EIC detector- or: What do we need where

1/29/2018

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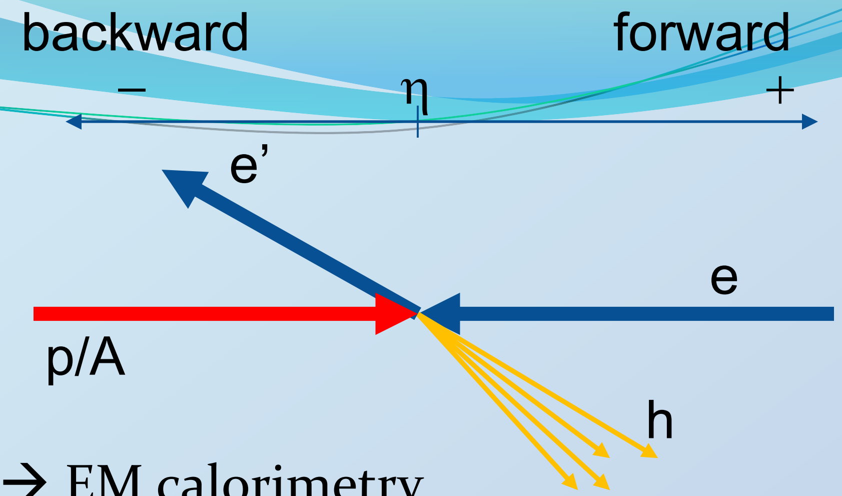
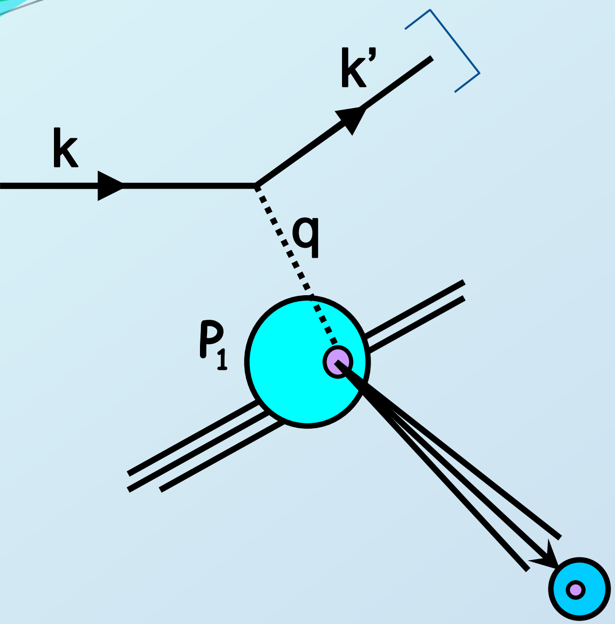
Several slides taken from EICUG Detector discussion meeting:
https://indico.bnl.gov/conferenceDisplay.py?confId=3737
Also: excellent information about kinematics etc can be found at:
https://wiki.bnl.gov/eic/index.php/DIS_Kinematics

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

Unpolarized proton structure

$$\frac{d^2\sigma^i}{dxdy} = \frac{2\pi\alpha^2}{xyQ^2}\eta^i\left[Y_+F_2^i \pm Y_- xF_3^i - y^2F_L^i\right]$$
$$F_L^i = F_2^i - 2xF_1^i$$
$$Y_\pm = 1 \pm (1-y)^2$$

$$F_2^\gamma = x\sum_q e_q^2(q+\overline{q})$$

Neutral current

- F_2 (and F_1) measure the sum of quark and antiquark distribution in the nucleon or nucleii
- The majority of our knowledge on the unpolarized PDFs is coming from F_2 measurements

polarized proton structure

$$\frac{d^2\Delta\sigma^i}{dxdy} = \frac{2\pi\alpha^2}{xyQ^2}\eta^i\left[Y_+ 2g_5^i - g_L^i \mp Y_- 2xg_1^i + y^2 g_L^i\right]$$

$$g_L^i = g_4^i - 2xg_5^i$$

$$Y_\pm = 1 \pm (1-y)^2$$

- g_1 measures charge square weighted total quark spin contribution to the nucleon
- Flavor information from γZ interference, Z exchange and in particular charged current (W exchange) interactions

$$g_1^\gamma = x\sum_q e_q^2(\Delta q + \Delta\bar{q})$$

$$g_1^{\gamma Z} = x\sum_q 2e_q g_V^q(\Delta q + \Delta\bar{q})$$

$$g_1^Z = x\sum_q ({g_V^q}^2 + {g_A^q}^2)(\Delta q + \Delta\bar{q})$$

$$g_5^{\gamma Z} = \sum_q 2e_q^2 g_A^q(\Delta q - \Delta\bar{q})$$

$$g_5^Z = \sum_q 2g_V^q g_A^q(\Delta q - \Delta\bar{q})$$

Neutral current

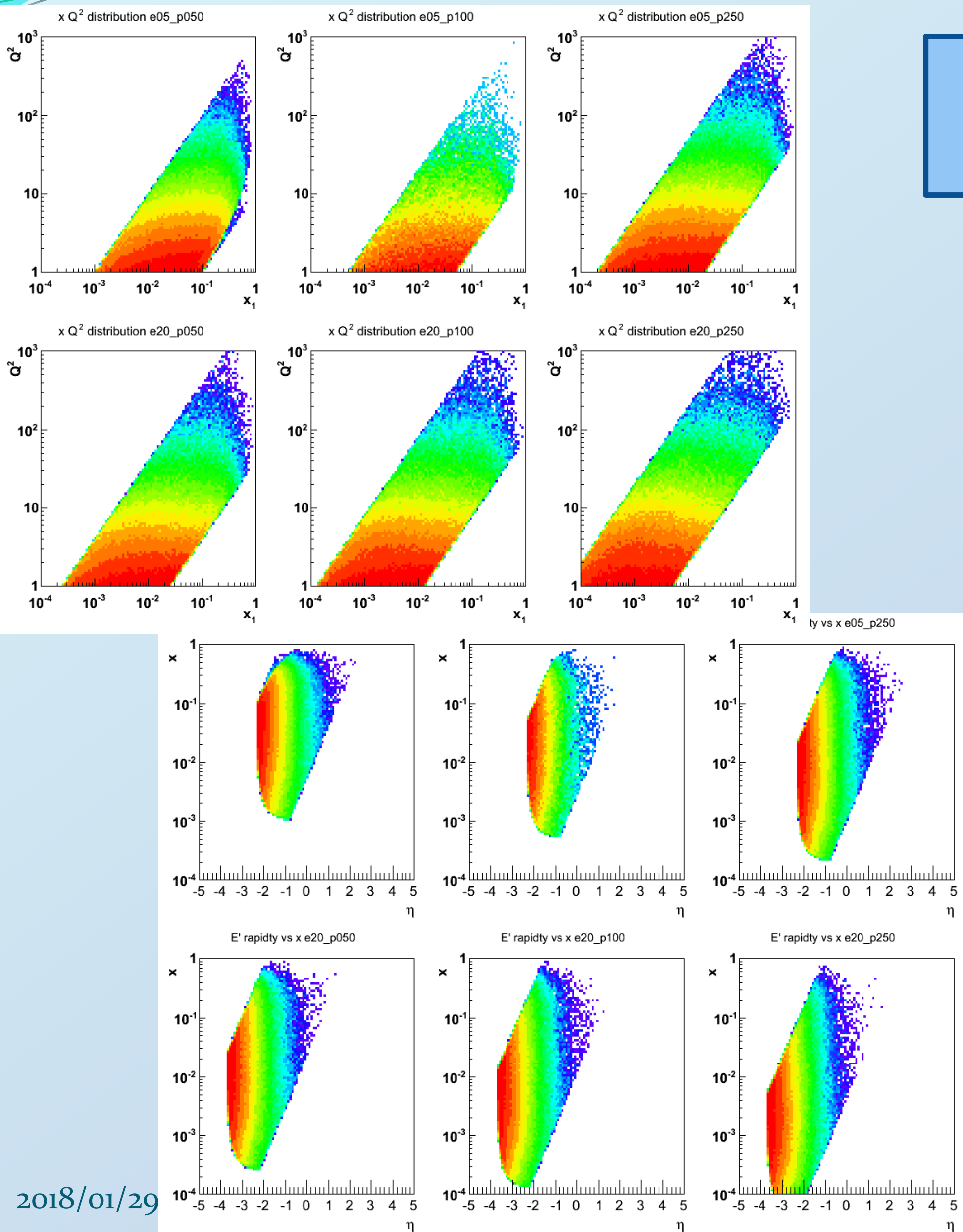
$$g_1^{W^-} = (\Delta u + \Delta\bar{d} + \Delta\bar{s} + \Delta c \ldots)$$

