eRHIC

A High Luminosity Polarized Beam Collider at Brookhaven National Laboratory

$e^{\pm}$ p $e^{\pm}$ He3 $e^{\pm}$ A

MIT Bates

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Brookhaven National Laboratory

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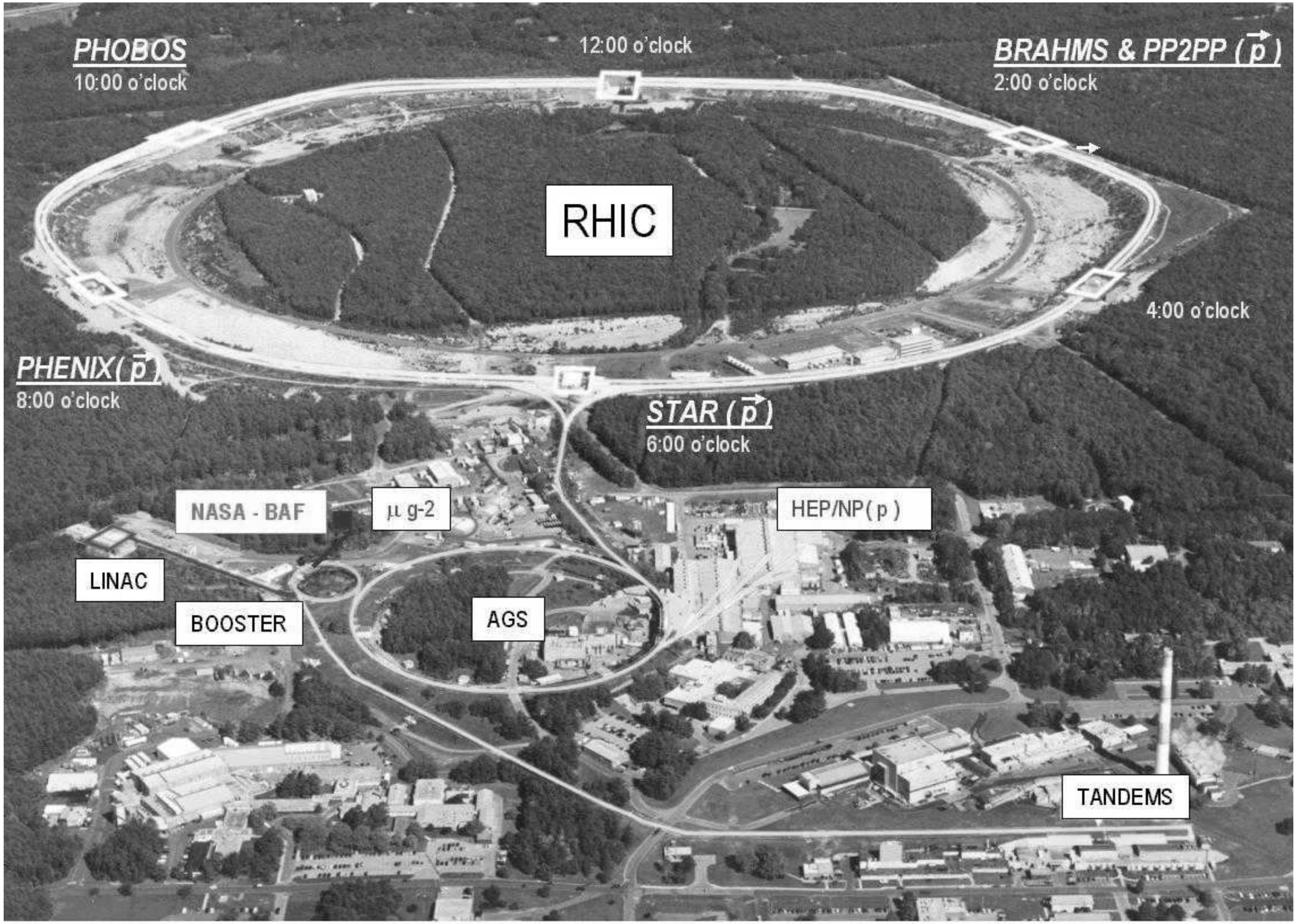
Budker Institue for Nuclear Physics

A.V. Otboev and Yu.M. Shatunov

Talk Outline

- eRHIC Project Overview
- RHIC modifications for eRHIC
- Lepton Systems for Ring-Ring Design
  - Lattice
  - Interaction Region
  - Polarization – Spin Rotators – Compton Polarimeter
  - 10 GeV electron/positron injector
  - Polarized electron photoinjector
- Energy Recovery Linac Option
- Project Status & Future Plans

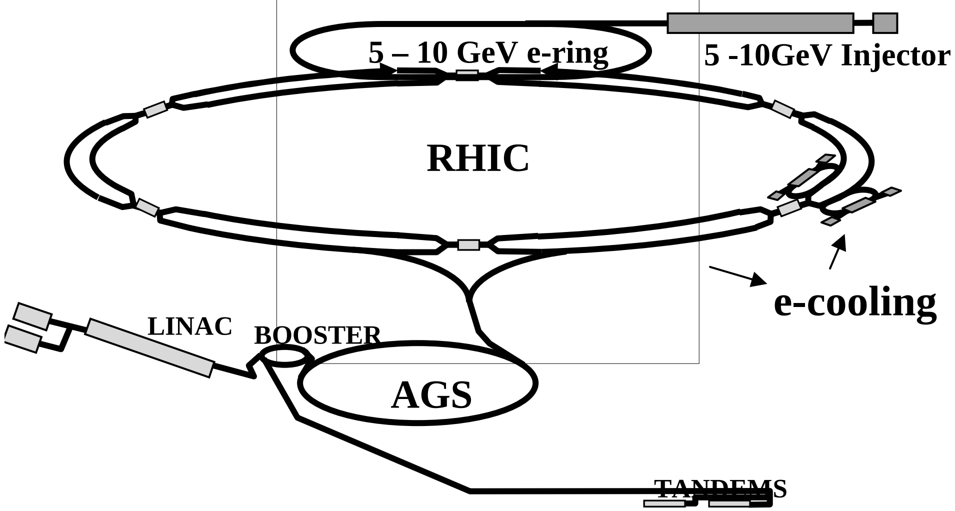
RHIC Complex at BNL



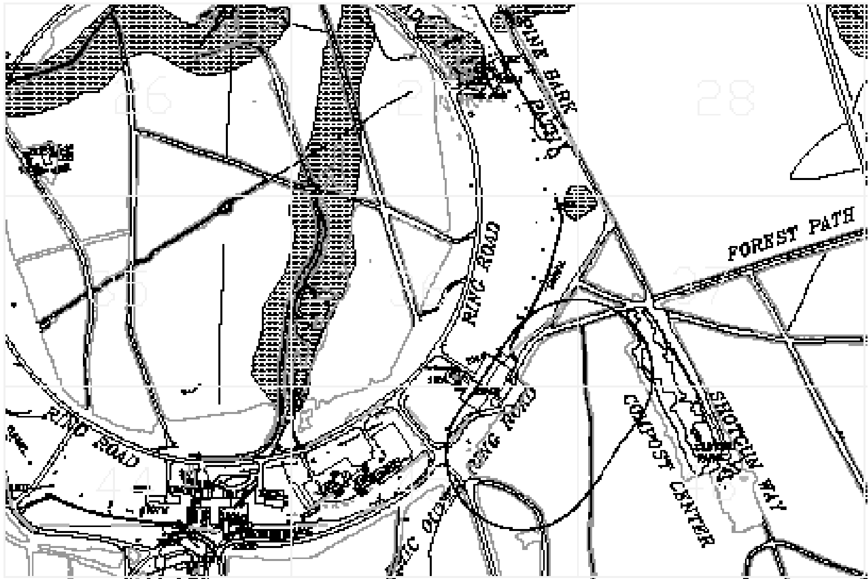
Possible eRHIC layout

- Collisions at 12 or 4 o'clock interaction region
- 10 GeV, 0.5 A e-ring with 1/3 of RHIC circumference
- Inject at full energy 5 – 10 GeV
- Existing RHIC interaction region allows for typical asymmetric detector (similar to HERA or PEP II detectors)

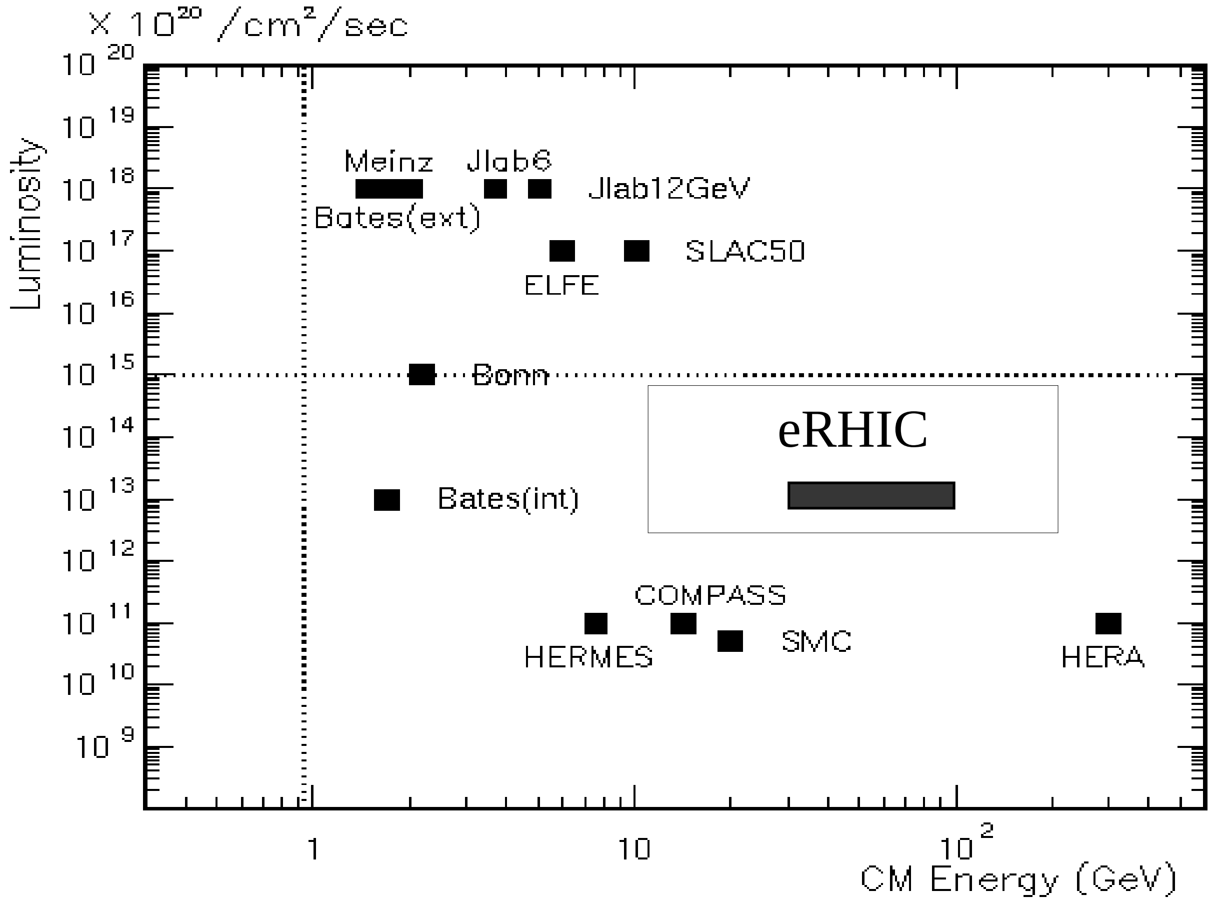
12 O'Clock



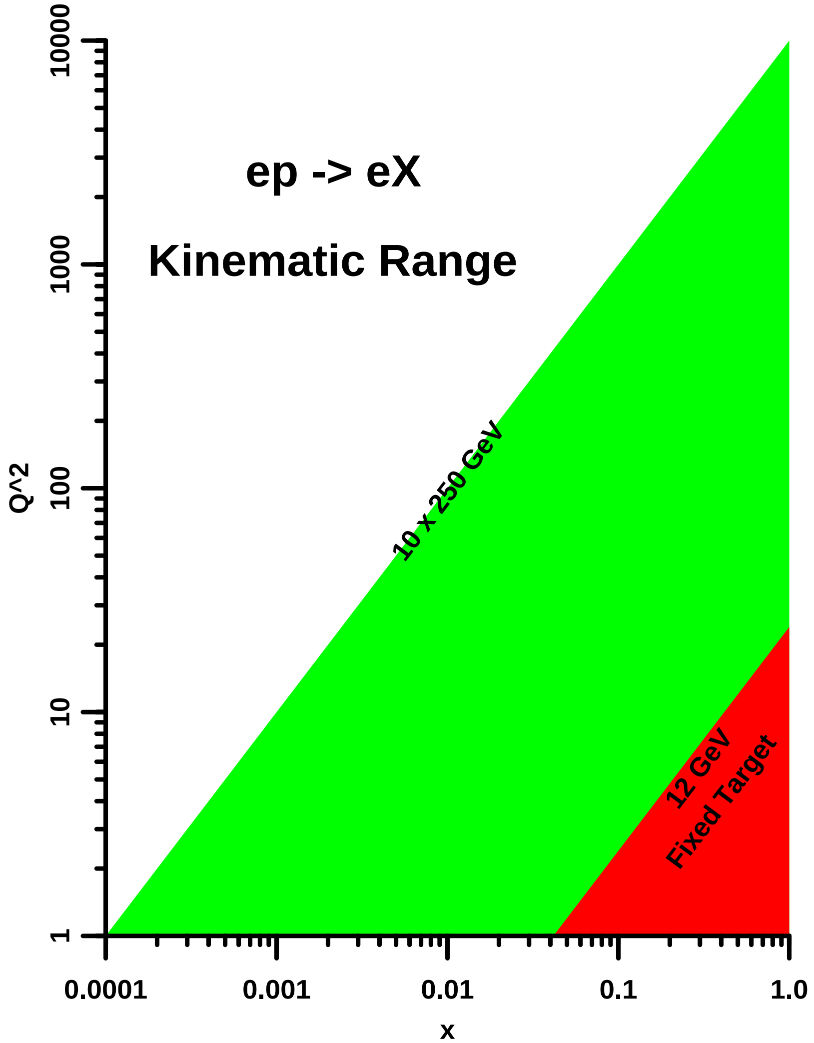
4 O'Clock



eRHIC will be a unique accelerator



Q^2 and x Range of eRHIC



- E_e=5-10 GeV
- E_p=50-250 GeV
- $s^{\frac{1}{2}}$=30-100 GeV
- x_{Bj}=10^{-4} to 0.7
- Q^2=0 to 10^4 $(GeV/c)^2$
- polarization of $e^{\pm}$, p, ^{3}He ~ 70%
- heavy ion beams of all elements
- high luminosity > 10^{33} cm^{-2} s^{-1}

