eRHIC and LHeC

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- Why we need electron-hadron colliders?
- eRHIC
- LHeC
- Conclusions

This talk is focused on possible designs and predicted performance if two proposed high-energy, high-luminosity electron-hadron colliders: eRHIC at BNL and and LHeC at CERN.
Both the eRHIC and the LHeC will add polarized electrons to the list of colliding species in these versatile hadron colliders: 10-20 GeV electrons to 250 GeV RHIC and 50-100 GeV electrons to 7 TeV LHC. Both colliders plan to operate in electron-proton (in RHIC case protons are polarized as well) and electron-ion collider modes. These two colliders are complimentary both in the energy range and in the physics goals.
I will discuss possible choices of the accelerator technology for the electron part of the collider for both eRHIC and LHeC, and will present predicted performance for the colliders. In addition, possible staging scenarios for these collider will be discussed.

Materials are from eRHIC R&D group at C-AD, BNL and LHeC Co

e–RHIC R & D
(V. Litvinenko), Head
V. Ptitsyn, Deputy
(A. Petway), Secretary

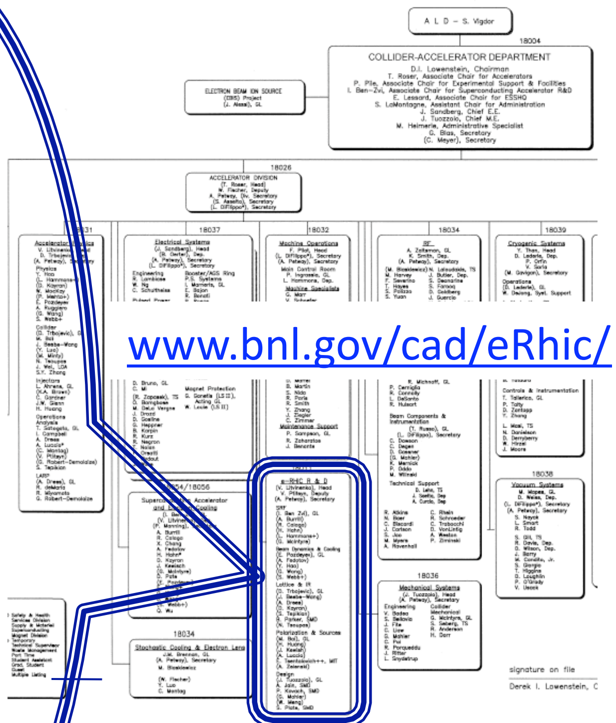
SRF
(I. Ben Zvi), GL
(A. Burrill)
(R. Calaga)
(H. Hahn)
(L. Hammons+)
(G. McIntyre)

Beam Dynamics & Cooling
(E. Pozdeyev), GL
(A. Fedotov)
(Y. Hao)
(G. Wang)
(S. Webb+)

Lattice & IR
(D. Trbojevic), GL
(J. Beebe–Wang)
(A. Drees)
(D. Kayran)
(S. Tepikian)
B. Parker, SMD
(N. Tsoupas)

Polarization & Sources
(M. Bai), GL
(H. Huang)
(J. Kewish)
(A. Luccio)
E. Tsentalovich++, MIT
(A. Zelenski)

Design
(J. Tuozzolo), GL
A. Jain, SMD
P. Kovach, SMD
(G. Mahler)
(W. Meng)
S. Plate, SMD



www.bnl.gov/cad/eRhic/

Inputs on Physics from BNL EIC task force lead by E.-C. Aschenauer, T. Ulrich, A.Cadwell, A.Deshpande, R. Ent, T. Horn, H. Kowalsky, M. Lamont, T.W. Ludlam, R. Milner, B. Surrow, S.Vigdor, R. Venugopalan, W.Vogelsang, ….

http://www.eic.bnl.gov/taskforce.html,

F. Zimmermann, F. Bordry, H.-H. Braun, O.S. Brüning, **H. Burkhardt**, A. Eide, A. de Roeck, R. Garoby, **B. Holzer**, J.M. Jowett, T. Linnecar, K.-H. Mess, **J. Osborne**, L. Rinolfi, D. Schulte, R. Tomas, J. Tückmantel, A. Vivoli, CERN

S.Chattopadhyay, J. Dainton, Cockcroft Inst., Warringto, **M. Klein**, U.Liverpool, UK

A.K. Ciftci, Ankara U.; H. Aksakal, U. Nigde; S. Sultansoy, TOBB ETU, Ankara, Turkey

T. Omori, J. Urakawa, KEK, Japan,

F. Willeke, BNL, U.S.A.

EIC activity & meetings are at http://web.mit.edu/eicc/

http://hbu.home.cern.ch/hbu/LHeC.html
http://www.ep.ph.bham.ac.uk/exp/LHeC/

Condense matter physics of strong force

Position paper on eA collider

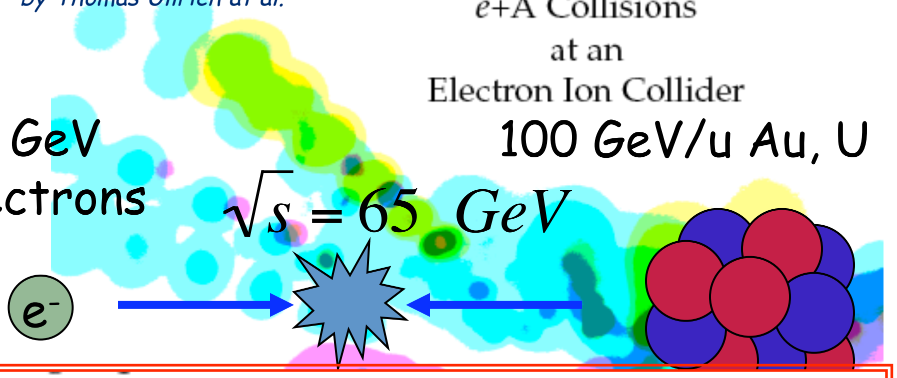
by Thomas Ullrich at al.

Physics Opportunities
with
e+A Collisions
at an
Electron Ion Collider

20 GeV electrons

100 GeV/u Au, U

$\sqrt{s} = 65\ GeV$



- The machine needs to provide collisions of at least $\sqrt{s} > 60\,\text{GeV}$ to go well beyond the range explored in past fixed target experiments. The higher the energy, the longer the lever-arm in Q^2 and the greater the low-x reach.
- The machine must be able to provide ion beams at different energies. Measurements at various $\sqrt{s}$ are mandatory for the study of many relevant distributions such as F_L. Note that it is kinematically better for any experimental setup to lower the ion beam energy then the electron energy.
- The machine must provide a wide range of ions. For saturation physics studies beams of very high mass numbers (A $\geq$ Au) are vital.
- To collect sufficient statistics luminosities with $L > 10^{30}\ \text{cm}^{-2}\text{s}^{-1}$ are required.

Nuclear "Oomph" Factor

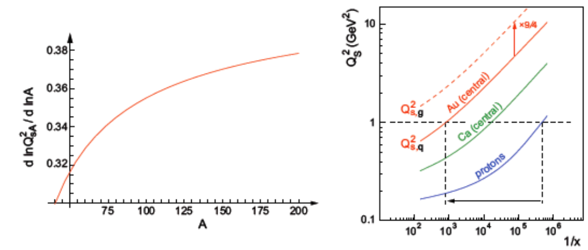


Figure 10: *Left: The A dependence of the saturation scale from the analysis of Ref. [16]. Right: The saturation scale at b = 0 in Au and Ca nuclei compared to the median saturation scale in a proton [15].*

Electron-Ion Collider Collaboration

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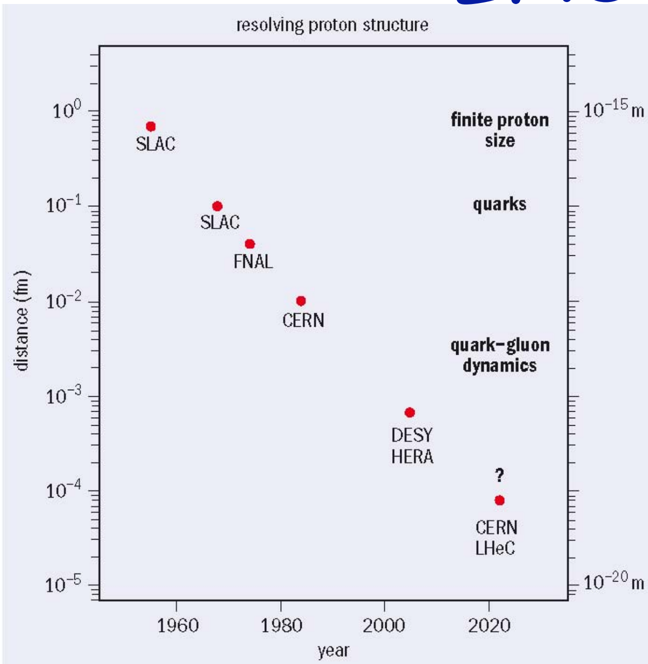
Accelerators
Documentation
Meetings
Conference/Seminar Presentations
News

Institutions

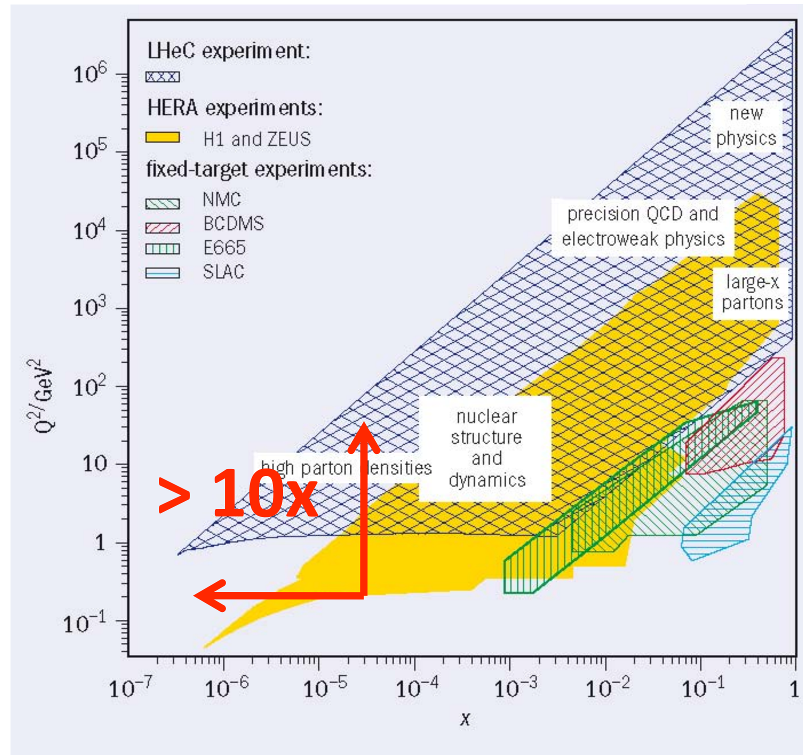
- Argonne National Laboratory, Argonne, IL
- Bhabha Atomic Research Centre, Mumbai, India
- Brookhaven National Laboratory, Upton, NY
- University of Buenos Aires, Buenos Aires, Argentina
- University of Colorado, Boulder, CO
- Columbia University, New York, NY
- University of Glasgow, Glasgow, United Kingdom
- Hampton University, Hampton, VA
- University of Illinois, Urbana-Champaign, IL
- Iowa State University, Ames, IA
- University of Kyoto, Kyoto, Japan
- Lawrence Berkeley National Laboratory, Berkeley, CA
- Los Alamos National Laboratory, Los Alamos, NM
- University of Massachusetts, Amherst, MA
- MIT Laboratory for Nuclear Science, Cambridge, MA
- MIT-Bates Linear Accelerator Center, Middleton, MA
- Max Planck Institut fur Physik, Munich, Germany
- University of Michigan, Ann Arbor, MI
- New Mexico State University, Las Cruces, NM
- Old Dominion University, Norfolk, VA
- Penn State University, PA
- RIKEN, Wako, Japan
- RIKEN-BNL Research Center
- Soltan Institute for Nuclear Studies, Warsaw, Poland
- Stony Brook University, Stony Brook, NY
- Tel Aviv University, Tel Aviv, Israel
- Thomas Jefferson National Accelerator Facility, Newport News, VA

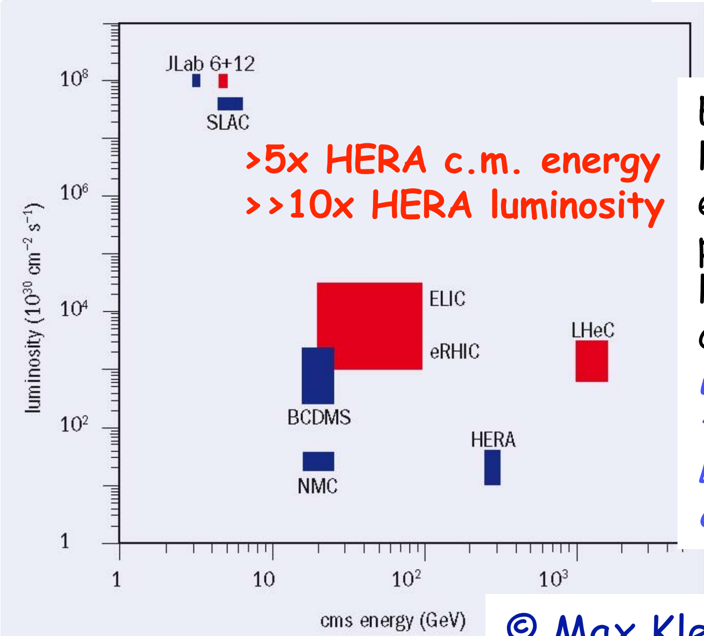
LHeC physics motivation



Distance scales resolved in lepton-hadron scattering experiments since 1950s, and some of the new physics revealed

Kinematic plane in Bjorken-x and resolving power Q^2, showing the coverage of fixed target experiments, *HERA* and *LHeC*





Energies and luminosities of existing and proposed future lepton-proton colliders

Electron energy up to 60-140 GeV, Luminosity ~10^{33} cm^{-2}s^{-1}

Particle physicists request both e^-p & e^+p collisions; lepton polarization is also "very much desired"

