Summary FCC-ee Sessions

U. Wienands
SLAC

Overview

- 18 Presentations on Wednesday; covering
  - Lattice and IR optics,
  - IR Design and Machine-Detector Interface
  - Collective effects, beam-beam
  - Injection/injectors and booster
  - Vacuum system
  - Polarization and energy calibration
  - Configurations and staging
- Several presentations for CepC

Lattice Work incl. IR Optics

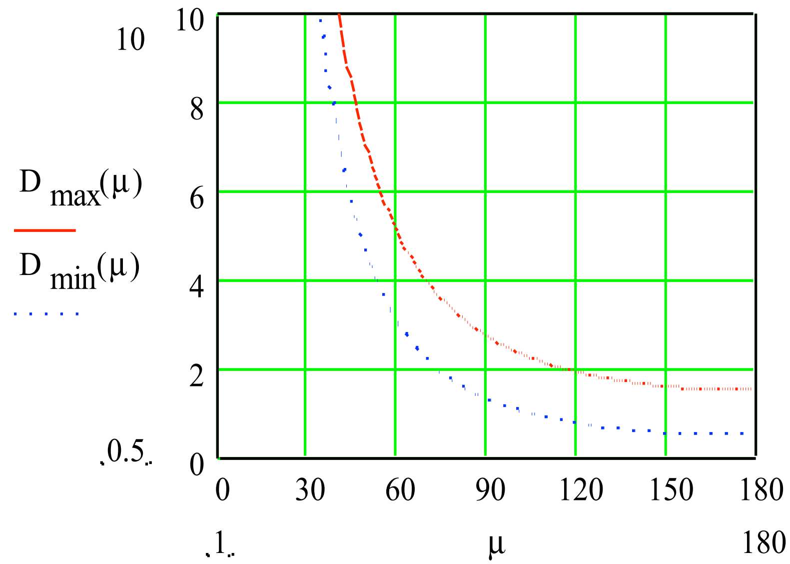
- CERN, Budker INP, KIT,IHEP
- Features:
  - ultralow β_y^* (1 mm); record momentum acceptance (2%)
  - ILC-type IR optics with local chromaticity correction
    - alternate investigation how far nonlocal correction can be pushed
  - possibility of crab waist.
  - wide range of emittance & parameters from Z to t-tbar
- Further study:
  - dynamic aperture of ring with IR is a challenge for both CepC and FCC-ee.
  - The assertion that the acceptance is dominated by the arc sextupoles is peculiar. Maybe try non-interleaved sextupoles?
  - Can the damping partitions be changed by radial steering?

Changing the horizontal emittance for lower energies

B. Haerer

$$\varepsilon = \left(\frac{\delta p}{p}\right)^2 \left(\gamma D^2 + 2\alpha D D' + \beta D'^2\right)$$

$$\hat{D} = \frac{L_{cell}^2}{\rho} \times \left(1 + \frac{1}{2}\sin\left(\frac{\Psi_{cell}}{2}\right)\right) \Big/ \sin^2\left(\frac{\Psi_{cell}}{2}\right)$$



Court. B. Holzer

There are two different possibilities:

1) Change the phase advance Ψ of the FODO cell

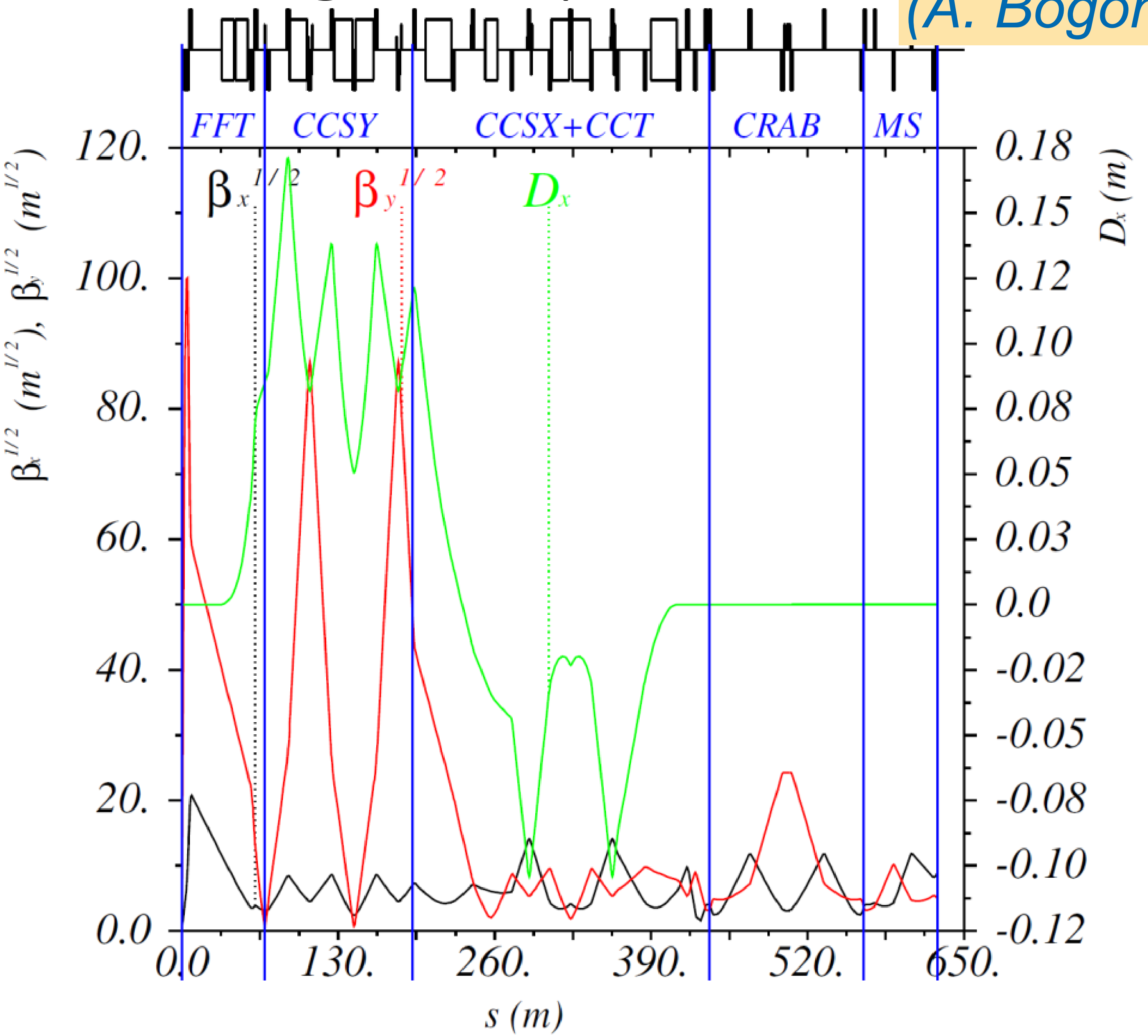
→ Larger emittance: smaller phase advance

2) Change the cell length

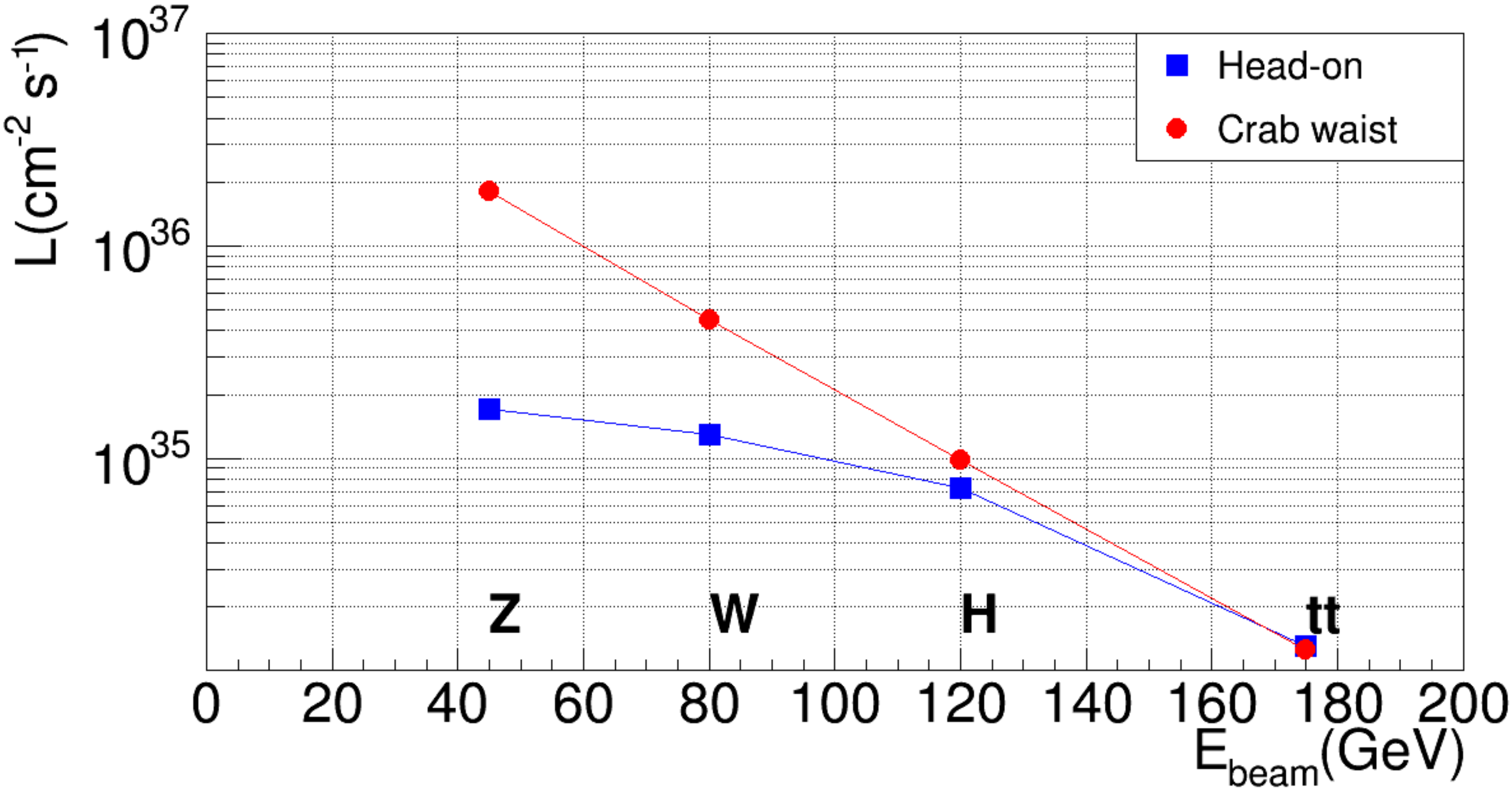
→ Larger emittance: increase cell length

