Electron Beam Polarimetry for EIC/eRHIC

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- Introduction
- Polarimetry at HERA
- Lessons learned from HERA
- Polarimetry at EIC

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EIC Objectives

- e-p and e-ions collisions
- 5-10 GeV electrons: 25-250 Gev protons: 100 Gev/u Au
- Luminosity:
  - $L \approx 3 \cdot 10^{32} \frac{1}{\text{sec} \cdot \text{cm}^2}$ for e-p collisions
  - $L \approx 10^{30} - 10^{31} \frac{1}{\text{sec} \cdot \text{cm}^2}$ for e-Au collisions
- Polarized electron and proton beams
- Longitudinal polarization at collision point: 70%
- 35 nsec minimum separation between bunches

How to measure Polarization of e^-, e^+ beams?

- Macroscopic:
  - polarized electron bunch: very week dipole (~10^{-7} of magnetized iron of same size)

- Microscopic:
  - spin-dependent scattering processes
    simplest → elastic processes:
    - cross section large
    - simple kinematic properties
    - physics quite well understood
  - three different targets used currently:

1. e^- - nucleus:	Mott scattering	100 - 300 keV
2. $e^\pm$ - electrons:	Møller (Bhabha) Scat.	MeV - GeV
3. $e^\pm$ - photons:	Compton Scattering	> GeV

Other Labs employing Electron Polarimeters

Many polarimeters are or *have been* in use:

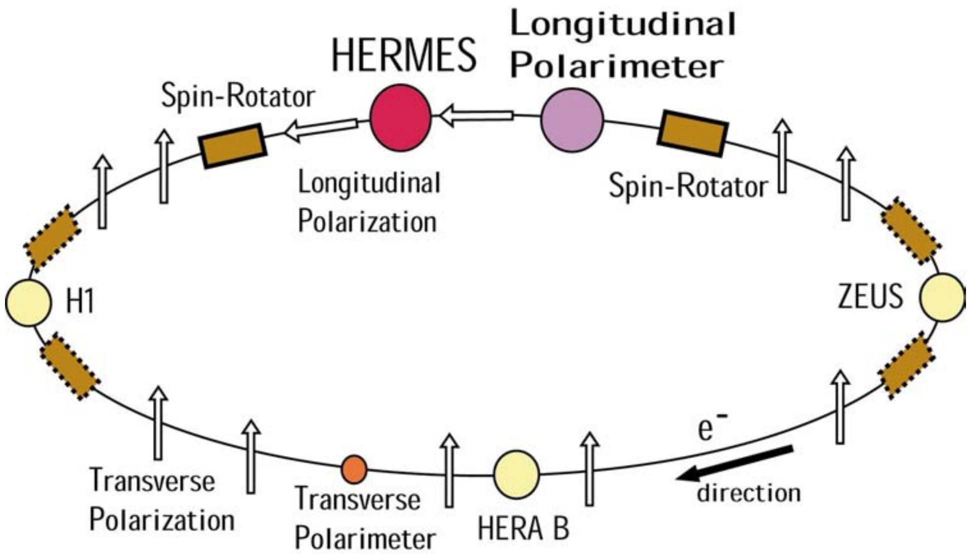
- Compton Polarimeters:

LEP	*mainly used as machine tool for resonant depolarization*
DESY	HERA, storage ring 27.5 GeV (two polarimeters)
Jlab	Hall A < 8 GeV
Bates	South Hall Ring < 1 GeV
Nikhef	*AmPS, storage ring < 1 GeV*

- Møller / Bhabha Polarimeters:

Bates	linear accelerator < 1 GeV
Mainz	Mainz Microtron MAMI < 1 GeV
Jlab	Hall A, B, C

