Beam Dynamics in MeRHIC

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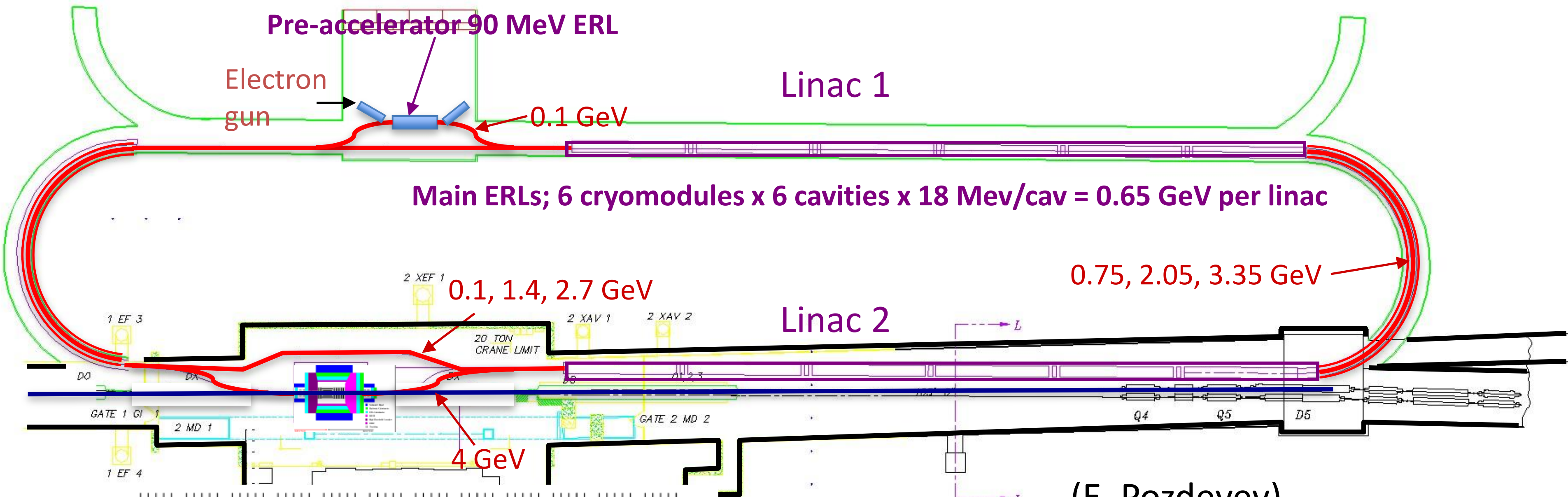
On behalf of MeRHIC/eRHIC working group

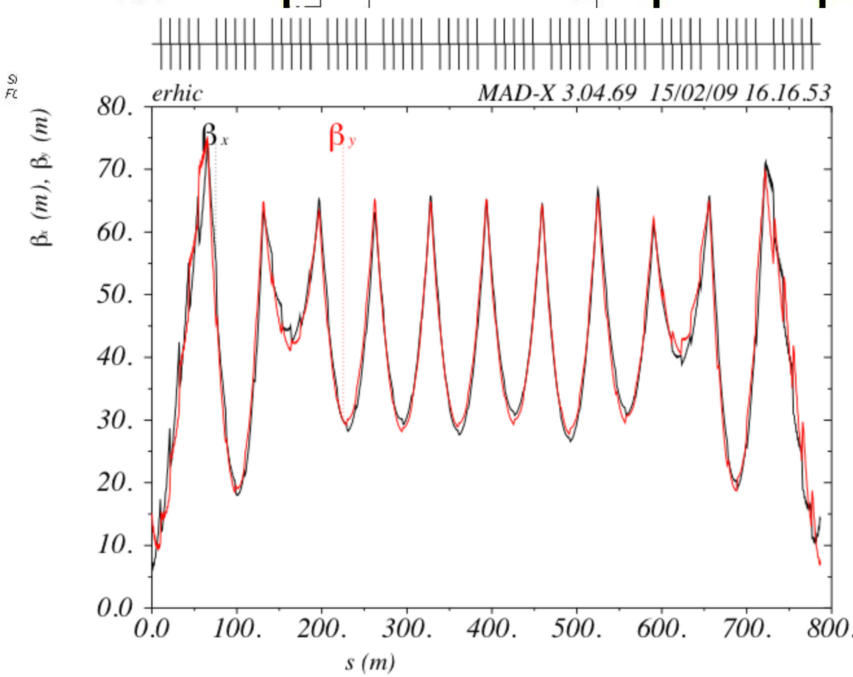
Outline

- Linac Design and BBU Study
- Energy losses and compensation
- Beam-beam effects
  - Electron disruption, magnet aperture requirement
  - Kink instability, Pinch effect
- Electron Errors