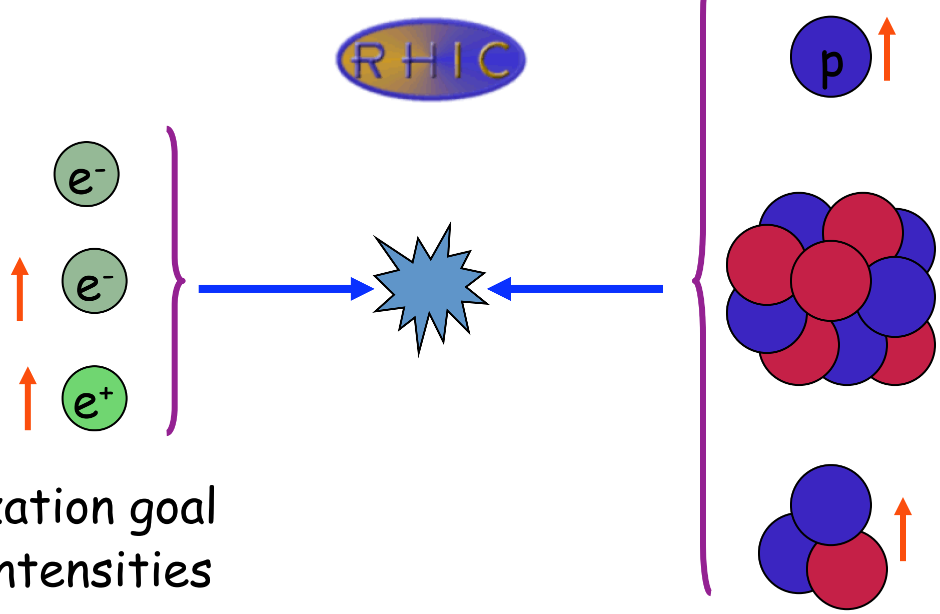
Many common features

eRHIC	LHeC
• Add 10-30 GeV polarized electron machine to RHIC with 250 GeV polarized protons and 100 GeV/u ions	• Add 50-150 GeV polarized electron machine to 7 TeV protons and 3 TeV/u ions
• CM energy 15-200 GeV	• CM energy 0.5-2 TeV
• Luminosity L~10^{32}-10^{34} is based on demonstrated hadron beam parameters	• Luminosity L~10^{32}-10^{34} is based on LHC hadron beam parameters
• First eRHIC paper, 1999, I. Ben. Zvi et al.,	• First LHeC paper in 1997 - E. Keil, "LHC ep option", LHC-Project-Report-093, CERN Geneva 1997
• First BNL Workshop on eRHIC, EPIC workshop at Indiana University, 1999.	• First LHeC workshop – 2008
• **"eRHIC Zeroth-Order Design Report" and cost estimate**, BNL 2004	• Pursues both ring-ring and linac-ring options
• 2007 – after detailed studies we found that linac-ring has 5-10 fold higher luminosity – it became the main option	• **The 2nd LHeC workshop will take place on 1-3 September, 2009 at Divonne**
• March 2008 – first staging option of eRHIC	• Two workshops (2008 and 2009) under the auspices of ECFA with the goal of having a Conceptual Design Report on the accelerator, the experiment and the physics.
• 2009 – focus on 4 GeV MeRHIC technical design, staging and cost estimates, first release – Fall 2009	• A Technical Design report will then follow if appropriate
• Regular semiannual EIC collaboration meeting (together with ELIC) since 2004 and EICAC (advisory committee) meetings starting Feb. 2009	

eRHIC Scope -QCD Factory

Electron accelerator

RHIC



Unpolarized and polarized leptons 4-20 (30) GeV

70% beam polarization goal
Positrons at low intensities

Polarized protons
25↓ 50-250 (325) GeV

Light ions (d,Si,Cu)
Heavy ions (Au,U)
50-100 (130) GeV/u

Polarized light ions
(He^3) 215 GeV/u

Center mass energy range: 15-200 GeV

eA program for eRHIC needs as high as possible energies of electron beams even with a trade-off for the luminosity.

<u>20 GeV is absolutely essential and 30 GeV is strongly desirable</u>

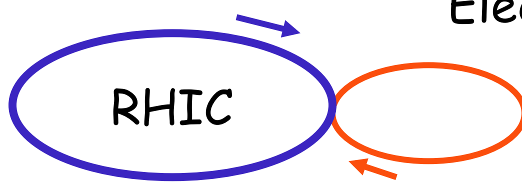
<u>Potential of future upgrading RHIC energy to 800 GeV</u>

2007 Choosing the focus: ERL or ring for electrons?

- Two main design options for eRHIC:
  - Ring-ring:

Electron storage ring

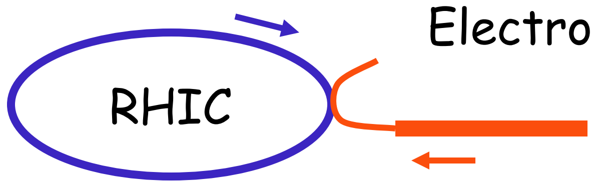
$$L = \left(\frac{4\pi\gamma_h\gamma_e}{r_h r_e}\right)(\xi_h\xi_e)\left(\sigma'_h\sigma'_e\right)f$$



  - Linac-ring:

Electron linear accelerator

$$L = \gamma_h f\, N_h \frac{\xi_h Z_h}{\beta_h^* r_h}$$



✔

L x 10

2008: Staging of eRHIC

- **MeRHIC**: Medium Energy eRHIC
  - Both Accelerator and Detector are located at IP2 of RHIC
  - 4 GeV e^- x 250 GeV p (45 or 63 GeV c.m.), L ~ 10^{32}-10^{33} cm^{-2} sec^{-1}
  - 90% of hardware will be used for HE eRHIC
- **eRHIC, High energy and luminosity phase,** inside RHIC tunnel

Full energy, nominal luminosity

- Polarized 20 GeV e^- x 325 GeV p (160 GeV c.m), L ~ 10^{33}-10^{34} cm^{-2} sec^{-1}
- 30 GeV e x 120 GeV/n Au (120 GeV c.m.), ~1/5 of full luminosity
- and 20 GeV e x 120 GeV/n Au (120 GeV c.m.), full liminosity

- **eRHIC up-grades – if needed**, inside RHIC tunnel

Higher luminosity at reduced energy

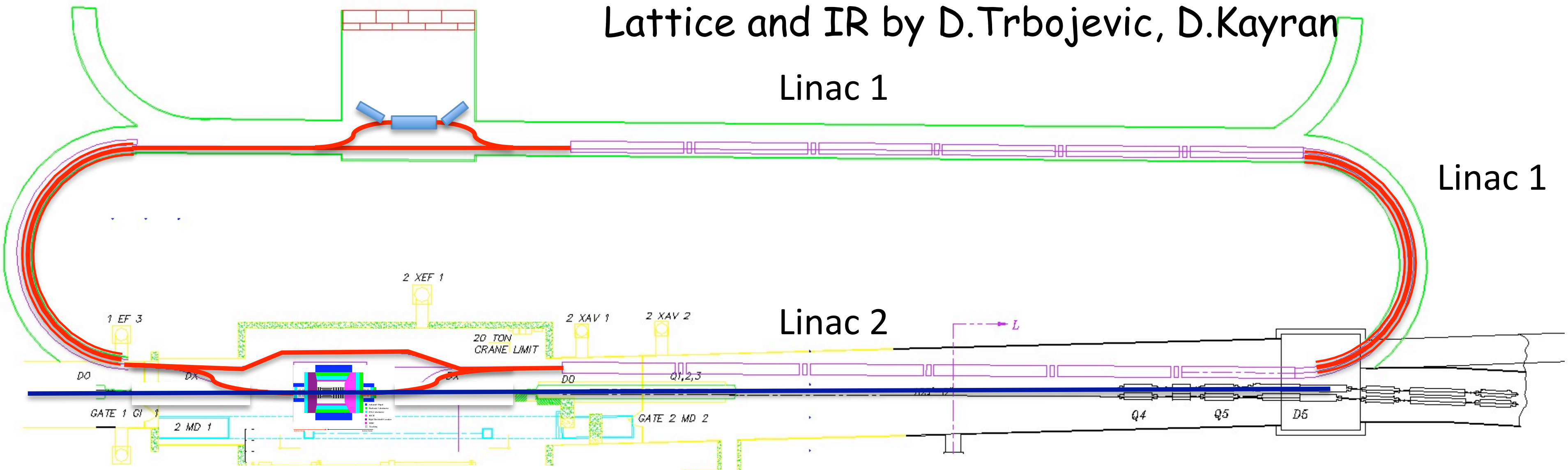
- Polarized 10 GeV e^- x 325 GeV p, L ~ 10^{35} cm^{-2} sec^{-1}

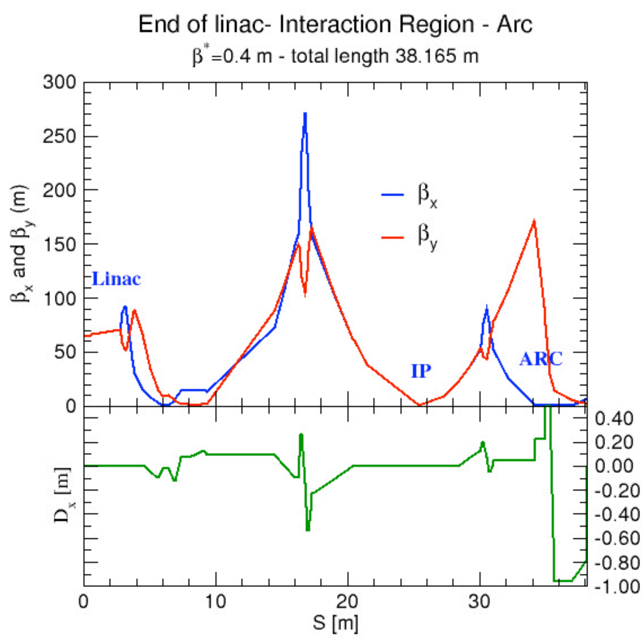
Or Higher energy operation with one new 800 GeV RHIC ring

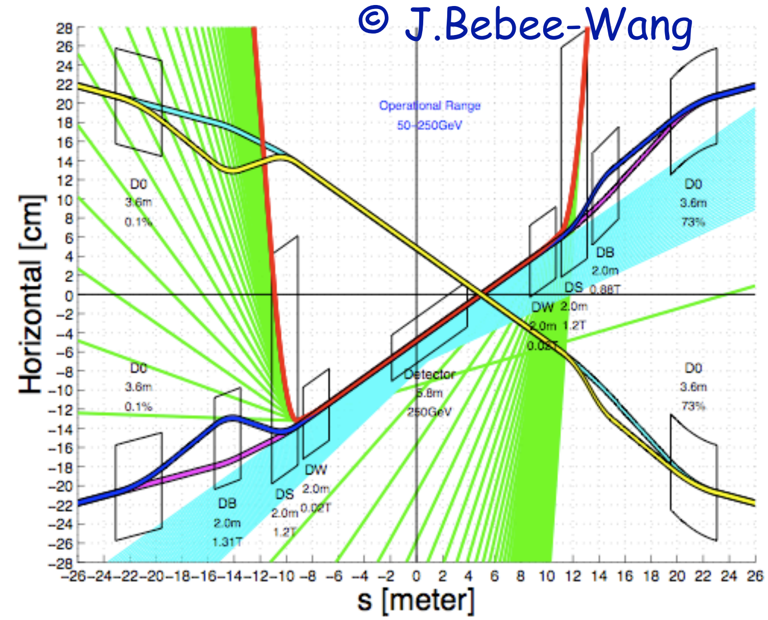
- Polarized 20 GeV e^- x 800 GeV p (~300 GeV c.m), L ~ 10^{34} cm^{-2} sec^{-1}
- 30 GeV e x 300 GeV/n Au (~200 GeV c.m.), L ~ 10^{32} cm^{-2} sec^{-1}

