HL-LHC alternatives

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Contents

- ★ News from Chamonix: SPS ramp, bunch rotation (competitor with 200MHz), 80 bunches
- ★ The scenario at $L_{lev}=7.5\times10^{34}cm^{-2}s^{-1}$
- ★ Alternatives for problems or for improved performance

Longer SPS ramp: turn-around time

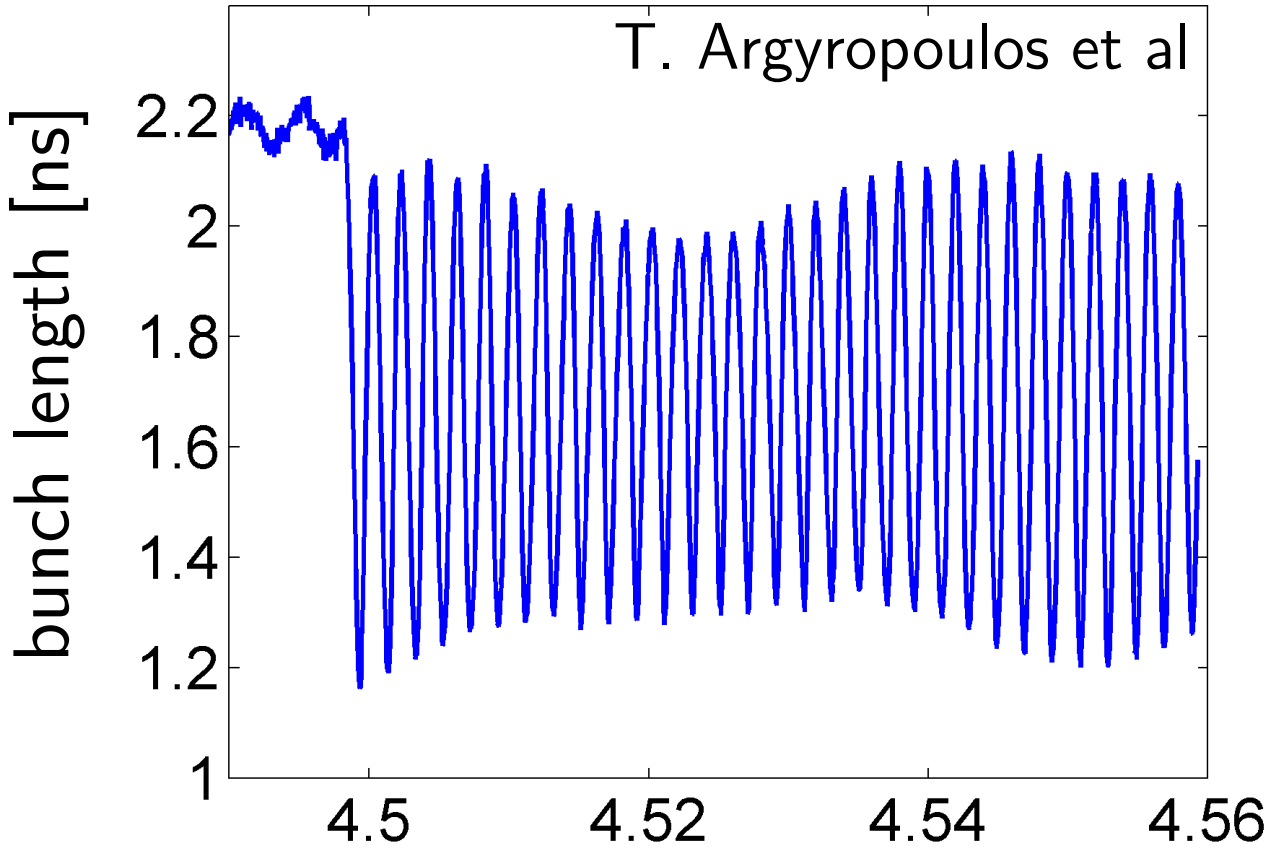
- ★ In Chamonix a longer SPS energy ramp is shown required
- ★ Slight increase of turn-around time:

G. Arduini et al

Phase	Time [minutes]	
Ramp down/precycle	60	
Pre-injection checks and preparation	15	
Checks with set-up beam	15	
Nominal injection sequence	~~20~~	27 } 32 @ inj.
Ramp preparation	5	
Ramp	25	
Squeeze	30	
Adjust/collisions	10	
Total	~~180~~	187

Extra 7 mins cause a 1% integrated luminosity loss (and 1-2% more IBS emit. growth→less margin)

Bunch rotation at SPS flattop



Might allow larger bunch charge in LHC.

Similar potential to the 200 MHz RF in the LHC.

200 MHz Vs 800 MHz

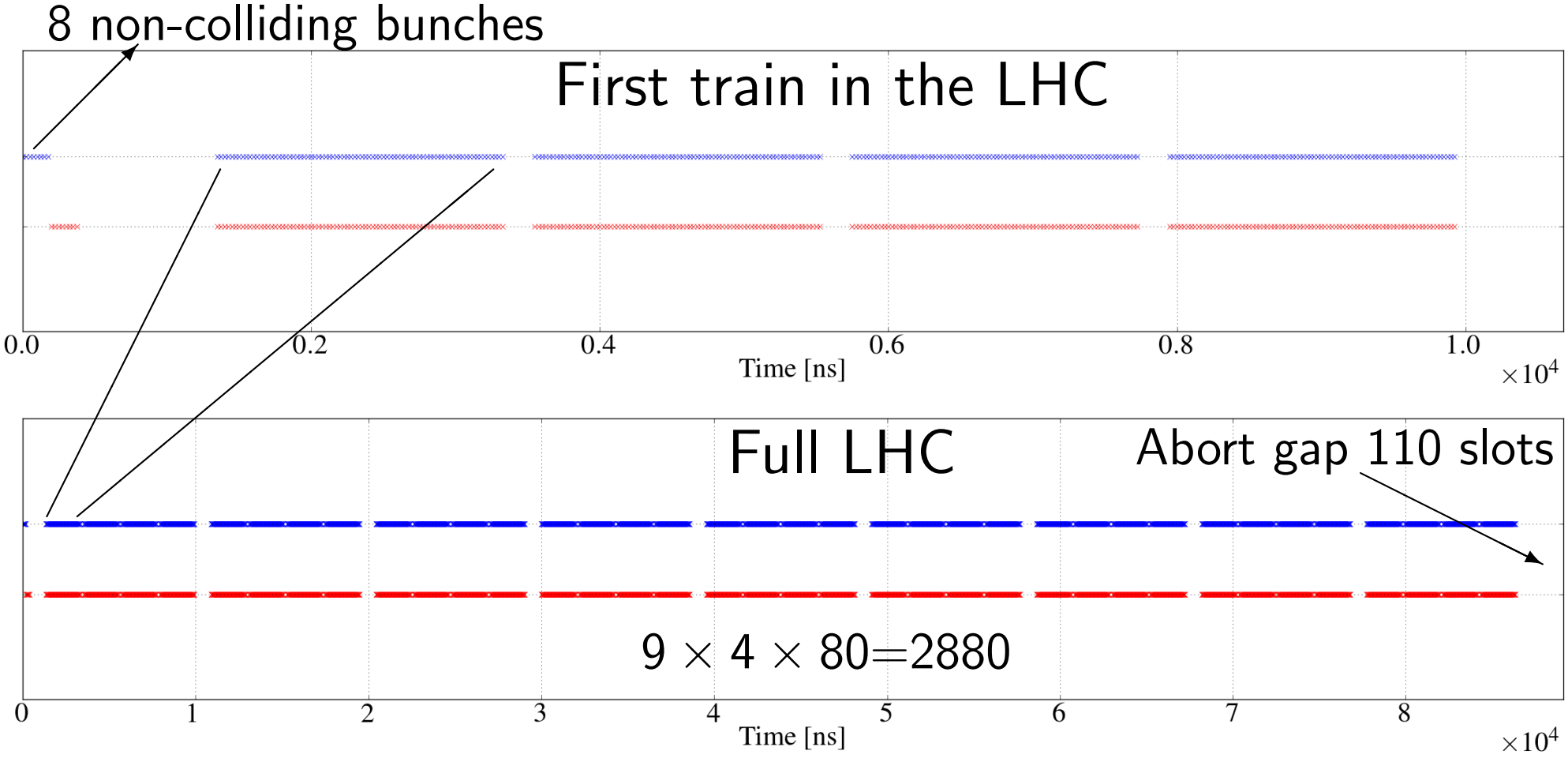
J. Esteban Müller

	N_b	Single RF	BSM	BLM
200 + 400 MHz 6 MV, 3 MV	2.4×10^{11}	3.25 eVs (1.8 ns)	13.5cm 2.38 eVs (1.31 ns)	9.8cm 0.70 eVs (1.25 ns)
400 + 800 MHz 16 MV, 8 MV	2.2×10^{11}	2.16 eVs (0.97 ns)	1.72 eVs (0.77 ns)	~0.45 eVs (0.65 ns)

Larger bunch charge if multi-bunch instabilities allow

For instabilities use either of the configurations in bunch shortening mode.

80 bunch scheme and 4 PS batch trains



Abort gap is a bit too short: slots could be gained from the non-colliding bunches and the SPS-LHC transfers.

80 bunches/4 trains merits and issues

Merits:

- ★ 5% more bunches than nominal (2746) $\rightarrow$ 5% more integrated luminosity
- ★ Faster injection (10 LHC injections instead of 12)

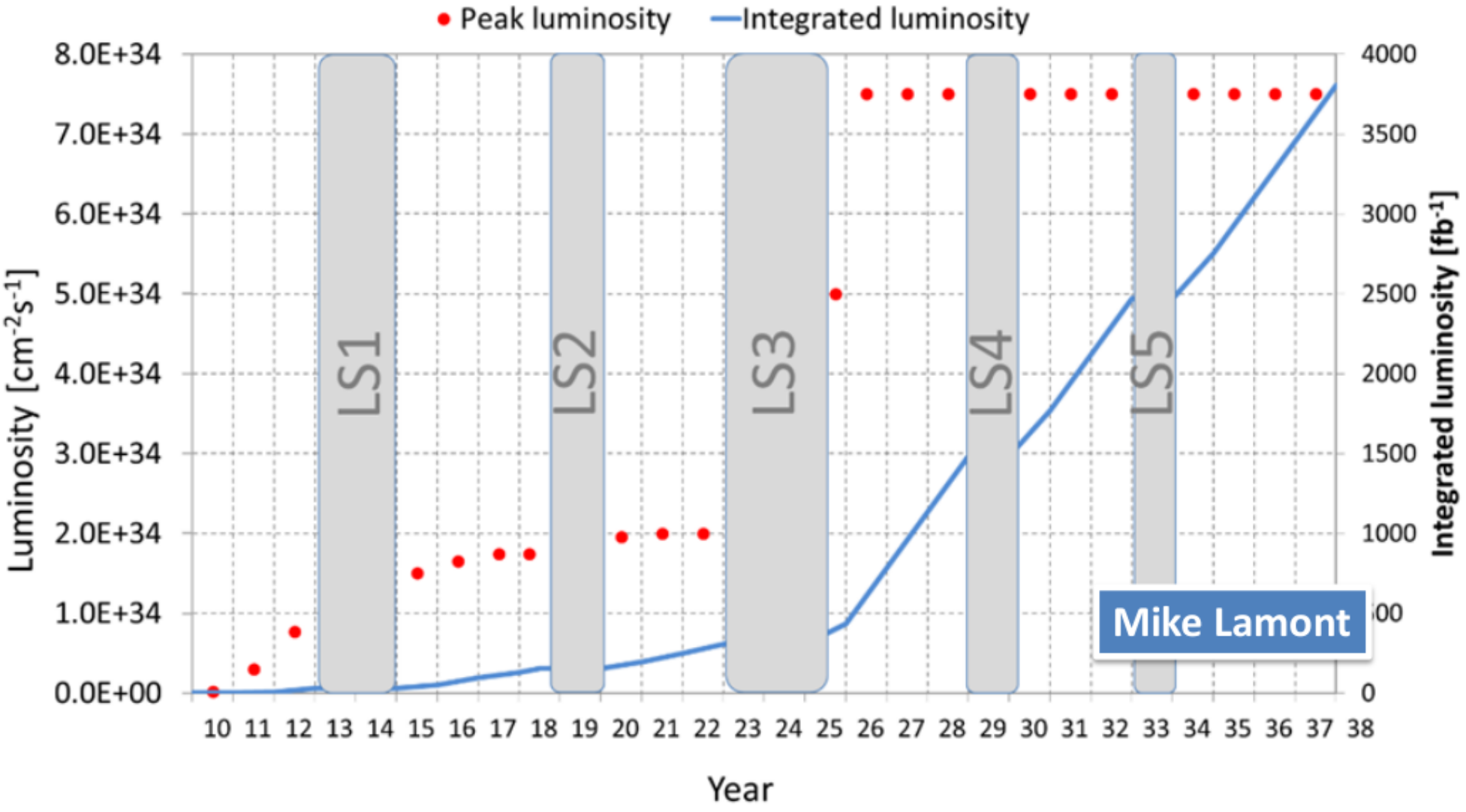
Issues:

- ★ SPS to LHC transfer with $4\times80=320$ bunches instead of $4\times72=288$
- ★ MKI pulse length needs to be extended (J. Uythoven, M. Barnes will do tests)
- ★ Injection protection devices (TDI, TCDI, etc) need to "survive" the extra charge

The $L_{lev}=7.5\times10^{34}cm^{-2}s^{-1}$ scenario

- ★ First considered by S. Fartoukh and L. Rossi in RLIUP
- ★ assuming crab kissing and $\beta^*=10cm$
- ★ 350 fb^{-1} per year

The $L_{lev}=7.5\times10^{34}cm^{-2}s^{-1}$ scenario, integrated lumi



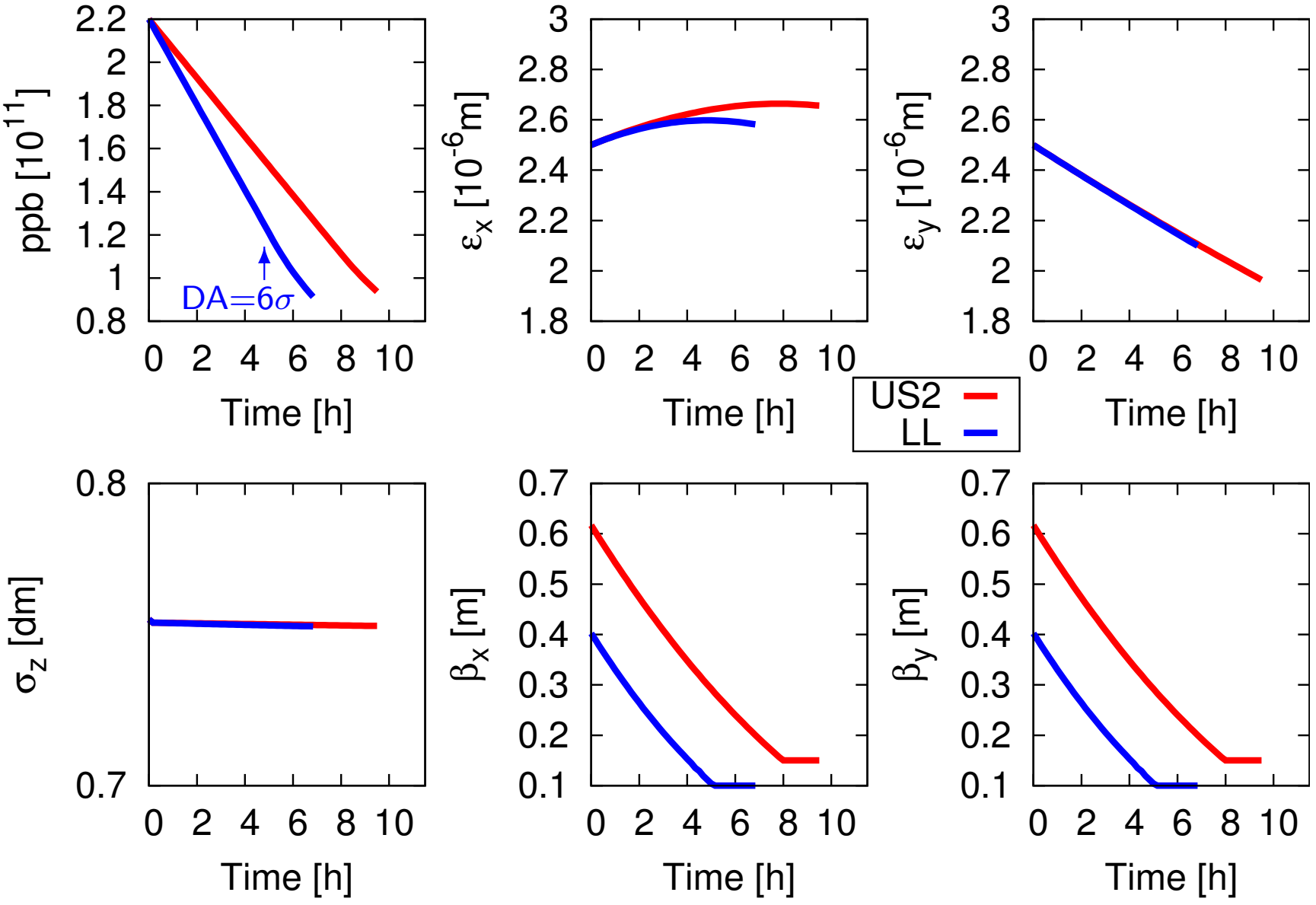
seems Mike is assuming 330 fb^{-1} per year.

