SBF Accelerator Principles

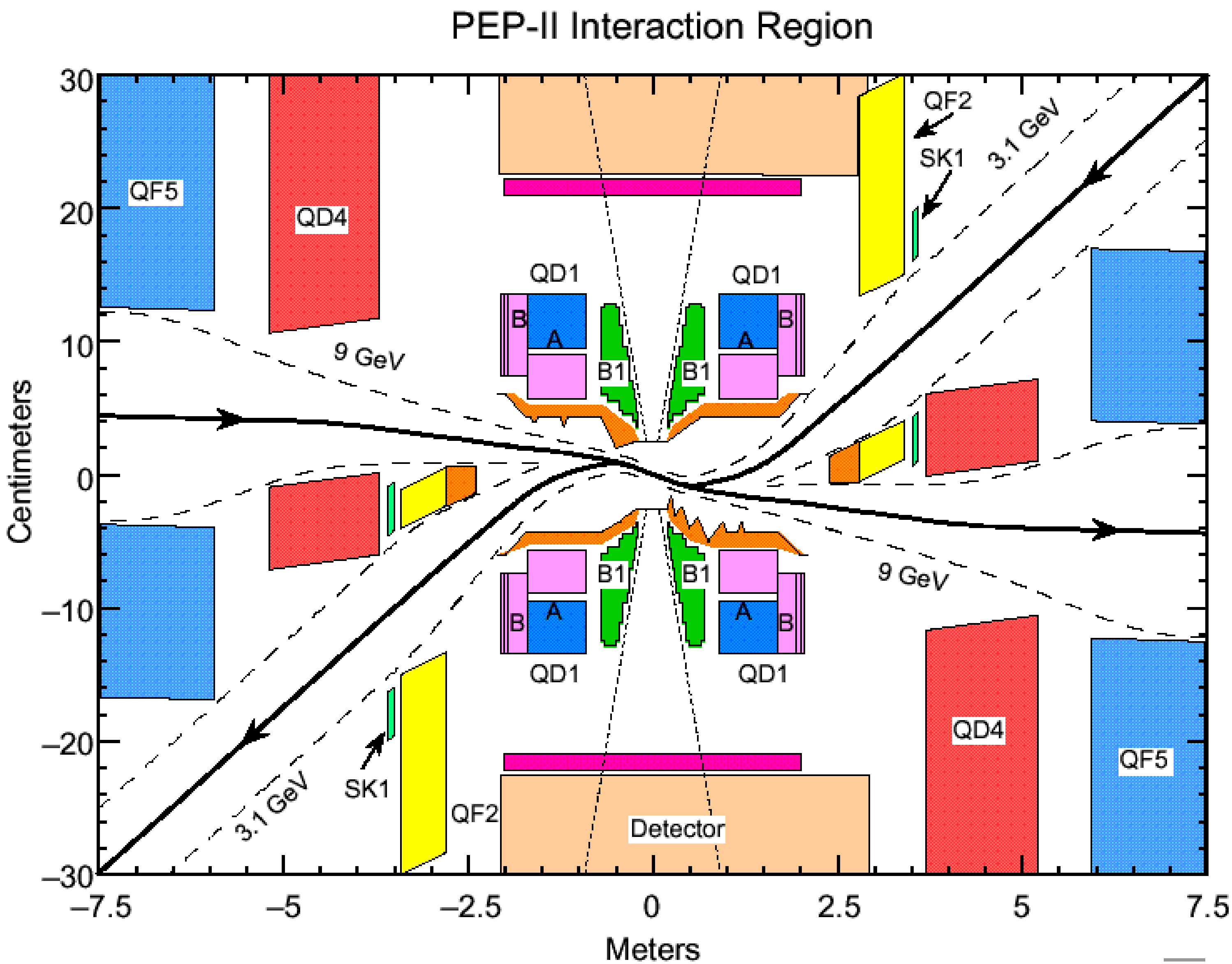
John Seeman
SLAC

Frascati Workshop
November 11, 2005

Topics

- The Collision Point
- Design constraints going backwards
- Design constraints going forward
- Parameter relations
- Luminosity optimization
- Damping ring examples

