Updated optics layout and machine performance

November, 2016. Paris

R. Tomás for WP2

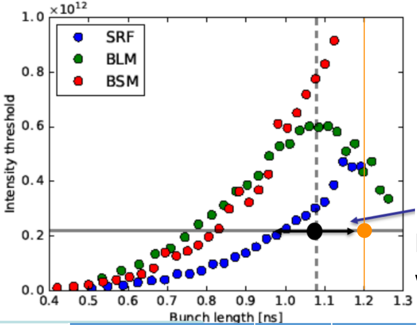
Many thanks to P. Azzi, G. Arduini, X. Buffat, R. de Maria, L. Medina & B. Petersen

Optics, layout and beam changes V1.2→V1.3

- Round β^*=20 cm, limited by realistic tolerances of the triplet beam screen and cold bore[1]
- Flat $\beta^*_{x/y}$=40/15 cm, limited by Q4 aperture
- Pre-squeeze β^* increased by 2 cm to 50 cm
- L^* shortened by 8 cm (L^*=22.92 m)
- IR1 & IR5:
  - Q4 & Q5: MQY @ 1.9 K, moved towards arc by 10 m and 11m, respectively
  - Q6: MQML @ 4.5 K
  - Additional MS in Q10
- IR6 Q5: Single MQY @ 1.9 K
- Crab cavities halved (2, compatible with 4)
- Bunch length increased to 1.2 ns (9 cm)

[1] we can protect an aperture of 12σ for elements protected by TCTs and 17-18σ for elements that are not protected by TCTs

E. Shaposhnikova, 78th WP2 Meeting



Need 10% margin taking into account bunch length variation bunch-to-bunch with **single RF** (no need for 800 MHz system)

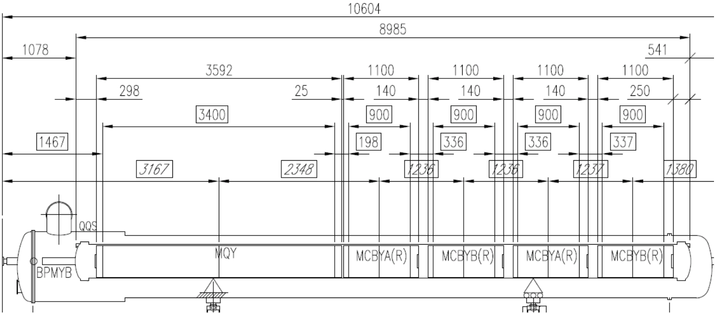
RF system	V1 [MV]	V2 [MV]	N_{th} [10^{11}]	Bunch length (4σ) [ns]	Emittance (2σ) [eVs]	dE/E (2σ) [10^{-4}]
400 MHz	16.0	0.0	2.2	1.2	3.0	2.36
400 & 800 MHz (BSM)	16.0	8.0	2.2	0.85	2.1	2.32
200 MHz	6.0	0.0	2.4	2.3	4.85	1.97
200 & 400 MHz (BSM)	6.0	3.0	2.4	1.7	3.6	2.0

1.1 ns (8.1 cm) for 400 MHz with 1.1×10^{11} ppb at the end of the fill OK

Q4: MQYY -> MQY

R. de Maria

- 2xMCBYY+MQYY replaced by Mask+4xMCBY+MQY.
- Mask: same of Q5 (1.5 m length, 1 m active material as first guess F. Cerutti)
- Q4 becomes bottleneck for flat optics.
- Work ongoing to reassess requirements of orbit correctors.

