Summary of Chamonix 2011 - session 8: HL-LHC

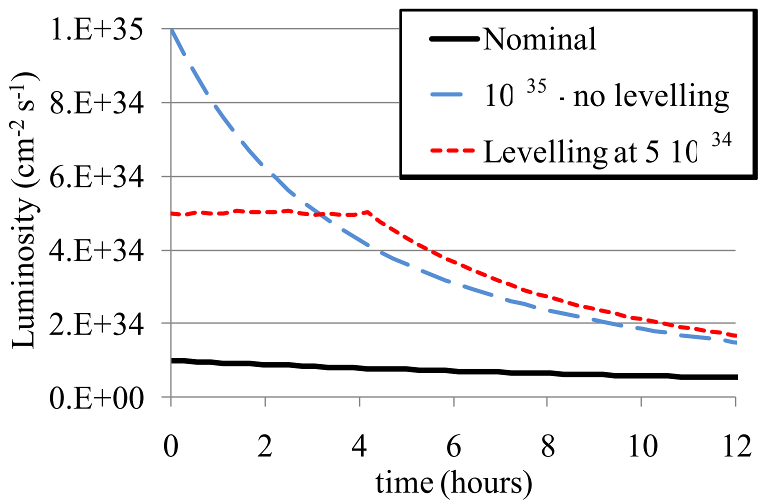
Lucio Rossi (chair)
Riccardo de Maria (scientific secretary)

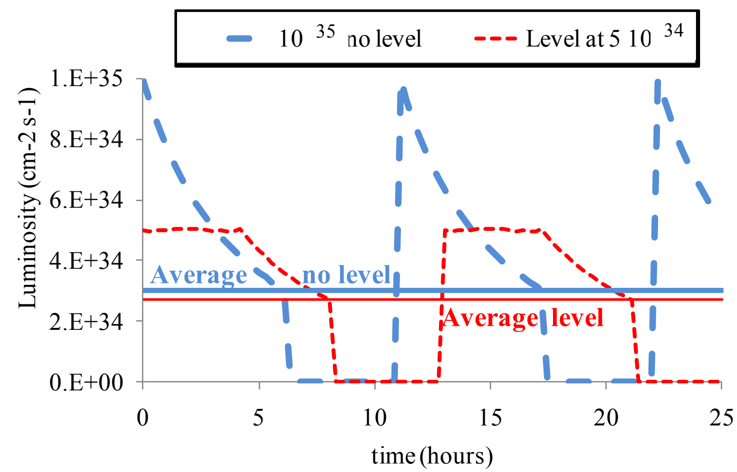
The goal of the High Luminosity LHc project

The main objective of HL-LHC is to implement a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

•A peak luminosity of **5×10^{34} $cm^{-2}s^{-1}$ with levelling**, allowing:

•An integrated luminosity of **250 fb^{-1}** per year, enabling the goal of **3000 fb^{-1}** twelve years after the upgrade. This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.





Leveling: having potential for a very high initial peak lumi,
Ceiling the peak lumi - by degrading a parameter - to limit proton burning and consequent lumi fast decay rate ($\propto$peak lumi). Keeping lumi constant by compensation of the beam intensity decay with the recovery of the degraded parameter. The parameters (run time and turnaround time) adjusted for same average lumi

Benefits: less pile up (design of detectors depends on peak lumi), reduced heat depo in IR magnets

Content of the session

- Do we really need the LHC luminosity upgrade? Or, which performance can we get without an upgrade? Oliver Bruning (CERN/BE)
- Breaching the Phase I optics limitations for the HL-LHC. Stephane Fartoukh (CERN/BE)
- HL-LHC: parameter space, constraints and possible options. Frank Zimmermann (CERN/BE)
- 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/DG)

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 Performance Estimates

Performance reach for existing machines + LINAC4:

Parameter	nominal	nominal emittance 25ns	nominal emittance 50ns
N	1.15E+11	**1.4E+11**	**2.5E+11**
n_b	2808	2808	1404
beam current [A]	0.58	0.71	0.64
x-ing angle [μrad]	300	**320**	**320**
beam separation [σ]	10	10	10
β* [m]	0.55	**0.5**	**0.5**
ε_n [μm]	3.75	3.75	3.75
ε_L [eVs]	2.51	2.2	2.5
energy spread	1.00E-04	1.00E-04	1.00E-04
bunch length [m]	7.50E-02	7.50E-02	7.50E-02
IBS horizontal [h]	80 -> 106	80	45
IBS longitudinal [h]	61 -> 60	41	23
Piwinski parameter	0.68	0.76	0.76
geom. reduction	0.83	0.80	0.80
beam-beam / IP	3.10E-03	**3.64E-03**	**6.5E-03**
Peak Luminosity	$1\ 10^{34}$	**$1.6\ 10^{34}$**	**$2.5\ 10^{34}$**

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**	[illegible]	**320**
beam separation [σ]	10	10	10	[illegible]	10
β* [m]	0.55	0.2	[illegible]	[illegible]	0.5
ε_n [μm]	3.75	[illegible]	[illegible]	2.5	3.75
ε_L [eVs]	2.51	[illegible]	[illegible]	**3.0**	**3.0**
energy spread	[illegible]	[illegible]	1.00E-04	1.00E-04	1.00E-04
bunch length [m[illegible]	[illegible]	**0.1**	**0.1**	**0.1**	**0.1**
IBS ho[illegible]	[illegible] 106	**>40**	**56**	**>40**	**56**
IBS lo[illegible]	61 -> 60	**>40**	**56**	**>40**	**56**
Piwinsk[illegible] 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	$1\ 10^{34}$	**$5.5\ 10^{34}$**	**$4.9\ 10^{34}$**	**$4.2\ 10^{34}$**	**$3.9\ 10^{34}$**

Yes!!! : we do need an upgrade!

