LHC expectations on injectors (after LS1 and in the long term…)

R. De Maria

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Introduction

General remark:

- As the aim of the LHC is saturating the experiments with useful luminosity, the Injectors aims at saturating the LHC capabilities.
- Once this regime is achieved, machine availability and reliability becomes the only effective lever arm for performances.

Tentative schedule before HL-LHC:

- Run II: Integrate luminosity at 13 TeV center of mass. Target 25 ns operations and only if necessary fall back to 50 ns or 8b+4e.
- Run III: Maximize LHC performance. Prepare for HL-LHC times.

Target performance:

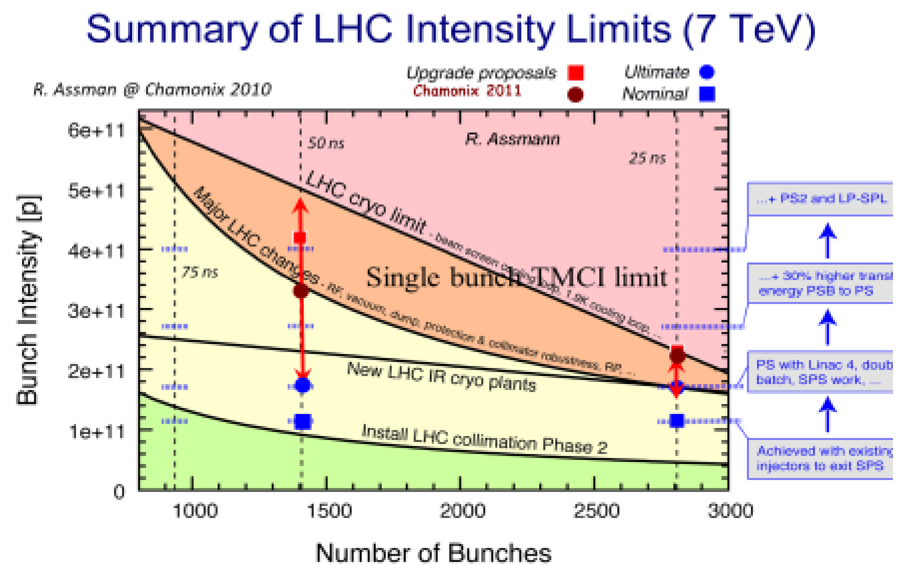
- LHC program: Integrate 300 fb^{-1} or more before LS3.
- HL-LHC program: Integrate 3000 fb^{-1} or more for the following decade.

Injectors’ parameters as seen by the LHC

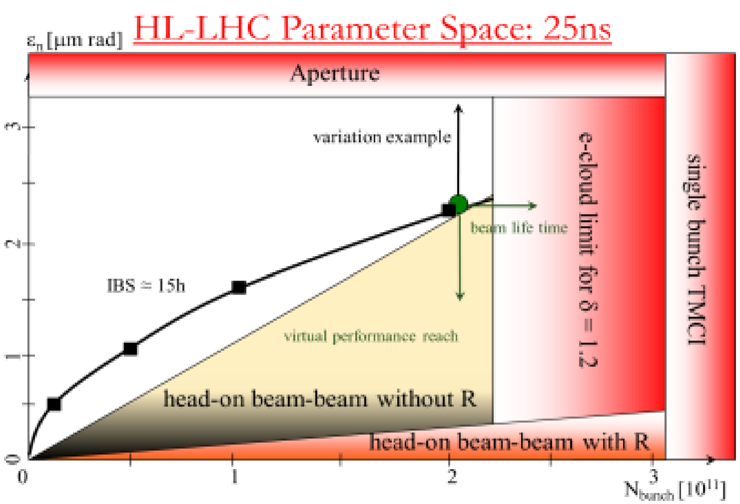
- Bunch intensity: Will beams saturate the cooling capacity due to e-cloud or be unstable?

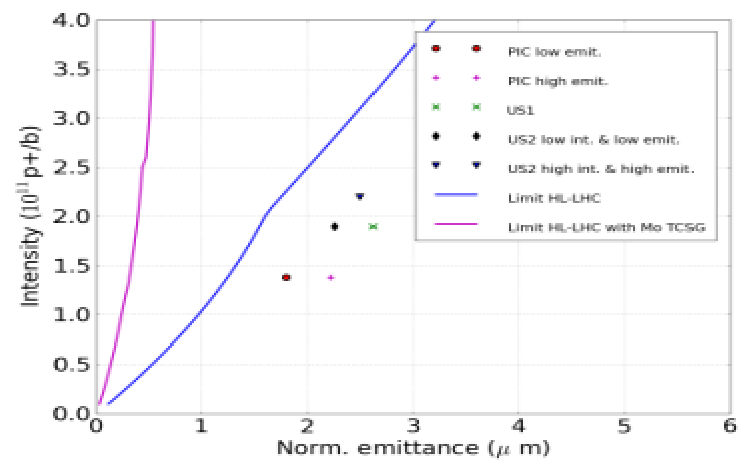
Beam current limitations

O. Bruning, R. Assmann,
E. Métral and teams



- Baseline 2.2 10^{11} ppb, current ~1 A.
- Assuming e-cloud issues solved.
- Couple bunch instability stabilized by the damper.
- Single bunch instability threshold far in the present model (with metallic collimator) or stabilized by head-on tune spread.





