eRHIC
-
Machine
and
Detector design aspects

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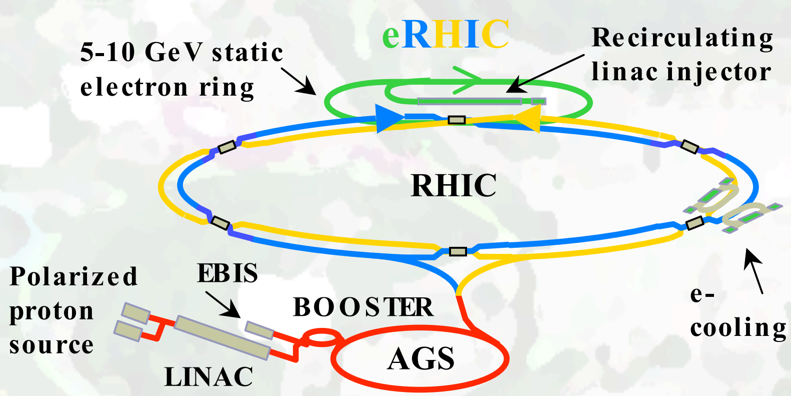
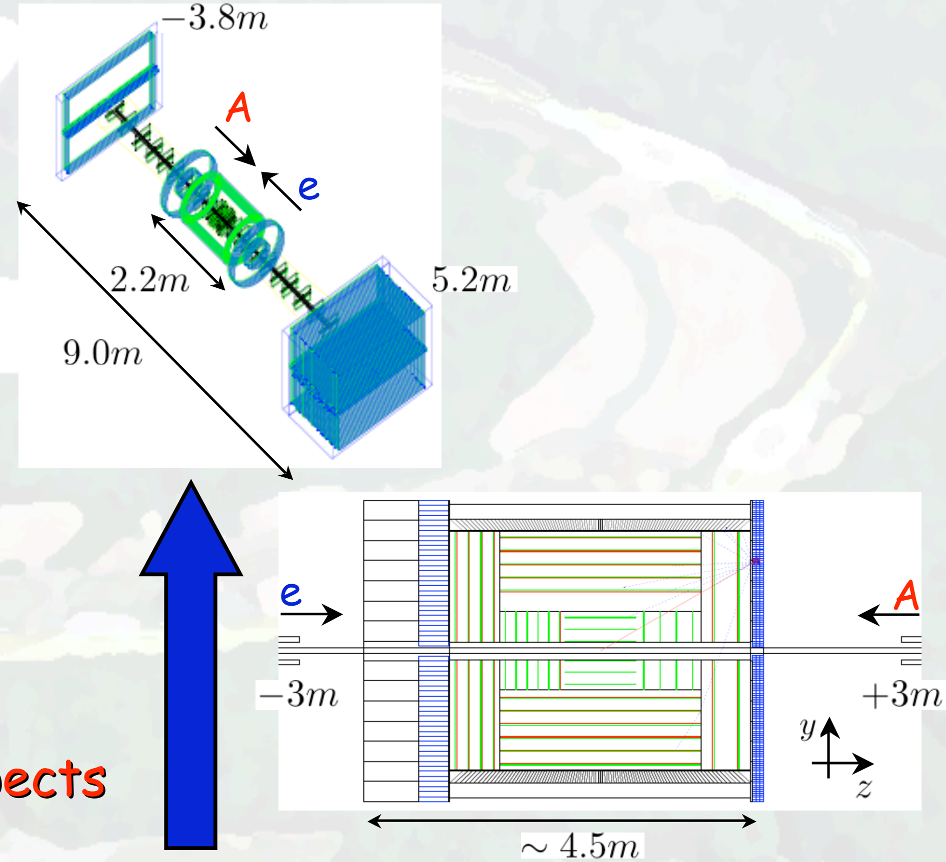
Technology



Outline

- **Introduction**
  - **eRHIC - Machine design aspects**
    - General design considerations
    - Ring-ring design
    - IR design
    - Ring-linac design
    - Polarimetry
  - **eRHIC - Detector design aspects**
    - General considerations
    - Design 1: Forward physics (unpolarized eA MPI-Munich group)
    - Design 2: General purpose (unpolarized/polarized ELECTRon-A)



- **Summary and Outlook**

eRHIC - Machine design aspects

Introduction

- First detailed document (252 pages) reporting on the eRHIC accelerator and interaction region (IR) design studies
- Collaborative effort between BNL, MIT-Bates, BINP and DESY
- Goal:
  - Develop an initial design for eRHIC
  - Investigate accelerator physics issues most important to its design
  - Evaluate luminosities that could be achieved with minimal R&D effort including IR design
  - Identify specific R&D extensive accelerator aspects which could lead to significantly higher luminosities
- Review planned in June 2005
- ZDR0 WWW-link:

eRHIC

Zeroth-Order Design Report

BNL: L. Ahrens, D. Anderson, M. Bai, J. Beebe-Wang, I. Ben-Zvi, M. Blaskiewicz, J.M. Brennan, R. Calaga, X. Chang, E.D. Courant, A. Deshpande, A. Fedotov, W. Fischer, H. Hahn, J. Kewisch, V. Litvinenko, W.W. MacKay, C. Montag, S. Ozaki, B. Parker, S. Peggs, T. Roser, A. Ruggiero, B. Surrow, S. Tepikian, D. Trbojevic, V. Yakimenko, S.Y. Zhang
MIT-Bates: W. Franklin, W. Graves, R. Milner, C. Tschalaer, J. van der Laan, D. Wang, F. Wang, A. Zolfaghari and T. Zwart
BINP: A.V. Otboev, Yu.M. Shatunov
DESY: D.P. Barber

Editors: M. Farkhondeh (MIT-Bates) and V. Ptitsyn (BNL)

http://www.bnl.gov/eic/

eRHIC - Machine design aspects

General design considerations

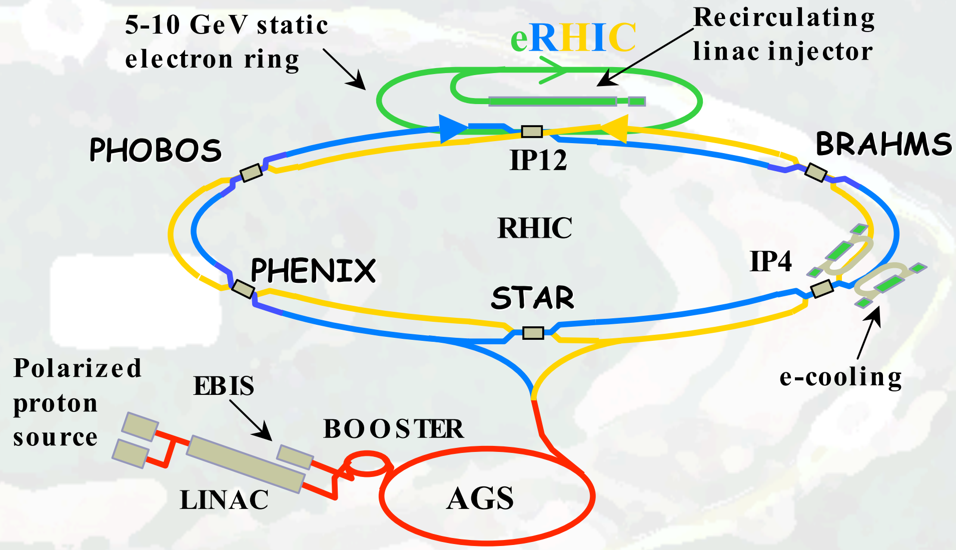
- Provide ep/eA collisions
  - Polarized (transverse/longitudinal up to 70%) electron (5-10GeV)/positron (10GeV)
  - Polarized (transverse/longitudinal up to 70%) protons (50-250GeV) and potentially polarized ^{3}He
  - Light and heavy nuclei (e.g. Au) 100GeV/u

