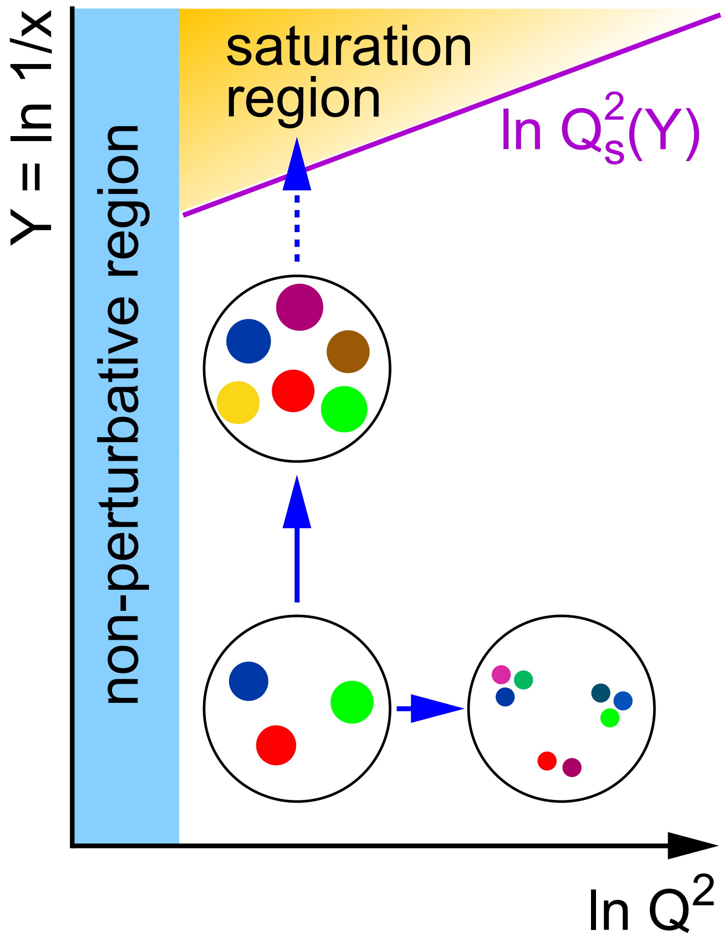

Investigation of Gluonic Structures

Henri Kowalski
DESY

4th of June 2010

using slides of

Thomas Ullrich (BNL)

BROOKHAVEN NATIONAL LABORATORY

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Gluon Factory Science Case

How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?

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- How gluons are shaping the forms of matter

Gluon Factory Science Case

How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?

- How gluons are shaping the forms of matter
  - Study the Physics of Strong Color Fields
    - Saturation region
    - Momentum & space distributions of the glue, what is the role of the glue in nuclei?
    - Spin of gluons $\Delta G(Q^2, x)$
    - precise study of the QCD evolution, what is the nature of color singlet excitations (Pomerons). Test and study the limits of universality (eA vs. pA)

Gluon Factory Science Case

How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?

- How gluons are shaping the forms of matter

EIC Science Case

EIC Science Case

- What is the internal landscape of the nucleons

EIC Science Case

- What is the internal landscape of the nucleons
  - What is the nature of the spin of the proton?
    - Spin of gluons $\Delta G(Q^2, x)$
    - Polarization of the sea quarks
    - Transverse spin and momentum measurements and correlations
  - What is the Three-Dimensional Spatial Landscape of Nucleons?
    - Transverse imaging of quarks and gluons in nucleons
    - Transverse momentum dependent measurements and correlations

EIC Science Case

- What is the internal landscape of the nucleons

EIC Science Case

- What governs the transition of quarks and gluons into pions and nucleons?
  - How do fast probes interact with the gluonic medium?
    - Energy loss of quarks and gluons
  - Mechanism of fragmentation?

  - Parity Violating deep inelastic scattering (PVDIS)
    - Quark helicity distributions
    - Isovector EMC effect
    - Potential ultraprecise weak mixing angle measurements
  - Lepton Flavor and Number Violation
    - Electron-tau lepton conversion

EIC Science Case

- What governs the transition of quarks and gluons into pions and nucleons?
  - How do fast probes interact with the gluonic medium?
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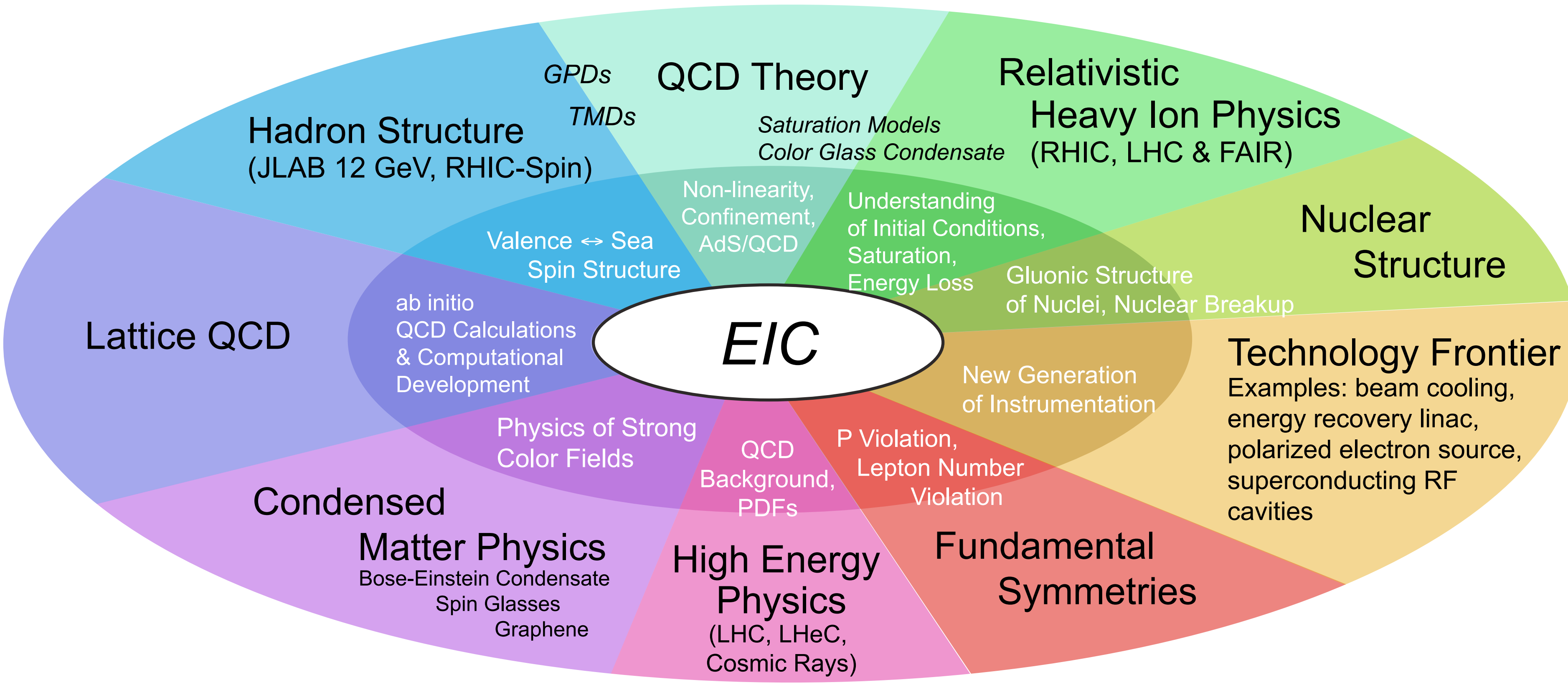
EIC Science Case

- What governs the transition of quarks and gluons into pions and nucleons?

EIC Science Case

How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?

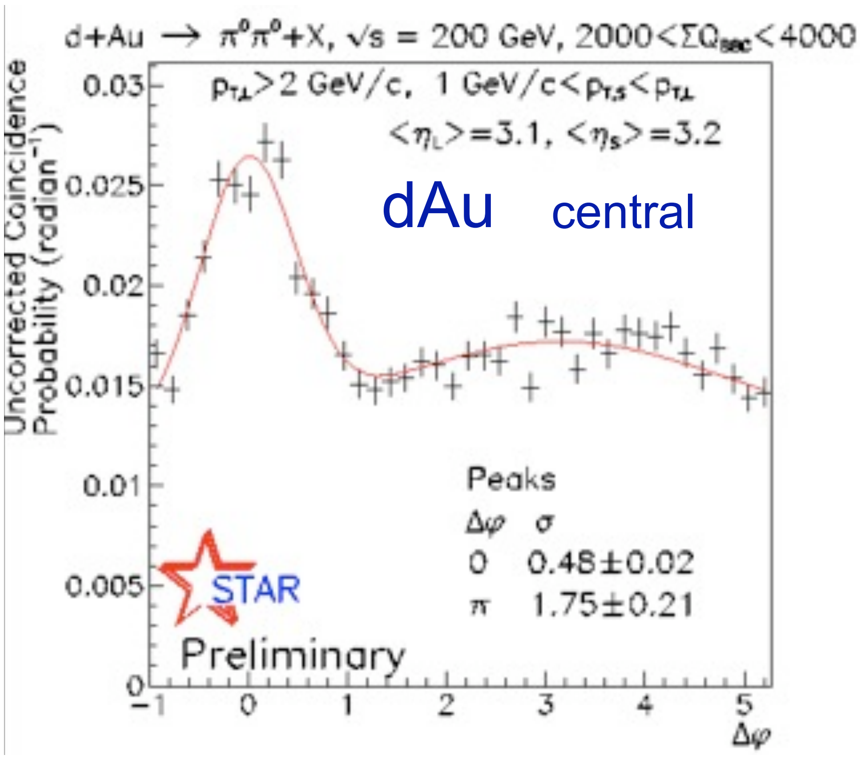
The machine presents a unique opportunity for fundamental physics:

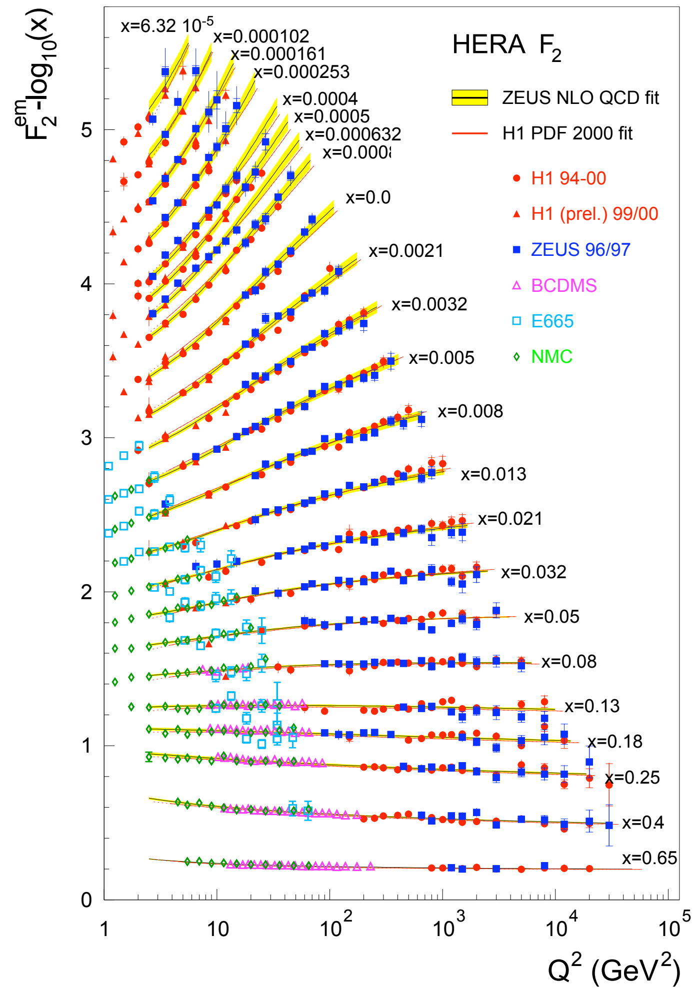


EIC - Reaching the Saturation Regime

Saturation:

- Au: Strong hints from RHIC at $x \sim 10^{-3}$
- p: Hints at Hera up to $x=6.32\cdot10^{-5}$, Q^2 = 1-5 GeV^2