Understanding intensity limitations in the LHC is constantly evolving.

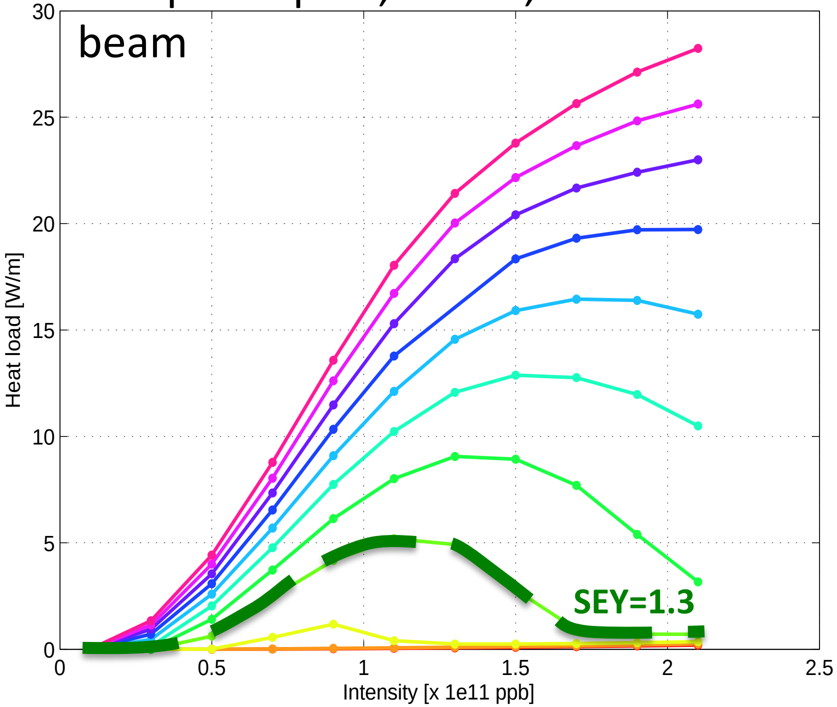
E-cloud

G. Rumolo, G. Iadarola

E-cloud solution currently relying on:

- Scrubbing for dipoles for suppression of electron cloud (SEY 1.3-1.4). (e.g. doublet beams for 25 ns scrubbing)
- Expected to be difficult to eliminate the electron cloud in the quadrupoles (SEY<1.2-1.3).
- Effects on on beam only at injection if ecloud in the dipoles. Can be cured if dipoles are scrubbed.
- Cryo power compatible with the electron cloud in the quadrupoles only.

Arc quadrupole, 2808b, 1 beam



Based on simulations

Injectors' parameters as seen by the LHC

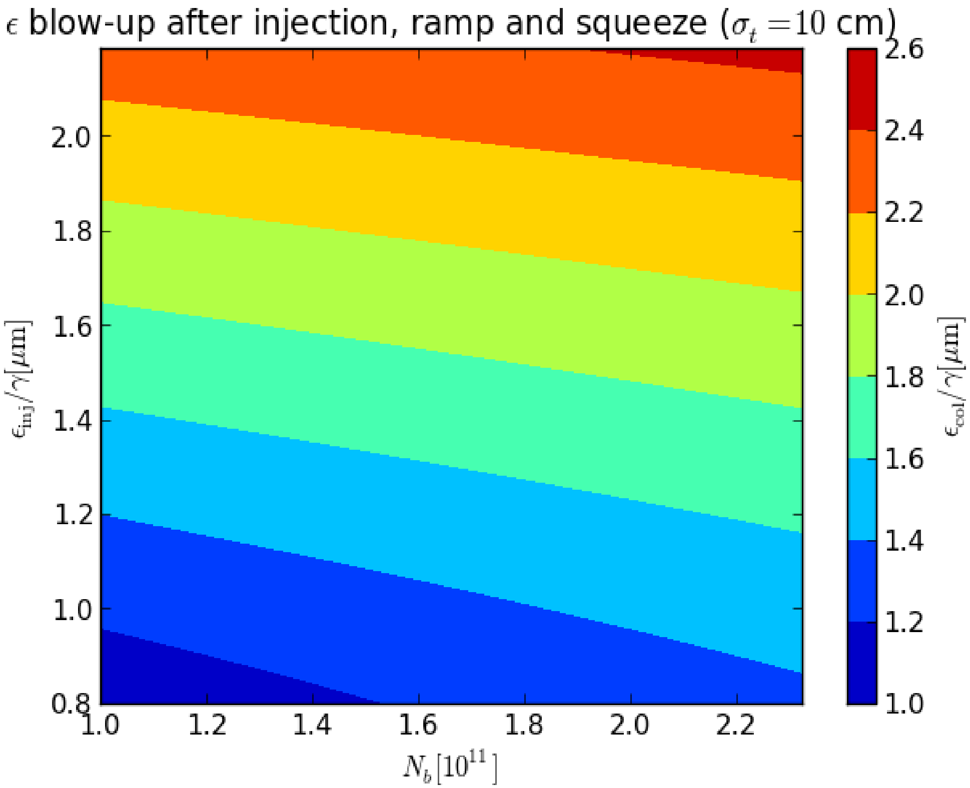
- Bunch intensity: Will beams saturate the cooling capacity due to e-cloud or be unstable?

- Emittance: Will the emittance be preserved during cycle? Is sufficiently small? Can small emittance be traded with intensity or number of bunches?

