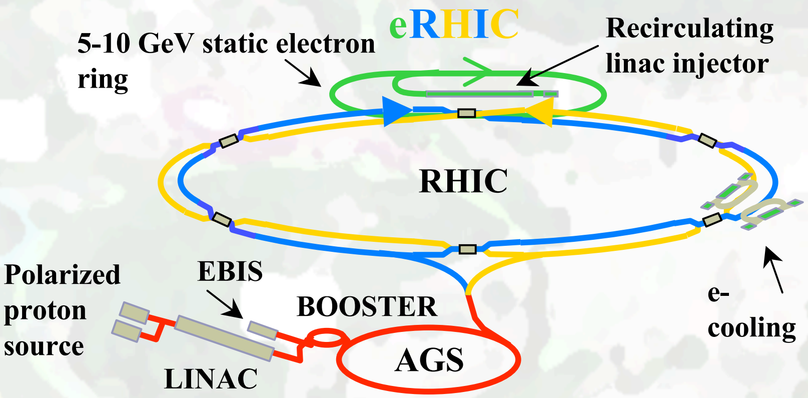
eRHIC

-

Detector design studies

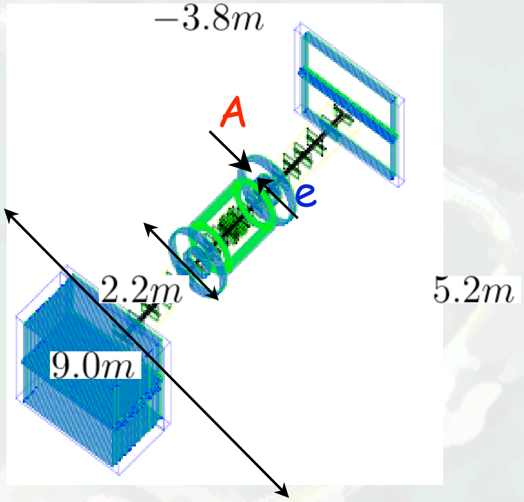
Bernd Surrow

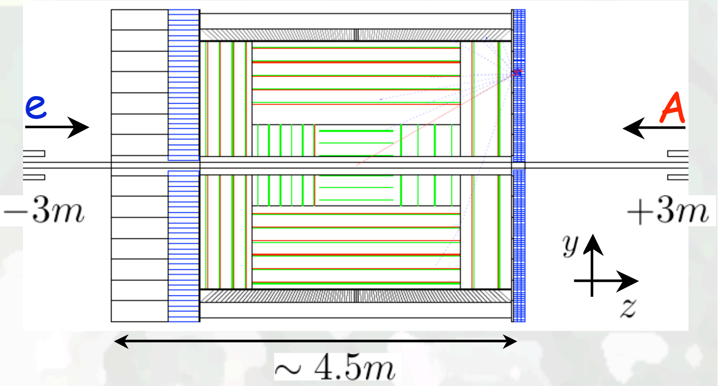
Massachusetts
Institute of
Technology



Outline

- Introduction
  - Constraints imposed by collider kinematics
  - Physics program driven requirements
  - eRHIC - Detector design aspects
    - General considerations
    - Design 1: Forward physics (unpolarized ep/eA MPI-Munich group)
    - Design 2: General purpose (unpolarized/polarized ELECTRon-A)
  - Constraints on accelerator/detector interface and background issues





- Summary and concluding remarks

Introduction

- Polarized ep physics
  - Precision measurement of g^p_1 over wide range in Q^2
    - Extraction of gluon polarization through DGLAP NLO analysis
    - Extraction of strong coupling constant
  - Precision measurement of g^n_1 (neutron) (Polarized ^{3}He)
  - Photoproduction measurements
  - Electroweak structure function g_5 measurements
  - Flavor separation through semi-inclusive DIS
  - Target and current fragmentation studies
  - Transversity measurements

Inclusive measurement - electron (Low x) and hadronic final state (High x) over wide acceptance range

In addition: p tagging in forward direction

Jet production

Hermetic detector configuration: Missing energy measurement

K/π separation - particle ID - Heavy flavor - Secondary vertex reconstruction

Forward acceptance: Tracking and calorimetry

Introduction

- Unpolarized ep/eA physics

☐ Precision measurement of F_2 at low x: Transition from hadronic to partonic behavior	Inclusive measurement involving electron at small polar angles (≈10mrad)
☐ Precision measurement of the longitudinal structure function F_L	Inclusive measurement involving electron (Low x) - Variable centre-of-mass energy
☐ Precision measurement of F_2 at high x	Inclusive measurement (hadronic final state in forward direction): Good forward acceptance
☐ Measurement of diffractive and exclusive reactions	Forward p tagging system
☐ DVCS	Forward p tagging system - photon/electron discrimination
☐ Precision measurement of eA scattering	Similar to ep case at low x - High x: Forward acceptance - careful study necessary!

Constraints imposed by collider kinematics

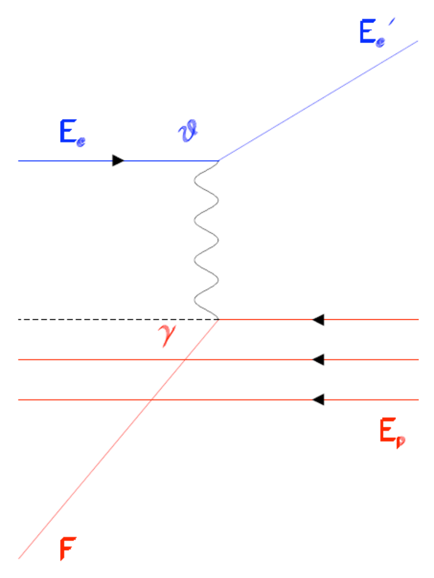
- Reconstruction of event kinematics

- Electron method: scattered electron

$$x_e = \frac{Q_e^2}{s y_e} = \frac{E'_e \cos^2\left(\frac{\theta'_e}{2}\right)}{E_p\left(1 - \frac{E'_e}{E_e}\sin^2\left(\frac{\theta'_e}{2}\right)\right)}$$

$$y_e = 1 - \frac{E'_e}{2E_e}\left(1 - \cos\theta'_e\right) = 1 - \frac{E'_e}{E_e}\sin^2\left(\frac{\theta'_e}{2}\right)$$

$$Q_e^2 = 2E_eE'_e\left(1 + \cos\theta'_e\right) = 4E_eE'_e\cos^2\left(\frac{\theta'_e}{2}\right) = \frac{p_{T,e}^2}{1 - y_e}$$



$$F = \frac{p_{T,h}^2 + (E - p_z)_h^2}{2\,(E - p_z)_h}$$

$$\cot\gamma = \frac{p_{T,h}^2 - (E - p_z)_h^2}{p_{T,h}^2 + (E - p_z)_h^2}$$

- Jacquet-Blondel method: hadronic final state

$$x_{JB} = \frac{Q_{JB}^2}{s y_{JB}}$$

$$y_{JB} = \frac{(E - p_z)_h}{2E_e}$$

$$Q_{JB}^2 = \frac{p_{T,h}^2}{1 - y_{JB}}$$

$$p_{T,h}^2 = \left(\sum_h p_{x,h}\right)^2 + \left(\sum_h p_{y,h}\right)^2$$

$$(E - p_z)_h = \sum_h \left(E_h - p_{z,h}\right)$$

Constraints imposed by collider kinematics

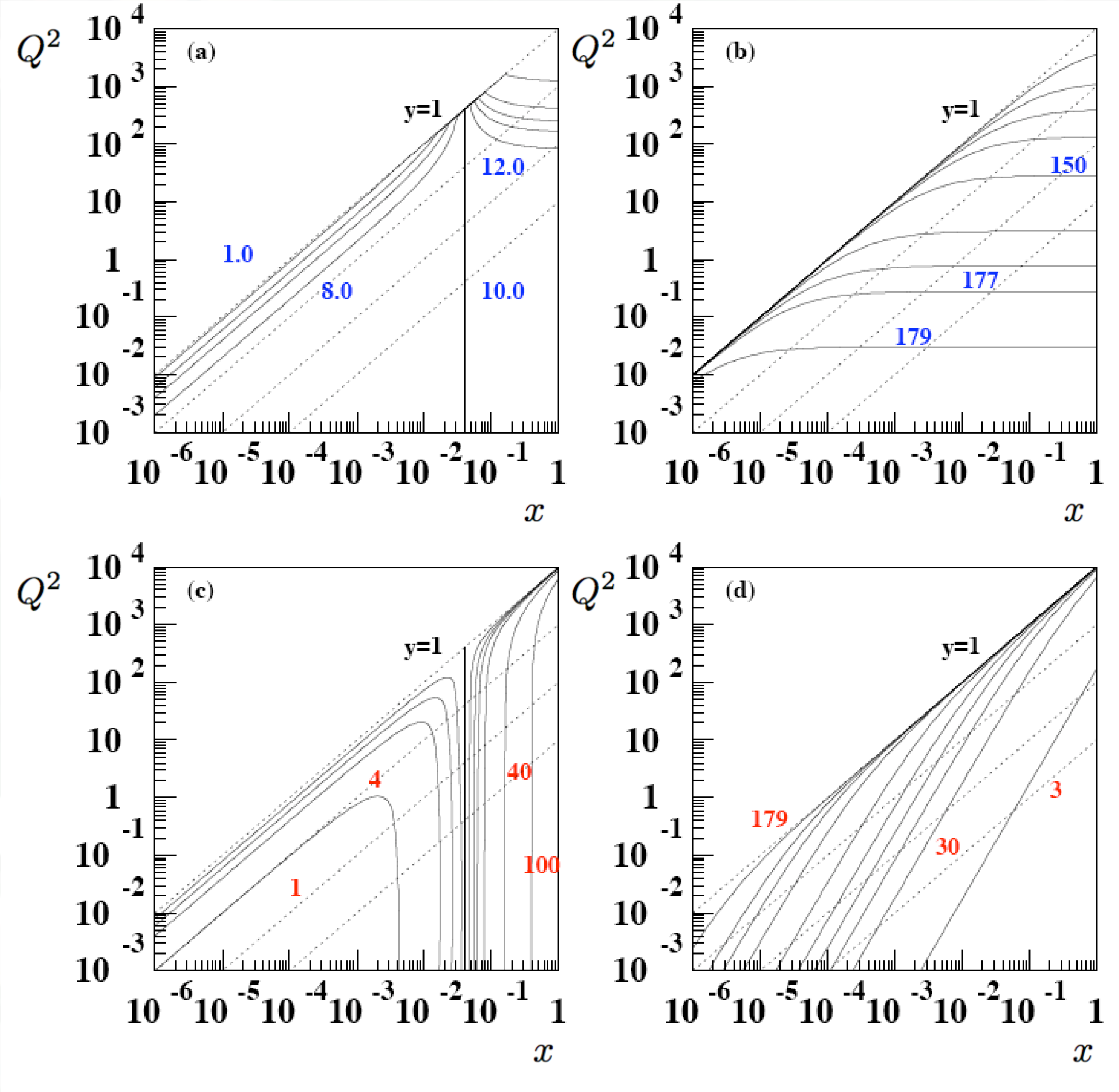
- Event kinematics (10GeV electron on 250GeV proton)

