EIC detector considerations- or: What do we need where

4/15/2018
Pre-DIS EIC workshop, Kobe

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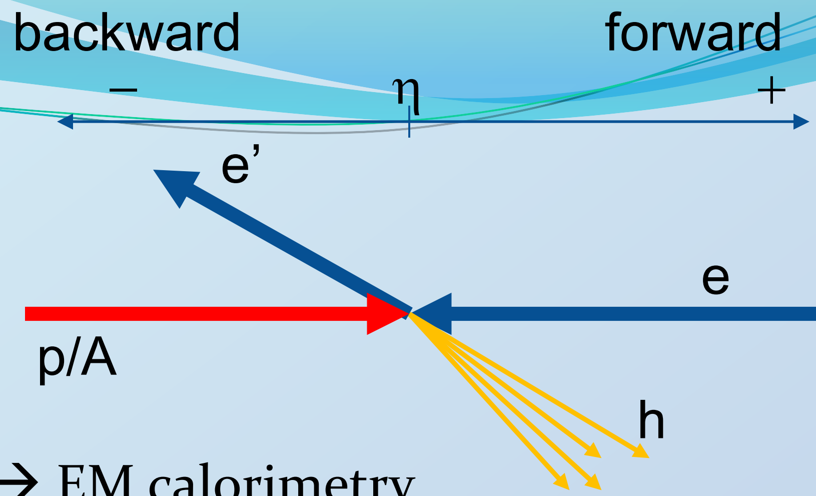
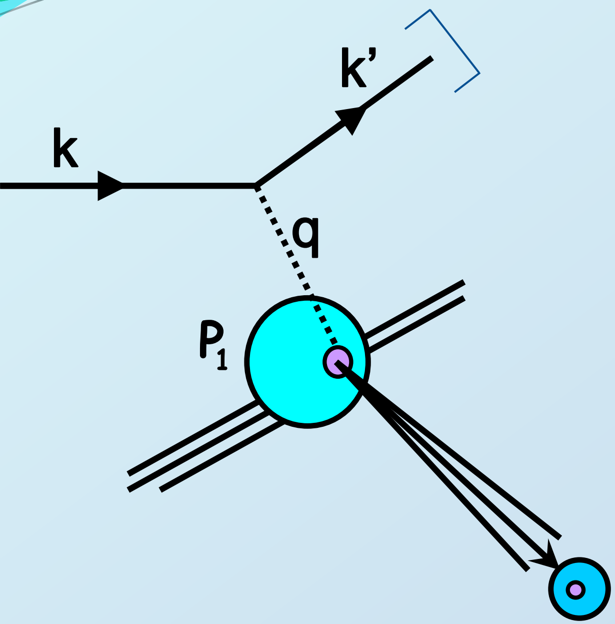
Several slides taken from EICUG Detector discussion meeting:
https://indico.bnl.gov/conferenceDisplay.py?confId=3737
Also: excellent information about kinematics etc can be found at:
https://wiki.bnl.gov/eic/index.php/DIS_Kinematics

Outline



- DIS kinematics
  - Electron energy measurements → EM calorimetry
  - Electon PID and Tracking
- SIDIS kinematics
  - Hadron momentum and energy measurements → Hcal + tracking
  - Hadron PID
- Exclusive/diffractive reactions
  - Proton detection needs→ roman pots, etc
  - DVCS/HEMP needs
- Other measurements/needs
- Different detector proposals
- Outlook

DIS Kinematics



$$\frac{d\sigma}{dQ^2} \propto \sum_q e_q^2 f_q(x_1)$$

Quark distribution functions: quark q in nucleon

$$Q^2 = -q^2 = -(k-k')^2$$

- Squared Momentum transfer of photon/Z (*Resolution*)

$$x_B = \frac{Q^2}{2Pq}$$

$$k^+ = xP^+$$

- Bjorken scaling variable, at high Q^2 momentum fraction of quark

$$y = \frac{qP}{kP}$$

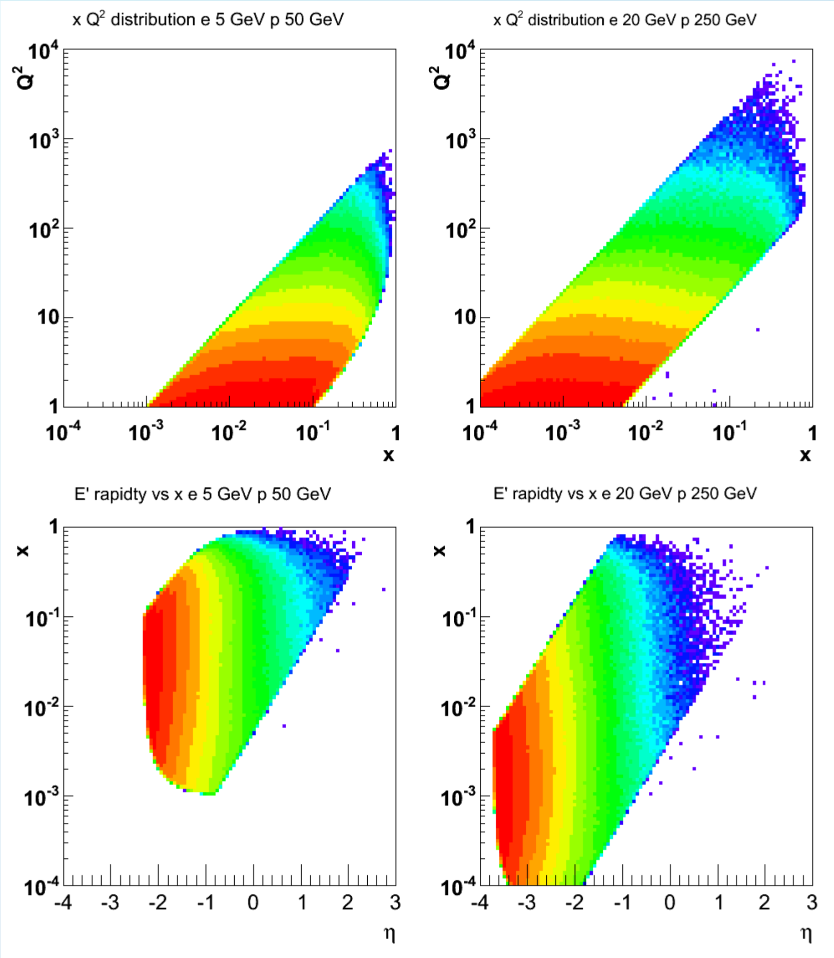
- Inelasticity (sometimes called depolarization factor)

$$W^2 = (P+q)^2$$

- Mass of hadronic final state

•Hard scales: $Q^2 >> 1$ GeV^2 otherwise photoproduction

DIS needs → bread and butter

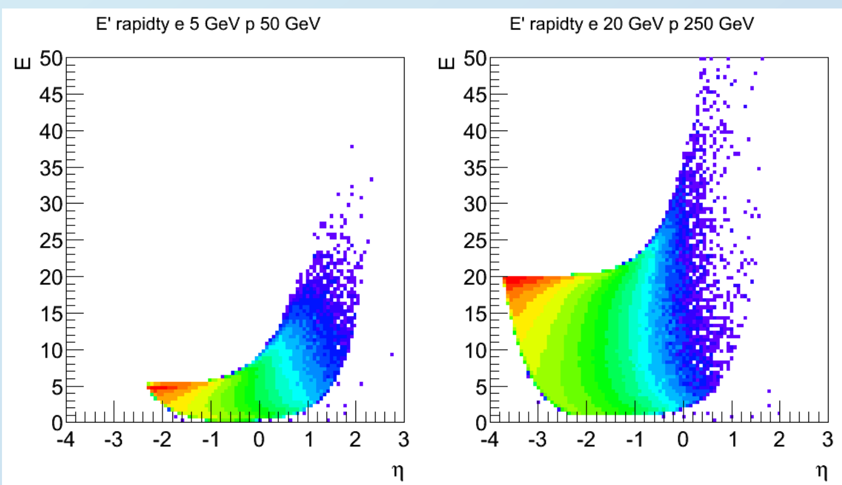


DIS cuts:
$Q^2 > 1\ \mathrm{GeV}^2$, $0.01 < y < 0.95$, $W^2 > 10\,\mathrm{GeV}^2$