$$g_5^{W^-} = (\Delta u - \Delta\bar{d} - \Delta\bar{s} + \Delta c \ldots)$$

$$W^+ : u \rightarrow d \ldots$$

Charged current

DIS needs → bread and butter

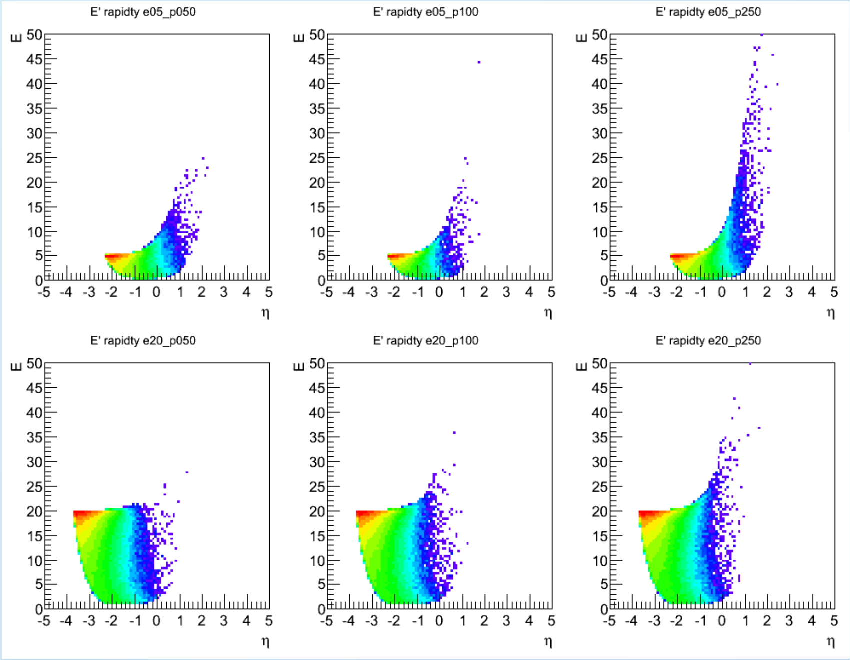


DIS cuts:
$Q^2 > 1$ GeV², $0.01 < y < 0.95$, $W^2 > 10$ GeV²

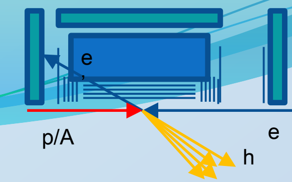
- Low-x and low Q²:
  - Scattered lepton mostly in lepton-going direction ($\eta < 0$)
- Higher-x and high Q²:
  - Scattered lepton more central and eventually in hadron-going direction ($\eta > 0$)

DIS needs II: Energy ranges

DIS cuts



- Scattered lepton energies mostly bound by lepton energy, except high Q^2 where it can go higher



