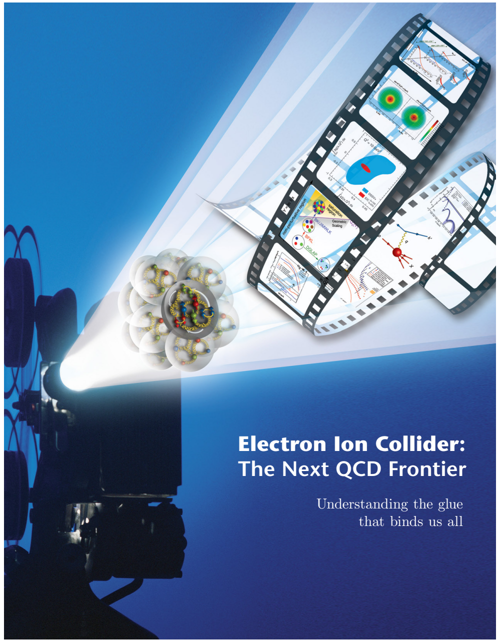
Probing sea quarks and gluons at an EIC at Horizon 2025

Claude MARCHAND
CEA Saclay, IRFU, Service de Physique Nucléaire

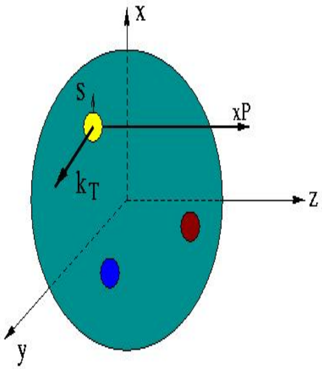


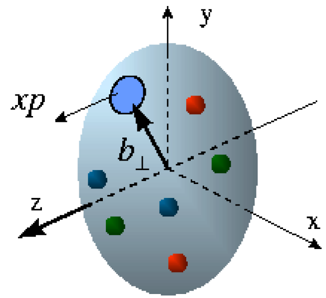
1. Present status on polarized PDF
2. Improvements expected from an EIC
3. EIC projects: machine layouts
4. EIC projects: detectors and overview of R&D

Unified view of Nucleon structure

$W_p^u(x,k_T,r)$ Wigner distributions

6D Dist.





d^3r

$d^2k_T\, dr_z$

TMD PDFs $f_1^u(x,k_T)$, .. $h_1^u(x,k_T)$

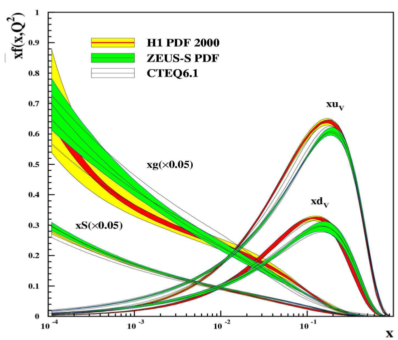
GPDs/IPDs

3D imaging

d^2k_T

d^2r_T

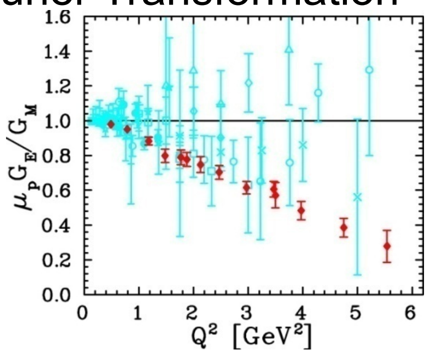
dx & Fourier Transformation



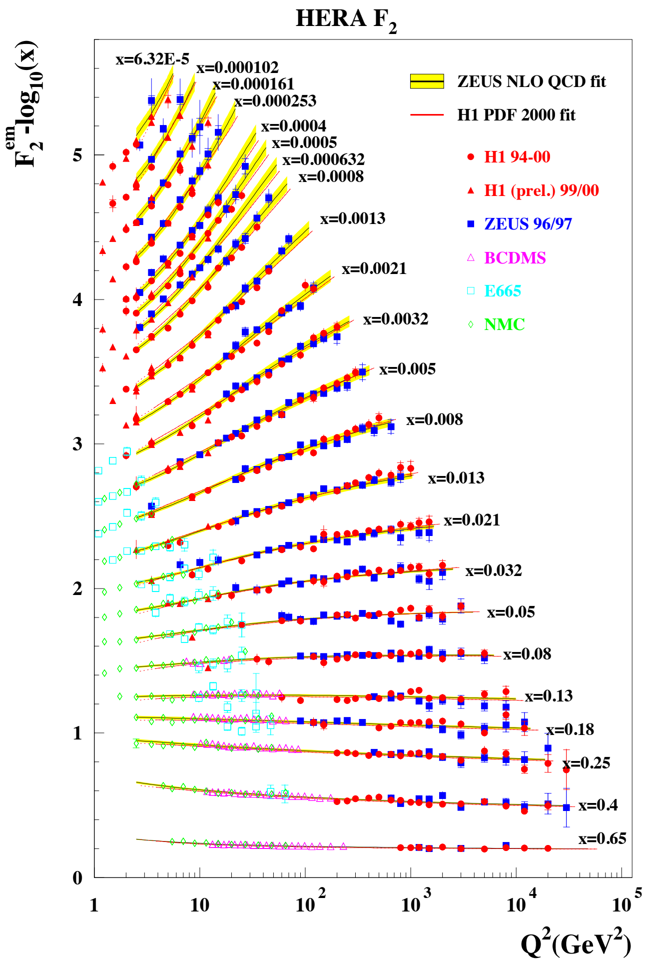
(pol) PDFs
$f_1^u(x)$, .. $h_1^u(x)$
DIS - SIDIS

1D

Form Factors
$G_E(Q^2)$,
$G_M(Q^2)$

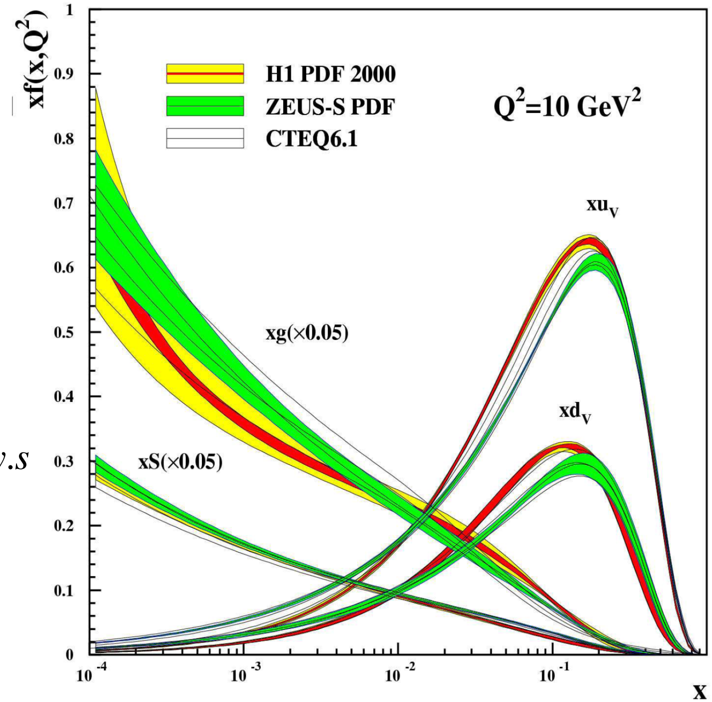


State of the art: unpol. PDF q(x)



Next-to-Leading-Order (NLO) perturbative QCD (DGLAP) fits

$$Q^2 = x.y.s$$



State of the art: pol. PDF q(x)

