



A Circular Higgs Factory

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Outline



- Physics motivation
- Parameters determination and limits
- Preliminary design of accelerator
- Further studies
- Conclusion

1. Physics motivation



HF (240 - 250GeV):

- High precision probe of Higgs gauge couplings and some Yukawa couplings.
- Discriminate new Electroweak Symmetry Breaking Mechanisms from SM.

Major Physics Questions to Answer:

- How does this 125GeV Boson differ from SM Higgs?
 - Is it really the God Particle? How does it couple to all light fermions?
 - An e^-e^+ Higgs Factory (250GeV) can more precisely measure Higgs properties than LHC: mass, J^{PC} , couplings, especially h-Z-Z, h-b-b, h- τ - τ , h-g-g couplings, and invisible decays. h-c-c Coupling can also be measured, which cannot be carried out at LHC.
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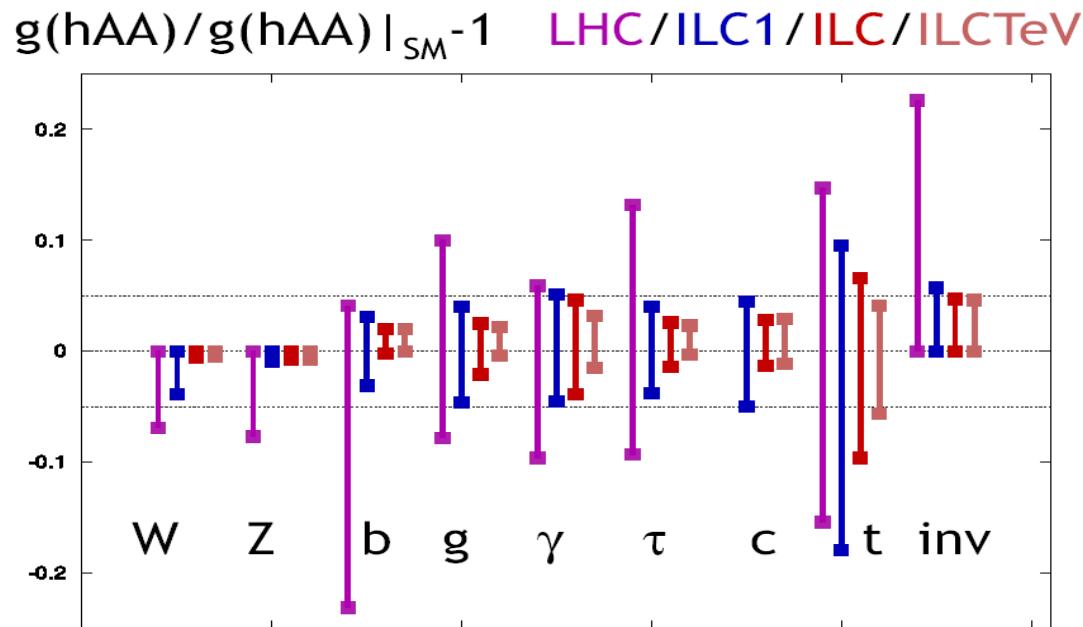


pp collider (50TeV or higher):

- Probe Yukawa Couplings of light Fermions.
- Discover associated New Heavier States for Fermion Mass Generation.
- Discovery any New Heavy States associated with Gauge and Fermion Sector, from New Gauge Group, SUSY, Compositeness, Extra-dimension, etc.
- More than 1 God Particle exist? Any related New Heavy States?



- Most of important Precision-Higgs-Tests can be already done at HF(250GeV) , without ILC350-500. Higgs self-couplings will be probed at pp collider (50TeV).



M. E. Peskin,
arXiv:1207.2516v2

We need A Discovery Machine



- Model-Dependent Results: Higher Energy gives more powerful direct reach of New Physics beyond the Standard Model.

