Pile-Up and density at HL-LHC: discussion

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Collider-Experiment day, 5th HiLumi annual meeting

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Contents

- **The HL-LHC baseline**
- **The “crab-kissing” option**
- **What else to gain confidence or ease the decision?**

The HL-LHC baseline (1/4)

- Short description

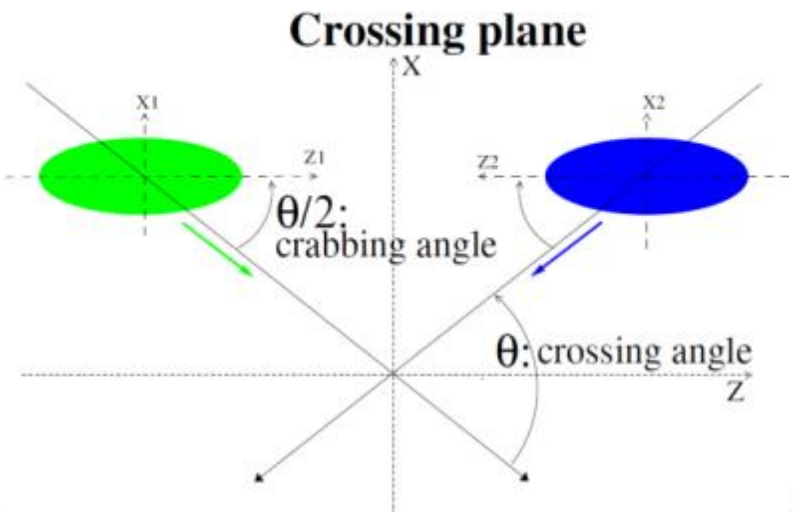
→ **``Round'' optics** (β^*=15 cm in H & V)

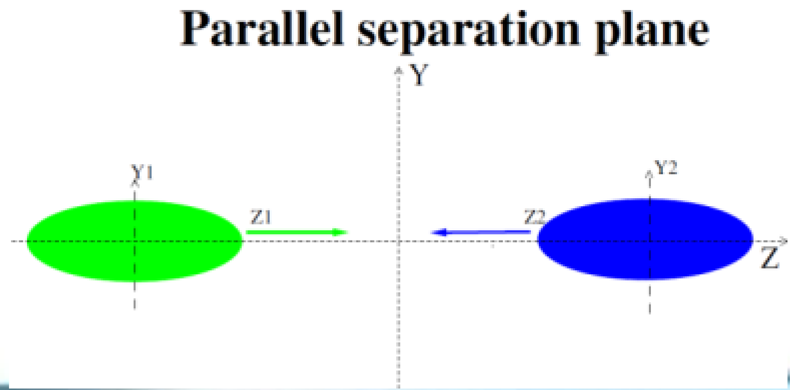
→ **``Large'' X-angle** (590 μrad)

→ Loss factor compensated by **crab-cavities**

→ **Lumi leveling @ 5E34 with β^* and full crabbing** (i.e. at max CC voltage)

# Collisions at IP1 and IP5	2736 (25 ns)
p/bunch [10^{11}]	2.2 (1.11 A)
$\gamma\varepsilon_{x,y}$ [μm]	2.5
σ_z [cm]	8.1
β^*	66 → 15
X-angle [μrad]	590 (12.5 σ)
Virtual lumi [10^{34}] (including HG and RF curvature effect)	18.9
Leveled lumi [10^{34}]	**5.0**
$T_{leveling}$ [h] @ 5E34	**8.1**
Average PU events / crossing	**138 (~200 for "worst collisions")**





Luminosity the main ingredients

$$L_0 = 1 \cdot 10^{34}\ cm^{-2}s^{-1}$$

$$\dot{N}_{evt} = L \times \sigma_{evt} ; N_{evt} = \int L dt \times \sigma_{evt}$$

L_{int}

Beam current

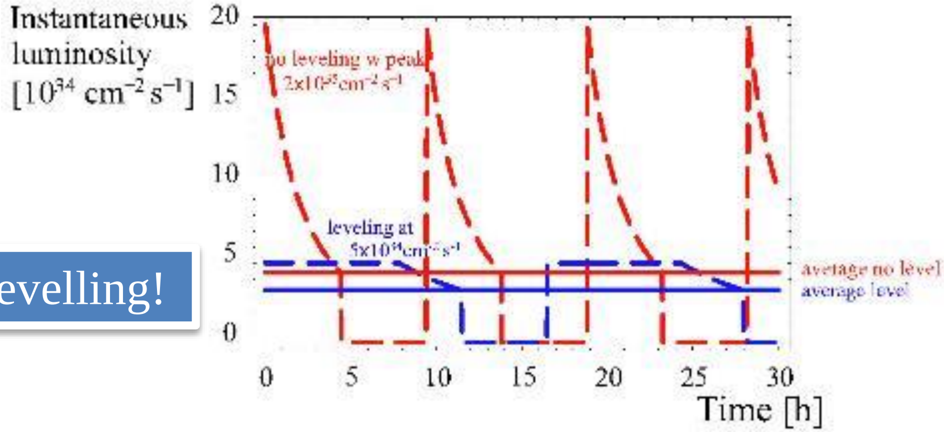
$$L = \gamma \frac{f_{rev}\, n_b\, N_b^2}{4\pi \varepsilon_n \beta^*} R$$

