Summary Session 8: High Luminosity (HL-LHC) Chamonix 2011

Conveners: Lucio Rossi (Chair) , Riccardo De Maria (Scientific Secretary)

- Do we really need the LHC luminosity upgrade? Or, which performance can we get without an upgrade? Oliver Bruning (CERN)
- Breaching the Phase I optics limitations for the HL-LHC.
  Stephane Fartoukh (CERN)
- HL-LHC: parameter space, constraints and possible options.
  Frank Zimmermann (AB/ABP)
- Expectations on Management and Performance Evolution: Lessons from Tevatron and Other Colliders. Vladimir Shiltsev (Fermilab)
- Alice and LHCb in the HL-LHC era. Sergio Bertolucci (CERN)

Performance goal for the HL-LHC (1/2)

→ Integrated luminosity:

3000 fb^{-1} → ~250-300 fb^{-1} /year → ~1 fb^{-1} per fill (~240 days/year and a bit more than one good fill in average per day): the LHC target for 2011!

→ Running luminosity:

Sustained to 5E34 $cm^{-2}s^{-1}$ with leveling during 3-5 h + decay of a few hours:

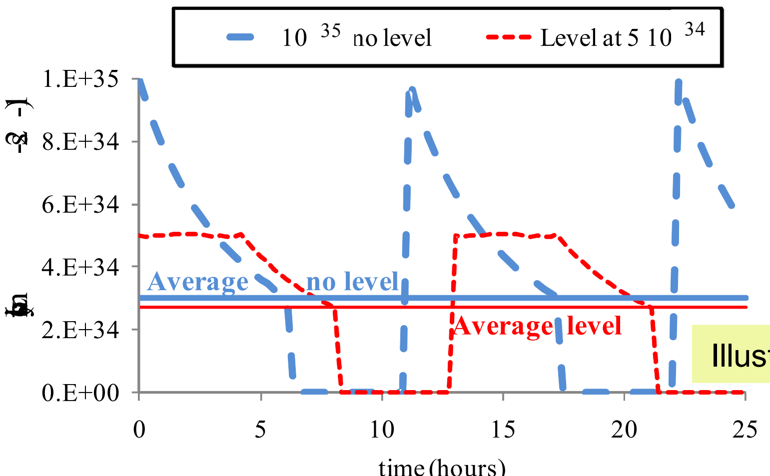


Illustration from E. Todesco

Technique for leveling not yet decided: Crab-cavity, X-angle, β^*,… (see e.g. J.P.Koutchouk, Cham. 2010)

→ Concept of "Virtual" luminosity:

Need more than 5E34, typically ~1.E35 $cm^{-2}s^{-1}$ "stored", even if not usable due to limitations on the detector or on the machine side (e.g. pile-up or beam-beam).

→ In this respect, the "effective HL-LHC target" is still the nominal lumi × 10, which requires pushing both the beam parameters and the optics (β^*).

Do We Really Need the LHC Luminosity Upgrade?

<u>Many thanks for help from:</u>

Ralph Assmann, Gianluigi Arduini, Christian Carli, Elena Chaposhnikova, Haiko Damerau, Wolfram Fischer, Stephane Fartoukh, Werner Herr, John Jowett, Riccardo de Maria, Vladimir Shiltsev, Simone Gilardoni, Massimo Giovannozzi, Elias Metral, Laurent Tavian, Maurizio Vretenar, Frank Zimmermann

O. Brüning

LHC Performance Estimates

Performance reach for existing machines @ 7 TeV:

Parameter	nominal	nominal emittance 25ns	nominal emittance 50ns	small emittance 50ns
N	1.15E+11	1.2E+11	1.7E+11	1.7E+11
n_b	2808	2808	1404	1404
beam current [A]	0.58	0.61	**0.43**	**0.43**
x-ing angle [μrad]	300	**320**	**320**	**270**
beam separation [σ]	10	10	10	10
β^* [m]	0.55	**0.5**	**0.5**	**0.5**
ε_n [μm]	3.75	3.75	3.75	2.5
ε_L [eVs]	2.51	2.5	2.5	2.5
energy spread	1.00E-04	1.00E-04	1.00E-04	1.00E-04
bunch length [m]	7.50E-02	7.50E-02	7.50E-02	7.50E-02
IBS horizontal [h]	80 -> 106	101	71	**29**
IBS longitudinal [h]	61 -> 60	58	41	**25**
Piwinski parameter	0.68	0.76	0.76	0.78
geom. reduction	0.83	0.80	0.80	0.79
beam-beam / IP	3.10E-03	**3.1E-03**	**4.4E-03**	**6.6E-03**
Peak Luminosity	$1\ 10^{34}$	**$1.0\ 10^{34}$**	**$1.2\ 10^{34}$**	**$1.7\ 10^{34}$**

