

eRHIC Realization

- Why is it important and timely to study the partonic origin of matter?
- Why a high luminosity lepton-ion collider?
- Why now?
- Why eRHIC?
- eRHIC conceptual design
- Cost
- Schedule

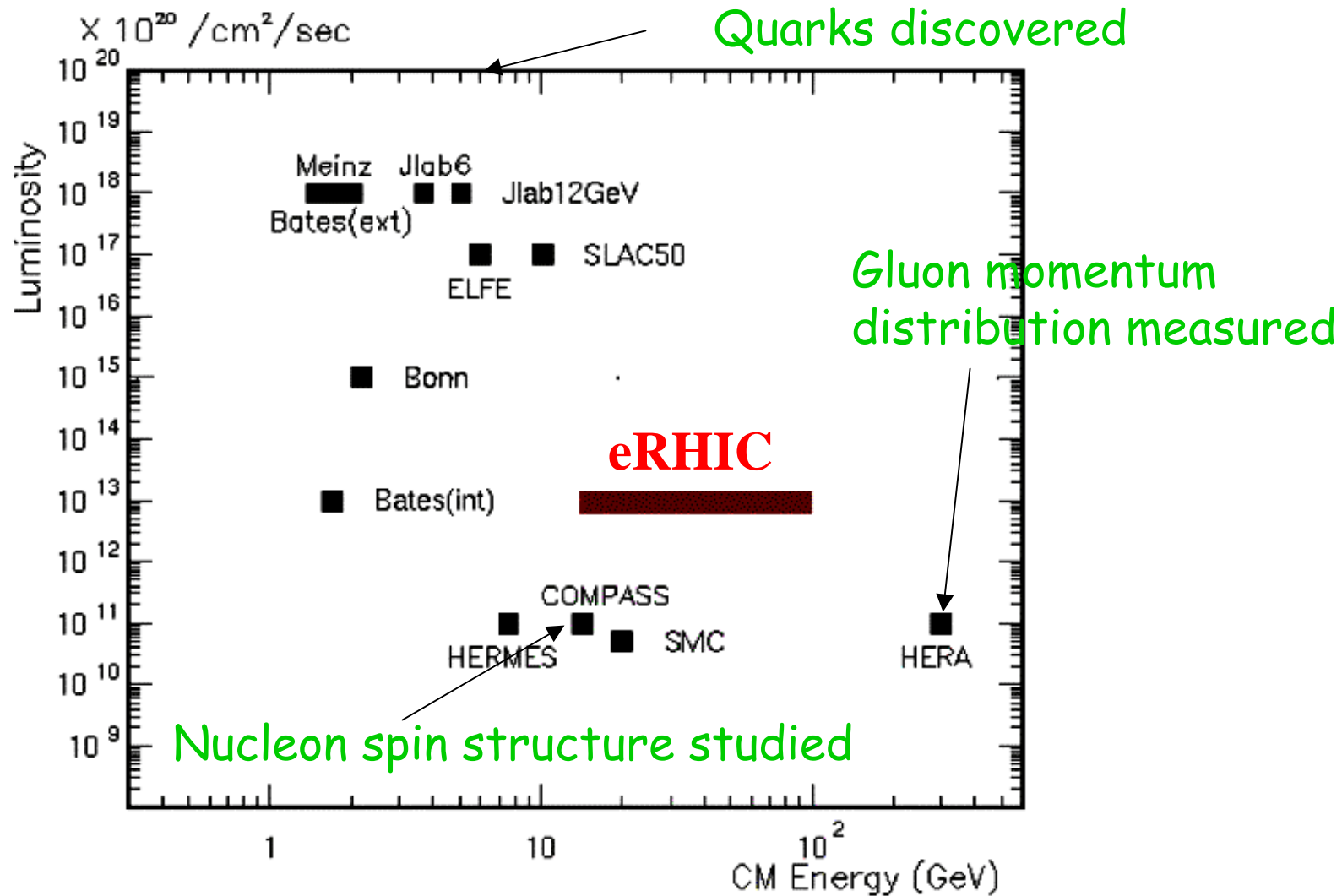
Why do we need to understand the partonic origin of matter?

- Because it is **the fundamental basis of 99.9% of observable matter in the physical universe**
- The partonic structure of atomic nuclei is essential to understanding the physics of hadrons, e.g. relativistic heavy ion collisions
- Over the next decade we expect full *ab initio* QCD calculations of many experimental observables => precise tests of QCD