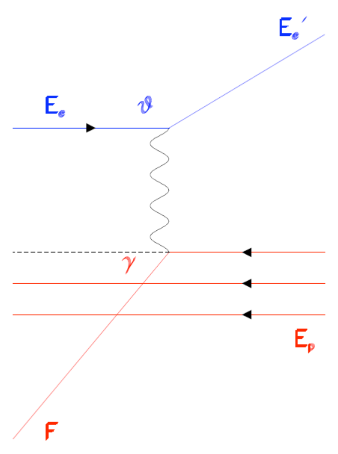
Lines of constant electron energy (E'_e)

Lines of constant electron angle (ϑ'_e)

Lines of constant hadron energy (F)

Lines of constant hadron angle (γ)



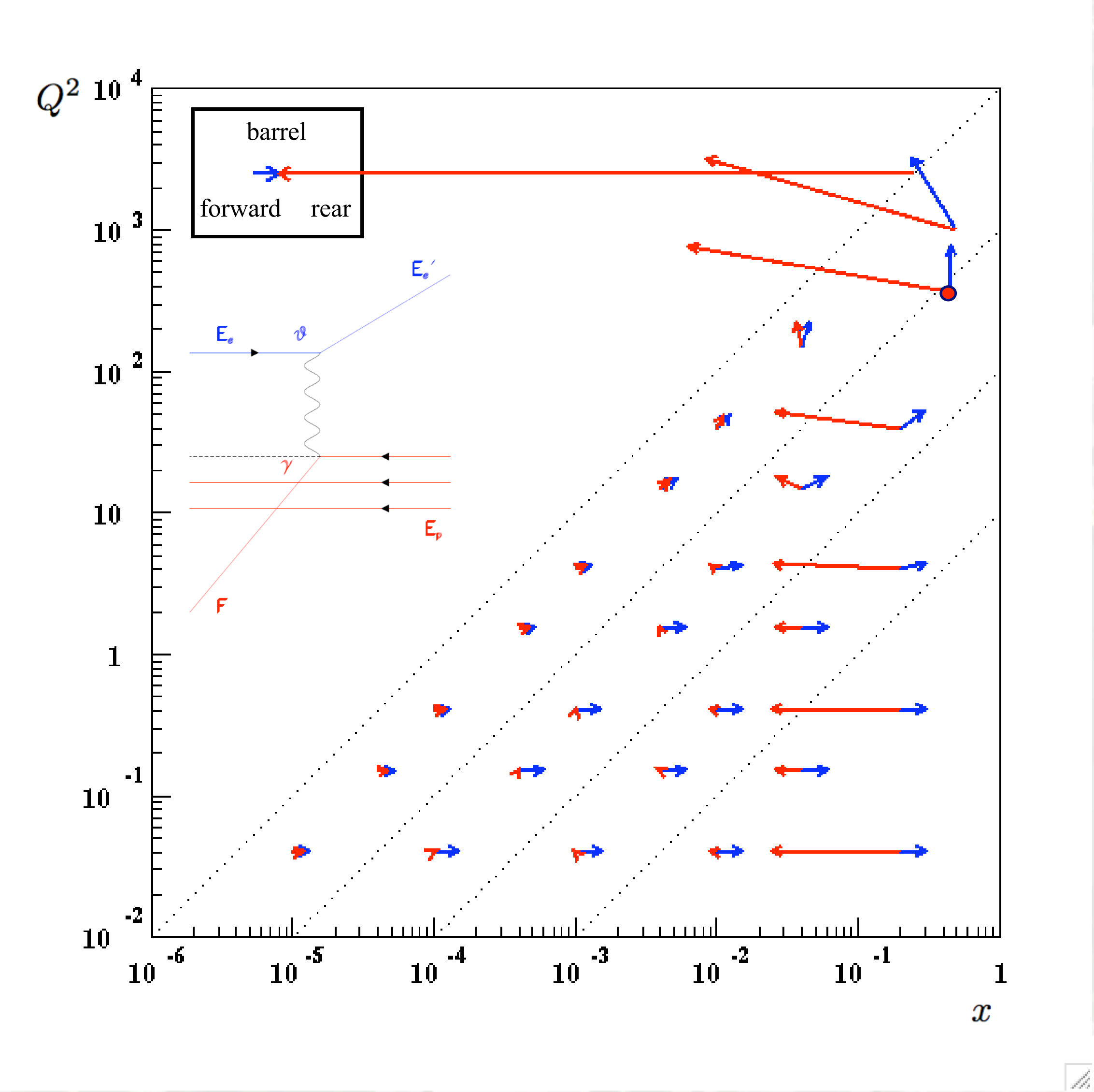


Constraints imposed by collider kinematics

- Event topology (10GeV electron on 250GeV proton)

- Low-x-low Q^2: Electron and current jet (low energy) predominantly in rear direction

- High-x-low Q^2: Electron in rear and current jet (High energy) in forward direction



- High-x-high Q^2: Electron predominantly in barrel/forward direction (High energy) and current jet in forward direction (High energy)

●

$Q^2 = 361 GeV^2 \quad x = 0.45$

$E_e' = 18 GeV \quad F = 104 GeV$

$\vartheta_e' = 90^\circ \quad \vartheta_h = 10^\circ$

Physics program driven requirements

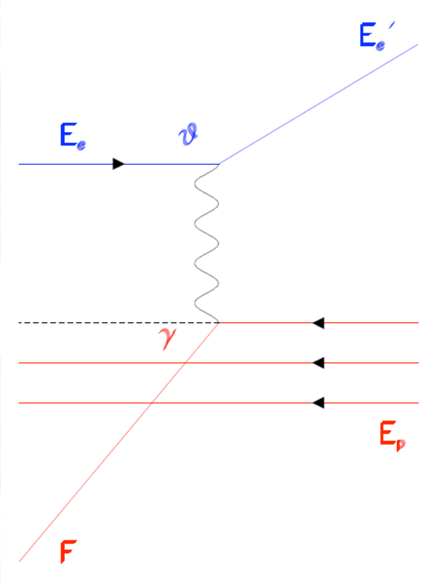
- Resolution of event kinematics

  - Electron method: scattered electron

$$\left(\frac{\delta x_e}{x_e}\right) = \left(\frac{1}{y_e}\right)\frac{\delta E'_e}{E'_e} \otimes \left[\frac{x_e}{E_e/E_p} - 1\right]\tan\left(\frac{\theta'_e}{2}\right)\delta\theta'_e$$

$$\left(\frac{\delta y_e}{y_e}\right) = \left(1 - \frac{1}{y_e}\right)\frac{\delta E'_e}{E'_e} \otimes \left[\frac{1}{y_e} - 1\right]\cot\left(\frac{\theta'_e}{2}\right)\delta\theta'_e$$

$$\left(\frac{\delta Q^2_e}{Q^2_e}\right) = \frac{\delta E'_e}{E'_e} \otimes \tan\left(\frac{\theta'_e}{2}\right)\delta\theta'_e$$



$$F = \frac{p^2_{T,h} + (E - p_z)^2_h}{2\,(E - p_z)_h}$$

$$\cot\gamma = \frac{p^2_{T,h} - (E - p_z)^2_h}{p^2_{T,h} + (E - p_z)^2_h}$$

  - Jacquet-Blondel method: hadronic final state

$$\left(\frac{\delta x_{JB}}{x_{JB}}\right) = \left(\frac{1}{1 - y_{JB}}\right)\frac{\delta F}{F} \otimes \left[2\cot\gamma + \left(\frac{2y_{JB} - 1}{1 - y_{JB}}\right)\cot\left(\frac{\gamma}{2}\right)\right]\delta\gamma$$

$$\left(\frac{\delta y_{JB}}{y_{JB}}\right) = \frac{\delta F}{F} \otimes \cot\left(\frac{\gamma}{2}\right)\delta\gamma$$

$$\left(\frac{\delta Q^2_{JB}}{Q^2_{JB}}\right) = \left(\frac{2 - y_{JB}}{1 - y_{JB}}\right)\frac{\delta F}{F} \otimes \left[2\cot\gamma + \left(\frac{y_{JB}}{1 - y_{JB}}\right)\cot\left(\frac{\gamma}{2}\right)\right]\delta\gamma$$

