Beam Parameters, Optics & Beam-Dynamics Issues

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beam parameters

beam energy ~16.5 TeV
corresponds to dipole magnet of 20 T
assuming the same filling factor as for LHC

peak luminosity at 33 TeV ~2x10^{34} cm^{-2}s^{-1}
IR radiation similar to HL-LHC at 5x10^{34} cm^{-2}s^{-1}
assuming that radiation sensitivity scales with *LxE*

IP beta*: 0.4 - 1.0 m
similar to nominal LHC, larger than for HL-LHC

normalized transverse emittances: 1.8-3.8 μm
similar to nominal & present LHC

#bunches = 1404 (50 ns spacing) at ≥ nominal intensity
to limit **beam-screen heat load from SR & image**;
to keep **stored beam energy (480 MJ)** close to 360-MJ
value for nominal LHC (machine protection) ;
side benefit: **electron cloud** more benign than for 25 ns;
e-cloud also mitigated by coatings & clearing electrodes

bunch intensity 1.3×10^{11}
well below ultimate; sufficient to get target luminosity

alternatively 2808 bunches (25 ns spacing) of half the bunch charge and half the transverse emittance
more challenging for collimation and machine protection

dipole coil aperture = 40 mm

same value as original SSC

present LHC 56 mm

beam half aperture = 1.3 cm

with margin for vacuum tube & beam screen ;

about 30% lower than present LHC (~2.0 cm) ;

maximum aperture needed at injection

injection energy ≥ 1 TeV

to limit HE-LHC energy ramp to factor ≤ 16 as for LHC;

presently 450 GeV from SPS → new injector

events per crossing ~76
about 4 times nominal
similar to, or less than, HL-LHC

longitudinal emittance damping time ~1 h
13 h for nominal LHC ;
SR shrinks all three emittances, control by noise injection ;
natural leveling of luminosity and/or tune shift

SR heat load = 2.8 W/m/aperture
0.17 W/m/aperture is nominal

SR power / ring = 66 kW
3.6 kW nominal

RF voltage 32 MV

twice nominal value 16;

keeps synchrotron tune approximately the same as for

LHC (beam & particle stability)

[we could also choose 16 MV (E. Shaposhnikova)]

longitudinal emittance 4eVs

larger than nominal 2.5 eVs;

follows general trend of increasing emittance w. energy ;

constant Landau damping at constant σ_z requires

$\varepsilon_{||} \propto \Delta E \propto E$ (at constant impedance) – LHC PN 394;

our assumed blowup is about half this factor ;

yields a bunch length not much shorter than nominal

(6.5 cm vs. 7.6 cm)

beam lifetime due to *p* consumption ~13 h

46 h for nominal LHC

optimum run time ~10 h

assuming 5 h turnaround time ;

15 h run time for nominal LHC

total beam-beam tune shift for 2 IPs: 0.01 – 0.03

can be restricted through transverse emittance control;

interplay of SR, IBS and beam-beam !?

optimum average luminosity per day ~0.8/fb

~0.5/fb for nominal LHC

equivalent flat & round beam scenarios for HE-LHC

initial values	nominal LHC	HE-LHC	
		flat	**round**
$\gamma\varepsilon$ [μm]	3.75	3.75 (x), 1.84 (y)	2.59 (x & y)
β*[m]	0.55	1 (x), 0.43 (y)	0.6 (x & y)
σ*[μm]	16.7	14.6 (x), 6.3 (y)	9.4 (x & y)
θ_c [μrad]	285 (9.5 $\sigma_{x,y}$)	175 (12 σ_{x0})*	188.1 (12 $\sigma_{x,y0}$)*

