

# Inclusive physics at the EIC

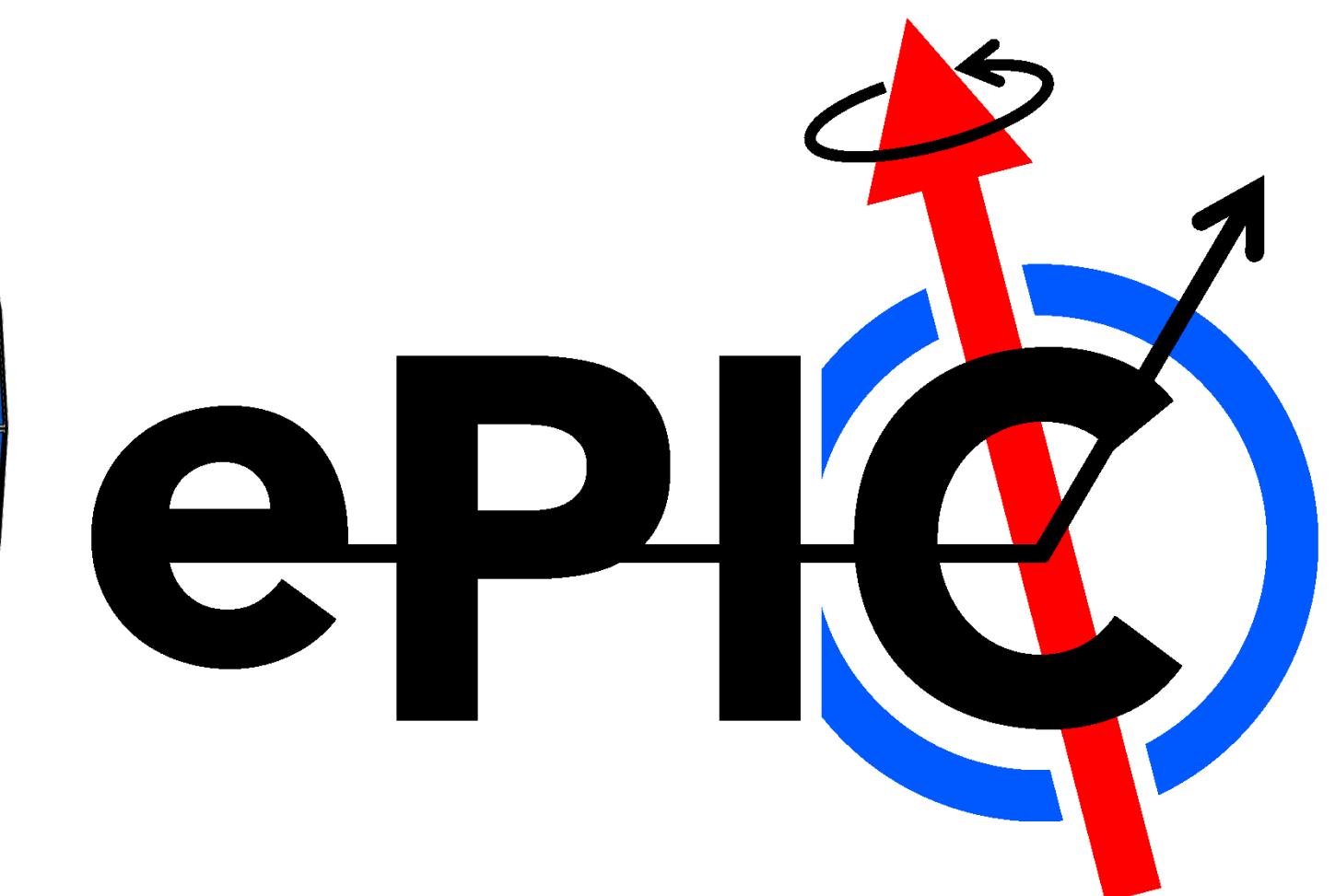
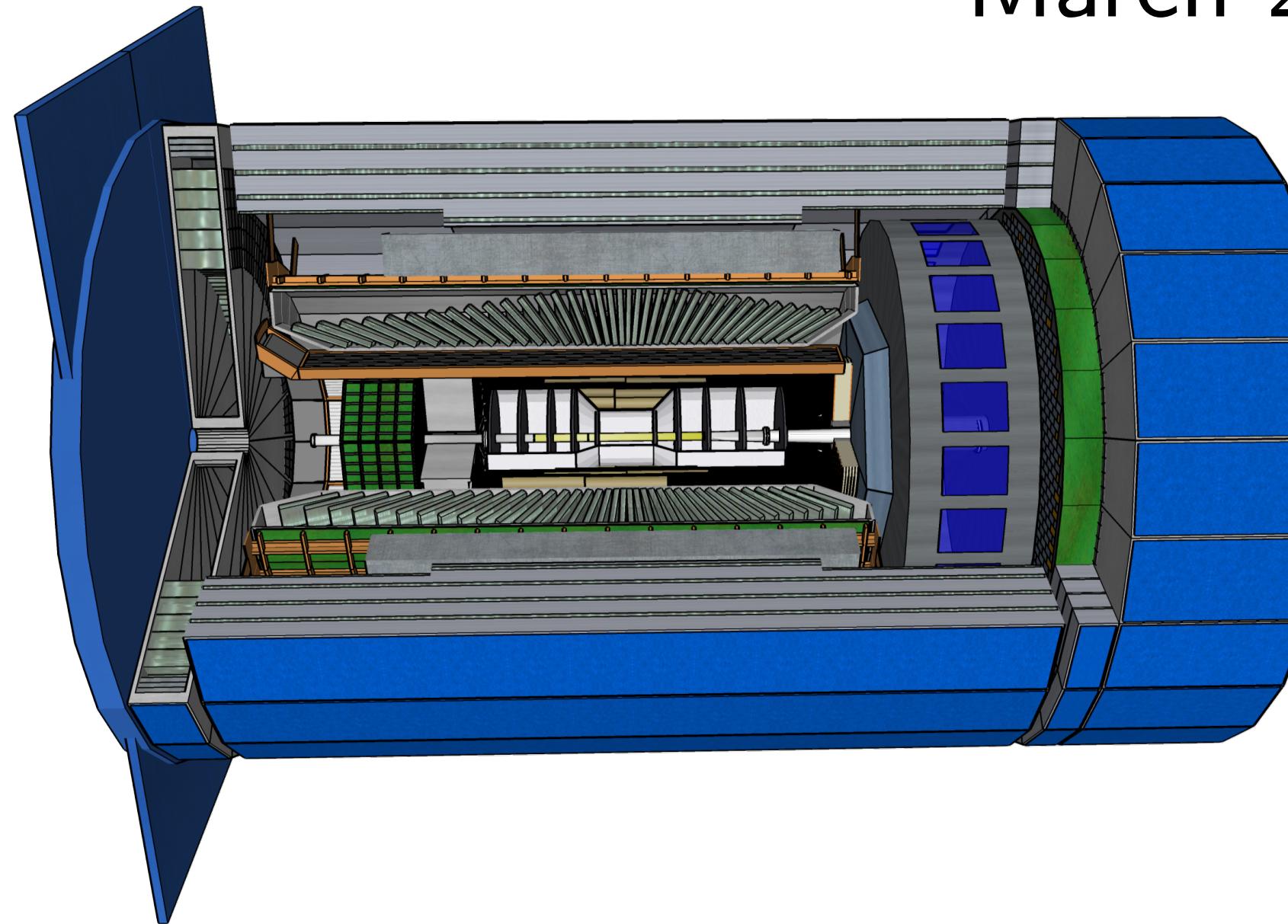
Tyler Kutz (MIT)

with Claire Gwenlan (Oxford), Paul Newman (Birmingham), and  
Barak Schmookler (UC Riverside) ***for the ePIC collaboration***

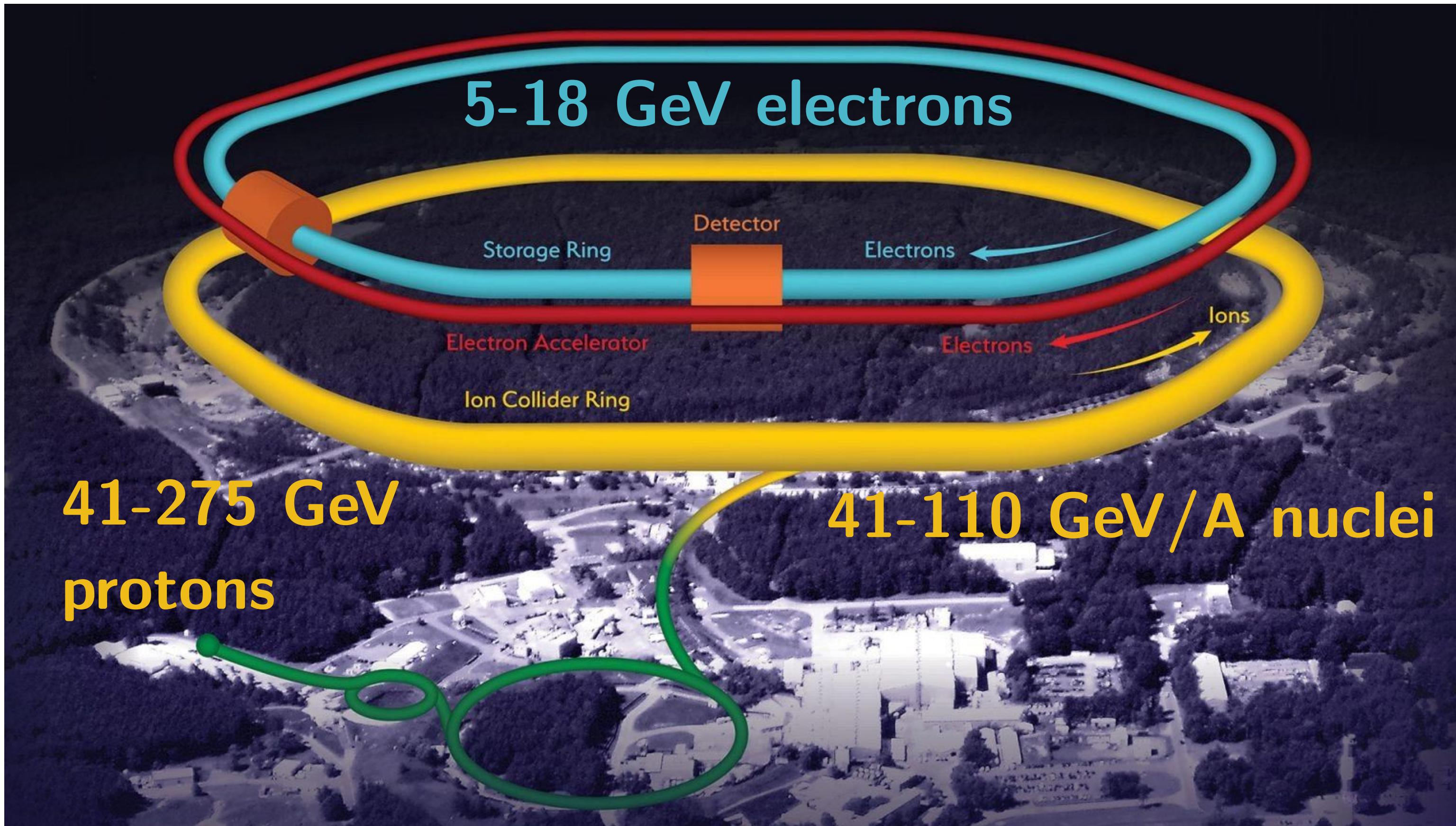
DIS2023

East Lansing, Michigan

March 29, 2023



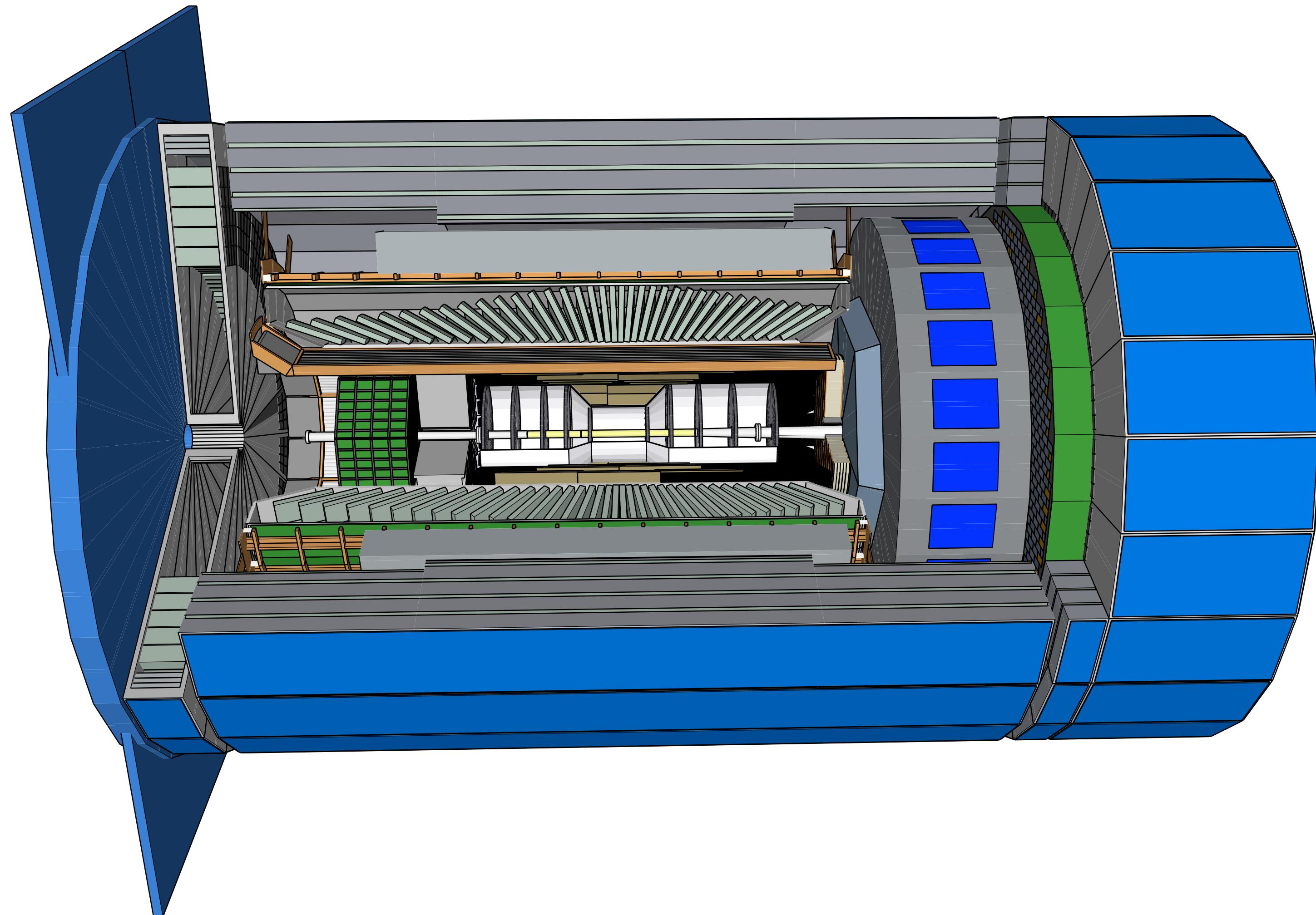
# The electron-ion collider will be built at Brookhaven National Lab



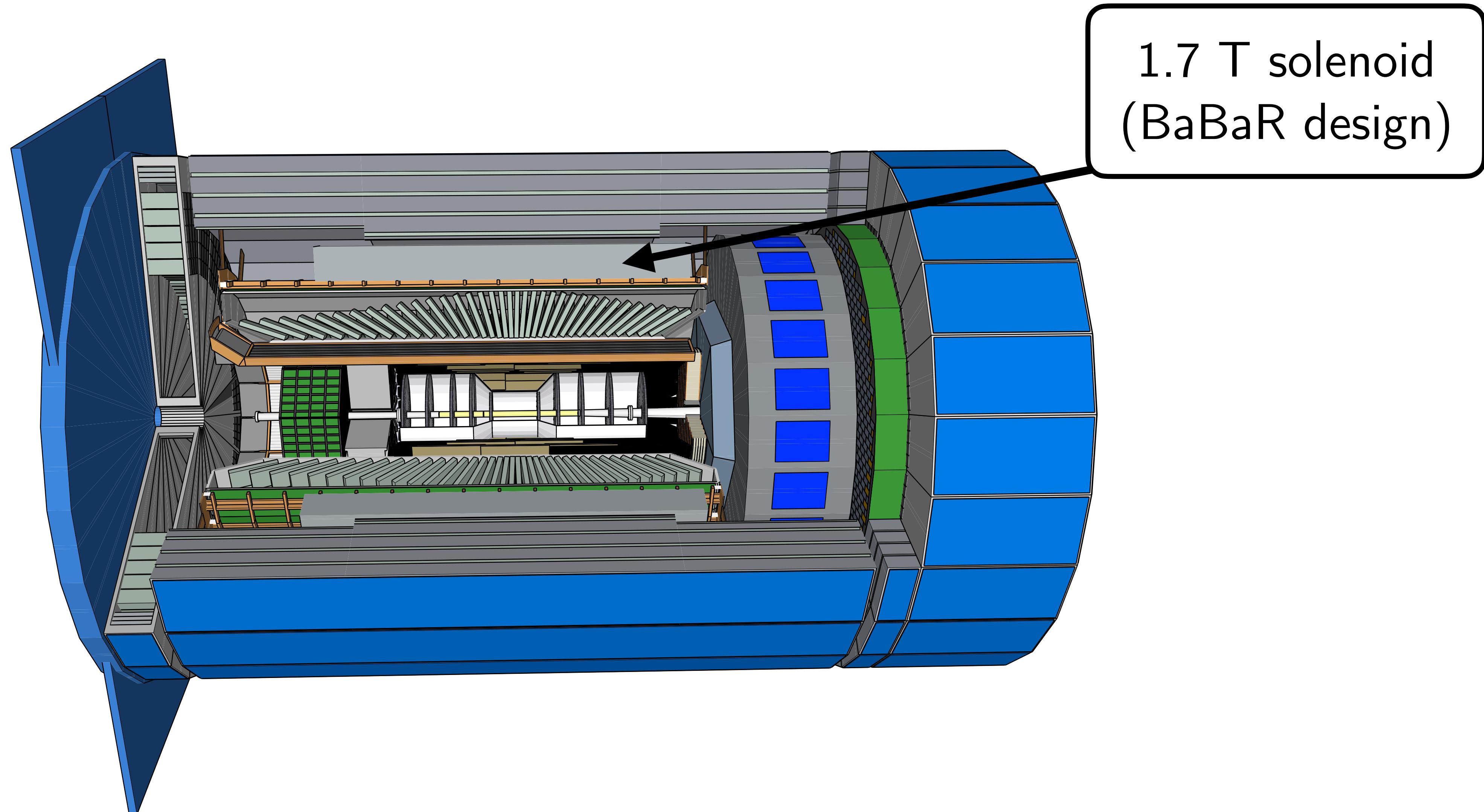
Fully polarized  $ep$ ,  $eA$  collisions

$$20 < \sqrt{s} < 140 \text{ GeV}$$

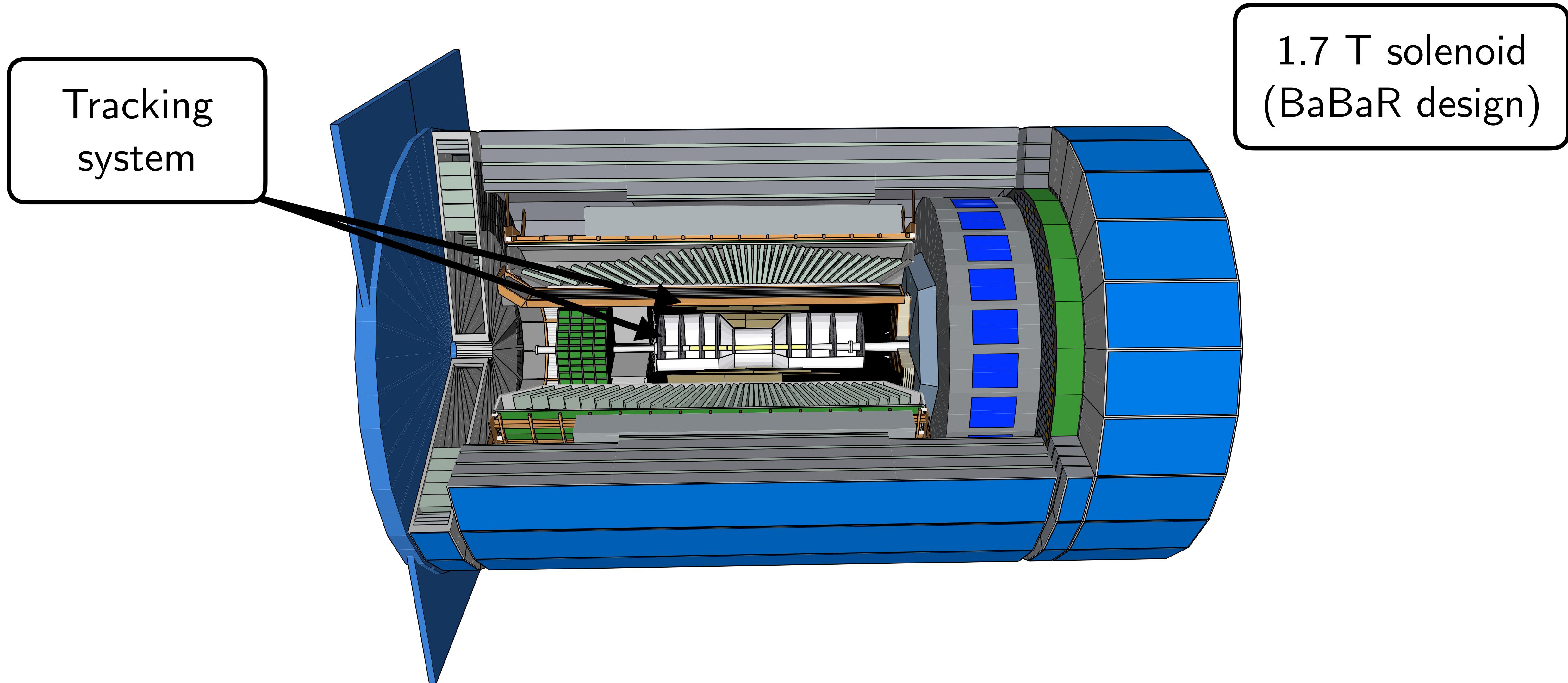
# Electron-proton/ion collider (ePIC) experiment



