Session 9

Topic	Contributer
Parameter space beyond 10^{34}	F. Zimmermann
Implications of higher intensities in the LHC	R. Assmann
Crab Cavities	R. Calaga
Luminosity optimization and leveling	J.P. Koutchouk
What do the experiments want ?	M. Nessi
Comparison of integrated luminosities	M. Lamont

Parameter space

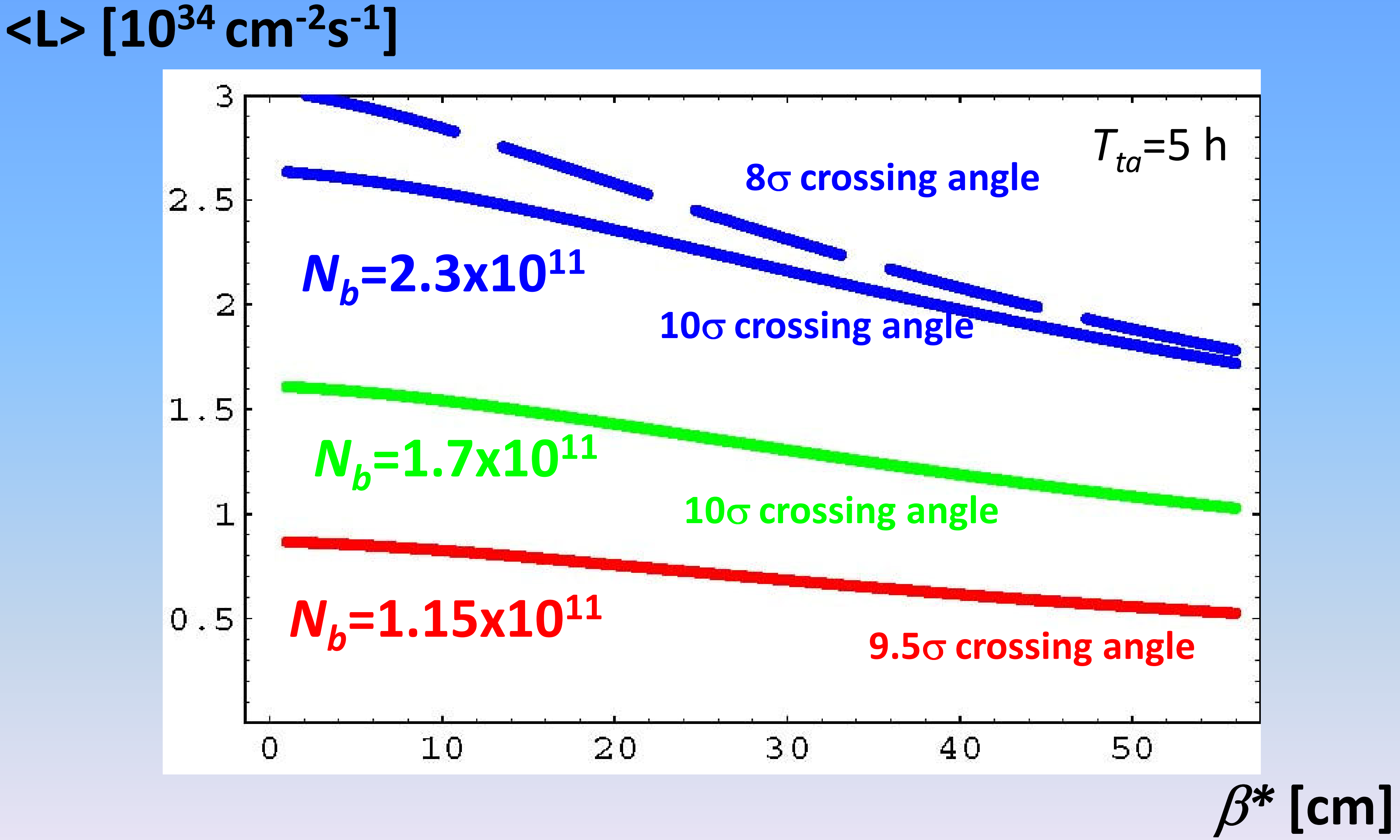
- β^* – IP beta function
- θ_c – (full) crossing angle
- ε_N – normalized emittance
- N_b – bunch intensity
- n_b – number of bunches
- longitudinal bunch profile ("flat" vs "Gaussian")
- number of collision points (IP's)
- T_{ta} – turn-around time

Nominal settings for 10^{34} cm^{-2} s^{-1} in 1 and 5	
Beam energy (TeV)	7.0
Number of particles per bunch	1.15 10^{11}
Number of bunches per beam	2808
Crossing angle (μrad)	285
Norm transverse emittance (μm rad)	3.75
Bunch length (cm)	7.55
Beta function at IP 1, 2, 5, 8 (m)	0.55,10,0.55,10

Constraints

- **total beam-beam tune shift** $\Delta Q_{bb} \propto \frac{N_b}{\varepsilon_N} \frac{1}{\sqrt{1+\frac{\theta_c^2 \, \sigma_s^2}{4 \, \beta^* \varepsilon}}}$
  - SPS p-pbar experience suggests **≤ 0.01**
- long-range beam-beam → **crossing angle ≥ 9σ**
- **arc cooling capacity**
  - global & local limitations, cooling shares with IR
  - heat load from SR, image currents, & e-cloud
  - **25ns bunch intensity limited to 2.3 10^{11}**
- IR layout & optics → β* (0.55 .. 0.3 .. 0.14)
- **event pile up** in the detectors (≤300, ≤150?)
- **luminosity lifetime** (≥ 2h?)

