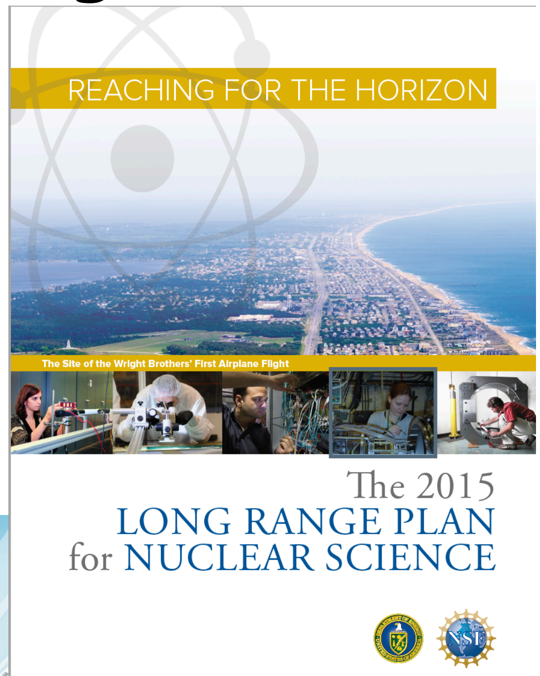
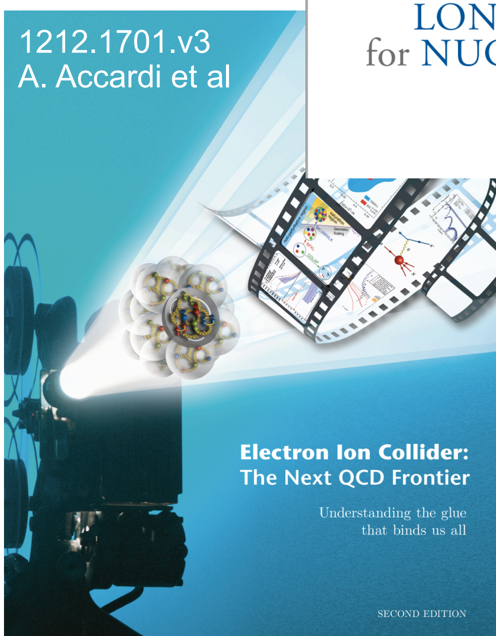
Physics Driving the Design of the EIC Detectors

Yulia Furletova

GHP meeting, Washington DC, Feb 1-3, 2017

Long Range Plan



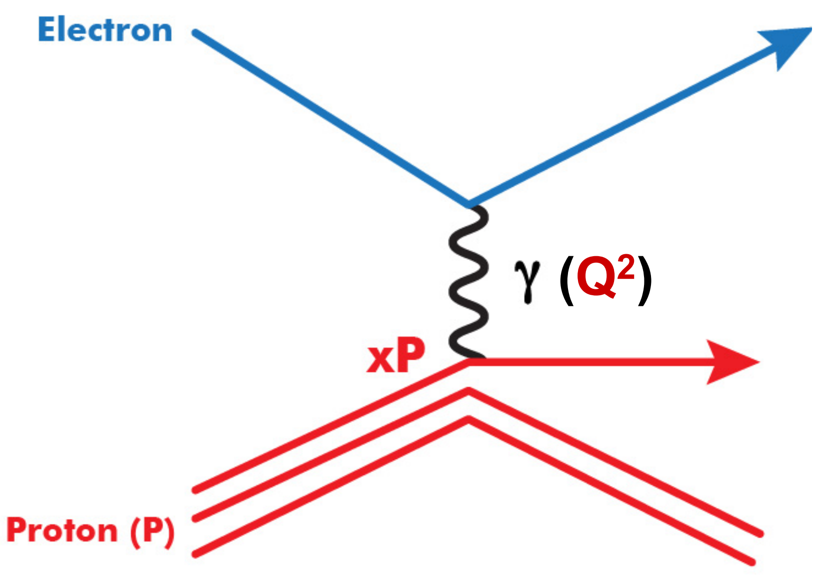


The NSAC recommend "a high-energy high-luminosity polarized Electron-Ion Collider (EIC) as the highest priority for new facility construction.."

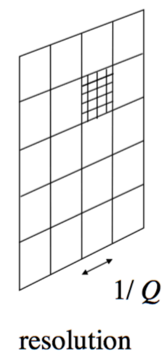
The Next QCD Frontier

- 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)

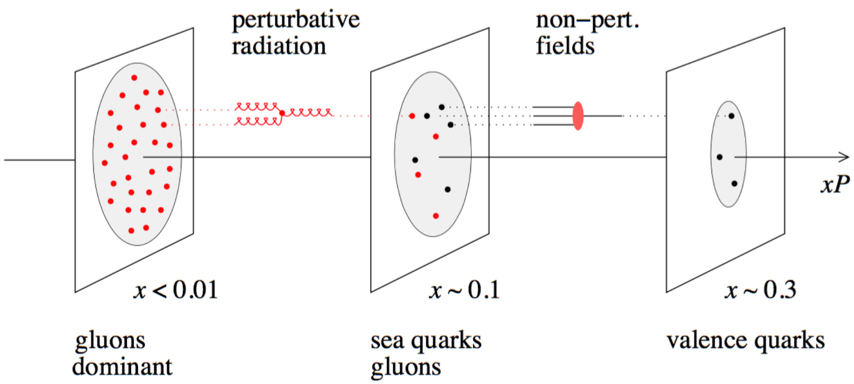
Electron proton scattering



Ability to change Q^2 changes the resolution scale



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



Electron-Ion Collider range (x)

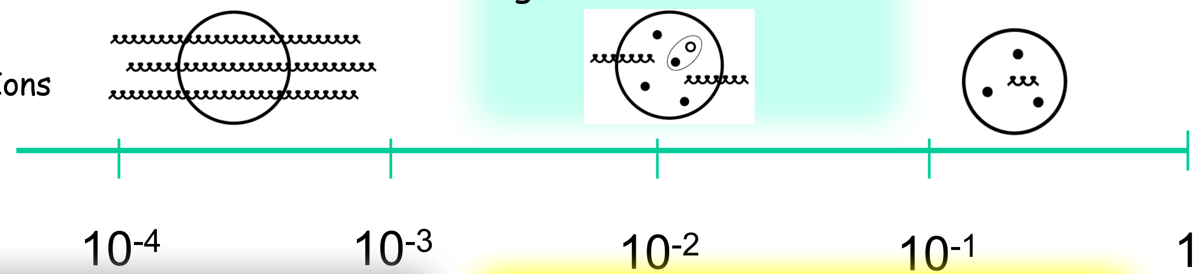
Saturation Regime:

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



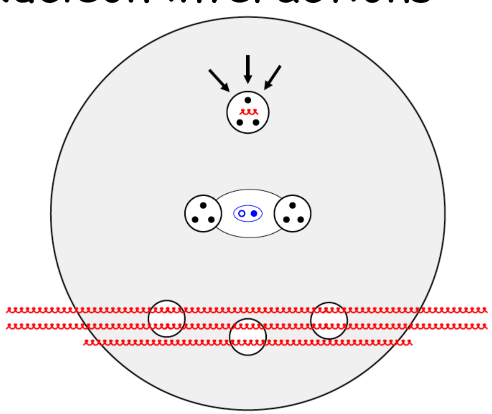
Fraction of momentum carried by the parton
x
(for proton)

QCD Radiation Dominated
(Studied at HERA)

Hadron Structure Dominated

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

Nucleon interactions

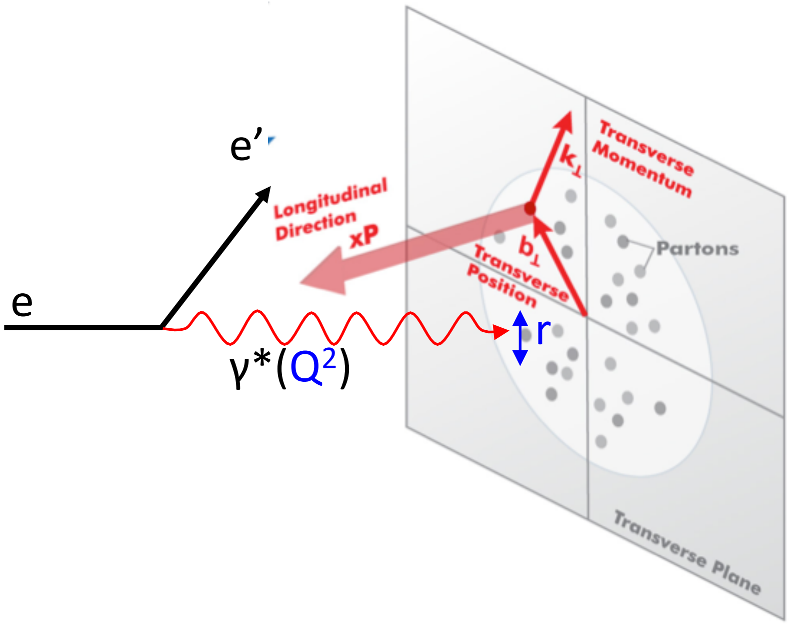


- x > 0.3 “EMC effect”
Modified single-nucleon structure? Non-nucleonic degrees of freedom?