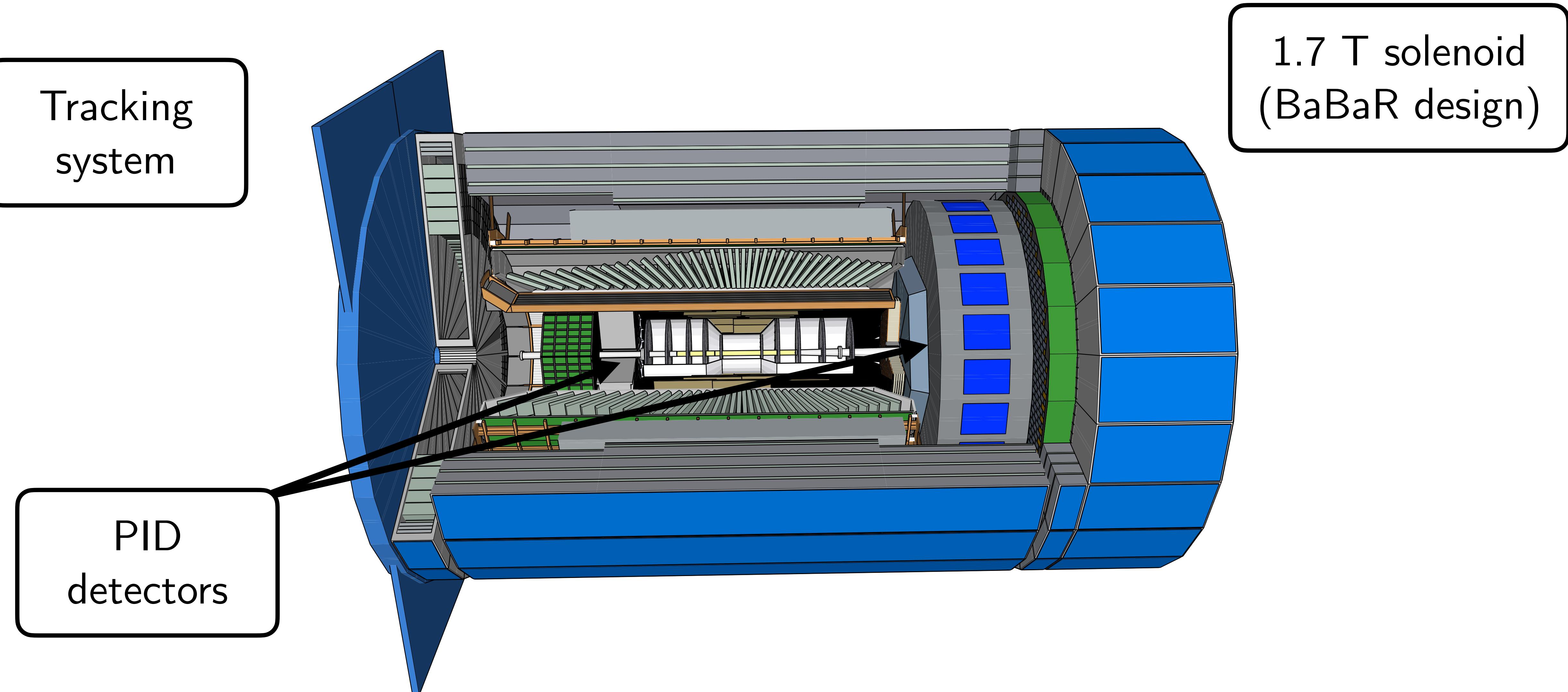
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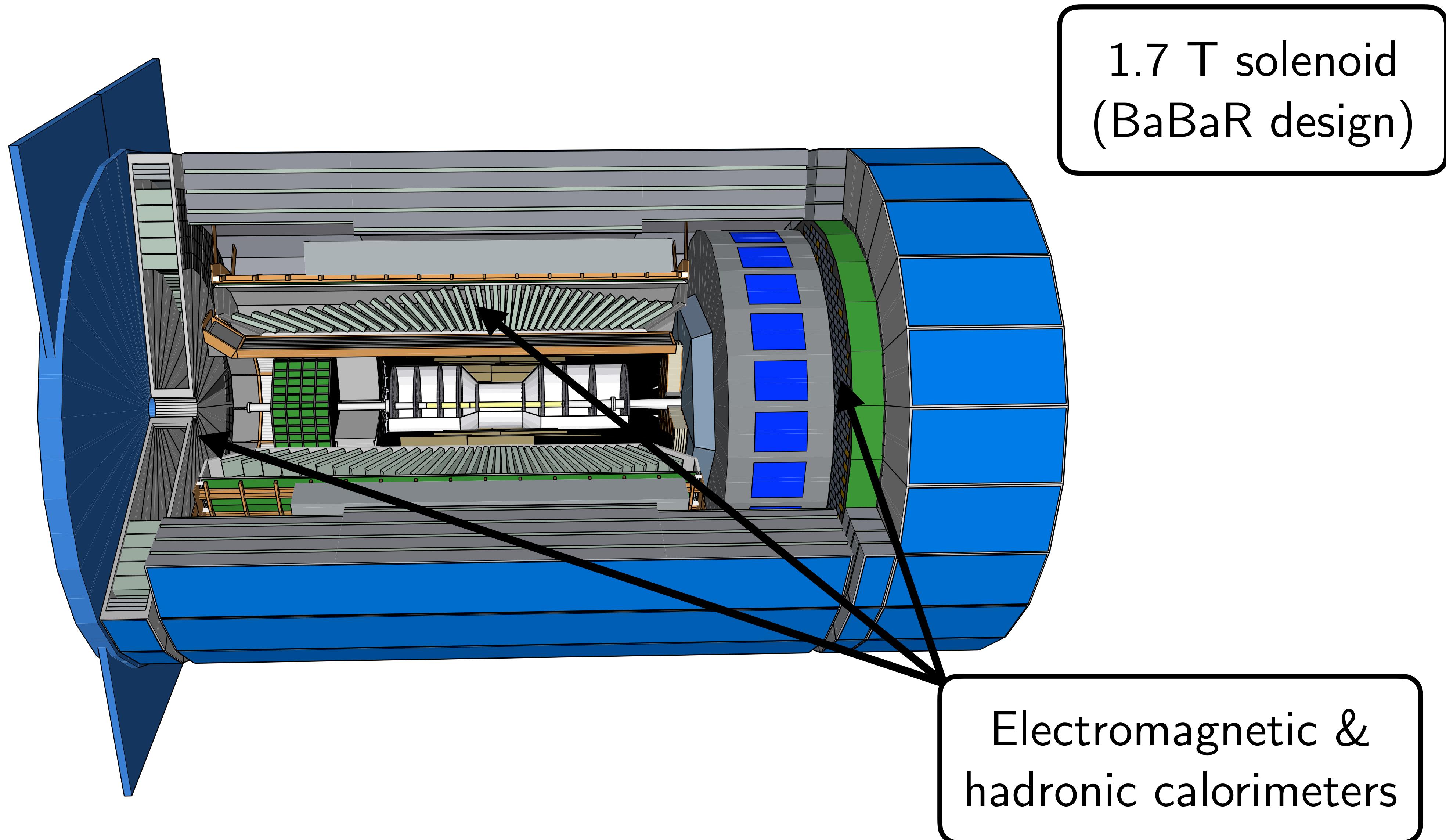
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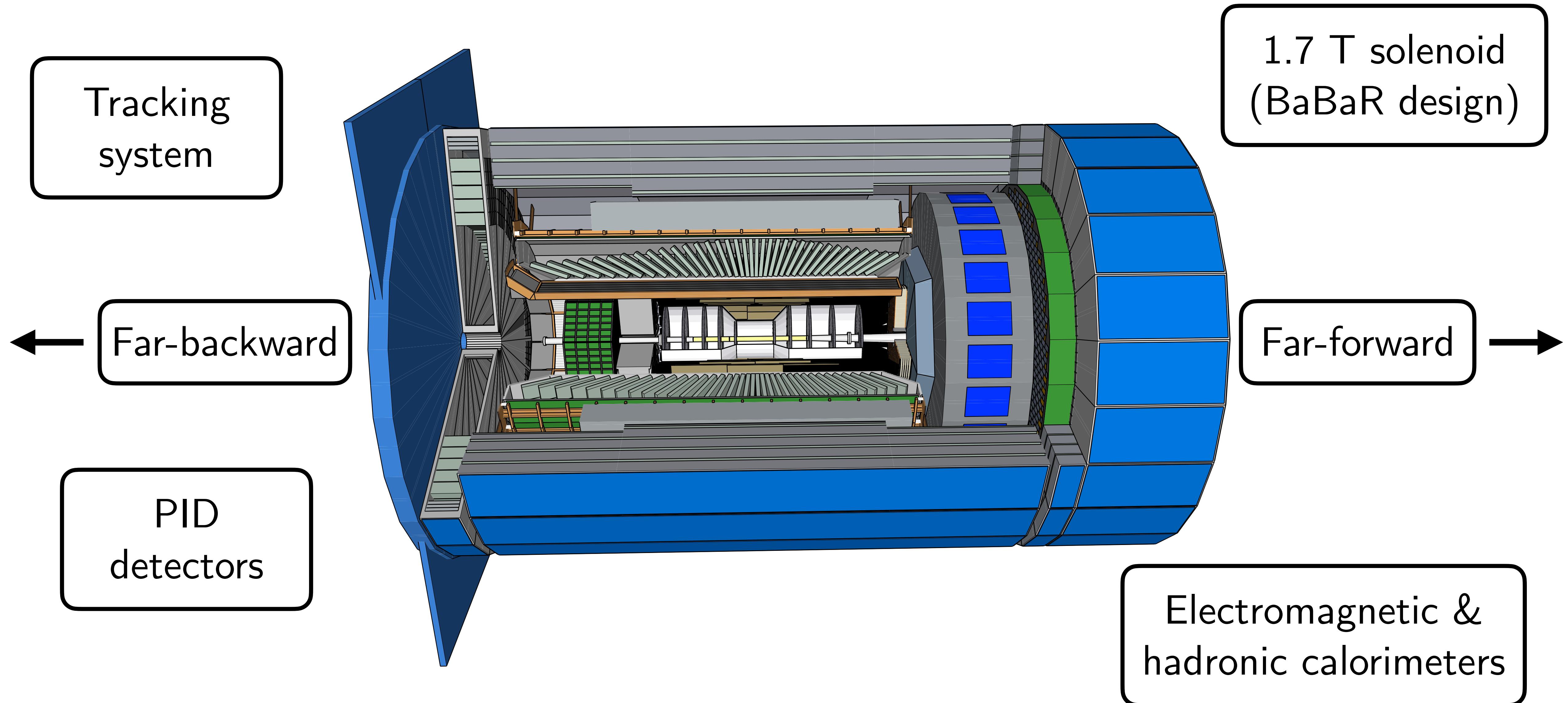
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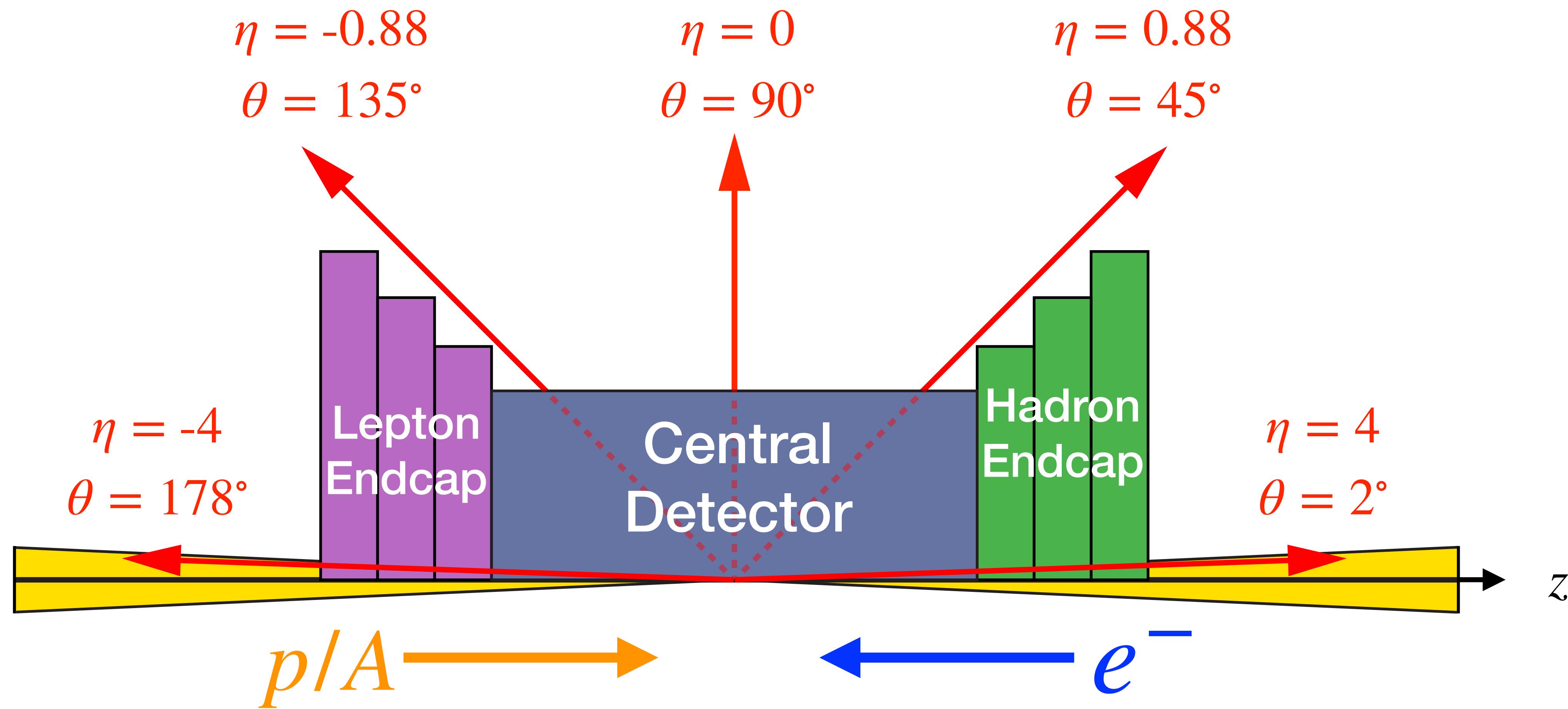
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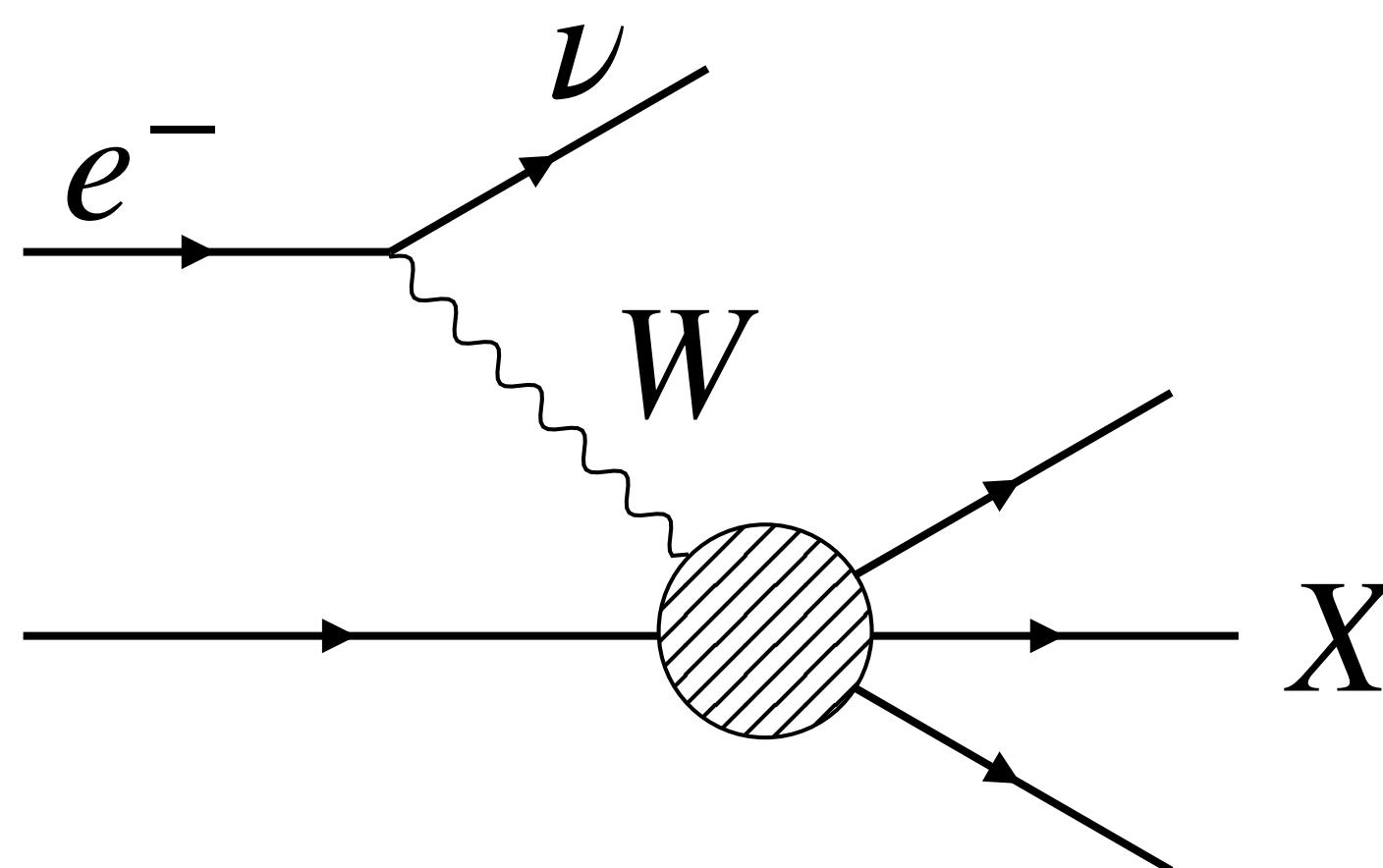
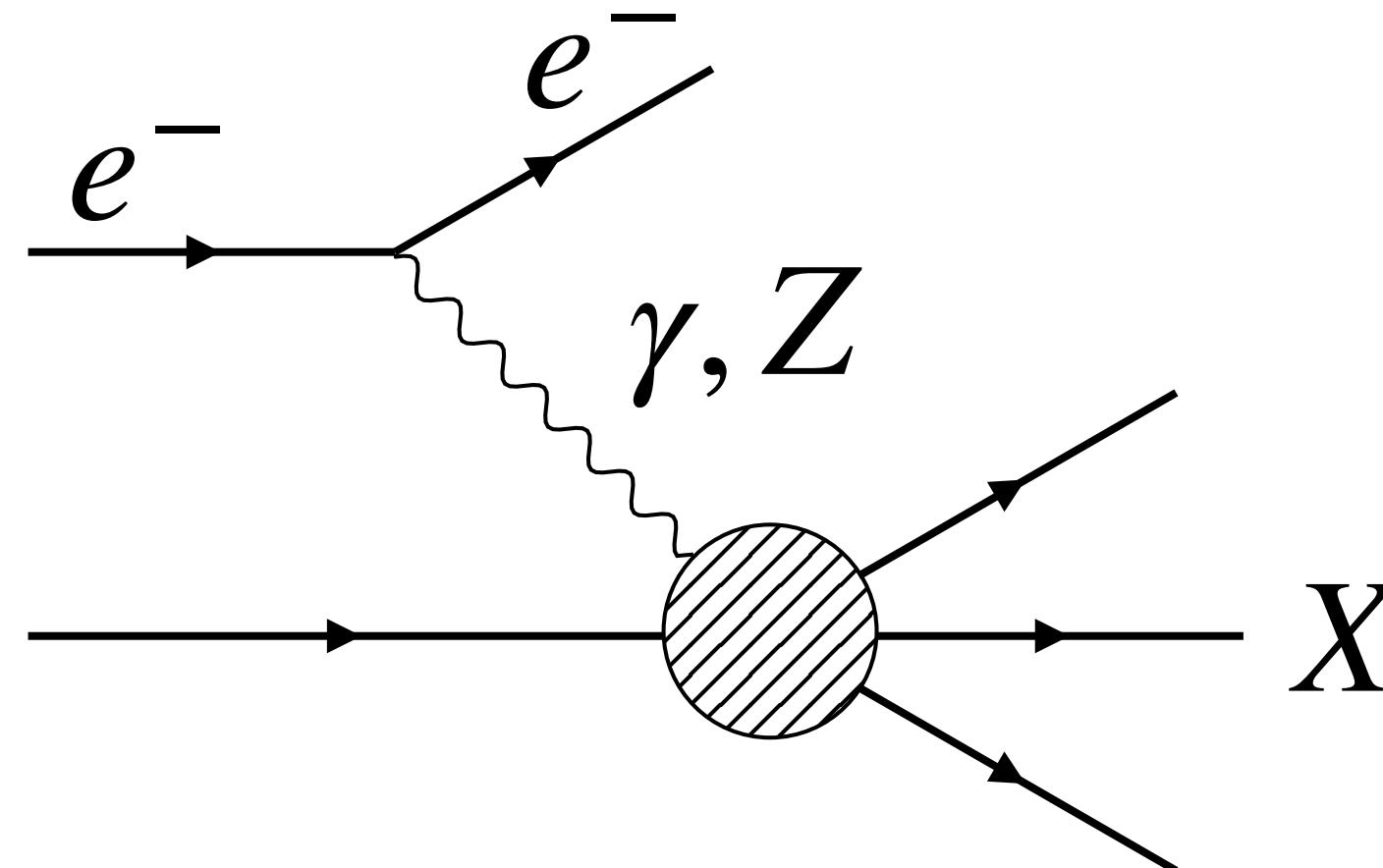
# Electron-proton/ion collider (ePIC) experiment



ePIC must provide excellent electron acceptance and reconstruction over wide phase space



