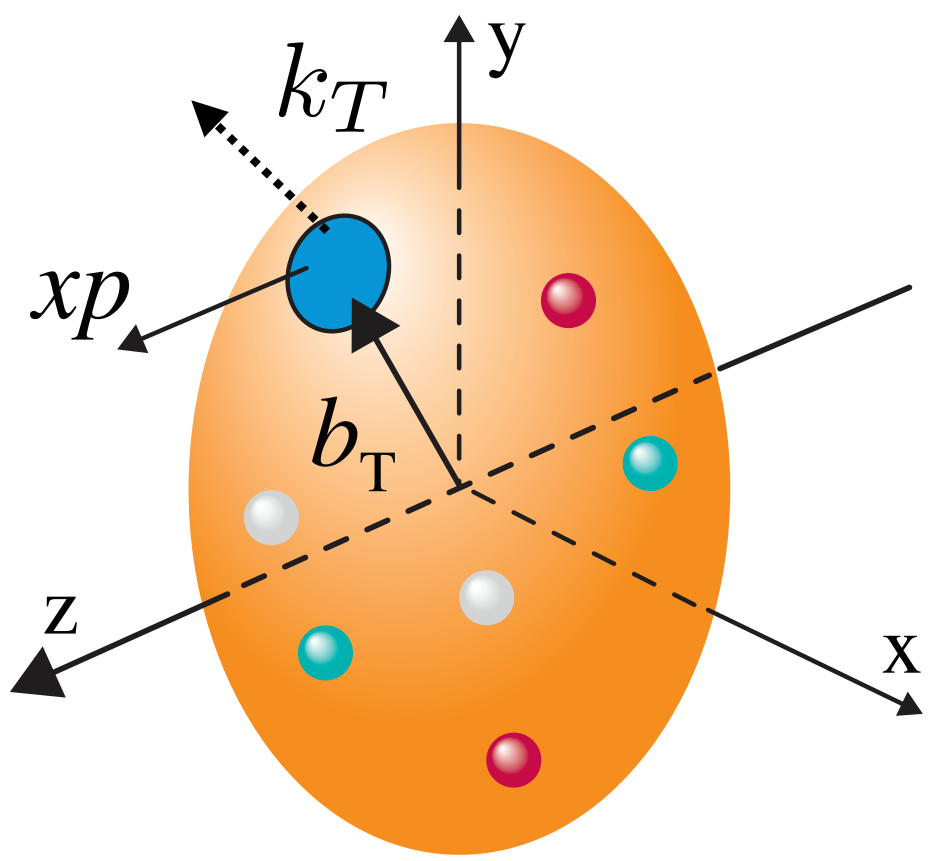
probing saturation





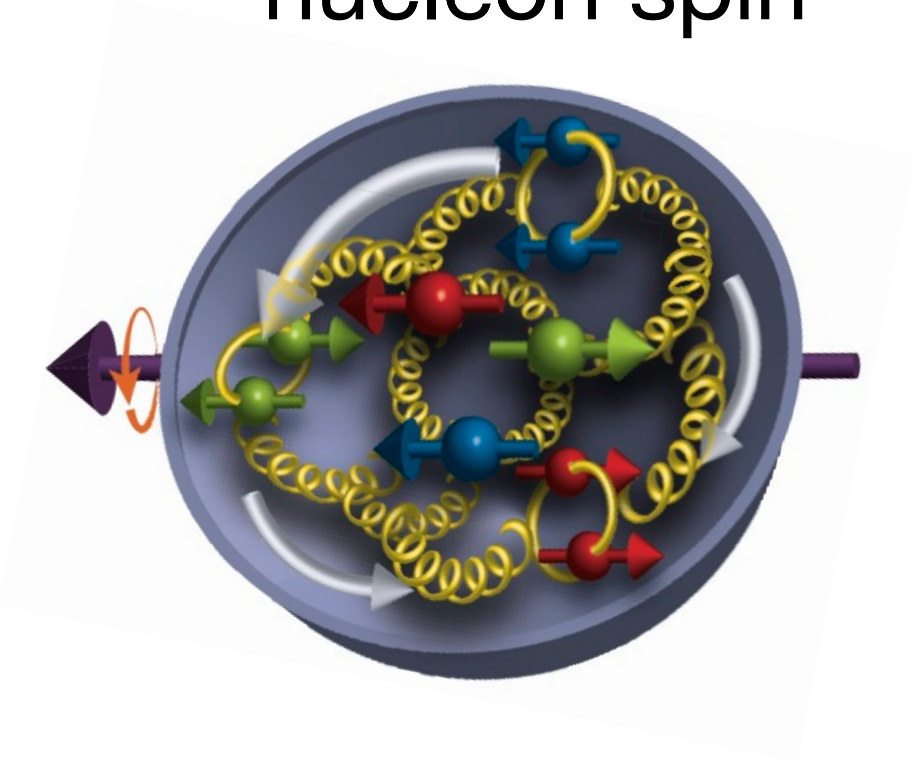
$A^{1/3}$ enhancement
of saturation effect for ions

spin-dependent nucleon multi-dimensional structure

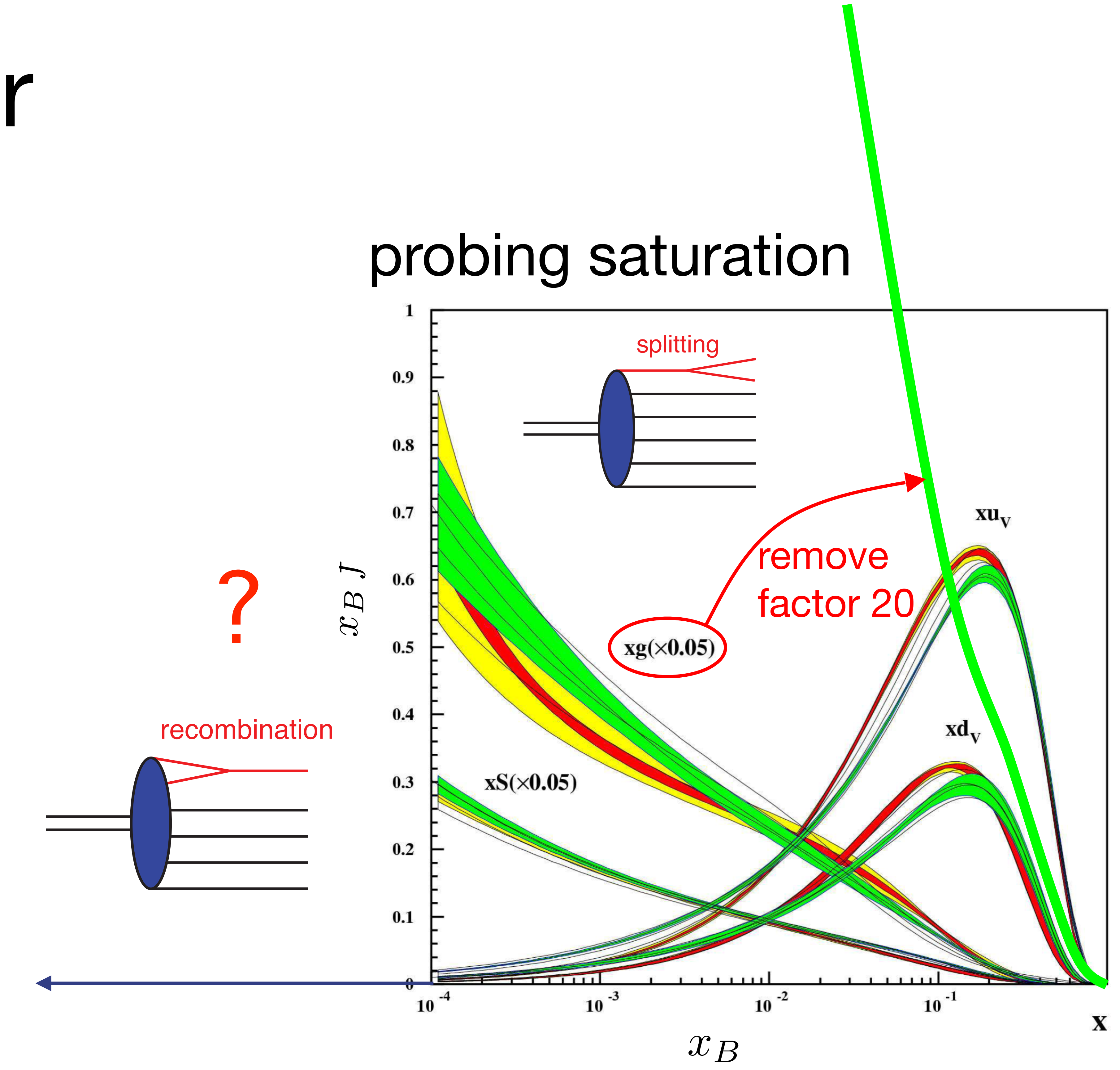


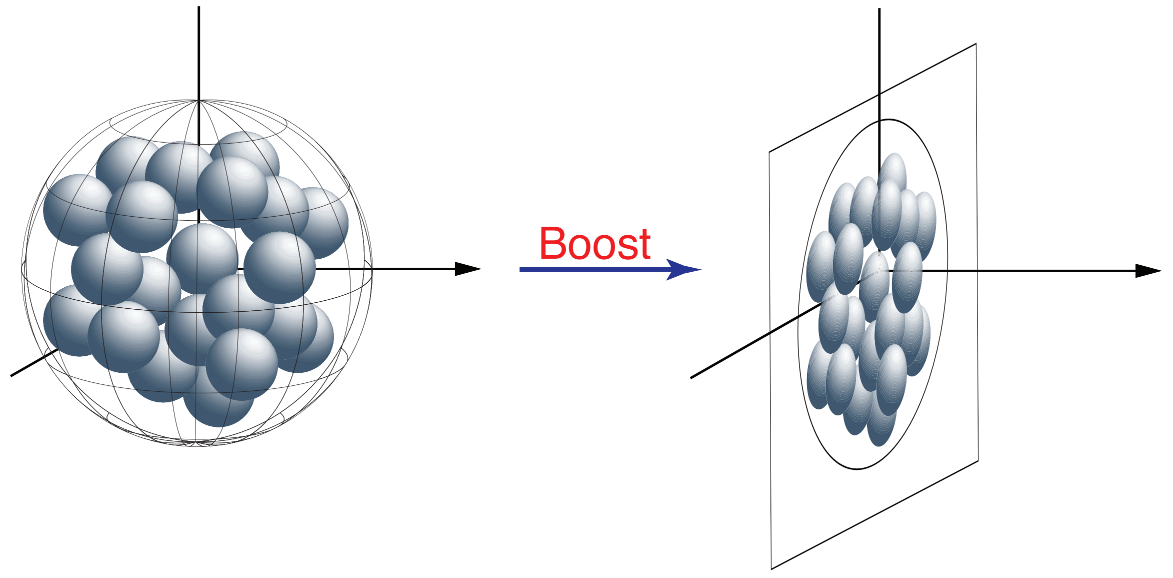
Why an electron-ion collider

nucleon spin



probing saturation





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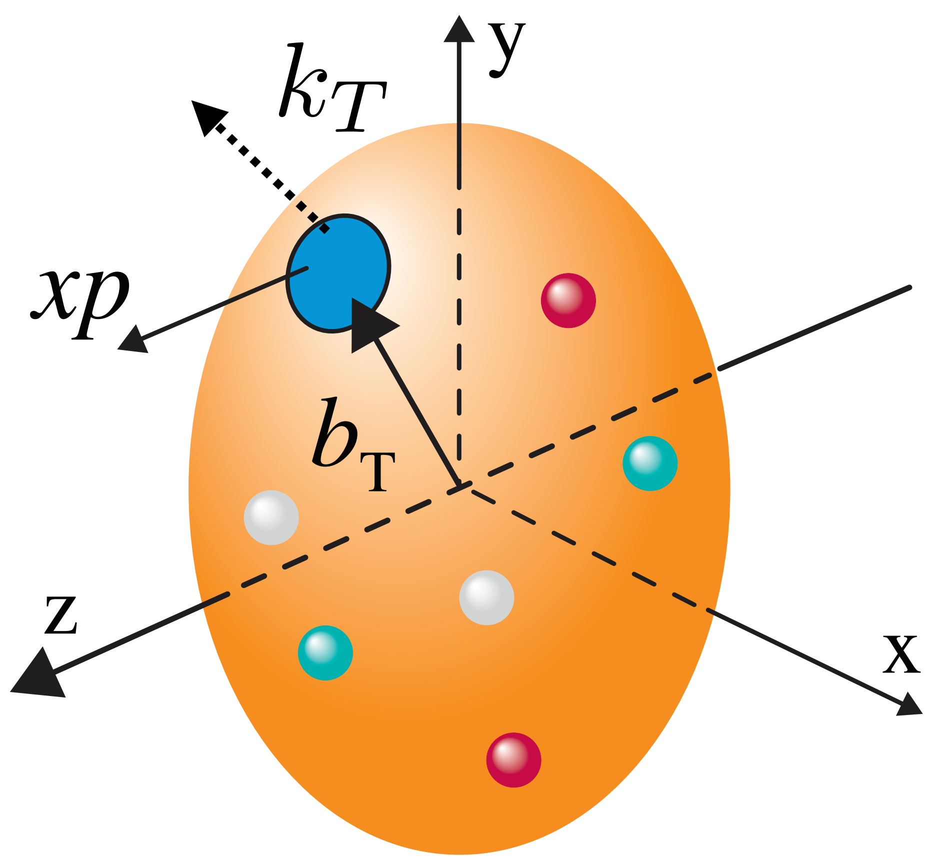
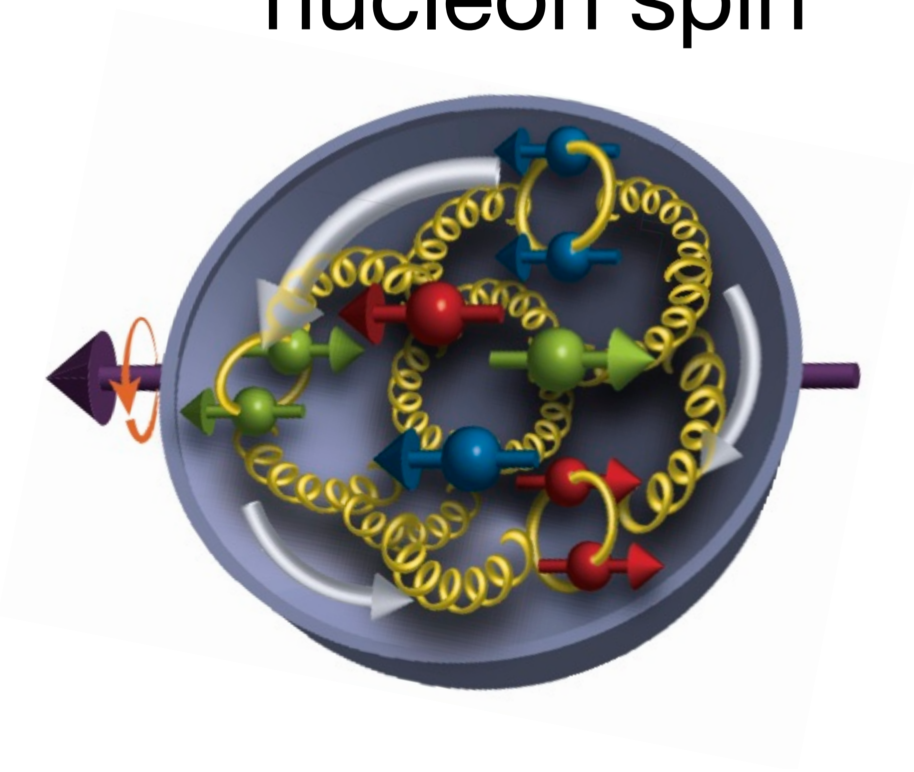


hadronisation

Why an electron-ion collider

nucleon spin



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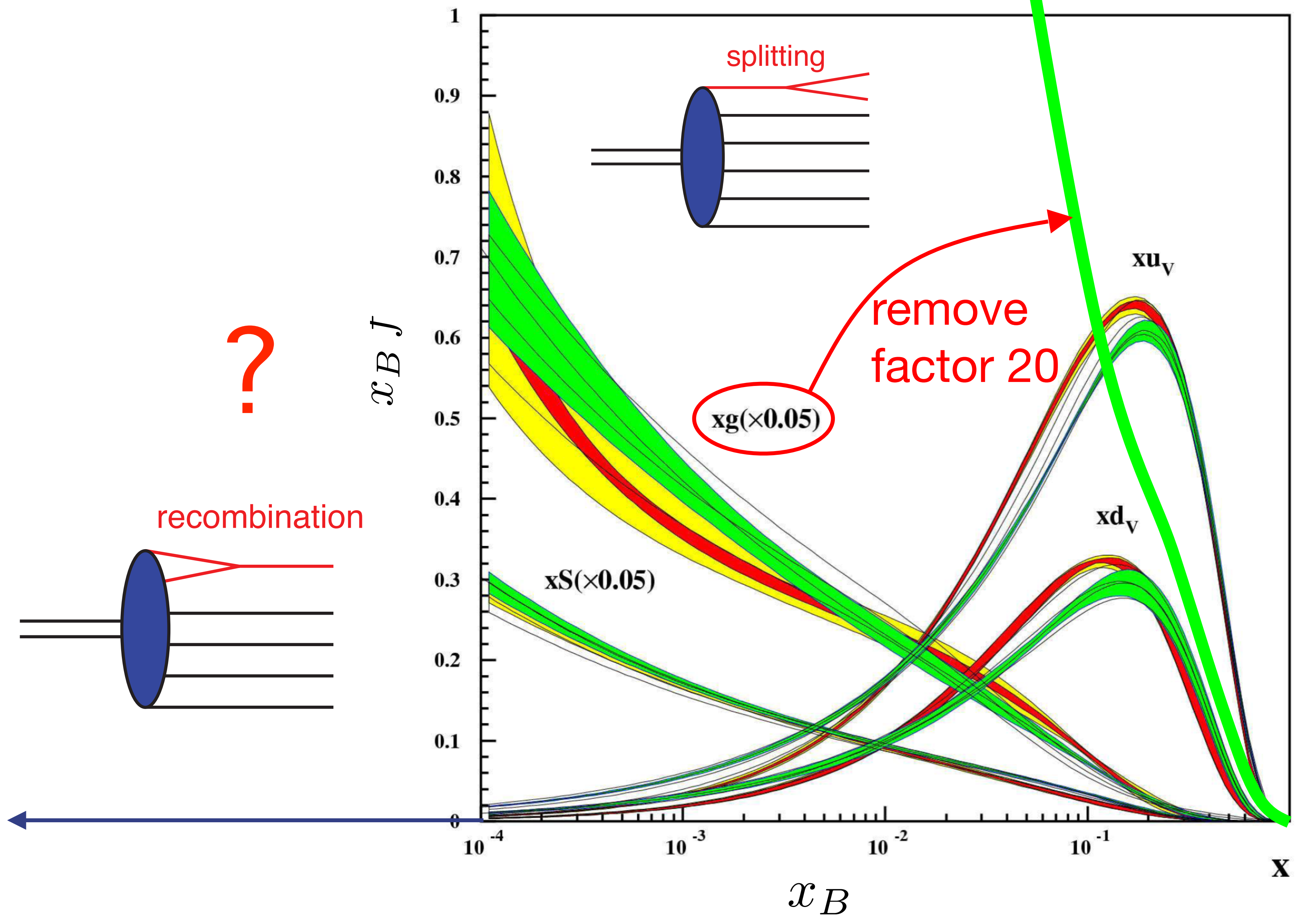