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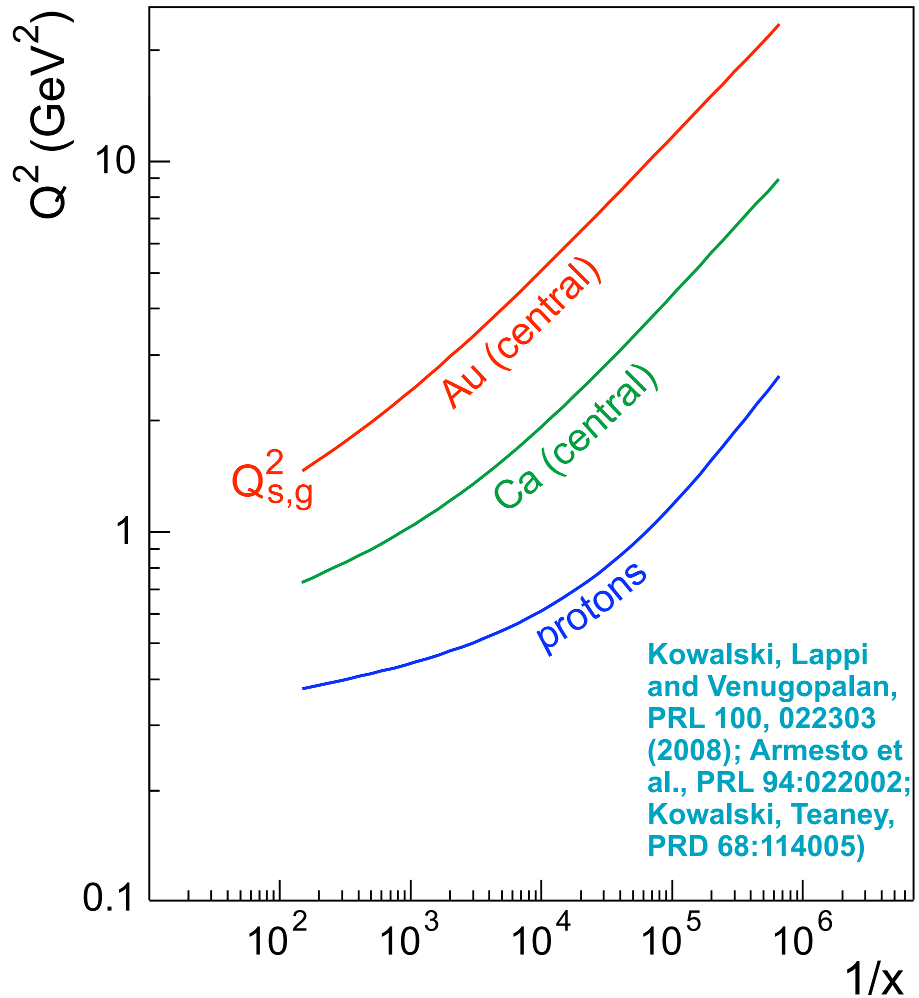
Nuclear Enhancement:

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



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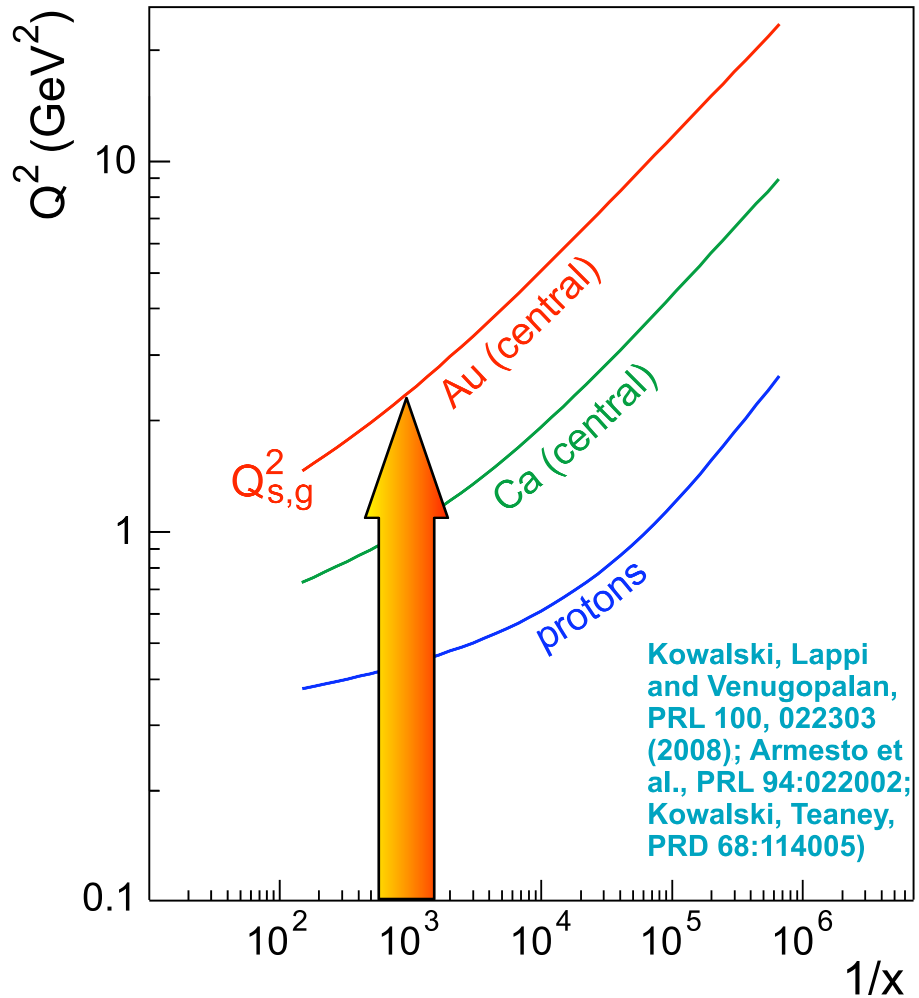

EIC - Reaching the Saturation Regime

Saturation:

- Au: Strong hints from RHIC at x ~ 10^{-3}
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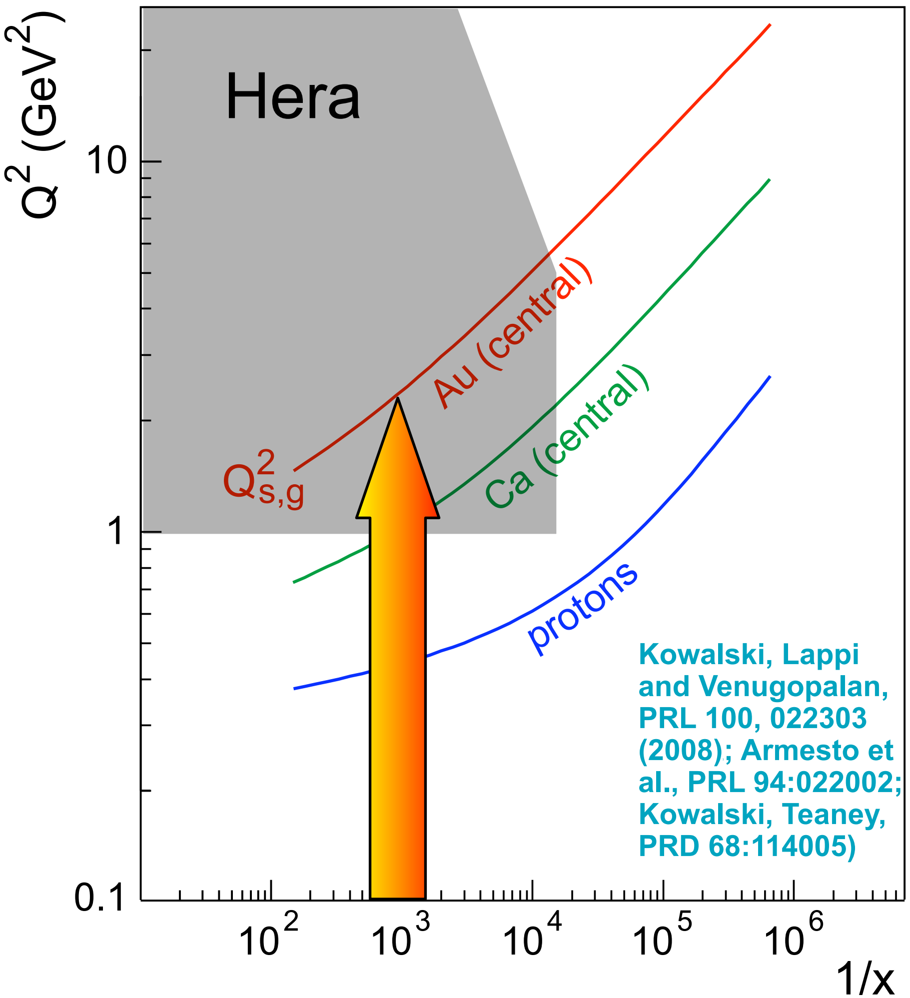
Nuclear Enhancement:

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



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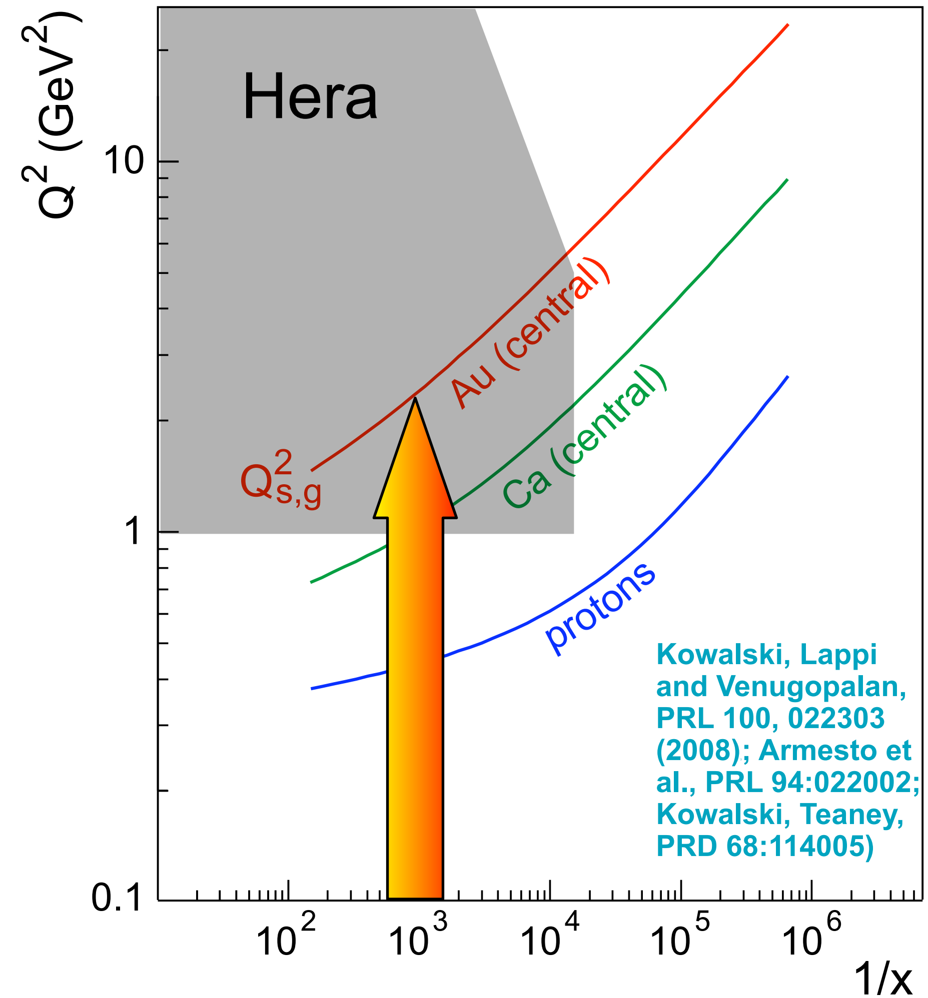
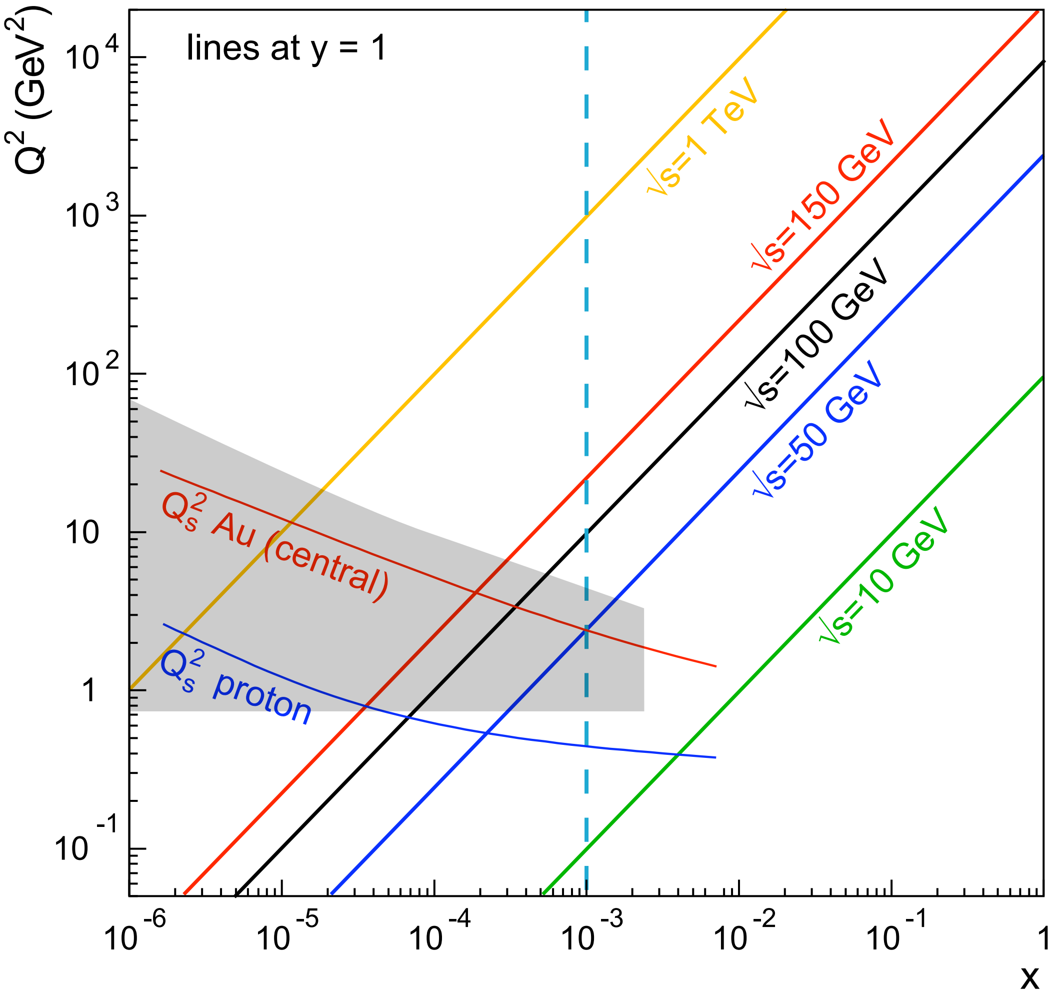
Nuclear Enhancement:

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

Finding RHIC and Hera & Q_s scalings consistent



EIC - Energy Requirements

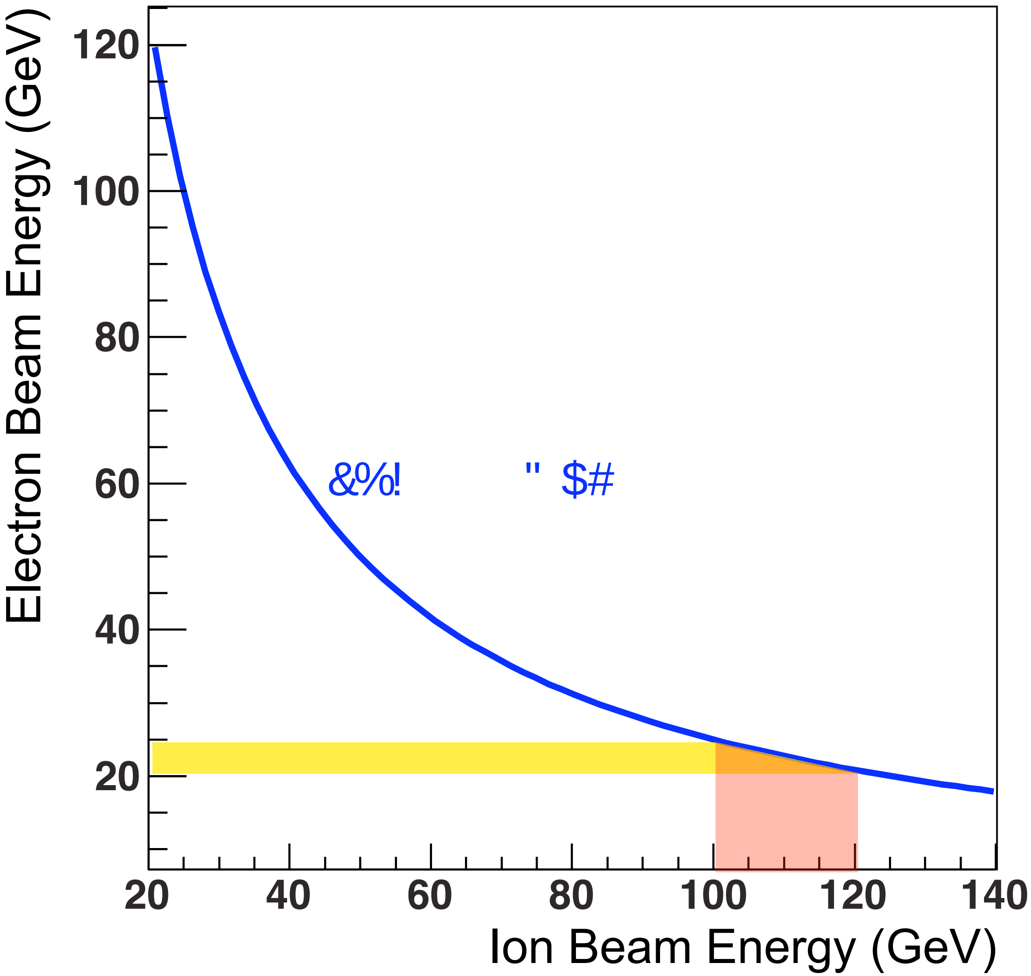


Coverage

- Need lever arm in Q^2 at fixed *x* to constrain models
- Need $Q > Q_s$ to study onset of saturation

- ep: even 1 TeV is on the low side
- eA: √s = 50 GeV is marginal, around √s = 100 GeV desirable

EIC - Energy Requirements



Coverage

- Need lever arm in Q^2 at fixed *x* to constrain models
- Need $Q > Q_s$ to study onset of saturation

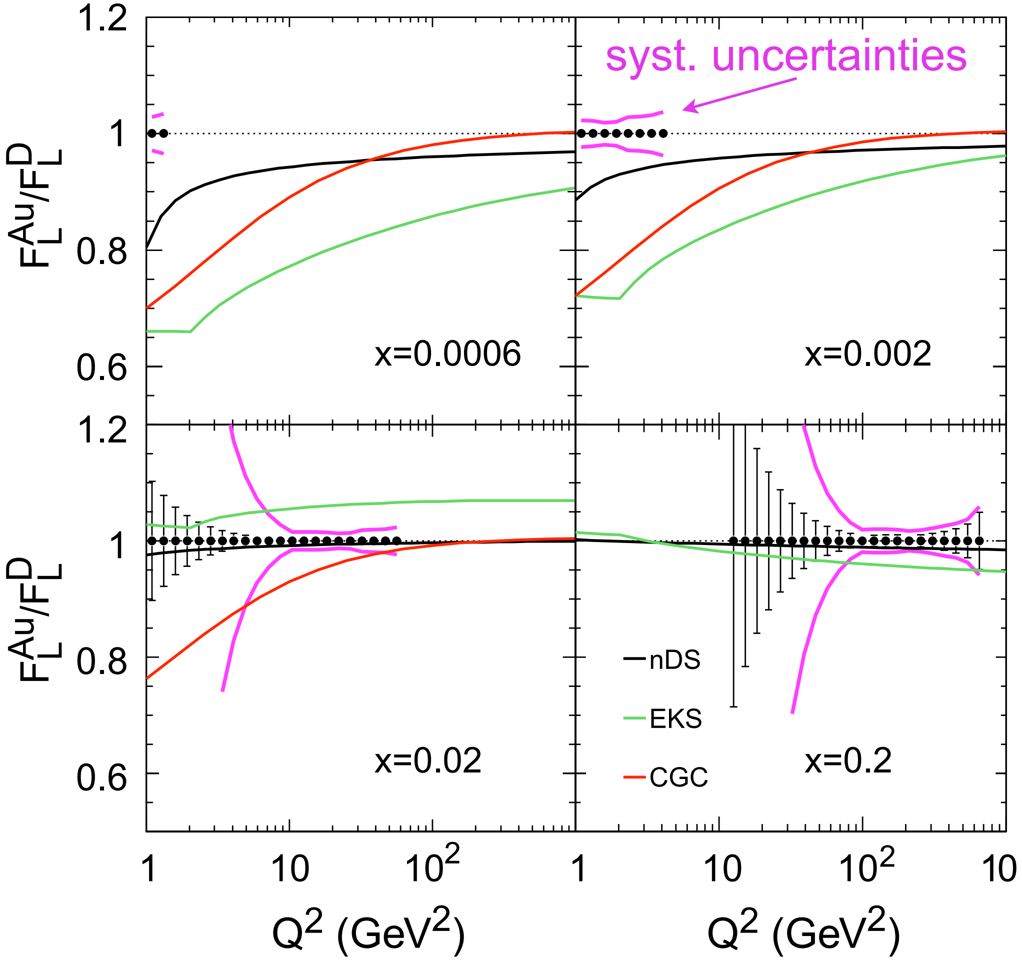
Current best estimate to study saturation:

Electron energy ~ 20 GeV x Ion Energy ~ 100 GeV

EIC - What Luminosity is Needed?

Hera suffered from low luminosity: $L = 1.6\text{-}3.8 \cdot 10^{31}$ cm^{-2} s^{-1}

EIC-Example F_L: *inclusive* measurements at different $\sqrt{s}$, assume 1% energy-to-energy normalization



$\int \mathcal{L}dt$ = 4/A fb^{-1} (10+100) GeV &
4/A fb^{-1} (10+50) GeV &
2/A fb^{-1} (5+50) GeV

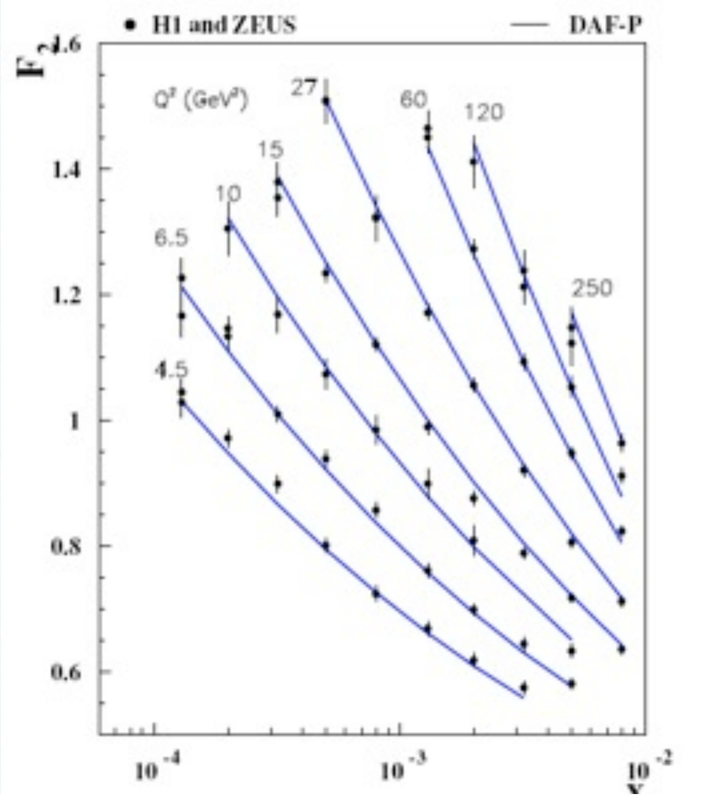
All together 10 weeks at $L \sim 4 \cdot 10^{33}$ cm^{-2} s^{-1} and 50% duty cycle
(Note: 100x Hera L)

Conclusion from this study:

- Dominated by sys. uncertainties
- More statistics does not provide higher accuracy

Pure BFKL description of the HERA F_2 data (above the saturation region) ➤ existence of the QCD-Pomeron ≡ set of quasi-bound states of two gluons

