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PUBLICATION

Circular Higgs Factories: LEP3, TLEP and SAPPHiRE

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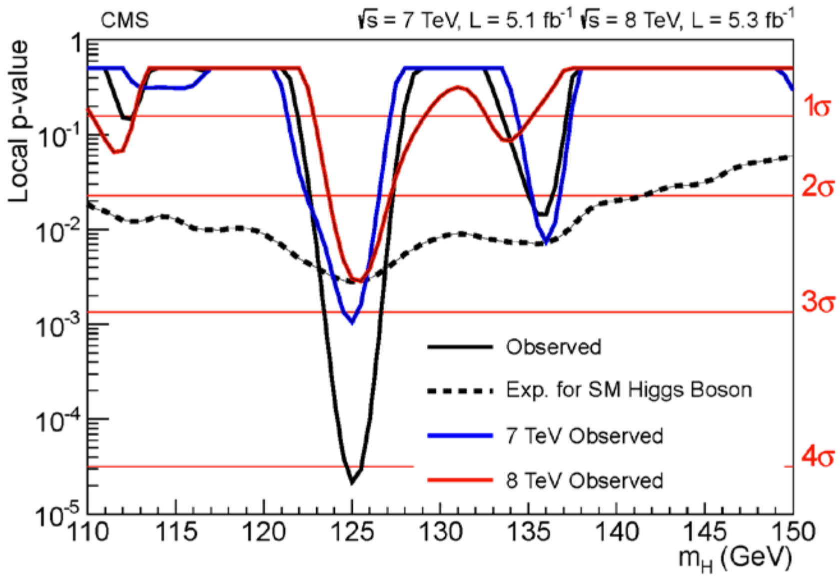
Circular Higgs Factories: LEP3, TLEP and SAPPHiRE

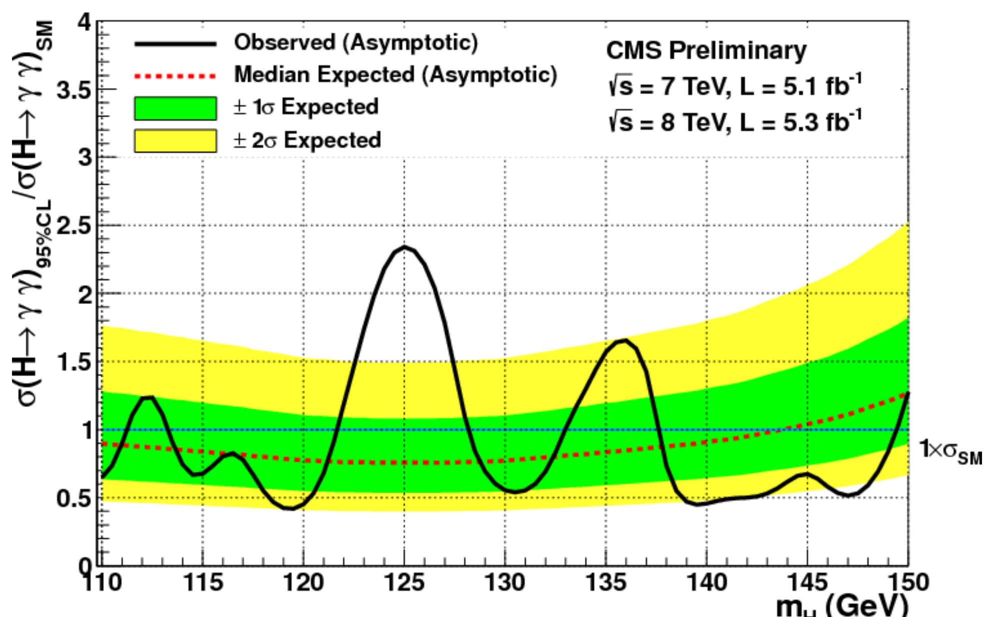
Frank Zimmermann

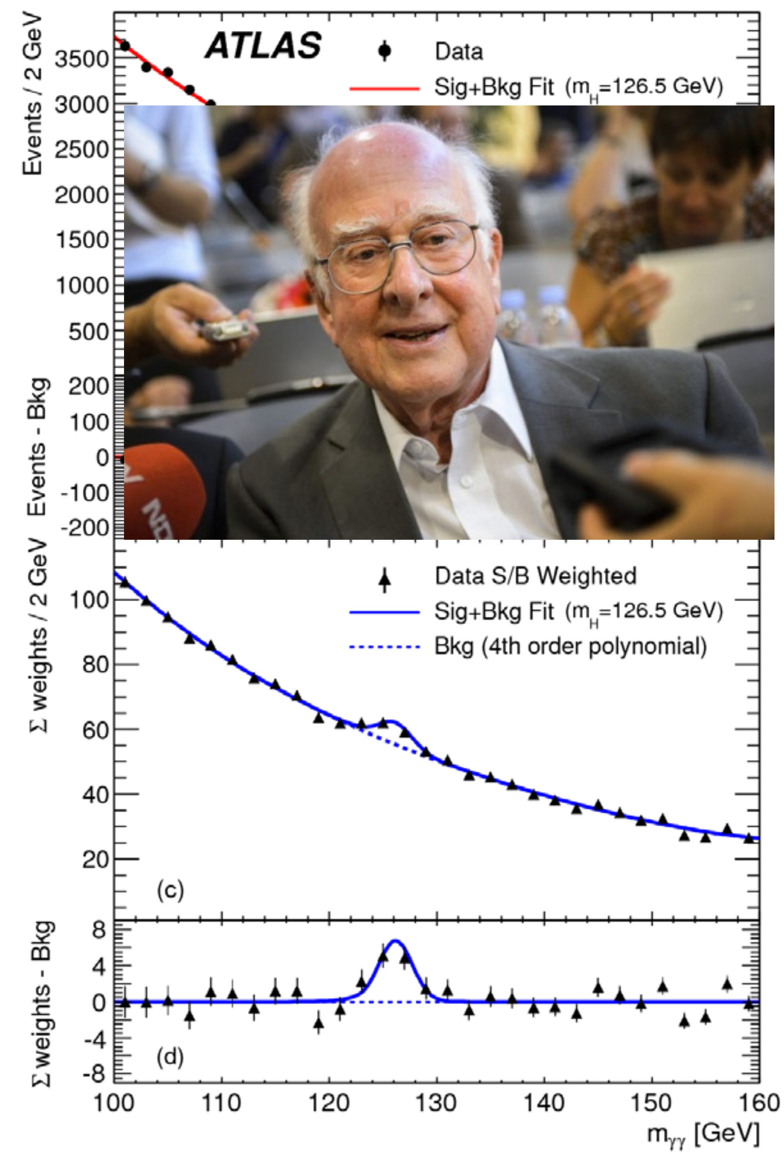
J.A.I., Oxford, 1 November 2012

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

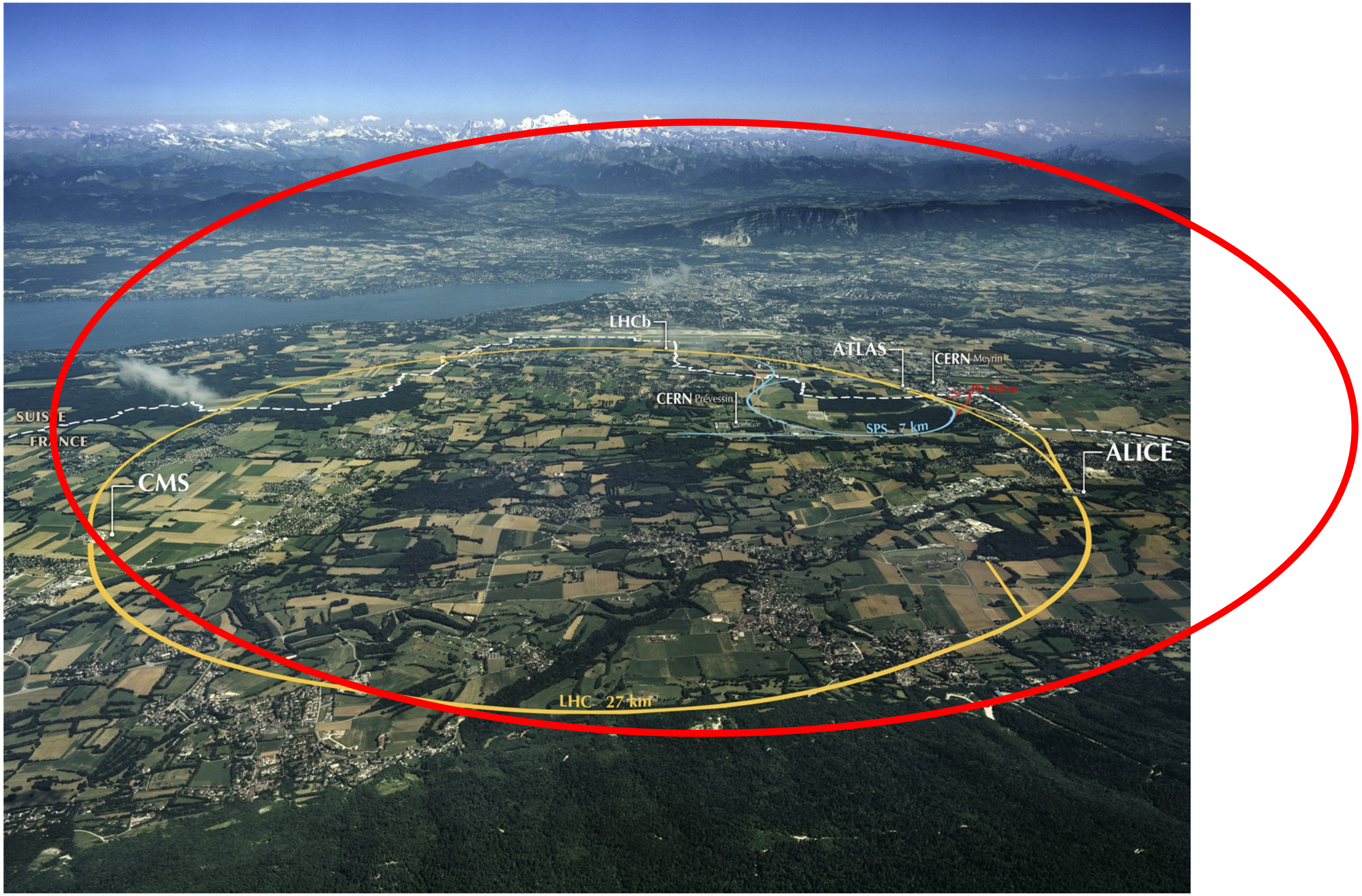
4 July 2012 - X(125) “Higgs” discovery







Part 1 – LEP3 / TLEP



Higgs e^+e^- production cross section

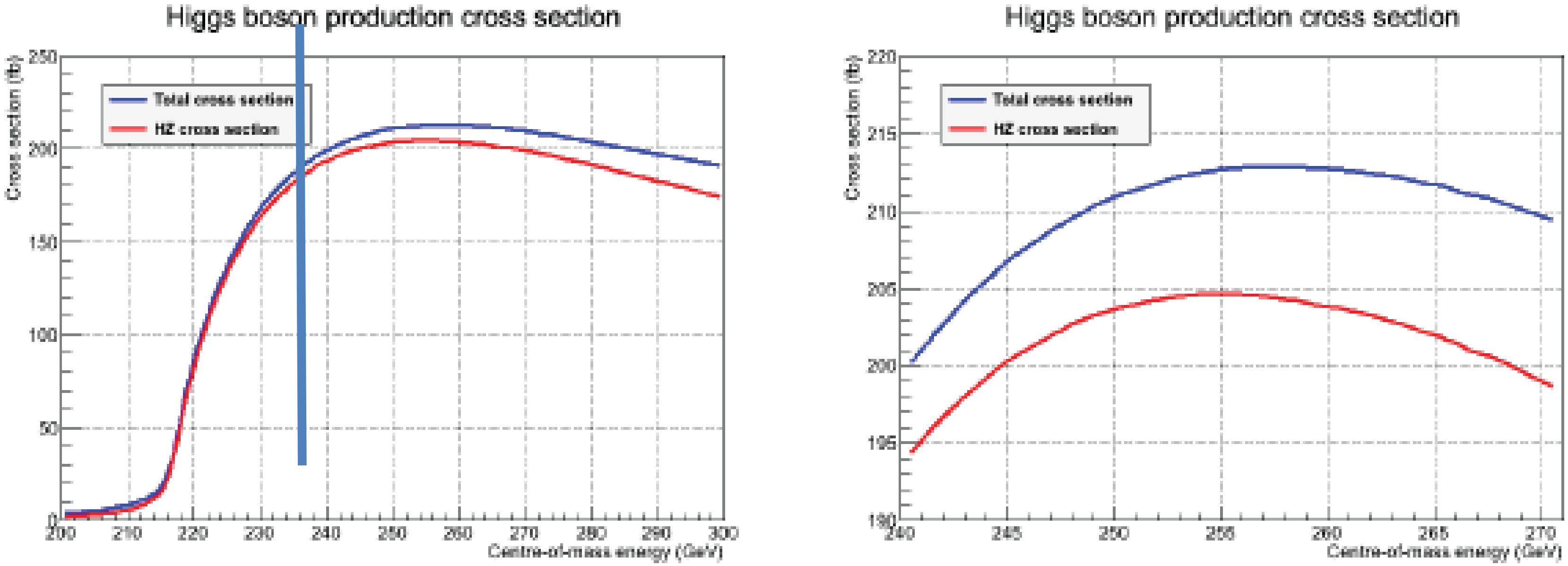


Figure 5: The Higgs boson production cross section as a function of the centre-of-mass energy. The red curve corresponds to the Higgsstrahlung process only, $e^+e^- \rightarrow HZ$, and the blue curve includes the WW and ZZ fusion processes as well, together with their interference with the Higgsstrahlung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

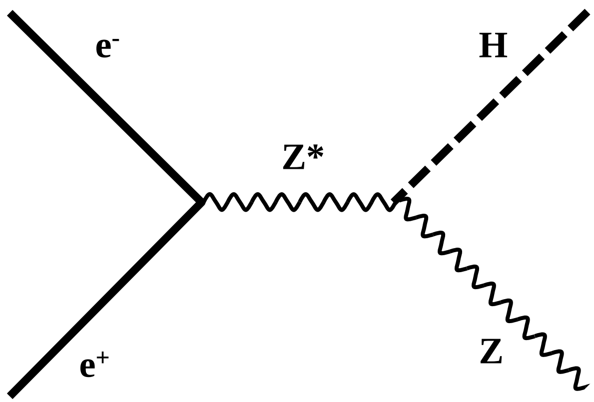
take 240 GeV

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.



