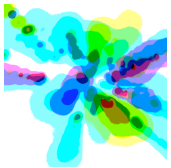

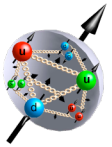

Staging of eRHIC

Increased Reach in c.m. Energy and Luminosity

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Contributions:

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eRHIC Scope -QCD Factory

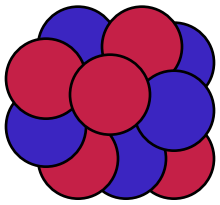
Electron accelerator

Unpolarized and polarized leptons 2-20 (30) GeV

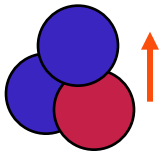
70% beam polarization goal
Positrons at low intensities

RHIC

Polarized protons
25 ↓ 50-250 (325) GeV



Heavy ions (Au)
50-100 (130) GeV/u



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

Center mass energy range: 15-200 GeV

New requirements: *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
  - 2 or 4 GeV e^- x 250 GeV p (45 or 63 GeV c.m.), L ~ 10^{32}-10^{33} cm^{-2} sec^{-1}
- **eRHIC, High energy and luminosity phase**, inside RHIC tunnel

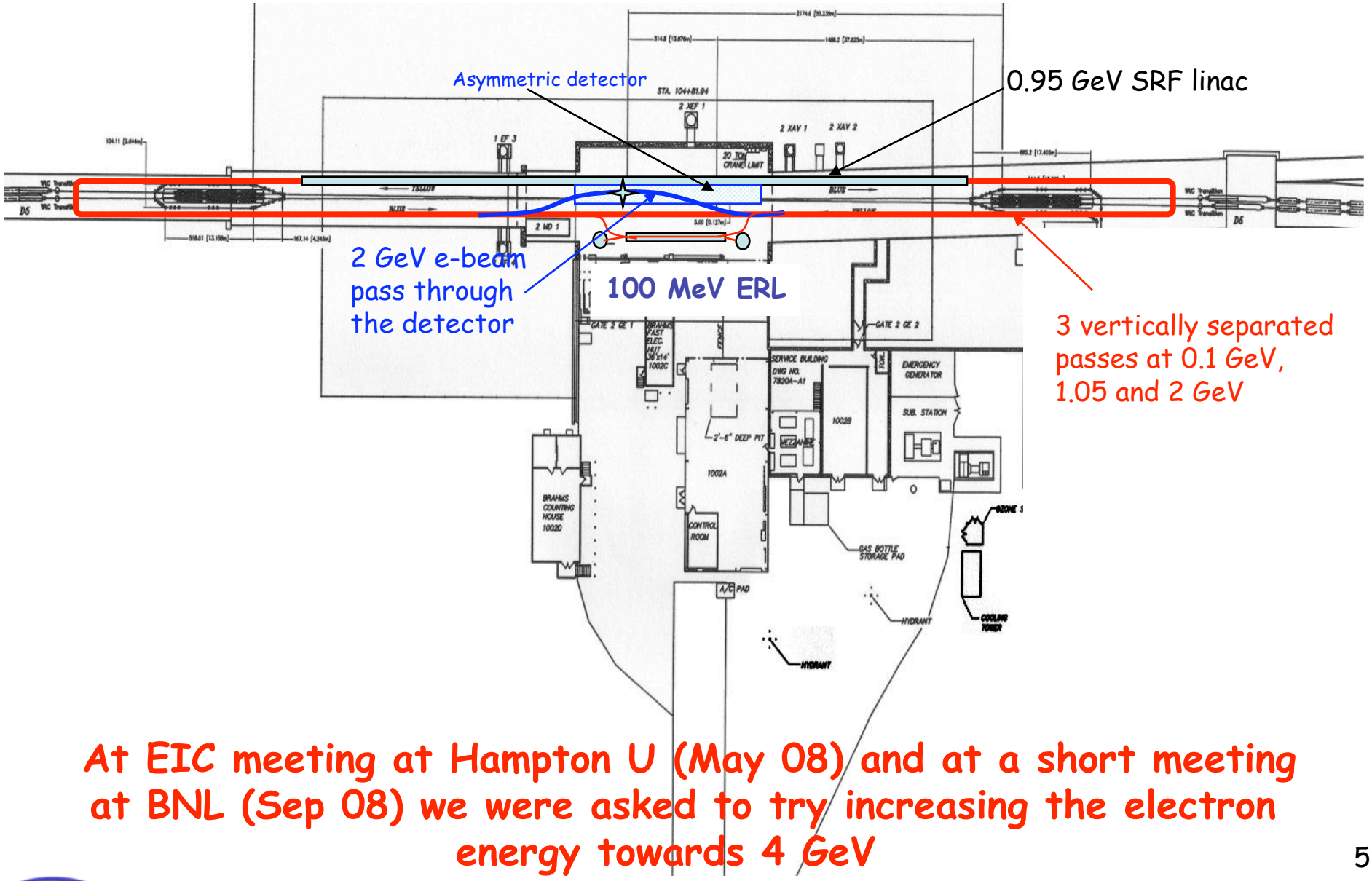
  Full energy, nominal luminosity,
  - Polarized 20 GeV e^- x 325 GeV p (160 GeV c.m), L ~ 10^{33}-10^{34} cm^{-2} sec^{-1}
  - 30 GeV e x 120 GeV/n Au (120 GeV c.m.), ~1/5 of full luminosity
  - and 20 GeV e x 120 GeV/n Au (120 GeV c.m.), full liminosity
- **eRHIC, 10 GeV elevated luminosity phase**,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

  Higher luminosity at reduced energy, can be added if needed
  - Polarized 10 GeV e^- x 325 GeV p, L ~ 10^{35} cm^{-2} sec^{-1}
  - Smaller improvements (3-4 fold) in e-Ion collisions

Staging of eRHIC: Cost, Re-use, Beams and Energetics

- **MEeIC**: Medium Energy electron-Ion Collider
  - **Cost estimate - $150M (in 2007 $) for 2 GeV e^- version**
    cost of 4 GeV version will be estimated before next EIC meeting
  - Polarized beam current of 50 mA
  - 90% of ERL hardware will be use in the phase I (and will reduce cost of eRHIC)
  - Possible use of the detector components for eRHIC detectors
- **eRHIC – High energy and luminosity phase**
  - **Based on present RHIC beam intensities**
  - With coherent electron cooling requirements on the electron beam current is 25 mA
  - 20 GeV, 25 mA electron beam losses 1.92 MW total for synchrotron radiation.
  - 30 GeV, 5 mA electron beam loses 1.98 MW for synchrotron radiation
  - Power density is 1 kW/meter and is well within B-factory limits (8 kW/m)
- **eRHIC – 10 GeV elevated luminosity phase**
  - **Requires crab cavities, new injections, Cu-coating of RHIC vacuum chambers, new level of intensities in RHIC**
  - Polarized electron source current of 400 mA
  - 10 GeV, 400 mA electron beam losses 1.96 MW total for synchrotron radiation, power density is 1 kW/meter

Initial (Spring 08) sketch of MEeIC with 2 GeV ERL @ IP2



At EIC meeting at Hampton U (May 08) and at a short meeting at BNL (Sep 08) we were asked to try increasing the electron energy towards 4 GeV

Contest to name first MEeIC experiment

- Inspired by the physics and history :
  - **OompheP** (sug. pron: U u m ff e P)
  - eP-Oomph……