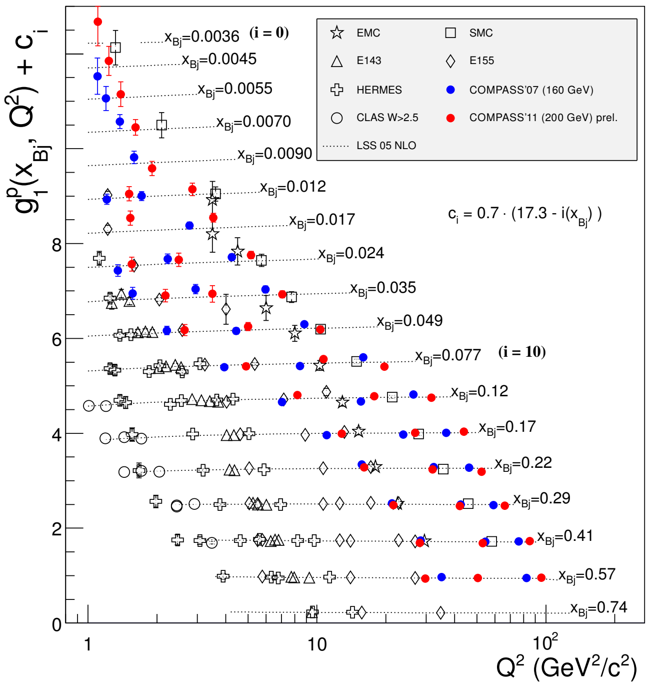
Inclusive DIS

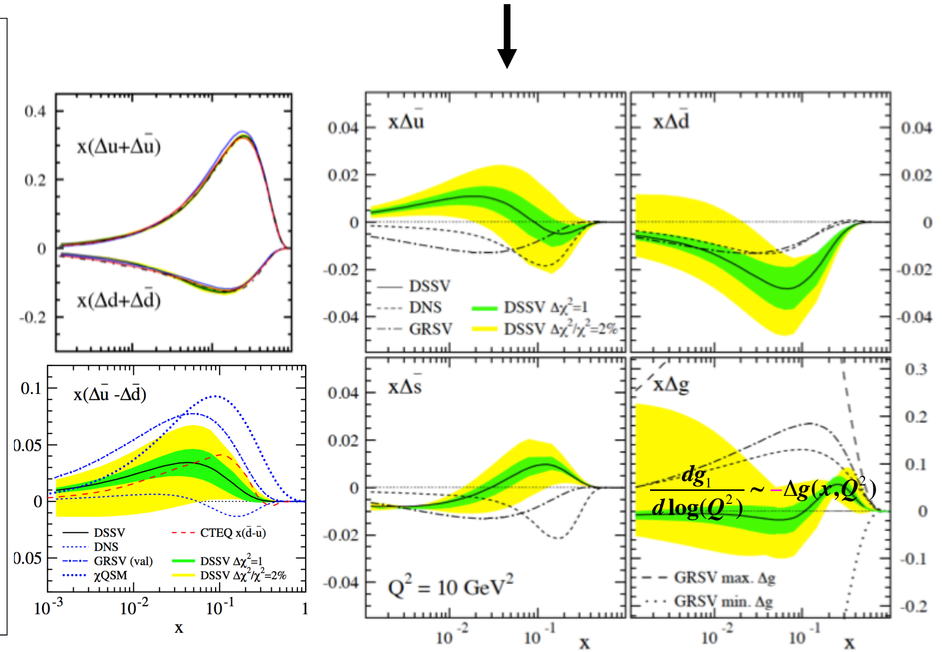
$$A_1(x,Q^2) = \frac{\sigma_{\uparrow\downarrow}-\sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow}+\sigma_{\uparrow\uparrow}} \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)} = \frac{g_1(x,Q^2)2x(1+R)}{F_2(x,Q^2)}$$

+

Semi Inclusive DIS

$$A_1^{h\,(p/d)}(x,z,Q^2) \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

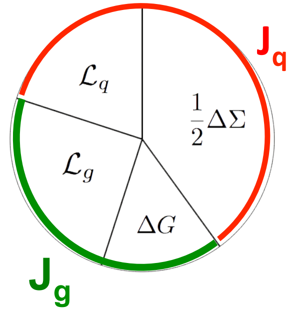


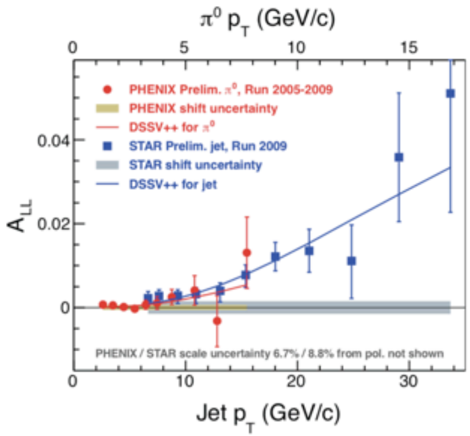


$$\int_0^1 \Delta g(x)dx = 0.013^{+0.702}_{-0.314} (\Delta\chi^2/\chi^2 = 2\%)$$

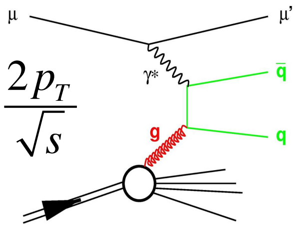
How q and g share nucleon spin?

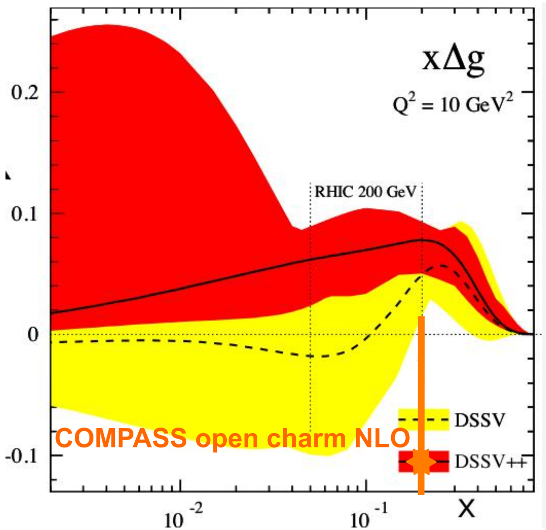
$$\frac{S_z^N}{\hbar} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$