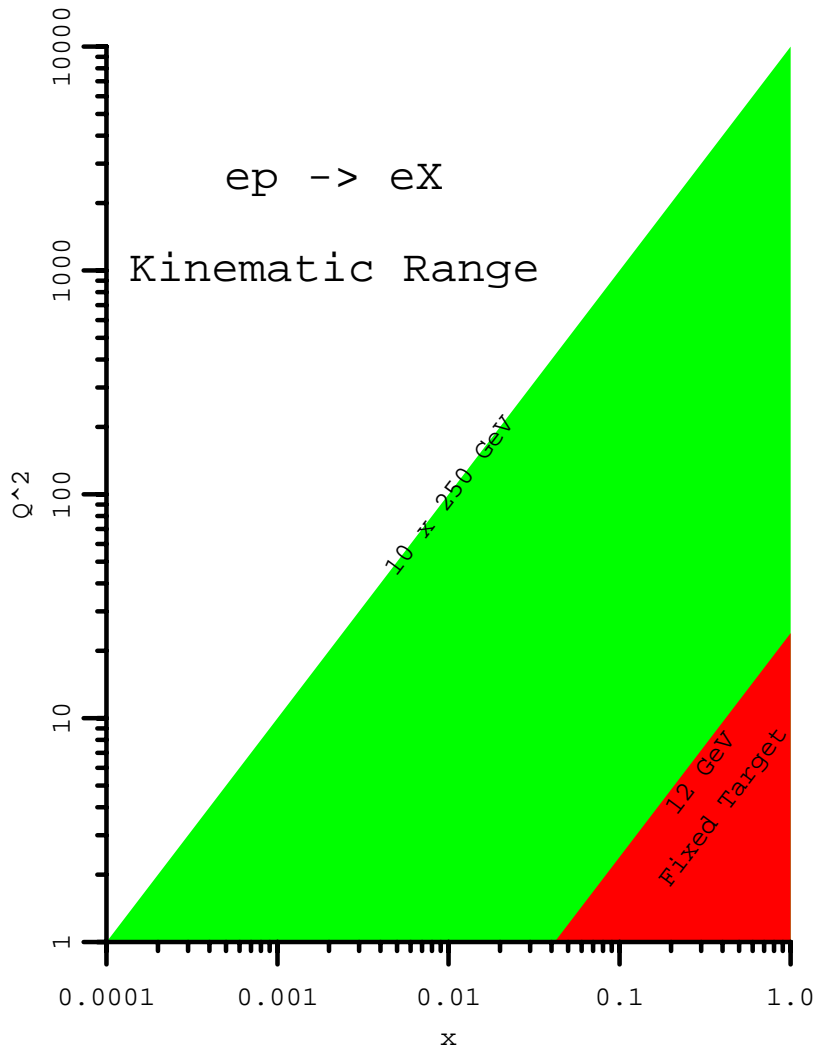
Why a high luminosity lepton-ion collider ?

- Lepton probe provides precision but requires high luminosity to be effective
- High $E_{\text{cm}} \Rightarrow$ large range of x , Q^2 $Q_{\text{max}}^2 = E_{\text{CM}}^2 \cdot x$
 - x range: valence, sea quarks, glue
 - Q^2 range: utilize evolution equations of QCD
- High polarization of lepton, nucleon achievable
- Complete range of nuclear targets
- Collider geometry allows complete reconstruction of final state

eRHIC will be a unique accelerator



Q^2 and x Range of eRHIC



- $E_e = 5-10 \text{ GeV}$
- $E_p = 30-250 \text{ GeV}$
- $s^{\frac{1}{2}} = 25-100 \text{ GeV}$
- $x_{Bj} = 10^{-4}$ to 0.7
- $Q^2 = 0$ to 10^4 (GeV/c)^2
- polarization of e^\pm , p, $^3\text{He} \sim 70\%$
- heavy ion beams of all elements
- high luminosity $> 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

Why now?

- *Parton structure of matter of great current interest in physics*
- **Spin structure of nucleon**
 - $g_1^p(x)$ at low x **dramatic QCD prediction**
 - gluon and sea quark polarization
 - Bjorken sum rule **QCD test**
 - new (GPD, transversity) parton distributions
- **Partonic understanding of nuclei**
 - gluon momentum distribution in nuclei: **essential to understand hot QCD in RHIC collisions**
 - fundamental explanation of nuclear binding
 - saturation
- *Lepton-nucleon capability disappearing at high energy lepton facilities (SLAC, Fermilab, CERN, and DESY)*
=> **planning of next generation facility a matter of urgency**

Why eRHIC?

- Collider with both polarized nucleon and heavy ion beams exists at BNL
- Capitalize on ~ \$ 1 billion investment in RHIC
- Strong scientific interest from RHIC community
- Strong leadership from BNL in evolution of lepton-ion collider since 1999
- In March 2002, the leading lepton-collider option was identified as a ring-ring configuration using the existing RHIC collider: eRHIC
- eRHIC is an opportunity for the United States to enhance leadership worldwide in an important subfield of science

eRHIC evolution

- Substantial international interest in high luminosity ($\sim 10^{33} \text{cm}^{-2}\text{s}^{-1}$) 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

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.)

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

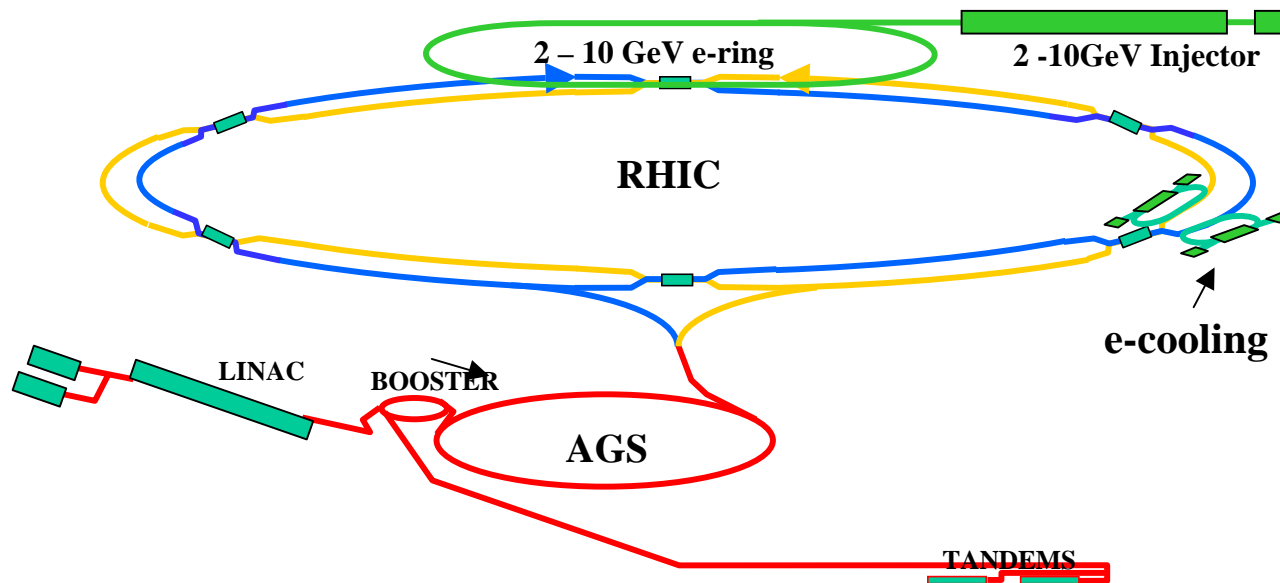
Editors: M. Farkhondeh (MIT-Bates) and V. Ptitsyn (BNL)