Interaction region: optical fun

R. Martin
(A. Bogomyagkov)

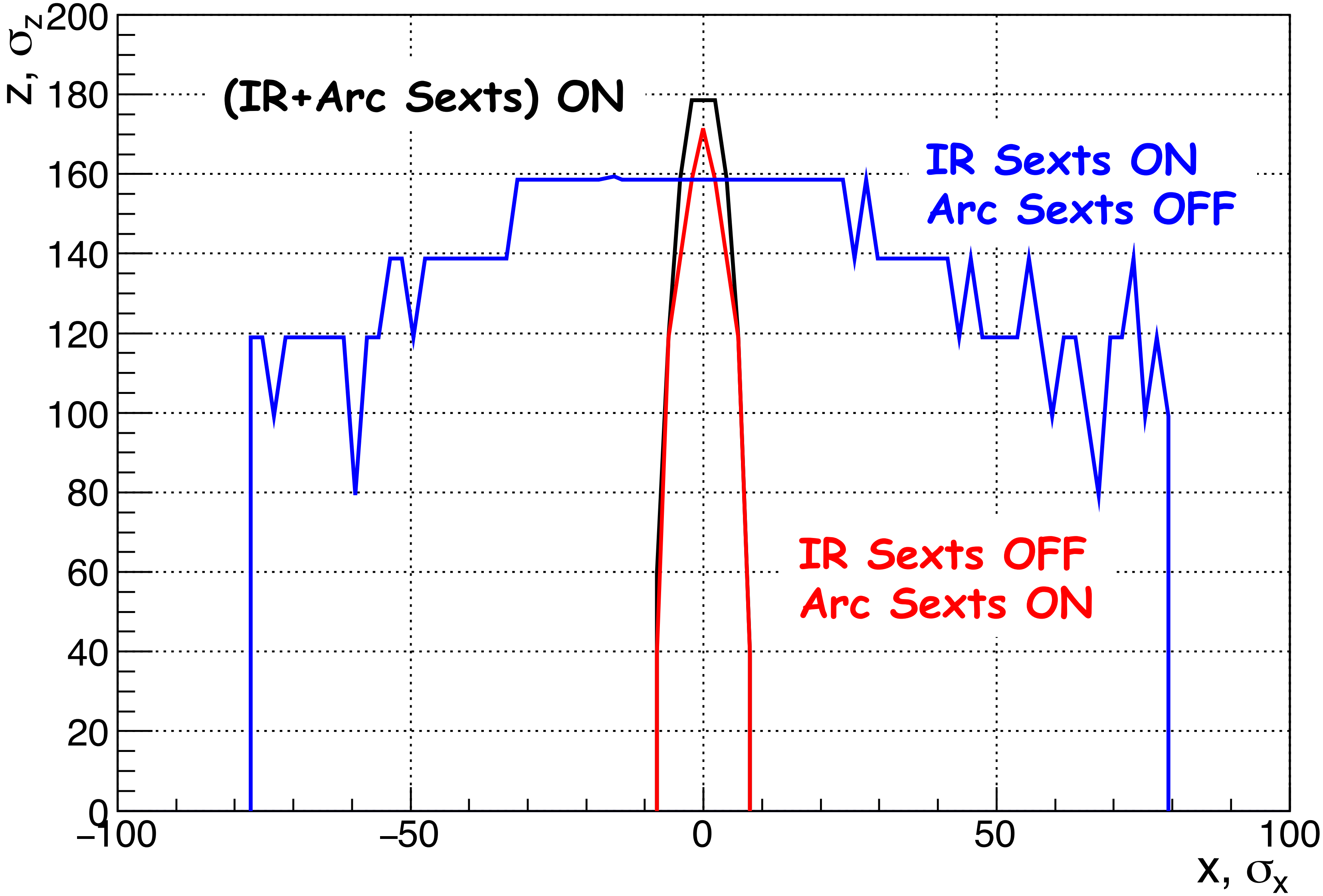


Luminosity (per IP) comparison



Dynamic aperture at IP: where is a bottleneck?

R. Martin (A. Bogomyagkov)

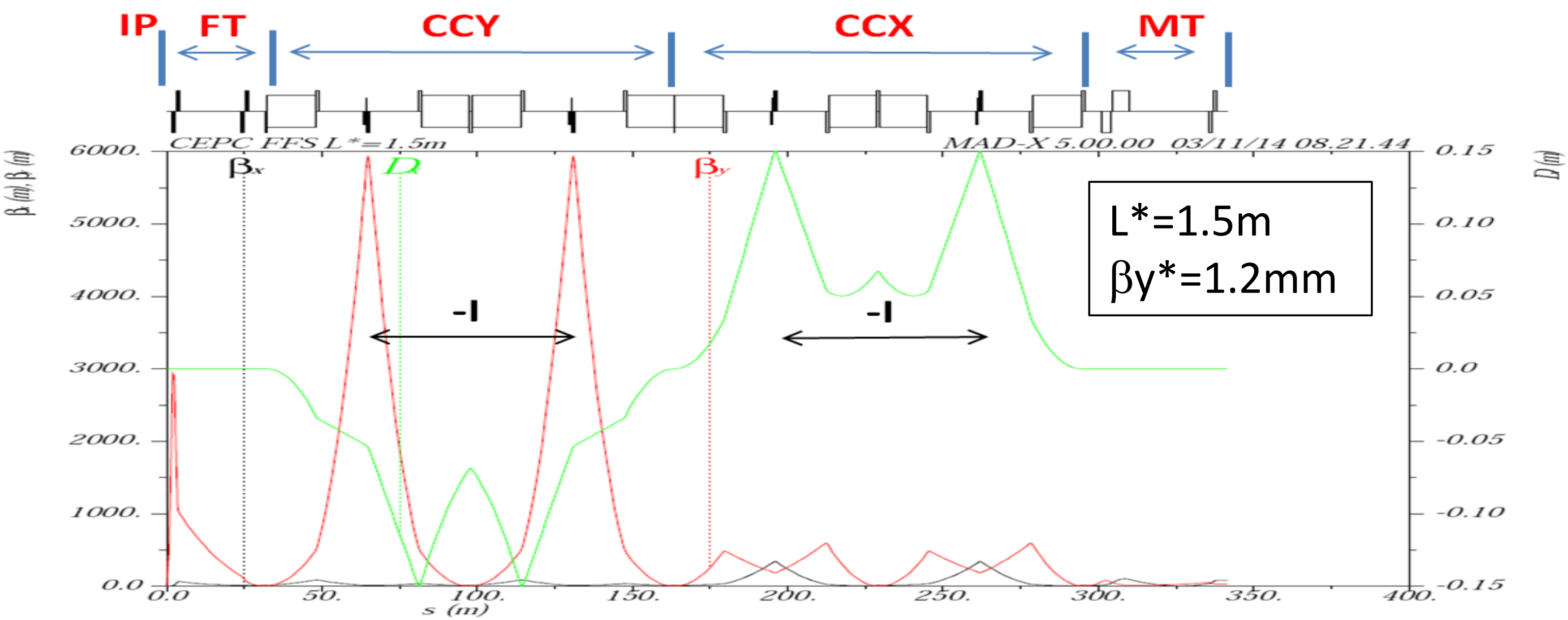


$E=175$ GeV, $\varepsilon_x=1.3$ nm, $\varepsilon_y=0.002\,\varepsilon_x$, $\beta_x = 0.5$ m, $\beta_y = 0.001$ m

Interaction region design

Y. Wang

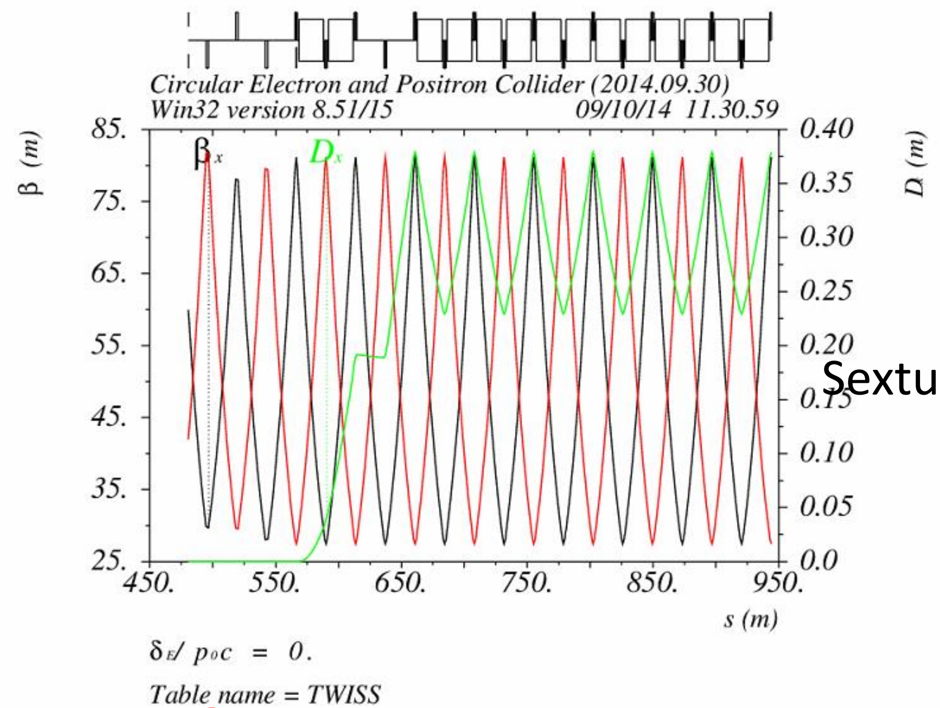
- L*=1.5m chosen to facilitate design
- length constraint by overall layout consideration
  - maximum 350m for per side



Effects of pretzel orbit (1)

