HE-LHC & VHE-LHC

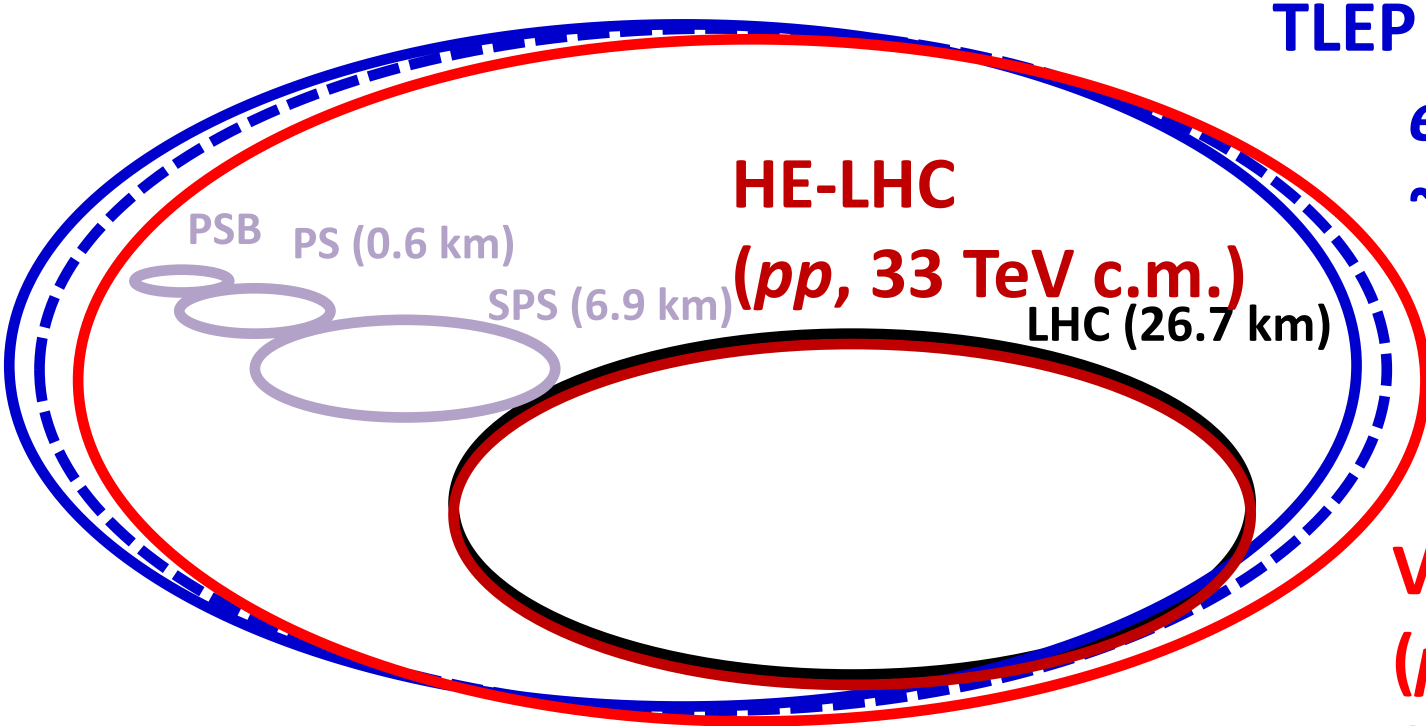
accelerator overview, injector chain, and main parameter choices

Frank Zimmermann

Joint Snowmass-EuCARD/AccNet-HiLumi LHC meeting
'Frontier Capabilities for Hadron Colliders 2013'
21 February 2013

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

possible long-term strategy



also: ***e***$^{\pm}$ **(120 GeV) – *p* (7 & 50 TeV)** collisions

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

LHC & LHC upgrades

LHC is the 1st Higgs factory!