The key plot



beam intensity is much more important than β^*

Can the LHC swallow > ultimate intensities ?

- Ultimate intensity is already challenging for the LHC
- Many systems at technological limits with little or no margin
- Long (incomplete) list of required LHC work collected:
  - Two new cryoplants (assuming one installed for ultimate) ⇒ $2.3\ 10^{11}$
  - New RF system, possibly requiring civil engineering.
  - New DSL in IR3, review of potted magnets, radiation damage.
  - Upgrade of permanent vacuum bake-out system.
  - Essentially all protection devices to be replaced with more robust designs, possibly requiring also layout changes.
  - Upgrade of the beam dump system. Additional hardware.
  - Half of the phase 1 collimation system to be reviewed (replaced).
  - Remote handling becomes mandatory in parts of the machine.
  - Additional service galleries could be required
  - Absolute filters and modifications of ventilation system.
  - Additional shielding in some areas.

In order to reach high intensities

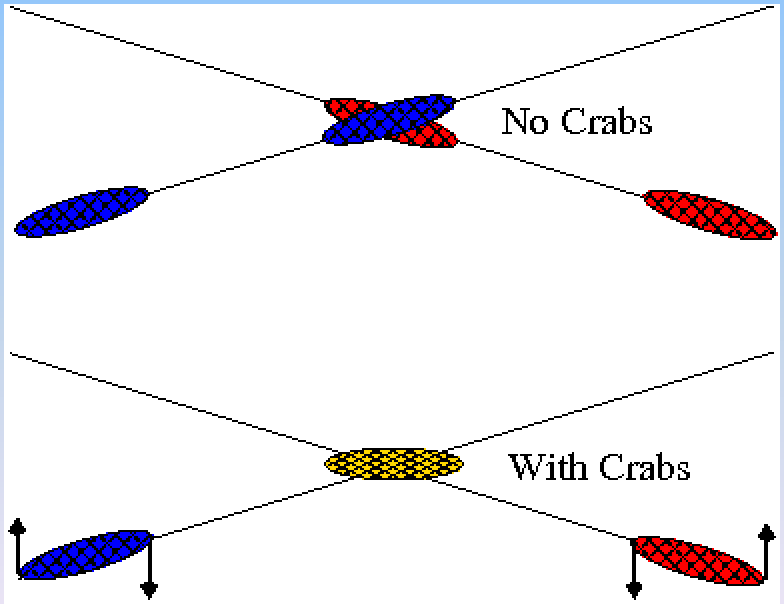
- A coherent upgrade plan should also address the LHC system limits!
- To get a clear picture further work is required. All colleagues pointed out that detailed work is required to understand feasibility and limitations.
- Detailed studies and HiRadMat tests will give clearer picture.
- Nobody argued that an LHC intensity upgrade to beyond ultimate is impossible.

- “With enough money everything is possible…:-)”
- Yes, but effort and cost might be significant…