MeRHIC with 4 GeV ERL at 2 **o'clock** IR of RHIC

Lattice and IR by D.Trbojevic, D.Kayran



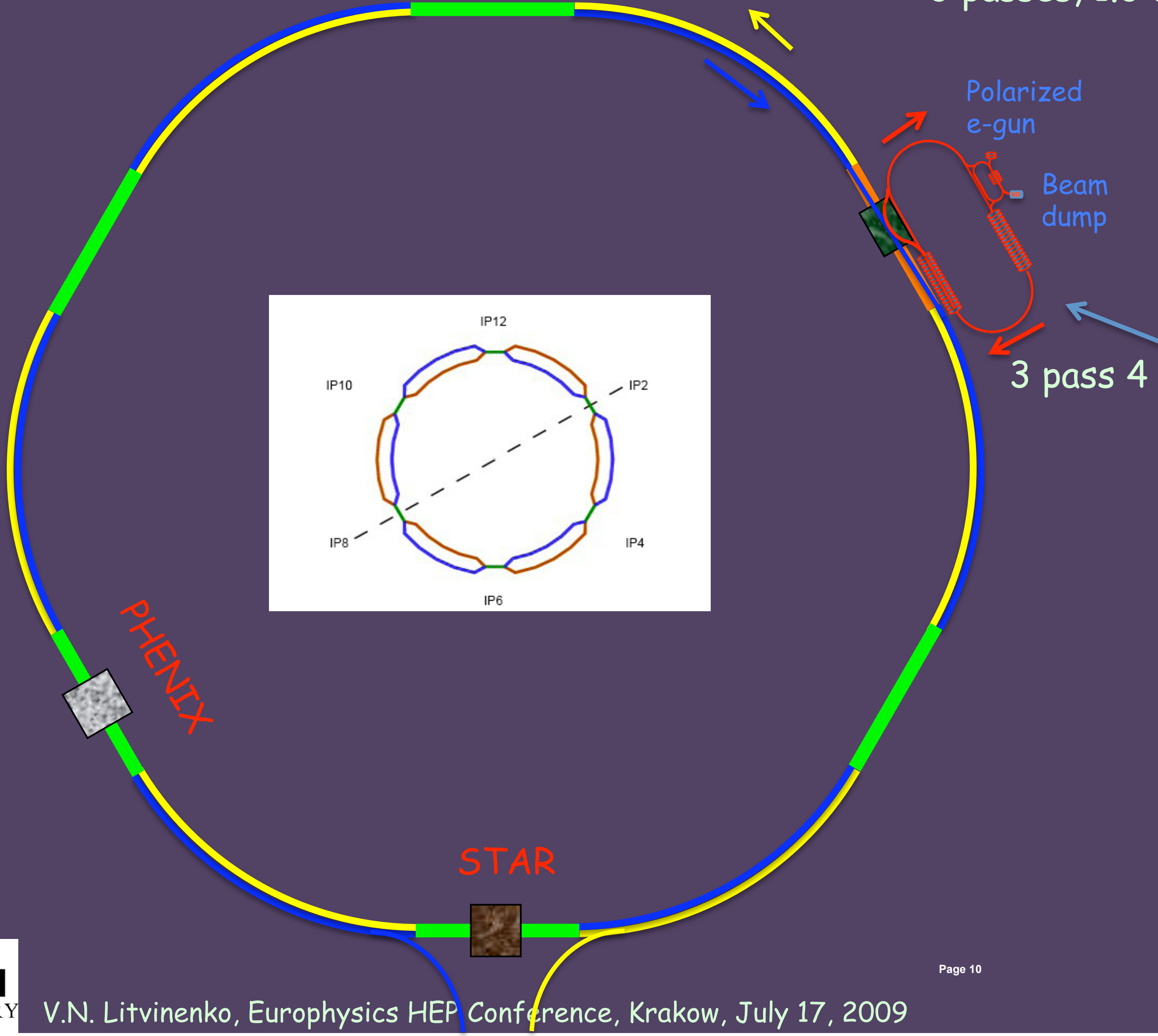




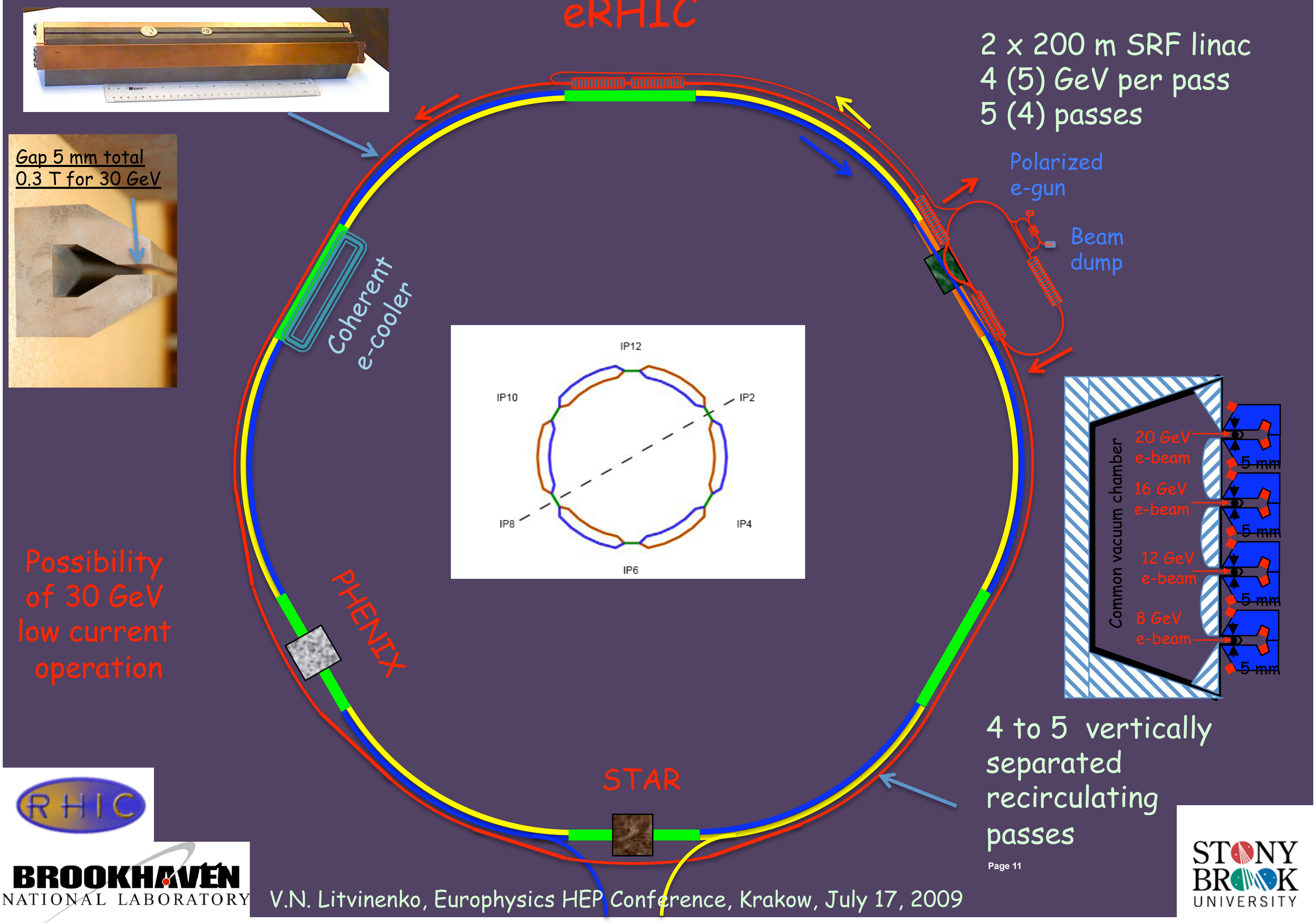
4 GeV e x 250 GeV p – 100 GeV/u Au

MeRHIC

2 x 60 m SRF linac
3 passes, 1.3 GeV/pass



20 GeV e x 325 GeV p – 130 GeV/u Au
eRHIC



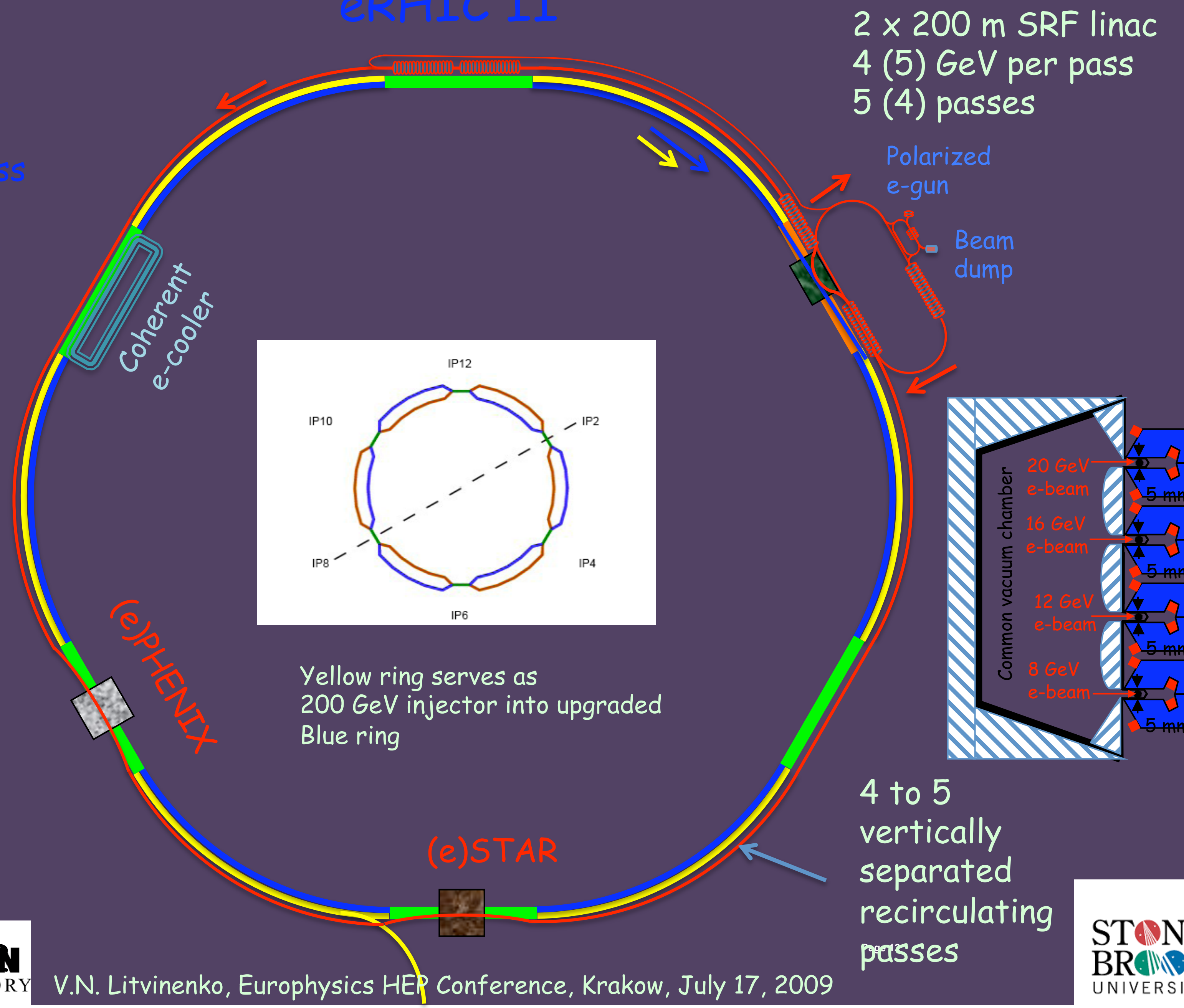
RHIC BROOKHAVEN NATIONAL LABORATORY STONY BROOK UNIVERSITY

20 GeV e x 800 GeV p – 320 GeV/u U

eRHIC II

Up-grade:
New LHC-class
SC magnets
in Blue ring

Possibility
of 30 GeV
low current
operation



eRHIC parameters

	MeRHIC		eRHIC with CeC		eRHIC II 8T RHIC	
	p (A)	e	p (A)	e	p/A	e
Energy, GeV	250 (100)	4	325 (125)	20 <30>	800 (300)	20 <30>
Number of bunches	111		166		166	
Bunch intensity (u) , 10^{11}	2.0	0.31	2.0 (3)	0.24	2.0 (3)	0.24
Bunch charge, nC	32	5	32	4	32	4
Beam current, mA	320	50	420	50 <5>	420	50 <5>
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.2	18	1	10
Polarization, %	70	80	70	80	70 (?)	80
rms bunch length, cm	20	0.2	4.9	0.2	4.5	0.2
β*, cm	50	50	25 (5)	25 (5)	25 (5)	25 (5)
Luminosity, × 10^{33}, $cm^{-2}s^{-1}$	0.1 -> 1 with CeC		2.8 (14)		6 (30)	

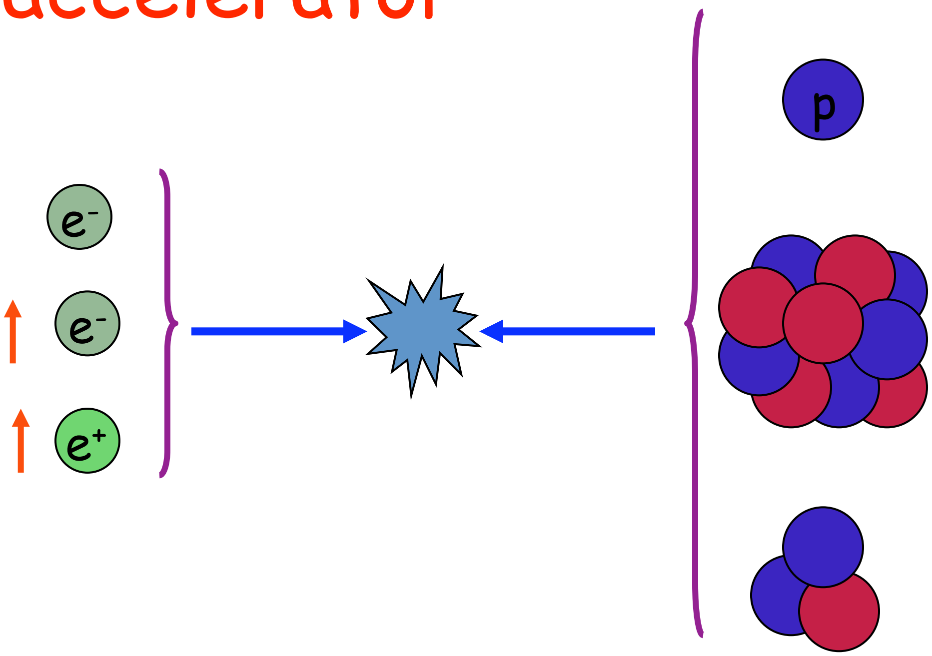
< Luminosity for 30 GeV e-beam operation will be at 10% level>

LHeC Scope

Electron accelerator

LHC

Unpolarized and
polarized leptons
60-140 GeV



Protons up to 7 TeV

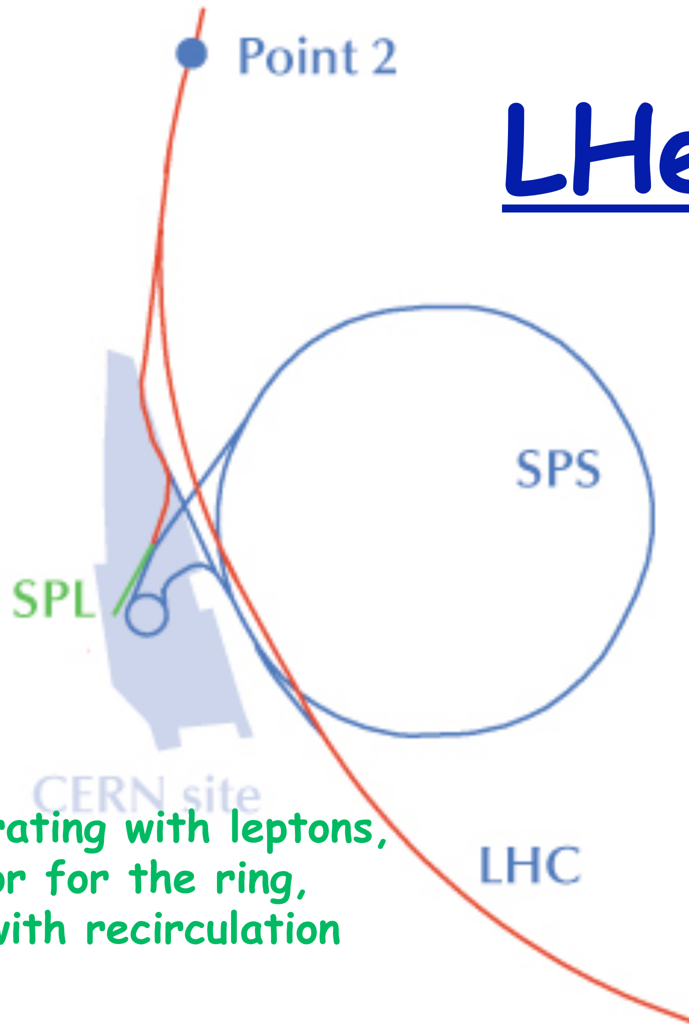
Heavy ions
3 TeV/u

Other ions?

Center mass energy range: 0.5- 2 TeV

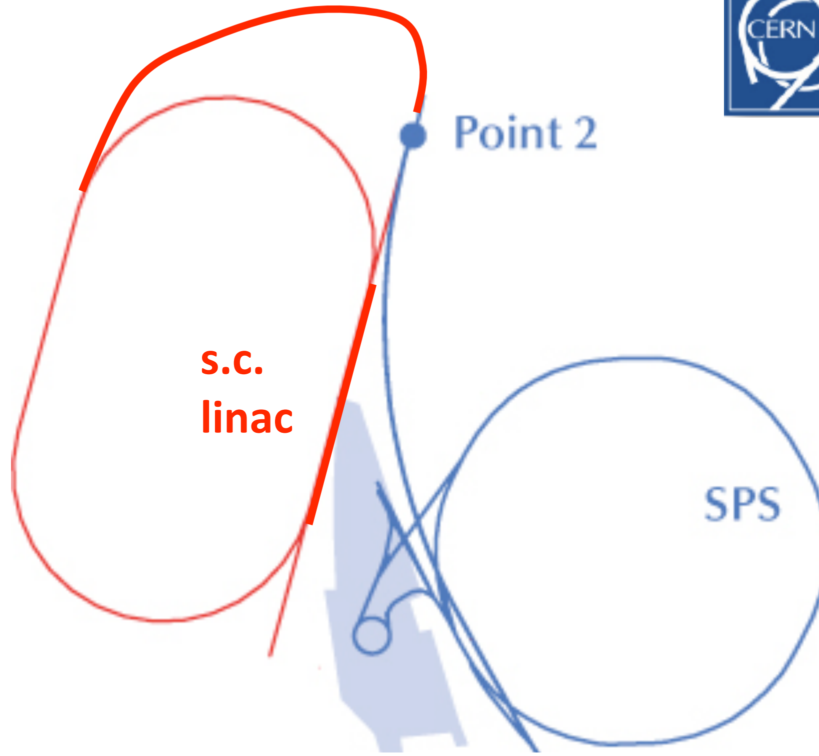
LHeC

Option 1: "ring-ring" (RR)
e-/e+ ring in LHC tunnel



SPL, operating with leptons, as injector for the ring, possibly with recirculation

Option 2: "ring-linac" (RL)



up to 70 GeV: option for cw operation and recirculation with energy recovery;
> 70 GeV: pulsed operation at higher gradient ; g-hadron option

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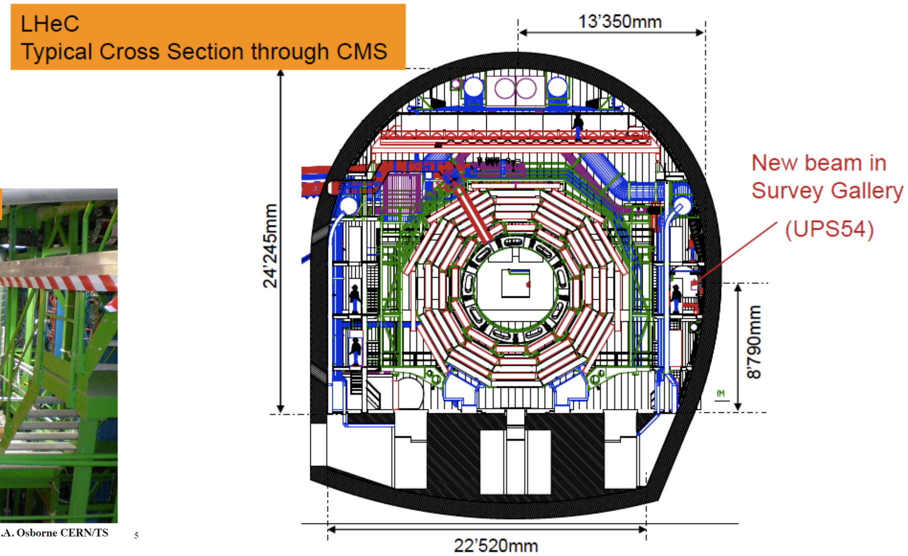
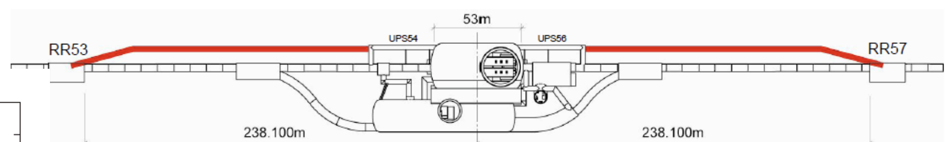
Geometry constrains: circular machines have to go around LHC detectors

