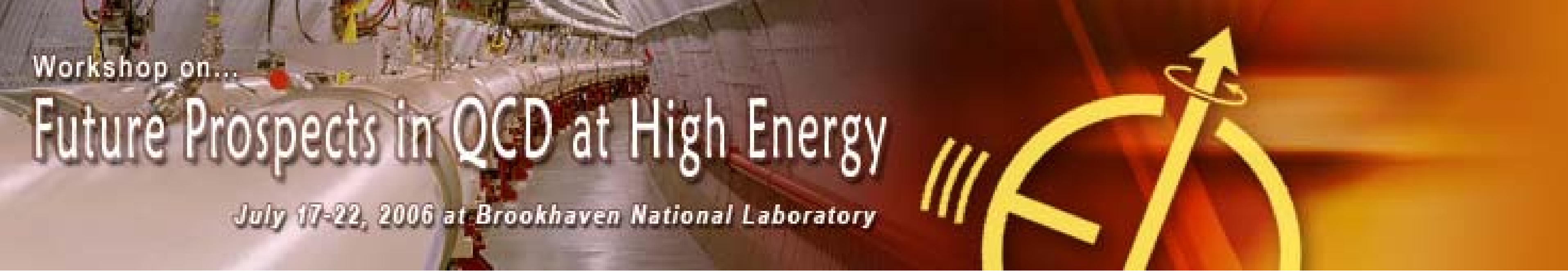


Summary of the Accelerator Physics Meeting

Lia Merminga

Center for Advanced Studies of Accelerators

Jefferson Laboratory

Workshop on Future Prospects in QCD at High Energy
Joint EIC2006 & Hot QCD Meeting Hosted by
Brookhaven National Laboratory
July 17-22, 2006

Outline

- EIC Science and Machine Requirements
- Experience with High Luminosity Asymmetric Colliders
- Accelerator Physics and Technology Issues of the EIC
- Machine Designs
  - eRHIC – Ring-Ring
  - eRHIC – Linac-Ring
  - ELIC
- Cost Estimates
- Summary

EIC Science

A large community believes a high luminosity polarized electron ion collider is the ultimate tool to understand the structure of quark-gluon systems, nuclear binding, and the conversion of energy into matter to such detailed level that we can use/apply QCD.

- Spin Structure of the Nucleon
  - Gluon and sea quark polarization
  - The role of orbital momentum
- Partonic Understanding of Nuclei
  - Gluon momentum distributions in Nuclei
  - Fundamental explanation of Nuclear Binding
  - Gluons in saturation, the Colored Glass Condensate
- Precision Tests of QCD
  - Bjorken Sum Rule
  - Hard diffraction

Ent (JLab)

An Electron Ion Collider will allow us to look in detail into the sea of quarks and gluons, to create and study gluons, and to discover how energy transforms into matter.

From DOE 20-year plan

EIC Physics Specifications

- Various Drivers: High L at HERMES+ Energies (E_{cm} ~ 20 GeV): Polarized H, D, ^{3}He

  Large Reach in x (down to 10^{-4}?) for large range in A
- Energy Asymmetry of ~ 10-20
- Needs Flexible Center-of-mass energy for L/T Separation
- CW Luminosity ~1×10^{33} cm^{-2} sec^{-1} per Interaction Point to access gluons

  Higher is essential at lower E_{cm} range for "super- HERMES"
- Many Ion species of interest (Many of us Nuclear Physics Funded!)
  - Proton and neutron: Polarized H and D for sure, ^{3}He good
  - Light-medium ions not necessarily polarized
  - Up to Calcium for "EMC Effect"
  - Up to A = 200+ for Saturation/CGC
- Longitudinal polarization of both beams in the interaction region (+Transverse polarization of ions +Spin-flip of both beams)

  all polarizations >70% desirable, need good ion polarimetry
- Positron Beams desirable, but lower luminosity seems o.k.

Heavy Ion Beams and Plasmas

Warm dense plasma physics driven by heavy ion beams: science opportunities and requirements

Logan (LBL)

Study fundamental material properties of matter under extreme states of density and temperature: Equation of state, radiative opacity, conductivity, viscosity

At GSI, unique experimental areas designed for HED experiments with intense heavy-ion beams. Similar concepts explored for FAIR.

RHIC should collaborate with GSI.

GSI is the closest role model for how RHIC might approach WDM experiments. Premium is on low beam emittance for sub-millimeter focal spots-planned use of electron cooling for RHIC would be very helpful; however; can RHIC
→Compress beam ions into < 100 ns bunches required?
→handle target experimental area activation (heavy ion fragments)?

Experience with High Luminosity Asymmetric Colliders

Experience with HERA

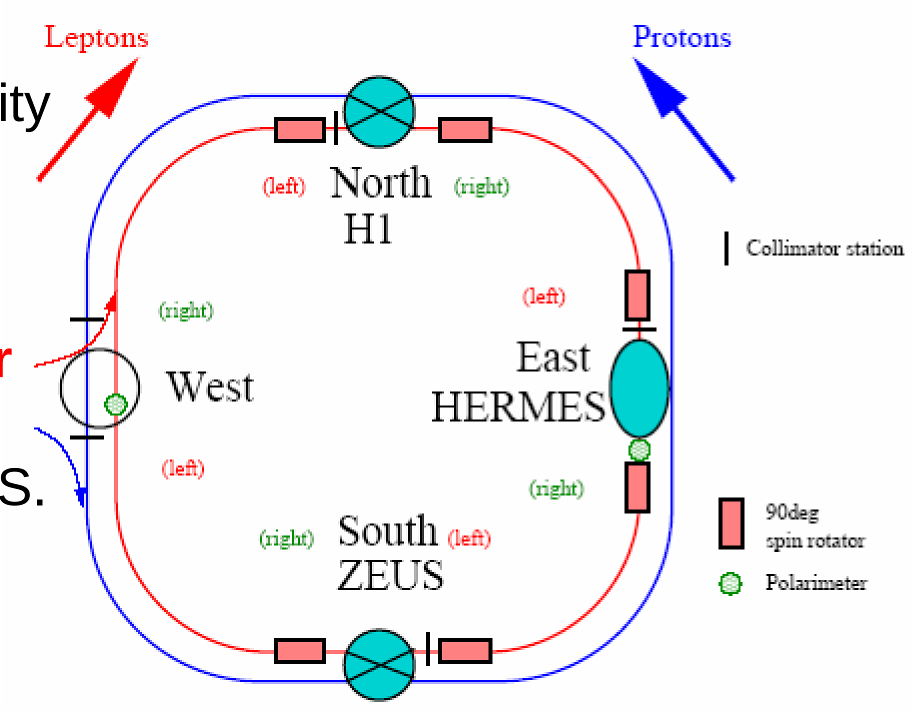
Vogt (DESY)

920 GeV protons on 26.7 GeV e^+/e-
Leptons longitudinally polarized at all 3 experiments.
$L_{peak} = 4.9 \times 10^{31}$ cm^{-2} sec^{-1}

e+/e- issues:
Maintaining good conditions for luminosity and polarization.

Beam-beam depolarization:
-> New spin code developed which includes weak-strong bb model. **Barber**

Proton issues:
Longitudinal emittance growth due to IBS. More RF voltage required to counteract IBS.