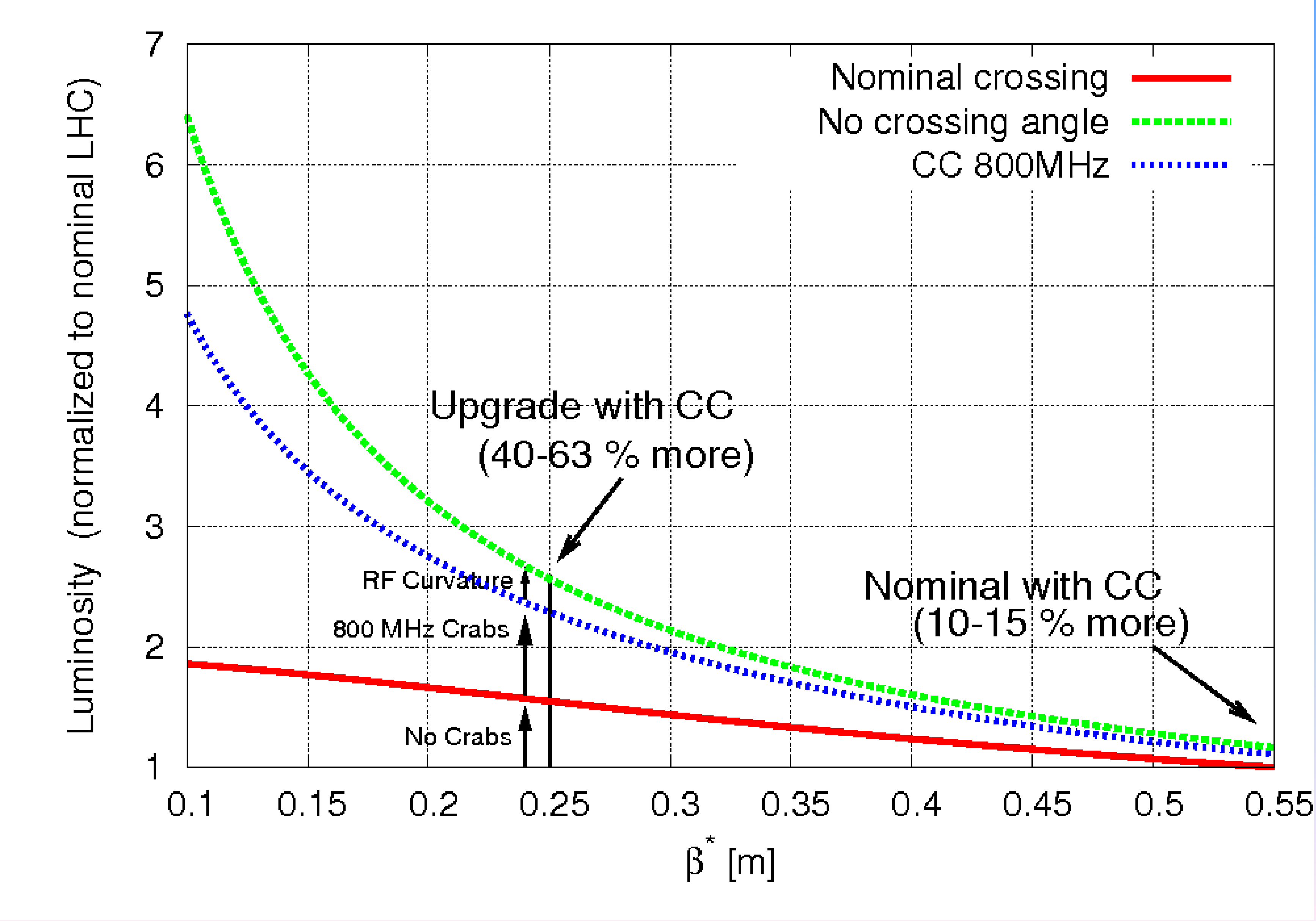
Crab crossings

$$R_\phi = \frac{1}{\sqrt{1+\phi^2}}; \quad \phi \equiv \frac{\theta_c \sigma_z}{2\sigma_x^*}$$

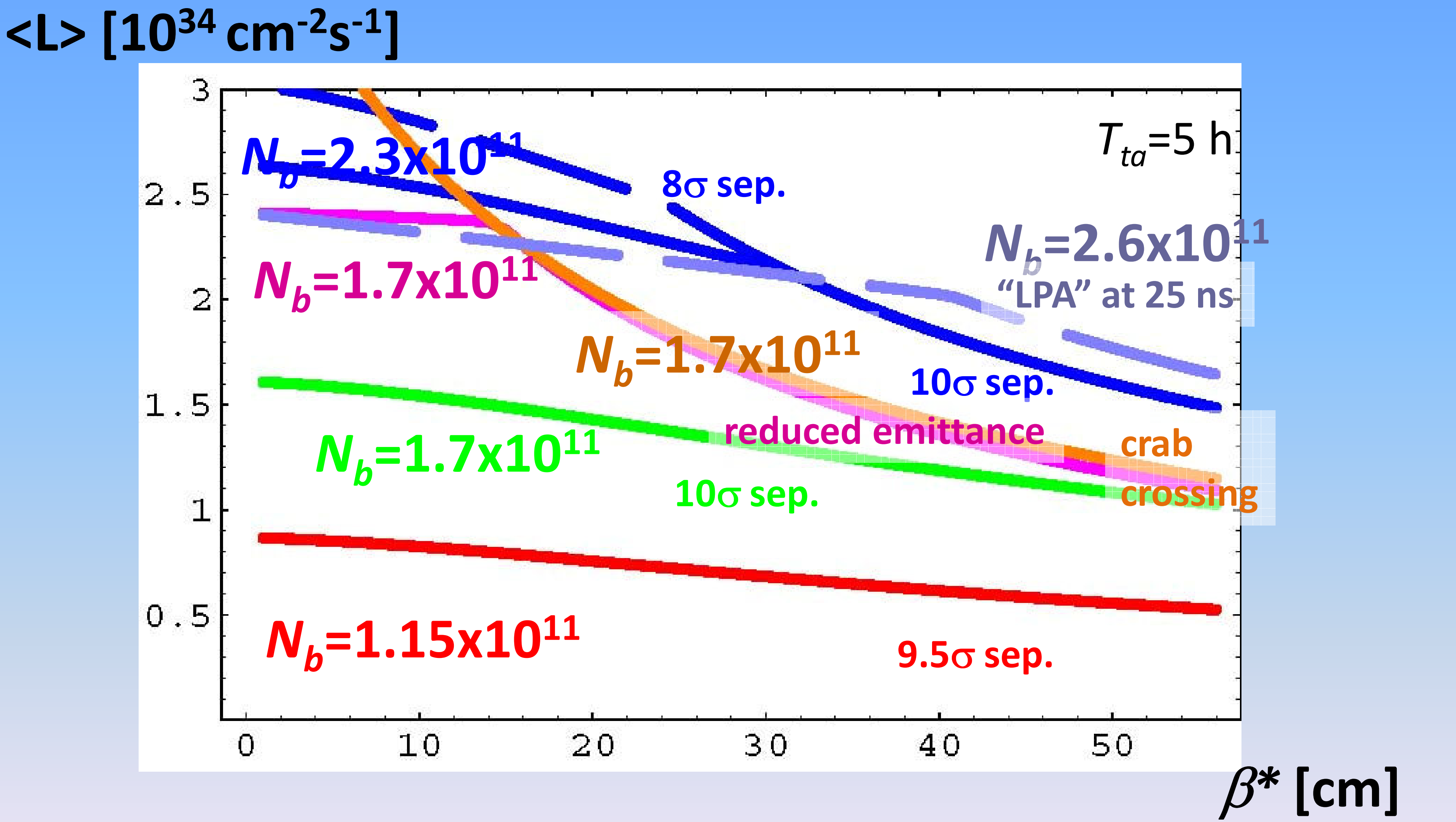
- Crossing angle reduces luminosity
- Can be recovered by opposite deflection of head-tail
- Achieved by so-called RF crab cavities
- Proposed in 1998, in operation at KEKB since 2007