LHC Injection to Collisions

R. Tomas, O. Dominguez

- **5% intensity** loss assumed: when and where do we loose? Transfer lines, septa, TDI, LHC (BLM sunglasses), injection, ramp and setup limits should be assessed.
- **20% emittance blow-up budget**, implies:
  - Control of the additive sources of blow-up.
  - Control of the blow-up due to electron clouds.
  - Impedance reduction with metallic collimators.
  - 10 cm bunch length during injection to stable beam.
  - Lower limit on starting emittance.



$\epsilon_{col} \approx \epsilon_{inj} + 0.2\ N_b / \epsilon_{inj}\ [10^{11}/\mu m]$

Assuming: 10% blowup on top of IBS

High Luminosity LHC

Transmission of Beam parameters

	Bunch Spacing	Bunch Population Inj.	Emit. Std/BCMS Inj.	Bunch Population Coll.	Emit. Std/BCMS Coll.
LHC	25 ns	$1.3 \cdot 10^{11}$	2.4 µm	$1.2 \cdot 10^{11}$	2.8 µm
			1.3 µm		1.7 µm
	50 ns	$1.7 \cdot 10^{11}$	1.6 µm	$1.6 \cdot 10^{11}$	2.0 µm
			1.1 µm		1.6 µm
	8b+4e	$1.8 \cdot 10^{11}$	2.3 µm	$1.7 \cdot 10^{11}$	2.7 µm
			1.4 µm		1.9 µm
LIU	25 ns	$2.0 \cdot 10^{11}$	1.4 µm	$1.9 \cdot 10^{11}$	1.9 µm
			1.9 µm	$1.9 \cdot 10^{11}$	2.3 µm
HL-LHC	25 ns	$2.3 \cdot 10^{11}$	2.3 µm	$2.2 \cdot 10^{11}$	2.5 µm
	50 ns	$3.7 \cdot 10^{11}$	2.7 µm	$3.5 \cdot 10^{11}$	3.0 µm

High Luminosity LHC

Injectors' parameters as seen by the LHC

- Bunch intensity: Will beams saturate the cooling capacity due to e-cloud or be unstable?
- Emittance: Will the emittance be preserved during cycle? Is sufficiently small? Can small emittance be traded with intensity or number of bunches?
- Bunch spacing: Will collisions saturate the experiments?

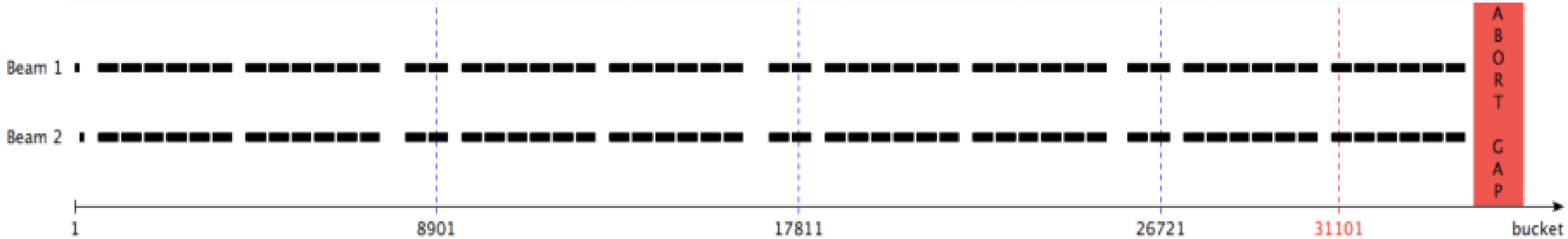
Bunch Spacing and Filling Schemes

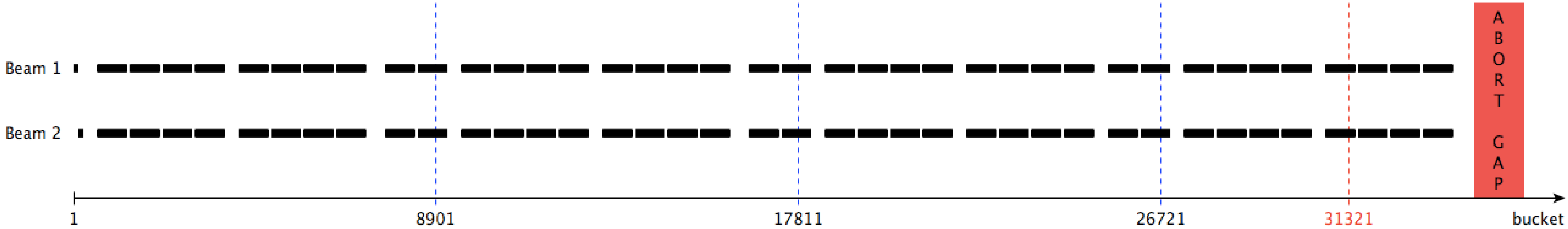
Luminosity is proportional to $n_{bunches}$. If experiments limited by pile-up, maximum luminosity and integrated luminosity is proportional to $n_{bunches}$ too.

- Filling schemes with 12 SPS injections in the LHC.
- 25ns: 2592; 50 ns: 1296; 8b+4e: 1728.

