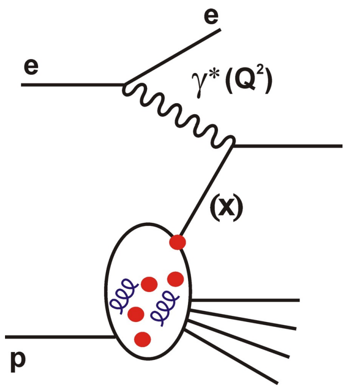
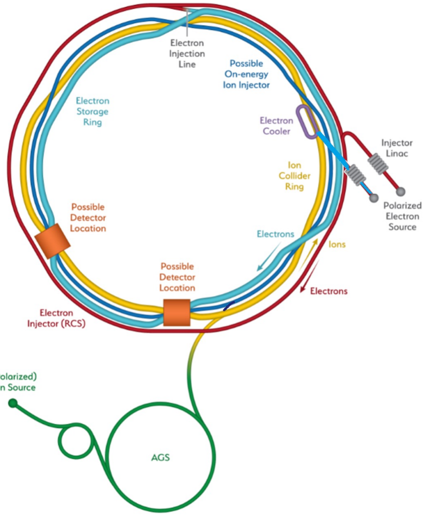
Lepton-Hadron Scattering and The Electron Ion Collider



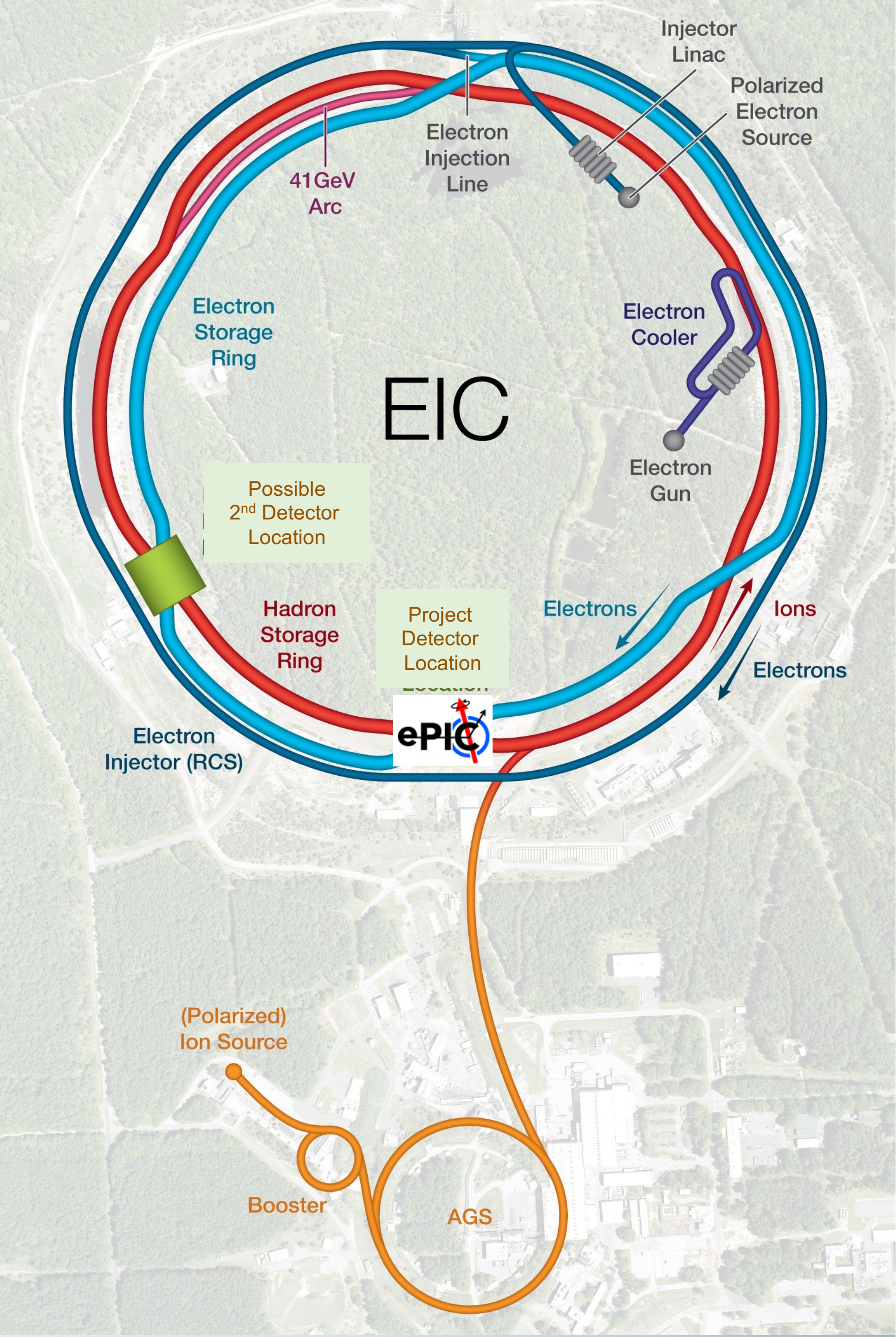
Paul Newman (Birmingham)

UCL Seminar
26 April 2024



1) DIS History and Context
2) Overview and Machine
3) The ePIC detector
4) Physics motivations
5) Timeline
6) UK involvement

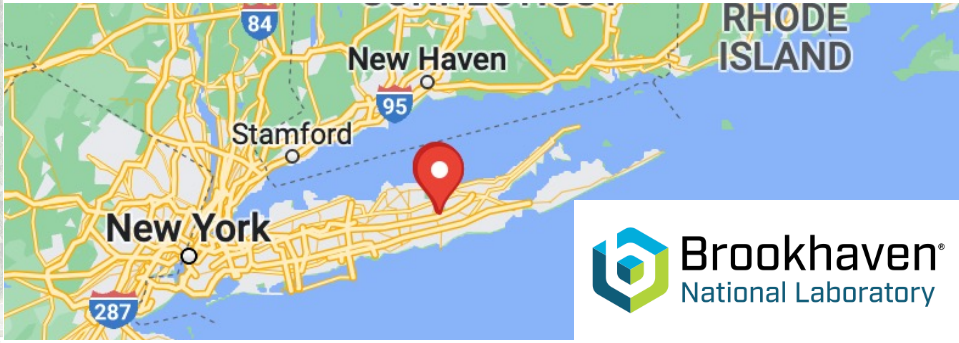
The Electron Ion Collider



New electron storage ring at BNL accelerator complex, to collide with existing RHIC proton / ion beams

On target to be the world's next high energy* collider, starting from the early 2030s

Scientific remit: exploration of strongly interacting matter using Deep Inelastic Scattering



Brookhaven National Laboratory

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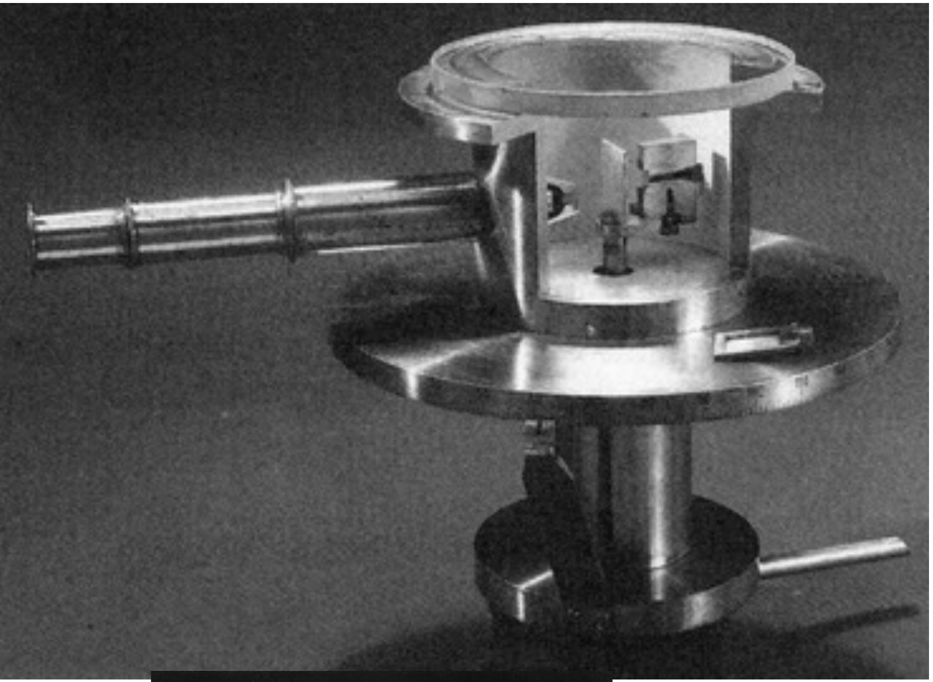
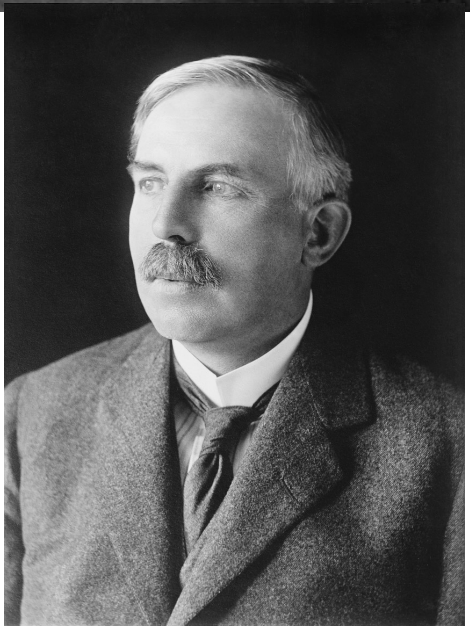
* High energy ≠ energy frontier

Rutherford (1927, as President of Royal Society)



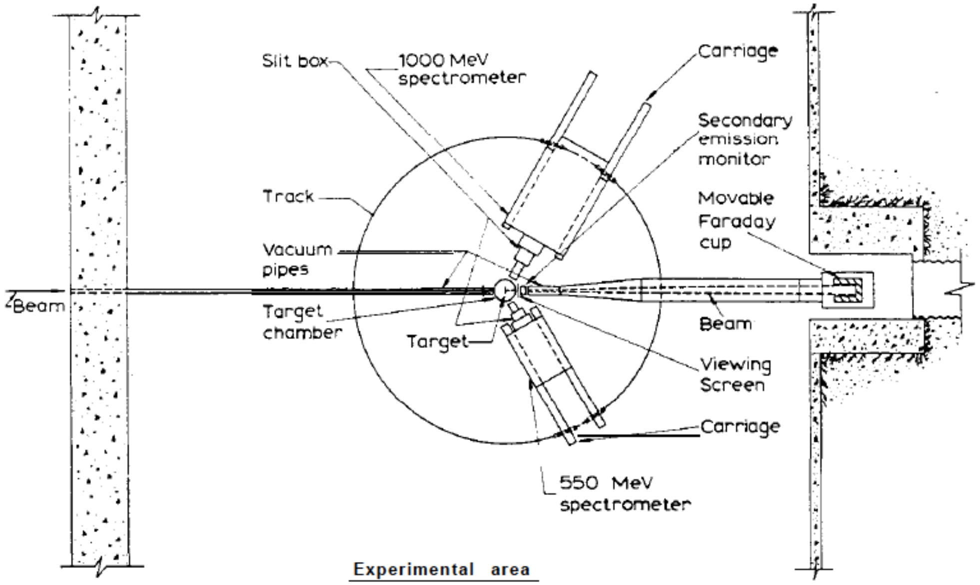
Following from the original scattering experiments (α particles on gold foil target) …



"It would be of great scientific interest if it were possible to have a supply of electrons … of which the individual energy of motion is greater even than that of the alpha particle."

Hofstadter (Nobel Prize 1961)

200 MeV Electrons on a fixed target …

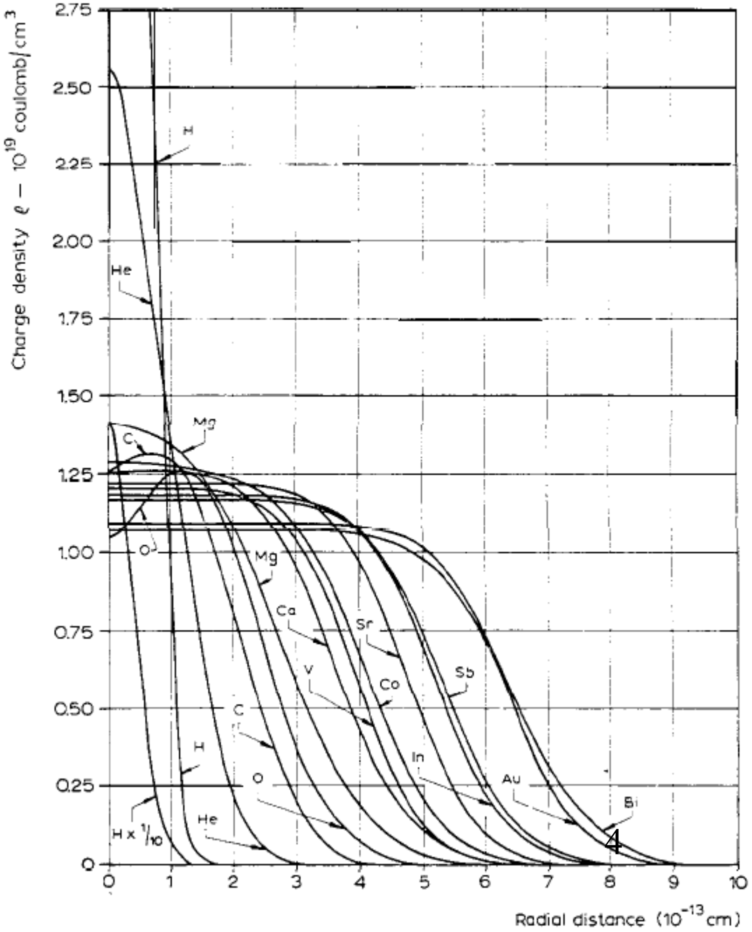


- Electron scattering reveals nuclear form factors (i.e. sizes)

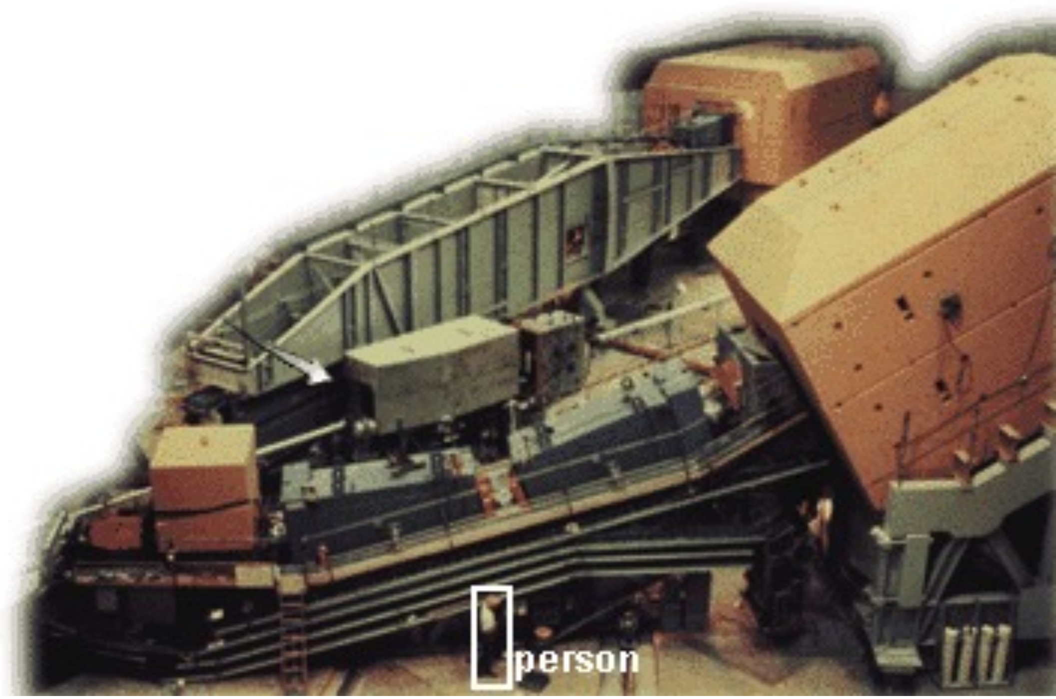
… even a hydrogen nucleus (proton)
has finite size

… electric charge uniformly spread?

… “soft spheres” …

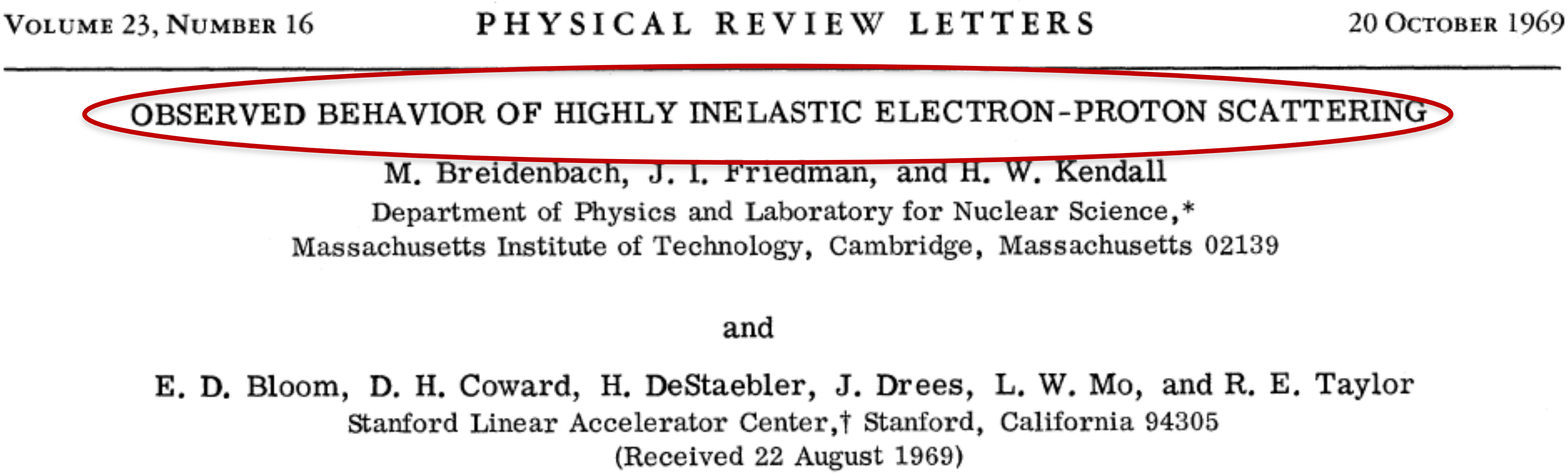


SLAC 1969: 20 GeV electrons on protons



… observed significant scattering
through wide angles
(like Rutherford's alphas),
implying 'point-like'
scattering centres

First Observation Of Proton Structure



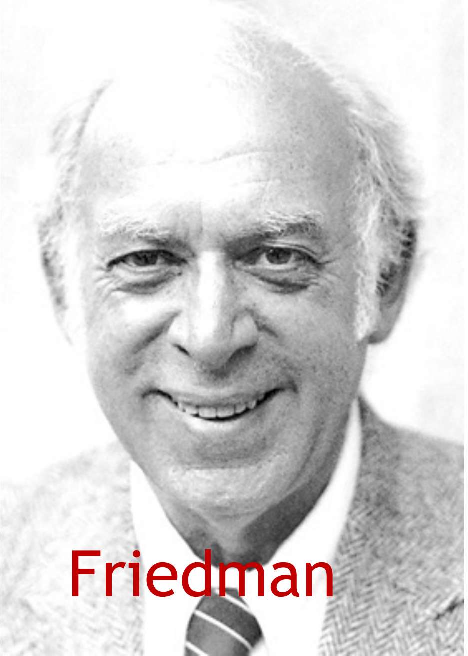
VOLUME 23, NUMBER 16 PHYSICAL REVIEW LETTERS 20 OCTOBER 1969

OBSERVED BEHAVIOR OF HIGHLY INELASTIC ELECTRON-PROTON SCATTERING

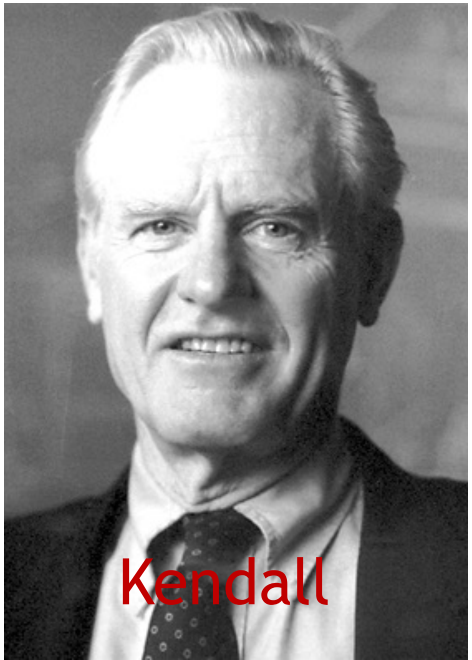
M. Breidenbach, J. I. Friedman, and H. W. Kendall
Department of Physics and Laboratory for Nuclear Science,*
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

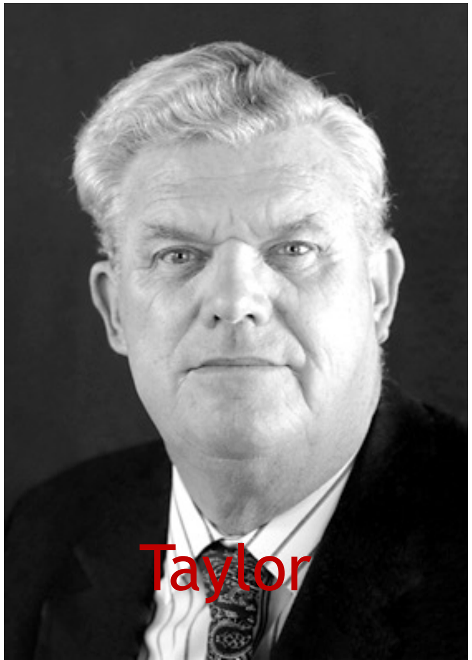
E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, L. W. Mo, and R. E. Taylor
Stanford Linear Accelerator Center,† Stanford, California 94305
(Received 22 August 1969)



Friedman



Kendall



Taylor

Nobel
Prize
1990

HERA, DESY, Hamburg

$\sqrt{s_{ep}}$ ~ 300 GeV

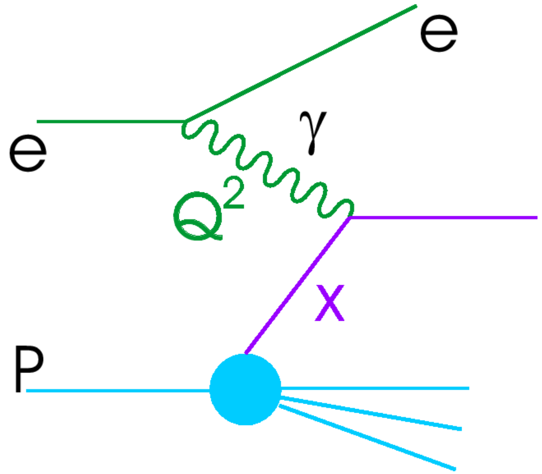
… equivalent to a 50 TeV beam on a fixed target proton

