# An overview of recent design studies on future circular colliders

**D. Zhou**

With materials from: T. Kono, M. Koratzinos, D. Wang, Y. Wang, Y. Zhang, and F. Zimmermann

Accelerator physics seminar, KEK

Jan. 16, 2014

# Outline

- ➤ **Introduction**
- ➤ **Highlights of Int. Workshop on Future High Energy Circular Colliders (IHEP, Dec.16-17, 2013)**
- ➤ **TLEP**
- ➤ **CEPC**
- ➤ **Summary and outlook**

# Outline

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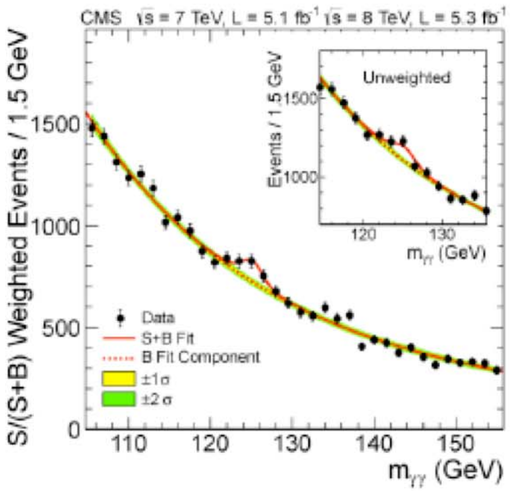
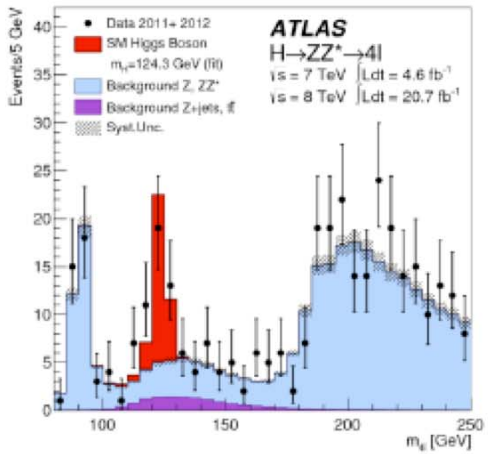
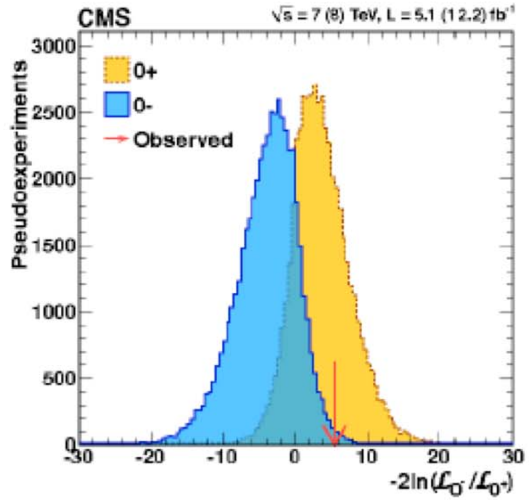
# 1. Introduction

## ➤ Thoughts about Post-LHC era

- **LHC: Higgs mass** T. Kono




- **ILC/CLIC: Precise measurements of Higgs boson**
- **Circular colliders: Becoming active recently - Extendable to hadron colliders**
- **Series of TLEP collaboration meetings**
- **Int. Workshop at IHEP (Dec.16-17, 2013)**
- **FCC kick off meeting to be held at CERN (Feb.12-15, 2014)**

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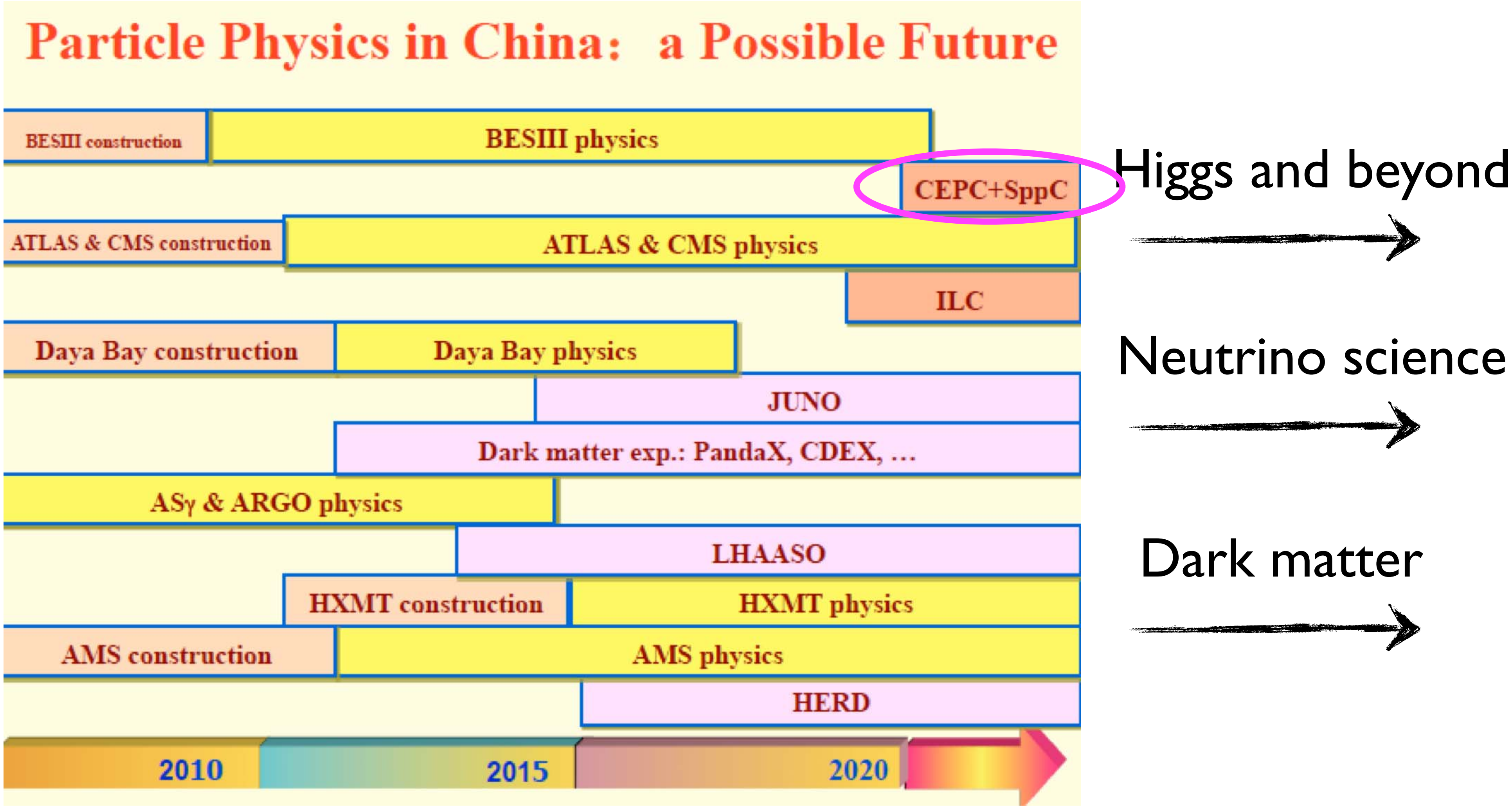
# 2. Highlights of Int. Workshop on FHECC

- **Host: IHEP**
- **Participants: ~120**
  - **KEK: S. Kurokawa, Takanori Kono and D. Zhou**
- **Univ. & Institutes: >30**

# 2. Highlights of Int. Workshop on FHECC

➤ **Y. Wang: Outlook of particle physics in China**




**LHAASO: Large High Altitude Air Shower Observatory; AMS: Alpha Magnetic Spectrometer**
**HXMT: Hard X-ray Modulation Telescope; HERD: High Energy cosmic Radiation Detection**

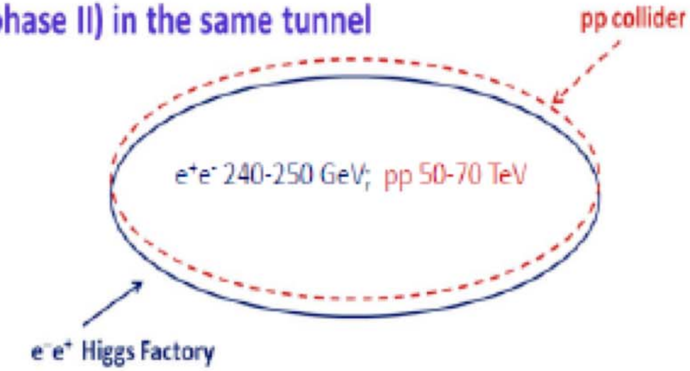
# 2. Highlights of Int. Workshop on FHECC

➤ Y. Wang: Outlook of particle physics in China

## CEPC+SppC

- We are looking for a machine after BEPCII
- A circular Higgs factory fits our strategic needs in terms of timing, science goal, technological & economical scale, manpower reality, etc.
- Its life can be extended to a pp collider: great for the future

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




- ➢ Circular Higgs factory is complementary to ILC
  - ➢ Push-pull option
  - ➢ Low energy vs high energy

We hope to collaborate with anyone who is willing to host this machine. Even if the machine is not built in China, the process will help us to build the HEP in China

# 2. Highlights of Int. Workshop on FHECC

➤ **Y. Wang: Outlook of particle physics in China**

## CEPC+SppC

- When(dream):
  - CPEC
    - Pre-study, R&D and preparation work
      - Pre-study: 2013-15
      - R&D: 2015-2020 → 13th 5-year plan of Chinese government
      - Engineering Design: 2015-2020
    - Construction: 2021-2027
    - Data taking: 2028-2035
  - SPPC
    - Pre-study, R&D and preparation work
      - Pre-study: 2013-2020
      - R&D: 2020-2030
      - Engineering Design: 2030-2035
    - Construction: 2035-2042
    - Data taking: 2042 -

# 2. Highlights of Int. Workshop on FHECC

## ➤ CFHEP@IHEP inaugurated on Dec.17, 2013

**"The main goal of this center is to study the potential for a Higgs factory and a VLHC in a circular tunnel."**

FHEP

**Center for Future High Energy Physics**

高能物理前沿研究中心

**Director:** Nima Arkani-Hamed (IAS, USA)
**Deputy Director:** Cai-Dian Lu (IHEP, China)

**Academic Committee:**
Sally Dawson (BNL, USA), Tao Han (U. Pittsburgh/Tsinghua U.), Hongjian He (Tsinghua U.), Michelangelo Mangano (CERN), Shufang Su (U. Arizona), Lian-Tao Wang (U. Chicago), Zhizhong Xing (IHEP), Jin Min Yang (ITP), Xinmin Zhang (IHEP), Shouhua Zhu (Peking U.)

**Advisory Board:**
Chao-Hsi Chang (ITP), Kuang-Ta Chao (Peking U.), Hesheng Chen (IHEP), Savas Dimopoulos (Stanford U.), Sally Dawson (BNL), John Ellis (CERN), Sheldon Glashow (Boston U.), David Gross (UC, Santa Barbara), Xiangdong Ji (SJTU), Yu-Ping Kuang (Tsinghua U.), Luciano Maiani (Rome U.), Michelangelo Mangano (CERN), Yifang Wang (IHEP), Steven Weinberg (U. Texas, Austin), Edward Witten (IAS), Yue-Liang Wu (ITP/UCAS), S.T. Yau (Harvard U.)