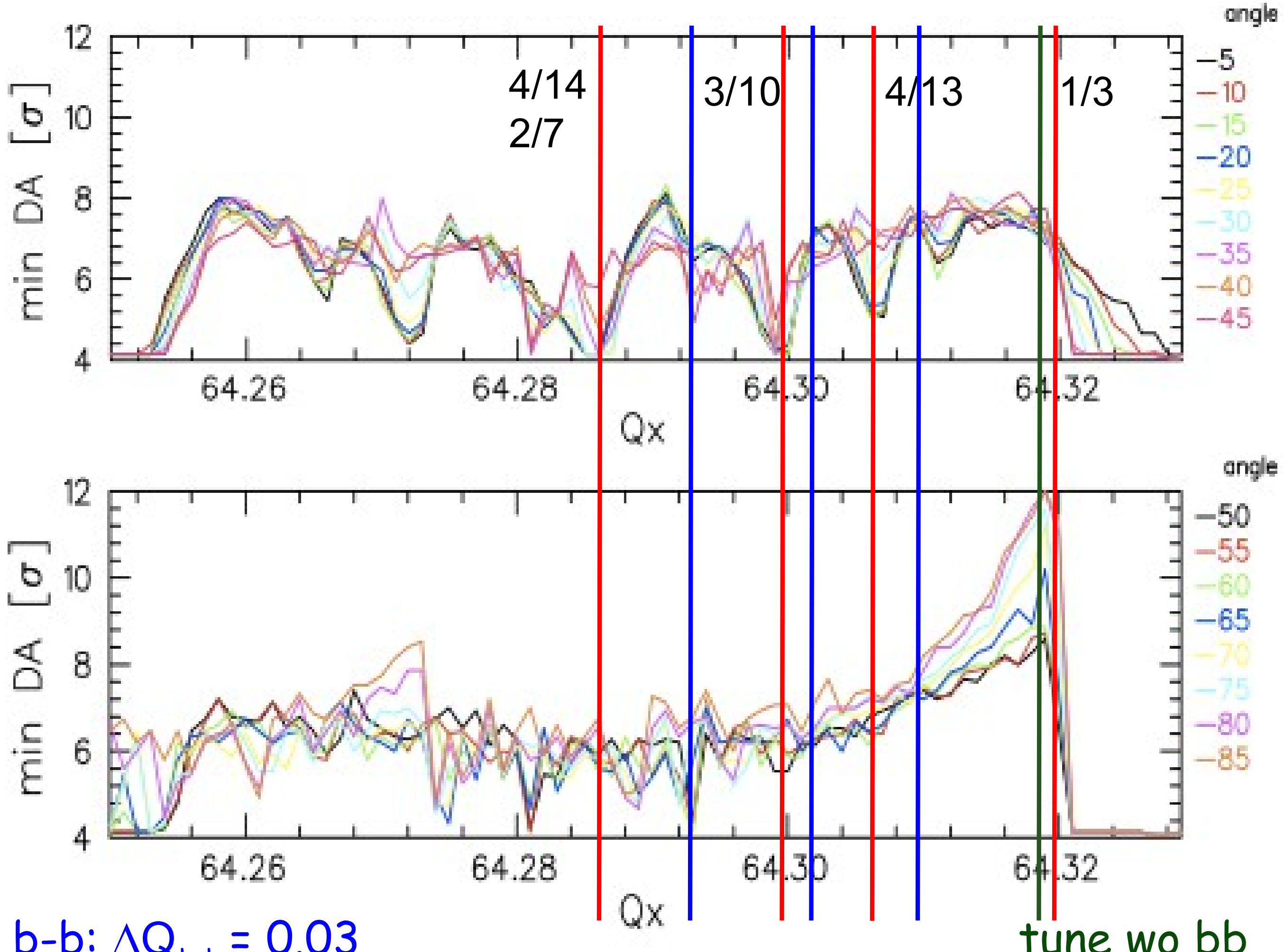
Radiation damping:
hor: 26h
ver: 13h

LHC Challenges: Beam-Beam Interaction

Werner Herr & Dobrin Kaltchev

Simulation @ injection

- DA from simulations:



Assume in the following:

$\Delta Q_{tot} = 0.02$

and

$\xi_{bb} = 0.007$

with 3 b-b: $\Delta Q_{tot} = 0.03$

$\xi_{bb} = 10\ 10^{-3}$

Performance estimates in terms of β^* :

- Minimum β^* at 7 TeV for existing triplet:
  -β^* of 0.3m to 0.4 based on measured aperture and nominal settings

- HL LHC Upgrade:
  -β^* of 0.15m accessible for round beams @ 7 TeV
  -β^* of 0.3m / 0.075m accessible for flat beams @ 7 TeV

  S. Fartoukh

- Long range b-b can be alleviated by β^* increase ('soft landing'):
  ➔ assume 20% larger β^* as quoted for normal operation

  ➔ β^* of 0.5m accessible for round beams @ 7 TeV with nom
  ➔ β^* of 0.2m accessible for round beams @ 7 TeV with HL

  J. Gareyte

Assumptions on Injector Performance I:

PAC'07; CERN-AB-2007-037

- Existing injector performance:

-50ns: 1.2 10^{11} ppb; ε_n = 2.5μm to 3 μm (SB injection into PS)

-50ns: 1.2 10^{11} ppb; ε_n = 1.5 μm (DB 2008 MD [EM])

-50ns: 1.7 10^{11} ppb; ε_n = 3μm to 4 μm (SB injection into PS)

➔ limited by SPS single bunch

➔ 1.7 10^{11} ppb; ε_n = 1.8μm to 2.5μm with DB?!?

-25ns: 1.2 10^{11} ppb; ε_n = 3μm to 4 μm (GA)

-25ns: 1.4 10^{11} ppb; ε_n = 4μm to 10μm (limited by SPS instabilities [EC])

- Existing injector performance with LINAC4:

-50ns: 2.5 10^{11} ppb; ε_n = 3.5 μm (if not limited by e-cloud; scaled from 2008 MD and relying on lower γ-t SPS lattice)

-25ns: 1.4 10^{11} ppb; ε_n =3.5μm – 10μm (single batch [MV 2010& EC])

LHC Performance Estimates

Performance reach for LINAC4 + LIU + HL triplet: long bunch

Parameter	nominal	small β* 25ns	small β* 50ns	'large' β* 25ns	'large' β* 50ns
N	1.15E+11	**2.0E+11**	**3.3E+11**	**2.0E+11**	**3.3 E+11**
n_b	2808	2808	1404	2808	1404
beam current [A]	0.58	**1.02**	**0.84**	**1.02**	**0.84**
x-ing angle [μrad]	300	**420**	**520**	**270**	**320**
beam separation [σ]	10	10	10	10	10
β* [m]	0.55	0.2	0.2	0.5	0.5
ε_n [μm]	3.75	2.5	3.75	2.5	3.75
ε_L [eVs]	2.51	**3.0**	**3.0**	**3.0**	**3.0**
energy spread	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
bunch length [m]	7.50E-02	**0.1**	**0.1**	**0.1**	**0.1**
IBS horizontal [h]	80 -> 106	**>40**	**56**	**>40**	**56**
IBS longitudinal [h]	61 -> 60	**>40**	**56**	**>40**	**56**
Piwinski parameter	0.68	**2.57**	**2.59**	**1.04**	**1.00**
geom. reduction	0.83	**0.36**	**0.36**	**0.69**	**0.70**
beam-beam / IP	3.10E-03	**3.6E-03**	**4.9E-03**	**6.8E-3**	**7.6E-3**
Peak Luminosity	$1\ 10^{34}$	**$5.5\ 10^{34}$**	**$4.9\ 10^{34}$**	**$4.2\ 10^{34}$**	**$3.9\ 10^{34}$**

Summary Performance Reach:

Do we really need the LHC luminosity upgrade? Yes

-Existing LHC & injectors can reach nominal performance with 25ns and 50ns beams: $L = 1\ 10^{34}\ cm^{-2}\ sec^{-1}$

-Small emittance option with 50ns operation can reach:

$L = 1.7\ 10^{34}\ cm^{-2}\ sec^{-1}$

@ half nominal total beam current for 50ns beam option

-Nominal machine with LINAC4 and 50ns operation can reach:

$L = 2.5\ 10^{34}\ cm^{-2}\ sec^{-1}$

with approximately nominal total beam current

-Full upgrade can reach:

$L \geq 5\ 10^{34}\ cm^{-2}\ sec^{-1}$

with geometric reduction factor!