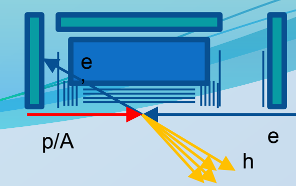
- Low-x and low Q^2:
  - Scattered lepton mostly in lepton-going direction ($\eta < 0$)
- Higher-x and high Q^2:
  - Scattered lepton more central and eventually in hadron-going direction ($\eta > 0$)

DIS needs II: Energy ranges

DIS cuts



- Scattered lepton energies mostly bound by lepton energy
- At high Q² the electron starts moving into the hadron direction
- …and can have higher momenta



Detector requirements DIS

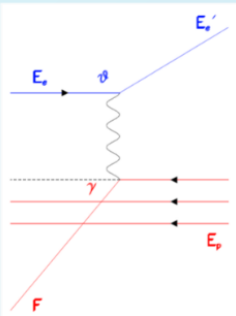
Requirement

- Electron identification for
  - $\eta<0.5$: $E_e < 20$GeV
  - $\eta>0.5$: E_e up to 50 GeV
  - Mostly E/h separation needed
- Good tracking everywhere important for precise DIS kinematics determination

Detector option

- Good EM Calorimeter in backward/central region
- Likely additional e/hadron separation via preshower, Postshower/HCAL in main regions
- Central tracking via TPC(outer)+Silicon(inner)
- Forward/backward tracking augmented by Silicon/GEM/thinGapChamber

CC DIS requirements + very high Q^2

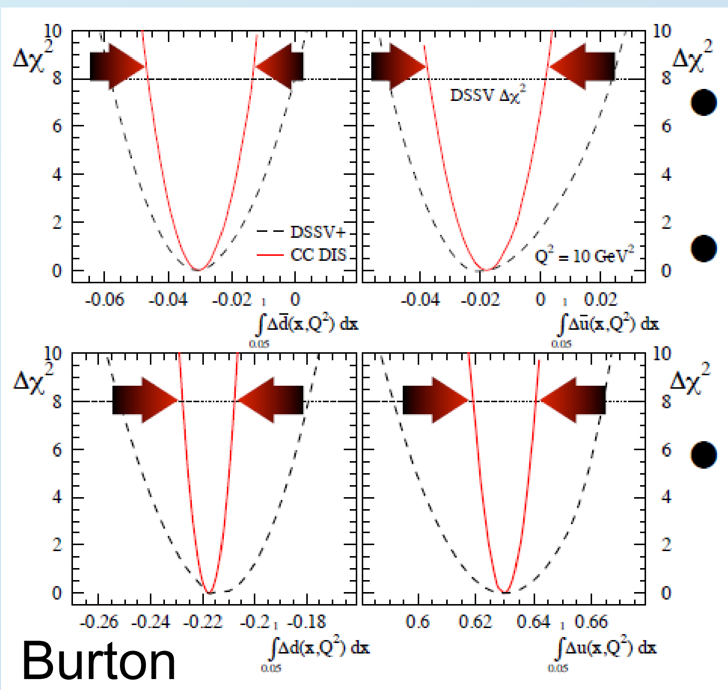


Jacquet-Blondel method: hadronic final state:

$$F = \frac{p_{t,h}^2 + (E-p_z)_h^2}{2(E-p_z)_h} \qquad p_{t,h}^2 = \left(\Sigma_h p_{x,h}\right)^2 + \left(\Sigma_h p_{y,h}\right)^2$$

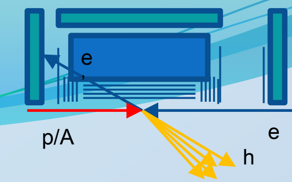
$$\cot\gamma = \frac{p_{t,h}^2 - (E-p_z)_h^2}{p_{t,h}^2 + (E-p_z)_h^2} \qquad \left(E-p_z\right)_h = \Sigma_h\left(E_h - p_{z,h}\right)$$

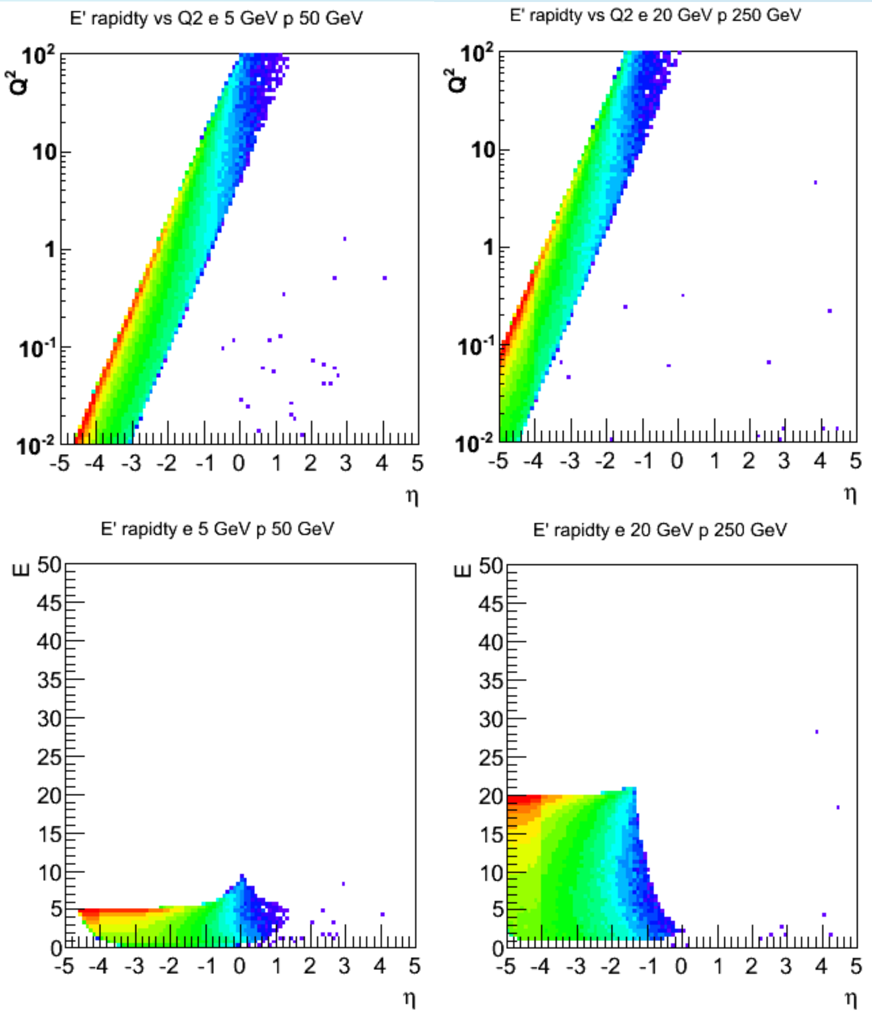
$$x_{JB} = \frac{Q_{JB}^2}{s y_{JB}}; \quad y_{JB} = \frac{(E-p_z)_h}{2E_e}; \quad Q_{JB}^2 = \frac{p_{t,h}^2}{1-y_{JB}}$$



- Need to "find" missing electron track
- Kinematics using hadronic final state (Jacquet-Blondel method)
- Requires hadronic calorimetry and tracking in forward region

