The Electron-Ion Collider at BNL

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Center for Accelerator Science and Education

Talk on ELIC is at 18:45 today

Hence, this talk is focused on eRHIC

Proposed Electron Ion Colliders

BNL & MIT

- *Add 10-20 GeV electron machine* to RHIC with 250 GeV polarized protons and 100 GeV/n ions
- Luminosity $L \sim 10^{33}$ - 10^{34} is based on hadron beam parameters demonstrated in RHIC
- First eRHIC paper/workshop – 1999
- **"eRHIC Zeroth-Order Design Report" and cost estimate**, BNL 2004
- 2007 – after detailed studies we found that linac-ring has 5-10 fold higher luminosity – it became the main option
- March 2008 – first staging option of eRHIC

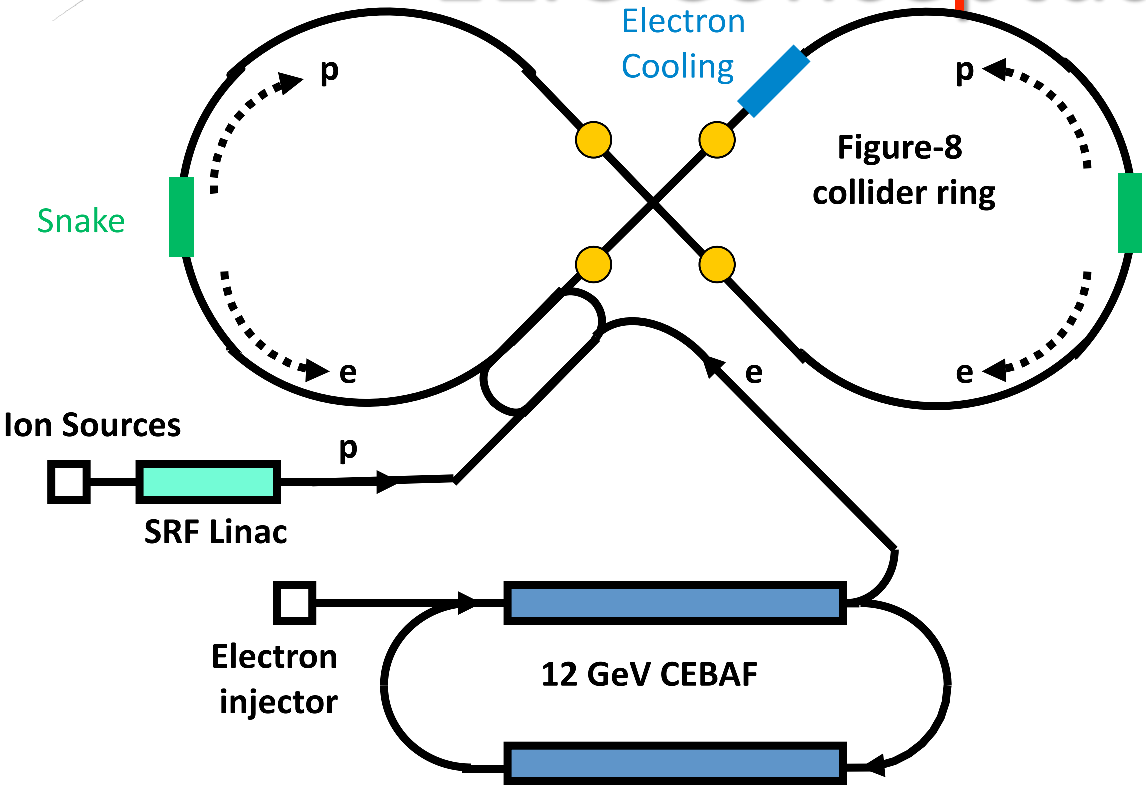
TJNAF

- ELIC - Electron-Light-Ion Collider – *new electron and hadron accelerators* taking advantage of CEBAF as injector. Energy range (and species) evolved from 7 x 65 GeV to 10 x 250 GeV
- Started later than eRHIC and aimed from the beginning at $L \sim 10^{35}$
- **"ELIC Zeroth-Order Design Report"**, TJNAF, 2008
- **Cost Estimate** – February 2009
- December 2008, Staging option for ELIC

At this Work

eRHIC	ELIC
• "Proton polarization dynamics in RHIC", Mei BAI, tomorrow, Friday, 29 May 2009, 09:00	• "The ELIC conceptual design" Yuhong ZHANG, today, Thursday, 28 May 2009, 18:45
• "ERL and polarised gun for eRHIC", Ilan BEN-ZVI, tomorrow, Friday, 29 May 2009, 11:00	• "Simulations of beam-beam-effects in ELIC", Yuhong ZHANG, tomorrow, Friday, 29 May 2009, 11:45
• "Beam-Beam-effect in eRHIC", Vadim PTITSYN, tomorrow, Friday, 29 May 2009, 12:15	• "Interaction region at ELIC", Saturday, 30 May 2009, Rolf ENT, 10:30
• "Interaction region and lattice of eRHIC", Dejan TRBOJEVIC, 30 May 2009, Rolf ENT, 10:00	

ELIC Conceptual Design

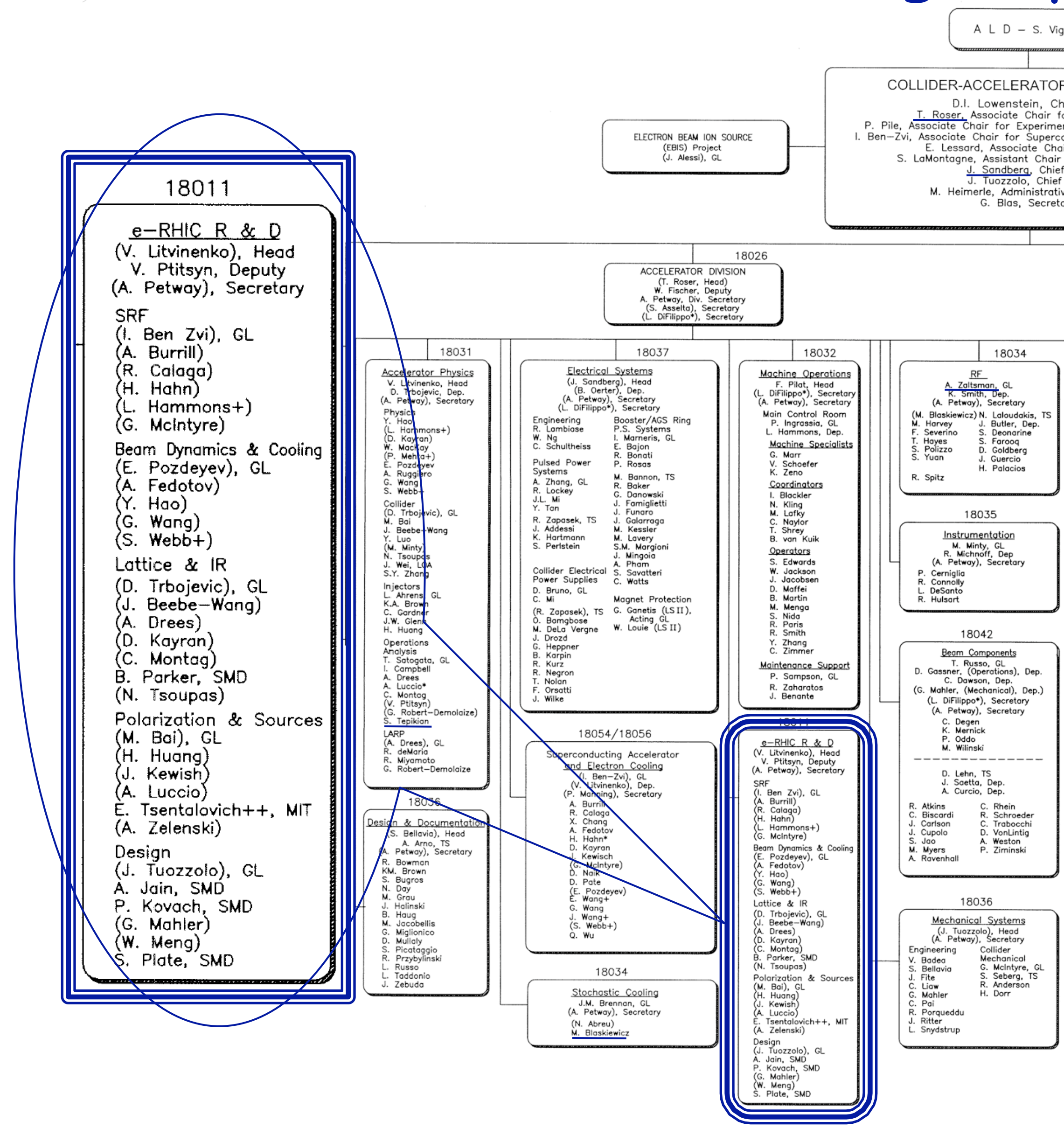


- **Yuhong ZHANG**
- **<u>Today</u>**
- **Thursday, 28 May**
- **18:45**

Stage		Maximum Energy (GeV/c)		Ring Size (M)		Ring Type	
		Per ion	Electron	Ion	Electron	Ion	Electron
1	Low Energy	5	5	400	400	Warm	Warm
2	Medium Energy	30	5	400	400	Superconducting	Warm
3	Medium Energy	30	10	400	1800	Superconducting	Warm
4	High Energy	250	10	1800	1800	Superconducting	Warm

Slide is the Courtesy of G. Krafft

eRHIC R&D group at C-AD, BNL



Inputs on Physics

E.-C. Aschenauer, A. Deshpande, R. Ent,

T. Horn, M. Lamont, T.W. Ludlam, R. Milner,

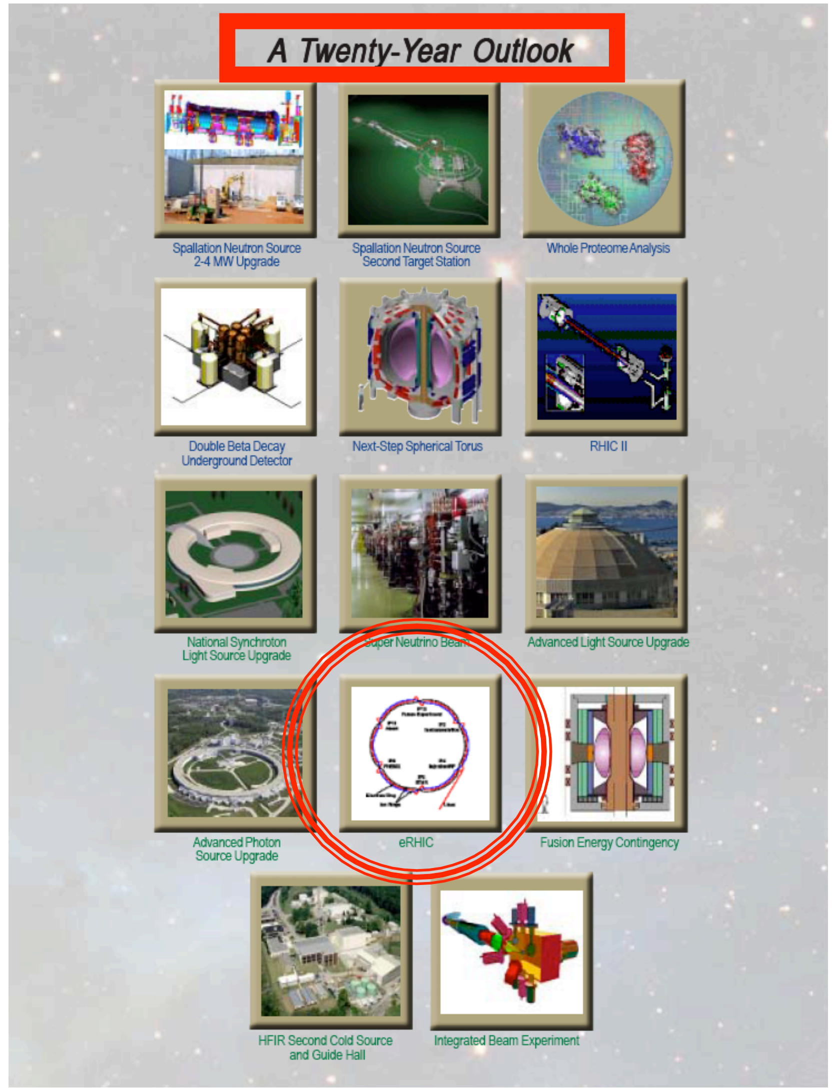
B. Surrow, T. Ulrich, S.Vigdor,

Raju Venugopalan, Werner Vogelsang, …..

Content

- Preamble
- eRHIC
- eRHIC staging and MeRHIC
- Conclusion

eRHIC in 2003 DoE's 20-year Outlook



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)

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Goals for eRHIC

RHIC

ZDR March 11, 2004

Physics Requirements

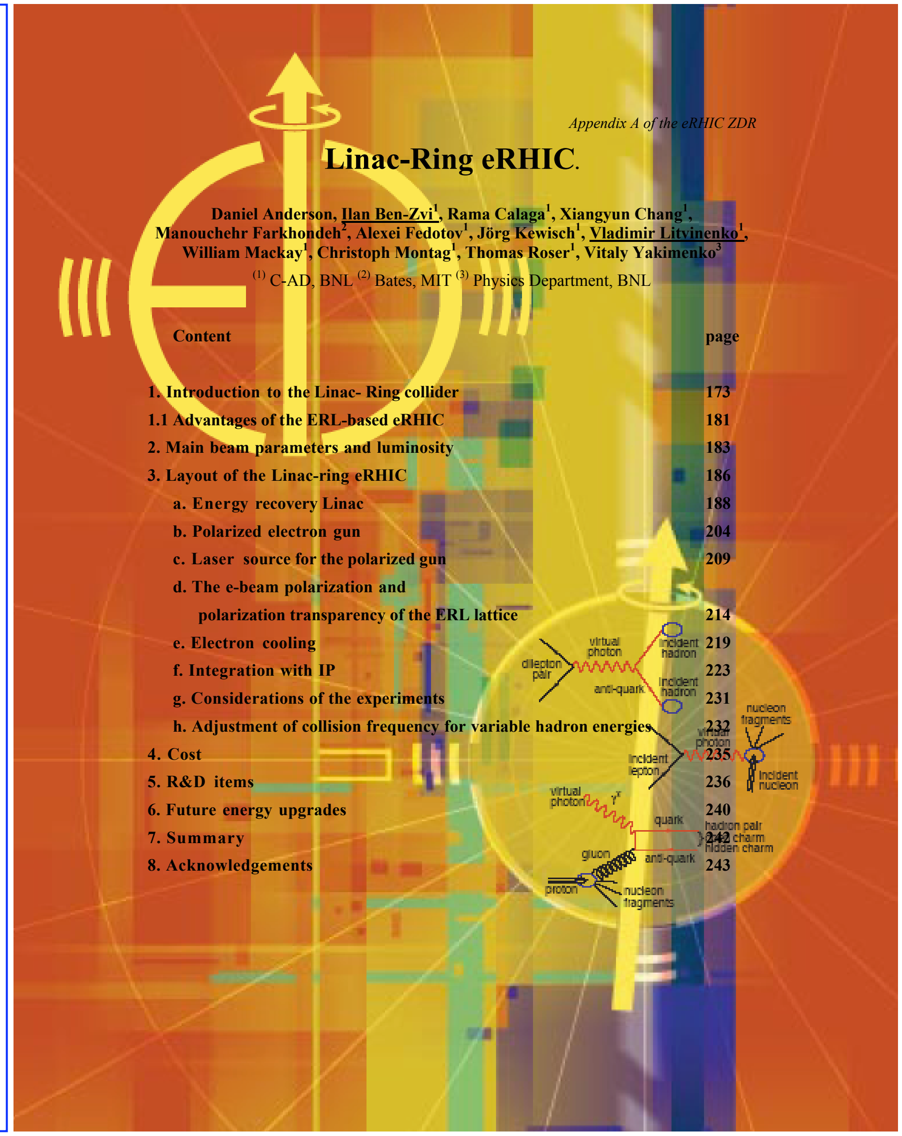
- To provide electron-proton and electron-ion collisions
- Energy ranges:
  - 2-10 GeV polarized e^- or 10 GeV polarized e^+
  - 26-250 GeV polarized protons or 100 GeV/u Au
- Luminosities:
  - $> 10^{33}$ $cm^{-2}s^{-1}$ region for e-p
  - $> 10^{31}$ $cm^{-2}s^{-1}$ region for e-Au
- >70% polarization degree for both lepton and proton beams
- Longitudinal polarization in the collision point

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, T. Roser, A. Ruggiero, B. Surrow, S. Tepikian, D. Trbojevic, V. Yakimenko, S.Y. Zhang
MIT-Bates: 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, Yu.M. Shatunov
DESY: D.P. Barber

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

http://www.agsrhichome.bnl.gov/eRHIC/


Appendix A of the eRHIC ZDR

Linac-Ring eRHIC.

Daniel Anderson, Ilan Ben-Zvi[1], Rama Calaga[1], Xiangyun Chang[1], Manouchehr Farkhondeh[2], Alexei Fedotov[1], Jörg Kewisch[1], Vladimir Litvinenko[1], William Mackay[1], Christoph Montag[1], Thomas Roser[1], Vitaly Yakimenko[3]
(1) C-AD, BNL (2) Bates, MIT (3) Physics Department, BNL

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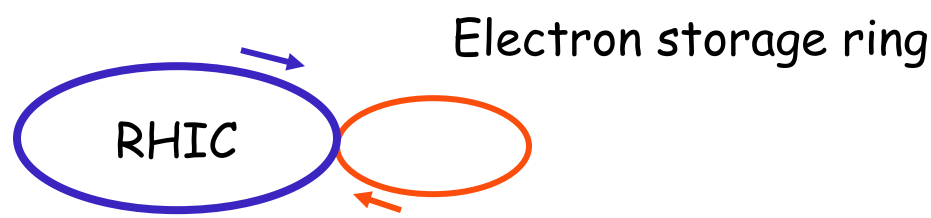
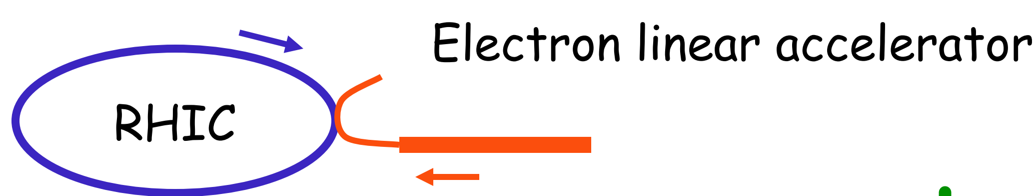
2007 Choosing the focus: ERL or ring for electrons?

