EINN 2009

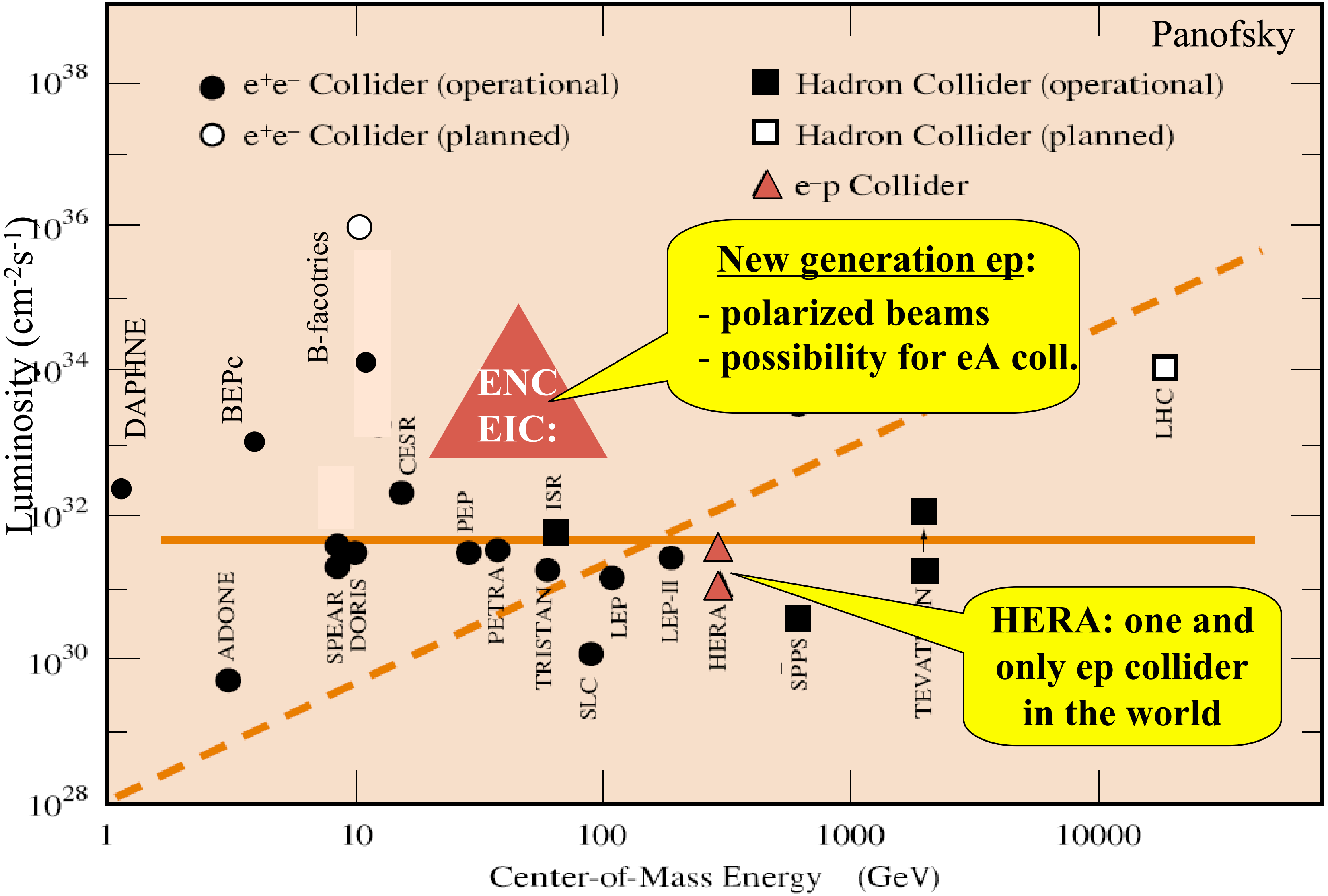
Electromagnetic Interactions with Nucleons and Nuclei

Workshop Summary: Electron Ion Collider

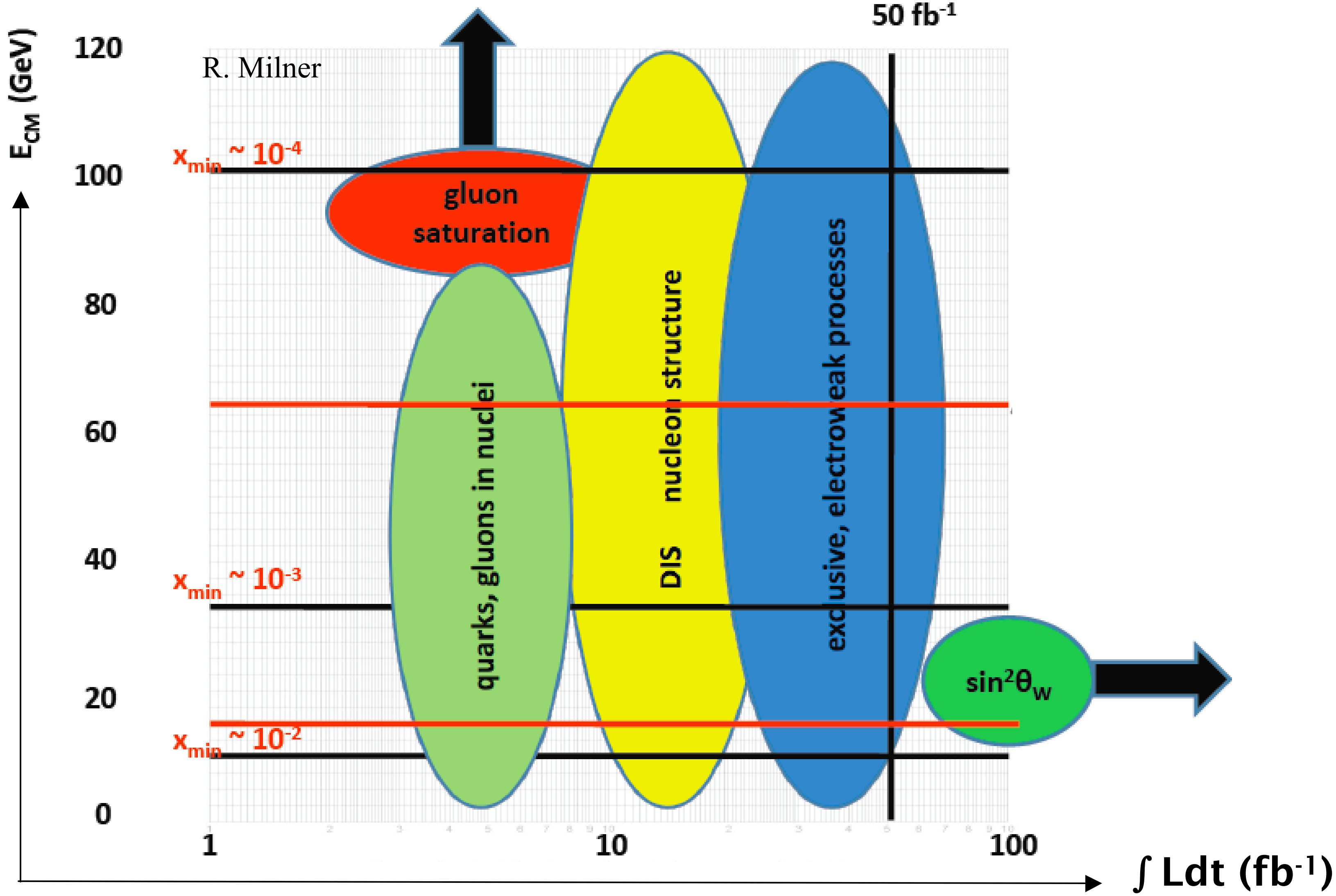
Conveners:
Achim Denig (Mainz)
Abhay Deshpande (Stony Brook)

Milos Island, Greece
September 27 - October 3, 2009

Electron Nucleon (Ion) Collider



Why Electron Nucleon (Ion) Collider ?



Open Questions
in Theory and Experiment

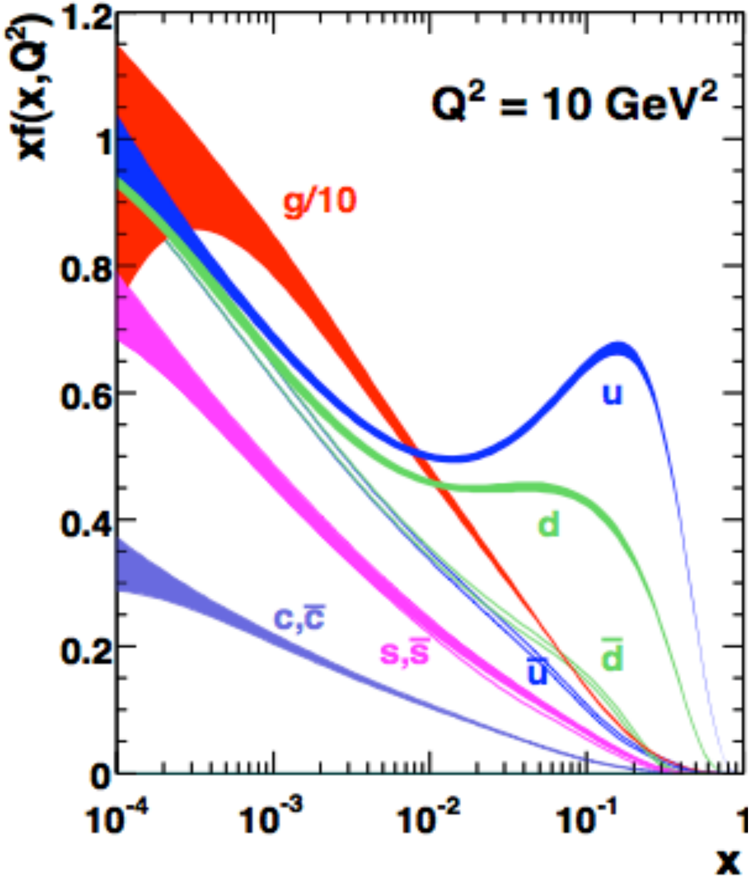
Daniel de Florian (Theory)
Dietrich von Harrach (Expt.)

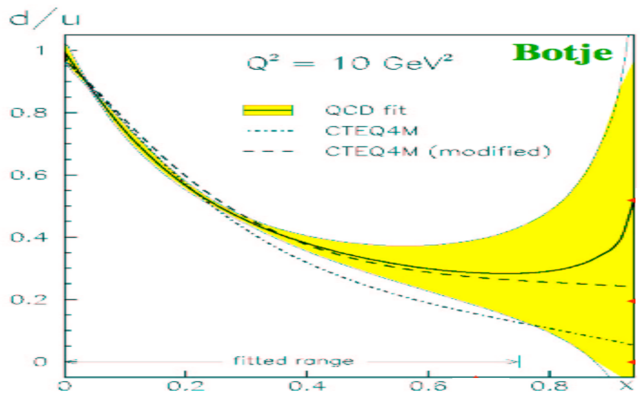
Daniel de Florian

Open Questions - Theory

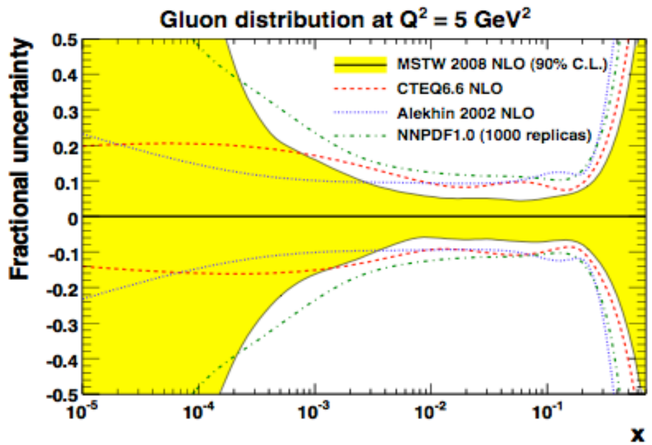
✓ **Unpolarized PDFs : OK for LHC, some kinematical regions uncovered**

QCD in the precision era : pdfs





large x : large uncertainties



small x : Saturation?

