EINN 2009

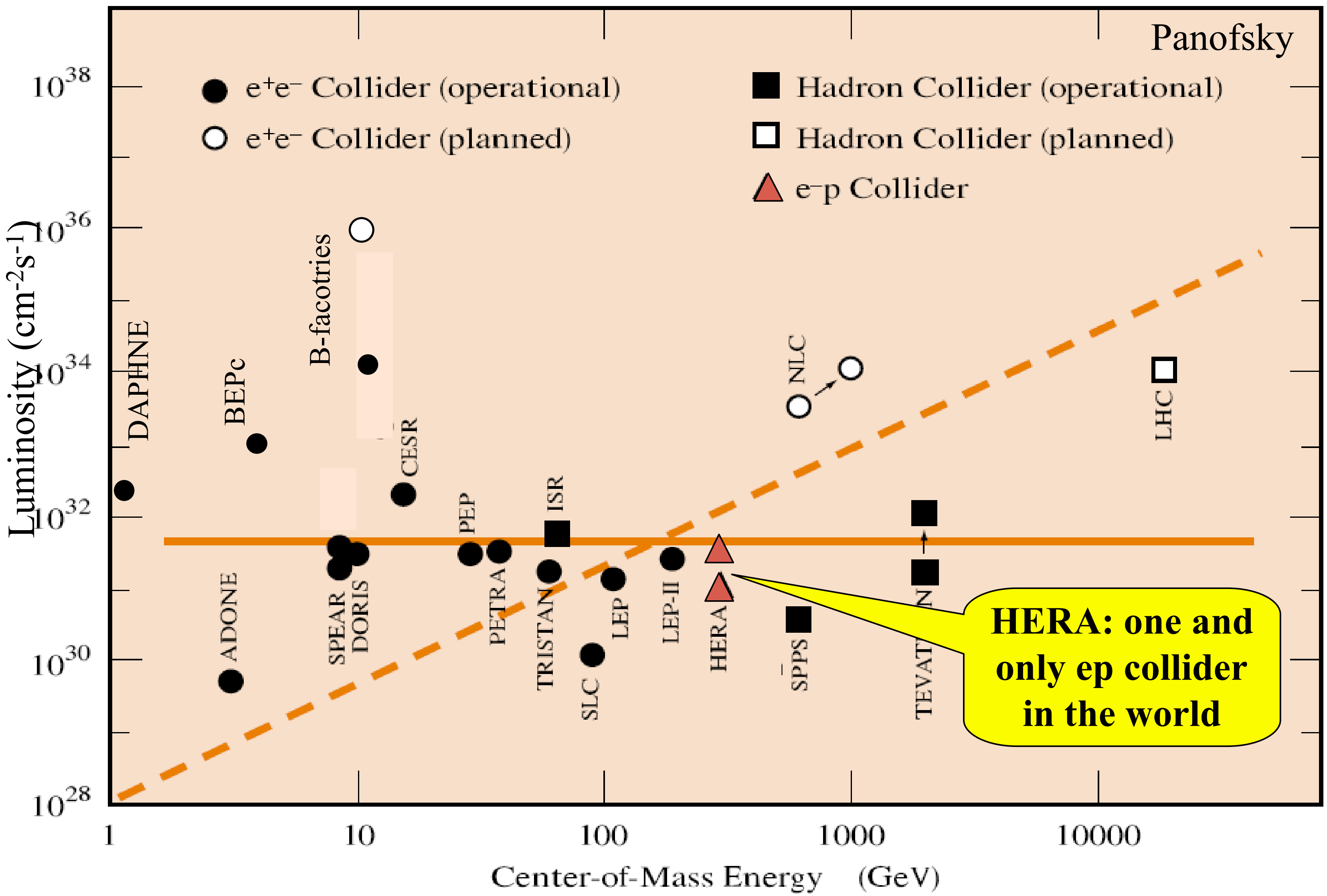
Electromagnetic Interactions with Nucleons and Nuclei

Workshop Summary: Electron Ion Collidere

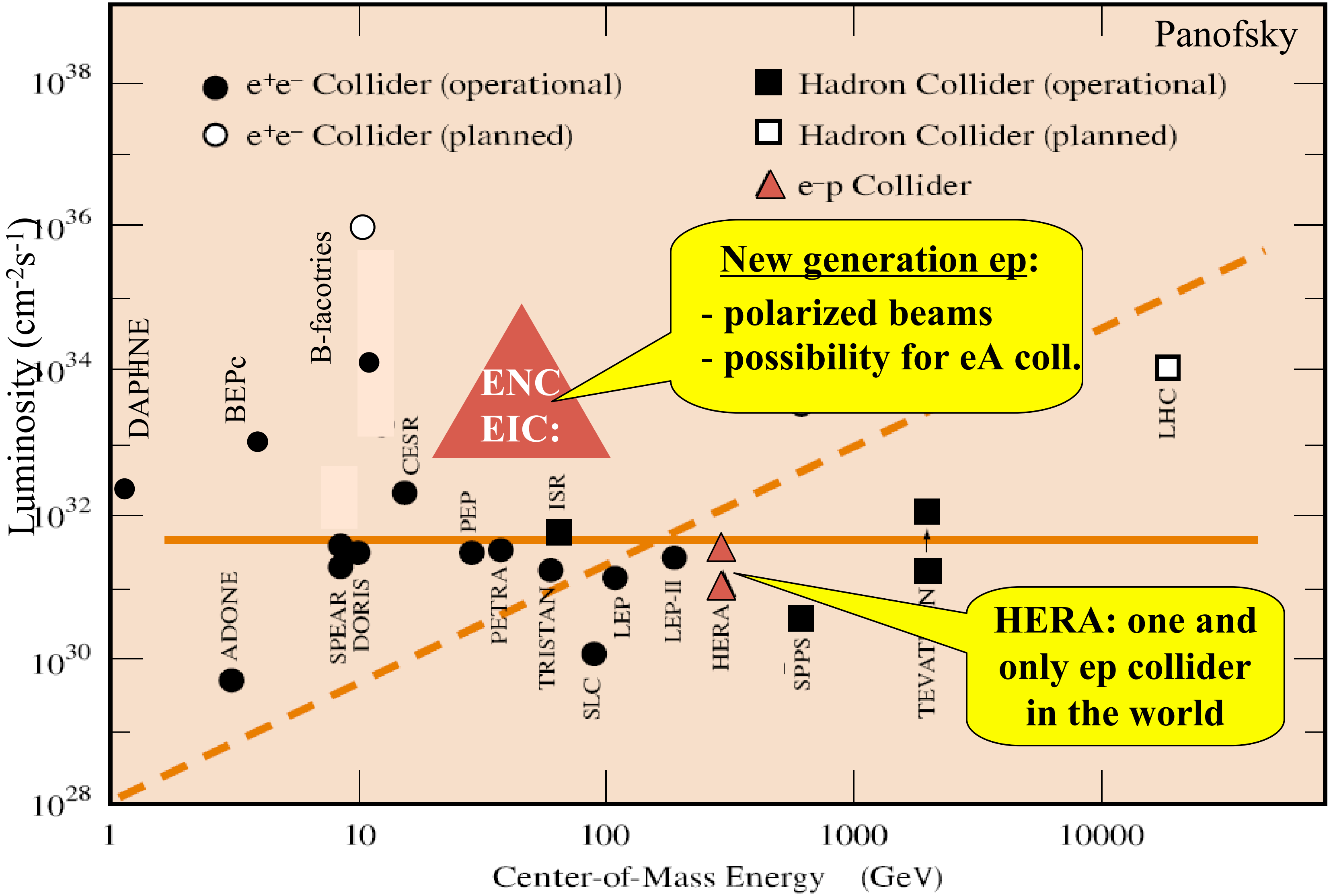
Conveners:
Achim Denig (Mainz)
Abhay Deshpande (Stony Brook)

Milos Island, Greece
September 27 - October 3, 2009

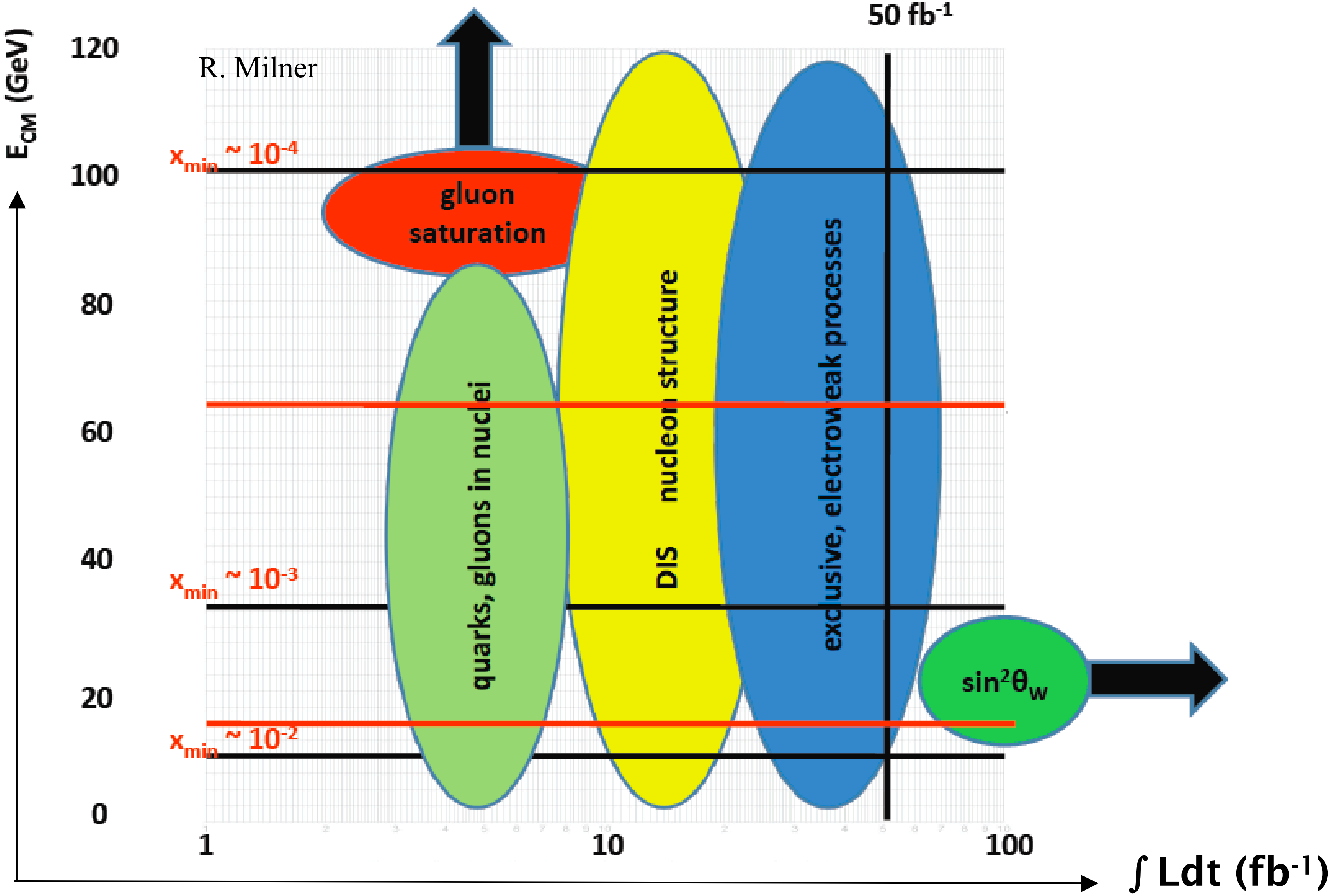
Electron Nucleon (Ion) Collider



Electron Nucleon (Ion) Collider



Why Electron Nucleon (Ion) Collider ?



Open Questions in Theorie and Experiment

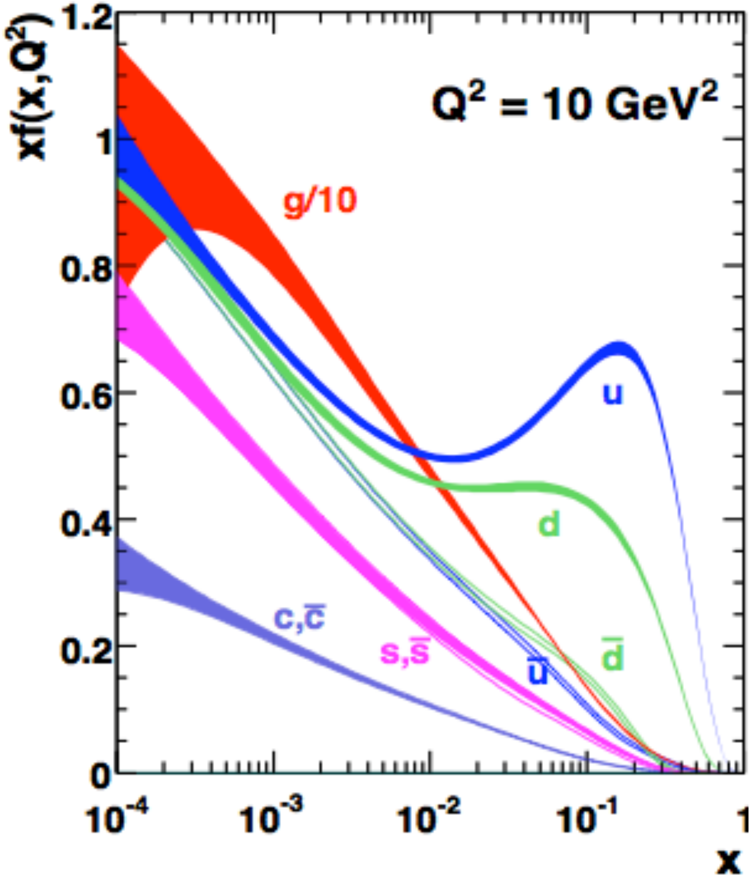
Daniel de Florian (Theory)
Dietrich von Harrach (Expt.)