The $L_{lev}=7.5\times10^{34}cm^{-2}s^{-1}$ scenario

- First considered by S. Fartoukh and L. Rossi in RLIUP
- assuming crab kissing and $\beta^*=10cm$
- 350 fb^{-1} per year
- What about $7.5\times10^{34}cm^{-2}s^{-1}$ **with β^*-leveling** as in the baseline?
  assuming 160 days, turn-around=187min,
  50% efficiency, 6.5 TeV

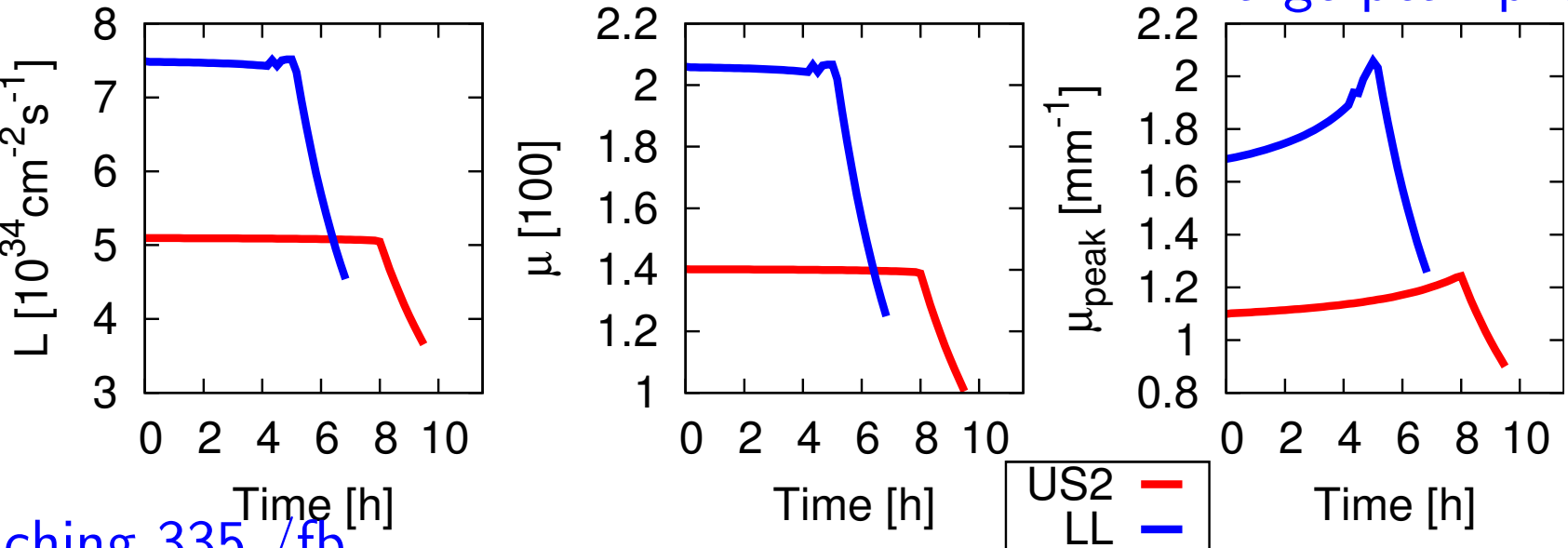
$L_{lev}=7.5\times10^{34}cm^{-2}s^{-1}$, β^* leveling, I

US2=HL-LHC baseline

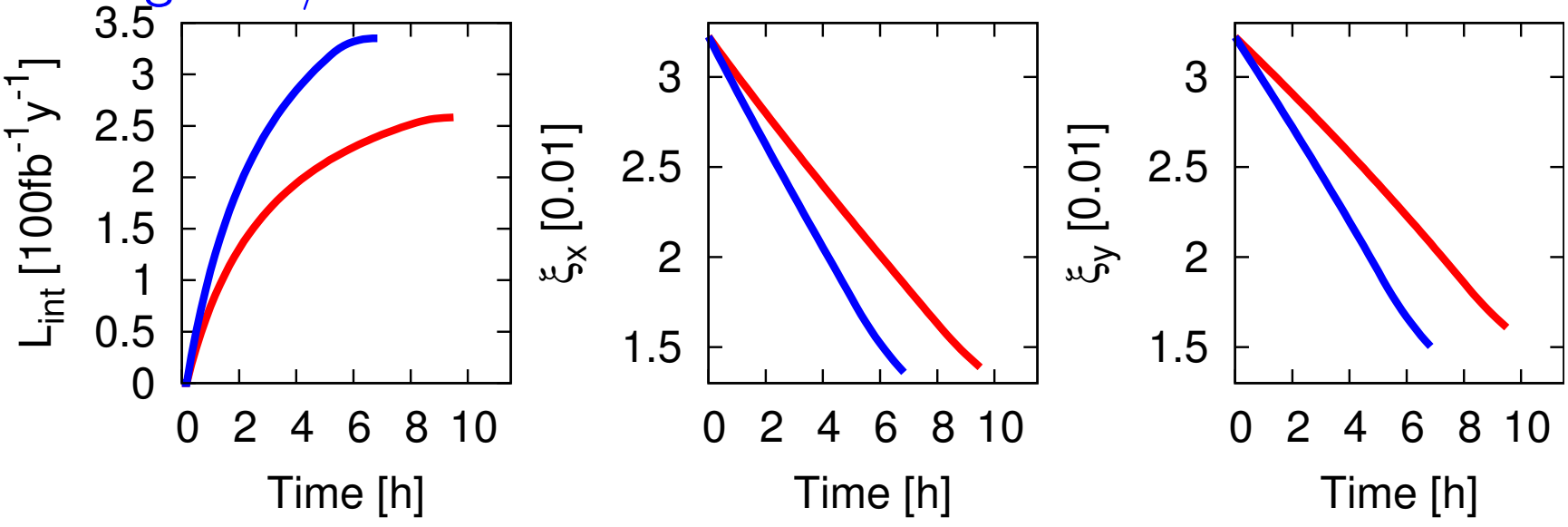


$L_{lev}=7.5\times10^{34}cm^{-2}s^{-1}$, β^* leveling, II

large peak pile-up



reaching 335 /fb

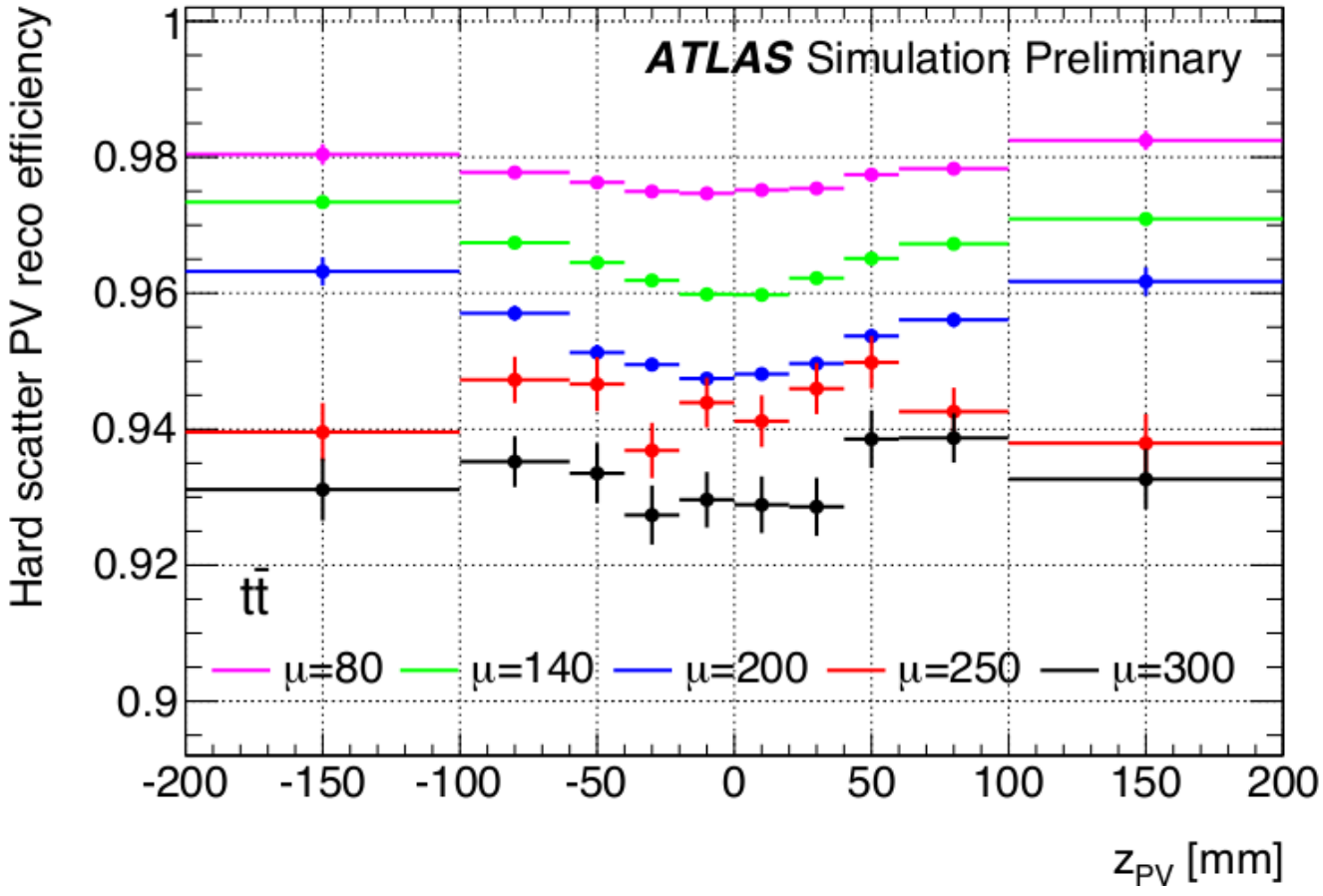


Detectors looking at 200 pile-up and beyond

ttbar PV efficiency vs z

Pippa Wells

Without crab kissing



Only 1% loss between μ=140 and 200

Alternatives in case of problems

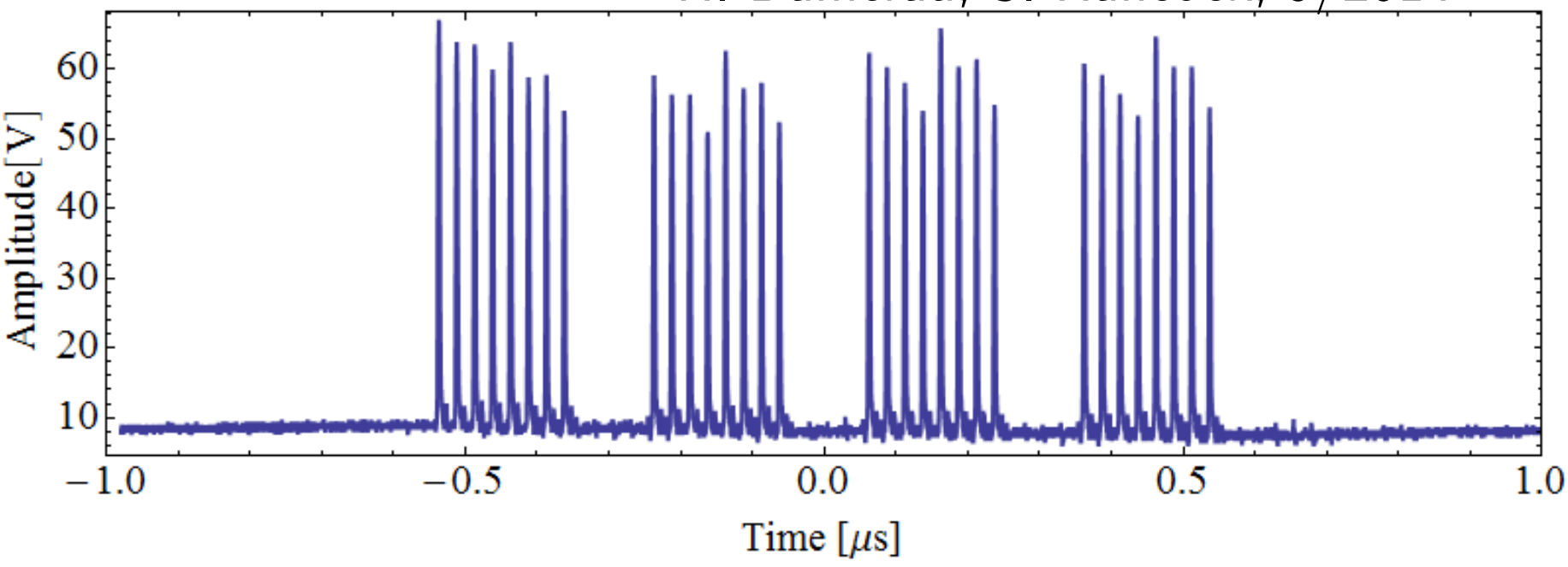
- ★ Longitudinal (multi-bunch) instabilities :
  - 800 MHz (second harmonic)
  - 200 MHz (main RF + 400 MHz)
- ★ e-cloud unbearable:
  - **Pushed** 8b+4e filling scheme
  - 200 MHz
- ★ Crab cavities not operational:
  - Flat optics at the IP
  - Flat optics at the IP + BBLRC

