Beam-Beam Interaction Study

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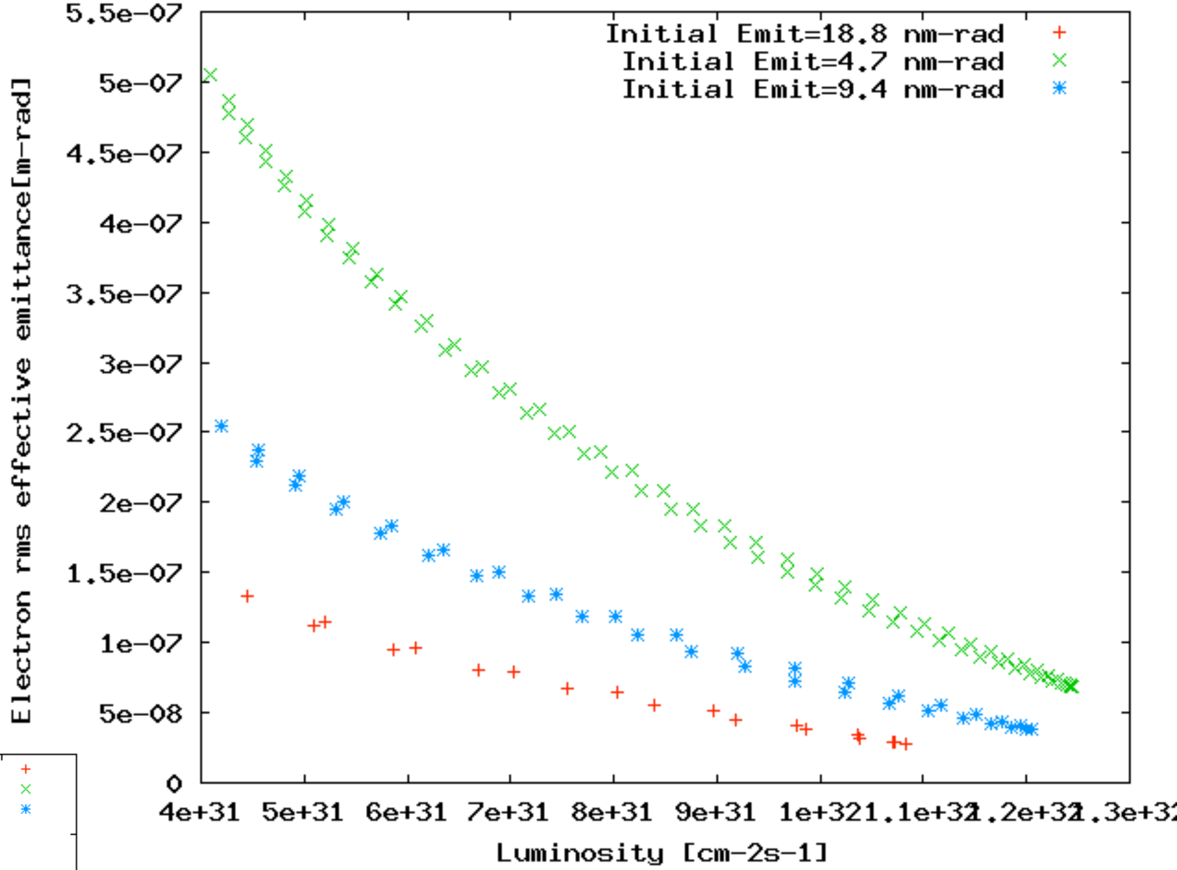
MEEIC parameters for e-p collisions