Daniel de Florian

Open Questions - Theory

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

QCD in the precision era : pdfs



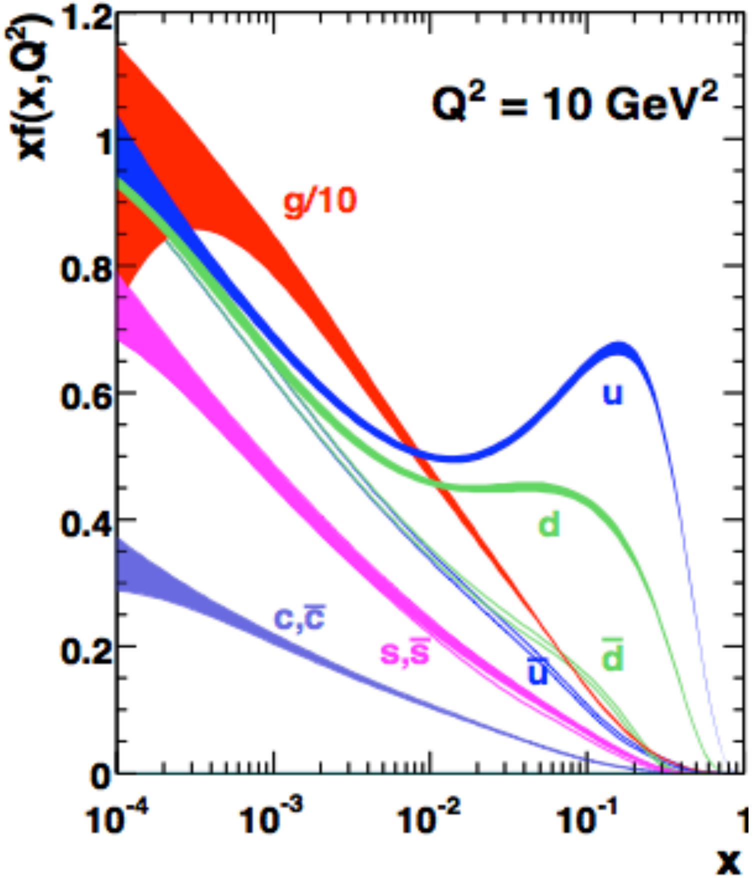
Burkard Reisert: HERA Physics
Hubert Spiesberger: Rad. corrections

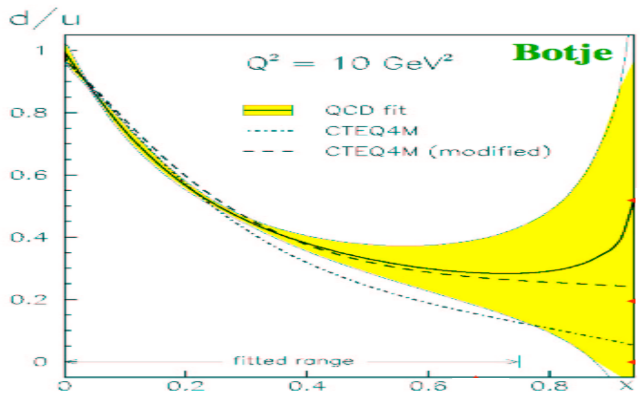
Daniel de Florian

Open Questions - Theory

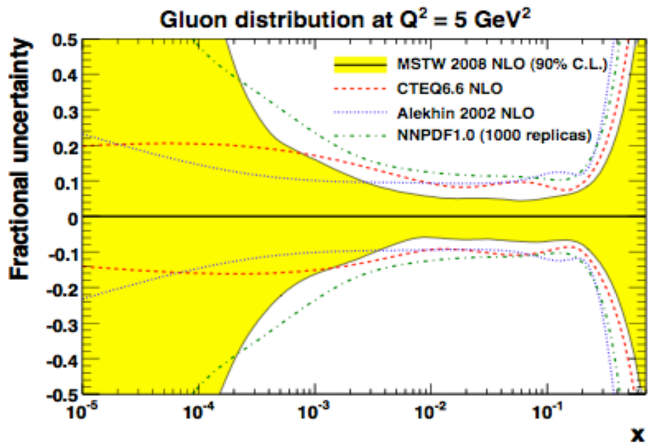
✓ **Unpolarized PDFs : OK for LHC, some kinematical regions uncovered**

QCD in the precision era : pdfs





large x : large uncertainties



small x : Saturation?

Burkard Reisert: HERA Physics

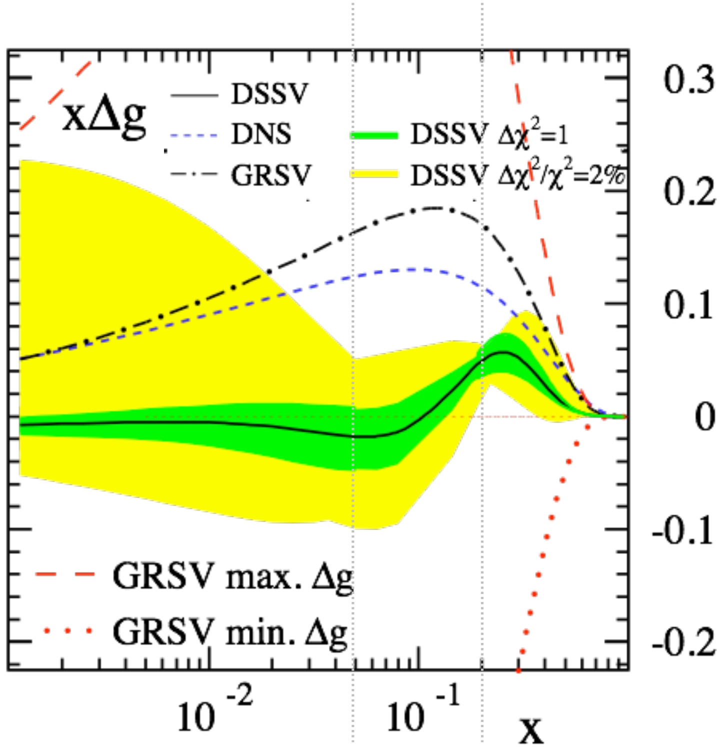
Daniel de Florian

Open Questions - Theory

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

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

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

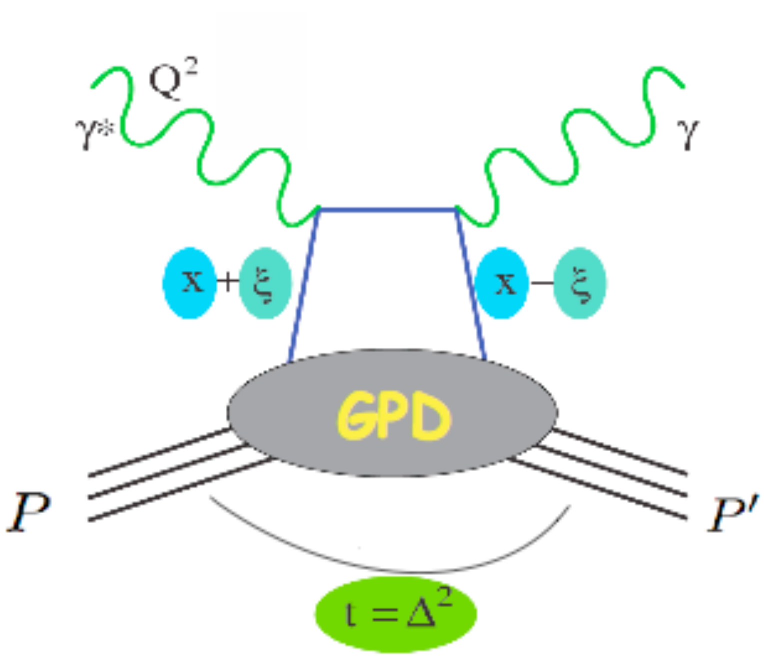


Without polarized ep collider : spin 'crisis' has NO solution

Daniel de Florian

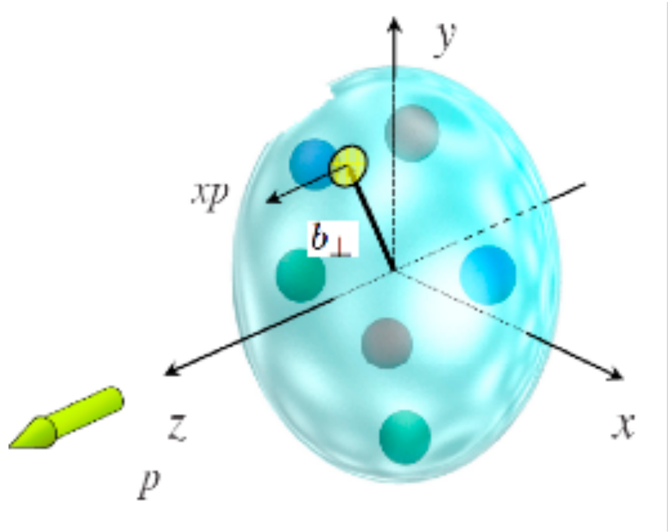
Open Questions - Theory

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



Tomographic images of nucleon
Orbital Angular Momentum ?

transverse profile of the nucleon



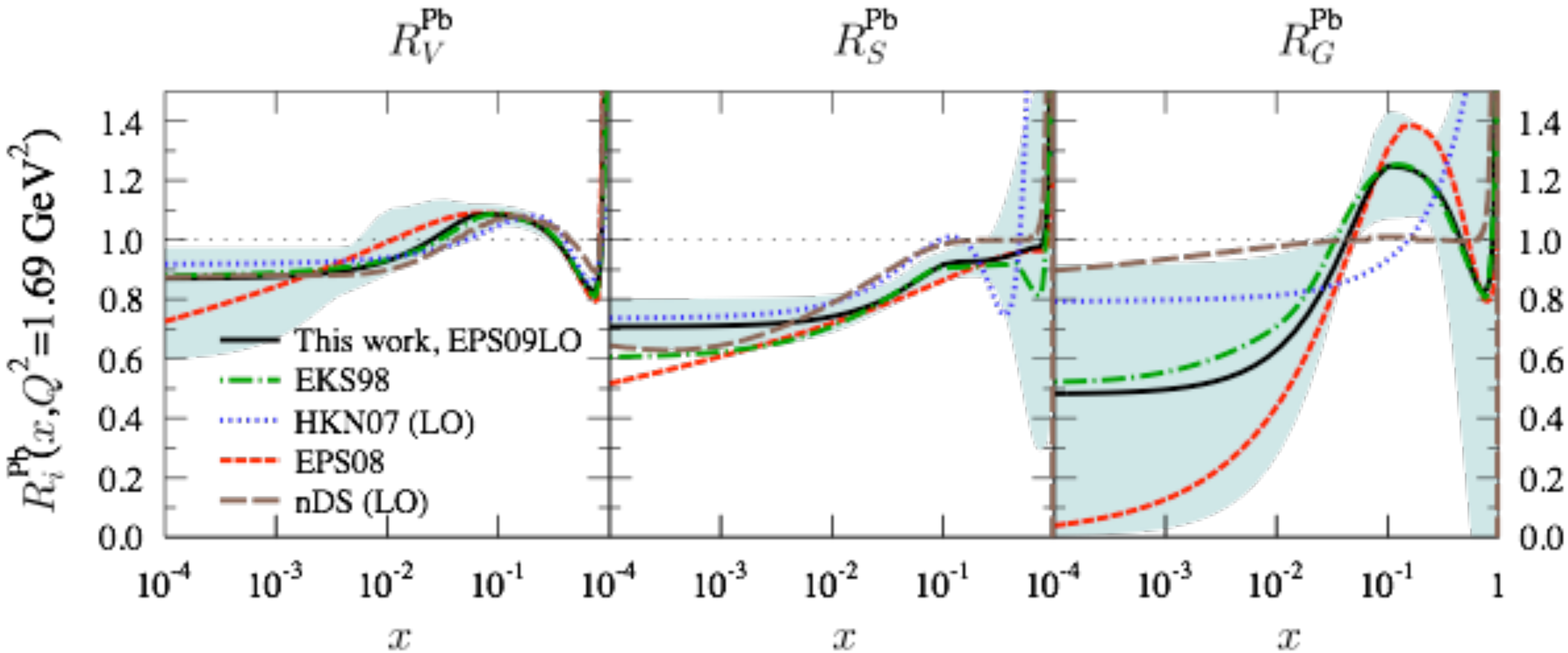
EINN09: Compass, JLAB, Hermes: limited by statistics

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 GPD...

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 $\mathcal{L}^{eff} \gtrsim 10^{32} cm^{-2} s^{-1}$

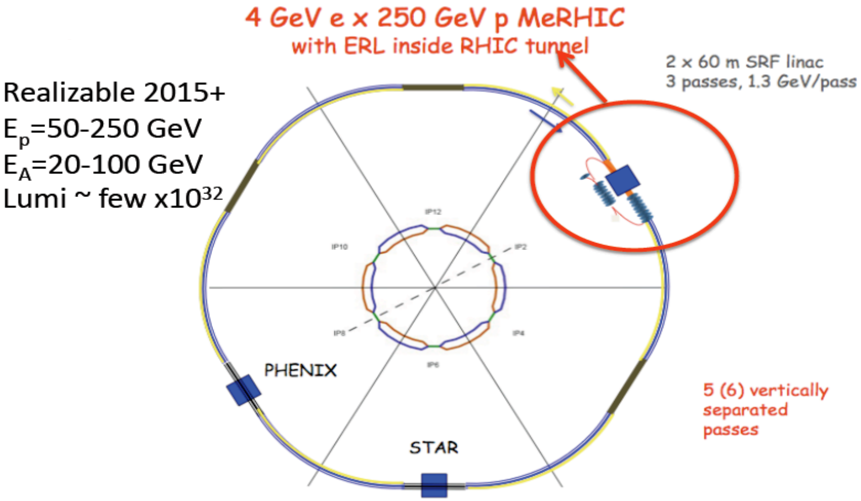
... transversly polarized protons and deuterons

... 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 ...

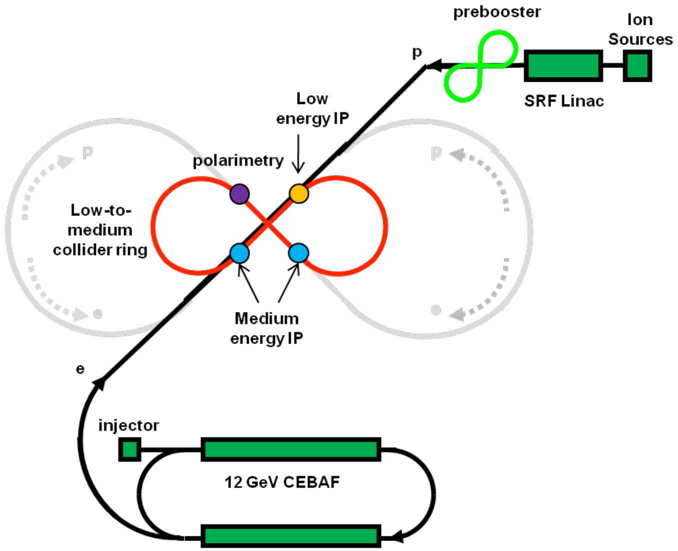
Machine Concepts:
- EIC (BNL & JLAB) Vladimir Litvinenko
- ENC Andreas Lehrach

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

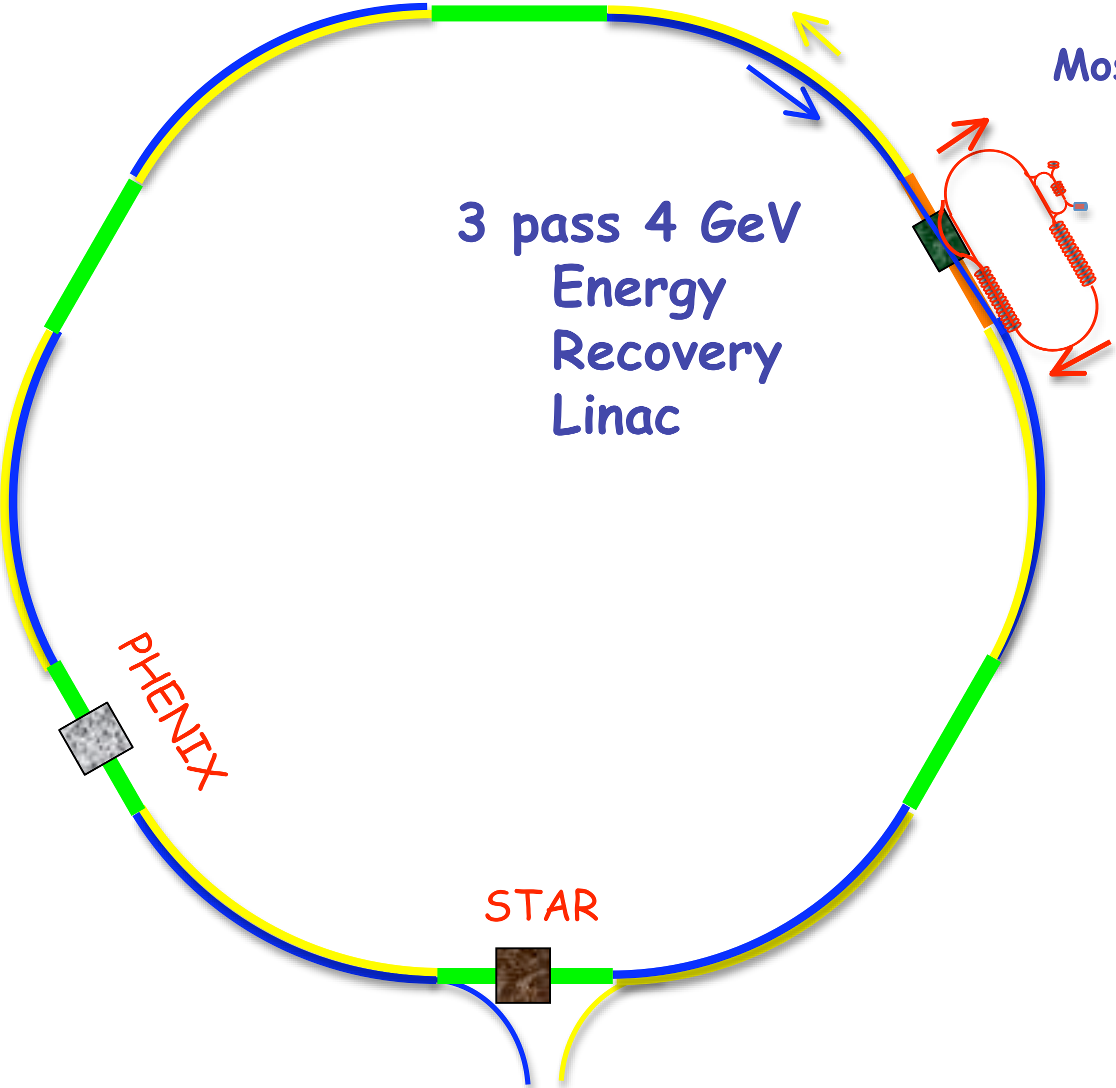


EIC@JLAB
Ring-Ring

- 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)