eRHIC ZDR Base Line Design

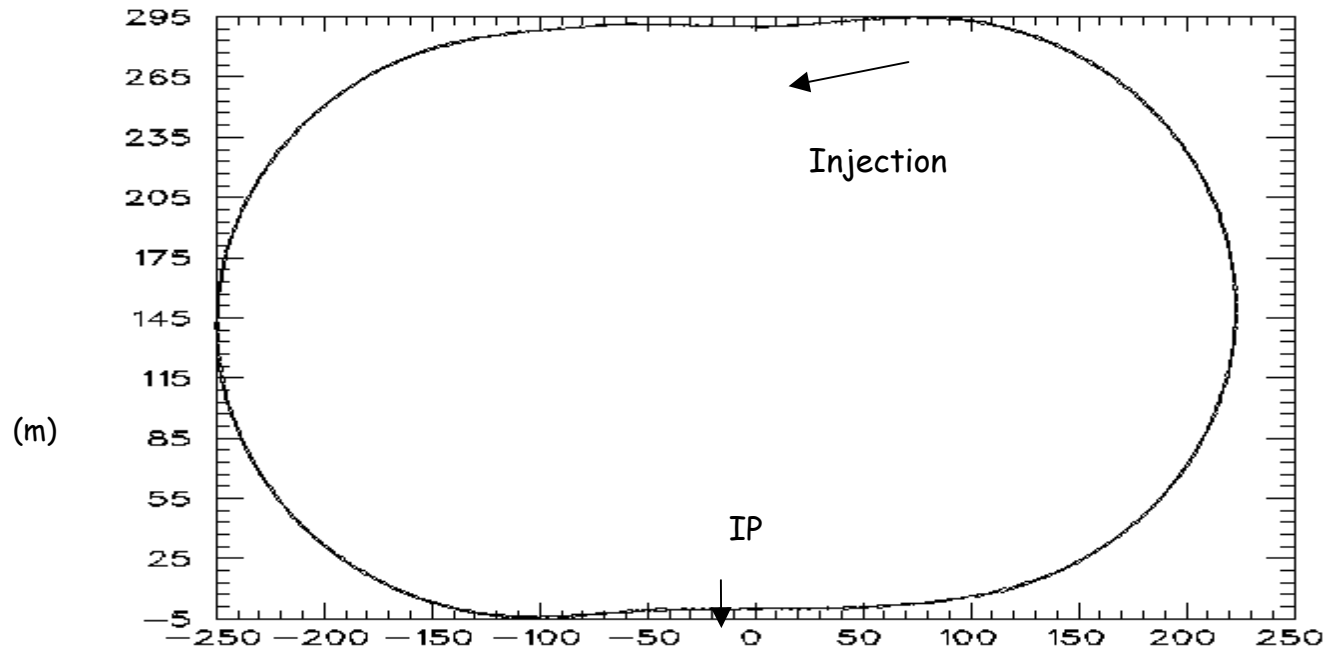
- 5- 10 GeV electrons and positron beams
- 250 GeV p, 100 GeV/nucleon heavy ions
- Maximum Luminosity 10^{33} nucleons $\text{cm}^{-2}\text{s}^{-1}$
- High integrated luminosity, up to 90 $\text{pb}^{-1}/\text{day}$
- Longitudinal polarization 70% for e^- @ 5 - 10 GeV, e^+ @ 10 GeV
- Polarized protons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

Possible eRHIC layout

- Collisions at 12 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)