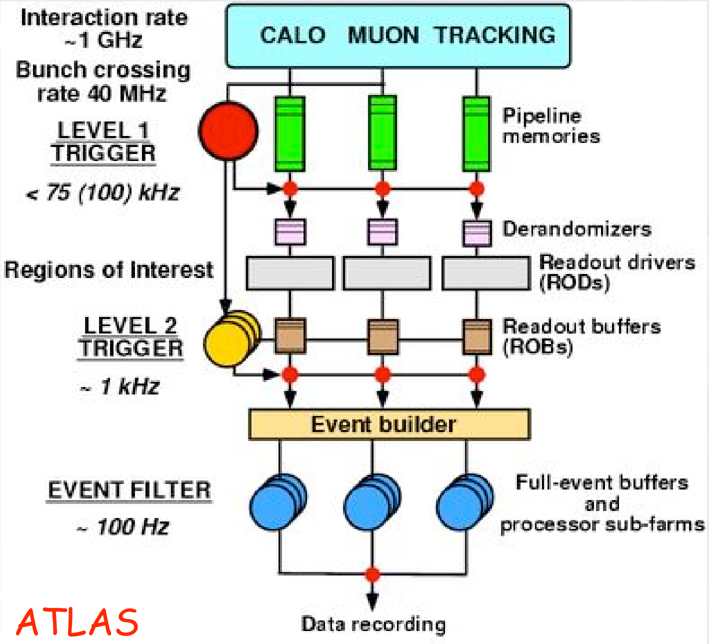
Physics program driven requirements

- Detector specifications (1)
  - Tracking over wide acceptance range operating in high-rate environment similar to LHC (35ns bunch-crossing time) - Contribute to reconstruction of event kinematics besides calorimetry in particular at very small energies
  - Calorimetry over wide acceptance range (e/h separation critical): Transverse and longitudinal segmentation (Track-calorimeter cluster matching essential)
  - Specialized detector systems
    - Zero-degree photon detector (Control radiative corrections and luminosity measurement)
    - Tagging of forward particles (Diffraction and nuclear fragments) such as…:
      - Proton remnant tagger
      - Zer0-degree neutron detector
    - Forward proton and neutron tagger
  - Particle ID systems (K/π separation) and secondary vertex reconstruction capabilities

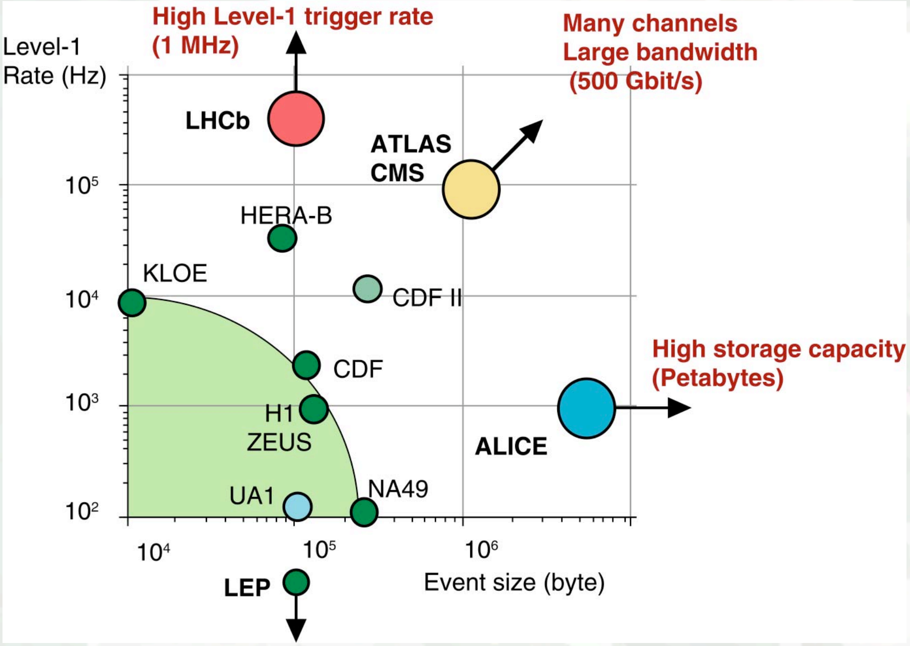
Physics program driven requirements

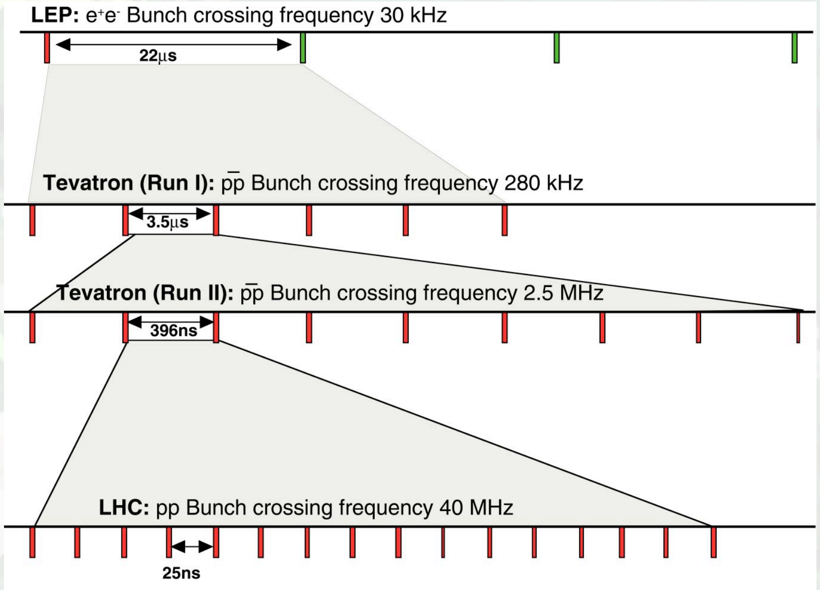
Detector specifications (2)

- Rate requirements: Bunch-crossing time 35ns
- Background rejection: Timing requirements e.g. calorimetry timing essential to reject beam related background
- Trigger: Multi-level trigger system involving calorimetry and fast tracking information to enhance data sample for rare processes over inclusive ep/eA and photoproduction



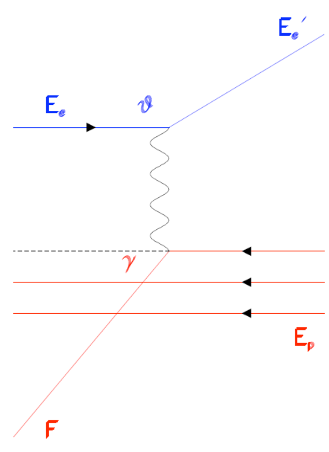
ATLAS





Physics program driven requirements

General considerations: Detector aspects

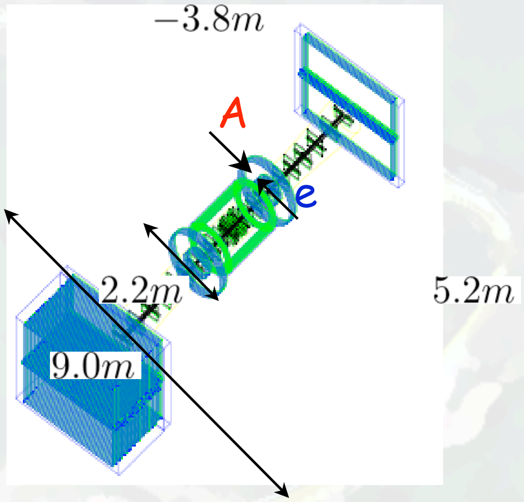


- Measure precisely scattered electron over large polar angle region (Kinematics of DIS reaction)
- Tag electrons under small angles (Study of transition region: DIS and photoproduction)
- Measure hadronic final state (Kinematics, jet studies, flavor tagging, fragmentation studies, particle ID)
- Missing E_T for events with neutrinos in the final state (W decays) (Hermetic detector)
- Zero-degree photon detector: Control radiative corrections and luminosity measurement (ep/eA Bremsstrahlung)
- Tagging of forward particles (Diffraction and nuclear fragments) such as...:
  - Proton remnant tagger
  - Zero degree neutron detector
- Challenge to incorporate above in one detector: Focus on two specific detector concepts for now!