Linac—Constant Gradient Quad

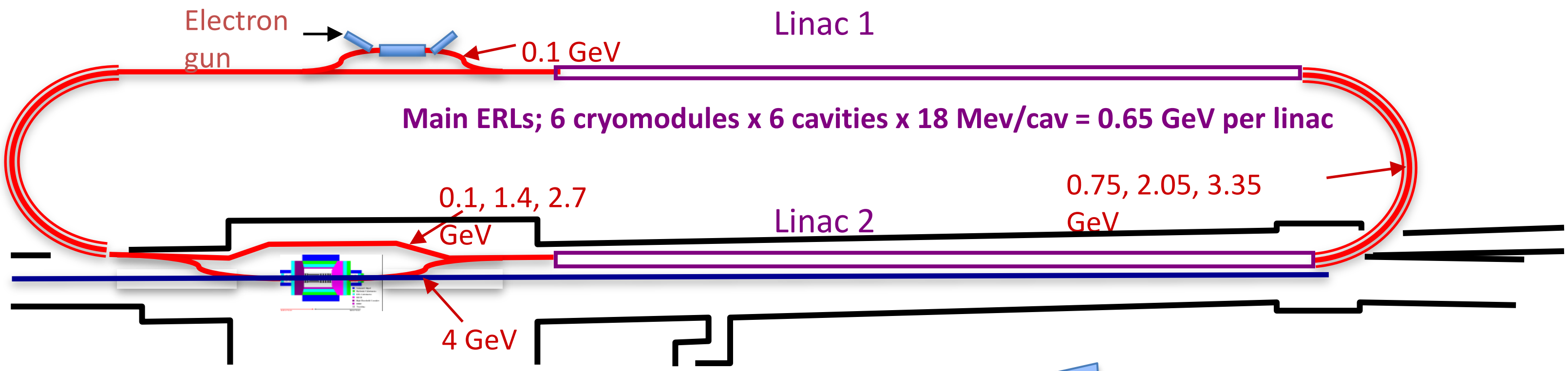


(E. Pozdeyev)

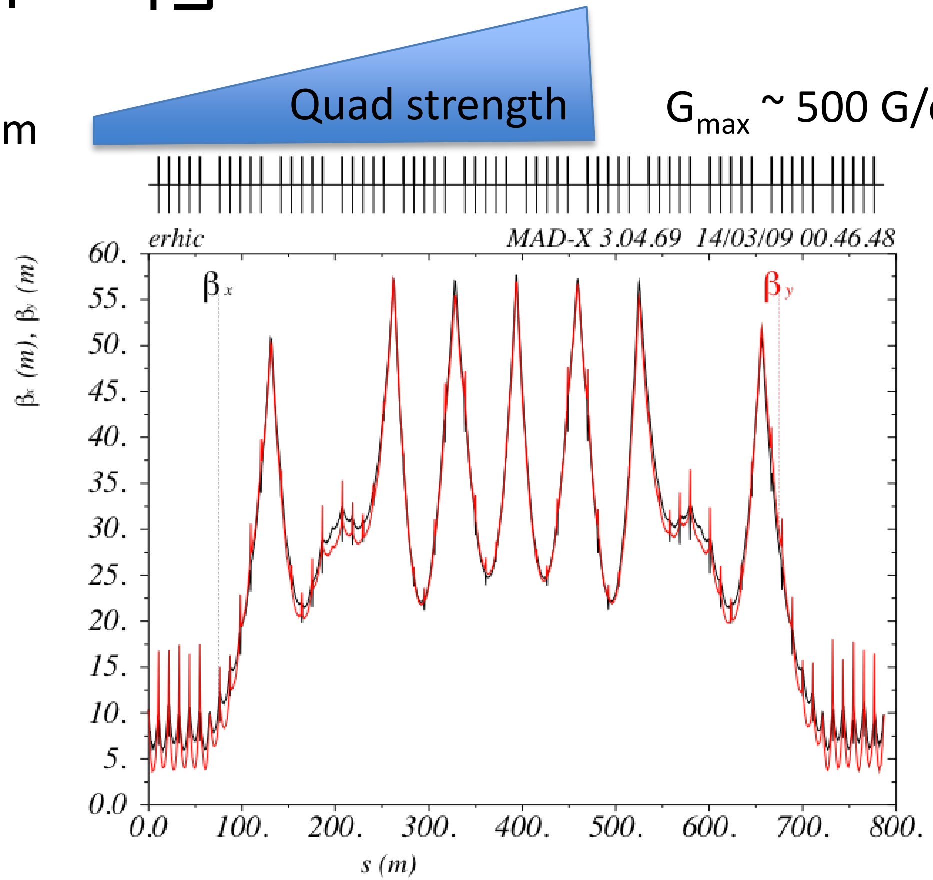


- **Bunch: Q_b=5 nC, σ_z=2mm**
- **E_{inj}/E_{max} = 100MeV / 4GeV**
- **3 acc./decel. passes**
- **N cavities = 72 (total)**
- **L module/period = 9.6 / 11.1m**
- **E_f = 18.0 MeV/cav**
- **dE/ds ~ 10 MeV/m**