# Inclusive kinematics



$$Q^2 = -q^2 = -(k - k')^2$$

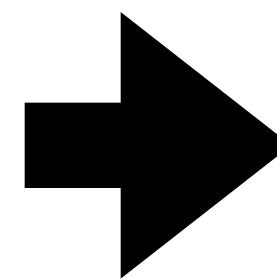
$$x_B = \frac{Q^2}{2p \cdot q} \approx \frac{Q^2}{sy}$$

- Reconstruct from scattered electron *or* hadronic final state
- Leverage over-constrained kinematics to maximize resolution in NC processes
- Must use hadronic final state for CC processes
- Working towards advanced reconstruction methods:
  - Energy/particle flow for hadronic final state
  - Kinematic fitting (stay for next talk by S. Maple)

# Inclusive observables and underlying physics

- Reduced cross sections

$$\sigma_{red}(x_B, Q^2) \rightarrow F_2, F_L$$



- Nucleon PDFs

$$q(x_B, Q^2), g(x_B, Q^2)$$

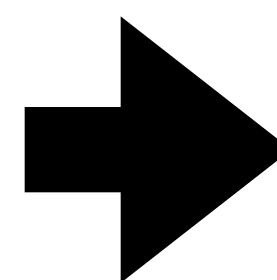
- Nuclear PDFs

$$q(x_B, Q^2), g(x_B, Q^2)$$

- Nonlinear QCD dynamics

- Double-spin asymmetries

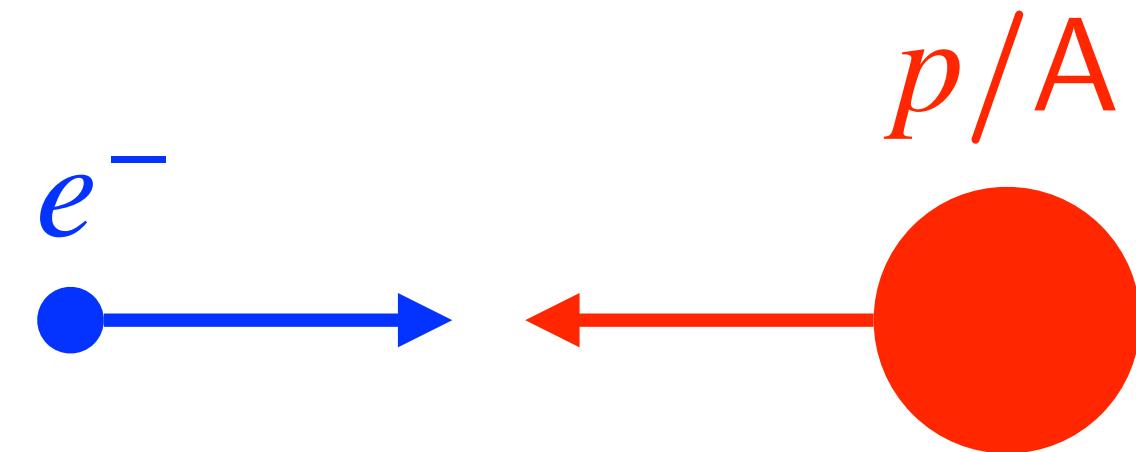
$$A_{\parallel}, A_{\perp} \rightarrow A_1$$



- Quark and gluon helicity

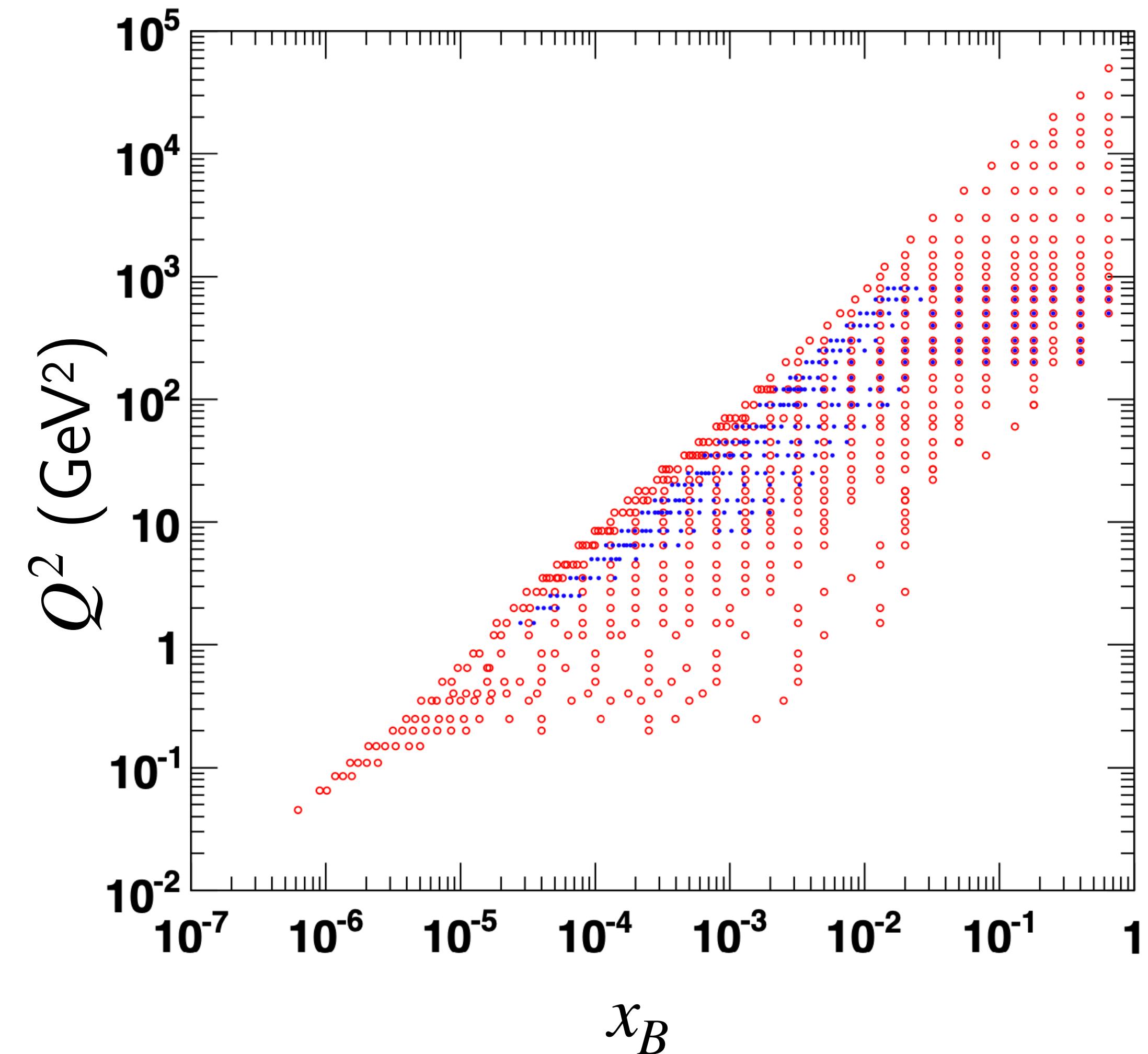
$$\Delta q(x_B, Q^2), \Delta g(x_B, Q^2)$$

# Inclusive cross sections

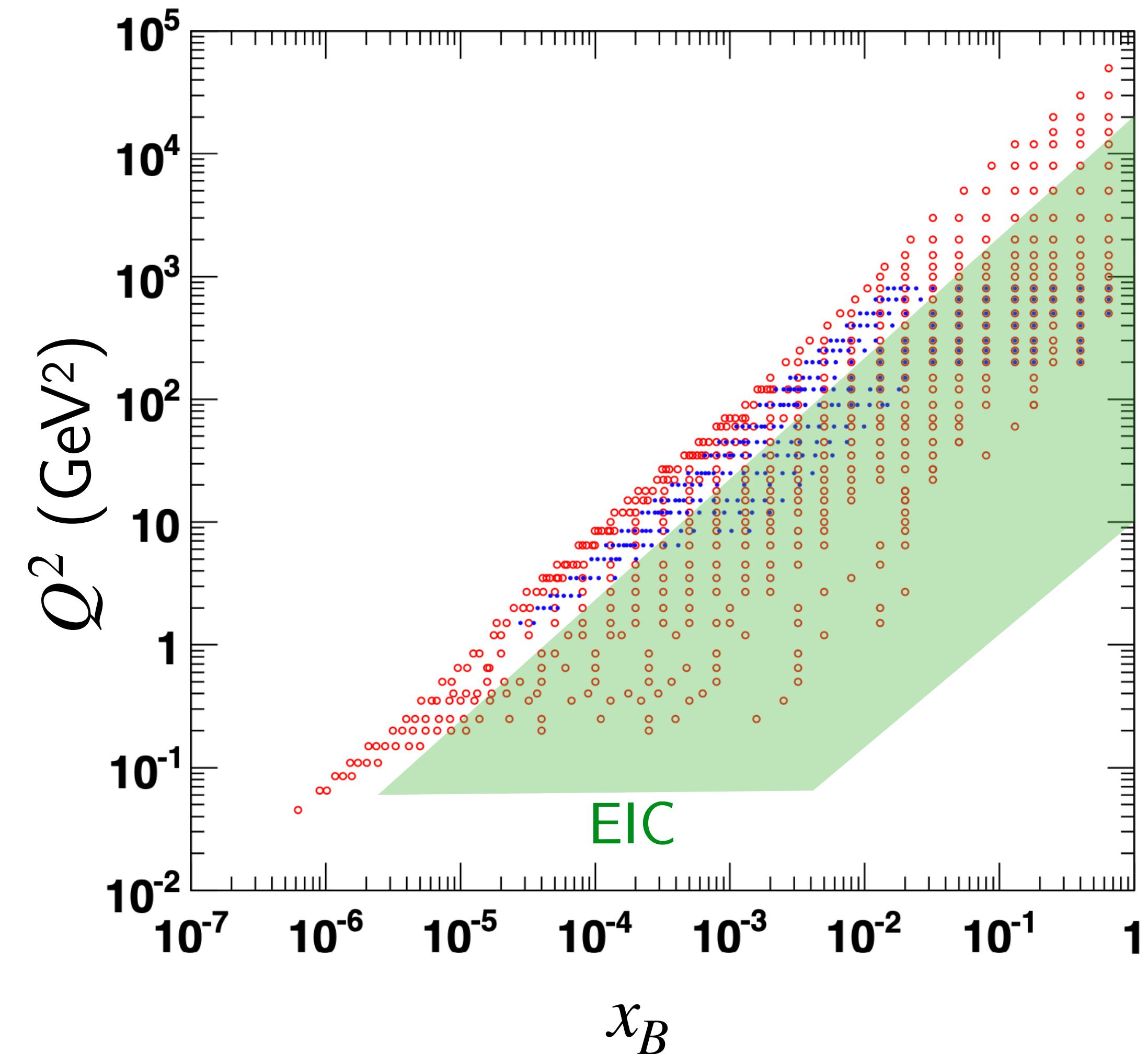


- Unpolarized reduced cross sections  $\sigma_{red}(x_B, Q^2)$
- Obtain  $F_2, F_L$  from Rosenbluth separation
  - Must utilize multiple beam energies to increase  $y$  lever arm
- Proton and light nuclei (deuterium and helium-3) for nucleon structure
- Heavier nuclei for nuclear modification, gluon saturation studies