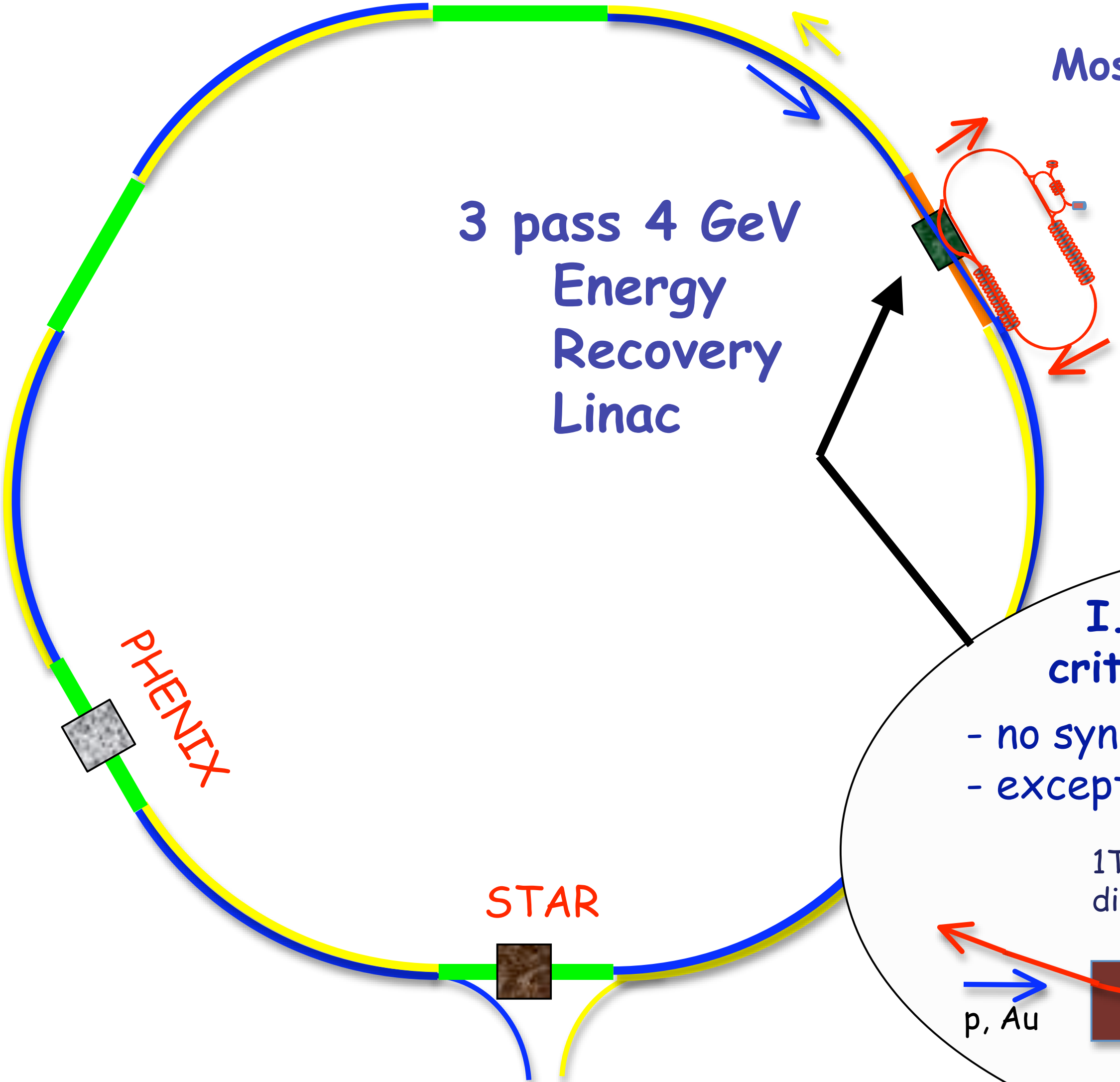


Most challenging: polarized gun!

- 2 x 60 m
- 1.3 GeV/pass

Vladimir Litvinenko

EIC@BNL (MeRHIC - 4 x 250 GeV)



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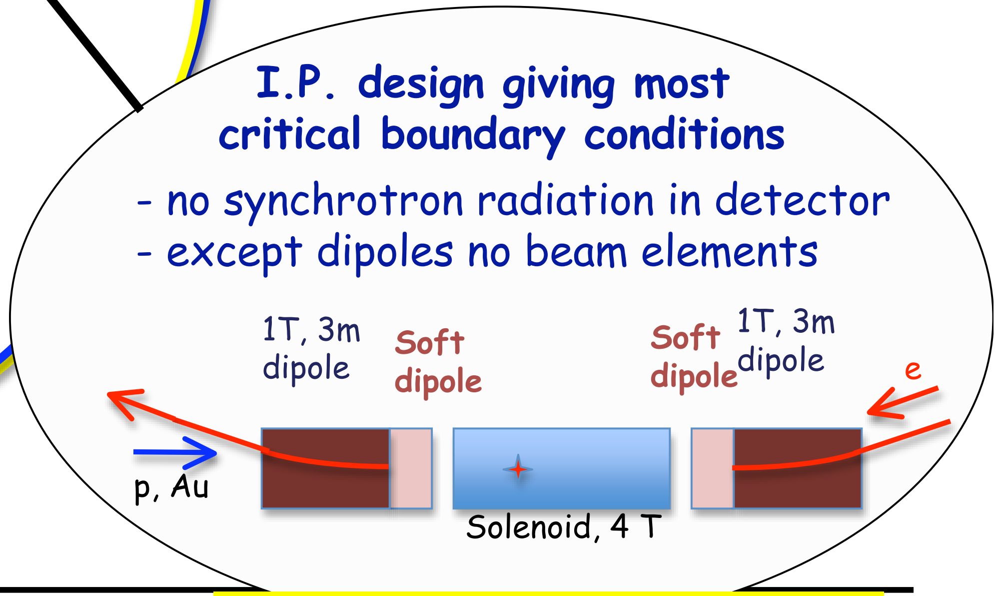


HERA I.P. Uwe Schneekloth

Vladimir Litvinenko

eRHIC Parameters

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

111 bunches

High degrees of polarization

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

Vladimir Litvinenko

eRHIC Parameters

Coherent Electron Cooling

111 bunches

High degrees of polarization

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

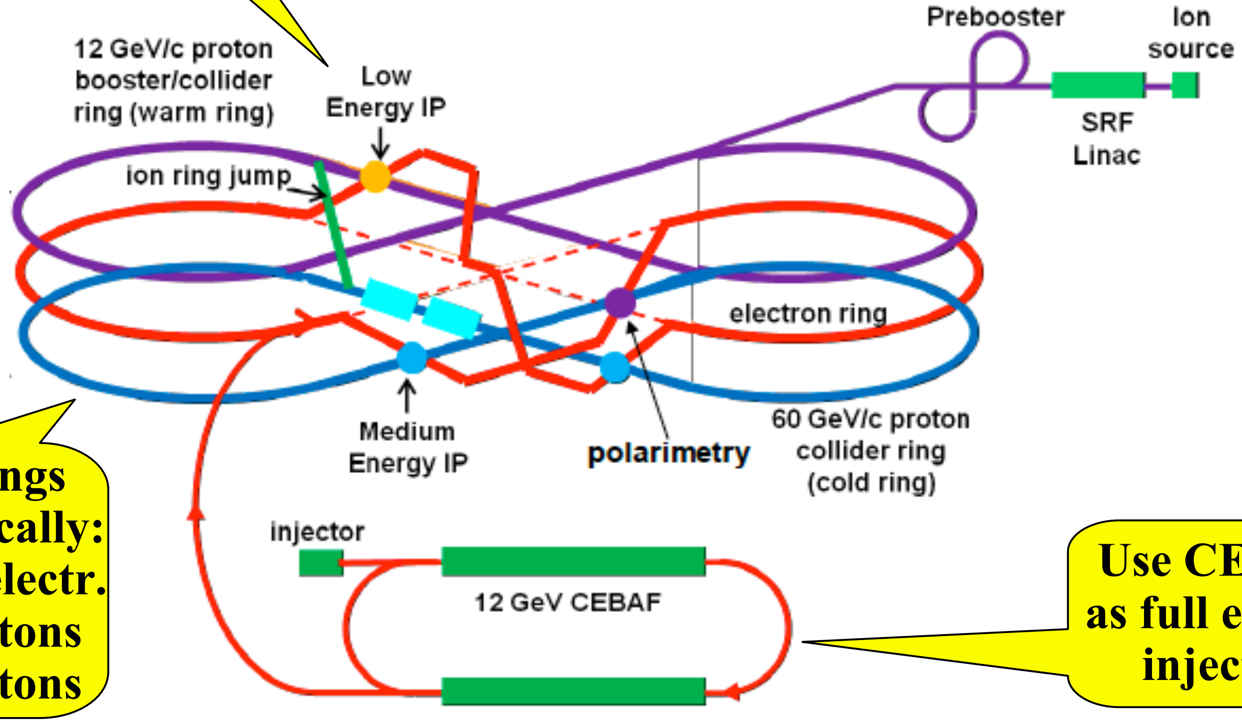
	MeRHIC		eRHIC with CeC	
	p (A)	e	p (A)	e
Energy, GeV	250 (100)	4	325 (125)	20 <30>
Number of bunches	111		166	
Bunch intensity (u) , 10^{11}	2.0	0.31	2.0 (3)	0.24
Bunch charge, nC	32	5	32	4
Beam current, mA	320	50	420	50 <10>
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.2	25
Polarization, %	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)	

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

Up to 4 I.P.s with different c.m.s. energies and luminosities



3 figure 8 rings stacked vertically:
-5 (11) GeV electr.
- 12 GeV protons
- 60 GeV protons