B. Gorini

Filling scheme	Total	IP1-5	IP2	IP8
BCMS: 48b 6 Ps inj, 12 SPS inj	2604	2592	2288	2396
Standard: 72b 4 Ps inj, 12 SPS inj	2748	2736	2452	2524





Assumptions on experimental conditions

- Average pile-up limit in IP1, IP5:
  - Maximum 50 event per crossing for after LS1;
  - Maximum 140 events per crossing for HL-LHC with
  - 1.3 event/mm baseline but 0.7 event/mm stretched target;
- Average pile-up limit in IP8: 4.5 events per crossing.
- Max lumi leveled in IP2: $2\ 10^{31}\ cm^{-2}s^{-1}$.

- Burn-off and pile-up estimation based on:
  - Assumed visible cross-section: 85 mb in IR1/5, 75 mb in IP8;
  - Assumed total cross-section: 110 mb.

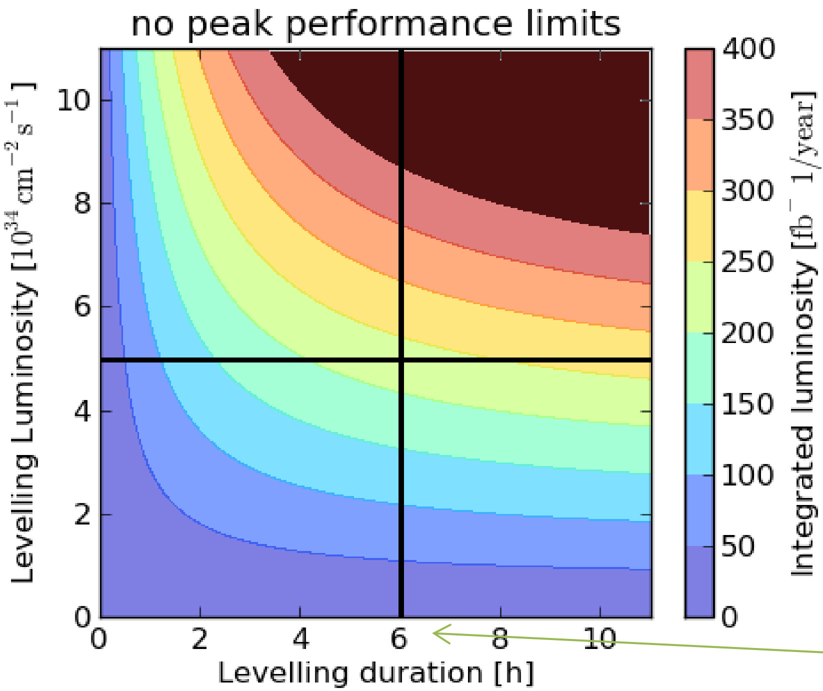
A. Ball, B. Di Girolamo, B. Gorini, R. Jacobsson

Bunch spacing and pile-up

	Bunch Spacing	Bunch Population	Emit. Std BCMS	Pile-up Max/Lev	Daily Lumi [fb^{-1}]	Fill duration [h]
LHC 6.5 TeV β*=60cm	25 ns	$1.2 \cdot 10^{11}$	2.8 µm	30/50	0.58	10.1
			1.7 µm	50/50	0.78	7.5
	50 ns	$1.6 \cdot 10^{11}$	2.0 µm	76/50	0.53	8.1(5.6)
			1.6 µm	95/50	0.52	7.8(4.4)
	8b+4e	$1.7 \cdot 10^{11}$	2.7 µm	75/50	0.72	8.5(4.7)
			1.9 µm	90/50	0.70	8.3(5.9)
LIU 7 TeV β*=15cm	25 ns	$1.9 \cdot 10^{11}$	2.3 µm	419/140	2.99	7.2(5.7)
		$1.9 \cdot 10^{11}$	1.9 µm	510/140	2.93	7.8(6.7)
HL-LHC 7 TeV β*=15cm	25 ns	$2.2 \cdot 10^{11}$	2.5 µm	517/140	3.17	8.6(7.3)
	50 ns	$3.5 \cdot 10^{11}$	3.0 µm	517/140	1.75	15(14.1)

HL-LHC Performance reach $L_{\mathrm{lev}} \sim n_{\mathrm{pileup}} \cdot n_{\mathrm{bunches}}$

- Assuming 80 days of successful fills limited by leveled luminosity and fill durations, how much luminosity may we integrate in one year?



