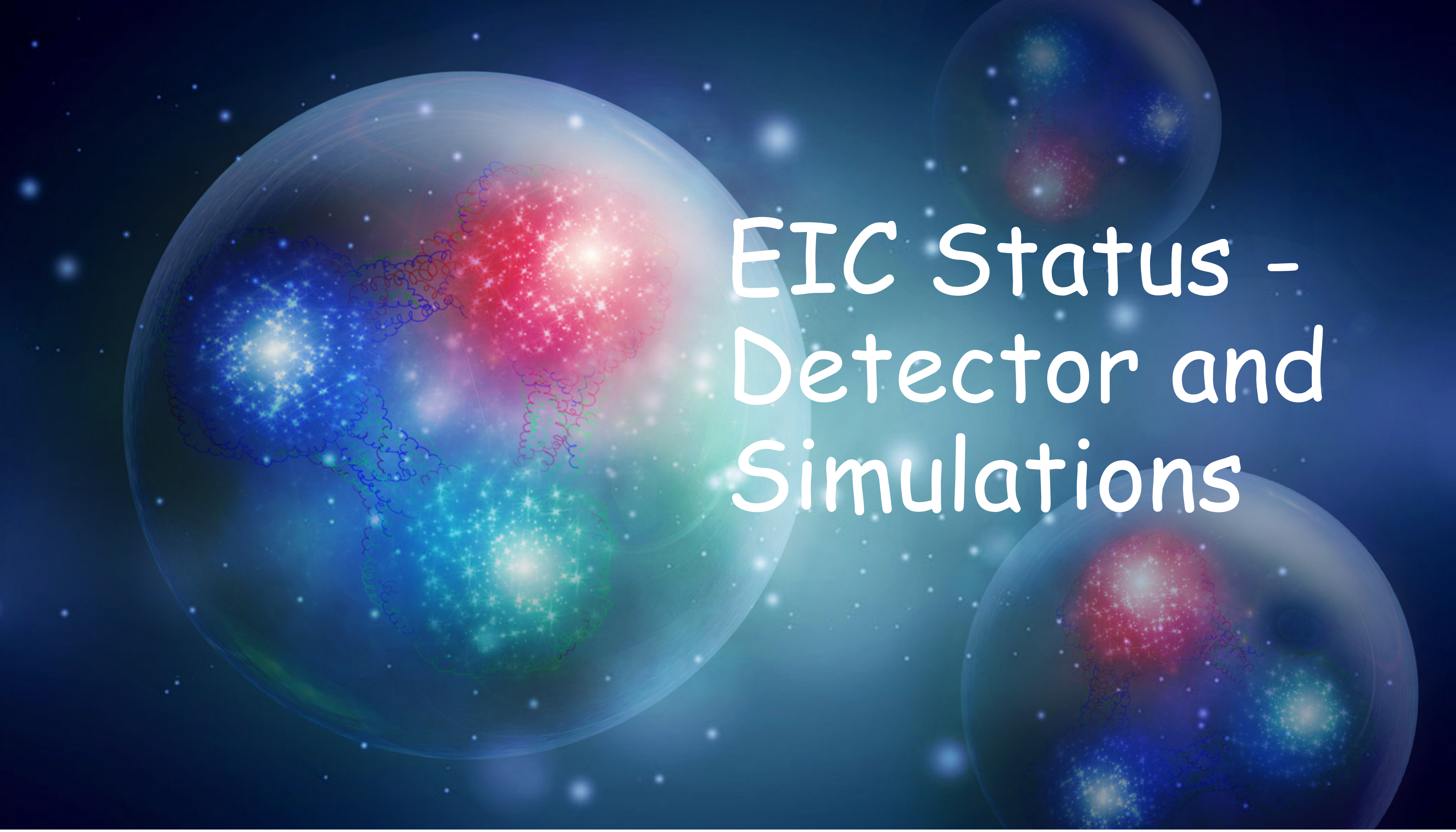


EIC Status - Detector and Simulations

Yulia Furletova

Inspired by lectures/talks of Rolf Ent, Rik Yoshida, Jianwei Qiu, Elke Aschenauer, Abhay Deshpande

HUGS lectures

U.S. DEPARTMENT OF ENERGY JSA Jefferson Lab

Outline

- Introduction to Electron Ion Collider
  - Highlights of EIC physics
  - US based EIC accelerators proposals
- Introduction to Deep Inelastic Scattering
  - DIS kinematic
- EIC detector design
  - Tracking
  - Vertex
  - Calorimeter
  - Muon detectors
  - Particle Identification detectors
    - dE/dx
    - Time of flight
    - Cherenkov
    - Transition radiation
- Detector simulation and reconstruction
- Conclusions

Lecture-1

Lecture-2

Lecture-3

Lecture-4

Lecture-5

Our mission

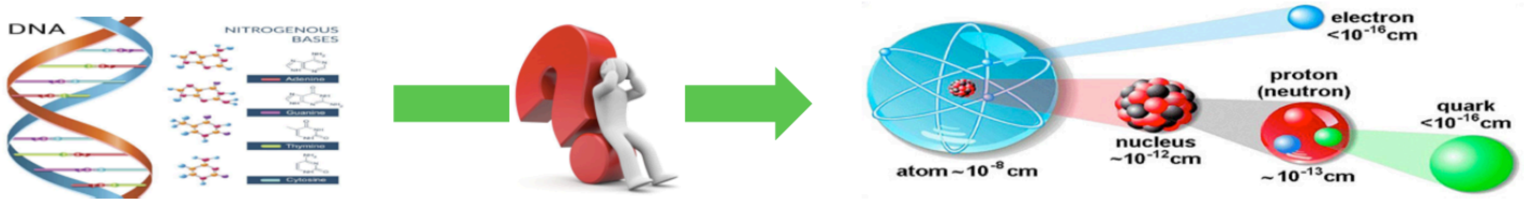
Jianwei Qiu (DIS2018)

- Where did we come from?

Global Time: →

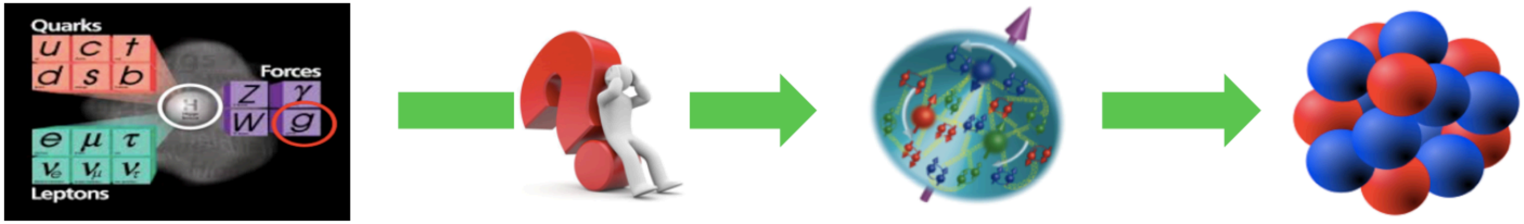
How did hadrons are emerged from the energy, the quarks and gluons?

- What are we made of?



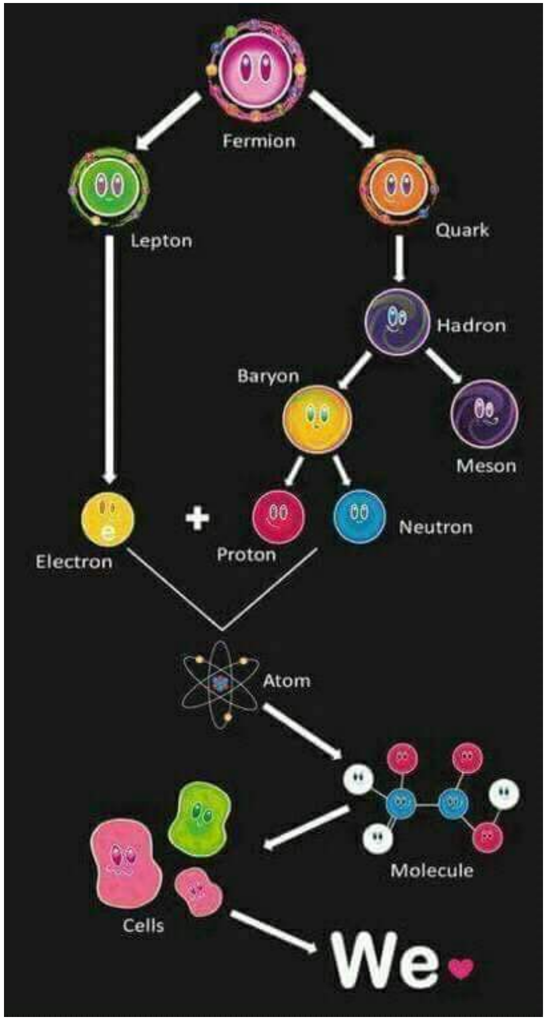
What is the internal structure and dynamics of hadrons?

- What holds us together?

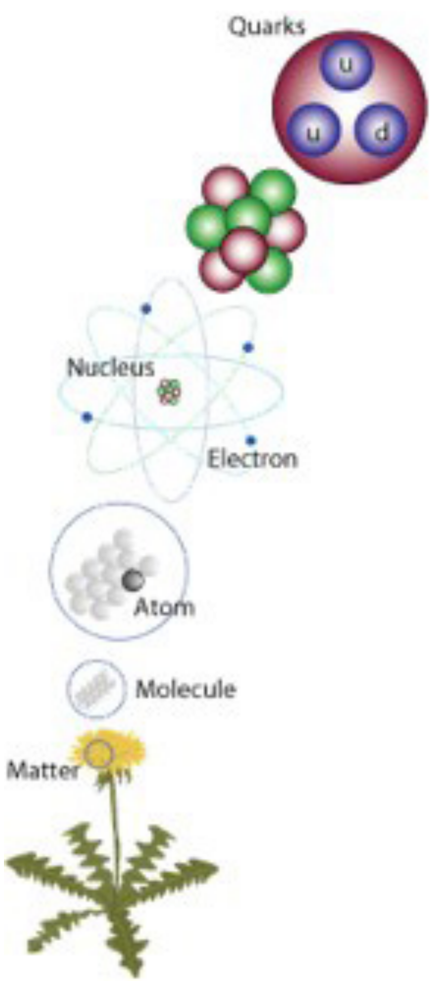


How does the glue bind us all?

Definition of "Nuclear particle physicist" – it is an ability of quarks and gluons to think about quarks and gluons.



Structure of Matter



Can we manipulate quarks and gluons?

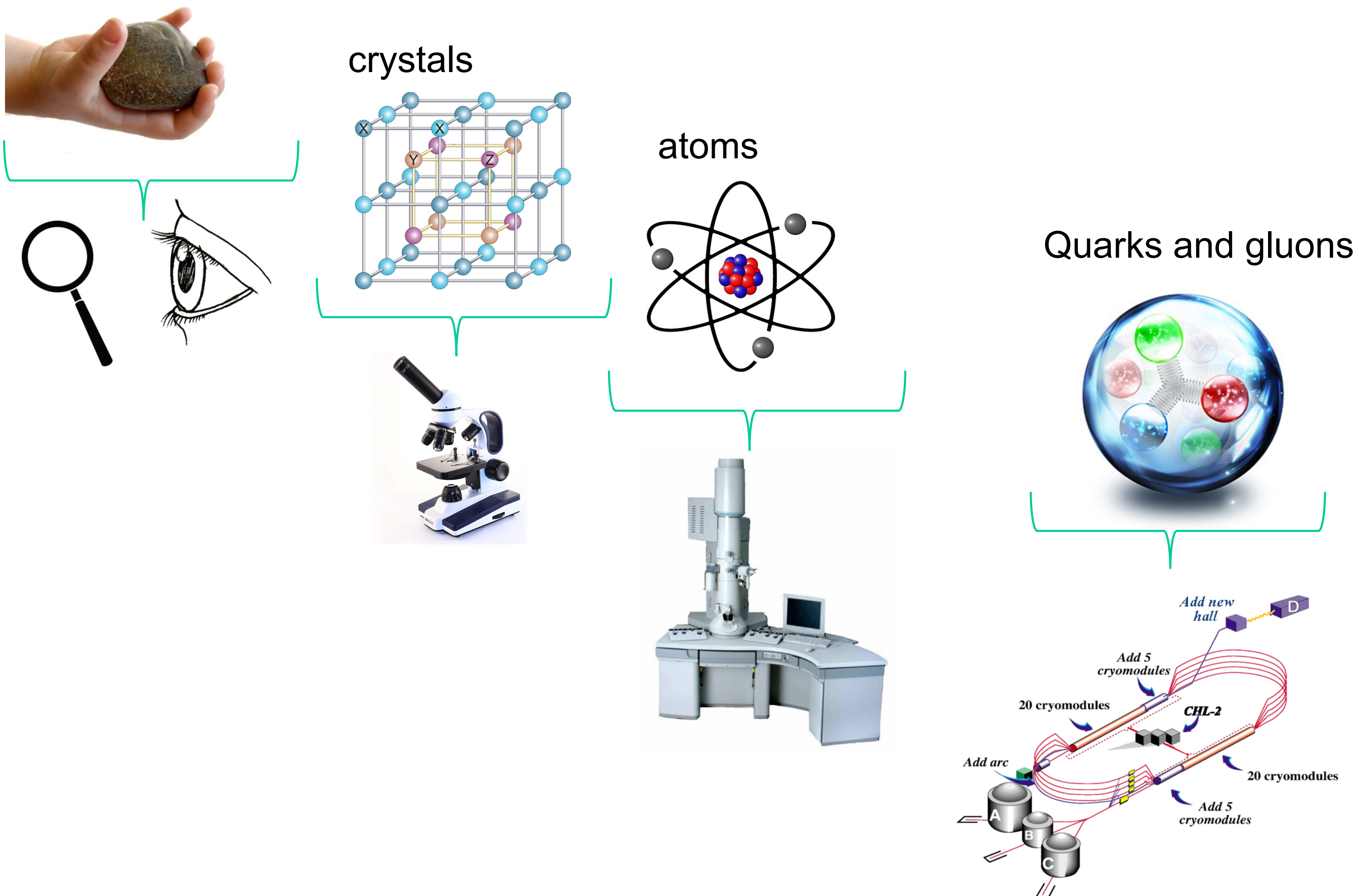
Femtoworld (scale ~10^{-15} meters)

A million times smaller

Nanoworld (scale ~10^{-9} meters)

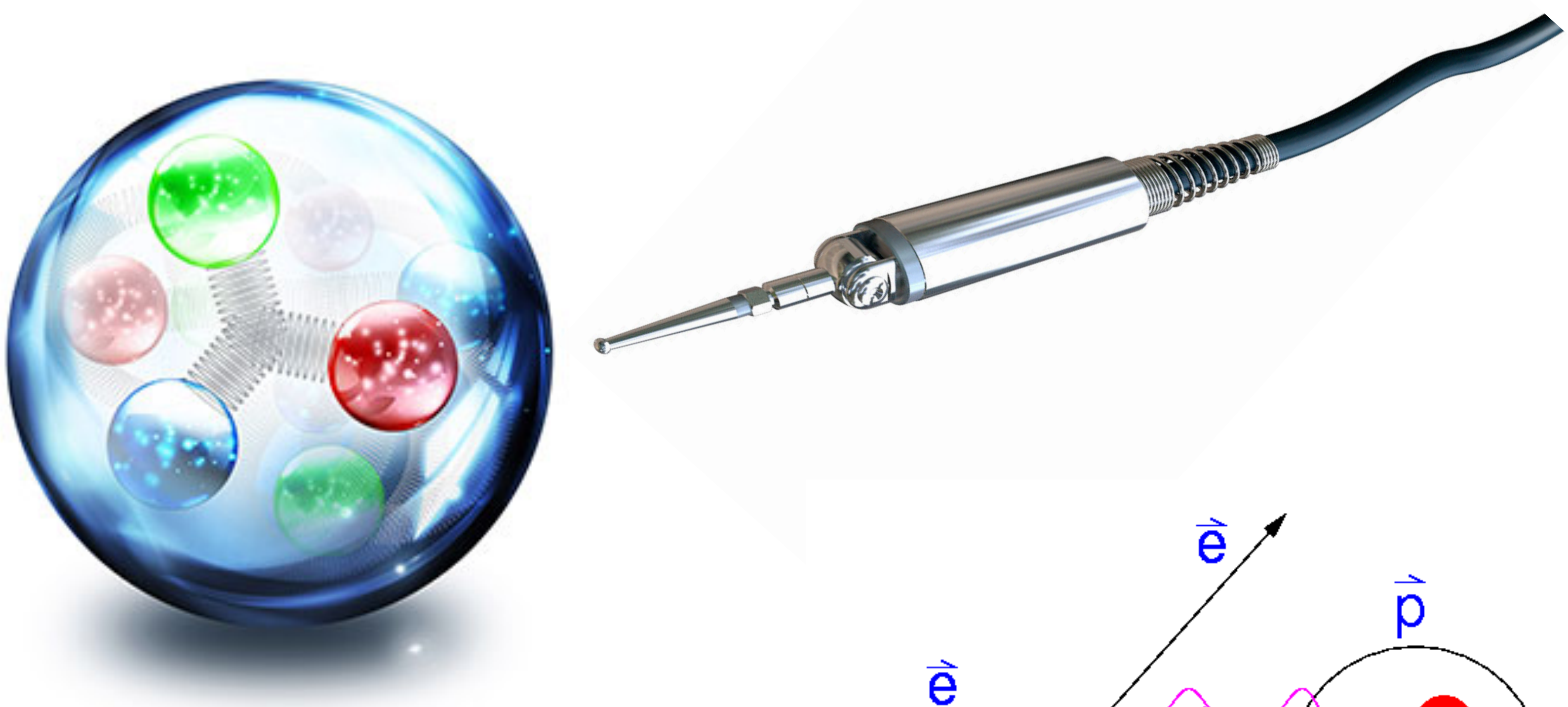
We have known for half a century that quarks (and gluons) and their interactions make up **99% of mass** in the visible universe.. however.. no way to map quarks and gluons in the nucleus.. until now!

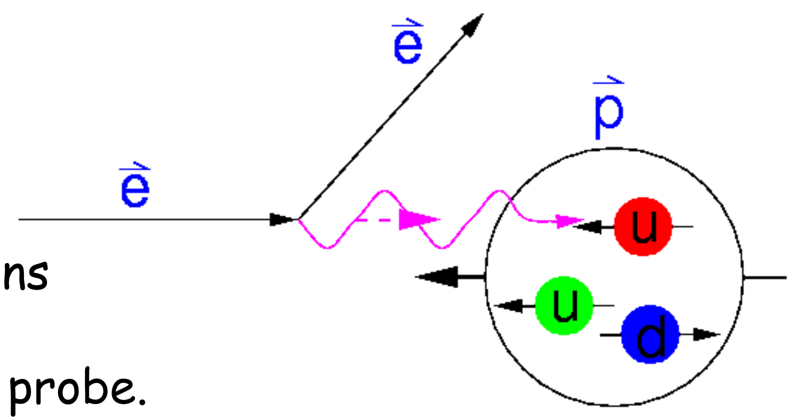
Understanding Matter: Size and Instruments



How can we probe the Femto-world ?

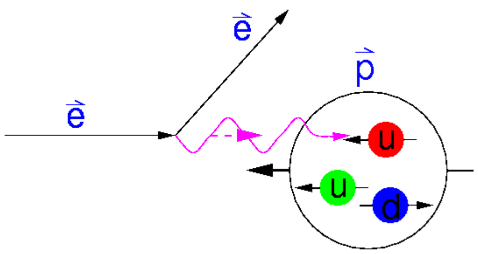
How can we do this? Ordinary instruments are a million billion times too big!





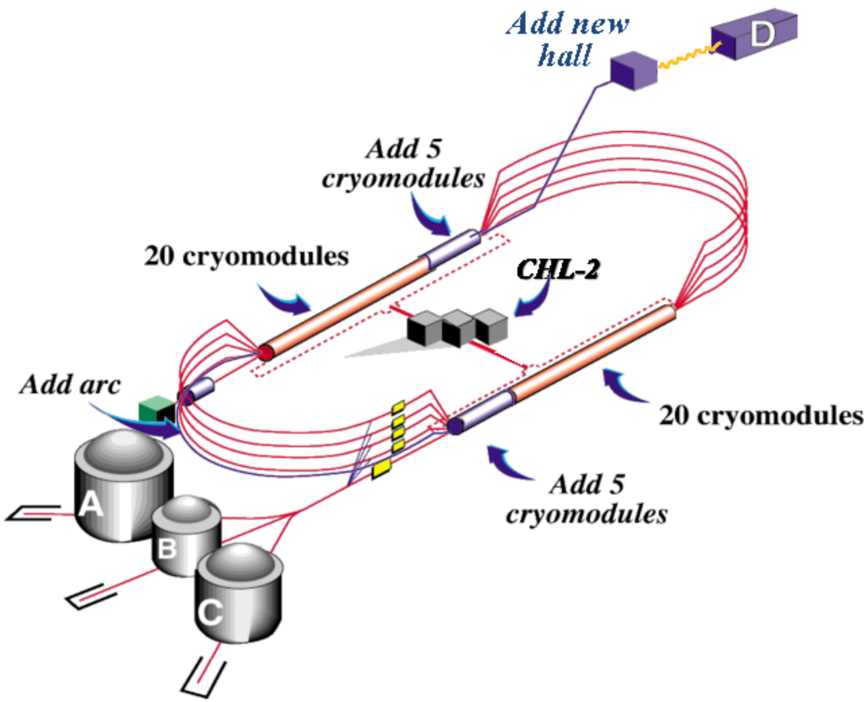
High energy collisions of electrons with nuclei, proceed via "virtual photon", which acts as a probe.

we could probe the Femto-world



The first steps in Nuclear Femtography starts just now with the 12 GeV CEBAF!

Higher the collision energy, smaller the probe.



CEBAF 12 GeV
Probe about 40th of the proton diameter

Electron-Ion Collider:
Probe about 500th of the proton diameter

EIC vs other DIS facilities: Improving resolution

Current situation

Resolution is a few times smaller than target

EIC vs other DIS facilities: Improving resolution

Current situation

Resolution is a few times smaller than target

CEBAF 12 GeV

Resolution **10's** of times smaller than target

EIC vs other DIS facilities: Improving resolution

Current situation

Resolution is a few times smaller than target

CEBAF 12 GeV

Resolution **10's** of times smaller than target

Electron-Ion Collider

Resolution **100's** of times smaller than target

HERA

World FIRST electron(positron) proton collider
Operation: 1992-2007

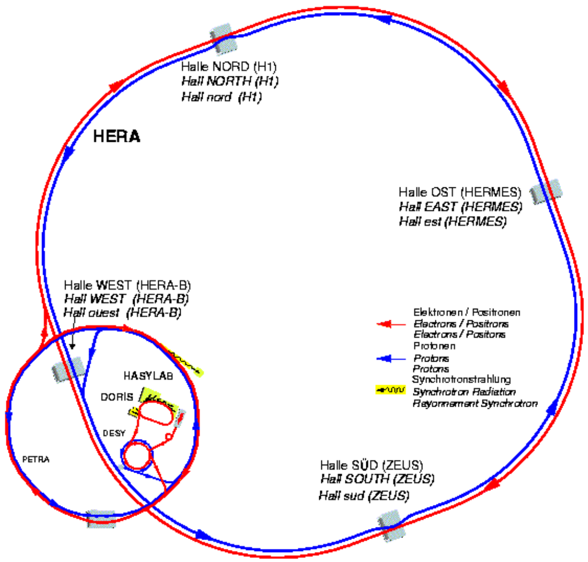
Energy:
e-/e+ : 27.5 GeV
p: 820 (920) GeV
$\sqrt{s} \sim 320$ GeV
Electron only polarization

180 bunches
96ns bunch spacing

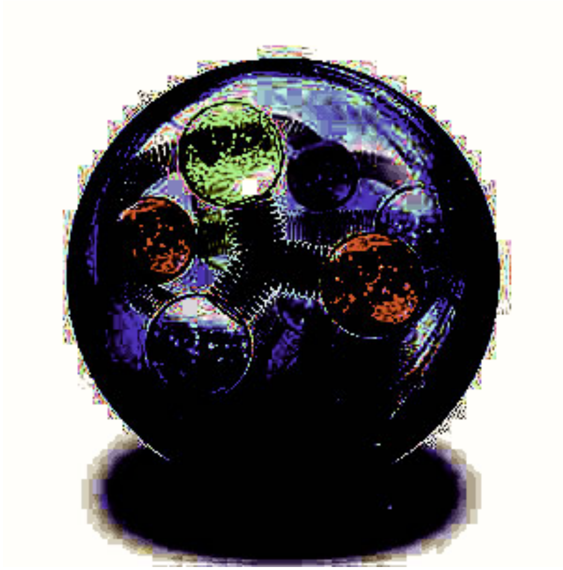
2 Collider experiments (H1, ZEUS),
Fixed target (e): HERMES
Fixed target (p): HERA-B

HUGE success, a lot of new physics

Integrated luminosity for H1+ZEUS:
~ 1 fb^{-1} (after 10 years of operation)



EIC vs other DIS facilities: Improving resolution



100(1000) times higher luminosity

Electron-Ion Collider

HERA: last electron-proton collider (1992-2007)

Advances in Femto-science

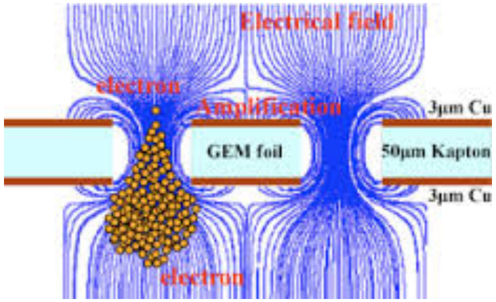
Accelerator Technologies

Theory

$$
\begin{aligned}
\frac{\mathrm{d}\sigma}{\mathrm{d}Q^2\,\mathrm{d}y\,\mathrm{d}q_{\mathrm{T}}^2} = {} & \frac{4\pi^2\alpha^2}{9Q^2 s} \sum_{j,j_A,j_B} e_j^2 \int \frac{\mathrm{d}^2\boldsymbol{b}_{\mathrm{T}}}{(2\pi)^2} e^{i\boldsymbol{q}_{\mathrm{T}}\cdot\boldsymbol{b}_{\mathrm{T}}} \\
& \times \int_{x_A}^{1} \frac{\mathrm{d}\xi_A}{\xi_A} f_{j_A/A}(\xi_A;\mu_{b_*})\, \tilde{C}^{\mathrm{CSS1,\,DY}}_{j/j_A}\left(\frac{x_A}{\xi_A}, b_*; \mu_{b_*}^2, \mu_{b_*}, C_2, a_s(\mu_{b_*})\right) \\
& \times \int_{x_B}^{1} \frac{\mathrm{d}\xi_B}{\xi_B} f_{j_B/B}(\xi_B;\mu_{b_*})\, \tilde{C}^{\mathrm{CSS1,\,DY}}_{\bar{j}/j_B}\left(\frac{x_B}{\xi_B}, b_*; \mu_{b_*}^2, \mu_{b_*}, C_2, a_s(\mu_{b_*})\right) \\
& \times \exp\left\{ -\int_{\mu_{b_*}^2}^{\mu_Q^2} \frac{\mathrm{d}\mu'^2}{\mu'^2} \left[A_{\mathrm{CSS1}}(a_s(\mu');C_1) \ln\left(\frac{\mu_Q^2}{\mu'^2}\right) + B_{\mathrm{CSS1,\,DY}}(a_s(\mu');C_1,C_2) \right] \right\} \\
& \times \exp\left[-g^{\mathrm{CSS1}}_{j/A}(x_A, b_{\mathrm{T}}; b_{\max}) - g^{\mathrm{CSS1}}_{\bar{j}/B}(x_B, b_{\mathrm{T}}; b_{\max}) - g^{\mathrm{CSS1}}_{K}(b_{\mathrm{T}}; b_{\max}) \ln(Q^2/Q_0^2) \right] \\
& + \text{suppressed corrections.}
\end{aligned}
$$

Computing

Detector Technologies

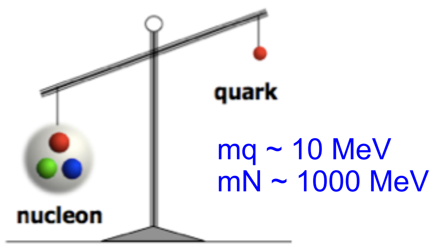


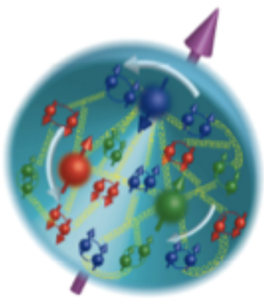
Steady advances in all of these areas mean that →

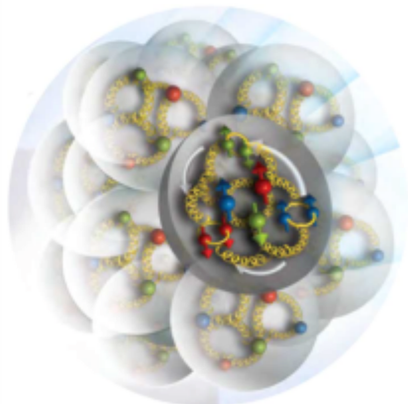
We are ready to probe a femto-world!

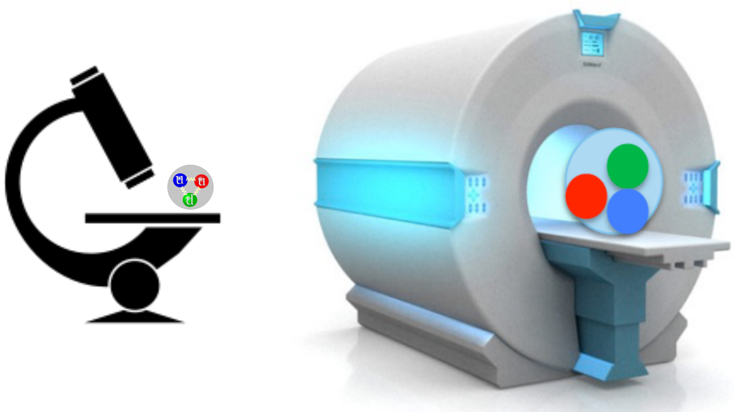
EIC is a QCD facility to study a structure and dynamics of matter (our world).

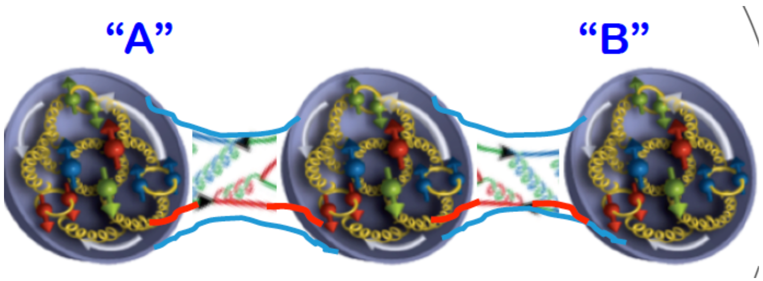
- ✓ Property of Hadrons (Mass, Spin)
- ✓ Structure or Imaging of Hadrons (PDF, TMD, GPD)
- ✓ QCD at Extreme Parton Densities
- ✓ Emergence of hadrons











Jianwei Qiu (DIS2018)

EIC physics goals: Mass and Spin

- **Mass – intrinsic to a particle:**

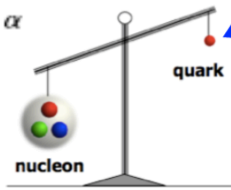
  = Energy of the particle when it is at the rest

  - **QCD energy-momentum tensor in terms of quarks and gluons**

$$T^{\mu\nu} = \frac{1}{2}\,\overline{\psi} i \overleftrightarrow{D}^{(\mu}\gamma^{\nu)}\psi + \frac{1}{4}\, g^{\mu\nu}F^2 - F^{\mu\alpha}F^{\nu}{}_{\alpha}$$

  - **Proton mass:**

$$m = \frac{\langle p|\int d^3x\, T^{00}\,|p\rangle}{\langle p|p\rangle} \sim \text{GeV}$$



Higgs Mech.

$m_q \sim 10$ MeV

$m_N \sim 1000$ MeV

"Mass without mass"

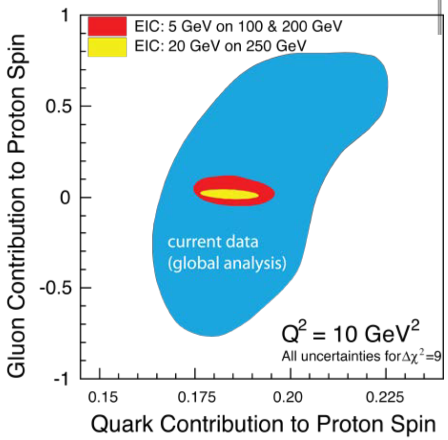
- **Spin – intrinsic to a particle:**

Proton spin =1/2

"Helicity sum rule"

$$\frac{1}{2}\hbar = \frac{1}{2}\Delta\Sigma + \Delta G + \sum_q L_q^z + L_g^z$$

quark contribution ~ 30% | gluon contribution ~ 40% | orbital angular momentum ~?



EMC found:
$\Delta\Sigma = 0.12 \pm 0.17 \sim 30\%$

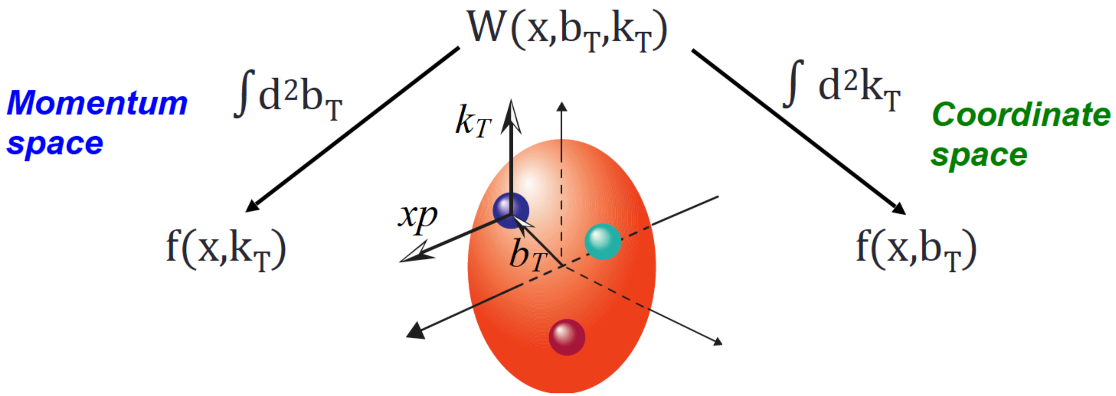
If we do not understand proton mass & spin, we do not understand QCD!

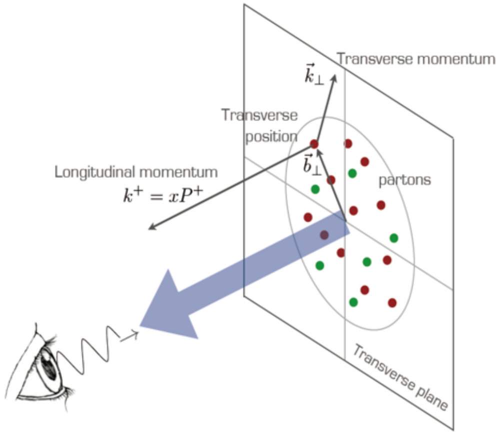
Jianwei Qiu (DIS2018)

EIC physics goals: 3-Dimentional imaging

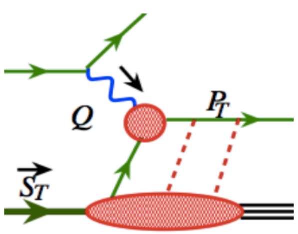
Wigner functions $W(x,b_T,k_T)$

offer unprecedented insight into confinement and chiral symmetry breaking.