What is the gain ?

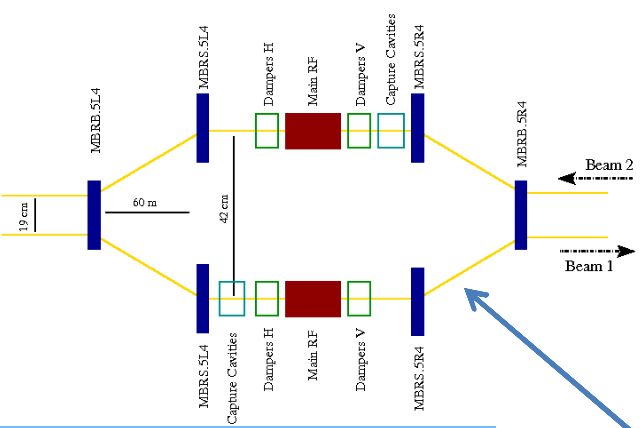


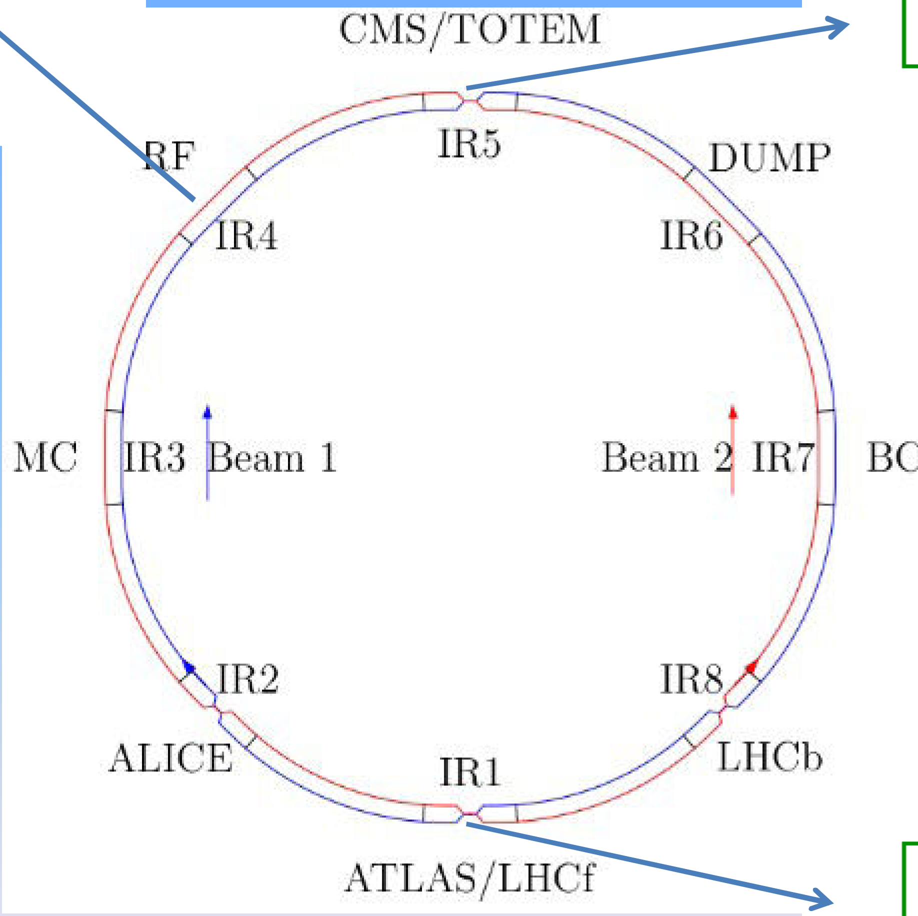
The key plot again

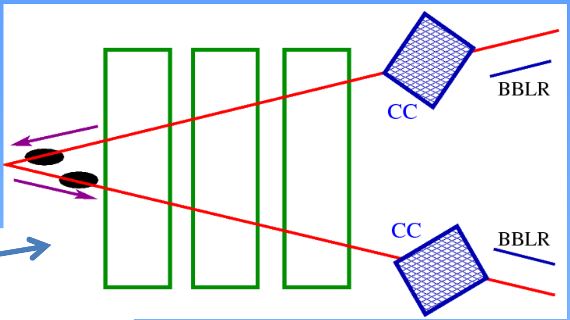


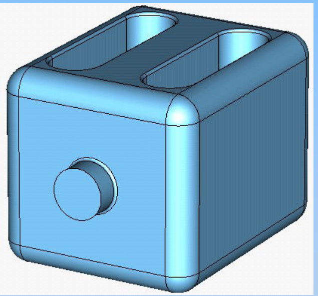
beam intensity is much more important than β^*, reducing β^* only helps with crab cavities or with smaller emittance