  } Variable centre-of-mass energy: 30-100GeV
- Main design option: 10GeV electron/positron storage ring
  - Electron beam injector system: Recirculating linac and polarized electron source
  - Polarized positron beam at 10GeV: Self-polarization mechanism in storage ring
  - Luminosities: ep (10^{32} - 10^{33}cm^{-2}s^{-1}) (10GeV on 250GeV) and eA (10^{30} - 10^{31}cm^{-2}s^{-1}) 10GeV on 100 GeV/u)
- Alternative design option: Energy recovery superconducting linac (ERL)
  - Preliminary estimates suggest:ep (~10^{34}cm^{-2}s^{-1}) and eA (~10^{32}cm^{-2}s^{-1})
  - Significant R&D effort necessary for polarized electron source and energy recovery technology for high energy and high current beams (Long-term)

eRHIC - Machine design aspects

Ring-ring design (1)

- RHIC:
  - 3834m circumference
  - 10.8-100GeV/u ions
  - 25-250GeV polarized protons
- Electron storage ring design
  - Intersection with RHIC blue beam
  - RHIC Yellow beam: 3m excursion around IR region
  - Injection system: Polarized electron source and recirculating linac including conversion system for positrons
  - Storage energy: 5-10GeV (electrons)
  - Self-polarization of positrons in storage ring (20min. at 10GeV) injected at 10GeV
  - Spin rotator setup in e-ring and blue RHIC ring around eRHIC IR region



- Required modifications at RHIC:
  - Electron cooling system: Achieve and maintain small beam emittances
  - Increase of total current: Increasing the number of bunches from 120 (present design) to ultimately 360 bunches consistent with RF frequency of the present RF system
  - Additional spin rotator magnets in ep interaction region

eRHIC - Machine design aspects

Ring-ring design (2)

- Luminosity considerations:
  - General expression: $\mathcal{L} = \frac{f_c n_i n_e}{4\pi\sigma_x\sigma_y}$
  - Luminosity limitation due to beam-beam effects and interaction region magnet aperture limitations
  - Luminosity in terms of beam-beam parameters (ξ) and rms angular spreads in the IR region (σ'):

$$\mathcal{L} = f_c \frac{\pi\gamma_i\gamma_e}{r_i r_e}\xi_i\xi_e\sigma_i'\sigma_e'\frac{(1+K)^2}{K}$$

$K = \sigma_y/\sigma_x$ Beam aspect ratio at IP

    - For protons: Limit for beam-beam parameter: 0.02 (Experience from other proton machines and initial experience at RHIC)
    - For electrons: Limit for beam-beam parameter: 0.08 at 10GeV (Beam-beam simulations and experience from other electron machines)
  - Matched beam sizes at the IP (IR design: Low beta focusing for elliptical beams K=1/2)
  - Collision frequency: With 120 bunches in electron ring and 360 bunches in RHIC: f_c=28.15MHz

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- Ring-ring design (3): ep beam parameters

	High energy setup		Low energy setup	
	p	e	p	e
Energy (GeV)	250	10	50	5
Bunch intensity (10^{11})	1	1	1	1
Ion normalized emittance π mm · mrad, x/y	15/15		5/5	
Rms emittance, nm, x/y	9.5/9.5	53/9.5	16.1/16.1	85/38
β^*, cm, x/y	108/27	19/27	186/46	35/20
Beam-beam parameters, x/y	0.0065/ 0.00325	0.029/ 0.08	0.019/ 0.0095	0.036/ 0.04
$k = \varepsilon_y/\varepsilon_x$	1	0.18	1	0.45
Luminosity ($10^{32}cm^{-2}s^{-1}$)	4.4		1.5	

High energy setup: No cooling, 2 p-p IPs assumed

Low energy setup: Cooling needed, No p-p IPs allowed

eRHIC - Machine design aspects

- Ring-ring design (4): eAu beam parameters

	High energy setup		Low energy setup	
	Au	e	Au	e
Energy (GeV/u)	100	10	100	5
Bunch intensity (10^{11})	0.01	1	0.0045	1
Ion normalized emittance π mm · mrad, x/y	6/6		6/6	
Rms emittance, nm, x/y	9.5/9.5	54/7.5	9.5/9.5	54/13.5
β^*, cm, x/y	108/27	19/34	108/27	19/19
Beam-beam parameters, x/y	0.0065/ 0.0035	0.0224/ 0.08	0.0065/ 0.0035	0.02/ 0.04
$k = \varepsilon_y/\varepsilon_x$	1	0.14	1	0.25
Luminosity (10^{30}, $cm^{-2}s^{-1}$)	4.4		2.0	

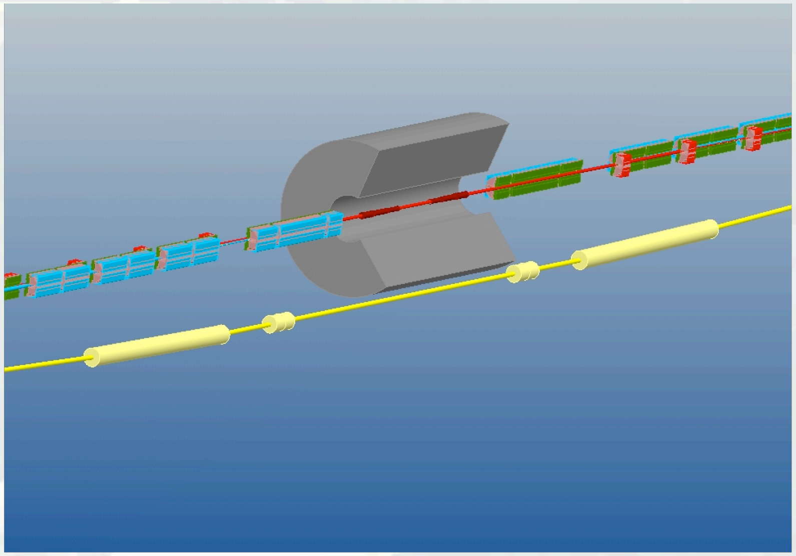
⇒ Electron cooling of Au beam is required to achieve and maintain Au emittance values!

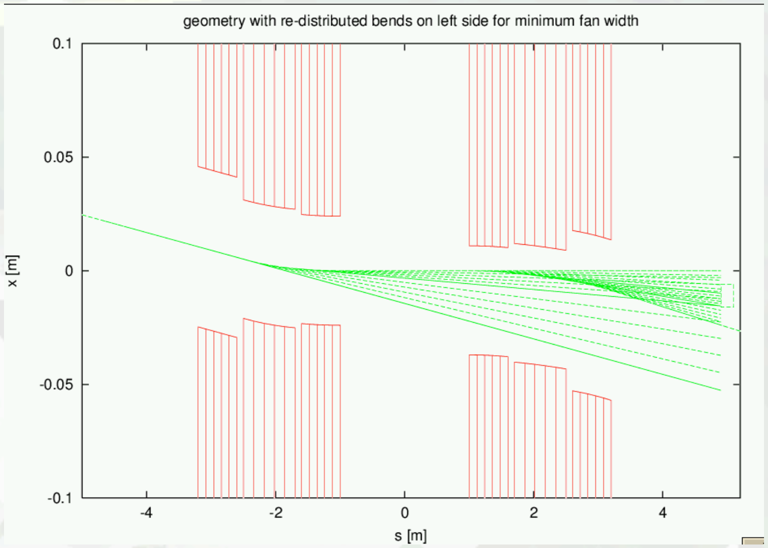
eRHIC - Machine design aspects

IR design (1)