How the beams enter and exit the SBF Interaction Region



The Collision Point

- Center of mass energy spread should be less than 10 MeV for luminosity yield and data analysis efficiency
- The beam energy spread entering the IR after the length compressor must be no more than 10^{-3}.
- Beam-beam interaction makes large disruptions D.
- Large D makes enlargement of emittances which need to be damped.
- Large D pinches the beam and increases the effective luminosity.
- Round beams may be better.

Luminosity Enhancement (Flat)

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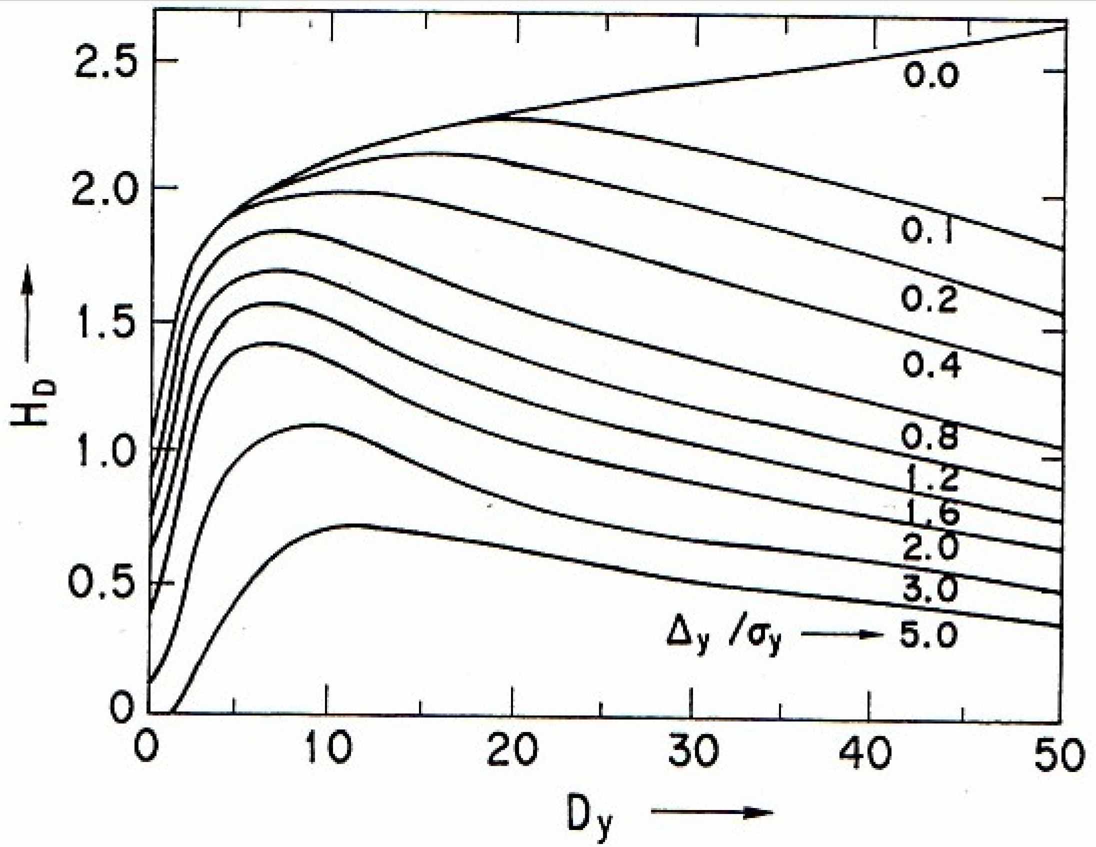

Fig. 1. Enhancement factor H_D for flat Gaussian beams as a function of the disruption parameter D_y. A_y is assumed to be 0.2 and Δ_y/σ_y is varied from 0 to 5.0.

