Physics opportunities at the future Electron Ion Collider

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INFN Ferrara

IWHSS 2020 - Workshops on Hadron Structure and Spectroscopy
November 16, 2020 ECSAC, Trieste - Italia

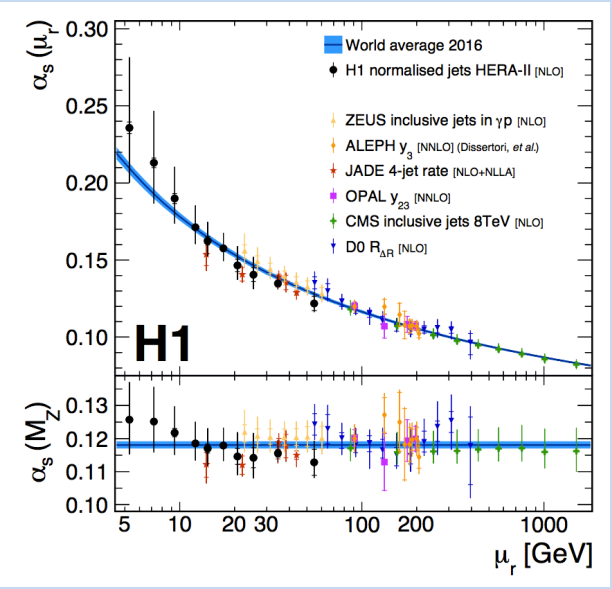
HERA Legacy and Perturbative QCD

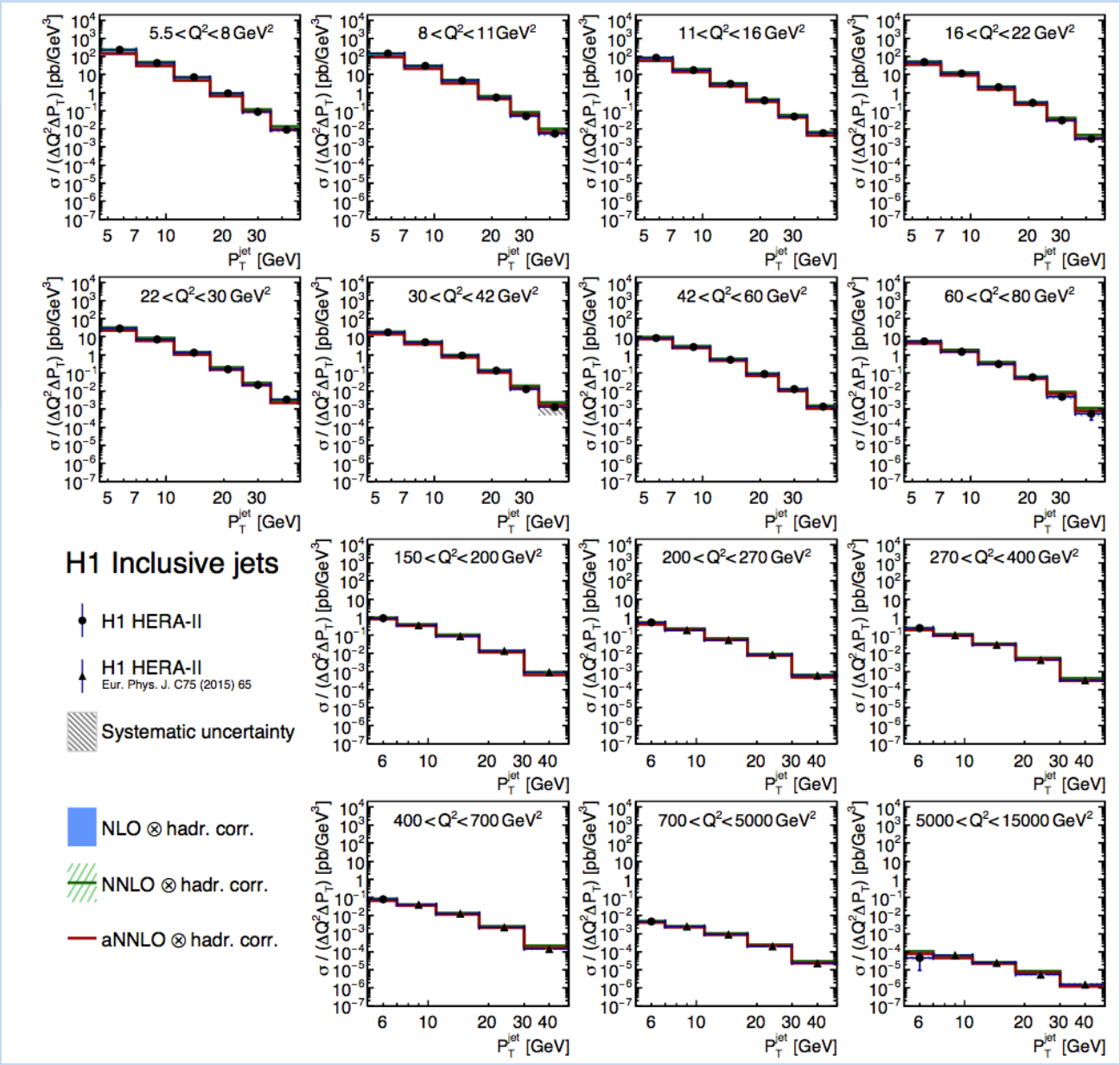
Good perturbative description (hard gluon emission)

p_T>5 GeV Q^2>5 GeV^2

Part in a p_T<<Q TMD regime

H1 [arXiv: 1611.03421]

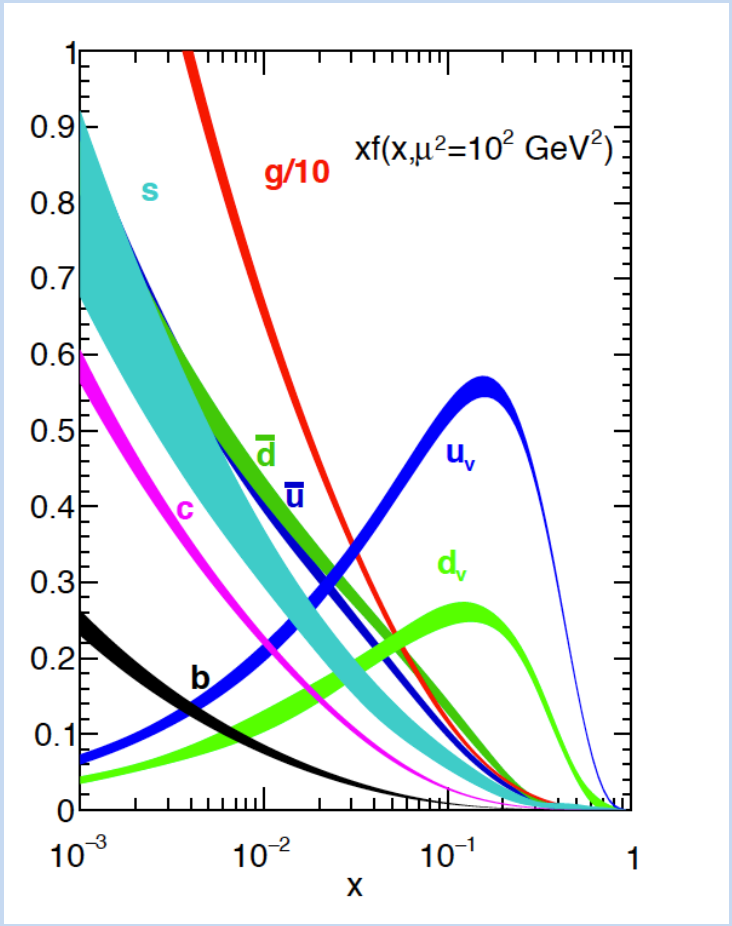


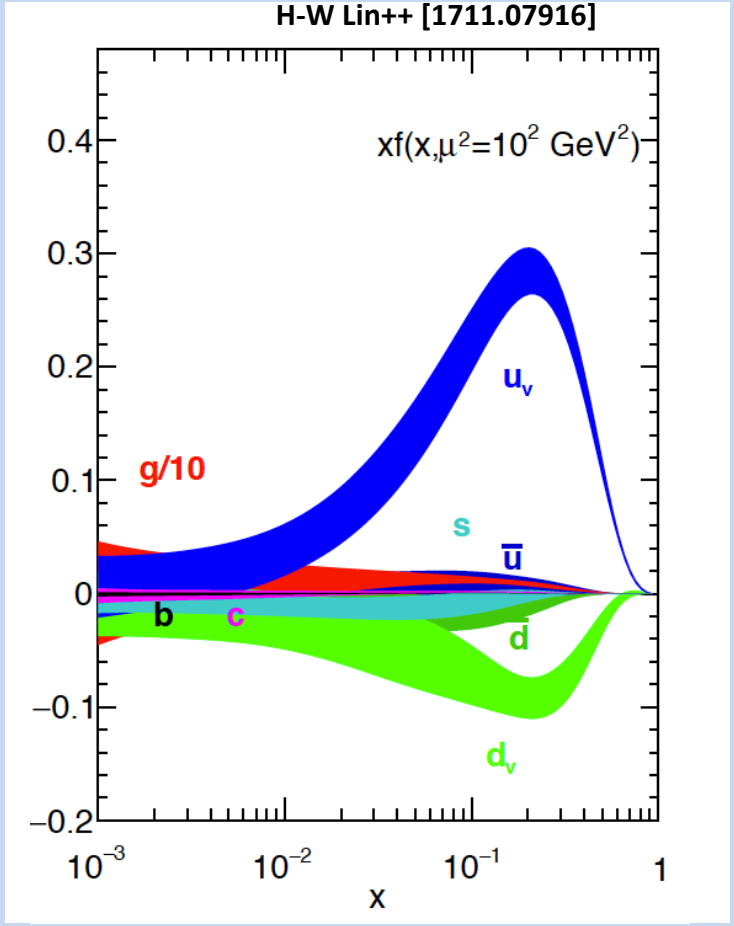


Parton Content

MMHT [arXiv 1412.3989]
HERAPDF2.0 [arXiv 1506.06042]
CT14 [arXiv 1506.07443]
CJ15 [arXiv 1602.03154]
ABMP16 [arXiv 1701.05838]
NNPDF3.1 [arXiv 1706.00428]

BB [arXiv 1005.3113]
LSS [arXiv 1010.0574]
DSSV [arXiv 1404.4293]
BS [arXiv 1408.7057]
NNPDF [arXiv 1406.5539]
JLAM [arXiv 1601.07782]