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



  - Linac-ring:



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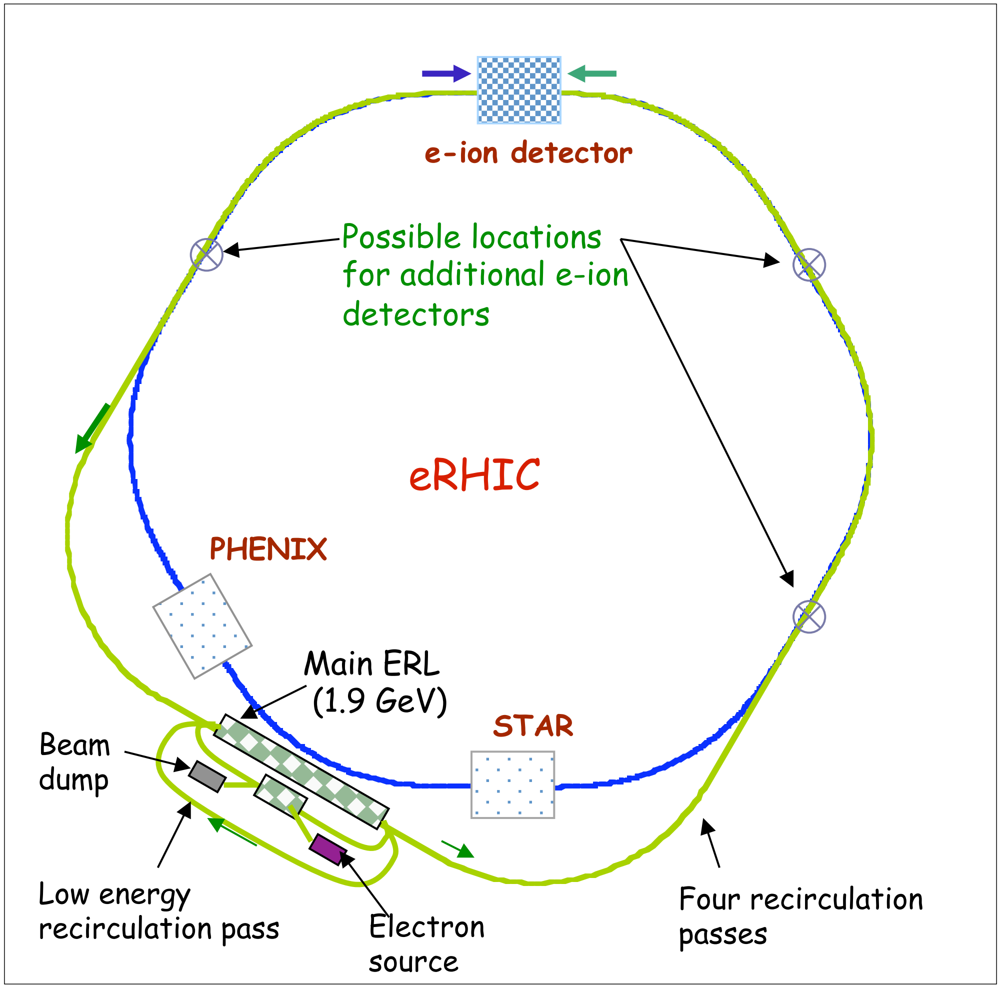
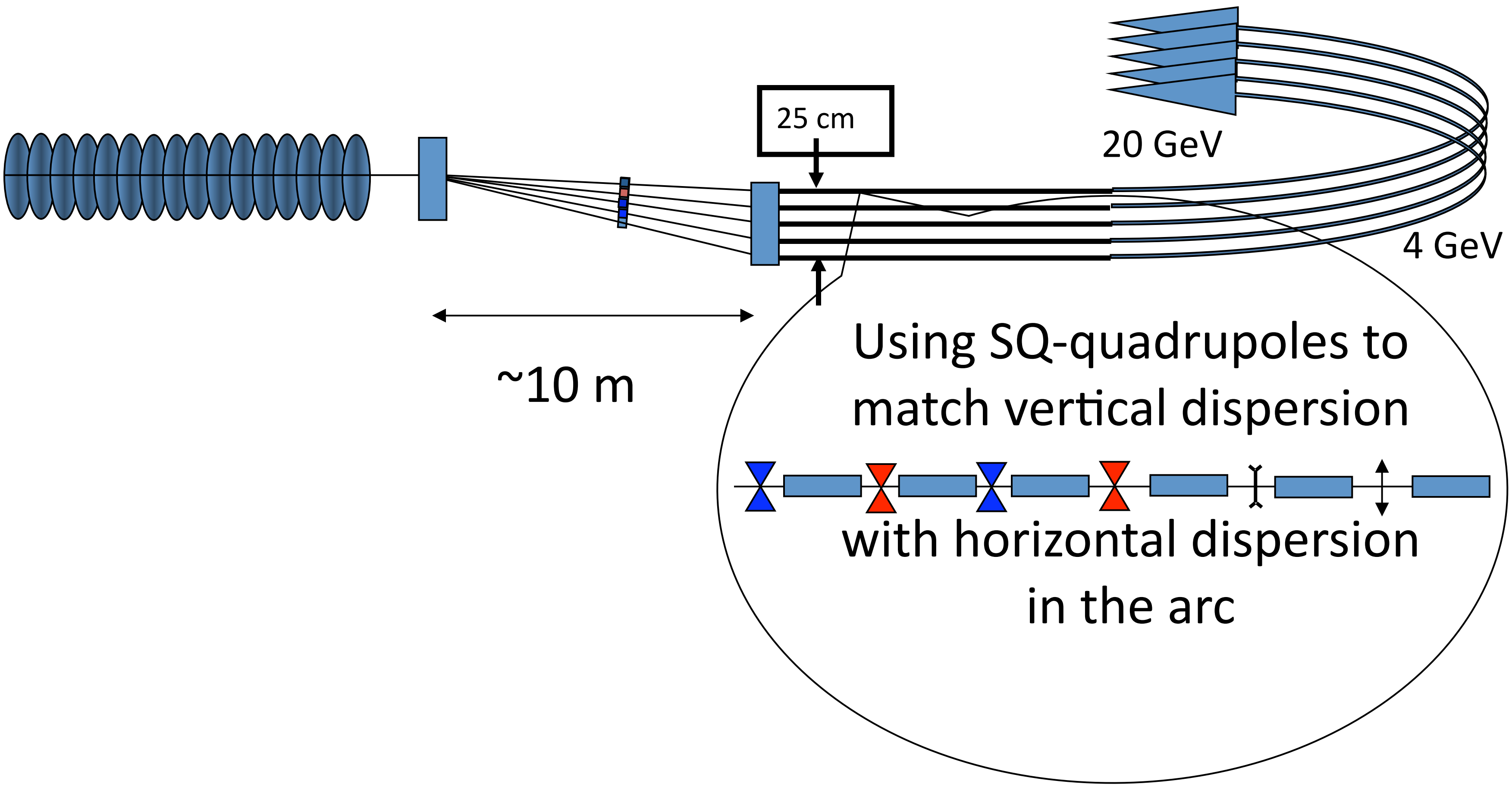
L x 10

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.

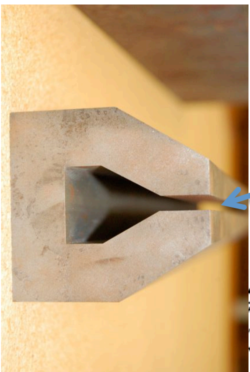
Compact spreaders/combiners



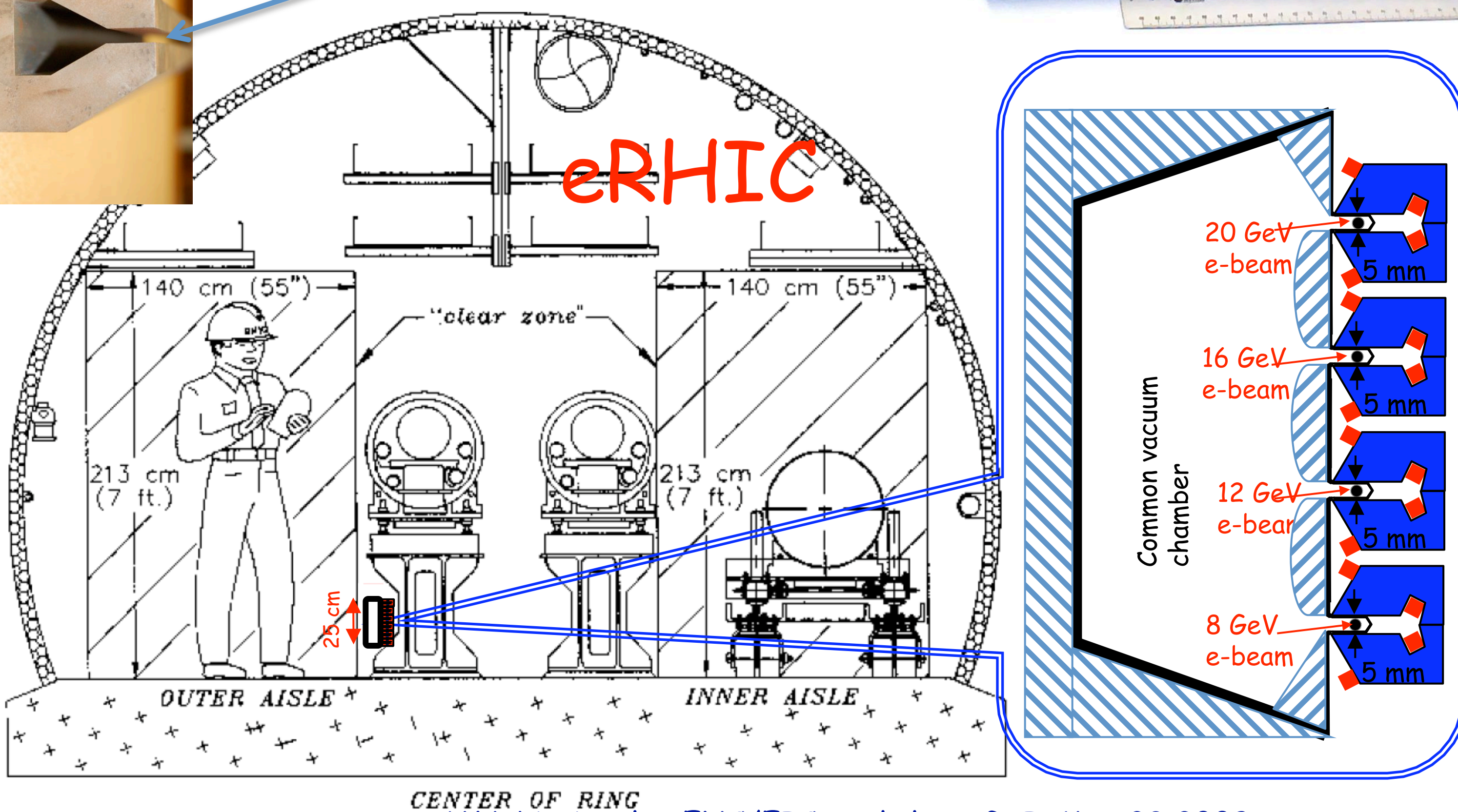
This concept allows to use most of the RHIC straight sections for SF linacs and to use part of the arcs for matching

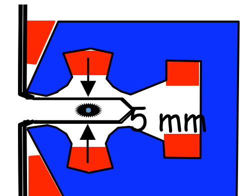
eRHIC loop magnets: LDRD project

- Small gap provides for low current, low power consumption magnets
  - -> **low cost eRHIC**
- Magnetic design - W.Meng, mechanical engineering - G.Mahler
- Beam dynamics – Y.Hao, J.Bengtsson

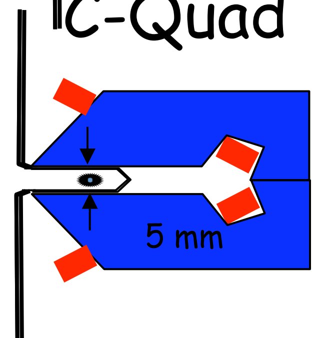


Gap 5 mm total
0.3 T for 30 GeV





C-Quad



C- Dipole

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ERL spin transparency at all energies

RHIC

Bargman, Mitchel,Telegdi equation

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

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

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

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

Total angle

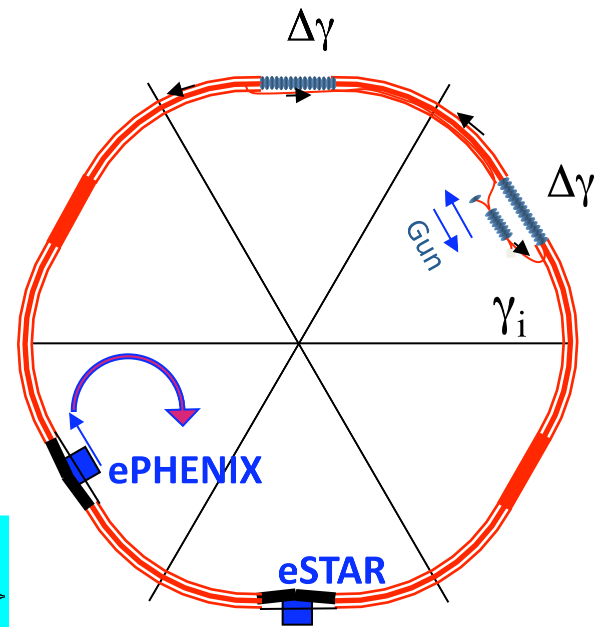
$$\varphi = 2\pi a\cdot\left((n-1/2)\gamma_i + \{2n(n-2)-1/6\}\Delta\gamma\right) + \varphi_i$$

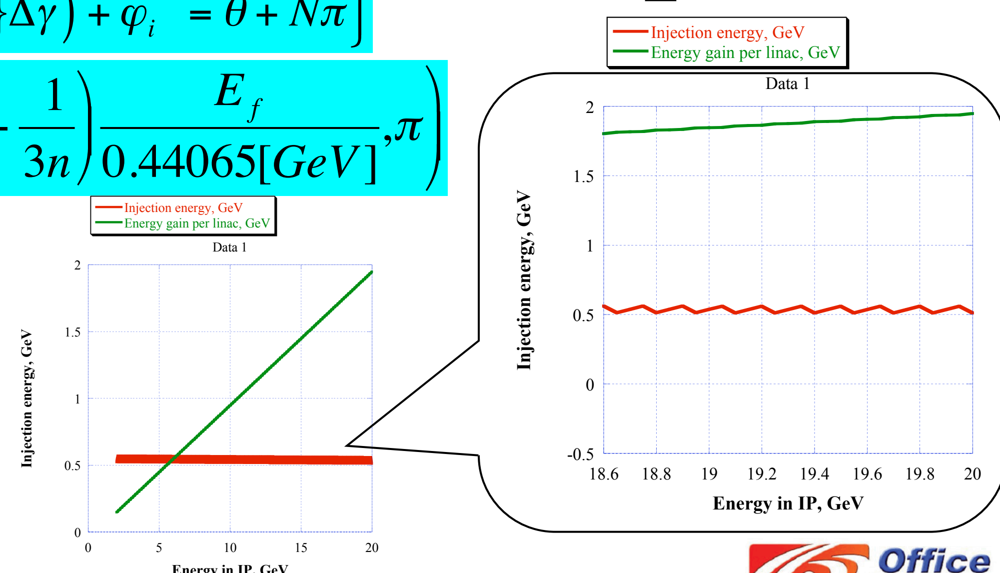
Has solution for all energies!

$$\begin{cases} \Delta\gamma = \left(\gamma_f - \gamma_i\right)/2n \\ 2\pi a\cdot\left((n-1/2)\gamma_i + \{n(n-2)-1/3\}\Delta\gamma\right) + \varphi_i = \theta + N\pi \end{cases}$$

$$E_i = \frac{0.44065[GeV]}{n+1+1/3n}\bmod\left(\varphi_f - \varphi_i - \left(n-2-\frac{1}{3n}\right)\frac{E_f}{0.44065[GeV]}, \pi\right)$$

$$\delta E_{i\,\max} = \pm 37 \;\; MeV \;\; \vee \; n = 5$$





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ERL-based eRHIC Parameters: e-p mode

	High energy setup		Low energy setup	
	p	e	p	e
Energy, GeV	250	10	50	3
Number of bunches	166		166	
Bunch spacing, ns	71	71	71	71
Bunch intensity, 10^{11}	2	1.2	2	1.2
Beam current, mA	420	260	420	260
Normalized 95% emittance, π mm.mrad	6	460	6	570
Rms emittance, nm	3.8	4	19	16.5
β^*, x/y, cm	26	25	26	30
Beam-beam parameters, x/y	0.015	0.59	0.015	0.47
Rms bunch length, cm	20	1	20	1
Polarization, %	70	80	70	80
Peak Luminosity, 1.e33 $cm^{-2}s^{-1}$	2.6		0.53	
Aver.Luminosity, 1.e33 $cm^{-2}s^{-1}$	0.87		0.18	
Luminosity integral /week, pb^{-1}	530		105	