EIC Steering Committee

- A. Caldwell (MPI Munich)
- A. Deshpande (StonyBrook)
- R. Ent (JLab)
- G. Garvey (LANL)
- R. Holt (ANL)
- E. Hughes (Caltech)
- K.-C. Imai (Kyoto Univ.)
- R. Milner (MIT)
- P. Paul (BNL)
- J.-C. Peng (Illinois)
- S. Vigdor (Indiana Univ.)

eRHIC evolution

- Substantial international interest in high luminosity (~$10^{33}cm^{-2}s^{-1}$) polarized lepton-ion collider over decade
- Workshops

Seeheim, Germany	1997	MIT, USA	2000
IUCF, USA	1999	BNL, USA	2002
BNL, USA	1999	JLab, USA	2004
Yale, USA	2000		

- eRHIC received favorable review of science case in US 2001 Nuclear Physics Long Range Plan, with strong endorsement for R&D
- At BNL Workshop in March 2002, a plan was formulated to produce a conceptual design for eRHIC within three years
- NSAC in March 2003, declared eRHIC science `absolutely central' to future of Nuclear Physics
- eRHIC identified in November 2003 as future priority in DOE Office of Science 20 year planning

Zero-order Design Report (ZDR)

- A Zero-order Design Report (ZDR) has been developed
- The leading eRHIC design concept is a ring-ring configuration
- The present design includes a full energy linac injecting polarized electrons (positrons) into a 10 GeV electron ring
- A more futuristic linac-ring concept is also under consideration

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, V. Ptitsyn , T. Roser, A. Ruggiero, B. Surrow, S. Tepikian, D. Trbojevic, V. Yakimenko, and S.Y. Zhang

MIT-Bates: M. Farkhondeh, 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 and Yu.M. Shatunov

DESY: D.P. Barber

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

http://locus.lns.mit.edu/~accelphy/eic/

eRHIC ZDR Base Line Design

- 5- 10 GeV electrons and positron beams
- 250 GeV p, 100 GeV / nucleon heavy ions:
- Maximum Luminosity 10^{33} nucleons $cm^{-2}s^{-1}$
- High integrated luminosity, up to 90 pb^{-1}/day
- Longitudinal polarization 70% for e^- @ 5 – 10 GeV, e^+ @ 10 GeV
- Polarized protons > 70%, polarized neutrons (^3He) > 70%
- One interaction region
- Operational flexibility for collisions with various ion species of different energies

RHIC Systems

RHIC Number of Bunches (n_b)

V. Ptitsyn - BNL

- Present eRHIC design: 360 bunch mode.
  Factor 6 from the current RHIC operation.
- Why 360?
  The luminosity is proportional to number of bunches. So, it is worth to evaluate if one can use maximum number of bunches allowed by existing acceleration RF system.

- Bunch separation (~35ns) gets close to LHC value (25ns). Should be similar issues (electron cloud) and, therefore, learning from LHC knowledge and experience.

- Present problems: vacuum pressure rise and electron cloud in warm sections.
  Hopes: NEG pipes will be a cure and push the limits to (? will see)
  Other remedies: baking, solenoids.
- In cold sections: cryogenic heat load of the beam pipe.
  Two main sources: parasitic loss and electron cloud
- Long range parasitic beam-beam effects.
  Serious issue since the work on proton-proton collision are assumed in parallel with e-p collisions. Beam studies should be considered

RHIC Beam Emittances

V. Ptitsyn - BNL

	Presently achieved	eRHIC ring-ring	eRHIC linac-ring
Au	10	6	1.5-6
Protons E < 150GeV	12-15	5	4-14.5
Protons E > 150GeV	Nota Bene	15	

Normalized emittance, $\pi\ 10^{-6}$ m

- To maximize luminosity the transverse cooling is needed for ions and lower energy protons. (also for high energy protons in linac-ring in dedicated mode, e-p collision only)
- Longitudinal cooling to maintain shorter rms bunch length (<20cm) for Au.
- Electron cooling system is under development on RHIC as well as studies on possible stochastic cooling.
- Electron cooling is not very effective for protons. Thus the investigation if one can reduce emittance blowup in the injectors would be quite helpful.

(Blowup sources: Booster target, BtA matching, AGS emittance increase at acceleration) *(*H.Huang)

Lepton Systems

Electron/Positron Ring Strategy

F.Wang

<u>Goals: Maximum luminosity and maximum polarization</u>

Fixed energy ring – no ramping

- -Most stable operation
- -Fixed energy allows injection of prepolarized electrons – P>70%
  (no ramping induced depolarization)
- -Prepolarized electron injection allows large dipole curvature (ρ = 81 m)
  (radiative polarization not required)
- -Large dipole curvature reduces RF synchrotron load & vacuum chamber heating
- -Fixed energy allows "top-up" operation
- -Top up maintains maximum (optimal) current
- -Top up allows shorter lifetime & therefore higher luminosity
  (higher beam-beam tune shift permitted)

But … self polarization of positrons still required – 22 min. at 10 GeV

But … fixed energy ring requires expensive 10 GeV injector

Distinguishing features of eRHIC-e

Comparison to existing lepton rings

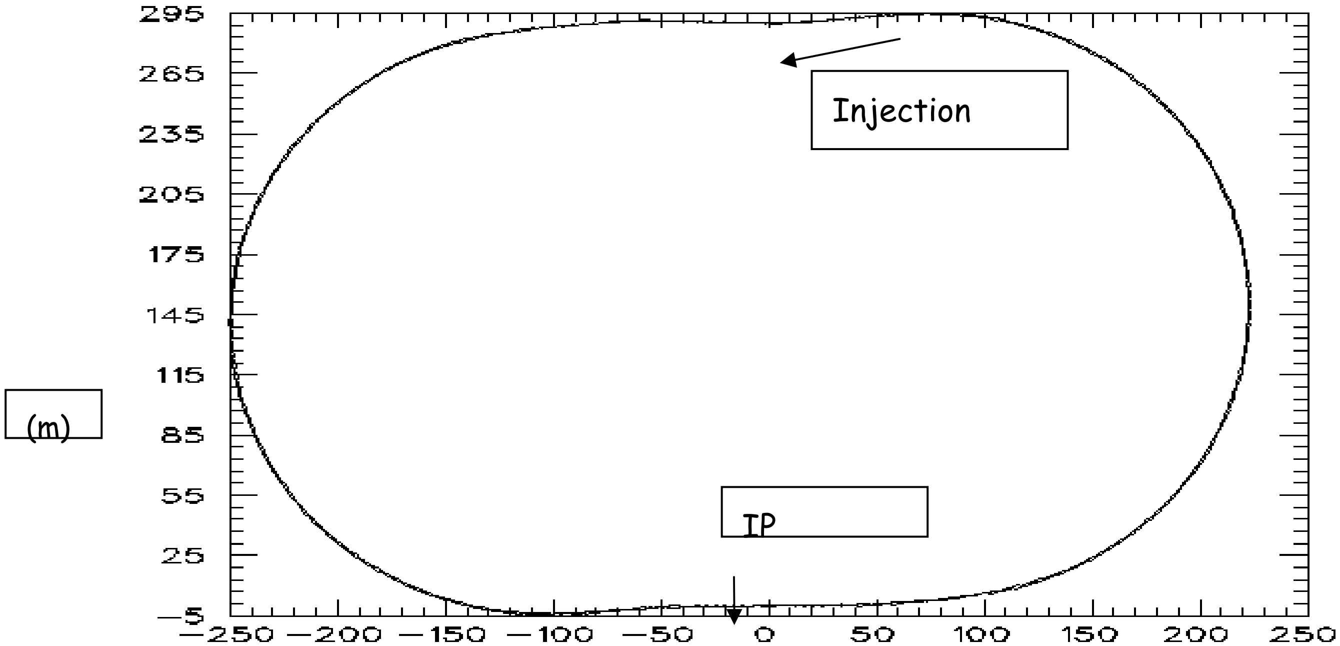
	HERA-e	***B-Factory***	***eRHIC-e***
Energy (GeV)	*~ 27*	*~3(L), ~9(H)*	*5 - 10*
Current (A)	*0.05*	*1.0 – 2.5*	*0.45 – 1.0*
Polarization	*Yes*	*No*	*Yes*
BB para.	*~0.05*	*~0.08*	*0.08*

eRHIC-e: a combination of

- wide operating energy range
- high intensity, though not extremely high
- longitudinal polarization

Lattice

The Electron / Positron Ring



- Race track shaped storage ring in one plane
- Vertical polarization in arcs – spin rotators for long. pol. (> 70%) at IP
- Polarized electron injection from 5-10 GeV
- Unpolarized positron injection from 5-10 GeV. Self polarization of positrons

at 10 GeV τ_p = 20 minutes, at 5 GeV τ_p=1 hour

eRHIC e± Ring Parameters

10 GeV electrons – 250 GeV protons

- Electron ring design limits consistent with B factories
- Ion ring limits performance - extrapolation from current RHIC param.s
- Luminosity assumes ion collisions at two other IPs
- Dedicated operations yields Luminosity ~ 10^{33} cm^{-2} s^{-1}

Circumference (m)	1278	3834
Electron Energy (GeV)	10	250
Bending radius (m)	81	
Bunch spacing (m)	10.6	
Number of bunches	**120**	**360**
Bunch population	1.0 10^{11}	1.0 10^{11}
Beam current (A)	0.45	
Energy loss/turn (MeV)	11.7	
Acc. Voltage (MV)	25	
Total rad. Power (MW)	5.28	
Syn. Rad. Power / m (KW) in Arc	9.66	
Self-pol. Time at 10GeV (min.)	22.03	
Emittance-x, no coupling (nm.rad)	56.6	9.4
Beta function at IP (cm) β_y^*/β_x^*	19.2/26.6	
Emittance Ratio (ε_y / ε_x)	0.18	1
beam-beam parameter (x)	0.03	**0.0065**
beam-beam parameter (y)	**0.08**	0.0033
Beam size at IP(um) σ_x	104	
Beam size at IP(um) σ_y	52	
Bunch length (cm) σ_z	1.17	
S.R. damping time(x) (ms)	7.3	
Beta tune μ_x /μ_y	26.105/22.145	
Natural chromaticity ξ_x/ξ_y	-35.63/-33.84	
Luminosity (10^{33}/cm^2/s)	**0.44**	

Luminosity Considerations

F. Wang, D. Barber, C. Montaug, S.Peggs, D. Wang

$$L = \frac{\pi}{r_e r_i} F_c \gamma_e \gamma_i \xi_i \xi_e \sigma'_{i,x} \sigma'_{e,x} k_e \frac{(1+k)^2}{k^2}$$

F_c is the collision frequency

ξ the beam-beam tune shift

$k_e = \varepsilon_{e,y}/\varepsilon_{e,x}$ is the electron beam emittance ratio

$k=\sigma_y/\sigma_x$ is the beam aspect ratio at IP.

σ' is the beam angular amplitude at IP.