***long-range collisions** should be no problem

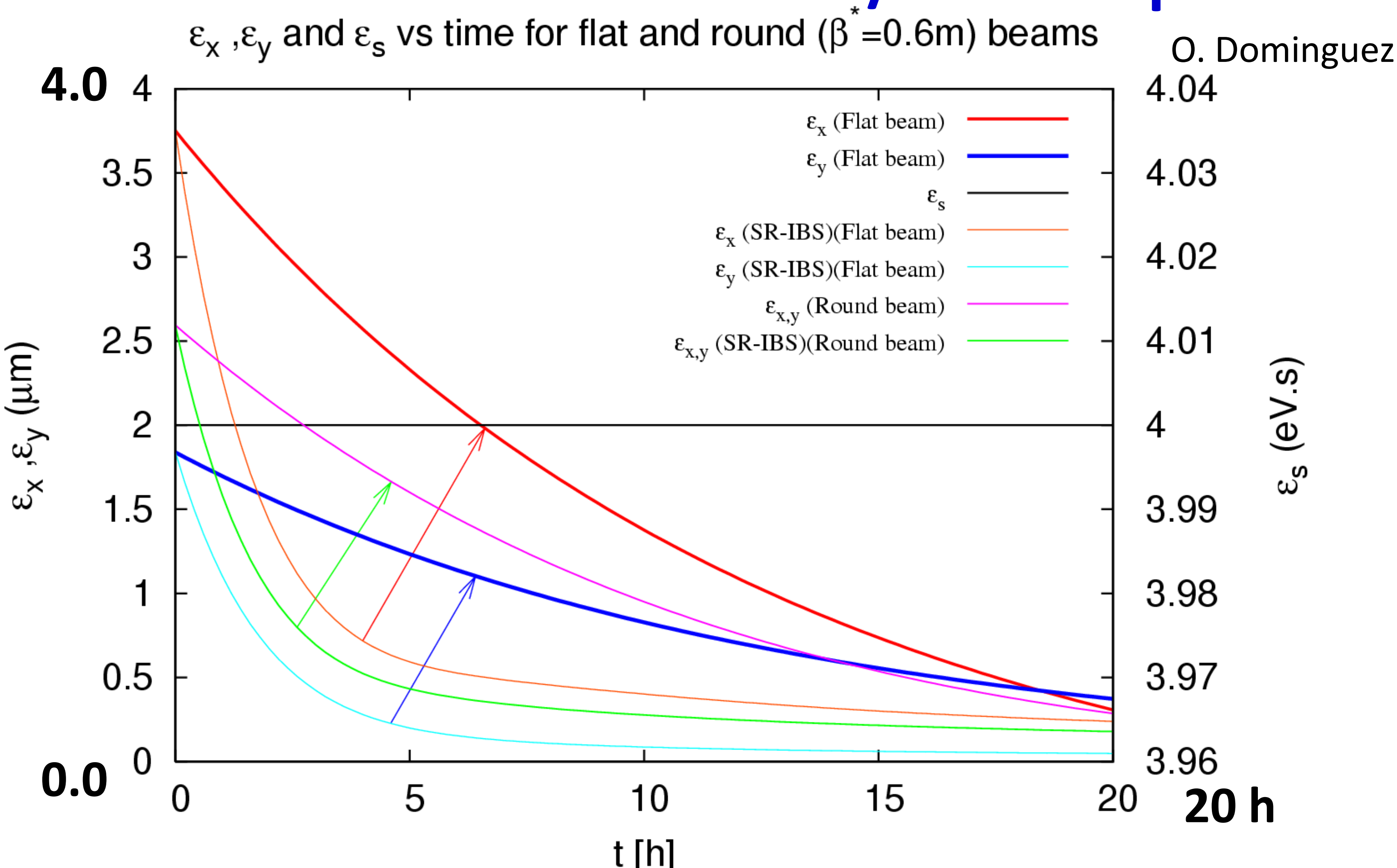
full parameter list part 1

	nominal LHC	HE-LHC	
beam energy [TeV]	7	16.5	
dipole field [T]	8.33	20	
dipole coil aperture [mm]	56	40	
beam half aperture [cm]	2.2 (x), 1.8 (y)	1.3	
injection energy [TeV]	0.45	>1.0	
#bunches	2808	1404	
bunch population [10^{11}]	1.15	1.29	1.30
initial transverse norm. emittance [μm]	3.75	3.75 (x), 1.84 (y)	2.59 (x & y)
initial longitudinal emittance [eVs]	2.5	4.0	
number of IPs contributing to tune shift	3	2	
initial total beam-beam tune shift	0.01	0.01 (x & y)	
maximum total beam-beam tune shift	0.01	0.01	
beam circulating current [A]	0.584	0.328	
RF voltage [MV]	16	32	
rms bunch length [cm]	7.55	6.5	
rms momentum spread [10^{-4}]	1.13	0.9	
IP beta function [m]	0.55	1 (x), 0.43 (y)	0.6 (x & y)
initial rms IP spot size [μm]	16.7	14.6 (x), 6.3 (y)	9.4 (x & y)
full crossing angle [μrad]	285 (9.5 $\sigma_{x,y}$)	175 (12 σ_{x0})	188 (12 $\sigma_{x,y0}$)