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

total cross section at 8 TeV: 22 pb

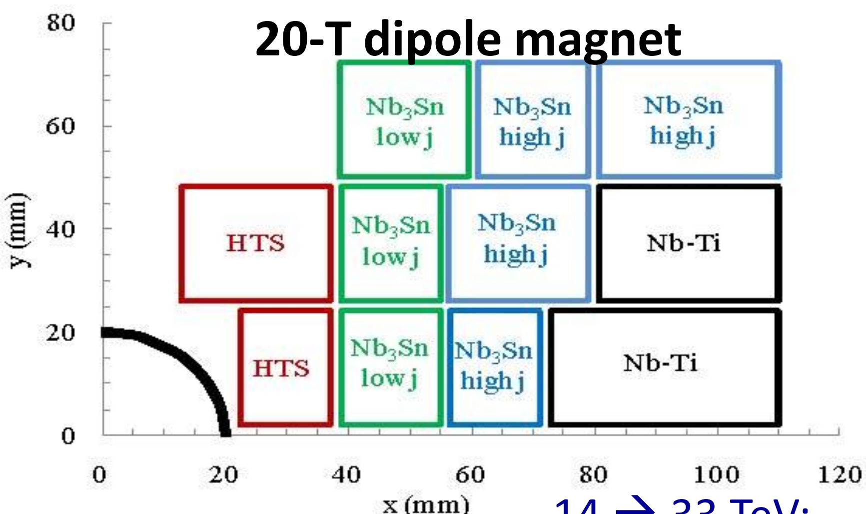
1 M Higgs produced so far – more to come

15 H bosons / min – and more to come

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

HE-LHC: in LHC tunnel (2035-)

$\boldsymbol{E_{CoM}=33}$ **TeV,** $\boldsymbol{\widehat{L} = 5x10^{34} cm^{-2}s^{-1}}$



14 → 33 TeV:

HH x6

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

HL-LHC (~2022-2030)

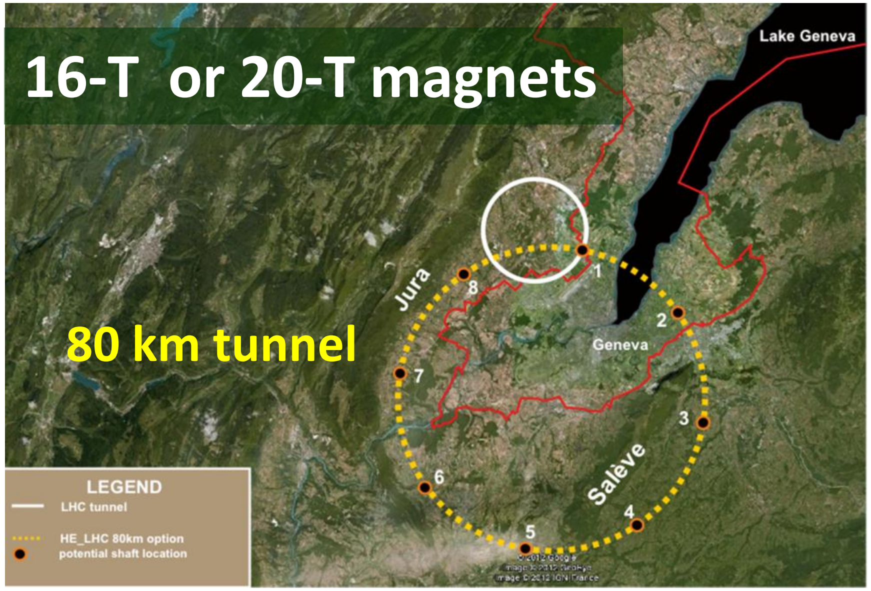
will deliver ~9x more H bosons!