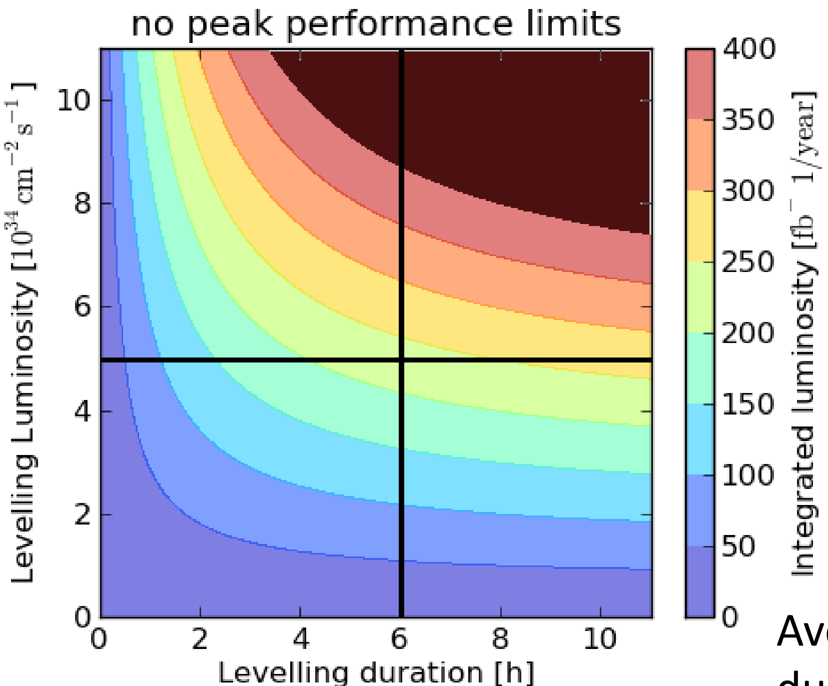
Average fill duration 2012

Simplest model that bounds integrated performance:
run at max allowed luminosity for half of the scheduled physics until a failure occurs.

$$L_{\mathrm{int}} = 0.5\, t_{\mathrm{phys}} L_{\mathrm{lev}} \frac{t_{\mathrm{fill}}}{t_{\mathrm{fill}} + t_{\mathrm{turnaround}}}$$

HL-LHC Performance reach $L_{\text{lev}} \sim n_{\text{pileup}} \cdot n_{\text{bunches}}$

- Assuming 80 days of successful fills and a given peak luminosity, available current, how much luminosity could we integrate in one year?



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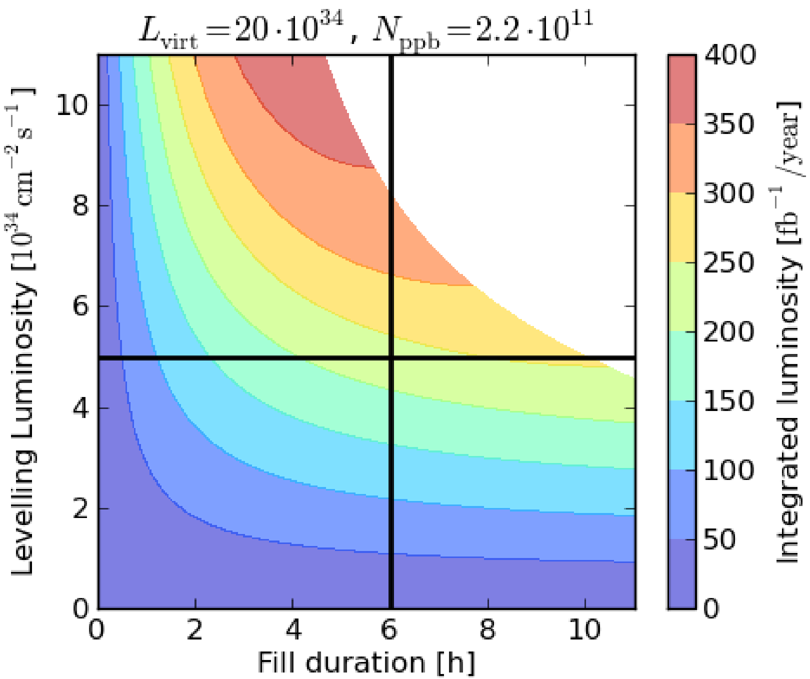

Adding a simple model of peak machine luminosity and burn-off decay (F. Zimmerman).

HL-LHC Performance reach $L_{\mathrm{lev}} \sim n_{\mathrm{pileup}} \cdot n_{\mathrm{bunches}}$