Beam current well beyond ultimate design is needed

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

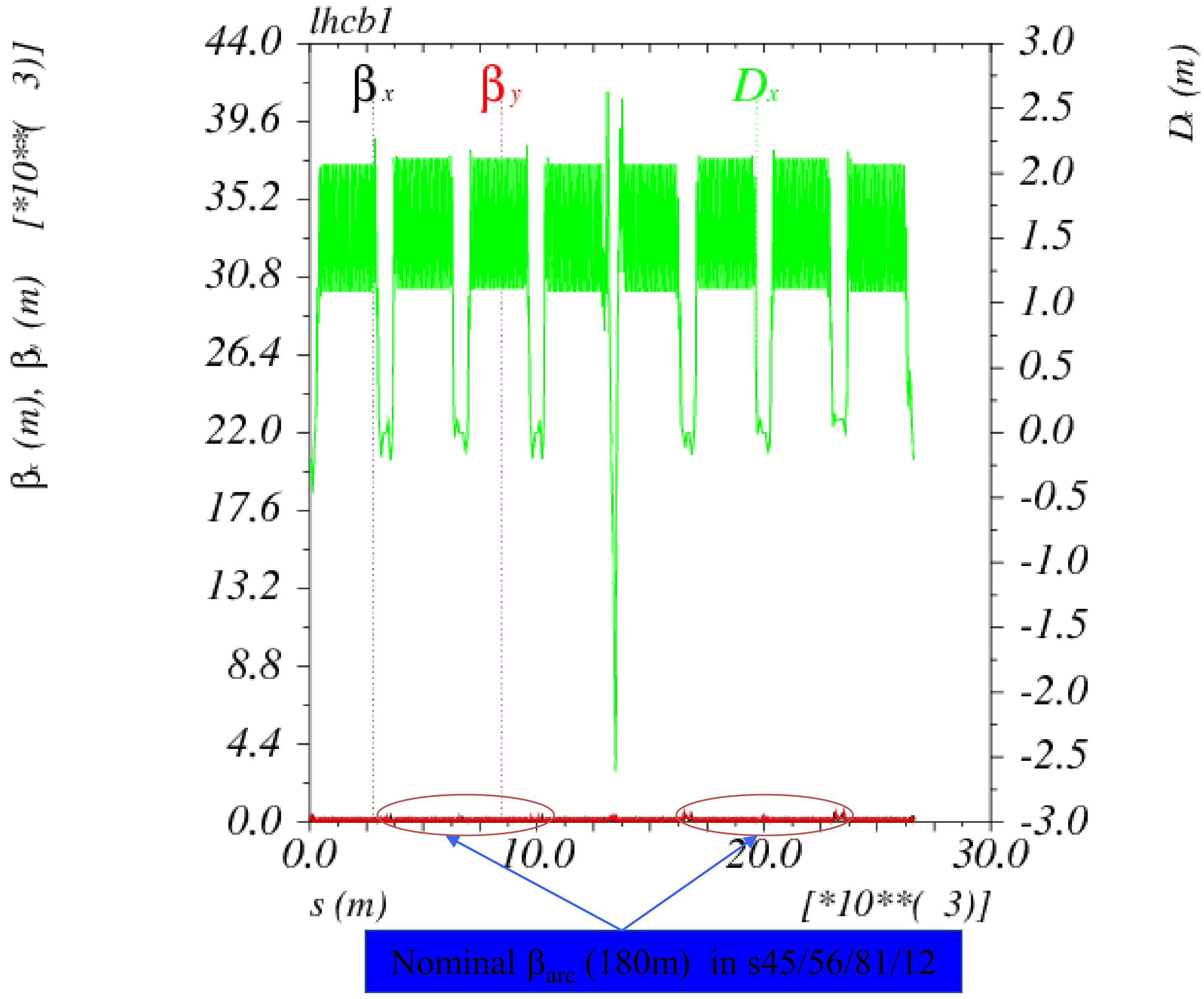
→ A possible parameter set for the HL-LHC w/o crab-cavity

→ What can be tested now in the machine?