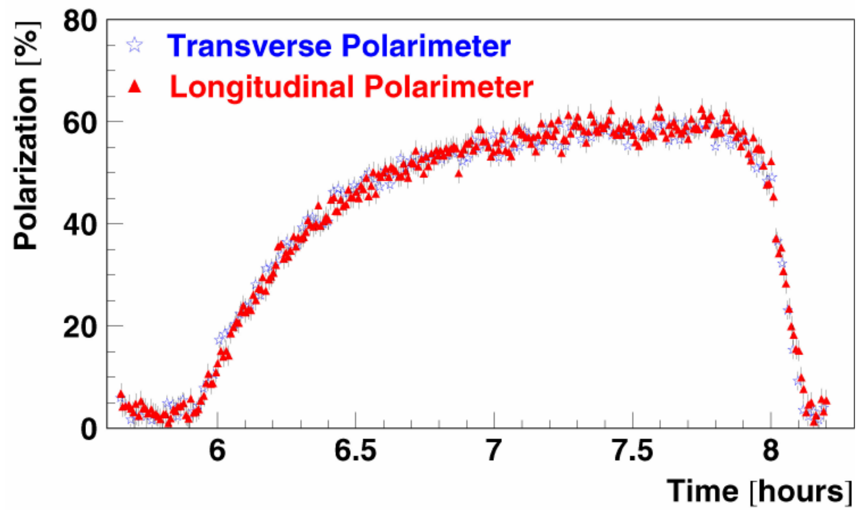
Electron Polarization at HERA



Self polarization of electrons by Synchrotron radiation emission in curved sections:

Sokolov-Ternov effect ($\tau \sim 30$ min.)

$$P(t) = P_\infty \cdot (1 - e^{-t/\tau})$$



Principle of the P_e Measurement with the Longitudinal Polarimeter

Compton Scattering:

$e + \lambda \rightarrow e' + \gamma$

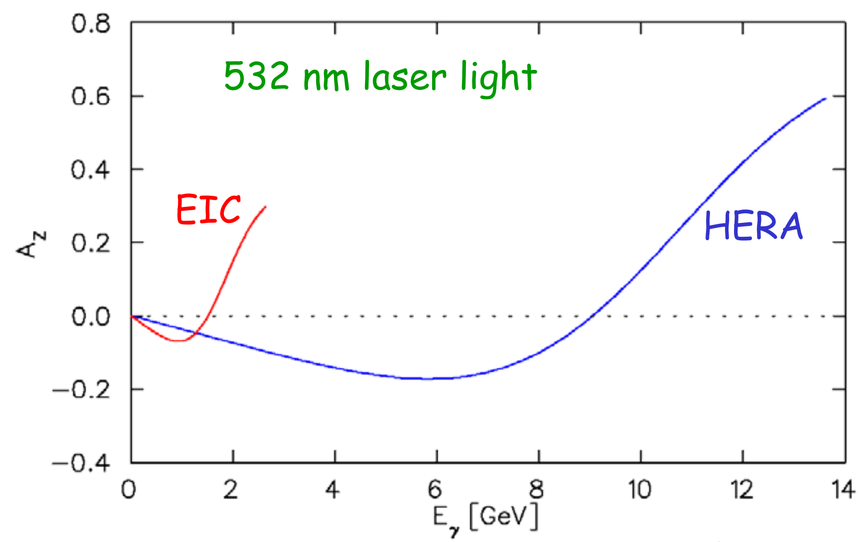
Cross Section:

$d\sigma/dE_\gamma = d\sigma_0/dE_\gamma[1 + P_e P_\lambda A_z(E_\gamma)]$

$d\sigma_0$, A_z: known (QED)

