European Coordination for Accelerator Research and Development

**PUBLICATION**

# Future Possibilities for Precise Studies of the X(125) Higgs Candidate – Higgs Factories

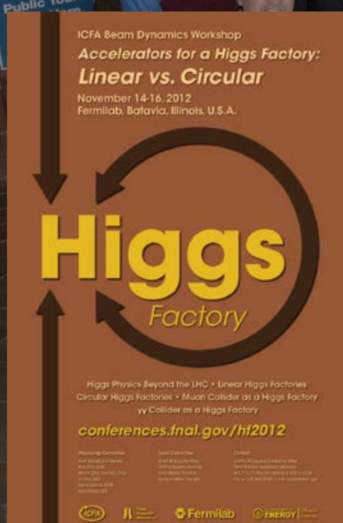
Zimmermann, F (CERN, Switzerland)

06 December 2012

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579.

This work is part of EuCARD Work Package **4: AccNet: Accelerator Science Networks**.

# Future Possibilities for Precise Studies of the X(125) Higgs Candidate – *Higgs Factories*

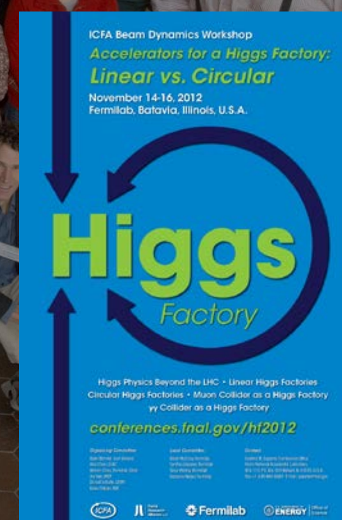




Frank Zimmermann


CERN Colloquium

22 November 2012





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# Higgs Factory (HF) candidates

- LHC & upgrades
- linear colliders
- circular $e^+e^-$ colliders
- lepton-hadron collider
- gamma-gamma colliders
- muon collider

# HF quality indicators

- readiness / maturity
- cost , electrical power
- peak luminosity , #IPs
- integrated luminosity
  - Hübner (*H*) factor = integrated lumi/(peak lumi x calendar time for physics)

    $H_{\mathrm{LEP}} \approx 0.2$, $H_{\mathrm{LHC}} \approx 0.2$, $H_{\mathrm{KEKB}} \approx 0.7$
- commissioning time
- expandability

# *LHC Higgs Factory & LHC upgrades*

# *LHC* Higgs factory & upgrades

**LHC is the 1st Higgs factory!**

$E_{CoM}$=8-14 TeV, $\hat{L}\sim 10^{34}cm^{-2}s^{-1}$

total cross section at 8 TeV: 22 pb

**1 M Higgs produced so far – more to come**

**15 H bosons / min – and more to come**

8 → 14 TeV: ggH x1.5 F. Cerutti, P. Janot

**HL-LHC** (~2022-2030)

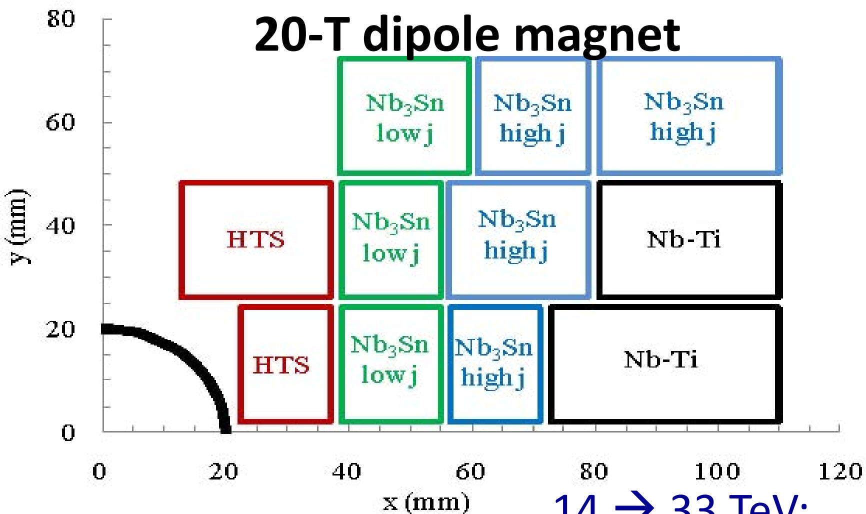
**will deliver ~9x more H bosons!**

**$E_{CoM}$=14 TeV, $\hat{L}\sim 5x10^{34}cm^{-2}s^{-1}$**

with luminosity leveling

**HE-LHC**: in LHC tunnel (2035-)

**$E_{CoM}$=33 TeV, $\hat{L}=2x10^{34}cm^{-2}s^{-1}$**



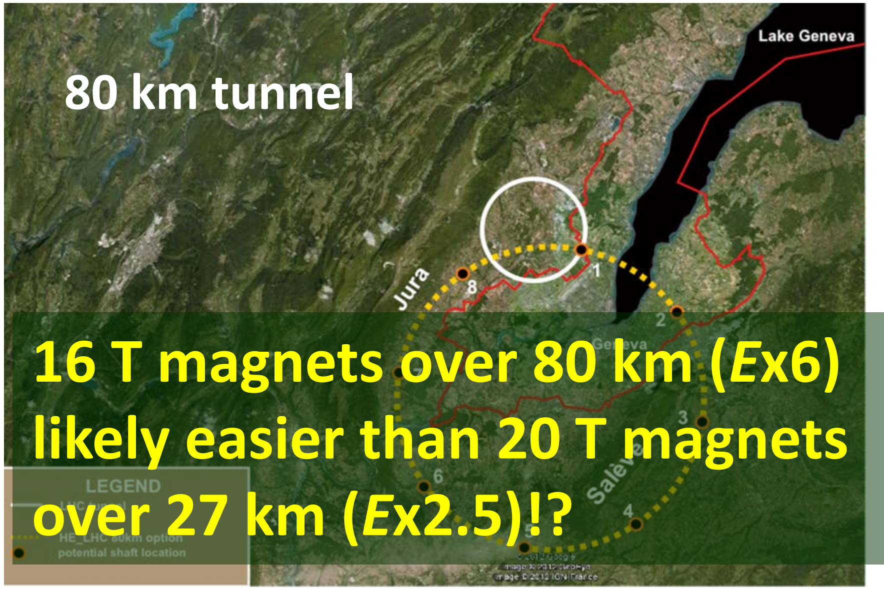

14 → 33 TeV:

ggH→ HH x6

E. Todesco, L. Rossi, P.. McIntyre

**SHE-LHC**: new 80 km tunnel

**$E_{CoM}$=84-104 TeV, $\hat{L}=2x10^{34}cm^{-2}s^{-1}$**

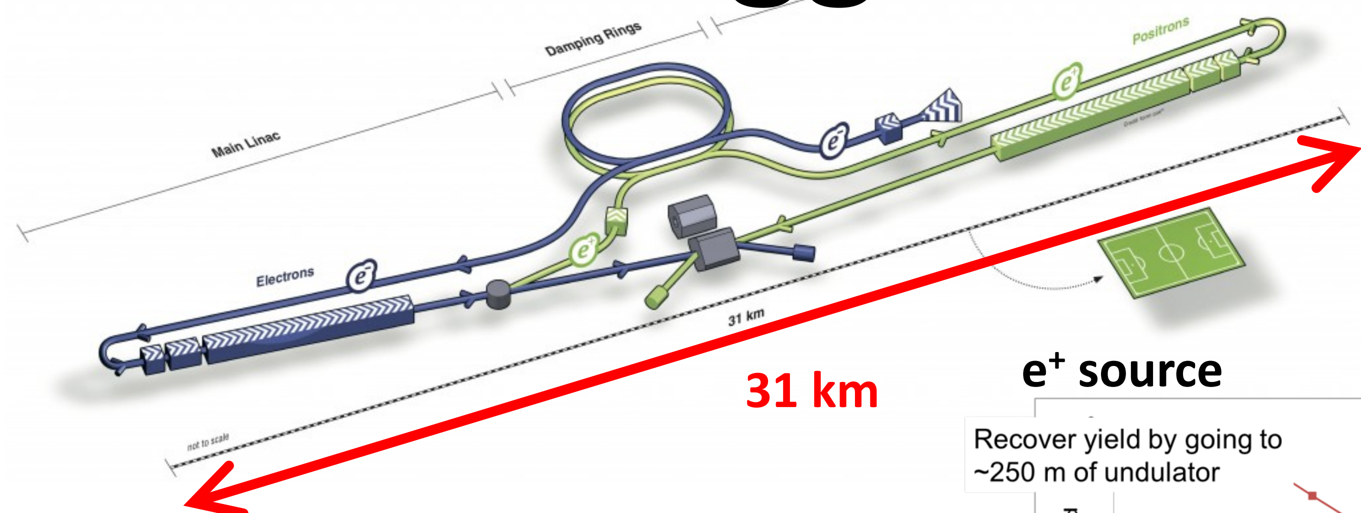



**16 T magnets over 80 km (*E*x6) likely easier than 20 T magnets over 27 km (*E*x2.5)!?**

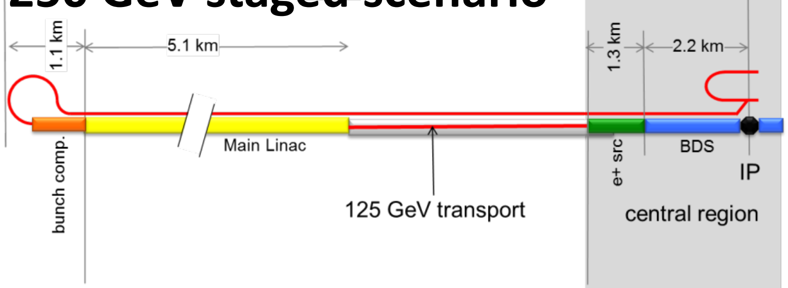
J. Osborne, C. Waaijer, S. Myers

# *Linear Collider Higgs Factories*

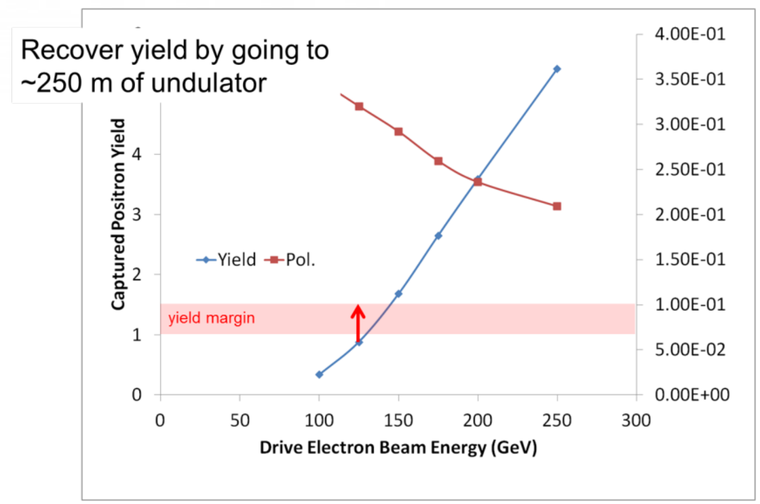
# *ILC* as Higgs factory




## 250 GeV staged scenario



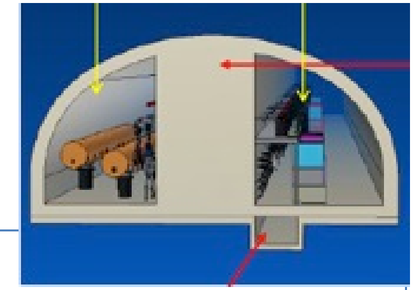

## $e^+$ source

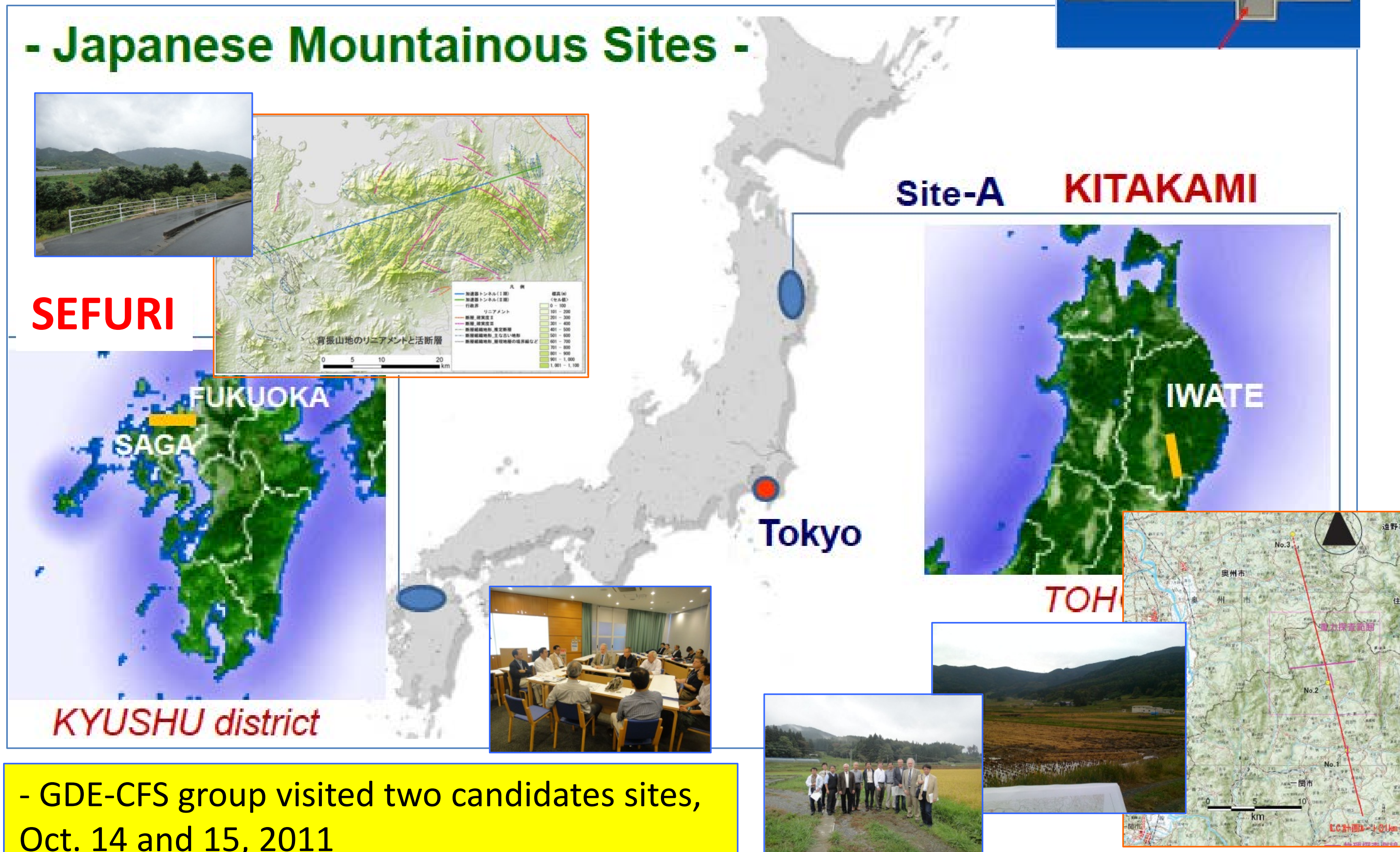



## ILC Summary (Nick Walker, DESY)

ILC (500 GeV) "contains" light Higgs factor; luminosity **$7.5\times10^{33}$ cm$^{-2}$ s$^{-1}$** (**possible upgrade x2**) ; Standalone machine for LHF: reduced cost by ~35% ($P_{AC}$ ~ 100 MW). **Only makes sense as part of 1st-stage machine**; scope still ~500 GeV, TeV optional