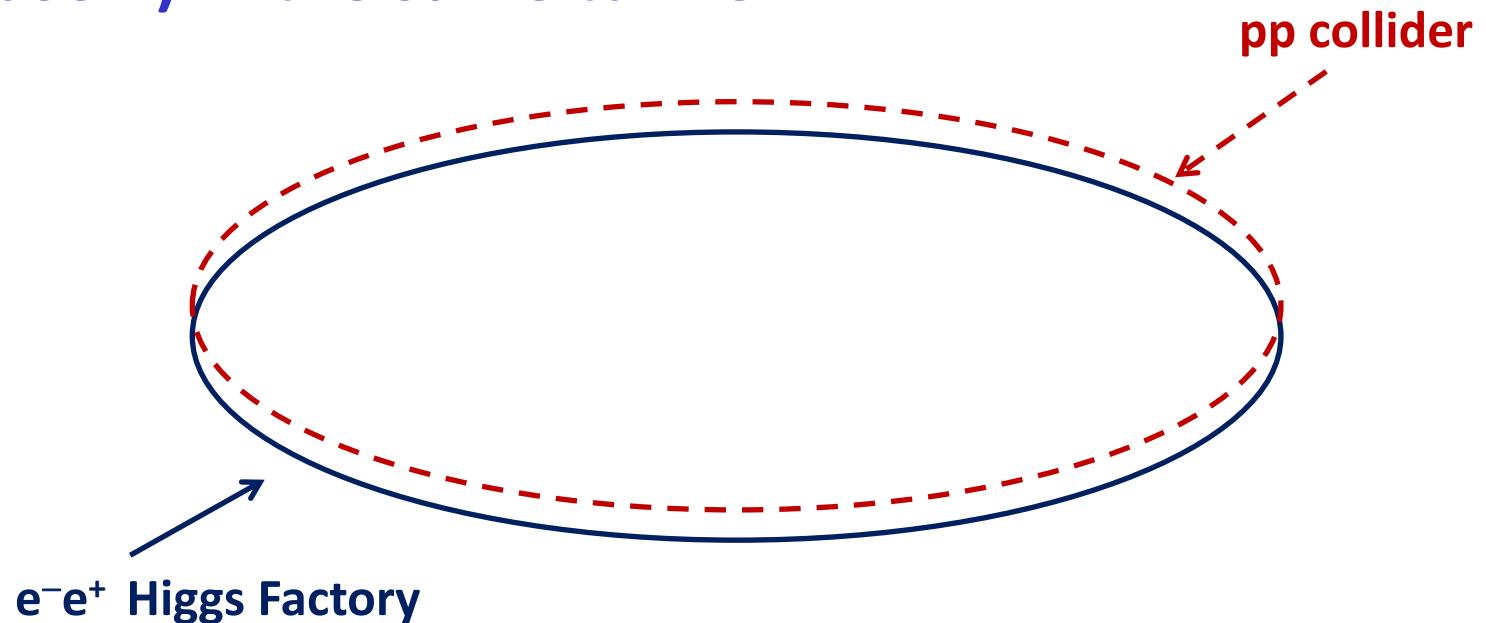
Beyond SM New Physics	LHC 14TeV 100/fb	SLHC 14TeV 1/ab	ILC 0.8TeV 500/fb	CPPC 40 TeV 100/fb	CPPC 200TeV 100/fb
Z'	5 TeV	6 TeV	8 TeV (*)	11 TeV	35 TeV
Squark	2.5 TeV	3 TeV	0.4 TeV	5 TeV	20 TeV
Extra Dimension ($\delta=2$)	9 TeV	12 TeV	5-8.5 TeV(*)	25 TeV	65 TeV
Compositeness	30 TeV	40 TeV	100 TeV	50 TeV	100 TeV

(*) Indirect reach from precision measurements

What is a (CHF + SppC)



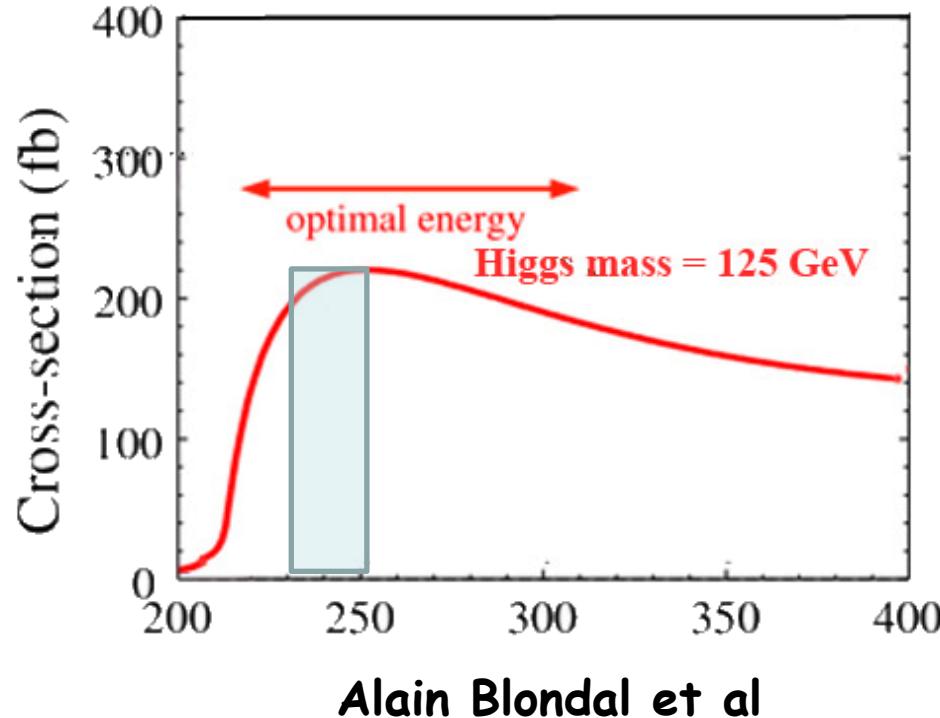
- Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel



2. Parameters determination and limits



- Beam energy of CHF
- ✓ $E_b = 120 - 125 \text{ GeV}$
- ✓ Beamstrahlung limits
luminosity near 125 GeV
- ✓ $E_b = 120 \text{ GeV}$ is chosen.
Cross-section = 200 fb