# 2. Highlights of Int. Workshop on FHECC

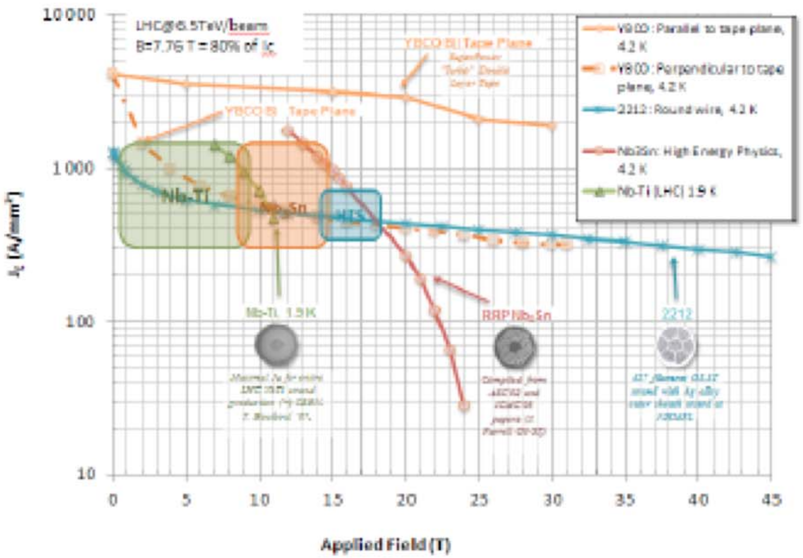
## ➤ F. Zimmermann: CERN Future Circular Colliders Study

**European Strategy Update (ESU) on Particle Physics**

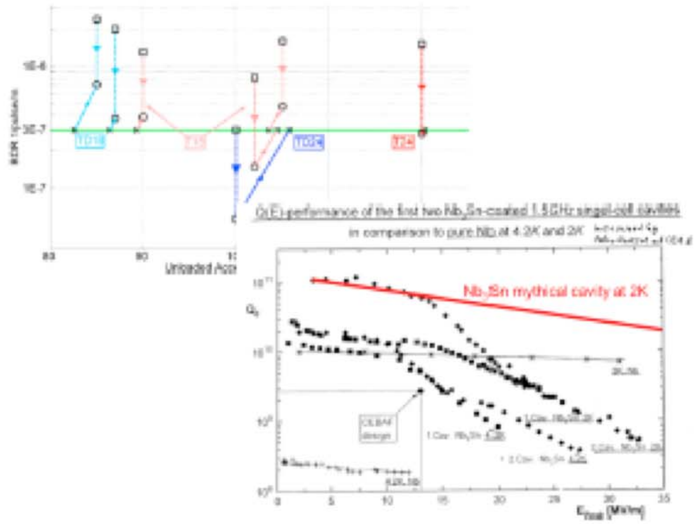
*Design studies and R&D at the energy frontier*

"to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update":

d) ***CERN should undertake design studies for accelerator projects in a global context,***
*with emphasis on **proton-proton and electron-positron high-energy frontier machines**. These design studies should be coupled to a vigorous accelerator **R&D programme**, including **high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.***



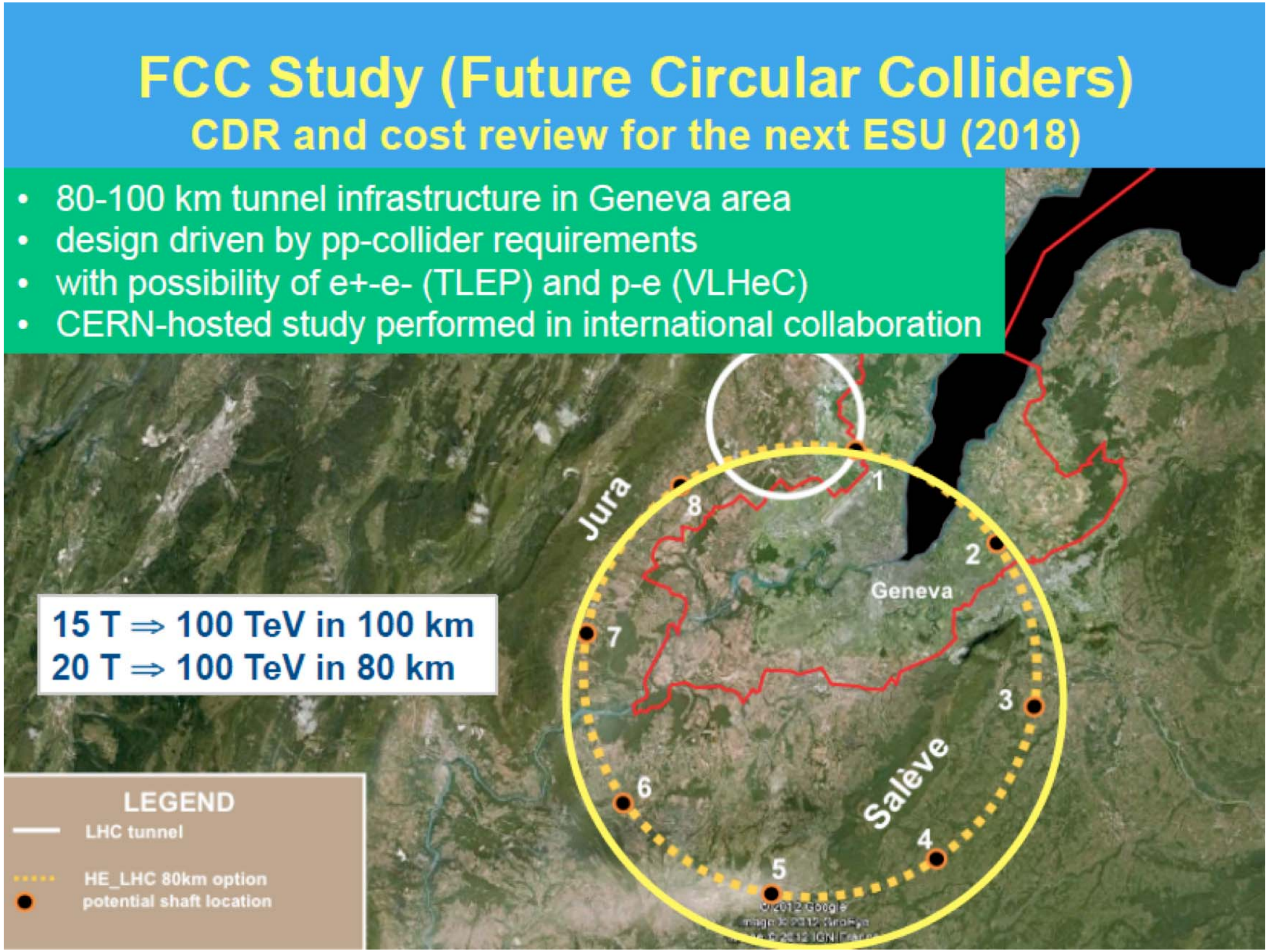

high-field magnets: VHE-LHC/FHC




high-gradient acceleration: CLIC and TLEP/FLC

# 2. Highlights of Int. Workshop on FHECC

➤ F. Zimmermann: CERN Future Circular Colliders Study



# 2. Highlights of Int. Workshop on FHECC

## ➤ F. Zimmermann: CERN Future Circular Colliders Study

### Kick-Off Meeting for FCC Study

- To prepare international collaborations, study scope and topics will be discussed in kick-off meeting at U. Geneva 12-15 February 2014
- CERN is interested in global collaboration of future circular collider studies

UNIVERSITÉ DE GENÈVE FCC

Future Circular Colliders Study Kickoff Meeting

12-15 February 2014
University of Geneva, Geneva
Europe/Zurich timezone

Search

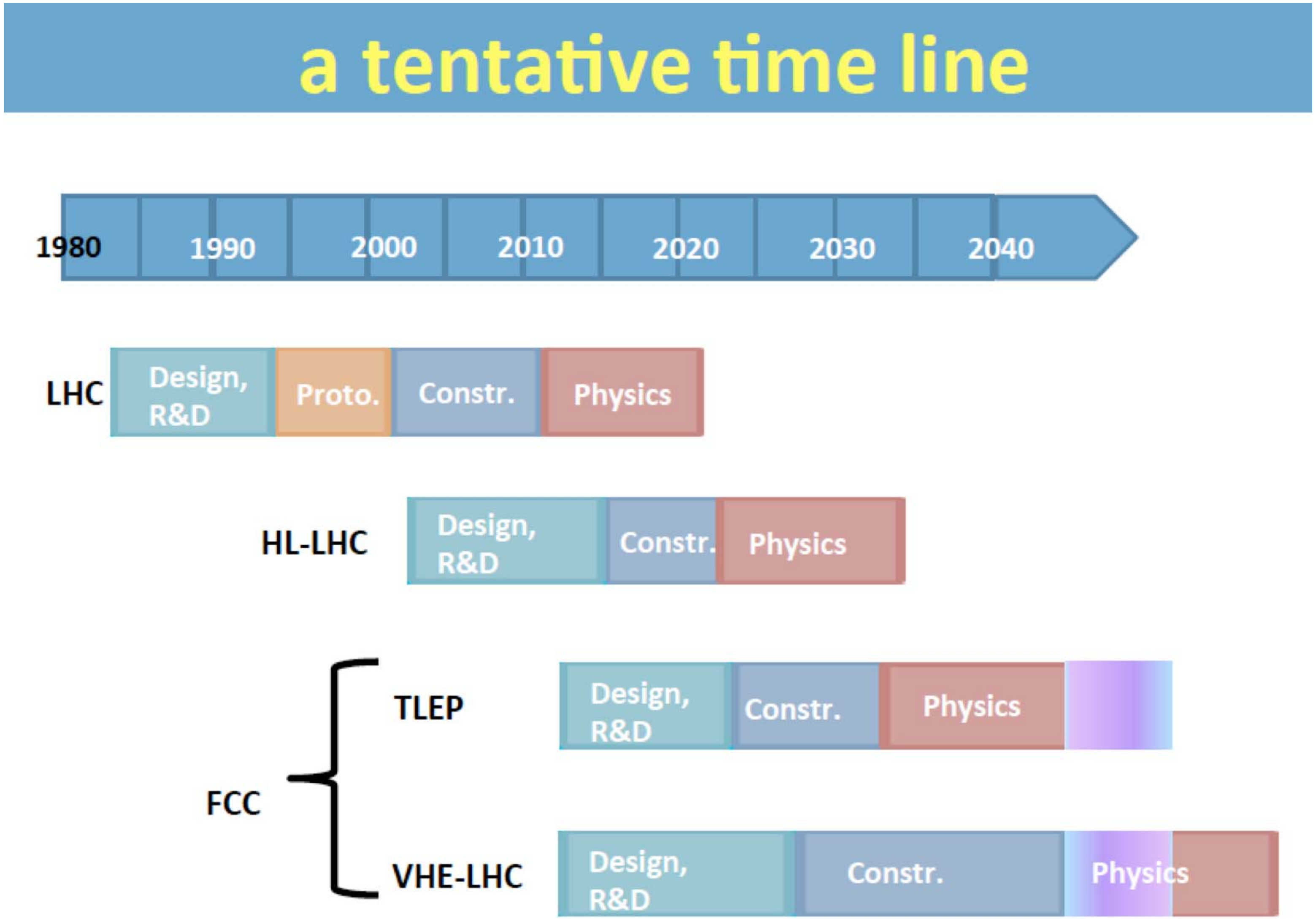
Future Circular Colliders Kickoff Meeting

http://indico.cern.ch/e/fcc-kickoff

- Earlier topical workshops on HE-LHC (2010), LEP3/TLEP (6 meetings in 2012-13) and VHE-LHC (2013) in the frame of EuCARD
- Kick-off meeting covers accelerator, detectors, physics case, technology, infrastructure & tunnel construction
- Total no. of participants limited to 500 (early registration suggested)

# 2. Highlights of Int. Workshop on FHECC

➤ F. Zimmermann: CERN Future Circular Colliders Study



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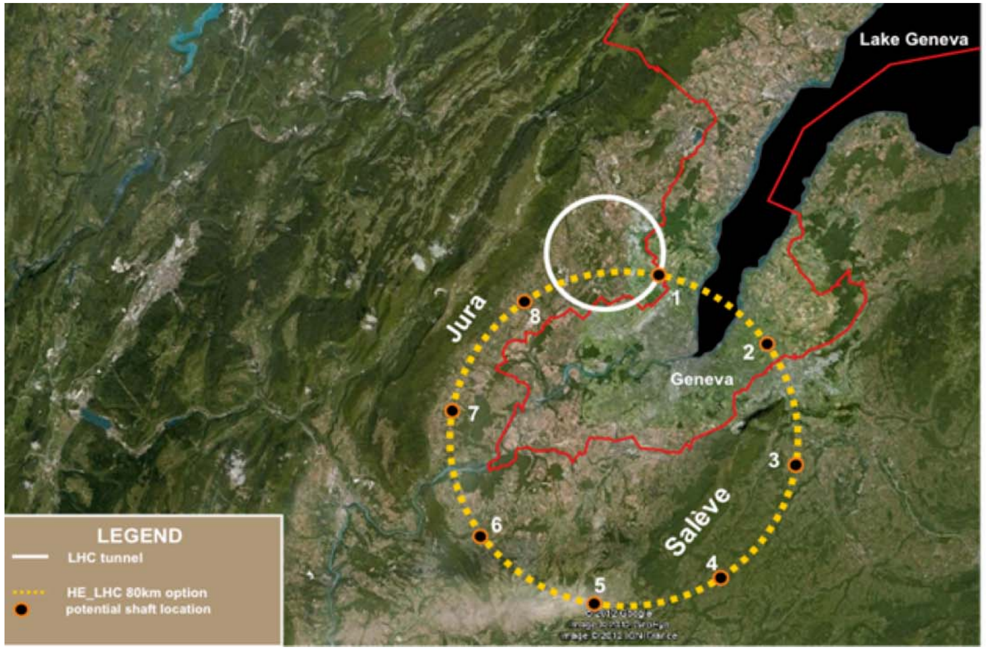
# 3. TLEP

➤ **TLEP as a future e+e- circular collider to study the Higgs boson and physics at the electroweak scale**



