

Issues for Optimization of a Super-B Factory

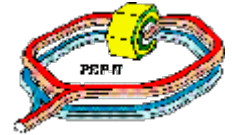
John T. Seeman

SBF Workshop

SLAC

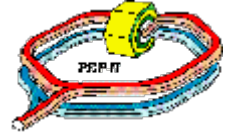
June 14, 2006

High Luminosity Topics



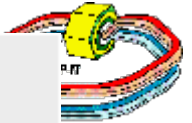
- **Horizontal emittance**
- **Vertical emittance**
- **Bunch length and compression**
- **Maximum beam-beam parameter**
- **Crab cavities**
- **Crab waist**
- **Damping ring circumference**
- **IR design**
- **AC power vs synchrotron radiation power**
- **Beam-beam effects makes optimum “non-linear”**

History



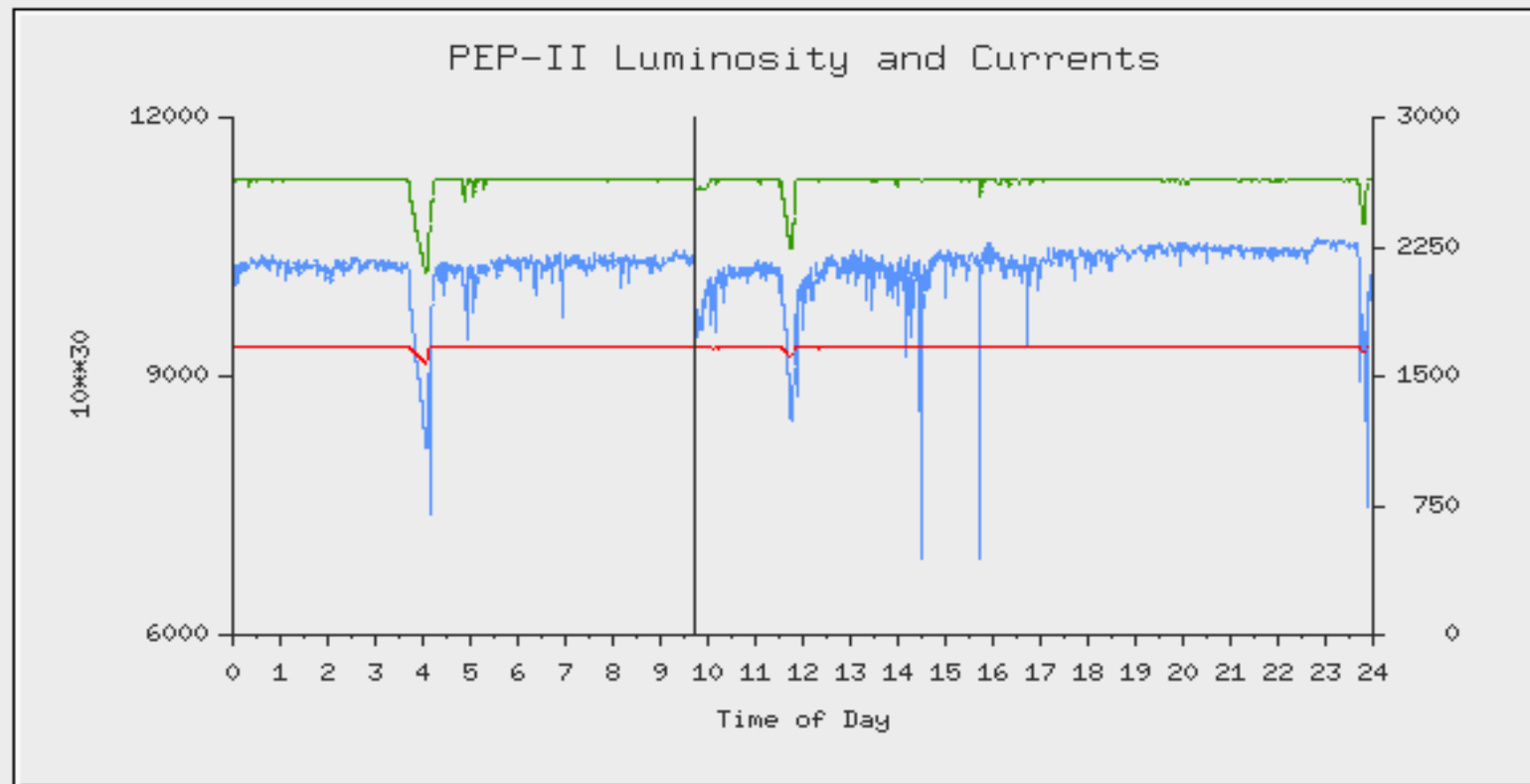
- **2003-2005: Both KEKB and PEP-II B-Factories have reached over 1×10^{34} /cm²/s!**
- **2002-2005: Both KEK and SLAC pursued Super-B upgrades with significantly higher currents and lower β_y^* .**
- **2004: Super-KEKB design is presented to the KEK Laboratory.**
- **March 2005: Emerged from the Super-B Workshop in Hawaii a concept of a single pass Linear Super-B Factory**
- **November 2005: Frascati workshop outlined a Super-B design with single pass collisions, bunch compression, and energy recovery linacs.**
- **March 2006: Frascati workshop outlines a Super-B Collider design that collides every turn but with bunch compression or large crossing angles. Crab waists help.**
- **May 2006: Beam-beam simulations with more slices show larger tune shifts.**

PEP-II



I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1680.41	2649.57	10366	4.01	8917	3120	10549
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV
HER N Buckets / Pattern			LER N Buckets / Pattern			
1722 0=1;3442=0.96;0:3442:2=			1722 0:3442:2			
Last Owl/Day/Swing/24hr			293.9	290.4	299.4	883.7 Shift: 65.85 /pb
Peak Luminosities			10510	10587	10608	10515

Best shift and 24 hr



06/12/2006 09:45:16

PEP-II Records

Last update:
June 12, 2006 

Peak Luminosity

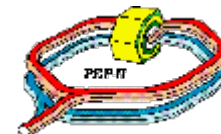
$10.877 \times 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$