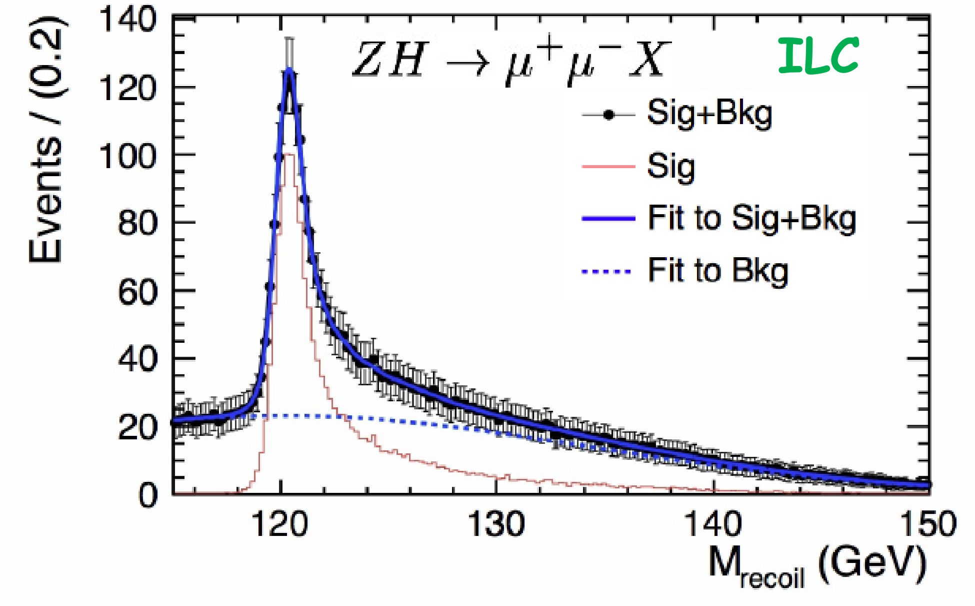
Z **– tagging by missing mass**

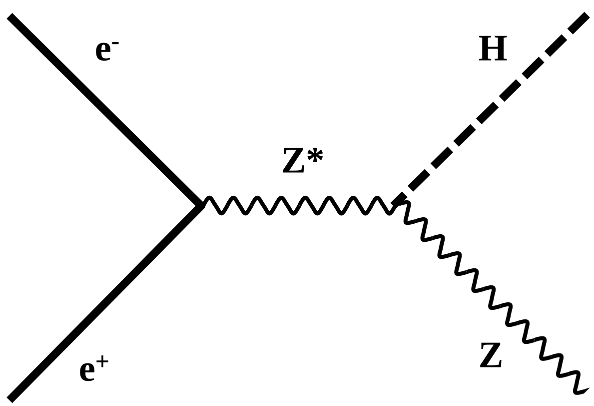
For a Higgs of 125GeV, a centre of mass energy of 240GeV is sufficient ➔ kinematical constraint near threshold for high precision in mass, width, selection purity

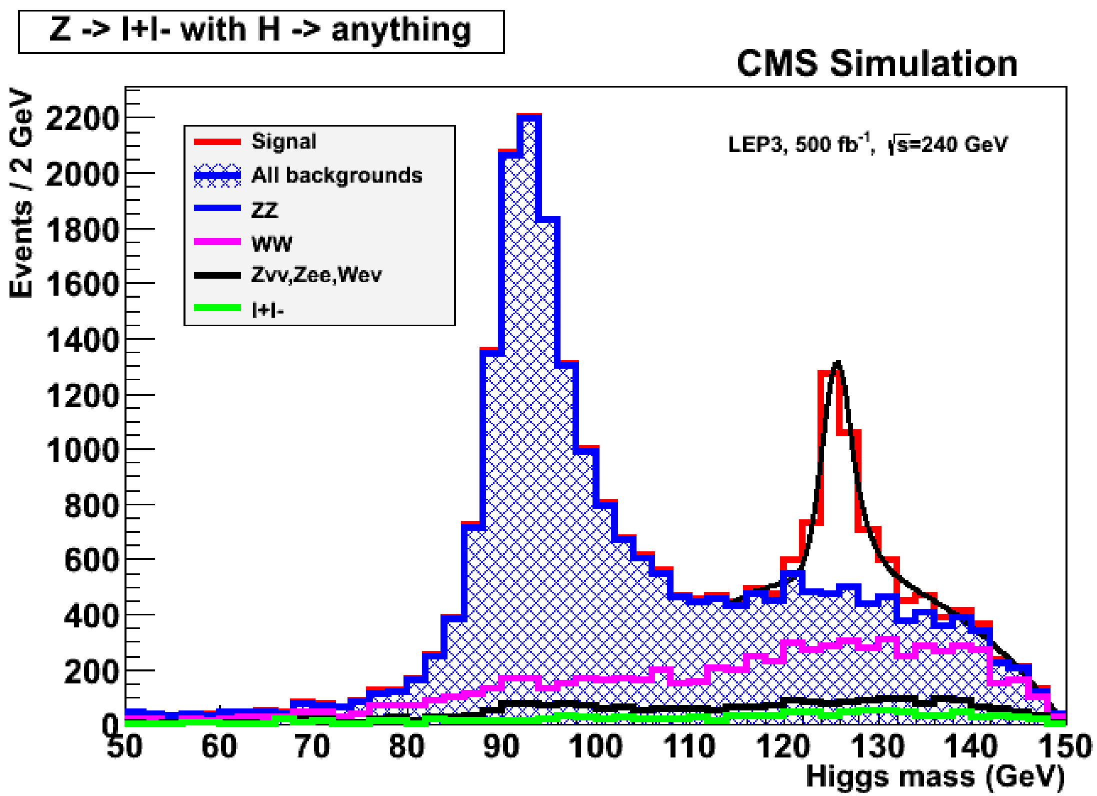
A. Blondel

A. Blondel

Z – tagging by missing mass

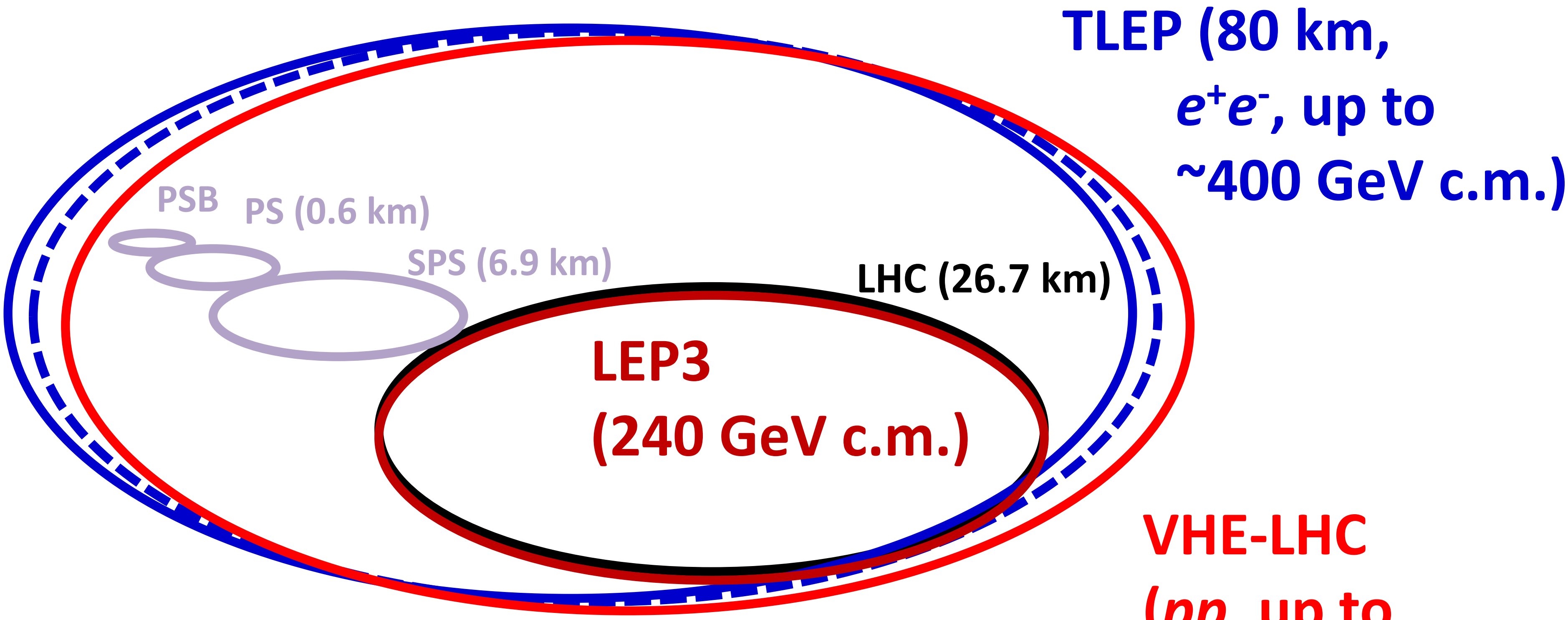






total rate $\propto g_{HZZ}^2$
ZZZ final state $\propto g_{HZZ}^4 / \Gamma_H$
➔ measure total width Γ_H

possible future projects at CERN



also: $e^{\pm}$ **(200 GeV) – *p* (7 & 50 TeV)** collisions

two 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 “DLEP” or “TLEP”
  - + higher energy reach, 5-10x higher luminosity
  - + decoupled from LHC and HL-LHC operation and construction
  - + tunnel can later serve for HE-LHC (factor 2-3 in energy from tunnel alone) with LHC remaining as injector
  - - 3-4x more expensive (new tunnel, cryoplants, detectors?)

LEP3

(e^+e^- -> ZH, $e^+e^- \rightarrow W^+W^-$, $e^+e^- \rightarrow Z$)

key parameters

circumference: 26.7 km (LHC tunnel)

maximum beam energy: ≥120 GeV

luminosity in each of 2-4experiments:

≥ 10^{34} $cm^{-2}s^{-1}$ at 'Higgs energy' (~240 GeV c.m.)

≥ $5x10^{34}$ $cm^{-2}s^{-1}$ at $2xM_W$ (~160 GeV c.m.)

≥ $2x10^{35}$ $cm^{-2}s^{-1}$ at the Z pole (~90 GeV c.m.)

LEP3 key 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
- small momentum compaction (short bunch length)
- assume $\varepsilon_y/\varepsilon_x$ ~5×10^{-3} similar to LEP (ultimate limit ε_y ~ 1 fm from opening angle)

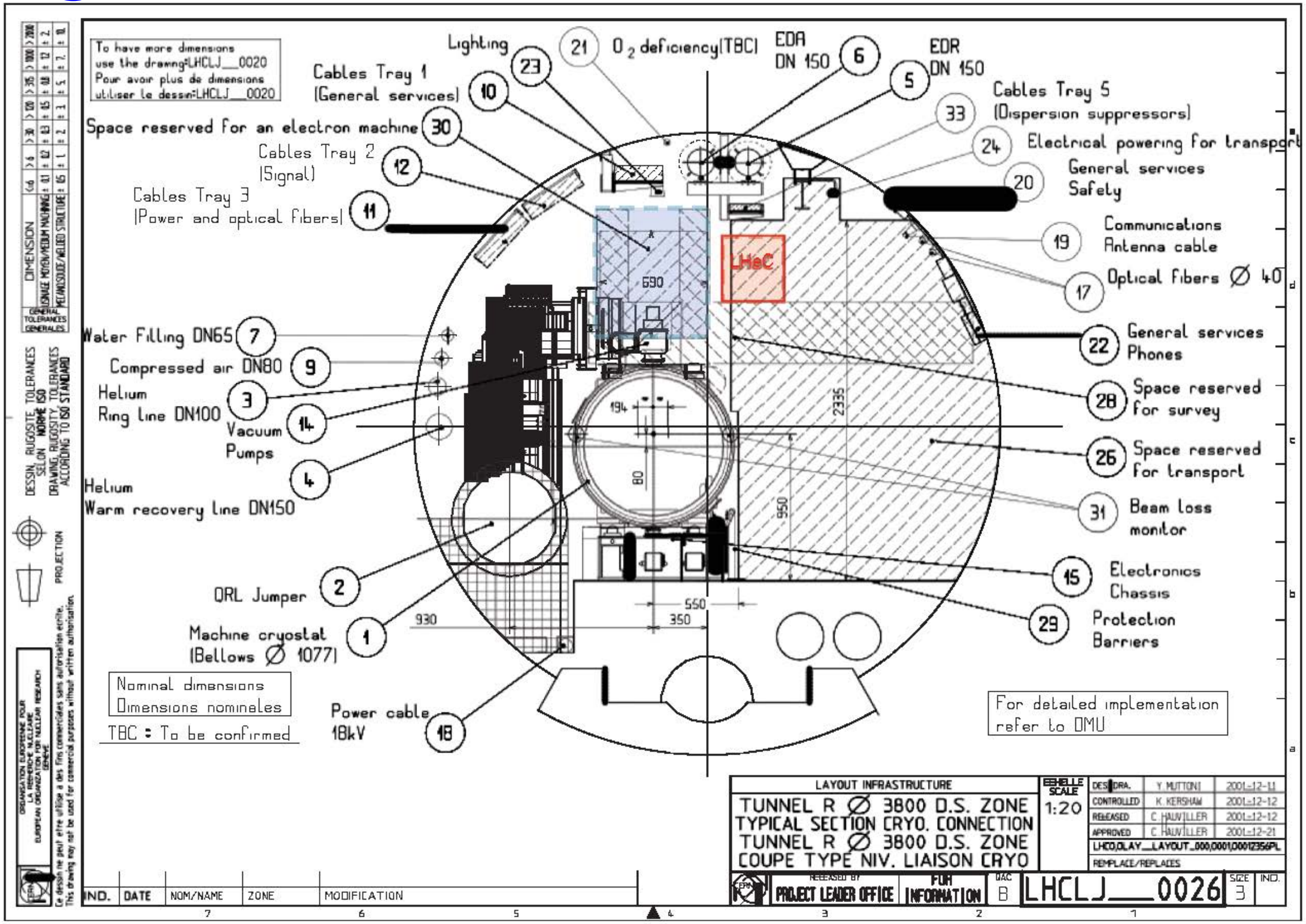
RF

- RF frequency 1.3 GHz or 700 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 <1/2 LHC

synchrotron radiation

- energy loss / turn: $E_{loss}[\mathrm{GeV}]=88.5\times10^{-6}\,(E_b[\mathrm{GeV}])^4/\rho[\mathrm{m}]$.
- 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)→4×10^{12} $e^{\pm}$/beam

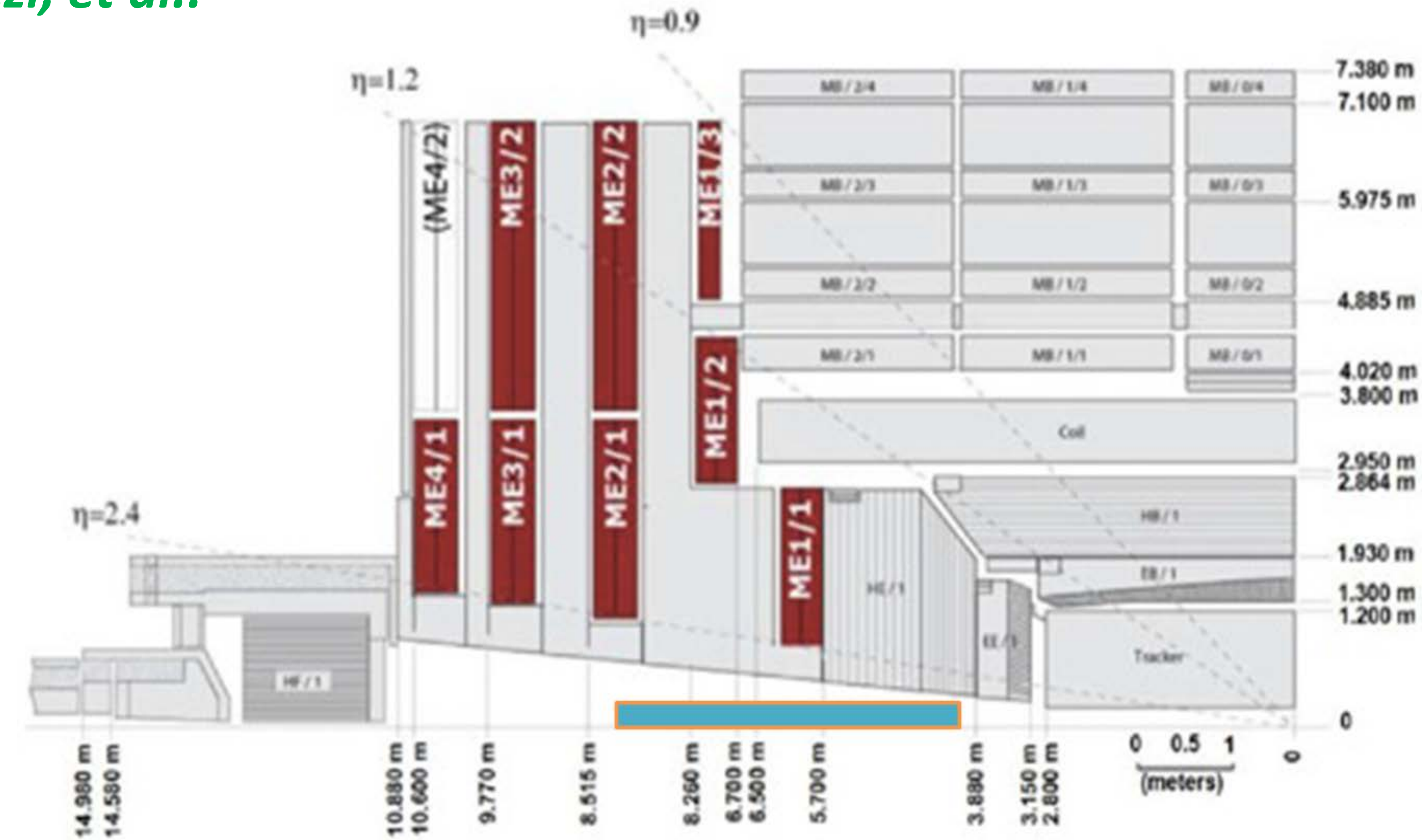
putting LEP3 into the LHC tunnel?