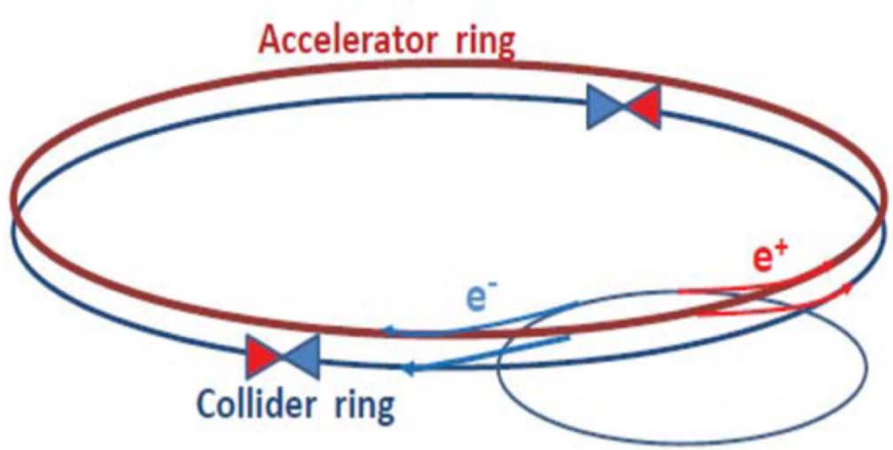




Figure from http://tlep.web.cern.ch/

Possible site and schematic layout for TLEP

# 3. TLEP

F. Zimmermann

| Parameter | TLEP-Z | TLEP-W | TLEP-H | TLEP-t | LEP2 |
|---|---|---|---|---|---|
| E (GeV) | 45 | 80 | 120 | 175 | 104 |
| I (mA) | 1400 | 150 | 30 | 7 | 4 |
| $N_b$ [$10^{11}$] | 4.0 | 1.0 | 3.7 | 0.88 | 5.8 |
| $\sigma_z$ [mm] | 2.93 | 1.98 | 2.11 | 0.77 | 16..1 |
| $\beta^*_{x/y}$ (mm) | 500 / 1 | 200 / 1 | 500 / 1 | 1000 / 1 | 1500 / 50 |
| $\varepsilon_{x,y}$(nm, pm) | 30, 60 | 3.3, 17 | 7.5, 15 | 2, 2 | 40,~250 |
| $\xi_{x,y}$/IP | .068 | .086 | .094 | .057 | .066 (*y*) |
| L/IP($10^{32}$cm$^{-2}$s$^{-1}$) | 5800 | 1600 | 500 | 132 | 1.2 |

Baseline (analytical)

# 3. TLEP

**F. Zimmermann**

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Baseline (analytical)

| Parameter | TLEP-Z | TLEP-W | TLEP-H | TLEP-t |
|---|---|---|---|---|
| $N_b$ [$10^{11}$] | 1.5 | 1.0 | 3.0 | 0.88 |
| $\sigma_z$ [mm] | 1.7 | 1.6 | 1.65 | 0.84 |
| $\varepsilon_{x,y}$(nm, pm) | 30, 90 | 4.1, 22 | 8.8, 19 | 2.3, 2.3 |
| $\xi_{x,y}$/IP | .029/.024 | .068, .051 | .065, .054 | .055, .036 |
| L/IP($10^{32}$cm$^{-2}$s$^{-1}$) | 2100 | 1150 | 350 | 175 |

Baseline (simulated+ opt.)

S. White, TLEP6 WS

# 3. TLEP

**F. Zimmermann**

| Parameter | TLEP-Z | TLEP-W | TLEP-H | TLEP-t | LEP2 | |
|---|---|---|---|---|---|---|
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| $\sigma_z$ [mm] | 2.93 | 1.98 | 2.11 | 0.77 | 16..1 | |
| $\beta^*_{x/y}$ (mm) | 500 / 1 | 200 / 1 | 500 / 1 | 1000 / 1 | 1500 / 50 | |
| $\varepsilon_{x,y}$(nm, pm) | 30, 60 | 3.3, 17 | 7.5, 15 | 2, 2 | 40,~250 | |
| $\xi_{x,y}$/IP | .068 | .086 | .094 | .057 | .066 (*y*) | |
| L/IP($10^{32}$cm$^{-2}$s$^{-1}$) | 5800 | 1600 | 500 | 132 | 1.2 | |
| $N_b$ [$10^{11}$] | **1.5** | 1.0 | 3.0 | 0.88 | | Baseline (simulated+ opt.) S. White, TLEP6 WS |
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| $\varepsilon_{x,y}$(nm, pm) | 30, 90 | 4.1, 22 | 8.8, 19 | 2.3, 2.3 | | |
| $\xi_{x,y}$/IP | **.029/.024** | **.068, .051** | **.065, .054** | .055, .036 | | |
| L/IP($10^{32}$cm$^{-2}$s$^{-1}$) | **2100** | 1150 | 350 | **175** | | |
| $\beta^*_{x/y}$ (mm) | 500 / 1 | 500 / 1 | 500 / 1 | 500 / 1 | | Nano-beam option A.Bogomyagkov, E.Levichev, D.Shatilov, TLEP6 WS |
| $N_b$ [$10^{11}$] | **1.0** | 4.0 | 4.7 | **4.0** | | |
| $\sigma_z$ [mm] | **5.9** | **9.1** | **8.2** | **6.6** | | |
| $\varepsilon_{x,y}$(nm, pm) | **0.14, 1** | **0.44, 2** | **1, 2** | 2.1, **4.3** | | |
| $\xi_{x,y}$/IP | .032/.175 | .031, .187 | .029, .160 | .024, .077 | | |
| L/IP($10^{32}$cm$^{-2}$s$^{-1}$) | **22970** | **3980** | **933** | **129** | | |

**higher luminosity + much better beamstrahlung lifetime (>100 min)**

# 3. TLEP: Compare with SuperKEKB

| | SuperKEKB[1] | | TLEP H | |
|---|---|---|---|---|
| | LER | HER | Baseline[2] | Crab waist[3] |
| C(km) | 3.016 | | 100 | |
| E(GeV) | 4 | 7.007 | 120 | |
| # of IPs | 1 | | 4 | |
| $N_b$ | 2500 | | 167 | 133 |
| $N_p(10^{11})$ | 0.904 | 0.653 | 3.7 | 4.5 |
| Xangle | 0.083 | | 0 | 0.07 |
| $\varepsilon_x$(nm) | 3.2 | 4.6 | 7.5 | 1 |
| $\varepsilon_y$(pm) | 8.64 | 11.5 | 15 | 2 |
| $\beta_x^*$(m) | 0.032 | 0.025 | 0.5 | |
| $\beta_y^*$(mm) | 0.27 | 0.3 | 1 | 0.8 |
| $\sigma_x$(μm) | 10.1 | 10.7 | 61 | 22.4 |
| $\sigma_y$(μm) | 0.048 | 0.059 | 0.12 | 0.04 |
| $\sigma_z(\text{mm})^{SR}$ | 6 | 5 | 0.98 | 7.5[4] |
| $\sigma_\delta(10^{-3})^{SR}$ | 0.808 | 0.637 | 1.4 | 1.4[5] |
| Lum./IP($10^{34}\text{cm}^{-2}\text{s}^{-1}$) | 80 | | 5.08 | 5.5 |

[1]No crab waist; [2]2013 summer parameters provided by F. Zimmermann; [3]Crab waist option proposed by A. Bogomyakov at TLEP6 Workshop; [4]w/ beamstrahlung; [5]Assumed

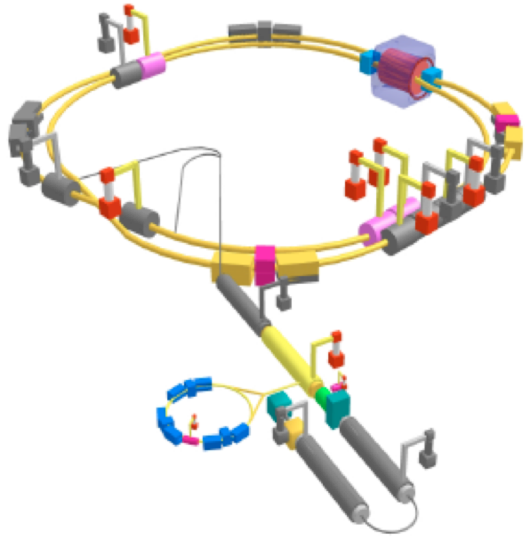
# 3. TLEP

**M. Koratzinos**

## SuperKEKB: a TLEP demonstrator

TLEP
$HZ^0W^-W^+t\bar{t}$

- SuperKEKB will be a TLEP demonstrator
  - Beam commissioning starts early 2015
- Some SuperKEKB parameters :
  - Lifetime : 5 minutes
    - TLEP : 15 minutes
  - $\beta^*_y$ : 300 μm
    - TLEP : 1 mm
  - $\sigma_y$ : 50 nm
    - TLEP : ~100 nm
  - $\varepsilon_y/\varepsilon_x$ : 0.25%
    - TLEP : 0.20%-0.10%
  - Positron production rate : $2.5 \times 10^{12}$ / s
    - TLEP : < $1 \times 10^{11}$ / s
  - Off-momentum acceptance at IP : ±1.5%
    - TLEP : ±2.0 to ±2.5%



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# 3. TLEP

**F. Zimmermann**

## Some Challenges for FLC *(TLEP)*

- Lifetime limitation by **beamstrahlung** from 120 GeV requires **robust ring optics with small $\beta^*_y$ (~ 1 mm) & large momentum acceptance (≥ 2%).**
  - *Nano-beam / crab waist schemes are considered as options*
- Reaching **small vertical emittance** in large machine
- Optimization of the machine layout compatible with **high currents and larger number of bunches at Z**
  - *Number of rings and size of the RF system*
- **Polarization & precise energy calibration at *Z* pole**, with nat. polarization time ~150 h, **& at *WW*** (~5 h)
- RF w **>50% wall-plug to beam power efficiency**
- **Optics changes with energy; lepton injector chain**

# 3. TLEP

**F. Zimmermann**

## lifetime values (summer 2013 baseline)

| parameters | TLEP Z | TLEP W | TLEP H | TLEP t | |
|---|---|---|---|---|---|
| $E_{c.m.}$ [GeV] | **91** | **160** | **240** | **350** | |
| **beam current [mA]** | **1440** | **154** | **29.8** | **6.7** | |
| # bunches/beam | 7500 | 3200 | 167 | 160 | 20 |
| $\#e^{\pm}$/bunch [$10^{11}$] | 4.0 | 1.0 | 3.7 | 0.88 | 7.0 |
| $\varepsilon_x$, $\varepsilon_y$ [nm] | 29.2, 0.06 | 3.3,0.017 | 7.5, 0.015 | 2, .002 | |
| $\beta^*_{x,y}$ [mm] | 500, 1 | 200, 1 | 500, 1 | 1000, 1 | |
| $\sigma^*_{x,y}$[$\mu$m] | 121, 0.25 | 26, 0.13 | 61, 0.12 | 45,.045 | 126,.13 |
| $\sigma^{tot}_{z,rms}$ [mm] (w BS) | 2.93 | 1.98 | 2.11 | 0.77 | 1.95 |
| $E^{SR}_{loss}$/turn [GeV] | 0.03 | 0.3 | 1.7 | 7.5 | |
| $V_{RF}$,tot [GV] | 2 | 2 | 6 | 12 | |
| **$\mathcal{L}$ /IP[$10^{34}$cm$^{-2}$s$^{-1}$]** | **59** | **16** | **5** | **1.3** | **1.0** |
| **#IPs** | **4** | **4** | **4** | **4** | |
| **$\tau_{beam}$[min] (r.Bhabha)** | 99 | 38 | **24** | **21** | **26** |
| **$\tau_{beam}$[min] (BS,$\eta$=2%)** | $>10^{25}$ | $>10^{6}$ | **9** | **3.5** | **0.5** |

**multiple beamstrahlung increases bunch length**

**single beamstrahlung limits beam lifeitme**

**based on Telnov formula**

# 3. TLEP

**F. Zimmermann**

## lifetime limit: beamstrahlung (BS)

synchrotron radiation in the strong field of opposing beam

*Note:* Many theoretical beamstrahlung studies in 1980's. Example R. Blankenbecler, S.D. Drell, "A Quantum Treatment of Beamstrahlung," Phys.Rev. D36 (1987) 277

makes some $e^{\pm}$ emit significant part of their energy
& then be lost→ **limited beam lifetime**

$$\tau_{BS} \approx \frac{20\sqrt{6\pi} r_e}{n_{IP}\alpha^2} \frac{C}{c} \frac{\gamma}{\eta} u^{3/2} e^u \quad \text{with} \quad u = \eta \frac{\alpha}{3(r_e)^2} \frac{1}{\gamma} \frac{\sigma_z \sigma_x}{N_b}$$