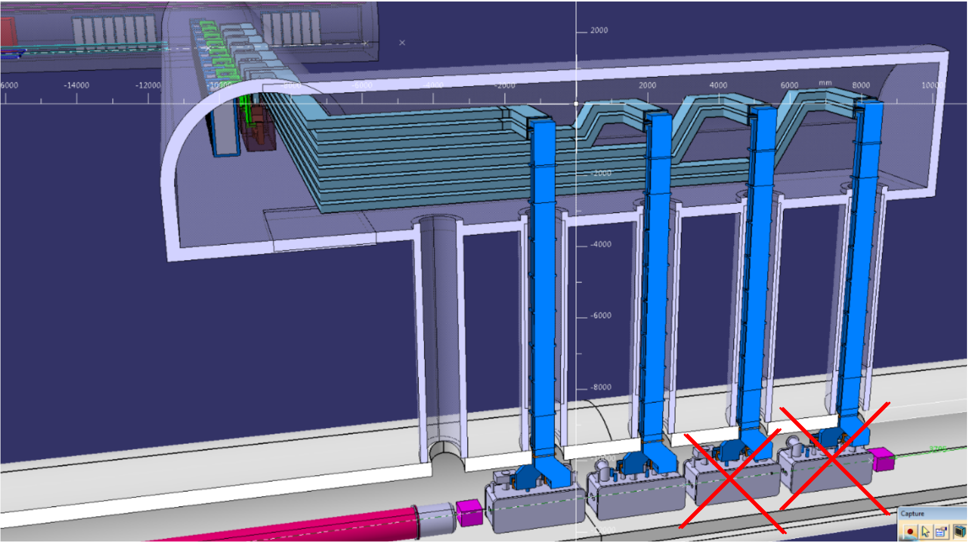


H. Prin, 8/8/2016

Can we have 3 MCBY instead of 4?

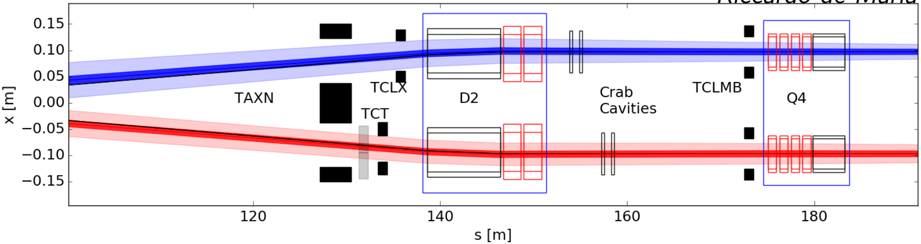
- Requirements:
  - Allow orbit control at CC of ± 0.5mm
  - Allow IP orbit offset of up to ± 2mm $\rightarrow$ to be confirmed by the experiments
  - Allow for crossing angle in both planes
- The present CC assembly alignment range might be smaller than required
- Present actions:
  - Review of CC alignment possibilities
  - Implications on operational flexibility
  - Clarification from detectors on maximum IP offset