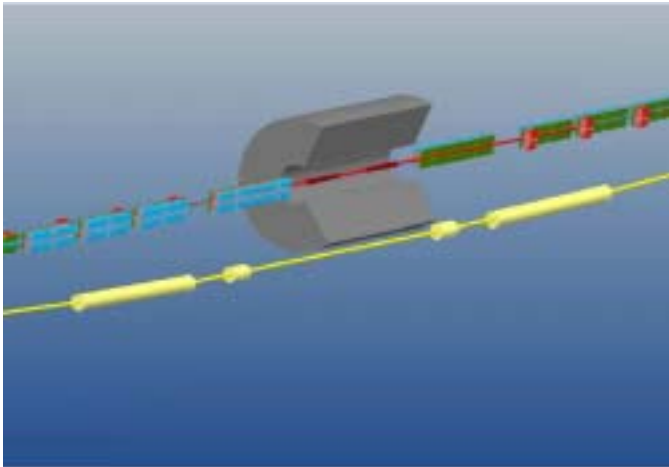
The Electron / Positron Ring



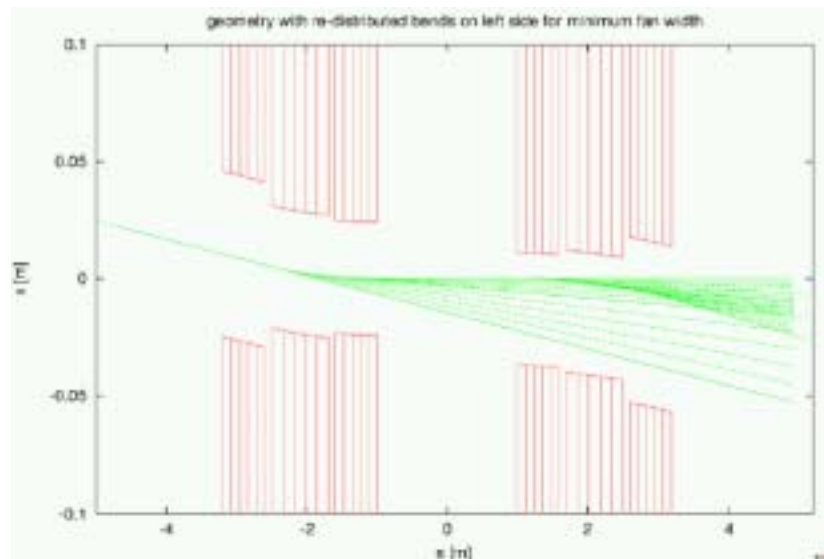
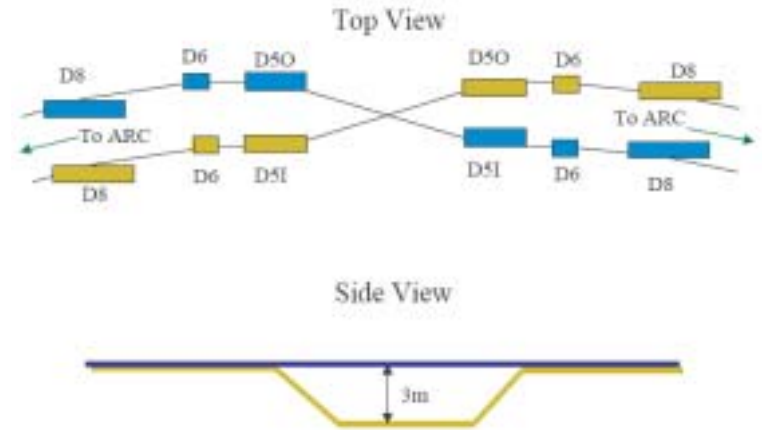
- Race track shaped storage ring in one plane
- Vertical polarization in arcs - spin rotators for long. pol. ($> 70\%$) at IP
- Polarized electron injection from 5-10 GeV
- Unpolarized positron injection from 5-10 GeV. Self polarization of positrons at 10 GeV $\tau_p = 20$ minutes, at 5 GeV $\tau_p = 1$ hour

IR Design

Synchrotron radiation, Hadron beam modification



Side view



e^\pm beam

eRHIC e^\pm Ring Parameters

10 GeV electrons - 250 GeV
protons

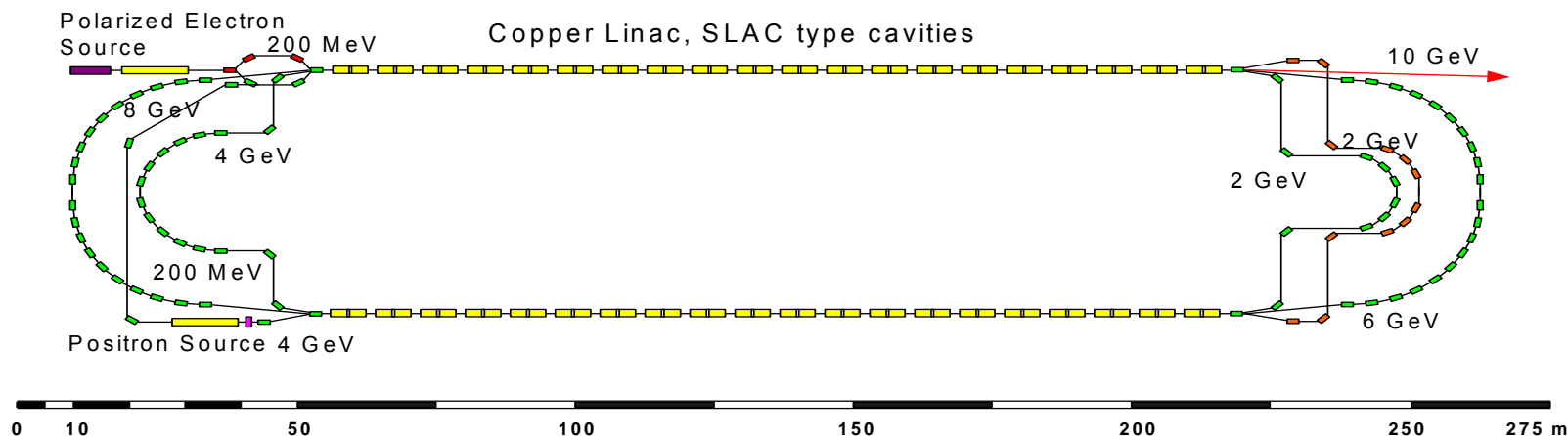
- Electron ring design limits consistent with B factories
- Ion ring design limits extrapolation from current RHIC performance
- Luminosity assumes ion collisions at two other IPs
- Dedicated operations yields luminosity $\sim 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