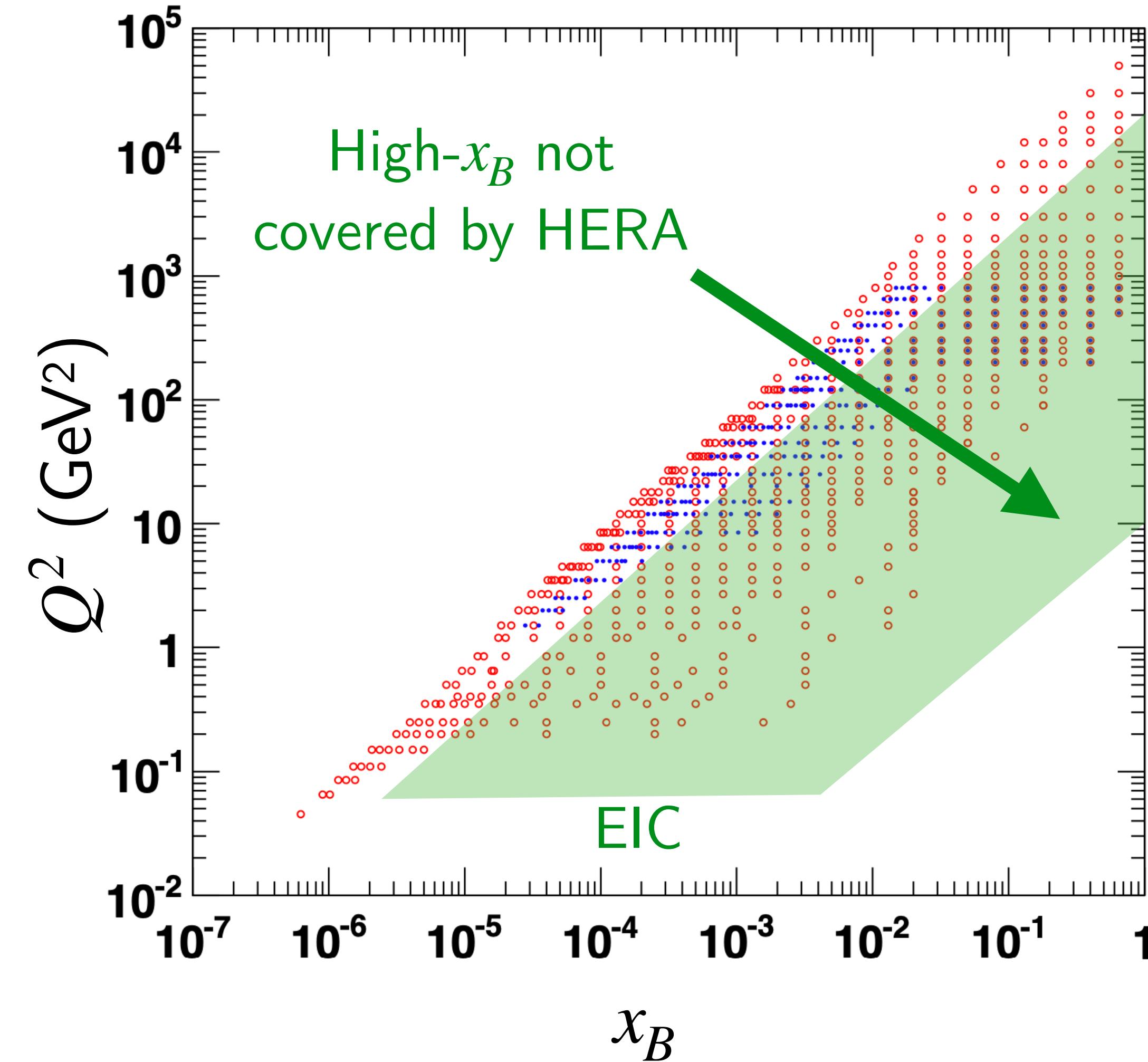
# Projected impact on proton PDFs



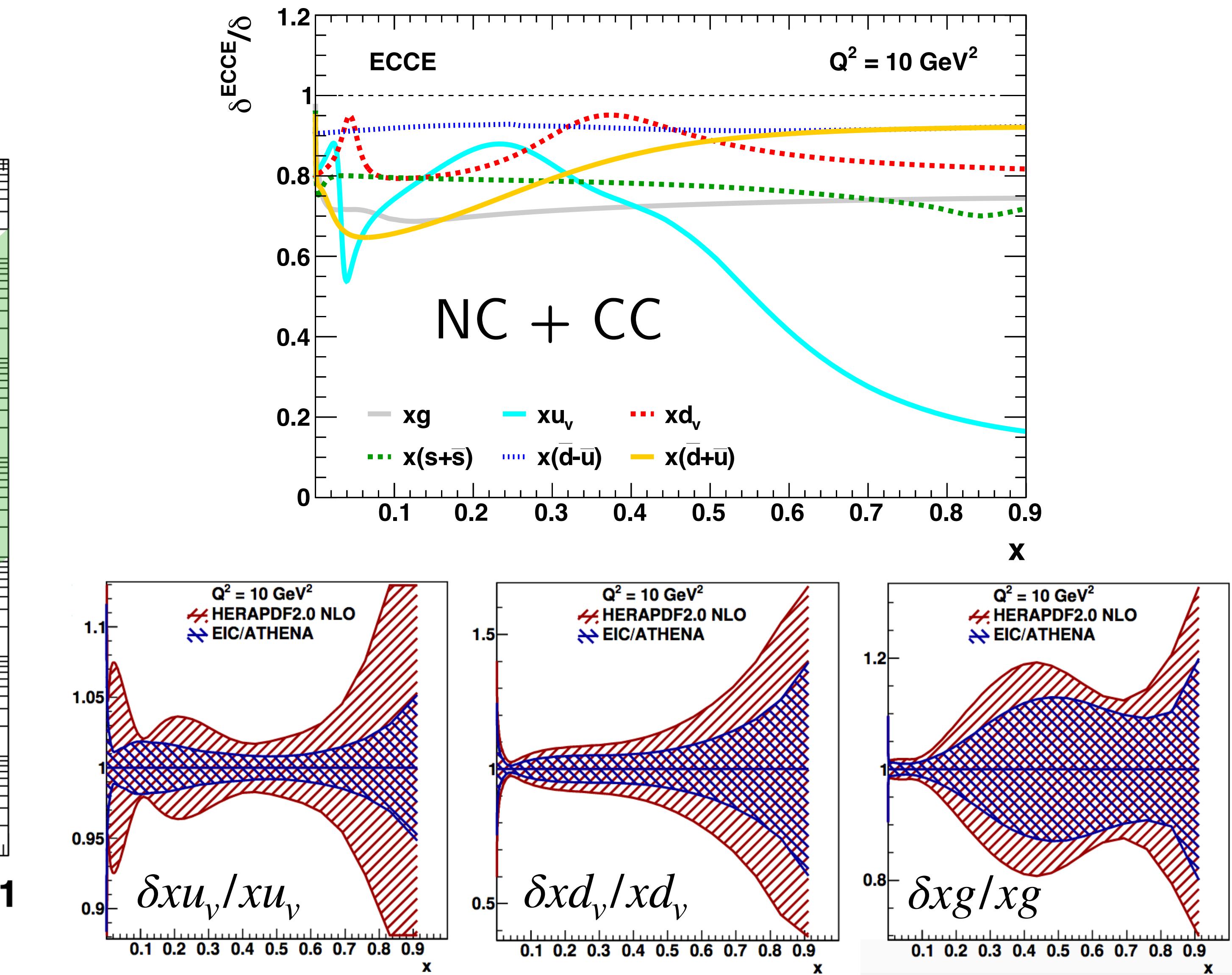
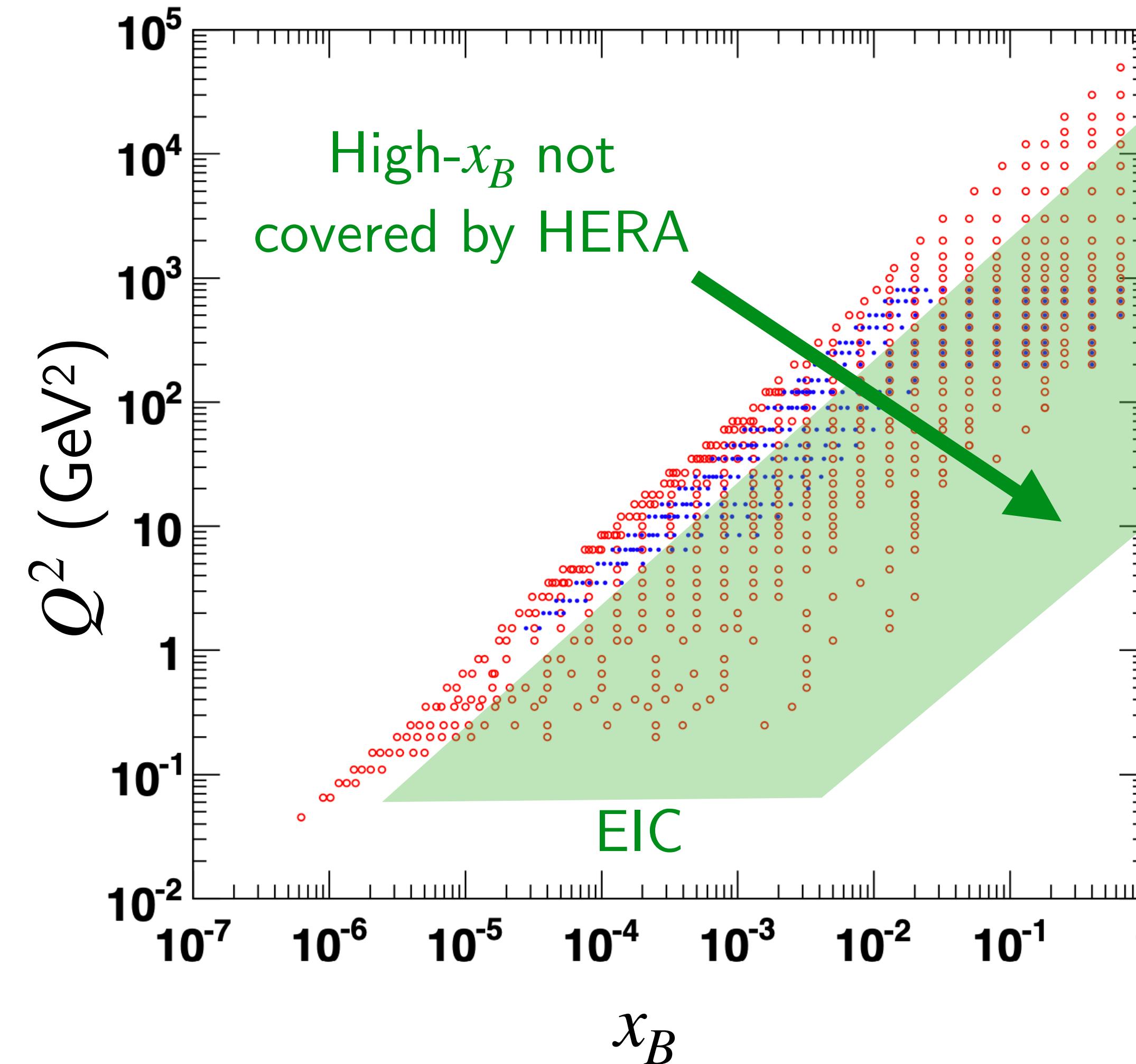
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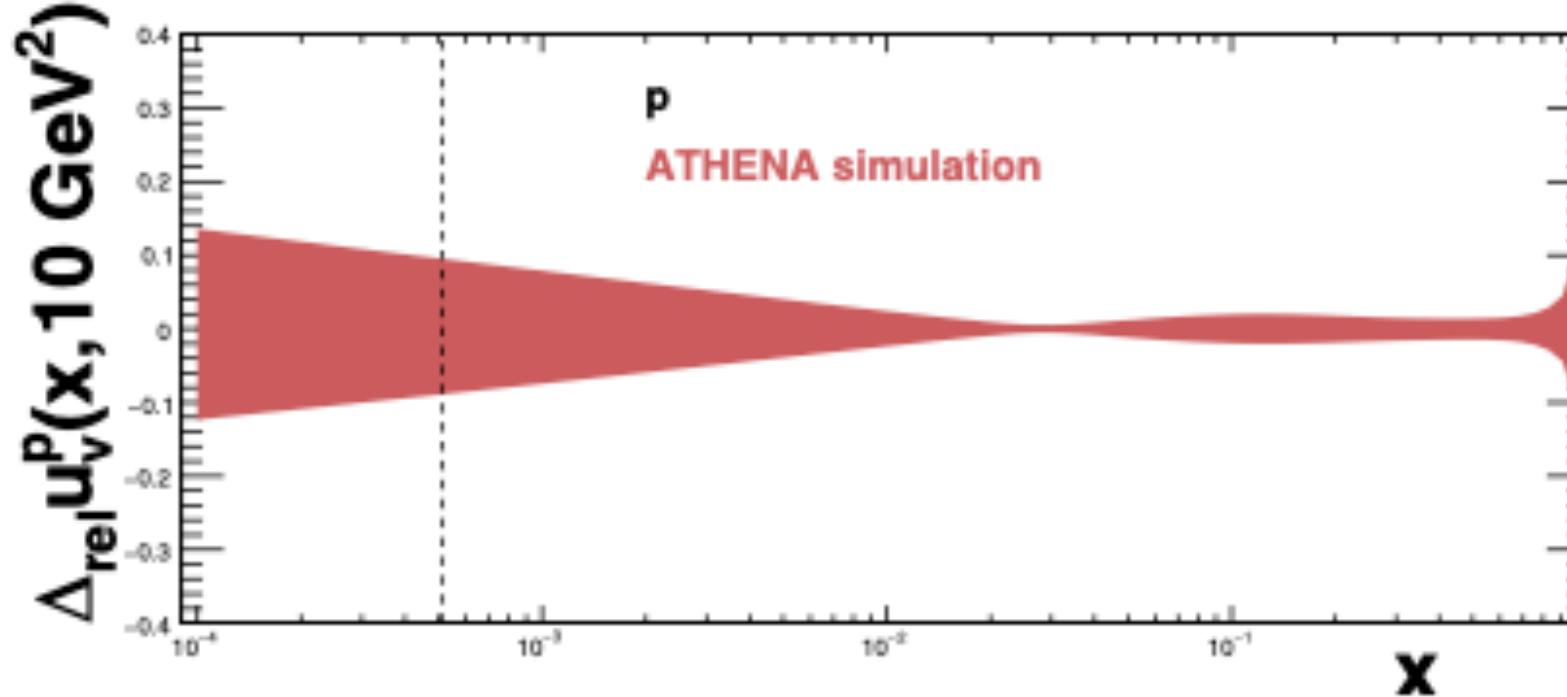
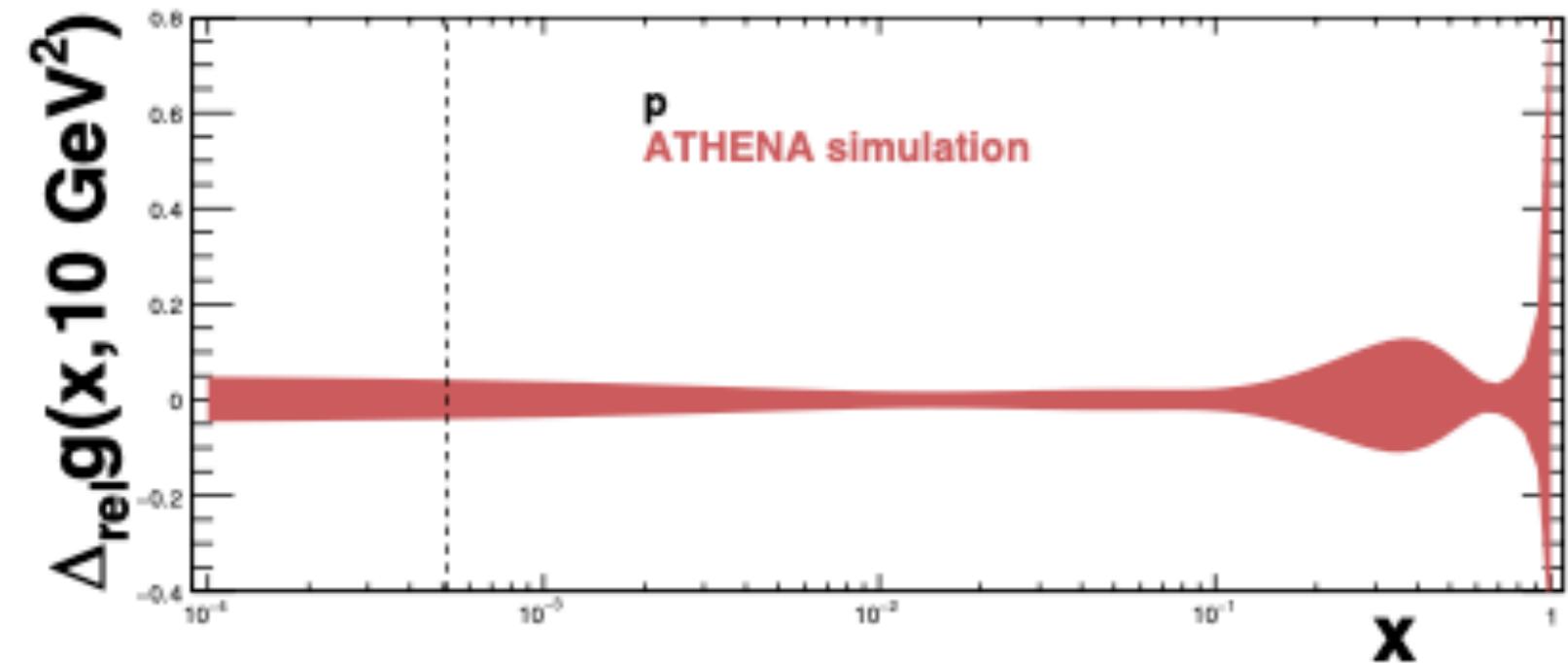
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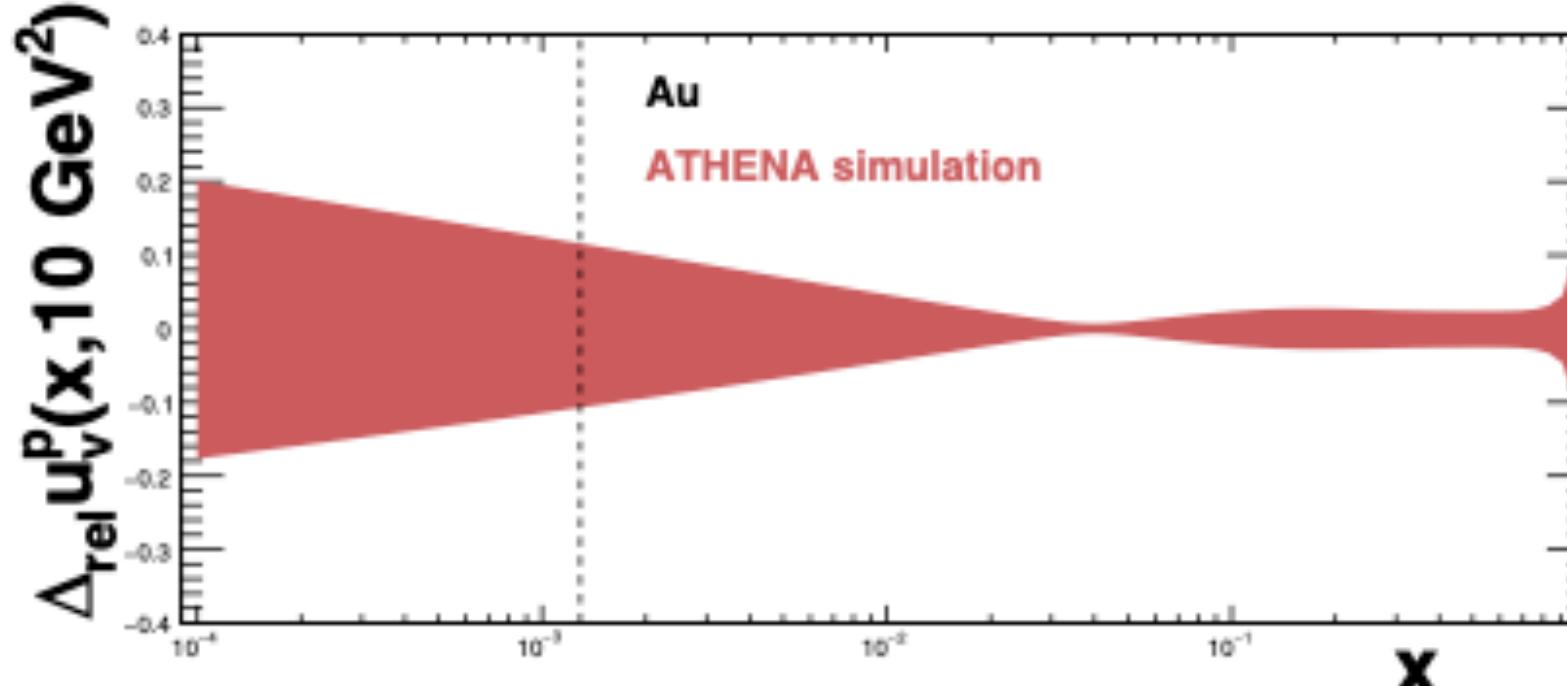
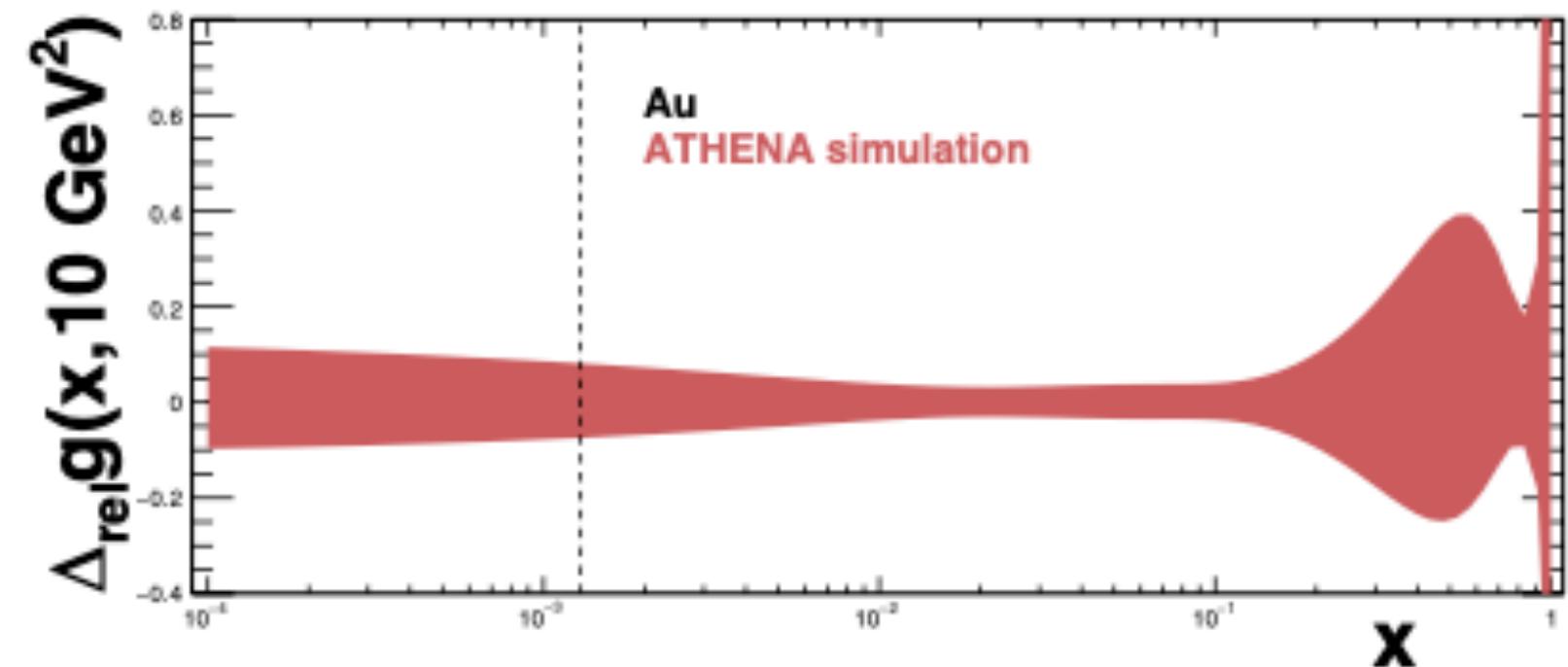
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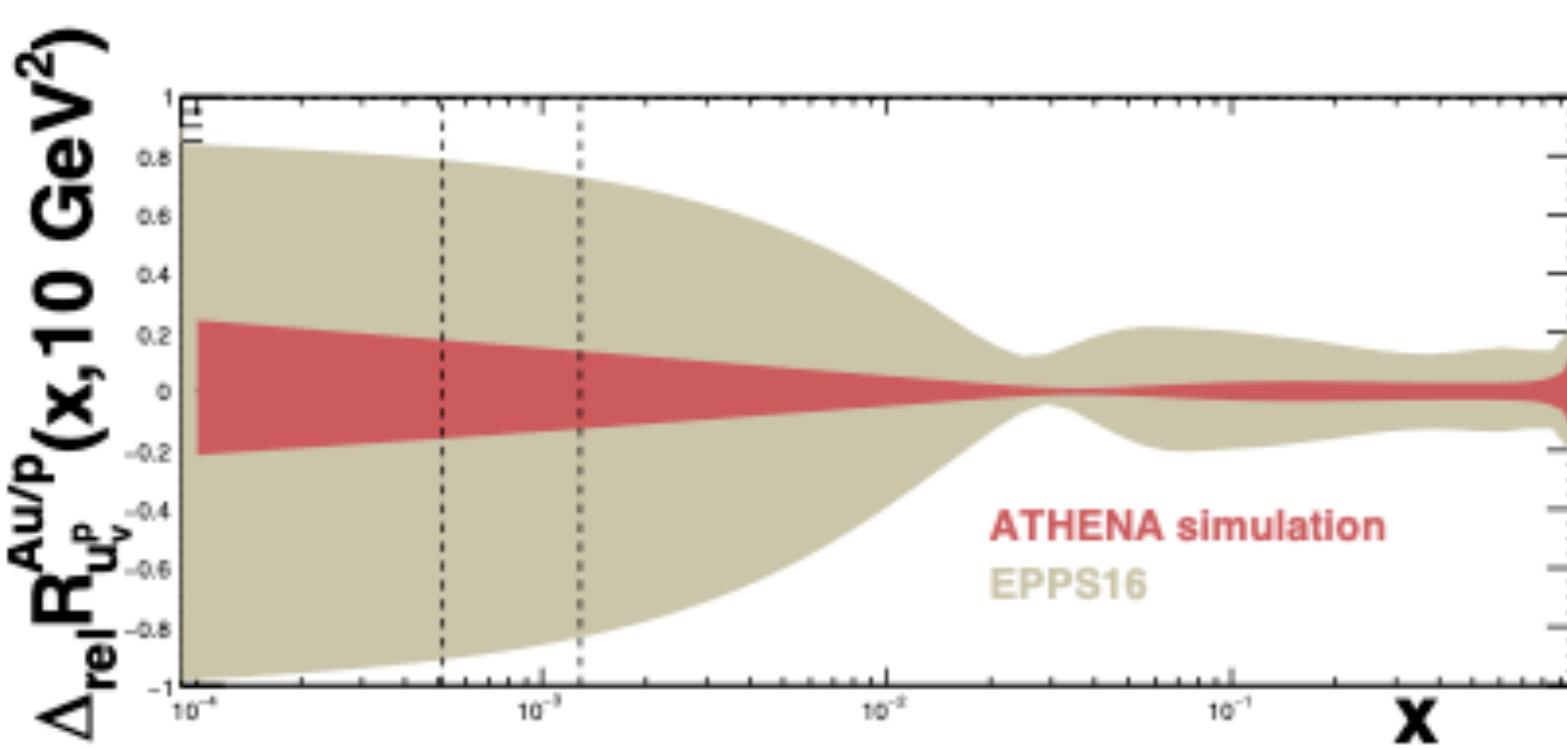
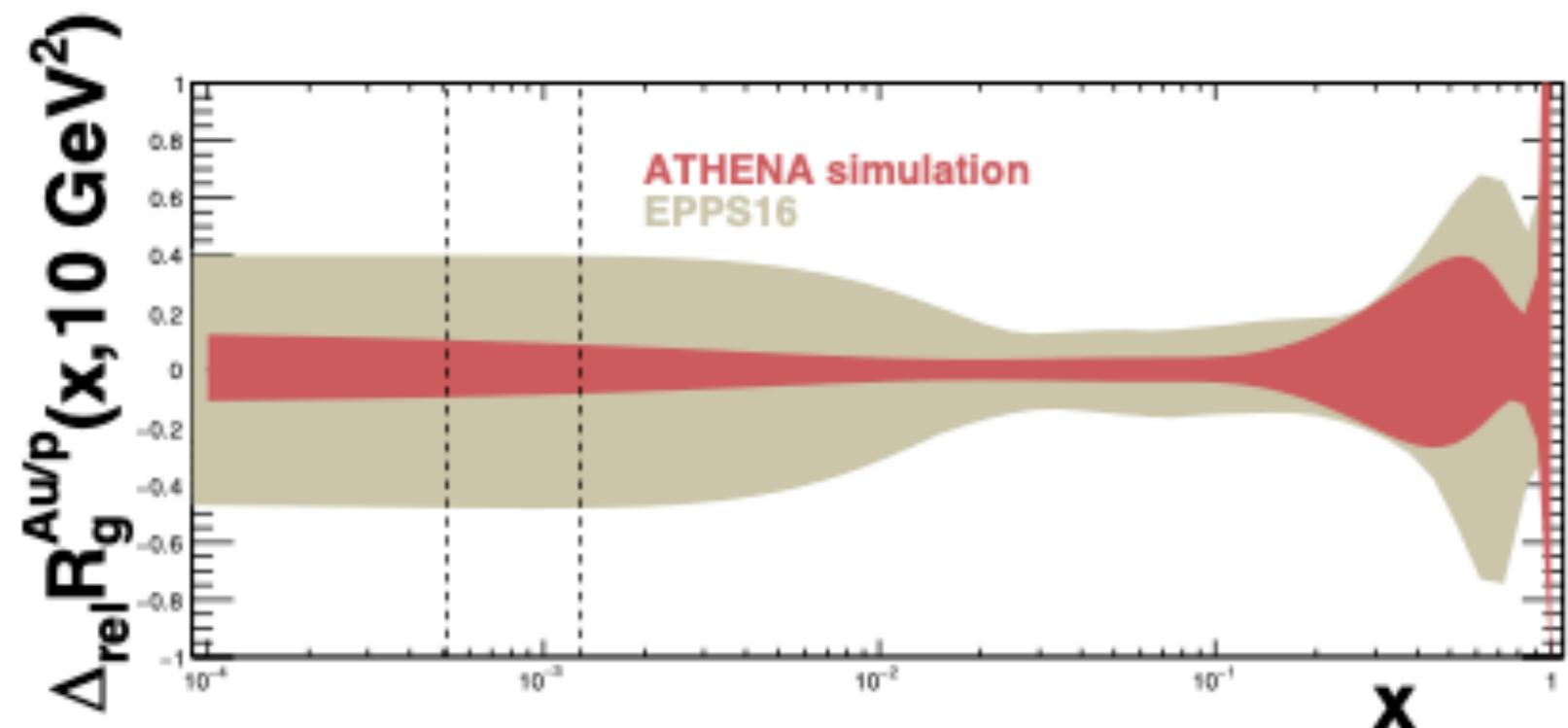
# Impact of on nuclear PDFs