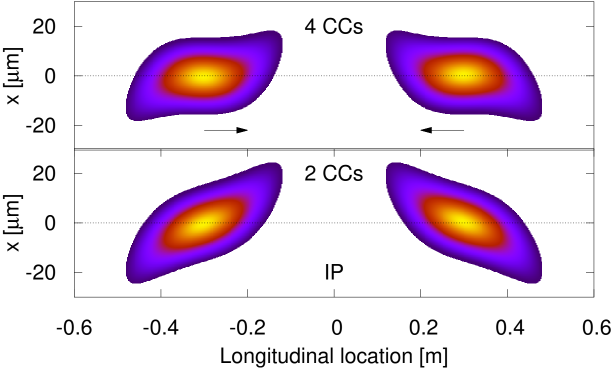
Number of crab cavities halved



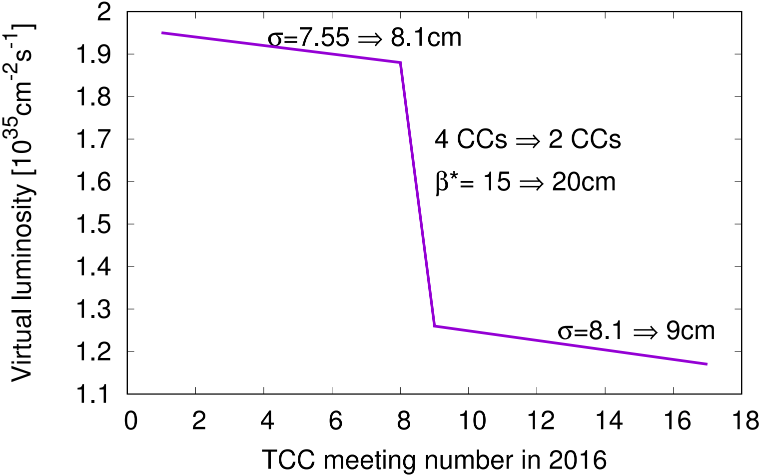
Number of crab cavities halved

Riccardo de Maria





HL-LHC virtual luminosity in 2016

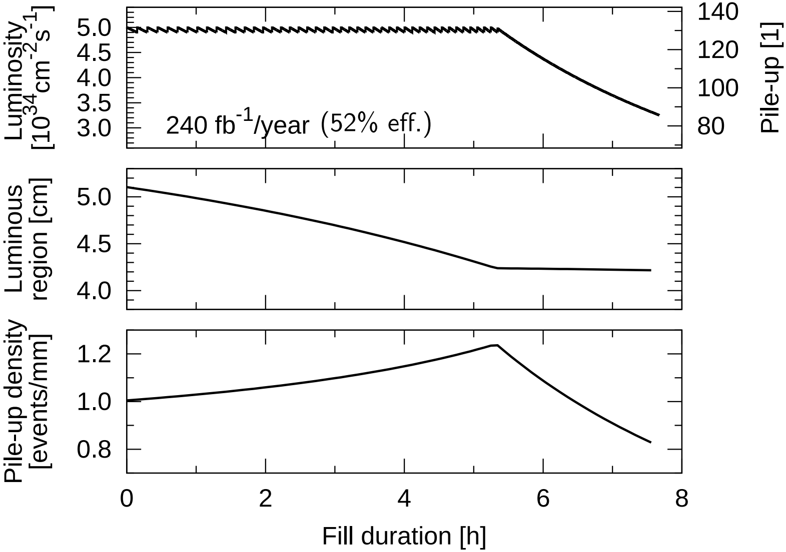


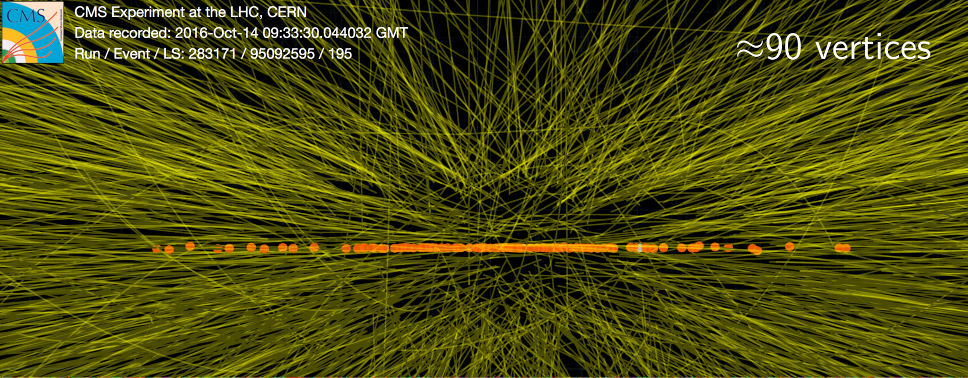
TCC meetings: https://indico.cern.ch/category/7361/

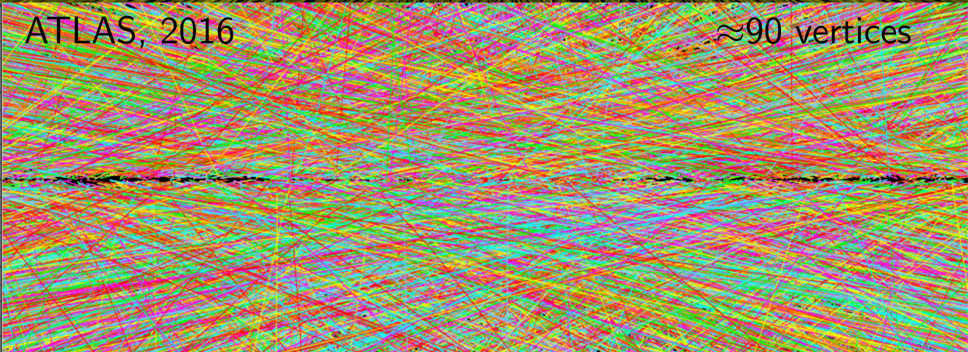
Assumptions for performance evaluation

- Round β^*=20 cm, flat $\beta^*_{x/y}$=40/15 cm
- Crossing angle: round 12.5σ, flat 11.9σ
- bunch length 9 cm
- Leveled luminosity of 5×10^{34}cm^{-2}s^{-1}
- 160 days of physics (Run 4)
- ≈50% efficiency for 3000 fb^{-1}
- Burn-off with total cross section (111 mb)
- Ultimate: 7.5×10^{34}cm^{-2}s^{-1} and
  ≈60% efficiency for 4000 fb^{-1}