Use CEBAF as full energy injector

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

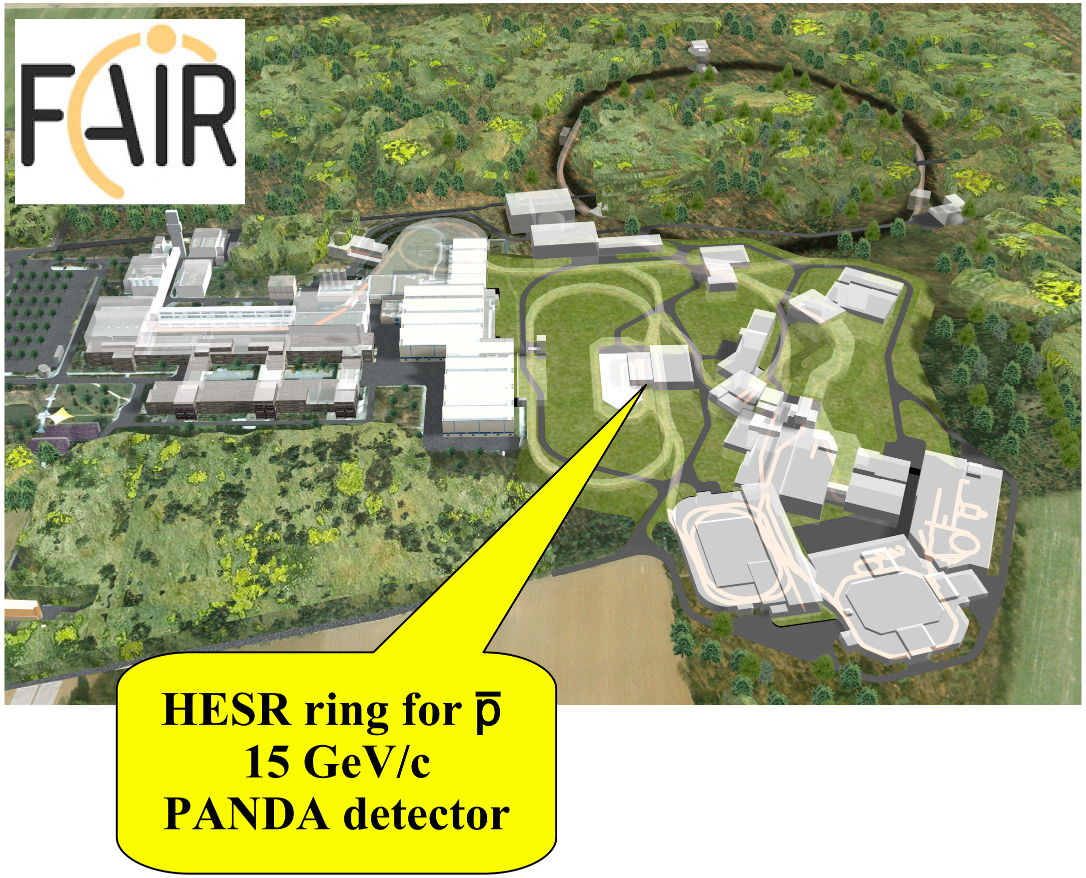
w energy | MEIC | High energy

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

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

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

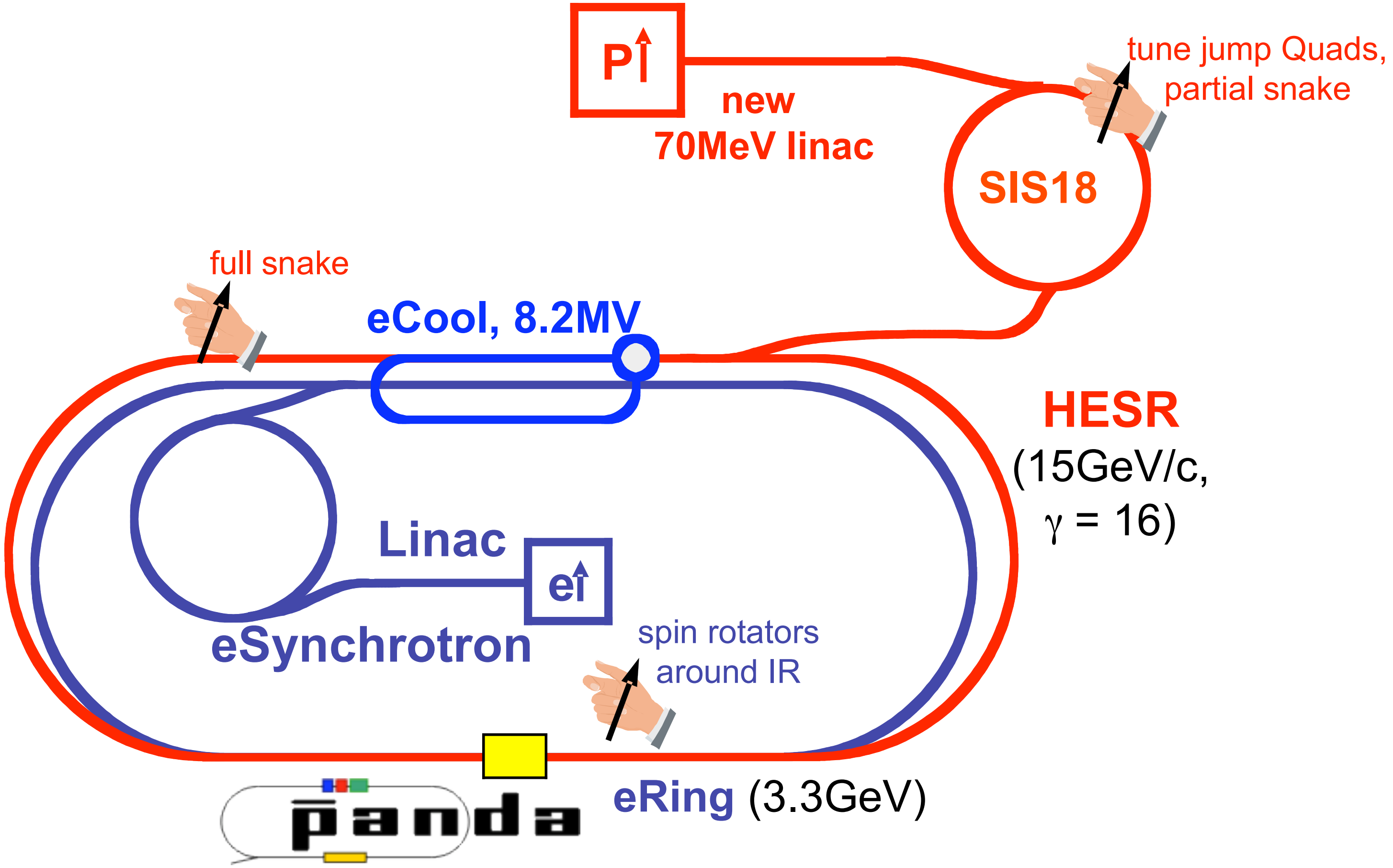
polarized e^- (> 80%)
↔
polarized p / d (> 80%)
(transversal + longitudinal)

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

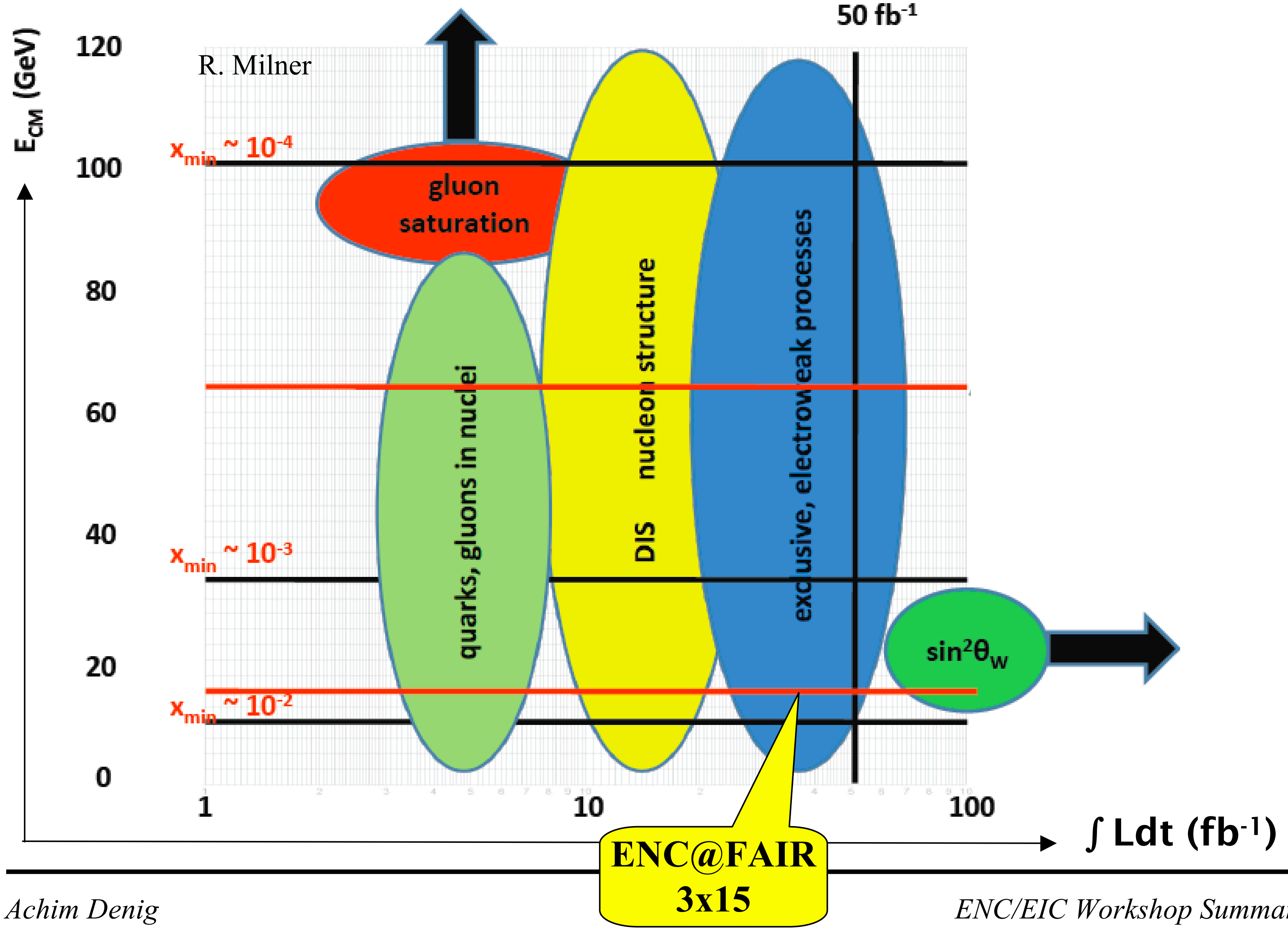
  Modifications of the IP concept required

- 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 ?



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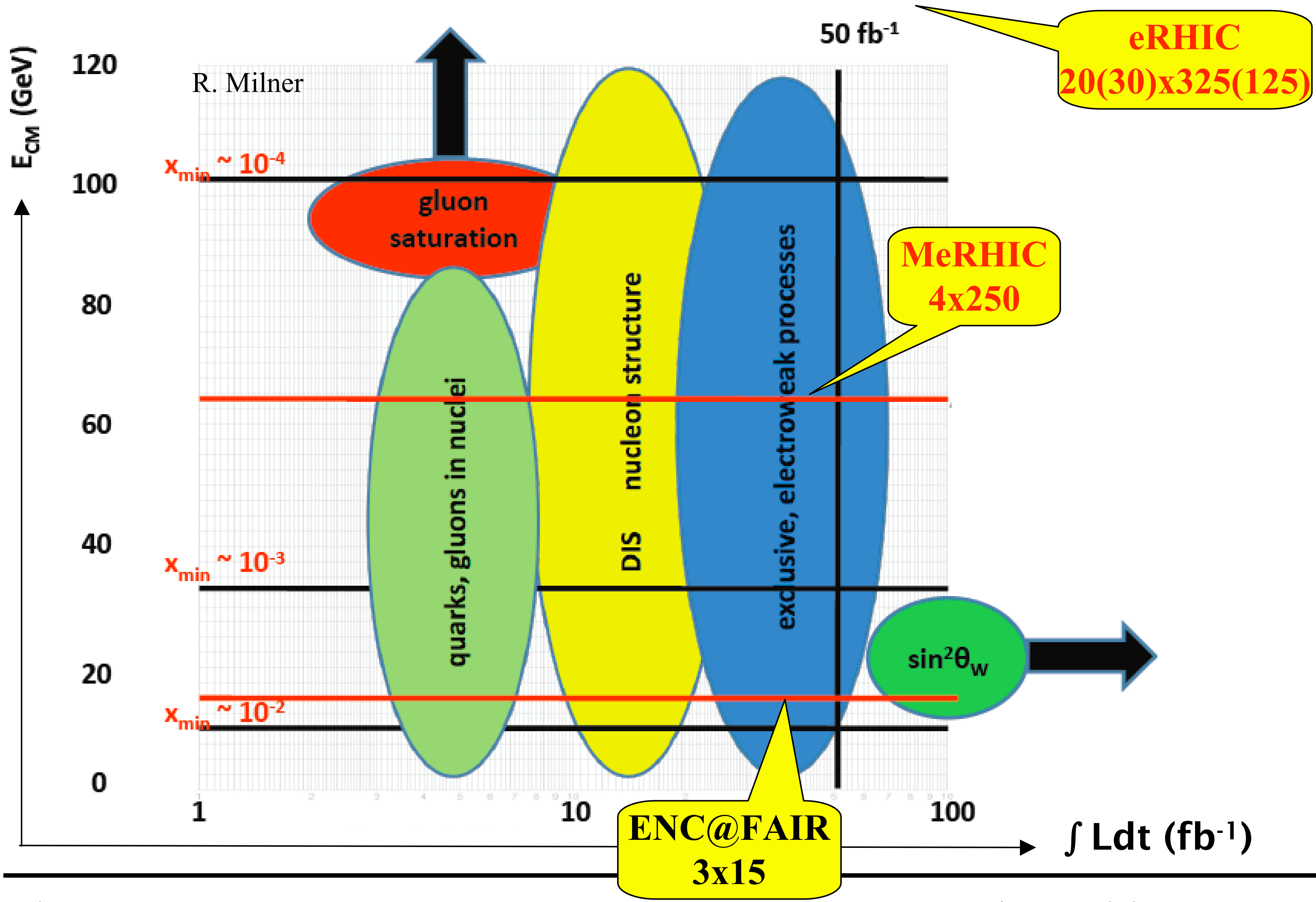
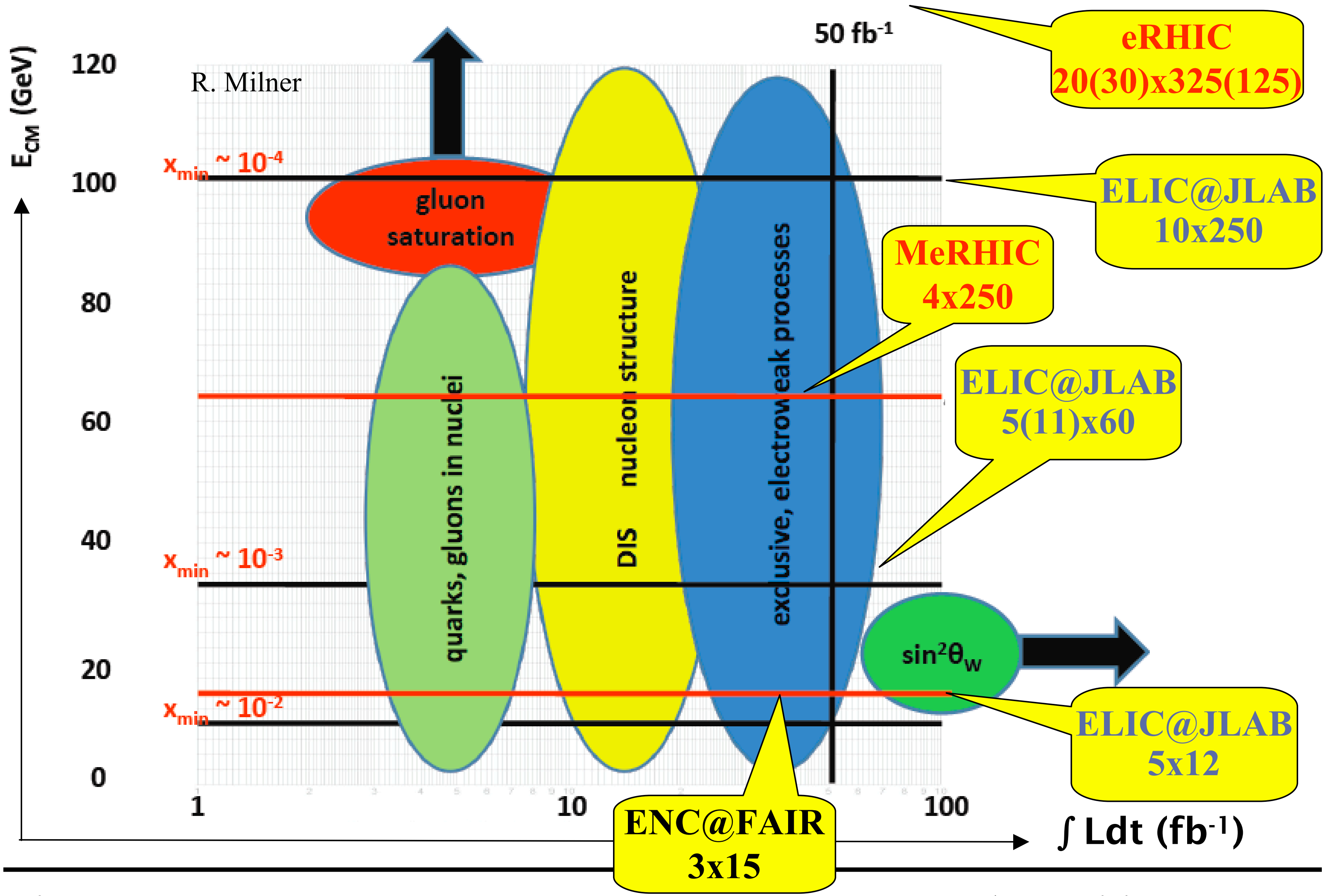


Why Electron Nucleon (Ion) Collider ?