$$f^p(x, Q^2)$$

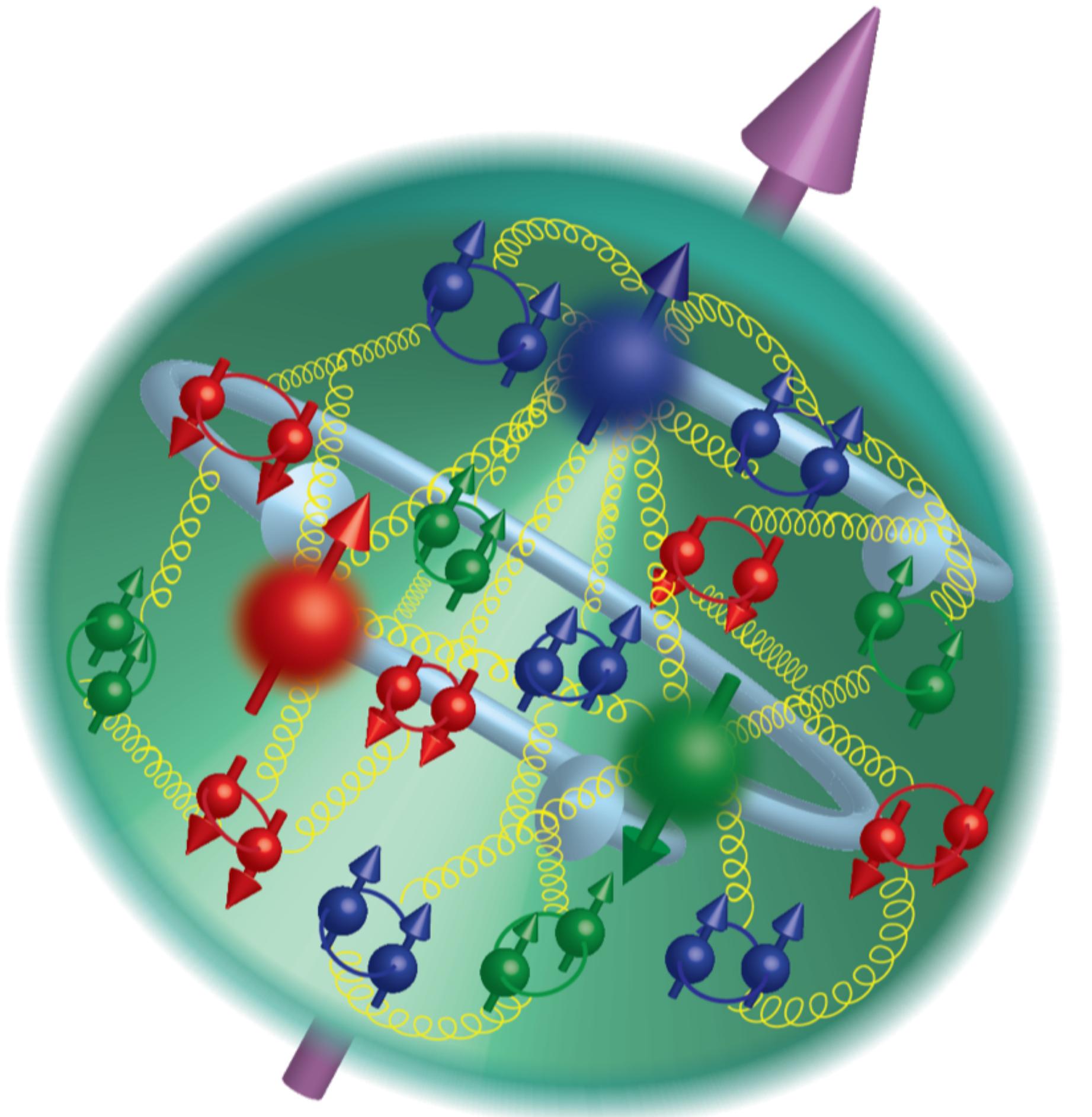


$$f^{p/A}(x, Q^2)$$



$$R(x, Q^2) = f^{p/A} / f^p$$

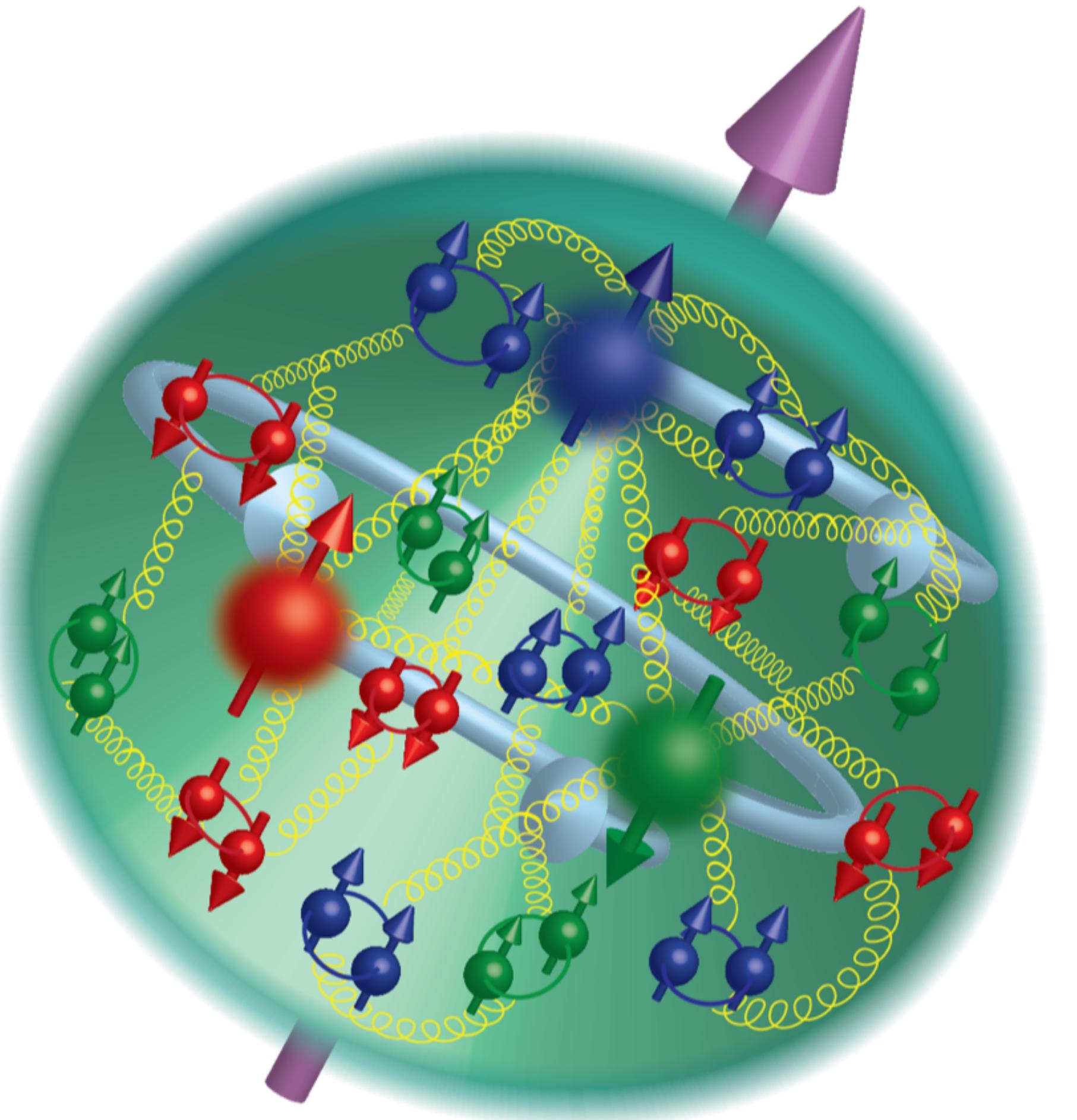
# Origin of nucleon spin



# Origin of nucleon spin

Quark spin

$$\Delta\Sigma = \int_x \sum_q (\Delta q + \Delta \bar{q})$$



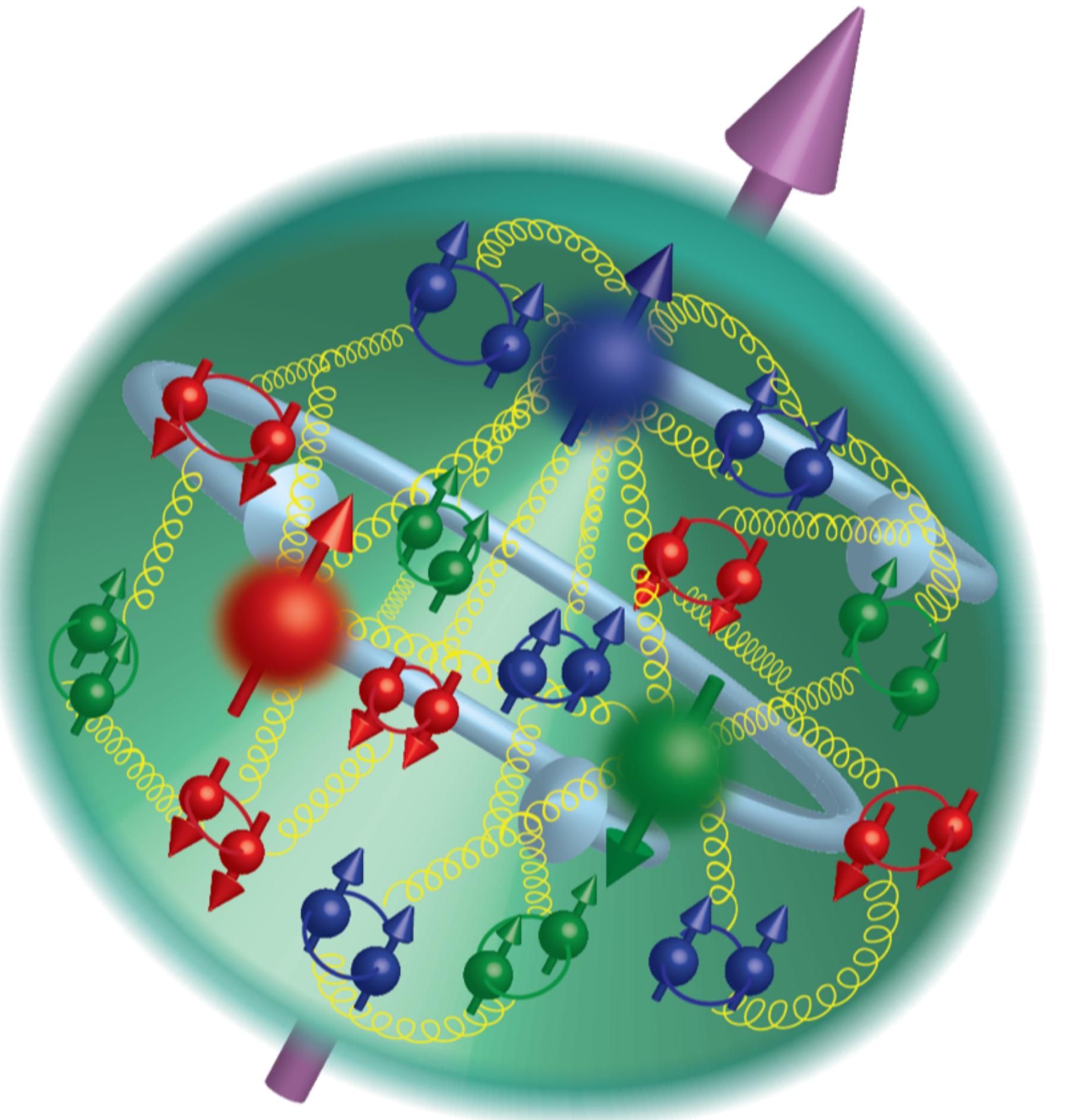
# Origin of nucleon spin

Quark spin

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Quark orbital  
angular momentum

$$L_q$$



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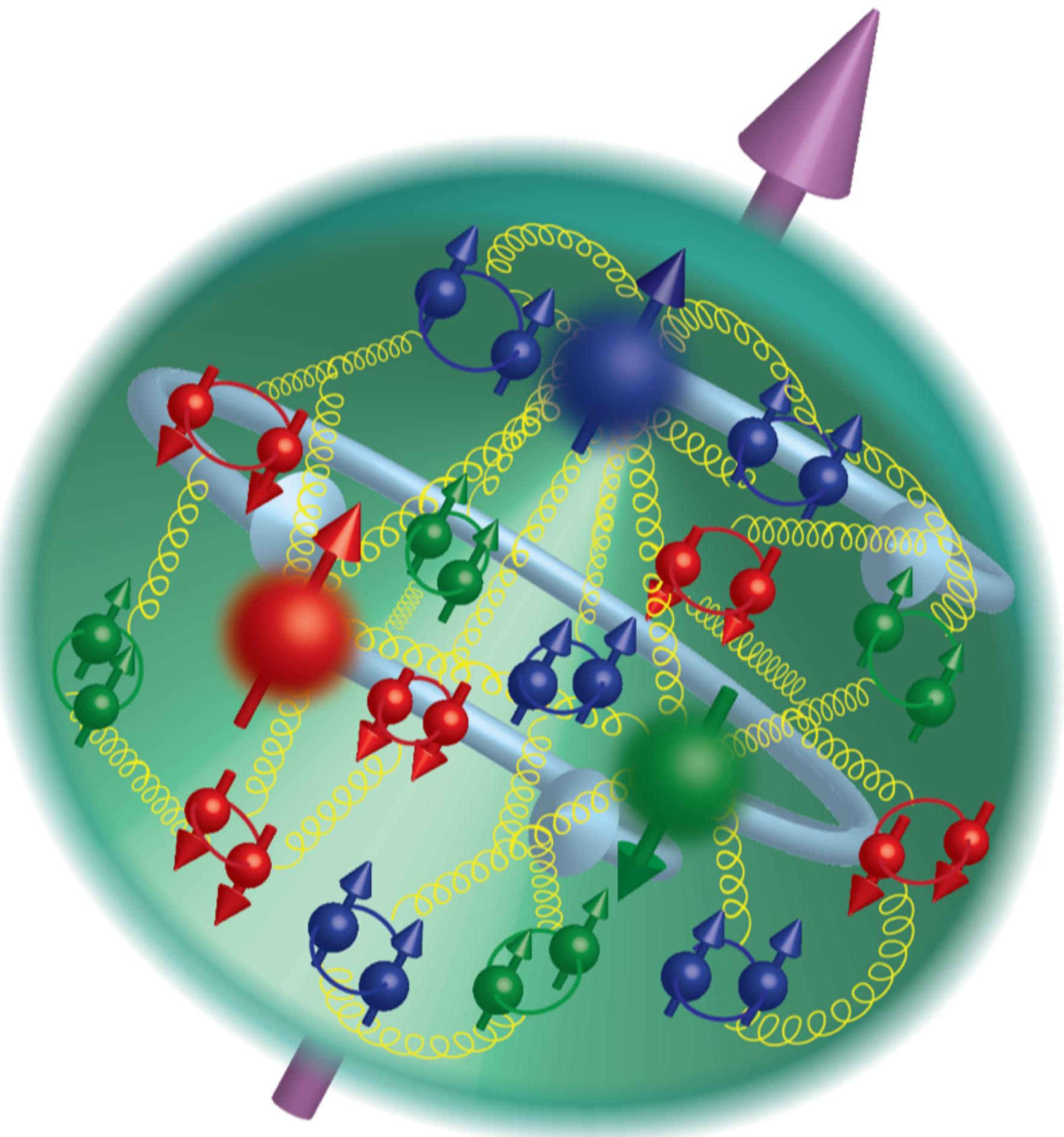
$$L_q$$

Gluon spin

$$\Delta G = \int_x \Delta g$$

Quark orbital  
angular momentum

$$L_g$$



# Origin of nucleon spin

Quark spin

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Quark orbital  
angular momentum

$$L_q$$

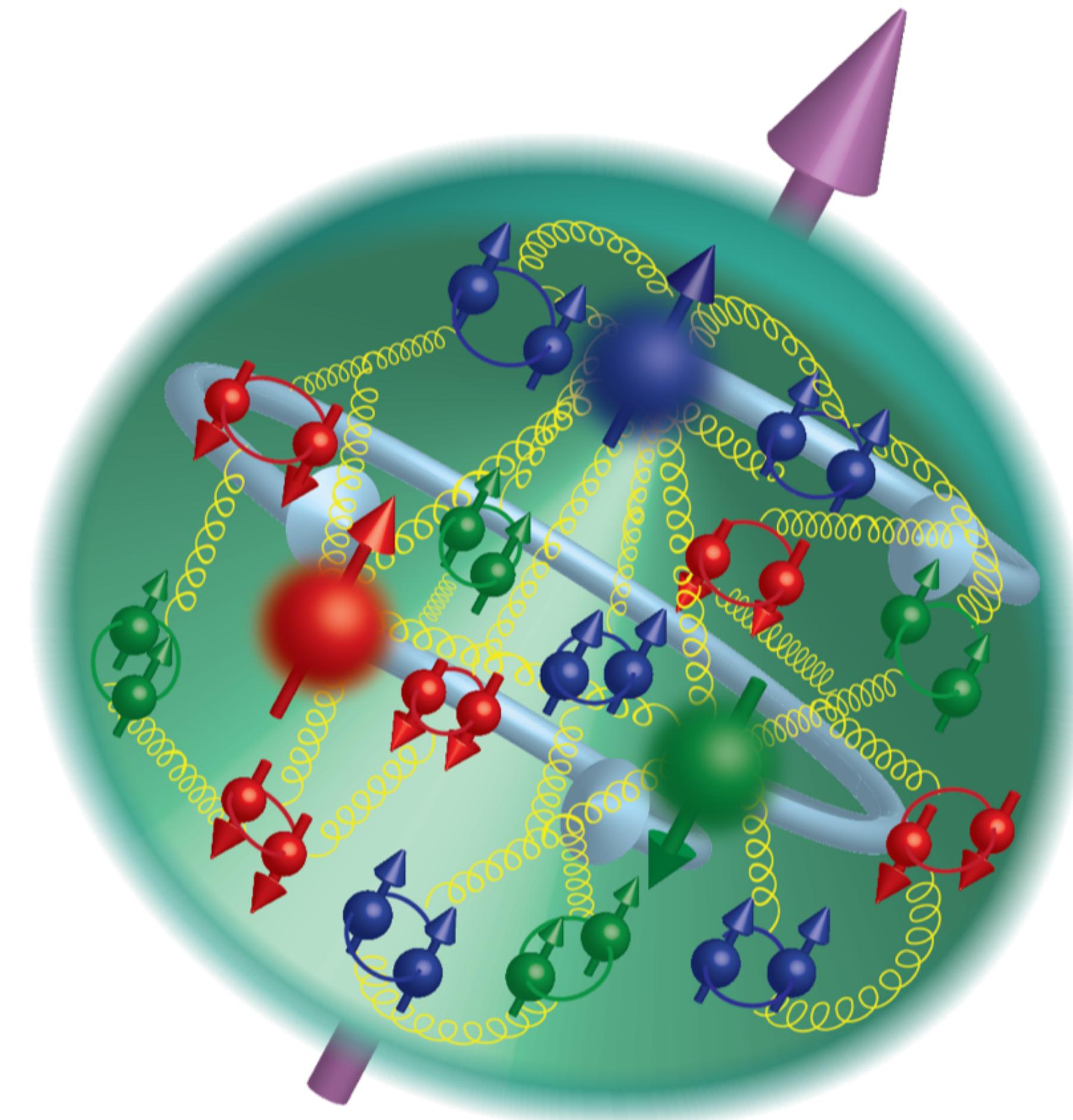
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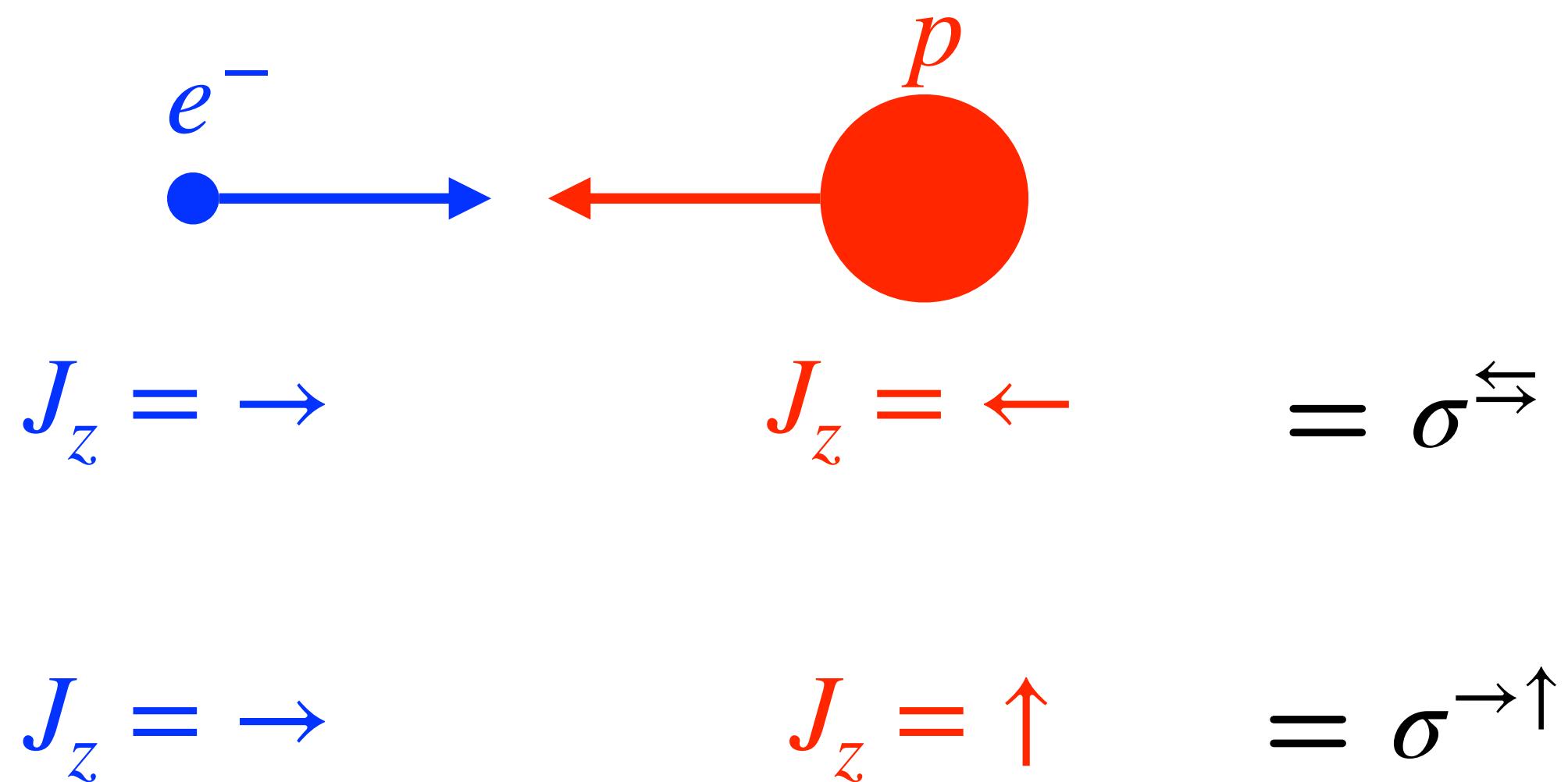
Quark orbital  
angular momentum