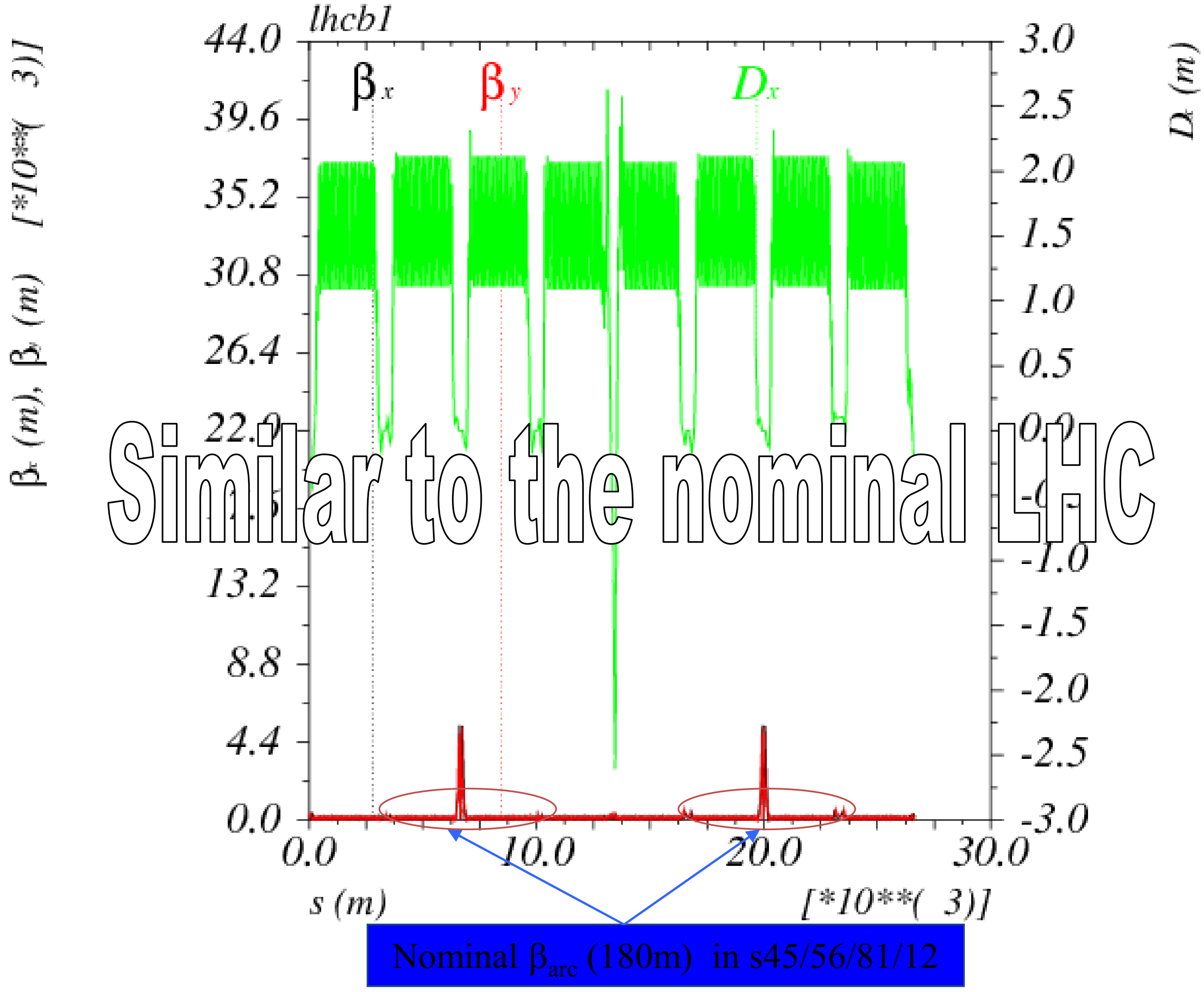
→ Conclusions

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

Injection optics: $\beta^* = 14$ m in IR1 and IR5

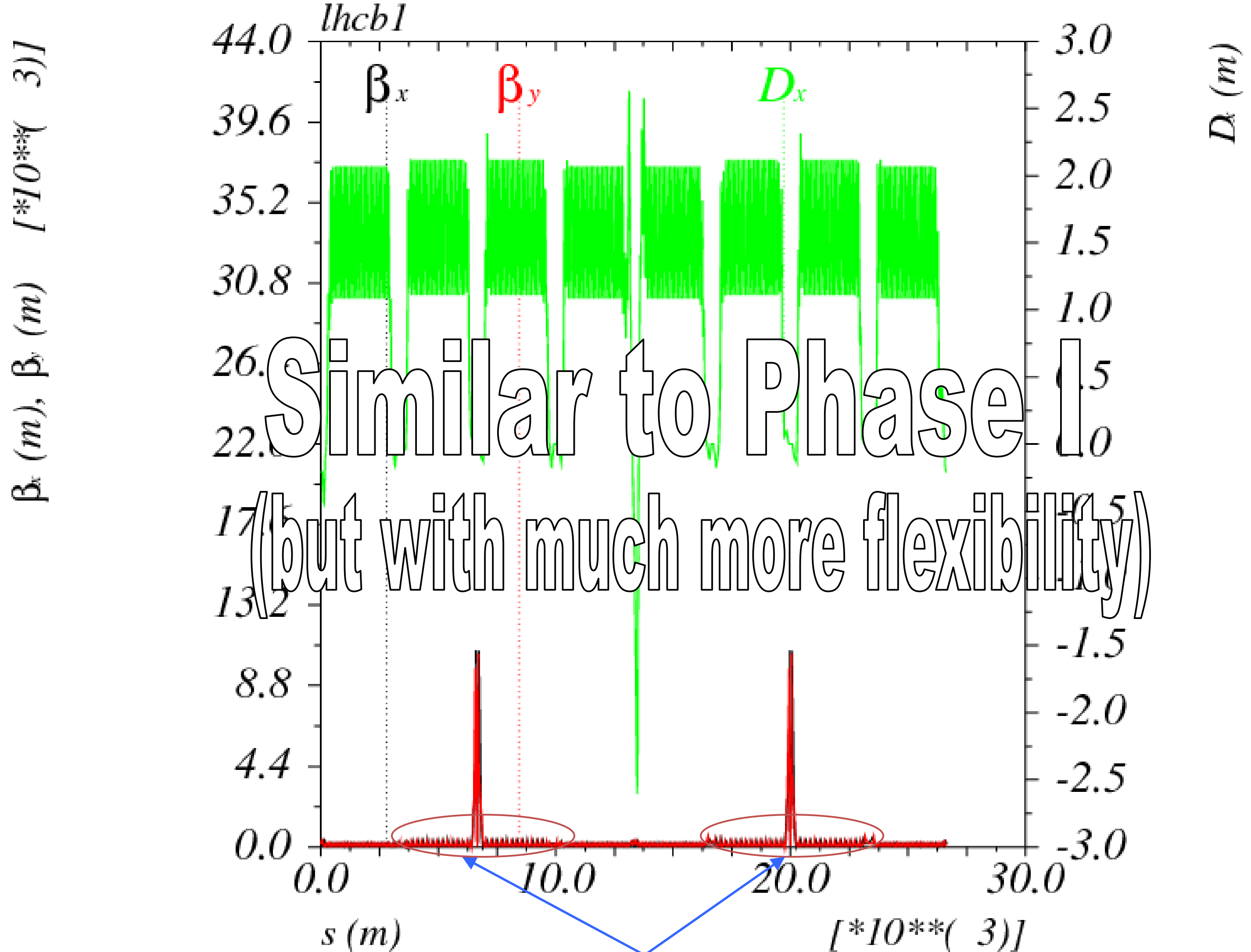


Pre-squeezed optics: $\beta^* = 60$ cm in IR1 and IR5: "1111"



Similar to the nominal LHC

Intermediate squeezed optics: β^* = 30 cm in IR1 and IR5: "2222"

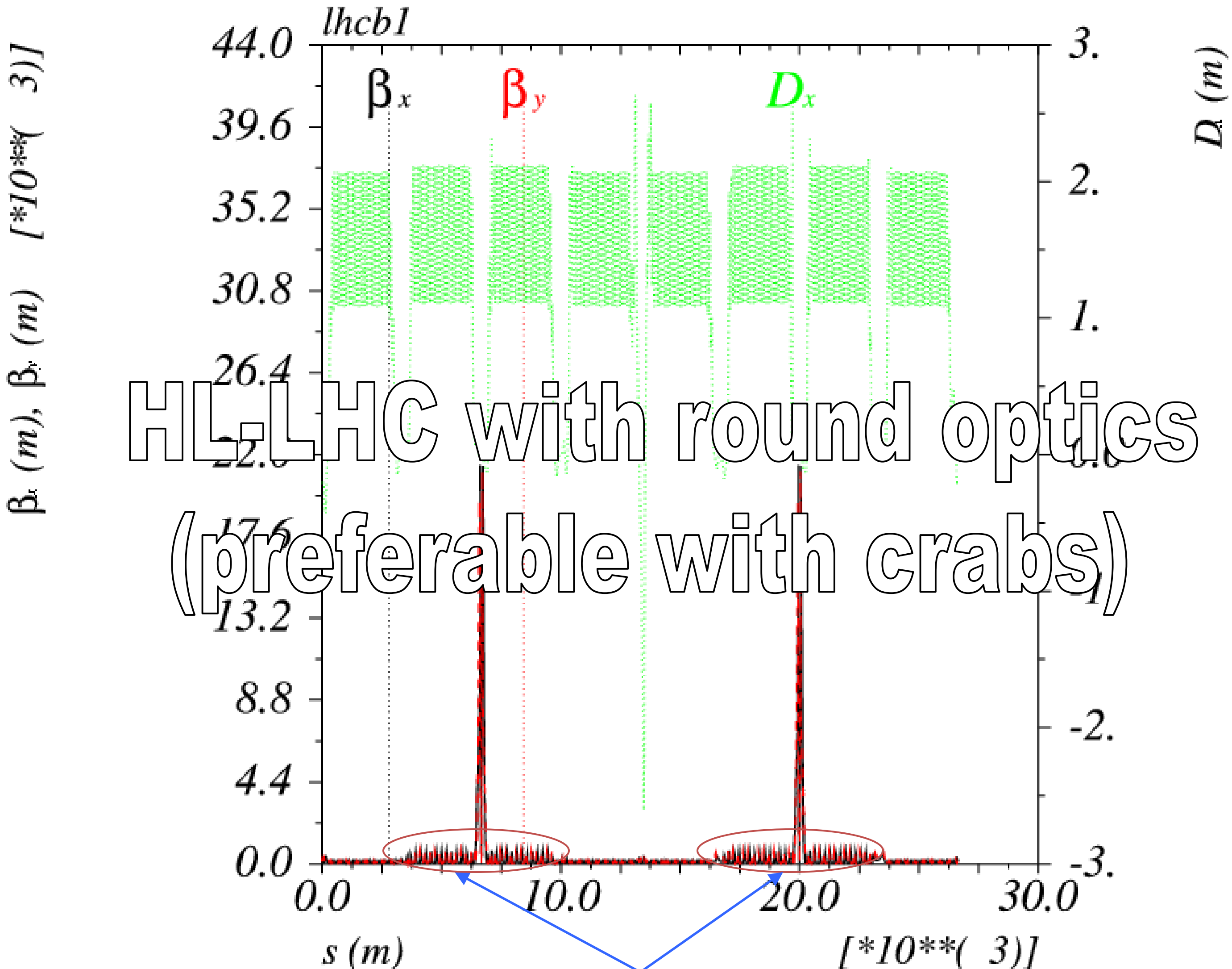


Similar to Phase I

(but with much more flexibility)