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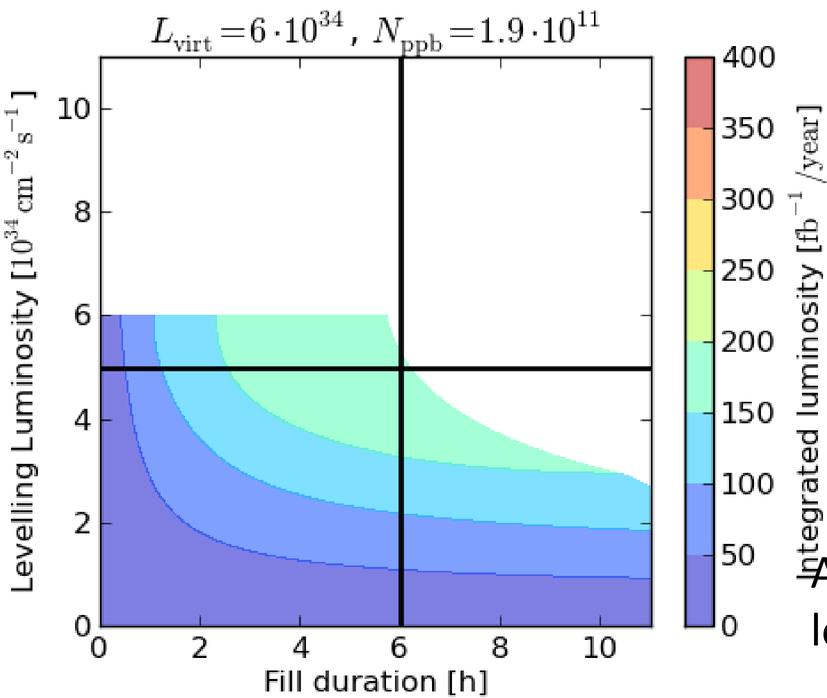
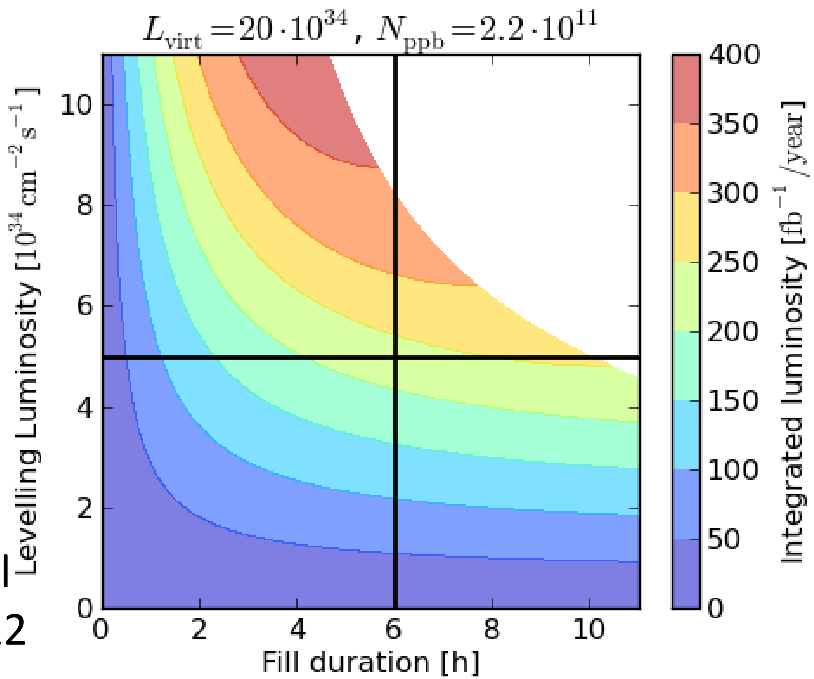


Average fill length 2012



→ Maximize leveled luminosity by pile-up limit and number of bunches,

→ Maximize probability of long fills

→ Obtain long fills

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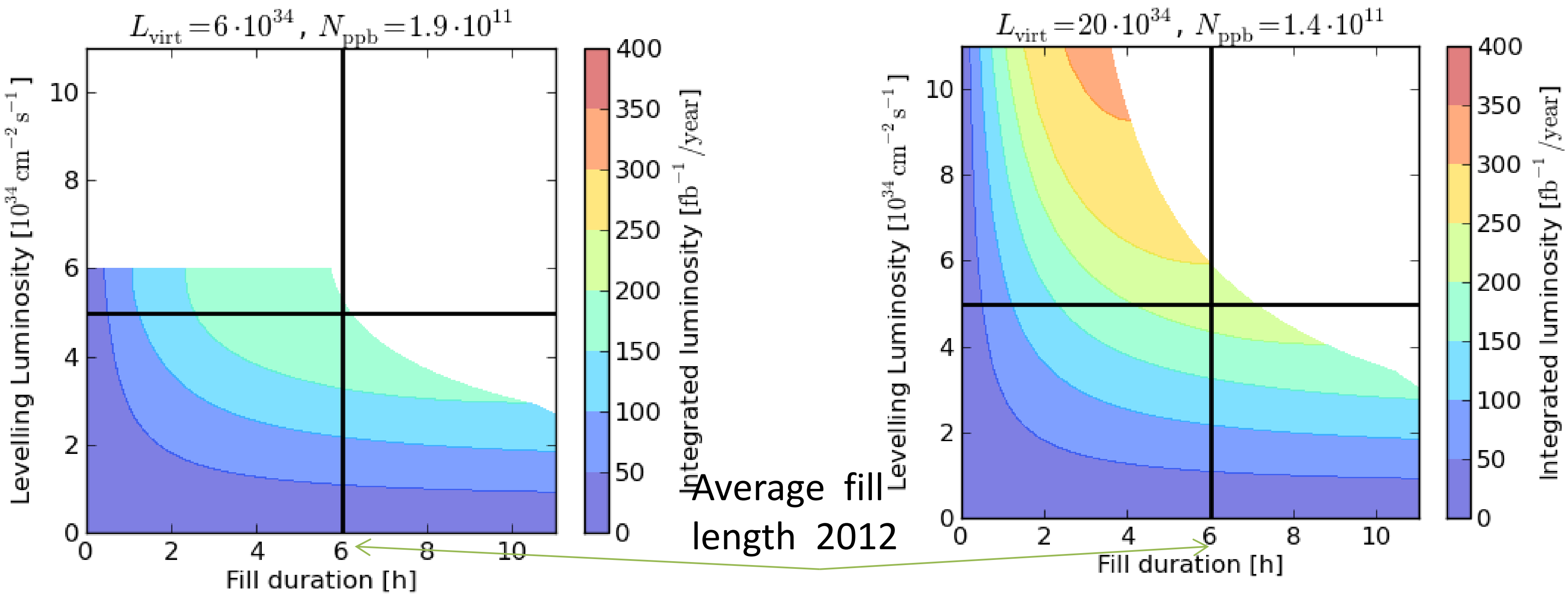

