BCMS beams for LHC run II: Luminosity reach and beam production

E. Métral, F. Antoniou, G. Arduini, H. Bartosik, X. Buffat, E. Benedetto, O. Berrig, M. Delonca, R. Folch, S. Gilardoni, M. Giovannozzi, G. Iadarola, J. Jowett, V. Kain, A. Lechner, F.X. Nuiry, Y. Papaphillipou, G. Rumolo, J. Uythoven, V. Vlachoudis, M. Zerlauth

- How is the "classical" BCMS beam prepared in PS?
- Beam parameters: BCMS vs. nominal
- What would be safe BCMS beams? => See also 1st talk
- How can these beams be prepared (reliably) in the injectors?
- Luminosity computations with IBS and SR & pile-up
- Potential transverse beam stability issues
- Conclusions

HOW IS THE "CLASSICAL" BCMS BEAM PREPARED IN PS?

BCMS "**B**atch **C**ompression, **M**erging and **S**plitting in PS"

LHC 25(50)ns alternative Production in PS

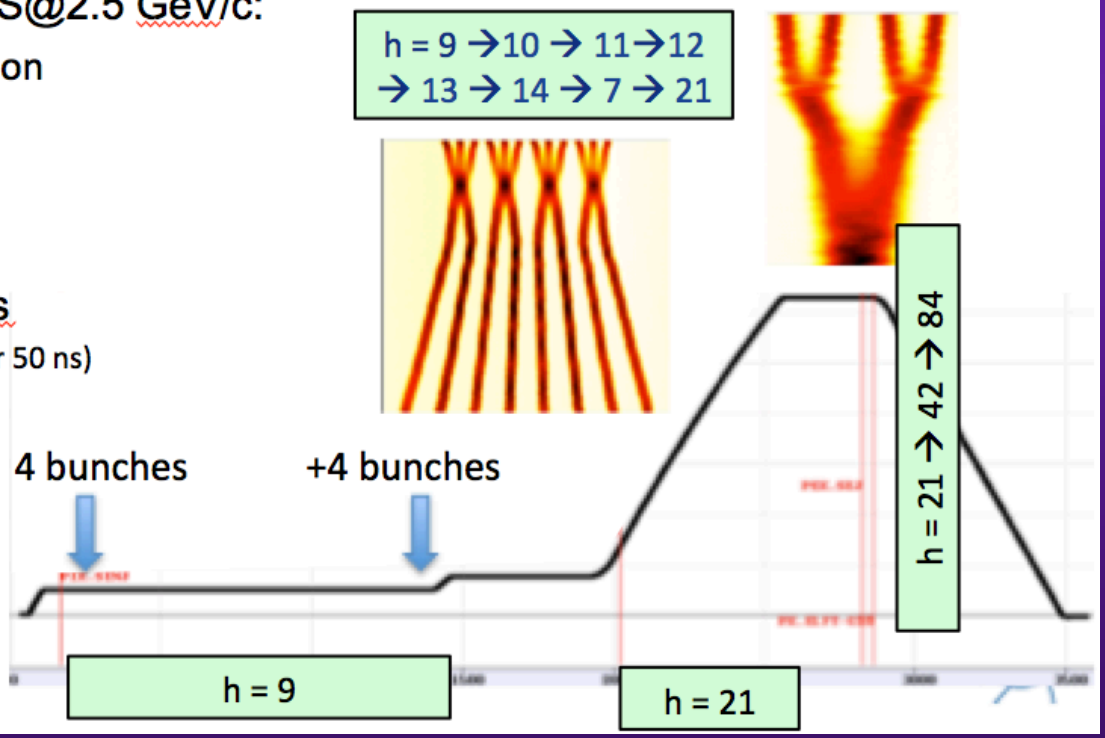
Production scheme:

a) Double batch injection from PSB (**4 + 4 bunches, 8 bunches for PS at h=9**)

b) Up to 5 batches of **48 bunches** each transferred to the SPS (240 bunches)

Transverse emittance produced in the PSB, longitudinal in the PS

- - Multiturn proton injection in PSB with **shaving**
- RF gymnastics in PS@2.5 GeV/c:
  - Batch compression
  - Bunch merging
  - Triple splitting
- Acceleration
- 2 x Double splittings
  (1 Double splitting for 50 ns)
- Bunch rotation



S. Gilardoni

BEAM PARAMETERS: BCMS VS. NOMINAL

	BCMS (Run II)	NOMINAL (Run II)
Bunch intensity N_b [10^{11} p]	1.3	1.2
Norm. rms. transv. emittance ε [μm]	1.4	2.6
Transv. brightness $B = N_b / \varepsilon$ [10^{11} p / μm]	0.93	0.46
# bunches / PS batch	48	72
# SPS batches (bunches) / LHC injection	1 (48), 2 (96), 3 (144), 4 (192), 5 (240), 6 (288)	1 (72), 2 (144), 3 (216), 4 (288)