1722 bunches 2700 mA LER 1775 mA HER

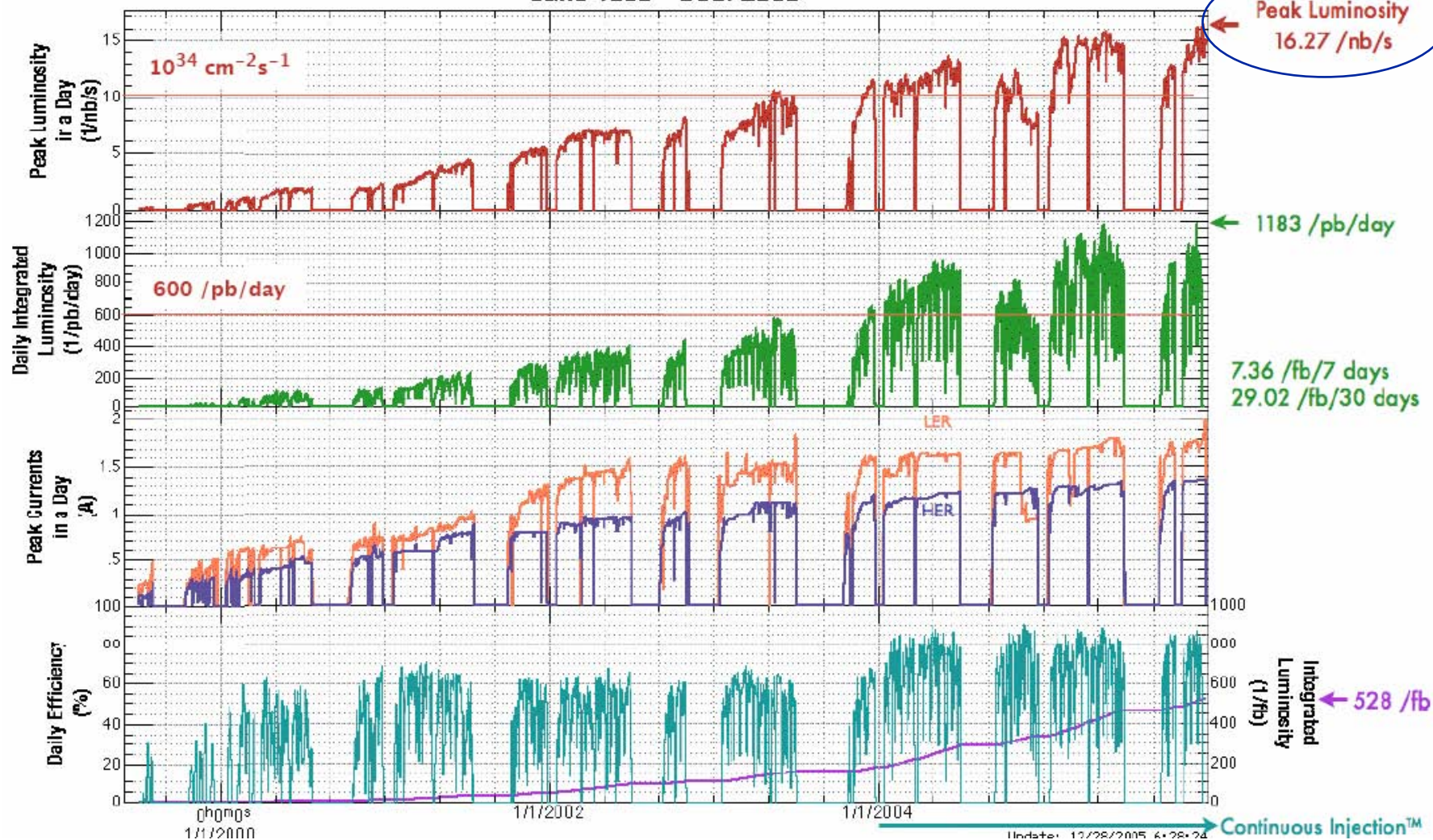
May 25, 2006

Integration records of delivered luminosity

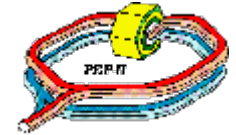
Best shift (8 hrs, 0:00, 08:00, 16:00)	299.4 pb ⁻¹	Jun 11, 2006
Best 3 shifts in a row	883.7 pb ⁻¹	Jun 11-12, 2006
Best day	786.3 pb ⁻¹	Jun 11, 2006
Best 7 days (0:00 to 0:00)	4.464 fb ⁻¹	Jul 25-Jul 31, 2004
Best week (Sun 0:00 to Sat 24:00)	4.464 fb ⁻¹	Jul 25-Jul 31, 2004
Peak HER current	1776 mA	May 31, 2006
Peak LER current	2995 mA	Oct 10, 2005
Best 30 days	16.720 fb ⁻¹	Jul 2 – Jul 31, 2004
Best month	17.036 fb ⁻¹	July 2004
Total delivered	371 fb ⁻¹	



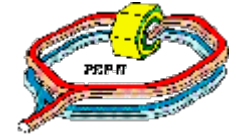
Luminosity of KEKB June 1999 - Dec. 2005



Super-B Basic concepts



- Higher currents and large number of bunches make more luminosity but needs higher RF power.
- Faster damping allows stronger collisions but needs higher RF power.
- Shorter bunches allow smaller vertical spot sizes but larger HOMs. Crab waists helps.
- Lower emittance makes for smaller spot sizes but leads to single ring enlargement issues.
- Need small energy spread ($\sim 10^{-3}$) in the collisions to match Y4S resonance shape.



Luminosity

- The luminosity for a linear collider is:

$$L = H_d N_p P / 4\pi E \sigma_x \sigma_y$$

H_d : disruption enhancement

P : average beam power

- For a storage ring is:

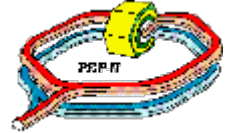
$$L = 2.17 \times 10^{34} (1+r) \xi_y EI / \beta_y$$

I : beam current

ξ_y : vertical tune shift

β_y : IP vertical beta function

Scaling laws to optimize the single pass IP parameters



○ Disruption:

$$D \approx \frac{N \sigma_z}{(\sigma_x \sigma_y)}$$

Decrease σ_z + decrease N
Increase spotsize

○ Luminosity

$$L \approx \frac{N^2}{(\sigma_x \sigma_y)}$$

Increase N
Decrease spotsize

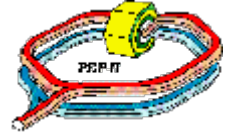
○ Energy spread:

$$\delta_E \approx \frac{N^2}{(\sigma_x^2 \sigma_z)}$$

Contradicting
requests!

Increase σ_z + decrease N
Increase spotsize

More Detailed Luminosity Equation



$$L = 5 \times 10^{35} \left[\frac{\xi_y}{0.1} \right] \left[\frac{N}{10^{11}} \right] \left[\frac{1 \text{ mm}}{\beta_y^*} \right] \left[\frac{1 \text{ m}}{s} \right] \left[\frac{E}{5 \text{ GeV}} \right] F$$

ξ_y^* = beam-beam parameter = $D_y/4\pi$.

N = number of particles

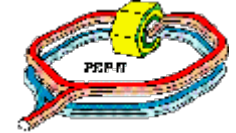
β_y^* = vertical beta function

s = bunch spacing

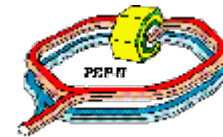
E = beam energy

F = Hourglass + parasitic collision factor ($\sim < 1.0$)

Parameters of Super-B Designs



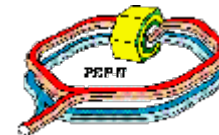
Collider		ξ_y	N	β_y^*	s	E	F	Lumin
Units			10^{10}	mm	m	GeV	(~Hd)	10^{35}
PEP-II	Normal	0.07	8	10	1.26	3.1	0.84	0.11
KEKB	Normal	0.065	5.8	6	2.1	3.5	0.76	0.16
Super-PEP-II	High I low β_y	0.12	10	1.7	0.32	3.5	0.81	7
Super-KEKB	High I low β_y	0.28	12	3	0.59	3.5	0.85	8
Linear SuperB	Single pass	29.	10	0.5	250	4	1.07	10
SuperB	Bunch shorten	0.14	6	0.4	0.63	4	0.75	10
SuperB	X'ing angle	0.045	2	0.08	0.5	5	0.8	10