Chen, Yokoya)

Enhancement (flat)

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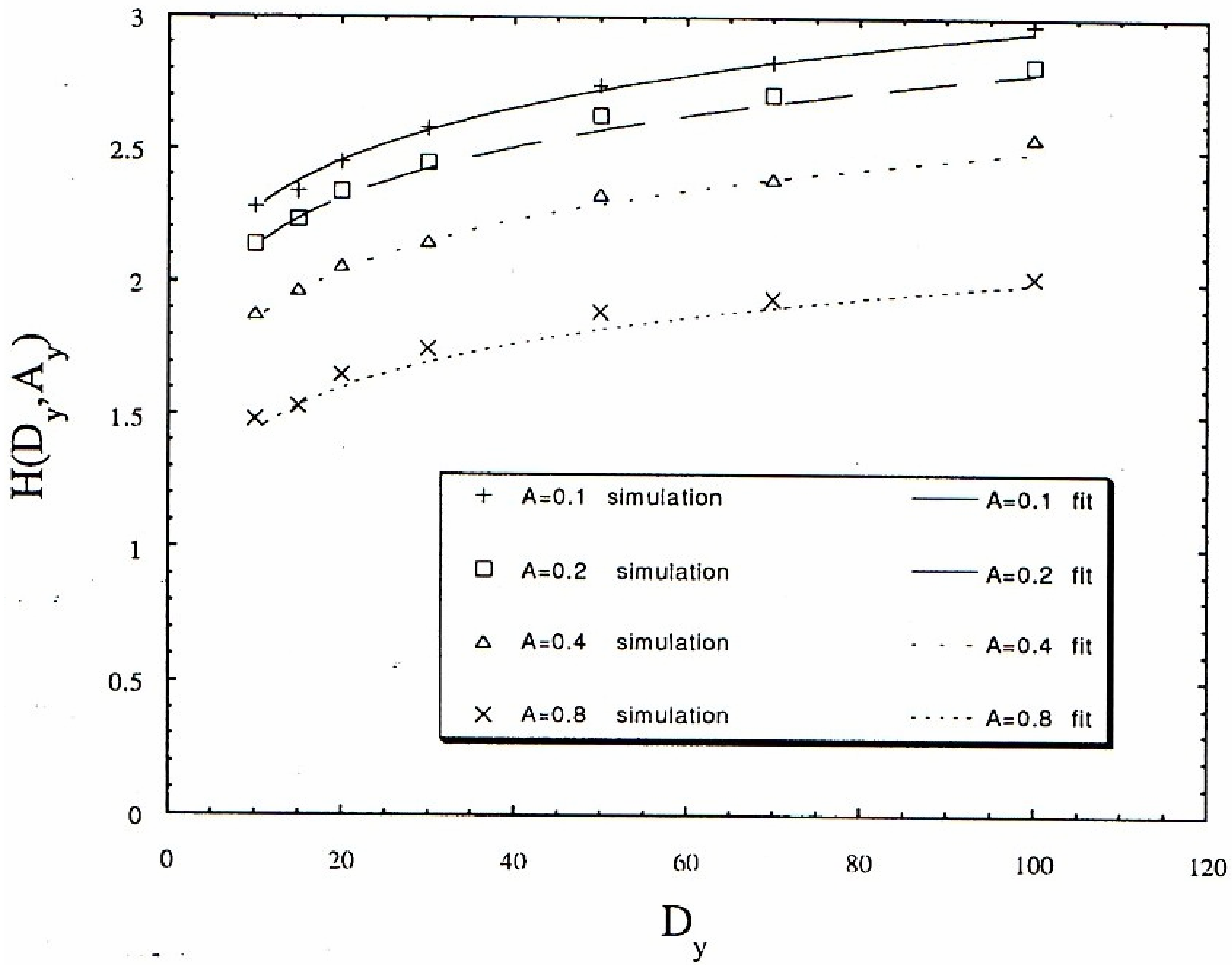
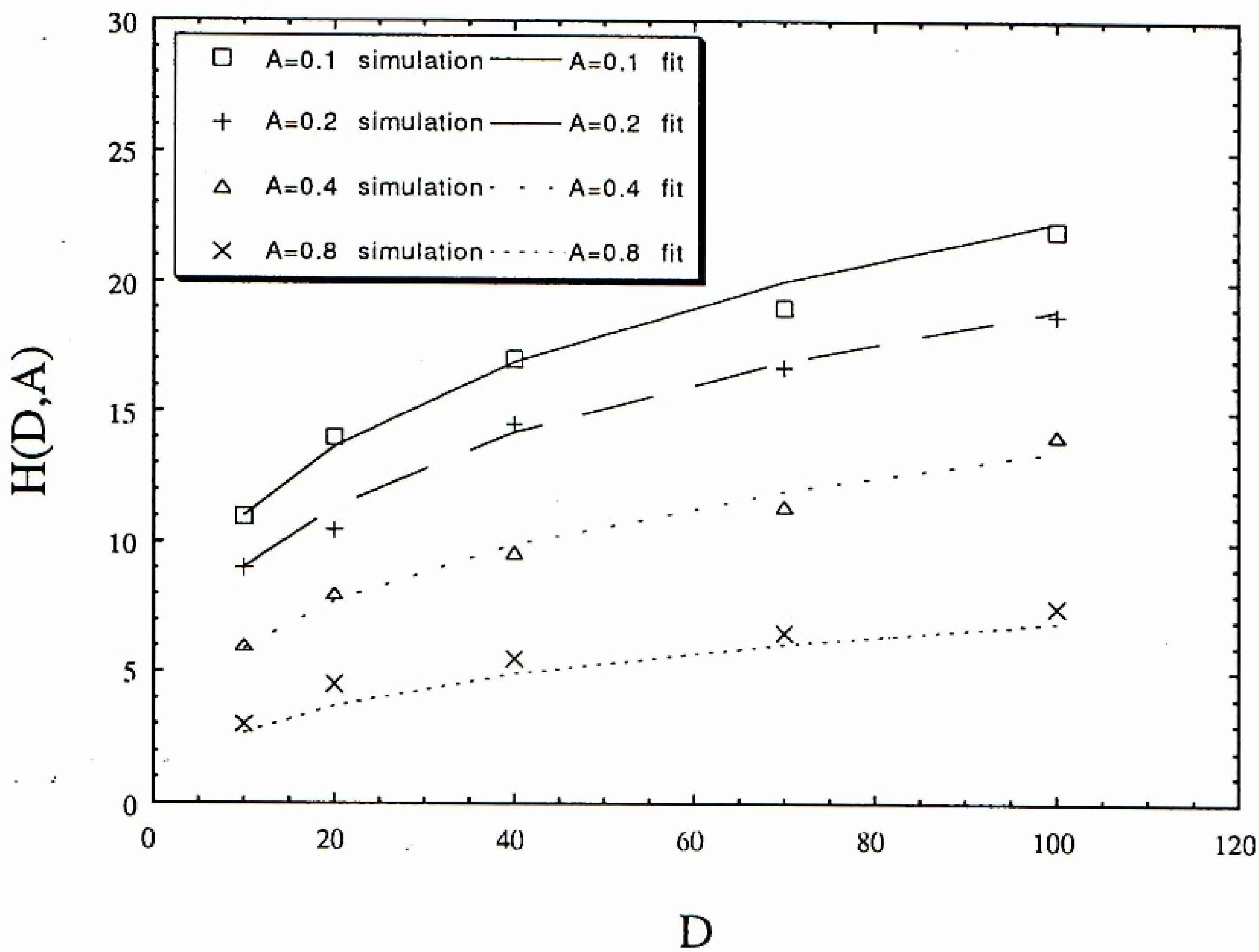


Enhancement (round)

- 

Design Constraints Going Backwards

- The bunch must be compressed by about a factor of 3 to 5 (~4 mm → 1 mm).
- Thus, the energy spread at the output of the last damping ring should be about $2\text{-}3 \times 10^{-4}$.
- Damping ring needs soft bends, light radiation, and big circumference.