✧ **Semi-inclusive DIS:**

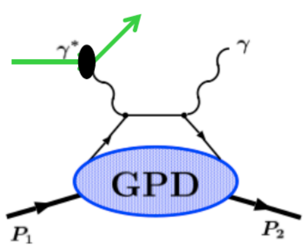


+ …

SIDIS: $Q \gg P_T$

Parton's confined motion encoded into TMDs

✧ **Exclusive DIS:**



+ …

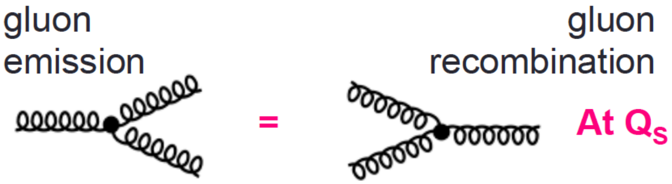
DVCS: $Q^2 \gg |t|$

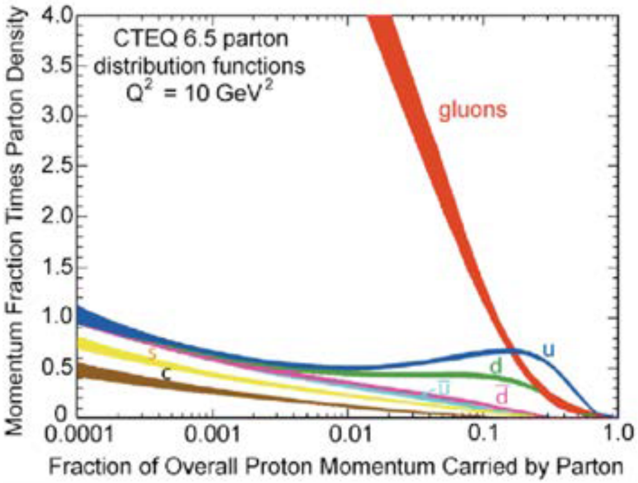
Parton's spatial imaging from Fourier transform of GPDs' t-dependence

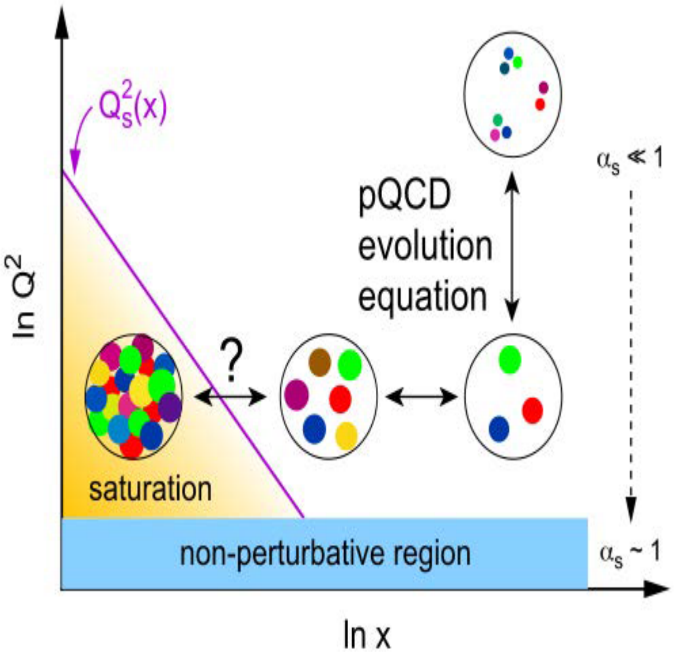
EIC physics goals: Extreme Parton Densities

Low-x

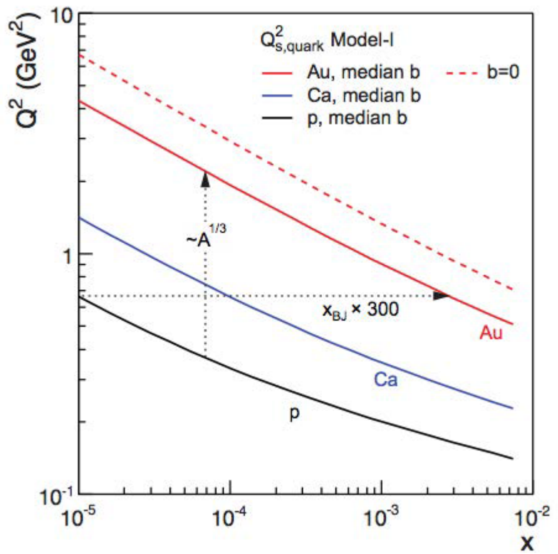
At very low x, cross-section will saturate.
could be investigated in transition region







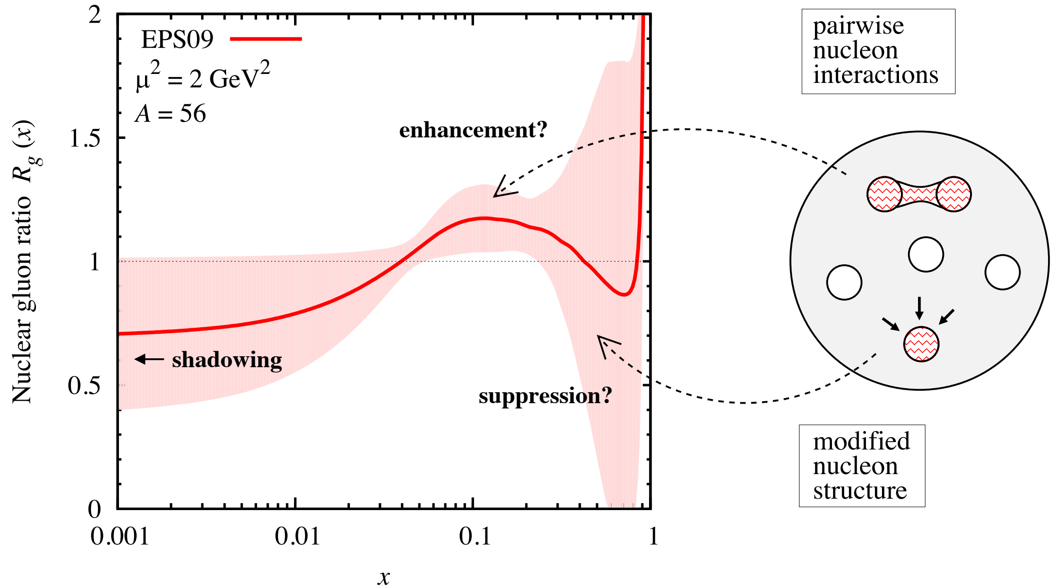
Saturation regime reached at significantly lower energy in nuclei



EIC physics goals: Extreme Parton Densities

High-x

- Compare quark/gluon densities of nucleus with those of a system of free nucleons: $A \neq \sum N$, "nuclear modifications"
- Learn about QCD substructure of nucleon interactions — how they emerge from the microscopic theory?
- "Next step" after exploring single nucleon structure!

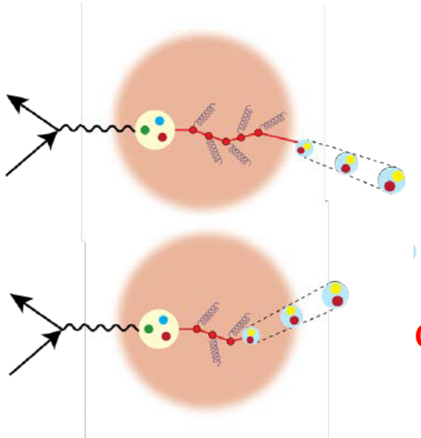


0.3 < x < 0.8	Suppression? EMC effect	Interactions at short distances cf. short-range NN correlations JLab 6/12 GeV
0.05 < x < 0.2	Enhancement? Antishadowing	Interactions at average distances
$x \ll 0.1$	Shadowing	Coherent interactions enabled by diffraction Gribov 70s Suppression effect calculable Frankfurt, Strikman Guzey 12+ Observed in J/ψ photoproduction on nuclei ALICE, CMS Suggests large antishadowing

EIC physics goals: Emergence of Hadrons

➤ EIC as Femtometer sized detector:

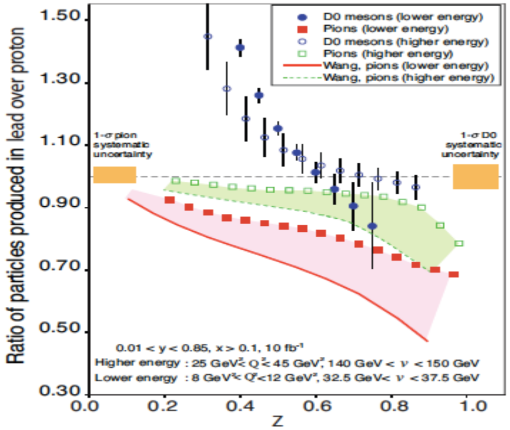
(colored) Quark passing through cold QCD matter emerges as color-neutral hadron.



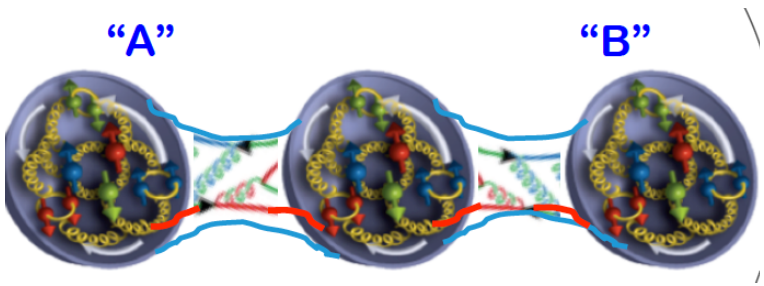
$$\nu = \frac{Q^2}{2mx}$$

Control of ν and medium length!

Understand energy loss of light vs. heavy quarks traversing the cold nuclear matter:
Connect to energy loss in Hot QCD



➤ What does a nucleus look like?
Does the color of "A" know the color of "B"?

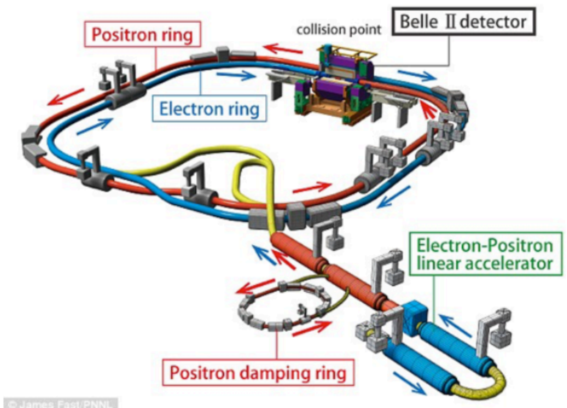


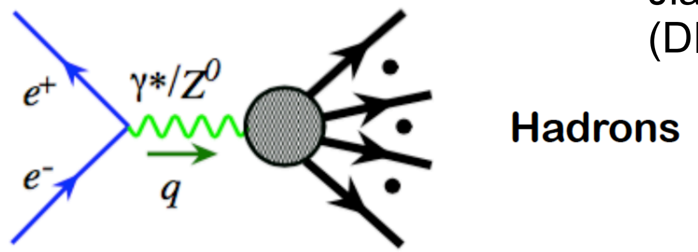
Need the collider energy of EIC and its control on parton kinematics!

Why Electron- Ion scattering ? Hard probes

Jianwei Qiu (DIS2018)

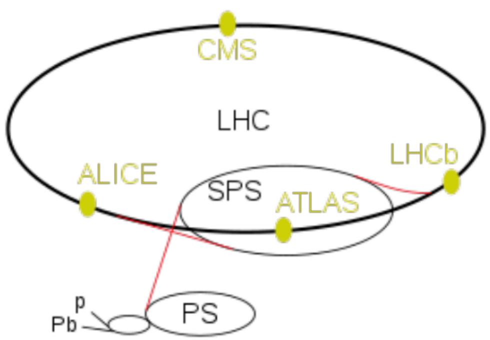
- ❑ **Lepton-lepton collisions:**

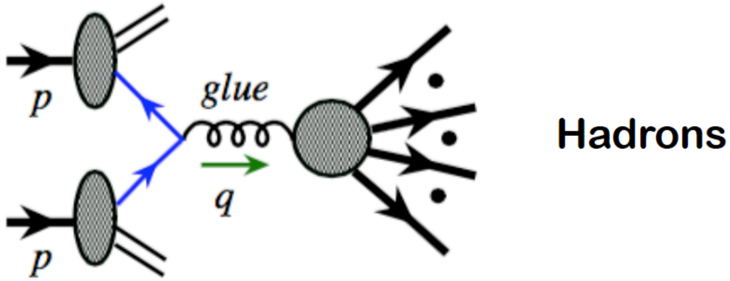




- ✧ No hadron in the initial-state
- ✧ Hadrons are emerged from energy
- ✧ Not ideal for studying hadron structure

- ❑ **Hadron-hadron collisions:**





- ✧ Hadron structure – motion of quarks, …
- ✧ Emergence of hadrons, …
- ✧ Initial hadrons broken – collision effect, ..

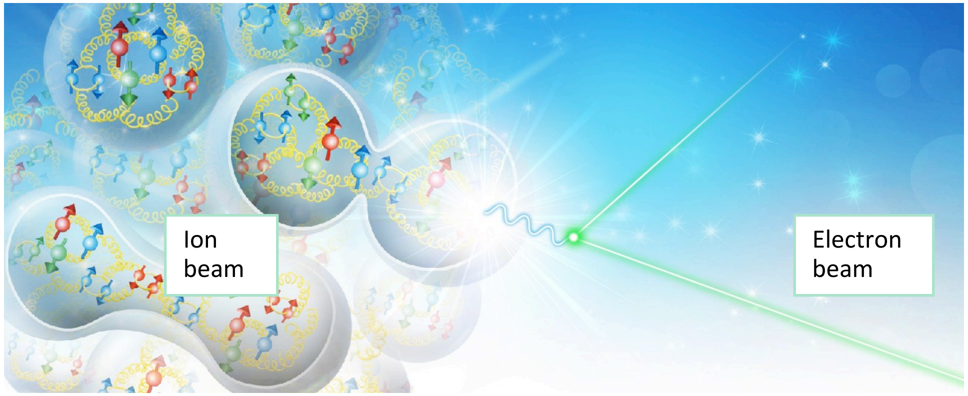
- ❑ **Lepton-hadron collisions:**

Hard collision without breaking the initial-state hadron – spatial imaging, …

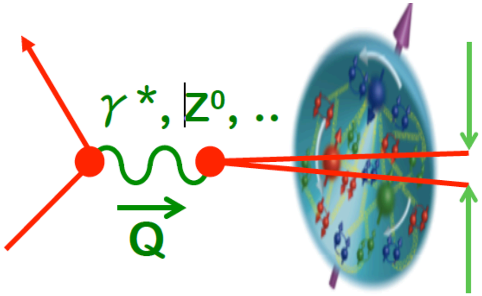
Why Electron- Ion scattering is special?

Jianwei Qiu (DIS2018)

- Many complementary probes at one facility:



A giant "Microscope" – "see" quarks and gluons by looking/breaking the hadron



Inclusive events: e+p/A → e'+X

Detect only the scattered lepton in the detector

(Modern Rutherford experiment!)

Semi-Inclusive events: e+p/A → e'+h(π,K,p,jet)+X

Detect the scattered lepton in coincidence with identified hadrons/jets

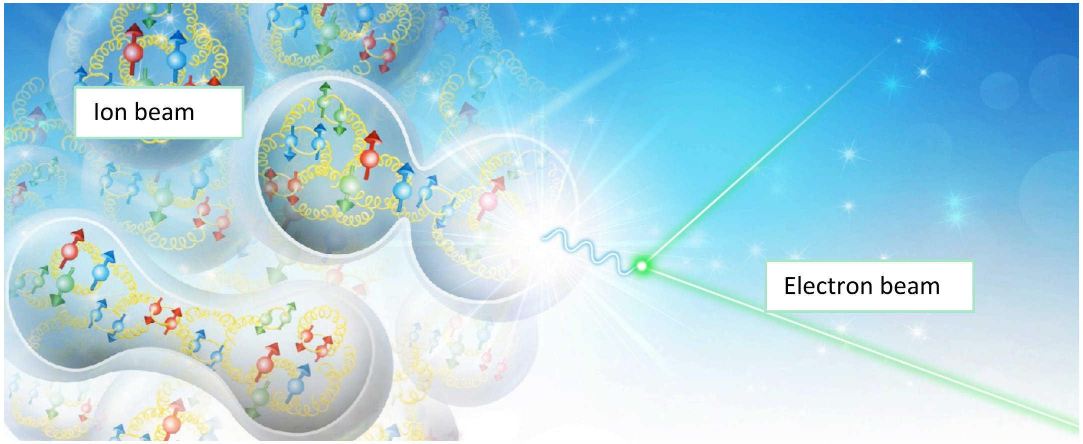
(Initial hadron is broken – confined motion! – cleaner than h-h collisions)

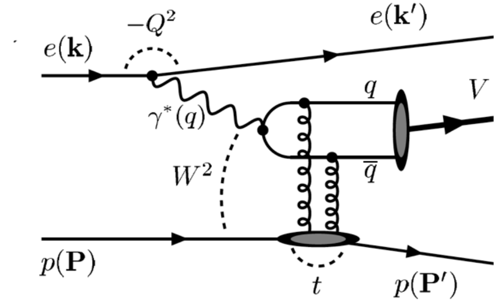
Exclusive events: e+p/A → e'+ p'/A'+ h(π,K,p,jet)

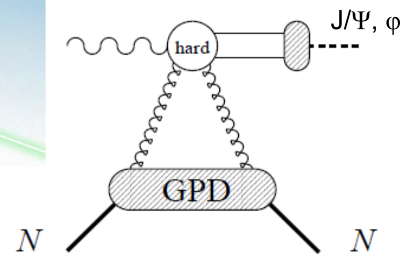
Detect every things including scattered proton/nucleus (or its fragments)

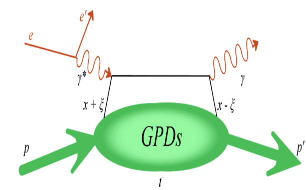
(Initial hadron is NOT broken – tomography! – almost impossible for h-h collisions)

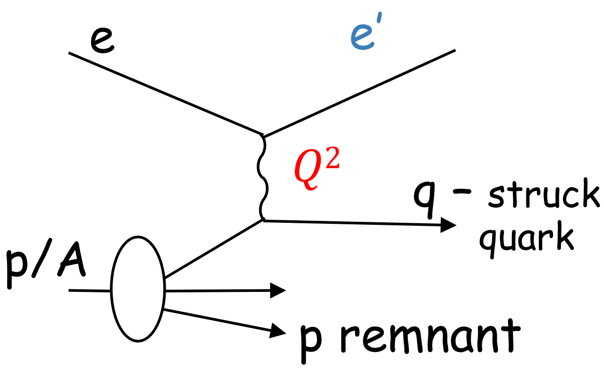
Electron proton scattering

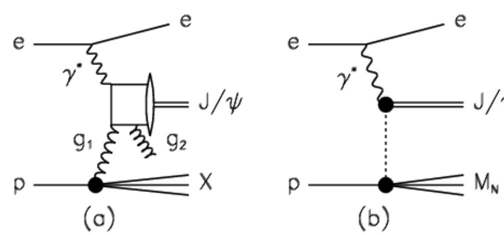


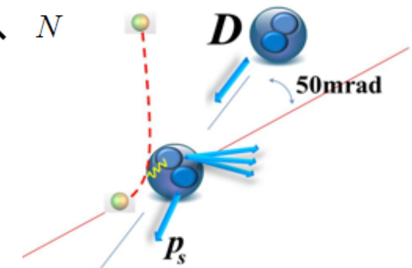


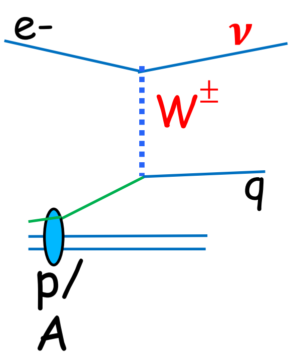


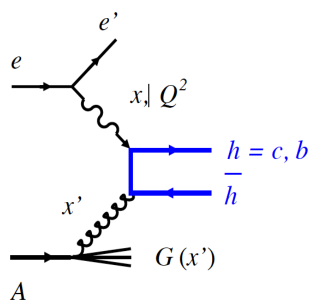


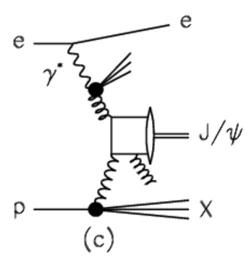


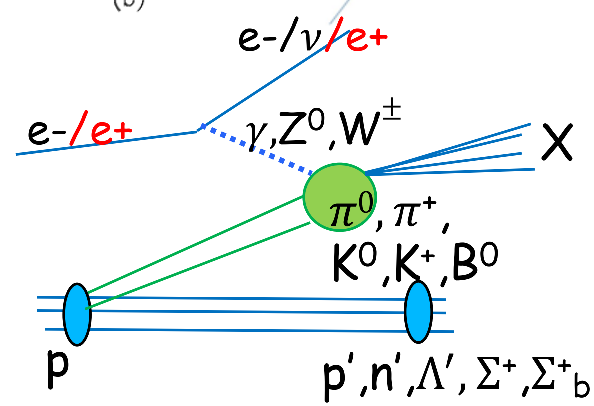




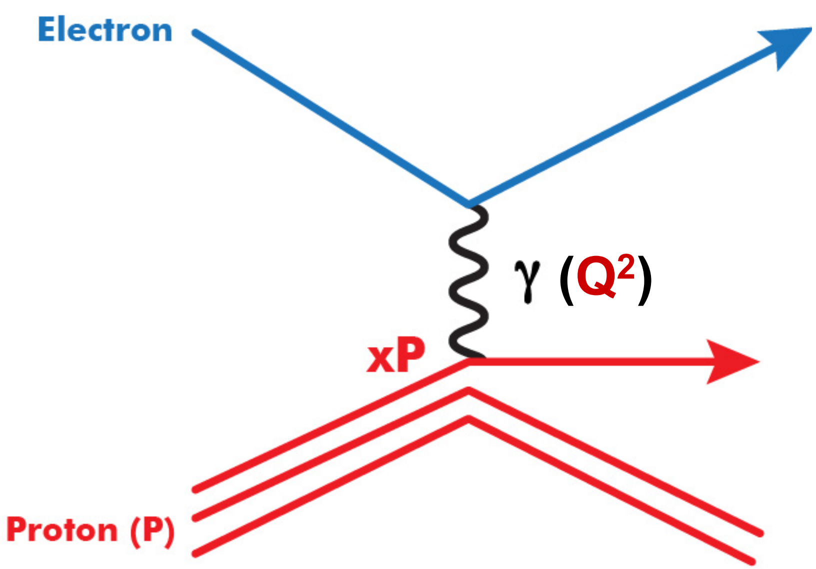




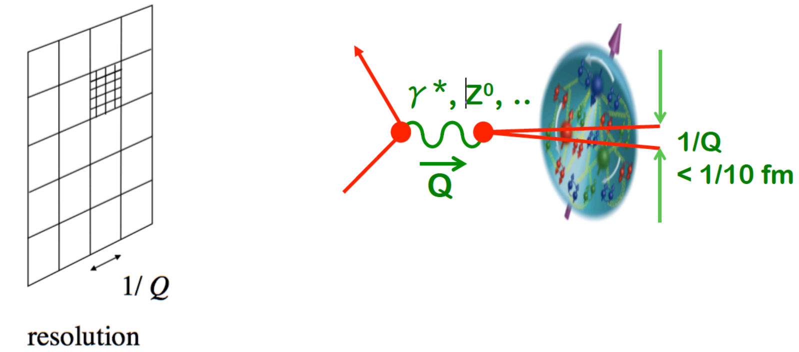




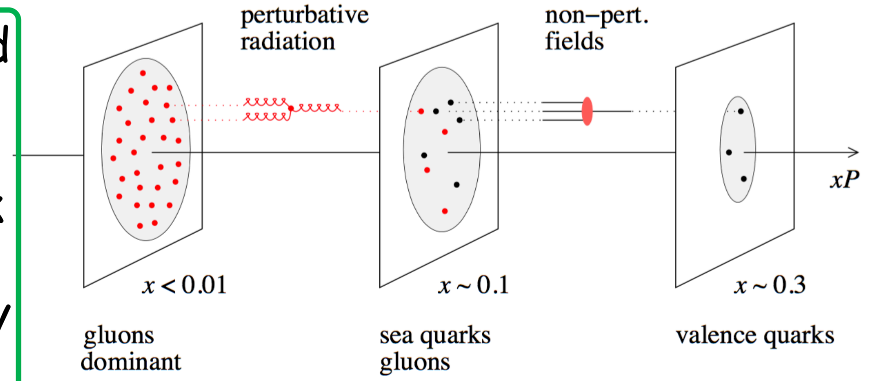
Electron proton scattering



Ability to change Q^2 changes the resolution scale



Ability to change **x** projects out different configurations where different dynamics dominate



$Q^2 = -q^2$: 4-momentum transfer squared

x (0<x<1) - fraction of proton momentum carried by the struck quark

y (0<y<1)=(Ee-Ee')/Ee - fractional energy transfer

Electron-Ion Collider range (x)

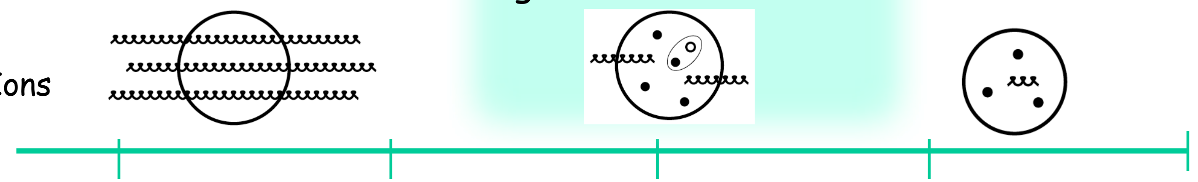
Saturation Regime:

Needs to be Accessed via Ions

Radiative Regime: mostly gluons

Many-body Regime: Valence and sea quarks, gluons

Few-body Regime: valence quarks, Some gluons



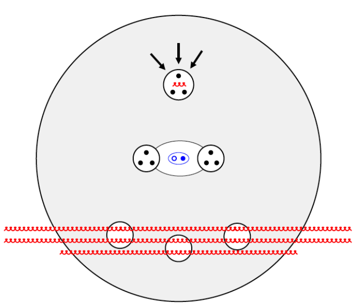
Fraction of momentum carried by the parton
x
(for proton)

QCD Radiation Dominated
(Studied at HERA)

Hadron Structure Dominated

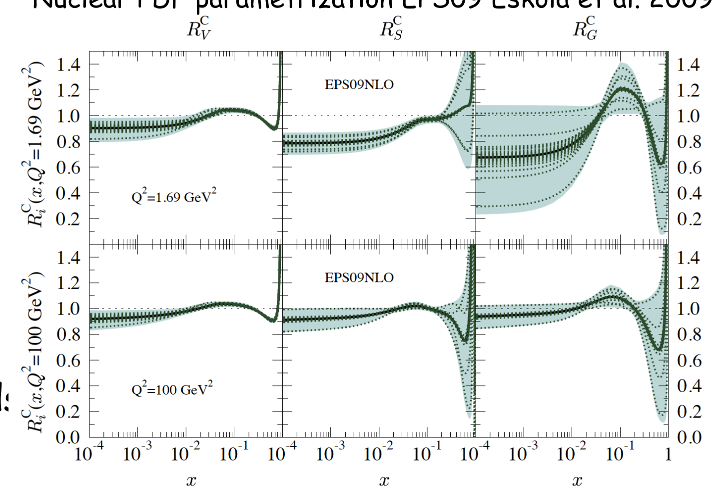
Main interest for EIC
Nucleon/Nuclear Program: Spin, TMD, GPD…

Nucleon interactions

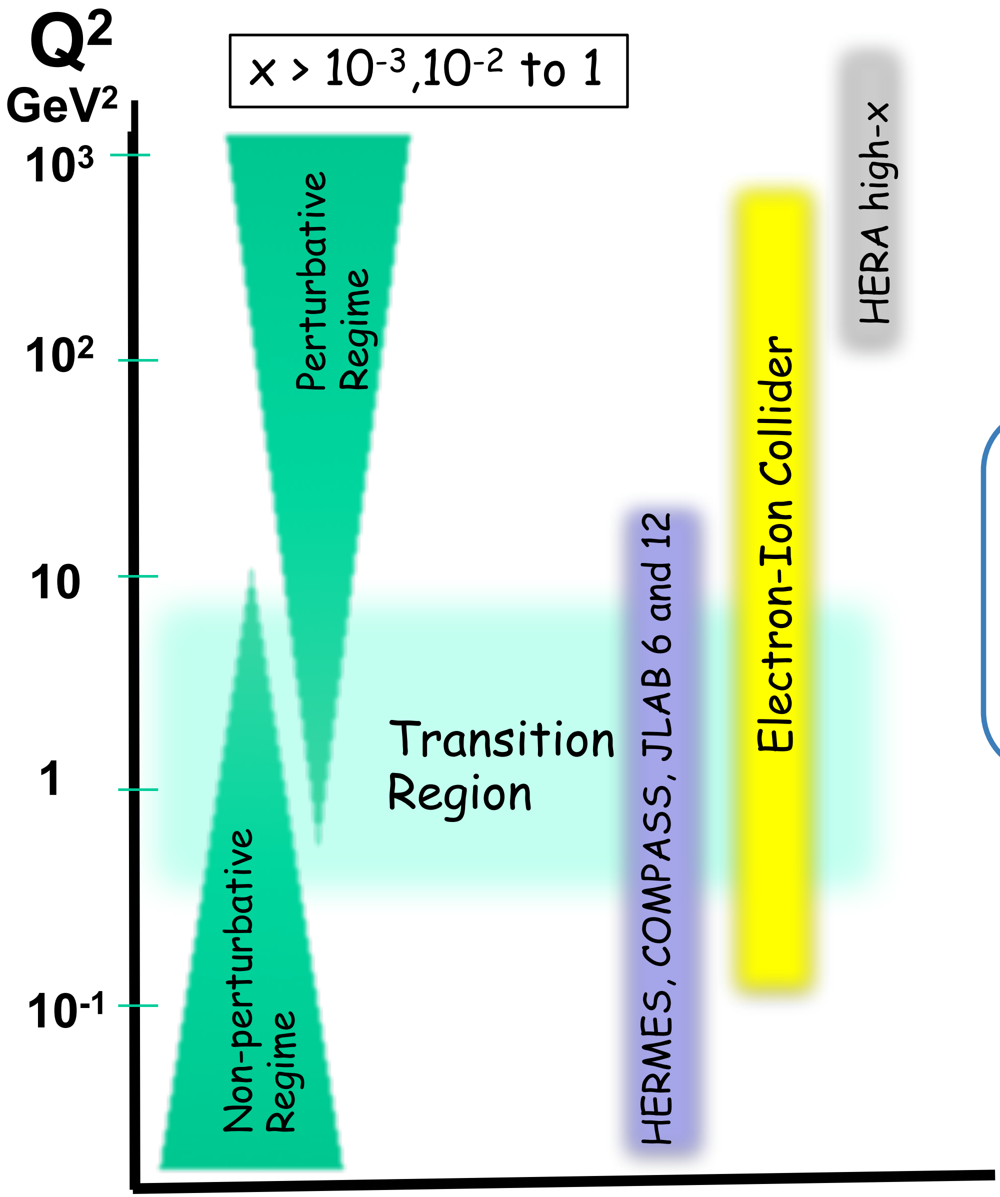


- x > 0.3 "EMC effect"
Modified single-nucleon structure? Non-nucleonic degrees of freedom?
- x ~ 0.1 "Antishadowing"
QCD structure of pairwise NN interaction, exchange mechanisms
- x < 0.01 "Shadowing"
QM interference, collective gluon field:

Nuclear PDF parametrization EPS09 Eskola et al. 2009

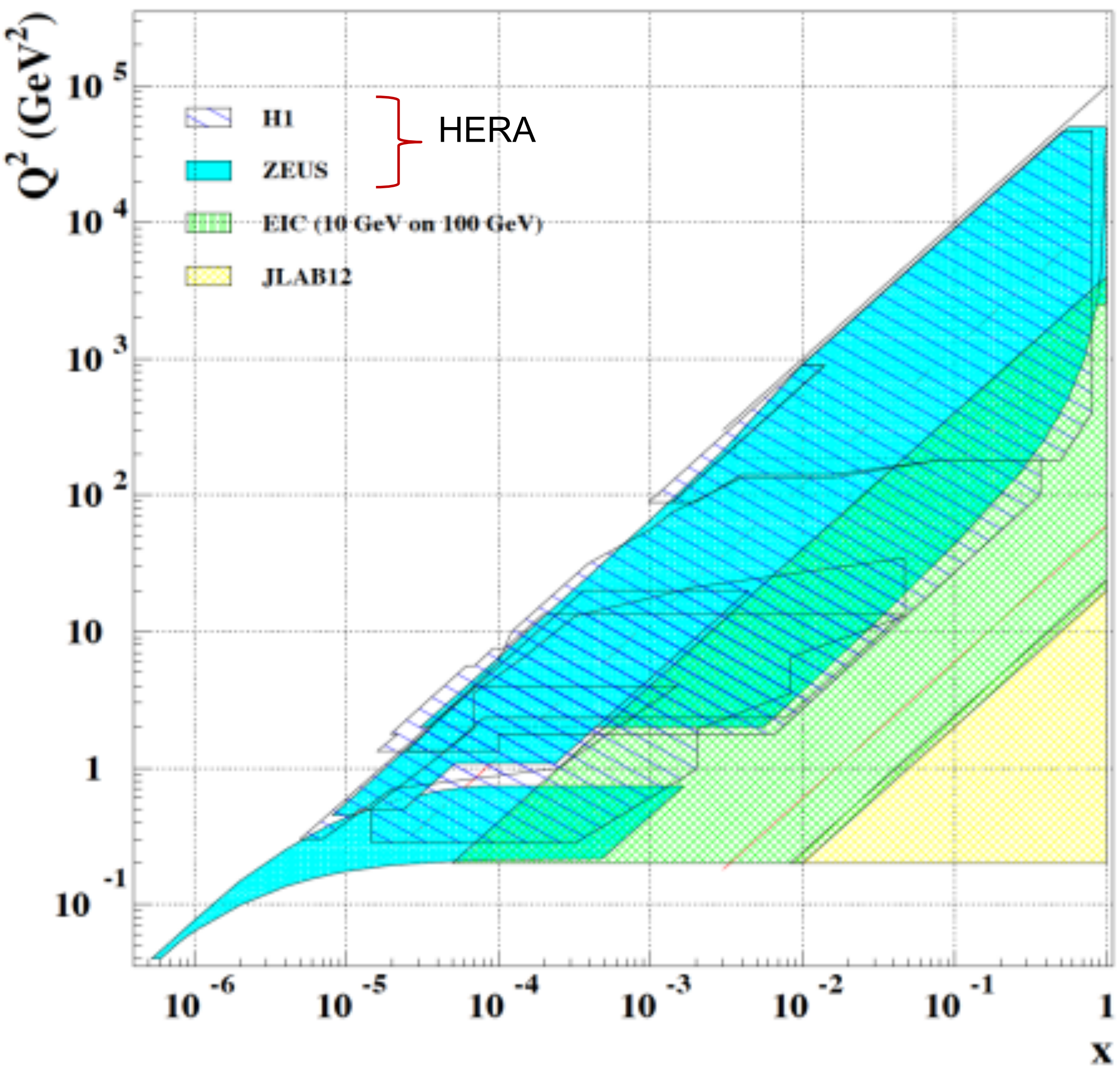


Electron-Ion Collider range (Q2)