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

with luminosity leveling

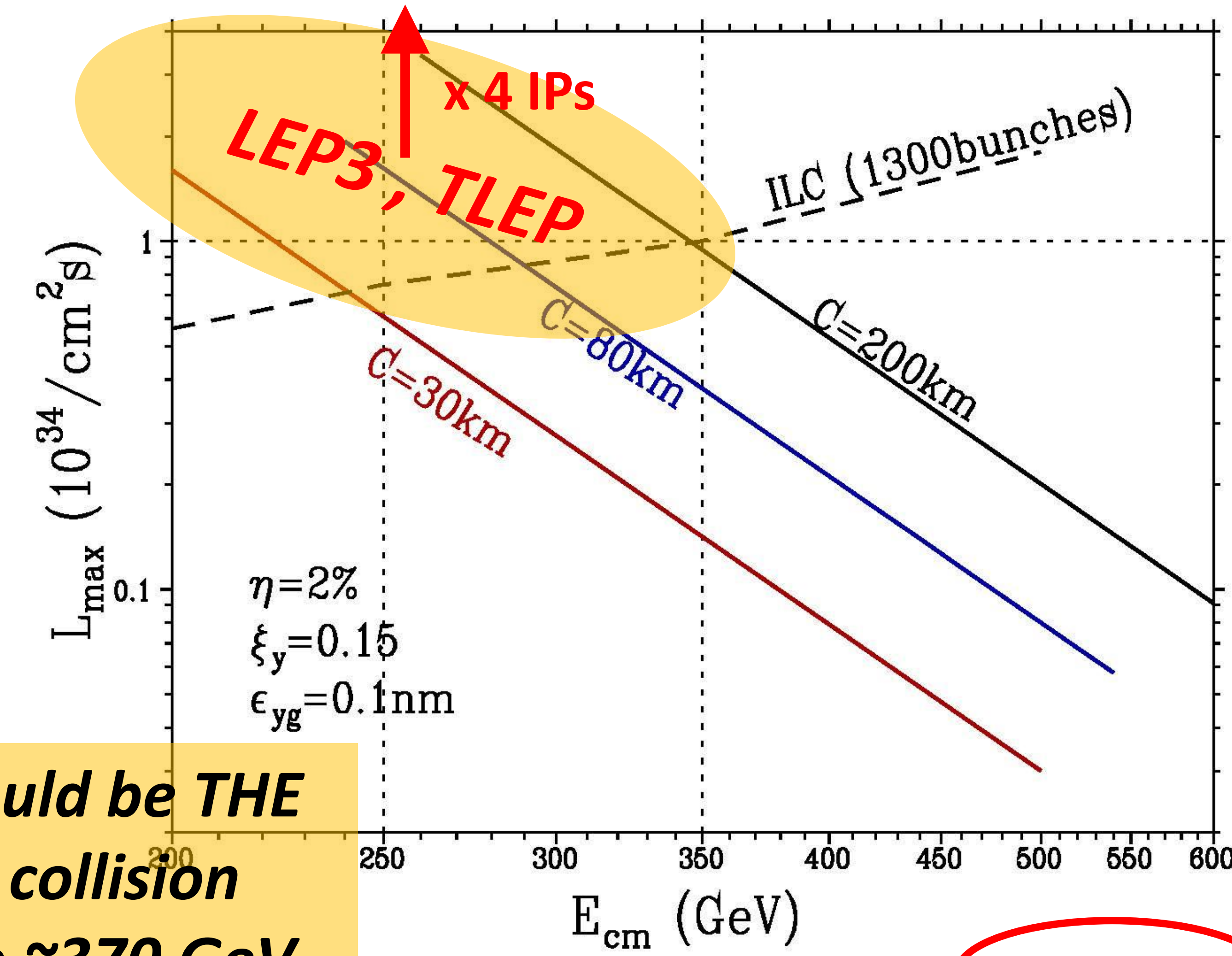
VHE-LHC: new 80 km tunnel

$\boldsymbol{E_{CoM}=84\text{-}104}$ **TeV,** $\boldsymbol{\widehat{L} = 5x10^{34} cm^{-2}s^{-1}}$



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

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%	~2[illegible]% (~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%	3%	--	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]