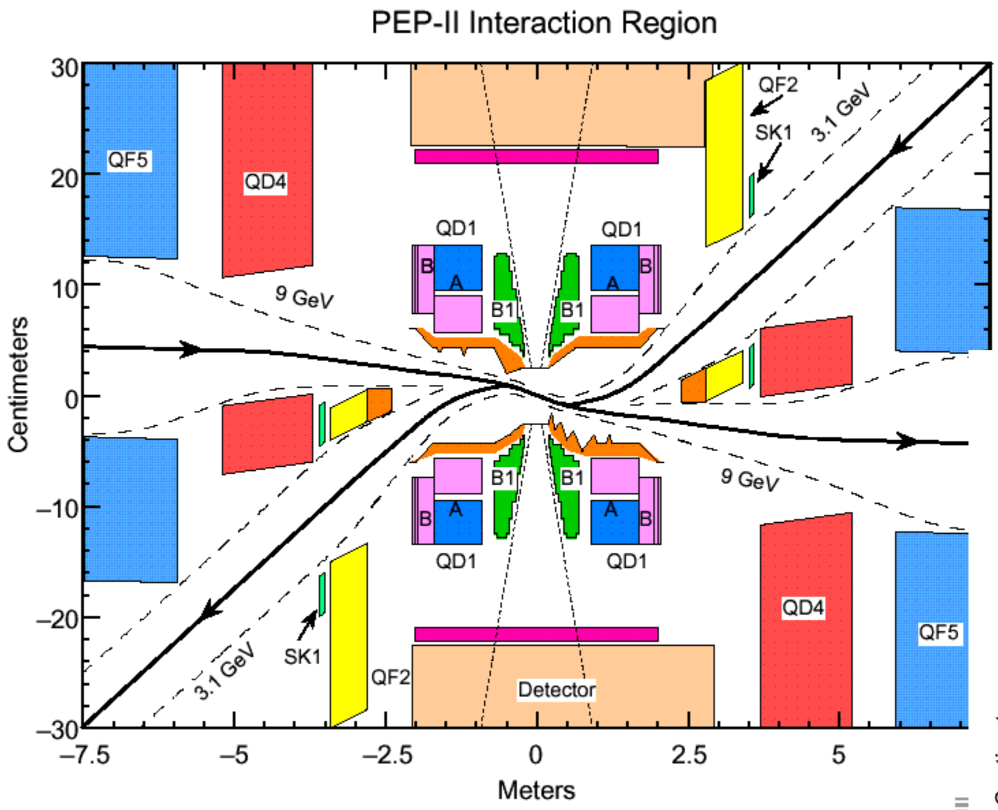


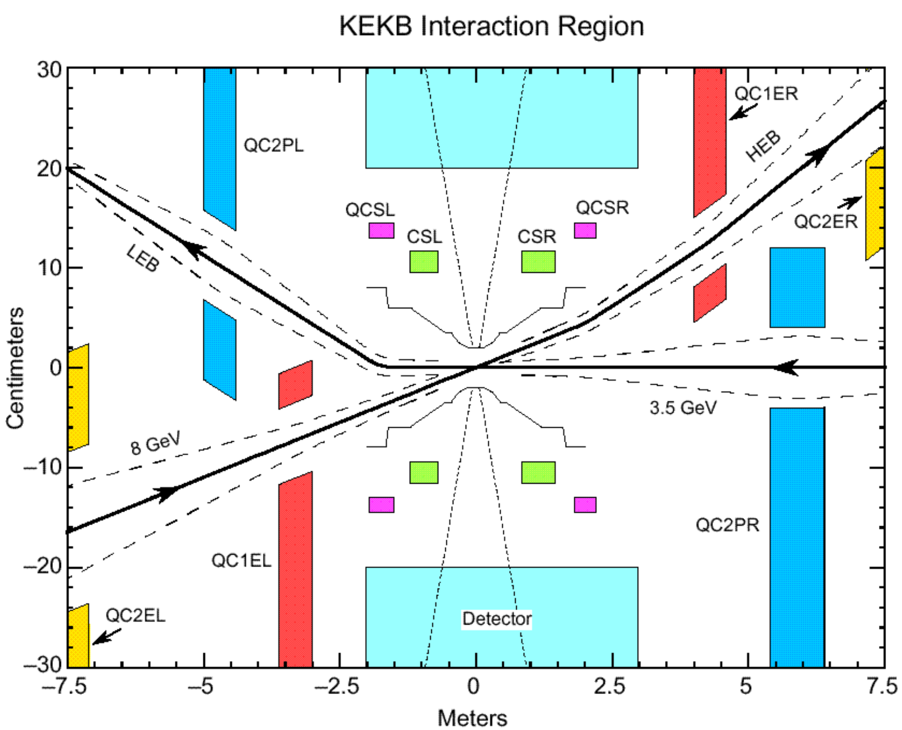
Background extremely sensitive to orbit in mini-beta's.

…it has been done, you can do it again!

PEP-II and KEKB Interaction Regions

Seeman (SLAC)





Success of PEP-II IR Design

Backgrounds from Synchrotron Radiation (SR) are acceptable.

Heating from SR are OK

HOM heating <30 kW

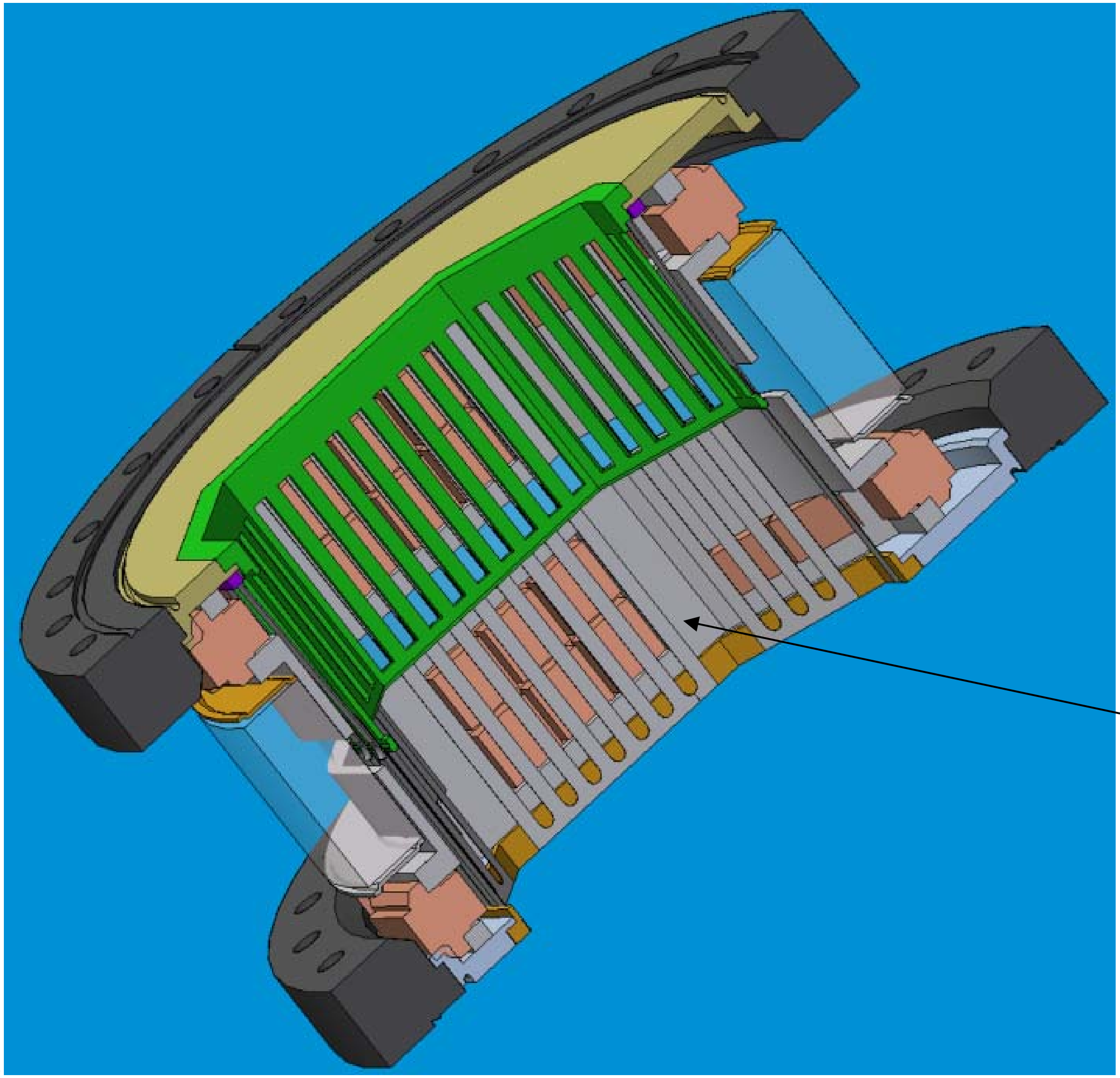
Backgrounds from Beam-Gas and Coulomb are OK

Beams separated enough at 1st parasitic crossing

>10s of the largest of the 4 beam sigmas (+/-, x, y)

Beams separated enough at 1st septum magnet (~100 mm)