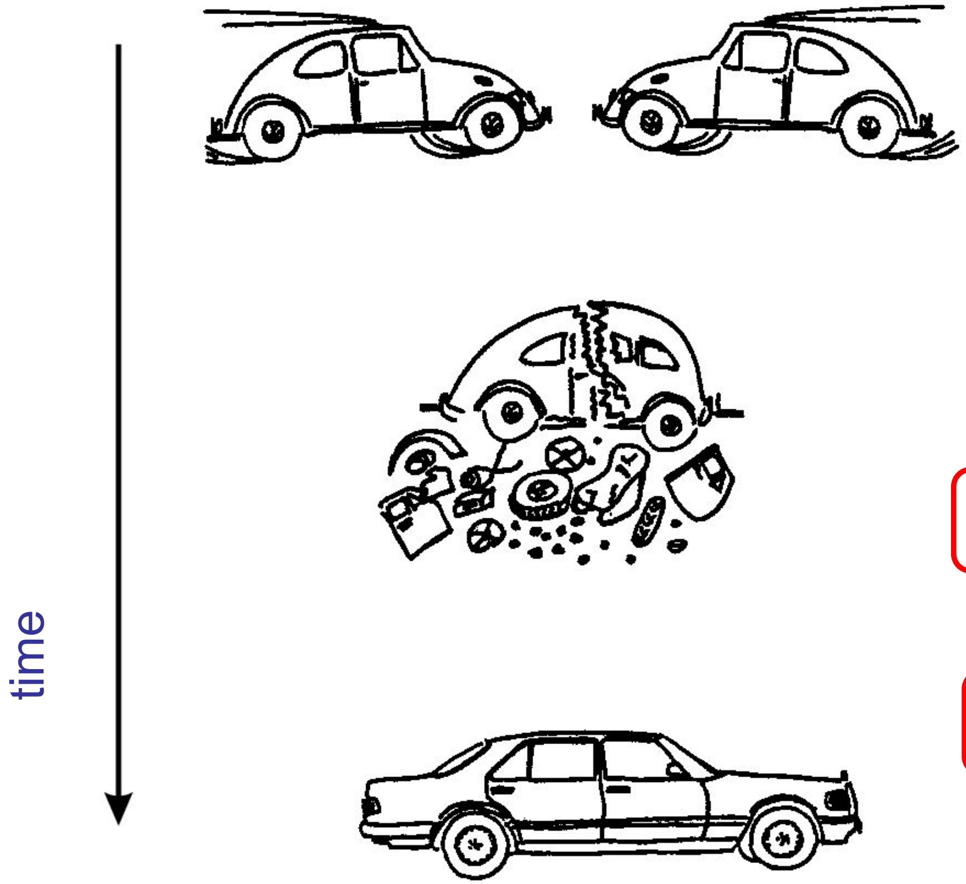


- Include non-perturbative, perturbative and transition regimes
- Provide long evolution length and up to Q^2 of ~1000 GeV^2 (~.005 fm)
- Overlap with existing measurements

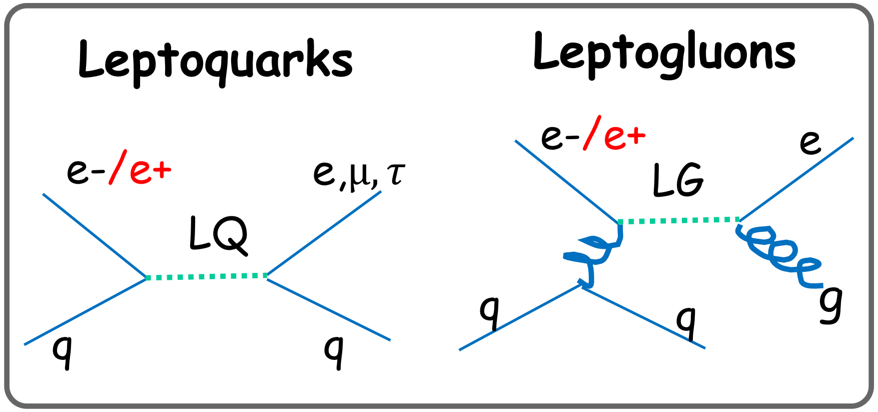
Electron proton scattering x-Q2 coverage



Electron proton scattering



Exotic (BSM) particle production



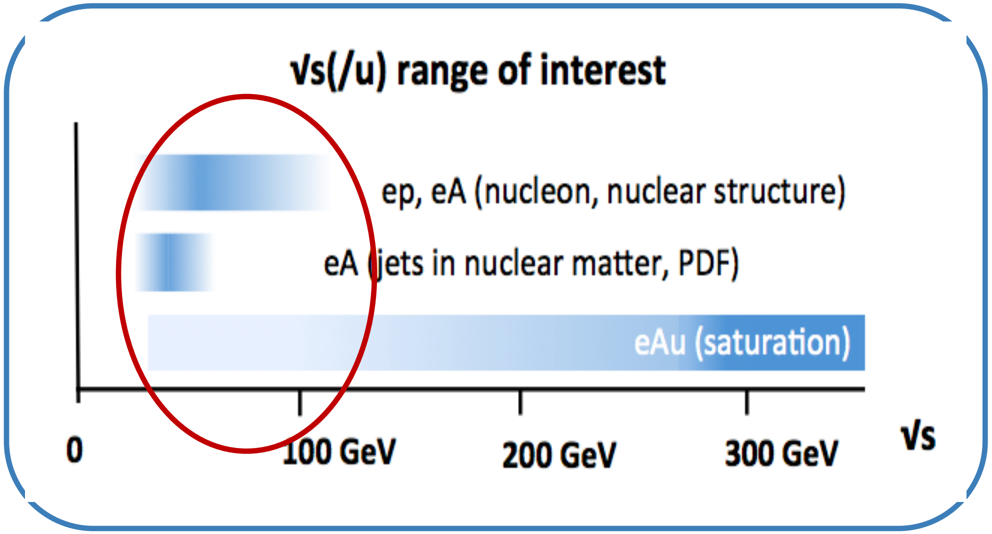
$\sqrt{s}$ – center of mass energy of ep collision

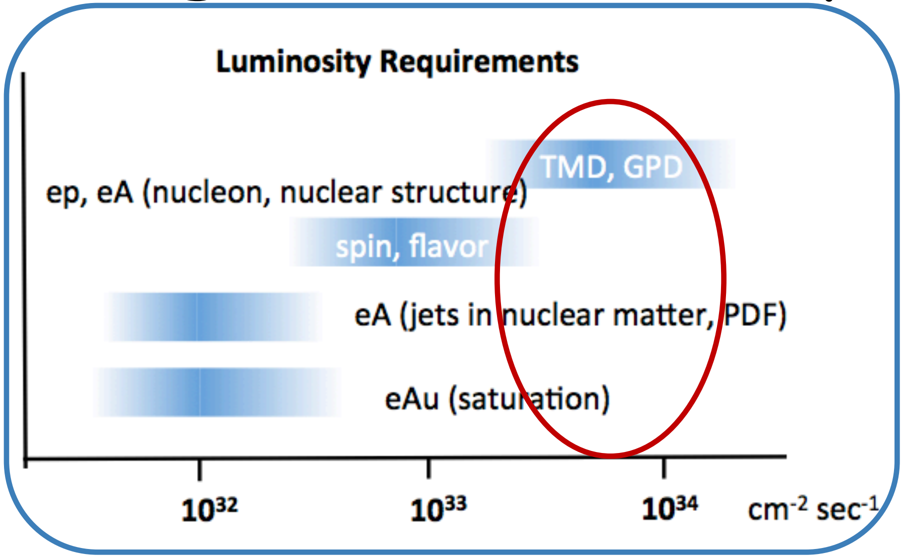
$s=4\cdot E_e\cdot E_p$

$Q^2=sxy$

Cartoon by Claus Grupen, University of Siegen

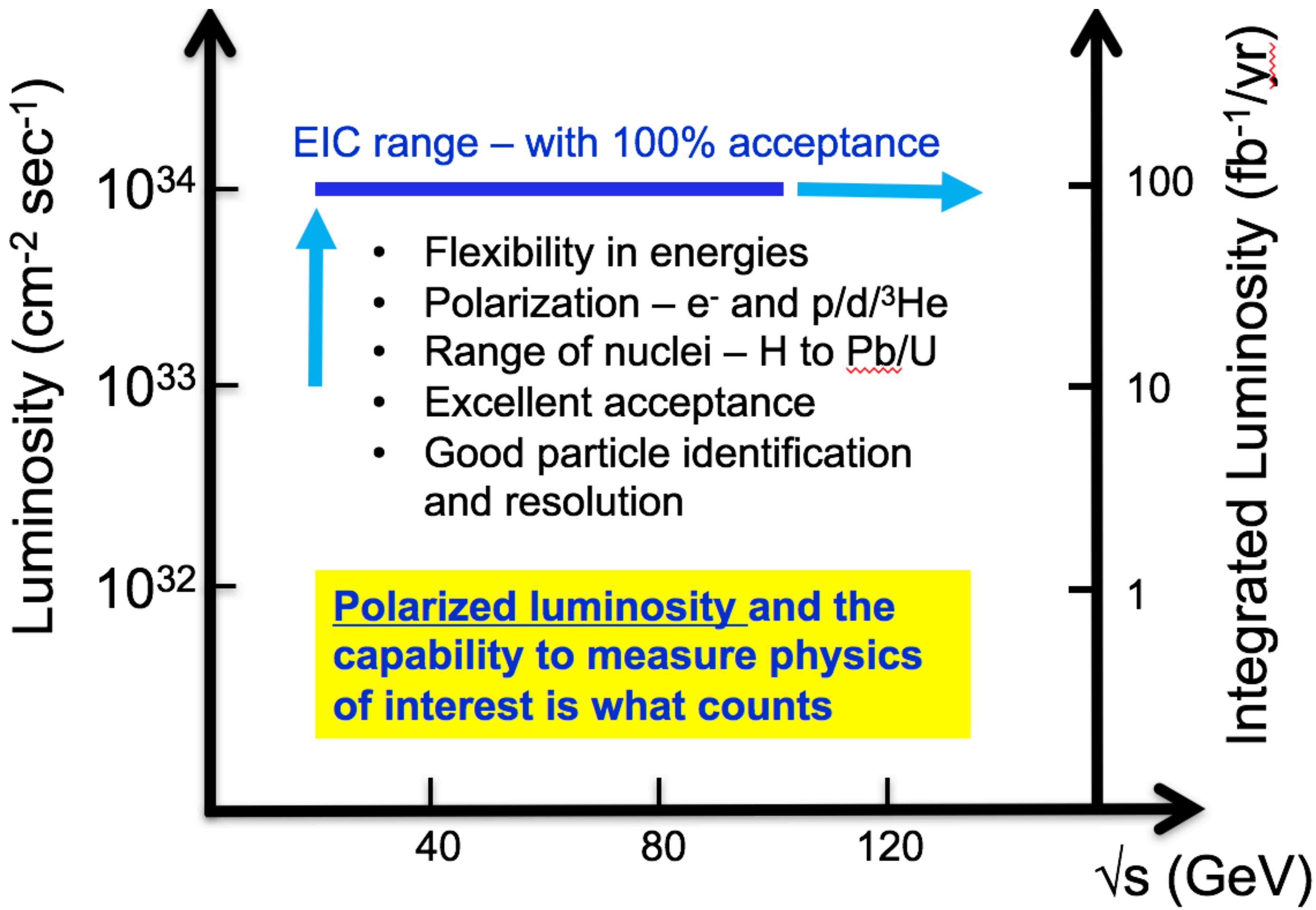
Electron-Ion Collider: √s range and luminosity





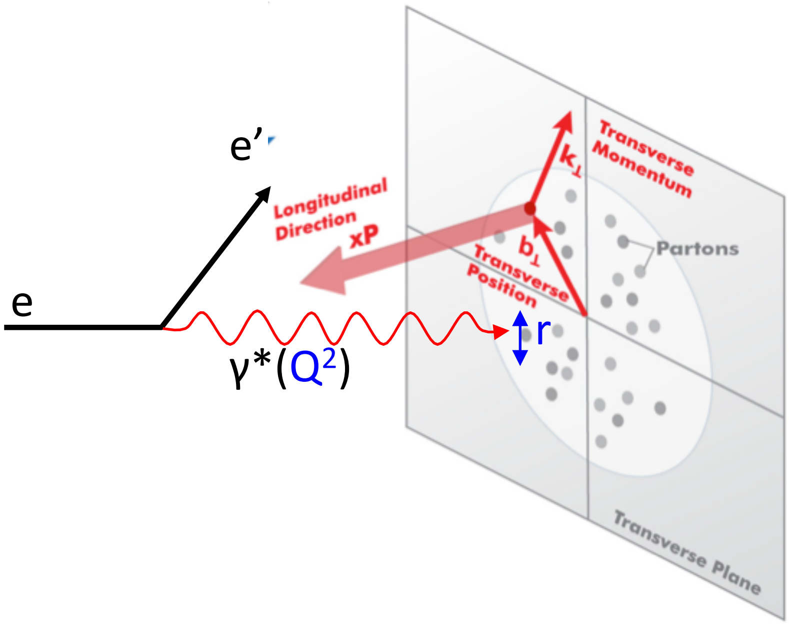
Beam energy:
Various center of mass energy (low, medium, high)
High luminosity :
- high precision physics
- rear physics
- various measurements/configurations: (different ions, different center of mass energies, different polarizations)

Electron-Ion Collider: $\sqrt{s}$ range and luminosity



A high luminosity is needed to carry out the EIC physic program

3D Structure of Nucleons and Nuclei

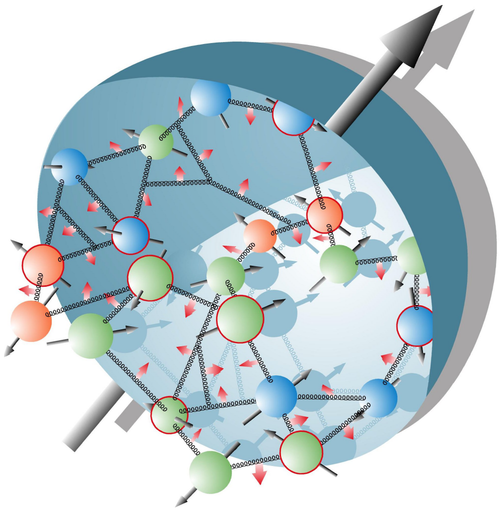


3D Structure of Nucleons and Nuclei:

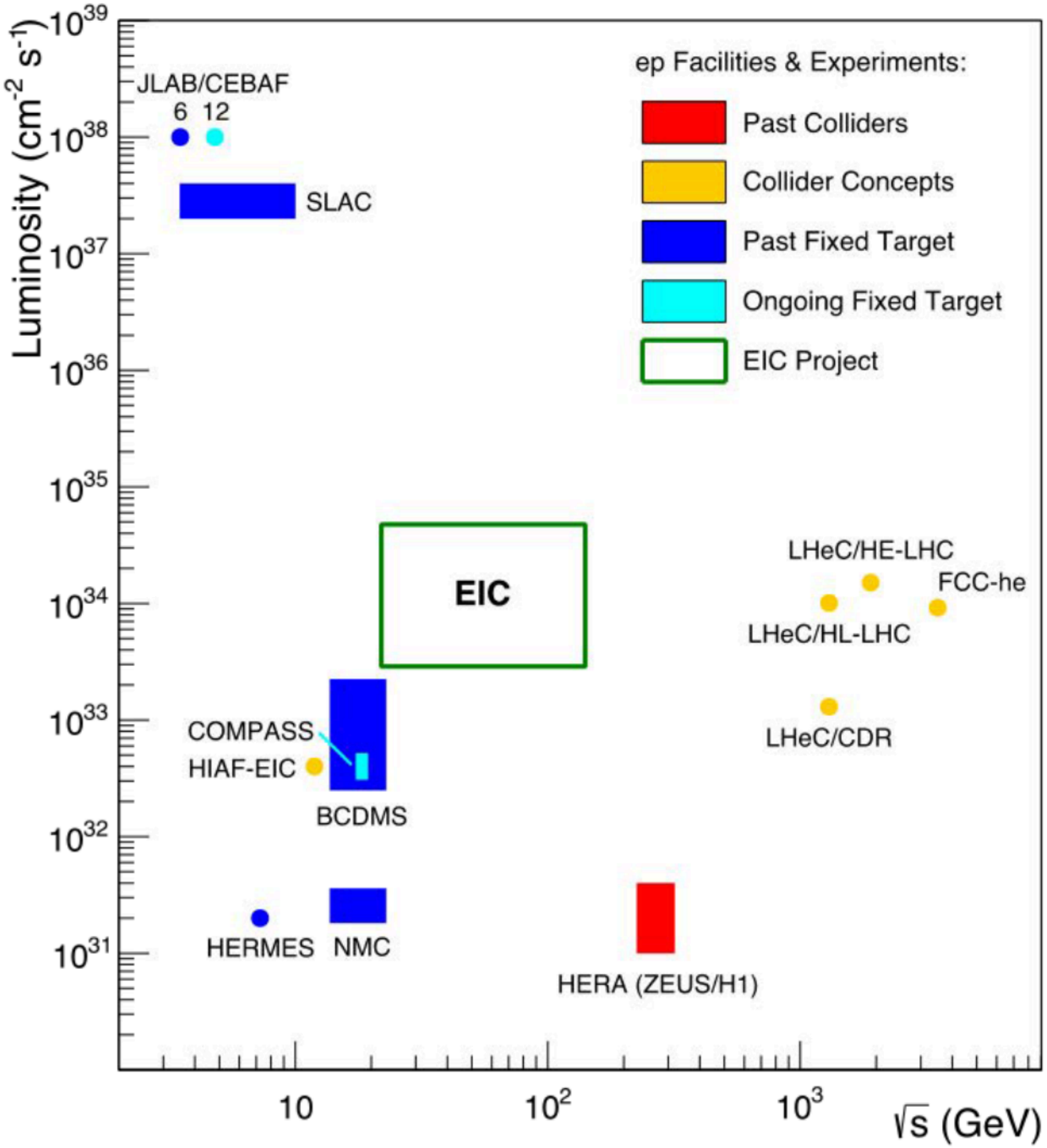
- Need to measure positions and momenta of the partons transverse to its direction of motion.
- These quantities (k_T, b_T) are of the order of a few hundred MeV.

Transverse Momentum Dependent Distributions (TMD): k_t
Generalized Parton Distributions (GPD): b_t

Polarizaton
Understanding hadron structure cannot be done without understanding spin:
- polarized electrons and
- polarized protons/light ions

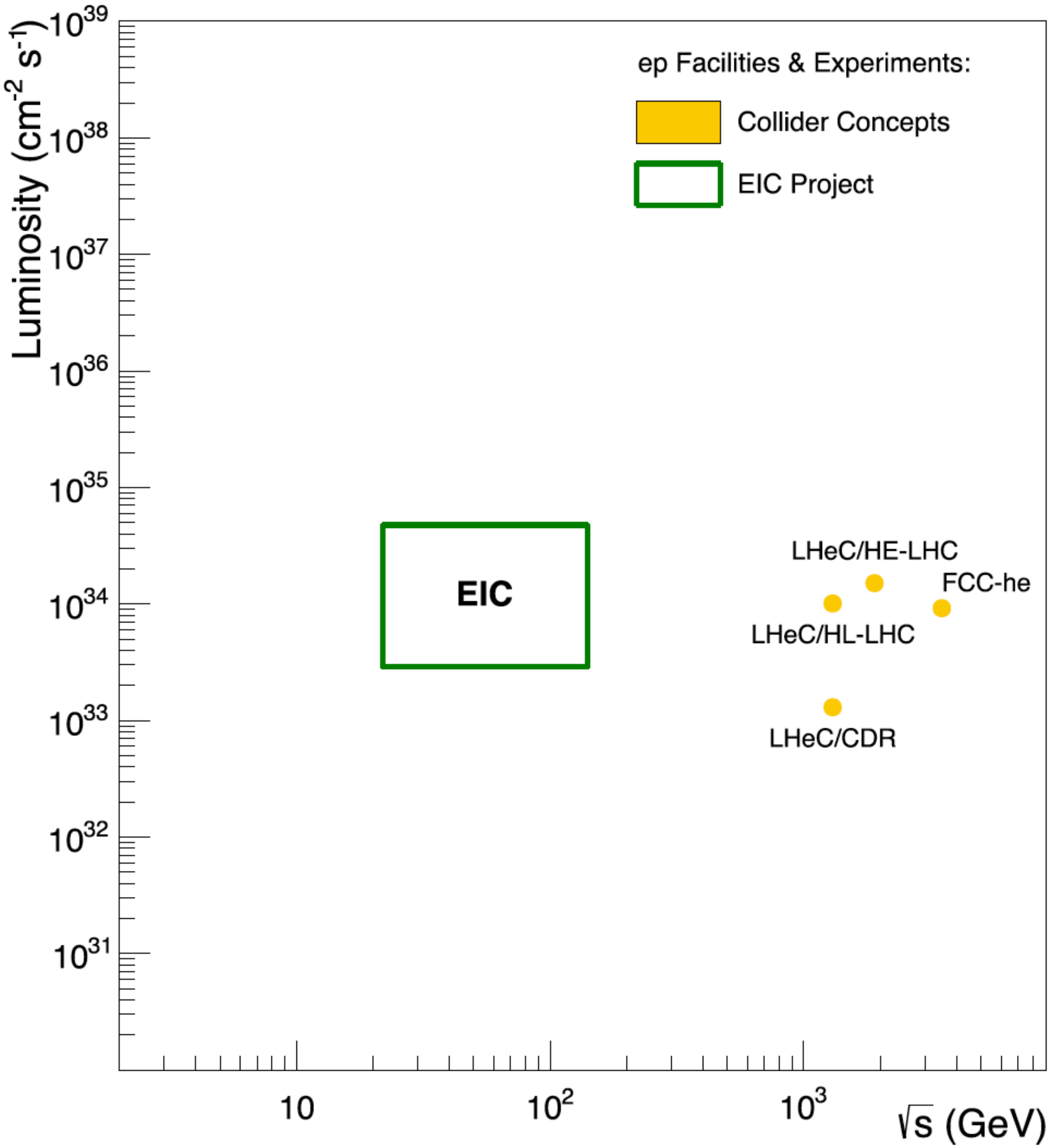


Past, existing and proposed DIS facilities



All DIS facilities in the world.

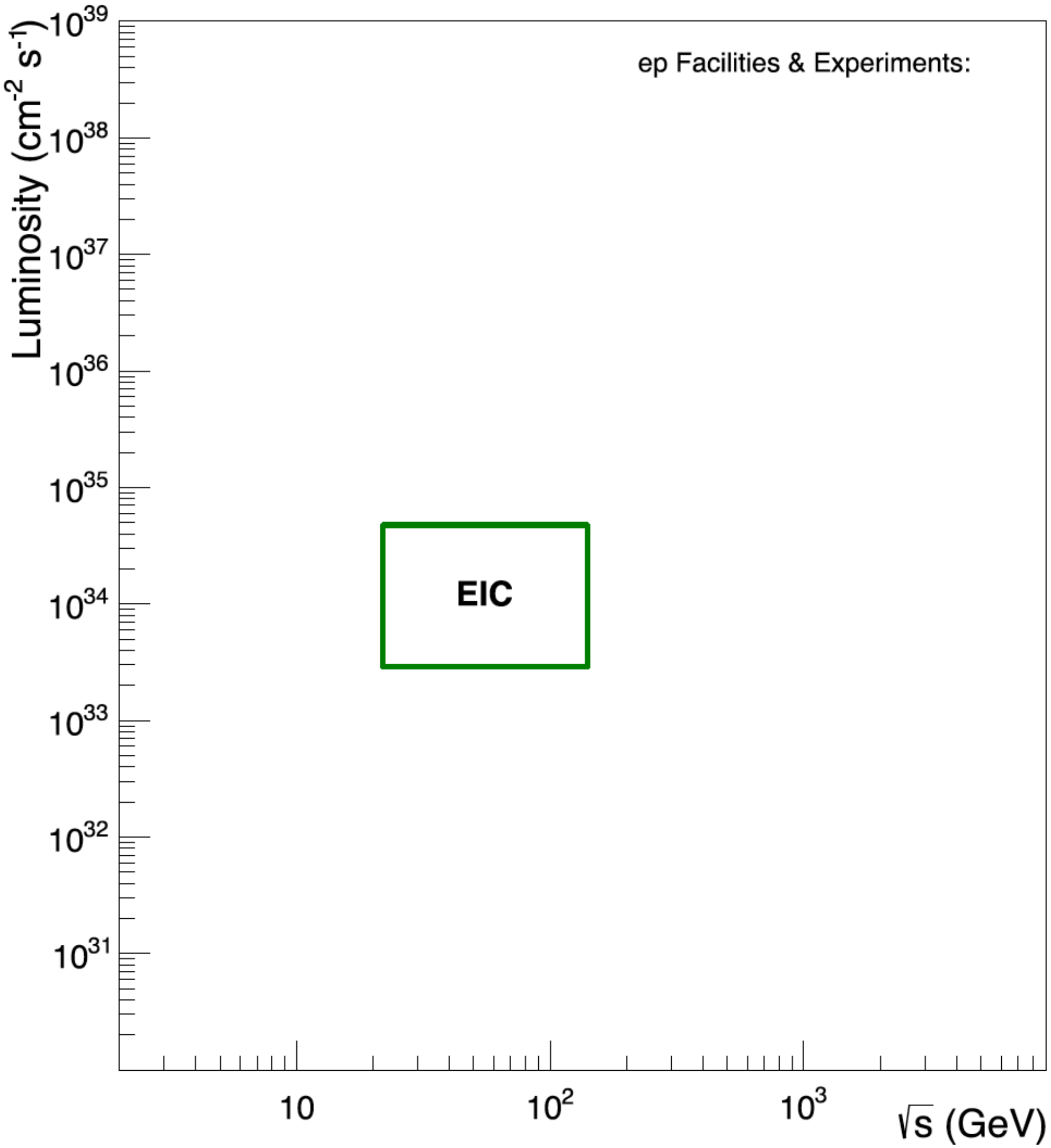
Past, existing and proposed DIS facilities



However,
if we ask for:

- high luminosity & wide reach in $\sqrt{s}$

Past, existing and proposed DIS facilities



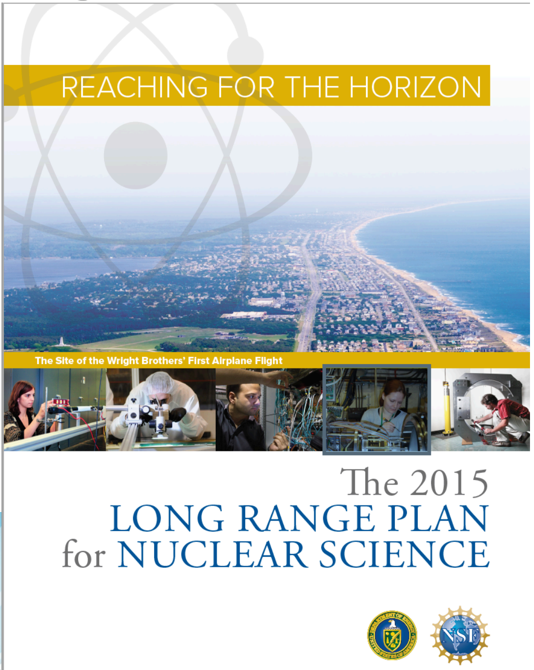
However,
if we ask for:

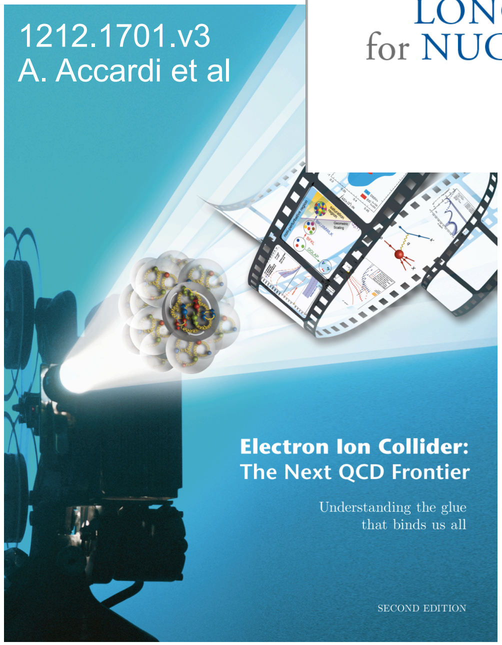
- high luminosity & wide reach in $\sqrt{s}$
- polarized lepton & hadron beams
- nuclear beams

EIC will be a unique facility.

No other machine, existing or planned can address the physics of interest satisfactorily.

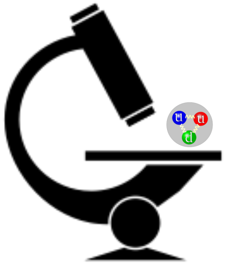
Long Range Plan





The NSAC recommend "a high-energy high-luminosity polarized Electron-Ion Collider (EIC) as the highest priority for new facility construction.."

The Next QCD Frontier

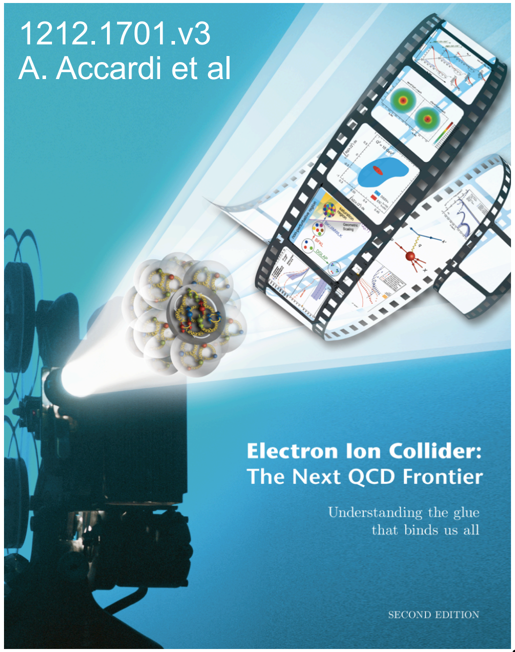


- Understanding of nucleon and nuclear structure and associated dynamics (3D structure)
- Probe the nucleon and nuclei in different interaction regimes.
- Extend our understanding of QCD (saturation, propagation of quarks/jets in cold nuclear matter)

World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

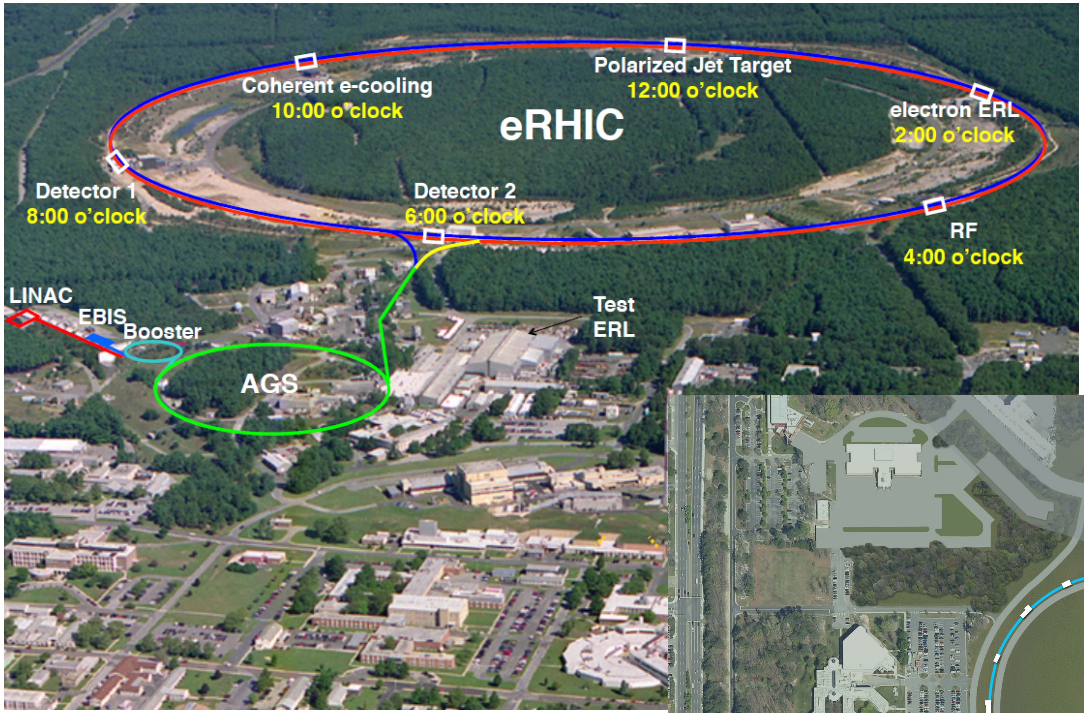
Wide range of nuclei
CM energy $\sqrt{s}(eN) \sim 20\text{–}140$ GeV
Luminosity $L \sim 10^{34}\ cm^{-2}\ s^{-1}$
Polarized beams
Next generation of detectors

first eA collider
acceptance coverage x, Q^2
Imaging, rare processes
Spin effects
final states

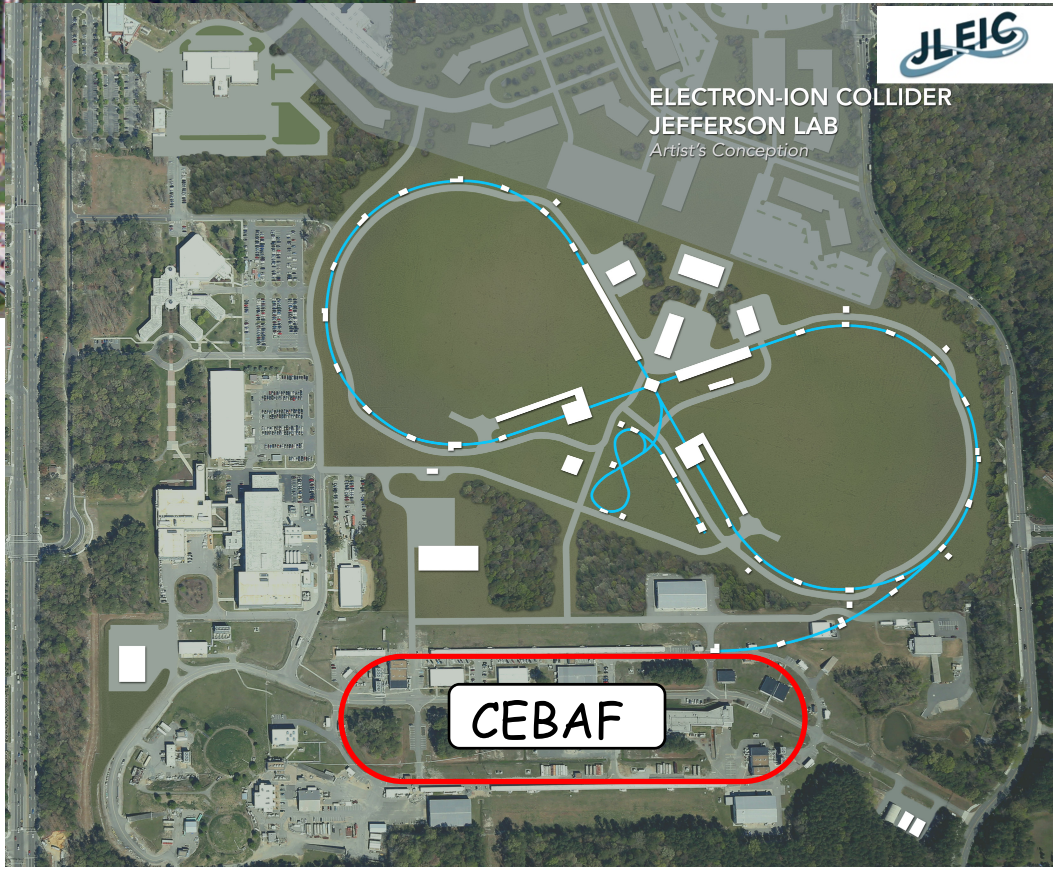


Two proposals for realization of the science case -
both designs use DOE's significant investments in infrastructure

US-Based EIC Proposals



Brookhaven Lab
Long Island, NY



Jefferson Lab
Newport News, VA

Luminosity

- Luminosity:

$$L = f\frac{n_1 n_2}{4\pi\sigma_x\sigma_y}$$

- Integrated luminosity:

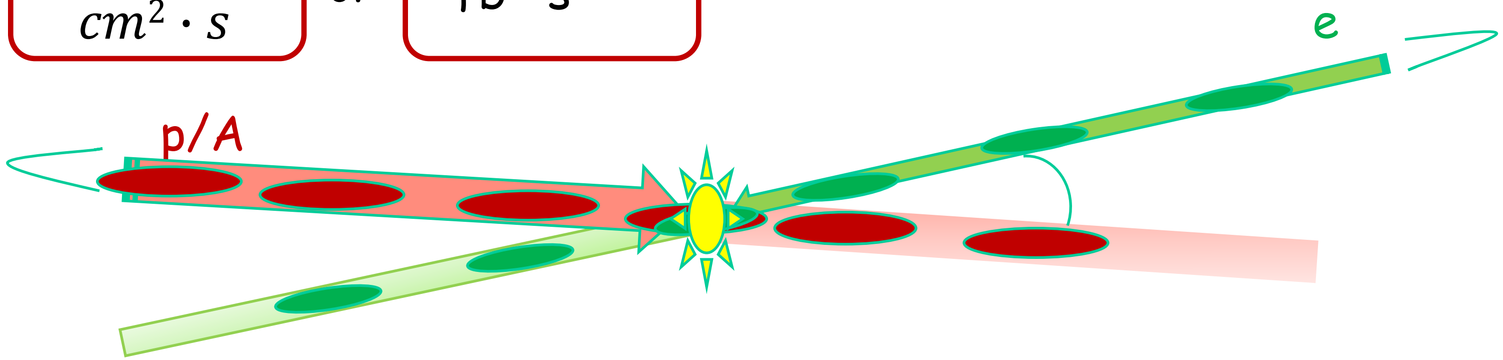
$$L_{int} = \int L dt \quad [fb^{-1}]$$

n1,n2 – number of particles in each bunch
f-collision frequency
σ_x , σ_y -width of beams