Circumference

- The circumference of CHF is determined by that of the SppC.
 - ✓ dipole field $B = 20 \text{ T}$  proton beam energy
 - ✓ 2 schemes are considered: $C = \sim 50\text{km}$ & $\sim 70\text{km}$
-- here we take $C = 50\text{km}$
- Beam-beam tune shifts
 - ✓ $\xi_y = 0.1$ (e machine) & 0.004 (p machine)

e^- - e^+ collider



- SR power of beam = 50MW
- Beam current:

$$P[\text{GW}] = C_\gamma \frac{E[\text{GeV}]^4}{\rho[\text{m}]} I[\text{A}]$$
$$C_\gamma = 88.5 \times 10^{-6} \frac{\text{m}}{\text{GeV}^3}$$

$$P_{sr} = 50\text{MW} \Rightarrow I = k_b I_b = 16.9\text{mA}$$

- Take filling factor of the ring = 0.78 $\rightarrow \rho = 6.2\text{km}$



- Beam-beam parameter

$$L[\text{cm}^{-2}\text{s}^{-1}] = 2.17 \times 10^{34} (1+r) \xi_y \frac{E[\text{GeV}] I[\text{A}]}{\beta_y [\text{cm}]}$$

- Choose

$$\xi_y = 0.1, \quad \beta_y = 1\text{mm}$$



$$L = 4.42 \times 10^{34} [\text{cm}^{-2}\text{s}^{-1}]$$

(Hour glass effect excluded)

Beamstrahlung



- Beamstrahlung fractional energy spread^[1]:

$$\delta_{BS} = \frac{2r_e^3 N_e^2 \gamma F}{3\sigma_x \sigma_y \sigma_z} \quad R = \frac{\sigma_x}{\sigma_y}, F(R=1) = 0.325, F(R \gg 1) \approx \frac{1.3}{R}$$

- Beamstrahlung bending radius : $\rho \approx \frac{\gamma \sigma_x \sigma_z}{2r_e}$

$$\frac{E_c}{E_0} = \frac{3\gamma r_e^2 N}{\alpha \sigma_x \sigma_z} \quad u = \frac{\eta E_0}{E_c} \quad n_{col} \approx 10 \frac{\sqrt{6\pi} r_e \gamma u^{3/2}}{\alpha^2 \eta l} e^u$$

the collision length $l \approx \sigma_z / 2$ for head-on and $l \approx \beta_y / 2$
for crabbed waist collision

[1] H. Wiedemann, SLAC-PUB-2849, 1981.

Lifetime of limited by beamstrahlung



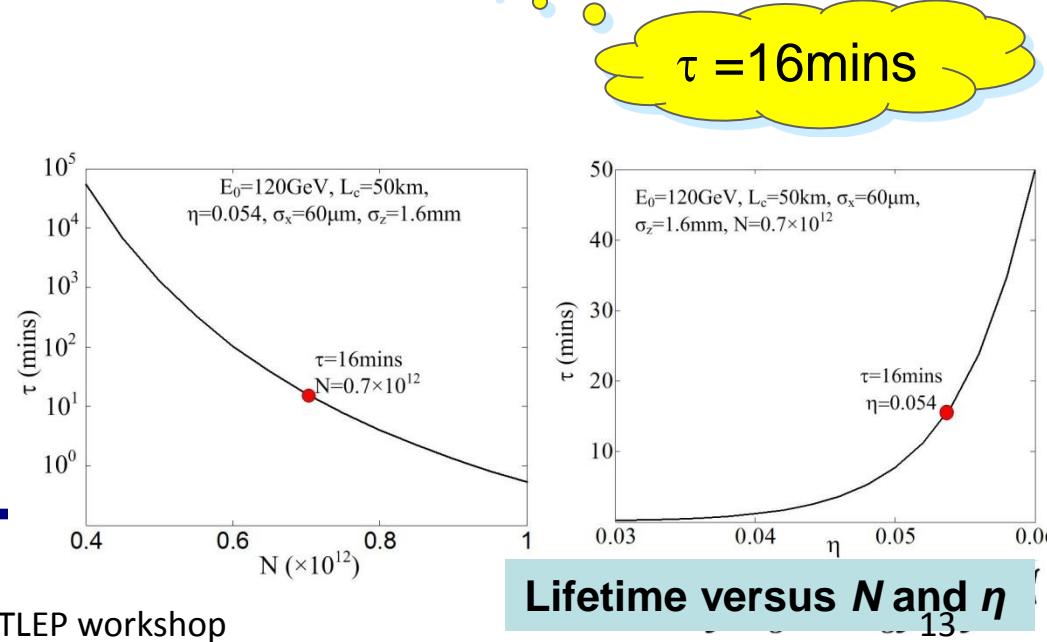
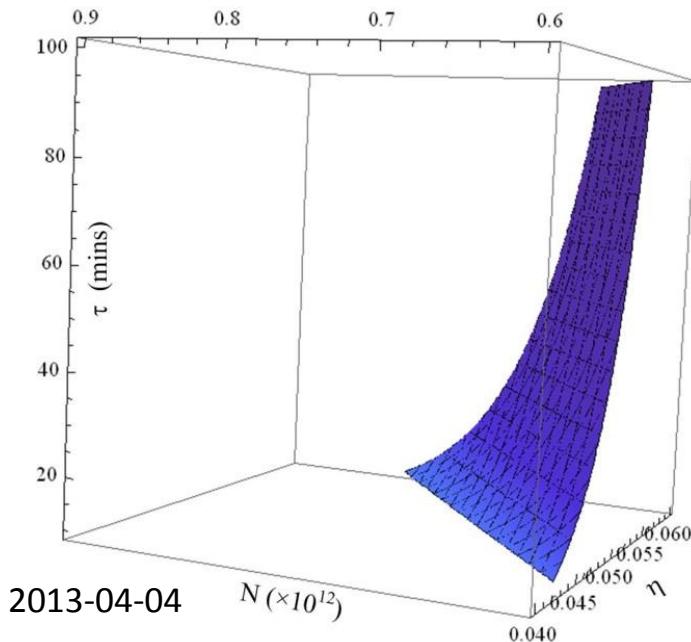
$$\tau = \frac{20C\sqrt{6\pi}r_e\gamma}{\alpha^2\eta c\sigma_z} u^{3/2} e^{-u}$$