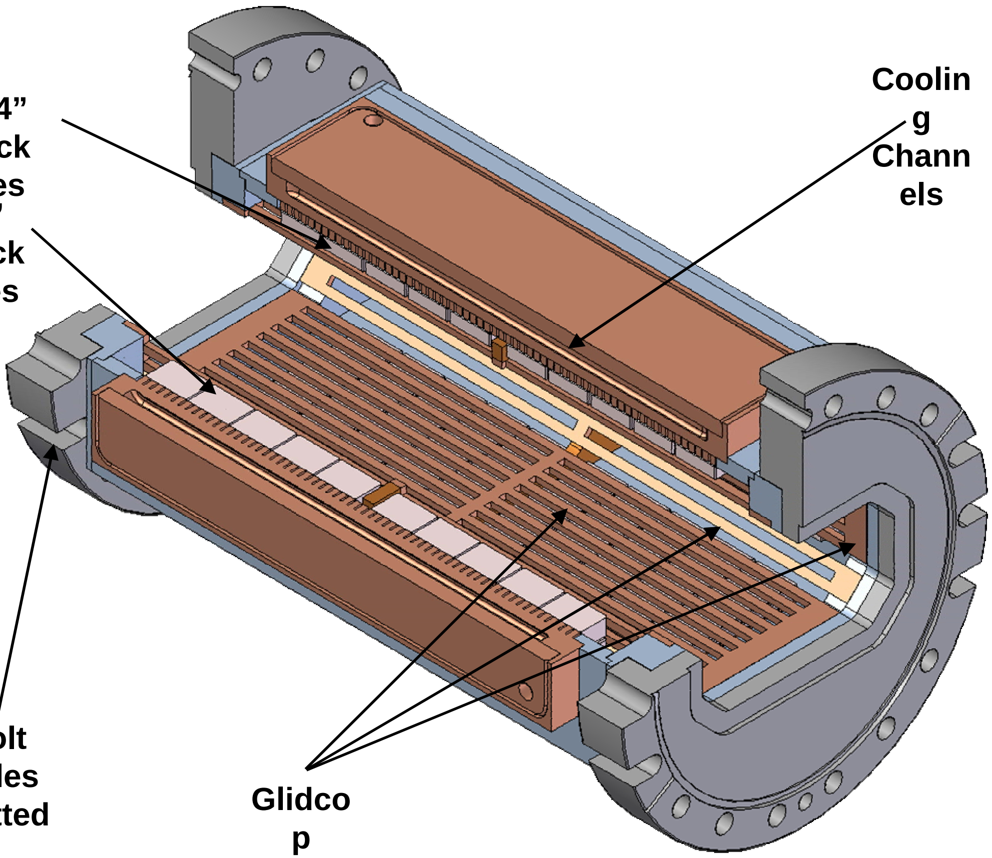
New HOM bellows design for Fall 2006



Tiles behind Fingers

N. Kurita
Novokhatski
Weathersby
April 2006

New PEP-II IR HOM absorber



New absorber helps a factor of two in power

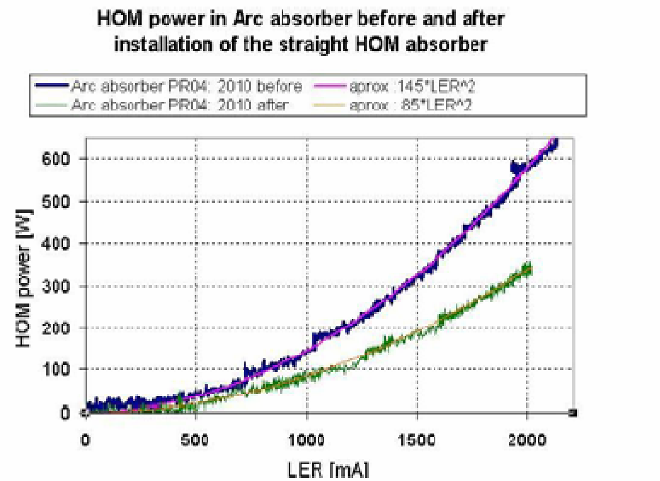


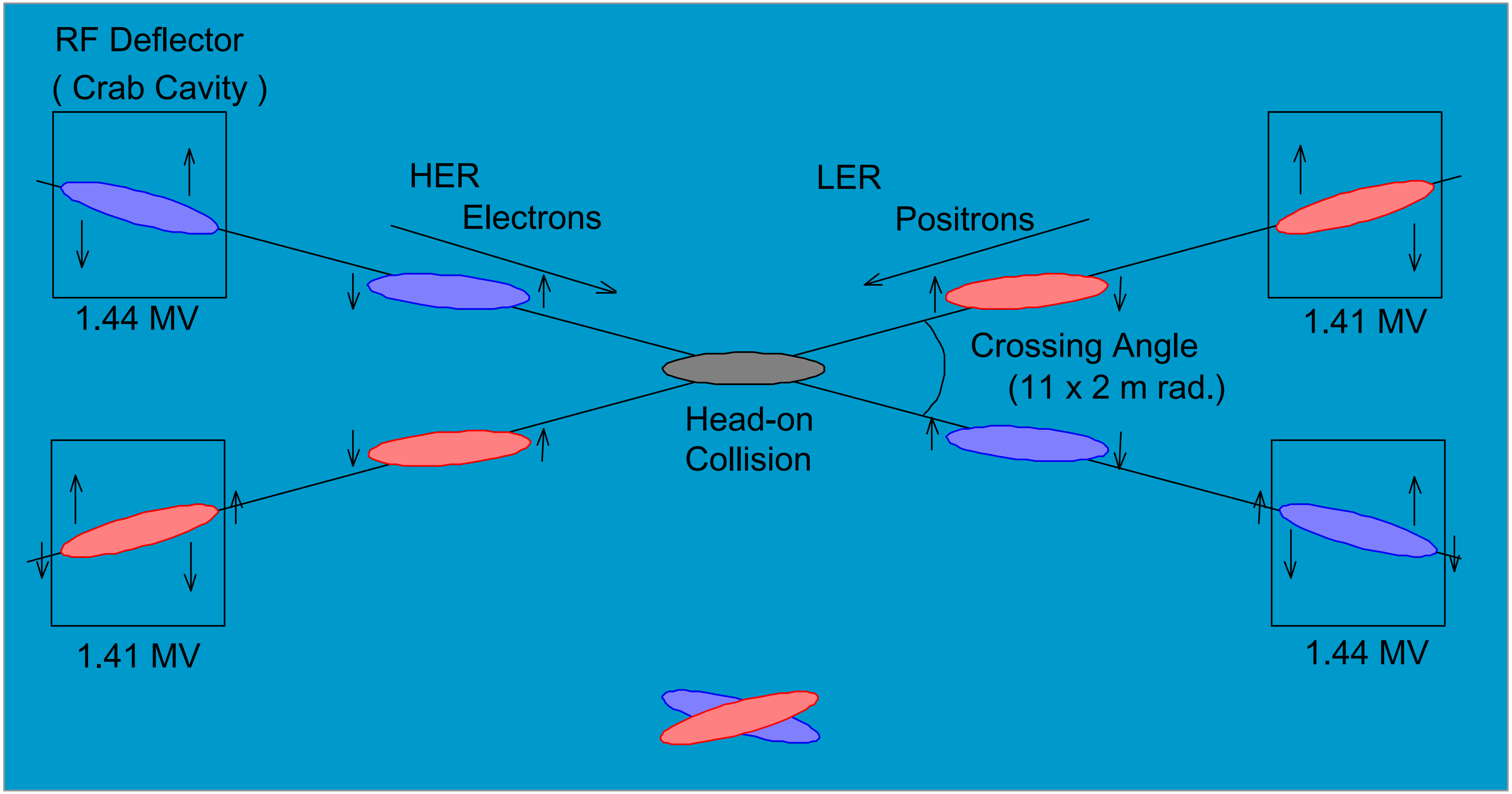
Figure 8: Effectiveness of straight bellows device is evaluated from a power estimation from cooling water flow and temperature in a downstream LER arc antichamber.

Crab Cavities

- With an IR with a crossing angle, these cavities tilt the beams to make them act like head on collision for the beam-beam interaction.
- Should increase the luminosity (~50 to 100%)
- Will soon be tested at KEKB (~1 year)

KEKB Crab Crossing

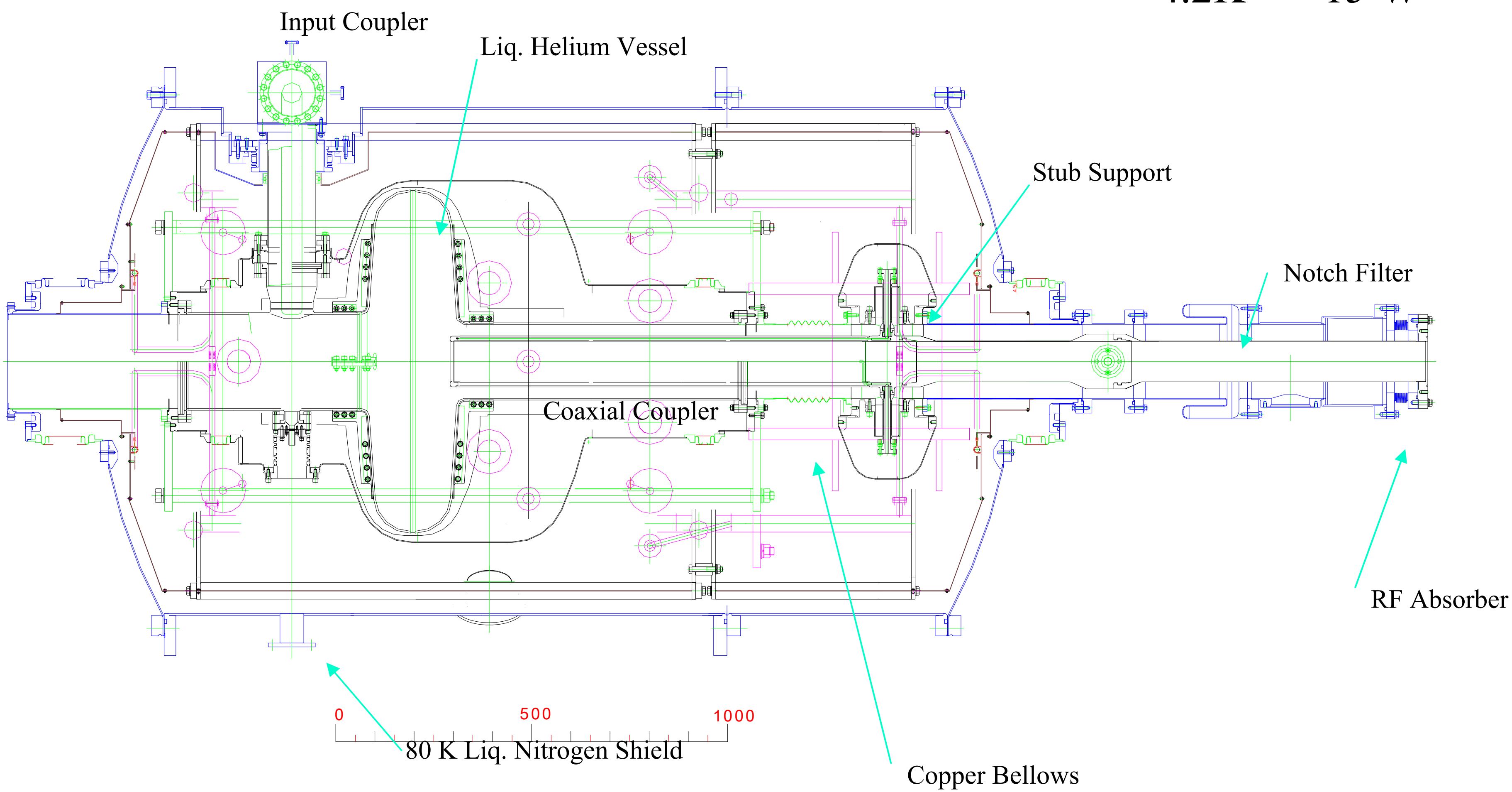
1) R.B.Palmer, SLAC-PUB-4707,1988
2) K.Oide and K.Yokoya, SLAC-PUB-4832,1989



Crab Cavity in Cryostat   Top View

Heat Loss

80K	110 W
4.2K	15 W



PEP-II and KEKB

Experience from B-Factories, especially the HER's, are existence proofs that the high intensity electron rings of EIC designs are feasible.