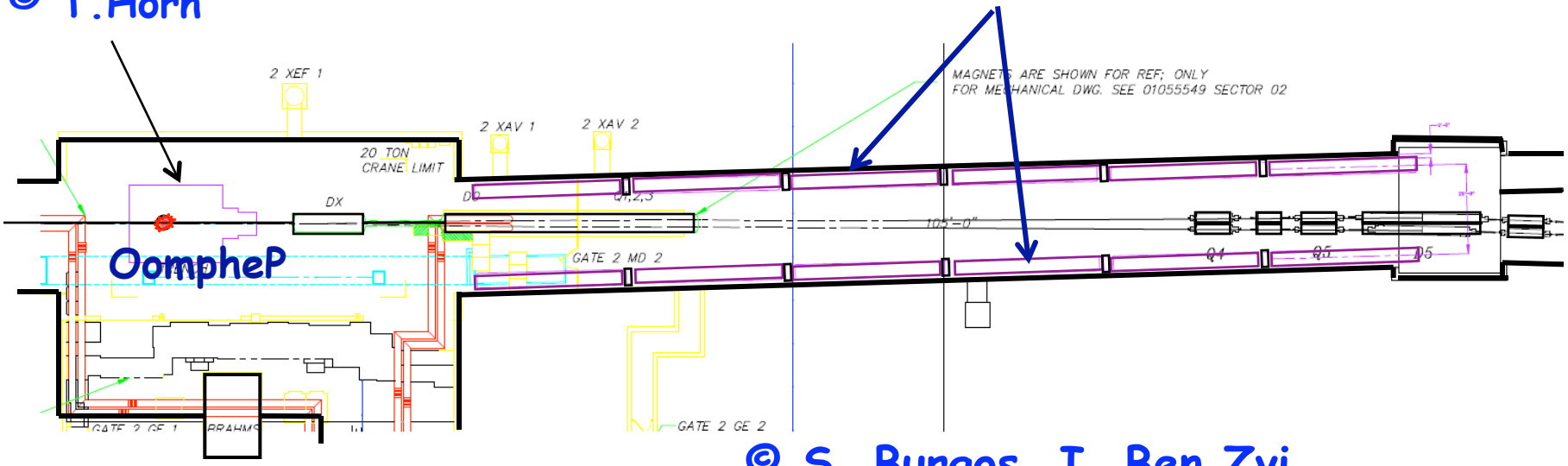
Prize – A bottle of good champagne

Send suggestions to vl@bnl.gov

Geometry of IP2 for MEeIC

Detector boundaries
© T.Horn

Main SRF Linacs:
Six 10 m SRF modules each

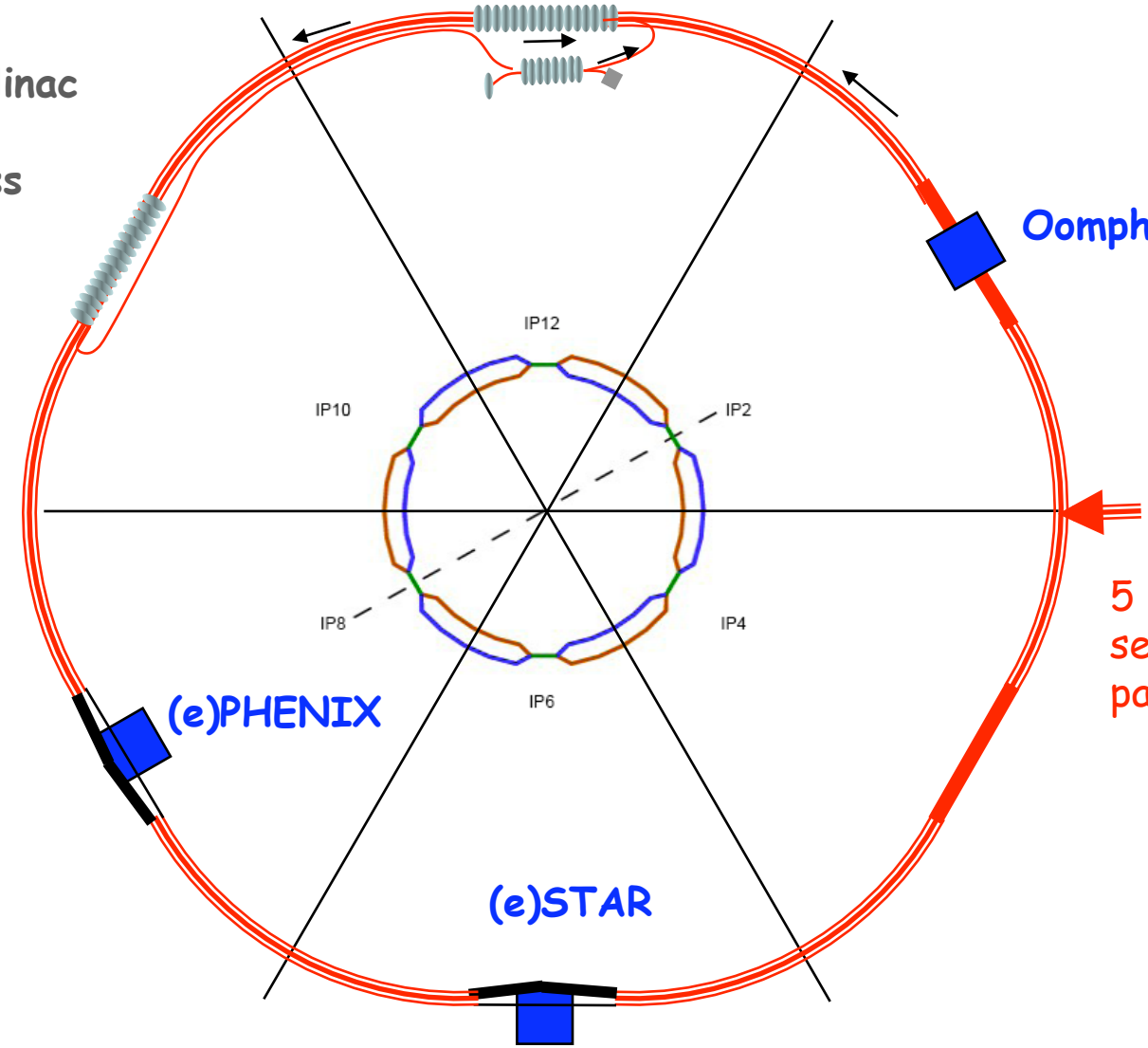


OompheP

© S. Burgos, I. Ben Zvi

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

Gains from coherent e-cooling:

Coherent Electron Cooling vs. IBS

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

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

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

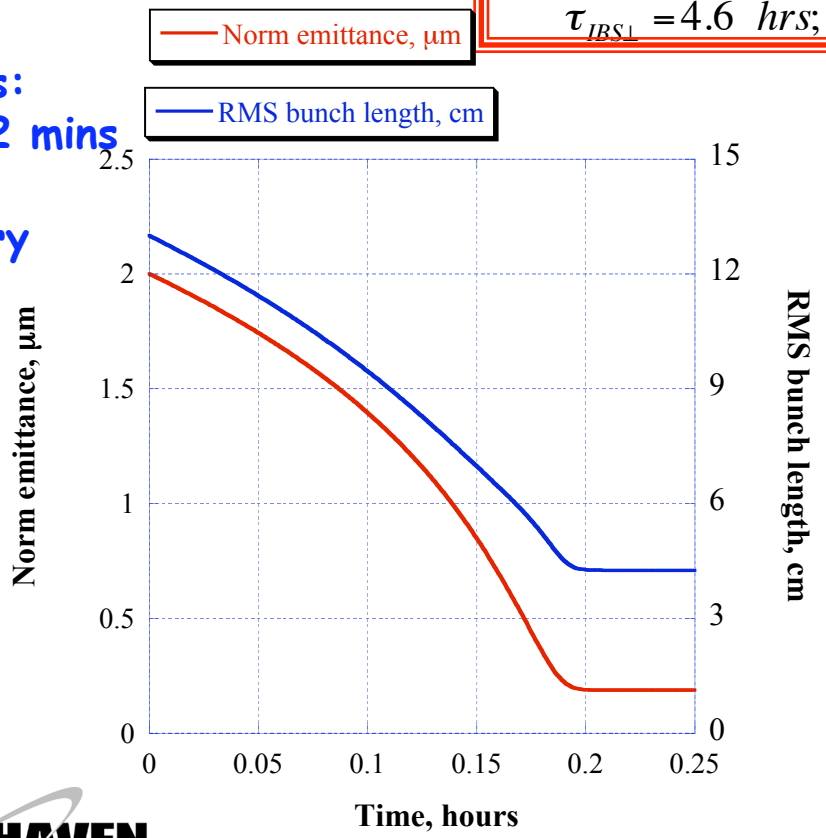
$$X=\frac{\tau_{CeC}}{\sqrt{\tau_{IBS//}\tau_{IBS\perp}}}\frac{1}{\sqrt{\xi_\perp(1-2\xi_\perp)}};\quad S=\frac{\tau_{CeC}}{\tau_{IBS//}}\cdot\sqrt{\frac{\tau_{IBS\perp}}{\tau_{IBS//}}}\cdot\sqrt{\frac{\xi_\perp}{(1-2\xi_\perp)^3}}$$

$$\varepsilon_{xn0}=2\,\mu m;\ \sigma_{s0}=13\ cm;\ \sigma_{\delta 0}=4\cdot 10^{-4}$$

$$\tau_{IBS\perp}=4.6\ \ hrs;\ \tau_{IBS//}=1.6\ \ hrs;$$

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



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

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

RHIC BROOKHAVEN NATIONAL LABORATORY

Office of Science U.S. DEPARTMENT OF ENERGY

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

- **eRHIC II**: replacing RHIC-ring magnets by new with 8 T
  - 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}