Beam separation

- Cross-angle could in principle be used:
  - Required angle: 5mrad
  - Use crab-crossing scheme (Rotate ion bunch into direction of electron beam): Required deflecting RF voltage: $V_{\perp}$=14.4MV $\Rightarrow$ Factor 10 larger then for KEKB crab cavities
  - Therefore: Design IR region with zero crossing angle
- S over C shaped bending preferred
- Initial design: Dipole winding in the superconducting electron low-β quadrupoles
  - Problem: ±1m machine element free region



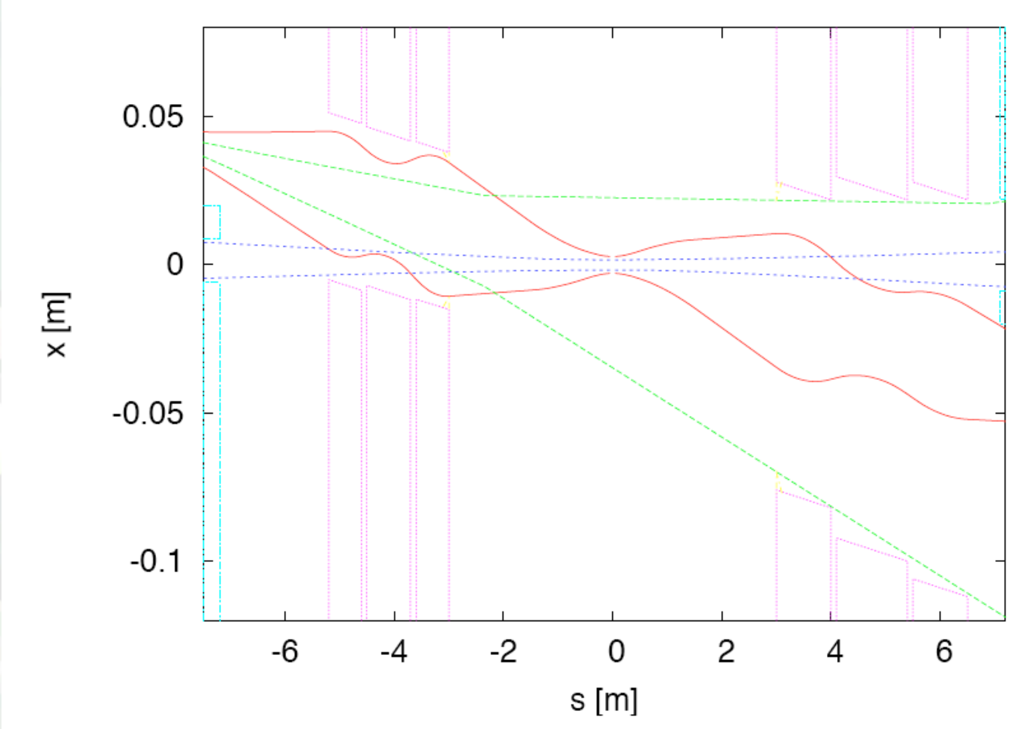


eRHIC - Machine design aspects

IR design (2)

- Beam separation cont.
  - Recent idea: Dipole coils superimposed on detector solenoid
  - Advantage: ±3m machine element free region
  - Preliminary estimate of luminosity reduction: Factor 2
- Accomodation of synchrotron radiation generated by beam separation
- Beam focusing
  - Electron beam: Superconducting quadrupole triplet configuration around IR (ZDR0 design: ±1m - Recent idea: ±3m)
  - Hadron beam: Normal conducting septum-quadrupole triplet configuration (ZDR0 design: ±5m - Recent idea: ±7.2m)

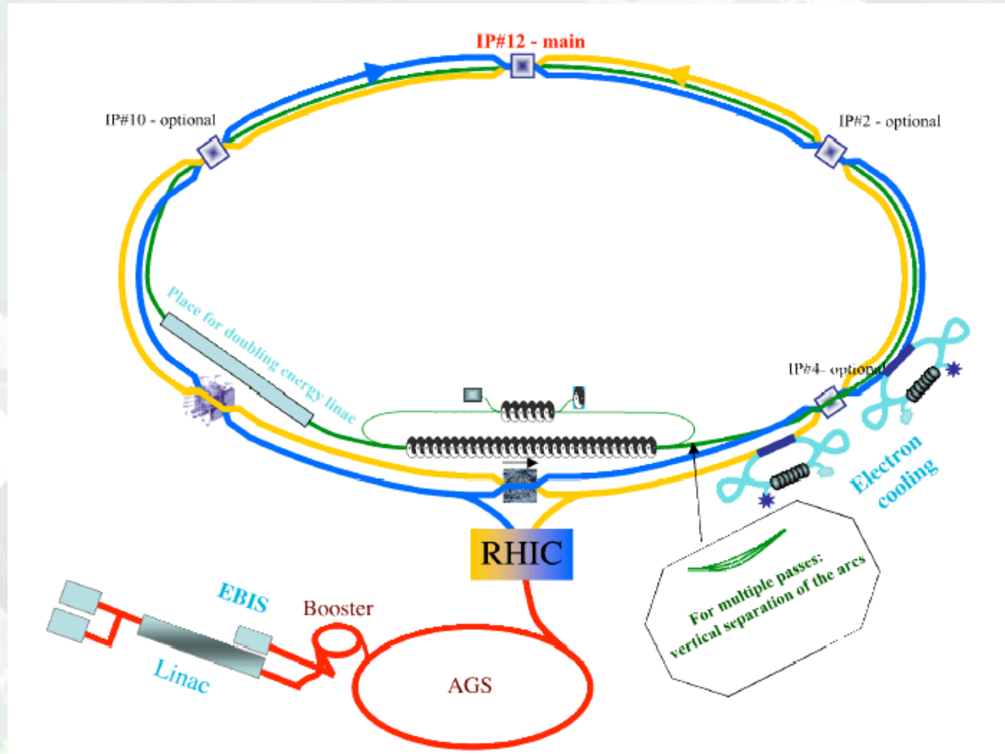
C. Montag, B. Parker



eRHIC - Machine design aspects

Ring-linac design (1)

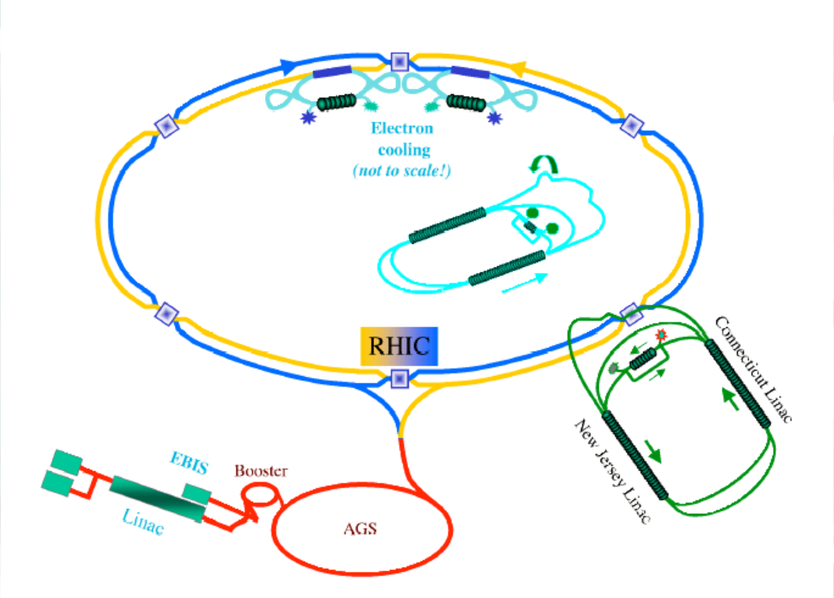
- Two possible designs are presented in the ZDR Appendix A (V. Litvinenko et al.)
- Electron beam is transported to collision point(s) directly from superconducting energy recovery linac (ERL)
- Features:
  - High degree of polarization at any energy (>80%)
  - Machine elements free region approx. ±5m
  - Simpler IR region design: Round beams possible
  - Upgrade to higher energies beyond 10GeV possible
  - Multiple interaction regions
  - No positrons