LHC tunnel cross section with space reserved for a future lepton machine like LEP3 [blue box above the LHC magnet] and with the presently proposed location of the LHeC ring [red]

integrating LEP3 IR in CMS detector?

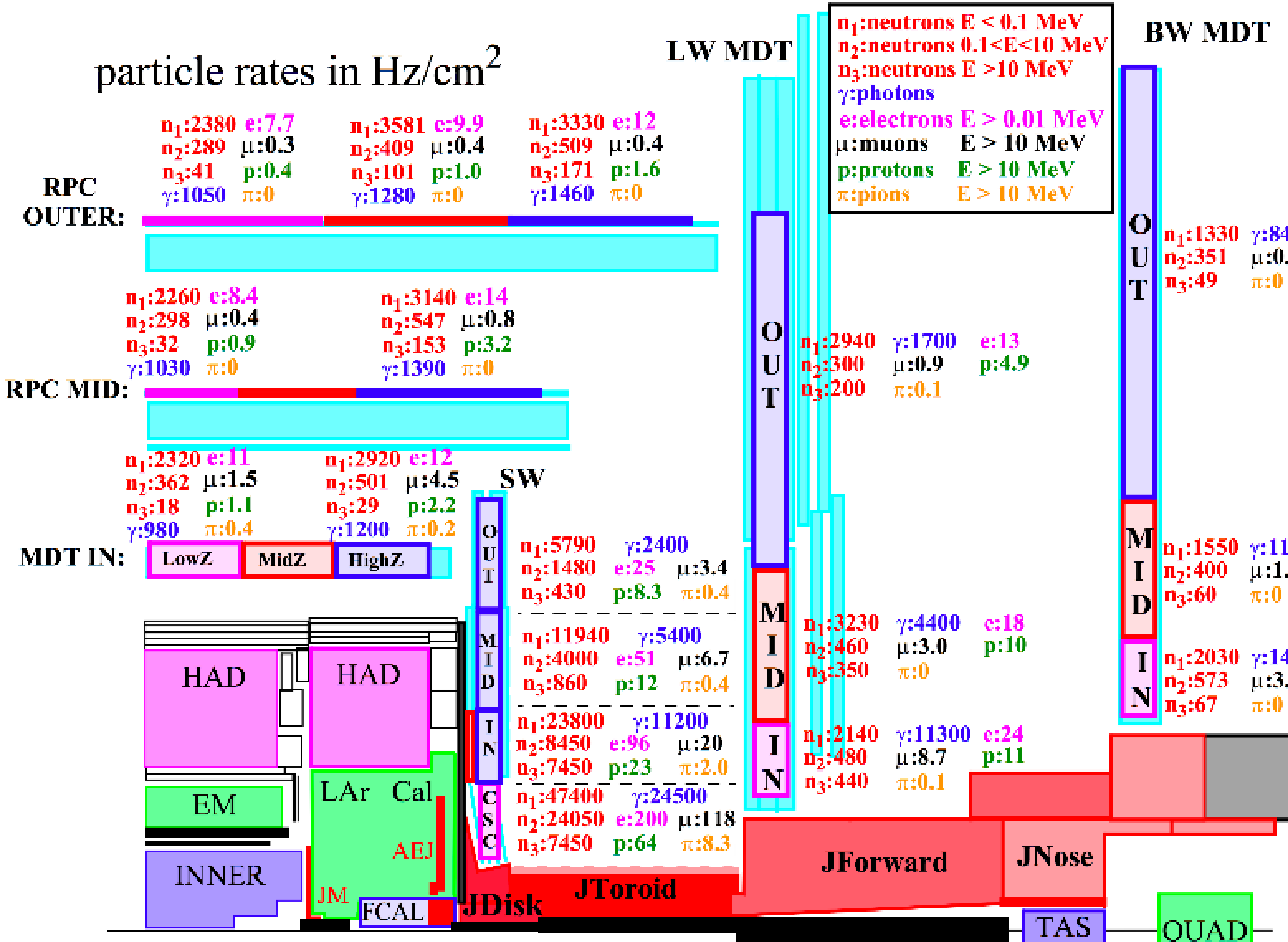
Azzi, et al..



QUADS insertions in the CMS detector

integrating LEP3 IR in ATLAS detector?

based on
M. Nessi
CARE-HHH
IR'07



z=3.49-4.58 m
r_{max}=18 cm

z=6.8-8.66 m
r_{max}=43 cm

z=8.69-12.870 m
r_{max}=87 cm

z=12.95-18.60 m
r_{max}=150 cm

TLEP

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

key parameters

circumference: ~80 km (3x LHC)

maximum beam energy: ≥175 GeV

luminosity in each of 2-4 experiments:

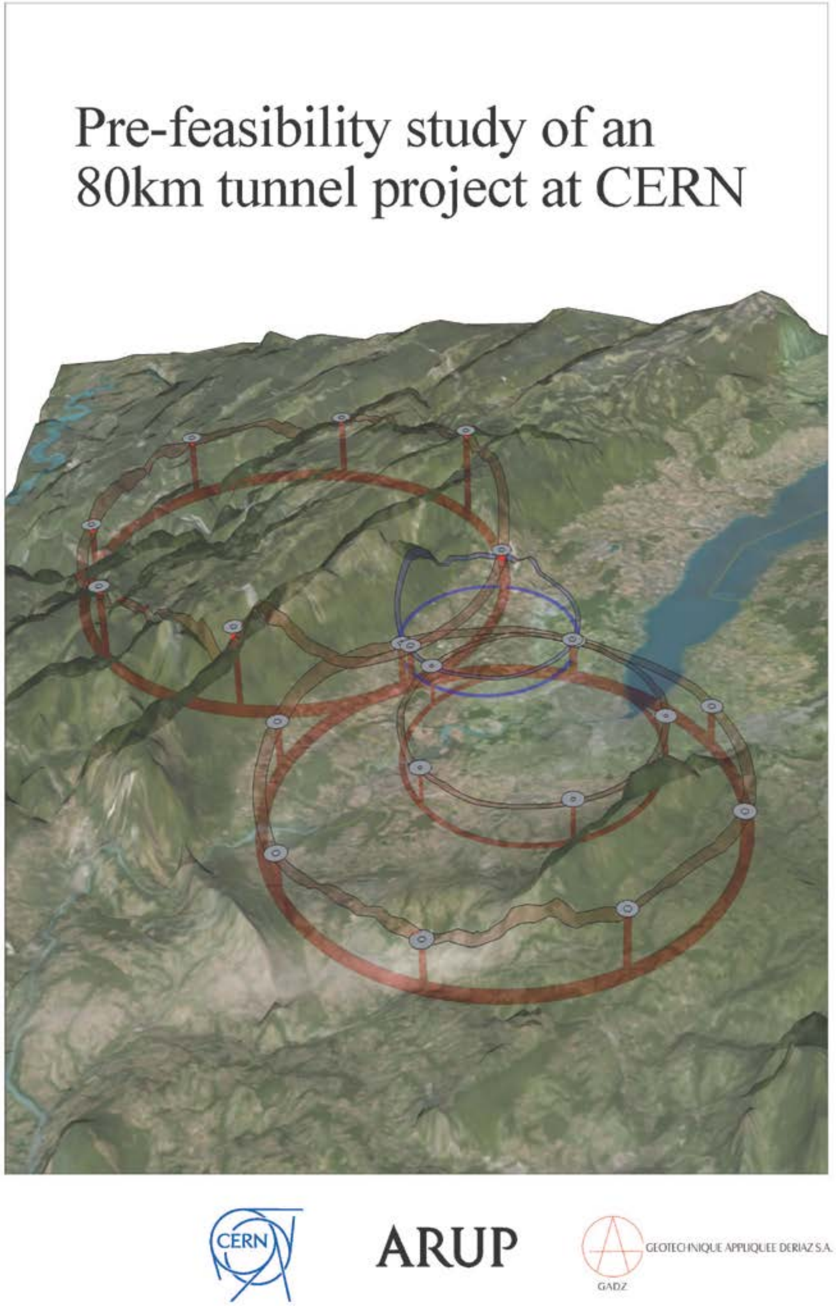
~ 10^{34} cm^{-2}s^{-1} at $t\bar{t}$ threshold (~350 GeV c.m.)

≥ $5\text{x}10^{34}$ cm^{-2}s^{-1} at ‘Higgs energy’ (~240 GeV c.m.)

≥ $1.5\text{x}10^{35}$ cm^{-2}s^{-1} at 2xM_W (~160 GeV c.m.)

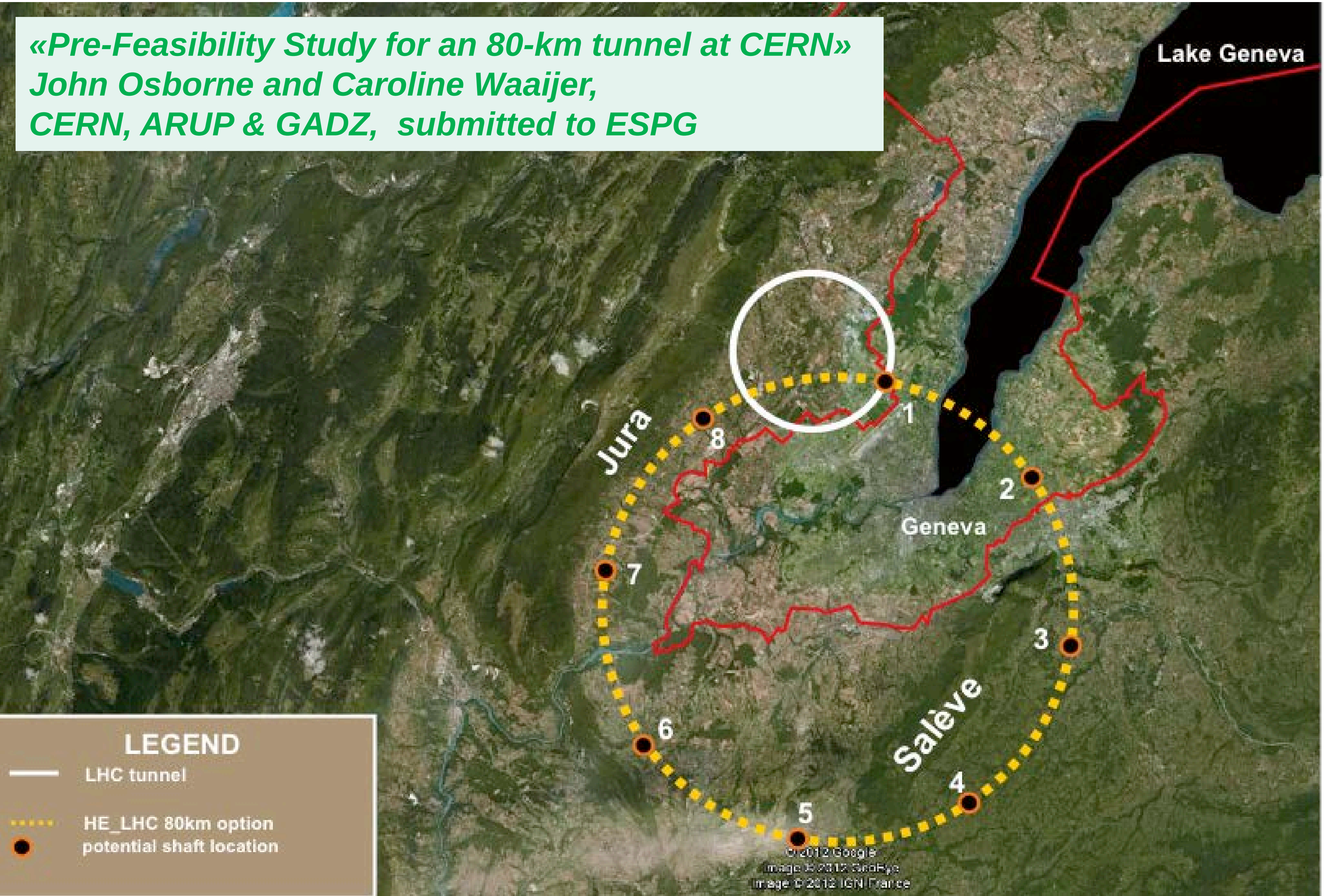
≥ 10^{36} cm^{-2}s^{-1} at the Z pole (~90 GeV c.m.)

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




SuperTRISTAN 40
薬王院
八郷植物センター
TLEP tunnel in the KEK area?
12.3 km
KEK
SuperTRISTAN in Tsukuba: 40-80 km ring
Proposal by K. Oide, 13 February 2012

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

optimum LEP3/TLEP luminosity

minimizing

$\kappa_\varepsilon = \varepsilon_y / \varepsilon_x$

$\beta_y \sim \beta_x (\varepsilon_y / \varepsilon_x)$ [so that $\xi_x = \xi_y$]

increases the luminosity independently of previous limits

respect $\beta_y \geq \sigma_z$ (hourglass effect)

LEP3/TLEP parameters -1

	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

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.)

beam lifetime

LEP2:

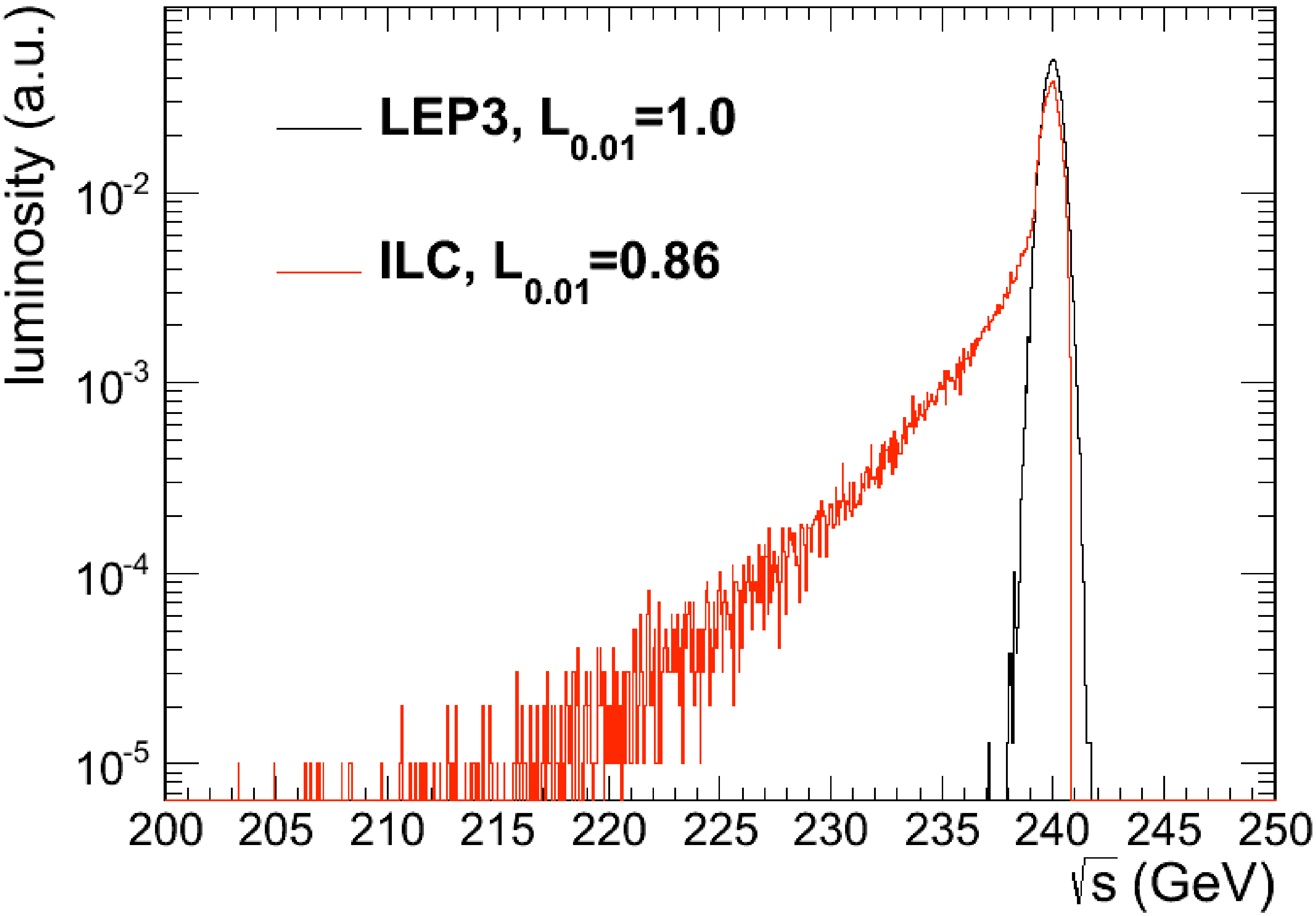
- beam lifetime ~ 6 h
- dominated by radiative Bhahba scattering with cross section σ~0.215 barn [11]