Accelerator Physics and Technology Challenges of the EIC

High Intensity Polarized Electron Sources

State of art

- Routinely operated productive quality guns (SLAC, JLAB, Mainz, Bates…)
- State of art ~ 0.3 mA average current.
- GaAs photocathodes with strained, superlattice crystals with polarization approaching 90%

Tsentalovich (MIT)

Polarized electron gun for ring-ring EIC version is based on proven technology and doesn't require any significant R&D

Polarized electron gun for linac-ring schemes extremely demanding:

Required >40-50 mA

Technical challenges:

Cathode lifetime

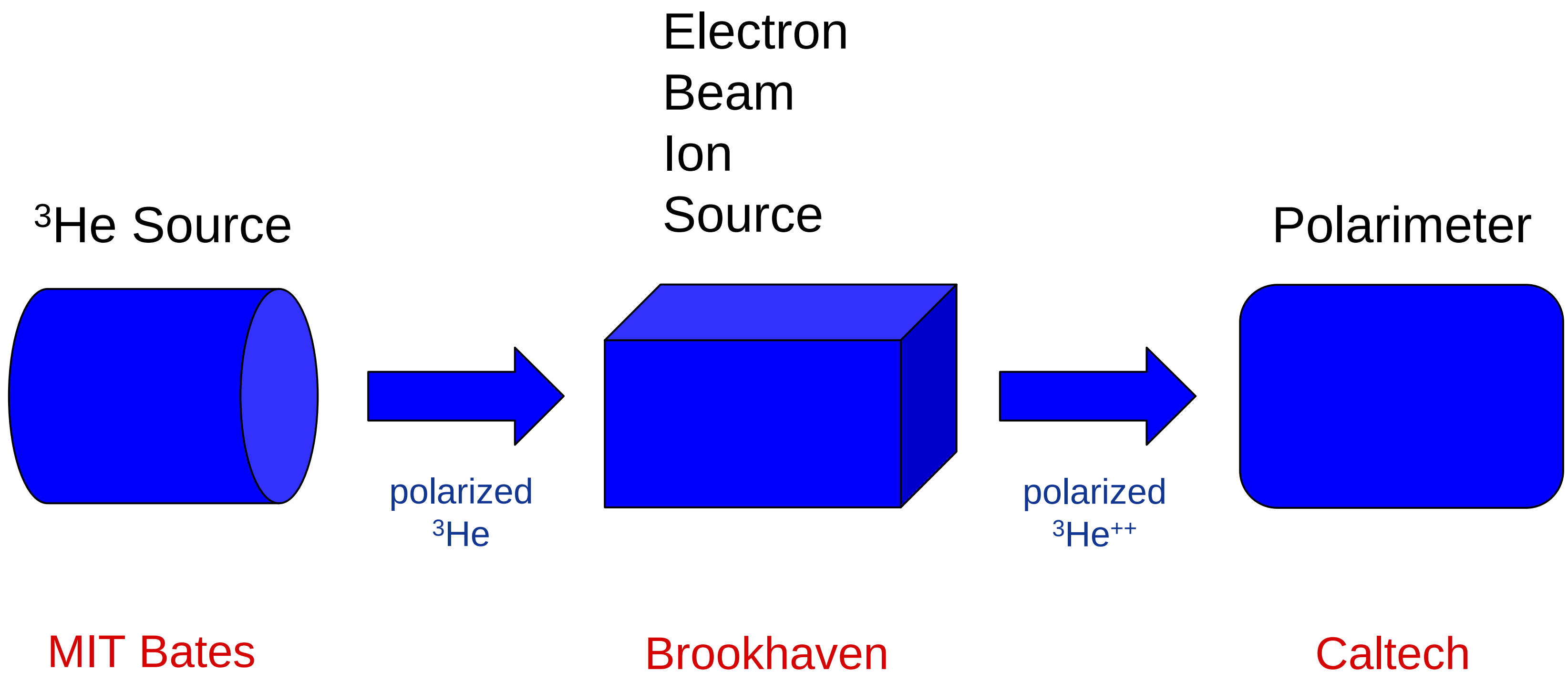
High power laser

Heat load

New photocathode materials
New gun concepts

Polarized ^3He beams for EIC

O'Connell (Caltech)



EXPECTATION: Polarization ~70-80% with fiber laser

EXPECTATION: Production rate of ~10^{15} polarized atoms/s.

High Energy Hadron Cooling

Lebedev (FNAL)

Stochastic cooling

- Inexpensive, may be implemented fast for all 3 planes (1-2 years)
- Can address near term RHIC problems

Electron cooling

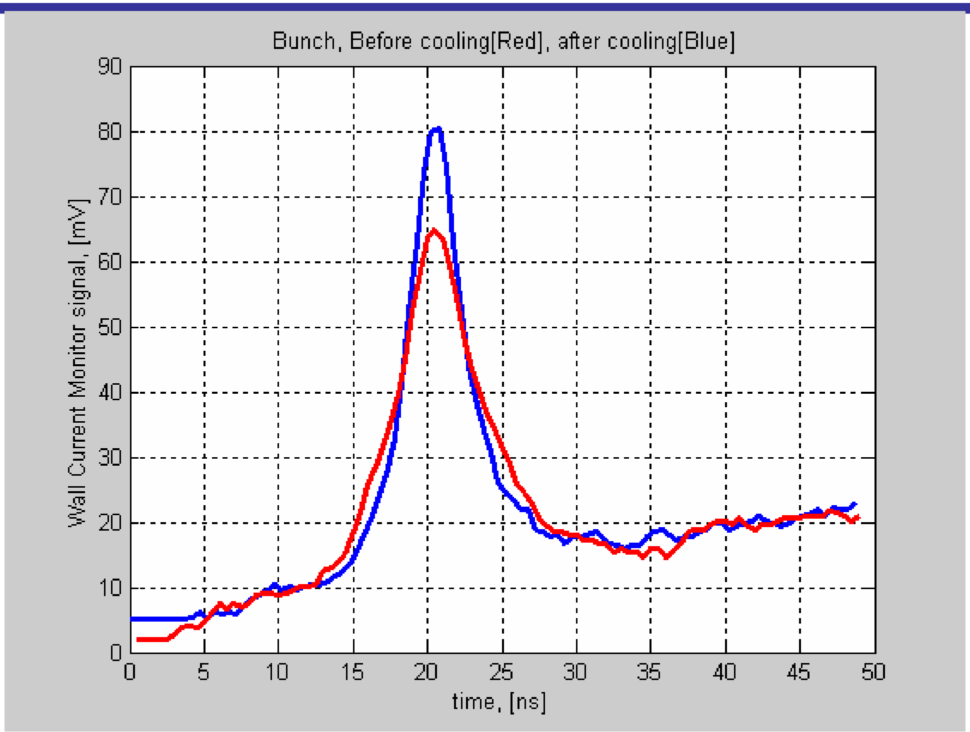
- Very effective for heavy ions, more difficult for protons
- Very ambitious project

Optical stochastic cooling

- In theory it is promising
- Not tested experimentally

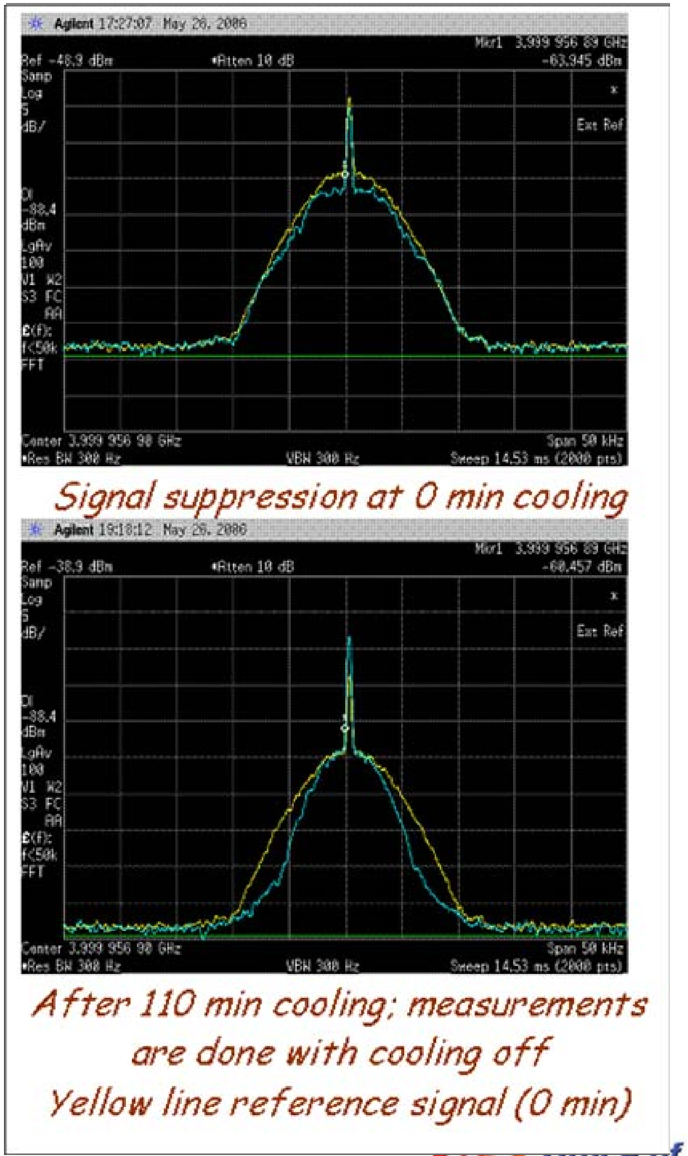
No "silver" bullet; Electron cooling looks OK but challenging

Bunched Beam Stochastic Cooling at RHIC



Wall Current Monitor signal of cooled bunch. The higher bunch (Blue) has been cooled for about 90 minutes.
The lower trace (Red) is the bunch before cooling started.