H. Kowalski, L.N. Lipatov, D.A. Ross and G. Watt
arXiv 1005.0355

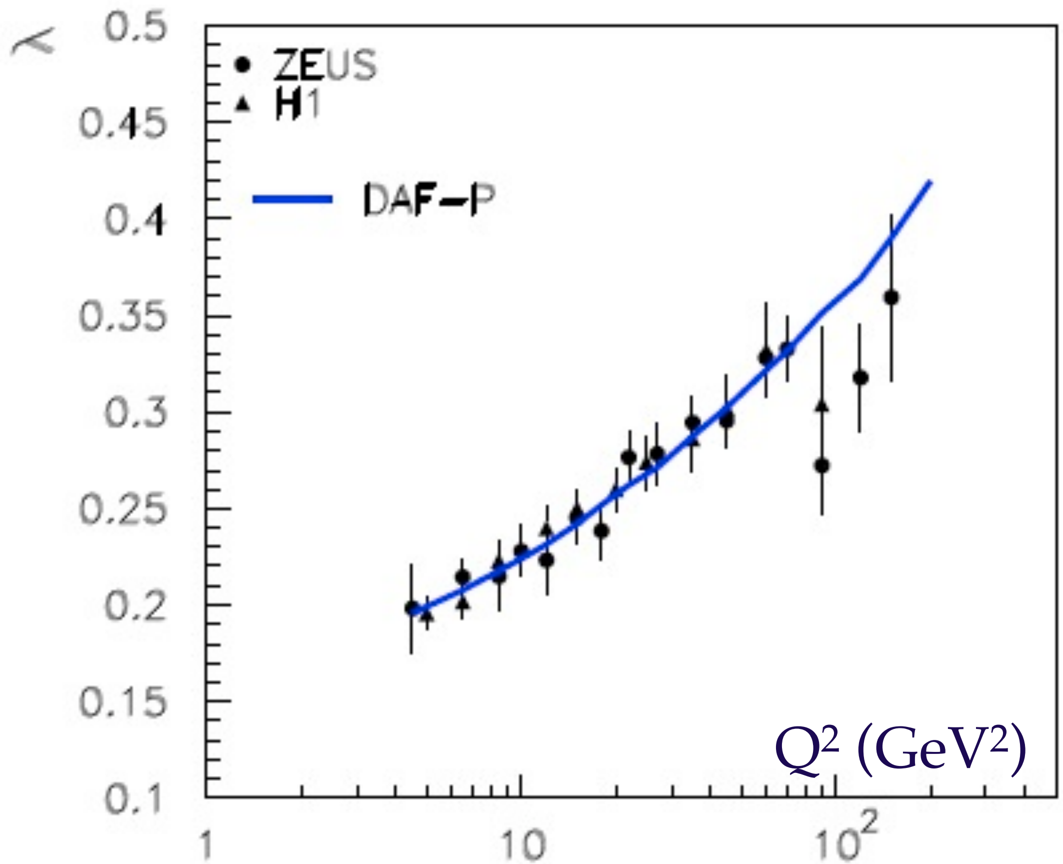


χ^2/N_{df}	κ	A	b
154.7 /125	0.65	1660	20.6

high precision of F_2 data is crucial for disentangling the Pomeron structure

The rate of rise λ

$F_2 \sim (1/x)^{\lambda}$



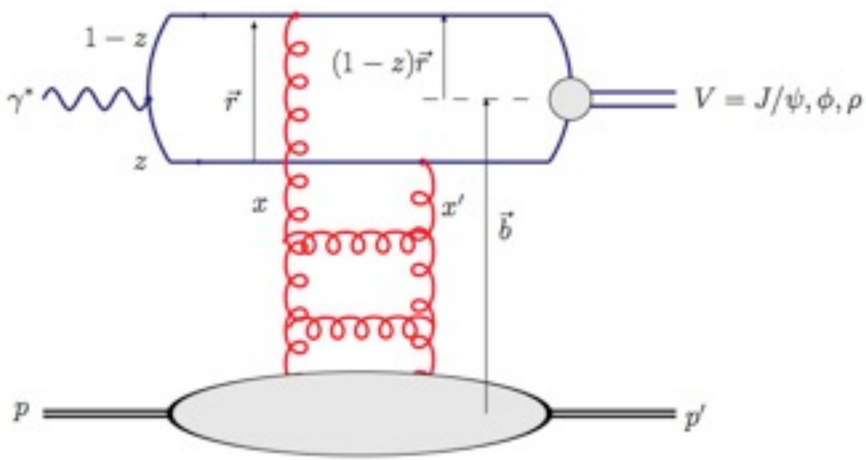
The first successful pure BFKL description of the λ plot.

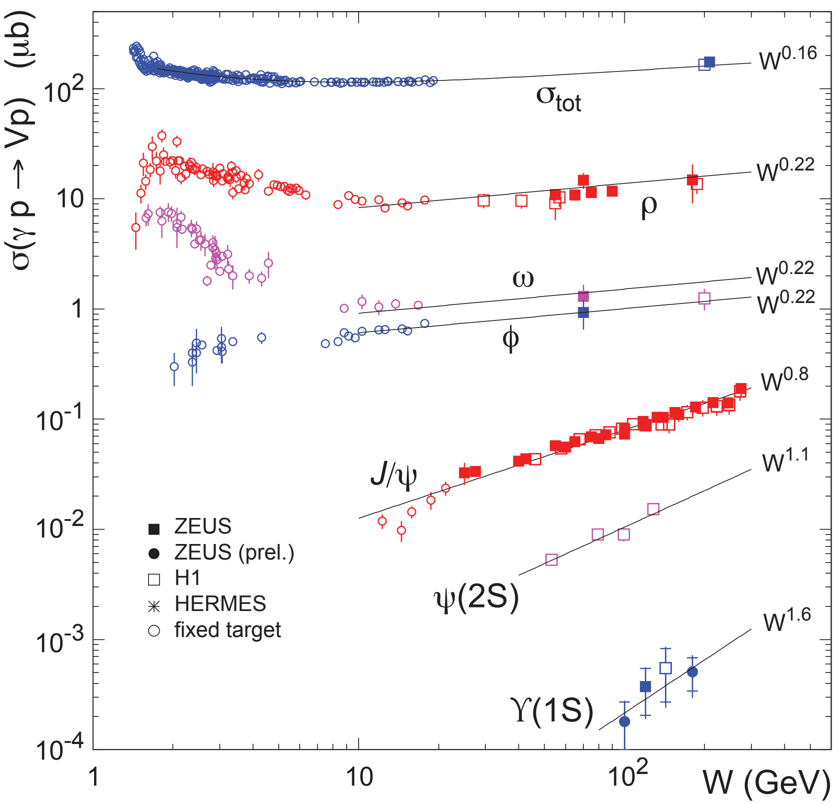
For many years it was claimed that BFKL analysis was not applicable to HERA data because of the observed substantial variation of λ with Q^2

Universality of the QCD-Pomeron
can be tested in diffractive reactions
measured with high precision
on proton and nuclei

EIC - What Luminosity is Needed?

Key measurement: exclusive diffractive vector meson production: e A → e' A' V





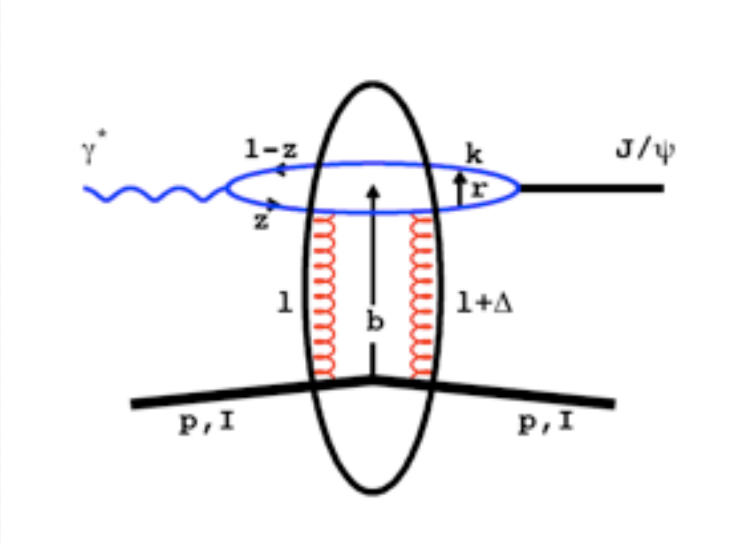
Sensitive means to probe $G(x,Q^2)$ and saturation: $\sigma \propto G(x,Q^2)^{2}$

$\sigma(x_{IP}, x, Q^2, t)$ double/triple differential & small σ

⇒ high L required (statistical >> systematic errors),

(DVCS even more L hungry → GPDs)

J/ψ p_T resolution at EIC or LHeC



In photoproduction, J/psi p_T is determined from p_T of ee or $\mu\mu$ decay pair

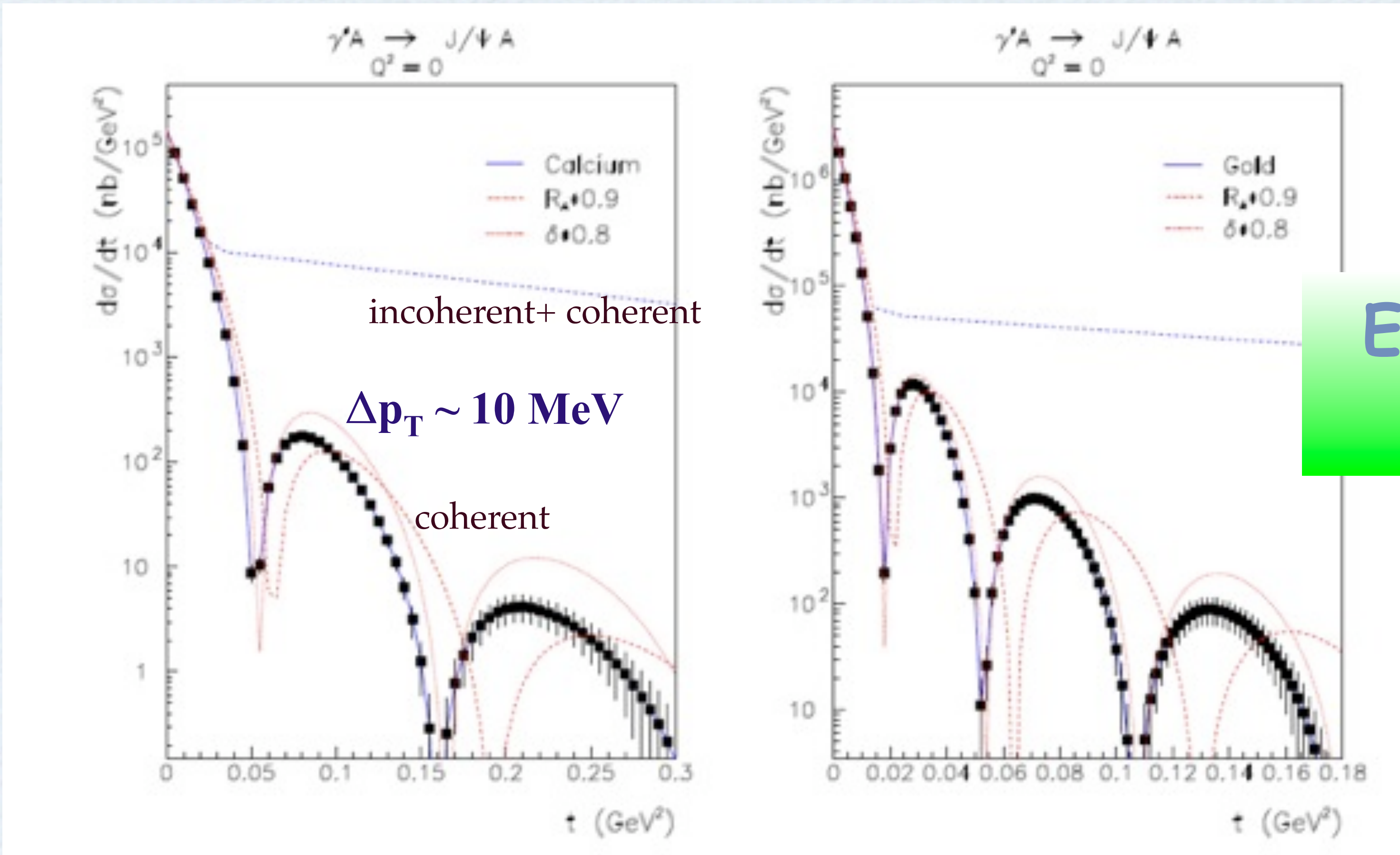
p_T resolution for J/psi - O(1) MeV for a TPC with 2m radius

no measurement of a proton or ion momentum necessary

beam electron p_T < 1 MeV (0.2 with cooling MeV) for E_e < 5 GeV

scattered electron can be easily detected in the forward detector

Nuclear gluonic shapes
Coherent and incohernt eA → J/ψA photoproduction



EIC ~ x^{-3}

Coherent - nucleus remains in the ground state
incoherent - nucleus gets excited or breaks up, no additional particles are produced