- x ~ 0.1 “Antishadowing”
QCD structure of pairwise NN interaction, exchange mechanisms

- x < 0.01 “Shadowing”
QM interference, collective gluon fields

3D Structure of Nucleons and Nuclei



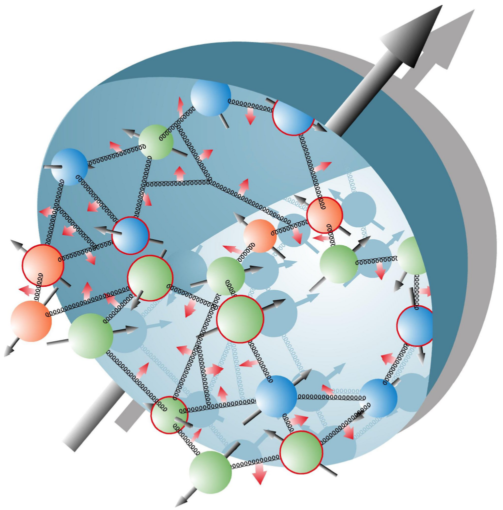
3D Structure of Nucleons and Nuclei:

- 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.

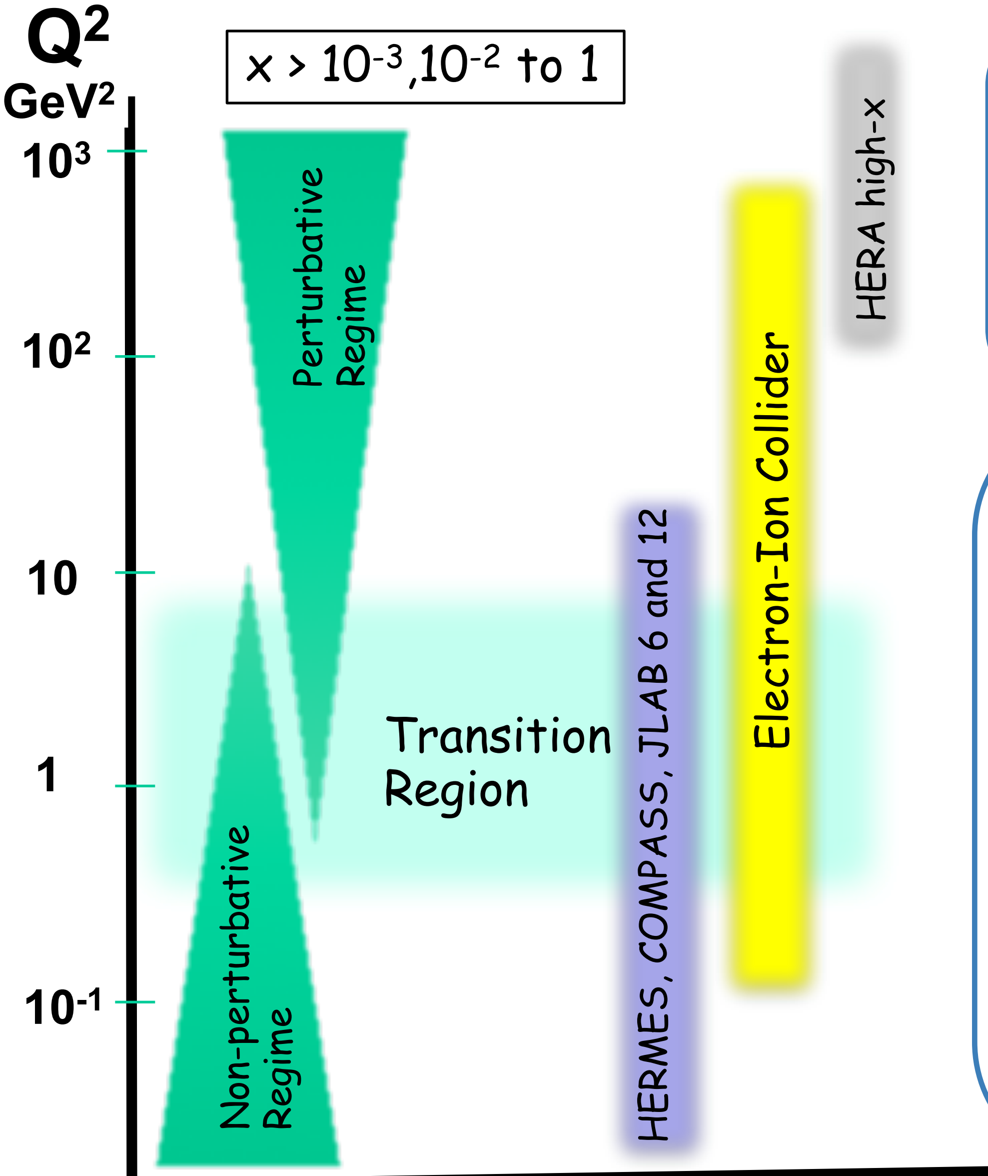
Transverse Momentum Dependent Distributions (TMD): k_t
Generalized Parton Distributions (GPD): b_t

Polarizaton
Understanding hadron structure cannot be done without understanding spin:

- polarized electrons and
- polarized protons/light ions



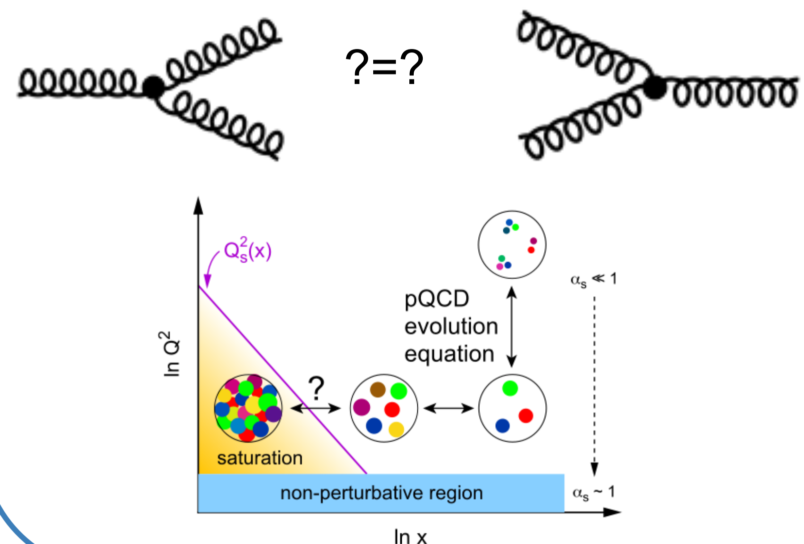
Electron-Ion Collider range (Q2)



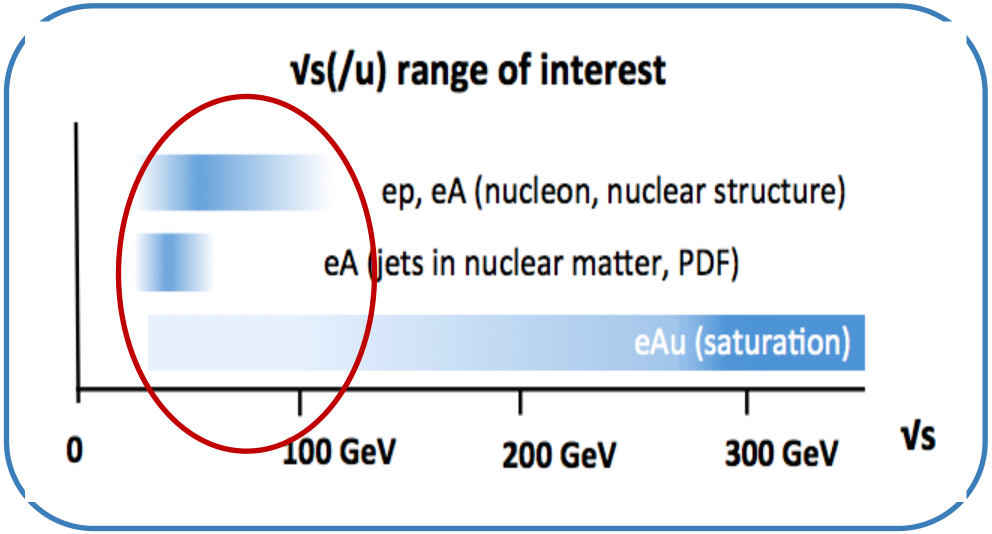
- Include non-perturbative, perturbative and transition regimes
- Provide long evolution length and up to Q^2 of ~1000 GeV² (~.005 fm)
- Overlap with existing measurements