Cooling time ~ 7 hours
Achieved cooling rate barely sufficient to counteract IBS



Relativistic Electron Cooling at FNAL

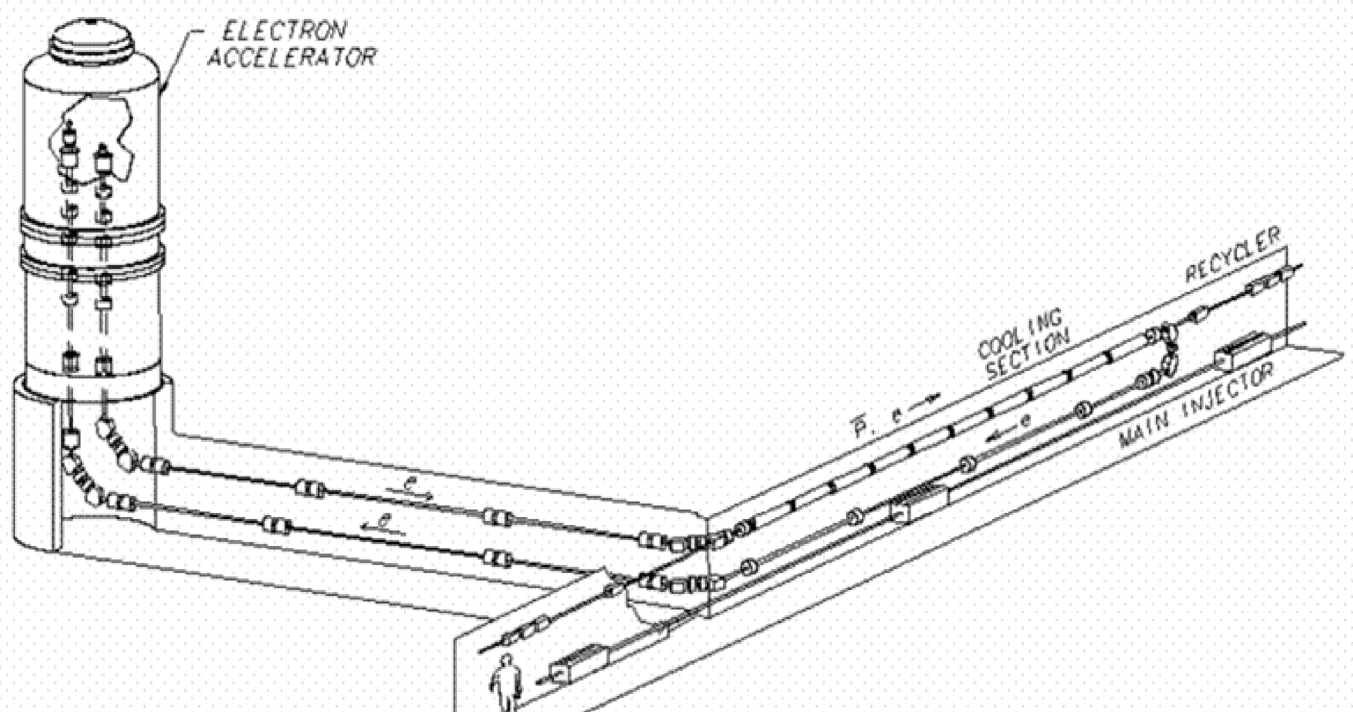
- Fermilab made next step in electron cooling technology
- Main Parameters

  4.34 MeV pelletron

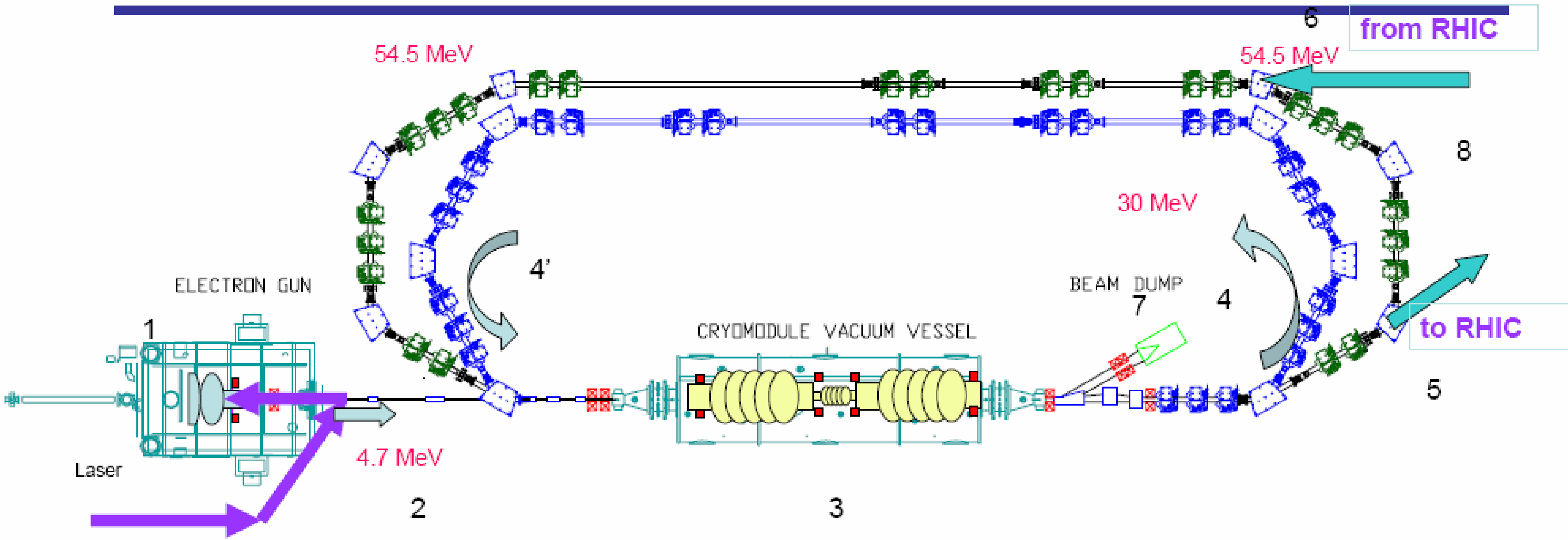
  0.5 A DC electron beam with radius of about 4 mm

  Magnetic field in the cooling section - 100 G

  Interaction length – 20 m (out of 3319 m of Recycler circumference)



RHIC Electron Cooler: ERL Layout



1. SRF Gun,
2. Injection merger line
3. SRF Linac two 5-cell cavities and 3rd harmonic cavity

4, 4'. 180° achromatic turns

5, 6. Transport lines to and from RHIC,

7. Ejection line and beam dump
8. Short-cut for independent run of the ERL.

Interaction region design and limitations

Montag (BNL)