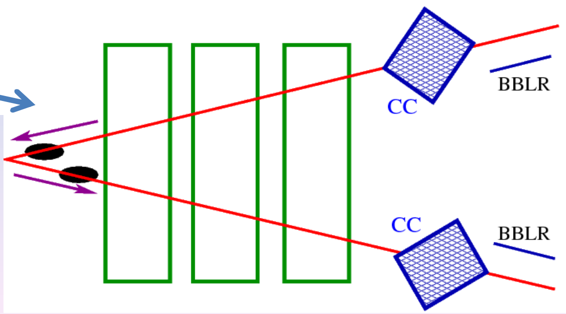
Possibilities











New cavities

- IR 4
- IR 1 and IR 5

New technology

LHC-CC09 Guideline

1. Following the success of KEKB, CERN must pursue the use of crab cavities for the LHC, since the potential luminosity increase is significant.
2. A final crab cavity implementation for the LHC has not yet been settled. Both “local” and “global” crabbing schemes are still under consideration for the LHC upgrade phase II. Future R&D should focus on compact cavities which are suitable for both schemes.
3. One possible showstopper has been highlighted: machine protection, which is critical for LHC. The effect of fast cavity changes needs to be looked at with high priority. Mitigation schemes will be studied.
4. ..
5. ..
6. ..
7. ..
8. ..
9. ..
10. ..
11. ..
12. Crab cavities can increase the LHC luminosity without an accompanying increase in beam intensity, thereby avoiding negative side effects associated with high intensity and high stored beam energy. This opinion has been endorsed by the general purpose highluminosity experiments.

Luminosity leveling – why ?

At a luminosity level of $10^{35} cm^{-2}s^{-1}$, whatever the scenario, the luminosity lifetime becomes close to operations "time constants" (cycling and filling, travel time to remote buildings and repairs,…).

Hence, **luminosity leveling** could be raised as a requirement for all scenarios. Leveling is also useful for the machine: peak energy deposition, beam-beam effect, operation efficiency.

Accordingly, the performance goal of Phase II would become $L_{average} \sim 5$ to $6\ 10^{34}\ cm^{-2}s^{-1}$, almost constant over one shift (multiplicity ~ 100 for 25 ns spacing).

Luminosity leveling – how ?

$$L \propto \frac{1}{\beta^* \sqrt{1 + \frac{\theta_c^2 \sigma_s^2}{4 \beta^* \varepsilon}}}$$

Leveling via the **Xing angle** appears to have the best potential (performance, complexity) but requires unexplored solutions (Crab Crossing) or some interference with detectors (Early Separation).

Leveling via the **bunch length** is worth a detailed study to understand its feasibility.

Leveling by **β*** has an inherent performance limit, is probably complex to implement but is cheap.

Beam-beam compensation

$$\Delta Q_{bb} \propto \frac{N_b}{\varepsilon_N} \frac{1}{\sqrt{1+\frac{\theta_c^2 \sigma_s^2}{4 \beta^* \varepsilon}}}$$

The **long-range beam-beam compensation** addresses a fundamental LHC performance limit; it appears effective and robust from several simulations, experiments and one implementation in DaΦne.