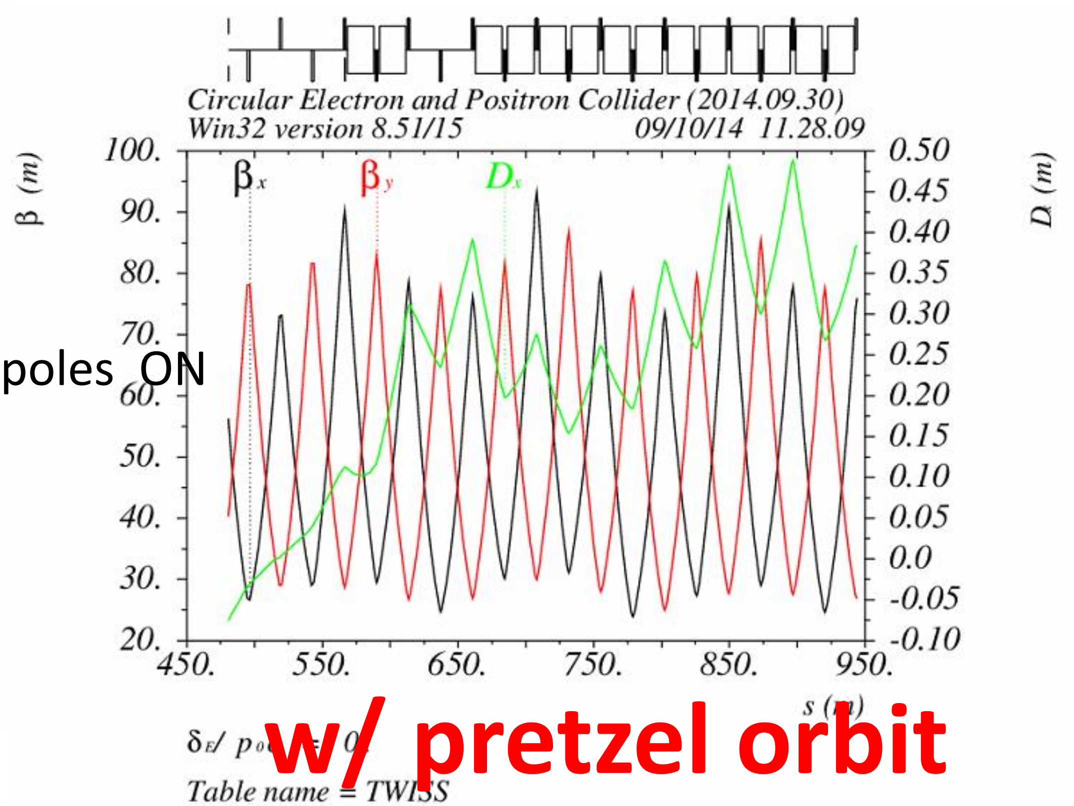
H. Geng

- Pretzel orbit has effects on:
  - Beta functions, thus tune
  - Dispersion function, thus emittance
  - Dynamic aperture



w/o pretzel orbit

Sextupoles ON



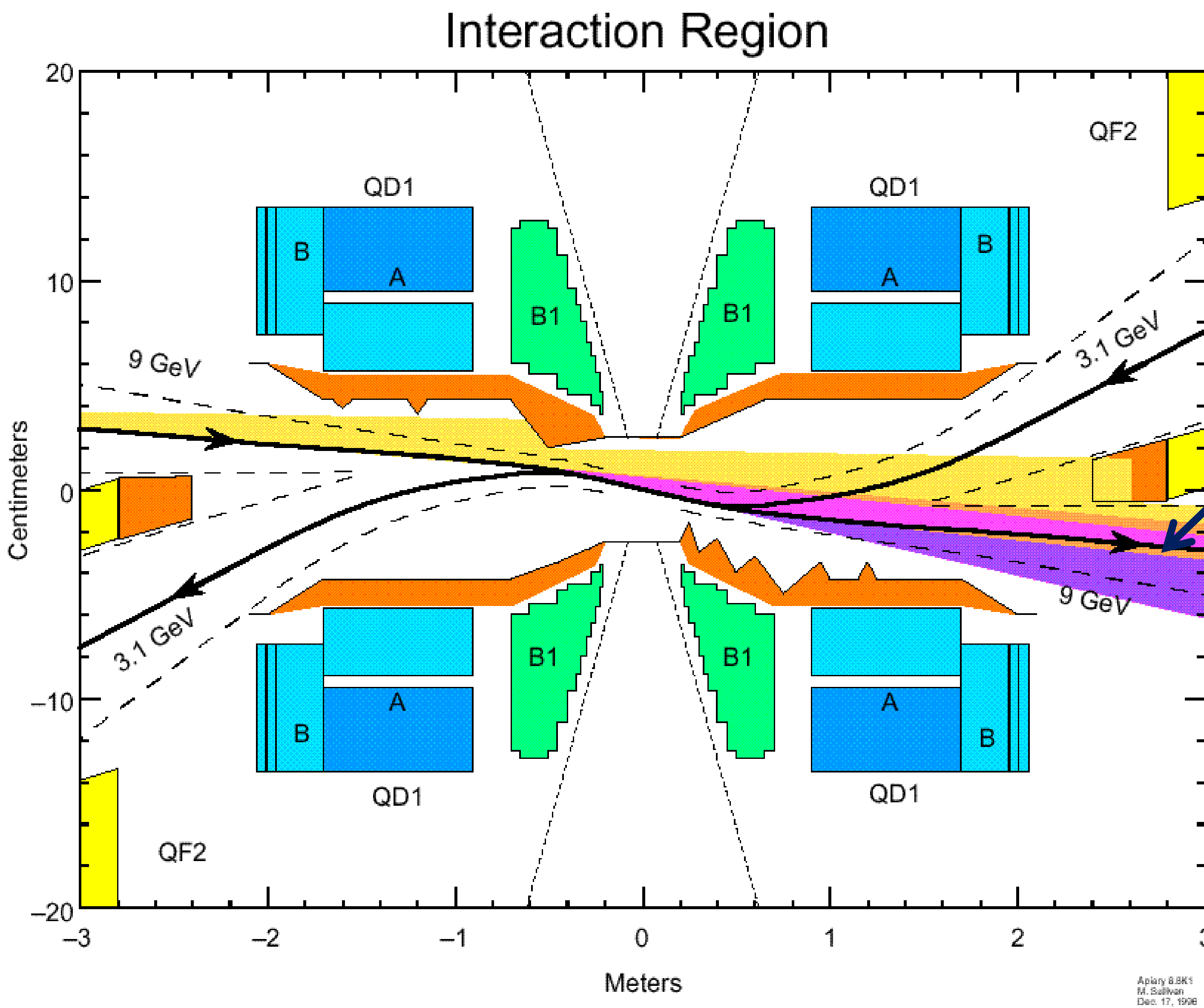
w/ pretzel orbit

IR Design and MDI

- CERN, SLAC, IFIP
- Potential for MW of hard Xrays aimed at detector
  - has to be mitigated; masking these is difficult
- L* (2 m in FCC-ee) an important parameter
  - need to find a workable compromise
  - affects overall energy acceptance
- Further study:
  - the dipoles near the IR to get longer.
  - and/or include “soft bends” near the detector.
  - try to take most s.r. through the beam pipe to the other side.
  - monochromatization feasible?

HER SR fans

M. Sullivan



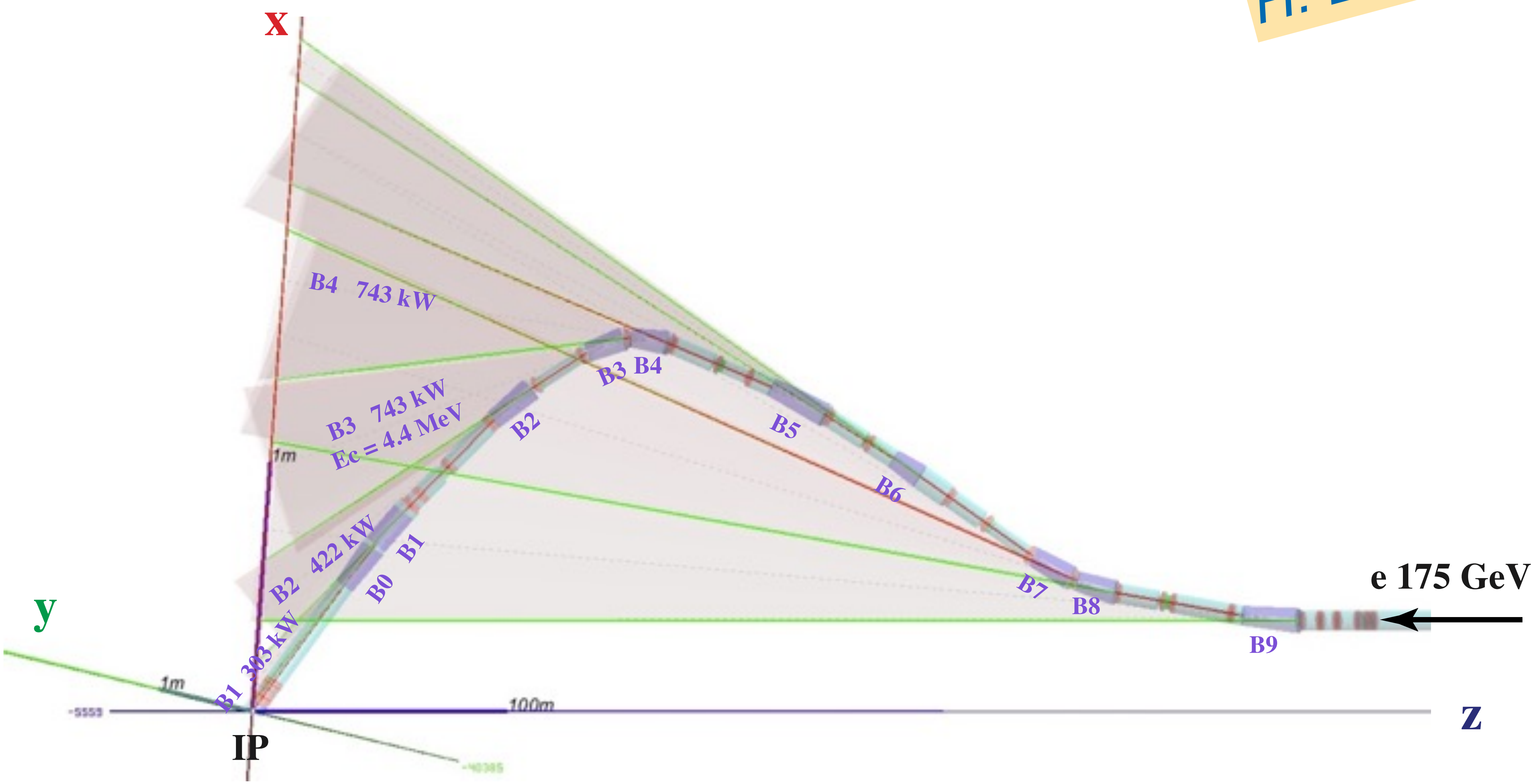
HEB SR fans from the bend magnets (B1) overlap and miss all local surfaces and strike the beam pipe wall starting at 10 m from the IP. k_c was 40 keV. Fan power was ~200 kW.