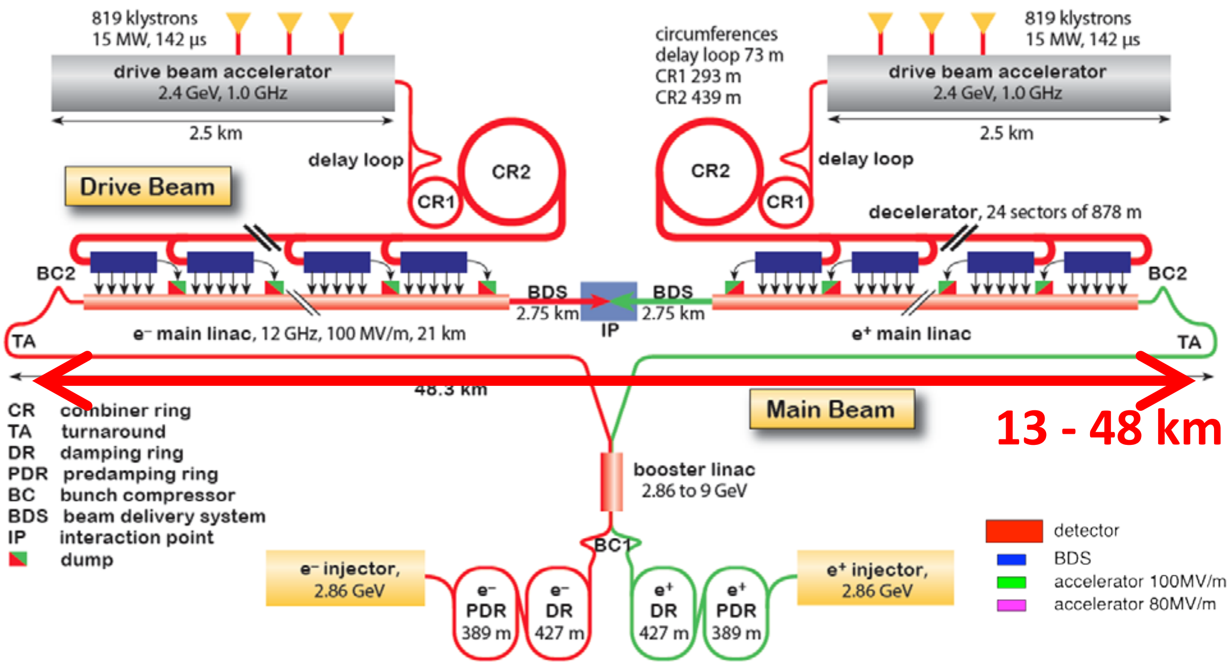
# Two *ILC* Candidate Sites in Japanese mountainous locations

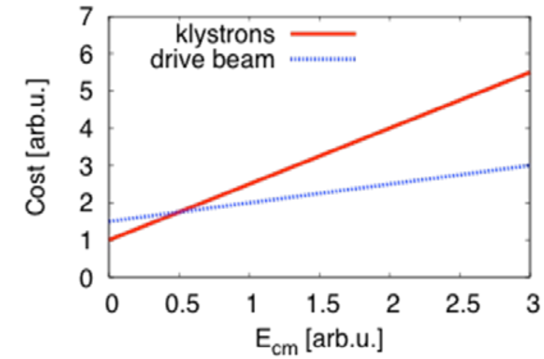


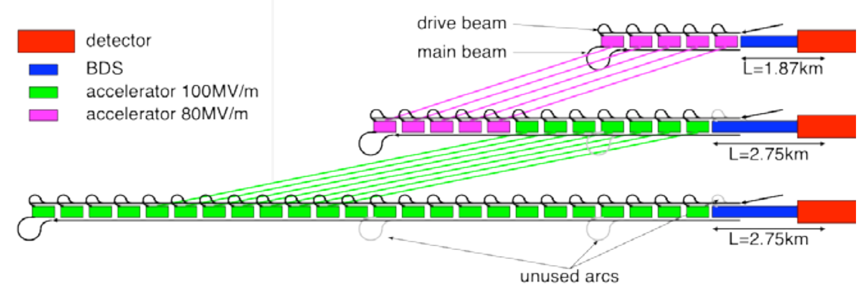




- GDE-CFS group visited two candidates sites, Oct. 14 and 15, 2011

# *CLIC* as Higgs factory



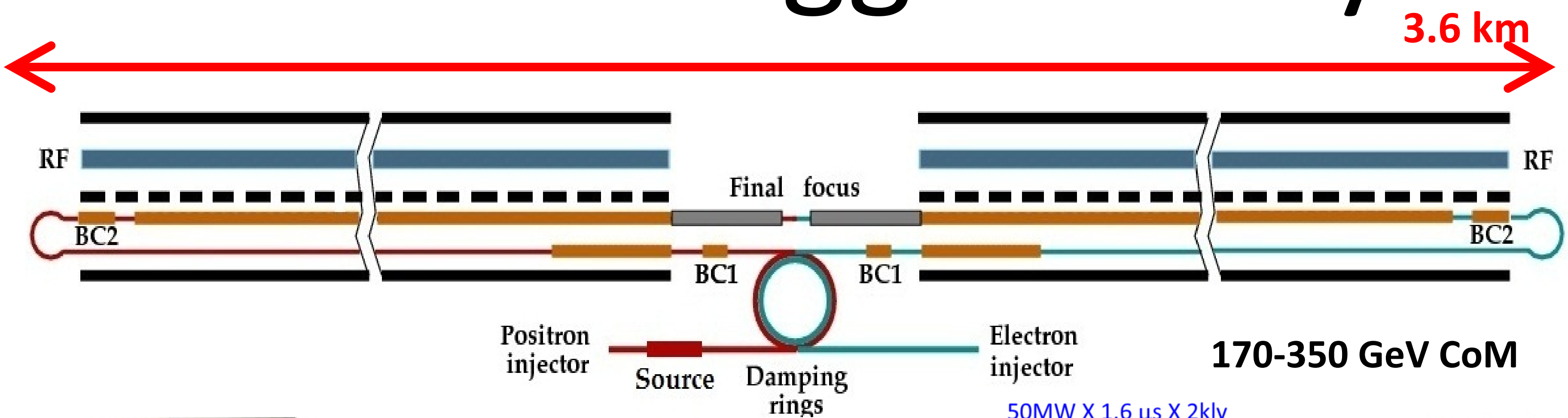




**CLIC Summary (Daniel Schulte, CERN)**

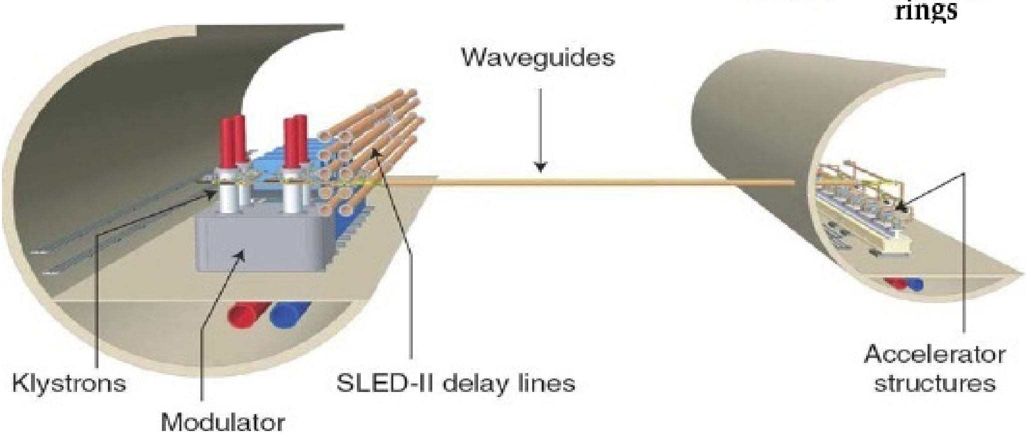
**The feasibility of the CLIC scheme has been established.**

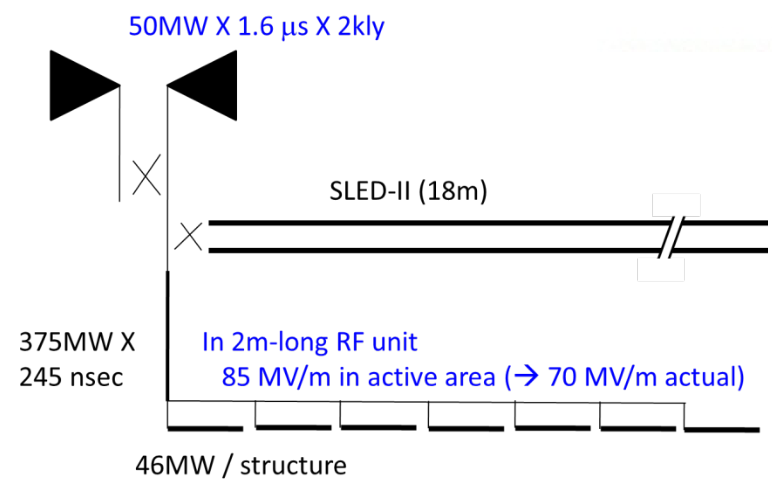
CLIC proposes a **staged approach to reach 3 TeV**: Stages with 500fb$^{-1}$ at 375-500GeV, 1500fb$^{-1}$ at 1-2TeV, 2000fb$^{-1}$ at 3 TeV; **$2.3\times10^{34}$ cm$^{-2}$ s$^{-1}$ at 500 GeV**. **First stage with klystrons** is being explored - promising alternative; Construction could start in 2022; commissioning in 2030.

# *X-band* Higgs factory




**170-350 GeV CoM**




- highly versatile Higgs factory
- first stage of operation ($\gamma\gamma \rightarrow \mathrm{H}$) fits on KEK site
- genuine test facility for CLIC

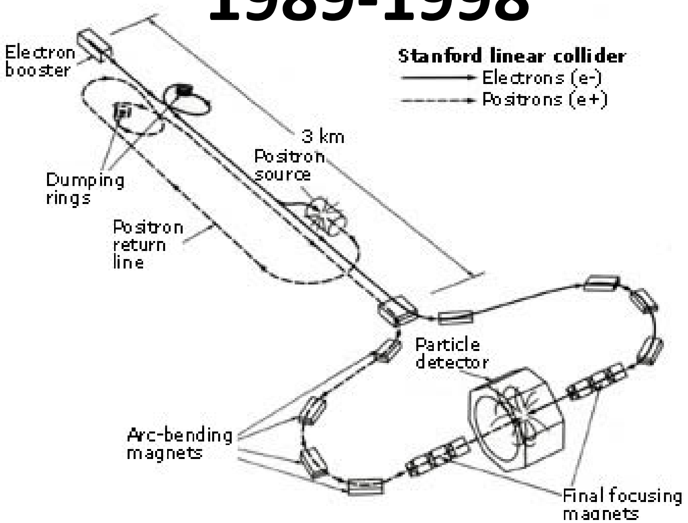
R. Belusevic & T. Higo, KEK

# **NCRF vs SCRF** (Tor Raubenheimer, SLAC)

- NCRF may be more cost effective than SCRF for a low energy (Higgs Factory) LC
- Topic may be re-examined if a project is formed but hard to make progress at this time

| | | | | |
|---|---|---|---|---|
| Costs (M$) | 0.5 TeV ILC | 596 rf units: 1 Mod, 1 Klys + 3 CM | 0.5 TeV NLC | 2232 rf units: 1 Mod, 2 Kly, 8 Accel |
| | | | | |
| Mods and Klys | 410 | 420 k$ Mod, 268k$ Kly+LLRF | 498 | 83 k$ Mod, 70 k$ Kly+LLRF |
| RF Dist (Klys - Accel) | 151 | 253 K$ per rf unit | 536 | 240 k$ per rf unit |
| Accel Structures | 1287 | 720 k$ per Tested CM | 379 | 170 k$ per rf unit |
| Water Cooling | 185 | 142 MW at 1.3 $/W | 261 | 201 MW at 1.3 $/W |
| Cryo Cooling | 225 | | 0 | |
| Electrical Dist | 170 | 142 MW at 1.2 $/W | 241 | 201 MW at 1.2 $/W |
| Tunnel | 672 | 2*22.4 km at 15 k$/m | 360 | 2*12 km at 15 k$/m |
| | | | | |
| Totals (w/o EDIA, Install, | 3100 | | 2275 | |
| Global Cntrls or Return Lines) | | | | |

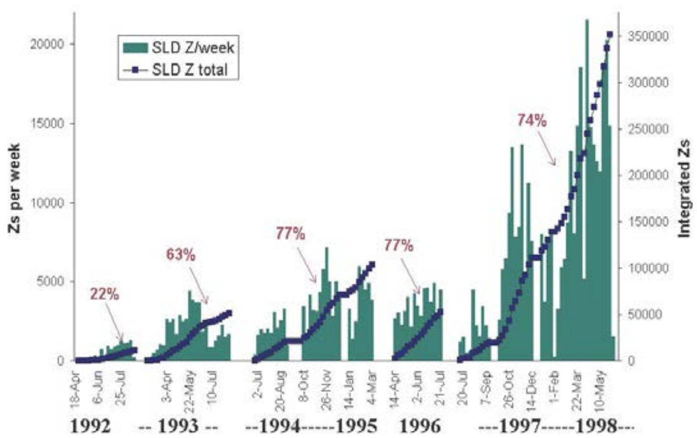
# LC experience: SLAC Linear Collider (SLC) 1989-1998