Detector requirements DIS

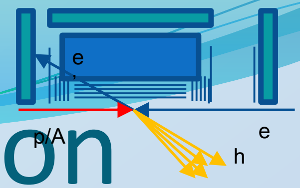
Requirement

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

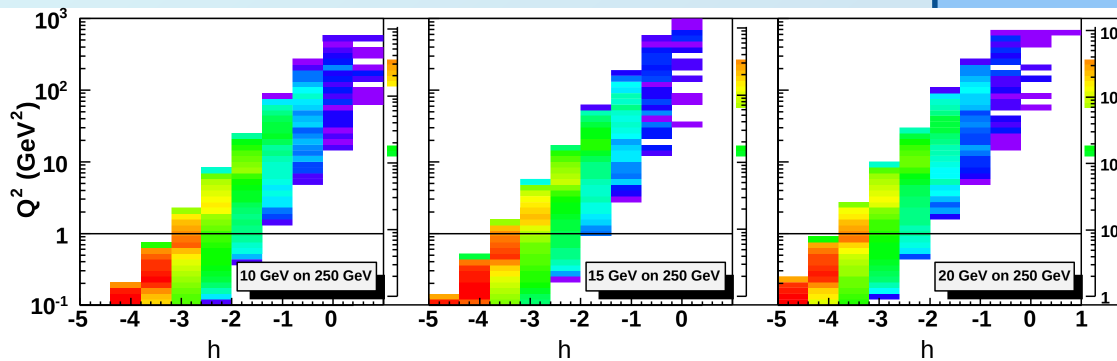
Detector option

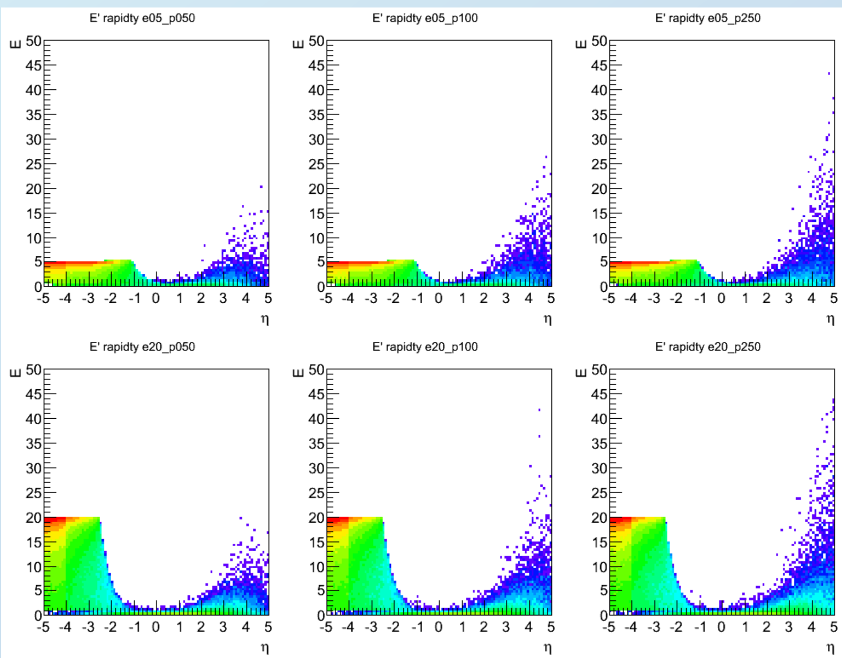
- Good EM Calorimeter in backward/central region
- Likely additional e/hadron separation via preshower, Postshower/HCAL in main regions
- Central tracking via TPC(outer)+Silicon(inner)
- Forward/backward tracking augmented by Silicon/GEM/thinGapChamber

DIS needs III: Photoproduction



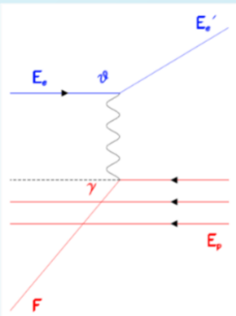
Photoproduction:
$Q^2 < 1$ GeV²





- Essentially all electrons go into very backward region (h<-5)
- Energy close to e beam energy
- Needs close coordination with accelerator group

CC DIS requirements

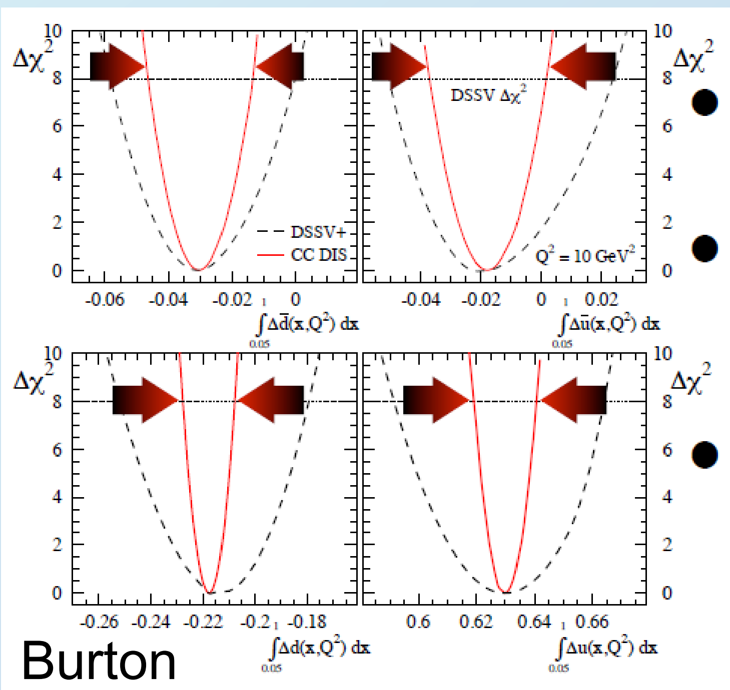


Jacquet-Blondel method: hadronic final state:

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

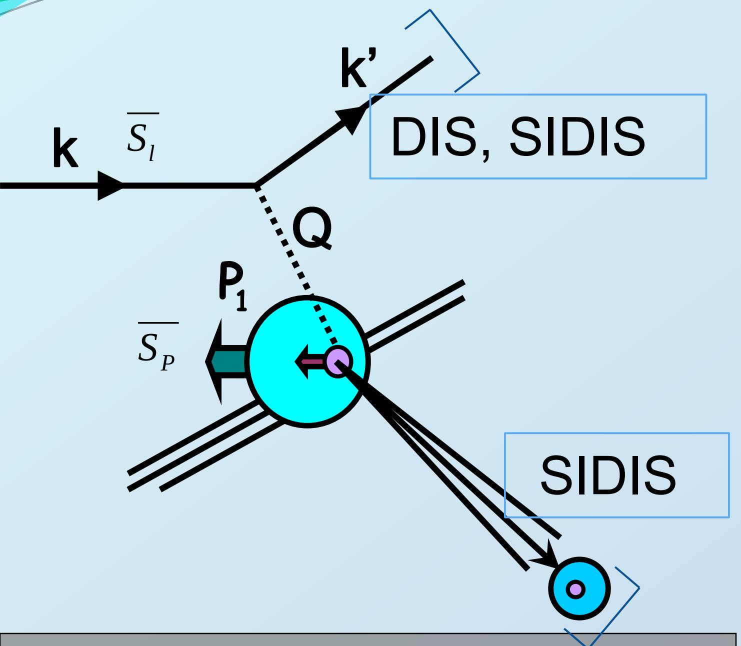
$$\cot\gamma = \frac{p_{t,h}^2 - (E-p_z)_h^2}{p_{t,h}^2 + (E-p_z)_h^2} \qquad \left(E-p_z\right)_h = \Sigma_h\left(E_h - p_{z,h}\right)$$