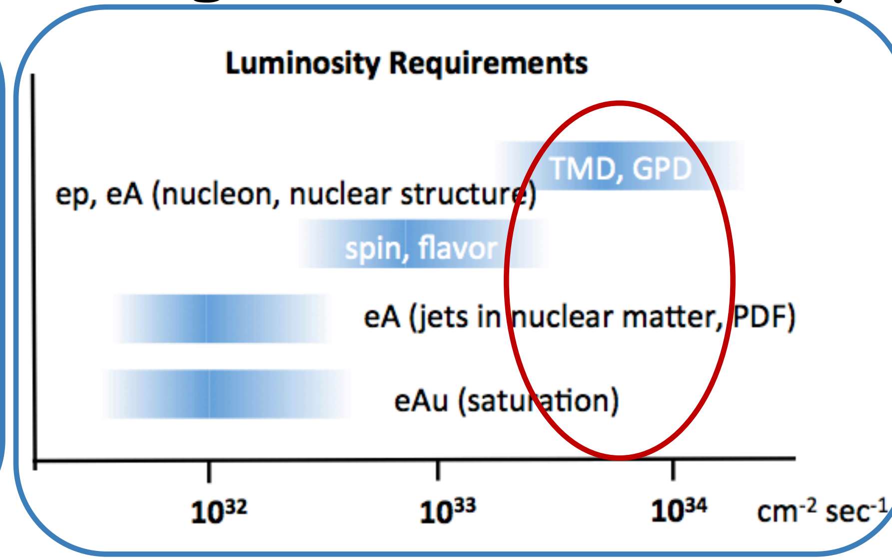
Saturation regime at EIC

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



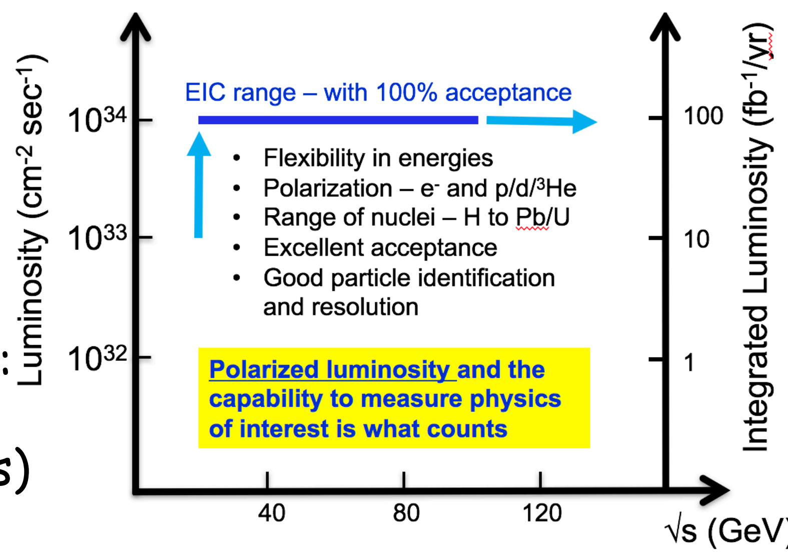
Electron-Ion Collider: √s range and luminosity





Beam energy:
Various center of mass energy (low, medium, high)
High luminosity :

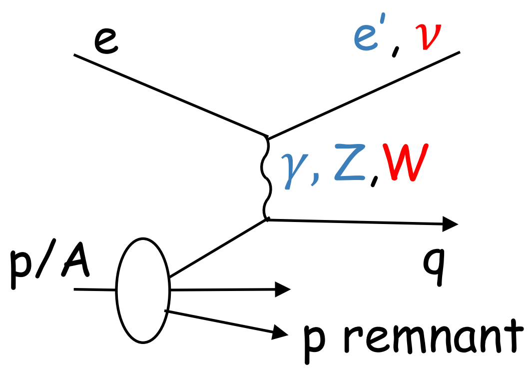
- high precision physics
- rear physics
- various measurements/configurations: (different ions, different center of mass energies, different polarizations)



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

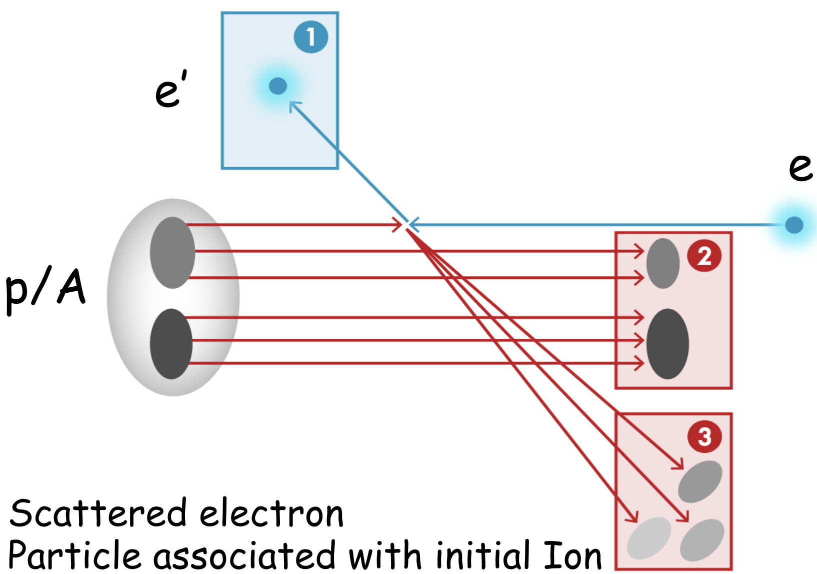
Deep inelastic scattering and General detector design considerations

Total acceptance detector



Aim of EIC is nucleon and nuclear structure beyond the longitudinal description.
This makes the requirements for the machine and detector different from all previous colliders including HERA.

"Statistics"=Luminosity × Acceptance



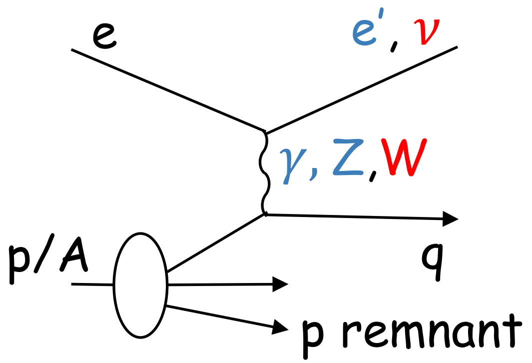
1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark

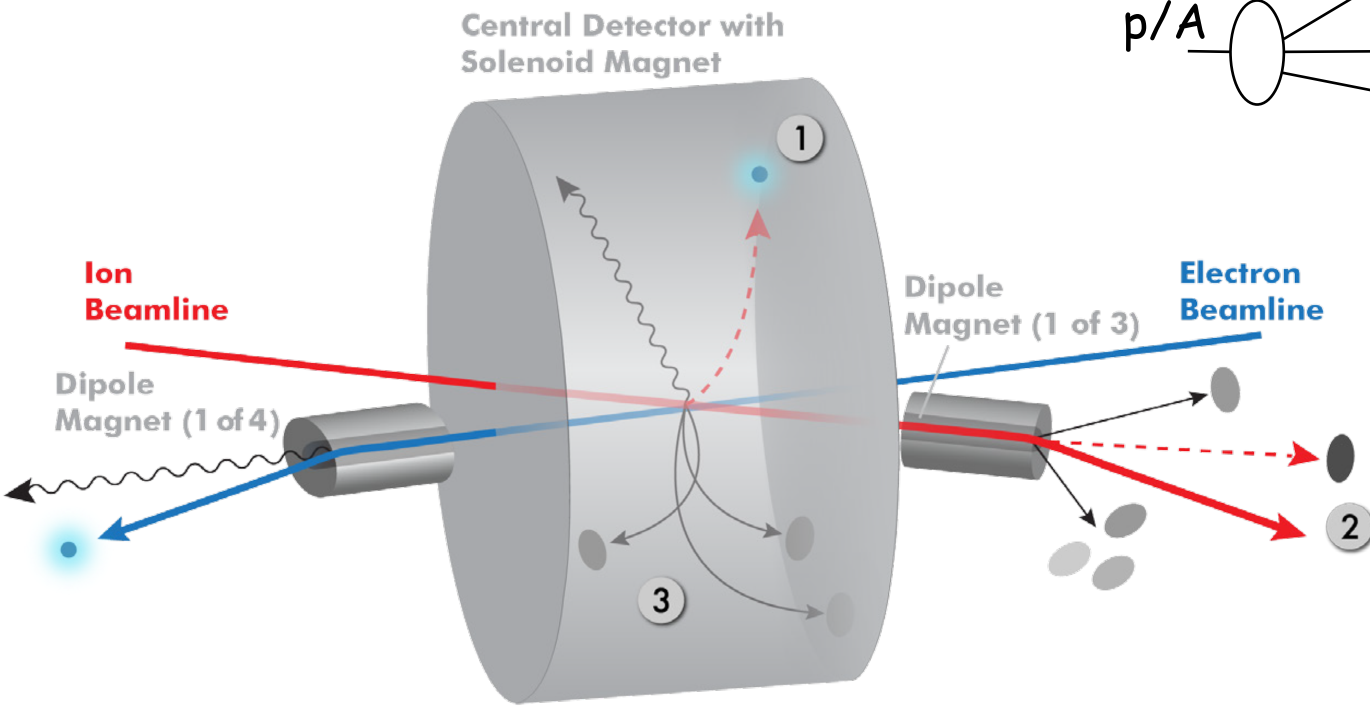
EIC Physics demands ~100% acceptance for all final state particles (including particles associated with initial ion)

Ion remnant is particularly challenging
- not usual concern at colliders
- Higher the Ion Beam energy, more difficult to achieve.