➔ CC & LRBB wires are ideal tool for leveling!

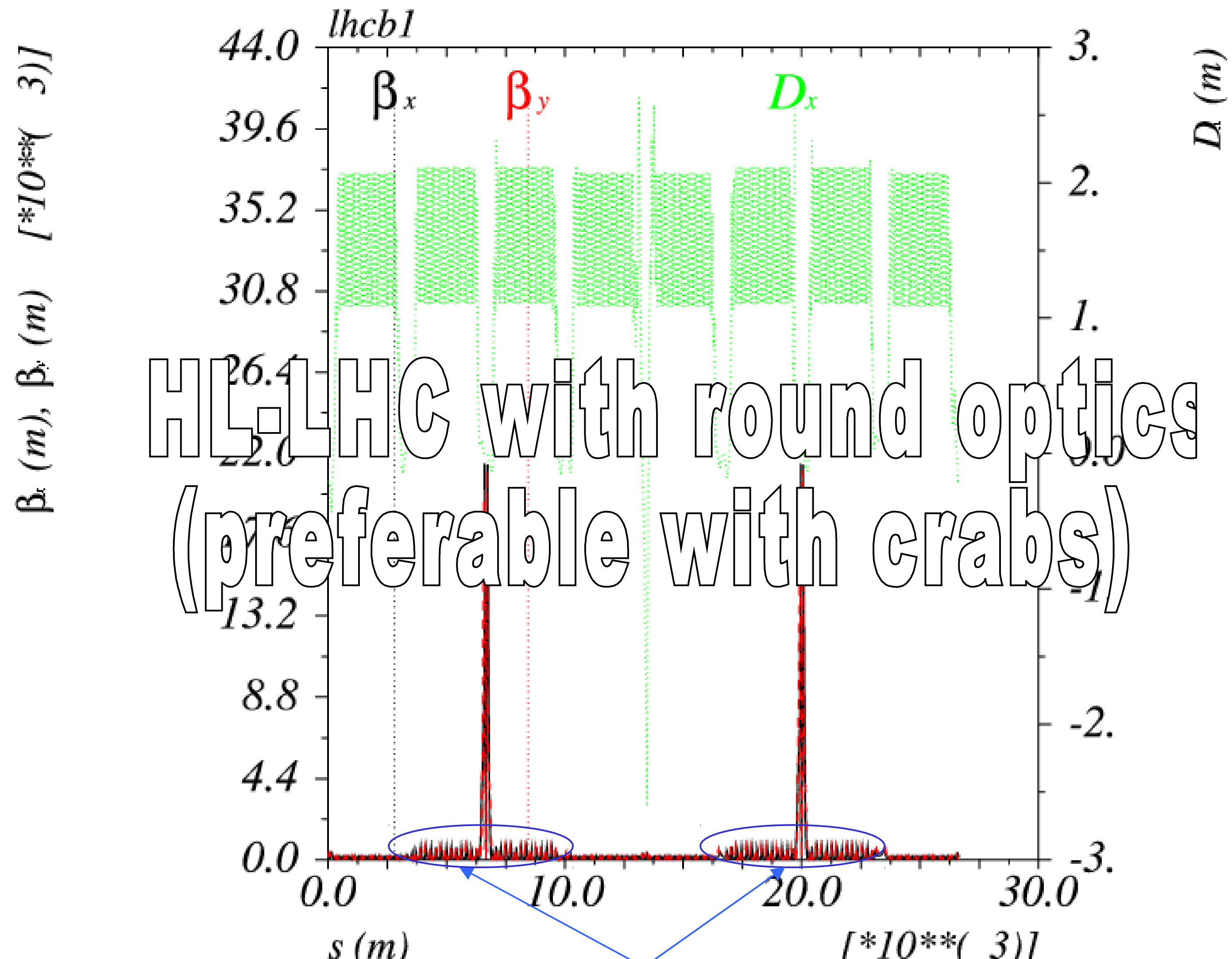
Breaching the Phase I optics limitations for the HL-LHC

S. Fartoukh BE-AP
with contributions from **R. De Maria**

- → Performance goal of the HL-LHC
- → An "Achromatic Telescopic Squeezing" (ATS) scheme to overcome the Phase I optics limitations
- → Main weak point and mitigation measures
- → Requested hardware modifications
- → A possible parameter set for the HL-LHC w/o crab-cavity
- → What can be tested now in the machine?
- → Conclusions

Main References:
S. Fartoukh, sLHC-PR0049 & LMC 21/07/2010
R. D. Maria, S. Fartoukh, sLHC-PR0050 & LMC 21/07/2010
Optics & Layout repository:
/afs/cern.ch/eng/lhc/optics/SLHCV3.0

Squeezed optics (round): β^* = 15 cm in IR1 and IR5: "4444"



HL-LHC with round optics (preferable with crabs)

β_{arc} increased by a factor of 4 in s45/56/81/12

Request for hardware changes

- Longer Q5 (MQY) needed in IR6 for squeezing IR5 (~25% int. strength missing)

→ New MQY type needed: MQYL (4.8 m ~MQML)