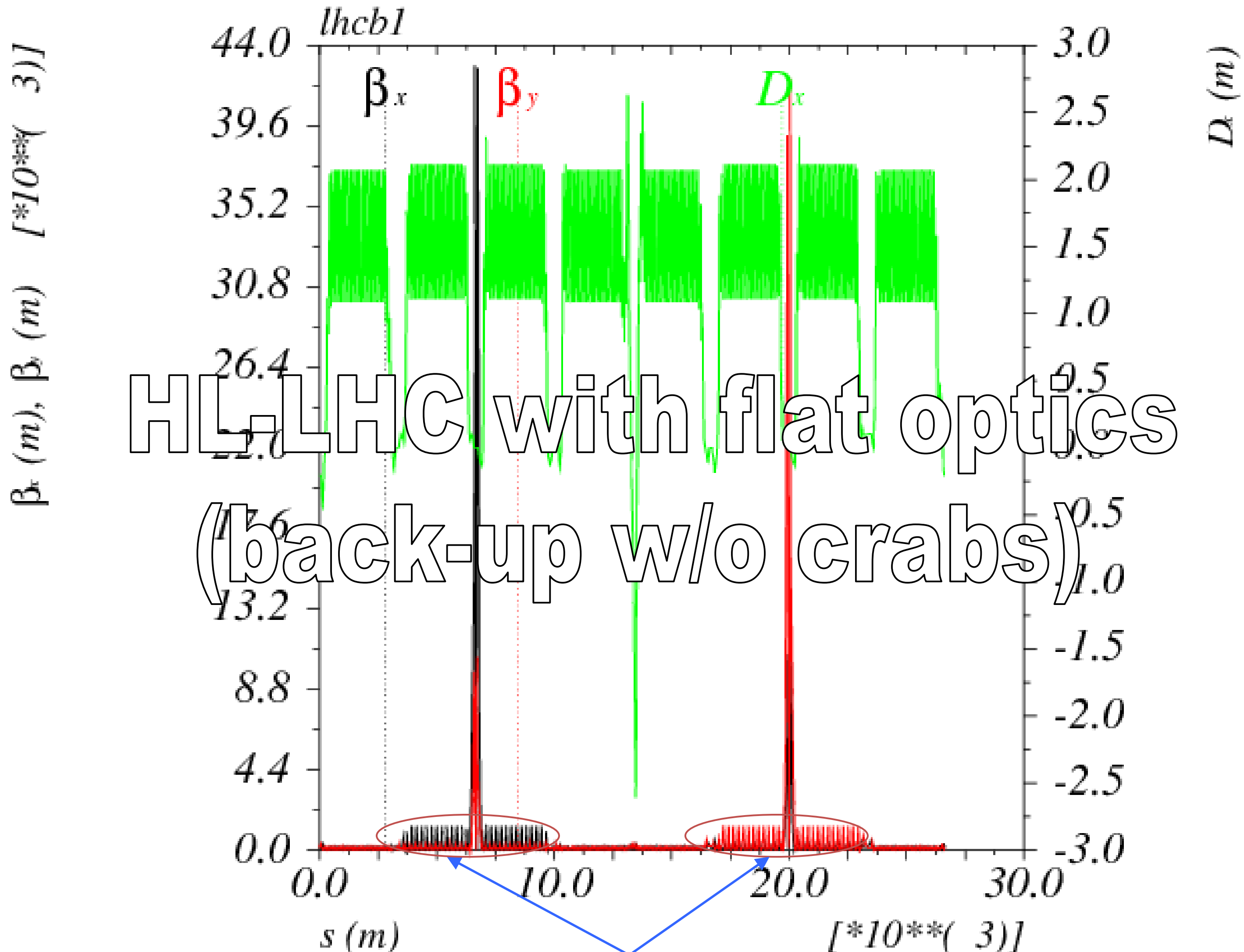
β_{arc} increased by a factor of 2 in s45/56/81/12

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



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

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



HL-LHC with flat optics (back-up w/o crabs)

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

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 … IT, i.e. feed-box installed on the non-IP side of D1 or no … technology).
2) Stronger and larger aperture … Q4 (and possibly Q5/Q6)
3) Nb3Sn technolo… …ly preferable for the new IT, e.g. reducing further the … , the number of parasitic collisions (gain of 3-4 LR's per IP … requirements in the new 2-in-1 magnets D2 and Q4 (by ~10%).
4) … and TAN with larger aperture and certainly new TCT like absorbers close to Q4 and Q5 both for the incoming and out-going beams.

THIS NOVEL SCHEME MAY BECOME THE BASE FOR ANY UPGRADE (However deep study and scrutiny for machine protection and experimental test are needed)

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

Photo: courtesy R. Assmann

changes since Chamonix 2010

- (head-on) beam-beam limit at least 2x higher

(reduced effect of resonances…)

- possibility to operate with lower emittance & higher brightness

(but also higher IBS)

- longer beam lifetime (better vacuum!!!)
- we know HL-LHC will use leveling
- leveled luminosity is defined: $5 \times 10^{34}\ cm^{-2}s^{-1}$
- “ATS optics” solution for $\beta^* < 30$ cm