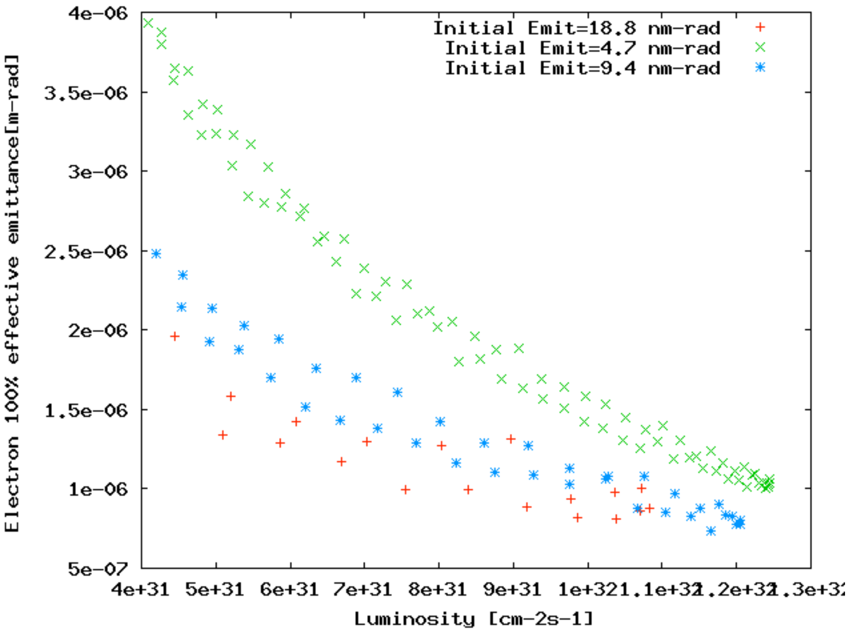
	not cooled		pre-cooled		high energy cooling	
	p	e	p	e	p	e
Energy, GeV	**250**	**4**	**250**	**4**	**250**	**4**
Number of bunches	**111**		**111**		**111**	
Bunch intensity, 10^{11}	**2.0**	**0.31**	**2.0**	**0.31**	**2.0**	**0.31**
Bunch charge, nC	**32**	**5**	**32**	**5**	**32**	**5**
Normalized emittance, 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-03**	**3.1**	**3.8E-03**	**7.7**	**0.015**	**7.7**
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	**0.93**		**2.3**		**9.3**	

'Not Cooled' Case

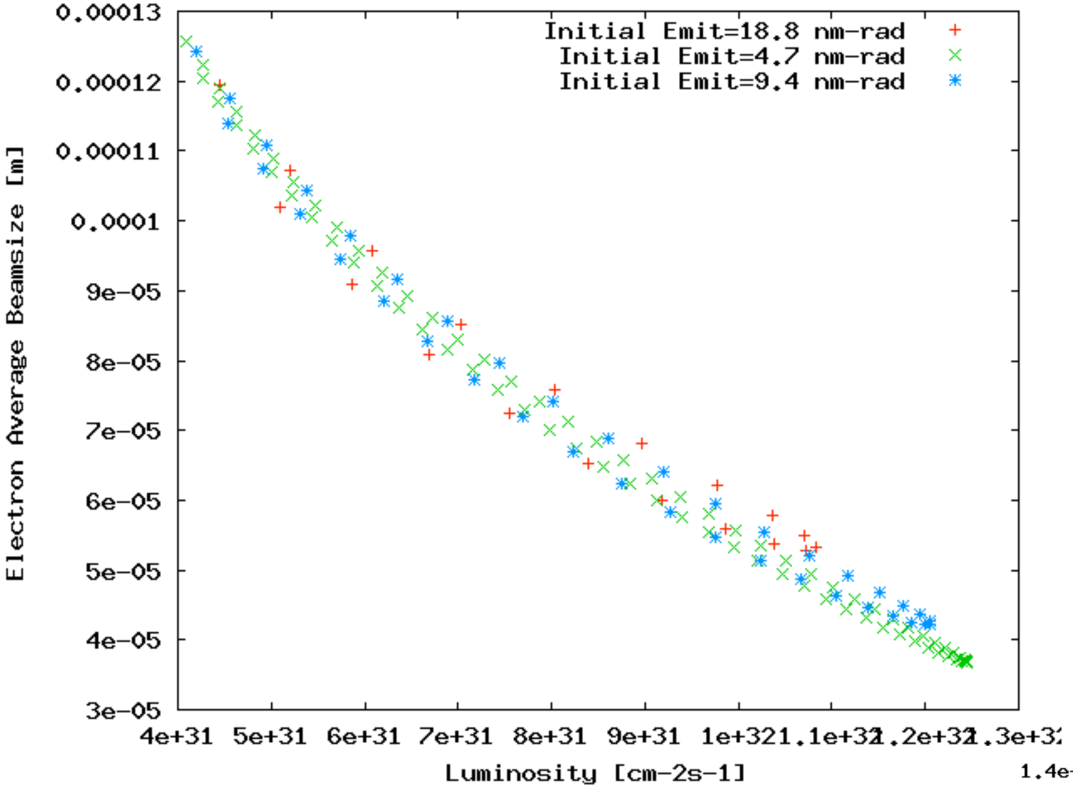
What is the optimized electron optics parameter?