HE-LHC - *studies*

CERN working group in 2010

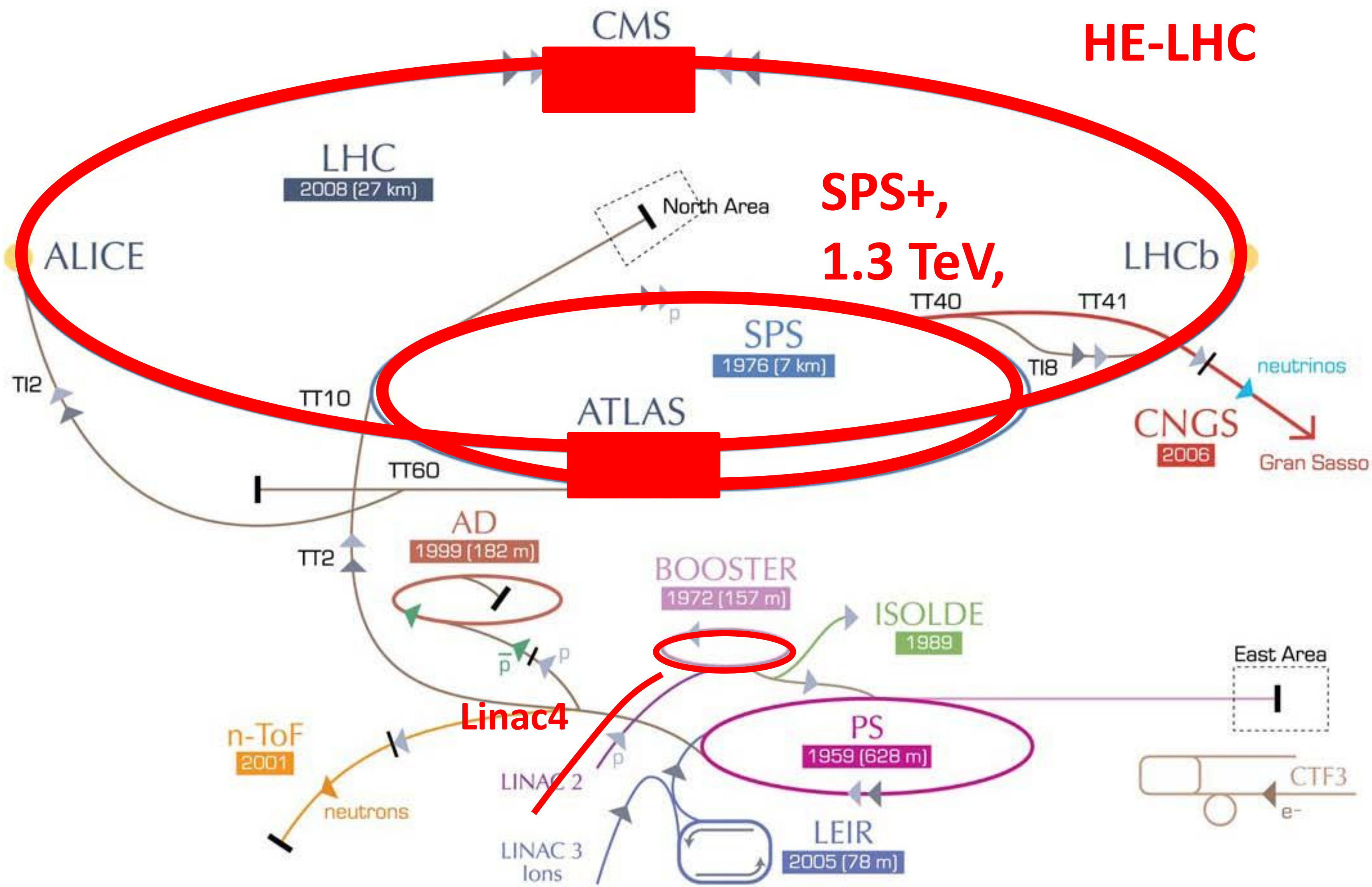
published report R. Assmann et al,
"First Thoughts on a Higher-Energy LHC"
CERN-ATS-2010-177

EuCARD-AccNet workshop HE-LHC'10

Proceedings (ed. E. Todesco, F. Zimmermann)
"EuCARD-AccNet-EuroLumi Workshop:
The High-Energy Large Hadron Collider"
arXiv:1111.7188 ; CERN-2011-003

HiLumi LHC WP16

HE-LHC – *LHC modifications*



VHE-LHC - *studies*

80-km tunnel study

John Osborne, C. Waaijer,

"Pre-Feasability Assessment for an 80 km Tunnel Project at CERN"

