Circular Higgs Factories: LEP3, TLEP and SAPPHiRE

Frank Zimmermann

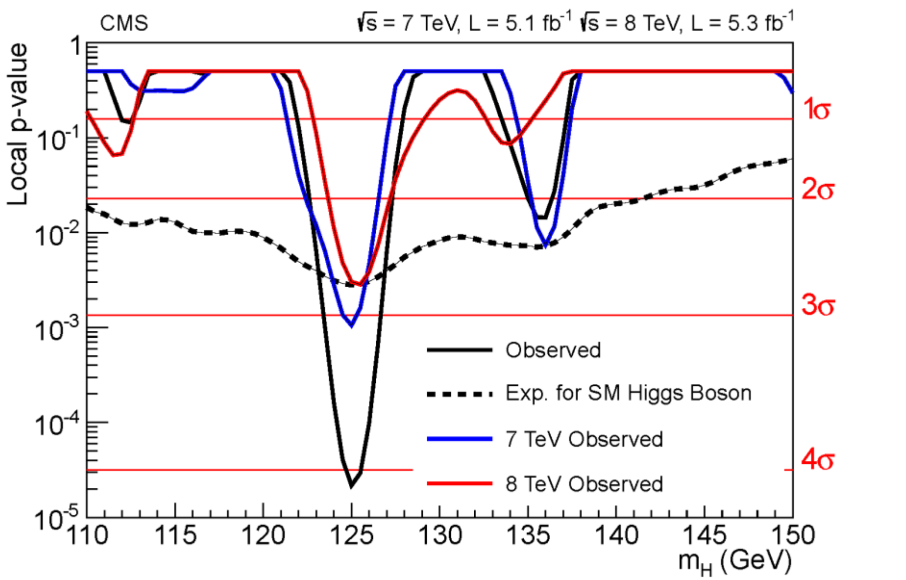
Saclay, 25 February 2013

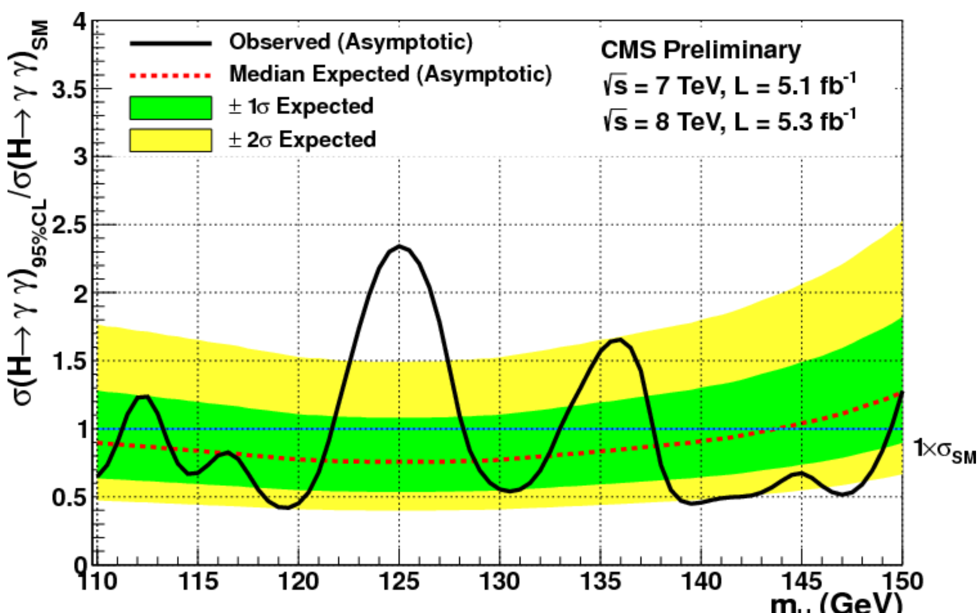
cern.ch/accnet

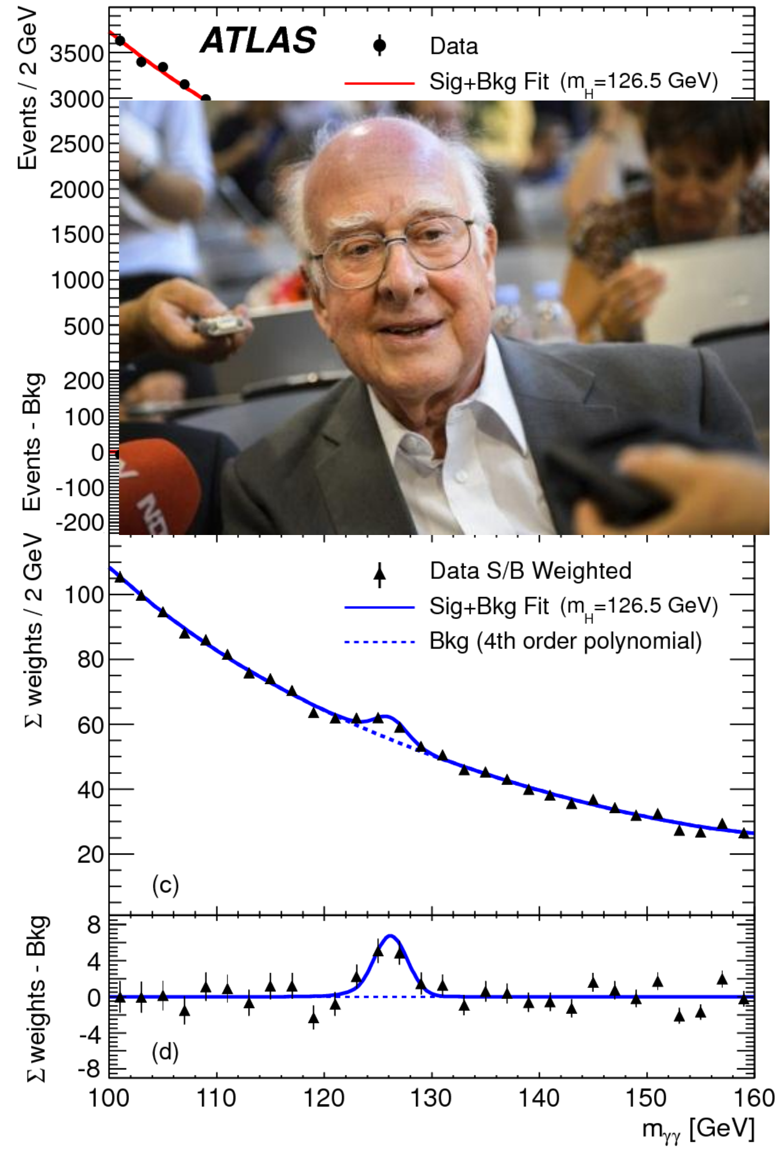
Thanks to R. Aleksan, R. Assmann, P. Azzi, M. Bai, A. Blondel, O. Bruning, H. Burkhardt, A. Butterworth, Y. Cai, A. Chao, W. Chou, P. Collier, J. Ellis, M. Fitterer, P. Janot, E. Jensen, M. Jimenez, M. Klein, M. Klute, M. Koratzinos, A. Milanese, M. Modena, S. Myers, K. Ohmi, K. Oide, J. Osborne, H. Piekarz, L. Rivkin, L. Rossi, G. Roy, D. Schulte, J. Seeman, V. Shiltsev, M. Silari, D. Summers, V. Telnov, R. Tomas, J. Wenninger, U. Wienands, K. Yokoya, M. Zanetti, …

work supported by the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579

4 July 2012 - X(125) “Higgs” discovery







pp Higgs factories LHC & LHC upgrades

LHC is the 1st Higgs factory!

E_{CoM}=8-14 TeV, $\widehat{L} \sim 10^{34}$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)

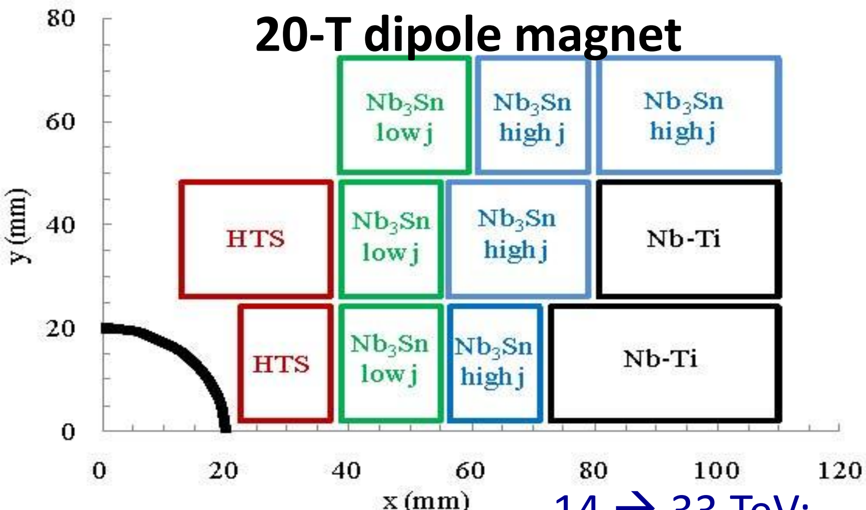
will deliver ~9x more H bosons!

***E_{CoM}*=14 TeV, $\widehat{L} \sim 5\text{x}10^{34}$cm^{-2}s^{-1}**

with luminosity leveling

HE-LHC: in LHC tunnel (2035-)

***E_{CoM}*=33 TeV, $\widehat{L} = 5\text{x}10^{34}$cm^{-2}s^{-1}**

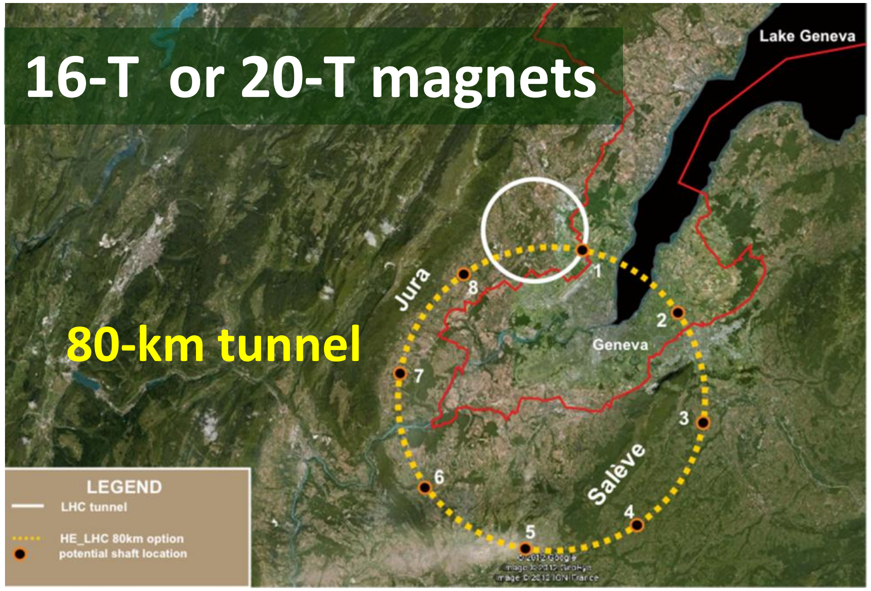


14 → 33 TeV: HH x6

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

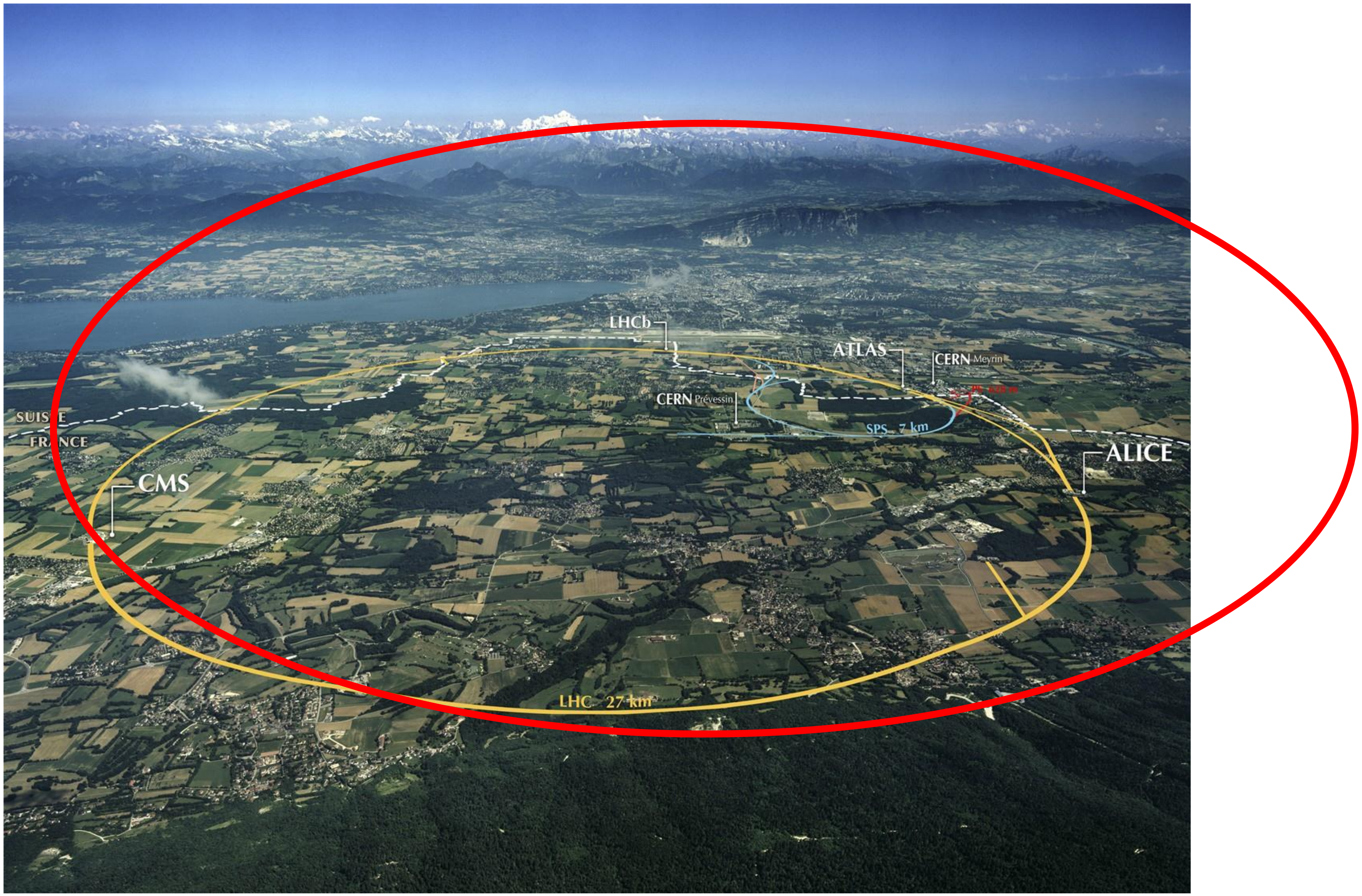
VHE-LHC: new 80 km tunnel

***E_{CoM}*=84-104 TeV, $\widehat{L} = 5\text{x}10^{34}$cm^{-2}s^{-1}**



J. Osborne, C. Waaijer, S. Myers HH x42

LEP3 / TLEP


LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
ALICE
CMS
LHC 27 km

Higgs e^+e^- production cross section

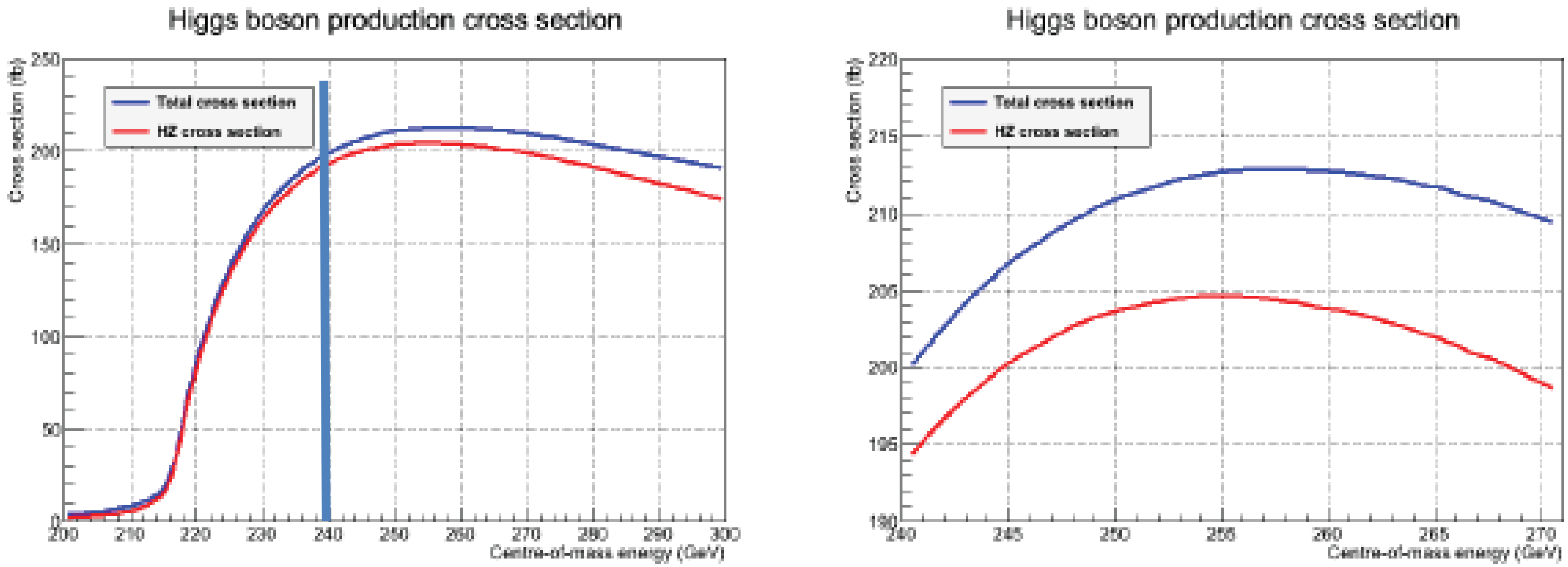


Figure 5: The Higgs boson production cross section as a function of the centre-of-mass energy. The red curve corresponds to the Higgsstrahlung process only, $e^+e^- \rightarrow HZ$, and the blue curve includes the WW and ZZ fusion processes as well, together with their interference with the Higgsstrahlung process. The right graph is a zoom of the left graph around the maximum of the cross section.

Prospective Studies for LEP3
with the CMS Detector

Patrizia Azzi[3], Colin Bernet[1], Cristina Botta[1], Patrick Janot[1],
Markus Klute[2], Piergiulio Lenzi[1], Luca Malgeri[1], and Marco Zanetti[2]

[1] CERN, Geneva
[2] Massachusetts Institute of Technology
[3] INFN, Sezione di Padova

best for tagged *ZH* physics:

Ecm= m_H+111±10

W. Lohmann et al LCWS/ILC2007

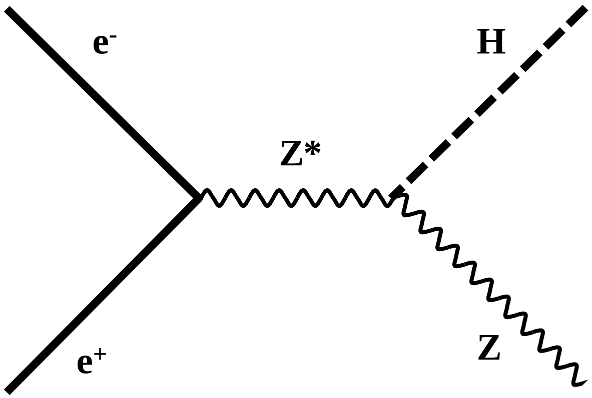
take 240 GeV

A. Blondel

Higgs production mechanism

in e^+e^- collisions a light Higgs is produced by the "Higgstrahlung" process close to threshold ; production section has a maximum at near threshold ~200 fb

$10^{34}/cm^2/s$ ➔ 20'000 *H-Z* events per year



Z-tagging, missing mass

total rate $\propto g_{HZZ}^2$
ZZZ final state $\propto g_{HZZ}^4/\Gamma_H$
➔ **measure total width** Γ_H

for a Higgs of 125GeV, a centre of mass energy of 240 GeV is sufficient ➔ kinematical constraint near threshold for high precision in mass, width, selection purity

A. Blondel

e^+e^- Higgs factories LEP3 & TLEP options

- installation in the LHC tunnel "LEP3"
  + inexpensive (<0.1xLC)
  + tunnel exists
  + reusing ATLAS and CMS detectors
  + reusing LHC cryoplants
  - interference with LHC and HL-LHC
- new larger tunnel "TLEP"
  + higher energy reach, 5-10x higher luminosity
  + decoupled from LHC/HL-LHC operation & construction
  + tunnel can later serve for HE-LHC (factor 3 in energy from tunnel alone) with LHC remaining as injector
  - 4-5x more expensive (new tunnel, cryoplants, detectors)

LEP3, TLEP

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

key parameters

	LEP3	TLEP
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.	-	0.7×10^{34} cm^{-2}s^{-1}
luminosity at 240 GeV c.m.	10^{34} cm^{-2}s^{-1}	5×10^{34} cm^{-2}s^{-1}
luminosity at 160 GeV c.m.	5×10^{34} cm^{-2}s^{-1}	2.5×10^{35} cm^{-2}s^{-1}
luminosity at 90 GeV c.m.	2×10^{35} cm^{-2}s^{-1}	10^{36} cm^{-2}s^{-1}

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

other LEP3 parameters

arc optics

- same as for LHeC: $\varepsilon_{x,LHeC}$<1/3 $\varepsilon_{x,LEP1.5}$ at equal beam energy,
- optical structure compatible with present LHC machine (not optimum!)
- small momentum compaction (short bunch length)
- assume $\varepsilon_y/\varepsilon_x$ ~5x10^{-3} similar to LEP (ultimate limit ε_y ~ 1 fm from opening angle)