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





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

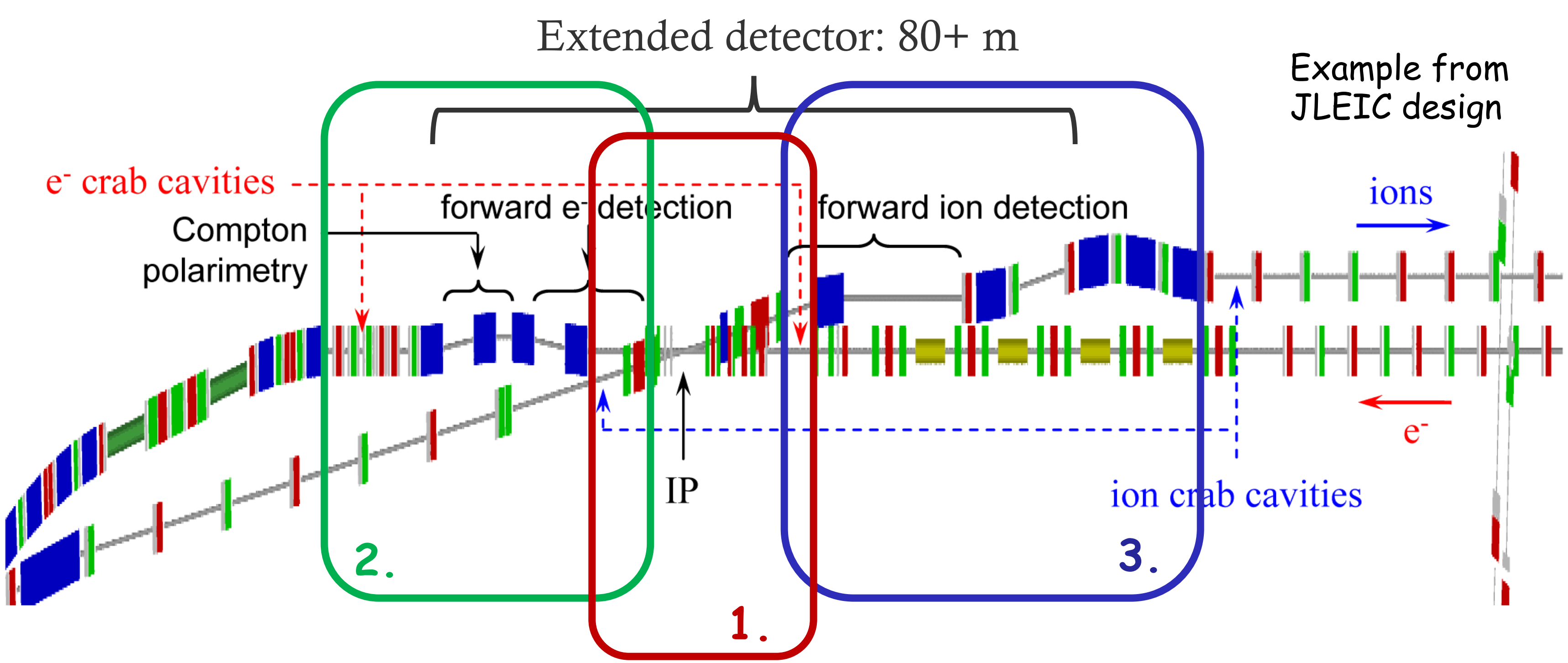
Need a Total acceptance detector (and IR) also for variable beam energies.