Protons require cooling

ERL-based eRHIC Parameters: e-Au mode

	High energy setup		Low energy setup	
	Au	e	Au	e
Energy, GeV	100	10	50	3
Number of bunches	166		166	
Bunch spacing, ns	71	71	71	71
Bunch intensity, 10^{11}	1.1	1.2	1.1	1.2
Beam current, mA	180	260	180	260
Normalized 95% emittance, π mm.mrad	2.4	460	2.4	270
Rms emittance, nm	3.7	3.8	7.5	7.8
β*, x/y, cm	26	25	26	25
Beam-beam parameters, x/y	0.015	0.26	0.015	0.43
Rms bunch length, cm	20	1	20	1
Polarization, %	0	0	0	0
Peak e-nucleon luminosity, 1.e33 $cm^{-2}s^{-1}$	2.9		1.5	
Average e-nucleon luminosity, 1.e33 $cm^{-2}s^{-1}$	1.0		0.5	
Luminosity integral /week, pb^{-1}	580		290	

RHIC
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eRHIC Scope -QCD Factory

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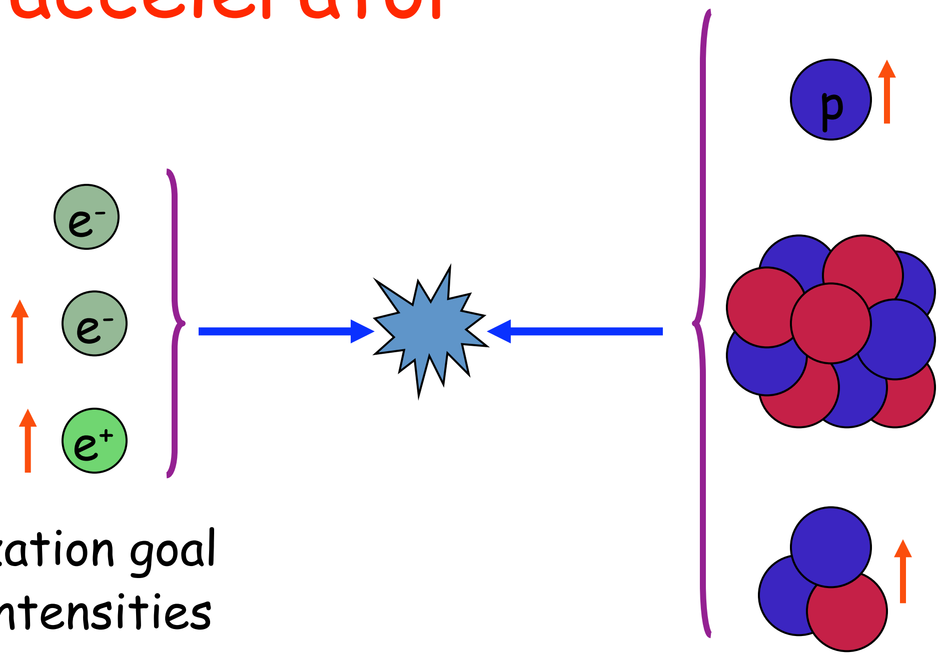
RHIC

Electron accelerator

RHIC

Unpolarized and polarized leptons 4-20 (30) GeV



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

70% beam polarization goal
Positrons at low intensities

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.
20 GeV is absolutely essential and 30 GeV is strongly desirable.

Staging of eRHIC: Energy Reach and Luminosity

- **MEIC**: Medium Energy Electron-Ion Collider
  - 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}
  - *2 GeV option was moved into a back-up*
- **eRHIC, High energy and luminosity phase,** inside RHIC tunnel

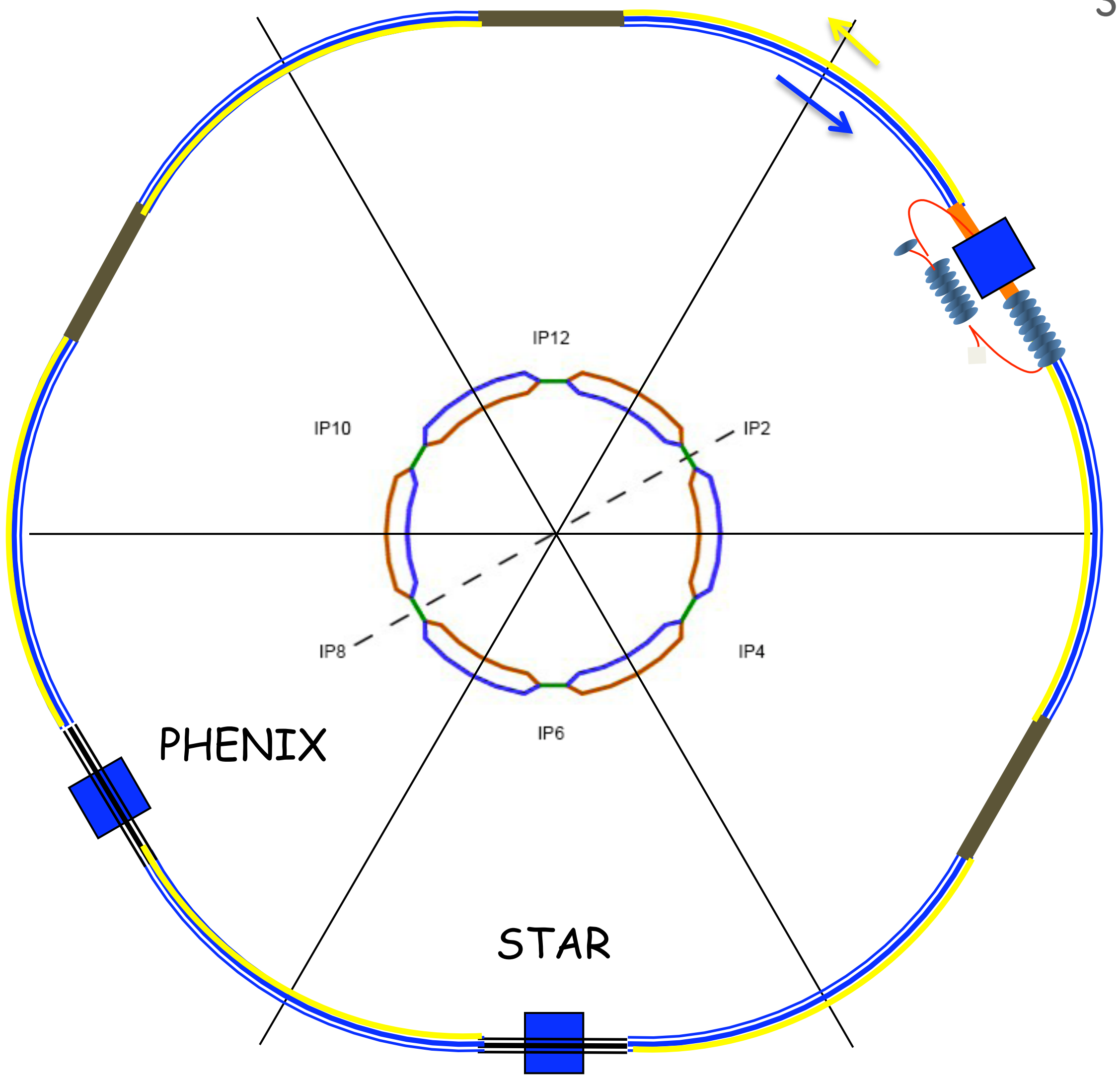
  Full energy, nominal luminosity
  - Polarized 20 GeV e^- x 325 GeV p (160 GeV c.m), L ~ 10^{33}-10^{34} cm^{-2} sec^{-1}
  - 30 GeV e x 120 GeV/n Au (120 GeV c.m.), ~1/5 of full luminosity
  - and 20 GeV e x 120 GeV/n Au (120 GeV c.m.), full liminosity
- **eRHIC up-grades – if needed,** inside RHIC tunnel

  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}

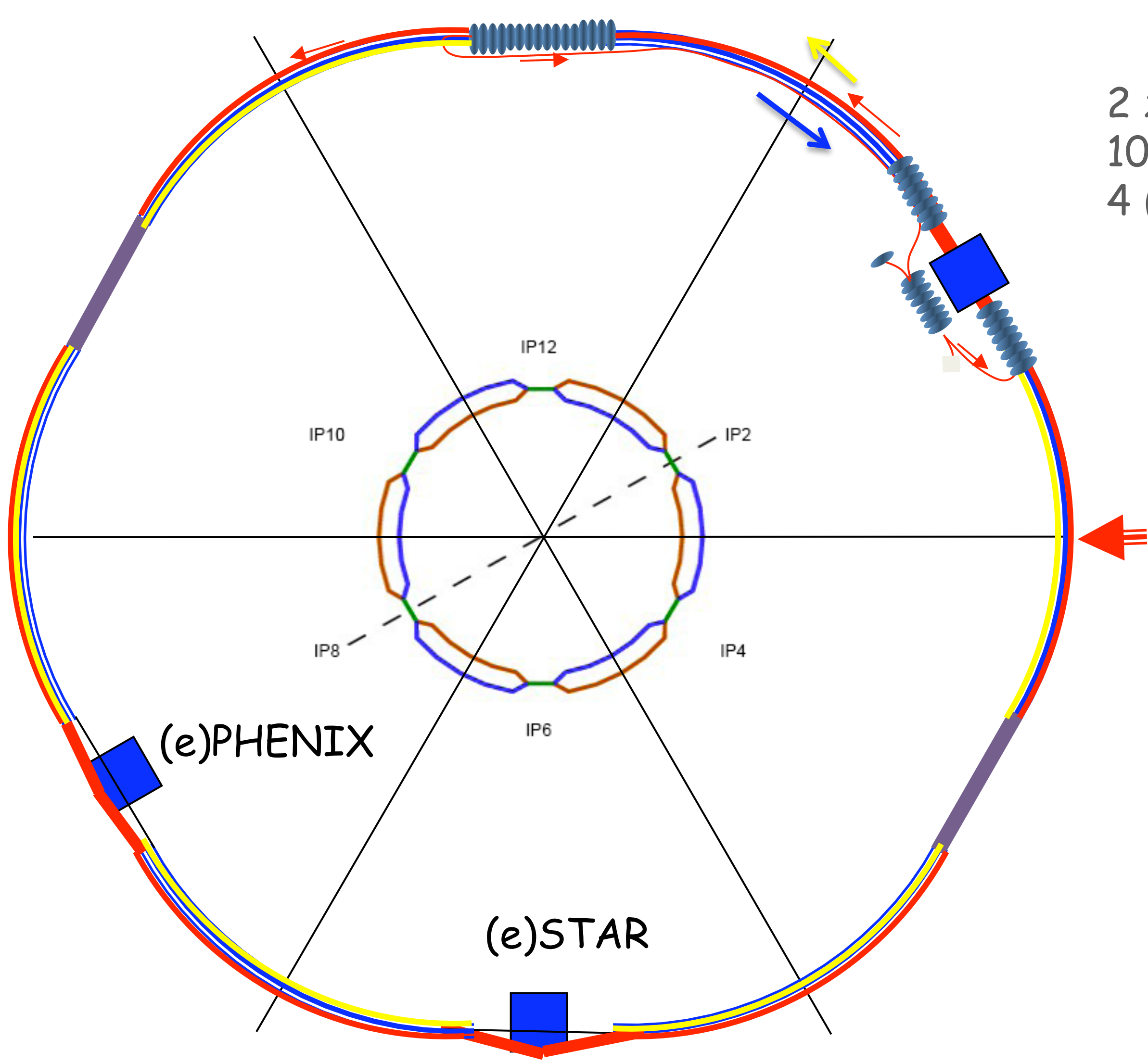
4 GeV e x 250 GeV p MeRHIC
with ERL inside RHIC tunnel

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



5 (6) vertically separated passes

20 (10 & 30) GeV e x 325 GeV p eRHIC with ERL inside RHIC tunnel



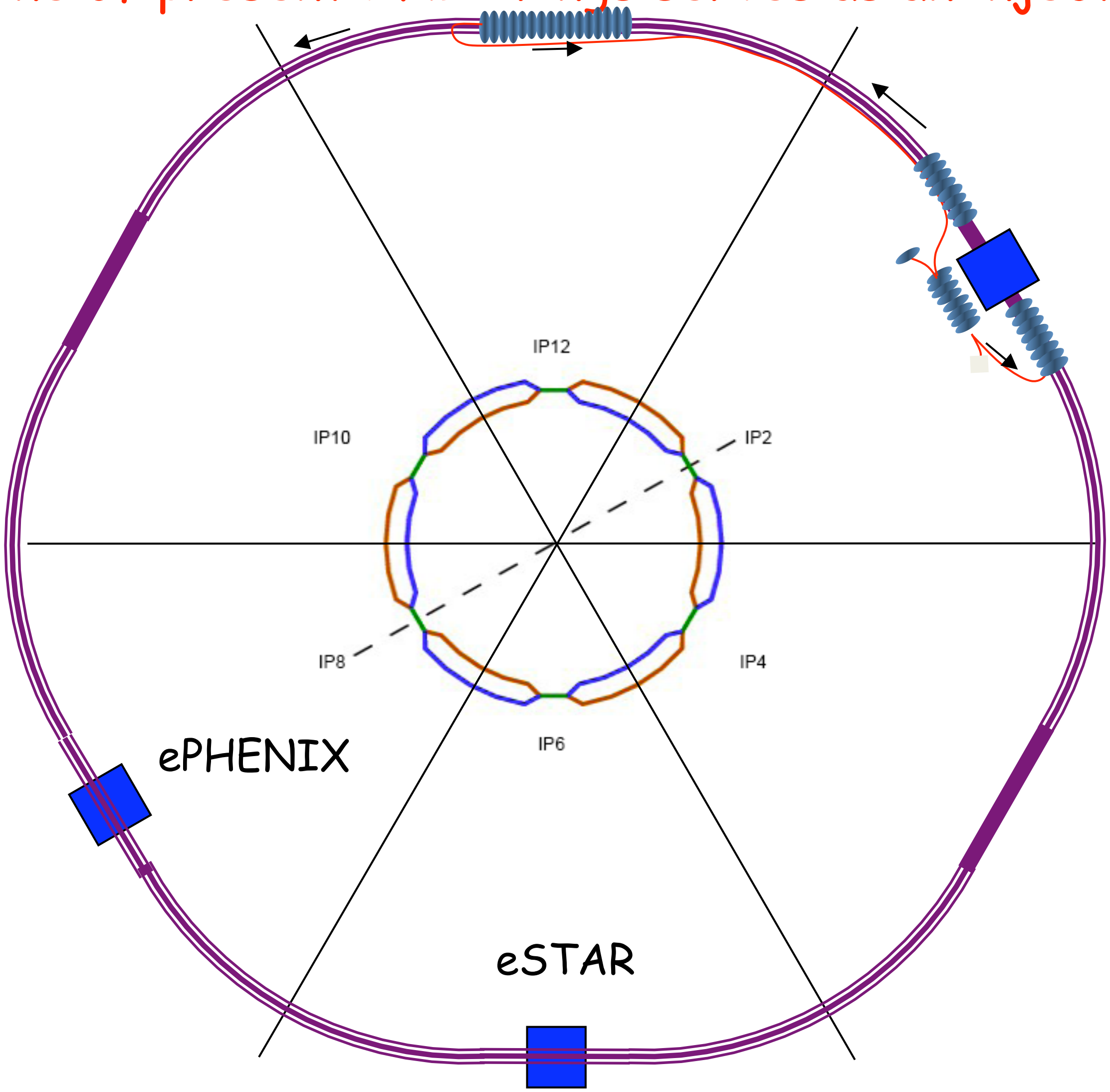
2 x 200 m SRF linac
10 (12.5) MeV/m
4 (5) GeV per pass

5 (6) vertically separated passes

20 (10 & 30) GeV e x 800 GeV p eRHIC

with ERL inside RHIC tunnel

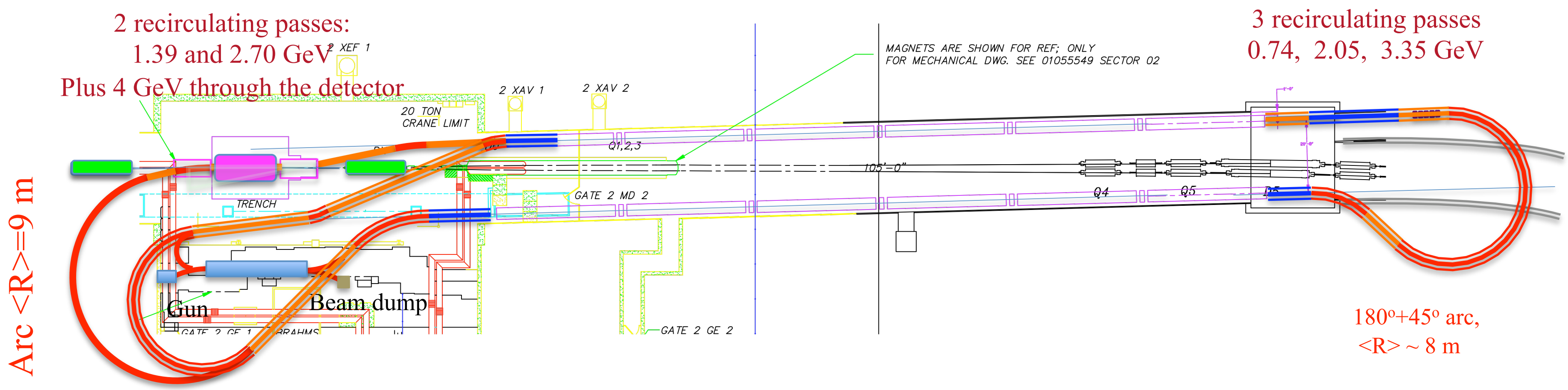
One of present RHIC rings serves as an injector