FCC-ee IR MDI

SynRad bend cones for TLEP_V14_IR_6-13-2 BINP IR

H. Burkhardt

MDISIM/root/ 3d-OGL display



Synchrotron radiation into IR major challenge : **2.3 MW** / beam of MeV γ's into detector region

Monochromatization principle Monochomatization factor

A. Faus-Golfe

1) Case with: $D^*_{x,y}=0$

$$L_0 = \frac{k_b f_r N_+ N_-}{4\pi \sigma^*_{x\beta} \sigma^*_{y\beta}}$$

2) Case with: $D^*_{x+} = - D^*_{x-} = D^*_x$
$D^*_{y+} = - D^*_{y-} = D^*_y$

Monochromatization factor

$$\lambda = (1 + \sigma_\varepsilon^2 (\frac{D_x^{*2}}{\sigma_{x\beta}^{*2}} + \frac{D_y^{*2}}{\sigma_{y\beta}^{*2}}))^{1/2}$$

$$L = \frac{L_0}{\lambda}$$

$$\Sigma_w = \frac{\sqrt{2} E_0 \sigma_\varepsilon}{\lambda}$$

- Opposite dispersions at the IP enhance energy resolution without detriment of the differential luminosity while dispersion which have the same sign degrade both differential and total luminosity
- When $\sigma^*_y <<< \sigma^*_x$ is more efficient to produce dispersion in the vertical plane trying to keep it zero horizontally

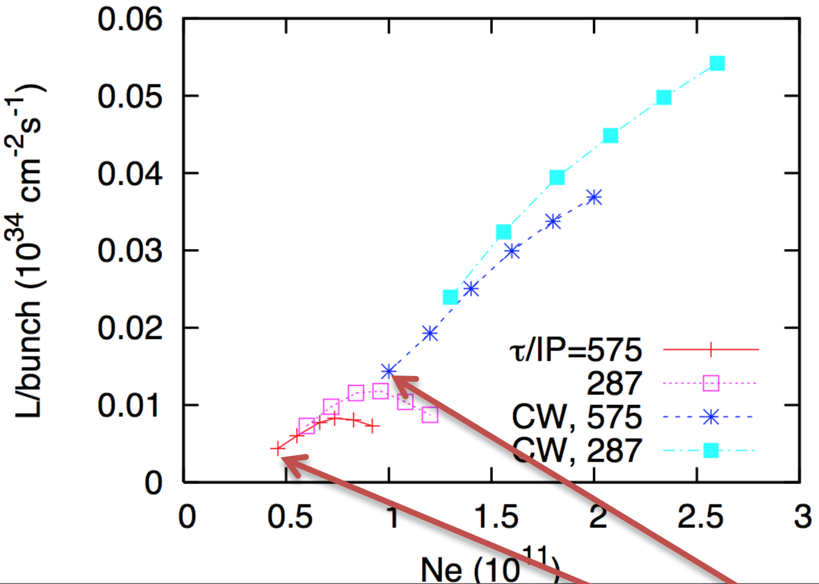
Collective Effects, Beam-Beam etc.

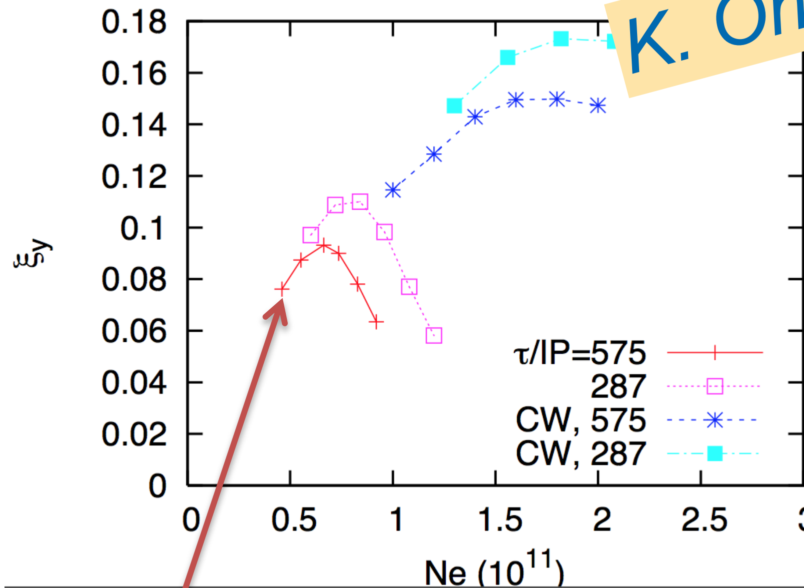
SLAC

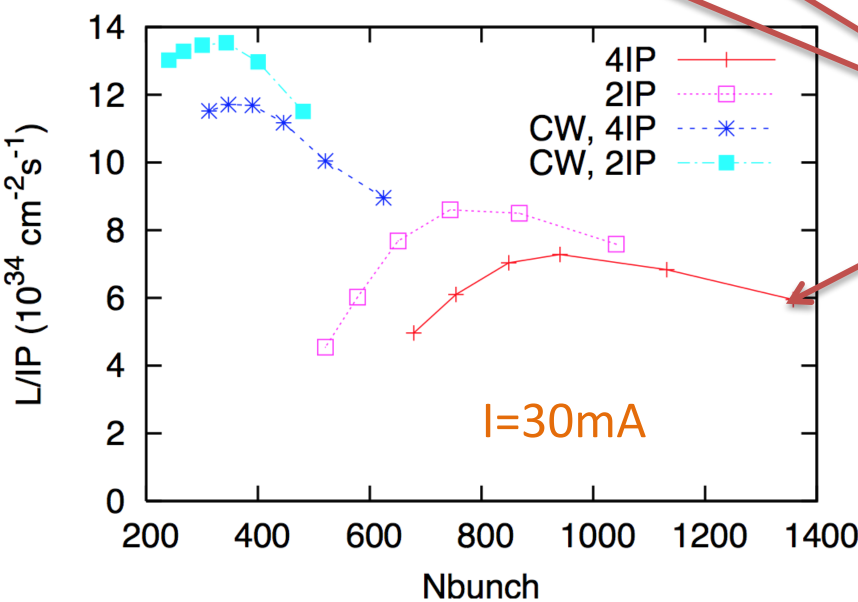
- INFN, KEK, CERN
- Large machine, high beam current @ Z
  - affects vac. chamber size, other vacuum components
  - need for feedback
- Touschek, IBS: Unlikely to be a major issue
- Beam-beam: Simulations appear to support the claimed beam-beam parameters in most cases.
- Further study:
  - Double-check the details of the rf cavity (taper)
  - Resistive Wall sets the chamber size, material
  - Rf system impedance a potential issue
  - Loss factor needs to come down, significant @ Z energy/current
  - Crab waist has potential to increase L at Z.

Luminosity and beam-beam parameter for H

K. Ohmi







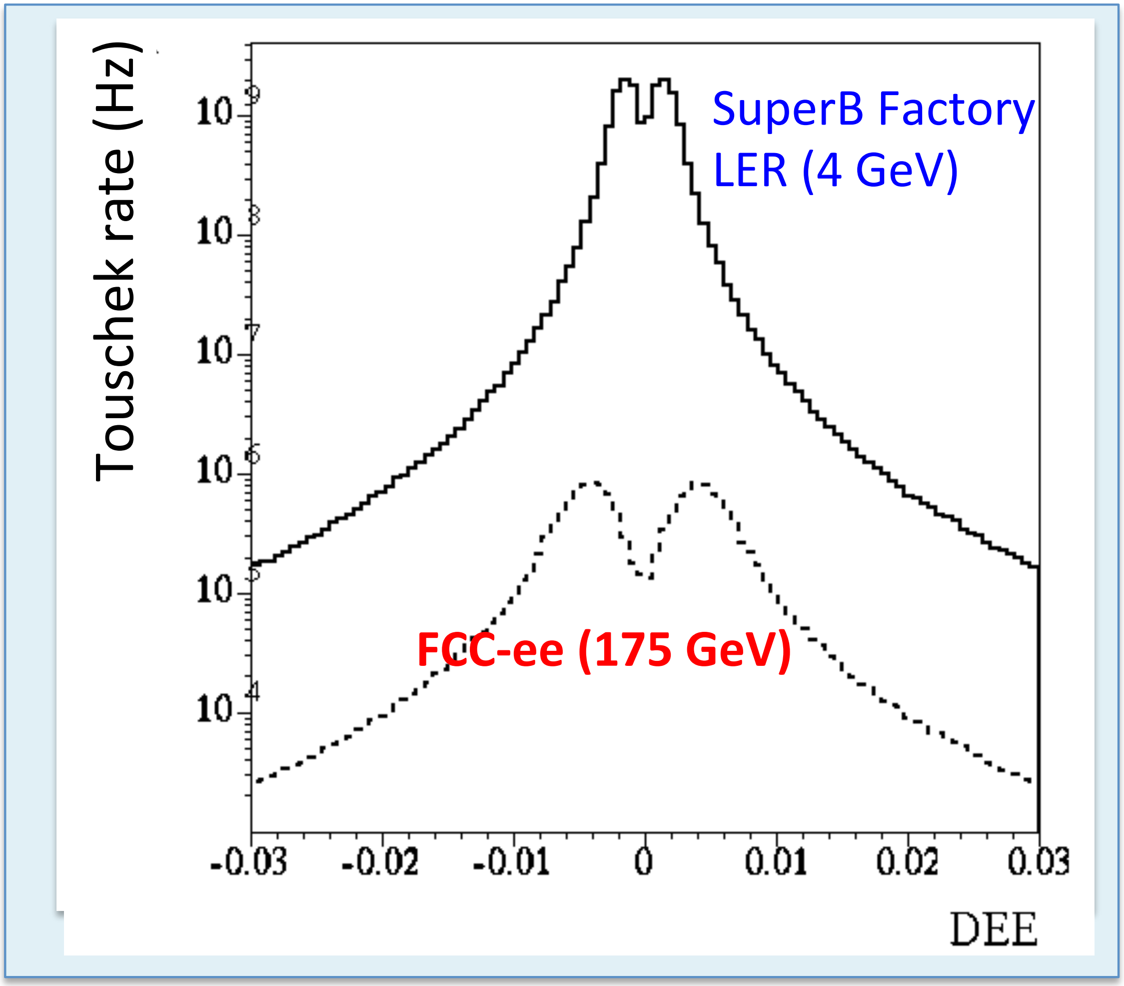
$$\xi_y \equiv \frac{2 r_e \beta_y L}{\gamma N_e f_{col}}$$

Design Ne: the lowest value in figure

Highest luminosity performance is achieved at the peak of ξ.