- Round Beams would be preferable for maximum luminosity.
  → Comparable balanced beam-beam tune shifts (x,y)
- But problematic for polarization
- Bates Siberian Snake is an example of a possible local emittance xformer
- Flat Beams Adopted for the baseline ZDR

Variable Emittance for Optimum Luminosity

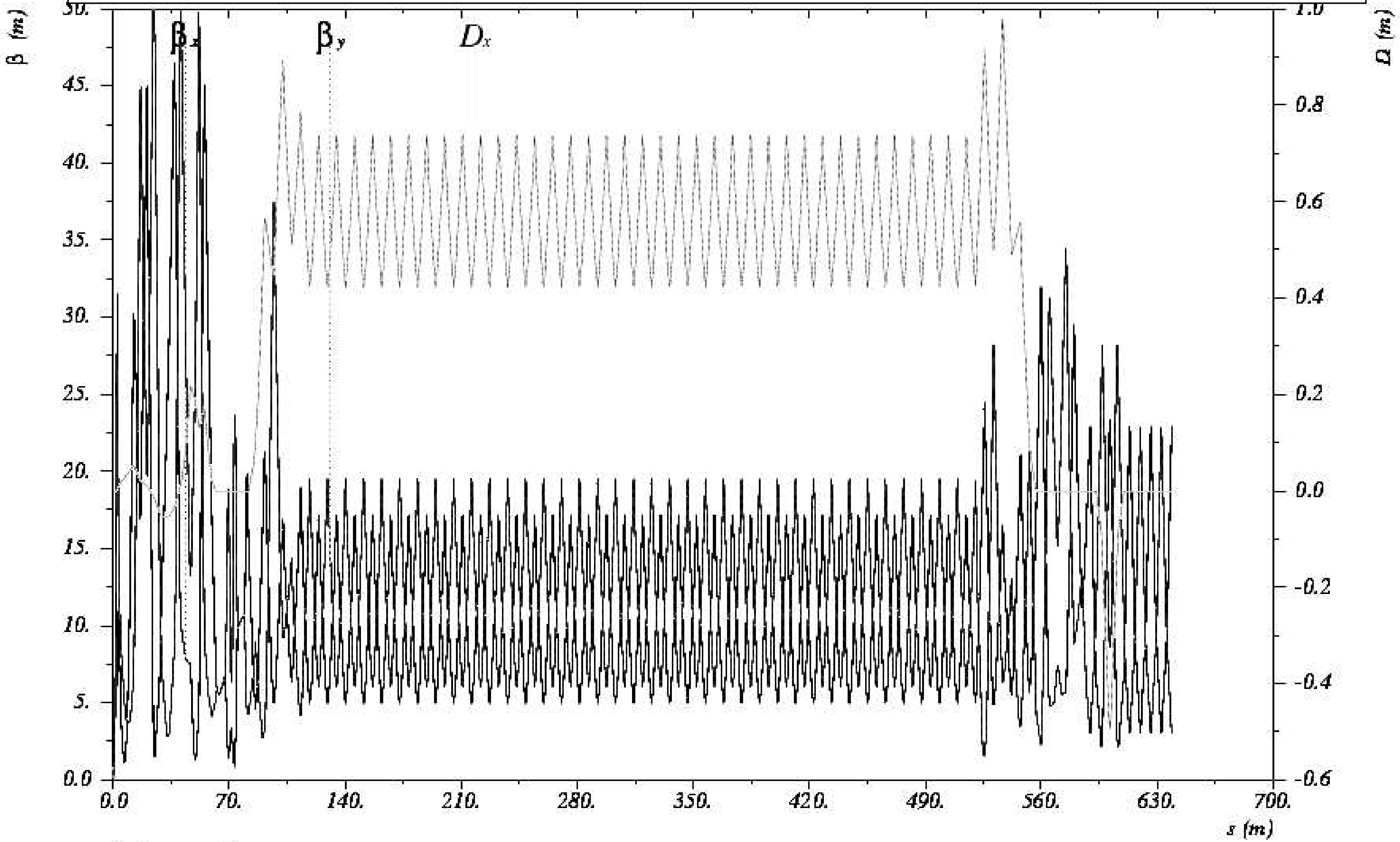
F.Wang

Ke= εe,y/εe,x	$\varepsilon_{e,x}$ (nm.rad)	$\beta_{e,x}$* (m)	$\beta_{e,y}$* (m)	Protons ($1e^{11}$) per bunch	ξx	ξy	L 1e32 ($cm^{-2}s^{-1}$)
0.1	54	0.19	0.47	0.57	0.016	0.08	2.5
0.15	54	0.19	0.31	0.85	0.024	0.08	3.8
0.18	54	0.19	0.26	1.0	0.029	0.08	4.5
0.20	54	0.19	0.23	1.13	0.032	0.08	5.0
0.25	54	0.19	0.19	1.41	0.04	0.08	6.3
0.30	45	0.23	0.19	1.41	0.048	0.08	6.3
0.5	27	0.38	0.19	1.41	0.08	0.08	6.3

Lowest emittance substantially larger than 3rd generation light sources

e-/e+ Ring Half Lattice

D.Wang

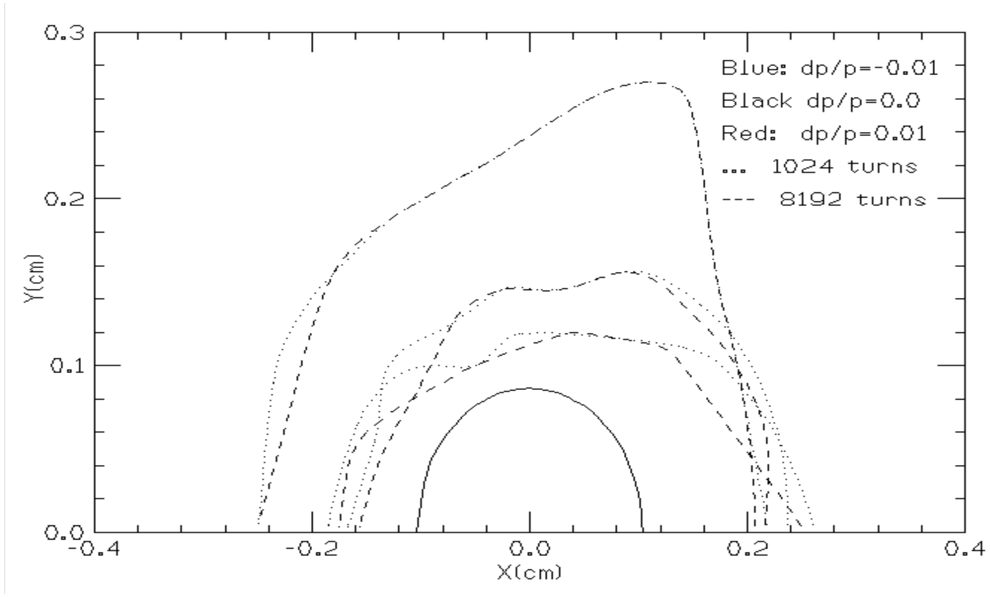


IP Injection

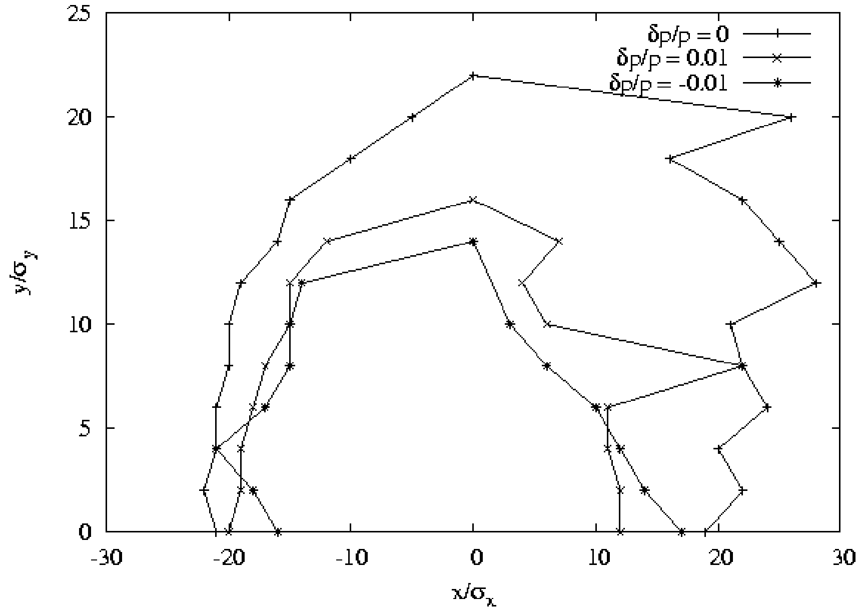
Dynamic Aperture

D. Wang, A. V.Otboyev

Goal of 10σ in both momentum and transverse phase space in the presence of alignment and magnetic errors and colliding beam conditions.



LEGO (Beam size at IP)



SAD (Normalized Beam Size)

Also - Acceptance Issues for Positron Injection

Intensity Parameters: Not Extreme

	eRHIC lepton ring	PEP-II LER/HER	KEKB LER/HER	CESR-III
Energy (GeV)	**5 ~ 10**	3.1/9.0	3.5/8.0	5.3
Circumference (m)	**1278**	2200	3016	776
RF freq. (MHz)	**478.6 or 506.6**	476	508	500
RF voltage (MV)	**5~25**	6/15	10/18	3
Total current (A)	**0.45**	2.4/1.4	1.9/1.2	1.0
Particle/bunch (10^{11})	**1.0**	1.0/0.6	0.9/0.7	2.0
Bunch spacing (m)	**10.6**	1.9	2.4	2.4
Energy loss/turn (MeV)	**0.72/11.7**	1.2/3.6	1.6/3.5	1.0
Average beta (m)	**~15**	~17	~10	~20
Bunch length (cm)	**1~2**	1.0	0.4	1.5

Single bunch parameters of BF and CESR: in routine operation, not the limits.

IR

C. Montag, B. Parker -BNL

Constraints for low-β & separation sections

- Beam-beam determine $\beta_{x,y}^*$ and $\varepsilon_{x,y}$

  β_x^*=19-35cm, β_y^*= =19~34cm, 4 collision optics

- Magnets., aperture/field gradient,

  $Q_{1,2,3}$: SC magnets, diff. apertures/pole tip fields,

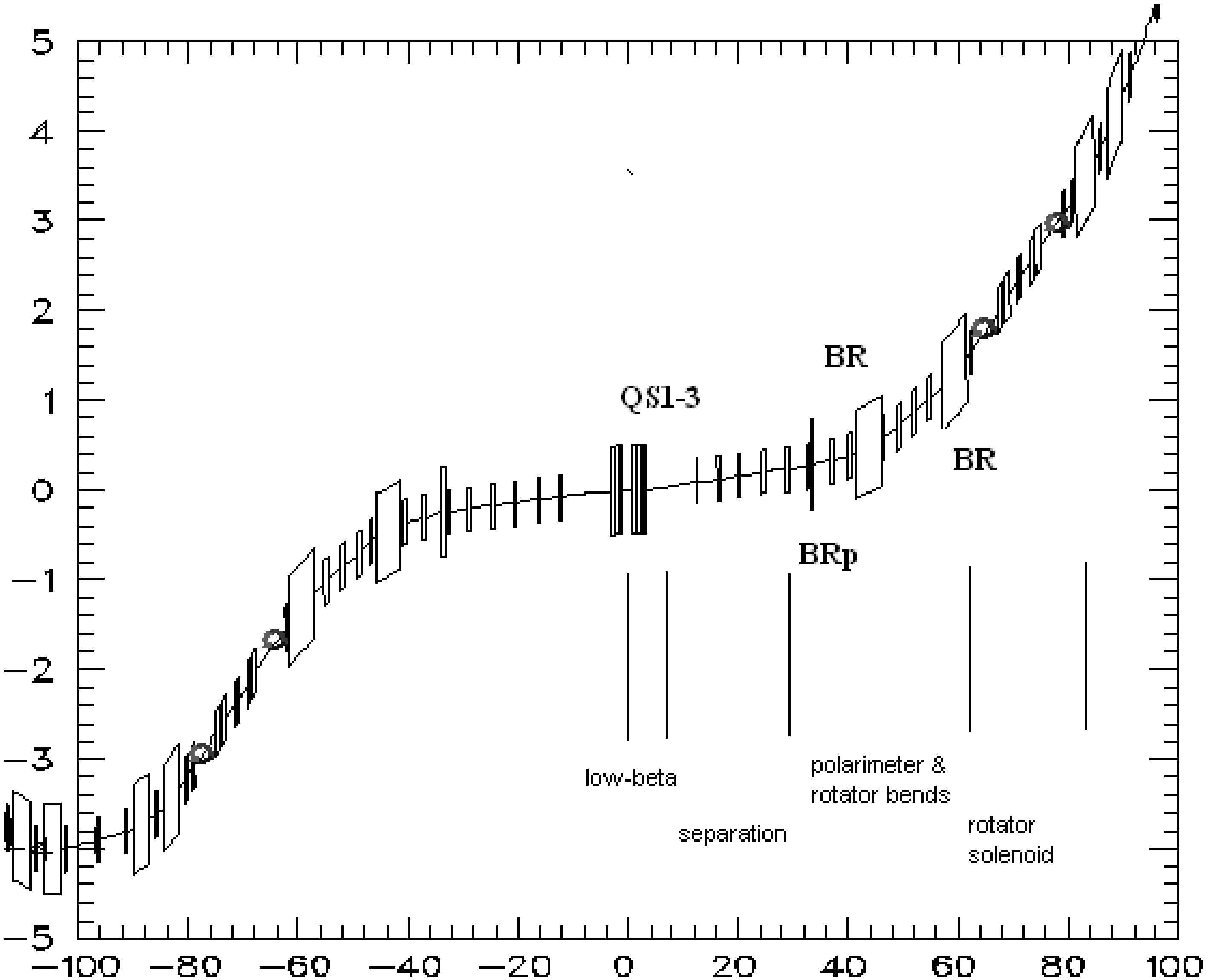
- Synch. Radiation: limit bending angles