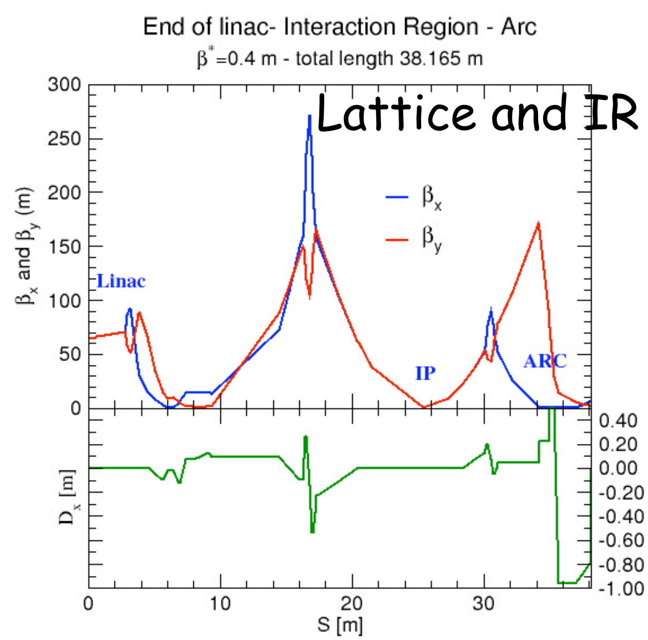
2 x 200 m SRF linac
10 (12.5) MeV/m
4 (5) GeV per pass

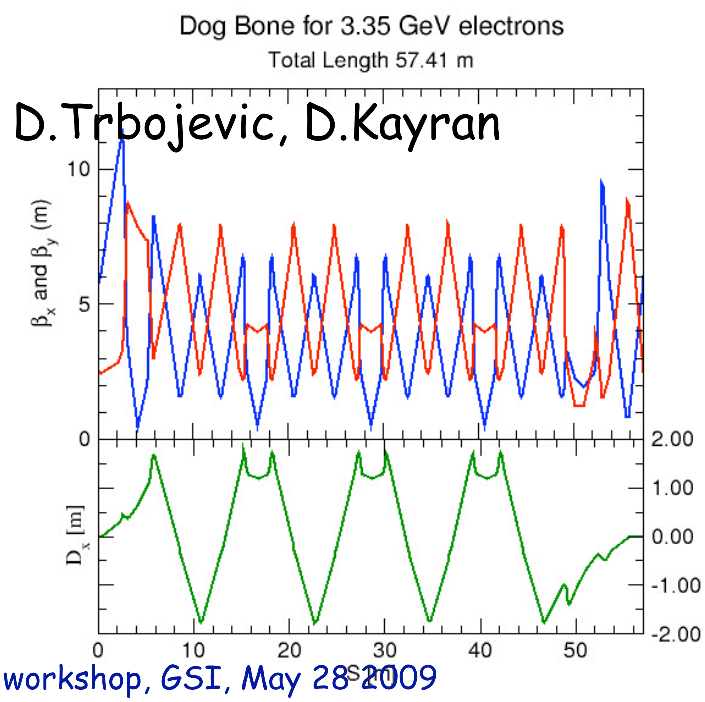
5 (6) vertically separated passes

MeRHIC at 2 o'clock IR at RHIC (Dec 08)



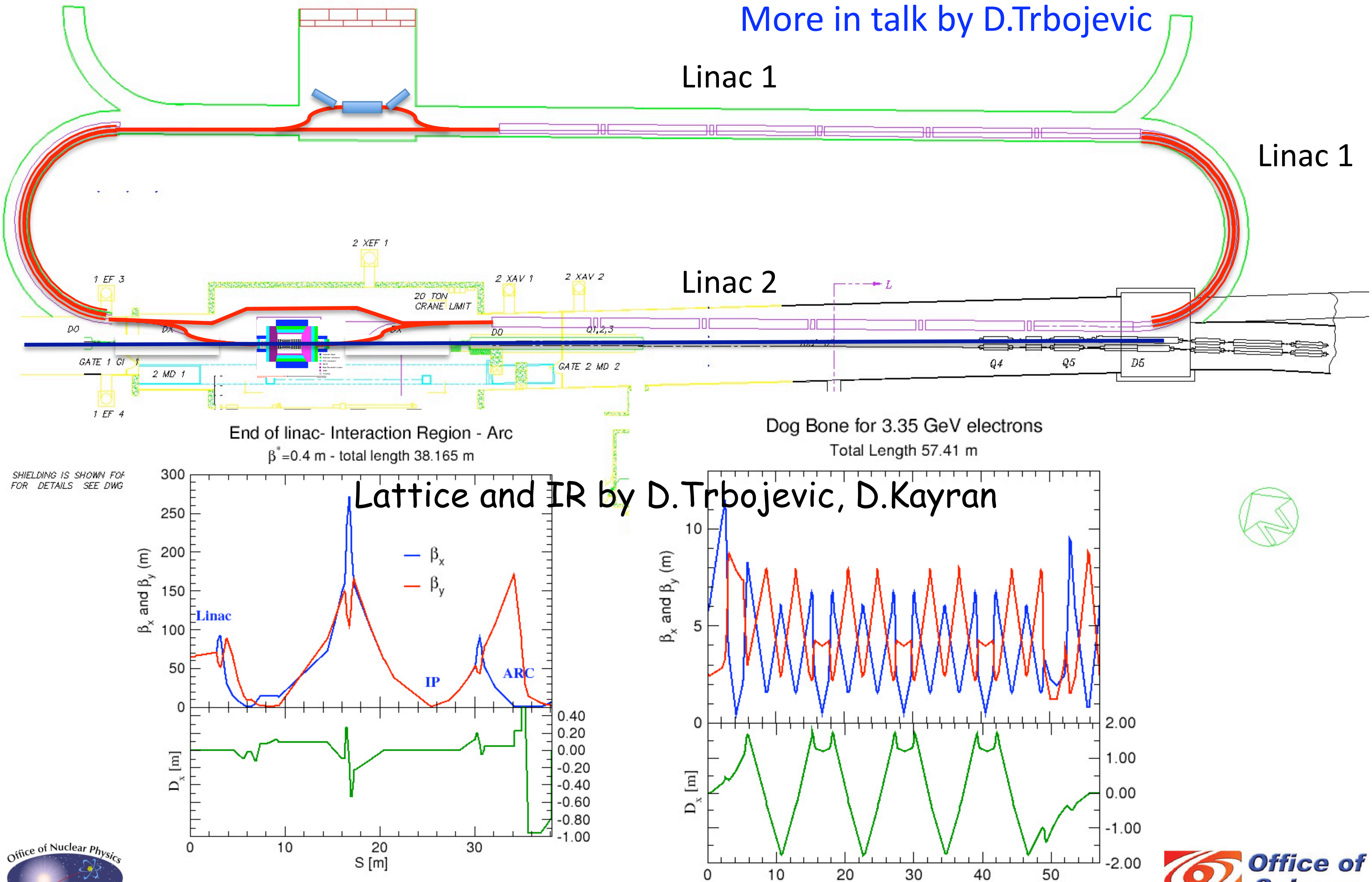
Lattice and IR by D.Trbojevic, D.Kayran





MeRHIC at 2 o'clock IR at RHIC

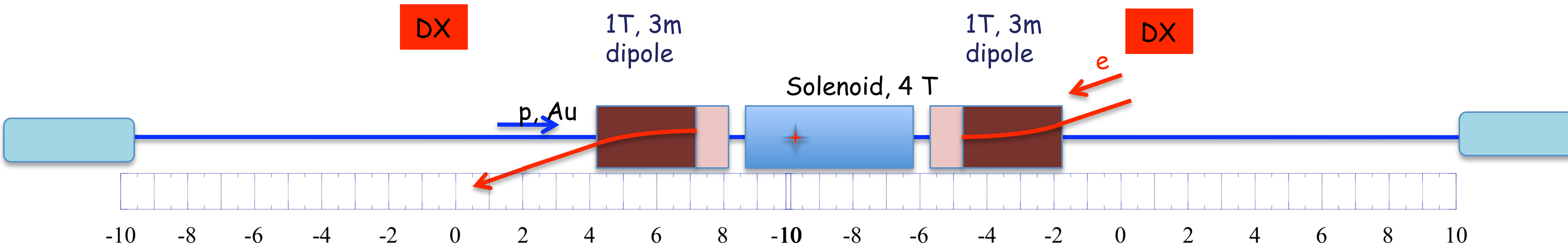
More in talk by D.Trbojevic



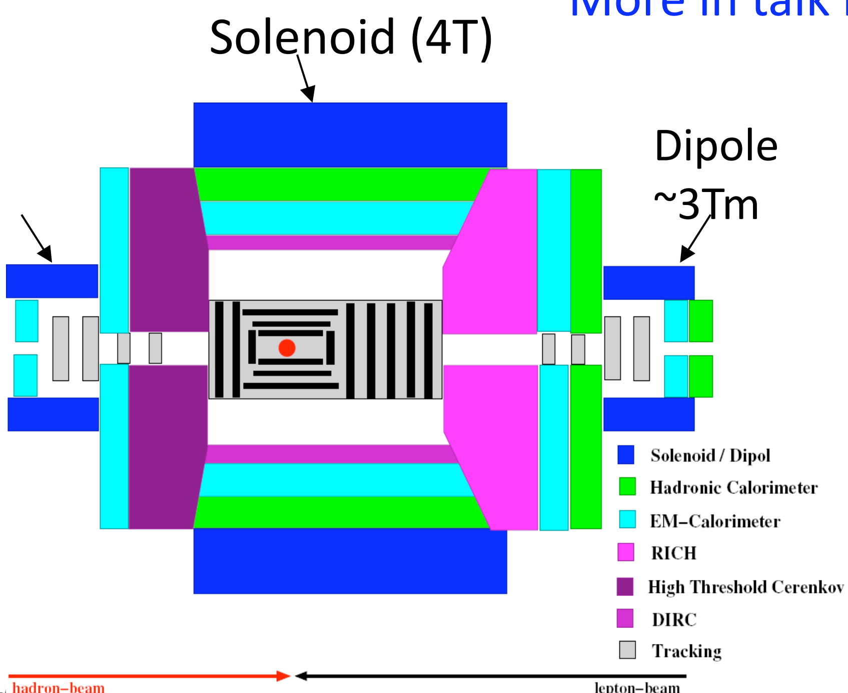
Detector field layout

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

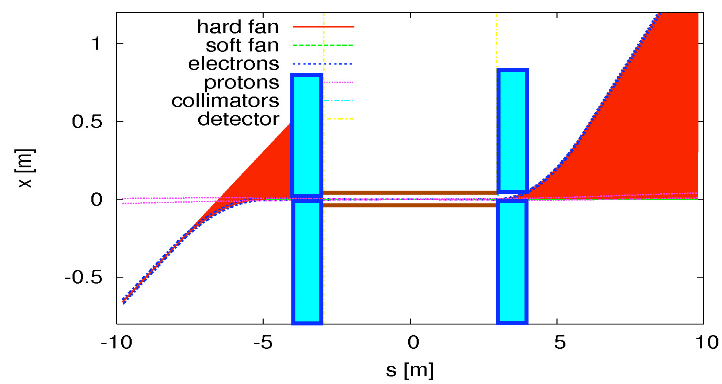
Remove Dxes – 40 m to detect particles scattered at small angles



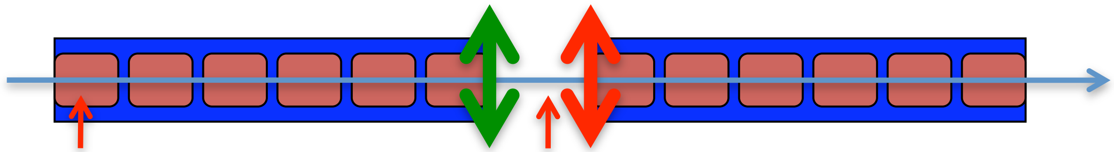
More in talk by D.Trbojevic



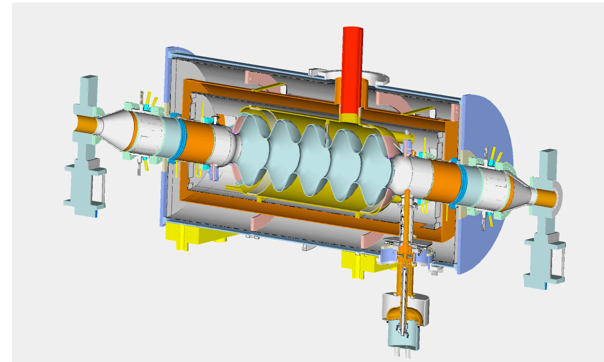
To provide effective SR protection:
-soft bend (~0.05T) is used for final bending of electron beam



MeRHIC Linac Design



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

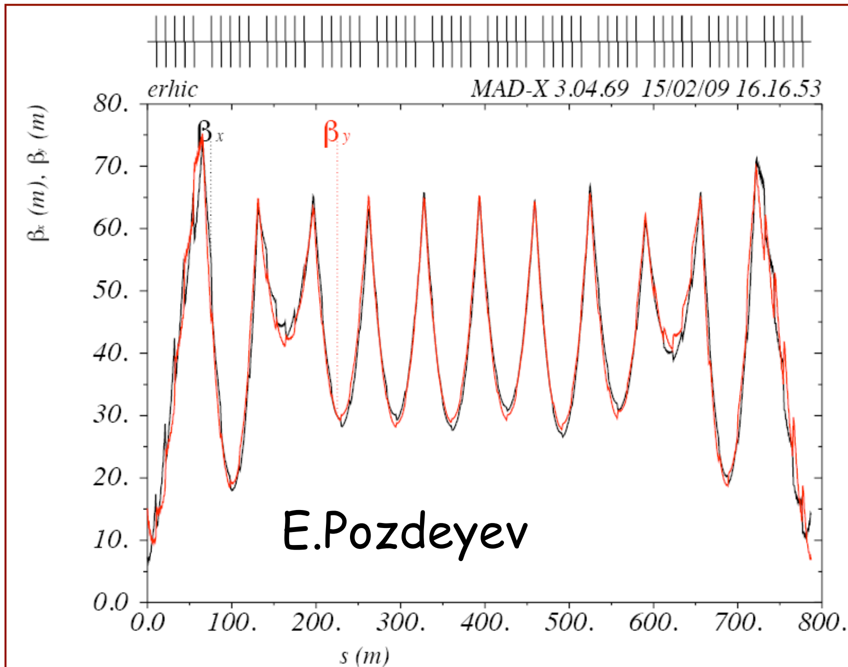


Based on revolutionary BNL SRF cavity with fully suppressed HOMs – reached design parameters last week
Critical for high current multi-pass ERL

100 MeV → 4 GeV → 100 MeV

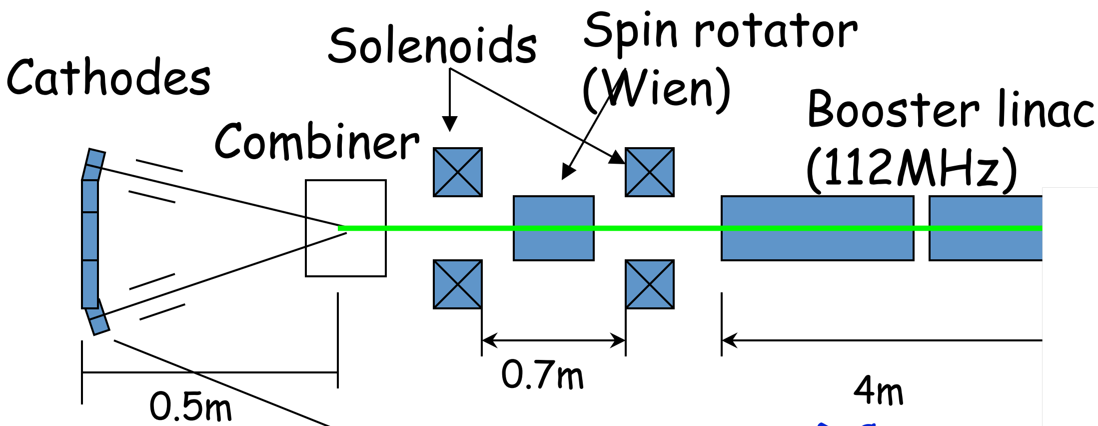
Current breakdown of the linac

- 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



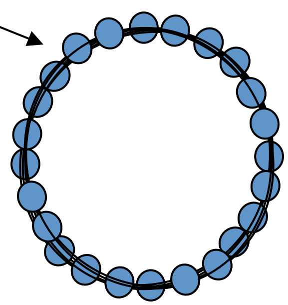
Main technical challenge: 50 mA CW polarized gun: we are building it