FCC-ee Touschek Rate

M. Boscolo



Touschek lifetime SuperB = 400 s with momentum acceptance ~1 % and realistic physical aperture

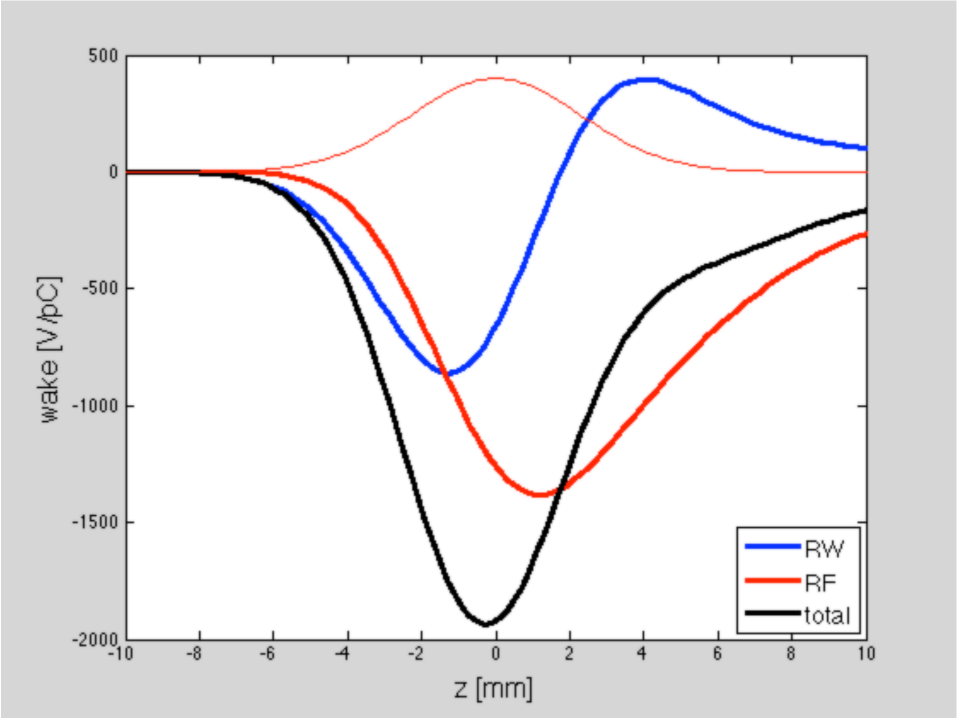
Touschek Rate scales like $1/E^{2.5}$ wrt $1/E^3$ naïve expectation -> Energy scaling largely dominates

First look confirms that Touschek not a dominant effect also for energy acceptance comparable to SuperB Factories

Longitudinal Impedance Budget

M. Migliorati

Element	R [kΩ]	L [nH]	k_{loss} [V/pC]	|Z/n| (mΩ)
Resistive wall (Al)	7.5	148	276	1.1*+2.8
RF cavities	26.9	-	1000	3.9*
total	34.3	148	1276	7.8
CEPC total	37.8	128.8	1205.1	4.4



* at $\omega = c / \sigma_z$

- The total loss factor, with a bunch charge of about 29 nC gives an energy lost per turn of about 0.037 GeV.
- The RF cavities contribute mainly to the real part of the impedance and to the total loss factor.
- The impedance budget is comparable to CEPC.

Injection/Injectors/Boosters

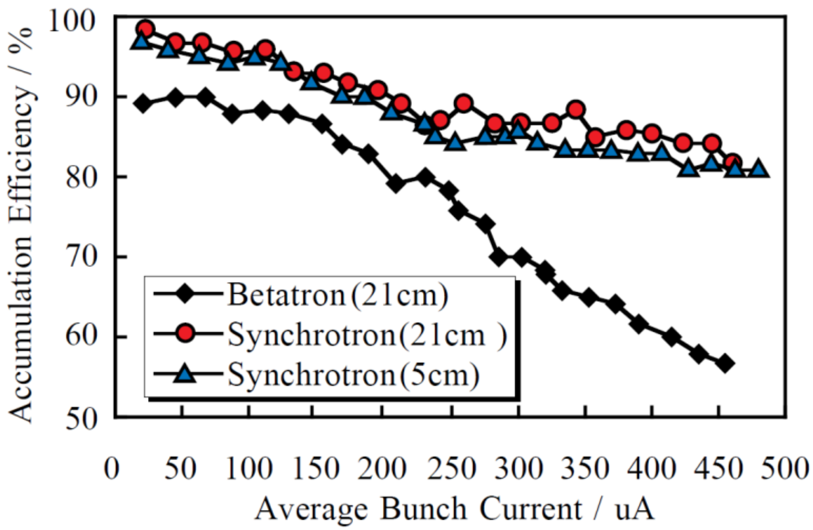
SLAC

- Presentations from PSI, IHEP, SLAC
- Significant cost driver.
  - Scaled-up Cornell synchrotron a viable full-scale Booster?
- “Innovative injection schemes” deserve investigation
  - Top-up injection will put stringent limits on injection background
  - Synchrotron injection proven at LEP
  - Higher-order magnetic field injection used in some light sources; need careful investigation whether performance better.
- Further study:
  - e+ system
  - Injection systems for the collider rings
  - Modifications necessary for PS, SPS

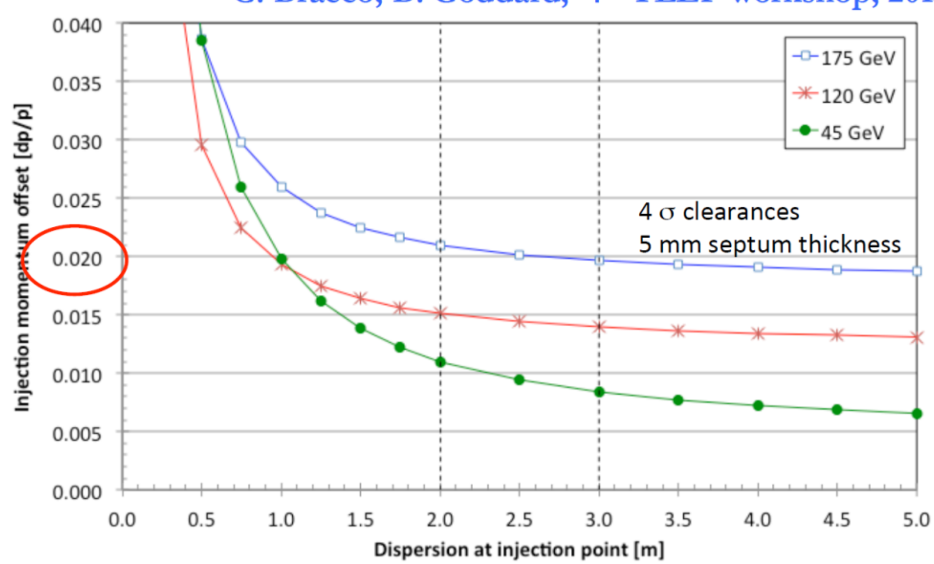
M. Aiba

Synchrotron phase space injection (2)

Injection efficiency at LEP
P. Collier, PAC 1995



C. Bracco, B. Goddard, 4th TLEP workshop, 2013



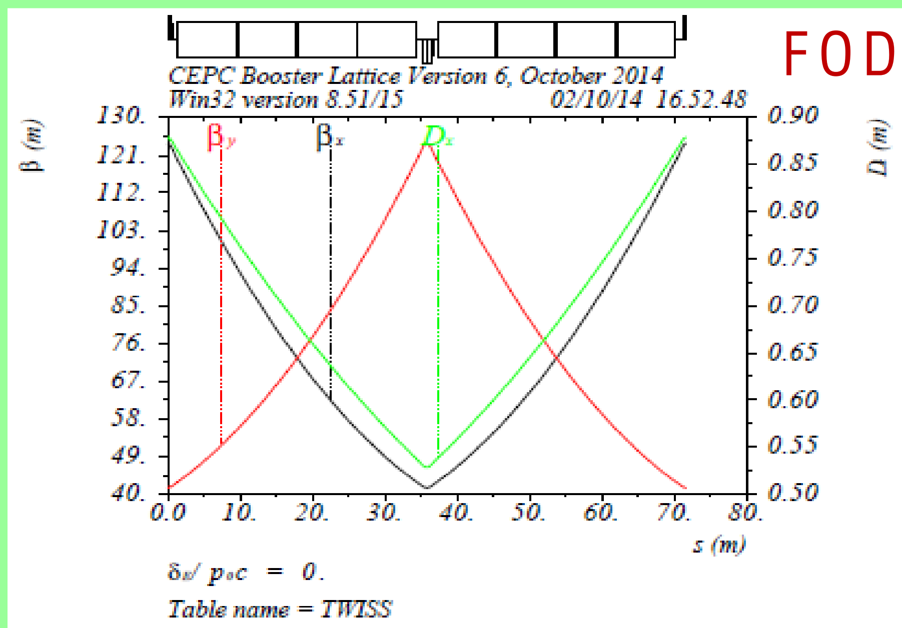
On-axis injection realised
better injection efficiencies
despite off-momentum injection beam!