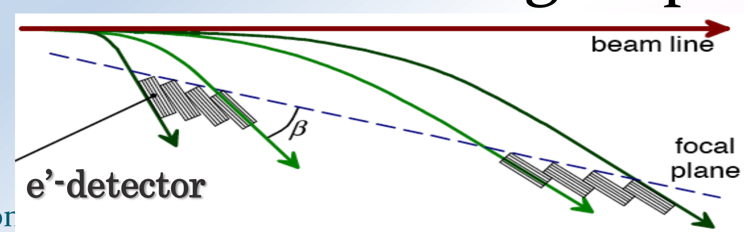
Photoproduction



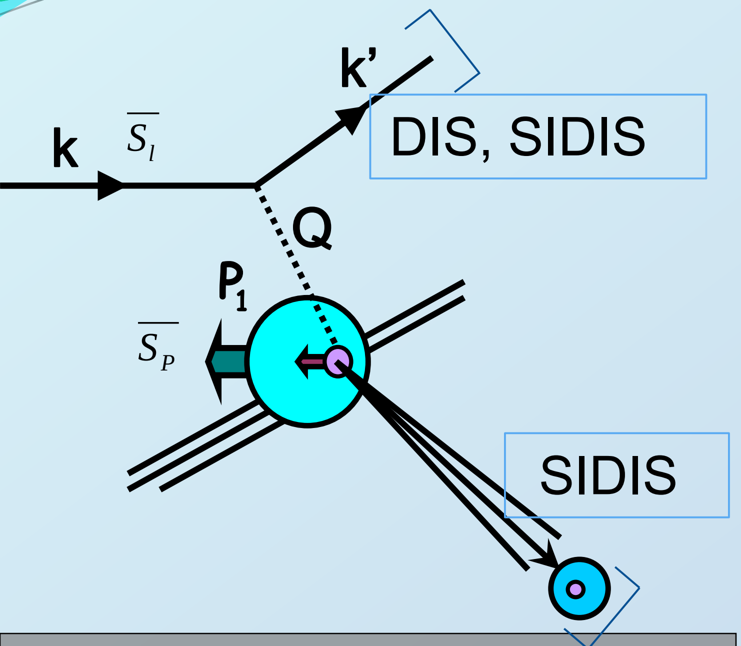


Photoproduction: Q^2 <1 GeV^2

- Essentially all electrons go into very backward region (η<-4)
- Energy close to e beam energy
- Needs close coordination with accelerator group



SIDIS Kinematics



$$\frac{d\sigma}{dQ^2} = f_q(x_1) \otimes \tilde{\sigma} \otimes D^h(z)$$

Quark distribution functions: quark q in nucleon

Fragmentation functions functions: quark q →hadron h

$$Q^2 = -q^2 = -(k-k')^2$$

- Squared Momentum transfer of photon/Z

$$x_B = \frac{Q^2}{2Pq}$$

- Bjorken scaling variable, at high Q^2 momentum fraction of quark

$$k^+ = xP^+$$

$$y = \frac{qP}{kP}$$

- Inelasticity (sometimes called depolarization factor)

$$W^2 = (P+q)^2$$

- Mass of hadronic final state

$$z = \frac{PP_h}{pq}$$

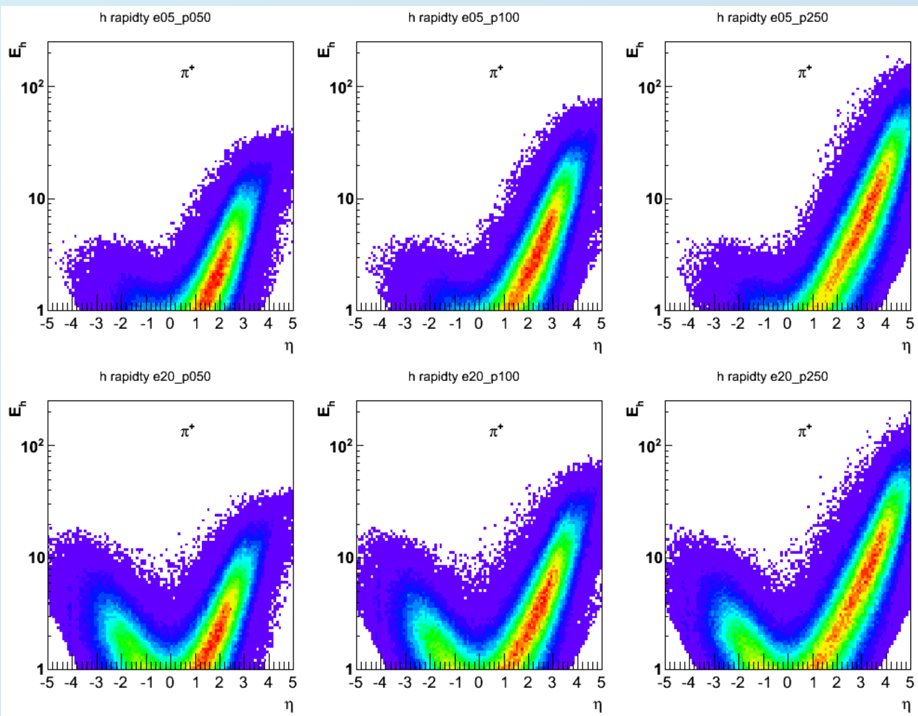
- Fractional hadron momentum

$$P_h^- = zk^-$$

•Hard scales: Q^2>>1 GeV^2 otherwise photoproduction

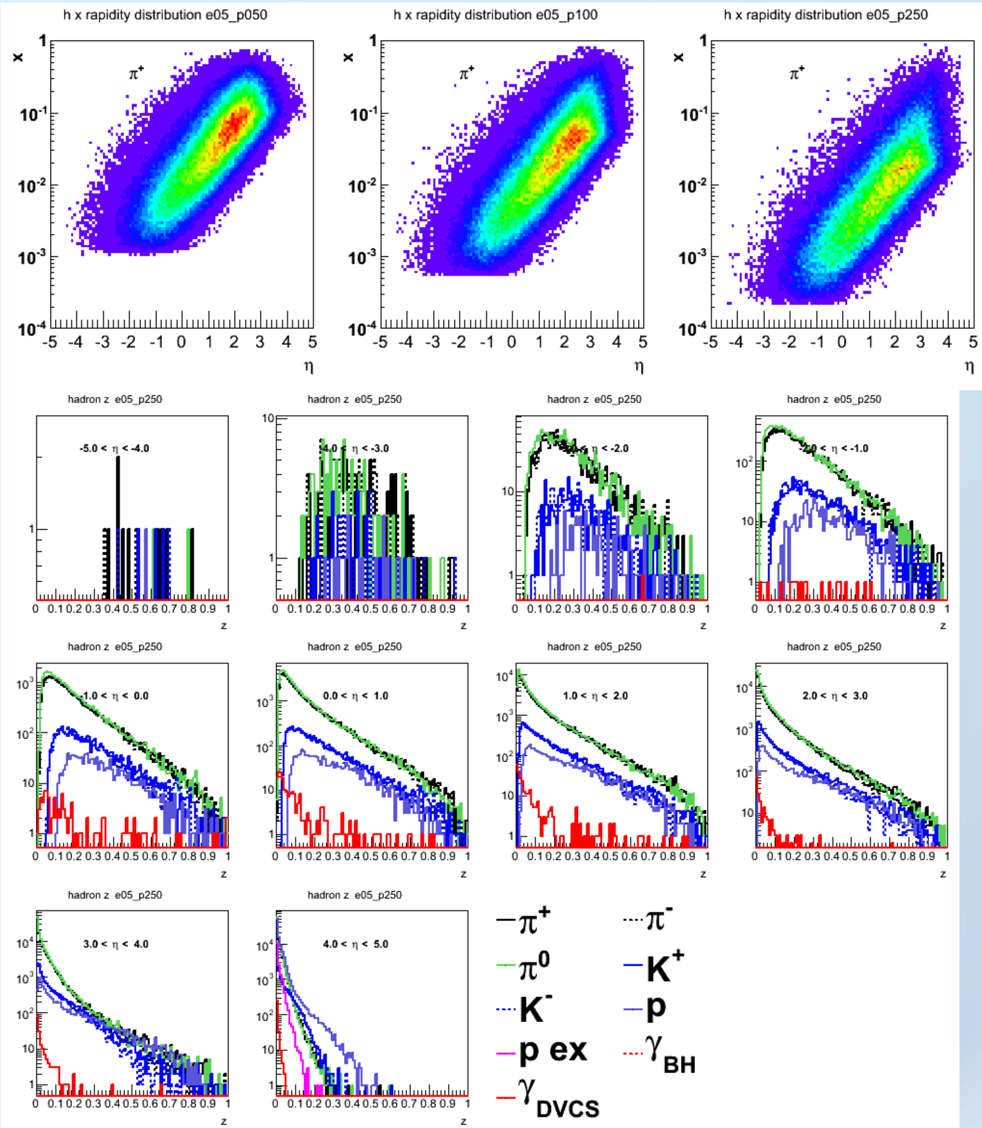
Hadron kinematics

DIS cuts

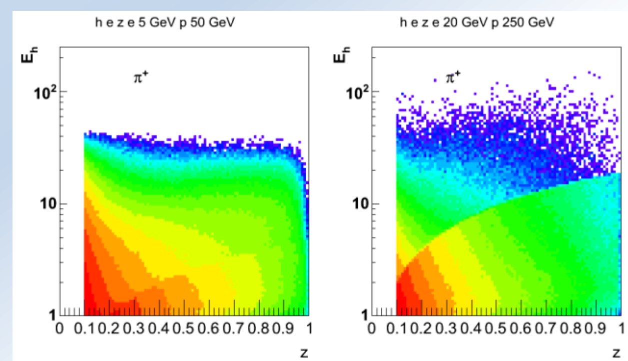


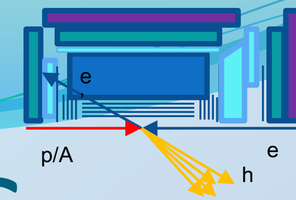
- Hadron energy in forward direction follows hadron beam energy, no dependence on electron beam energy → Energies of up to 100 GeV
- Central rapidity sees hadrons of a few GeV
- Backward hadron energies follow electron beam energies → up to 10-20 GeV