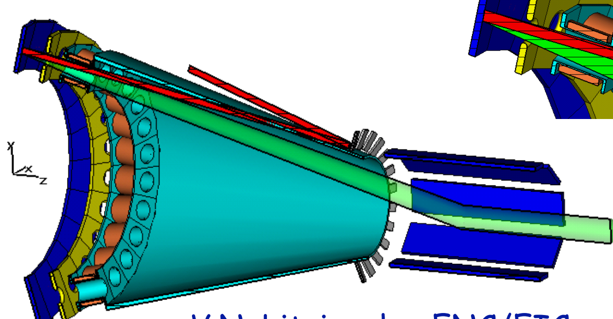
More in talk by I. Ben Zvi

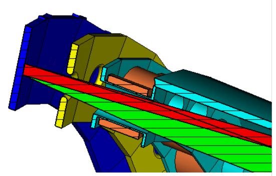


DC gun with 24 cathodes

Based on demonstrated current technology developed at JLab

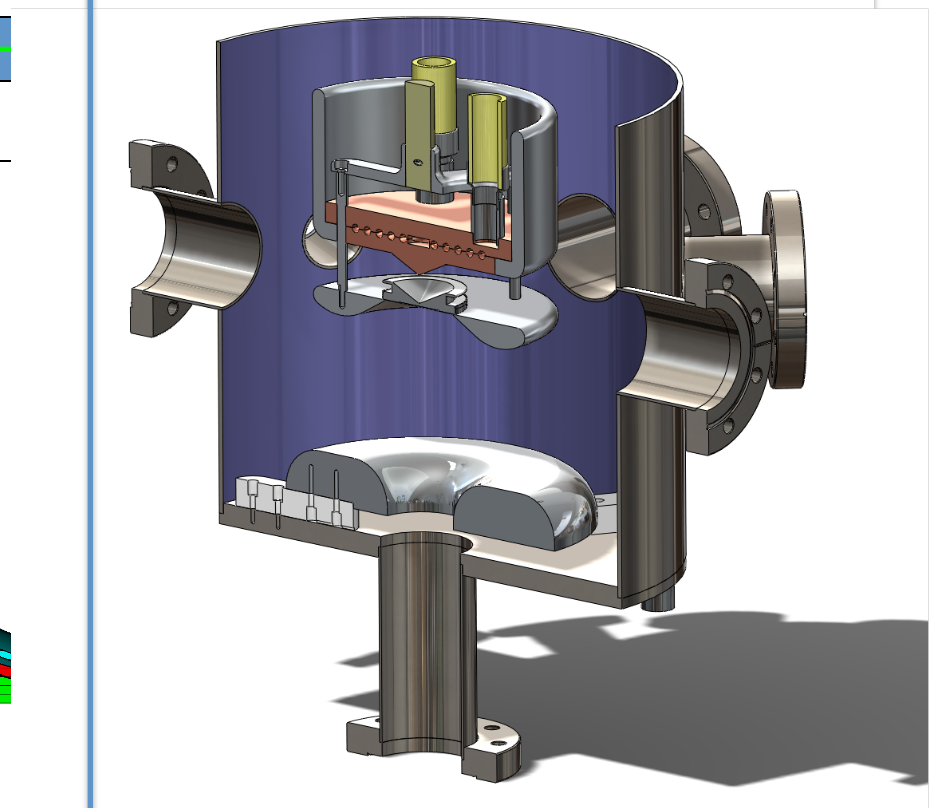




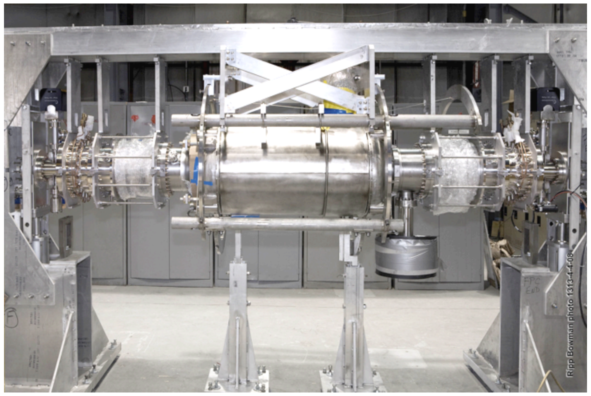


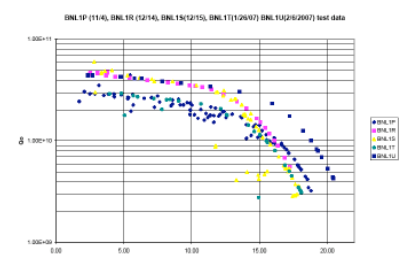
Single cathode DC gun

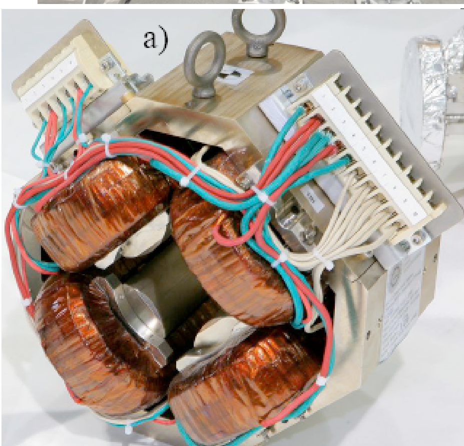
E.Tsentalovich, MIT

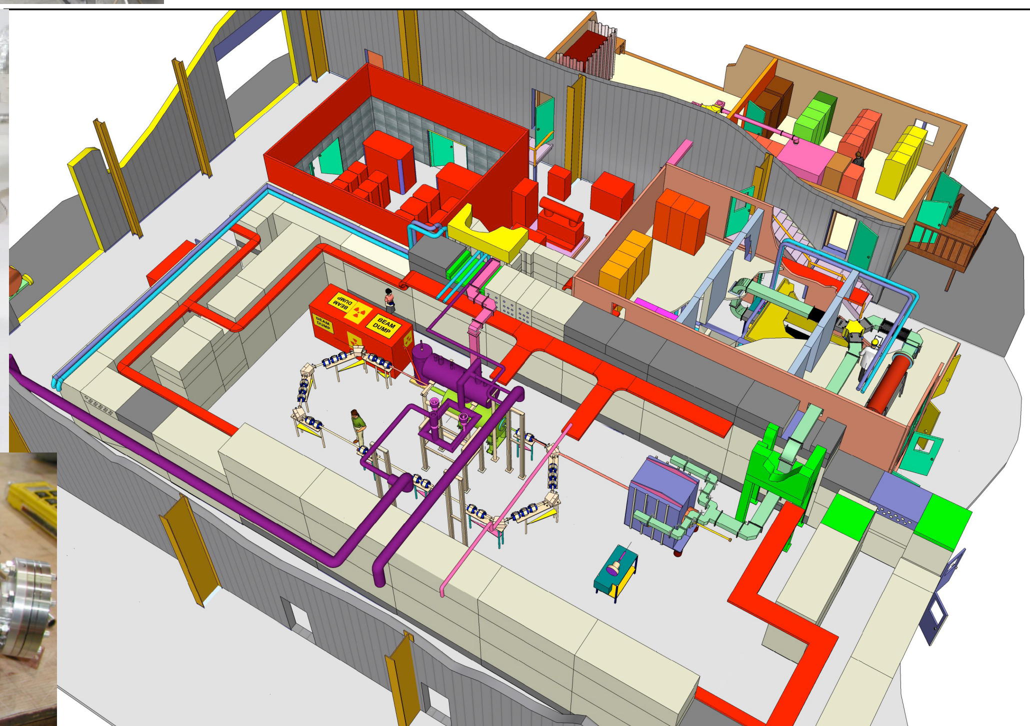


R&D ERL Commissioning start 2009





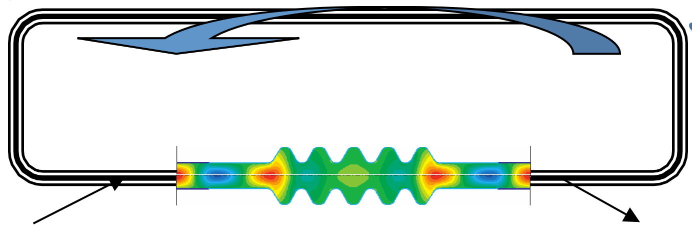




More in talk by I. Ben Zvi

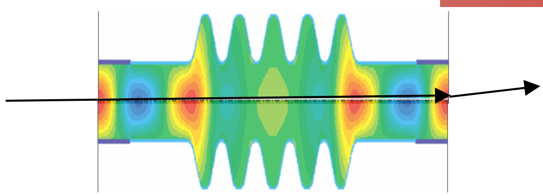
TBBU stability (©E. Pozdeyev)

- 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

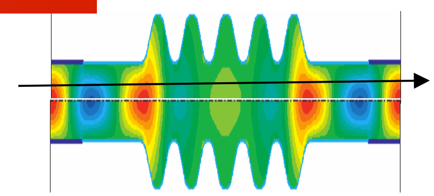


Simulated BBU threshold (GBBU) vs. HOM frequency spread. Beam current 50 mA

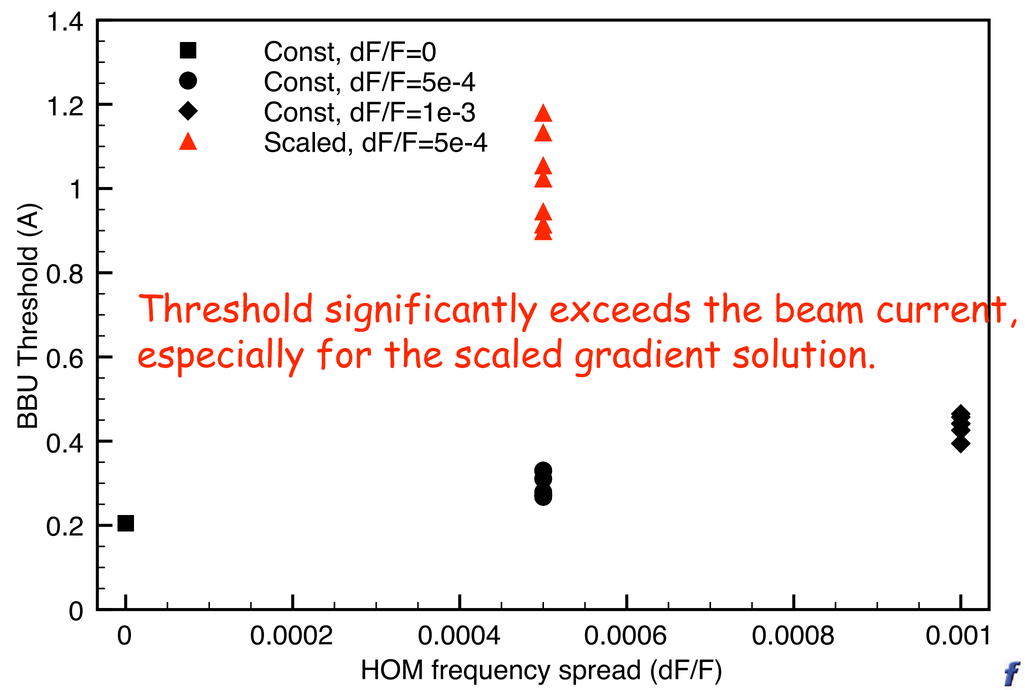
Excitation process of transverse HOM



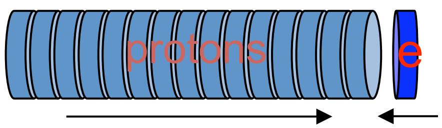
$$\begin{bmatrix} \boldsymbol{x} \\ x' \end{bmatrix}_{return} = \begin{bmatrix} m11 & \boldsymbol{m12} \\ m21 & m22 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ \boldsymbol{x'} \end{bmatrix}_{comming}$$

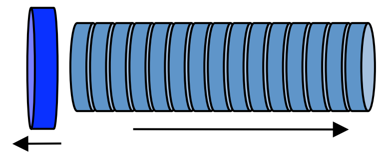


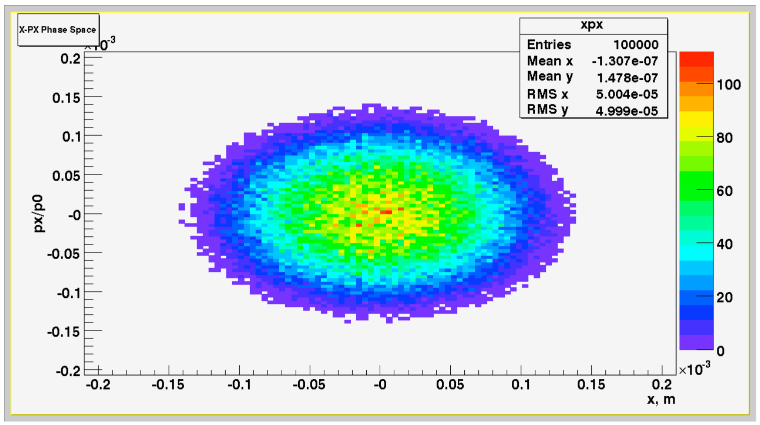
F (GHz)	R/Q (Ω)	Q	(R/Q)Q
0.8892	57.2	600	3.4e4
0.8916	57.2	750	4.3e4
1.7773	3.4	7084	2.4e4
1.7774	3.4	7167	2.4e4
1.7827	1.7	9899	1.7e4
1.7828	1.7	8967	1.5e4
1.7847	5.1	4200	2.1e4
1.7848	5.1	4200	2.1e4



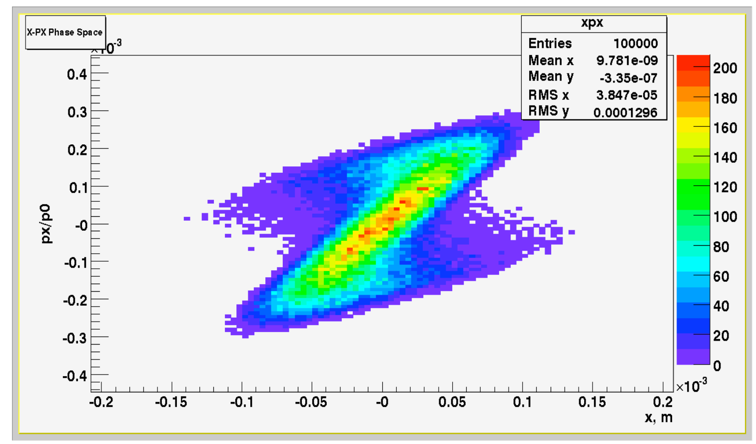
Beam Disruption



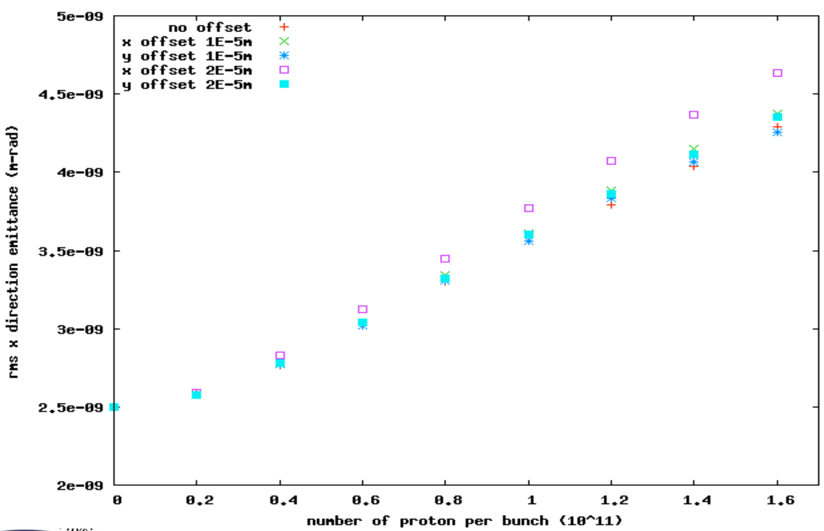


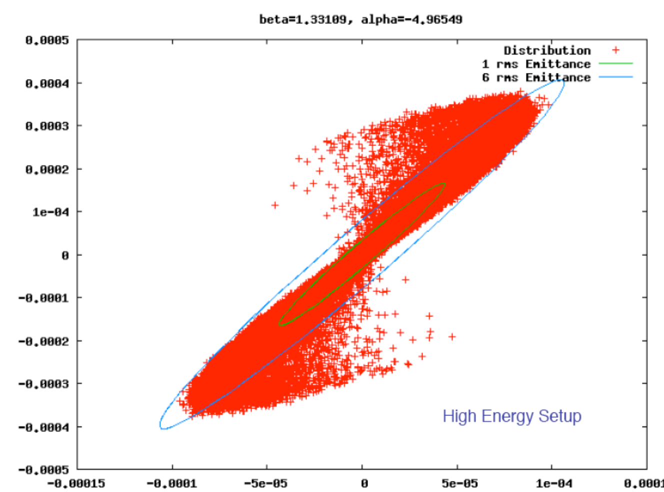


Interaction



Optimized





©Y. Hao – more in talk by V.Ptitsyn

MeRHIC parameters for e-p collisions

© V.Ptitsyn

	not cooled		With cooling	
	p	e	p	e
Energy, GeV	250	4	250	4
Number of bunches	111		111	
Bunch intensity, 10^{11}	2.0	0.31	2.0	0.31
Bunch charge, nC	32	5	32	5
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.5	7.3
rms emittance, nm	9.4	9.4	0.94	0.94
beta*, cm	50	50	50	50
rms bunch length, cm	20	0.2	5	0.2
beam-beam for p /disruption for e	1.5e-3	3.1	0.015	7.7
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	0.93		9.3	

Luminosity for light and heavy ions is the same as for e-p if measured per nucleon!

eRHIC parameters

	2007 ERL design		Advanced, In tunnel, Coherent eCooling		eRHIC II 8T RHIC	
	p (A)	e	p (A)	e	p/A	e
Energy, GeV	250 (100)	10	325 (125)	20 (30)	800 (300)	20 (30)
Number of bunches	166		166		166	
Bunch intensity (u) , 10^{11}	2.0 (3)	1.2	2.0 (3)	0.24	2.0 (3)	0.24
Bunch charge, nC	32	20	32	4	32	4
Beam current, mA	420	260	420	50 (5)	420	50 (5)
Normalized emittance, 1e-6 m, 95% for p / rms for e	6	80	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	26	25	5	5	5 (?)	5
Luminosity, x 10^{33}, $cm^{-2}s^{-1}$	2.6		14		30	

Luminosity for light and heavy ions is the same as for e-p if measured per nucleon!