SR
- **Head-on collisions vs. crossing angle**

Crab Crossing
- **Open issues related to beam stability to be addressed**

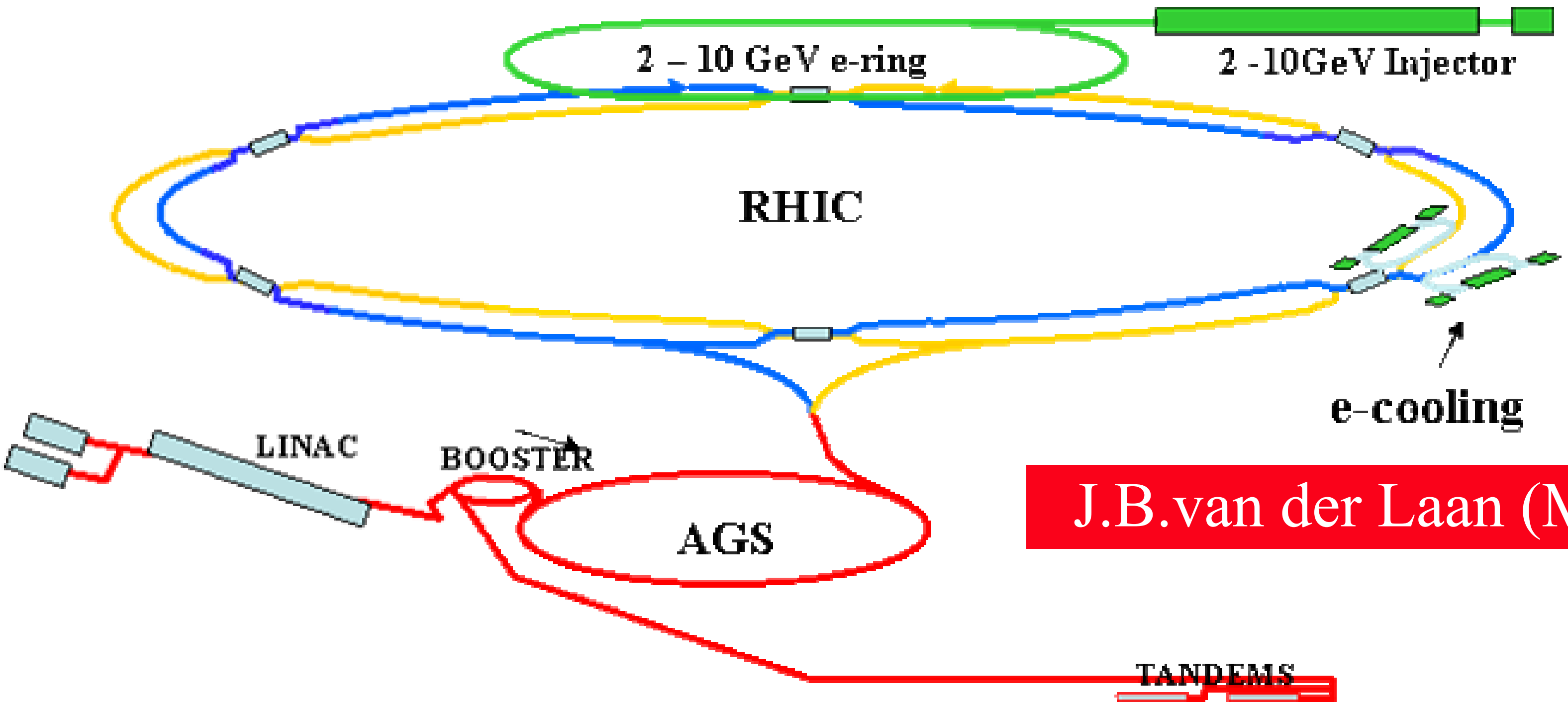
Bunch Spacing
- **2 ns ok, 2/3 ns probably not**

Free Space around IP
- **+/- 5 m desired**

Number of IR's/Detectors

Machine Designs

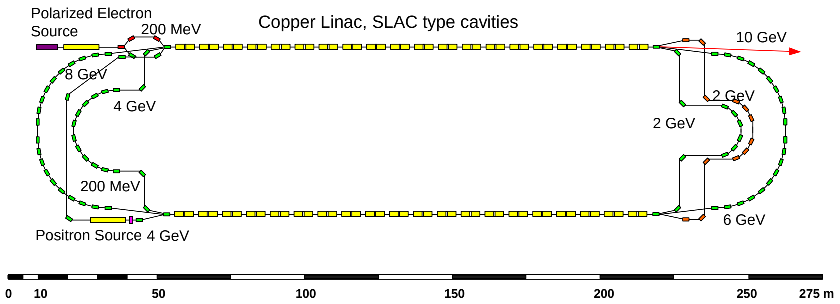
eRHIC Ring-Ring Design



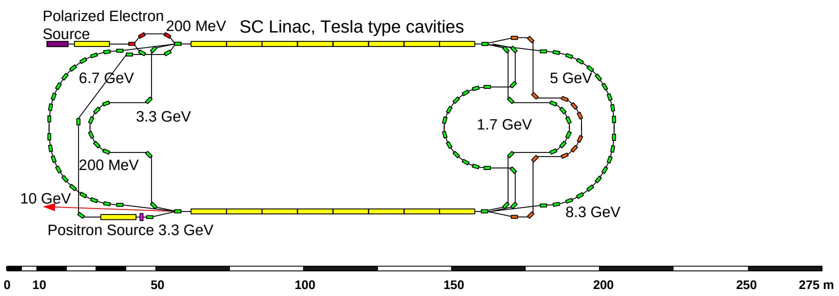
J.B.van der Laan (MIT)

- 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
- Polarized electrons, positrons

eRHIC R-R: Full Energy Injection Options



Recirculating NC linac



Recirculating SC linac

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

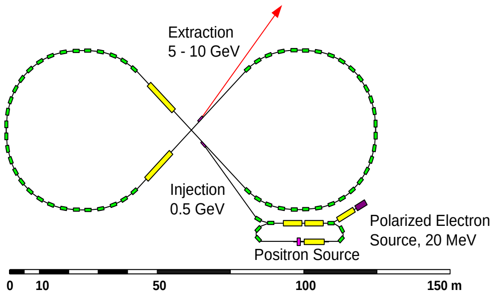


Figure 8 booster synchrotron, FFAG or simple booster

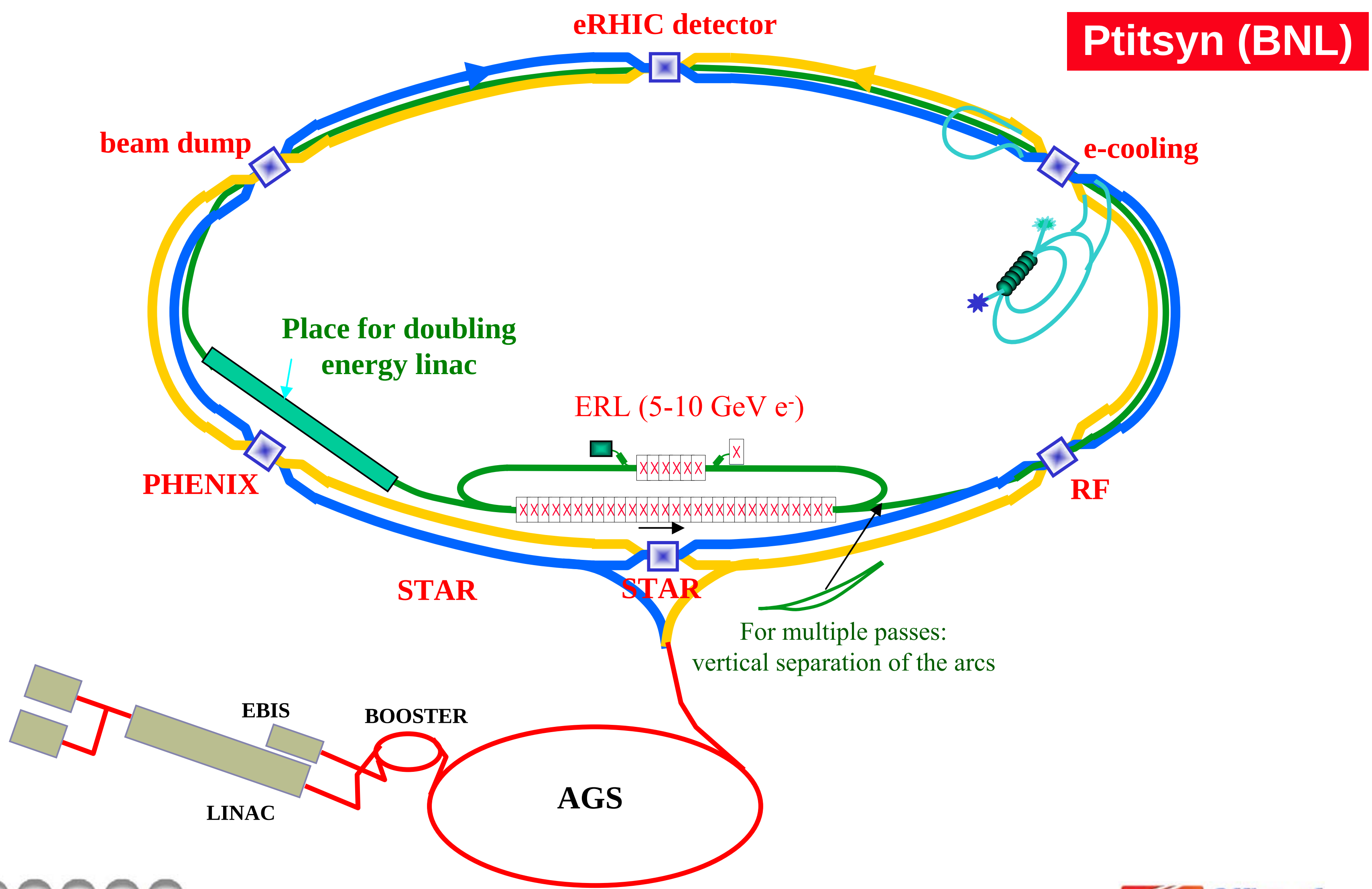
eRHIC Ring-Ring Luminosity

		ZDR Design, l*=1m		Single IP, IR l*=1m		Single IP, IR l*=3m	
		Electron	Proton	Electron	Proton	Electron	Proton
Energy E	[GeV]	10	250	10	250	10	250
k=εy/εx		0.18	1	0.18	1	0.18	1
Kσ=σy/σx		0.50	0.50	0.50	0.50	0.50	0.50
ε_n (ion)	[π mm mrad]		15.0		15.2		15.2
Emittancs εx	[nm.rad]	53.0	9.4	53.0	9.5	53.0	9.5
Emittancs εy	[nm.rad]	9.5	9.4	9.5	9.5	9.5	9.5
βx*	[m]	0.19	1.08	0.19	1.08	0.39	2.16
βy*	[m]	0.27	0.27	0.27	0.27	0.54	0.54
ξx		0.029	0.0065	0.029	0.016	0.029	0.016
ξy		0.08	0.1000	0.08	0.0080	0.08	0.0080
Particles/Bunch		1.00E+11	9.98E+10	2.50E+11	9.91E+10	2.49E+11	9.98E+10
Luminosity L	[$cm^{-2}s^{-1}$]		4.4E+32		**1.1E+33**		**5.5E+32**