V. Telnov, PRL 110 (2013) 114801
**note recent new formula from BINP!**

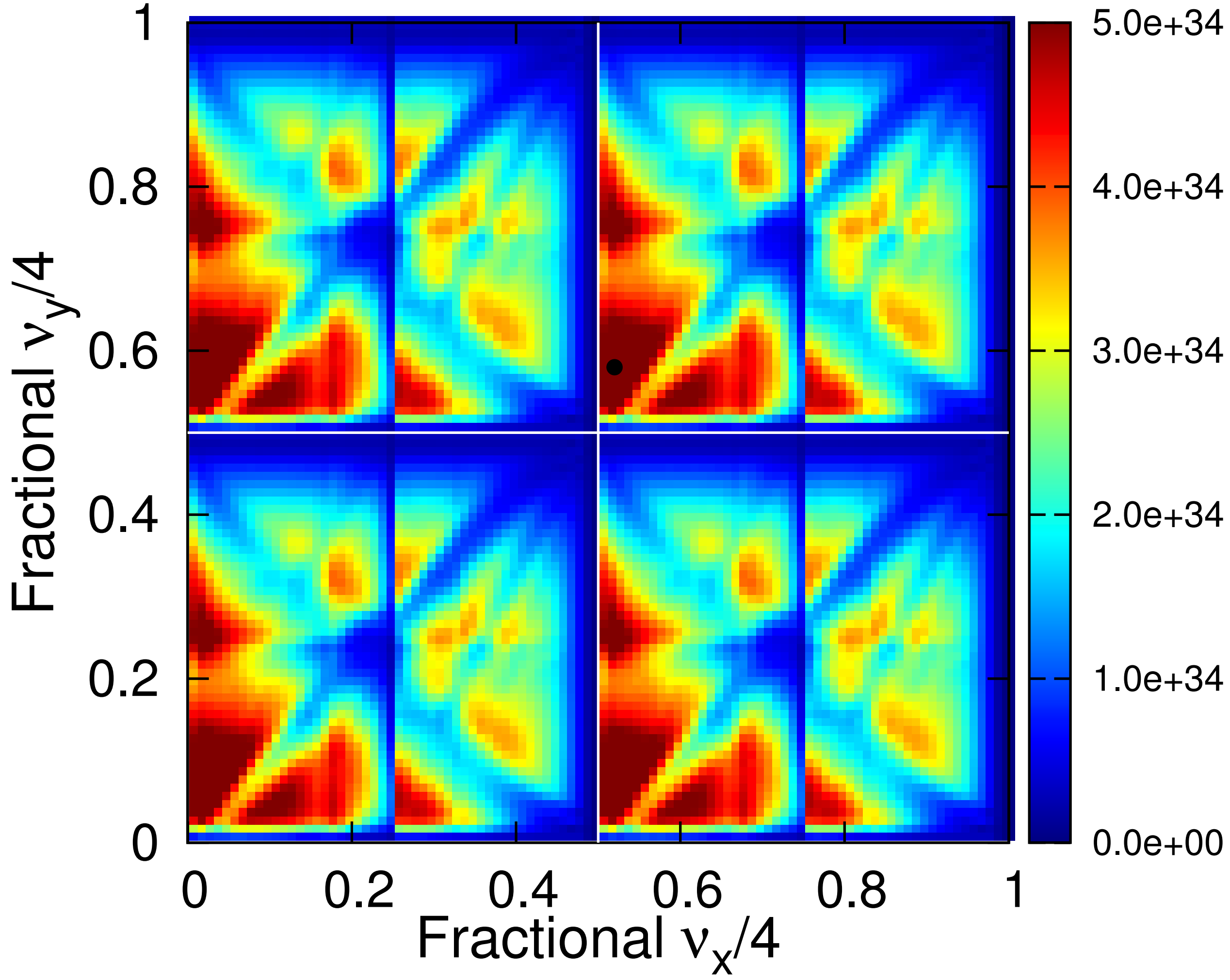
$\eta$: momentum acceptance
$\sigma_x$: horizontal beam size at IP

mitigations:

(1) large momentum acceptance $\eta$
(2) flat beams [i.e. small $\varepsilon_y$ & large $\beta_x^*$]
→minimize $\kappa_\varepsilon=\varepsilon_y/\varepsilon_x$, $\beta_y \sim \beta_x(\varepsilon_y/\varepsilon_x)$ & respect $\beta_y \geq \sigma_z$
(3) fast top up

# 3. TLEP H: Baseline design: Lum. tune scan

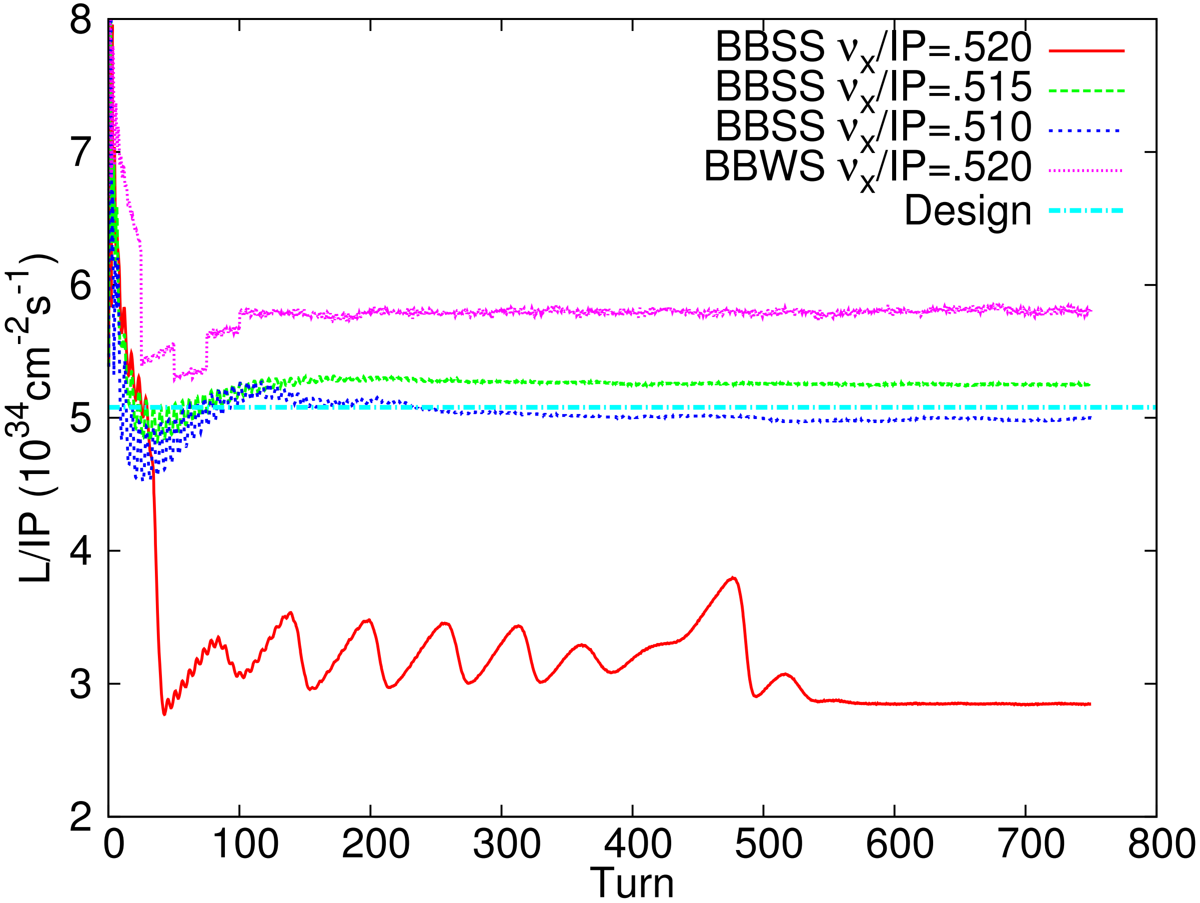
- **Tune scan for baseline design**
  - **Done by BBWS w/ beamstrahlung**
  - **Good work point around (.52, .58)×4 IPs**



# 3. TLEP H: Baseline design: Working point

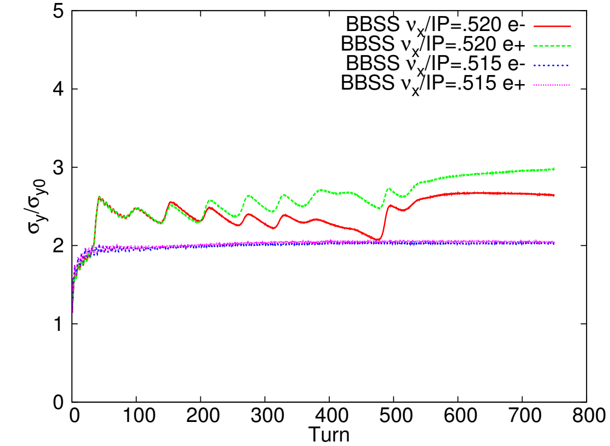
➤ **Turn-by-turn data for baseline design: luminosity**

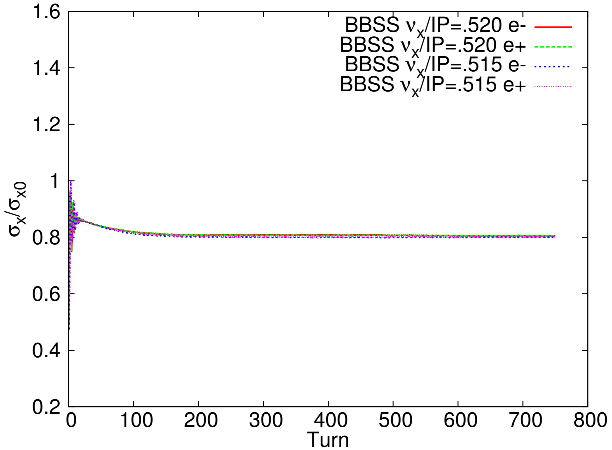
- **Done by BBSS w/ beamstrahlung**
- **Beams unstable at work point (.52, .58)×4 IPs**
- **Beams stable at work point (.515, .58)×4 IPs**

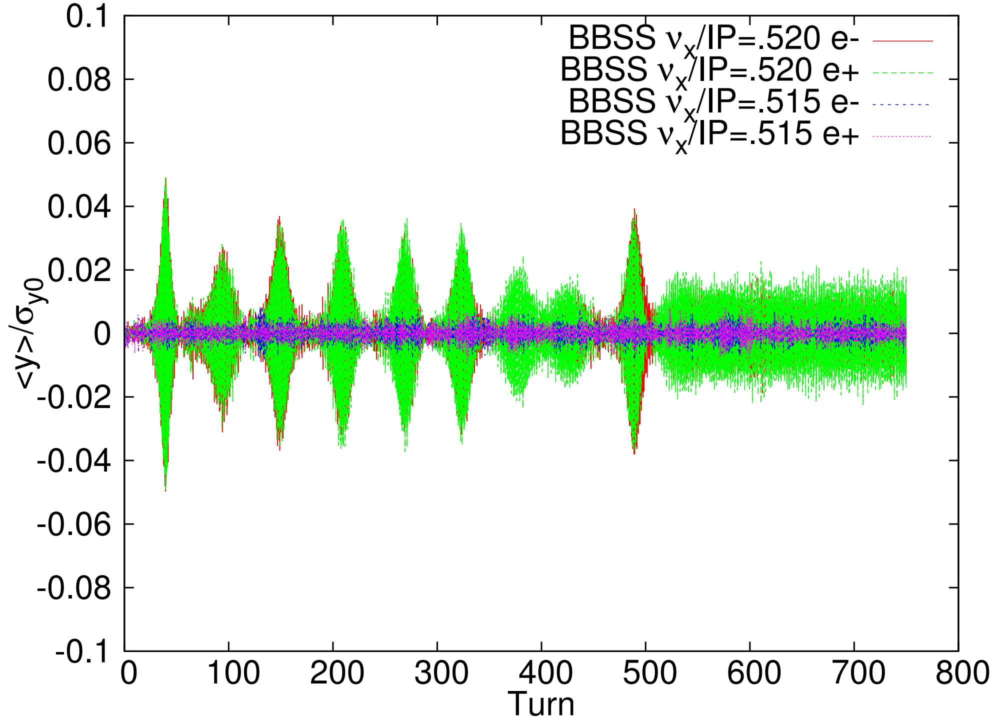


# 3. TLEP H: Baseline design: Working point

- **Turn-by-turn data for baseline design: beam sizes**
  - **Done by BBSS w/ beamstrahlung**
  - **Beams unstable at work point (.52, .58)×4 IPs**
  - **Beams stable at work point (.515, .58)×4 IPs**