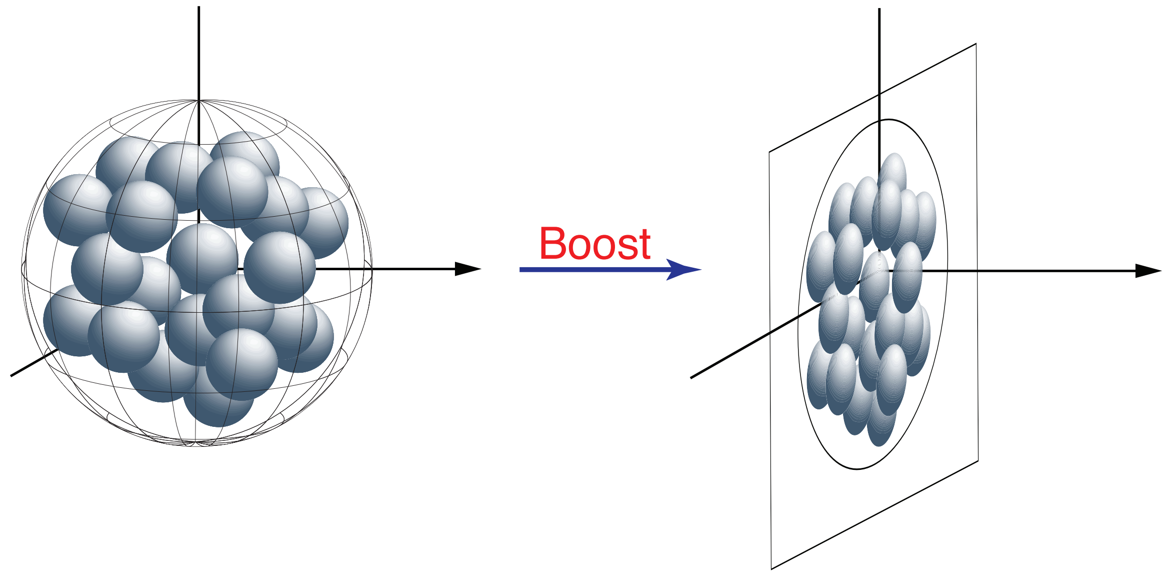

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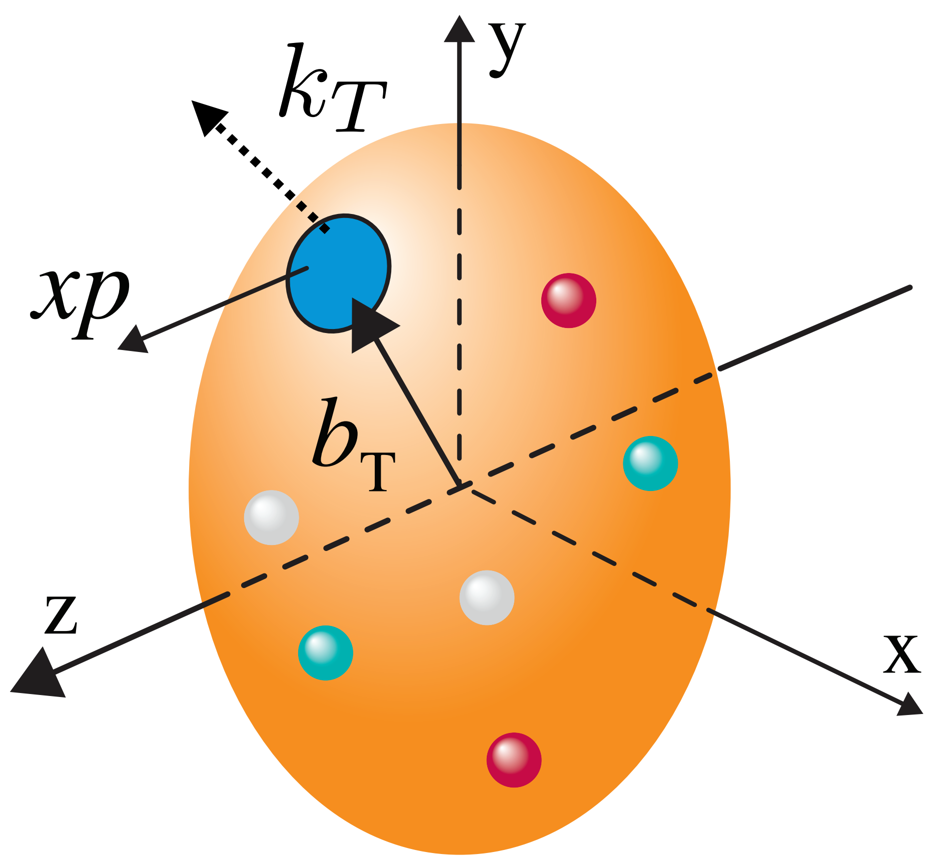
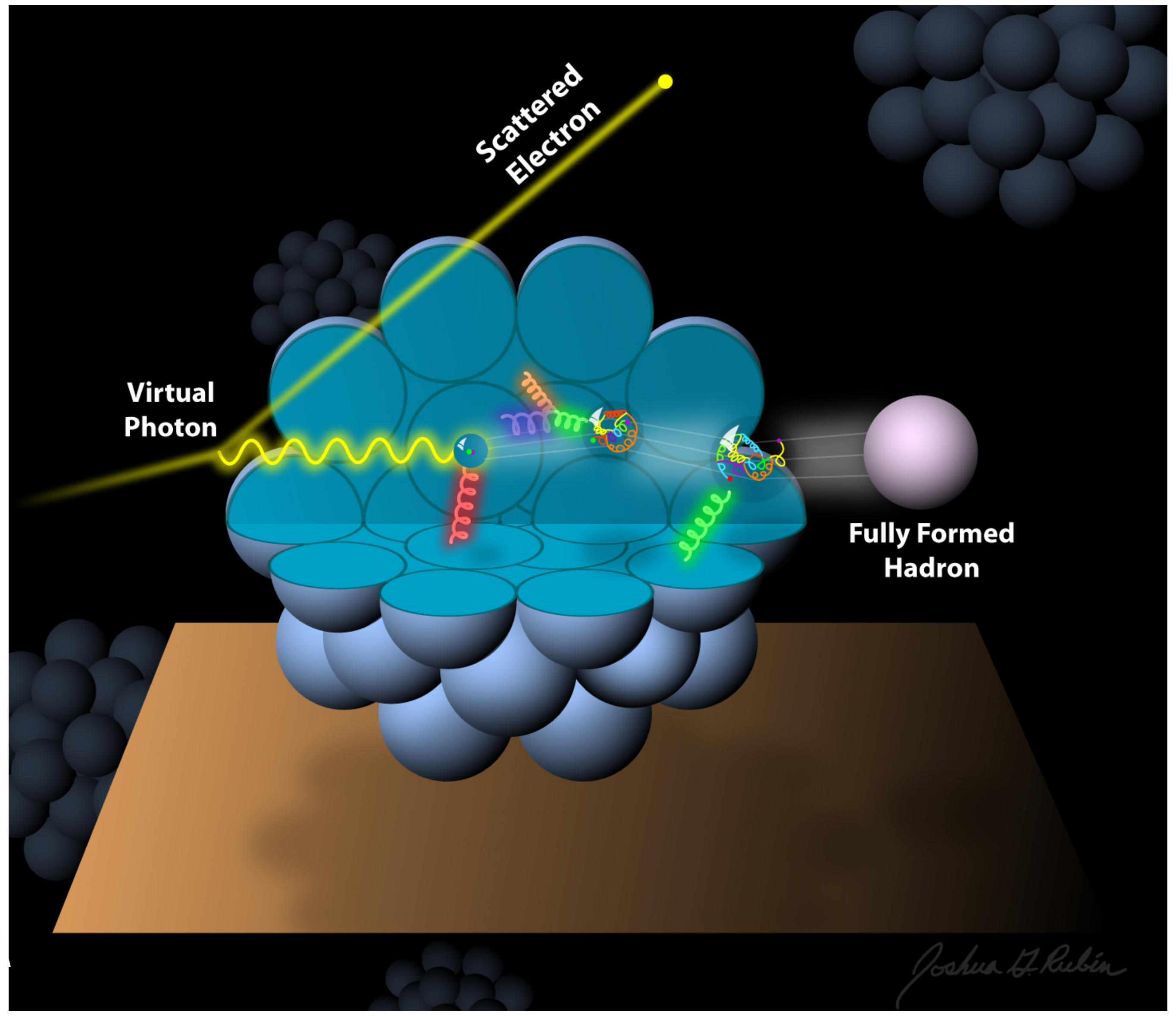
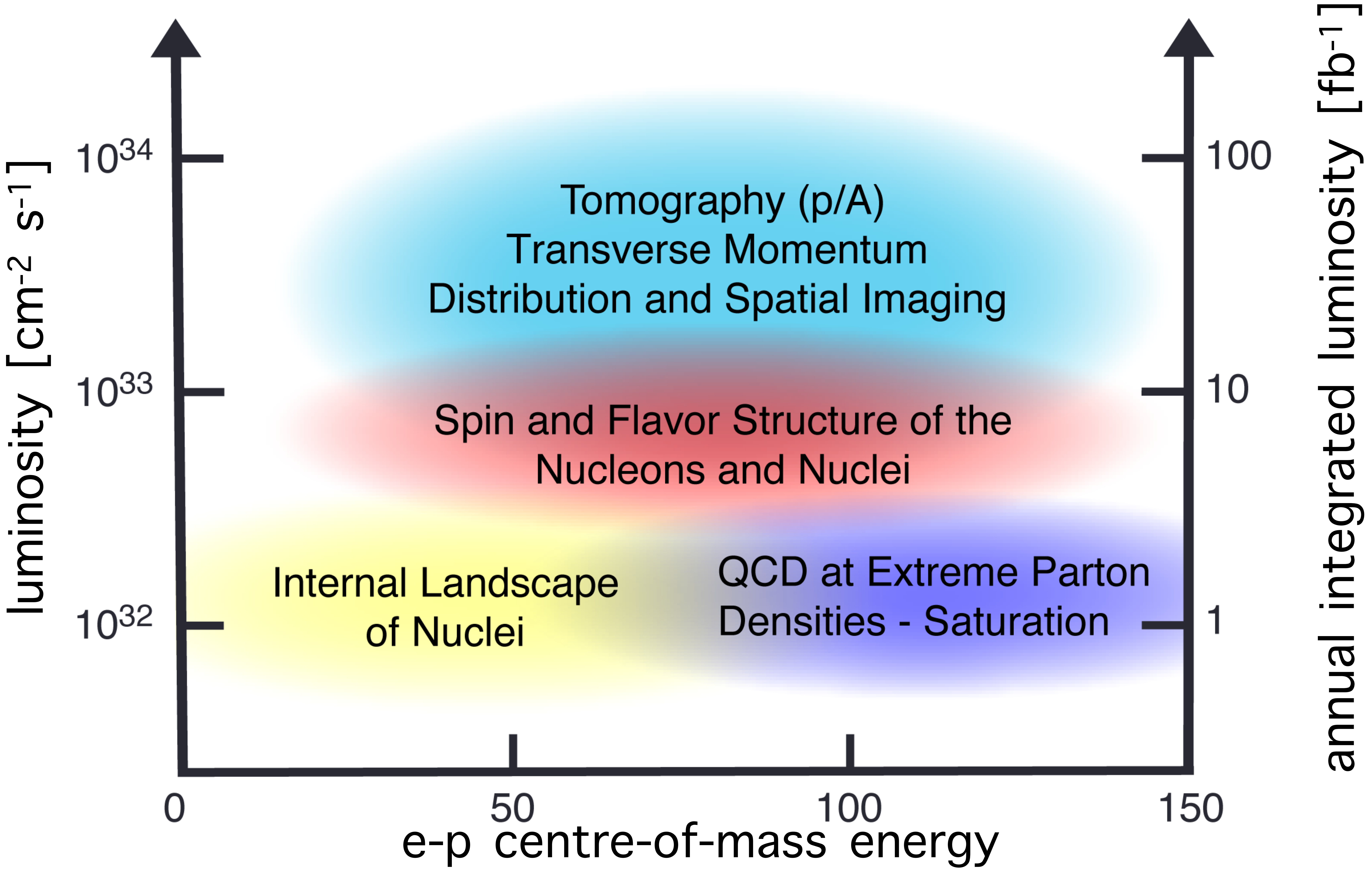


hadronisation

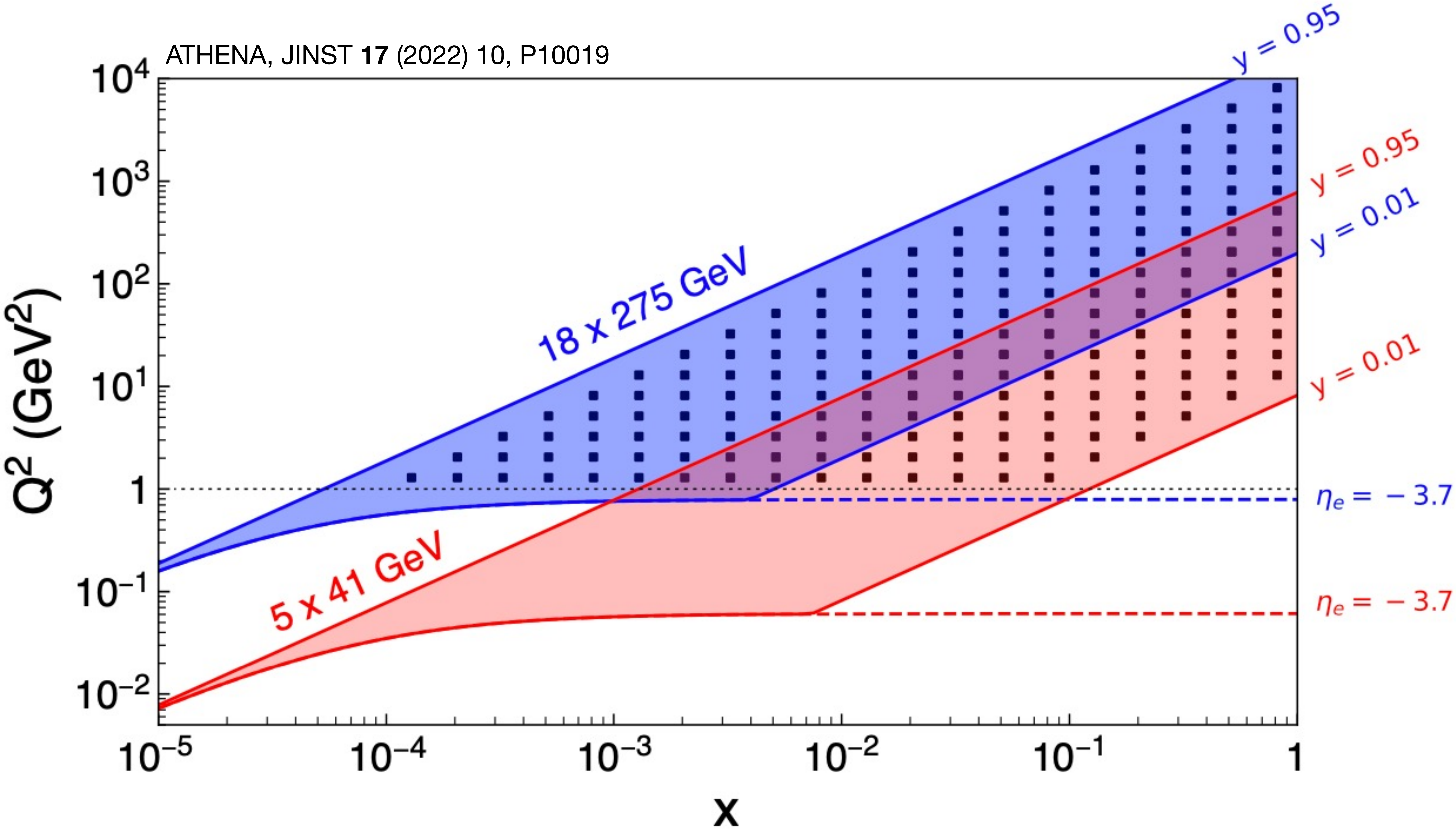


Luminosity and COM E needs for physics topics

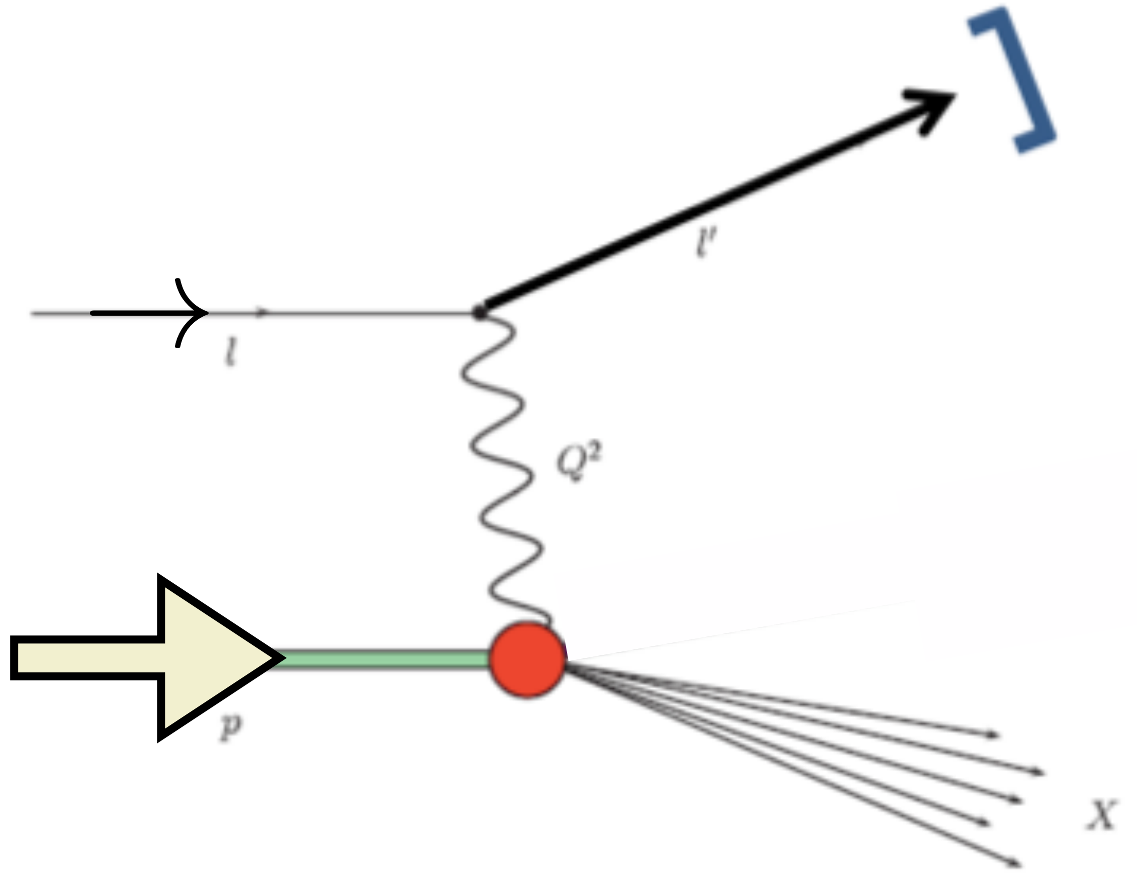


Kinematic coverage at the EIC

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



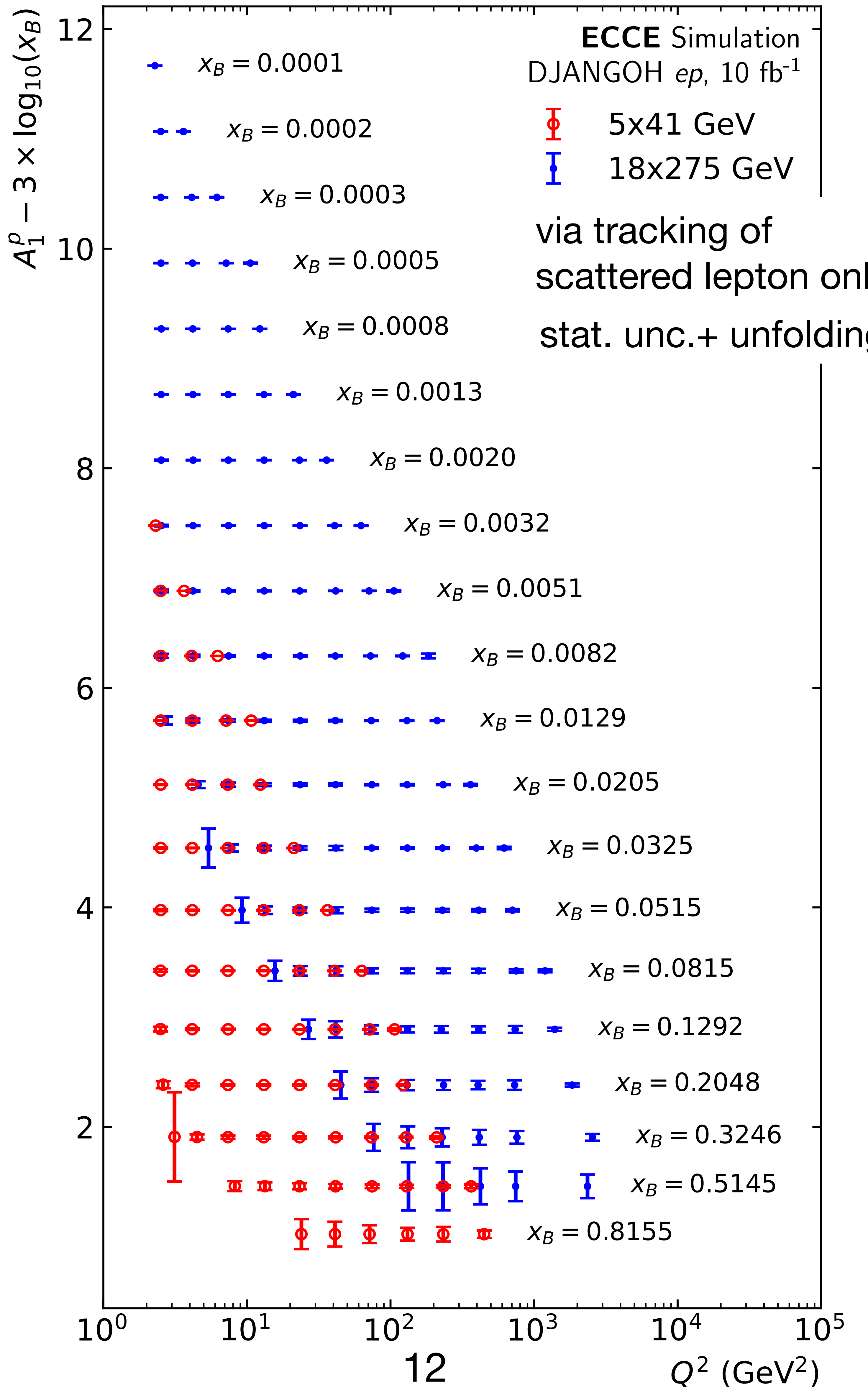
Helicity structure of the nucleon: gluons