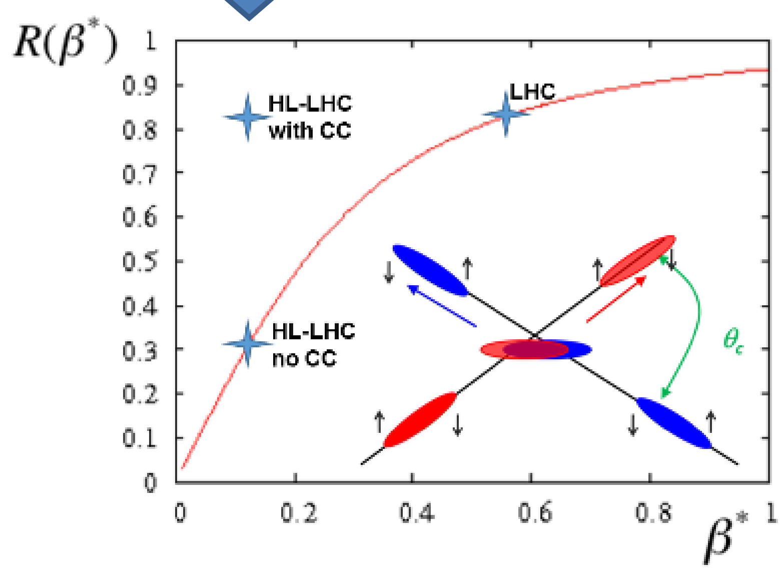
energy

Beam size

$$R = \frac{1}{\sqrt{1 + \frac{\gamma(\theta_c \sigma_s)^2}{4\epsilon_n \beta^*}}}$$

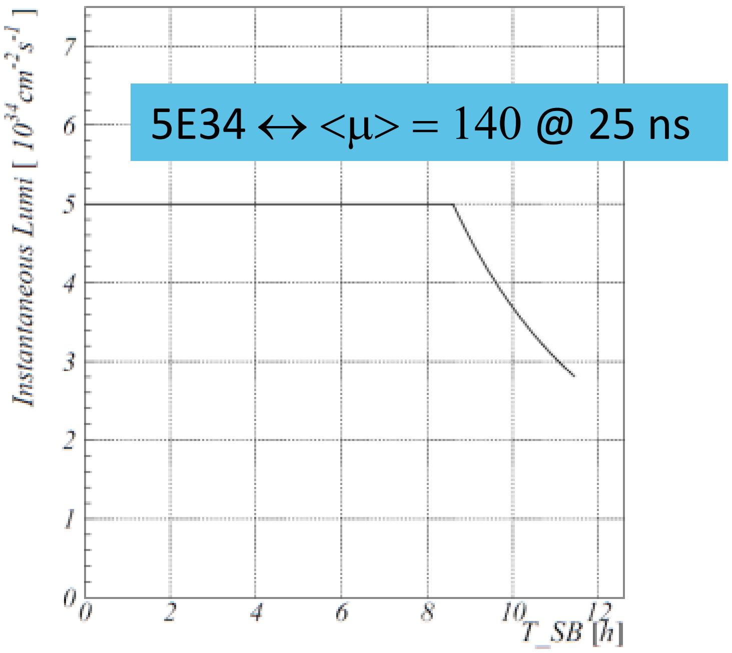
Levelling!



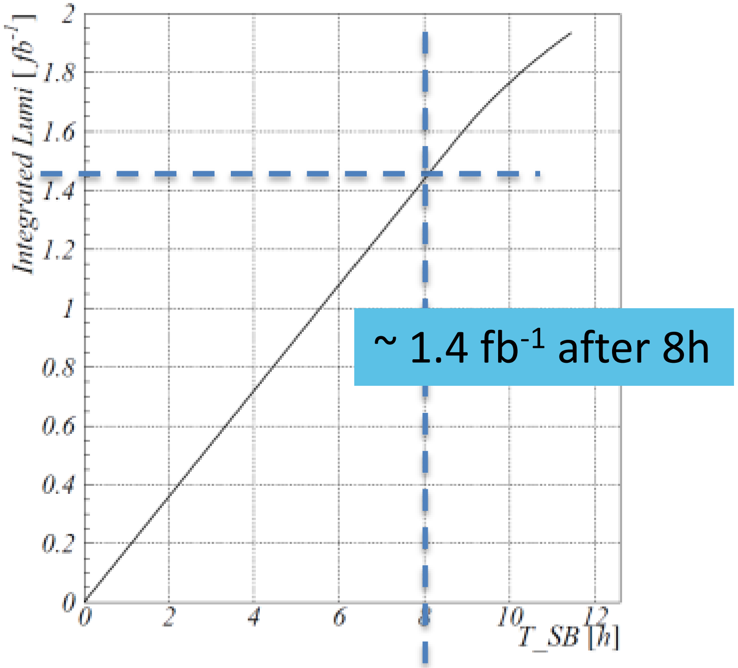


The HL-LHC baseline (2/4)

