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 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 ?

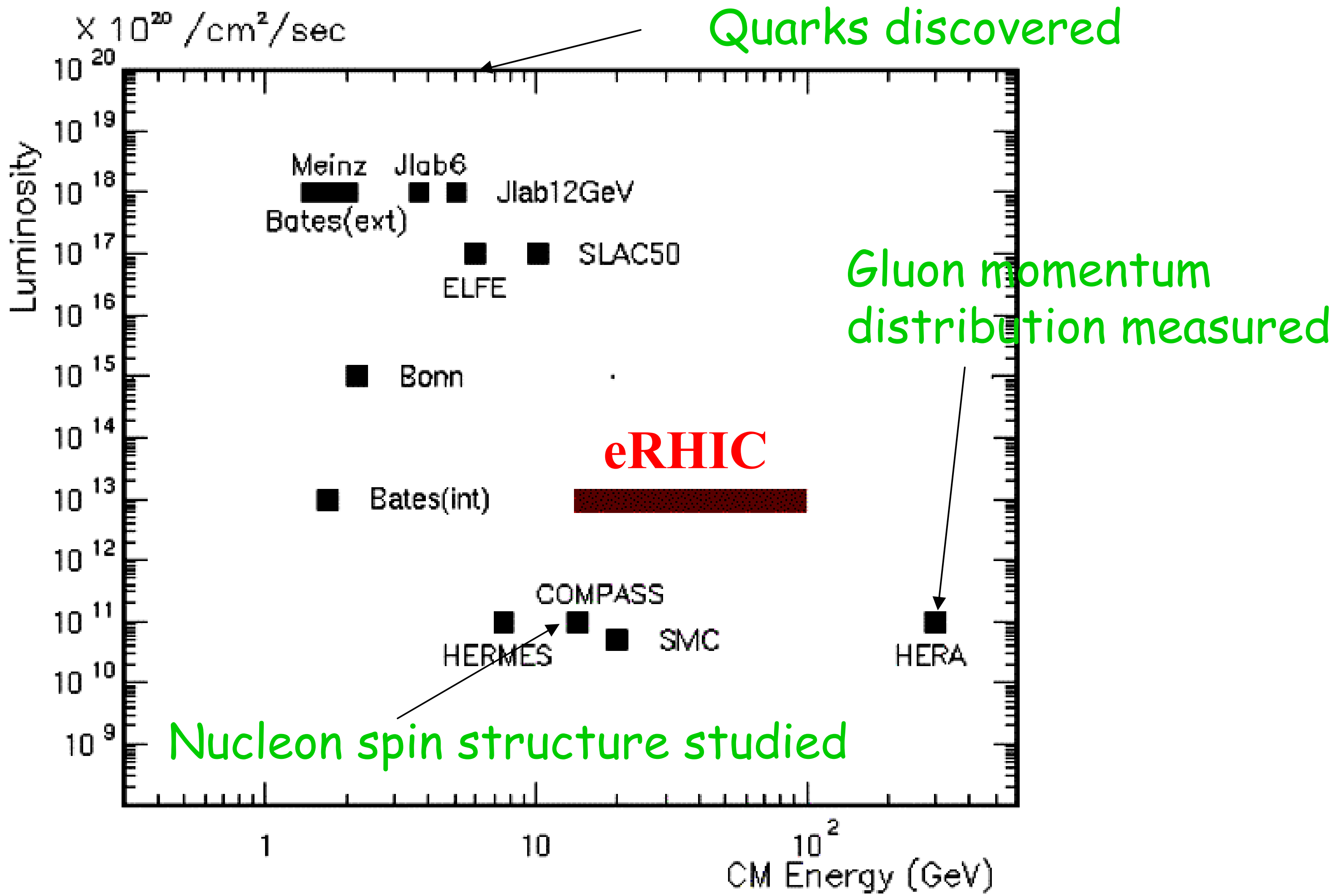
- Lepton probe provides precision but requires high luminosity to be effective
- High $E_{cm} \Rightarrow$ large range of x, Q^2