Feasibility Studies ENC / EIC

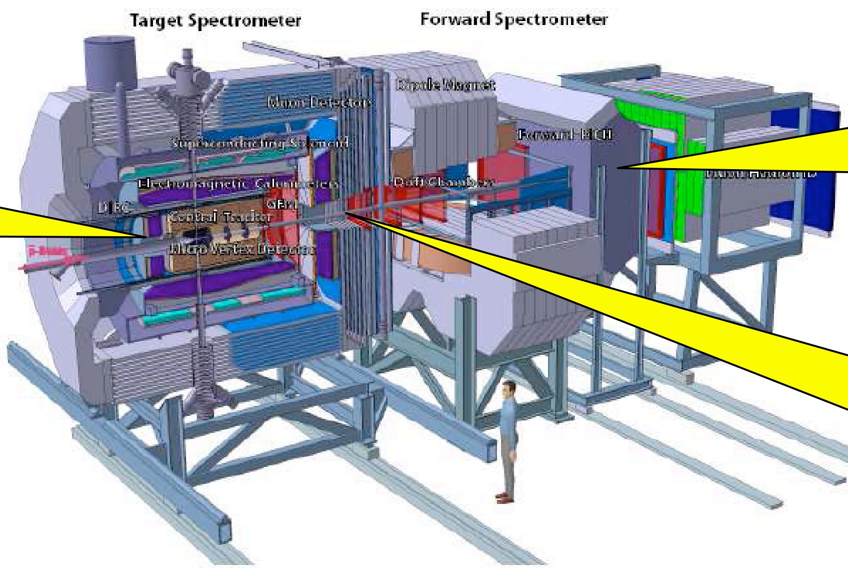
Jörg Pretz (ENC)
Arut Havakian (ep - EIC)
Matt Lamont (eA - EIC)

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
$\mathcal{L}/(1/\mathrm{cm}^2/\mathrm{s})$	$\approx 10^{38}$	$\approx 10^{32}$	$\approx 10^{32}$	$\approx 10^{32}$

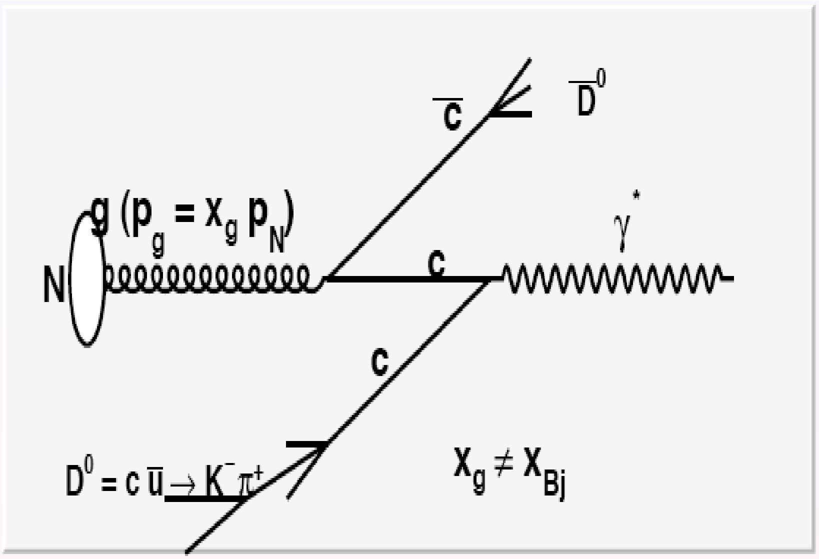
$$\mathrm{FOM} = (\text{diluting factors})^2\,\mathcal{L}$$

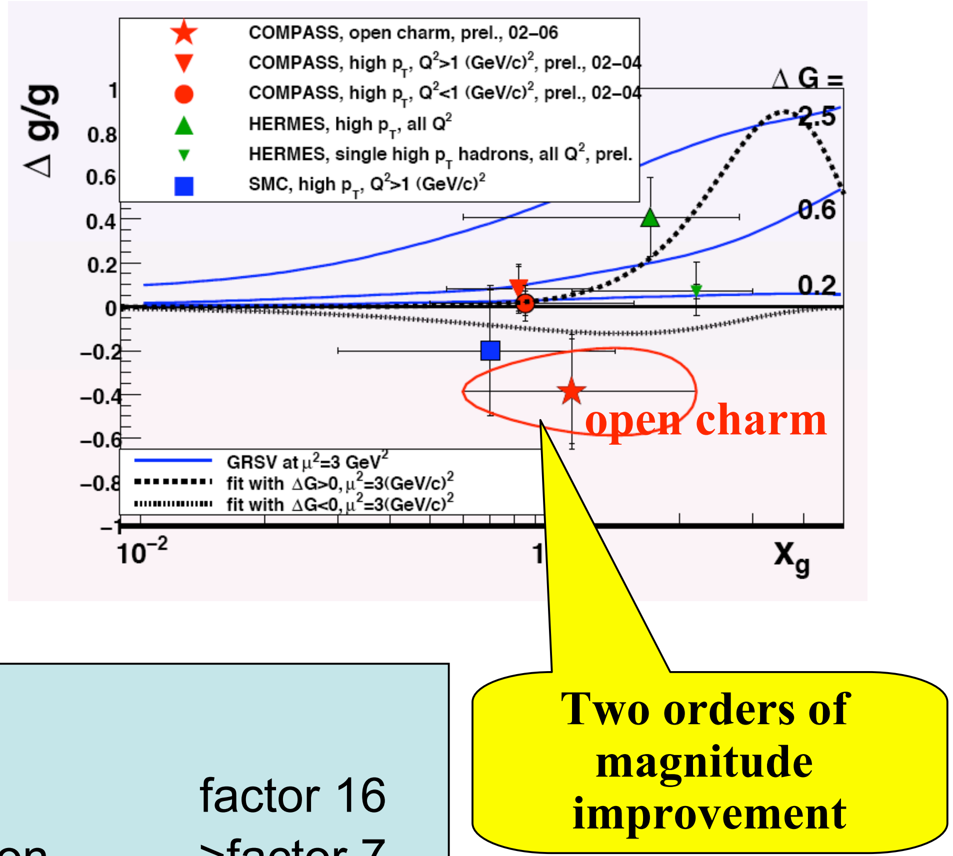
Beam polarization
Target polarization
Target dilution factor
Acceptance

	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!

ΔG @ ENC



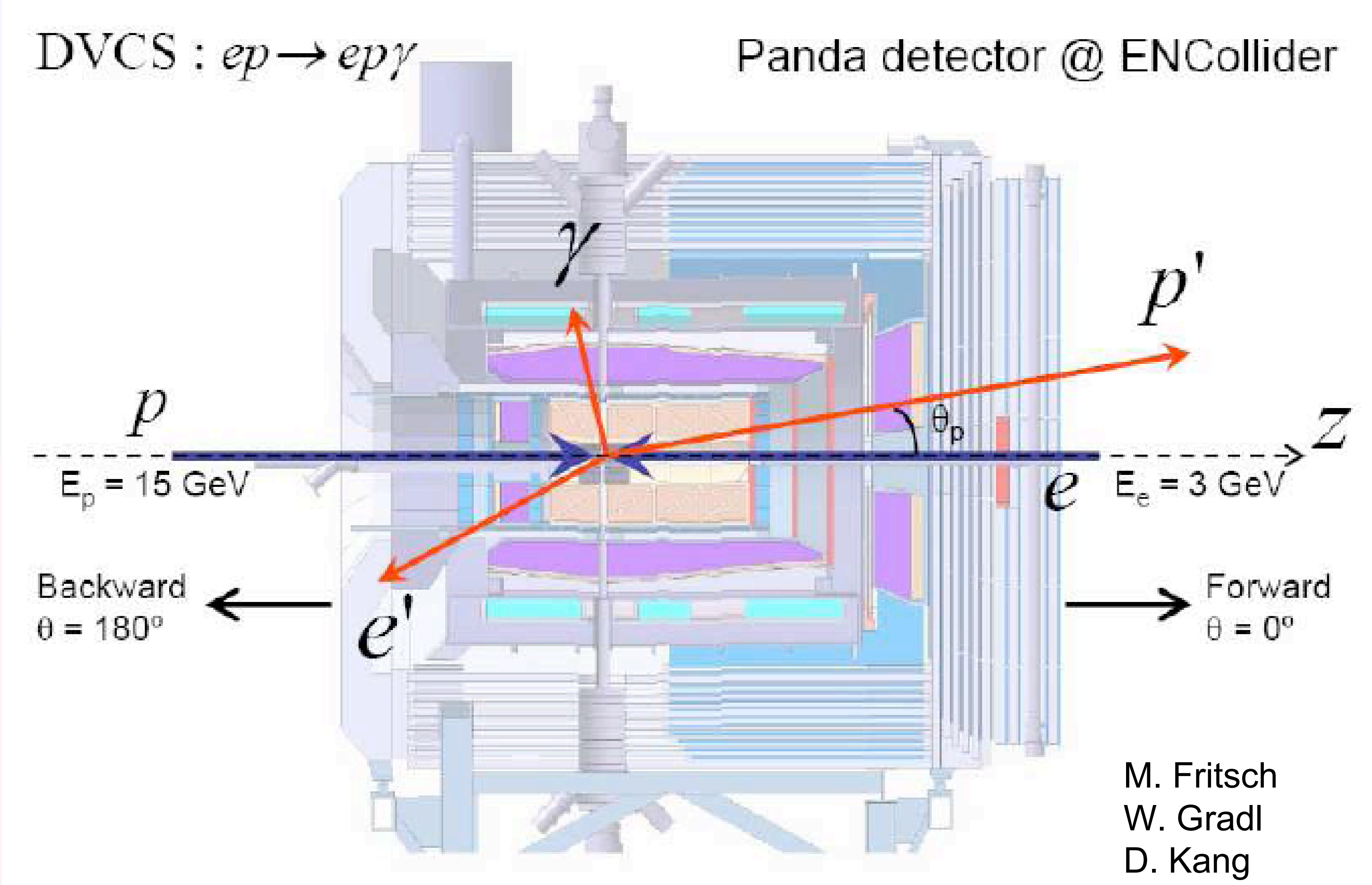


Improvements wrt. COMPASS:

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

Jörg Pretz

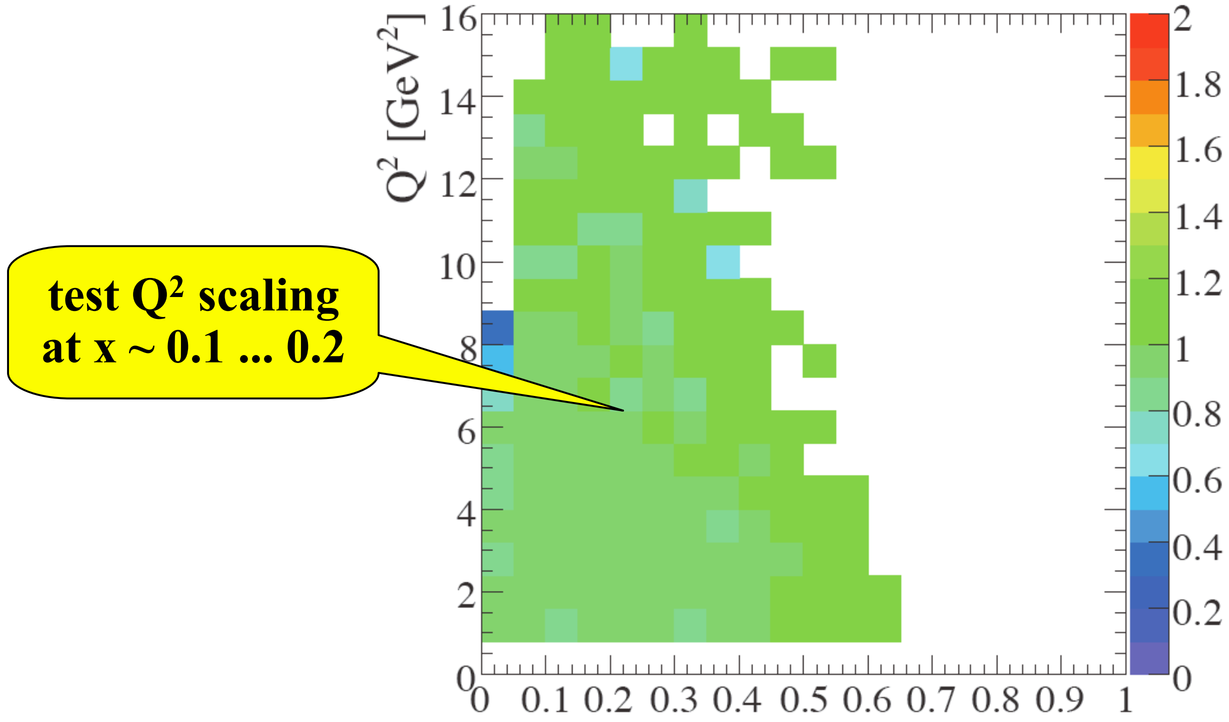
DVCS @ ENC



M. Fritsch
W. Gradl
D. Kang

Jörg Pretz

DVCS @ ENC: Efficiency Studies

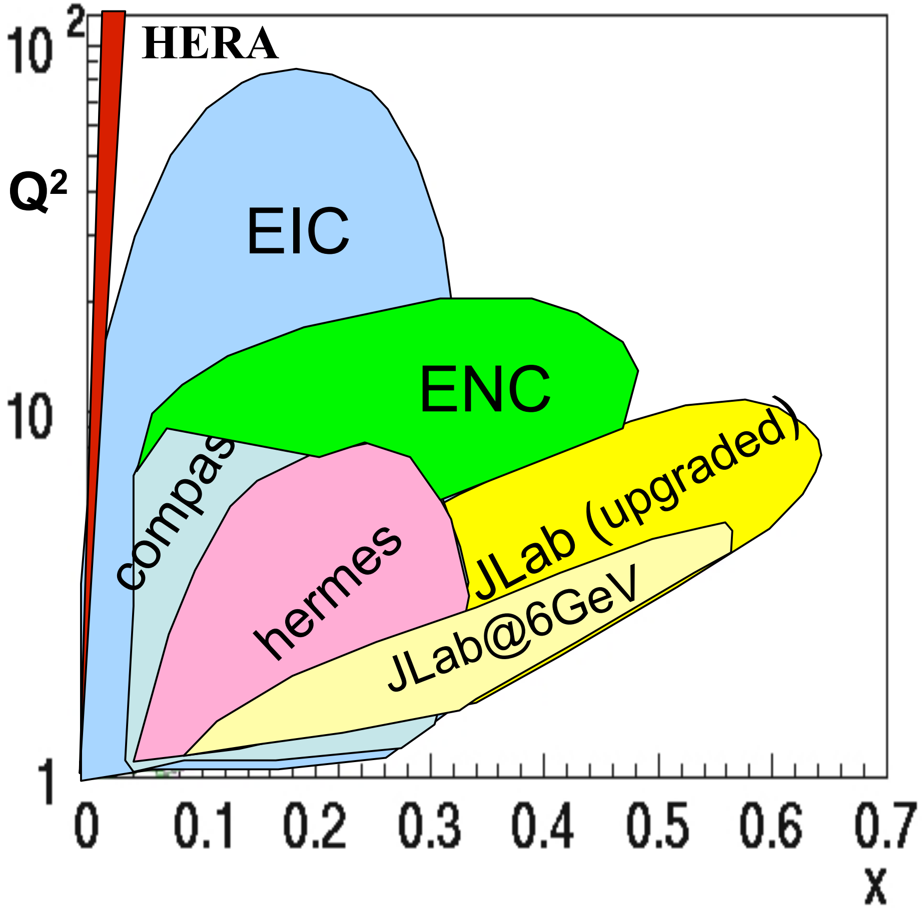


W. Gradl @ ENC/EIC Workshop, May 09 , GSI

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

Harut Avakian
for EIC

Electro Production Kinematics



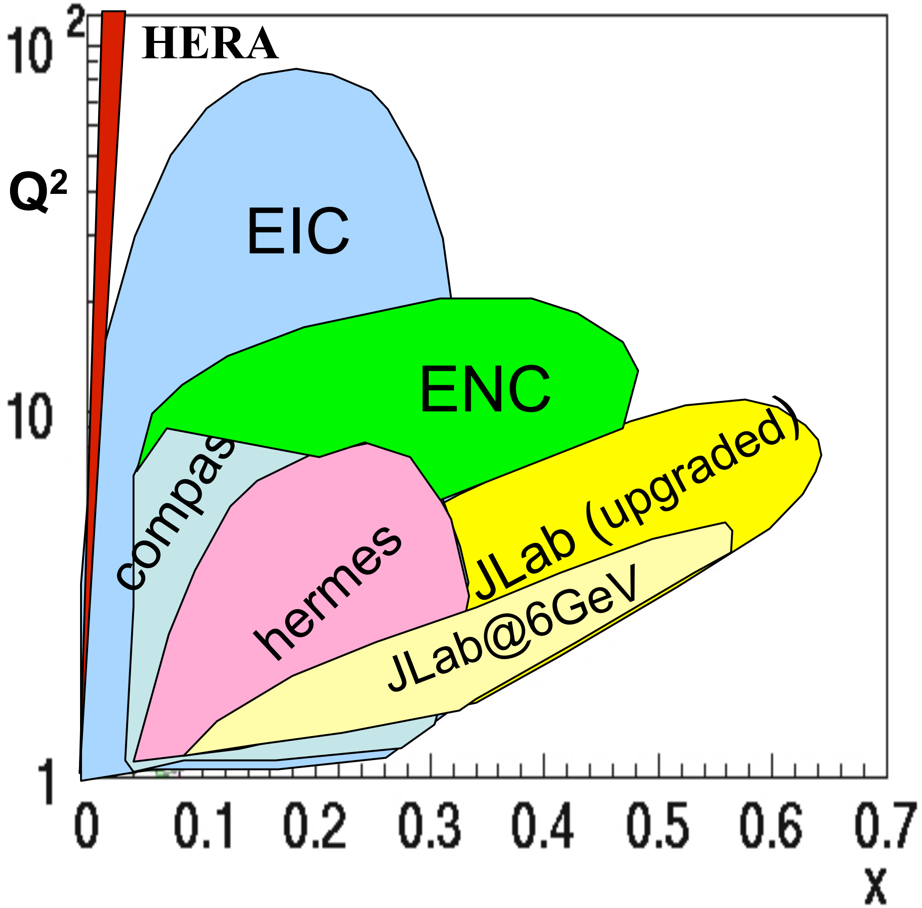
HERA:
very small x, large Q^2

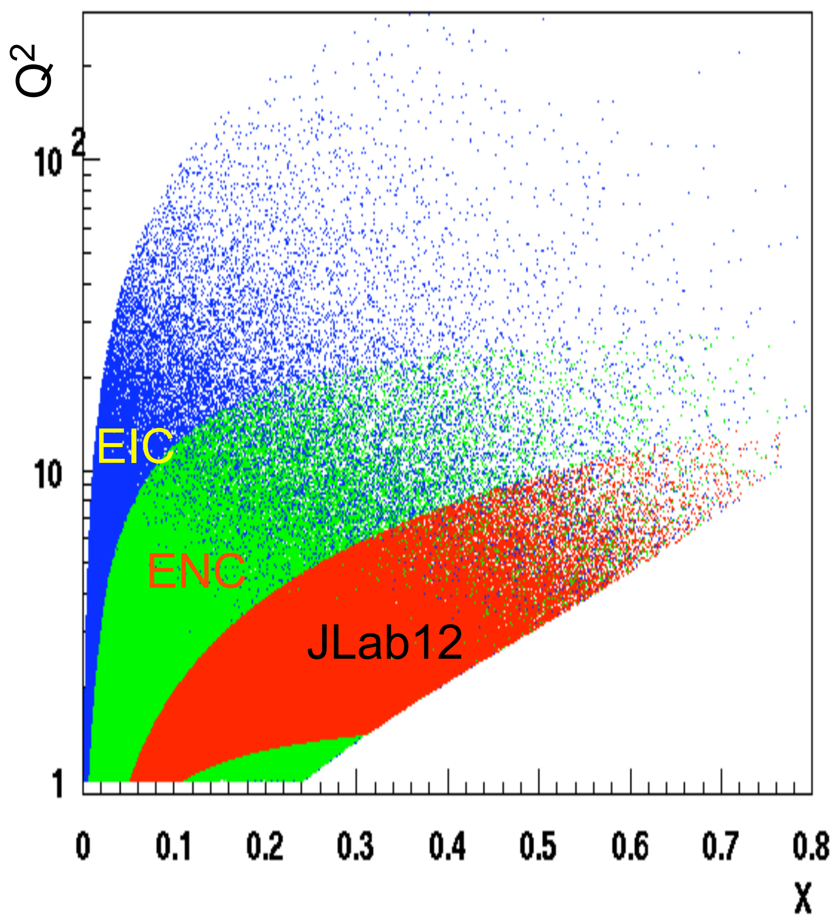
JLAB 6/12 GeV
large x, limited Q^2

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

Electro Production Kinematics

Harut Avakian for EIC





Harut Avakian

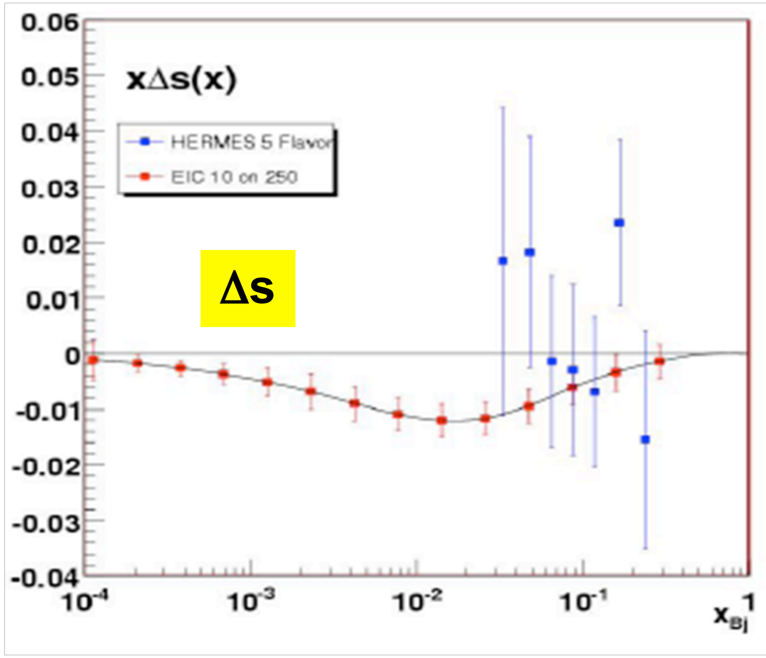
Feasibility Studies for EIC

- 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



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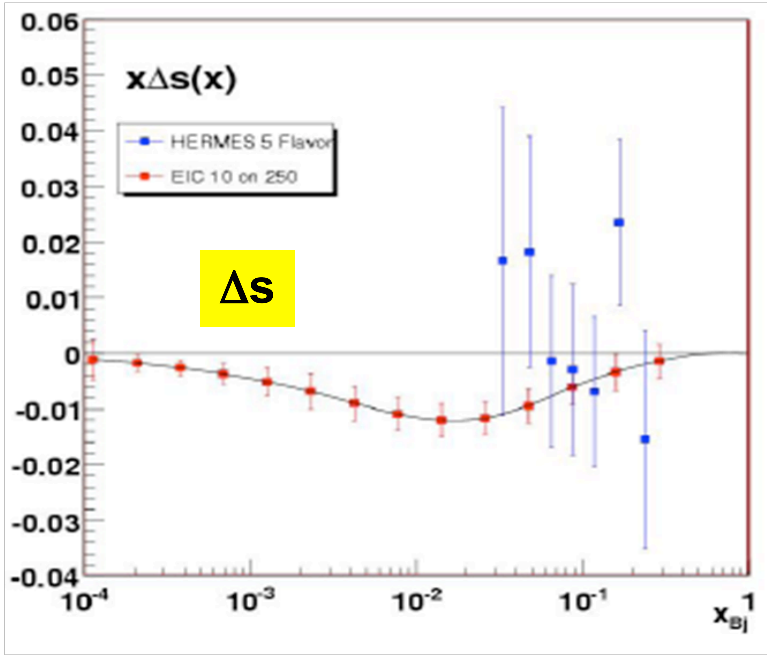
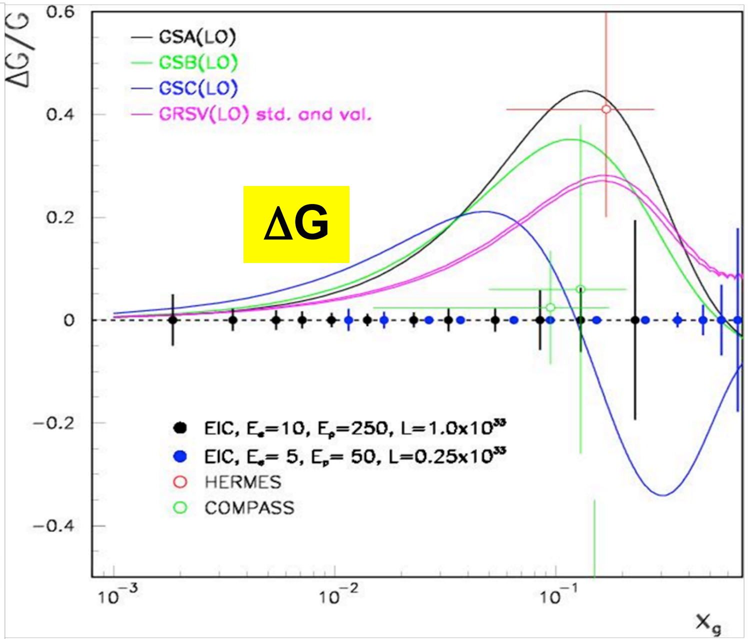
Harut Avakian

Feasibility Studies for EIC





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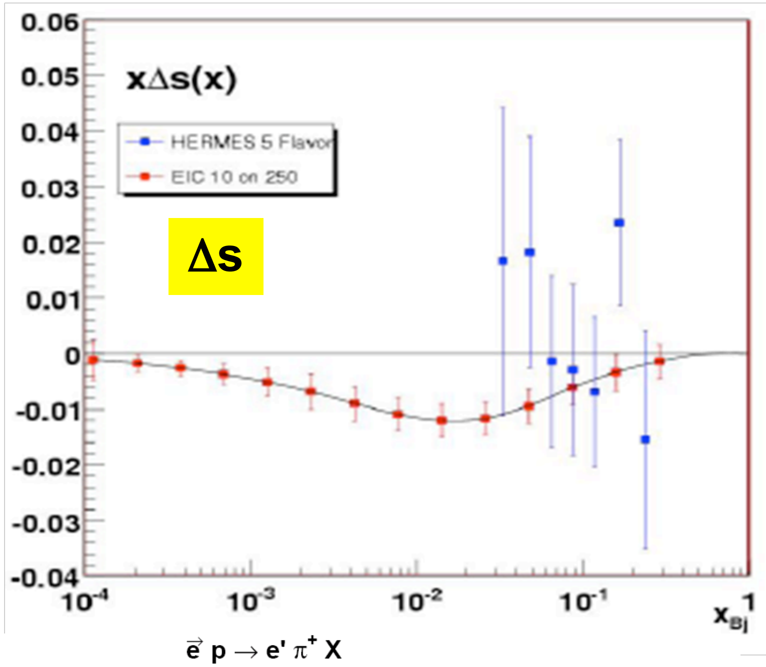
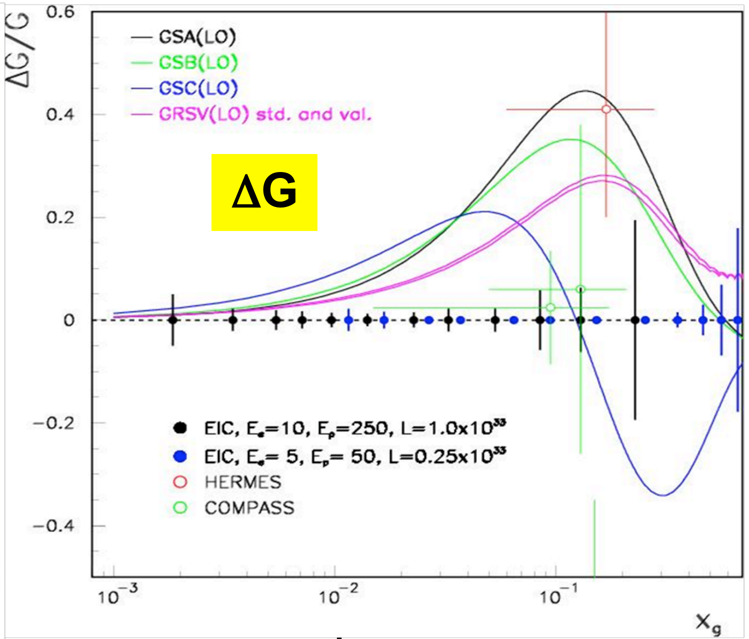
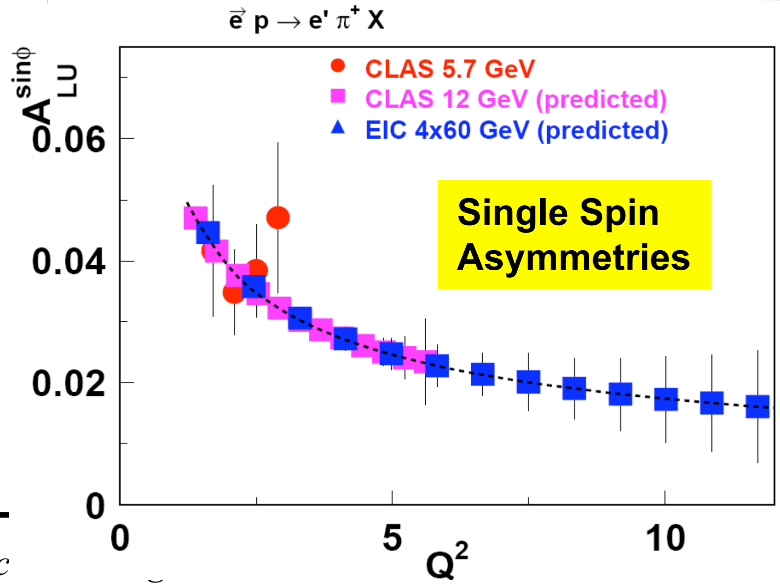
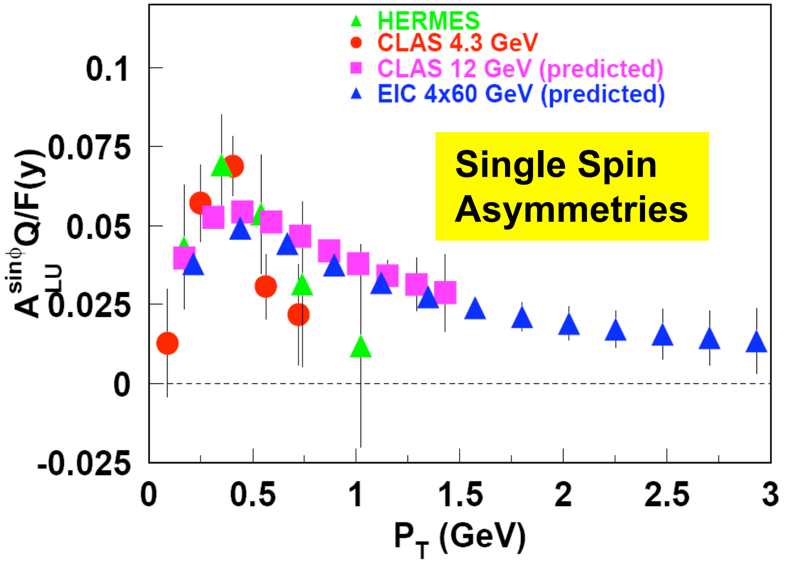
Harut Avakian