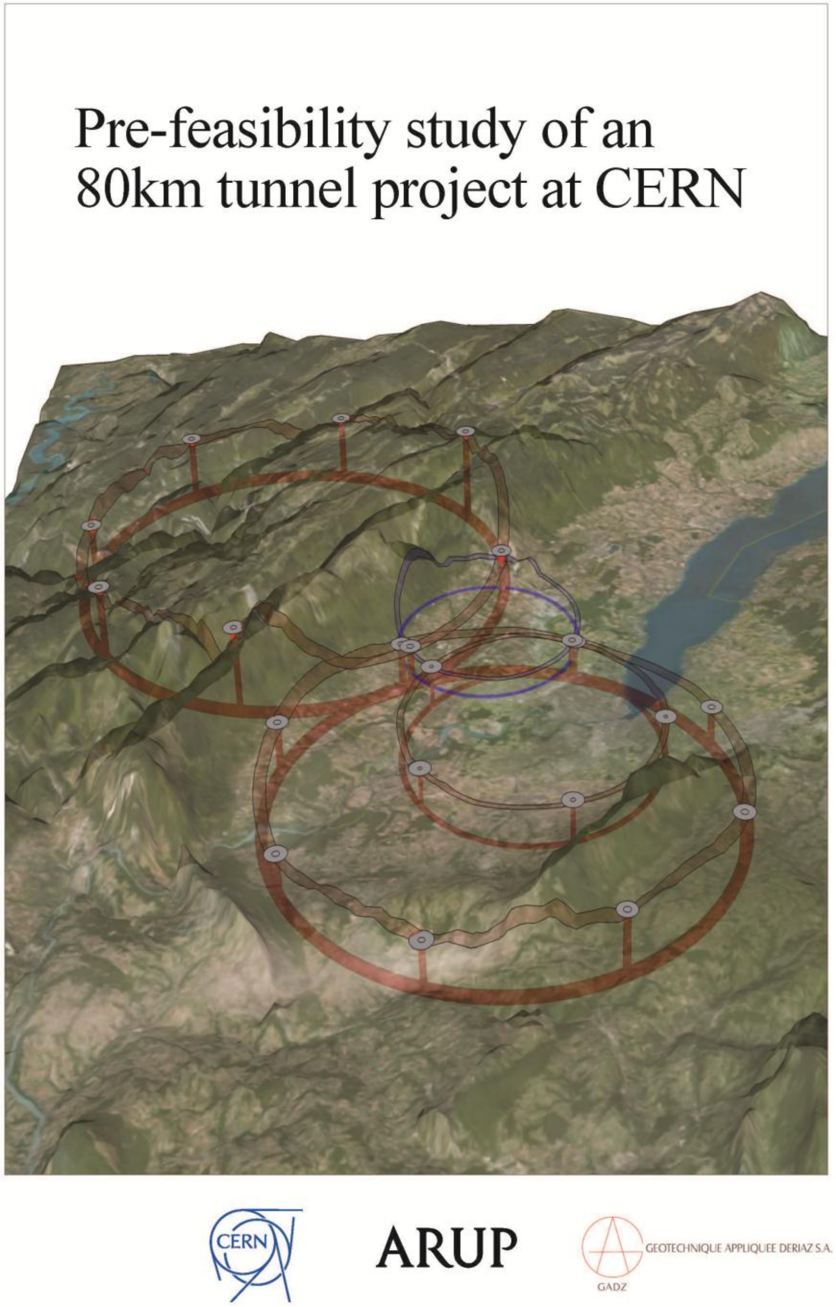
RF

- RF frequency 1.3 GHz, 700 MHz or 800 MHz
- ILC/ESS-type RF cavities high gradient (20 MV/m assumed, 2.5 times LEP gradient)
- total RF length for LEP3 at 120 GeV similar to LEP at 104.5 GeV
- short bunch length (small β^*_y)
- cryo power ≤LHC

synchrotron radiation

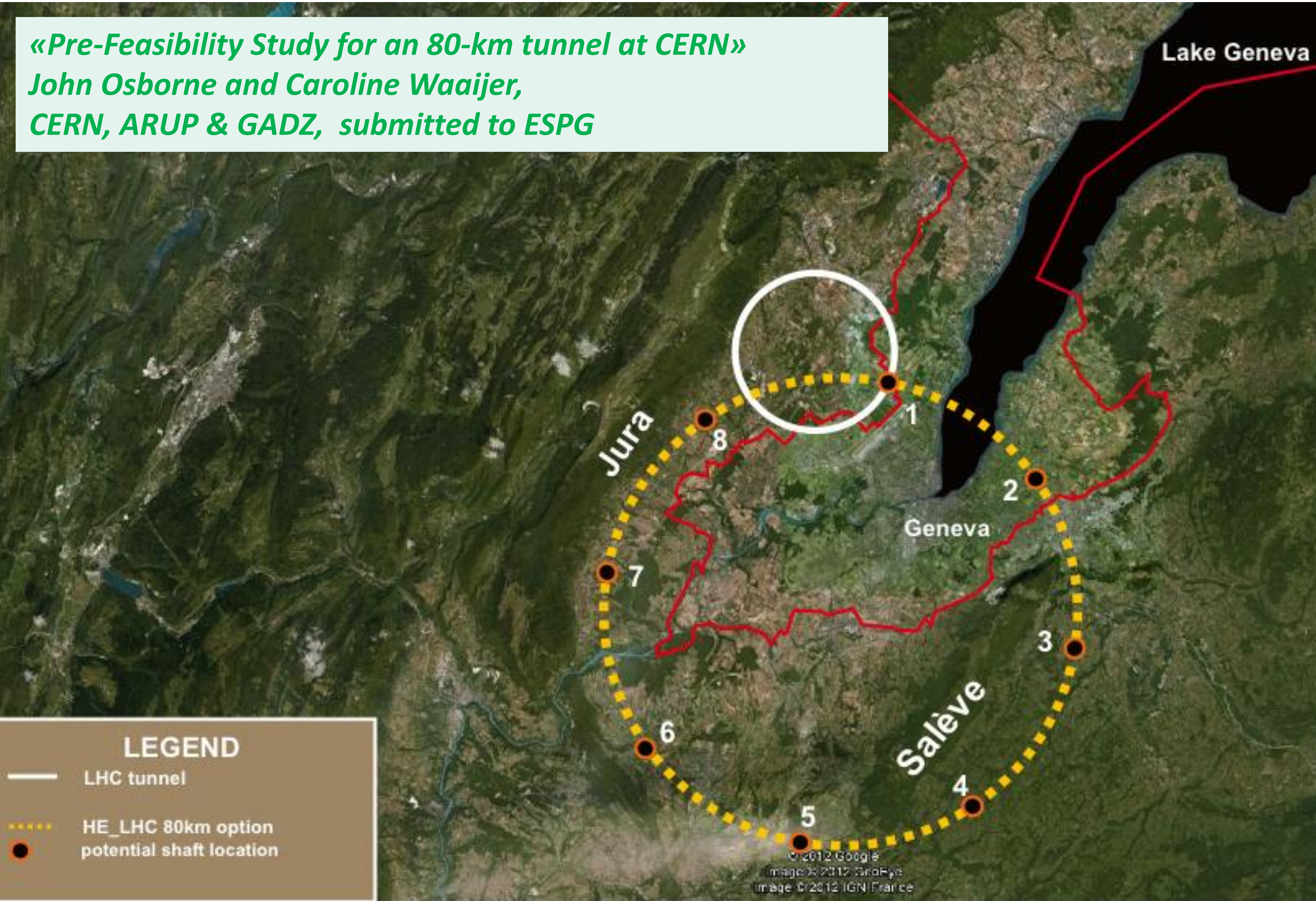
- energy loss / turn: E_{loss}[GeV]=88.5×10^{-6} (E_b[GeV])^4 /ρ[m].
- higher energy loss than necessary
- arc dipole field = 0.153 T
- compact magnet
- critical photon energy = 1.4 MeV
- 50 MW per beam (total wall plug power ~200 MW ~ LHC complex)→4x10^{12} e$^{\pm}$/beam

a new tunnel for TLEP in the Geneva area?



TLEP tunnel in the Geneva area – “best” option

«Pre-Feasibility Study for an 80-km tunnel at CERN»
John Osborne and Caroline Waaijer,
CERN, ARUP & GADZ, submitted to ESPG

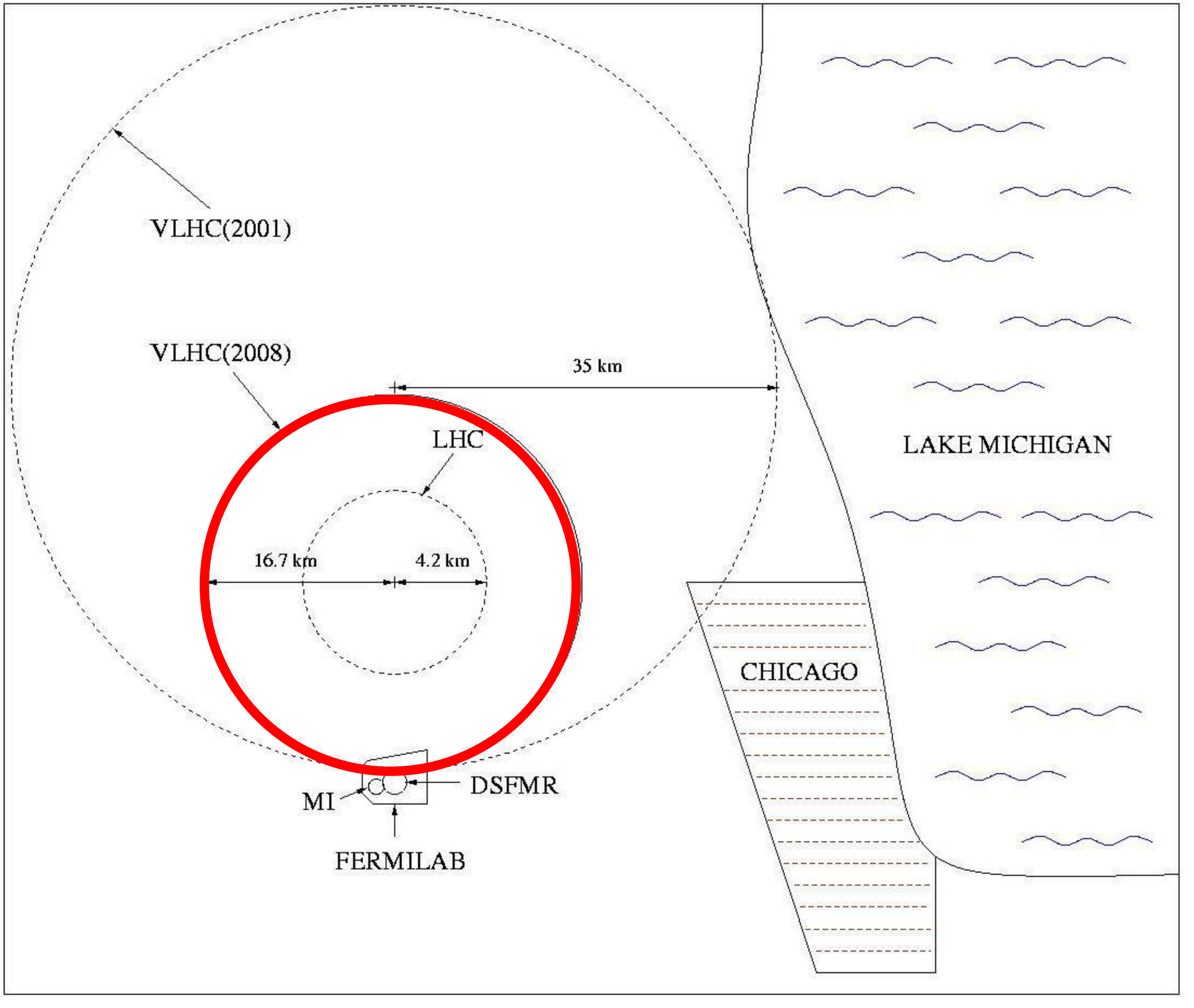


TLEP tunnel in the KEK area?

SuperTRISTAN in Tsukuba: 40 km ring

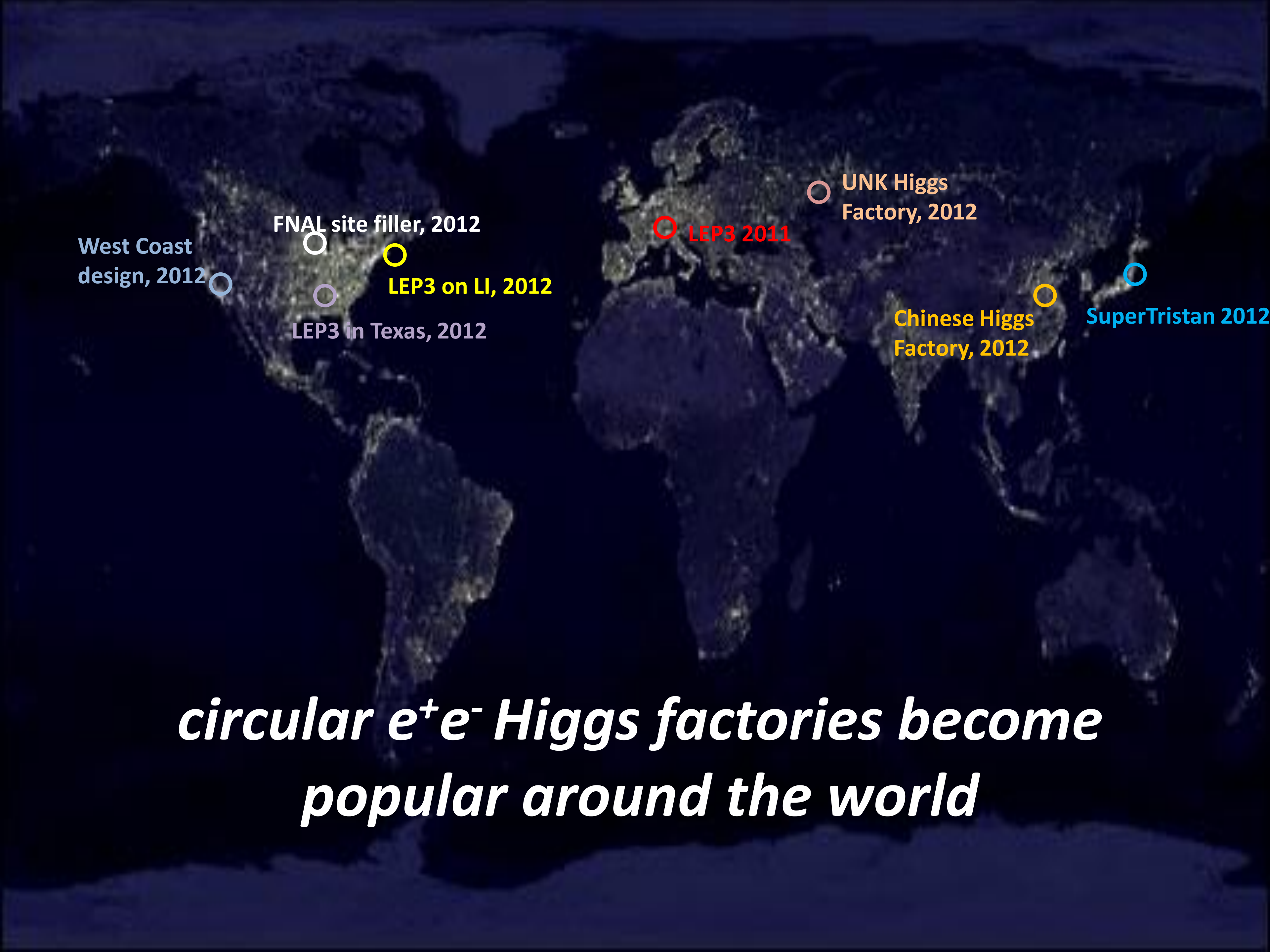
Proposal by K. Oide, 13 February 2012

105 km tunnel near FNAL



(+ FNAL plan B from R. Talman)

H. Piekarz, "… and … **path to the future of high energy particle physics**," JINST 4, P08007 (2009)



circular e^+e^- Higgs factories become popular around the world

luminosity formulae & constraints

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

$$(f_{rev} n_b N_b) = \frac{P_{SR}\, \rho}{8.8575 \times 10^{-5} \frac{\mathrm{m}}{\mathrm{GeV}^{-3}} E^4}$$

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, β_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: β_x^*=0.03 m, β_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_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_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
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [µm]	270	30	71	78	43	63
σ^*_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
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3

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

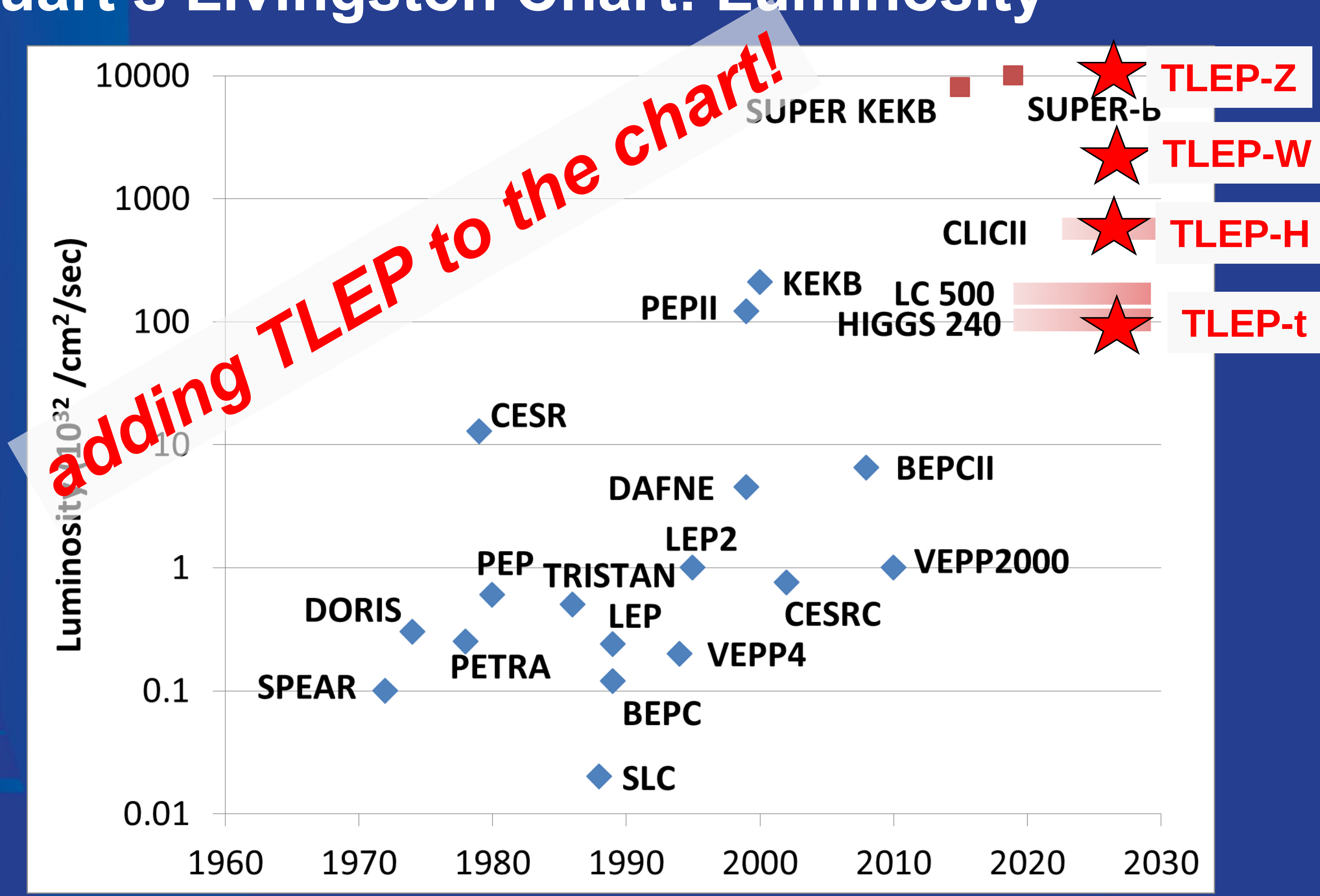
LEP3/TLEP parameters -2

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
ξ_x/IP	0.025	N/A	0.09	0.12	0.10	0.05
ξ_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
δ^{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
Υ_{BS} [10^{-4}]	0.2	0.05	9	4	15	15
n_γ/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.)

Stuart's Livingston Chart: Luminosity



beam lifetime

LEP2:

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

SuperKEKB: τ~6 minutes!

TLEP:

- with L~5x10^{34} cm^{-2}s^{-1} at each of four IPs:

  $\tau_{beam,TLEP}$~16 minutes from rad. Bhabha
- **additional beam lifetime limit due to beamstrahlung** requires: (1) large momentum acceptance ($\delta_{max,RF} \geq 3\%$), and/or (2) flat(ter) beams and/or (3) fast replenishing

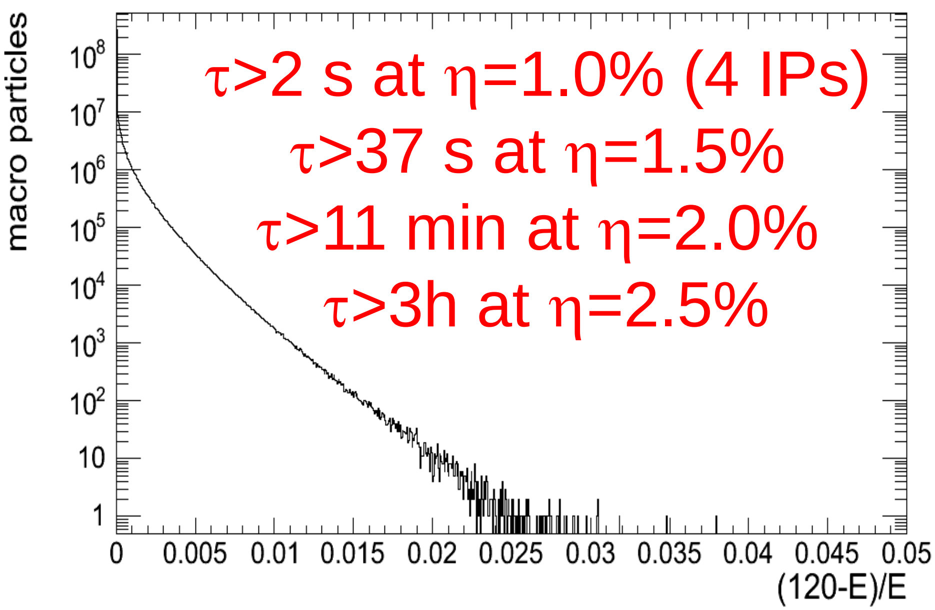
  (Valery Telnov, Kaoru Yokoya, Marco Zanetti)

circular HFs – beamstrahlung
energy spectrum after 1 collision

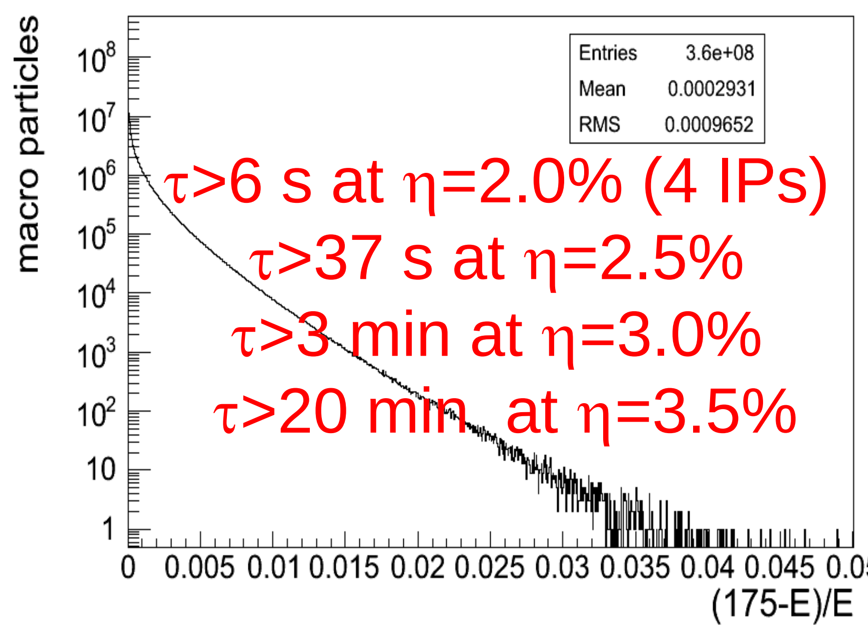
- simulation w 360M macroparticles
- τ varies exponentially w energy acceptance η
- post-collision *E* tail → lifetime τ

M. Zanetti (MIT)

TLEP at 240 GeV:



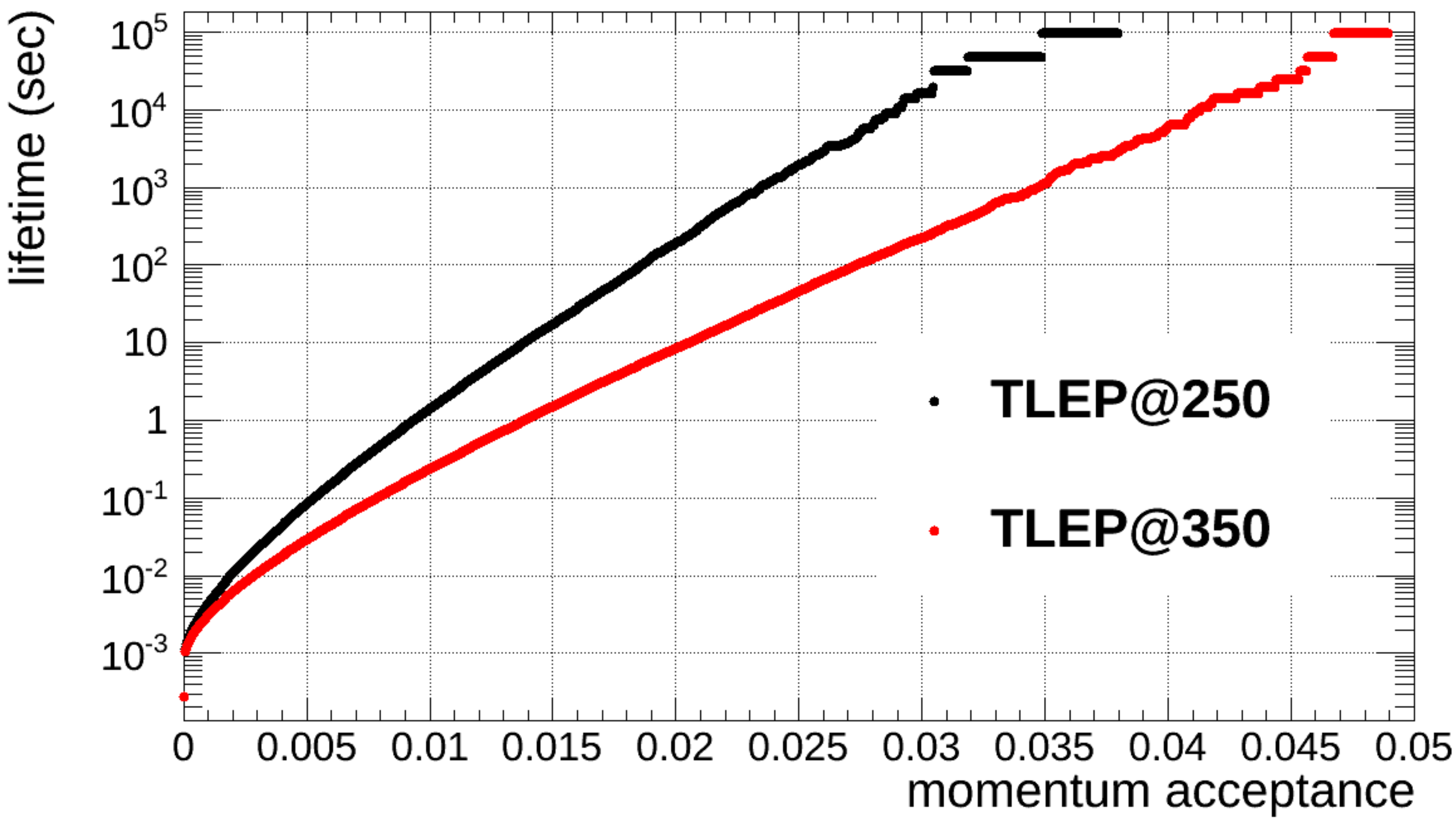
TLEP at 350 GeV:



circular HFs – beamstrahlung

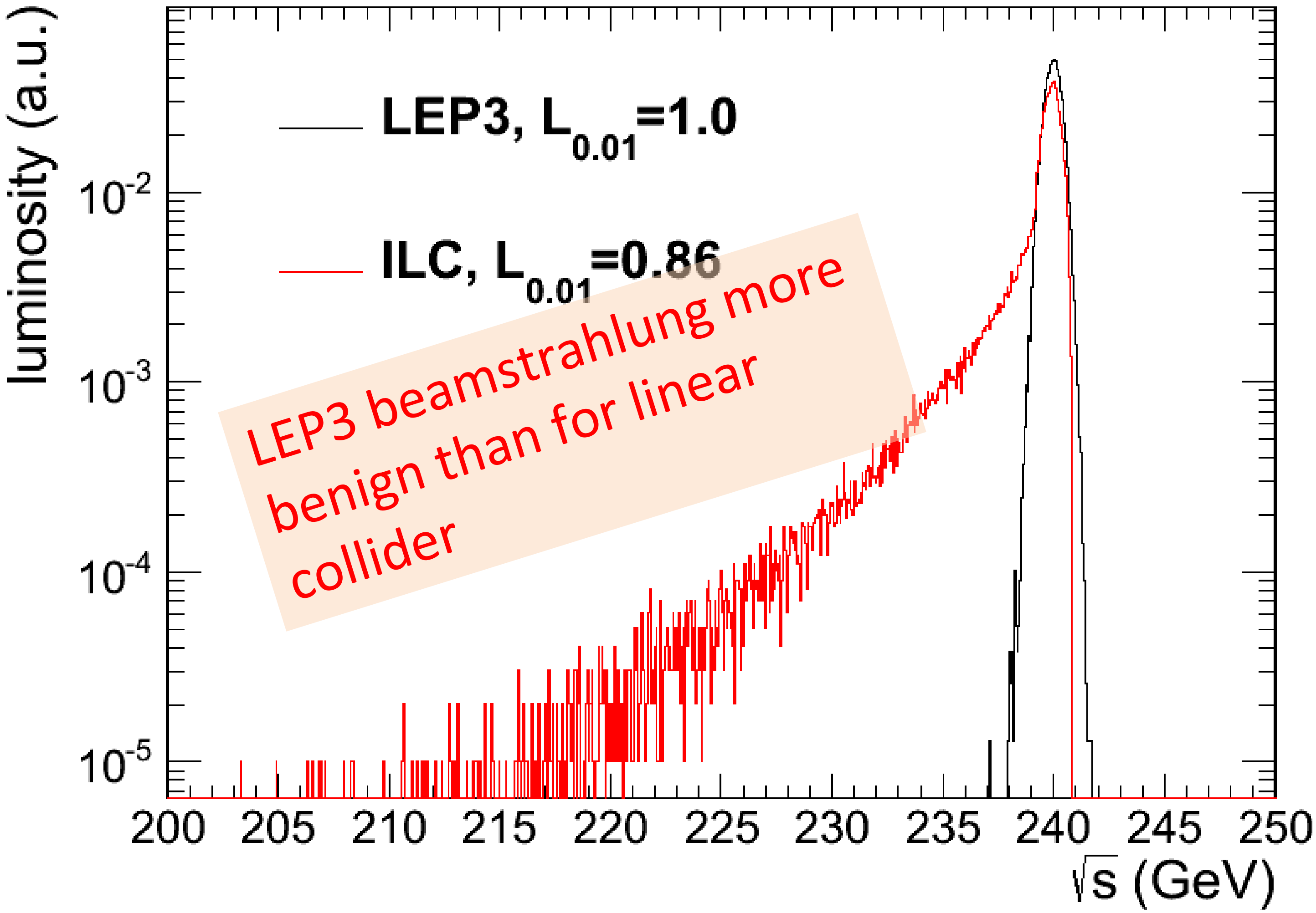
- simulation w 360M macroparticles
- τ varies exponentially w energy acceptance η
- post-collision *E* tail → lifetime τ

beam lifetime versus acceptance η for 1 IP:



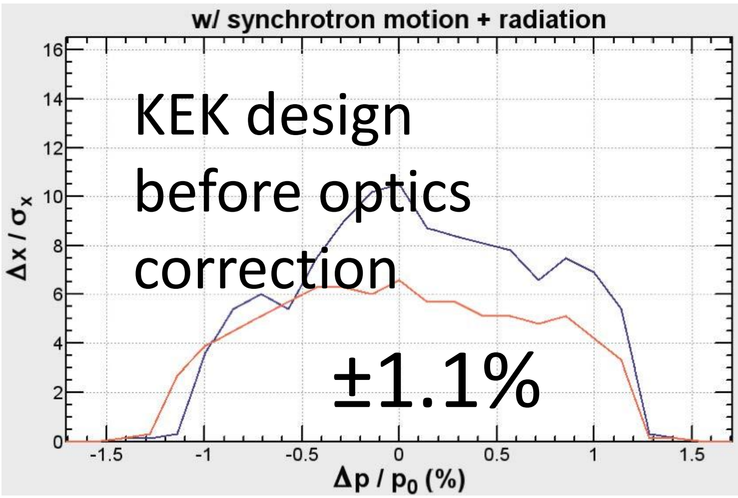
beamstrahlung luminosity spectrum

LEP3 & ILC:

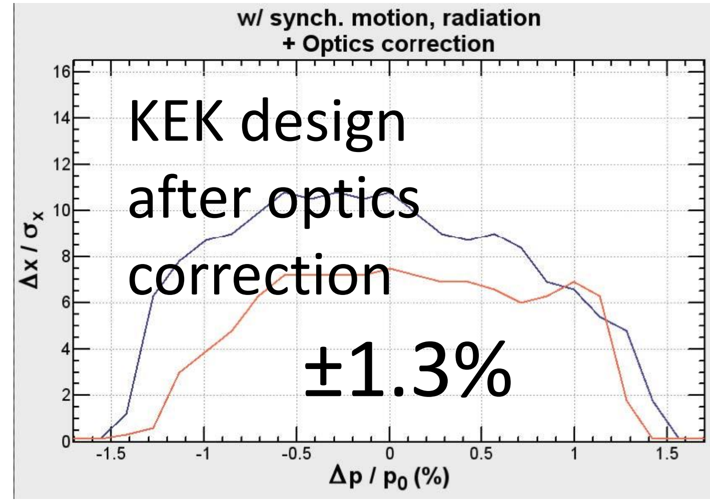


M. Zanetti (MIT)

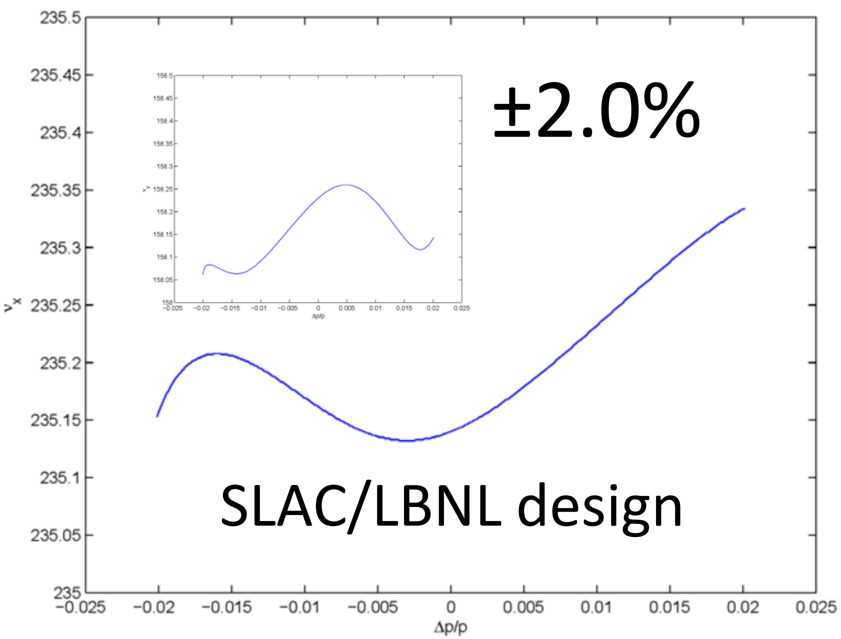
circular HFs - momentum acceptance

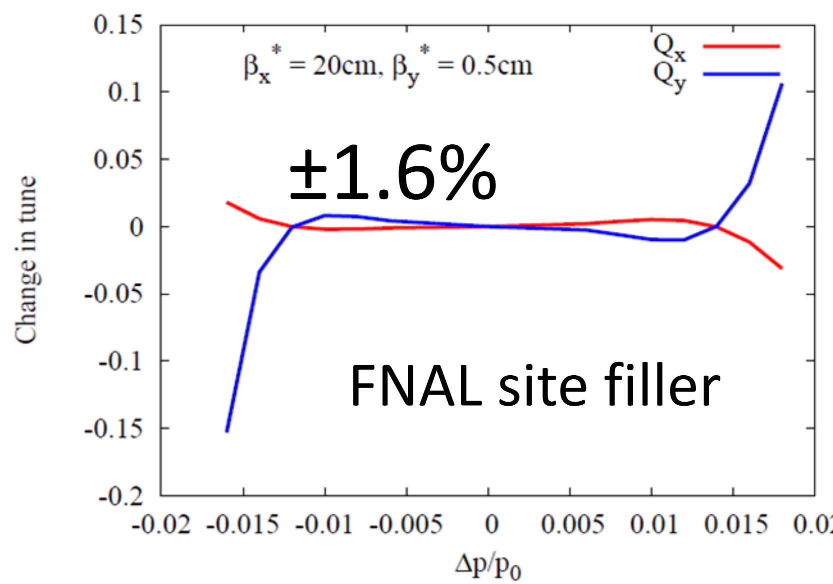


with synchrotron motion & radiation (sawtooth)



K. Oide





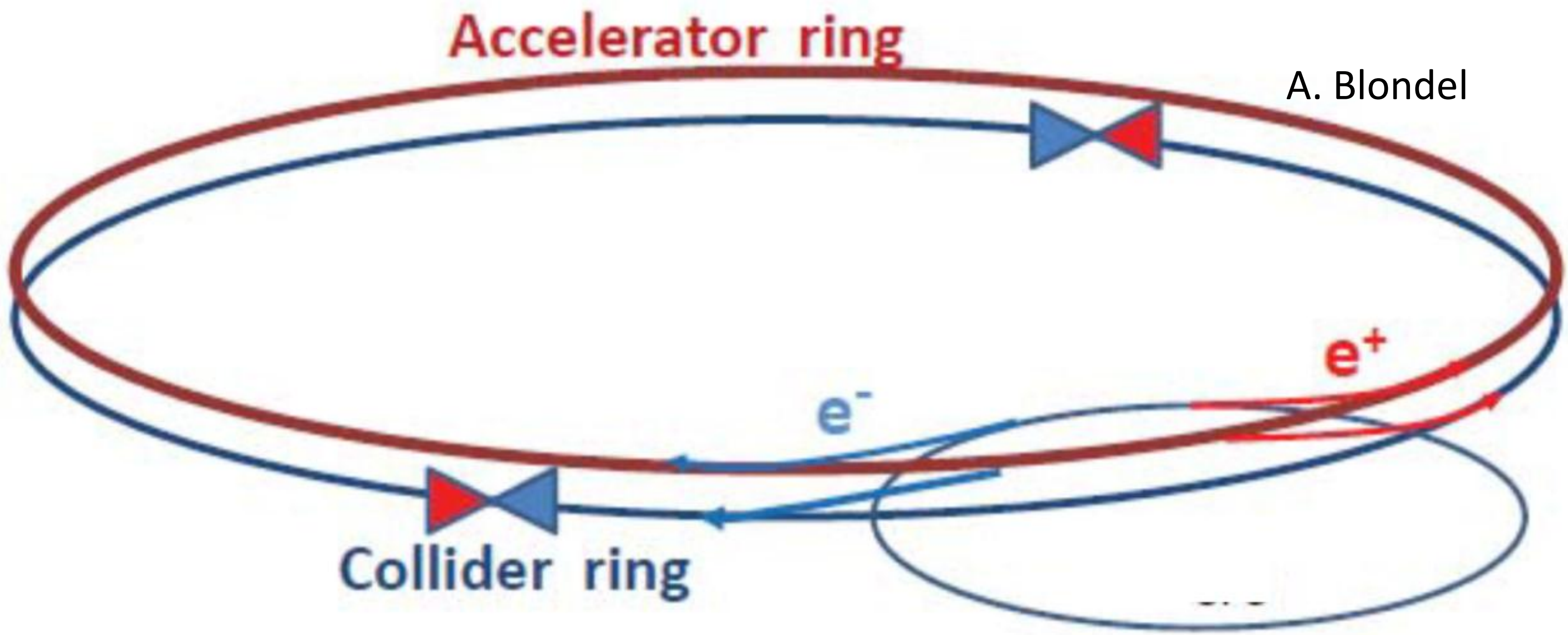
Y. Cai

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

SPS-LEP experience:

- $e^{\pm}$ from 3.5 to 20 GeV (later 22 GeV) in 265 ms (~62.26 GeV/s) [K. Cornelis, W. Herr, R. Schmidt, EPAC1988]

injection sequence [P. Collier, G. Roy]:

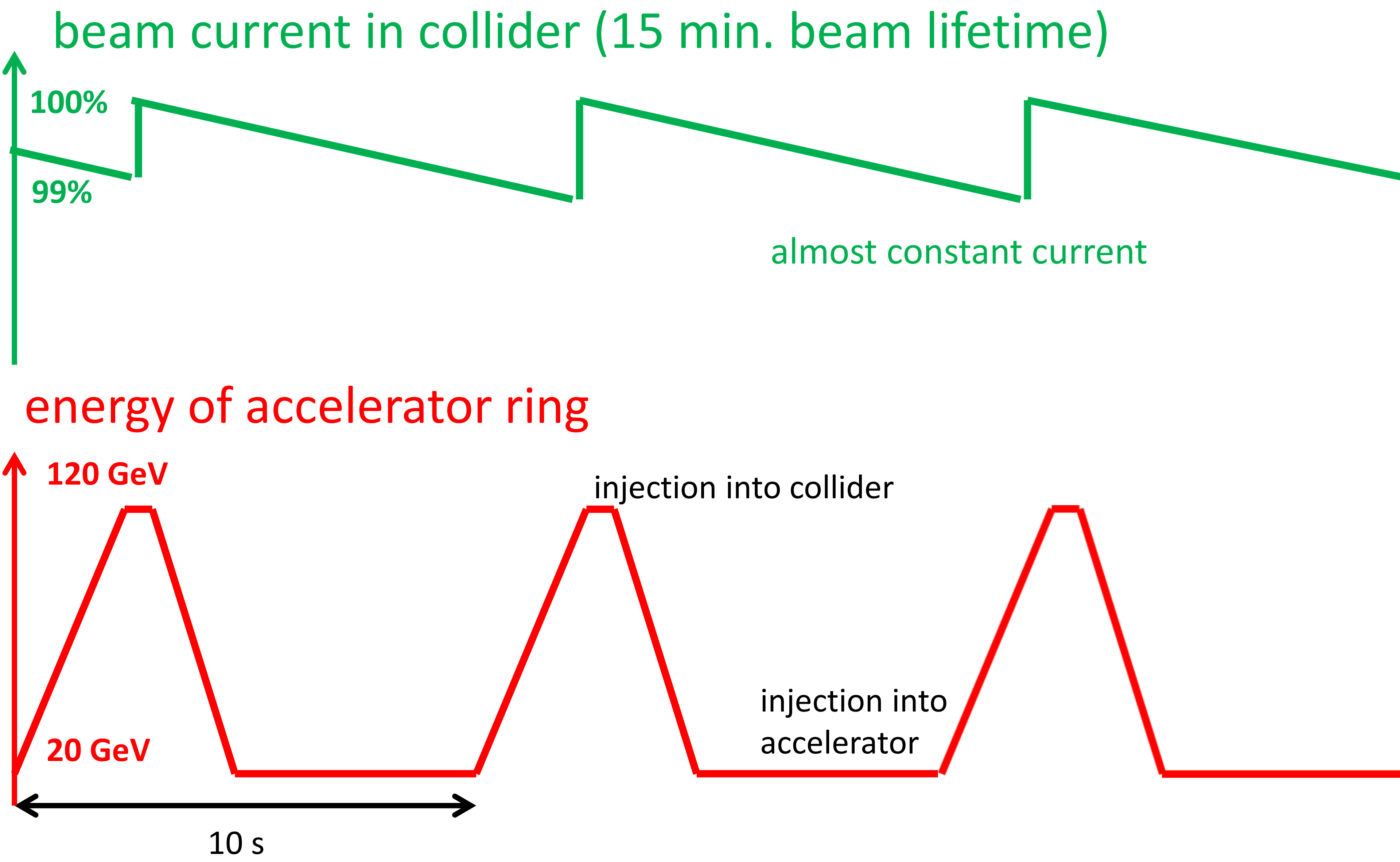
- SPS-> top-up accelerator at 20 (22) GeV
- acceleration from 20 (22) to 120 GeV
- synchroton injection (like SuperKEKB!)

overall acceleration time = 1.6 s

total cycle time = 10 s looks conservative

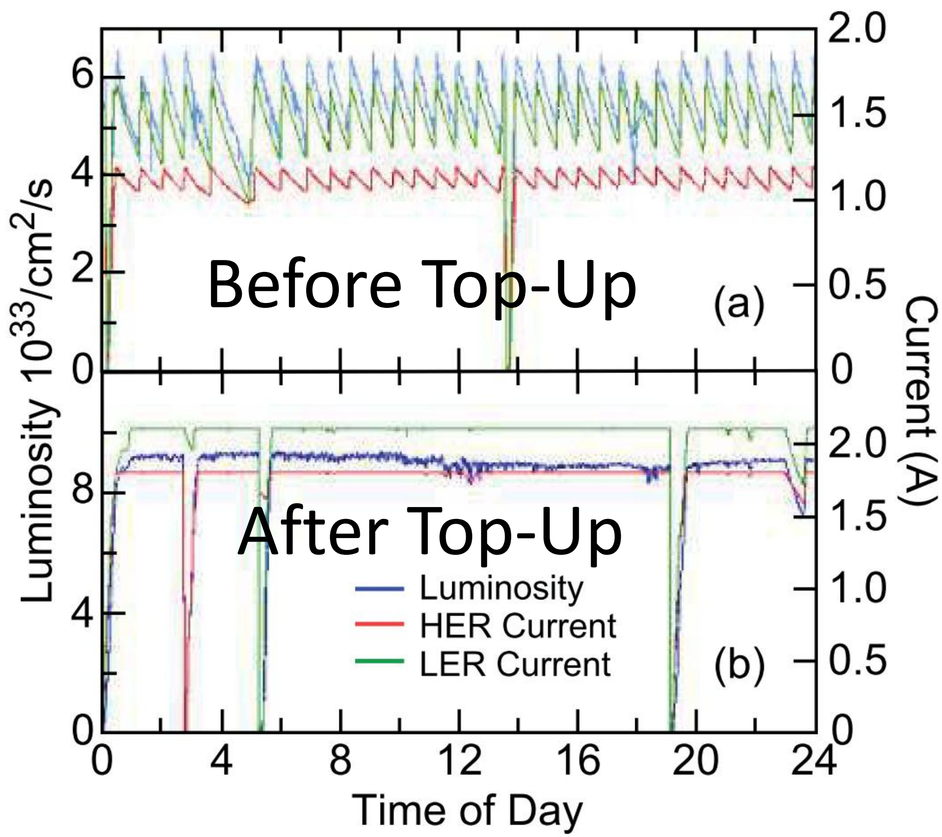
(→ refilling ~1% of the TLEP beam, for τ_{beam}~16 min)

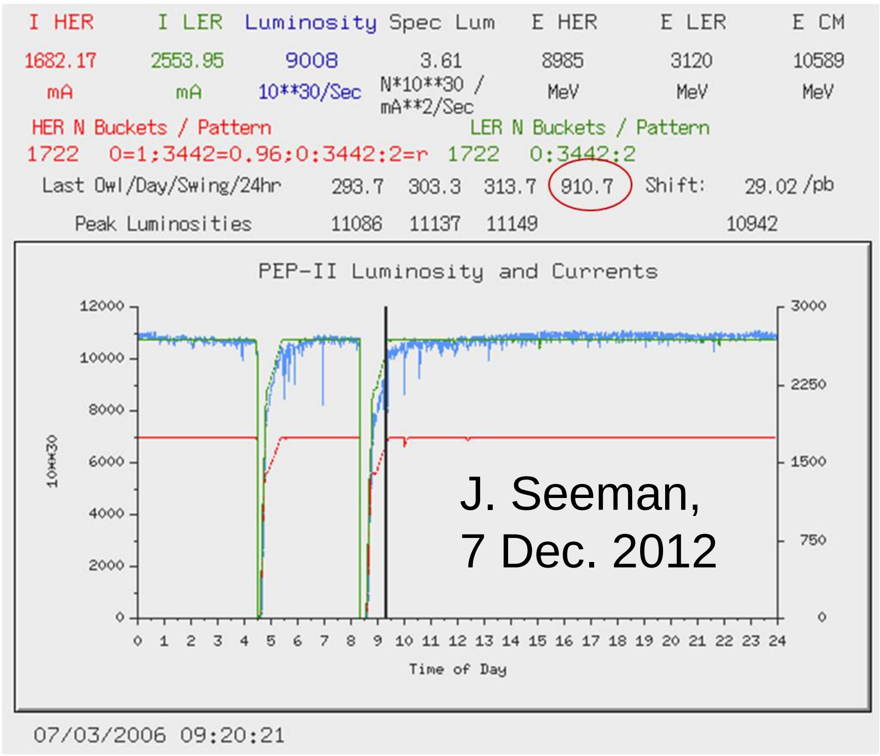
top-up injection: schematic cycle



top-up performance at PEP-II/BaBar

J. Seeman





Hübner factor *H* not from 1:

- for one day (July 3, 2006): $H \approx 0.95$
- for one month (August 2007): $H \approx 0.63$