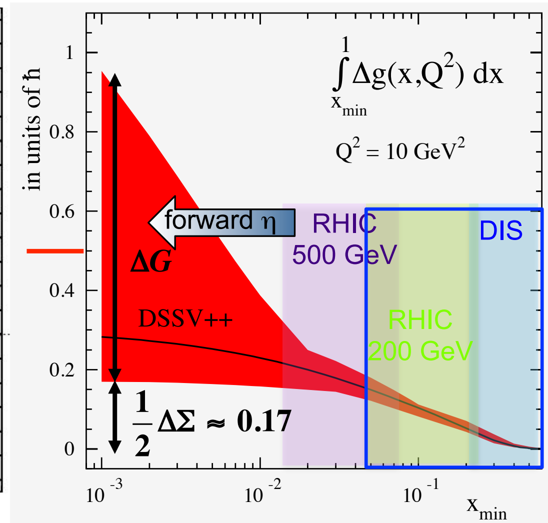




$$x_G = \frac{2p_T}{\sqrt{s}}$$







Nucleon spin « puzzle » still open

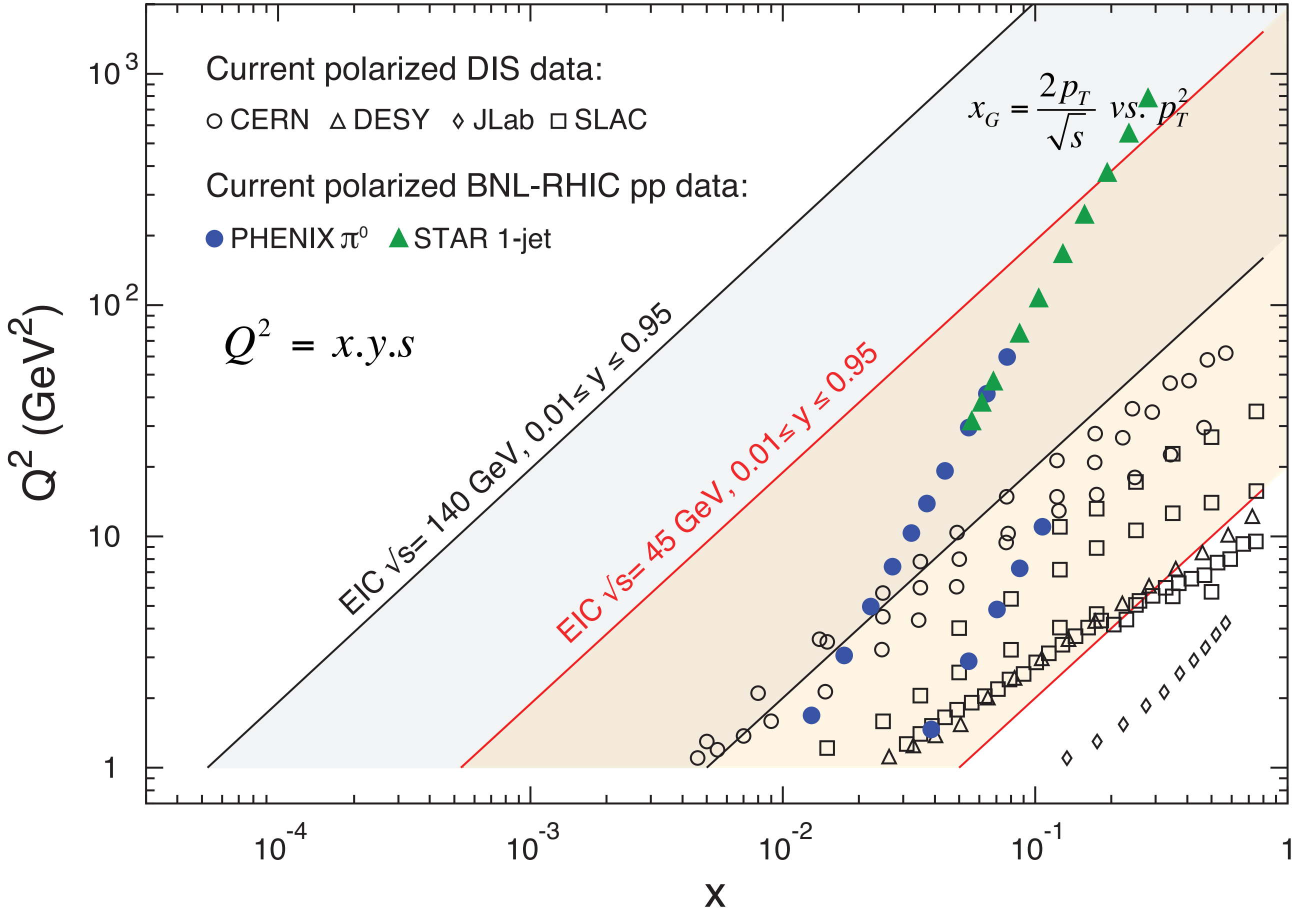
Merits of collider vs fixed target

- Easier to reach high Center of Mass energies ($E_{CM}^2 = s$)
  - $s = 4E_eE_p$ for colliders (E_{CM} = 45 GeV/5*100, 140 GeV/20*250)
  - $s = 2E_eM_p$ for fixed target experiments (E_{CM} = 17 GeV/160 at COMPASS)
  - → access to lower x and higher Q^2 (Q^2=x.y.s)

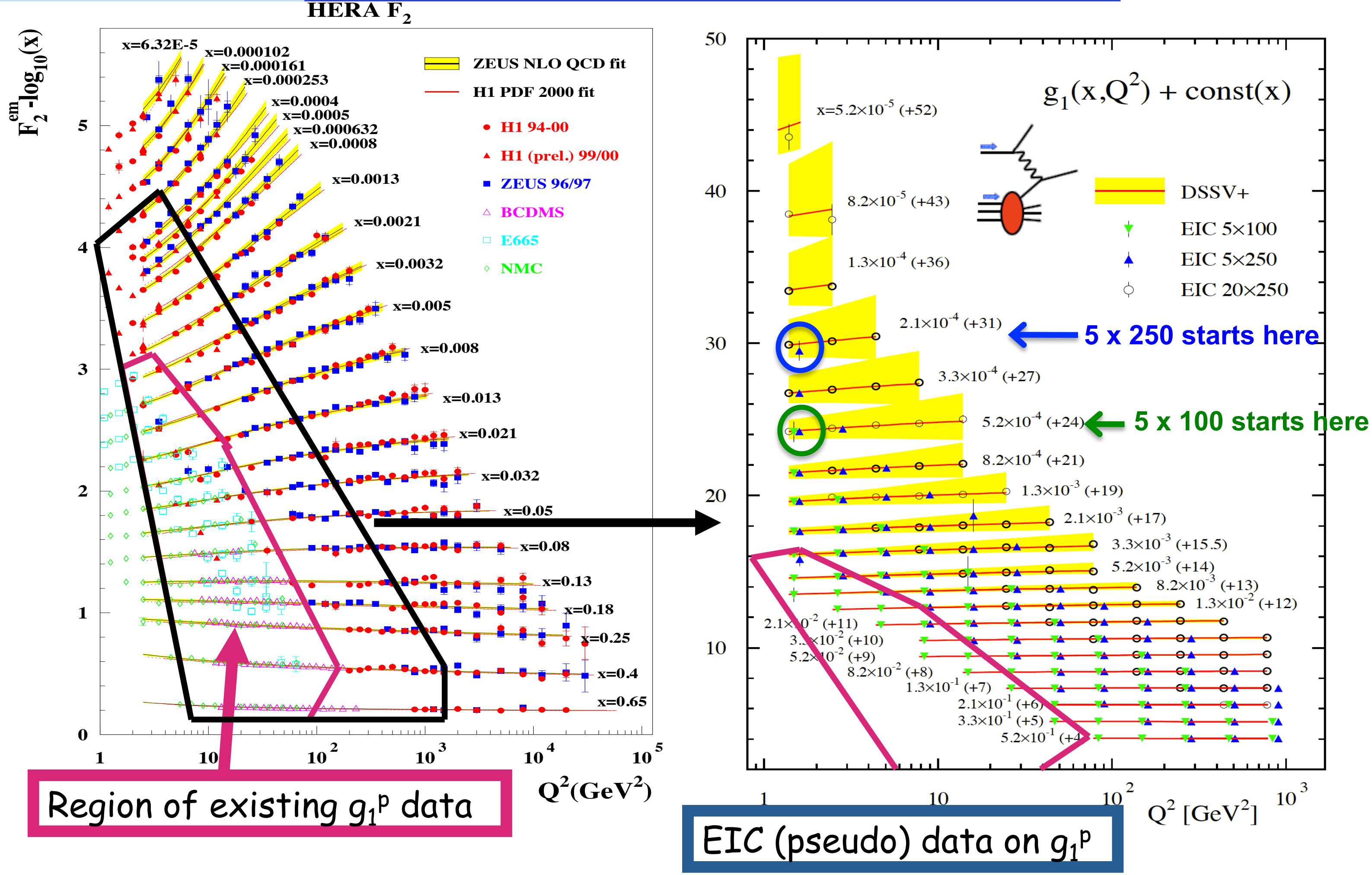
- Spin physics with high Figure Of Merit (FOM)
  - Unpolarized FOM = **Rate = Luminosity x Cross Section x Acceptance**
  - Polarized **FOM = Rate x (Target Polarization)^2 x (Target Dilution)^2**
  - No *dilution* and high ion polarization (also *transverse*): $P^2.D^2$> 10/fixed target
  - Higher luminosity then HERA/COMPASS, no holding fields (*acceptance*)
  - No *backgrounds* from target (Moller electrons)

- Easier detection of reaction products
  - Can optimize kinematics by adjusting beam energies
  - No matter between IP and detectors: can use displaced vertex to tag charm