Shi (Univ. of Kansas)

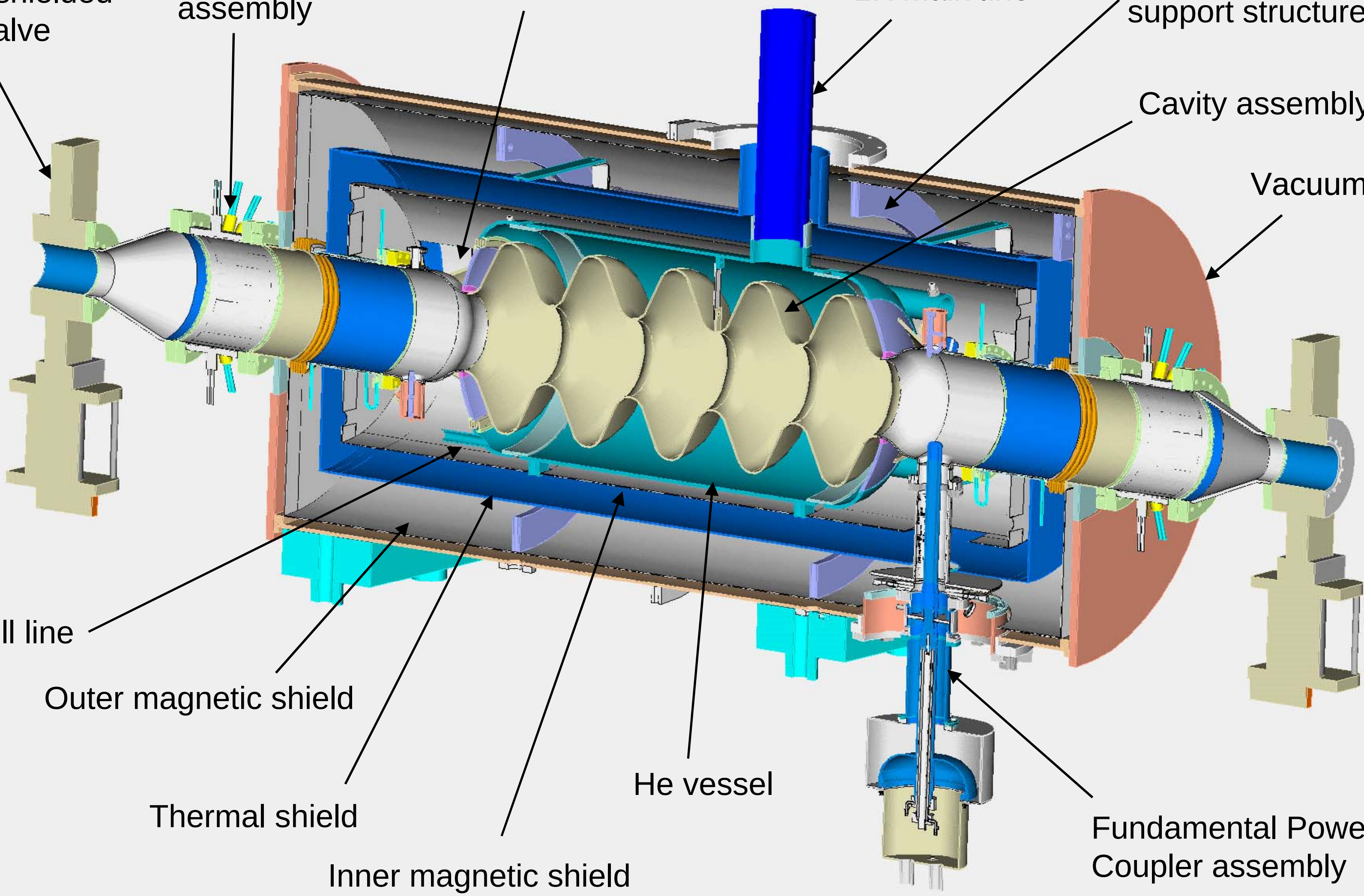
Wang (MIT)

eRHIC Linac-Ring Design



Cryomodule Design

Ben-Zvi (BNL)



BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

Advanced Energy Systems, Inc.

eRHIC Linac-Ring Luminosity

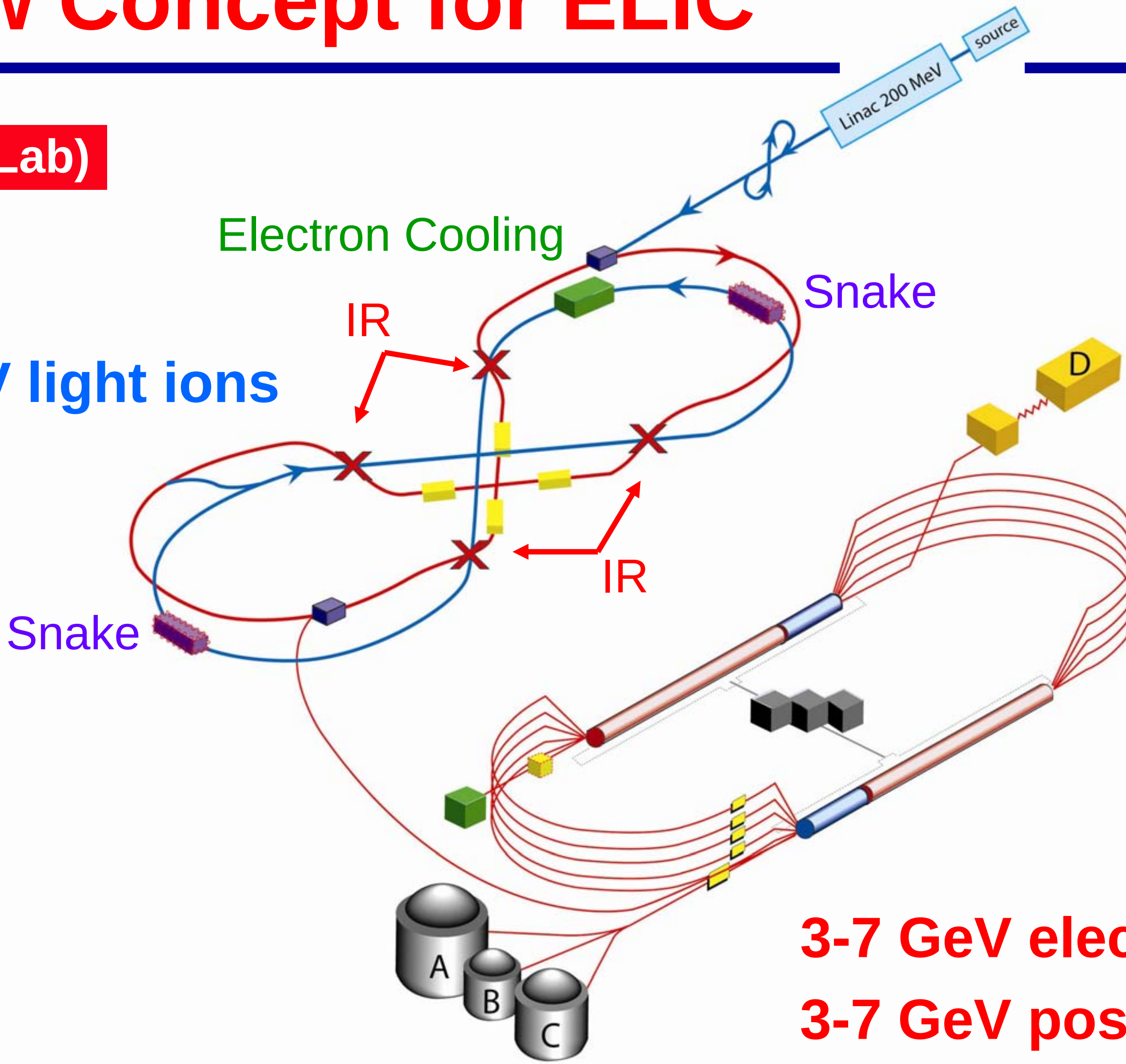
		main case	option
RHIC			
	Ring circumference [m]	3834	
	Number of bunches	360	
	Beam rep-rate [MHz]	28.15	
Protons:	number of bunches	360	*120*
	Beam energy [GeV]	26 - 250	
	Protons per bunch (max)	2.0×10^{11}	*6×10^{11}*
	Normalized 96% emittance [µm]	14.5	
	β^* [m]	0.26	
	RMS Bunch length [m]	0.2	
	Beam-beam tune shift in eRHIC	0.005	
	Synchrotron tune, Qs	0.0028	
Gold ions:	number of bunches	360	*120*
	Beam energy [GeV/u]	50 - 100	
	Ions per bunch (max)	2.0×10^{9}	*6×10^{9}*
	Normalized 96% emittance [µm]	6	
	β^* [m]	0.25	
	RMS Bunch length [m]	0.2	
	Beam-beam tune shift	0.005	
	Synchrotron tune, Qs	0.0026	
Electrons:			
	Beam rep-rate [MHz]	28.15	*9.38*
	Beam energy [GeV]	2 - 10	
	RMS normalized emittance [µm]	5- 50 *for $N_e = 10^{10} / 10^{11}$ e^- per bunch*	
	β^*	~ 1m, *to fit beam-size of hadron beam*	
	RMS Bunch length [m]	0.01	
	Electrons per bunch	$0.1 - 1.0 \times 10^{11}$	
	Charge per bunch [nC]	1.6 – 16	
	Average e-beam current [A]	0.045 – 0.45	*0.015 – 0.15*