$$u = \frac{\alpha\eta\sigma_x\sigma_z}{3r_e^2\gamma N}$$

V. I. Telnov, "Restriction on the energy and luminosity of e^+e^- storage ring due to beamstrahlung"

η : energy acceptance; N : number of particles per bunch, C : circumference
The lifetime is decreased exponentially with the increase of $N\gamma / \eta\sigma_x\sigma_z$

e. g. $E_0=120\text{GeV}$, $C=50\text{km}$, $\eta=0.054$, $\sigma_x=60\mu\text{m}$, $\sigma_z=1.6\text{mm}$, $N=0.7\times 10^{12}$



N_b , N_e and ε_x



$$\delta_{\text{BS}} \equiv \frac{\langle \Delta E_{\text{BS}} \rangle}{E} = 0.864 r_e^3 \gamma \left(\frac{N_e}{\sigma_z (\sigma_x + \sigma_y)} \right)^2 \beta_y \approx 0.864 r_e^3 \gamma \frac{r}{\sigma_z^2} \frac{2\pi\gamma}{r_e} \xi_y N_e$$

$$\xi_y = \frac{r_e N_e \beta_y}{2\pi \sigma_y (\sigma_x + \sigma_y)} = 0.1$$

$$N_e = 5.26 \times 10^{19} \varepsilon_x$$

- Small N_e will reduce δ_{BS} , but increase N_b and decrease ε_x to keep luminosity
- $N_b \leq 50 \rightarrow N_e = 3.52 \times 10^{11}, \varepsilon_x = 6.69 \text{ nm}$

Aspect ratio and luminosity



$$L_{\text{limit}} = 0.4565 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \frac{\rho(\text{km}) P_{\text{SR}}(100\text{MW}) \sqrt{\delta_{\text{BS}}(0.1\%)}}{(E/100\text{GeV})^{4.5} \sqrt{\varepsilon_y(\text{nm})}}$$
$$= 0.4565 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \frac{\rho(\text{km}) P_{\text{SR}}(100\text{MW})}{(E/100\text{GeV})^{4.5}} \cdot \frac{\sqrt{\delta_{\text{BS}}(0.1\%)}}{\sqrt{r \varepsilon_x(\text{nm})}}$$

- Take $P_{\text{SR}} = 50\text{MW}$, $E = 120\text{GeV}$, $\varepsilon_x = 6.69\text{nm}$,
 $r = 0.005$ (empirical value)

RF frequency and voltage



- Energy spread and acceptance due to SR

$$\sigma_e = \gamma \sqrt{\frac{C_q}{J_e \rho}} \quad \eta = \sqrt{\frac{U_0}{\pi \alpha_p h E}} F_q$$

- Synchrotron tune and bunch length:

$$\nu_s = \sqrt{-\frac{\alpha_p h V_{rf} \cos \varphi_s}{2\pi E}} \quad \sigma_z = \frac{\alpha_p R \sigma_{e0}}{\nu_s}$$