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



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

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

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

$$k^+ = xP^+$$

- 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

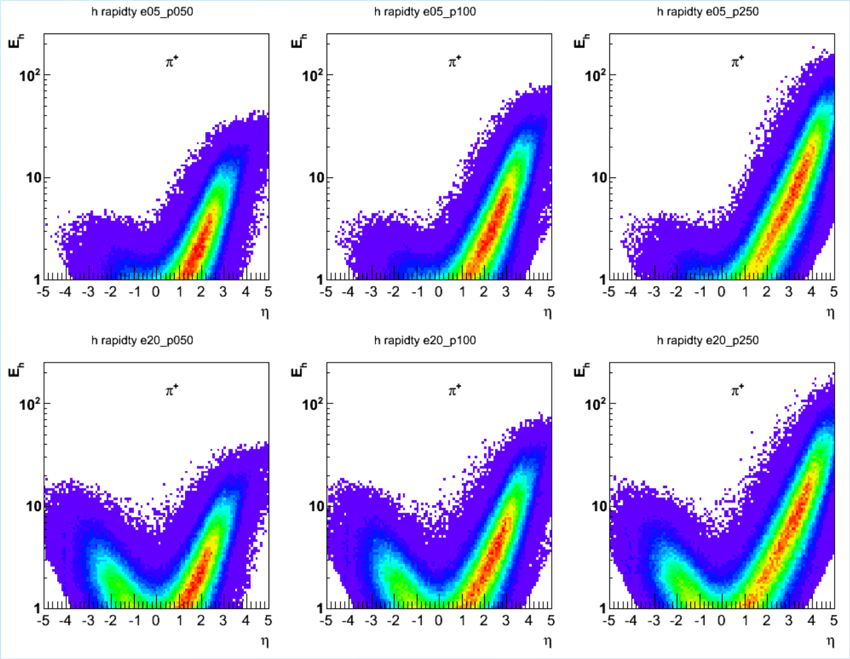
$$z = \frac{PP_h}{pq}$$

$$P_h^- = zk^-$$

- Fractional hadron momentum

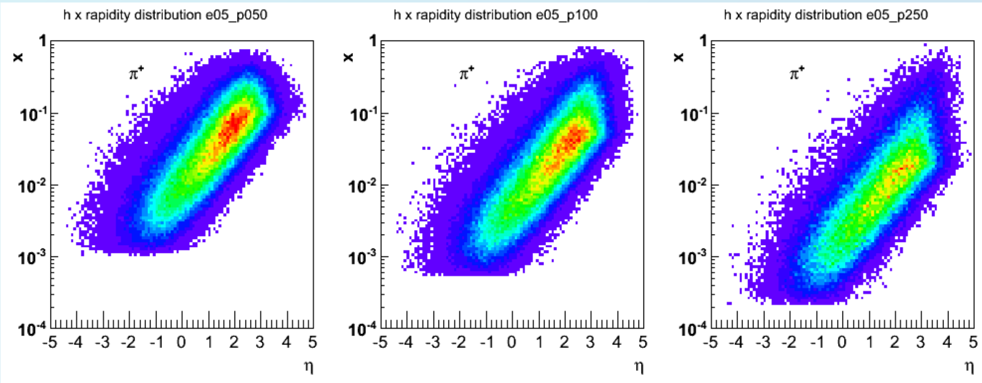
•Hard scales: Q^2>>1 GeV^2 otherwise photoproduction

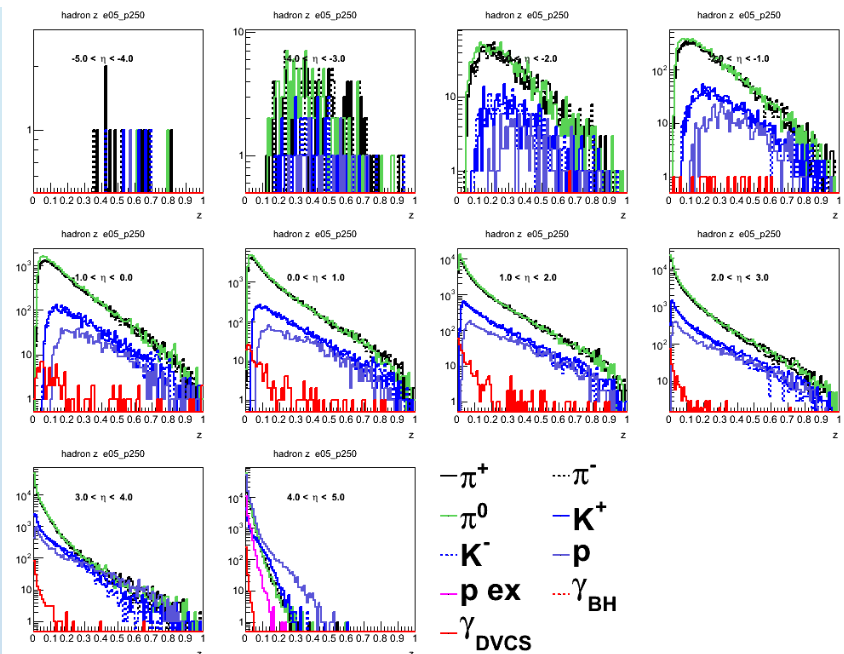
Hadron kinematics



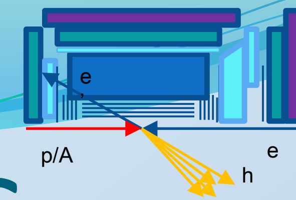
- Hadron energy in forward direction follows hadron beam energy, no dependence on beam energy → Energies of up to 100 GeV
- Central rapidity sees hadrons of a few GeV
- Backward hadron energies follow electron beam energies → up to 10 GeV

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



Detector requirements SIDIS

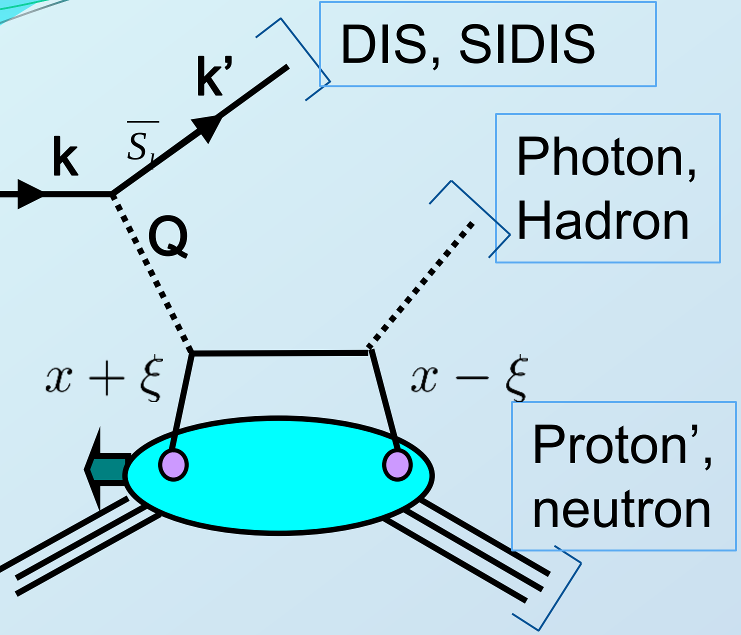
Requirements

- 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
- 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

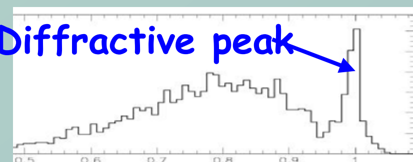
Exclusive Reactions

How can we select events: two methods

Elke

proton/neutron tag method

- Measurement of t
- Free of p-diss background
- Higher M_X range
- to have high acceptance for Roman Pots / ZDC challenging → IR design