(1992-2007)

- So far still the only collider of electron and proton beams ever

→ Taught us much of what we know about proton structure
→ Only ~0.5 fb^{-1} per experiment
→ No deuteron or nuclear targets

Inclusive Neutral Current DIS: ep→ eX … a 2 Variable Problem



$$Q^2 = -q^2 \qquad x = \frac{-q^2}{2p \cdot q}$$

x = fraction of proton momentum carried by struck quark

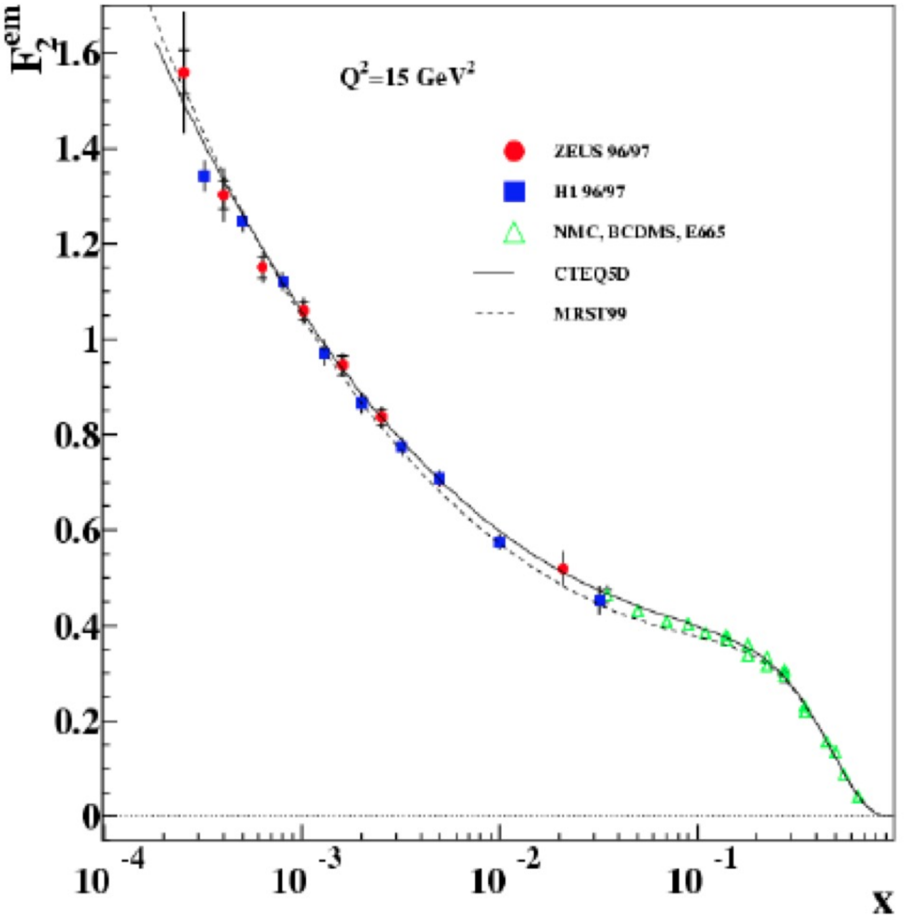
Q^2 = |4-momentum transfer squared| (photon virtuality)

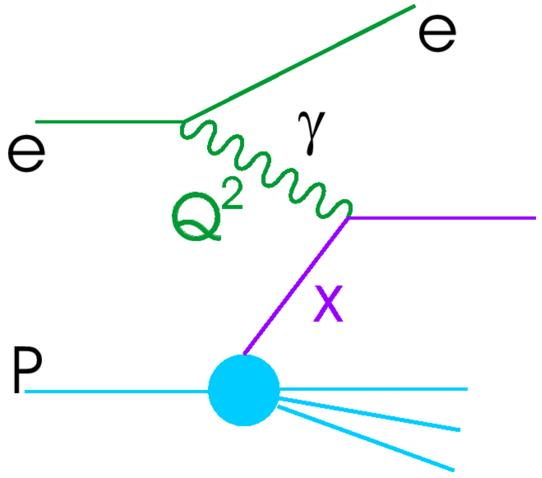
… measures the hardness /scale of collision

… inverse of (squared) resolved dimension

Note $x \geq \frac{Q^2}{s}$ … i.e. Maximum Q^2 and minimum x governed by CMS energy

Example Inclusive Neutral Current Data from Previous Experiments

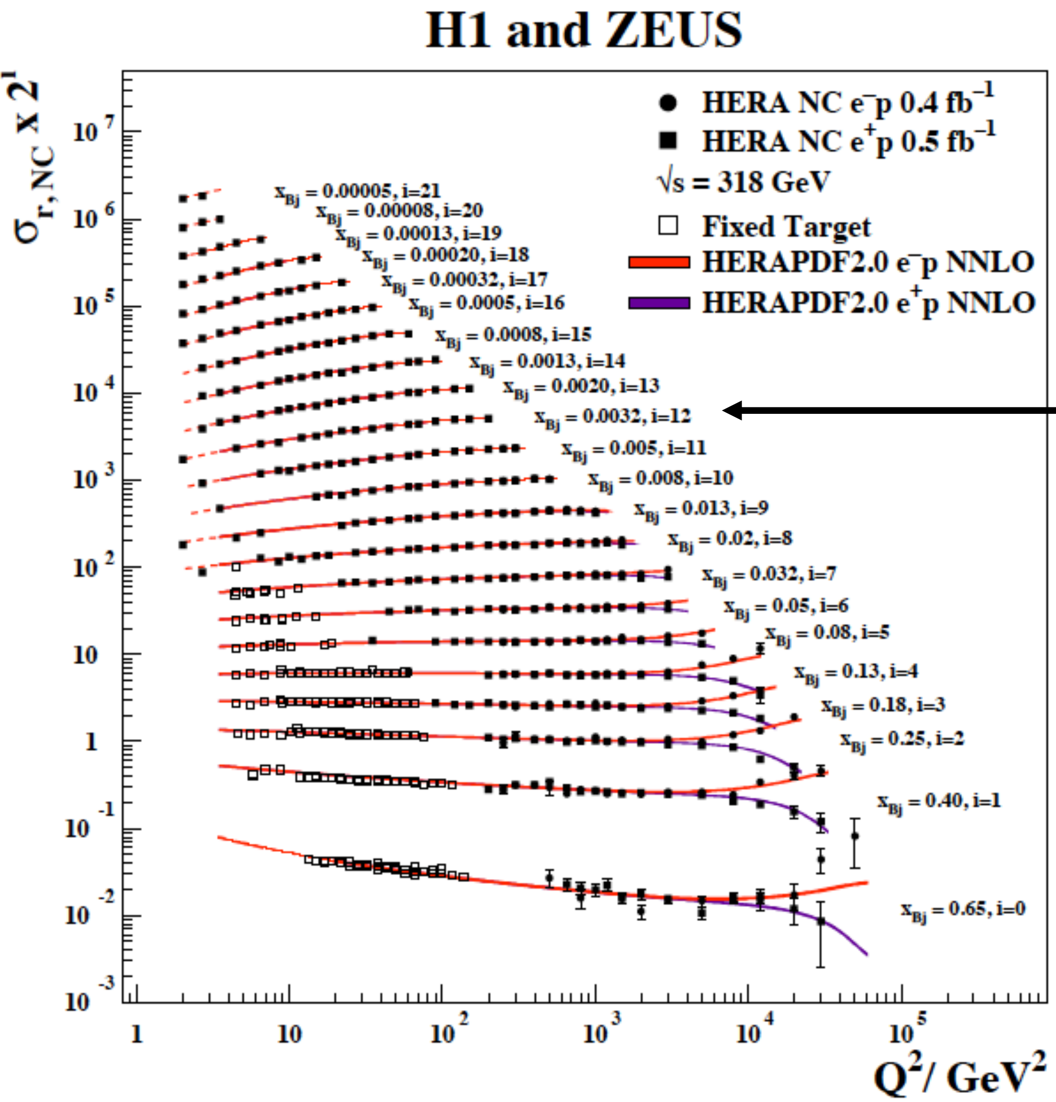




- Inclusive cross section measures (charge-squared weighted) sum of quark densities

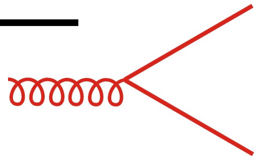
- Similar / better data at many other values of Q^2

QCD Evolution and the Gluon Density



- Q^2 dependence directly sensitive to the gluon density via splitting function …

$$g \rightarrow q\bar{q}$$

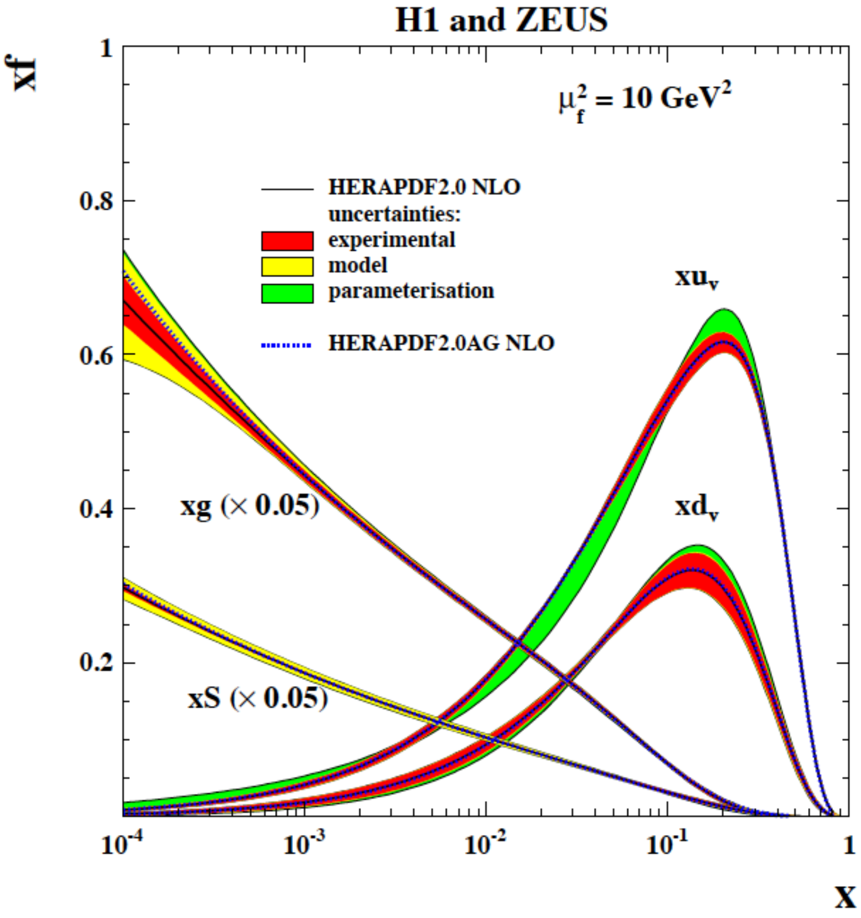


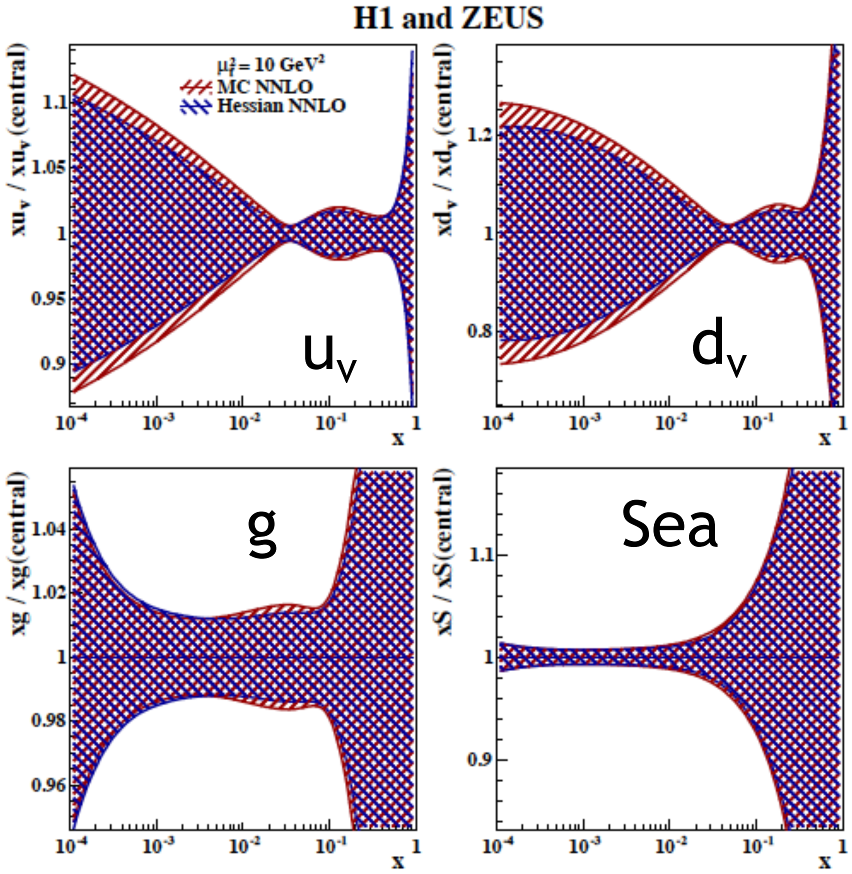
- DGLAP equations describe QCD evolution (to NNLO and approximate N^{3}LO accuracy)

- EW effects give different quark sensitivities (Z-exchange separates e^+p v e^-p, W-exchange gives charged current (ep → νX)

→ Fits to data to extract proton parton densities

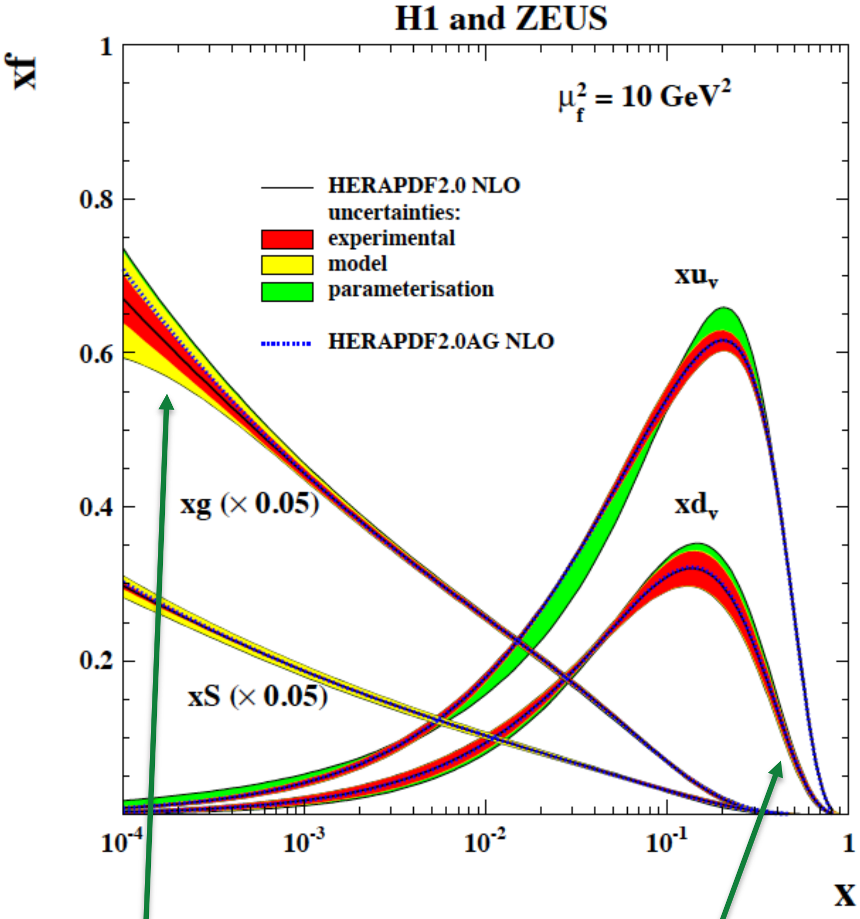
Proton PDFs from HERA only (HERAPDF2.0)

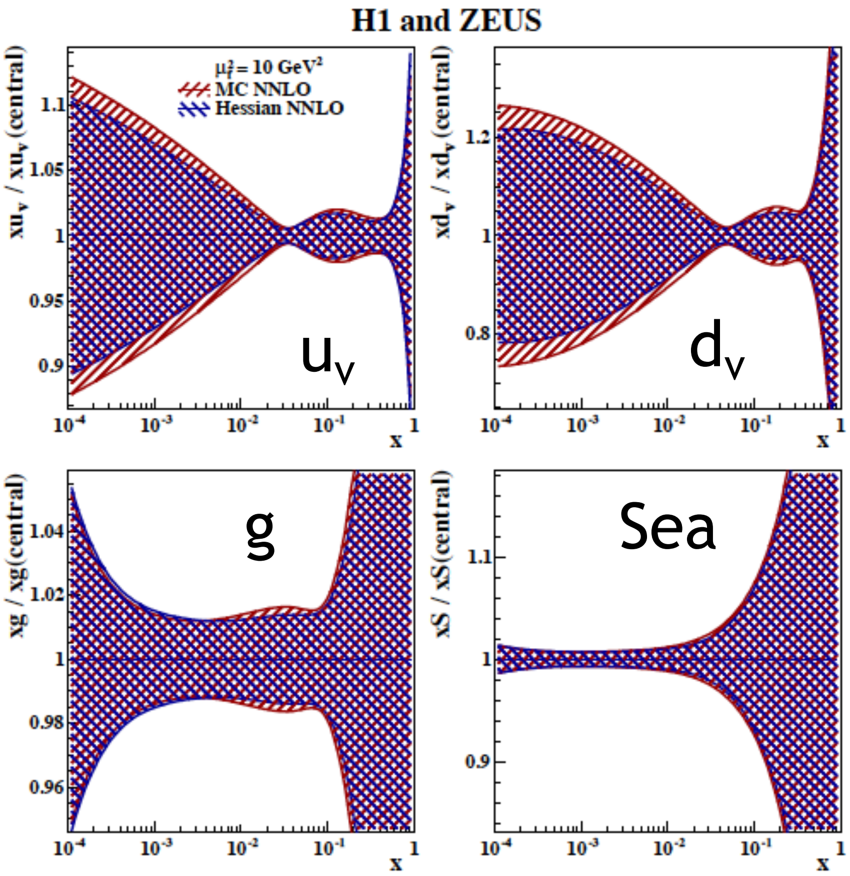




- At x ~ 10^{-2} : ~2% gluon, 1% quark precision
- Uncertainty explodes:
  - below x=10^{-3} (kinematic limit)
  - above x=10^{-1} (limited lumi)

Proton PDFs from HERA only (HERAPDF2.0)



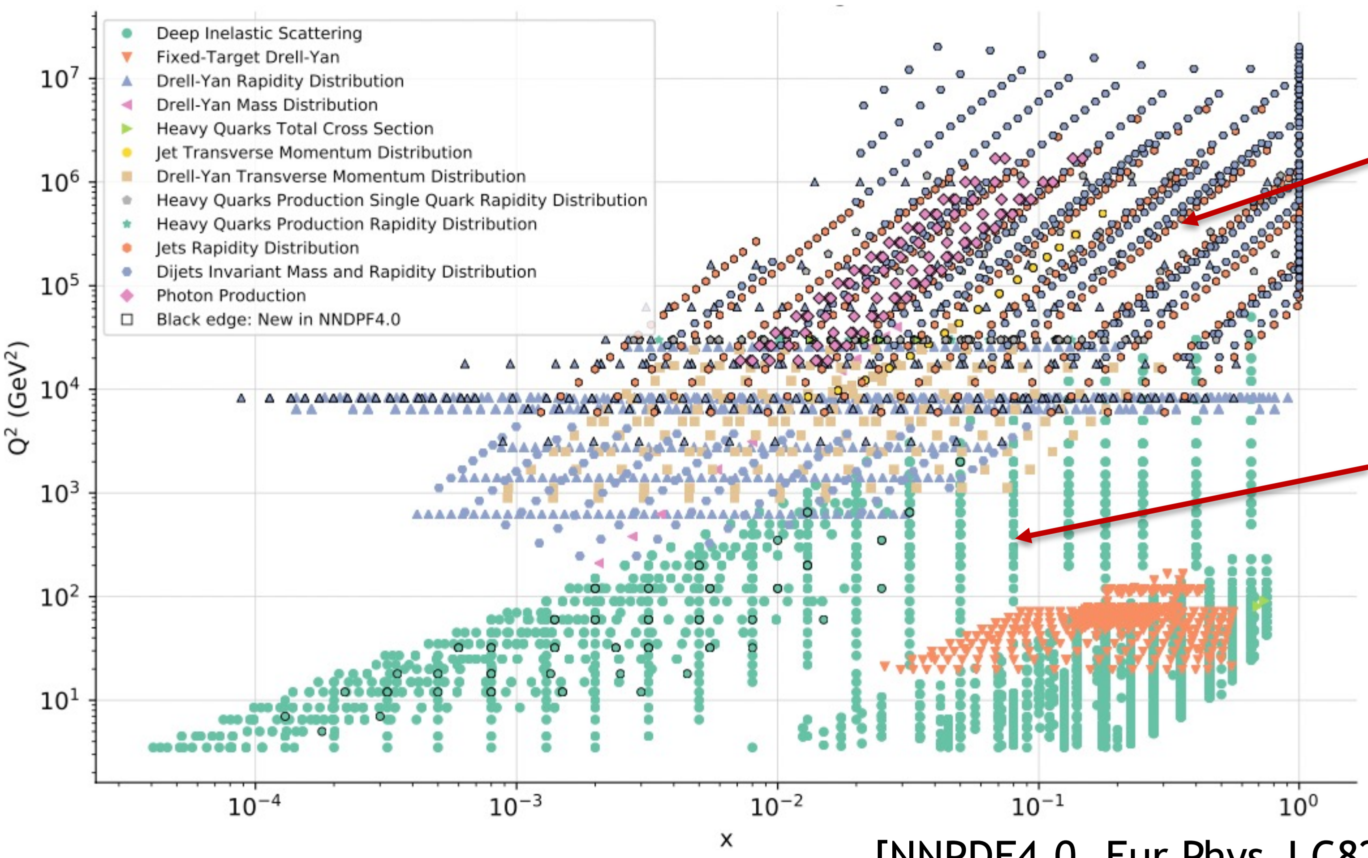


Strong interaction dragons?

Input to energy frontier discovery?