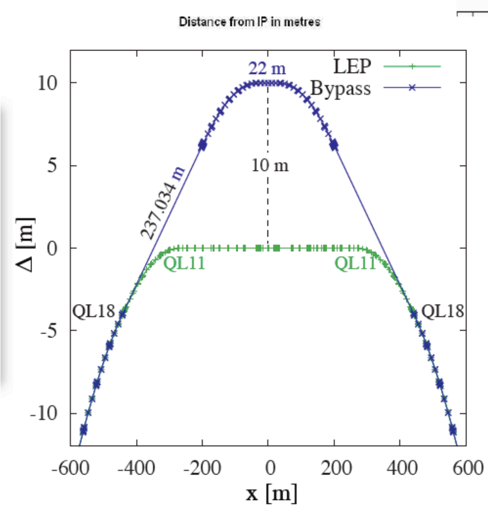


from J.A. Osborne CERN/TS 5

from J.A. Osborne CERN/TS 4



from J.A. Osborne CERN/TS 3



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	Point 1 ATLAS	Point 5 CMS	Point 2 and/or 8 RF	Point 3 Collimators	Point 7 Collimators	total
Type	Bypass Experiment	Bypass Experiment	Bypass ; allow for space for e - ring RF	Bypass Collimation	Bypass Collimation	
Approximate Tunnel length	900 m	900 m	500 m	500 m	500 m	about 3 km

Luminosity vs e-beam energy

for AC-plug power consumption set at 100 MW

	$N_{b,p}$	T_{sep}	$\varepsilon_p\gamma_p$	$\beta^*_{p,min}$
LHC phase-I upgrade	1.7×10^{11}	25 ns	3.75 μm	0.25 m
LHC phase-II upgrade ("LPA")	5×10^{11}	50 ns	3.75 μm	0.10 m

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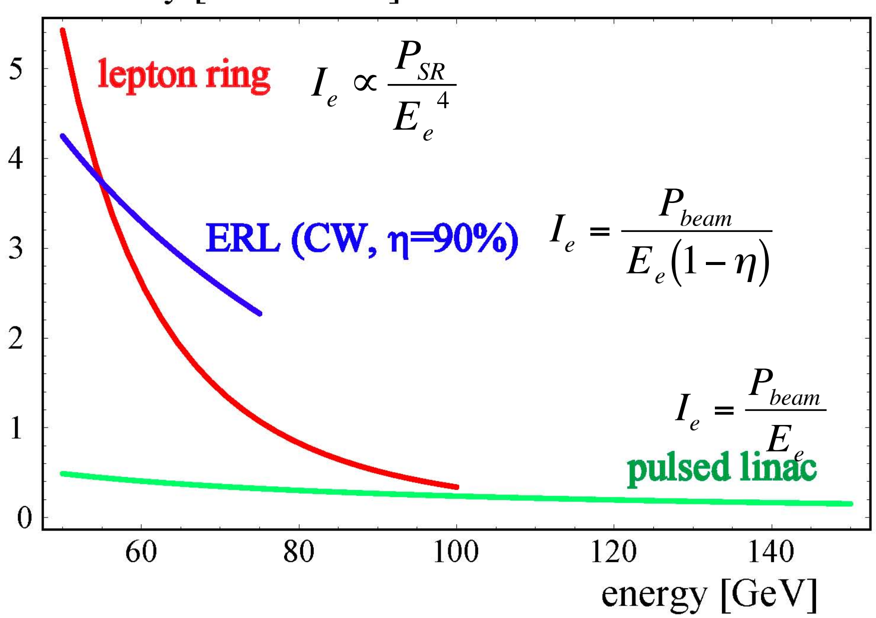
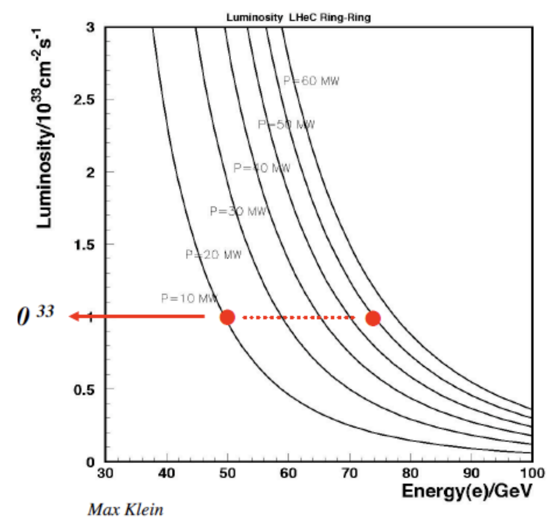


Ring SR power = Linac beam power & cryo power
= electrical power set to 100 MW
linac has much lower current

Luminosity Ring Ring & Performance Limit

Design values are for 14 MW synrad loss (beam power) and 50 GeV on 7000 GeV. May have 50 MW and energies up to about 70 GeV.

$$L = \frac{\sum_{i=1}^{n_b}(I_{ei} * I_{pi})}{e^2 f_0 2\pi \sqrt{\sigma_{xp}^2+\sigma_{xe}^2} * \sqrt{\sigma_{yp}^2+\sigma_{ye}^2}}$$



Luminosity Performance Limit:
E_e, I_e due to Synchrotron Radiation

$$P_\gamma = \frac{e^2 c}{6\pi\,\varepsilon_0} * \gamma^4 * r^2 * N_e$$

10^{33} can be reached in RR

E_e = 50 GeV ↔ P_{syn} = 10MW
*E_e = 75 GeV ↔ P_{syn} = 50MW * 2*

klystron efficiency: 50%

Overall power consumption: limited to 100MW

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BROOKHAVEN NATIONAL LABORATORY

STONY BROOK UNIVERSITY

IR layout & crab crossing (for RR)

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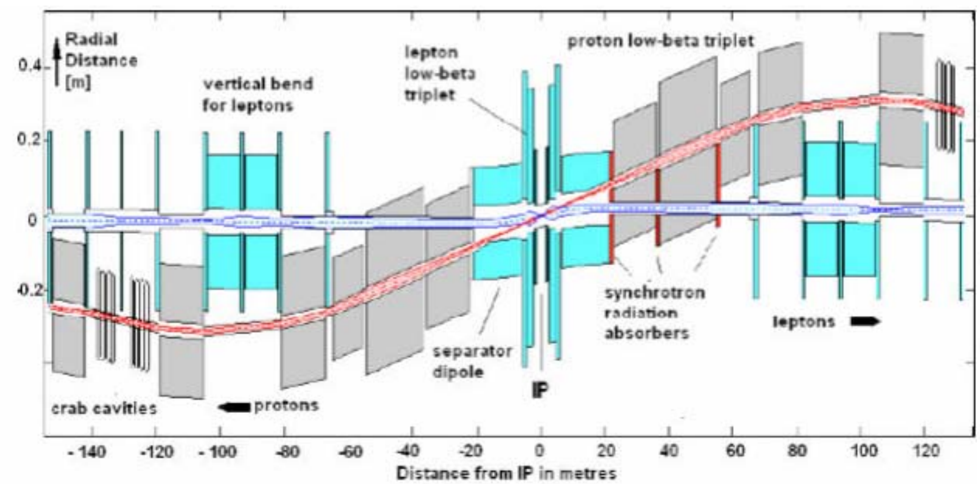
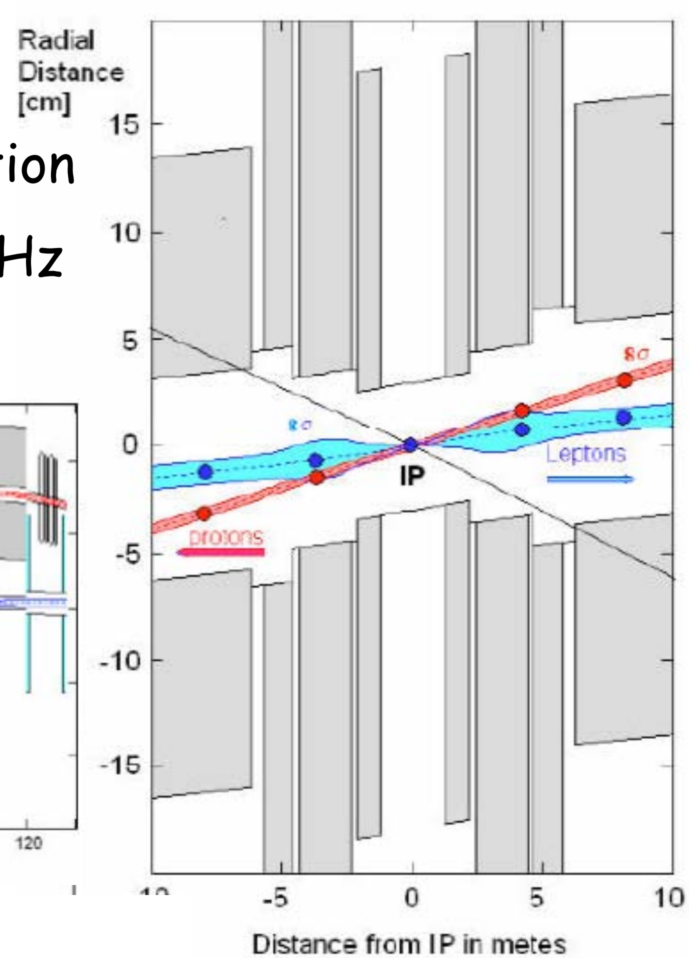
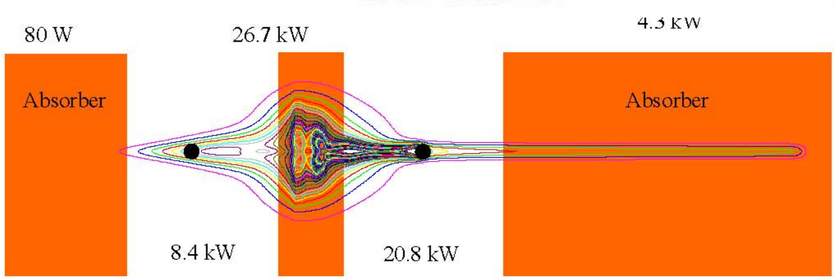
1-2 mrad crossing angle for early separation

Proton crab cavities: 15-30 MV at 800 MHz







Boris Nagorny

SC half quadrupoles
synchrotron radiation

Positrons

Ring

A rebuilt conventional e^+ source would suffice

Linac

True challenge: 10x more e^+ than ILC!

Large # bunches → damping ring difficult

Candidate e^+ sources under study :

- **ERL Compton** source for CW operation
  e.g. 100 mA ERL w. 10 optical cavities
- **undulator source using spent e- beam**
- **Linac-Compton** source for pulsed operation

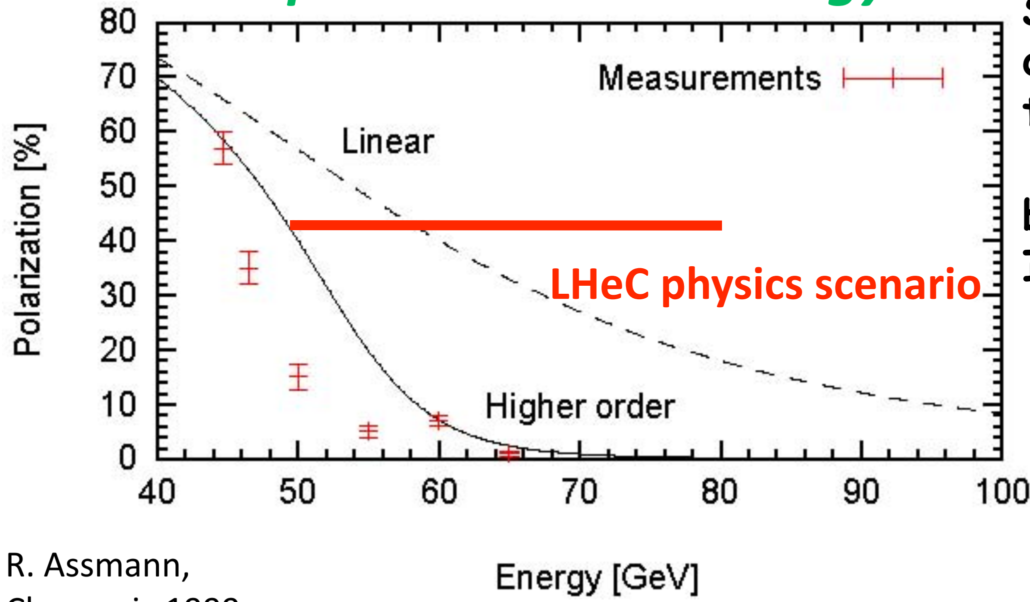
Complementary options: collimate to shrink emittance, extremely fast damping in laser cooling ring?, recycle e+ together with recovering their energy?