Integration with accelerator

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

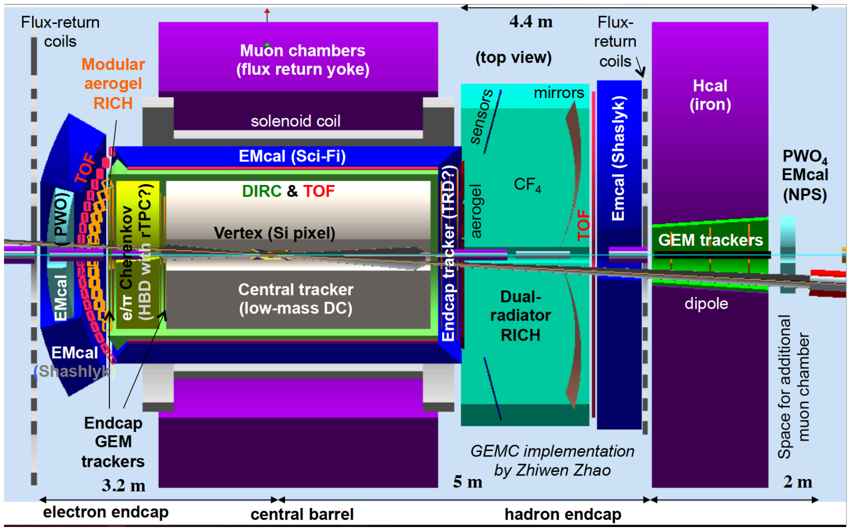
- Total size ~80m

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

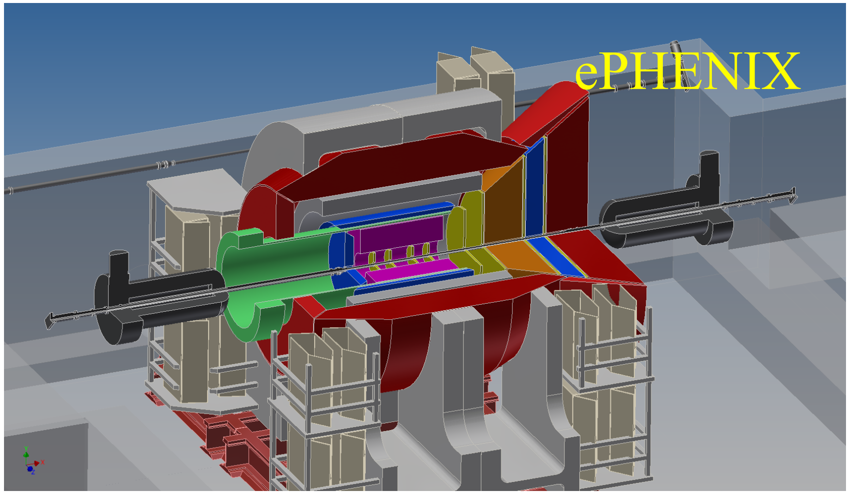


EIC Central detector overview

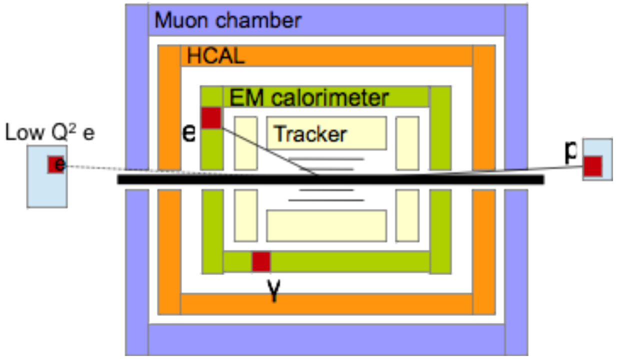
Jefferson Lab



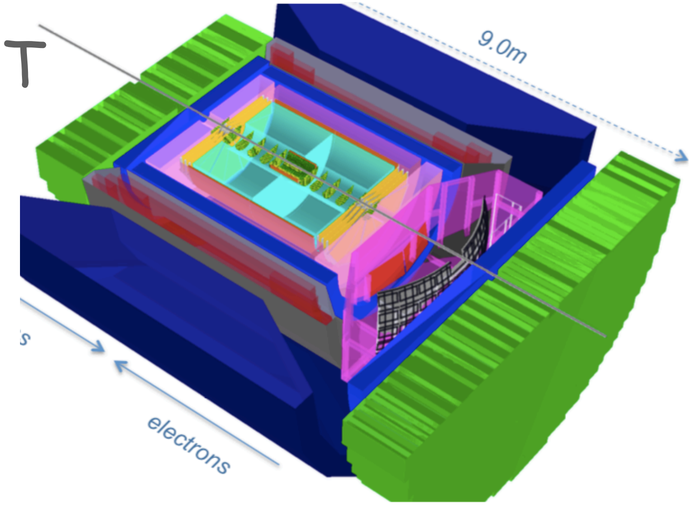
Brookhaven



2nd IP for jets



BeAST

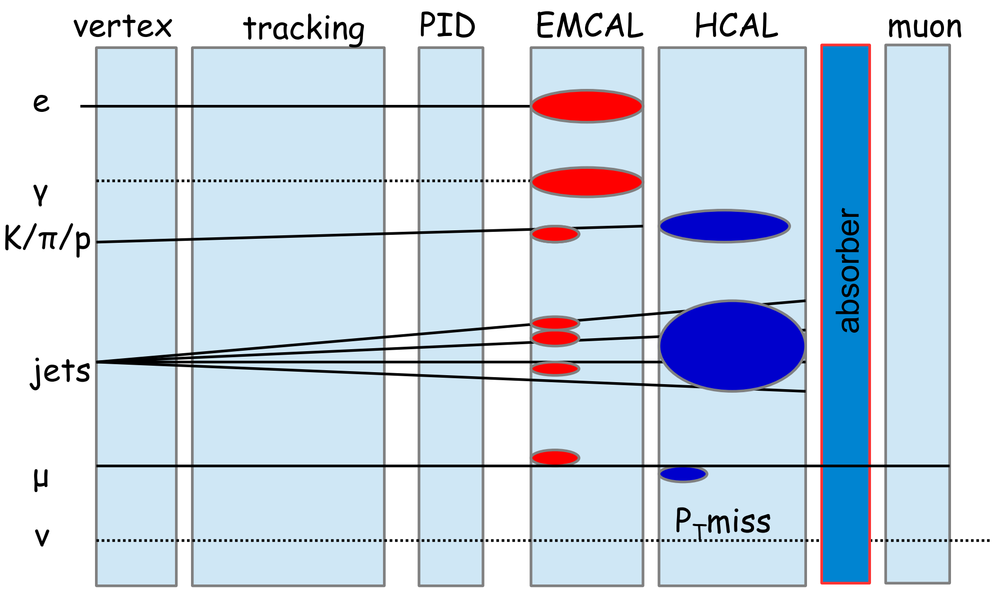


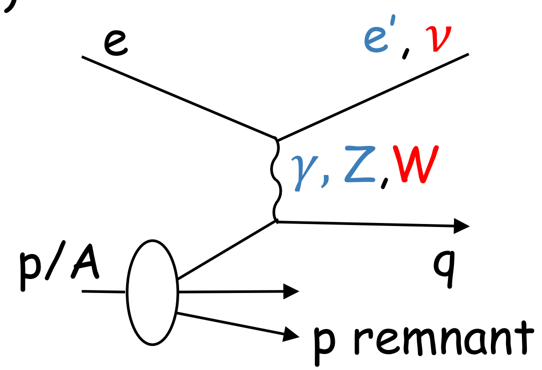
Modular design of the central detector

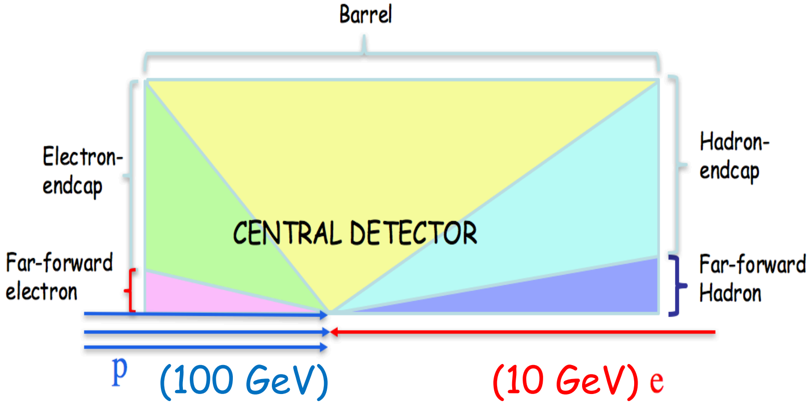
Yulia Furletova

General structure of detectors

Stable particles (e,μ,π,K,p, jets(q,g), gamma, ν - P_t^{miss}):
Momentum/Energy, Type(ID), Direction, vertex







bunch crossing is every ~2ns

Pythia Minbias EIC (Q2> 10^{-6}) σ ~ 200 μb (HERA ~165 μb)
N events = σ•L ~ 2· 10^6 ev. per sec (2MHz) ~ 2 events / μs

ZEUS/HERA(ep) ~3kHz

In order to reconstruct the kinematic x and Q^2 it is, in principle, sufficient to measure any two of these $E'_{e'}, \theta_{e'}, E_q, \theta_q$

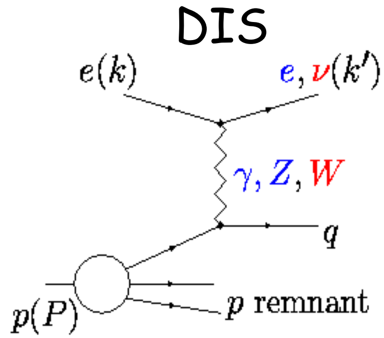
EM Calorimeter

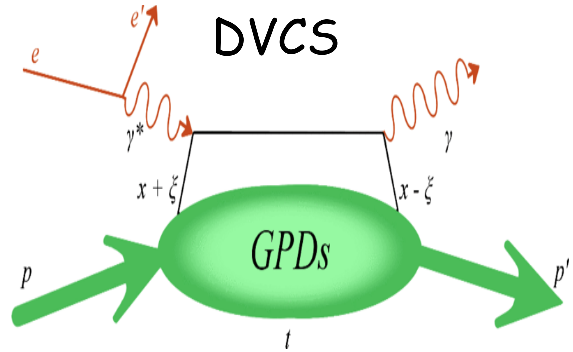
Electromagnetic Calorimeters measure EM showers and early hadron showers:
Energy, position, time

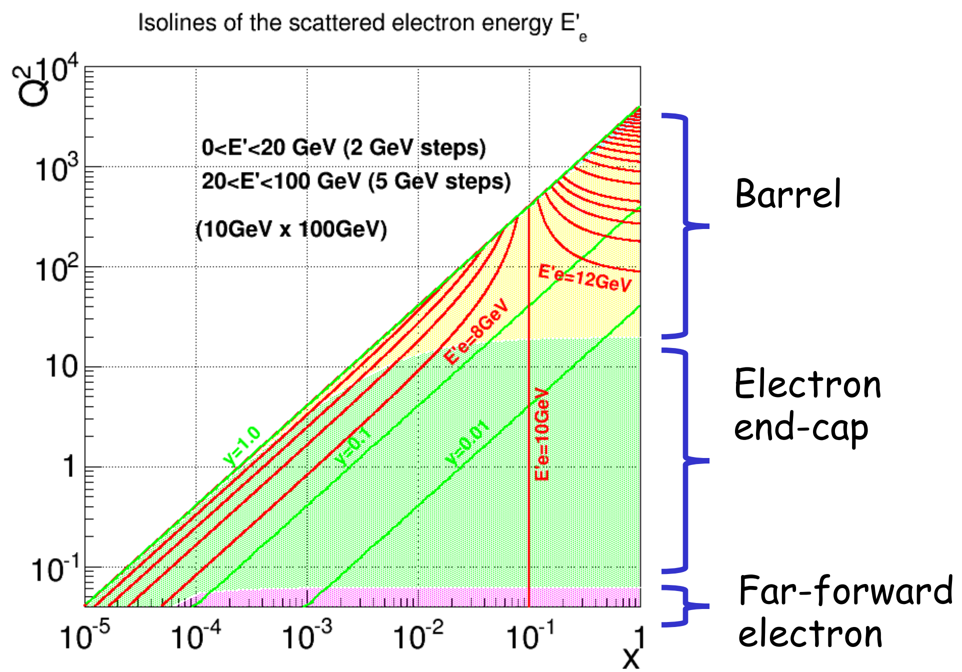
$PbWO_4$ Crystal EM Calorimeter
-Tungsten glass, similar to CMS or PANDA
- Time resolution: <2 ns
- Energy resolution: <2%/√E(GeV) + 1%
- Cluster threshold: 10 MeV
- Produced at two places (China, Russia)
- For CMS it took 10 years to grow all crystals !!!