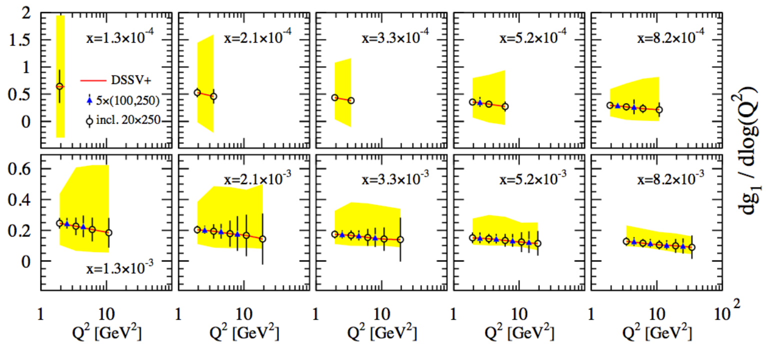
EIC kinematic coverage for DIS



Quark and gluon helicities EIC

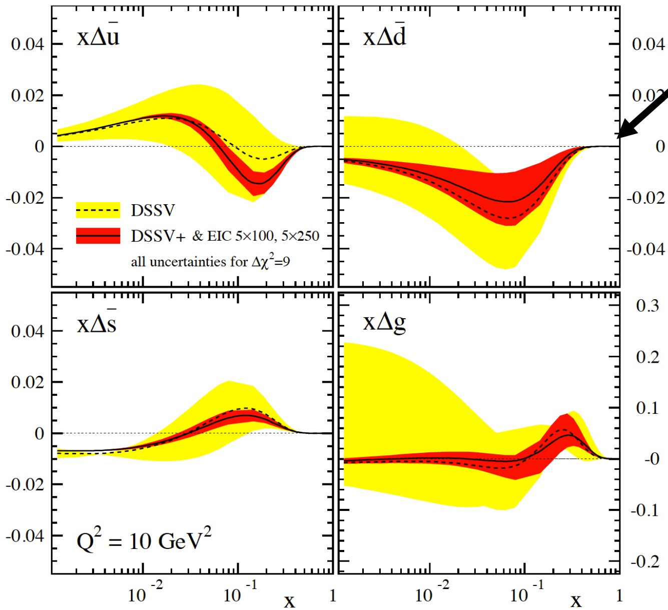


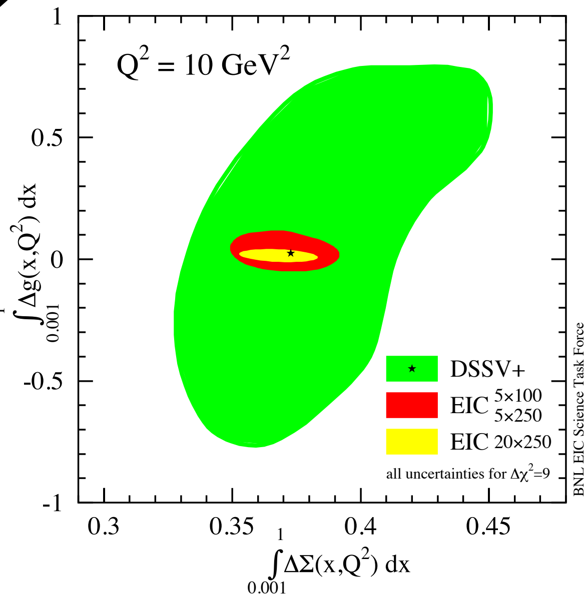
Quark and gluon helicities EIC



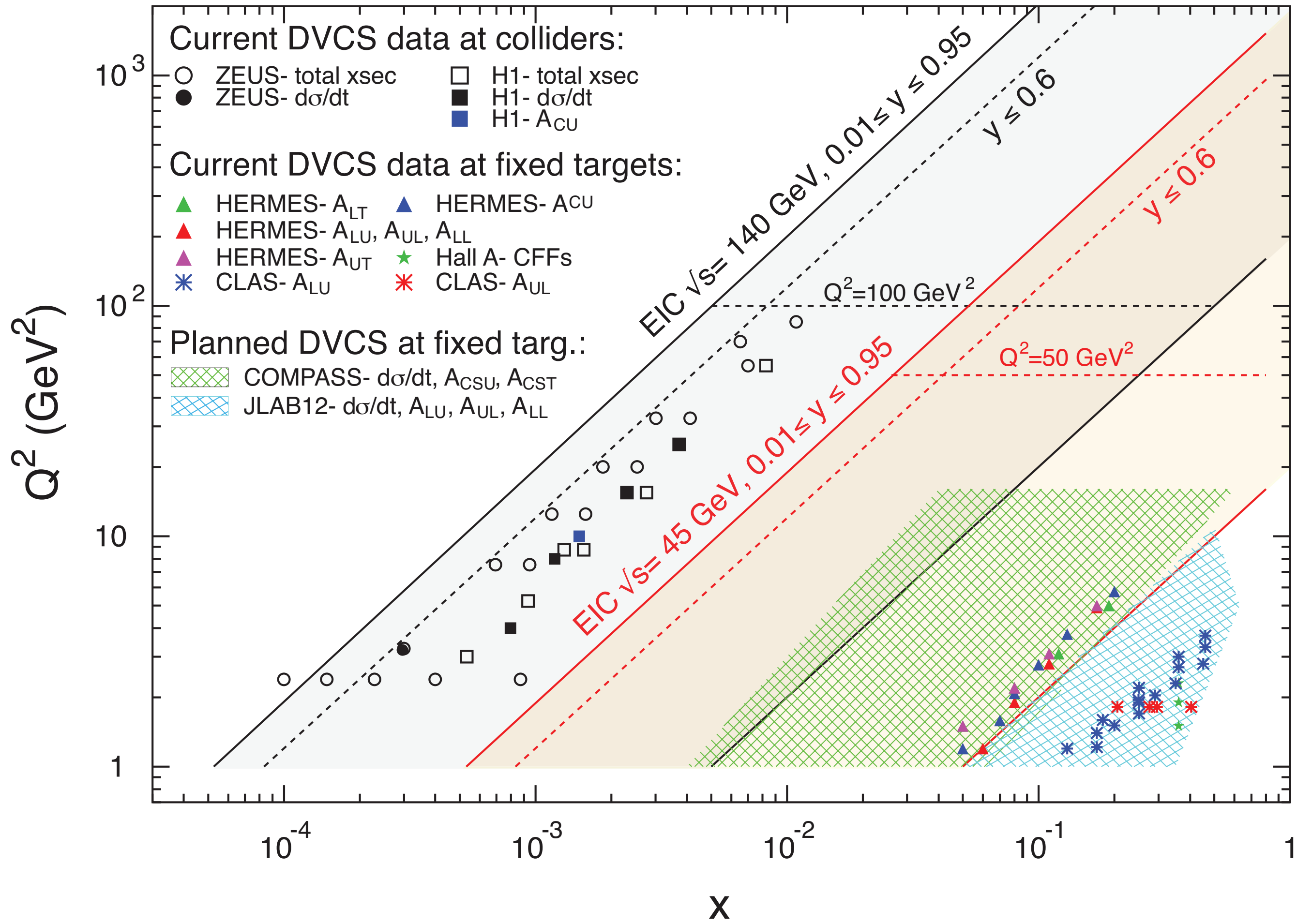
$$\frac{dg_1}{d\log(Q^2)} \sim -\Delta g(x,Q^2)$$

+ SIDIS

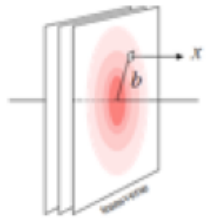




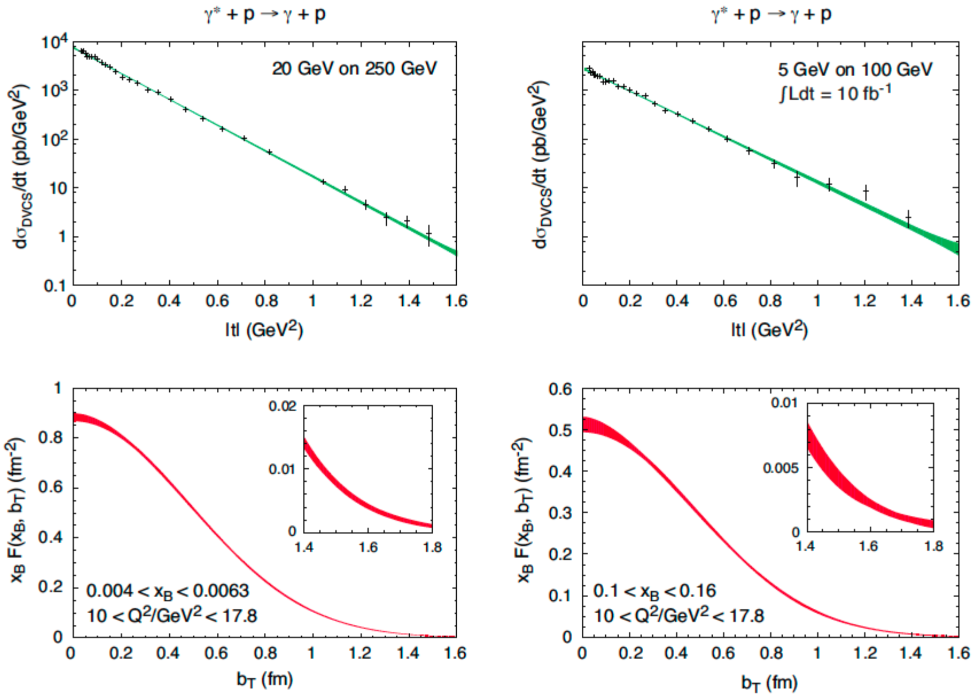
3D imaging EIC (GPD)



3D imaging EIC (DVCS)