Units:

$$\frac{1}{cm^2 \cdot s}$$ or $fb^{-1}\, s^{-1}$

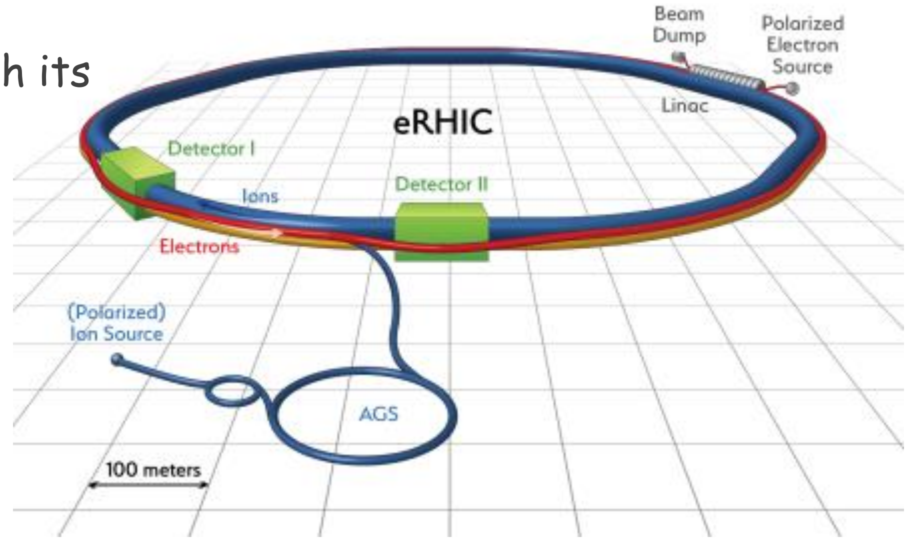
Units:
1 barn = 10^{-24} cm^2
femtobarn (fb) = 10^{-39} cm^2 = 10^{-15}b



eRHIC design (BNL)

From F. Willecke, BNL

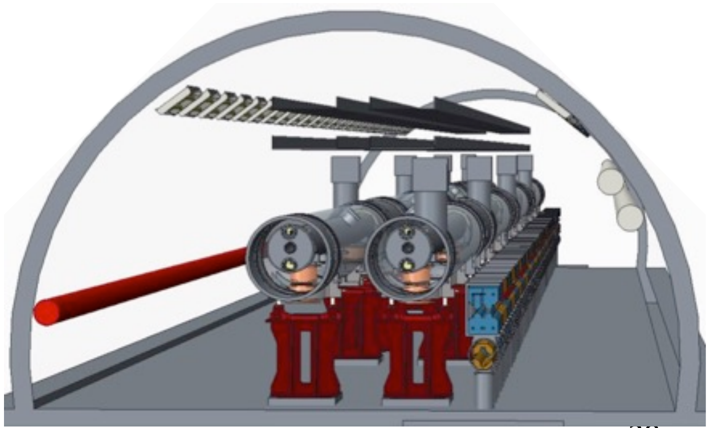
Exploiting existing Hadron complex RHIC with its
- superconducting magnets, 275 GeV protons
- its large accelerator tunnel and
- its long straight sections
- its existing Hadron injector complex



Adding an electron accelerator
of 18 GeV in the same tunnel

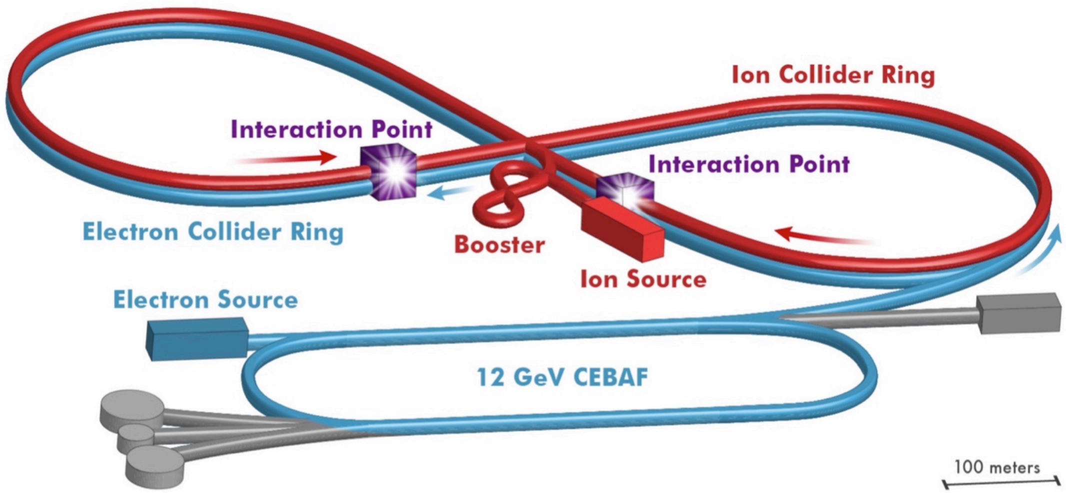
-> achieve high luminosity electron-Hadron collisions over a large range of CM Energies

e-:	18 GeV
p :	50-275 GeV
$\sqrt{s}$:	**60- 140 GeV**
Luminosity	10^{33} (10^{34}) $cm^{-2}s^{-1}$



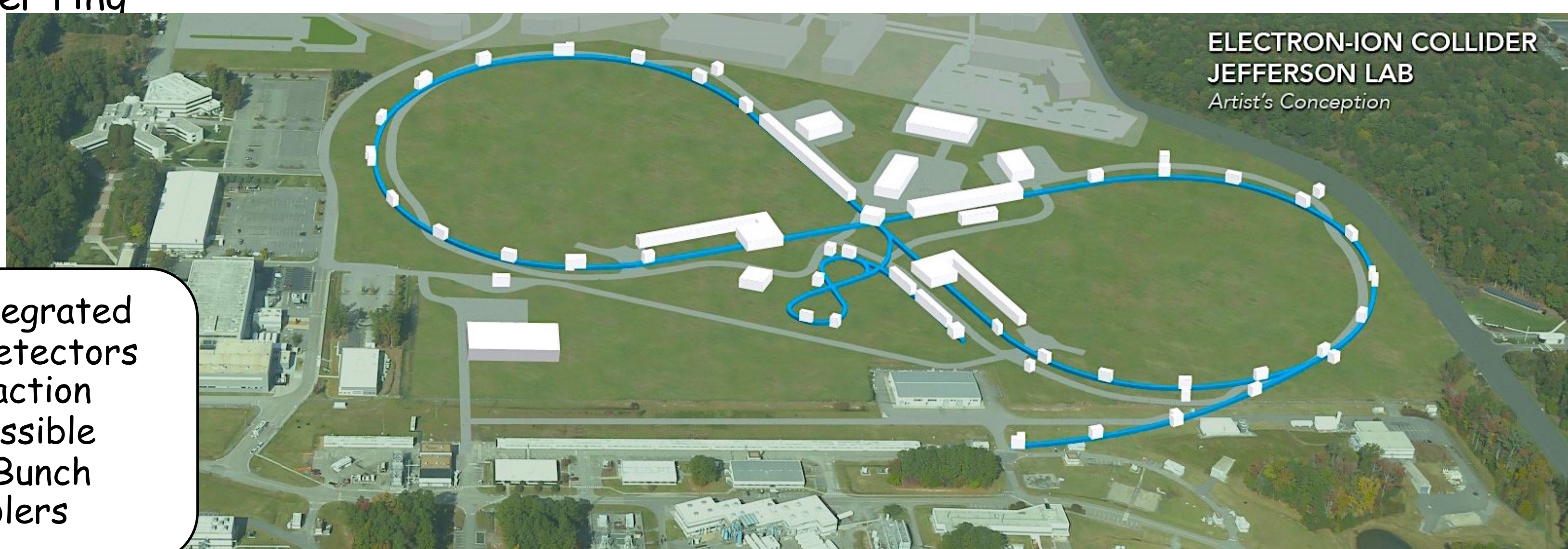
JLEIC design (JLab)

e-: 3 to 10 -12 GeV
p : 20 to 100 (400) GeV
$\sqrt{s}$: 20 to **65 (140) GeV**
(Magnet Technology Choice)
Luminosity: ~10^{34} $cm^{-2}s^{-1}$



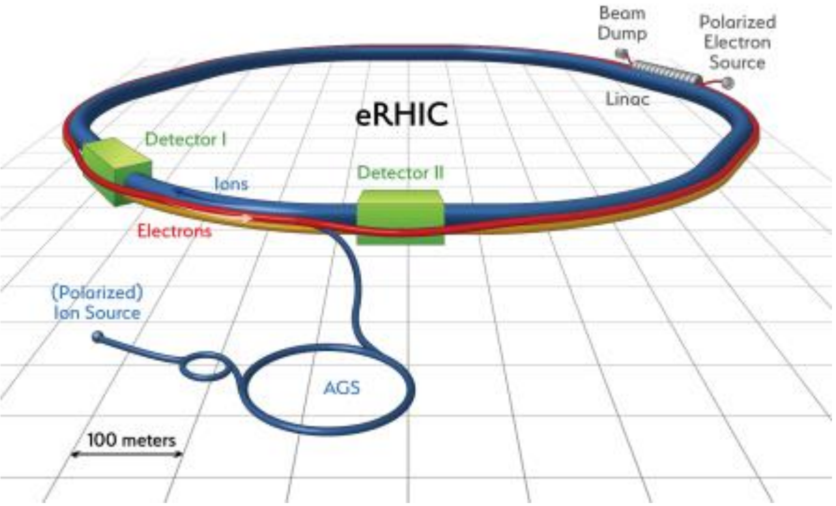
Exploring existing Electron complex
CEBAF (adding Electron collider ring)
Adding Ion complex
Ion source, SRT linac, Booster, Ion collider ring

Figure 8: High polarization (~80%)

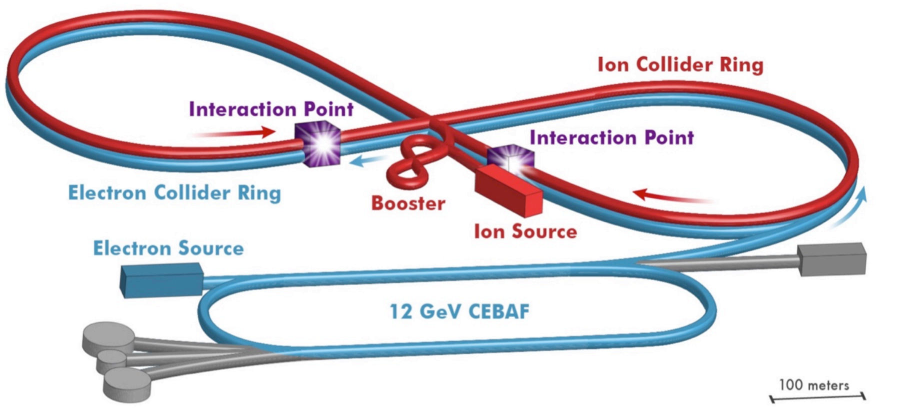


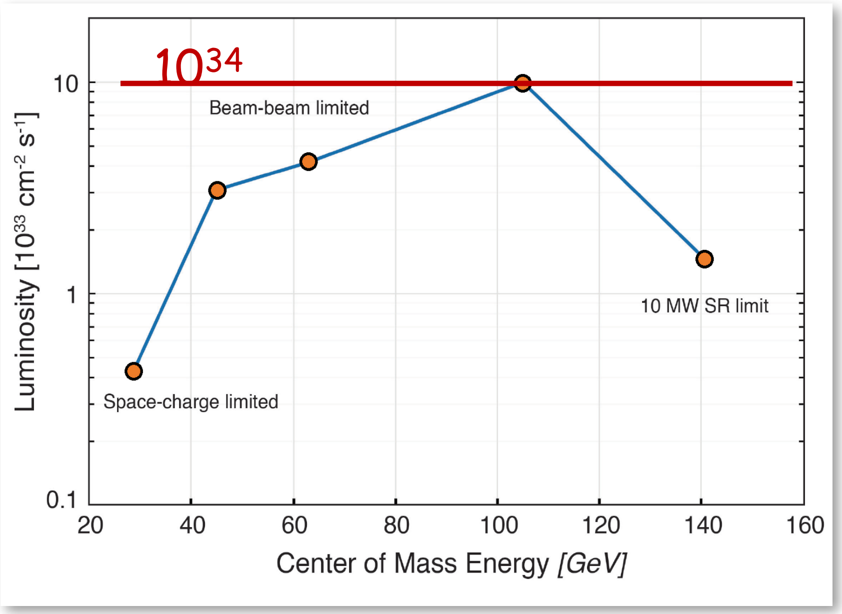
-Fully integrated IR and detectors
-2 Interaction Points possible
-DC and Bunch beam coolers

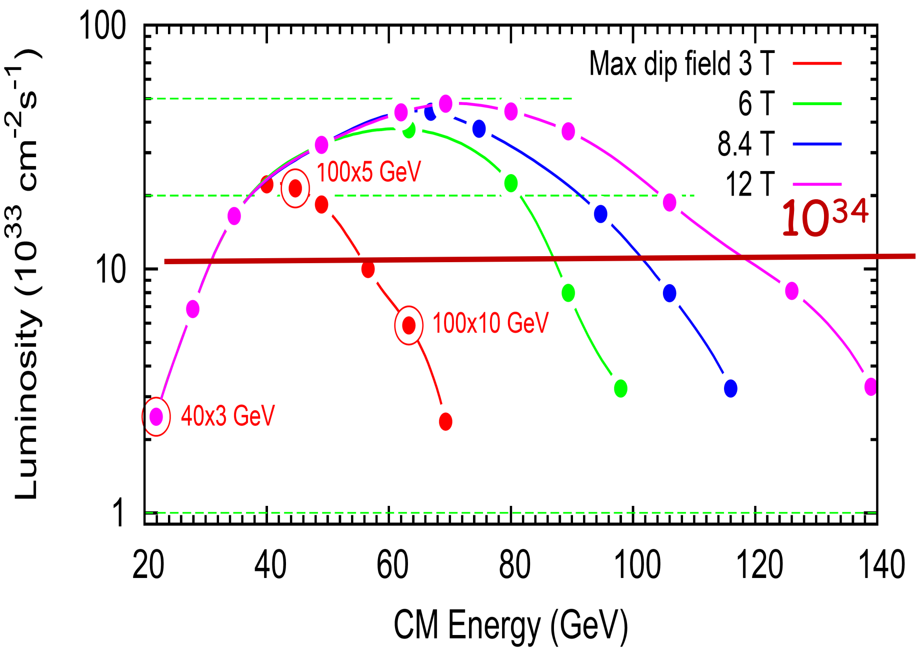
eRHIC design (BNL)



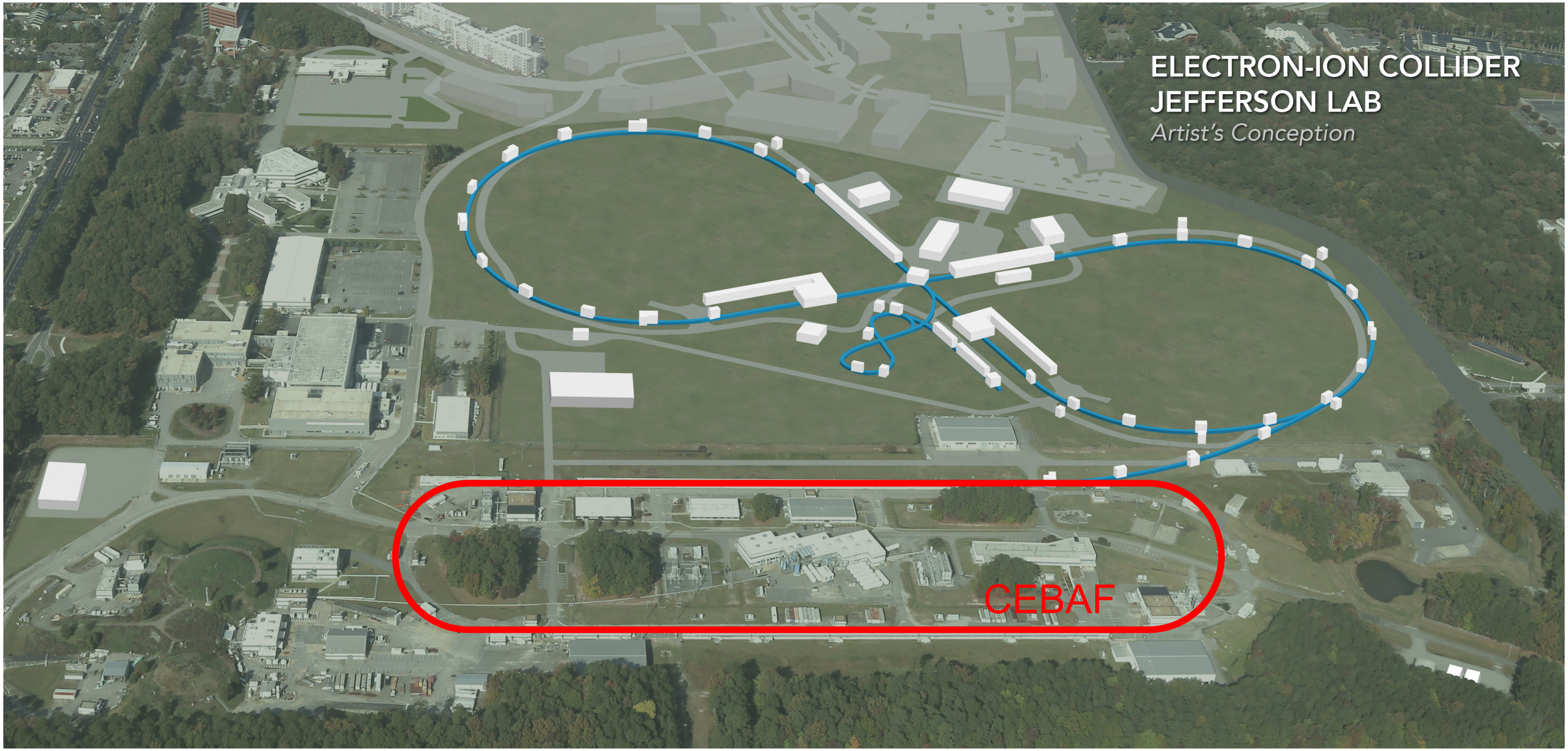
JLEIC design (JLab)





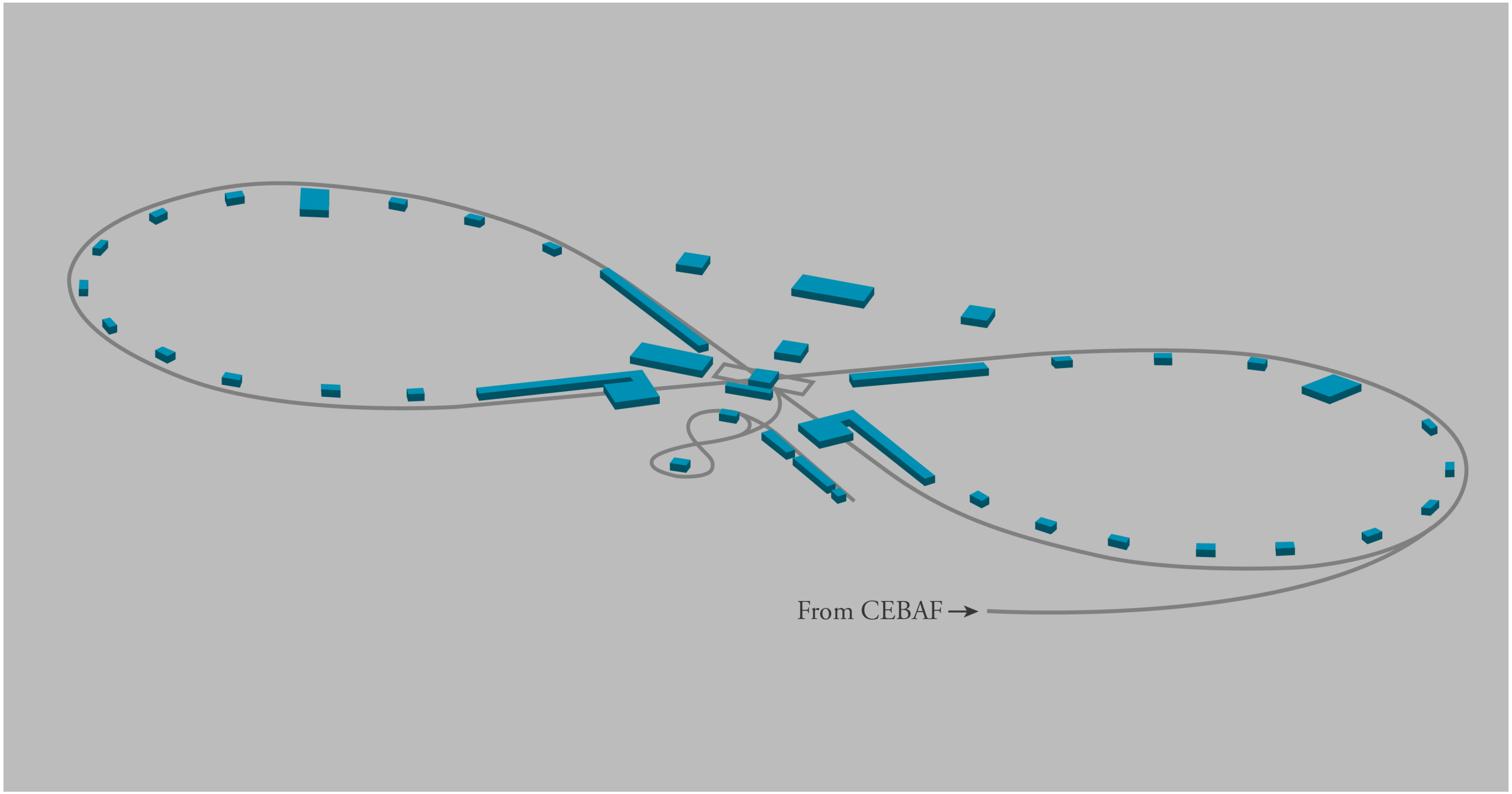


Electron-Ion Collider at Jefferson Lab (JLEIC)



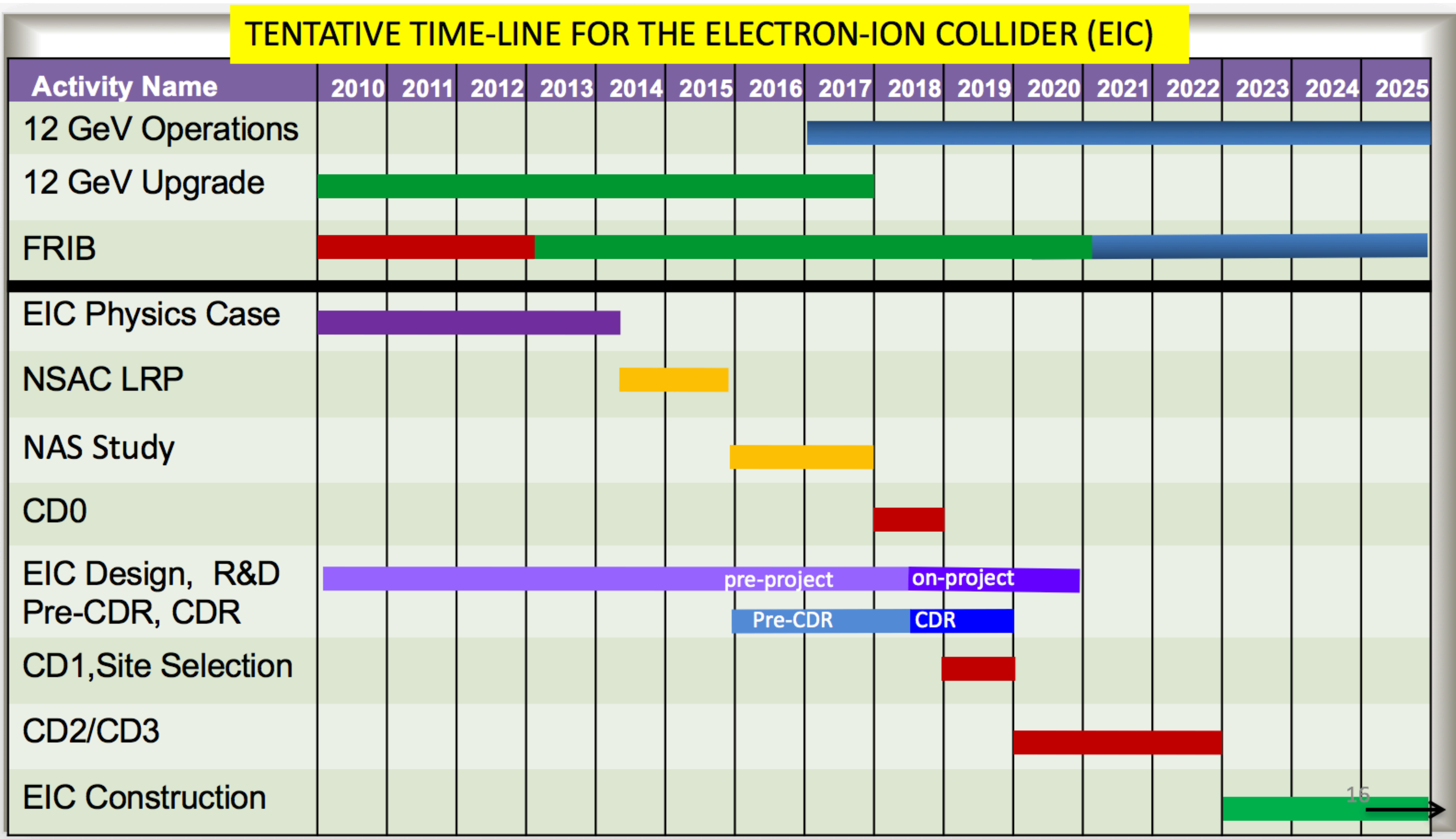
Electrons: up to 12 GeV
Protons: 2—100 (upgrade upto 400GeV)

JLEIC



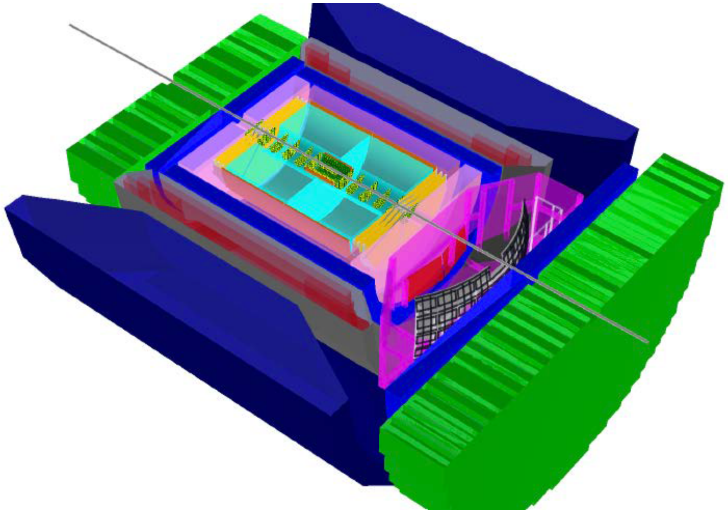
JLEIC Parameters (3T option)

CM energy	GeV	21.9 (low)		44.7 (medium)		63.3 (high)	
		p	e	p	e	p	e
Beam energy	GeV	40	3	100	5	100	10
Collision frequency	MHz	476		476		476/4=119	
Particles per bunch	10^{10}	0.98	3.7	0.98	3.7	3.9	3.7
Beam current	A	0.75	2.8	0.75	2.8	0.75	0.71
Polarization	%	**80%**	**80%**	**80%**	**80%**	**80%**	**75%**
Bunch length, RMS	cm	3	1	1	1	2.2	1
Norm. emittance, hor / ver	μm	0.3/0.3	24/24	0.5/0.1	54/10.8	0.9/0.18	432/86.4
Horizontal & vertical β*	cm	8/8	13.5/13.5	6/1.2	5.1/1.0	10.5/2.1	4/0.8
Ver. beam-beam parameter		0.015	0.092	0.015	0.068	0.008	0.034
Laslett tune-shift		0.06	7×10^{-4}	0.055	6×10^{-4}	0.056	7×10^{-5}
Detector space, up/down	m	3.6/7	3.2/3	3.6/7	3.2/3	3.6/7	3.2/3
Hourglass(HG) reduction		1		0.87		0.75	
Luminosity/IP, w/HG, 10^{33}	$cm^{-2}s^{-1}$	**2.5**		**21.4**		**5.9**	

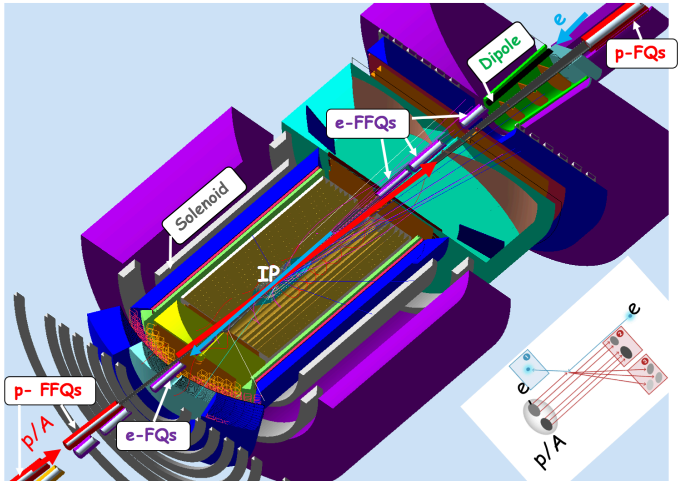

TENTATIVE TIME-LINE FOR THE ELECTRON-ION COLLIDER (EIC)
Activity Name
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
12 GeV Operations
12 GeV Upgrade
FRIB
EIC Physics Case
NSAC LRP
NAS Study
CD0
EIC Design, R&D
Pre-CDR, CDR
pre-project
on-project
Pre-CDR
CDR
CD1,Site Selection
CD2/CD3
EIC Construction
16

US-Based EIC Proposals: detectors

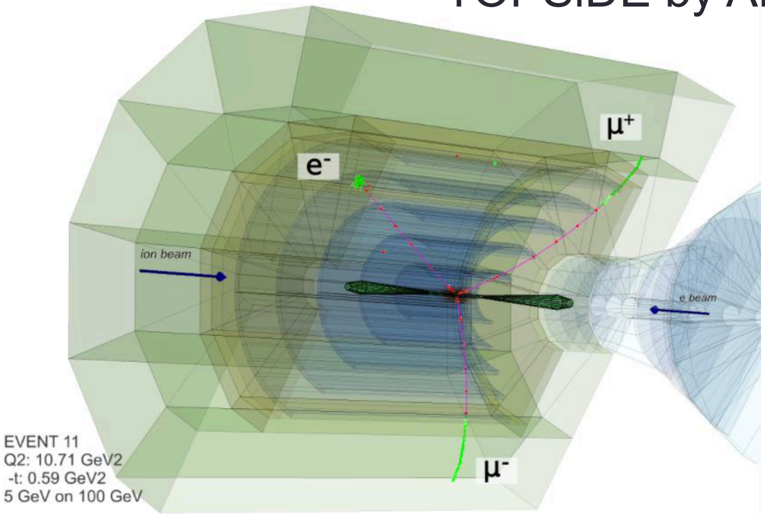
eRHIC Detector



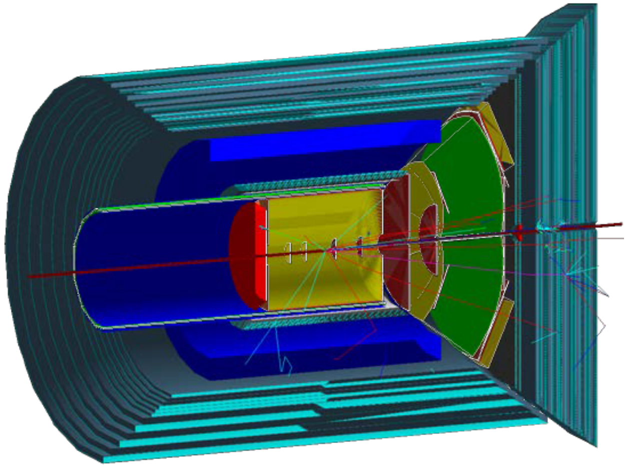
JLEIC Detector



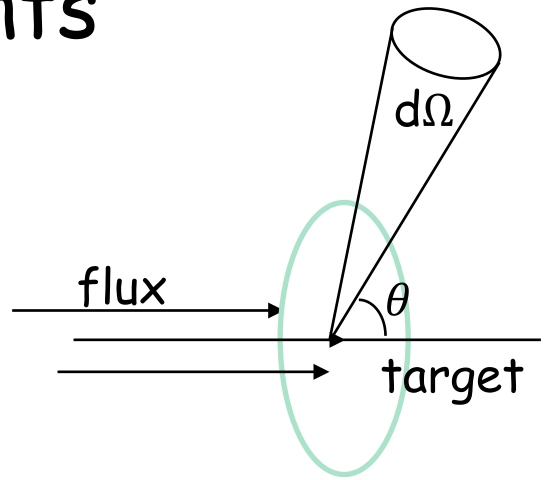
TOPSiDE by ANL



eRHIC "Day 1" Detector



Cross section, number of events



- Differential cross section :

the number of particles scattered into direction (θ, φ) of solid angle dΩ (depends on incident flux)

$$d\sigma \sim flux \frac{dN}{d\Omega dt}$$

- Total cross section:

$$\sigma \sim \int d\sigma d\theta$$

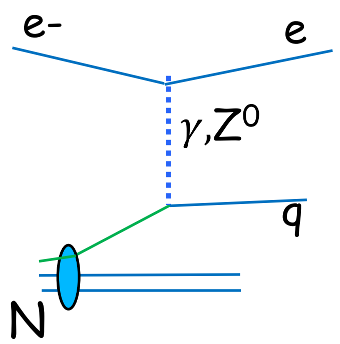
- Number of events:

$$N = \frac{L\sigma}{a}$$

where a is acceptance

Units:
1 barn = 10^{-24} cm^2
milibarn (mb) = 10^{-27} cm^2 = 10^{-3}b
microbarn (μb) = 10^{-30} cm^2 = 10^{-6}b
nanobarn (nb) = 10^{-33} cm^2 = 10^{-9}b
picobarn (pb) = 10^{-36} cm^2 = 10^{-12}b
femtobarn (fb) = 10^{-39} cm^2 = 10^{-15}b
attobarn (ab) = 10^{-42} cm^2 = 10^{-18}b
….