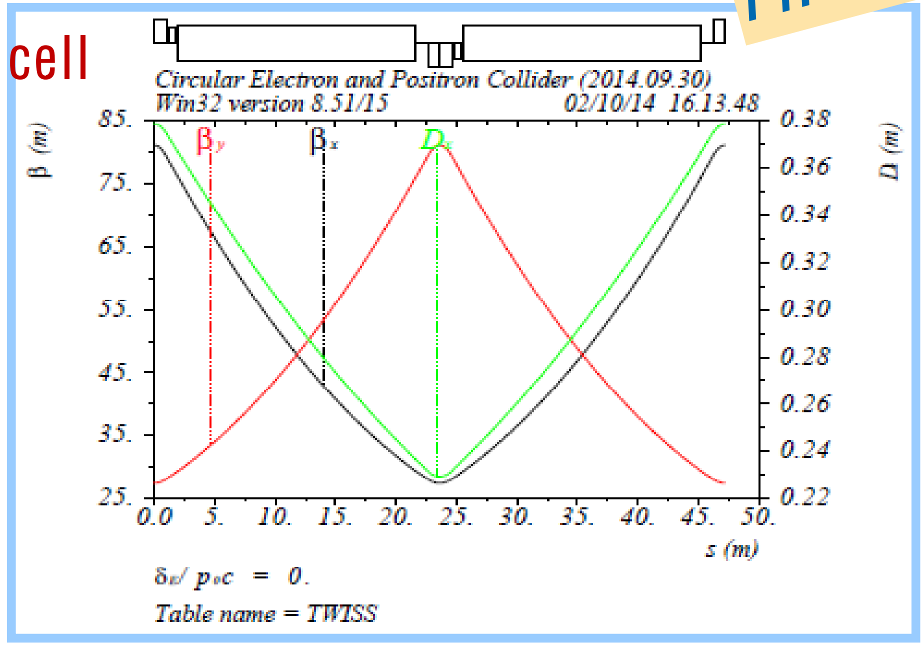
Applicable to FCCee:
4σ clearance for 5 mm septum thickness
with δ=2%

2.2 Lattice functions: booster vs. collider

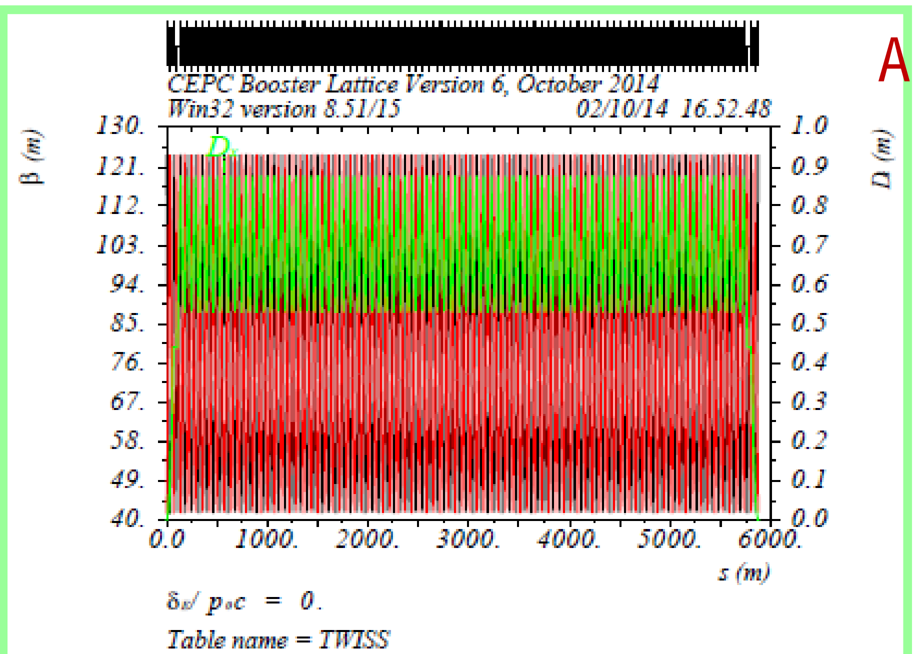
H. Geng

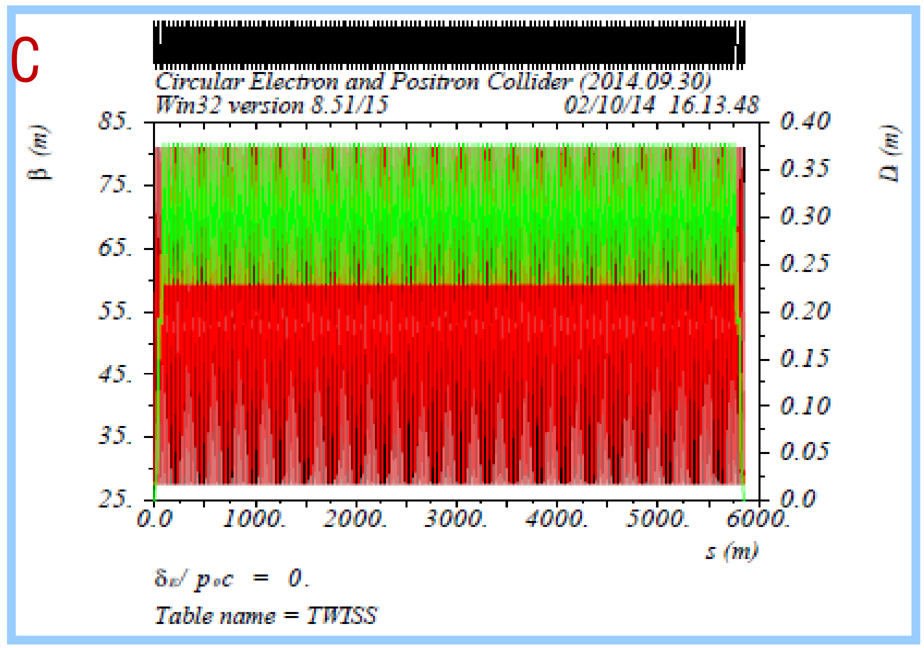
FODO cell





ARC





How to modify the 12 GeV Cornell Synchrotron for HF injector at 120 GeV (100 km)

J. Seeman

SLAC

1) Build 10 x number of Cornell magnets (620 m to 6200 m) to get to 120 GeV.
2) Space each lamination by a factor of 14 (6200 m to 87,000 m) with same beam energy.
3) The bending radius is 13,850 m so loss per turn is 1.4 GeV.
4) The magnets are combined function so no extra quadrupoles are needed.
5) Need to check anti-damping.
6) The field is reduced from 4000 gauss to 256 Gauss at 120 GeV.
7) Magnetic field at injection (12 GeV) is 26 gauss.
8) Residual field in Cornell magnets is 2 gauss at minimum energy. Lower for HF with spaced laminations.
9) Mount the laminations on a strong back to keep the magnet straight. No concrete.
10) The ramp rate is low (5 sec) so an extruded aluminum vacuum chamber can be used using NEG strip pumping and holding ion pumps similar to PETRA-4.
11) The coil current is still 508 A at 24 turns. Due to lower eddy currents, a new coil configuration can likely use solid bus bars with cooling holes to reduce power losses.

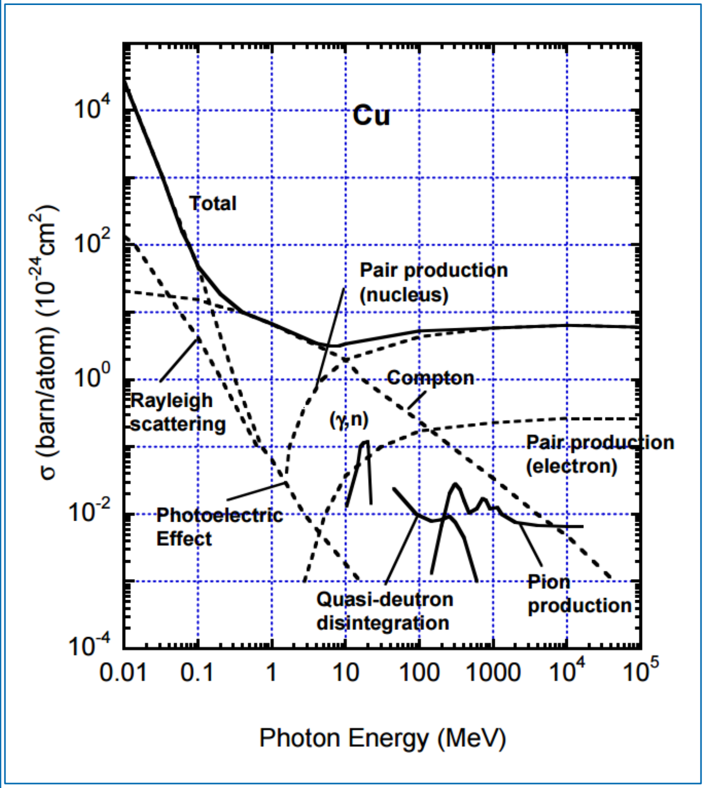
Vacuum System

- CERN
- Overall s.r. power density within envelope of what has been done @ the B-Factories.
- Hardness of radiation causing radiological hazards is new
  - drives layout towards discrete photon stops.
- Further study:
  - from B-Factory experience: consider antechamber for e-clioud mitigation
    - solenoid windings likely not enough due to lack of space.