- At x ~ 10^{-2} : ~2% gluon, 1% quark precision
- Uncertainty explodes:
  - below $x=10^{-3}$ (kinematic limit)
  - above $x=10^{-1}$ (limited lumi)

Adding more data: Global PDF fits



Lots of PDF-sensitive observables at LHC

HERA limited at low x by kinematic range and high x by luminosity

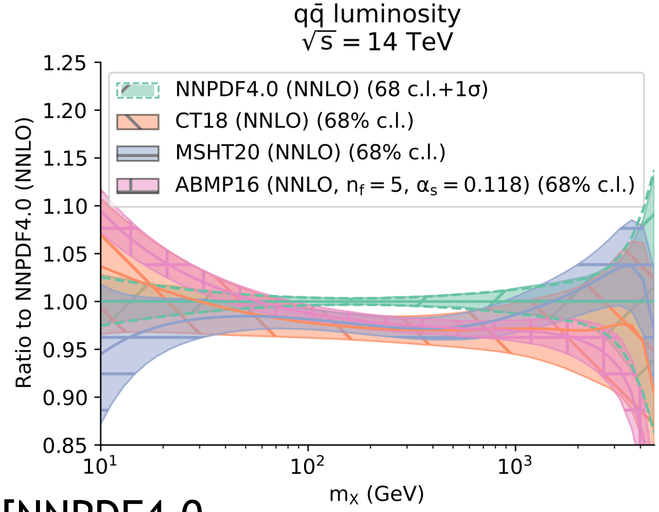
[NNPDF4.0, Eur Phys J C82 (2022) 428]

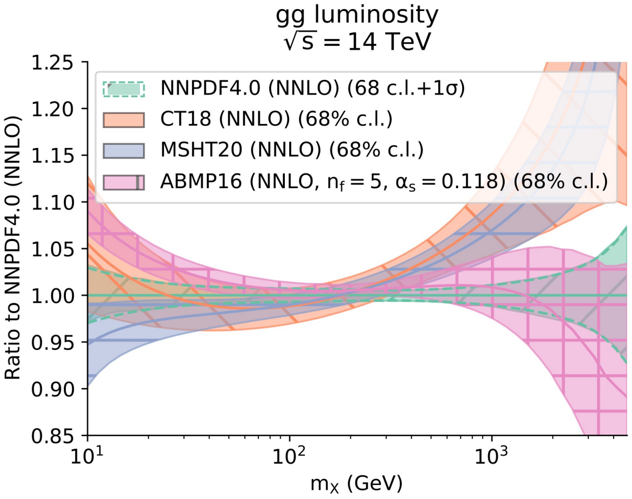
Including LHC data brings:
Advantages: improve precision at mid-high x, exploit all available inputs

Caveats: use of data that may contain BSM effects, theoretical complexity (eg non-perturbative input), some incompatibilities between data sets

Global Fits and LHC Parton Luminosities

e.g. Comparisons between current global fits on LHC $q\bar{q}$ and gg luminosities





[NNPDF4.0 ,
Eur Phys J C82 (2022) 428]

Global Fits and LHC Parton Luminosities

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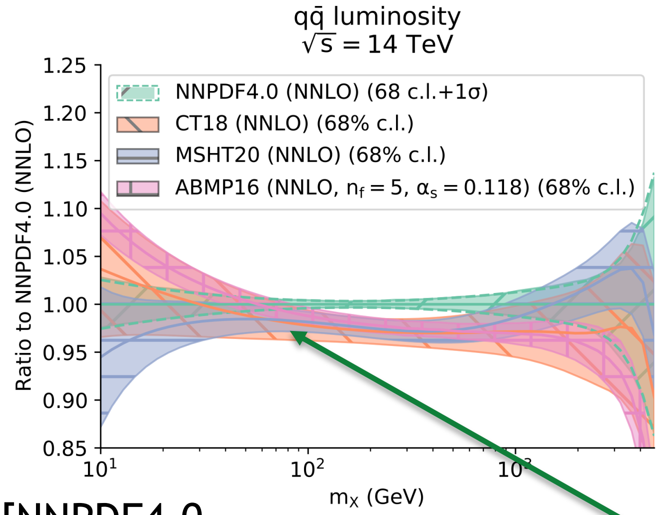
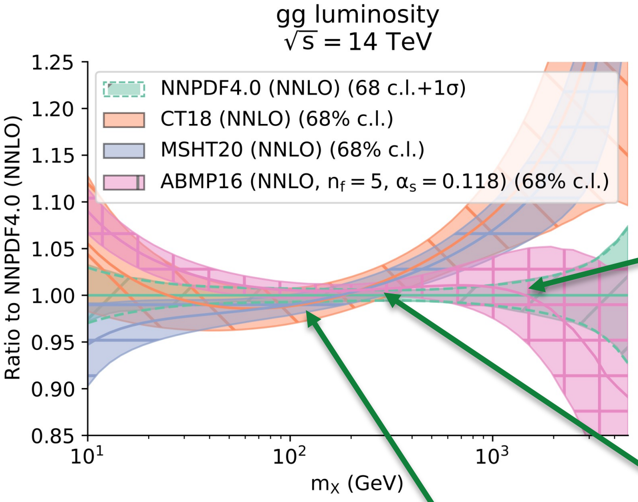
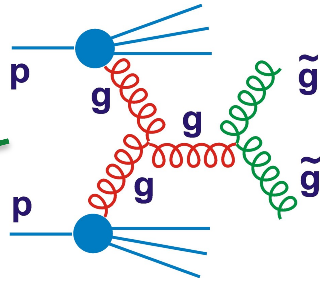
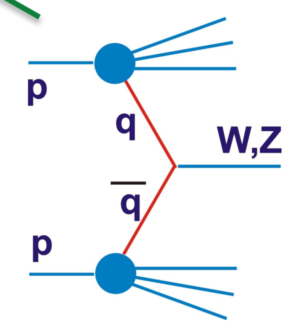
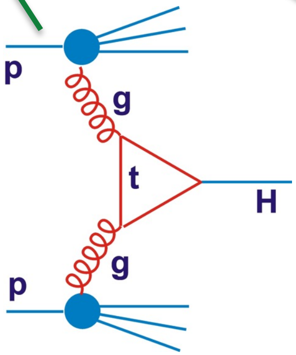


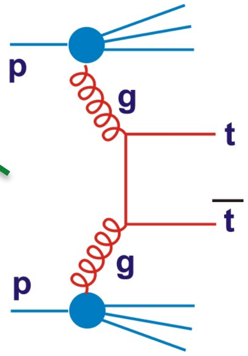


[NNPDF4.0 ,
Eur Phys J C82 (2022) 428]









- Knowing initial state often limits LHC precision measurements & searches

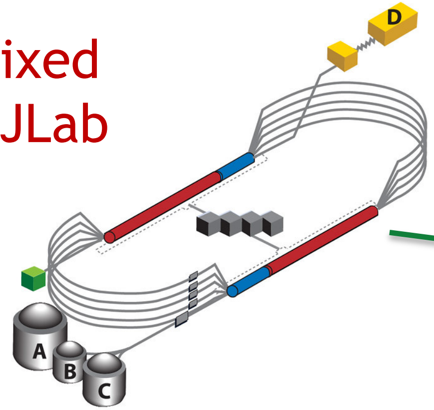
- Immense recent progress, but still large uncertainties and some tensions

Many more reasons to improve PDF precision:

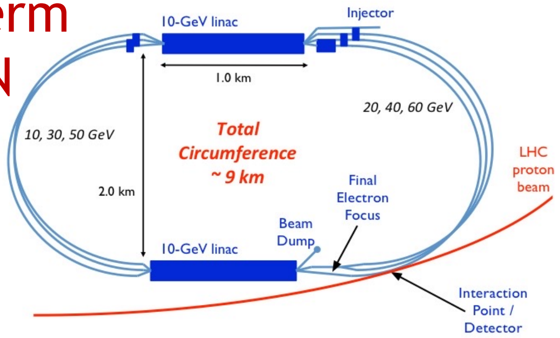
… Cosmic ray air showers, ν matter interactions, strong int’n dynamics …

Current and Future ep Colliders

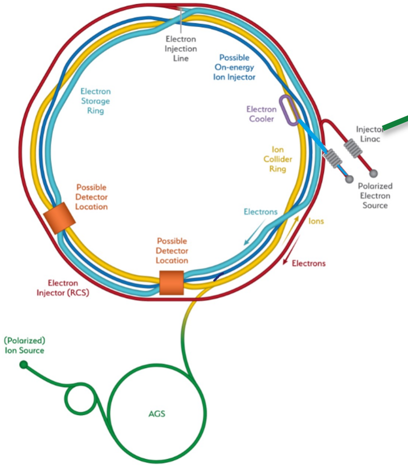
Ongoing fixed target @ JLab

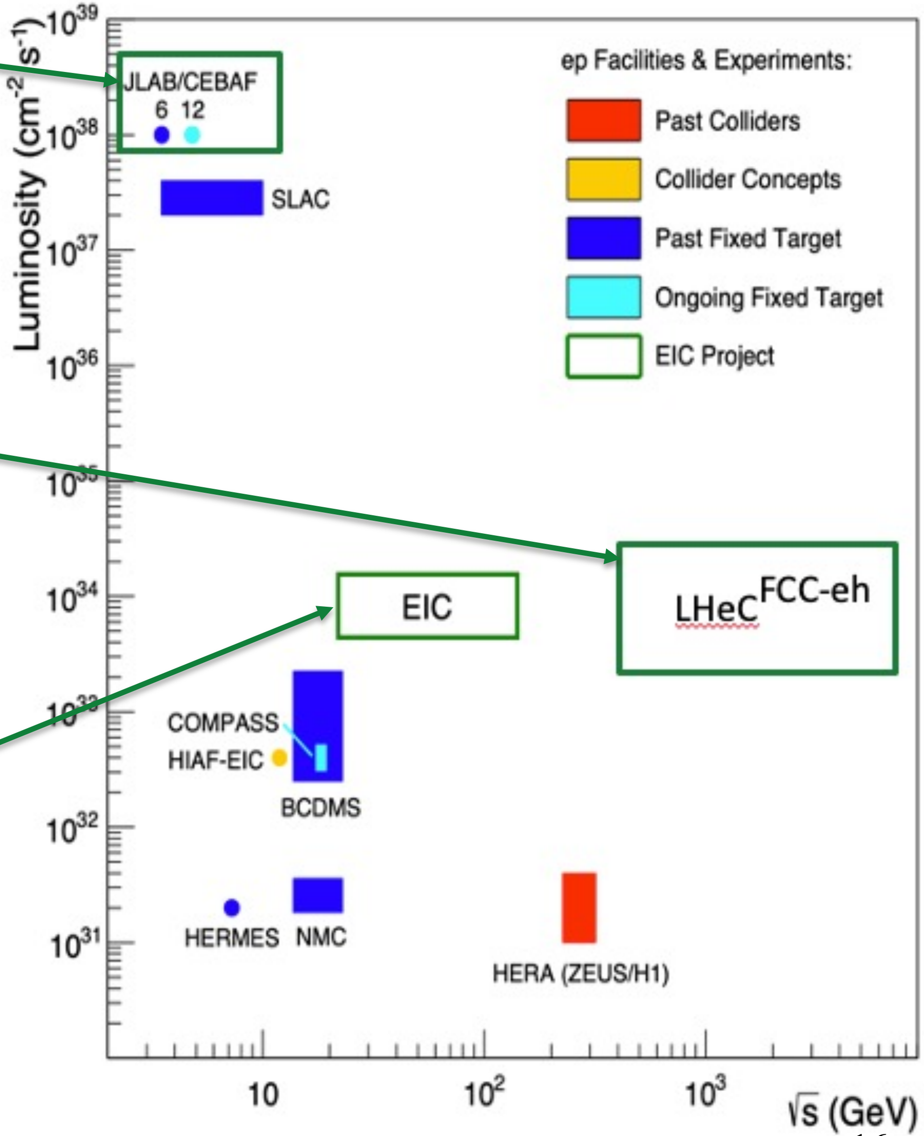


Longer-term @ CERN



On-target for early 2030s @ BNL

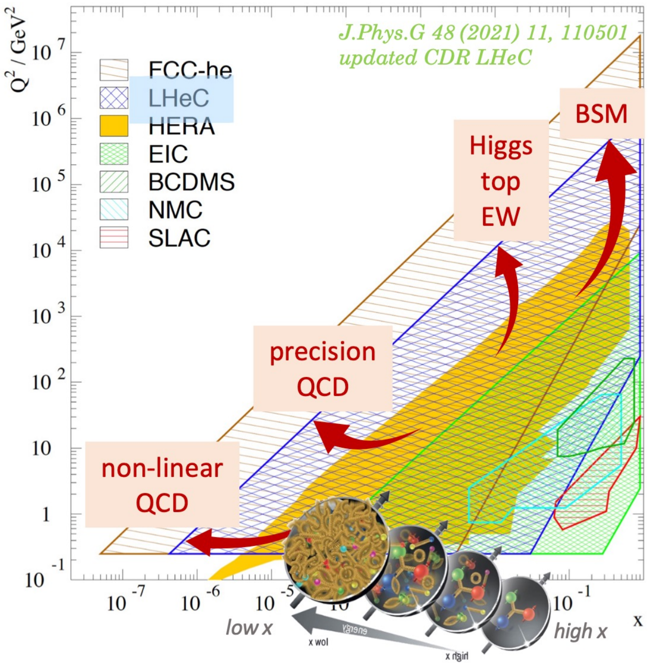




Future Energy Frontier ep and eA Options at CERN

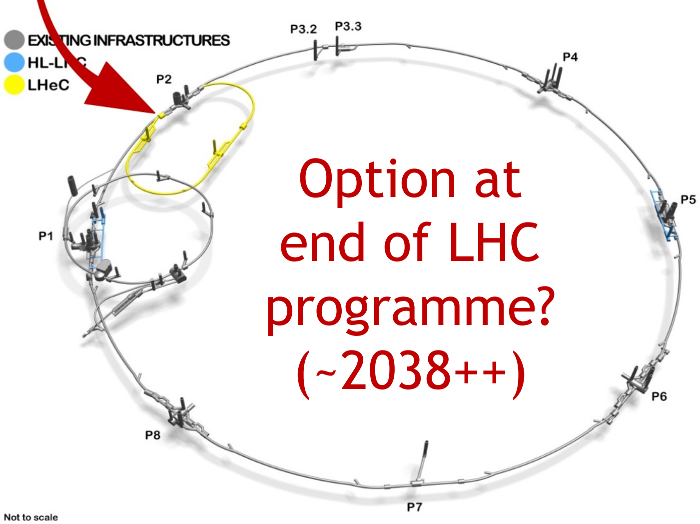
Renewed mandate and structure, towards next Euro Strategy

See https://indico.cern.ch/event/1335332/
https://indico.cern.ch/event/1367865/

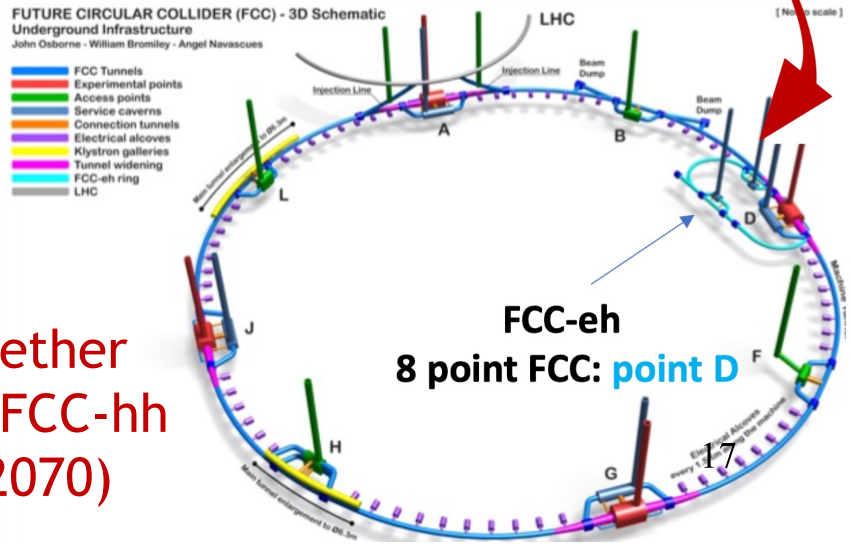


LHeC (>50 GeV electron beams)
E_{cms} = 0.2 – 1.3 TeV, (Q^2,x) range far beyond HERA
run ep/pp together with the HL-LHC (≳Run5)

FCC-eh (60 GeV electron beams)
E_{cms} = 3.5 TeV, described in CDR of the FCC
run ep/pp together: FCC-hh + FCC-eh



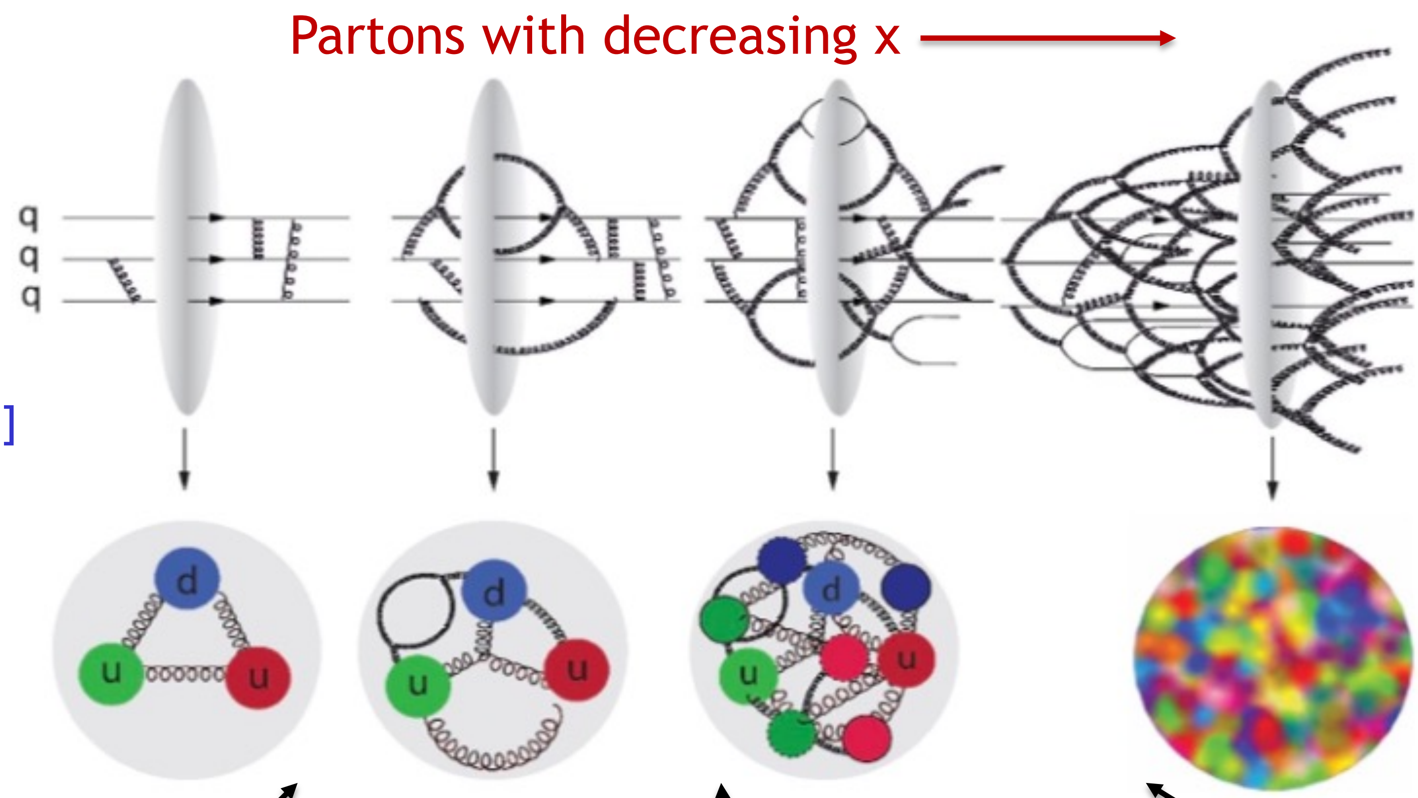
Option at end of LHC programme? (~2038++)



FCC-eh
8 point FCC: point D

Together with FCC-hh (~2070)

Crude Mapping Between Physics & Facilities



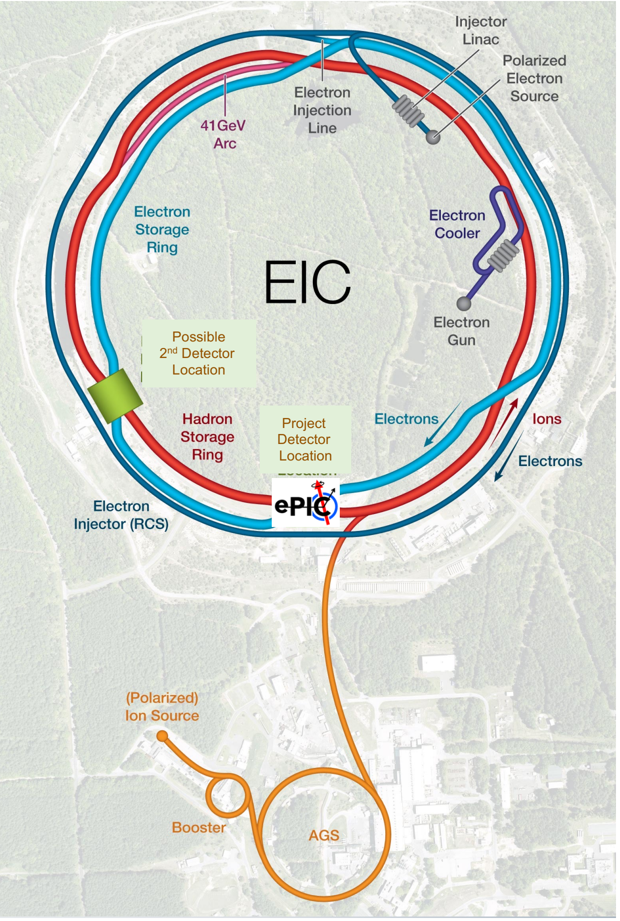
[Kong Tu]

High x (fixed Target)
Basic Structure

Intemediate x (EIC)
Emergent properties

Low x (HERA / LHeC)
QCD radiation
dynamics

The Electron-Ion Collider (BNL)



New electron ring, to collide with RHIC p, A

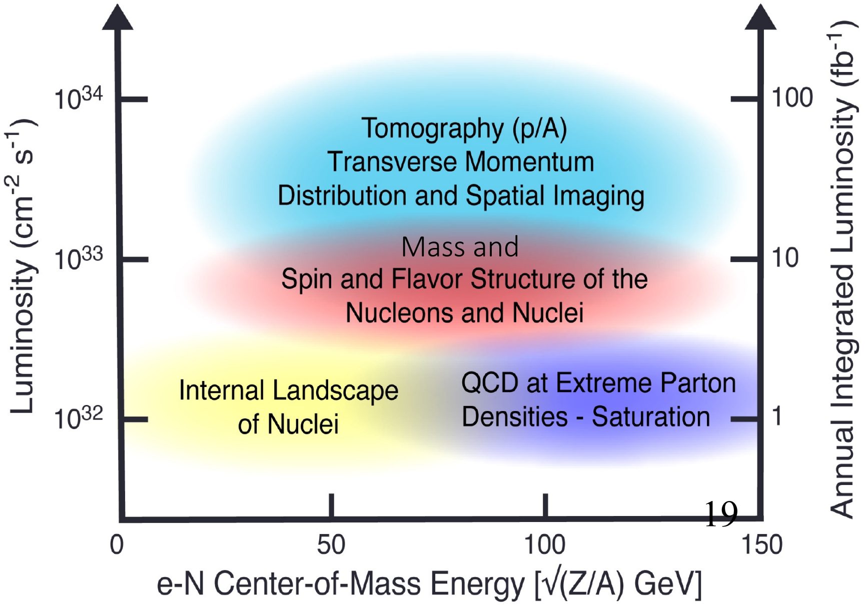
- Energy range **$28 < \sqrt{s} < 140$ GeV**, accessing moderate / large x values compared with HERA