full parameter list part 2

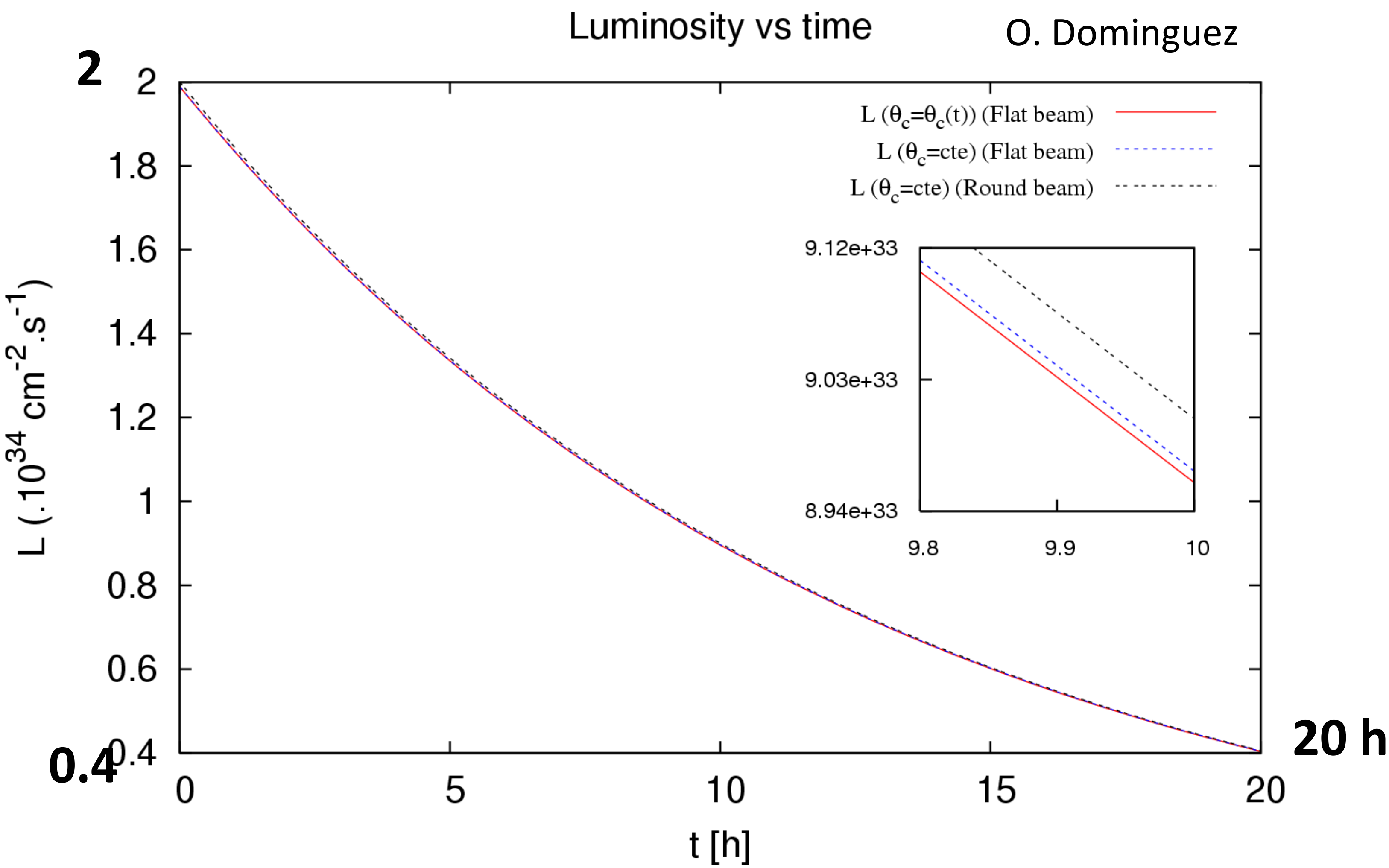
	nominal LHC	HE-LHC	
Piwinski angle	0.65	0.39	0.65
geometric luminosity loss from crossing	0.84	0.93	0.84
SR power per ring [kW]	3.6	65.7	66.0
arc SR heat load dW/ds [W/m/aperture]	0.21	2.8	2.8
energy loss per turn [keV]	6.7	201.3	
critical photon energy [eV]	44	575	
photon flux [10^{17}/m/s]	1.0	1.3	
longitudinal SR emit. damping time [h]	12.9	0.98	
horizontal SR emit. damping time [h]	25.8	1.97	
initial longit. IBS emit. rise time [h]	61	64	~68
initial horiz. IBS emit. rise time [h]	80	~80	~60
initial vert. IBS emit. rise time [h] (κ=0.2)	~400	~400	~300
events per crossing	19	76	
initial luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0	
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0	
beam lifetime due to *p* consumption [h]	46	12.6	
optimum run time t_r [h] (t_{ta}=5 h)	15.2	10.4	
integrated luminosity after t_r [fb^{-1}]	0.41	0.50	0.51
opt. av. int. luminosity per day [fb^{-1}]	0.47	0.78	0.79