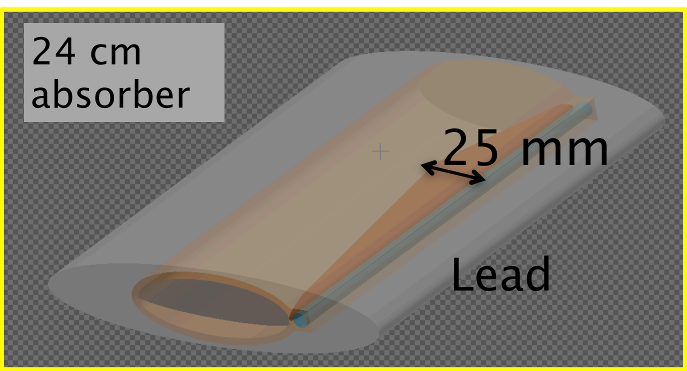
Impact of SR on Machine and Tunnel Components

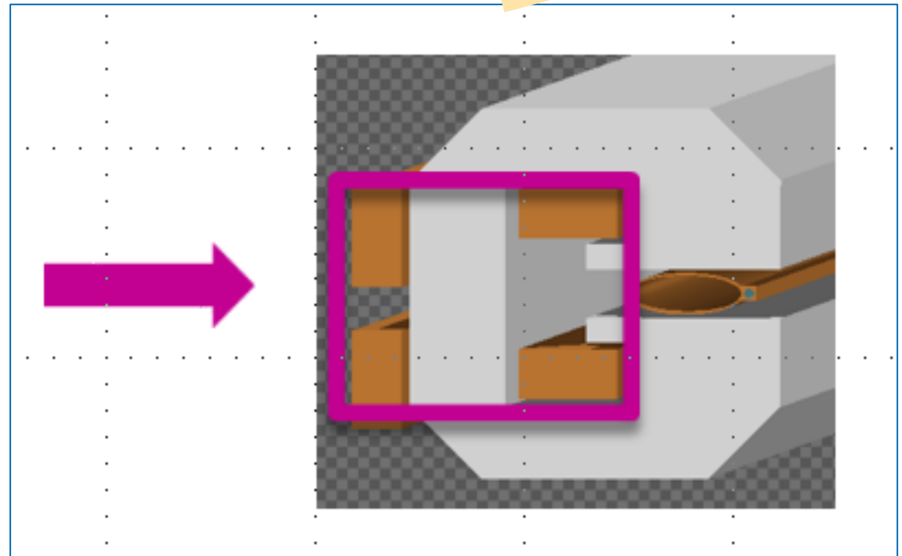
R. Kersevan

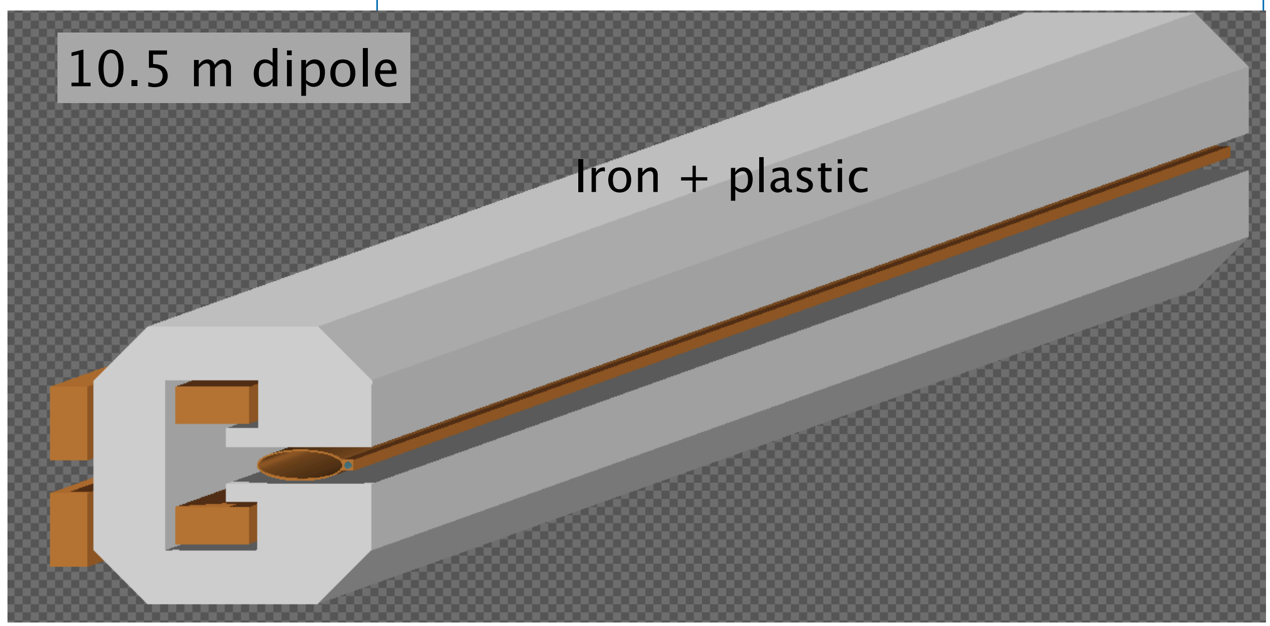
Ref.: “Impact of synchrotron radiation in lepton collid
F. Cerutti et al., FCC Kick-off Meeting, Univ. Gen



[8] E. Frytag, “Strahlenschutz an hochenergiebeschleunigern”, (G. Braum, Karlsruhe, 1072).







Polarization/Energy Calibration

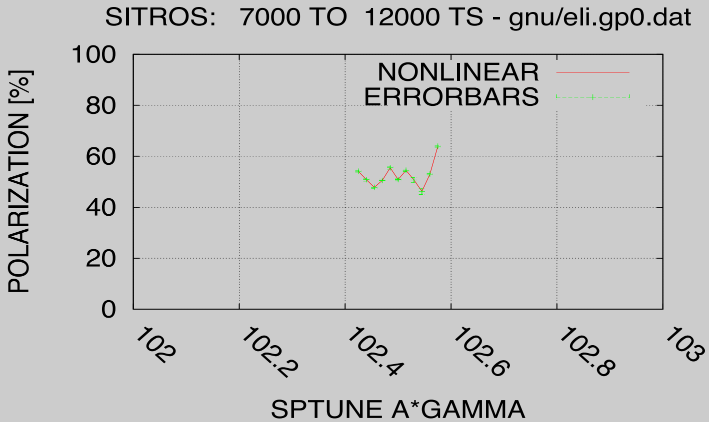
- FNAL/BINP, U. de Geneve
- At Z, wigglers may be used to get usable polarization
  - LEP is existence proof of polarization at ≤ 50 GeV
    - larger FCC ring should be better (but note Q_s!)
  - s.r. would limit beam current (factor 2 or more)
  - emittance would be enlarged
- Energy calibration requires 5…10% polarization:
  - likely available up to ≈ 80 GeV
  - high statistical accuracy
- Further study:
  - Double-check spin tracking in light of LEP experience (P->0 for δE > 52 MV)
  - Assess systematic E-calibration error from energy sawtooth for separate rings.

It is expected the strength of the sidebands to be proportional to the parent resonances through the factor

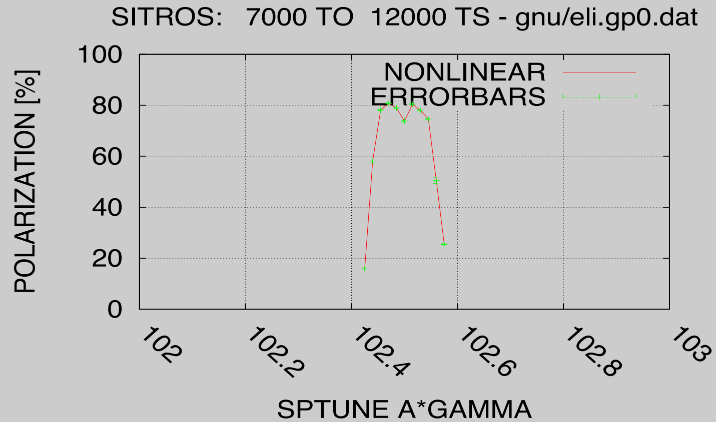
$$\xi = \left(\frac{a\gamma}{Q_s}\frac{\Delta E}{E}\right)^2$$

E. Gianfelice

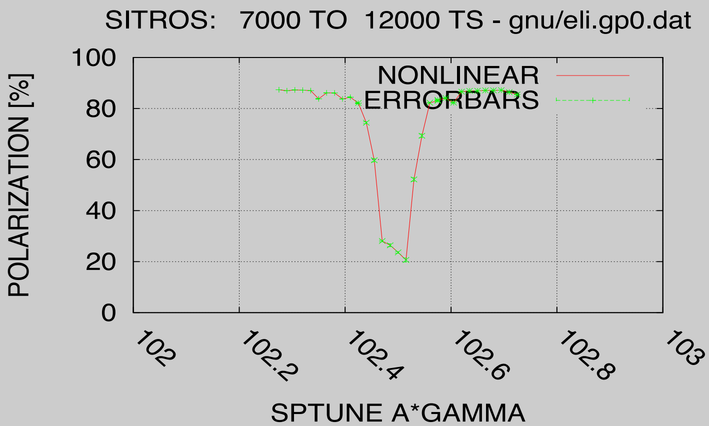
B_+=3.9 T , δ_y^Q= 200 μm, SVD correction



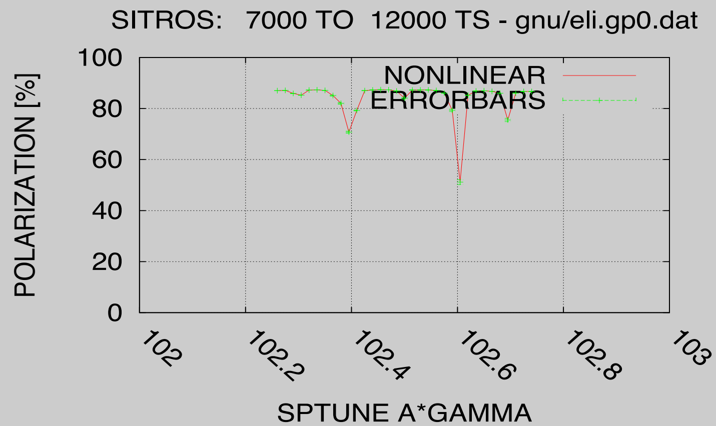
Q_s=0.08



Q_s=0.21



Q_s=0.48

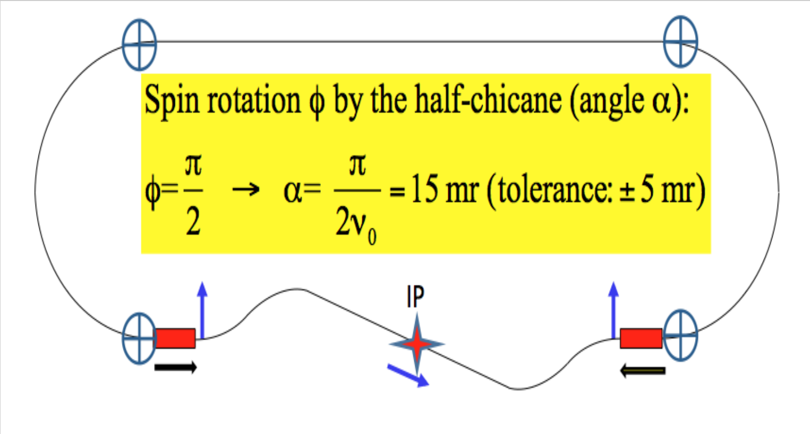


Q_s=0.80

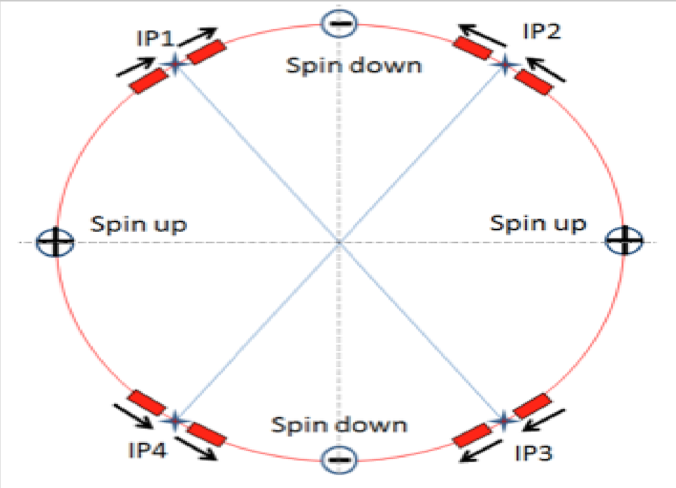
Longitudinal Polarization [a]