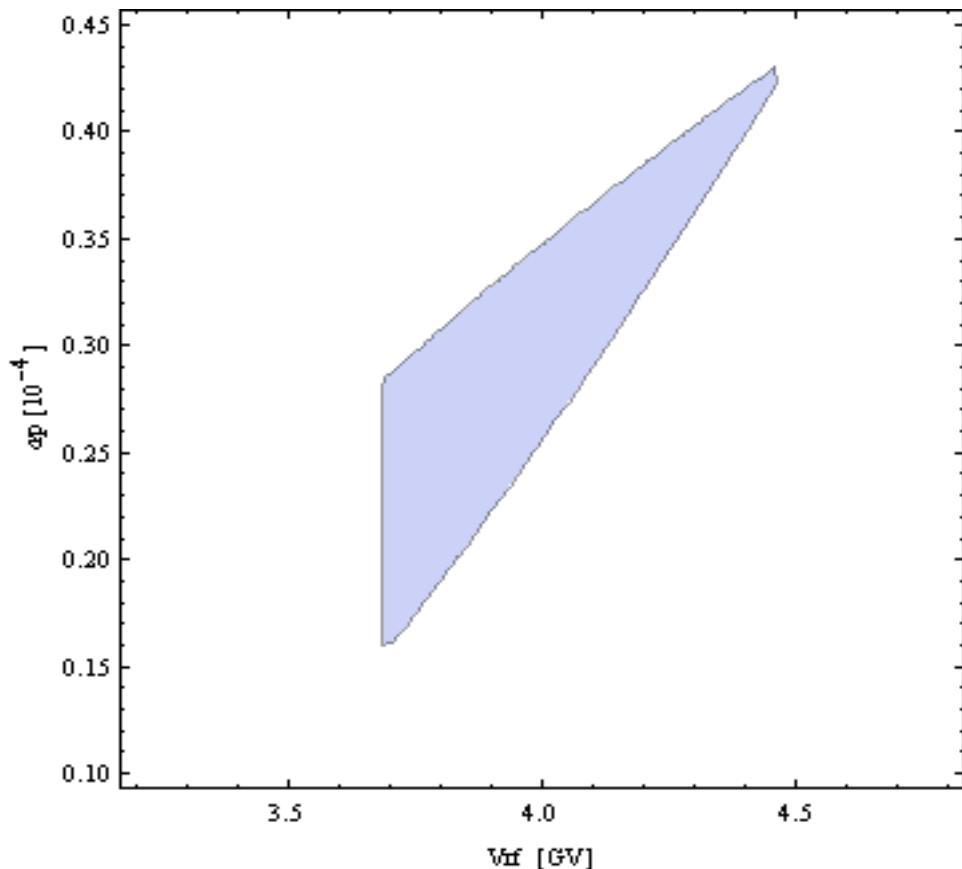
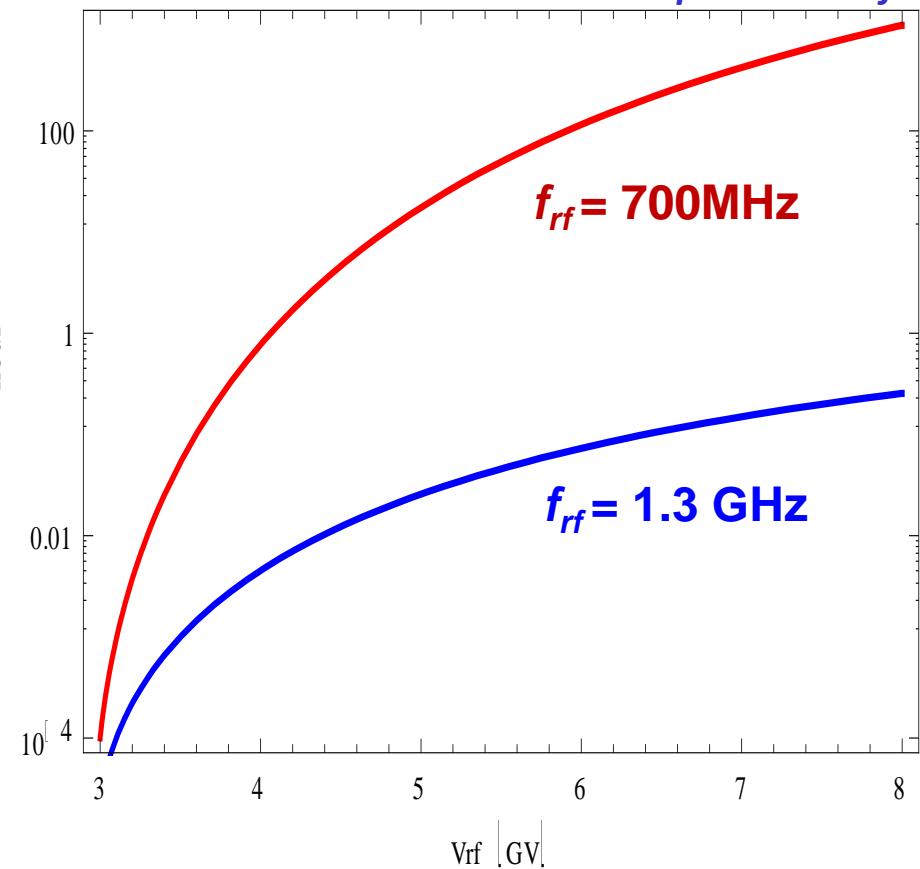
- Lifetime from beamstrahlung:

$$E_{cb} = \frac{3\gamma r_e^2 N_e E}{\alpha \sigma_x \sigma_z}, \quad u = \frac{\sigma_e E}{E_{cb}}, \quad n_{col} = \frac{20\sqrt{6\pi} r_e \gamma u^{3/2}}{\alpha^2 \sigma_e \sigma_z} e^u$$

$$\tau = n_{col} T_0$$



- For chosen transvers bunch size and N_e , beam lifetime due to beamstrahlung as a function of V_{rf} at different f_{rf} .
- For $\sigma_z < 3\text{mm}$, $\nu_s < 0.3$, $\delta_{BS} < \sigma_e/3$, $\eta < 0.05$ & $\tau > 10\text{min}$, the correlation between α_p and V_{rf} can be got.