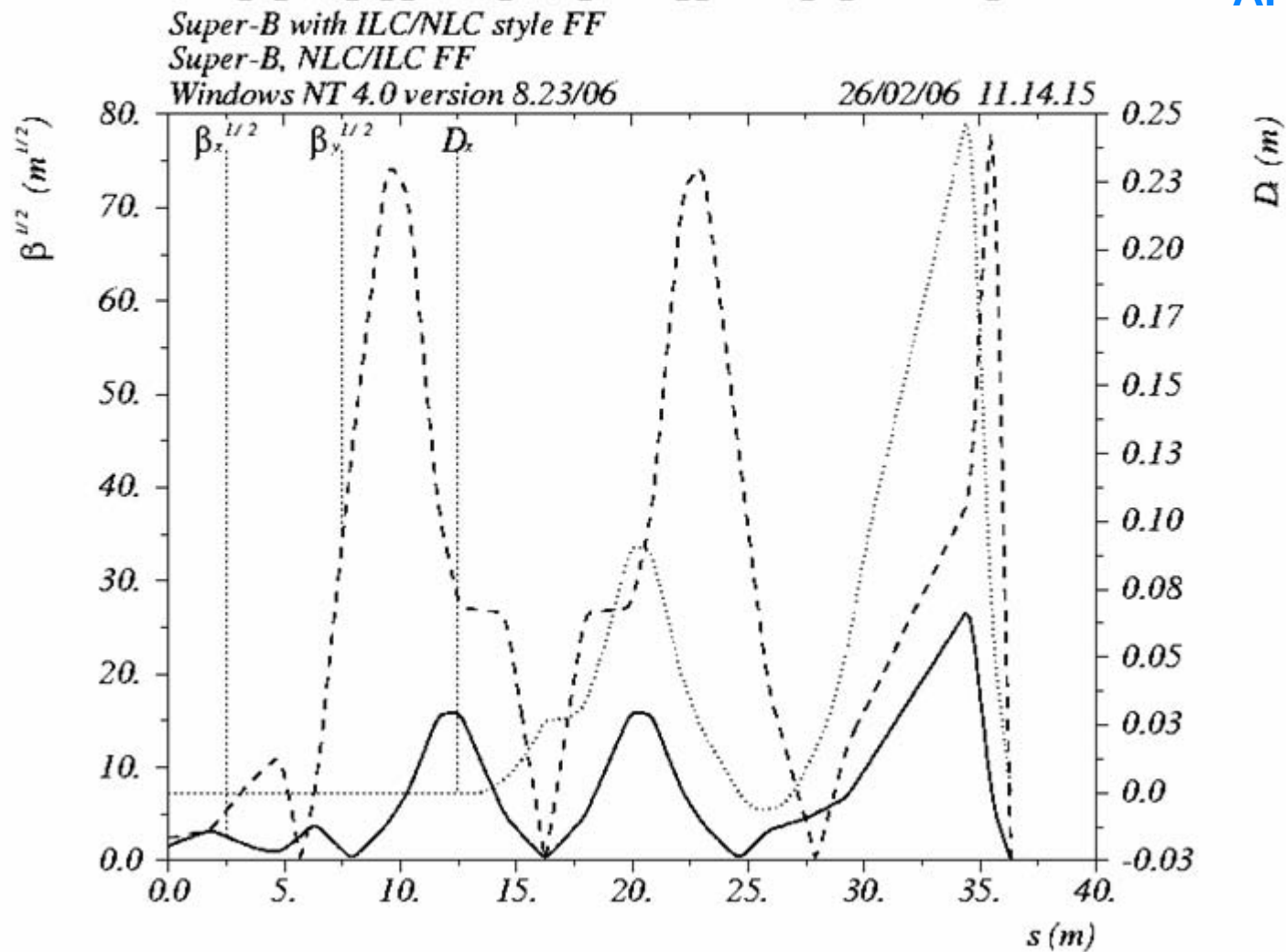
Final Focus

- **Use ILC final focus concept**
- **Scale to B Factory energies**
 - ↪ (4 x 7 GeV) (3.75x7.5 GeV) (3.5 x 8 GeV) (3.1 x 9 GeV).
- **Use small superconducting quadrupoles for the final doublet.**
- **Chromatic corrections done in the IR with sextupoles.**

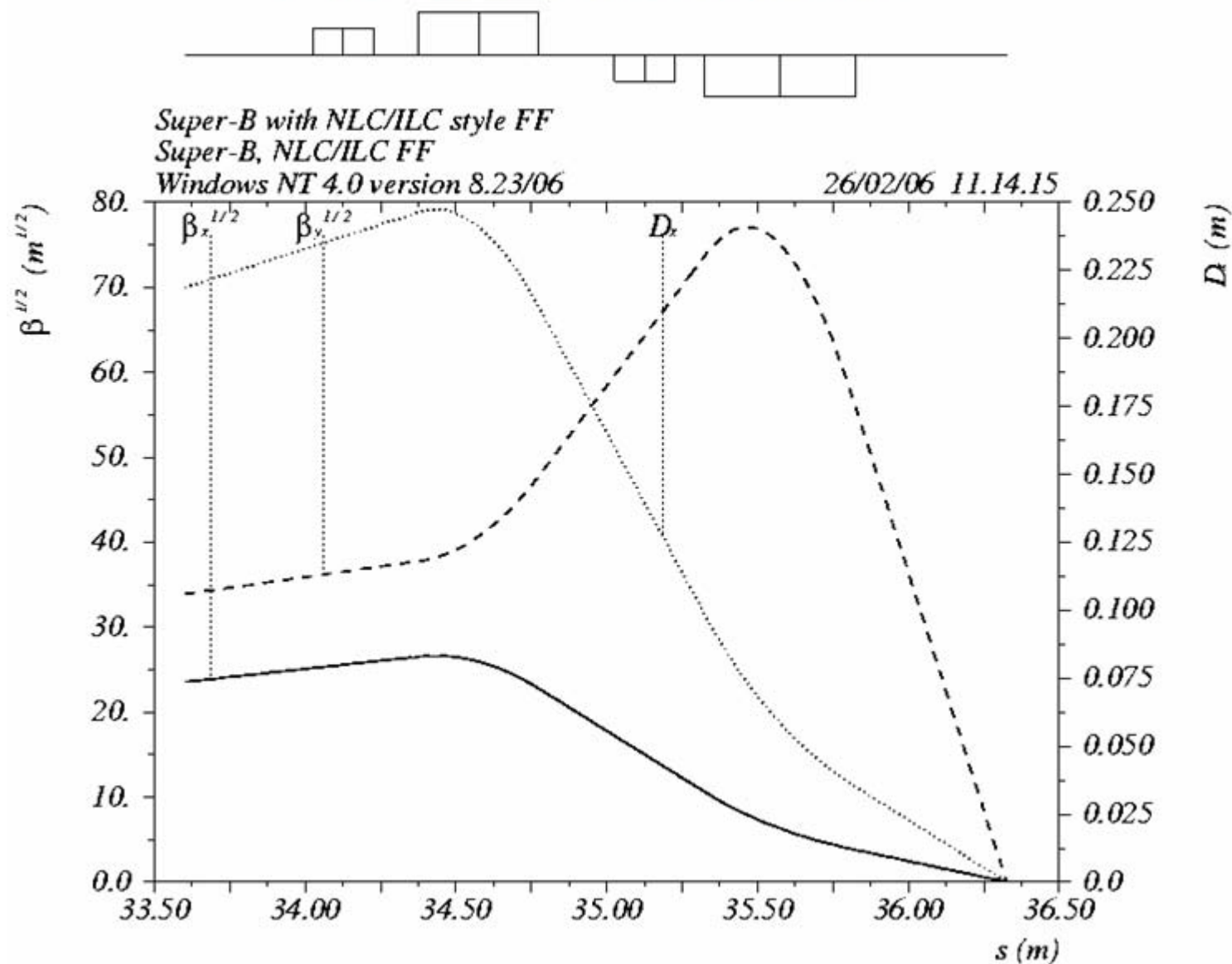
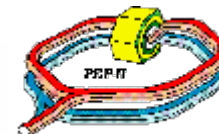
Optics of FF