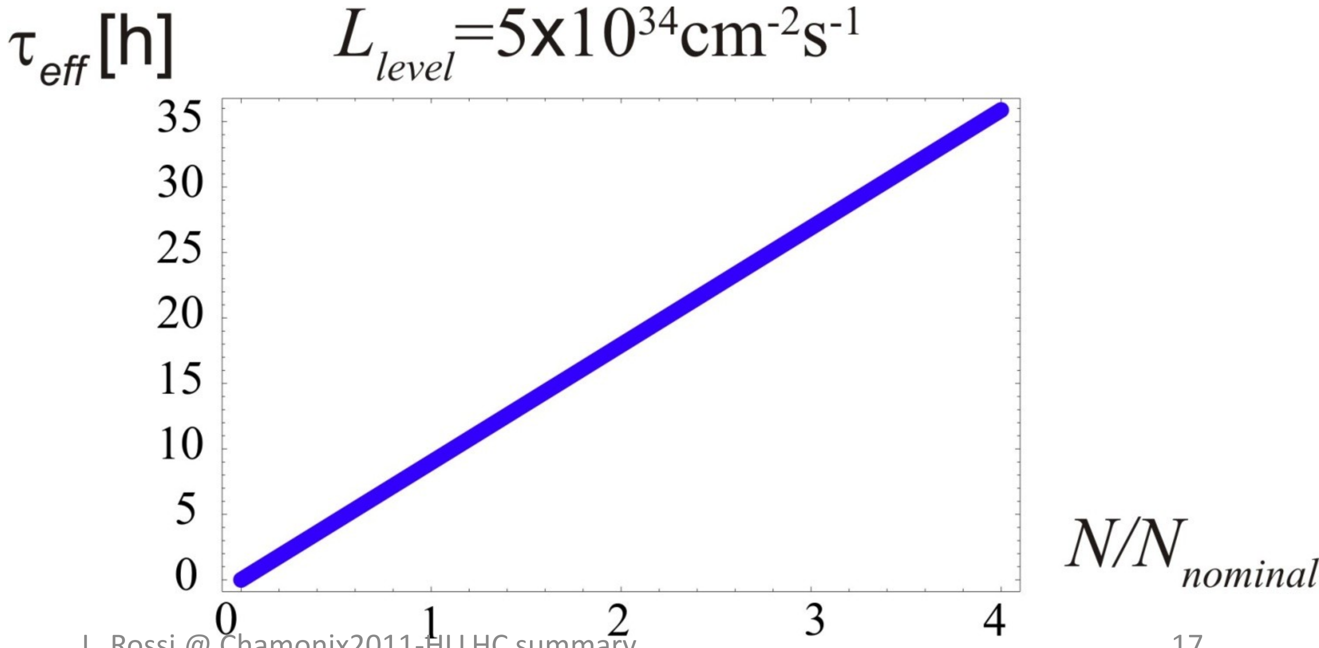
effective beam lifetime

for given luminosity

τ_{eff} scales with total beam current

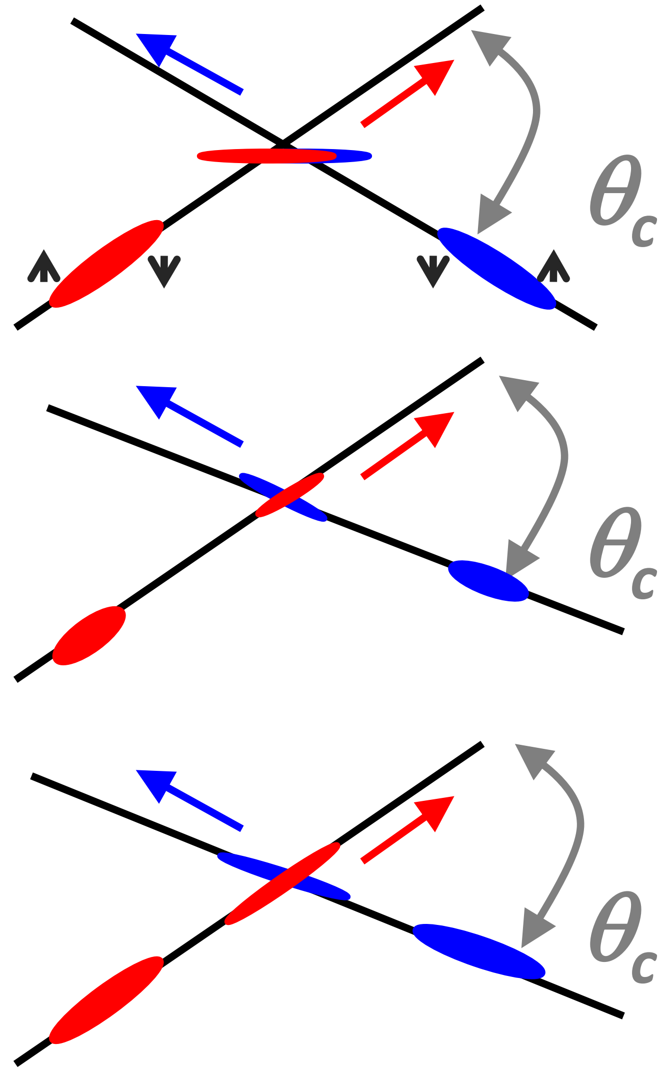
$$\frac{dN_{tot}}{dt} = -\frac{N_{tot}}{\tau_{eff}} = -\sigma L_{lev}$$ (σ=100 mbarn)

$$\tau_{eff} = \frac{N_{tot}}{n_{IP}\sigma L_{lev}}$$



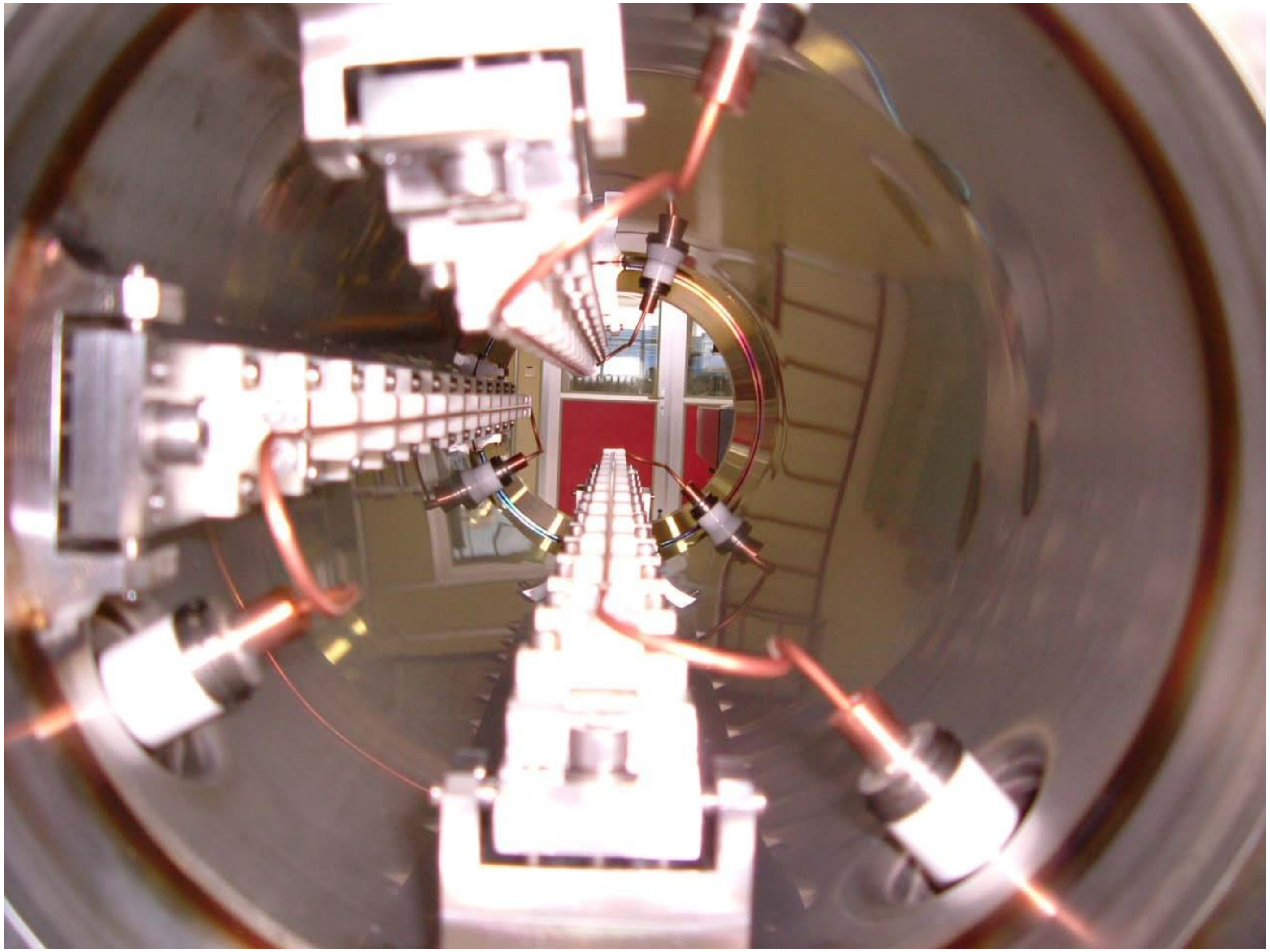
approaches to boost LHC luminosity

- 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



always pushing intensity to "limit"