- Typical lumi profile and performance



Lumi profile in SB

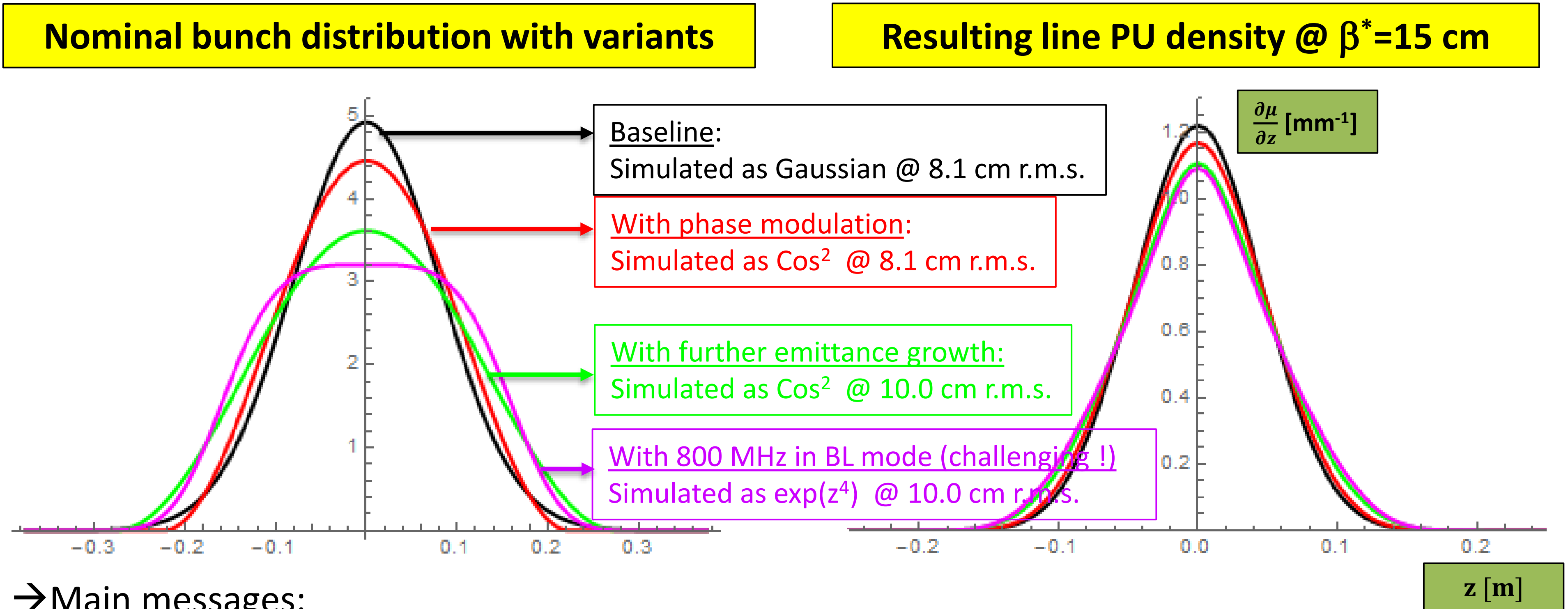


Performance profile in SB

29/10/2015

The HL-LHC baseline (3/4)

- Luminous region and line PU line density



→Main messages:

a) **Marginal sensitivity to bunch length and bunch shape at low β^* : < 10%**

b) **Another 10% could be gained by using one ingredient of the crab-kissing scheme (see later), that is leveling the peak PU density instead of lumi with β^* (see R. Tomas @ RLIUP)**

c) **All together 1-1.1 evt/mm @ μ_{tot}=140 seems to be the best possible reach at cst HW and performance**

The HL-LHC baseline (4/4)

- Time PU density:

→ Two different possible concepts may be relevant

a) How many events per unit of time detected at 90º (high-PT)?

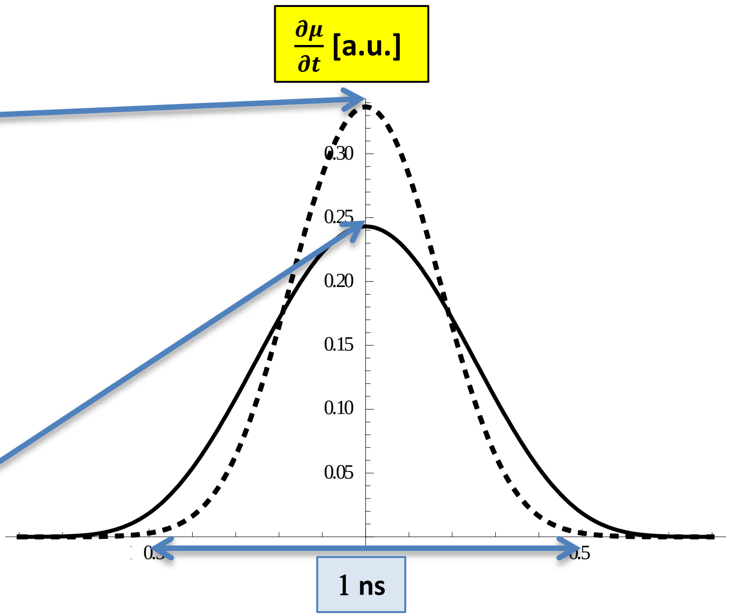
→ simple z-integration of the 2D density of luminosity

$$\frac{\partial \mu}{\partial t}(t) \propto \int dz \frac{\partial^2 L}{\partial z \partial t}(z,t)$$

b) How many events per unit of time detected forward (low-PT) ?