Open Symposium - European Strategy Preparatory Group

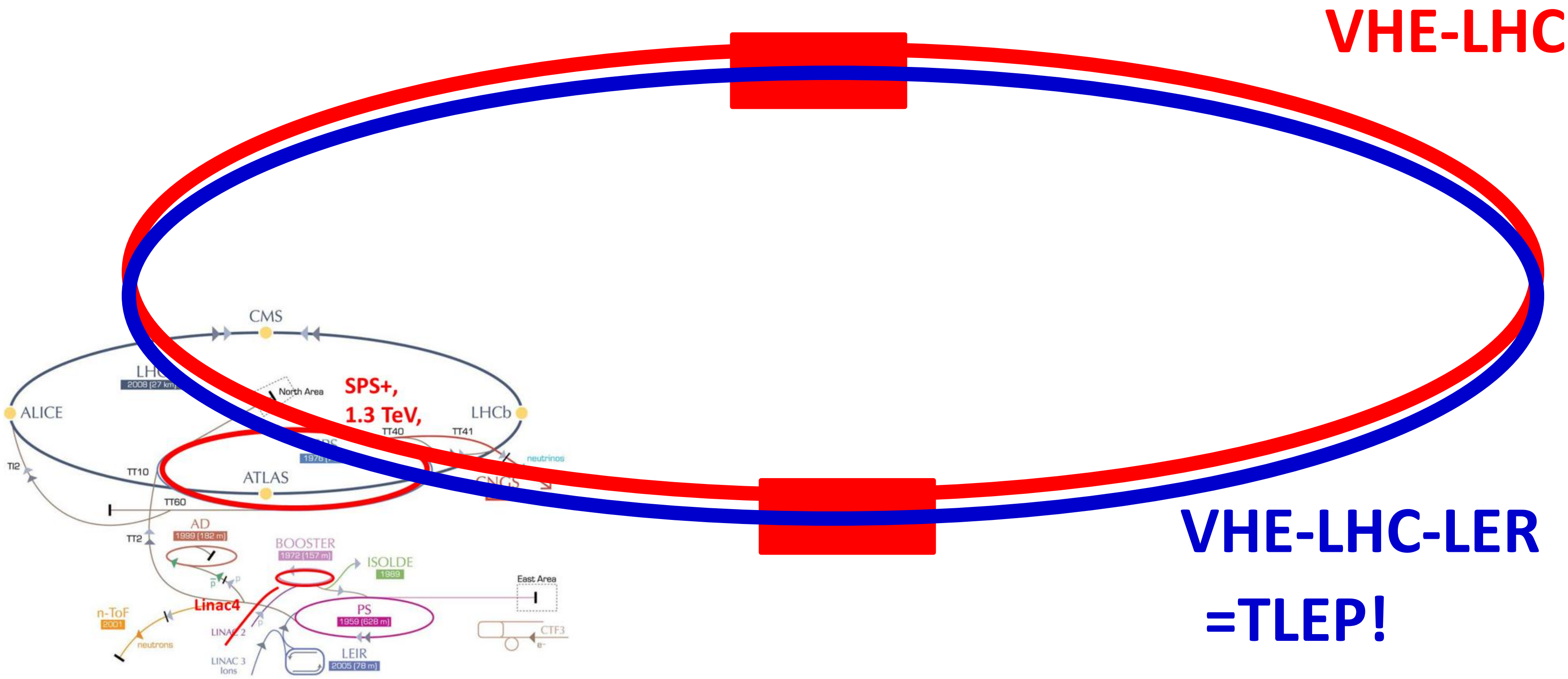
Contribution ID : 165

European Strategy briefing booklet

section in accelerator chapter

R. Aleksan, C. Biscari, M. Lindroos, L. Rivkin, F. Zimmermann

VHE-LHC



(Lucio Rossi)

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.

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.

radiation damping

use controlled blow up by noise injection:

- longitudinal plane
  (constant bunch length, Landau damping)

- transverse planes
  (constant beam-beam tune shift)

choose round ($\varepsilon_x=\varepsilon_y$) or flat beams ($\varepsilon_x>>\varepsilon_y$)

peak luminosity, pile up, radiation

are 5×10^{34} $cm^{-2}s^{-1}$ and pile up of 190 good targets for HE-LHC and VHE-LHC?