Long-Range Compensation



2x2 water-cooled units presently installed in the SPS (two with remote control)

1x2 spare units ready

1st RHIC BBLR stored at CERN

2nd RHIC BBLR being shipped

in total 5 sets available

J.-P. Koutchouk, G. Burtin, et al

Summary form first 3 talks:

Do no exploit « only »

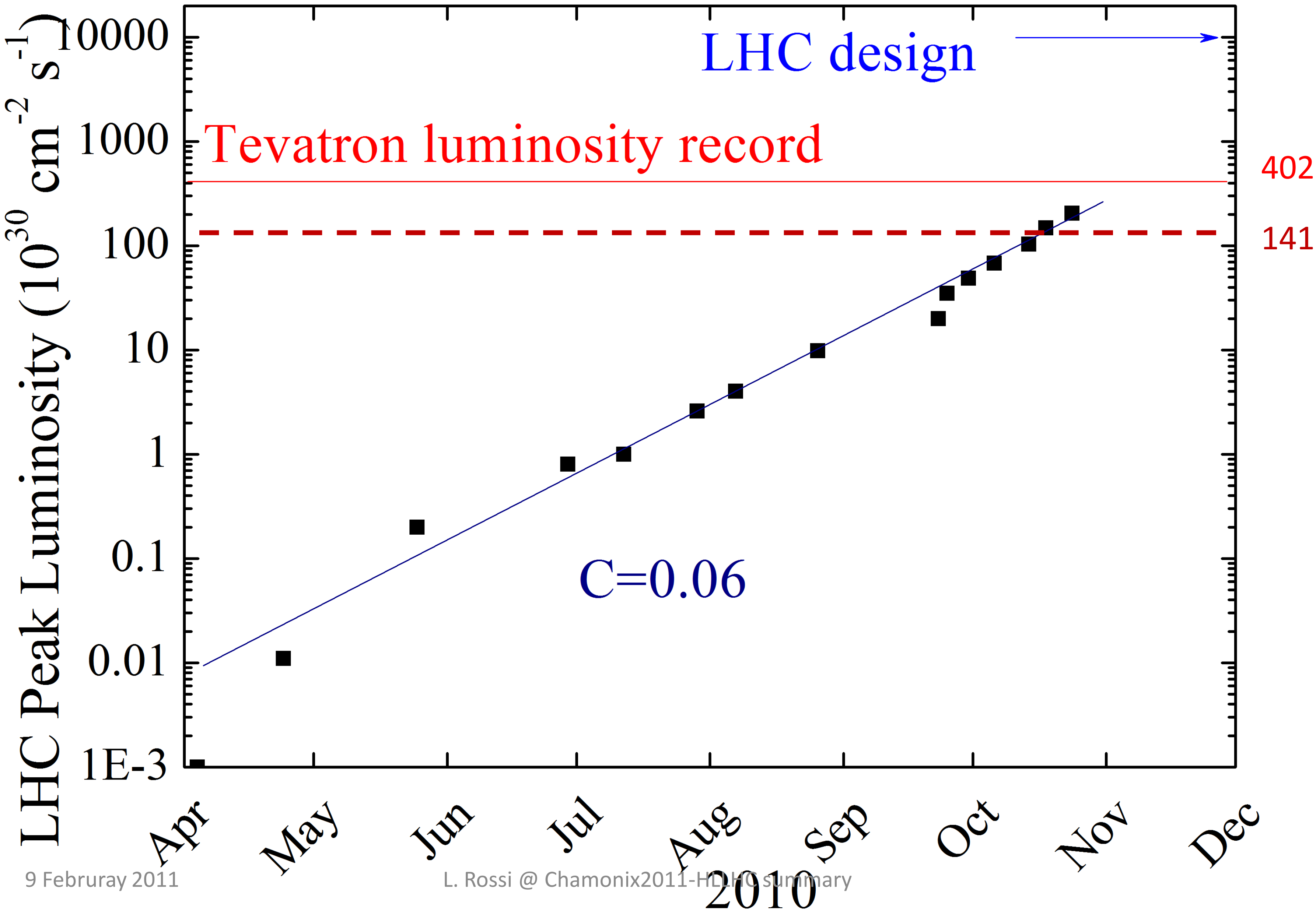
- **Invest on future (time needed in 2011-12):**
  - MDs to understand what is really the maximum current LHC can digest at different structures (25 vs 50 ns)
  - MDs (or better : optics recommissioning) to validate and understand the actual limit of the **ATS** !!!
  - Beam-Beam Long range compensation by eelctric wires
  - (MDs on leveling experiments)
- **Continue on long term hardware R&D:**
  - HF, heat depo tolerant, SC magnets
  - Crab cavities
  - Collimators and Machine protection
  - R2E (Sc links for EPC relocation)
  - Improved cryogenics…

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

Vladimir Shiltsev
Fermilab

Chamonix-2011
January 27, 2011

LHC 2010 Success in Numbers



"CPT Theorem for Accelerators"