Inclusive measurements
→ access to gluon spin

scaling violation from $g_1(x,Q^2)$

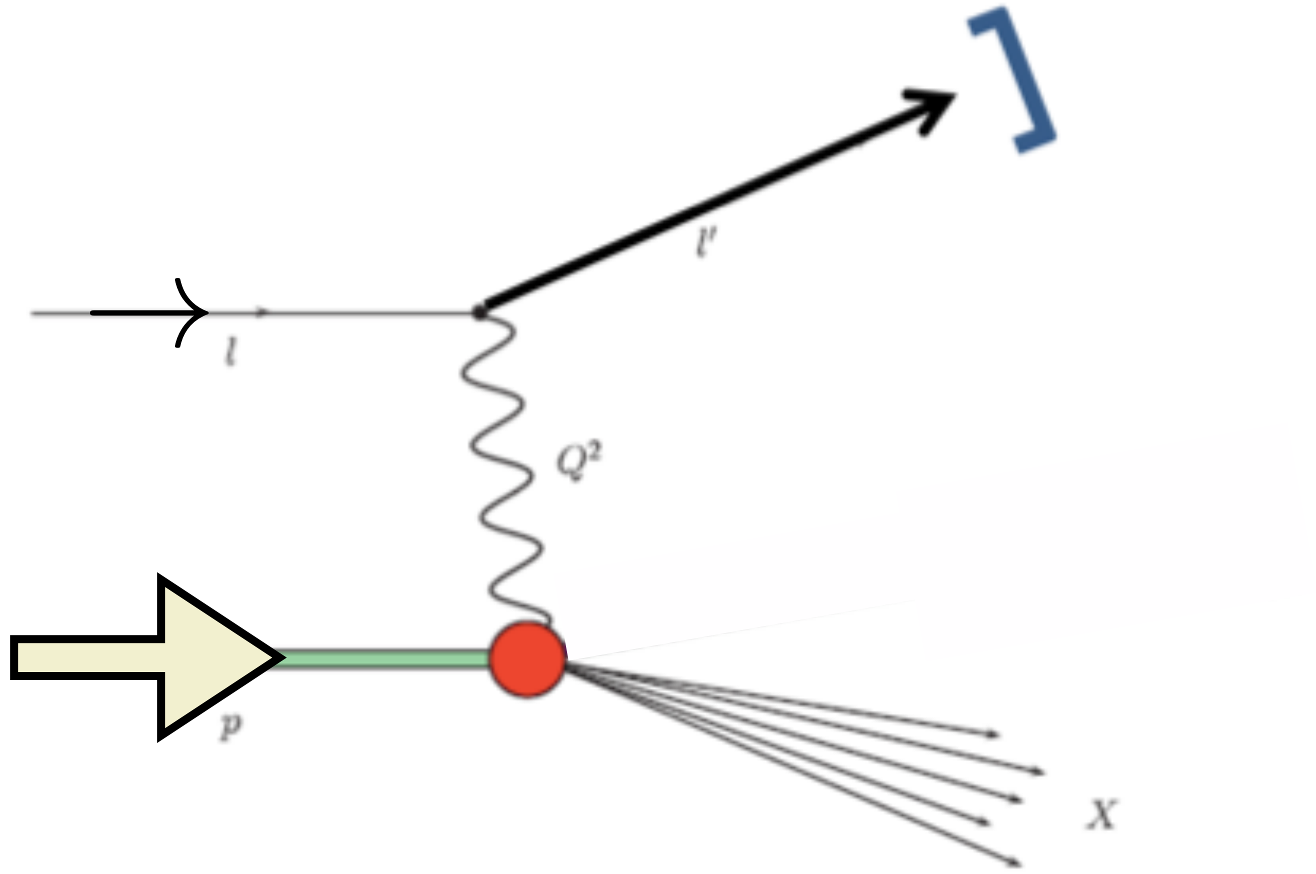
ECCE consortium, 10.5281/zenodo.6537587



via tracking of
scattered lepton only

stat. unc.+ unfolding

Helicity structure of the nucleon: gluons



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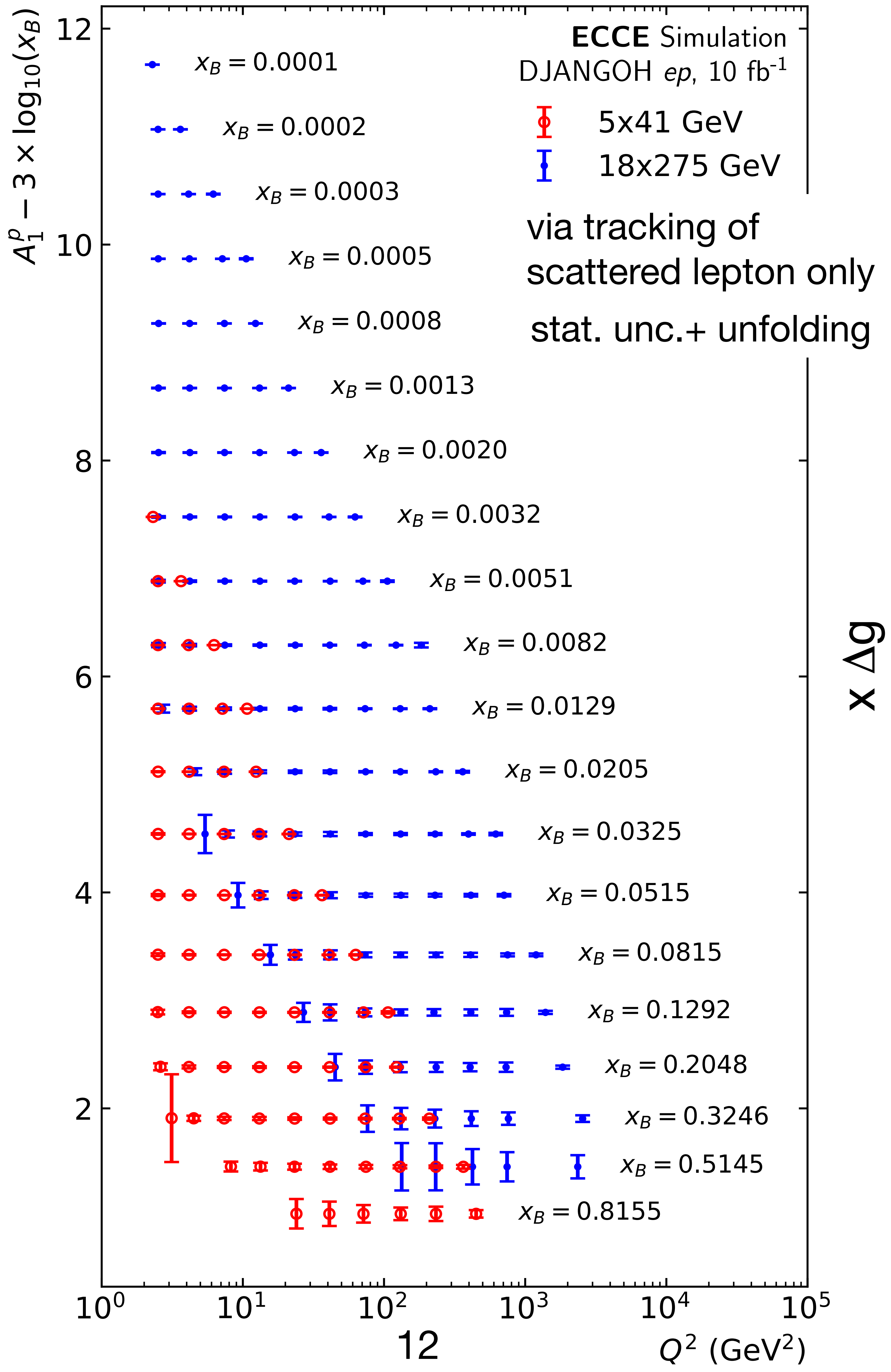
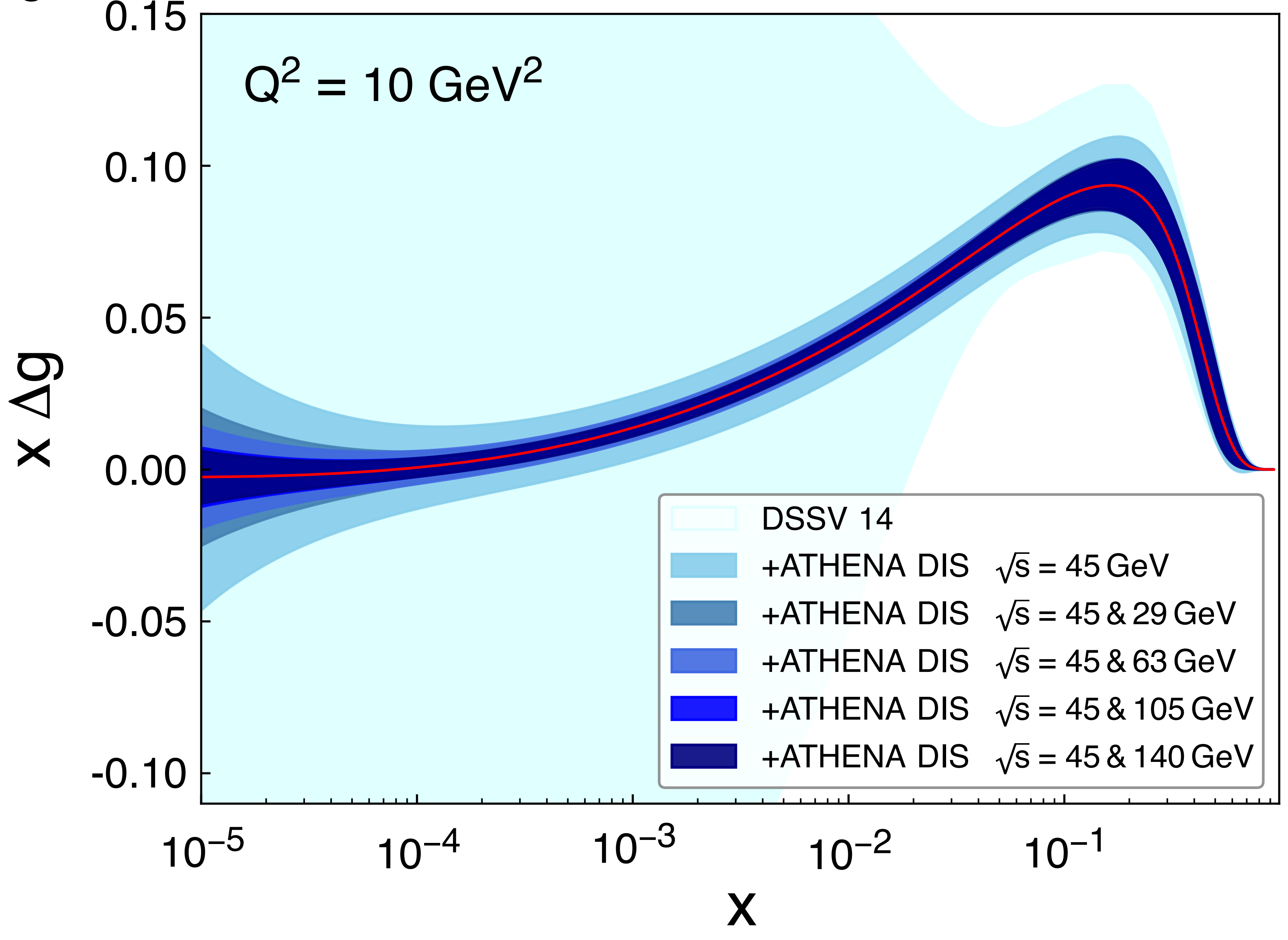
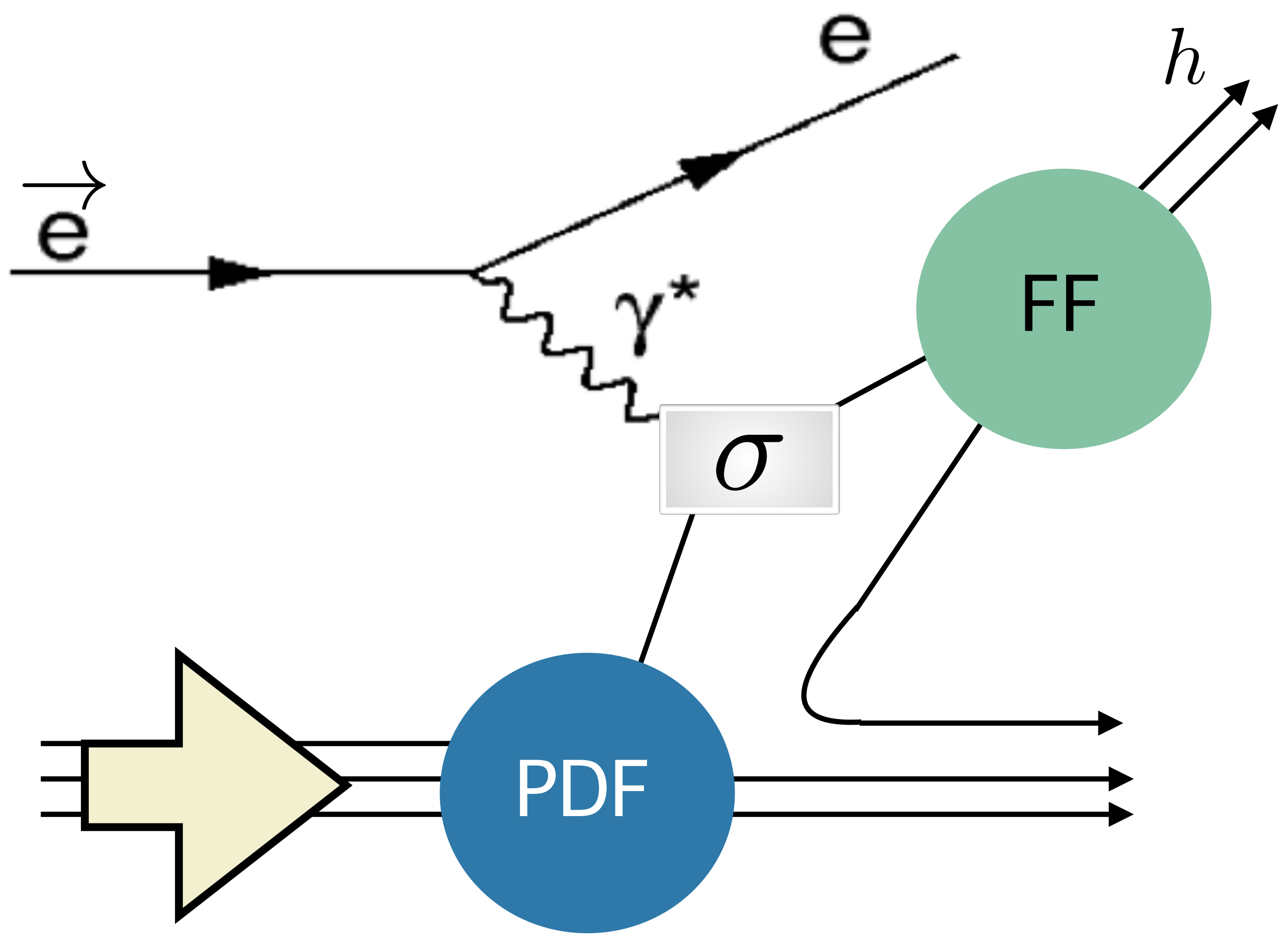