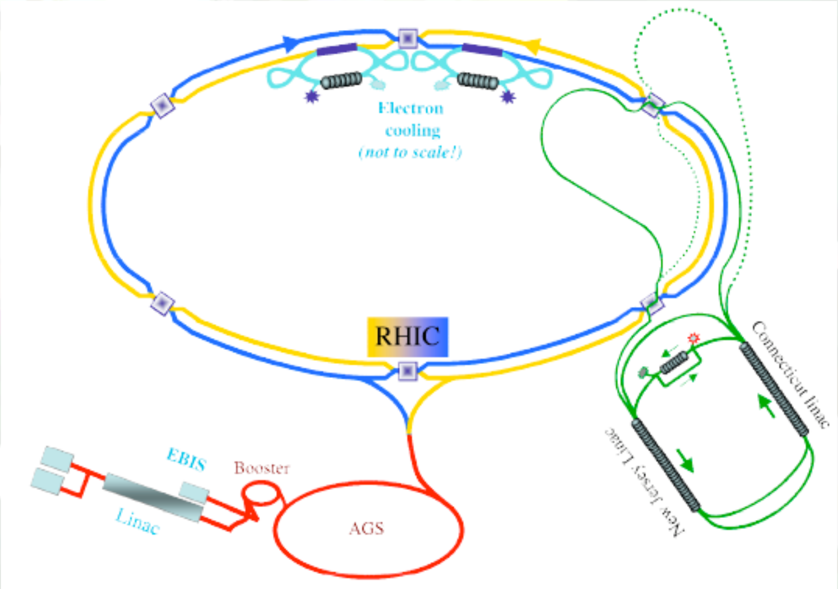
eRHIC - Machine design aspects

Ring-linac design (2)

- High luminosity:
  - No beam-beam limitation for electron beam (Use "fresh" electron beam)
  - Up to 10^{34} $cm^{-2}s^{-1}$ for ep and 10^{32} $cm^{-2}s^{-1}$ for eAu
- R&D issues:
  - High current polarized electron source
  - Energy recovery technology for high energy and high current beams



One IR configuration

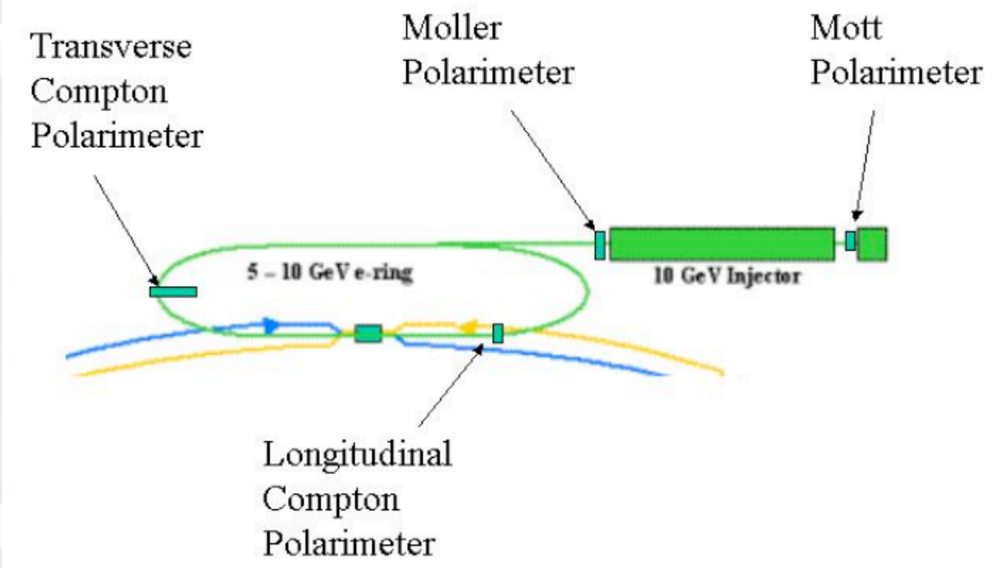


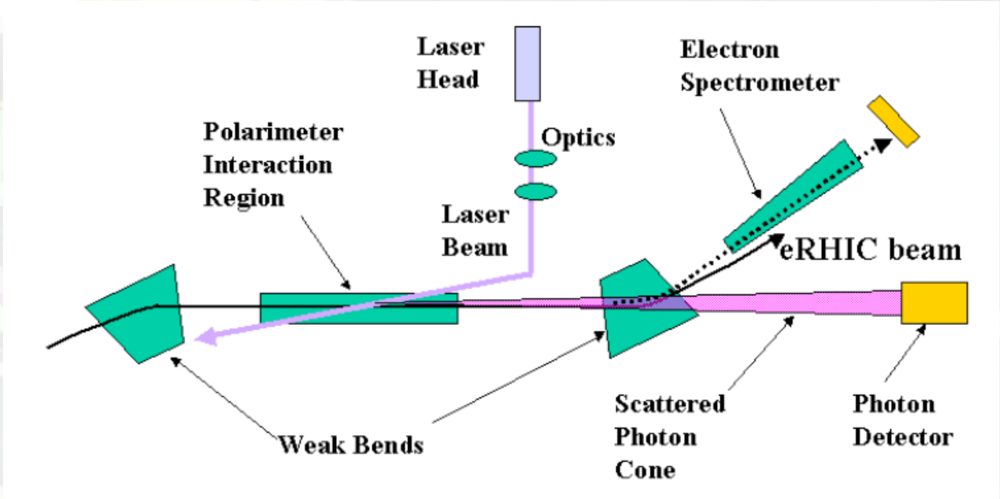
Two IR configuration

eRHIC - Machine design aspects

eRHIC Polarimetry

- Two category of measurements:
  - Prior to injection into electron storage ring:
    - Mott polarimeter
    - Moller polarimeter (SLAC, Jlab)
  - During storage:
    - Compton scattering of laser photons from stored beam
    - Two arrangements:
      - Longitudinal polarimeter
      - Transverse polarimeter
    - Successfully employed at HERA