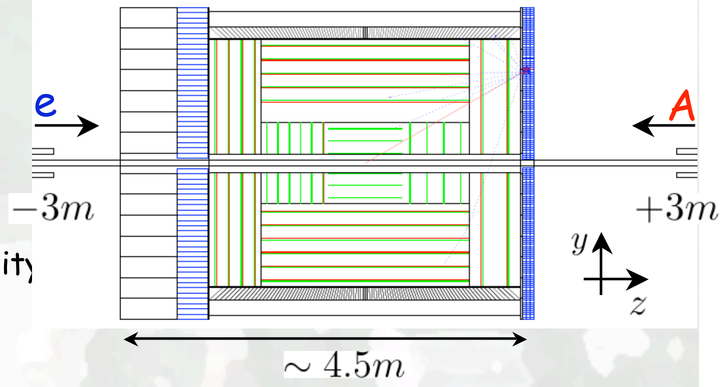
Constrain on machine layout!

eRHIC - Detector design aspects

General considerations



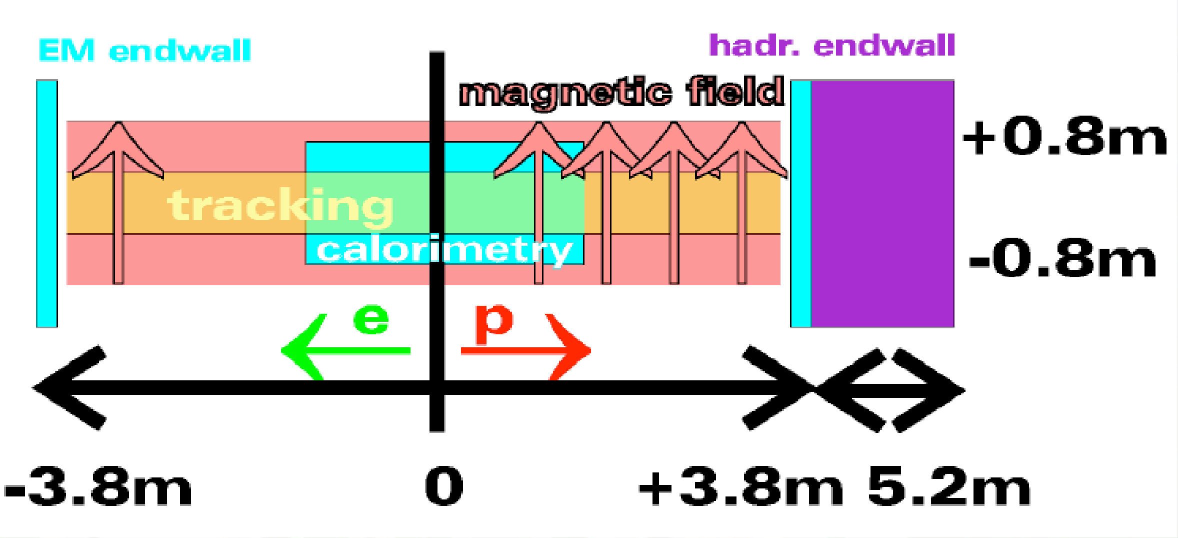
- Design 1: Forward physics (unpolarized eA MPI Munich group):
  - Specialized detector system to enhance forward acceptance of scattered electrons and hadronic final state
  - Main concept: Long inner dipole field (7m)
  - Required machine element-free region: approx. ±5m
- Design 2: General purpose (unpolarized/polarized ELECTRon-A):
  - Compact central detector (Solenoidal magnetic field) with specialized forward/rear tagging detectors/spectrometers to extend central detector acceptance
  - Required machine element-free region: approx. ±3m
- Detector sub-systems in both design concepts:
  - Zero-degree photon detector (Control radiative corrections and luminosity measurement)
  - Tagging of forward particles (Diffraction and nuclear fragments) such as…:
    - Proton remnant tagger
    - Zer0-degree neutron detector



eRHIC - Detector design aspects

I. Abt,
A. Caldwell,
X. Liu, J. Sutiak, MPP-2004-90, hep-ex 0407053

- Design 1: Forward physics (unpolarized eA MPI-Munich group) (1)
  - Detector concept
    - Compact detector with tracking and central EM calorimetry inside a magnetic dipole field and calorimetric end-walls outside:
      - Bend forward charged particles into detector volume
      - Extend rapidity compared to existing detectors
    - Tracking focuses on forward and backward tracks
    - No tracking in central region

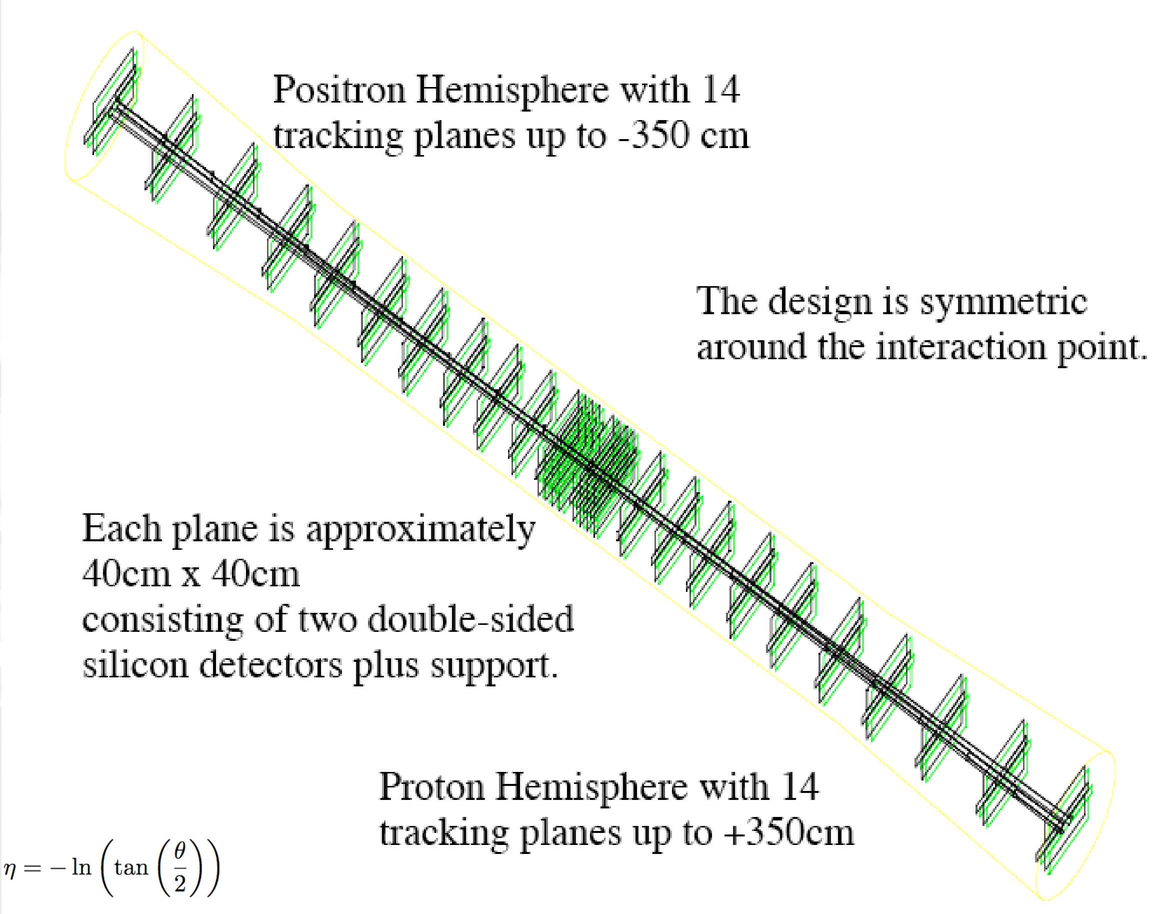


eRHIC - Detector design aspects

I. Abt, A. Caldwell, X. Liu, J. Sutiak, MPP-2004-90, hep-ex 0407053

Design 1: Forward physics (unpolarized eA MPI-Munich group) (2)

- Tracking system:
  - High-precision tracking with $\Delta p_T/p_T \sim 2\%$
  - Angular coverage down to $\eta \approx 6$ over the full energy range
  - Concept: 14 Si-strip tracking stations (40 X 40 cm)
  - Assumed hit resolution: 20μm
  - Momentum resolution from simulations: Few percent!



Positron Hemisphere with 14 tracking planes up to -350 cm

The design is symmetric around the interaction point.

Each plane is approximately 40cm x 40cm consisting of two double-sided silicon detectors plus support.

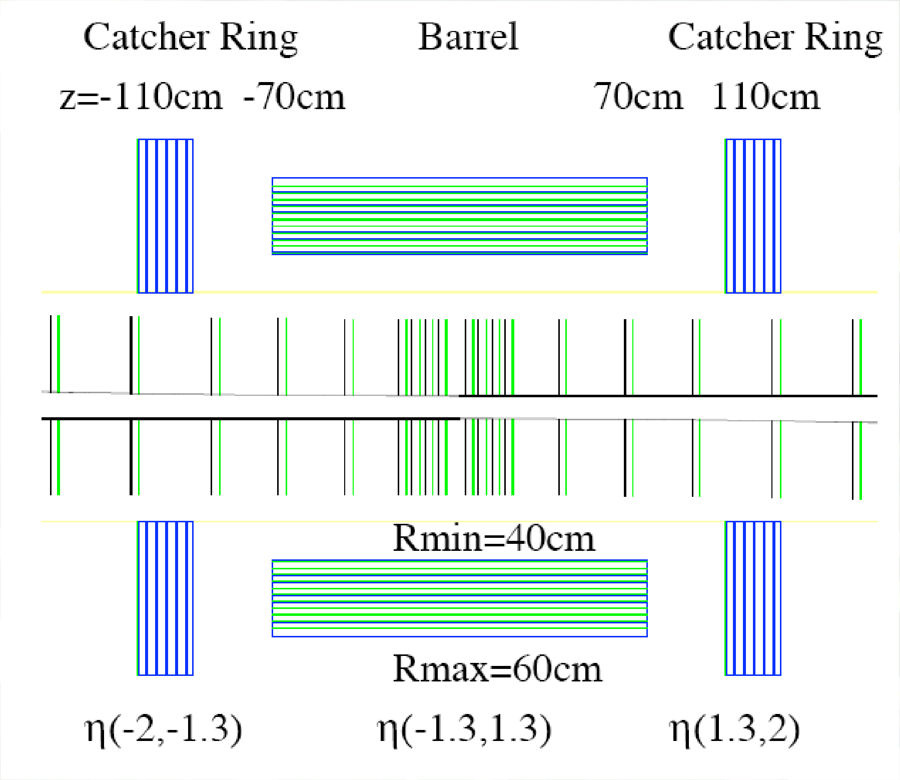
Proton Hemisphere with 14 tracking planes up to +350cm