$$L_g$$

$$\Delta\Sigma/2 + \Delta G + L_q + L_g = \frac{1}{2}$$



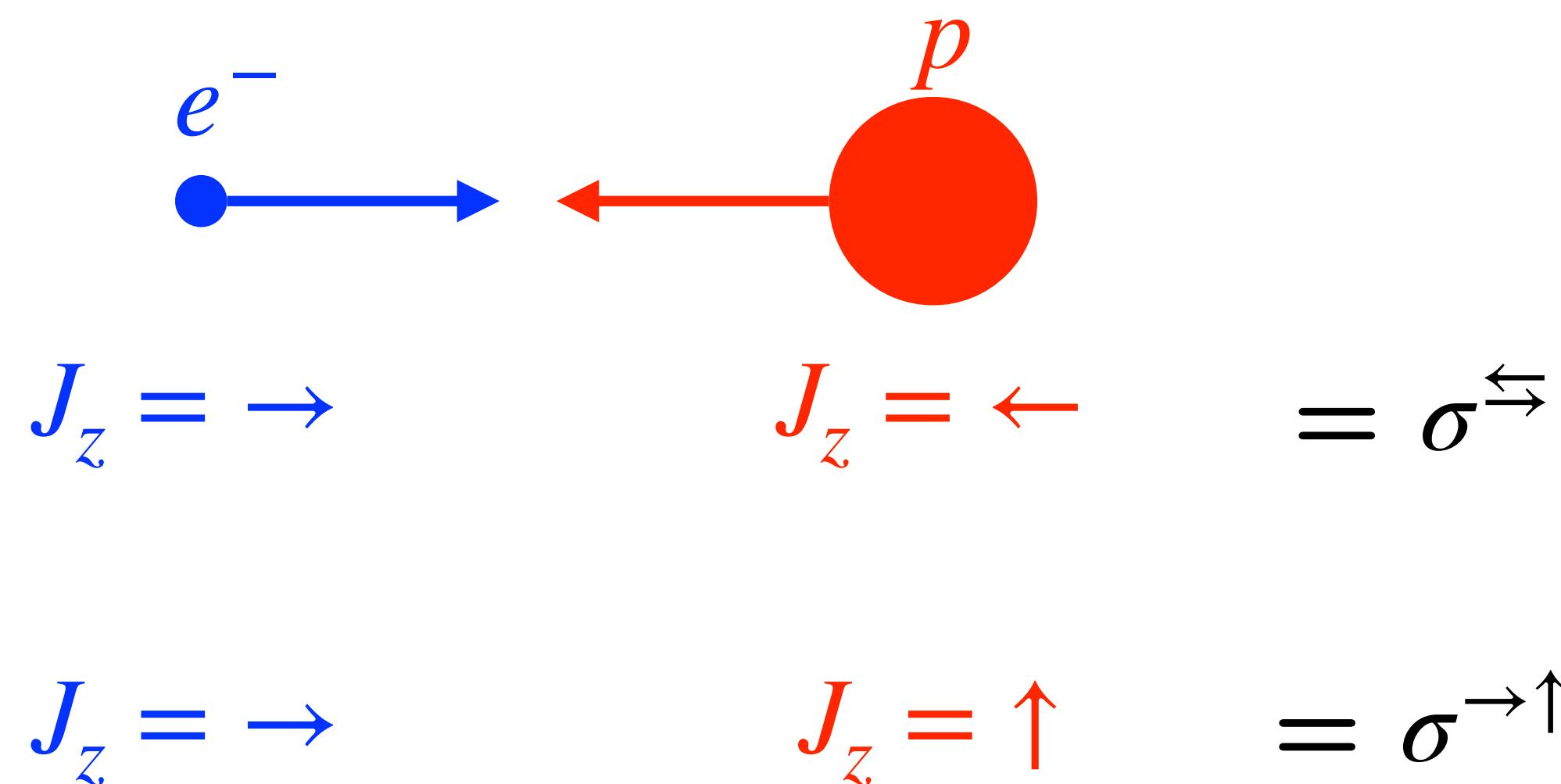
# Complementary measurements required to disentangle



## Quark & gluon helicity

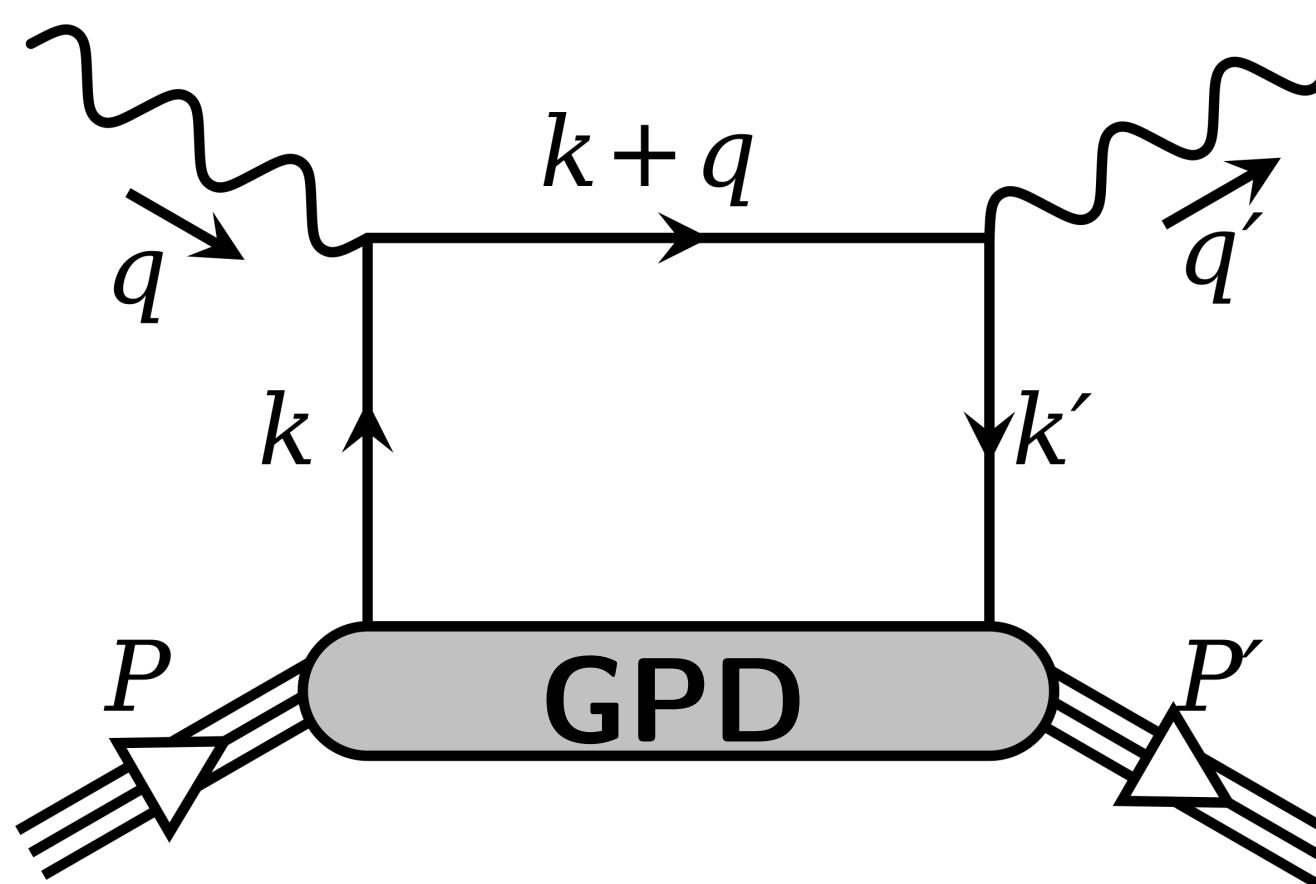
- Double-spin asymmetry  $A_{||}, A_{\perp} \rightarrow A_1$
- Sensitive to spin structure function
$$g_1(x) = \frac{1}{2} \sum_q e_q^2 (\Delta q(x) + \Delta \bar{q}(x))$$
- Gluon sensitivity from  $Q^2$  dependence

# Complementary measurements required to disentangle



## Quark & gluon helicity

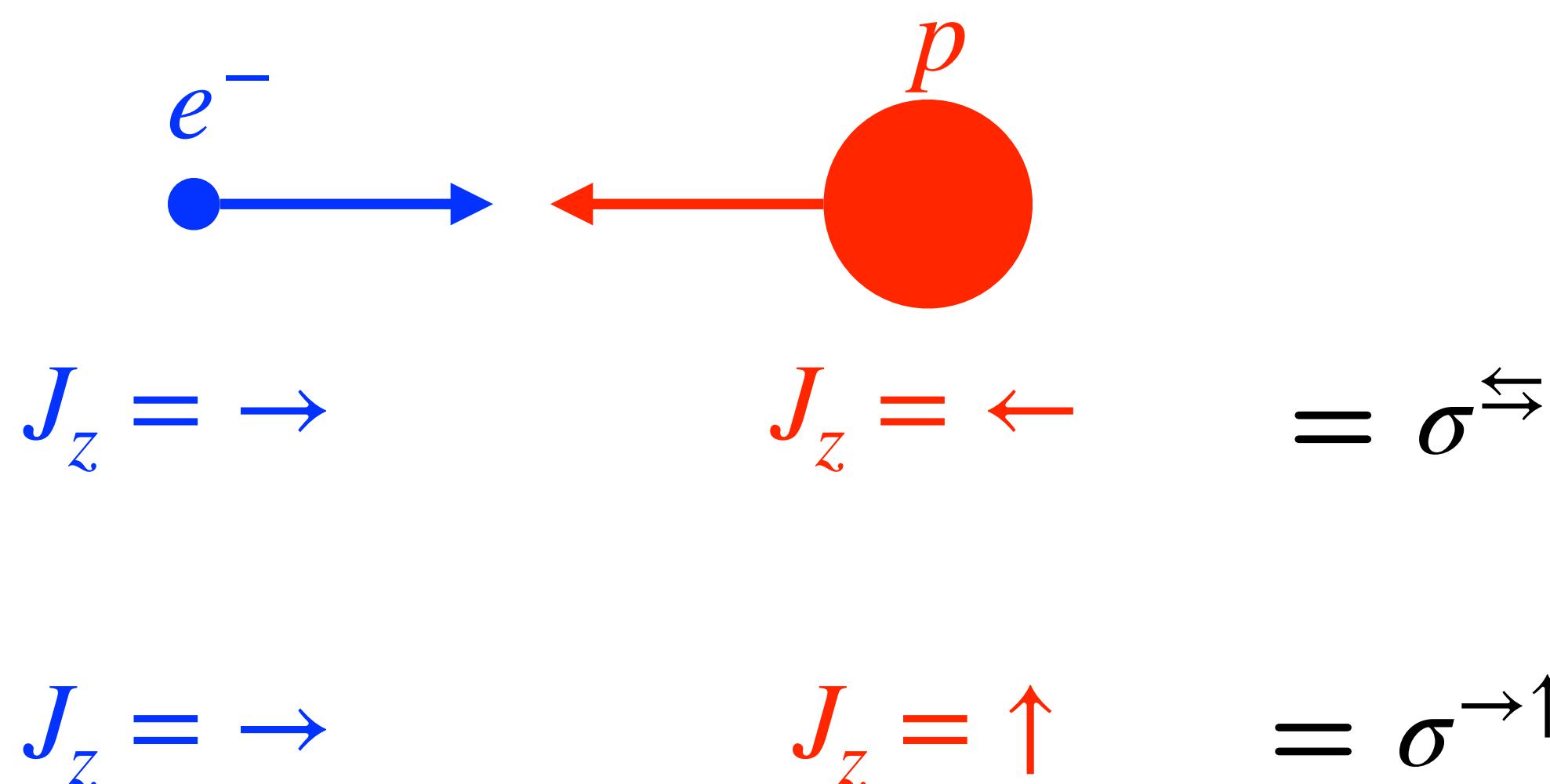
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## Orbital angular momentum

- GPDs from DVCS

# Complementary measurements required to disentangle



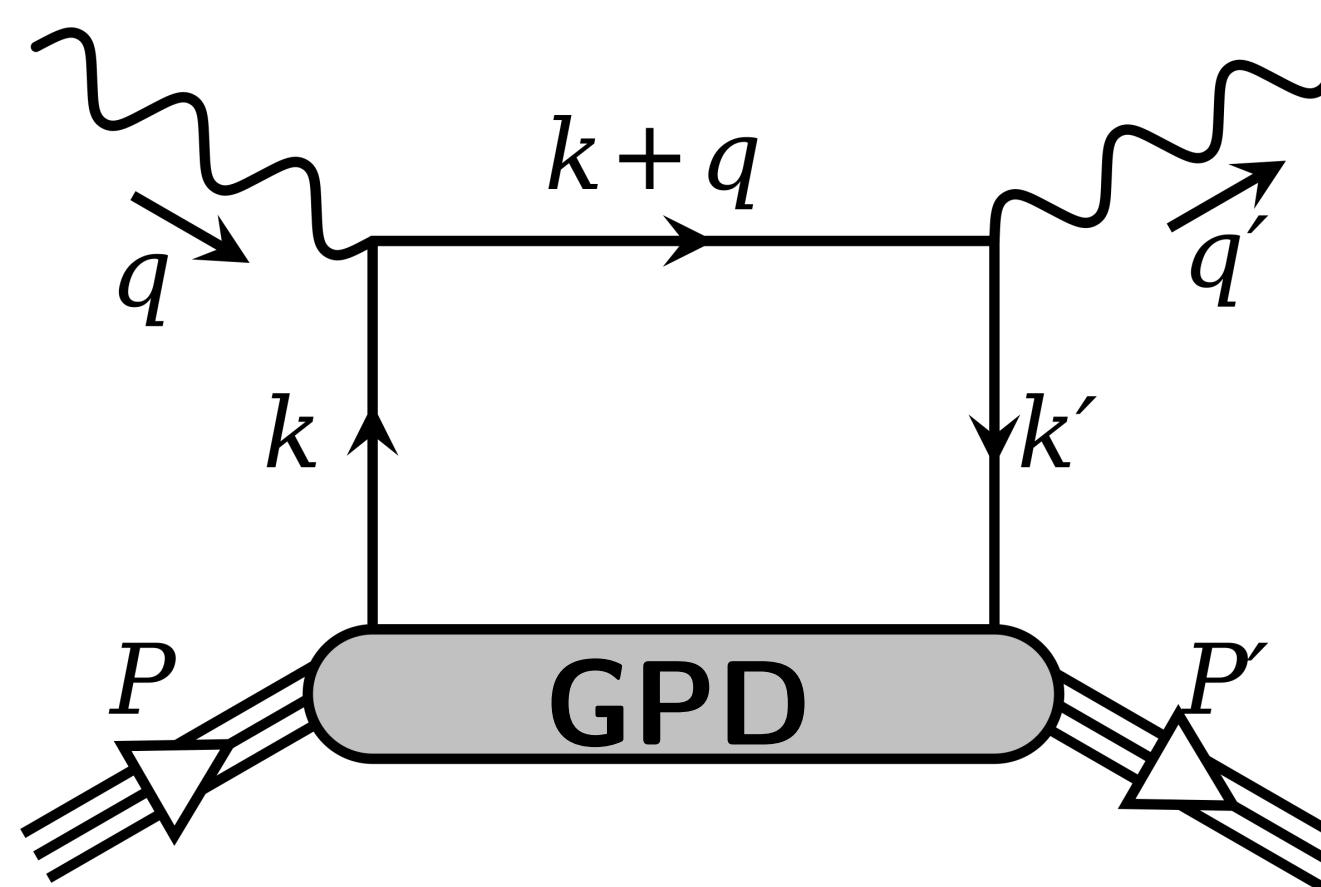
## Quark & gluon helicity

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## Inclusive reactions



## Orbital angular momentum

- GPDs from DVCS

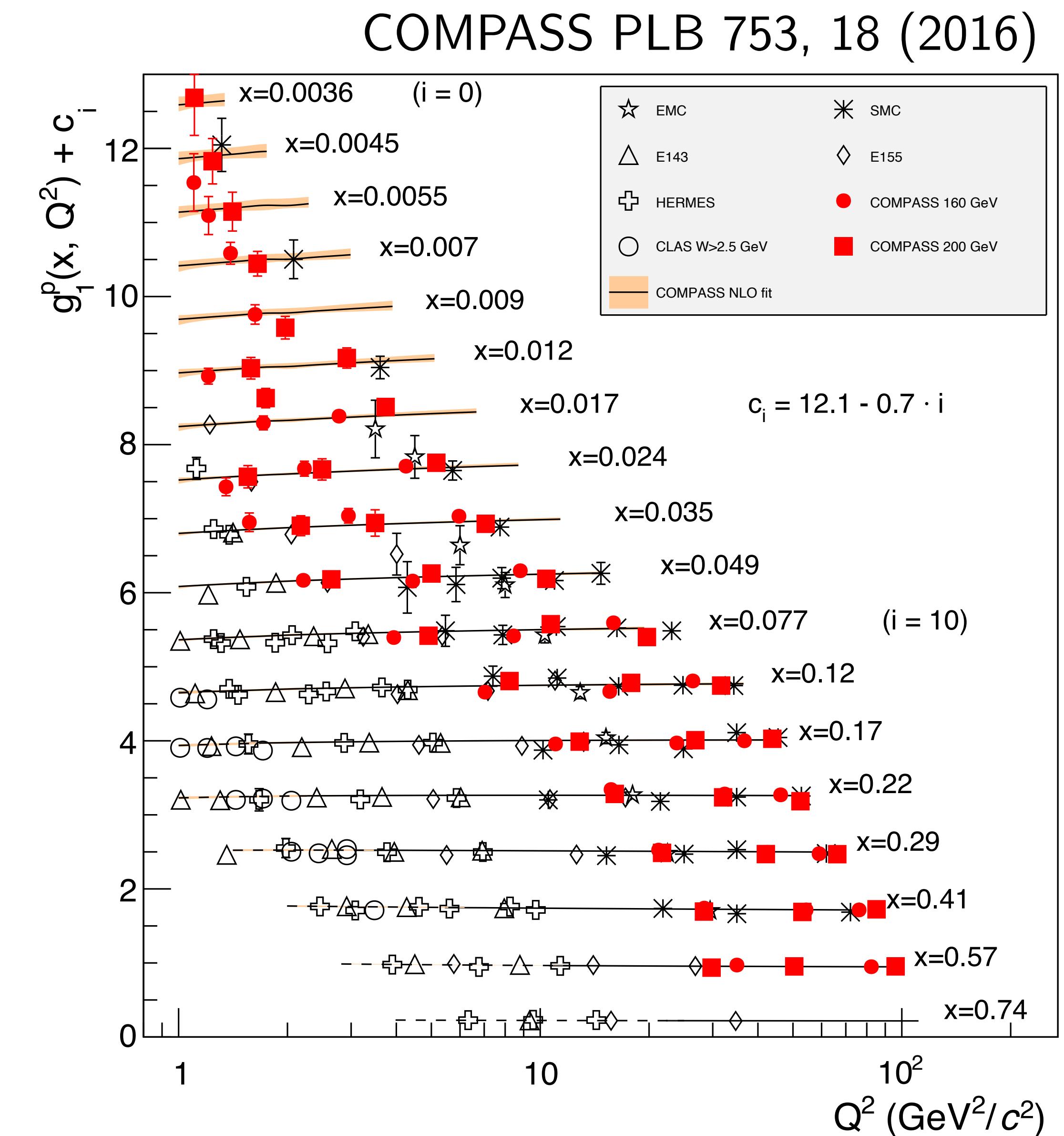
# Existing constraints on $\Delta\Sigma$ , $\Delta G$ limited by kinematic coverage