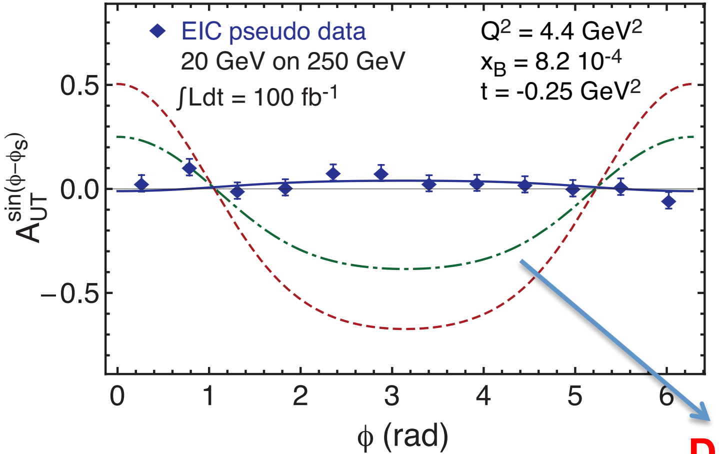
- **|t|-differential cross section is a very powerful tool**
  - **Gives precise access to GPD H**
  - **Fourier transform -> direct imaging in impact parameter s**

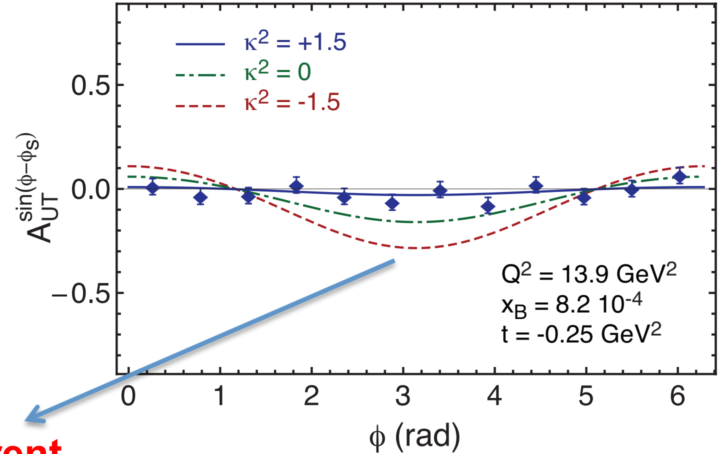


~ 1 year of data taking -gain of EIC thanks to high luminosity/HERA

$$q\left(x,b^2\right) \approx \int dt e^{-ibt} \frac{d\sigma}{dt}$$

Transverse target SSA - EIC





Different assumptions for E ($E=\kappa^2.H$)

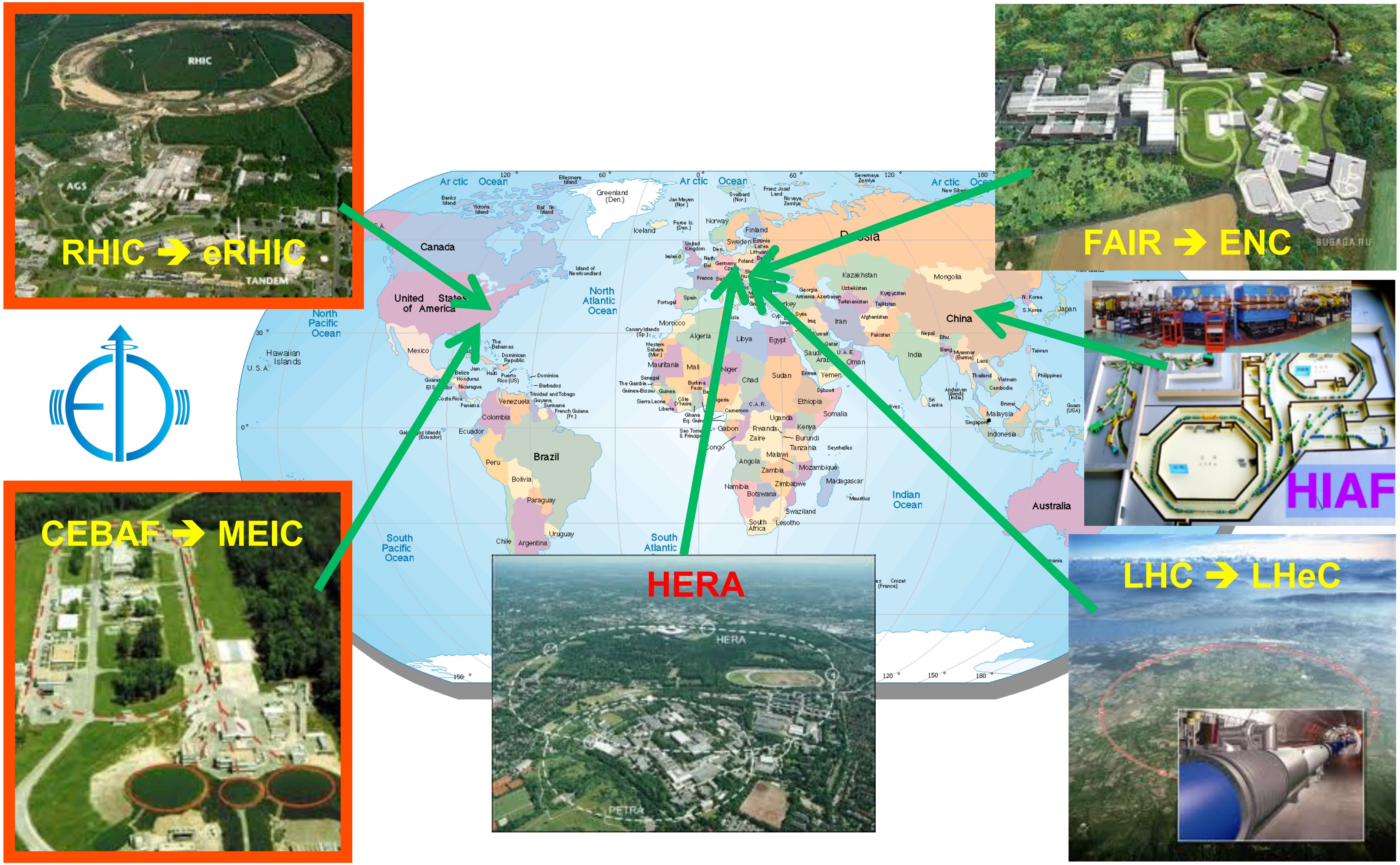
few years of data taking -gain of EIC thanks to high $L.P^2.D^2$

$$A_{UT} \propto \sqrt{\frac{-t}{4M^2}}\left[F_2(t)H\left(\xi,\xi,t,Q^2\right)-F_1(t)E\left(\xi,\xi,t,Q^2\right)+\ldots\right]$$