Baseline fill

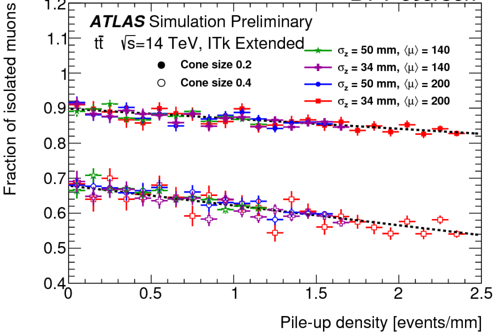


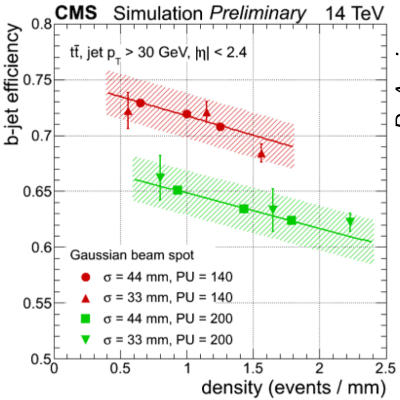

CMS
CMS Experiment at the LHC, CERN
Data recorded: 2016-Oct-14 09:33:30.044032 GMT
Run / Event / LS: 283171 / 95092595 / 195
≈90 vertices


ATLAS, 2016
≈90 vertices

Experimental Data Quality WG

B. Petersen

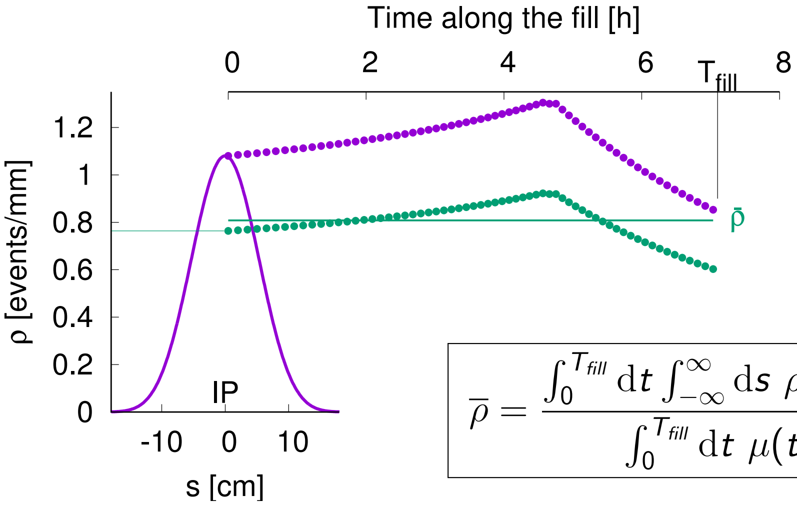




P. Azzi

Pile-up density deteriorates relevant *signals* in a linear fashion → **Effective density is the average**

Effective pile-up density, $\overline{\rho}$,for a fill



$$\overline{\rho} = \frac{\int_0^{T_{fill}} \mathrm{d}t \int_{-\infty}^{\infty} \mathrm{d}s \; \rho(t,s)^2}{\int_0^{T_{fill}} \mathrm{d}t \; \mu(t)}$$

The larger $\overline{\rho}$ is, the larger the inefficiency.