	Luminosity, 1e33, $cm^{-2}s^{-1}$
p 250 Gev	1.8
Au 100 Gev/u	0.02
p 250 Gev Dedicated mode	6.3

A New Concept for ELIC

Derbenev (JLab)

30-150 GeV light ions



3-7 GeV electrons

3-7 GeV positrons

Achieving the Luminosity of ELIC

For 150 GeV protons on 7 GeV electrons, L~ 7.7 x 10^{34} cm^{-2} sec^{-1} compatible with realistic Interaction Region design.

Beam Physics Concepts

- Beam – beam interaction between electron and ion beams

  ($\xi_{i/e}$ ~ 0.01/.086 per IP; 0.025 largest achieved presently in Tevatron, and ~.1 for electrons)

- High energy electron cooling
- Interaction Region
  - High bunch collision frequency (f = 1.5 GHz)
  - Short ion bunches (σ_z ~ 5 mm)
  - Very strong focus (β^* ~ 5 mm)
  - Crab crossing

ELIC Parameters

Parameter	Unit	ERL	Ring-Ring		
Beam energy	GeV	150/7	150/7	100/5	30/3
Bunch collision rate	GHz	1.5			
Number of particles/bunch	10^{10}	.4/1.0	.4/1.0	.4/1.1	.12/1.7
Beam current	A	1/2.4	1/2.4	1/2.7	.3/4.1
Cooling beam energy	MeV	75	75	50	15
Cooling beam current	A	2	2	2	.6
Energy spread, rms	10^{-4}	3/3			
Bunch length, rms	mm	5/5			
Beta-star	mm	5/5			
Horizontal emittance, norm	μm	1/86	1/86	.7/70	.2/43
Vertical emittance, norm	μm	.04/3.4	.04/3.4	.06/6	.2/43
Beam-beam tune shift (vertical) per IP		.01/.086	.01/.086	.01/.073	.01/.007
Laslett tune shift (p-beam)		.015	.015	.03	.06
Luminosity per IP, 10^{34}	$cm^{-2}\ s^{-1}$	7.7	7.7	5.6	.8
Number of interaction points		4			
Core & luminosity IBS lifetime	h	24	24	24	> 24

Advantages/Features of ELIC

- JLab DC polarized electron gun already meets beam current requirements for filling the storage ring.
- A conventional kicker already in use in many storage rings would be sufficient.
- The 12 GeV CEBAF accelerator can serve as an injector to the ring. RF power upgrade might be required later depending on the performance of ring.
- Physics experiments with polarized positron beam are possible.
- Possibilities for e^+e^-, e^-e^-, e^+e^+ colliding beams.
- No spin sensitivity to energy and optics.
- Collider operation appears compatible with *simultaneous* 12 GeV CEBAF operation for fixed target program.

Hadron Beam Intensity Limits

Fischer (BNL)

Considered hadron beam limitations from:

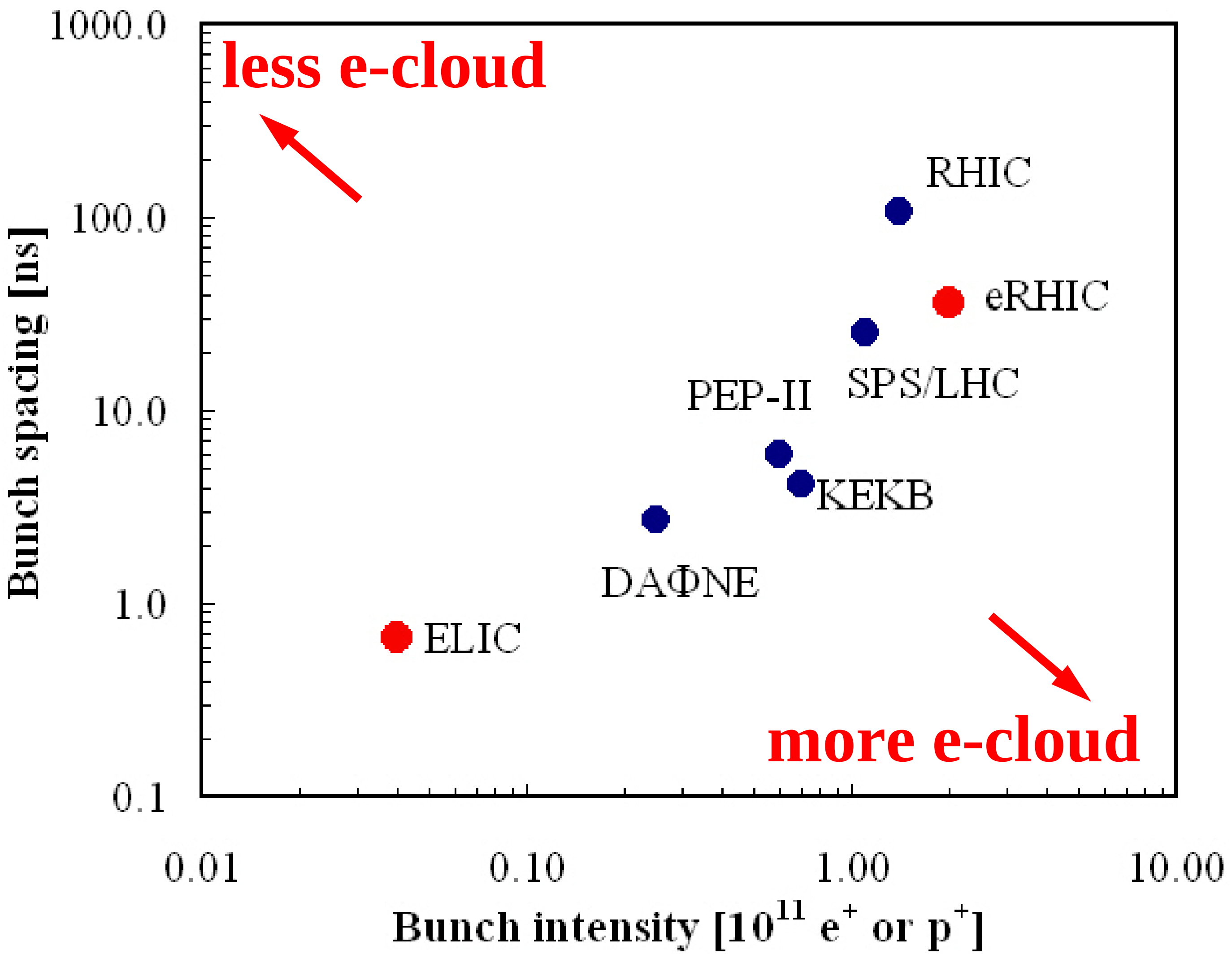
- Electron cloud
- Beam-beam
- Instabilities
- Intrabeam scattering
- Space charge
- Resistive wall heating

Of concern appear:

- Electron cloud in RHIC for N_b=2.0×10^{11} and 36 ns bunch spacing
- Beam-beam in ELIC with more than 2 IPs
- Intrabeam scattering in RHIC and ELIC
- Possibly space charge at low energies

Significant challenges for cooling, crab cavities (ELIC)

Selected machines with electron clouds



R&D Required

eRHIC Ring-Ring

No significant R&D required. Design optimization ongoing.

eRHIC Linac-Ring

- High current polarized electron source
- Energy recovery for high energy and high current beams
- Increasing total ion current (ions per bunch and number of bunches)

ELIC

- Beam dynamics issues with crab crossing

Common R&D topics:

- High energy hadron cooling (electron, stochastic)
- Polarized ^{3}He production and acceleration
- Beam-beam interactions

Cost Estimates

eRHIC Ring-Ring:

Estimated cost presented by session Chair, Chris Tschalaer: $250-300 M

eRHIC Linac-Ring:

Estimated cost presented by Vladimir Litvinenko: $250-300M

ELIC:

No cost estimates made for ELIC, and none planned before necessary R&D identifies feasibility of technical approach and costs associated with approach.

Important to note: These estimates are equipment costs only and do not include important factors that enter DoE costs, such as overhead, installation, contingency, commissioning, etc.

Summary

- A compelling scientific case is developing for a high luminosity, polarized electron-ion collider, to address fundamental questions in hadron Physics.
- Much progress over the past years: Design concepts are maturing through innovation and design optimization.
- Electron cooling is prerequisite for all EIC design scenarios. A rigorous electron cooling R&D program established at BNL.
- Important to continue collaboration and cross-fertilization of ideas among different design options.
- Thank you to all the speakers for outstanding and thought-provoking presentations.