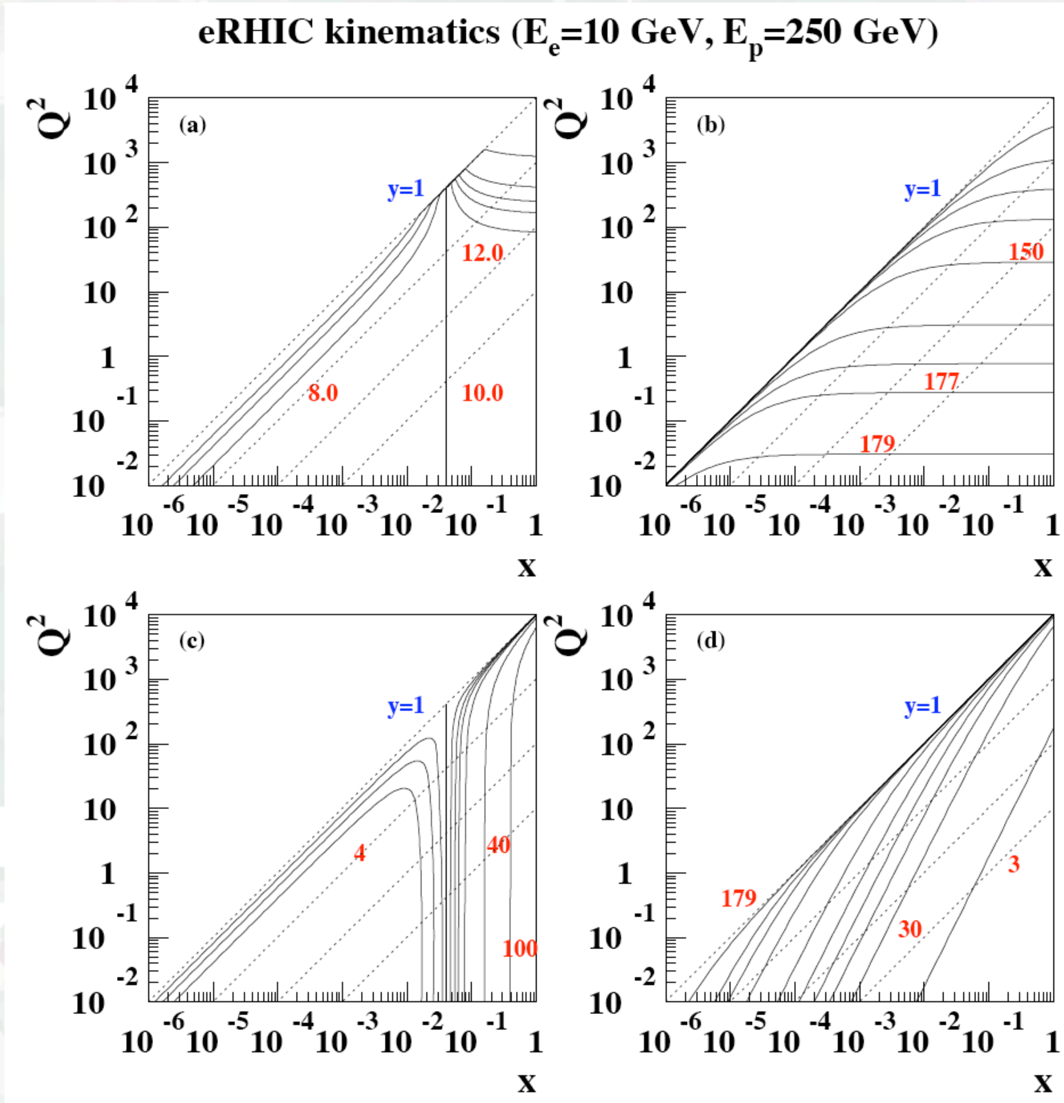


eRHIC - Detector design aspects

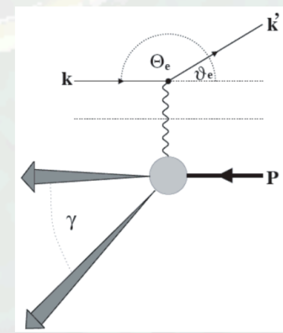
- General considerations (1)

Lines of constant electron energy

Lines of constant hadron energy



Lines of constant electron angle (θ_e)



Lines of constant hadron angle (γ)

eRHIC - Detector design aspects

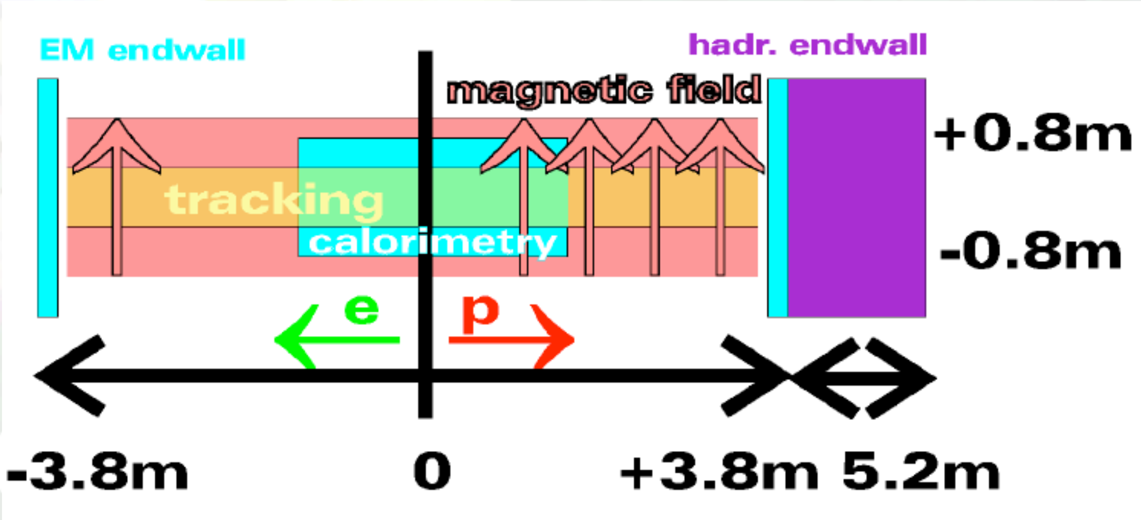
General considerations (2)

- 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) and Physics beyond the SM (Hermetic detector)
- Zero-degree photon detector to control radiative corrections
- 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 ideas!