it would be easy to get more luminosity

SR heat load

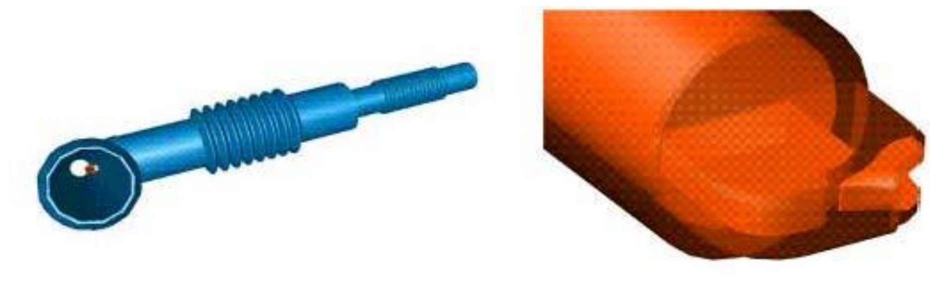
HE-LHC: 3.5 W/m

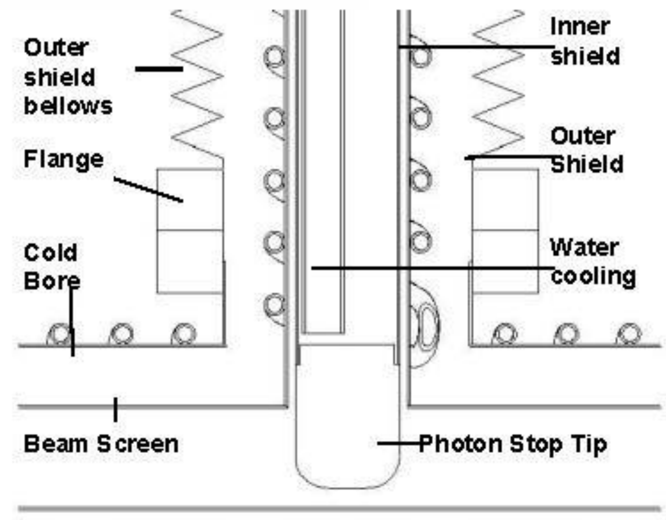
beam screen at 40-60 K (instead of 4.6-20 K)
+ warm photon absorbers for vacuum?

VHE-LHC: 33 W/m

dedicated photon stops

as developed by FNAL for VLHC by P. Bauer et al. (2001-2003)