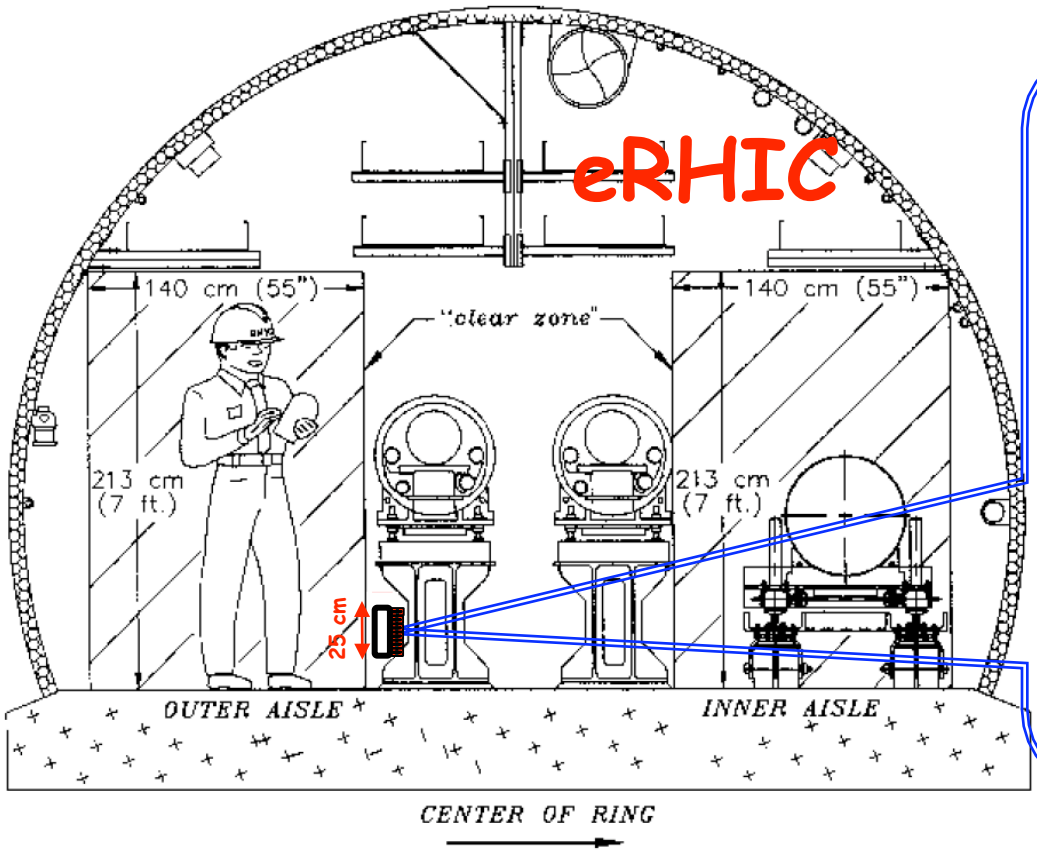
Note: It will cost at the ELIC level – they plan to use 2.5 km of 8 T magnets for its two-turn (figure-8) hadron ring. eRHIC II will need about 20-30% more of magnets, but 3.8 km RHIC tunnel and RHIC refregirator facility already exists!…….

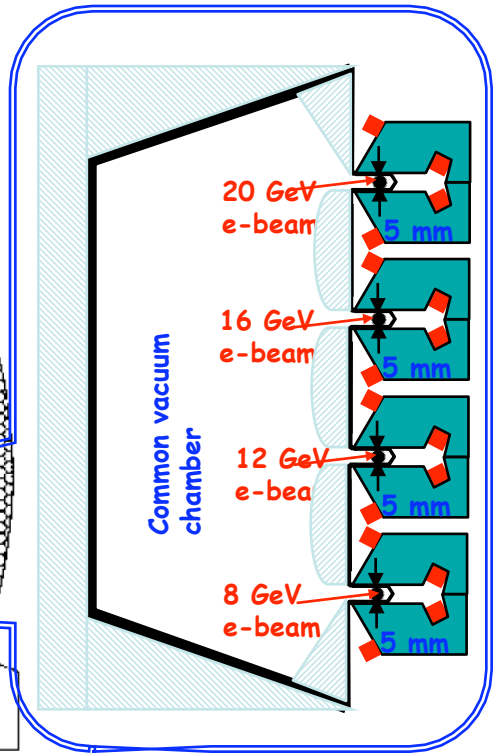
eRHIC parameters evolution

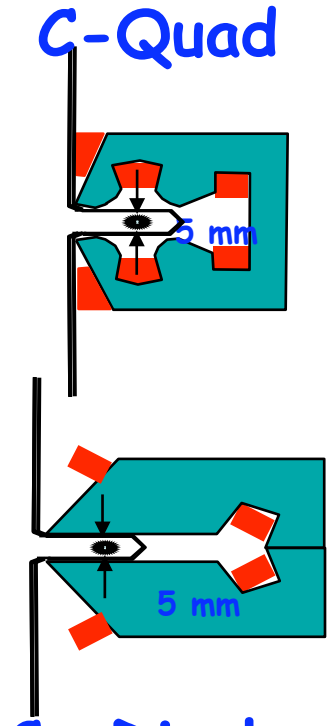
	Base ERL design	
	p (A)	e
Energy, GeV	250 (100)	10
Number of bunche	166	
Bunch intensity (u) , 10^{11}	2.0 (3)	1.2
Bunch charge, nC	32	20
Beam current, mA	420	260
Normalized emittance, 1e-6 m, 95% for p / rms for e	6	80
Polarization, %	70	80
rms bunch length, cm	20	0.2
β*, cm	26	25
Luminosity, x 10^{33}, $cm^{-2}s^{-1}$	2.6	

eRHIC loop magnets: LDRD project

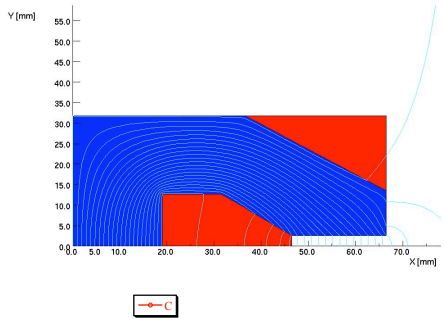
- Small gap provides for low current, low power consumption magnets
- Magnetic design - W.Meng, mechanical engineering - G.Mahler
- Beam dynamics – Y.Hao, J.Bengtsson

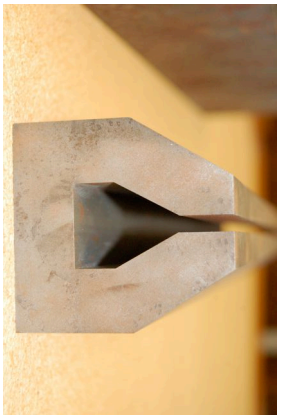


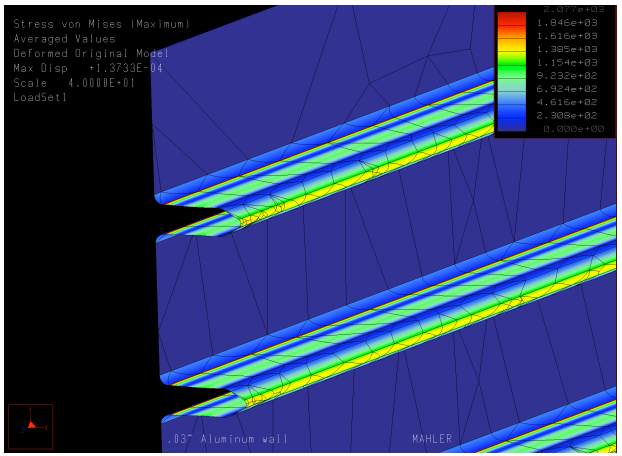


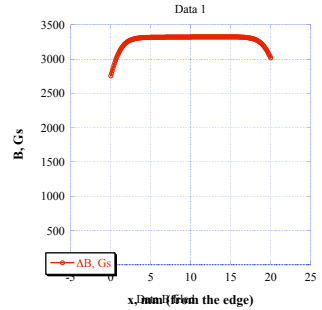


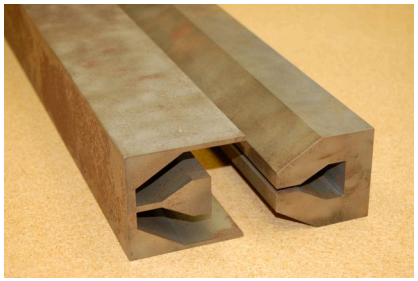
eRHIC loop magnets and vacuum chamber: progress