$$C \times P = T$$

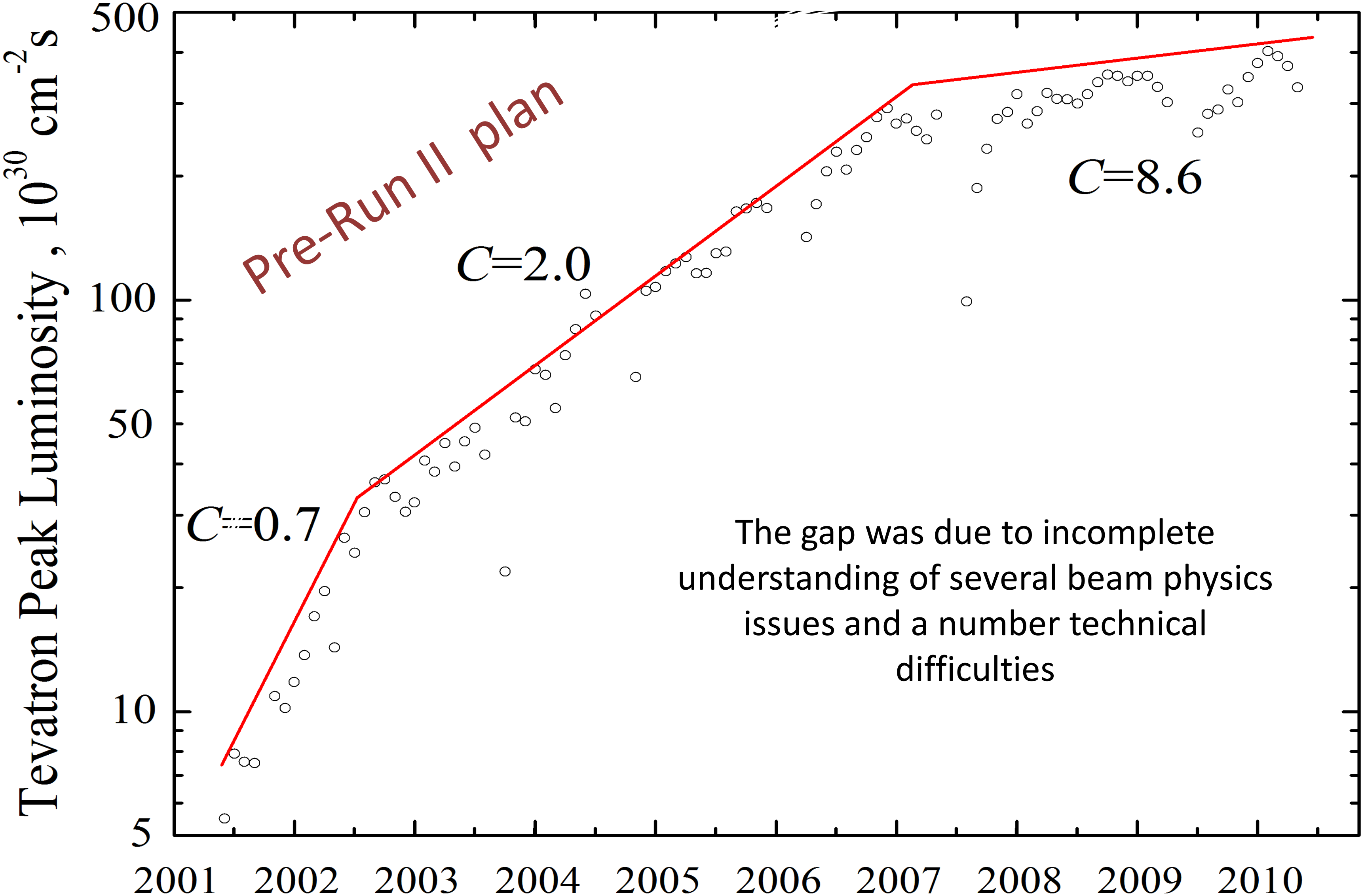
C **= Complexity of the machine**

P = Performance (or Challenge)

= $\ln$ (Luminosity Increase)

T = Time to reach ***P***

Run II Luminosity Progress



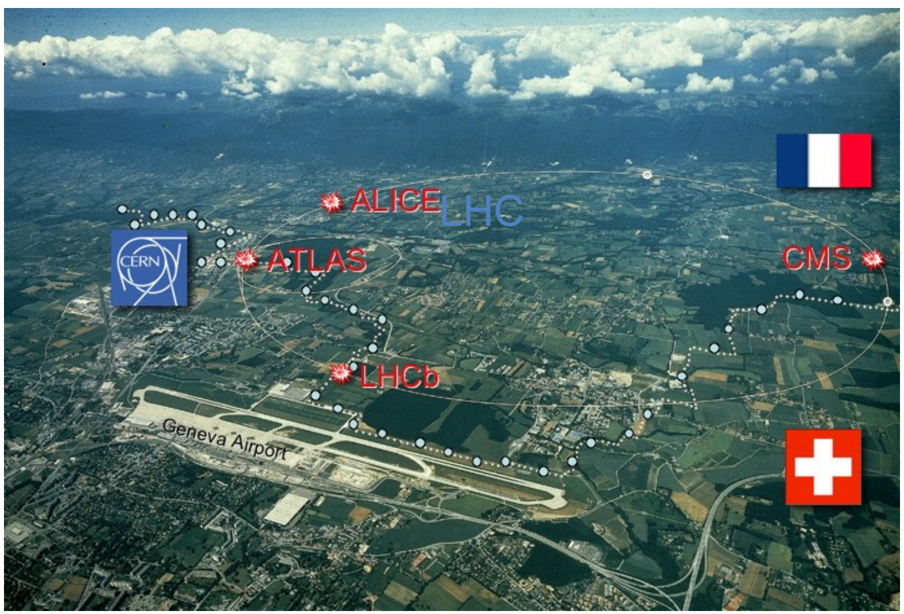
The gap was due to incomplete understanding of several beam physics issues and a number technical difficulties

Conclusions (2)

- Expectations management is crucial
- As in the case of the Tevatron, the LHC goals may need to be expressed in terms of two goals:
  - “design” or “stretched” goal that represents your “best … the limit of performance to which the facility can be …
  - with the most likely outcome … between
- The goals and … “base” to “design” goals depend on the … understanding of the machine

DONE: 1 fb-1 is the baseline for 2011, however 2-3 fb-1 seems at hands, i.e. stretched golas)