Sampling EM Calorimeter
- **Shashlyk** (scintillators +absorber)
-WLS fibers for readout
-**Sci-fiber EM(SPACAL):**

- Compact W-scifi calorimeter, developed at UCLA
- Spacing 1 mm center-to-center
- Resolution ~12%/√E
- On-going EIC R&D

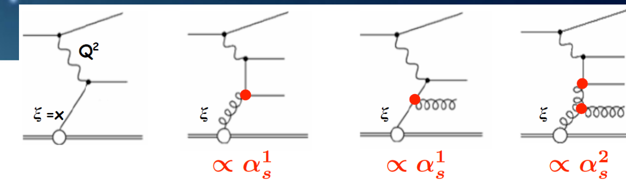






- PWO for e-endcap - close to the beam – more precise and more radiation hard.
- Shashlyk for barrel– less expensive

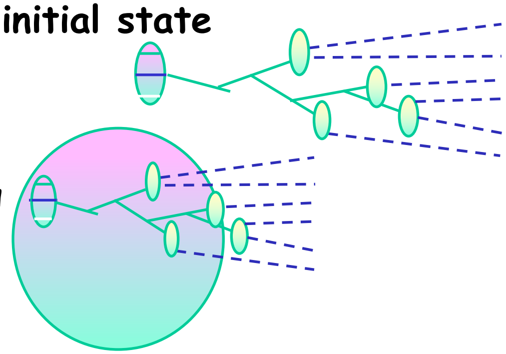
Jets at EIC and HCAL



1) **Jets evolution and dynamics (jet == struck quark)**

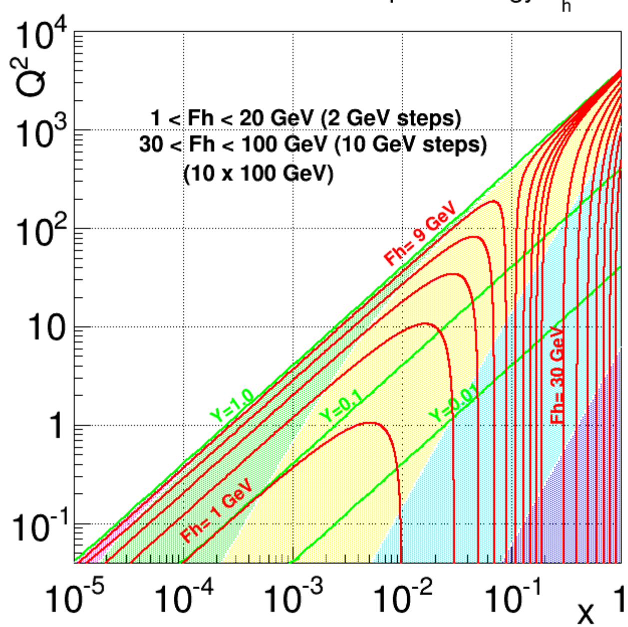
2) **Jets as a probe of partonic initial state**

3) **Jets in medium (cold nuclear matter)**
- ✓ energy loss, quenching
- ✓ broadening
- ✓ multiple-scattering.



At EIC for the first time will be able to study in-medium propagation and hadronization of heavy quarks (charm and beauty)

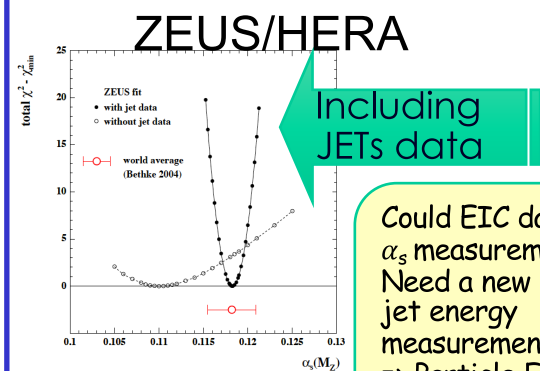
Isolines of the struck quark energy F_h



Charged current DIS

Neutrino in the final state =>
- Could use only jets to reconstruct a kinematics(x,Q2)
- Need 4π HCAL coverage for $P_T$miss

Determination of α_s from the inclusive jet cross section in DIS



Could EIC data improve α_s measurements? Need a new method for jet energy measurements! => Particle Flow Calorimeter

In a typical jet :
60 % of jet energy in charged hadrons
30 % in photons (mainly from $\pi 0 \rightarrow \gamma\gamma$)
10 % in neutral hadrons (mainly n, K_L)

Traditional calorimetric approach:
-E_{JET}=EMCAL+HCAL
-70% of energy measured in HCAL with poor resolution : $\sigma_E / E \sim 60\%/\sqrt{E}$
Uranium Calorimeter at ZEUS: $\sigma_E / E \sim 35\%/\sqrt{E}$

Particle Flow Calorimetry:
$E_{JET} = E_{track} + E_\gamma + E_n$
-charged particles measured in tracker (essentially perfectly)
-Photons in ECAL: : $\sigma_E / E \sim 2\text{-}10\%/\sqrt{E}$
-Neutral hadrons (ONLY) in HCAL =>
Only 10 % of jet energy from HCAL
much improved jet resolution!!!

Tracking

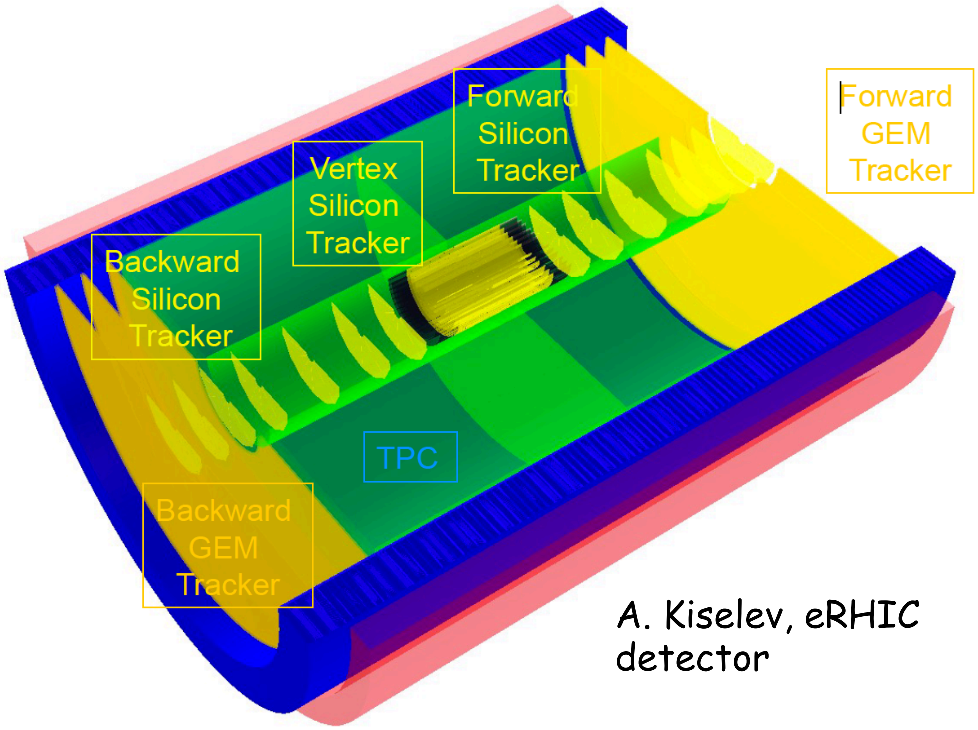
Main purpose of tracking:
-reconstruct charged tracks and measure their momenta precisely (~few %)
-dE/dx (PID) for low momentum tracks.

Barrel: TPC or drift chambers

- relatively fast detector,
- minimal multiple scattering
- limited PID

Endcaps: GEM

- High multiplicity in forward region – we need a high granularity tracker
  resolution ~50 μm.
- Radiation hardness



A. Kiselev, eRHIC detector

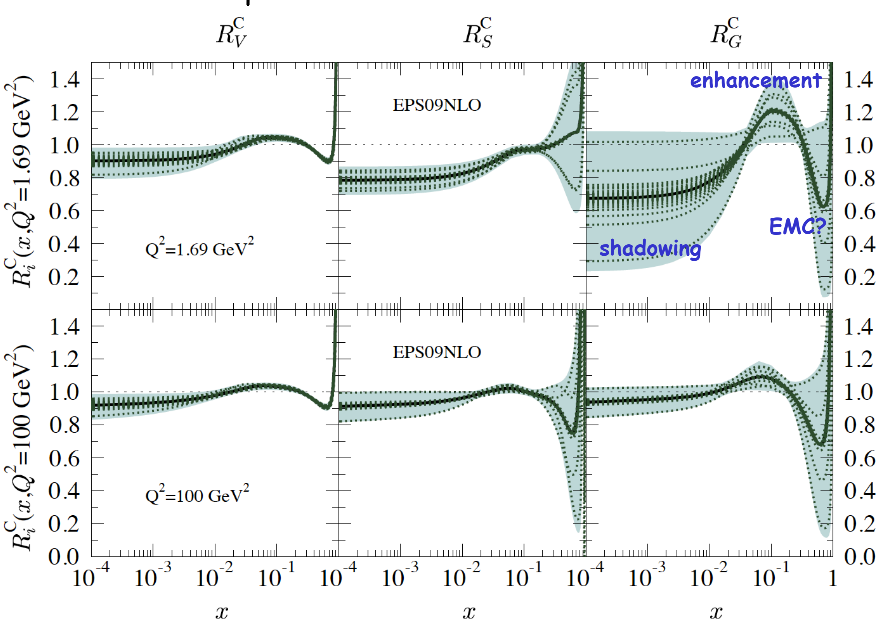
Vertex

Main purpose of vertex detector:
- -Reconstruction of a primary vertex
- -Reconstruct secondary vtx:

Tagging of c and b quarks (decay length ~100-500μm)

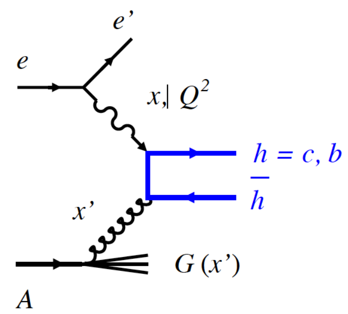
- -improve momentum resolution of outer tracker
- -provide stand-alone measurements of low-Pt particles
- -dE/dx measurements for PID

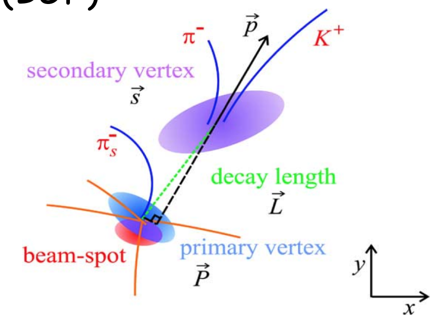
Nuclear PDF parametrization EPS09 Eskola et al. 2009



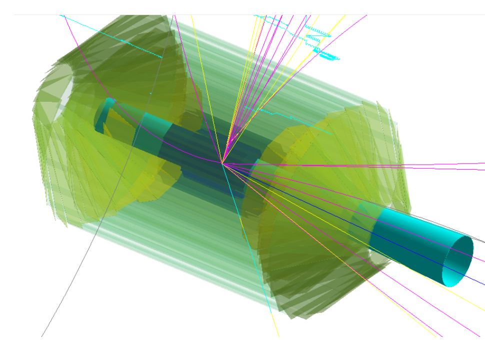
Heavy quarks

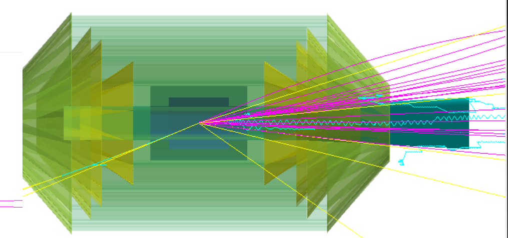
Boson (photon)- Gluon Fusion (BGF)





Charm high-Q2 event in the vertex detector

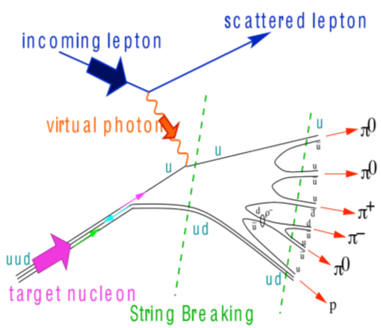




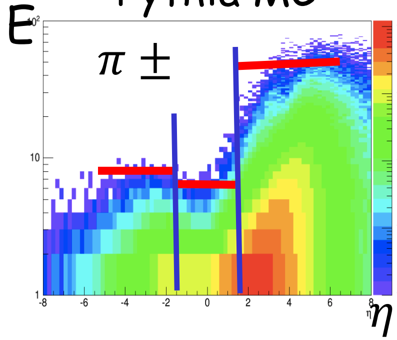
Vertex detector is a closest to IP detector.
Background increase an occupancy.
High granularity detector is needed (pixels)
Beam related background could cause a radiation damage.

Hadrons Identification

<u>Semi-inclusive DIS:</u> involves measurements of one or more final-state hadrons in addition to the detection of the scattered lepton.

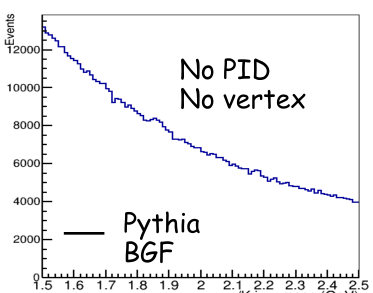


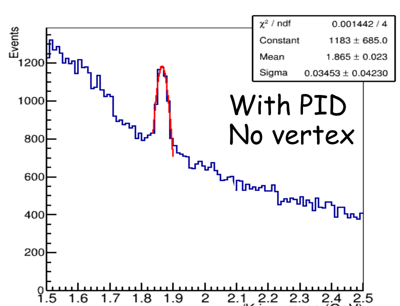
Pythia MC



<u>Exclusive processes:</u>

D0 mass plots: $D^o \rightarrow K^- \pi^+$





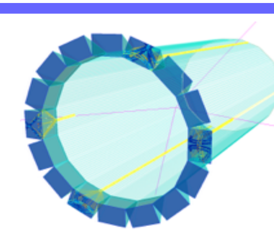
Time of Flight: MRPC

Multi-gap Resistive Plate Chamber (MRPC) R&D: achieved ~18 ps resolution with 36-105 μm gap glass MRPC π/K <3.5GeV

Electron end-cap: Modular RICH

- Modular aerogel RICH (eRD14 detector R&D)
- π/K separation up to ~10 GeV

Barrel: DIRC



- radially compact (2 cm)
- Particle identification (3σ) p/K < 10 GeV, π/K < 6 GeV, e/π < 1.8 GeV

Hadron end-cap: dual-radiator RICH

- JLEIC design geometry constraint: ~160 cm length
- Aerogel in front, followed by CF4
- covers energy for π/K up to 50GeV
- Sensitive to magnetic field=> New 3T solenoid minimized a field in RICH region

Electron Identification

σ(Zc[3900]) ~5 nb
σ(PhP, Q^2<1GeV) ~ 10^4nb

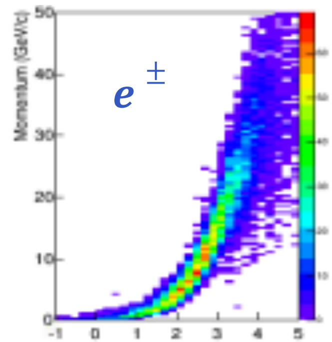
Physics:

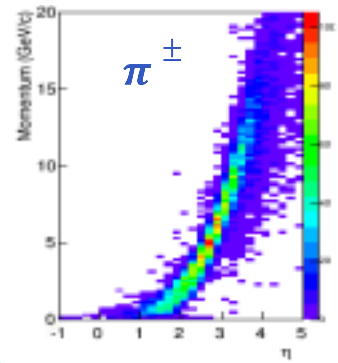
- ✓ For rare physics, based on electron identification
- ✓ Charmonium, light vector mesons (ρ,ω,φ)
- ✓ Tetraquarks and Pentaquarks (and other XYZ states)
- ✓ Open Charm and Beauty physics
- ✓ Di-lepton production
- ✓ Scattered electron identification at Large-x, large-Q2

Transition radiation (TRD) for electron/hadron rejection: GEM/TRD

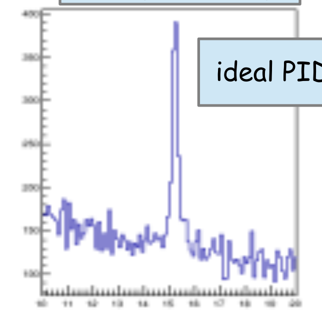
- combined high granularity tracker and PID.
- cover energy range 1-100GeV.
- provide additional e/hadron rejection factor 10-100.

New XYZ stage Zc[3900]

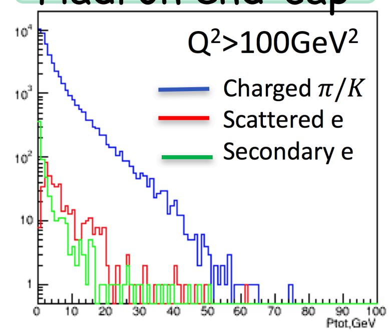




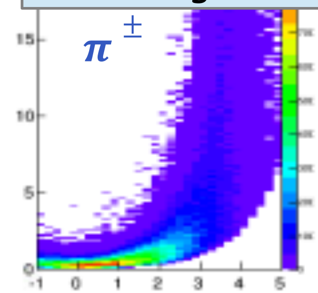
Zc[3900] m^2 (e+e-π+)