World's first …

- High lumi ep Collider **(~ 10^{34} cm^{-2} s^{-1})**
- Double-polarised DIS collider
  (~70% for leptons and light hadrons)
- eA collider **(Ions ranging from H to U)**

Specifications driven by science goals:

- 3D proton structure
- Proton mass
- Proton spin
- Dense partonic systems in nuclei



EIC Machine Design Parameters

<table>
<tr><th colspan="2">Double Ring Design Based on Existing RHIC Facilities</th></tr>
<tr><td>Hadron Storage Ring: 40, 100 - 275 GeV</td><td>Electron Storage Ring: 5 - 18 GeV</td></tr>
<tr><td>RHIC Ring and Injector Complex: p to Pb</td><td>9 MW Synchrotron Radiation</td></tr>
<tr><td>1A Beam Current</td><td>Large Beam Current - 2.5 A</td></tr>
<tr><td colspan="2">10 ns bunch spacing and 1160 bunches</td></tr>
<tr><td>Light ion beams (p, d, ^{3}He) polarized (L,T) > 70%</td><td>Polarized electron beam > 70%</td></tr>
<tr><td>Nuclear beams: d to U</td><td>Electron Rapid Cycling Synchrotron</td></tr>
<tr><td>Requires Strong Cooling: new concept →CEC</td><td>Spin Transparent Due to High Periodicity</td></tr>
<tr><td colspan="2">One High Luminosity Interaction Region(s)</td></tr>
<tr><td colspan="2">25 mrad Crossing Angle with Crab Cavities</td></tr>
</table>

Challenges from high lumi requirement include short bunch spacing and high beam currents …

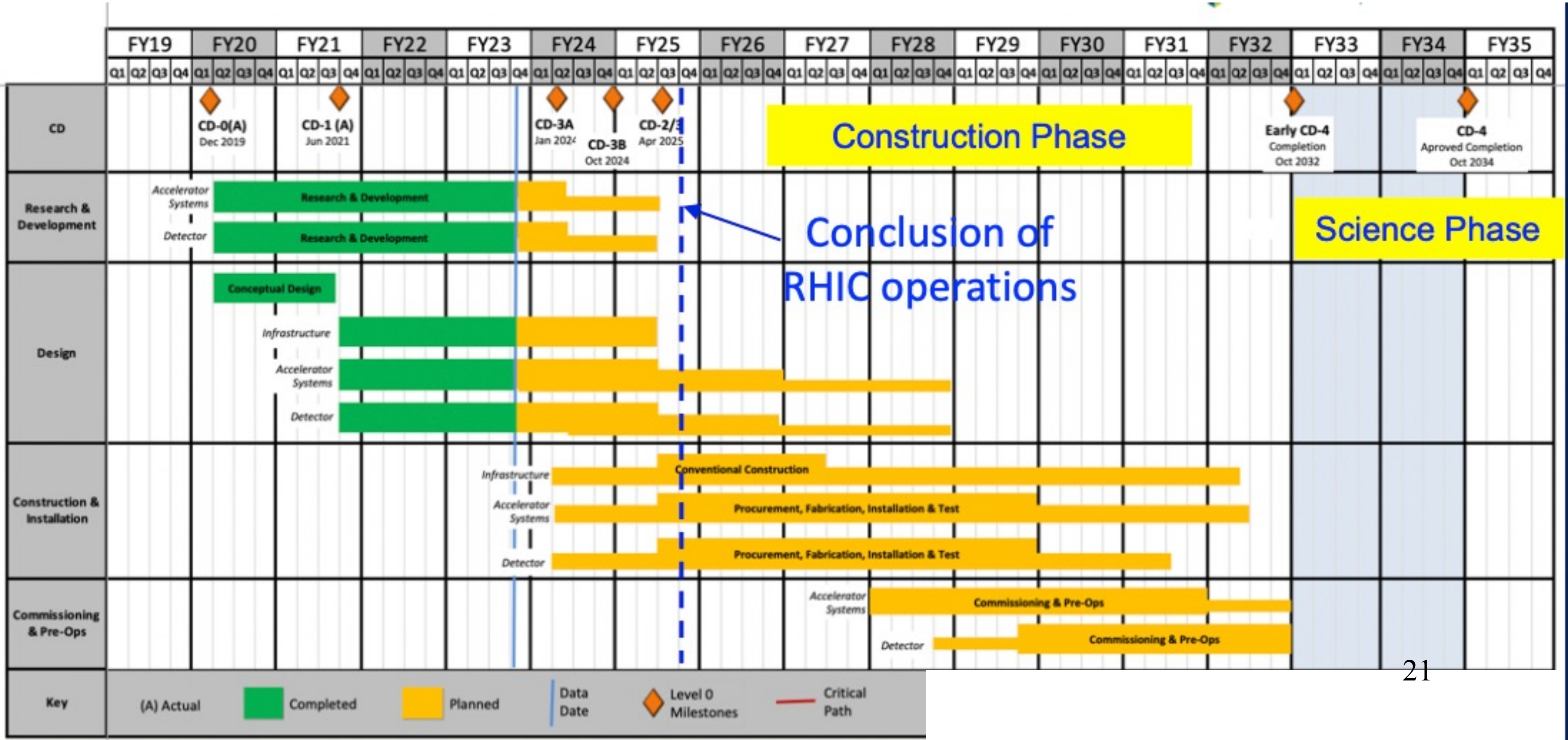
→ Synchrotron load management
→ Significant crossing angle

Status / Timeline

- Total cost ~$2Bn (US project funds accelerator + one detector)

- Still several steps to go, but on target for operation early/mid 30s

CD-0 (Mission need)	Dec 2019
CD-1 (Cost range)	June 2021
CD-3A (Start construction)	April 2024
CD-3B	Oct 2024
CD-2 (Performance baseline)	April 2025
CD-4 (Operations / completion)	2032-34
Technical Design Report	end 2024



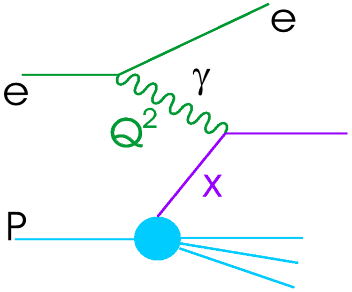
Construction Phase

Conclusion of RHIC operations

Science Phase

Observables / Detector Implications

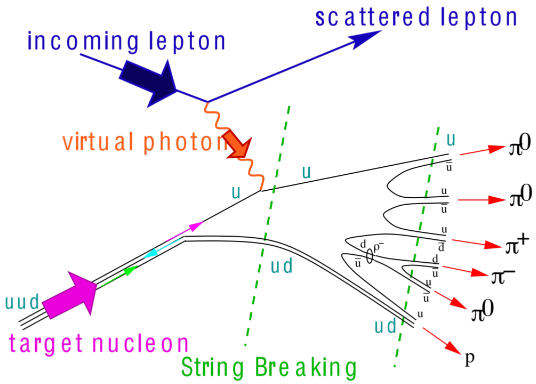
Inclusive



- Traditional DIS, following on from fixed target experiments and HERA → Longitudinal structure

… high acceptance, high performance electron identification and reconstruction

Semi-Inclusive



- Single particle, heavy flavour & jet spectra

→ p_T introduces transverse degrees of freedom

- Quark-flavour-identified DIS

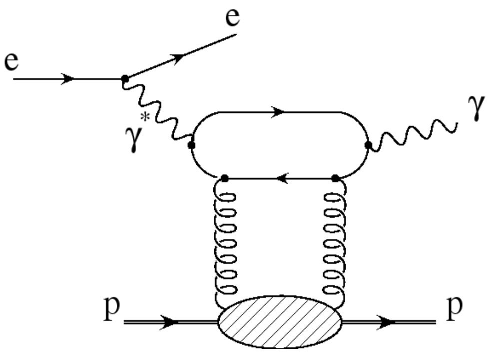
→ Separation of u,d,s,c,b and antiquarks

… tracking and hadronic calorimetry

… heavy flavour identification from vertexing

… light flavours from dedicated PID detectors

Exclusive / Diffractive



- Processes with final state ‘intact’ protons

→ Correlations in space or momentum between pairs of partons

… efficient proton tagging over wide acceptance range

… high luminosity

A Detector for the EIC

Magnet

- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking

- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

PID

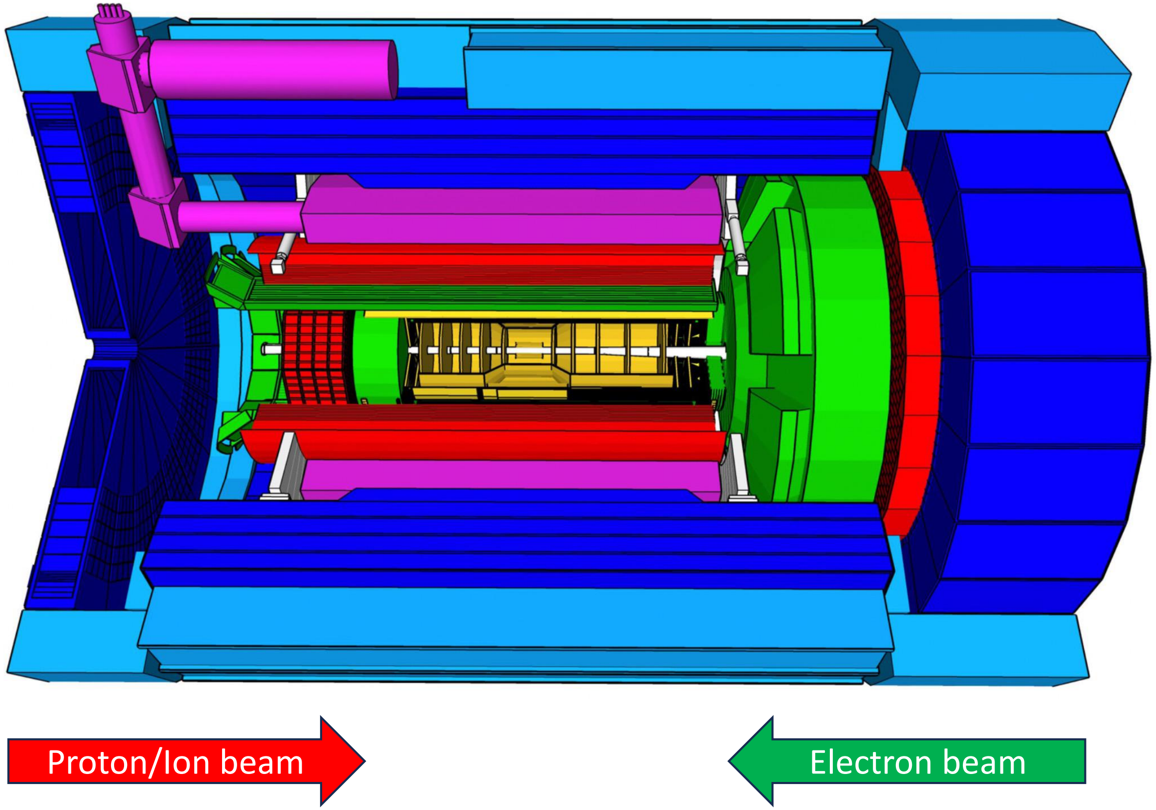
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry

- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry

- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



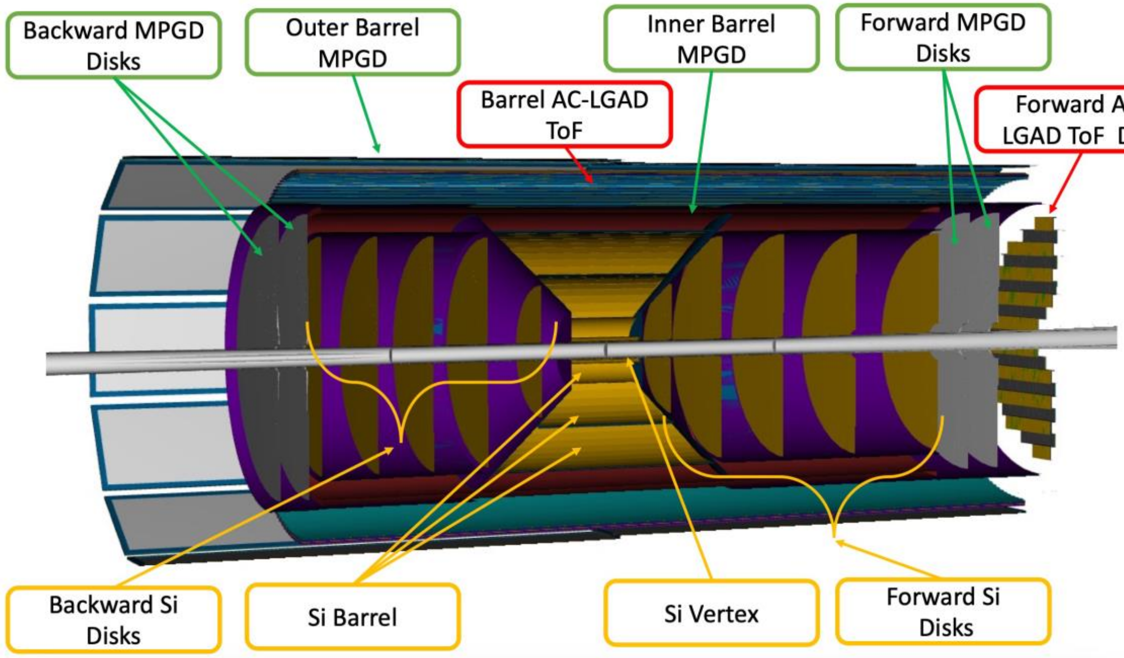
- 9m long x 5m wide
- Extensive beamline instrumentation not shown (see later)
- Continuous streaming readout with emphasis on FEB zero-suppression
- Much lower radiation fluxes than LHC widens technology options

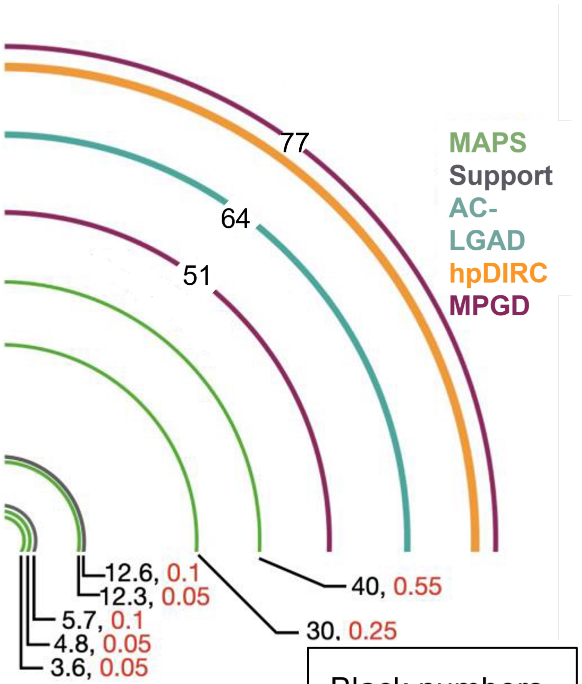
[ongoing work towards a second, complementary detector]

Tracking Detectors

Primarily based on MAPS silicon detectors (65nm technology)

- Leaning heavily on ALICE ITS3
- Stitched wafer-scale sensors, thinned and bent around beampipe
  → Very low material budget (0.05X_0 per layer for inner layers)
- 20x20μm pixels
- 5 barrel layers + 5 disks (total 8.5m^2 silicon)





Black numbers are radii in cm

Red numbers are material in % X0

LGAD layers provide fast timing (~20ns)

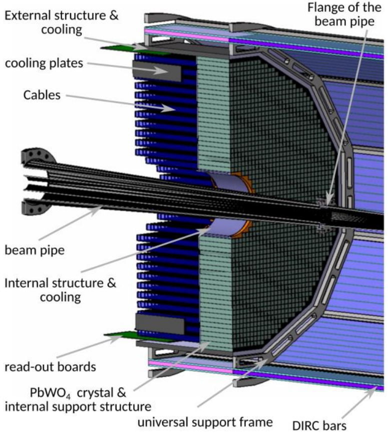
Outer gaseous detectors add additional hit points for track reconstruction

Calorimeter Overview

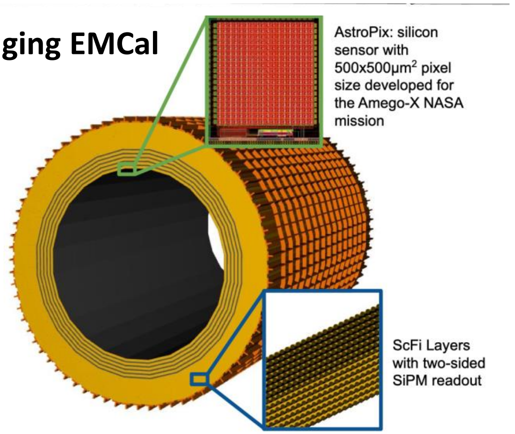
- Different technologies in barrel and end-caps, as required for varying performance targets
- New ECAL designs / technologies,
- HCAL partially recycles previous detectors
- All read out with Si PMs

Electron Endcap EMCal

PbWO$_4$ crystals



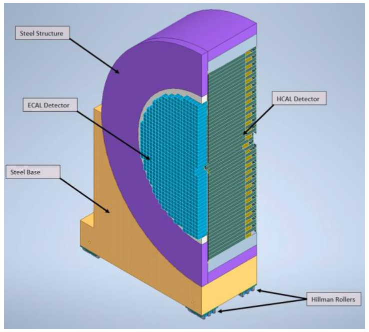
Barrel Imaging EMCal



AstroPix: silicon sensor with 500x500μm^2 pixel size developed for the Amego-X NASA mission

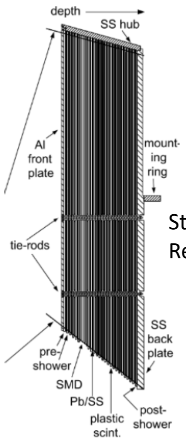
ScFi Layers with two-sided SiPM readout

Hadron Endcap EMCal



High granularity W-powder/SciFi EMCal

Electron Endcap HCal



Steel/Scint Sandwich (10 layers)
Reuse of STAR scint. tiles

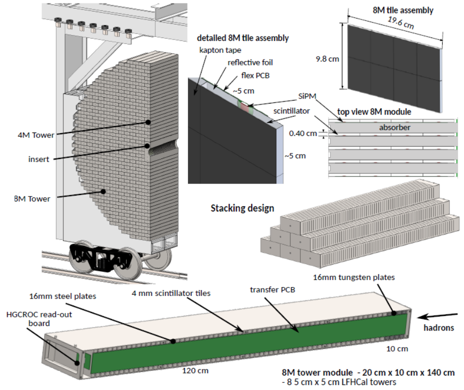
Barrel HCal

sPHENIX barrel calorimeter with new SiPMs

Hadron Endcap HCal

Longitudinally separated HCAL Steel/Sc & W/Sc sandwich

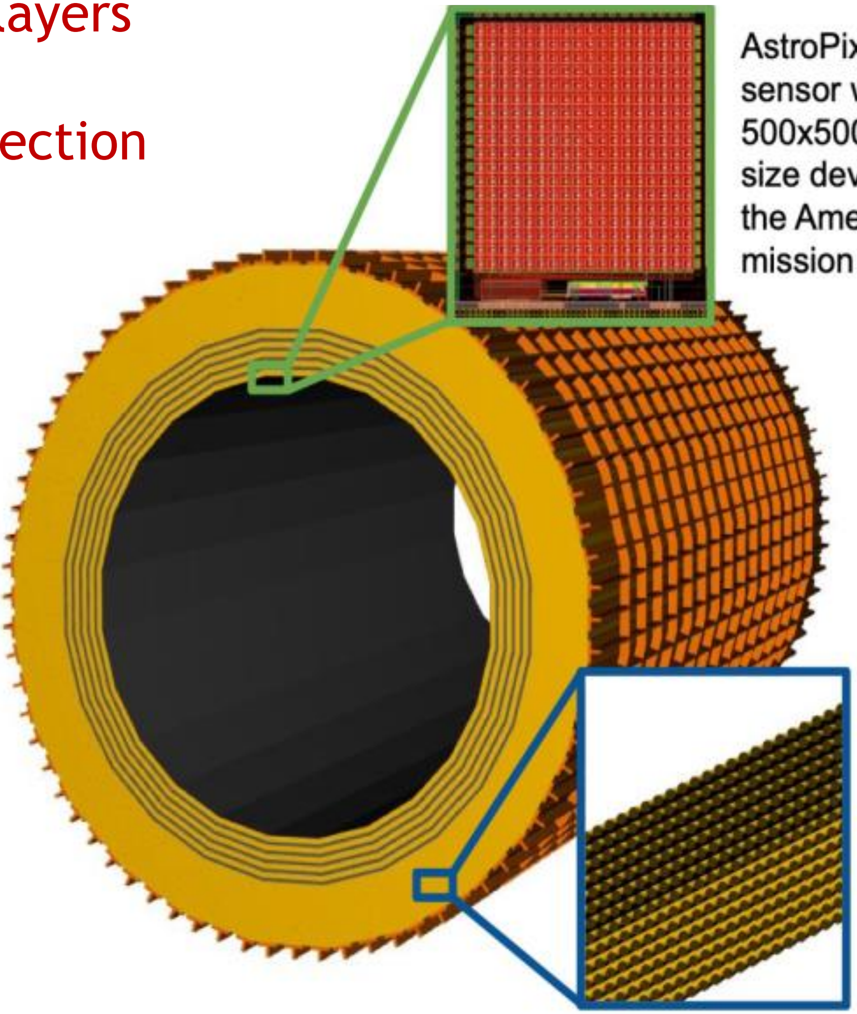
SiPM-on-tile readout



+ high granularity insert at largest η

Barrel ‘Imaging ECAL’

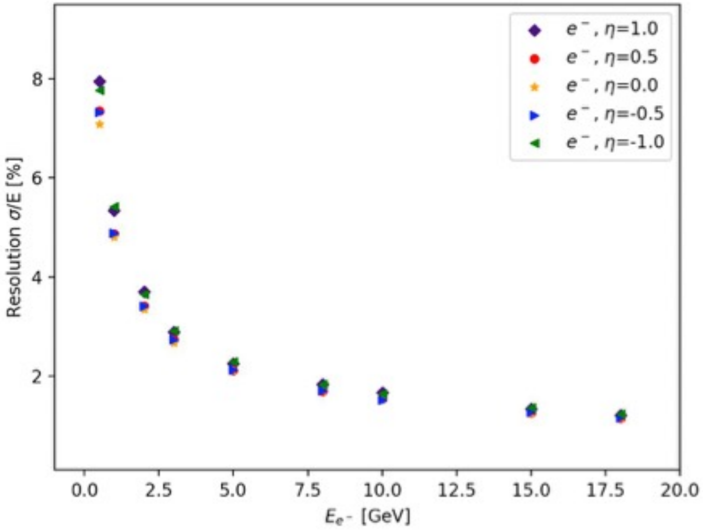
- 4 MAPS (Astropix) layers for position resolution.
- Interleaved with 5 Pb/SciFi layers for energy resolution
- Followed by large Pb/SciFi section



AstroPix: silicon sensor with 500x500μm^2 pixel size developed for the Amego-X NASA mission