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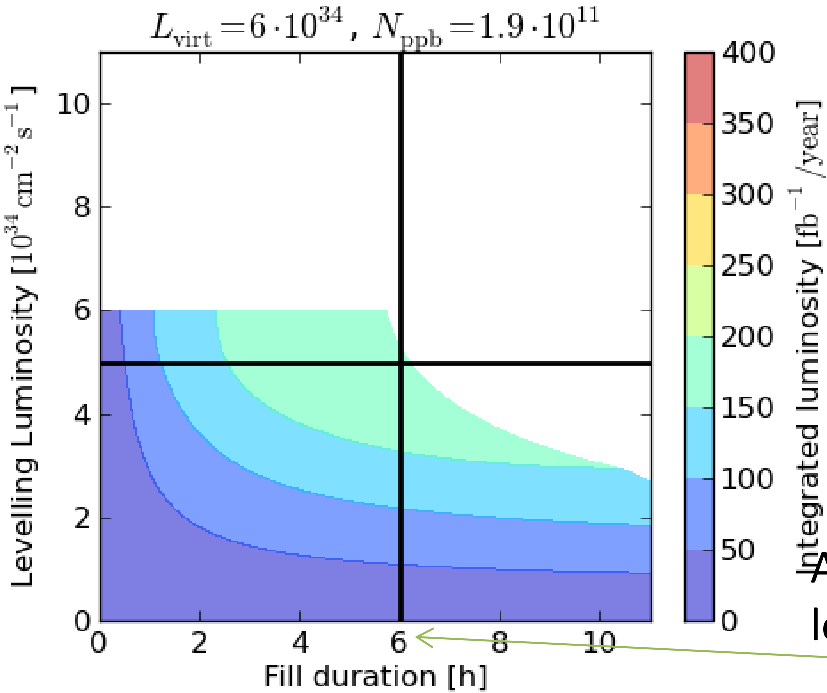

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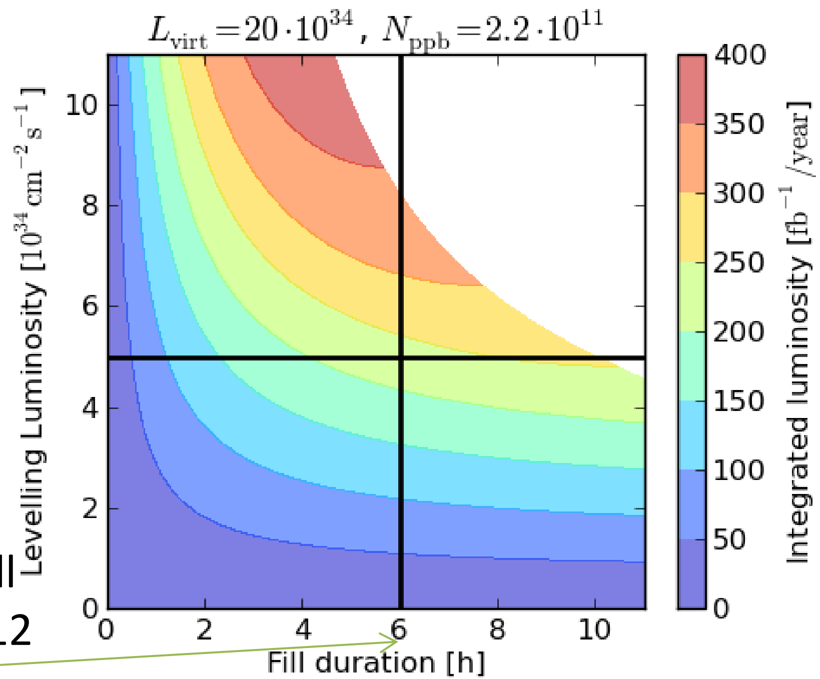

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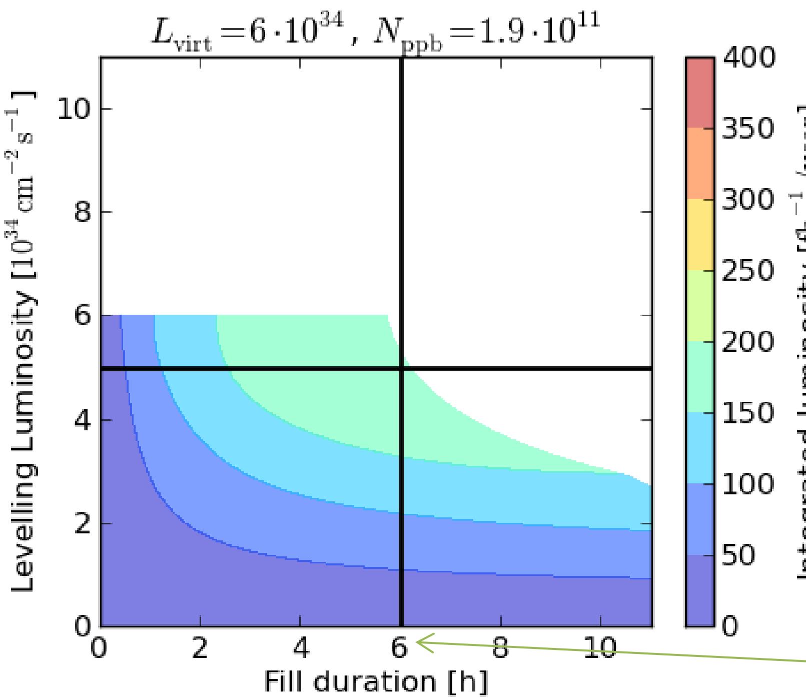