ATHENA, JINST **17** (2022) 10, P10019

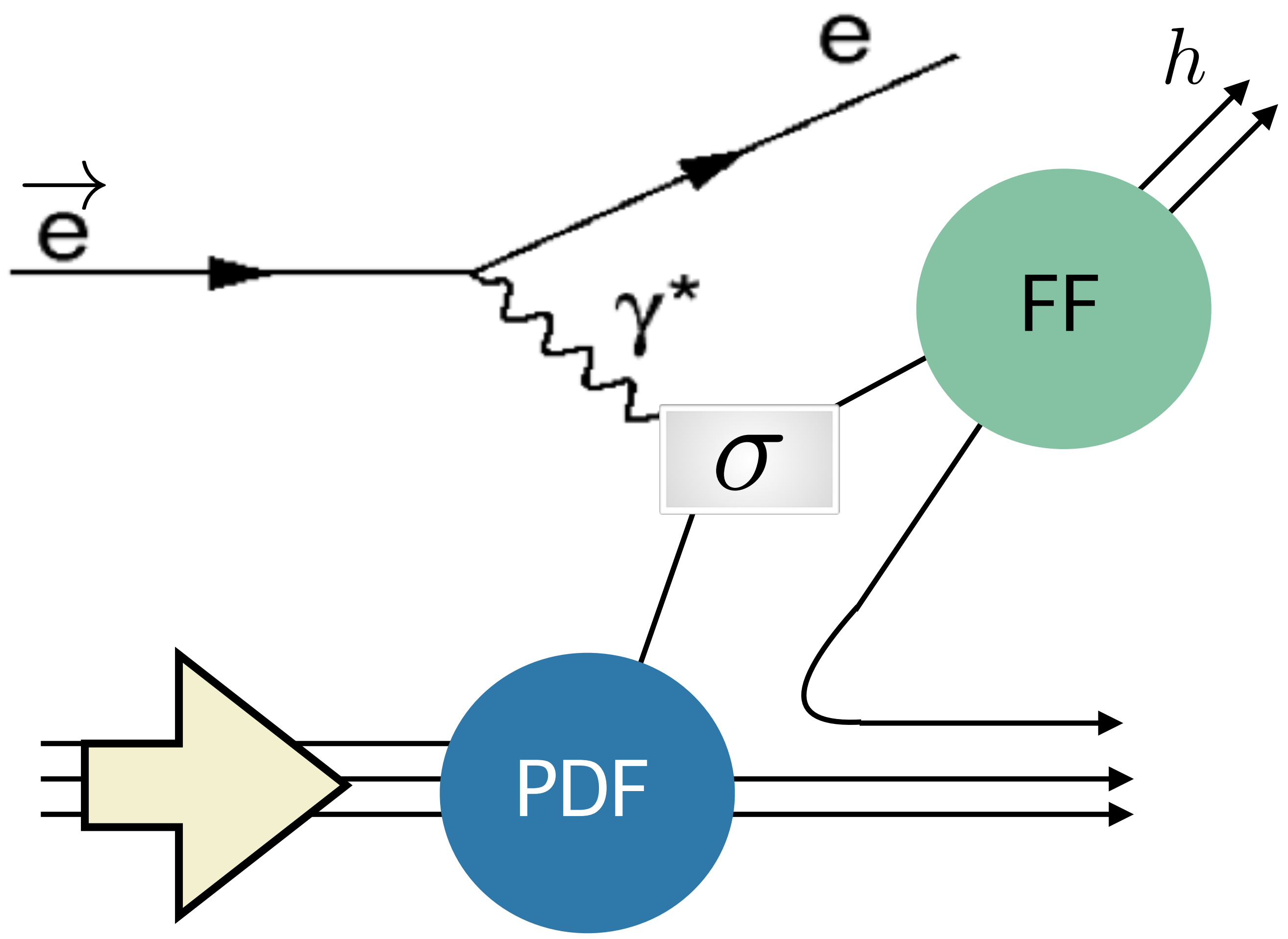


Helicity structure of the proton: sea quarks



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

Helicity structure of the proton: sea quarks



Semi-inclusive measurements, via good hadron PID
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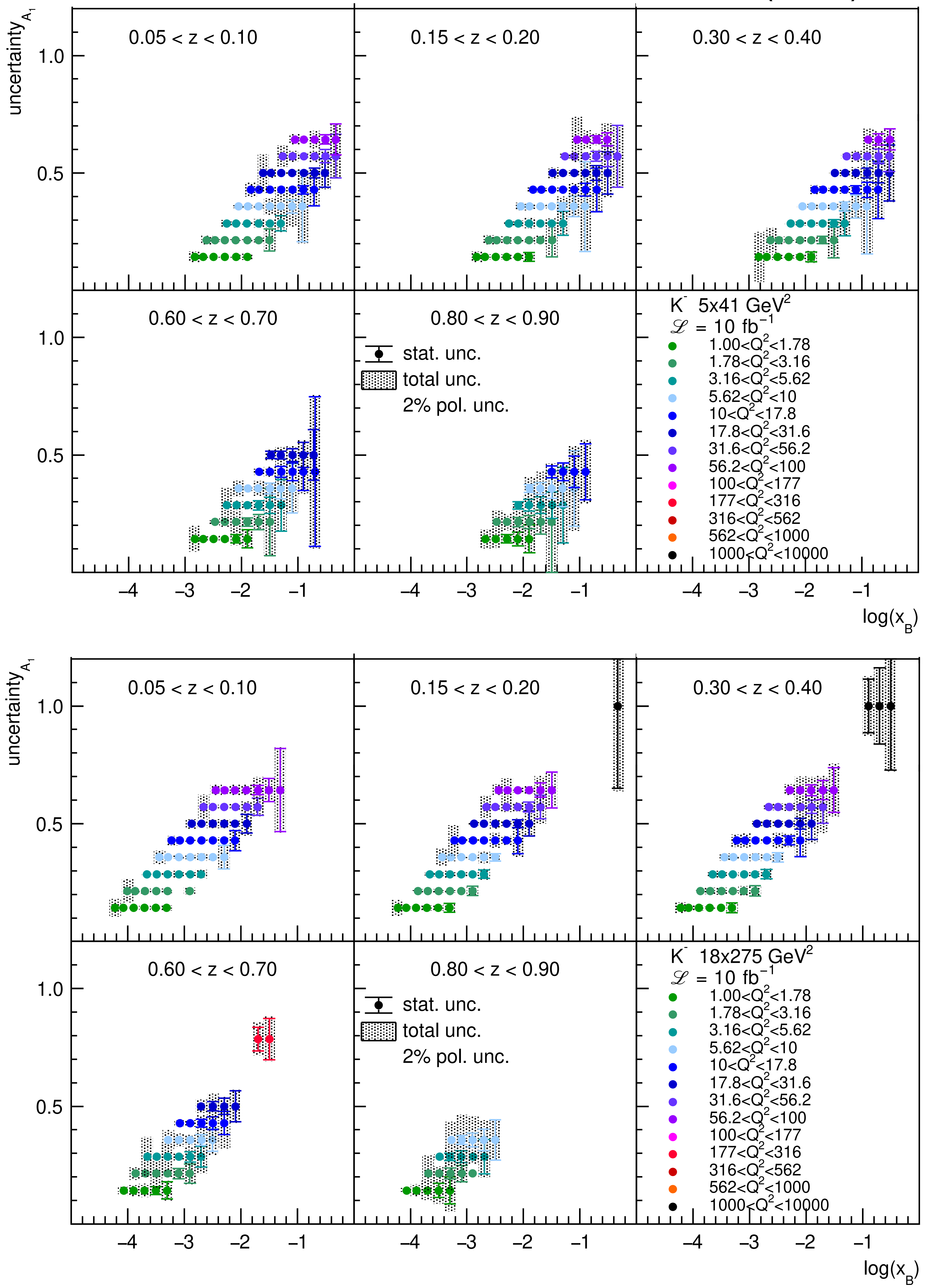
CVH et al., NIM A 1056 (2023) 168563



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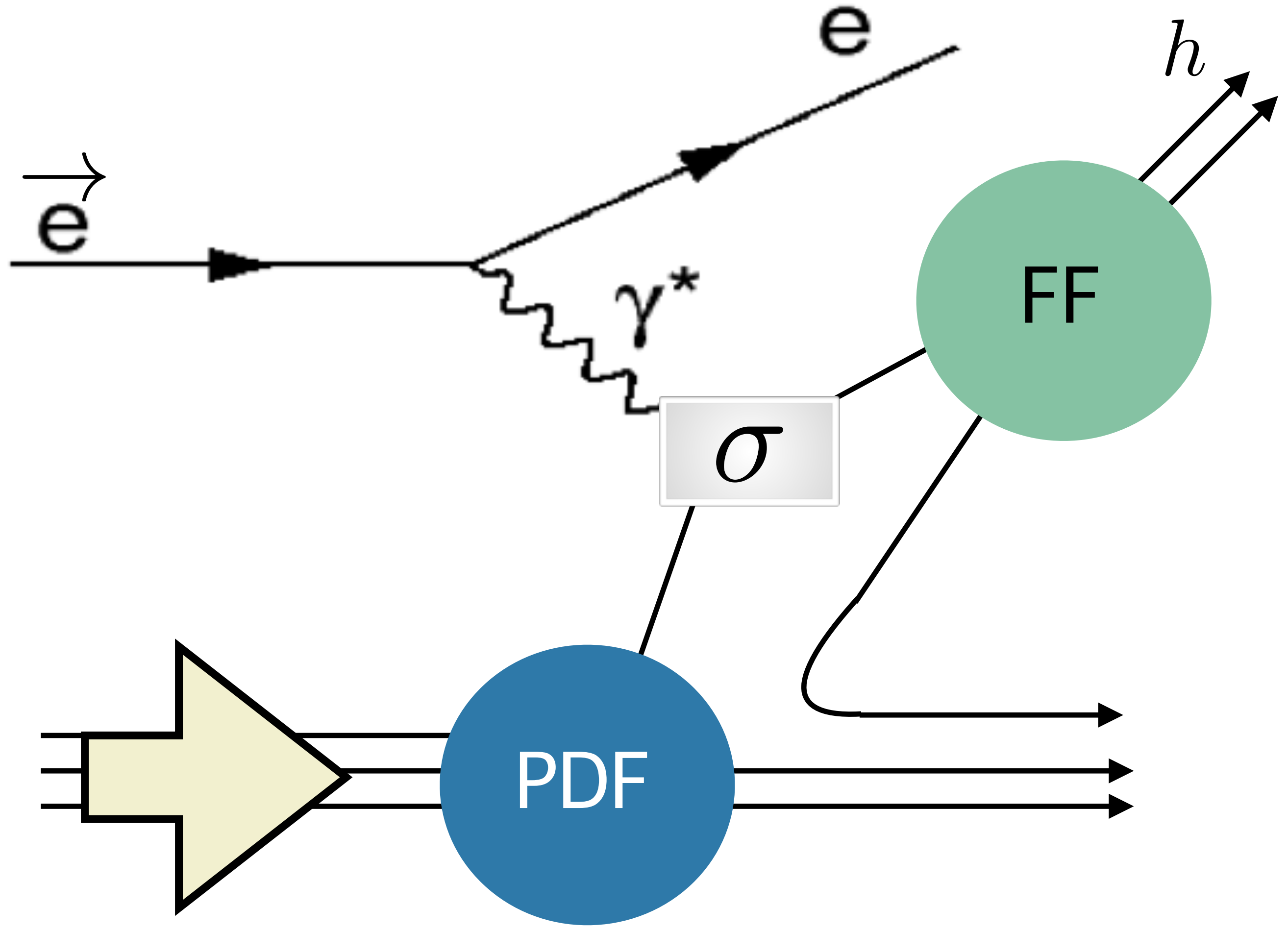
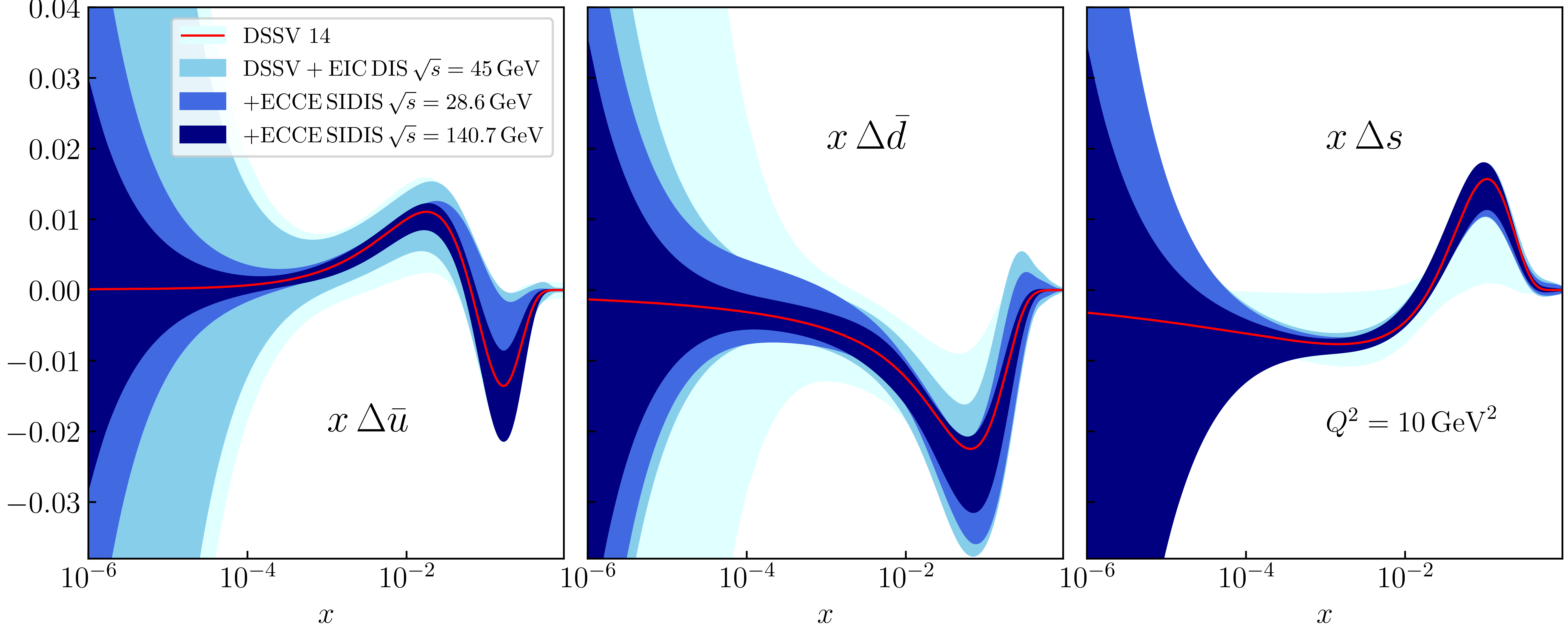


CVH et al., NIM A 1056 (2023) 168563



Semi-inclusive measurements, via good hadron PID
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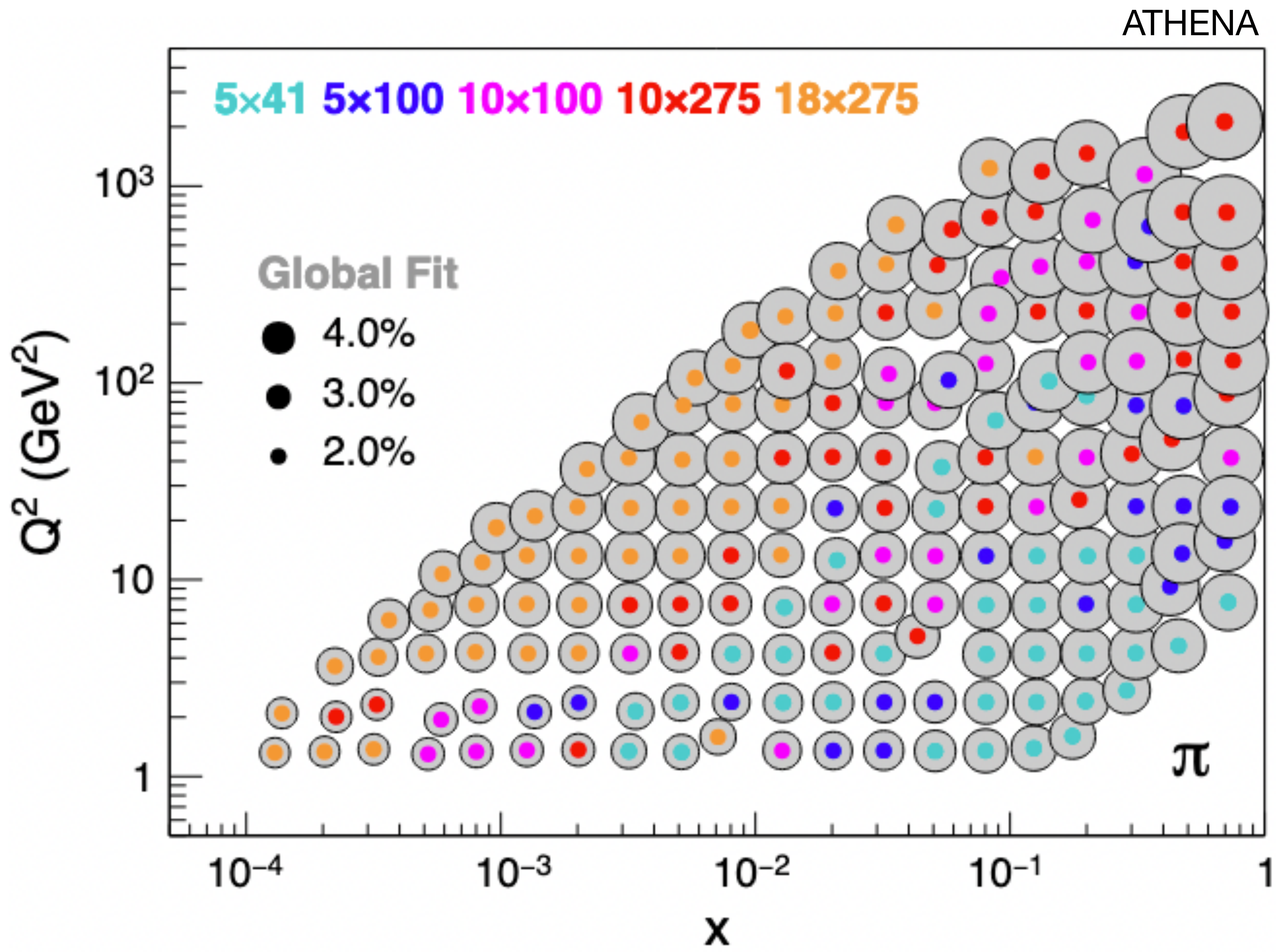
Spin-independent TMD PDFs at EIC



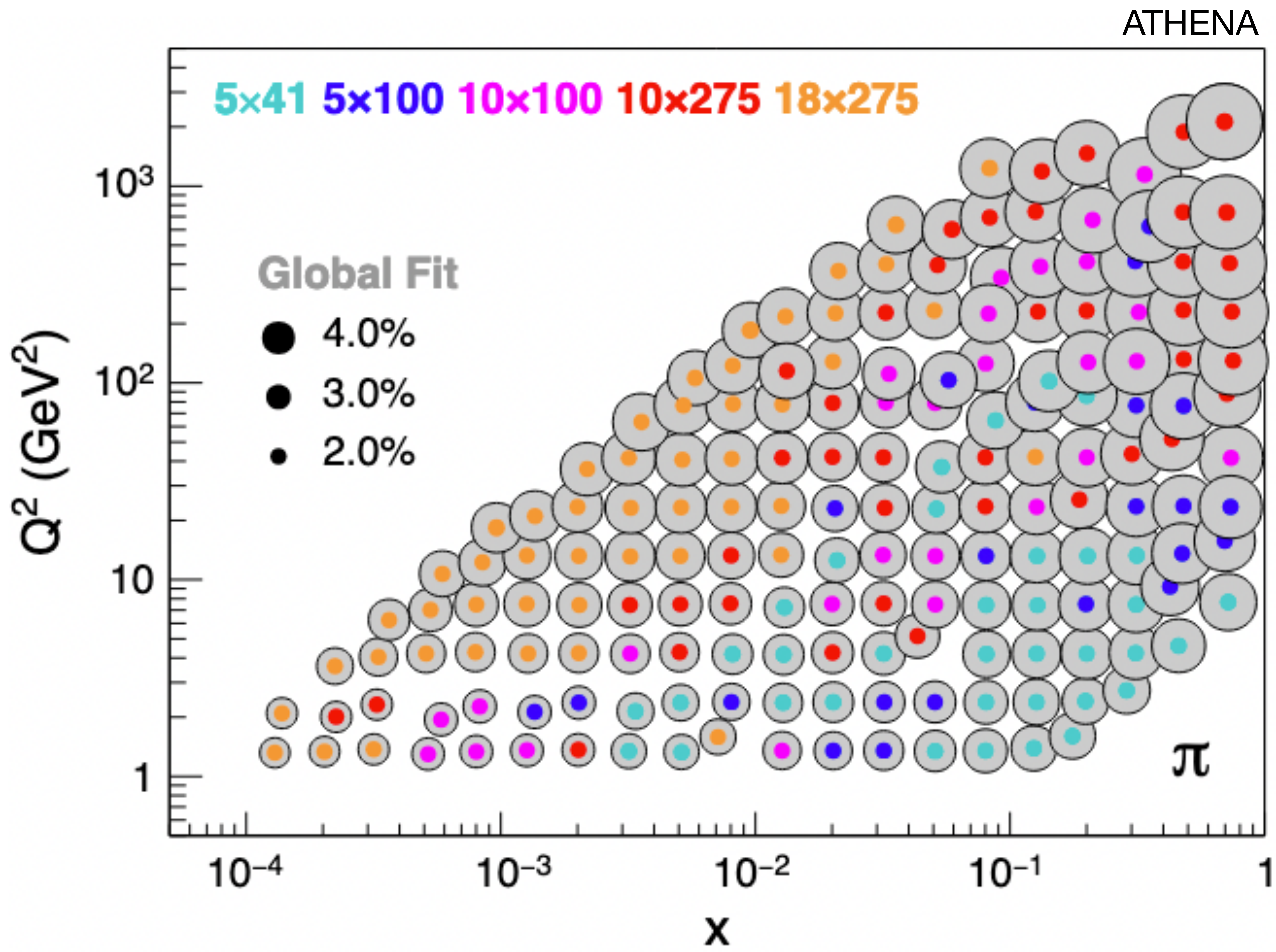
Fit:
A. Bacchetta et al.,
JHEP 06 (2017) 081,
JHEP 06 (2019) 051 (erratum)

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

Theory uncertainties dominated by TMD evolution.