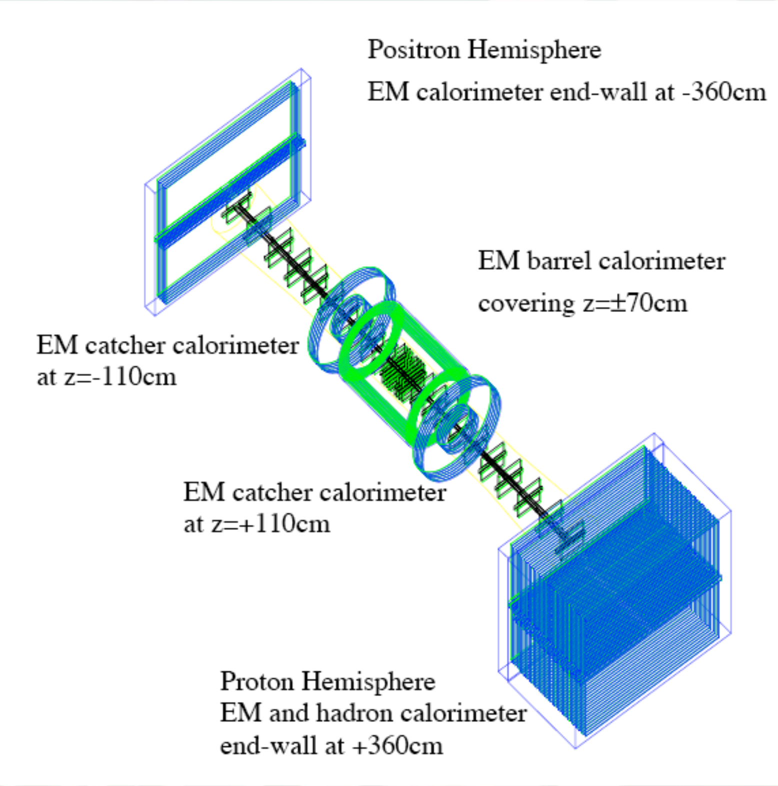
$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

eRHIC - Detector design aspects

I. Abt, A. Caldwell, X. Liu, J. Sutiak, MPP-2004-90, hep-ex 0407053

- Design 1: Forward physics (unpolarized eA MPI-Munich group) (3)
  - Calorimeter system:
    - Compact EM calorimeter systems: Si-Tungsten
    - Forward hadron calorimeter: Design follows existing ZEUS calorimeter



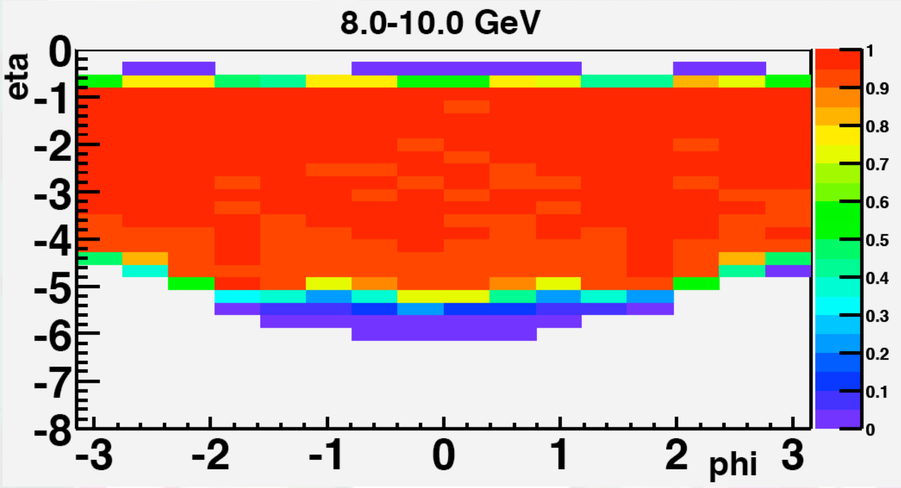


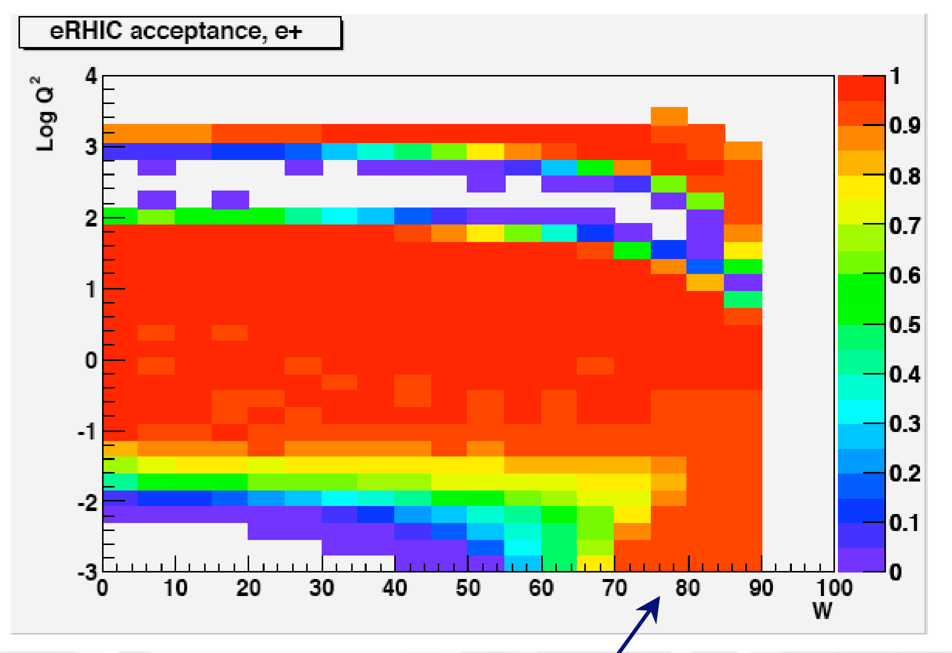
eRHIC - Detector design aspects

I. Abt, A. Caldwell, X. Liu, J. Sutiak, MPP-2004-90, hep-ex 0407053

Design 1: Forward physics (unpolarized eA MPI-Munich group) (4)

- Acceptance:
  - Full tracking acceptance for |η| > 0.75 - No acceptance in central region |η| < 0.5
  - Q^2 acceptance down to 0.05GeV^2 (Full W range) - Full acceptance down Q^2=0GeV^2 for W>80GeV
  - High x: Electron (Q^2) and Jet (x) to determine event kinematics





Track efficiency:

- Full efficiency below 6GeV for η > -8
- For larger energies, full efficiency for η > -5

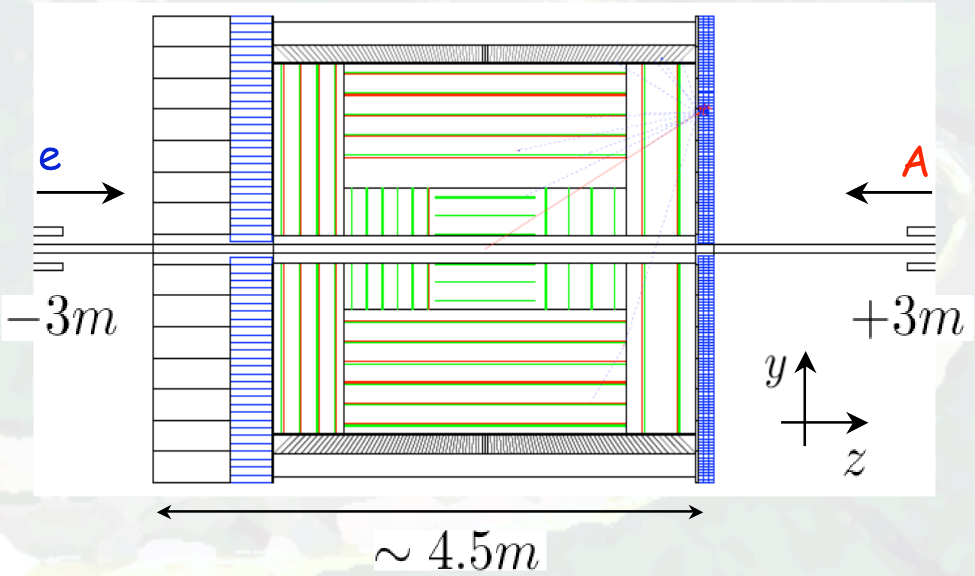
$$W^2 \approx \frac{Q^2}{x}$$

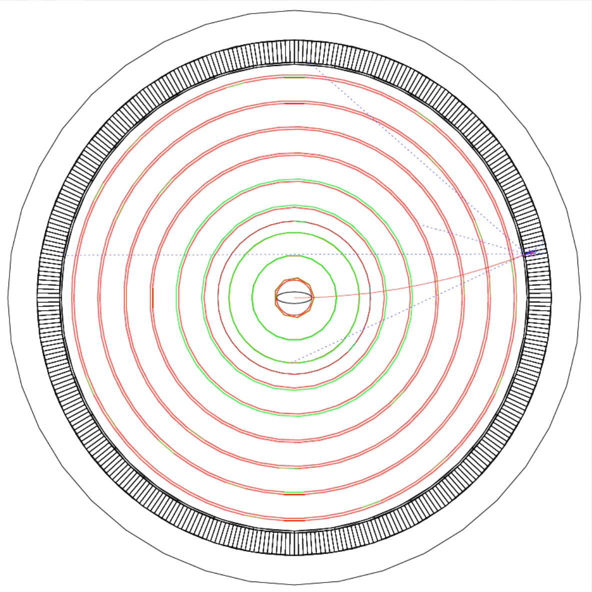
eRHIC - Detector design aspects

J. Pasukonis,
B.S.

Design 2: General purpose (unpolarized/polarized ELECTRon-A) (1)