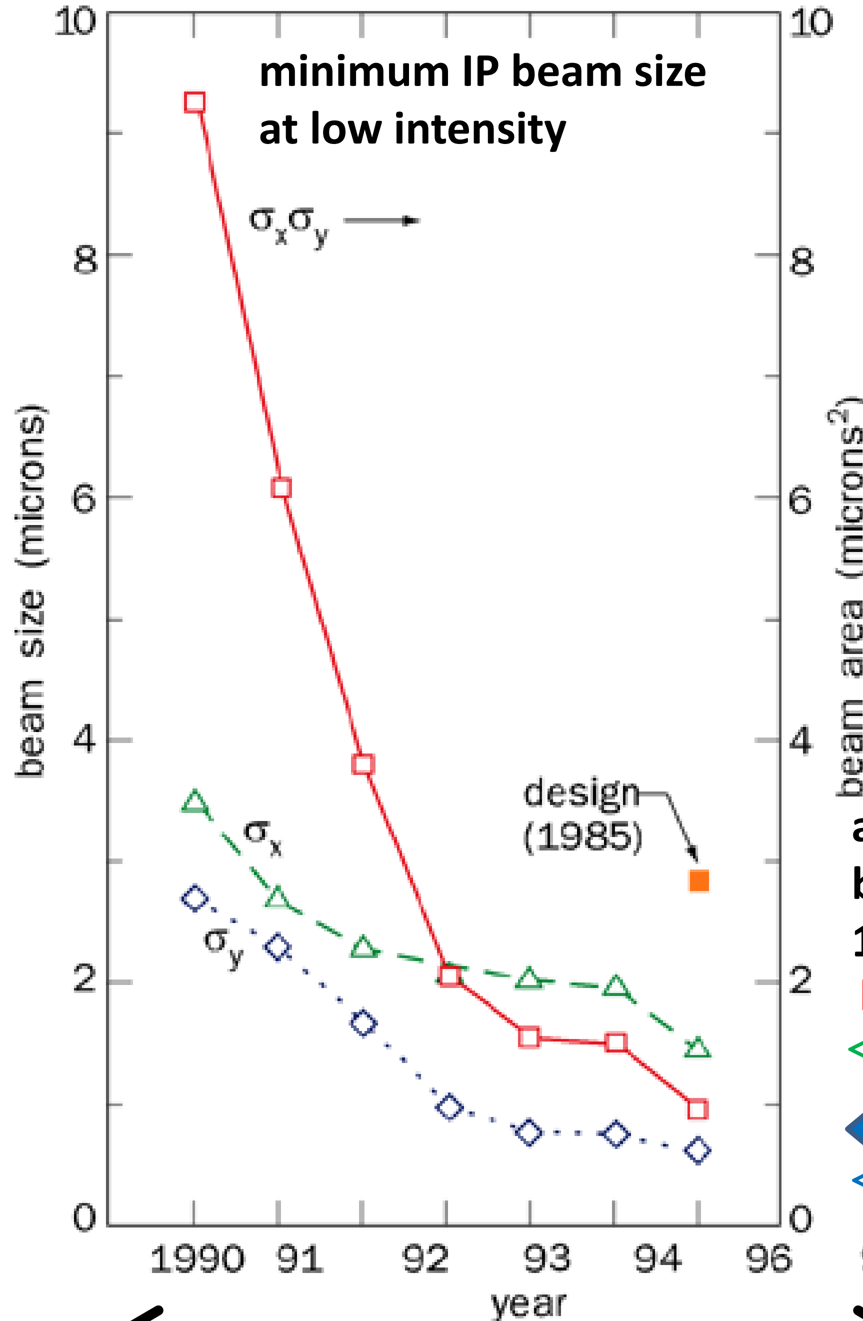



**after 10 years of operation:**

$\widehat{L}$=3x10$^{30}$ cm$^{-2}$s$^{-1}$ ~ ½ $L_{design}$

& <$L$> ~0.2 x $\widehat{L}$?




up to 77% $e^-$ polarization

**average IP beam size 1998**

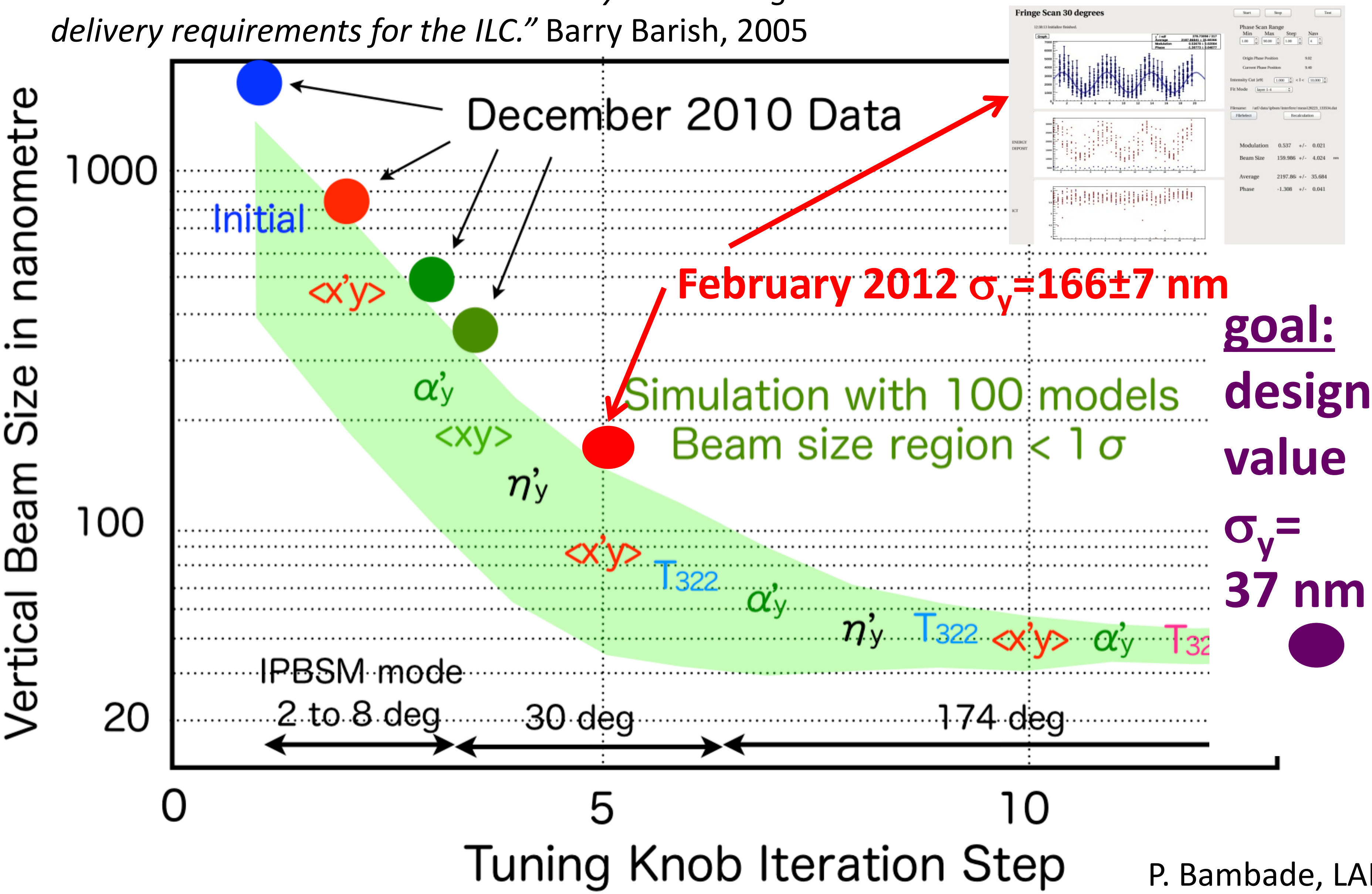
**<$\sigma_x$*>~1.8 μm**

**<$\sigma_y$*>~1 μm**

**10 years**

# LC experience: final-focus test facility KEK-ATF2 in operation since early 2009 - IP spot size tuning

*"…ATF2 will enable us to … test the very demanding beam delivery requirements for the ILC."* Barry Barish, 2005




P. Bambade, LAL

# *Circular Higgs Factories*

# circular HFs – a few examples


K. Oide, KEK

**SLAC/LBNL design: 27 km**

Y. Cai, SLAC


A. Blondel, J. Osborne, F. Zimmermann

**IHEP Chinese HF**
**+ Super pp Collider**


Q. Qin, IHEP


T. Sen, E. Gianfelice-Wendt, Y. Alexahin, FNAL

# LEP3, TLEP (LEP4)

($e^+e^-$ -> ZH, $e^+e^- \rightarrow W^+W^-$, $e^+e^- \rightarrow Z$,[$e^+e^- \rightarrow t\bar{t}$] )

## key parameters

| | LEP3 | TLEP (LEP4) |
|---|---|---|
| circumference | 26.7 km | 80 km |
| max beam energy | 120 GeV | 175 GeV |
| max no. of IPs | 4 | 4 |
| luminosity at 350 GeV c.m. | - | $0.7\times10^{34}$ cm$^{-2}$s$^{-1}$ |
| luminosity at 240 GeV c.m. | $10^{34}$ cm$^{-2}$s$^{-1}$ | $5\times10^{34}$ cm$^{-2}$s$^{-1}$ |
| luminosity at 160 GeV c.m. | $5\times10^{34}$ cm$^{-2}$s$^{-1}$ | $2.5\times10^{35}$ cm$^{-2}$s$^{-1}$ |
| luminosity at 90 GeV c.m. | $2\times10^{35}$ cm$^{-2}$s$^{-1}$ | $10^{36}$ cm$^{-2}$s$^{-1}$ |

at the *Z* pole repeating LEP physics programme in a few minutes…

# circular HFs – beam lifetime

LEP2:

- beam lifetime ~ 6 h
- dominated by radiative Bhahba scattering with cross section $\sigma$~0.215 barn

(H. Burkhardt)

LEP3:

- with $L$~$10^{34}$ $cm^{-2}s^{-1}$ at each of several IPs:

  **$\tau_{beam,LEP3}$~18 minutes from rad. Bhabha scattering**

  **→ solution: top-up injection** (A. Blondel)

- **additional beam lifetime limit due to beamstrahlung:**

  (1) large momentum acceptance ($\eta \geq 3\%$), and/or

  (2) flat(ter) beams and/or

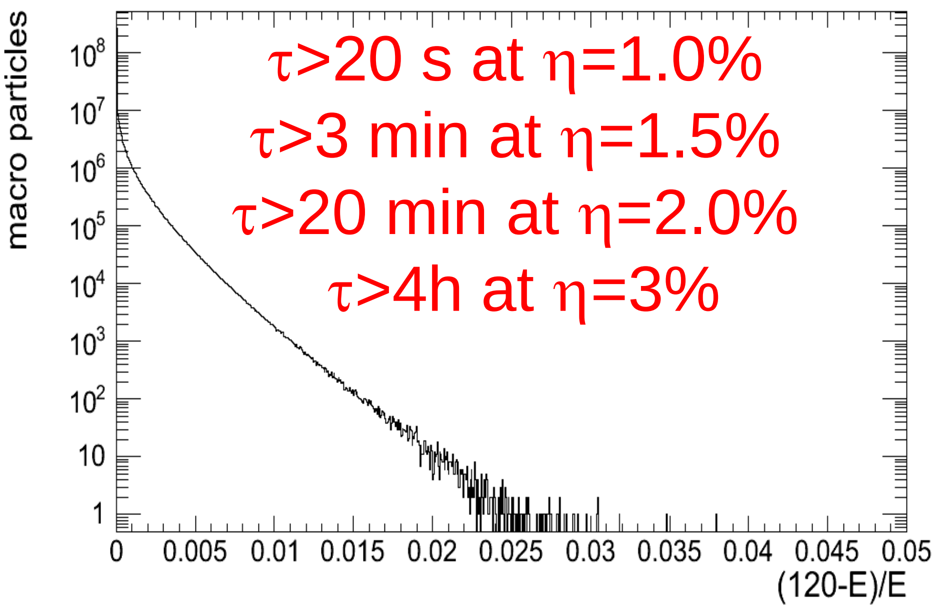
  (3) fast replenishing

(V. Telnov, K. Yokoya, M. Zanetti)

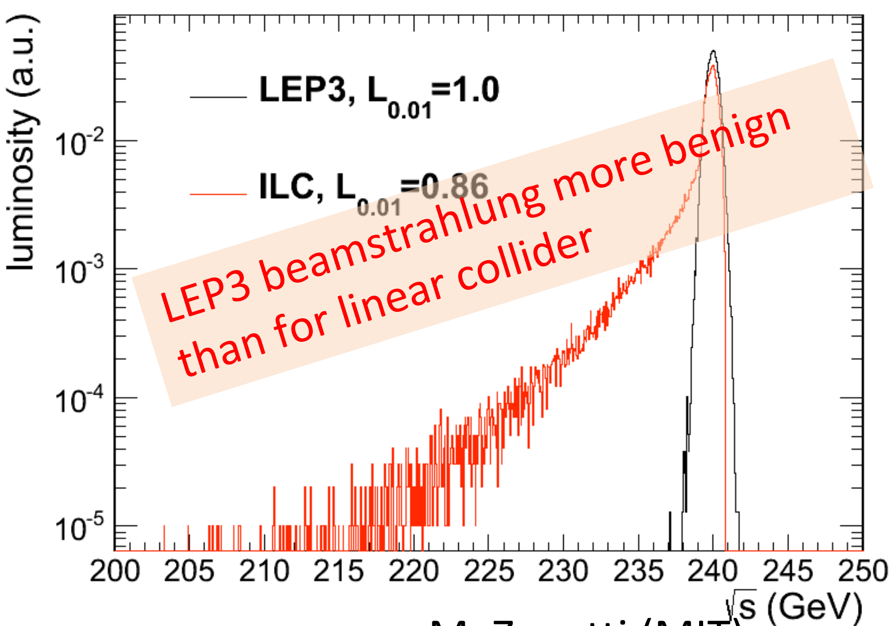
# circular HFs – beamstrahlung

- simulation w 360M macroparticles
- τ varies exponentially w energy acceptance η