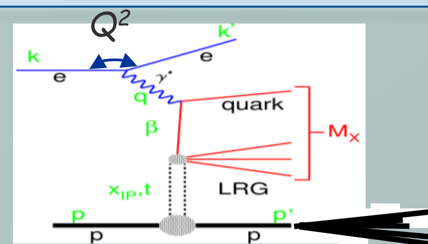


$$x_L = \frac{p'_z}{p_z} \approx 1 - x_{IP}$$

Need for Roman Pot spectrometer and ZDC

Large Rapidiy Gap method

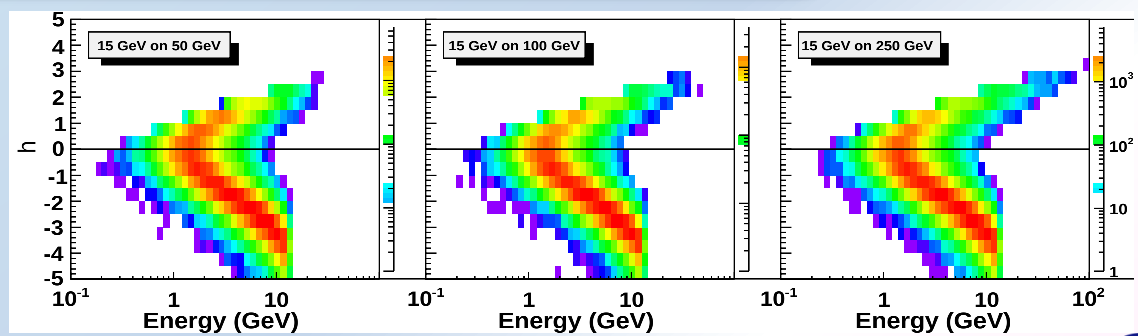
- X system and e′ measured
- Proton dissociation background
- High acceptance in η for detector



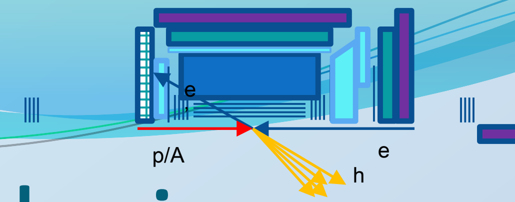
Need for HCal in the forward region

DVCS – photon kinematics

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



increasing Hadron Beam Energy: influences max. photon energy at fixed η
photons are boosted to negative rapidities (lepton direction)



Detector requirements exclusive

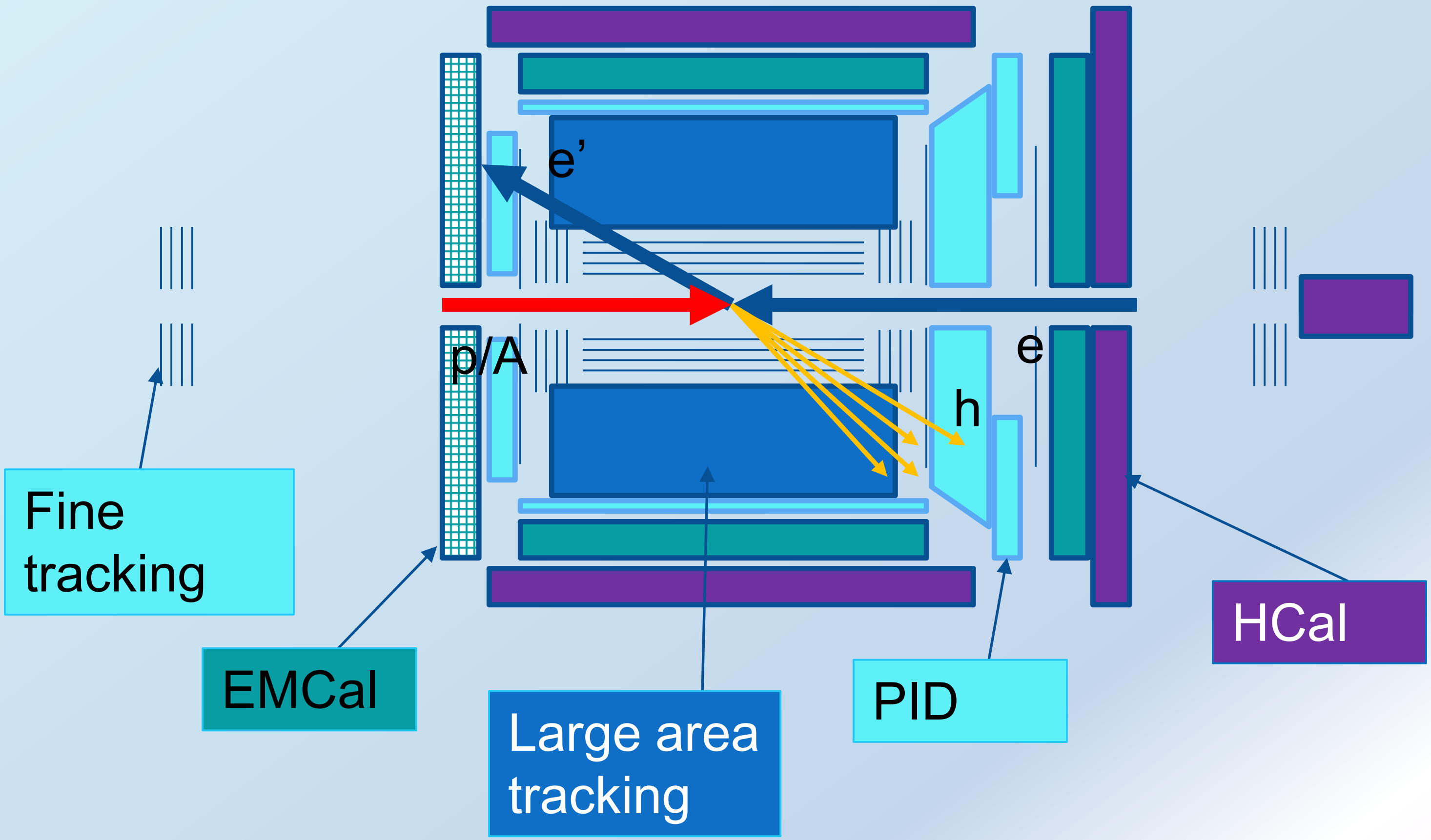
Requirements

- 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

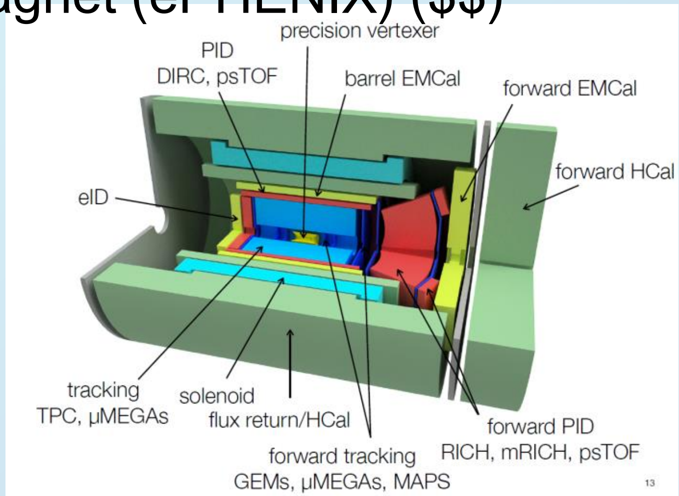
- Roman pots close to the hadron beamline
- Zero Degree Calorimeter after outgoing hadron beam is bent away
- Hermetic detector (at least $|\eta|<4$, better more), forward HCAL
- High granularity EMCal in Backward region