Burkard Reisert: HERA Physics

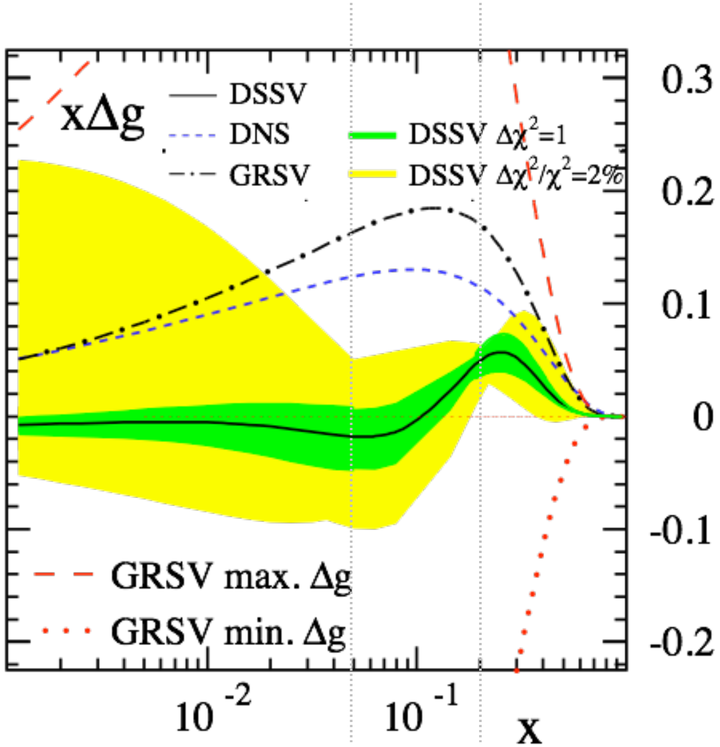
Daniel de Florian

Open Questions - Theory

✓ **Polarization : where is the spin of the proton?**

Gluonic contribution requires small x : only possible at high energy ep collider

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



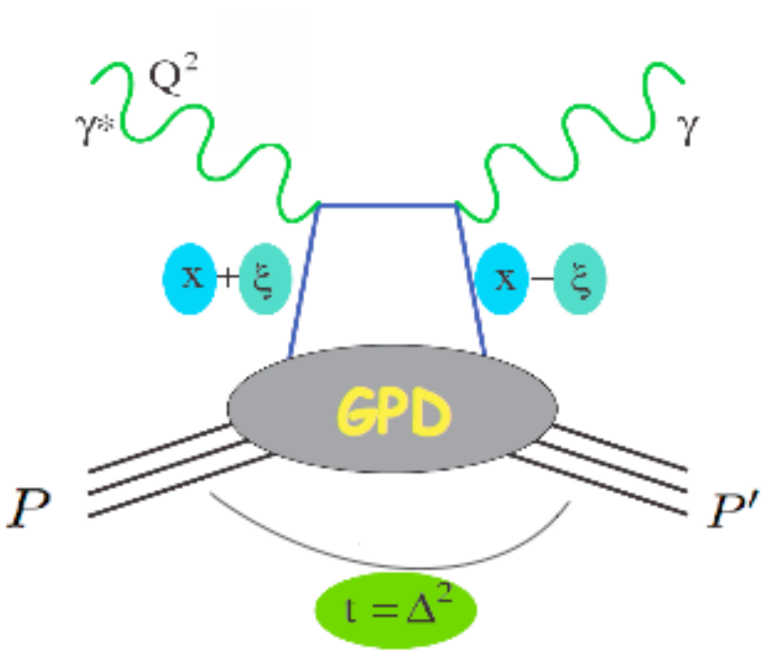
Without polarized ep collider : spin 'crisis' has NO solution

Daniel de Florian

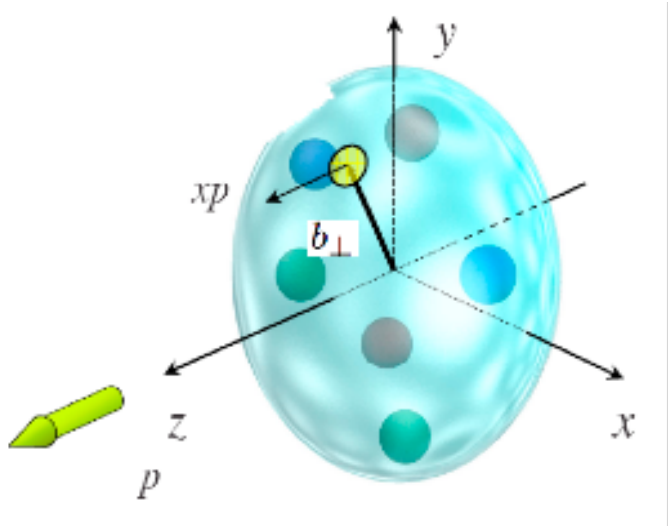
Open Questions - Theory

✓ **Generalized Parton Distributions : Powerful description of nucleon structure**

Tomographic images of nucleon
Orbital Angular Momentum ?



transverse profile of the nucleon



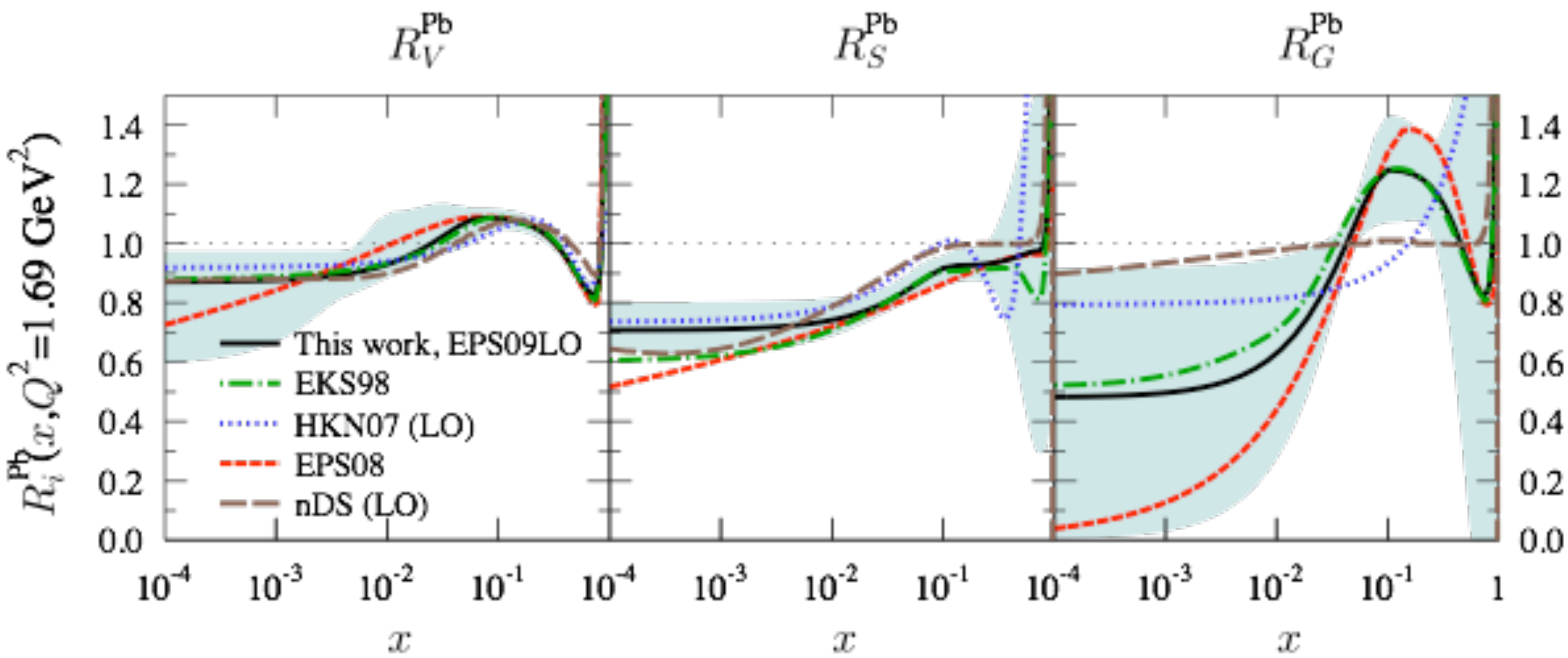
EINN09: Compass, JLAB, Hermes: limited by statistics

Daniel de Florian

Open Questions - Theory

✓ **eA collisions : nuclear modified pdfs**

large uncertainties at present
complementary measurements with pA/AA



Background for QGP physics

Dietrich von Harrach

Open Questions - Experiment

Priority 1: The Exclusive Program

- Validation of the concept of GPDs and their extraction: scale dependence, factorisation properties
- Precision determination of the four GPDs and their flavour components

Guidal has made a list of processes and their relevance to extract H , $\tilde{H}$, E, $\tilde{E}$:

DVCS

of longitudinally **polarized electrons and positrons** on longitudinally or transversely **polarized deuteron and protons**

Priority 2: The Transversity an $k_\perp$ Program

- study of azimuthal hadron distributions with transversly polarized protons and deuterons
- First evidence of Collins and Sivers asymmetries on proton and deuterium from HERMES and COMPASS
- high statistics multidimensional analysis $(x, Q^2, p_\perp, z, ..)$ needed, leading to subleading correlations ...

Dietrich von Harrach

Open Questions - Experiment

Priority 1: The Exclusive Program

- Validation of the concept of GPDs and their extraction: scale dependence, factori... n properties

- Precision determination of the four GPDs ...

Guidal has made ...

- CEBAF 6 /12 GeV and COMPASS are the only places to do experiments now
  - beam and target polarisation, high effective luminosity $\mathcal{L}^{eff} = \mathcal{L} \cdot f^2 \cdot P_e^2 \cdot P_t^2$ is for parton distributions and GPDs $s \gtrsim 50 - 100\,GeV$ might be sufficient
  - a new fixed target option at 25-50 GeV or a collider would be equally welcome at $\mathcal{L}^{eff} \gtrsim 10^{32} cm^{-2} s^{-1}$

... transversly polarized protons and deuterons

... of Collins and Sivers asymmetries on proton and deuterium from HERMES and COMPASS

- high statistics multidimensional analysis $(x, Q^2, p_\perp, z, ..)$ needed, leading to subleading correlations ...