ALICE and LHCb in the HL-LHC era

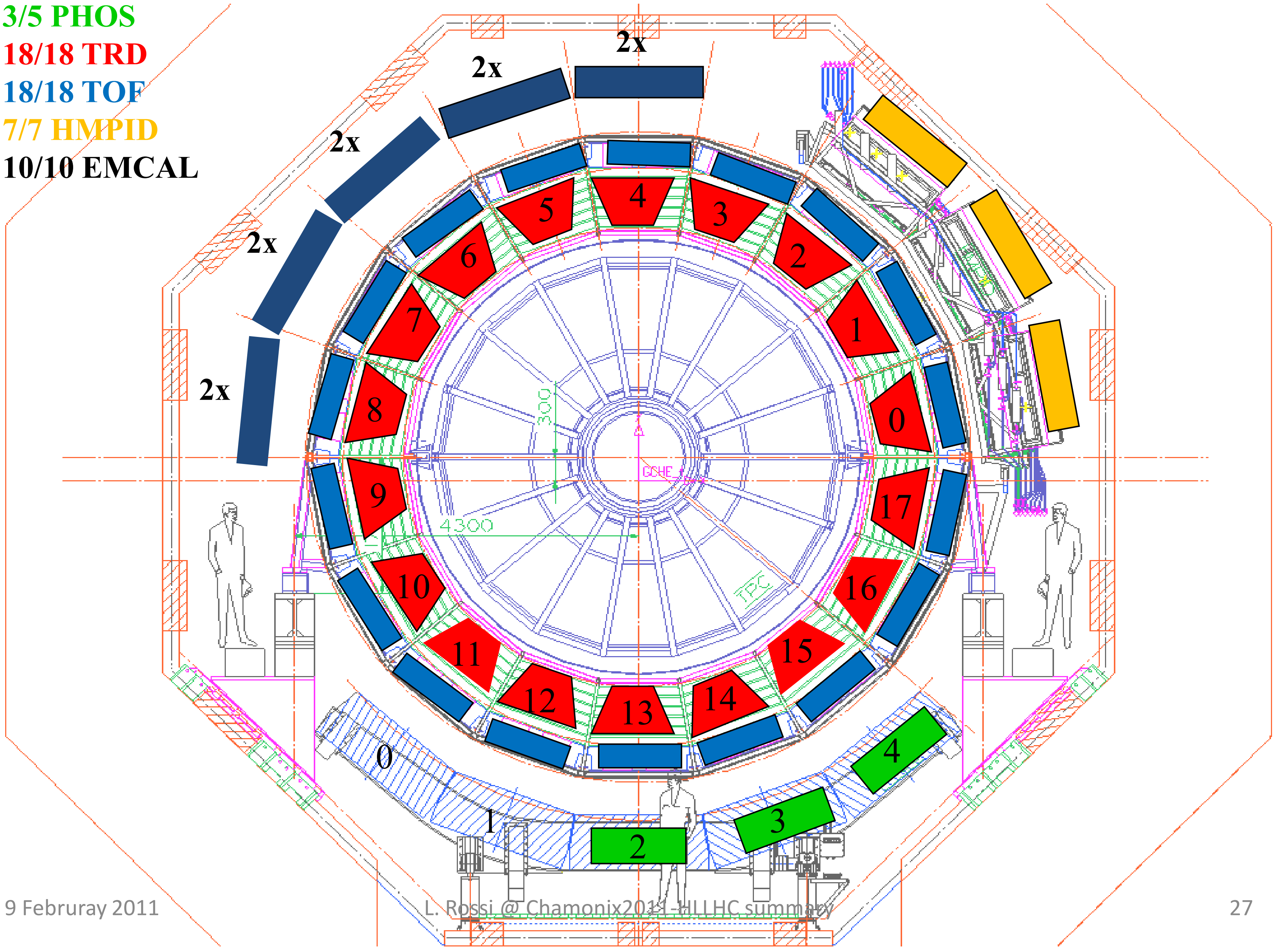


CHAMONIX 2011

January 27, 2011

Sergio Bertolucci
CERN

ALICE 2012



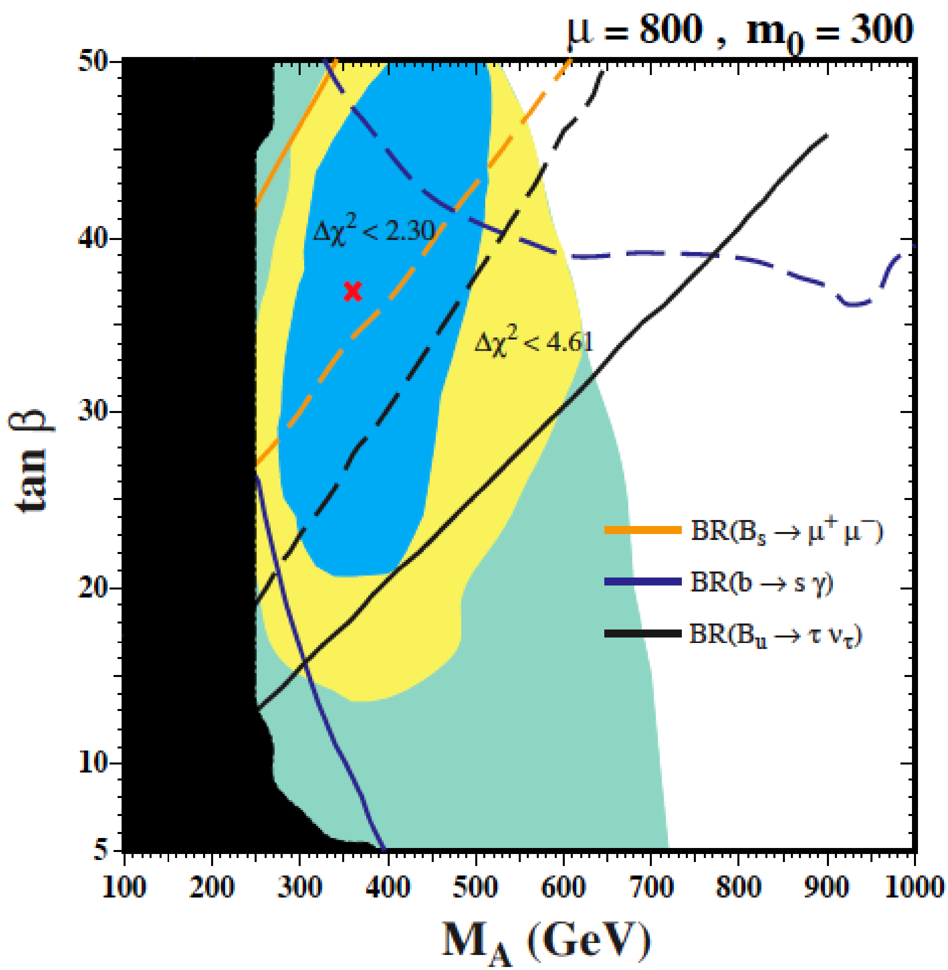
3/5 PHOS
18/18 TRD
18/18 TOF
7/7 HMPID
10/10 EMCAL
2x
2x
2x
2x
2x
2x
300
4300
TPC

ALICE Program

- Baseline Program:
  - initial Pb-Pb run in 2010 (< 1/20th design L, i.e. ~ 3 x 10^{25})
  - 2-3 Pb-Pb runs (medium -> design Lum. L ~ 10^{27}, 2.75 TeV -> 5.5 TeV) **integrate at least ~ 1nb^{-1}** at the higher energy, and as close as possible to 1nb^{-1} at the lower one
  - 1-2 p A runs (measure cold **nuclear** matter **effects**, e.g. shadowing)
  - 1-2 low mass ion run (**energy density & volume** dependence) typ. ArAr
  - **continuous running with pp** (comp. data, genuine pp physics)
- **-> Baseline Program more than fills the 8 "HI runs" to ~ 2019**
- Following or included:
  - lower energies (energy dependence, thresholds, RHIC)
  - additional AA & pA combinations
- **NEXT (after long shutdown at the end of the decade):**
  - details of program and priorities to be decided based on results, but **Increase int. Luminosity** by an order of magnitude (to **~ 10nb^{-1}**)
    - Address rare probes (statistics limited: for example, with 1nb^{-1} :J/Y: excellent, Y': marginal, Y: ok (14000) , Y': low (4000), Y'': very low (2000))

Strongest constraints on MSSM Higgs come not from direct searches but from $B_s \rightarrow \mu\mu$, $b \rightarrow s\gamma$ and $b \rightarrow \tau\nu$

LHCb



By measuring BR($B_s \rightarrow \mu\mu$) LHCb will probe the entire best-fit region of parameters with 2011 data. Direct searches would require several years running at nominal L to achieve this goal

In addition to the approved programme of b (and c) heavy flavour physics, LHCb is adaptable to other physics studies, with its unique coverage of the forward region

Lepton Flavour physics:

- ✓ *Search for Majorana neutrino*
- ✓ *Search for Lepton Flavour violation in τ decays*

Physics beyond Flavour:
(with large data samples in forward direction)

- ✓ *Exotics (in particular "hidden sector")*
- ✓ *Electro-Weak physics*
- ✓ *Central Exclusive Production (CEP)*

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 … both have good reason t… …d 2020…
- … also i… …n of the not overwhelming … …w machines.

UNDERSTOOD: will be trivial but study to integrate the extra physics possibilties into HL-LHC will start soon, to be ready for a proper decision

I really hope (and I tend to believe) that new Physics will make the choice very easy!