More on hadron kinematics



- Again, in higher x/Q^2 events hadrons are in forward direction
- Lower x/Q^2 have hadrons more into the central directions
- For fragmentation functions highest high-z access at slightly forward direction (and higher energies)





Detector requirements SIDIS

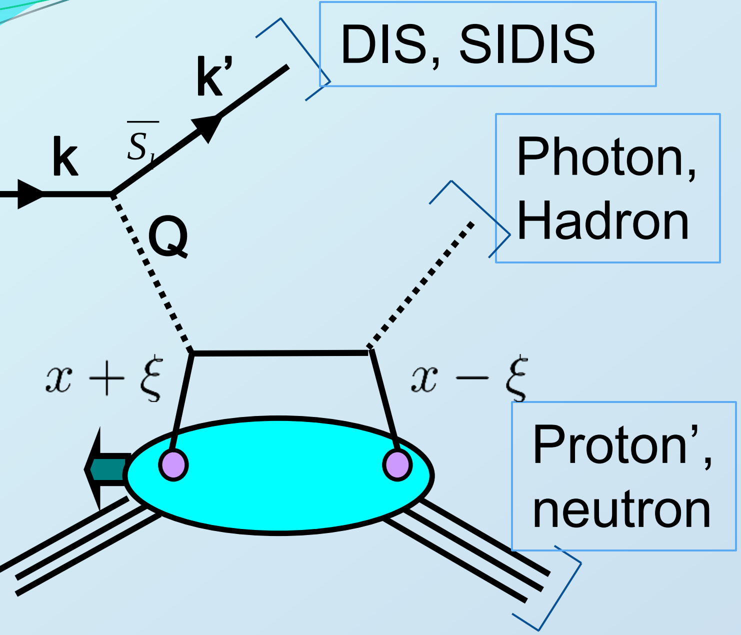
Requirements

- Hadron identification for
  - $-3<\eta<1$: E_h < 5-10GeV
  - $\eta>1$: E_h up to 100 GeV
- Good tracking everywhere: important for determination of z, $P_{h\perp}$ and azimuthal angle and PID
- Additional hadron energy determination required at least forward

Detector option

- Central PID ($|\eta|<1$): DIRC or fastTOF
- Slightly forward($\eta<2$) /backward ($\eta<-1$) PID: same or Aerogel based RICH
- Forward ($\eta>1$) PID: gas RICH
- Forward ($\eta>2$) Hadronic Calorimeter

Exclusive Kinematics



$$\int_{-1}^{1} dx C(\xi, x) \left(H, E, \tilde{H}, \tilde{E}\right)$$

Compton Form Factors are experimentally accessible

Generalized parton distributions

$$t = \Delta^2 = (p - p')^2$$

- Total momentum transfer to the proton

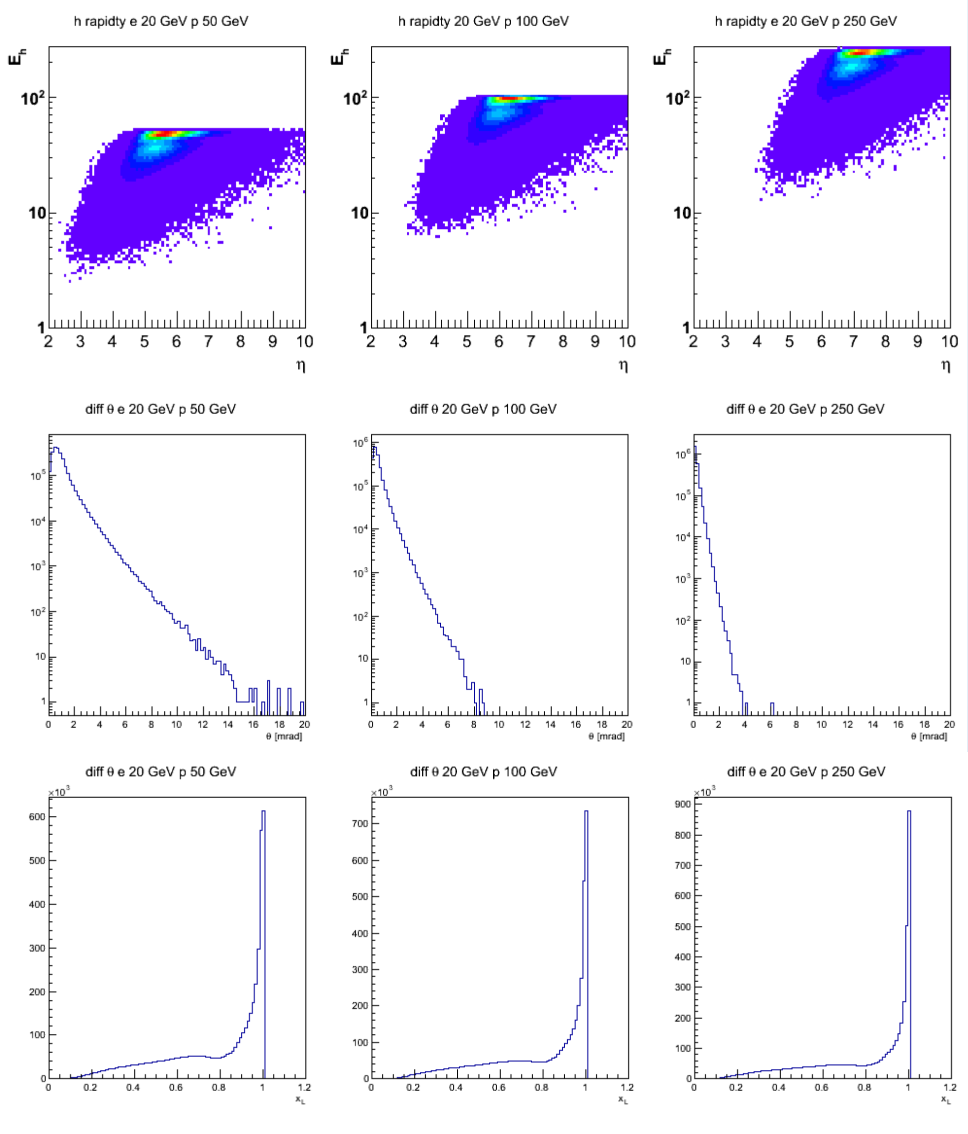
$$\mathbf{\Delta} = (\mathbf{p} - \mathbf{p}')^2$$

- 3-momentum transfer to proton (transverse part FT of impact parameter)

$$\xi$$

- Skewedness parameter

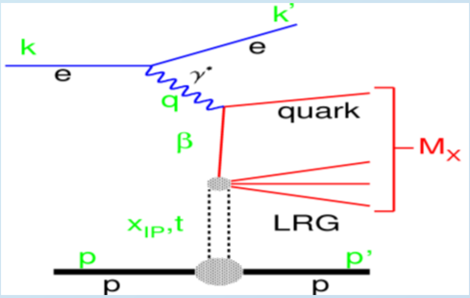
Forward (Diffractive) protons



- Very forward protons at close to the Beam energy
- Rapidities only determined by the hadron beam energies
- Requires Roman pots as close to the beamline as possible
- Closely related kinematics for neutrons (ZDCs)
- Needs close coordination with Accelerator design