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: $\delta F_2/\delta \ln Q^2$
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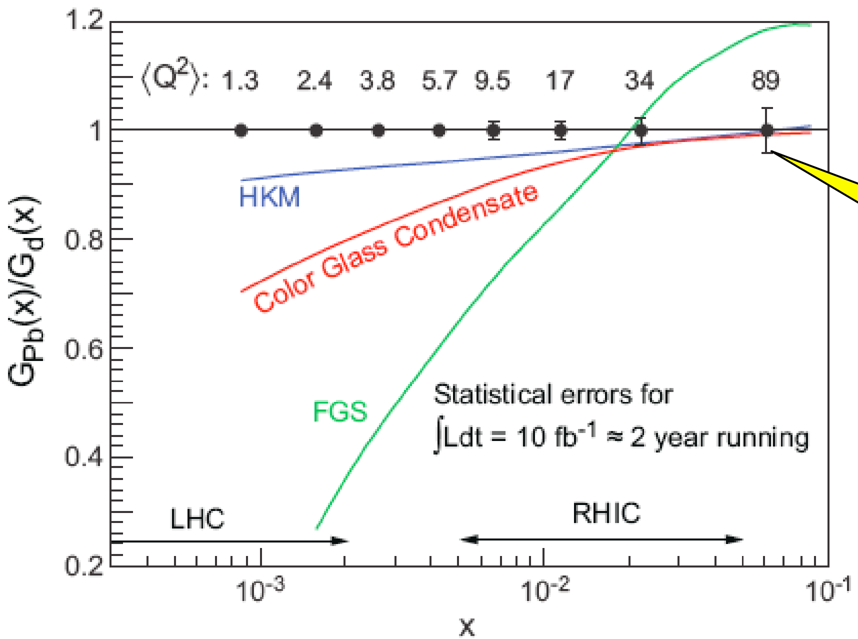
  - ➡ 2+1 jet rates
  - ➡ Inelastic vector meson production (*e.g.* J/ψ)
  - ➡ Diffractive vector meson production ~ $[xG(x,Q^2)]^2$

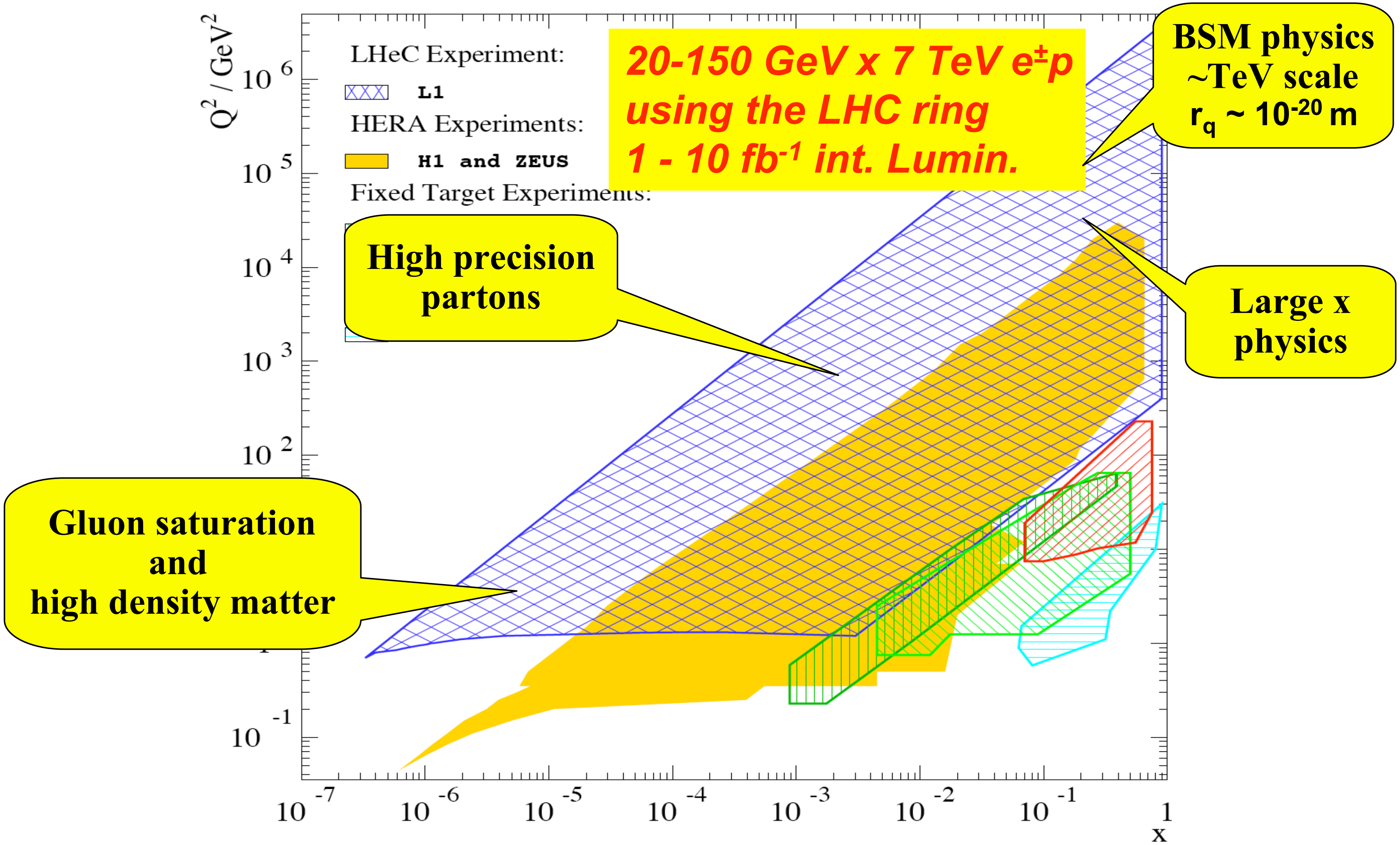
Gluon saturation regime can be studied in eA with 10 ... 100 smaller c.m.s. energy wrt. ep: nucl. enhancement $Q_s^2 \sim \tilde{A}^{1/3}$



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

High Energy Frontier: LHeC

Uwe Schneekloth
Olaf Behnke



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

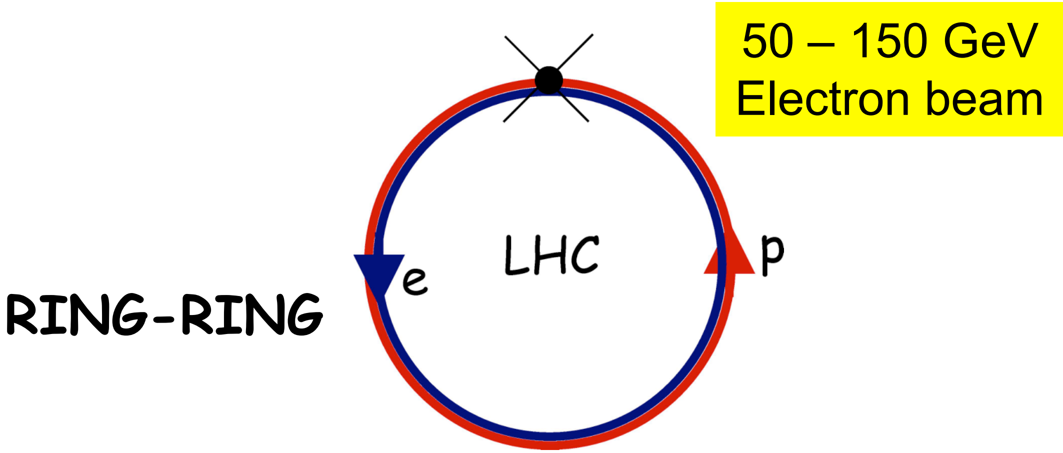
- International community seeking to realize a high luminosity electron-ion collider for studying QCD.
- Four concepts are being pursued at present:

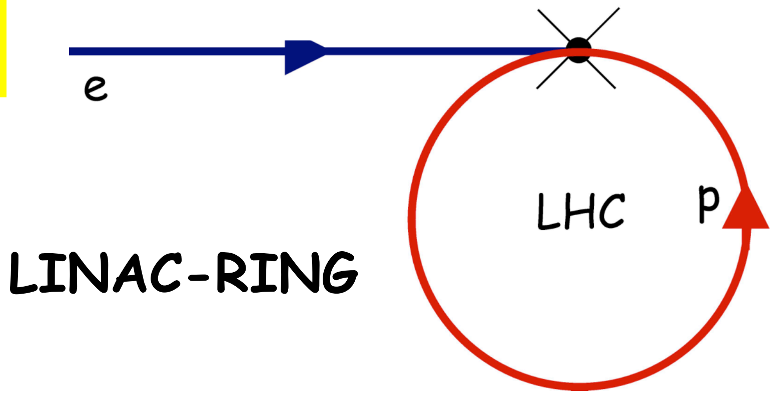
  BNL/eRHIC, CERN/LHeC, GSI/ENC, JLab/ELIC
- Different designs and energies complementary in physics scope.
- Cooperation btw. different design studies desirable, competition as well.


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

Uwe Schneekloth

High Energy Frontier: LHeC



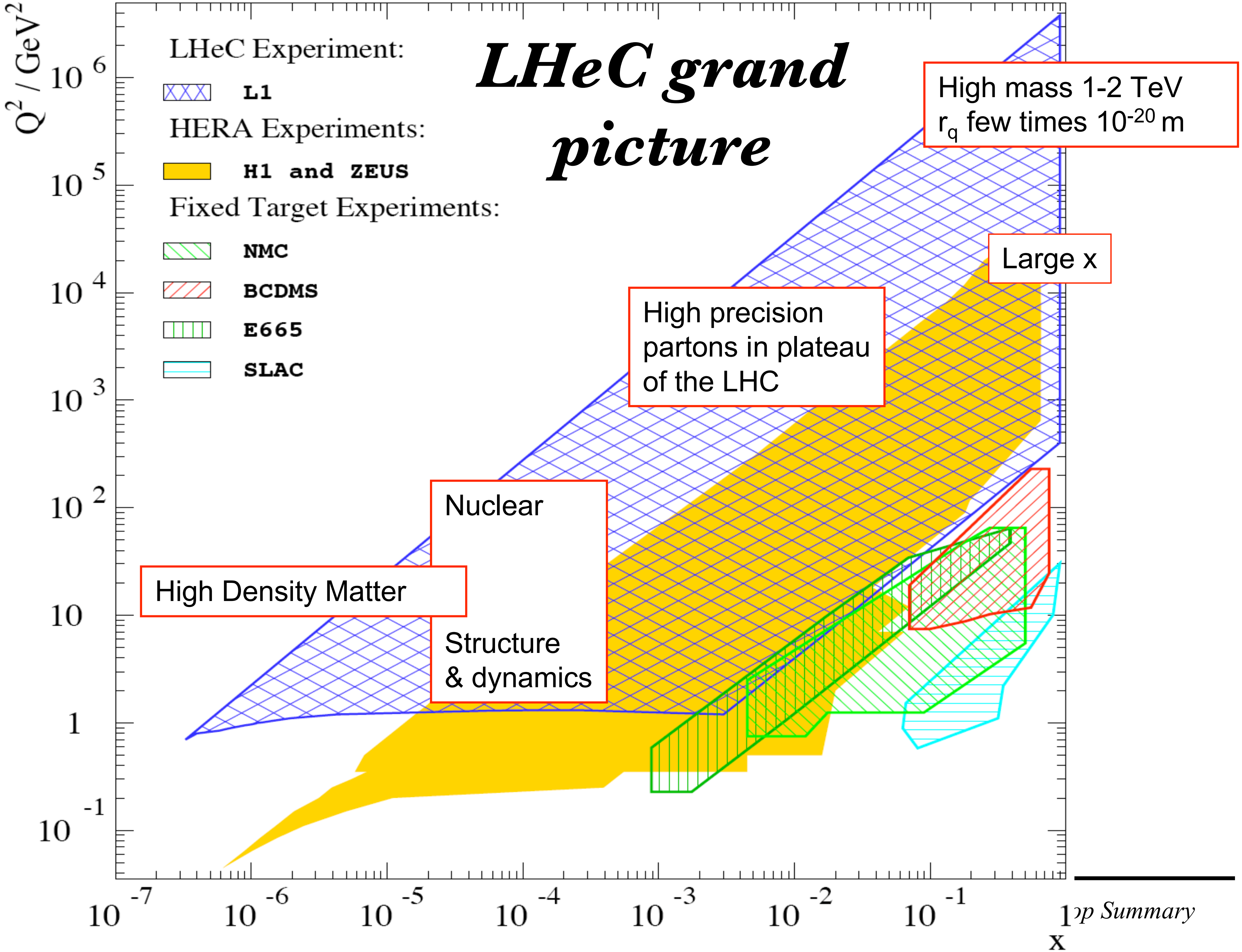


- Lots of experience: HERA, LEP and LHC
- Electron ring inside LHC tunnel
- Proven technology
- Electron energy about 70 GeV
- Luminosity $8.2 \cdot 10^{32}$ to $1.4 \cdot 10^{33}$ cm^{-2} s^{-1}
- Need few km (~ 2km) of new tunneling

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



LHeC grand picture
High mass 1-2 TeV
r_q few times 10^{-20} m
Large x
High precision partons in plateau of the LHC
Nuclear
Structure & dynamics
High Density Matter
LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
Q^2 / GeV^2
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

ɔp Summary

ENC / EIC Collider Workshop @ Milos EINN09
Electromagnetic Interactions with Nucleons and Nuclei

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

(1) Projects and physics overview — SUNDAY
Chair: Achim Denig

1.1 Electron Ion Collider (eRHIC, ELIC)	13:45 – 14:30	Vladimir Litvinenko (BNL)
1.2 ENC@FAIR	14:30 – 15:15	Andreas Lehrach (FZ Jülich)
BREAK		
1.3 Open Questions – Theory view	15:45 – 16:30	Daniel de Florian (Buones Aires)
1.4 Open Questions – Experimental view	16:30 – 17:15	Dietrich von Harrach (Mainz)
General discussion	**from 17:15**	

(2) Perspectives — MONDAY
Chair: Marc Vanderhaeghen

2.1 Feasibility Studies ENC	9:15 – 9:50	Jörg Pretz (Bonn)
2.2 Feasibility Studies EIC Nucleon Prog	9:50 – 10:25	Harut Avakian (JLAB)
2.3 Feasibility Studies EIC Ion Prog.	10:25 – 11:00	Matt Lamont (BNL)
BREAK		
2.4 HERA experiences: Physics Aspects	11:30 – 12:05	Burkard Reisert (MPI Munich)
2.5 Theory Tools (Rad. Corrections)	12:05 – 12:40	Hubert Spiesberger (Mainz)

(3) High energies and BSM aspects — TUESDAY
Chair: Dietrich von Harrach

3.1 HERA ep Interaction Regions	9:15 – 9:55	Uwe Schneekloth (DESY)
3.2 Parity violation and BSM Aspects	9:55 – 10:40	Krishna Kumar (Amherst)
BREAK		
3.3 LHeC Machine	11:10 – 11:55	Uwe Schneekloth (DESY)
3.4 LHeC Physics Program	11:55 – 12:40	Olaf Behnke (DESY)
General discussion	**from 12:40**	

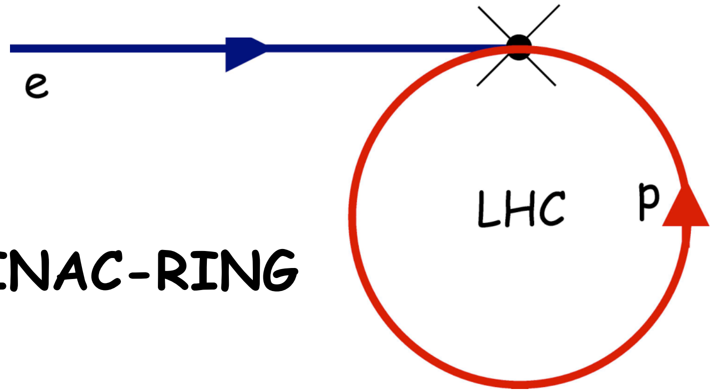
The future after EIC: LHeC

Uwe Schneekloth

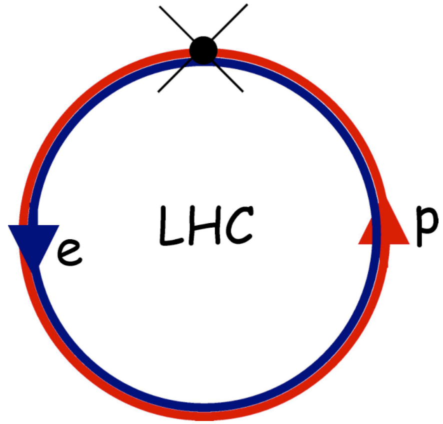
The LHeC Collider

50 – 150 GeV
Electron beam

LINAC-RING



RING-RING



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- Staged construction possible
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- Maximum luminosity 2-3·10^{32} $cm^{-2}s^{-1}$
- In principle, energy recovery could boost luminosity above 10^{34}, but so far only demonstrated at low energies

Challenging design

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- Proven technology
- Electron energy about 70 GeV
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Conceptual design quite advanced!