T. Omori, J. Urakawa, *et al*

Polarization

Ring

LEP polarization vs. energy



R. Assmann,
Chamonix 1999,
& Spin2000

Sokolov-Ternov polarization time decreases from 5 hr at 46 GeV to ½ hr at 70 GeV

but depolarizing rate Increases faster

© R. Assmann, D. Barber

Linac

e- : from polarized dc gun with ~90% polarization,
10-100 mm normalized emittance
e+: up to ~60% from undulator or Compton-based source

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Conclusions

- eRHIC designs provide for both polarized e-p and unpolarized eA collisions with high luminosity ~ 10^{33}-$10^{34}cm^{-2}sec^{-1}$ (L_{eRHIC}>>L_{HERA})
  - eRHIC choice of ERL for electron acceleration provides higher luminosity compared with ring-ring scenario
  - eRHIC's ERL has a natural staging strategy with increasing the energy of of the ERL is increasing length of linacs and the number of passes
  - if physics justify the cost – RHIC could be upgraded to 800 GeV by replacing magnets in one of its rings with LHC-class
  - MeRHIC technical design and cost estimate are progressing with plan to complete first release in Fall 2009
- LHeC could provide high-energy high-luminosity e±p & e±A collisions
  - two major designs under study:
    - ring-ring option with $10^{33}cm^{-2}s^{-1}$ and e-beam up to 80 GeV
    - Optics design for ring-ring is in very advanced stage
    - linac-ring option can deliver similar luminosity only using energy recovery, possible extension to 140 GeV with lower luminoity
- Both colliders provide for intriguing accelerator-physics R&D on ERLs, polarized guns, e+ production, crab cavities, polarization and advanced cooling techniques

Back up

Example Parameters

	LHeC-RR	LHeC-RL high lumi	LHeC-RL 100 GeV	LHeC-RL high energy	ILC	XFEL
e^- energy at IP [GeV]	60	60	100	140	(2×)250	20
luminosity [10^{32} cm^{-2}s^{-1}]	29	$29^\dagger$ ($2.9^\ddagger$)	2.2	1.5	200	N/A
bunch population [10^{10}]	5.6	$0.19^\dagger$ ($0.02^\ddagger$)	0.3 (1.5)	0.2 (1.0)	2	0.6
e^- bunch length [μm]	~10,000	300	300	300	300	24
bunch interval [ns]	50	50	50 (250)	50 (250)	369	200
norm. hor.&vert. emittance [μm]	4000, 2500	50	50	50	10, 0.04	1.4
average current [mA]	135	$7^\dagger$ ($0.7^\ddagger$)	0.5	0.5	0.04	0.03
rms IP beam size [μm]	44, 27	7	7	7	0.64, 0.006	N/A
repetition rate [Hz]	CW	CW	10 [5% d.f.]	10 [5% d.f.]	5	10
bunches/pulse	N/A	N/A	71430	14286	2625	3250
pulse current [mA]	N/A	N/A	10	10	9	25
beam pulse length [ms]	N/A	N/A	5	5	1	0.65
cryo power [MW]	0.5	20	4	6	34	3.6
total wall plug power [MW]	100	100	100	100	230	19

Example LHeC-RR and RL parameters. Numbers for LHeC-RL high-luminosity option marked by `†' assume energy recovery with $\eta_{ER}$=90%; those with `‡' refer to η_{ER}=0%. ILC and XFEL numbers are included for comparison. Note that optimization of the RR luminosity for different LHC beam assumptions leads to similar luminosity values of about 10^{33}cm^{-2}s^{-1}

Linac Ring Options:

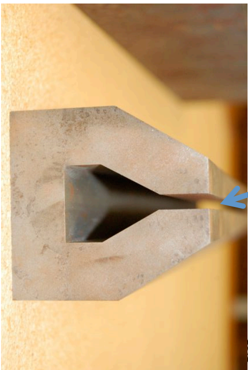
SPL ... or a recirculating Linac

e- energy [GeV]	30	100 (Pulsed)	100 (CW)
comment	SPL* (20)+TI2	LINAC	LINAC
#passes	4+1	2	2
wall plug power RF+Cryo	100 (1 cr.)	100 (3 cr.)	100 (35 cr.)
bunch population [10^9]	10	3.0	0.1
duty factor [%]	5	5	100
average e- current [mA]	1.6	0.5	0.3
emittance $\gamma\varepsilon$ [μm]	50	50	50
RF gradient [MV/m]	25	25	13.9
total linac length β=1 [m]	350+333	3300	6000
minimum return arc radius [m]	240 (final bends)	1100	1100
beam power at IP [MW]	24	48	30
e- IP beta function [m]	0.06	0.2	0.2
ep hourglass reduction factor	0.62	0.86	0.86
disruption parameter D	56	17	17
luminosity [10^{32} cm^{-2} s^{-1}]	**2.5**	**2.2**	**1.3**

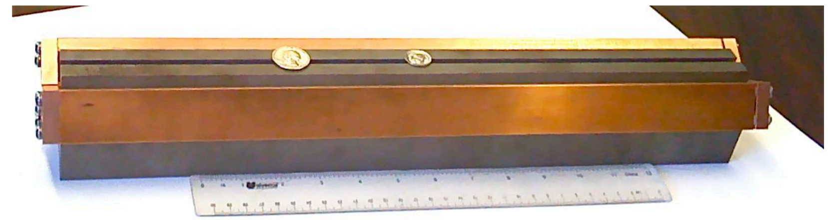
F.Zimmermann, S. Chattopadhyay

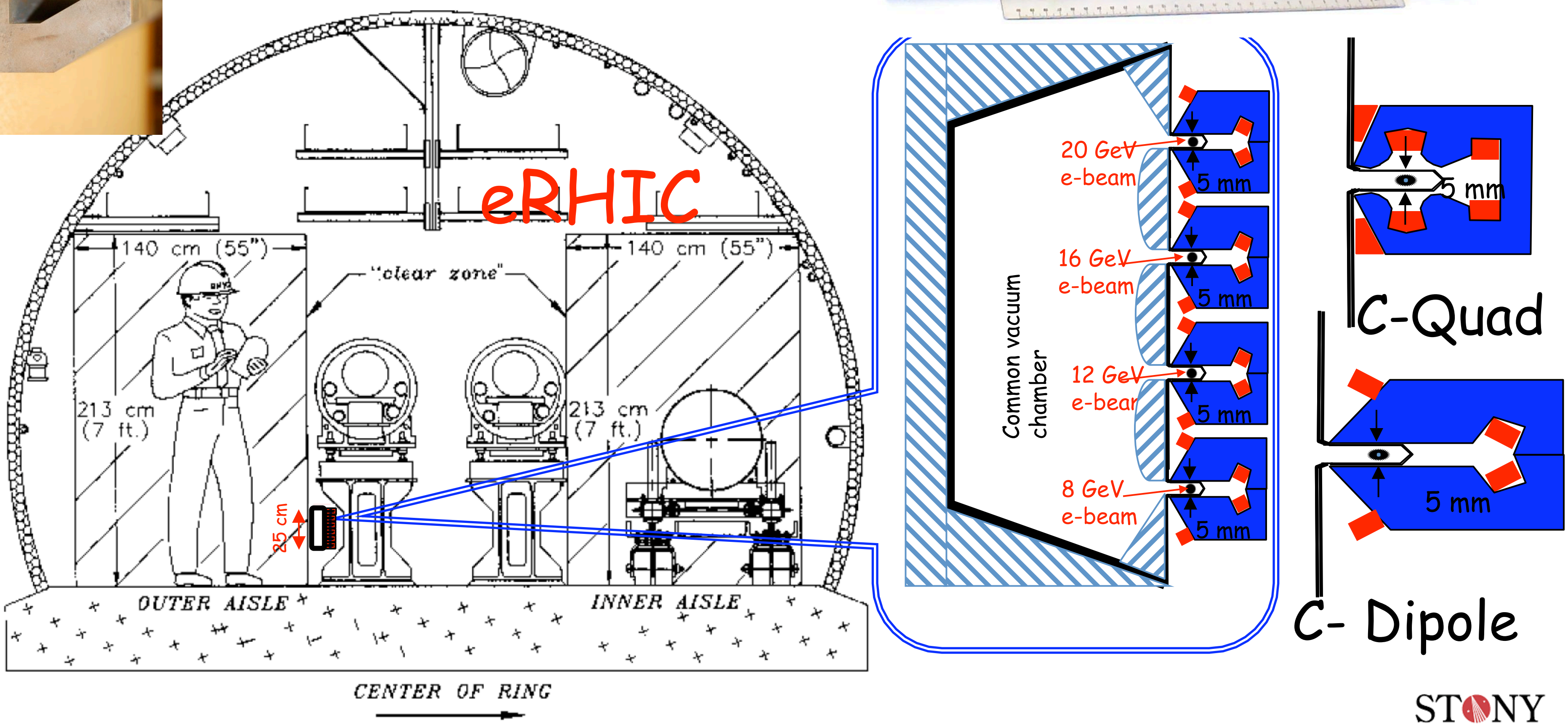
eRHIC loop magnets: LDRD project

- Small gap provides for low current, low power consumption magnets
  - -> **low cost eRHIC**



Gap 5 mm total
0.3 T for 30 GeV

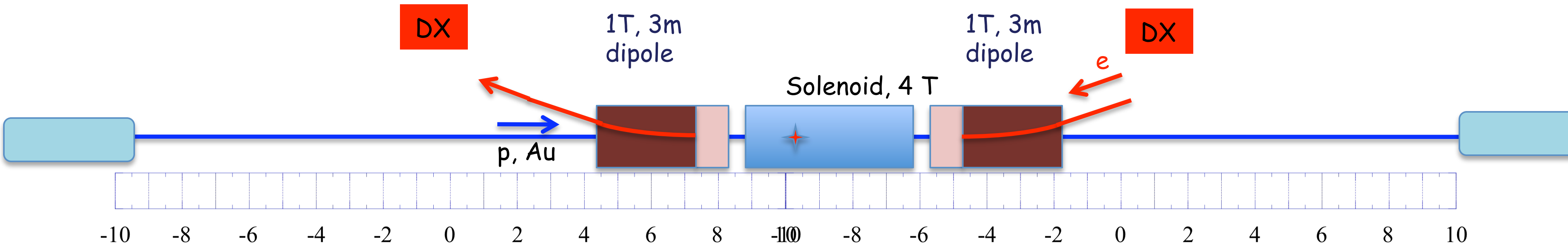


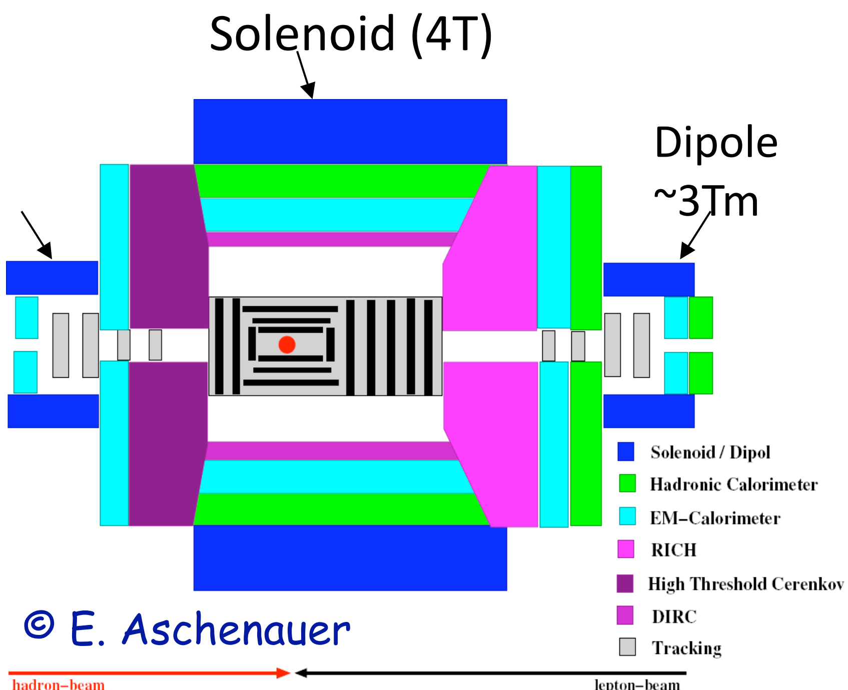


Detector field layout

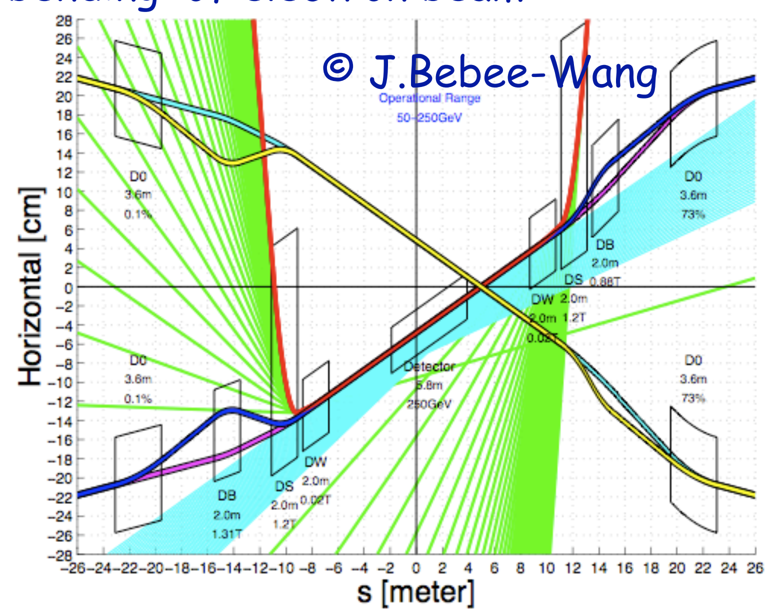
MeRHIC 4 GeV e x 250 GeV p/100 GeV Au

Remove Dxes – 40 m to detect particles scattered at small angles





To provide effective SR protection:
-soft bend (~0.05T) is used for final bending of electron beam



ERL spin transparency at all energies

Bargman, Mitchel,Telegdi equation

$$\frac{d\hat{s}}{dt} = \frac{e}{mc}\hat{s}\times\left[\left(\frac{g}{2}-1+\frac{1}{\gamma}\right)\vec{B} - \frac{\gamma}{\gamma+1}\left(\frac{g}{2}-1\right)\vec{\beta}\left(\vec{\beta}\cdot\vec{B}\right) - \left(\frac{g}{2}-\frac{\gamma}{\gamma+1}\right)\left[\vec{\beta}\times\vec{E}\right]\right]$$

$$a = g/2-1 = 1.1596521884\cdot 10^{-3}$$

$$\hat{\mu} = \frac{g}{2}\frac{e}{m_o}\hat{s} = (1+a)\frac{e}{m_o}\hat{s}; \qquad \nu_{spin} = a\cdot\gamma = \frac{E_e}{0.44065[GeV]}$$

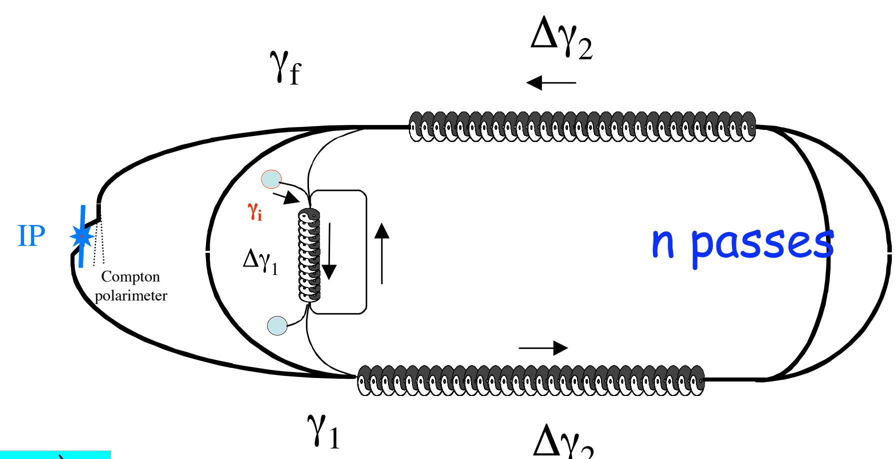
$$\Downarrow$$

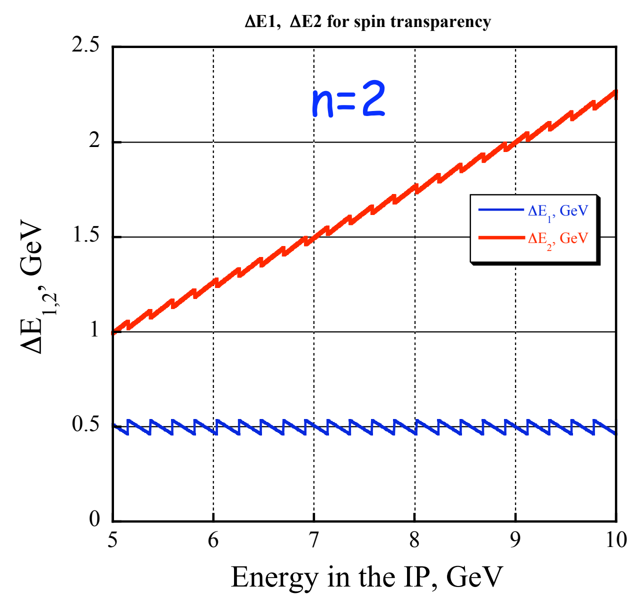
$$\Delta\varphi = a\cdot\gamma\theta$$

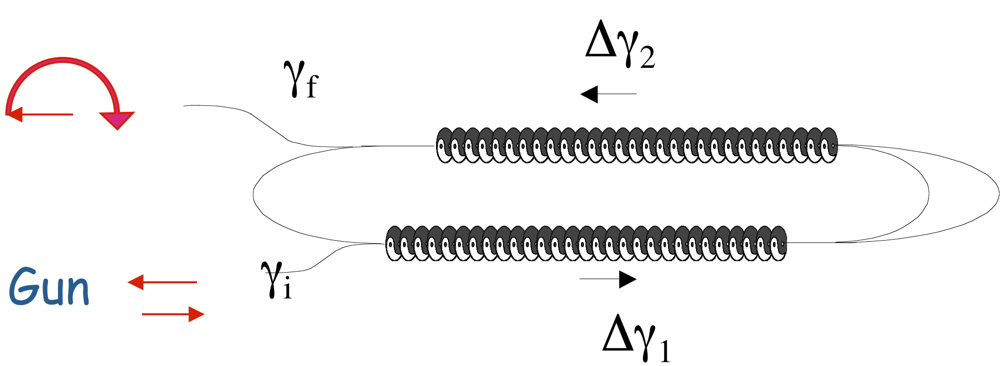
Total angle $\varphi = \pi a\cdot\left(\gamma_i(2n-1) + n(\Delta\gamma_1\cdot n + \Delta\gamma_2(n-1)\right)$

Has solution for all energies!