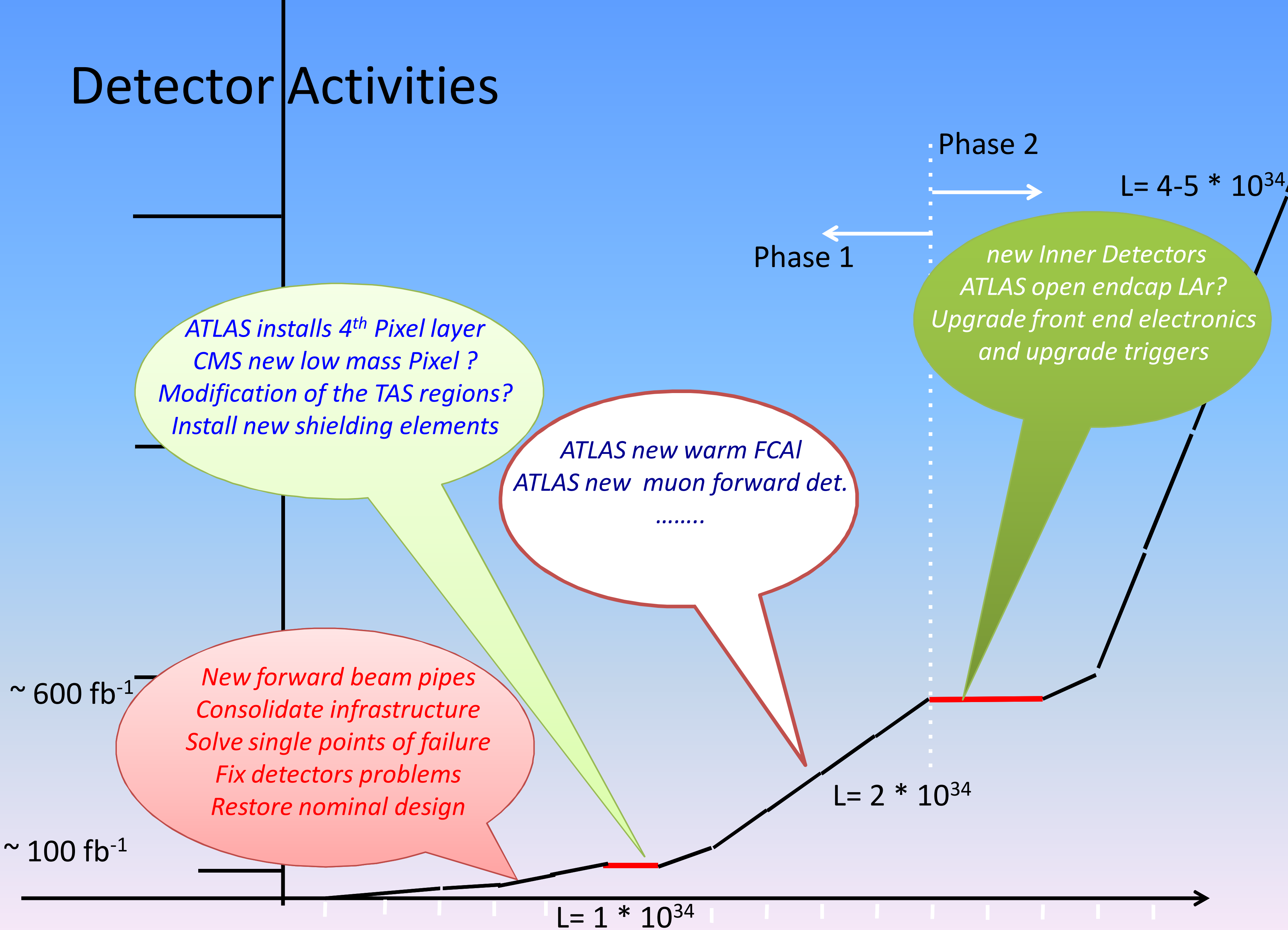
It is mature for implementation at the LHC. *An early dc implementation would allow the study of the beam-beam limits well before the LHC can reach this performance level.*

Detector limitations

- Some detectors will age at a given integrated Luminosity (different case by case)
  - ATLAS b-layer PIXEL — $\sim L_{int} = 200\text{-}300\ fb^{-1}$
  - ATLAS Silicon Tracker (SCT + PIXEL) — $\sim L_{int} = 600\text{-}700\ fb^{-1}$
  - ATLAS LAr Hadron Calorimeter FE Electronics — $\sim L_{int} = 1000\ fb^{-1}$
  - CMS PIXEL — $\sim L_{int} = 300\ fb^{-1}$
  - CMS Silicon Tracker — $\sim L_{int} = 600\text{-}700\ fb^{-1}$
  - ……

- Some detectors will become inefficient or problematic at a given peak Luminosity
  - ATLAS TRT (transition radiation tracker) — $\sim L = 2\text{-}3\ 10^{34}$
  - ATLAS FCAL (forward calorimeters) — $\sim L = 2\text{-}3\ 10^{34}$
  - ATLAS SS external beam pipes (activation) — $\sim L = 1\ 10^{34}$
  - ATLAS&CMS Silicon trackers — $\sim L = 2\text{-}3\ 10^{34}$
  - ……

Detector Activities



Detector upgrades

- In general some detector components will need to be replaced, upgraded or just consolidated. A large fraction of the front-end electronics and trigger electronics will need to be upgraded before going to sLHC Luminosity

- In the early half of the last decade, some detector components necessary to run at nominal Luminosity have been staged and need now to be restored

- We do not yet know how the various detector components will react once we stress them by operation nearer to design rates. Special corrective interventions and consolidation programmes may prove to be necessary

- The experiments urgently need a plan for shutdowns over the next 5-6 years (LINAC 4) to organize the first stage of upgrade work