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	$1.0 \cdot 10^{11}$	$1.0 \cdot 10^{11}$
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 ($10^{33}/\text{cm}^2/\text{s}$)	0.44	

Full energy injection

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

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



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 for X 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

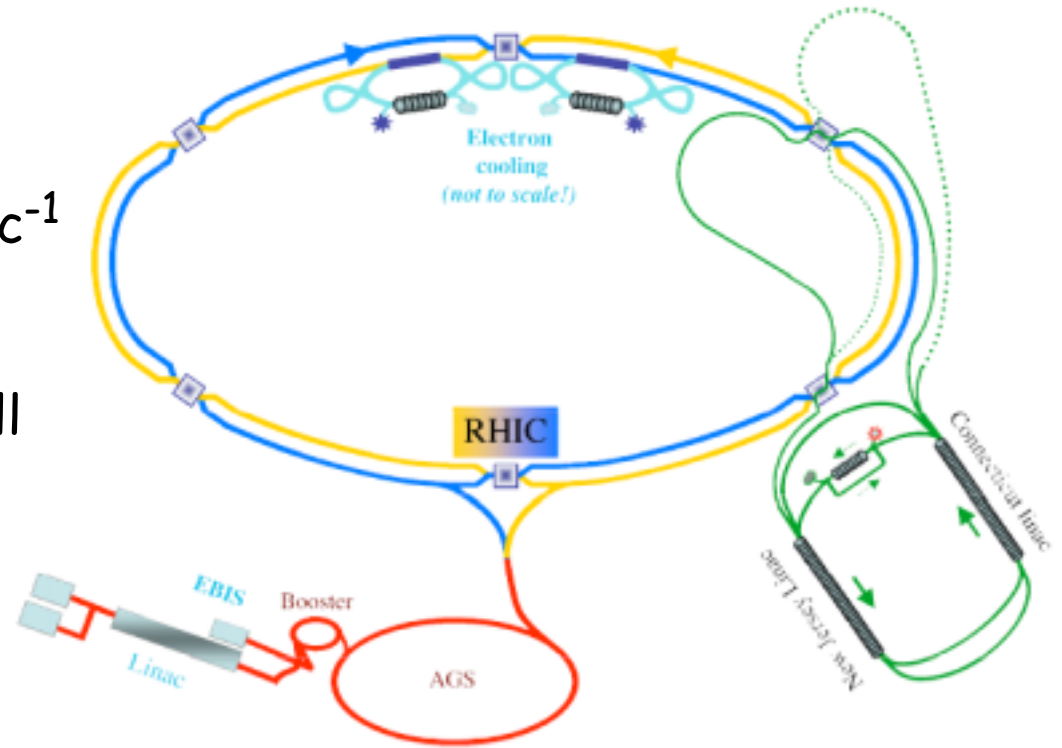
Linac-Ring eRHIC example: Stand-alone ERL with two IPs

Features:

- $L_{\max} \sim 1.2 \text{ to } 2.5 \times 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$
- Full range of CM energies
- Polarization transparency at all energies
- STAR & PHENIX still run

Limitations:

- No e^+ beam



eRHIC ring-ring design concept estimated cost (FY03\$)

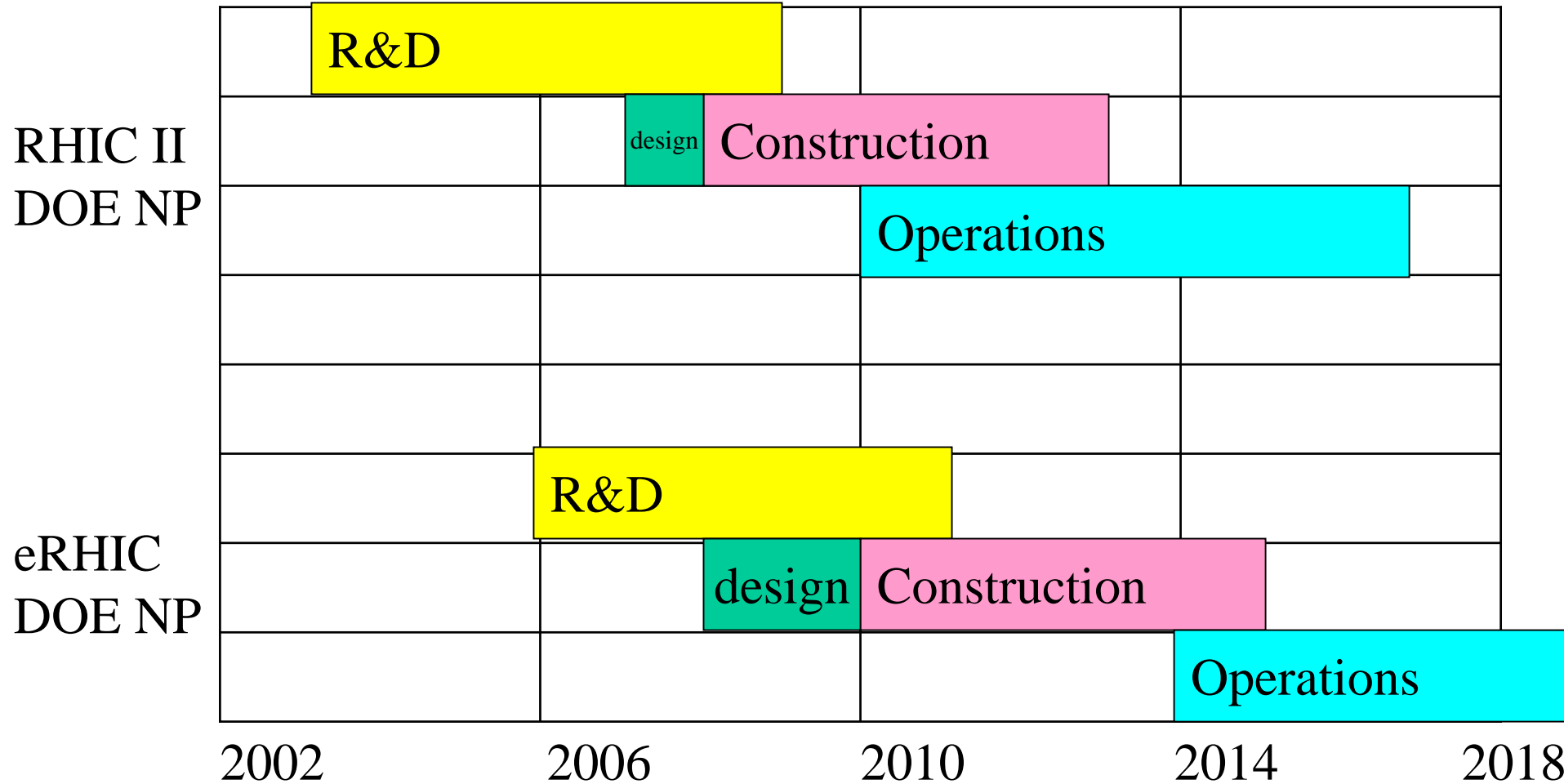
10 GeV Electron injector	\$ 110M
10 GeV Storage ring	\$ 130M
Detector	\$ 100M
Interaction region	\$ 10M
Total Estimated Direct Costs	\$350M
EDIA@15%; Conting@25%; ProjG&A@13%	\$186M
Total Estimated Costs (w/o escalation)	\$536M