Linac—Alternate Gradient Quad



G_{min} ~ 100 G/cm



G_{max} ~ 500 G/cm

Scaling gradient with energy produces more focusing and increases BBU threshold

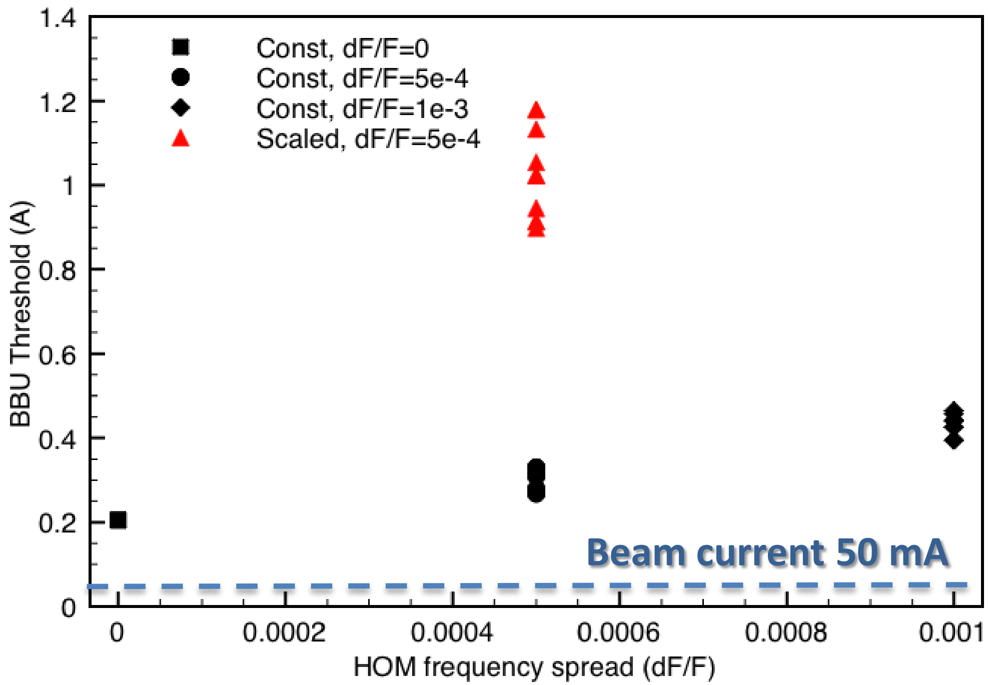
(E. Pozdeyev)

BBU simulations

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

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

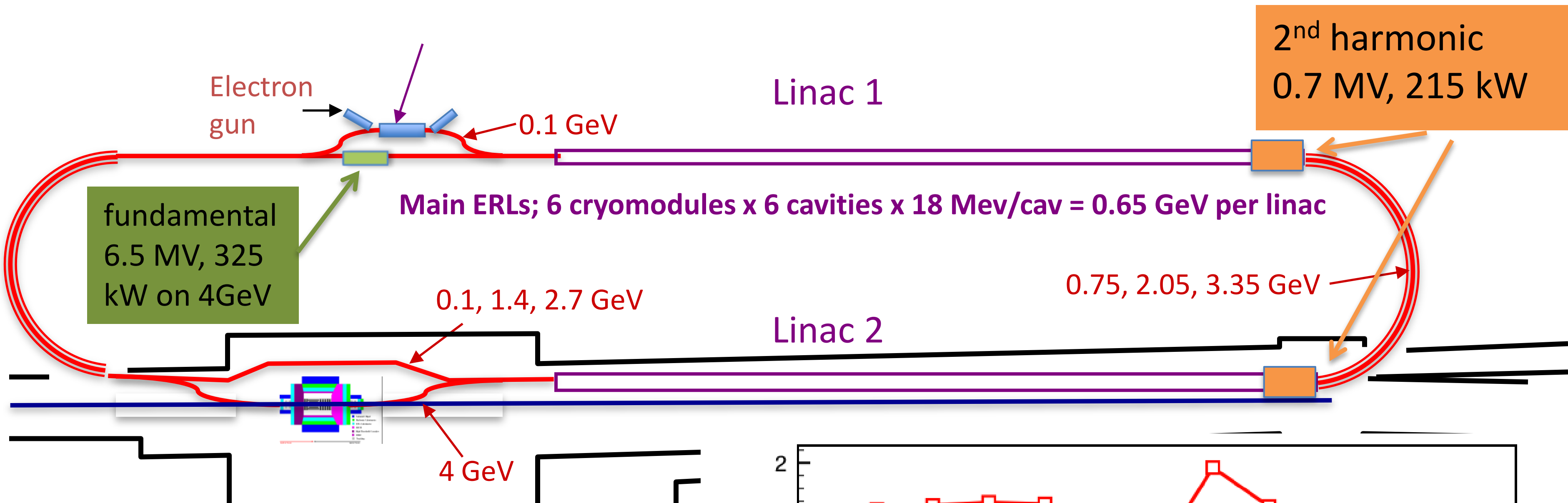
Simulated BBU threshold (GBBU) vs. HOM frequency spread. Beam current 50 mA



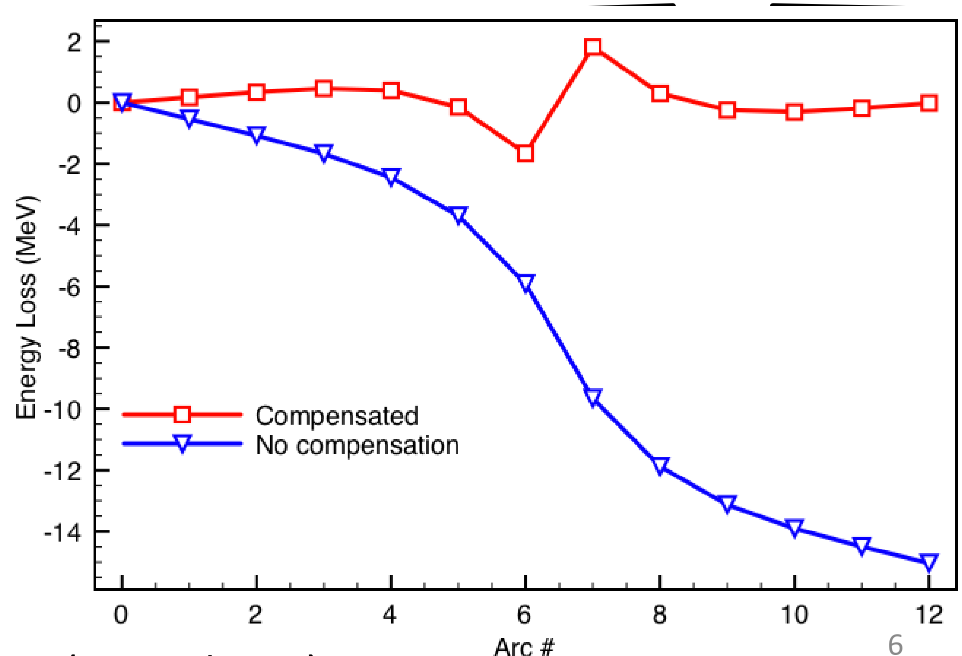
Threshold significantly exceeds the beam current, especially for the scaled gradient solution.