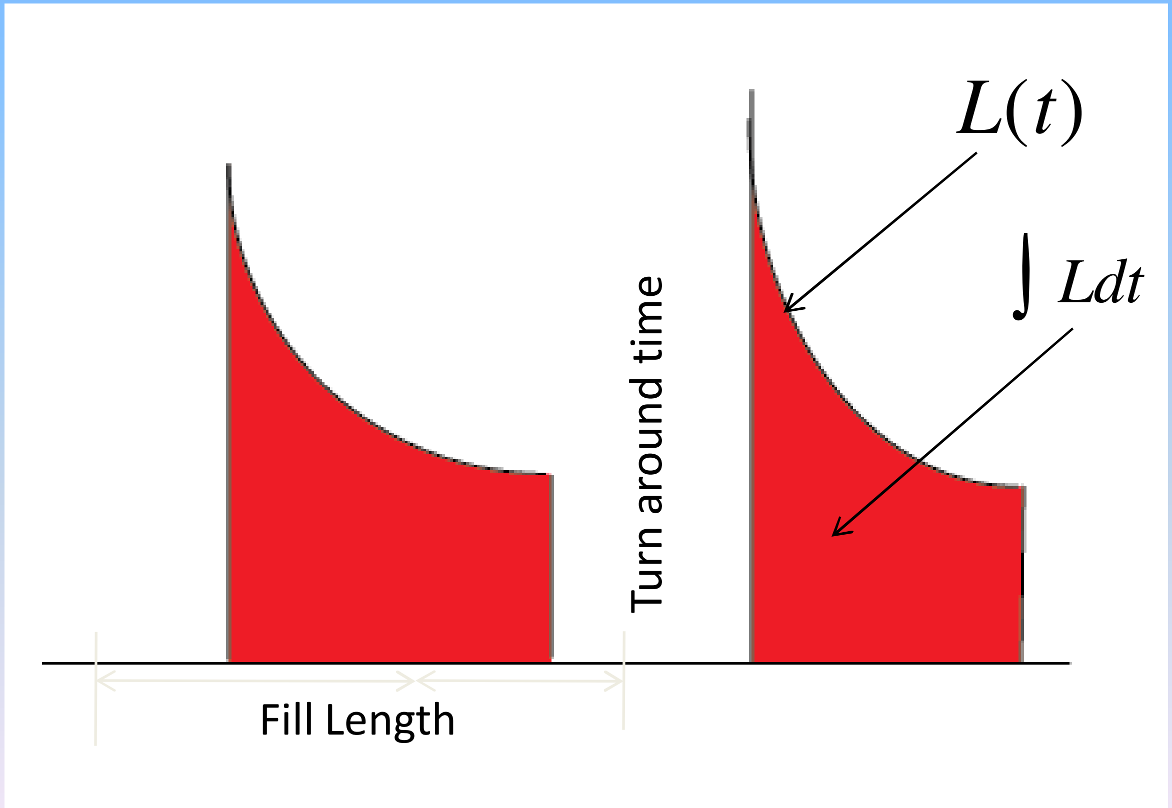
- We need a credible programme of long-term LHC operation in order to be able to justify planning and resources for the phase II upgrades

- The compatibility between running CMS and ATLAS at sLHC and at the same time colliding at point 2 and 8 should be urgently clarified