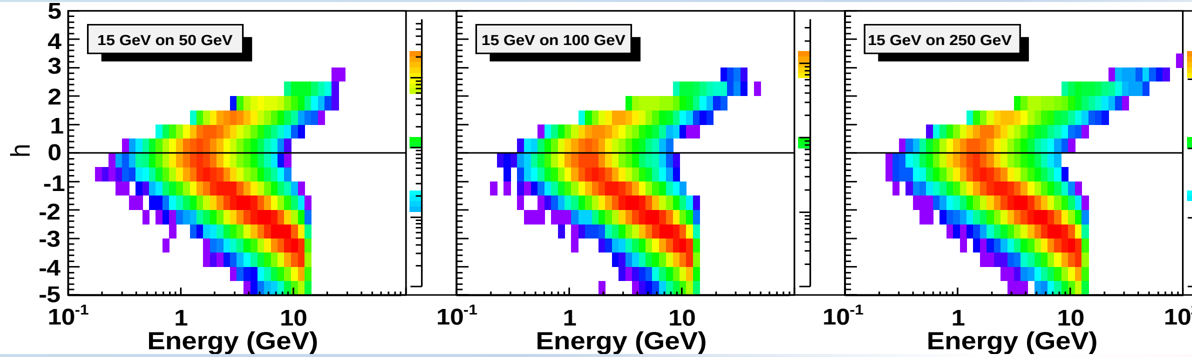
Other Exclusive Reactions

- Find large rapidity gap → nearly hermetic detector (large acceptance)



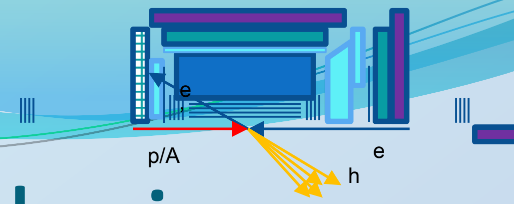
Elke

- DVCS photon or exclusive hadron:
  - Mostly in lepton-going direction (bound by lepton energy)
  - Hadron going photons follow hadron energy



DVCS – photon kinematics

Cuts: Q^2>1 GeV, 0.01<y<0.85,



Detector requirements exclusive

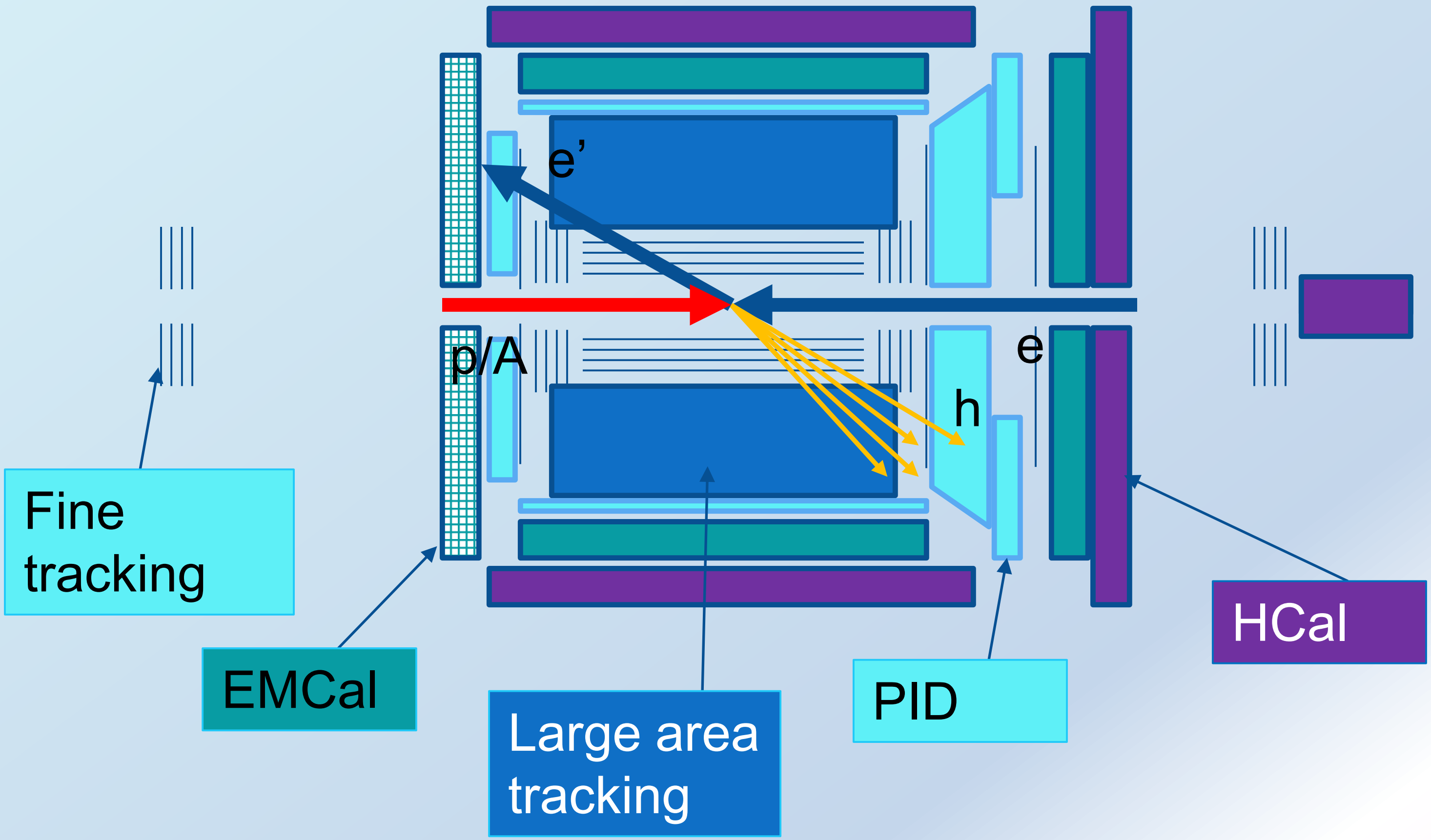
Requirements

- Proton detection and momentum reconstruction at very forward rapidities (η>>5)
- Neutron detection and momentum reconstruction at very forward rapidities (η>>5)
- Rapidity gap detection
- DVCS photon detection and reconstruction

Detector option

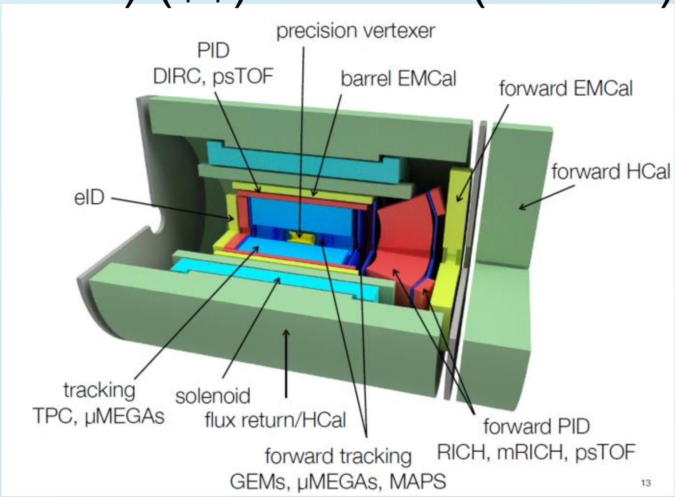
- Roman pots close to the hadron beamline
- Zero Degree Calorimeter after outgoing hadron beam is bent away
- Hermetic detector (at least $|\eta|<4$, better more), forward HCAL
- High granularity EMCal in Backward region, more backward coverage?