- Sextupole scheme

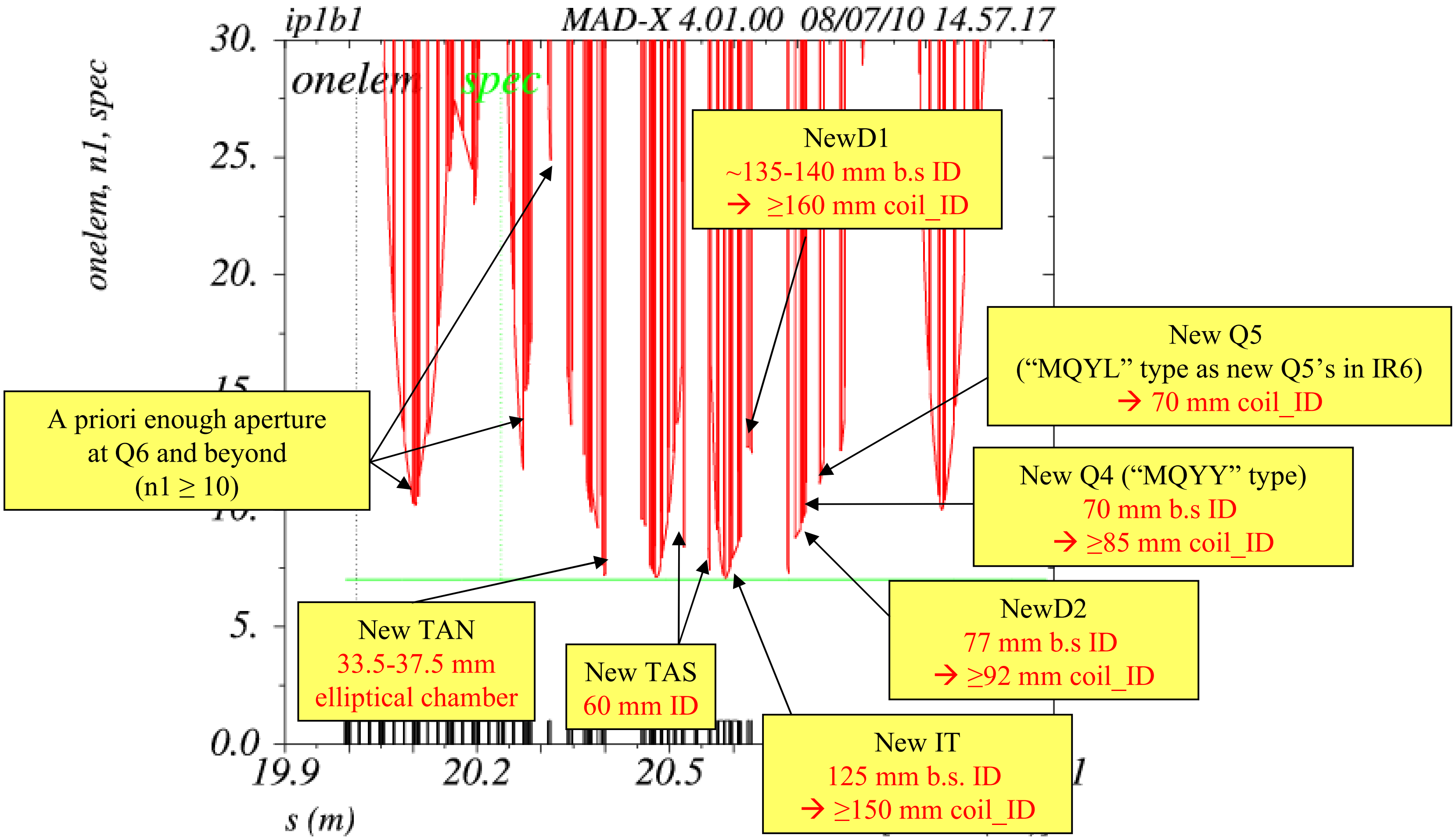
1) Four additional sextupoles at Q10.L/R in IR1 and IR5
2) Sextupoles pushed to 600 A (or more!?) in sectors 45/56/81/12, at least the RSD circuits

→ pushing the pre-squeezed optics down to β^*= 50 cm (or below?) instead of 60 cm.

- LSS1 and LSS5 (more details in next slide)

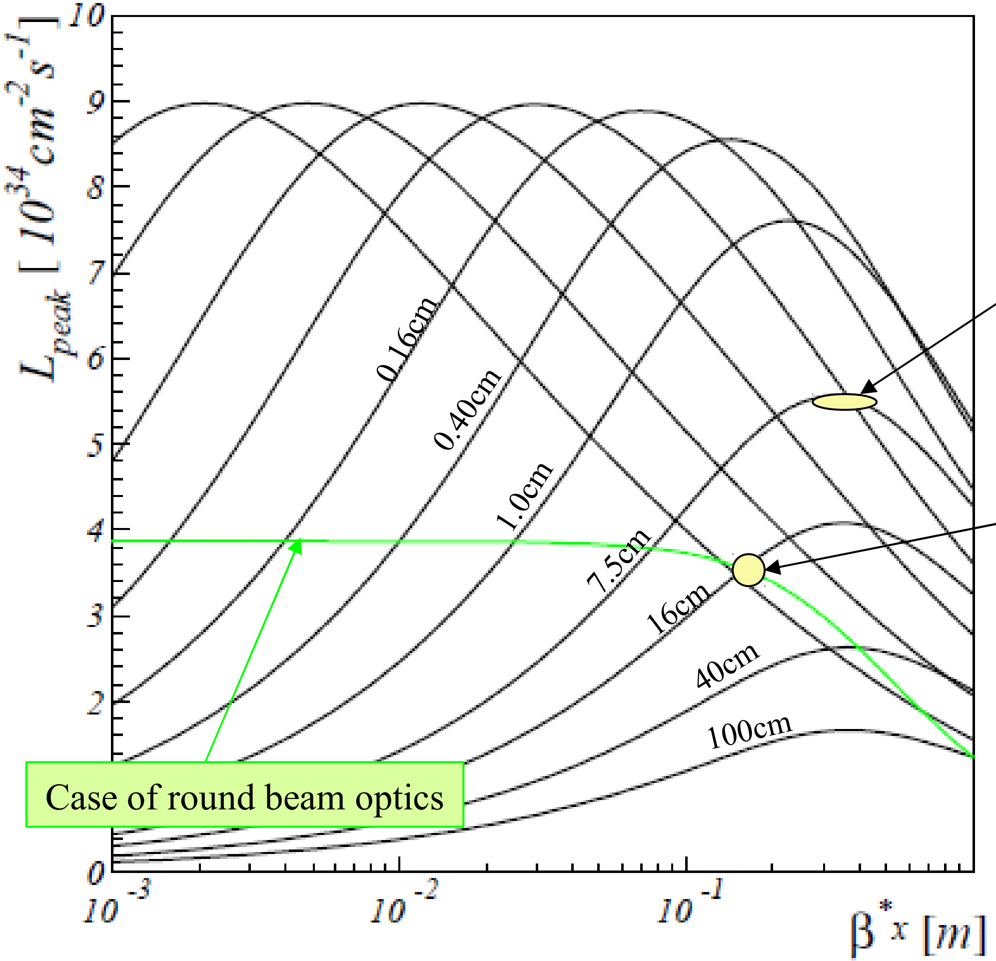
1) New IT, D1, D2, Q4, Q5 with larger aperture (D1 as close as possible to the IT, i.e. feed-box installed on the non-IP side of D1 or no feed-box at all with HTS technology).
2) Stronger and larger aperture MCBY orbit corrector at Q4 (and possibly Q5/Q6)
3) Nb3Sn technology not mandatory but highly preferable for the new IT, e.g. reducing further the peak β's in the arcs by 25%, the number of parasitic collisions (gain of 3-4 LR's per IP side) and the aperture requirements in the new 2-in-1 magnets D2 and Q4 (by ~10%).
4) New TAS and TAN with larger aperture and certainly new TCT like absorbers close to Q4 and Q5 both for the incoming and out-going beams.