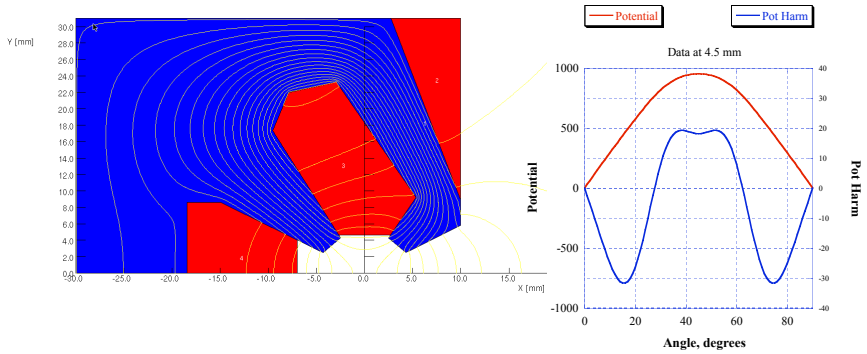


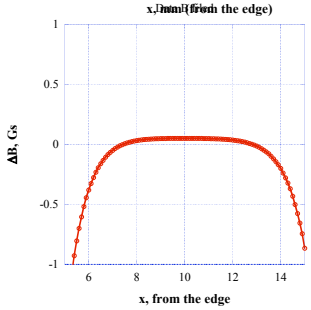


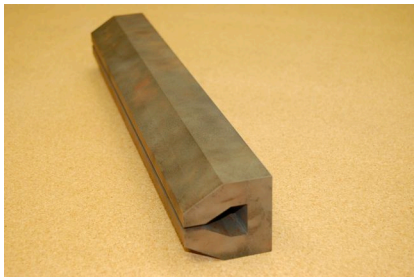


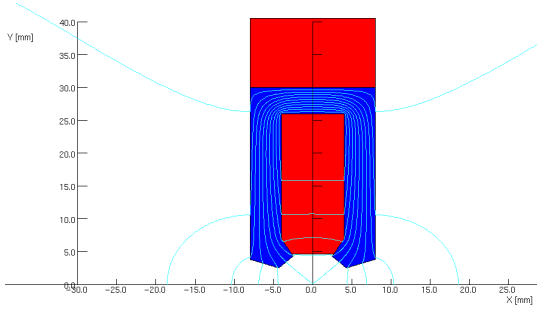












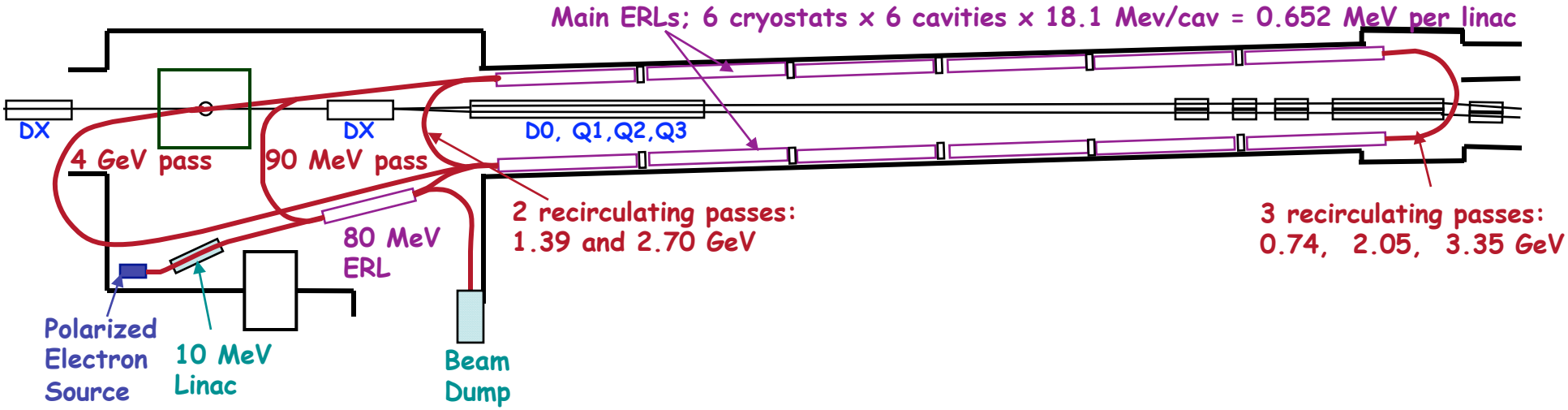
MEeIC progress

- Staging & MEeIC idea first discussed - March 2008
- Presented at EIC Collaboration meeting – May 2008
- Add-hoc MEeIC meeting at BNL – September 2008, two options with 2 and 4 GeV electrons discussed
- MEeIC Technical Design, **Leader – Vadim Ptitsyn,**

  Goal is to complete the design in Spring 2009
  - Chosed IP-2 at RHIC as preferable location for MEeIC and its IP
  - ERL-based e-beam, 2 GeV and 4 GeV options
  - Kick-off meeting, October 2008
  - Bi-weekly meetings on MEeIC
  - Defined the main beam parameter and possible up-grades
  - Defined the geometry of the accelerator
  - Defined SRF-linac structure (no 3rd harmonic) and layout
  - Addressed potential show-stoppers: SR, CSR, power losses, beam-beam….
  - **Plan to present MEeIC Technical Design at next EICC meeting**

MEeIC Layout

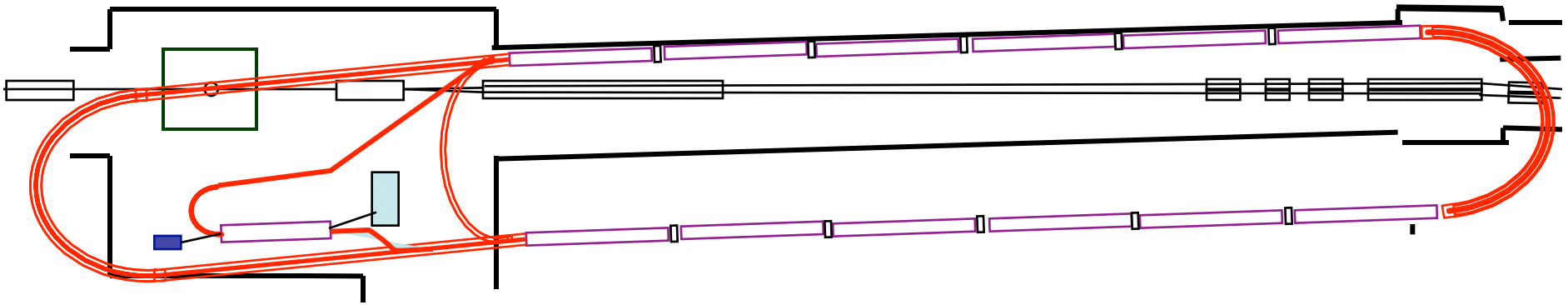
pass energies are shown for 4 GeV top energy