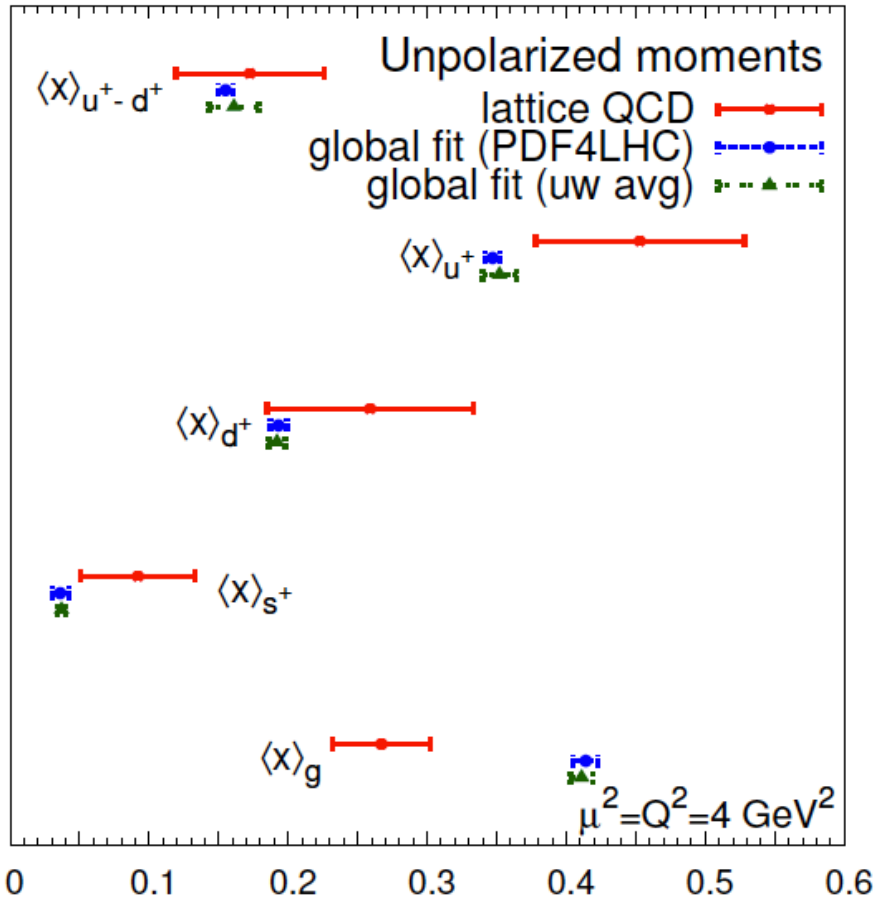


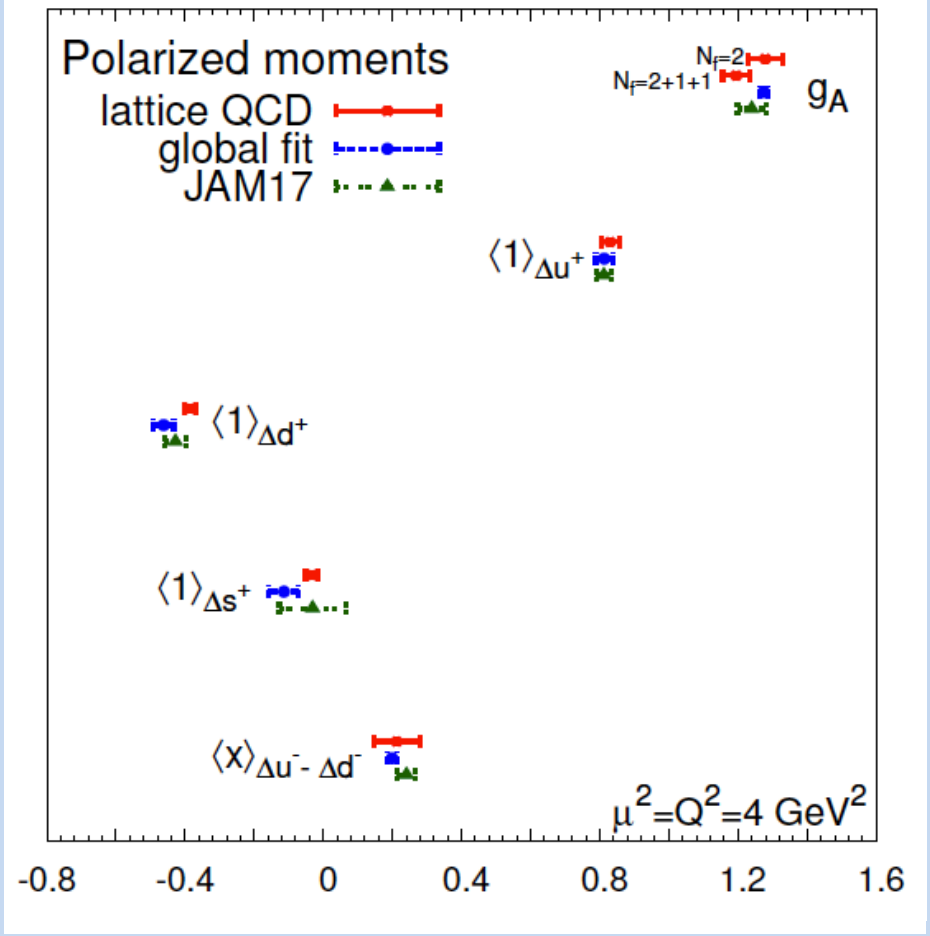


Parton Content

Unpolarized moments

Polarized (helicity) moments



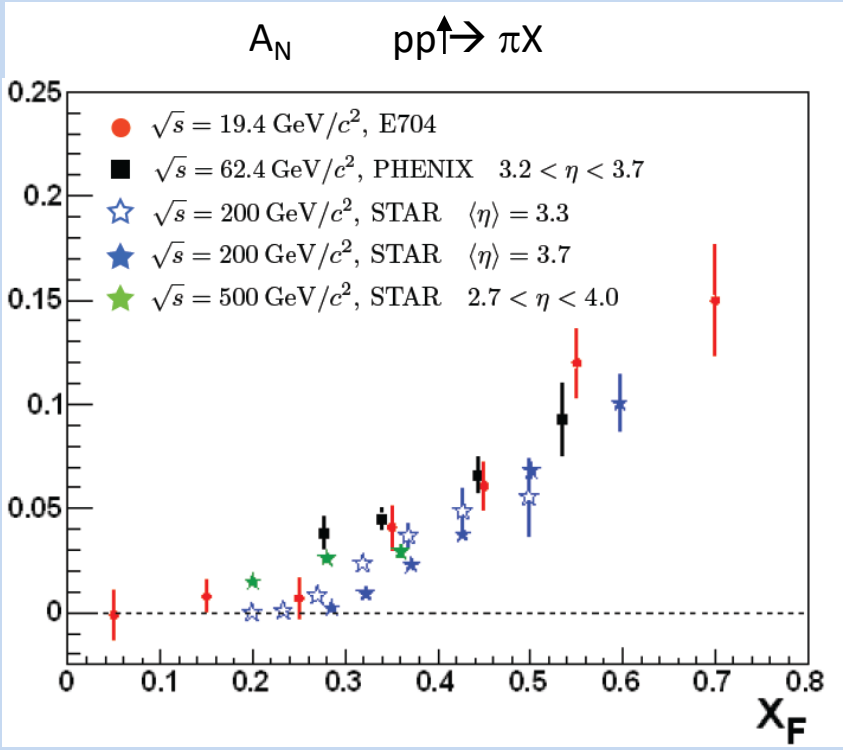


QCD vs pQCD

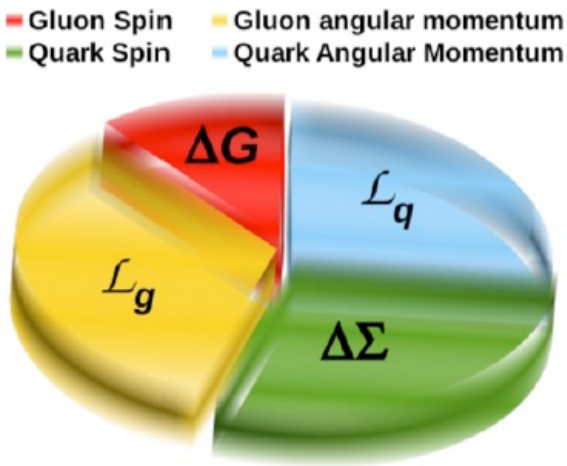
Can QCD be a precision science ?

Should not be confused with pQCD, which already can,
but is not touching the intimate nature of the strong interaction

Single Spin Asymmetries



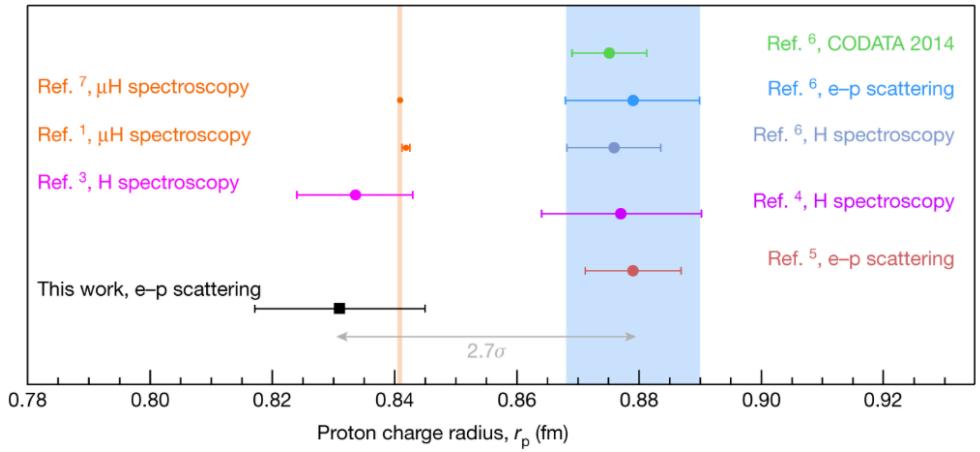
Proton Spin Budget



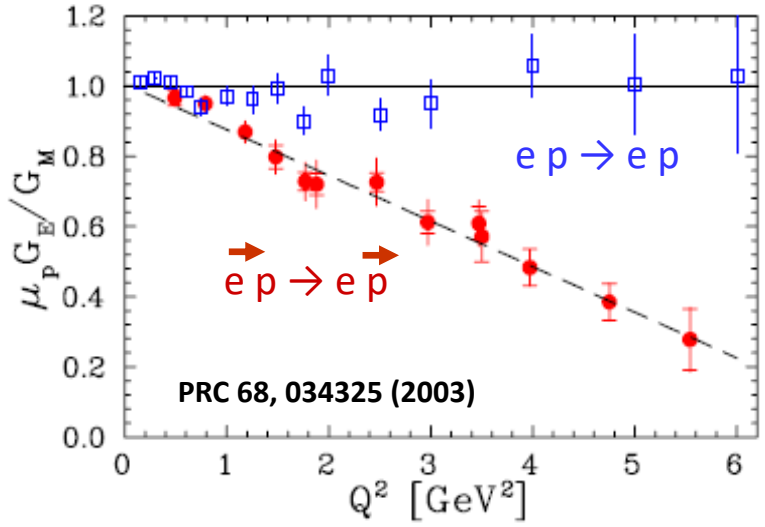
$$\frac{1}{2} = \frac{1}{2}\sum_f (q_f^+ - q_f^-) + L_q + \Delta G + L_g$$

Still Surprising Proton

Do we control the proton form factor and radius ?

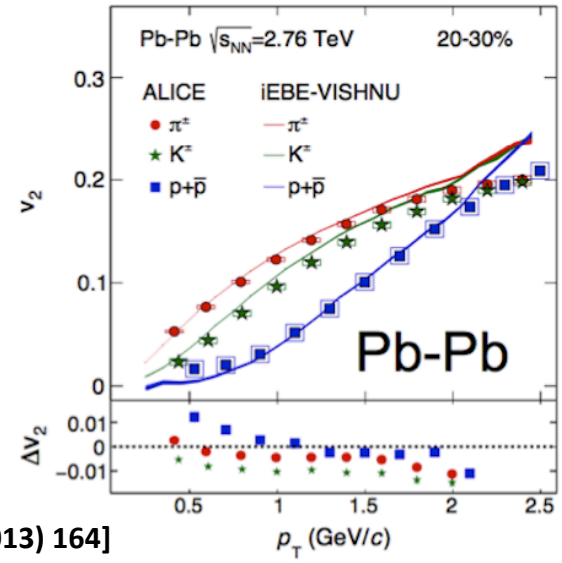


Nature 575 147 (2019)

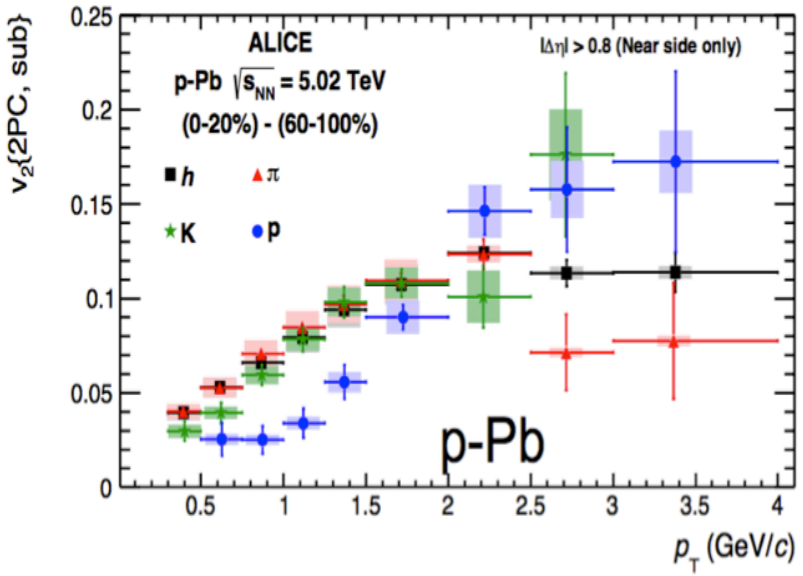


Is there a collective motion in small systems ?

$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}\left(1 + 2v_1\cos(\varphi - \Psi_1) + 2v_2\cos[2(\varphi - \Psi_2)] + \dots\right)$$



ALICE [PLB 726 (2013) 164]

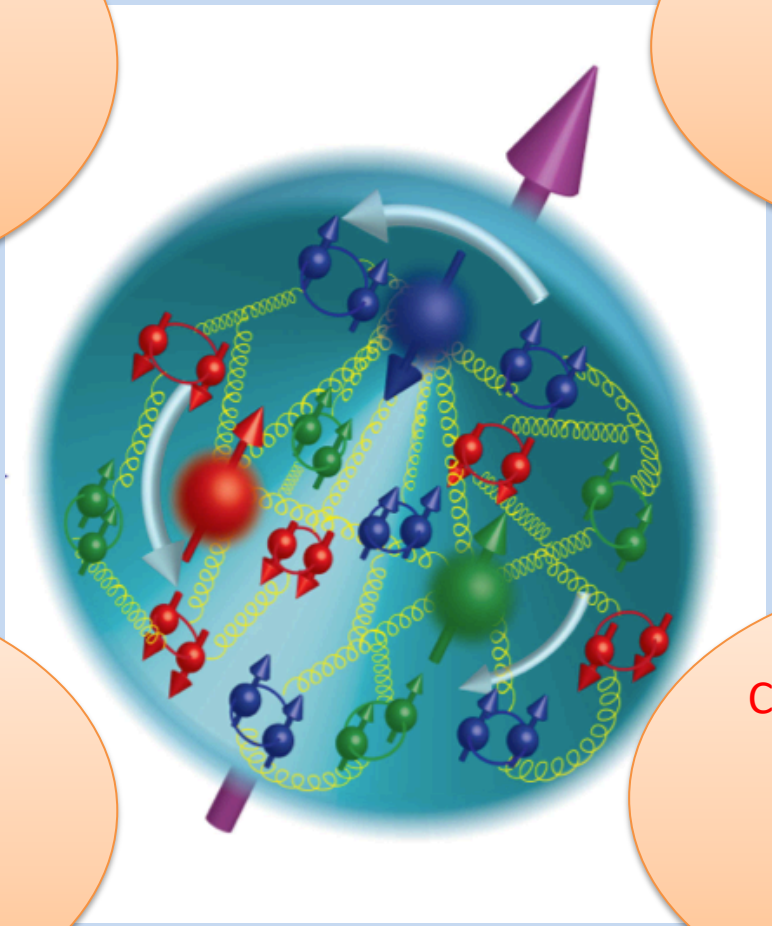


New Vision

Non-perturbative & Multi-body

Dynamic Spin
- Parton polarization
- Orbital motion
- Form Factors
- Magnetic Moment

Parton Correlations
- dPDFs
- Short range
- MPI



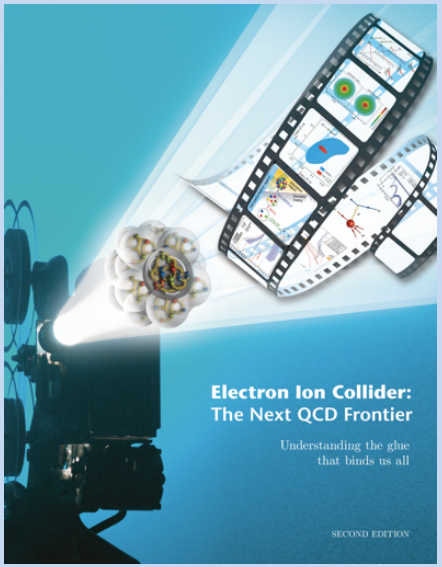
Hadronization
- Spin-orbit effects
- Parton energy loss
- Jet quenching

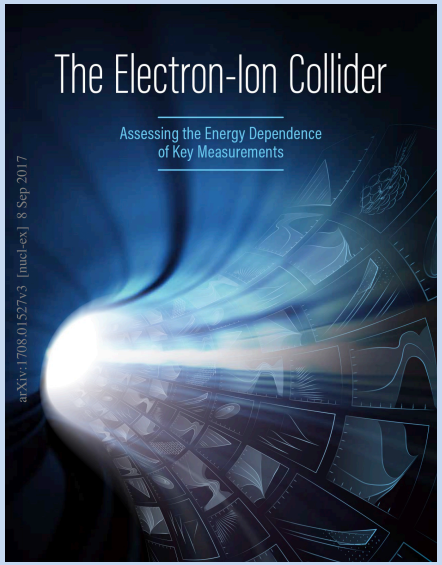
Color charge density
- Nucleon tomography
- Diffractive physics
- Gluon saturation
- Color force

The EIC Case

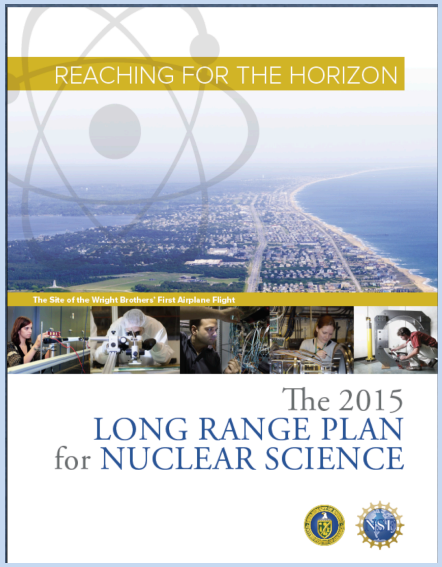
Physics 2010++

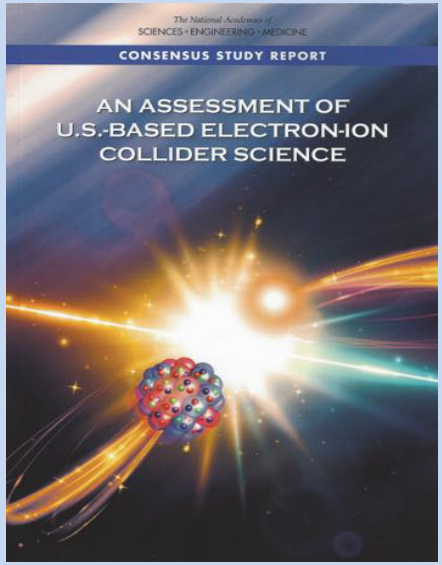
Prequel: HERMES, COMPASS, JLAB, ….