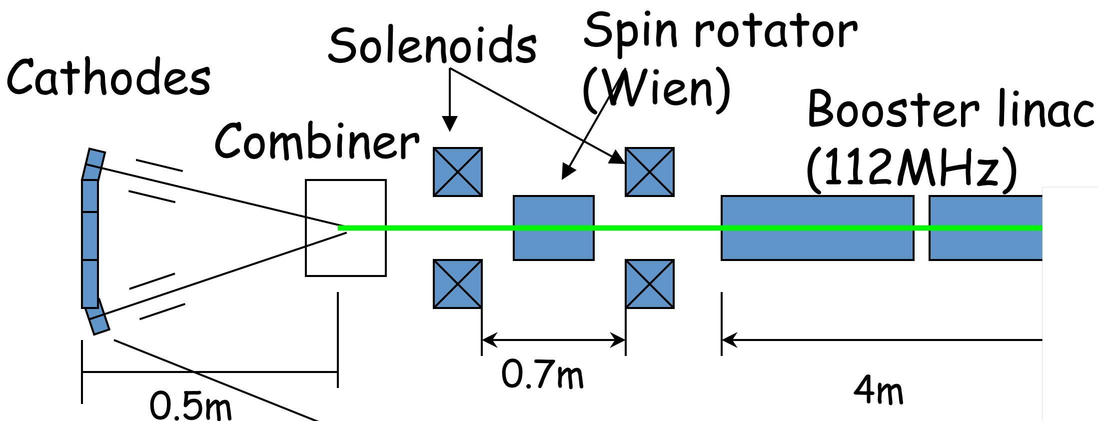
$$\begin{Bmatrix} \gamma_i + 2\cdot(\Delta\gamma_1+\Delta\gamma_2) & = \gamma_f \\ a\cdot\left(\gamma_i(2n-1)+n(\Delta\gamma_1\cdot n+\Delta\gamma_2(n-1)\right) & = N \end{Bmatrix}$$



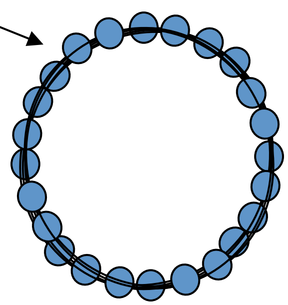




Main technical challenge is 50 mA CW polarized gun: we are building it

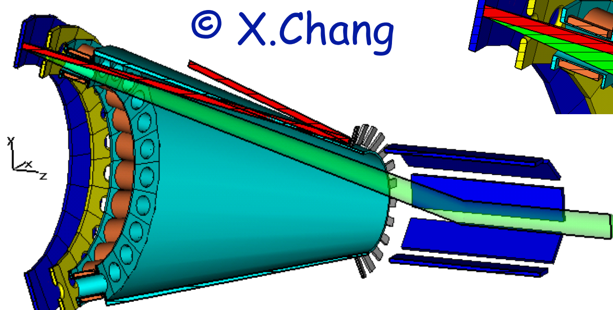


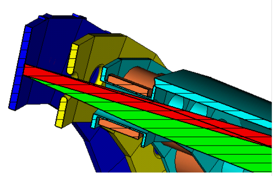
Based on demonstrated current technology developed at JLab



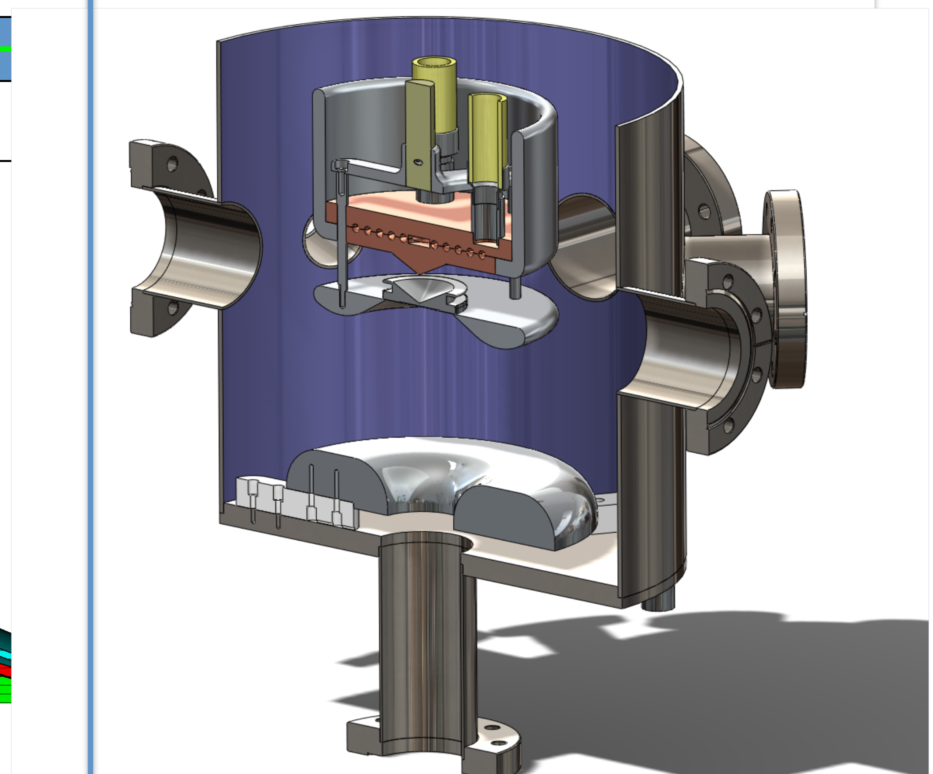
DC gun with 24 cathodes

© X.Chang



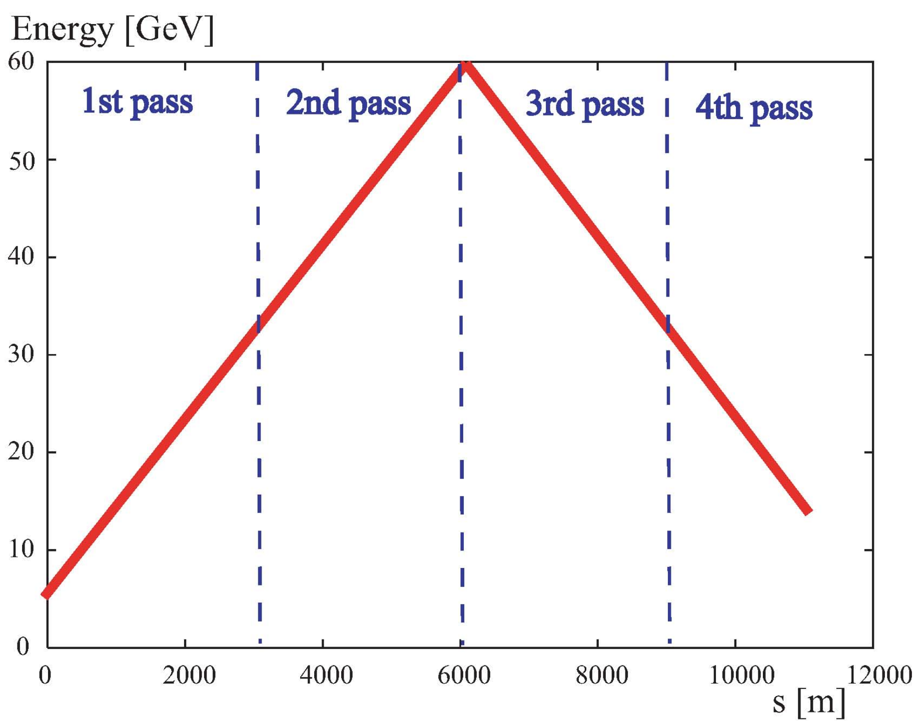


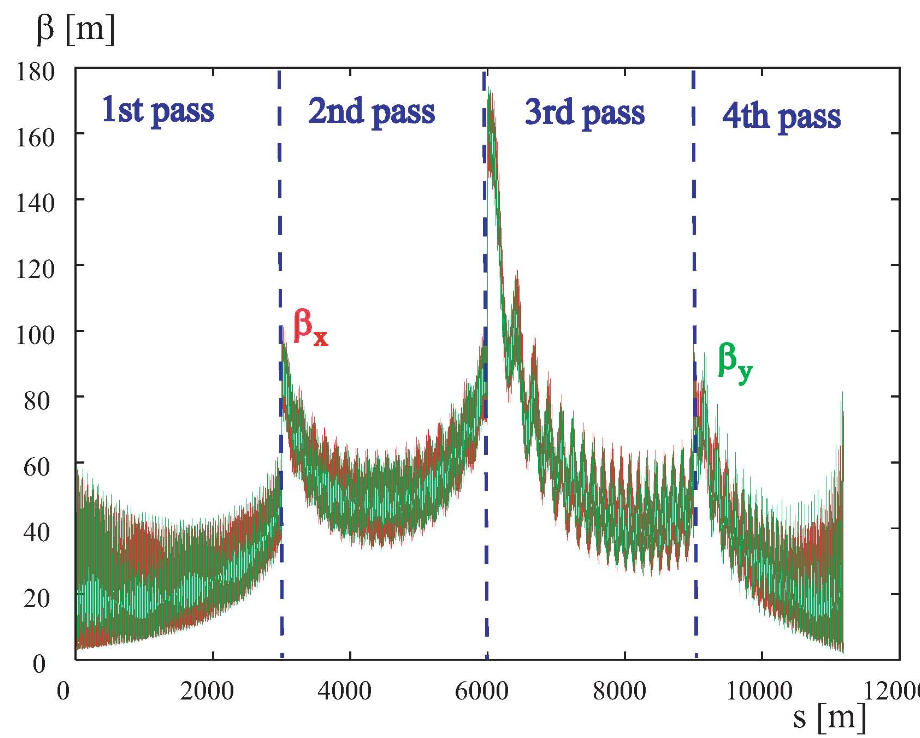
Single cathode DC gun



© E.Tsentalovich, MIT

example linac optics for 4-pass ERL option





Anders Eide

tentative SC linac parameters for RL

LHeC-RL scenario	lumi	baseline	energy
final energy [GeV]	60	100	140
cell length [m]	24	24	24
cavity fill factor	0.7	0.7	0.7
tot. linac length [m]	3000	2712	3024
cav. gradient [MV/m]	13	25	32
operation mode	CW (ERL)	pulsed	pulsed

RF frequency: ~700 MHz

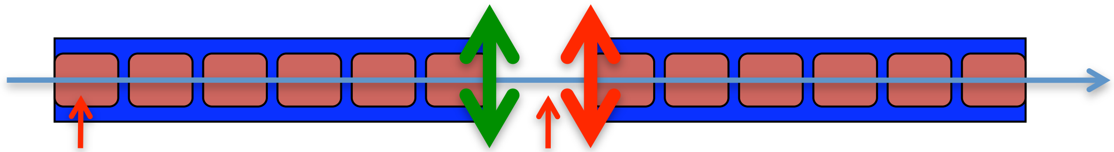
4 passes **2 passes**

Anders Eide

Challenges and Advantages

- Main Challenge –
  50 mA polarized gun for e-p program
- Main advantage – RHIC
  - Unique set of species from d to U
  - The only high energy polarized proton collider
  - Large size of RHIC tunnel (3.8 km)
- Main disadvantage is caused by nature
  - Ion cloud limitation of the hadron beam intensity

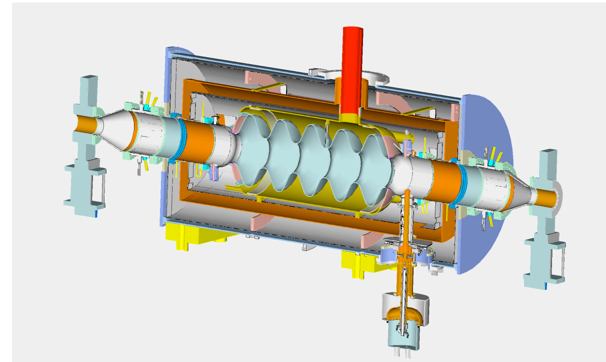
MeRHIC Linac Design



703.75 MHz
1.6 m long

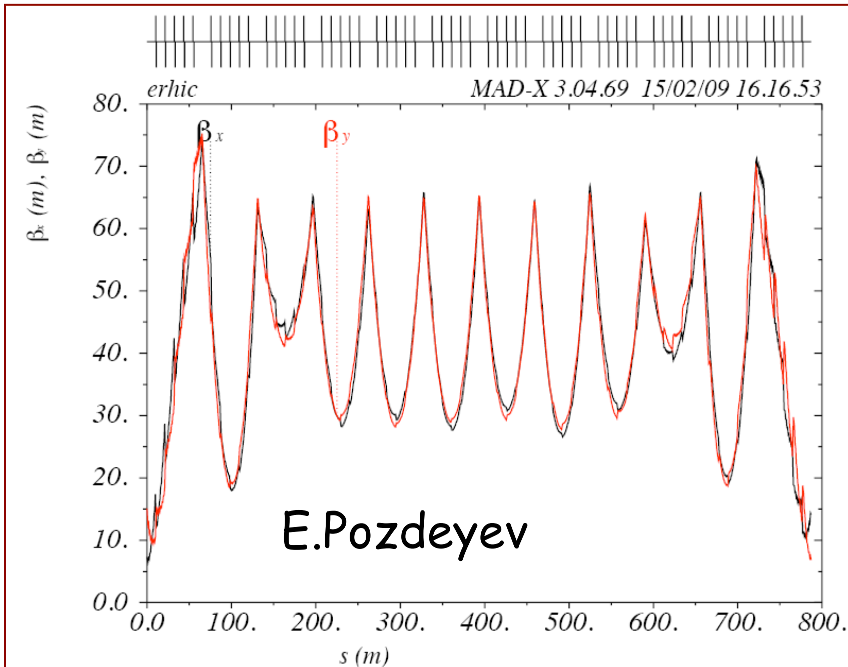
Drift
1.5 m long

65m total linac length
All cold: no warm-to-cold transition



Based on revolutionary BNL SRF cavity with fully suppressed HOMs – reached design parameters last week
Critical for high current multi-pass ERL