P_e: longitudinal polarization of e beam

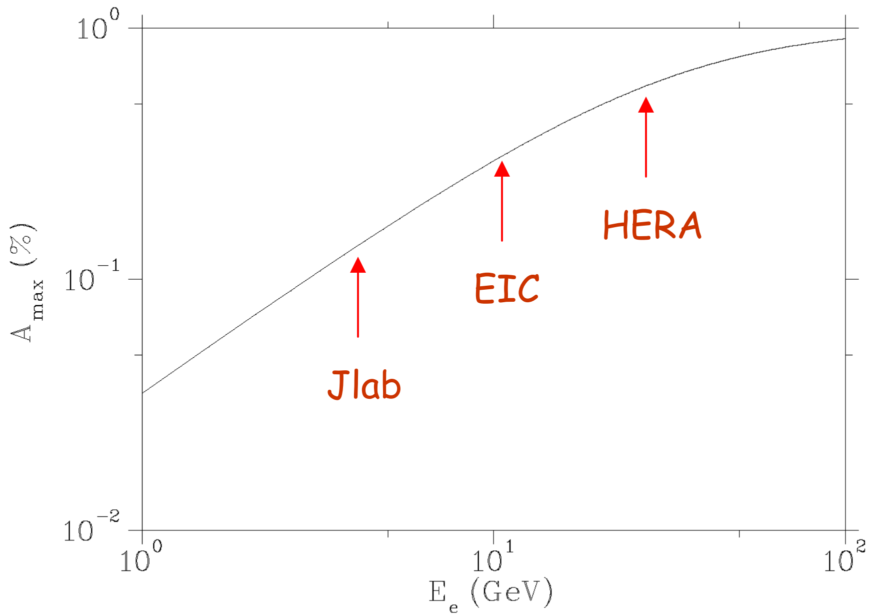
P_λ: circular polarization (± 1) of laser beam



Compton edge: $E_\gamma^{max} \propto E_e^2 E_\lambda$

Compton Polarimetry

- Detecting the γ at 0° angle
- Detecting the e$^-$ with an energy loss
- Strong $\frac{dA}{dE_\gamma}$ $\rightarrow$ good energy resolution for photons
- Photon energy cutoff
- Time need for a measurement:
  $T \propto 1/(\sigma \cdot A^2) \propto 1/E_\lambda^3 \times 1/E_e^4$
- Small crossing angle needed
- non-invasive measurement



Asymmetry: $A \propto E_e E_\lambda$

Very good polarimetry at high energy or/and high currents (storage rings)

Compton Polarimetry at HERA

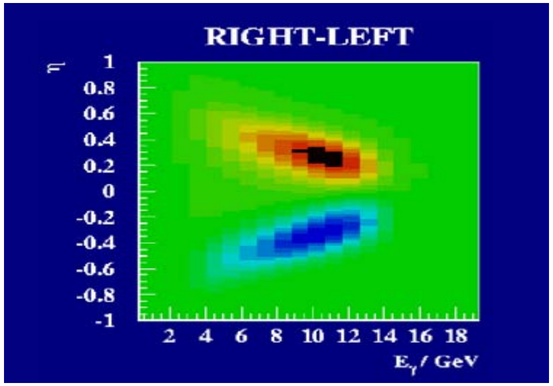
Operating Modes and Principles

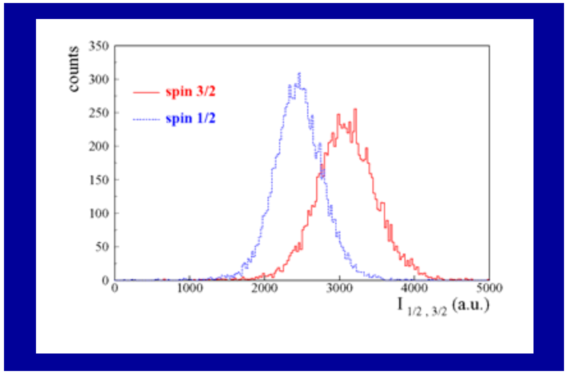
Laser Compton scattering off HERA electrons