  small offset, must lower h-beta at septum

- ep Beam separation

  long space, several half-quads,

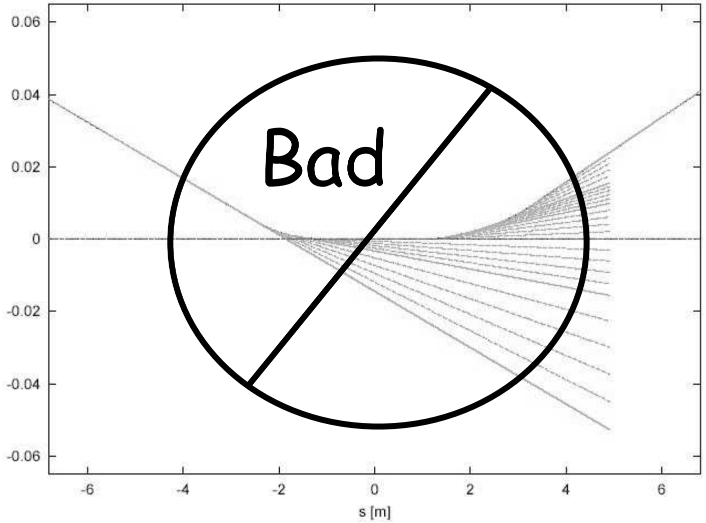
IR “Straight” Layout

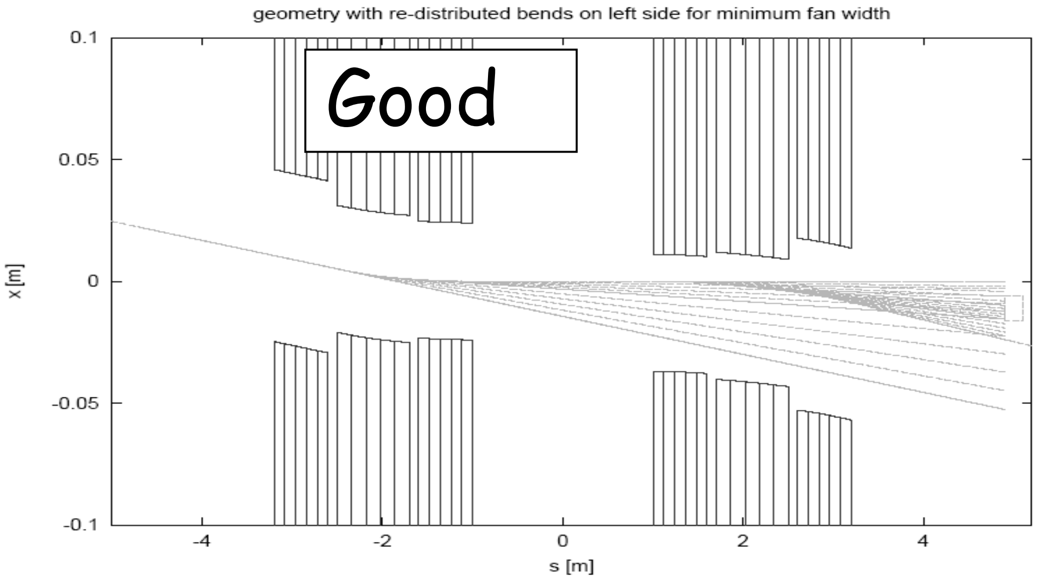


Low- β insertions

C. Montag -BNL

Combined function sc quads.
Bending angles: (Asymmetric!)
right side: q1: =-2.74 mrad, q2:=-2.01 mrad, q3:=-4.19 mrad
left side: q1: = 2.5 mrad, q2:= 5.3 mrad, q3:= 0.0 mrad

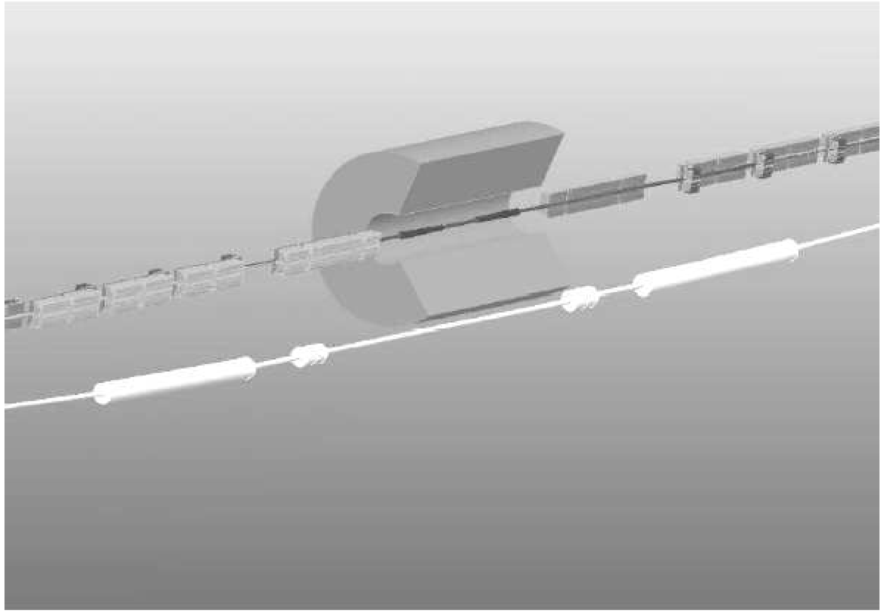




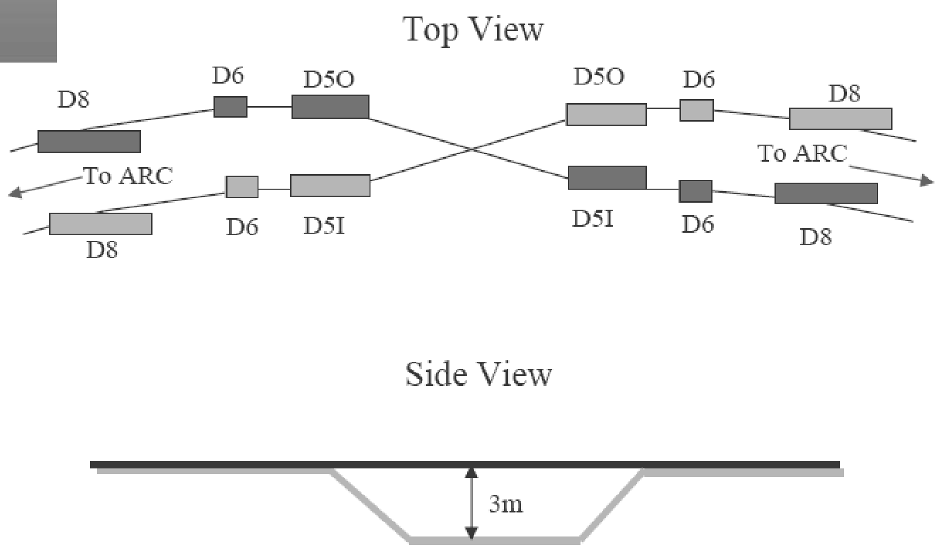
Small bending angle means small offset at septum and longer space for complete separations

IR Design

Synchrotron radiation, Hadron beamline modification

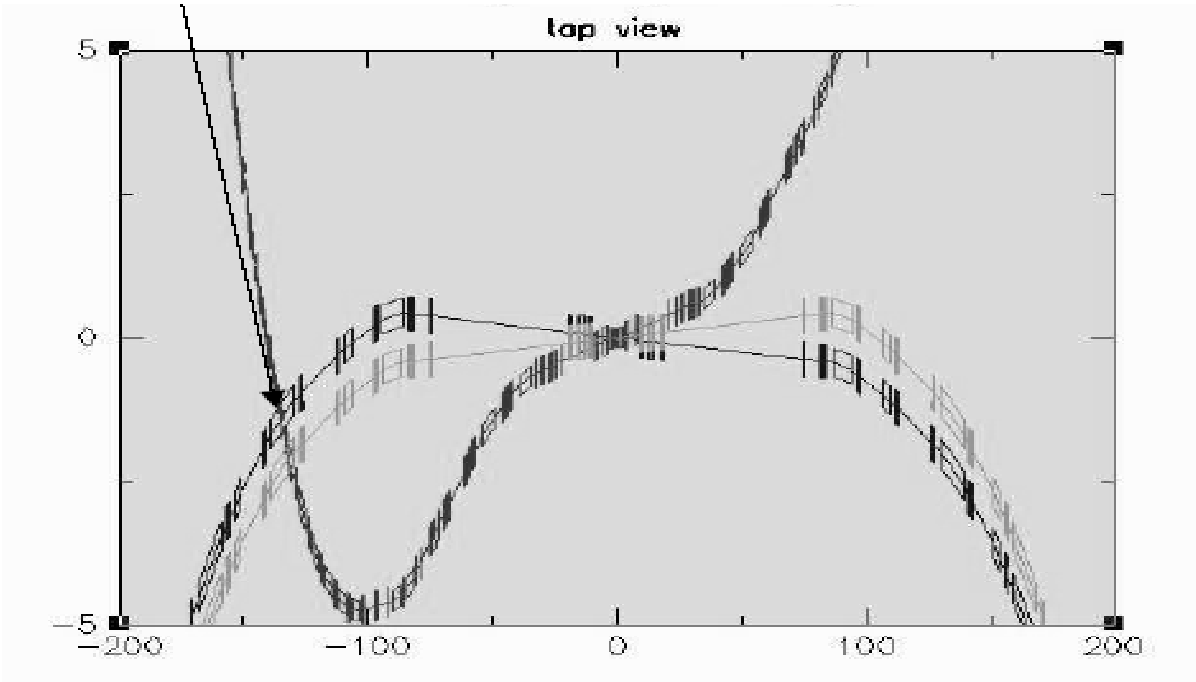


C. Montag -BNL



IR geometry

electron-ring and RHIC rings



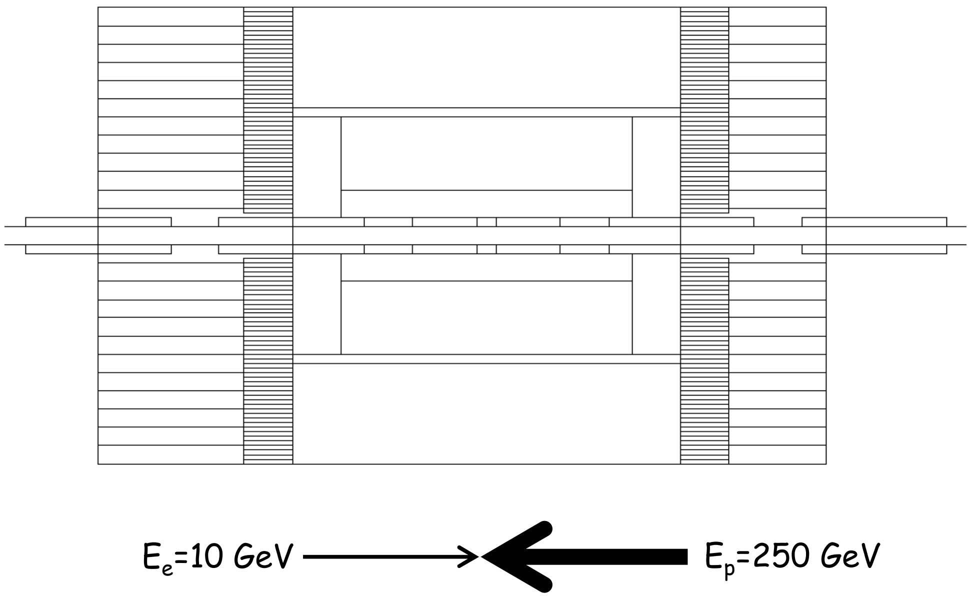
hadron rings need some vertical offsets at IP

'second' crossing problem.

eRHIC Detector Design Studies

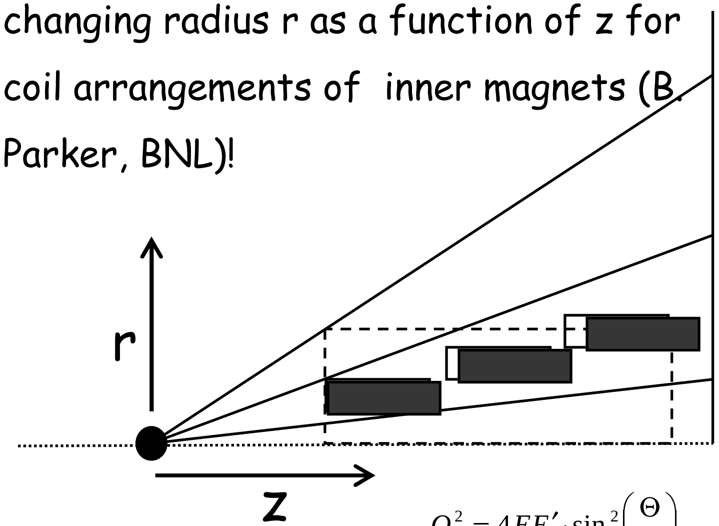
B. Surrow - MIT

- GEANT simulation started of a central detector geometry
- Study of synchrotron radiation background is underway (Contacts to DESY colleagues)
- Crucial: Forward and rear tagging devices and acceptance limitation of inner machine elements



⇨ **Very preliminary acceptance limitation studies by inner machine magnets:**

Better acceptance at low scattering angles down to $Q^2 \sim 0.5\ \text{GeV}^2$ with changing radius r as a function of z for coil arrangements of inner magnets (B. Parker, BNL)!