Circular Collider & SR Experience

…

CESR

BEPC

LEP

Tevatron

LEP2

HERA

DAFNE

PEP-II

KEKB

BEPC-II

LHC

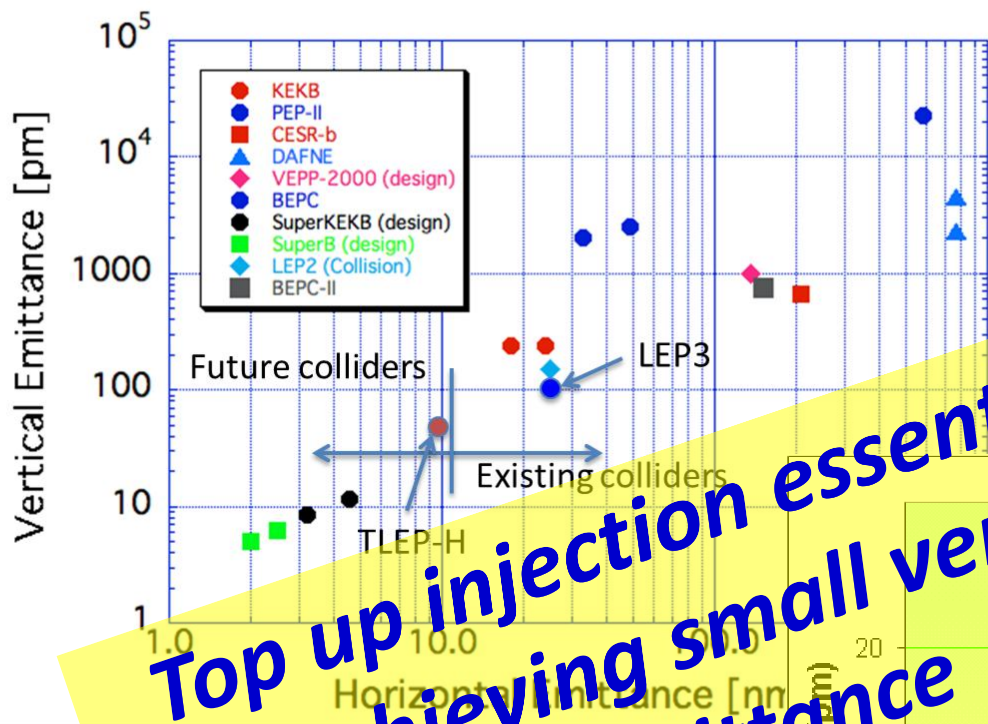
SuperKEKB (soon)

3rd generation light sources

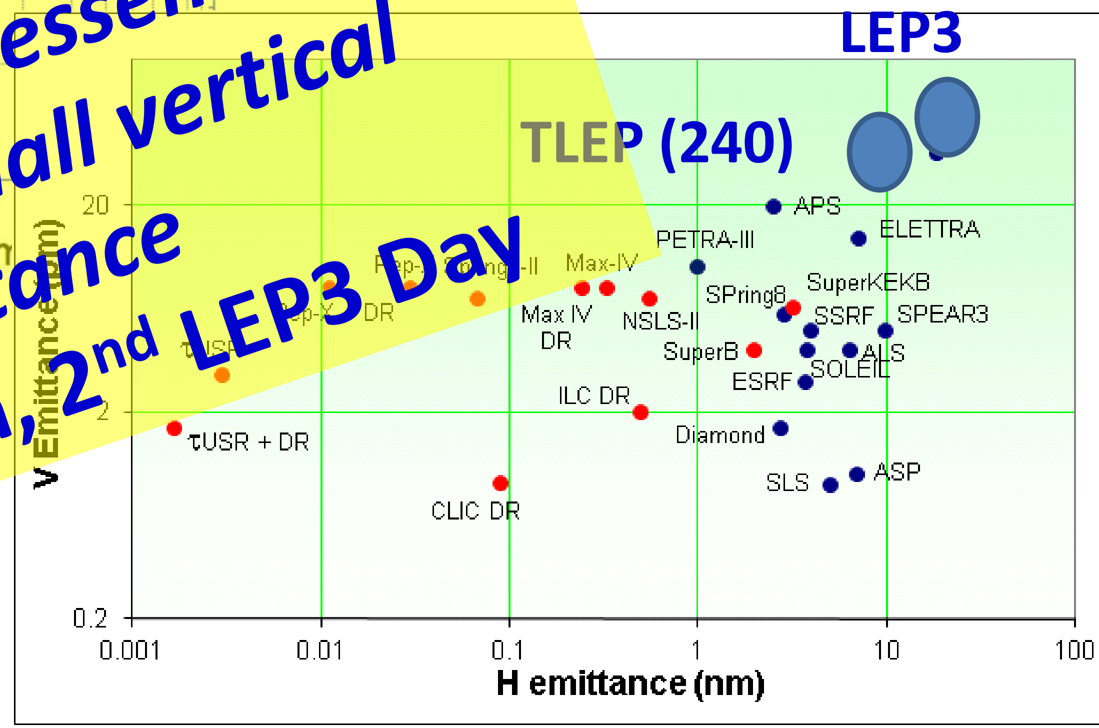
1992	**ESRF**, France (EU)	6 GeV
	ALS, US	1.5-1.9 GeV
1993	**TLS**, Taiwan	1.5 GeV
1994	**ELETTRA**, Italy	2.4 GeV
	PLS, Korea	2 GeV
	MAX II, Sweden	1.5 GeV
1996	**APS**, US	7 GeV
	LNLS, Brazil	1.35 GeV
1997	**Spring-8**, Japan	8 GeV
1998	**BESSY II**, Germany	1.9 GeV
2000	**ANKA**, Germany	2.5 GeV
	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)

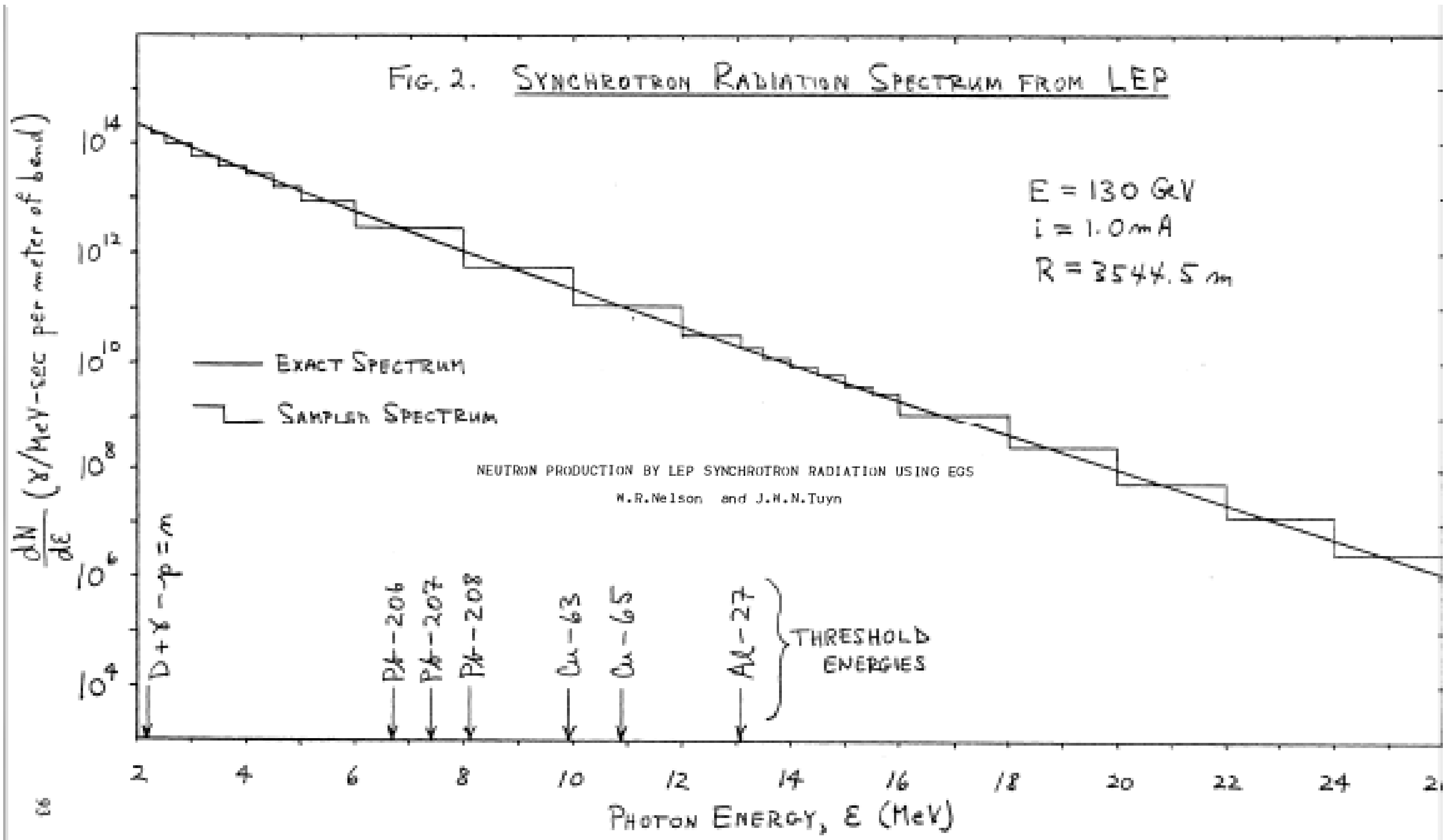
N. Kurita, U. Wienands, SLAC

synchrotron radiation - activation

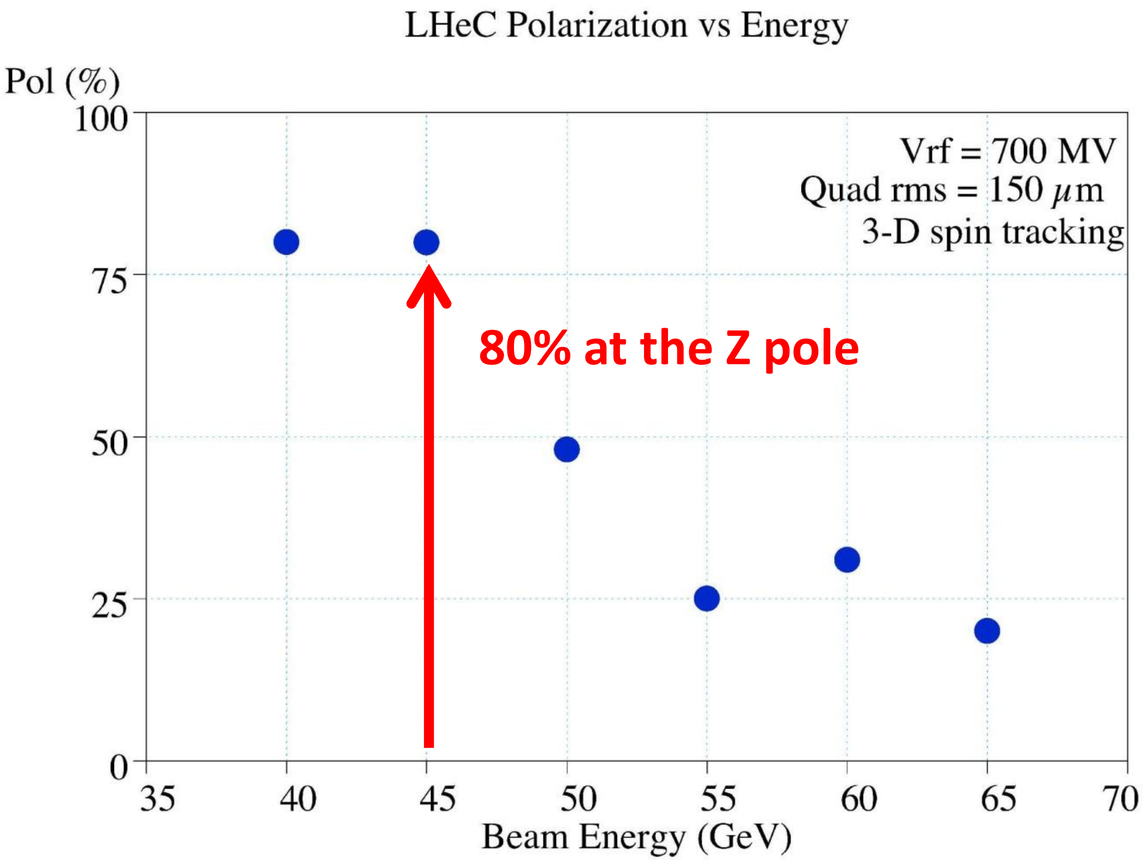
NEUTRON PRODUCTION BY LEP SYNCHROTRON RADIATION USING EGS

W.R.Nelson and J.W.N.Tuyn

A. Fasso
3rd TLEP3 Day



TLEP polarization



LHeC equilibrium polarisation vs ring energy, full 3-D spin tracking results (D. Barber, U. Wienands, in LHeC CDR, J. Phys. G: Nucl. Part. Phys. 39 075001)

"… by adopting the levels of alignment that are now standard for synchrotron-radiation sources and by applying harmonic closed-orbit spin matching, there is reason to hope that high polarisation in a flat ring can … be obtained"

TLEP/LEP3 key components

- tunnel
- SRF system
- cryoplants
- magnets
- injector ring
- detectors

tunnel is main cost:

3x LEP tunnel = 2.1 BCHF

9x LHeC tunnel cost estimate = 2.25 BCHF

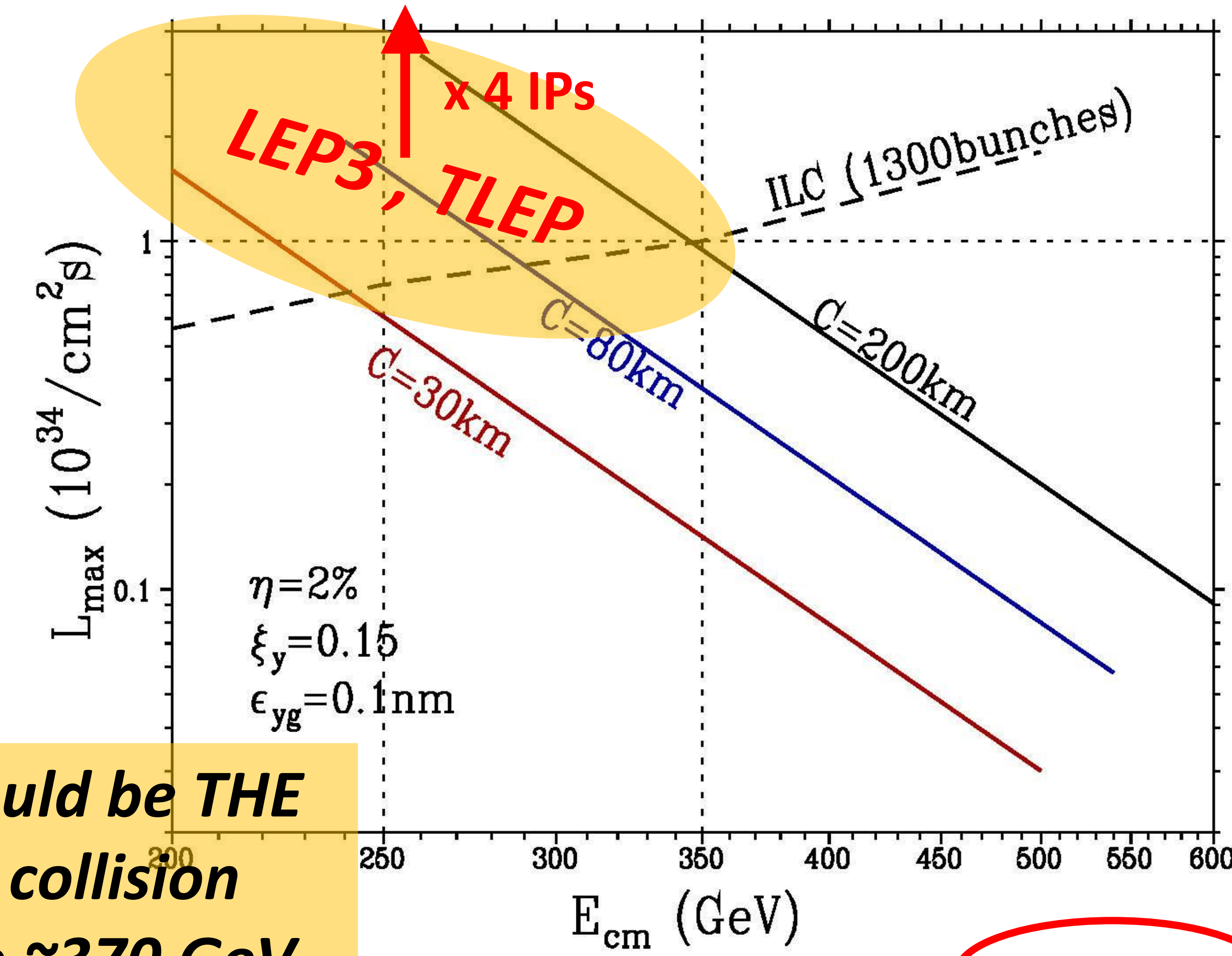
inofficial/official TLEP tunnel cost ~3.5 BCHF

TLEP/LEP3 key issues

- SR handling and radiation shielding
- optics effect energy sawtooth
  [separate arcs?! (K. Oide)]
- beam-beam interaction for large Q_s
  and significant hourglass effect
- IR design with large momentum acceptance
- integration with LHC or VHE-LHC
- Pretzel scheme for TERA-Z operation?
- impedance effects for high-current running
  at Z pole

Circular & Linear HF: peak luminosity vs energy

example with
- η=2%
- ξ_y=0.15
- ε_{gy}=0.1nm



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

K. Yokoya, KEK

comparing expected performance on Higgs coupling

Table 2.1: Expected performance on the Higgs boson couplings from the LHC and e^+e^- colliders, as compiled from the Higgs Factory 2012 workshop. Many studies are quite recent and still ongoing.

Accelerator → Physical Quantity ↓	**LHC** 300 fb^{-1} /expt	**HL-LHC** 3000 fb^{-1} /expt	**ILC** 250 GeV 250 fb^{-1} 5 yrs	**Full ILC** 250+350+ 1000 GeV 5yrs each	**CLIC** 350 GeV (500 fb^{-1}) 1.4 TeV (1.5 ab^{-1}) 5 yrs each	**LEP3, 4 IP** 240 GeV 2 ab^{-1} (*) 5 yrs	**TLEP, 4 IP** 240 GeV 10 ab^{-1} 5 yrs (*) 350 GeV 1.4 ab^{-1} 5 yrs (*)
N_H	1.7×10^7	1.7×10^8	6×10^4 ZH	10^5 ZH 1.4×10^5 Hνν	7.5×10^4 ZH 4.7×10^5 Hνν	4×10^5 ZH	2×10^6 ZH 3.5×10^4 Hνν
m_H (MeV)	100	50	35	35	100	26	7
$\Delta\Gamma_H / \Gamma_H$	--	--	10%	3%	ongoing	4%	1.3%
$\Delta\Gamma_{inv} / \Gamma_H$	Indirect (30%?)	Indirect (10% ?)	1.5%	1.0%	ongoing	0.35%	0.15%
$\Delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$	6.5 – 5.1%	5.4 – 1.5%	--	5%	ongoing	3.4%	1.4%
$\Delta g_{Hgg} / g_{Hgg}$	11 – 5.7%	7.5 – 2.7%	4.5%	2.5%	< 3%	2.2%	0.7%
$\Delta g_{Hww} / g_{Hww}$	5.7 – 2.7%	4.5 – 1.0%	4.3%	1%	~1%	1.5%	0.25%
$\Delta g_{HZZ} / g_{HZZ}$	5.7 – 2.7%	4.5 – 1.0%	1.3%	1.5%	~1%	0.65%	0.2%
$\Delta g_{HHH} / g_{HHH}$	--	< 30% (2 expts)	--	~30%	~21% (~11% at 3 TeV)	--	--
$\Delta g_{H\mu\mu} / g_{H\mu\mu}$	< 30%	< 10%	--	--	10%	14%	7%
$\Delta g_{H\tau\tau} / g_{H\tau\tau}$	8.5 – 5.1%	5.4 – 2.0%	3.5%	2.5%	≤ 3%	1.5%	0.4%
$\Delta g_{Hcc} / g_{Hcc}$	--	--	3.7%	2%	2%	2.0%	0.65%
$\Delta g_{Hbb} / g_{Hbb}$	15 – 6.9%	11 —2.7%	1.4%	1%	1%	0.7%	0.22%
$\Delta g_{Htt} / g_{Htt}$	14 – 8.7%	8.0 – 3.9%	--	5%	[illegible]	--	30%

TLEP has the best capabilities

(*) The total luminosity is the sum of the integrated luminosity at four IPs.

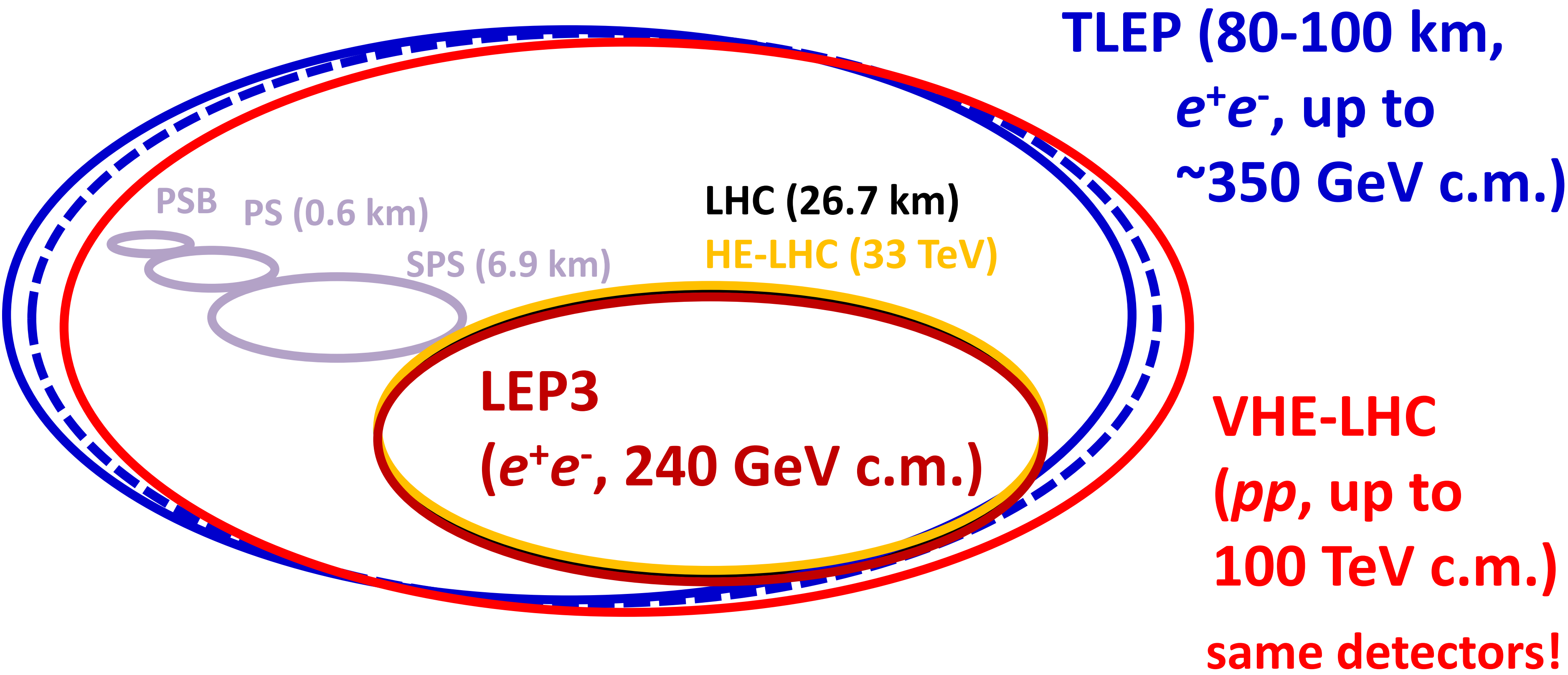
Report of the ICFA Beam Dynamics Workshop ***"Accelerators for a Higgs Factory: Linear vs. Circular"*** **(HF2012) by** Alain Blondel, Alex Chao, Weiren Chou, Jie Gao, Daniel Schulte and Kaoru Yokoya, FERMILAB-CONF-13-037-APC, IHEP-AC-2013-1, SLAC-PUB-15370, CERN-ATS-2013-032, arXiv:1302.3318 [physics.acc-ph]

risk?

extrapolation from past experience

	LEP2→TLEP-H	SLC→ILC 250
peak luminosity	x400	x2500
energy	x1.15	x2.5
vertical geom. emittance	x1/5	x1/400
vert. IP beam size	x1/15	x1/150
e^+ production rate	x1/2 !	x65
commissioning time	<1 year → ?	>10 years →?

circular Higgs factories at CERN & beyond



& $e^\pm$ **(120 GeV) – *p* (7, 16 & 50 TeV)** collisions (**[(V)HE-]TLHeC**)

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

a long-term strategy for HEP!