(E. Pozdeyev)

Energy Loss and Compensation



- **Total energy loss: 15.5 MeV**
  - Linac cavities: 6.5 MeV (0.54 MeV/linac)
  - Synch. radiation: 8.8 MeV
  - RW: 0.15 MeV, CSR: negligible
- **Total power loss: 765 kW**
- **Energy difference in arcs (max)**
  - Before compensation: 2%
  - After compensation: 0.06%



(E. Pozdeyev)

Beam losses

- Touschek
  - Total loss beyond ±6 MeV is 200 pA.
  - Small but, maybe, not negligible. We will look more carefully.
- Scattering on residual gas (elastic)
  - Total loss beyond 1 cm aperture at 100 MeV is 1 pA
  - Negligible
- Bremsstrahlung on residual gas
  - Total loss beyond ±6 MeV is < 0.1 pA
  - Negligible

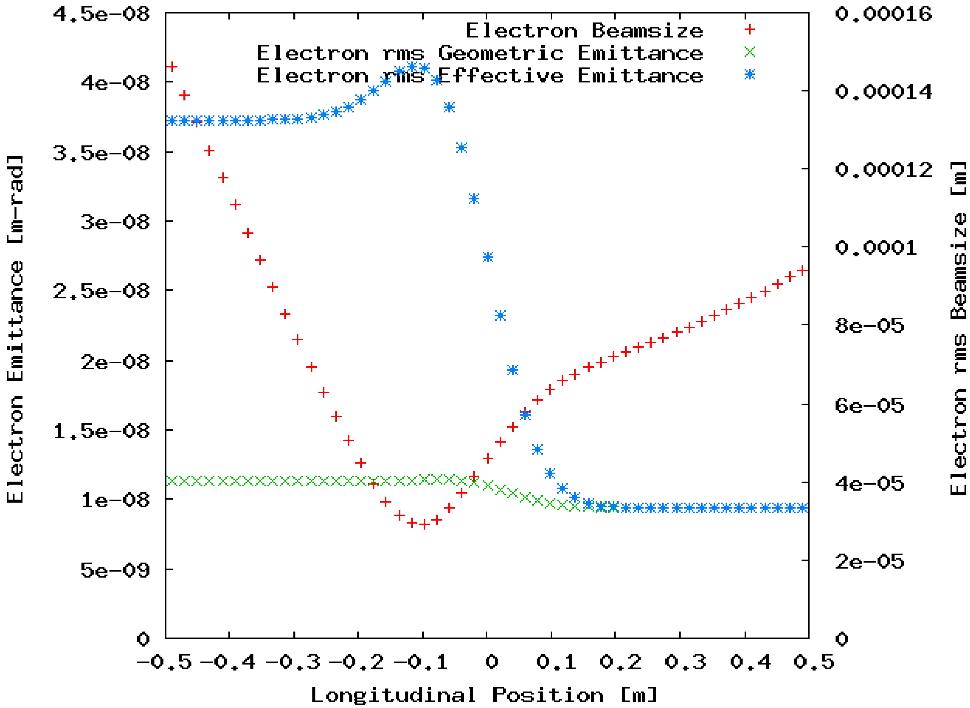
(A. Fedotov, G. Wang)