LEP3:

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

  $\tau_{beam,LEP3}$~18 minutes
- additional beam lifetime limit due to beamstrahlung requires large momentum acceptance ($\delta_{max,RF} \geq 3\%$) and/or flat beams and/or fast repleneshing

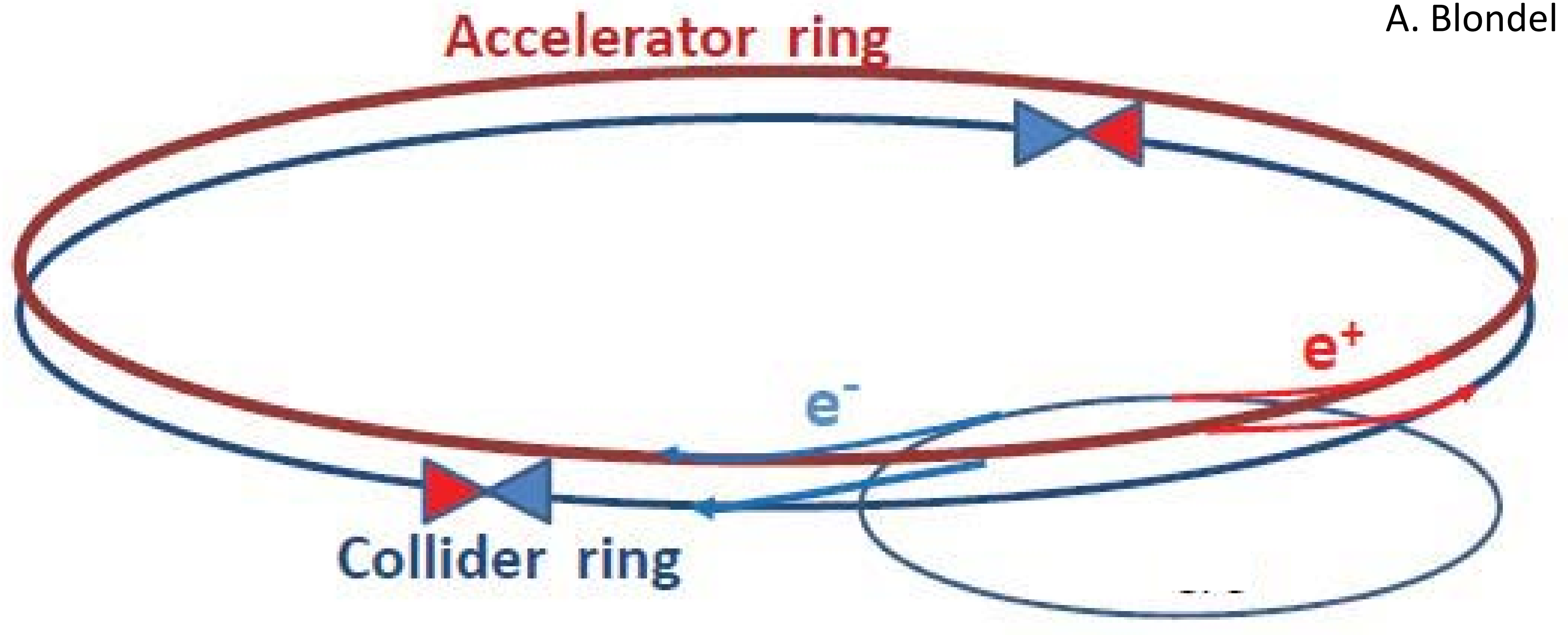
  (Valery Telnov, Kaoru Yokoya, Marco Zanetti) note: beamstrahlung effect at LEP3 much smaller than for ILC, ~monochromatic luminosity profile



M. Zanetti, MIT
2nd LEP3 Day

LEP3/TLEP: **double ring w. top-up injection** supports short lifetime & high luminosity

A. Blondel



a first ring accelerates electrons and positrons up to operating energy (120 GeV) and injects them at a few minutes interval into the low-emittance collider ring, which includes high luminosity $\geq 10^{34}$ cm^{-2} s^{-1} interaction points

top-up injection: e^+ production

top-up interval << beam lifetime

→ average luminosity ≈ peak luminosity!

LEP3 needs about 4×10^{12} e^+ every few minutes, or of order 2×10^{10} e^+ per second

for comparison:

LEP injector complex delivered of order 10^{11} e^+ per second (5x more than needed for LEP3!)

top-up injection: magnet ramp

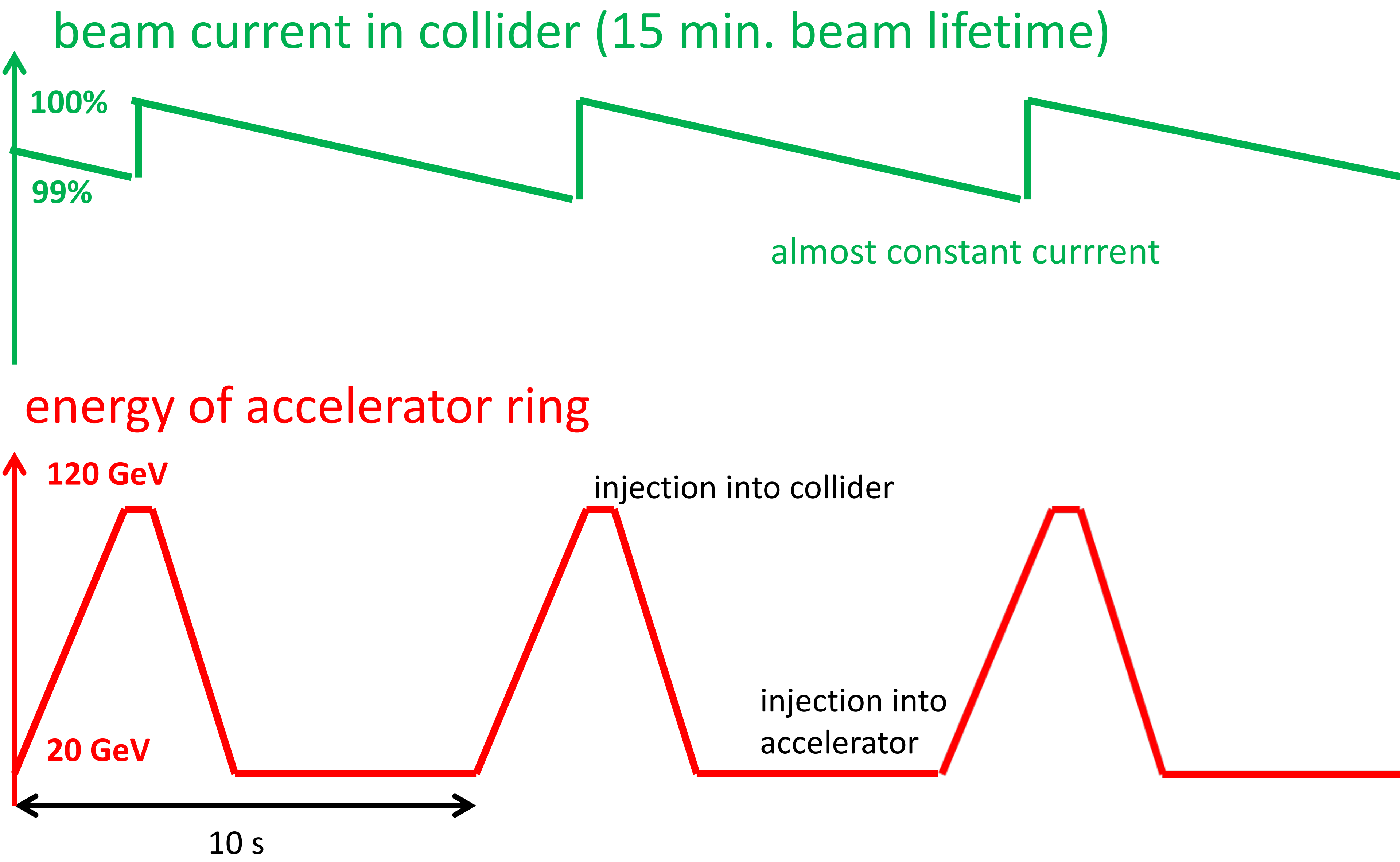
SPS as LEP injector accelerated $e^{\pm}$ from 3.5 to 20 GeV (later 22 GeV) on a very short cycle:
acceleration time = 265 ms or about 62.26 GeV/s
Ref. K. Cornelis, W. Herr, R. Schmidt, "Multicycling of the CERN SPS: Supercycle Generation & First Experience with this mode of Operation," Proc. EPAC 1988

LEP3/TLEP: with injection from SPS into top-up accelerator at 20 GeV and final energy of 120 GeV → **acceleration time = 1.6 seconds**

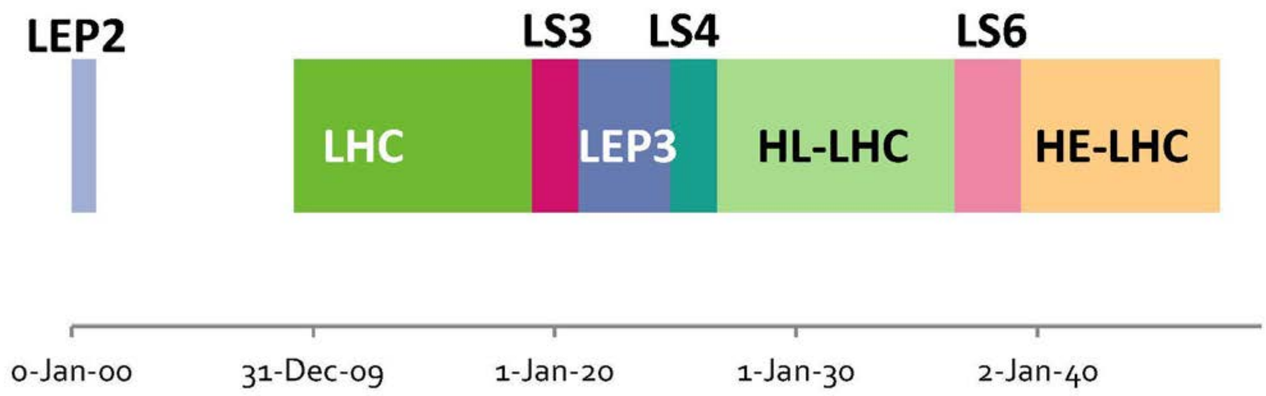
total cycle time = 10 s looks conservative (→ **refilling ~1% of the LEP3** beam, for τ_{beam}~16 min)

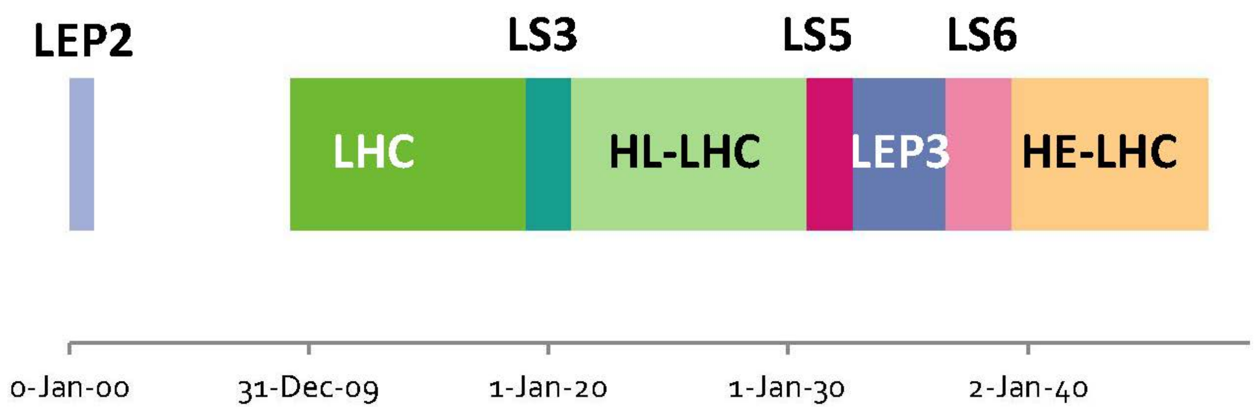
Ghislain Roy & Paul Collier

top-up injection: schematic cycle



two schematic time schedules for LEP3





(LEP3 run time likely to be longer than shown)

of course TLEP would be constructed independently and would pave direct path for VHE-LHC

LEP3/TLEP R&D items

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

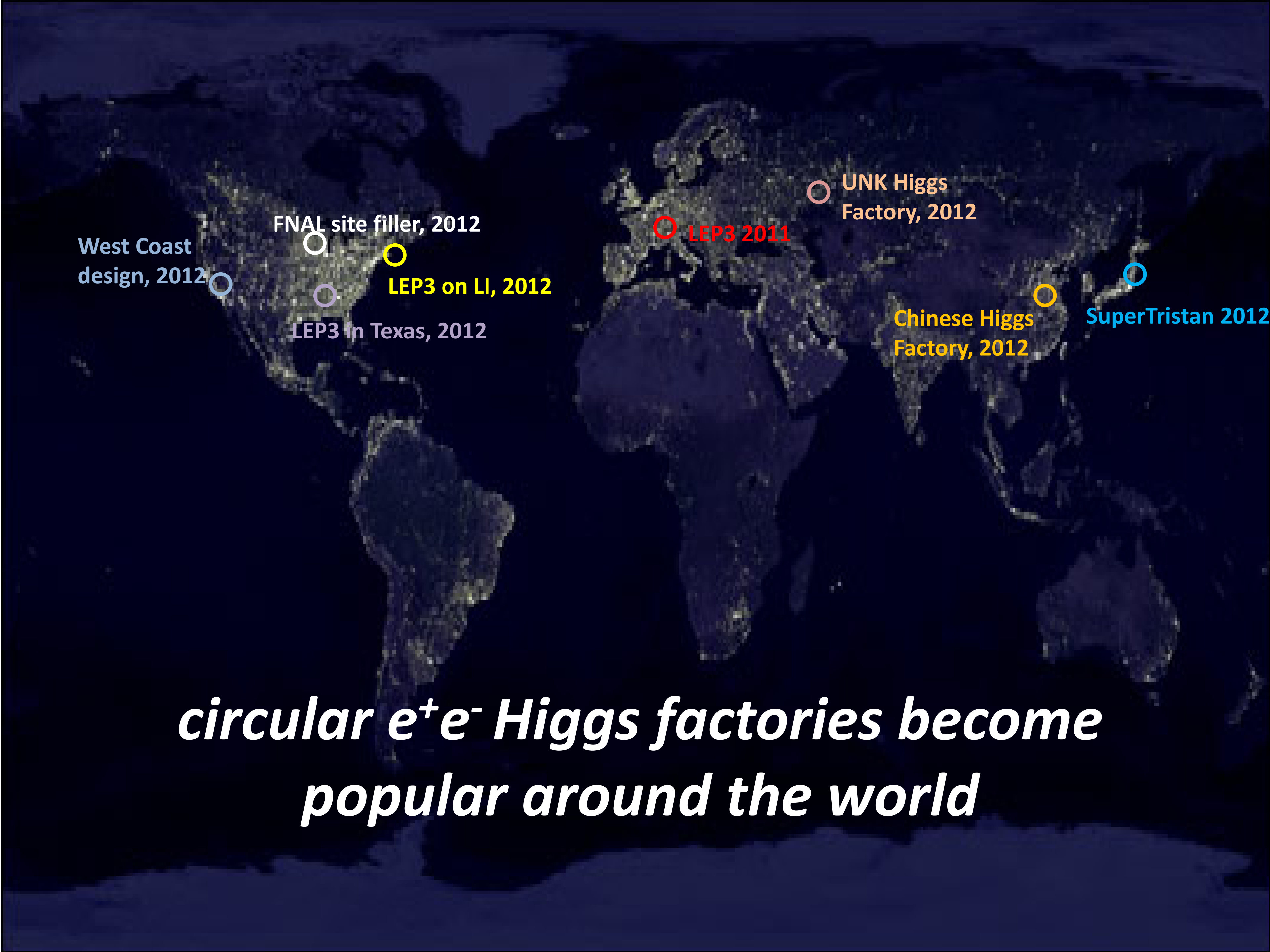
summary of LEP3/TLEP physics measurements

- **Comparison with LHC and HL-LHC** (CMS and SFitter projections) [8,23]