ScFi Layers with two-sided SiPM readout

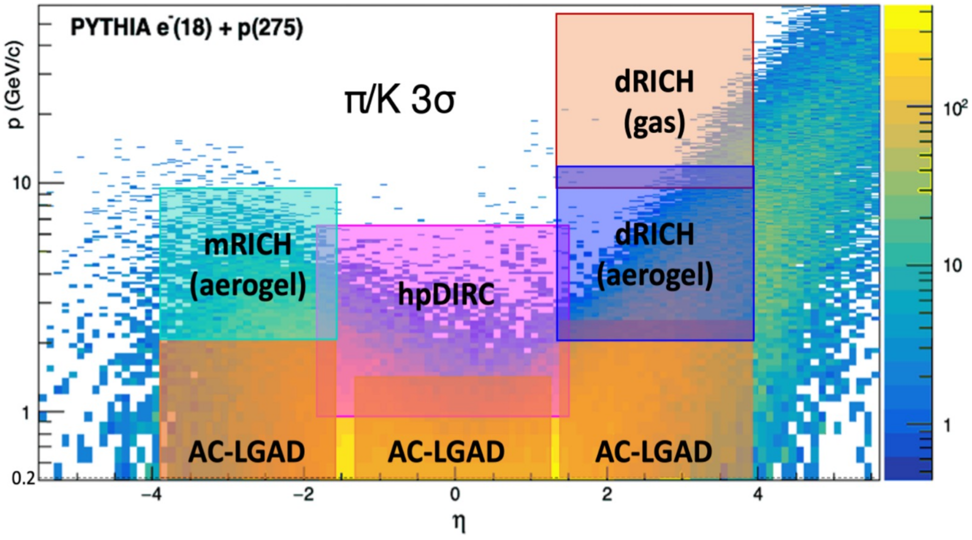
$$\boxed{\frac{\sigma}{E} \sim \frac{5\%}{\sqrt{E}} + 0.5\%}$$



Particle Identification

- SIDIS programme relies on π / K / p (and other PID) separation …

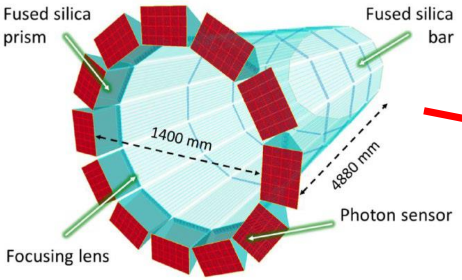
- Cerenkov detectors at high momentum, augmented by AC-LGADs / ToF at low momentum



ePIC detector design – PID

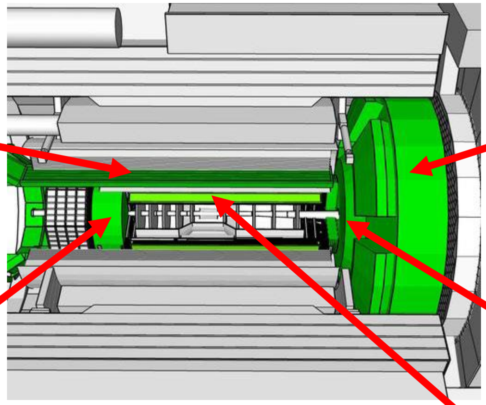
High-Performance DIRC

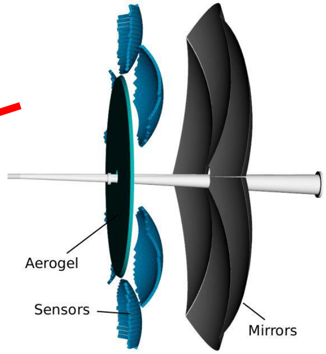
- ○ Quartz bar radiator (reuse BaBAR bars)
- ○ Sensors: MCP-PMTs
- ○ π/K separation up to 6 GeV/c

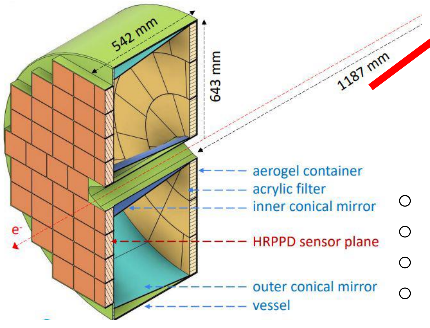


Dual-Radiator RICH (dRICH)

- ○ C_2F_6 Gas Volume and Aerogel
- ○ Sensors: SiPMs tiled on spheres
- ○ π/K separation up to 50 GeV/c





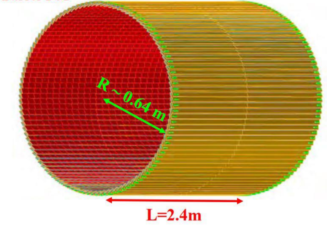


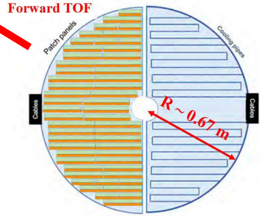
Proximity Focused (pfRICH)

- ○ Long Proximity gap (~40 cm)
- ○ Sensors: HRPPDs (also provides timing)
- ○ π/K separation up to 10 GeV/c
- ○ e/π separation up to 2.5 GeV/c

AC-LGAD TOF

- ○ t = ~30 psec / s = 30 μm
- ○ Accurate space point for tracking
- ○ forward disk and central barrel

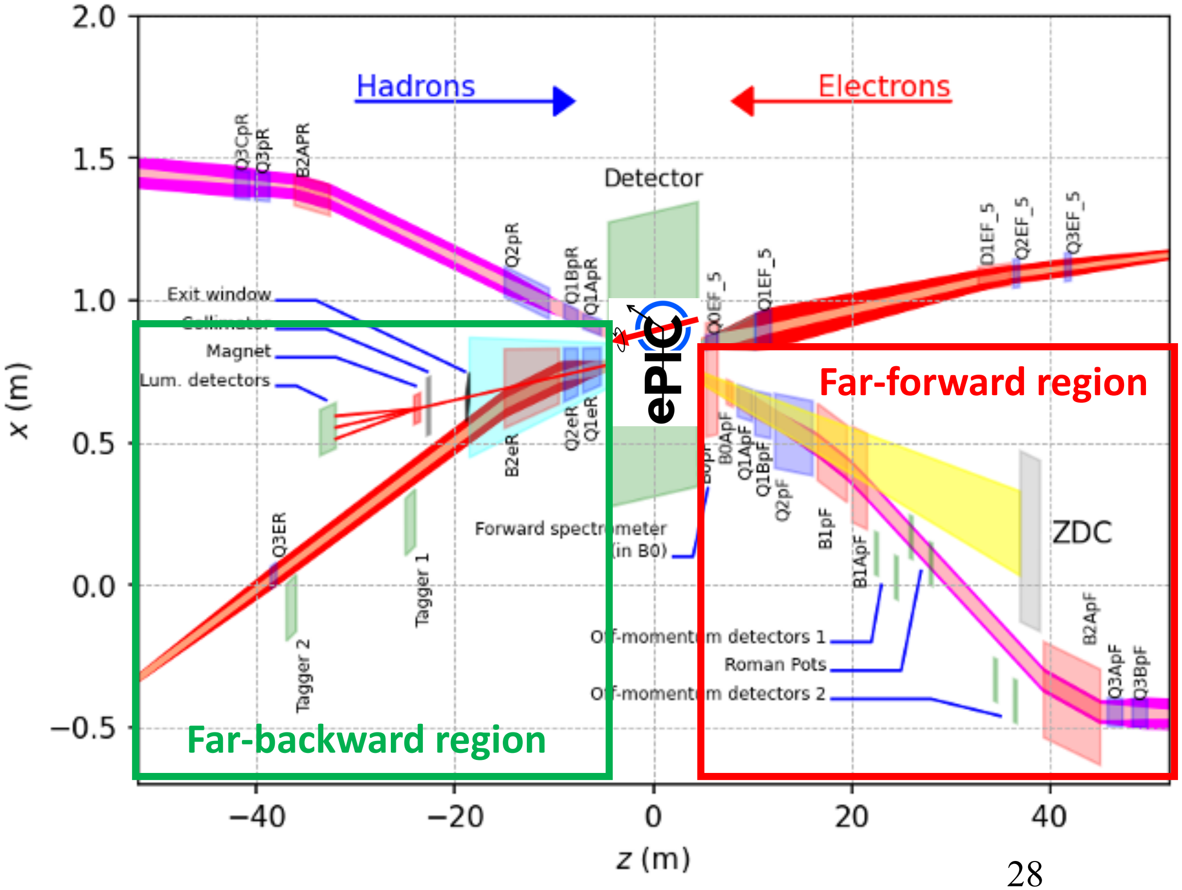




Interaction Region / Beamline Instrumentation

- Extensive beamline instrumentation integrated into IR design

- Tagging electrons and photons in backward direction for lowest Q^2 physics studies and lumi monitoring via $ep \rightarrow ep\gamma$



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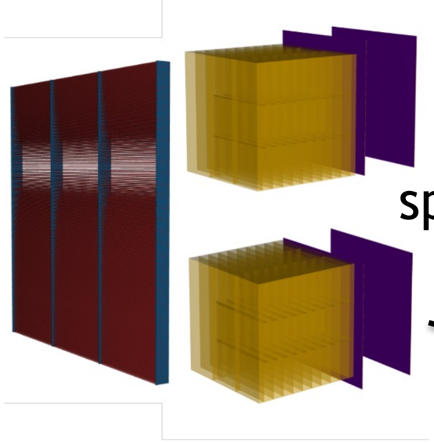
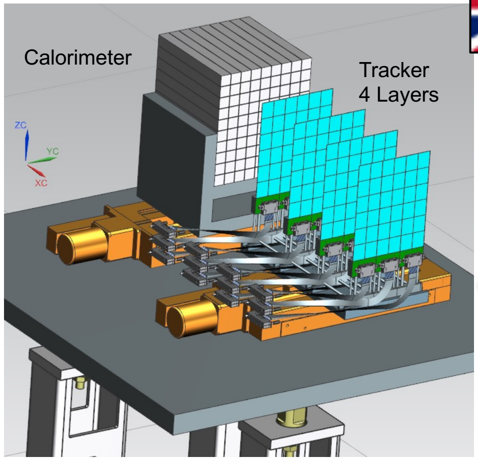
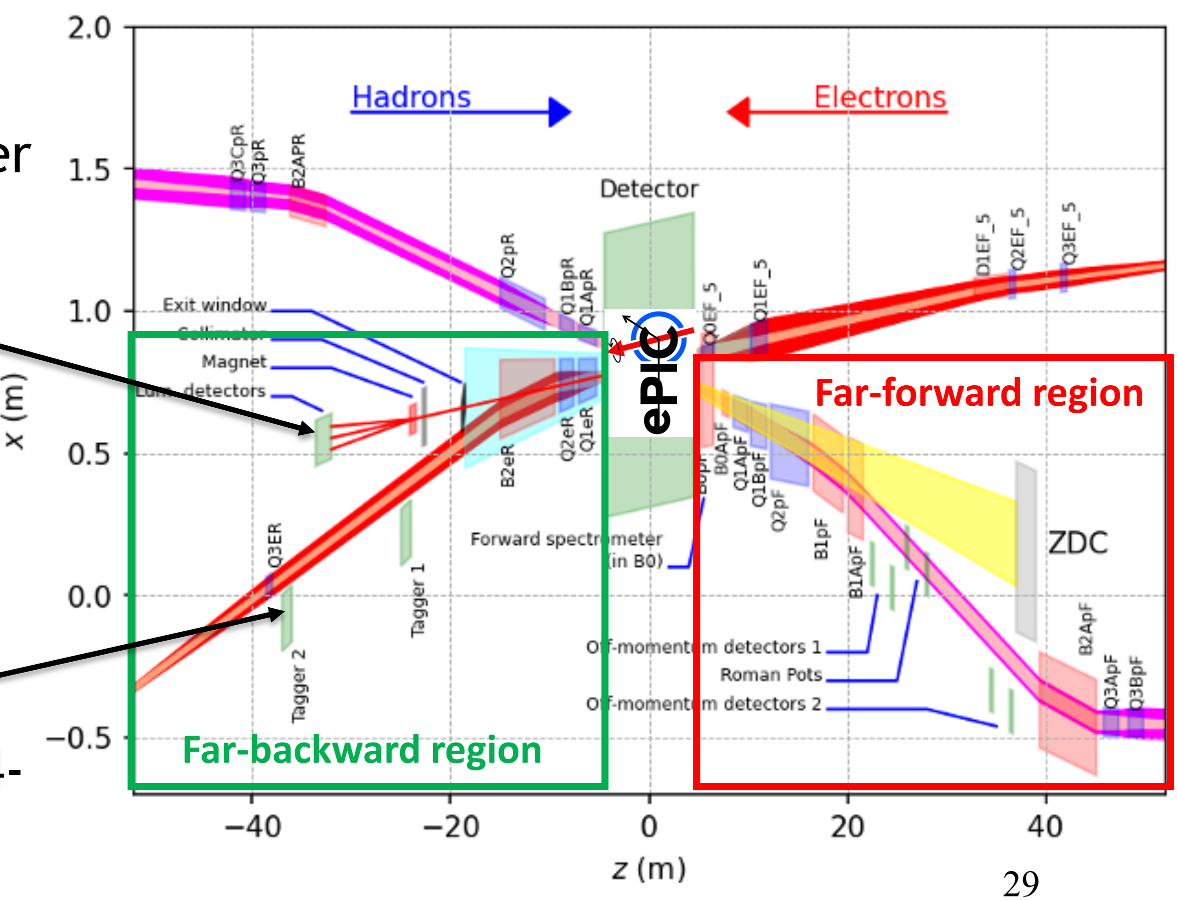


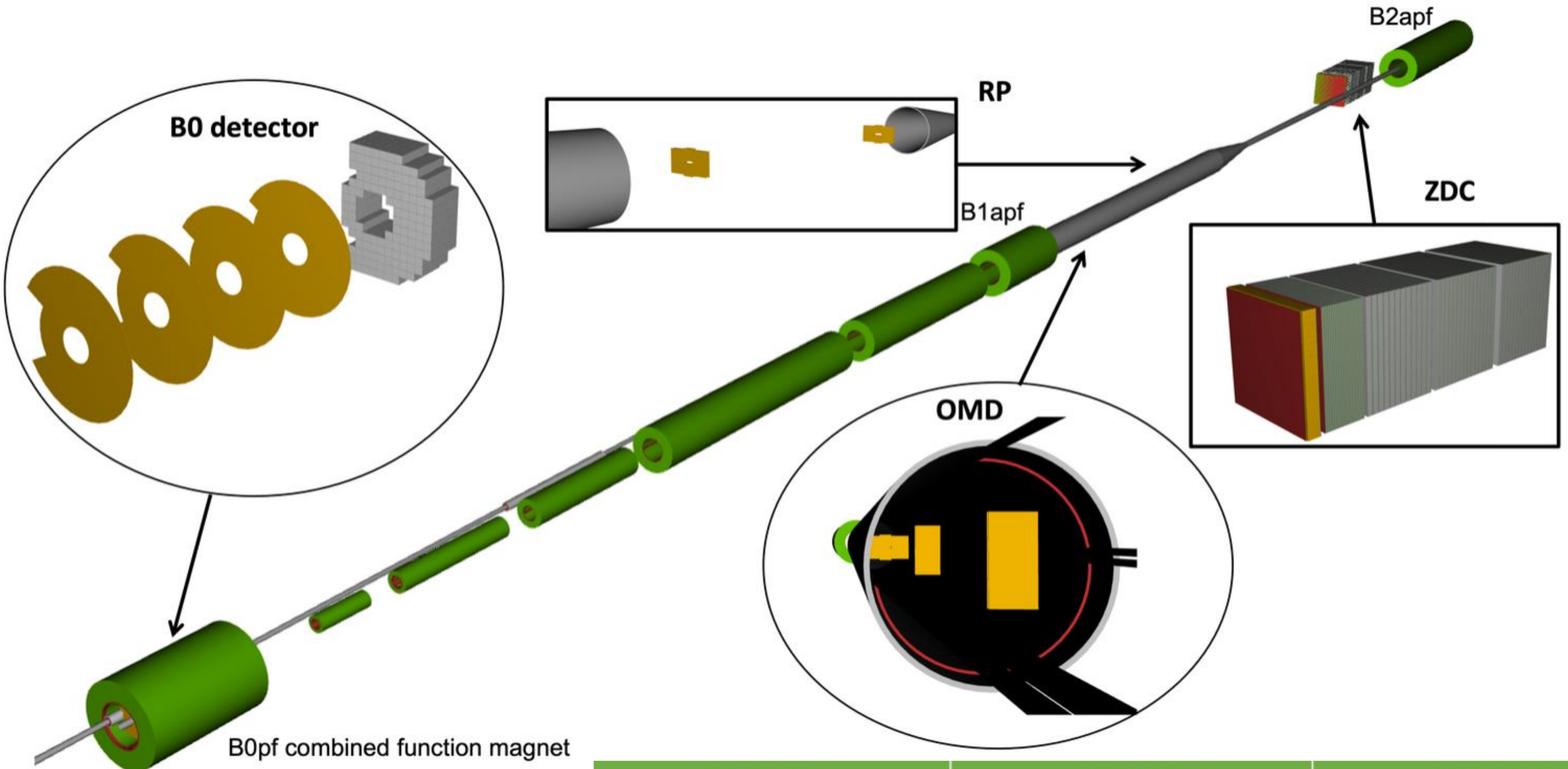
W-Sci-Fi
Lumi Pair
spectrometer



Timepix4-
based
tracker



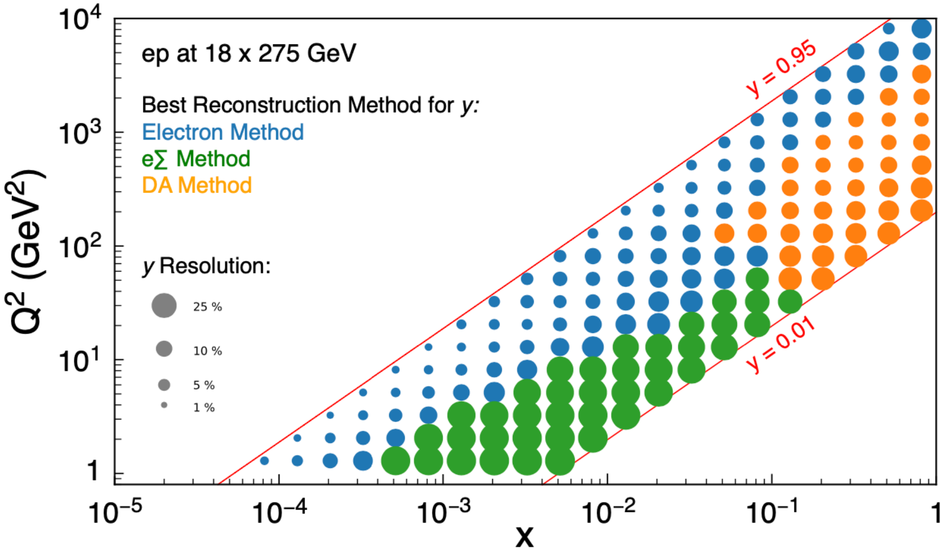
Far Forward Region



Detector	Acceptance	Particles
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5\, mrad$	Neutrons, photons
Roman Pots (2 stations)	$0^{*} < \theta < 5.0\, mrad$ (*10σ beam cut)	Protons, light nuclei
Off-Momentum Detectors (2 stations)	$0 < \theta < 5.0\, mrad$	Charged particles
B0 Detector	$5.5 < \theta < 20\, mrad$	Charged particles, tagged photons

Hermetic forward coverage except for beampipe

Performance and Measurement Strategy



- Choose reconstruction methods exploiting the hadronic final state as well as the electron to optimise (x, Q^2) resolutions throughout phase-space

- Exploit overlaps between data at different $\sqrt{s}$ to avoid ‘extreme’ phase space regions

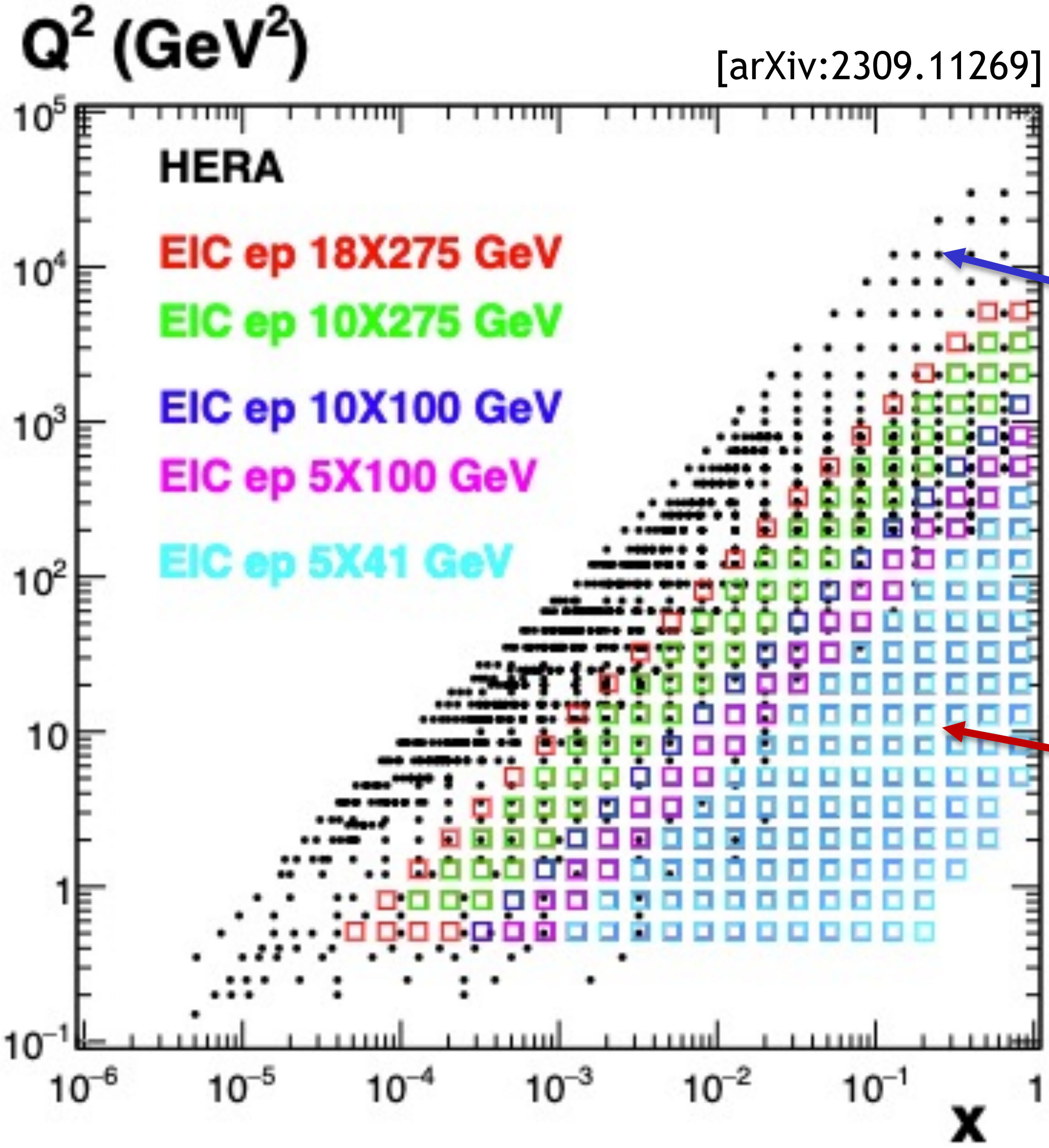
e-beam E	p-beam E	$\sqrt{s}$ (GeV)	inte. Lumi. (fb^{-1})
18	275	140	15.4
10	275	105	100.0
10	100	63	79.0
5	100	45	61.0
5	41	29	4.4