Alternatives for performance

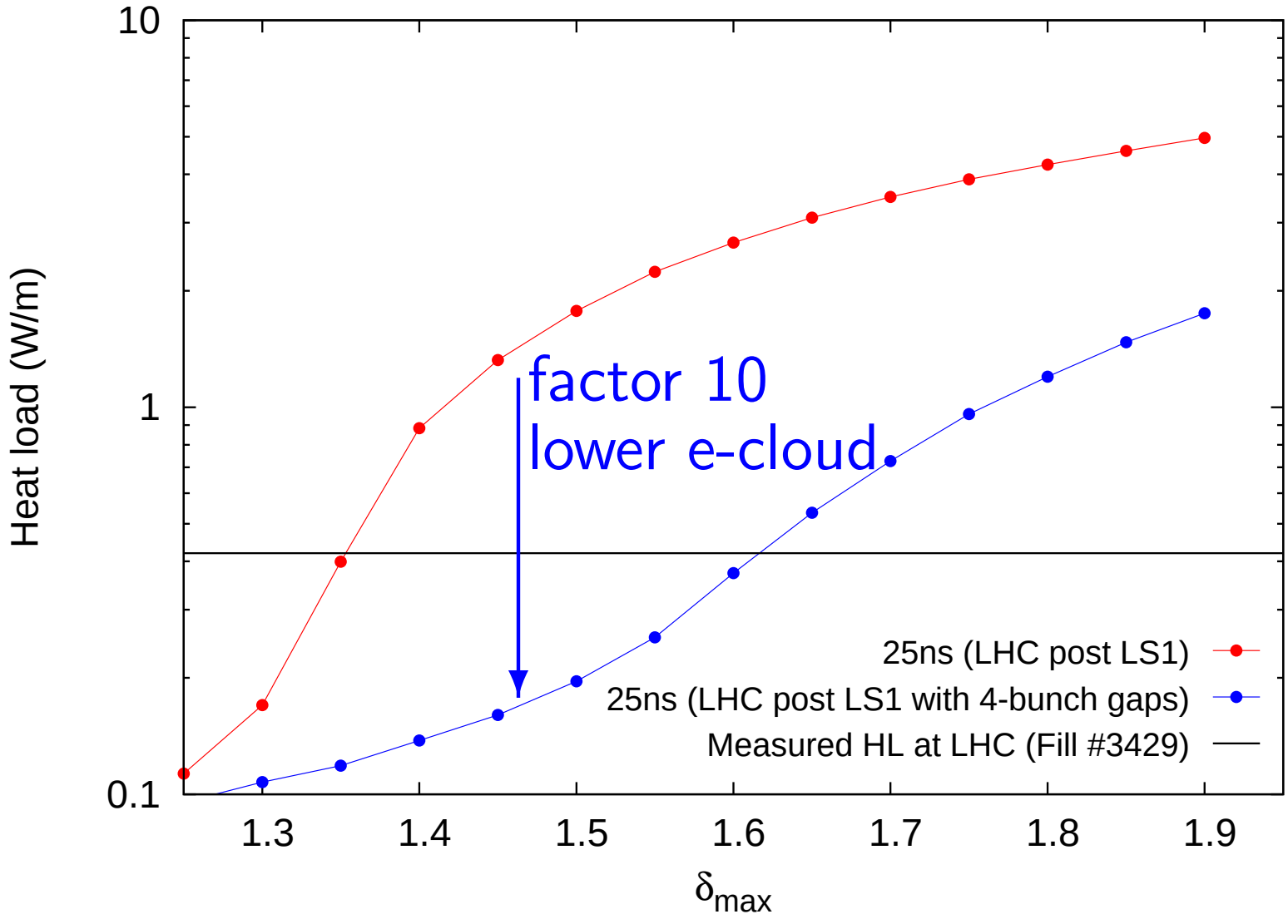
- ★ More bunches: trains of 4 PS batches with 80 bunches
- ★ Larger bunch charge:
  - 200 MHz
  - Bunch rotation at the SPS flattop
- ★ Lower β^*: 10cm round or 5/20cm flat
- ★ Peak pile-up mitigation:
  - β^* leveling (for peak pile-up)
  - Crab kissing
  - Flat profile: 200, 800 MHz or phase modulation
  - **Detector precision timing** T. Tabarelli

8b+4e: First PoP experiments in the PS

H. Damerau, S. Hancock, 9/2014

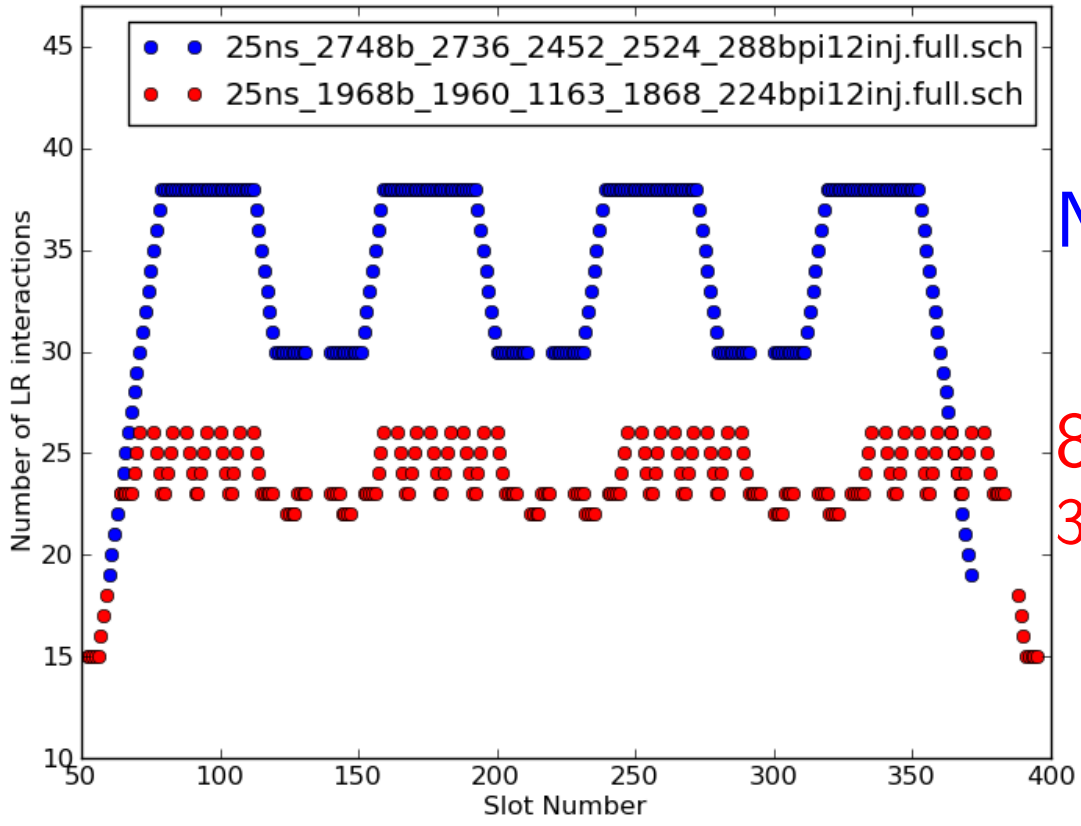


e-cloud unbearable: the 8b+4e solution



Pushed 8b+4e

T. Pieloni
C. Tambasco



Nominal

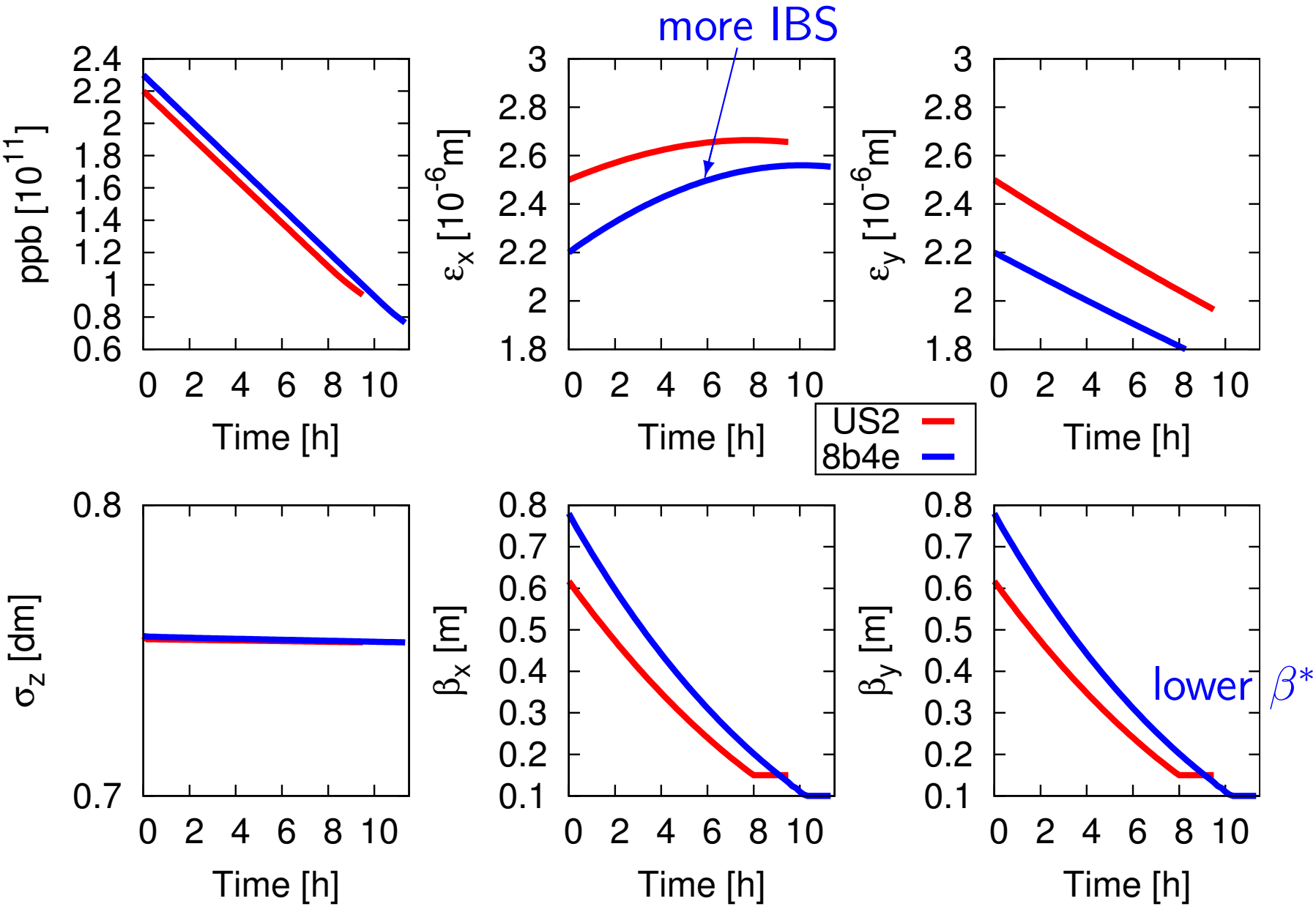
8b+4e
30% fewer LRs

Lower number of long range encounters allows for smaller crossing angle $\rightarrow$ 8-8.5σ (T. Pieloni)

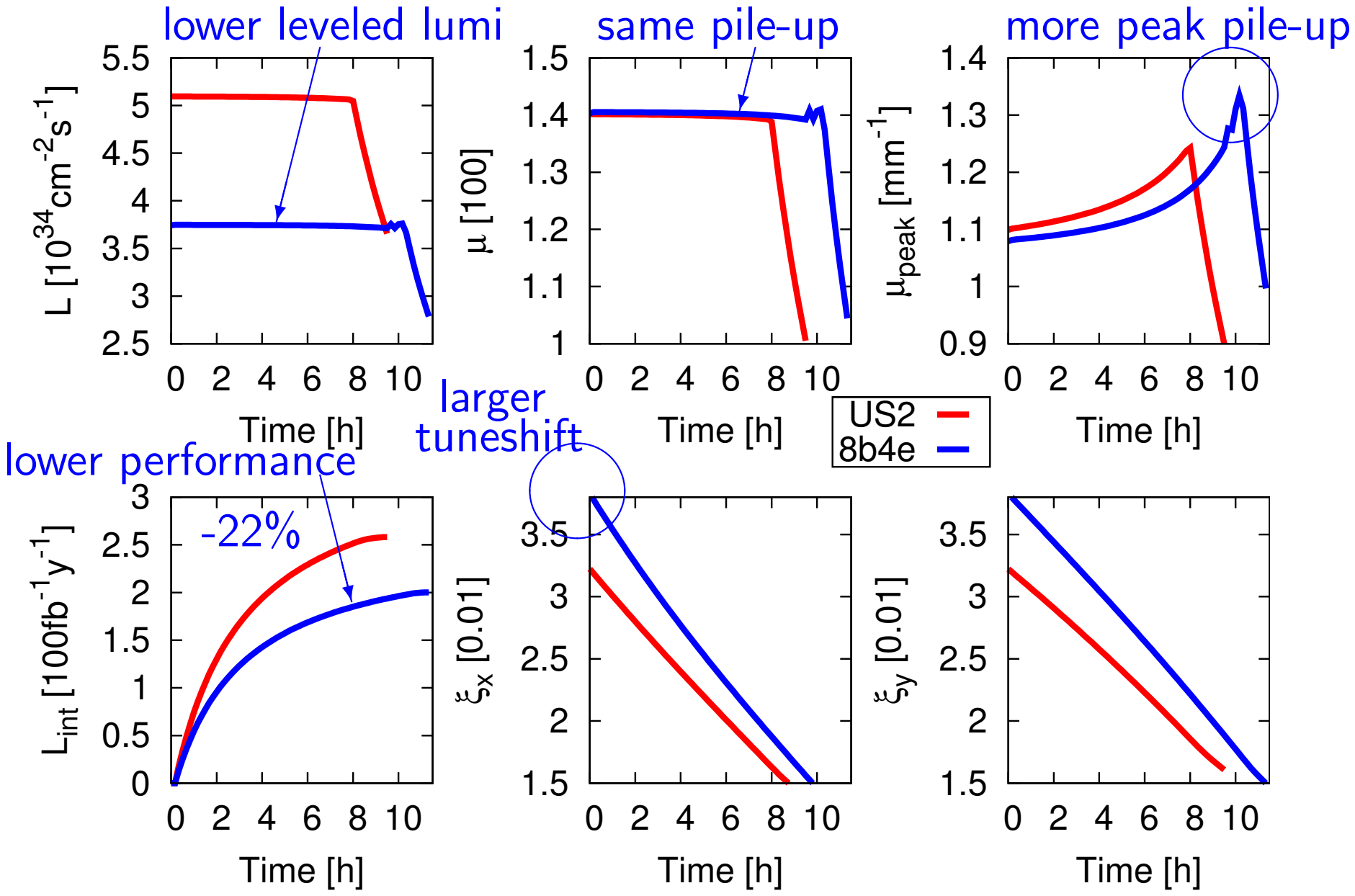
Pushed 8b+4e

- ★ Crossing angle of 8σ
- ★ Using a 80 bunches scheme could provide $56\times4\times9=2016$ bunches in the LHC
- ★ Minimum β^* could be reduced to 0.1m