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





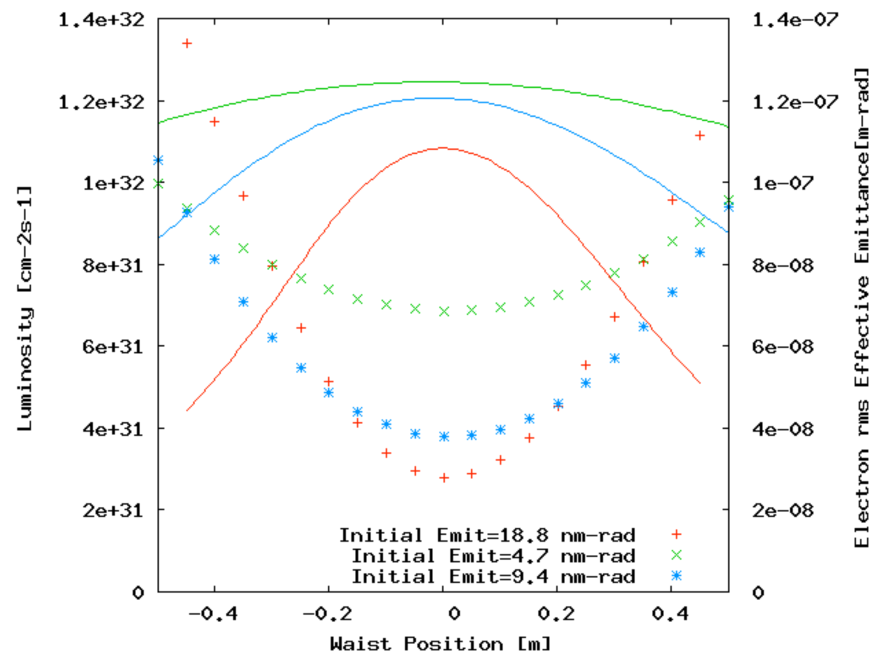
- Luminosity Decreases when lower final emittance is achieved.
- For specific luminosity, a larger initial electron emittance yields a smaller final emittance



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

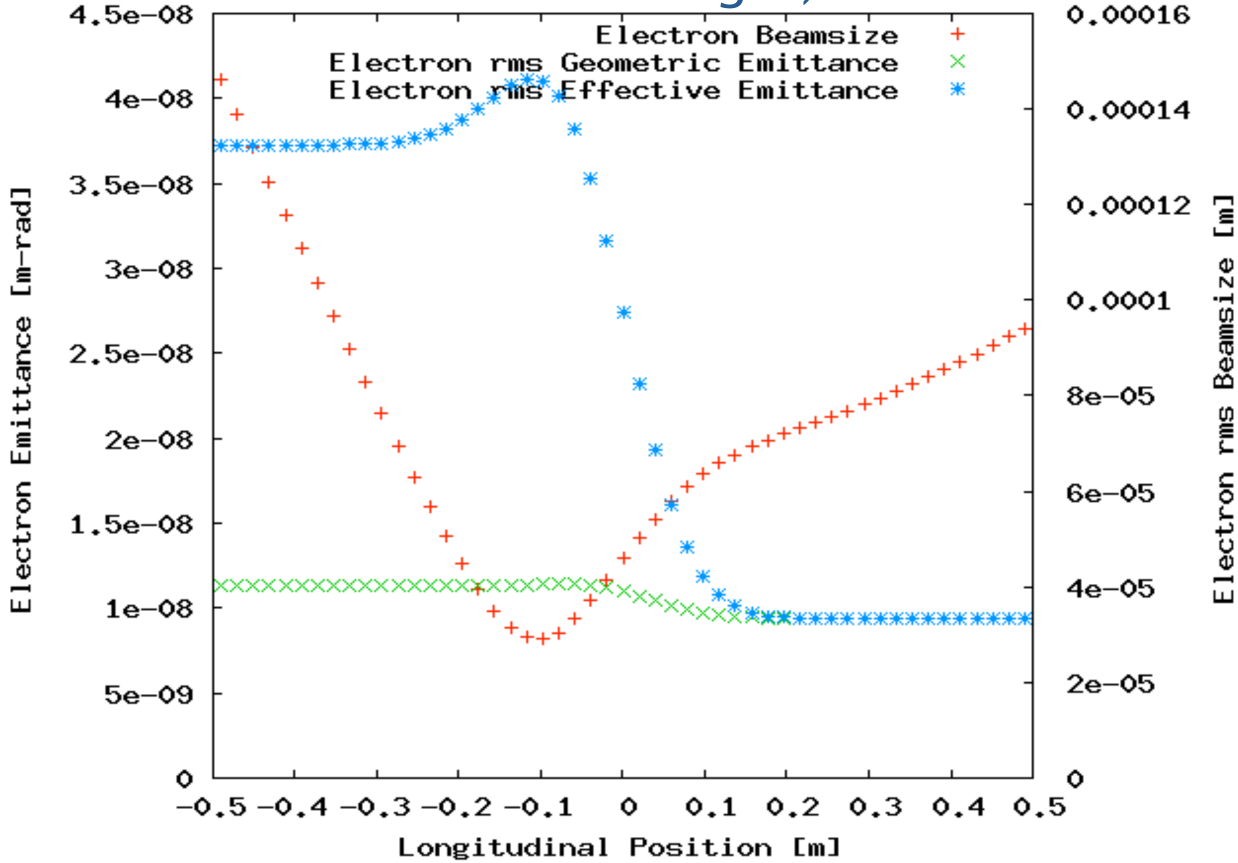
In 'not cooled' case, even the largest luminosity gives a safe value of electron beam size during collision.