- Detector concept:
  - Hermetic detector system inside ±3m machine element free region
  - Starting point:
    - Barrel and rear EM system: e.g. Si-Tungsten (Similar to Design 1)
    - Forward EM/hadron calorimeter: e.g. Pb-scintillator
    - Tracking system and barrel EM inside solenoidal magnetic field
    - Tracking system based on high-precision Si (inner) and micro-pattern technology (Triple-GEM) (outer)



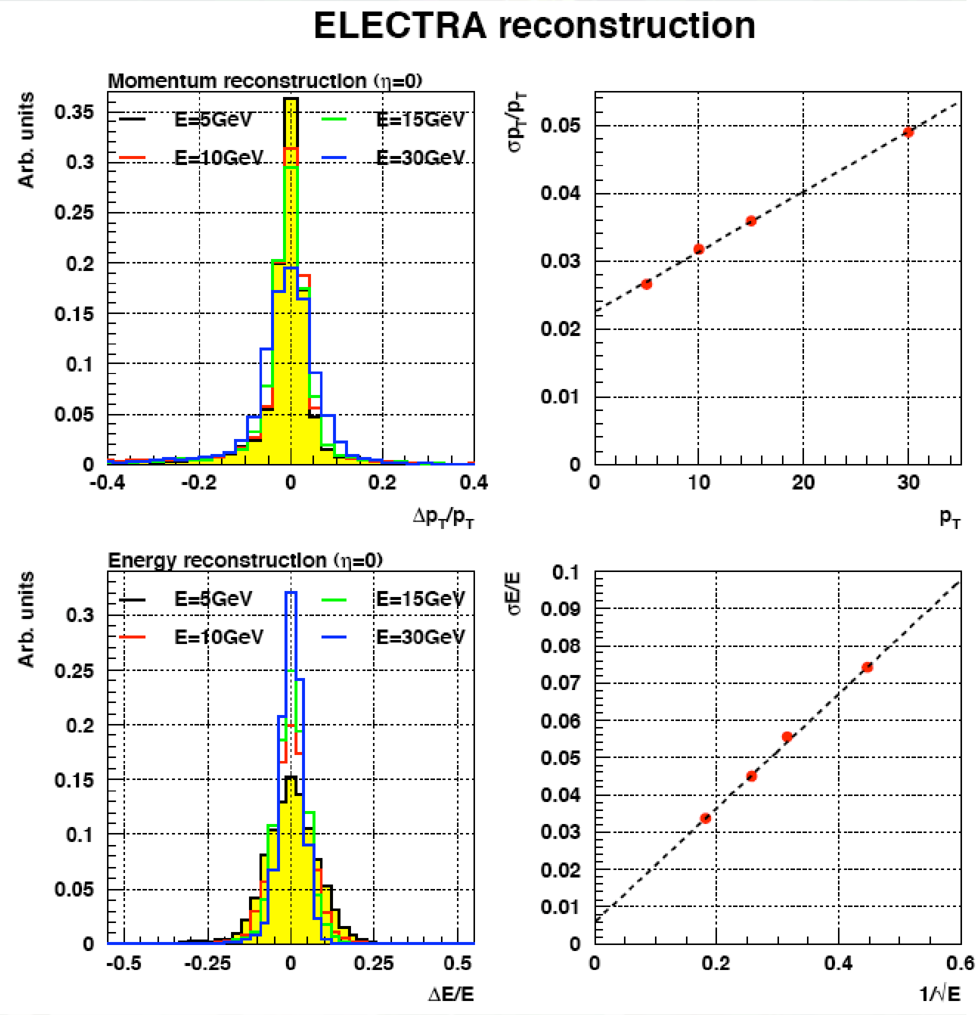


eRHIC - Detector design aspects

J. Pasukonis,
B.S.

Design 2: General purpose (unpolarized/polarized ELECTRon-A) (2)

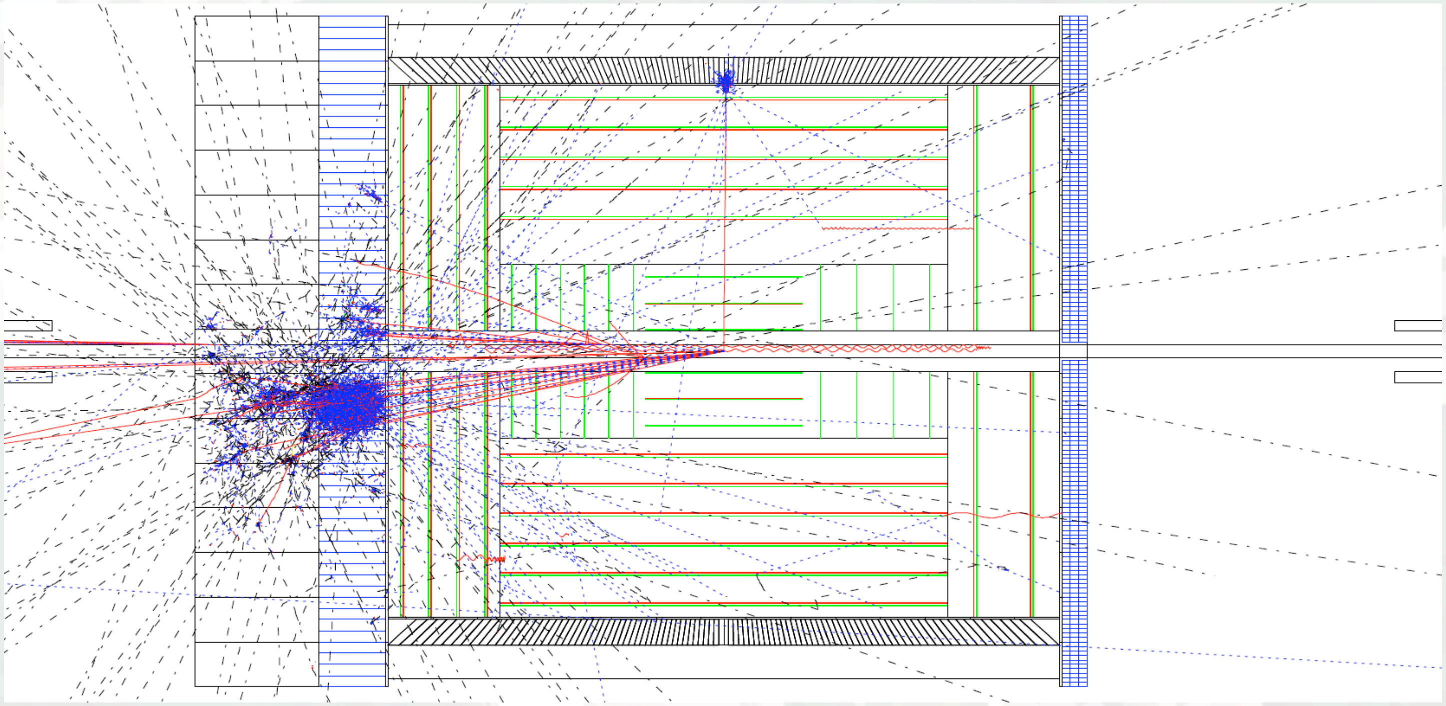
- ELECTRA detector simulation and reconstruction framework:
  - GEANT simulation of the central detector part (tracking/calorimetry) available: Starting point
  - Calorimeter cluster and track reconstruction implemented
  - Code available through CVS repository: http://starmac.lns.mit.edu/~erhic/electra/
  - To-do-list:
    - Evaluate and optimize detector configuration - In particular: Type of magnetic field configuration
    - Design of forward tagging system and particle ID systems
    - Rear detection systems
    - For eA events: Optimize forward detector system for high-multiplicity environment


ELECTRA reconstruction

eRHIC - Detector design aspects

J. Pasukonis,
B.S.

- Design 2: General purpose (unpolarized/polarized ELECTRon-A) (3)
  - Simulated ep DIS event (LEPTO)