Luminosity Yield on Y4S versus E_{cm} Spread

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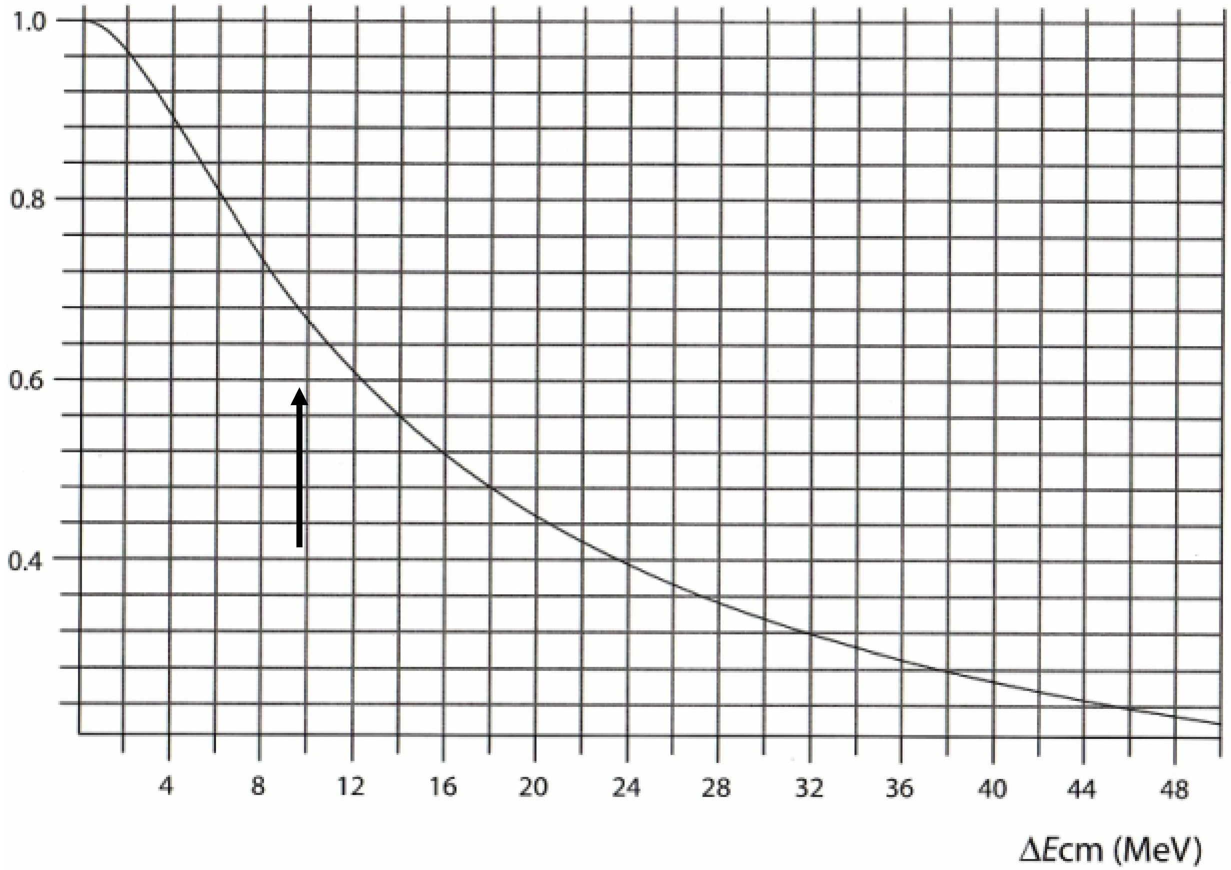
Yield



D. Hitlin

Design Constraints Going Forward

- The beam-beam collision enlarges the transverse emittance of both beams and both planes. (x4 to x50)
- Before these bunches can collide again, the emittances of these bunches must be damped and rapidly.
- Damping rings need fast damping, short bending radii, enlarged radiation and small circumference.