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



Beamsize and Emittance evolution of electron beam:

(Electron beam comes from right)



Example:

Initial Emittance:
9.4 nm-rad

Waist beta function:
0.5 m

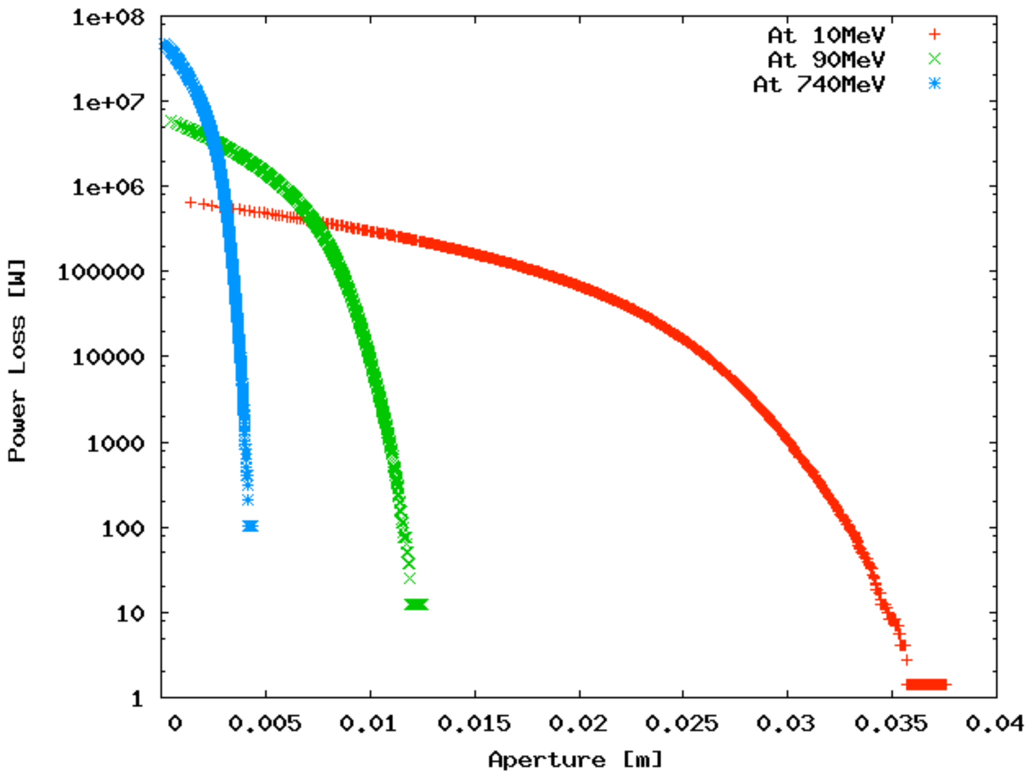
Waist position:
0 m (at IP)

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.