Mikhail S. Gorbachev

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

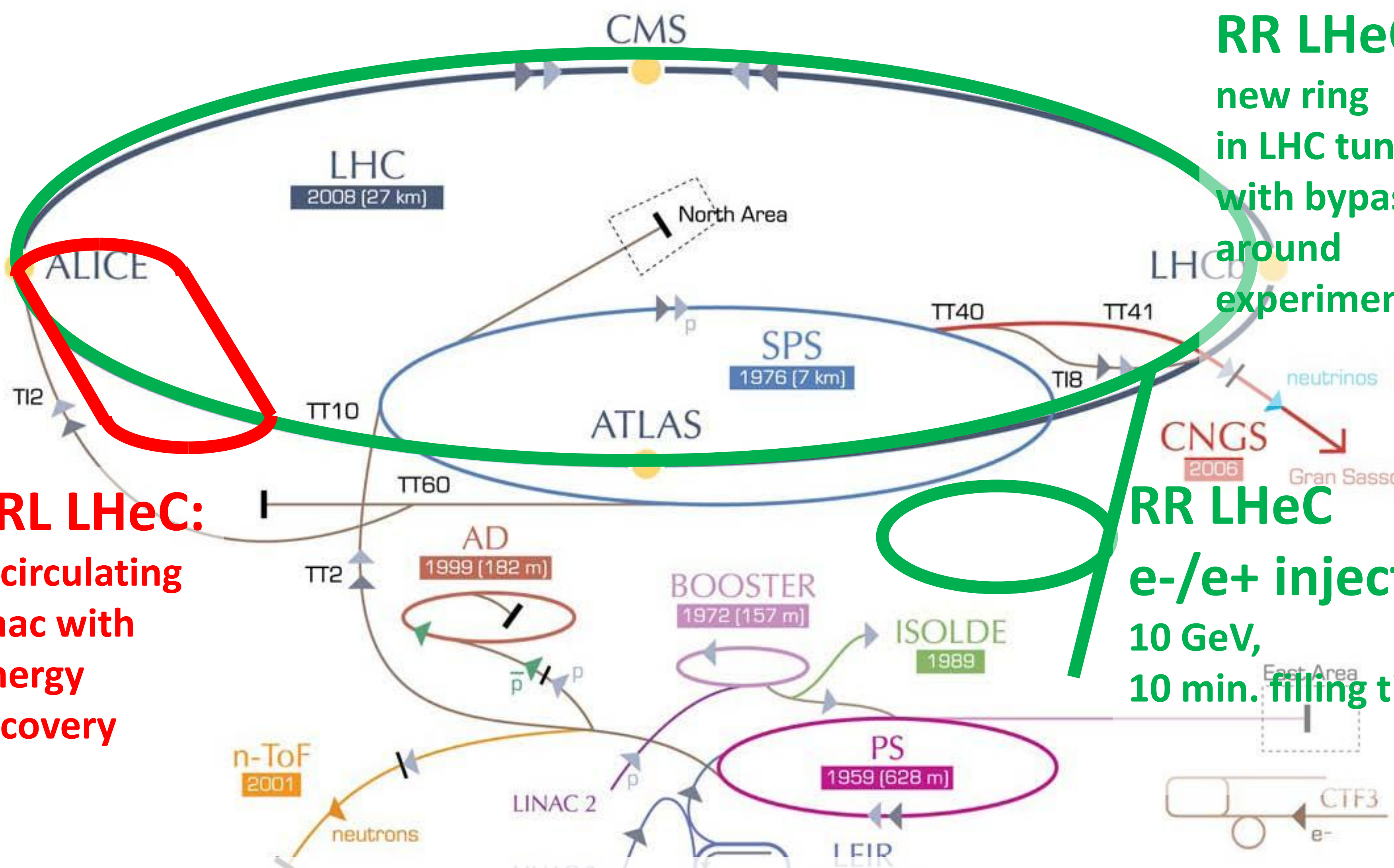
further pushing TLEP luminosity

- **charge compensation** - counteracting the electric field of the incoming beam by a second beam of opposite charge
- 4-beam collisions at DCI, Orsay, 1971

  - not a spectacular success
- new idea (V. Telnov, M. Koratzinos): use charge compensation to **suppress beamstrahlung and push luminosity in crab-waist scheme**
- **potential gain: factor 10 ($\rightarrow 5\times10^{35}$ cm^{-2}s^{-1})**

LHeC

Large Hadron electron Collider (LHeC)



RR LHeC:
new ring
in LHC tunnel,
with bypasses
around
experiments

ERL LHeC:
recirculating
linac with
energy
recovery

RR LHeC
e-/e+ injector
10 GeV,
10 min. filling time

At 2012 CERN-ECFA-NuPECC LHeC workshop ERL-LHeC was selected as baseline (*RR LHeC issues: HL-LHC schedule, tunnel work, interference*)

LHeC Conceptual Design Report

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

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

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

http://cern.ch/lhec

LHeC Study Group

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About 150 Experimentalists and Theorists from 50 Institutes
Tentative list

Thanks to all and to CERN, ECFA, NuPECC

~600 pages

LHeC Higgs physics

- 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*) vertices

L-R LHeC road map to ≥10^{33} cm^{-2}s^{-1}

luminosity of LR collider:

(round beams)

H_D~1.3

D. Schulte LHeC2010

$$L = \frac{1}{4\pi e} \frac{N_{b,p}}{\varepsilon_p} \frac{1}{\beta_p^*} I_e H_{hg} H_D$$

highest proton beam brightness "permitted" (ultimate LHC values)

$\gamma\varepsilon$=3.75 μm

N_b=1.7x10^{11}

bunch spacing 25 or 50 ns

smallest conceivable proton β* function:

- reduced *l** (23 m → 10 m)
- squeeze only one *p* beam
- new magnet technology Nb_3Sn

β^*_p=0.1 m

average e$^-$ current limited by energy recovery efficiency

I_e=6.4 mA

maximize geometric overlap factor

- head-on collision
- small e- emittance

θ_c=0

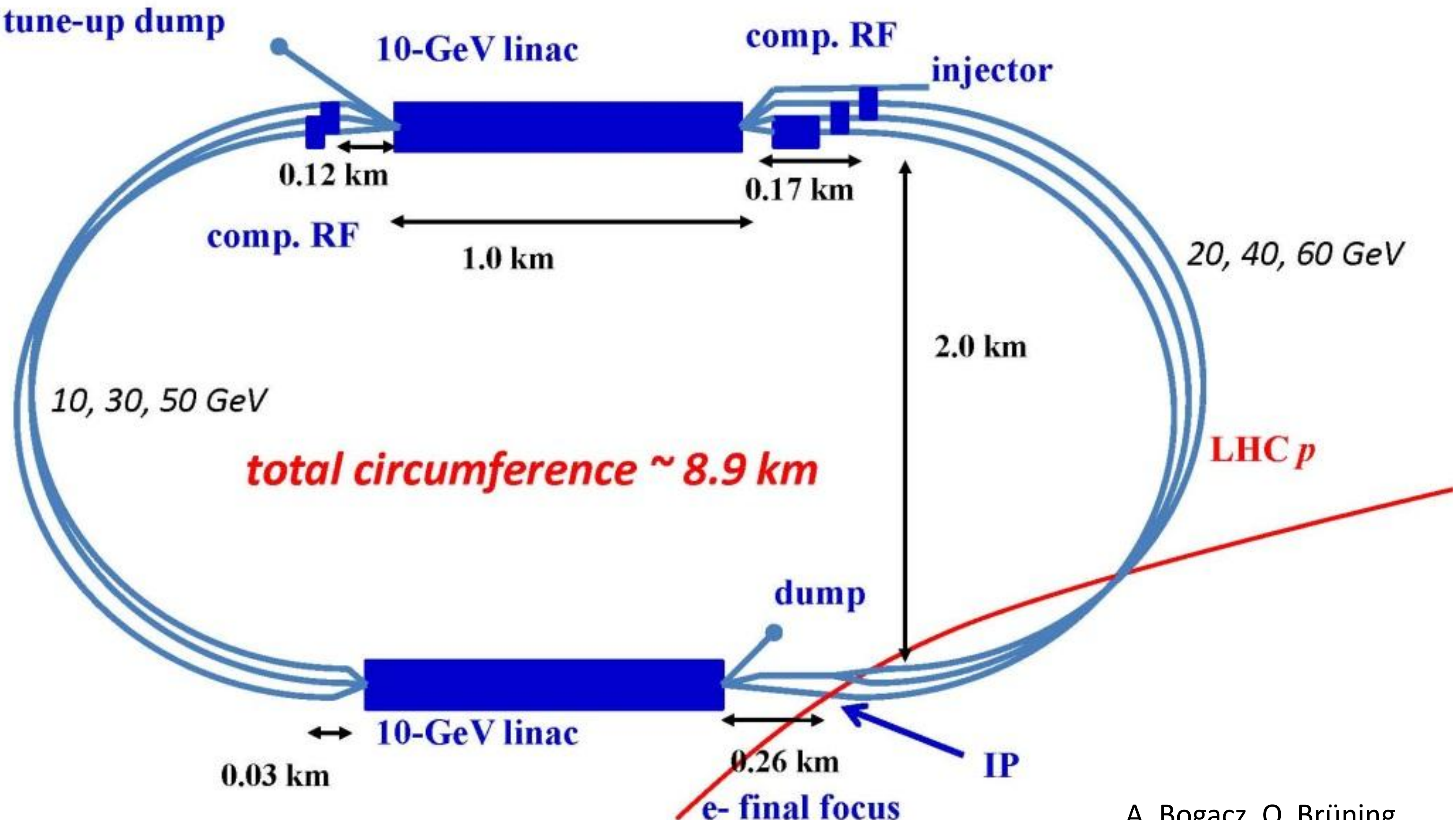
H_{hg}≥0.9

LHeC baseline (& pushed) parameters

parameter [unit]	LHeC	
species	***$e^{\pm}$***	***p, $^{208}Pb^{82+}$***
beam energy (/nucleon) [GeV]	60	7000, 2760
bunch spacing [ns]	25, 100	25, 100
bunch intensity (nucleon) [10^{10}]	0.1 (0.2), 0.4	17 (22), 2.5
beam current [mA]	6.4 (12.8)	860 (1110), 6
rms bunch length [mm]	0.6	75.5
polarization [%]	90 (e^+ none)	none, none
normalized rms emittance [μm]	50	3.75 (2.0), 1.5
geometric rms emittance [nm]	0.43	0.50 (0.31)
IP beta function $\beta^*_{x,y}$ [m]	0.12 (0.032)	0.1 (0.05)
IP rms spot size [μm]	**7.2 (3.7)**	**7.2 (3.7)**
synchrotron tune	-	0.0019
hadron beam-beam parameter	0.0001 (0.0002)	
lepton disruption parameter D	6 (30)	
hourglass reduction factor H_{hg}	0.91 (0.67)	
pinch enhancement factor H_D	1.35 (0.3 for e^+)	
luminosity/ nucleon [10^{33} cm^{-2}s^{-1}]	**1 (10), 0.2**	

LHeC ERL layout

two 10-GeV SC linacs, 3-pass up, 3-pass down; 6.4 mA, 60 GeV e^-'s collide w. LHC protons/ions



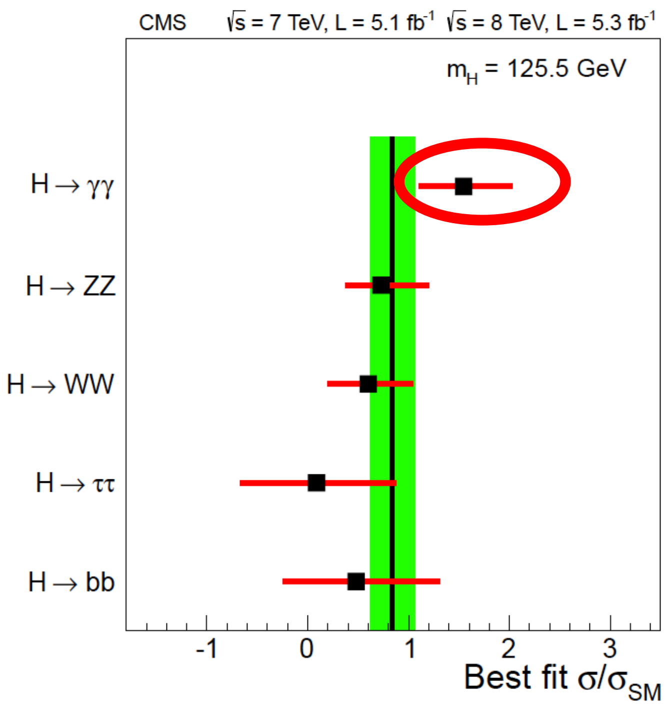
(C=1/3 LHC allows for ion clearing gaps)

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

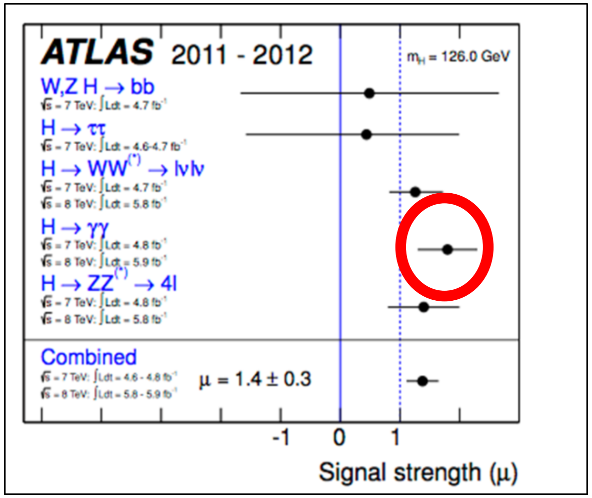

SAPPHiRE

X(125) seems to strongly couple to $\gamma\gamma$

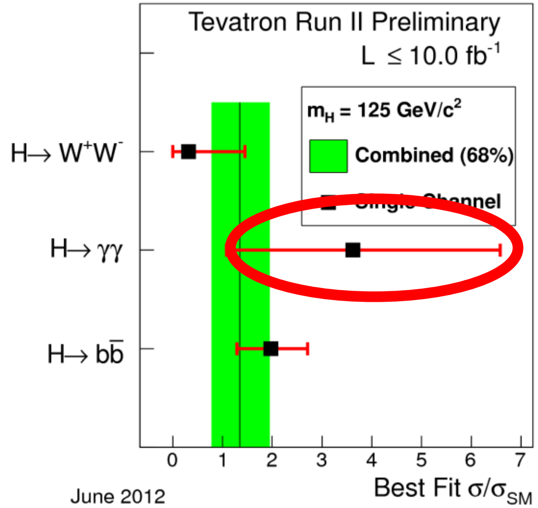
LHC CMS result (2012)



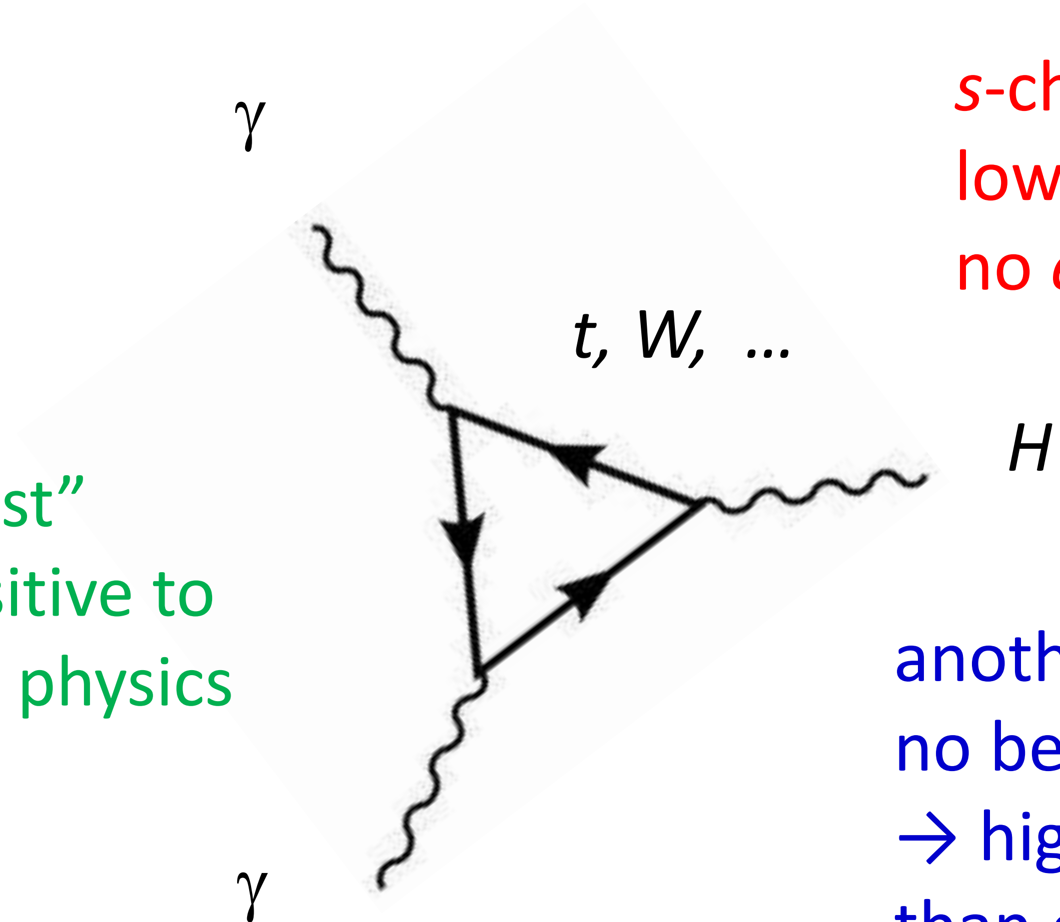
LHC ATLAS result (2012)



TeV Run-II result



a new type of collider?



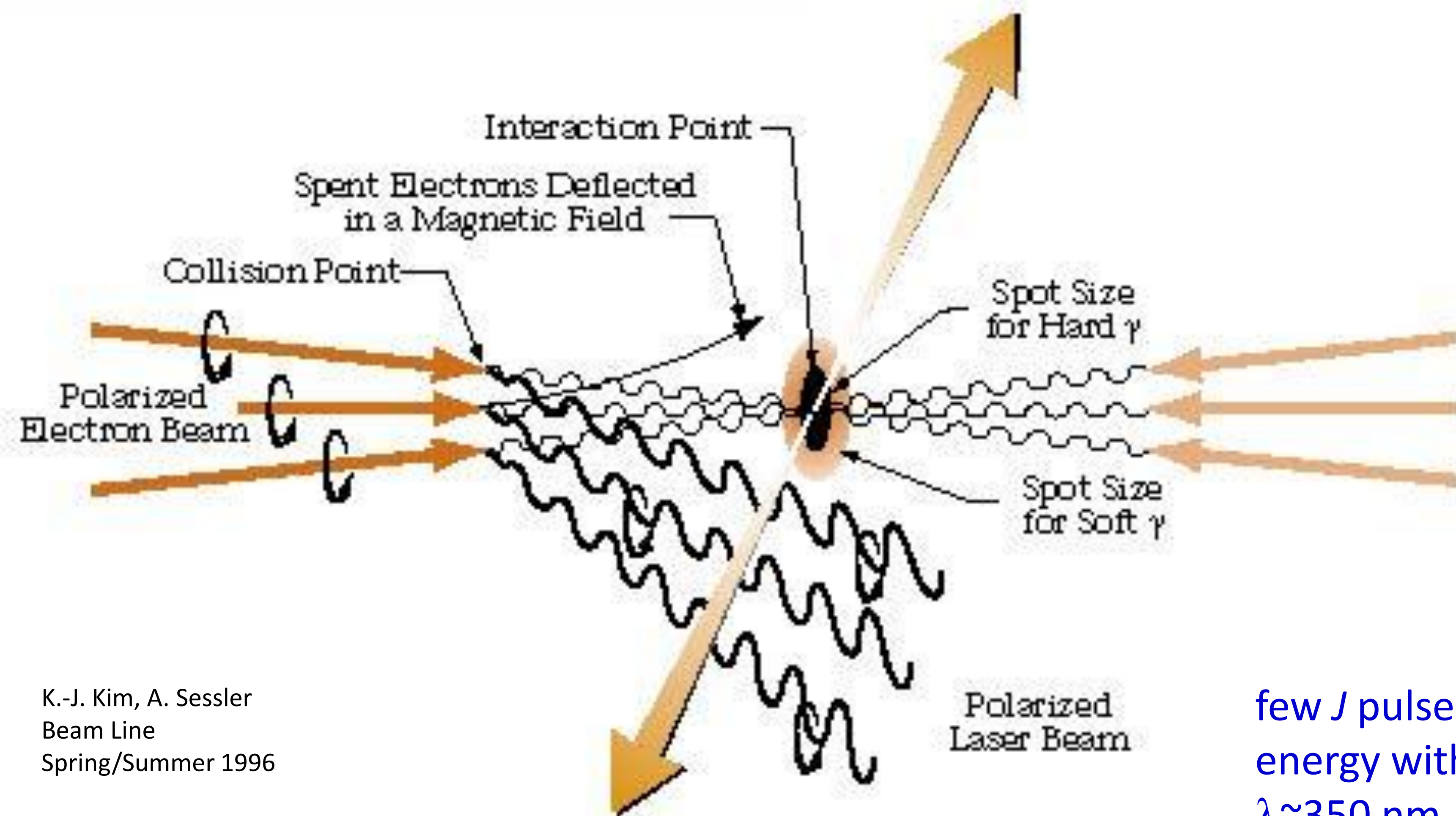
s-channel production;
lower energy;
no e^+ source

“most”
sensitive to
new physics

another advantage:
no beamstrahlung
→ higher energy reach
than e^+e^- colliders

γγ collider Higgs factory

$\gamma\gamma$ collider based on e^-



K.-J. Kim, A. Sessler
Beam Line
Spring/Summer 1996

few *J* pulse energy with λ~350 nm

combining photon science & particle physics!

which beam & photon energy / wavelength?

$$E_{\gamma,max} = \frac{x}{1+x} E_{beam}$$

$$x = \frac{4E_e \omega_L}{m_e^2} \cos^2 \frac{\theta}{2}$$

example $x \approx 4.3$

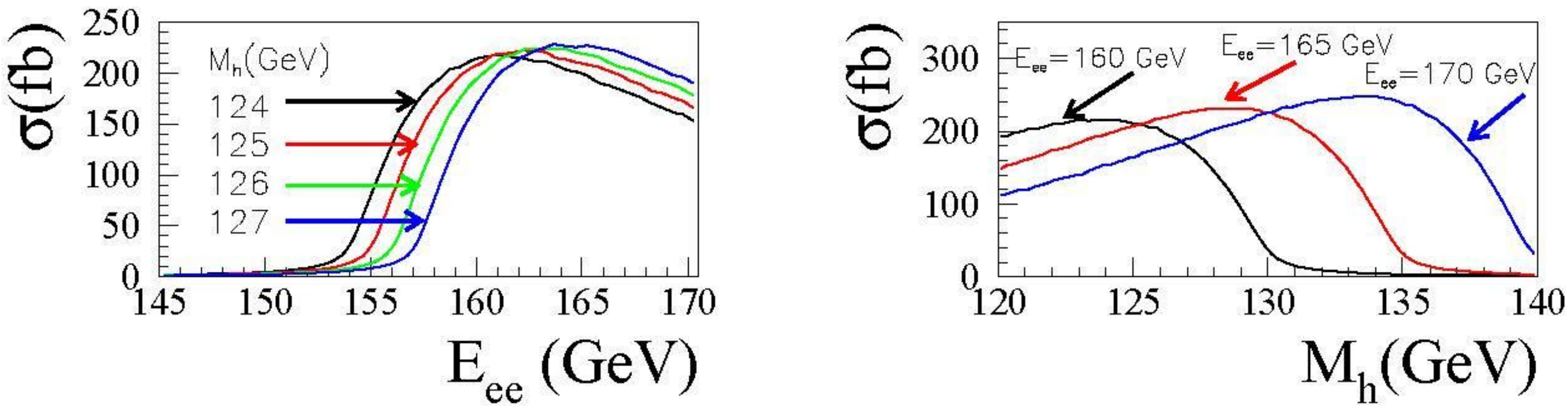
(for x>4.83 coherent pair production occurs)

with $E_{beam} \approx 80$ GeV: $E_{\gamma,max} \approx 66$ GeV

$E_{CM,max} \approx 132$ GeV

E_{photon} ~3.53 eV , λ~351 nm

Higgs $\gamma\gamma$ production cross section



Left: The cross sections for $\gamma\gamma \to$ h *for different values of* M_h *as functions of* E_{CM}*(*e^-e^-*).*

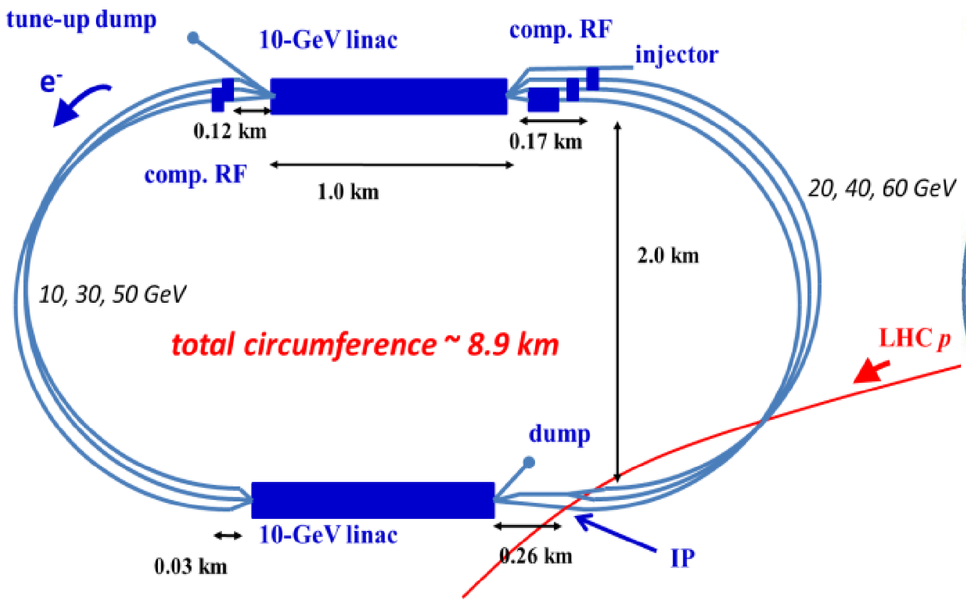
Right: The cross section for $\gamma\gamma \to$ h *as a function of* M_h *for three different values of* E_{CM}*(*e^-e^-*).*

Assumptions: electrons have 80% longitudinal polarization and lasers are circularly polarized, so that produced photons are highly circularly polarized at their maximum energy.