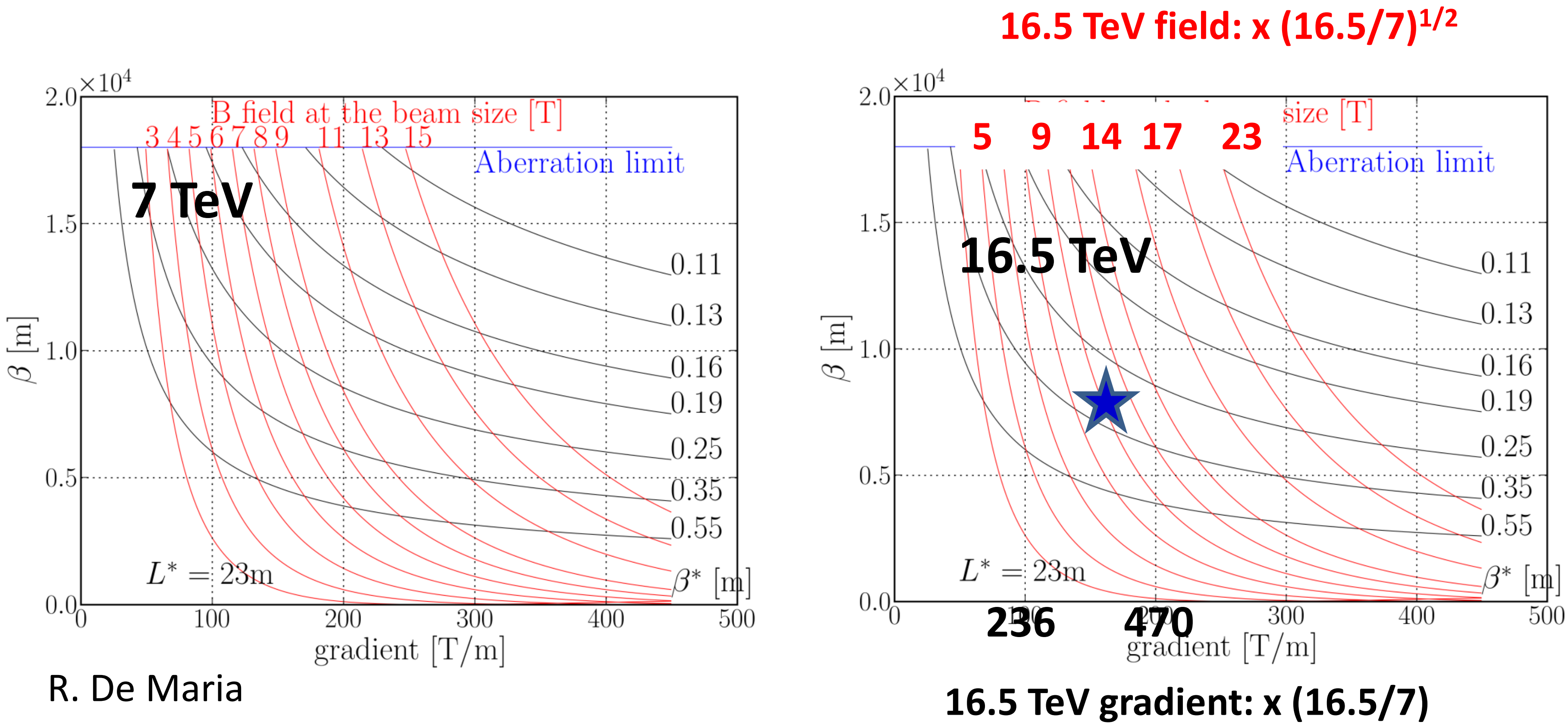
collimation challenges

- higher energy density
  → need for more robust materials
- cross section for single diffractive scattering increases with energy → degraded cleaning efficiency
- smaller beam sizes & smaller gaps → higher precision in collimator control
- (warm? or shielded SC) magnets in the collimator insertions

R. Assmann, HE-LHC'10

IR quadrupoles

how do IR magnets scale with energy and beta*?



R. De Maria

peak beta function as a function of quadrupole gradient (horizontal axis), β* (red curves) and magnetic field at 16.5σ+11 mm (black curves) for 7 & 16.5 TeV

e.g.: β^*=0.3 m, 400 T/m, β_{peak}~8 km, γε=2.10 μm, full ap. (33 σ) ~32 mm (16.5 TeV)
β^*=0.9 m, 700 T/m, β_{peak}~1 km, γε=3.37 μm, full ap. (33 σ) ~8 mm (50 TeV)