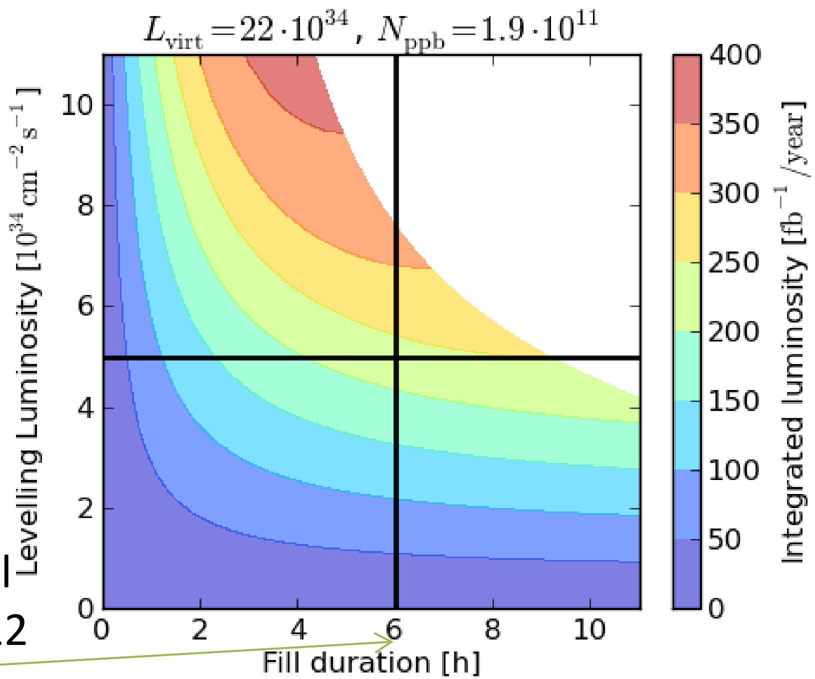

Average fill length 2012

→ Maximize leveled luminosity by pile-up limit and number of bunches,

→ Maximize probability of long fills

→ Obtain long fills by bunch population

Open questions for the LHC

- 200 MHz: If used as main RF in LHC, can it lift SPS bunch population limit?
- Bunch-by-bunch variations: Does it affect performance (or how much the differences will limit the average)?

Performance of different scenarios (7 TeV)

	$N_{b\,coll}$ [10^{11}]	$\varepsilon^*_{n\,coll}$ [μm]	Min β* (xing / sep) [cm]	Xing angle [μrad]	# Coll. Bunches IP1,5	L_{peak} [10^{34} $cm^{-2}s^{-1}$]	L_{lev} [10^{34} $cm^{-2}s^{-1}$]	Lev. time [h]	Opt. Fill length [h]	η_{6h} [%]	η_{opt} [%]	Avg. Peak-pile-up density [ev./mm]
RLIUP2	*1.5*	*1.3*[6]	*15/15*	*341*	*2592*	*19.0*	*4.8*	*4.7*	*6.0*	*63.4*	*63.4*	*0.94*
LIU-BCMS	*1.9*	*1.65*[6]	*13.5/13.5*[3]	*405*	*2592*	*23.4*	*4.8*	*6.7*	*7.8*	*61.0*	*57.5*	*0.98*
LIU-STD	*1.9*	*2.26*	*14.5/14.5*[3]	*457*	*2736*	*17.0*	*5.06*	*5.7*	*7.2*	*58.2*	*56.4*	*1.01*
HL-Flat	**2.2**	**2.5**	**30/7.5**[1]	**335**[2]**/*550***	**2736**	**18.6**	**5.06**	**7.0**	**8.4**	**57.8**	**53.5**	**1.12**
HL-Round	**2.2**	**2.5**	**15/15**	**476**[2]**/*590***	**2736**	**20.1**	**5.06**	**7.3**	**8.6**	**57.8**	**53.1**	**1.03**
LIU-BCMS	*1.9*	*1.65*	*13.5/13.5*[3]	*579*	*2592*	*23.4*	*6.87*[5]	*4.6*	*6.4*	*51.4*	*51.3*	*1.34*
HL-Round	*2.2*	*2.5*	*15/15*	*473*	*2736*	*20.1*	*7.24*[5]	*4.8*	*7.0*	*48.2*	*47.4*	*1.37*
HL-SRound	*2.2*	*2.5*	*10/10*[4]	*600*	*2736*	*26.8*	*7.24*[5]	*5.8*	*7.6*	*47.6*	*45.7*	*1.55*

1) compatible with crab kissing scheme (S. Fartoukh)
2) BBLR wire compensator assumed to allow 10σ
3) β* could be reduced to 14.5 and 13.5 cm at constant aperture
4) Ultimate collimation settings
5) Pile-up limit at 200 event/ crossing
6) 30% blow-up from IBS makes 1.85 um is more likely

High Luminosity LHC

Conclusion

- Injector beam parameters should aim at saturating the LHC and experiment capabilities.
- When experiments are not limited by total pileup, BCMS beams are an effective tool for increasing performance.
- For HL-LHC times, the LHC expects maximum injectable bunch population with the maximum number of bunches.
- Present LIU offer is a close match, but increasing bunch population is a key to exploit large accepted luminosity or long fill durations.