© V.Ptitsyn

Option for 4 GeV e-beam

- Less expensive magnets
- Need for some civil construction

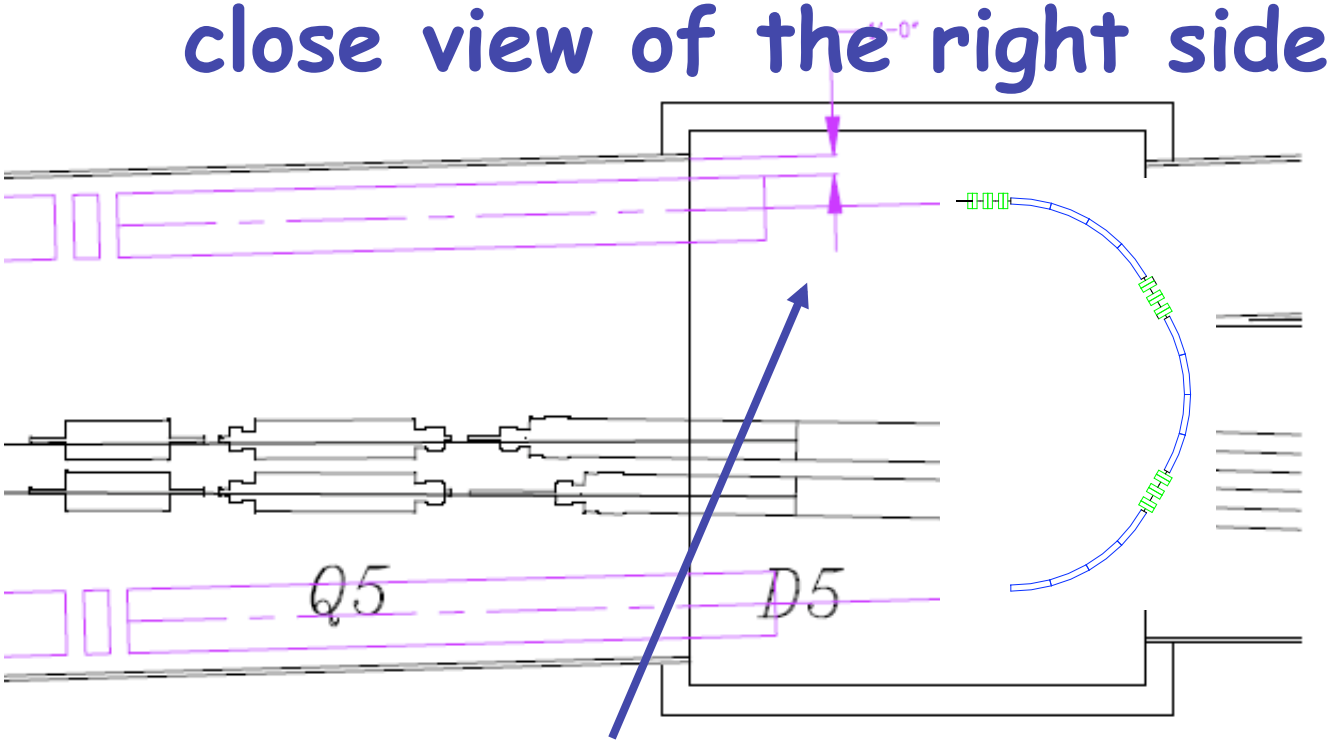


Choice for 4 GeV option will be driven by $$$$$ cost

MEeIC parameters for e-p collisions

	not cooled		pre-cooled		high energy cooling	
	p	e	p	e	p	e
Energy, GeV	250	4	250	4	250	4
Number of bunches	111		111		111	
Bunch intensity, 10^{11}	2.0	0.31	2.0	0.31	2.0	0.31
Bunch charge, nC	32	5	32	5	32	5
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	6	29	1.5	7.3
rms emittance, nm	9.4	9.4	3.8	3.8	0.94	0.94
beta*, cm	50	50	50	50	50	50
rms bunch length, cm	20	0.2	20	0.2	5	0.2
beam-beam for p /disruption for e	1.5e-3	3.1	3.8e-3	7.7	0.015	15
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	0.93		2.3		9.3	

MEeIC: IP2 for ERL location close view of the right side



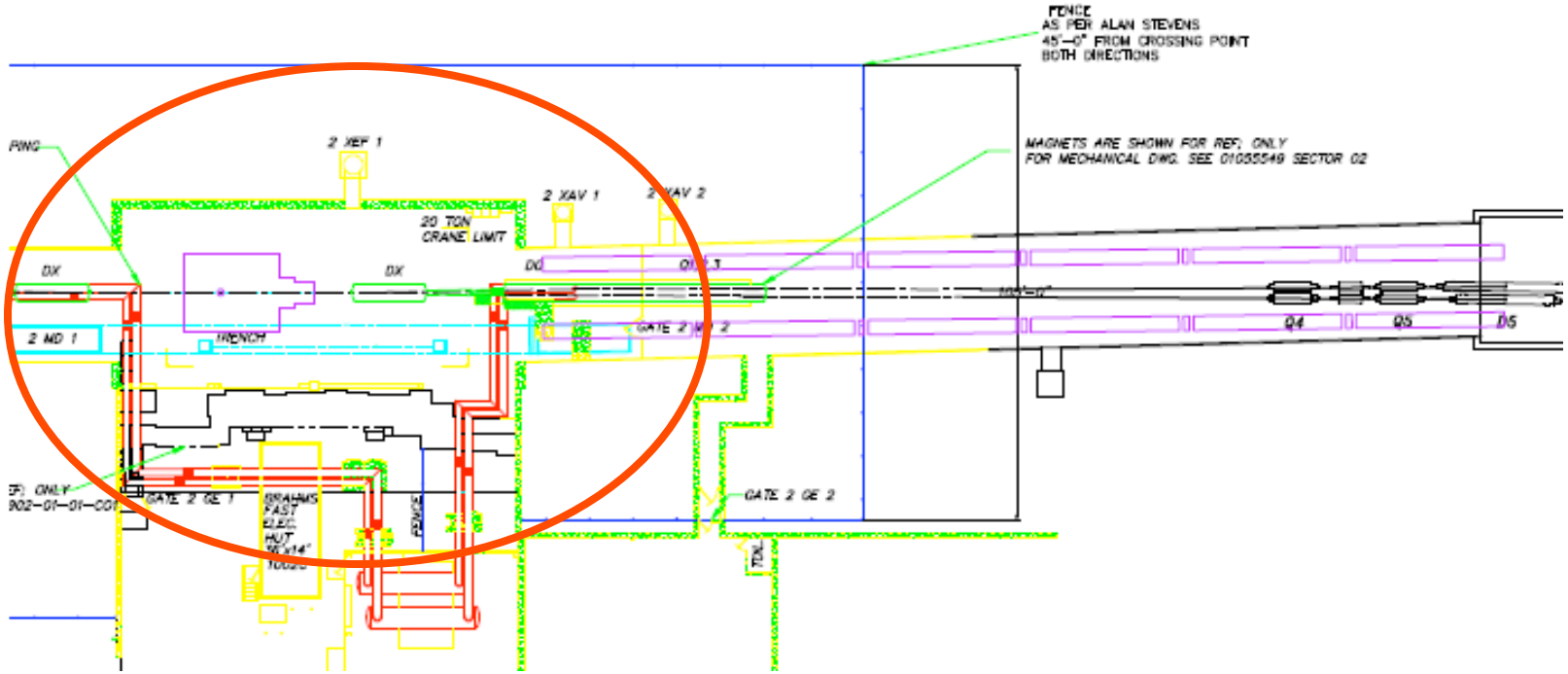
The distance between the linacs axis is 6.3 m

80% fill factor gives the radius 2.5 m

Assuming no cryostats and quads size 15 cm

MEeIC: IP2 for ERL location

Left side is about twice wider, we may assume the maximum radius 5 m



MEeIC: Some of ERL parameters

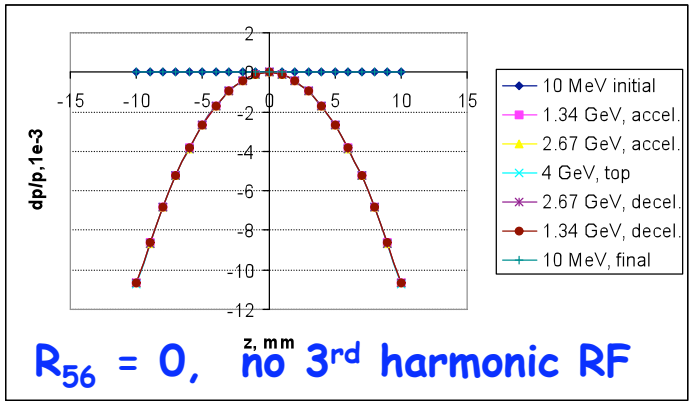
e-Beam energy in the last right arc: $E_{max}-\Delta E_{perpass}/2$

Energy losses full turn [KeV]=88.5 E[GeV]^4 /R[m]

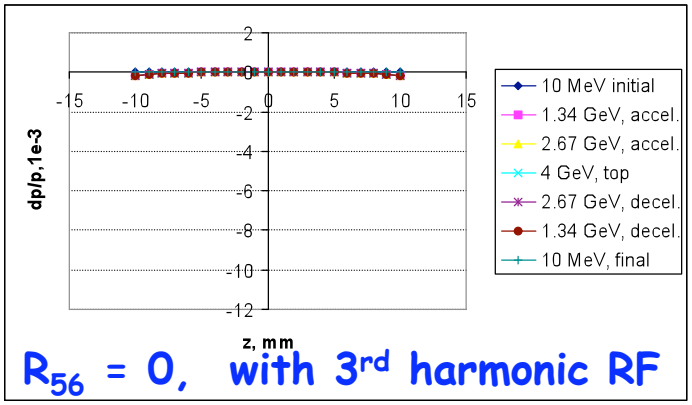
E_{col}, GeV E_{arc}, GeV	2 1.67	3 2.5	4 3.33	4 4
R, m (80% filling factor)	2.5	2.5	2.5	**5**
Current, mA	50	50	50	**50**
Number of passes	3	3	3	**3**
Dipole magnetic field, T	2.2	3.3	**4.4**	**2.7**
Energy losses per arc (half turn), MeV	0.05	0.7	2.2	**2.3**
Power losses per arc, kW Density, kW/m	2.5 0.32	35.2 4.5	110.7 **14.1**	**115.2** **7.33**

Do we need 3rd harmonic RF system?