emittance evolution with & w/o blow up



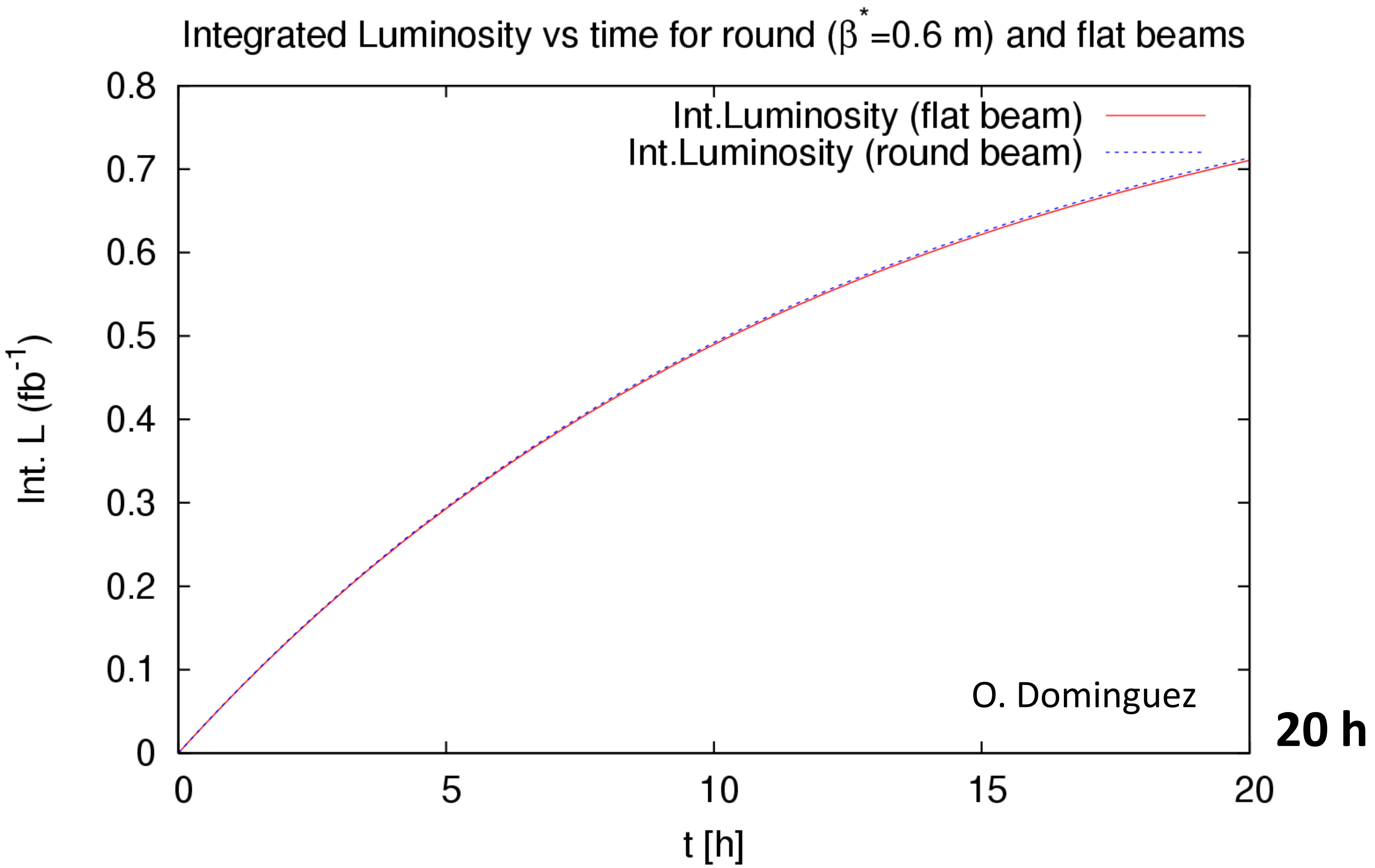
Evolution of the HE-LHC emittances, for flat and round beams, during a physics store with controlled blow up and constant longitudinal emittance of 4 eVs plus constant crossing angle (the thicker lines on the top), and the natural transverse emittance evolution due to radiation damping and IBS only (the thinner lines at the bottom) – still for constant longitudinal emittance and constant crossing angle –, which might lead to an excessive tune shift.

luminosity evolution with ε blow up & ΔQ=0.01



Time evolution of the HE-LHC luminosity, for both flat and round beams, including emittance variation with controlled blow up and proton burn off. Curves with constant or varying crossing angle lie on top of each other if the beam-beam tune shift is kept constant as assumed here.

integrated luminosity evolution with ΔQ=0.01



Time evolution of the HE-LHC integrated luminosity, for both flat and round beams, during a physics store including emittance variation with controlled blow up and proton burn off.