Cost framework well understood and stable

Technically Driven Schedule

- 2005/6 NSAC approval
- 2006 CD0
- 2006/7 R&D funding
- 2007/9 e-cooling becomes available
- 2007/8 CD1
- 2008/9 CD2
- 2010/11 CD3 (begin construction)
- 2013/14 First electron-ion collisions

Technically driven schedule



Summary

- 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
- An eRHIC accelerator design has been developed based on realistic considerations and which can deliver luminosity close to $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ - 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

Backup slides

Luminosity Considerations

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

- F_c is the collision frequency (28 MHz) $r_e = 2.82 \times 10^{-15}$ m
- ξ the beam-beam tune shift $r_p = 1.53 \times 10^{-18}$ m
- $k_e = \varepsilon_{e,y}/\varepsilon_{e,x}$ 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 ... virtually impossible through IP and ... problematic for polarization
- Flat beams adopted for the baseline ZDR

eRHIC cost estimates (FY03 \$)

Include:

- Design
- Procurement
- Hardware delivered to the lab
- Some magnets (quads) magnetically mapped.

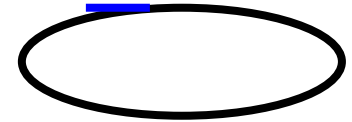
Do not Include

- Installation
- Commissioning
- Any contingency

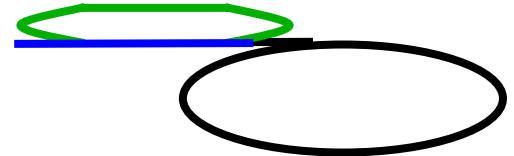
Injection Options

COST(w/o ring)

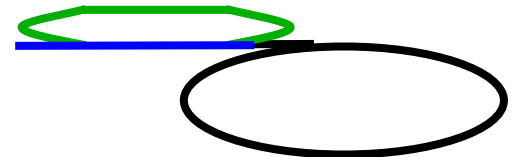
M\$ 56 * 2 GeV Copper Linac
2-10 GeV Ramping Ring
** including extra costs for ramping the storage ring*



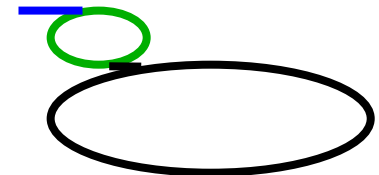
M\$ 110 5 GeV Copper Linac +
One Recirculation
5-10 GeV Static Ring



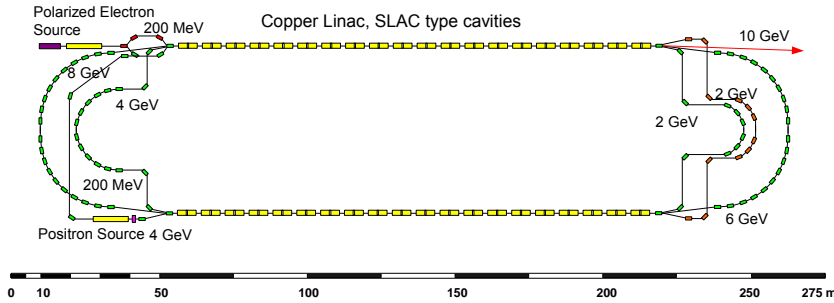
M\$ 150 5 GeV Superconducting Linac +
One Recirculation
5-10 GeV Static Ring



M\$ 90 1 GeV Copper Linac
1-10 GeV Ramping Booster Ring (Figure 8 ?)
5-10 GeV Static Ring