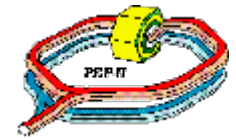


A. Seryi



Final doublet part

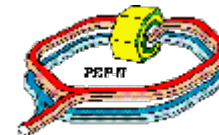




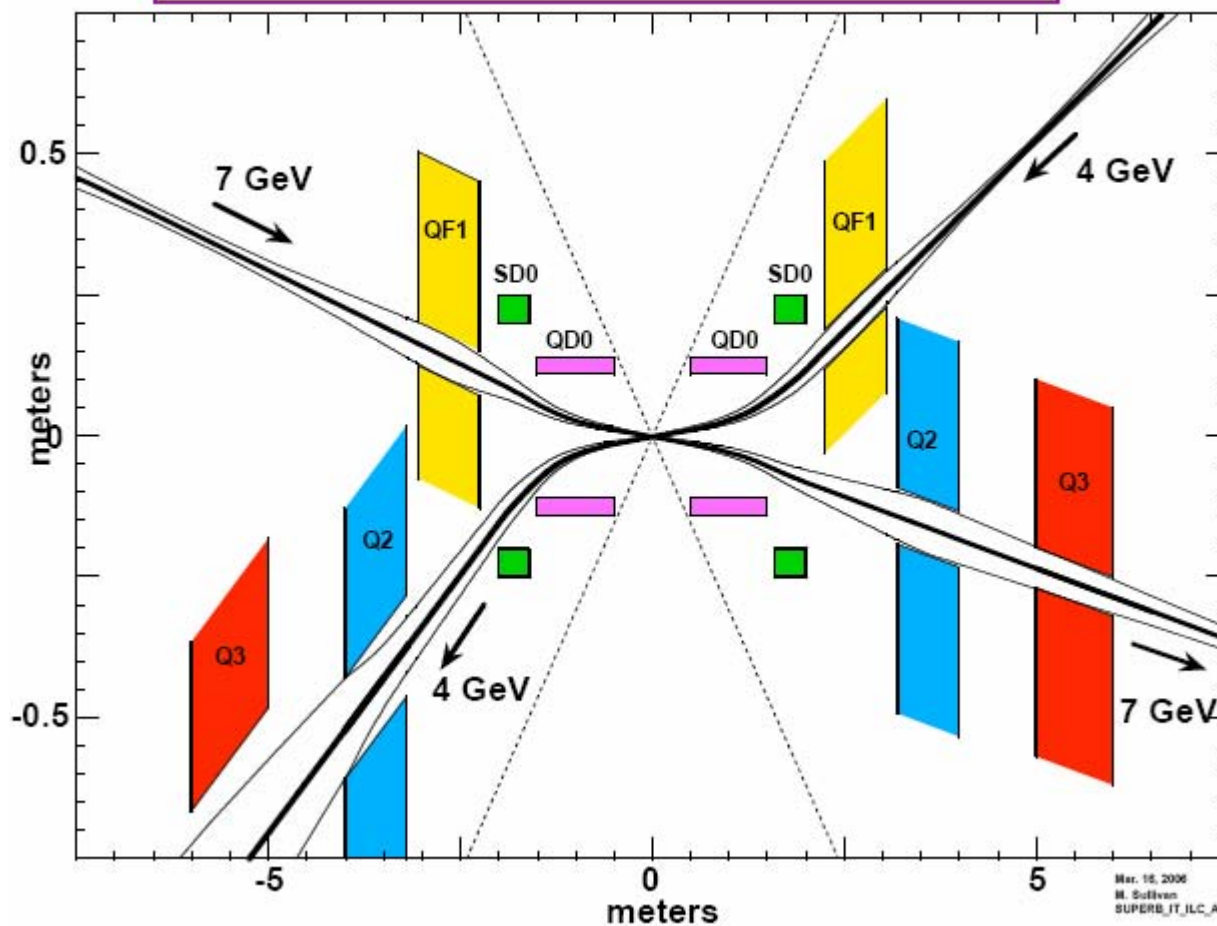
IR Design
M. Sullivan

Some IP Parameters

	HER	LER
• Beta x (mm)	2.5	2.5
• Beta y (mm)	0.08	0.08
• Emittance x (nm-rad)	0.4	0.4
• Emittance y (nm-rad)	0.002	0.002
• Sigma x (μm)	2.67	2.67
• Sigma y (μm)	0.0126	0.0126
• Bunch spacing (m)	0.6	
• Crossing angle (mrad)	± 25	
• Luminosity	0.8×10^{36}	

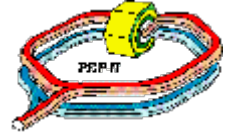


Layout of IR orbits for ILC version Super B Factory

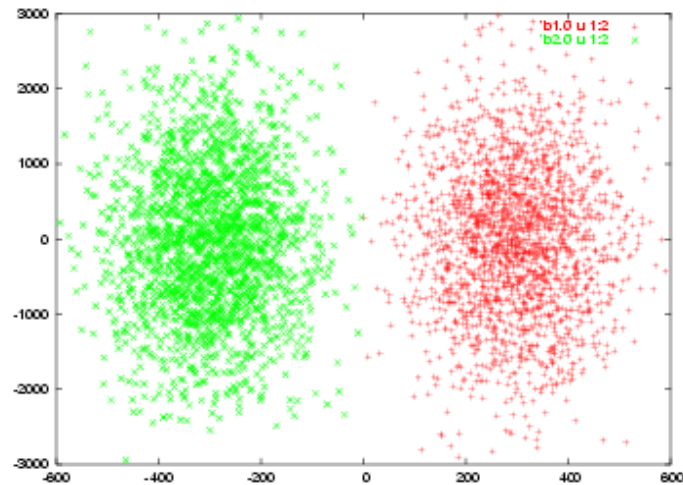
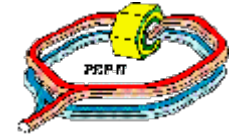


M. Sullivan

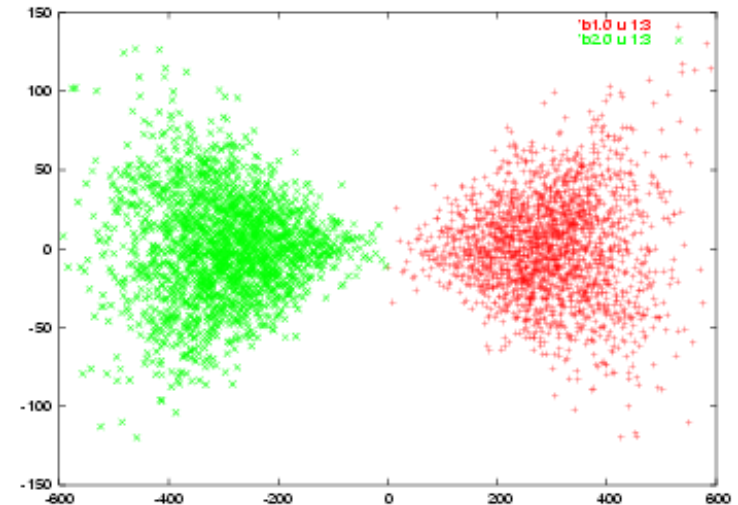
Beam-Beam Simulations



- **Track macro-particles through the collision to see blow up effects. (Guinea Pig code from ILC + Ohmi beam-beam code + Cai beam-beam code)**
- **Compare single pass beam-beam effects with ring beam-beam effects.**
- **Couple single pass collisions with damping in a ring.**



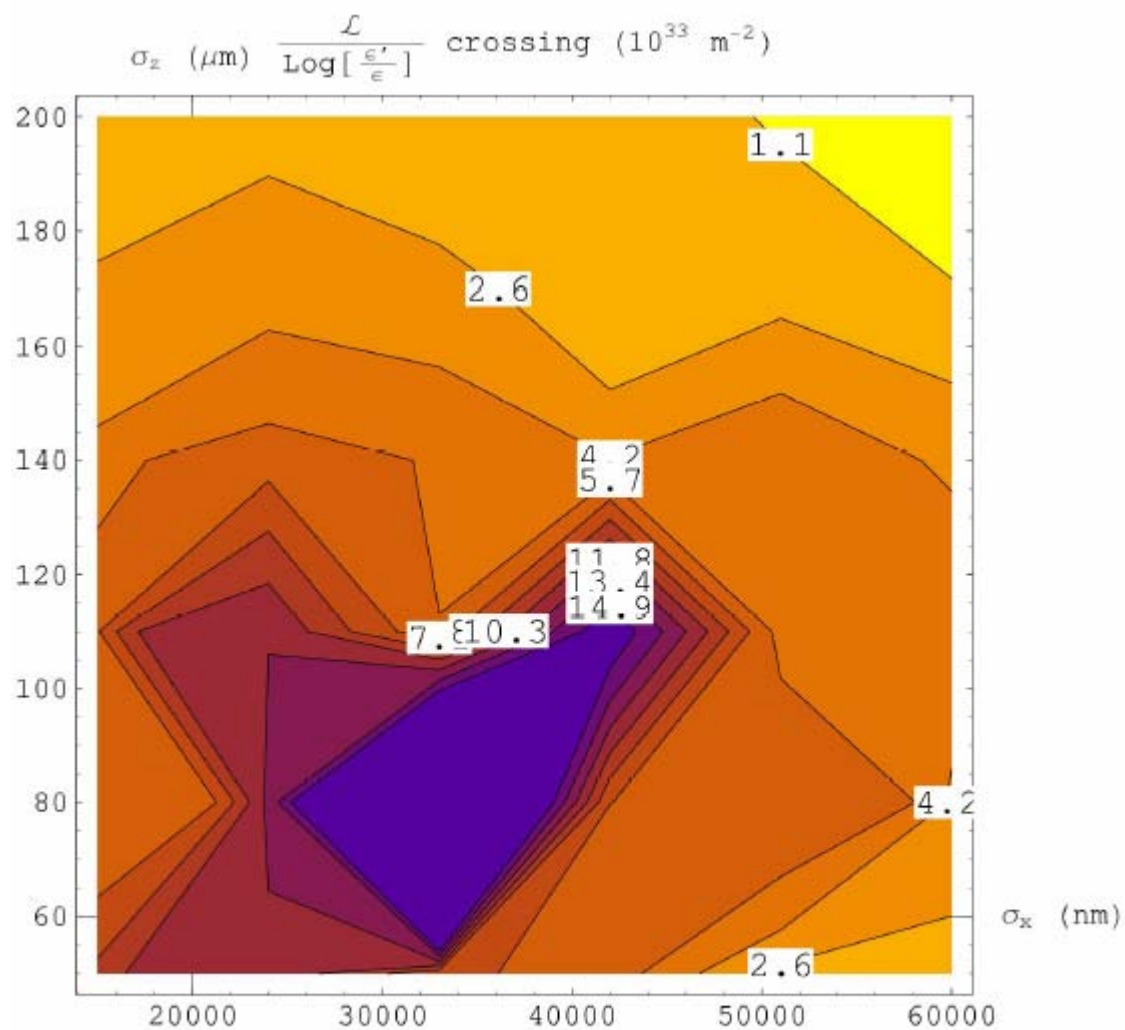
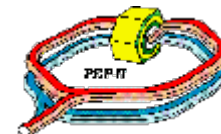
Horizontal Collision