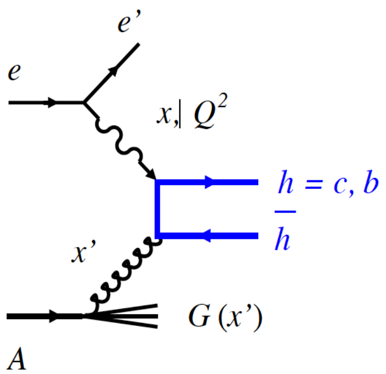
Cross section



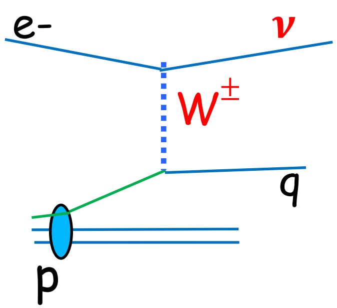
- ✓ Could be calculated numerically

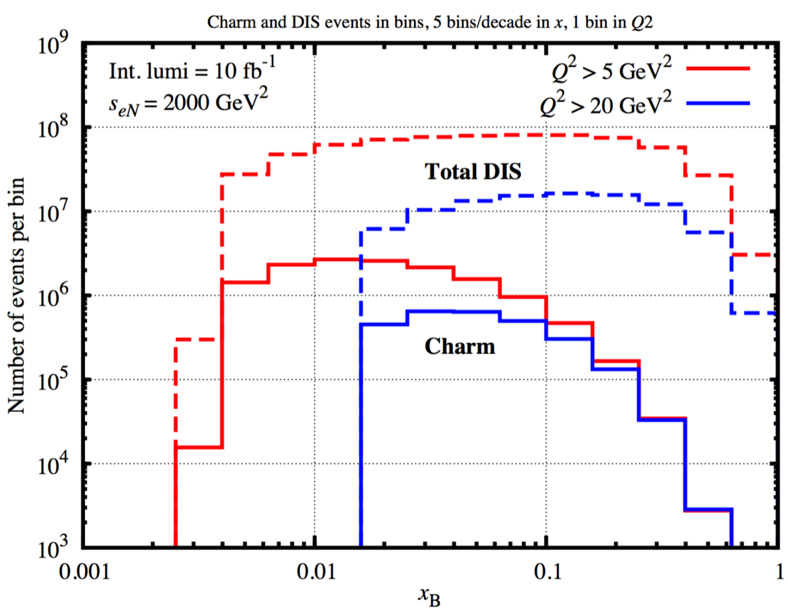
$$d\sigma(e+N\to e'+X) = \mathrm{Flux}(x,y,Q^2)\, F_2(x,Q^2)\, dx\, dQ^2 \quad (1)$$

$$d\sigma(e+N\to e'+c\bar{c}+X') = \mathrm{Flux}(x,y,Q^2)\, F_2^{c\bar{c}}(x,Q^2)\, dx\, dQ^2 \quad (2)$$



$$\frac{\sigma_{\rm SM}^{e^-p}(P_e)}{dx\,dQ^2} = (1-P_e)\frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[u(x,Q^2)+c(x,Q^2)+(1-y)^2\left(\bar{d}(x,Q^2)+\bar{s}(x,Q^2)\right)\right].$$





But .... =>

Yulia Furletova

Event generators

… But, as experimentalists, we need to know also final state particles

$\Rightarrow$ Need to generate an event (with it's cross section, kinematics, fragmentation, hadronization and decay modes)

$\Rightarrow$ PYTHIA, HERWIG, etc…

Event generators: Pythia

At startup:

```
** An archive of program versions and documentation is found on the web:  **
** http://www.thep.lu.se/~torbjorn/Pythia.html                             **
**                                                                         **
** When you cite this program, the official reference is to the 6.4 manual: **
** T. Sjostrand, S. Mrenna and P. Skands, JHEP05 (2006) 026                **
** (LU TP 06-13, FERMILAB-PUB-06-052-CD-T) [hep-ph/0603175].                **
```

```
Welcome to the Lund Monte Carlo!

PPP  Y   Y TTTTT H   H III   A
P  P  Y Y    T   H   H  I   A A
PPP    Y     T   HHHHH  I  AAAAA
P      Y     T   H   H  I  A   A
P      Y     T   H   H III A   A

This is PYTHIA version 6.413
Last date of change: 12 Sep 2007

Now is  0 Jan 2000 at  0:00:00

Disclaimer: this program comes
without any guarantees. Beware
of errors and use common sense
when interpreting results.

Copyright T. Sjostrand (2007)
```

Initial beam parameters:

```
*******************************************
proton beam energy:   100.000000     GeV
lepton beam energy:   5.00000000     GeV
resulting sqrt(s):   44.721359252929688      GeV
crossing angle:  -5.0000000745058060E-002 rad
*******************************************
                      5.0000000000000000      -1065.8147865668698       -5.00000000
1****************** PYINIT: initialization of PYTHIA routines *****************
                      HIA-TYPE LHAGLUE INTERFACE ====
LHAPDF 6.1.5 loading /home/yulia/yulia/EIC-soft/pythia_jlab_v2/LHAPDF/share/LHAPDF/cteq6l1/cteq6l1_0000.dat
                   , version 4; LHAPDF ID = 10042

==============================================================================
I                                                                            I
I      PYTHIA will be initialized for gamma/e- on p+ user configuration      I
I                                                                            I
I                px (GeV/c)   py (GeV/c)   pz (GeV/c)      E (GeV)           I
I       gamma/e-       0.000        0.000       -5.000        5.000          I
I       p+            -4.998       -0.000       99.875      100.004          I
I                                                                            I
I          corresponding to     44.718 GeV center-of-mass energy             I
I                                                                            I
==============================================================================
```

Processes:

```
******** PYMAXI: summary of differential cross-section maximum search ********

          ==========================================================
          I                                      I                 I
          I  ISUB  Subprocess name               I  Maximum value  I
          I                                      I                 I
          ==========================================================
          I                                      I                 I
          I   91   Elastic scattering            I    3.6254D-03   I
          I   92   Single diffractive (XB)       I    2.9300D-03   I
          I   93   Single diffractive (AX)       I    2.4189D-03   I
          I   94   Double  diffractive           I    2.0204D-03   I
          I   95   Low-pT scattering             I    1.8227D-02   I
          I   96   Semihard QCD 2 -> 2           I    1.4282D-01   I
          I                                      I                 I
          ==========================================================
```

Output:

```
==============================================================================
I                                                                            I
I                 -2.000D+00 <  m_hard (GeV/c^2)  <  9.471D+00               I
I    -1.000D+00 (  1.000D+00) <  p_T_hard (GeV/c)  <  4.735D+00              I
I                              m_finite (GeV/c^2) =  1.000D+00               I
I                 -1.000D+01 <    y*_subsystem    <  1.000D+01               I
I                 -4.000D+01 <      y*_large      <  4.000D+01               I
I                 -4.000D+01 <      y*_small      <  4.000D+01               I
I                 -4.000D+01 <     eta*_large     <  4.000D+01               I
I                 -4.000D+01 <     eta*_small     <  4.000D+01               I
I                 -1.000D+00 < cos(theta*)_large  <  1.000D+00               I
I                 -1.000D+00 < cos(theta*)_small  <  1.000D+00               I
I                  0.000D+00 <        x_1         <  1.000D+00               I
I                  0.000D+00 <        x_2         <  1.000D+00               I
I                 -1.000D+00 <        x_F         <  1.000D+00               I
I                 -1.000D+00 <  cos(theta_hard)   <  1.000D+00               I
I                  2.000D+00 < m'_hard (GeV/c^2)  <  9.471D+00               I
I                                                                            I
==============================================================================
The charm mass used is:    1.5000000000000000
==================================================
Pythia total cross section normalisation:  0.25167791484759577      microbarn
Total Number of generated events       100000
Total Number of trials       100000
==================================================
```

Total cross section :

 # events

Event generators: Pythia

Per event: # particles, x, y,Q2 …

Per particle: ID, stable/unstable, mother, (Px,Py,Pz) (Vx,Vy,Vz)

yulia@yuliapc:work

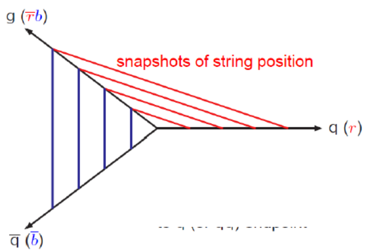
File Edit View Search Terminal Help

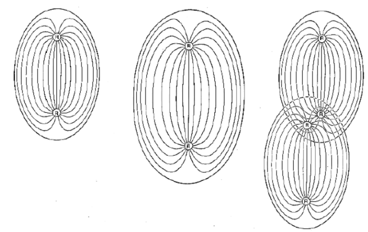
```
    26  .40006E-01  .21205E+02  .50972E+03  .10000E+01  .26502E+00  .39649E+00  .49559E+01  .96356E-05  .26935E+00
  1  -1   0      11     3     4     0.000000     0.000000    -5.000000     5.000000     0.000510     0.000000
  2   1   0    2212     5     0    -4.997917     0.000000    99.875026   100.004402     0.938270     0.000000
  3  -1   0      11     0     0    -0.286915    -3.940876    -2.621122     4.741635     0.000510     0.000000
  4   0   0      22     0     0     0.286915     3.940876    -2.378877     0.258366    -4.604902     0.000000
  5   1   0    2212     0     0    -4.997917     0.000000    99.875025   100.004401     0.938270     0.000000
  6   0   1      22     0     0     0.286727     3.947424    -2.369555     0.272087    -4.604902     0.000000
  7   0   0       2     0     0    -0.199730    -0.000262     3.991042     3.996037     0.000000     0.000000
  8   0   1      22     0     0     0.286727     3.947424    -2.369555     0.272087    -4.604902     0.000000
  9   0   0       2     0     0    -0.199730    -0.000262     3.991042     3.996037     0.000000     0.000000
 10   0   0       2     0     0     0.086997     3.947162     1.621487     4.268124     0.000000     0.000000
 11  -1   1      11     0     0    -0.286915    -3.940876    -2.621122     4.741635     0.000510     0.000000
 12   0   0       2    15    19     0.268949     4.194358     2.034984     4.669704     0.000000     0.000000
 13   0   0    2101    15    19    -4.979951    -0.253482    95.461164    95.593063     0.579330     0.000000
 14   0   0      92    15    19    -4.711002     3.940876    97.496148   100.262766    22.569877     0.000000
 15   0   0     113    20    21     0.006513     1.049519     0.984218     1.682433     0.871988     0.000000
 16   0   0     223    22    24     0.663467     2.714914     1.473597     3.254829     0.781971     0.000000
 17   1   1     321     0     0    -0.446333     0.166227     2.491995     2.584671     0.493600     0.000000
 18  -1   1     321     0     0    -0.865438     0.696718     8.332379     8.420604     0.493600     0.000000
 19   1   1    2212     0     0    -4.069211    -0.686502    84.213959    84.320229     0.938270     0.000000
 20   1   1     211     0     0    -0.139763     0.874913     0.296526     0.944676     0.139570     0.000000
 21  -1   1     211     0     0     0.146276     0.174606     0.687693     0.737757     0.139570     0.000000
 22   1   1     211     0     0     0.094669     0.753815     0.228744     0.805607     0.139570     0.000000
 23  -1   1     211     0     0     0.017227     0.141868     0.077126     0.214130     0.139570     0.000000
 24   0   0     111    25    26     0.551571     1.819231     1.167728     2.235093     0.134980     0.000000
 25   0   1      22     0     0     0.055067     0.253076     0.112069     0.282204     0.000000     0.000004
 26   0   1      22     0     0     0.496504     1.566155     1.055659     1.952888     0.000000     0.000004
    22  .10368E+00  .32155E+01  .28679E+02  .10000E+01  .15507E-01  .32911E+00  .15869E+01  .67435E-04  .31788E+00
  1  -1   0      11     3     4     0.000000     0.000000    -5.000000     5.000000     0.000510     0.000000
  2   1   0    2212     5     0    -4.997917     0.000000    99.875026   100.004402     0.938270     0.000000
  3  -1   0      11     0     0    -1.773208     0.223301    -4.805921     5.127476     0.000510     0.000000
  4   0   0      22     0     0     1.773208    -0.223301    -0.194077    -0.127474    -1.793195     0.000000
  5   1   0    2212     0     0    -4.997917    -0.000000    99.875024   100.004400     0.938270     0.000000
  6   0   1      22     0     0     1.794342    -0.229589     0.375840     0.445064    -1.793195     0.000000
  7   0   0       1     0     0    -0.506305     0.000634    10.017575    10.030362     0.000000     0.000000
  8   0   1      22     0     0     1.794342    -0.229589     0.375840     0.445064    -1.793195     0.000000
  9   0   0       1     0     0    -0.506305     0.000634    10.017575    10.030362     0.000000     0.000000
 10   0   0       1     0     0     1.288036    -0.228954    10.393416    10.475426     0.000000     0.000000
 11   0   1    2112     0     0    -3.217918    -0.230615    70.273602    70.353892     0.939570     0.000000
 12  -1   1      11     0     0    -1.773208     0.223301    -4.805921     5.127476     0.000510     0.000000
 13   0   0       1    16    18     1.214583     0.019765     9.816243     9.891119     0.000000     0.000000
 14   0   0       2    16    18    -1.221373    -0.012451    19.591102    19.631915     0.330000     0.000000
 15   0   0      92    16    18    -0.006791     0.007314    29.407345    29.523034     2.611030     0.000000
 16   0   0     113    19    20     0.174899     0.416131     6.190305     6.240081     0.644193     0.000000
 17   1   1     211     0     0    -0.717503    -0.779348    12.685437    12.730357     0.139570     0.000000
 18   0   0     111    21    22     0.535813     0.370531    10.531603    10.552596     0.134980     0.000000
 19   1   1     211     0     0    -0.049526     0.120359     4.492805     4.496856     0.139570     0.000000
 20  -1   1     211     0     0     0.224425     0.295773     1.697500     1.743225     0.139570     0.000000
 21   0   1      22     0     0     0.115348     0.030448     2.465489     2.468373     0.000000     0.000025
 22   0   1      22     0     0     0.420464     0.340083     8.066115     8.084222     0.000000     0.000025
    43  .43775E-01  .33182E+01  .73362E+02  .10000E+01  .37900E-01  .32321E+00  .36555E+01  .62757E-04  .33484E+00
  1  -1   0      11     3     4     0.000000     0.000000    -5.000000     5.000000     0.000510     0.000000
  2   1   0    2212     5     0    -4.997917     0.000000    99.875026   100.004402     0.938270     0.000000
pythia.txt
```

Event generators and hadronization models

- String Model (Lund) : **JETSET, PYTHIA**

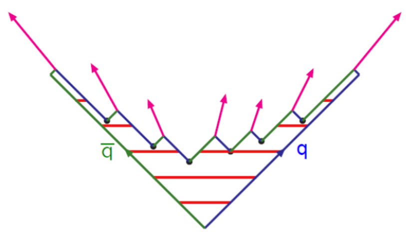
(the most used hadronization model, very successfully tested in e+e-)

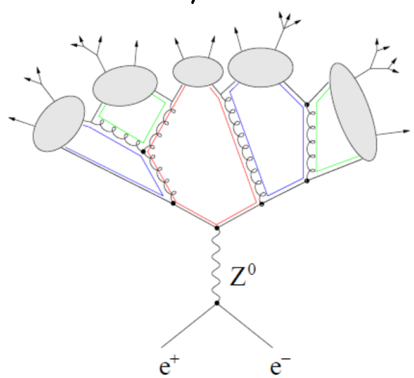




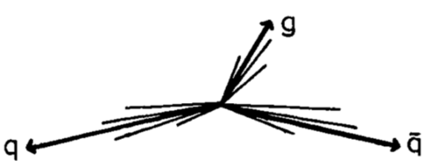
- Cluster Fragmentation Model: **HERWIG**

force gluon decays into quarks and antiquarks, q-qbar form colorneutral clusters , clusters decay isotropically into 2 hadrons , which can decay further into stable hadrons.





- Independent model (Field-Feynman model) quarks and gluons fragment independently



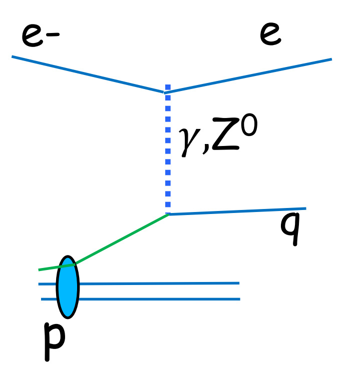
Note, those models lead to different distributions for low momentum particles . For high momentum (β-> 1) particles the differences vanish.

Cross section

e (10GeV) x p (100GeV)

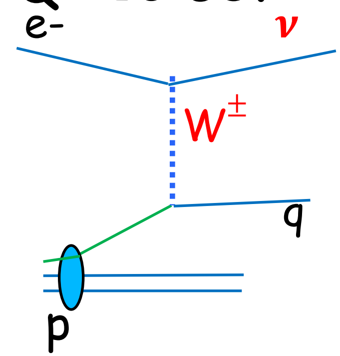
Neutral current, Q^2>0 GeV

σ~200 **μb**



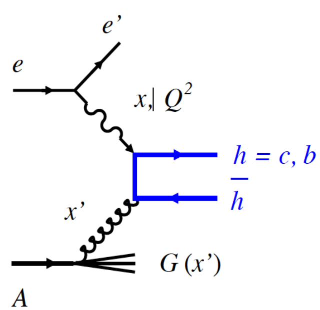
Charged current, Q^2>10 GeV

σ~100 **pb**



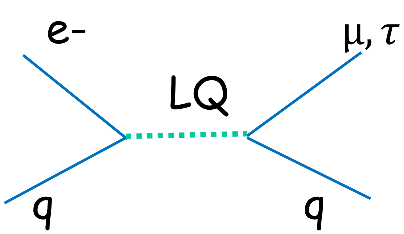
Boson-gluon-fusion, Q^2>10 GeV

σ~60 **nb**



Beyond the Standard Model
Leptoquarks, Q^2>100GeV

σ~1 **fb**



Cross section

N=$\sigma \cdot L$

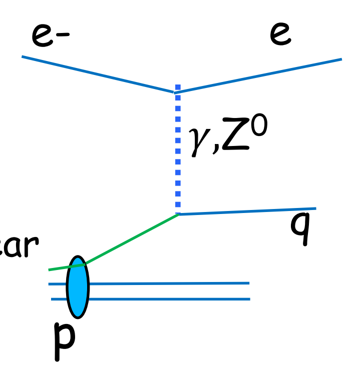
e (10GeV) x p (100GeV)

L ~ 100 fb^{-1} /year

Neutral current, Q^2>0 GeV

σ~200 **μb**

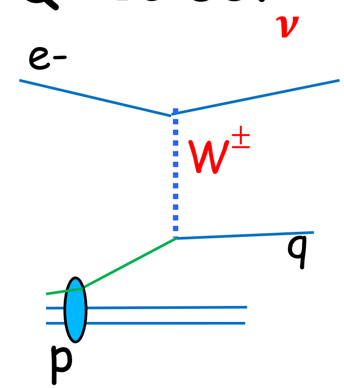
N~ $2 \cdot 10^{14}$ events/year



Charged current, Q^2>10 GeV

σ~100 **pb**

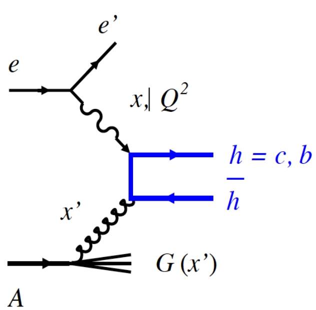
N~ 10^7 events/year



Boson-gluon-fusion, Q^2>10 GeV

σ~60 **nb**

N~ $6 \cdot 10^9$events/year

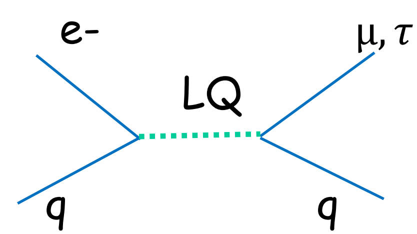


Beyond the Standard Model
Leptoquarks, Q^2>100GeV

σ~1 **fb**

N~ 100 events/year

Nobel Prize!



Cross section

$N = \sigma \cdot L$

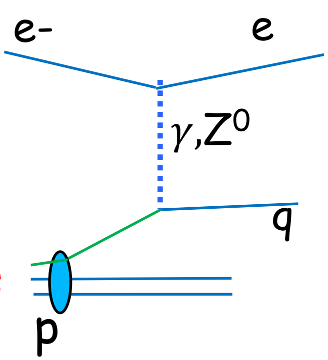
ZEUS/HERA(ep)= 165 ·10 $^{-30}$ ·2 ·10 ^{31} ~ 3.3· 10^3 per sec (~3kHz)

e (10GeV) x p (100GeV)
L ~ 10^{34} cm^{-2} s^{-1} (476MHz)

Neutral current, Q^2>0 GeV

σ~200 μb

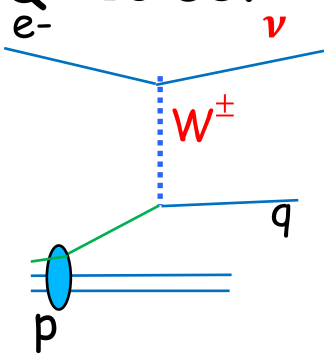
N~ 2· 10^6 ev. per sec (2MHz) ~ 2 events / µs



Charged current, Q^2>10 GeV

σ~100 pb

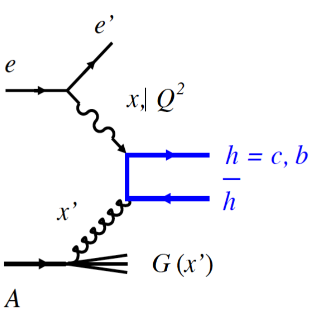
N~ 1 events/sec



Boson-gluon-fusion, Q^2>10 GeV

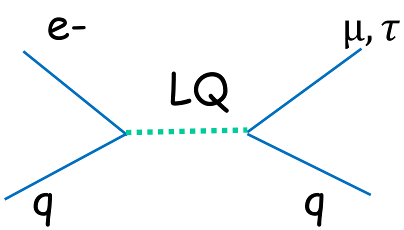
σ~60 nb

N~ 600 events/sec



Beyond the Standard Model
Leptoquarks, Q^2>100GeV

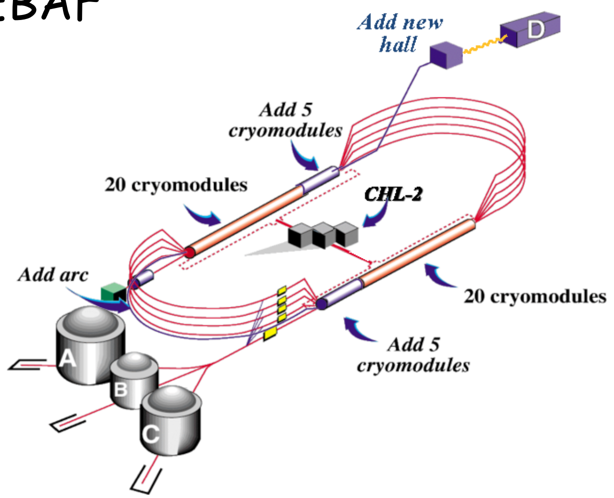
σ~1 fb



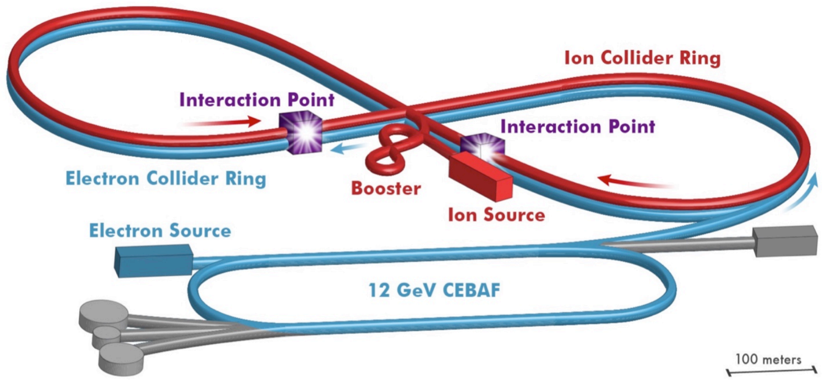
Deep inelastic scattering and General detector design considerations

From CEBAF to Electron-Ion Collider

CEBAF

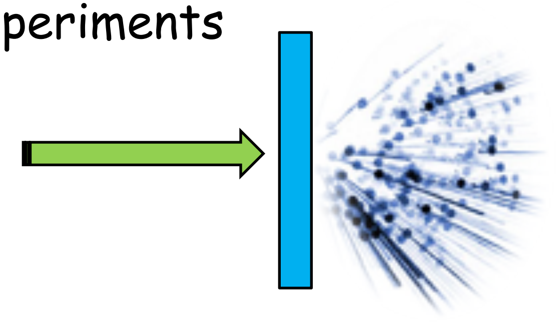


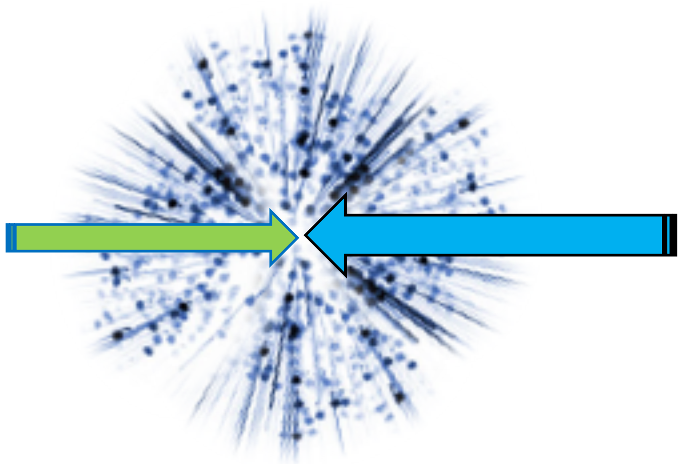
Electron-Ion Collider



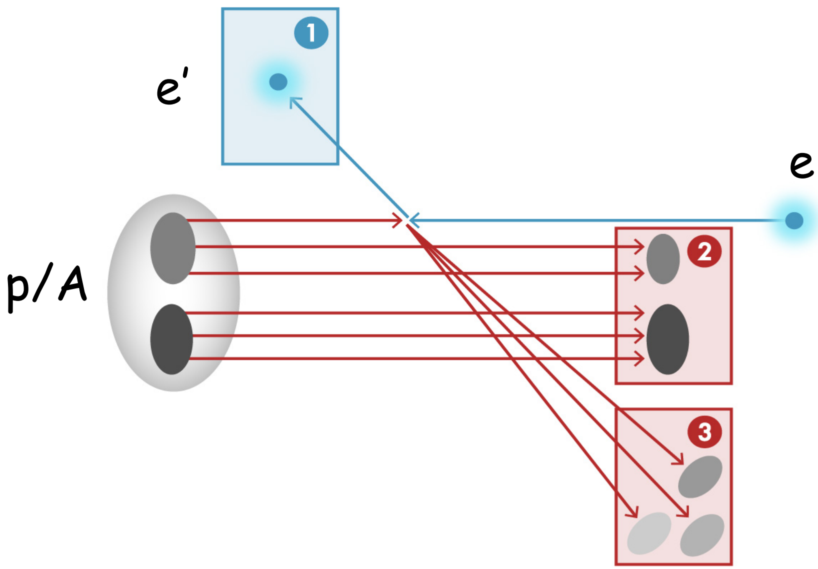
Collider experiments

Fixed target experiments





Total acceptance detector



1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark

Total acceptance and **identification** of all final state particles:

- Charge and Momentum measurements
- Energy measurements
- Vertex origination
- Particle ID

Forward going particles or ion remnant is particularly challenging

- ➢ not usual concern at colliders
- ➢ Higher the Ion Beam energy, more difficult to achieve.

=> Integration with accelerator is very important

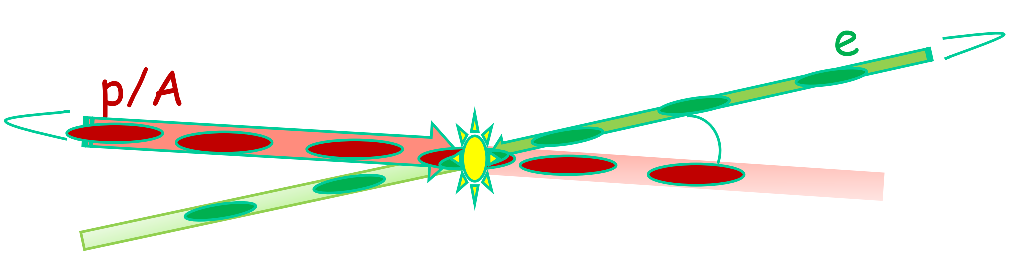
The integration with accelerator

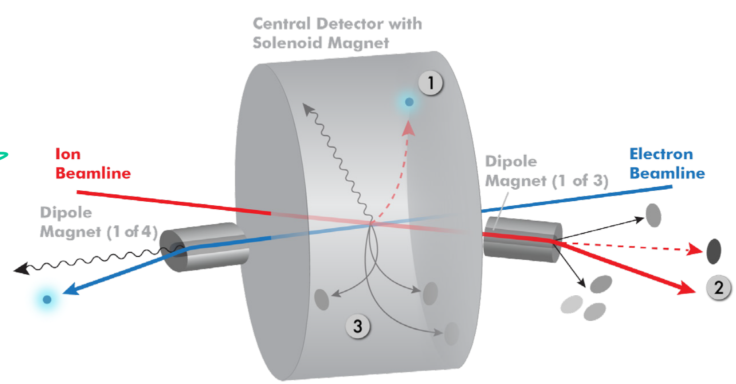
- Minimize a background at the detector area:
  - Synchrotron radiation shielding
  - Beam gas events
  - Neutrons
  - Beam halo

- Optimize a placement of magnets (final focusing) => acceptance, luminosity

- Optimize a magnetic field for all magnets

- Synchronization (between detector components and accelerator)

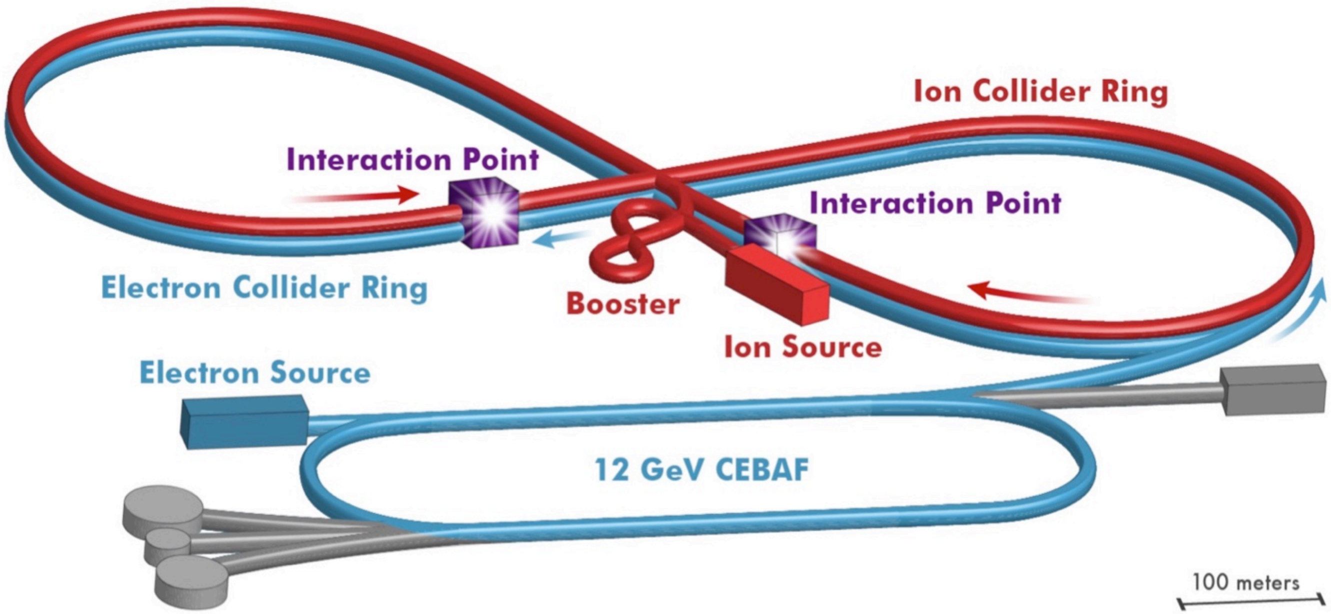




The integration with accelerator (IP placement)

- IP placement (to reduce a background)

-Far from electron bending magnets (**synchrotron radiation**)
-close to proton/ion bending (**hadron background**)

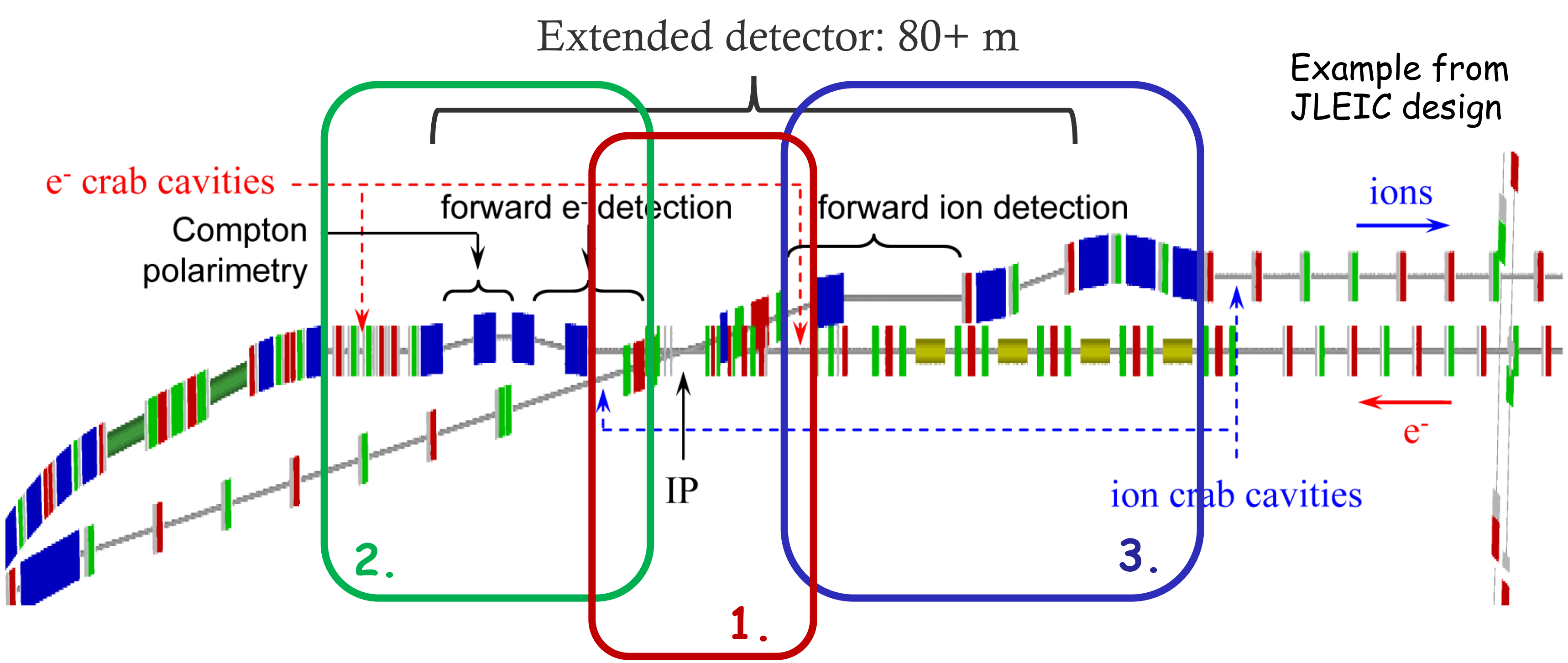


The integration with accelerator

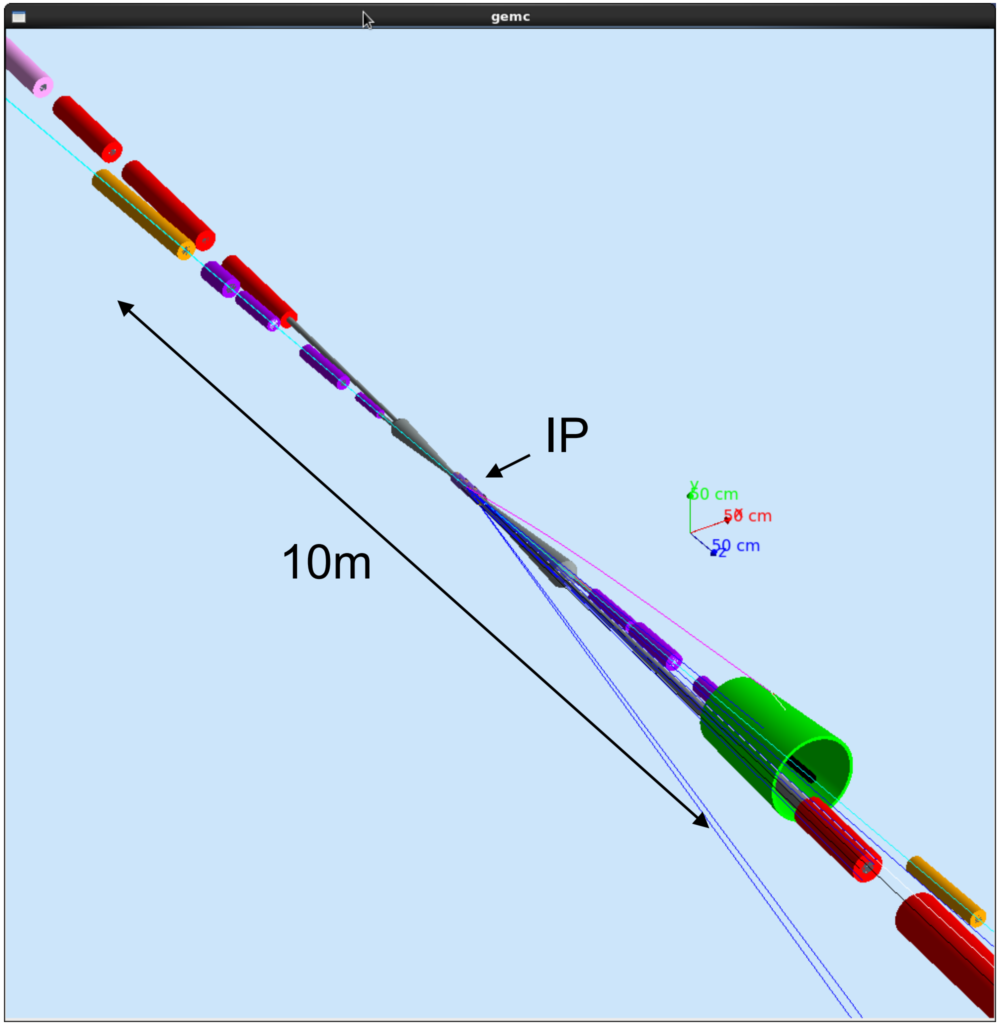
- Total size ~80m
1. **Central detector** ~10m
2. **Far-forward electron detection** ~30m
3. **Forward hadron spectrometer** ~40m