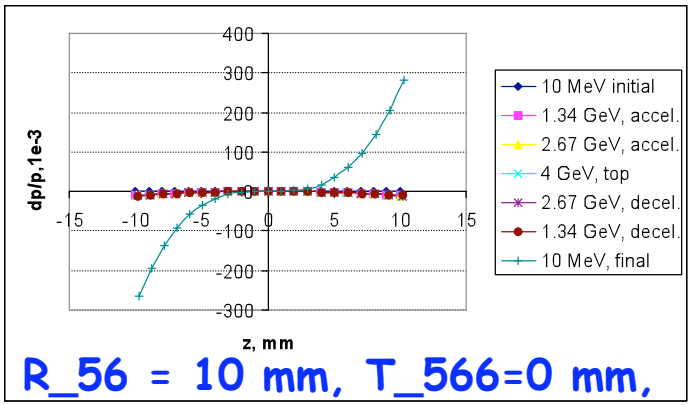
Momentum spread vs. longitudinal coordinate: acceleration/ deceleration



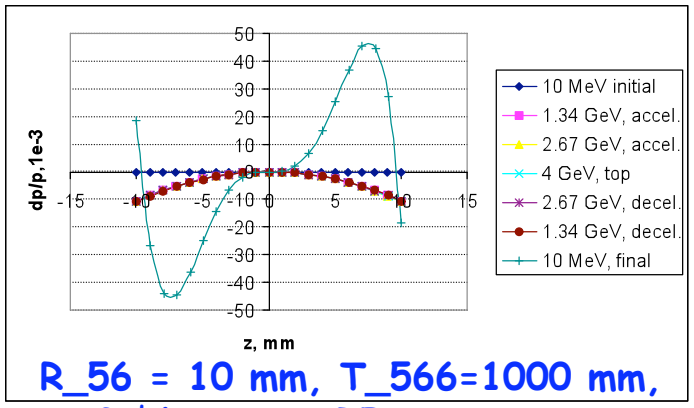
R_{56} = 0, no 3rd harmonic RF



R_{56} = 0, with 3rd harmonic RF



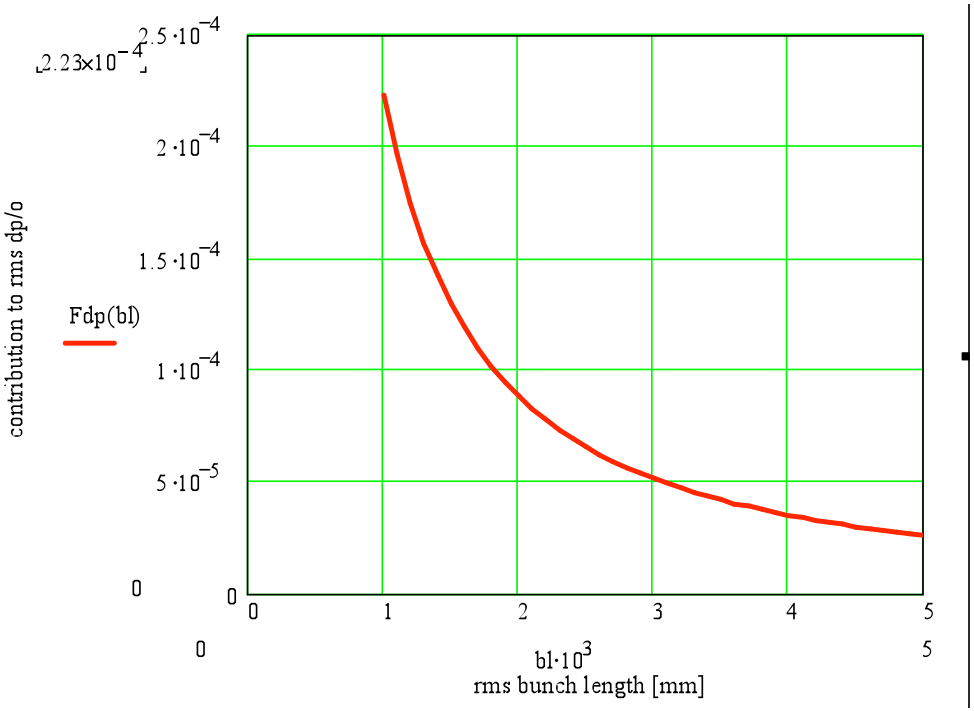
R_56 = 10 mm, T_566=0 mm, no 3rd harmonic RF



R_56 = 10 mm, T_566=1000 mm, no 3rd harmonic RF

Coherent Synchrotron Radiation (CSR) and bunch length for MEeIC – free space

Increase in rms dp/p after passing full arc (R=2m) at 2GeV



$$\left\langle \frac{p-p_0}{p_0} \right\rangle = -0.35 \frac{r_e N_e L_{eff}}{\gamma (R^2 \sigma_{es}{}^4)^{1/3}}$$

$$\sigma_p = 0.25 \frac{r_e N_e L_{eff}}{\gamma (R^2 \sigma_{es}{}^4)^{1/3}}$$

$$\frac{P_{coh}}{P_{inc}} = \frac{3^{7/6}}{4\pi} \Gamma(2/3) \frac{N_e}{\gamma^4} \left(\frac{R}{\sigma_z} \right)^{4/3}$$

For N_e=3e10 (5nC), σ_z=5mm:
P_{ratio} is 0.017 for 4 GeV
P_coh=280W/m for R=3m
P_coh=370W/m for R=2m

© A.Fedotov

Can be important! for 1mm rms bunch length & R=2m, P_coh is already 3 kW/m

Suppression of CSR by wall shielding

where h is beam pipe full height, and R is the radius of the orbit in bending magnet.

For radiation to be coherent the bunch length should be:

$$\sigma_z \le \frac{h}{\pi}\sqrt{\frac{3h}{2\pi R}}$$

CSR suppression parameter

Effectiveness of shielding is described by parameter:

$$x_{th} = \frac{2\pi^3 R\sigma_z^2}{3h^3}$$

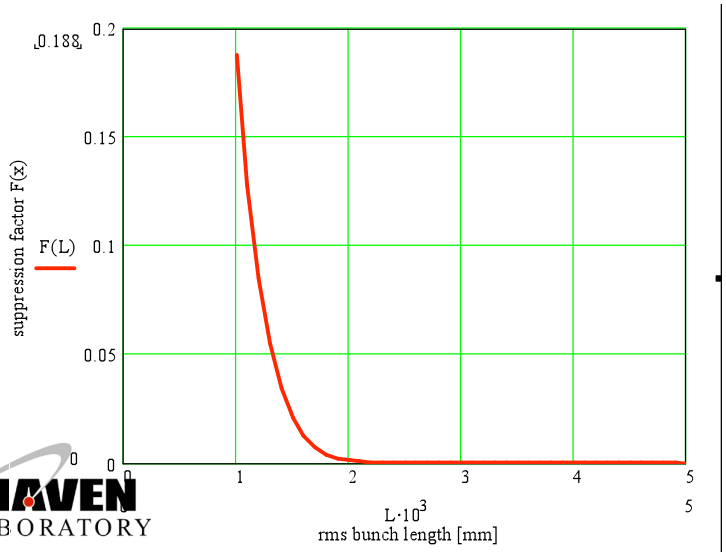
For x < 1, there is no suppression from shielding.

For 1 < x< 4p², there is strong reduction of CSR:

$$F(x) = x^{-1/3}e^{-x}$$

For x > 4p², CSR is completely suppressed by shielding:

$$\sigma_{th,\min} = \sqrt{\frac{6h^3}{\pi R}}$$

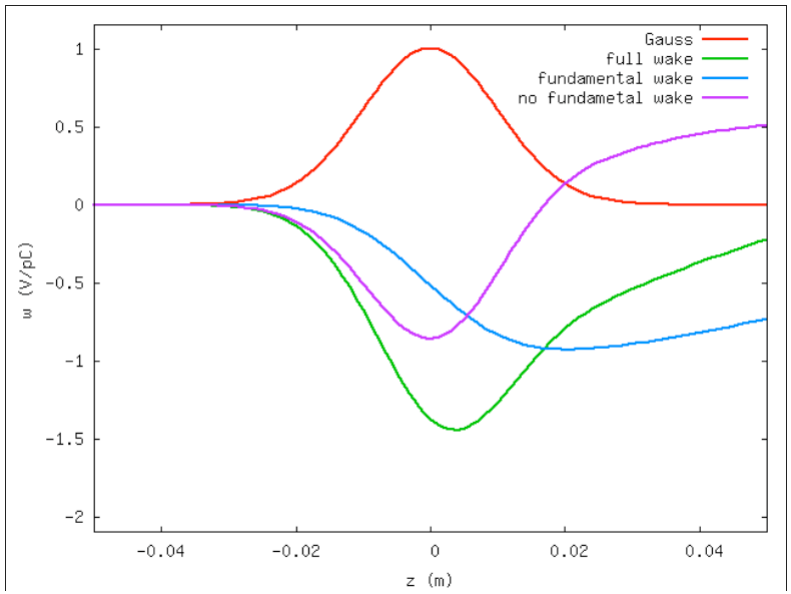


- If h=1cm then CSR will be completely shielded for bunch
length 1mm rms (full length 4.8mm) or larger.