***$\sin(\Phi_T-\phi_N)$* governed by E and H**

Gives access to GPD E

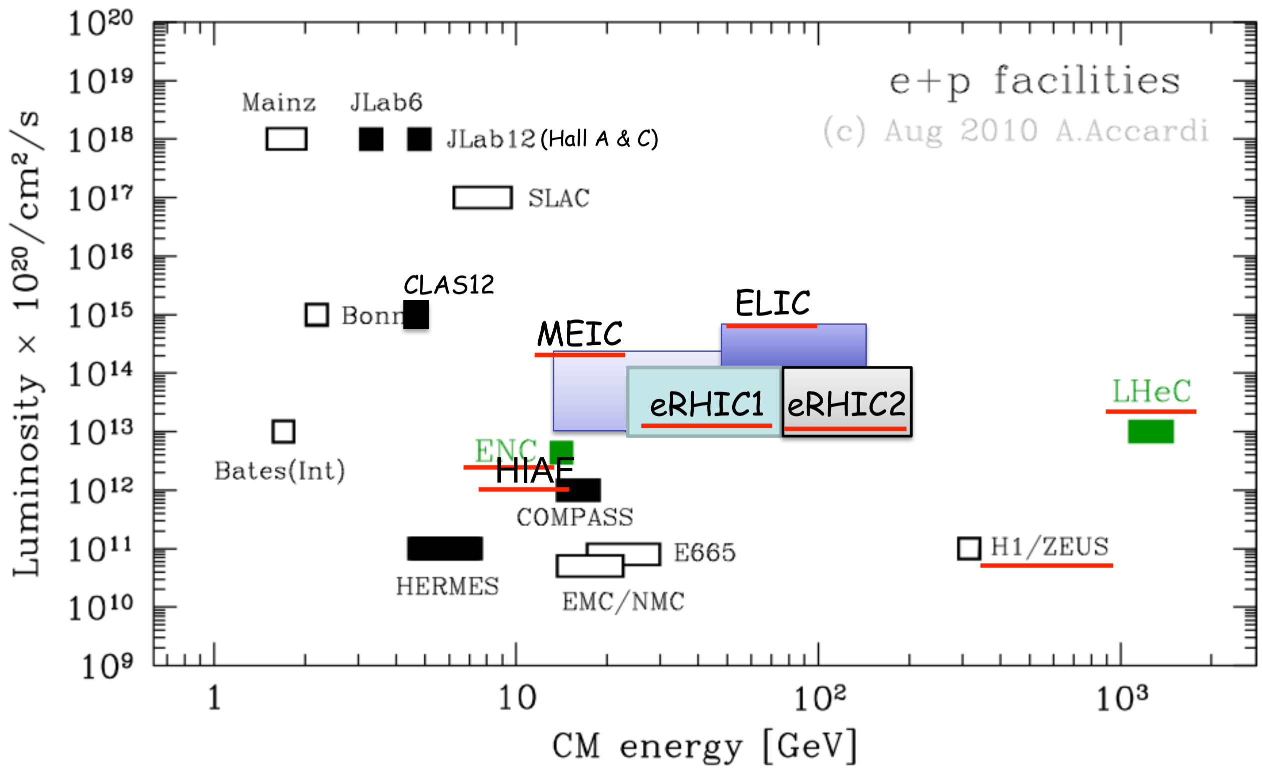
Overview of EIC projects



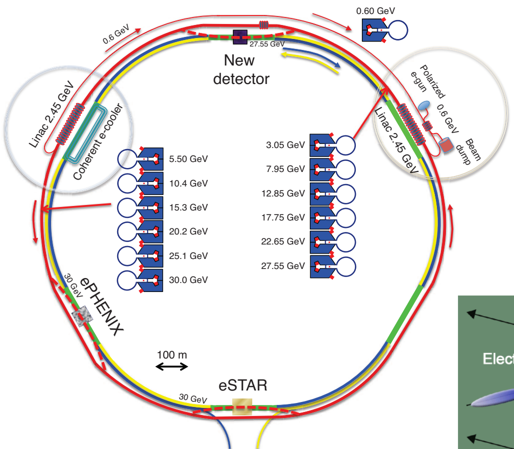
Overview of EIC projects

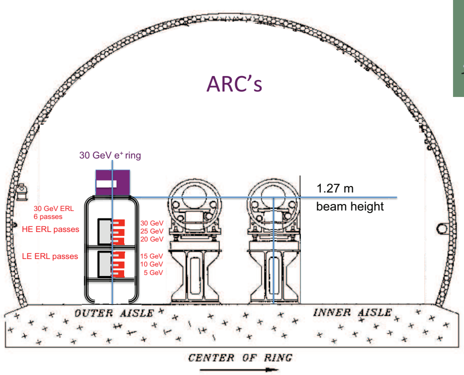
Lepton-Proton/Ion machines world-wide

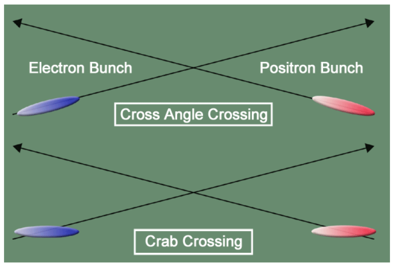
—— : **colliders**



eRHIC/BNL – MEIC-EIC/JLAB







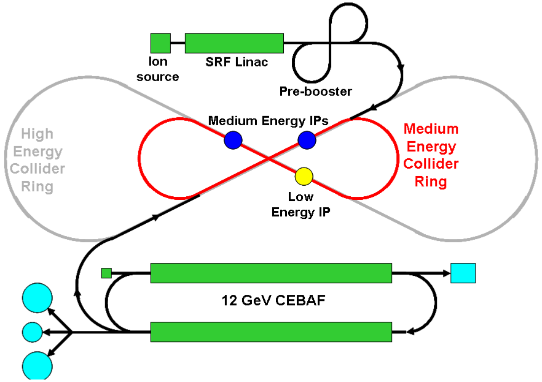


Figure 3.1: A schematic drawing of MEIC. The high energy ring is a future possibility.

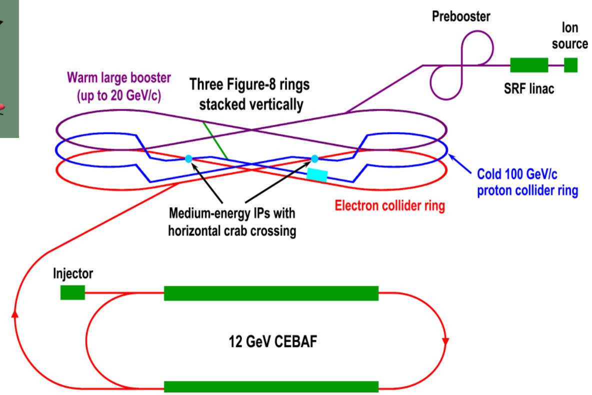
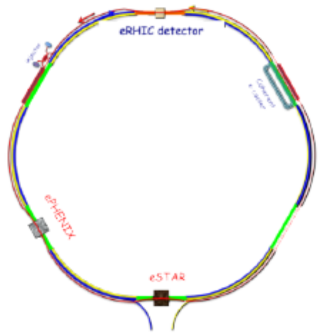


Figure 3.2: The MEIC electron and ion collider rings and the large ion booster rings are stacked vertically and housed in the same tunnel.

eRHIC and MEIC staging scenario

EIC – staging at BNL and JLab

eRHIC @ BNL



Stage I

$\sqrt{s}$ = **34 – 71** GeV

E_e = 3 – 5 (10 ?) GeV

E_p = 100 – 255 GeV

E_{Pb} = up to 100 GeV/A

Stage II

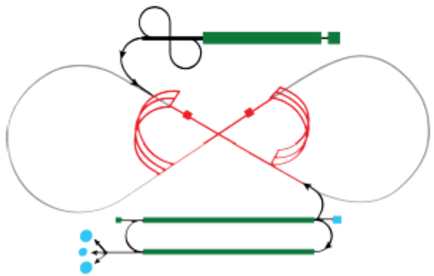
$\sqrt{s}$ = up to ~**180** GeV

E_e = up to ~30 GeV

E_p = up to 275 GeV

E_{Pb} = up to 110 GeV/A

MEIC / EIC @ JLab



$\sqrt{s}$ = **13 – 70** GeV

E_e = 3 – 12 GeV

E_p = 15 – 100 GeV

E_{Pb} = up to 40 GeV/A

(MEIC)