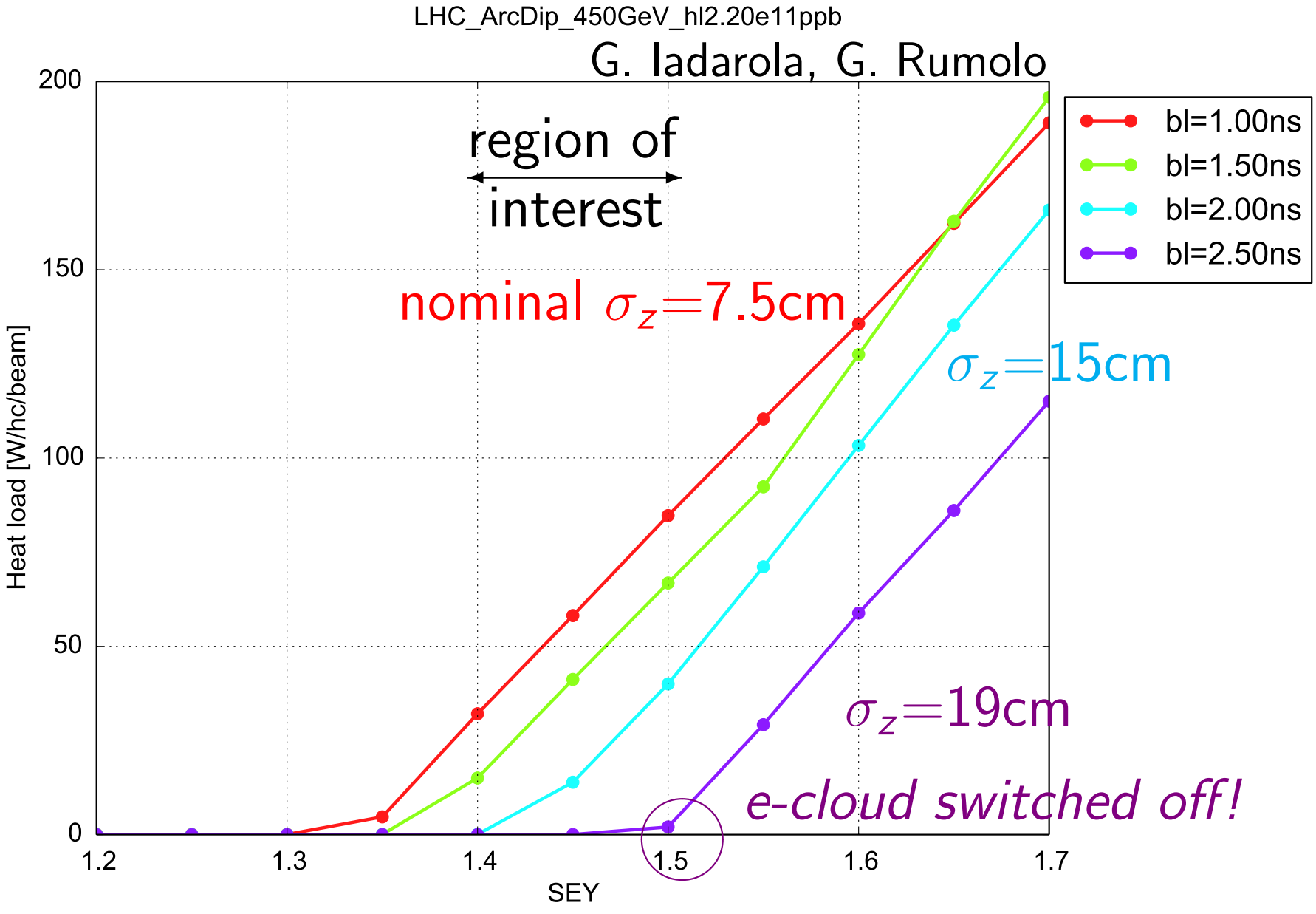
Pushed 8b+4e: Performance I



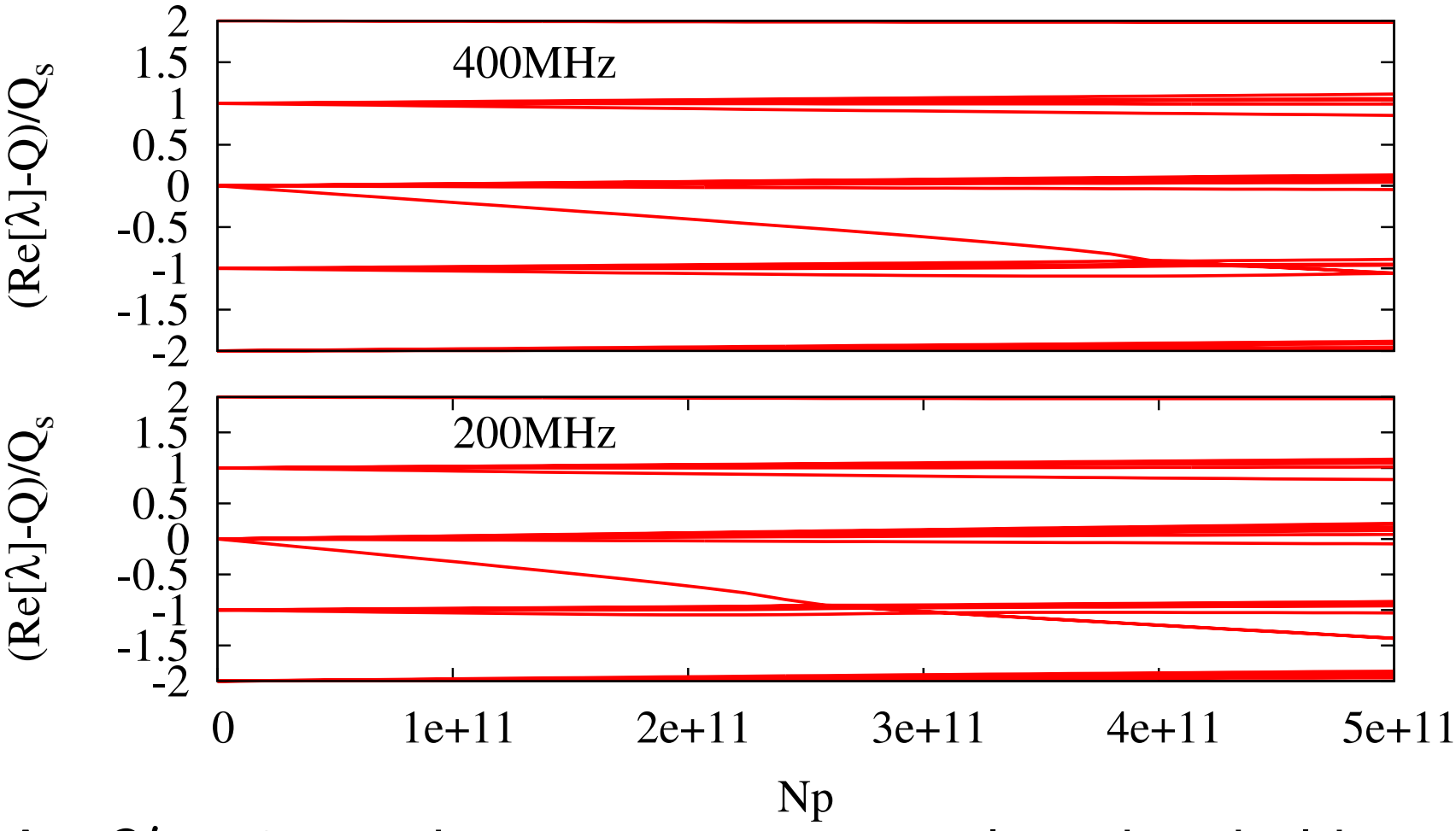
Pushed 8b+4e: Performance II



200 MHz: e-cloud in dipoles, injection

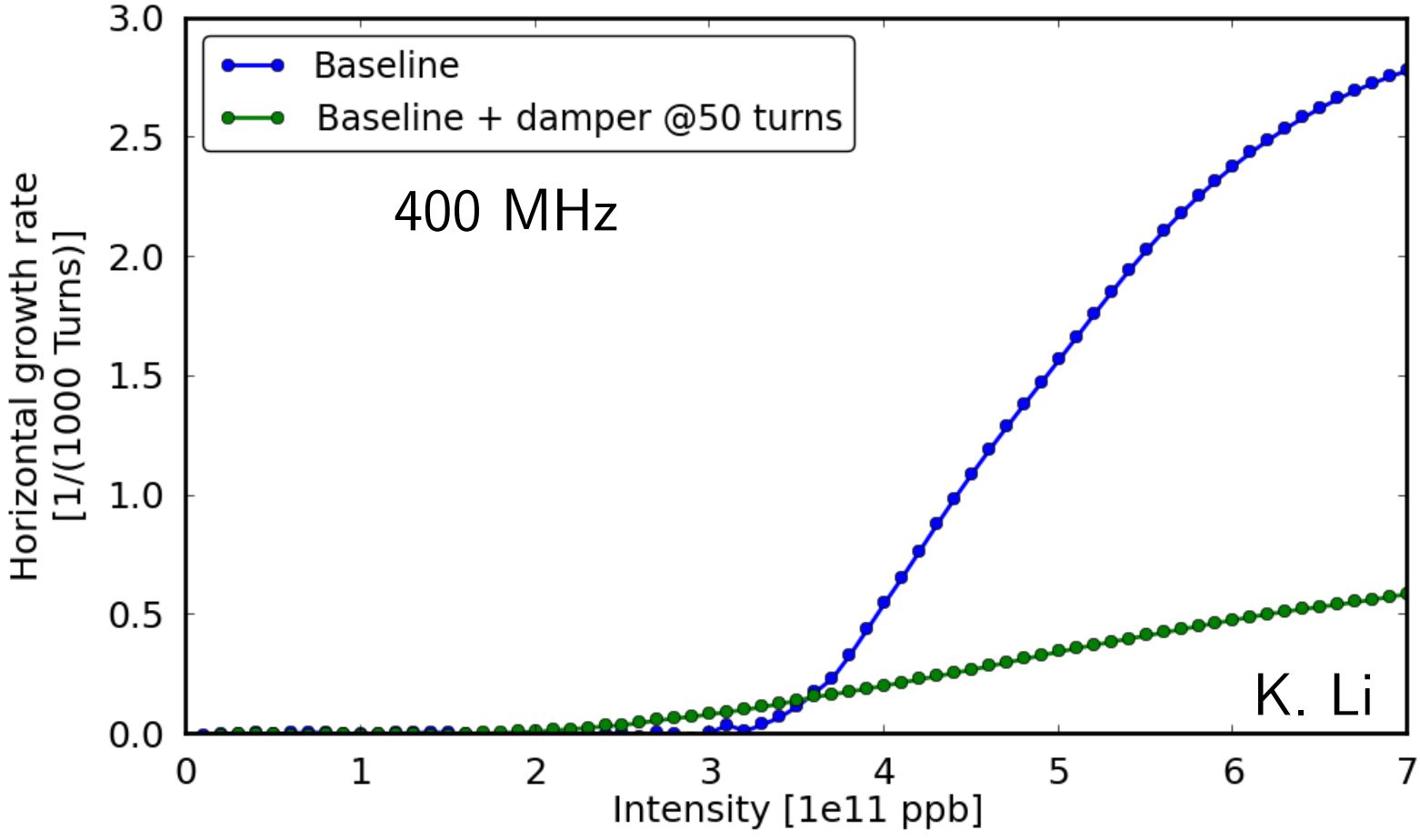


200 MHz single little *contra*: TMCI



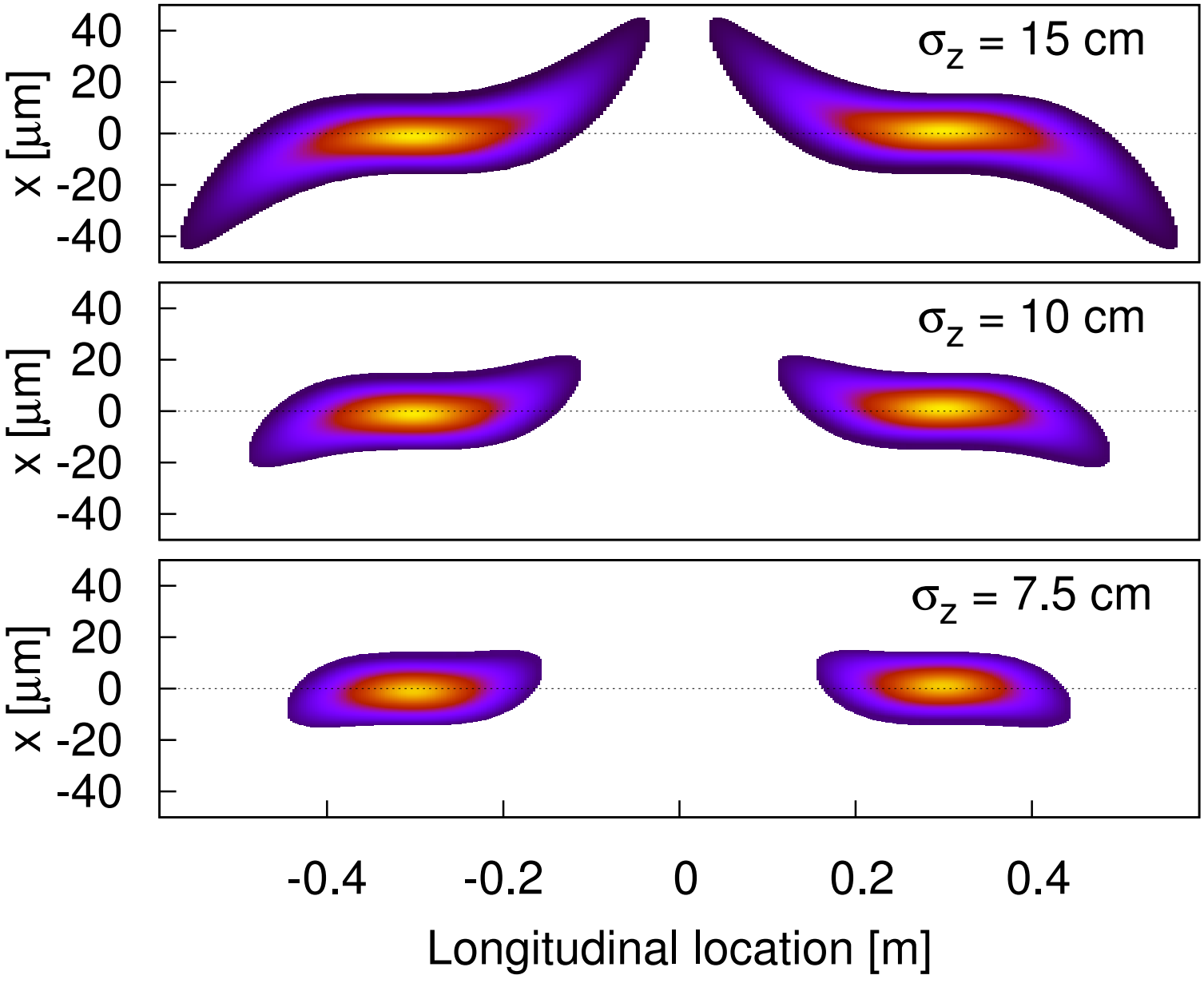
At $Q' = 0$, no damper, zero octupoles, threshold goes down from 4×10^{11} to 2.5×10^{11}, still ok...

Illustration of damper helping with TMCI



Considerable reduction of growth rate with $Q' = 0$ and no octupoles, thanks to *normal* damper.