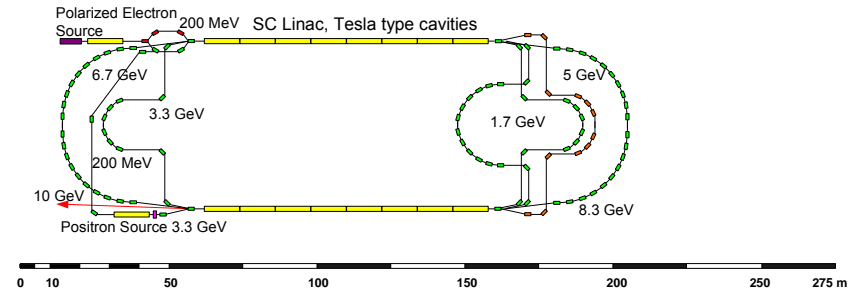


Accelerator options (in ZDR)



Recirculating NC linac

M\$ 110



Recirculating SC linac

M\$ 150

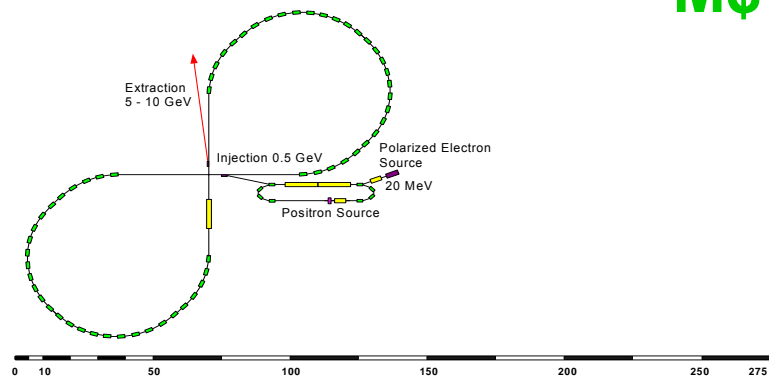
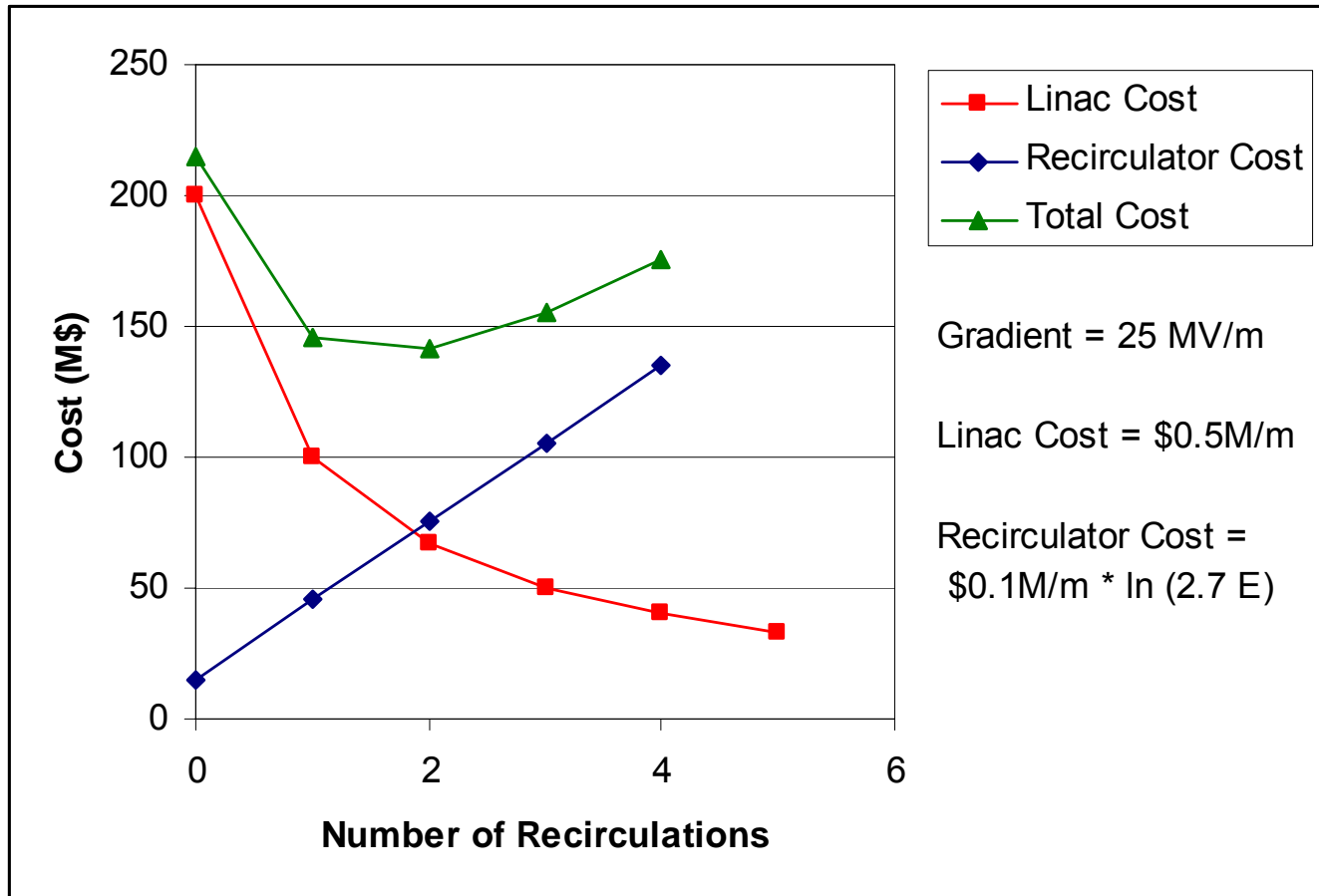