	ILC	LEP3 (2)	LEP3 (4)	TLEP (2)	LHC (300)	HL-LHC
σ_{HZ}	3%	1.9%	1.3%	0.7%	–	–
$\sigma_{HZ} \times BR(H \to b\bar{b})$	1%	0.8%	0.5%	0.2%	–	–
$\sigma_{HZ} \times BR(H \to \tau^+\tau^-)$	6%	3.0%	2.2%	1.3%	–	–
$\sigma_{HZ} \times BR(H \to W^+W^-)$	8%	3.6%	2.5%	1.6%	–	–
$\sigma_{HZ} \times BR(H \to \gamma\gamma)$	?	9.5%	6.6%	4.2%	–	–
$\sigma_{HZ} \times BR(H \to \mu^+\mu^-)$	–	–	28%	17%	–	–
$\sigma_{HZ} \times BR(H \to \text{invisible})$	?	1%	0.7%	0.4%	–	–
g_{HZZ}	1.5%	0.9%	0.6%	0.3%	13%/5.7%	4.5%
g_{Hbb}	1.6%	1.0%	0.7%	0.4%	21%/14.5%	11%
$g_{H\tau\tau}$	3%	2.0%	1.5%	0.6%	13%/8.5%	5.4%
g_{Hcc}	4%	?	?	0.9%	?/?	?
g_{HWW}	4%	2.2%	1.5%	0.9%	11%/5.7%	4.5%
$g_{H\gamma\gamma}$	?	4.9%	3.4%	2.2%	?/6.5%	5.4%
$g_{H\mu\mu}$	–	–	14%	9%	?	?
g_{Htt}	–	–	–	–	14%	8%
m_H (MeV/c^2)	50	37	26	11	100	100

- LEP3/TLEP exceed substantially LHC sensitivity
  - ➨ Even in its highest luminosity version

P. Janot, CERN PH seminar 30 October, attended and watched by >400 physicists



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

LEP3/TLEP baseline w established technology

I had thought (and still think) that the possible use of **cheap, robust, established technology is a great asset for LEP3/TLEP**

However, in Cracow the **argument** has been put forward **that any future collider should be a *Hi-Tech facility*** (i.e. ~18 GV SRF not enough, 350 GeV SRF being much better! - In other words a reasoning that we should fill a large tunnel with expensive objects instead of with cheap "concrete" magnets like LEP/LEP2)

by the way, LEP2 technology worked well

Parameter	Design LEP1 / LEP2	Achieved LEP1 / LEP2
Bunch current	0.75 mA	1.00 mA
Total beam current	6.0 mA	8.4 / 6.2 mA
Vertical beam-beam parameter	0.03	0.045 / 0.083
Emittance ratio	4.0 %	0.4 %
Maximum luminosity	16 / 27 10^{30} $cm^{-2}s^{-1}$	34 / 100 10^{30} $cm^{-2}s^{-1}$
IP beta function β_x	1.75 m	1.25 m
IP beta function β_y	7.0 cm	4.0 cm
Max. beam energy	95 GeV	104.5 GeV
Av. RF gradient	6.0 MV/m	7.2 MV/m

A. Blondel, P, Janot

LEP3/TLEP(/VHE-LHC) hi-tech options

examples-

novel SC cavities for LEP3/TLEP collider

fast ramping HTS magnets
for LEP3/TLEP double ring

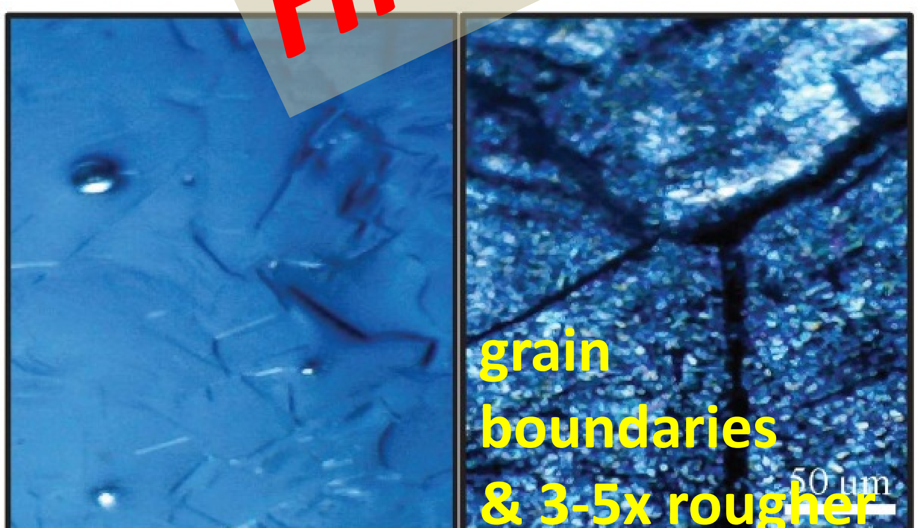
VHE-LHC 20-T high-field magnets

SC cavities based on material other than bulk niobium e.g. thin films or Nb_3Sn

E. Jensen, LHeC 2012; JLAB, IPAC12

- extensive studies at CERN (T. Junginger) and JLAB
- CERN/Legnaro/Sheffield cavities - first prototypes tested at Legnaro in 2012! HiPIMS technique; SIS concept,…
- sputtered *Nb* will reduce cost & and may show better performance; even more HTS SIS cavities
- *Nb_3Sn* could be studied at CERN (quad resonator) in collaboration with other labs

Hi-Tech cavities!



micrographs of sample surface of a micrometer thin niobium film sputtered on top of a copper substrate (left) and a bulk niobium (right) sample

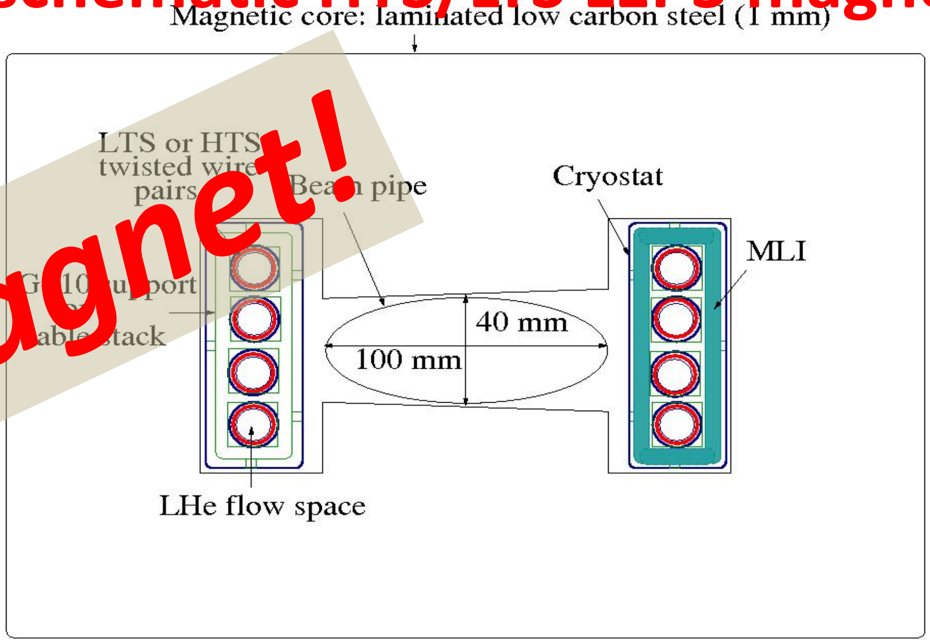
T. Junginger et al, IPAC2011

fast ramping HTS/LTS magnets

H. Piekarz,
1st EuCARD LEP3 Day

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

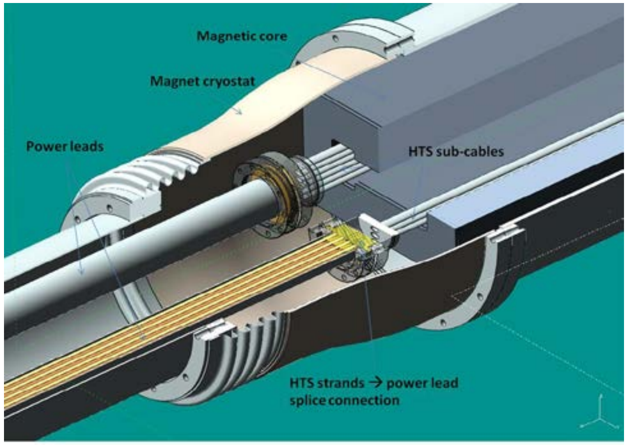
schematic HTS/LTS LEP3 magnet



Hi-Tech magnet!

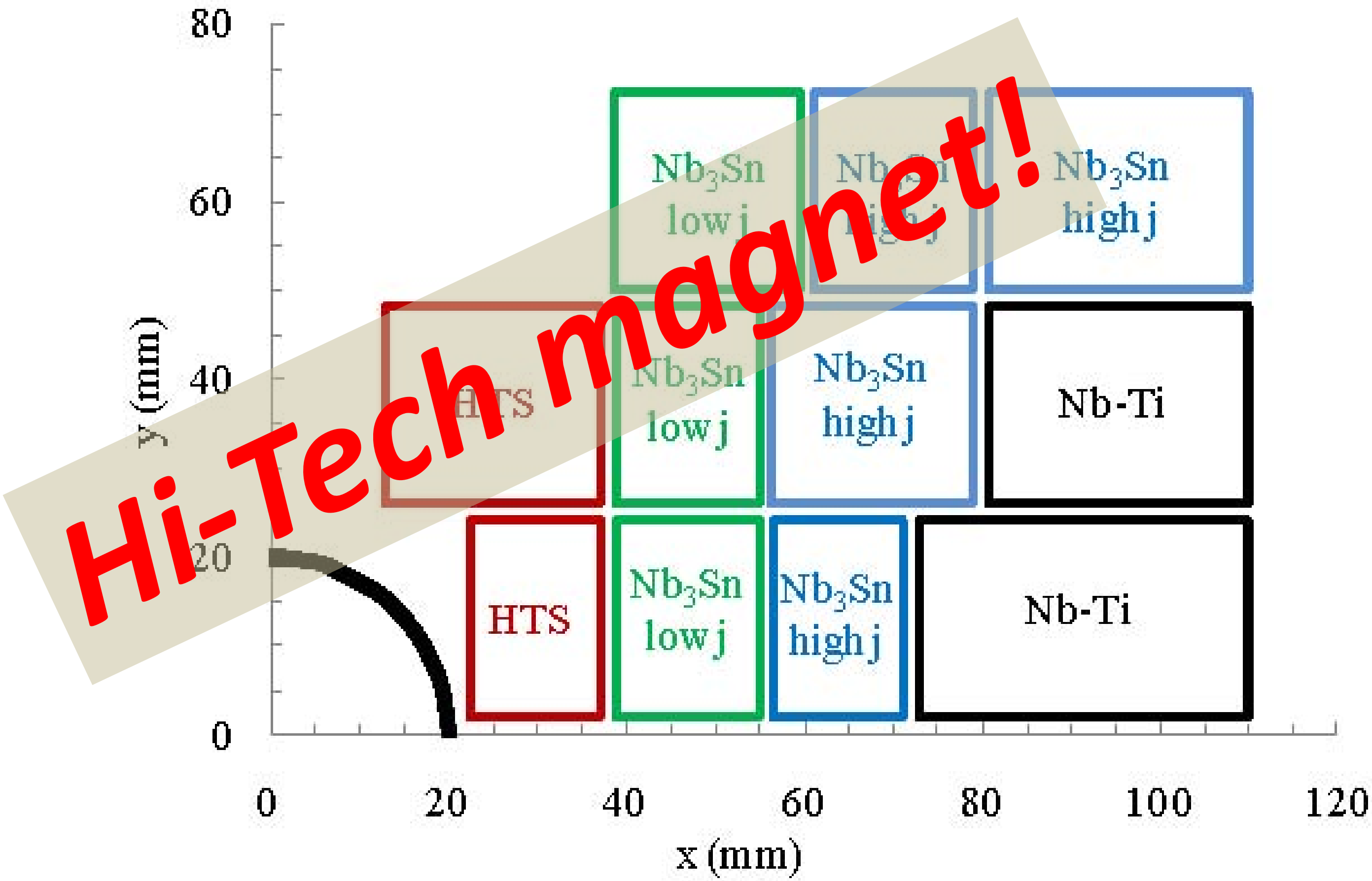
HTS prototype dipole at FNAL

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!

(V)HE-LHC 20-T hybrid magnet



E. Todesco,
L. Rossi,
P. McIntyre

block layout of *Nb-Ti* & *Nb$_3$Sn* & *HTS* (*Bi*-2212) 20-T dipole-magnet coil. Only one quarter of one aperture is shown.

example opinion on LEP3/TLEP

«a ring e^+e^- collider LEP3 or TLEP can provide an economical and robust solution with higher statistics than LC and >1 IP for studying the X(125) with high precision and doing many precision measurements on H, W, Z (+top quark) within our lifetimes»