The beam loss at different position:
(Use beta=5m everywhere, easily scale later)

Position	Energy
Lowest energy at arc	740 MeV
At the exit of main linac	90 MeV
Before beam dump	10 MeV



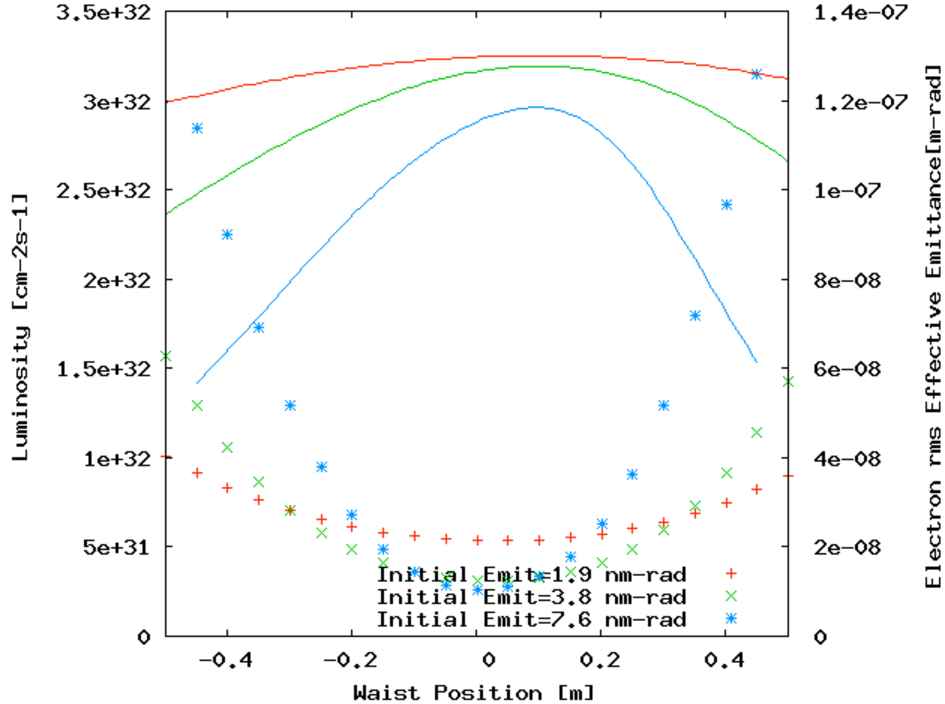
The required aperture if 1KW power loss is required.

Energy	Aperture
740 MeV	4 mm
90 MeV	11 mm
10 MeV	38 mm

‘Pre Cooled’ Case:

Similar results are achieved.

The electron beta function waist is 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:

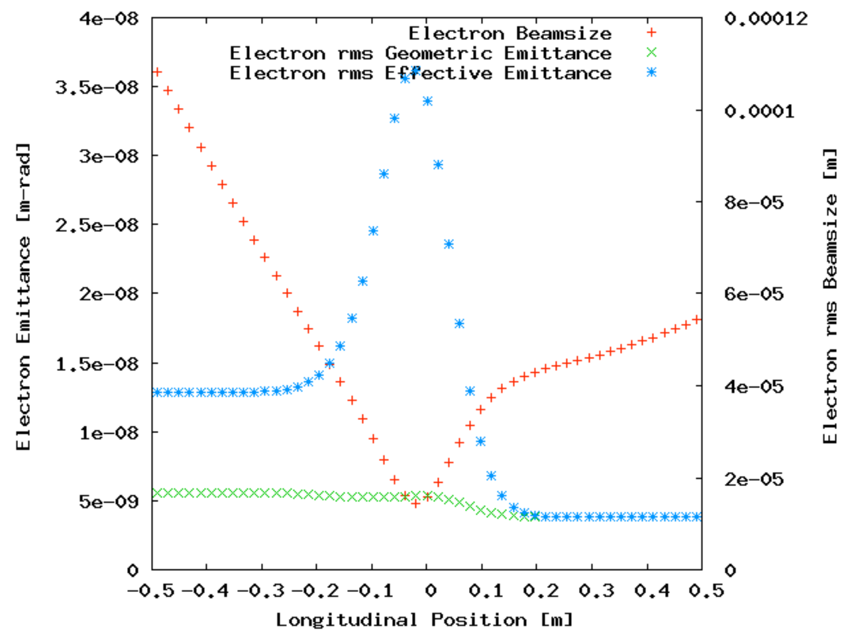
0.5 m

Waist position:

0.1 m (ahead of IP)

Luminosity:

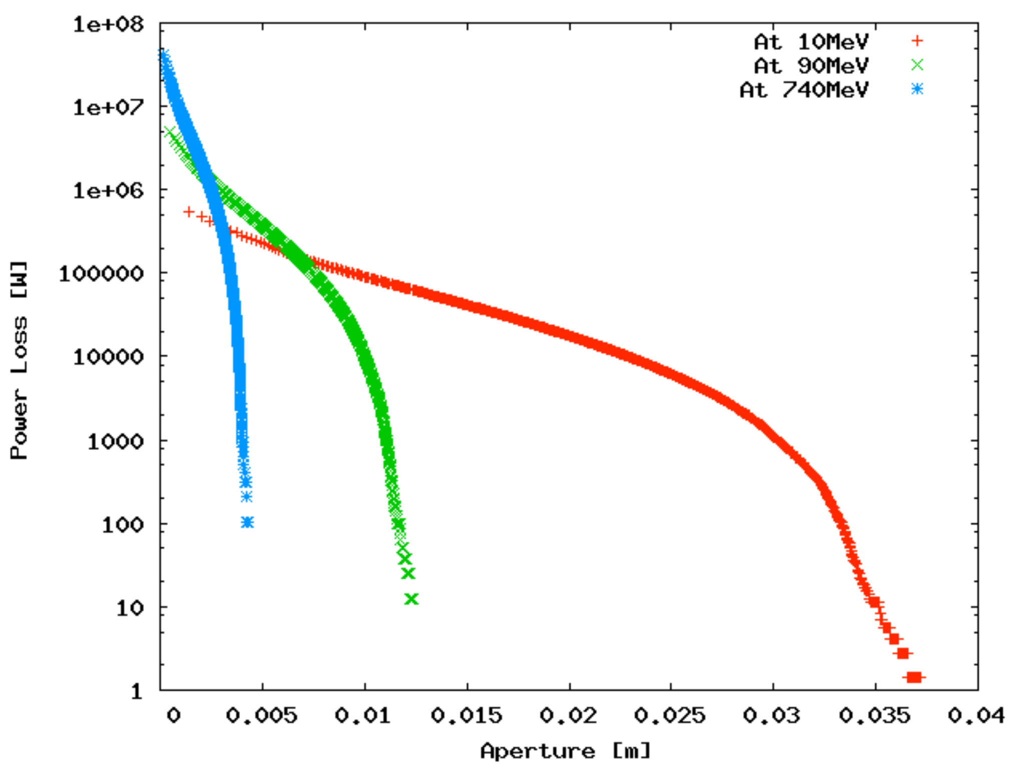
3.2×10^{32} $cm^{-2}s^{-1}$



The beam loss at different position for 'pre-cooled' case:

(Use beta=5m everywhere, easily scale later)

Position	Energy
Lowest energy at arc	740 MeV
At the exit of main linac	90 MeV
Before beam dump	10 MeV



The required aperture if 1KW power loss is required.