$$Q_{max}^2 = E_{CM}^2 \cdot x$$

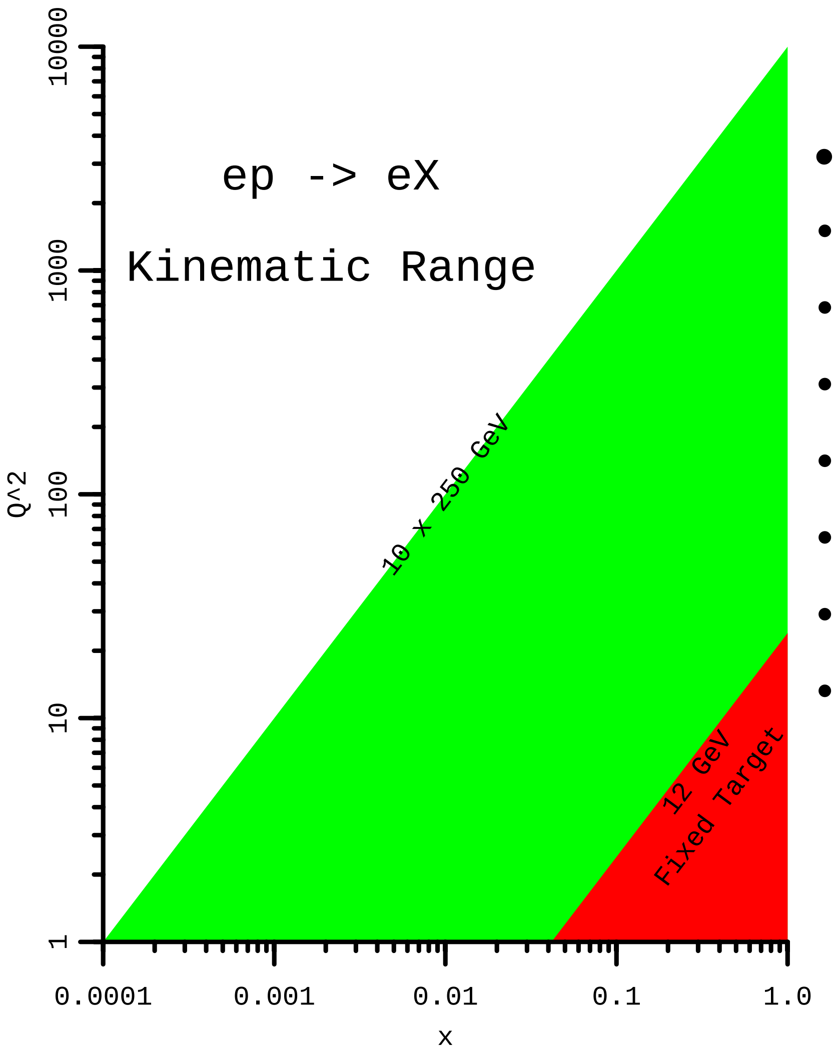
  x range: valence, sea quarks, glue

  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 GeV
- E_p=30-250 GeV
- $s^{\frac{1}{2}}$=25-100 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}

Why now?

- ***Parton structure of matter of great current interest in physics***
- **Spin structure of nucleon**

  - $g^p_1(x)$ 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 RHI 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 (~$10^{33} cm^{-2} s^{-1}$) 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

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

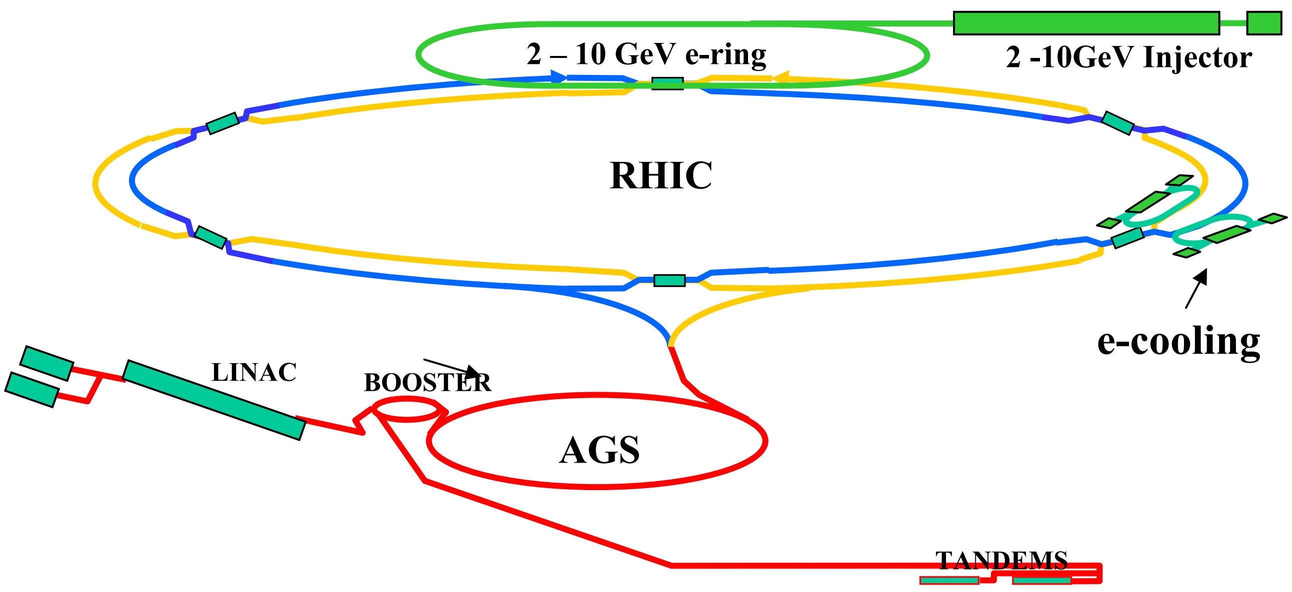
Editors: M. Farkhondeh (MIT-Bates) and V. Ptitsyn (BNL)