TPOL	LPOL
CW Laser - Single Photon	Pulsing Laser - Multi Photon

Flip laser helicity and measure scattered photons

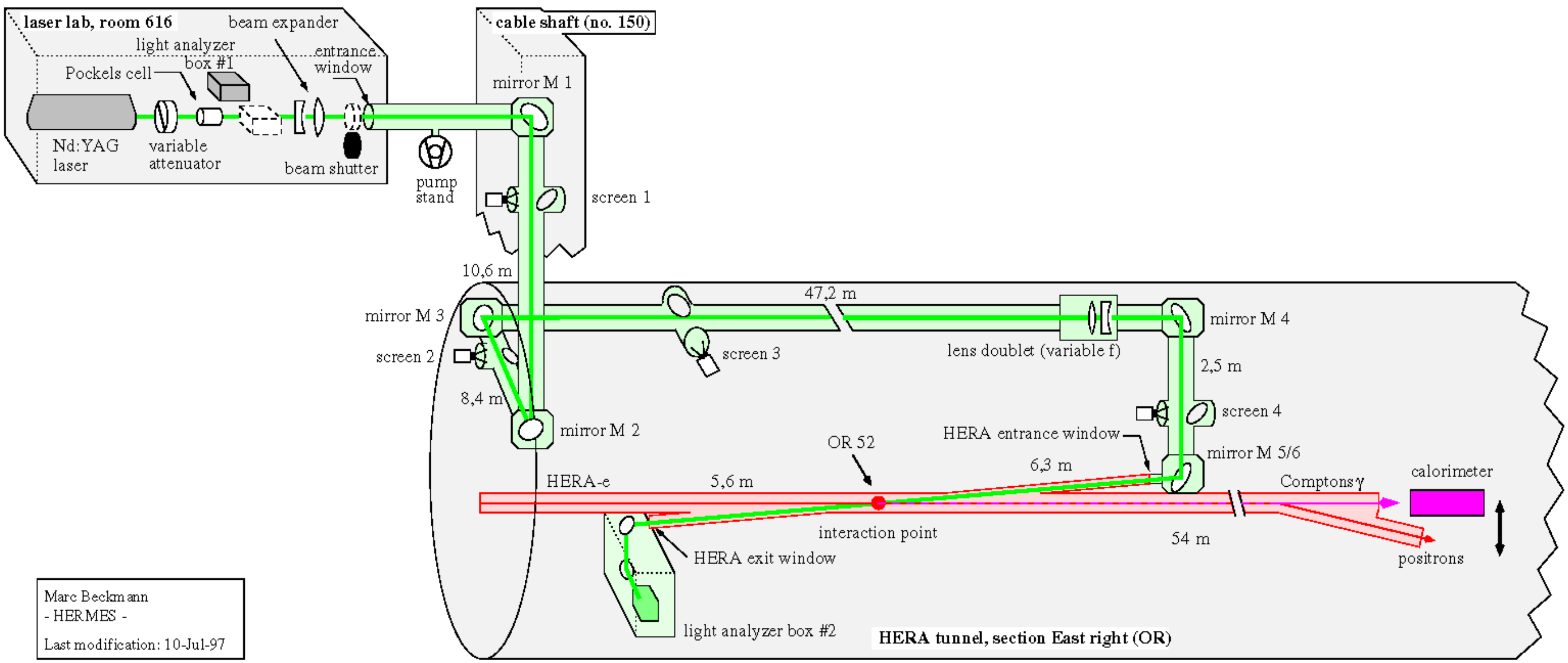
$P_y = 0.59$	$P_z = 0.59$
Spatial Asymmetry	Rate or energy Asymmetry