Nuclear gluonic shapes
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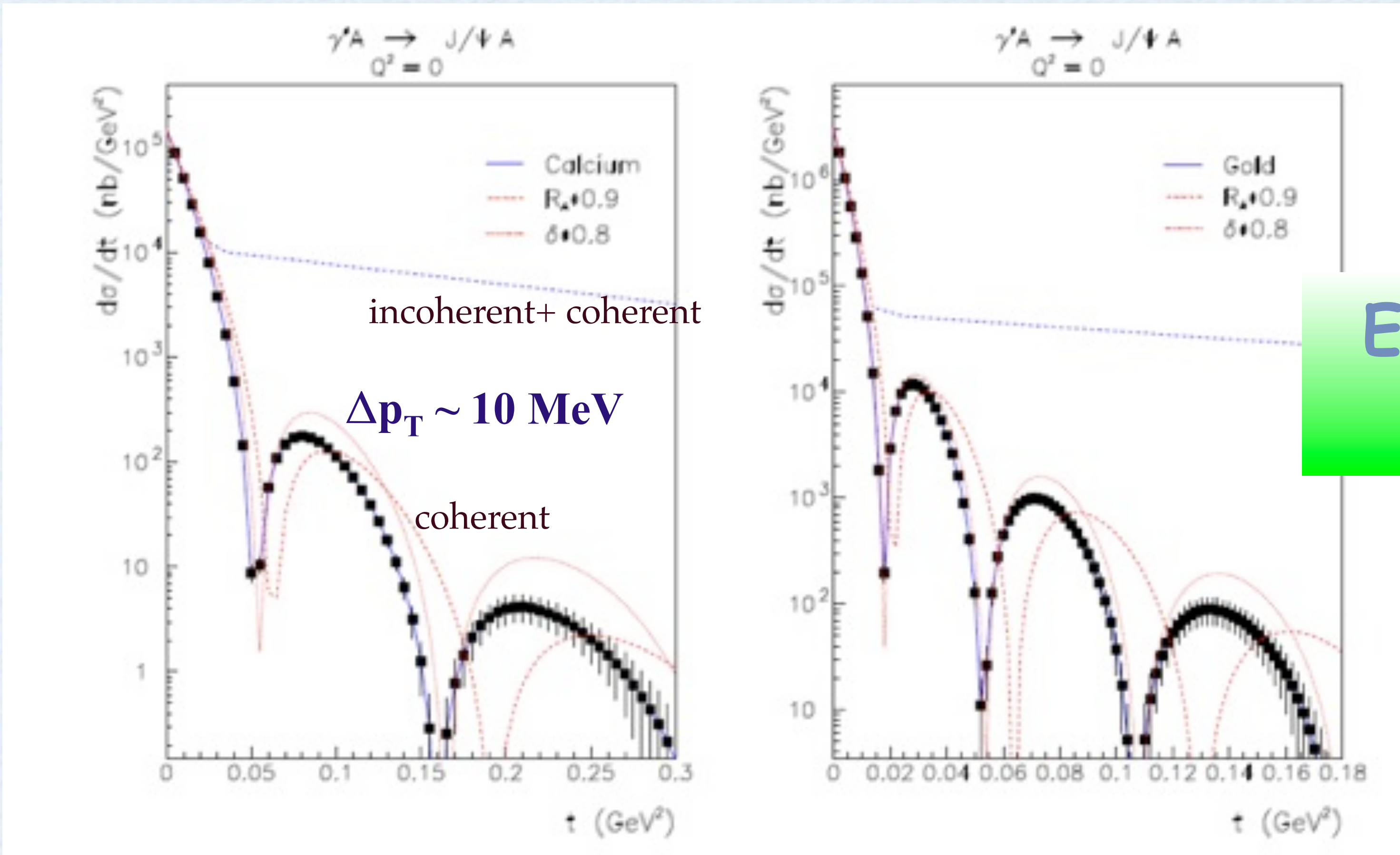


EIC ~ x^{-3}

Coherent - nucleus remains in the ground state

incoherent - nucleus gets excited or breaks up, no additional particles are produced

Forward em and had detectors required

Measurement of momenta of J/ψ decay muons

Expected resolution of drift chambers:

$$(\sigma_{p_t}/p_t)_{meas} = \frac{p_t\,\sigma_{r\phi}}{0.3L^2B}\sqrt{\frac{720}{N+4}}$$

$$(\sigma_{p_t}/p_t)_{MS} = \frac{0.05}{LB\beta}\sqrt{1.43\frac{L}{X_0}[1+0.038\log(L/X_0)]}$$

TPC parameters

1. outer radius R = 2 m
2. solenoidal field B = 3.5 T
3. gas density X0 = 450 m
4. point resolution σ = 100 μm
5. measurement N = 200 points.

meas *MS*

$$\sigma_{p_t}/p_t = 0.005\cdot p_t \oplus 0.045/\beta\ \%$$

⇓

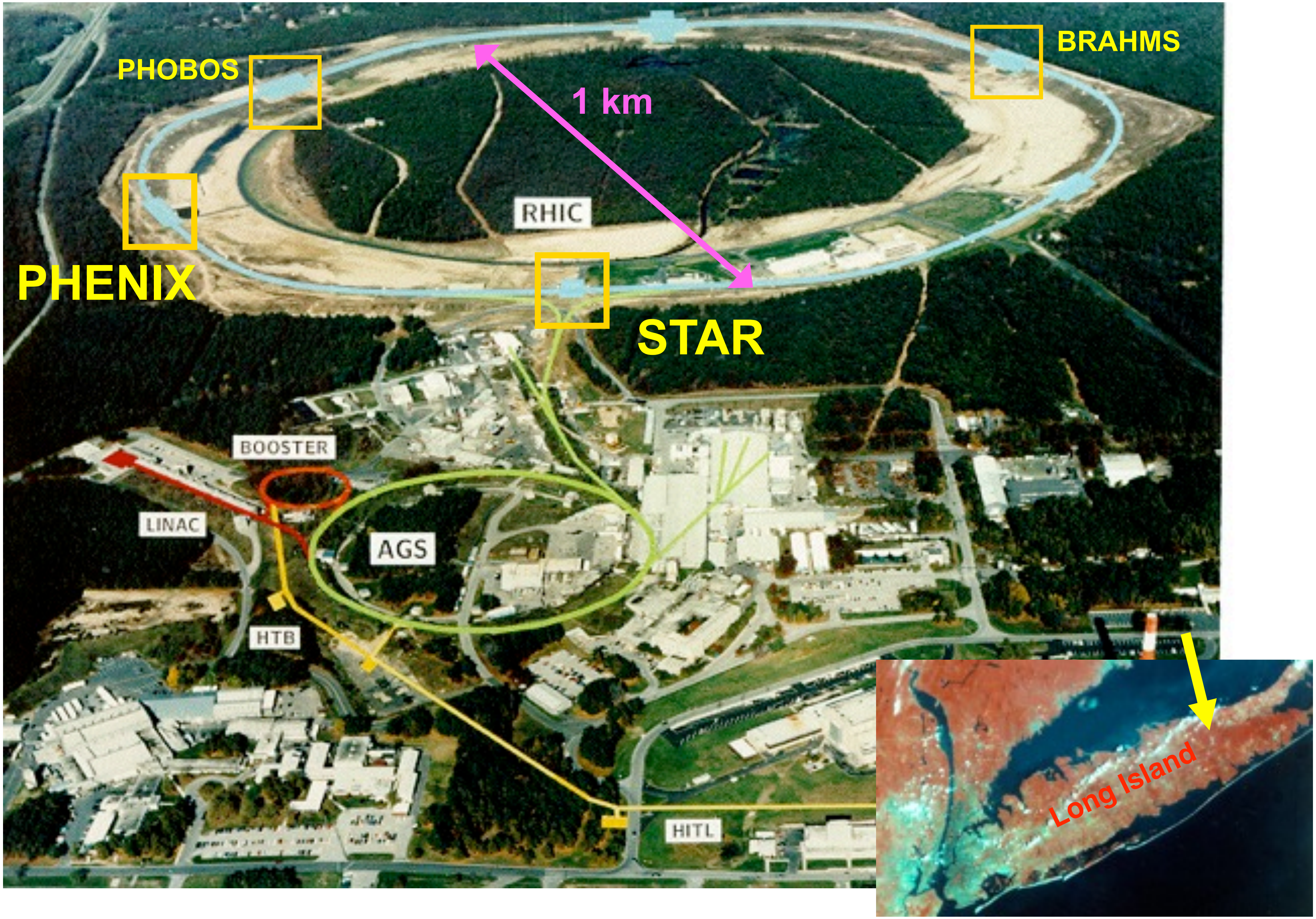
Δp_T < 1 MeV

EIC - Realization

High $\sqrt{s}$, high L machine: costs too high to build in one step ⇒ staged approach

- QCD Community: JLAB & RHIC
  - BNL: EIC Task Force, eRHIC-CAD
  - JLAB: User Group
- EIC Collaboration (http://web.mit.edu/eicc/)
  - Collaboration Meetings, Working Groups
  - Steering Committee
- International Advisory Committee
  - Members from broad community, chair: W. Henning
- EIC Concepts
  - eRHIC (RHIC/BNL)
  - ELIC (CEBAF/JLAB)
- Timeline: ~2020 (vital: NSAC Long Range Plan 2012/13)

EIC Concept: RHIC → eRHIC @ BNL

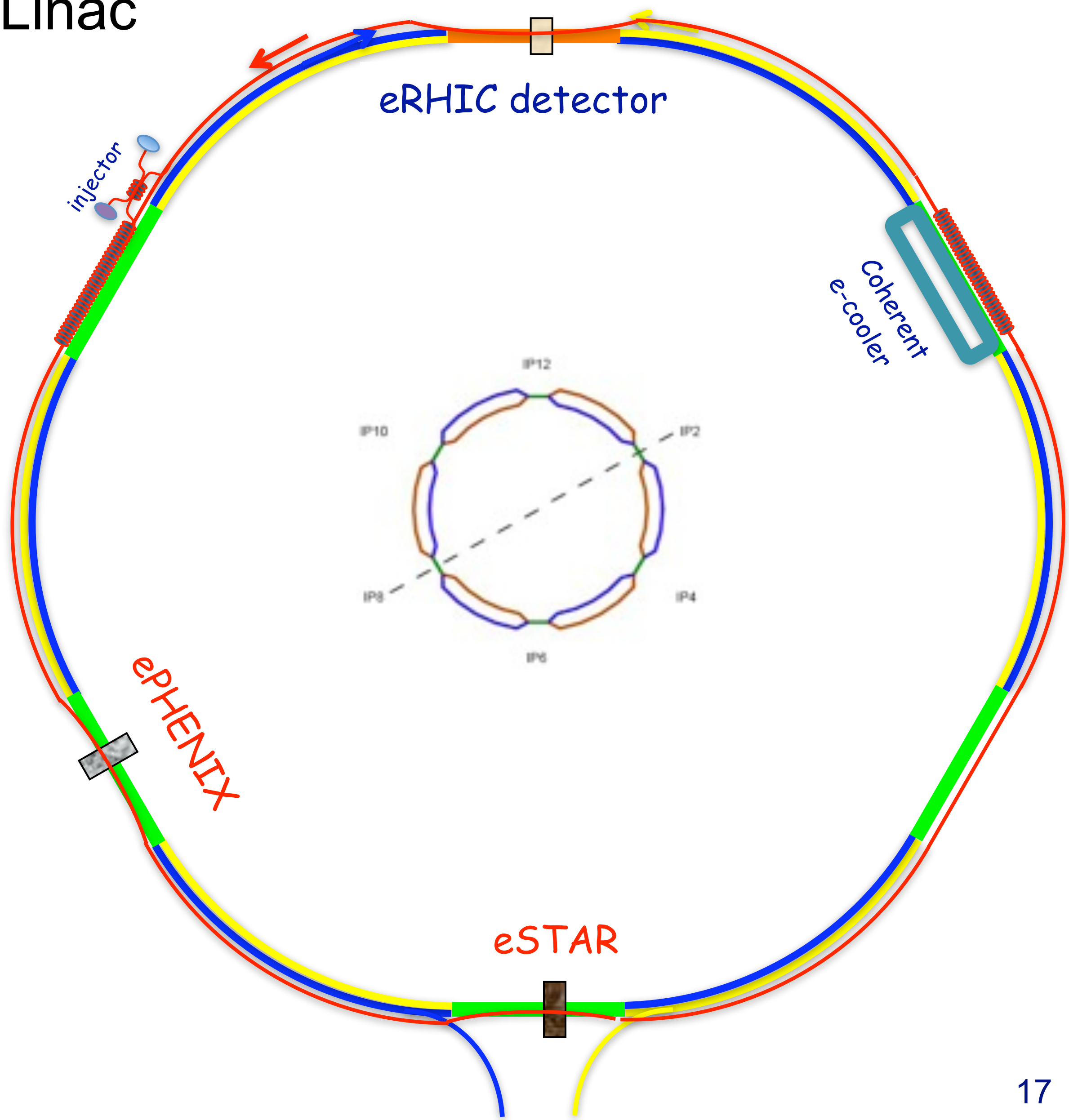


EIC Concept: RHIC → eRHIC @ BNL

ERL: Energy Recovery Linac

1 - 5 GeV per pass

4 (6) passes



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ERL: Energy Recovery Linac
1 - 5 GeV per pass
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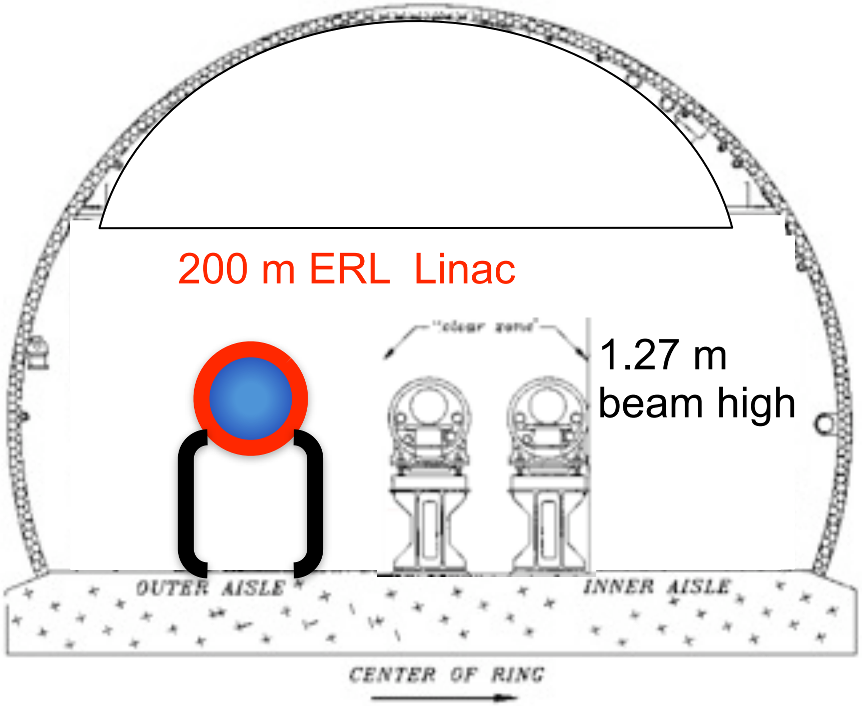