- IP placement (to reduce a background)
  -Far from electron bending magnets (**synchrotron**)
  -close to proton/ion bending (**hadron background**)

Example from JLEIC design



The integration with accelerator: beam pipe and FFQs



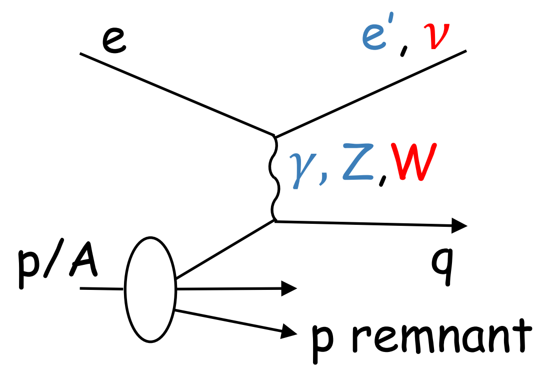
Need magnets to deliver beam to IP

Need magnets close to IP: the closer FFQs to IP the larger our luminosity

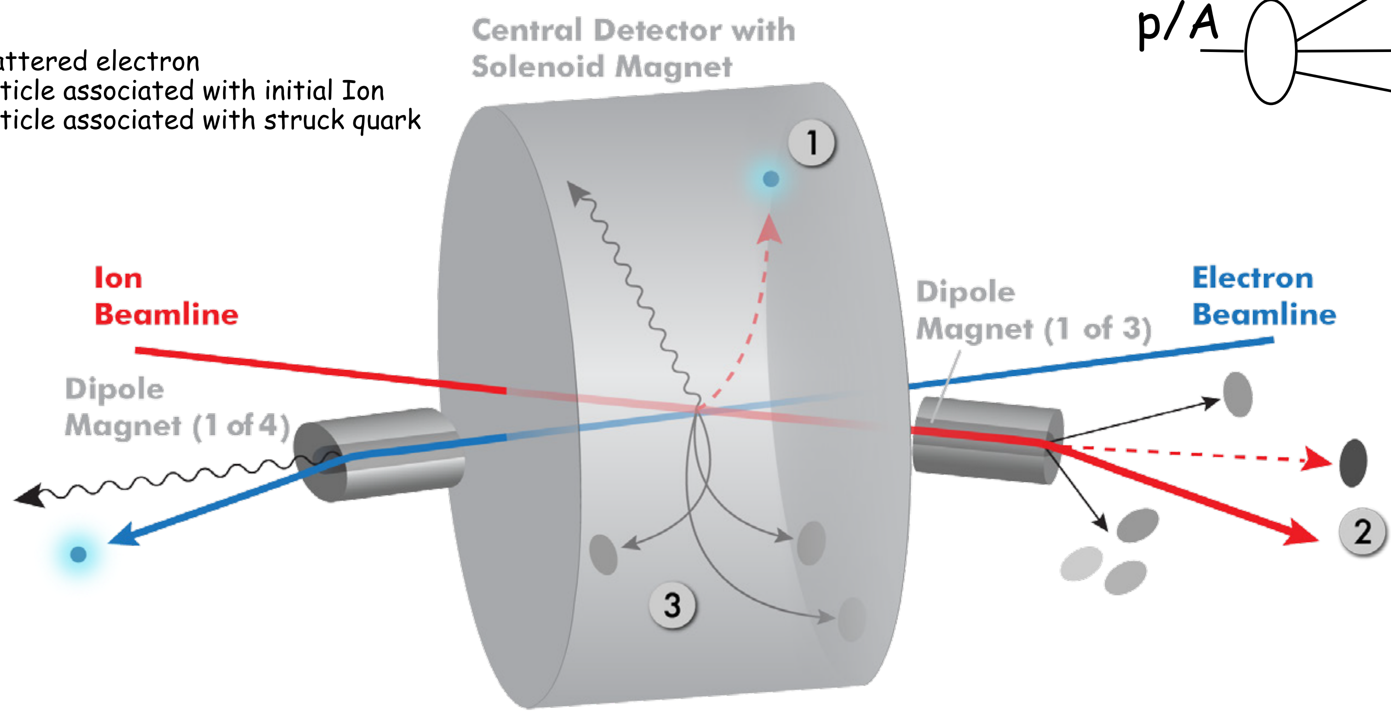
But they limit acceptance

Total acceptance detector

Beam elements limit forward acceptance
Beam crossing angle creates room for forward dipoles and gives a space for detectors in the forward regions



1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark



- Central detector - limitation in size:
  -in R – size of solenoid magnet
  -in L - a distance between ion quadrupoles which inverse proportional to luminosity

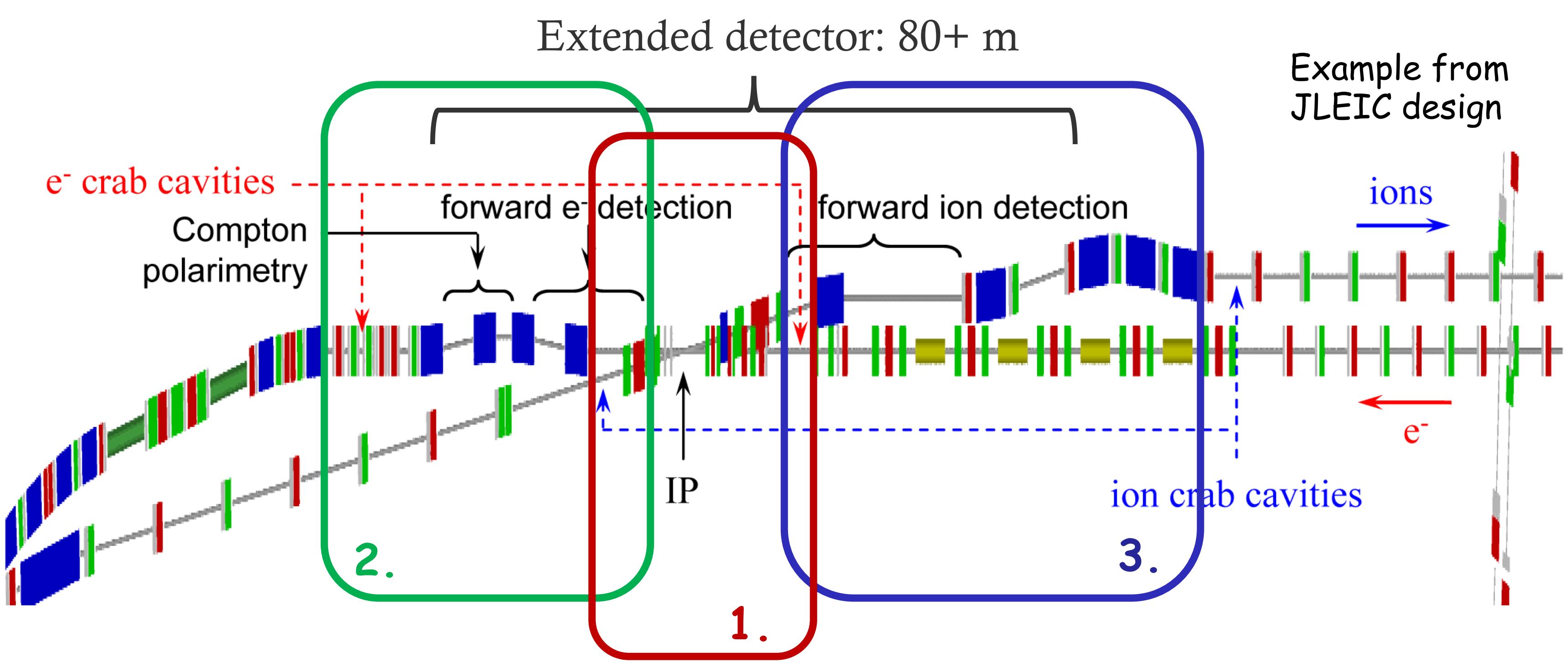
Need a Total acceptance detector (and IR) also for variable beam energies.

The integration with accelerator

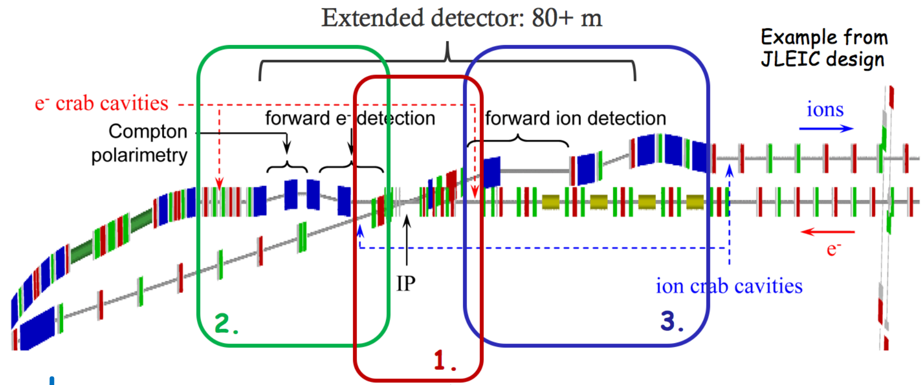
- Total size ~80m

1. **Central detector** ~10m
2. **Far-forward electron detection** ~30m
3. **Forward hadron spectrometer** ~40m

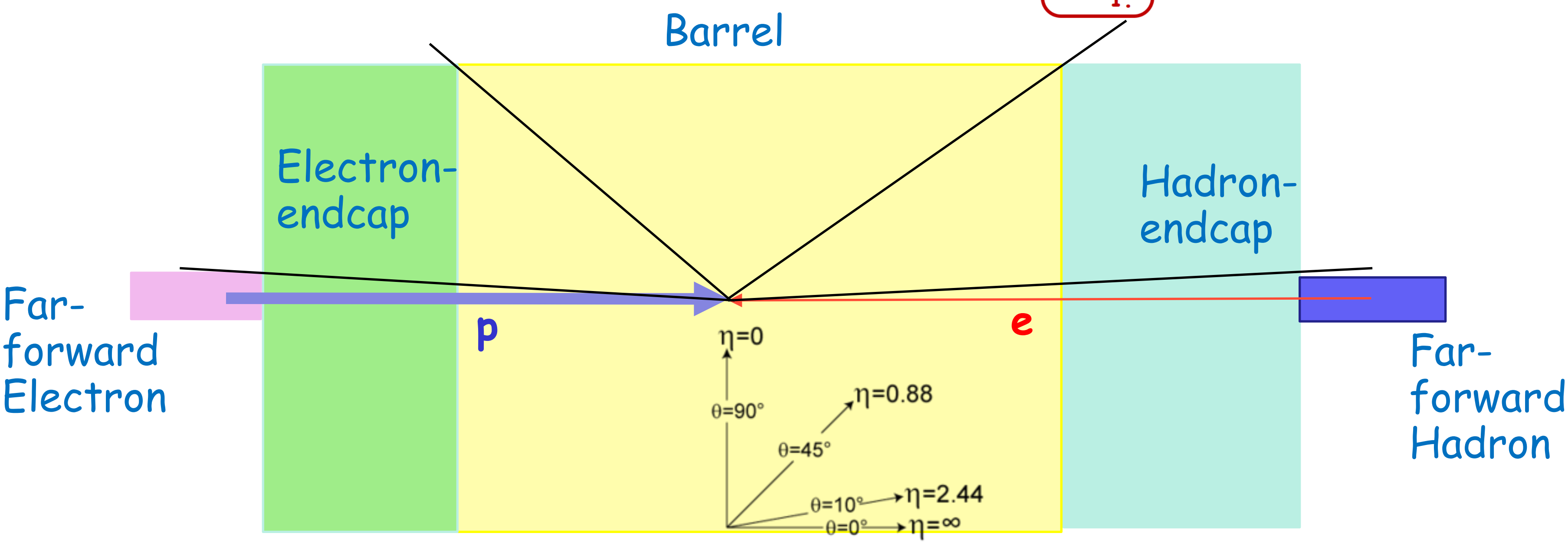
- IP placement (to reduce a background)
  - -Far from electron bending magnets (**synchrotron**)
  - -close to proton/ion bending (**hadron background**)



Detector coverage



Example from JLEIC design



Pseudorapidity:

$$\eta = -\ln(\tan(\theta/2))$$

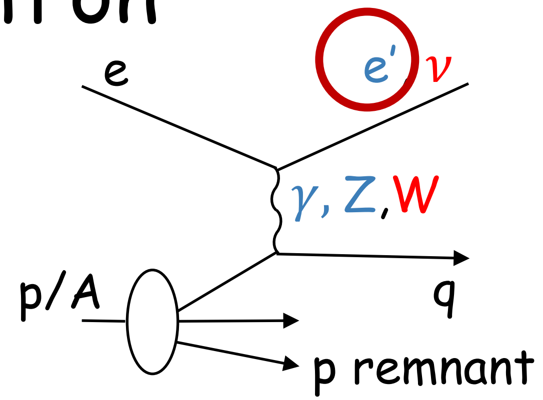
For JLEIC:

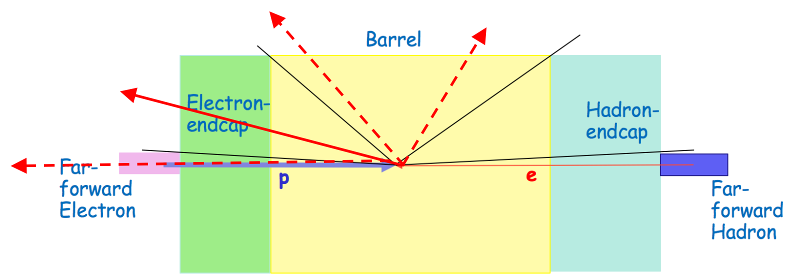
Asymmetric design (due to asymmetric beam energy):

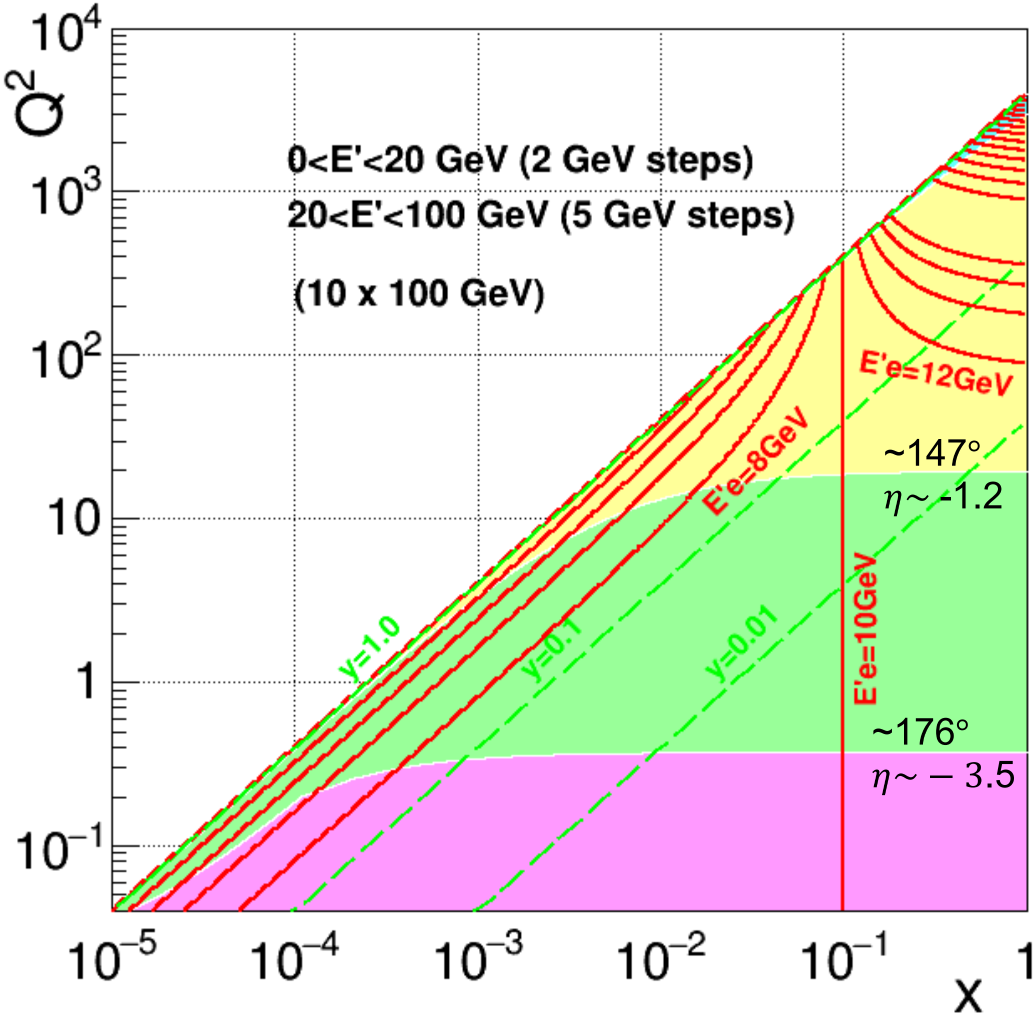
currently 40cm IP shift

$-1.1 < \eta < 1.5$ (or ca $30 < \theta < 25$)

Event kinematic: scattered electron



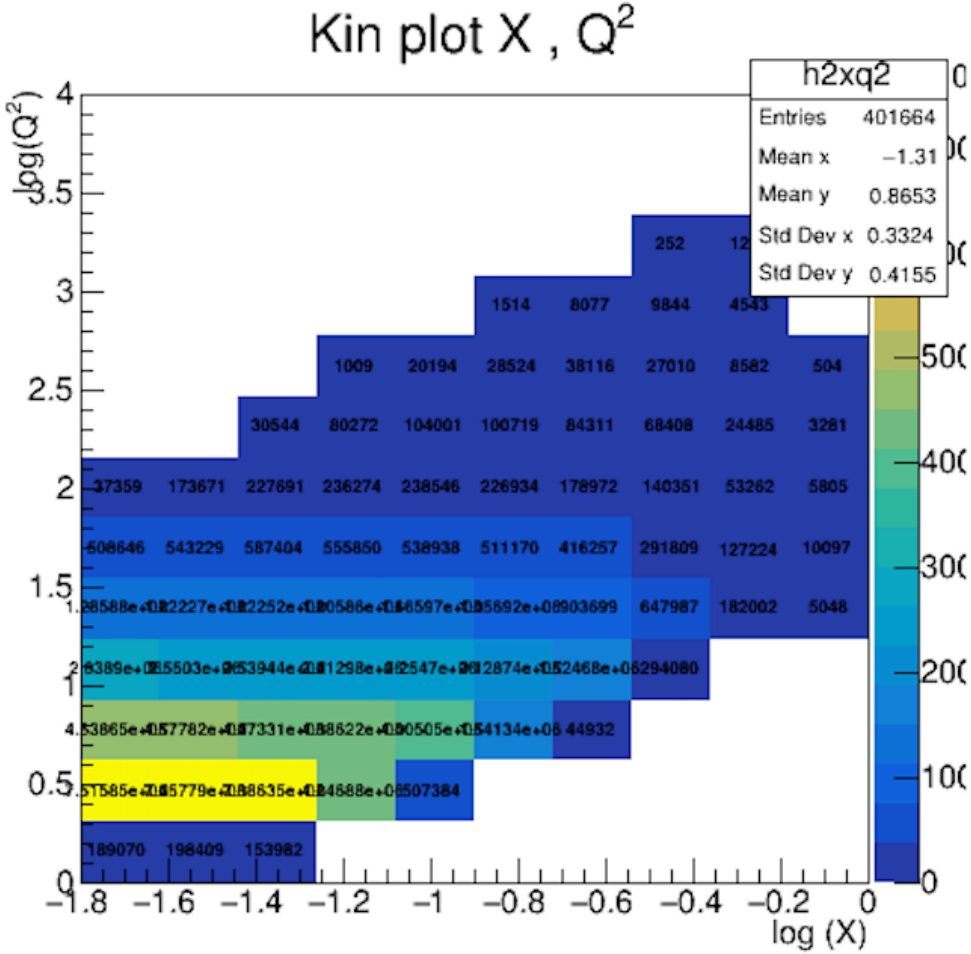




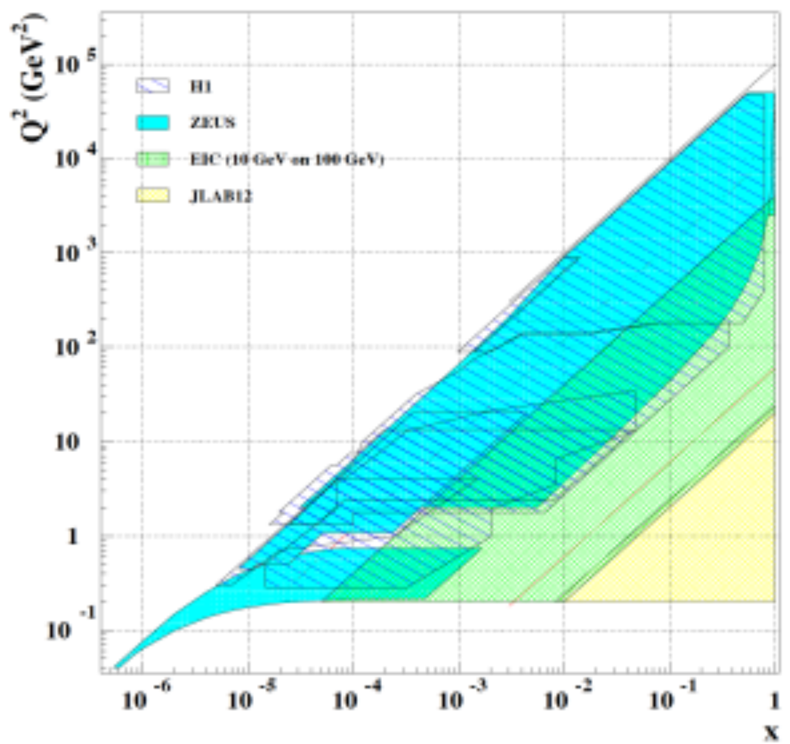
Scattered angle => Q^2

- Electrons mostly scatters to electron-endcap (green)
- PhP (low Q2) – along beampipe- far-forward electron direction
- High-Q2 – bounce back with very high energy - barrel, hadron-endcap (yellow)

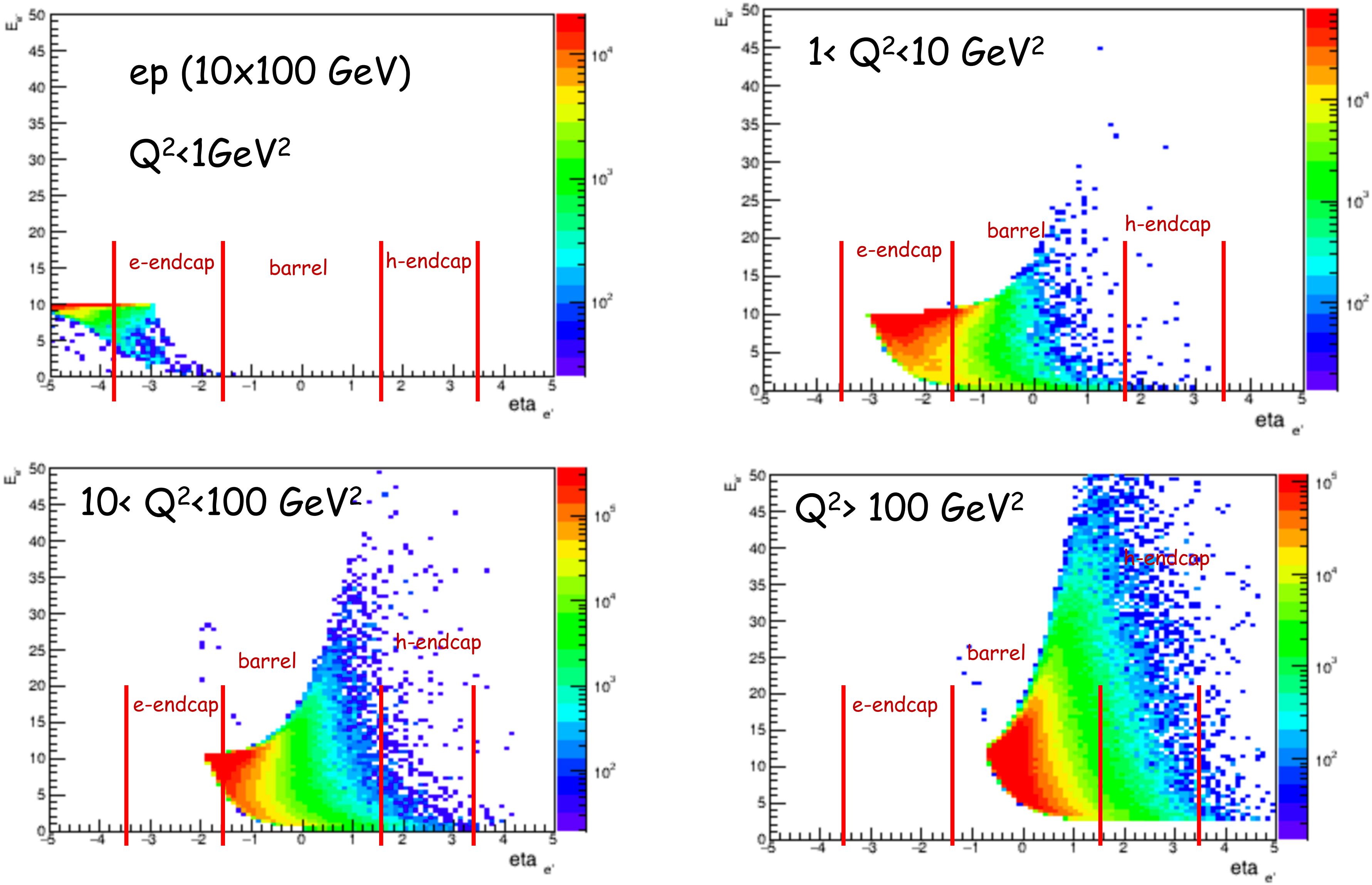
EXAMPLE



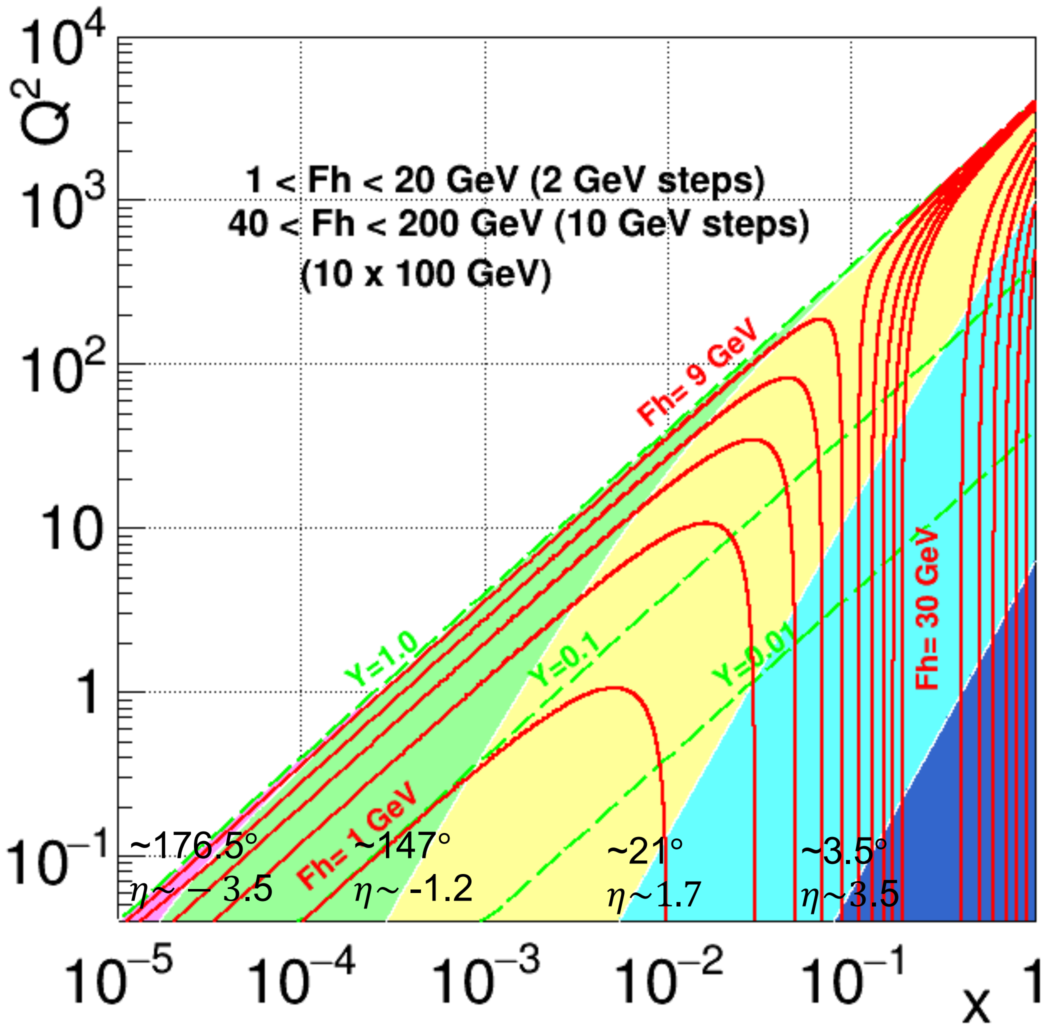
Minbias: number of events in bins of x,Q^2 (Q^2>2GeV), high-x



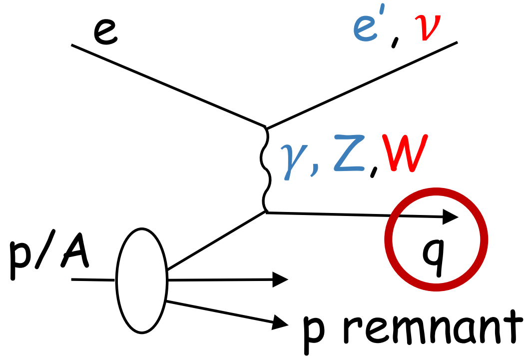
DIS kinematic -Part 1 Scattered electron

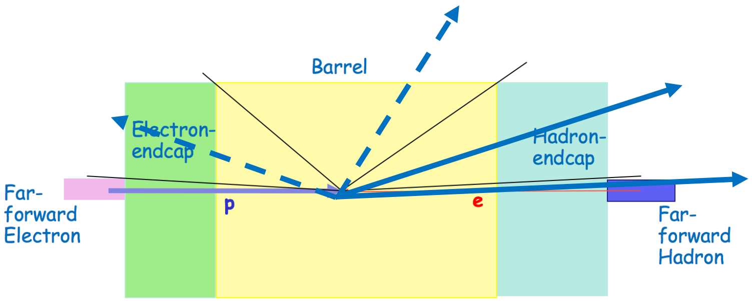


Event kinematic: struck quark



Hadron energy => x

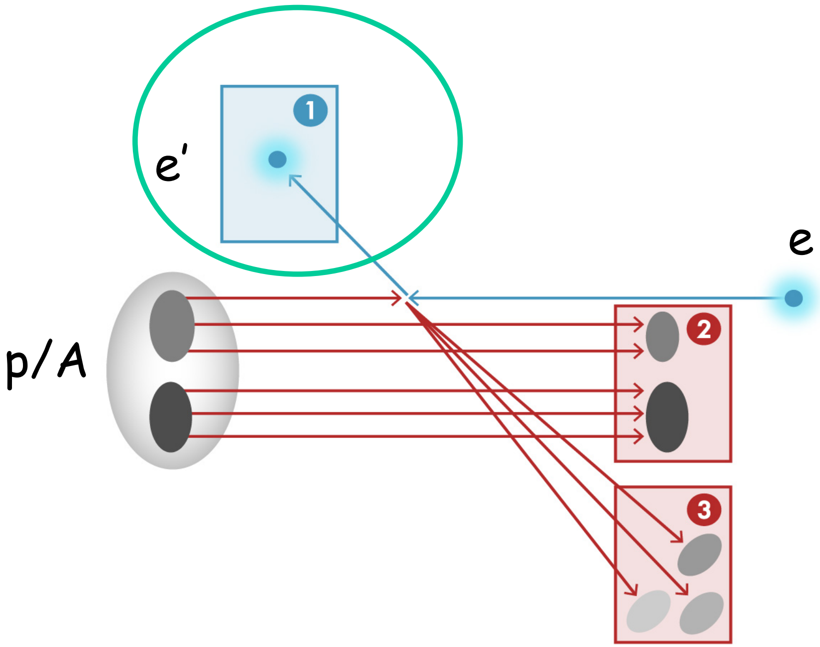




- Quarks/hadrons scatters to hadron-endcap
- The higher the energy more forward
- Measurements of Energy of quarks equal to measurements of x

DIS kinematic -Part 1

Scattered electron



Kinematic reconstruction

a) *Electron method* uses **information from scattered electron ONLY:**

$$Q^2_{\mathrm{EM}} = 2E_e E_{e'}\,(1 + \cos\theta_{e'})\,,$$

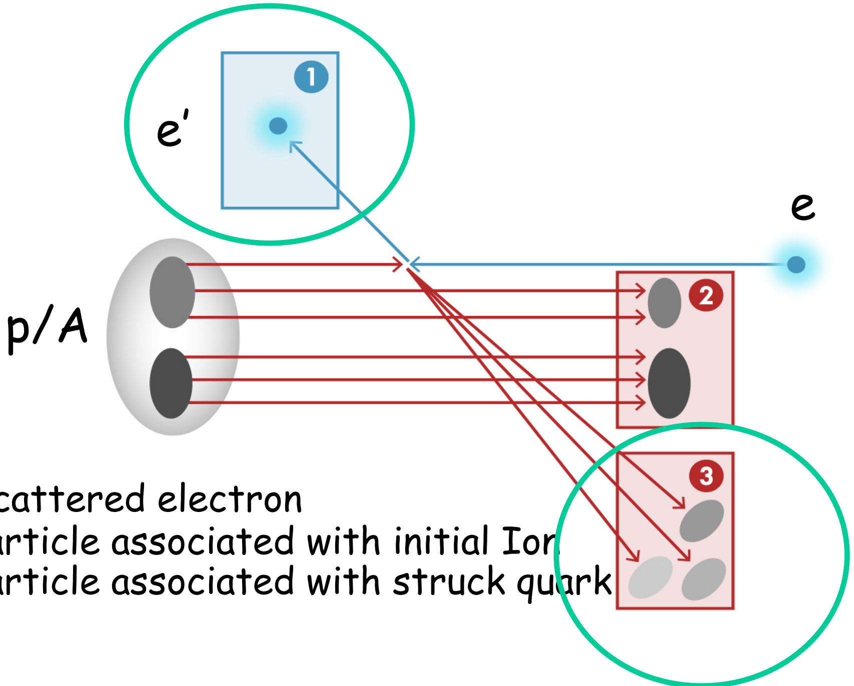
$$y_{\mathrm{EM}} = 1 - \frac{E_{e'}}{2E_e}(1 - \cos\theta_{e'})\,,$$

$$x = \frac{Q^2}{4E_e E_{\mathrm{ion}}}\,\frac{1}{y}$$

Notes:

- Linear dependence on $E_{e'}$ of the Q^2
- This method could NOT be used for $y < 0.1$