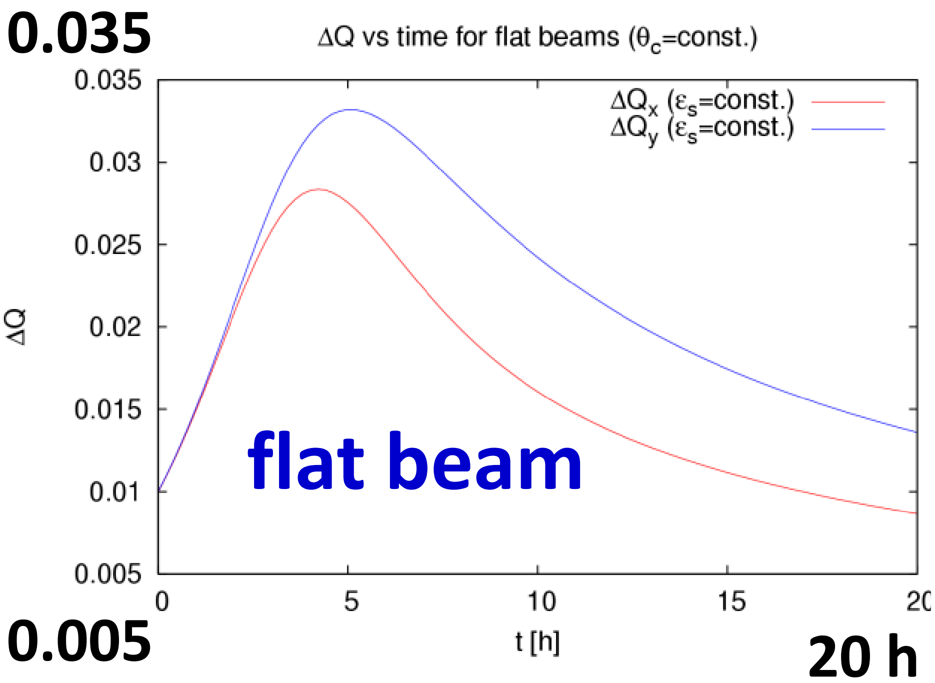
dropping the constraint $\Delta Q_{tot} \leq 0.01$

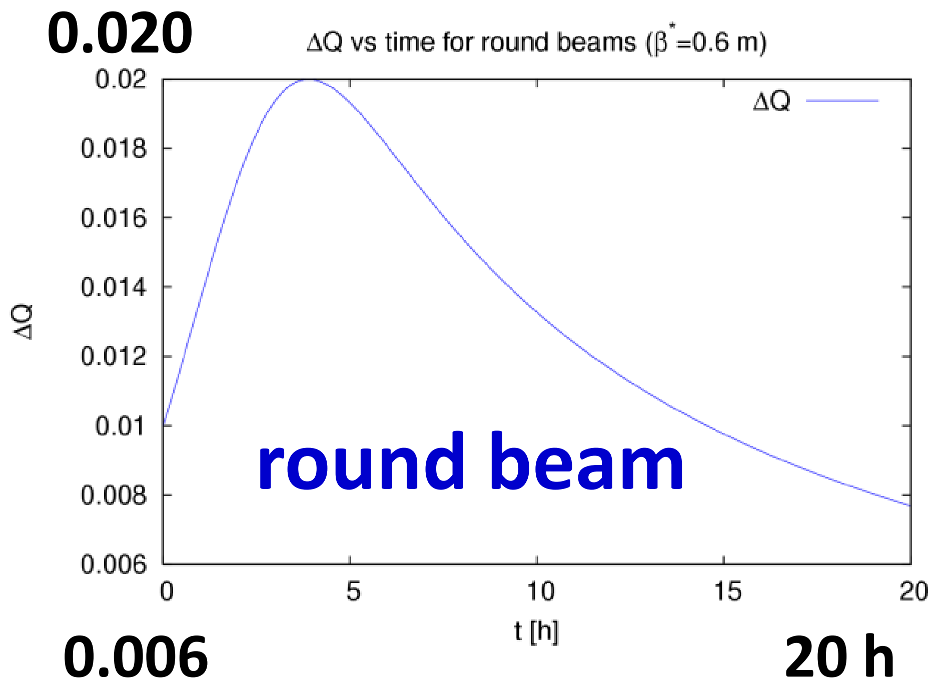
- LHC already reached ΔQ_{tot} ~0.02 (~2x design) without evidence for beam-beam limit