Beam-Beam parameters

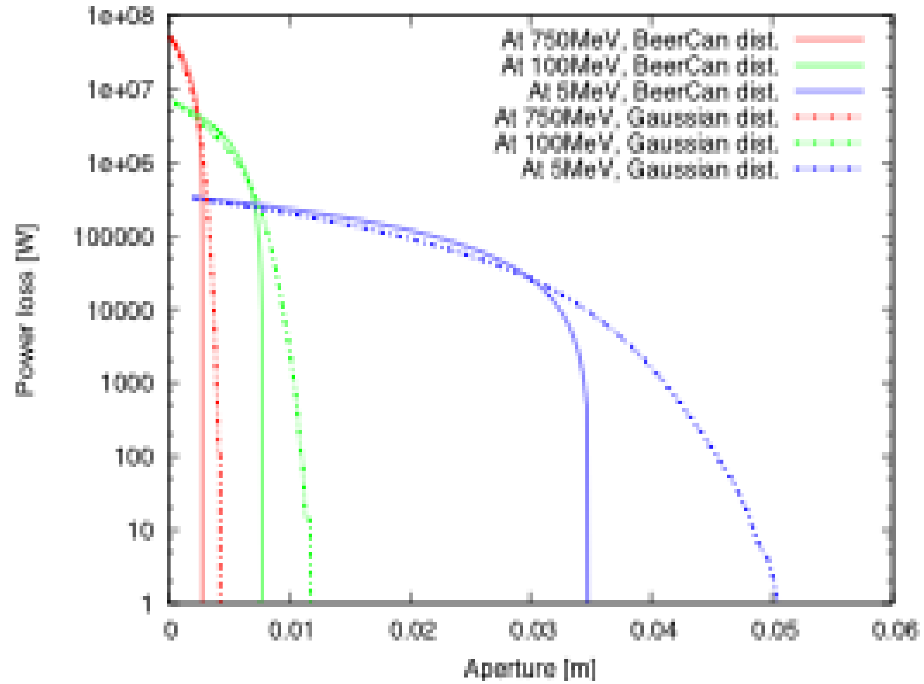
	p	e
Energy, GeV	250	4
Number of bunches	111	
Bunch intensity, 10^{11}	2.0	0.31
Bunch charge, nC	32	5
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73
rms emittance, nm	9.4	9.4
beta*, cm	50	50
rms bunch length, cm	20	0.2
beam-beam for p /disruption for e	1.5e-3	3.1
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	0.93	

Beam-Beam: electron beam disruption

Emittance growth in collision



Power loss if beam is not re-matched (Beer-can and Gaussian cut at 4σ)



- Growth of r.m.s. emittance is small. However, mismatch is large.
- Pinch effect for ‘Not-Cooled’ case is less significant (Compare with eRHIC)
- Re-matching section might be required
- Re-matching section has to accommodate the RHIC abort gap (fast quad, electron lens)

Beam-Beam: kink instability

Without Landau damping, the beam parameters are above the threshold of kink instability for proton beam. Proper energy spread and chromaticity is needed to suppress the emittance growth.

To avoid strong head-tail instability:

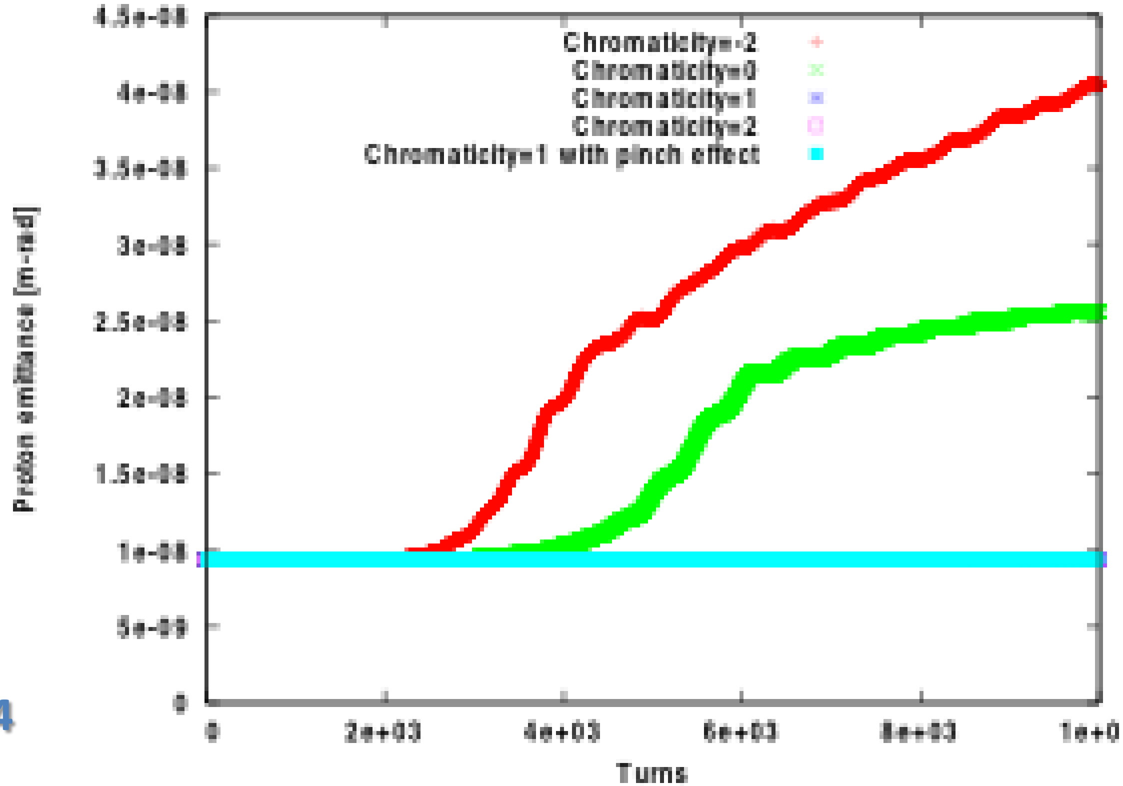
$$\frac{a\beta}{8\nu_s} < 1$$

$$a = \frac{\sigma_{pz}}{2 f_p f_e} = \frac{N_p N_e r_p r_e \sigma_{pz}}{2\sigma_{px}^2 \sigma_{ex}^2 \gamma_p \gamma_e}$$

Not Cooled MeRHIC case

$$\frac{a\beta}{8\nu_s} : \; 2.5$$

Chromaticity of 1 and dE/E of 5e-4 Suppress the instability



Recently, a feedback scheme is carried out. We demonstrated that feedback can suppress kink instability in eRHIC, which originally needs large chromaticity.