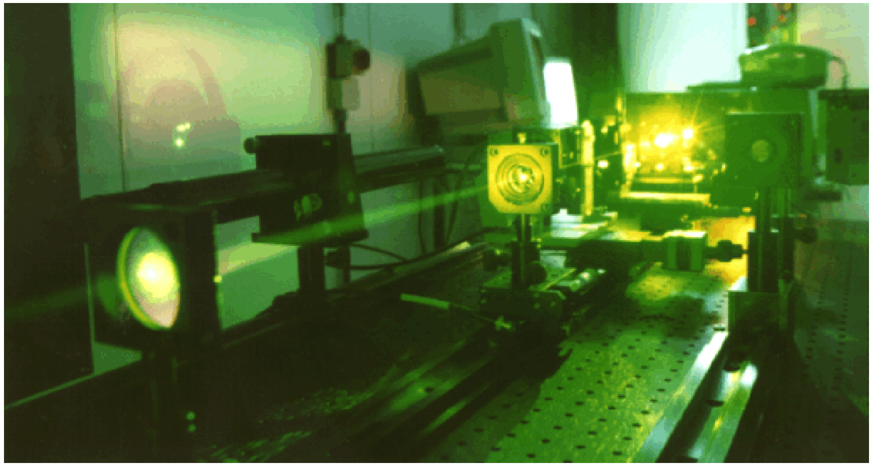
Statistical Error $\Delta P = 1\%$ per minute @ HERA average currents