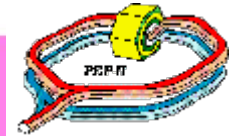
Vertical collision

Effective horizontal size during collision about 10 times smaller, vertical size 10 times larger

Simulations by D.Schulte/Raimondi/Biagini



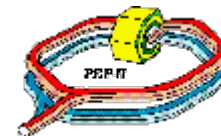
New Parameter Set for 8×10^{35} -- by K. Ohmi



May 2006

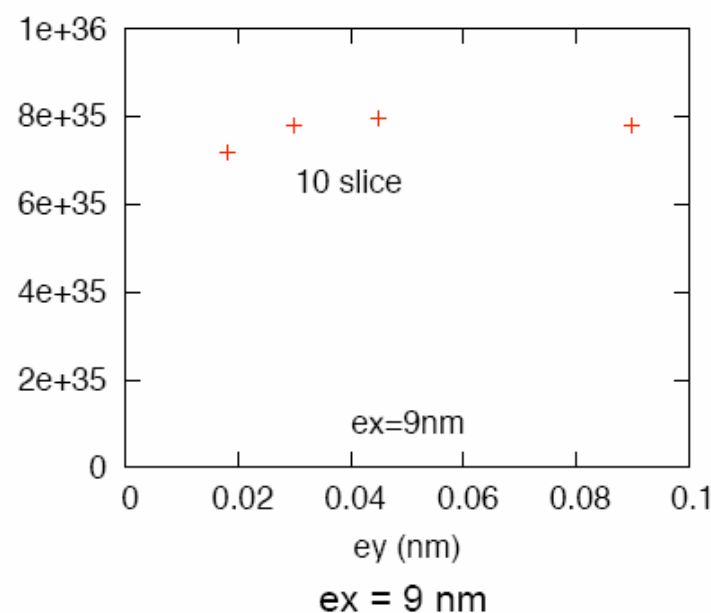
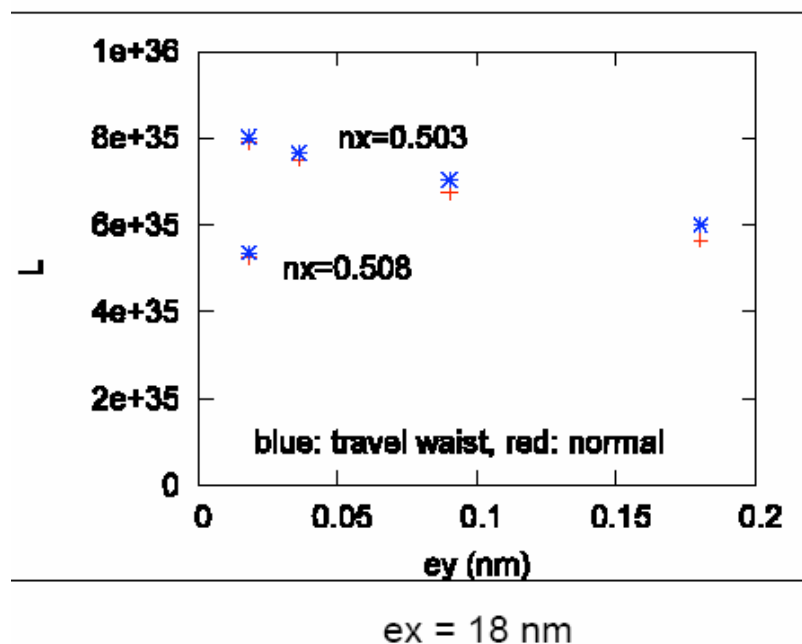
	SuperKEKB	Crab waist			
ϵ_x	9.00E-09	6.00E-09	6.00E-09	6.00E-09	6.00E-09
ϵ_y	4.50E-11	6.00E-11	6.00E-11	6.00E-11	6.00E-11
β_x (mm)	200	100	50	100	50
β_y (mm)	3	1	0.5	1	0.5
σ_z (mm)	3	6	6	4	4
vs	0.025	0.01	0.01	0.01	0.01
ne	5.50E+10	5.50E+10	5.50E+10	3.50E+10	3.50E+10
np	1.26E+11	1.27E+11	1.27E+11	8.00E+10	8.00E+10
$\phi/2$ (mrad)	0	15	15	15	15
ξ_x	0.397	0.0418	0.022	0.0547	0.0298
ξ_y	0.794 → 0.24	0.1985	0.179	0.178	0.154
Lum (W.S.)	8E+35	6.70E+35	1.00E+36	3.95E+35	4.80E+35
Lum (S.S.)	8E35	4.77E35	5.65E36	3.94E35	4.27E35

- Good parameters are not yet found with crab waist.

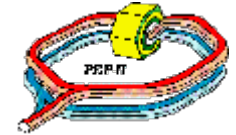


Smaller emittances

K. Ohmi



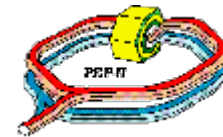
- For $ex = 18$ nm, smaller ey gives higher luminosity.
- For $ex = 9$ nm, luminosity is high up to $ey/ex < 1\%$.



K. Oide May 2006

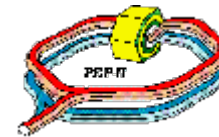
○ Why was higher luminosity made possible?

- $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ is achievable with same beam currents, beta, bunch length as $4 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$.
- The simulation was improved by more longitudinal slices to reduce the numerical noises and the instability, using a new supercomputer at KEK.
- A new choice of parameters with smaller emittance ratio or smaller horizontal emittance.
- Crab crossing is necessary.
- No crab waist, travel focus are needed for luminosity, but may help the lifetime.