100 MeV → 4 GeV → 100 MeV

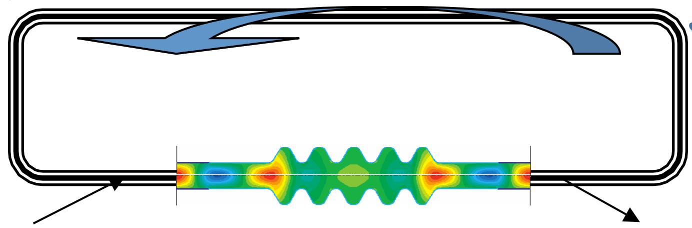


Current breakdown of the linac

- **N cavities = 6 (per module)**
- **N modules per linac = 6**
- **N linacs = 2**
- **L module = 9.6m**
- **L period = 10.6 m**
- **E_f = 18.0 MeV/m**
- **$\langle dE/ds \rangle$ = 10.2 MeV/m**

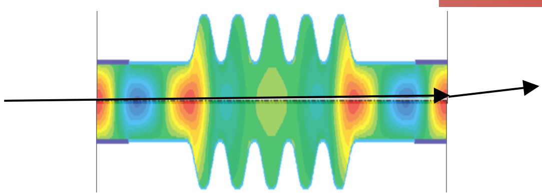
TBBU stability (©E. Pozdeyev)

- HOMs based on R. Calaga's simulations/ measurements
- 70 dipole HOM's to 2.7 GHz in each cavity
- Polarization either 0 or 90°
- 6 different random seeds
- HOM Frequency spread 0-0.001

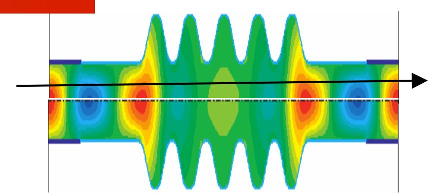


Simulated BBU threshold (GBBU) vs. HOM frequency spread. Beam current 50 mA

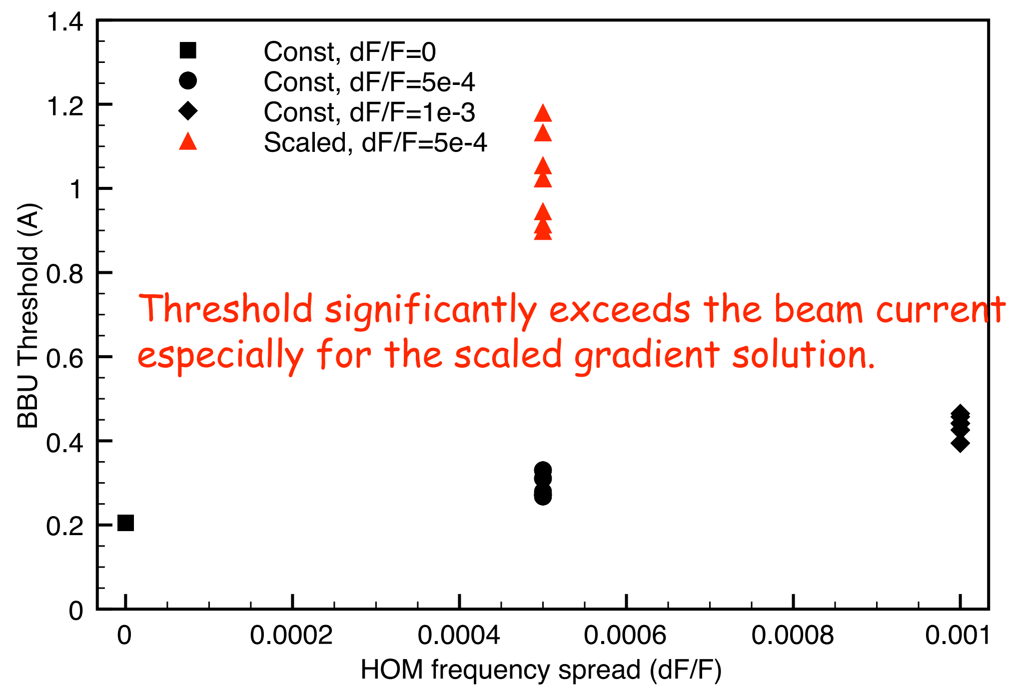
Excitation process of transverse HOM



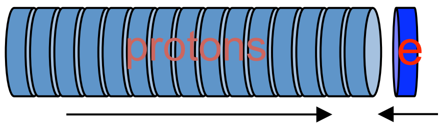
$$\begin{bmatrix} x \\ x' \end{bmatrix}_{return} = \begin{bmatrix} m11 & \boldsymbol{m12} \\ m21 & m22 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ \boldsymbol{x'} \end{bmatrix}_{comming}$$

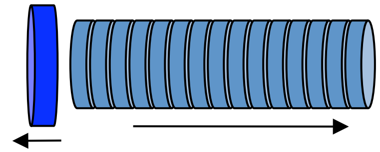


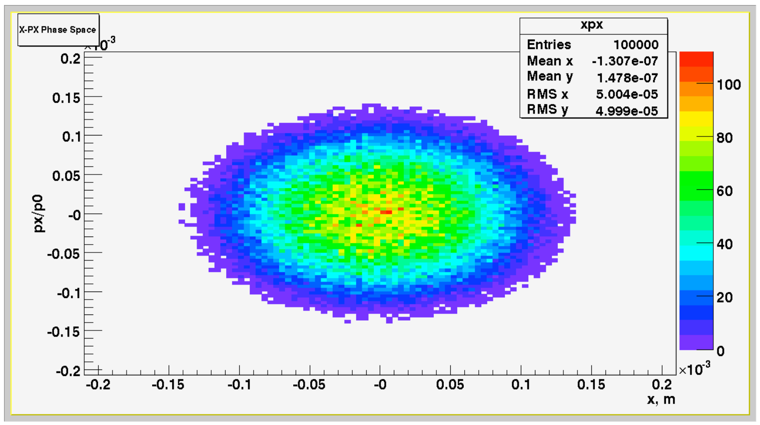
F (GHz)	R/Q (Ω)	Q	(R/Q)Q
0.8892	57.2	600	3.4e4
0.8916	57.2	750	4.3e4
1.7773	3.4	7084	2.4e4
1.7774	3.4	7167	2.4e4
1.7827	1.7	9899	1.7e4
1.7828	1.7	8967	1.5e4
1.7847	5.1	4200	2.1e4
1.7848	5.1	4200	2.1e4



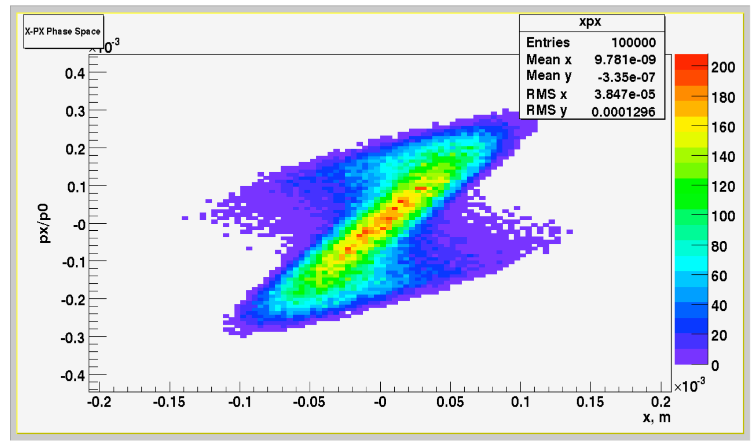
Beam Disruption



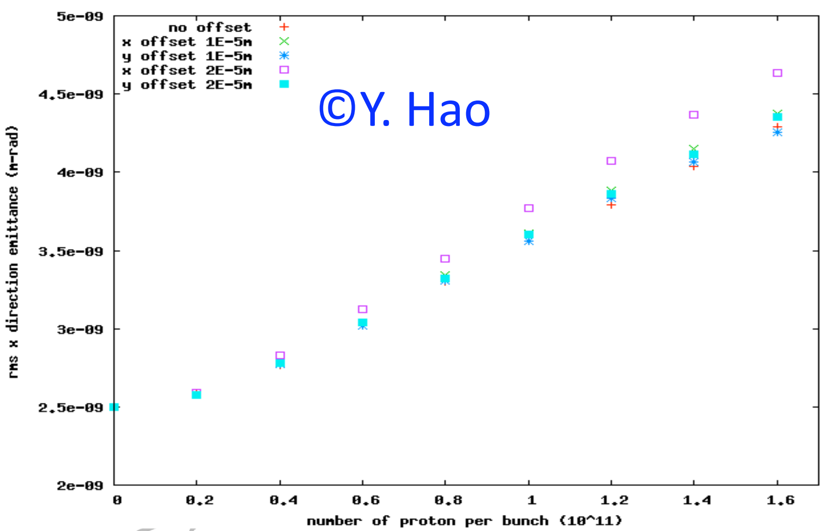


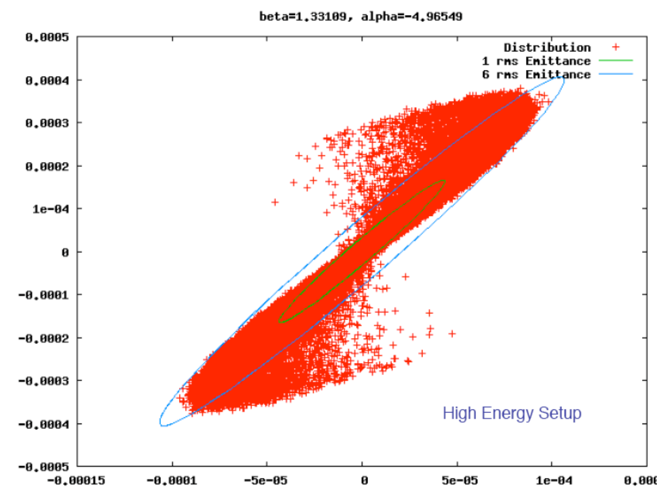


Interaction



Optimized





Gains from coherent e-cooling:

Coherent Electron Cooling vs. IBS

PRL **102**, 114801 (2009) PHYSICAL REVIEW LETTERS week ending 20 MARCH 2009

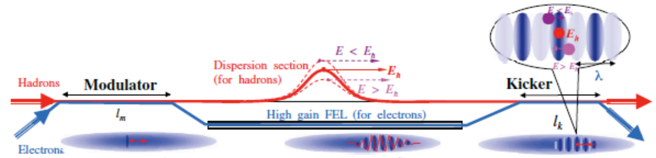


FIG. 1 (color). A general schematic of the Coherent Electron Cooler (CEC) comprising three sections: A modulator; a FEL plus a dispersion section; and, a kicker. The FEL wavelength, λ, in the figure is grossly exaggerated for visibility.

$$X = \frac{\varepsilon_x}{\varepsilon_{xo}};\ S = \left(\frac{\sigma_s}{\sigma_{so}}\right)^2 = \left(\frac{\sigma_E}{\sigma_{sE}}\right)^2;$$

$$\frac{dX}{dt} = \frac{1}{\tau_{IBS\perp}}\frac{1}{X^{3/2}S^{1/2}} - \frac{\xi_\perp}{\tau_{CeC}}\frac{1}{S};$$

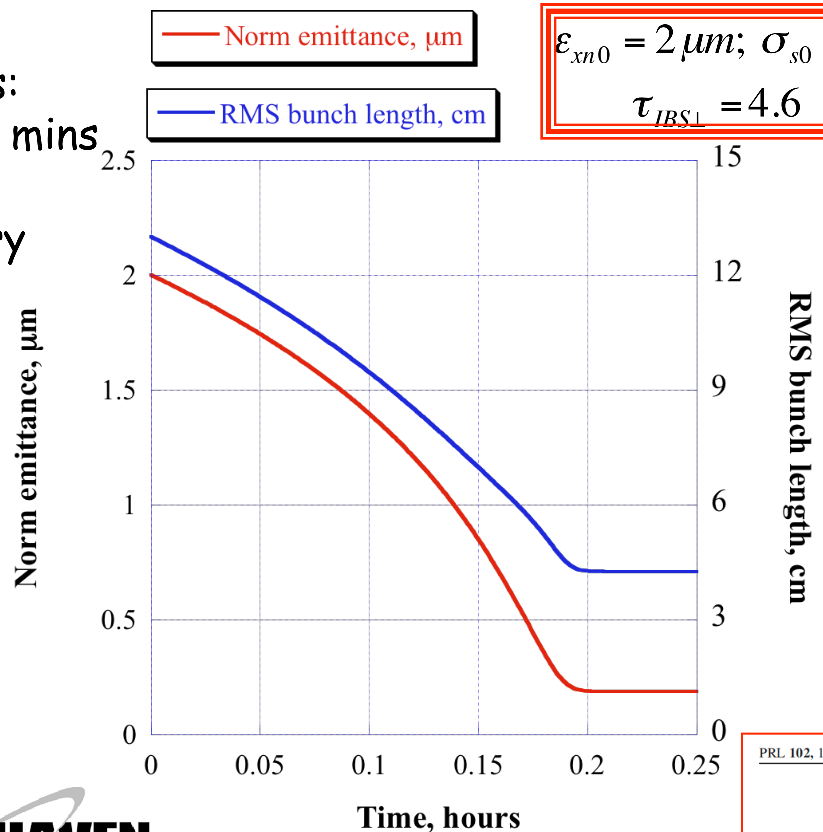
$$\frac{dS}{dt} = \frac{1}{\tau_{IBS//}}\frac{1}{X^{3/2}Y} - \frac{1-2\xi_\perp}{\tau_{CeC}}\frac{1}{X};$$

$$X = \frac{\tau_{CeC}}{\sqrt{\tau_{IBS//}\tau_{IBS\perp}}}\frac{1}{\sqrt{\xi_\perp(1-2\xi_\perp)}};\quad S = \frac{\tau_{CeC}}{\tau_{IBS//}}\cdot\sqrt{\frac{\tau_{IBS\perp}}{\tau_{IBS//}}}\cdot\sqrt{\frac{\xi_\perp}{(1-2\xi_\perp)^3}}$$

$$\varepsilon_{xn0} = 2\,\mu m;\ \sigma_{s0} = 13\ cm;\ \sigma_{\delta 0} = 4\cdot 10^{-4}$$
$$\tau_{IBS\perp} = 4.6\ \ hrs;\ \tau_{IBS//} = 1.6\ \ hrs;$$

IBS in RHIC for eRHIC, 250 GeV, N_p=2·10[11]
Beta-cool, ©A.Fedotov

Dynamics:
Takes 12 mins to reach stationary point



$$\varepsilon_{xn} = 0.2\,\mu m;\ \sigma_s = 4.9\ \ \mathrm{cm}$$

This allows

a) keep the luminosity as it is
b) reduce polarized beam current down to 25 mA (5 mA for e-I)
c) increase electron beam energy to 20 GeV (30 GeV for e-I)
d) increase luminosity by reducing β* from 25 cm down to 5 cm