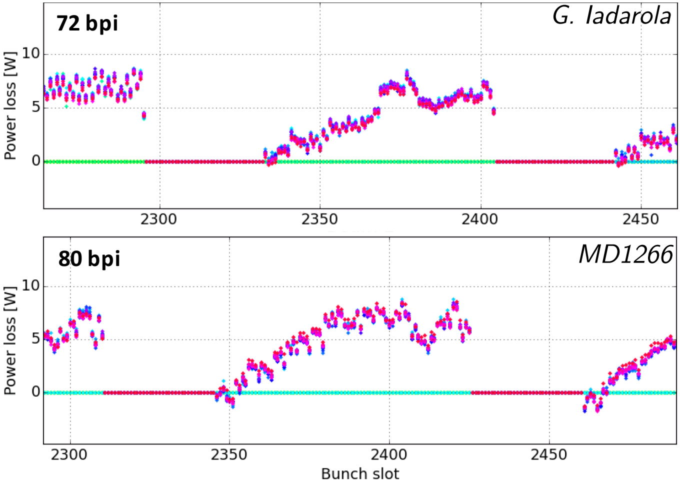
Potential improvements

- ★ # of bunches 2736 $\rightarrow$ 2800 with 80 bunch trains
- ★ Crossing angle 12.5σ $\rightarrow$ 10σ, β^*=15 cm
  - Need improved MKD-TCT phase and
  - TCT reduced retraction.
  - LHC shows 10σ is OK for BBLR at 1.1×10^{11}ppb

For the future:

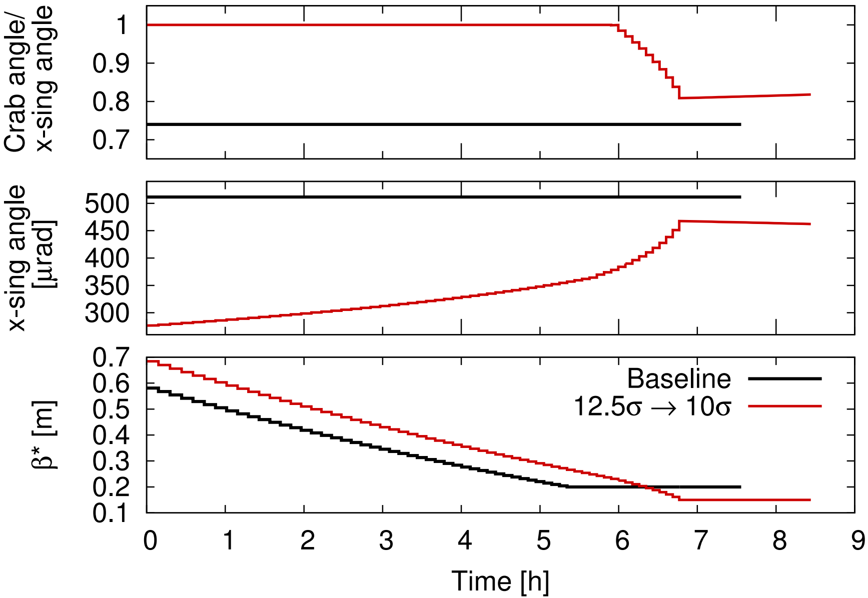
- ★ Burn-off cross section 111 mb $\rightarrow$ 81 mb
  - Recent MDs show 81 mb would be too optimistic
  - DA issues?
  - Need further simulations
- ★ Bunch length 9 cm $\rightarrow$ 8.1cm

Trains of 80 bunches in the LHC

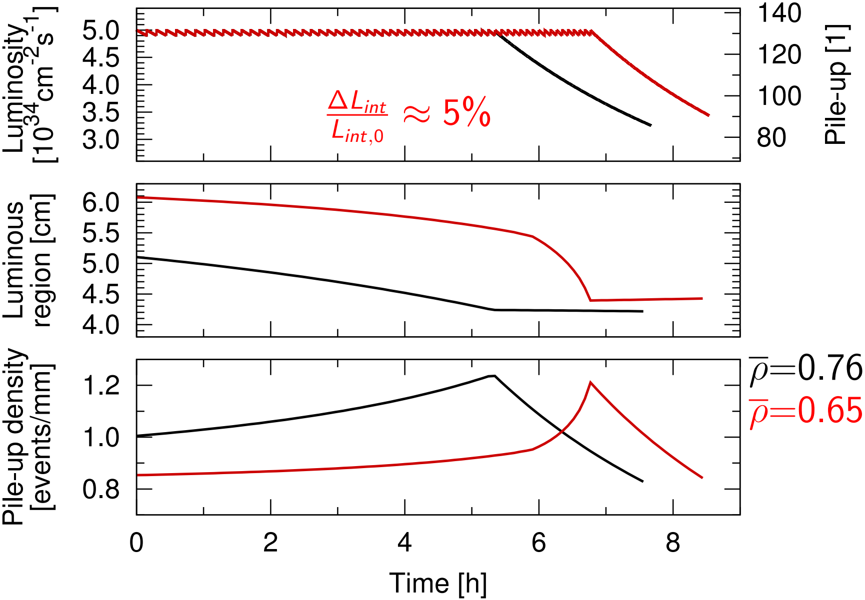


Trains of 80 bunches should allow for ≈2800 collisions in IP1&5 (≈+2% in lumi)