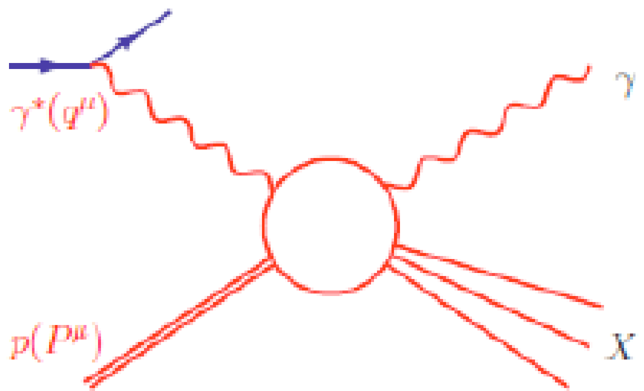
Hubert Spiessberger

Status of Radiative Corrections

- High precision needs careful treatment of radiative corrections
- Closely related to experimental conditions
- Interesting physics: DVCS, TPE, electroweak effects

More dedicated efforts needed to include:

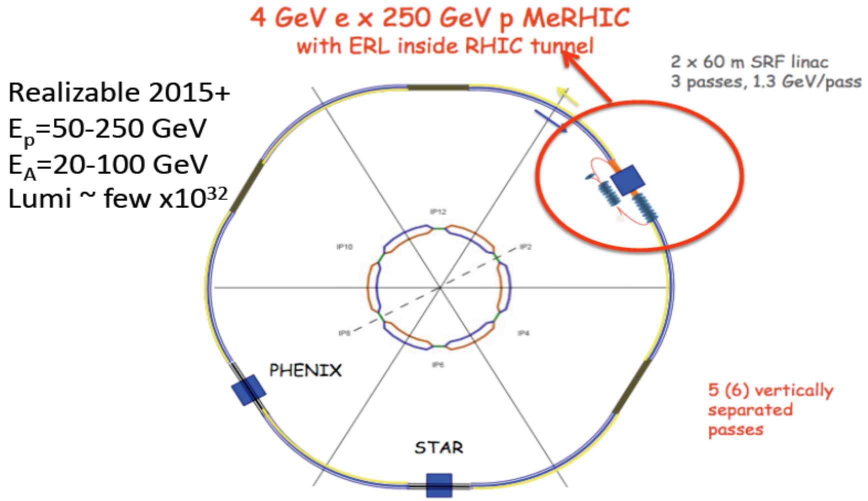
- IR/soft photon exponentiation
- multi-photon emission
  radiator functions at $O(\alpha^2)$
- 2-photon exchange
- radiation from quarks:

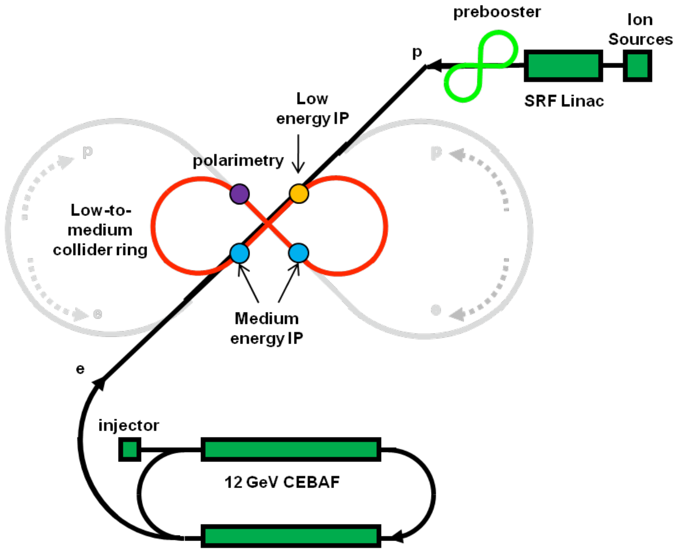


DVCS (+ other processes in hadron physics):
radiation is part of the physics process
and not treated as perturbation to it!

Machine Concepts:
- EIC (BNL & JLAB) Vladimir Litvinenko
- ENC Andreas Lehrach

Overview EIC (BNL&JLAB)





EIC@BNL
Linac-Ring

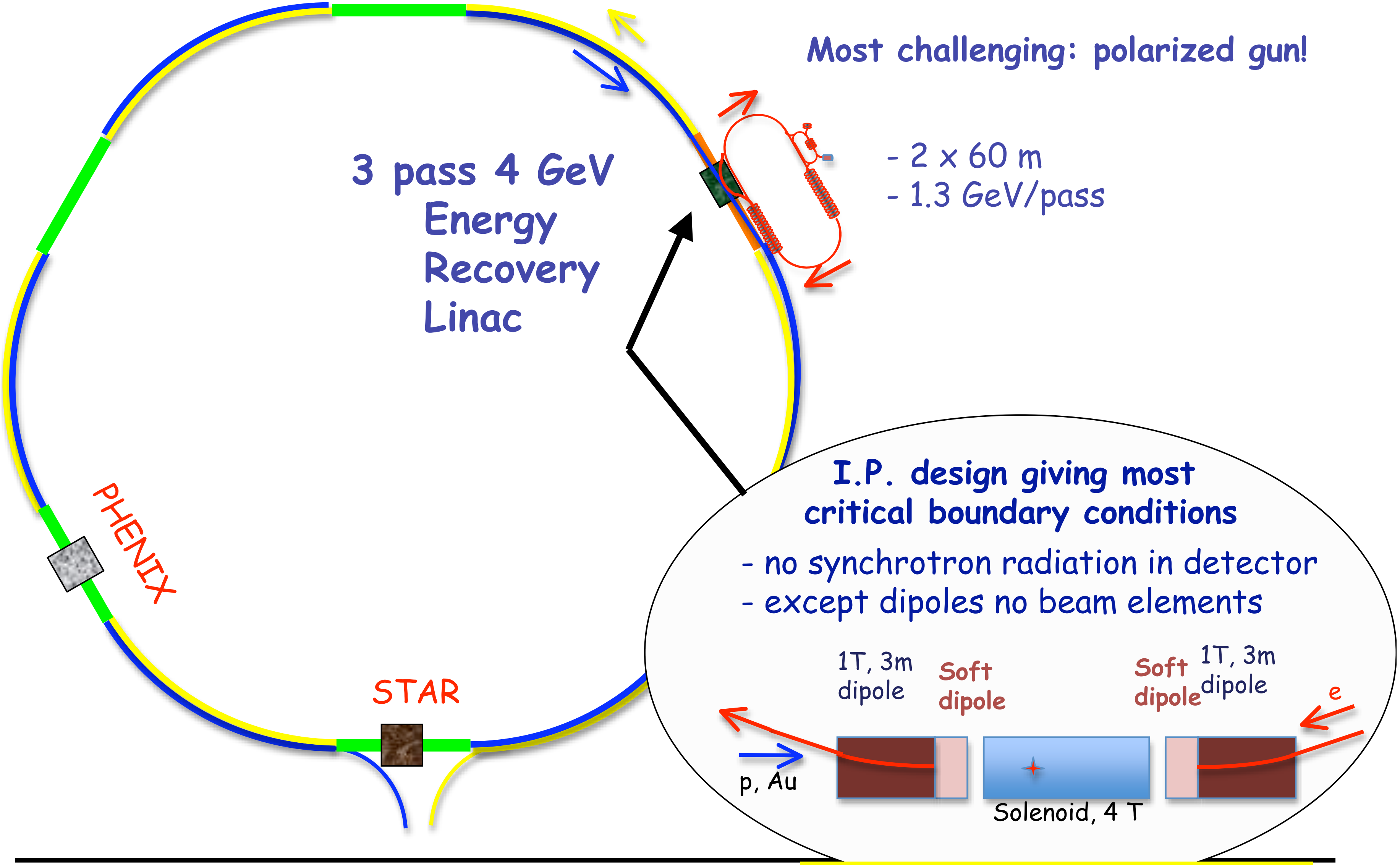
- RHIC can be re-used
- Energy Recovery Linac for e^- ring (50 mA)
- 10^{32} ... 10^{33} $cm^{-2}s^{-1}$ luminosities
- staged approach

EIC@JLAB
Ring-Ring

- 3 figure 8 - shaped rings
- 12 GeV CEBAF can be re-used
- 10^{34} ... 10^{35} $cm^{-2}s^{-1}$ luminosities
- Crab cavities and further challenging machine concepts
- staged approach

Vladimir Litvinenko

EIC@BNL (MeRHIC - 4 x 250 GeV)



HERA I.P. Uwe Schneekloth

Vladimir Litvinenko

eRHIC Parameters

Coherent Electron Cooling

	MeRHIC		eRHIC with CeC	
	p (A)	e	p (A)	e
Energy, GeV	250 (100)	4	325 (125)	20 <30>
Number of bunches	111		166	
Bunch intensity (u) , 10^{11}	2.0	0.31	2.0 (3)	0.24
Bunch charge, nC	32	5	32	4
Beam current, mA	320	50	420	50 <10>
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.2	25
Polarization, %	70	80	70	80
rms bunch length, cm	20	0.2	4.9	0.2
β*, cm	50	50	25 (5)	25 (5)
Luminosity, x 10^{33}, $cm^{-2}s^{-1}$	0.1 -> 1		2.8 (14)	

111 bunches

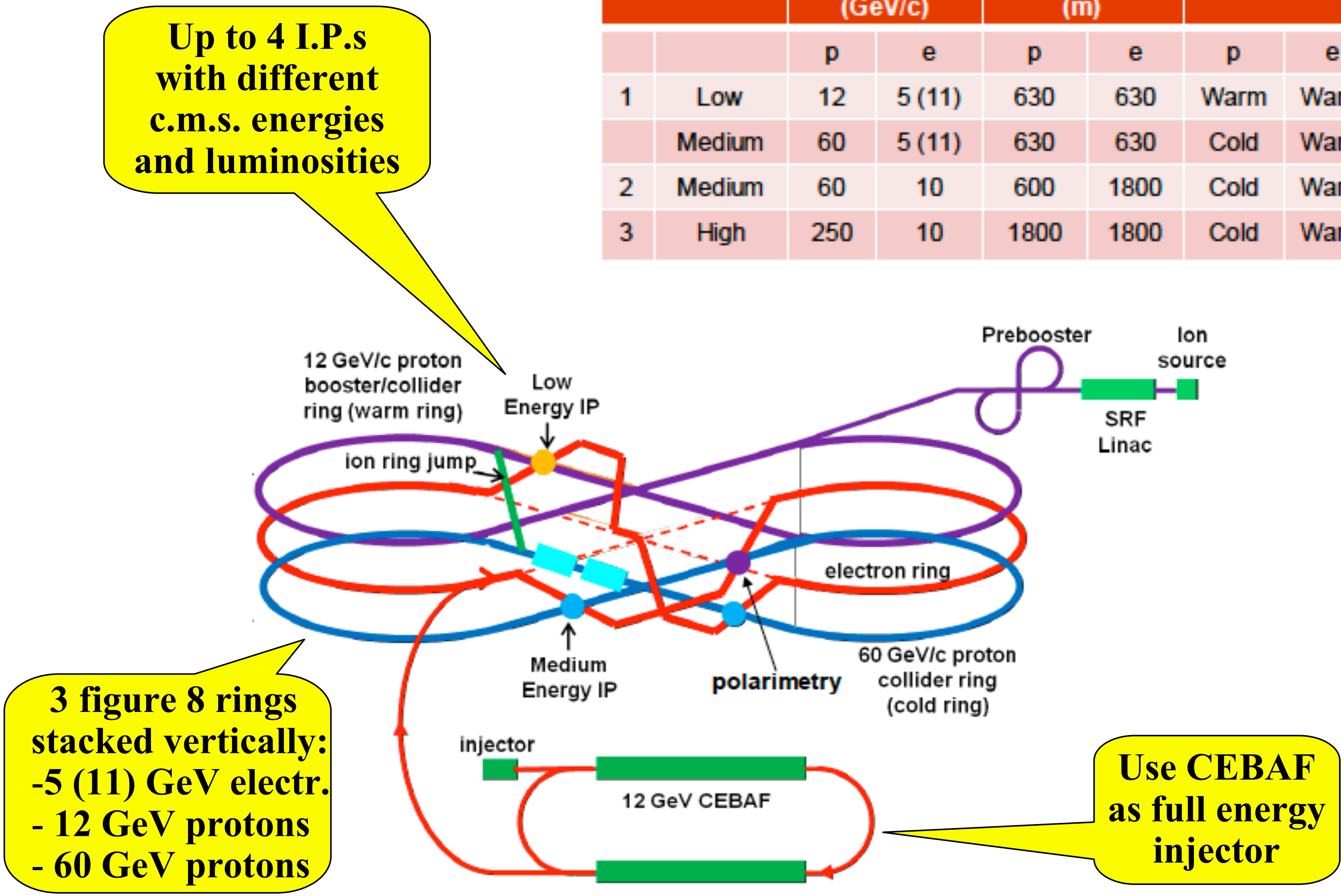
High degrees of polarization

β* for given I.P. main limit. for luminosity!