→ z-integration but taking account the time of flight of the collision product

$$\frac{\partial \mu}{\partial t}(t) \propto \int dz \frac{\partial^2 L}{\partial z \partial t}(z, t + z/c)$$

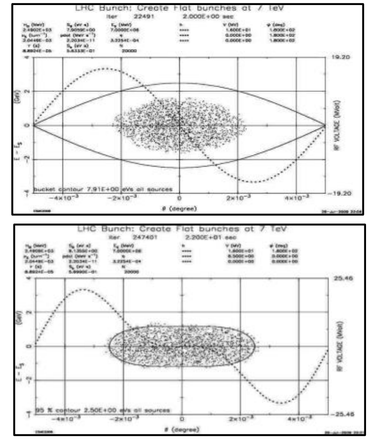


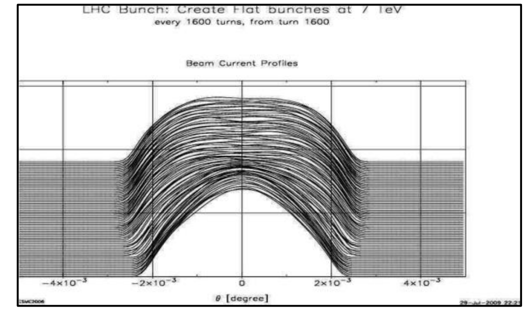
→ <u>In terms of collision time:</u>
160 ps r.m.s. in the first case
230 ps r.ms. in the second case

29/10/2015

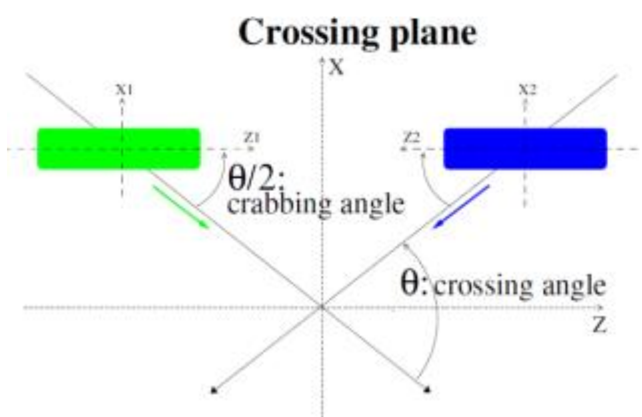
The crab-kissing (CK) scheme (1/5)

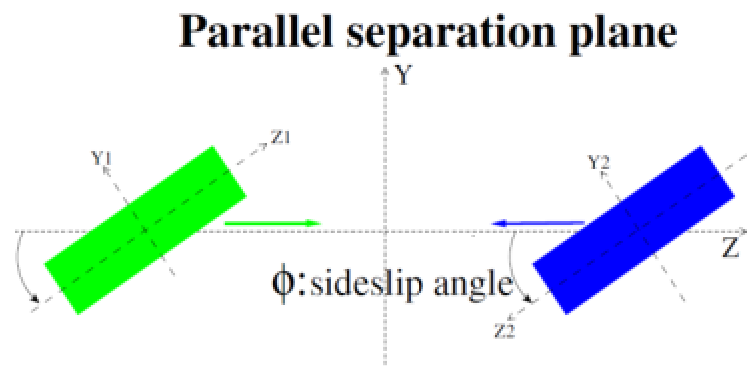
- Main assumptions
- Ideally 400+800 MHz in bunch lengthening (BL) mode → is challenging for the machine
- If not, RF phase modulation with existing RF for flattening the bunch distribution (LHC RF team)
- **Longer bunches of ~ 1.2 ns (10 cm r.m.s.)**





- **Additional crab-cavities acting on the beam in the <u>parallel separation plane</u>,**



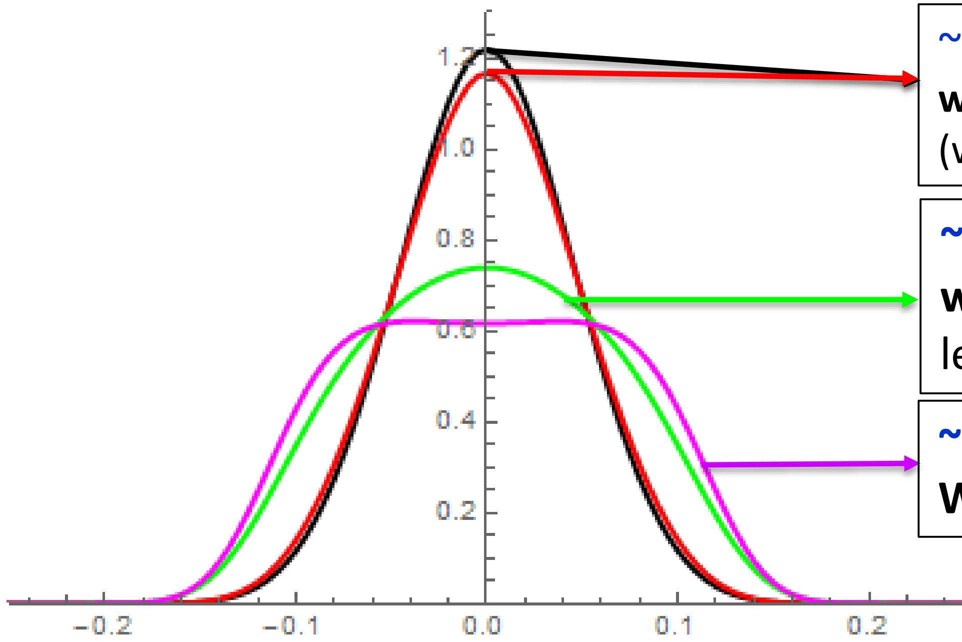


→ Full crabbing kept in X-plane

→ "Sideslip" angle induced in || plane used to level the luminosity at cst (min. β^*)