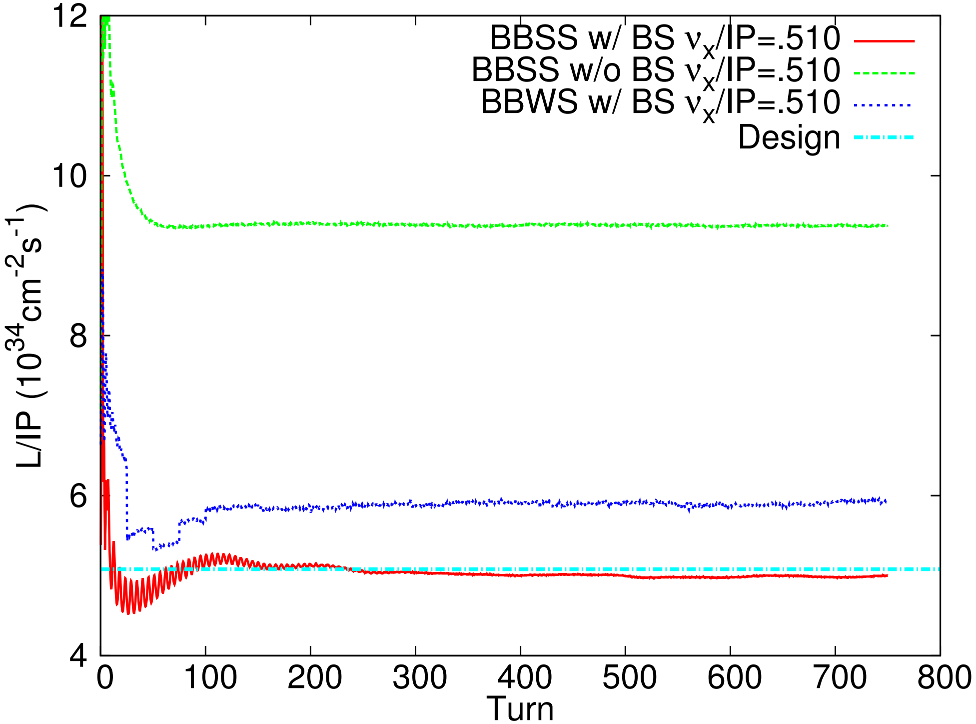



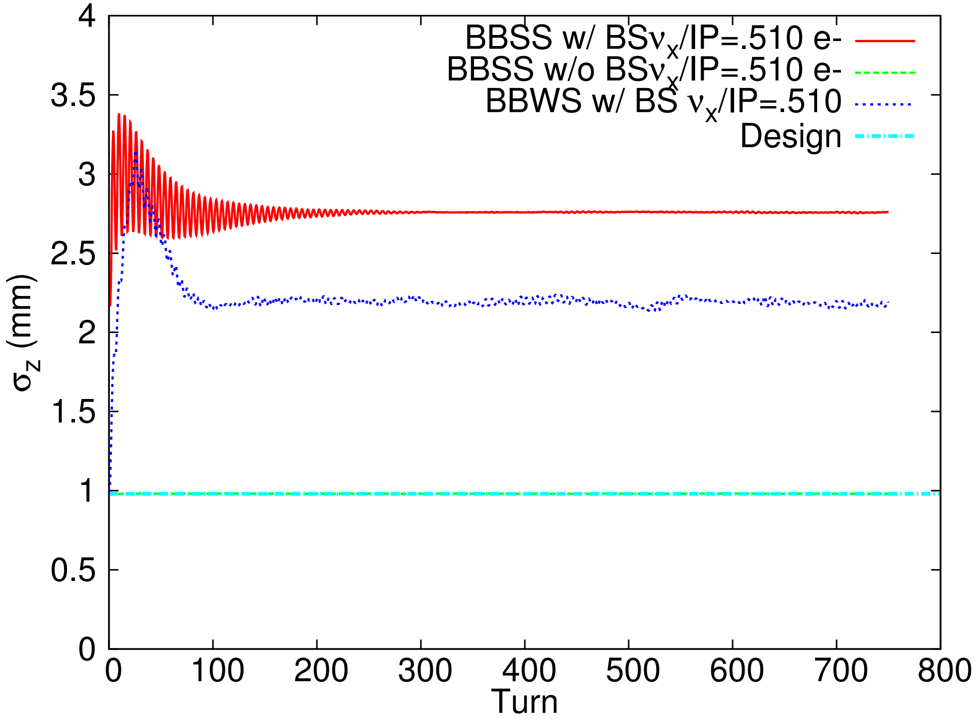



# 3. TLEP H: Baseline design: Beamstrahlung

➤ **BB induced synchrotron radiation**

- **Become significant at TLEP**
- **Cause bunch lengthening and enlarge energy spread**
- **Worsen hourglass effect**
- **Vertical beam size blowup**

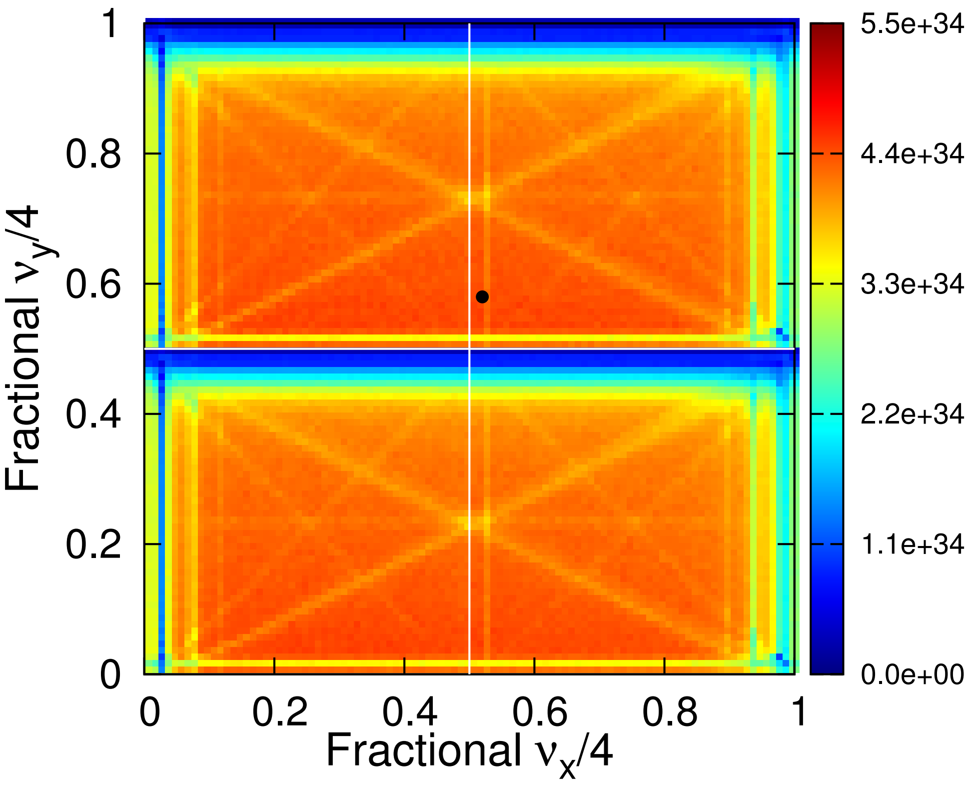


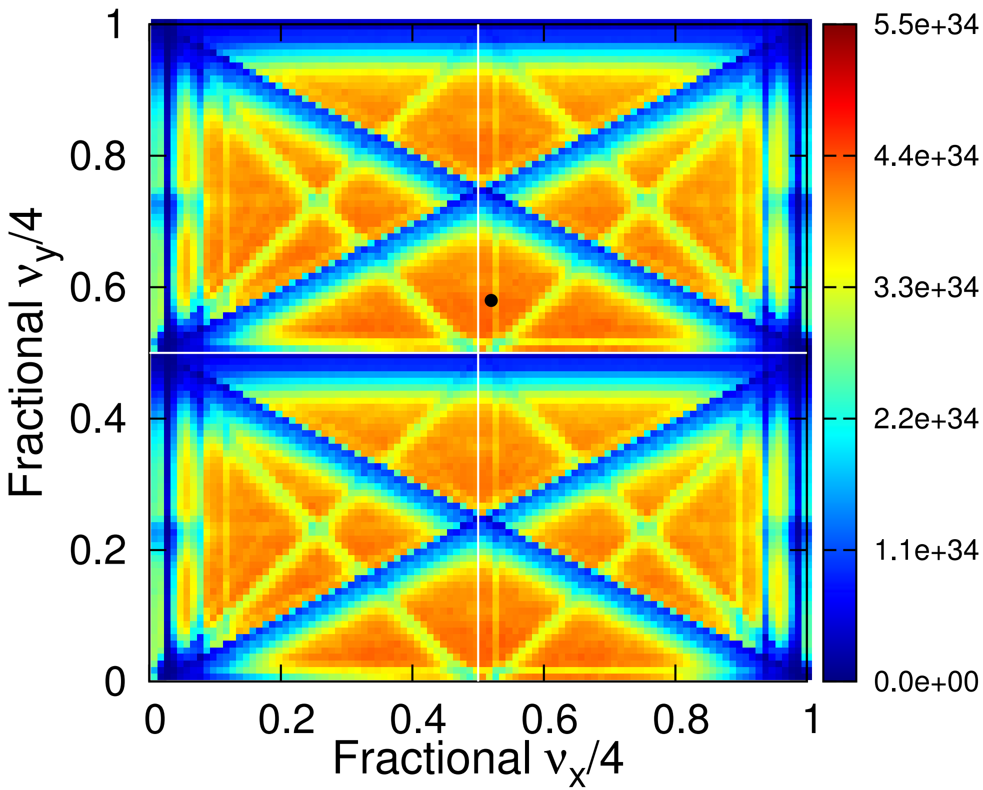
# 3. TLEP H: Nano-beam option: Lum. tune scan

➤ **Tune scan for nano-beam option**

- **Done by BBWS w/ beamstrahlung**
- **CW suppress coupling resonances**
- **Simulated luminosity lower than design because of incorrect bunch length used!**




**w/ CW**

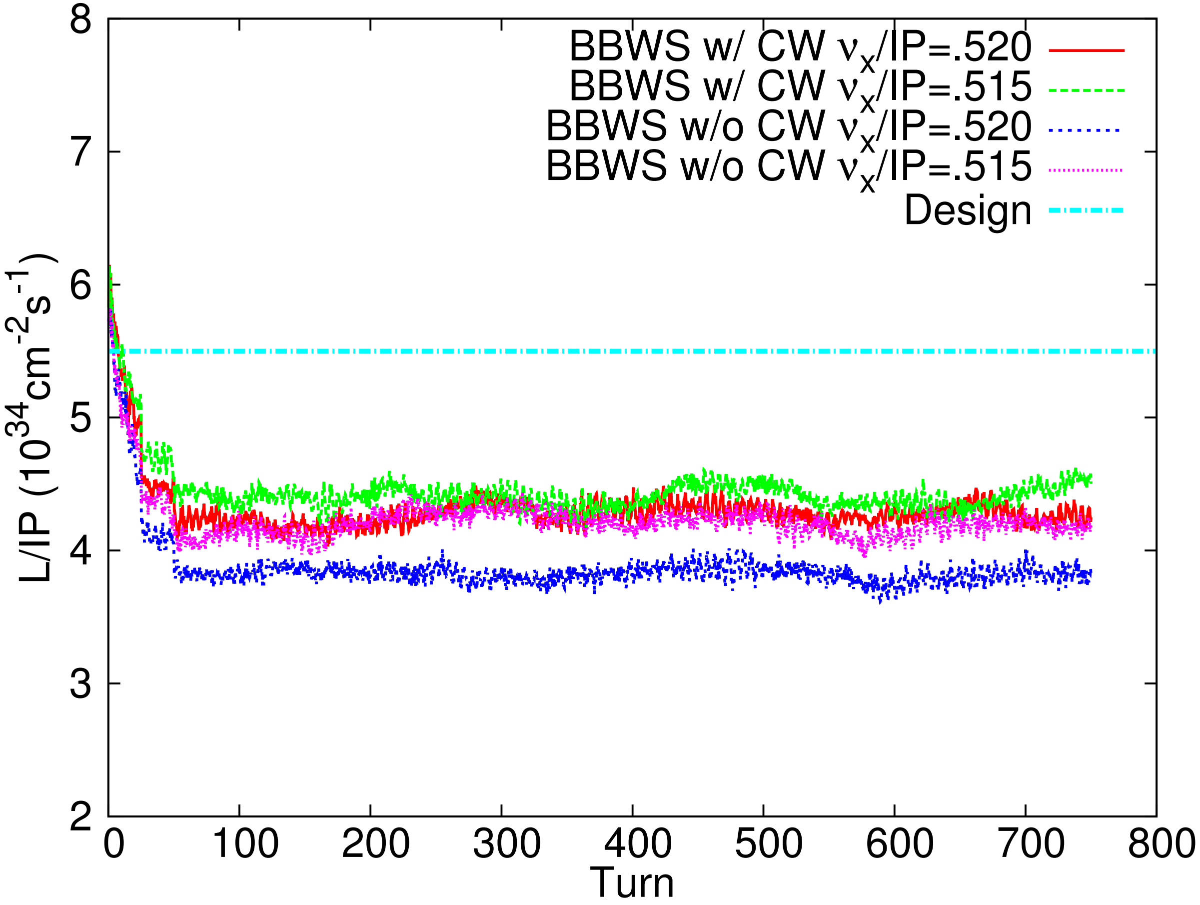



**w/o CW**

# 3. TLEP H: Nano-beam option: Working point

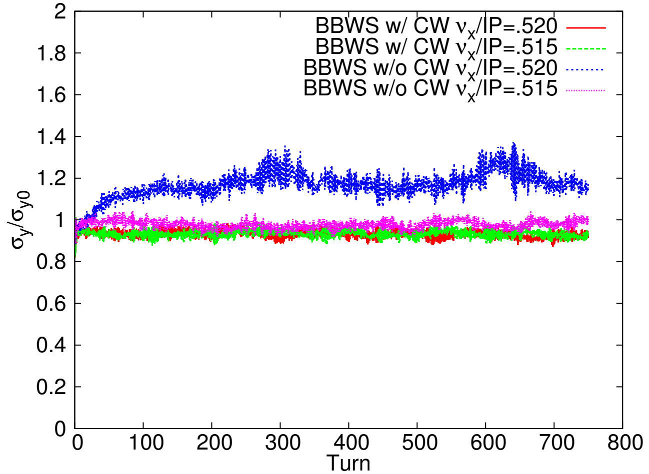
➤ **Turn-by-turn data for nano-beam option: luminosity**

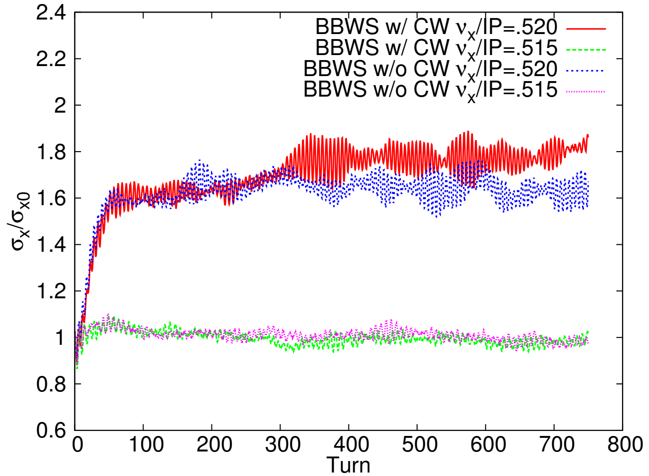
- **Done by BBWS w/ beamstrahlung**
- **BBSS simulation not feasible due to long computing time**
- **Working point (.515,.58) seems to be good**