Collision (400 MHz CC) vs bunch length

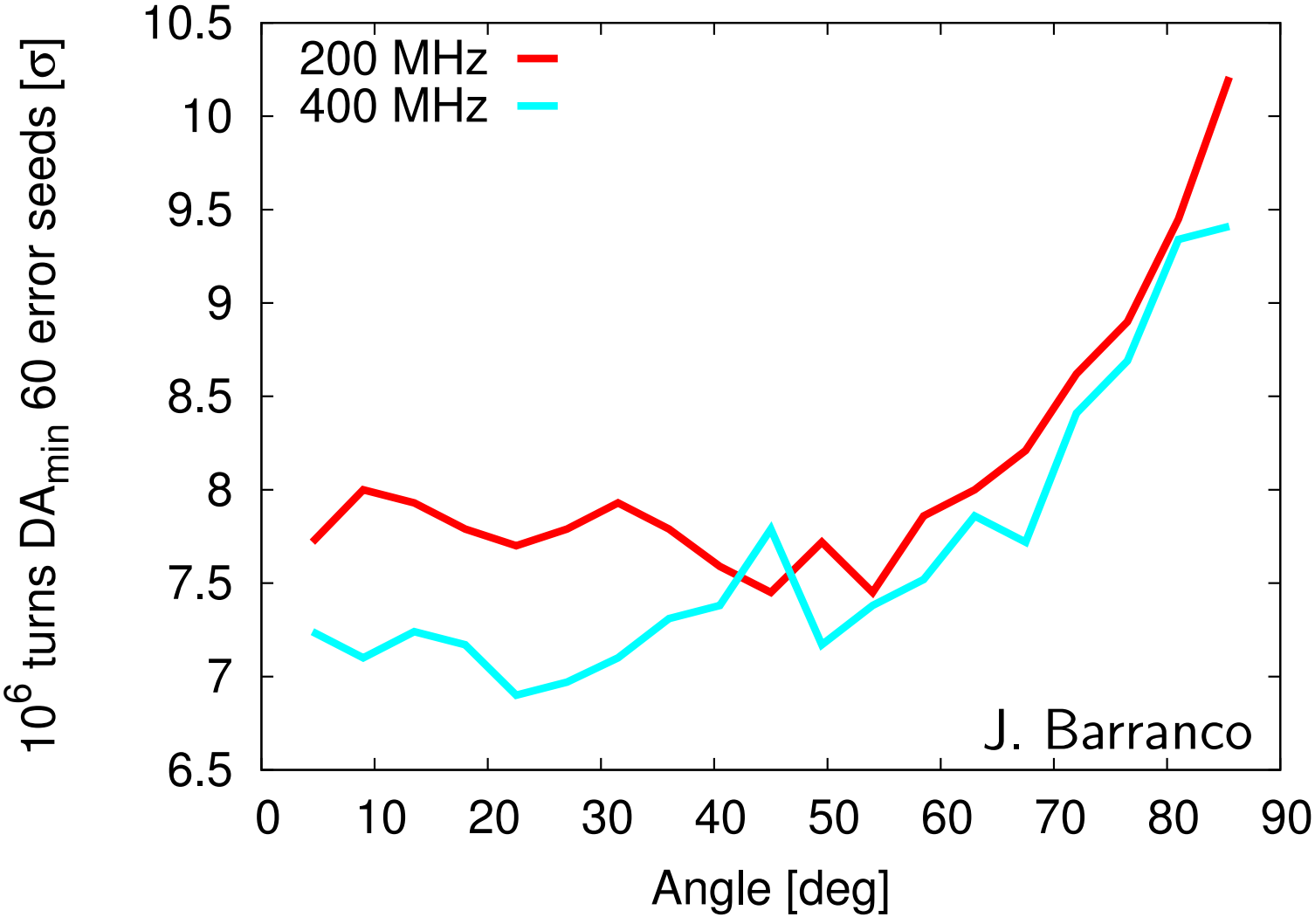


only @ 200MHz

likely situation for any scenario

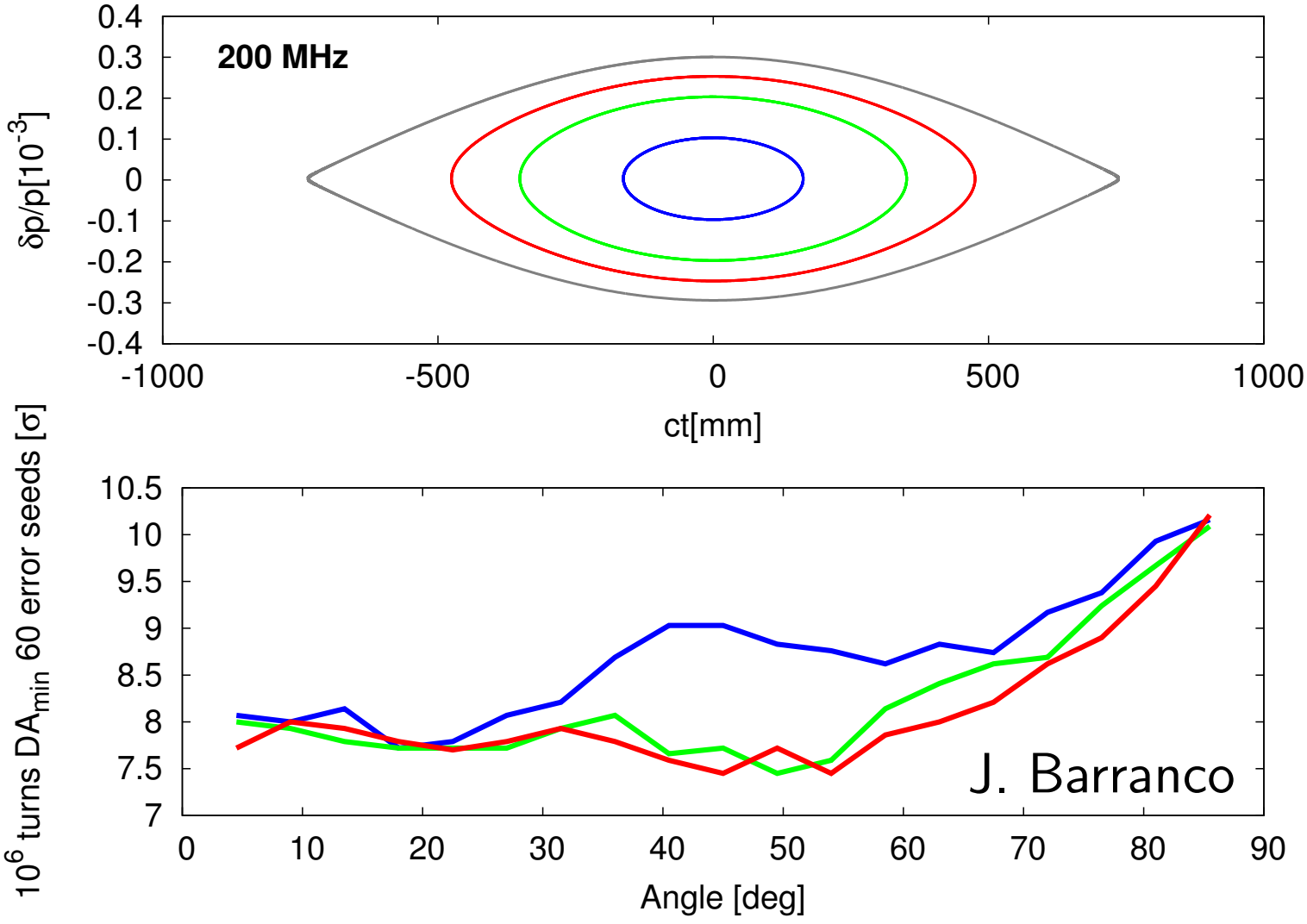
400MHz

DA with RF curv., beam-beam and errors



DA for 200 MHz similar to 400 MHz.

200 MHz: DA and RF bucket

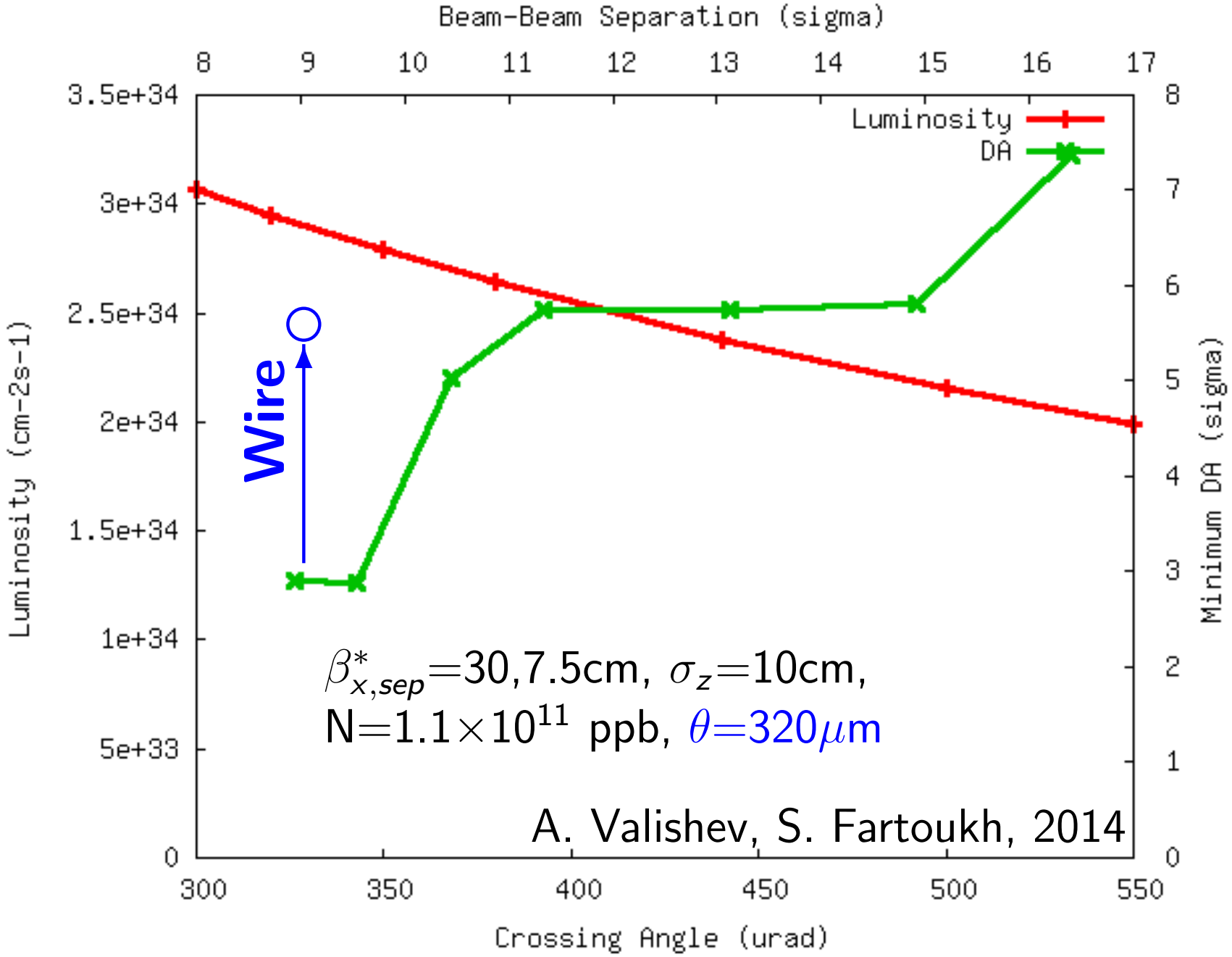


e-cloud, performances & tagline

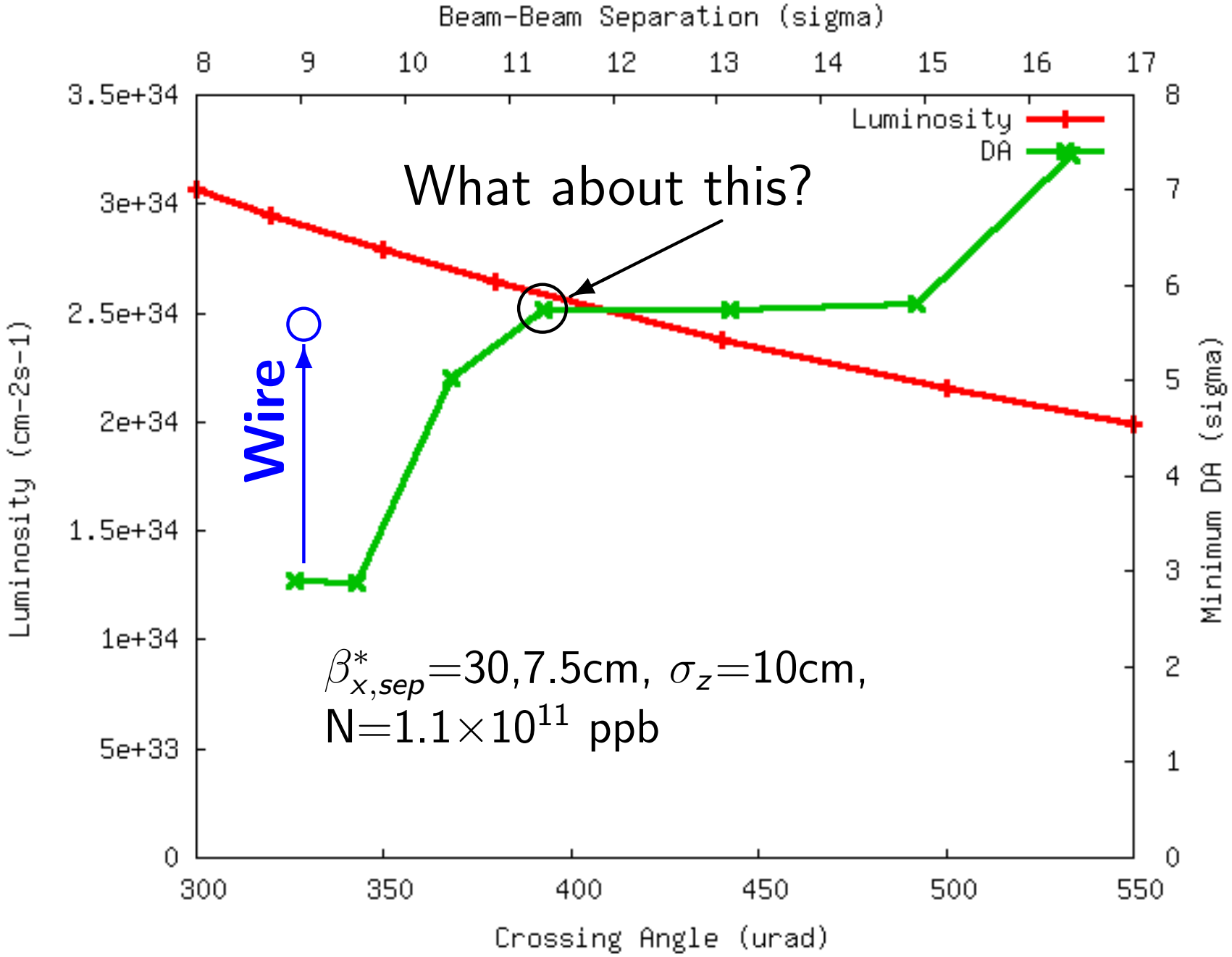
	N 10^{11}	ϵ $[\mu m]$	$\beta^*_{x,y}$ [cm]	$L_{year}[fb^{-1}]$ Opt.	6h	fill [h]	Pile-up	$[\frac{1}{mm}]$
pushed 8b+4e	2.3	2.2	10,10	200	168	11	140	1.3
200MHz σ_z=15cm	2.4	2.5	15,15	**251**	**228**	9	140	**1.1**