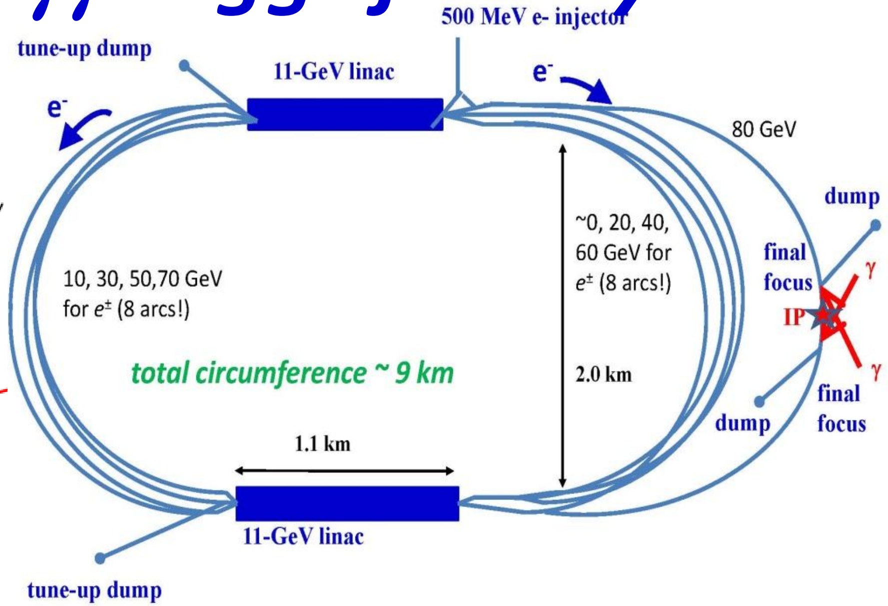
S.A. Bogacz et al, arXiv:1208.2827v1

Reconfiguring *LHeC → SAPPHiRE*

LHeC-ERL

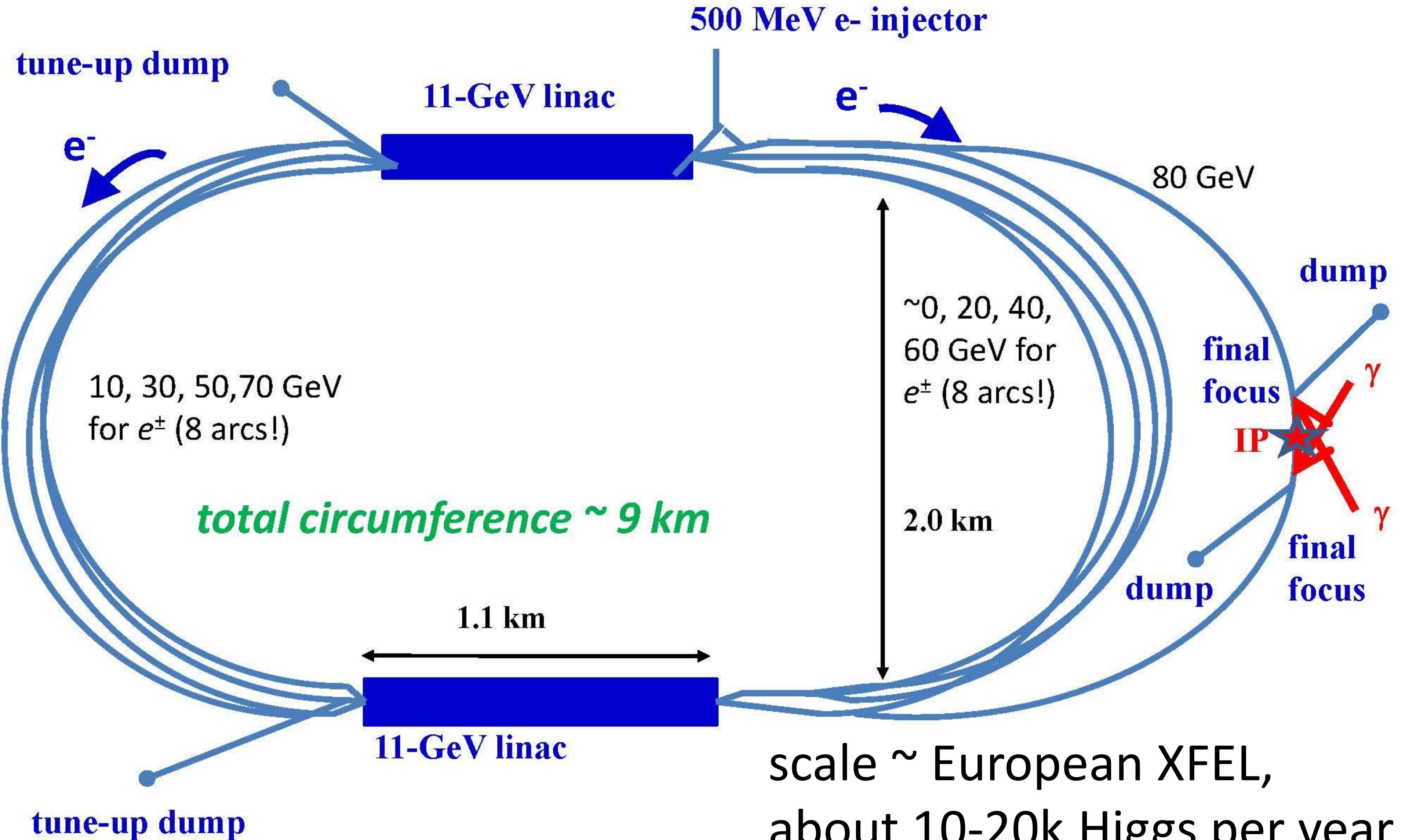


*SAPPHiRE**
γγ Higgs factory



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

SAPPHiRE: a Small $\gamma\gamma$ Higgs Factory



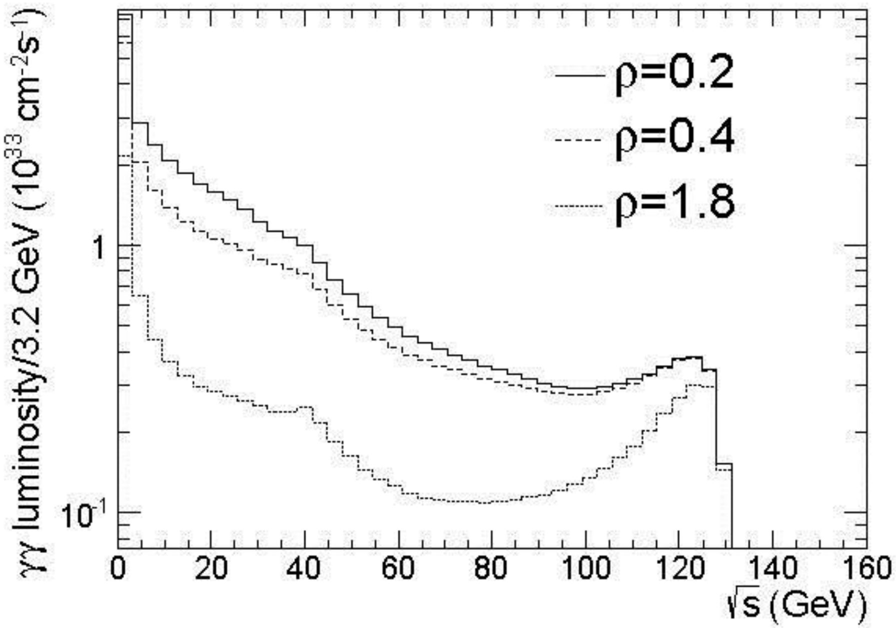
scale ~ European XFEL,
about 10-20k Higgs per year

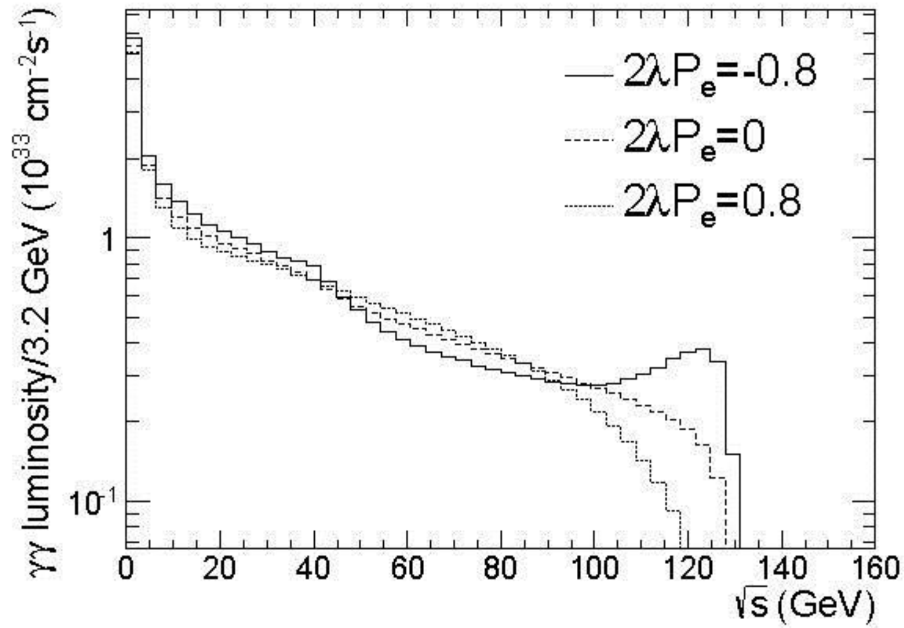
SAPPHiRE: Small Accelerator for Photon-Photon Higgs production using Recirculating Electrons

SAPPHiRE	symbol	value
total electric power	P	100 MW
beam energy	E	80 GeV
beam polarization	P_e	0.80
bunch population	N_b	10^{10}
repetition rate	f_{rep}	200 kHz
bunch length	σ_z	30 μm
crossing angle	θ_c	≥20 mrad
normalized horizontal/vert. emittance	$\gamma\varepsilon_{x,y}$	5,0.5 μm
horizontal IP beta function	β_x^*	5 mm
vertical IP beta function	β_y^*	0.1 mm
horizontal rms IP spot size	σ_x^*	400 nm
vertical rms IP spot size	σ_y^*	18 nm
horizontal rms CP spot size	σ_x^{CP}	400 nm
vertical rms CP spot size	σ_y^{CP}	440 nm
e^-e^- geometric luminosity	L_{ee}	$2\text{x}10^{34}$ $cm^{-2}s^{-1}$

SAPPHiRE $\gamma\gamma$ luminosity

M. Zanetti





luminosity spectra for SAPPHiRE as functions of $E_{CM}(\gamma\gamma)$, computed using Guinea-Pig for **three possible normalized distances** $\rho \equiv l_{CP\text{-}IP}/(\gamma\sigma_y^*)$ (left) and **different polarizations of in-coming particles** (right)

synchrotron radiation - energy loss

- energy loss per arc: $$\Delta E[GeV] = 8.864 \times 10^{-5} \frac{E^4[GeV]}{2\rho[m]}$$
- Sapphire (LHeC): ρ=764m => electrons lose 4 GeV
- can be compensated by increasing linacs to 10.5 GeV

beam energy [GeV]	ΔE_{arc} [GeV]	$\Delta\sigma_E$ [MeV]
10	0.0006	0.038
20	0.009	0.43
30	0.05	1.7
40	0.15	5.0
50	0.36	10
60	0.75	20
70	1.39	35
80	1.19	27
total	**3.89**	**57 (0.071%)**

e^- beam emittance growth due to SR

- **horizontal emittance growth** of the electron beam may be a severe limitation:

$$\Delta\varepsilon_N = \frac{2\pi C_q r_e}{3\rho^2}\gamma^6\langle H\rangle$$

- LHeC optics (l_{bend}=10m, ρ=764m, <H>=1.2x10^{-3}m) leads to too high an emittance growth ($\Delta\varepsilon_N$=13μm at 60 GeV)
  - 80 GeV instead of 60
  - <H> scale as l^3_{bend}/ρ^2 => **shorten l_{bend} by factor 4=> down to 1μm at 80 GeV**

flat polarized e- guns

FNAL A0 line injector test facility:

- starting with $\gamma\varepsilon$~4-5 μm at 0.5 nC, achieved emittances of 40 μm horizontally and 0.4 μm vertically (**$\varepsilon_x/\varepsilon_y$~100**)

SAPPHiRE needs only $\varepsilon_x/\varepsilon_y$=10, but:

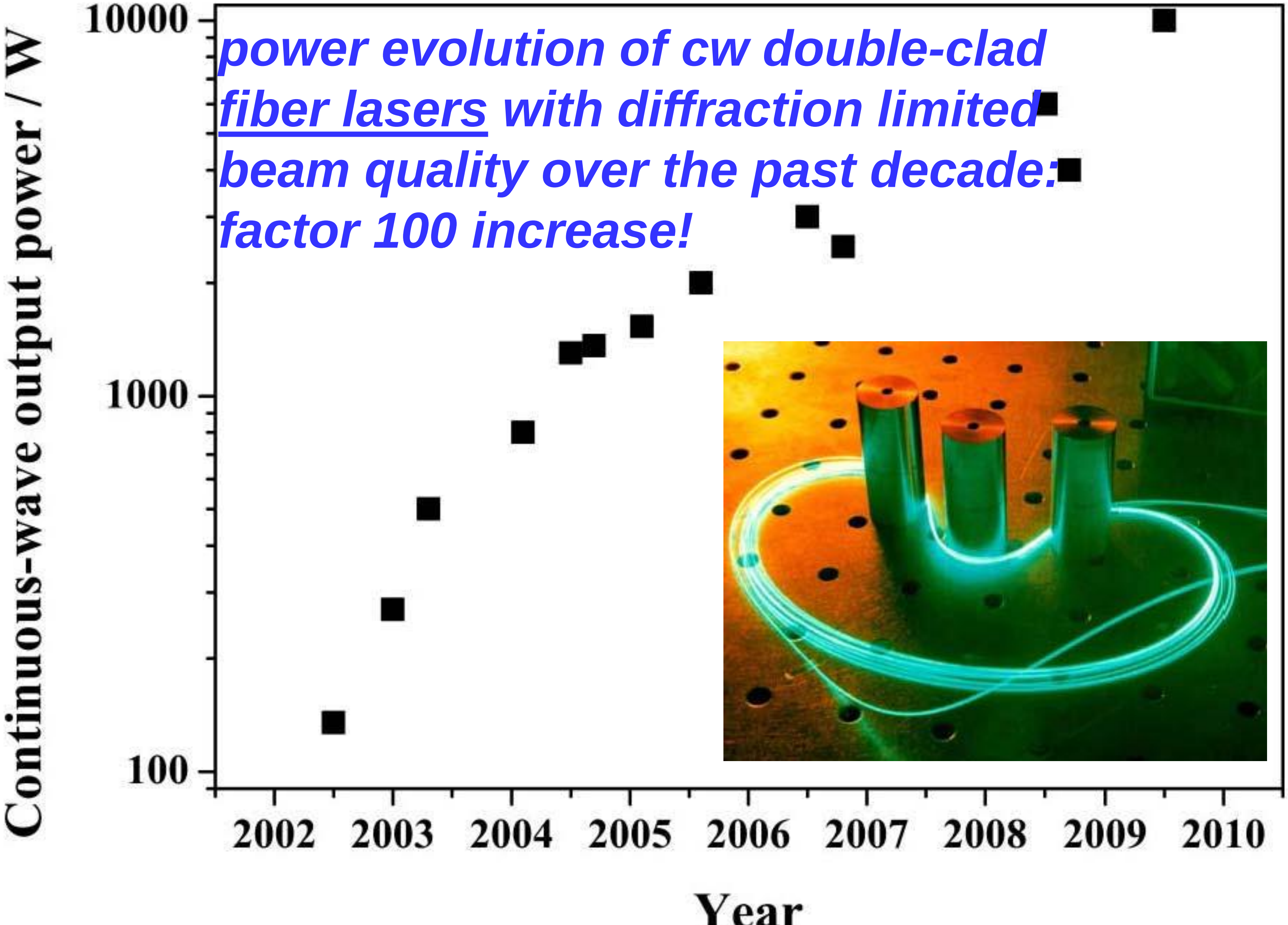
- **larger bunch charge 1.6 nC and smaller initial $\gamma\varepsilon$ ~1.5 μm**
- altogether, within state of the art

main question is whether we can get **polarized beams with SAPPHiRE parameters**

ongoing efforts:

- **low-emittance DC guns**
  - MIT-Bates, Cornell, JAEA, KEK [E. Tsentalovich, I. Bazarov, et al]
- **polarized SRF guns**
  - FZD, BNL, etc. [J. Teichert, J. Kewisch, et al]

laser progress: example fiber lasers



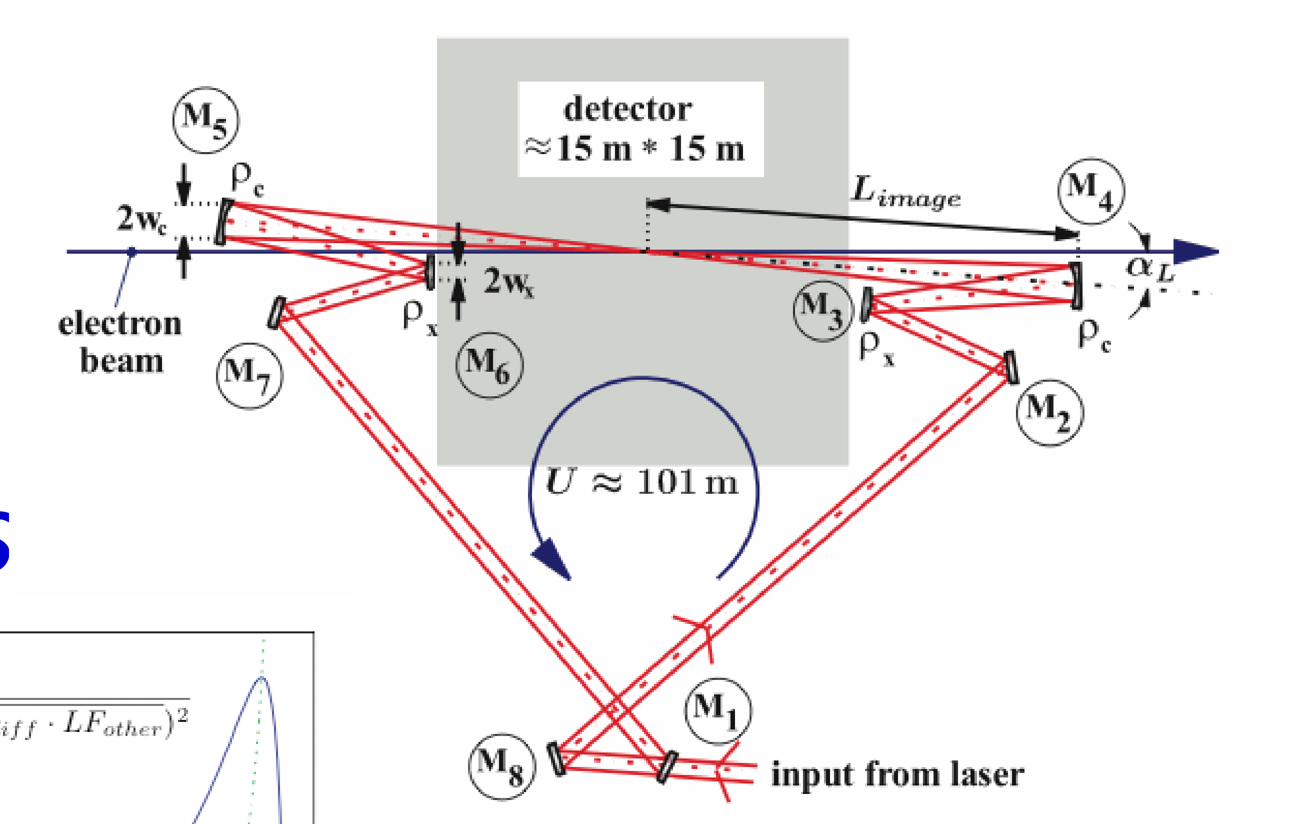
power evolution of cw double-clad fiber lasers with diffraction limited beam quality over the past decade: factor 100 increase!