Vladimir Litvinenko

EIC@JLAB (ELIC)

Stage		Max. Energy (GeV/c)		Ring Size (m)		Ring Type		IP #
		p	e	p	e	p	e	
1	Low	12	5 (11)	630	630	Warm	Warm	1
	Medium	60	5 (11)	630	630	Cold	Warm	2
2	Medium	60	10	600	1800	Cold	Warm	4
3	High	250	10	1800	1800	Cold	Warm	4



Vladimir Litvinenko

ELIC Parameters

High collission frequency

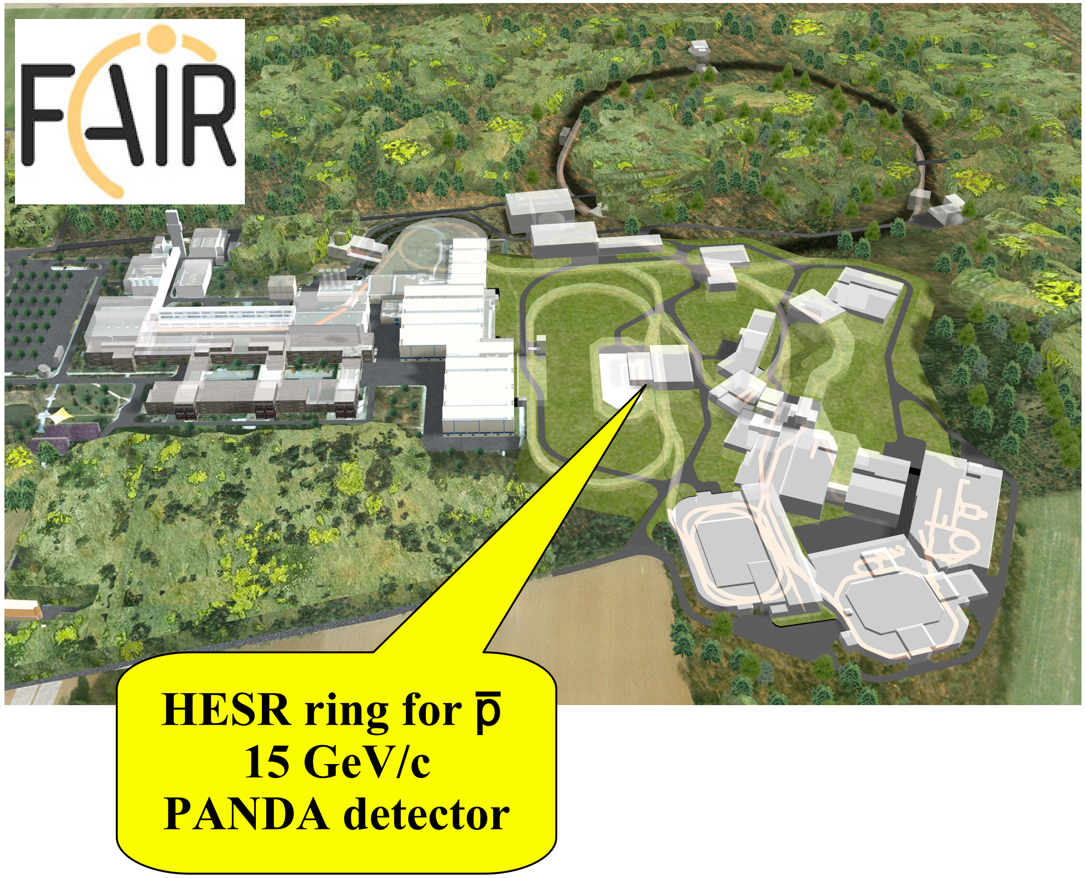
Beam Energy	GeV	12/3	60/5	60/3	250/10
Collision freq.	MHz		499		
Particles/bunch	10^{10}	0.47/2.3	0.74/2.9	1.1/6	1.1/3.1
Beam current	A	0.37/2.7	0.59/2.3	0.86/4.8	0.9/2.5
Energy spread	10^{-4}		~ 3		
RMS bunch length	mm	50	5	5	5
Horz. emit., norm.	µm	0.18/80	0.56/85	0.8/75	0.7/51
Vert. emit. Norm.	µm	0.18/80	0.11/17	0.8/75	0.03/2
Horizontal β^*	mm	5	25	25	125
Vertical β^*	mm		5		
Vert. b-b tuneshift/IP		15/.013	0.01/0.03	.015/.08	0.01/0.1
Laslett tune shift	p-beam	0.1	0.1	0.054	0.1
Peak Luminosity/IP, 10^{34}	$cm^{-2}s^{-1}$	0.59	1.9	4.0	11
		w energy	MEIC		High energy

Very high luminosities

was 500 mm in MeRHIC

Andreas Lehrach

A “simple” idea: ENC@FAIR



Idea emerged 08/2008
use HESR as p ring
add e ring

L > 10^{32} cm^{-2}s^{-1}

$s^{1/2}$ > 10GeV
(3.3GeV/c e^- ↔ 15GeV/c p)

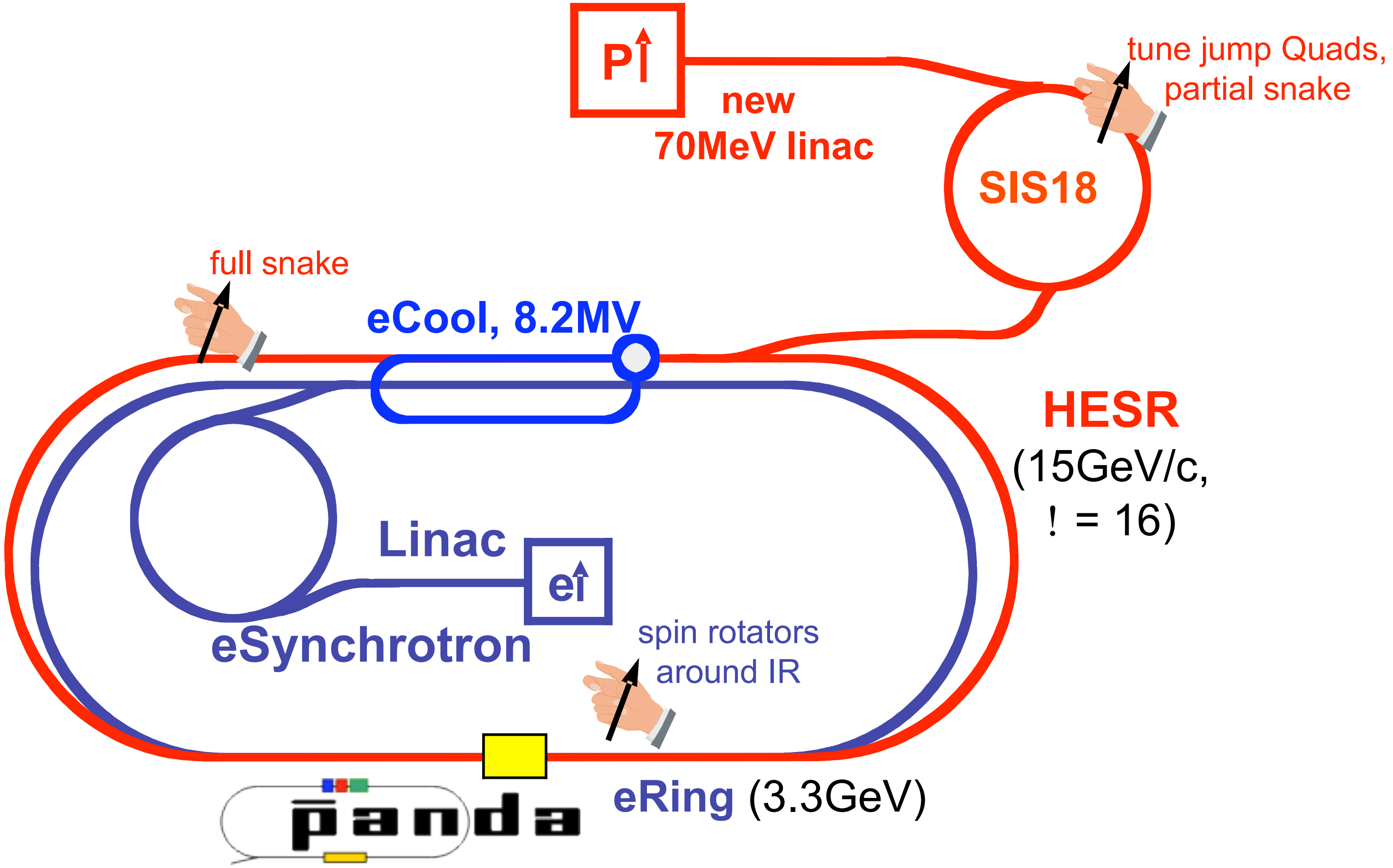
polarized e^- (> 80%)
↔
polarized p / d (> 80%)
(transversal + longitudinal)

using the PANDA detector and HESR as much as possible

doubly polarized
Electron Nucleon Collider
Luminosity: ~10 × HERA (unpol.)