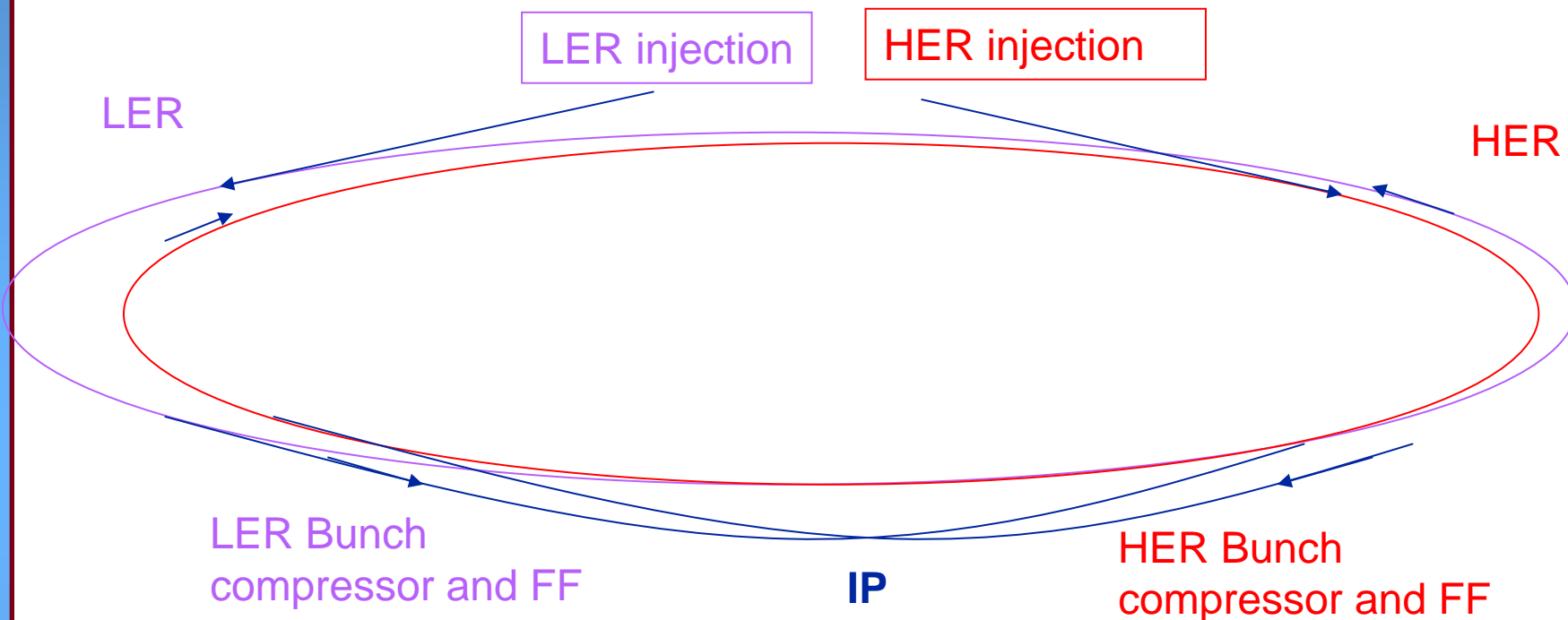


Single Pass Linear Super-B

- **Collide each bunch once very hard making a lot of luminosity.**
- **Use very small beta functions at the IP like ILC.**
- **Re-inject into the damping rings and damp for several damping times.**
- **Collide again after the disrupted emittances have damped.**
- **Simulations show vertical emittance blow up is about 300 times.**
- **Need about 6 damping times between collisions.**
- **Need very short damping times → high power.**



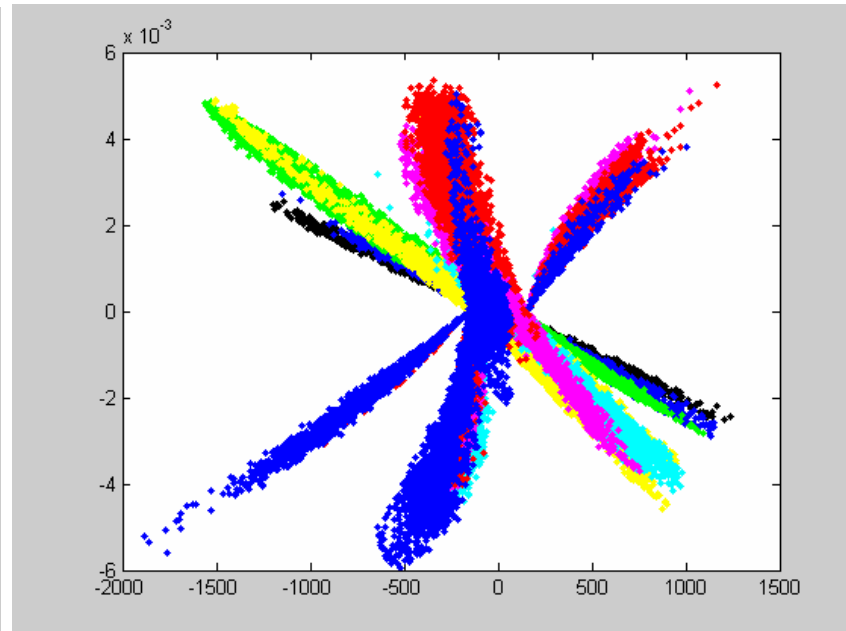
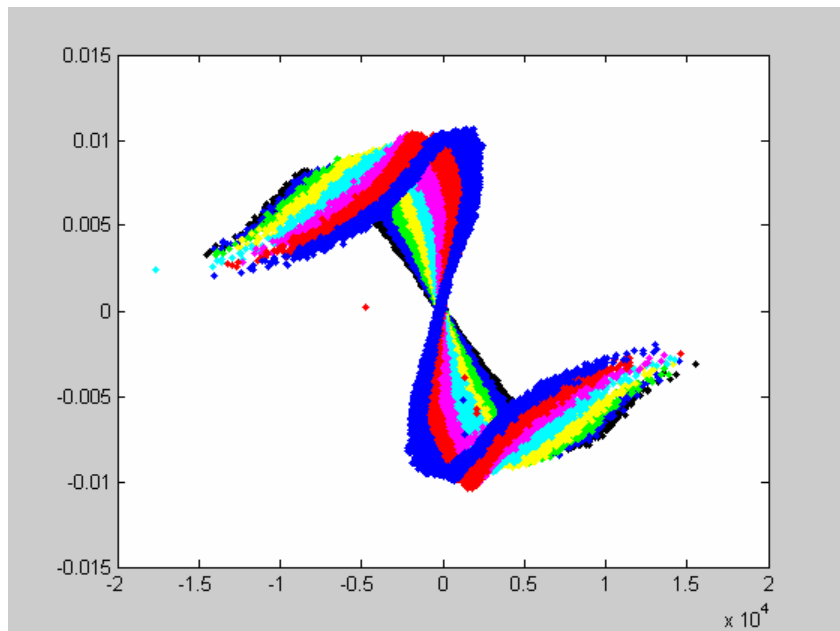
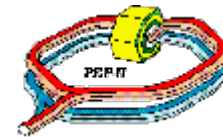
Linear-B scheme



Overall ring length about 6Km,

Collision frequency about $120\text{Hz} \times 10000\text{bunch_trains} = 1.200\text{MHz}$

Bunch train stays in the rings for 8.3msec, then is extracted, compressed and focused. After the collision the bunch is reinjected in its ring



Horizontal phase after the collision

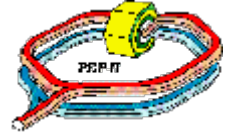
Vertical phase after the collision

IP Parameters set considered at the workshop caused large increase of the emittance due to the collision:

$$\epsilon_{x_out}/\epsilon_{x_in}=12 \quad \epsilon_{y_out}/\epsilon_{y_in}=300$$

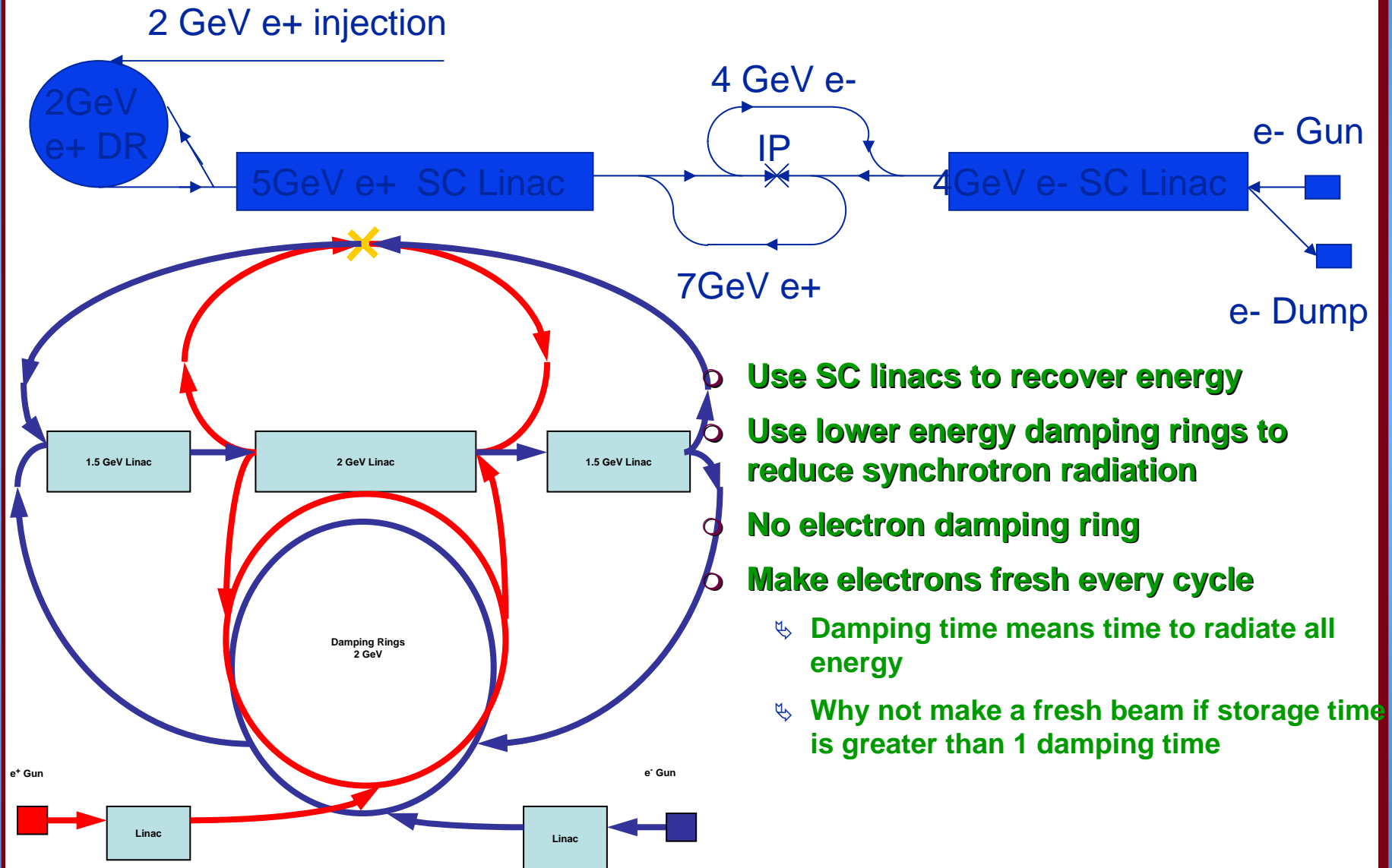
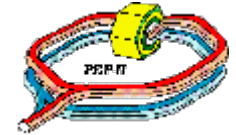
M. Biagini studies