- If h=3cm will be completely shielded for 5mm (full length 2.6cm) or larger. But even for 1mm rms – reduction factor is F=0.2.

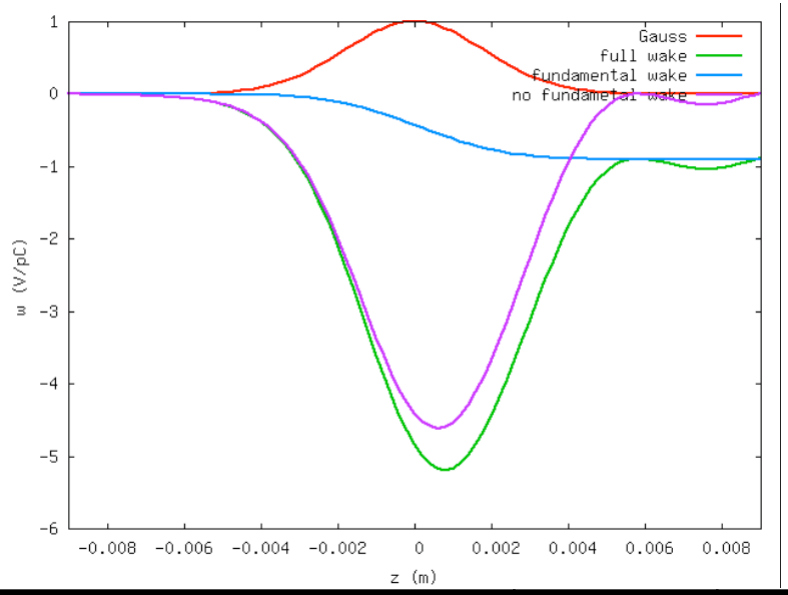
Energy loss in the SRF structures: 2 mm is OK!

σ=1 cm, 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=1.8 mm, Gauss



	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

© E.Pozdeyev

Energy loss to Cavity Wakes

E.Pozdeyev

qb (pC)	5000	I(A)	0.05
fb (Hz)	1.00E+007	ncav	360

sig(mm)	kii (V/pC)	kii_adj (V/pC)	Vloss (MV)	Ploss (kW)	dVtot (MV)
1.500	-4.336	-3.817	-6.8706	-343.530	-9.288
1.800	-3.797	-3.281	-5.9058	-295.290	-8.136
2.000	-3.504	-2.990	-5.382	-269.100	-7.47
2.500	-2.951	-2.437	-4.3866	-219.330	-6.138
5.000	-1.744	-1.232	-2.2176	-110.880	-3.186
7.500	-1.304	-0.796	-1.4328	-71.640	-1.872
10.000	-1.071	-0.567	-1.0206	-51.030	-1.548

Related issues:

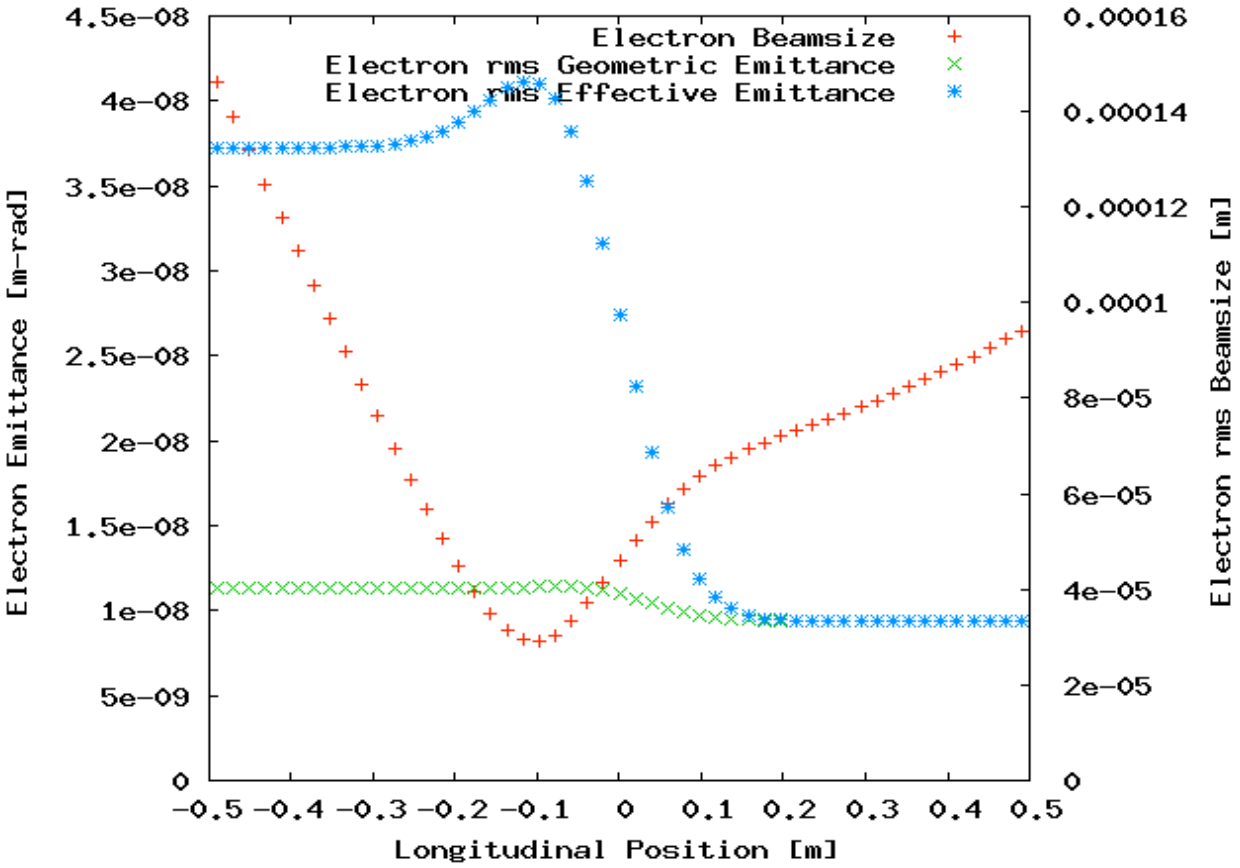
-Compensation of average energy loss (Vloss), to eliminate energy difference in the same pass for accelerating and decelerating beam. (Second harmonic cavities?)

-Managing HOM power output.

-Reduction of the energy spread (dVtot) for lower energy (10 MeV) transfer

Beamsize and Emittance evolution of electron beam: © Y.Hao

(Electron beam comes from right)



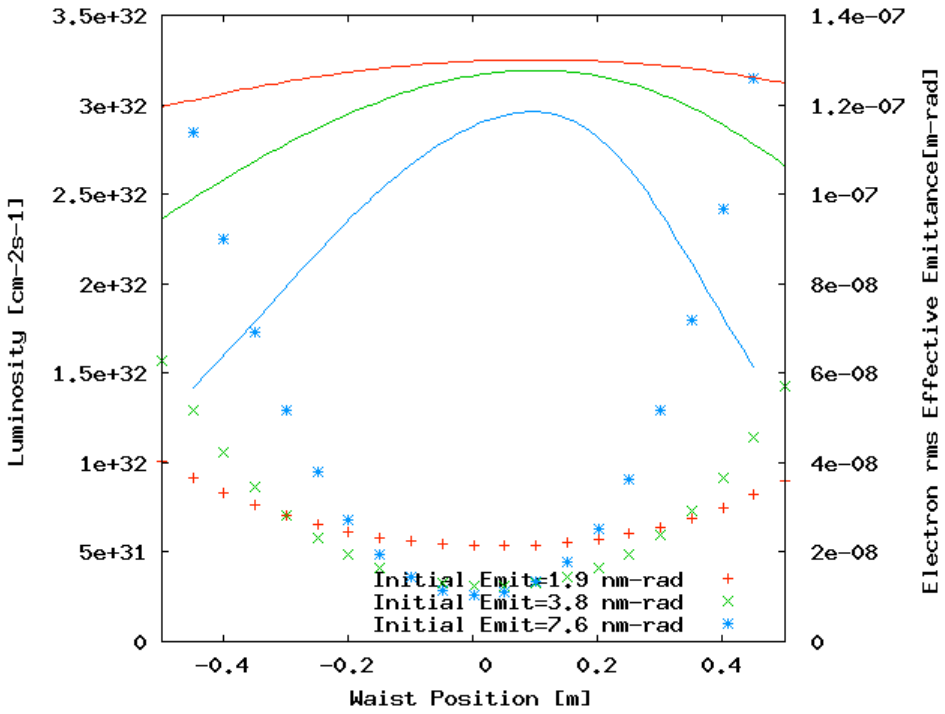
Example:
Initial Emittance:
9.4 nm-rad
Waist beta function:
0.5 m
Waist position:
0 m (at IP)
Luminosity:
1.2×10^{32} $cm^{-2}s^{-1}$

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.