The general strawman detector

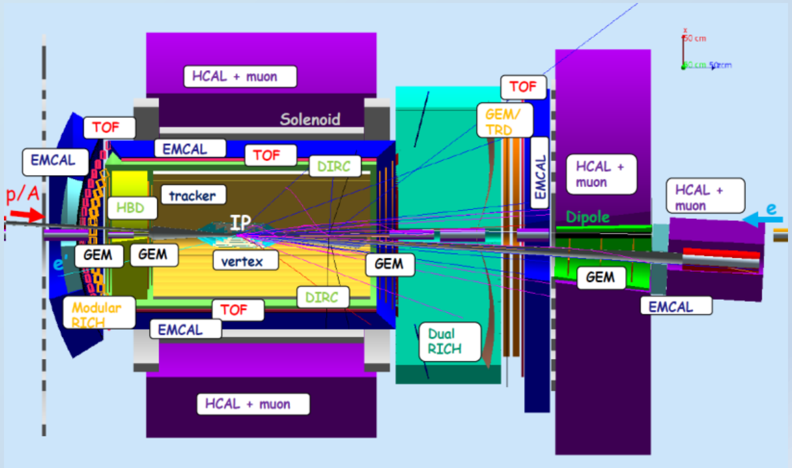


The actual contenders (for now)

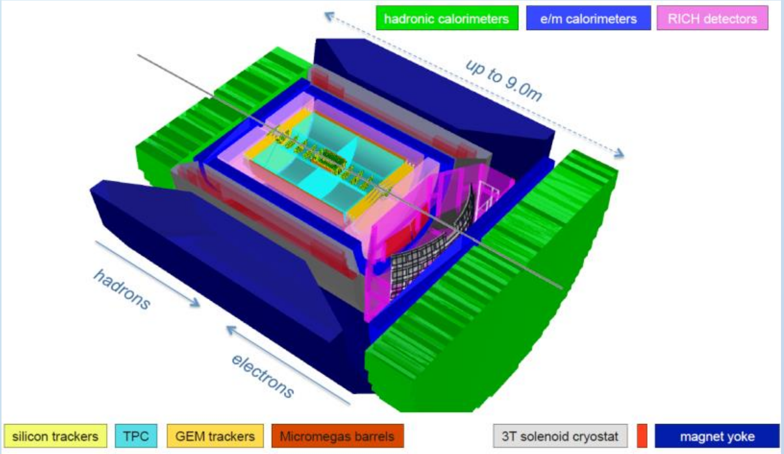
Detector based on BaBar magnet (ePHENIX) ($$) or STAR(eSTAR) ($)



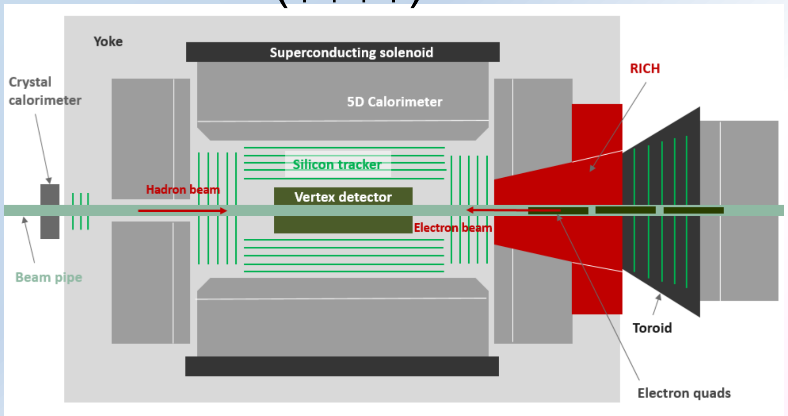
Jlab dedicated detector ($$$)



BNL dedicated detector (BEAST) ($$$)



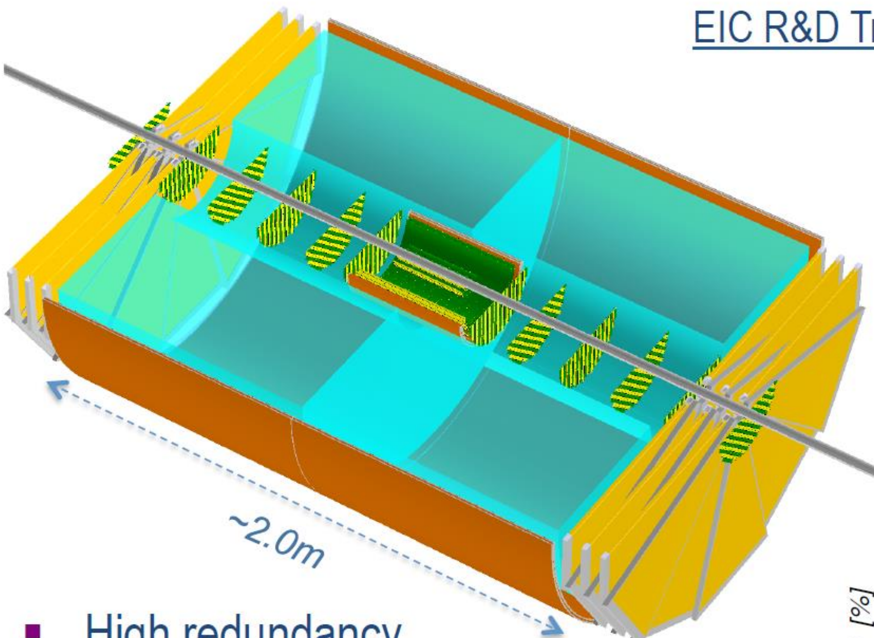
Argonne (TOPside): silicon to the max($$$$)



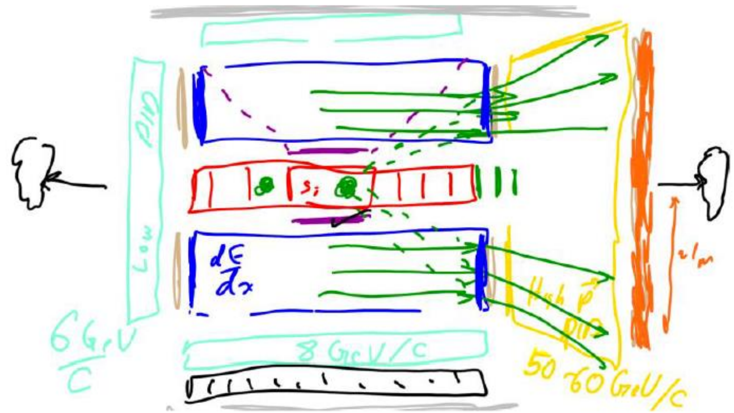
Tracking

Kisselev

Tracker



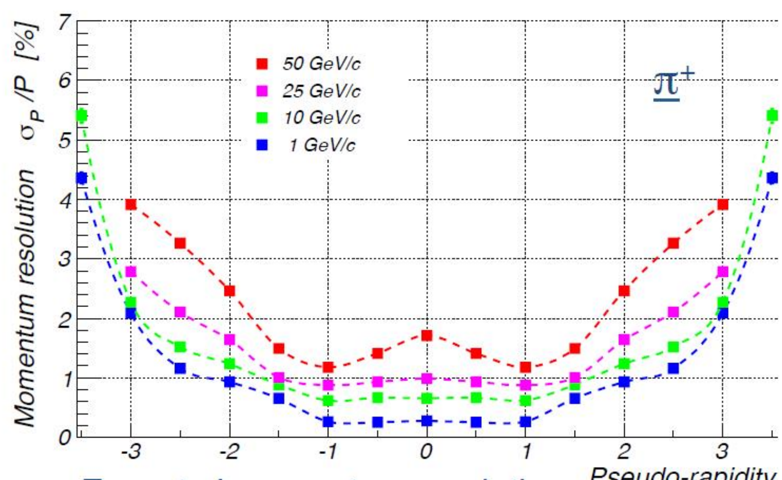
EIC R&D Tracking Consortium meeting in Temple (May'17)



Hand-drawn consensus EIC detector design

- High redundancy
- Material budget ~5% rad.length or so
- Pretty much "basic" components