→ Aperture requirement assuming an NbTi IT (nominal emittance, 7.5/30 cm or 30/7.5 cm flat optics, 13σ full X-angle, spurious H&V dispersion corrected via orbit bumps in the arcs)



→ The above requirements are also compatible with a 15/15 cm β^*round optics and could be relaxed by ~10% (but for the TAS) with Nb3Sn triplet .

Luminosity vs. β^* in the Xing plane (with hour-glass effect) for different values of β^* in the other plane: nominal emittance and bunch length, ultimate intensity, <u>no crab-cavity</u>



<u>Example of flat optics</u>:

β^* =30 cm in the crossing-plane

β^* = σ_z =7.5 cm in the other plane

Θ_c = 10σ in the plane of biggest β^*

→ Peak lumi ~5.6 $10^{34} cm^{-2} s^{-1}$

<u>"Equivalent" round optics</u>:

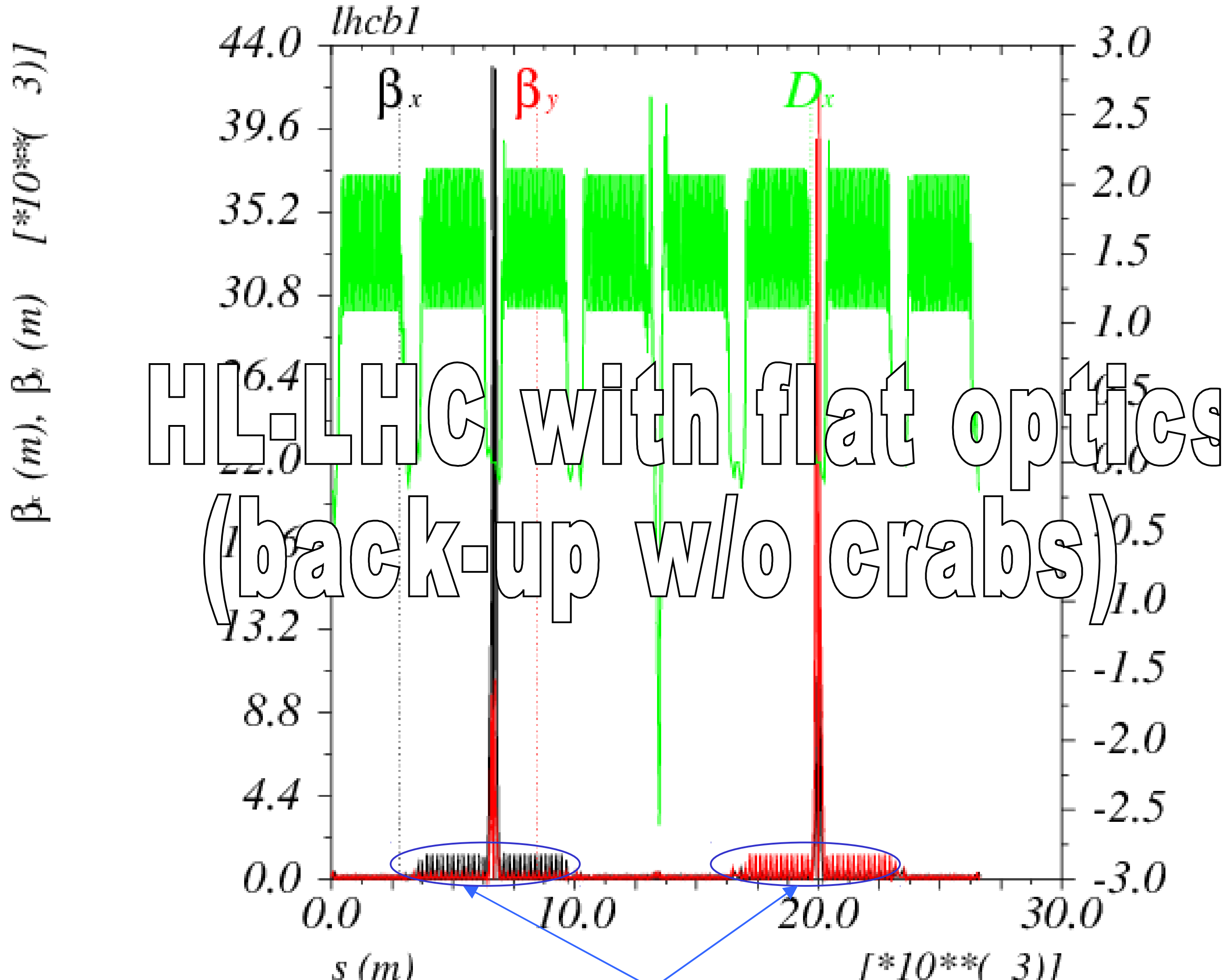
β^* =15 cm in both planes

Θ_c = 10σ

→ Peak lumi ~3.5 $10^{34} cm^{-2} s^{-1}$

1. The "virtual" performance of the two optics is equivalent with crab-cavity (~8-9E34),
2. In all cases the two options requires to push β* well beyond the Phase I limit of 30 cm. … Nb3Sn can only improve the situation by ~25%, not more!

Squeezed optics (flat): $\beta^*_{x/y}$ = 7.5/30 cm alternated in IR1 and IR5: “8228”



β_{arc} increased by a factor of 2 or 8 in s45/56/81/12 depending on the β^* aspect ratio in IP1 and IP5

HL-LHC: parameter space, constraints & possible options

Many thanks to
R. Assmann, C. Bhat, O. Brüning,
R. Calaga, R. De Maria,
S. Fartoukh, J.-P. Koutchouk,
S. Myers, L. Rossi, W. Scandale,
E. Shaposhnikova, R. Tomas,
J. Tuckmantel ,...