$\sqrt{s}$ = up to ~**140** GeV

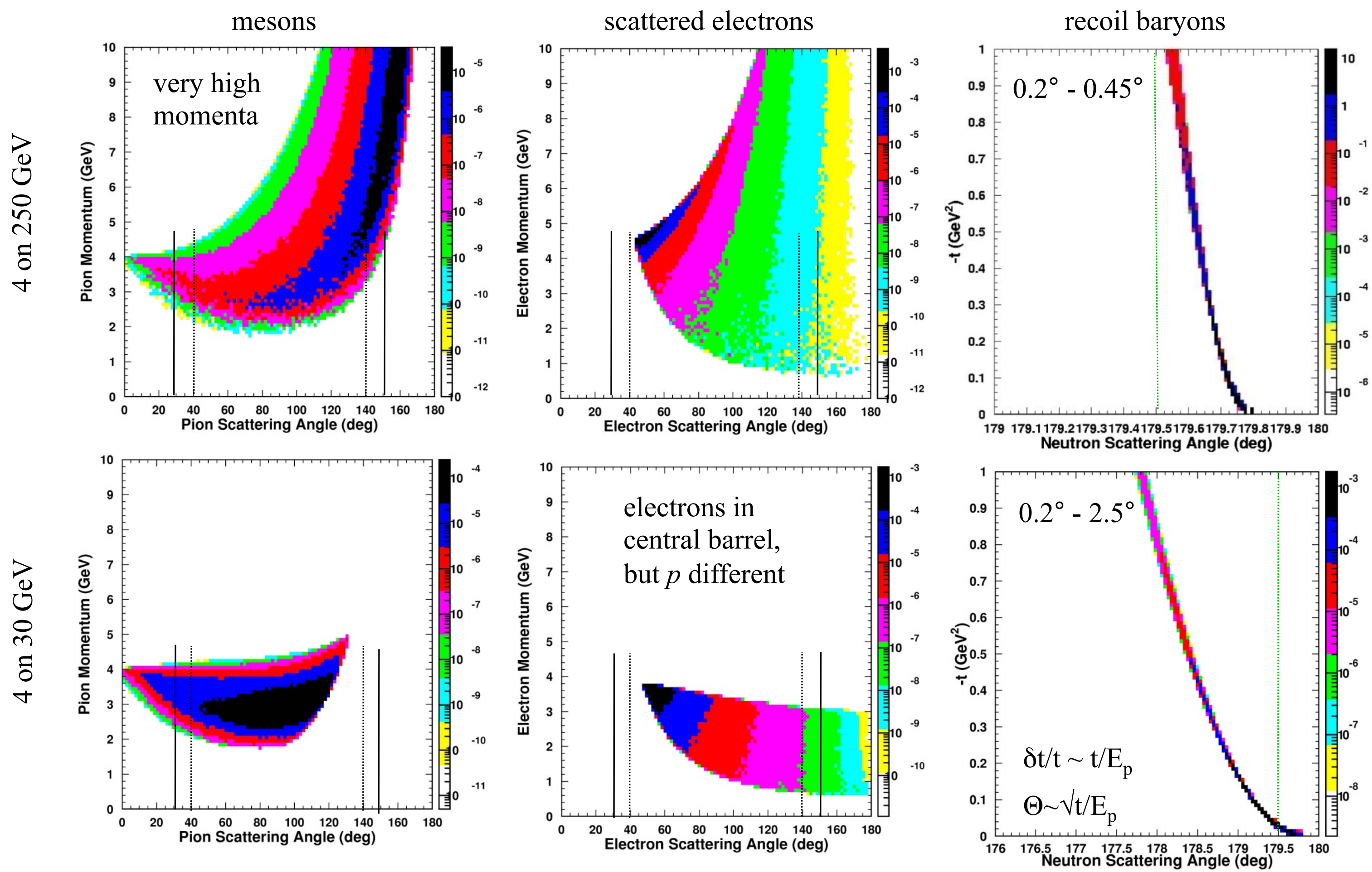
E_e = up to 20 GeV

E_p = up to at least 250 GeV

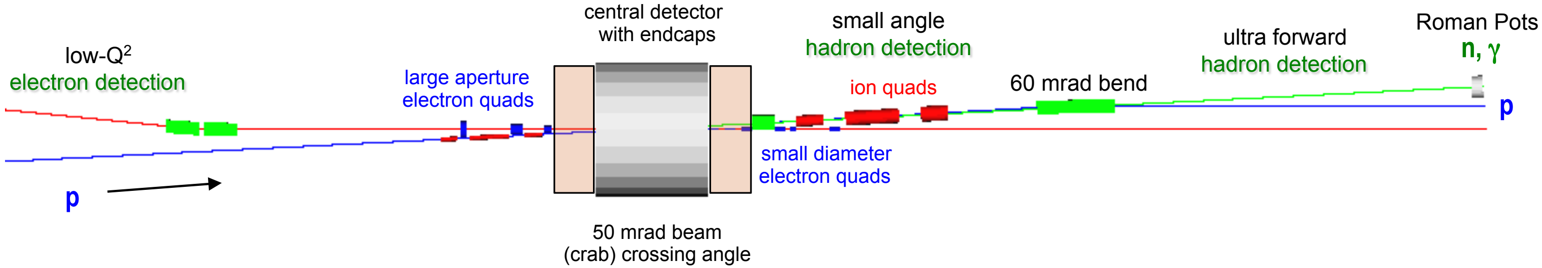
E_{Pb} = up to at least 100 GeV/A

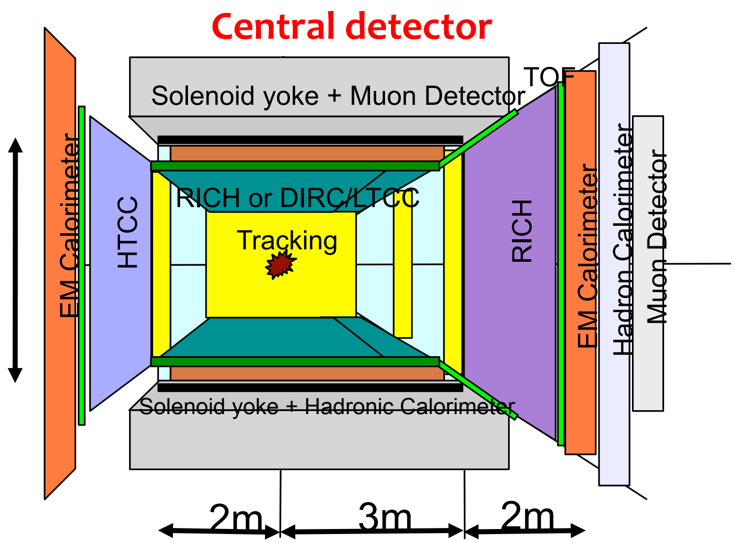
(EIC)

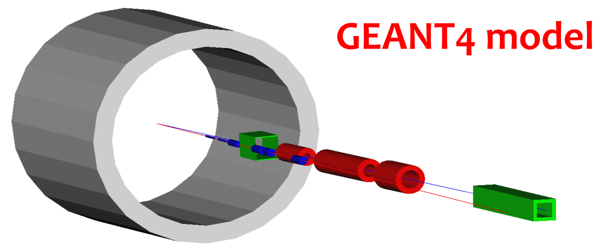
ep→e’πn (or γp) kinematics



MEIC/EIC at JLAB – detector design







- Detect particles with angles down to 0.5°. **Need 1-2 Tm dipole**.
- Detect particles with angles below 0.5°.
- Very-forward detector, Large dipole bend @ 20 meter from IP allows for **very-small angle detection (<0.3°)**

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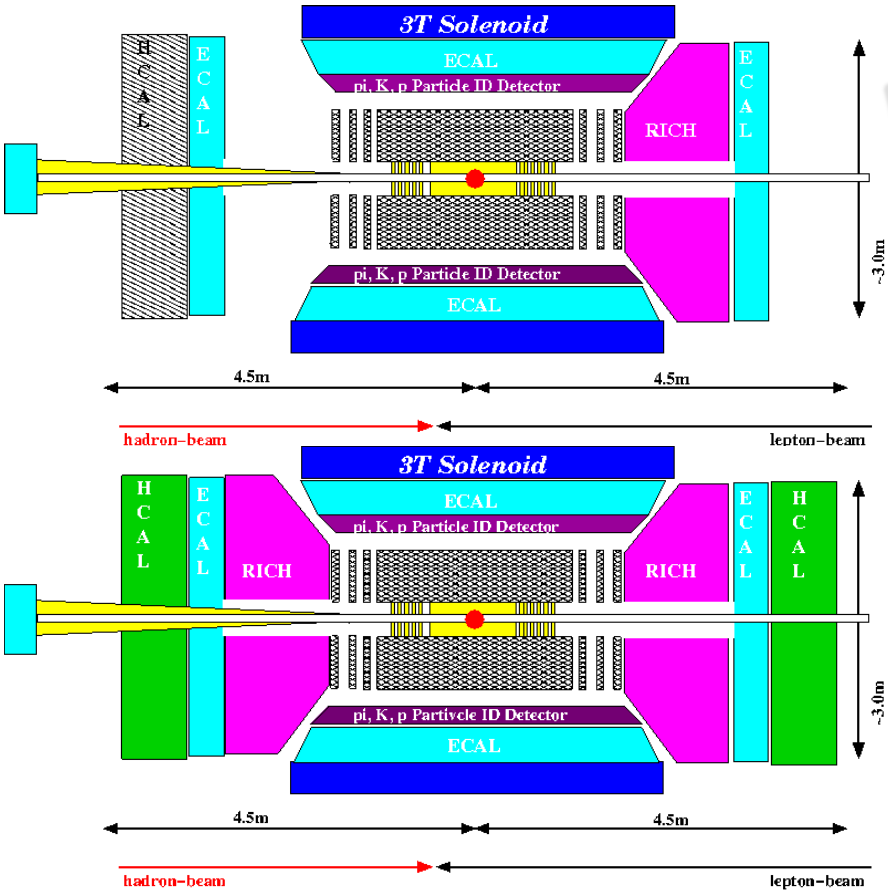
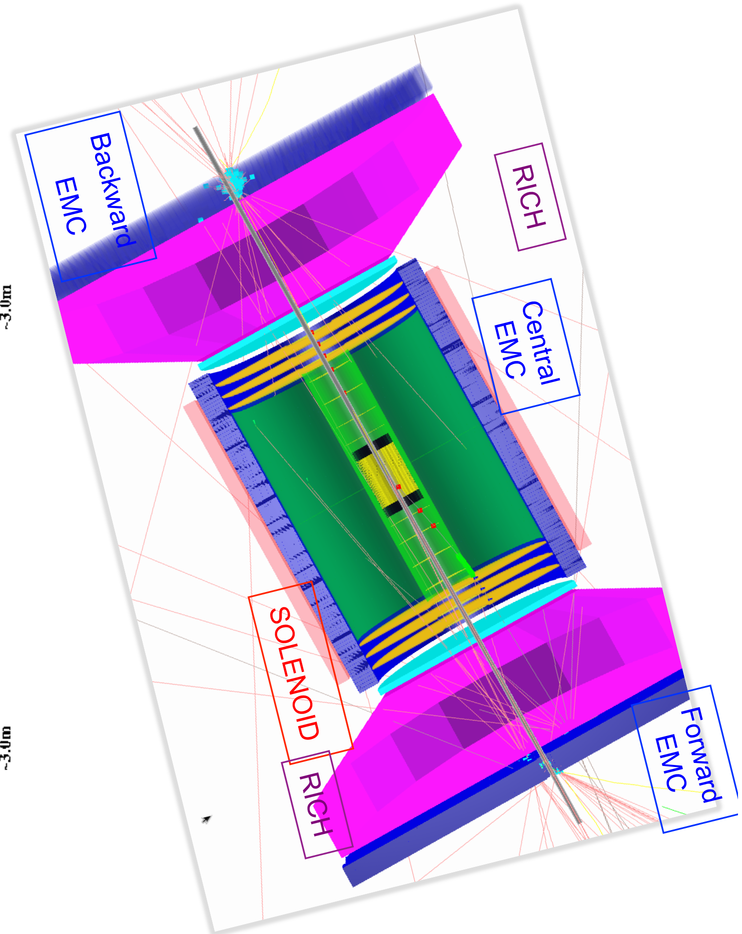
eRHIC at BNL – detector design