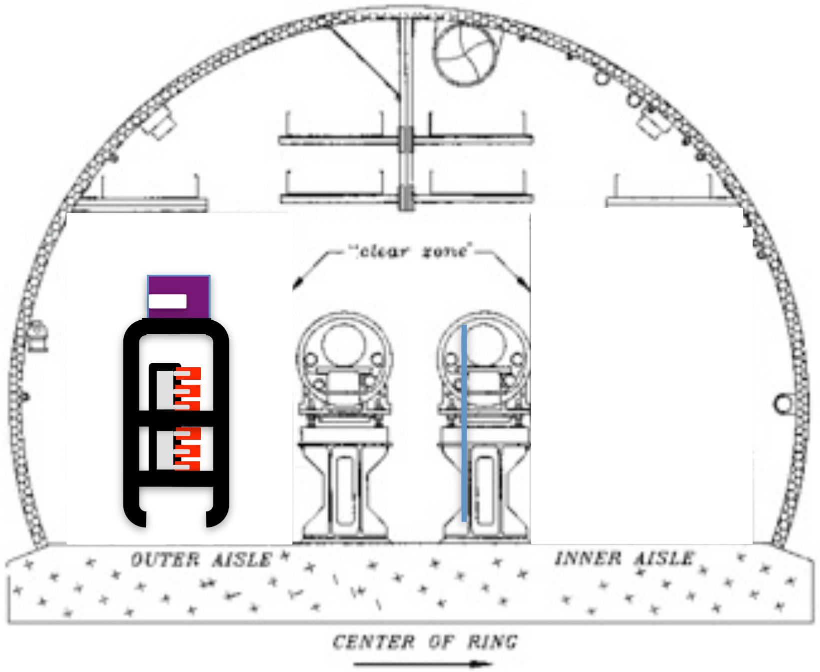

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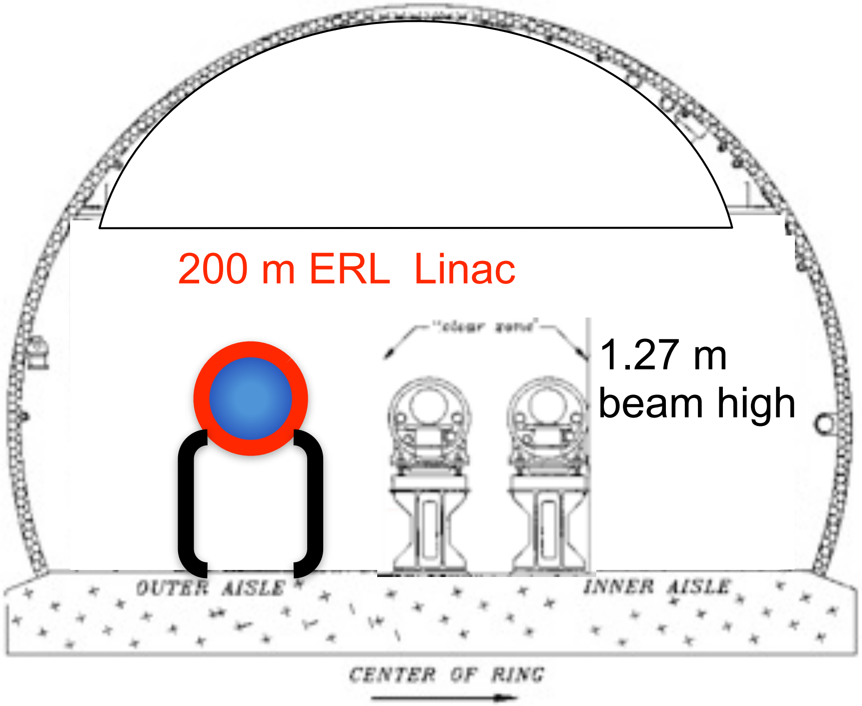
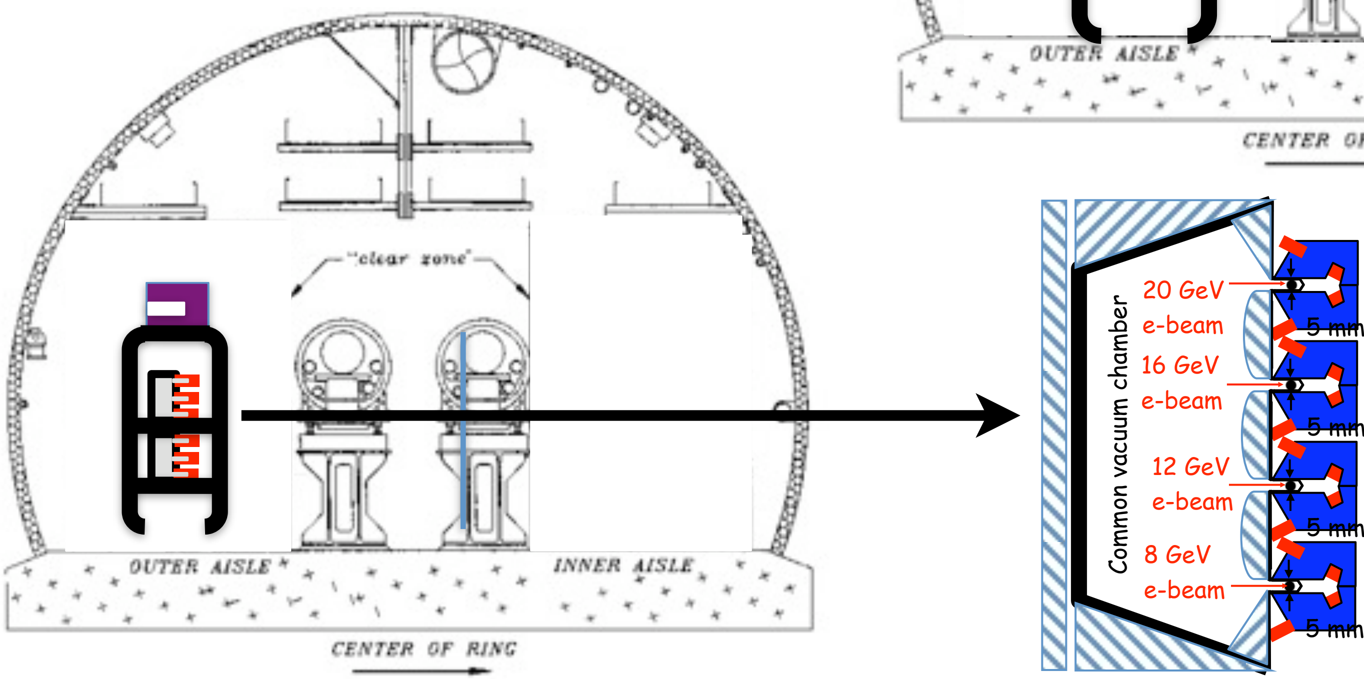




EIC Concept: RHIC → eRHIC @ BNL

eRHIC (stage 1):

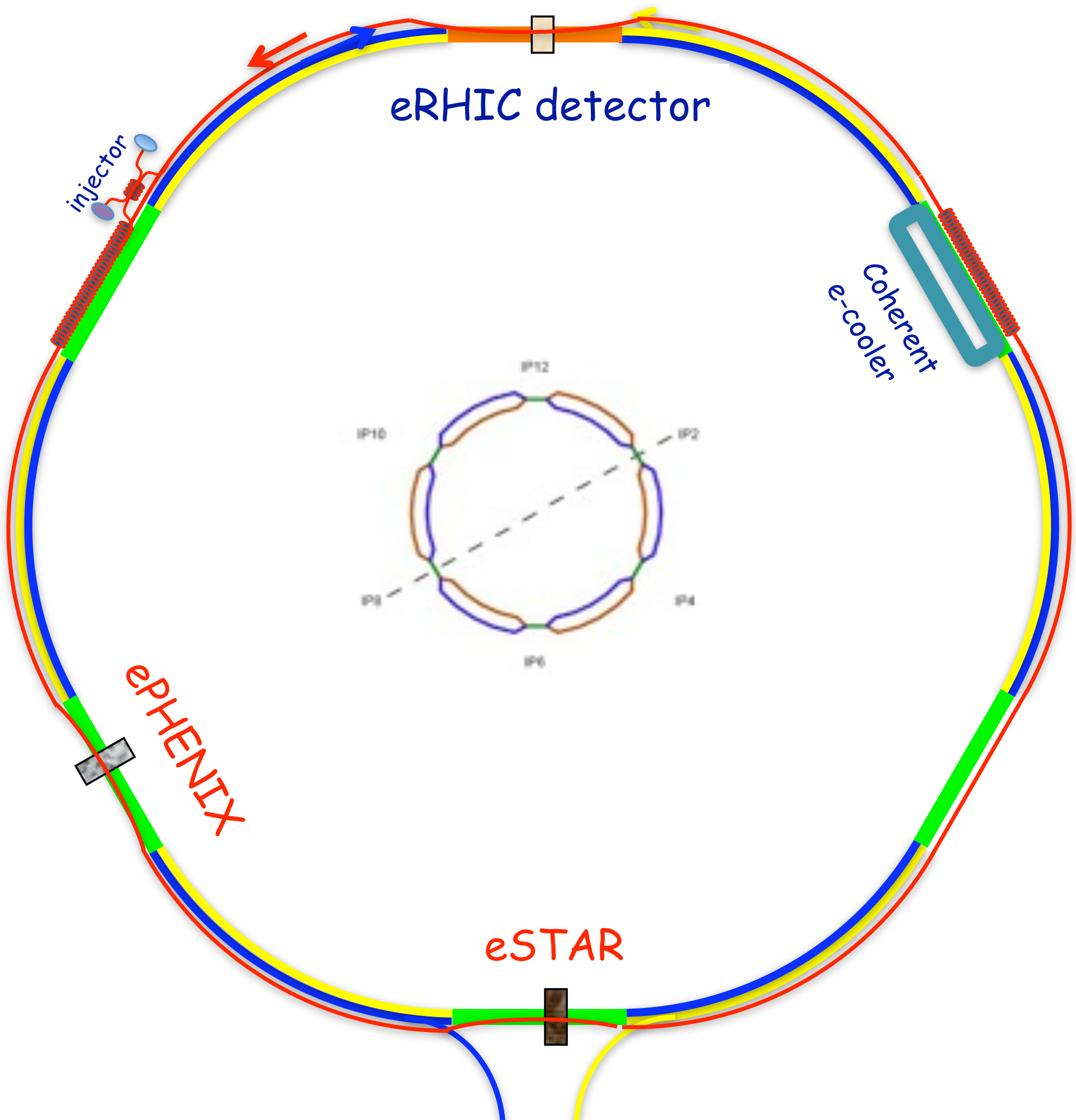
- 4 GeV e x 250 GeV p ($\sqrt{s}$ = 63 GeV)
- 4 GeV e- x 100 GeV/n Au ($\sqrt{s}$ = 40 GeV)
- L ~ 10^{32}-10^{33} cm^{-2} s^{-1}

eRHIC (stage 2):

- 20 GeV e x 325 GeV p ($\sqrt{s}$ = 160 GeV)
- 20 GeV e x 120 GeV/n Au ($\sqrt{s}$ = 98 GeV)
- L ~ 10^{33}-10^{34} cm^{-2} s^{-1}