TLEP at 240 GeV:
post-collision *E* tail → lifetime τ

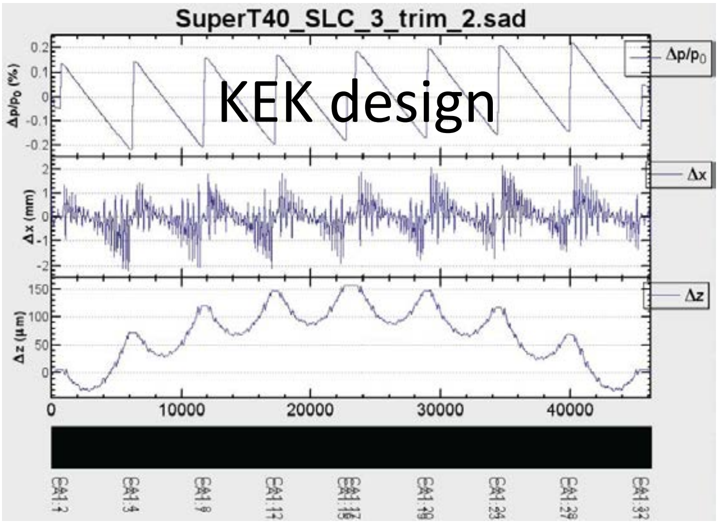



LEP3 & ILC:
luminosity *E* spectrum

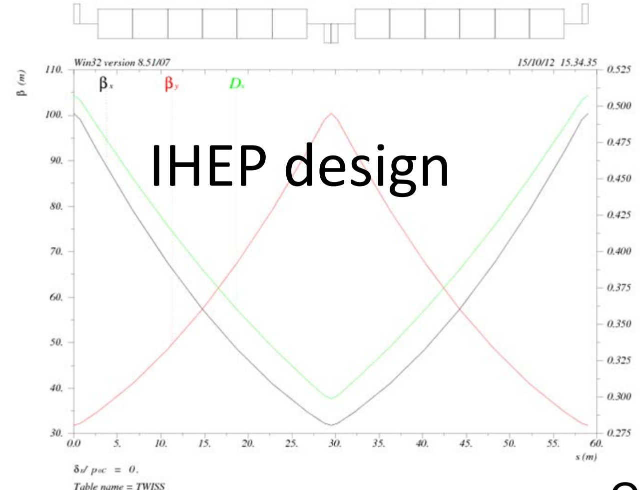



M. Zanetti (MIT)

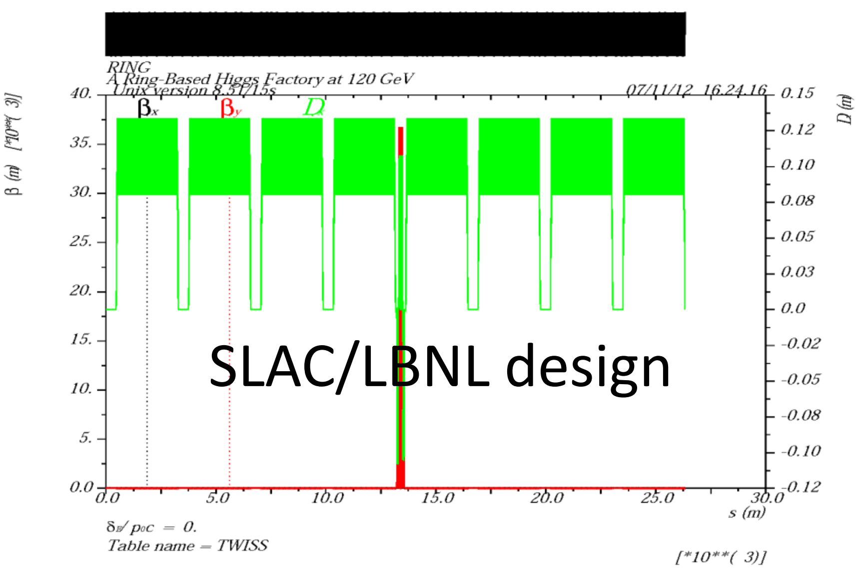
# circular HFs – arc lattice



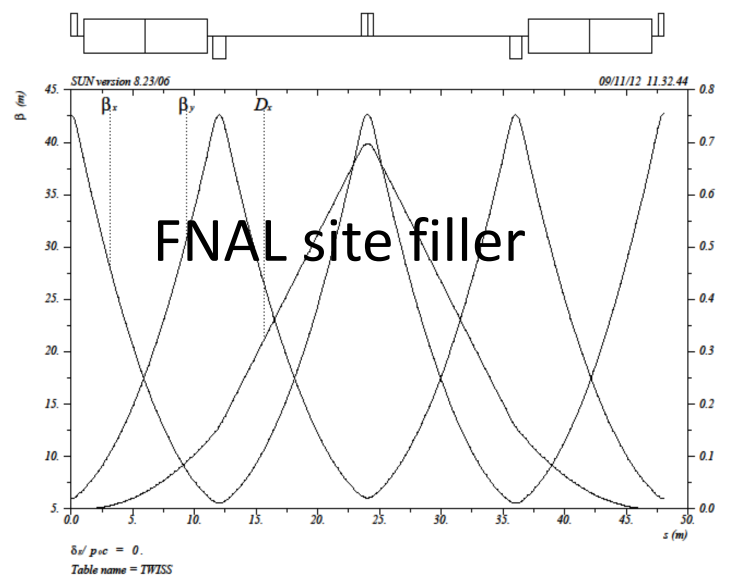

K. Oide




Q. Qin

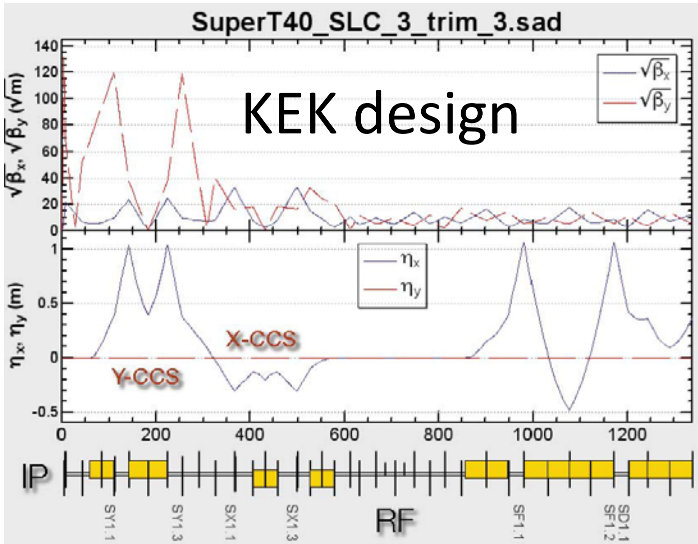



Y. Cai

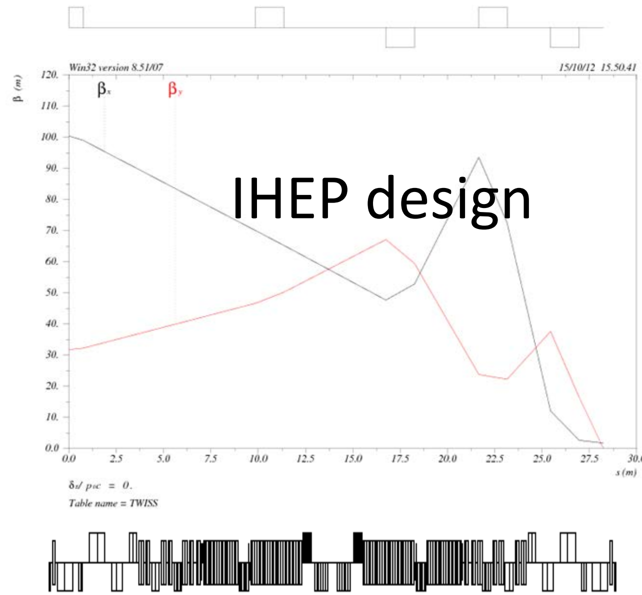



T. Sen, E. Gianfelice-Wendt, Y. Alexahin

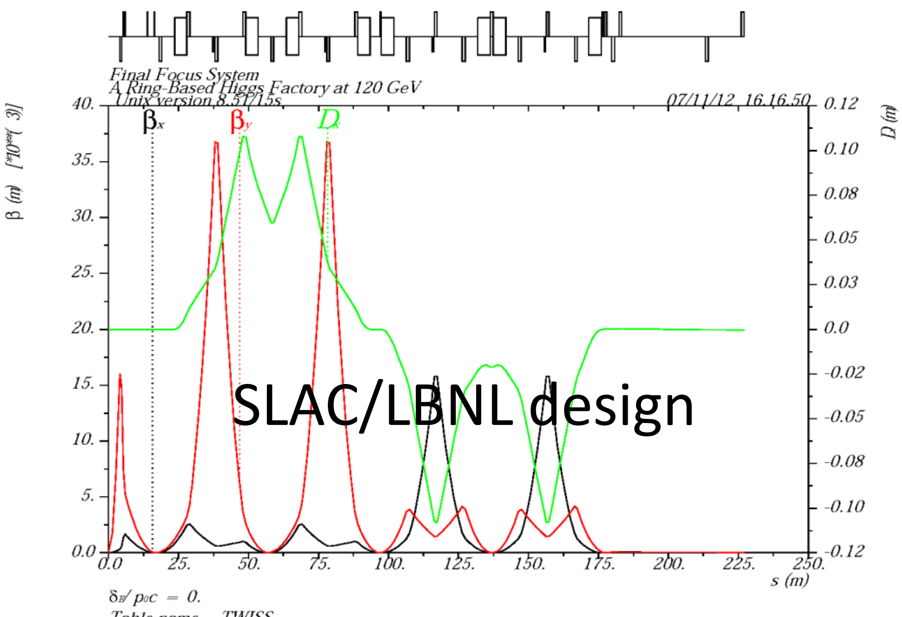
# circular HFs – final-focus design



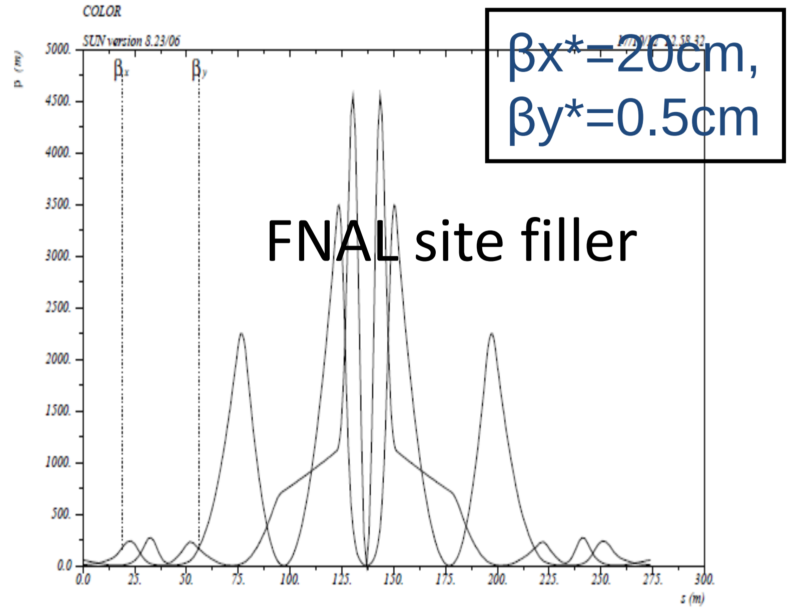

K. Oide




Q. Qin

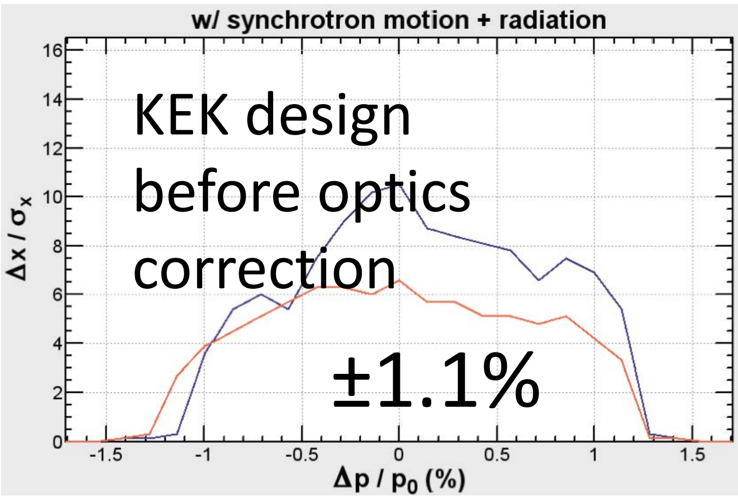



Y. Cai

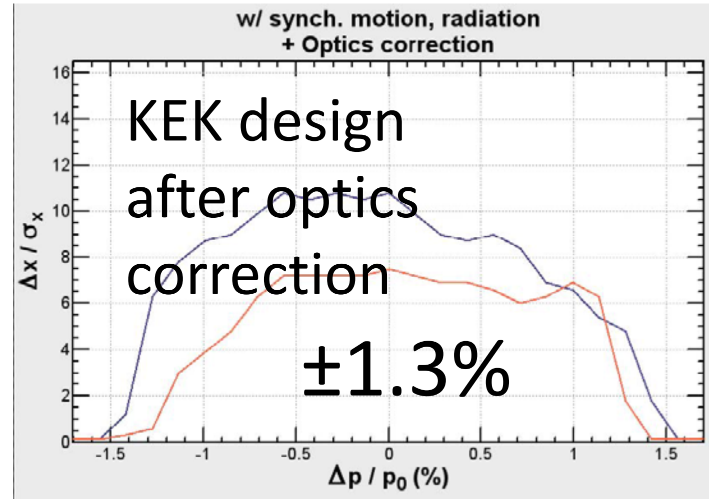



T. Sen, E. Gianfelice-Wendt, Y. Alexahin

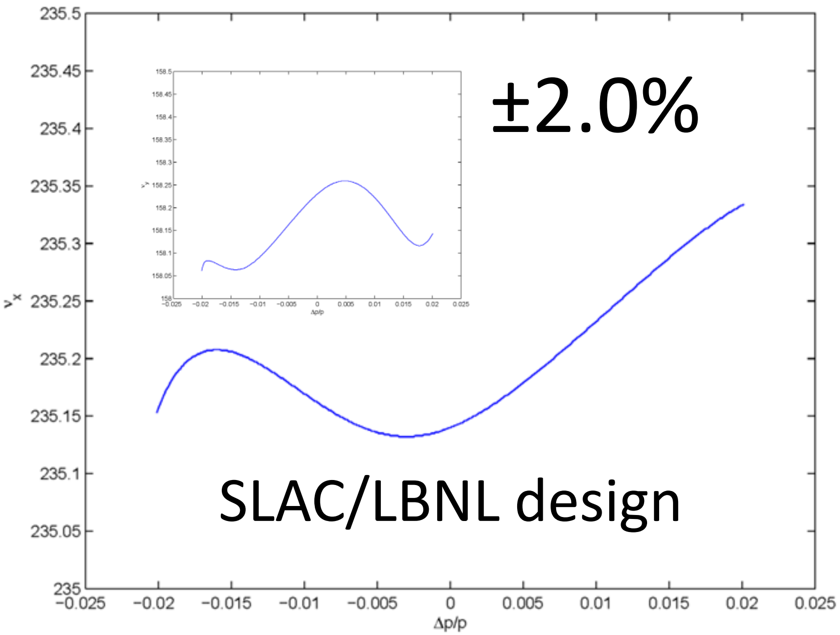
# circular HFs - momentum acceptance

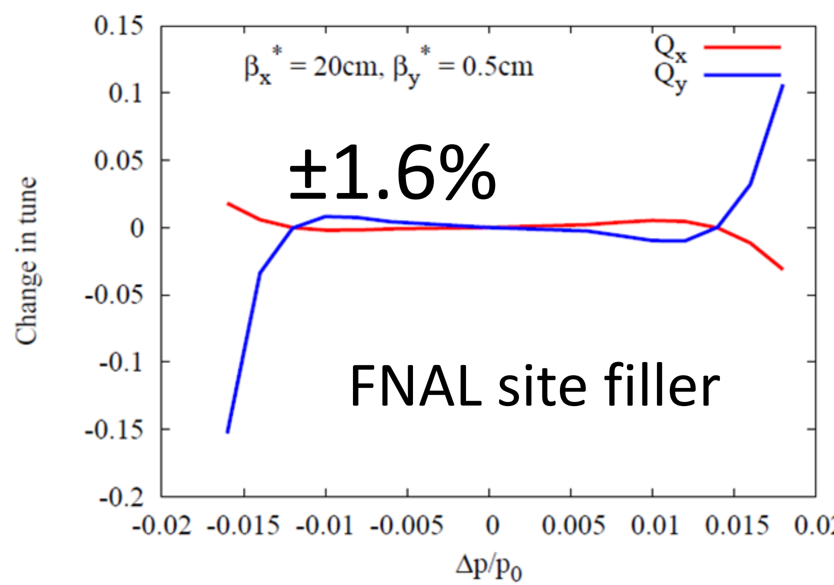



with
synchrotron
motion &
radiation
(sawtooth)