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

Conclusion

- EIC designs provide for both polarized e-p and unpolarized eA collisions with high luminosity ~ 10^{33}-10^{34} $cm^{-2}sec^{-1}$ (L_{EIC}>>L_{HERA})
- eRHIC design is based on existing hadron collider and can offer higher energies (325 GeV p, 130 GeV/u HI, 20 (30) GeV e), while ELIC is “green field” design is focused on high luminosity based on a number of novel ideas
- 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
- Recently ELIC team suggested to build chain of multiple colliders starting from low energy and going high energy. It suggest converting some of the early collider rings for injection purposes to mitigate the cost

Back up

Gains from coherent e-cooling:

Coherent Electron Cooling vs. IBS

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

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

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

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

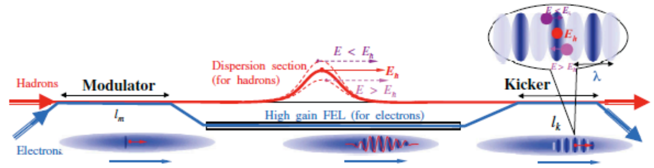


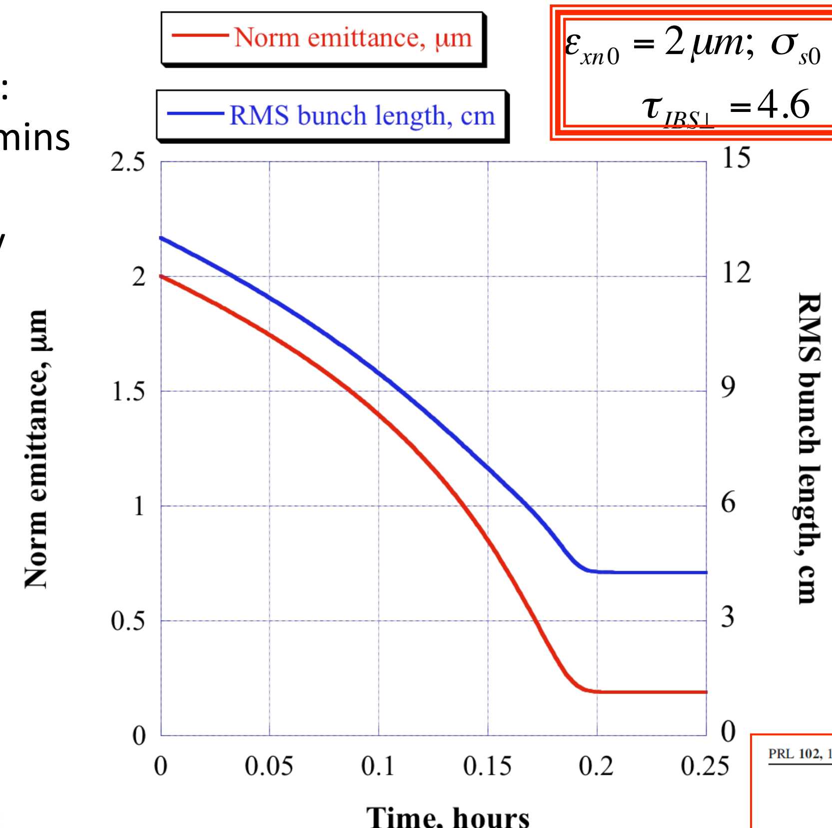
FIG. 1 (color). A general schematic of the Coherent Electron Cooler (CEC) comprising three sections: A modulator; a FEL plus a dispersion section; and, a kicker. The FEL wavelength, λ, in the figure is grossly exaggerated for visibility.

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

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

IBS in RHIC for eRHIC, 250 GeV, $N_p=2\cdot 10^{11}$
Beta-cool, ©A.Fedotov

Dynamics: Takes 12 mins to reach stationary point



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

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]
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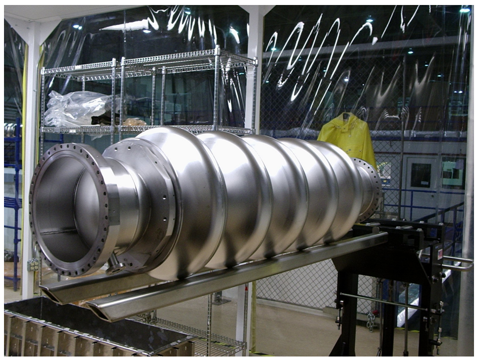
[2]Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA

(Received 24 September 2008; published 16 March 2009)

SRF Linac

I. Ben-Zvi, A.Burrill, R.Calaga, H.Hahn, L.Hammons …

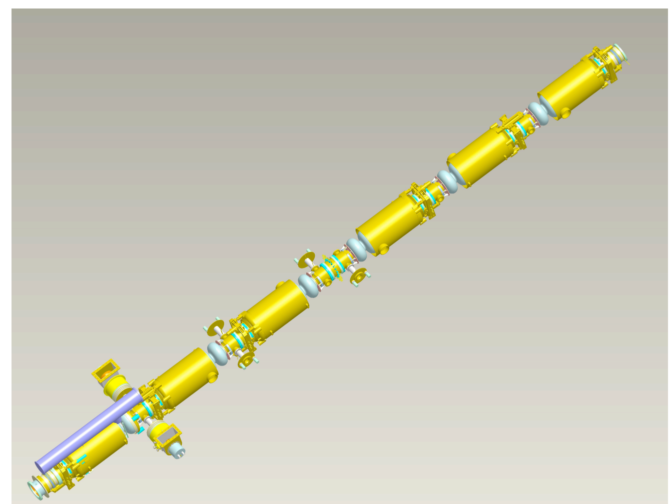


The ERLs will use 703 MHz superconducting RF cavities for the acceleration and the energy recovery.
State-of-the-art cavity design for high current beam operation.

Recently: successful cooldown of a test cavity (ERL Test Facility), first measurements of EM modes.

36 cavities per linac. Design of individual crymodule, incorporating 6 SRF cavities is under development.

The challenge: to make the design (fundamental couplers, HOM dampers, tuners ..) as compact as possible, to fit the existing straight section of the tunnel.



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**

Beyond eRHIC-> eRHIC II
c.m. Energy of HERA and 1000x Luminosity

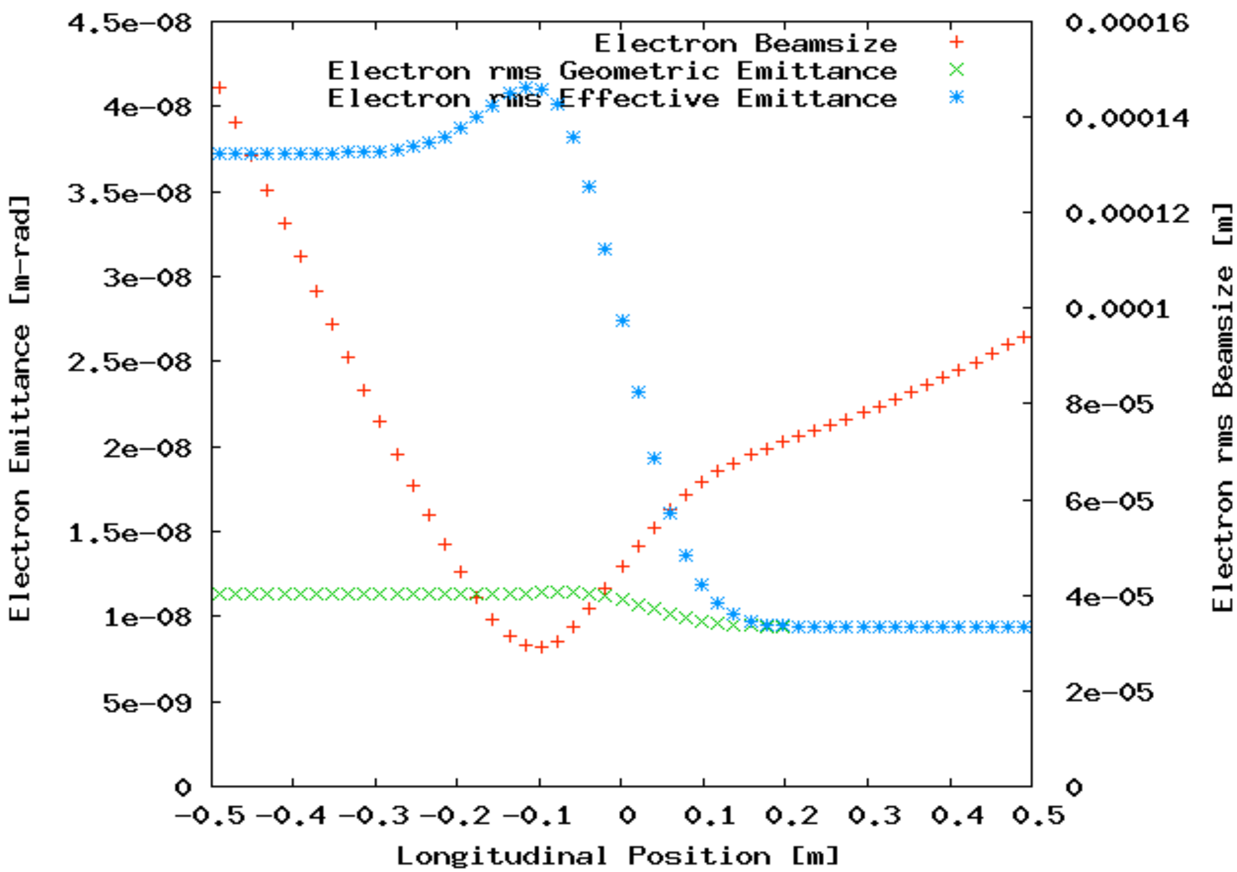
- **eRHIC II:** replacing RHIC-ring with 8 T magnets
  - proton energy in RHIC to ~ 800 GeV – c.m.e. 250 GeV
  - will require more snakes for polarized proton operation
  - heavy ions with ~ 300 GeV/n, c.m.e. 200 GeV
- **eRHIC II - Full energy, nominal luminosity**
  - inside RHIC tunnel
  - Polarized 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}

Note: 3.8 km RHIC tunnel and RHIC refrigerator facility already exists!.......

Beamsize and Emittance evolution of electron beam:

© Y.Hao

(Electron beam comes from right)



Example:

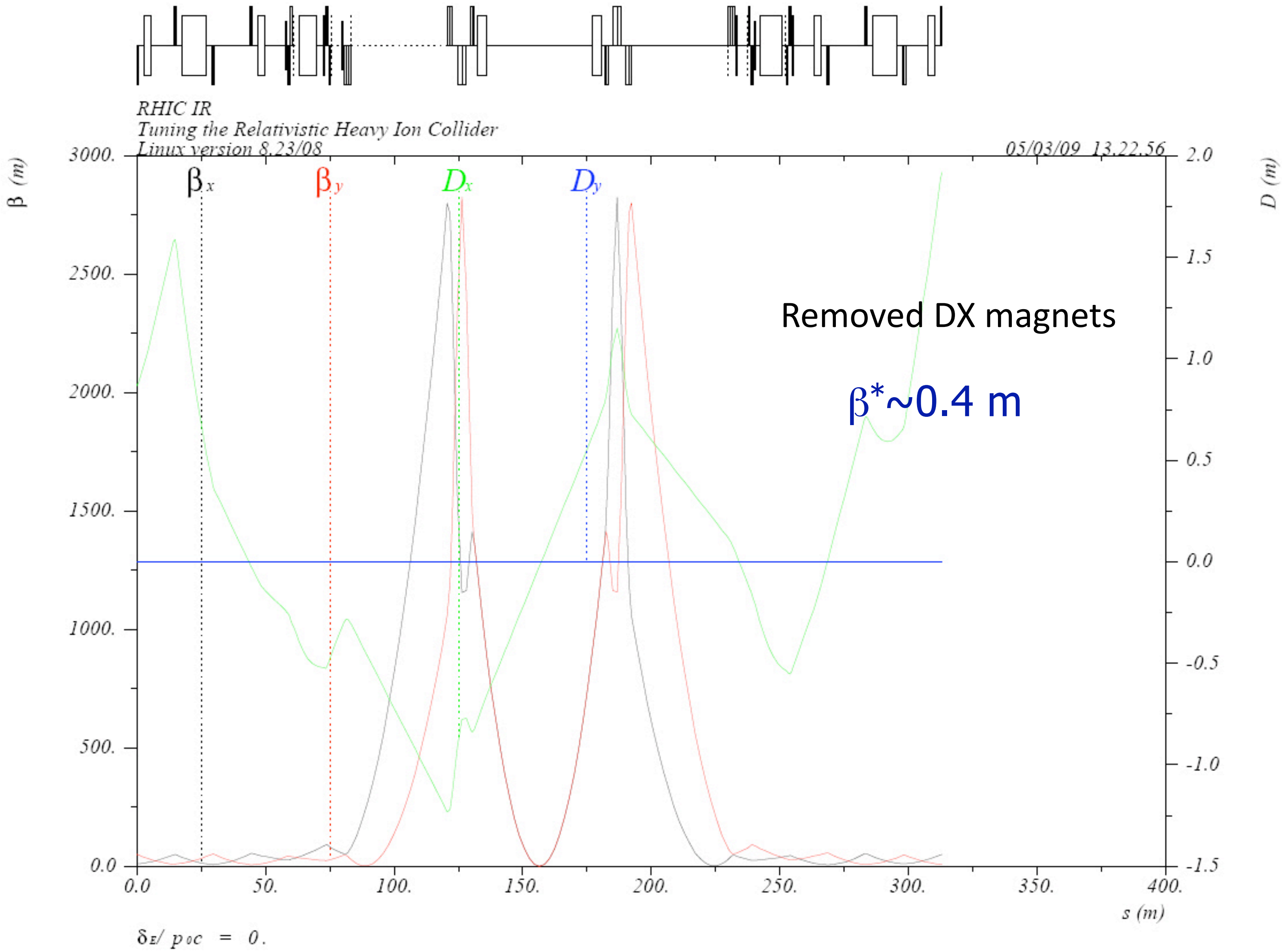
Initial Emittance:
9.4 nm-rad

Waist beta function:
0.5 m

Waist position:
0 m (at IP)

Luminosity:
1.2×10^{32} $cm^{-2}s^{-1}$

Effective emittance growth during collision due to mismatch between the electron distribution and design lattice. This is main effect comparing with the geometric emittance growth due to pure nonlinear effect.



RHIC IR
Tuning the Relativistic Heavy Ion Collider
Linux version 8.23/08
05/03/09 13.22.56
β_x
β_y
D_x
D_y
β (m)
D (m)
s (m)
$\delta_E/p_0c = 0.$
Removed DX magnets
β*~0.4 m

Beam Dynamics Studies

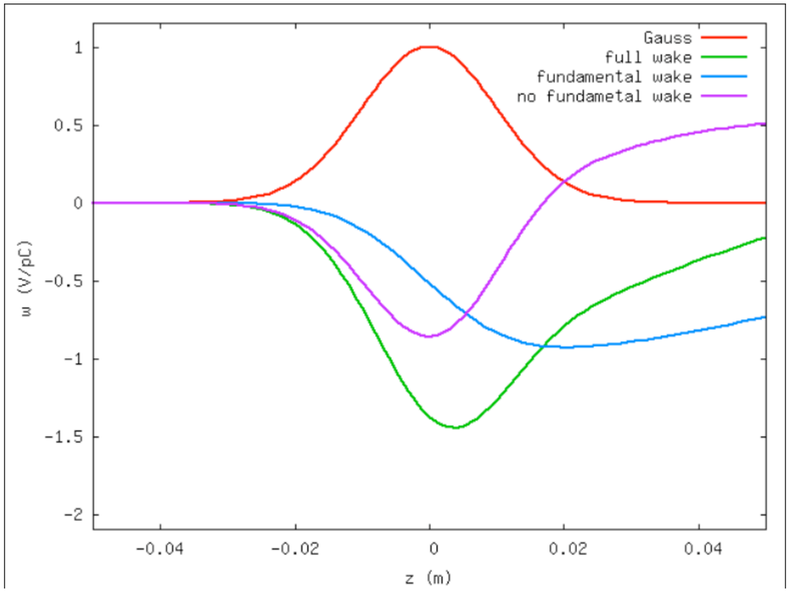
E.Pozdeyev, A.Fedotov, Y.Hao, G.Wang

Main factors affecting the beam dynamics have been evaluated:

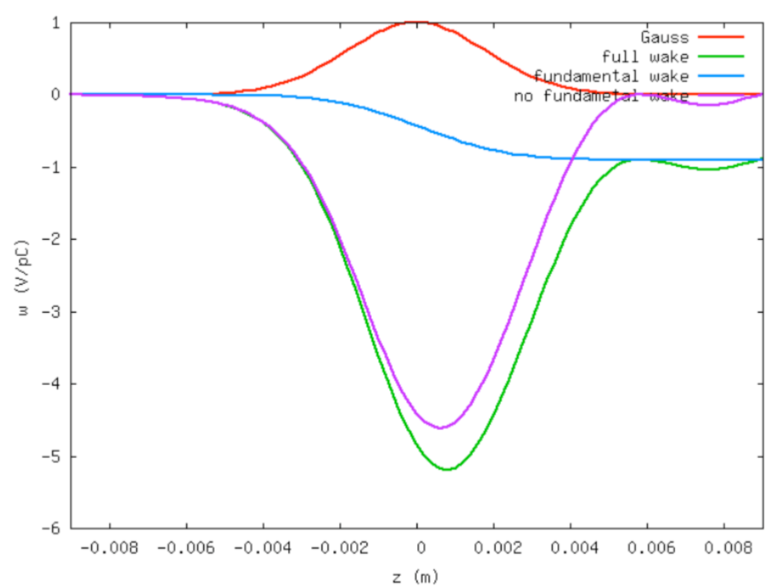
- **-Beam-beam interactions, including kink instability (protons) and electron beam disruption**
- **-BBU instability**
- **-Energy losses due to cavity wakes**
- **-Toushek and Beam-gas scattering**
- **-Coherent Synchrotron Radiation (possible experiment at ATF)**

Energy loss in the SRF structures: 2 mm is OK!