Type 2 Energy Recover Linear Super-B

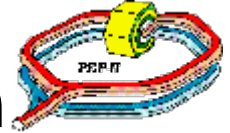


- **Use single pass collider idea but use energy recovery linacs (ERLs) to accelerate, collide, then decelerate the beams to reduce damping ring energy and energy loss to synchrotron radiation.**
- **This technique saves energy lost in damping rings between $\sim E^2$ and $\sim E^4$.**
- **Acceleration also adiabatically damps emittance and energy spread making bunch compression easier.**

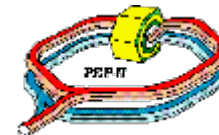
Linear Super B schemes with acceleration and energy recovery, to reduce power



Type 3 Super-B with Bunch Compression



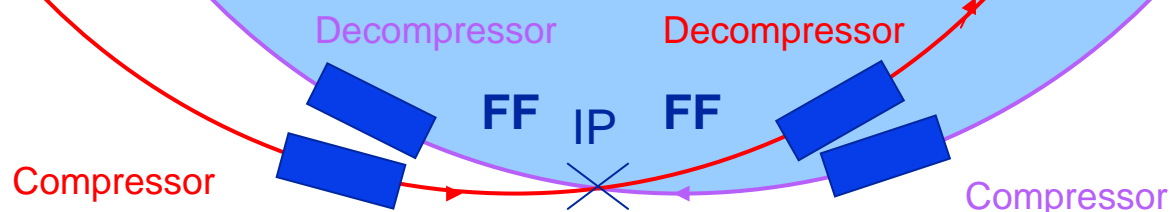
- **Collide every turn in the damping ring.**
- **Install an ILC like final focus.**
- **Choose parameters to cause small emittance blow up.**
- **Use bunch compressor to shorten the bunches at the IP. Decompress after the IP.**
- **Use monochromator scheme at IP to compensate the energy spread to match the small Y4S resonance.**

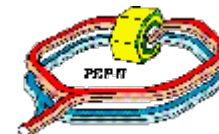


P. Raimondi

Simplified layout in the
Small
Disruption
Regime
Collisions every Turn

ILC ring with ILC FF
ILC Compressor, 0.4GeV S-Band or 1GeV L-Band
Crossing angle optional

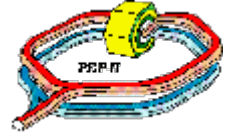




ILCDR Nominal Parameters

Number of Bunches/train	2820
Bunch charge	$2 \cdot 10^{10}$
Train repetition rate	5 Hz
Injected bunch separation	330 ns
Maximum injected norm. betatron amplitude (e+)	0.09 m-rad
Injected full width energy spread (e+)	1%
injected norm. emittance (e-)	45 μm
Injected full width energy spread (e-)	0.1%
Extracted norm. horizontal emittance	8 μm
Extracted norm. vertical emittance	20 nm
Extracted bunch length	6 mm
Extracted energy spread	$1.4 \cdot 10^{-3}$

Approximate AC Power



○ PEP-II (2200 m) (1 ring LER and HER)

↗ RF AC Power LER at 3.1 GeV = 1 MeV/turn x 4 A x 2 = 8 MW

↗ RF AC Power HER at 9.0 GeV = 3.6 MeV/turn x 2 A x 2 = 14.5 MW

↗ Total RF AC power = 22.5 MW.

○ Super-B factory (4400 m) (2 rings LER and HER)

↗ RF AC Power LER at 4 GeV ~ 1.8 MeV/turn x 4 A x 2 x 2 = 29 MW

↗ RF AC Power HER at 7.0 GeV ~ 2.2 MeV/turn x 2.5 A x 2 x 2 = 22 MW

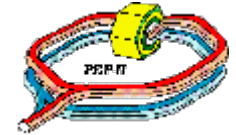
↗ Total RF AC power = 51 MW.



Type 4 Super-B with Large Crossing Angles

- **Collide with a large crossing angle (2×25 mrad)**
- **Thus, only a small longitudinal part of each bunch collides with a small longitudinal part of the opposing bunch. (luminosity loss)**
- **However, the vertical beta function can be made very small while keep the overall bunch length long. (luminosity gain) (better for beam instabilities)**
- **Use ILC final focus.**
- **Do not need strong damping.**

**Simplified layout in the
Small Disruption
Regime
Collisions every turn
Uncompressed bunches
Crossing angle = 2×25
mrad
Crabbed Y-Waist**



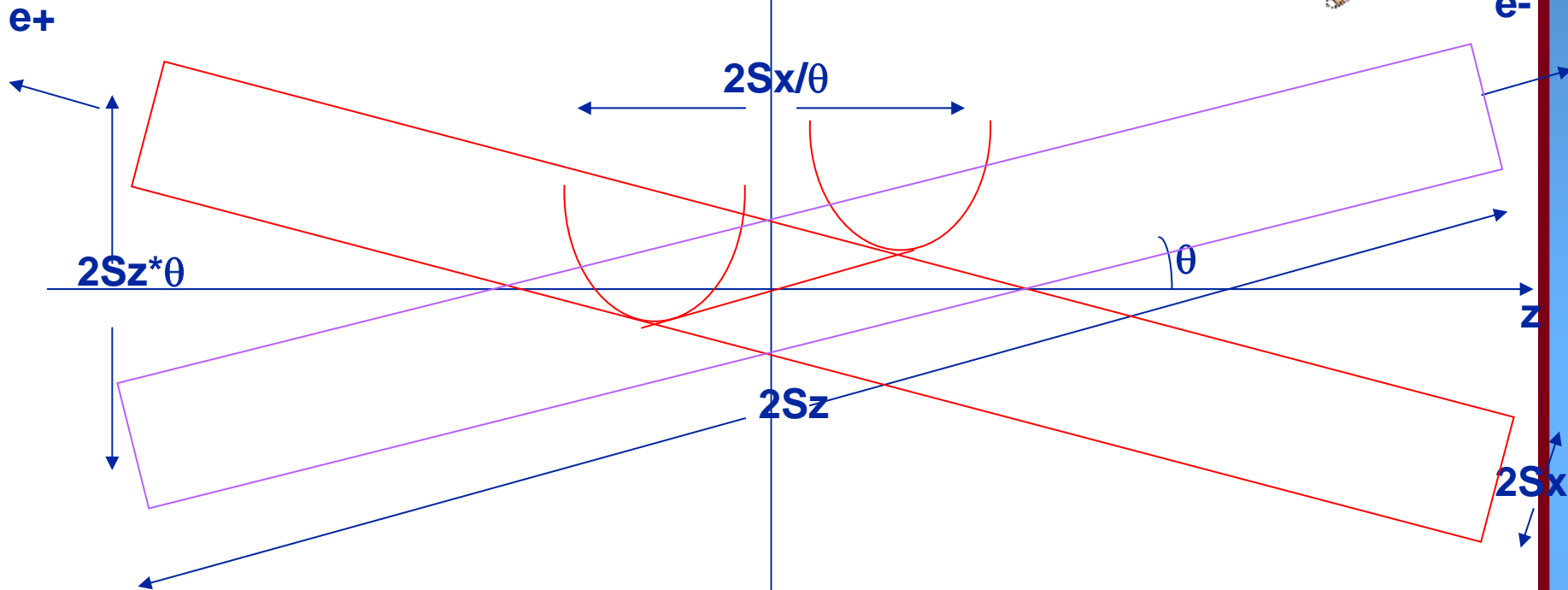
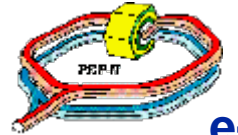
**ILC ring &
ILC FF**