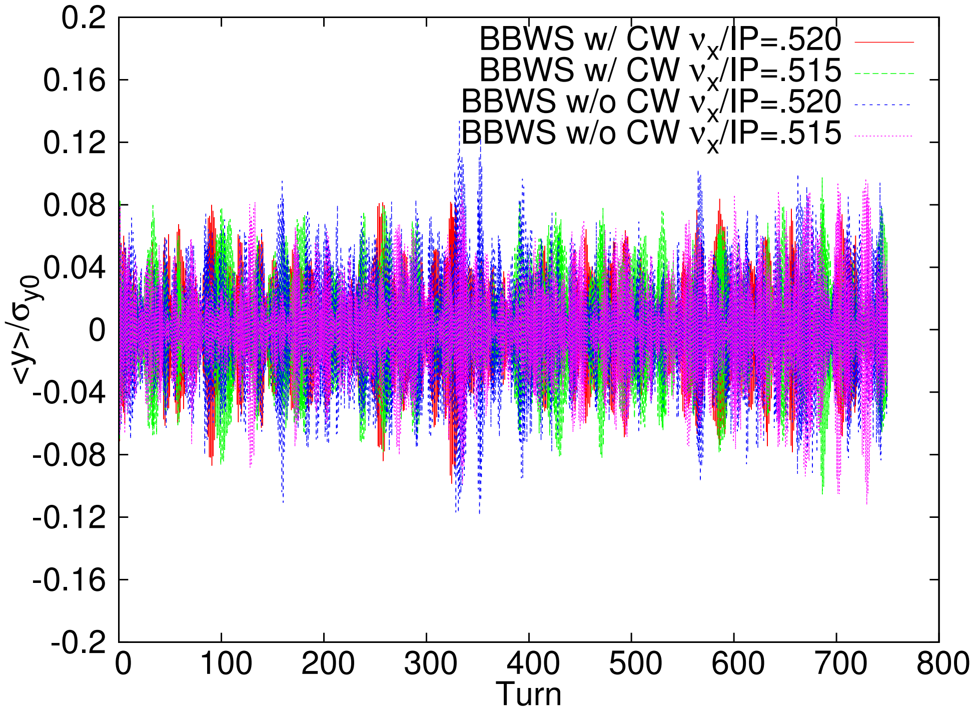


# 3. TLEP H: Nano-beam option: Working point

- **Turn-by-turn data for nano-beam option: beam sizes**
  - **Done by BBWS w/ beamstrahlung**
  - **Vert. beam size blowup not serious**
  - **Hor. blowup when working point close to $2\nu_x - 2\nu_s$=Integer**



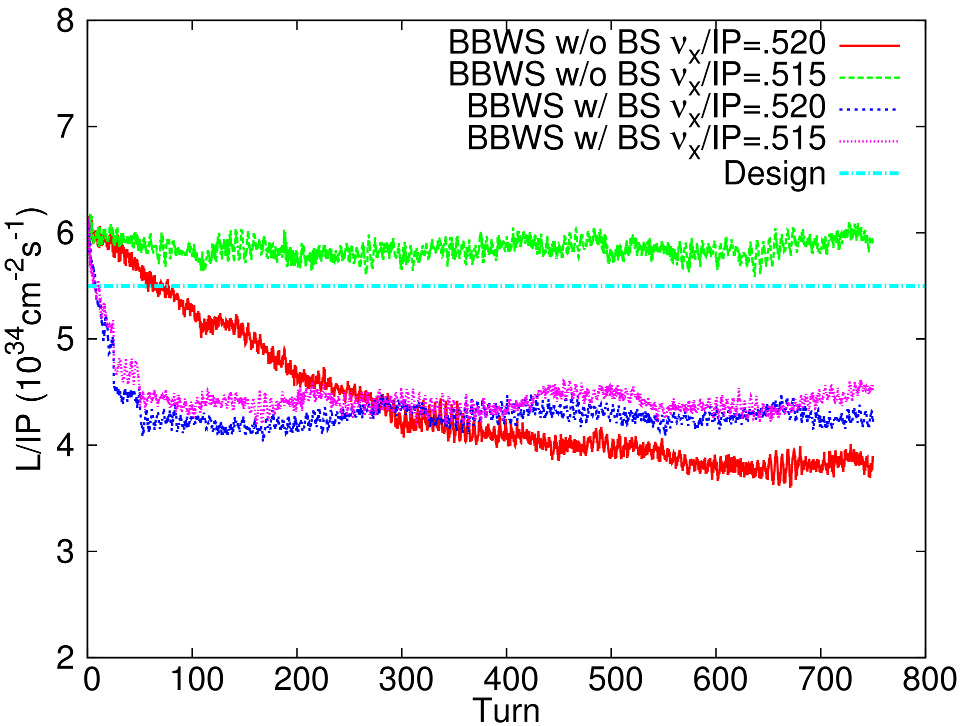



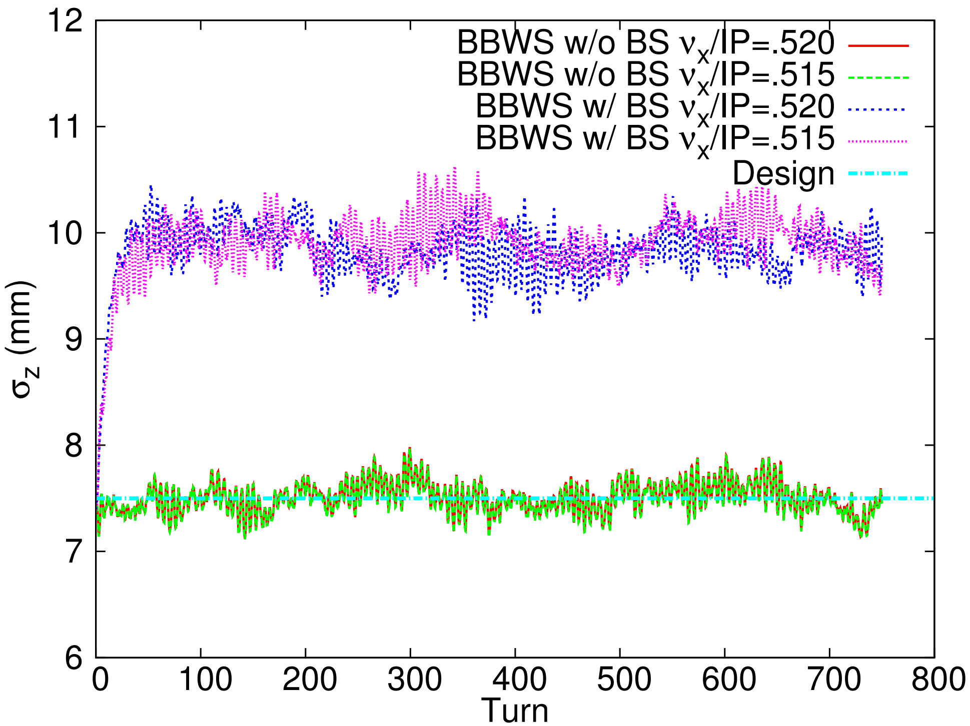



# 3. TLEP H: Nano-beam option: Beamstrahlung

➤ **BB induced synchrotron radiation**

- **Become significant at TLEP**
- **Cause bunch lengthening and enlarge energy spread**



# Outline

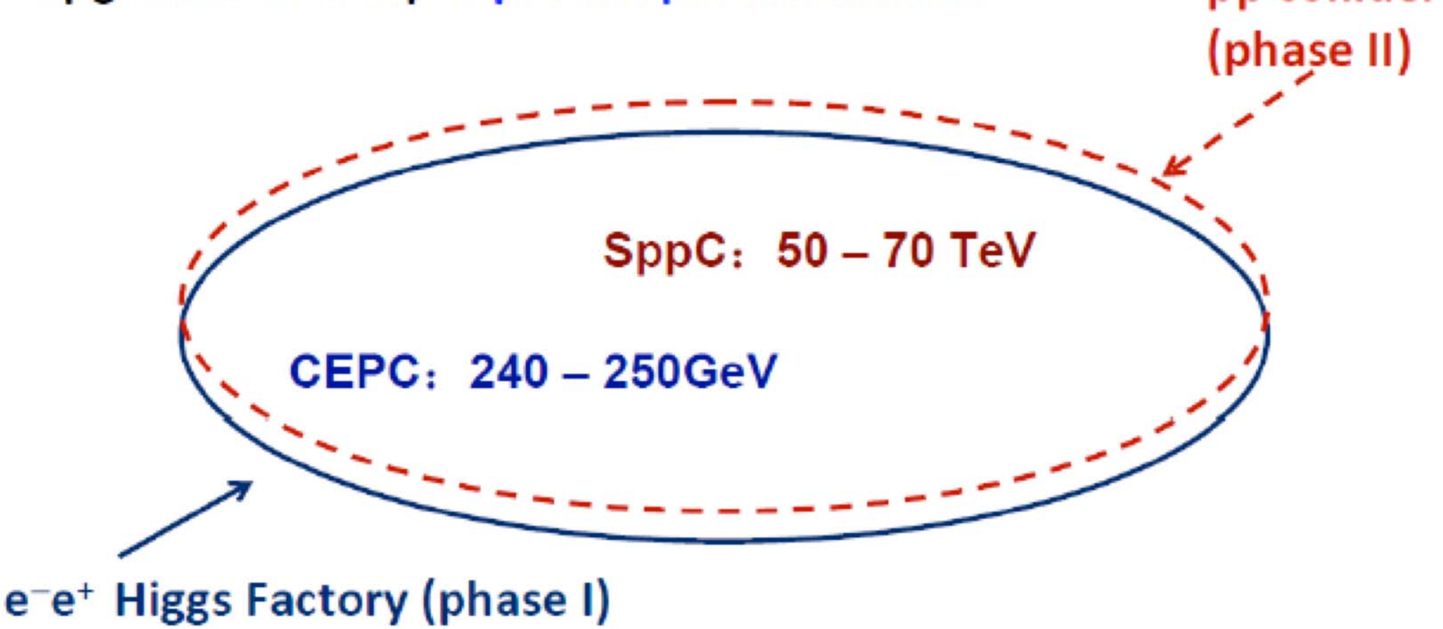
- ➤ Introduction
- ➤ Highlights of Int. Workshop on Future High Energy Circular Colliders (IHEP, Dec.16-17, 2013)
- ➤ TLEP
- ➤ **CEPC**
- ➤ Summary and outlook

# 4. CEPC

**Y. Zhang**

## CEPC is

- an Circular Electron Positron Collider
- proposed to carry out high precision study on Higgs bosons
- to be upgraded to a super proton-proton collider



# 4. CEPC

Y. Zhang

## CEPC basic parameter:

- Beam energy ~120 GeV.
- Synchrotron radiation power ~50 MW.
- 50/70 km in circumference.

## SppC basic parameter:

- Beam energy ~50-70 TeV.
- 50/70 km in circumference.
- Needs $B_{max}$ ~20T.

The circumference of CEPC is determined by that of the SppC, which is determined by the final energy of proton beam and the achievable dipole field strength.