σ=1 cm, Gauss



σ=1.8 mm, Gauss



	σ_E / E	δE_{full}
Gaussian, σ=1 cm, cut at ±2σ	1.2e-2	4.3e-2
BC, σ=1 cm, (L=0.62cm)	1e-2	3.4e-2

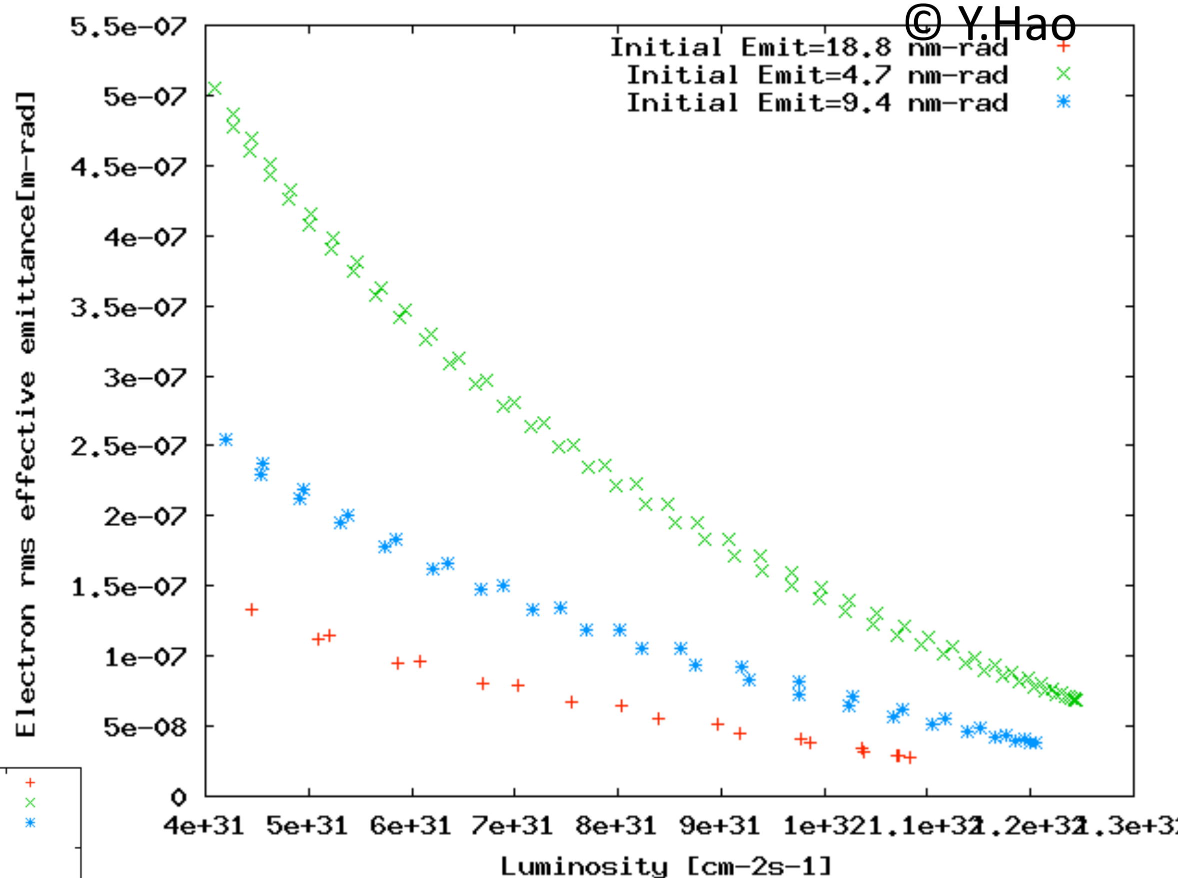
	σ_E / E	δE_{full}
Gaussian, σ=0.18cm, cut at ±2σ	4.0e-4	1.4e-3
BC, σ=0.18cm, (L=0.62cm)	3.1e-4	1.1e-3

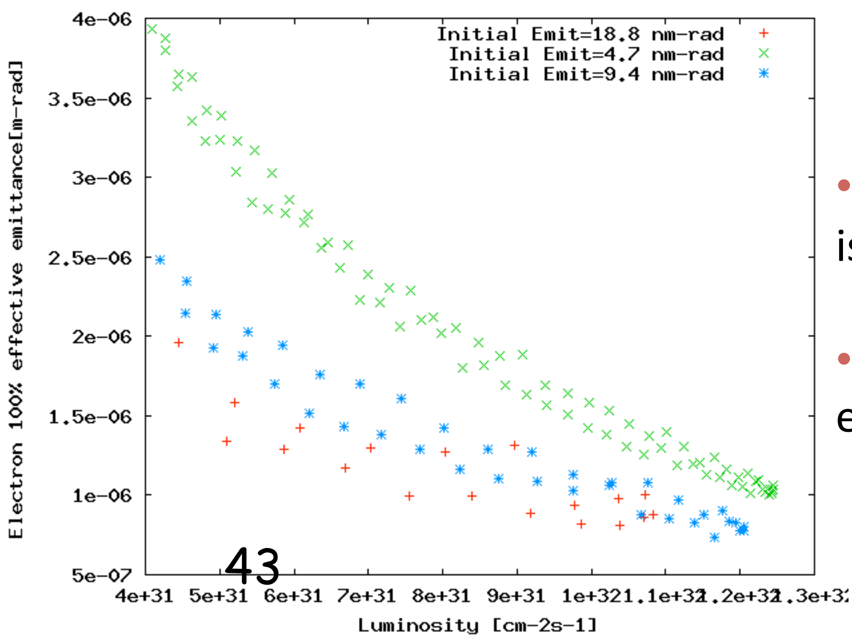
‘Not Cooled’ Case

What is the optimized electron optics parameter?

Designed Electron beam size matches the proton beam size:
18.8nm-rad---0.25m beta waist
4.7nm-rad----1m beta waist
9.4nm-rad-----0.5m beta waist

The beta waist position (alpha function at IP) varies.



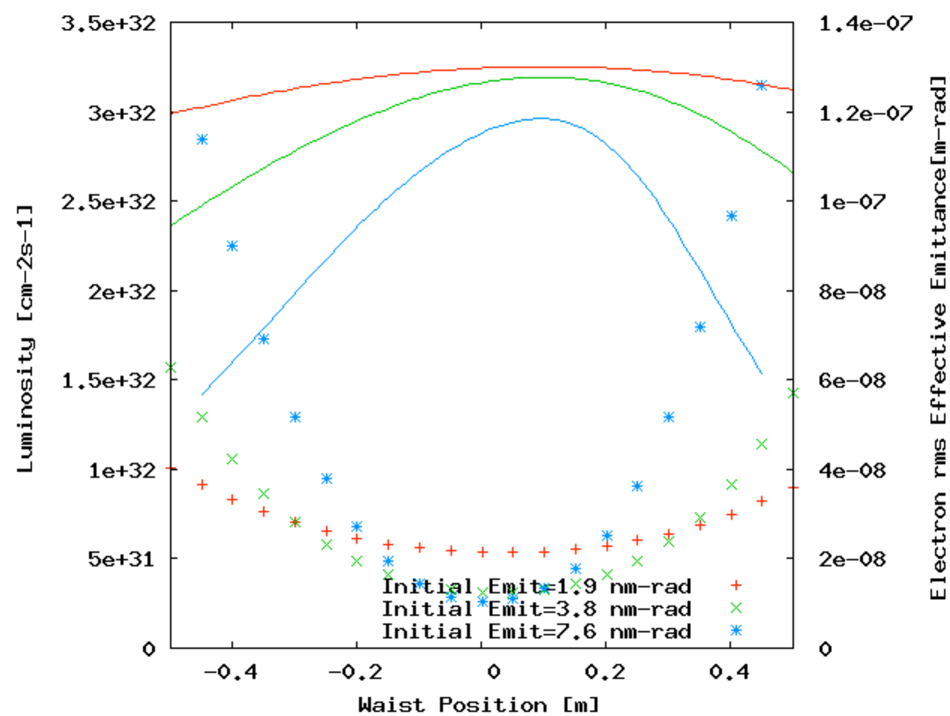


- Luminosity Decreases when lower final emittance is achieved.
- For specific luminosity, a larger initial electron emittance yields a smaller final emittance

‘Pre-Cooled’ Case

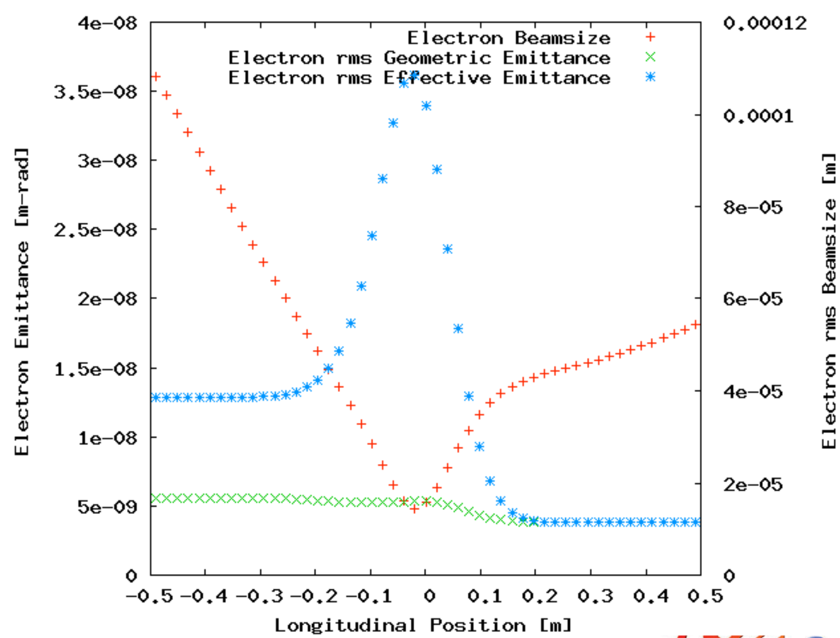
Similar results are achieved.

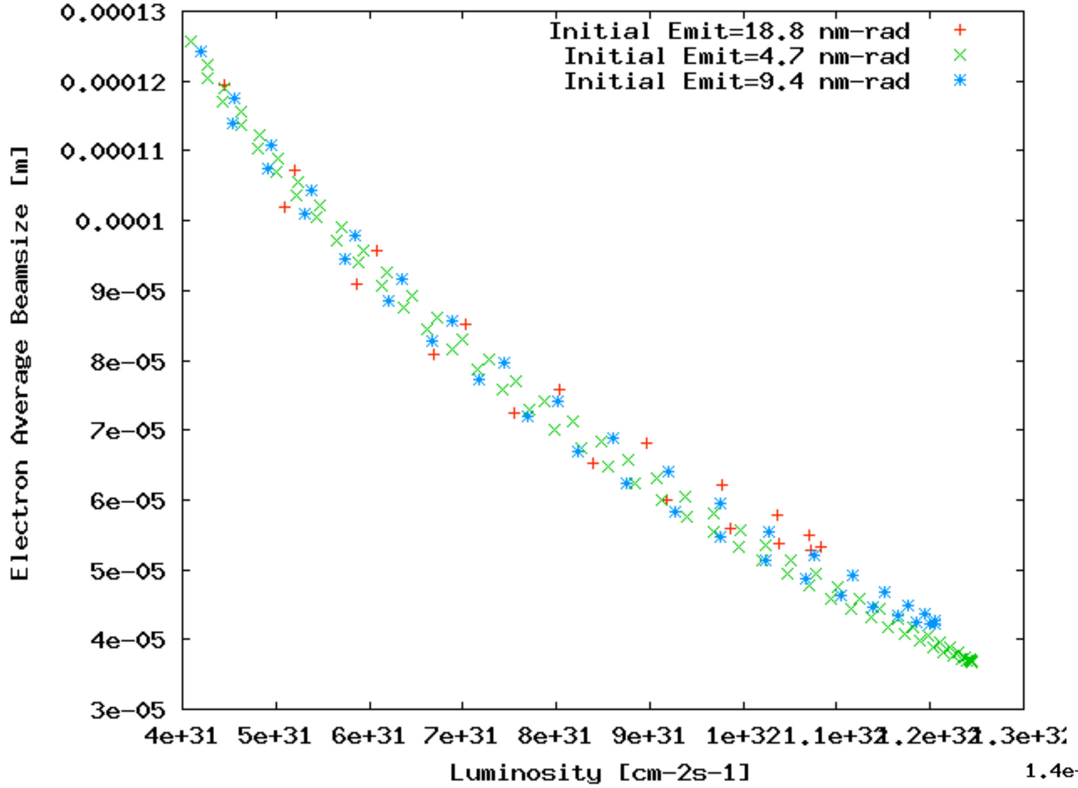
The electron beta function waist is at s=0.1m (ahead of IP from electron point of view) to maximize the luminosity.



An example of electron optics:

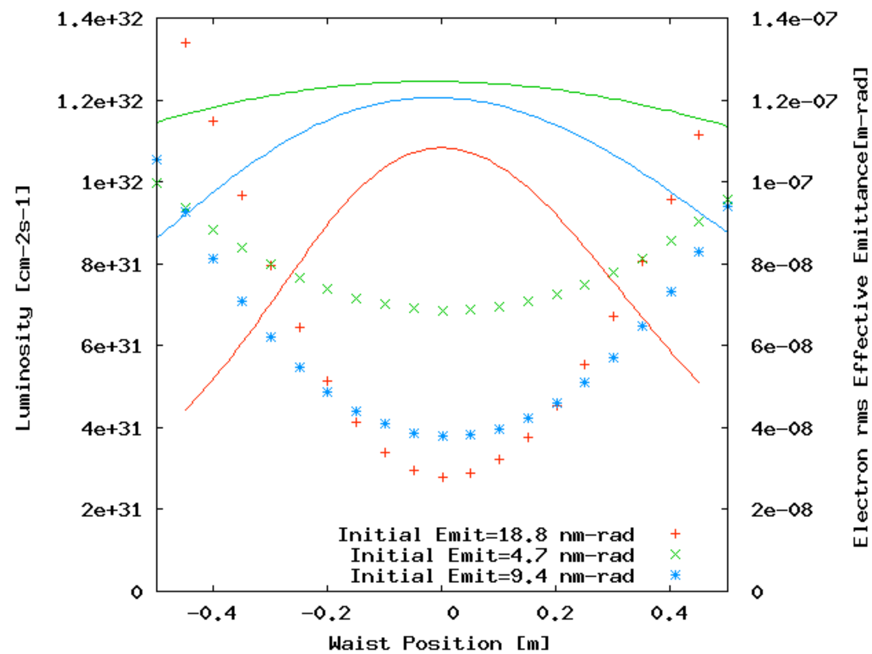
Initial Emittance: 3.8 nm-rad
Waist beta function: 0.5 m
Waist position: 0.1 m (ahead of IP)
Luminosity: 3.2×10^{32} $cm^{-2}s^{-1}$





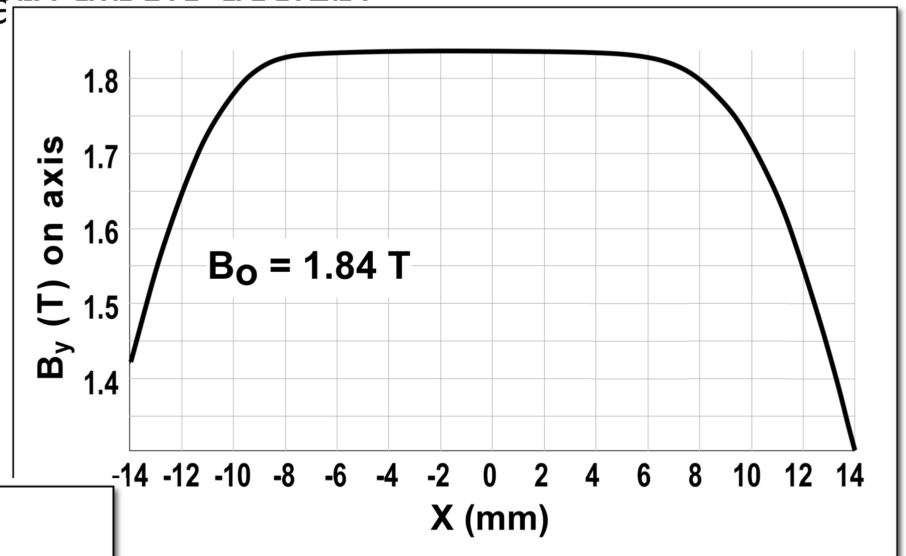
In order not to drive the proton beam unstable, the electron beam size must be controlled.

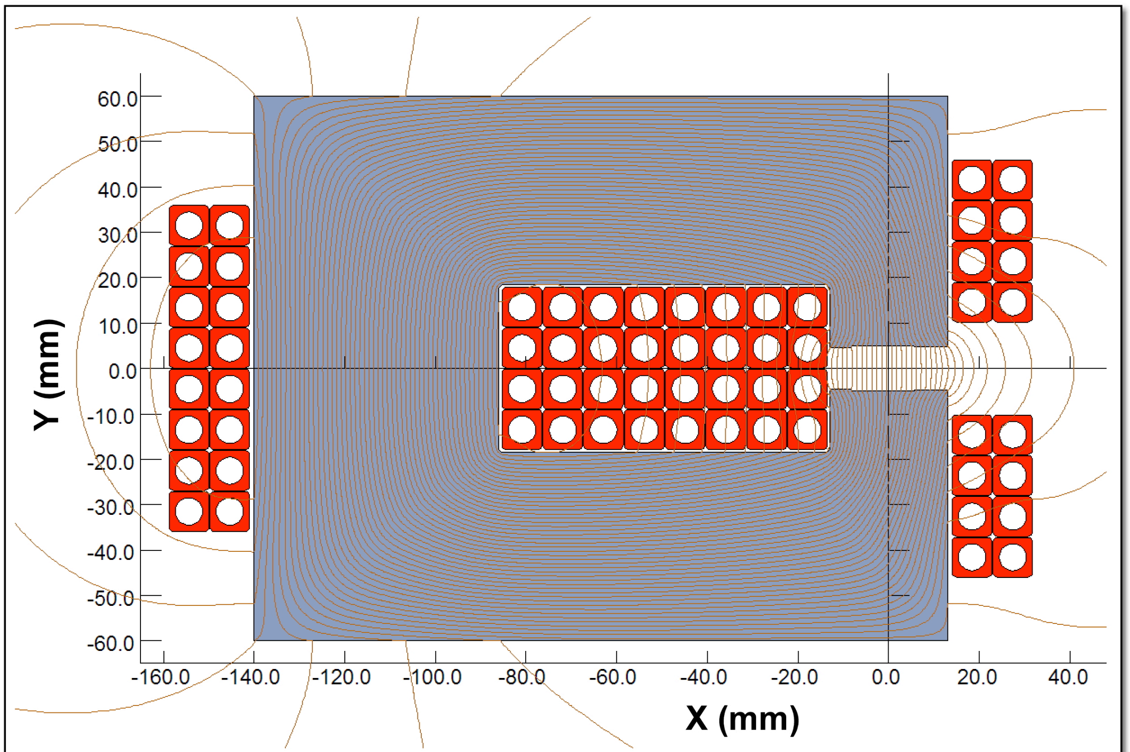
In 'not cooled' case, even the largest luminosity gives a safe value of electron beam size during collision.