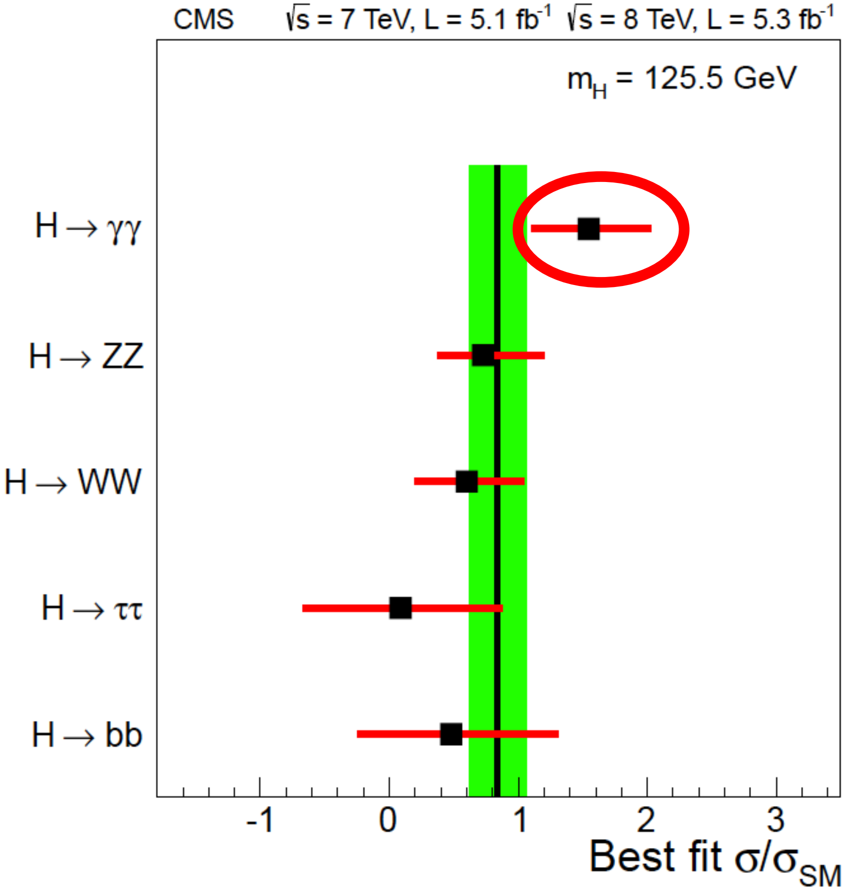
Alain Blondel

ATLAS Meeting
4 Oct. 2012

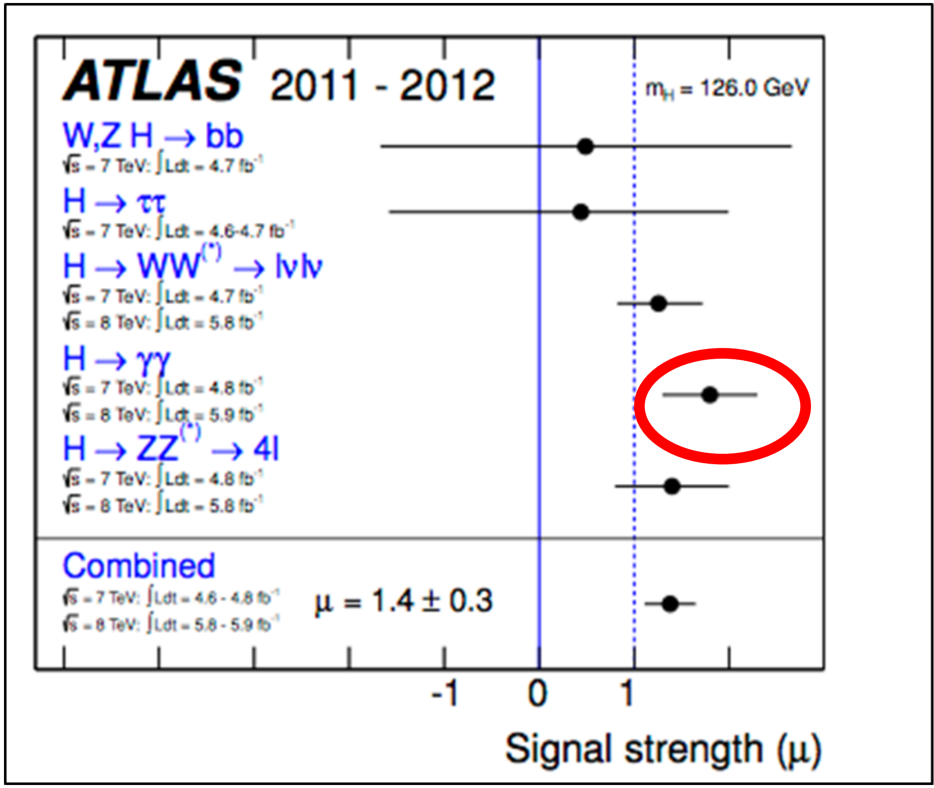
Part 2 - SAPPHiRE

"Higgs" strongly couples to $\gamma\gamma$

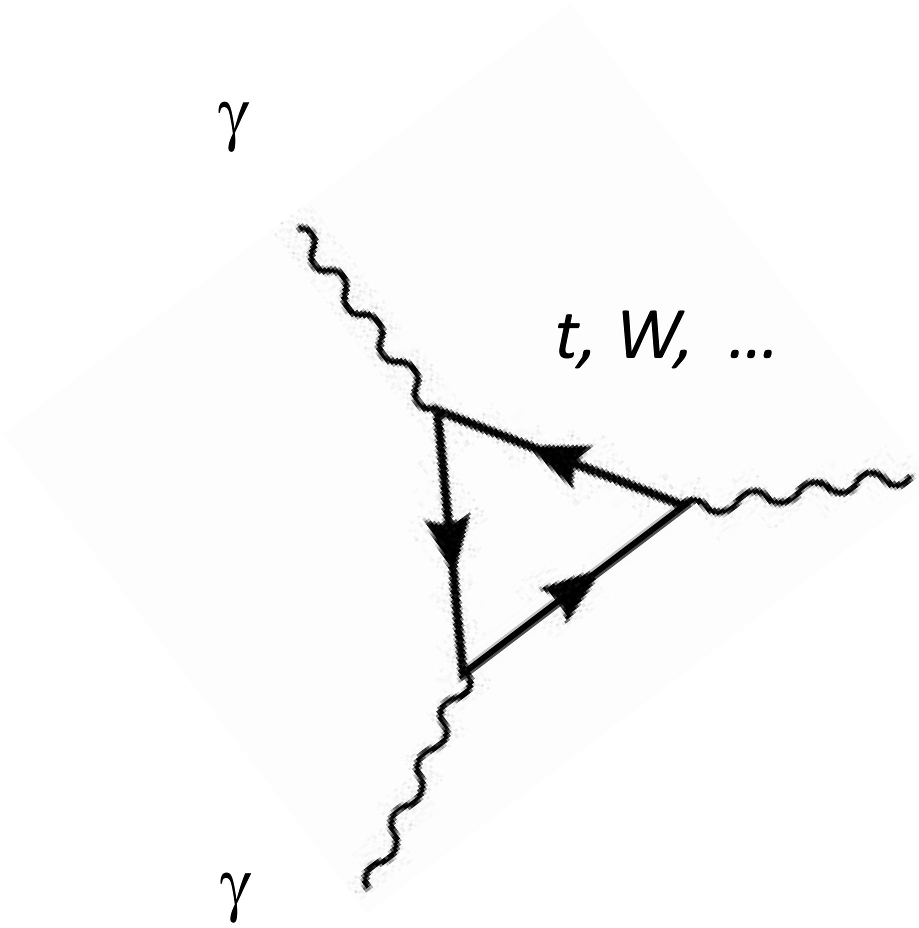
LHC CMS result



LHC ATLAS result



a new type of collider?

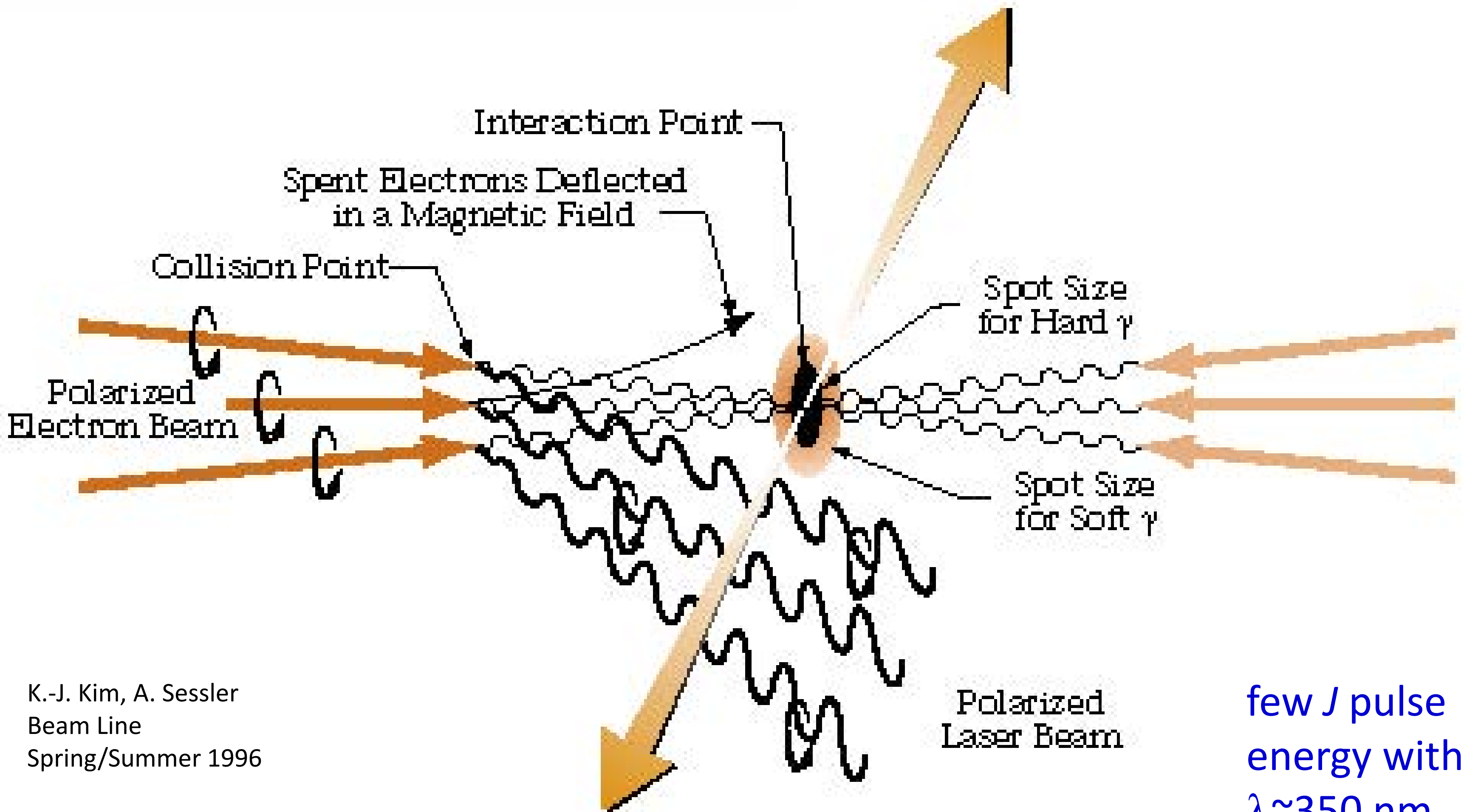


s-channel production;
lower energy;
no e^+ source

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

γγ collider Higgs factory

γγ collider



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?

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

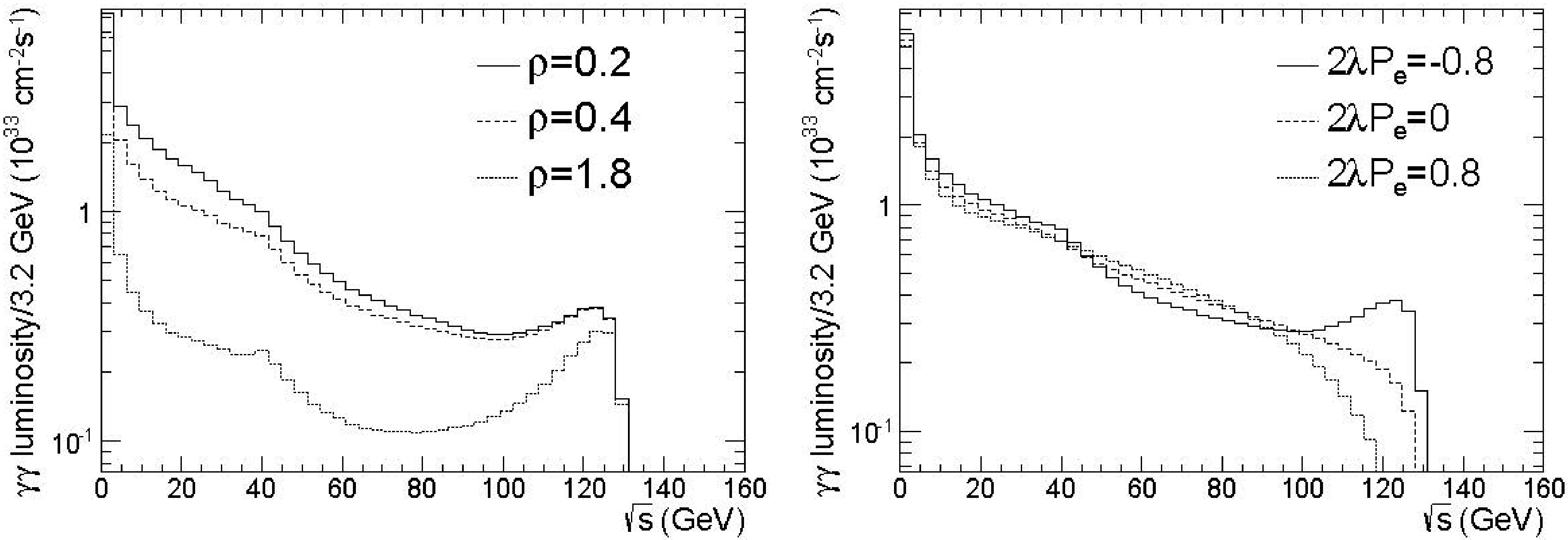
example $x \approx 4.3$
(for x>4.83 coherent pair production occurs)

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

SAPPHiRE $\gamma\gamma$ luminosity

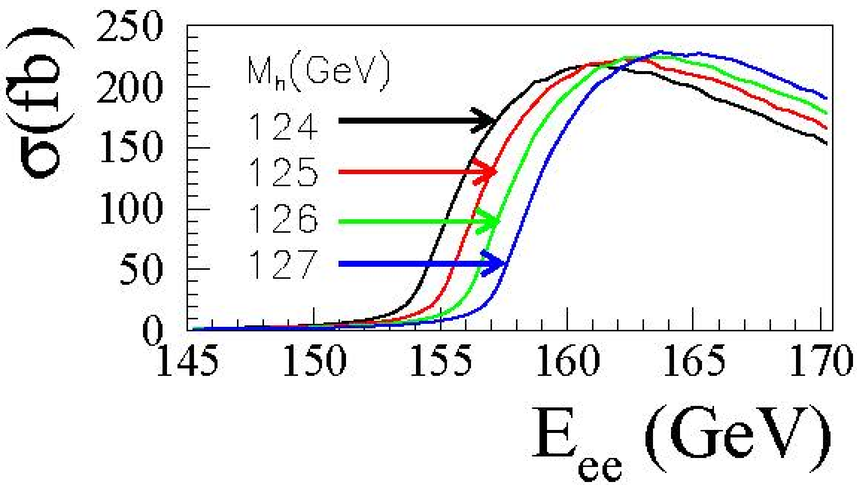
M. Zanetti

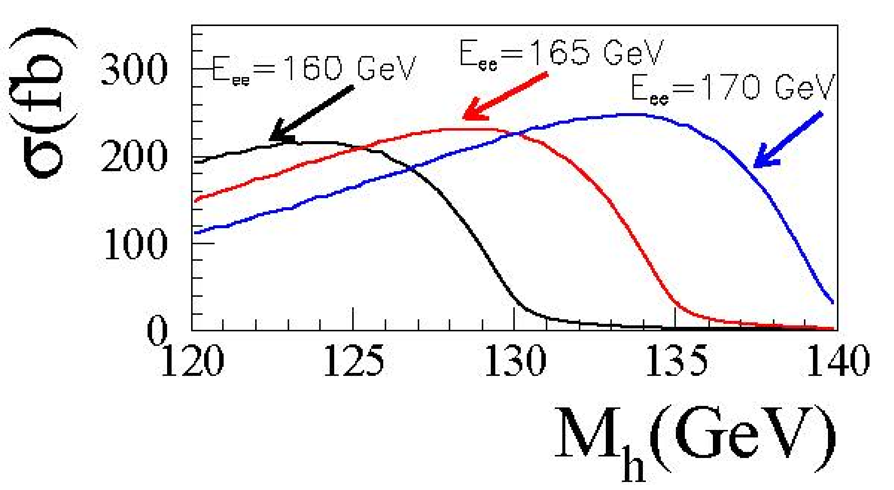


luminosity spectra for SAPPHiRE as functions of $E_{CM}(\gamma\gamma)$, computed using Guinea-Pig for **three possible normalized distances** $\rho \equiv l_{CP\text{-}IP}/(\gamma\sigma_y^*)$ (left) and **different polarizations of in-coming particles** (right)

Higgs $\gamma\gamma$ production cross section

M. Zanetti



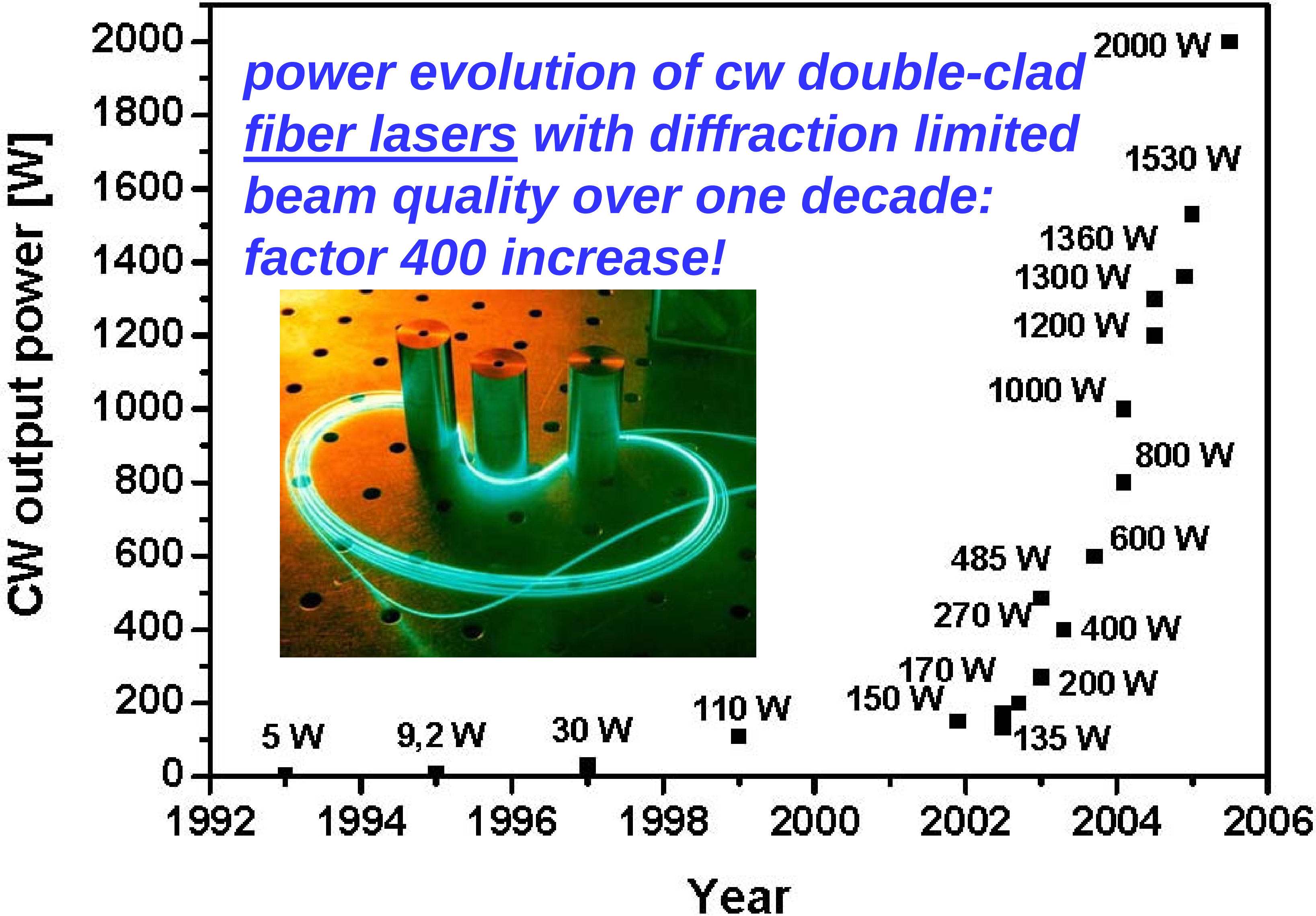


Left: The cross sections for $\gamma\gamma \to h$ *for different values of M_h as functions of E_{CM}*(e^-e^-).