Andreas Lehrach

Preliminary Scheme for ENC



Scheme of the ENC@FAIR for electron-proton collisions

Andreas Lehrach

ENC@FAIR Parameters

- Protons (baseline) : $L = 2 \cdot 10^{32}\ cm^{-2}s^{-1}$

  β_{IP} [m] = 0.3 m, $\Delta Q_{sc} \geq 0.05$, $E_{ecooler} = 8.2$ MeV, $I_{ecooler} = 3$ A

  Upgrade of the planned electron cooler needed

- Deuterons (baseline): $L = 1.8 \cdot 10^{32}\ cm^{-2}s^{-1}$

  β_{IP} [m] = 0.1 m, $\Delta Q_{sc} \geq 0.1$, $E_{ecooler} = 4.1$ MeV, $I_{ecooler} = <1$ A

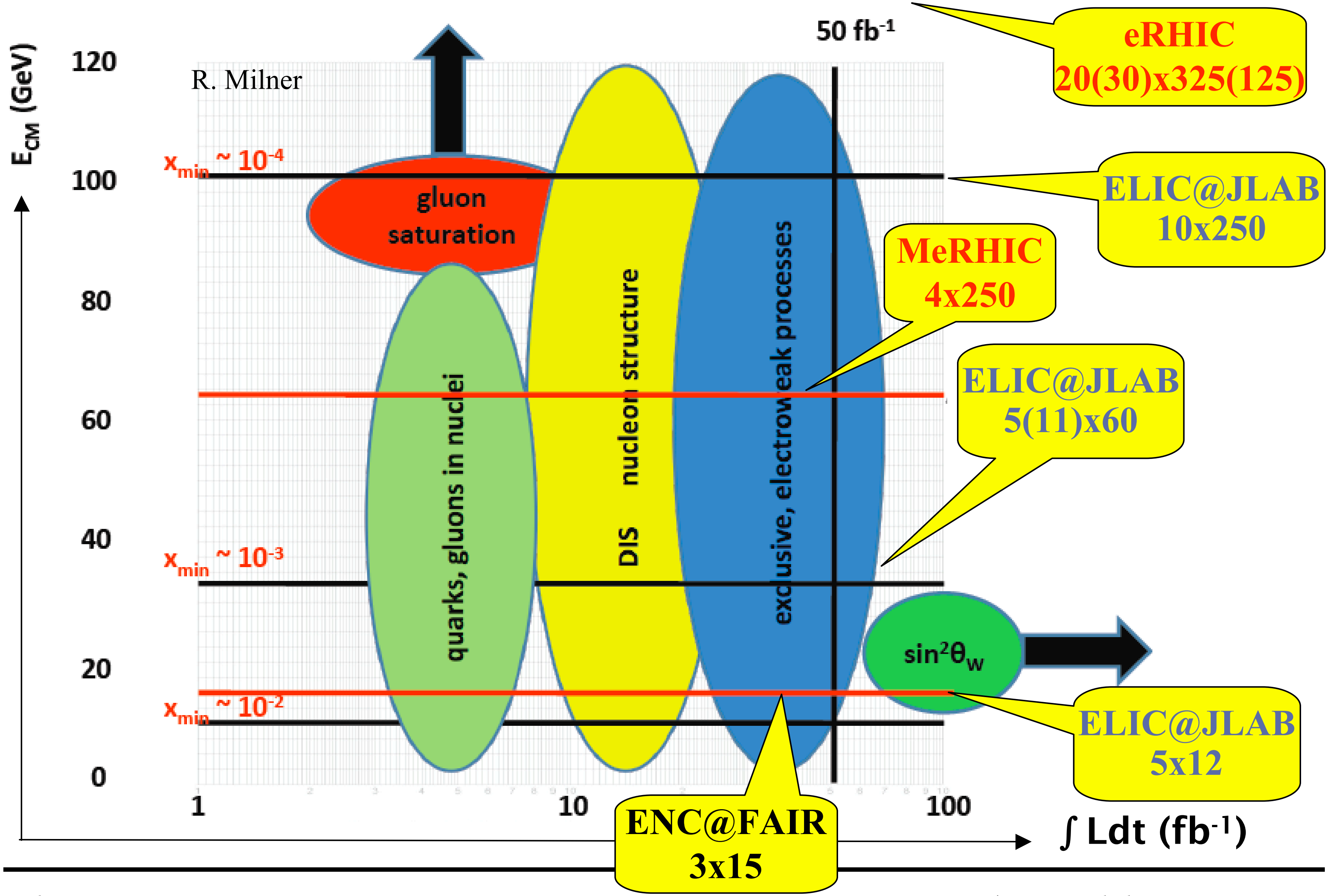
  Modifications of the IP concept required

- Protons (advanced): $L = 6 \cdot 10^{32}\ cm^{-2}s^{-1}$

  200 bunches

  β_{IP} [m] = 0.1 m, $\Delta Q_{sc} \geq 0.1$, $E_{ecooler} = 8.2$ MeV, $I_{ecooler} = 3$ A

Why Electron Nucleon (Ion) Collider ?



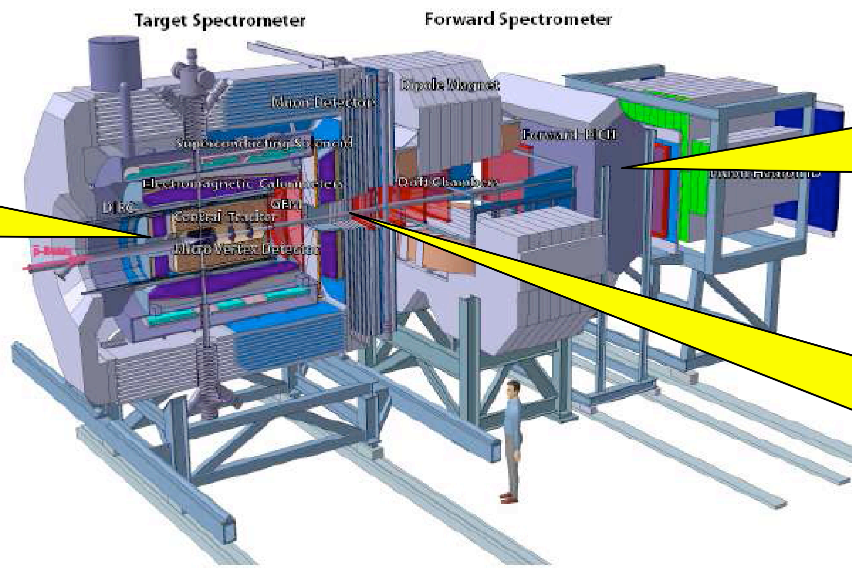
Feasibility Studies
ENC / EIC

Jörg Pretz (ENC)
Harut Avakian (ep - EIC)
Matt Lamont (eA - EIC)

Jörg Pretz

Physics at the ENC@FAIR

- Physics Channels
  - Gluon Helicity
    quark helicity, structure functions g_1, g_2
  - Generalized Parton Distributions: DVCS
  - Transversity & Transverse Momentum Distributions (TMD)
  - Factorization in hadronization process



Use as much as possible Target Spectr.

Modified Forward Spectr. use PANDA Dipole

I.R. design requires acceptance hole 5° - 20°

Jörg Pretz

Figure of Merits wrt. Fixed Target

Experiment	JLab(12 GeV)	HERMES	ENC	COMPASS
s/GeV^2	23	50	180	300
$\mathcal{L}/(1/\mathrm{cm}^2/\mathrm{s})$	$\approx 10^{38}$	$\approx 10^{32}$	$\approx 10^{32}$	$\approx 10^{32}$

$$\mathrm{FOM} = (\text{diluting factors})^2\,\mathcal{L}$$

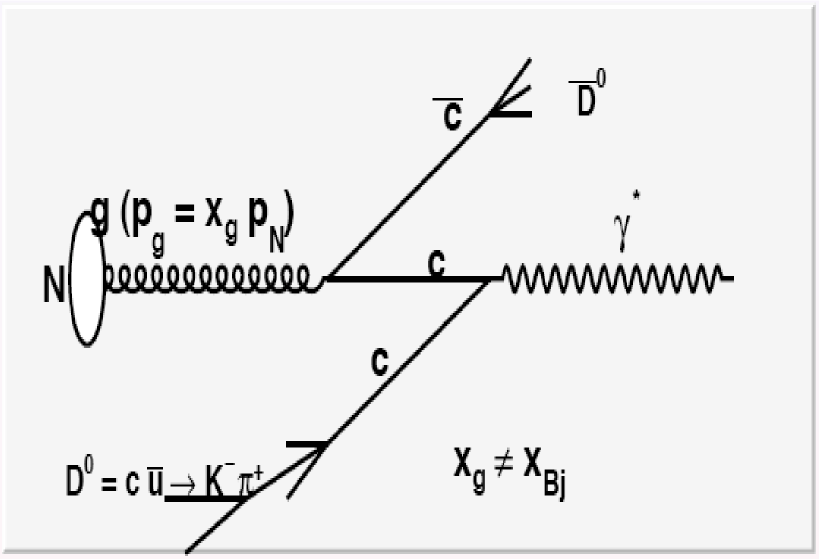
Beam polarization
Target polarization
Target dilution factor
Acceptance

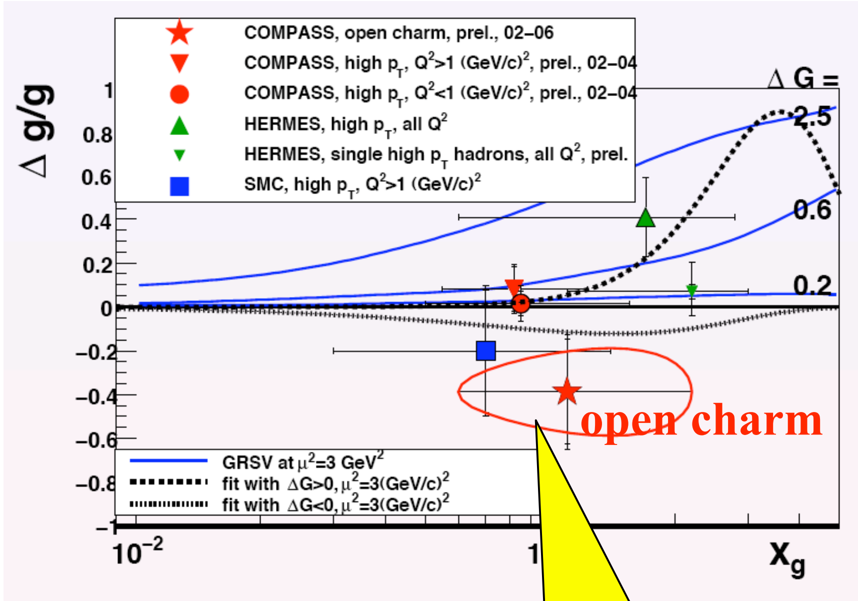
	diluting factor		
	COMPASS	ENC	
unpolarized	1	1	
single spin target $(P_T f)^2$	0.04	0.64	$16^{a)}$
double spin asymmetries $(P_T f P_B)^2$	0.026	0.41	$16^{a)}$
reconstruction of hadronic final state			
mass resolution	☹	☺	
displaced vertices	☹	☺	
target fragmentation	☹	☺	

FOM for collider factor 16 higher than fixed target!