eRHIC ZDR Base Line Design

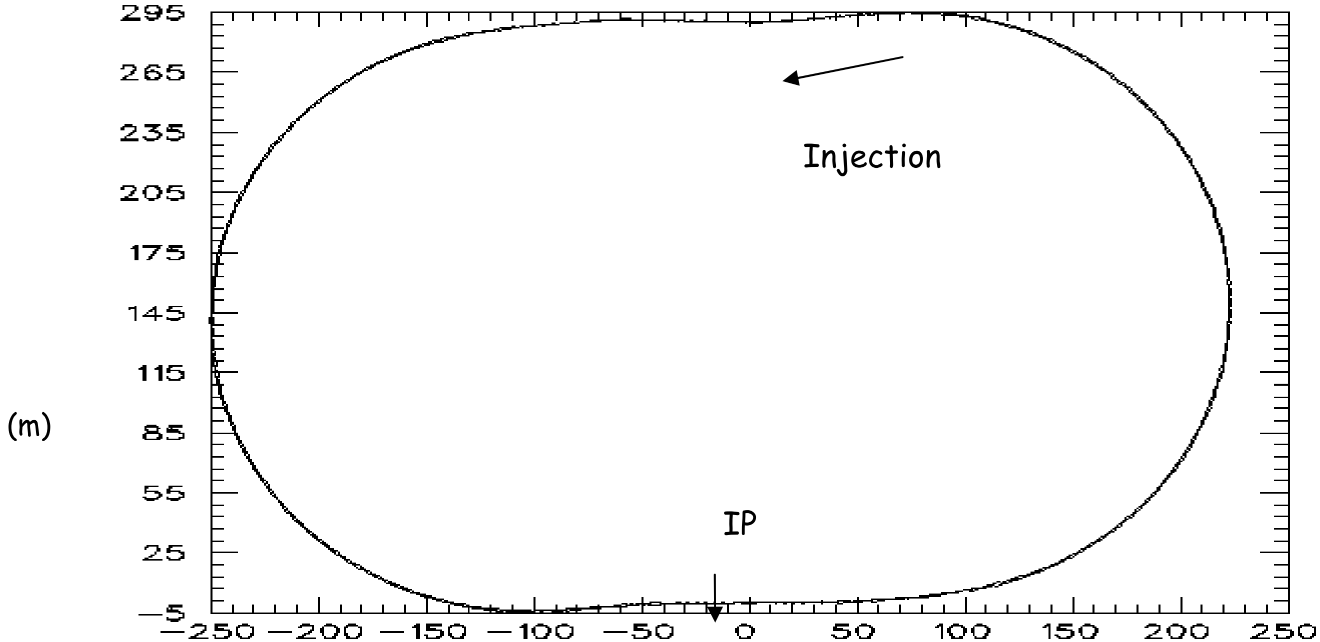
- 5- 10 GeV electrons and positron beams
- 250 GeV p, 100 GeV/nucleon heavy ions
- Maximum Luminosity 10^{33} nucleons $cm^{-2}s^{-1}$
- High integrated luminosity, up to 90 pb^{-1}/day
- Longitudinal polarization 70% for e^- @ 5 – 10 GeV, e^+ @ 10 GeV
- Polarized protons > 70%, polarized neutrons (^{3}He) > 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)