Chamonix 2011
LHC Performance Workshop

Frank Zimmermann

hoto: courtesy R. Assmann

leveling schemes

- vary beam offset Δx (successful in 2010)

$$L_{lev} = \hat{L}\exp\left(-\left(\frac{\Delta x}{2\sigma}\right)^2\right); \quad \Delta Q_{lev} = \Delta \{ \hat{Q}\, 2\left(\left[\exp\left(-\frac{(\Delta x)^2}{2\sigma^2}\right) - 1\right]\frac{\sigma^2}{(\Delta x)^2} + \exp\left(-\frac{(\Delta x)^2}{2\sigma^2}\right)\right) ¿$$

- vary Piwinski angle ϕ_{piw} ,that is σ_z, θ_c, or *Vcrab*

$$L_{lev} \approx \hat{L}\frac{1}{\sqrt{1+\varphi_{piw}^2}}; \quad \Delta Q_{lev} \approx \Delta \hat{Q}\frac{1}{\sqrt{1+\varphi_{piw}^2}}$$

for two IPs with alternating crossing

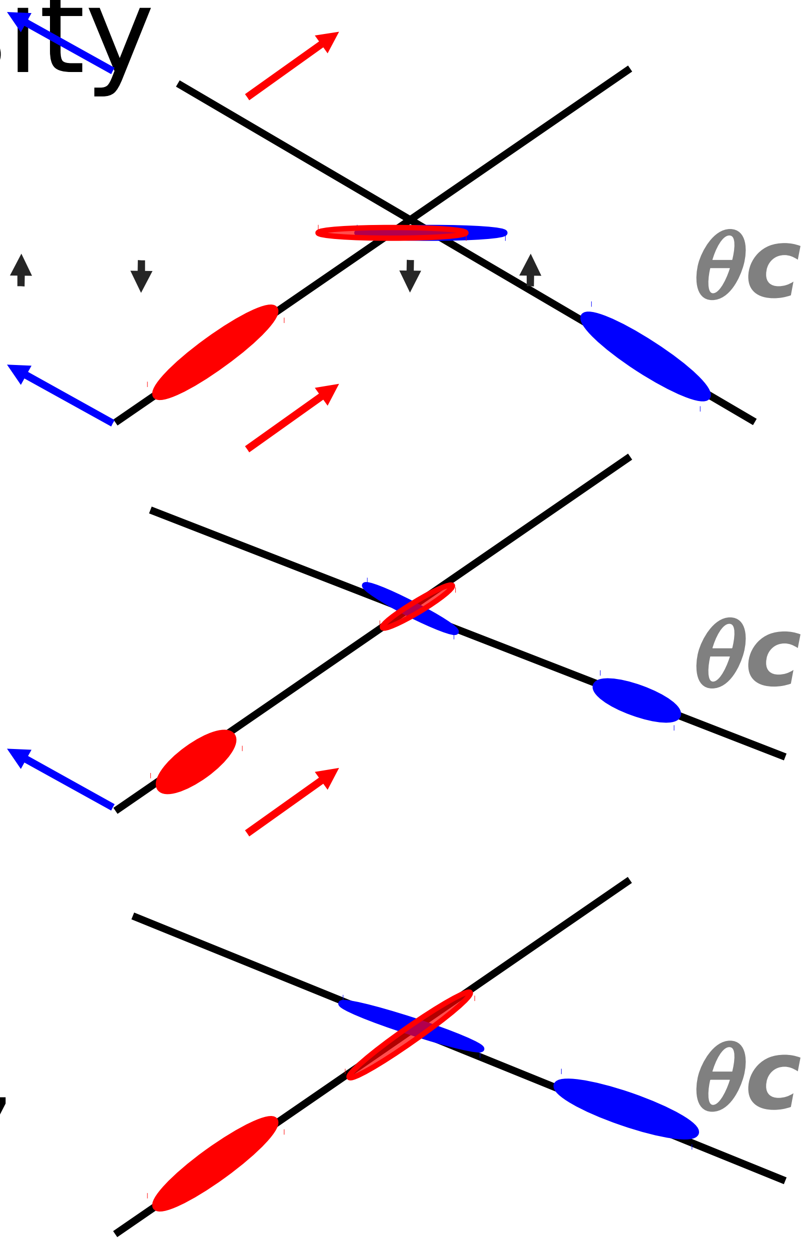
- vary IP beta function β^* e.g. at constant ϕ_{piw}

$$L_{lev} \approx \hat{L}\frac{\hat{\beta}}{\beta_{lev}}; \qquad \Delta Q_{lev} \approx \Delta \hat{Q}$$

formulae above assume round beams

approaches to boost LHC luminosity

- low β* & crab cavities (80 MV)
- low β* & higher harmonic RF (7.5 MV @800 MHz) + LR compensation
- large Piwinski angle (& “flat” bunch shape) + LR-BB compensation



example HL-LHC parameters, β*=15 cm

parameter	symbol	**nom.**	nom.*	**HL crab**	**HL sb + lrc**	**HL 50+lrc**
protons per bunch	*Nb* [1011]	**1.15**	1.7	**1.78**	**2.16**	**3.77**
bunch spacing	Δt [ns]	**25**	50	**25**	**25**	**50**
beam current	I [A]	**0.58**	0.43	**0.91**	**1.09**	**0.95**
longitudinal profile		**Gauss**	Gauss	**Gauss**	**Gauss**	**Gauss**
rms bunch length	σz [cm]	**7.55**	7.55	**7.55**	**5.0**	**7.55**
beta* at IP1&5	β* [m]	**0.55**	0.55	**0.15**	**0.15**	**0.15**
full crossing angle	θc [μrad]	**285**	285	**(508-622)**	**508**	**508**
Piwinski parameter	ϕ=θcσz/(2*σx*)	**0.65**	0.65	**0.0**	**1.42**	**2.14**
tune shift	*ΔQtot*	**0.009**	0.0136	**0.011**	**0.008**	**0.010**
potential pk luminosity	*L* [1034 cm-2s-1]	**1**	1.1	**10.6**	**9.0**	**10.1**
events per #ing		**19**	40	**95**	**95**	**189**
effective lifetime	τeff [h]	**44.9**	30	**13.9**	**16.8**	**14.7**
run or level time	trun,level [h]	**15.2**	12.2	**4.35**	**4.29**	**4.34**
e-c heat SEY=1.2	P [W/m]	**0.2**	0.1	**0.4**	**0.6**	**0.3**
SR+IC heat 4.6-20 K	PSR+IC [W/m]	**0.32**	0.30	**0.62**	**1.30**	**1.08**
IBS ε rise time (*z, x*)	τIBS,z/x [h]	**59, 102**	40, 69	**38, 66**	**8, 33**	**18, 31**
annual luminosity	*Lint*[fb-1]	**57**	58	**300**	**300**	**300**

preliminary conclusions - 1

HL-LHC parameter space well defined

to achieve 300 fb-1 per year:

- about 1 A beam current (+/- 10%)
- potential peak luminosity 1035 cm-2s-1
- run time 4.3 h ~ assumed turnaround time of 5 h
- β* between 15 and ~30 cm

high(er) beam intensity helps in every regard

both 50-ns and 25-ns scenarios

200 fb-1 per year would relax intensity demand

F, Zimmermann

preliminary conclusions - 2

beam-beam limit (at 0.02) no longer a constraint

three alternative scenarios for 300 fb-1 / year:

- crab cavities
- higher harmonic RF (shorter bunches) + LR compensation
- 50 ns bunch spacing, large Piwinski angle, + LR compensation

decreasing β^* from 30 to 15 cm is equivalent to 10-20% beam current increase (scenario -dependent)

effect of smaller ε similar to (better) than smaller β^*

F, Zimmermann

proposed roadmap & branching points

- ***LHC MDs*** for HL-LHC – starting in **2011**
  - ATF optics ingredients
    (telescope, phase changes)
  - LR beam-beam limits
  - effect of crossing angle on HO b-b limit
  - electron cloud limits
  - “flat beam” optics [S. Fartoukh, LHCMAC19, e.g. r~2, Δn1~1
  - effect of crossing plane (H-V, V-V, H-H)
- ***install LR-BB compensators in LHC*** (**2013**)
- develop & prototype ***compact crab cavity (2011-16) for beam test in (SPS+) LHC (2017)***
- develop&install ***LHC 800-MHz system*** (**2016**?)

several MDs may be done regardless of HL-LHC and also benefit nominal LHC performance

F, Zimmermann

Beam-beam limit:

-Actual beam-beam limit in the LHC is vital input for LHC upgrade strategy (HL and LIU [e.g ε vs intensity optimization]) O. Bruening

Test the new scheme for squeezing at least one of the two IRs

S. Fartoukh

Performance Evolution and Expectations Management: Lessons from Tevatron and Other Colliders