Spin-independent TMD PDFs at EIC

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



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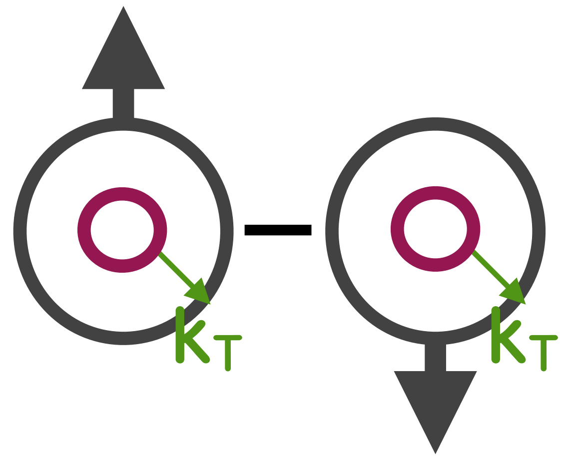
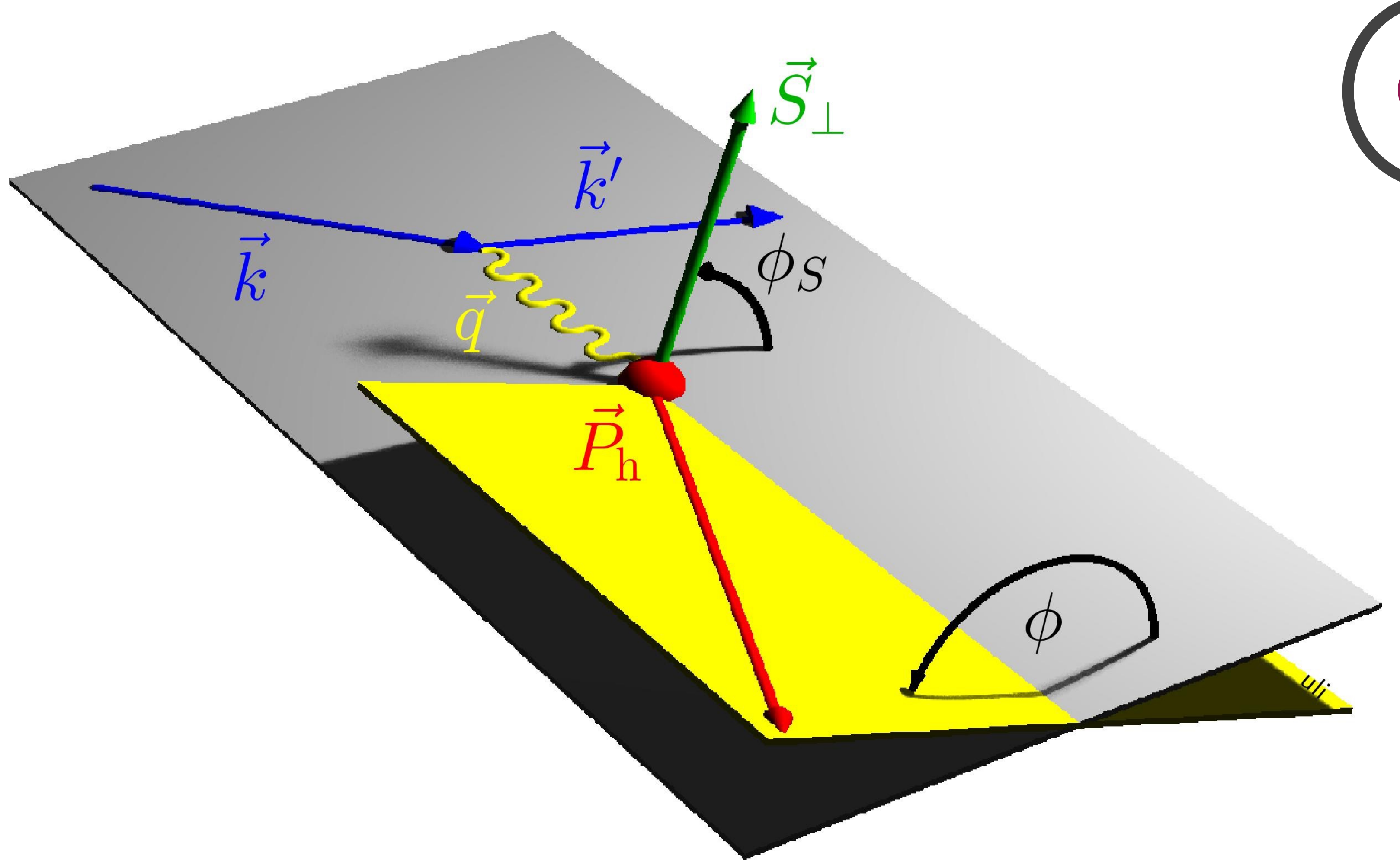
Spin-dependent TMD PDFs: Sivers

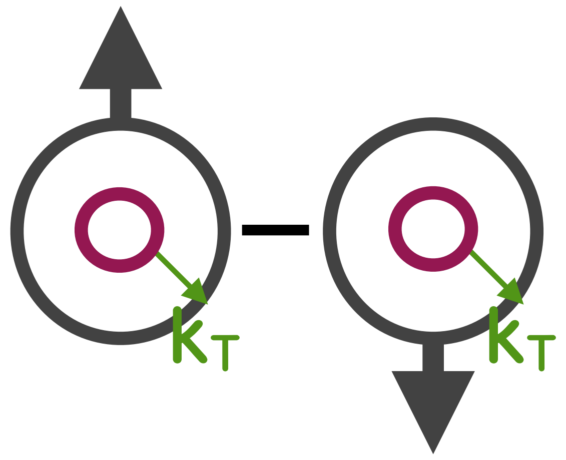


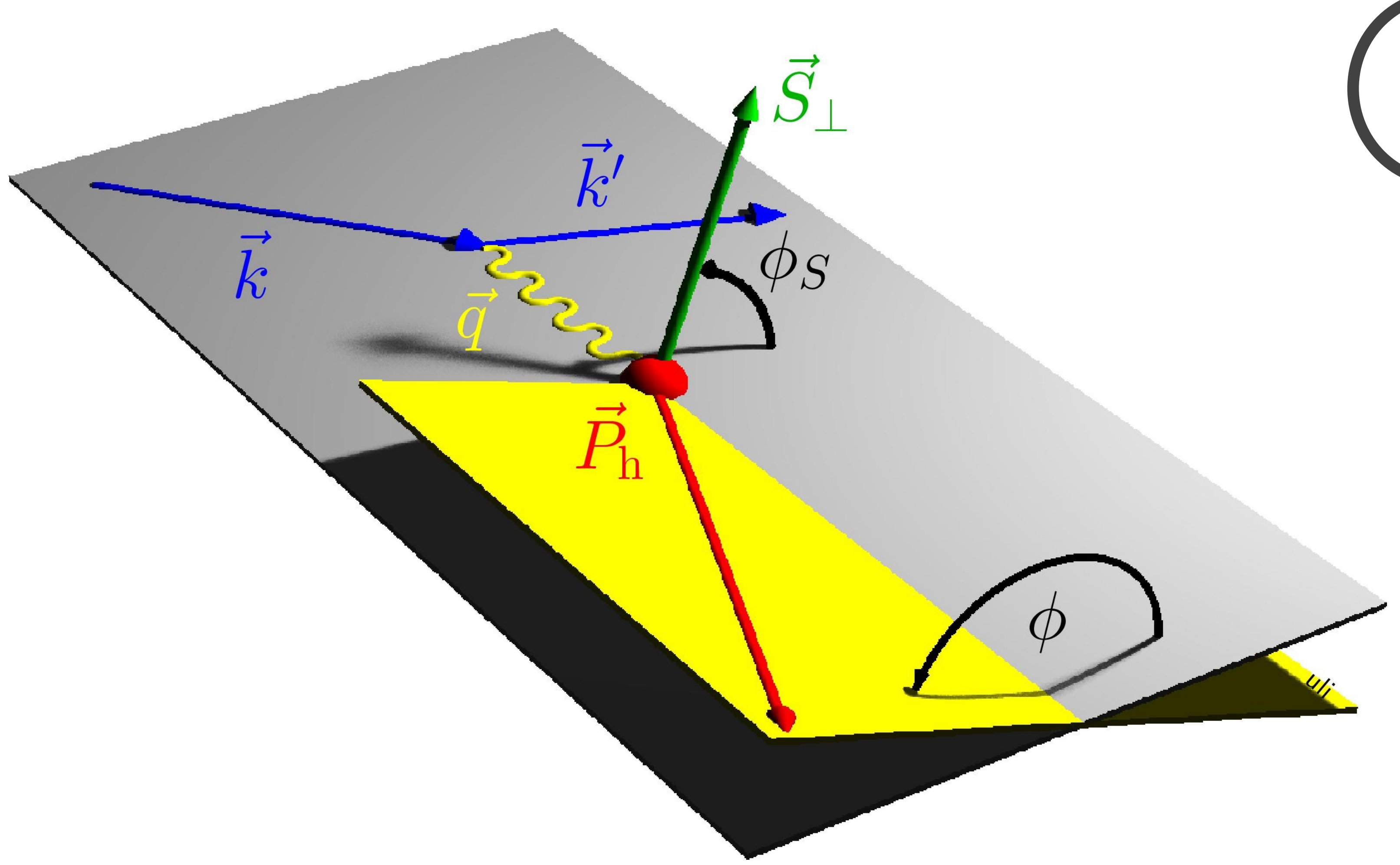
Sivers asymmetry

$$\sigma^h(\phi, \phi_S) \propto S_T\, 2\langle \sin(\phi - \phi_S)\rangle^h_{UT} \sin(\phi - \phi_S) \longrightarrow \mathcal{C}[f_{1T}^{\perp} \times D_1^{q\to h}]$$



Spin-dependent TMD PDFs: Sivers





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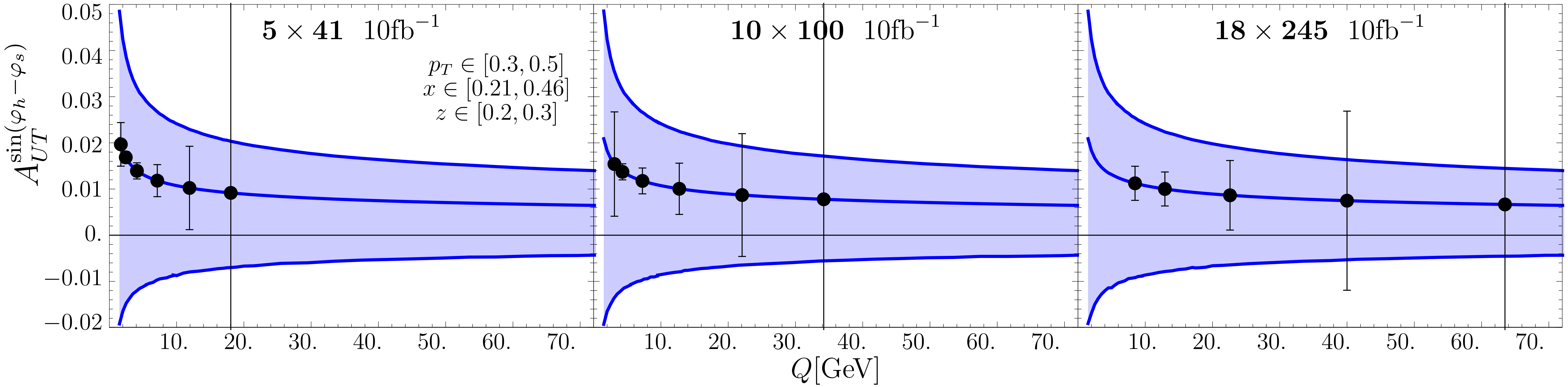
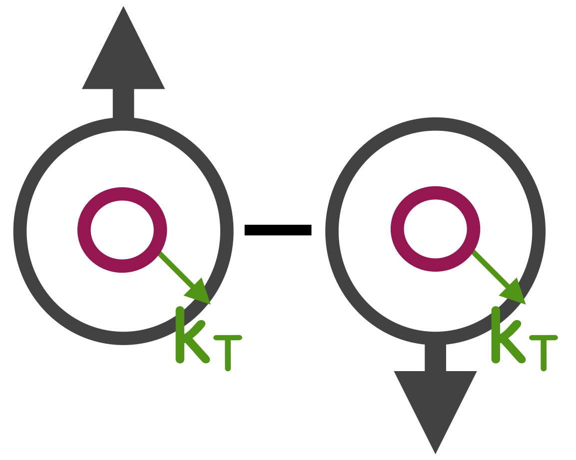
R. Seidl, A. Vladimirov et al., NIM A **1055** (2023) 168458

Parametrisation: M. Bury et al., JHEP **05** (2021)151

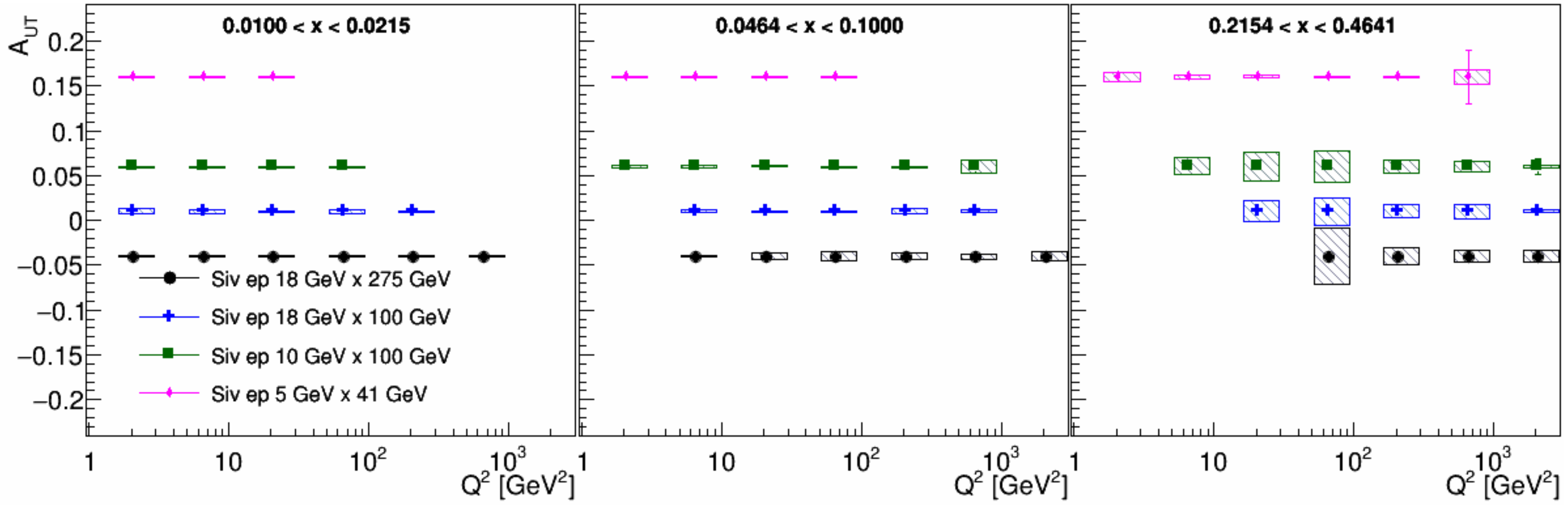


Decrease of asymmetry with increasing Q^2 → need high precision (<1%) to measure asymmetry at high Q^2