E. Gianfelice (I. Koop)

- Beams are vertically polarized prior to injection into the collider (see previous slide)
- Solenoid type spin rotators (solenoid + h-bend) bring $\hat{n}_0$ in the longitudinal direction at the IP



- It requires large solenoid integrated field: $\gamma\times$ 27 Gauss m for 90^0 rotation
- By arranging the polarity of the solenoids and assuming even number of IPs they act as Siberian Snakes



- Energy calibration is through resonant depolarization

[a] from I. Koop HF2014 presentations

Resonant depolarization accuracy at TLEP/FCCee – wild extrapolation

Per beam, not ECM

Source	$\Delta E/E$	ΔE (E=45.6 GeV)
Electron mass	$3 \cdot 10^{-7}$	15 keV
Revolution frequency	10^{-10}	0 keV
Frequency of the RF magnet	$2 \cdot 10^{-8}$	1 keV
Width of excited resonance	$2 \cdot 10^{-6}$	90 keV
Interference of resonances	$2 \cdot 10^{-6}$	90 keV
Spin tune shifts from long. fields	$1.1 \cdot 10^{-7}$	5 keV
Spin tune shifts from hor. fields	$2 \cdot 10^{-6}$	100 keV
Quadratic non-linearities	10^{-7}	5 keV
Total error	$4.4 \cdot 10^{-6}$	200 keV

Table 1: The accuracy of the beam energy calibration method by resonant depolarization is summarized for LEP. A standard energy calibration with a well corrected vertical closed orbit is assumed. All errors are understood to be RMS errors.

Correlated/Z mass	Uncorrelated/Z width
15keV	0keV
0keV	0keV
1keV	0keV
1keV	1keV
9keV	9keV
5keV	5keV
3keV	1keV
5keV	5keV
~20keV	~12keV
~40keV	~20keV
~45keV	~23keV

IP specific errors

total

- Statistical errors are divided by sqrt(10,000) – negligible
- This is a zeroth order working hypothesis
- The table should eventually also include effects that were negligible at the time of LEP

Configuration/Staging

- KEK, SLAC
- 1-ring vs 2-ring
  - cost for facility vs cost per fb^{-1}
- What constitutes meaningful initial performance
- One (rf-) size fits all *vs* reconfiguration for different operating point (Z vs H)
- Further study:
  - Cavity and HOM-damper design and space needs
  - More realistic length of 400-MHz cryo module
  - 400-MHz only vs 400/800 MHz system.
  - Too many cavities at Z energy?

$$\mathcal{L} = \frac{\pi c}{C}\left(\frac{\gamma n_{\rm sep}}{r_e}\right)^2 \frac{\xi_y \xi^{\rm PC} \varepsilon_x}{\beta_y^*}$$

K. Oide

With the FCC-ee numbers at Zh:

$$\mathcal{L} = \frac{c\pi}{r_e^2}\left(\frac{100\ \text{km}}{C}\right)\left(\frac{\gamma}{(120\ \text{GeV})}\right)^2\left(\frac{n_{\rm sep}}{5}\right)^2\left(\frac{\xi_y}{0.1}\right)\left(\frac{\xi^{\rm PC}}{0.1}\right)\left(\frac{\varepsilon_x}{1\ \text{nm}}\right)\left(\frac{1\ \text{mm}}{\beta_y^*}\right)$$
$$= 1.6 \times 10^{33}\ \text{cm}^{-2}\text{s}^{-1}$$

FCC-ee: 5e34/IP

And at Z:

$$\mathcal{L} = \frac{c\pi}{r_e^2}\left(\frac{100\ \text{km}}{C}\right)\left(\frac{\gamma}{(46\ \text{GeV})}\right)^2\left(\frac{n_{\rm sep}}{5}\right)^2\left(\frac{\xi_y}{0.1}\right)\left(\frac{\xi^{\rm PC}}{0.1}\right)\left(\frac{\varepsilon_x}{29\ \text{nm}}\right)\left(\frac{3\ \text{mm}}{\beta_y^*}\right)$$
$$= 2.3 \times 10^{33}\ \text{cm}^{-2}\text{s}^{-1}$$

FCC-ee: 27e34/IP

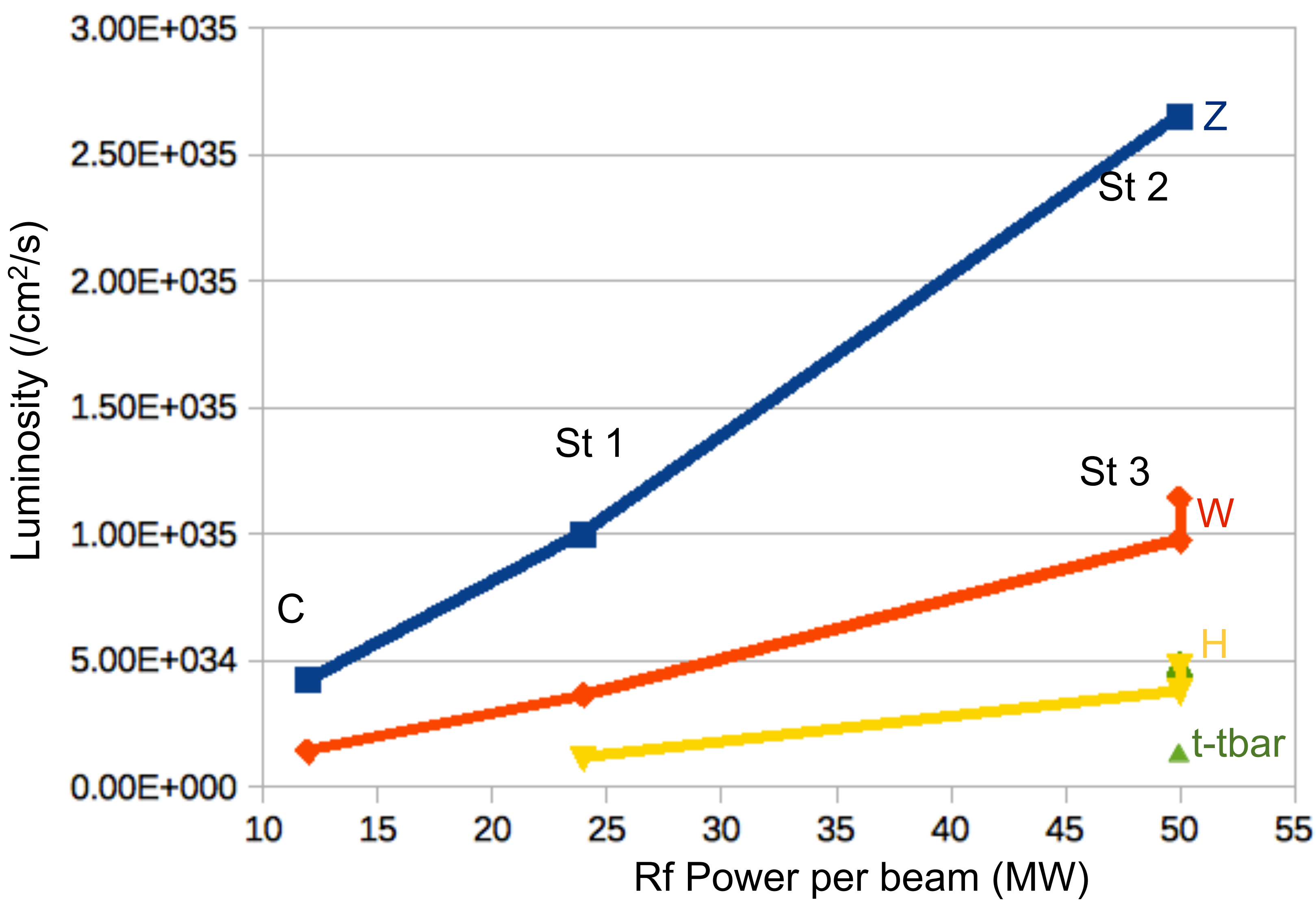
	Double Ring	Single Ring Pretzel	Bunch Train Separation
Common Arc		😁	😁
Parasitic crossing		😓	
Orbit stability		😓	
Common Local CCS		😒	
Common RF		😁	😁
RF uneven loading			😒
Electrostatic Separators		😒	😒
Optics deformation		😓	
E-cloud / ions	😒	😒	only in separated sections 😒
Energy sawtooth	solvable 😁	😒	😒

K. Oide

400 MHz Cavities only, shared last Stage

U. Wienands

SLAC



Relation to US Capabilities and Experience

SLAC

- US labs with e^+e^- experience:
  - Cornell, JLab, SLAC
  - Light sources: ALS, NSLS II, etc...
- Of these, SLAC stands out due to its collider experience
  - Spear, PEP, SLC, PEP-II
- Potential contributors for the identified areas:
  - Lattice – SLAC, JLab, LBNL (ALS)
  - IR/MDI – SLAC, Cornell
  - Rf – JLab, Cornell
  - Collective effects – SLAC, FNAL, BNL (NSLS-II)
  - Injectors/Injection – Cornell, SLAC, JLab
  - Polarization – BNL, JLab, SLAC
- POCs to coordinate collaborations exist
  - M. Syphers (FCC-hh); U.W. (FCC-ee)
  - In most cases; individuals, eager and with relevant experience, can be identified.

It remains to thank the organizers, esp. Michael and Frank, for the friendly invitation to attend this stimulating workshop.