→H1 : $0.6\%*P_t + 1.5\%$
→ZEUS : $0.5\%*P_t + 1.5\%$



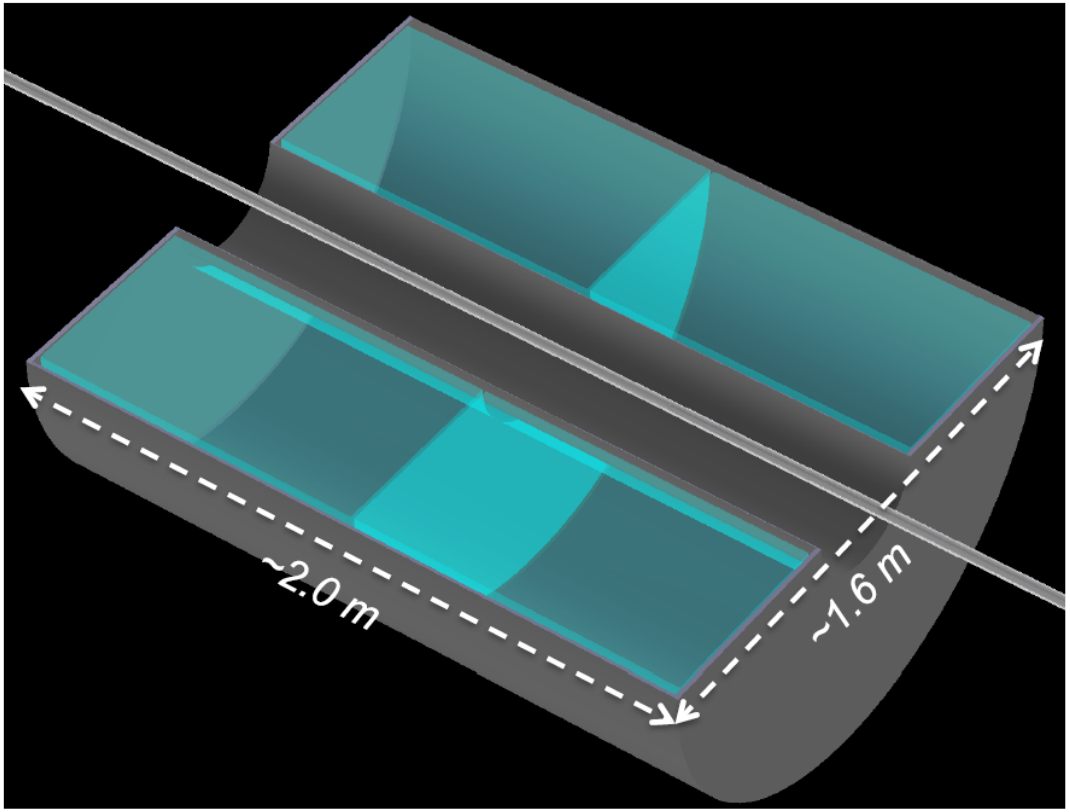
Expected momentum resolution

TPC

Kisselev

- ~2m long; gas volume radius [225..775] mm
- 1.2% X/X_0 IFC, 4.0% X/X_0 OFC; 15.0% X/X_0 end-caps
- assume 5 mm long GEM pads and ~250 μm single point {rϕ} resolution for the max. drift distance of ~1m
- A gas mixture like T2K at ~250 V/cm (very small transverse dispersion in 3T field) will do the job

Pretty much in sync with sPHENIX prototype



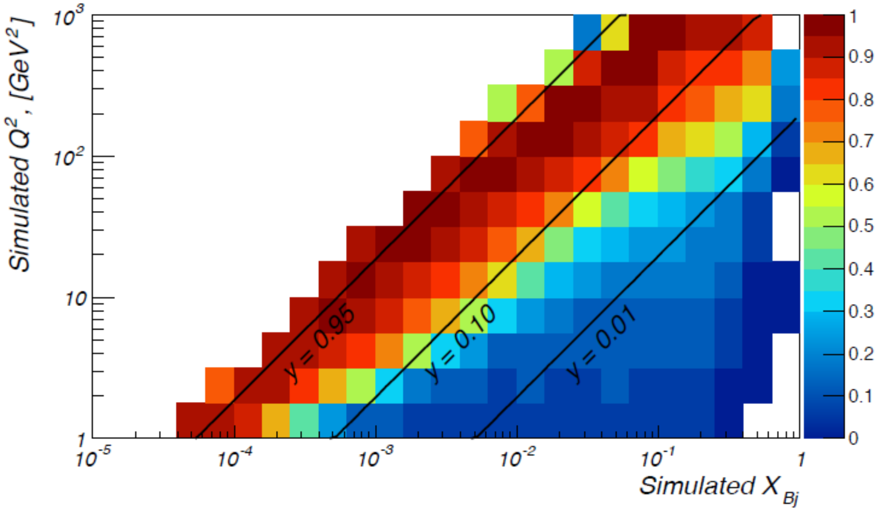
These days this is seen as a medium size and medium resolution TPC

"Purity" in (x,Q^2) kinematic bins

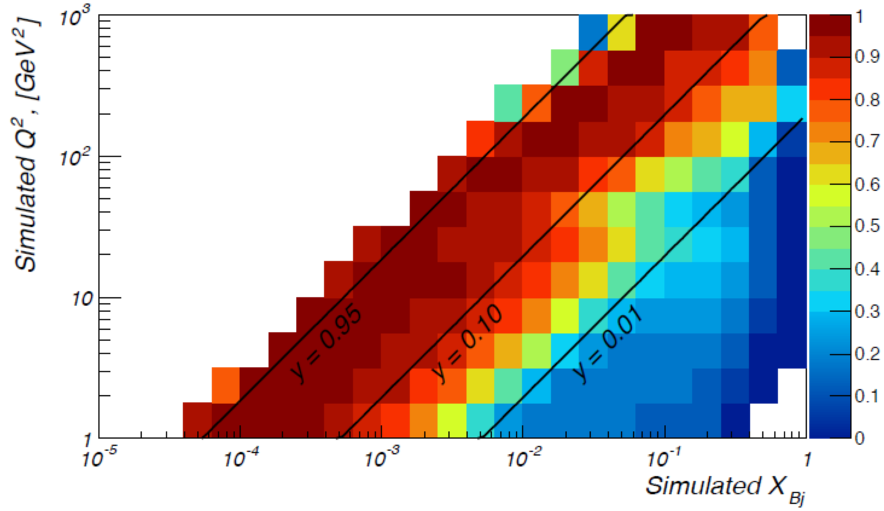
Kisselev

→ a trivial observation: tracker momentum resolution rapidly degrades at backward rapidities; this clearly affects $\{x,Q^2\}$ reconstruction quality

- A possible solution: use e/m calorimeter in addition to tracking
  - ~2%/√E energy resolution (and ~0 constant term) for $\eta < -2$ (PWO crystals)
  - ~7%/√E energy resolution for $-2 < \eta < 1$ (tungsten powder scint. fiber sampling towers)
- Consider "bremsstrahlung off " case here for simplicity



Lepton tracking only

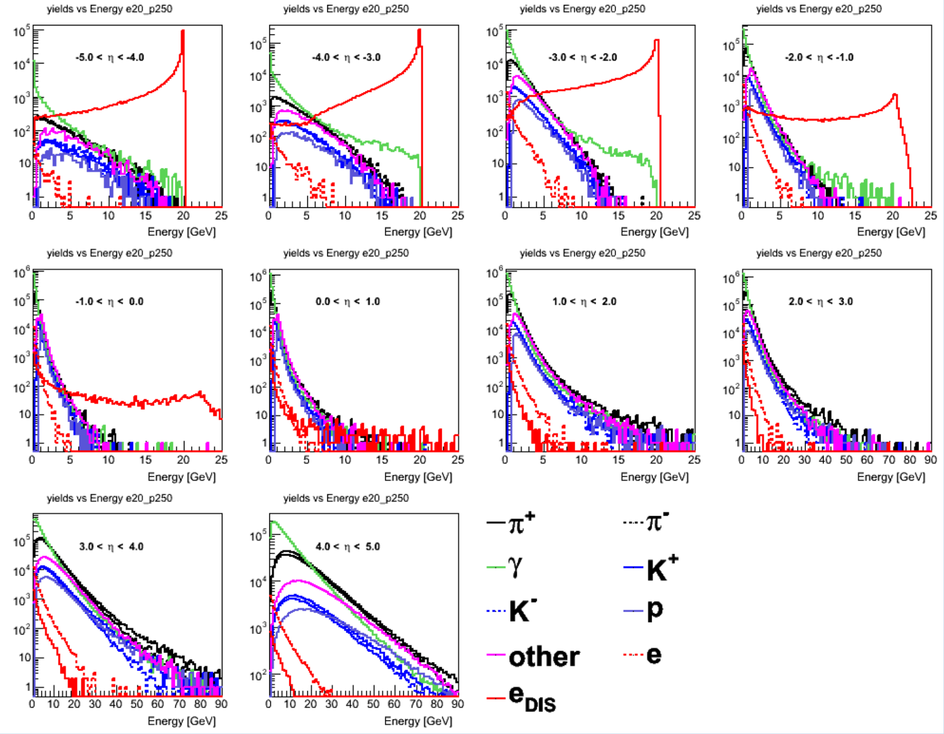


Lepton tracking + EmCal

High-resolution crystal calorimeter at very backward rapidities should definitely help to increase available ***y*** range