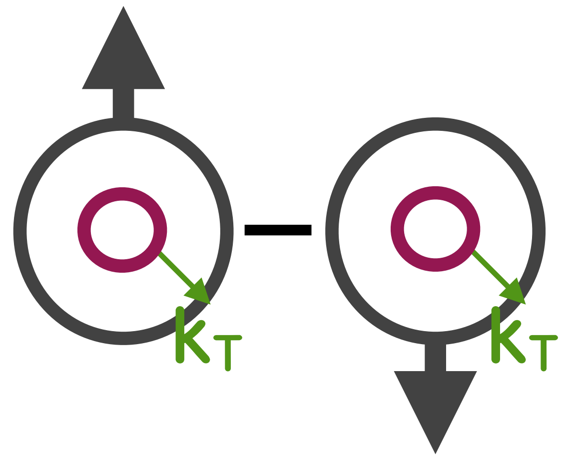
Impact of EIC on Sivers TMD PDF



R. Seidl, A. Vladimirov et al., NIM A **1055** (2023) 168458



Impact of EIC on Sivers TMD PDF



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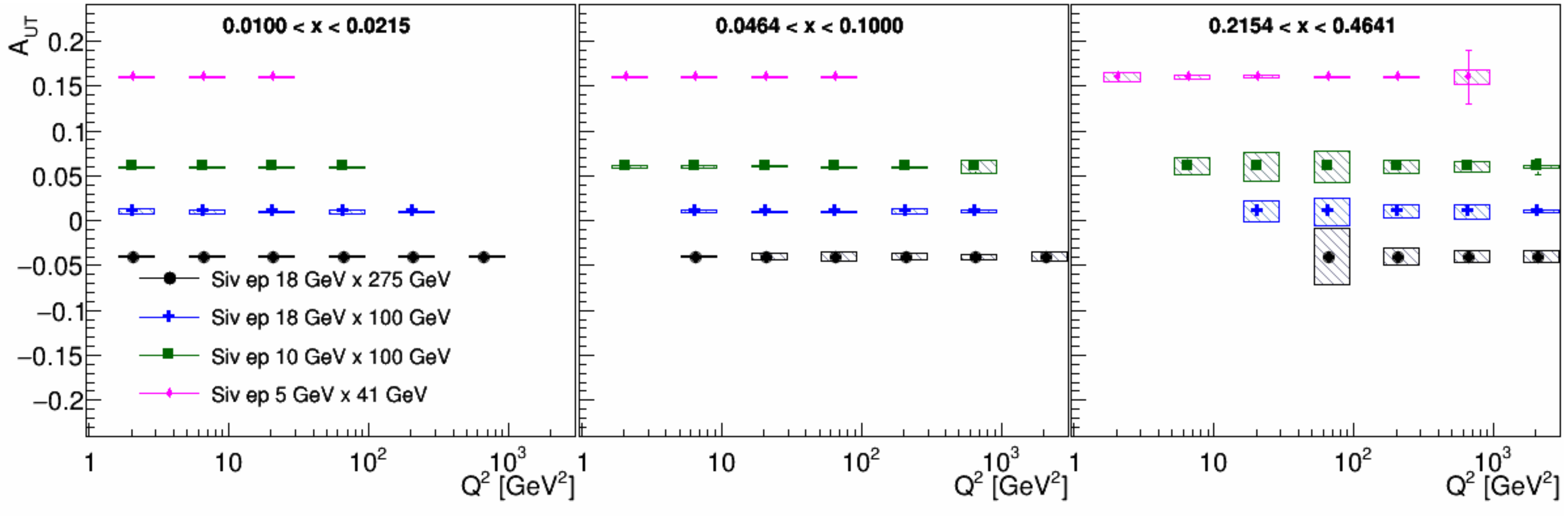
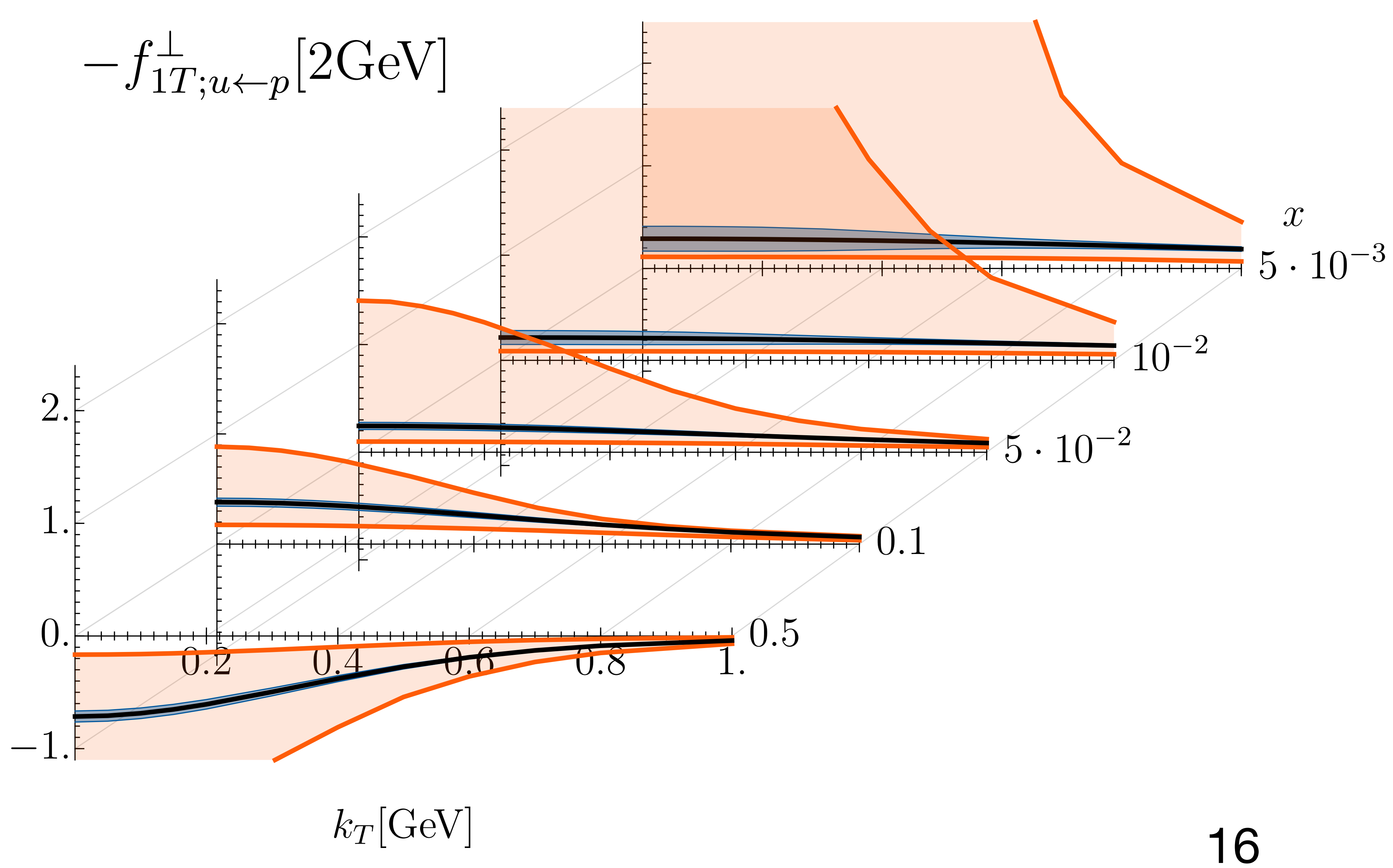
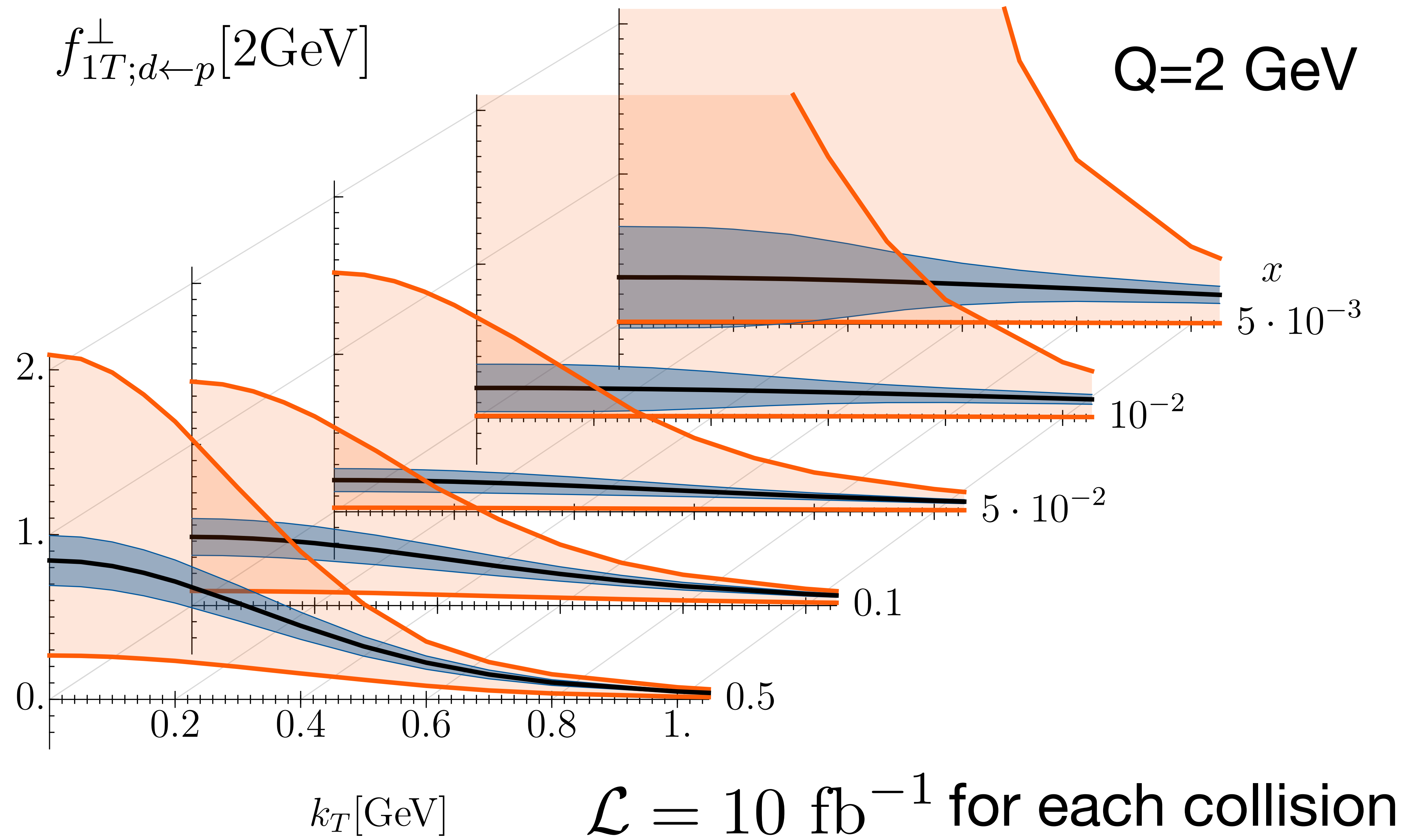




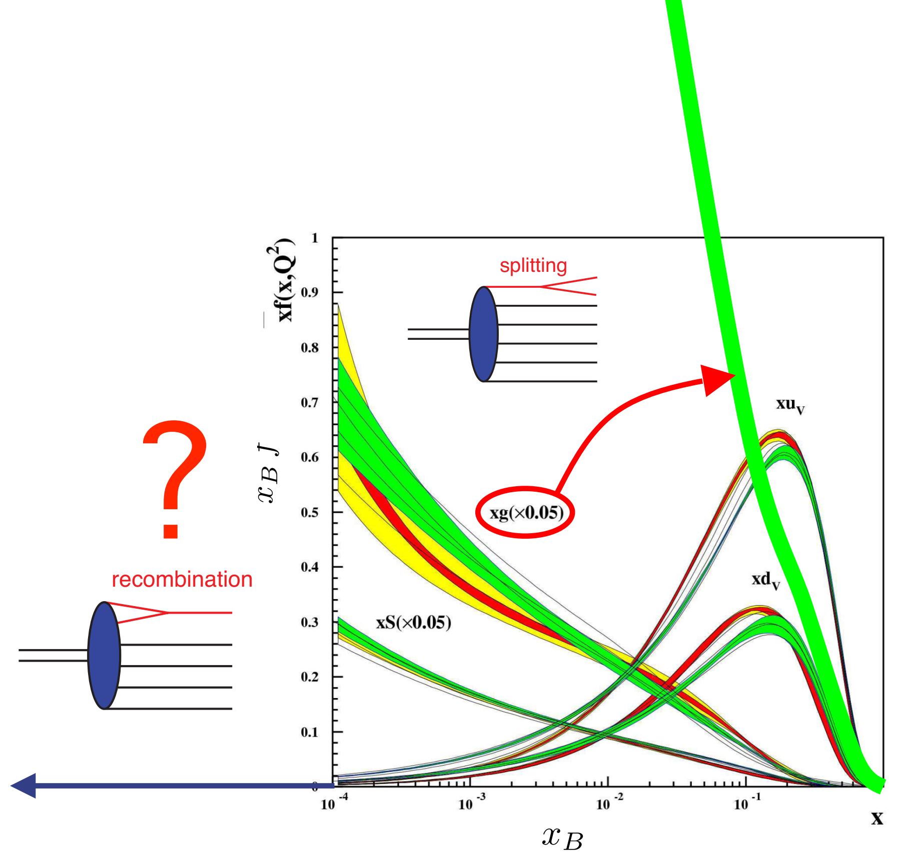


Q=2 GeV

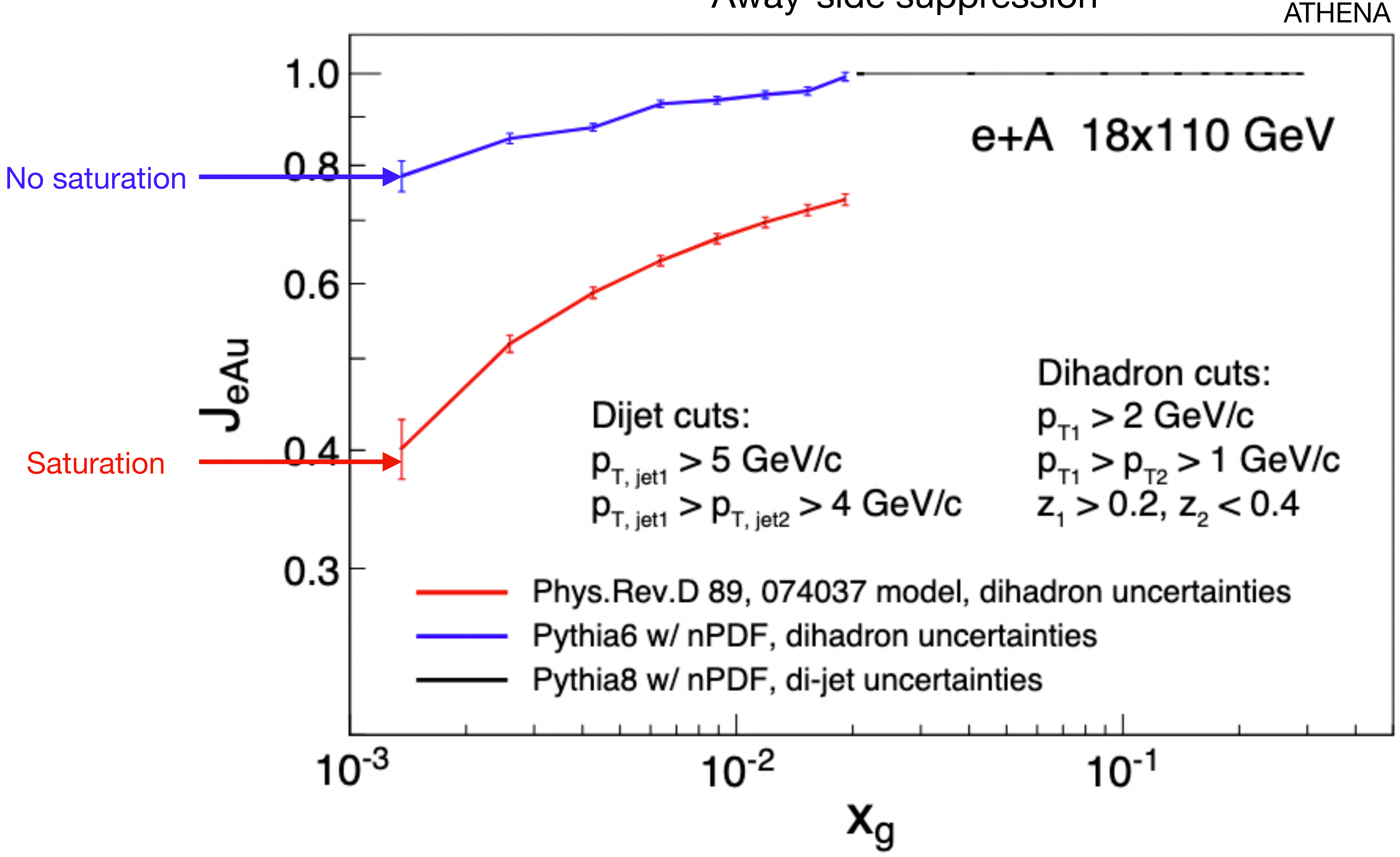
$\mathcal{L} = 10\ \text{fb}^{-1}$ for each collision energy

Di-hadron production and jets in eA

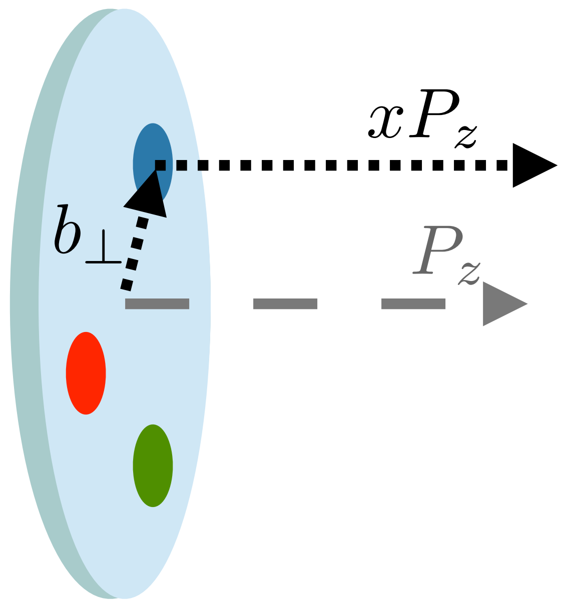
- Complementarity region covered by dihadron and jet production



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

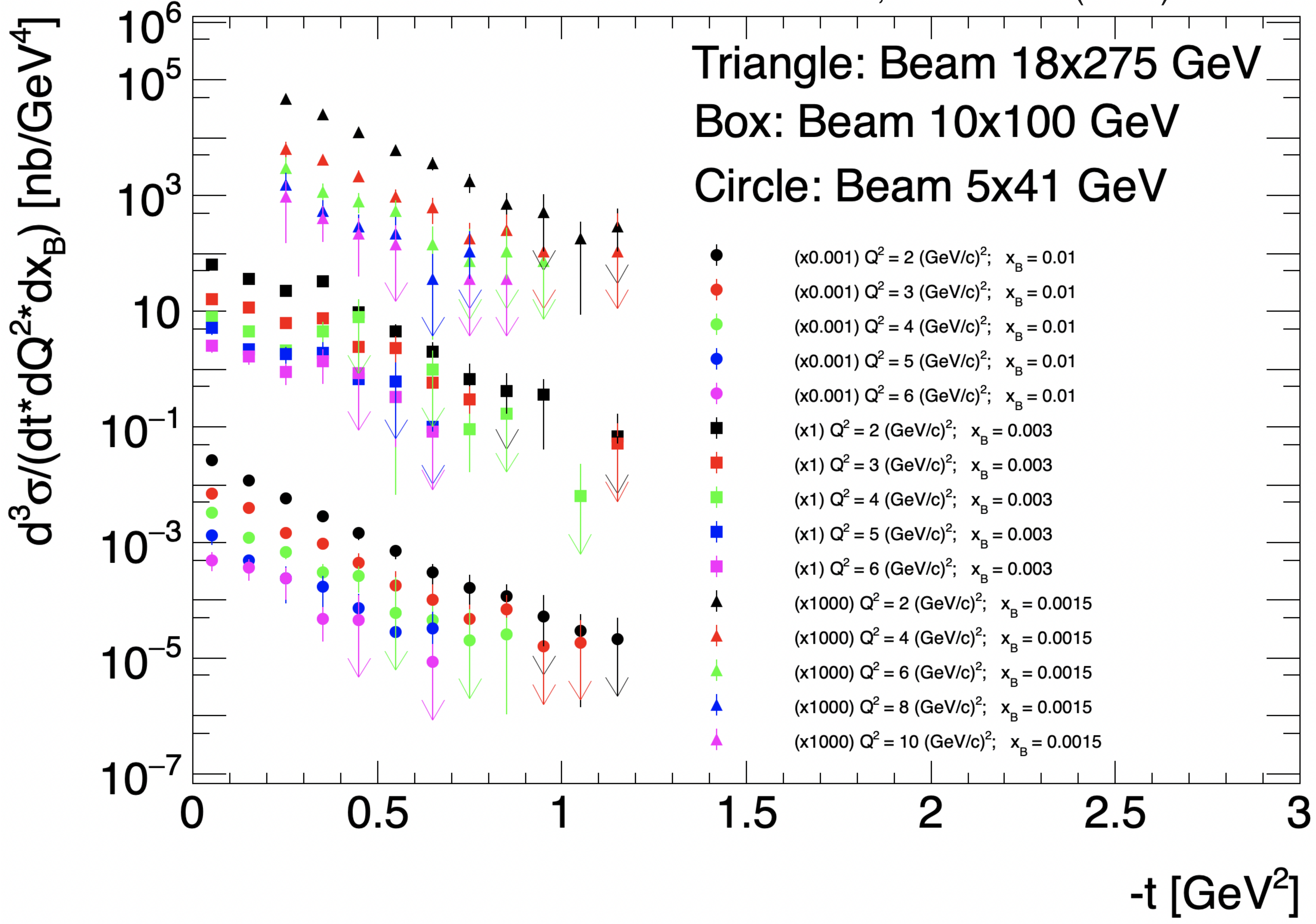


Exclusive measurements on p with the EIC



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

ECCE, NIMA **1052** (2023) 168238



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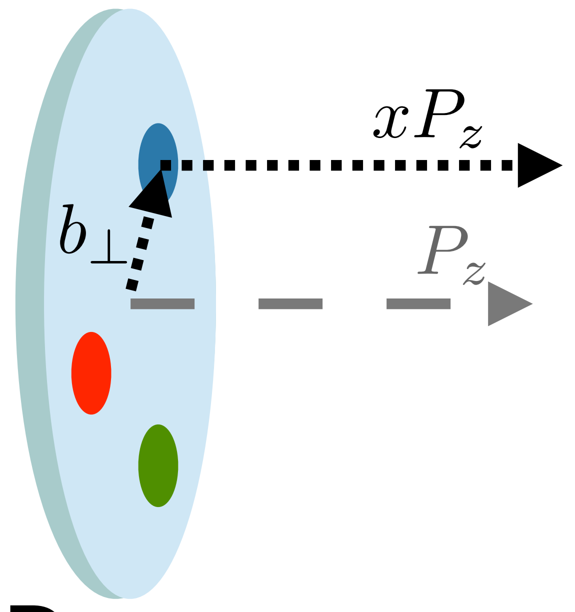