# 4. CEPC

D. Wang

## Optimization Parameter Design of CEPC

| | 350 MHz (LEP2-like) technology | 700 MHz technology | | 1.3 GHz (LEP3-like) technology |
|---|---|---|---|---|
| Number of IPs | 1 | 1 | 2 | 1 |
| Energy (GeV) | 120 | 120 | 120 | 120 |
| Circumference (km) | 50 | 50 | 50 | 50 |
| SR loss/turn (GeV) | 2.96 | 2.96 | 2.96 | 2.96 |
| $N_e$/bunch ($10^{12}$) | 1.61 | 0.79 | 1.12 | 0.33 |
| Bunch number | 11 | 22 | 16 | 53 |
| Beam current (mA) | 16.9 | 16.9 | 16.9 | 16.9 |
| SR power /beam (MW) | 50 | 50 | 50 | 50 |
| $B_0$ (T) | 0.065 | 0.065 | 0.065 | 0.065 |
| Bending radius (km) | 6.2 | 6.2 | 6.2 | 6.2 |
| Momentum compaction ($10^{-4}$) | 0.43 | 0.38 | 0.38 | 0.21 |
| $\beta_{IP}$ x/y (m) | 0.2/0.001 | 0.2/0.001 | 0.2/0.001 | 0.2/0.001 |
| Emittance x/y (nm) | 29.7/0.15 | 14.6/0.073 | 29.1/0.15 | 6.1/0.03 |
| Transverse $\sigma_{IP}$ (um) | 77/0.38 | 54/0.27 | 76/0.38 | 35/0.17 |
| $\xi_x$/IP | 0.103 | 0.103 | 0.073 | 0.103 |
| $\xi_y$/IP | 0.103 | 0.103 | 0.073 | 0.103 |
| $V_{RF}$ (GV) | 4.1 | 6 | 6 | 9.3 |
| $f_{RF}$ (MHz) | 350 | 704 | 704 | 1304 |
| $\sigma_z$ (mm) | 4.6 | 2.2 | 2.2 | 0.95 |
| Energy spread (%) | 0.13 | 0.13 | 0.13 | 0.13 |
| Energy acceptance (%) | 3.5 | 5 | 5 | 7.7 |
| $\gamma_{BS}$ ($10^{-4}$) | 9.7 | 13.8 | 13.8 | 21.3 |
| $n_\gamma$ | 0.86 | 0.6 | 0.6 | 0.39 |
| $\delta_{BS}$ ($10^{-4}$) | 4.3 | 4.3 | 4.3 | 4.3 |
| Life time due to beamstrahlung (minute) | 30 | 30 | 30 | 30 |
| F (hour glass) | 0.49 | 0.68 | 0.68 | 0.87 |
| $L_{max}$/IP ($10^{34}cm^{-2}s^{-1}$) | 2.2 | 3.1 | 2.2 | 4.0 |

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# 4. CEPC

D. Wang

## Lower power design of CEPC

| | Baseline | Low power design | | |
|---|---|---|---|---|
| Number of IPs | 1 | 1 | 1 | 1 |
| Energy (GeV) | 120 | 120 | 120 | 120 |
| Circumference (km) | 50 | 50 | 50 | 50 |
| SR loss/turn (GeV) | 2.96 | 2.96 | 2.96 | 2.96 |
| $N_e$/bunch ($10^{12}$) | 0.79 | 0.38 | 0.33 | 0.28 |
| Bunch number | 22 | 23 | 21 | 19 |
| Beam current (mA) | 16.9 | 8.45 | 6.76 | 5.07 |
| SR power /beam (MW) | 50 | 25 | 20 | 15 |
| $B_0$ (T) | 0.065 | 0.065 | 0.065 | 0.065 |
| Bending radius (km) | 6.2 | 6.2 | 6.2 | 6.2 |
| Momentum compaction ($10^{-4}$) | 0.38 | 0.38 | 0.38 | 0.38 |
| $\beta_{IP}$ x/y (m) | 0.2/0.001 | 0.071/0.00048 | 0.056/0.00042 | 0.041/0.00035 |
| Emittance x/y (nm) | 14.6/0.073 | 9.5/0.035 | 9.1/0.031 | 8.9/0.026 |
| Transverse $\sigma_{IP}$ (um) | 54/0.27 | 25.9/0.13 | 22.7/0.11 | 19.2/0.096 |
| $\xi_x$/IP | 0.103 | 0.076 | 0.069 | 0.06 |
| $\xi_y$/IP | 0.103 | 0.103 | 0.103 | 0.103 |
| $V_{RF}$ (GV) | 6 | 6 | 6 | 6 |
| $f_{RF}$ (MHz) | 704 | 704 | 704 | 704 |
| $\sigma_z$ (mm) | 2.2 | 2.2 | 2.2 | 2.2 |
| Energy spread (%) | 0.13 | 0.13 | 0.13 | 0.13 |
| Energy acceptance (%) | 5 | 5 | 5 | 5 |
| $\gamma_{BS}$ ($10^{-4}$) | 13.8 | 13.8 | 13.8 | 13.8 |
| $n_\gamma$ | 0.6 | 0.6 | 0.6 | 0.6 |
| $\delta_{BS}$ ($10^{-4}$) | 4.3 | 4.3 | 4.3 | 4.3 |
| Life time due to beamstrahlung (minute) | 30 | 30 | 30 | 30 |
| $F$ (hour glass) | 0.68 | 0.48 | 0.45 | 0.41 |
| $L_{max}$/IP ($10^{34}$cm$^{-2}$s$^{-1}$) | 3.1 | 2.31 | 1.97 | 1.58 |
| AC power for RF source/two beam (MW) | 286 | 143 | 114 | 86 |

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# 4. CEPC

**D. Wang**

## CEPC low power scheme with recovered luminosity

| | Baseline – 50 MW | Low power design – 25 MW | | |
|---|---|---|---|---|
| Aspect ratio (coupling factor) | ~200 | ~200 | ~550 | ~1200 |
| Number of IPs | 1 | 1 | 1 | 1 |
| Energy (GeV) | 120 | 120 | 120 | 120 |
| Circumference (km) | 50 | 50 | 50 | 50 |
| SR loss/turn (GeV) | 2.96 | 2.96 | 2.96 | 2.96 |
| $N_e$/bunch ($10^{12}$) | 0.79 | 0.38 | 0.51 | 0.079 |
| Bunch number | 22 | 23 | 17 | 111 |
| Beam current (mA) | 16.9 | 8.45 | 8.45 | 8.45 |
| SR power /beam (MW) | 50 | 25 | 25 | 25 |
| $B_0$ (T) | 0.065 | 0.065 | 0.065 | 0.065 |
| Bending radius (km) | 6.2 | 6.2 | 6.2 | 6.2 |
| Momentum compaction (10-4) | 0.38 | 0.38 | 0.38 | 0.38 |
| $\beta_{IP}$ x/y (m) | 0.2/0.001 | 0.071/0.00048 | 0.13/0.00024 | 0.11/0.0001 |
| Emittance x/y (nm) | 14.6/0.073 | 9.5/0.035 | 9.4/0.017 | 9.4/0.0073 |
| Transverse $\sigma_{IP}$ (um) | 54/0.27 | 25.9/0.13 | 34.9/0.063 | 32.4/0.027 |
| $\xi_x$/IP | 0.103 | 0.076 | 0.103 | 0.016 |
| $\xi_y$/IP | 0.103 | 0.103 | 0.103 | 0.103 |
| $V_{RF}$ (GV) | 6 | 6 | 6 | 6 |
| $f_{RF}$ (MHz) | 704 | 704 | 704 | 704 |
| $\sigma_z$ (mm) | 2.2 | 2.2 | 2.2 | 2.2 |
| Energy spread (%) | 0.13 | 0.13 | 0.13 | 0.13 |
| Energy acceptance (%) | 5 | 5 | 5 | 5 |
| $\gamma_{BS}$ ($10^{-4}$) | 13.8 | 13.8 | 13.8 | 13.8 |
| $n_\gamma$ | 0.6 | 0.6 | 0.6 | 0.6 |
| $\delta_{BS}$ ($10^{-4}$) | 4.3 | 4.3 | 4.3 | 4.3 |
| Life time due to beamstrahlung (minute) | 30 | 30 | 30 | 30 |
| $F$ (hour glass) | 0.68 | 0.48 | 0.32 | 0.18 |
| $L_{max}$/IP ($10^{34}cm^{-2}s^{-1}$) | 3.1 | 2.31 | 3.1 | 4.1 |
| AC power /two beam (MW) * | 286 | 143 | 143 | 143 |
| Technology Maturity | 🙂 | 😐 | ☹ | ☹☹ |

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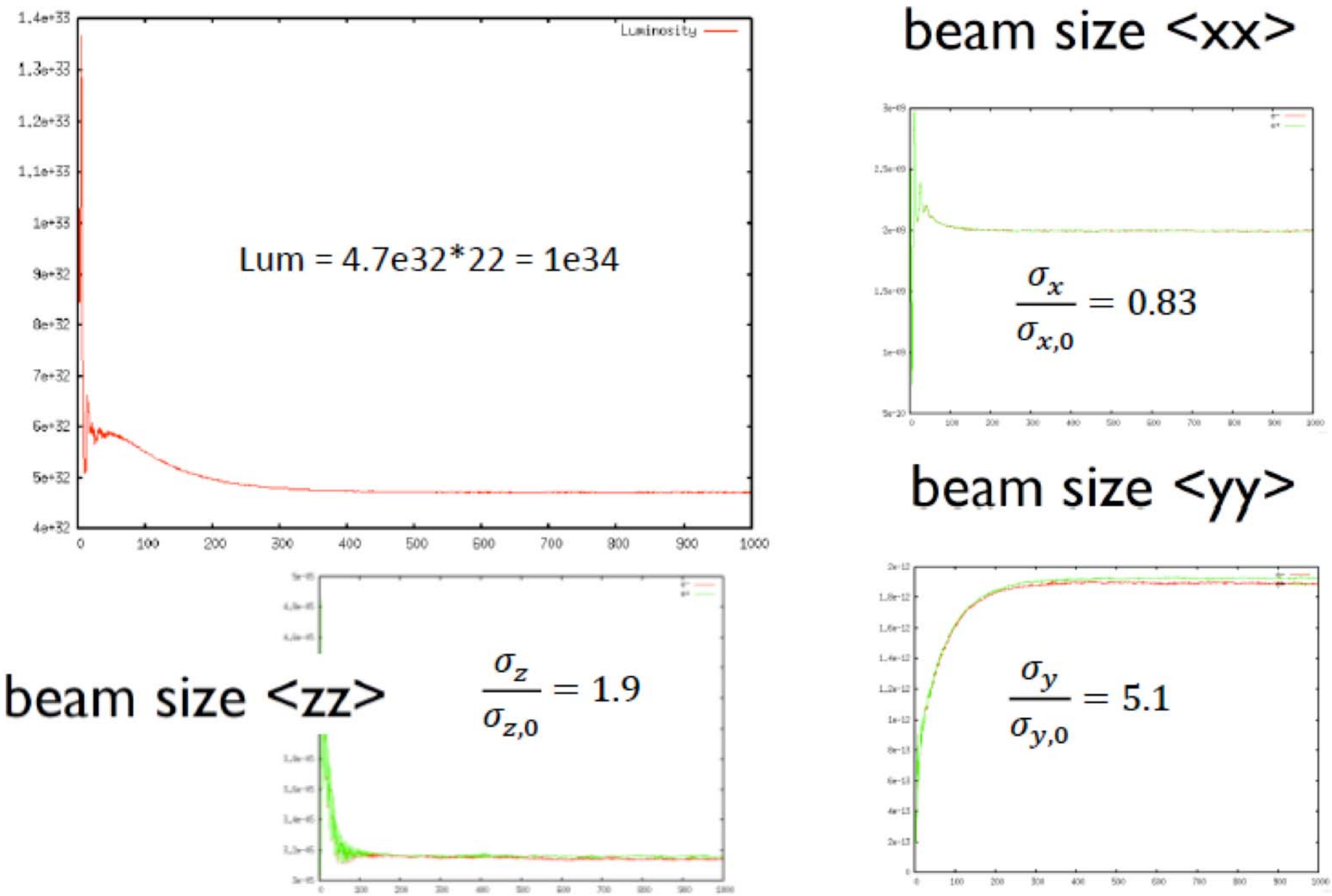
# 4. CEPC

➤ **Simulation by BBSS for baseline design**

- **Significant particle loss observed with $\beta_y^* \ll \sigma_z$**

Strong-Strong@(0.52,0.58)



# 4. CEPC

## ➤ z-dependent beam-beam tune shift

- **“aggravating factor” with $\beta_y^* \ll \sigma_z$**

    - nominal: 0.1

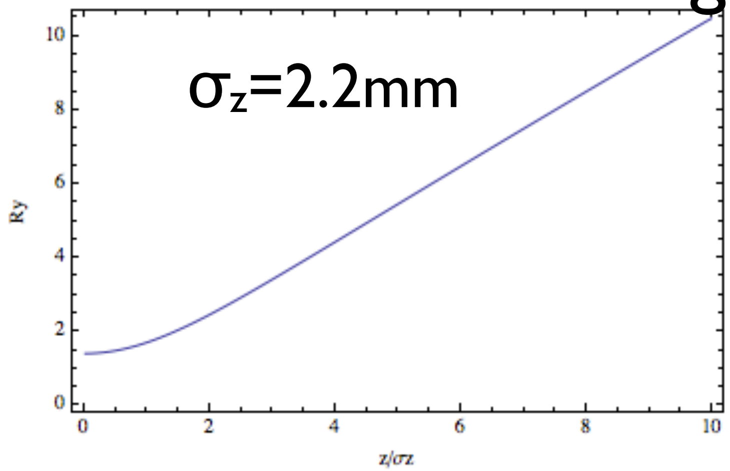
Ref. M. Furman, LBL-30833, ESG-137

$$R_{y+}(z) \equiv \xi_{y+}(z)/\xi_{0y+} = \int_{-\infty}^{\infty} \frac{dt}{\sqrt{\pi}} \frac{(1+t^2/t_1^2)\exp(-(t-t_0)^2)}{\sqrt{1+t^2/t_2^2}\left(v\sqrt{1+t^2/t_2^2}+h\sqrt{1+t^2/t_3^2}\right)} \quad (4)$$