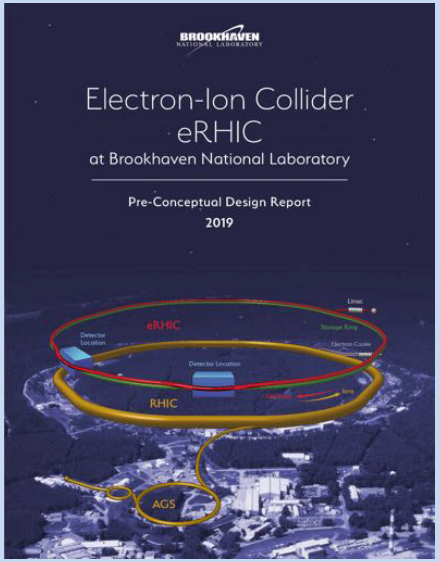


Evaluation 2015-2019



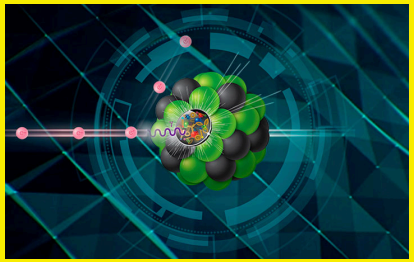


Realization. 2020++

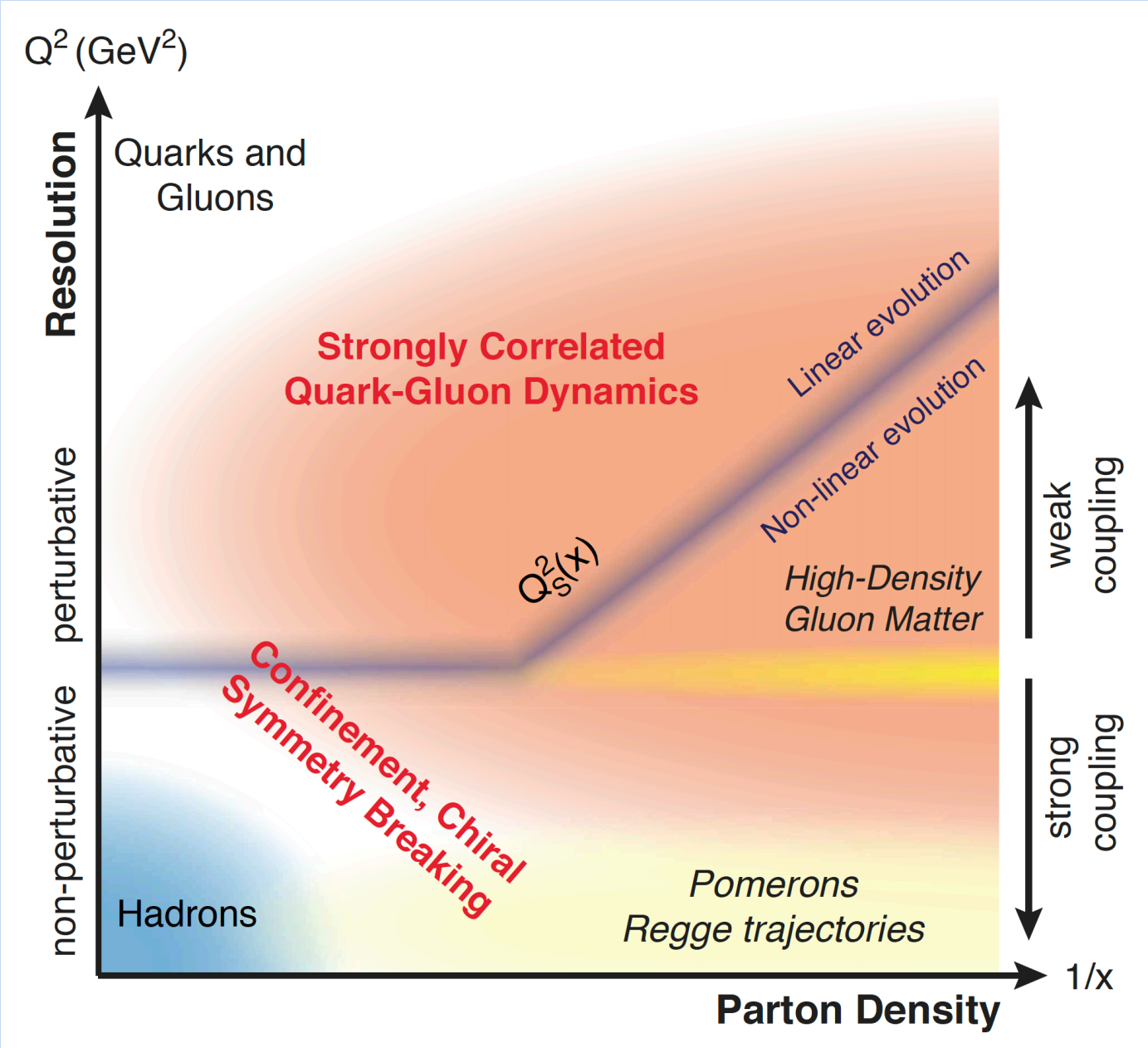


Yellow Report

……..

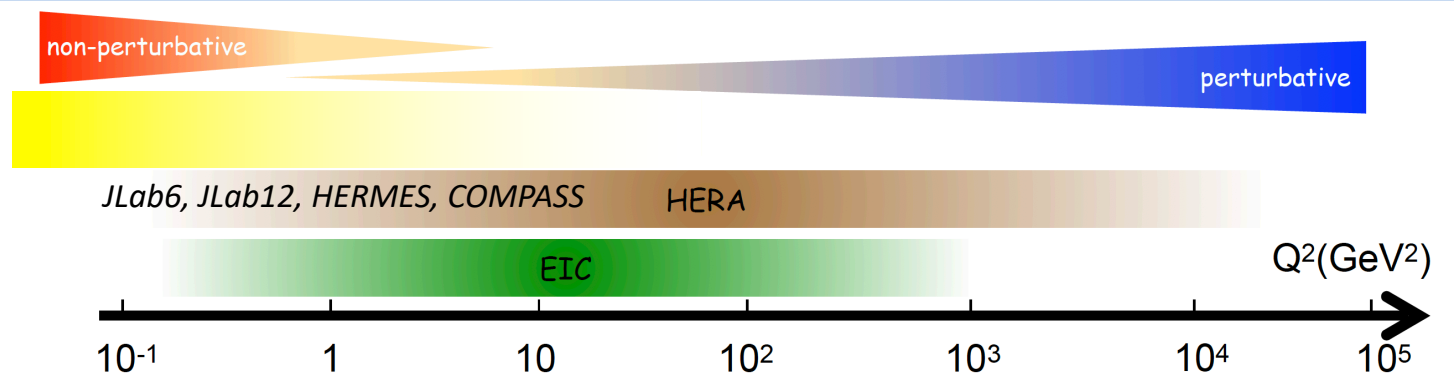


QCD Phase Space

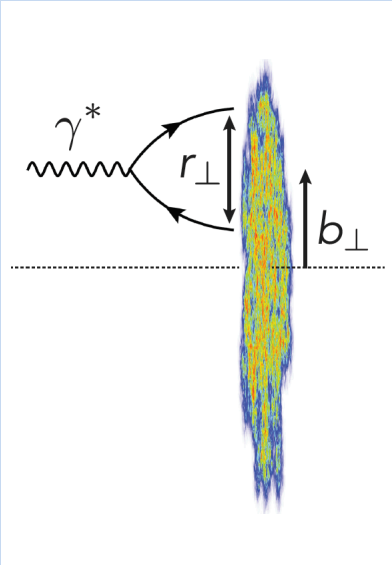


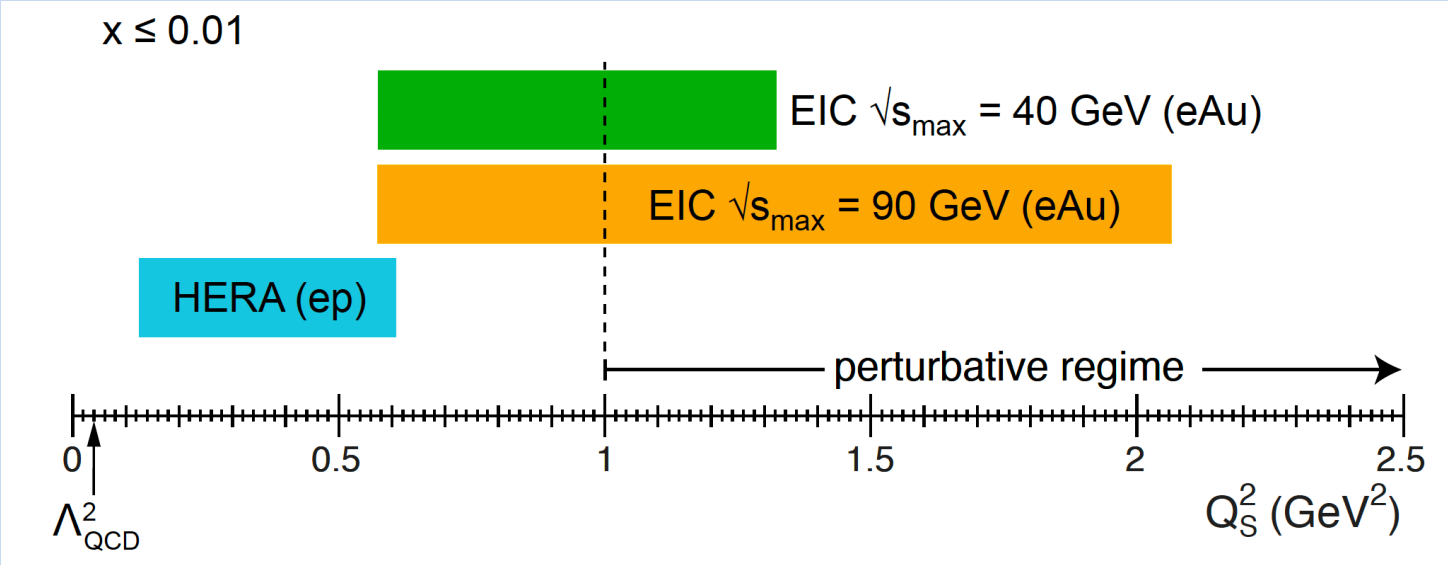
EIC Baseline

Energy range matching perturbative and non-perturbative regimes



Ion beams to extend the reach in saturation scale

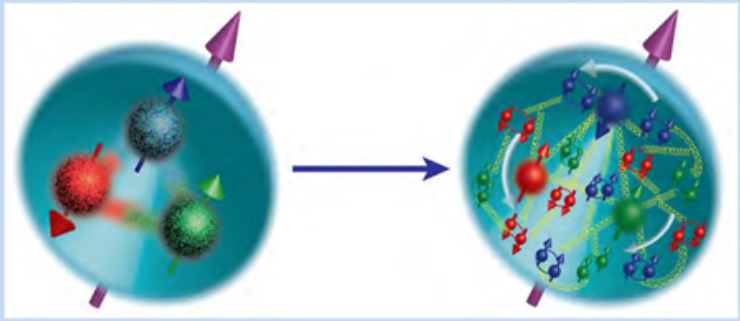




The EIC Menu

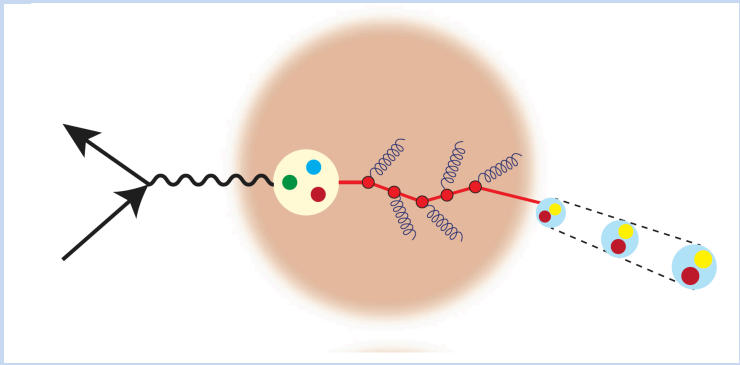
High-luminosity and polarization:

Parton distribution in space and momentum
Dynamic correlations with spin
Search for the source of hadron emerging properties
Search for new physics ($\sin^2\theta_W$, exotic states, …)



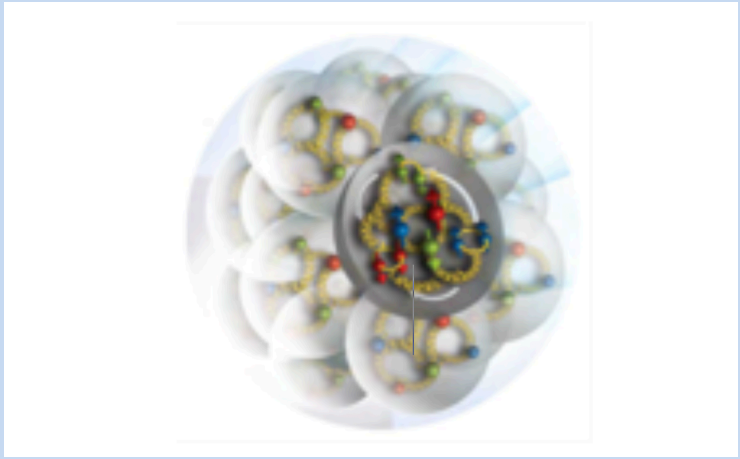
Ion beams:

Parton binding of nuclear matter
Color-interactions within cold nuclear matter
Hadron confined object formation
Search for confinement origin



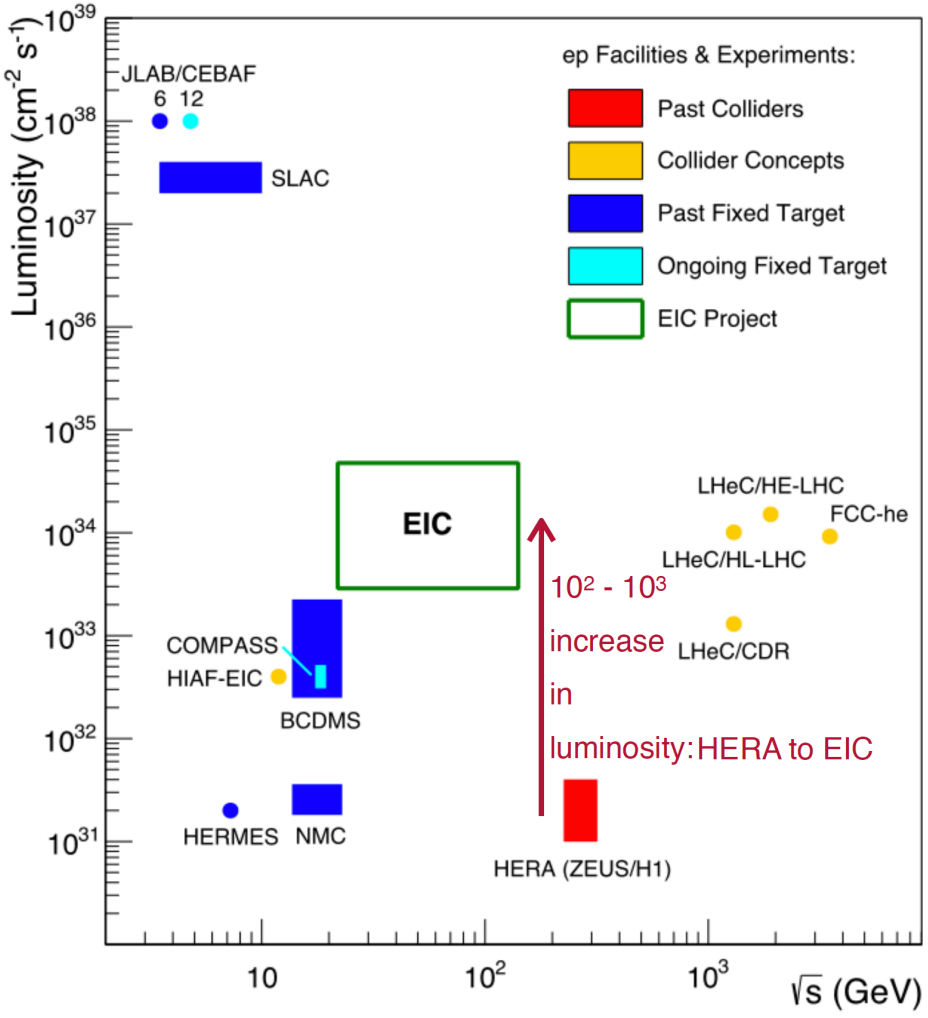
High-energy + Ions:

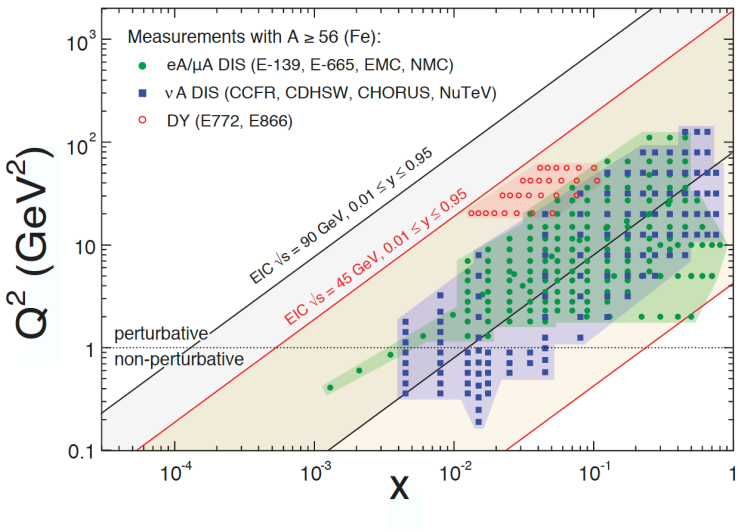
Jets and heavy flavor physics
Color-interactions within dense nuclear matter
Gluon dominted matter & saturation
Serch for new matter states (CGC)



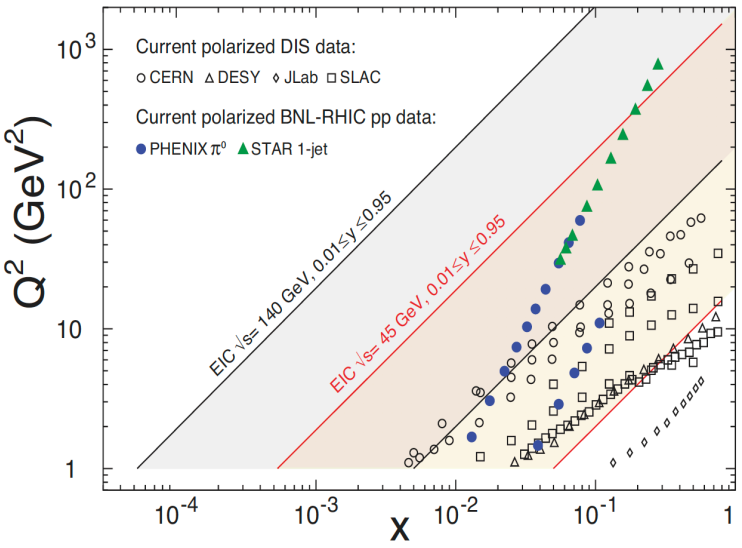
EIC Reach

- Luminosity / $\sqrt{s}$ / Kinematic coverage





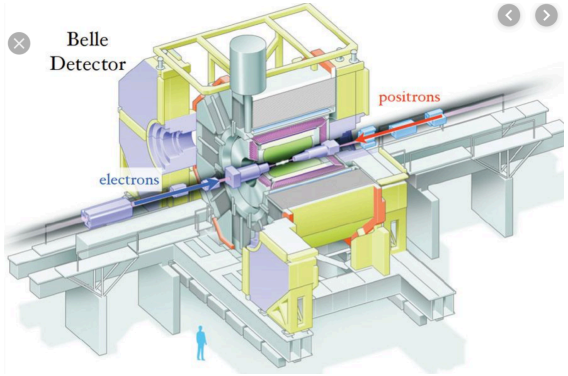
eA



ep

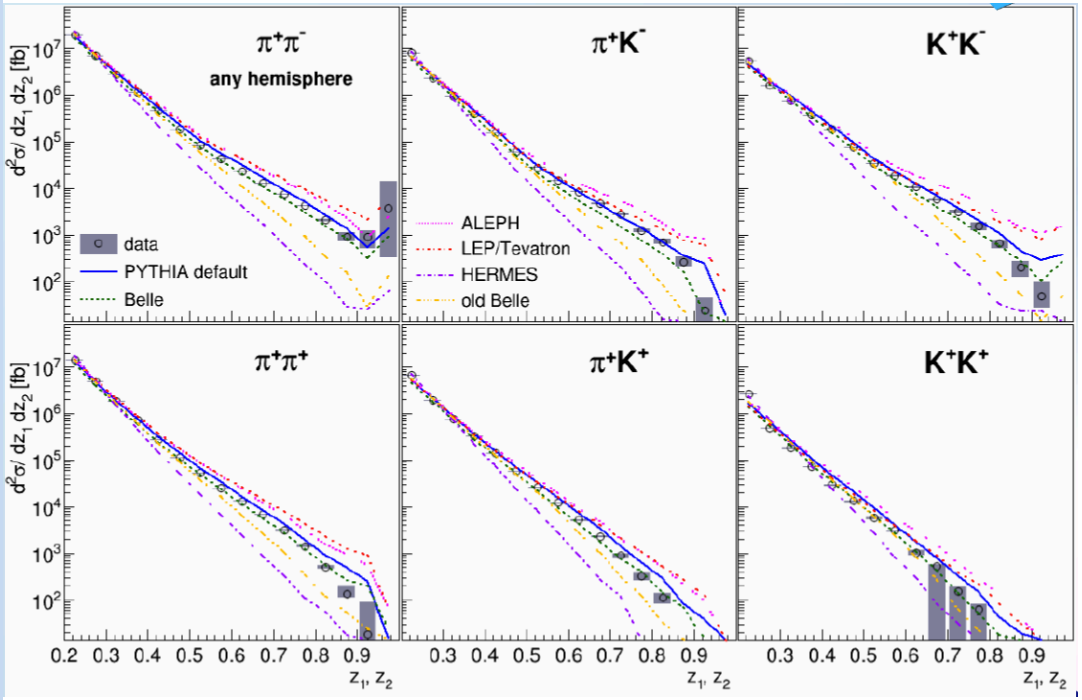
Ongoing: COMPASS A_{UT} on deuteron, JLab comprehensive investigation of valence region

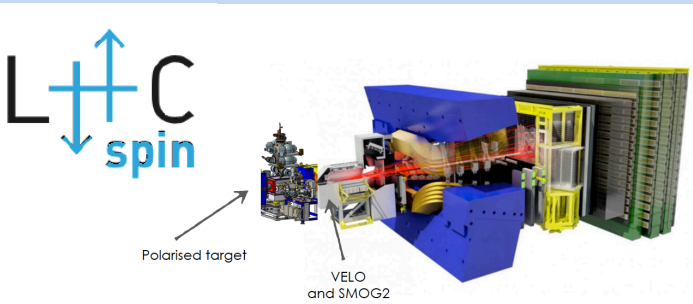
Experimental Landscape



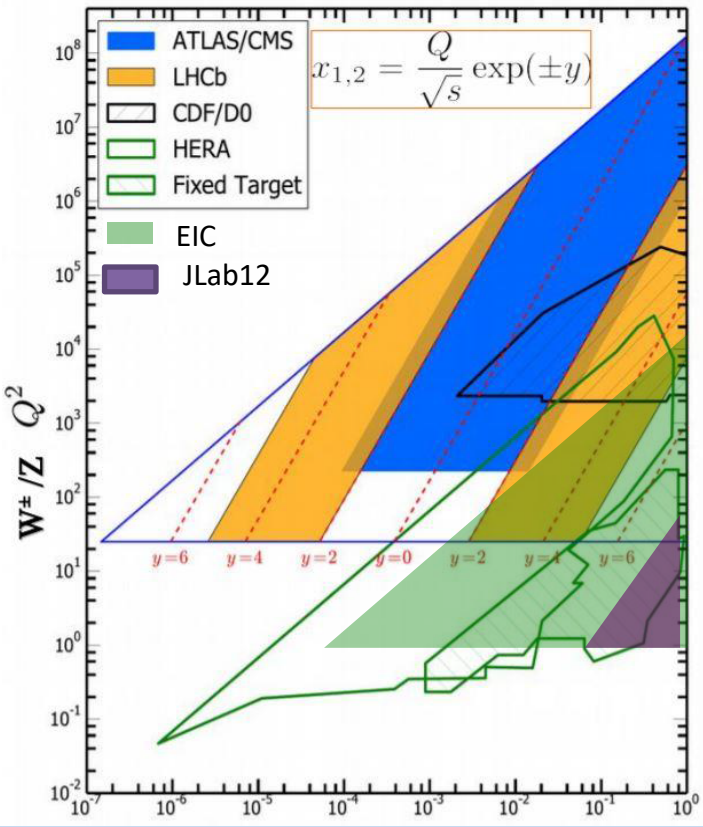
More and more precise Fragmentation Function information is becoming available

PRD 92 (2015) 092007





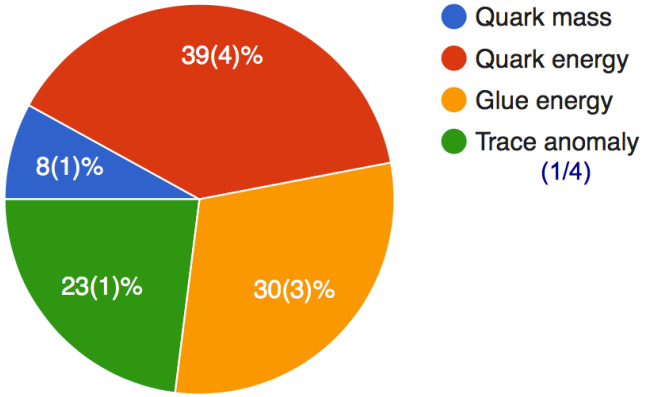
Bridge to hadron probes and future HEP



Lattice Achievements

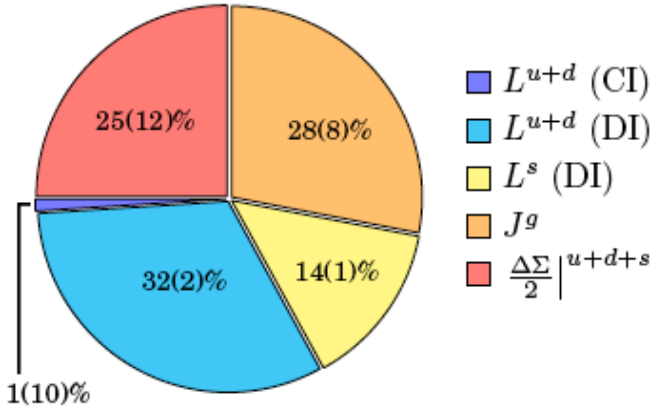
Nucleon mass components

K-F Liu @ this Conf.

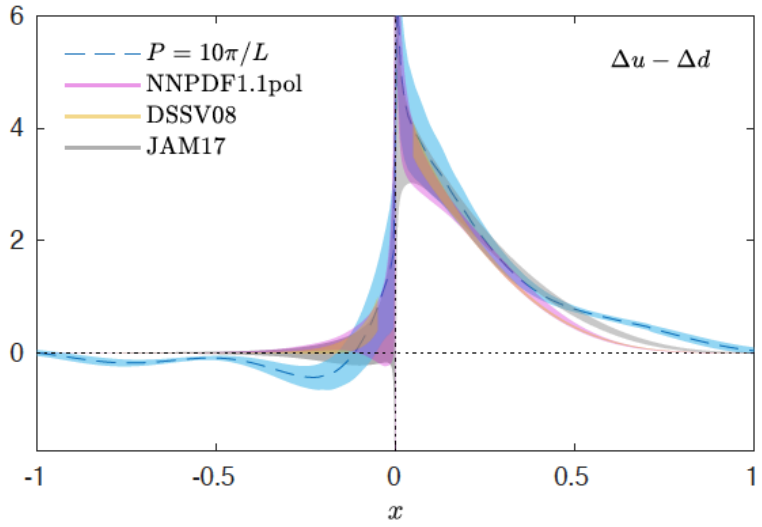


Spin decomposition

K-F Liu++ [arXiv 1203.6388]