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

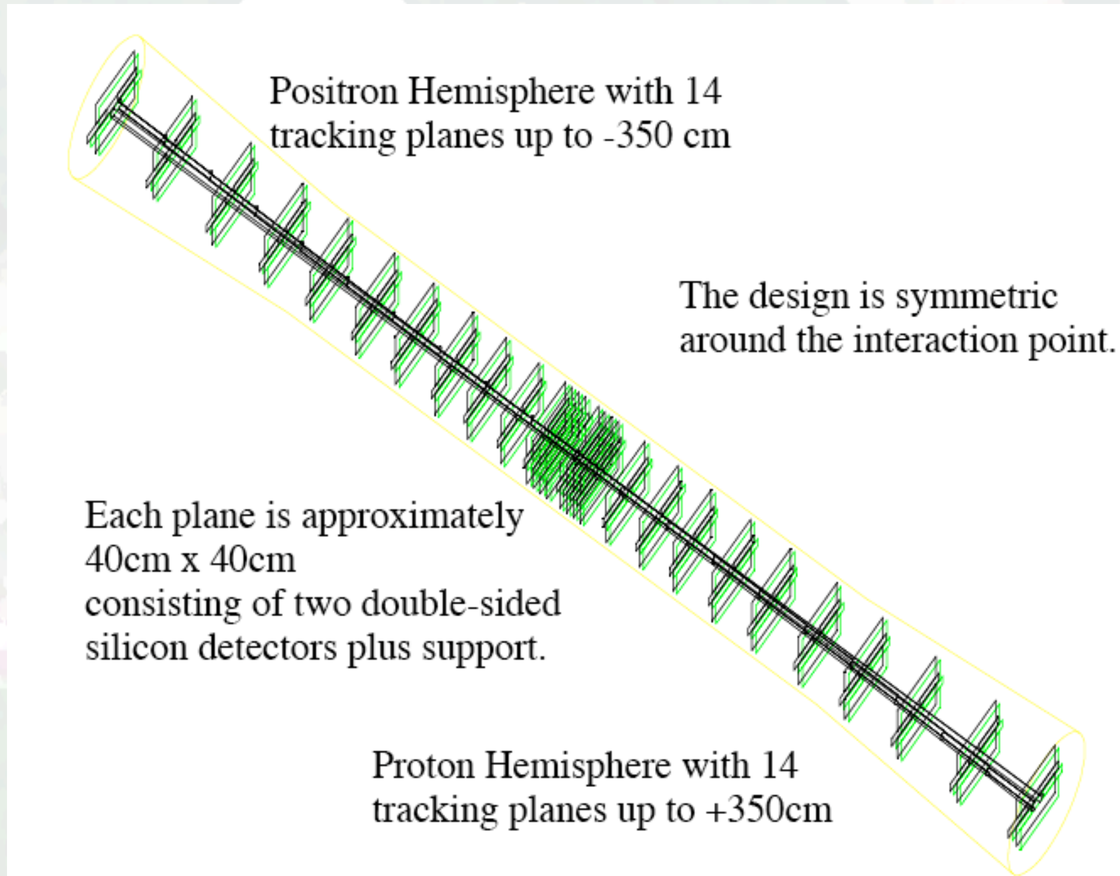


eRHIC - Detector design aspects

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

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

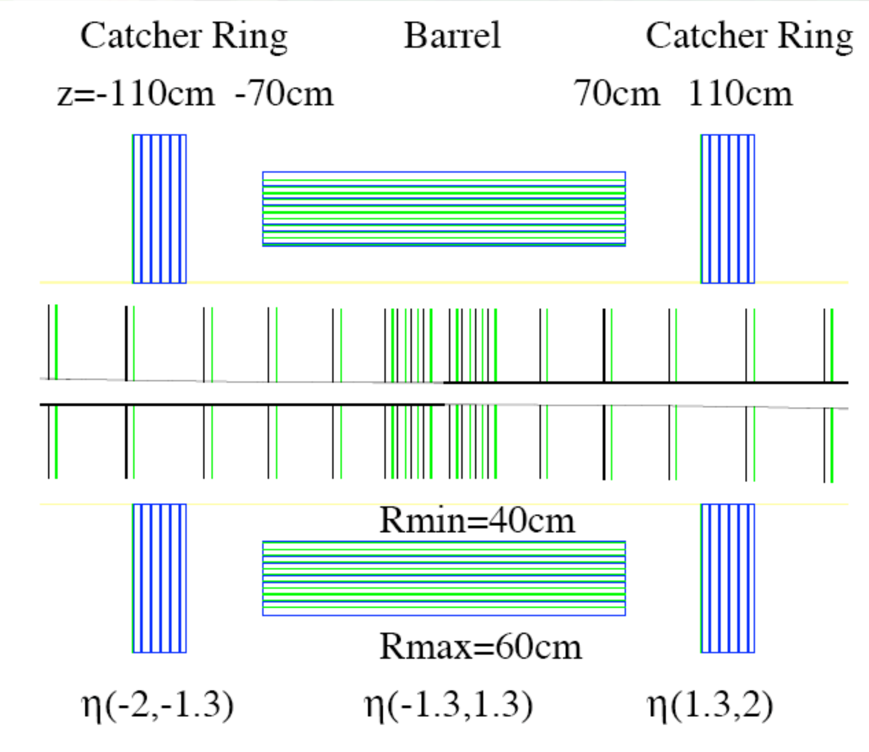
- Tracking system:
  - High-precision tracking with $\Delta p_T/p_T \sim 2\%$
  - Angular coverage down to $\eta \approx 6$ over the full energy range
  - Concept: 14 Si-strip tracking stations (40 X 40 cm)
  - Assumed hit resolution: 20μm
  - Momentum resolution from simulations: Few percent!

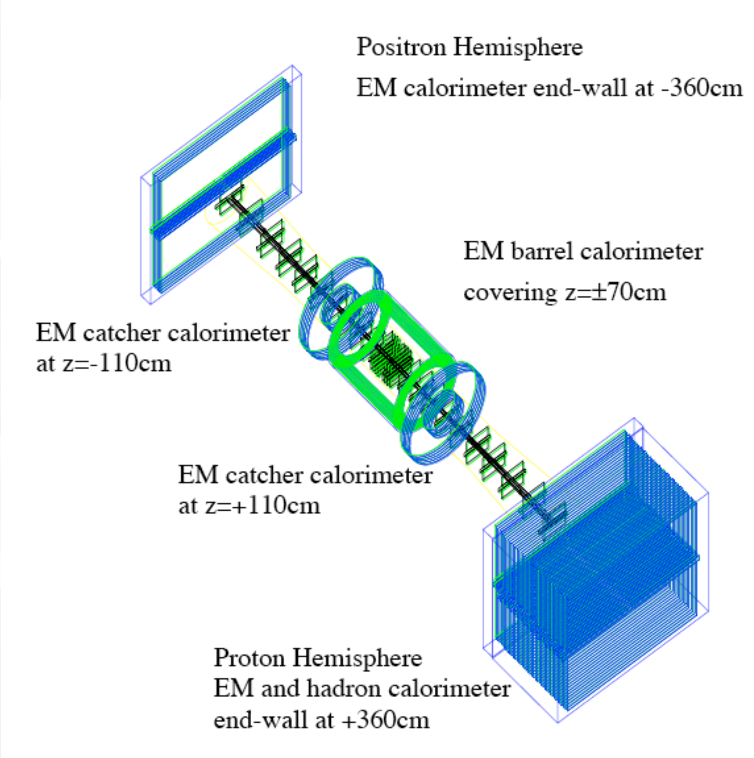


eRHIC - Detector design aspects

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



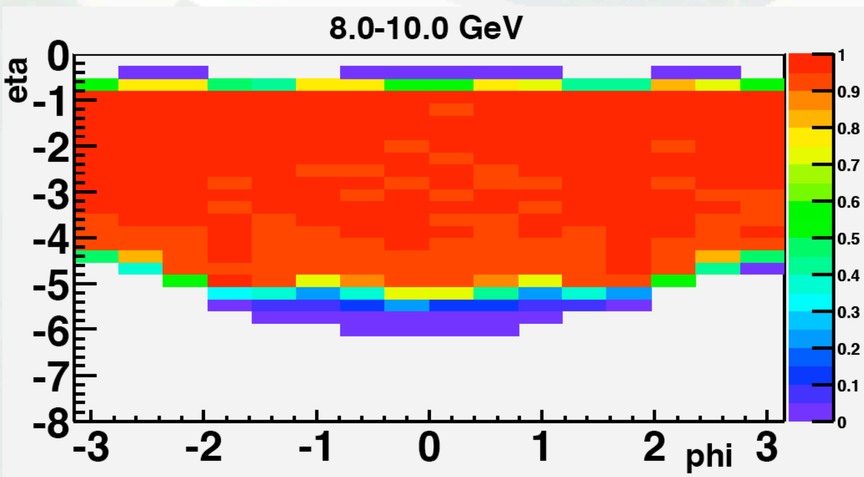


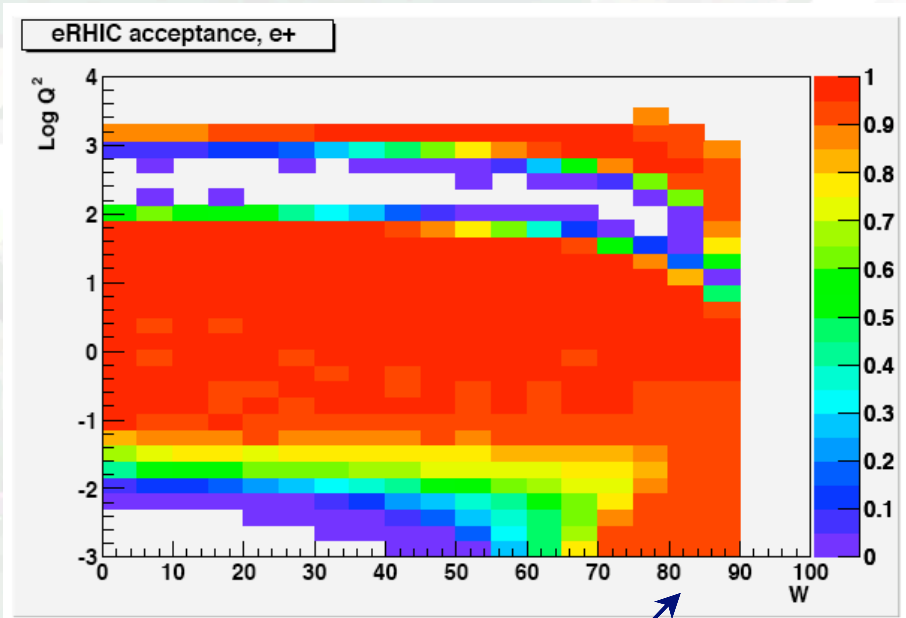
eRHIC - Detector design aspects

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 $|\eta| > 0.75$ - No acceptance in central region $|\eta| < 0.5$
  - 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:

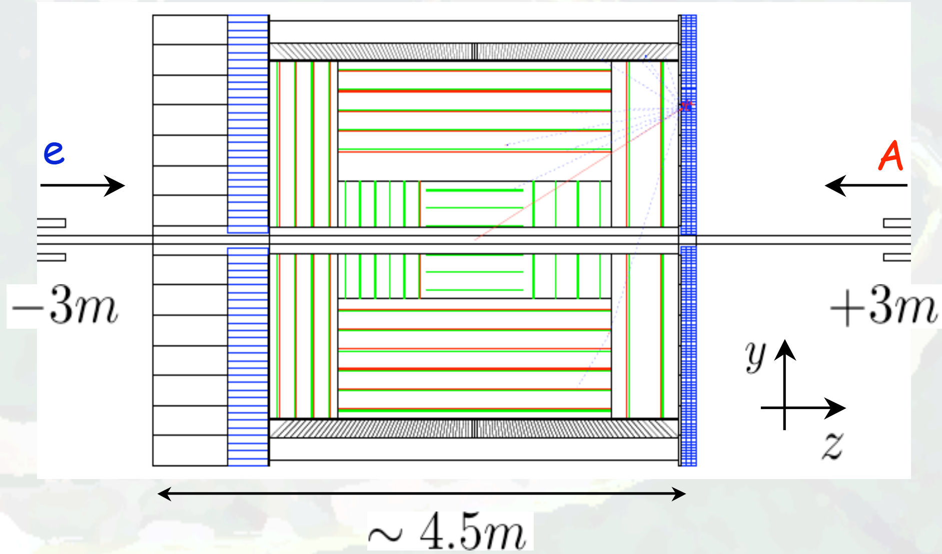
- Full efficiency below 6GeV for $\eta < -8$
- For larger energies, full efficiency for $\eta < -5$

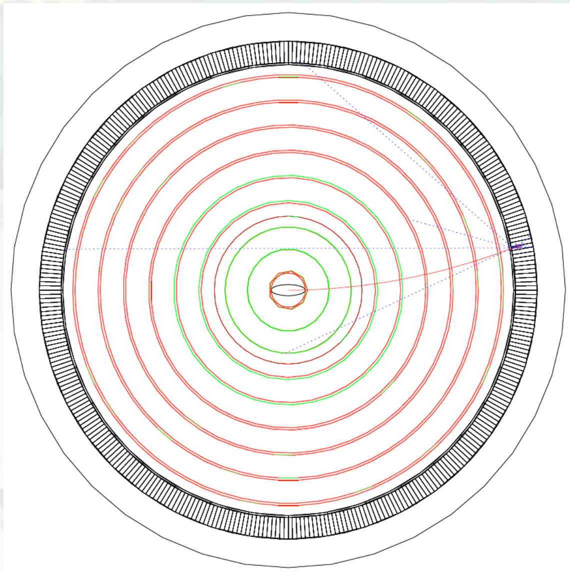
eRHIC - Detector design aspects

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
    - Forward EM/hadron calorimeter: e.g. Pb-scintillator
    - Tracking system and barrel EM inside solenoid magnetic field
    - Tracking system based in high-precision Si (inner) and micro-pattern technology (Triple-GEM) (outer)