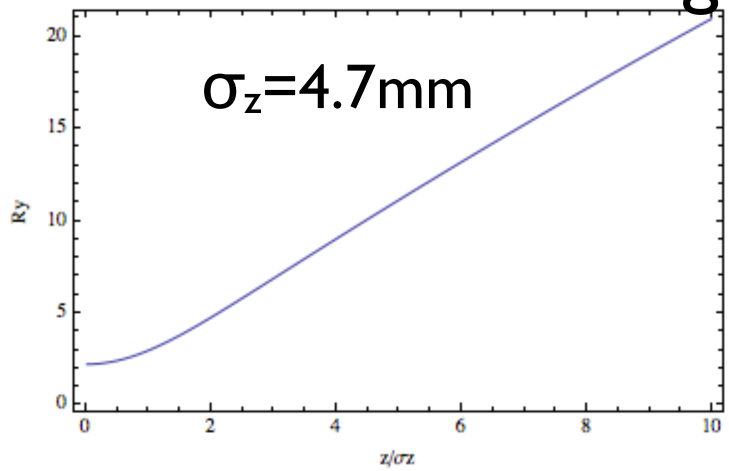
where $h = \sigma_{x-}^*/(\sigma_{x-}^* + \sigma_{y-}^*)$, $v = \sigma_{y-}^*/(\sigma_{x-}^* + \sigma_{y-}^*)$, $t_0 = z/\sqrt{2}\sigma_{s-}$, $t_1 = \sqrt{2}\beta_{y+}^*/\sigma_{s-}$, $t_2 = \sqrt{2}\beta_{y-}^*/\sigma_{s-}$ and $t_3 = \sqrt{2}\beta_{x-}^*/\sigma_{s-}$. The nominal (zero-bunch-length) vertical beam-beam parameter $\xi_{0y+}$ of the central positron is

$$\xi_{0y+} = \frac{r_0 N_- \beta_{y+}^*}{2\pi\gamma_+\sigma_{y-}^*(\sigma_{x-}^* + \sigma_{y-}^*)} \quad (5)$$

w/o beamstrahlung



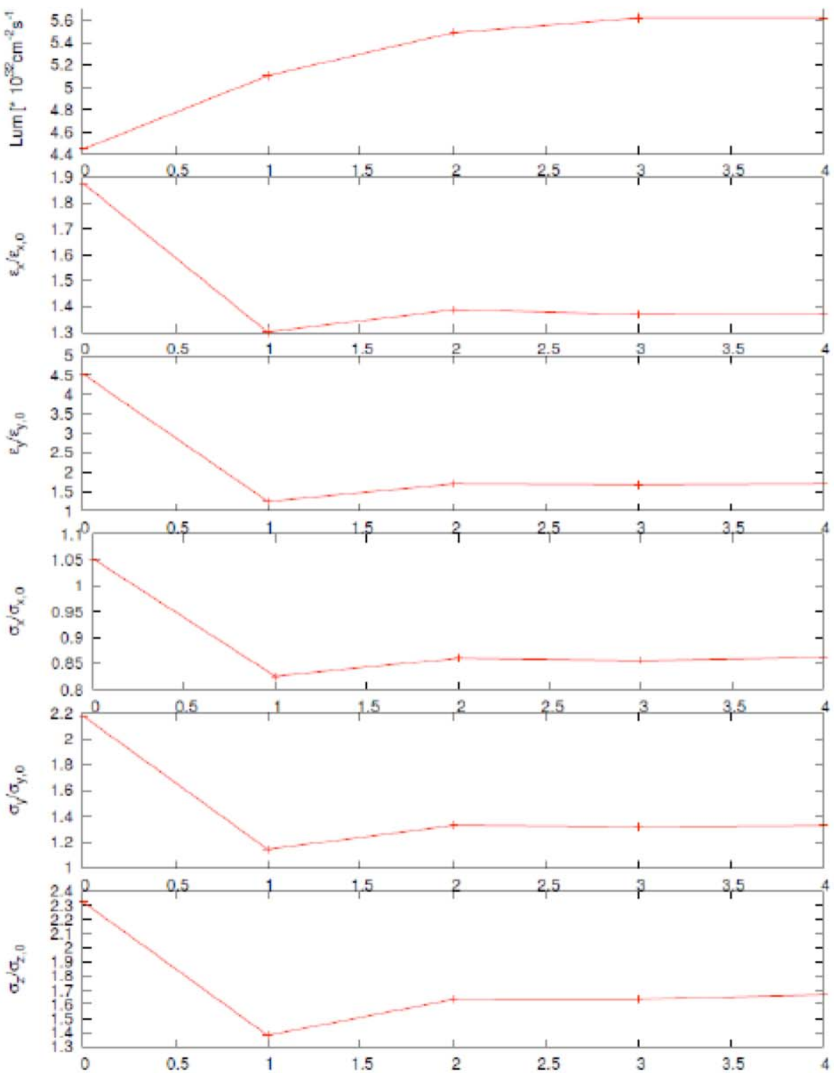

w/ beamstrahlung



# 4. CEPC

## ➤ Crossing looks to be attractive ...

**Y. Zhang**



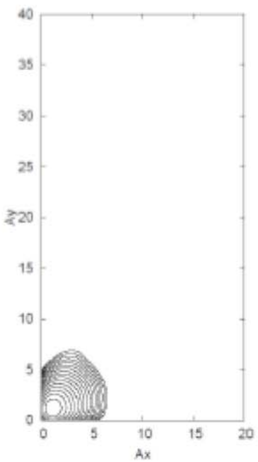
Quasi-Strong-Strong Simulation with LIFETRAC @(0.51, 0.63) with full crossing angle 40mrad in horizontal direction.

Lum = 1.2e34

Piwinski Angle:
1.1 before collision
2.1 after collision

Vertical blowup disappear!

Lifetime: 600 s !



# Outline

- ➤ Introduction
- ➤ Highlights of Int. Workshop on Future High Energy Circular Colliders (IHEP, Dec.16-17, 2013)
- ➤ TLEP
- ➤ CEPC
- ➤ **Summary and outlook**

# 5. Summary: TLEP H (personal comments)

- **Baseline design**
  - Good working point around (.515,.58) $\times$4 IPs
  - Strong beamstrahlung
  - Hourglass effects cause vert. blowup
  - $\beta_y^* \approx \sigma_z$ required with head-on collision (?)
- **Nano-beam option**
  - CW suppresses coupling resonances
  - Acceptable beamstrahlung
  - Hourglass effects relaxed with crossing angle
  - $\beta_y^* \ll \sigma_z$ is possible

# 5. Summary: CEPC

Y. Zhang

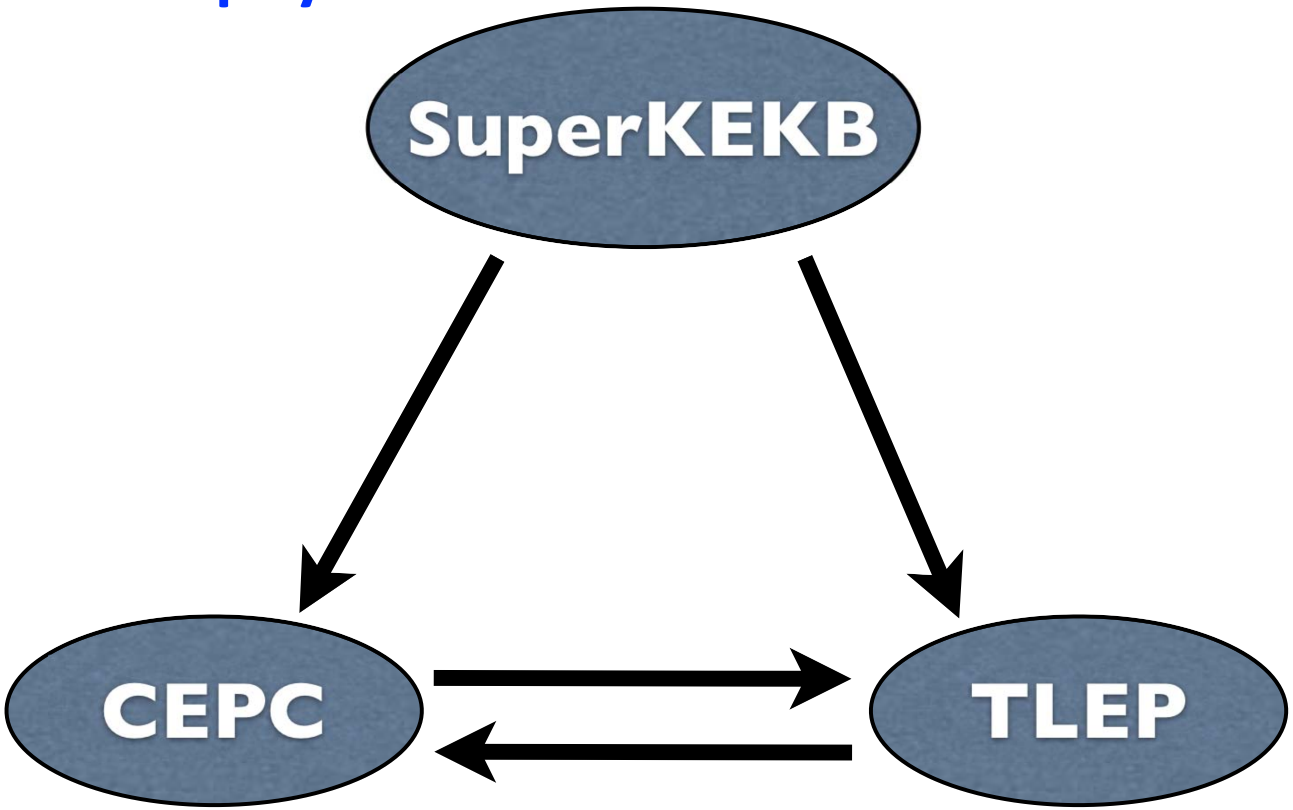
## Summary

- The pure weak-strong simulation does not work well
- Quasi-strong-strong could help us and save time. But the result should be checked by the strong-strong simulation
- The head-on collision scheme could only achieve 1e34 by simulation and lifetime is very bad
- We need to optimize machine parameters
- It seems the crossing angle could help us suppress hourglass effect, even though the bunch lengthening is unavoidable.
- We could achieve 1.5e34 with full crossing angle 40mrad and much better lifetime (need check by strong-strong simulation)

# 5. Outlook: Collaboration (very personal!)

➤ **SuperKEKB => TLEP and CEPC:**

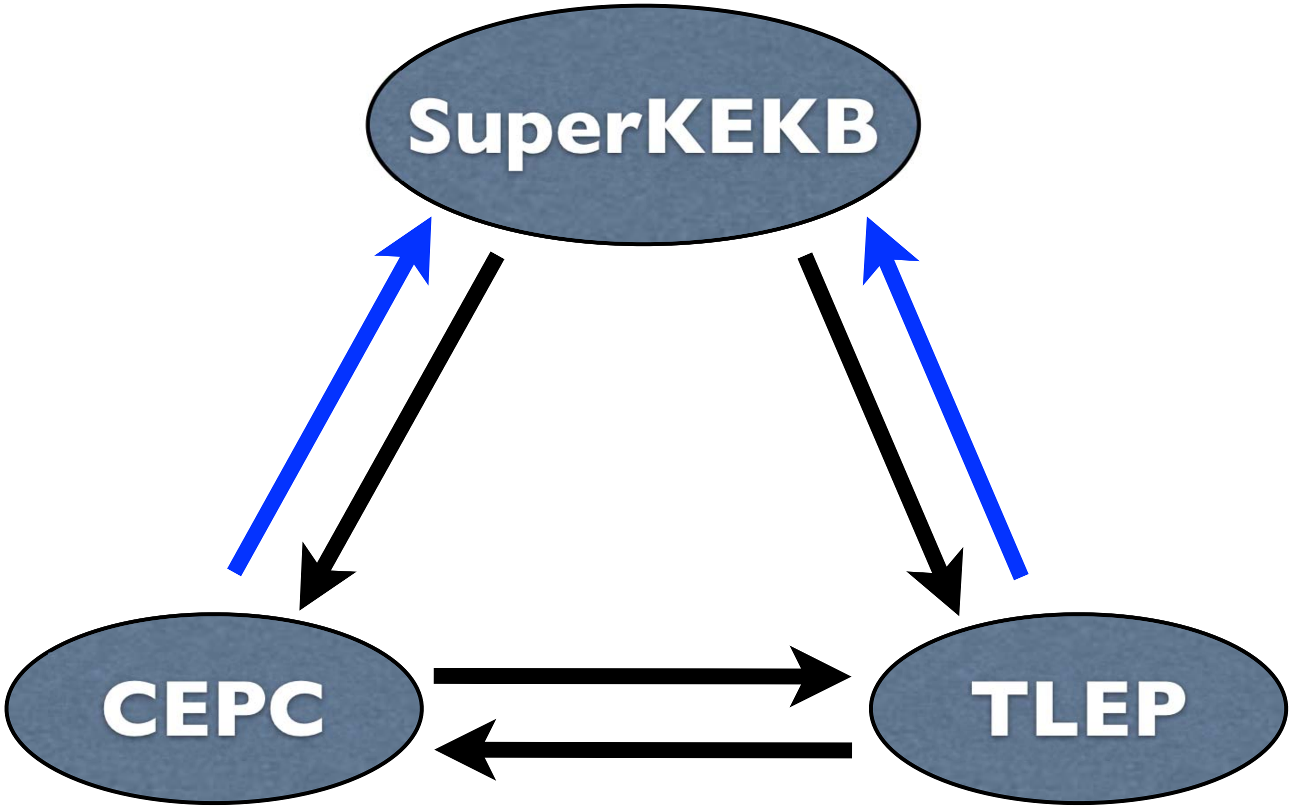
- Technologies
- Optics design
- Beam commissioning
- Accelerator physics
- ...



# 5. Outlook: Collaboration (very personal!)

➤ **SuperKEKB <= TLEP and CEPC:**

- Design tools
- Manpower and collaborations
- Accelerator physics
- ...



# Thanks for your attention!