The general strawman detector

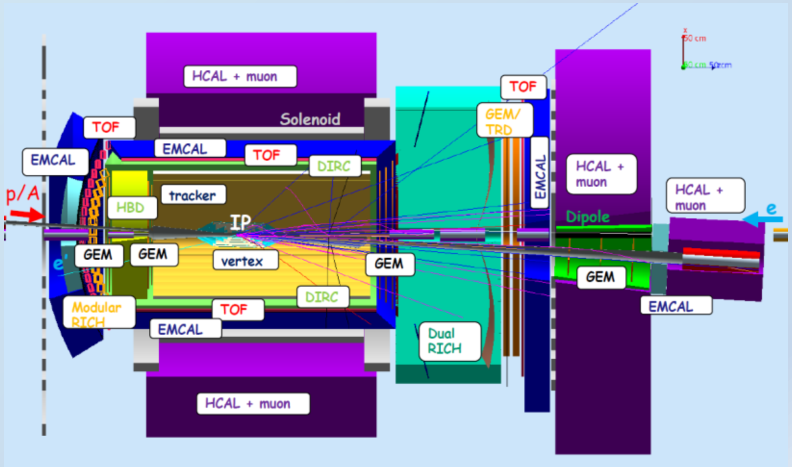


The actual contenders (for now)

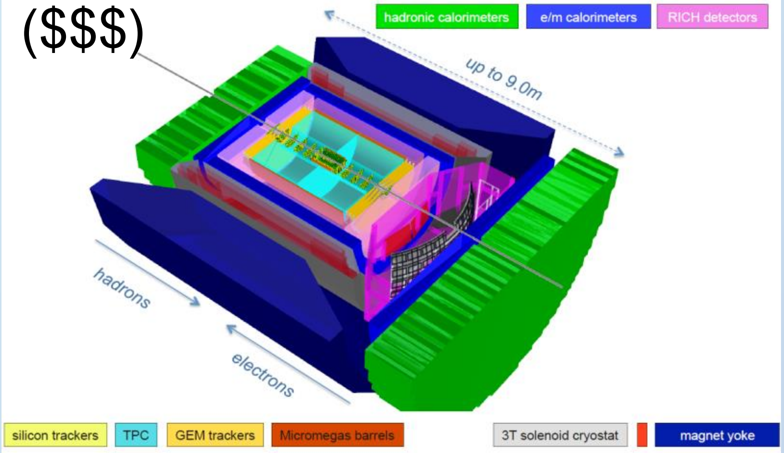
Detector based on BaBar magnet (ePHENIX) ($$)



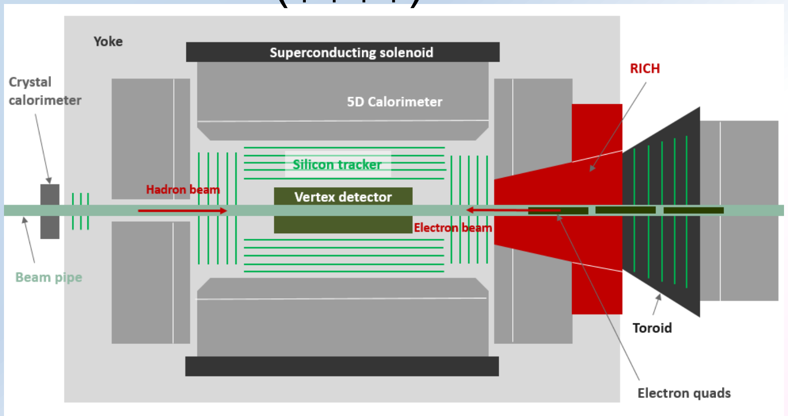
Jlab dedicated detector ($$$)



BNL dedicated detector (BEAST) ($$$)

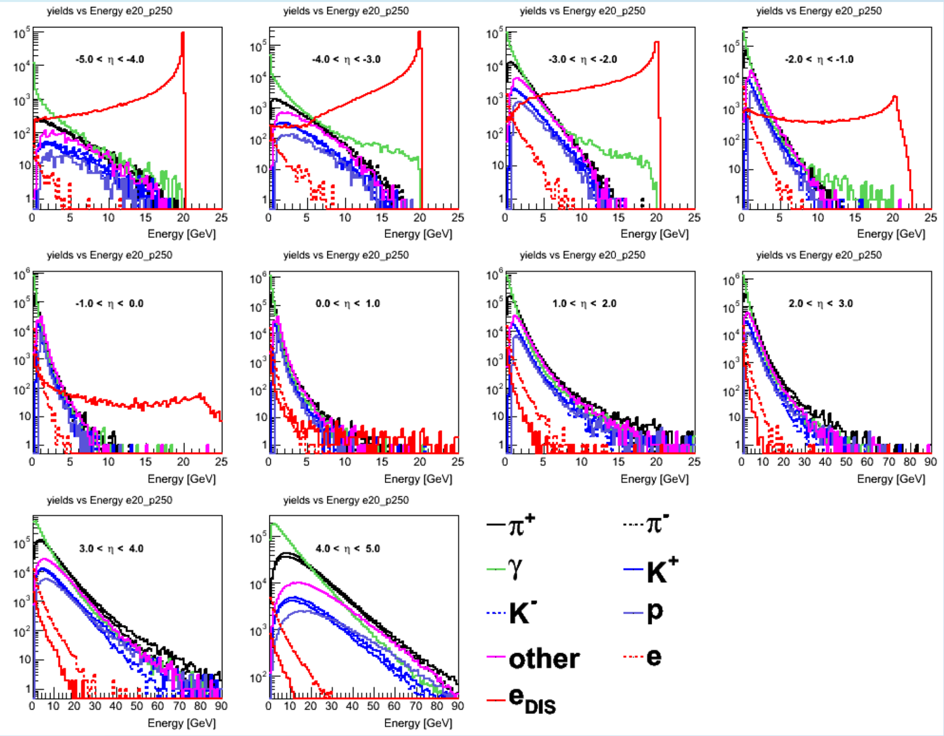


Argonne (TOPside): silicon to the max($$$$)



Not shown: eSTAR ($)