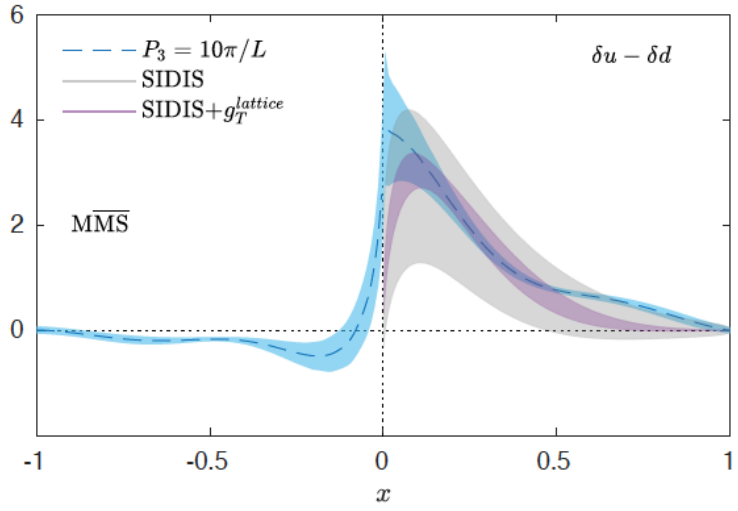


Helicity distribution



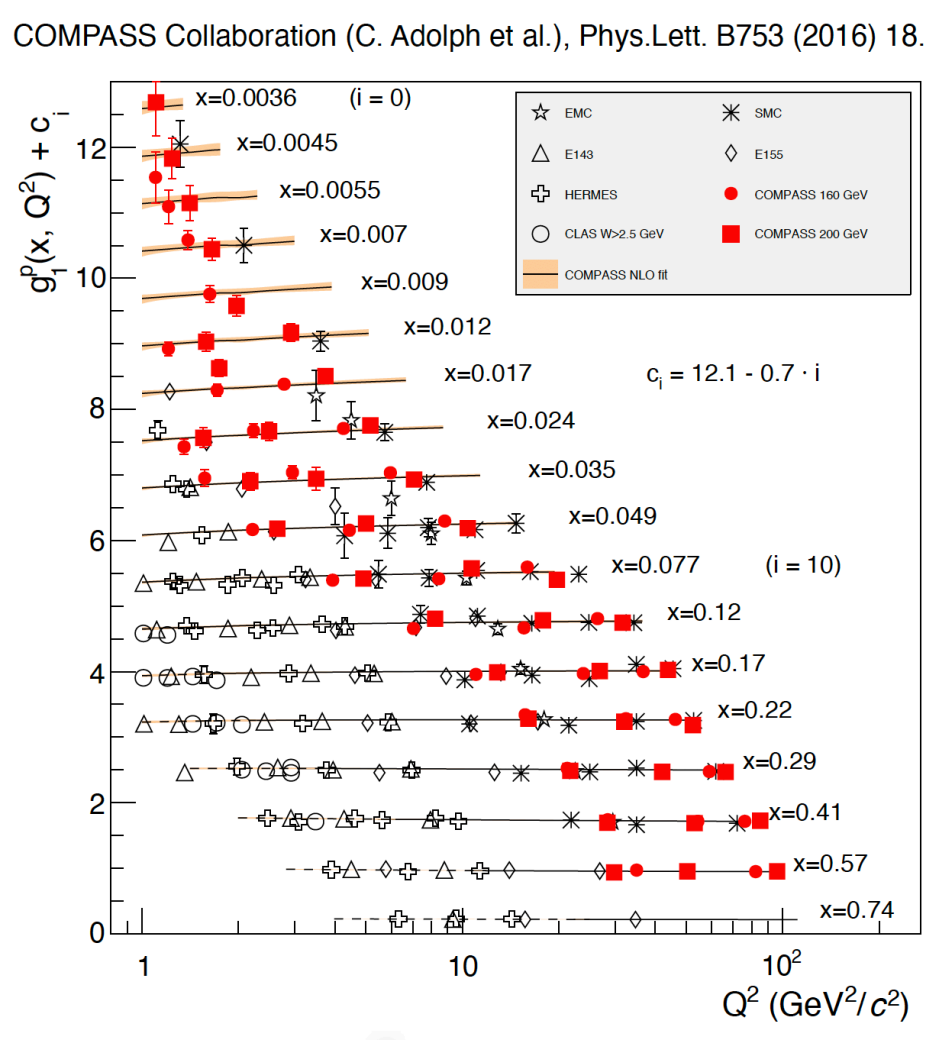
Transversity distribution

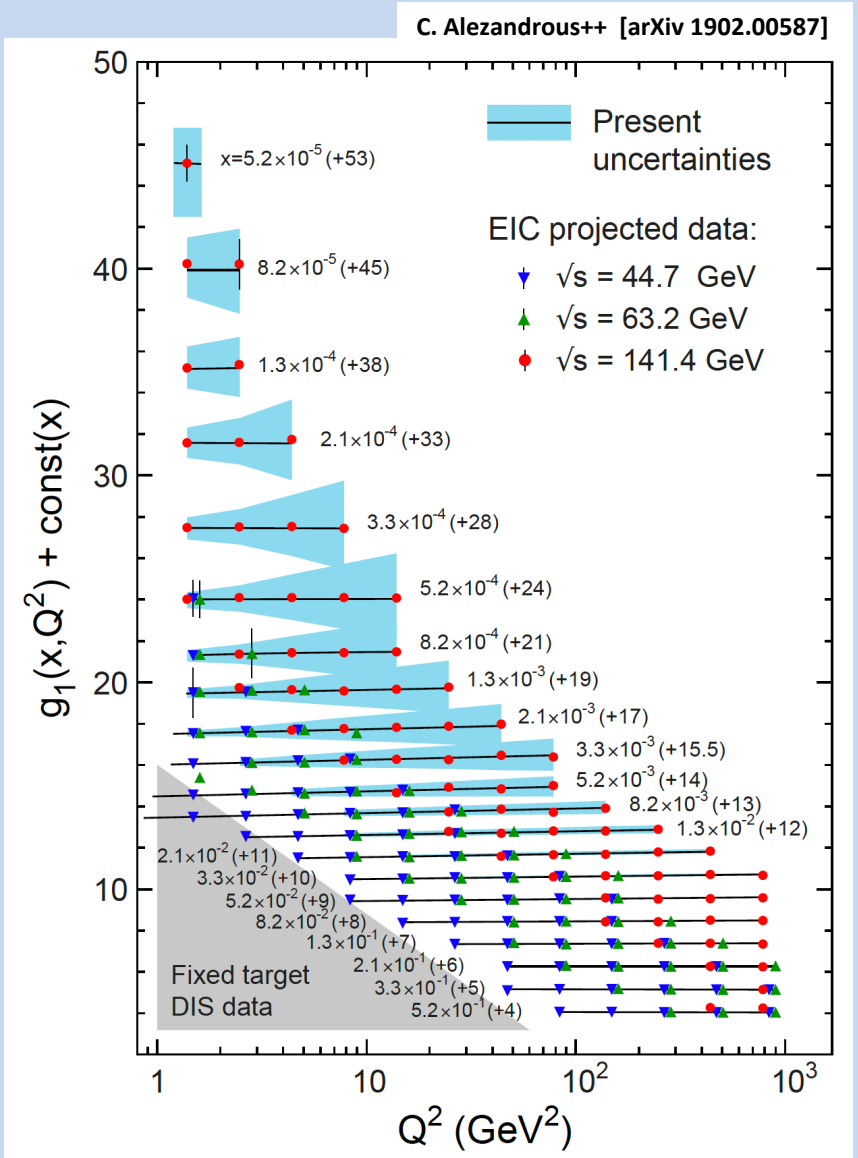
C. Alezandrous++ [arXiv 1902.00587]



Polarized Structure Functions

Extended range to reach perturbative regime and probe evolution (gluons)



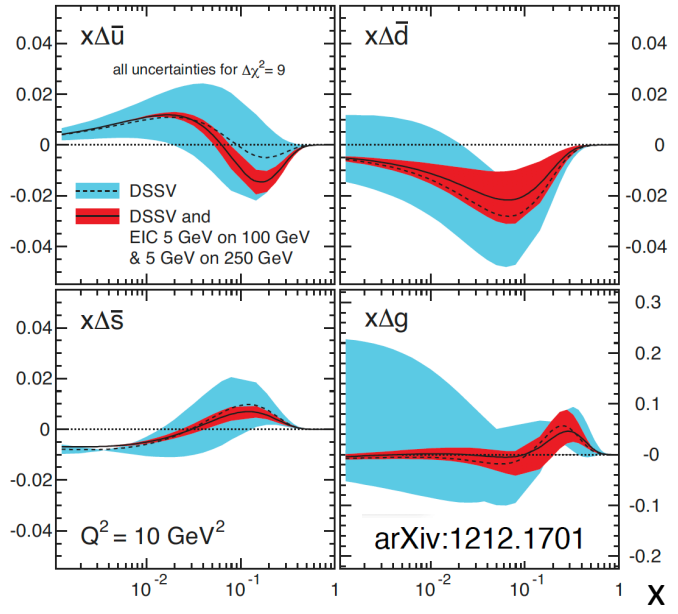


Spin Budget

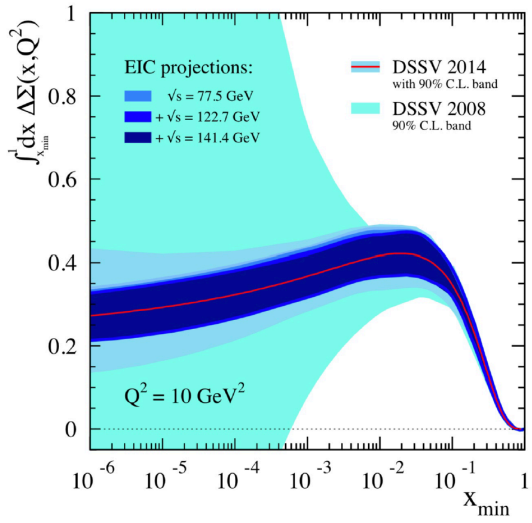
Spin puzzle and the quark correlations

$$\underbrace{\frac{1}{2}\Delta\Sigma}_{} + \underbrace{\Delta G}_{} + \langle L_q \rangle + \langle L_g \rangle = \frac{1}{2}$$

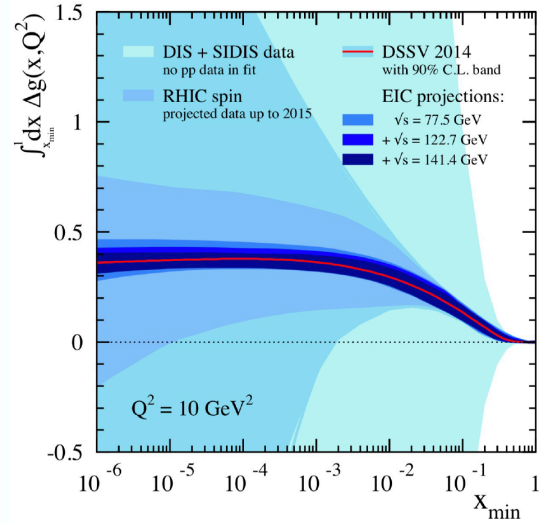
(R.L. Jaffe and A. Manohar, Nucl. Phys. B337, 509 (1990))



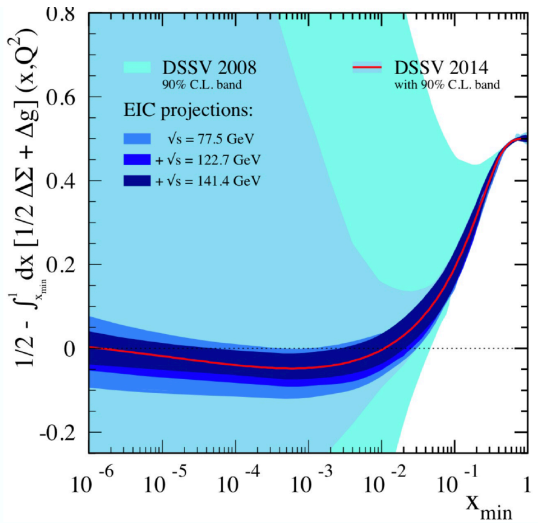
E. Aschenauer, R. Sassot and M. Stratmann, Phys. Rev. D92 (2015) 094030.



Quark Spin



Gluon Spin



Orbital Angular Momentum

3D Imaging

$f(x, k_T)$ 1+2D

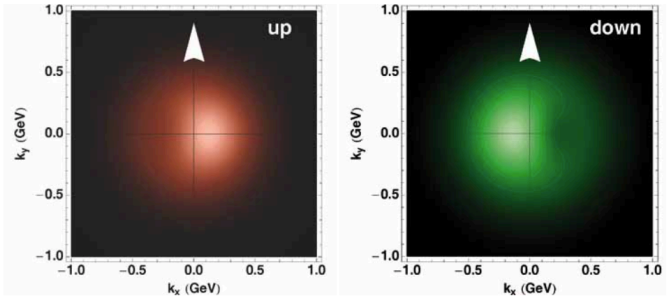
$\int d^2 b_T$ $W(x, b_T, k_T)$ $\int d^2 k_T$

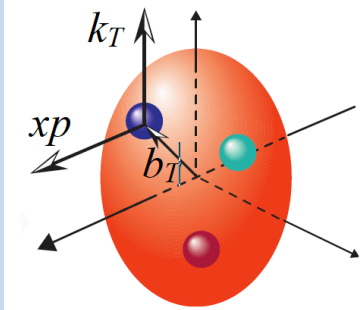
Wigner Distribution

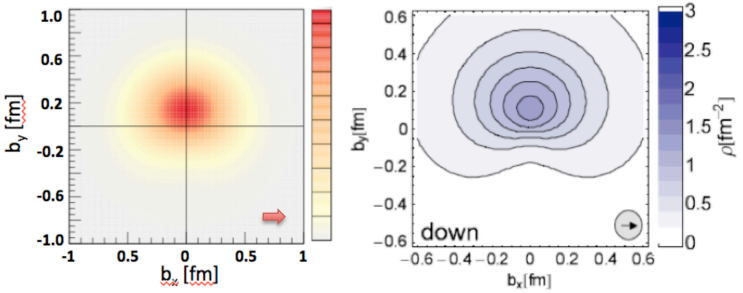
$f(x, b_T)$ 1+2D

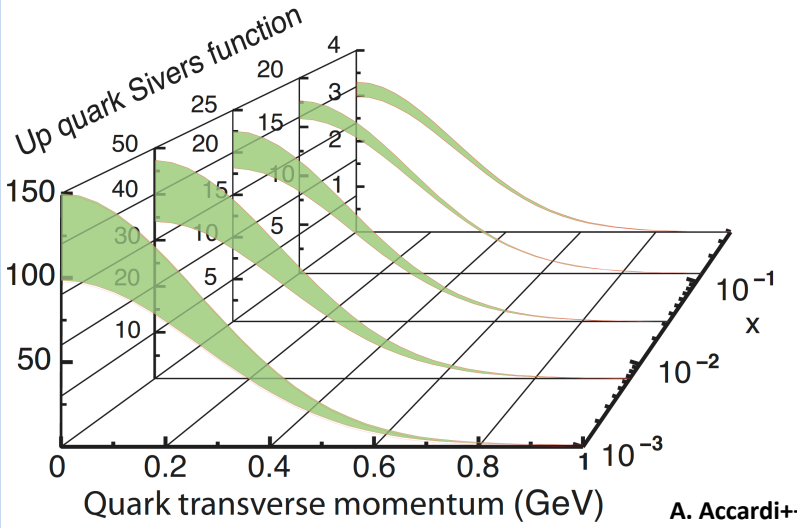
Transverse Momentum Distribution (TMD)

Impact Parameter Distribution

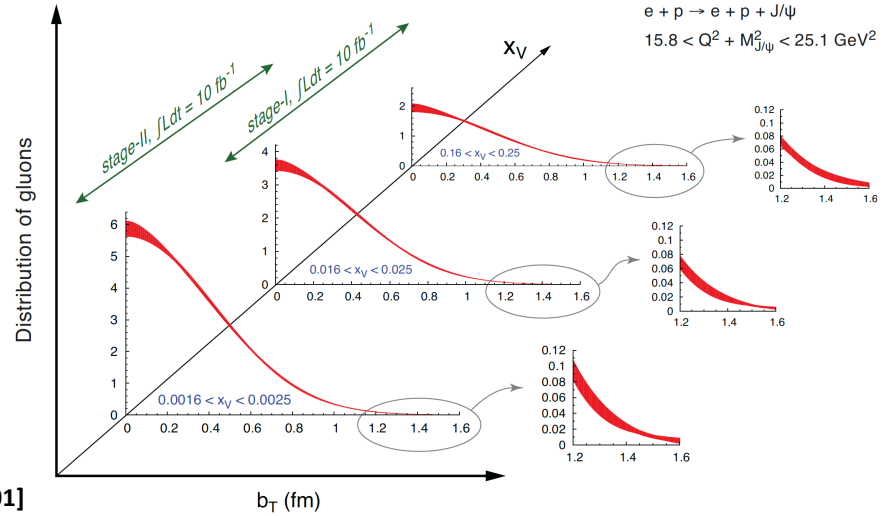








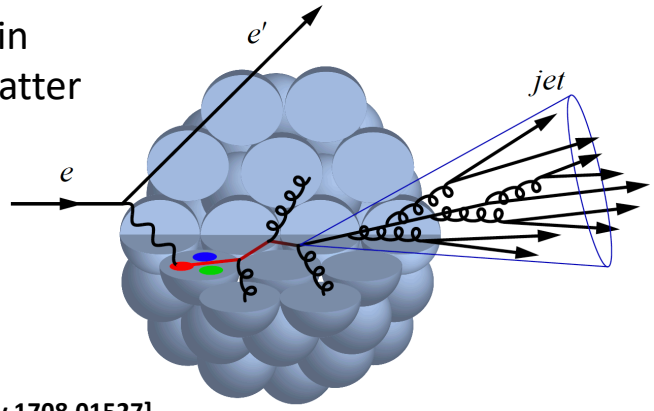
A. Accardi++ [arXiv 1212.1701]



Jet Physics

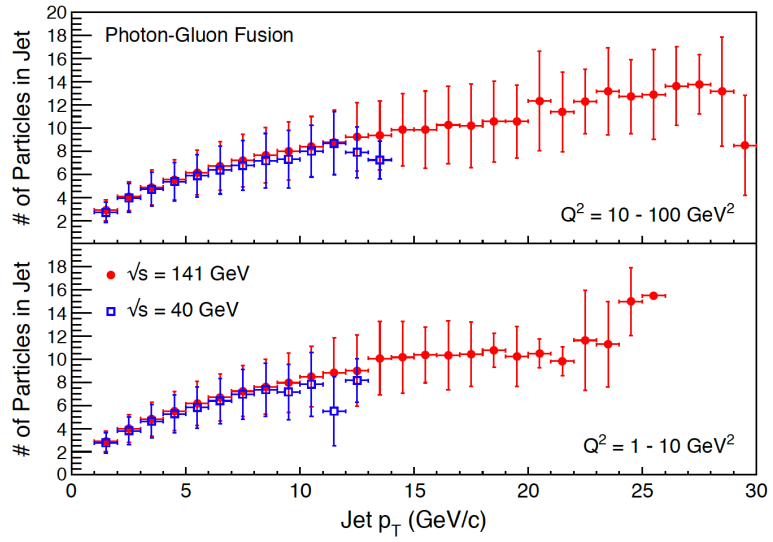
The best surrogate of the scattered parton:

Hadronization in cold nuclear matter

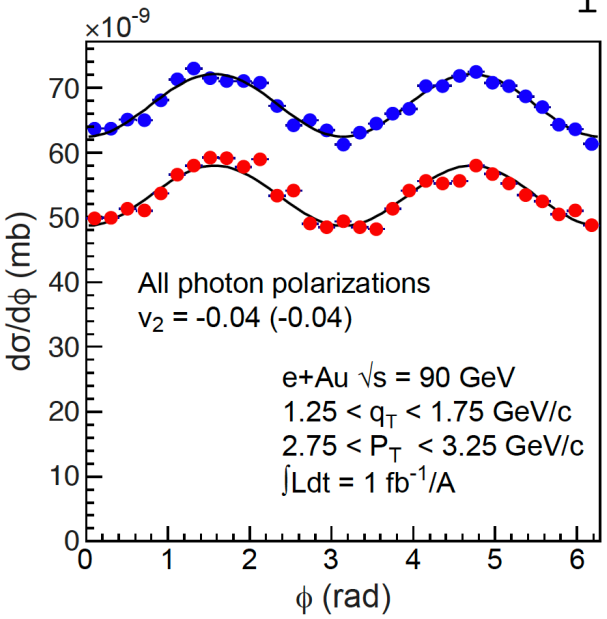


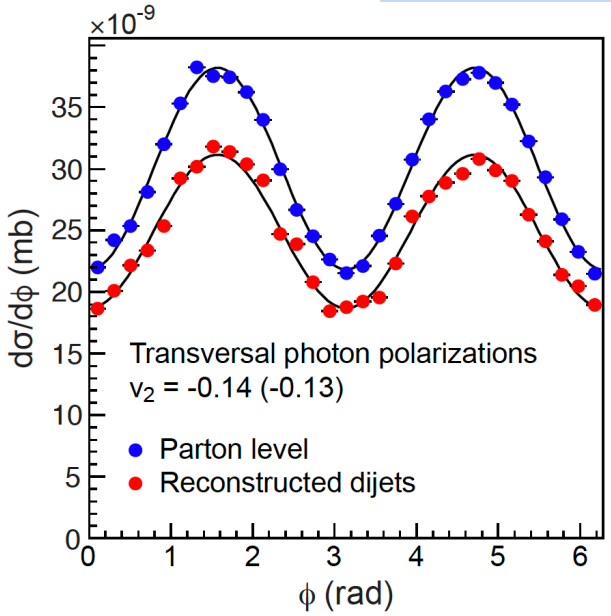
E.C. Aschenauer++ [arXiv 1708.01527]

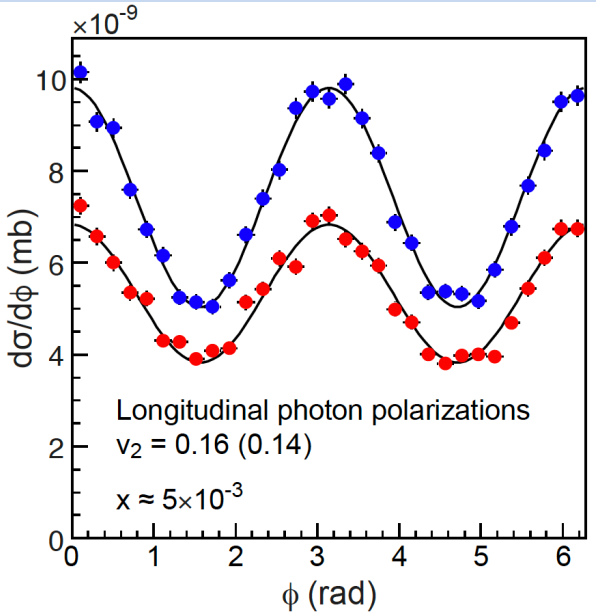
In-jet correlations



Di-jets correlations and gluon $h_{\perp}^{(1)}$ TMDs





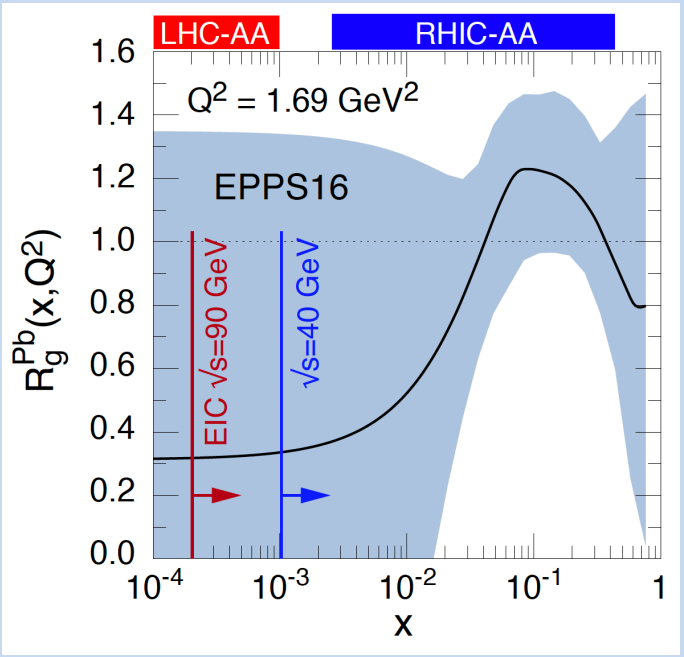


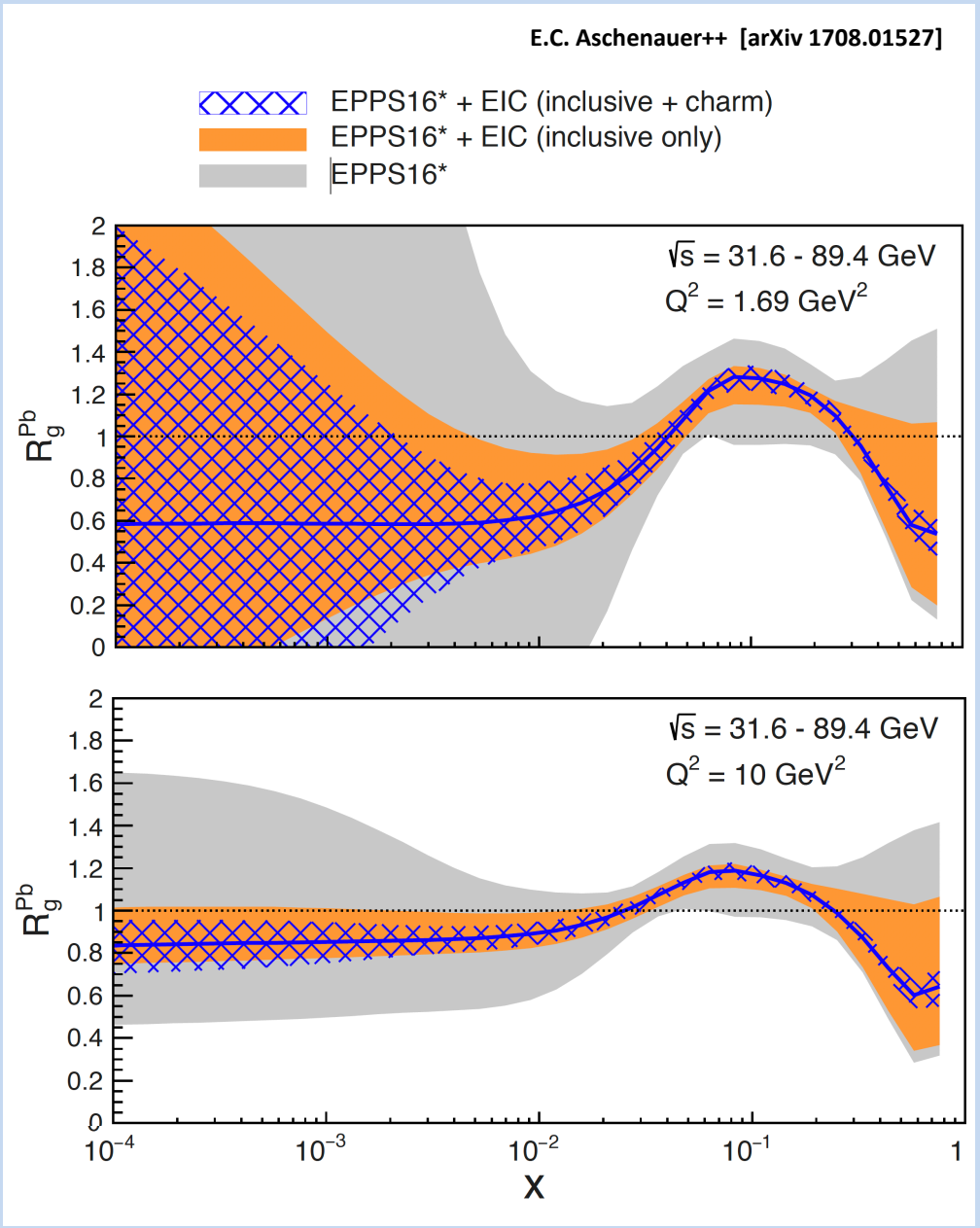
Nuclear PDFs

Important to constrain the
Initial state of heavy-ion collisions, such as

- momentum, distributions
- spatial distributions
- geometric fluctuations in gluon density

Good match with RHIC and LHC
heavy-ion collisions at mid-rapidity



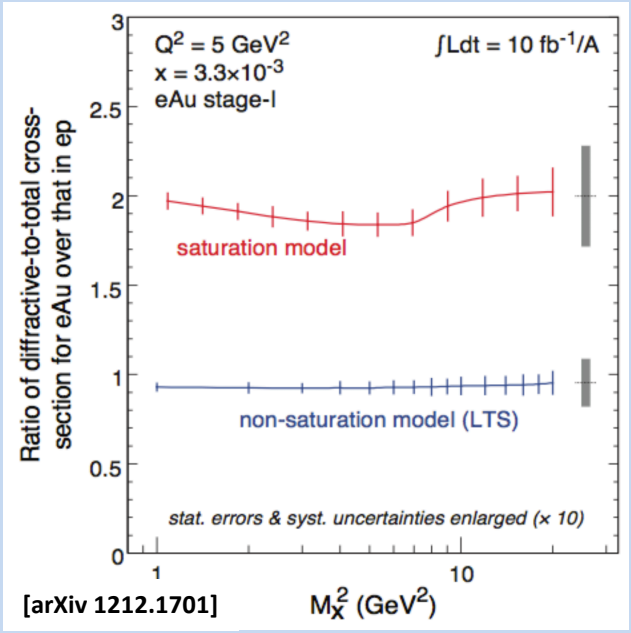


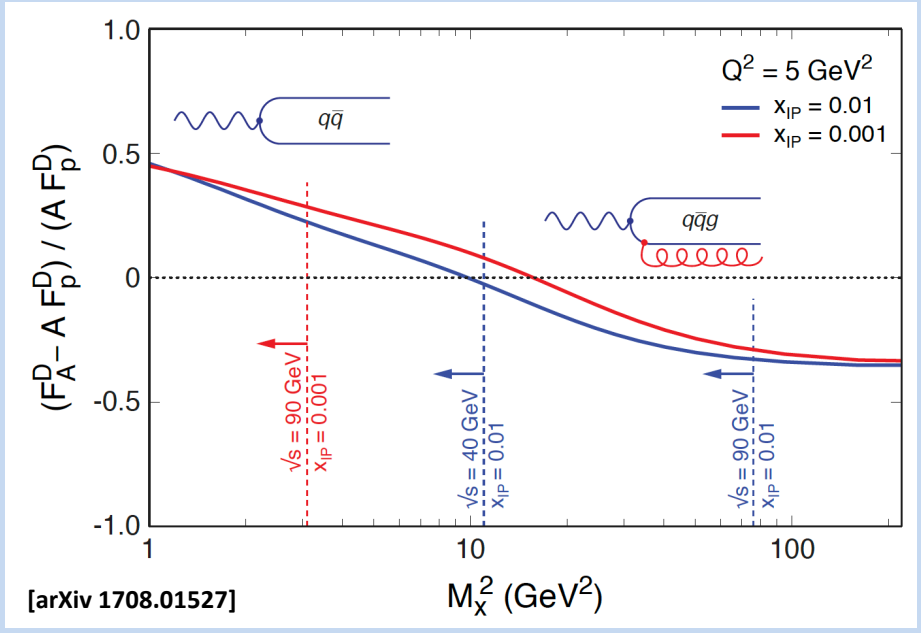
Saturation Regime

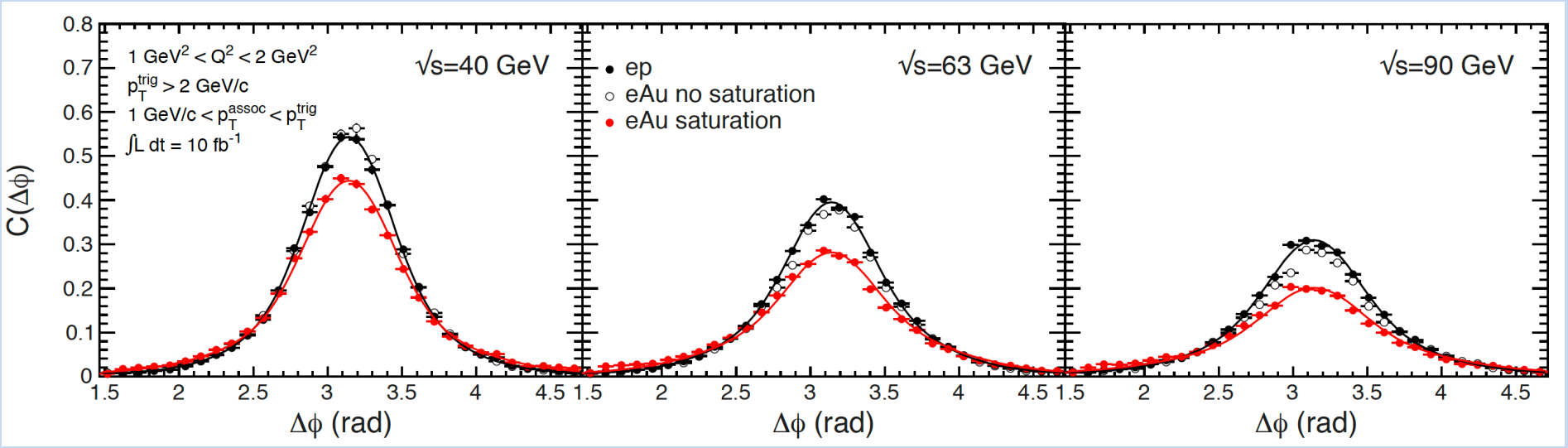
New regime with strong color-force but perturbative many-body interaction: a non-linear in QCD evolution

Diffraction

Back-to-back hadron correlations



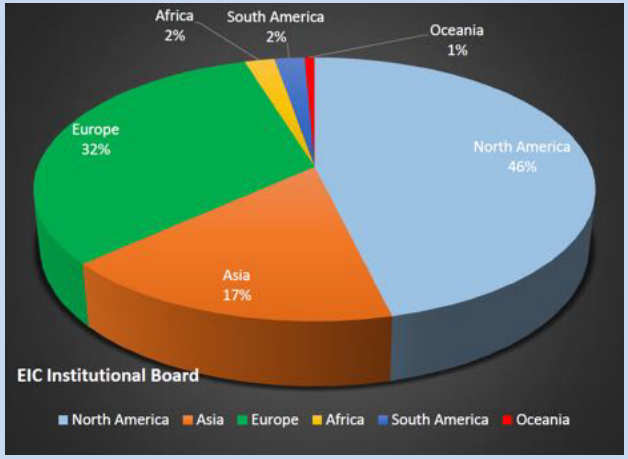




EIC User Group

EICUG.ORG
Formally established in 2016
~ 1092 Ph.D. members from 210 Institutions (31 countries)

New members are welcome



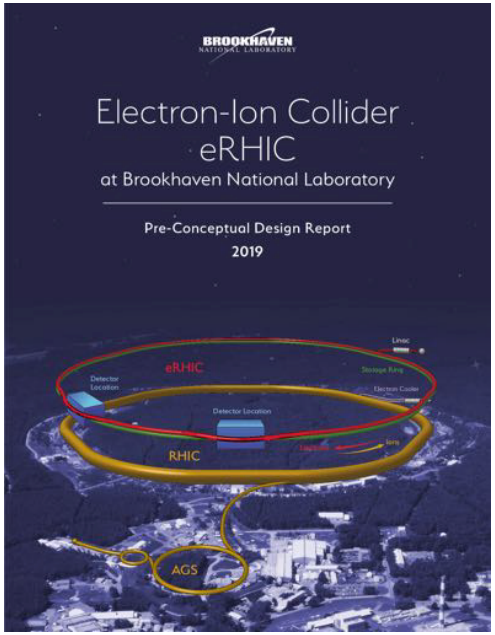
EIC Structure:

- Steering Committee
- Institutional Board
- Speaker's Committee
- Nomination Committee