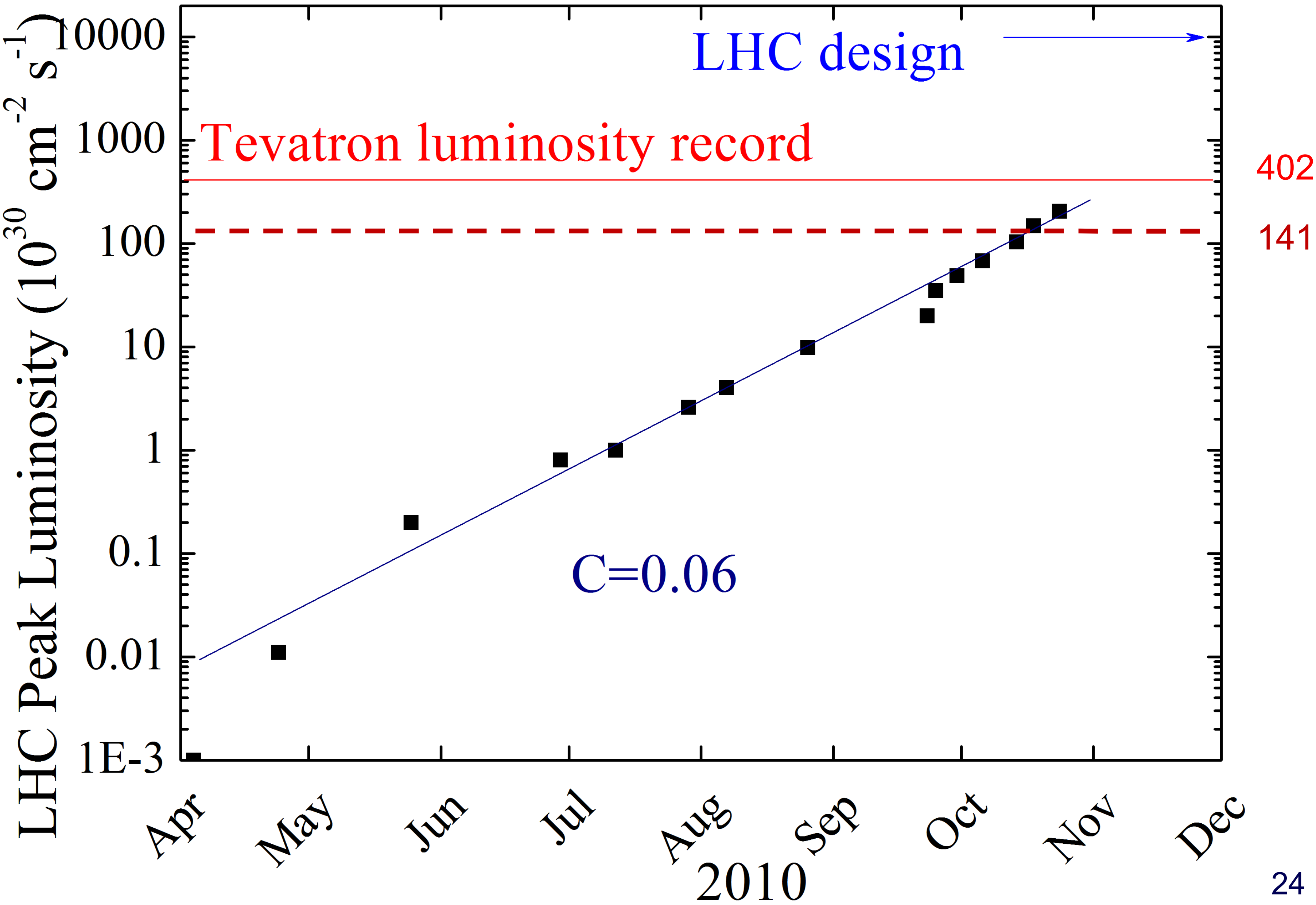
Vladimir Shiltsev

Fermilab

Chamonix-2011

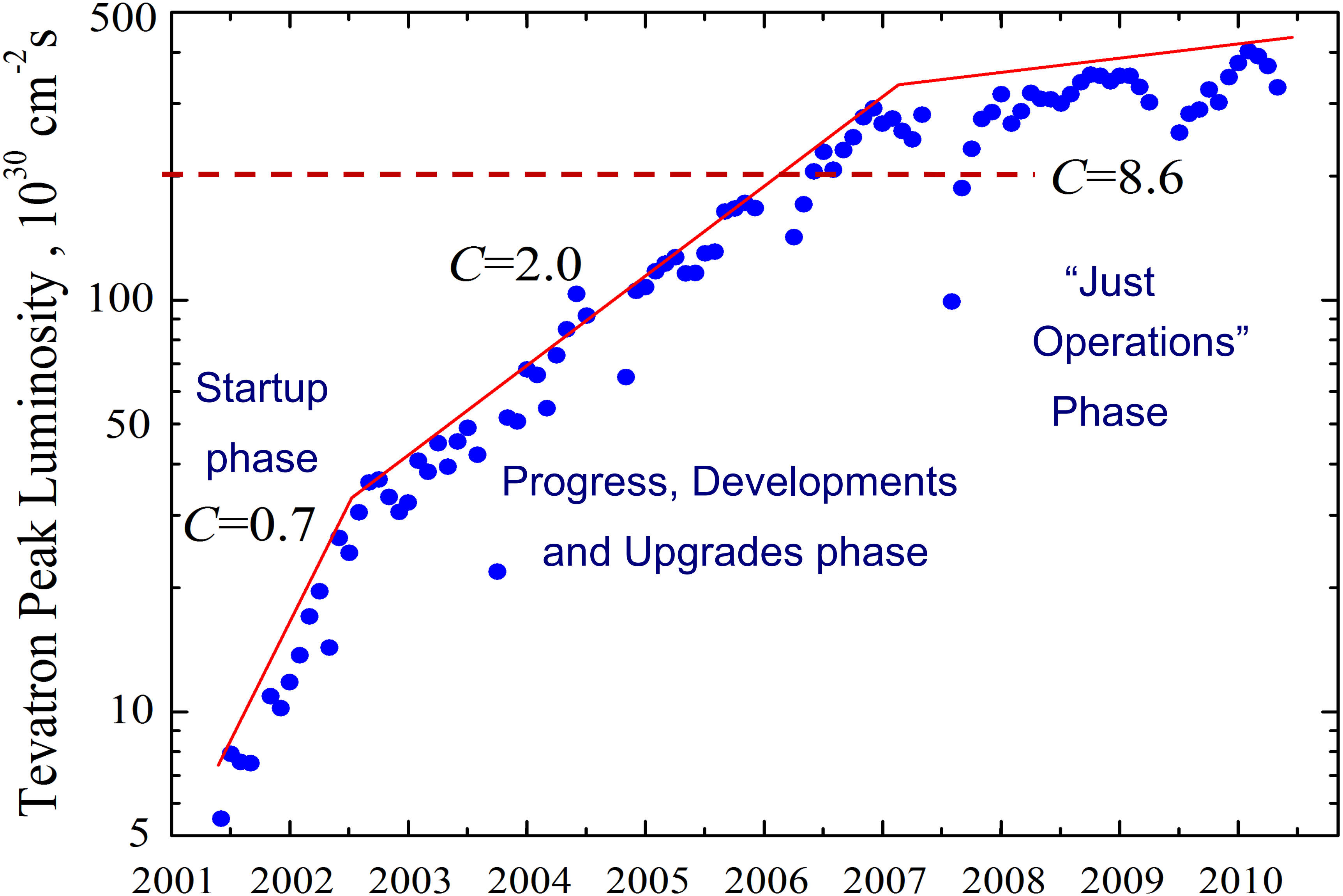
January 27, 2011

LHC 2010 Success in Numbers



V. Shiltsev

Tevatron Run II "Complexity"



V. Shiltsev

Run II Luminosity Progress

Some **30** steps, no "silver bullet"

Improvement		Luminosity Increase
Pbar injection line AA → MI optics	12/2001	25%
Tevatron quenches on abort stopped by TEL-1	02/2002	0%, reliability
Pbar loss at Tevatron squeeze step 13 fixed	04/2002	40%
New Tevatron injection helix	05/2002	15%
New AA lattice reduces IBS, emittances	07/2002	40%
Tevatron injection lines tuned up (BLT)	09/2002	10%
Pbar coalescing improved in MI	10/2002	5%
Tevatron C0 Lambertson magnets removed	02/2003	15%
Tevatron sextupoles tuned/ SEMs taken out of pbar lines	06/2003	10%
New Tevatron helix on ramp, losses reduced	08/2003	2%
Tevatron magnets reshimming & realignment	12/2003	10%
MI dampers operations/ store length increased	02/2004	30%
2.5MHz AA → MI transfer improved/Cool shots	04/2004	8%
Reduction of β^* to 35 cm	05/2004	20%
Antiprotons shots from both RR and AA	07/2004	8%
RR e-cooling operational	01-07/2005	~25%
Slip Stacking in MI	03/2005	~20%
Tevatron octupoles optimized at 150 GeV	04/2005	~5%
Reduction of of β^* to 28 cm	09/2005	~10 %
"Pbar production task force"	02/2006	~10 %
Tevatron 150 GeV heliximproved, more protons	06/2006	~10 %
Tev collision helix improved, better lifetime	07/2006	~15 %
New RR WP, smaller pbar emittances	07/2006	~25 %
Fast transfers AA→RR (60→15min)	12/2006	~15%
New Pbar target/higher gradient	01/2007	~10%
Tevatron sextupoles for new WP	(2007?)	~10(?)%
Tevatron zero 2nd order chromaticity	2008	~5%?
Shot-setup time reduction/multi-bunch proton injection	2008-09	~5%?
Scraping protons in MI	2008	~10%?
Pbar size dilution at collisions/B0 aperture increased	2008	5%?
Booster proton emittances reduced /P,A1lines tuneup	Apr 2010	10%?

Overall factor of **30** luminosity increase

V. Shiltsev

ALICE and LHCb in the HL-LHC era

CHAMONIX 2011

January 27, 2011

Sergio Bertolucci
CERN

General considerations(2)

A number of issues of consistency/compatibility, which could not be addressed in sufficient details at the time(s) of approval, are resurfacing now and are keeping our LPC/LMC meetings lively.

Just to quote a few:

- Running 4 IP's with widely different running conditions
- p- A runs (approved and forgotten for a long time)
- TOTEM
- **Long term upgrade scenarios**

Long Term (HL-LHC)

So far all the upgrade schemes have been studied assuming **only two general purpose detectors**, ATLAS and CMS, operating.

Taking into account the changed scenario:

- Will **ALICE** and **LHCb** run in HL-LHC time?
- When and what process to decide it?
- What are the beam parameters they want to exploit and the hardware changes they need in case of an upgrade?

Not a trivial bunch of questions, considering the implications on the machine upgrade, on its ultimate performances, not to talk about the costs

In summary

- Once approved, experiments are very reluctant to be terminated…..
- …usually for a number of good reasons, physics first.
- In the case of ALICE and LHCb, I think that both have good reason to think beyond 2020…
- … also in consideration of the not overwhelming offer of new machines.
- I really hope (and I tend to believe) that new Physics will make the choice very easy!