Electron beam random modulations

$$\ln\left\langle\frac{J(\theta)}{J(0)}\right\rangle = < 2u_n > = n\frac{\sigma_\epsilon^2}{2}\frac{1-e^{-2\alpha}}{1+e^{-2\alpha}-2\cos(4\pi Q)e^{-\alpha}}$$

for Quad Error

Reduction factor R

$$2\epsilon_{rms}\beta^* = < |U(k)|^2 > = |U_0|^2 + k(\epsilon\sigma_y)^2\frac{1-e^{-2\alpha}}{1+e^{-2\alpha}-2\cos(2\pi Q)e^{-\alpha}}$$

for Dipole Error

$$< \delta\epsilon_k \delta\epsilon_{m+k} > = \sigma_\epsilon^2 \exp(-\alpha|m|)$$

The correlation relation leads to a Lorentz distribution frequency spectrum $1/(\alpha^2\omega_0^2+\omega^2)$, ω_0 is the RHIC revolution frequency

More realistic than white noise.

An example:

$\alpha = 0.06$ $Q = 0.685$

$Rd = 0.06$

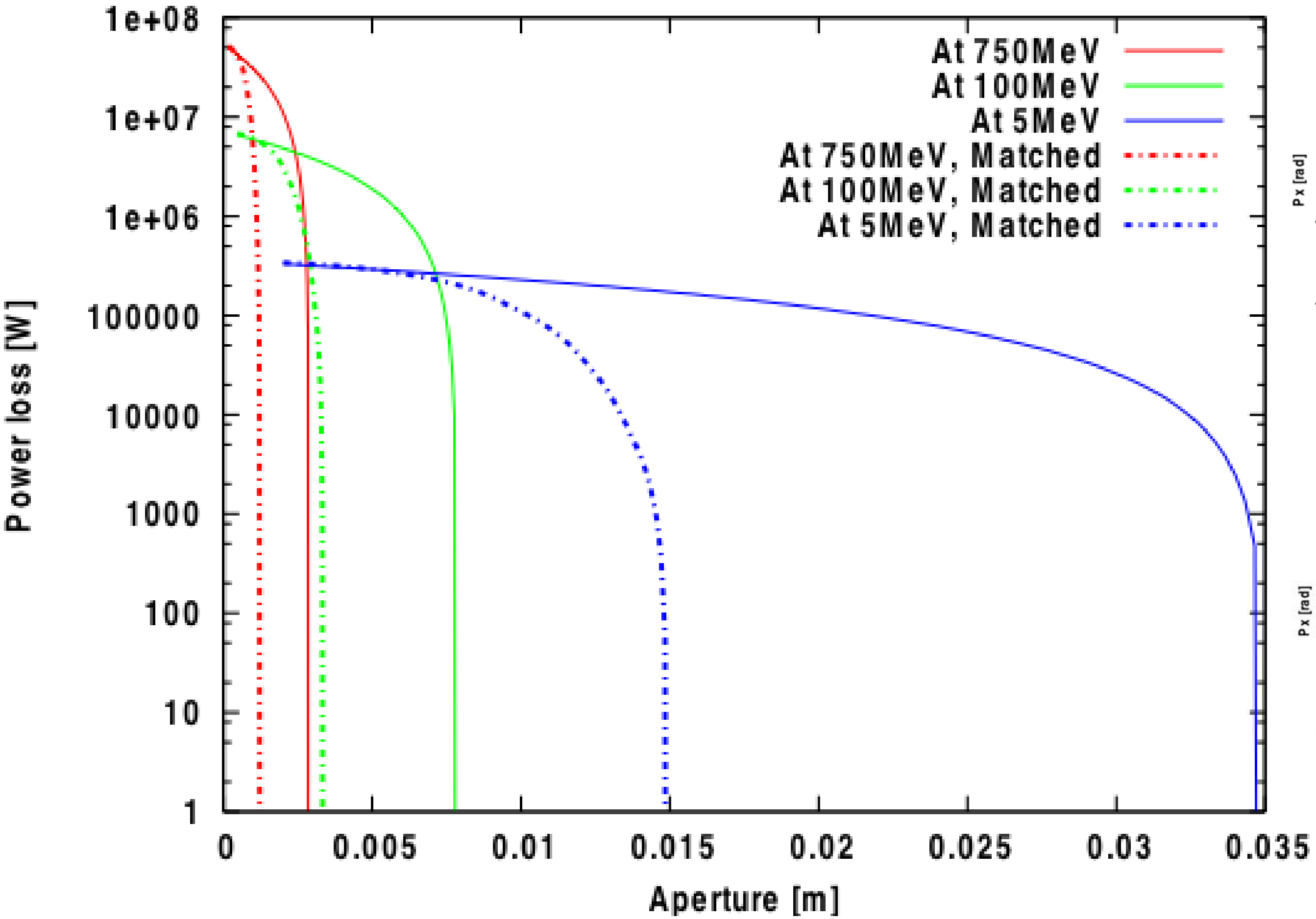
Which reduce the requirement of electron intensity by factor of ~16

(M. Blaskiewicz)