- LHC strong-strong beam-beam simulations by K. Ohmi of KEK predict the LHC beam-beam limit at $\Delta Q_{tot} > 0.03$

tune shift versus time with SR damping & no transverse ε blow up

O. Dominguez

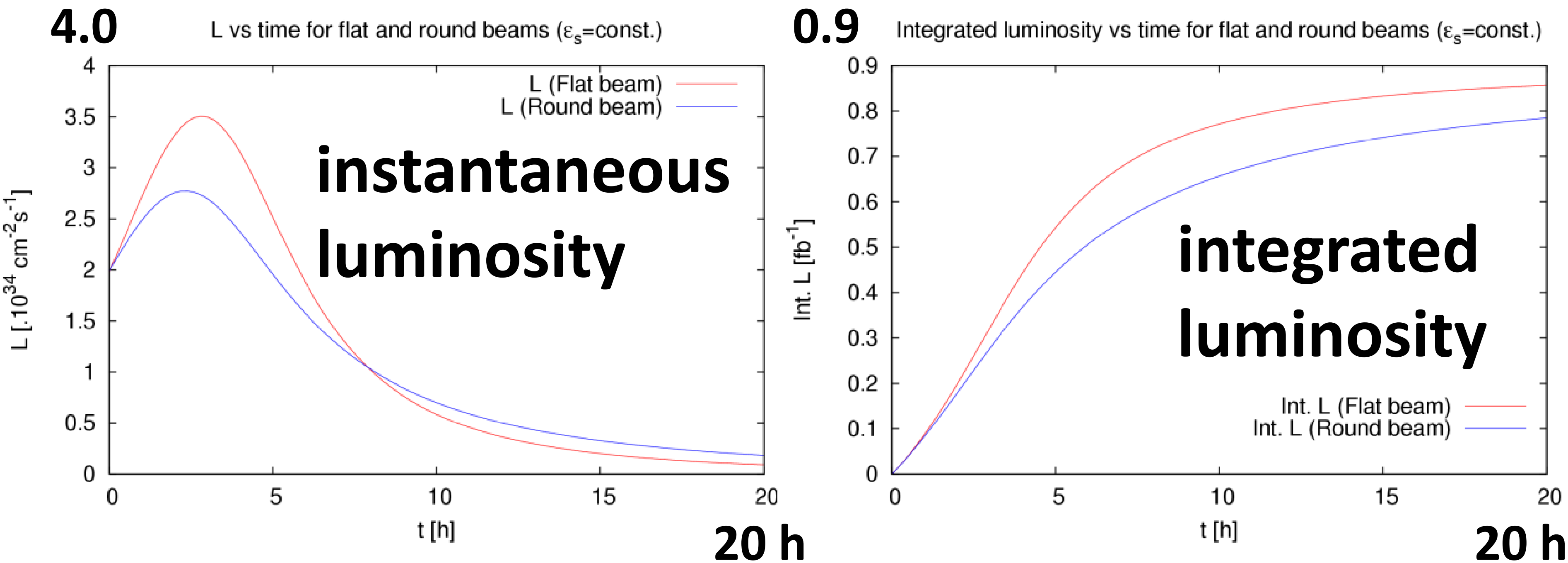




Time evolution of the HE-LHC tune shifts, for flat (left) and round beams (right), during a physics store including SR emittance shrinkage **without** controlled transverse blow up, and including proton burn off.

luminosity versus time with SR damping & no transverse ε blow up

O. Dominguez



Time evolution of the HE-LHC instantaneous (left) and integrated luminosity (right), for both flat and round beams, including SR emittance shrinkage without controlled transverse blow up and including proton burn off.

sensitivity of integrated luminosity to assumptions

baseline HE-LHC: 0.8/fb/day optimum average

without longitudinal blow up 5-20% lower

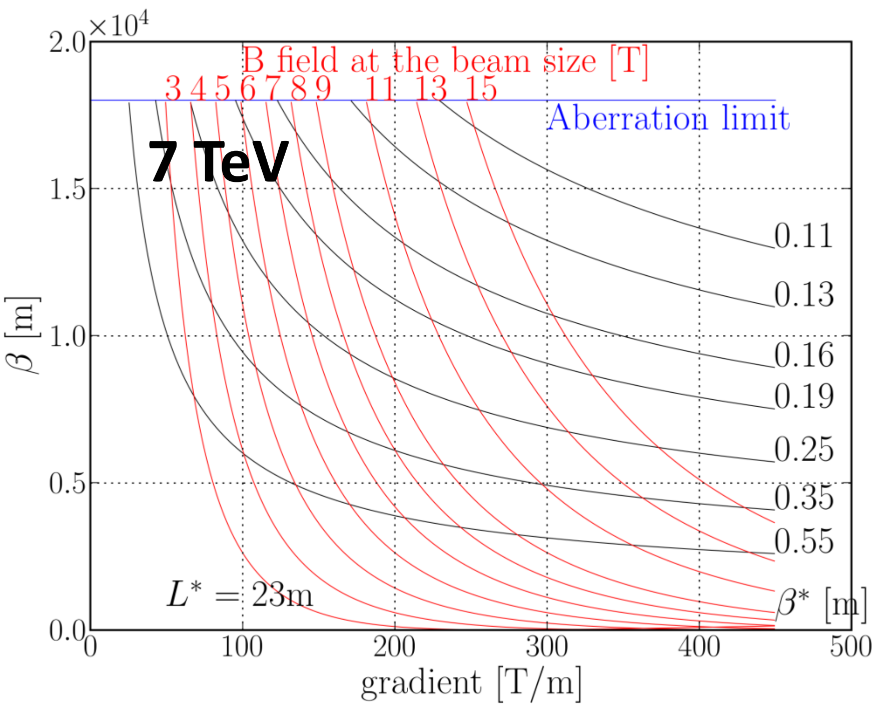
without transverse blow up 10-20% higher