Side view

$Q^2 = 361 GeV^2 \quad x = 0.45 \quad E_e = 18 GeV$

$E'_e = 18 GeV \quad F = 104 GeV$

$\vartheta'_e = 90° \quad \vartheta_h = 10°$

Lower Q^2

acceptance ≈ 0.1GeV2

DIS generators

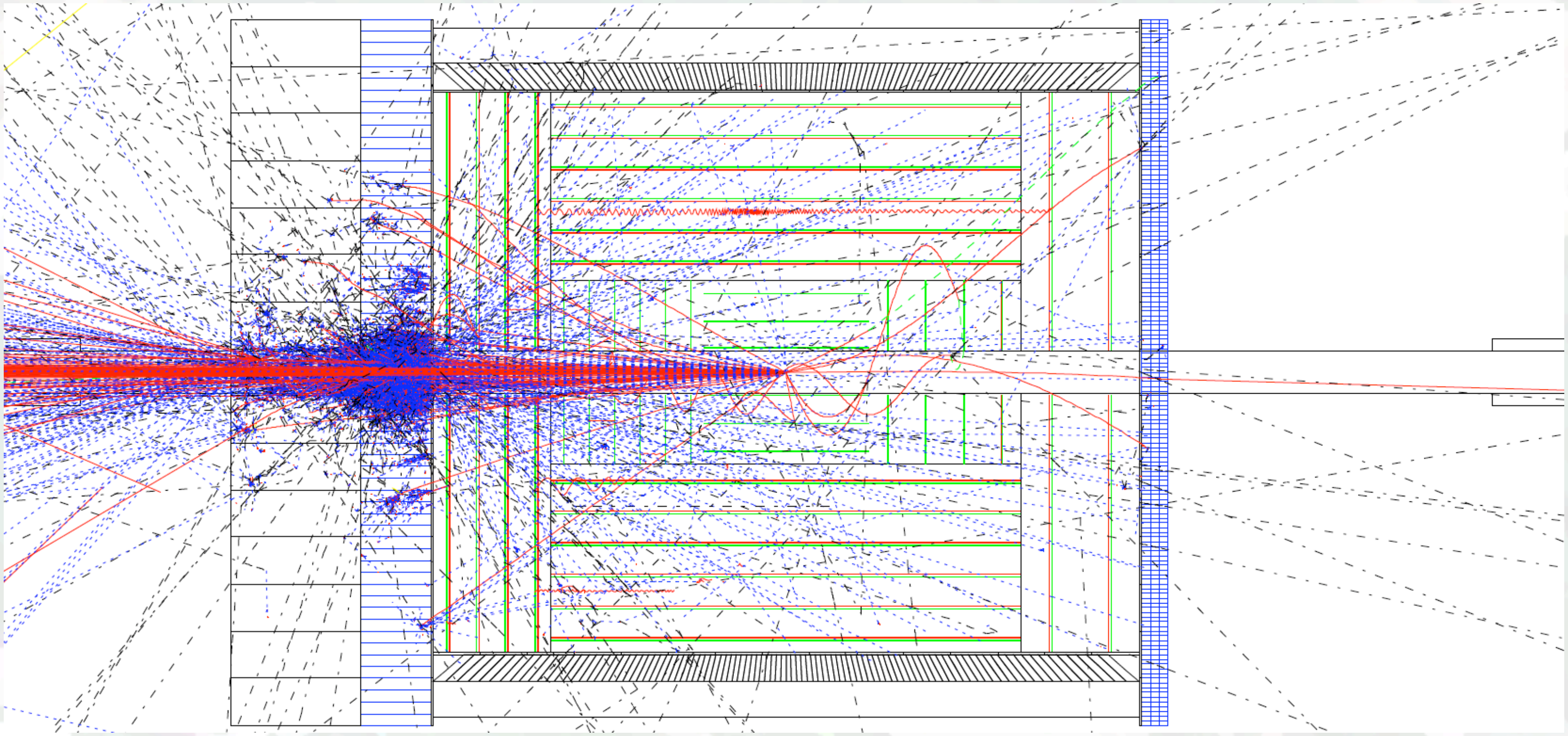
used so far:

- LEPTO
- DJANGO

eRHIC - Detector design aspects

J. Pasukonis,
B.S.

- **Design 2:** General purpose (unpolarized/polarized ELECTRon-A) (4)
  - ☐ Simulated eCa event (VNI)



Top view

Interaction region and background issues

- IR region
  - Design concept: Forward physics (unpolarized eA MPI-Munich group)
    - Machine element free-region: approx. ±5m
    - Physics program could be accomplished at lower luminosity
  - Design concept: General purpose (unpolarized/polarized ELECTRon-A)
    - Machine element free-region: approx. ±3m
    - Physics program requires high luminosity operation
- Synchrotron radiation background
  - Optimize beam pipe shape
    - Accommodate synchrotron radiation fan generated by e-beam as a result of beam separation
    - Maximize detector acceptance
  - Design of absorber and masking system
- Beam-gas background
  - Bremsstrahlung of electrons with residual gas and proton-beam gas background
    - Shielding and collimation
    - Minimize dead-material close to the beam
    - Good vacuum conditions crucial

Summary

- Detector design issues
  - Well-developed design of a Forward detector system focusing on low-x / high-x physics (Adaptation and optimization of a detector presented for the HERA III program)
  - Design of a compact central detector started: Detector simulation and reconstruction framework: ELECTRA (CVS repository http://starmac.lns.mit.edu/~erhic/electra/)
  - Possible scenarios of both design concepts:
    - 1 detector only (Staging): Start program with Forward physics detector system followed by an upgrade of the interaction region and installation of a central detector system re-using parts of the Forward detector system (e.g. rear and forward calorimeter): Very time consuming!
    - 2 IR regions would allow to accommodate both detector concepts independently
    - Incorporate both concepts in one design: New ideas of magnetic field layout crucial!
- Constraints and implications of machine/detector interface
  - Inner-most machine elements
  - Synchrotron radiation and other machine related background
  - Incorporate forward and rear tagging system including luminosity monitoring system into machine layout

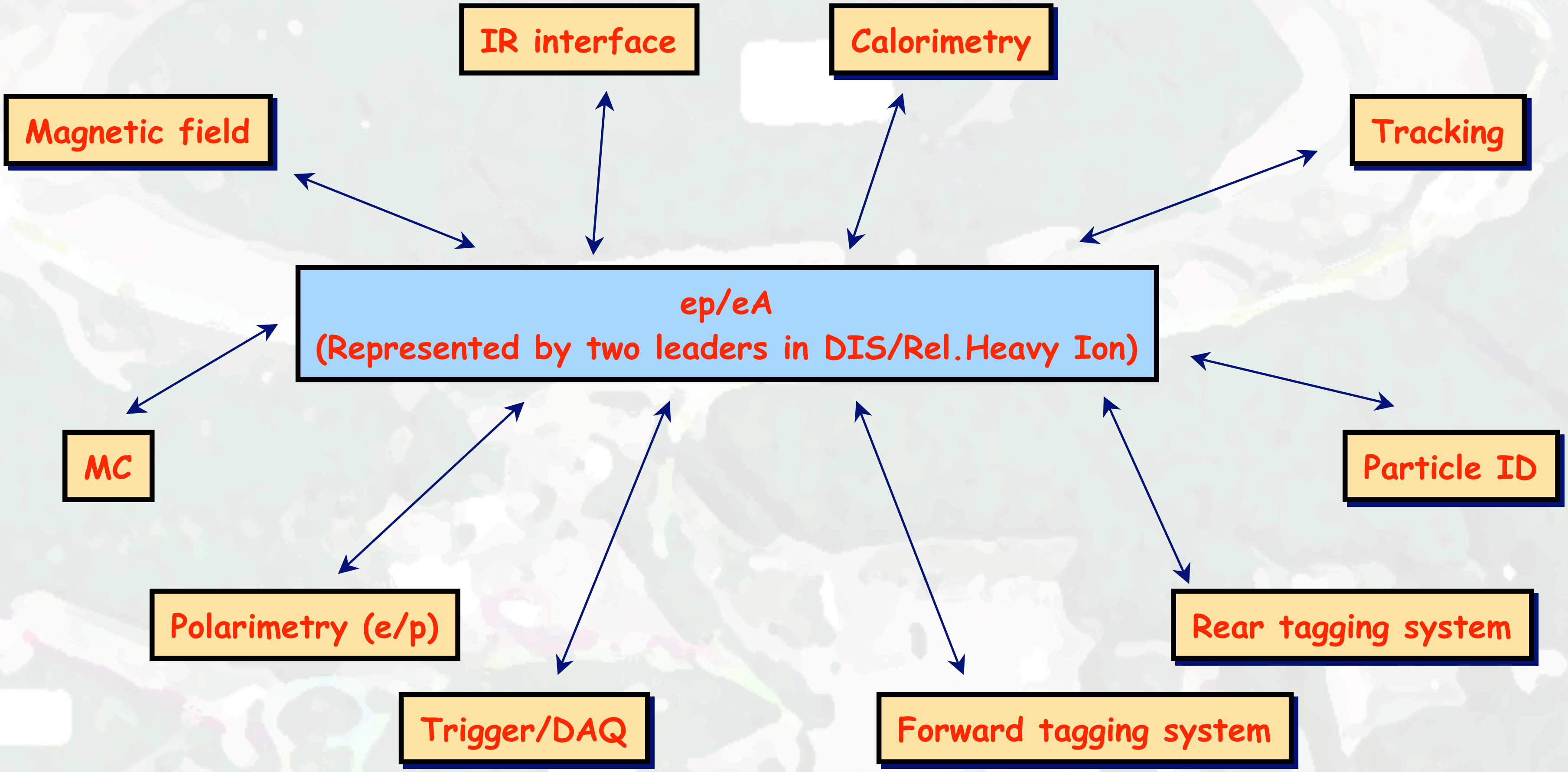
Concluding remarks

- Steps towards a new detector at BNL
  - Participation of RHIC and Jlab community essential to realize a detector for eRHIC - Cannot rely initially on strong participation from Europe - Dedicated new detector group at BNL urgently needed
  - Three-beam IR region too complicated
  - Switching between two IR regions unrealistic
  - Critical eRHIC detector R&D issues:
    - Calorimetry: Compact, high resolution, e/h separation
    - Tracking: High-rate, low dead material, high occupancy (Forward direction)
    - Forward/Rear instrumentation: Compact, high radiation environment
    - Magnetic field configuration: Combination of solenoid and dipole-type configuration
    - DAQ/Trigger system: Multi-level trigger system
    - Background: Synchrotron radiation absorber and shielding