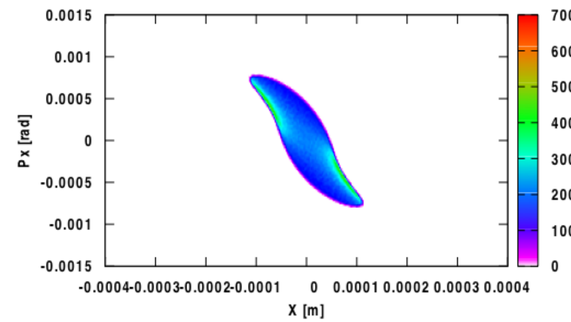
Conclusion

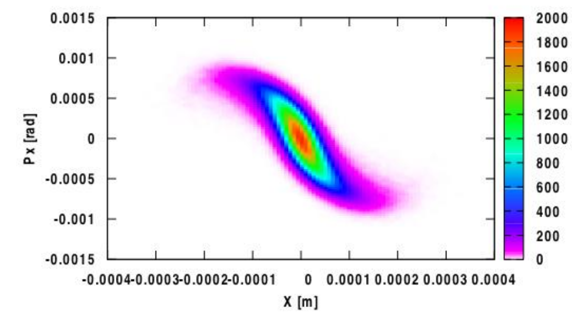
- Main Linac design has been developed
  - Constant gradient: weak identical quads, similar arcs, sufficiently high BBU threshold (250 mA)
  - Scaled gradient: higher BBU threshold (900 mA)
- No showstoppers are found in beam dynamics studies till now
- Works to do
  - Refine the simulation (BBU and Beam-Beam)
  - Ion trapping and countermeasures
  - Electron Noises, real frequency spectrum.

Beam-Beam: Matching scheme



Phase space of Beer-Can





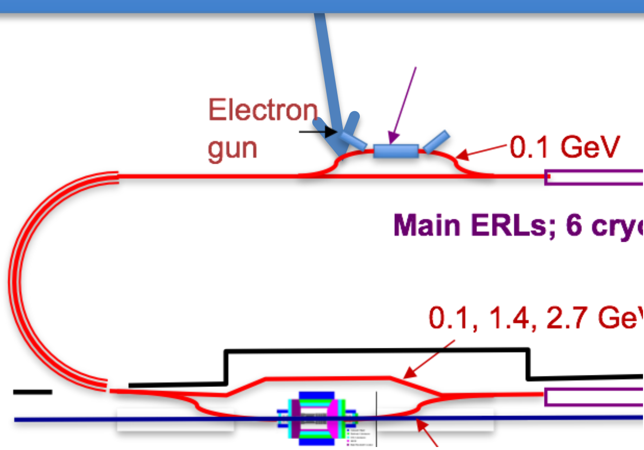
Phase space of Gaussian

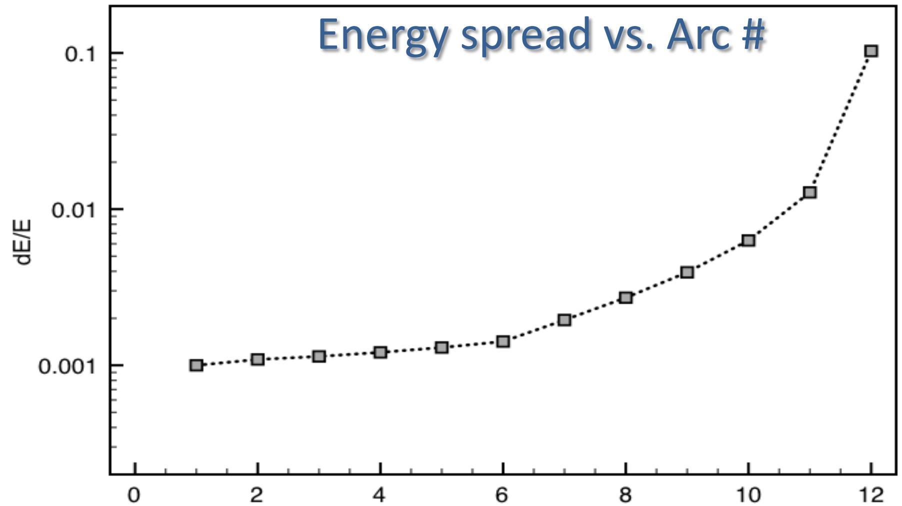
For Beer-Can distribution, if we match the optics after collision to the beam emittance shape, the required aperture will be largely reduced. The matching scheme for initial Gaussian distribution is more difficult and less effective because of the large tail.