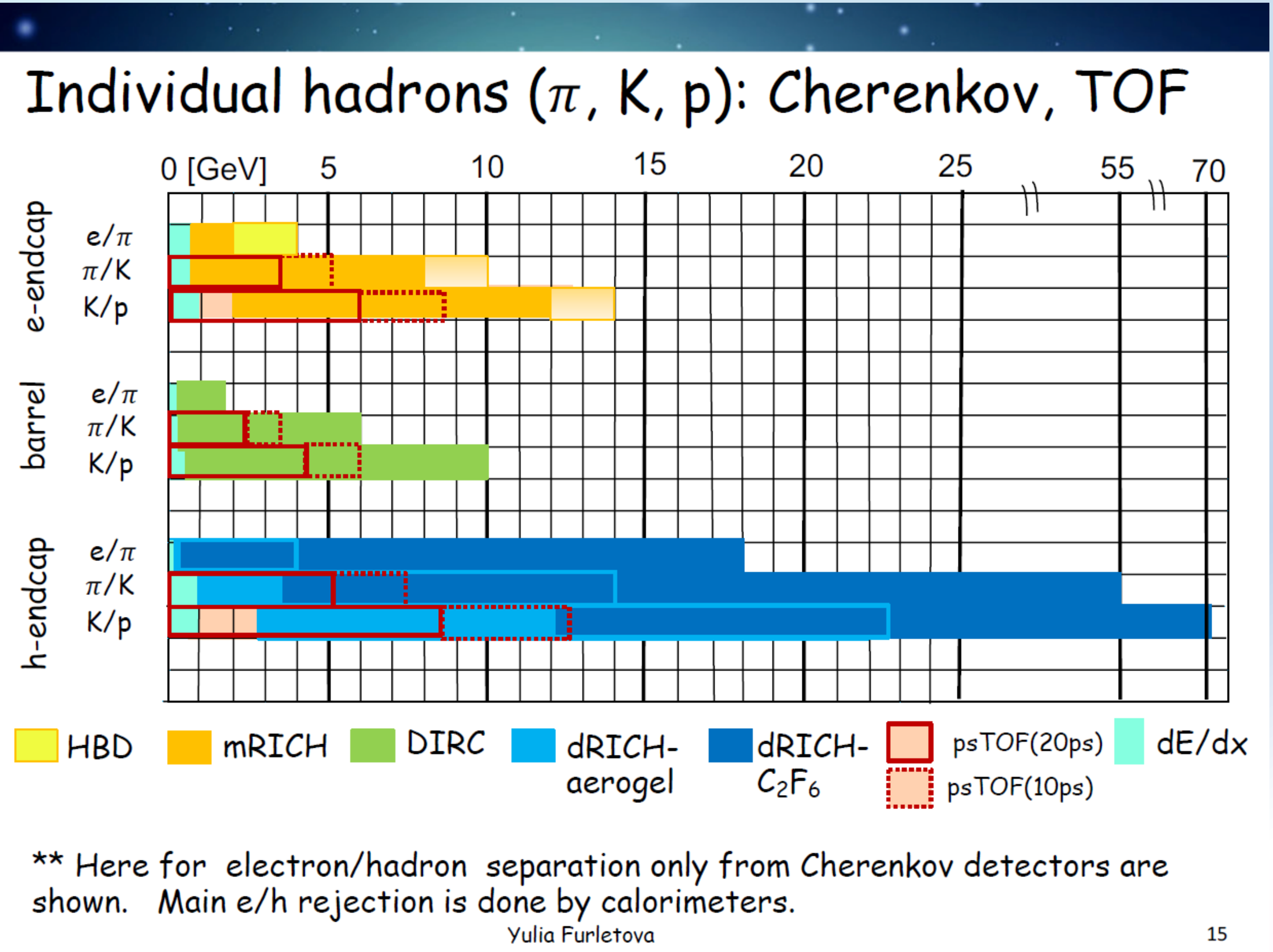
PID requirements



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

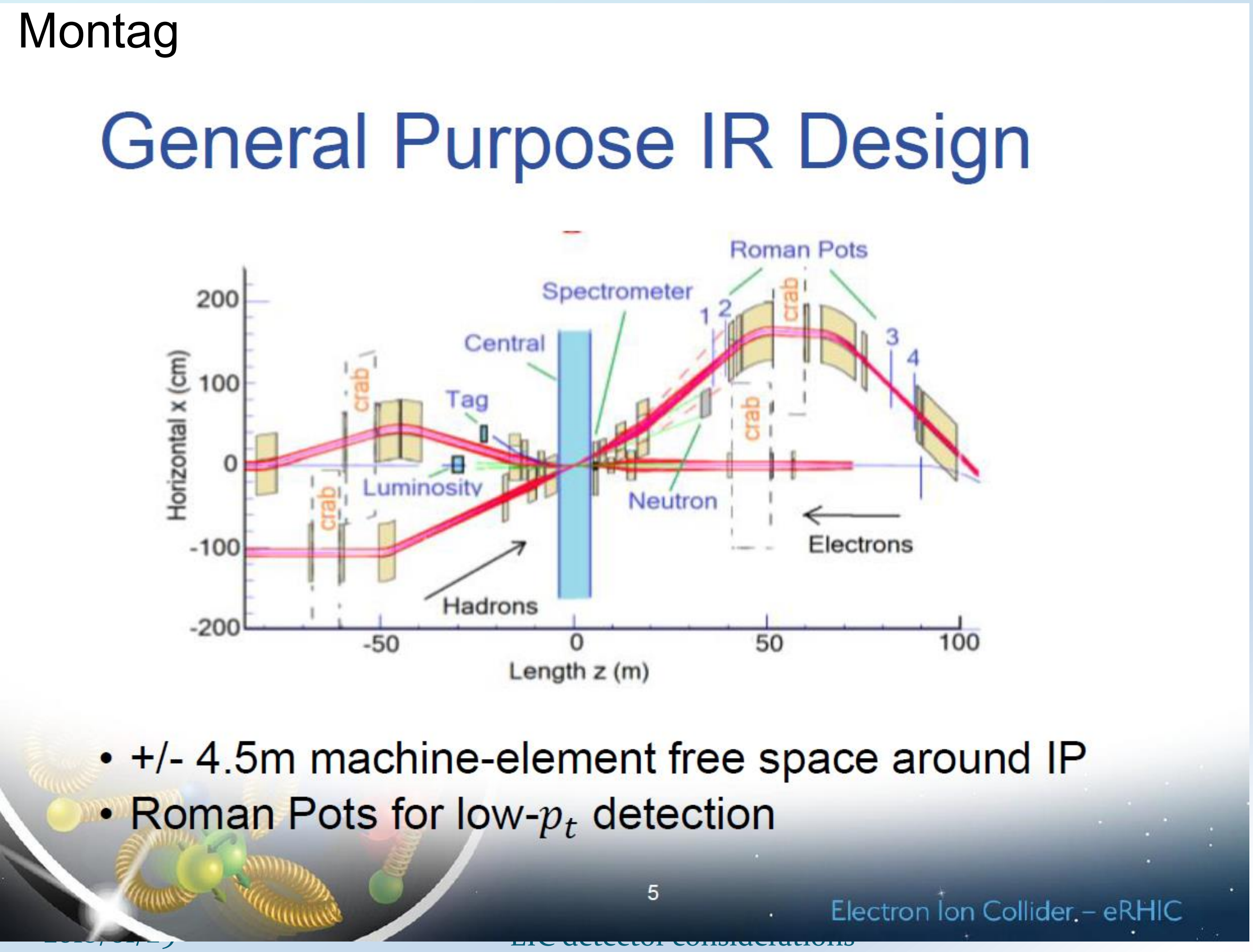
Technical challenges: PID

Furletova



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

Technical challenges: Envelope



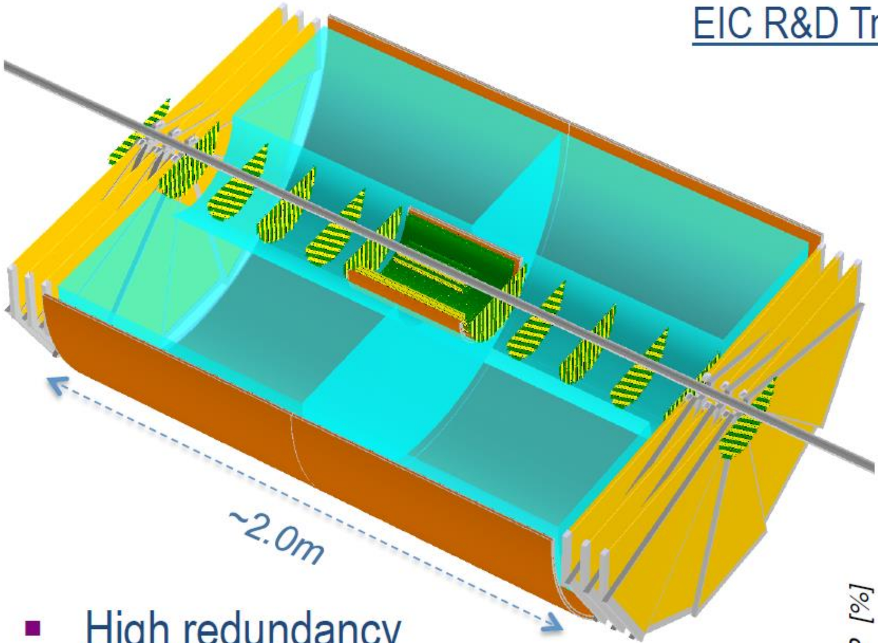
- Size of interaction region is limited by accelerator elements needed for high luminosity
- Eg eRHIC main detector envelope 4.5m
- Roman pots, ZDCs and very forward electron tracking need to be merged with Accelerator design

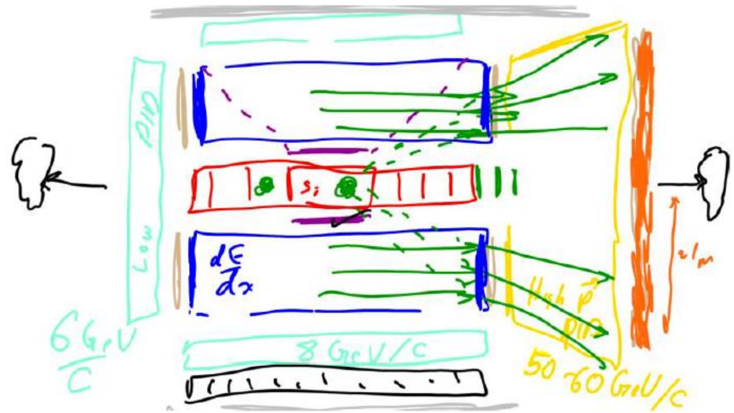
Tracking

Kisselev

Tracker

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

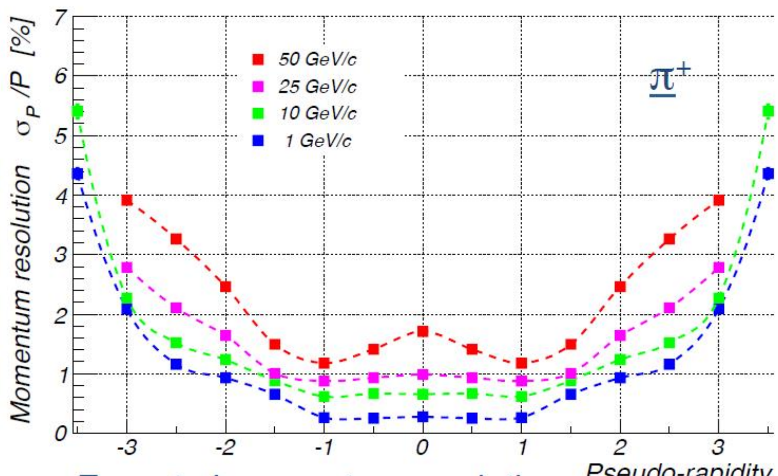




Hand-drawn consensus EIC detector design

- 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

Coordinated R&D ongoing

- As hardware requirements are 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

- **Project:** eRD1 **Title:** EIC Calorimeter Development
  Contact: H.Huang and C.Woody Report pdf
- **Project:** eRD3 **Title:** Design and assembly of fast and lightweight forward tracking prototype systems for an EIC
  Contact: Bernd Surrow Report pdf
- **Project:** eRD6 **Title:** Tracking & PID detector R&D towards an EIC detector
  Contact: Kondo Gnanvo Report pdf