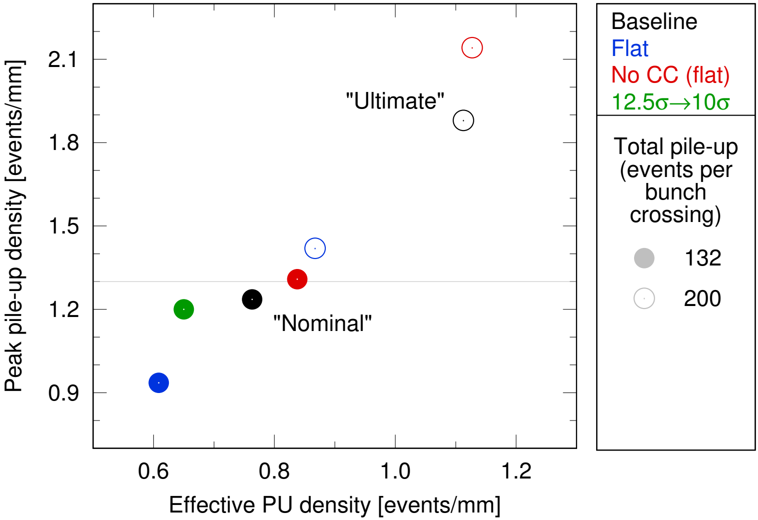
Crossing angle 12.5σ $\rightarrow$10σ, β^*=15cm



Crossing angle 12.5σ →10σ, β^*=15cm

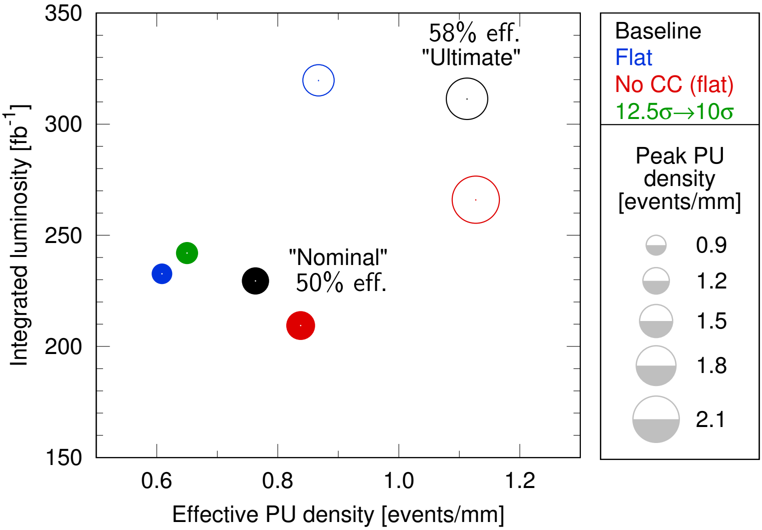


Effective Vs peak pile-up density



Almost linear relation since all luminous regions are almost Gaussian → Flatter luminous regions will deviate

Performance Vs $\overline{\rho}$



Not having crab cavities costs 10% of the luminosity in the nominal scenario and 17% in the ultimate (and ≈20% in $\overline{\rho}$)

Summary & outlook

- ★ HL-LHC integrated luminosity goals remain at reach thanks to efficiencies 52% & 60%
  - LHC has demonstrated about 60% efficiency
- ★ Potential improvements are under study
  - Optimization of $\overline{\rho}$
  - Crossing angle 12.5σ $\rightarrow$10σ, β^*=15cm
  - 80 bunch trains, etc
- ★ Risk mitigation requires studying:
  - 8b+4e and 200 MHz for unbearable e-cloud
  - Flat optics for CC failure