- ★ If scrubbing with doublets does not remove the e-cloud in 2015 *order* 200 MHz cavities!
- ★ *800 MHz does not help with e-cloud...*

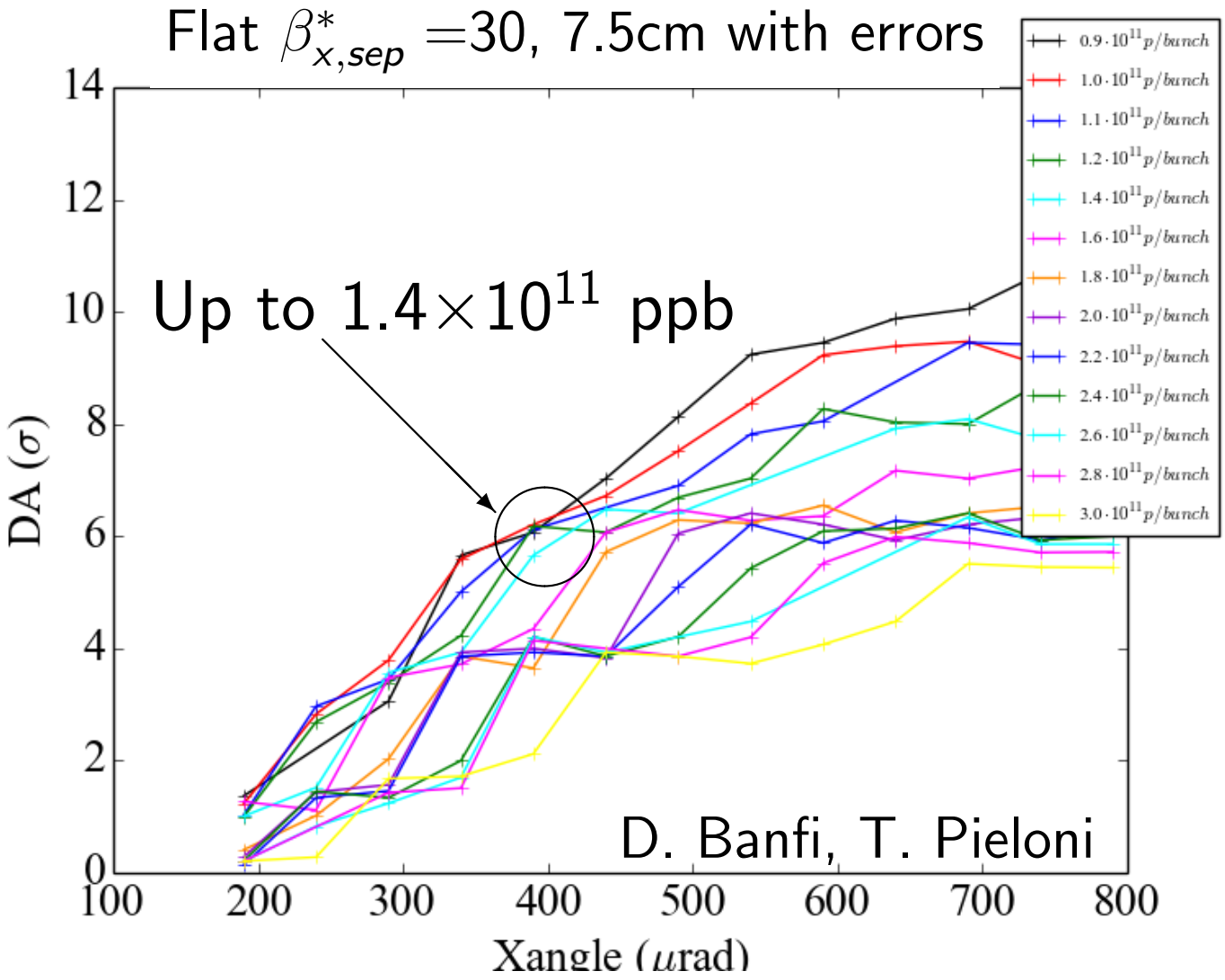
Crab Cavities not operational: flat+wire



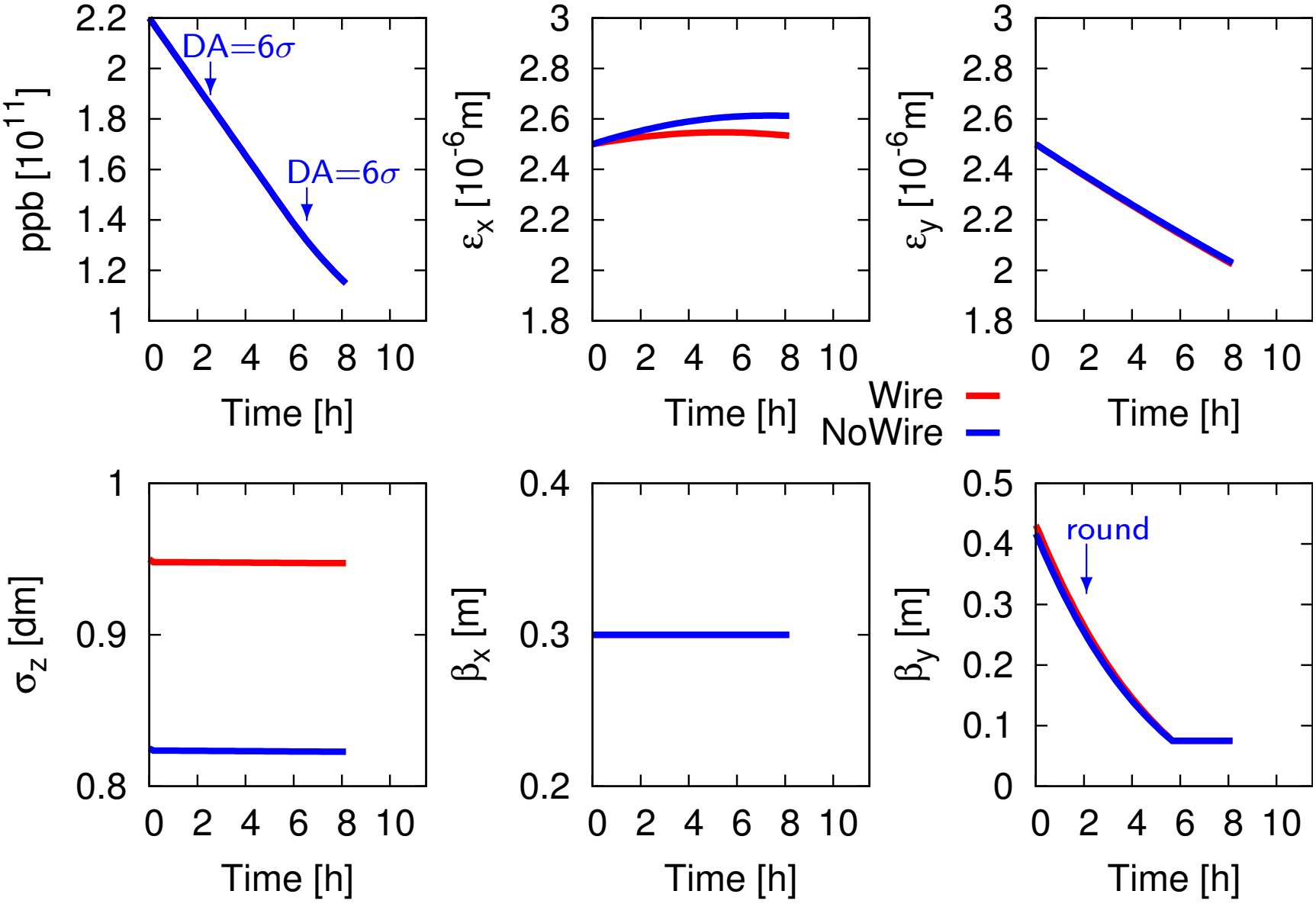
Crab Cavities not operational: no wire?



Flat beams, no wire



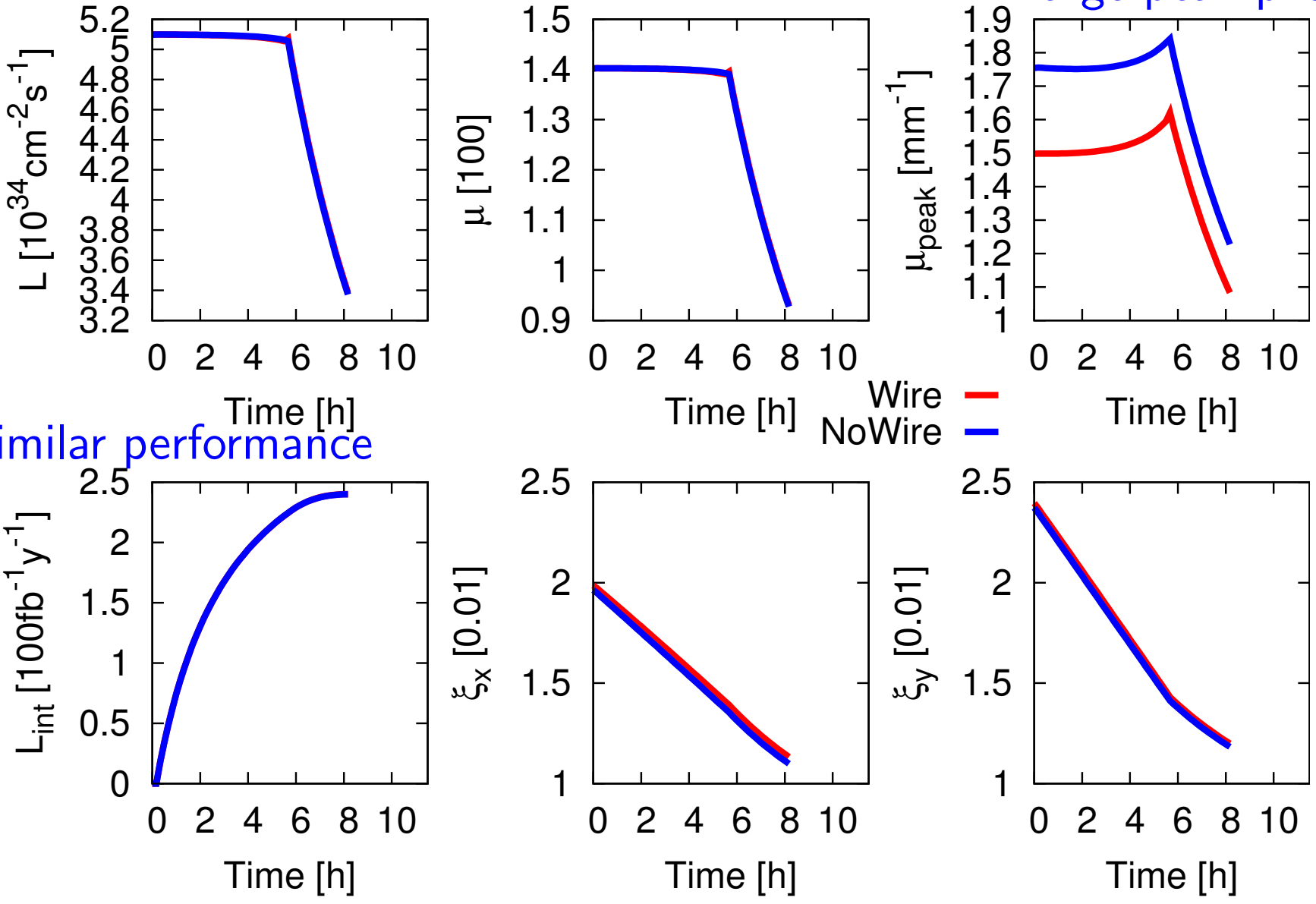
No CC, Flat, Wire Vs No-Wire, Perf. I



No CC, Flat, Wire Vs No-Wire, Perf. II

large peak pile-up

similar performance



No CC, Flat, Wire Vs No-Wire, summary

	N 10^{11}	ϵ $[\mu m]$	$\beta^*_{x,y}$ [cm]	$L_{year}[fb^{-1}]$ Opt.	6h	fill [h]	Pile-up	$[\frac{1}{mm}]$
Wire	2.2	2.5	30,7.5	240	229	7.8	140	**1.6**
NoWire	2.2	2.5	30,7.5	240	229	8.0	140	**1.8**

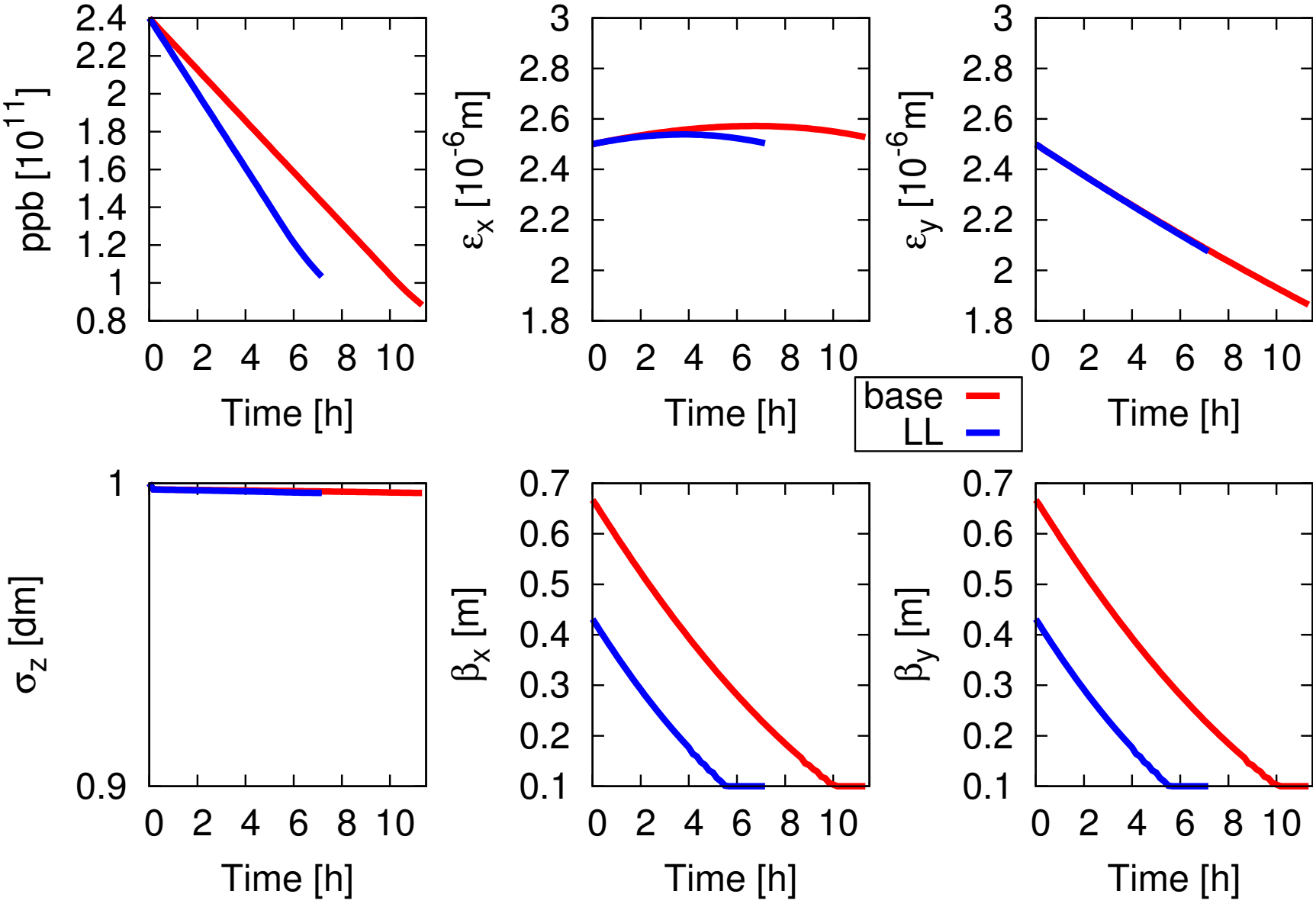
Without crab cavity performance lowers by $\approx$7%.