arc quadrupoles

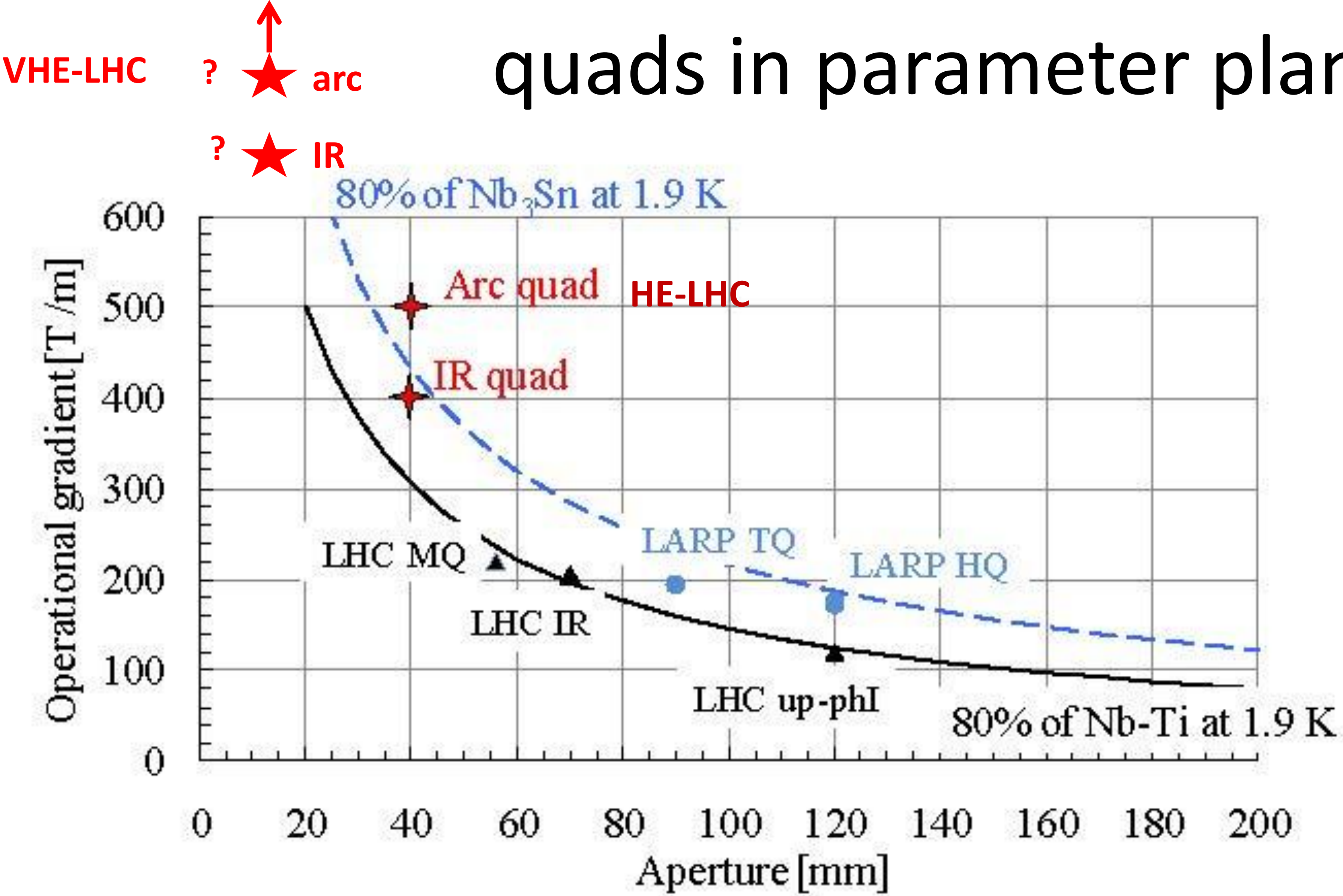
40 mm coil aperture as the dipoles

223 T/m x (16.5/7) = 526 T/m at 16.5 TeV
223 T/m x (50/7) = 1593 T/m at 50 TeV

(if we assume same length as now)

more demanding than IR quads?!

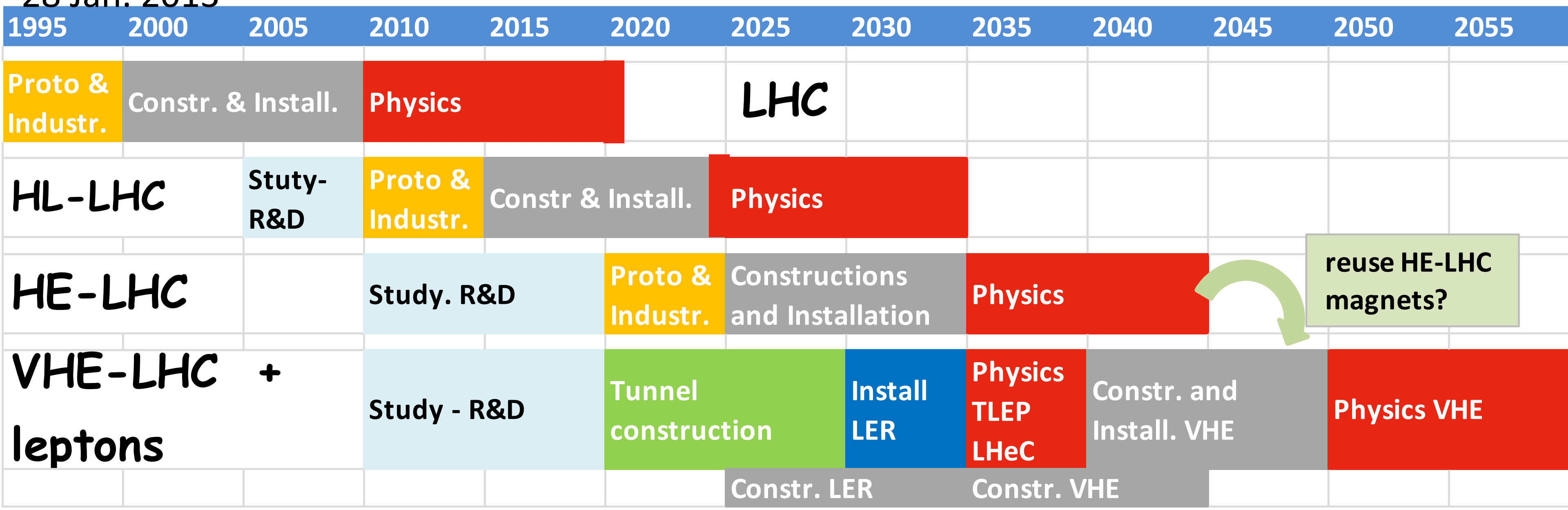
quads in parameter plane



Operational gradient as a function of coil aperture for LHC and US-LARP quadrupoles (markers), scaling laws for limits in Nb.Ti and Nb3Sn (solid curves) [7], and expected values for HE LHC arc and IR (stars).

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

“We don’t get a chance to do that many things and every one should be really excellent.”

Steve Jobs