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.

laser progress: example fiber lasers

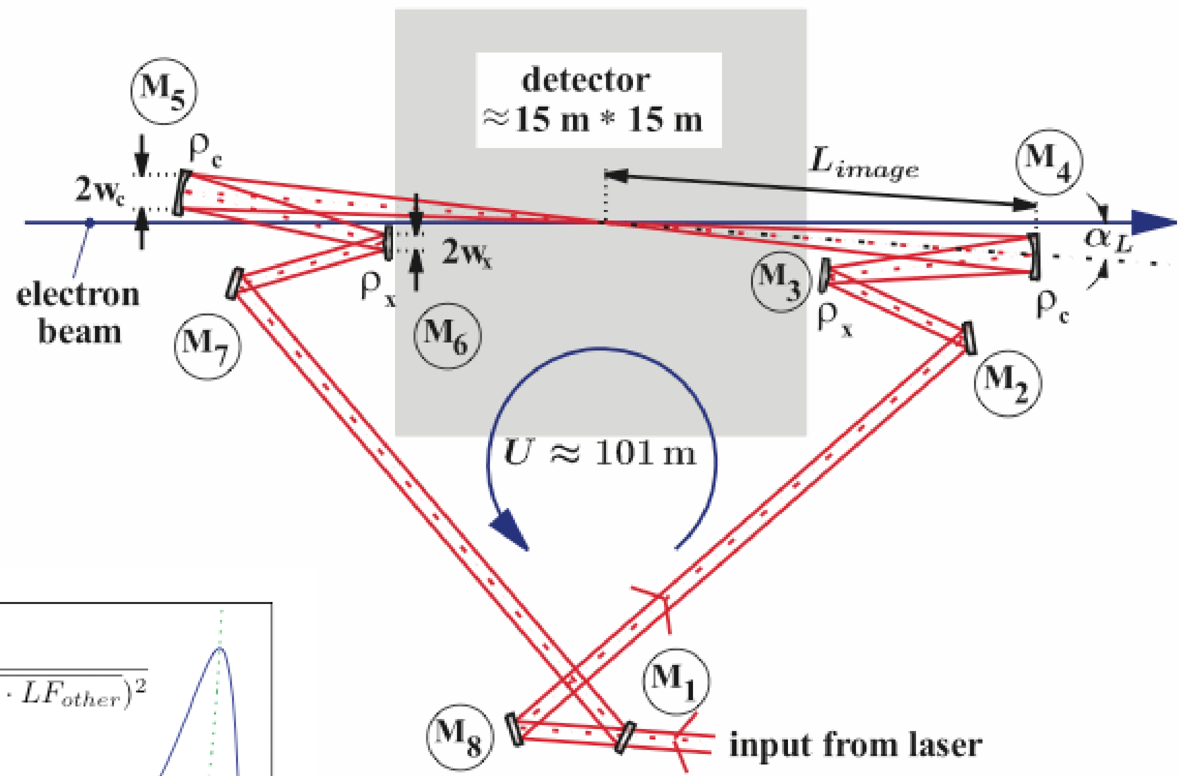


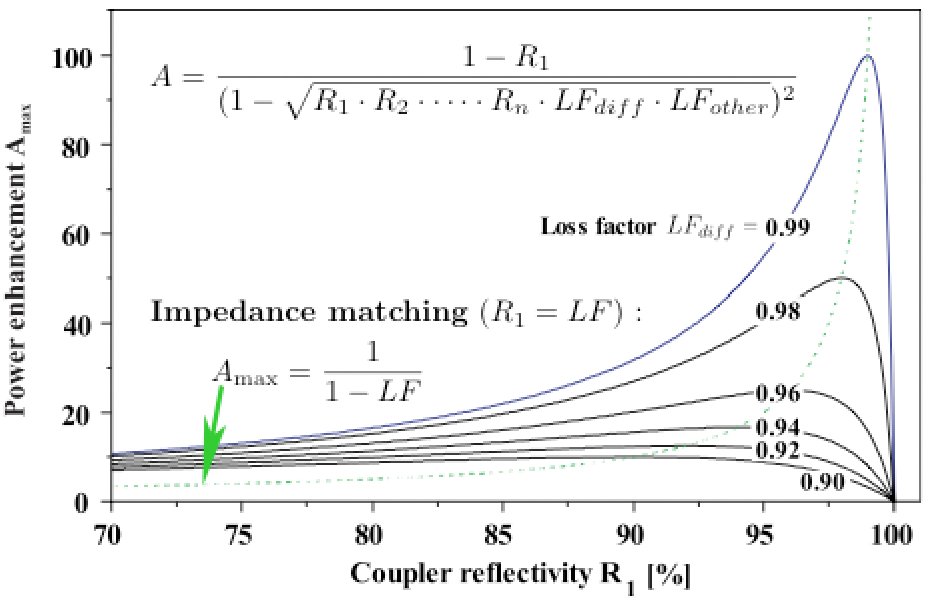
Source: Fiber Based High Power Laser Systems,
Jens Limpert, Thomas Schreiber, and Andreas Tünnermann

passive optical cavity

→

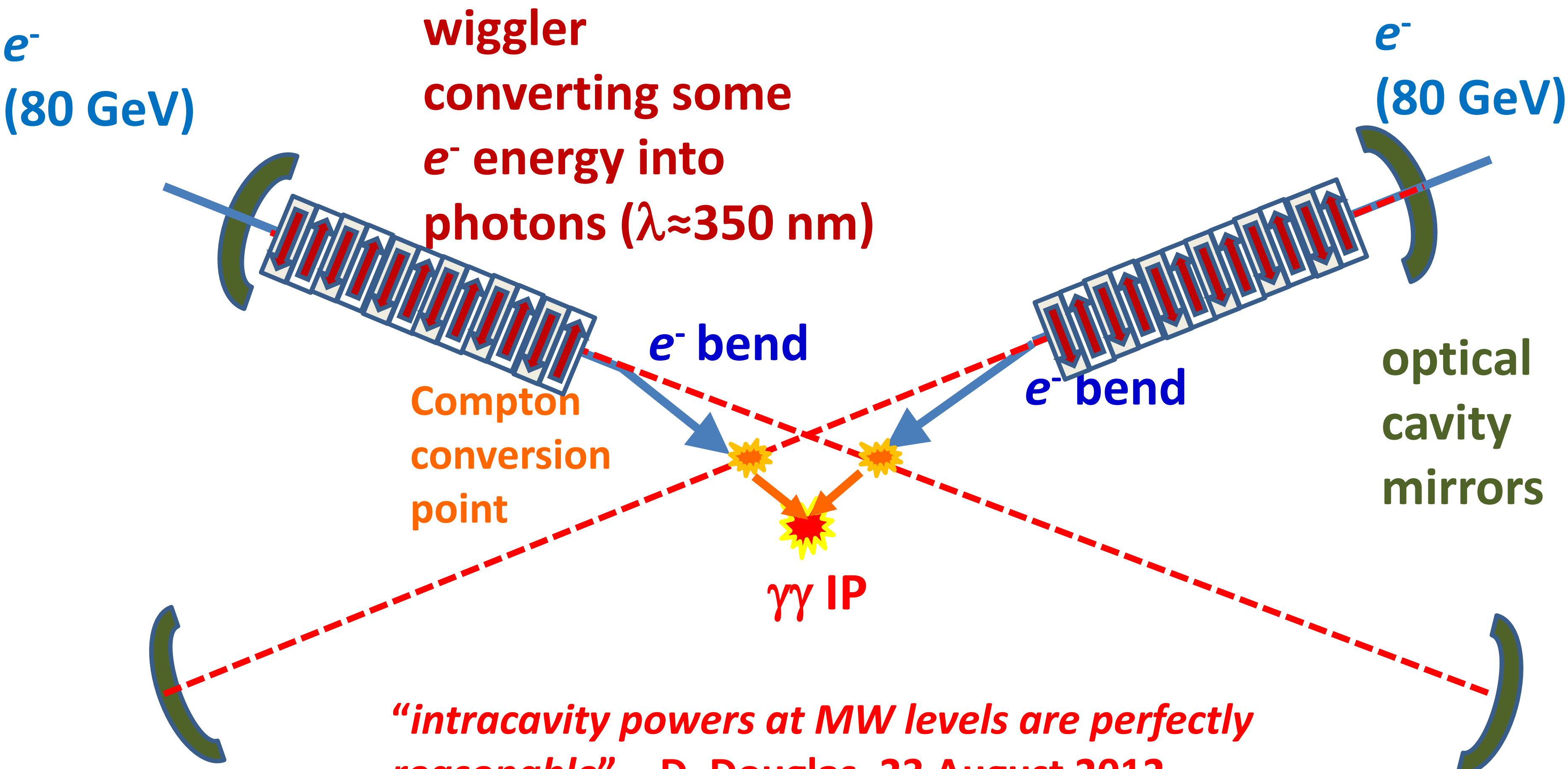
relaxed laser parameters





K. Moenig et al, DESY Zeuthen

self-generated FEL γ beams (instead of laser)?

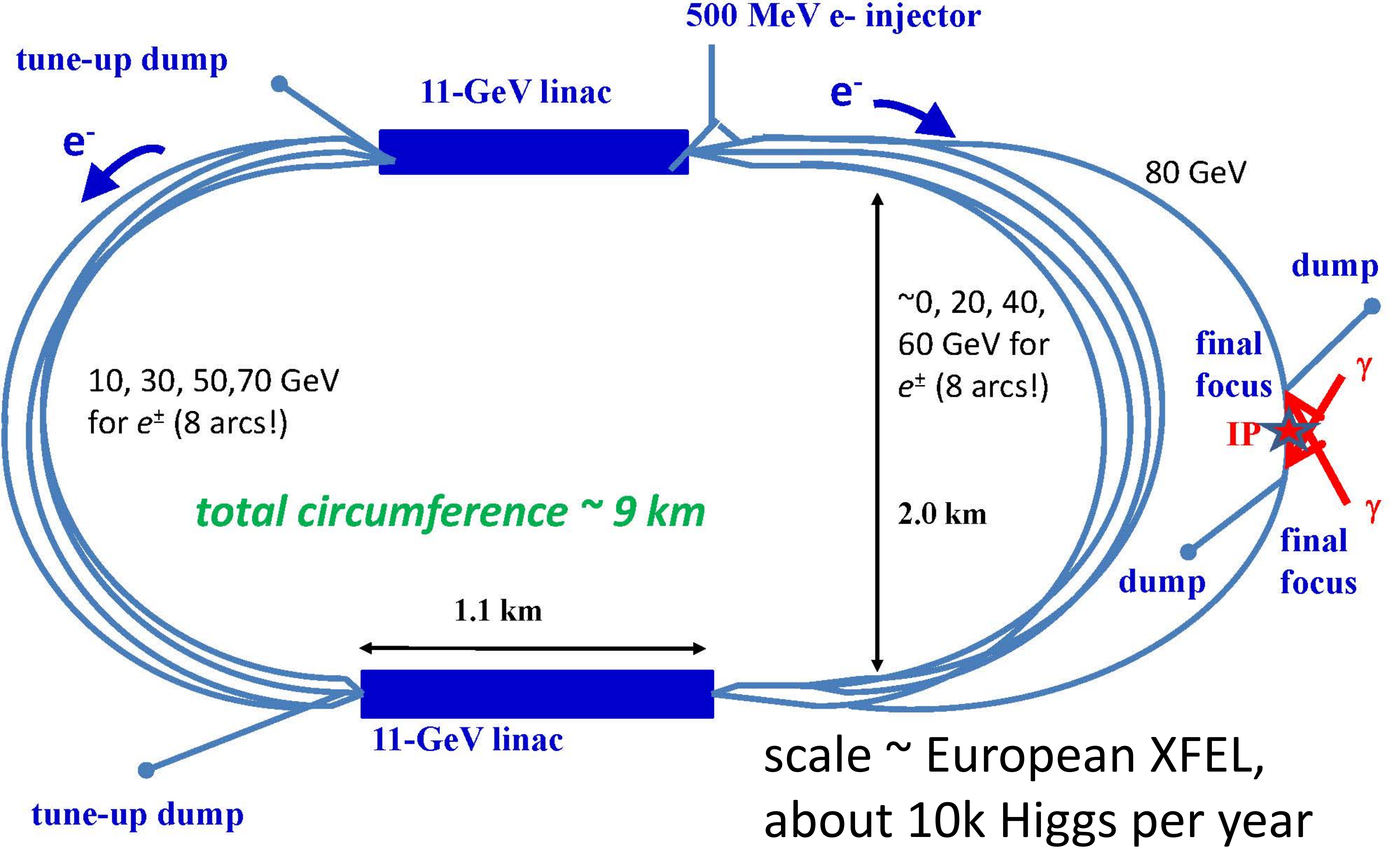


"intracavity powers at MW levels are perfectly reasonable" **– D. Douglas, 23 August 2012**

example: λ_u=50 cm, B=5 T, L_u=50 m, 0.1%P_{beam}≈25 kW

scheme developed with Z. Huang

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



scale ~ European XFEL, about 10k 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}	180 nm
e^-e^- geometric luminosity	L_{ee}	2×10^{34} cm^{-2}s^{-1}

Energy loss on multiple passes

The energy loss per arc is $\Delta E_{arc}\ [\mathrm{GeV}] = 8.846 \times 10^{-5} \frac{(E\ [GeV])^4}{2\rho[\mathrm{m}]}$

For **ρ=764 m** (LHeC design) the energy loss in the various arcs is summarized in the following table. e- lose about 4 GeV in energy, which can be compensated by increasing the voltage of the two linacs from 10 GV to 10.5 GV. We take 11 GV per linac to be conservative.

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%)**

Emittance growth

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

with C_q=3.8319x10^{-13} m, and ρ the bending radius.

For LHeC RLA design with l_{bend}~10 m, and ρ=764 m, <H>=1.2x10^{-3} m [Bogacz et al]. At 60 GeV the emittance growth of LHeC optics is 13 micron, too high for our purpose, and extrapolation to 80 GeV is unfavourable with 6th power of energy. From L. Teng we also have **scaling law $< H > \propto l_{bend}^3/\rho^2$** , which suggests that **by reducing the cell length and dipole length by a factor of 4 we can bring the horiz. norm. emittance growth at 80 GeV down to 1 micron**.