- Systematic precision estimated from experience at HERA, expected EIC detector performance, and guesswork

Simulations based on precision:
- 1.5-2.5% point-to-point uncorrelated
- 2.5% normalisation

Inclusive EIC Data Impact on Proton PDFs

[arXiv:2309.11269]



HERA data have limited high x sensitivity due to $1/Q^4$ factor in cross section and kinematic x / Q^2 correlation

EIC data fills in large x, modest Q^2 region with high precision

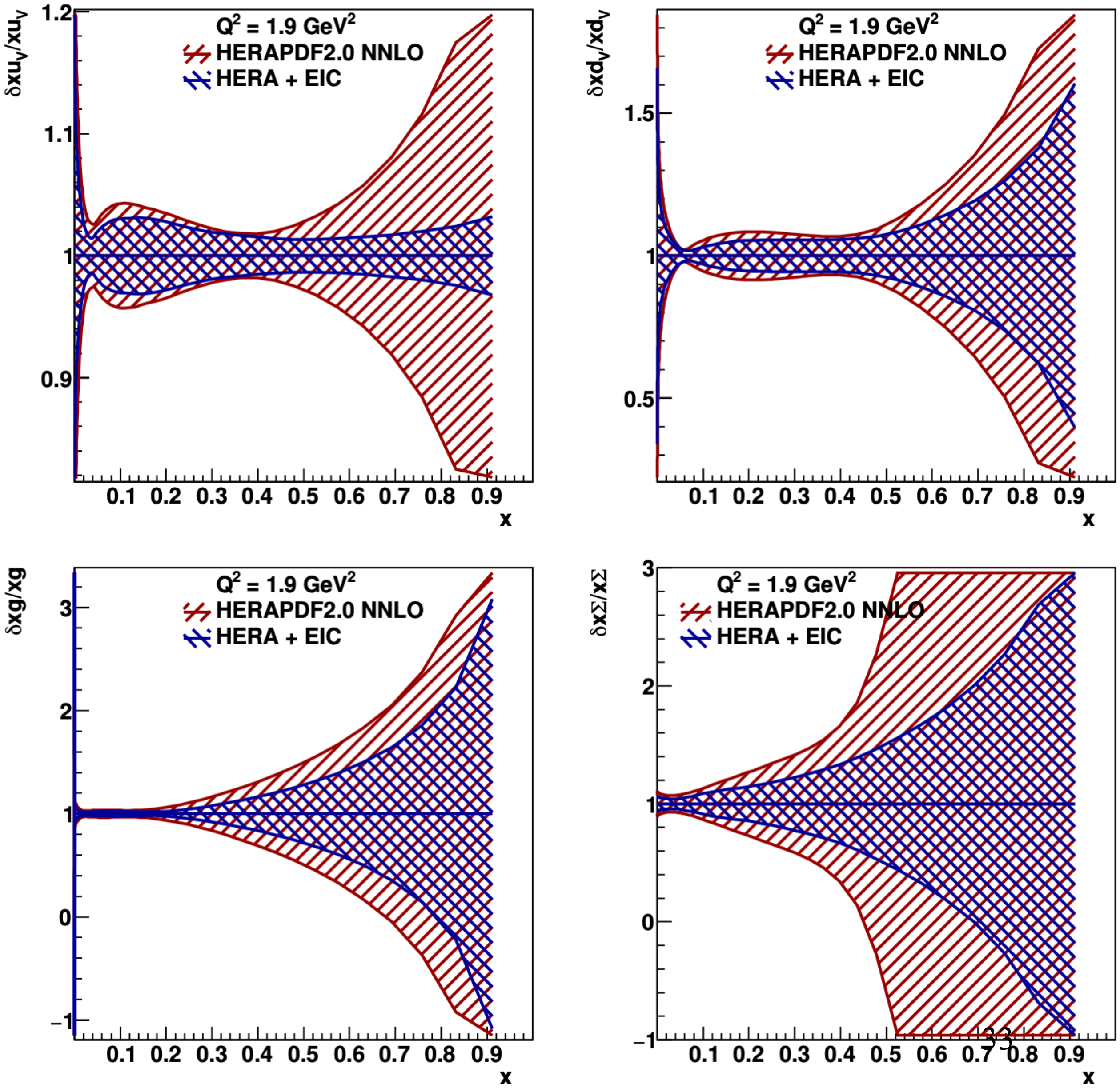
Impact of EIC/ATHENA on HERAPDF2.0

Fractional total uncertainties with / without simulated EIC data included with HERA

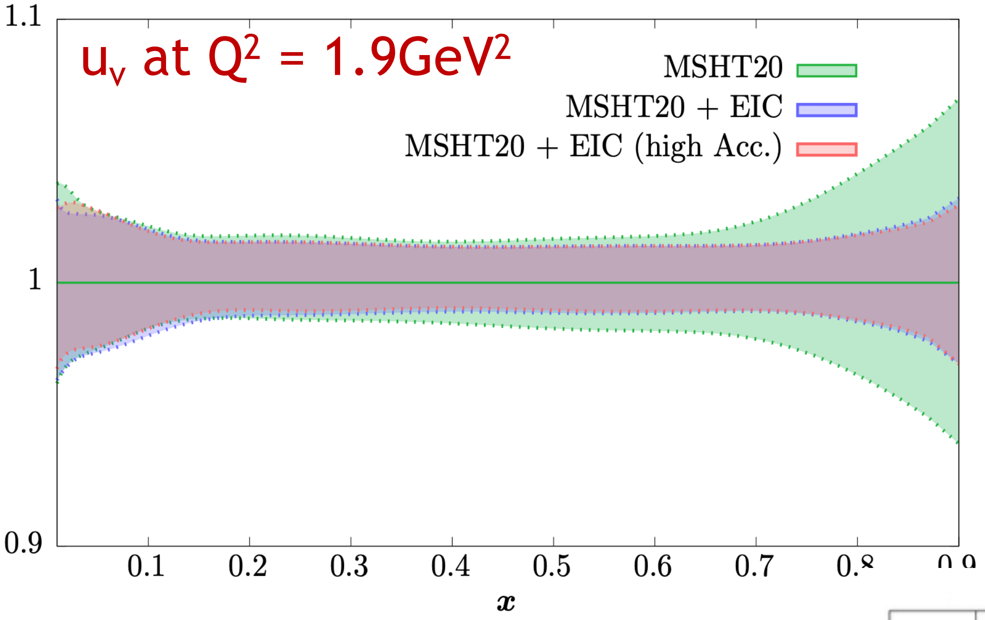
(linear x scale, $Q^2 = Q_0^2$)

… EIC will bring significant reduction in uncertainties for all parton species at large x

… most notable improvements for up quarks (charge-squared weighting)



EIC Impact relative to MSHT20 NNLO (as an example global fit)

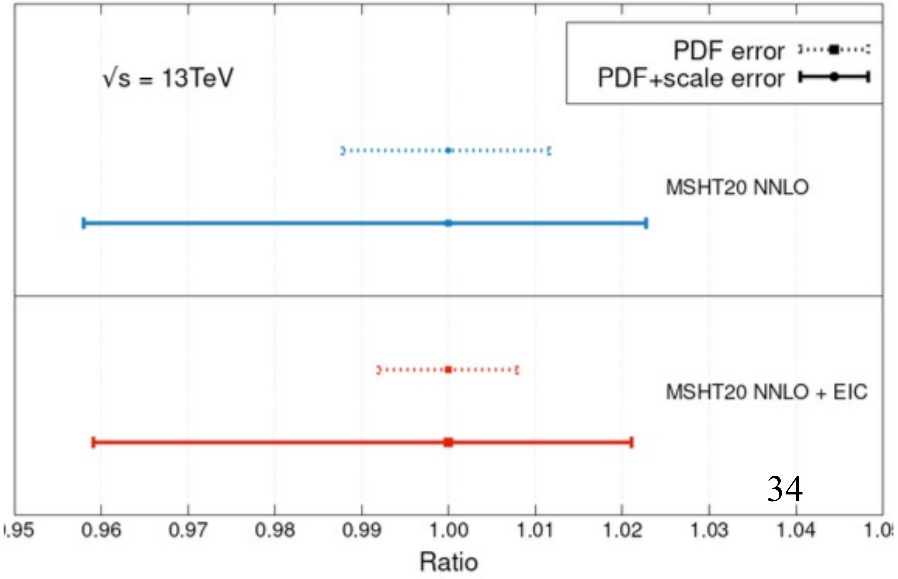


Significant impact of EIC simulated data in up quark precision as x→1

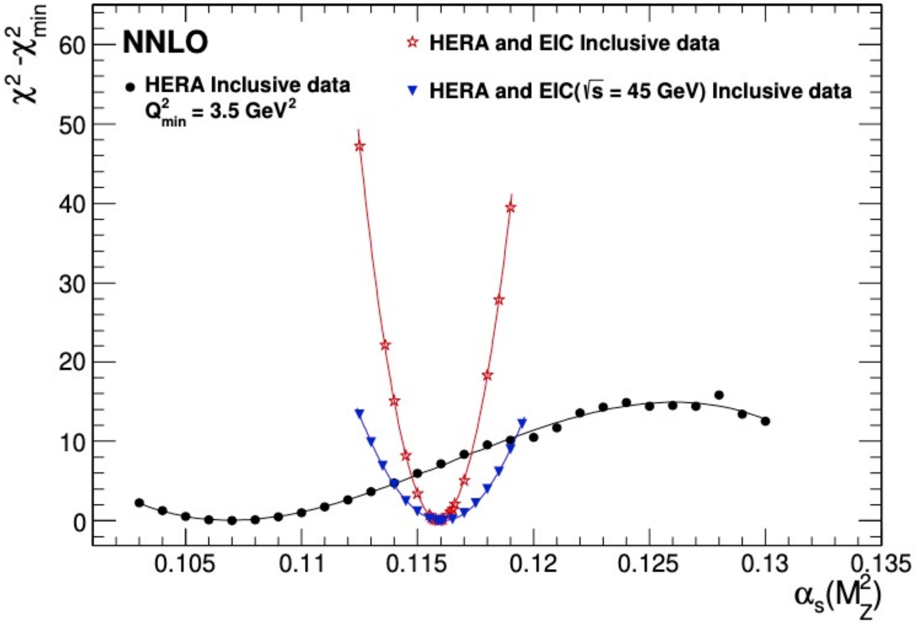
σ(gg→H) uncertainties @ LHC [N^{3}LO matrix elements with NNLO PDFs]

… small, but valuable improvements in all parton species at all x, Q^2

… e.g. gluon improvement feeds through parton-parton luminosities to significant improvement in PDF uncertainty on gg→H at LHC



Taking α_s as an additional free parameter



- HERA data alone (HERAPDF2.0) shows only limited sensitivity when fitting inclusive data only.

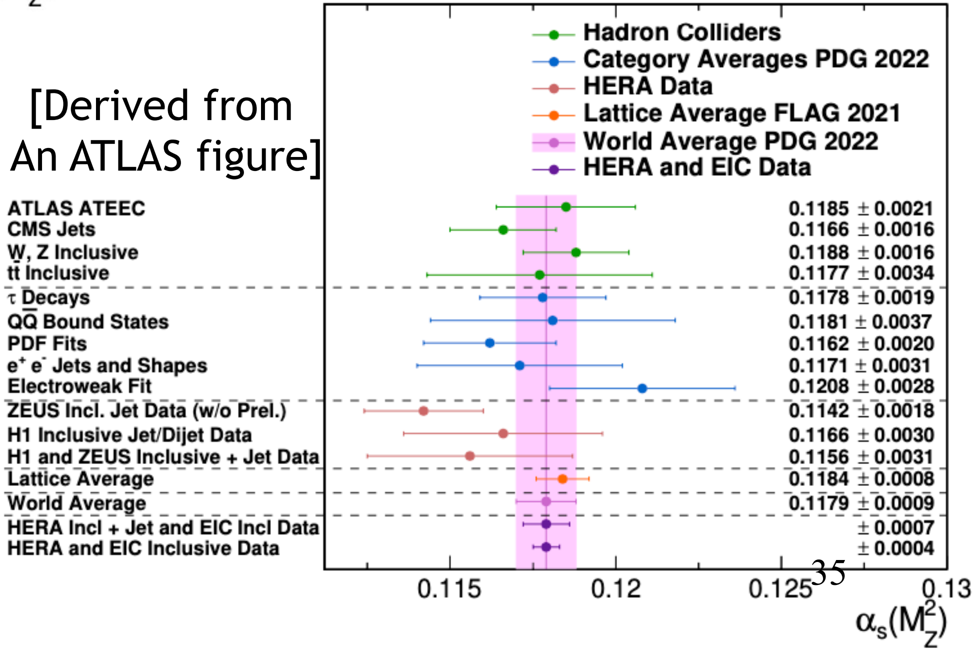
- Adding EIC simulated data has a remarkable impact

$$\alpha_s(M_Z^2) = 0.1159 \pm 0.0004\ (\text{exp})$$
$$^{+0.0002}_{-0.0001}\ (\text{model} + \text{parameterisation})$$

Adding EIC (<u>precision high x</u>) data to HERA can lead to α_s precision a factor ~2 better than current world experimental average, and than lattice QCD average

Scale uncertainties remain to be understood (ongoing work)

[Derived from An ATLAS figure]

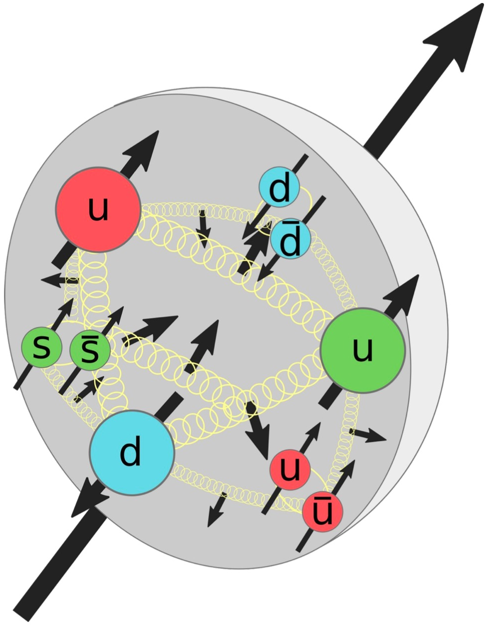


Physics Motivation: Proton Spin

- Spin ½ is much more complicated than ↑↑↓ …

- EMC ‘spin crisis’ (1987) … quarks only carry about 10% of the nucleon spin

- Viewed at the parton level, complicated mixture of quark, gluon and relative orbital motion, evolving with Q^2, but always = ½



Jaffe-Manohar sum rule:

$$\boxed{\Delta\Sigma/2}+\boxed{\Delta G}+\boxed{\ell_q}+\boxed{\ell_g}=\hbar/2$$

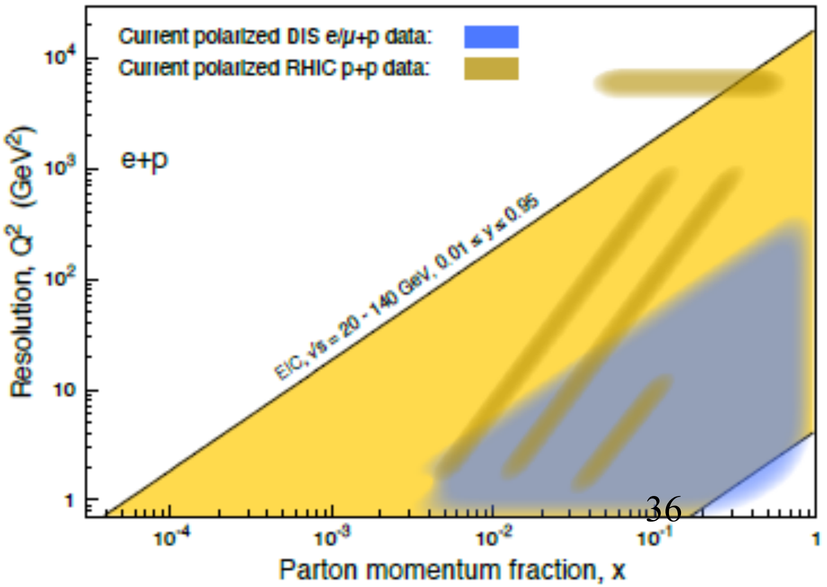
Quark helicity

Gluon helicity

Quark canonical orbital angular momentum

Gluon canonical orbital angular momentum

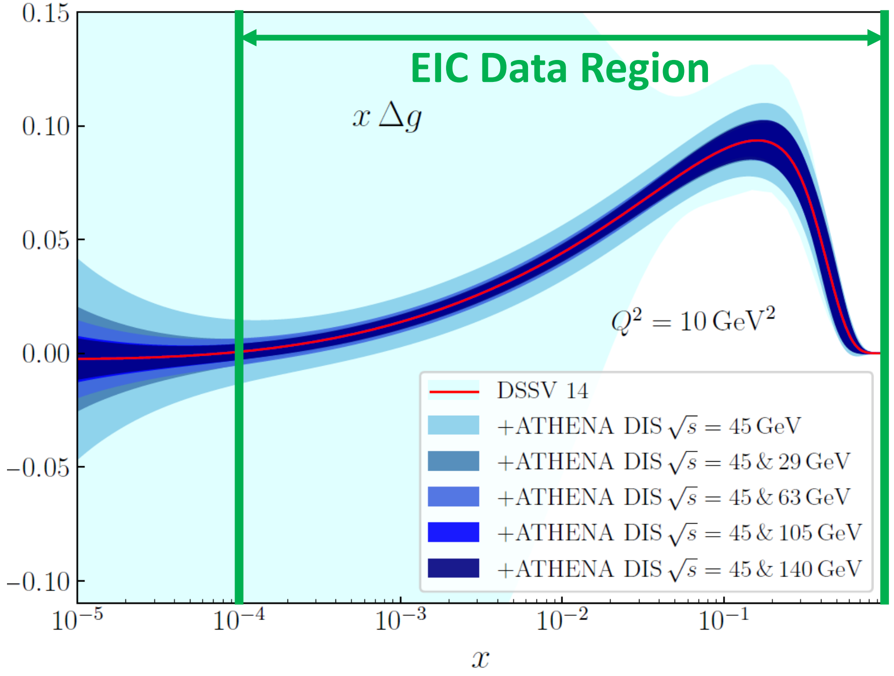
- Very little known about gluon helicity contribution or importance of low x region

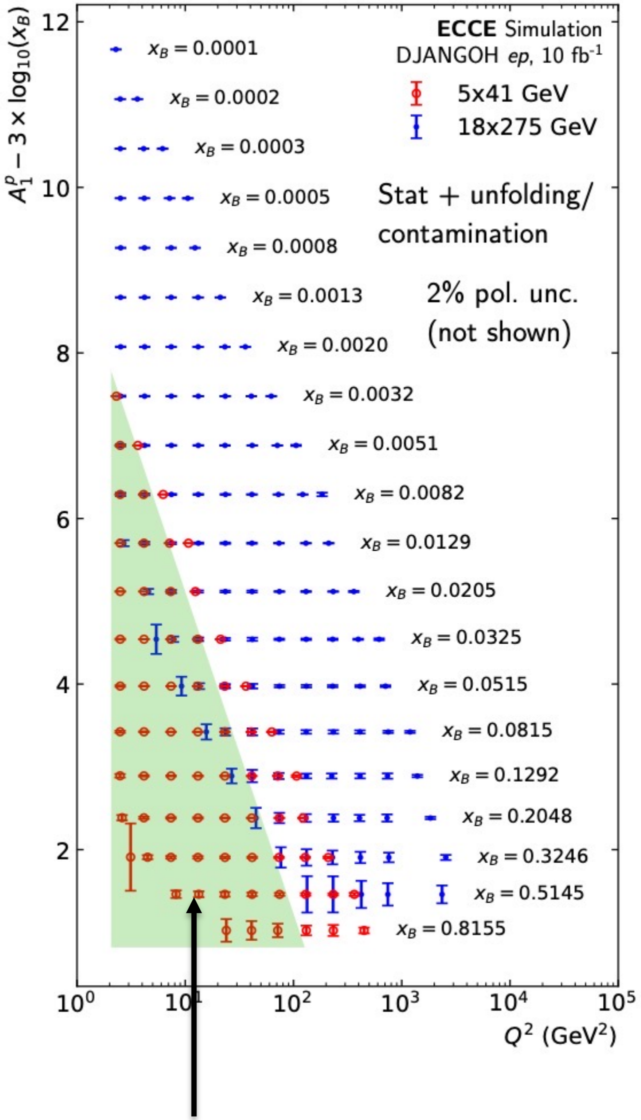


Proton Spin Simulation

Can be resolved in full with EIC inclusive, semi-inclusive and exclusive data

e.g. impact relative to recent global fit (DSSV14) of inclusive EIC data (double spin asymmetries 15fb^{-1} and 70% e,p polarization)





Previously measured region (green)

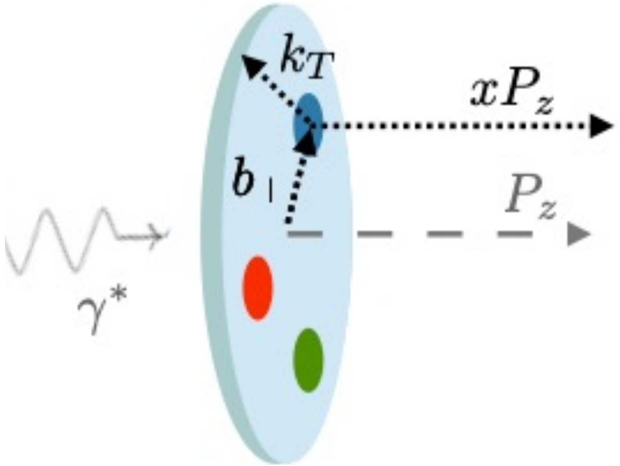
EIC measures down to x ~ 5 x 10^{-3} for 1 < Q^2 < 100 GeV^2