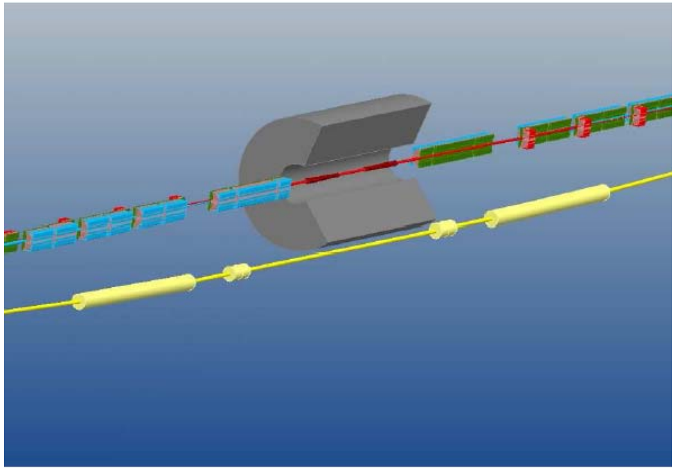
The Electron / Positron Ring

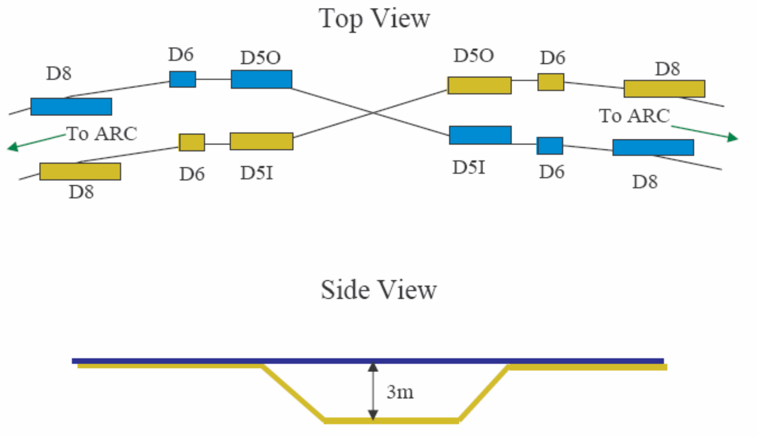


- Race track shaped storage ring in one plane
- Vertical polarization in arcs – spin rotators for long. pol. (> 70%) at IP
- Polarized electron injection from 5-10 GeV
- Unpolarized positron injection from 5-10 GeV. Self polarization of positrons at 10 GeV τ_p = 20 minutes, at 5 GeV τ_p=1 hour

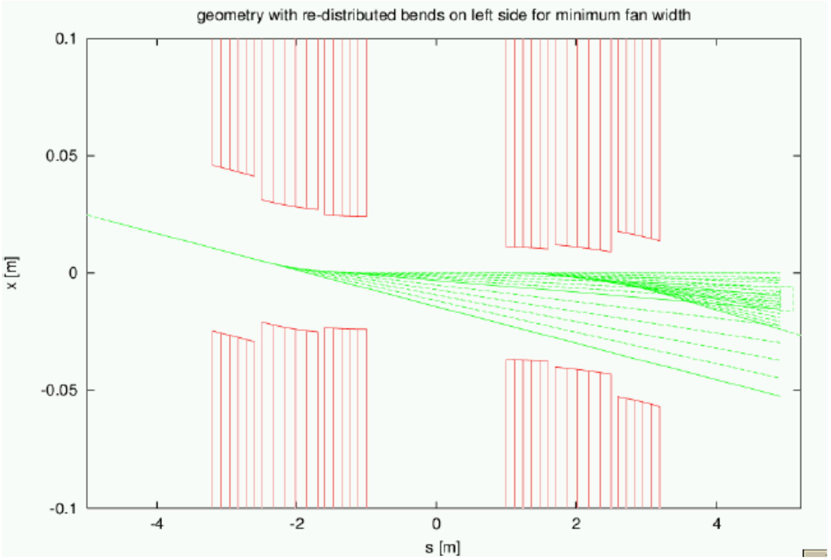
IR Design

Synchrotron radiation, Hadron beam modification





Side view



$e^{\pm}$ beam

eRHIC $e^{\pm}$ Ring Parameters

10 GeV electrons – 250 GeV protons

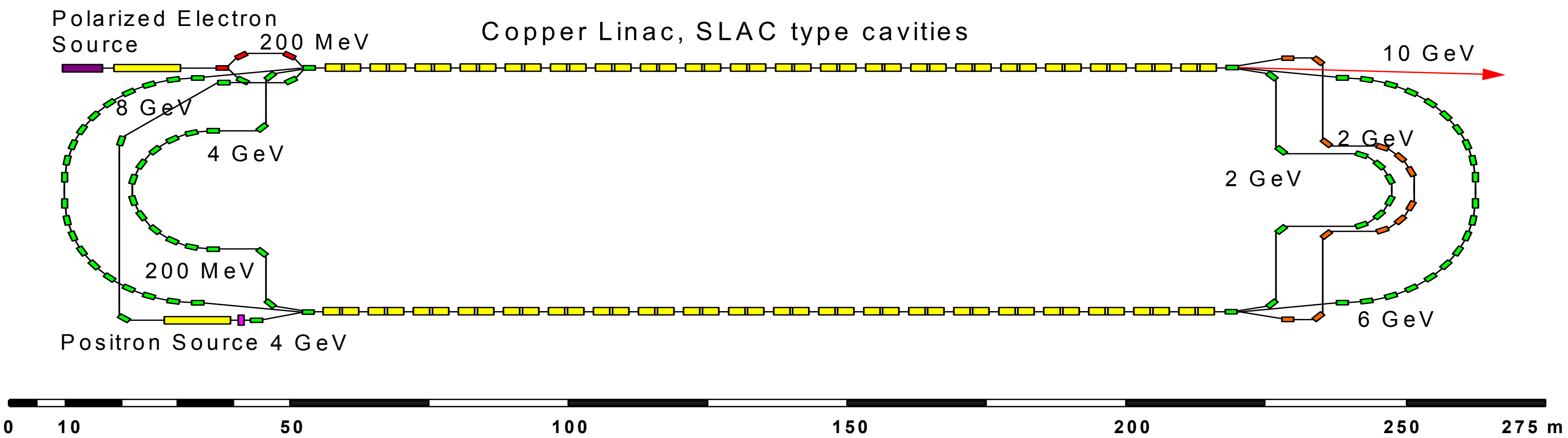
- Electron ring design limits consistent with B factories
- Ion ring design limits extrapolation from current RHIC performance
- Luminosity assumes ion collisions at two other IPs
- Dedicated operations yields Luminosity ~ 10^{33} cm^{-2} s^{-1}