$$\Delta\Sigma/2 + \Delta G + L_q + L_g = \frac{1}{2}$$

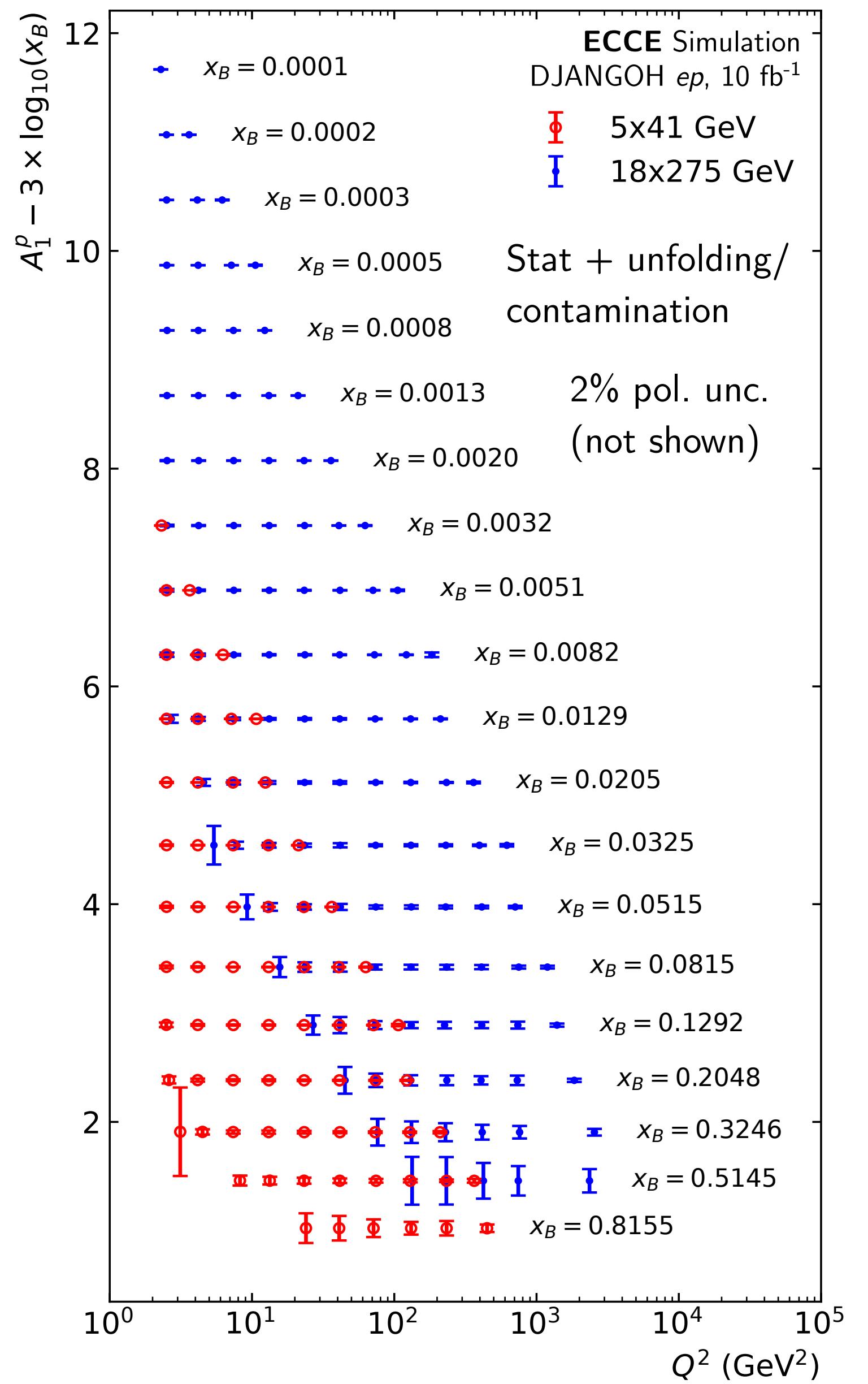
$\approx 30\%$

$\approx 40\%$

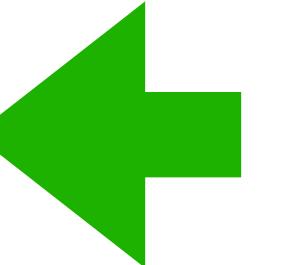
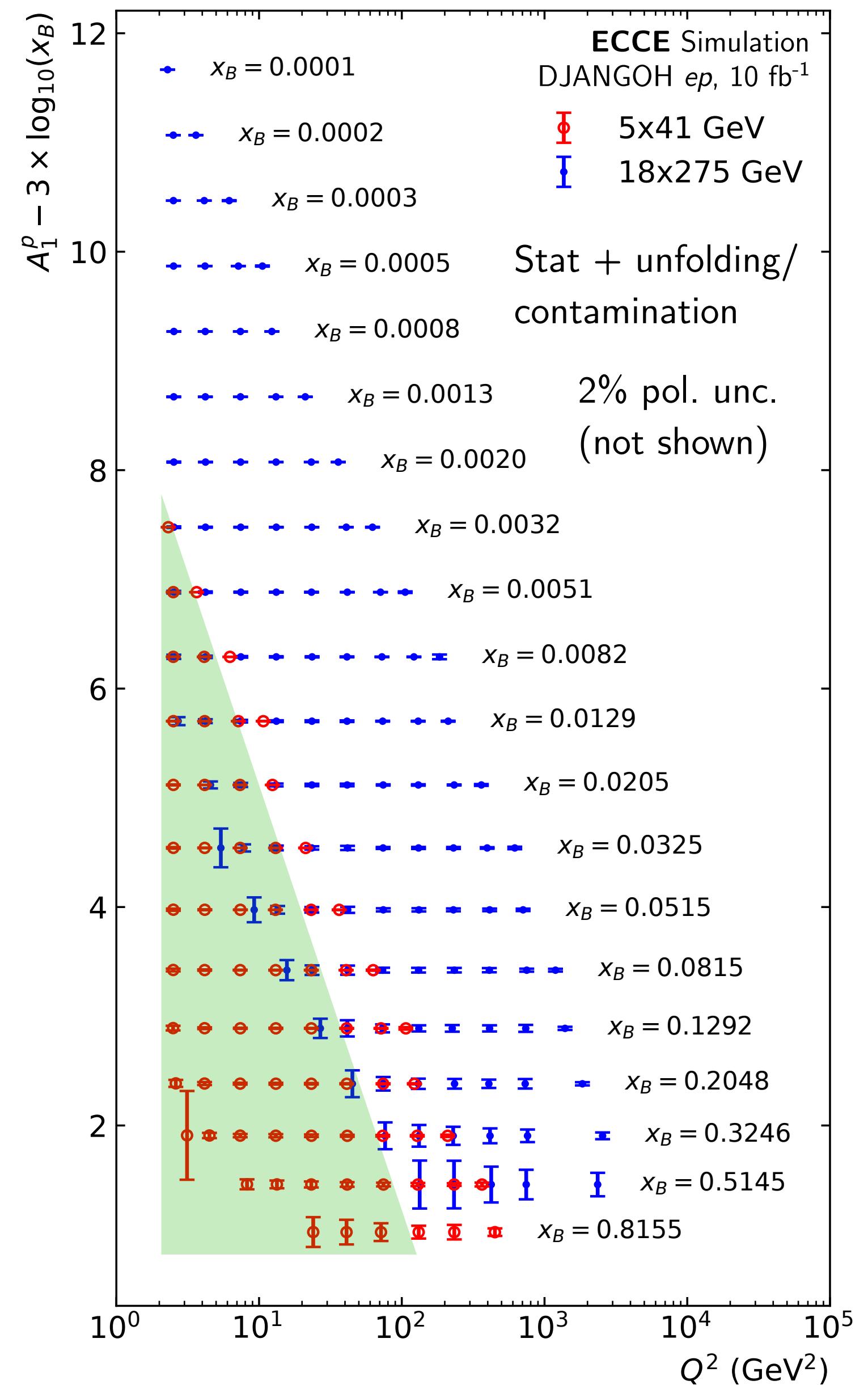
Large uncertainty!



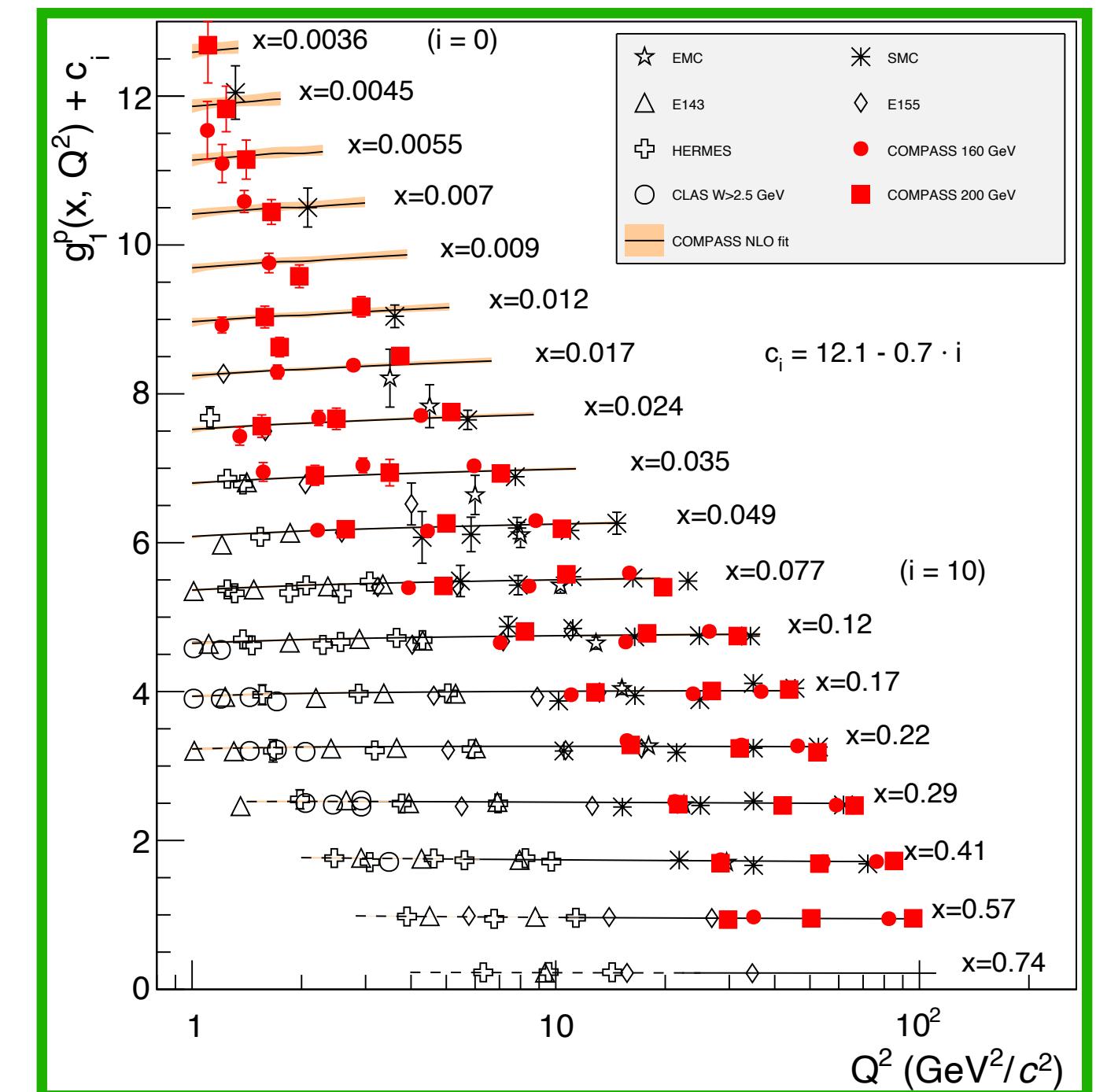
# Projected results for inclusive $A_1^p$



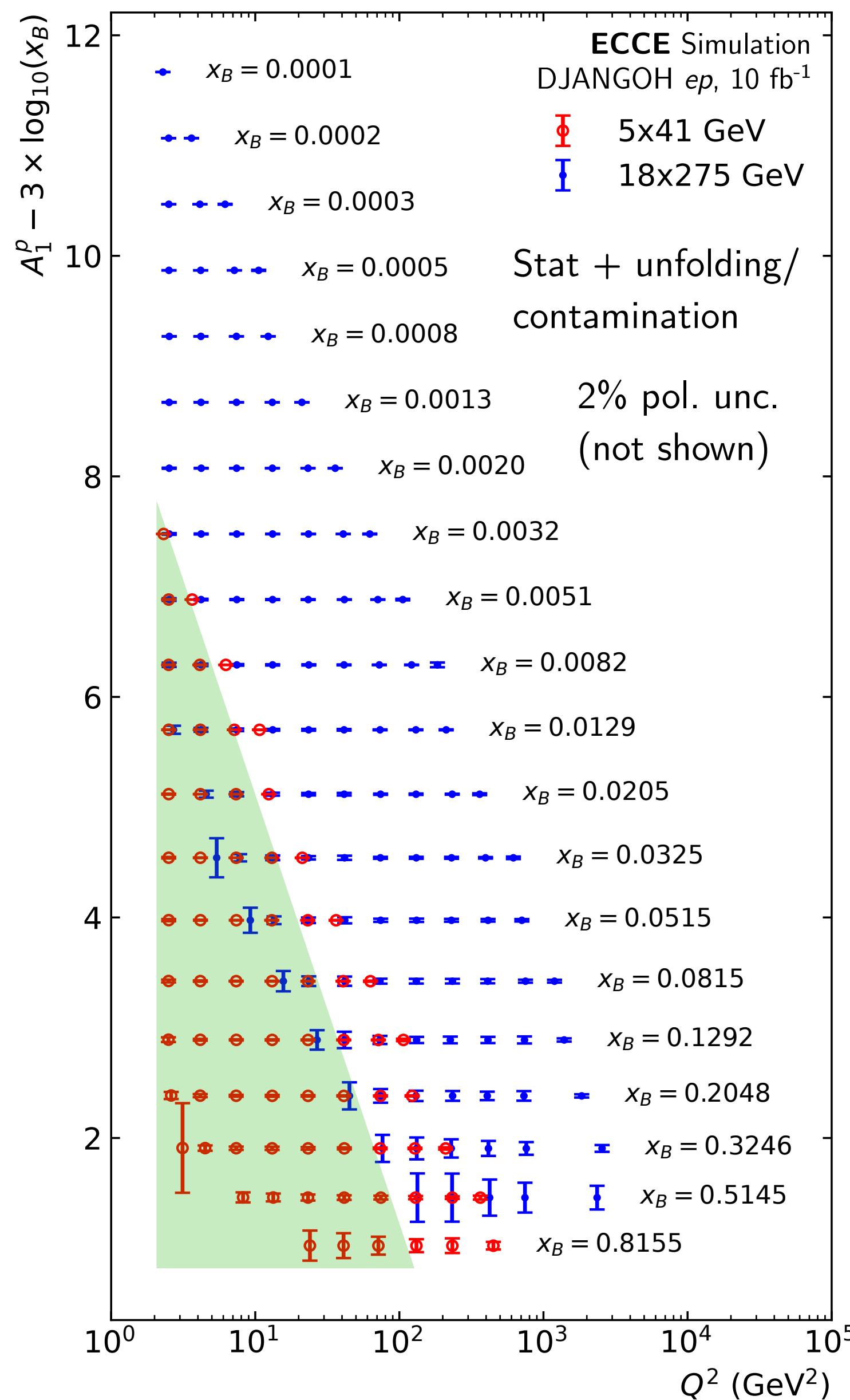
# Projected results for inclusive $A_1^p$



Current:  
Down to  $x \approx 0.005$ ,  
 $Q^2 \approx 1-100$  GeV<sup>2</sup>.



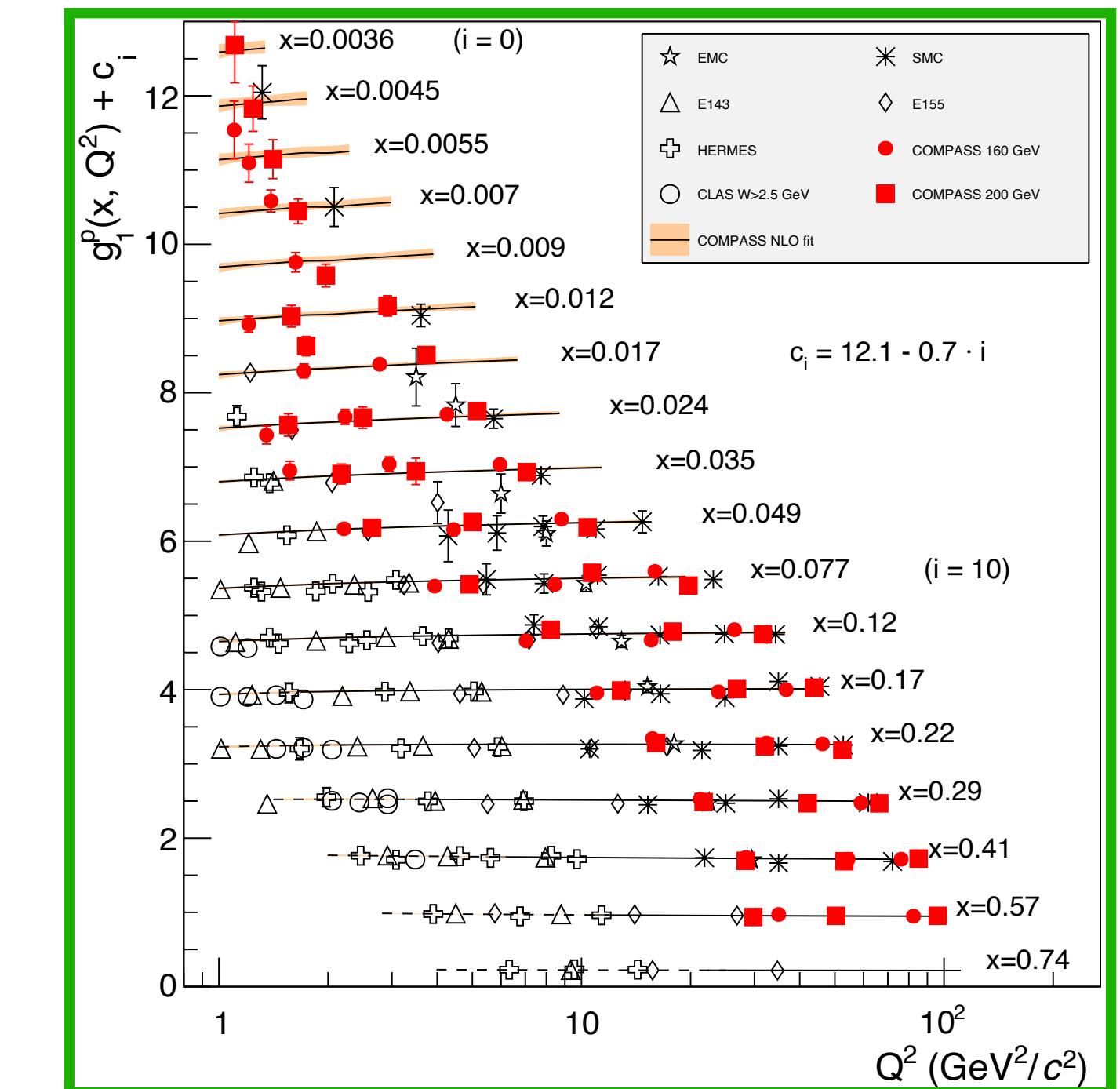
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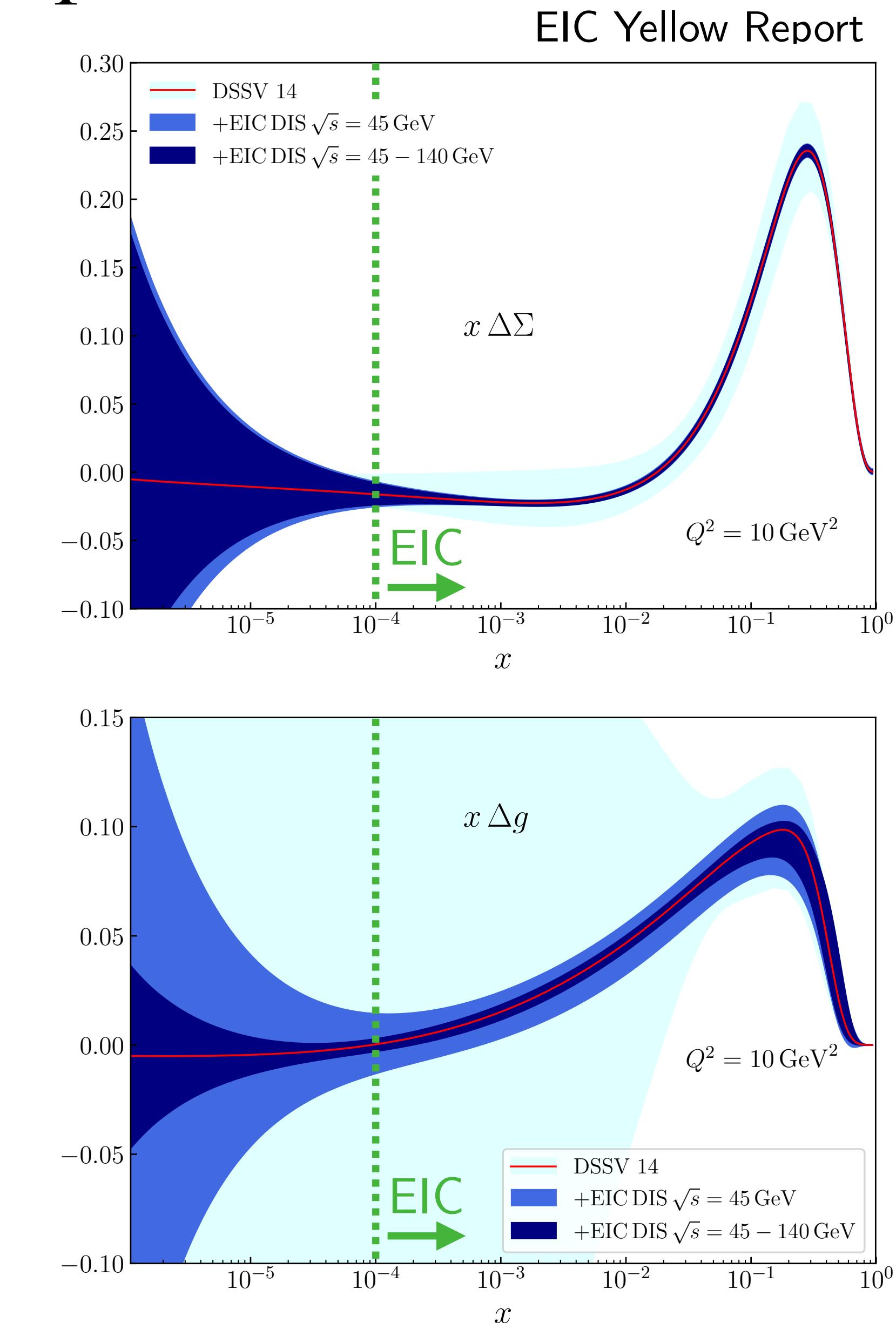
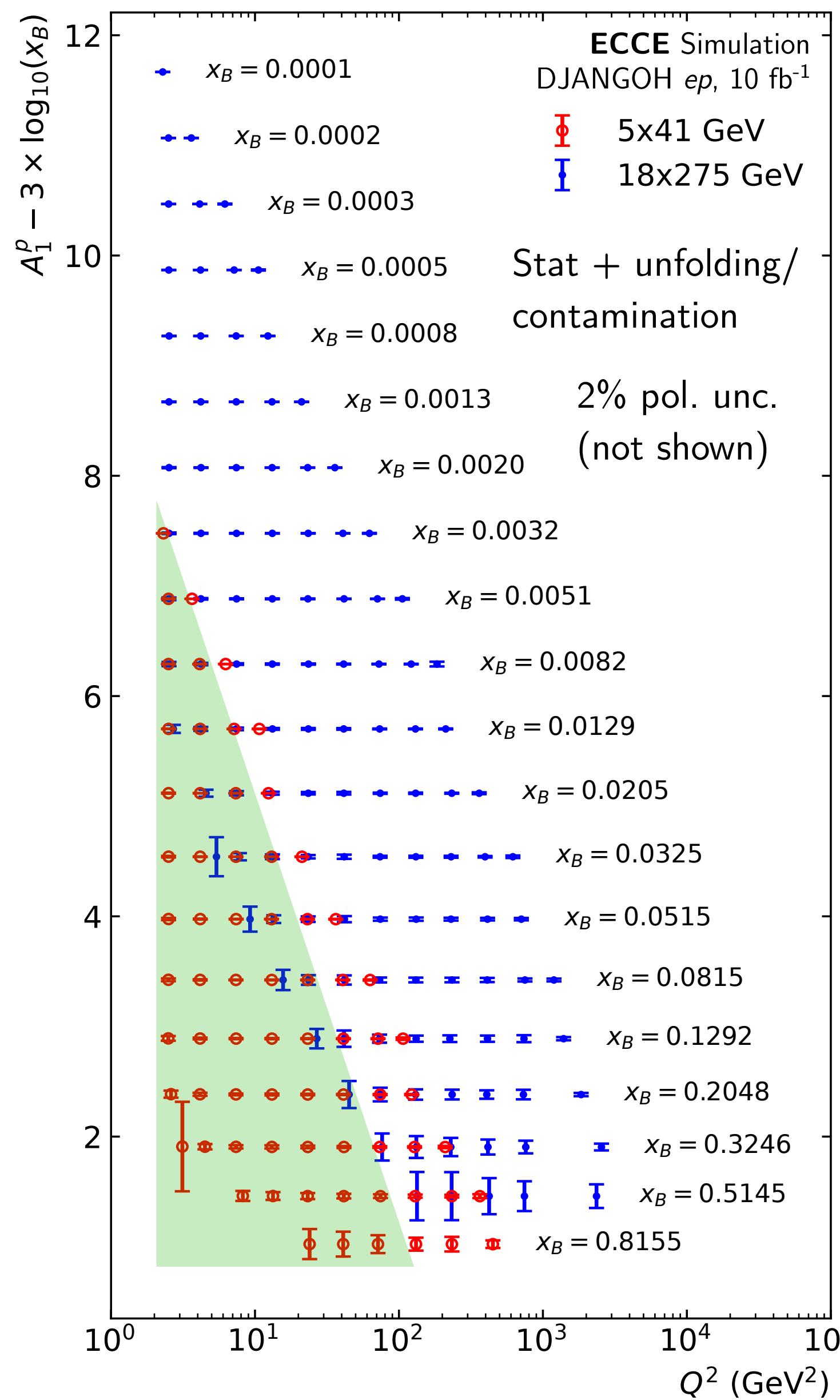
EIC: Down to  $x \approx 10^{-4}$ ,  $Q^2 \approx 1\text{-}10^3 \text{ GeV}^2$ !