Jörg Pretz

ΔG @ ENC





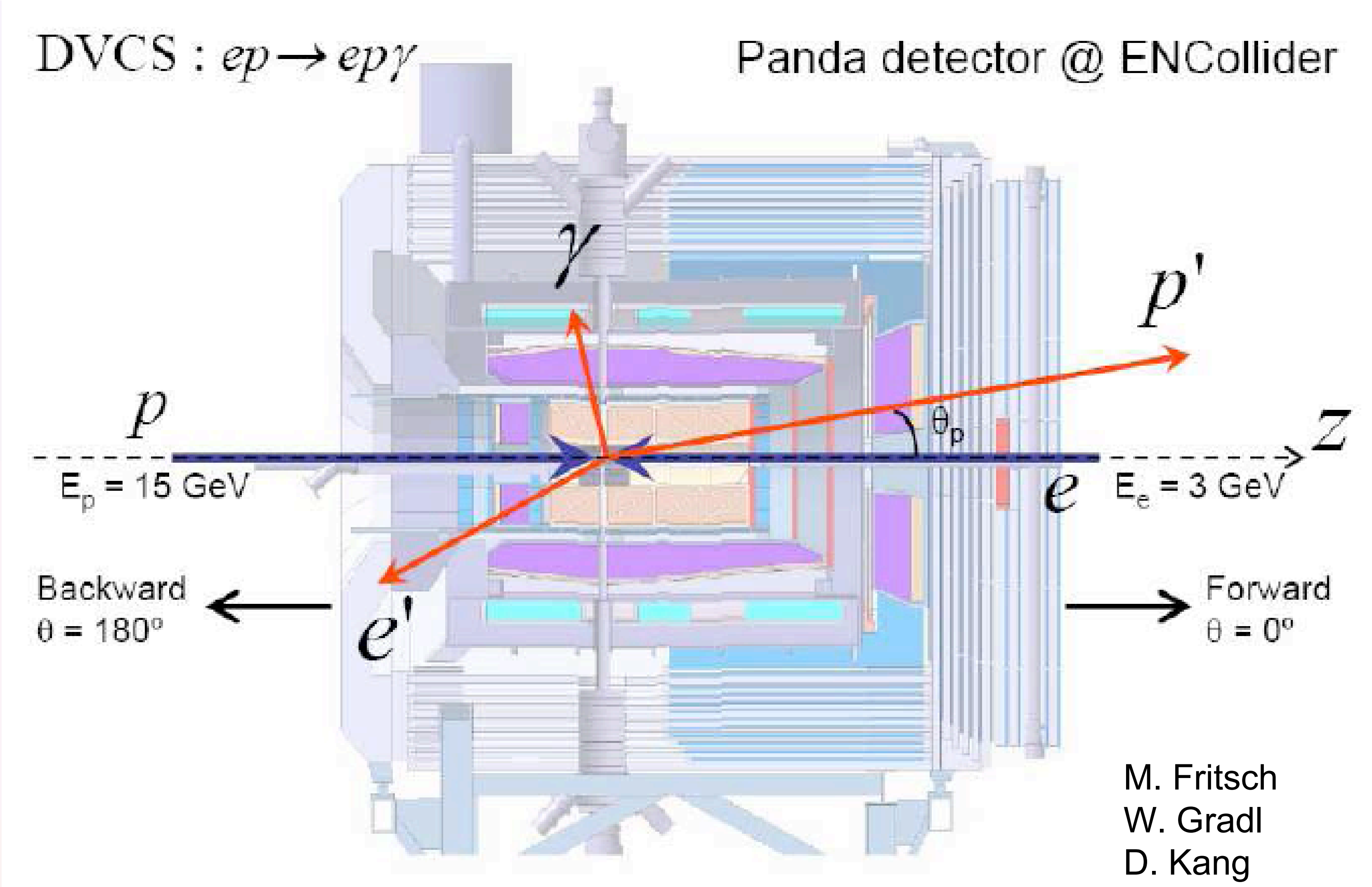
Two orders of magnitude improvement

Improvements wrt. COMPASS:

- FOM from polarization: factor 16
- Improved open charm reconstruction >factor 7
- low background
- reconstruction of x_g possibe (both D‘s reconstructed)

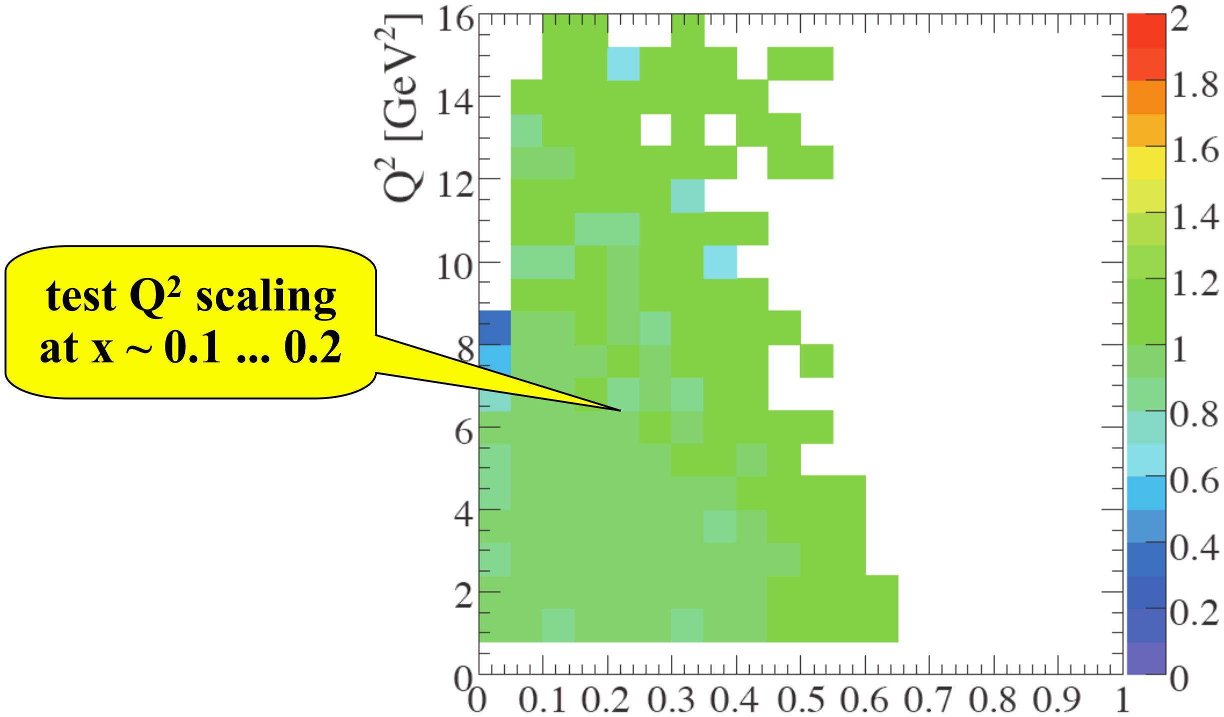
Jörg Pretz

DVCS @ ENC



Jörg Pretz

DVCS @ ENC: Efficiency Studies

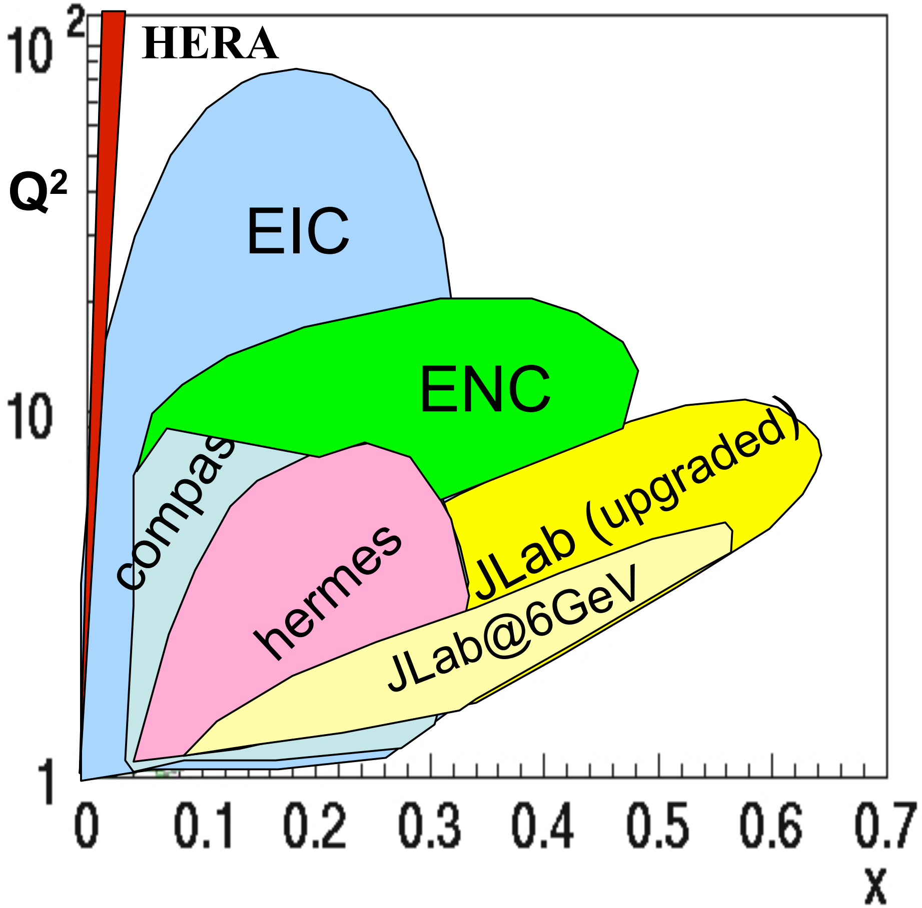


W. Gradl @ ENC/EIC Workshop, May 09 , GSI

- already with present PANDA setup good acceptance
- further studies needed (ensure exclusivity, ...) background