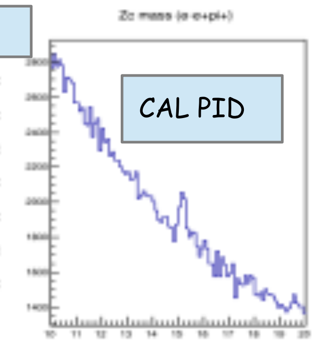


Hadron end-cap



PhP background

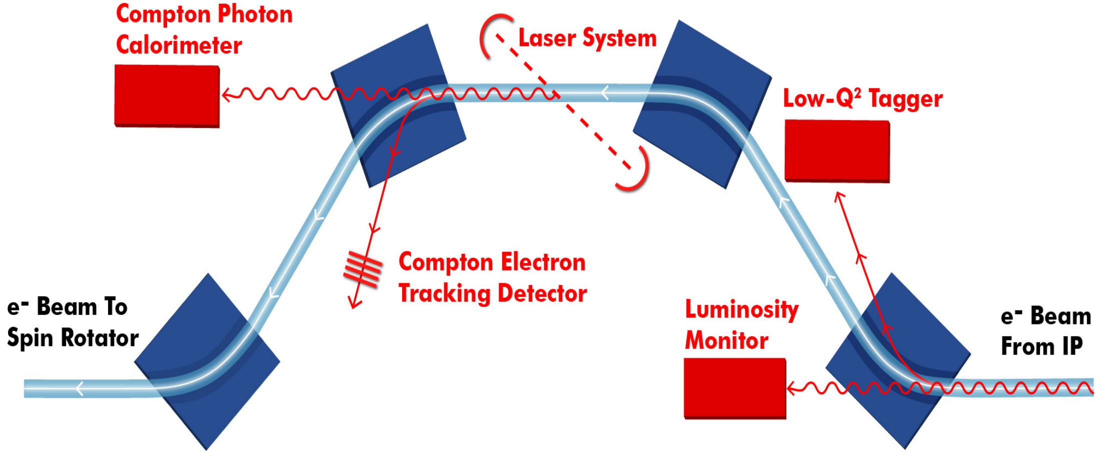


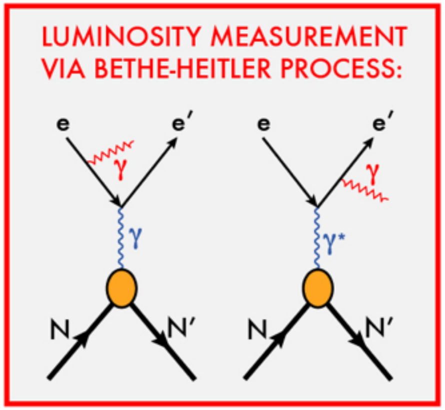


Excellent e/π PID in the hadron endcap region is needed for electrons with energy 1-100GeV

Chicane for Electron Far-Forward Area

Example from
JLEIC design



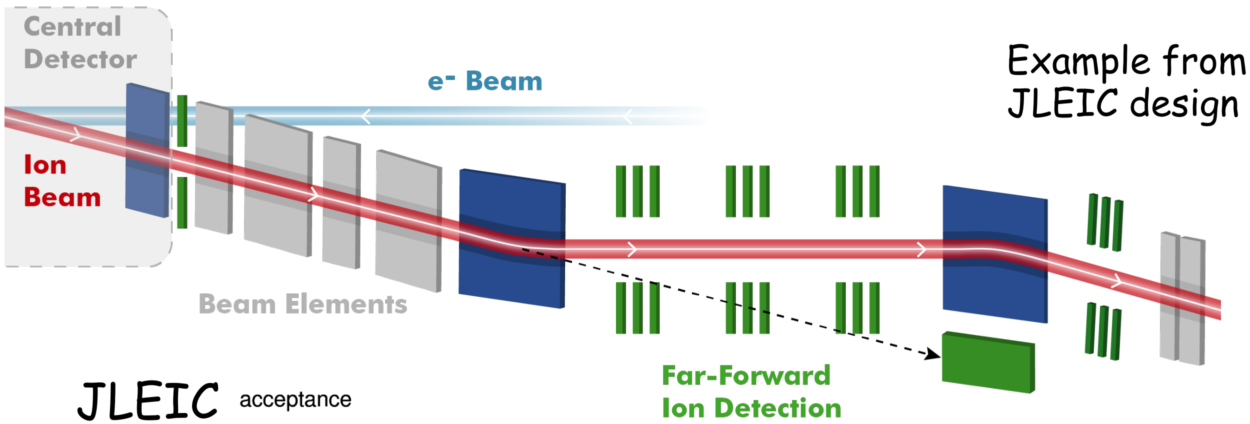


- **Low Q2 tagger**
- ✓ For low Q^2 electrons

- **Luminosity monitor:**
- ✓ Luminosity measurements via Bethe-Heitler process
- ✓ First dipole bends electrons
- ✓ Photons from IP collinear to e-beam

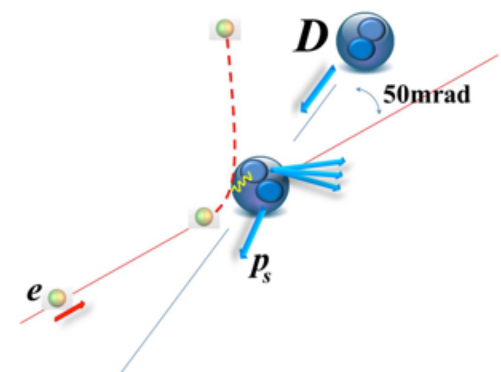
- **Polarization measurements**
- ✓ First two Dipoles compensate each other
- ✓ The same polarization as at IP
- ✓ Minimum background and a lot of space.
- ✓ Measurements of both Compton photons and electrons

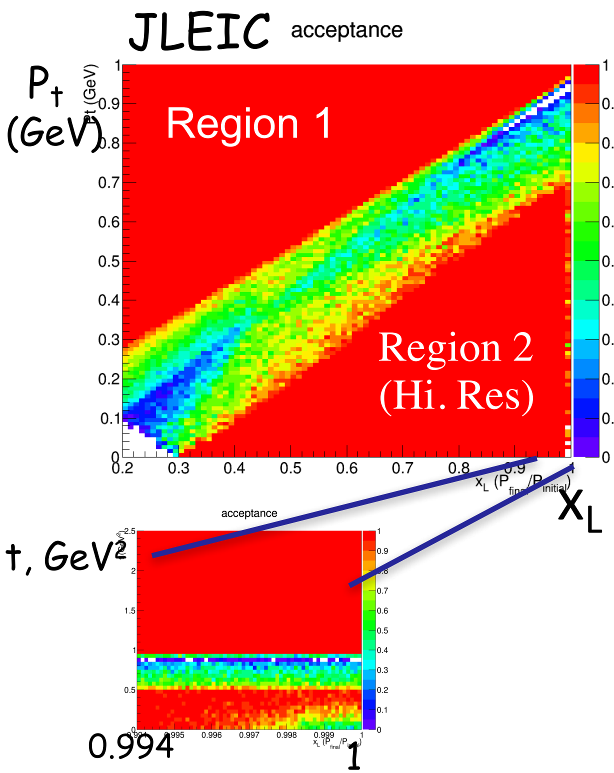
Far-forward ion direction area

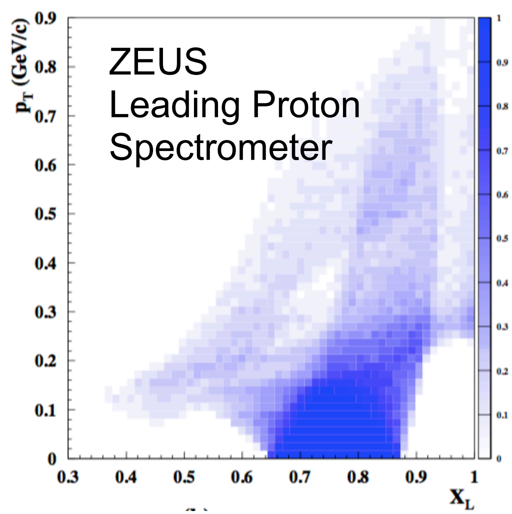


Example from JLEIC design

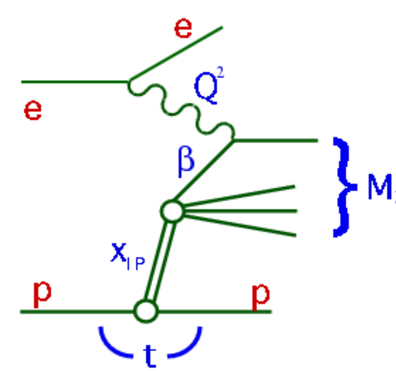
Ion remnant







Diffraction



Acceptance in diffractive peak (x_L>0.98):
ZEUS ~2%
JLEIC ~100%

One detector or two?

- Combine results for precision measurements
- Increase scientific productivity
- Cross-checks on discoveries and important physics results
- Provide complementary measurements

Summary

- Physics of nucleon and nuclear structure must drive the design.

High luminosity and polarization are essential for EIC physics program.

- EIC physics program demands a *total* acceptance detector. This means excellent forward/rear coverage in addition to the central coverage.

- R&D for accelerator, interaction region and detectors are progressing in a good collaboration among Accelerator Physicists, Experimentalists, and Theoreticians. Machine parameters, interaction region and detector design must go hand in hand, paying close attention to the emerging physics program of the EIC.

- It's important that many labs and universities - not only from within the Nuclear Physics community - get involved.

- Backup