K. Oide



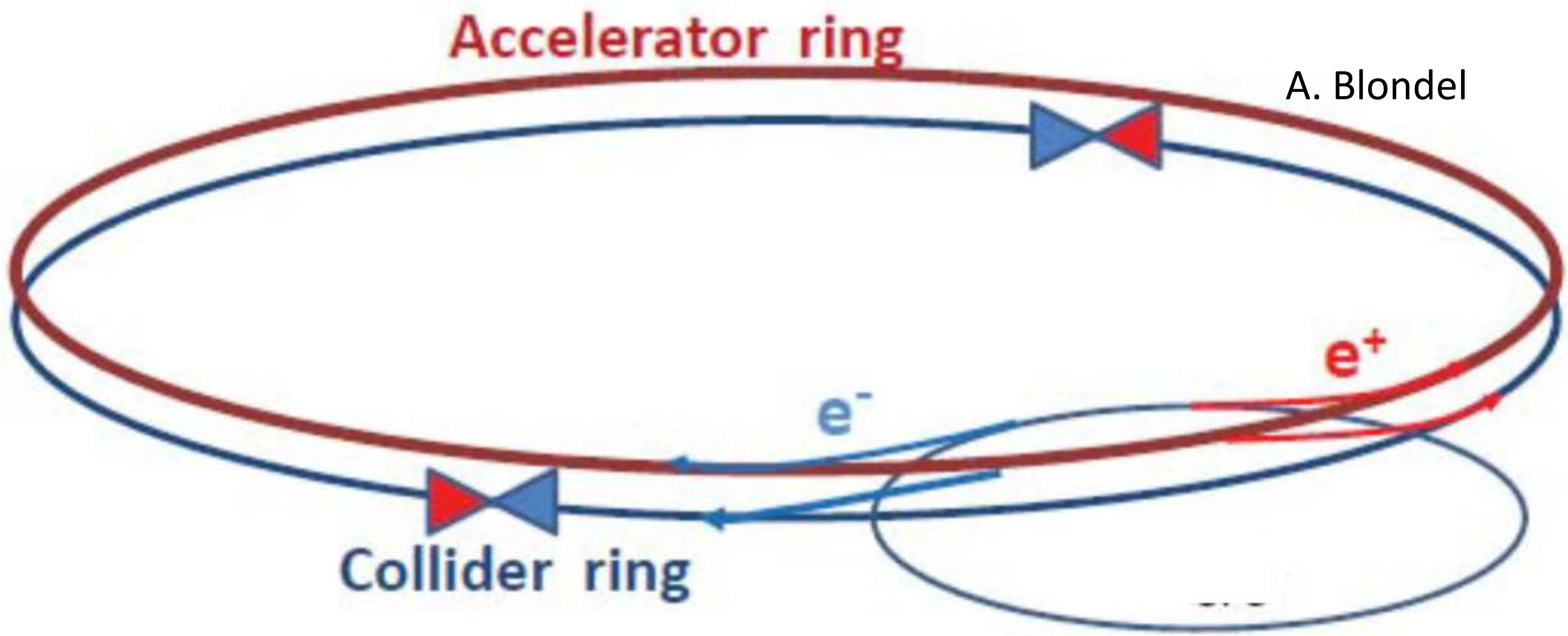

Y. Cai

T. Sen, E. Gianfelice-Wendt, Y. Alexahin

# circular HFs – top-up injection

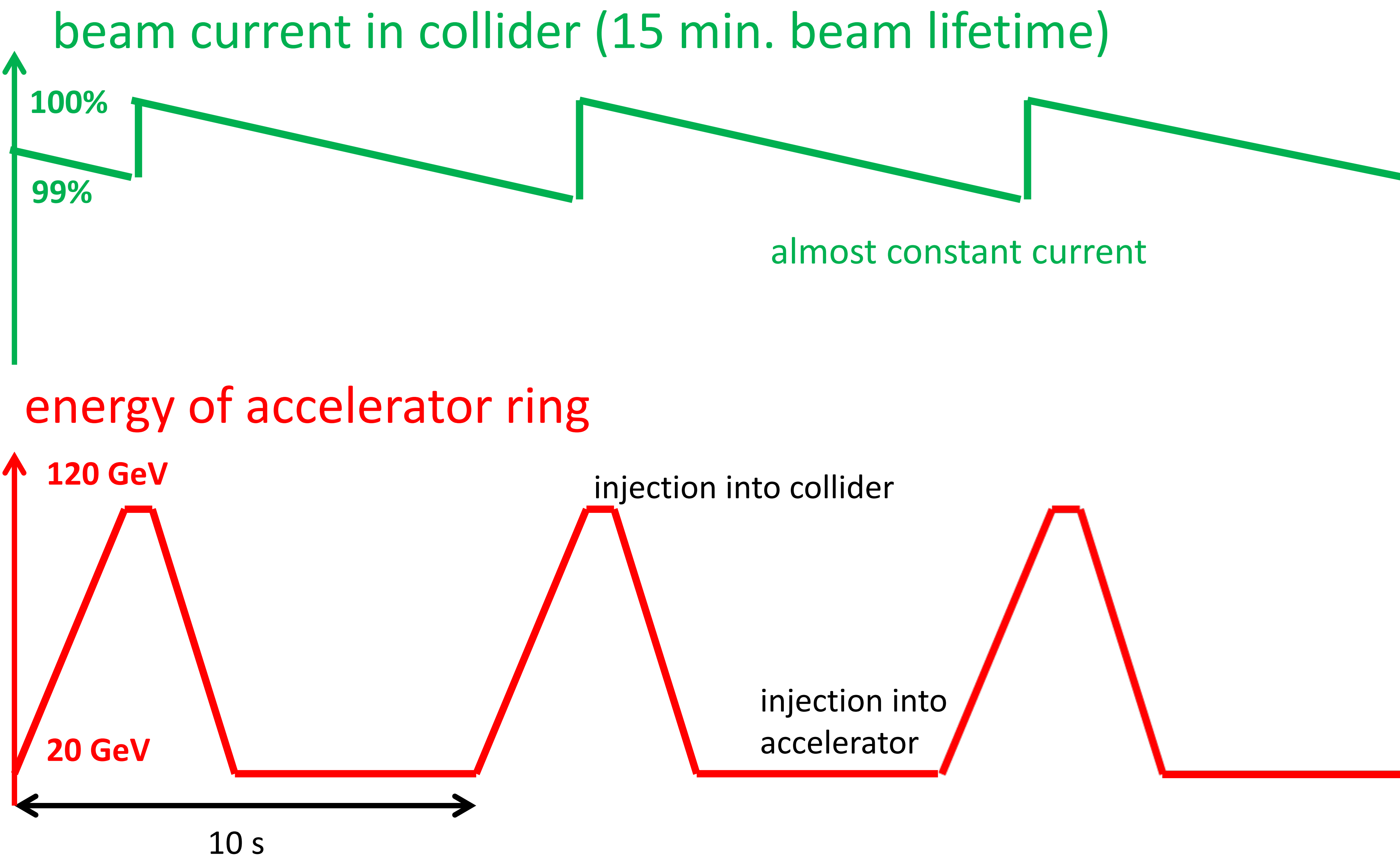
**double ring with top-up injection**

supports short lifetime & high luminosity

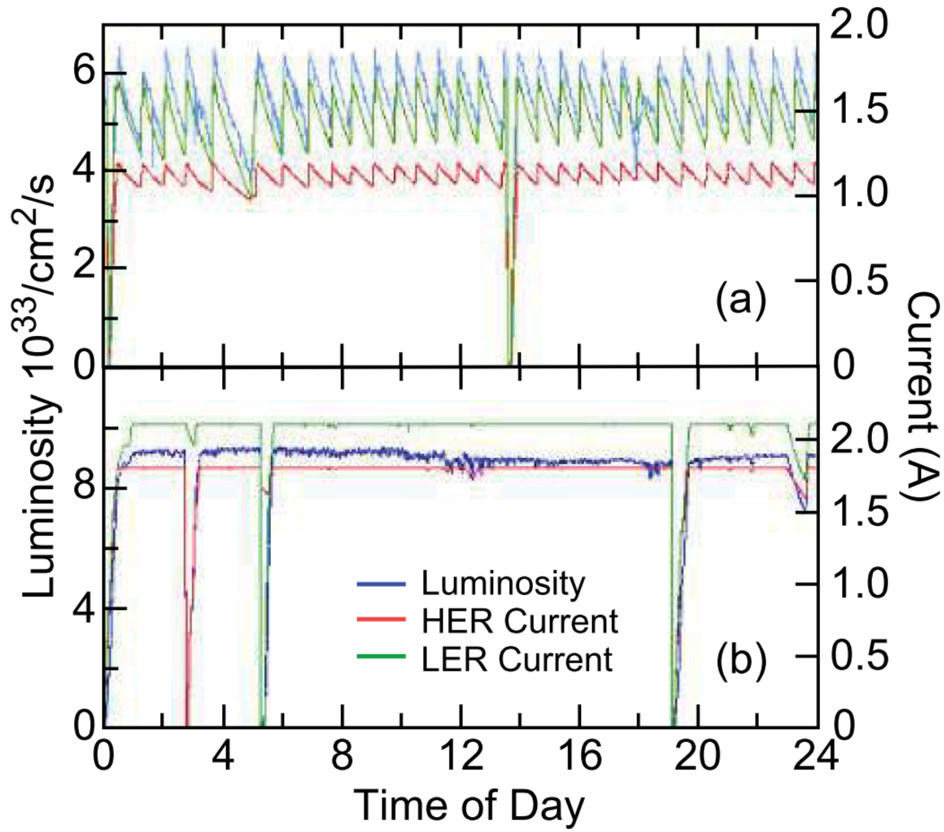



top-up experience: PEP-II, KEKB, light sources

# top-up injection: schematic cycle



# top-up injection at PEP-II/BaBar




Before Top-Up Injection

After Top-Up Injection

average ≈ peak luminosity ($H$≈1)!

J. Seeman

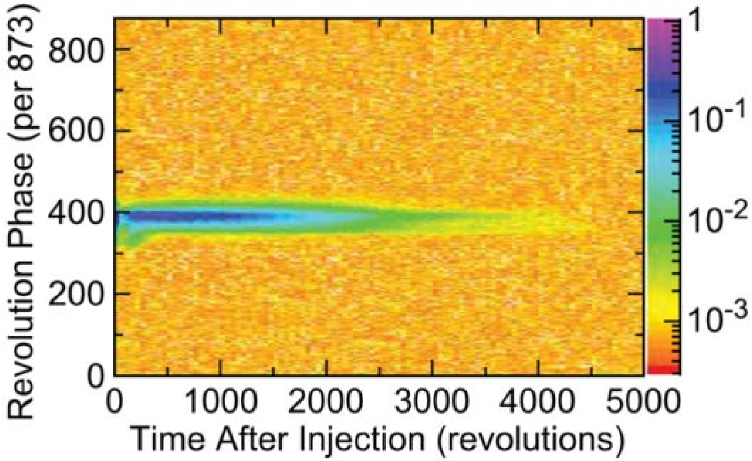
PEP-II: Luminosity and beam currents for a 24-hour period (a) before and (b) after the implementation of trickle injection.

# top-up injection: feasibility

**HF 2012 conclusions (John Seeman, SLAC):**

- Top-up injection will work for a Circular Higgs Factory.
- A full energy injector is needed.
- A synchrotron injector will work the best, but is more than is needed (60 Hz!).
- A rapidly ramped storage ring is likely adequate (4 sec).
- The detectors will need to mask out the buckets with damping injected bunches during data taking as had been done for PEP-II/BaBar:

<u>BaBar trigger masking:</u>
Mask all of ring a few tens of turns.
Mask injected bunch area for 1250 turns or about 0.9 msec.



# Circular Collider & SR Experience

...

**CESR**

BEPC

**LEP**

Tevatron

**LEP2**

HERA

DAFNE

**PEP-II**

**KEKB**

**BEPC-II**

**LHC**

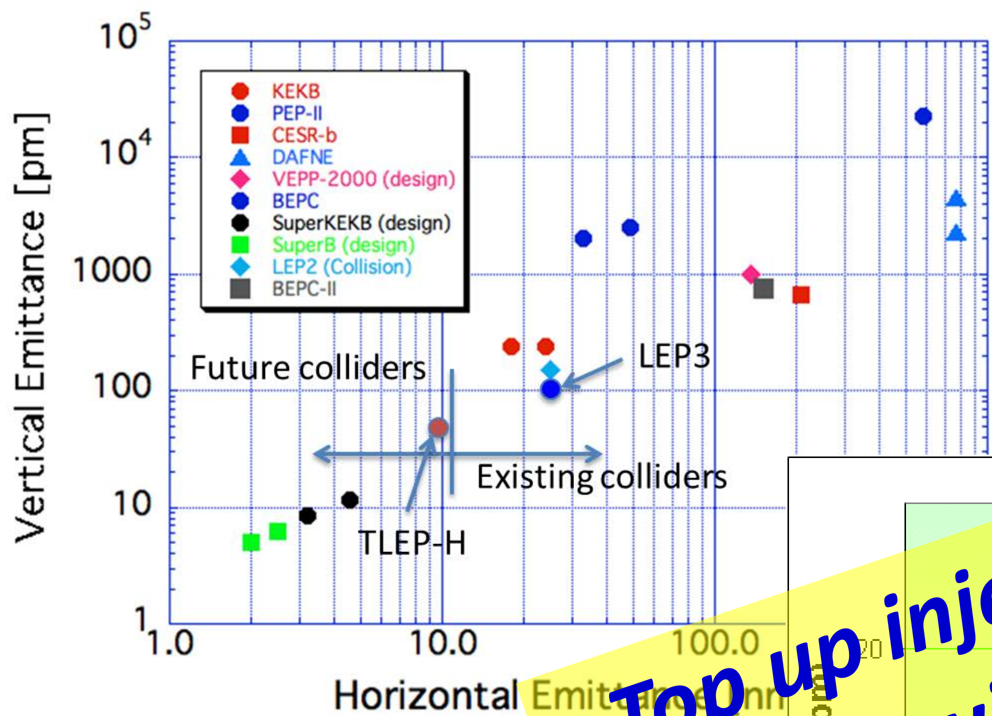
SuperKEKB (soon)

3rd generation light sources

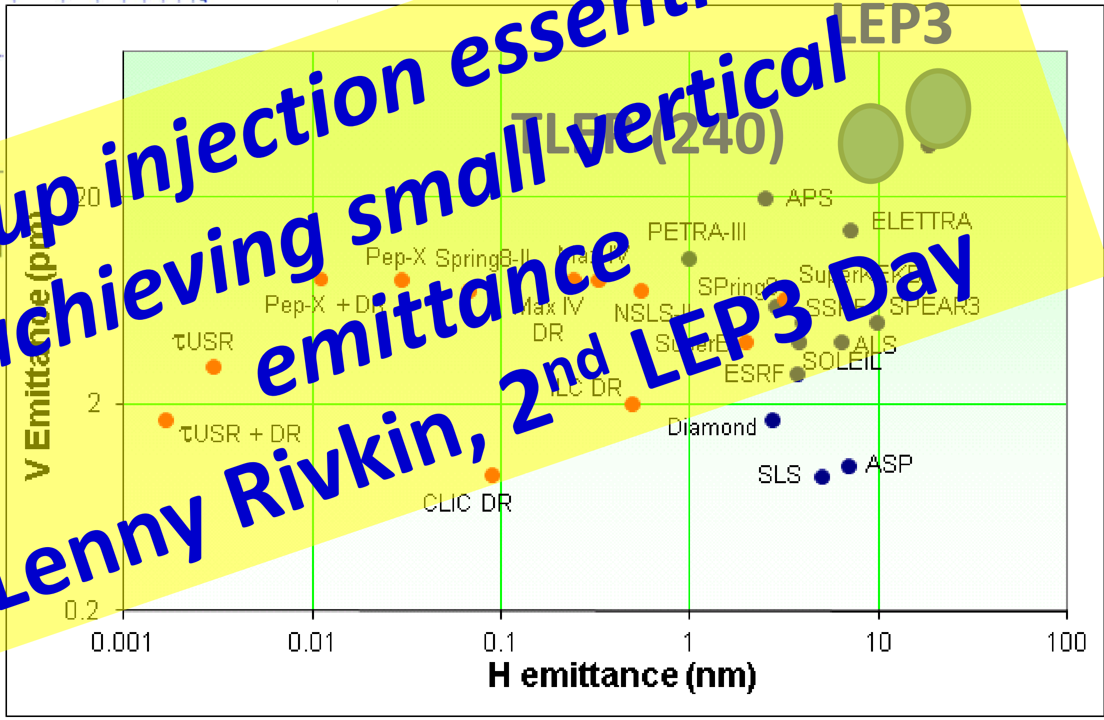
| | | |
|---|---|---|
| **1992** | **ESRF**, France (EU) | 6 GeV |
| | **ALS**, US | 1.5-1.9 GeV |
| **1993** | **TLS**, Taiwan | 1.5 GeV |
| **1994** | **ELETTRA**, Italy | 2.4 GeV |
| | **PLS**, Korea | 2 GeV |
| | **MAX II**, Sweden | 1.5 GeV |
| **1996** | **APS**, US | 7 GeV |
| | **LNLS**, Brazil | 1.35 GeV |
| **1997** | **Spring-8**, Japan | 8 GeV |
| **1998** | **BESSY II**, Germany | 1.9 GeV |
| **2000** | **ANKA**, Germany | 2.5 GeV |
| | **SLS**, Switzerland | 2.4 GeV |
| **2004** | **SPEAR3**, US | 3 GeV |
| | **CLS**, Canada | 2.9 GeV |
| **2006**: | **SOLEIL**, France | 2.8 GeV |
| | **DIAMOND,** UK | 3 GeV |
| | **ASP**, Australia | 3 GeV |
| | **MAX III**, Sweden | 700 MeV |
| | **Indus-II**, India | 2.5 GeV |
| **2008** | **SSRF**, China | 3.4 GeV |
| **2009** | **PETRA-III**, Germany | 6 GeV |
| **2011** | **ALBA**, Spain | 3 GeV |