The wire does not increase integrated luminosity but reduces peak pile-up from 1.8mm^{-1} to 1.6mm^{-1}.

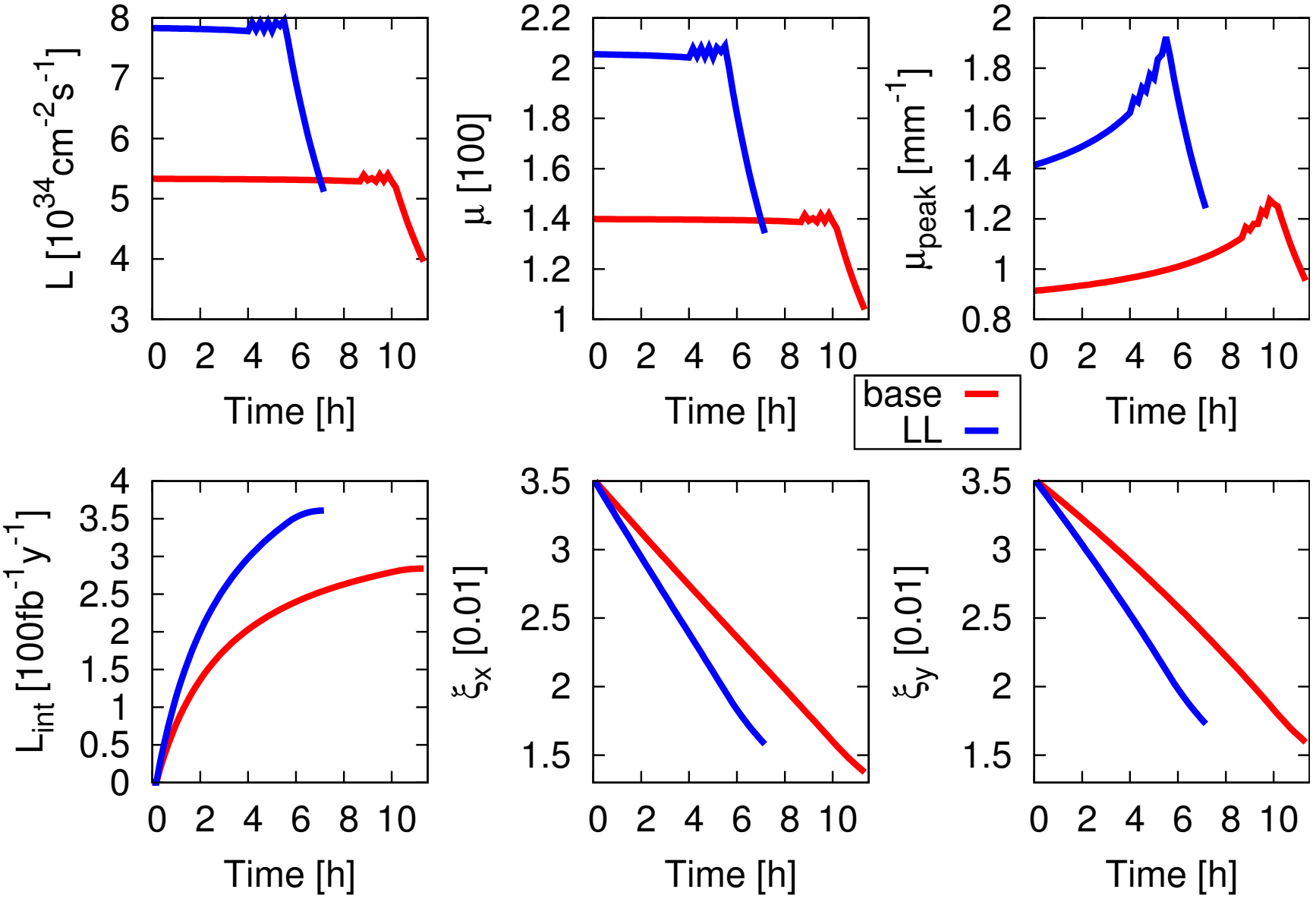
Let's be optimistic

- ★ **80 bunch scheme** $\rightarrow$ 2880 bunches
- ★ β^***=10cm**
- ★ Bunch intensity of 2.4×10^{11} ppb thanks to **200 MHz** or **bunch rotation**
- ★ Bunch length σ_z=10cm compatible with both 200 MHz and 400 MHz
- ★ For both 5 and $7.5\times10^{34}\text{cm}^{-2}\text{s}^{-1}$

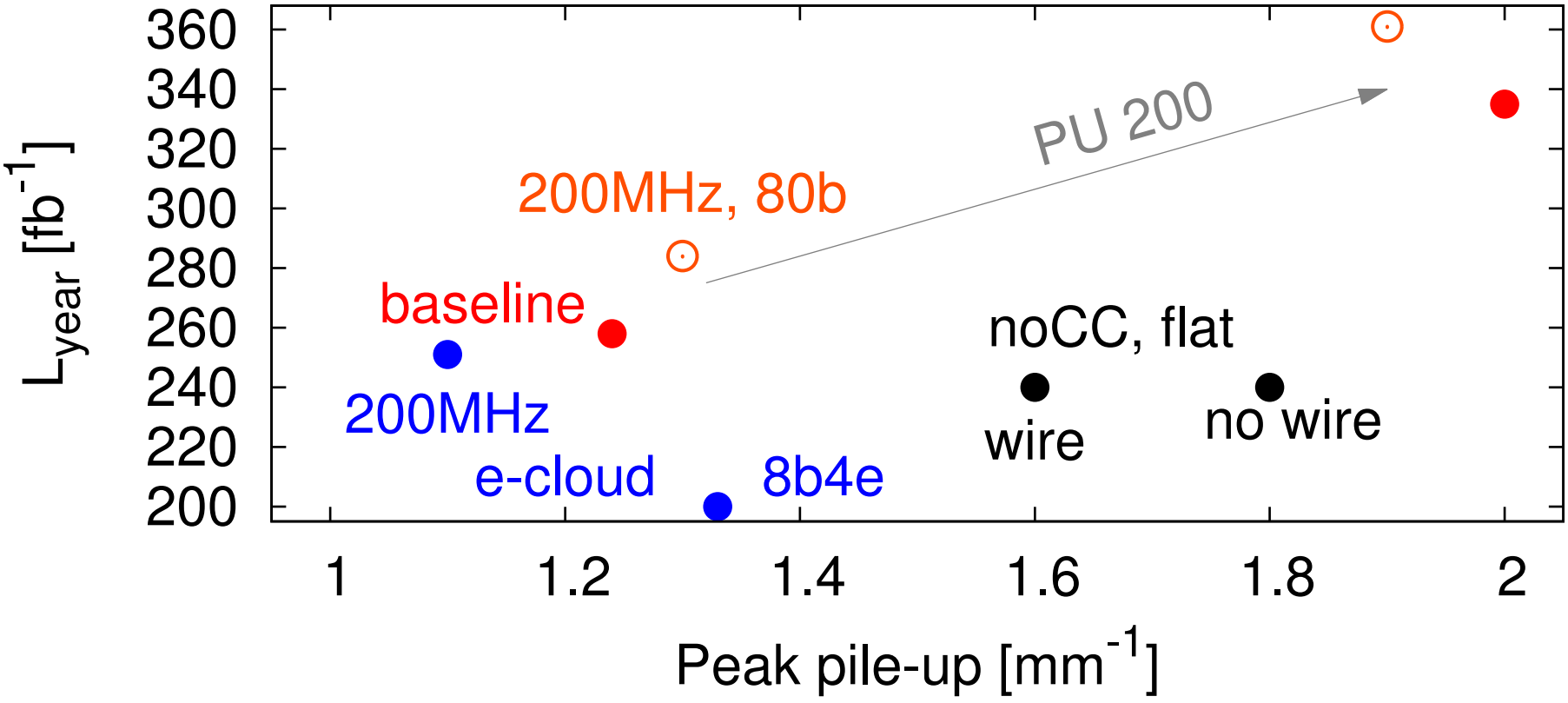
200 MHz, 80 bunches, I



200 MHz, 80 bunches, II



Conclusions



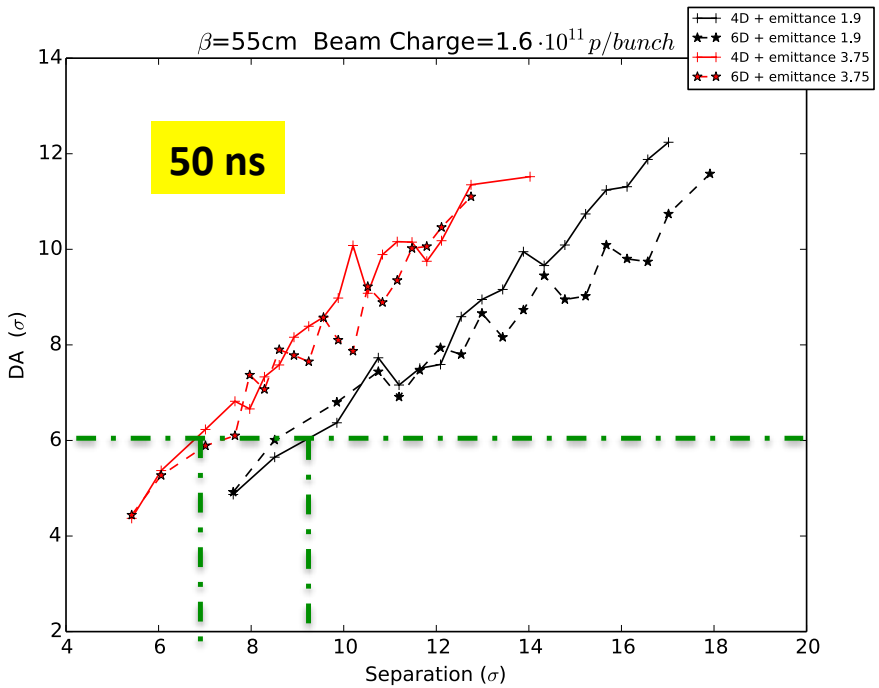
- ★ *200MHz-80bunch allows to dream of 4000fb^{-1}*
- ★ Peak pile up may be mitigated with β^* leveling, crab kissing or tolerated thanks to precision timing.

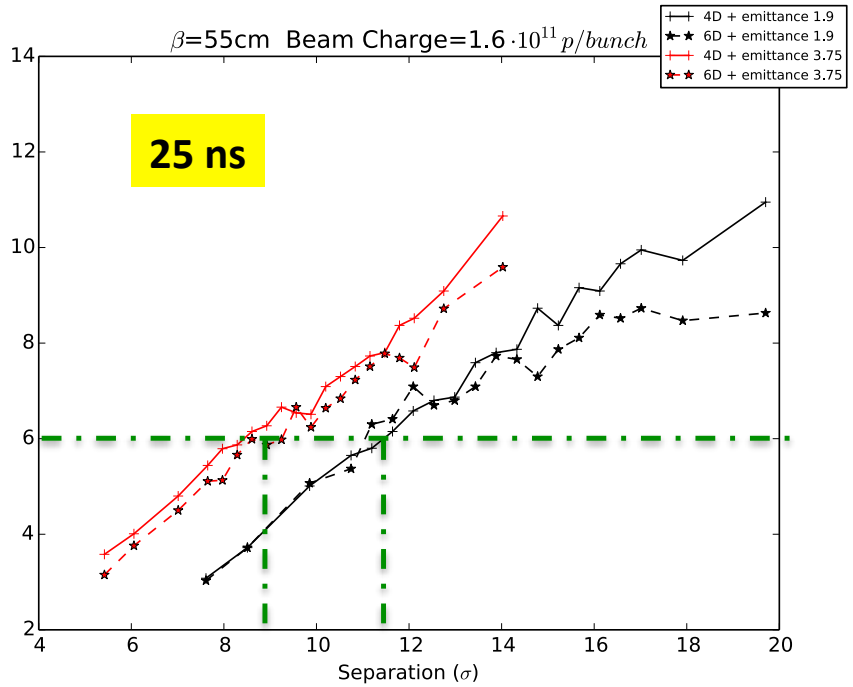
Back-up slides

from T. Pieloni

50 ns versus 25 ns beams

25 ns beams have 38 Long range encounters from IP1&IP5
50 ns beam will have 50% of them (16 LRs)





Roughly 2 σ more separation needed from 50 ns to 25 ns to ensure same 6 DA
If we have 70% of LR (8b+4e filling schemes) we can reduce the BB separation by 1.4 σ
In Crossing angle : 590 μrad → 520 μrad

Gain from β^*=0.1m in baseline

Turn-around time is 187 minutes. Nominal bunch length σ_z=7.5cm. θ= 12σ @ β^*=0.15m.