The crab-kissing (CK) scheme (2/5)

- Line PU density



~ **1.1-1.2 evt/m** @ β^*=15cm
w/o CK and baseline RF HW and parameters
(with and w/o RF phase modulation)

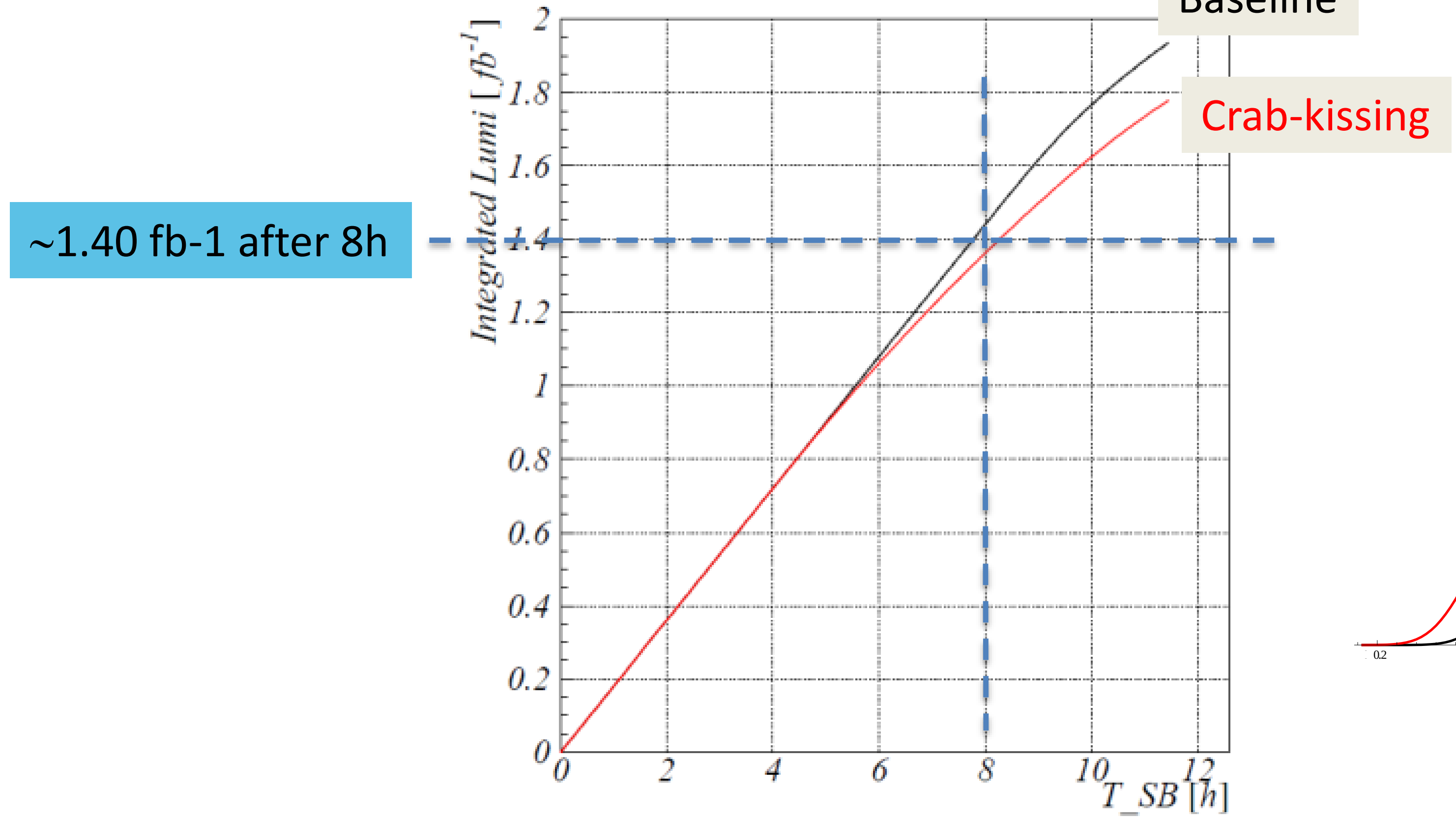
~ **0.7 evt/m** @ β^*=15cm
with CK (and bunch flattening and lengthening) but **no 800 MHz**

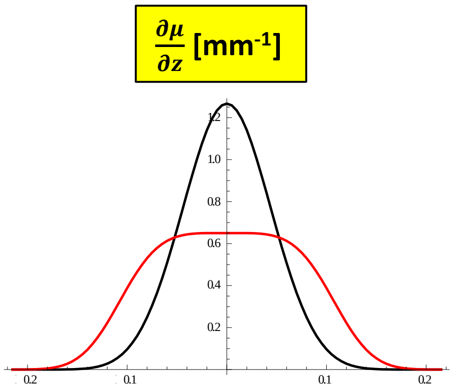
~ **0.6 evt/m** @ β^*=15cm
With CK and 800 MHz

A gain by a up to factor of 2 in terms of line PU density
But also halved head-on beam-beam tune shift … which is welcome with ``HiLumi LHCb'' entering into the game !