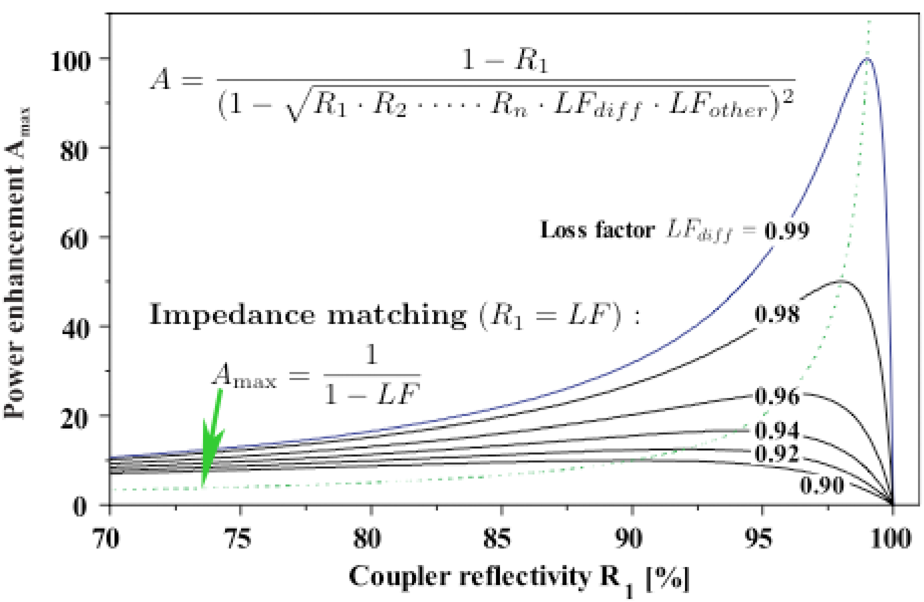
Source: Fiber lasers and amplifiers: an ultrafast performance evolution, Jens Limpert, Thomas Schreiber, and Andreas Tünnermann, Applied Optics, Vol. 49, No. 25 (2010)

passive optical cavity

→

relaxed laser parameters



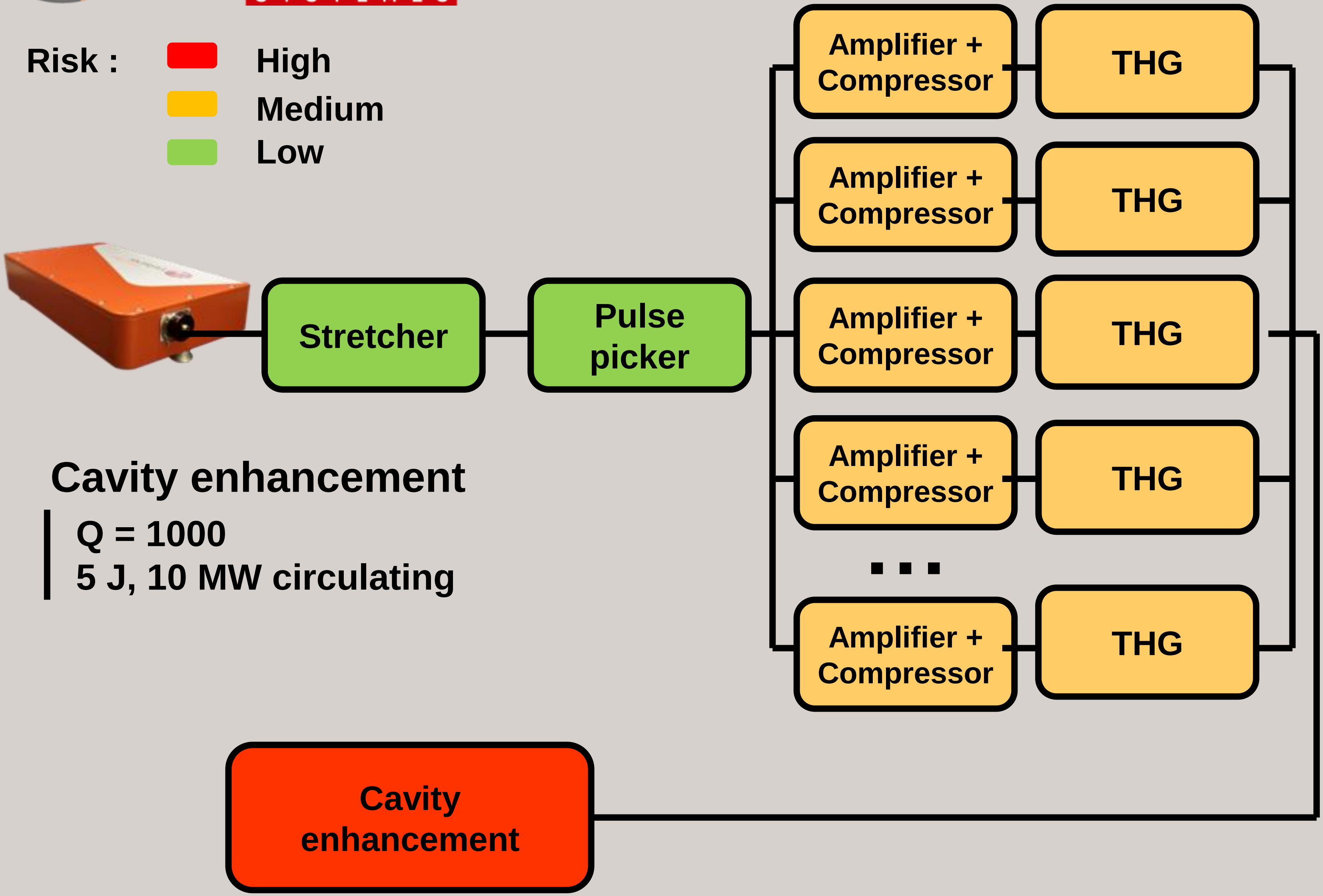


K. Moenig et al, DESY Zeuthen

Amplitude SYSTEMES

SAPPHiRE laser

Risk :
- High
- Medium
- Low



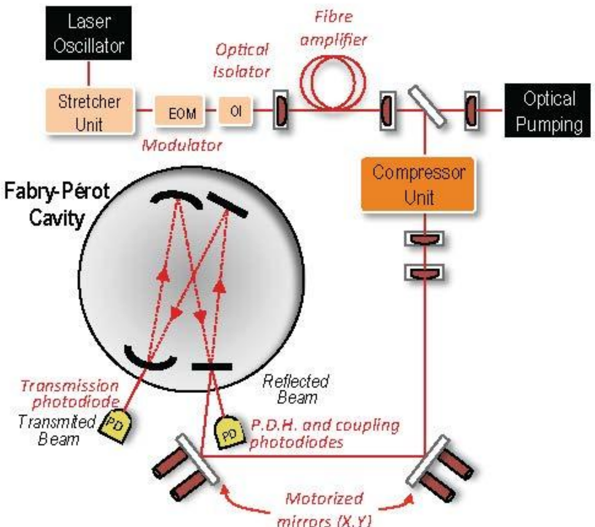
Cavity enhancement

Q = 1000
5 J, 10 MW circulating

www.amplitude-systemes.com

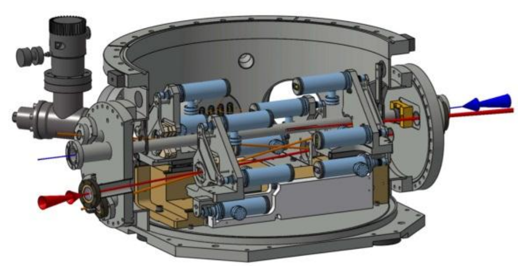
LAL *MightyLaser* experiment at **KEK-ATF**

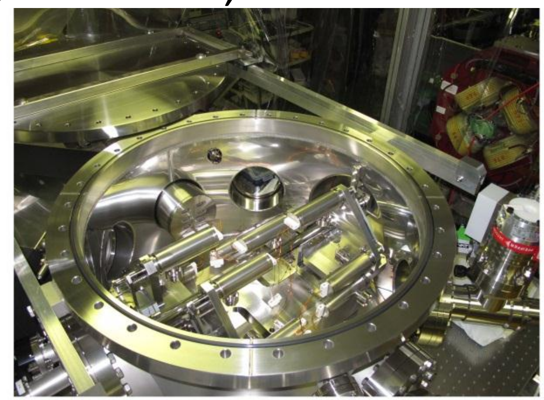
non-planar high finesse four mirror Fabry-Perot cavity; first Compton collisions observed in October 2010



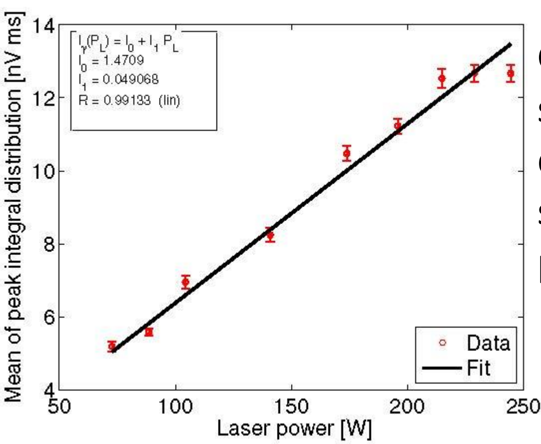
Optical system used for laser power amplification and to inject laser into FPC

I. Chaikovska, N. Delerue, A. Variola, F. Zomer et al

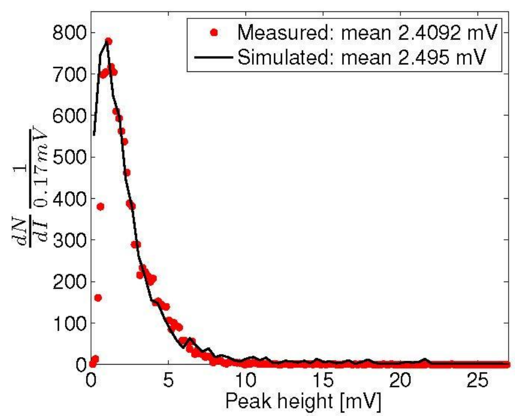




Vacuum vessel for Fabry-Perot cavity installed at ATF



Gamma ray spectrum for different FPC stored laser power

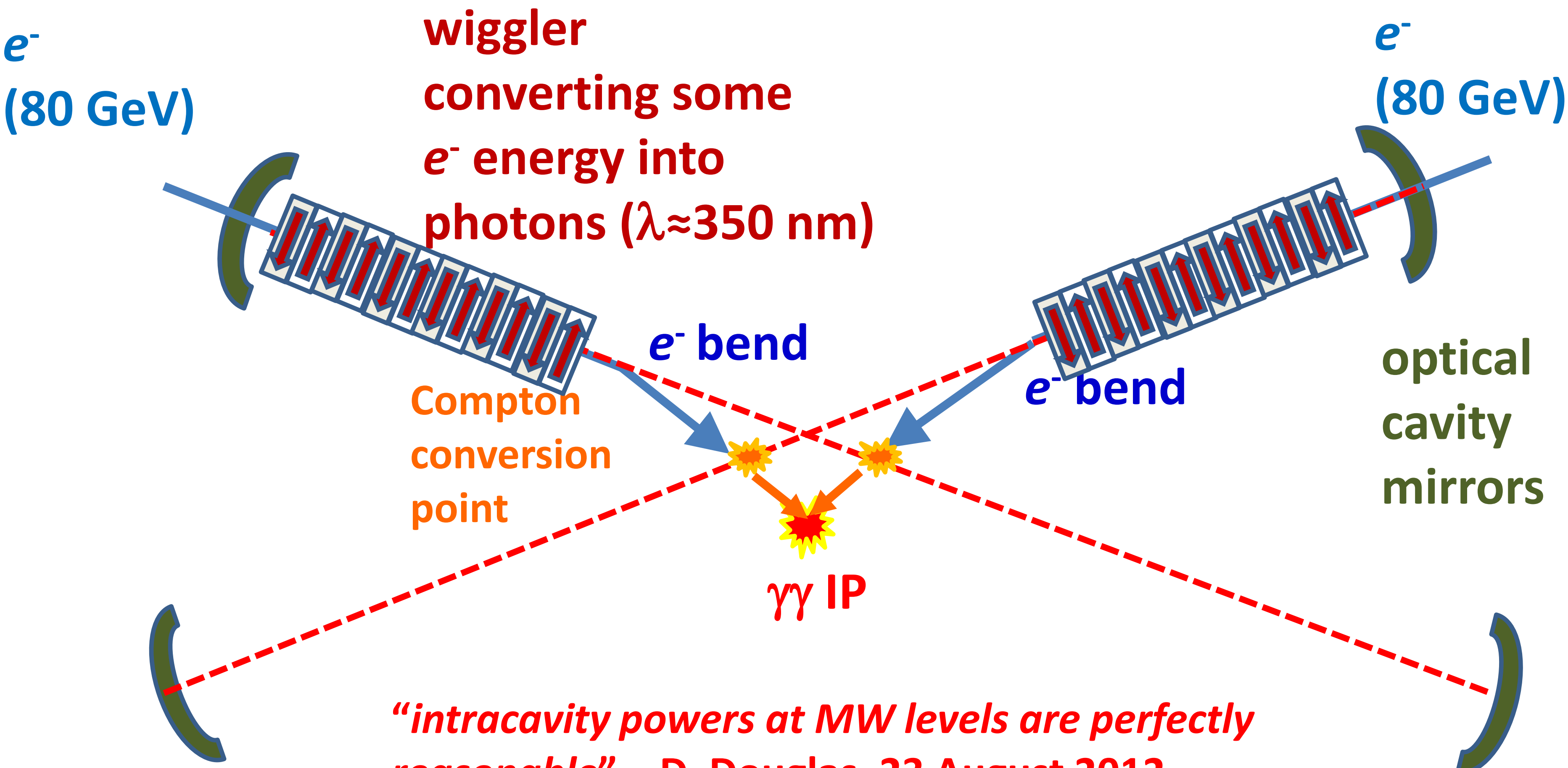


Comparison of measured and simulated gamma-ray energy spectra from Compton scattering

Plan: improve laser and FPC mirrors & gain several orders

I. Chaikovska, PhD thesis to be published

self-generated or separate FEL pulses (instead of laser)?



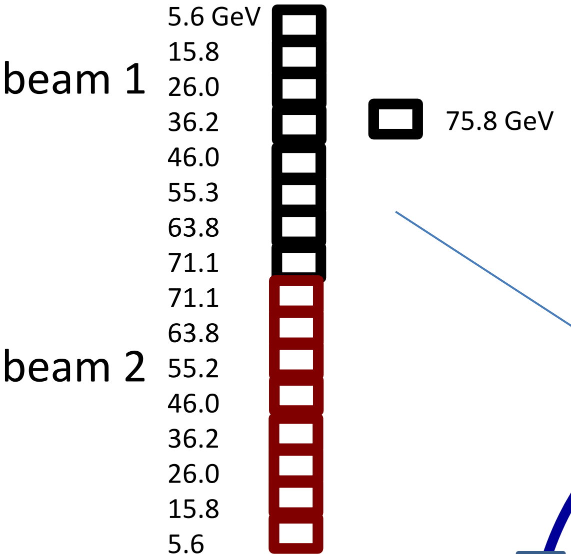
"intracavity powers at MW levels are perfectly reasonable" – D. Douglas, 23 August 2012

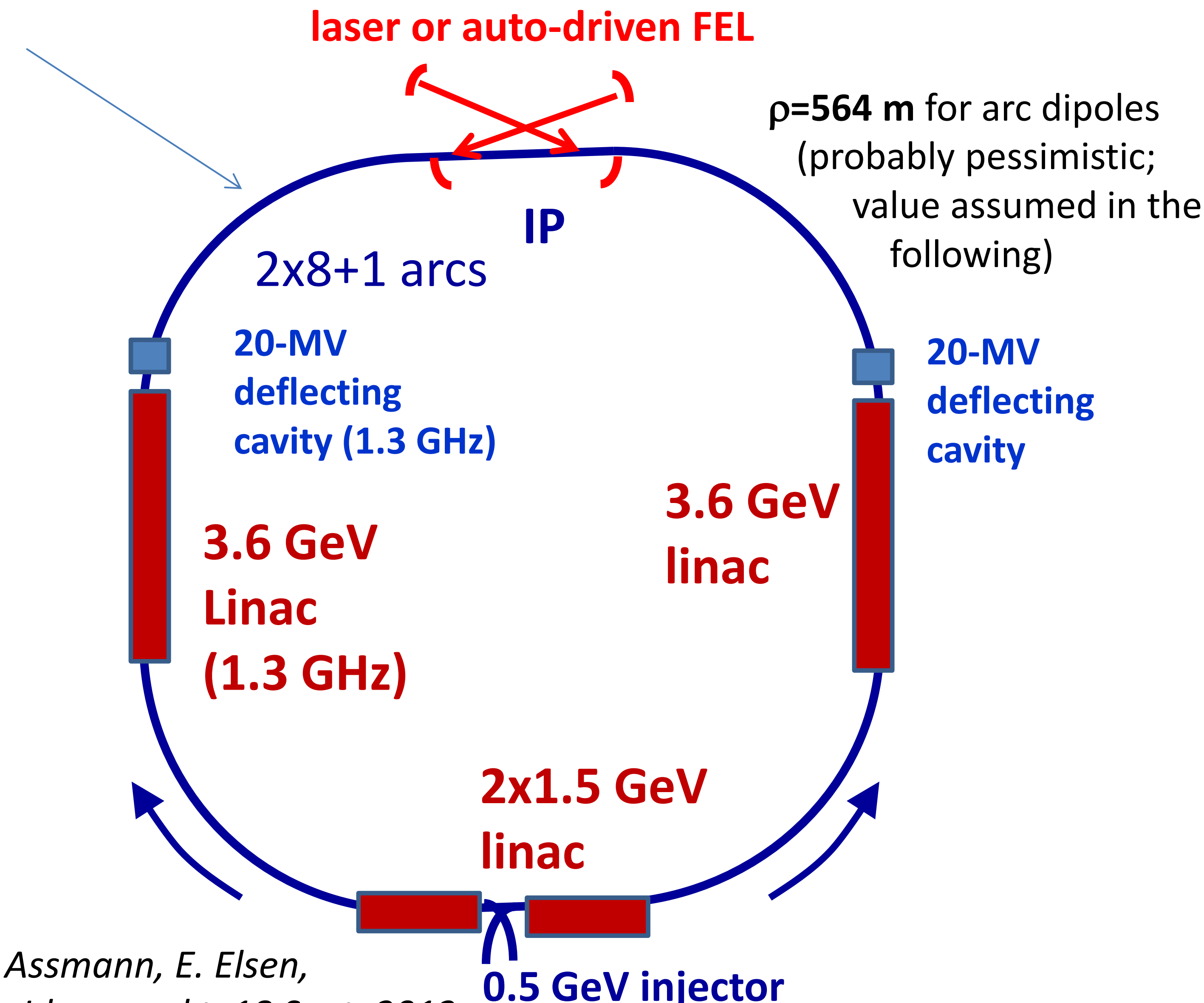
example:
λ_u=200 cm, B=0.625 T, L_u=100 m, $U_{0,SR}$=0.16 GeV, 0.1%P_{beam}≈25 kW

scheme developed with Z. Huang

HERA Tunnel Filler

arc magnets -17 passes!





real-estate
linac
Gradient
~ 10 MV/m

total
SC RF =
10.2 GV

F. Zimmermann, R. Assmann, E. Elsen,
DESY Beschleuniger-Ideenmarkt, 18 Sept. 2012

Edward Nissen

Town Hall meeting Dec 19 2011

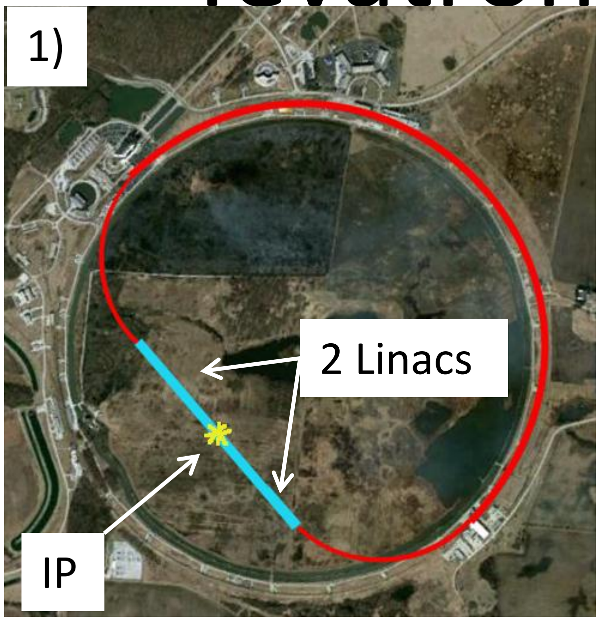
Possible Configurations at JLAB

85 GeV Electron energy
γ c.o.m. 141 GeV

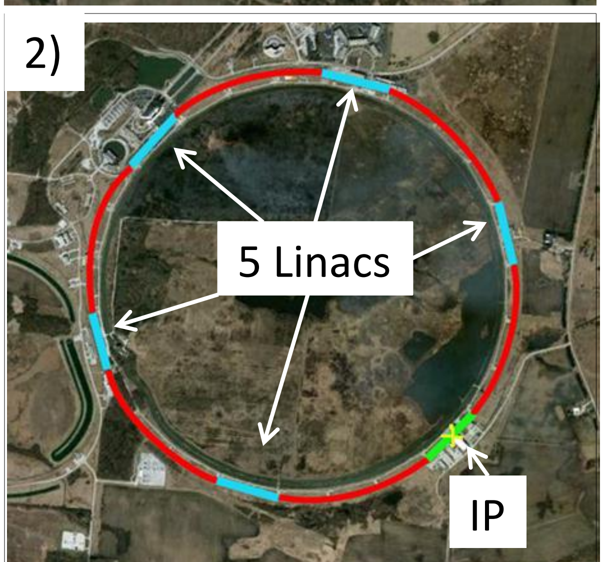
103 GeV Electron energy
γ c.o.m. 170 GeV

Edward Nissen

Possible Configurations at FNAL Tevatron Tunnel Filler Options



Top Energy	80 GeV	80 GeV
Turns	4	5
Avg. Mag. ρ	661.9 m	701.1 m
Linacs (2)	10.68GeV	8.64GeV
δp/p	8.84×10^{-4}	8.95×10^{-4}
ϵ_{nx} Growth	2.8μm	2.85μm



Top Energy	80 GeV	80 GeV
Turns	3	4
Magnet ρ	644.75 m	706.65 m
Linacs (5)	5.59GeV	4.23GeV
δp/p	6.99×10^{-4}	7.2×10^{-4}
ϵ_{nx} Growth	1.7μm	1.8μm

- Both versions assume an effective accelerating gradient of 23.5 MeV/m
- Option 1: would require more civil construction, but would only require two sets of spreader /recombiner magnets, and only two linacs, for greater simplicity.
- Option 2: would require 10 sets of spreader /recombiner magnets and 5 linacs but would achieve better beam parameters

SAPPHiRE R&D items

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

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	72 (*35*), 65
SuperKEKB	*50*
SAPPHiRE	***18***
ILC	*5 – 8*
CLIC	*1 – 2*

β_y^*: 5 cm→ 1 mm

LEP3/TLEP will learn from ATF2 & SuperKEKB

SAPPHiRE a step towards ILC/CLIC

Conclusions

LEP3, TLEP, SAPPHiRE & LHeC are exciting and popular projects

LEP3 and SAPPHiRE may be the **cheapest possible options to study the Higgs** (cost ~1BEuro scale), feasible, **"off the shelf", but**, esp. SAPPHiRE, **not easy**

TLEP is **more expensive** (~5 BEuro?), but **clearly superior in terms of energy & luminosity**, and it would be **extendable towards VHE-LHC**, preparing ≥50 years of exciting e^+e^-, *pp*, *ep/A* physics at highest energies

SuperKEKB will be TLEP demonstrator!