Electro Production Kinematics

Harut Avakian for EIC



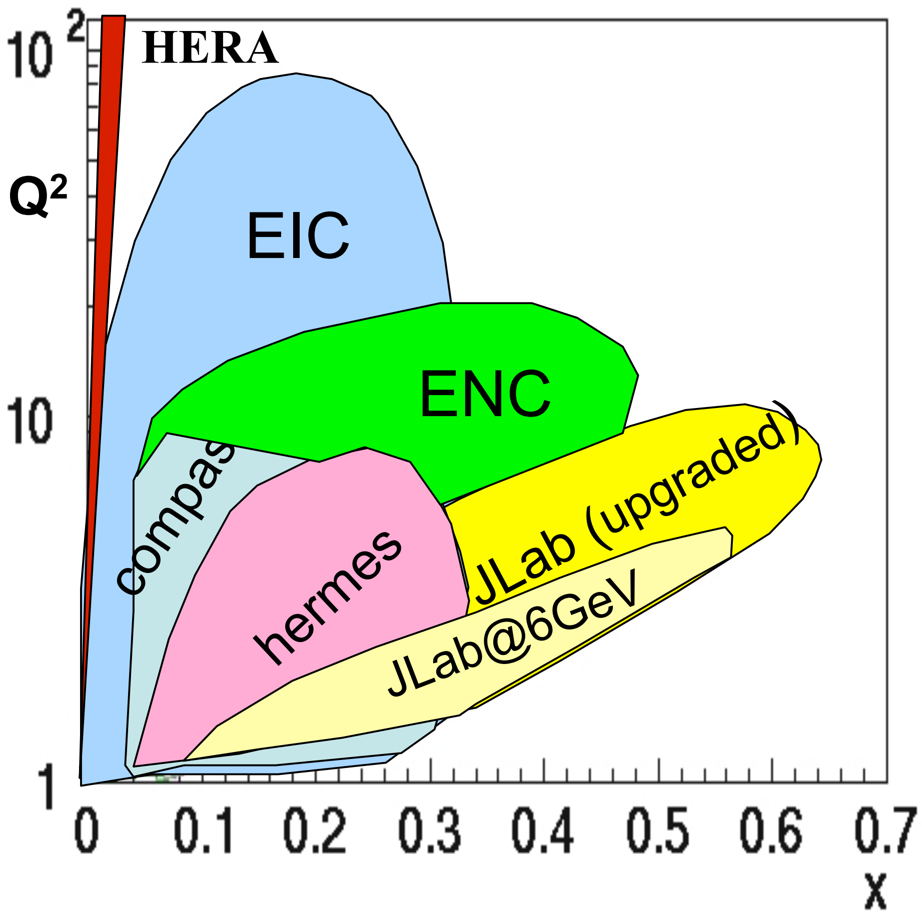
HERA:
very small x, large Q^2

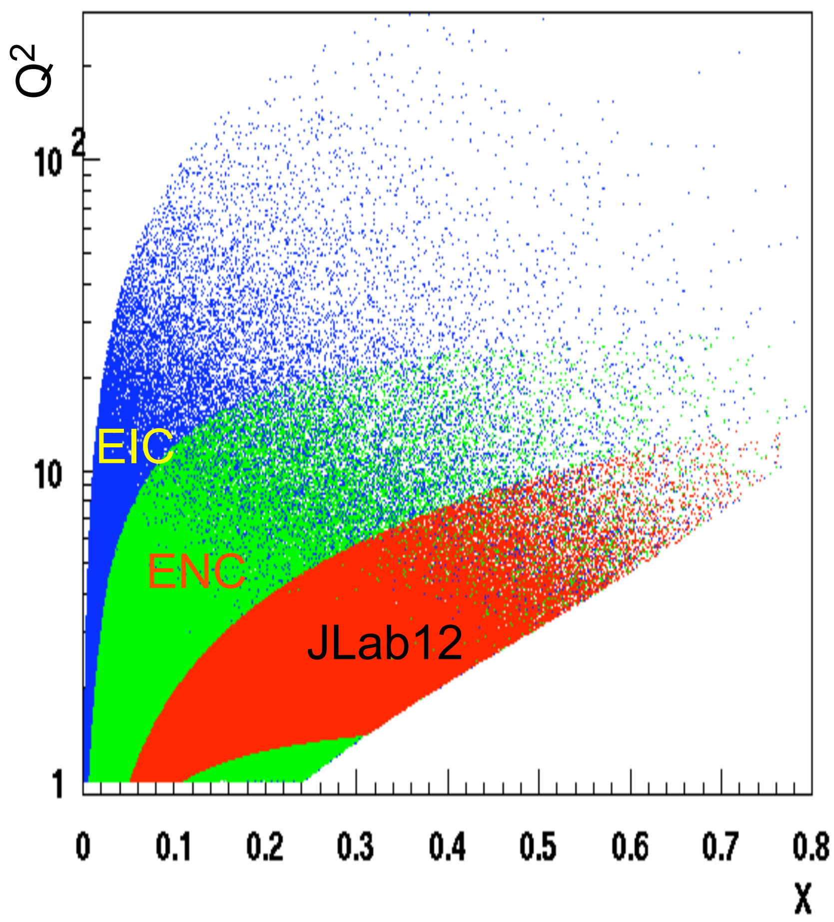
JLAB 6/12 GeV
large x, limited Q^2

ENC/EIC:
Wide range of x
Wide range of Q^2

Harut Avakian
for EIC

Electro Production Kinematics





Harut Avakian

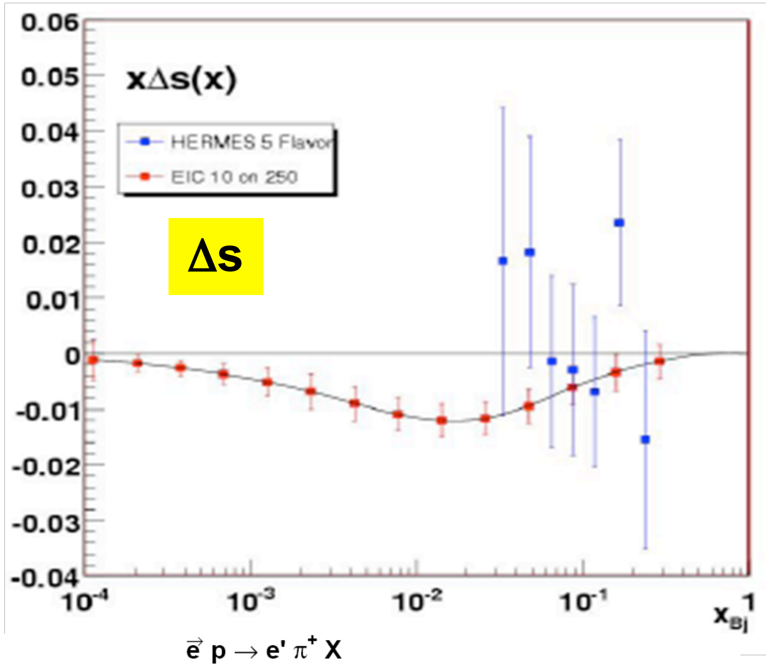
Feasibility Studies for EIC

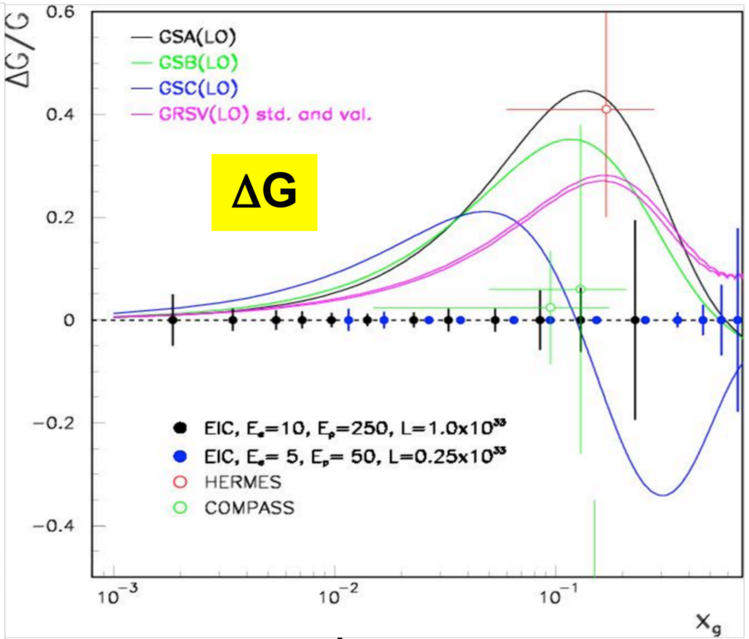
- Physics motivation
  - TMDs and spin-orbit correlations
    - Accessing TMDs in semi-inclusive DIS
    - Higher twists in SIDIS
  - GPDs and quark-gluon imaging
    - Accessing GPDs in hard exclusive processes
    - Higher twists in hard exclusive processes
- Projections for transverse SSAs at EIC and comparison with JLAB12

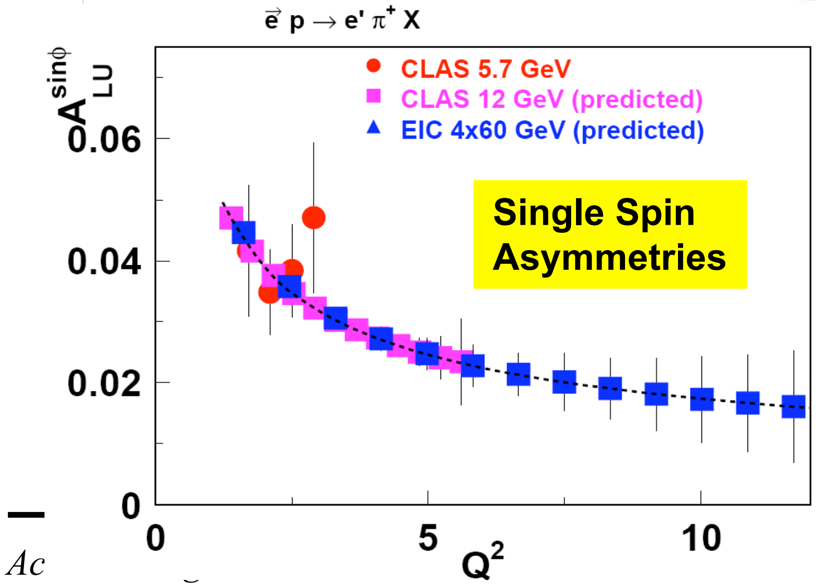
Huge improvement (statistics and systematics) in all fields wrt. fixed target

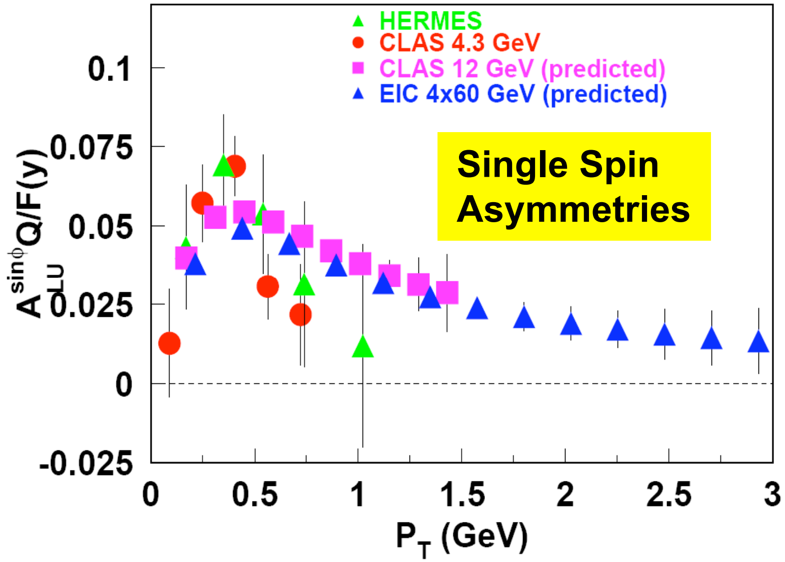
Harut Avakian

Feasibility Studies for EIC









Matt Lamont

Electron Ion eA Program

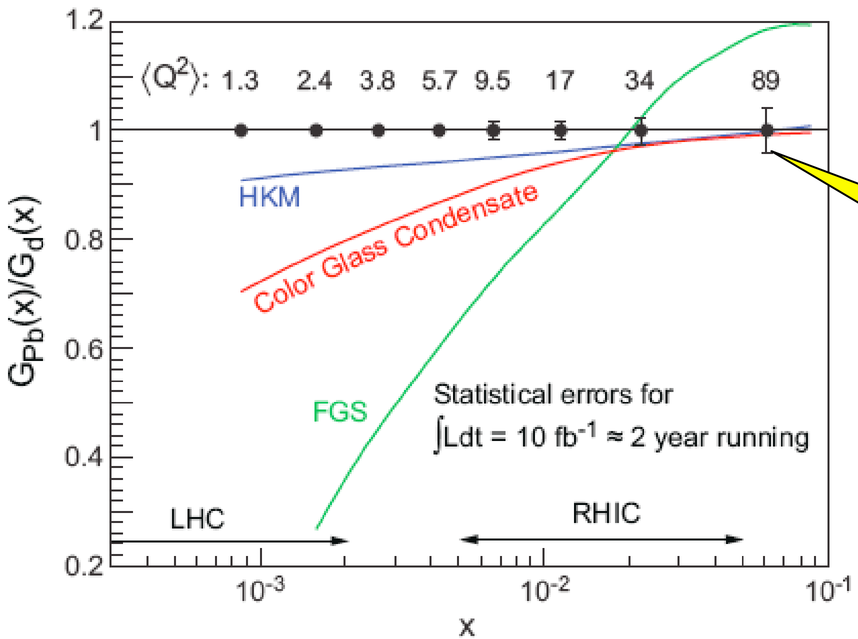
- ***Momentum* distribution of gluons $G(x,Q^2)$**
  - ➡ Extract via scaling violation in F_2: $\delta F_2/\delta \ln Q^2$
  - ➡ Direct measurement: $F_L \sim xG(x,Q^2)$ (requires √s scan)
  - ➡ 2+1 jet rates
  - ➡ Inelastic vector meson production (*e.g.* J/ψ)
  - ➡ Diffractive vector meson production ~ $[xG(x,Q^2)]^2$
- ***Space-time* distributions of gluons in matter**
  - ➡ Exclusive final states (*e.g.* vector meson production ρ, J/ψ)
  - ➡ Deep Virtual Compton Scattering (DVCS) - $\sigma \sim A^{4/3}$
  - ➡ F_2, F_L for various A and impact parameter dependence
- **Interaction of fast probes with *gluonic* medium?**
  - ➡ Hadronization, Fragmentation
  - ➡ Energy loss (charm!)
- **Role of colour neutral excitations (Pomerons)**
  - ➡ Diffractive cross-section $\sigma_{diff}/\sigma_{tot}$ (HERA/*ep*: 10% , EIC/eA: 30%?)
  - ➡ Diffractive structure functions and vector meson production
  - ➡ Abundance and distribution of rapidity gaps