The crab-kissing (CK) scheme (3/5)

- Performance





→ Very similar **delivered luminosity** compared to the baseline

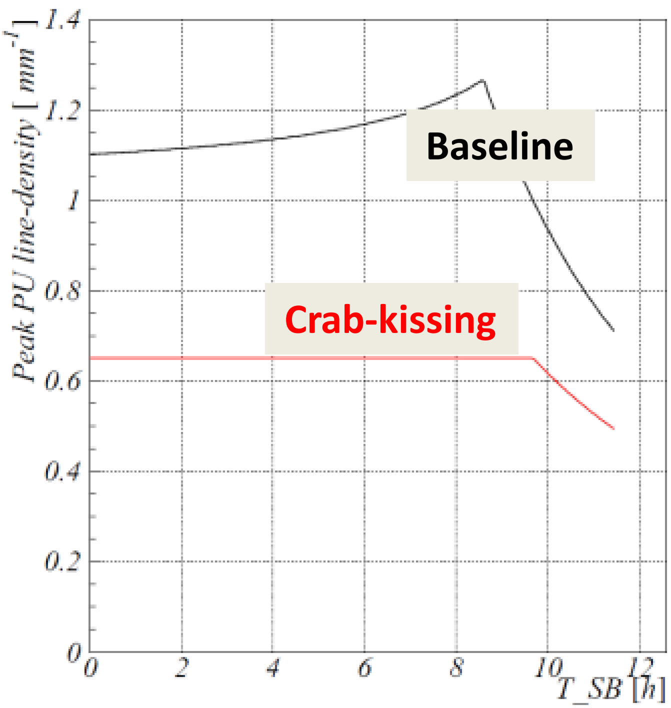
→ But is it really the **``same'' luminosity** ??

The crab-kissing (CK) scheme (4/5)

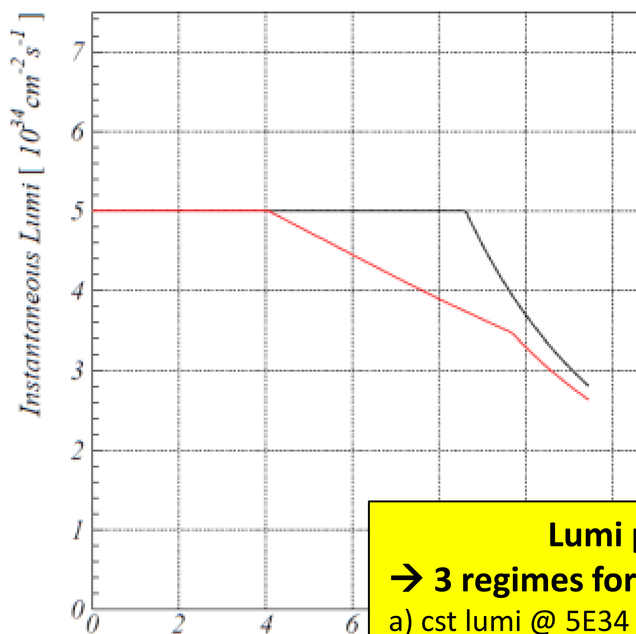
- Levelling

→ Keeping cst β* but acting on 2 knobs: CC in X-plane and CC in || plane.