**well understood technology &**
**typically exceeding design performance**
**within a few years**

# Emittances in Circular Colliders & Modern Light Sources




Y. Funakoshi, KEK




R. Bartolini, DIAMOND

**Top up injection essential for achieving small vertical emittance**

**Lenny Rivkin, 2nd LEP3 Day**

# circular HFs: synchroton-radiation heat load

| | PEPII | SPEAR3 | LEP3 | TLEP-Z | TLEP-H | TLEP-t |
|---|---|---|---|---|---|---|
| **E (GeV)** | 9 | 3 | 120 | 45.5 | 120 | 175 |
| **I (A)** | 3 | 0.5 | 0.0072 | 1.18 | 0.0243 | 0.0054 |
| **rho (m)** | 165 | 7.86 | 2625 | 9000 | 9000 | 9000 |
| **Linear Power (W/cm)** | 101.8 | 92.3 | 30.5 | 8.8 | 8.8 | 8.8 |

LEP3 and TLEP have 3-10 times less SR heat load per meter than PEP-II or SPEAR! (though higher photon energy)

N. Kurita, U. Wienands, SLAC

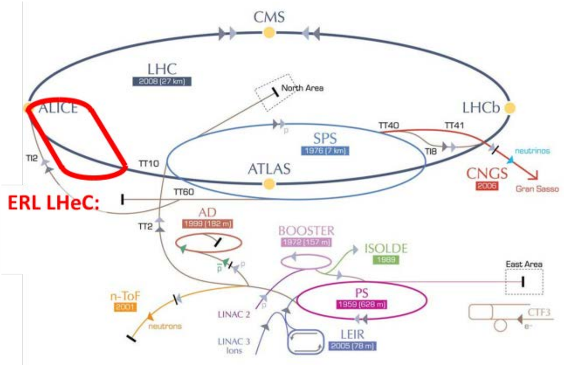
# circular Higgs Factories - R&D items

- choice of RF frequency: 1.3 GHz (ILC) or 700 MHz (ESS)? & RF coupler
- SR handling and radiation shielding (LEP experience)
- beam-beam interaction for large $Q_s$ and significant hourglass effect
- IR design with even larger momentum acceptance
- integration in LHC tunnel (LEP3)
- Pretzel scheme for TERA-Z operation

# LHeC Higgs Factory

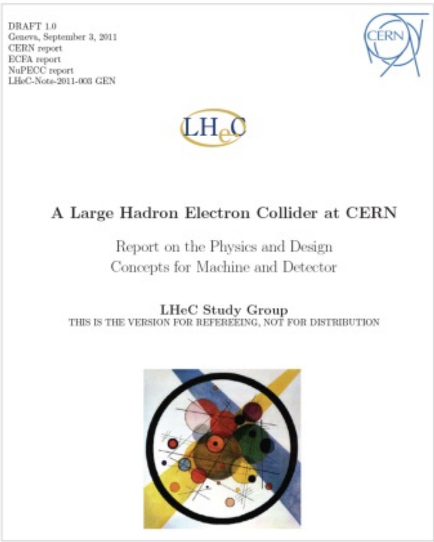
# Large Hadron electron Collider (LHeC) HF

two 10-GeV SC linacs, ERL with 3 passes up, 3 passes down; 6.4 mA $e^-$ current, 60 GeV $e^-$'s collide w. LHC protons/ions, $L$~$10^{33}$-$10^{34}$ cm$^{-2}$s$^{-1}$




- precision coupling measurements ($Hb\bar{b}$, $H\gamma\gamma$, $H4l$,...)
- reduction of theoretical QCD-related uncertainties in *pp* Higgs physics
- potential to find new physics at the cleanly accessible *WWH* (and *ZZH*)

**LHeC CDR published in J. Phys. G: Nucl. Part. Phys. 39 075001 (2012)**

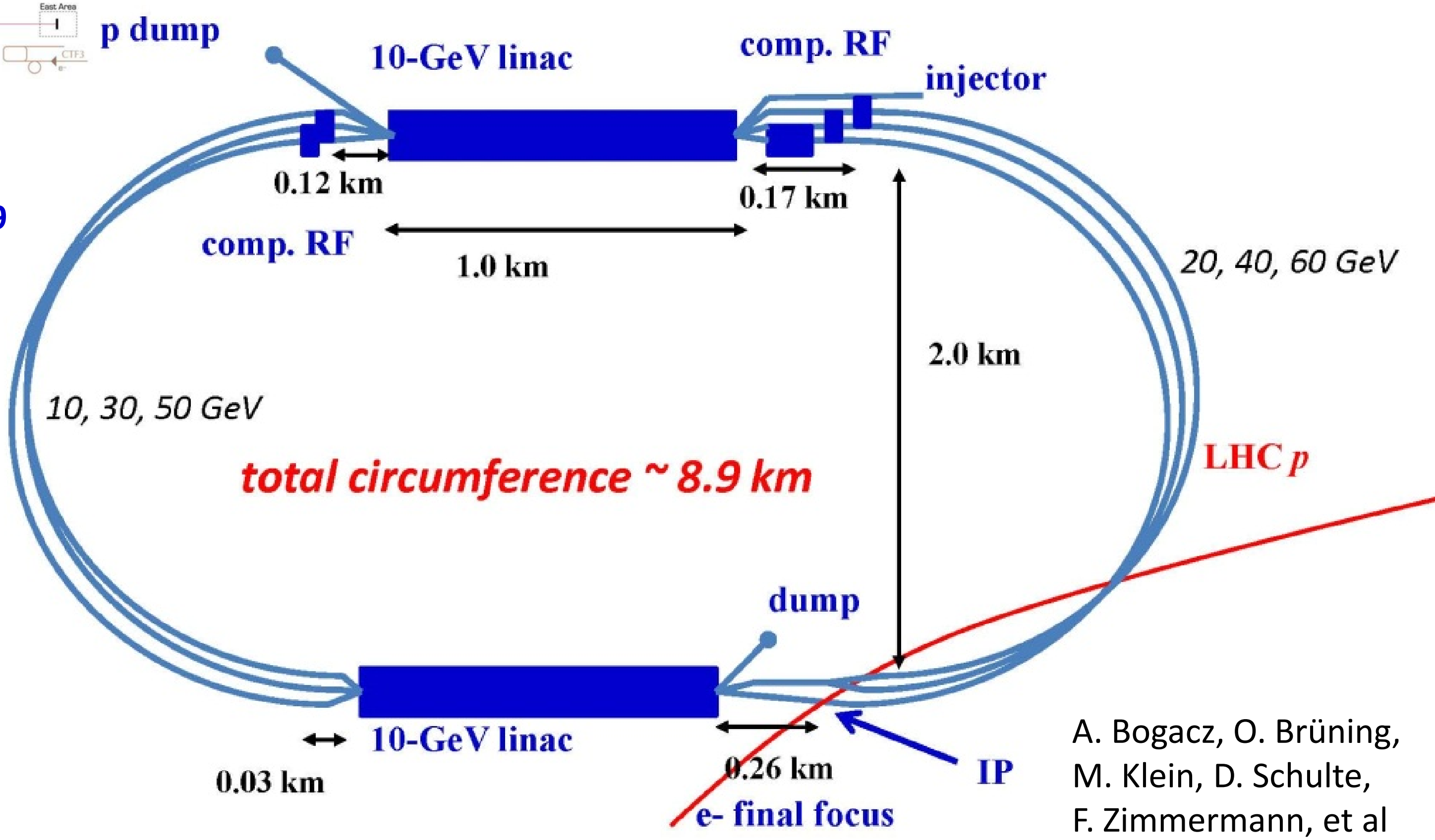

DRAFT 1.0
Geneva, September 3, 2011
CERN report
ECFA report
NuPECC report
LHeC-Note-2011-003 GEN

LHeC

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group
THIS IS THE VERSION FOR REFEREEING, NOT FOR DISTRIBUTION

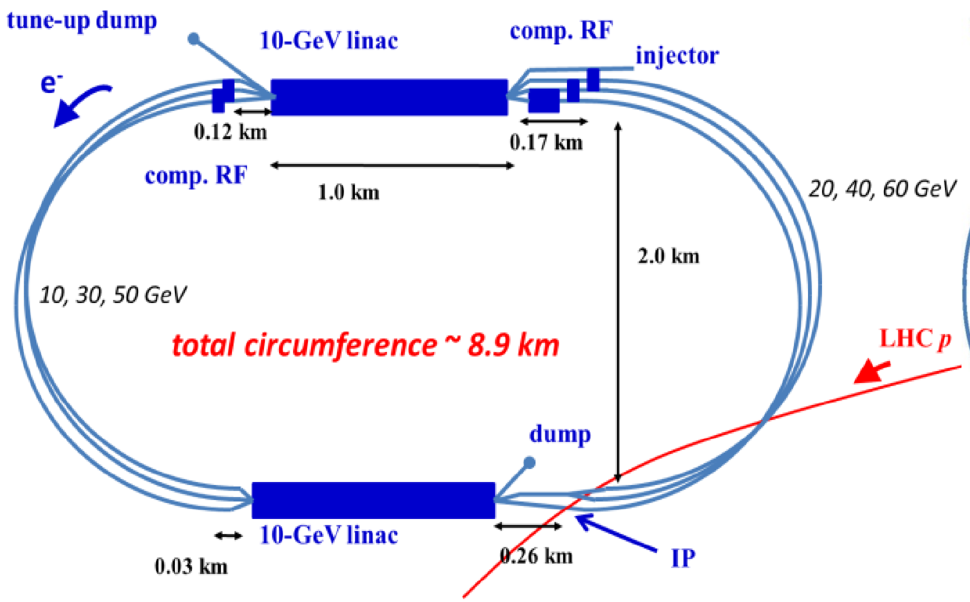



A. Bogacz, O. Brüning, M. Klein, D. Schulte, F. Zimmermann, et al

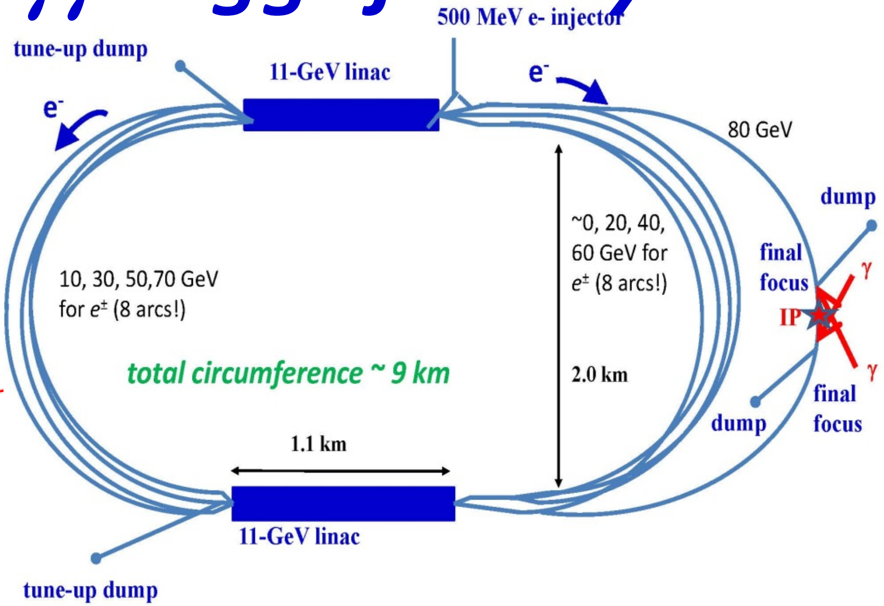
# $\gamma\gamma$ Higgs Factories

# Reconfiguring *LHeC* → *SAPPHiRE*

## *LHeC-ERL*



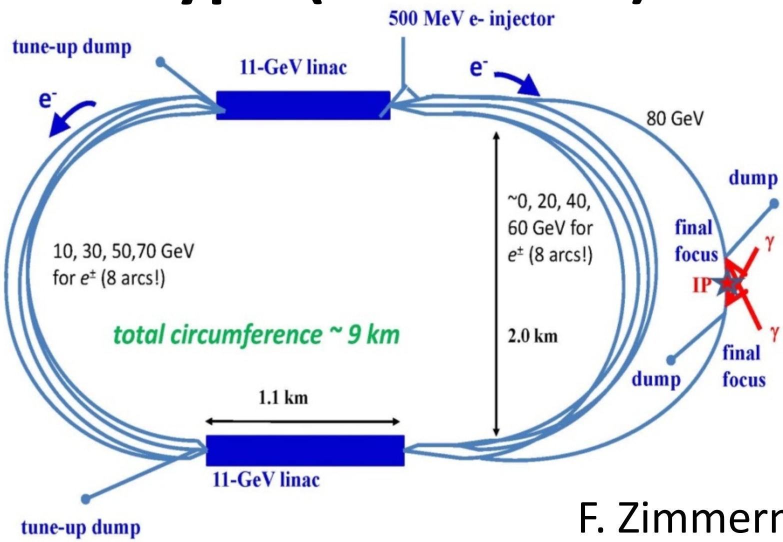

## *SAPPHiRE** *γγ Higgs factory*




*Small Accelerator for Photon-Photon Higgs production using Recirculating Electrons