Valery Telnov thinks this scaling is too optimistic reference

TM-1269
0102.000

Fermilab

Minimizing the Emittance in Designing the Lattice of an Electron Storage Ring

L.C. Teng

June 1984

flat polarized electron source

- target $\varepsilon_x/\varepsilon_y$ ~ 10
- flat-beam gun based on flat-beam transformer concept of Derbenev et al.
- starting with $\gamma\varepsilon$~4-5 μm at 0.5 nC, injector test facility at **Fermilab A0 line achieved emittances of 40 μm horizontally and 0.4 μm vertically**, with $\varepsilon_x/\varepsilon_y$~100
- for SAPPHiRE **we only need $\varepsilon_x/\varepsilon_y$~10, but at three times larger bunch charge (1.6 nC) and smaller initial $\gamma\varepsilon$~1.5 μm**
- these parameters are within the present state of the art (e.g. the LCLS photoinjector routinely achieves 1.2 μm emittance at 1 nC charge)
- however, **we need a polarized beam**…

Valery Telnov stressed this difficulty

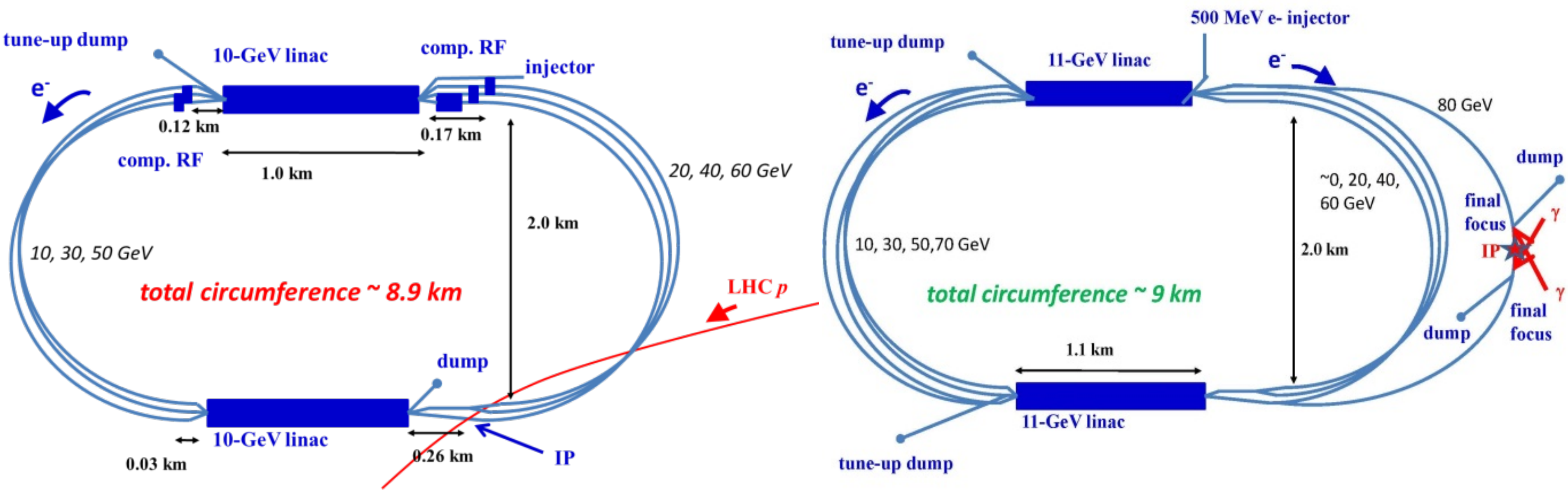
can we get ~ 1-nC polarized e^- bunches with ~1 μm emittance?

ongoing R&D efforts:

low-emittance DC guns
(MIT-Bates, Cornell, SACLA, JAEA, KEK…)
[E. Tsentalovich, I. Bazarov, et al]

polarized SRF guns (FZD, BNL,…)
[J. Teichert, J. Kewisch, et al]

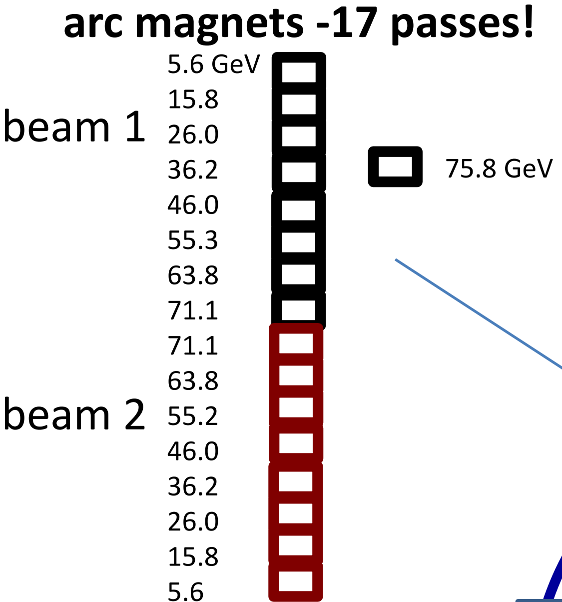
LHeC → SAPPHiRE

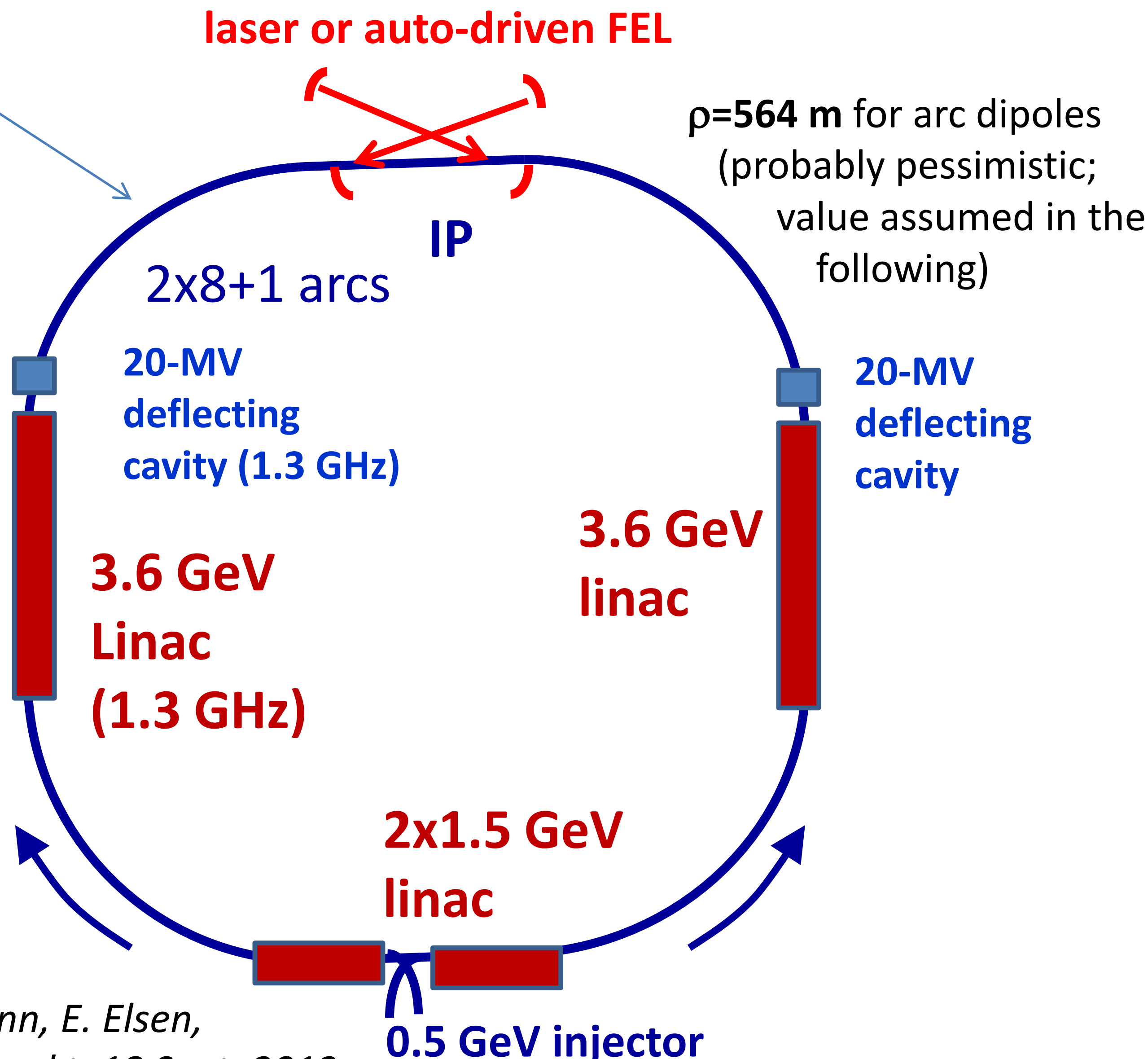


Schematic sketches of the layout for the LHeC ERL (left) and for a gamma-gamma Higgs factory based on the LHeC (right)

would it fit on SLAC site?

schematic of HERA-$\gamma\gamma$





real-estate linac Gradient ~ 10 MV/m

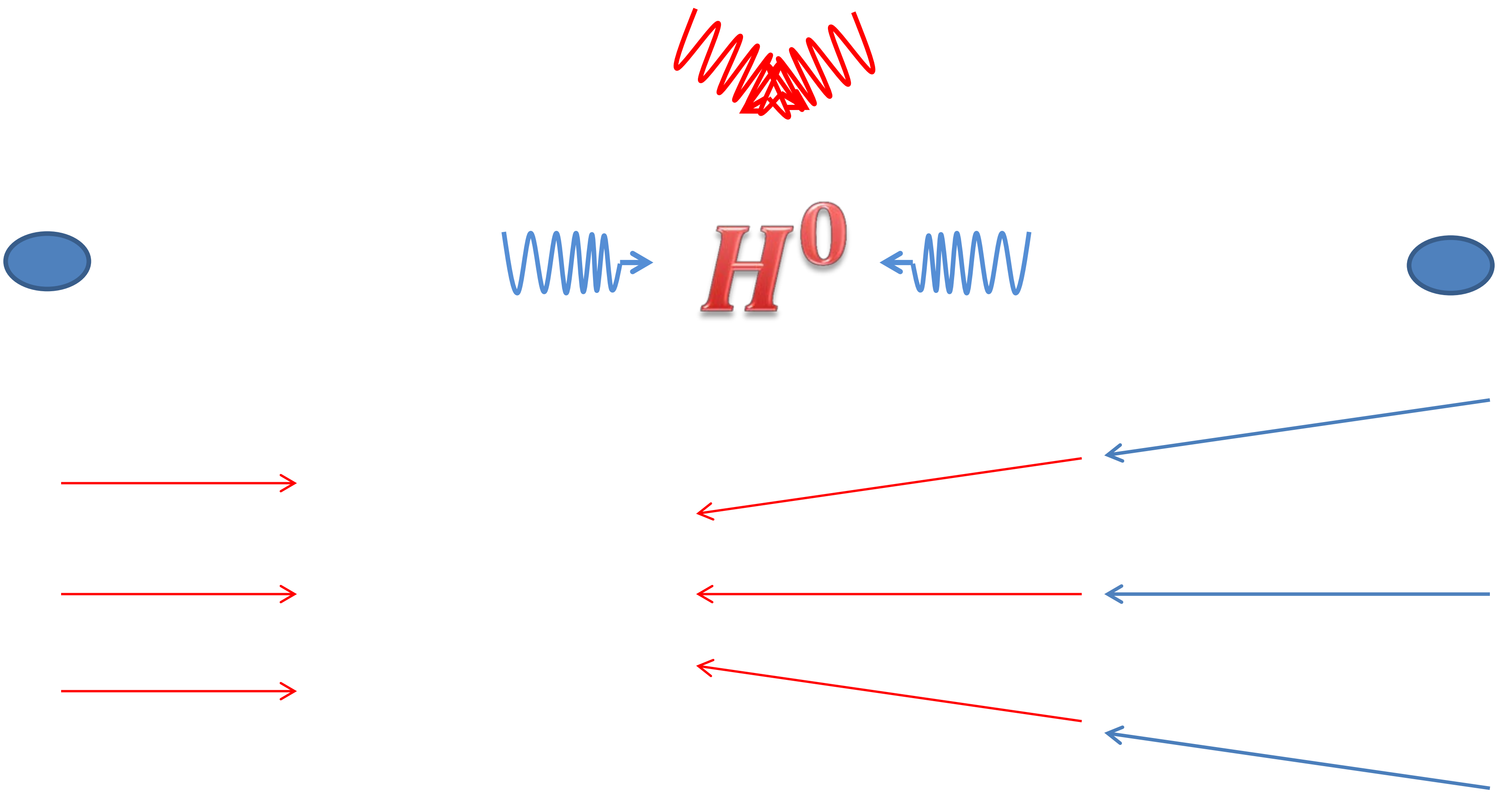
total SC RF = 10.2 GV

F. Zimmermann, R. Assmann, E. Elsen, DESY Bschleuniger-Ideenmarkt, 18 Sept. 2012 *similar ideas elsewhere*

$\gamma\gamma$ Collider at J-Lab

By Edward Nissen

Town Hall meeting Dec 19 2011

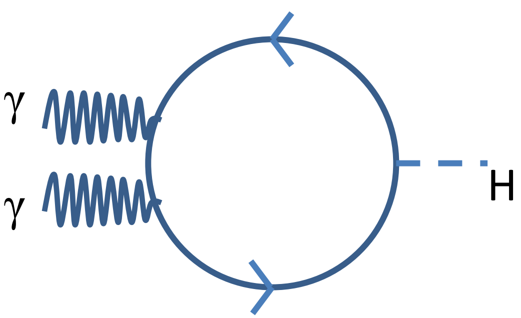


Background

Edward Nissen

$$x = \frac{12.3 E_e(TeV)}{\lambda_\gamma(\mu m)}$$

$$\hbar\omega_\gamma = \frac{x}{1+x} E_e$$



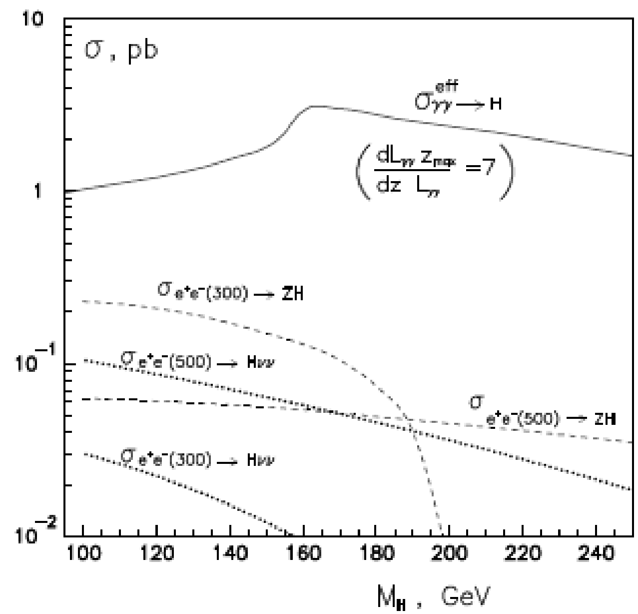


Figure 5: Cross sections for the Standard model Higgs in $\gamma\gamma$ and e^+e^- collisions.

arXiv:hep-ex/9802003v2

Edward Nissen

Possible Configurations at JLAB

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

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

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

vertical rms IP spot sizes in nm

LEP2	3500
KEKB	940
SLC	500
LEP3	320
TLEP-H	220
ATF2, FFTB	150?, 65
SuperKEKB	50
SAPPHiRE	18
ILC	5
CLIC	1

Conclusions

LEP3, TLEP and SAPPHiRE are exciting and popular projects

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

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

LEP3, TLEP, and SAPPHiRE are moving forward – please join

thank you for listening!

J. Adams, 1959

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[2] 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].

[3] J. Abelleira Fernandez et al, 'A 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 [physics.acc-ph].

backup slides

rf efficiency ($P_{wall} \rightarrow P_{SR}$)

compare **numbers from LHeC Conceptual Design Report**: J L Abelleira Fernandez et al, *"A Large Hadron Electron Collider at CERN Report on the Physics and Design Concepts for Machine and Detector,"* J. Phys. G: Nucl. Part. Phys. 39 075001 (2012):

conversion efficiency grid to amplifier RF output = 70%
transmission losses = 7%
feedbacks power margin = 15%
→ **total efficiency ~55%**

50% assumed for LEP3/TLEP at same frequency & gradient

transverse impedance & TMCI

LEP bunch intensity was limited by TMCI: ***$N_{b,thr}$*~5x10^{11} at 22 GeV**

LEP3 with 700 MHz: **at 120 GeV we gain a factor 5.5 in the threshold**, **which almost cancels a factor $(0.7/0.35)^3$ ~ 8** arising from the change in wake-field strength due to the different RF frequency

LEP3 Q_s~0.2, LEP Q_s~0.15: further **25% increase** in TMCI threshold?

only ½ of LEP transverse kick factor came from SC RF cavities

LEP3 beta functions at RF cavities might be smaller than in LEP

LEP3 bunch length (2-3 mm) is shorter than at LEP injection (5-9 mm)

M. Lamont, SL-Note-98-026 (OP)

beam-beam with large hourglass effect?

simulations by K. Ohmi presented at 2nd EuCARD LEP3 Day