Matt Lamont

Electron Ion eA Program

- ***Momentum*** **distribution of gluons** $G(x,Q^2)$
  - ➡ Extract via scaling violation in F_2: $\delta F_2/\delta \ln Q^2$
  - ➡ Direct measurement: $F_L \sim xG(x,Q^2)$ (requires $\sqrt{s}$ scan)
  - ➡ 2+1 jet rates
  - ➡ Inelastic vector meson production (*e.g.* J/ψ)
  - ➡ Diffractive vector meson production ~ $[xG(x,Q^2)]^2$

Gluon saturation regime can be studied in eA with 10 ... 100 smaller c.m.s. energy wrt. ep: nucl. enhancement $Q_s^2 \sim \tilde{A}^{1/3}$



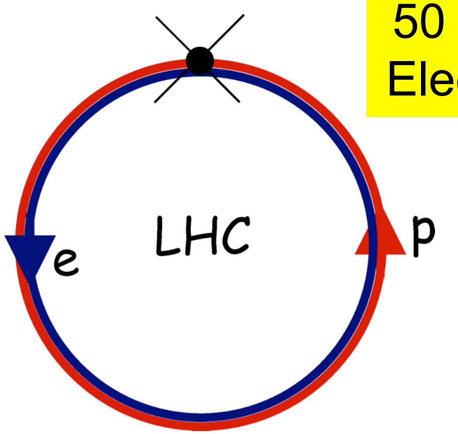
Statitical errors for G_{Pb}/G_d **ratio: sensitivity to distinguish btw. various models**

Uwe Schneekloth

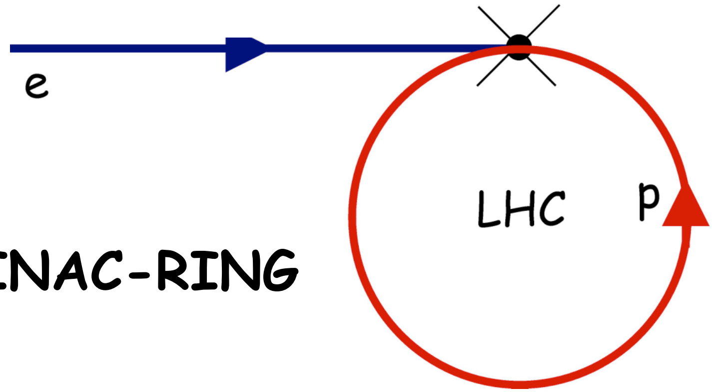
High Energy Frontier: LHeC

50 – 150 GeV
Electron beam

RING-RING



LINAC-RING



- Lots of experience: HERA, LEP and LHC
- Electron ring inside LHC tunnel
- Proven technology
- Electron energy about 70 GeV
- Luminosity $8.2 \cdot 10^{32}$ to $1.4 \cdot 10^{33}$ cm^{-2} s^{-1}
- Need few km (~ 2km) of new tunneling

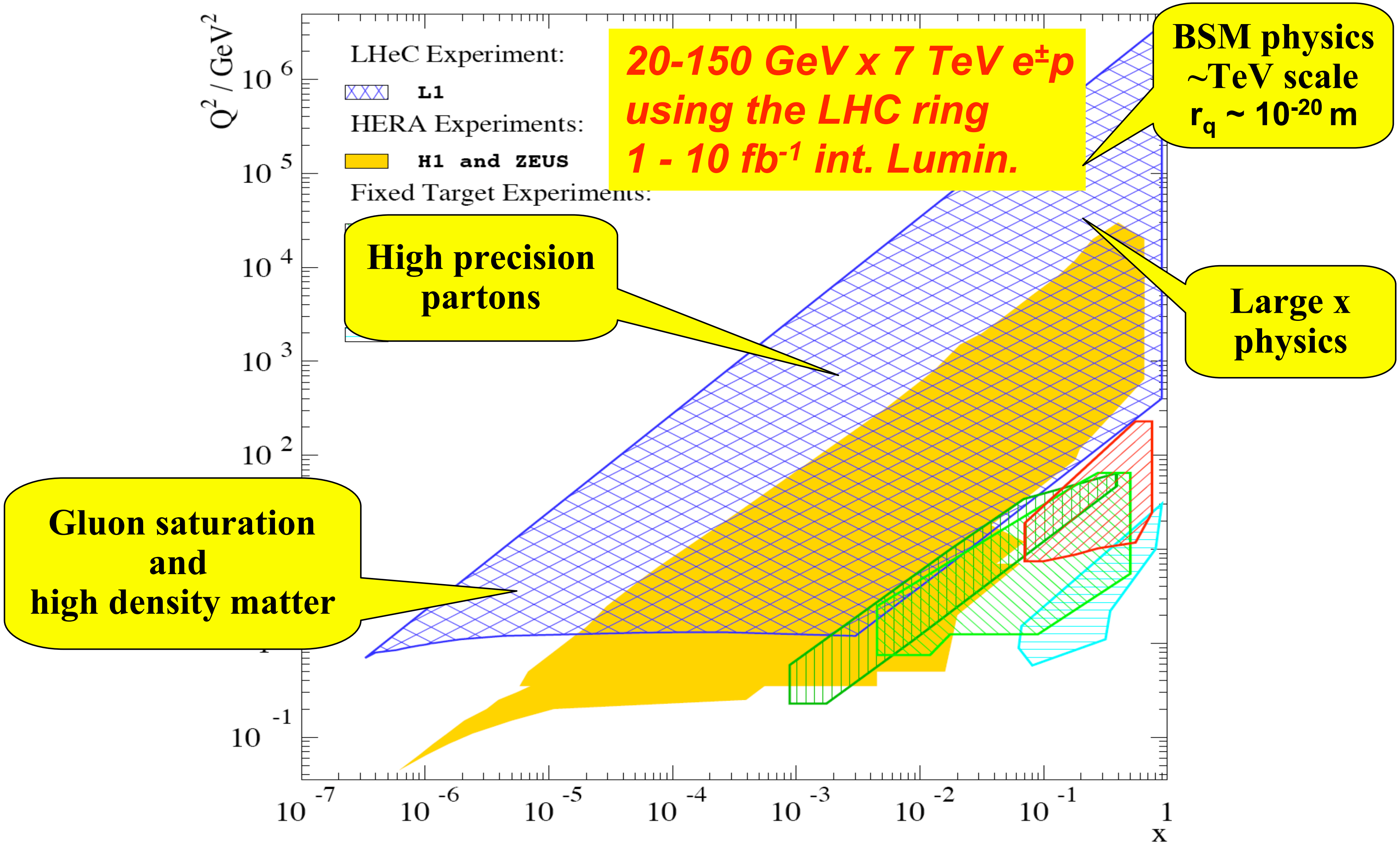
Conceptual design quite advanced!

- Need several km of new tunneling
- Staged construction possible
- High electron energy possible, increase in stages, w/o any limit
- Maximum luminosity $2\text{-}3 \cdot 10^{32}$ $cm^{-2}s^{-1}$
- In principle, energy recovery boosts luminosity above 10^{34}, but so far only demonstrated at low energies

Challenging design

Olaf Behnke

High Energy Frontier: LHeC



Olaf Behnke

High Energy Frontier: LHeC

The LHeC has potential to completely unfold the partonic content of the proton: u,d, c,s, t,b for the first time and in an unprecedent kinematic range. This is based on inclusive NC, CC cross sections complemented by heavy quark identification.

Puzzles as u/d at large x or a strange-antistrange asymmetry will be solved.

Precision measurements are possible of xg (up to large x) and the beauty density which are of particular relevance for the LHC. The (almost) whole p structure which the LHC assumes to know will become accurately known.

Determination of fundamental SM constants: light quark axial and vector couplings to Z boson, W propagator mass, strong coupling constant α_s with permille level precision

Wealth of QCD tests with final states (not much discussed in this talk : Jets (study also photon structure), heavy flavours, prompt photons, other identified particles

Low x and diffractive physics with ep and eA: Measuring multiple observables (F2, Fl, F2c, F2D, Vector mesons…) in ep and eA can lead to a microscopic understanding of non-linear evolution, unitarity constraints and parton saturation

Complementing LHC at the high energy frontier:
- SM Higgs production for H-> bb coupling
- New physics: e.g. Leptoquarks, determine quantum numbers

Krishna Kumar

Parity Violation and BSM Aspects

- Lepton Flavor Violation
  - DIS tau lepton conversion detectable at EIC kinematics
  - With vertexing and 1000 fb^{-1} : possibly 10^{-10} sensitivity
- Lepton-Quark Weak Neutral Current Couplings
  - EIC with highest luminosities may allow precision beyond planned facilities
- Parity Violating deep inelastic scattering at EIC
  - 100 fb^{-1} data set with polarized e-d collisions needed
    - interest level might be magnified depending on LHC results
    - theoretically very clean (e.g. higher twist effects)
    - detailed look at experimental systematics needed!
    - Can electron polarization be measured to 0.1%?
  - An optimized (smaller) data set with polarized proton and He-3
    - new parity-violating structure functions
    - separation of quark helicity distributions from x = 0.01 to 0.5
    - Possibly critical for disentangling new physics in W asymmetries
  - e-A with polarized electrons
    - novel probe of EMC effect?
    - available "for free" during e-A running if properly instrumented

Conclusions

Conclusions

- EIC / ENC is a unique opportunity for studying nucleon structure

  - tomogrophy and spin structure of the nucleon
  - transverse momentum distributions
  - study non-linear QCD, limit of gluon saturation

- EIC together with ongoing and other future facilities (e.g. FAIR, e+e- machines) will help to construct a better picture of hadrons, which is also important input to other field of physics (e.g. LHC, flavour factories)

Conclusions

- International community seeking to realize a high luminosity electron-ion collider for studying QCD.
- Four concepts are being pursued at present:

  BNL/eRHIC, CERN/LHeC, GSI/ENC, JLab/ELIC
- Different designs and energies complementary in physics scope.
- Cooperation btw. different design studies desirable, competition as well.


Thanks to all Speakers
and Participants ...
13 talks
2 discussion sessions
>20 participants
... for the stimulating Discussions.