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Coherent Electron Cooling

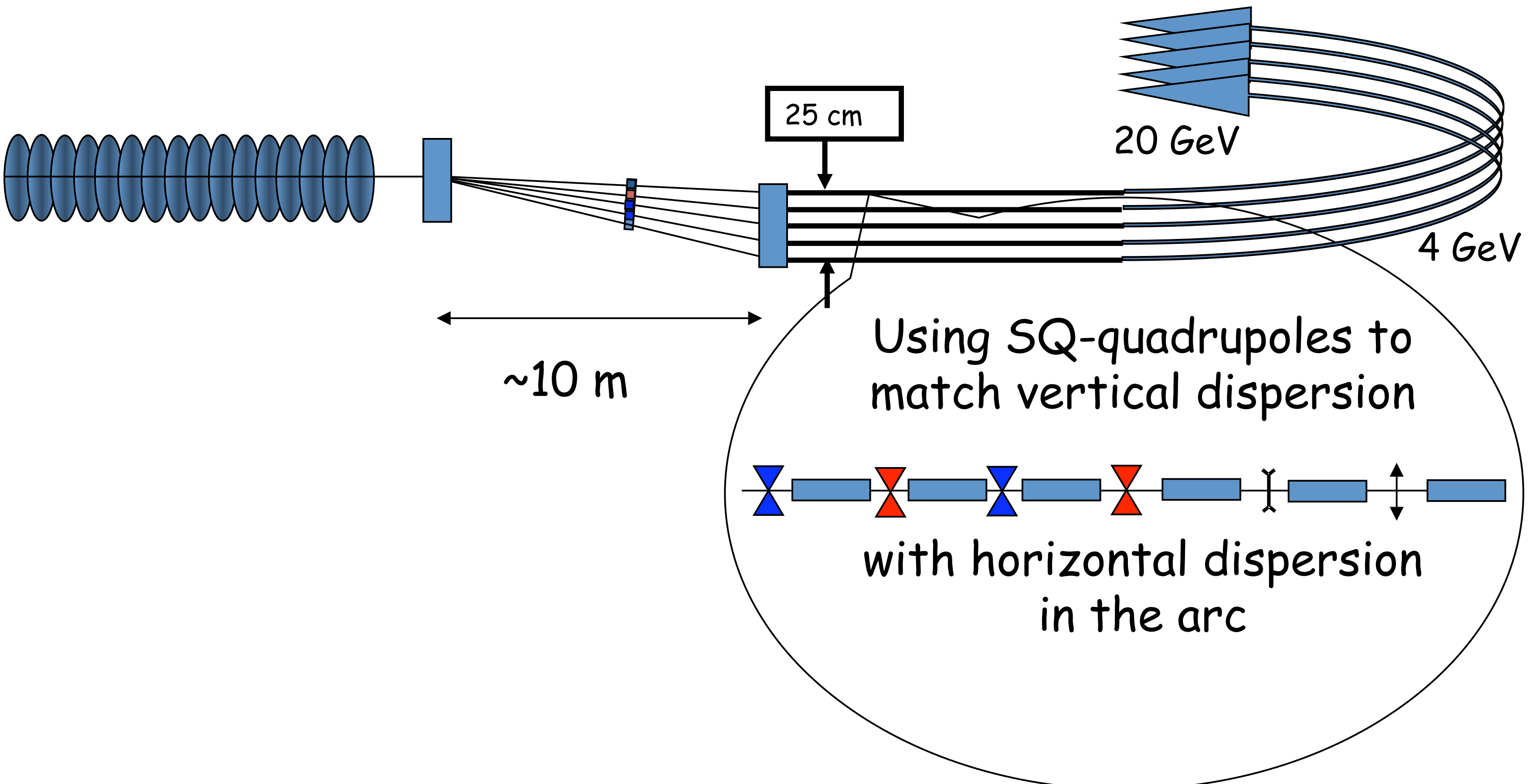
Vladimir N. Litvinenko[1,*] and Yaroslav S. Derbenev[2]
[1]Brookhaven National Laboratory, Upton, Long Island, New York, USA
[2]Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA

(Received 24 September 2008; published 20 March 2009)

BROOKHAVEN NATIONAL LABORATORY

STONY BROOK UNIVERSITY

Compact spreaders/combiners

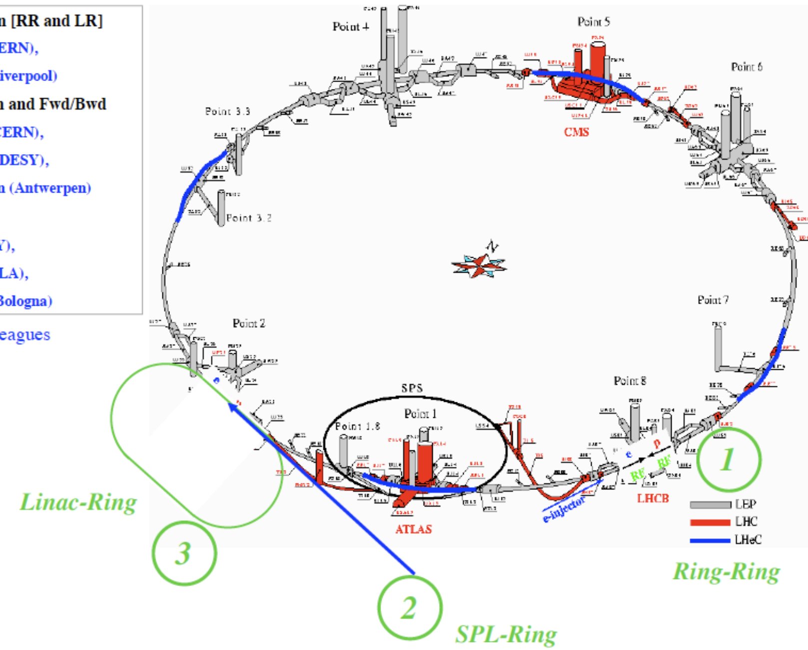


This concept allows to use most of the RHIC straight sections for SF linacs and to use part of the arcs for matching

The LHeC Study Group: Three Alternatives

Accelerator Design [RR and LR]
Oliver Bruening (CERN),
John Dainton (CI/Liverpool)
Interaction Region and Fwd/Bwd
Bernhard Holzer (CERN),
Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)
Detector Design
Peter Kostka (DESY),
Rainer Wallny (UCLA),
Alessandro Polini (Bologna)

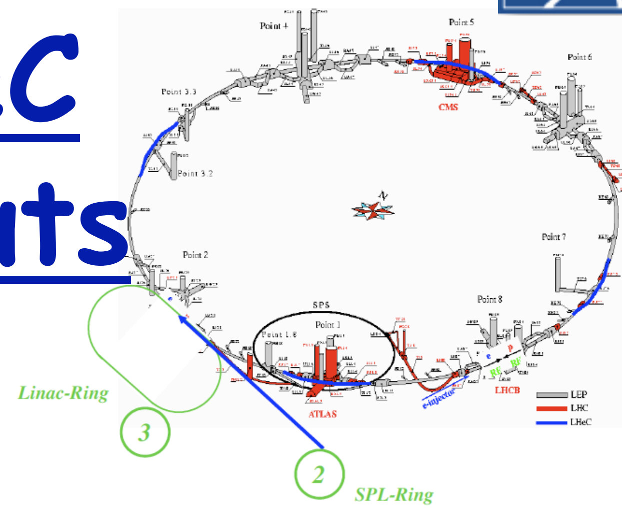
... and many colleagues



LHeC layouts

Linac Ring Options:

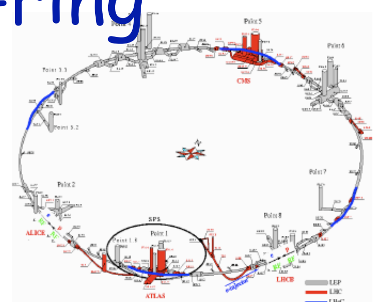
SPL ... or a recirculating Linac

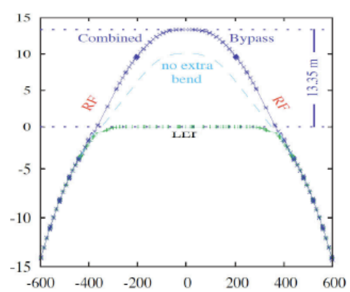


© H.Burkhard, B.Holzer

Electron Beam in IR 1 & 5

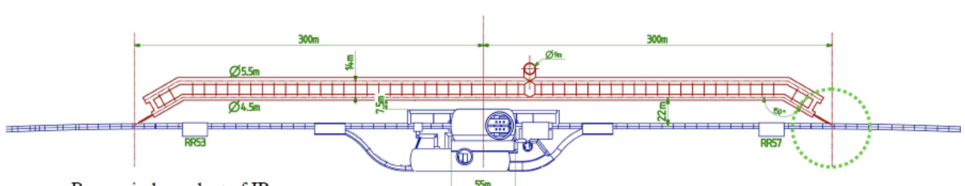
Ring-ring





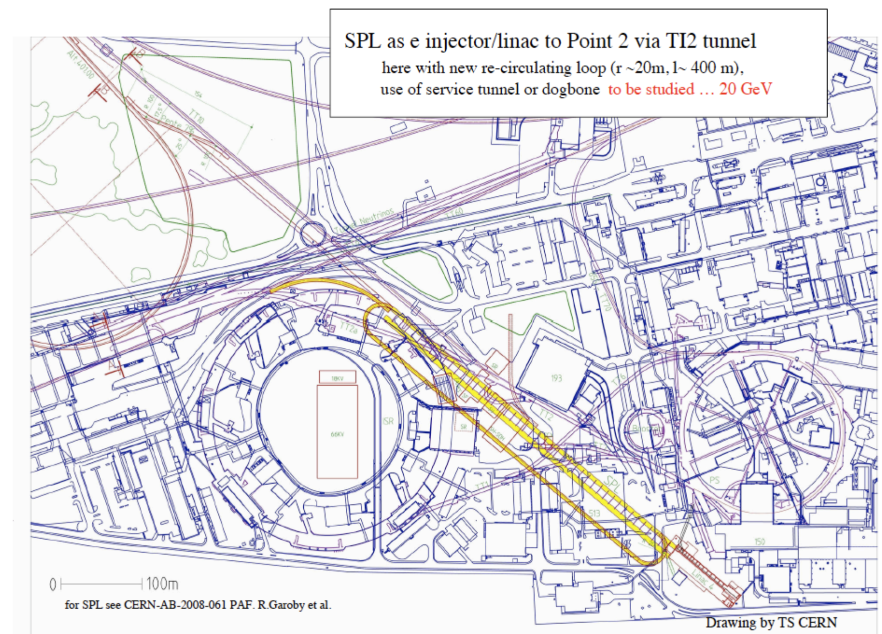
geometrical layout of the bypass sections

Helmut Burkhardt



Bypass independent of IR
~30m distance, 1 shaft

S.Myers, J.Osborne



eRHIC timeline

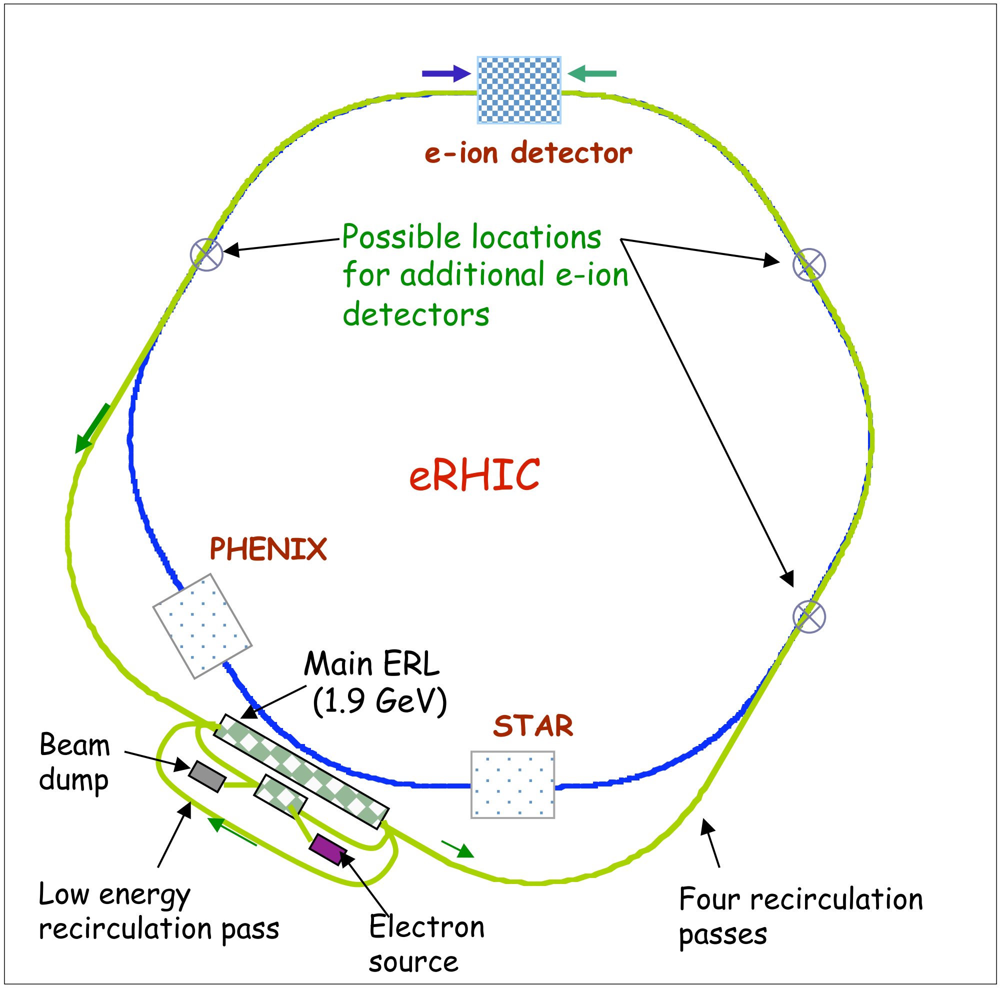
BNL & MIT

- *Add 10 GeV electron machine* to RHIC with 250 GeV polarized protons and 100 GeV/n ions
- Luminosity is based on hadron beam parameters demonstrated in RHIC complex
- First paper and workshop on eRHIC – 1999
- **"eRHIC Zeroth-Order Design Report" and cost estimate**, BNL 2004
  - Ring-ring (e-ring designed by MIT) was the main option, $L \sim 10^{32}$
  - 70+ page appendix on Linac (ERL) – Ring as back-up, $L \sim 10^{33}$
- 2007 – after detailed studies we found that linac-ring has 5-10 fold higher luminosity – it became the main option
- eA group made a case that 20 (or even 30 GeV) electrons are needed
- March 2008 – first staging option of eRHIC of all-in-the tunnel ERL with 2(4) GeV as the first stage, with 10 GeV and 20 GeV as next steps
  - there is potential for increase of RHIC energy to 800 GeV if physics justifies the cost
- 2009 – we plan to release first release of **Design Report** on MeRHIC (Medium energy eRHIC)

Staging of eRHIC: Re-use, Beams and Energetics

- **MeRHIC**: Medium Energy electron-Ion Collider
  - 90% of ERL hardware will be use for full energy eRHIC
  - Possible use of the detector in eRHIC operation
- **eRHIC – High energy and luminosity phase**
  - **Based on present RHIC beam intensities**
  - With coherent electron cooling requirements on the electron beam current is 50 mA
  - 20 GeV, 50 mA electron beam losses 4 MW total for synchrotron radiation.
  - 30 GeV, 10 mA electron beam loses 4 MW for synchrotron radiation
  - Power density is <2 kW/meter and is well within B-factory limits (8 kW/m)
- **eRHIC upgrade(s)**
  - **High luminosity, low energy requires crab cavities, new injections, Cu-coating of RHIC vacuum chambers, new level of intensities in RHIC**
    - Polarized electron source current of 400 mA at10 GeV, losses 2 MW total for synchrotron radiation, power density is 1 kW/meter
  - **High energy option requires replacing one of RHIC ring with 8 T magnets**

ERL-based eRHIC Design



- 10 GeV electron design energy. Possible upgrade to 20 GeV by doubling main linac length.
- 5 recirculation passes (4 of them in the RHIC tunnel)
- Multiple electron-hadron interaction points (IPs) and detectors;
- Full polarization transparency at all energies for the electron beam;
- Ability to take full advantage of transverse cooling of the hadron beams;
- Possible options to include polarized positrons: compact storage ring; compton backscattered; undulator-based. Though at lower luminosity.