	$e^{\pm}$ Ring	p Ring
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 (n m.rad)	56.6	9.4
Beta function at IP (cm) β_y^* / β_x^*	19.2/26.6	
Emittance Ratio ($\varepsilon_y/\varepsilon_x$)	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 $\xi x/\xi y$	-35.63/-33.84	
Luminosity (10^33/cm^2/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 pb^{-1}/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

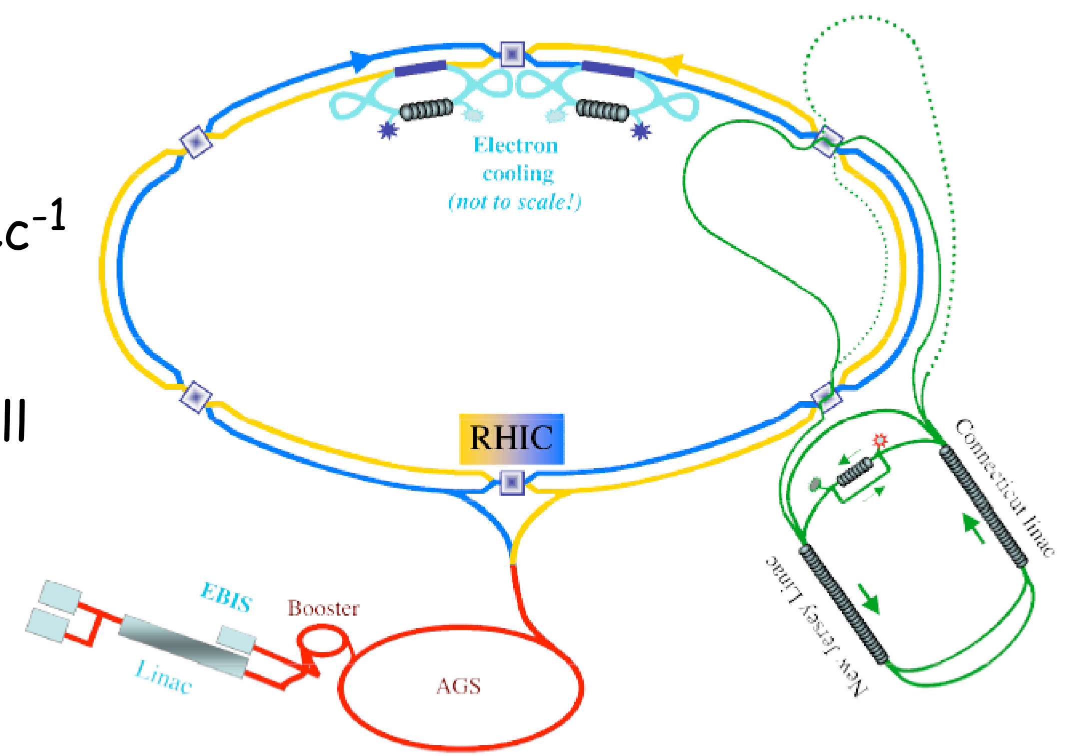
Linac-Ring eRHIC example: Stand-alone ERL with two IPs

Features:

- L_{max} ~ 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



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

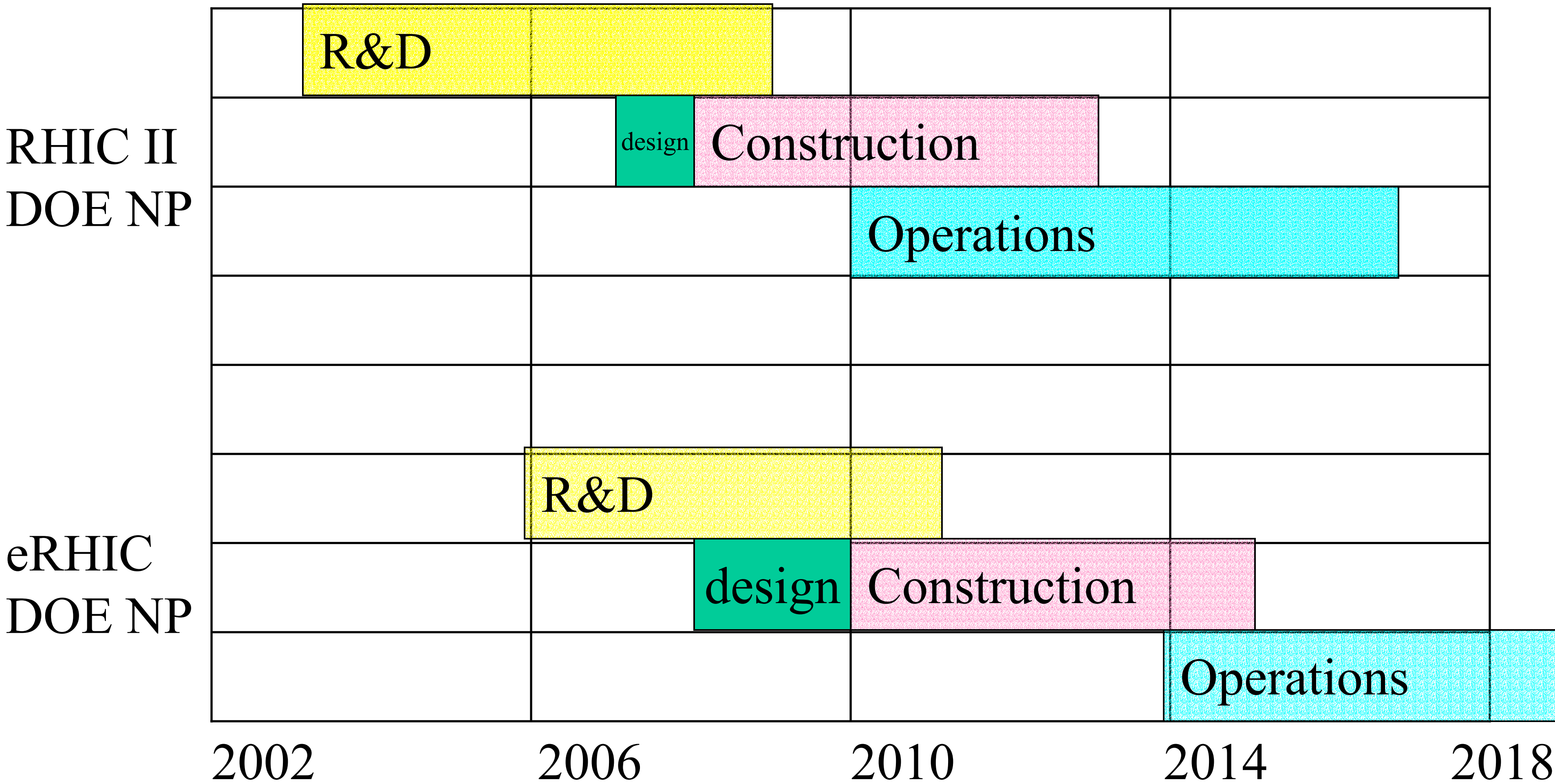
10 GeV Electron injector	$ 110M
10 GeV Storage ring	$ 130M
Detector	$ 100M
Interaction region	$ 10M
Total Estimated Direct Costs	$350M
EDIA@15%; Conting@25%; ProjG&A@13%	$186M
Total Estimated Costs (w/o escalation)	$536M

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
- 2011/12 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
- 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

Backup slides

Luminosity Considerations

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

Fc is the collision frequency

ξ the beam-beam tune shift

ke = εe,y/εe,x is the electron beam emittance ratio

k=σy/σx 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
- But … 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

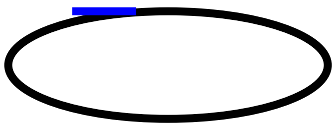
- Installation
- Commissioning
- Any contingency

Injection Options

COST(w/o ring)

M$ 56 *

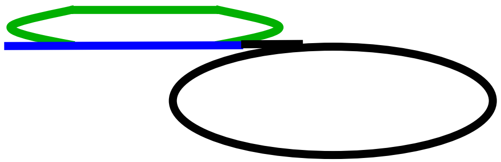
2 GeV Copper Linac
2-10 GeV Ramping Ring