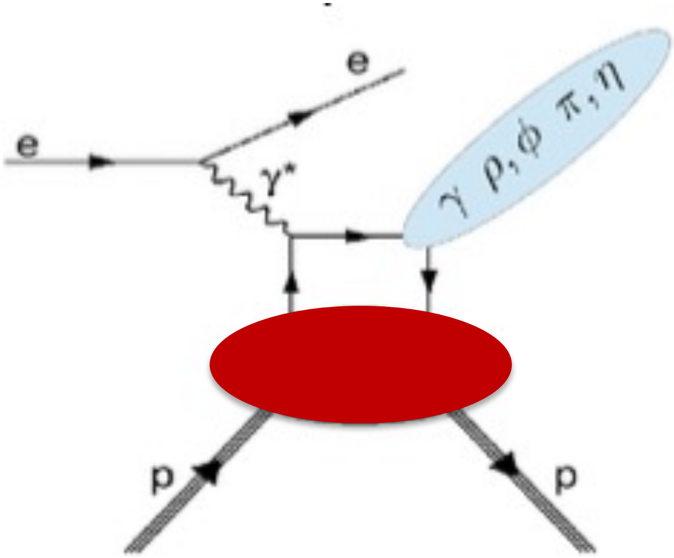
Physics Motivation: 3D Structure

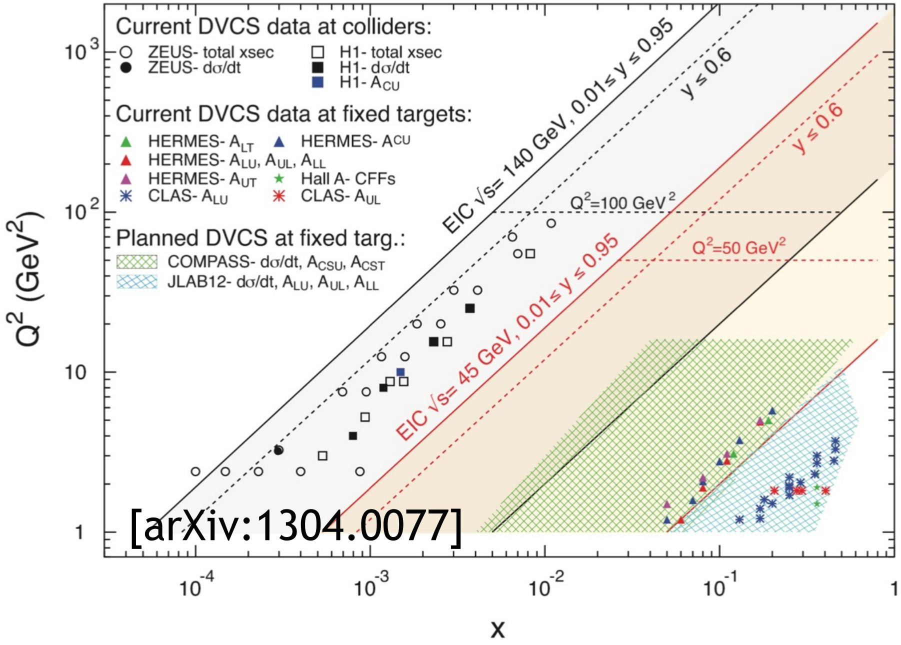
Exclusive processes, yielding intact protons, require (minimum) 2 partons exchanged

→ Sensitivity to correlations between partons in longitudinal / transverse momentum and spatial coordinates

→ access to 3D tomography





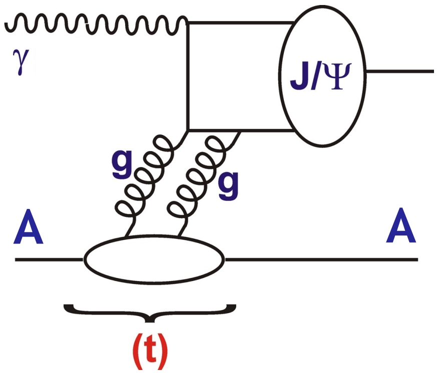


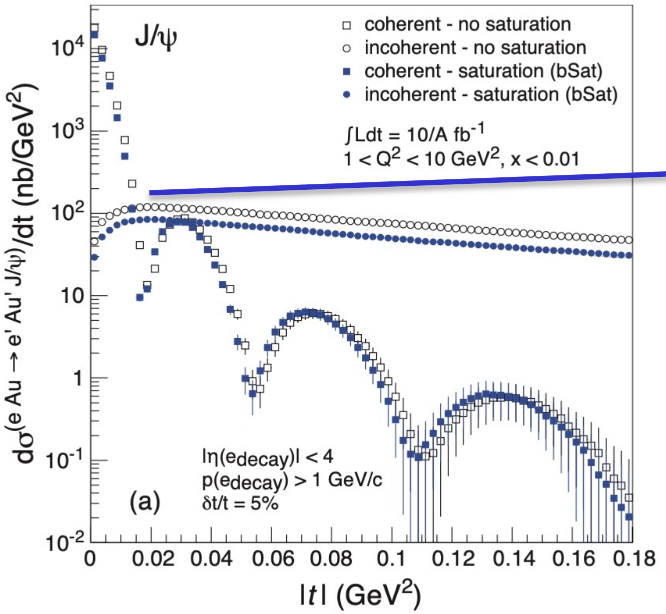
[arXiv:1304.0077]

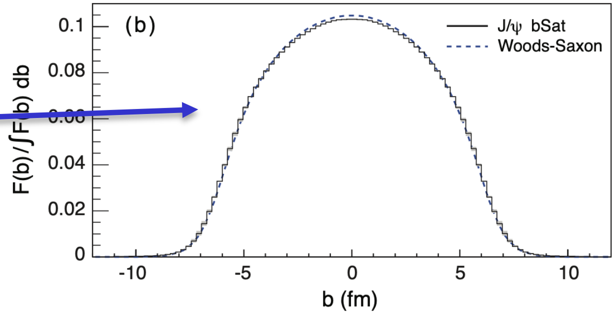
e.g. Deeply Virtual Compton Scattering, ep → eγp:

EIC fills gap between (high stats) fixed target & (low stats) HERA data

Physics Motivation: Dense Gluonic Systems







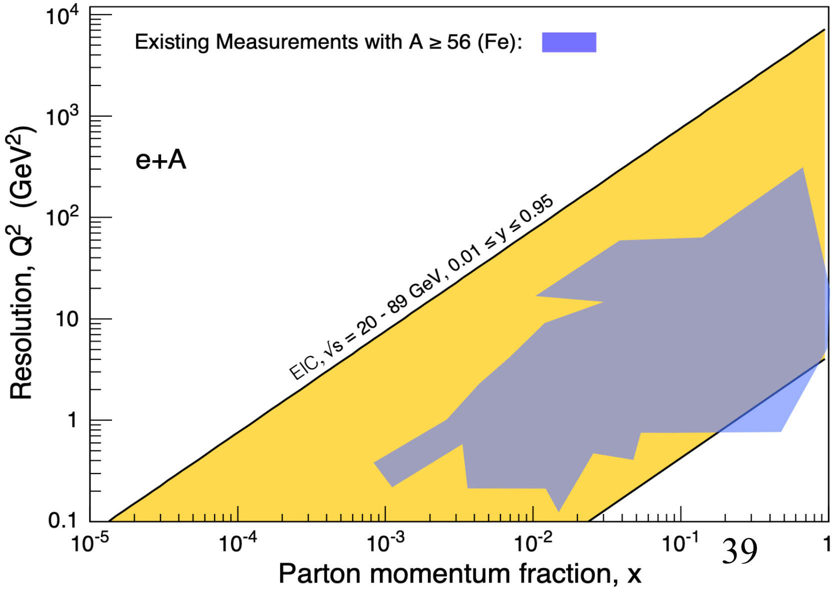
e.g. Coherent J/Ψ in eAu: dips sensitive to saturation

Mandelstam t in exclusive processes conjugate to transverse spatial distributions

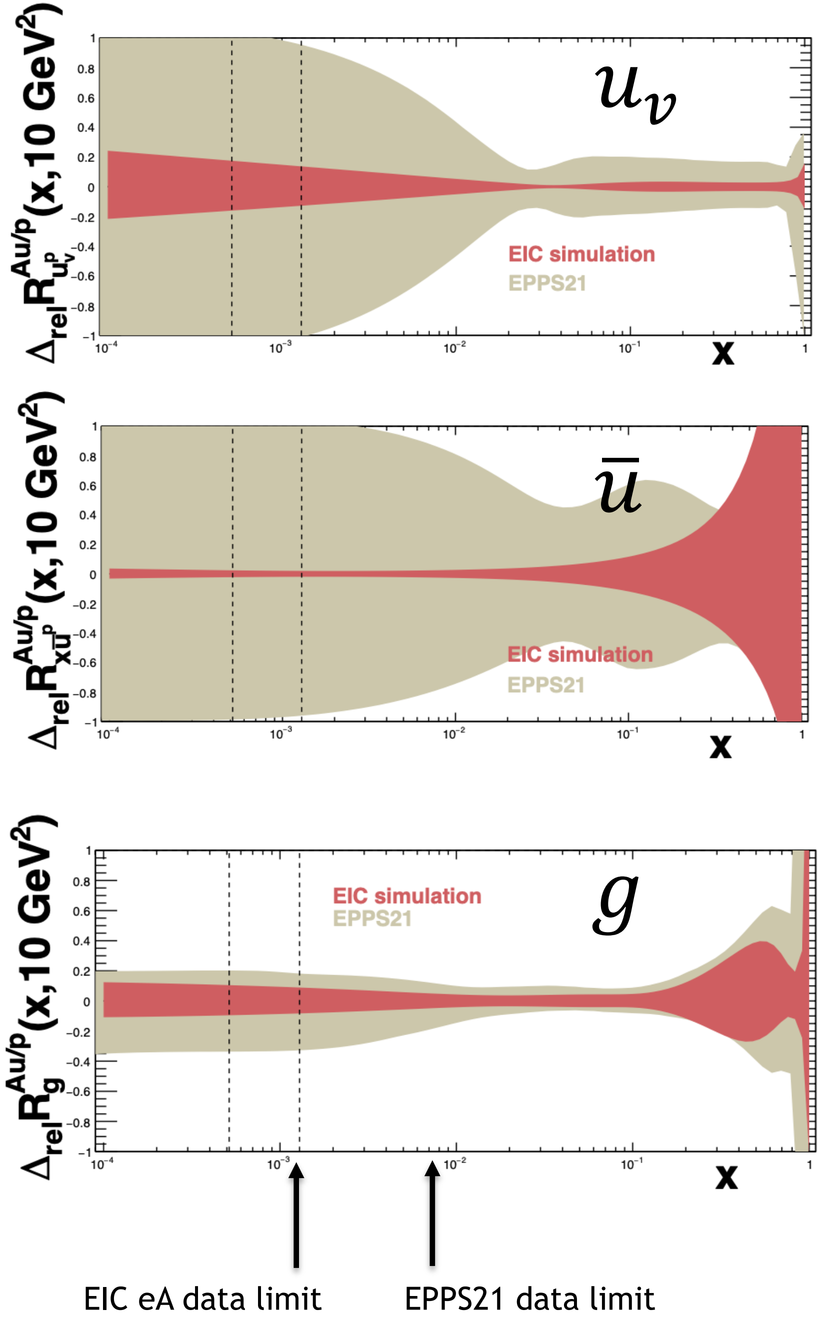
→ Fourier transform the target

Nuclei enhance density of partons (“ $A^{1/3}$ ” factor)

→ Very large impact on eA phase space, extending into expected region of density effects



Impact on Nuclear PDFs



- Nuclear effects in PDFs not fully understood.
- Important e.g. for initial State in QGP studies

Usually expressed in terms of nuclear modification ratio relative to scaled isospin-adjusted nucleons:

$$R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$$

Sensitivity of EIC relative to EPPS21 recent nuclear PDFs (EIC-only fit)

→ Factor ~ 2 improvement at x~0.1

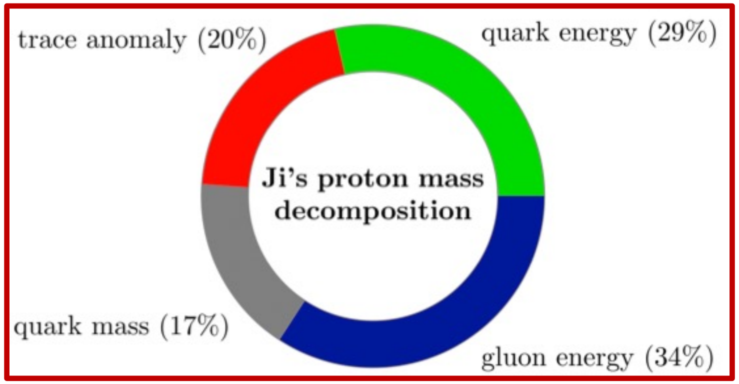
→ Very substantial improvement in newly accessed low x region

Physics Motivation: Proton Mass

- Constituent quark masses contribute ~1% of the proton mass

- Remainder is `emergent' → generated by (QCD) dynamics of multi-body strongly interacting system

- Decomposition along similar lines to spin:



$$\boxed{m_p = m_m + m_q + m_g + m_a}$$

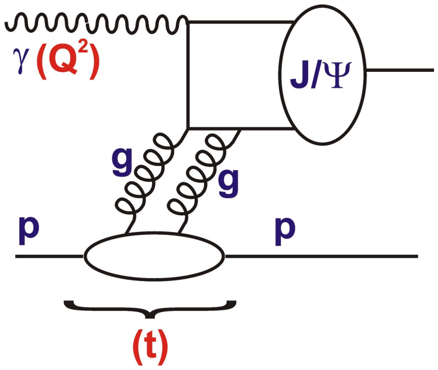
Valence and sea quark masses (including heavy quarks)

Quark and gluon 'KE' from confinement and relative motion

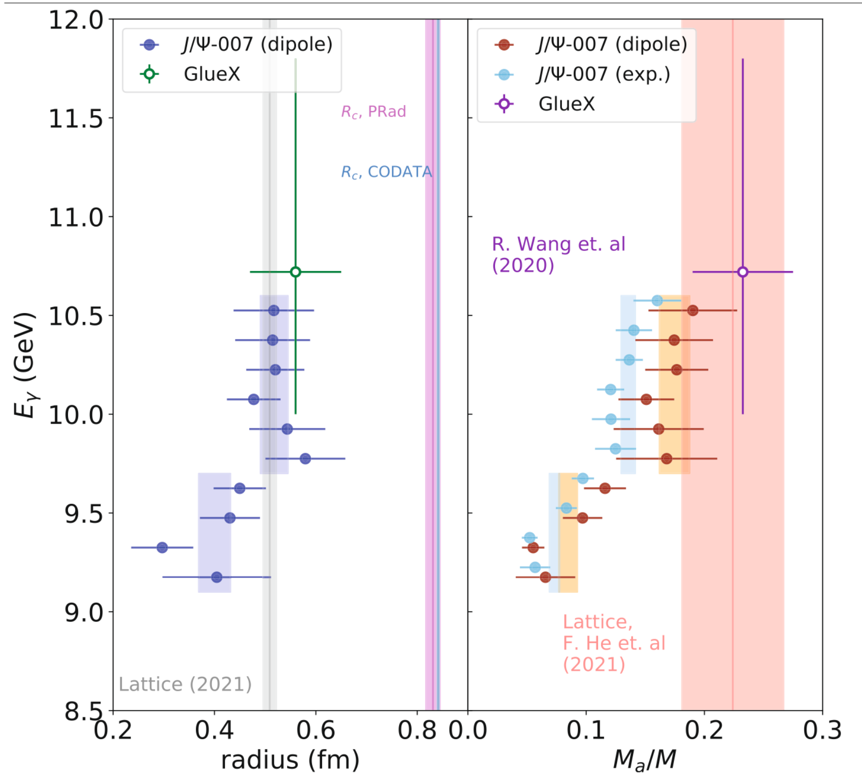
QCD trace anomaly (purely quantum effect - chiral condensates)

- Relations to experimental observables still being understood.
- Recent progress, eg with gravitational form factors of the proton

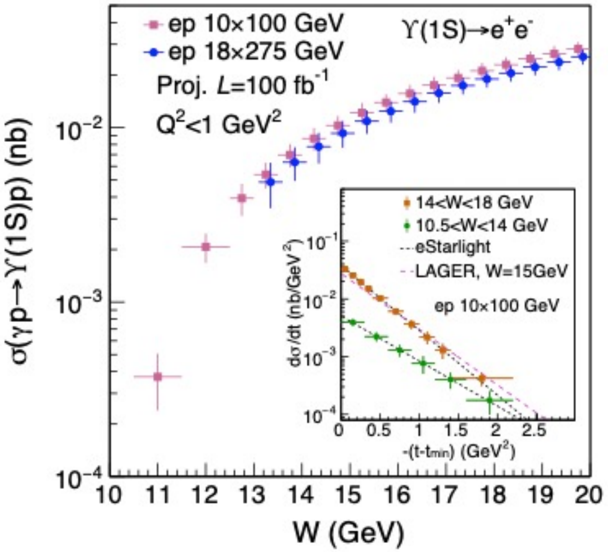
Proton Mass & Exclusive Vector Mesons

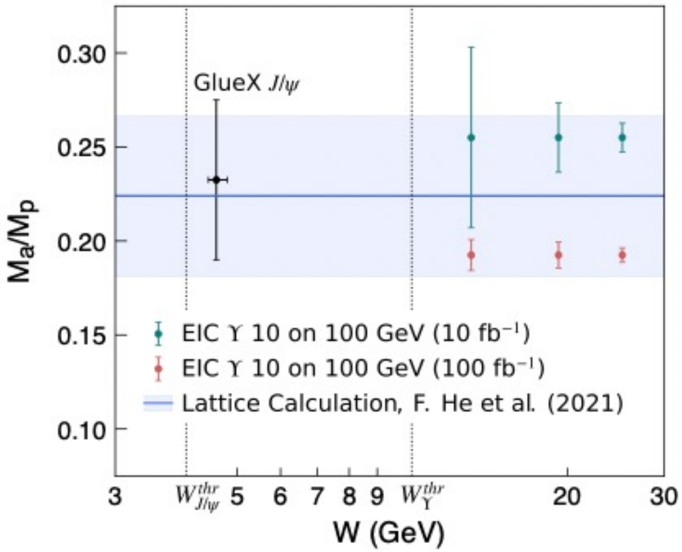


- Recent Jlab data on t dependences of J/Ψ production near threshold → Gravitational form factors



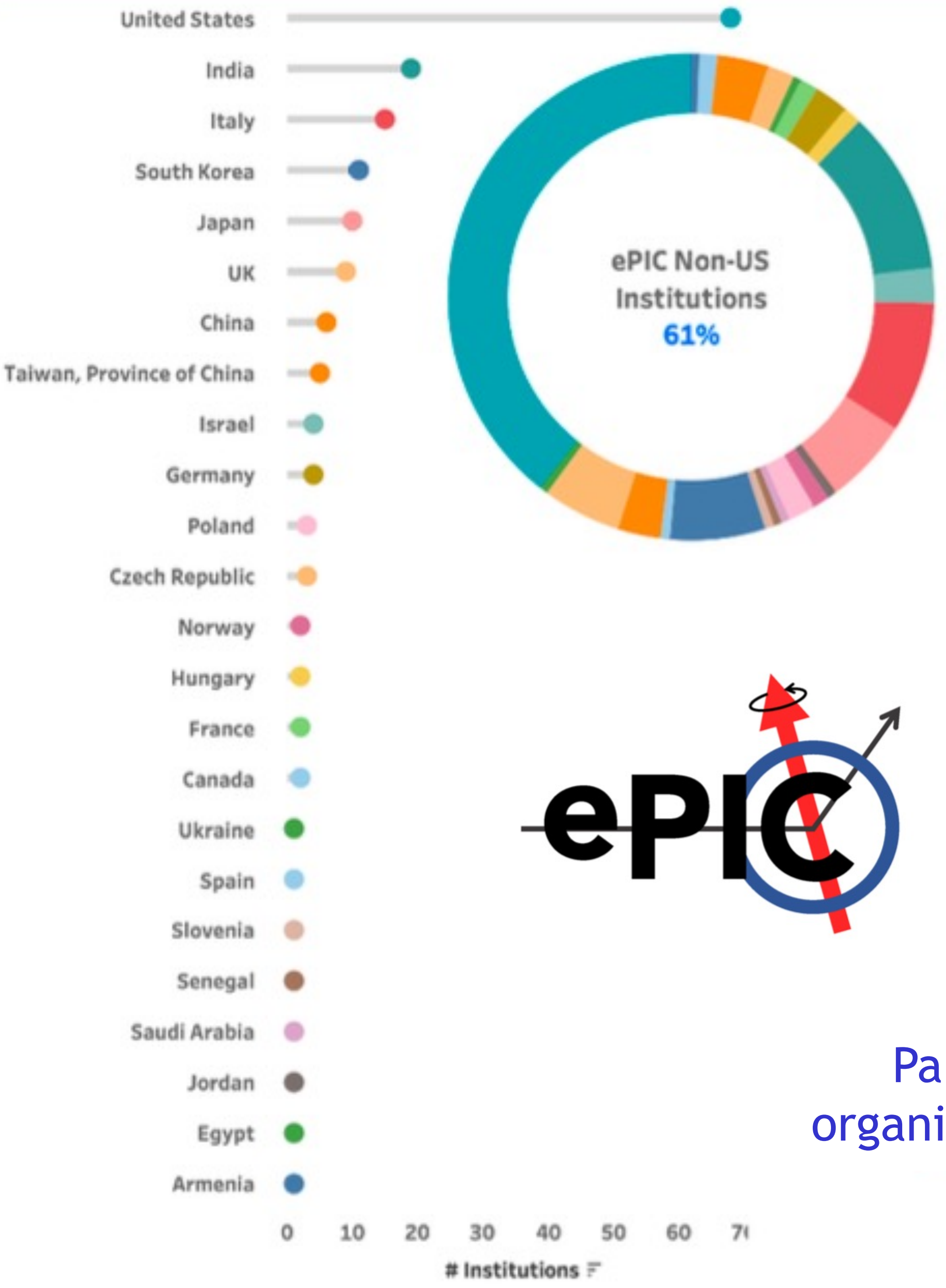
- Gluon radius smaller than charge radius
- Interpreted in terms of trace anomaly





Simulated EIC measurement extends the study to ϒ with much improved precision

ePIC Collaboration Demographics



Over 500 participants
so far, from ~171
institutes in 24 countries

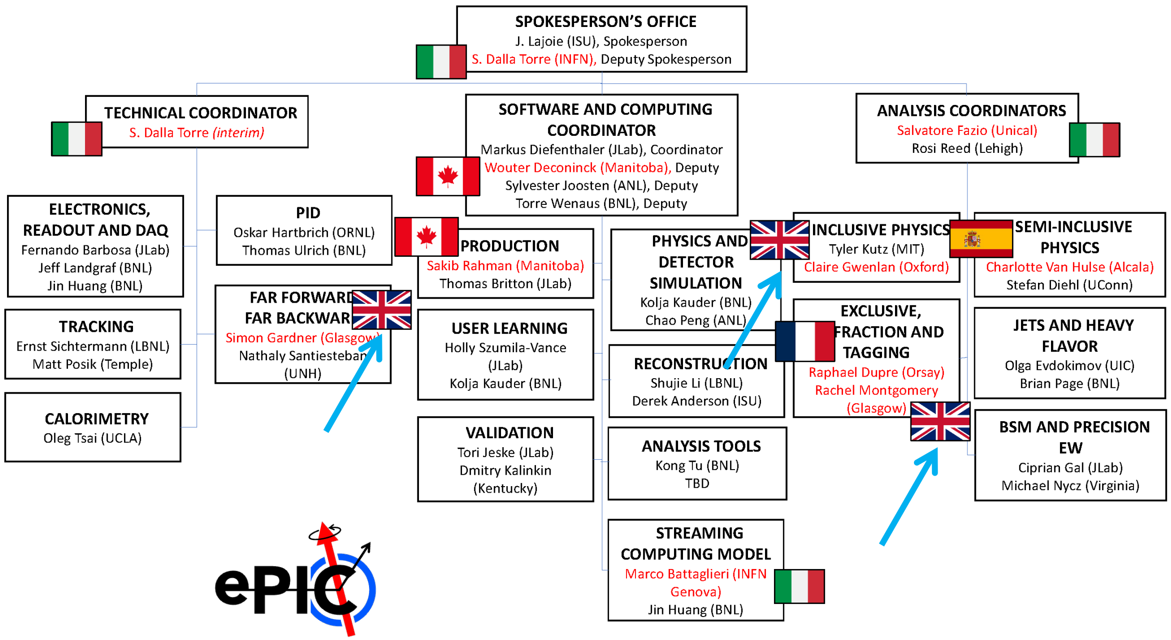
UK physicists deeply involved through initial motivation, collaboration formation and now ongoing roles.