Vladimir Litvinenko

Staged Version MELIC

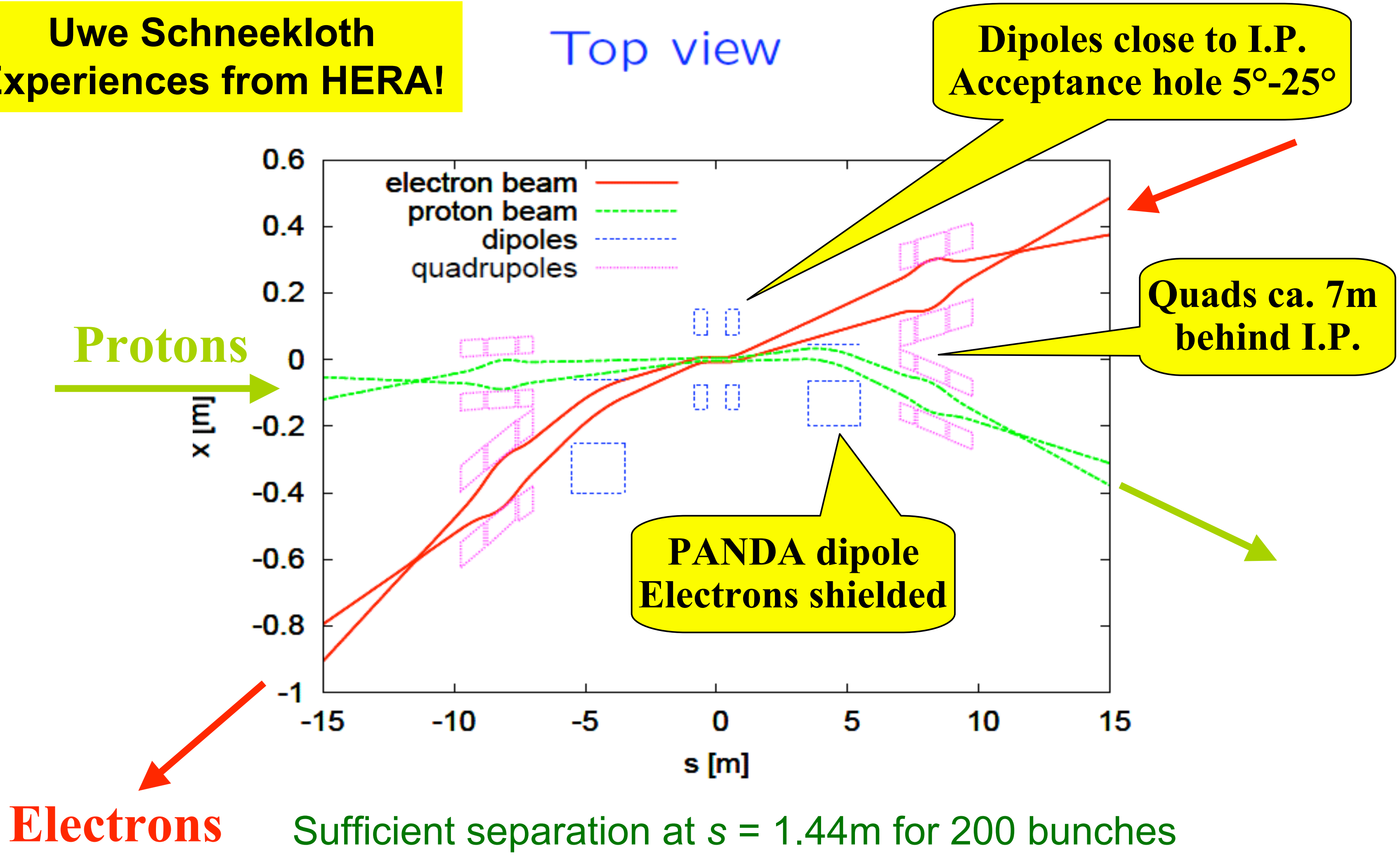
- At present, we regard a high luminosity low-to-medium energy EIC (from 12x3 GeV up to 60x11 GeV), MEIC, as the *next goal* for the EIC project at Jefferson Lab, and will keep the full energy EIC (250x10 GeV) as an upgrade option.
- MEIC seems to provide not only a rich & broad science program, but also a nicer balance between nuclear science, detector & accelerator R&D, and project cost.

Level of R&D	Low-to-Medium Energy (12x3 GeV/c) & (60x5 GeV/c)	High Energy (up to 250x10 GeV)
Challenging		Electron cooling
Semi Challenging	Electron cooling Traveling focusing (for very low ion energy)	Crab crossing/crab cavity
Likely	Crab crossing/crab cavity High intensity low energy ion beam Beam-beam	High intensity low energy ion beam Beam-beam
Know-how	Spin tracking IP design/chromaticity	Spin tracking IP design/chromaticity

Andreas Lehrach

ENC Interaction Region

Uwe Schneekloth
Experiences from HERA!



Sufficient separation at s = 1.44m for 200 bunches
$\beta_{x,y}{}^{*}$= 0.3m

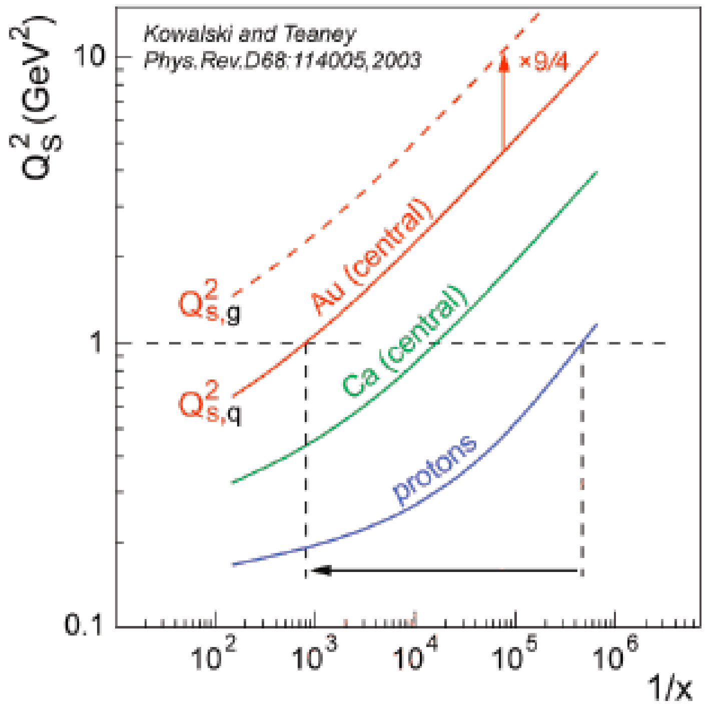
C. Montag, BNL

The Nuclear Enhancement Factor

$$Q_s^2 \propto \frac{\alpha_s x G(x, Q_s^2)}{\pi R_A^2} \qquad \mathrm{HERA:}\ \ xG \propto \frac{1}{x^{1/3}} \qquad \mathrm{A\ dependence:}\ \ xG_A \propto A$$

Nuclear Enhancement Factor: $$(Q_s^A)^2 \approx c\, Q_0^2 \left(\frac{A}{x}\right)^{1/3}$$

Enhancement of Q_S with A: $\Rightarrow$ non-linear QCD regime reached at significantly lower energy in e+*A* than in *e+p*



One would require an energy in e+p ~ 10-100 x e+A to get to same Q^2_S

Precision measurements from HERA

- inclusive NC & CC cross sections
- structure functions
- parton densities

Many more not shown:
QCD-Jets, Diffraction,
Exclusive vector mesons,
DVCS, searches BSM limits …

Issues:

- valence quarks constrained by NC & CC at high Q^2
  d_v will remain less precise than u_v
- sea quarks obtained from F_2 at low x
  possibility of an asymmetric light flavor sea $\bar{d}-\bar{u}\neq 0$
- gluons from scaling violations, F_L, jets, vector mesons, $c\bar{c}$ $b\bar{b}$
  ultimately precision to be seen, final uncertainty at high x?
- high x: extrapolating towards $x\rightarrow 1$
  How to assess uncertainties?
- low x: When does the strong rise saturate?

Major Tasks and Extensions

Beam dynamics simulations:

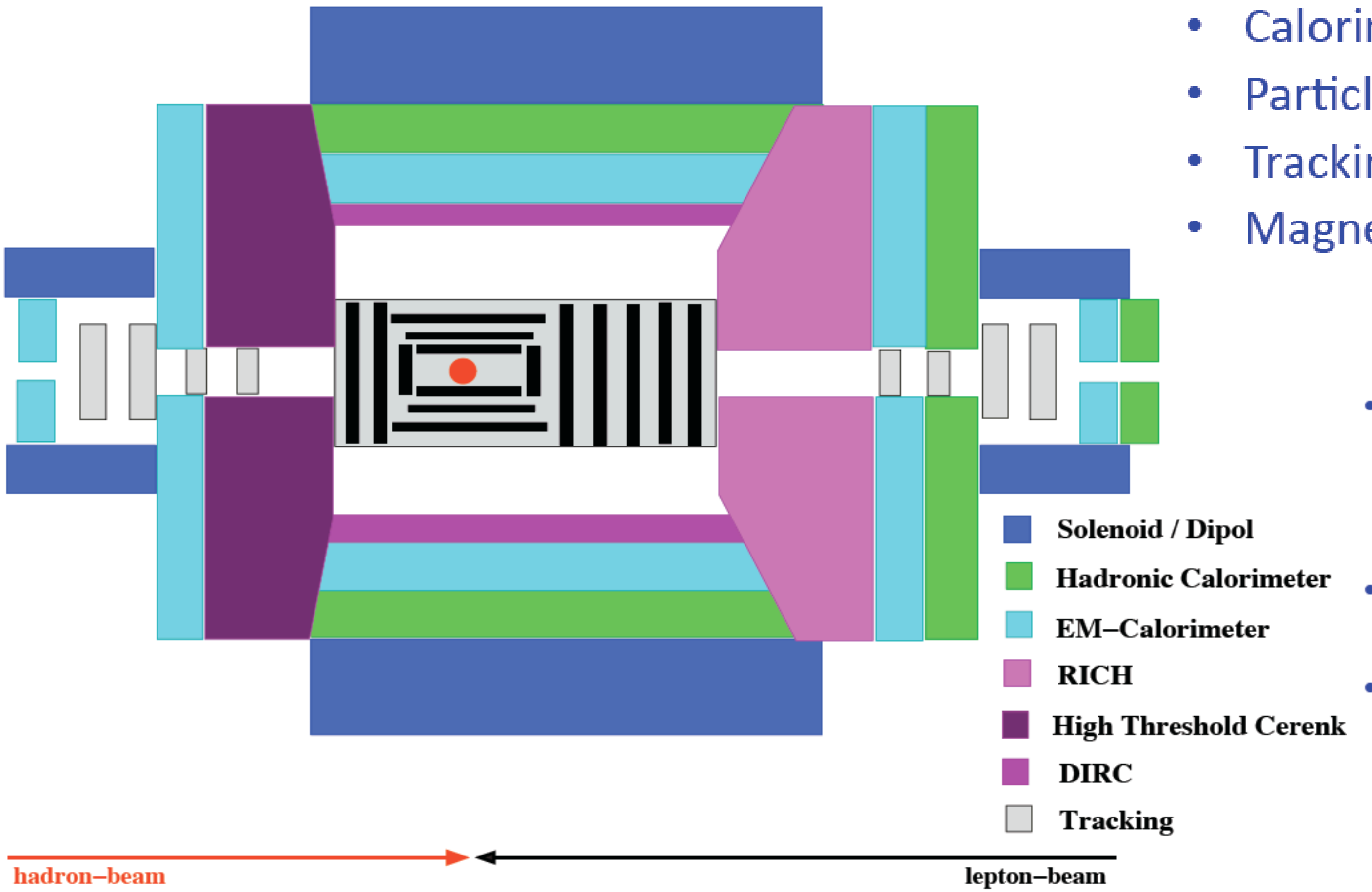
- Lattice for electron ring
- Accumulation, acceleration and bunching process in HESR
- Ion-optics at IP / detector integration / Crab crossing
- Chromaticity correction
- Beam – beam effect in low energy e-n collider
- Space charge for protons / deuterons

Hardware extensions and modifications:

- Polarized electron injector and ring
- Modification of the interaction region
- Extension of the electron cooler
- Additional 52 - 104 MHz, 300 kV cavity required

Harut Avakian

EIC Detector



- Calorimetry (EM & Hadronic)
- Particle ID (RICH, TRD ….)
- Tracking (central & forward)
- Magnets

- Tracking, calorimetry for very forward physics (low x, and low Q^2)
  - Diffraction
- Particle ID, spectrometer using beam elements
- Radiation hard, resistence

Wide kinematic coverage and large acceptance would allow studies of hadronization both in the target and current fragmentation regions

Vladimir Litvinenko

Staging of eRHIC

- **MeRHIC**: Medium Energy electron-Ion Collider
  - 90% of ERL hardware will be used for full energy eRHIC
  - Possible use of the detector in eRHIC operation
- **eRHIC – High energy and luminosity phase**
  - **Based on present RHIC beam intensities**
  - With coherent electron cooling requirements on the electron beam current is 50 mA
  - 20 GeV, 50 mA electron beam losses 4 MW total for synchrotron radiation.
  - 30 GeV, 10 mA electron beam loses 4 MW for synchrotron radiation
  - Power density is <2 kW/meter and is well within B-factory limits (8 kW/m)
- **eRHIC upgrade(s) if needed**

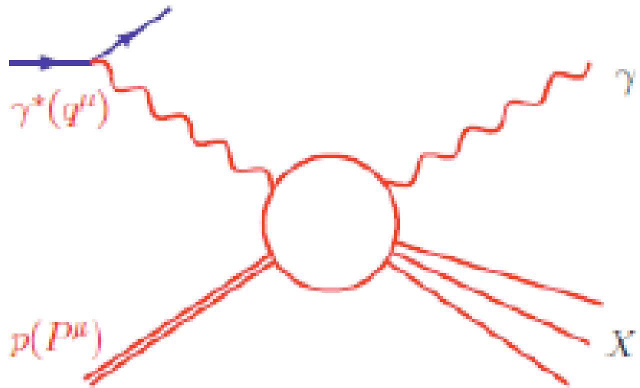
Hubert Spiessberger

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!