	N 10^{11}	ϵ [μm]	$\beta^*_{x,y}$ [cm]	$L_{year}[fb^{-1}]$ Opt.	6h	fill [h]	Pile-up	[$\frac{1}{mm}$]
β^*=15cm	2.2	2.5	15,15	258	229	9.3	140	1.24
β^*=10cm	2.2	2.5	10,10	**266**	229	10	140	**1.37**

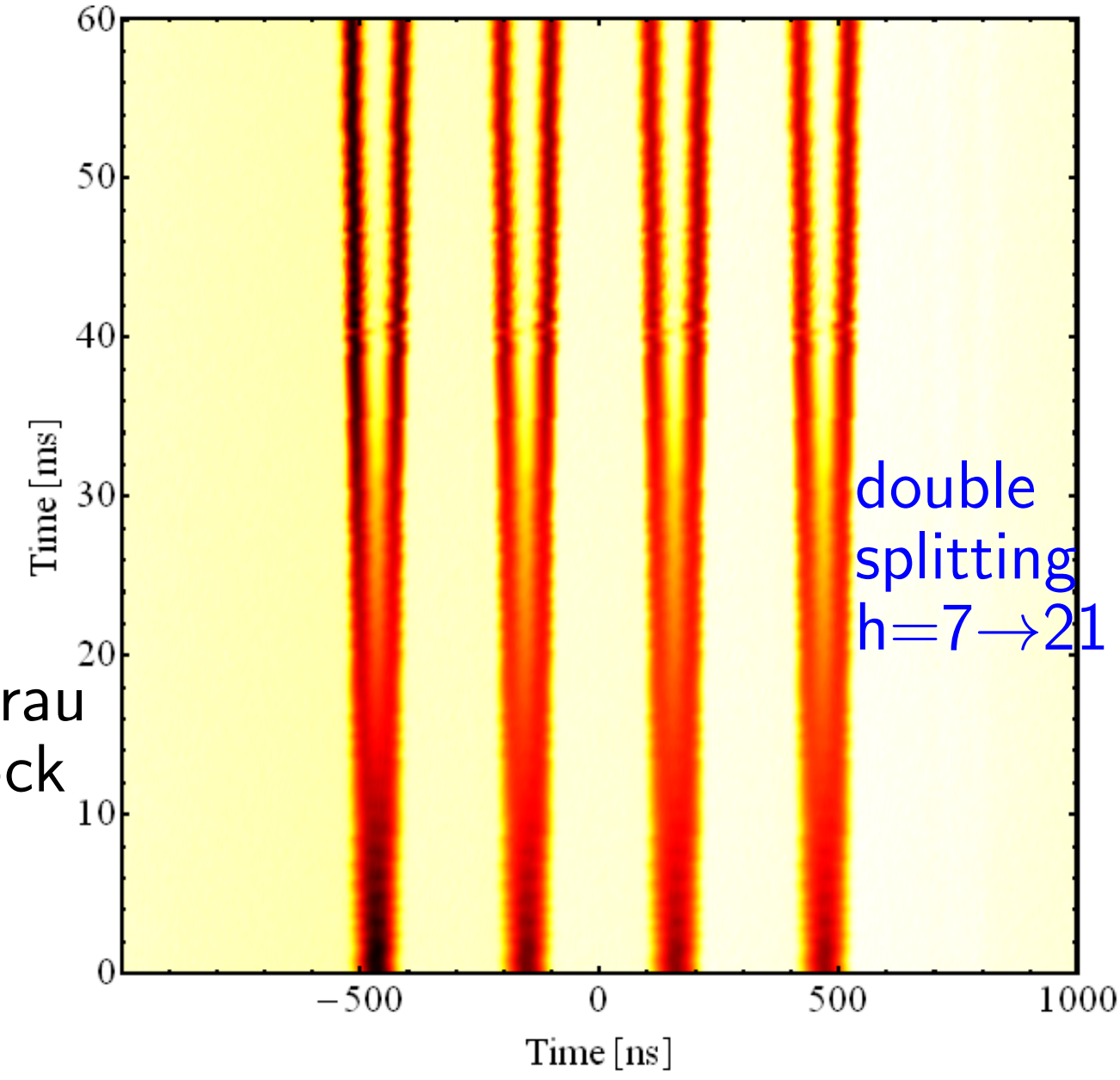
Reducing β^* to 10cm increases performance by 3% and peak pile-up density by 10%.

e-cloud unbearable: the 8b+4e solution

- ★ Double splitting instead of triple splitting in the PS for *more* bunch charge and 2/3 bunches. A PSB bunch becomes (in the PS):

- ★ In the LHC: 1960 bunches with 2.3×10^{11} ppb
- ★ Merits: Significantly lower e-cloud, no cost
- ★ First PoP experiments in the PS!

8b+4e: First PoP experiments in the PS



H. Damerau
S. Hancock
9/2014

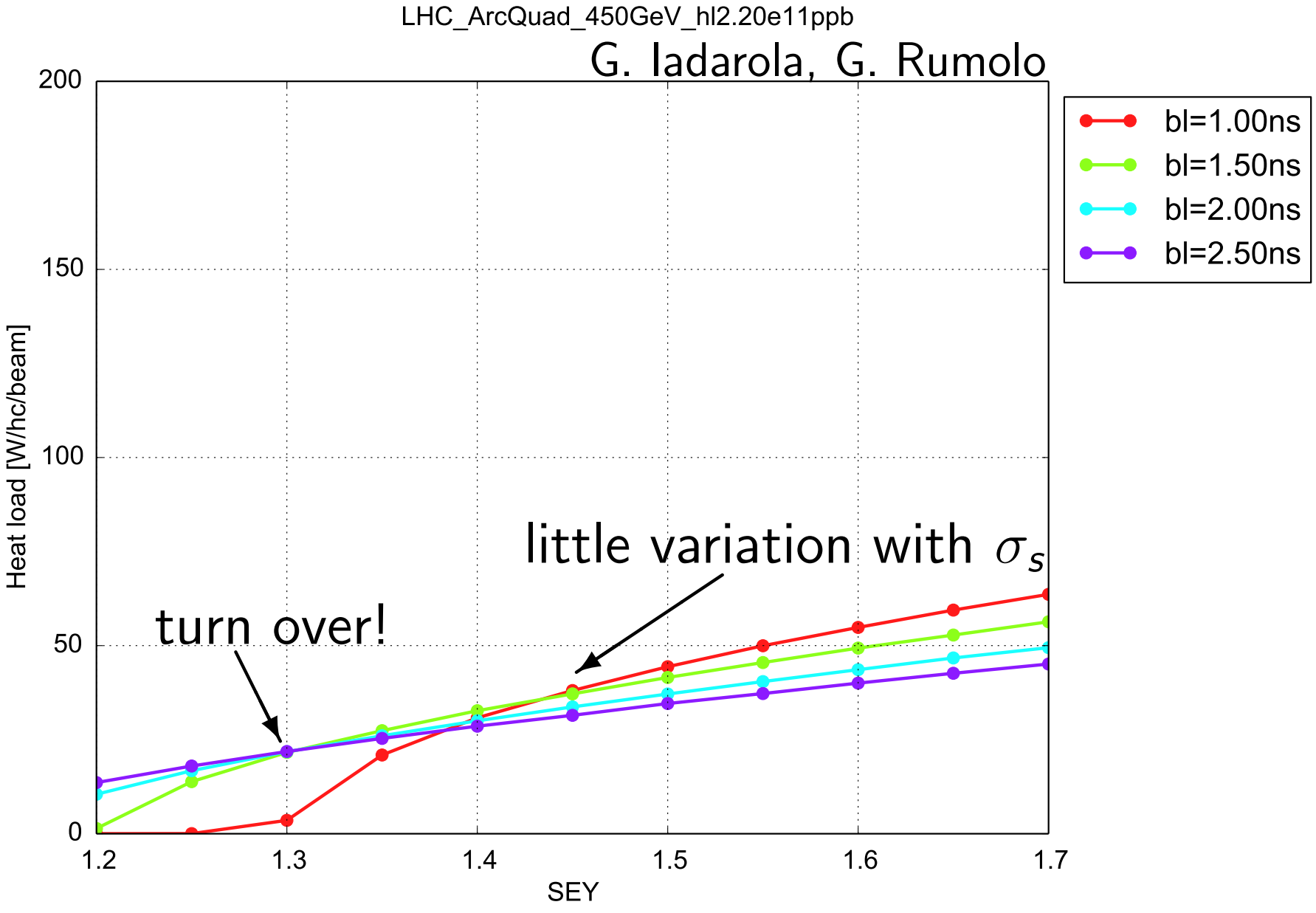
Assumptions

- ★ Efficiency is 50% and it is defined as

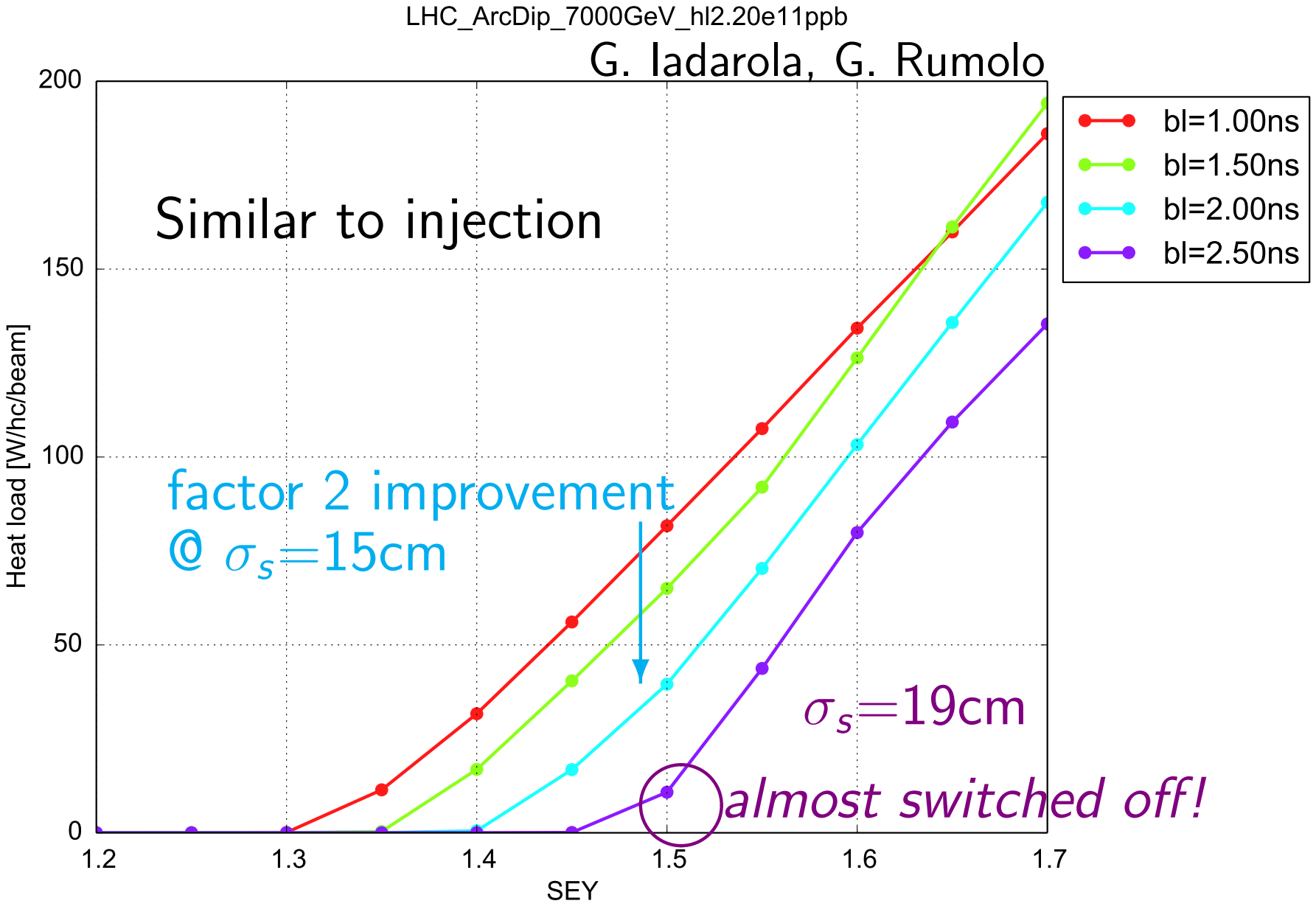
$$N_{fills}\frac{T_{fill}+T_{turn-around}}{T_{run}}$$

- ★ Average fill length is either optimum or 6 hours.
- ★ Turn-around of 187 minutes
- ★ US2 crossing angle is 12 σ,
- ★ US2 goal was 270 $fb^{-1}y^{-1}$

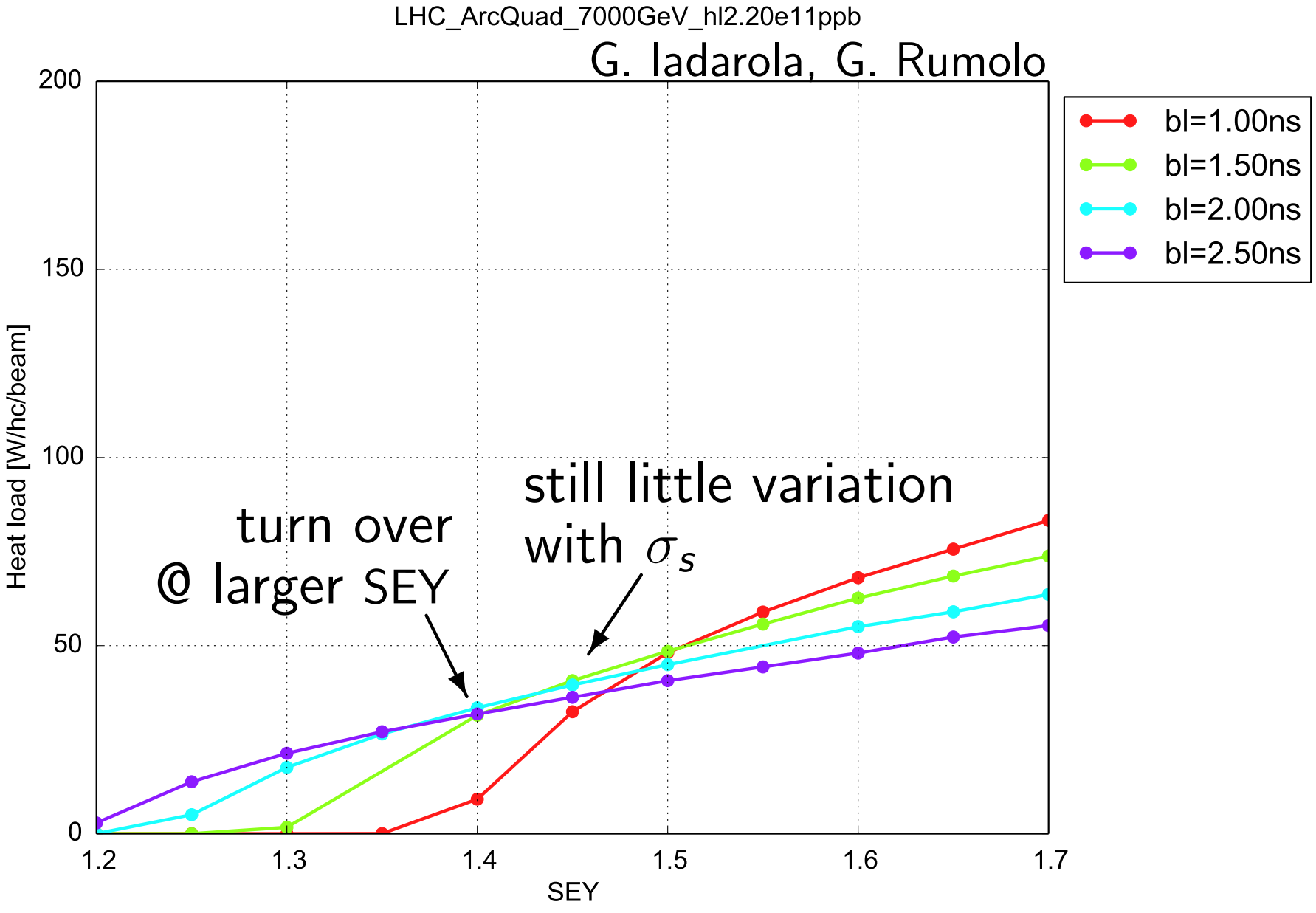
200 MHz: e-cloud in quadrupoles, inj.



200 MHz: e-cloud in dipoles, 7 TeV



200 MHz: e-cloud in quadrupoles, 7 TeV



Beam-beam tuneshift with CCs: new formula

J. Barranco

$$\Delta Q = \int_0^\infty dw \int_{-\infty}^\infty dz$$

$$\frac{\beta_x^* N r_p \left(1+\frac{z^2}{\beta_x^{*2}}\right)^2 e^{-\frac{\gamma^2 z^2}{2\gamma^2\sigma_z^2+w} - \frac{4\left(\frac{\theta}{2}\right)^2\left(-z+\frac{c\sin\frac{\omega_{cc}z}{c}}{\omega_{cc}}\right)^2}{2\sigma_x^2+w}}}{2\pi^{3/2}(2\sigma_x^2+w)^{3/2}\sqrt{(2\sigma_y^2+w)(2\gamma^2\sigma_z^2+w)}}$$

Flat beams (no wire): **leveling DA**

We have to make sure that DA$\geq 6\sigma$ throughout the leveling process!