'Pre Cooled' Case

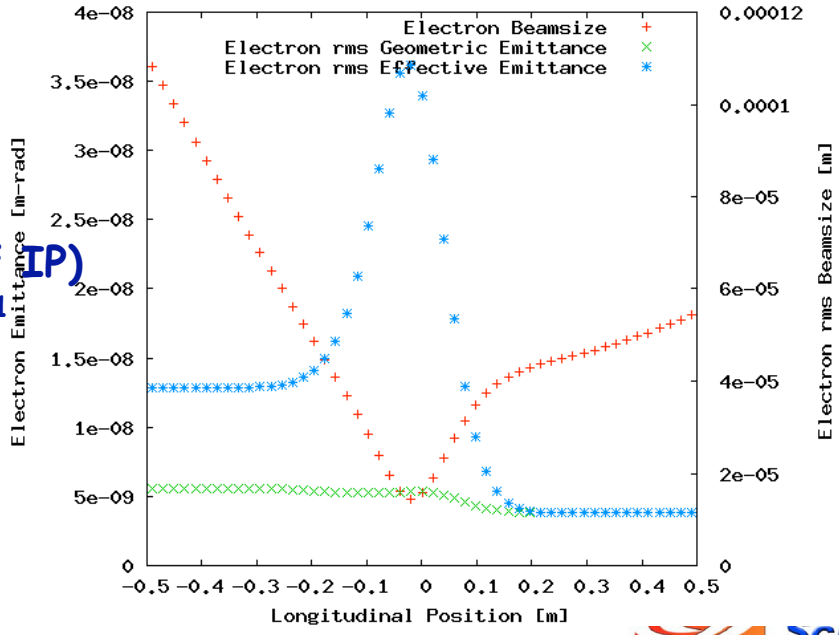
Similar results are achieved.

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}



© Y.Hao

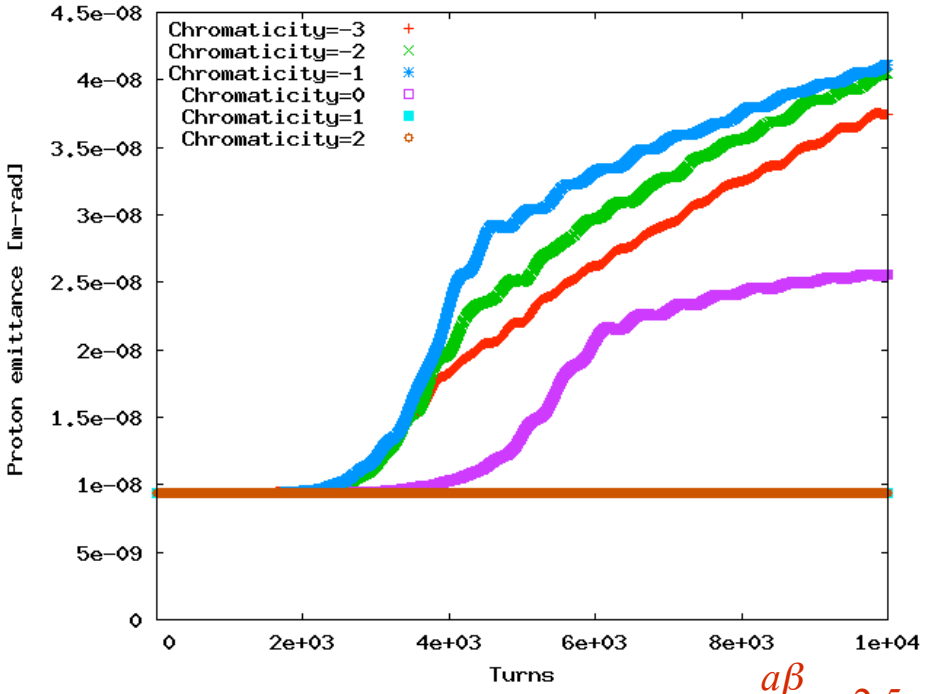
Proton beam instability can be suppressed by choosing value appropriate chromatisity

© Y.Hao

In both cases, the beam parameters are above the threshold of kink instability for proton beam. Proper energy spread is needed to suppress the emittance growth.

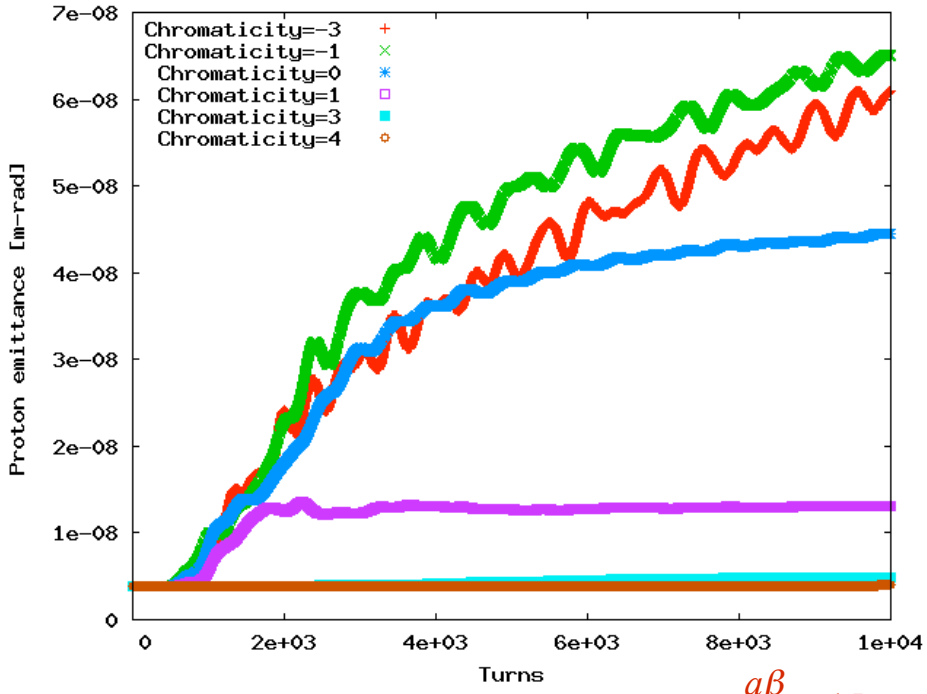
An estimation of strong head-tail instability threshold gives:

$$\frac{a\beta}{8\nu_s} < 1 \qquad a = \frac{\sigma_{pz}}{2f_p f_z} = \frac{N_p N_e r_p r_e \sigma_{pz}}{2\sigma_{px}^2 \sigma_{ex}^2 \gamma_p \gamma_e}$$



Not Cooled case $\frac{a\beta}{8\nu_s} \sim 2.5$

Chromaticity=1 is needed



Pre Cooled case $\frac{a\beta}{8\nu_s} \sim 15$

Chromaticity=4 is needed

Assuming the rms energy spread is 5e-4

Conclusions

- **eRHIC group at C-AD, BNL plans to complete technical design of MEeIC in Spring, 2009**
- MEeIC needs physics case
- **Staging eRHIC allows for a natural transition of the accelerator with significant (~90%) re-use of equipment from MEIC and reduction in the eRHIC cost ~ $135M**
- Coherent electron cooling test fit naturally into the scheme - i.e. coherent electron cooling will be tested in time when it is needed for full-energy, full-10^{34} $cm^{-2}sec^{-1}$ - luminosity eRHIC
- eRHIC future up-grade (if physics justifies additional $$) can bring c.m. energy to HERA level with x 1000 of HERA luminosity

Thank you for

Contest to name first MEeIC experiment

- Inspired by the physics:
  - **OompheP** (suggested pronunciation: UUMFEP)
  - eP-Oomph……(suggested pronunciation: I P_uumf)

Prize – A bottle of good champagne

Send suggestions to vl@bnl.gov

V.N. Litvinenko, EIC Collaboration Meeting, LBNL, 11-13 December, 2008