→ For levelling both the lumi (μ_{tot}) and peak-pile up density



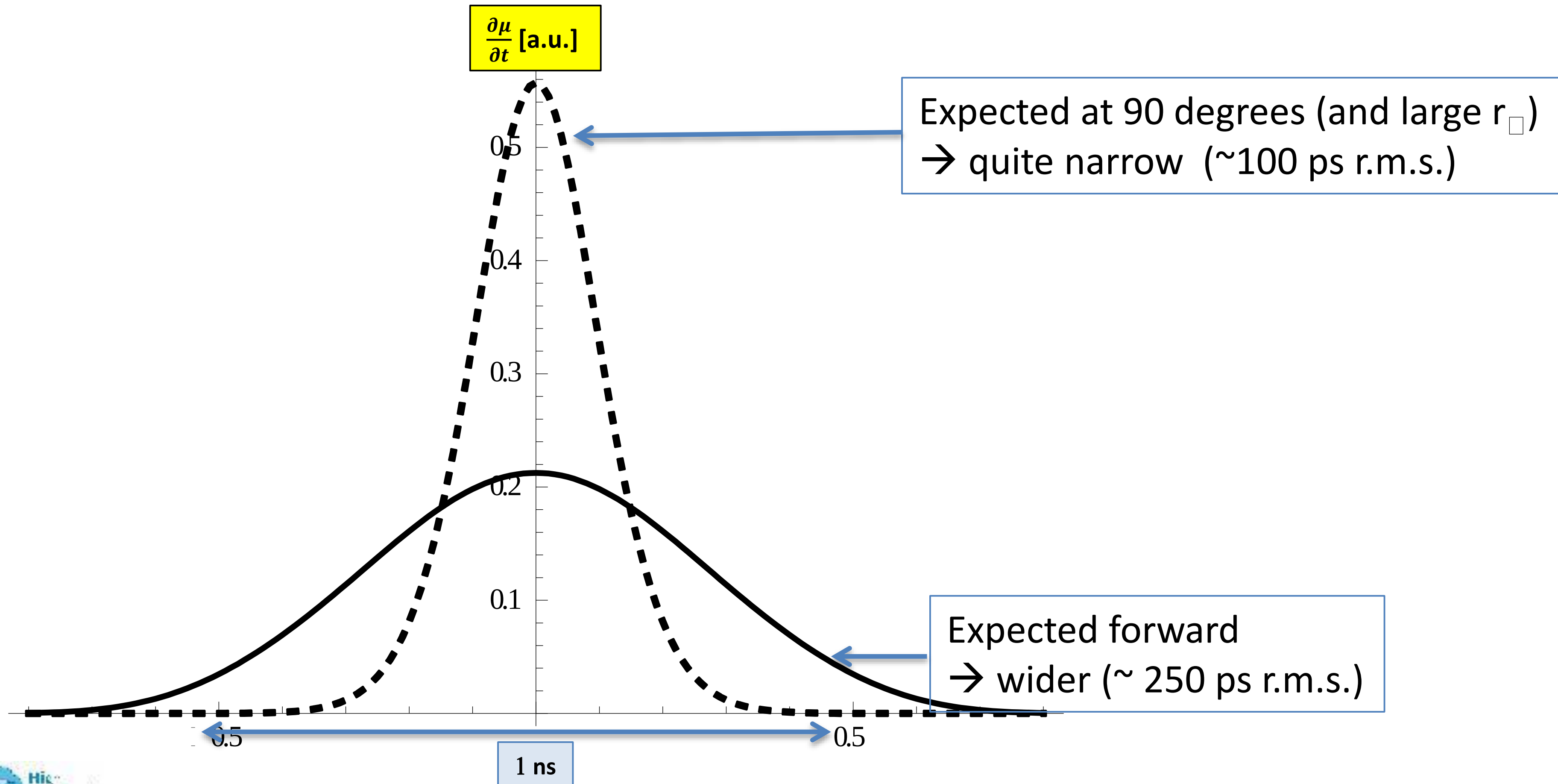
Peak z-density of PU in SB



Lumi profile
→ 3 regimes for CK (red)
a) cst lumi @ 5E34
b) "Controlled" decay at cst PU density
c) Natural decay

The crab-kissing (CK) scheme (5/5)

- Time PU density (at beginning of levelling only):



Important questions to be addressed

- Needed from experiments:
  - What is the maximum luminous region that the experiments can accept?
    - we do hope the new tracker efficiency will be compatible with a luminous region at least as large as the one we had in 2011, 1.2 ns bunch fw and 1 m β^*

Important questions to be addressed

- Needed from experiments:
  - Can the experiments provide an on-line measurement of the pile-up and pile-up density?
    - How frequent the online monitoring can transmit this calculated number via usual paths (as for luminosity monitor)

Important questions to be addressed

- Needed from experiments:
  - What would be an acceptable compromise between loss in integrated performance and reduction of the pile-up and pile-up density (1% for 1% or 1% for 10%)?
  - What would be an acceptable compromise between increase in levelled luminosity (and performance) and increase of the pile-up and pile-up density, 1% for 1% or 10% for 1%?
  - Reductions without crab-kissing is within 10%-20% via levelling pile-up density; lower reduction would mean going < 5E34

Alternative scenarios

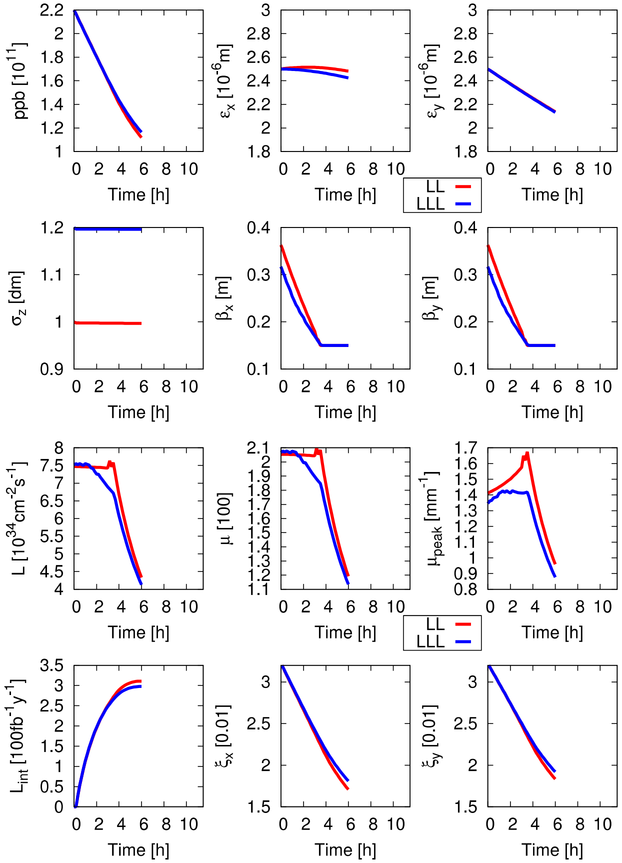


Figure 14: Performance for the baseline scenario with larger peak luminosity (LL) and another scenario where peak pile-up density is leveled with β^* (LLL).