- A FODO cell is adopted in arcs, and 60 degree is chosen as the phase advance, then α_p can be got roughly from

$$\alpha_p = \left(\frac{\phi}{2}\right)^2 \left(\frac{1}{\sin^2 \frac{\mu}{2}} - \frac{1}{12} \right) \quad \varepsilon_x = \frac{1 - \frac{3}{4} \sin^2 \frac{\mu}{2}}{\sin^3 \frac{\mu}{2} \cos \frac{\mu}{2}} C_q \gamma^2 \left(\frac{\phi}{2}\right)^3$$

$$\varepsilon_x = 6.69 \text{ nm} \quad \alpha_p = 0.4 \times 10^{-4} \quad \longrightarrow \quad V_{rf} = 4.2 \text{ GV}$$

- 5-cell RF cavity can be a candidate for RF system:

$$E_{acc} = 10 \text{ MV/m}, \quad V_c = 2 \text{ MV}, \quad N_{cav} = 420$$

Main beam parameters for e^- - e^+ collider



Parameter	Unit	Value	Parameter	Unit	Value
Energy	GeV	120	Circumference	km	50
Number of IP		1	SR loss	(GeV/turn)	2.96
N_e /bunch	1E11	3.52	N_b /beam		50
Beam current	mA	16.9	SR power/beam	MW	50
Partition Je		2	Long. damp. time	ms	6.7
Dipole field	Tesla	0.065	Bending radius	km	6.2
Dipole length	m	9.978	Bending angle	mrad	1.609
Emittance (x/y)	nm	6.69/0.033	β_{IP} (x/y)	mm	200/1
Trans. size (x/y)	μm	36.6/0.18	Mom. compaction	1E-4	0.4
$\xi_{x,y}$ /IP		0.1/0.1	Bunch length	mm	3



Parameters (cont.)

Parameter	Unit	Value	Parameter	Unit	Value
RF voltage V_{rf}	GV	4.2	RF frequency f_{rf}	GHz	0.7
Long. tune ν_s		0.13	Harmonic number		116747
Hourglass factor		0.6	n_γ		0.42
Energy spread SR		0.0013	Energy spread BS		0.00014
Energy acceptance	%	2.7	Lifetime BS	hr	1.6
$L_0/IP (10^{34})$	$cm^{-2}s^{-1}$	2.65	$L_{limit}/IP (10^{34})$	$cm^{-2}s^{-1}$	1.26

Design of 70km e⁻-e⁺ collider is still under way

Preliminary design of SppC



- pp collider (SppC) luminosity

$$L_0 = \frac{N_p^2 N_b f_{rep} \gamma}{4\pi \varepsilon_n \beta_{IP}} F \quad (F = \sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma_{x,IP}} \right)^2}) \quad \xi = \frac{N_p r_p}{4\pi \varepsilon_n} \leq 0.005$$

- SC dipole strength limit for SppC

Assume the dipole filling factor is 100%:

$$B_{\min} = \frac{2\pi(B\rho)}{C_0}$$

- For 50-km ring: $B_0 > 10.5\text{T}$, $B_{\max} = 20\text{T}$
 - For 70-km ring: $B_0 > 7.5\text{T}$, $B_{\max} = 20\text{T}$
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Parameters for pp colliders

Parameter	SppC-1	SppC-2
Beam energy (TeV)	25	45
Circumference (km)	49.78	69.88
Number of IPs	2	2
SR loss/turn (keV)	440	4090
$N_p/\text{bunch} (10^{11})$	1.3	0.98
Bunch number	3000	6000
Beam current (mA)	0.5	0.405
SR power /ring (MW)	0.22	1.66
B_0 (T)	12	19.24
Bending radius (km)	6.9	7.8
Momentum compaction (10^{-4})	3.5	2.5
$\beta_{\text{IP}} x/y$ (m)	0.1/0.1	0.1/0.1
Norm. trans. emit. x/y ($\mu\text{m}\cdot\text{rad}$)	4	3
ξ_y/IP	0.004	0.004
Geo. luminosity reduction factor F	0.8	0.9
Luminosity /IP ($10^{35}\text{cm}^{-2}\text{s}^{-1}$)	2.15	2.85