Part of a wider 'EIC User Group' organization with around 1400 members

ePIC structure and current UK Leadership

ePIC Collaboration

- International leadership



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S. Dalla Torre (INFN), Deputy Spokesperson

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S. Dalla Torre *(interim)*

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Wouter Deconinck (Manitoba), Deputy
Sylvester Joosten (ANL), Deputy
Torre Wenaus (BNL), Deputy

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Rosi Reed (Lehigh)

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PID
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Thomas Ulrich (BNL)

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Nathaly Santiesteban (UNH)

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Claire Gwenlan (Oxford)

EXCLUSIVE, FRACTION AND TAGGING
Raphael Dupre (Orsay)
Rachel Montgomery (Glasgow)

SEMI-INCLUSIVE PHYSICS
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Stefan Diehl (UConn)

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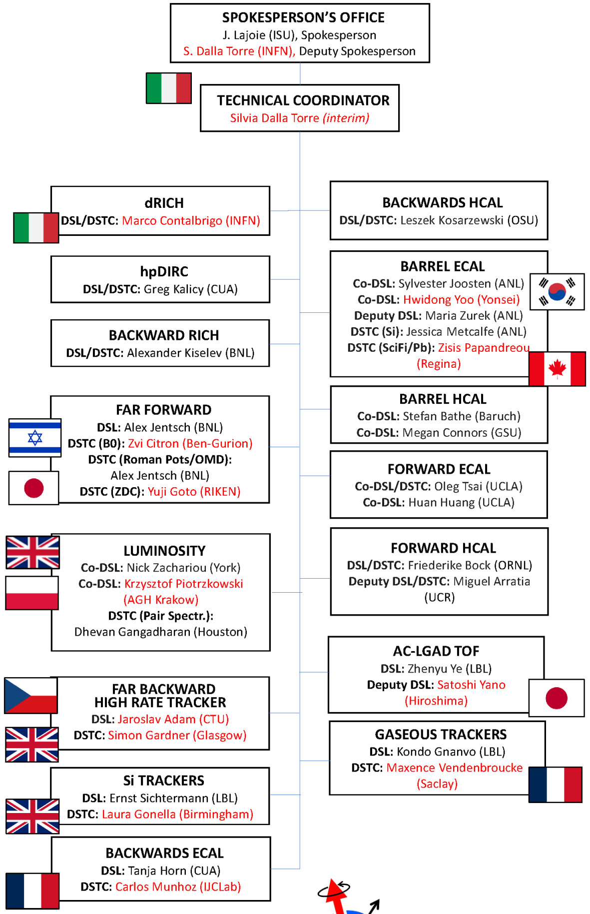
Brian Page (BNL)

BSM AND PRECISION EW
Ciprian Gal (JLab)
Michael Nycz (Virginia)

Working Groups



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TECHNICAL COORDINATOR
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hpDIRC
DSL/DSTC: Greg Kalicy (CUA)

BACKWARD RICH
DSL/DSTC: Alexander Kiselev (BNL)

FAR FORWARD
DSL: Alex Jentsch (BNL)
DSTC (B0): Zvi Citron (Ben-Gurion)
DSTC (Roman Pots/OMD): Alex Jentsch (BNL)
DSTC (ZDC): Yuji Goto (RIKEN)

LUMINOSITY
Co-DSL: Nick Zachariou (York)
Co-DSL: Krzysztof Piotrzkowski (AGH Krakow)
DSTC (Pair Spectr.): Dhevan Gangadharan (Houston)

FAR BACKWARD HIGH RATE TRACKER
DSL: Jaroslav Adam (CTU)
DSTC: Simon Gardner (Glasgow)

Si TRACKERS
DSL: Ernst Sichtermann (LBL)
DSTC: Laura Gonella (Birmingham)

BACKWARDS ECAL
DSL: Tanja Horn (CUA)
DSTC: Carlos Munhoz (IJCLab)

BACKWARDS HCAL
DSL/DSTC: Leszek Kosarzewski (OSU)

BARREL ECAL
Co-DSL: Sylvester Joosten (ANL)
Co-DSL: Hwidong Yoo (Yonsei)
Deputy DSL: Maria Zurek (ANL)
DSTC (Si): Jessica Metcalfe (ANL)
DSTC (SciFi/Pb): Zisis Papandreou (Regina)

BARREL HCAL
Co-DSL: Stefan Bathe (Baruch)
Co-DSL: Megan Connors (GSU)

FORWARD ECAL
Co-DSL/DSTC: Oleg Tsai (UCLA)
Co-DSL: Huan Huang (UCLA)

FORWARD HCAL
DSL/DSTC: Friederike Bock (ORNL)
Deputy DSL/DSTC: Miguel Arratia (UCR)

AC-LGAD TOF
DSL: Zhenyu Ye (LBL)
Deputy DSL: Satoshi Yano (Hiroshima)

GASEOUS TRACKERS
DSL: Kondo Gnanvo (LBL)
DSTC: Maxence Vendenbroucke (Saclay)

Detector Subsystem Collaborations

Paul Newman (Birmingham) – Executive Board
Nick Zachariou (York) – Conferences and Talks Committee

The UK Involvement Confirmed

27 March 2024

Recently announced major funding through UKRI infrastructure funding:

Major research and innovation infrastructure investment announced

Another project will receive £58.8 million from UKRI in a partnership with the US Department of Energy (DOE), to develop new detector and accelerator infrastructure to address fundamental questions on the nature of matter.

The technology will be built by:

- two STFC national laboratories, Daresbury Laboratory in Cheshire and the Rutherford Appleton Laboratory in Oxfordshire
- the universities of Birmingham, Brunel, Glasgow, Lancaster, Liverpool, Oxford and York
- the Cockcroft Institute for Accelerator Science and Technology in Cheshire

It will be installed at the Electron-Ion Collider (EIC), a major new particle accelerator facility at the Brookhaven National Laboratory in New York in the US.

University of Birmingham

Brunel University London

University of Glasgow

Lancaster University

Science & Technology Facilities Council
Daresbury Laboratory
Rutherford Appleton Laboratory
ASTeC

University of Liverpool

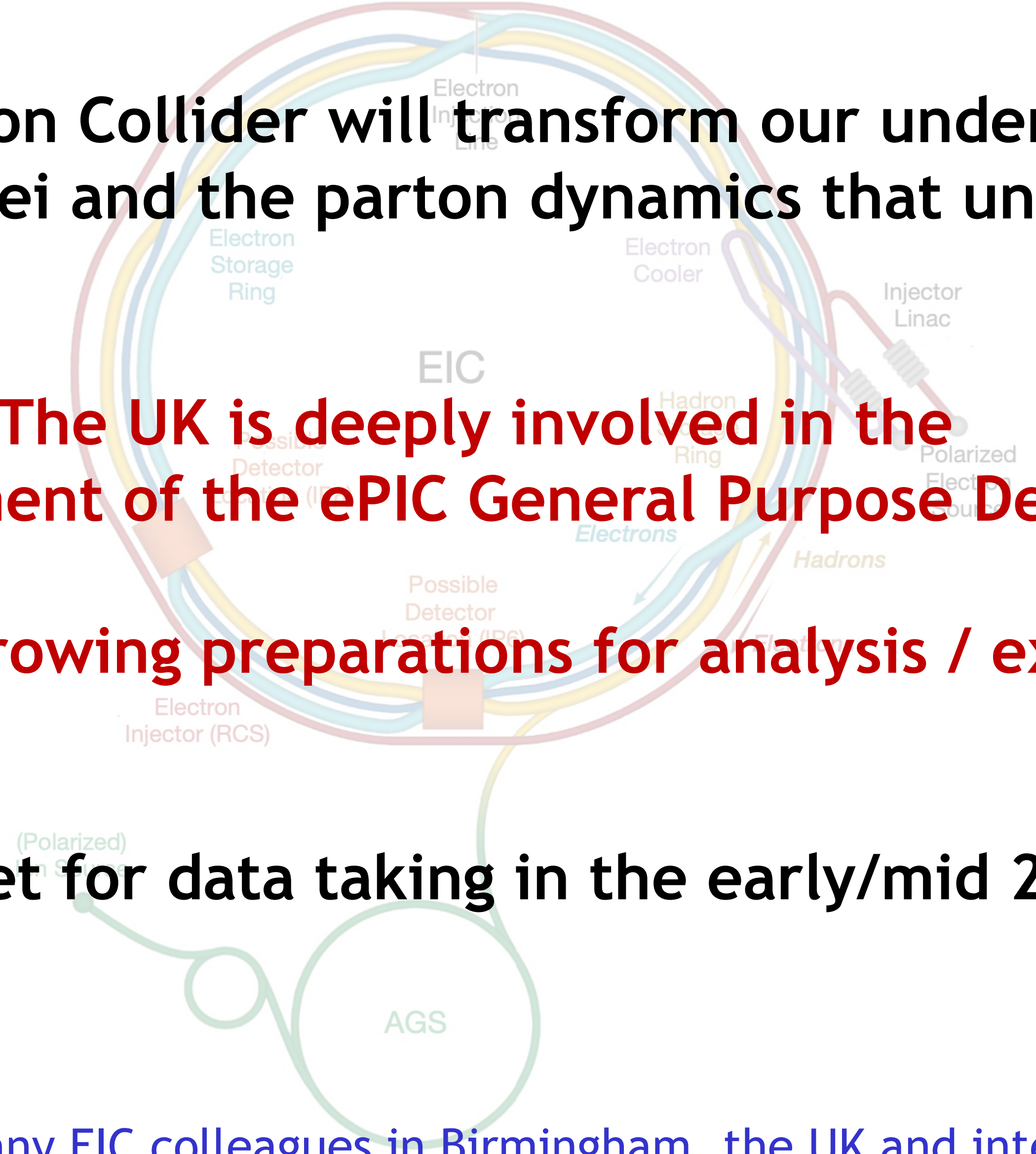
University of Oxford

University of York

The Cockcroft Institute of Accelerator Science and Technology

JAI John Adams Institute for Accelerator Science

Summary



The Electron Ion Collider will transform our understanding of nucleons, nuclei and the parton dynamics that underlie them

The UK is deeply involved in the development of the ePIC General Purpose Detector

… also with growing preparations for analysis / exploitation

On target for data taking in the early/mid 2030s

[with thanks to many EIC colleagues in Birmingham, the UK and internationally]

The UK Project in more detail

WP1: MAPS → 65nm CMOS (wafer scale) stitched sensors, developed from ALICE-ITS3, to be deployed in central tracker
→ Construction of 2 barrel layers, corresponding to around 1/3 of silicon tracker

WP2: Timepix → Application of pixel sensors for beamline electron tagger for luminosity and physics at $Q^2 \to 0$

WP3: Lumi Monitoring → Novel pair-spectrometer, beamline $\gamma \to ee$ counting

WP4: Accelerator → Primarily SRF systems for Energy Recovery cooler.
→ Also crab-cavity LLRF synchronisation, beam position monitoring, Energy Recovery modelling and design

UNIVERSITY OF BIRMINGHAM
Brunel University London
University of Glasgow
Lancaster University
Science & Technology Facilities Council
Daresbury Laboratory
Rutherford Appleton Laboratory
ASTeC
UNIVERSITY OF LIVERPOOL
UNIVERSITY OF OXFORD
UNIVERSITY of York
The Cockcroft Institute of Accelerator Science and Technology
JAI John Adams Institute for Accelerator Science

Impact of EIC on HERAPDF2.0

Fractional total uncertainties with / without simulated EIC data included with HERA

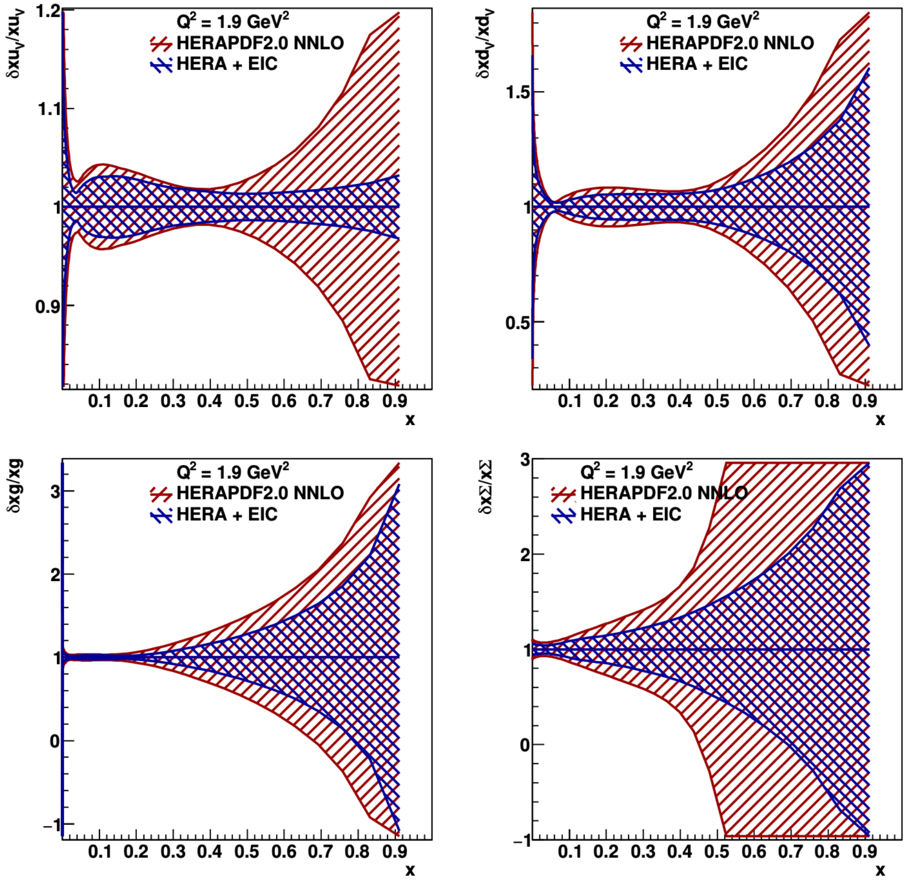
… EIC will bring significant reduction in uncertainties
for all parton species at large x

… most notable improvements for up quarks (charge-squared weighting)

Precision high x EIC data ideally suited to the extraction of α_s

… simulated result is factor ~2 better than current world experimental average, and than lattice QCD average

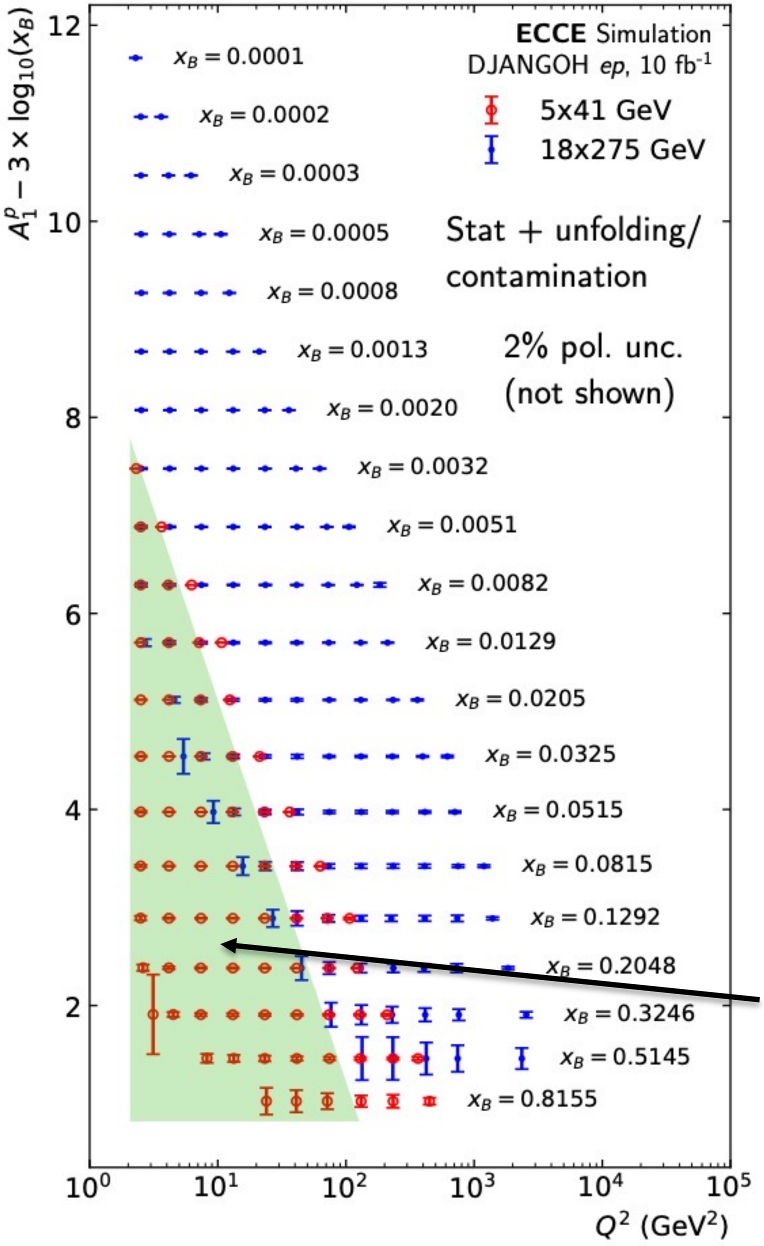
… scale uncertainties remain to be understood (ongoing work)



[Eur Phys J C83 (2023), 1011]
[arXiv:2309.11269]

$$\alpha_s(M_Z^2) = 0.1159 \pm 0.0004\ (\mathrm{exp})\ {}^{+0.0002}_{-0.0001}\ (\mathrm{model + parameterisation})$$

Spin: EIC Virtual γ Asymmetry sim'n (A_1^p)



Asymmetries between NC cross sections with different longitudinal and transverse polarisations …

$$A_{\parallel} = \frac{\sigma^{\leftrightarrows} - \sigma^{\rightrightarrows}}{\sigma^{\leftrightarrows} + \sigma^{\rightrightarrows}} \quad \text{and} \quad A_{\perp} = \frac{\sigma^{\rightarrow\uparrow} - \sigma^{\rightarrow\downarrow}}{\sigma^{\rightarrow\uparrow} + \sigma^{\rightarrow\downarrow}}$$

$$\rightarrow A_1(x) \approx g_1(x) \big/ F_1(x)$$

… measure the quark and antiquark helicity distributions …

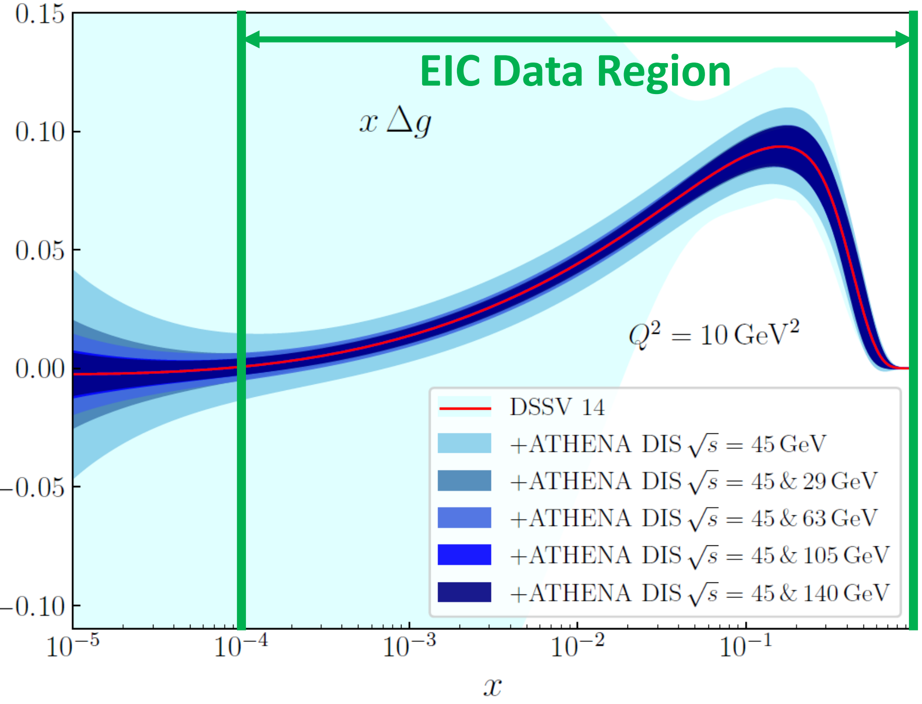
$$g_1(x) = \sum \left(\Delta q(x) + \Delta\bar{q}(x)\right)$$

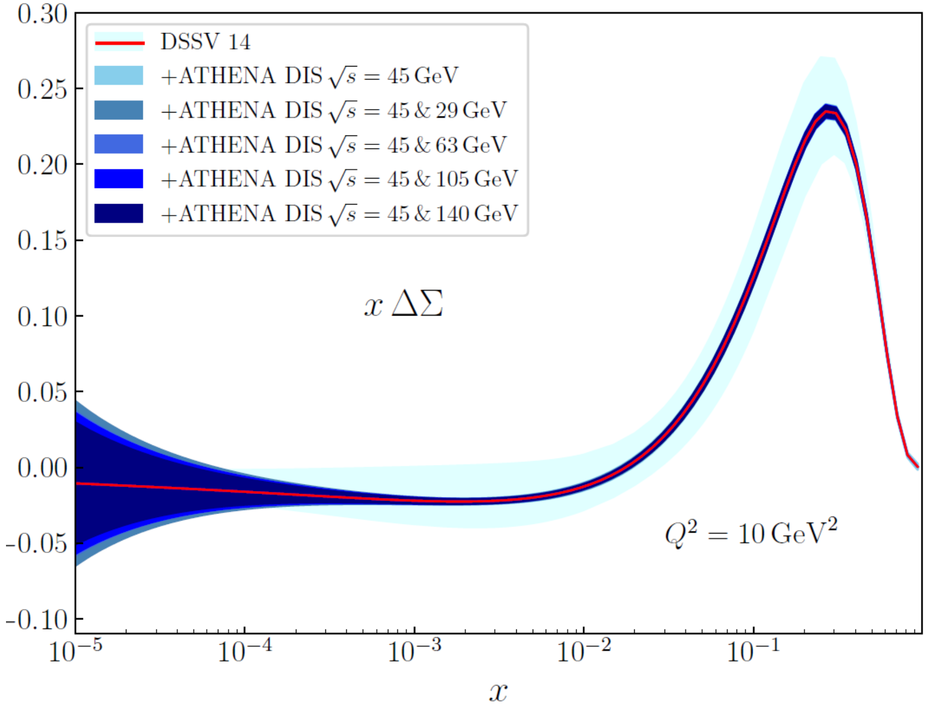
… which gives gluon sensitivity from Q^2 dependence (scaling violations)

Previously measured region (in green)

EIC measures down to x ~ 5 x 10^{-3} for 1 < Q^2 < 100 GeV^2

Impact on Helicity Distributions (Study in DSSV framework)





Study based on simulated NC data with integrated luminosity 15fb^{-1}, and 70% e,p polarization

Very significant impact on polarised gluon and quark densities using only inclusive polarised ep data