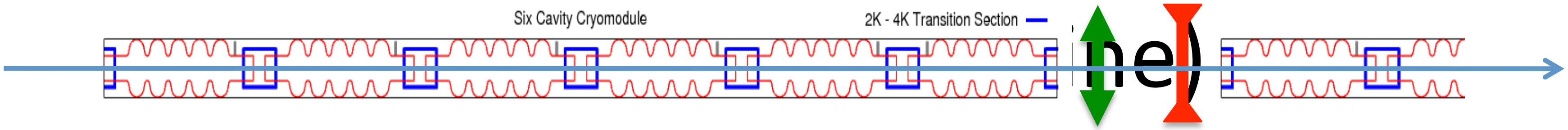
The luminosity (solid lines) and final effective emittance (dot lines) are optimized at around s=0, which is IP.

Brett Parker: Preliminary dipole design:

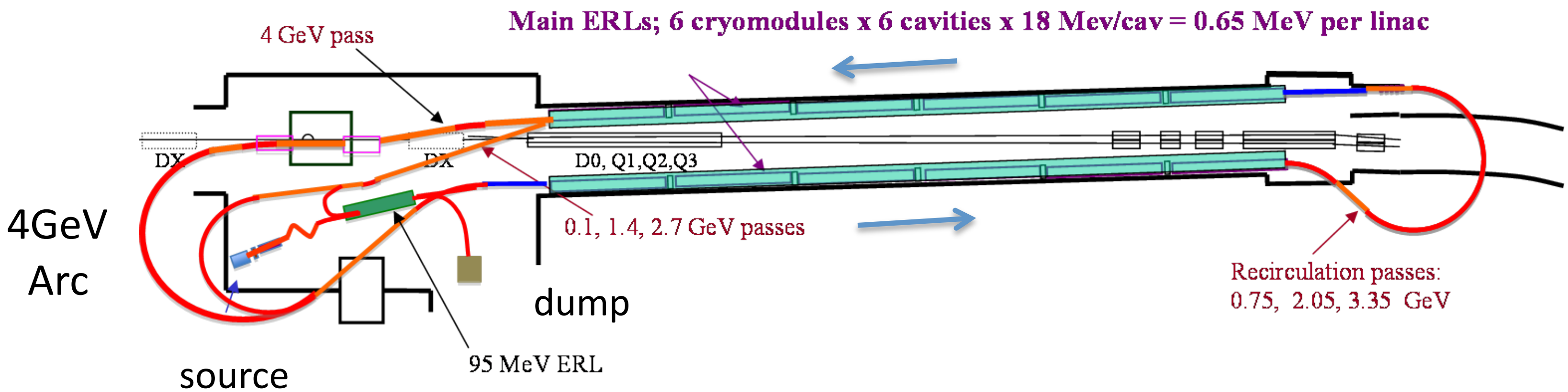


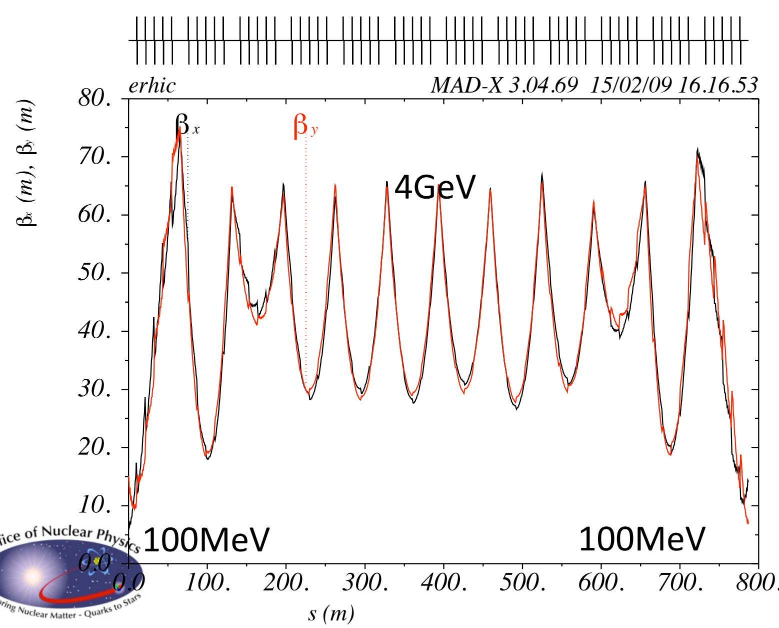


Linac design with const. grad quads



Cavity: 703.75 MHz, 1.6 m with dampers

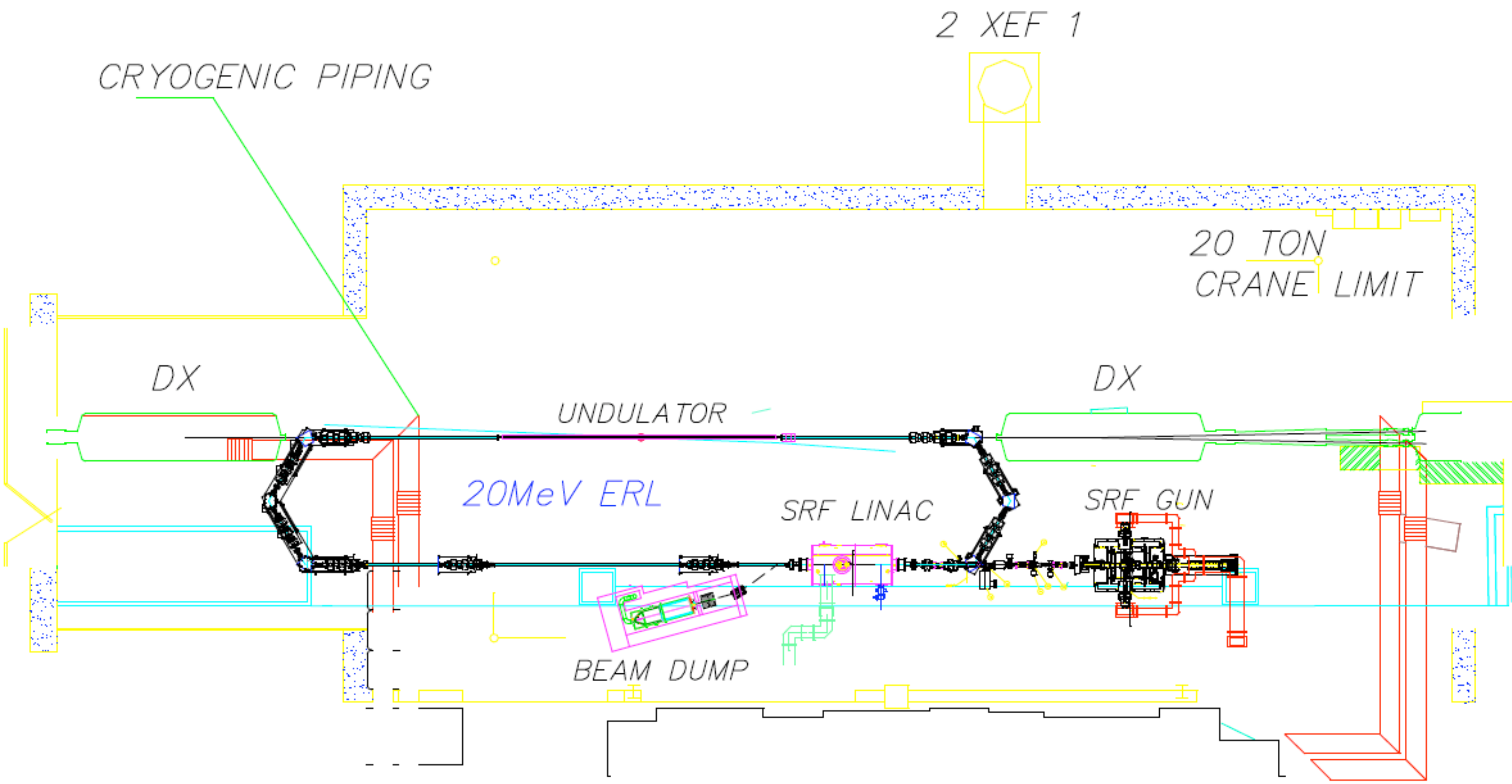




Constant gradient quads:
L=20 cm, G~100 Gauss/cm

- E_{inj}/E_{max} = 100MeV / 4GeV
- 3 acc./decel. passes
- N cavities = 72 (total)
- L module/period = 9.6 / 11.1m
- E_f = 18.0 MeV/m
- $\langle dE/ds \rangle$ = 10.2 MeV/m

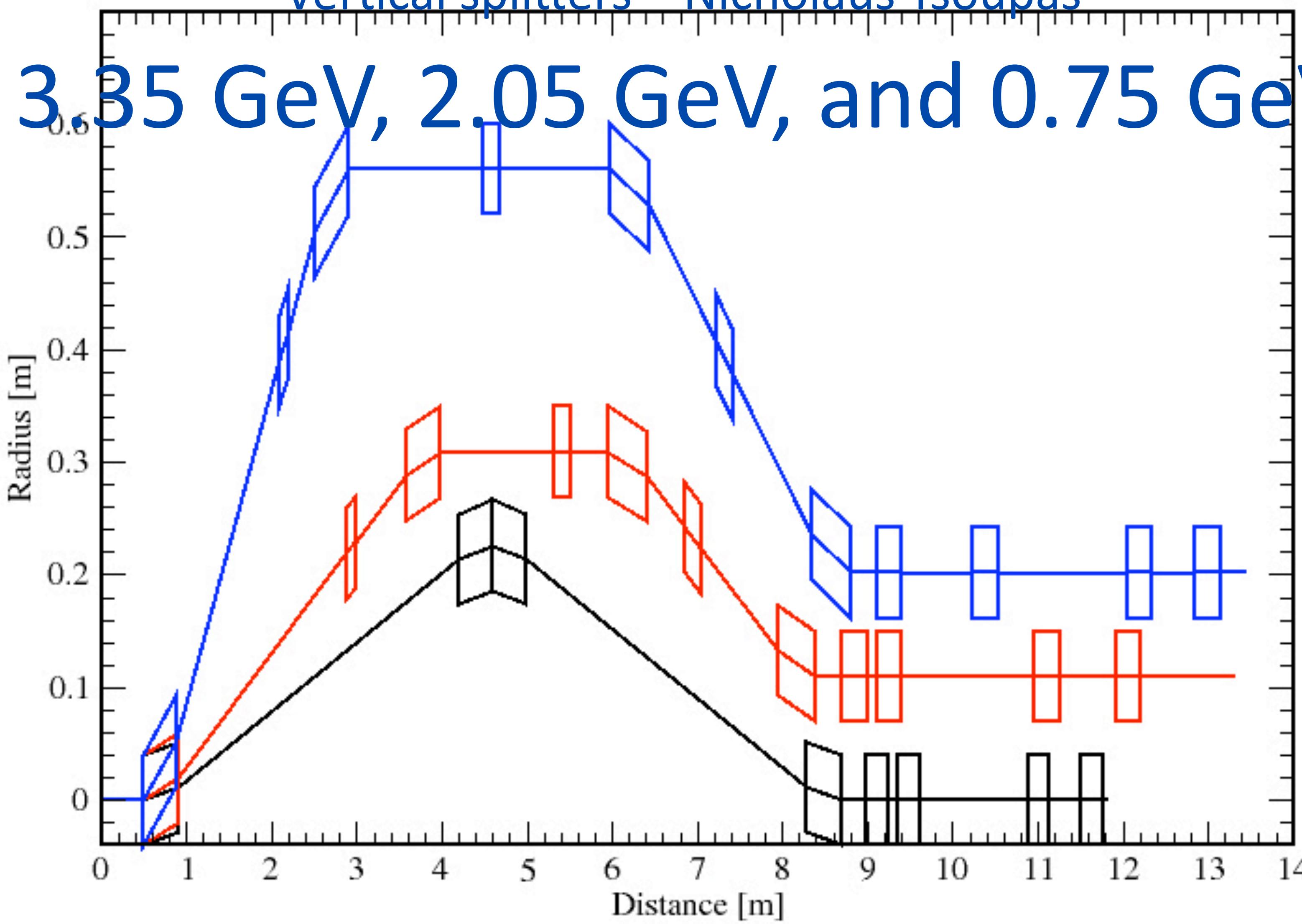
IR-2 for proof-of-principle for CEC



Presentation by D.Kayran at 3:10 p.m., Tue, May 20
At parallel session: Accelerators

Vertical splitters – Nicholaus Tsoupas

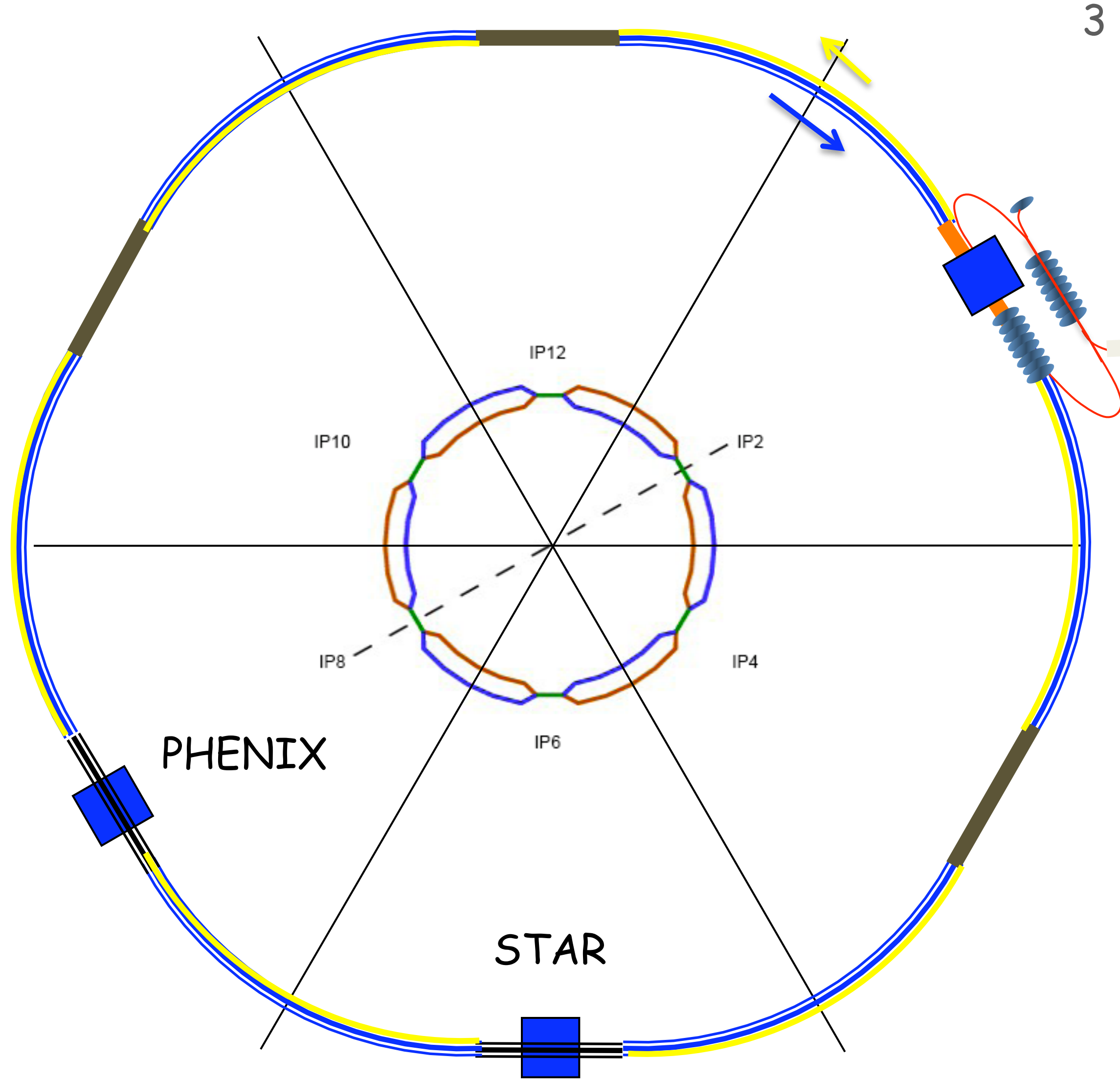
3.35 GeV, 2.05 GeV, and 0.75 GeV



Dejan Trbojevic
C-AD Machine
Advisory Committee

4 GeV e x 250 GeV p MeRHIC
with ERL inside RHIC tunnel

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



5 (6) vertically separated passes