$$Q^2 = 4EE' \cdot \sin^2\left(\frac{\Theta}{2}\right)$$

Using $E' = 5\text{GeV}$

$\Theta = 9^\circ \Rightarrow Q^2 = 1.2\,\text{GeV}^2$

$\Theta = 5.7^\circ \Rightarrow Q^2 = 0.5\,\text{GeV}^2$

Polarization

Derbenev Kondratenko Mane Formula

Vertical Polarization in Arcs

$$P_{eq} = \frac{8}{5\sqrt{3}} \frac{\left\{ \frac{1}{|\rho|^3} \hat{b} \cdot \left(\hat{n} - \gamma \frac{\partial \hat{n}}{\partial \gamma} \right) \right\}}{\left\{ \frac{1}{|\rho|^3} \left(1 - \frac{2}{9} (\hat{n} \cdot \hat{v})^2 + \frac{11}{18} \left(\gamma \frac{\partial \hat{n}}{\partial \gamma} \right)^2 \right) \right\}}$$

Time Constant

Not too long: e^+ Polarization

$$\tau^{-1} = \frac{5\sqrt{3}\gamma^5 \hbar e^2}{8\rho^3 m^2 c^2} \left(1 - \frac{2}{9} (\hat{n} \cdot \hat{v})^2 + \frac{11}{18} \left(\gamma \frac{\partial \hat{n}}{\partial \gamma} \right)^2 \right)$$

Synchrotron Radiation Power

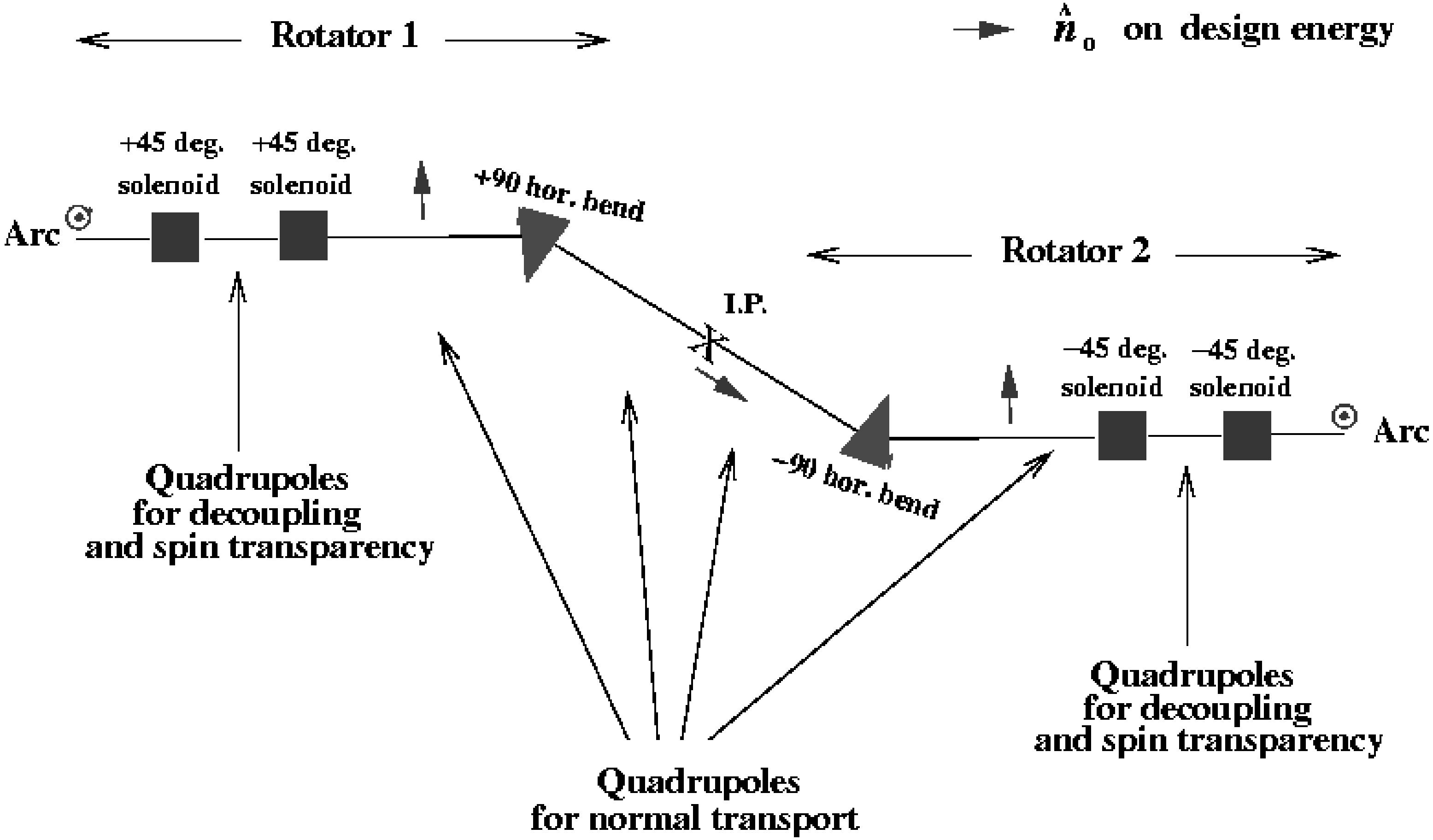
Not too large: Linear Wall Power

$$P = C_\gamma \gamma^4 R \left\langle \frac{1}{\rho^2} \right\rangle$$

T. Zwart

Solenoidal Spin Rotator

D.P.Barber, Y.M.Shatunov, Litvinenko



- No vertical bends
- Pure longitudinal polarization only at 8.5 GeV

Polarization Calculations

Spin matching:

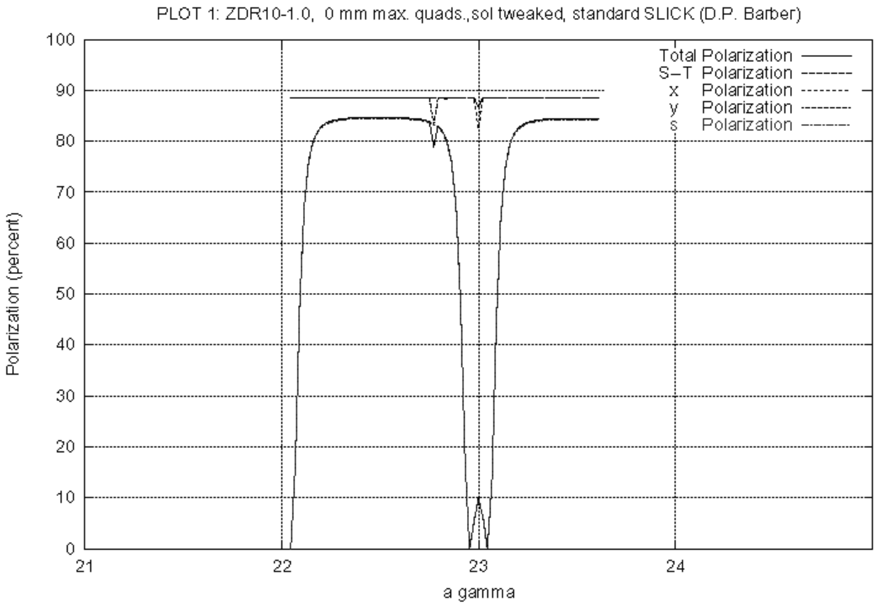
solenoid in rotator: locally spin-transparent

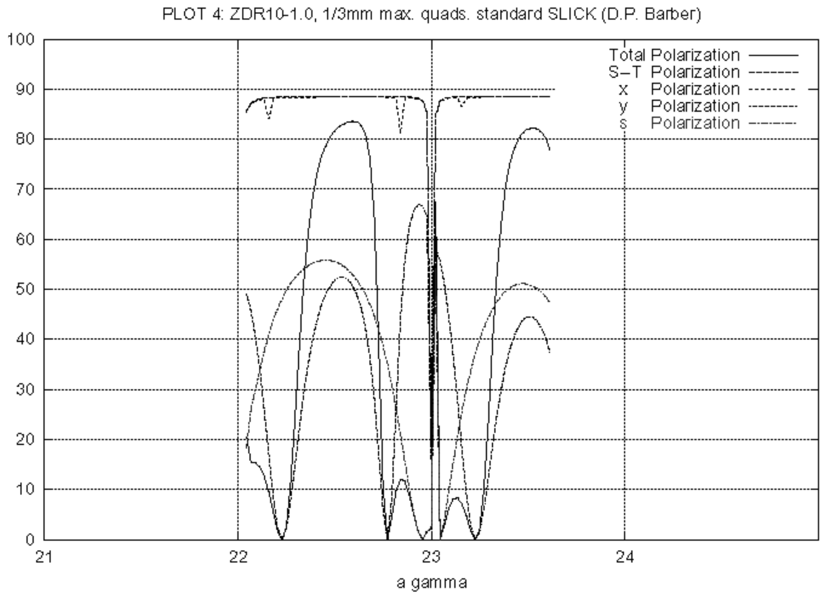
whole IR: spin-synchro term mainly.

SLICK simulation with lattice:

sensitive to orbit errors, not a surprise.

with good corrections, polarization is quite decent with 0.3mm rms COD





Compton Polarimetry

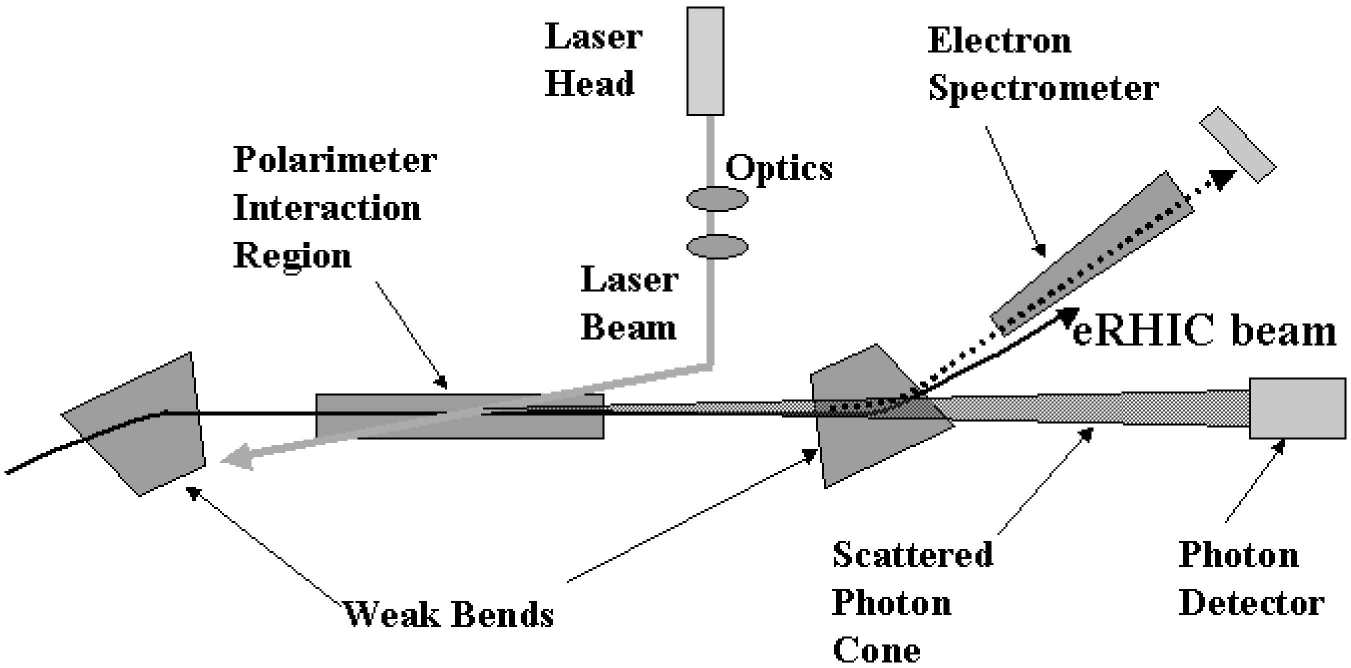
W.A.Franklin

• Compton scattering cross section is well known theoretically and has a term dependent on electron spin and laser helicity

> Can extract e^- polarization by measuring asymmetries in scattering rates for circularly polarized laser light

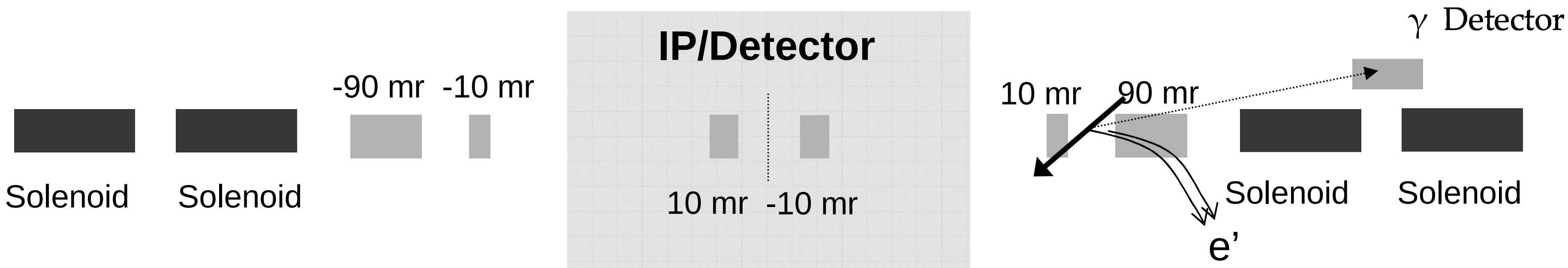
• Compton scattering in highly relativistic frame compresses angular distribution into a narrow kinematic cone and shifts photon frequencies into gamma regime