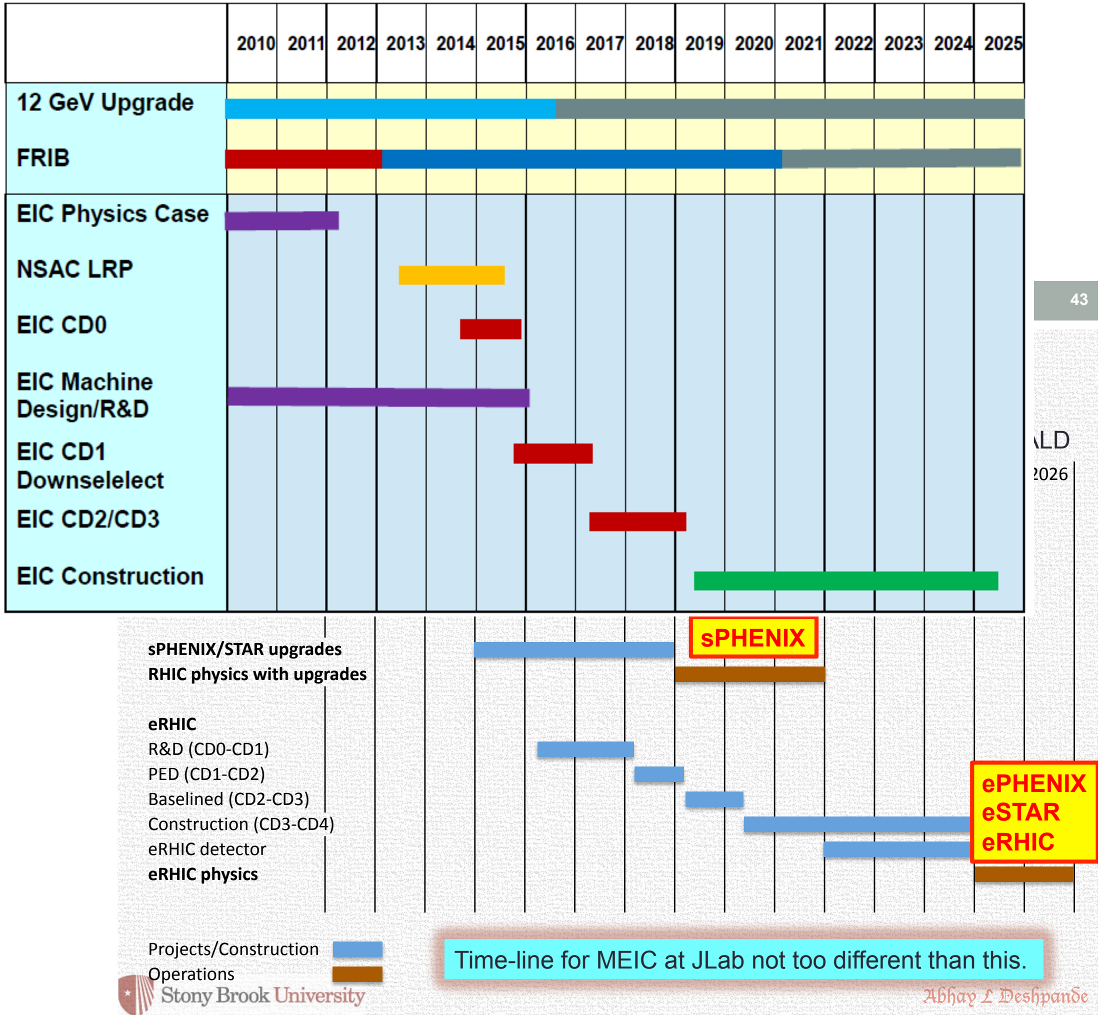


R&D projects on detectors

T. Ludlam

Prop. No.	Title	Contact	Institutions	
RD 2011-1; RD 2012-14	Tungsten fiber calorimeters	H. Huang/ C. Woody	UCLA, TAMU, Penn St., BNL, USTC	Compact Calorimetry
RD 2011-3; RD 2012-7	DIRC -based PID	P. Nadel-Turonski	Catholic Univ. of America, Old Dominion Univ., Univ. of South Carolina, JLab, GSI Darmstadt	Particle ID; Simulation; Hermiticity
RD 2011-5	Radiation resistant Si PM	C. Zorn	JLab	Hi density photon detector
RD 2011-6; RD 2012-9; RD 2012-16	Tracking/PID/Simulation	K. Dehmelt/ T. Hemmick	BNL, BNL/RBRC, Florida Inst. of Technology, Iowar State, LBNL, MIT, Stony Brook Univ., Temple Univ., Univ. Virginia, Yale Univ., JLab	Simulation; Tracking; Particle ID; Hermiticity
RD 2012-3	Tracking: GEM & Micromegas	B. Surrow, F. Sabatie	CEA Saclay, MIT, Temple Univ.	Compact tracking; Hermiticity
RD 2012-5	Physics simulations	T. Ullrich	BNL	Simulation tools
RD 2012-11	Spin-light polarimeter	D. Dutta	Mississippi State Univ., Coll. Of William & Mary, Stony Brook Univ., Gutenberg Univ. (Mainz), UV Charlottesville, ANL, JLab	Novel technique for e-beam polarimetry
RD 2012-12	Forward RICH detector	V. Kubarovsky	JLab, INFN Frascati, INFN Ferrara, Christopher Newport Coll., UTFSM (Valparaiso, Chile)	Compact RICH with Si PM
RD 2012-13	Forward EM pre-shower	W. Brooks	UTFSM (Valparaiso, Chile)	LYSO crystal-based design
RD 2012-15	Gem based TRD	Z. Xu, M. Shao	ANL, BNL, Indiana Univ., USTC (China), VECC (India)	e-tagging with GEM TRD
RD-2013-1	Magnetic cloak	A. Deshpande, N. Feege	Stony Brook, BNL, RIKEN	Magnetic Cloak for shielding beams
RD-2013-2	Dead area free silicon sensors	E. Kistenev, Z. Li	BNL	Dead area free sensors, radiation hardness

Possible timelines



Conclusion

- *Few EIC projects worldwide on the 2020-2025 horizon*
  - ➢ on the high energy, « high » luminosity side, 2 « concurrent » projects in US: eRHIC at BNL, MEIC/EIC at JLAB, with staged scenarios.

    Integral part of NSAC long range plan:

We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron Ion Collider. The EIC would explore the QCD frontier of strong color fields in nuclei and precisely image the gluons in the proton.

- *EIC very attractive to improve 1D and 3D imaging of nucleon (polarized DIS, GPD, TMD,…)*
  - ➢ thanks to increase of (x,Q^2) coverage due to higher E_{CM} (eg ΔG via DGLAP)
    thanks to improved FOM for asymetry measurements $(L.P^2.D^2)$
    but needs very good control of systematics to profit from above gain

- *Broad science case well documented in 2012 White Paper (1212.1701)*
- *Machine and detector designs advancing fast, as well as R&D*