* including extra costs for ramping the storage ring

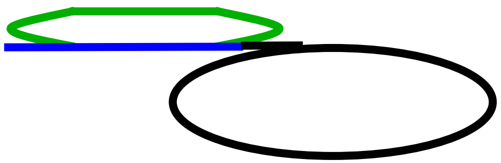
M$ 110

5 GeV Copper Linac +
One Recirculation
5-10 GeV Static Ring



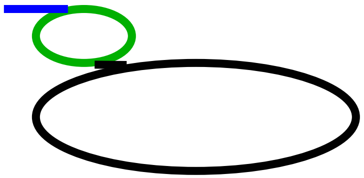
M$ 150

5 GeV Superconducting Linac +
One Recirculation
5-10 GeV Static Ring

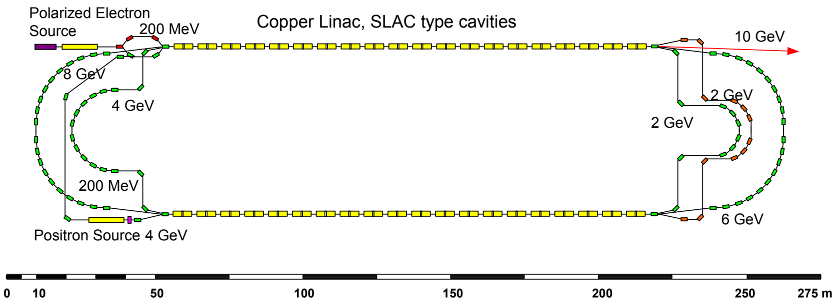


M$ 90

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

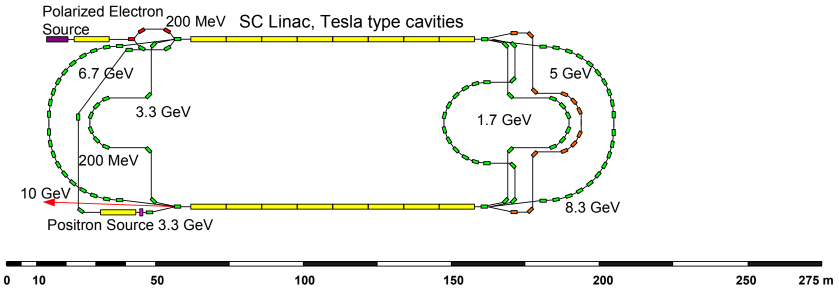


Accelerator options (in ZDR)



Recirculating NC linac

M$ 110



Recirculating SC linac

M$ 150

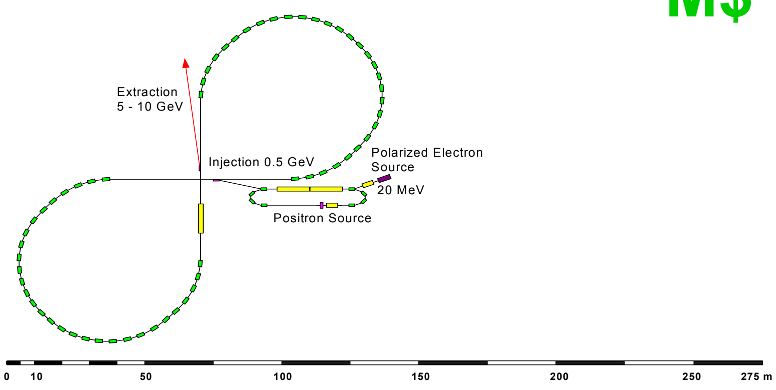
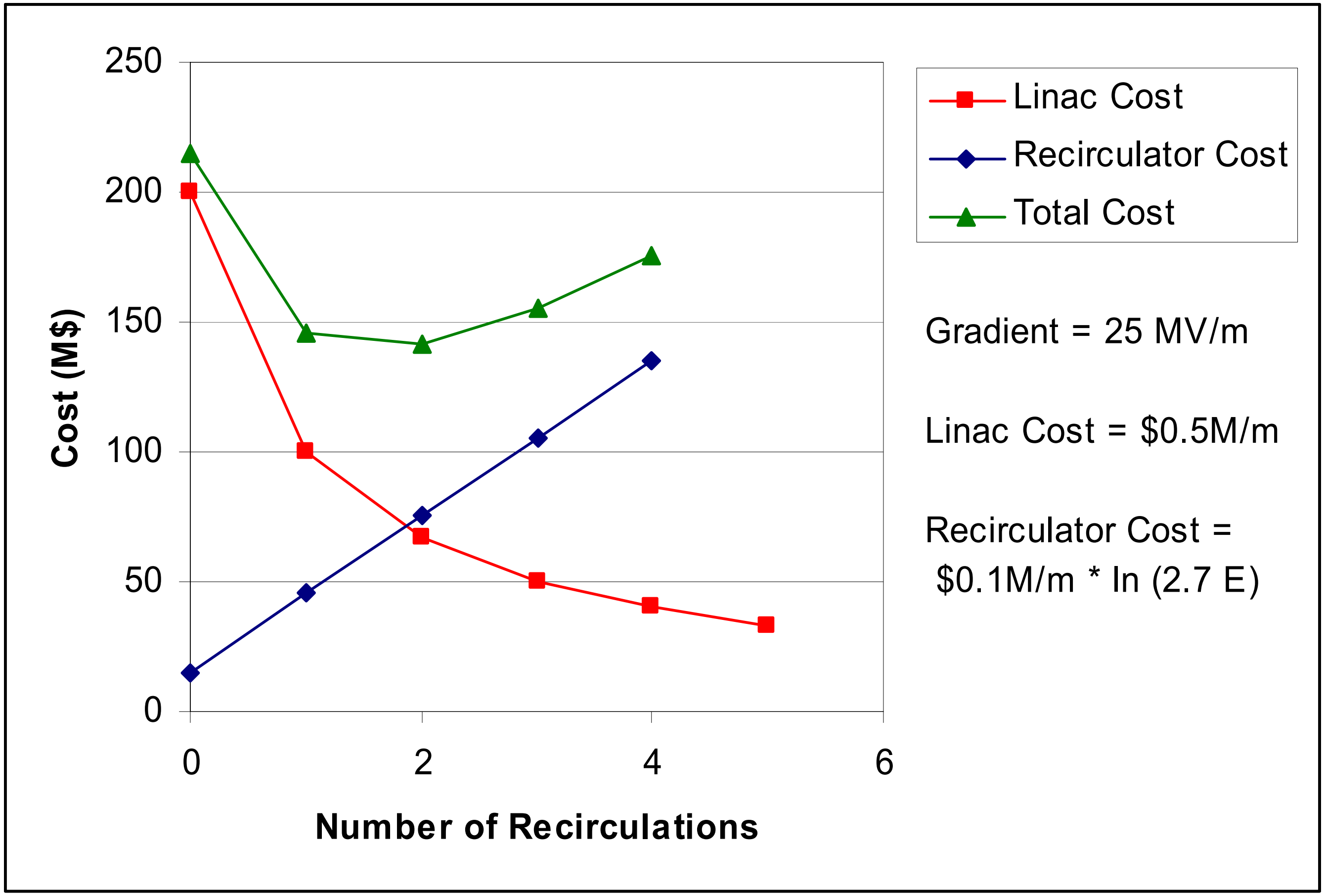