> Detect backscattered photons or scattered electrons with compact detector



Longitudinal Polarimeter Location

- Locate longitudinal polarimeter between spin rotators and downstream of electron-ion interaction point

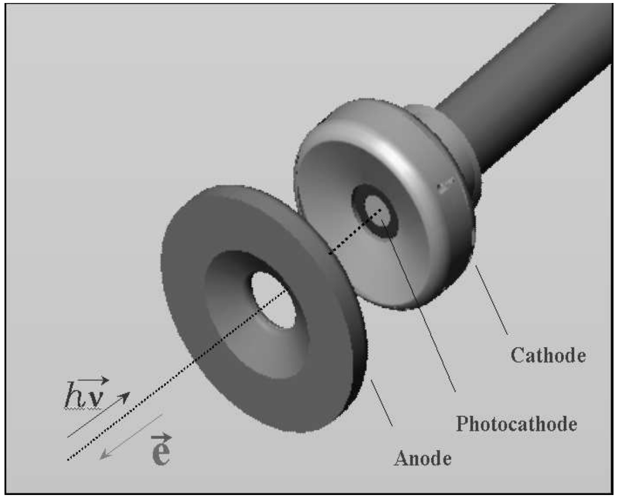


- Weak bend upstream of polarimeter compensates for spin precession due to detector's magnetic field
- Limit Compton scattering interaction region to short straight section (5 m) to reduce sensitivity to bremsstrahlung background
- Strong bend downstream of Compton interaction region provides sweep magnet for photon line clearance and momentum analysis for scattered electrons

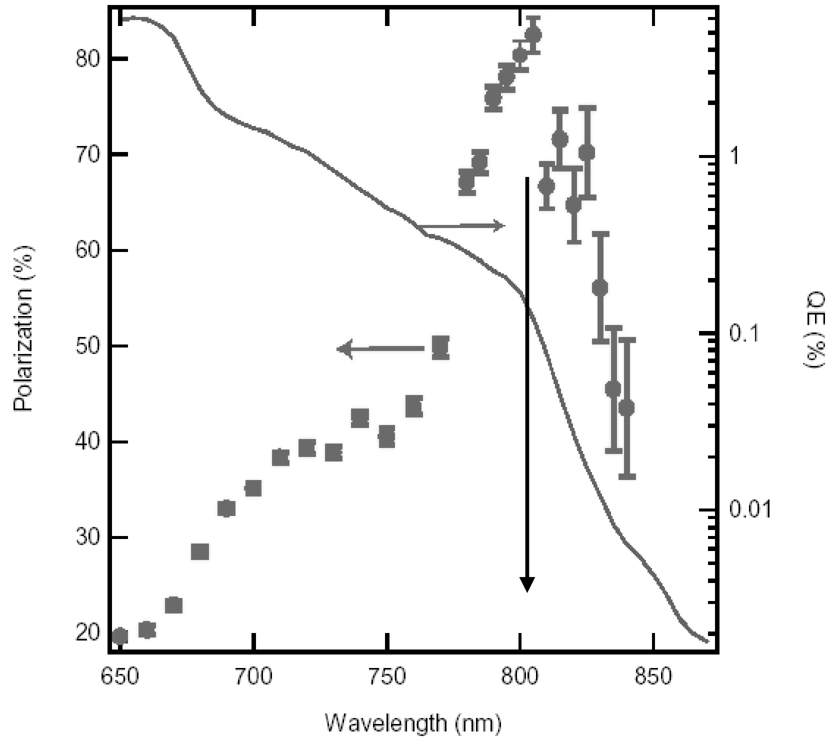
Polarized Electron Source
$P_e > 70\%$

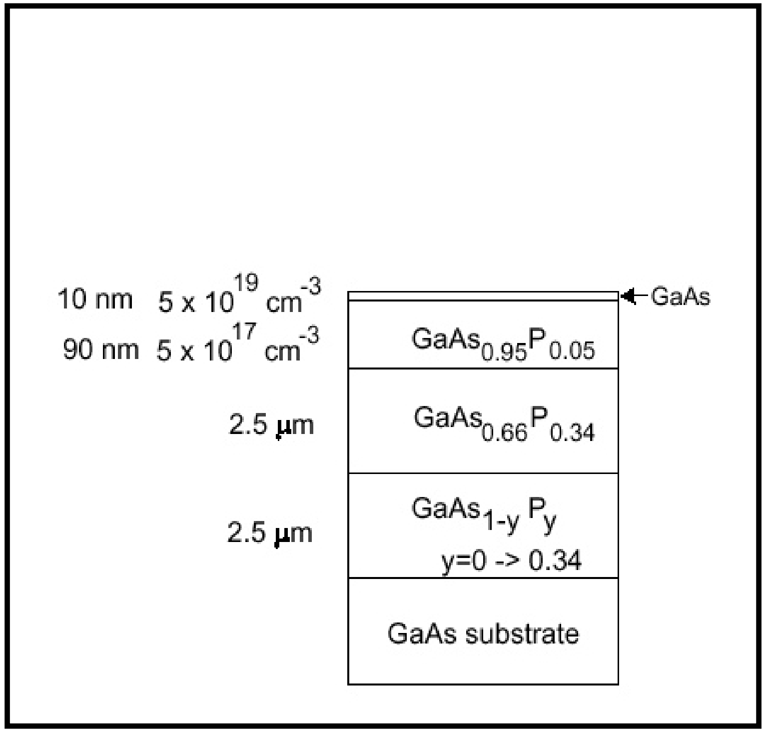
A Basic Polarized Electron Source

- A GaAs based photocathode in a gun structure
- Provisions in the gun chamber to achieve NEA (Cs and O_2, NF_3), heat cleaning to 600 C.
- A laser system to illuminate the surface of the photocathode with circularly polarized photons of correct wavelength
- An injector to transport and to accelerate the electrons



High Gradient doped GaAsP Photocathode



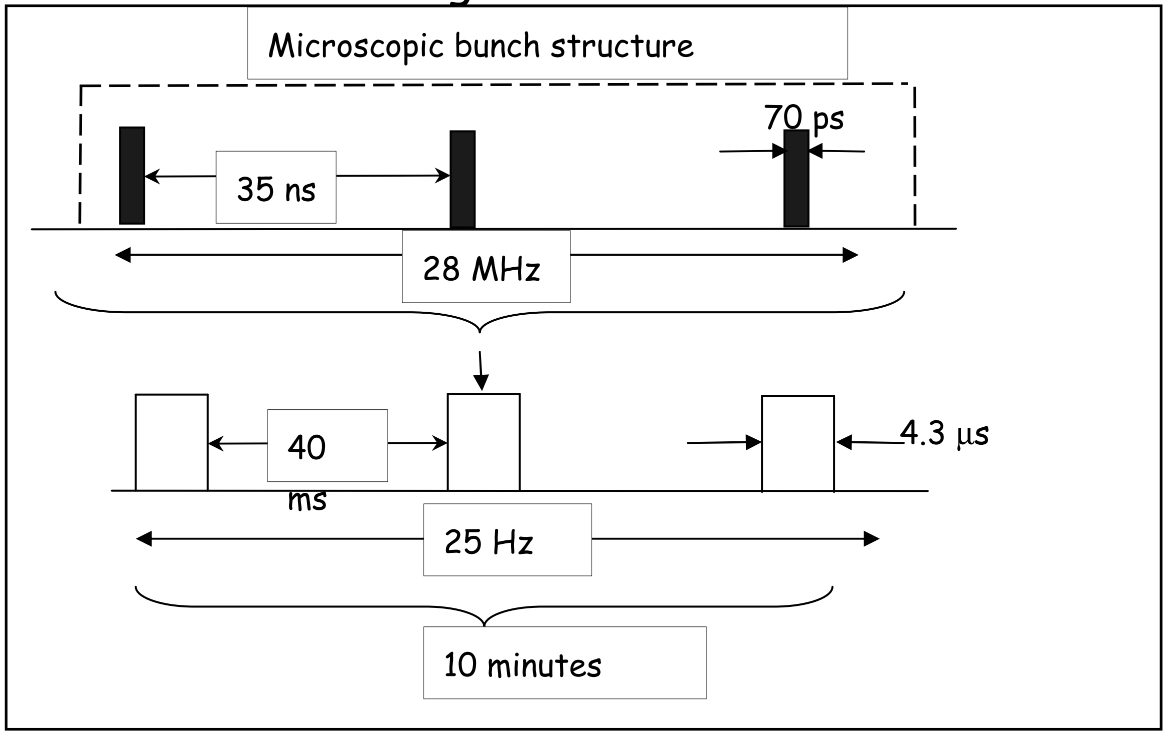


High polarization → Low QE

Polarized Photoinjector

M. Farkhondeh

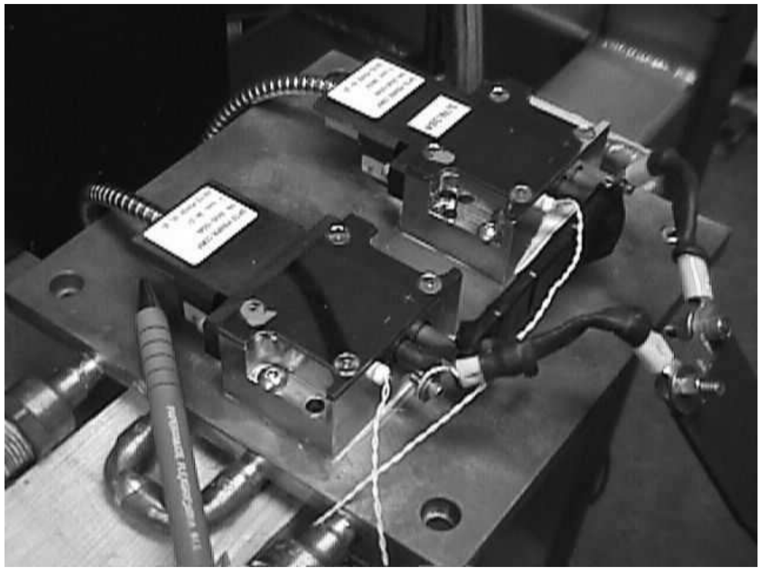
•Stack many pulse trains (15000) of 1.3 pC bunches at 25 Hz rates over 10 minutes to fill electron ring.



•Similar peak requirements as JLAB's G0 experiment, 40 uA, but very low macroscopic duty factor and average currents.

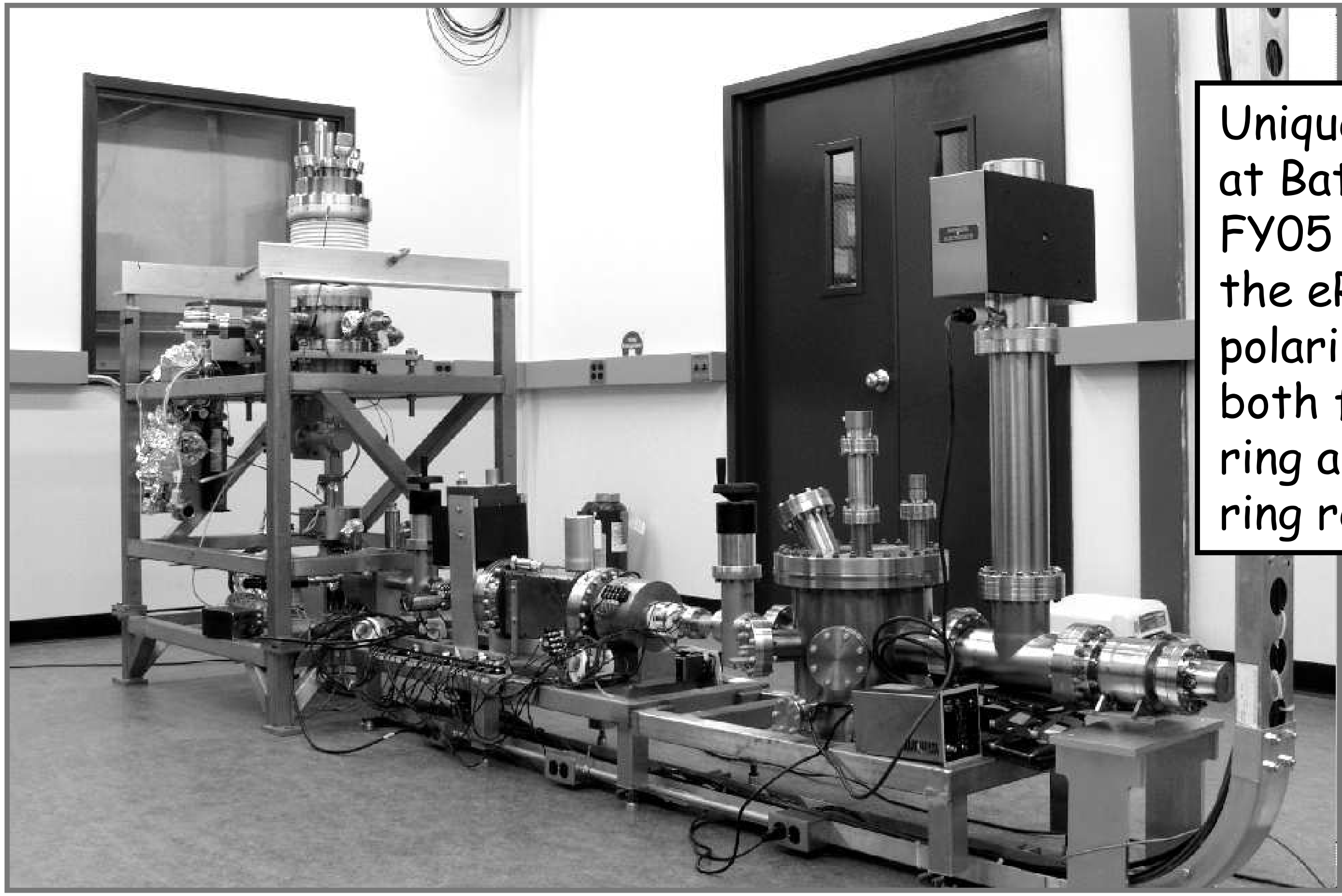
Two Possible Laser Systems

Mode locked laser system at J-lab



High Power Diode array laser system at MIT-Bates

eRHIC Source Development at MIT Bates



Unique opportunity at Bates beyond FY05 to do R&D on the eRHIC polarized source both for the ring-ring and the linac-ring requirements.