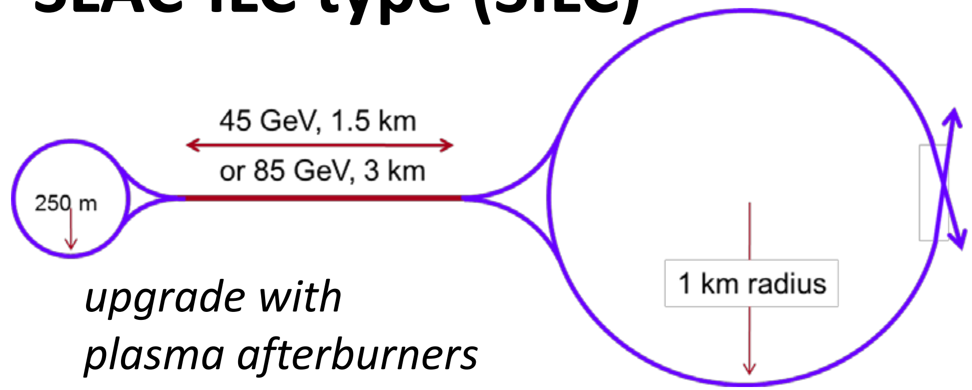
# γγ HFs – additional examples

## LHeC type (SAPPHiRE)



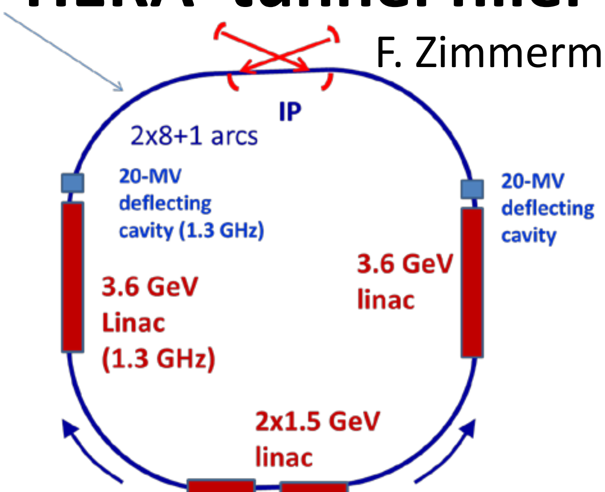

F. Zimmermann

## SLAC-ILC type (SILC)

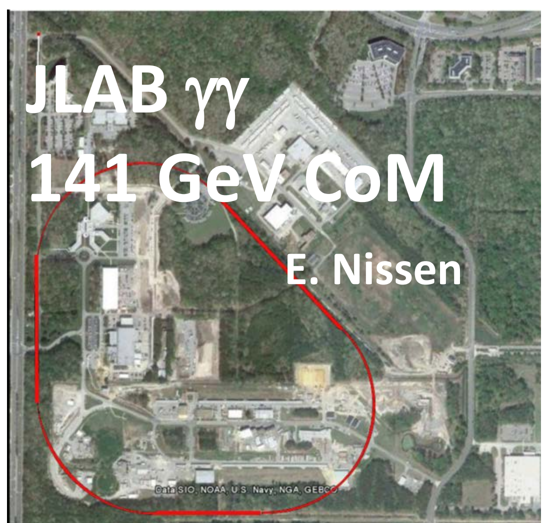



T. Raubenheimer, SLAC

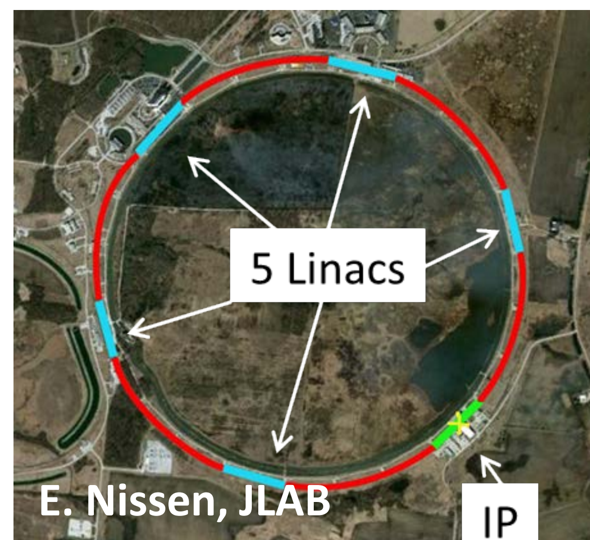
## HERA tunnel filler




F. Zimmermann




## Tevatron tunnel filler



# $\gamma\gamma$ Higgs Factories - R&D items

- $\gamma\gamma$ interaction region
- large high-finesse optical cavity
- high repetition rate laser
- and/or FEL in unusual regime
- separation scheme for beams circulating in opposite directions
- polarized low-emittance $e^-$ gun
- detector

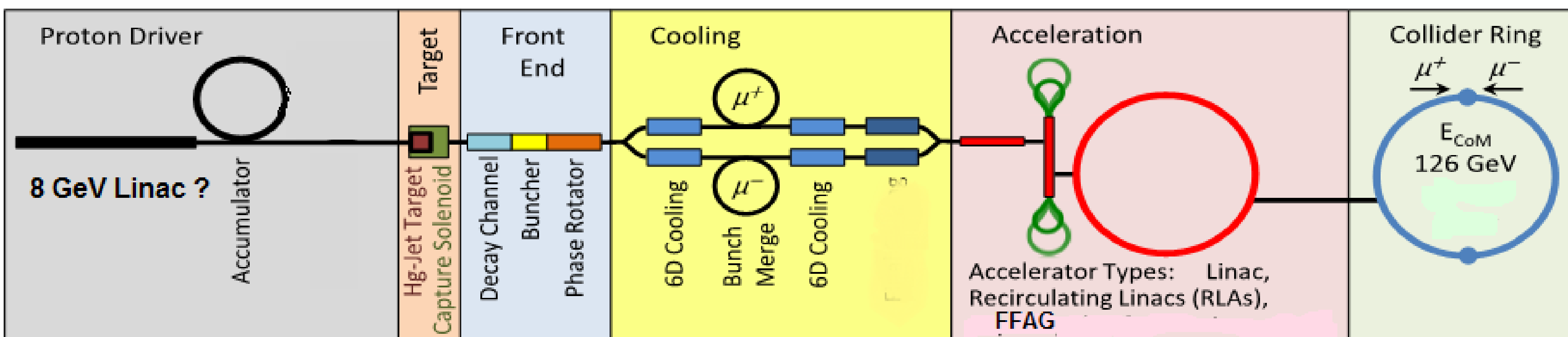
# *$\mu$ Collider Higgs Factory*

# μ collider HF

D. Neuffer, FNAL

- **8 GeV, 4MW *p* source (Project-X upgrade)**
  - 15 Hz, 4 bunches $5\times10^{13}$/bunch
- **π→μ collection, bunching, cooling**
  - $\varepsilon_{\perp,N}$ =400 π mm-mrad, $\varepsilon_{\parallel,N}$= 2 π mm, $10^{12}$ μ/ bunch
- **Accelerate, Collider ring**
  - δE = 4 MeV, C=300m
  - for energy measurement, $\delta E_{error}$ → 0.1 MeV

| Parameter | Symbol | Value |
|---|---|---|
| Collision Beam Energy | $E_{\mu+}, E_{\mu-}$ | 63GeV |
| Luminosity | $L_0$ | $10^{31}$ |
| Number of μ bunches | $n_B$ | 1 |
| $\mu^{+/-}$/ bunch | $N_\mu$ | $10^{12}$ |
| Transverse emittance | $\varepsilon_{t,N}$ | 0.0004m |
| Longitudinal emittance | $\varepsilon_{LN}$ | 0.002m |
| Energy spread | δE | 4MeV |
| Collision β* | β* | 0.05 m |
| Beam size at collision | $\sigma_{x,y}$ | 0.02cm |
| Beam size (arcs) | $\sigma_{x,y}$ | 1.0cm |
| Beam size IR quad | $\sigma_{max}$ | 5.4cm |
| Storage turns | $N_t$ | 1000 |
| Proton Beam Power | $P_p$ | 4 MW |
| Bunch frequency | $F_p$ | 60 Hz |
| Protons per bunch | $N_p$ | $5\times10^{13}$ |
| Proton beam energy | $E_p$ | 8 GeV |

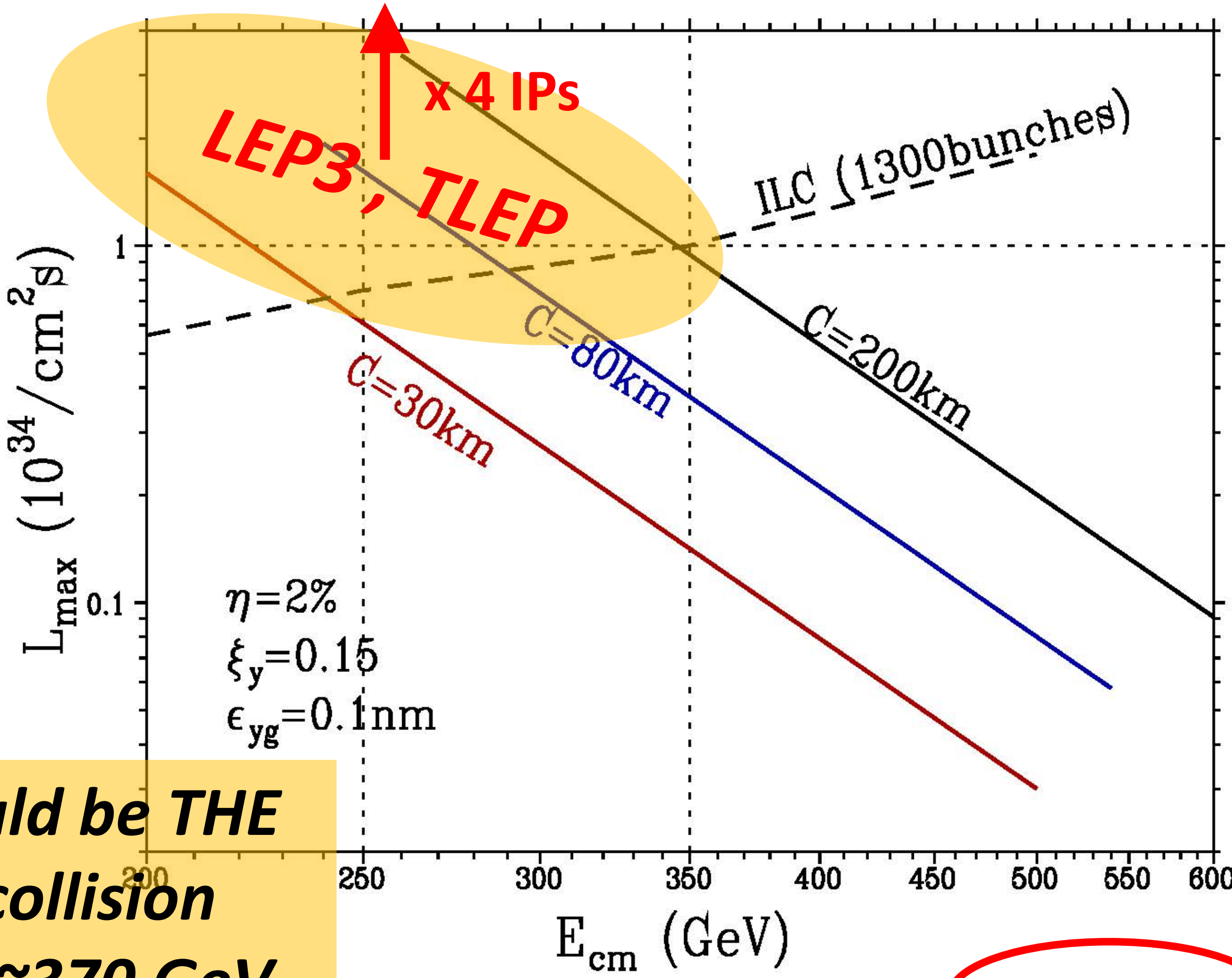



one challenge: rms momentum spread of 0.004%!

# *Comparison, Conclusions, & Outlook*

# Circular & Linear HF: peak luminosity vs energy

example with
- $\eta$=2%
- $\xi_y$=0.15
- $\varepsilon_{gy}$=0.1nm




***LEP3/TLEP* would be THE choice for $e^+e^-$ collision energies up to ~370 GeV**

K. Yokoya, KEK

# vertical rms IP spot sizes in nm

in regular font: achieved

in italics: design values

| LEP2 | 3500 |
|---|---|
| KEKB | 940 |
| SLC | 500 |
| ***LEP3*** | ***320*** |
| ***TLEP-H*** | ***220*** |
| ATF2, FFTB | 150? (*35*), 65 |
| *SuperKEKB* | *50* |
| ***SAPPHiRE*** | ***18*** |
| *ILC* | *5 – 8* |
| *CLIC* | *1 – 2* |

**$\beta_y^*$: 5 cm→ 1 mm**

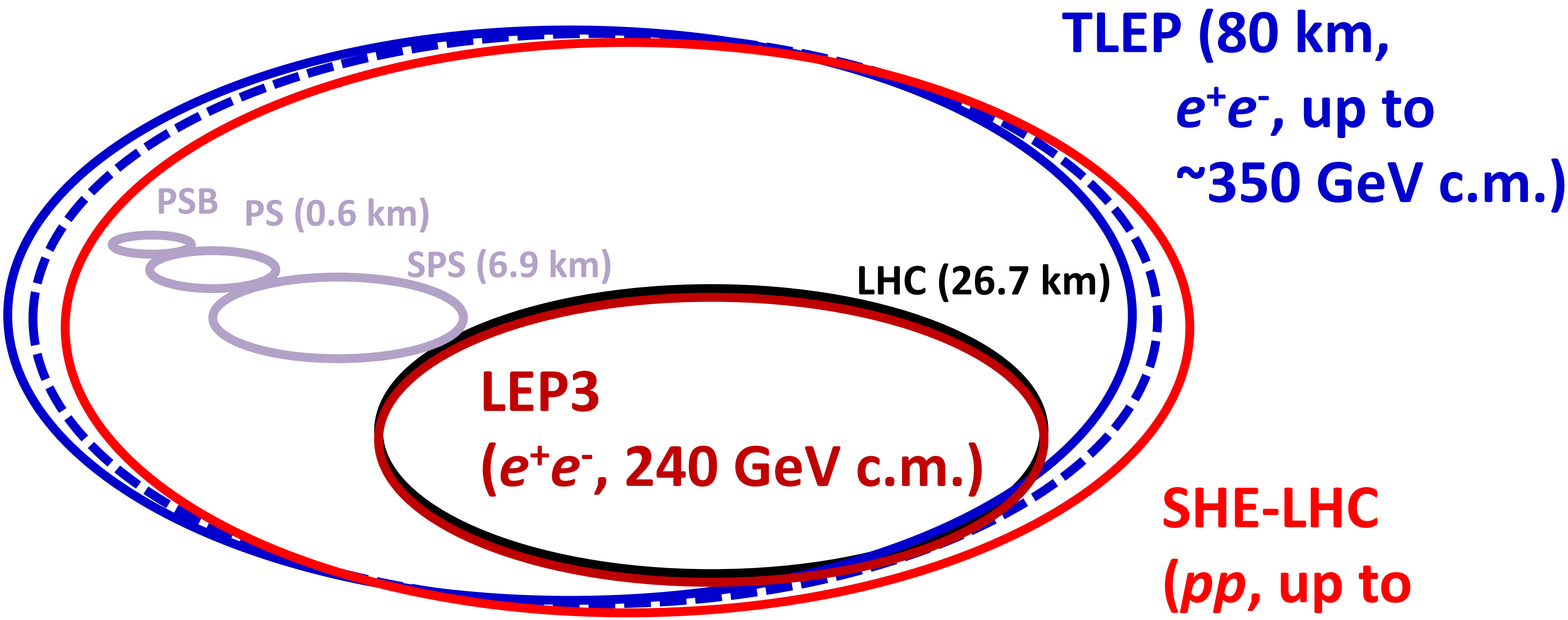
***LEP3/TLEP will learn from ATF2 & SuperKEKB***