3. Preliminary design of accelerator



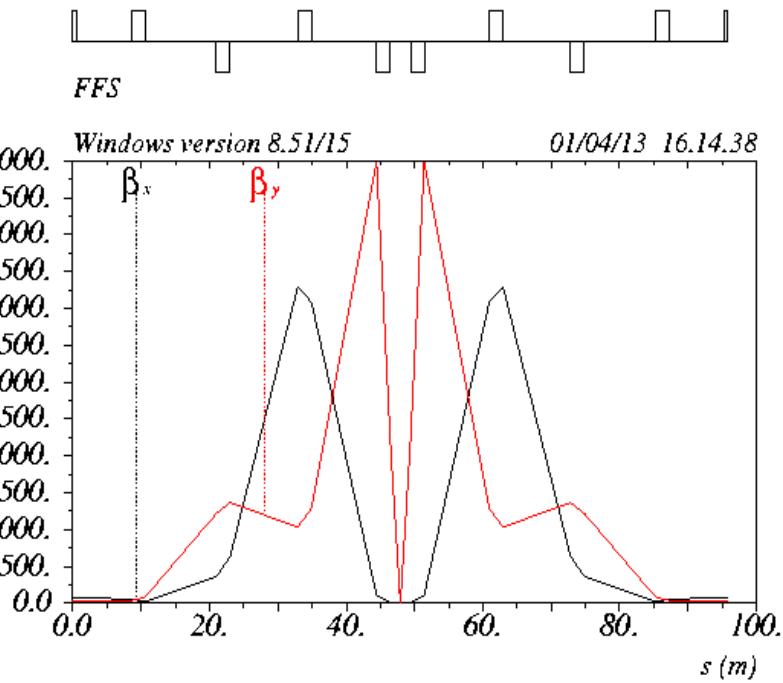
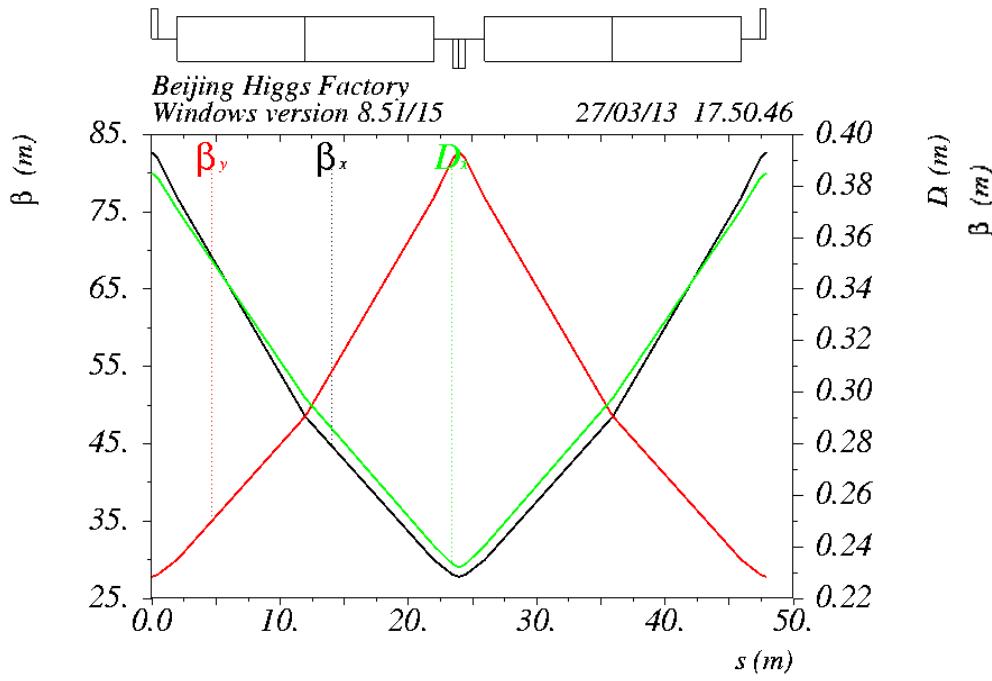
e^- - e^+ collider:

- A FODO lattice in arcs with 60 degree phase advances
 - 16-folder symmetry
 - RF sections distribute around the ring
 - Pretzel scheme will be adopted for multi-bunch collision
 - Booster is in the same tunnel of the collider (6 – 120 GeV), and a 6GeV–Linac will be adopted.
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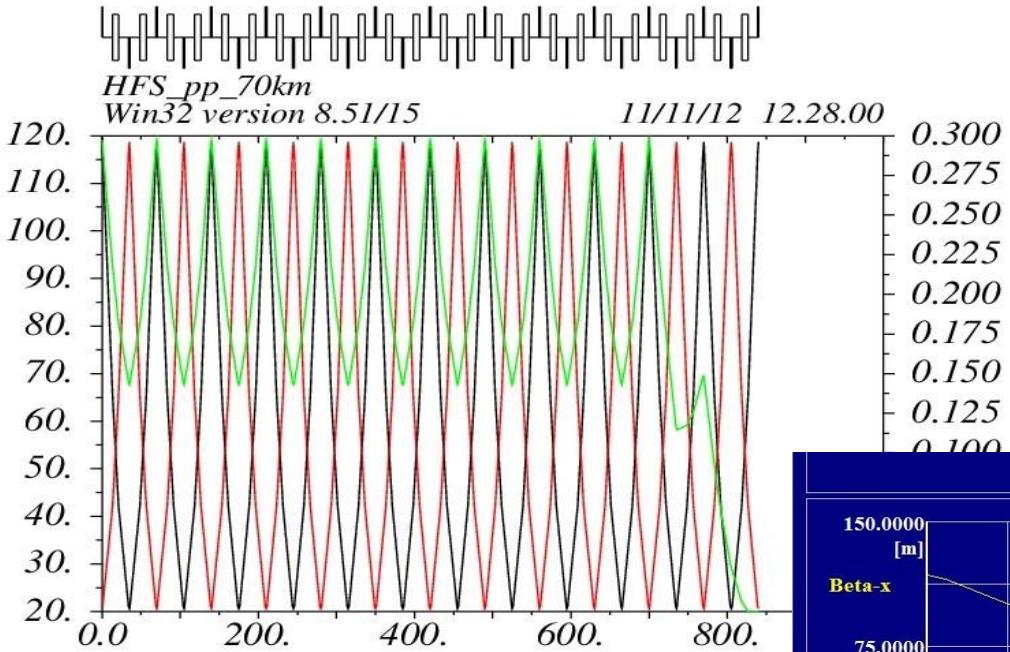
Linear lattice of rings (e^- - e^+ collider)