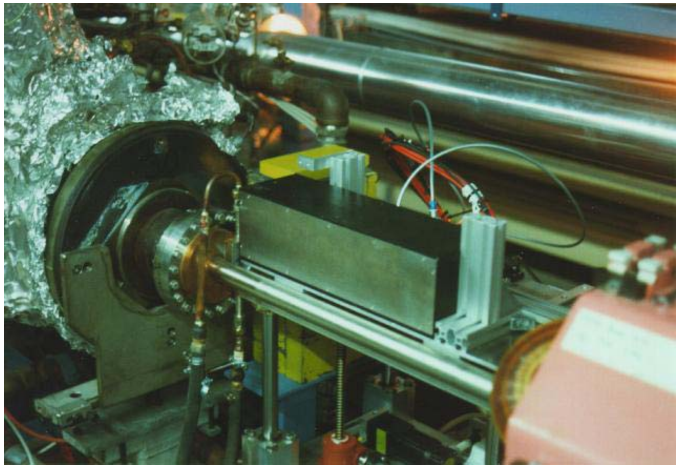
Experimental Setup - Laser System

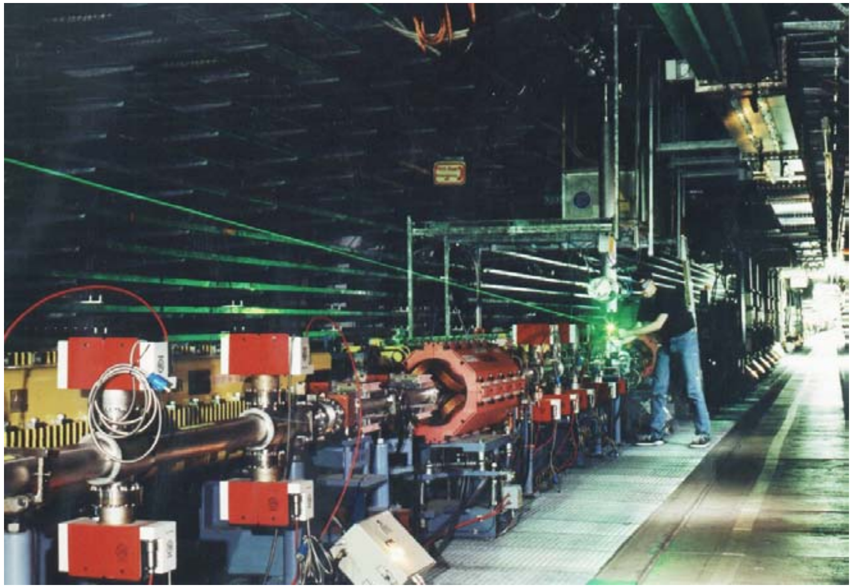


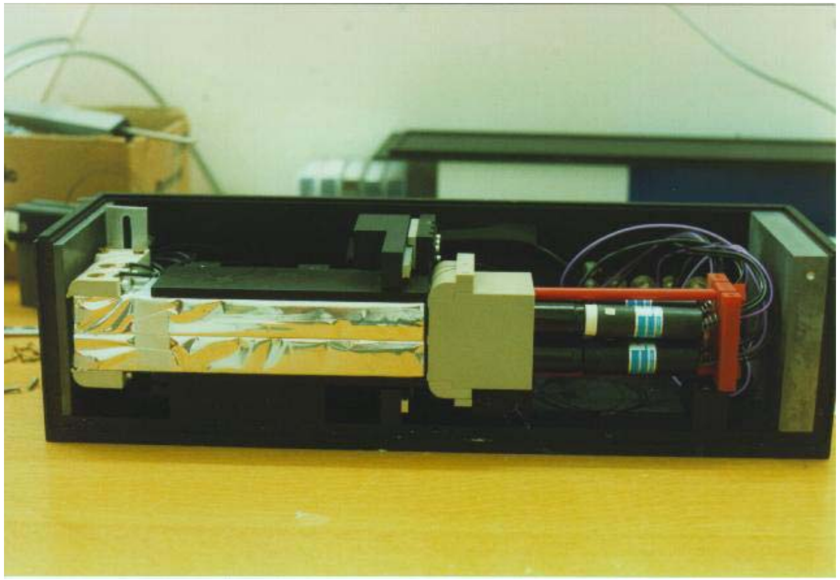
- M1/2 M3/4 M5/6: phase-compensated mirrors
- laser light polarization measured continuously in box #2

Experimental Setup - Details









Systematic Uncertainties

Source	$\Delta P_e/P_e$ (%) (2000)	$\Delta P_e/P_e$ (%) (>2003)
Analyzing Power A_p	+- 1.2[α]	+- 0.8
- response function	(0.9)	(+-0.2)
- single to multi photon transition	(0.8)	(+-0.8)
A_p long-term stability	+- 0.5	+- 0.5
Gain mismatching	+- 0.3[β]	+-0.2
Laser light polarization	+- 0.2	+-0.2
Pockels Cell misalignment	+- 0.4[β]	+-0.2
Electron beam instability	+- 0.8[β]	+-0.3
Total	**+-1.6**	**+-1.0**

[α]new sampling calorimeter built and tested at DESY and CERN

[β]statistics limited

expected precision (multi-photon mode)

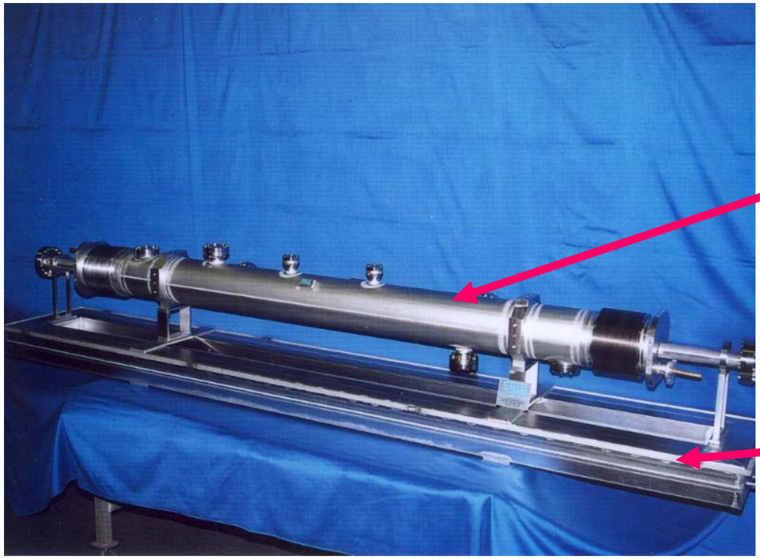
Polarization-2000

HERMES, H1, ZEUS and Machine Group

Goal: Fast and precise polarization measurements of each electron bunch

Task: major upgrade to Transverse Polarimeter (done)
upgrade laser system for Longitudinal Polarimeter (in progress)