Back-up slides

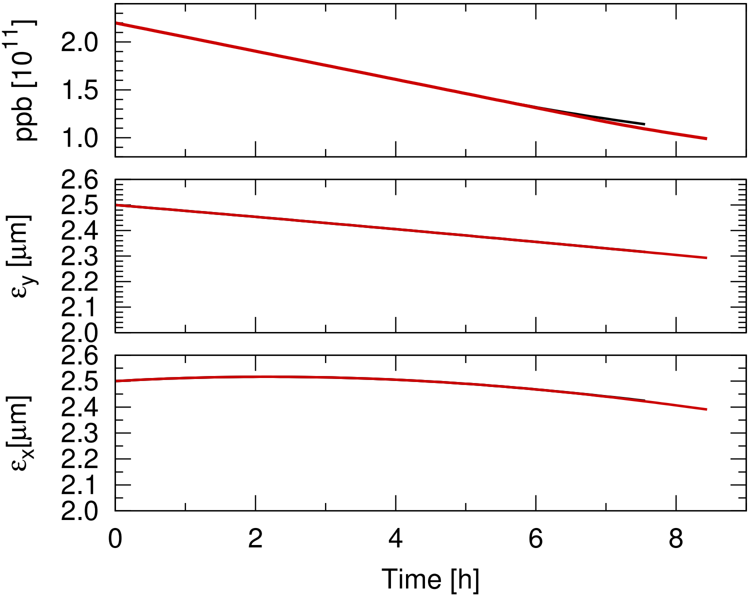
Parameter table I (1.2ns)

	Base	8b+4e
E [TeV]	7	7
N_b [10^{11}]	2.2	2.3
$n_{bunches}$	2748	1968
IP1&5 colls	2736	1960
N_{tot} [10^{14}]	6.04	4.53
beam current [A]	1.10	0.82
x-sing angle [μrad]	512	480
beam separation [σ]	12.5	12.5
β^* [m]	0.2	0.2
ϵ_n [μm]	2.5	2.5
ϵ_L [eVs]	3	3
E spread [10^{-4}]	1.2	1.2
bunch length [cm]	9.0	9.0
IBS horizontal [h]	22.1	16.1
IBS longitudinal [h]	29.5	24.2
Piwinski parameter	2.8	2.8

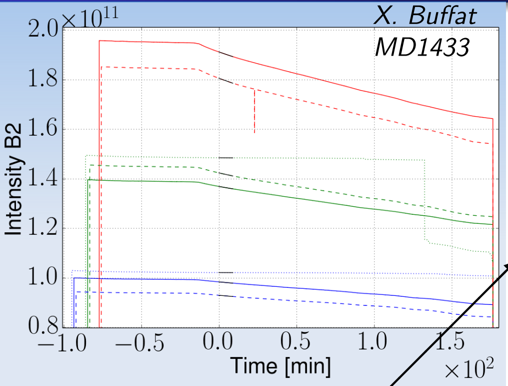
Parameter table II (1.2ns)

	base	8b+4e
Loss factor no CC	0.34	0.34
Loss factor with CC	0.67	0.69
beam-beam no CC [10^{-3}]	3.6	4.3
beam-beam with CC [10^{-2}]	0.86	1.1
Peak Lumi without CC [$cm^{-2}s^{-1}10^{34}$]	5.95	5.3
Virtual lumi with CC [$cm^{-2}s^{-1}10^{35}$]	1.17	1.09
Pile-up without lev CC	157	195
Leveled lumi [$cm^{-2}s^{-1}10^{34}$]	5.3	3.8
Pile-up with lev CC	140	140
Peak pile-up density	1.3	1.3
Leveling time [h]	4.7	5.9
Number of collisions IP2/IP8	2452/2524	1163/1868
N_b at injection [10^{11}]	2.3	2.4
n_b per injection	288	224
N_{tot} per injection [10^{13}]	6.6	5.4
Emittance at injection [μm]	2	1.7

Crossing angle 12.5σ $\rightarrow$10σ, β^*=15cm



Cross section for burn-off



Tune shift	Measured loss rate [%/h]	Burn-off [%/h]
0.018±0.001	7.4±0.5	6.7±0.3
0.012±0.001	5.5±0.5	4.9±0.3
0.007 ±0.001	3.4±0.2	3.5±0.2

$\epsilon = 1.5\mu\text{m},\ 1.9\times10^{11}\text{ppb}$

(40% above HL-LHC brilliance)

No long-range BB!

Consistent with 90 mb

Emittance growth?

Need further analysis