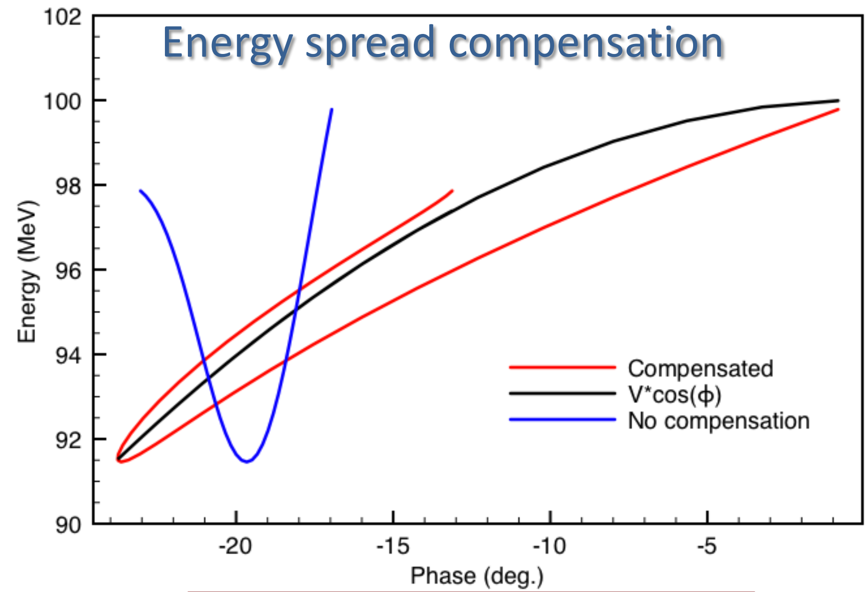
Energy spread and its compensation

	δE (MeV)
RF	0.17%
Cavity Wakes	8.9
Synch. Rad. (4•rms)	1.35
Resistive Wall	0.45
CSR	> 0.001
Total	10.7

100 MeV Arc with
M56=18 cm, M566=87 cm

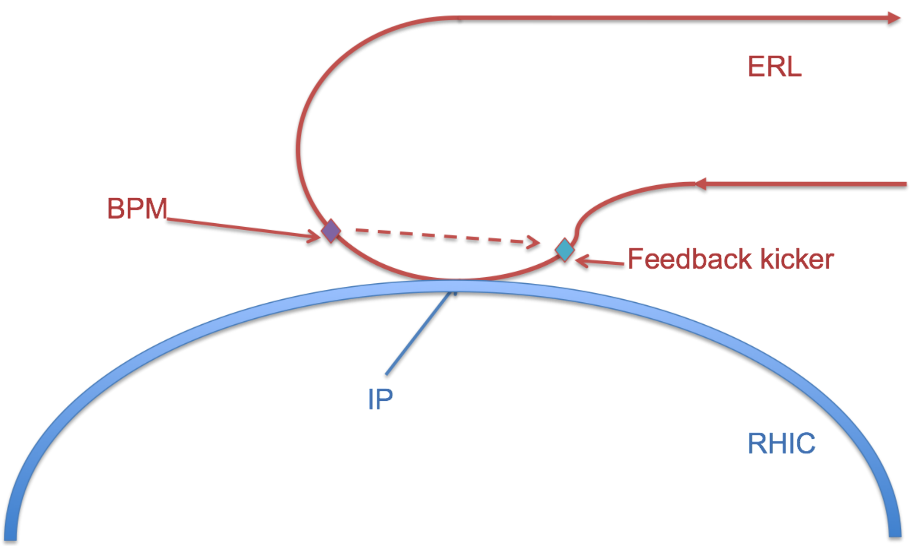


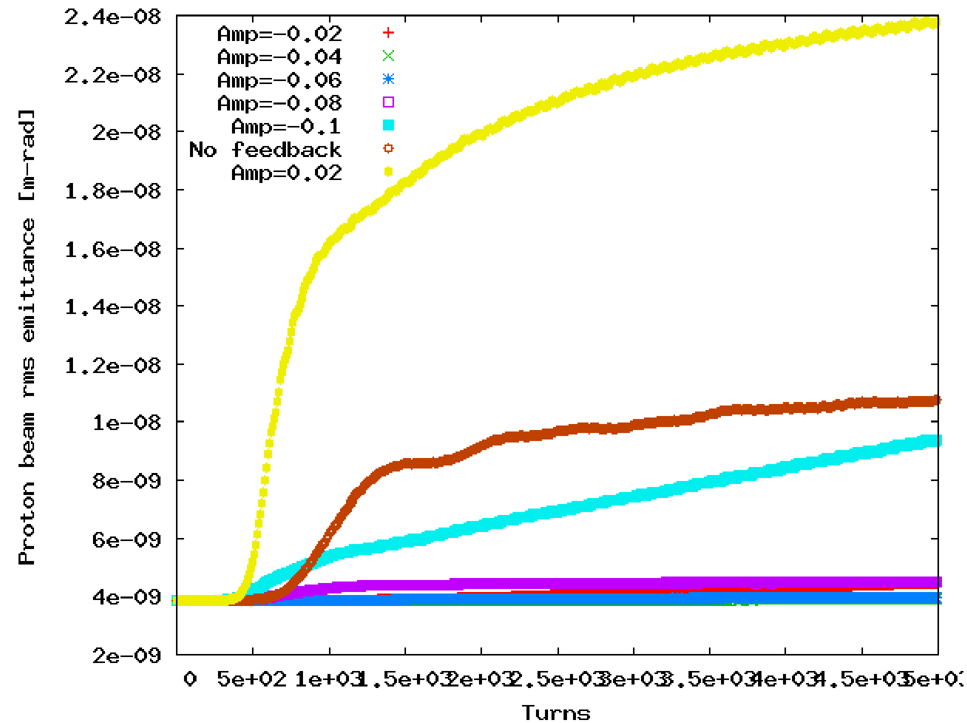




100 MeV: 9 MeV -> 2 MeV
200 MeV: 9 MeV -> 3 MeV

Feedback system for eRHIC kink instability





The feed back system measure the electron beam displacement after collision and the signal is amplified by certain factor A and feed through the next turn's electron bunch for specific proton bunch.

The factor Amp is determined by proton transverse tune, the position of BPM and kicker. It can also related to the noise level and how frequently the feedback is added.