another 25% increase with ultimate
bunch intensity and $\beta^* \sim 0.8$ m

O. Dominguez

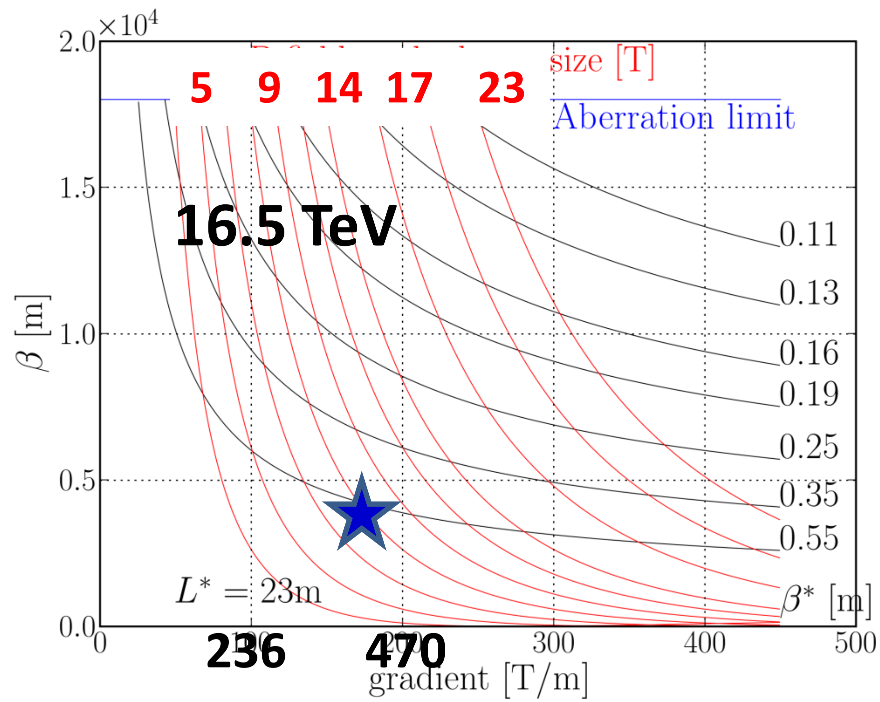
IR quadrupoles

how do the IR magnets scale with energy and beta*?
can we hope to get beta* of 0.5-0.6 m?



R. De Maria

16.5 TeV field: x $(16.5/7)^{1/2}$



16.5 TeV gradient: x (16.5/7)

for example: β^*=0.55 m, 400 T/m, β_{peak}~4 km, $\gamma\varepsilon$=2.64 μm, full aperture ~26 mm