TLEP deserves a detailed design study

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

the path forward for TLEP

- set up **international collaboration(s) & work structure**
  - **ERC proposal** on large-acceptance IR design by Rogelio Tomas
  - TLEP **Design Study Proposal** for ECFA
  - **CEA-Saclay could play a strong role!**
- goal: publish **TLEP Conceptual Design Study Report by 2014/2015!**

European Research Council

ERC Consolidator Grant 2013

Research proposal [Part B1]

(to be evaluated in Step 1)

Towards a Higgs factory Accepting Large Energy Spread

THALES

Cover Page:
Name of the Principal Investigator (PI): Rogelio Tomas Garcia

- Name of the PI's host institution for the project: CERN
- Proposal full title: Towards a Higgs factory Accepting Large Energy Spread
- Proposal short name: THALES
- Proposal duration in months: 60 months

A key issue for particle accelerators is to focus beams with the largest possible intensity so as to maximize collision rates. This issue has gained importance with the discovery in 2012 at the LHC of a Higgs-like particle. Among recent proposals for studying this particle are a new generation of circular e^+e^- colliders (Higgs factories) with higher energies and collision rates (luminosities) than LEP2. Achieving unprecedented Higgs production event rates will require squeezing the vertical beam sizes at the Interaction Point (IP) to a few 100 nm, requiring about a factor 50 lower vertical beta function at the collision point than at LEP2. This proposal will show how to meet this requirement, making technical advances that also have applications to a wide range of other accelerators. The performance of high-luminosity machines will be restricted by beamstrahlung, i.e., synchrotron radiation in the field of the opposing beam emitted during the collision, coupled with a limited momentum acceptance. Therefore, the first goal of the proposed project is to develop a low-beta interaction region (IR) and the associated non-linear ring optics for a circular Higgs factory collider with large momentum acceptance, so that particles with an energy error of 3% or more, suddenly introduced by the emission of highly-energetic beamstrahlung photons, circulate until they are damped back into the core of the beam by conventional synchrotron radiation in the collider arcs. The proposed study will produce a new type of final-focus design together with additional non-linear elements in the collider arcs to control remaining aberrations. In parallel, an IR design for a very-high-energy proton collider in the same tunnel with up to 100 TeV in the centre of mass will also be developed. This will open the way to a next-generation collider complex at the energy frontier. The novel IR concepts developed for these circular machines will have significant spin-offs that could be used to improve the design and performance of linear colliders, muon storage rings, light sources, and medical accelerators. In particular, there is a strong synergy with the laser-beam collision IR in the Compton storage ring for a polarized positron source, in which circulating electrons undergo large energy changes when they collide with the laser beam. This project is therefore of broad interest for a wide range of future accelerators with applications beyond high-energy physics.

ERC Consolidation Grant Proposal "THALES"

–

PI: Rogelio Tomas

includes international network for feeding new ideas, guidance, local support for experimental tests, review & collaboration

draft work topics: TLEP accelerator

- parameter optimization with regard to lifetime and luminosity, at different energies, & different tunnels
- RF system design, prototyping & integration for collider and accelerator ring
- optics design for collider ring including low-beta IRs, off-momentum dynamic aperture, different energies
- beamstrahlung: lifetime, steady state beam distribution, dependence on tune etc.
- beam-beam interaction with large hourglass effect
- emittance tuning studies, errors, tolerances, etc.
- optics design and beam dynamics for the accelerator ring, ramping speed etc
- impedance budget, CSR, instabilities
- cryogenics system design
- magnets design: collider ring dipole, accelerator ring dipole, low-beta quadrupole
- radiation, shielding, cooling for 100 MW SR power
- vacuum system design
- engineering study of 80-km tunnel
- design of injector complex including e+ source, and polarized e- source
- machine detector interface, integration of accelerator ring at detector (s), low-beta quadrupoles, shielding (e.g. against beamstrahlung)?
- injection scheme
- polarization, Siberian snakes, spin matching, acceleration & storage, polarized sources

(19 September 2012)

Draft 2.0

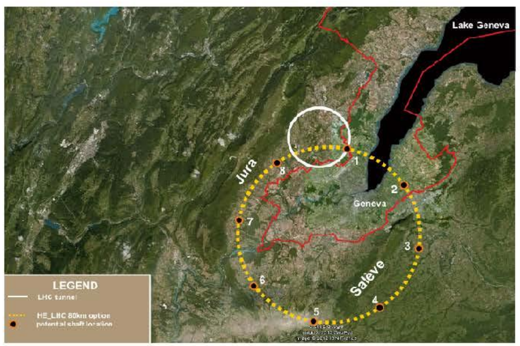
CERN, 13 February 2013

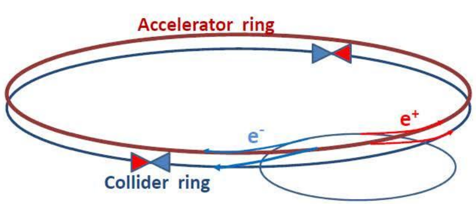
TLEP

A design study of high-luminosity e^+e^- circular colliders for precise measurements of the properties of the Higgs-like H(126) boson and physics at the electroweak scale

(DRAFT)

Author list to be expanded and ordered by institute: R. Aleksan (CEA-Saclay), Alain Blondel (Geneva), John Ellis (King's College London), Patrick Janot (CERN-PH), Mike Koratzinos (Geneva), Marco Zanetti (MIT), Frank Zimmermann (CERN-BE) … … …





Possible site layout and schematic for the TLEP collider

Abstract

We propose to carry out the design study of a high-energy, high-luminosity electron-positron storage ring collider operating in the energy range 90-350 GeV. Such a study was recommended as an outcome of the ICFA beam dynamics workshop on Higgs Factories and is in line with the proposed update of the European Strategy for Particle Physics. If situated in a 80km tunnel, this machine could be the precursor of a 80-100 TeV hadron collider as part of a possible long-term vision for CERN.

TLEP Design Study Proposal (*draft*)

to be submitted to ECFA

TLEP design study –preliminary structure for discussion

Institutional board

Steering group
web site, mailing lists,
speakers board, etc..

International Advisory board

Accelerator

1. Optics, low beta, alignment and feedbacks
2. Beam beam interaction
3. Magnets and vacuum
4. RF system
5. Injector system
6. Integration w/(SHE)-LHC
7. Interaction region
8. Polarization &E-calib.
9. Elements of costing

Experiments

1. H(126) properties
2. Precision EW measurements at the Z peak and W threshold
3. Top quark physics
4. Experimental environment
5. Detector design
6. Online and offline computing

Physics

1. Theoretical implications and model building
2. Precision measurements, simulations and monte-carlos
3. Combination + complementarity with LHC and other machines ; global fits

TLEP/LEP3 events & references

A. Blondel, F. Zimmermann, *"A High Luminosity e^+e^- Collider in the LHC Tunnel to study the Higgs Boson,"* arXiv:1112.2518v1, 24.12.'11

K. Oide, *"SuperTRISTAN - A possibility of ring collider for Higgs factory,"* KEK Seminar, 13 February 2012

1st EuCARD LEP3 workshop, CERN, 18 June 2012

A. Blondel et al, *"LEP3: A High Luminosity e+e- Collider to study the Higgs Boson,"* arXiv:1208.0504, submitted to ESPG Krakow

P. Azzi et al, *"Prospective Studies for LEP3 with the CMS Detector,"* arXiv:1208.1662 (2012), submitted to ESPG Krakow

2nd EuCARD LEP3 workshop, CERN, 23 October 2012

P. Janot, *"A circular e^+e^- collider to study H(125),"* PH Seminar, CERN, 30 October 2012

ICFA Higgs Factory Workshop: Linear vs Circular, FNAL, 14-16 Nov. '12

A. Blondel, F. Zimmermann, *"Future possibilities for precise studies of the X(125) Higgs candidate,"* CERN Colloquium, 22 Nov. 2012

3rd TLEP3 Day, CERN, 10 January 2013

4th TLEP mini-workshop, CERN, 4-5 April 2013

https://espace.cern.ch/LEP3 https://cern.ch/accnet

SAPPHiRE/LHeC events & references

S. A. Bogacz, J. Ellis, L. Lusito, D. Schulte, T. Takahashi, M. Velasco, M. Zanetti, F. Zimmermann, "SAPPHiRE: a Small Gamma-Gamma Higgs Factory," arXiv:1208.2827

D. Asner et al., "Higgs physics with a gamma gamma collider based on CLIC I," Eur. Phys. J. C 28 (2003) 27 [hep-ex/0111056].

J. Abelleira Fernandez et al, "Large Hadron Electron Collider at CERN - Report on the Physics and Design Concepts for Machine and Detector," Journal of Physics G: Nuclear and Particle Physics 39 Number 7 (2012) arXiv:1206.2913

Yuhong Zhang, "Design Concept of a γ–γ Collider-Based Higgs Factory Driven by Energy Recovery Linacs," arXiv:1211.3756

E. Nissen, "Optimization of Recirculating Linacs for a Higgs Factory," prepared for HF2012

ICFA Higgs Factory Workshop: Linear vs Circular, FNAL, 14-16 Nov. '12

J. Limpert, T. Schreiber, A. Tünnermann, "Fiber lasers and amplifiers: an ultrafast performance evolution," Applied Optics, Vol. 49, No. 25 (2010)

1st EuCARD SAPPHiRE Day, CERN, 19 February 2013

https://cern.ch/accnet

“A circle is a round straight line with a hole in the middle.”

Mark Twain,
in "English as She Is Taught",
Century Magazine, May 1887

back-up slides

- HE-LHC/VHE-LHC parameters
- TLHeC/VHE-TLHeC parameters
- TLEP/VHE-LHeC tunnel layout
- Lucio Rossi’es “plan for all”

HE/VHE-LHC parameters – 1

smaller?! (x1/4?)

parameter	LHC	HL-LHC	HE-LHC	VHE-LHC
c.m. energy [TeV]	14	14	33	100
circumference C [km]	26.7	26.7	26.7	80
dipole field [T]	8.33	8.33	20	20
dipole coil aperture [mm]	56	56	40	40
beam half aperture [cm]	~ 2	~ 2	1.3	1.3
injection energy [TeV]	0.45	0.45	>1.0	>3.0
no. of bunches n_b	2808	2808	1404	4210
bunch population N_b [10^{11}]	1.125	2.2	1.62	1.59
init. transv. norm. emit. [μm]	3.73,	2.5	2.10	3.37
initial longitudinal emit. [eVs]	2.5	2.5	5.67	17.2
no. IPs contributing to tune shift	3	2	2	2
max. total beam-beam tune shift	0.01	0.015	0.01	0.01
beam circulating current [A]	0.584	1.12	0.412	0.401
rms bunch length [cm]	7.55	7.55	7.7	7.7
IP beta function [m]	0.55	0.15	0.3	0.9
init. rms IP spot size [μm]	16.7	7.1	6.0	7.5

available now at LHC!

O. Dominguez, L. Rossi, F.Z.

HE/VHE-LHC parameters – 2

parameter	LHC	HL-LHC	HE-LHC	VHE-LHC
full crossing angle [μrad]	285	590	240	100
stored beam energy [MJ]	362	694	601	5410
SR power per ring [kW]	3.6	6.9	82.5	2356
arc SR heat load dW/ds [W/m]	0.21	0.40	3.5	33?
energy loss per turn [keV]	6.7	6.7	201.3	5857
critical photon energy [eV]	44	44	575	5474
photon flux [10^{17}/m/s]	1.0	1.9	1.6	1.3
longit. SR emit. damping time [h]	12.9	12.9	1.0	0.32
horiz. SR emit. damping time [h]	25.8	25.8	2.0	0.64
init. longit. IBS emit. rise time [h]	57	21.0	77	634
init. horiz. IBS emit. rise time [h]	103	15.4	40	306
peak events per crossing	19	140 (lev.) *100?	190	190
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	7.4	5.0	5.0
beam lifetime due to burn off [h]	45	11.6	6.3	18.6
optimum run time [h]	15.2	8.9	6.5	12.2
opt. av. int. luminosity / day [fb^{-1}]	0.47	3.7	1.5	2.3

O. Dominguez, L. Rossi, F.Z.

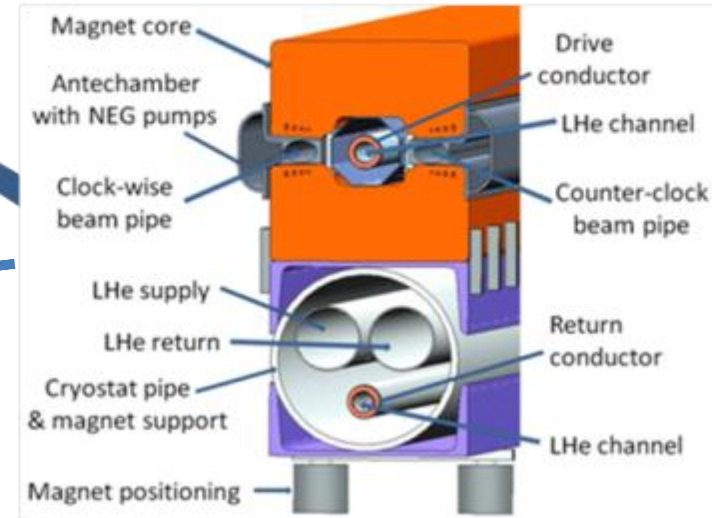
parameters for *TLHeC* & *VHE-TLHeC* (examples)

collider parameters	TLHeC		VHE-TLHeC	
species	***e***$^{\pm}$	*p*	***e***$^{\pm}$	*p*
beam energy [GeV]	**120**	**7000**	**120**	**50000**
bunch spacing [μs]	3	3	3	3
bunch intensity [10^{11}]	5	3.5	5	3.5
beam current [mA]	24.3	51.0	24.3	51.0
rms bunch length [cm]	0.17	4	0.17	2
rms emittance [nm]	10,2	0.40	10,2	0.06
$\beta_{x,y}$*[cm]	2,1	60,5	0.5,0.25	60,5
$\sigma_{x,y}$* [μm]	15, 4		6, 2	
beam-beam parameter ξ	0.05, 0.09	**0.03,0.01**	0.07,0.10	**0.03,0.007**
hourglass reduction	**0.63**		**0.42**	
CM energy [TeV]	1.8		4.9	
luminosity [10^{34}cm^{-2}s^{-1}]	**0.5**		**1.6**	

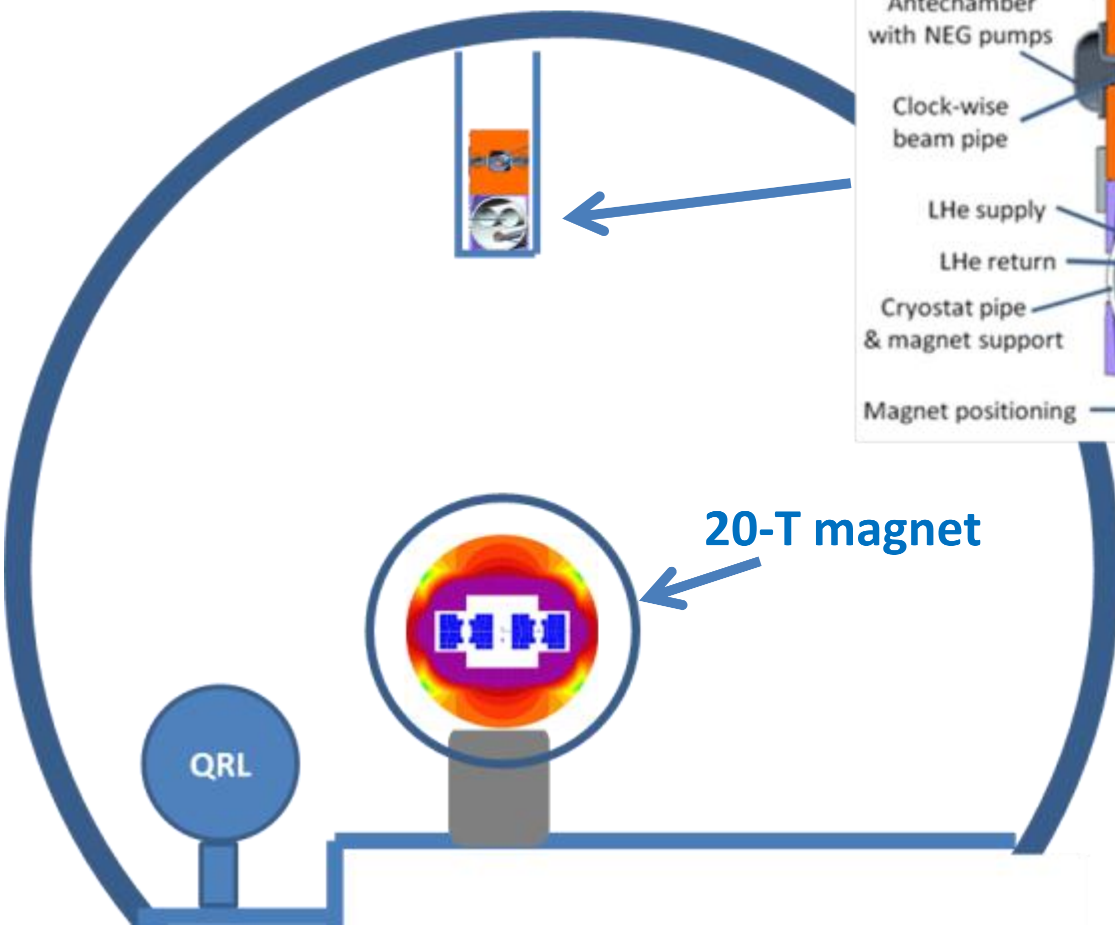
arrangement in VHE-LHC tunnel

Lucio Rossi
CLIC workshop
28 Jan. 2013

VHE-LHC injector ring "LER"
(using transmission line magnet)



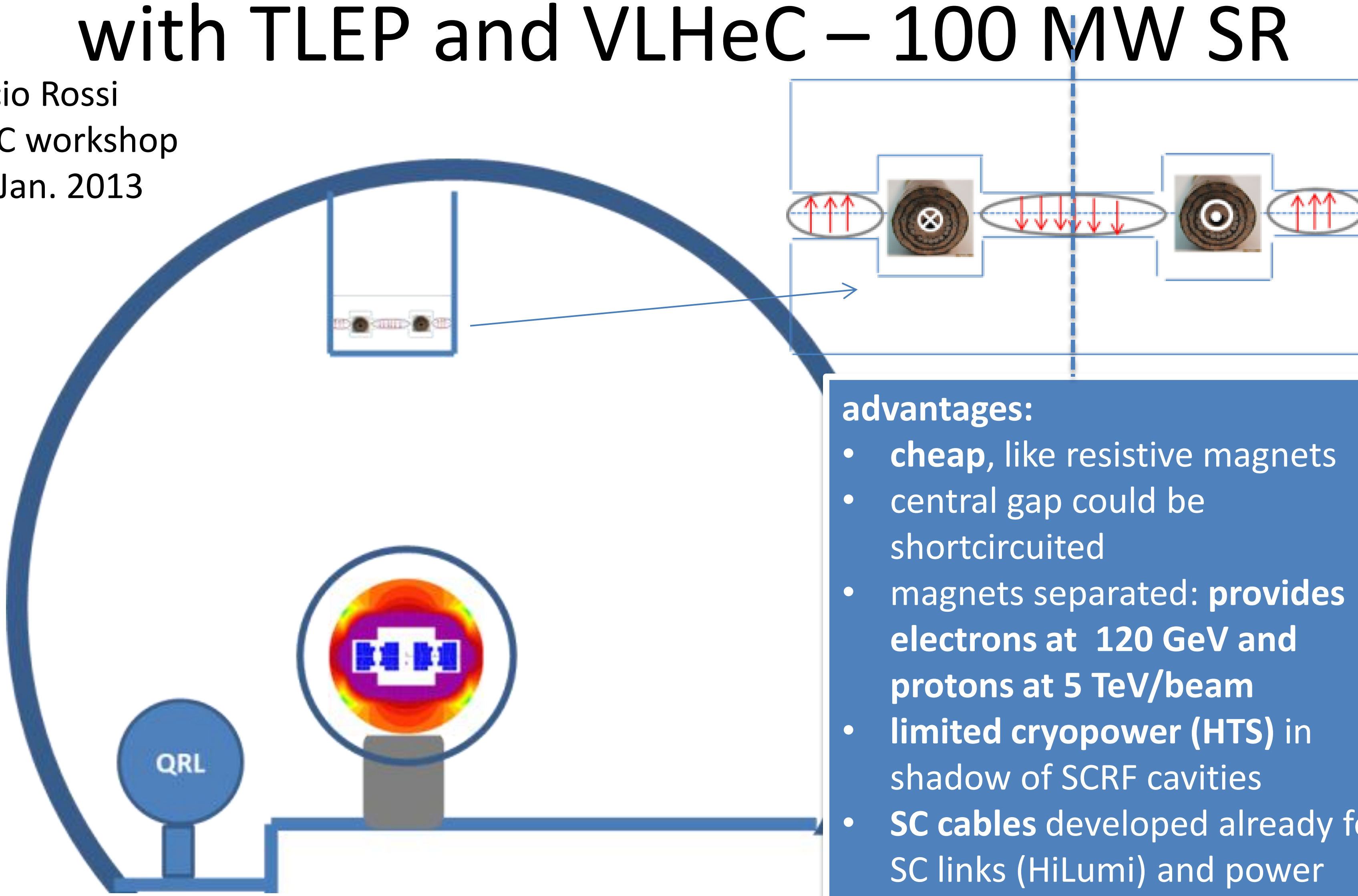
H. Piekarz, Proc. HE-LHC'10, p. 101



30 mm V gap
50 mm H gap
Bin = 0.5 T
Bextr = 1.5 T

VHE-LHC's LER magnets compatible with TLEP and VLHeC – 100 MW SR

Lucio Rossi
CLIC workshop
28 Jan. 2013

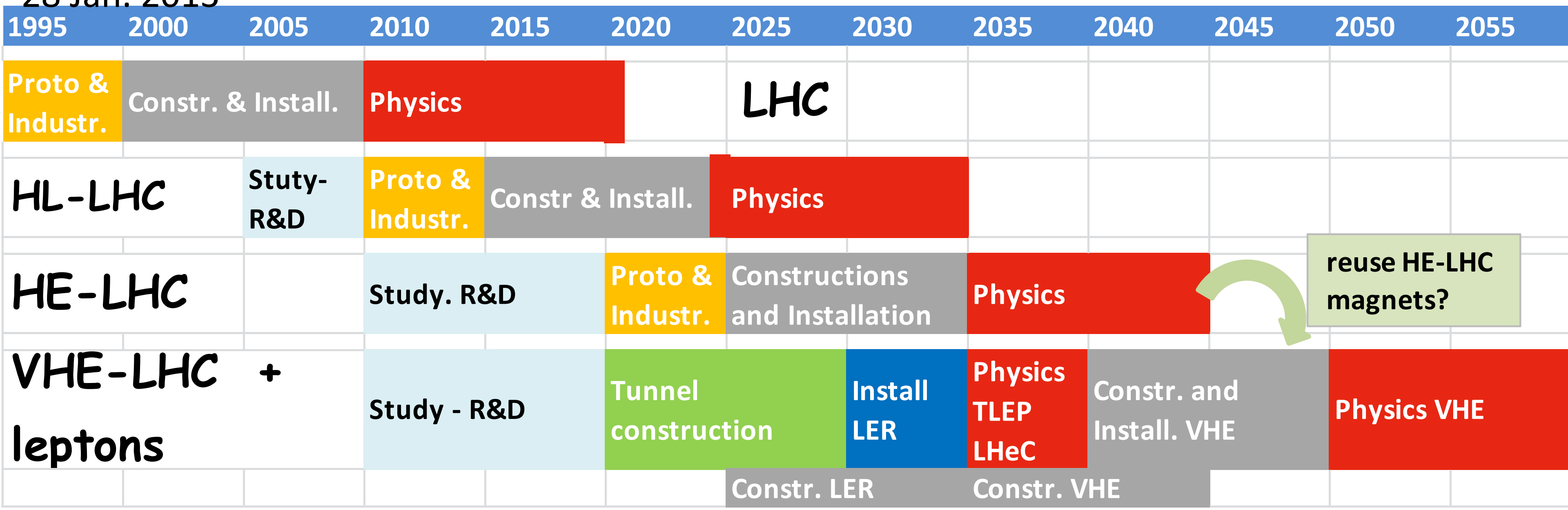


advantages:

- **cheap**, like resistive magnets
- central gap could be shortcircuited
- magnets separated: **provides electrons at 120 GeV and protons at 5 TeV/beam**
- **limited cryopower (HTS)** in shadow of SCRF cavities
- **SC cables** developed already for SC links (HiLumi) and power applications
- **SR taken at 300 K**

Lucio Rossi
CLIC workshop
28 Jan. 2013

«plan for all»



according to physics needs, the 80 km tunnel can:

– be alternative to HE-LHC
– or be complementary to HE-LHC
– **accommodate at negligible extra cost TLEP and VLHeC**
– modular detector design allows evolution from TLEP-H/TLHeC to VHE-LHC