# HF Accelerator Quality (My Opinion)

| | Linear C. | Circular C. | LHeC | Muon C. | γ–γ C. |
|---|---|---|---|---|---|
| maturity | ☺ | ☺ ☺ | ☺ ☺ | ☹ | ☹ |
| size | ☹ | ☹ | ☺ | ☺☺ | ☺ |
| cost | ☹ | ☺ - 😐 | ☺ | ☹ | ☺ |
| power | 😐 | 😐 | 😐 | 😐 | 😐 |
| #IPs | 1 | 4 | 1 | 1 | 1 |
| com. time | 10 yr | 2 yr | 2 yr | 10 yr | 5 yr |
| *H* factor | 0.2 (SLC) | 0.5 (1/2 PEP-II) | 0.2? | 0.1? | 0.1? |
| Higgs/IP/yr | 7 k [10 k] | 20-100 k | 5 k | 5 k | 10 k |
| expanda-bility | 1-3TeV $e^+e^-$, γγ C. | 100 TeV *pp* | γγ C. | 10 TeV μμ | LC later |

inspired by S. Henderson, FNAL

# *possible long-term strategy*




also: ***e*± (200 GeV) – *p* (7 & 50 TeV)** collisions

**≥50 years of *e*+*e*-, *pp*, *ep/A* physics at highest energies**


*having the tunnel is everything!*

# near-term outlook

ICFA HF2012 Organizing Committee (OC) will write **workshop report** including comparison tables & Executive Summary

**Target readers**:

- **Joint ICFA – Lab Directors meeting** (February 21-22, 2013 at TRIUMF)
- US **Snowmass 2013** conference
- **European Strategy** Updates meeting (January 21-22, 2013)
- **HEP roadmap study in Asia** (Japan and China)
- **World HEP and accelerator communities**

**HF2012 OC recommends these studies should continue!**

## HF accelerator R&D at CERN?

Mikhail S. Gorbachev

*If what you have done yesterday still looks big to you, you haven't done much today.*

# back-up slides

# luminosity formulae & constraints

$$L = \frac{f_{rev} n_b N_b^2}{4\pi\sigma_x\sigma_y} = (f_{rev} n_b N_b)\left(\frac{N_b}{\varepsilon_x}\right)\frac{1}{4\pi}\frac{1}{\sqrt{\beta_x\beta_y}}\frac{1}{\sqrt{\varepsilon_y/\varepsilon_x}}$$

$$(f_{rev} n_b N_b) = \frac{P_{SR}\,\rho}{8.8575\times10^{-5}\,\frac{\mathrm{m}}{\mathrm{GeV}^{-3}}\,E^4}$$ *SR radiation power limit*

$$\frac{N_b}{\varepsilon_x} = \frac{\xi_x 2\pi\gamma(1+\kappa_\sigma)}{r_e}$$ *beam-beam limit*

$$\frac{N_b}{\sigma_x\sigma_z}\frac{30\,\gamma r_e^2}{\delta_{acc}\,\alpha} < 1$$ *>30 min beamstrahlung lifetime (Telnov) → $N_b$, $\beta_x$*

→minimize $\kappa_\varepsilon=\varepsilon_y/\varepsilon_x$, $\beta_y\sim\beta_x(\varepsilon_y/\varepsilon_x)$ and respect $\beta_y\geq\sigma_z$

# LEP3/TLEP parameters -1

**soon at SuperKEKB:**
**$\beta_x$*=0.03 m, $\beta_Y$*=0.03 cm**

| | LEP2 | LHeC | LEP3 | TLEP-Z | TLEP-H | TLEP-t |
|---|---|---|---|---|---|---|
| beam energy $E_b$ [GeV] | 104.5 | 60 | 120 | 45.5 | 120 | 175 |
| circumference [km] | 26.7 | 26.7 | 26.7 | 80 | 80 | 80 |
| beam current [mA] | 4 | 100 | 7.2 | 1180 | 24.3 | 5.4 |
| #bunches/beam | 4 | 2808 | 4 | 2625 | 80 | 12 |
| #e-/beam [$10^{12}$] | 2.3 | 56 | 4.0 | 2000 | 40.5 | 9.0 |
| horizontal emittance [nm] | 48 | 5 | 25 | 30.8 | 9.4 | 20 |
| vertical emittance [nm] | 0.25 | 2.5 | 0.10 | 0.15 | 0.05 | 0.1 |
| bending radius [km] | 3.1 | 2.6 | 2.6 | 9.0 | 9.0 | 9.0 |
| partition number $J_\varepsilon$ | 1.1 | 1.5 | 1.5 | 1.0 | 1.0 | 1.0 |
| momentum comp. $\alpha_c$ [$10^{-5}$] | 18.5 | 8.1 | 8.1 | 9.0 | 1.0 | 1.0 |
| SR power/beam [MW] | 11 | 44 | 50 | 50 | 50 | 50 |
| $\beta^*_x$ [m] | 1.5 | 0.18 | 0.2 | 0.2 | 0.2 | 0.2 |
| $\beta^*_y$ [cm] | 5 | 10 | 0.1 | 0.1 | 0.1 | 0.1 |
| $\sigma^*_x$ [µm] | 270 | 30 | 71 | 78 | 43 | 63 |
| $\sigma^*_y$ [µm] | 3.5 | 16 | 0.32 | 0.39 | 0.22 | 0.32 |
| hourglass $F_{hg}$ | 0.98 | 0.99 | 0.59 | 0.71 | 0.75 | 0.65 |
| $\Delta E^{SR}_{loss}$/turn [GeV] | 3.41 | 0.44 | 6.99 | 0.04 | 2.1 | 9.3 |

**SuperKEKB: $\varepsilon_y/\varepsilon_x$=0.25%**

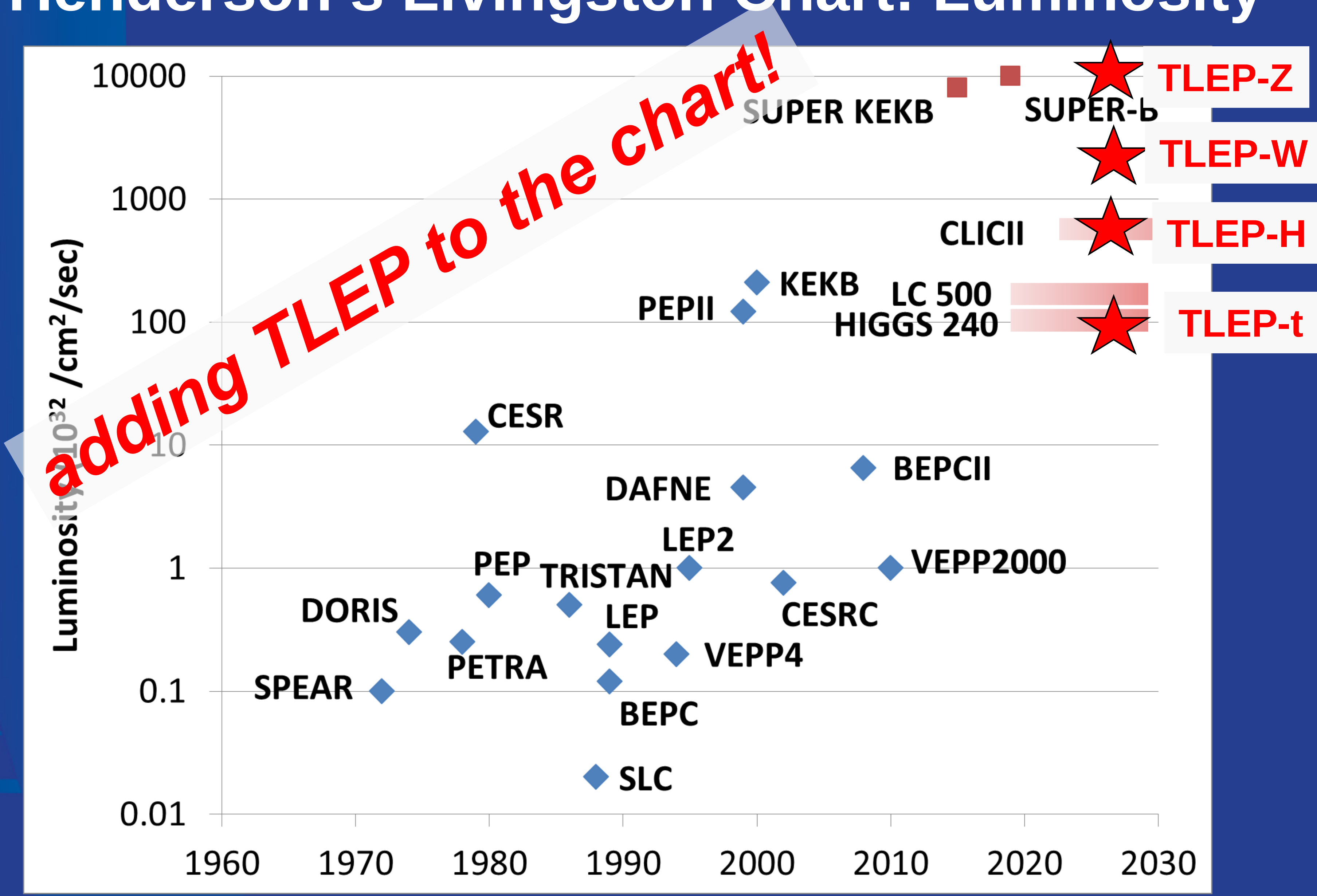
# LEP3/TLEP parameters -2

LEP2 was not beam-beam limited

| | LEP2 | LHeC | LEP3 | TLEP-Z | TLEP-H | TLEP-t |
|---|---|---|---|---|---|---|
| $V_{RF,tot}$ [GV] | 3.64 | 0.5 | 12.0 | 2.0 | 6.0 | 12.0 |
| $\delta_{max,RF}$ [%] | 0.77 | 0.66 | 5.7 | 4.0 | 9.4 | 4.9 |
| $\xi_x$/IP | 0.025 | N/A | 0.09 | 0.12 | 0.10 | 0.05 |
| $\xi_y$/IP | 0.065 | N/A | 0.08 | 0.12 | 0.10 | 0.05 |
| $f_s$ [kHz] | 1.6 | 0.65 | 2.19 | 1.29 | 0.44 | 0.43 |
| $E_{acc}$ [MV/m] | 7.5 | 11.9 | 20 | 20 | 20 | 20 |
| eff. RF length [m] | 485 | 42 | 600 | 100 | 300 | 600 |
| $f_{RF}$ [MHz] | 352 | 721 | 700 | 700 | 700 | 700 |
| $\delta^{SR}_{rms}$ [%] | 0.22 | 0.12 | 0.23 | 0.06 | 0.15 | 0.22 |
| $\sigma^{SR}_{z,rms}$ [cm] | 1.61 | 0.69 | 0.31 | 0.19 | 0.17 | 0.25 |
| $L$/IP[$10^{32}$cm$^{-2}$s$^{-1}$] | 1.25 | N/A | 94 | 10335 | 490 | 65 |
| number of IPs | 4 | 1 | 2 | 2 | 2 | 2 |
| Rad.Bhabha b.lifetime [min] | 360 | N/A | 18 | 74 | 32 | 54 |
| $\Upsilon_{BS}$ [$10^{-4}$] | 0.2 | 0.05 | 9 | 4 | 15 | 15 |
| $n_\gamma$/collision | 0.08 | 0.16 | 0.60 | 0.41 | 0.50 | 0.51 |
| $\Delta\delta^{BS}$/collision [MeV] | 0.1 | 0.02 | 31 | 3.6 | 42 | 61 |
| $\Delta\delta^{BS}_{rms}$/collision [MeV] | 0.3 | 0.07 | 44 | 6.2 | 65 | 95 |

LEP data for 94.5 - 101 GeV consistently suggest a beam-beam limit of ~0.115 (R.Assmann, K. C.)

# S. Henderson's Livingston Chart: Luminosity

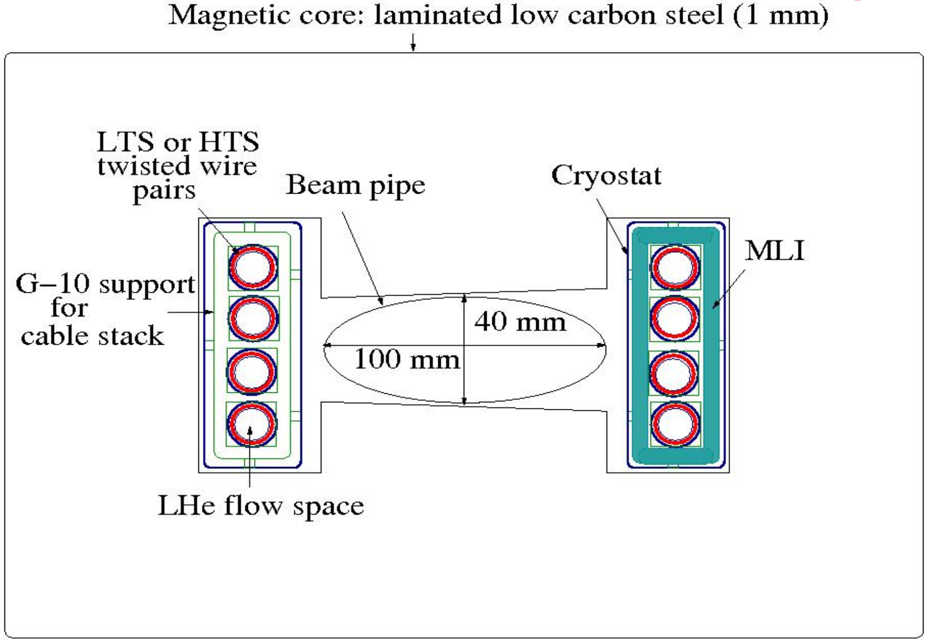


# Circular HF HiTech option

H. Piekarz,
1st EuCARD LEP3 Day

## transmission-line HTS/LTS magnets

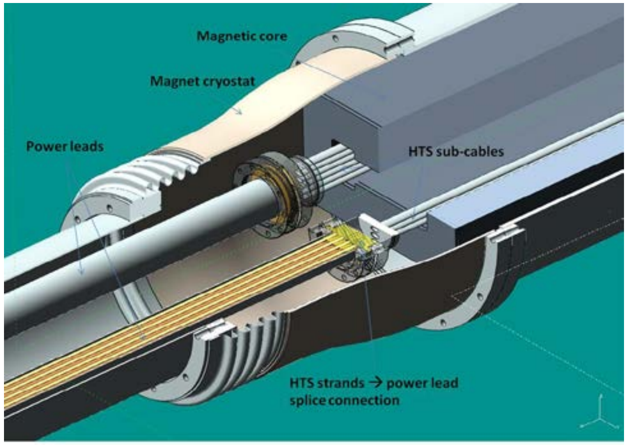
## schematic HTS/LTS LEP3 magnet




SC magnets require typically 10 x less space than NC magnet of the same field and gap; the magnet weight is very significantly reduced.

***HTS prototype dipole at FNAL***

***Test: $B_{max}$ = 0.5 T, $I_{max}$ = 27 kA, $dB/dt_{max}$ = 10 T/s , $T_{max}$ ~ 25 K***




***acceleration time ~0.1 s, total cycle ~1 s; fast SC magnets might support 1 minute lifetime in collider ring!***