Layout of SBF with Fast and Slow Dampers

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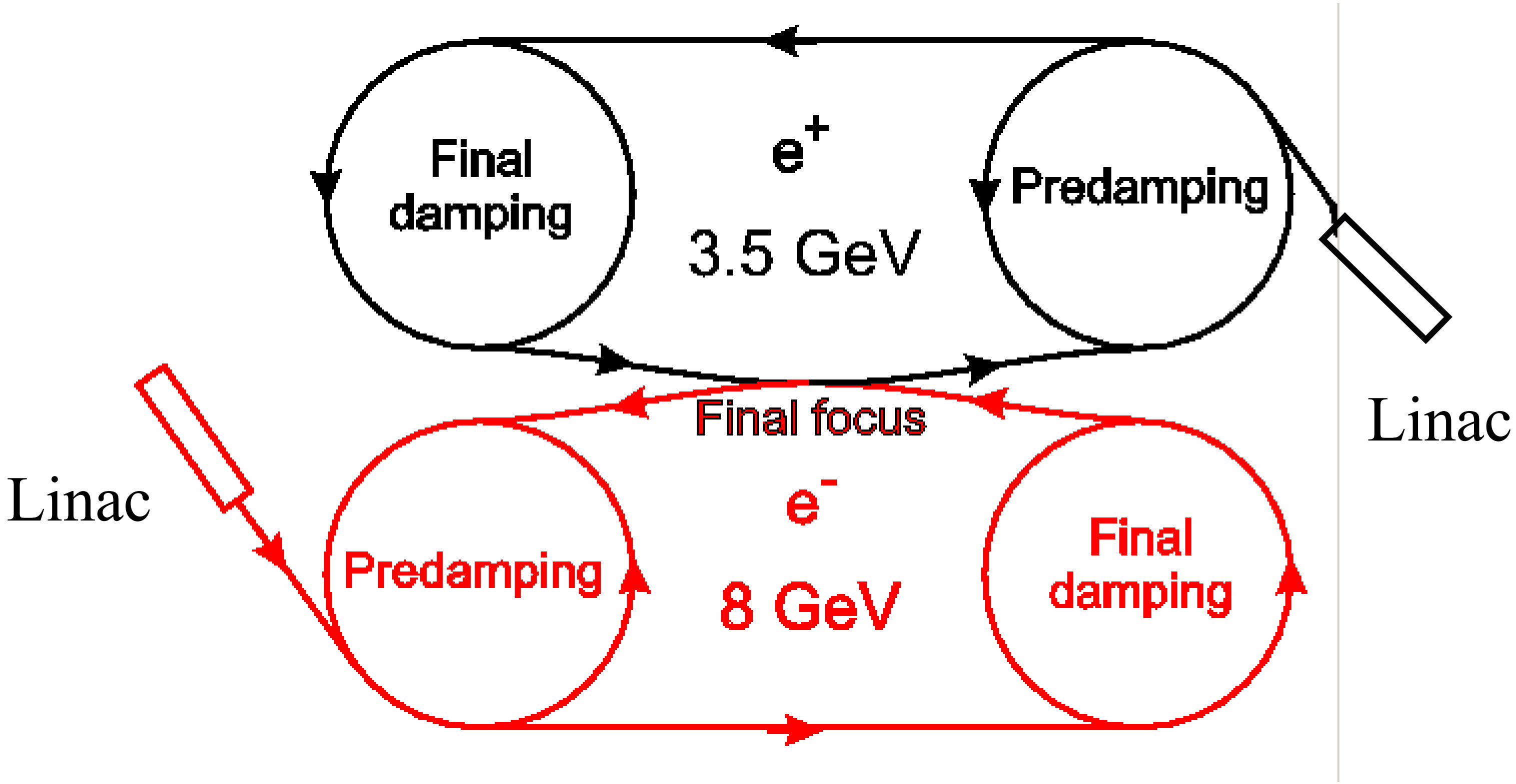

Bunch length compressors not shown.