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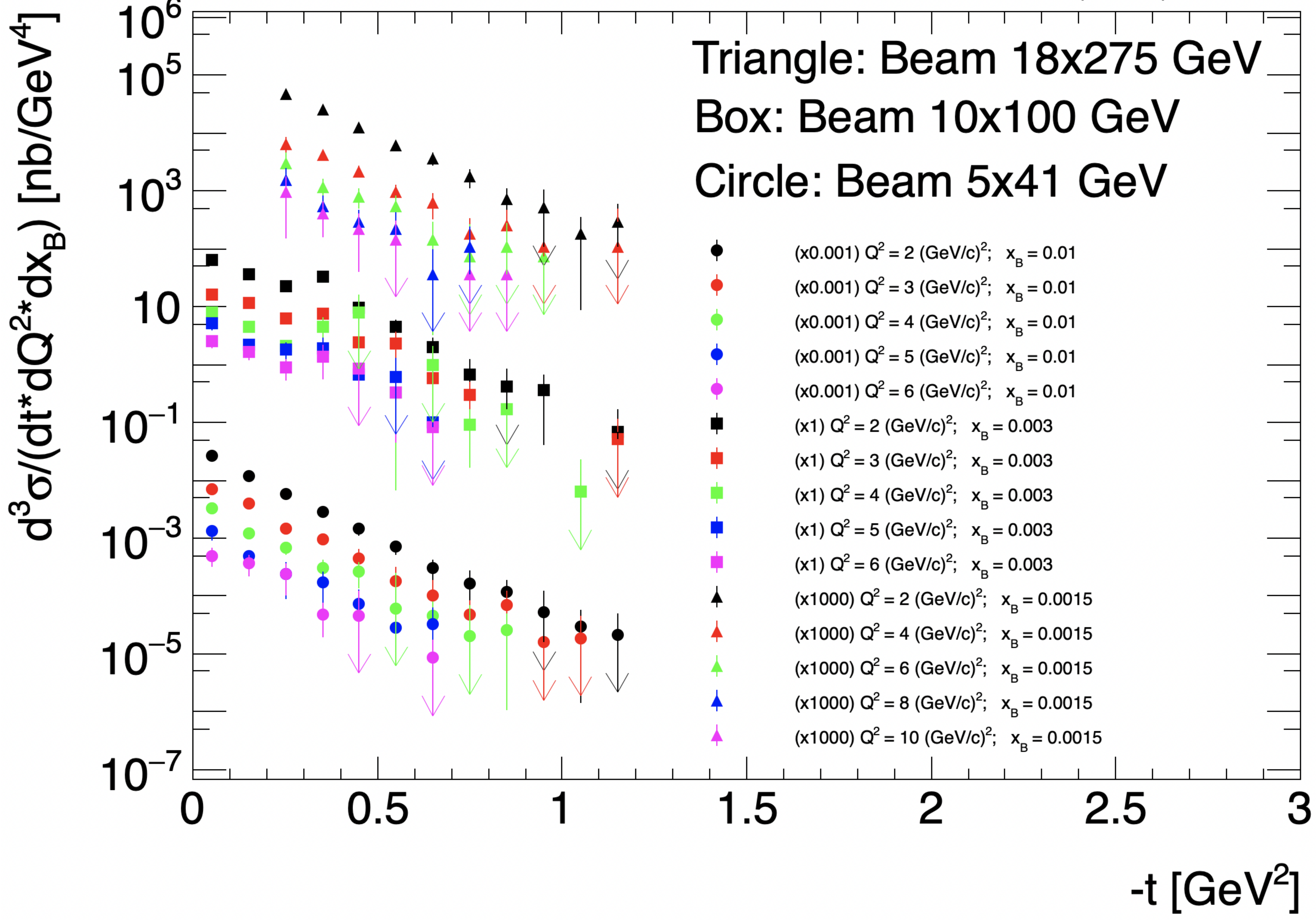
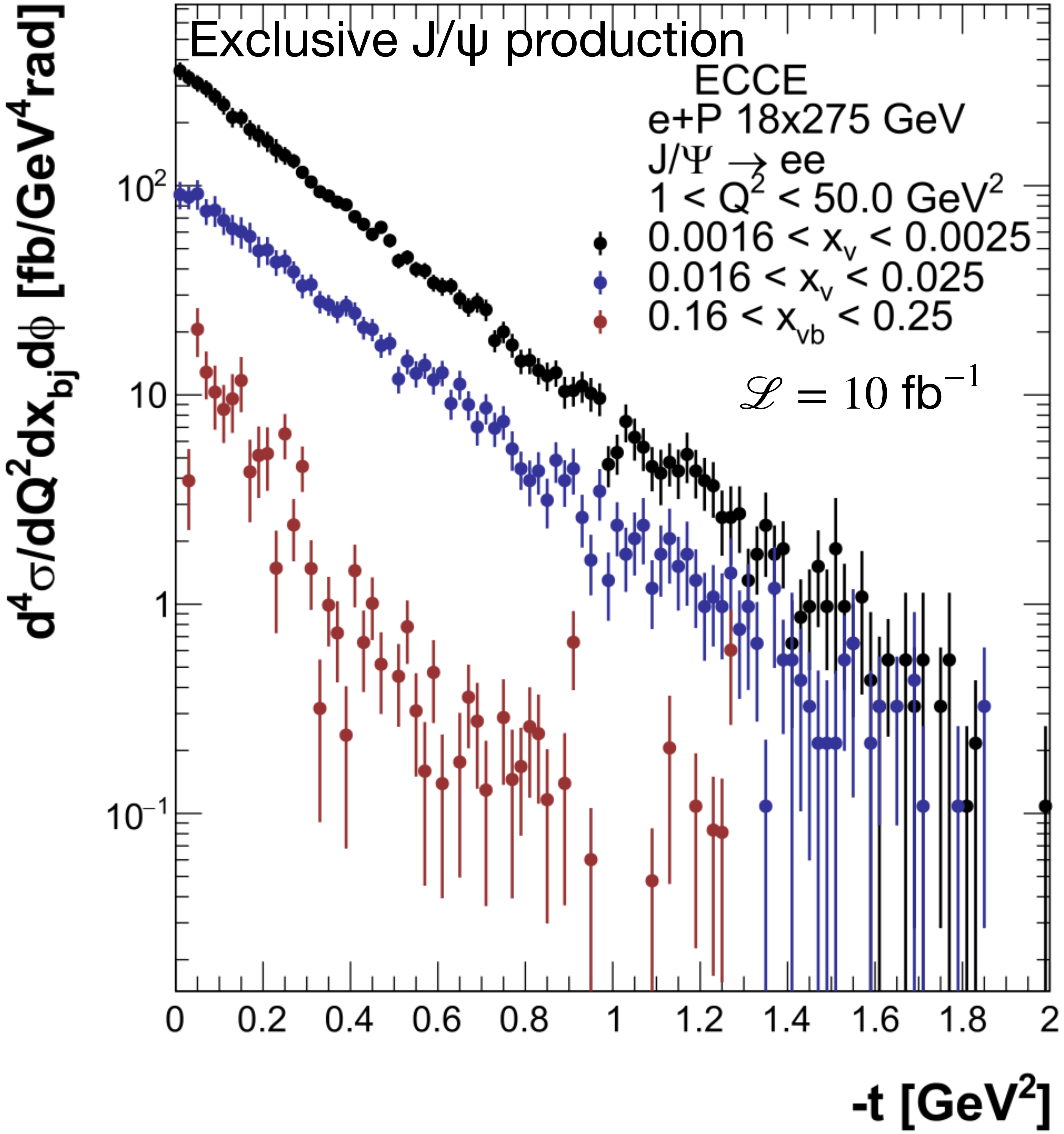
ECCE, NIMA **1052** (2023) 168238

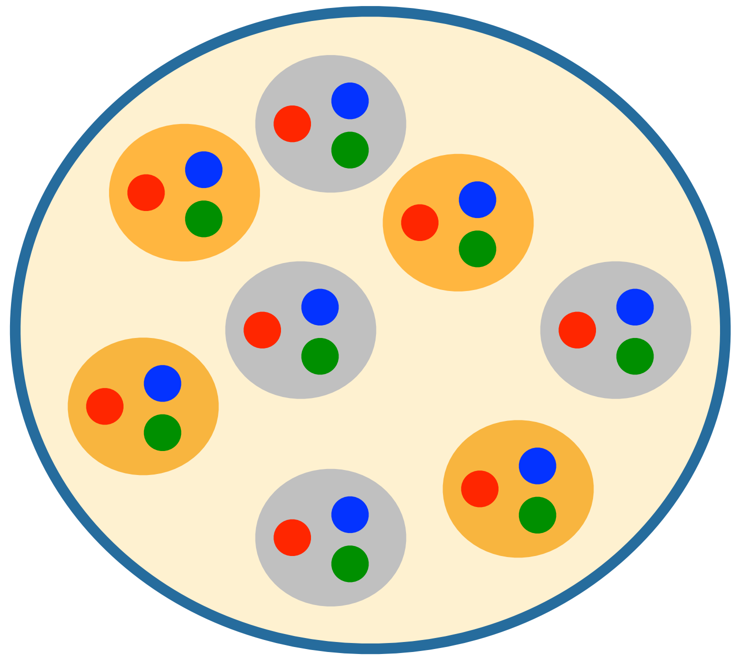


Exclusive J/ψ production
→ excellent to probe gluon GPDs

ECCE, NIMA **1052** (2023) 168238

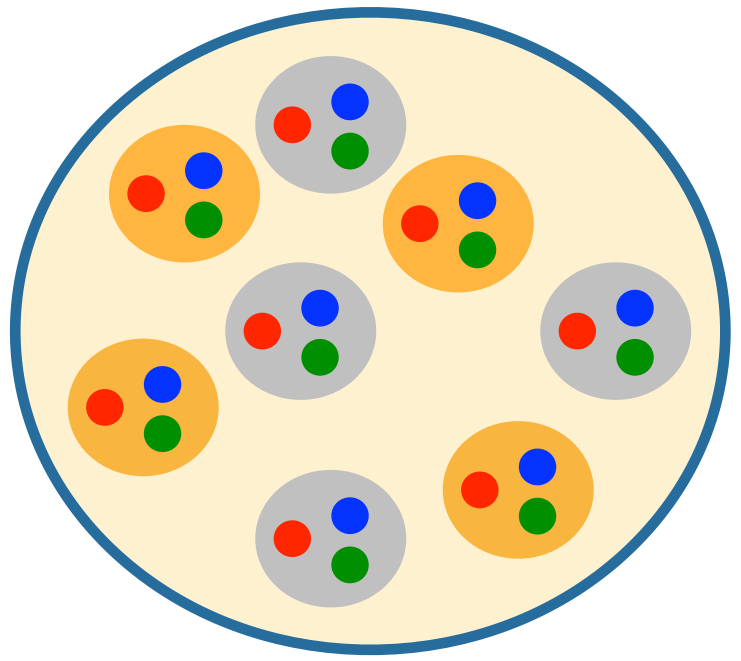


Exclusive measurements on nuclear targets



Exclusive measurements on nuclear targets

What object are we probing?



Exclusive measurements on nuclear targets

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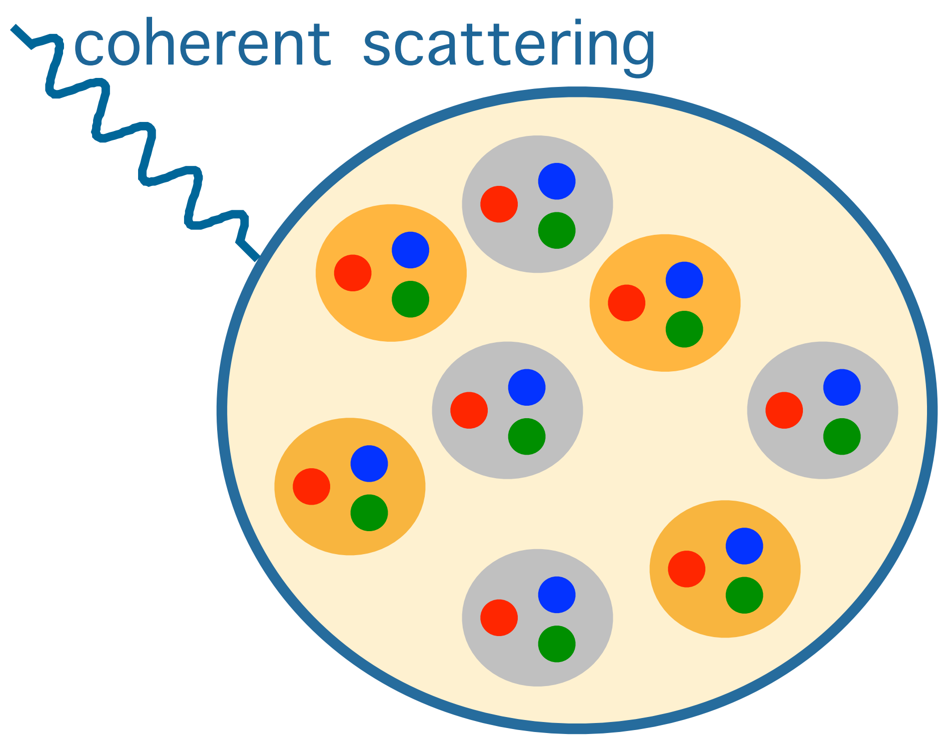
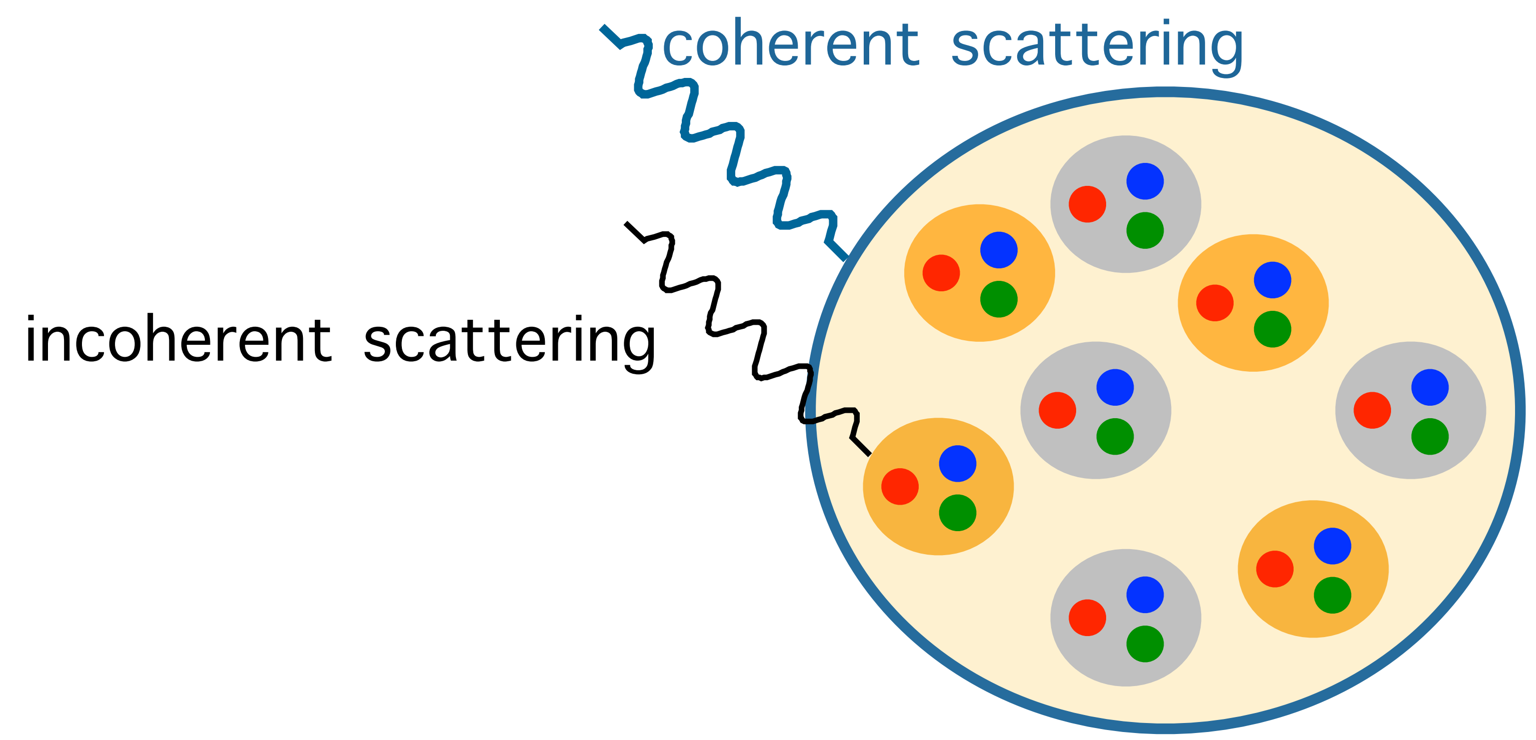


Coherent interaction: interaction with target as a whole.
~ target remains in same quantum state.

Exclusive measurements on nuclear targets

What object are we probing?

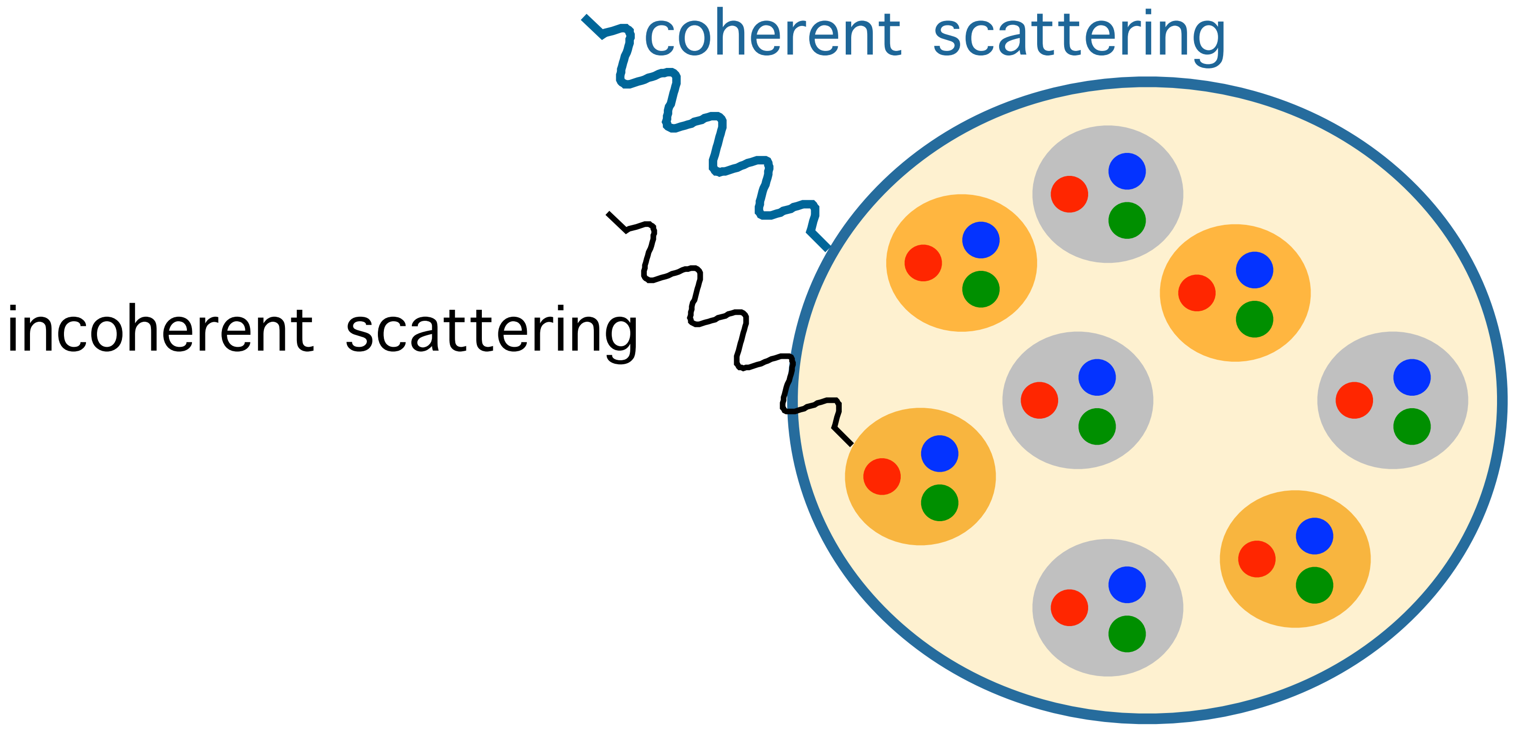


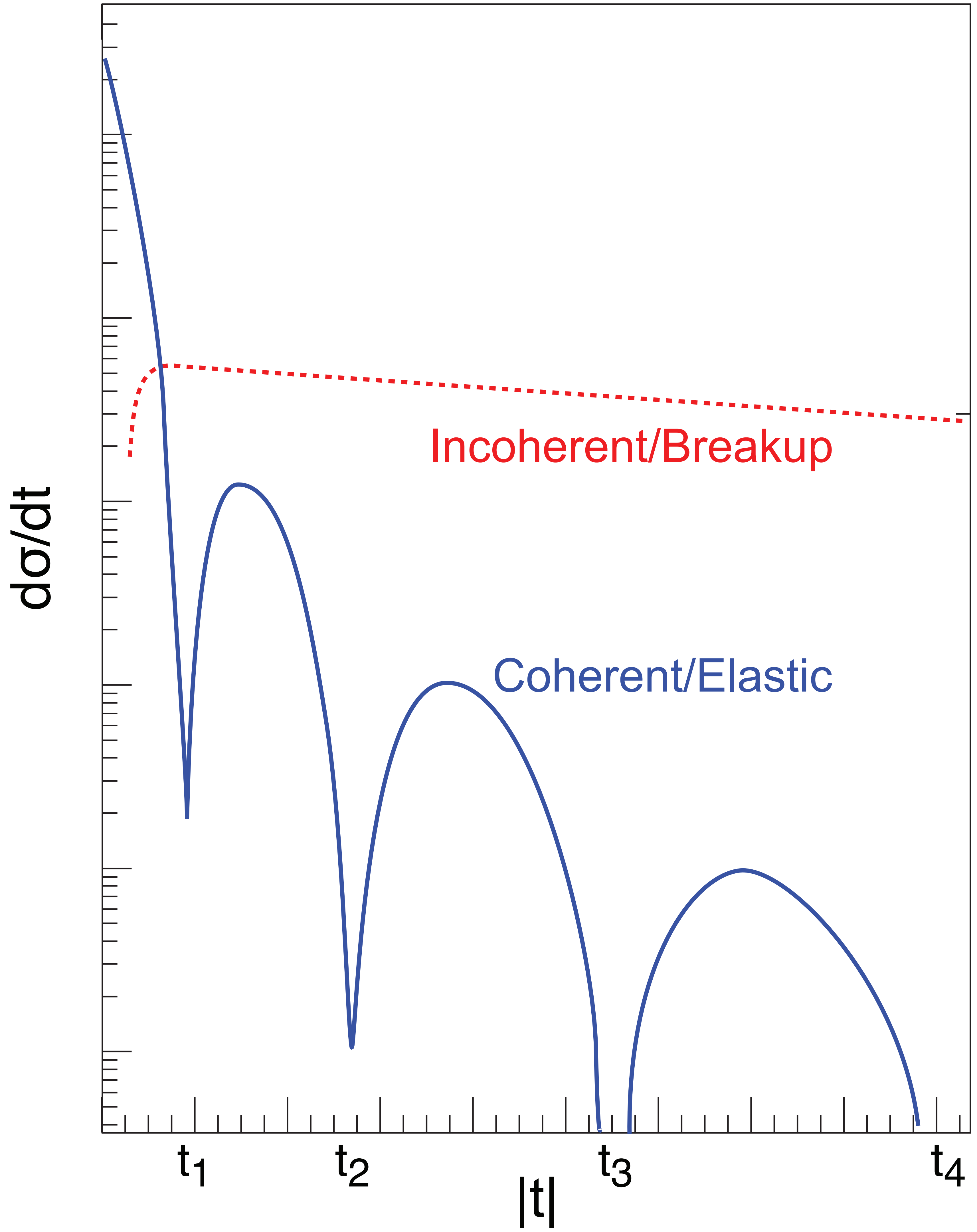
Coherent interaction: interaction with target as a whole.
~ target remains in same quantum state.