- **Project:** eRD14 **Title:** PID Consortium for an integrated program for Particle Identification (PID) at a future Electron-Ion Collider
  Contact: Yordanka Ilieva and Pawel Nadel-Turonski Report pdf
- **Project:** eRD15 **Title:** R&D for a Compton Electron Detector
  Contact: Alexandre Camsonne Report pdf
- **Project:** eRD16 **Title:** Forward/Backward Tracking at EIC using MAPS Detectors
  Contact: Ernst Sichtermann Report pdf
- **Project:** eRD17 **Title:** BeAGLE: A Tool to Refine Detector Requirements for eA Collisions
  Contact: Mark Baker Report pdf
- **Project:** eRD18 **Title:** Precision Central Silicon Tracking & Vertexing for the EIC
  Contact: Peter G. Jones Report pdf
- **Project:** eRD20 **Title:** Developing Simulation and Analysis Tools for the EIC
  Contact: M. Diefenthaler and A. Kiselev Report pdf
- **Project:** eRD21 **Title:** EIC Background Studies and the Impact on the IR and Detector
  Contact: Latifa Elouadrhiri and Charles Hyde Report pdf
- **Project:** eRD22 **Title:** GEM based Transition radiation detector and tracker
  Contact: Yulia Furletova Report pdf
- **LOI** **Title:** Low-Mass Silicon Pixel Sensor with In-Pixel Readout Electronics for EIC Tracking and Vertexing
  Contact: Shaorui Li

+several more that are mostly done with R&D (especially HCAL)

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