Maximize constraints on gluon spin with  
multiple  $\sqrt{s}$  settings

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Down to  $x \approx 0.005$ ,  
 $Q^2 \approx 1\text{-}100 \text{ GeV}^2$ .



# Projected results for inclusive $A_1^p$

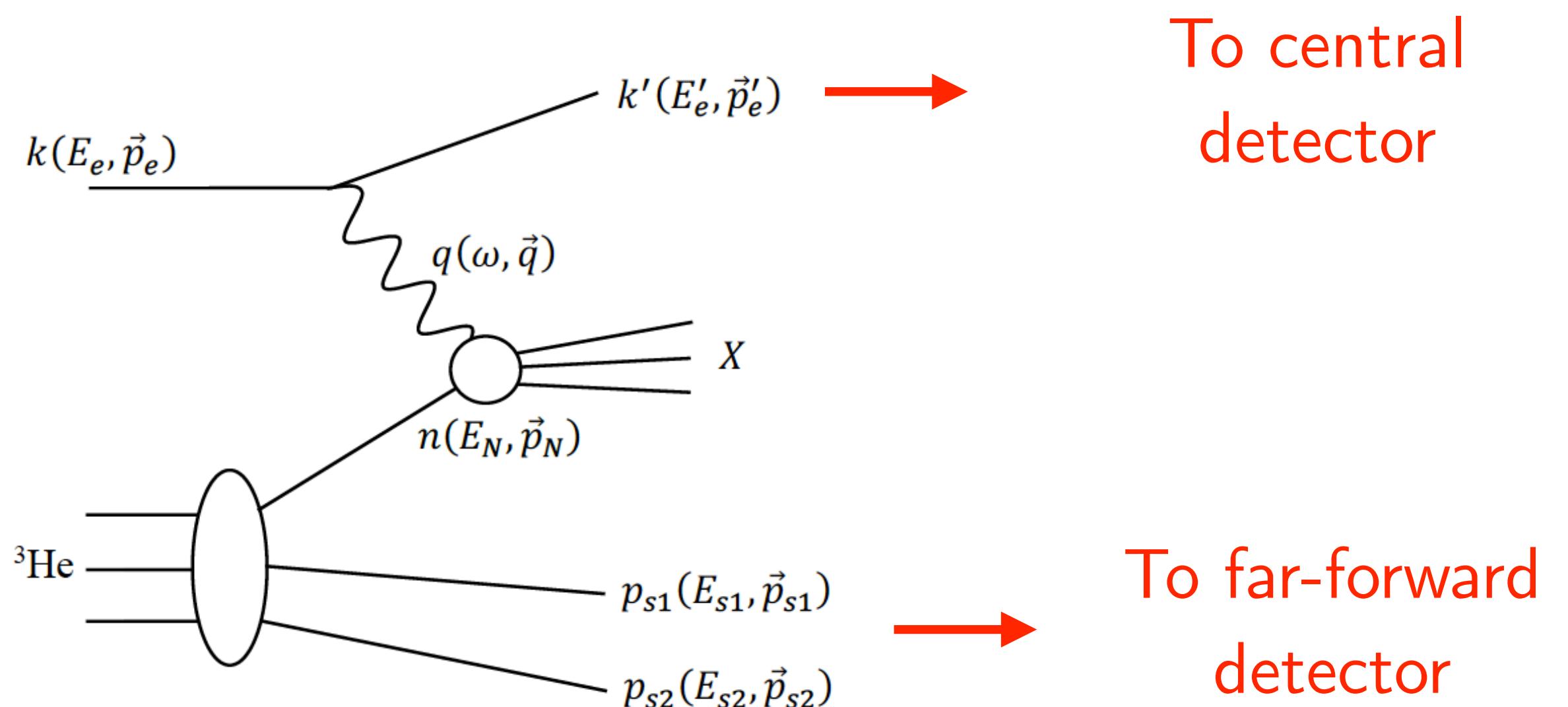


# Beyond inclusive: neutron structure with tagged DIS

- Tag DIS event with low-momentum spectator nucleon(s)  
→ measured quasi-free neutrons
- $F_2^n$  from spectator-tagged unpolarized eD collisions
- $A_1^n$  from double-spectator-tagged polarized eHe3 collisions

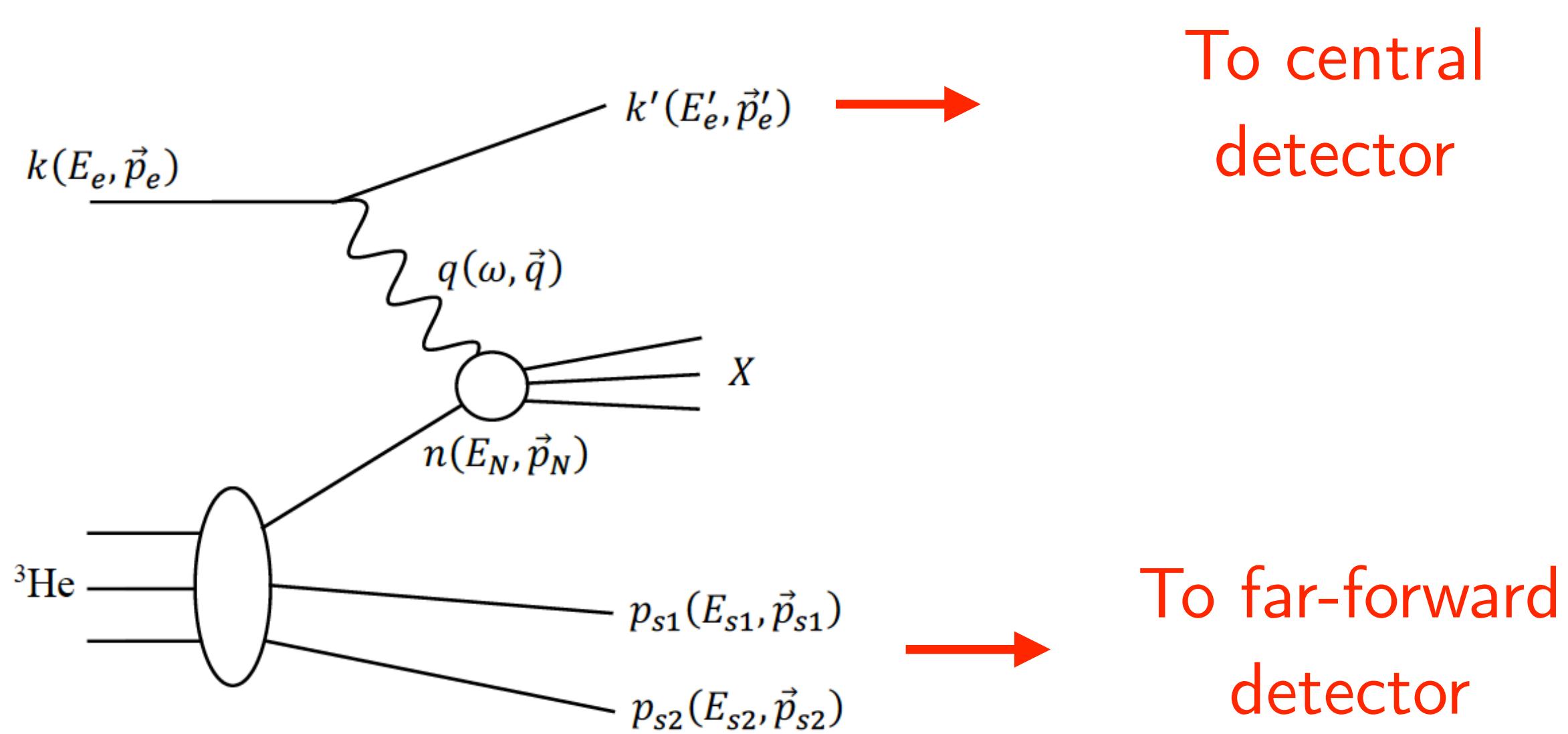
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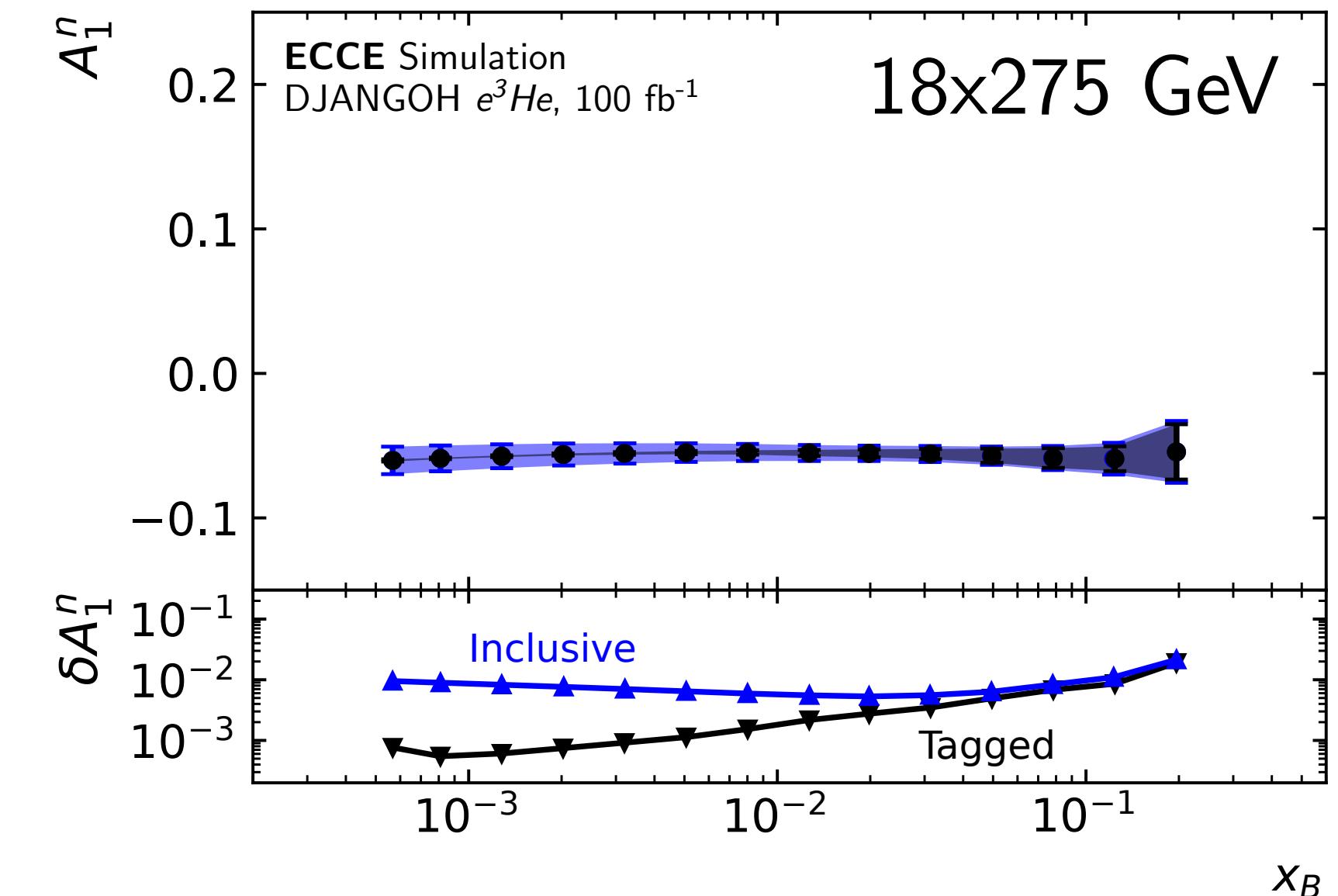
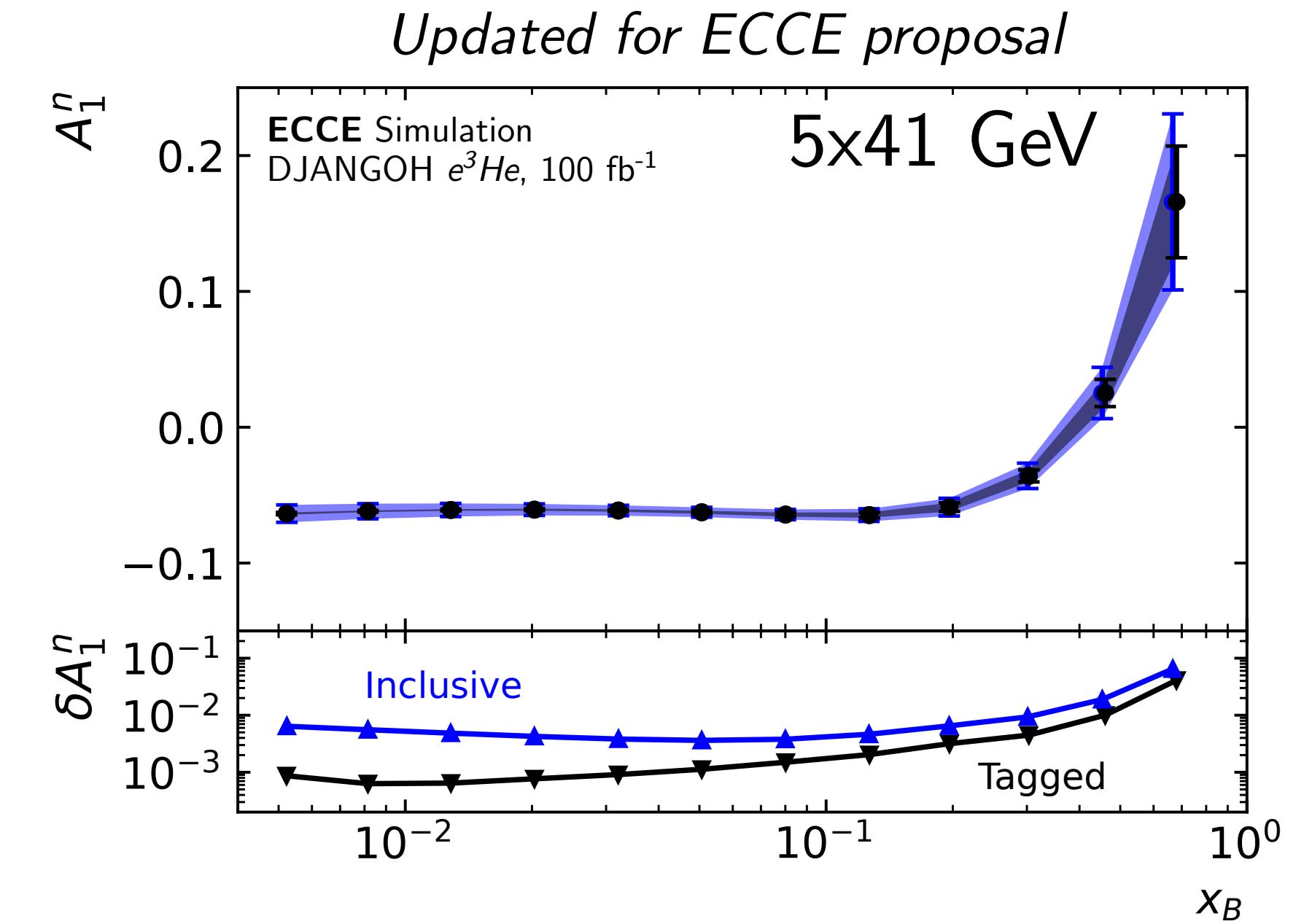


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Friscic, Nguyen, et al. PLB 823, 136726 (2021)



# Summary & outlook

- The EIC will provide groundbreaking DIS kinematic coverage
- Inclusive physics observables will vastly improve constraints on momentum and spin structure of nucleons and nuclei
- Design of ePIC detector being rapidly finalized
  - Focus on how *physics performance* informs *detector design/technology*
  - Lots of exciting work ahead!

# Join us!

## Inclusive working group

- Meetings: Monday 12pm EDT (approximately biweekly)
- Indico: <https://indico.bnl.gov/category/417/>
- Wiki: <https://wiki.bnl.gov/EPIC/index.php?title=Inclusive>
- Email list: [eic-projdet-Inclusive-l@lists.bnl.gov](mailto:eic-projdet-Inclusive-l@lists.bnl.gov)
- Subscribe: <https://lists.bnl.gov/mailman/listinfo/eic-projdet-inclusive-l>