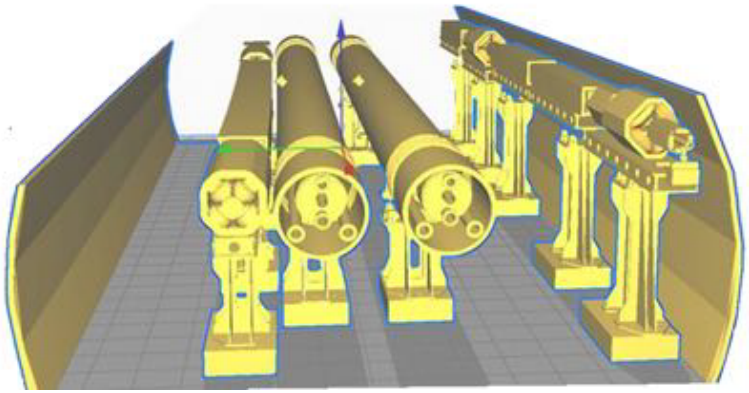
Annual Meetings: Stony Brook ('14), Berkeley ('15), ANL ('16),
Trieste ('17), CAU ('18), Paris ('19), FIU ('20), Warsaw ('21)

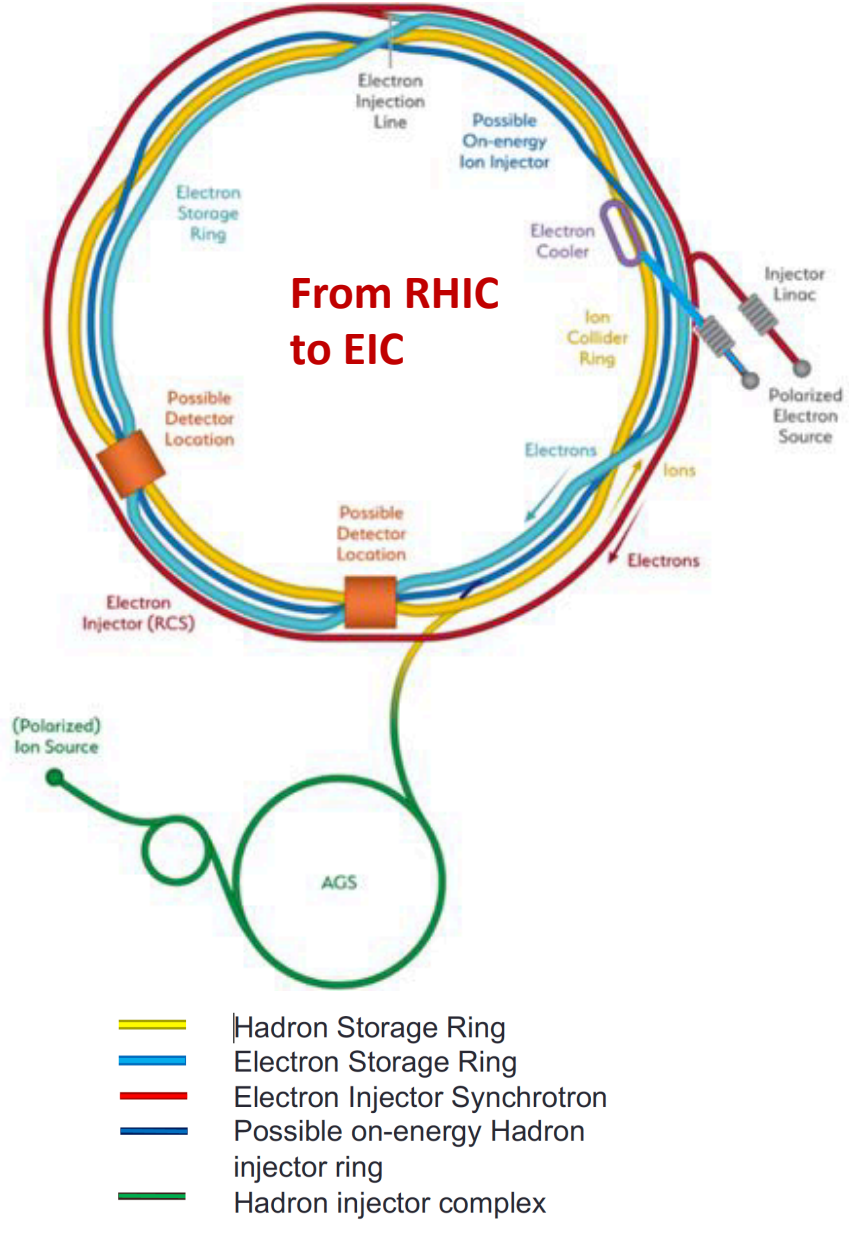
EIC Facility

A formal EIC project is setup at BNL after site selection in January 2020

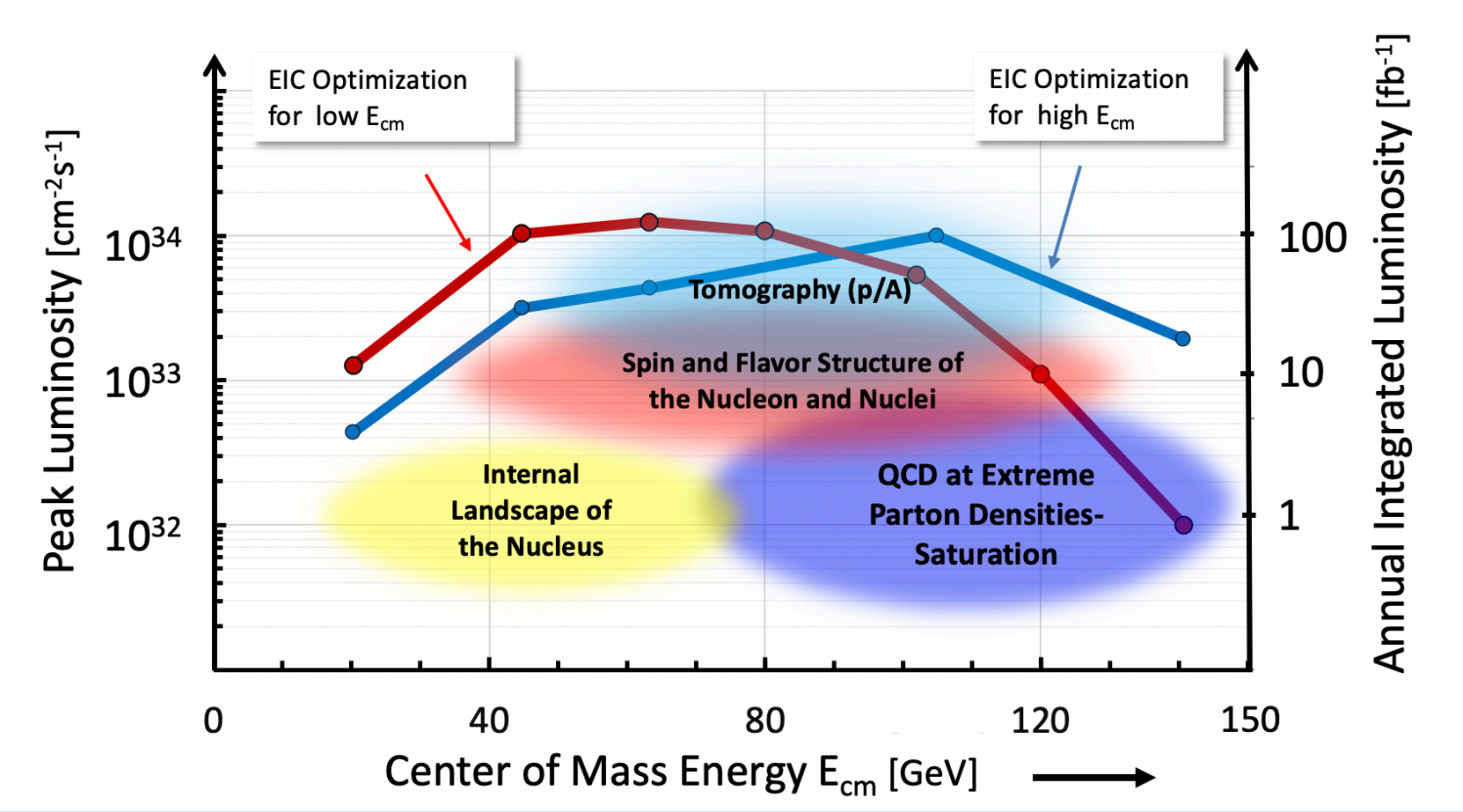


Pre-conceptual Design Report





EIC Design Parameters

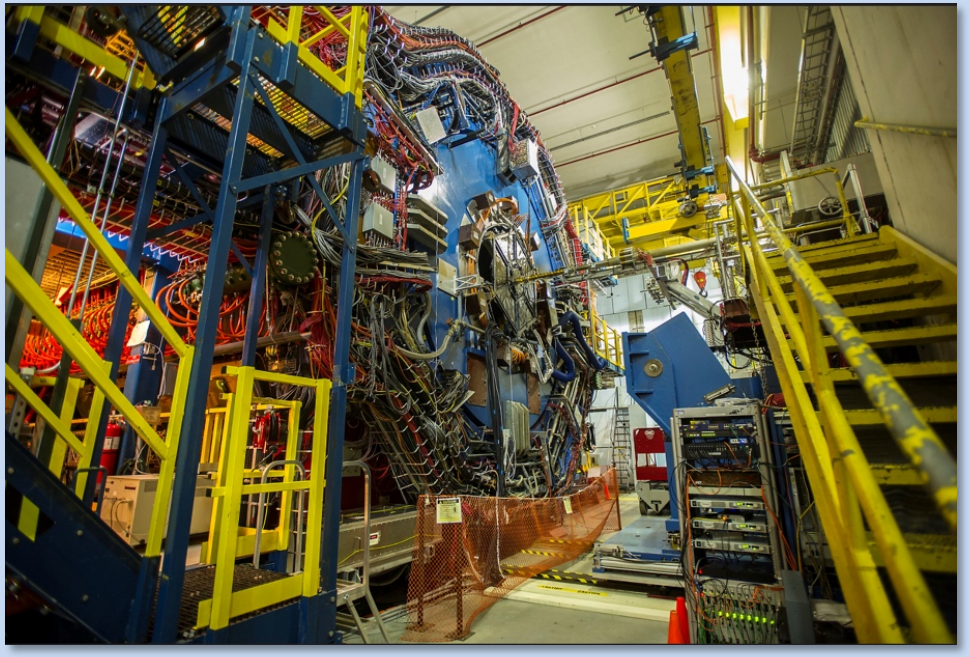


- High luminosity: 10^{33}-10^{34} $cm^{-2}sec^{-1}$ a factor 100-1000 times HERA (@DESY)
- Broad range in center-of-mass energy: 20 – 140 GeV
- Polarized beams e-, p, D, ^{3}He… C, Be with flexible spin patterns & spin orientation
- Wide range in hadron species: protons…. Uranium
- Up to two well-integrated detector(s) into the machine lattice for max. acceptance

EIC Second IP

EIC benefits from two large existing Halls IR6 and IR8

IR 8 detector hall with PHENIX detector (transitioning to sPHENIX)



IR 6 detector hall with STAR detector

- Both IRs can be implemented simultaneously in the BNL-EIC lattice and be accommodated within beam dynamics envelope
- 2 IR's: laid out identically or optimized for maximum luminosity at different E_{CM}

BNL TJNAF Partnership

BNL and JLab realize EIC as partners

- The EIC Project captures project delivery experience from BNL and TJNAF
- BNL-TJNAF Partnering Agreement Approved- May 7, 2020
- EIC Project Executive Management Team (EMT) Established:
  Elke Aschenauer, Rolf Ent, Diane Hatton, Allison Lung, Andrei Seryi, Ferdinand Willeke, and Jim Yeck
- Abhay Deshpande, EIC Science Director, participates in the EMT meeting as an ex-officio member providing an additional connection to the User community.

ELECTRON ION COLLIDER PROJECT

J. Yeck (BNL), Project Director

F. Willeke (BNL), Deputy Project Director and Technical Director

R. Ent (TJ), Co-Associate Director for the Experimental Program

E. Aschenauer (BNL), Co-Associate Director for the Experimental Program

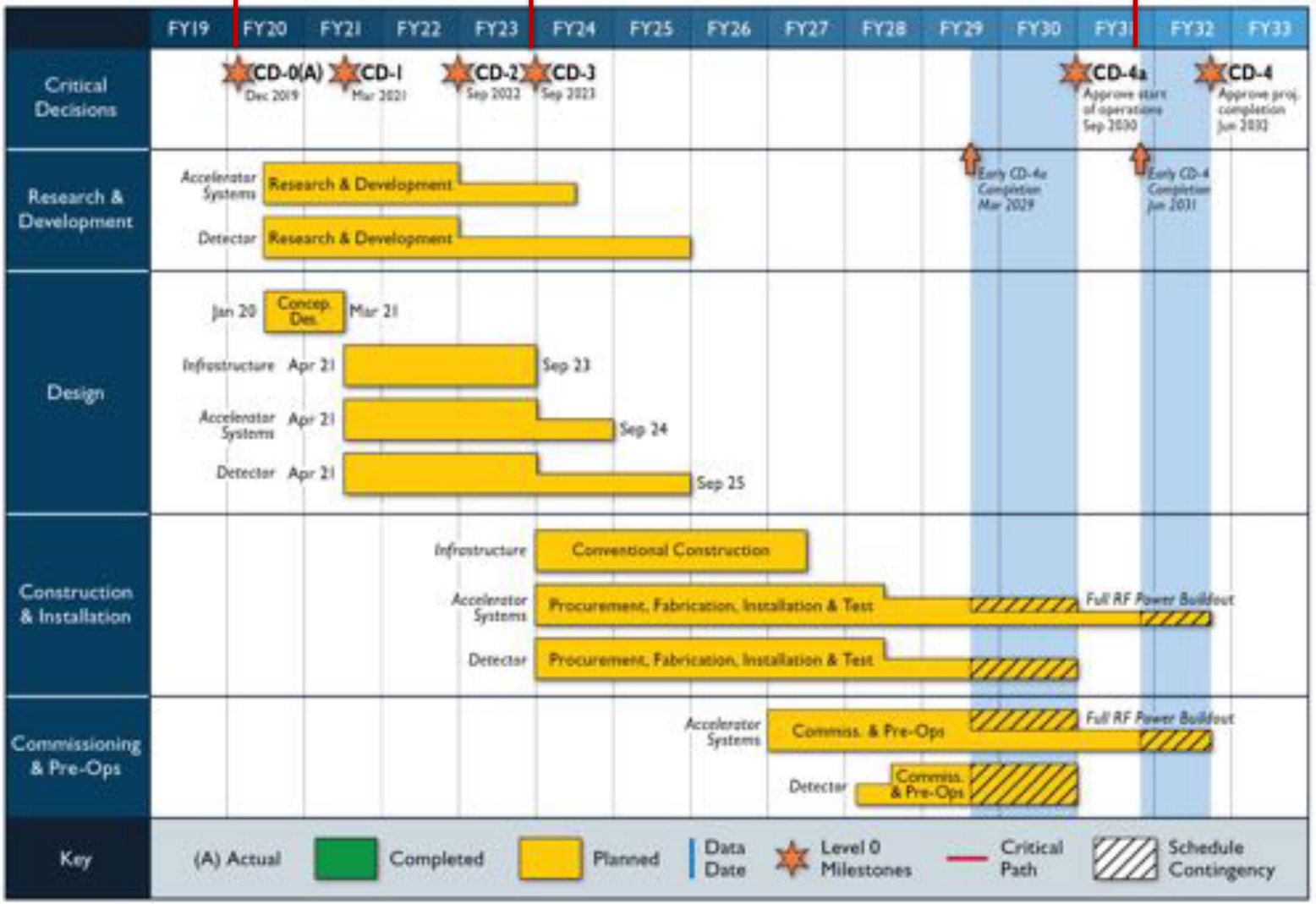
A. Lung (TJ), Deputy Project Director for TJNAF Partnership