MIT-Bates 60 keV polarized test beam setup

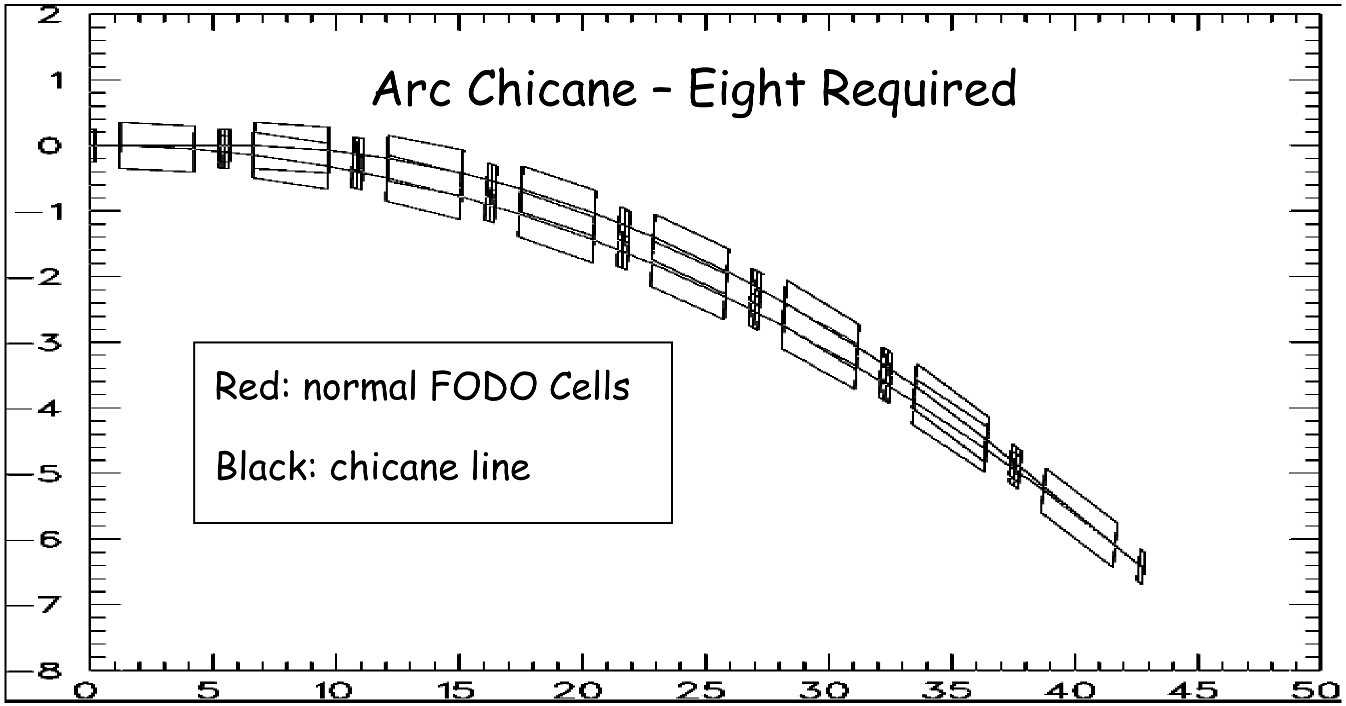
Path Length Adjustment

Variable Path Length for e-/e+

C. Tschalaer, B. Weng, S.Peggs, F. Wang

• The proton (heavy ion) velocity (energy) determines the collider frequency and consequently the electron path length. ΔL_{max} = 89 cm

• A minimum proton energy of 50 GeV (rather than 25 GeV) reduces ΔL_{max} to 22 cm



• Other schemes are possible – but this is an unsolved/uncosted item

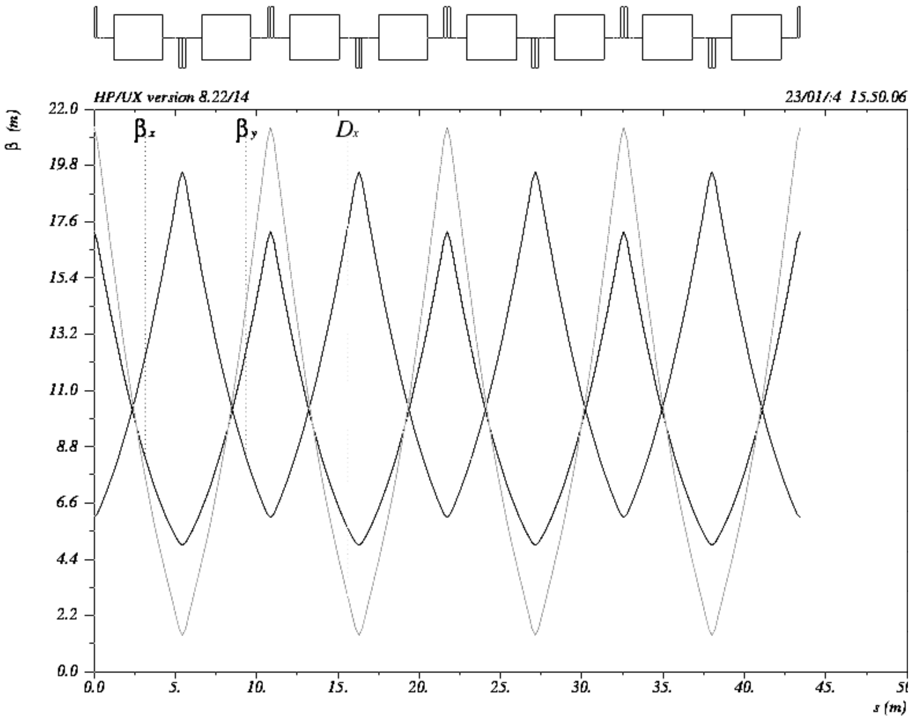
e-Ring Path length adjustment cont.

Proton Energy	Proton bunch spacing in time (ns)	Colliding frequency (MHz)	Electron ring RF frequency (MHz)	Electron bunch spacing (m)	Electron beam path length (m)	Electron beam path length changes (m)
25	35.5471	28.1317	478.238	10.6568	1278.812	0.8919
50	35.5283	28.1465	478.491	10.6511	1278.136	0.2161
100	35.5237	28.1503	478.554	10.6497	1277.967	0.0473
250	35.5223	28.1513	478.572	10.6493	1277.920	0.0

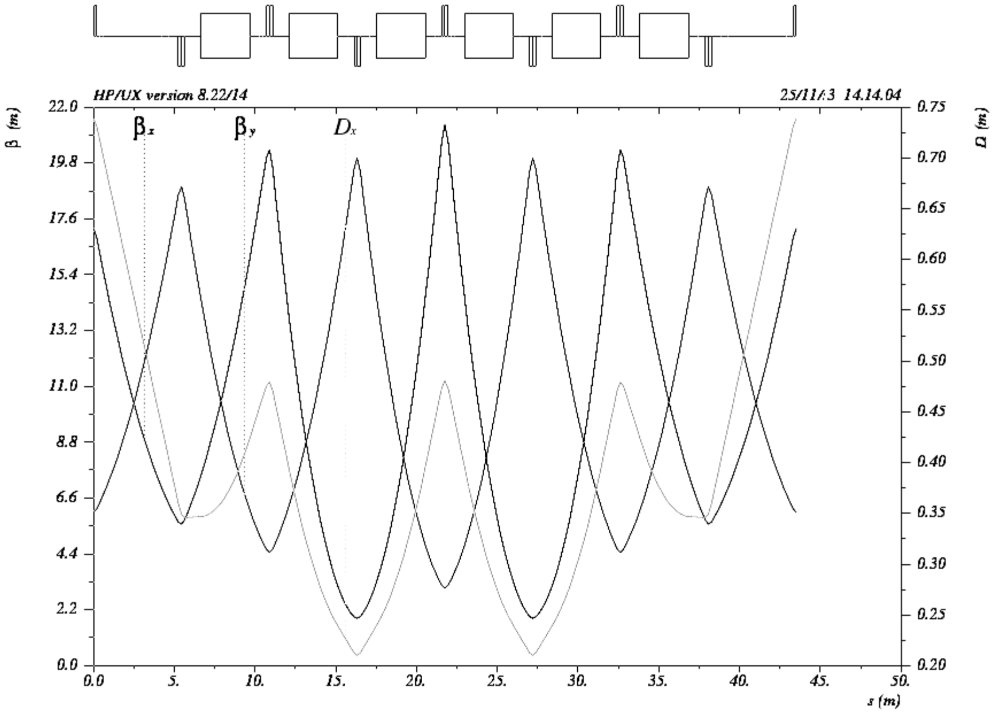
Possible solutions : All require engineering evaluation

- Multiple chicanes in arcs (Optics Distortion)
- Translate entire 180^0 arc (Trombone)

Distortion of Twiss parameters inside path length adjustment chicane



Original FODO



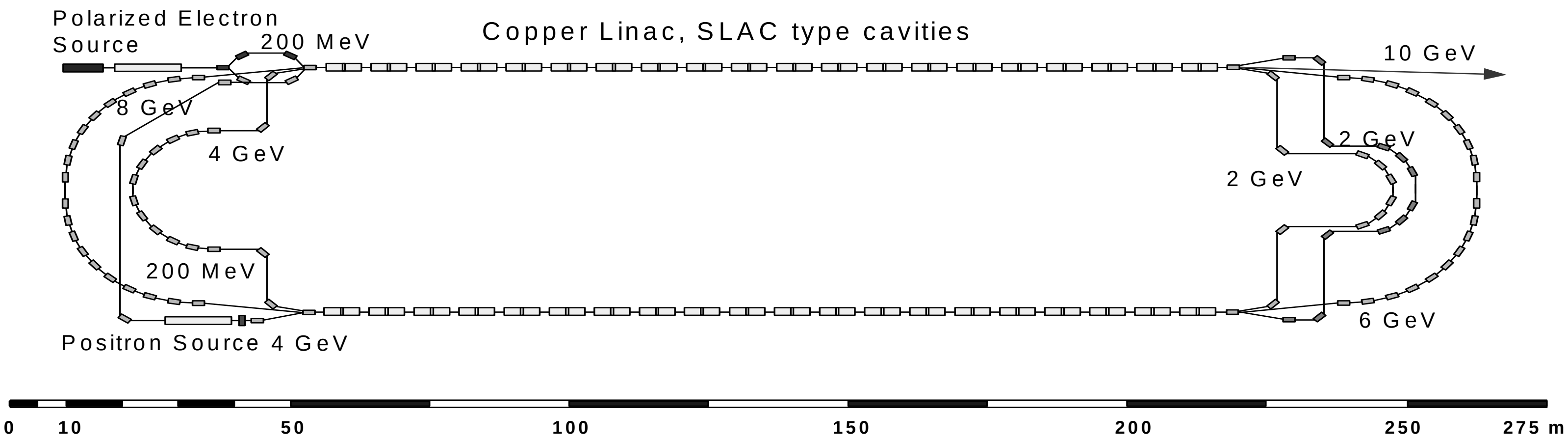
Eight-Dipole Chicane

Lepton Injector

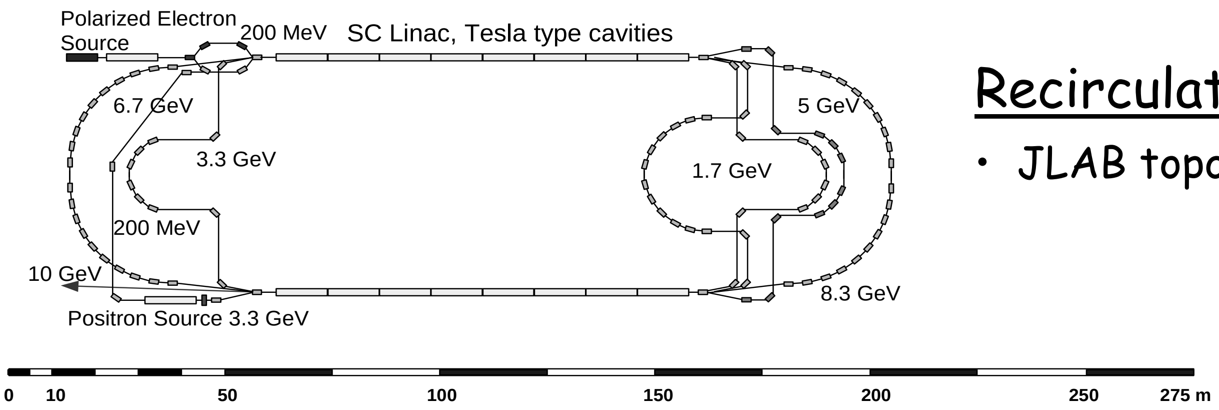
Full energy injection

- Injection of polarized electrons from source
- Ring optimized for maximum current ≥ 500 mA
- Top-off