Accelerator Parameters Relationships

Radiation loss:

$$U_0 = 8.85x10^{-5}\, meterGeV^{-3}\,\frac{E^4}{\rho}$$

- U_0 is the radiation loss per turn
- ρ is the damping ring dipole bend radius
- E is the particle energy
- For 7 GeV and 50 m radius, U_0 is 4.25 MeV/turn

Wall Plug Power

- Beam power (I = beam current)

$$P_{rad} = U_0 I^{+,-}$$

  – Example P_{rad}=4.25 MeV x 10 A =42.5 MW

- Wall power
  – Klystrons are 60% efficient and modulators 80% efficient.

$$P_{wall} = \frac{P_{rad}}{0.6x0.8} = 2P_{rad}$$

Example P_{wall} = 85 MW

Damping Time

- Longitudinal damping time is the time it takes to radiate the beam energy away. T_0 is the revolution time. C_{DR} is the damping ring circumference.

$$\tau_E = \frac{ET_0}{U_0} \sim \frac{\rho^2}{E^3} \qquad T_0 = \frac{C_{DR}}{c} \sim \rho$$

- Transverse damping time is ~twice the longitudinal.
- Emittances damp at twice the above "amplitude" rates.

Energy spread and transverse emittance

- Energy spread at equilibrium: ($E=\gamma mc^2$)

$$\left[\frac{\sigma_E}{E}\right]^2 = 3.84x10^{-13} m \frac{\gamma^2}{J_E \rho}$$

- Transverse is proportional to the energy spread (and lattice parameters):

$$\varepsilon_{x,y} \sim \left[\frac{\sigma_E}{E}\right]^2$$

Collision emittance enlargement

- The beam collisions enlarge the emittances in a single pass. This factor we will call F.
- The are four of the factors: two beams and two planes.

$$\varepsilon_{out} = F\varepsilon_{in}$$

- The time between collision for a single bunch is T_{coll} (naively ignoring the equilibium):

$$T_{coll} = F_x \tau_x = \frac{1}{f_{coll}}$$

Number of bunches

- The number of bunches n_b that collide is given by the circumference of the damping ring(s) and the RF wavelength λ_{RF} assuming every RF bucket is used.

$$n_b = \frac{C_{DR}}{\lambda_{RF}}$$

Parameter Relationships

- Luminosity traditional:

$$L = \frac{H_d N^- N^+ n_b f_{coll}}{4\pi\sigma_x\sigma_y}$$

- Luminosity with SBF inputs:

$$L \sim \frac{H_d N^- N^+ C_{DR} E}{\beta_x^{0.5} \beta_y^{0.5} \lambda_{RF} F \rho}$$

Luminosity Optimization

- Highest single bunch charges possible.
- Large circumference damping rings
- Short bending radii.
- Small β^* x and y subject to bunch length
- Small emittance blow up F.
- High RF frequency → more bunches

Damping ring options

E •	ρ	U_0	C_{DR}	Tau (E)	σ_E/E	n_b	Power wall
GeV	m	MeV	m	msec	$X10^{-4}$		MW at 10 A
4	4.5	5.0	48	0.13	16.2	76	100
4	13.5	1.7	2200	17.	9.3	3492	34
4	30	0.76	2200	39	6.3	3492	15
7	43	4.9	400	1.9	9.2	635	98
7	165	1.3	2200	40	4.7	3492	26
7	900	0.24	6280	593	2.0	1000	4.8

The PEP-II e^+e^- asymmetric collider

Conclusions

- There are many constraints for a SBF.
- But there are many options to try!
- We are trying to find a set of parameters that minimize the hardware cost and power costs.