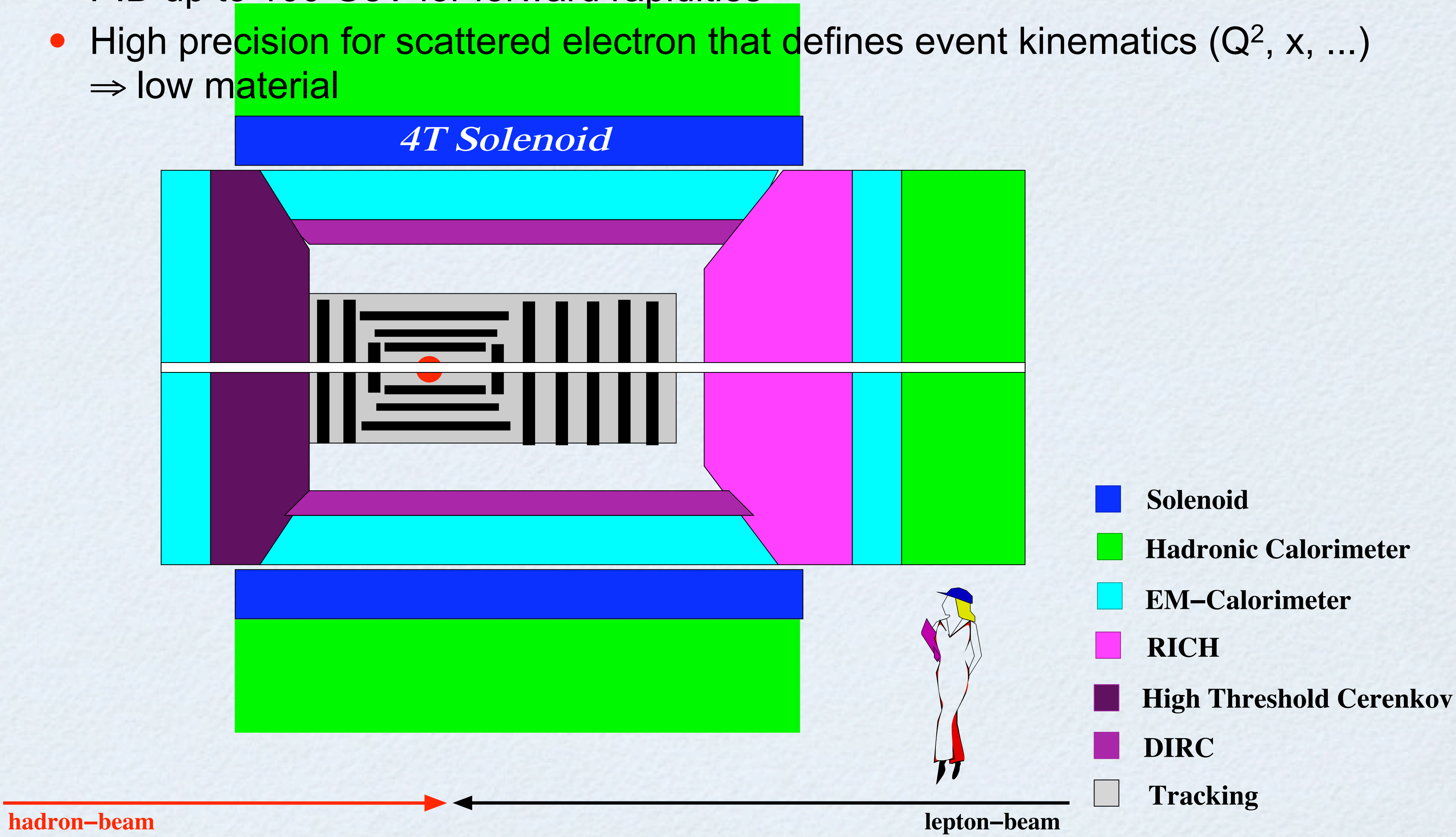
eRHIC upgrades

– Higher luminosity
– Higher hadron energy



Detector concept

- Hermeticity (diffraction ⇔ rapidity gap)
- Extreme forward angle ⇔ low-x physics
- PID < 4 GeV/c in central detector
- PID up to 100 GeV for forward rapidities
- High precision for scattered electron that defines event kinematics (Q^2, x, ...) ⇒ low material

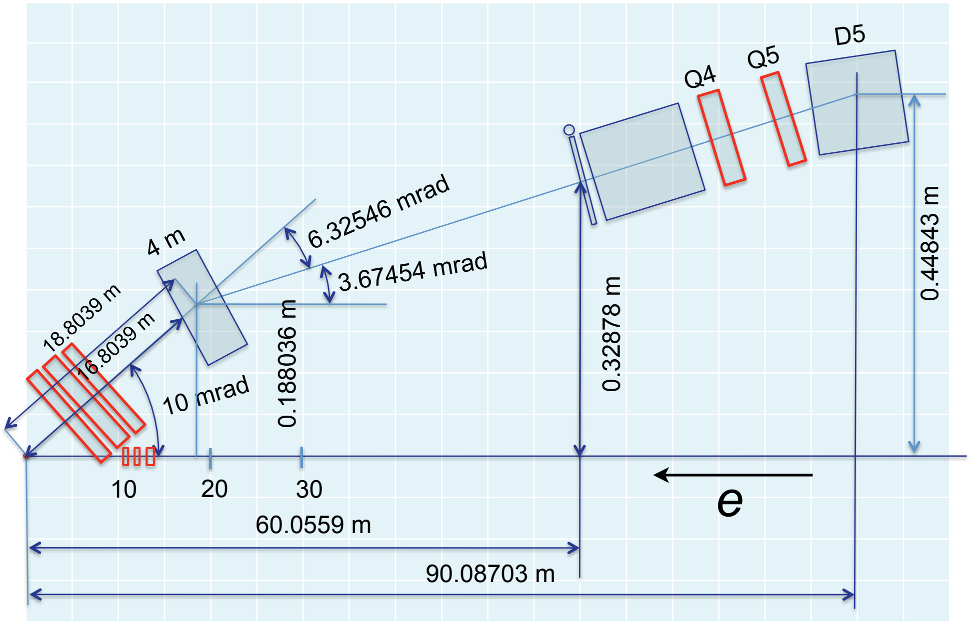


eRHIC: Detector ⇔ IR Design

IR:

- minimize synchrotron radiation (P and λ)
- minimize $\beta^* \Rightarrow$ L
- First quads: maximize aperture for particles at extreme forward angle $\Rightarrow$ detect n from breakup (diffraction)
- Design depends on presence/absence of pp/pA/AA ops

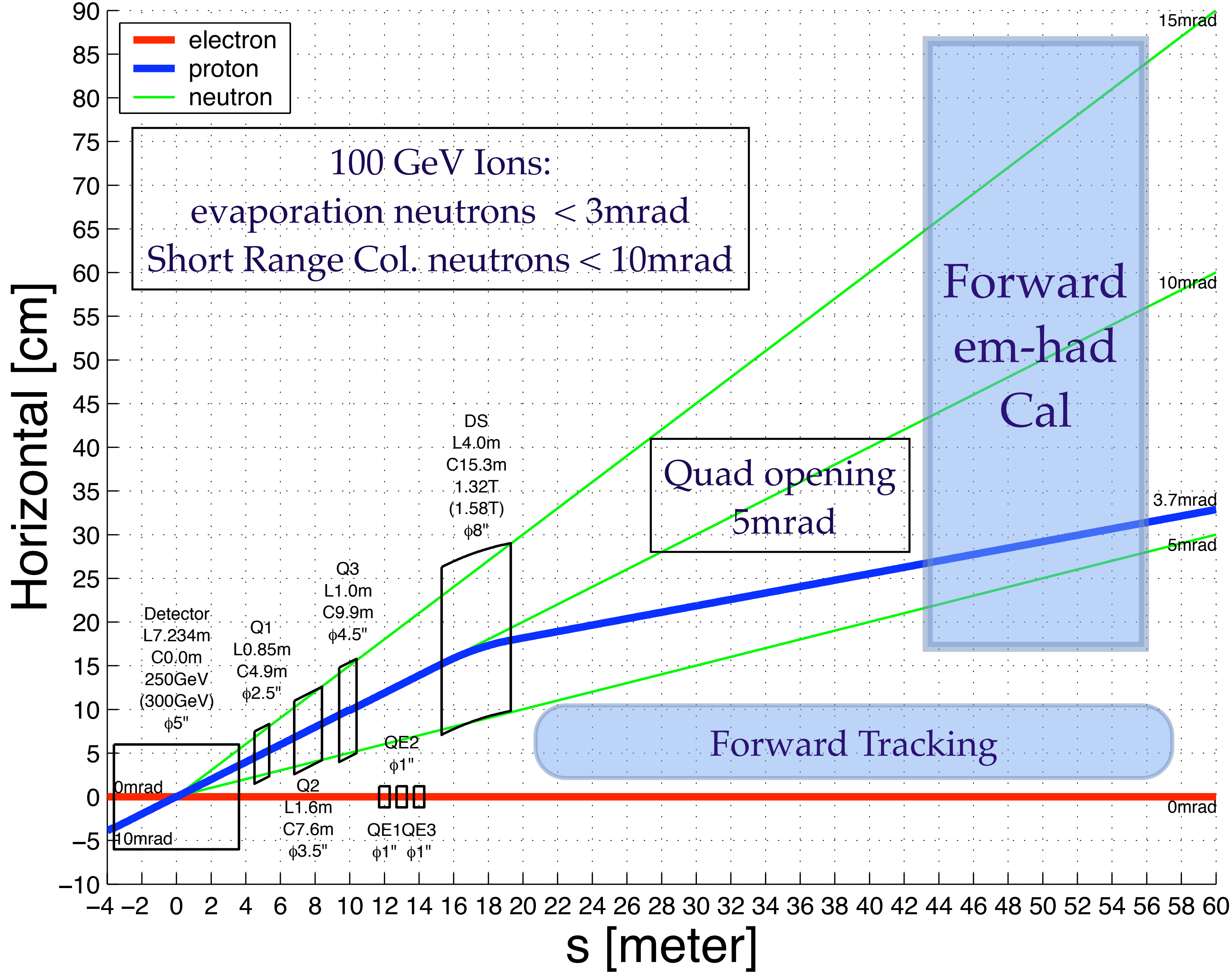
High Luminosity IR (β^* = 5 cm)



Dejan Trbojevic

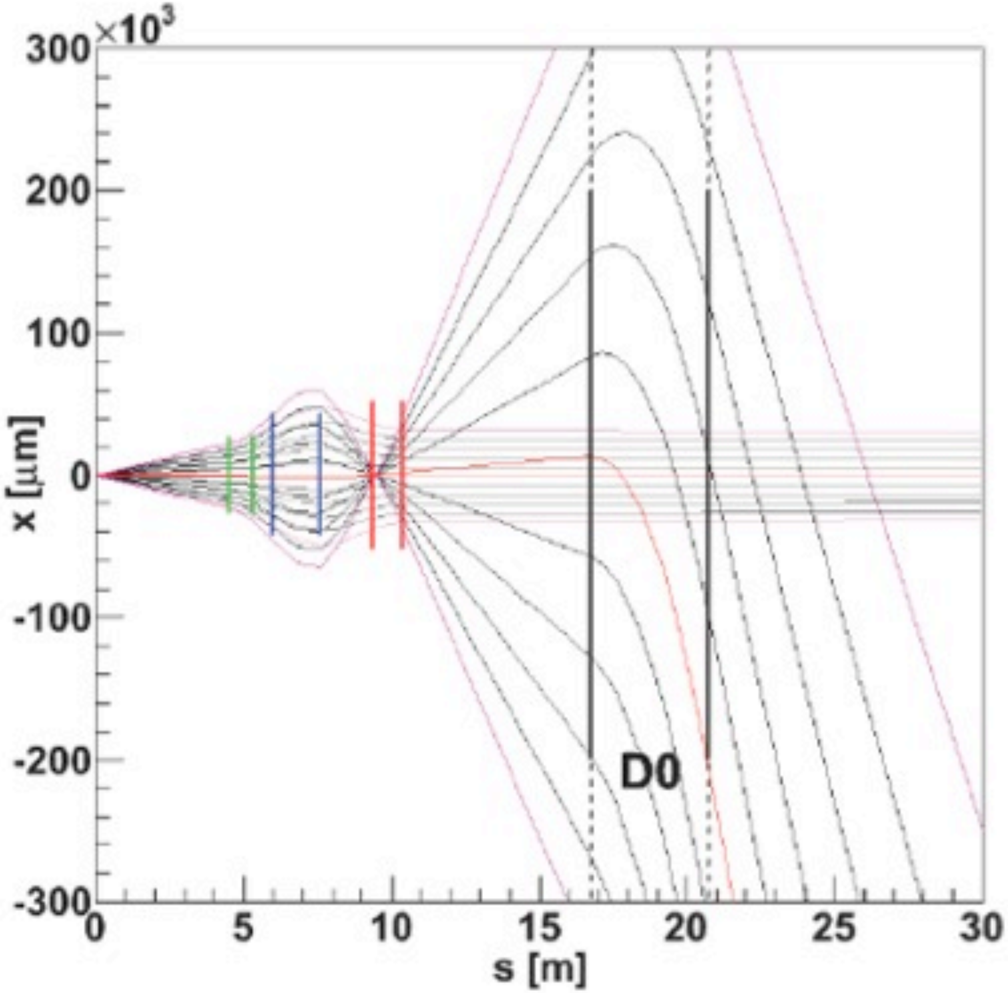
Latest Design:

- ep(A) crossing angle of 10 mrad
- straight e beamline $\Rightarrow$ almost no synchrotron radiation
- good separation of e/p beamlines
  - real estate for additional detectors
- need to fine tune for optimal instrumentation
- aperture of 1st quad: ±5 mrad
  - important for breakup-neutron detection