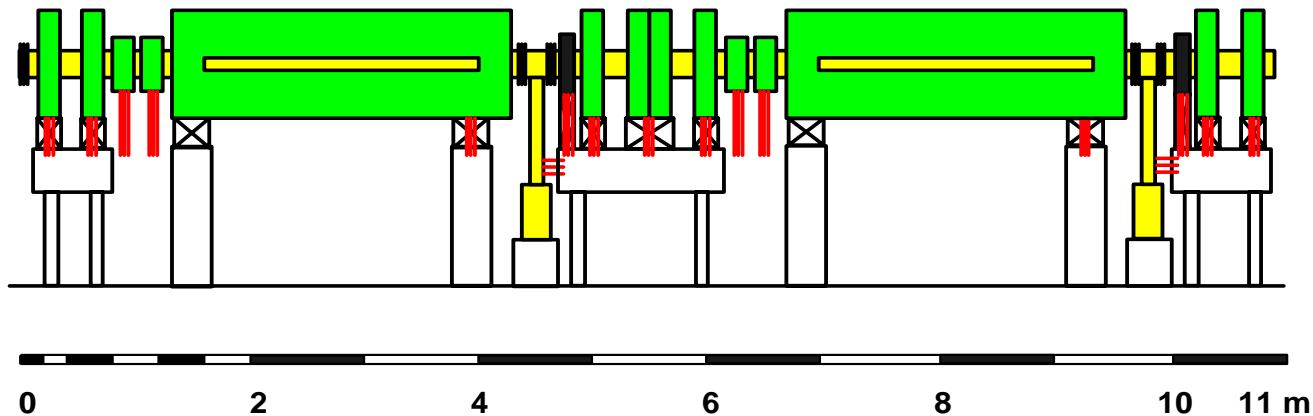
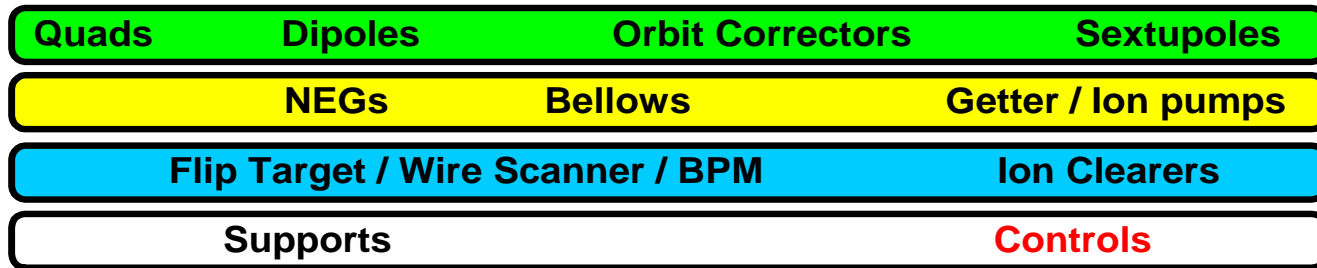
Figure 8 booster synchrotron

M\$ 90

Costs estimates (SC linac)



Bottom up costs estimates (arcs)



- Assembling "notebook" of quotations/component costs
- No RF, high power vacuum chambers, tunnel, ...
- Costs as delivered to the laboratory - no installation.

Costs:
59 k\$/m

Systems Costs Estimates: Main Ring (2003)

From APS
7 GeV ring

Storage Ring			
	Tunnel		13.9
	Magnets (incl. measurements)		53.2
	Support/Stands		2.5
	Vacuum		21.5
	Power conversion		8.5
	RF		13.7
	Feedback (transv. + long.)		3.7
	Diagnostics		3.1
	Control System		8.0
	<i>Subtotal Ring</i>		<i>128.1</i>
Interaction Region			
	Magnets		4.5
	Power conversion		1.8
	Support/Stands		0.6
	Vacuum		1.6
	Diagnostics		0.6
	<i>Subtotal Interaction Region</i>		<i>9.1</i>
Total Ring			137.2

Top Down Cost Estimates

Top down scaling from construction of other accelerators

Swiss Light Source Booster

Swiss Light Source

Argonne Booster

Bates SHR

JLAB

TESLA

eRHIC

• 10 GeV Main Ring + IR M\$ 140

• Injector 2 GeV M\$ 50

10 GeV M\$ 110

Reasonably consistent with bottoms up estimates

Large variability in injector due to choice of injector

Luminosity Limits for eRHIC (ring-ring and linac-ring)

- RHIC bunch spacing: 35 ns , 360 bunches/turn
- Ion beam beam-beam tune shift limits: 0.007-0.02 ?
- Ion beam intensity: total current and bunch intensity

Luminosity for 10GeV_e on 250 GeV p (ZDR IR design)

(360 bunches in RHIC)	ring-ring	linac-ring	Luminosity ratio L_{l-r}/L_{r-r}
Ion emittance [nm]	9.5	9.5	
Electron emittance (x/y) [nm]	53/9.5	2.5/2.5	
σ^* (x/y) [μm]	100/50	50/50	2
Ne/bunch [10^{11}]	1.0	1.4	1.4
Ni/bunch [10^{11}]	1.0	1.0 -2.0?	1-2?
Beam-beam limit ξ_{ion} (x/y)	0.007/0.0035	0.007/0.007	
ξ_e (x/y)	0.022/0.08	No limit	
L [$10^{33}\text{cm}^{-2}\text{sec}^{-1}$]	0.44	1.25-2.5	3-5