arc quadrupoles

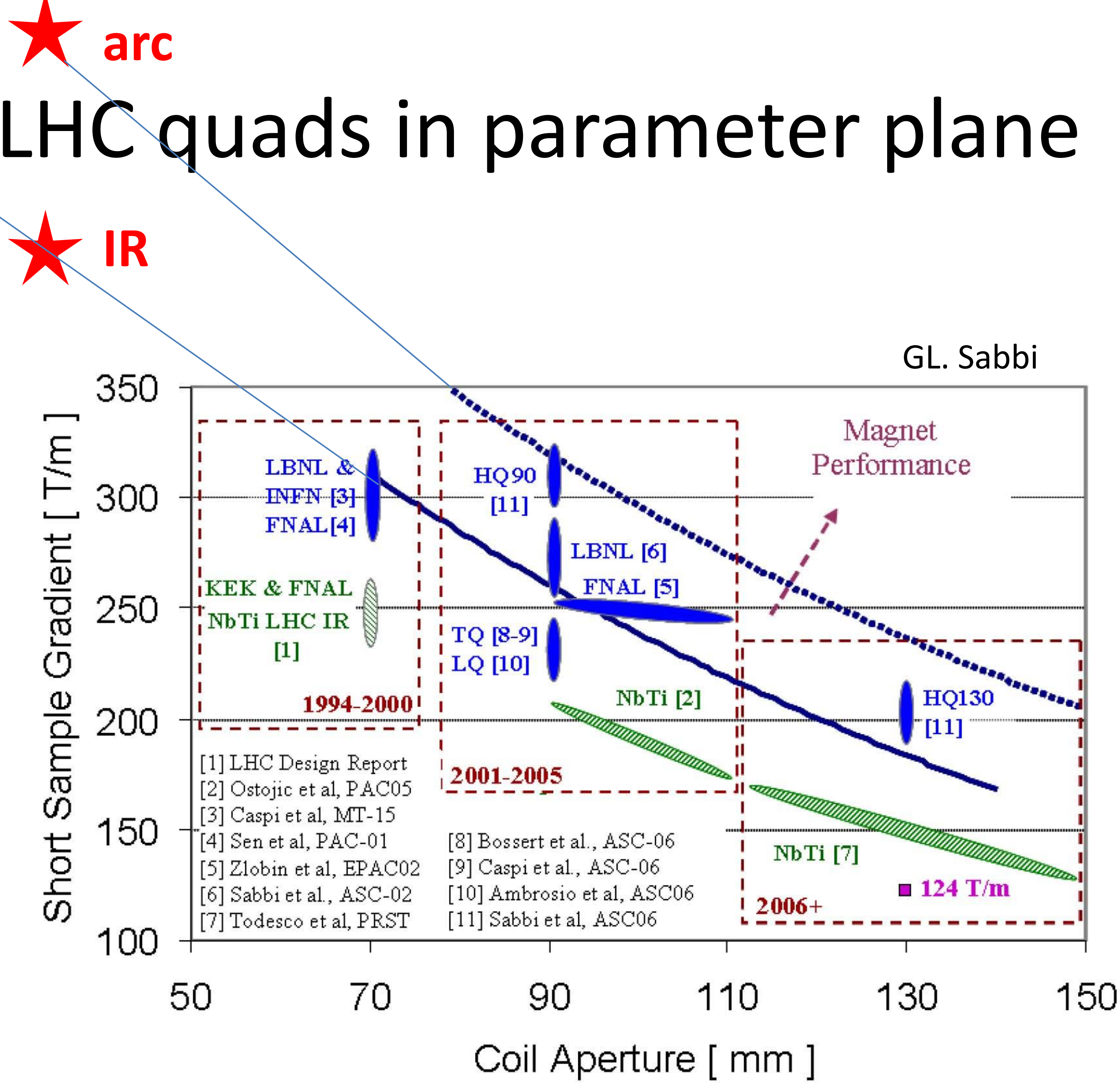
40 mm coil aperture as the dipoles

223 T/m x (16.5/7) = 526 T/m

(if we assume same length as now)

more demanding than IR quads?!

HE-LHC quads in parameter plane



miscellaneous issues

required cleaning efficiency assuming nominal quench levels

estimates of expected **local radiation levels** and implication on the **dog-leg magnets in the cleaning insertions**

required **power converter tracking accuracy** and potential implications if the HL-LHC features ca. **30-40 independent sectors** (higher stored EM energy in the magnets)

stronger **kicker elements** for beam diagnostics [tune measurements] and large oscillation amplitudes [AC dipole, aperture kicker]), injection kicker & beam transfer w. higher injection energy

more miscellaneous issues

beam diagnostics limits, e.g. on the use of beam screens and wire scanners

loss of longitudinal Landau damping; trade off between bunch length and longitudinal impedance

PC effects and field quality at injection will determine the minimum injection energy required

use of **crab cavities for HE-LHC**: Do we need them? (probably not). Could they be useful (suppose we have them from HL-LHC)?

workshop structure

Thursday 8:30-12:30
Introduction and Overview
Jean-Pierre Koutchouk, Roger Bailey (s. secr.)

Thursday 14:30-18:45
Magnets for arcs and IRs
Lucio Rossi, Ezio Todesco (s. secr.)

Friday 8:30-12:15
Synchrotron radiation and beam dynamics
Vladimir Shiltsev, Elias Metral (s. secr.)

Friday 15:15-19:10
HE-LHC injector & infrastructure
Eric Prebys, Luca Bottura (s. secr)

Saturday 8:45-11:15
Summing up
Steve Myers, Frank Zimmermann (s. secr)

convener & scientific secretary will record the discussion during the session, and also prepare a session summary for Saturday morning as well as a paper for the proceedings

HE-LHC'10 proceedings

To be published as a **CERN Yellow Report**
 - first ever proceedings on a higher-energy LHC

Length: free; advice: 3-10 pages

JACoW format, as used for the conferences of IPAC, PAC, EPAC, etc, A4 European format

Templates for word and latex are available from the JACoW website www.jacow.org

Submission of **both original and pdf files** to Editors **by deadline: 20 November 2010**

Editors: Ezio Todesco and Frank Zimmermann (EuCARD-AccNet-EuroLumi coordinators)

physics case & technical feasibility?

"there is no known physics which would justify a pp collider at energies higher than LHC"

"there has been no magnet progress since Tevatron and HERA; it will take 500 years to build 20-T magnets"

"CLIC and the muon collider are much more realistic"

three EuCARD SC members,

12 October 2010