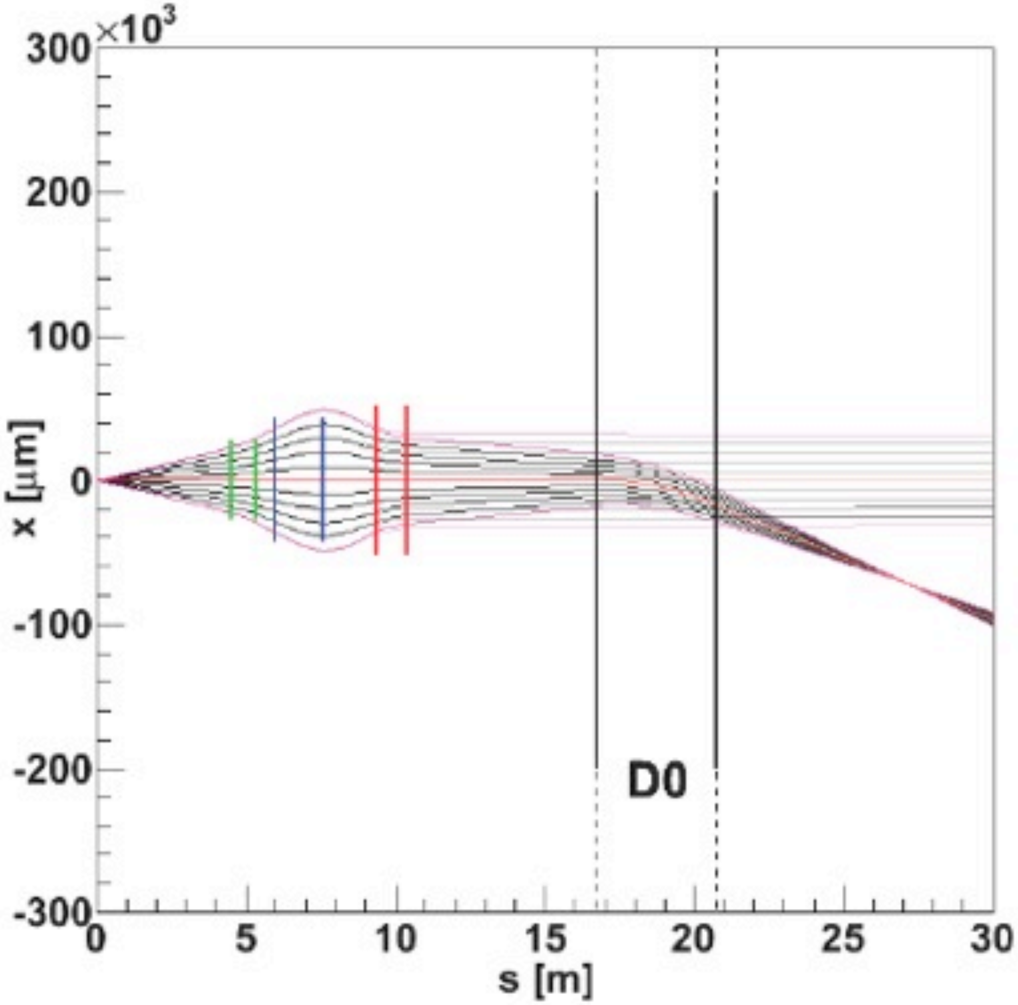
electron
proton
neutron
100 GeV Ions:
evaporation neutrons < 3mrad
Short Range Col. neutrons < 10mrad
Forward
em-had
Cal
Quad opening
5mrad
Forward Tracking
15mrad
10mrad
3.7mrad
5mrad
0mrad
0mrad
-10mrad
Detector
L7.234m
C0.0m
250GeV
(300GeV)
ϕ5"
Q1
L0.85m
C4.9m
ϕ2.5"
Q2
L1.6m
C7.6m
ϕ3.5"
Q3
L1.0m
C9.9m
ϕ4.5"
DS
L4.0m
C15.3m
1.32T
(1.58T)
ϕ8"
QE2
ϕ1"
QE1 QE3
ϕ1" ϕ1"
Horizontal [cm]
s [meter]

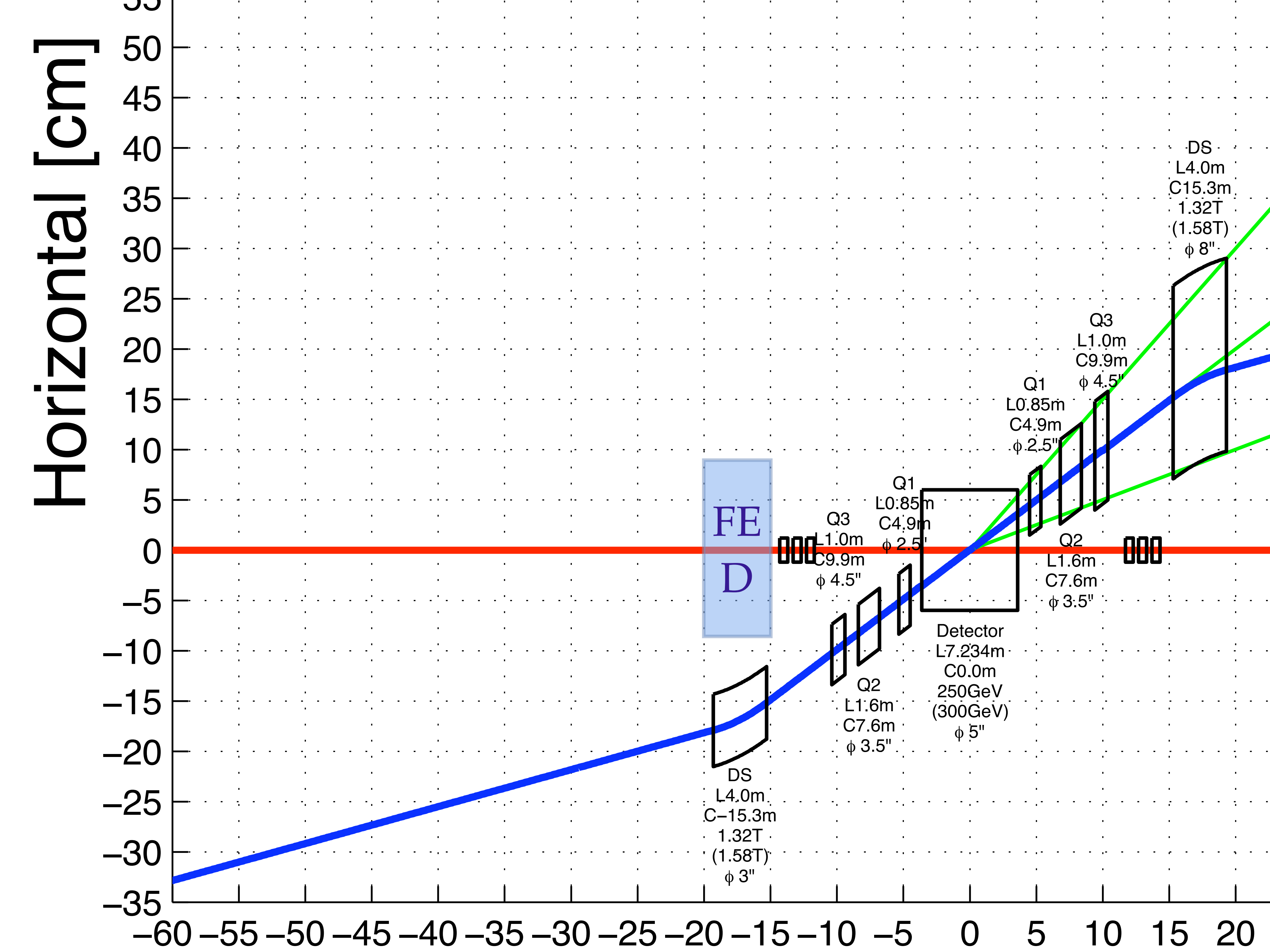
proton track with Δp = 40% (-5mrad - +5mrad)



- Δp = 40%: Equivalent of fragmenting proton from Au in Au optics (79/197)

proton track with Δp = 10% (-5mrad - +5mrad)





Horizontal [cm]
50
45
40
35
30
25
20
15
10
5
0
−5
−10
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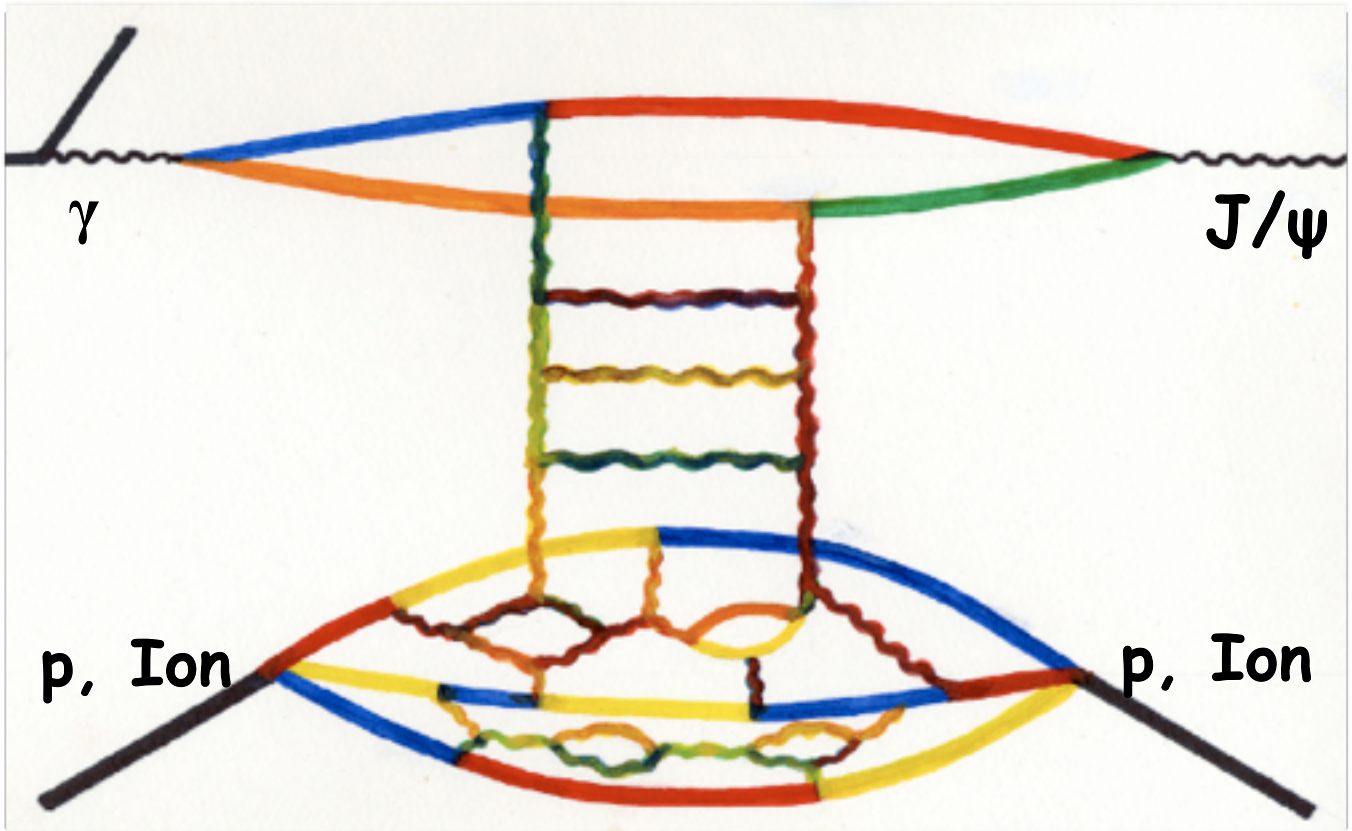
−25
−30
−35
−60 −55 −50 −45 −40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15 20
FE
D
DS
L4.0m
C−15.3m
1.32T
(1.58T)
ϕ 3"
Q3
L1.0m
C9.9m
ϕ 4.5"
Q2
L1.6m
C7.6m
ϕ 3.5"
Q1
L0.85m
C4.9m
ϕ 2.5"
Detector
L7.234m
C0.0m
250GeV
(300GeV)
ϕ 5"
Q1
L0.85m
C4.9m
ϕ 2.5"
Q2
L1.6m
C7.6m
ϕ 3.5"
Q3
L1.0m
C9.9m
ϕ 4.5"
DS
L4.0m
C15.3m
1.32T
(1.58T)
ϕ 8"

Outlook

- Increasing efforts at BNL & JLAB
- Concepts of eRHIC and ELIC are taking shape
    - substantial progress in machine & IR design
- Staged approach most promising path
    - Much can be done already at lower energy (e.g. F_L)
    - Saturation physics will require full ELIC/eRHIC
- At minimum one large multi-purpose detector
- ePHENIX/eSTAR under evaluation

Key Events:

- INT Workshop: Gluons and the Quark Sea at High Energies: Sep-Nov, 2010 $\Rightarrow$ Science Case for EIC
- LRP 2012: Town meetings and LRP


γ
J/ψ
p, Ion
p, Ion