P. Raimondi

FF IP FF



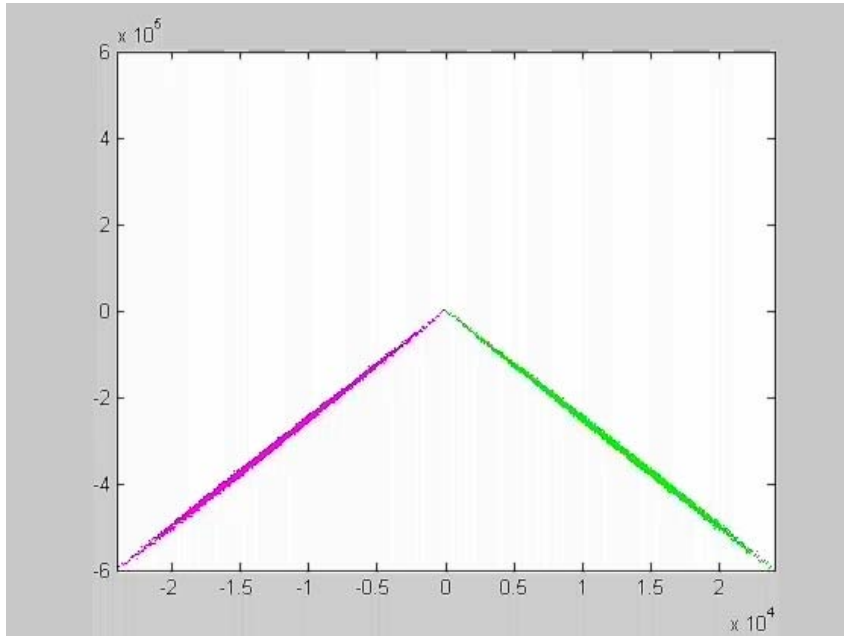
P. Raimondi



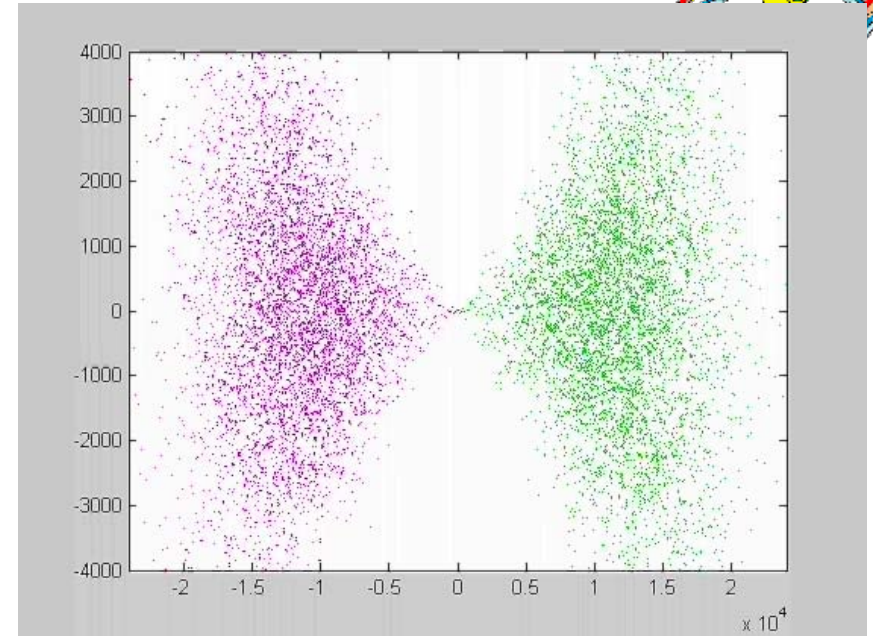
Vertical waist has to be a function of x :

$Z=0$ for particles at $-\sigma_x$ ($-\sigma_x/2$ at low current)

$Z= \sigma_x/\theta$ for particles at $+\sigma_x$ ($\sigma_x/2$ at low current)



Horizontal Plane



Vertical Plane

Collisions with uncompressed beams

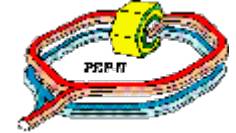
Crossing angle = $2 \times 25 \text{ mrad}$

Relative Emittance growth per collision about 1.5×10^{-3}

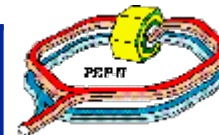
$$\epsilon_{yout}/\epsilon_{yin} = 1.0015$$

Raimondi

Parameters of Super-B Designs

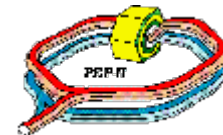


Collider		ξ_y	N	β_y^*	s	E	F	Lumin
Units			10^{10}	mm	m	GeV	(~Hd)	10^{35}
PEP-II	Normal	0.068	8	11	1.26	3.1	0.84	0.10
KEKB	Normal	0.065	5.8	6	2.1	3.5	0.76	0.16
Super-PEP-II	High I low β_y	0.12	10	1.7	0.32	3.5	0.81	7
Super-KEKB	High I low β_y	0.28	12	3	0.59	3.5	0.85	8
Linear SuperB	Single pass	29.	10	0.5	250	4	1.07	10
SuperB	Bunch shorten	0.14	6	0.4	0.63	4	0.75	10
SuperB	X'ing angle	0.045	2	0.08	0.5	5	0.8	10



		Round single pass	Flat single pass	Flat Ring with compressor	Flat Ring no compressor
Sigx*	μm	0.9	30 (2 betatron)	18 (2 betatron)	2.67
Etax	mm	0.0	+1.5	+5.0	0.0
Sigy	nm	900	12.6	63.2	12.6
Betx	mm	0.55	5.0	5.0	8.9
Bety	mm	0.55	0.080	0.500	0.080
Sigz_IP	mm	0.8	0.100	0.600	4.0
Sige_IP		1.0e-3	2.0e-2	3.5e-3	1.0e-3
Sige_Lum		0.7e-3	1.0e-3	1.0e-3	0.7e-3
Emix	nm	1.5	0.8	0.8	0.8
Emiy	nm	1.5	0.002	0.008	0.002
Emiz	μm	0.8	2.0	2.0	4.0
Cross_angle	mrاد	Optional	Optional	>2*12	2*25
Sigz_DR	mm	0.8	4.0	4.0	4.0
Sige_DR		1.0e-3	0.5e-3	0.5e-3	1.0e-3
Np	10e10	7.0	7.0	2.0	2.0
Nbunches		12000	12000	12000	12000
DR_length	km	6.0	6.0	6.0	6.0
Damping_time	msec	20	20	20	20
Nturns_betwe_coll		50	50	1	1
Collision freq	MHz	12.0	12.0	600	600
L _{singleturn}	1e36	1.5	1.5	1.7	1.3
L _{multiturn}	1e36	1.1	1.1	0.9	0.9

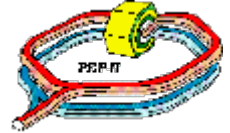
P. Raimondi
March 2006



Conclusions

- There has been rapid progress in the optimization of the Super-B Collider parameters and layout
- Workable parameter set contains:
 - ILC damping ring,
 - ILC bunch compressor,
 - ILC Final Focus
- The optimal collision rate seems to be every turn.

Conclusions (2) for large crossing angle collider



- Solution with a ILC DR + ILC FF seems very promising:
- **Crossing angle of about 25mrad allows low vertical beta function with no bunch compression**
- Thus: No compressor and no energy acceleration
- Uses all the work done for ILC
- Ring and FF layouts similar to ILC
- 6 km circumference rings
- Strong synergy with ILC
- Beam stay clear about 20 sigma assuming 1cm radius beam pipe
- Beam currents about 2 Amps
- Power around 70 MW, further optimization may be possible.
- Reuse PEP RF system, power supplies, vacuum pumps, etc.
- Standard injection system.