Highest efficiency, Integral Luminosity 90 pb^{-1}/day



Several Injector Variants Appear Viable



Recirculating SC linac

- JLAB topology/TESLA cavities

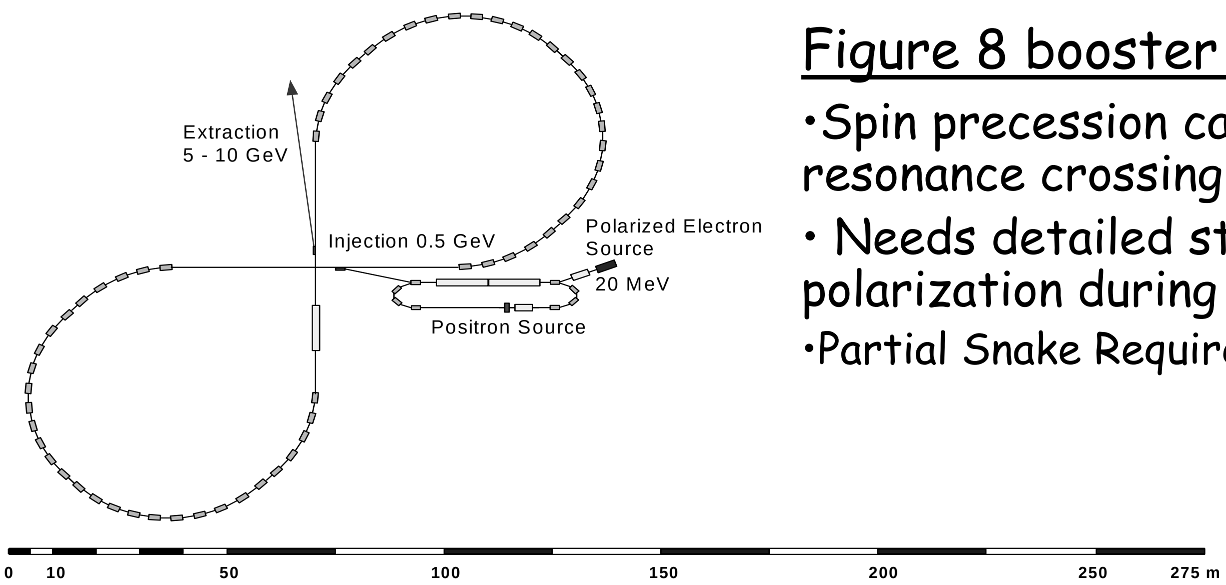


Figure 8 booster synchrotron

- Spin precession cancelled, no resonance crossing
- Needs detailed studies of polarization during ramp
- Partial Snake Required?

Figure Eight Synchrotron Parameters

Maximum Energy	10 GeV
Injection Energy	500 MeV
Circumference	500 m
Dipole Curvature	30 m
Synchrotron Radiation Losses / Turn	47 MV @ 10 GeV
Accelerated Current	1 mA
Peak Beam Power @ 10 GeV	50 kW
Installed RF Voltage	75 MV
Installed RF Power	100 kW
Synchrotron Cycling Frequency	<60 Hz
Polarization Damping Time	40 s
Equilibrium Polarization	0

Positron Production

	SLC 94	NC Linac	SC Linac	Figure Eight Synchrotron
Electron Drive Beam				
Energy (GeV)	30	4	3.3	0.5
Pulse Charge (nC)	5.6	2	4	20
Pulse Width (us)	Single Bunch	2	4	2
Repetion Rate (Hz)	120	30	30	60 (Linac freq)
Beam Energy/Pulse (J)	160	8	13	10
Avg. Beam Power (kW)	20	0.24	0.4	1.2
Positron Yield/e-	2.4	~0.1	~0.1	~0.01

Linac – Ring Collider
Energy Recovery Linac

I. Ben-Zvi *et. al.* -BNL

eRHIC ZDR Option: Linac-Ring eRHIC

Advantages :

- Round beam collision (Luminosity)
- Simplified IP geometry
- Waives in practice the e-beam beam-beam tune shift limit, possible higher ion bunch intensity (Luminosity)

potential factor 3-5 increase in collision luminosity

Issues:

- Substantial R&D on high-intensity, high-current polarized e source and High current ERLs
- No positron beam

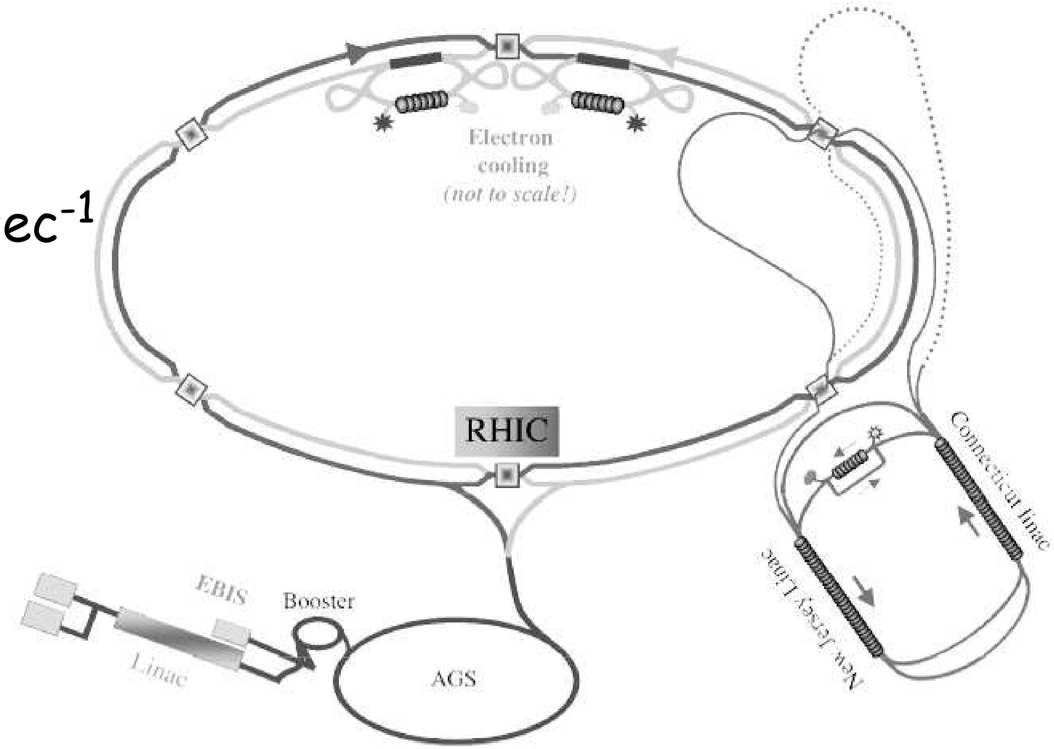
Linac-Ring eRHIC example:
Stand-alone ERL with two IPs

Features:

- L(ep) ~ 1.2 to 2.5 x $10^{33} cm^{-2} sec^{-1}$
- Full range of CM energies
- Polarization transparency at all energies
- STAR & PHENIX still run

Limitations:

- No e^{+} beam, physics implications?



Summary

Status of Ring – Ring Design

- We now have a Zero Order Design (ZDR) for eRHIC
- This achieves a luminosity of 0.4 x 10^{33} using conservative limits on:

    -Beam beam tune shift

    -Synchrotron Radiation Heating

    -Beam emittance aspect ratio and focusing through IP

using existing technologies for:

    -Polarized electron source

    -10 GeV injection accelerator

    -e-/e+ storage ring

http://locus.lns.mit.edu/~accelphy/eic/

Action Items for continuing eRHIC design effort:

-Layout on BNL site

-Interference/clearance w/ RHIC rings

-Detector/IR integration

-Path length adjustment for varying ion energies

-Continuing evaluation/simulation of equilibrium polarization due to alignment tolerances and magnetic errors

-Integrate downstream spin rotator w/ longitudinal Compton Polarimeter

-Compare merits of different injector architectures – eRHIC operation

-Positron production, acceleration and capture
    e-/e+ ring dynamic aperture

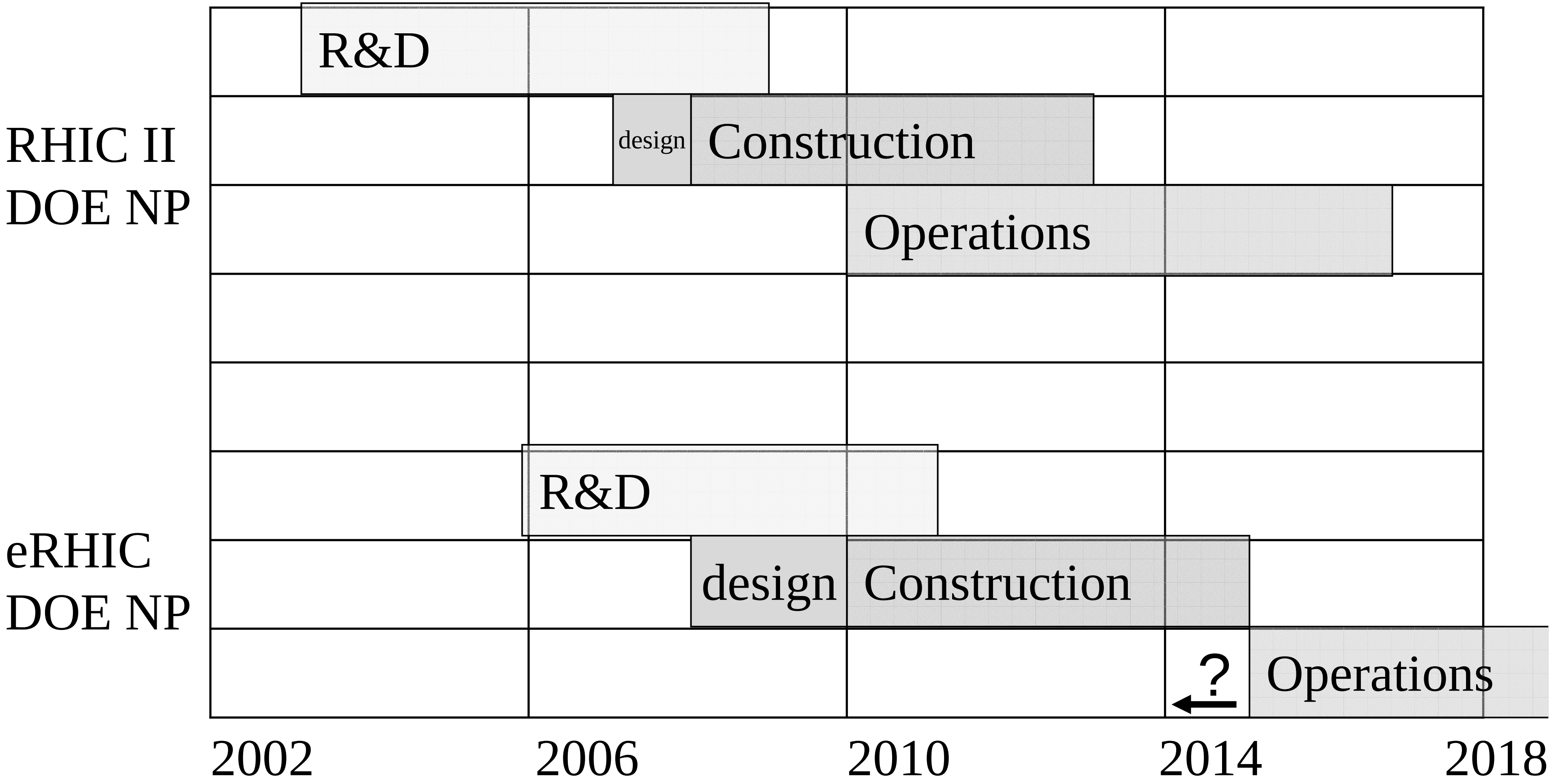
-Develop polarized photoinjector satisfying eRHIC requirements

-Refine cost models for eRHIC accelerator and rings

Possible Project Schedule

- 2005/6 NSAC approval
- 2006 CD0
- 2006/7 R&D funding
- 2007/9 e-cooling becomes available
- 2007/8 CD1
- 2008/9 CD2
- 2011/12 CD3 (begin construction)
- 2013/14 First electron-ion collisions

Technically driven schedule



Summary

R. Milner – June 2004 BNL DOE Review

- eRHIC is required within a decade to maintain progress in the study of the fundamental structure of matter
  - spin structure of nucleon
  - partonic basis of atomic nuclei
- eRHIC accelerator design has been developed based on realistic considerations and which can deliver luminosity close to 10^{33} cm^{-2} s^{-1} - cost model is well understood
- More futuristic concepts have potential to yield higher luminosity and are under development
- Urgency to realize eRHIC driven by strength of scientific case and interest from worldwide community