Figure 8 booster synchrotron

M$ 90

Costs estimates (SC linac)



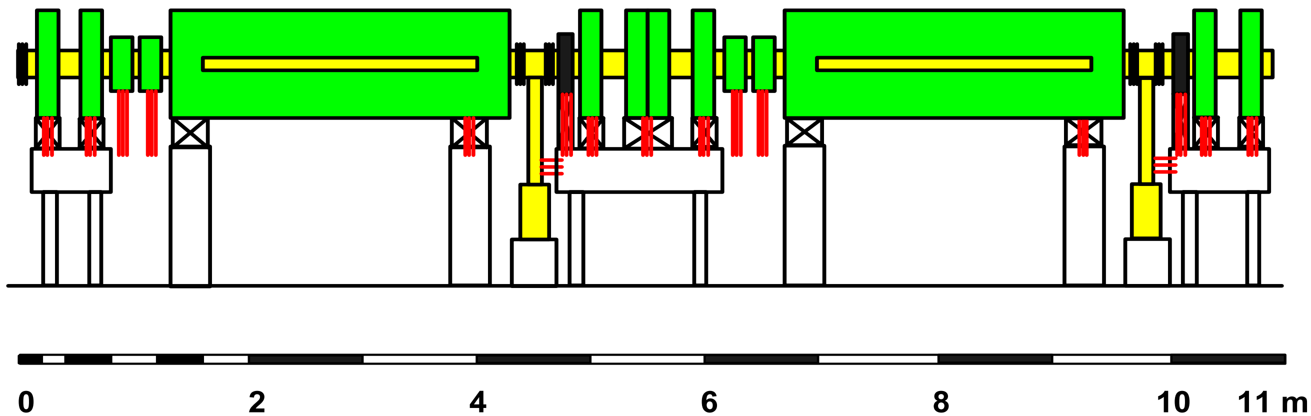
Bottom up costs estimates (arcs)

Quads Dipoles Orbit Correctors Sextupoles

NEGs Bellows Getter / Ion pumps

Flip Target / Wire Scanner / BPM Ion Clearers

Supports Controls



- 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
	Subtotal Ring		***128.1***
Interaction Region			
	Magnets		4.5
	Power conversion		1.8
	Support/Stands		0.6
	Vacuum		1.6
	Diagnostics		0.6
	Subtotal Interaction Region		***9.1***
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