A. Seryi (TJ), Associate Director for Accelerator Systems & International Partnership

D. Hatton (BNL), Project Manager

EIC Schedule

CD0 11/2019 **Construction start 09/2023** **Early completion 09/2031**



EIC Detector Challenges

Specific requirements to move beyond the longitudinal description

- Resolve partons in nucleons

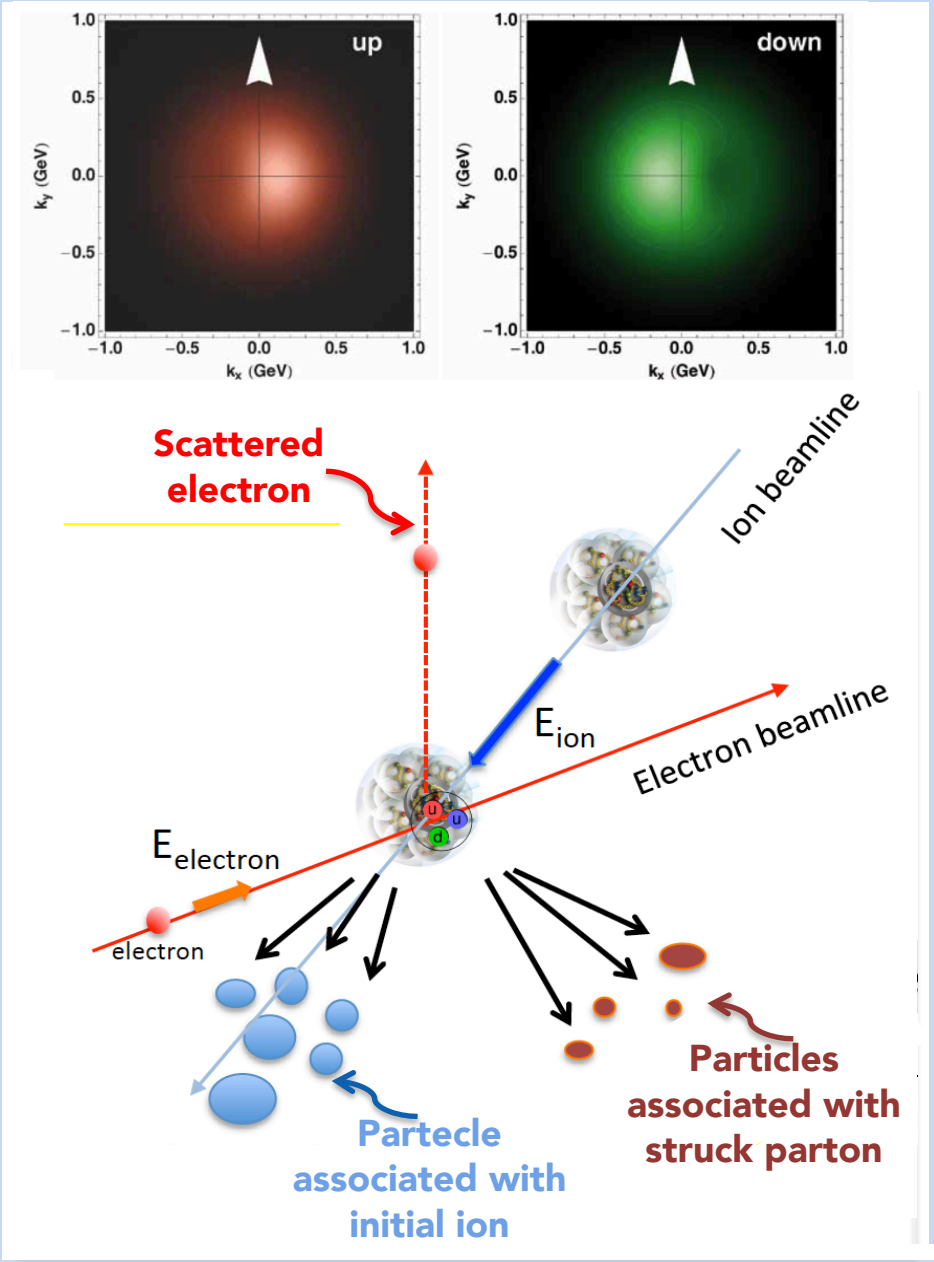
  ➔ high beam energies and luminosities Q^2 up to **~1000 GeV²**

- Need to resolve quantities (k_t, b_t) of the order **a few hundred MeV** in the proton Correlated quantities, multi-D analyses

  ➔ High Granularity, wide dynamic range

- Need to detect **all types of remnants** to seek for correlations:
  - scattered electron
  - particles associated with initial ion
  - particles associated with struck parton

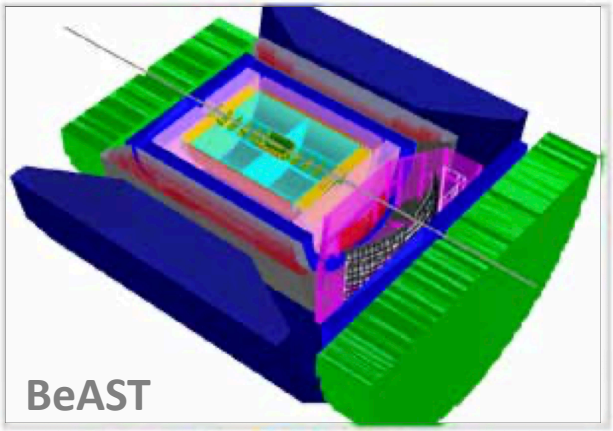
  ➔ Large acceptance, Forward particle detection, **Excellent PID**

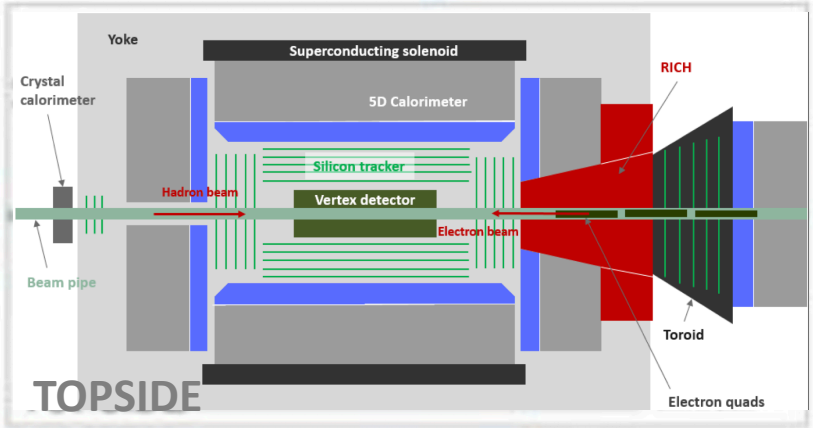


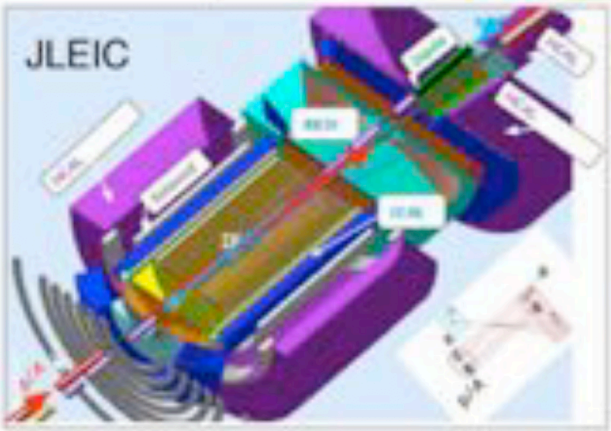
EIC Detector

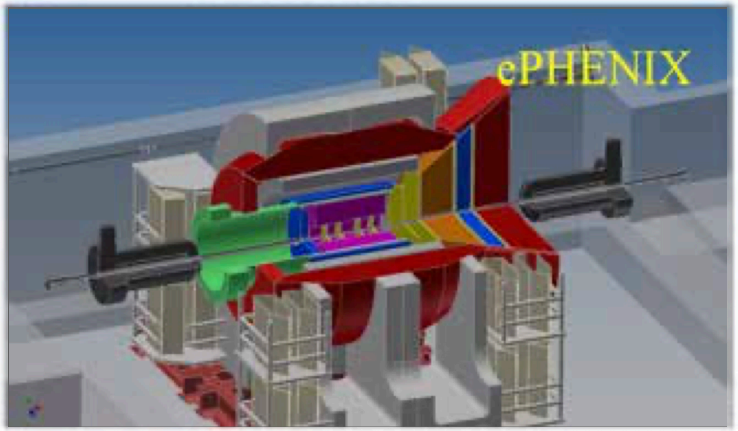
Similar concepts for an almost hermetic detector:

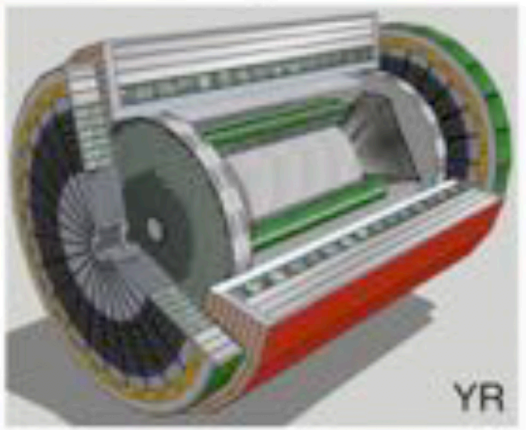
- Tracking: Si vertex + TPC / MPGD / Silicon
- PID: dE/dx, TOF, TRD, Cherenkov detectors: RICH, DIRC
- Calorimetry: Crystal, Shashlik, Powder
- Beam line: ZDC, Compton polarimeter, Roman pot, Luminosity monitor











EIC Middle-Term Horizon

2011>> R&D Program:

Generic detector R&D program for future EIC facility
Ongoing since January 2011 with about 1.5 M$/year

2020 Yellow Report Activity

Advance the state and detail of requirements and detector concepts
~ 1 year with 4 workshops: TU Mar. '20, Pavia May '20, CUA Sep '20, UCB Nov'20

Expression of Interest

Call for "Potential Cooperation on the EIC Experimental Program"
Published in May '20, closed in Nov '20: Evaluation ongoing.

2021 CD1 Alternative selection and cost range approval

Call for Detector Proposals

2nd IP Project

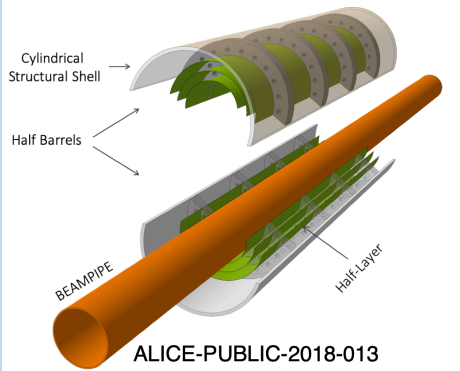
Series of workshops at CFNS to investigate physics and feasibility

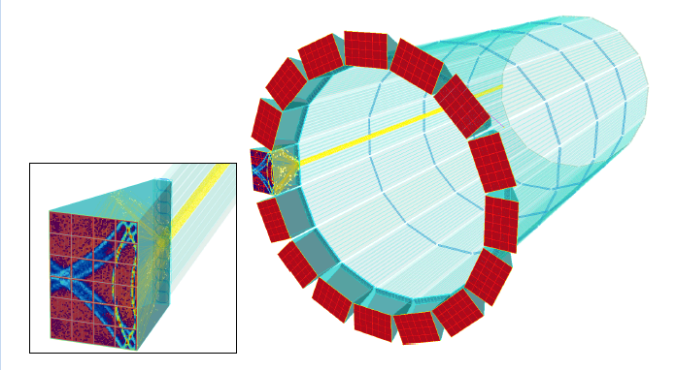
2022 CD2 Baseline design, cost and schedule approval

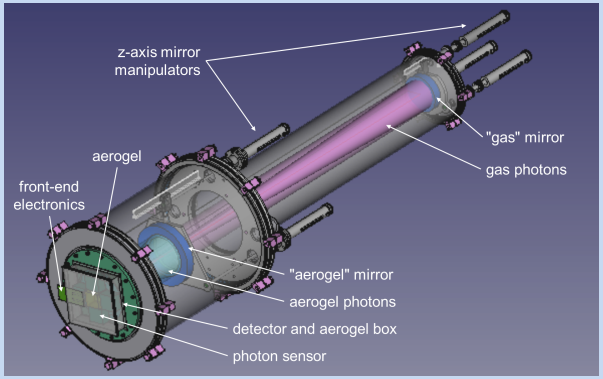
2023 CD3 Final design approval and start of construction

Examples of EU Based Developments

Si: tracking and vertexing (IT-UK-US) **DIRC:** hadron PID in barrel (GER-US) **RICH:** hadron PID in h-endcap (IT-US)

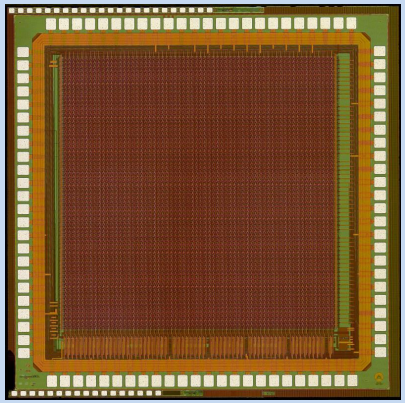


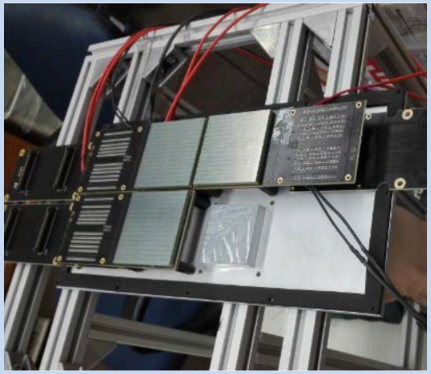




SiPM: Single-photon sensors for high B field

MAPS silicon:
Synergic with ALICE ITS3
New CMOS 65 nm tech.

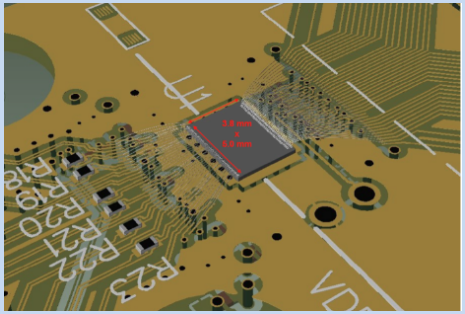


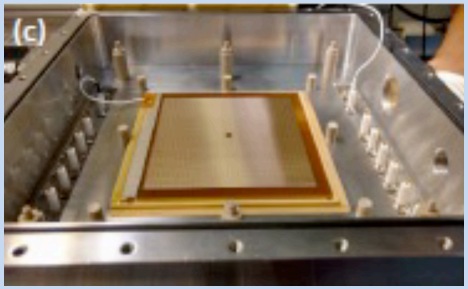


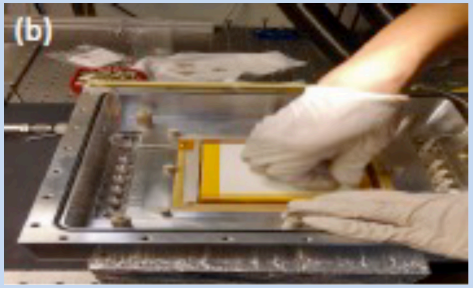
MPGD: Windowless, small-pad, nano-powder photocathode

ASICS:
ALCOR for SIPM

DAQ:
streaming readout







The Electron-Ion Collider

A high-energy, high-luminosity polarized e-p, e-A collider
Funded by DOE will be built in this decade and operate in 2030's

EIC is an unique opportunity for a comprehensive QCD study
moving from phenomenology to rigorous treatment
to reach breakthrough potential and predictive power

Up to two hermetic full acceptance detectors matching high-Q and low-PT sensitivity
EIC project account funds for 1 detector with wide space for external contributions

Aggressive timeline to have first collision in 2030 and design operation around 2032

High interest in international cooperation on detector and accelerator

Easy way to partecipate through the EIC User Group
http://www.eicug.org