Energy	Aperture
740 MeV	4 mm
90 MeV	11 mm
10 MeV	38 mm

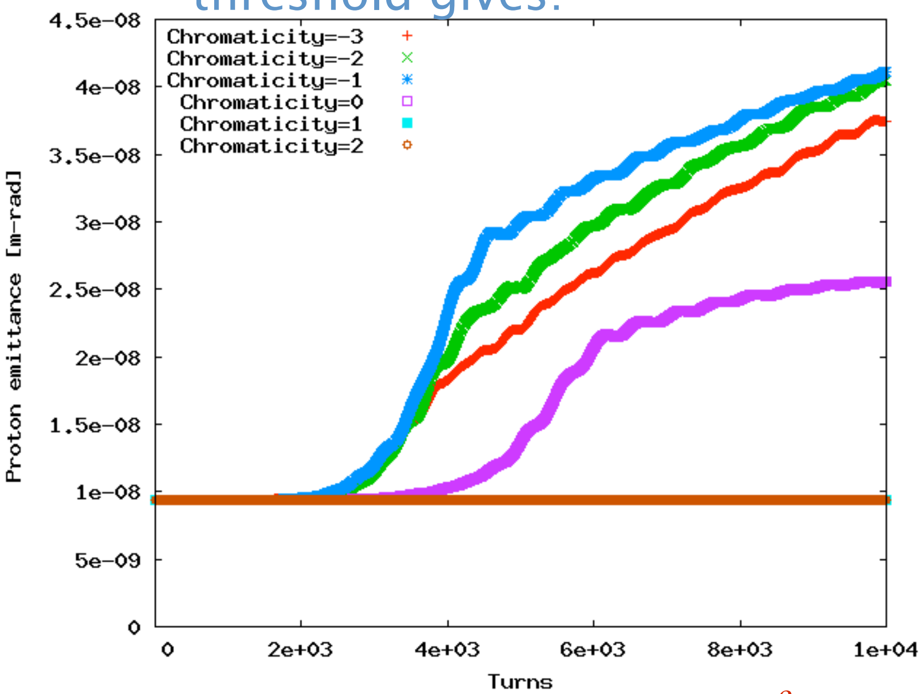
Proton beam instability due to collision with opposing beam

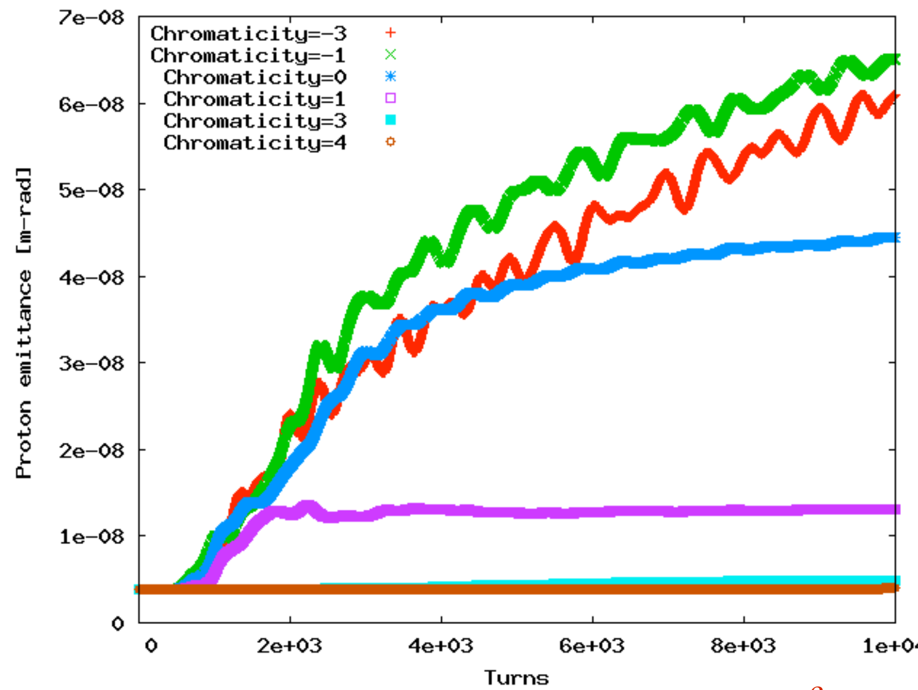
In both cases, the beam parameters are above the threshold of kink instability for proton beam. Proper energy spread is needed to suppress the emittance growth.

An estimation of strong head-tail instability threshold gives:

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

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





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

Chromaticity=1 is needed

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

Chromaticity=4 is needed

Assuming the rms energy spread is 5e-4

Conclusion

- Beam-beam study provide hints to optimize the luminosity and reduce the power loss in ERL
- Due to the focusing effect, the actual luminosity can be 20% larger (NotCooled) or 40% larger (PreCooled) than design values.
- The aperture required is easy to achieve for both cases.