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

Exclusive measurements on nuclear targets

What object are we probing?





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

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

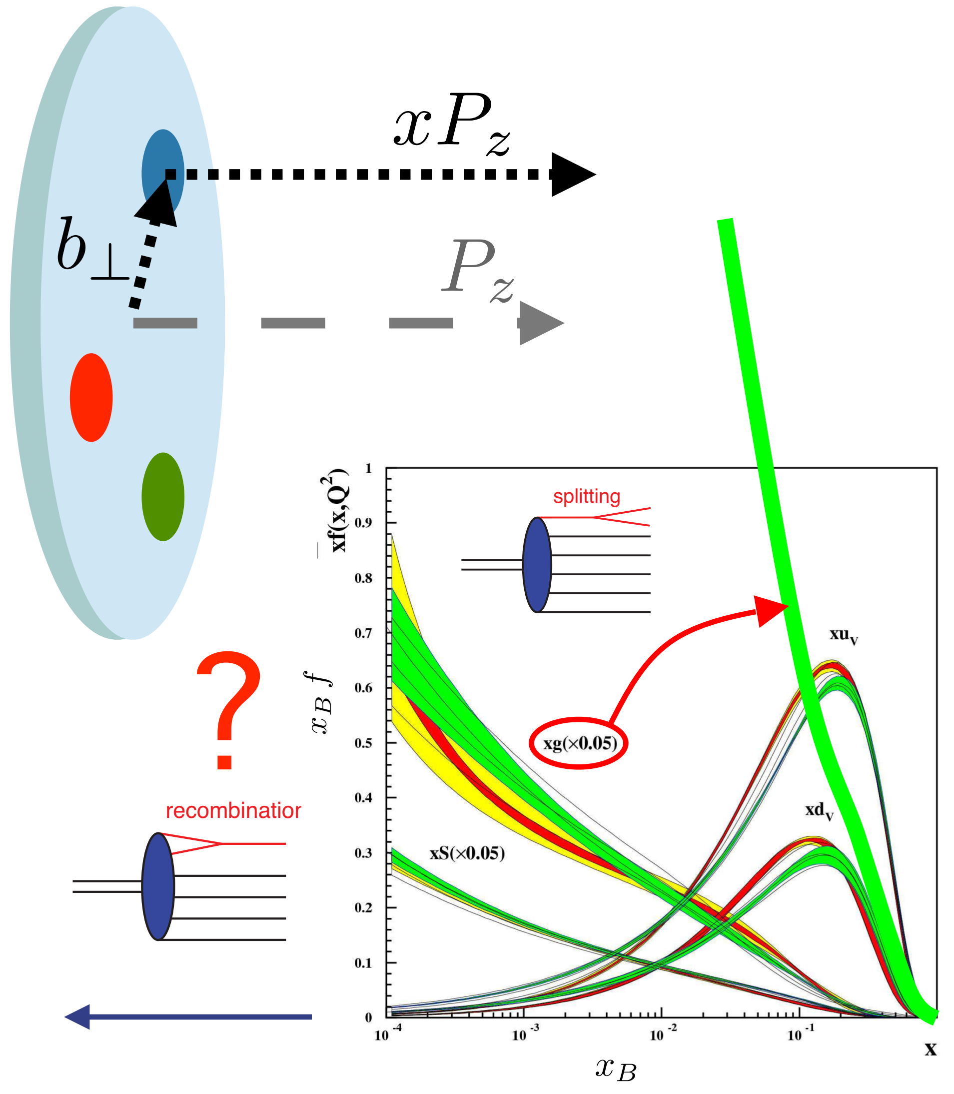
Coherent eA production

→ probe gluon saturation

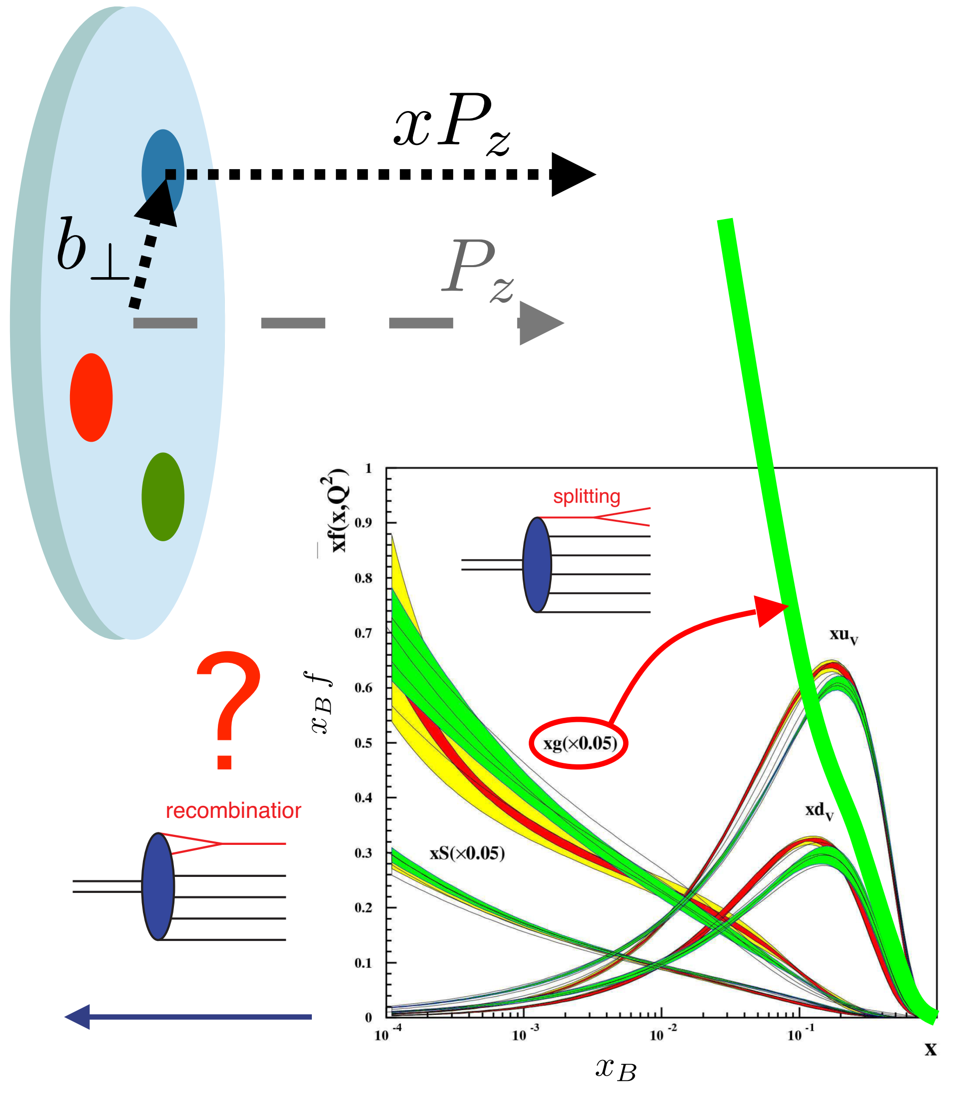
→ nuclear imaging in position space:

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

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



Coherent eA production



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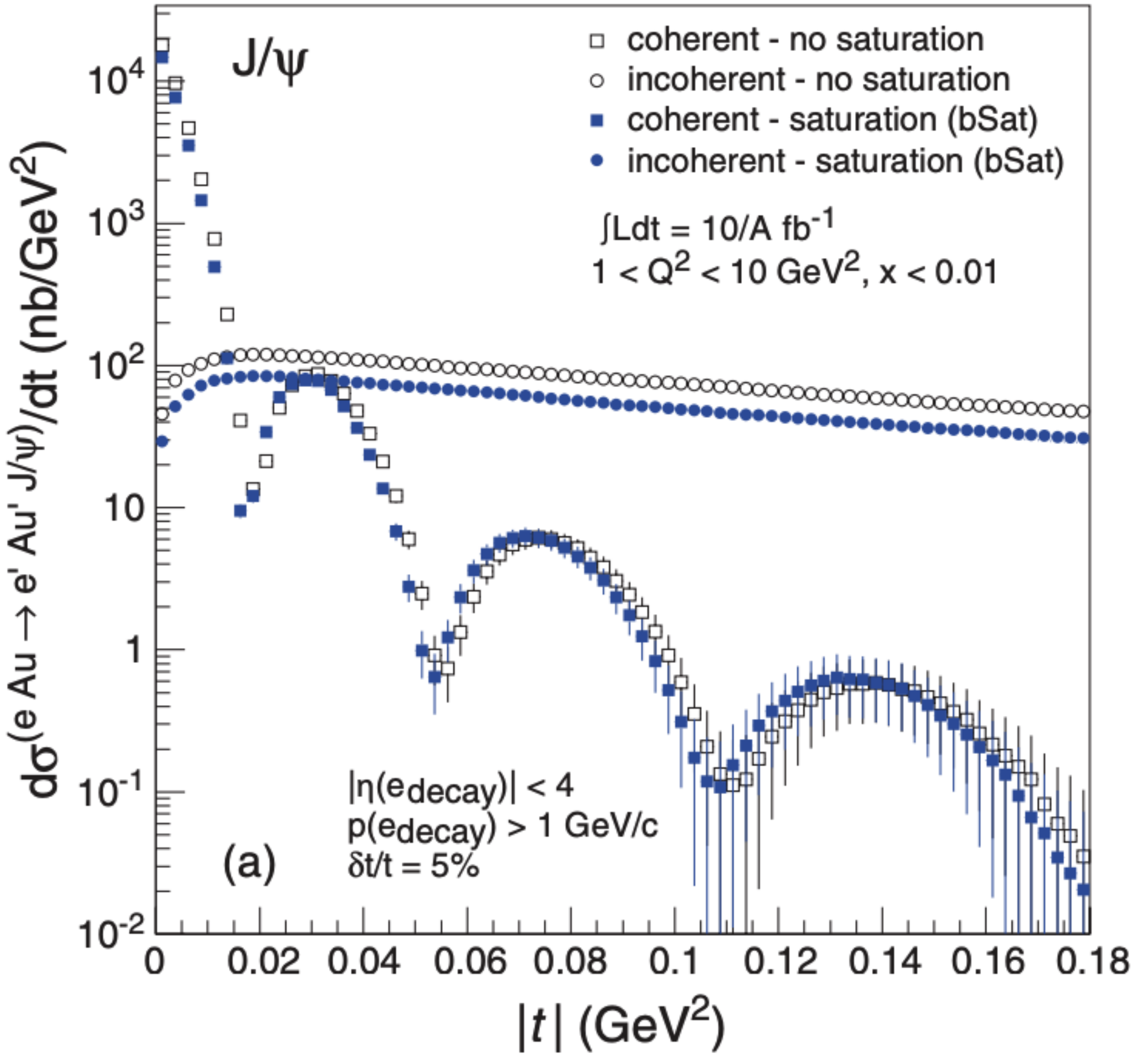
Toll, Ulrich, PRC **87** (13) 0249



→ resolving minima is crucial

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

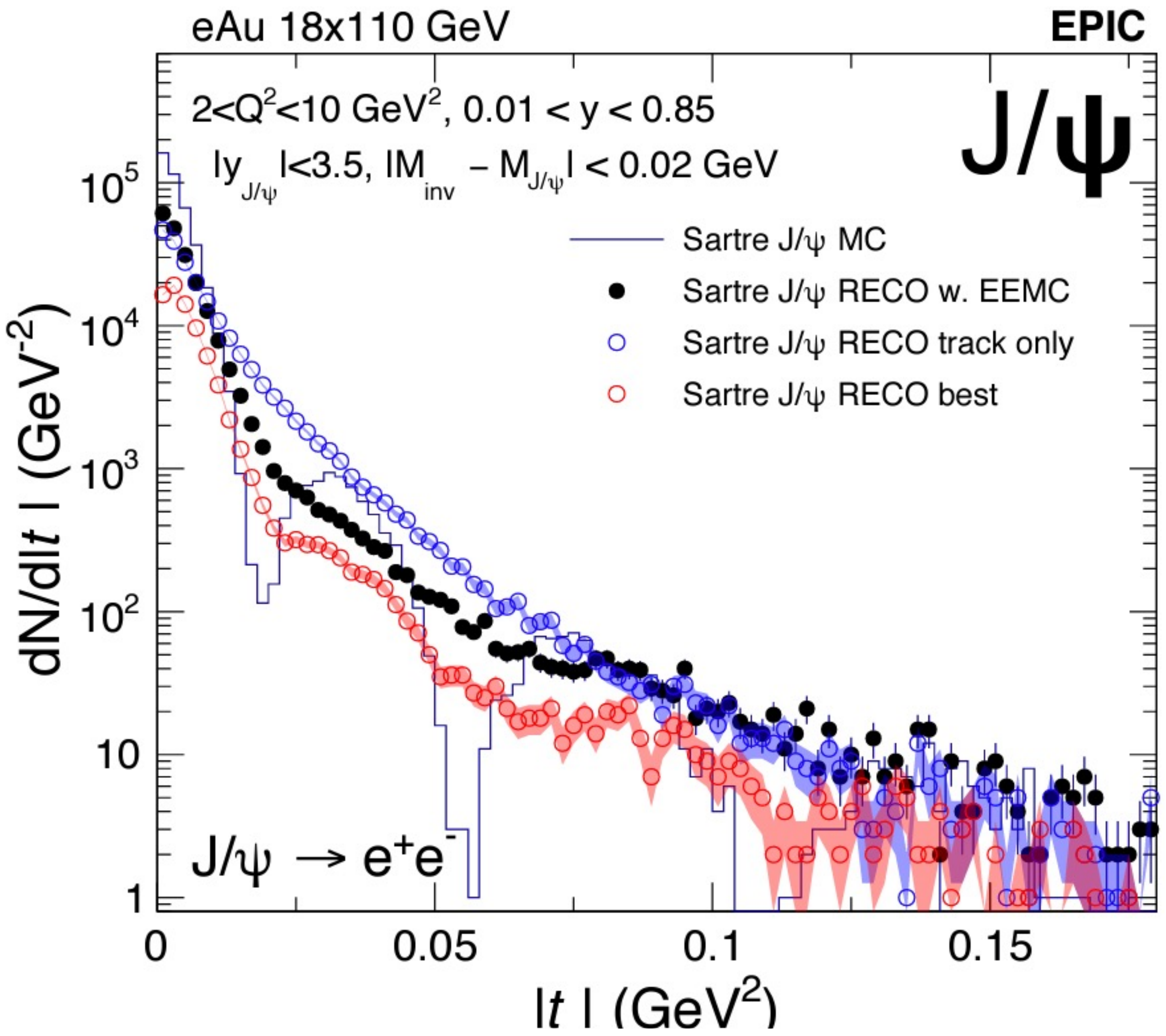
- veto of events where nuclei break up
  → use entire far-forward detector systems

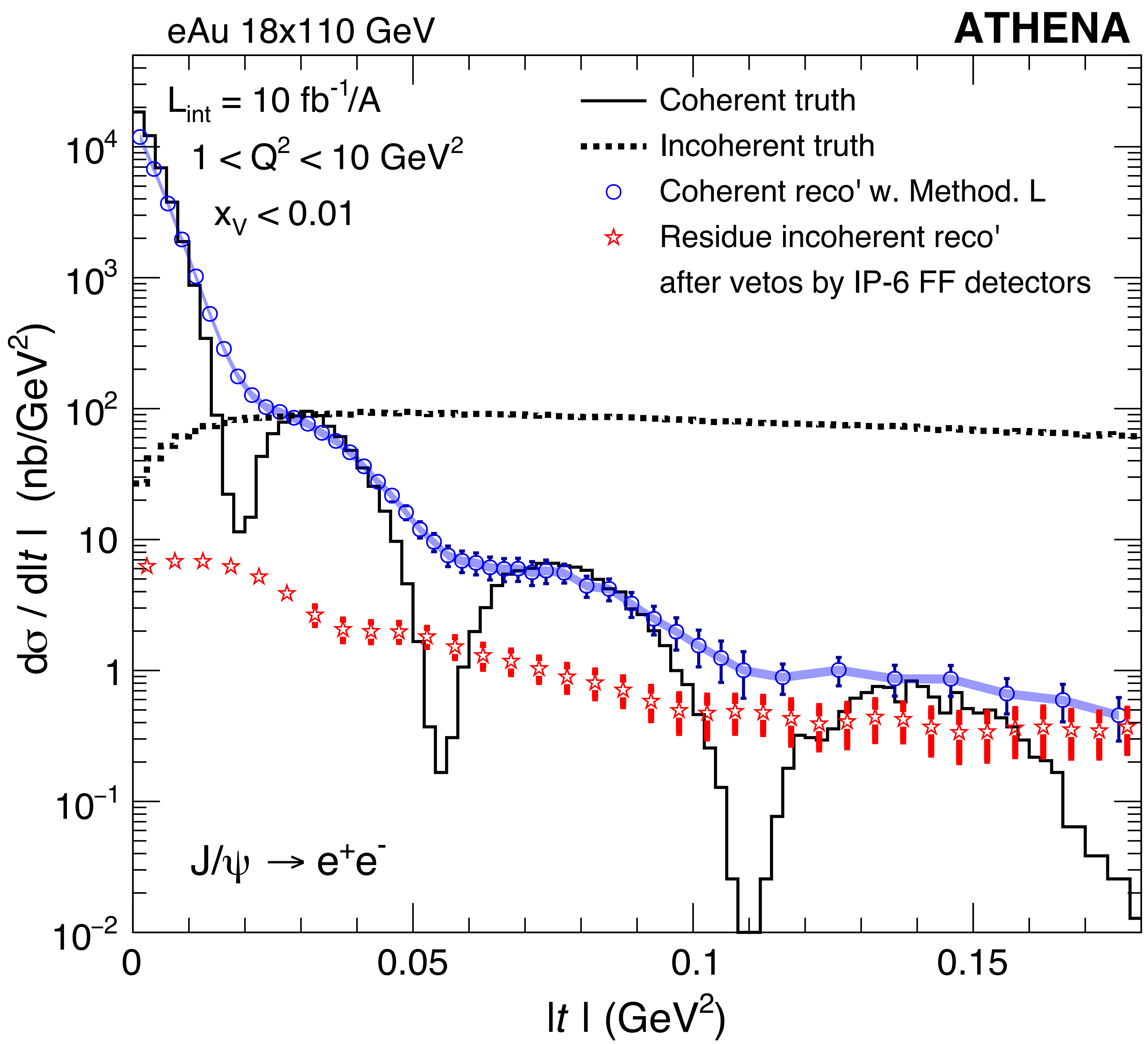
- Need precise determination of t

  reconstruction via scattered lepton and exclusively produced vector meson/photon

Exclusive measurements on nuclear targets with the EIC

K. Tu, DIS 2023





Summary

EIC with ePIC can address various aspects of the nucleon and nuclear structure through:

- Precise inclusive and semi-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.
- Exclusive measurements on protons, using the far-forward detector system.
- Diffractive and exclusive measurements with coherent/incoherent separation via very precise EM calorimeters and far-forward detector system.