Fabry-Perot laser cavity
[$(\delta P_e)_{stat}$ =1%/min/bunch]



Final Cavity

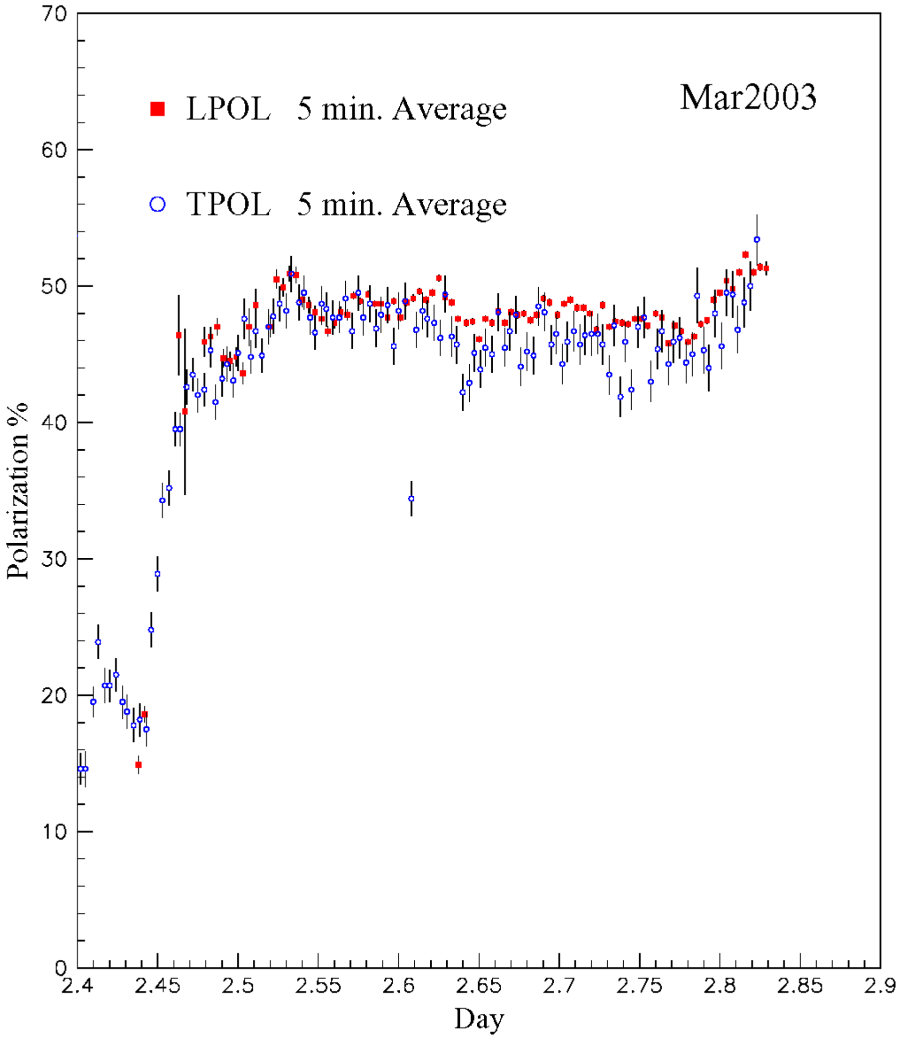
Mount for travel

(courtesy F. Zomer)