p.u. 200

	L_{int} [fb^{-1}]	Peak pile-up [mm^{-1}]
Larger Lumi.	310	1.8
Larger Lumi. leveled	300	1.4
Crab Kissing	300	0.9

Table 1: Scenarios with larger peak luminosity. Peak pile-up density is mitigated either with β^* leveling or with crab kissing.

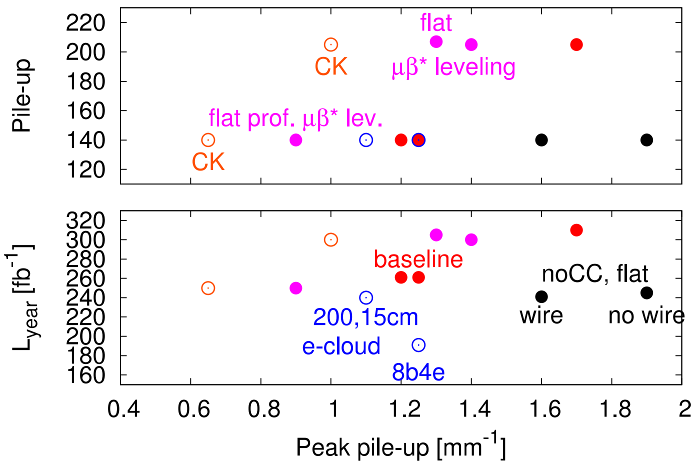
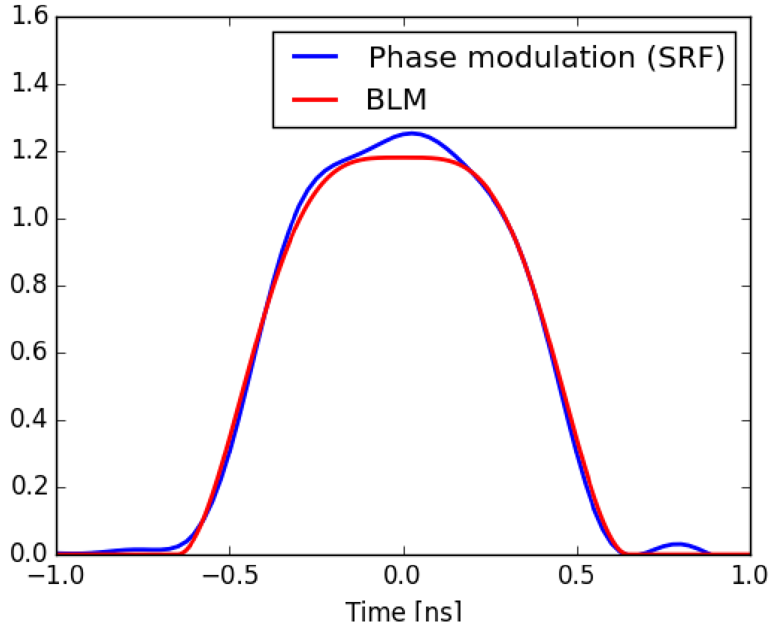


Figure 15: Summary chart showing pile-up (top) and integrated luminosity per year (bottom) versus peak pile-up density for the various scenarios considered in this work.

From https://indico.cern.ch/event/315665/session/6/contribution/28/attachments/605733/833604/proceedings.pdf

Feasibility studies already on LHC



Courtesy of Rogelio, Juan and Helga
Mail received 28 October 2015

- Flattening test during physics
  - Here one plot with the corrected profile for Beam 2. In the same plot a profile in BLM for comparison.
  - Very similar longitudinal profile. The main difference is in the center of the bunch, but we can probably optimize the phase modulation to flatten that part also.
  - Today we wanted to check the effect on luminosity and that is why we applied the same modulation as the previous time. Next time we can try with different parameters to affect more the core of the bunch.

Important questions to be addressed

- Needed from experiments:
  - It might be good to get an overview of the observations made by the experiments during the previous MDs at high pileup
    - Pile-up up to 70 at 3.5/4 TeV achieved in 2012 dedicated MD http://indico.cern.ch/event/200145/contribution/5/attachments/298125/416654/HighPileupMD2012.pdf

What else?

- **MD with a few fat bunches** are possible with

1. 200 PU/crossing (e.g. N_b=2E11, $\gamma\varepsilon$=2 μm, β^* =50 cm)
2. and/or > 2 evt/mm

→ Which settings are relevant

(i) to benchmark the existing tools and/or

(ii) test new PU rejection algorithms ?

- **Anything else to be tested in MD?**

→ sensitivity of data quality vs 25ns filling scheme variants, e.g. 8b4e, micro-batch (24b24e), etc. ?... **May be 50 ns if NO pile up limit -☺**

What else?