DIS kinematic - Part 2



1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark

All other methods require measurements of hadronic final states (particle associated with struck quark), here are just two examples

b) *Double angle method*

$$Q^2_{\mathrm{DA}} = \frac{4E_e^2 \sin\gamma_h \,(1+\cos\theta_{e'})}{\sin\gamma_h + \sin\theta_{e'} - \sin(\theta_{e'}+\gamma_h)},$$

$$y_{\mathrm{DA}} = \frac{\sin\theta_{e'}\,(1-\cos\gamma_h)}{\sin\gamma_h + \sin\theta_{e'} - \sin(\theta_{e'}+\gamma_h)},$$

Note: Does not require measurements of scattered electron energy, but require a good knowledge of hadronic final state :

$$\cos\gamma_h = \frac{P^2_{T,h} - \left(\sum_h (E_h - p_{z,h})\right)^2}{P^2_{T,h} + \left(\sum_h (E_h - p_{z,h})\right)^2}$$

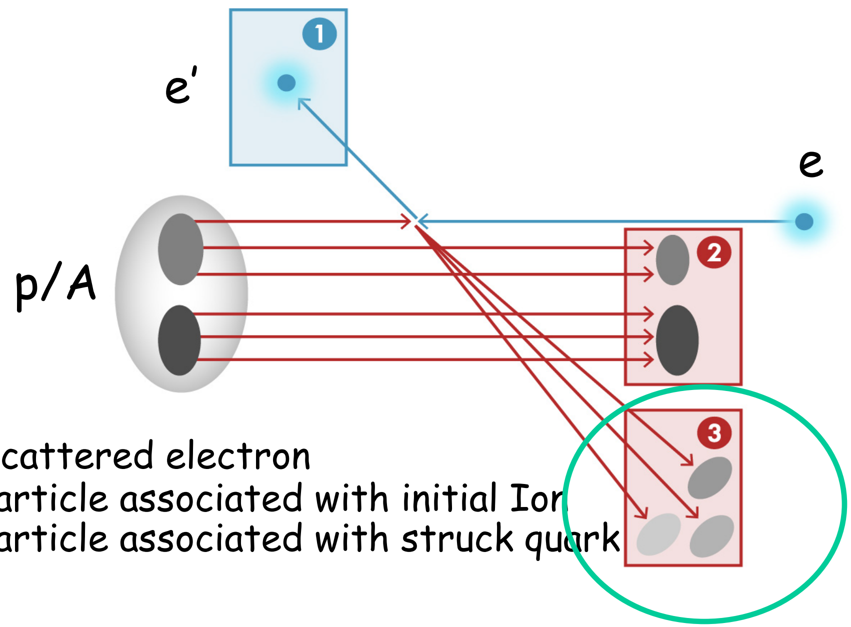
c) *Sigma method*

$$y_{e\Sigma} = \frac{\Sigma_h\,(E_h - p_{z,h})}{E - P_z},$$

$$Q^2_{e\Sigma} = \frac{(E_{e'}\sin\theta_{e'})^2}{1-y}.$$

Note: Does not depend on initial electron beam energy, less influenced by a initial state radiation

DIS kinematic - Part 3



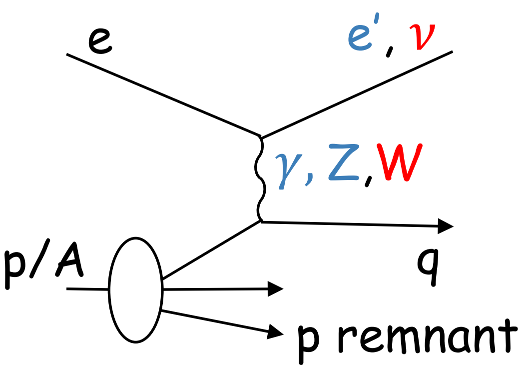
1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark

DIS kinematic could be reconstructed from hadronic final state only

d) Jacquet -Blondel method

$$y_{\mathrm{JB}} = \frac{1}{2E_e} \sum_h \left(E_h - p_{z,h} \right),$$

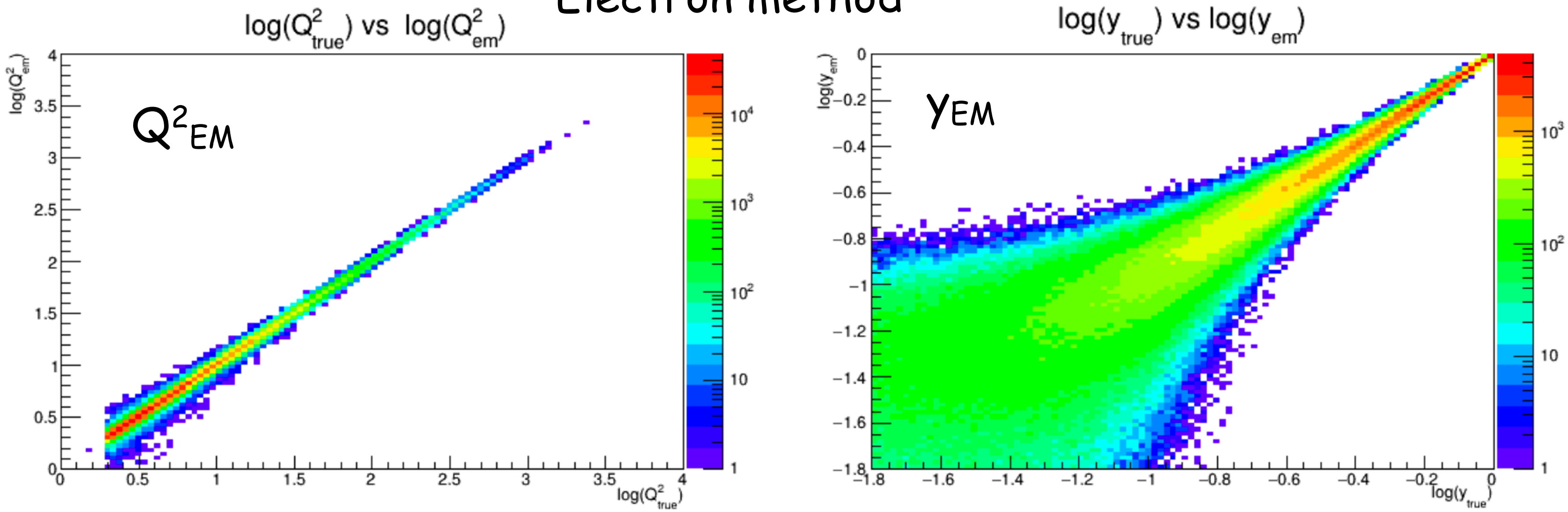
$$Q^2_{\mathrm{JB}} = \frac{1}{1 - y_{\mathrm{JB}}} \left[\left(\sum_h p_{x,h} \right)^2 + \left(\sum_h p_{y,h} \right)^2 \right].$$



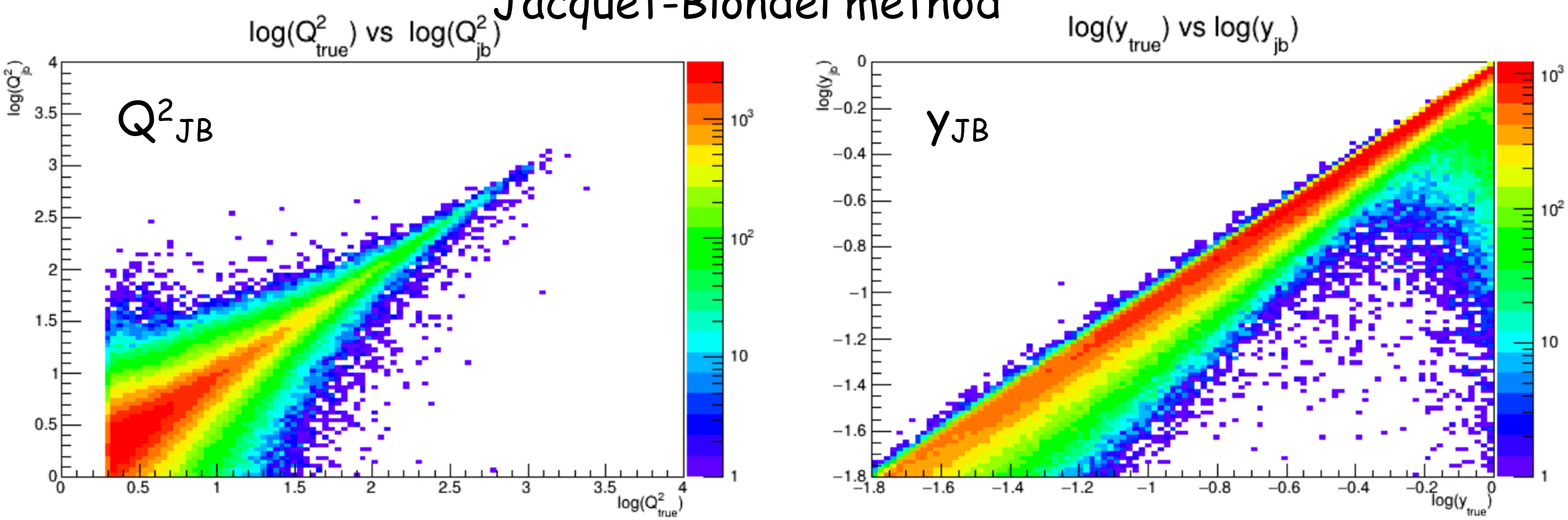
Note: poor resolution compare to other methods, but
this is the only method for Charged Current DIS events!!!

DIS kinematic

Electron method



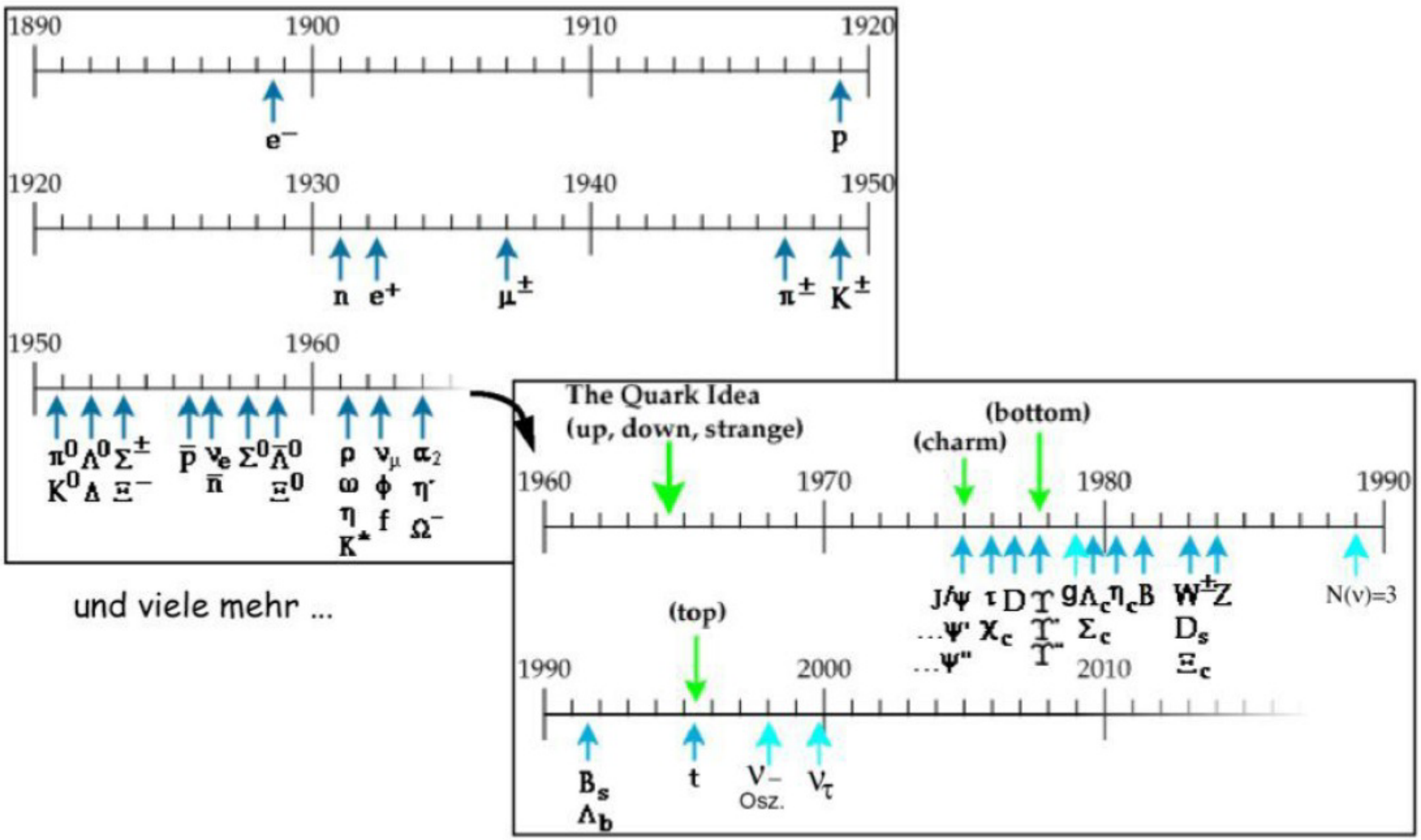
Jacquet-Blondel method



Other Particles

Today more then 200 particles listed in Particle Data Group (PDG)

But only 27 have cτ > 1μm
and only 13 have cτ > 500μm



und viele mehr ...

"Stable" Particles

Limited number of "stable" final state particles:

- Electrons/positrons ($e^{\pm}$)
- Gammas (γ)
- Individual hadrons ($\pi^{\pm}$, $K^{\pm}$,p)
- Neutral hadrons (n,K^0_L)
- Muons ($\mu^{\pm}$)
- Neutrinos (ν)

- Charge and Momentum measurements
- Energy measurements
- Vertex origination
- Particle ID

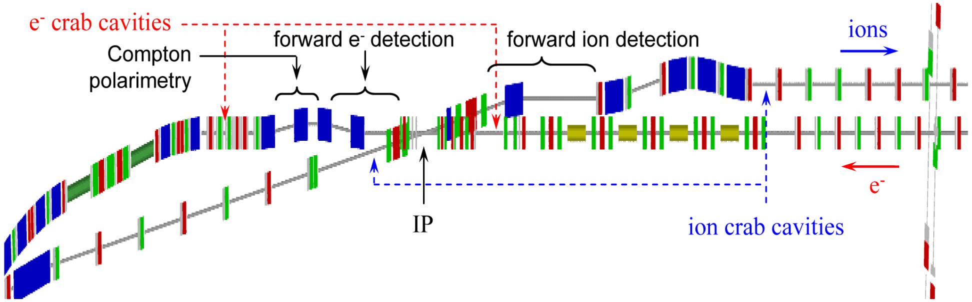
- Particles could be detected and identified via their interaction with a material of the detector.

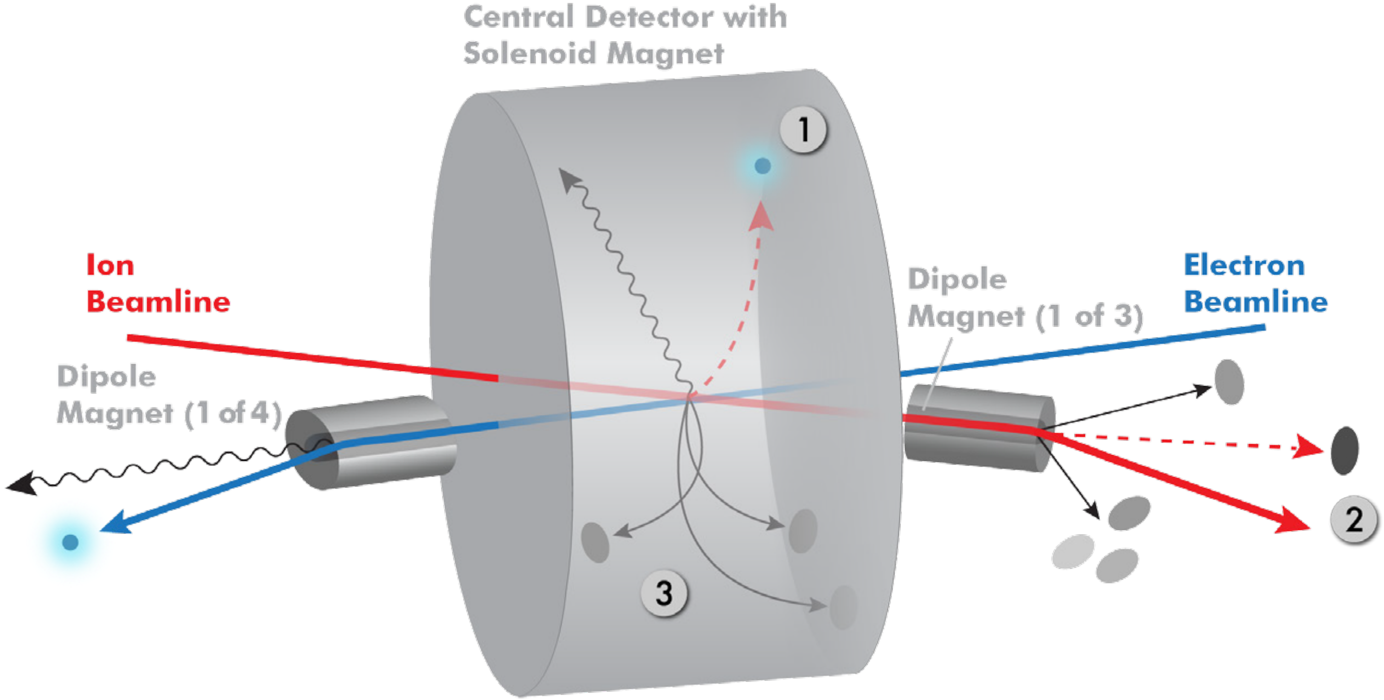
Particles associated with a struck quark

Position, origination and direction (x,y,z)	→	Tracking detectors
Momentum (p)	→	Tracking detectors in a magnetic field
Energy (E)	→	Calorimeter
Mass (m) or Velocity (β) PID	→	Time of flight, Cherenkov radiation, Transition radiation

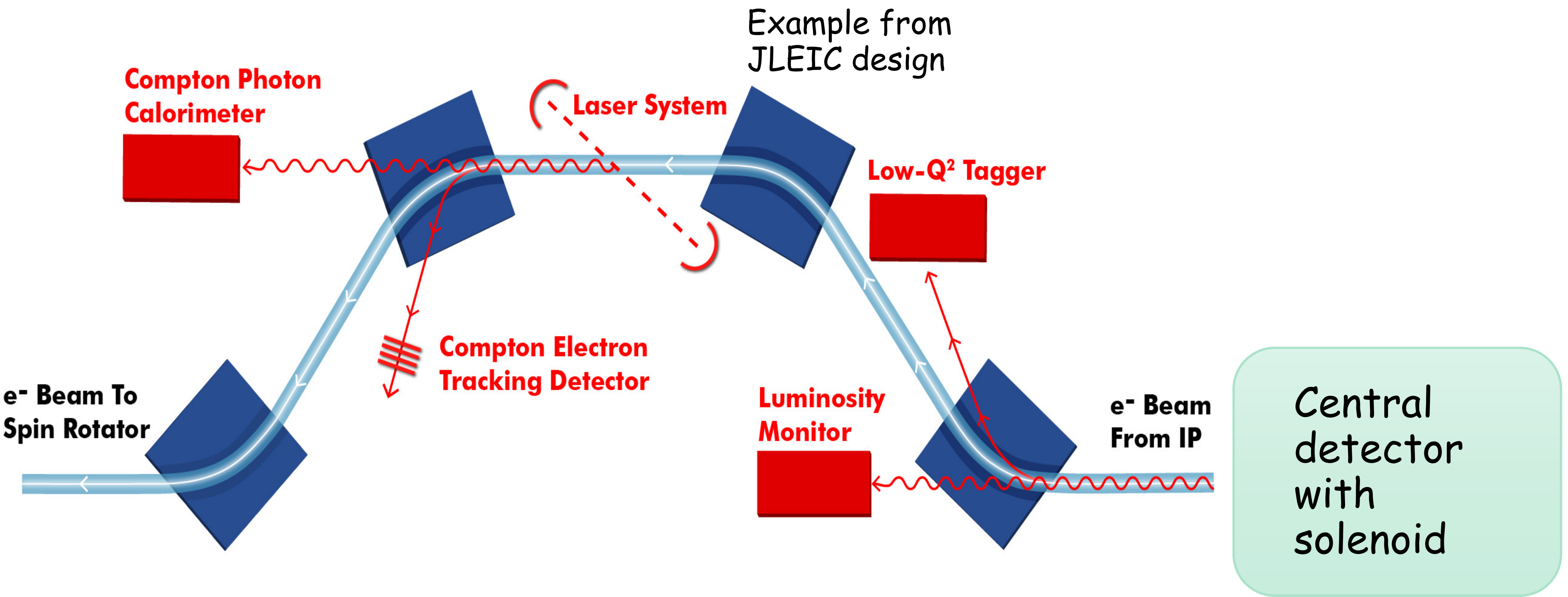
Far-Forward Areas

Extended detector: 80+ m





Chicane for Electron Far-Forward Area

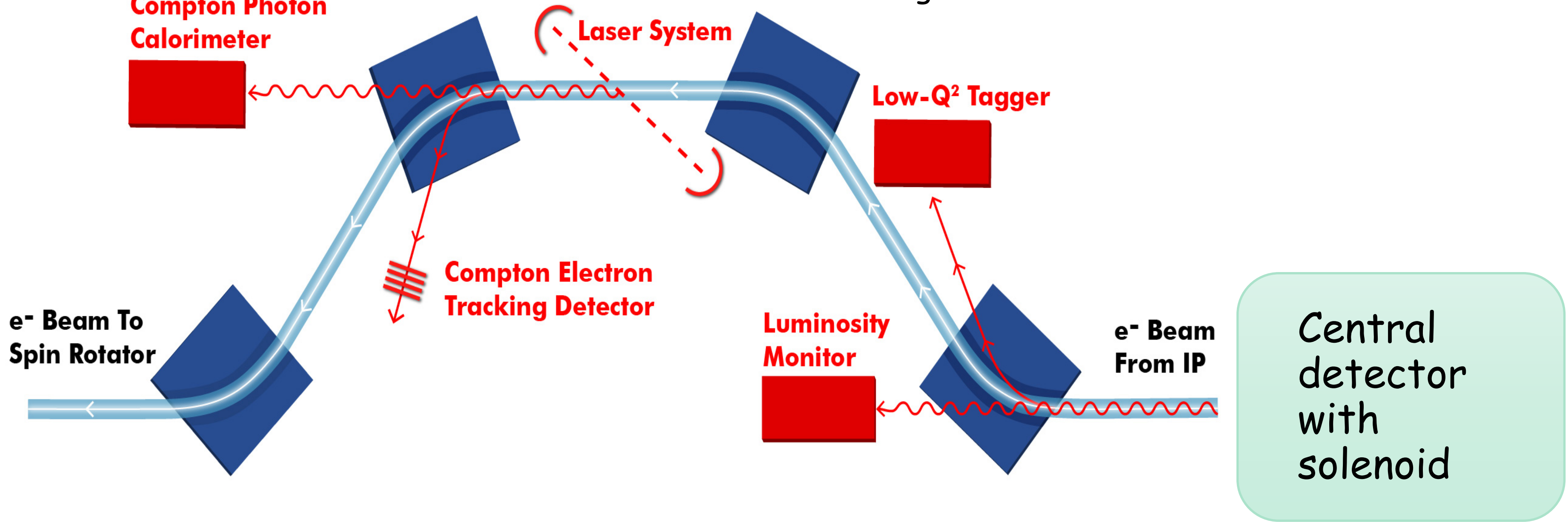


- **Low Q2 tagger**

✓ For low-Q^2 electrons

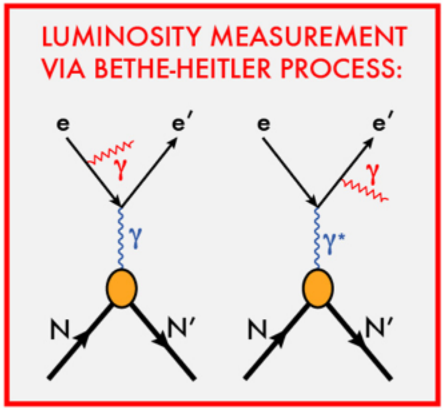
Chicane for Electron Far-Forward Area

Example from JLEIC design

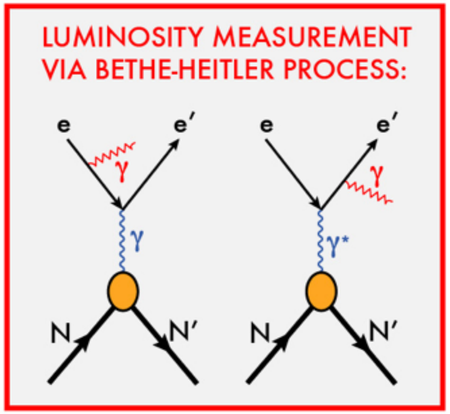


- **Luminosity monitor:**

✓ First dipole bends electrons
✓ Photons from IP collinear to e-beam



Luminosity (at HERA)



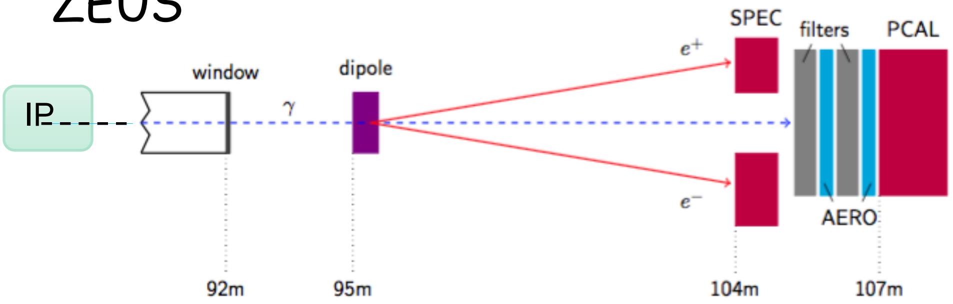
$$\frac{d\sigma_{BH}}{dy} = \frac{4\alpha r_e^2}{y}\left[1+(1-y)^2-\frac{2}{3}(1-y)\right]\left[\ln\frac{s(1-y)}{M_p m_e y}-\frac{1}{2}\right]$$

$y=E'/E_{beam}$

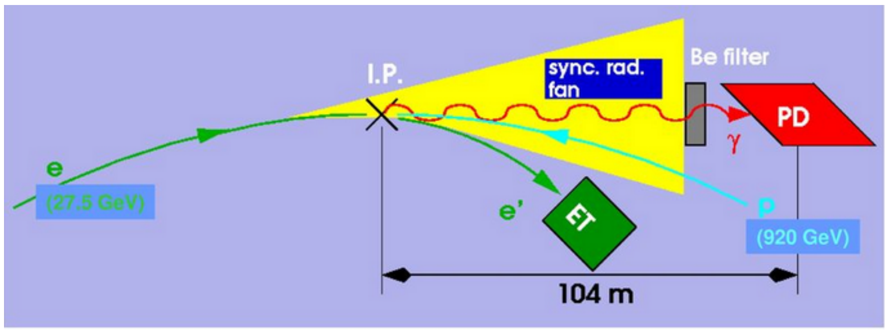
Online measurements:

- ✓ Detect electron in low-Q2 tagger
- ✓ In coincidence with photon

ZEUS

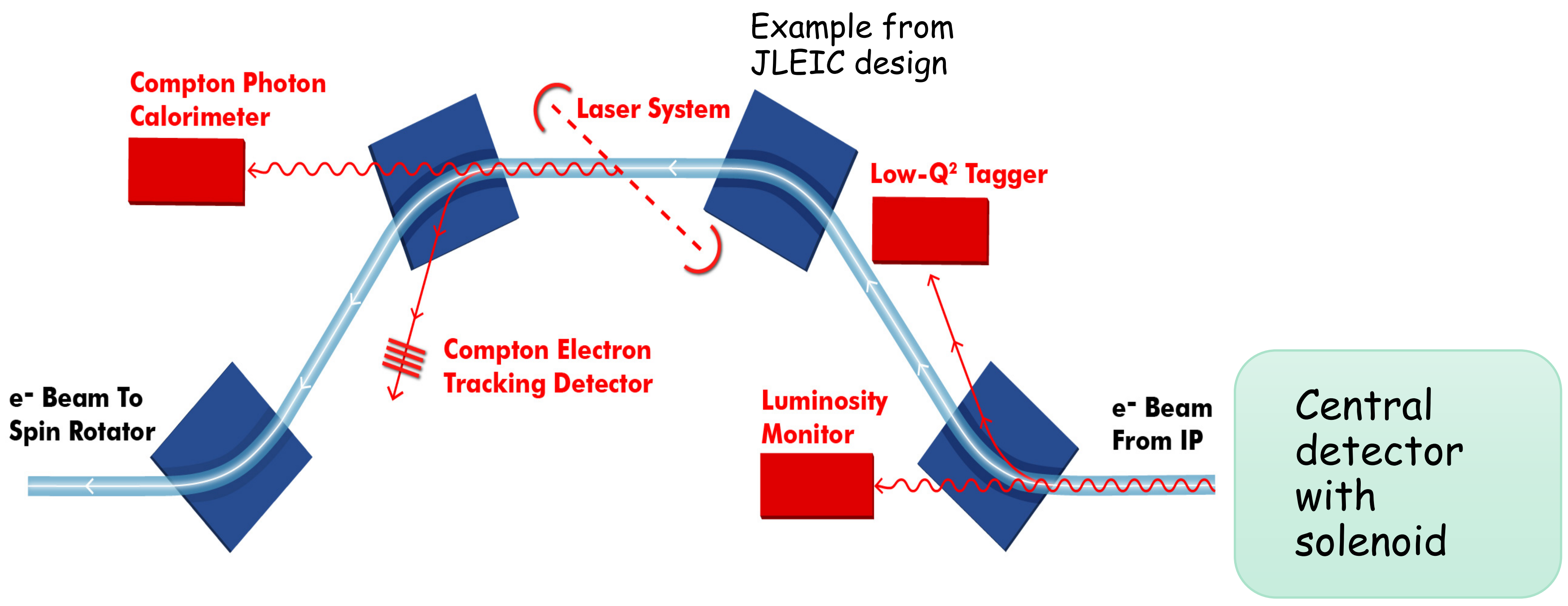


H1



Synchrotron radiation ?

Chicane for Far Electron-going Area



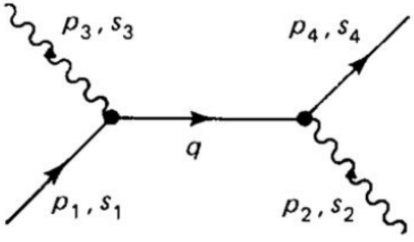
- **e Polarization measurements**

✓ First two Dipoles compensate each other
✓ The same polarization as at IP
✓ Minimum background and a lot of space.
✓ Measurements of both Compton photons and electrons

Electron polarization measurements

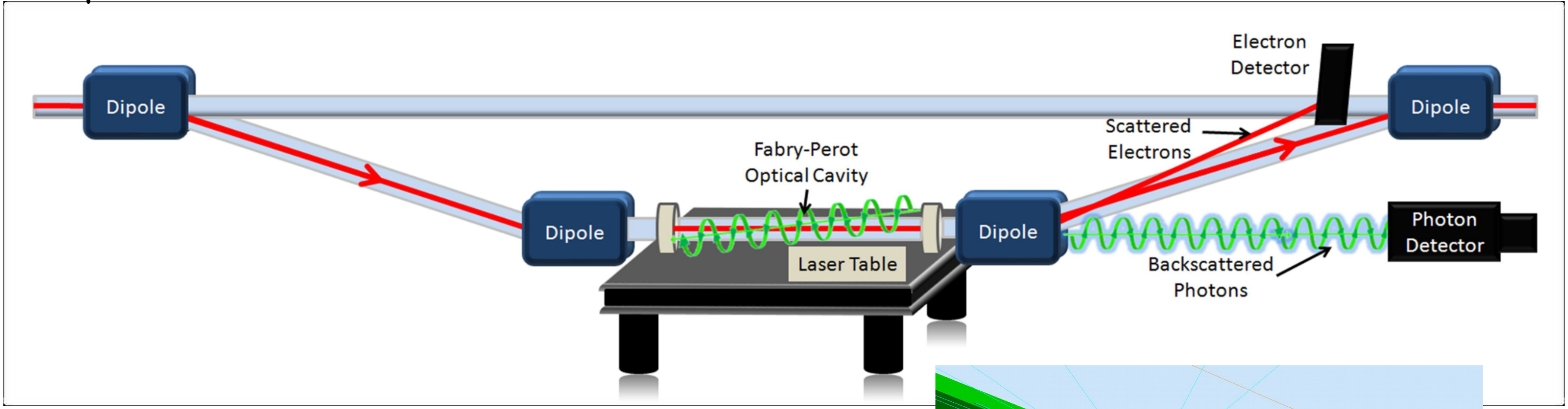
Compton polarimeter:

- Used to determine a polarization of electron beam
- Incoming photons scatters off electron

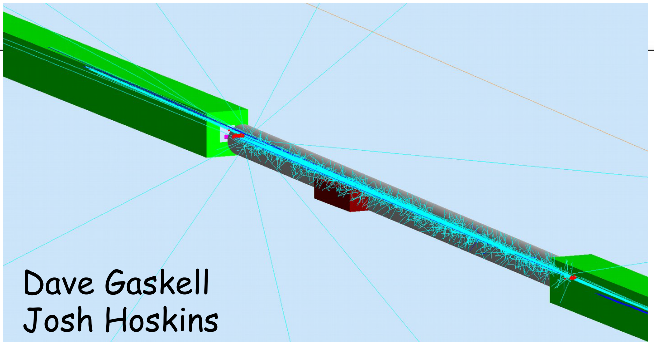


Compton Scattering

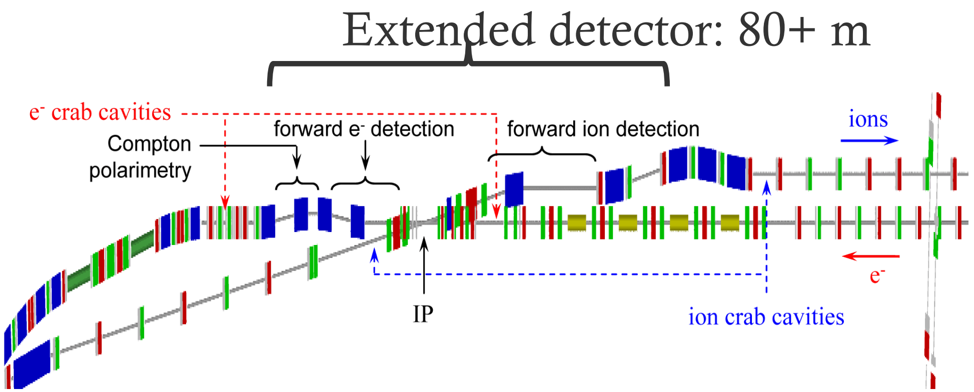
Setup in Hall C

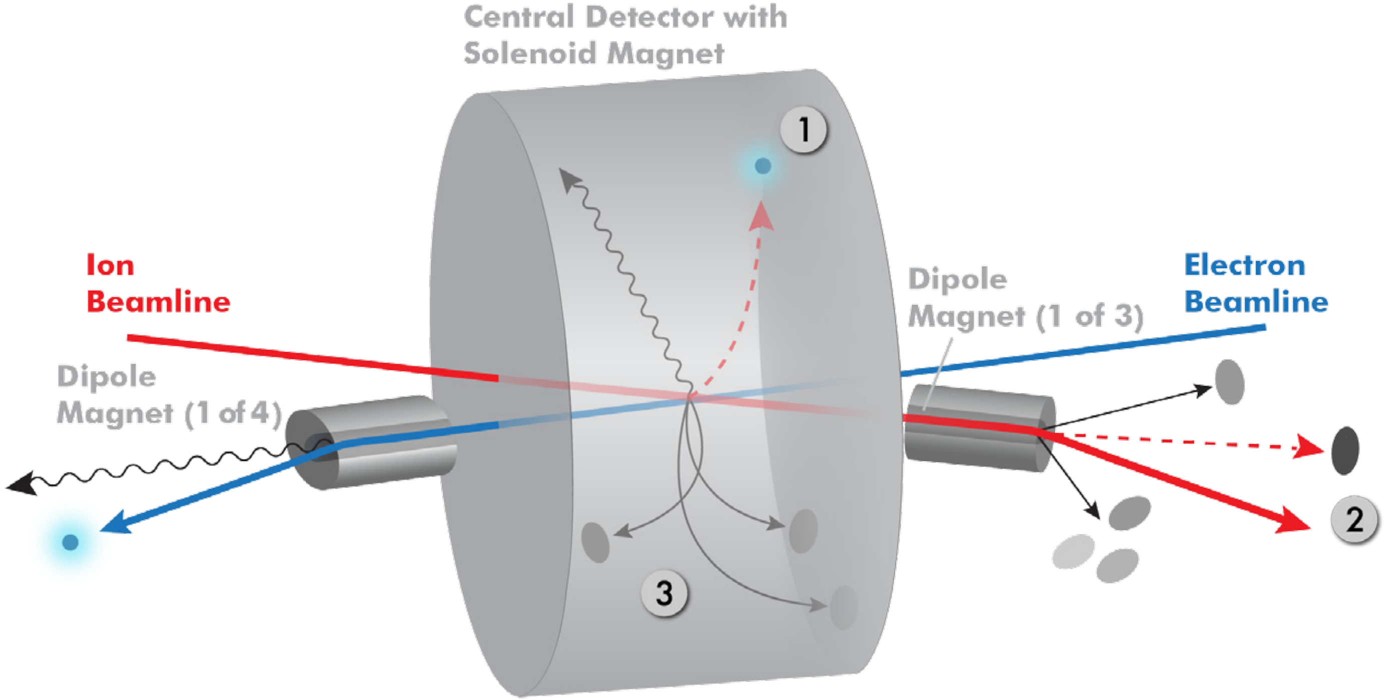


~1% electron beam polarization measurements
Simulation for EIC is ongoing



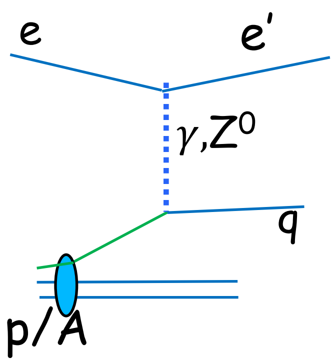
Far-Forward Areas



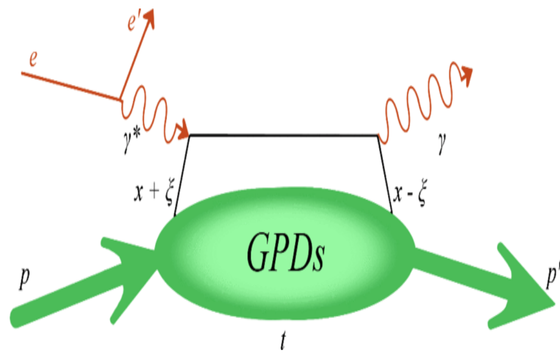


Far-forward ion direction area

Proton/Ion remnant



DVCS, VM production



Diffraction

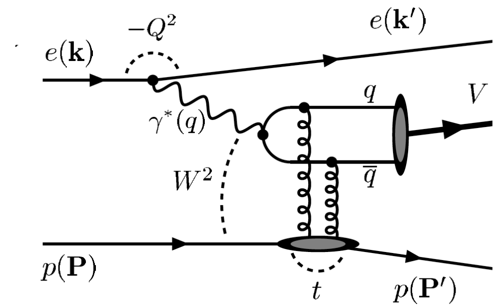
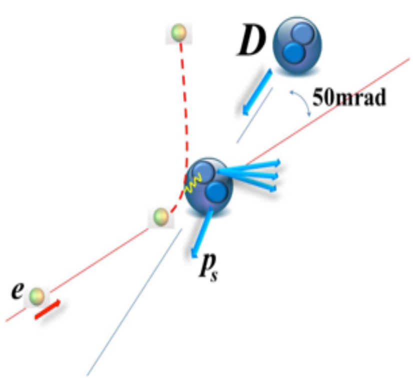
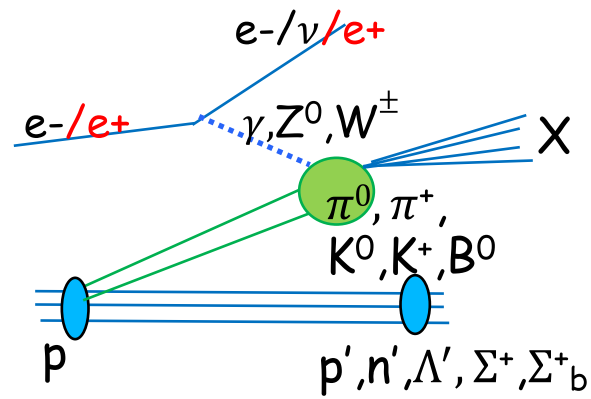


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.