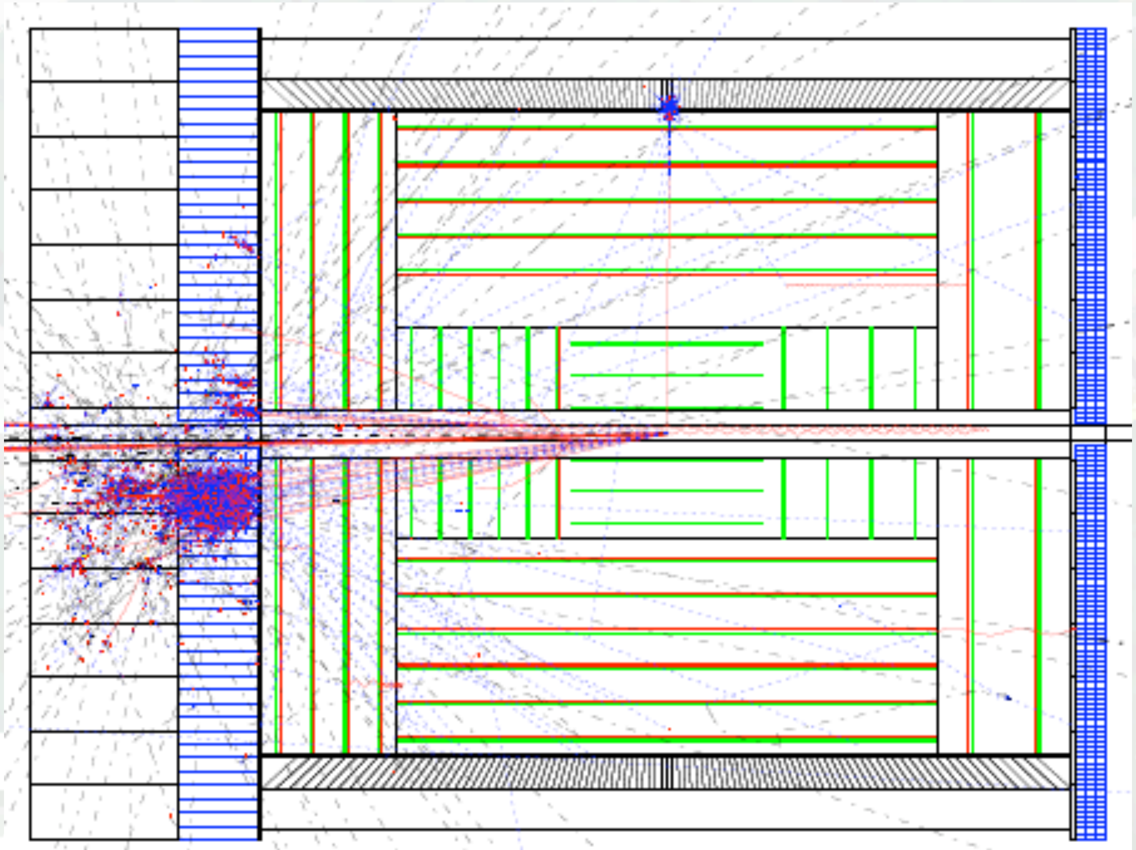




eRHIC - Detector design aspects

J. Pasukonis, B.S.

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



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

Lower Q^2 acceptance ≈ 0.1GeV2

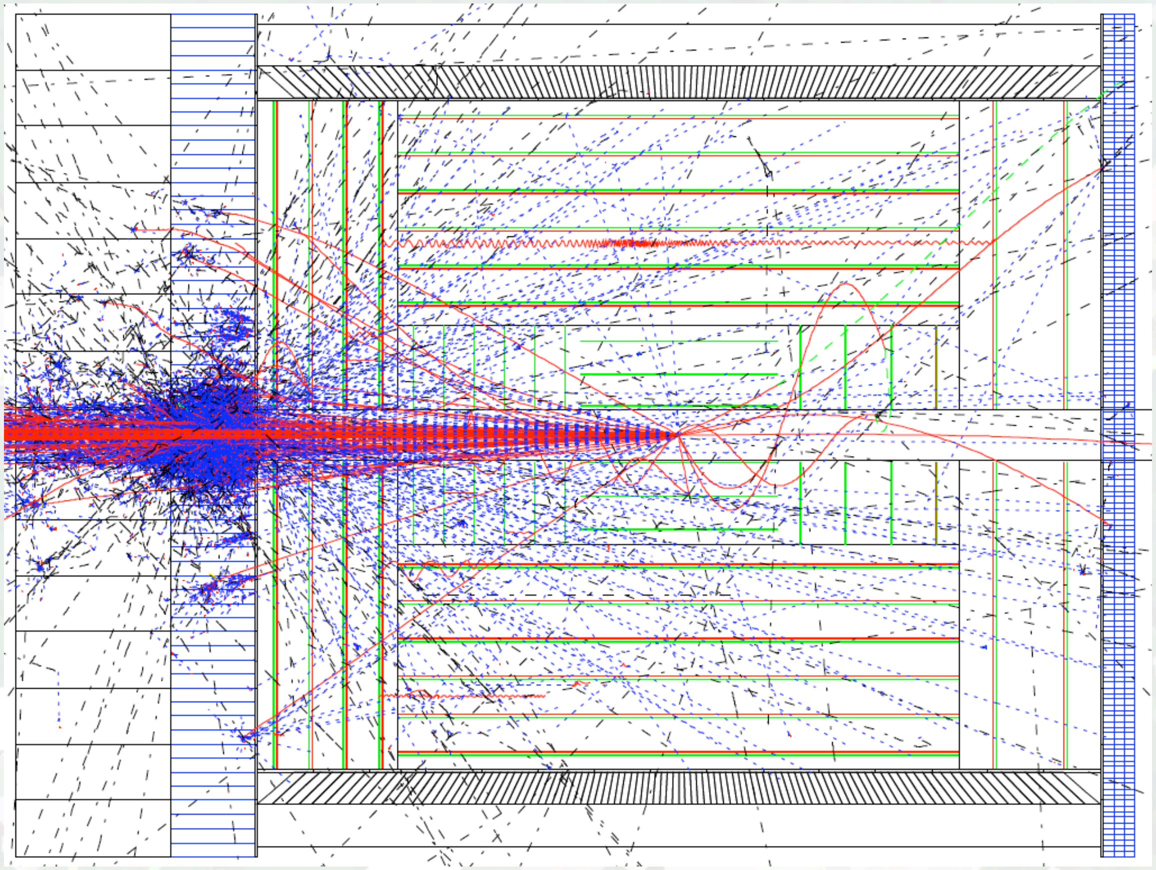
DIS generators used so far:

- LEPTO
- DJANGO

eRHIC - Detector design aspects

J. Pasukonis,
B.S.

- Design 2: General purpose (unpolarized/polarized ELECTRon-A) (3)
  - Simulated eCa event (VNI)



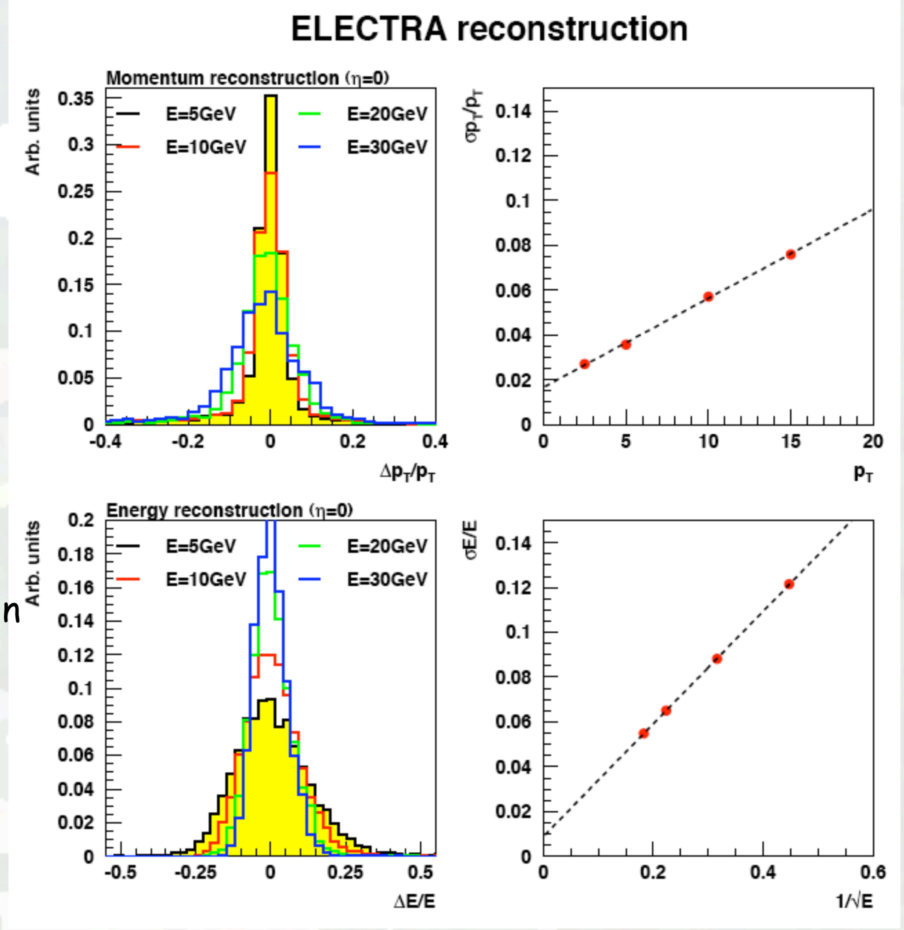
eRHIC - Detector design aspects

J. Pasukonis,
B.S.

Design 2: General purpose (unpolarized/polarized ELECTRon-A) (4)

- 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/
  - Help welcome on:
    - Evaluate and optimize detector configuration
    - Design of forward tagging system and needed particle ID systems for various exclusive processes
    - In particular for eA events: Optimize forward detector system for high-multiplicity environment



Summary and Outlook

Machine design:

- First detailed document (252 pages) reporting on the eRHIC accelerator and interaction region (IR) design studies
  - Ring-ring option
  - Linac-ring option
- Collaborative effort between BNL, MIT-Bates, BINP and DESY

Detector design:

- Well-developed design of a Forward detector system focusing on low-x / high-x physics
- Design of a compact detector started: Detector simulation and reconstruction framework: ELECTRA (CVS repository http://starmac.lns.mit.edu/~erhic/electra/)
- Goal: NSAC NRL (2005-2006) input and CD0 preparation
- Participation (In particular HERA community) very welcome on detector/IR design:
  - More information: (http://www.bnl.gov/eic/)

Backup slides

- IR design parameters

Table 4.1: Magnet parameters for the electron triplets.

	QE1	QE2	QE3
length [m]	0.6	0.8	0.6
gradient [T/m]	83.3	76.7	56.7
radius [mm]	24	26	35
bending angle left/right [mrad]	2.50/-2.74	5.30/-2.02	0.0/-4.19
shift w.r.t. detector axis left/right [mm]	0/-10	0/-10	0/-10
tilt w.r.t. detector axis left/right [mrad]	1.25/-1.37	3.90/-2.38	3.90/-4.48
synchrotron radiation power left/right [W]	735/882	2475/360	0/2063
synchr. rad. power on septum left/right [W]	466/360	0/360	0/0
critical photon energy left/right [keV]	9.3/10.1	14.7/5.6	0/15.5

Table 4.2. Parameter list of the hadron low-β septum quadrupoles

	Q1	Q1B	Q1C	Q2	Q2B	Q2C	Q2D	Q2F	Q2G
length [m]	0.8	2.8	1.2	1.5	1.5	1.5	1.5	1.5	1.5
gradient [T/m]	58.3	41.7	33.3	20.2	17.0	16.2	16.2	16.2	17.0
pole tip radius [mm]	17.1	24.0	30.0	49.4	58.9	61.8	61.8	61.8	58.9
pole tip field [T]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Backup slides

Court. T. Roser

- e cooling

Intra-Beam Scattering:
The ions collide with each other, leading to accumulation of random energy (heat) derived from the guide fields and the beam's energy.

Electron cooling:
The high-current high-brightness electron beam from an ERL will cool the RHIC ions in a high-precision, 26 m long superconducting solenoid.