PID requirements

DIS cuts

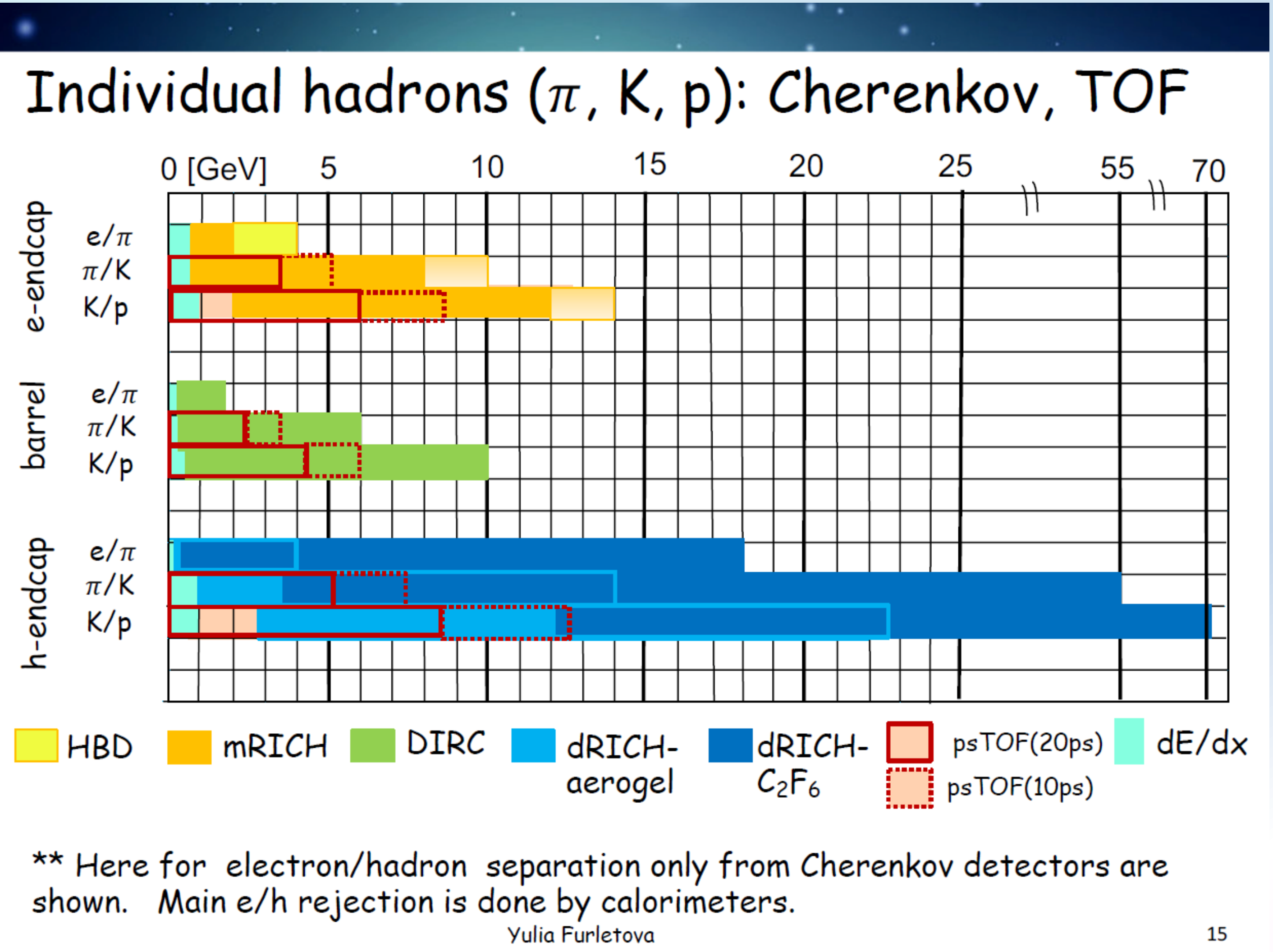


- Electron-hadron ID important at lower rapidities, hadrons dominating at low energies
- Hadron ID needed below 5-10 GeV for central detector
- Hadron Id up to 60 GeV in forward direction

High Q^2 electrons far below hadron yields (though topologically separated)

Technical challenges: PID

Furletova

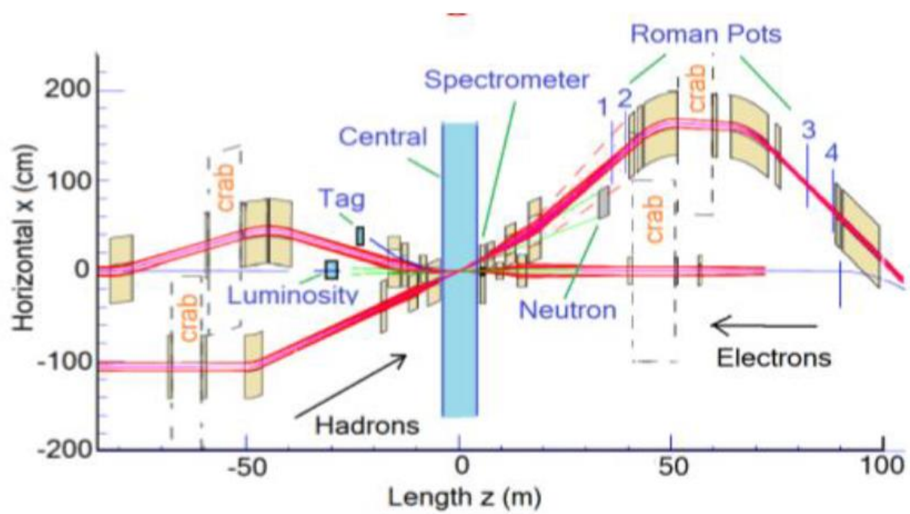


- Electron ID mostly ok via E/p separation
- Backward/central hadron ID covers most of the hadron energies
- Forward hadron ID requires gas RICH →long, low light yield, wavelength

Technical challenges: Envelope

Montag

General Purpose IR Design



- +/- 4.5m machine-element free space around IP
- Roman Pots for low-p_t detection

5

Electron Ion Collider – eRHIC

- Size of interaction region is limited by accelerator elements needed for high luminosity
- Eg eRHIC main detector envelope 4.5m
- Roman pots, ZDCs and very forward electron tracking need to be merged with Accelerator design

Coordinated R&D ongoing

Hardware requirements common due to the kinematics, many R&D consortia working together to find the best hardware solutions: https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

- eRD1 **Title:** EIC Calorimeter Development
- eRD3 **Title:** Design and assembly of fast and lightweight forward tracking prototype systems for an EIC
- eRD6 **Title:** Tracking & PID detector R&D towards an EIC detector
- eRD14 **Title:** PID Consortium for an integrated program for Particle Identification (PID) at a future Electron-Ion Collider
- eRD15 **Title:** R&D for a Compton Electron Detector
- eRD16 **Title:** Forward/Backward Tracking at EIC using MAPS Detectors
- eRD17 **Title:** BeAGLE: A Tool to Refine Detector Requirements for eA Collisions
- eRD18 **Title:** Precision Central Silicon Tracking & Vertexing for the EIC
- eRD20 **Title:** Developing Simulation and Analysis Tools for the EIC
- eRD21 **Title:** EIC Background Studies and the Impact on the IR and Detector
- eRD22 **Title:** GEM based Transition radiation detector and tracker

Summary

- The general detector considerations are very similar:
  - Good tracking everywhere for DIS kinematics, electron ID, hadron kinematics
  - EMCALs in all rapidities for electron energy and ID
  - Various hadron ID detectors necessary with increasingly larger momentum range with increasing rapidity
  - Hadronic calorimetry at least forward for hadron energy determination, hadronic determination of DIS and diffractive events
  - Roman pots and ZDCs for Diffractive events (accelerator coordination)
  - Photoproduction requires special electron tracking(accelerator coordination)
  - Close coordination with accelerator design in terms of envelopes, etc