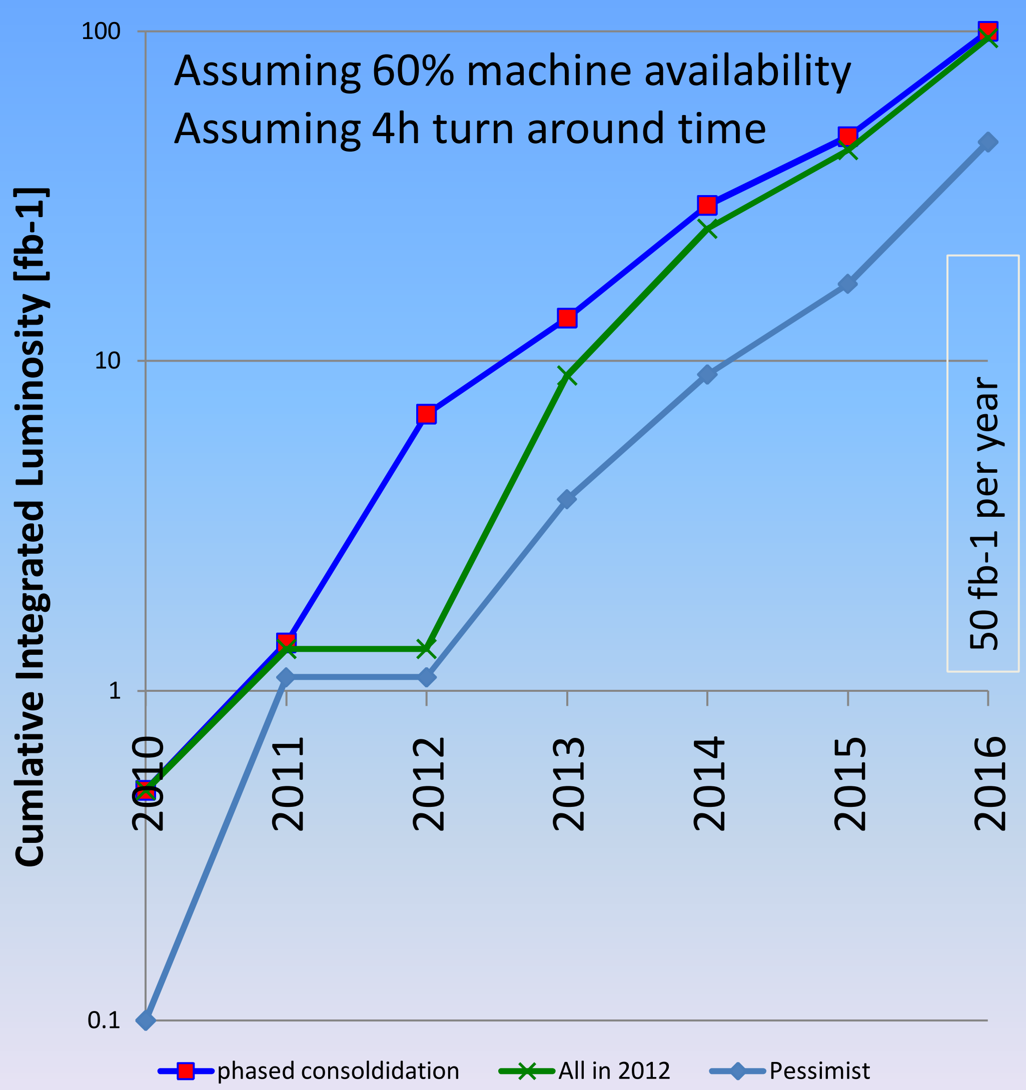
Estimating delivered luminosity

$$\tau_L = \frac{1}{\frac{1}{2\tau_{IBS}^x} + \frac{2}{\tau_{gas}} + \frac{1.54}{\tau_N}}$$

$$\tau_N = \frac{n_b N_b}{2L\sigma_{TOT}}$$

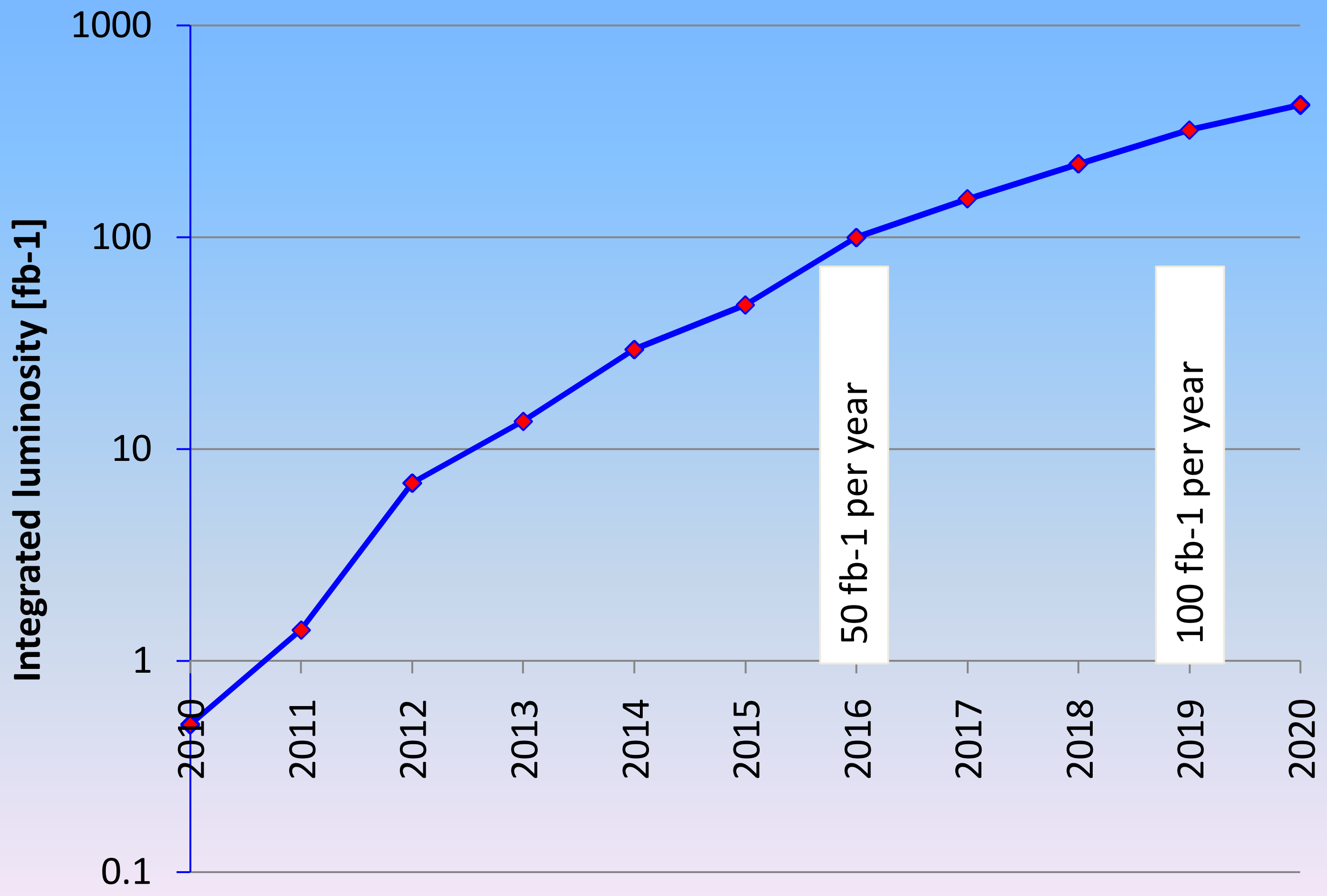


From now to nominal



And to ultimate (no LHC upgrade)

Assuming 60% machine availability
Assuming 4h turn around time



Upgrade or not