Polarization after Lumi Upgrade

All three spin rotators turned on

$P_e > 50\%$



Lessons learned from HERA

- Include polarization diagnostics and monitoring in design of beam lattice
  - more crucial for ring option than for linac option
  - measure beam polarization continuously $\rightarrow$ minimize systematic errors
- Two (three?) options to measure polarization
  - Compton Scattering ($\geq$ 5 GeV):
    - Longitudinal Polarization: rate or energy asymmetries ($\lesssim$ 30%)
    - Transverse Polarization: spatial asymmetries ($\lesssim$ 50μm)
  - Møller Scattering (100 MeV – many GeV):
    - under investigation: depolarization ($\propto I^2$) due to beam RF interaction with the e^- spins
- Consider three components
  - laser (transport) system:
    - conventional transport system: laser accessible at all times, robust, radiation damage to mirrors, proven technology
    - optical cavity: laser not accessible at all times, expensive, delicate, ring operation ?
  - laser-electron interaction region:
    - minimize bremsstrahlung and synchrotron radiation: introduce a chicane
    - optimize Compton rate: small crossing angle
  - Compton detector:
    - radiation hard, fast (<35ns): Cerenkov detectors superior to scintillation detectors
    - record energy and position of individual Compton events

EIC: Collider Layout

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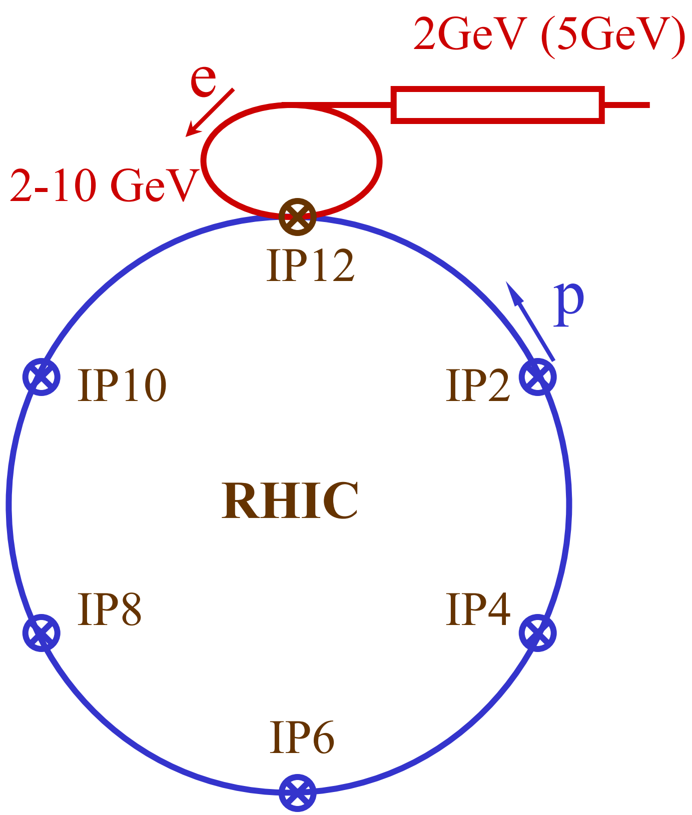

- Proposed by BINP and Bates
- e-ring is ¼ of RHIC ring length
- Collisions in one interaction point
- Collision e energies: 5-10 GeV
- Injection linac: 2-5 GeV
- Lattice based on "superbend" magnets
  - polarization time: 4-16 minutes
- Conventional magnets (Sokolov-Ternov)
  - polarization time: 10-320 minutes
- 25-250 GeV protons,

  100 GeV/u Au ions (+79)

Polarimetry at EIC

- Ring - Ring Option
  - measure beam polarization continuously -> minimize systematic errors (~1%)
- Compton Scattering (5-10 GeV):
  - Longitudinal Polarization &Transverse Polarization
    -> two independent measurements with vastly different systematic uncertainties
- Laser (transport) system
  - either conventional transport system or optical cavity
    -> wait for experience at HERA (both systems available)
- Laser-electron interaction region
  - introduce a chicane to minimize bremsstrahlung and synchrotron radiation
- Compton detector
  - needs to be radiation hard and fast (<35ns)
  - record energy and position of individual Compton events
    -> operate in single or few photon mode
    -> monitor linearity of detector: brems edge, Compton edge, asymmetry zero crossing
  - detect scattered electron and photon: in coincidence -> suppress background

Include Electron Beam Polarimetry in Lattice Design