Concluding remarks

- Towards a new detector group at BNL

🟨 : Several participating institutes chaired by 2 conveners



ep/eA
(Represented by two leaders in DIS/Rel.Heavy Ion)

IR interface

Calorimetry

Magnetic field

Tracking

MC

Particle ID

Polarimetry (e/p)

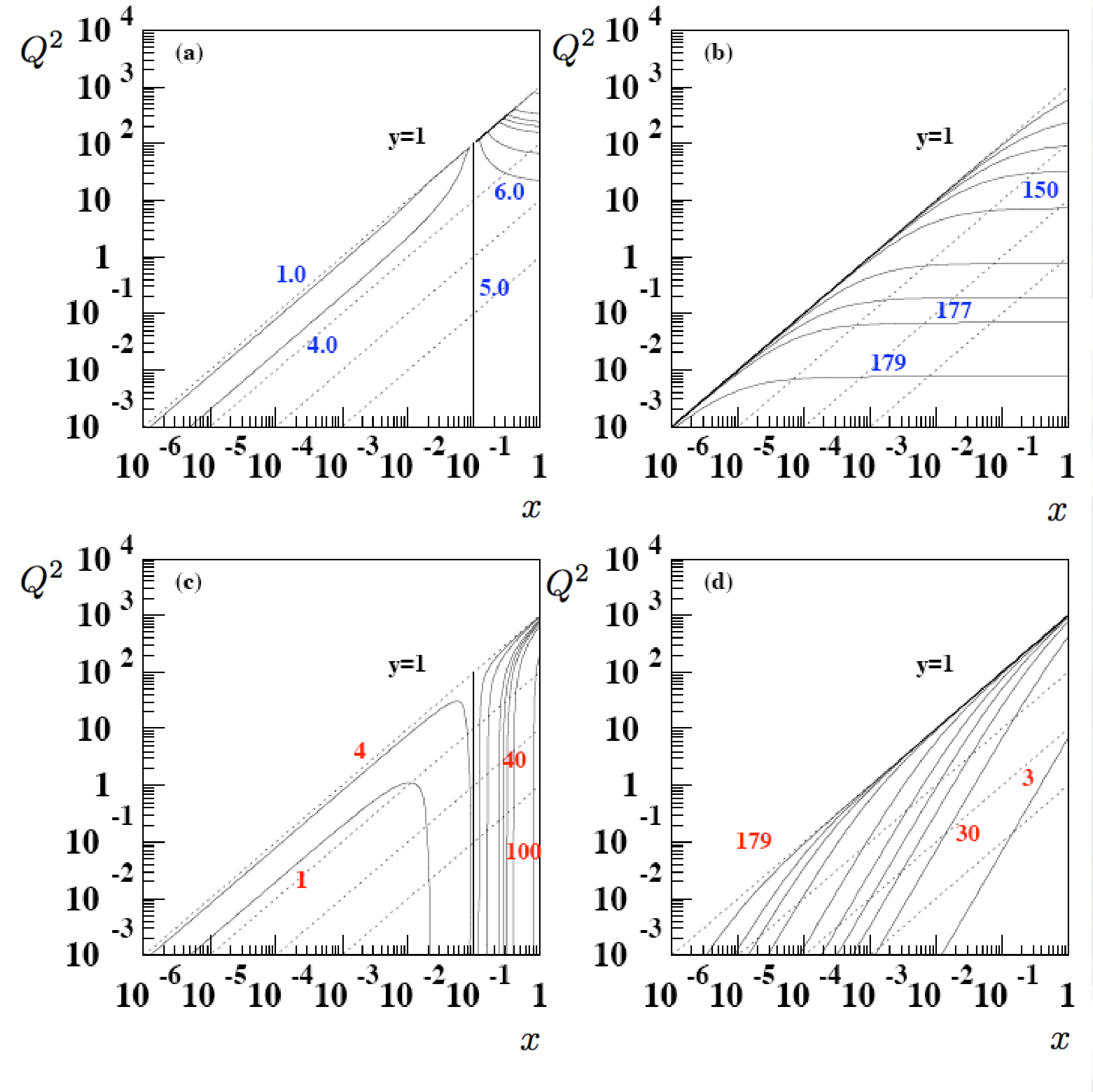
Rear tagging system

Trigger/DAQ

Forward tagging system

Backup

- Event kinematics (5GeV electron on 50GeV proton)

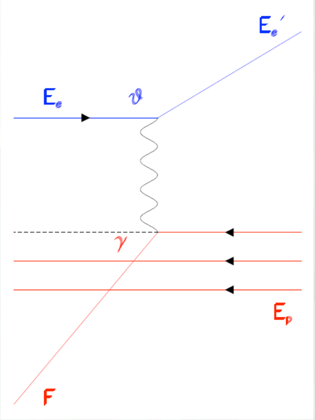


Lines of constant electron energy (E'_e)

Lines of constant electron angle (ϑ'_e)

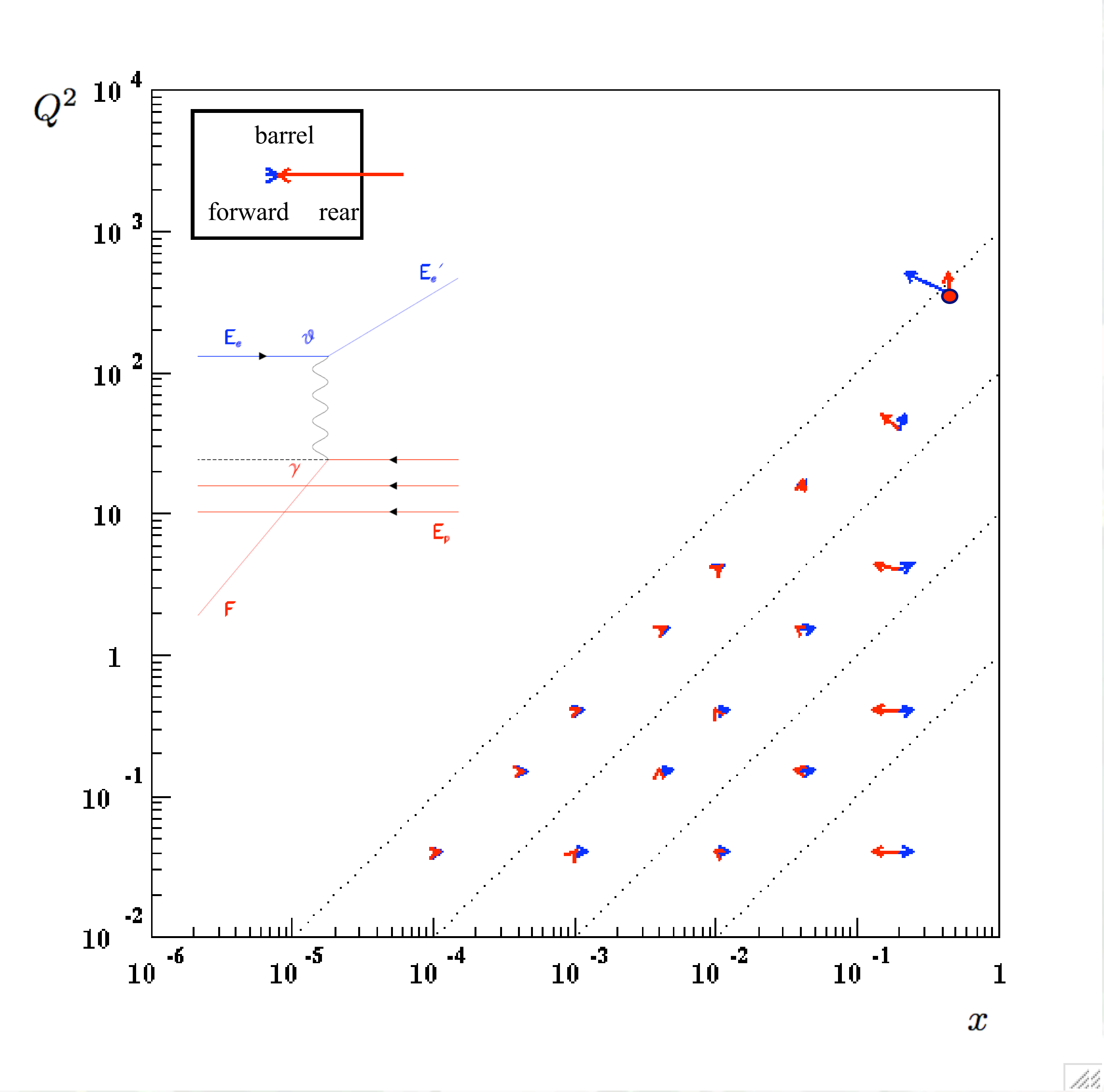
Lines of constant hadron energy (F)

Lines of constant hadron angle (γ)



Backup

- Event topology (5GeV electron on 50GeV proton)



- Low-x-low Q^2: Electron and current jet (low energy) predominantly in rear direction

- High-x-low Q^2: Electron in rear and current jet (High energy) in forward direction

- High-x-high Q^2: Electron predominantly in barrel/forward direction (High energy) and current jet in forward direction (High energy)

●

$Q^2 = 361 GeV^2 \quad x = 0.45$

$E_e' = 19 GeV \quad F = 8.5 GeV$

$\vartheta_e' = 26° \quad \vartheta_h = 87°$