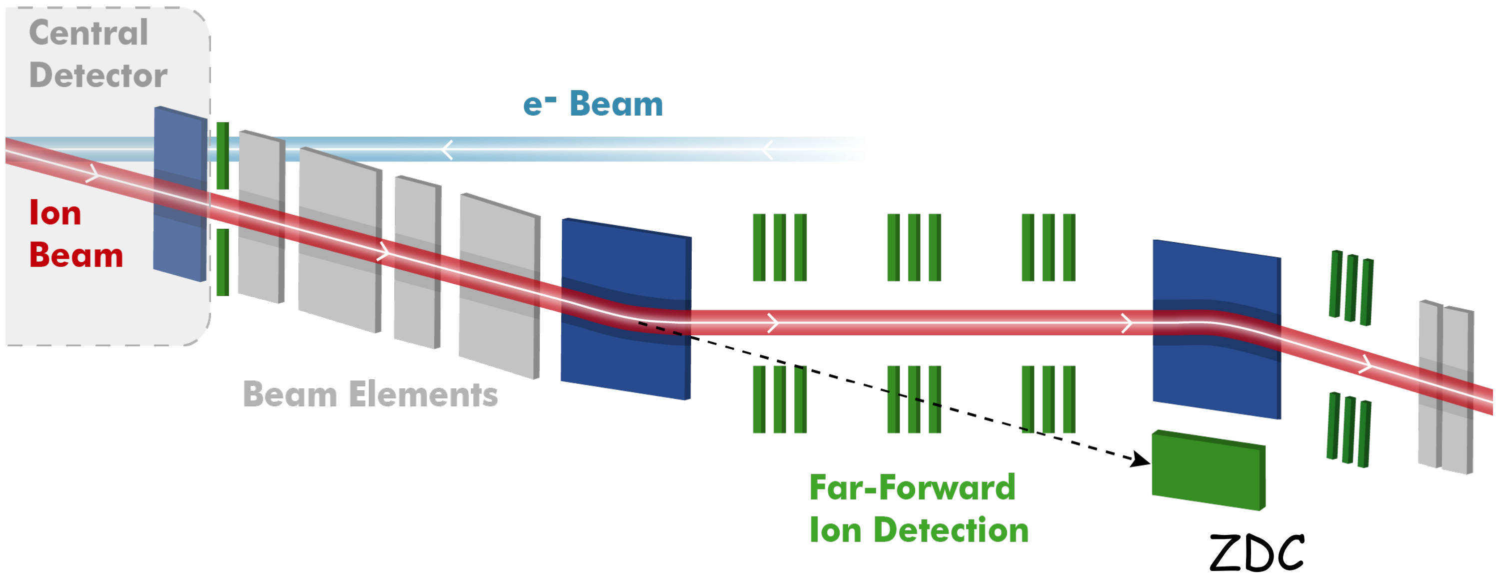
Scattering on deuteron
Double tagging



Pion/Kaon structure

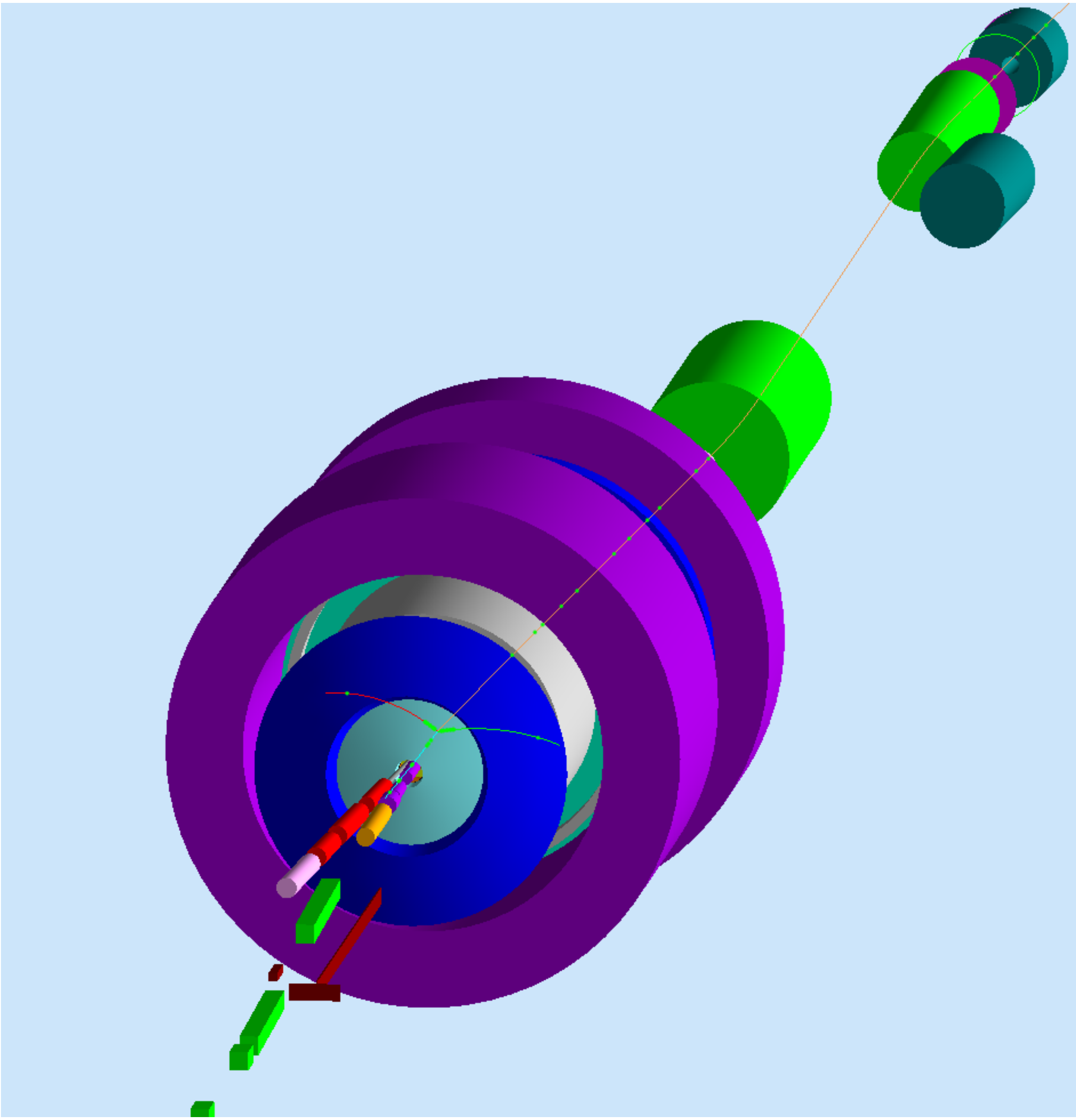


Far-forward ion direction area



- **Tracking detectors** (decay products of Λ', Σ (π, K))
- **Roman-pots** for (p)-tagging
- **Zero degree calorimeter** for (n)-tagging

Exclusive J/ψ with JLEIC detector



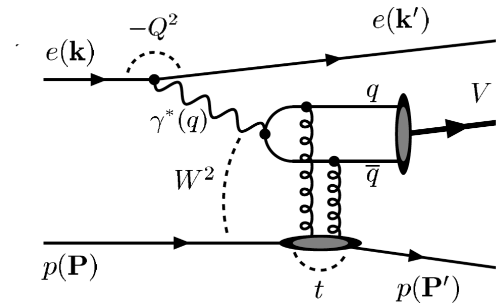
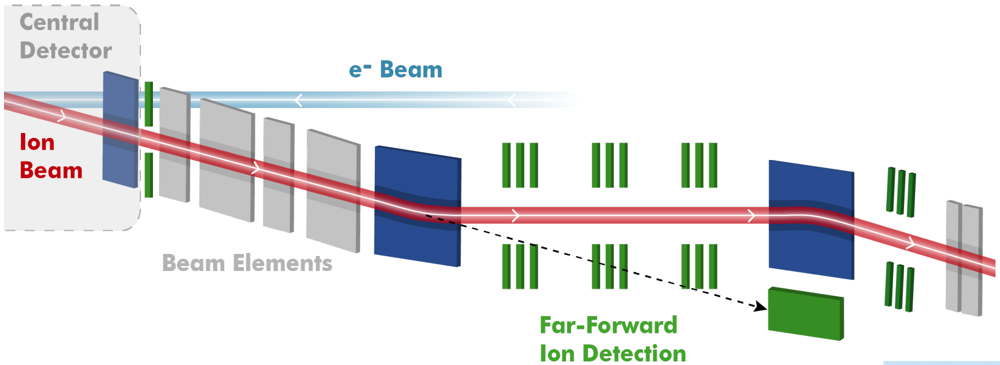


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.

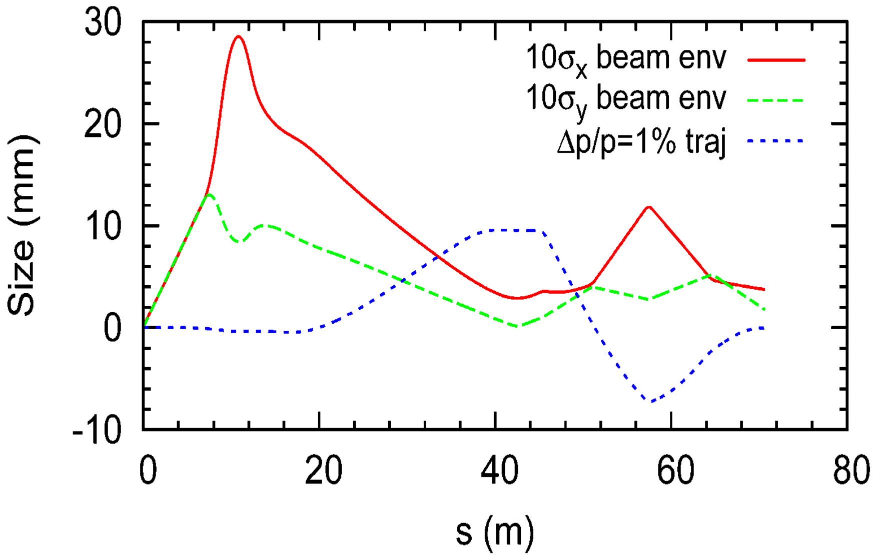
$e + p \rightarrow e' + J/\psi + p'$

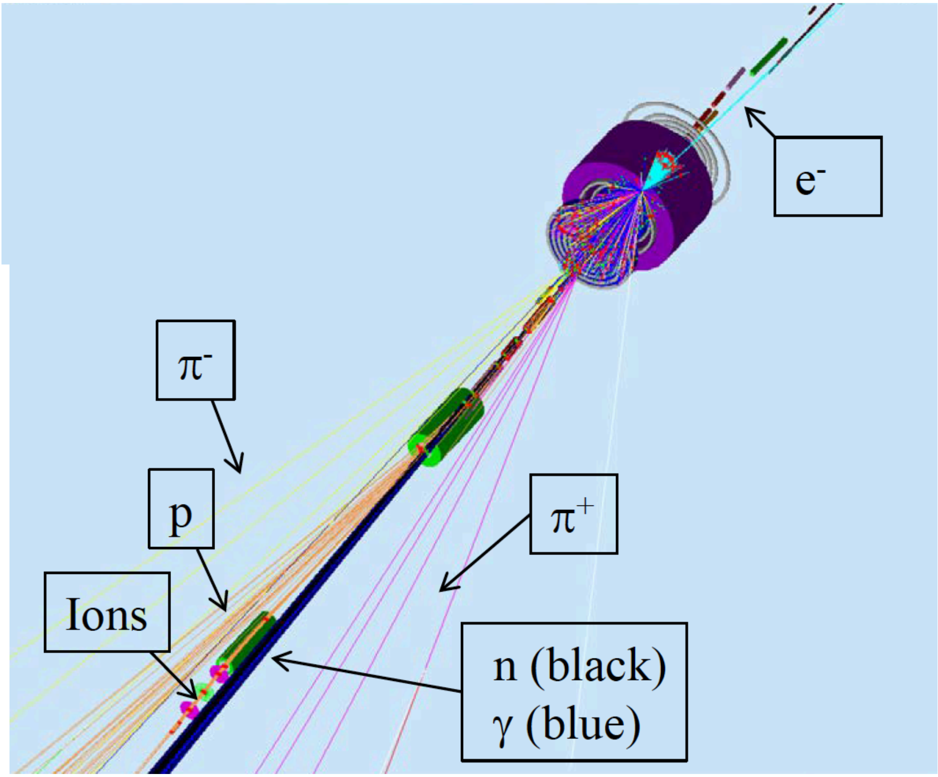
Using events, generated by Sylvester J. Joosten

Far-forward ion direction area



- Main beam is focused
- High dispersion for off momentum particles

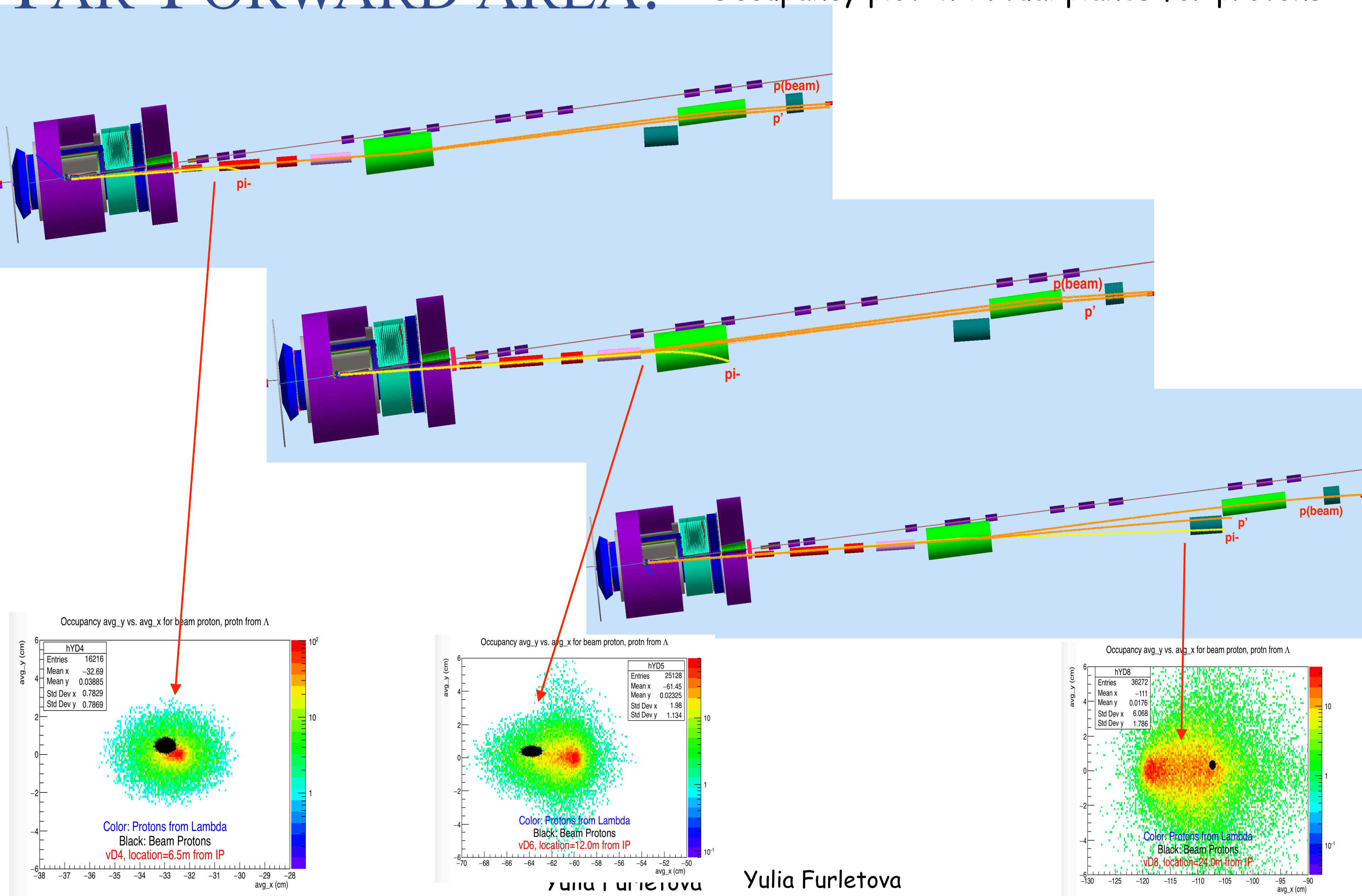




FAR-FORWARD AREA:

Kijun Park

Occupancy plot in virtual planes for protons



Yulia Furletova

Summary

- Physics must drive the detector design.

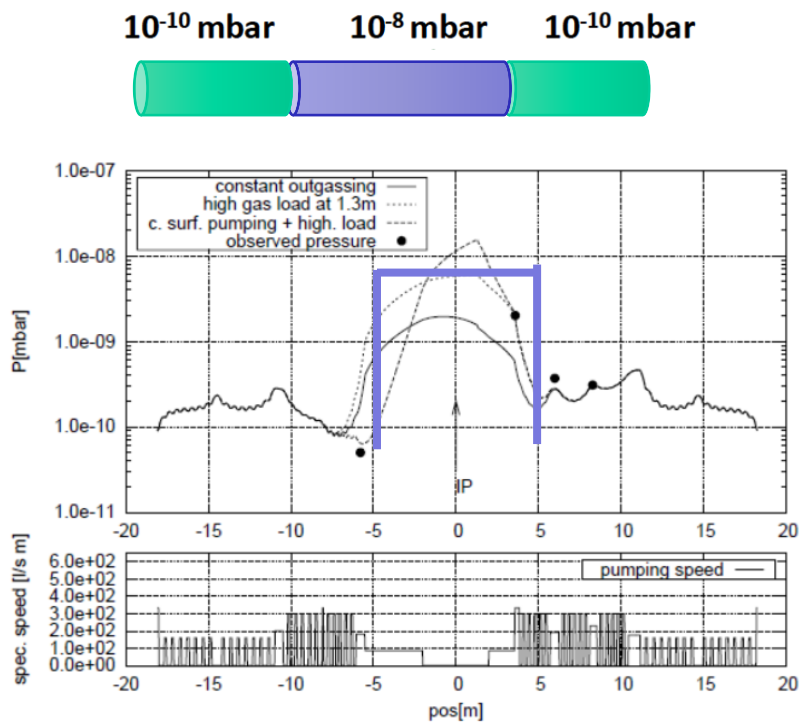
- JLEIC detector design is based on a *total* acceptance detector and particle identification concept. This means excellent forward/rear coverage in addition to the central coverage, as well as on identification of individual particle species.

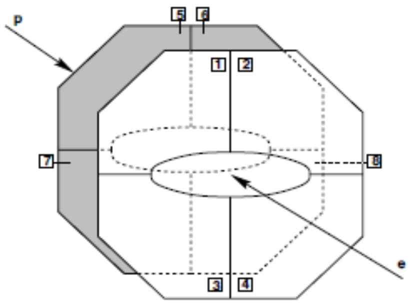
- **Machine parameters**, **interaction region** and **detector design** must go hand in hand, paying close attention to the emerging **physics program** of the EIC (a good collaboration among Accelerator Physicists, Experimentalists, and Theoreticians)

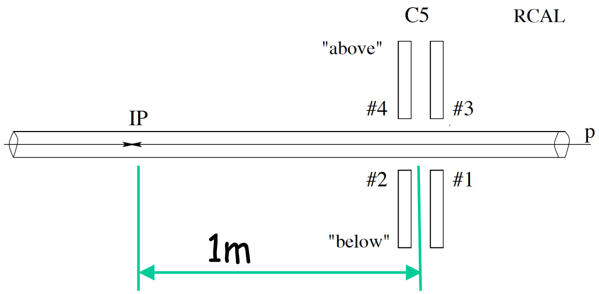
- Backup

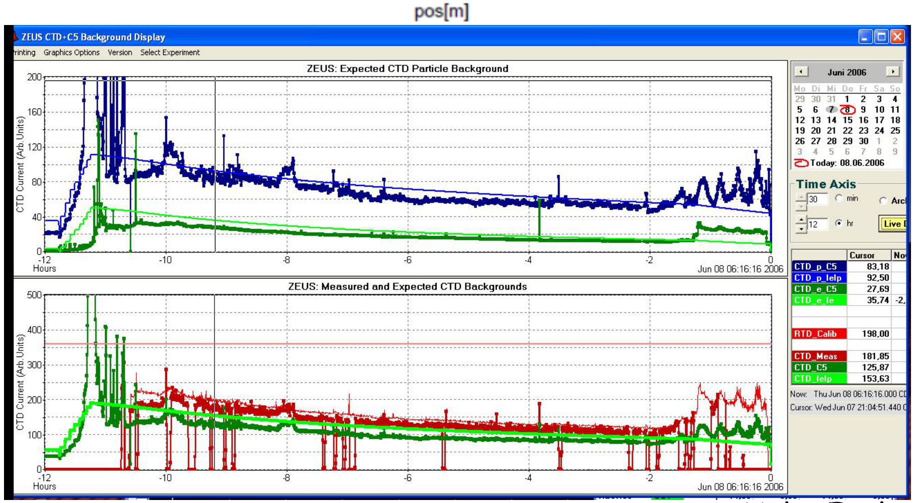
Background

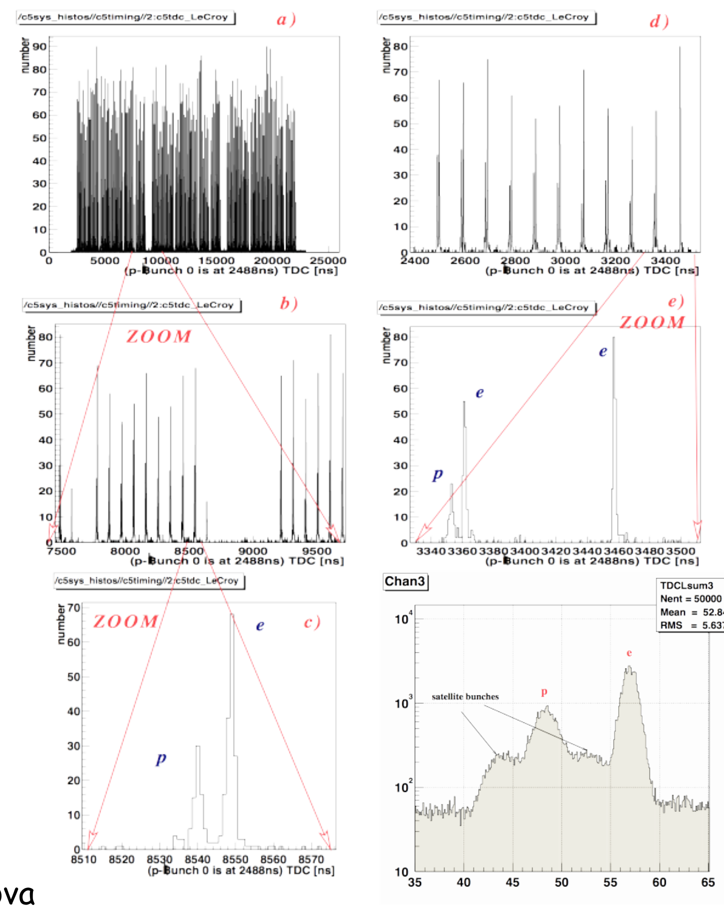
ZEUS/C5 beam background monitor detector











Bunch structure: 96ns

At C5: $\Delta T \sim 8.3$ns

σ_{PMT} ~1 ns

Yulia Furletova

Polarization

Elke Aschenauer

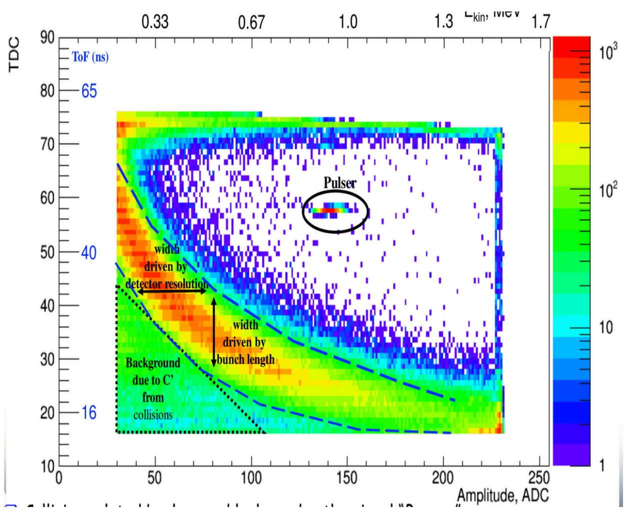
Hadron polarimetry at EIC

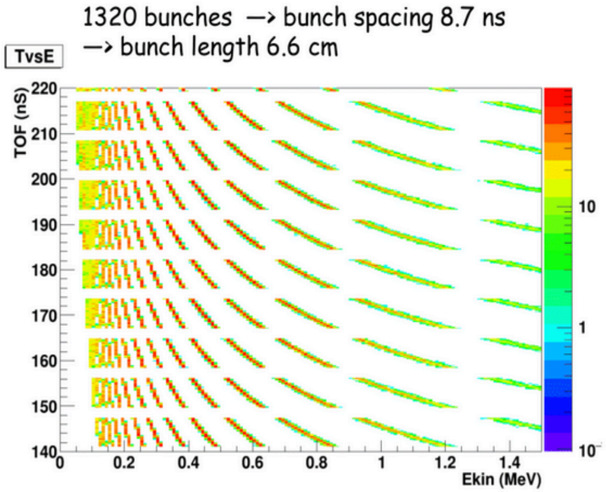
At RHIC:

- Polarized hydrogen Jet Polarimeter (HJet): absolute polarization, but slow.
- Proton-Carbon Polarimeter (pC): very fast and high precision, but needs to be normalized

BUT EIC is not RHIC!

- Higher bunch frequency and current.
- Background?

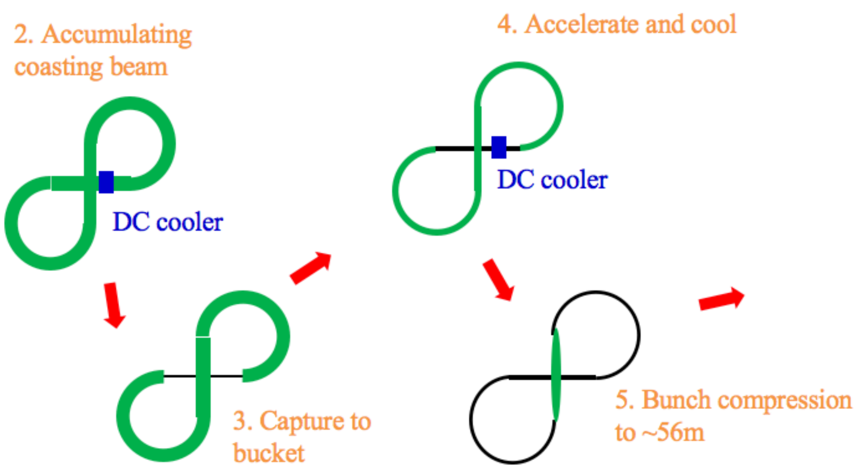


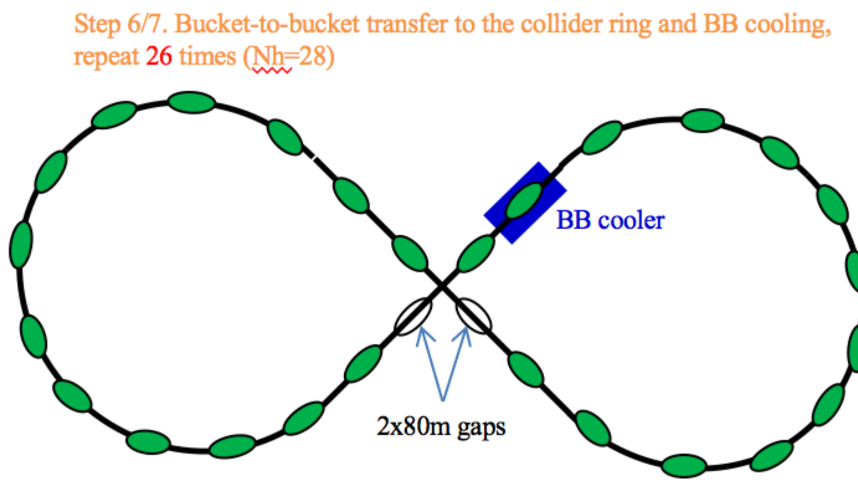


New detector technology (fast ~ 10ps Si?)
Reduce TOF ?
Polarized D and He-3

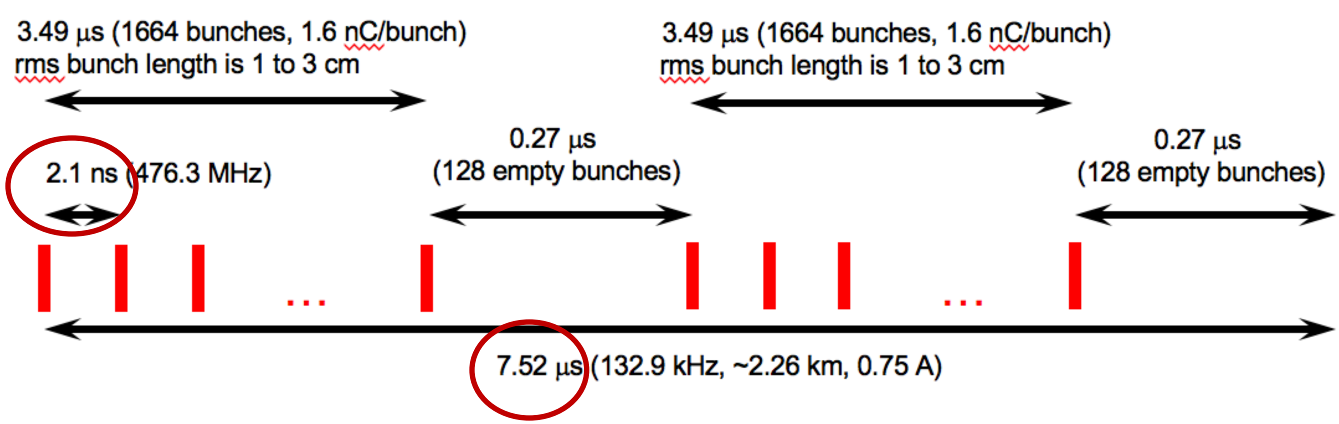
Ion Bunch Structure

- Ion bunch formation





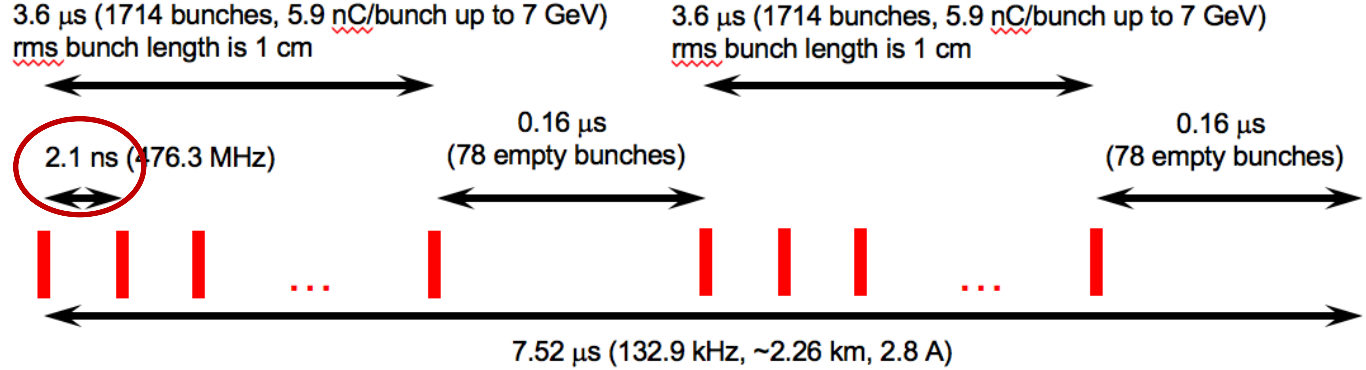
- Bunch structure in the ion collider ring



Yulia Furletova

Electron Bunch Structure

- Bunch structure in the electron collider ring



- Electron injection scheme
  - f_{ring} / f_{CEBAF} = 476.3 MHz / 1497 MHz = 7 / 22