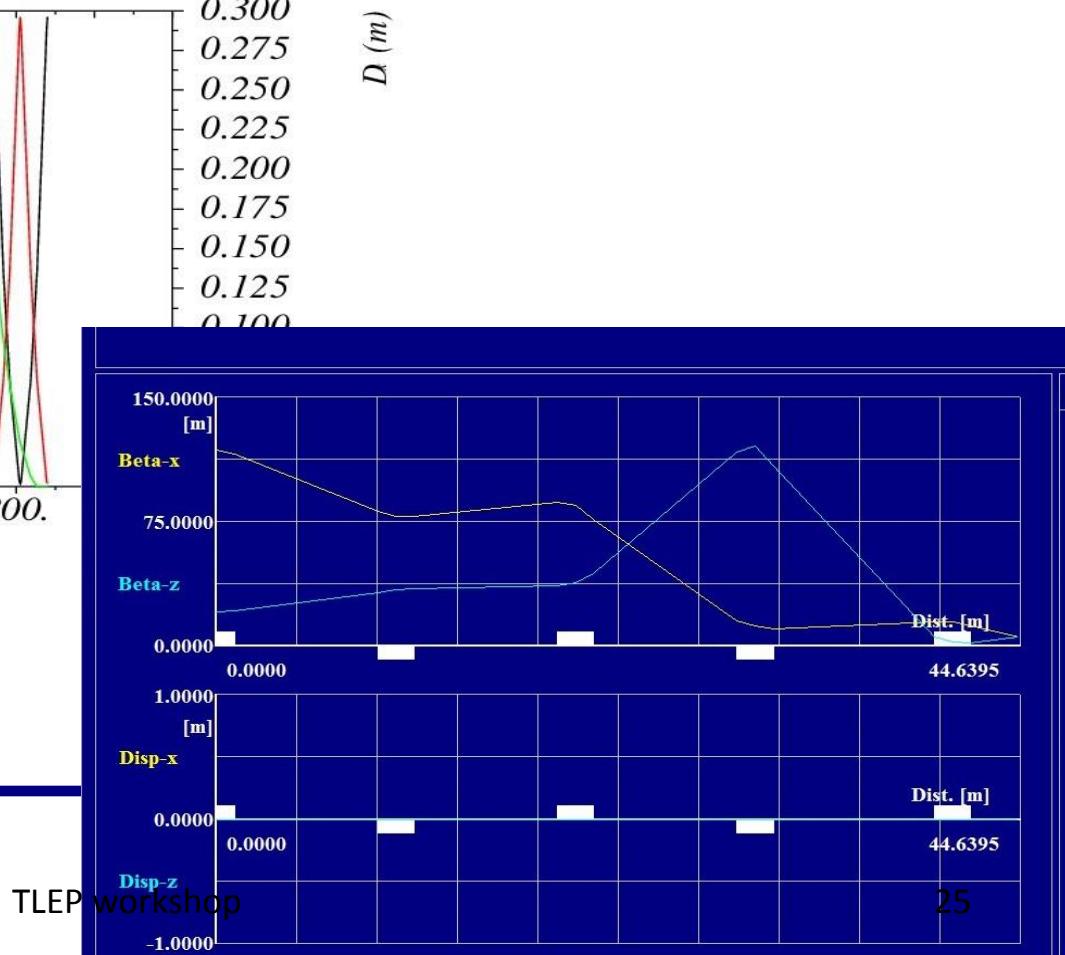
- Standard FODO lattice in arc and FFS in IR



Linear lattices for arcs and FFS of SppC



2013-04-04



4. Further studies



- Different lattices for small emittance, will be tried.
 - Chromaticity correction, chromatic effect, together with dynamic aperture optimization is being taken into account.
 - Beamstrahlung effect, together with beam-beam simulation.
 - Imperfections of magnets, ground motion effect on luminosity.
 - Impedance issue and collective effect.
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Conclusion



- A CHF + SppC was proposed in IHEP for high precise probe of Higgs, and new discovery of physics as well.
- Main parameters and basic lattices are being studied and further iterations are required.
- More accelerator technology issues have not been covered, and will be investigated soon.
- Budget and time schedule are not yet estimated.

Thanks for your attention !