=> Potentially, a factor ~ 2 could be gained in the luminosity, but

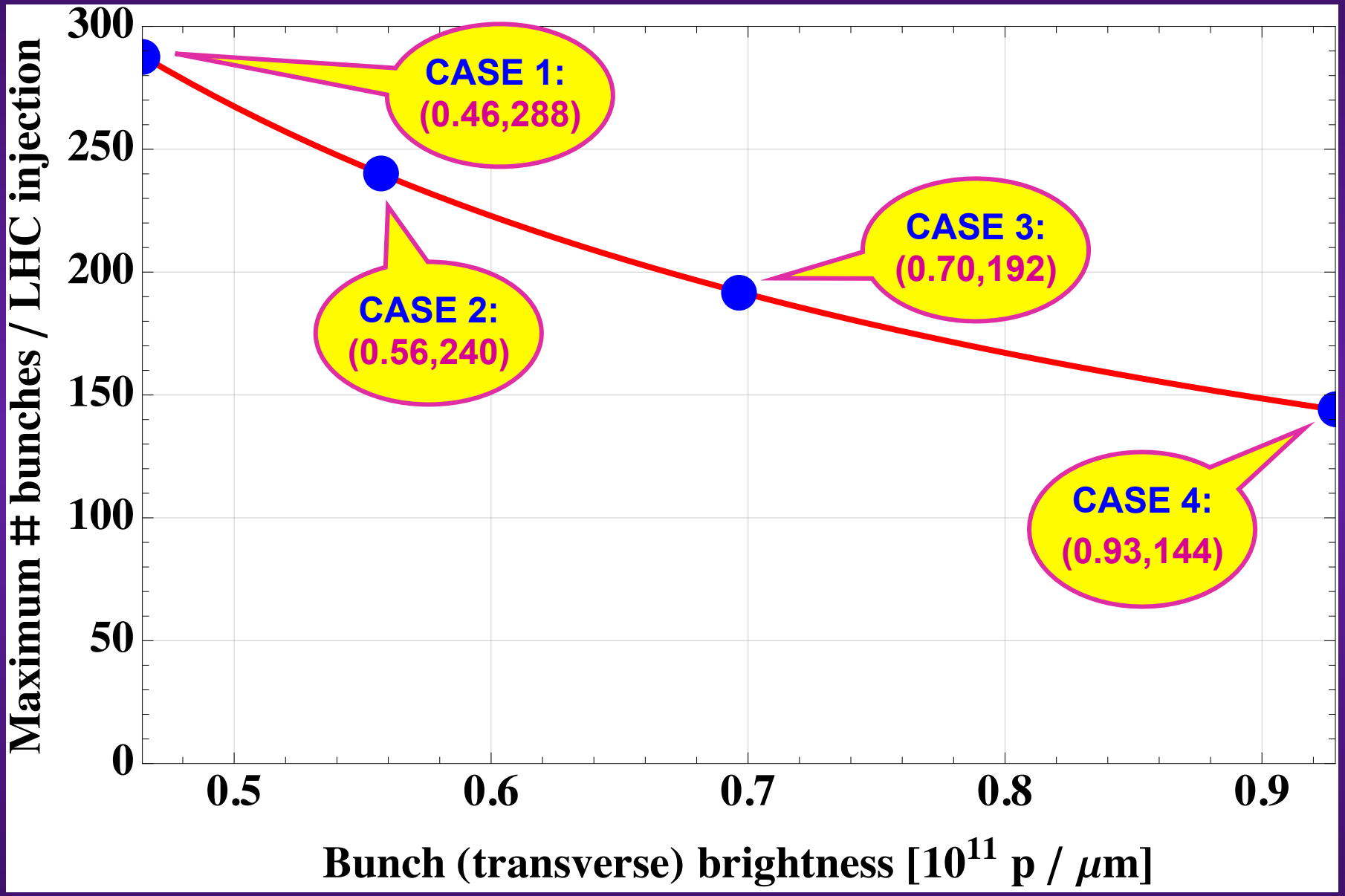
- What about machine protection? => See talk before and after
- What about IBS (and SR)?
- What about pile-up?
- What about (transverse) beam stability?

WHAT WOULD BE SAFE BCMS BEAMS? (1/2)

- **Starting point: Slides / Paper from V. Kain @ Chamonix14**
  - **Slides:** https://indico.cern.ch/event/315665/session/5/contribution/22/material/slides/0.pdf
  - **Paper:** https://indico.cern.ch/event/315665/session/5/contribution/22/material/paper/0.pdf

- **Conclusions (see also 1st talk)**
  - **Most critical case: collimators in the injection transfer line**
  - **Limit given by 144 bunches with BCMS brightness due to limit in attenuation for TCDI**
  - **Limit / LHC injection given by $M \times B$ with M total # of bunches / LHC injection ($= 144 \times 0.93 \approx 134$)**

WHAT WOULD BE SAFE BCMS BEAMS? (2/2)



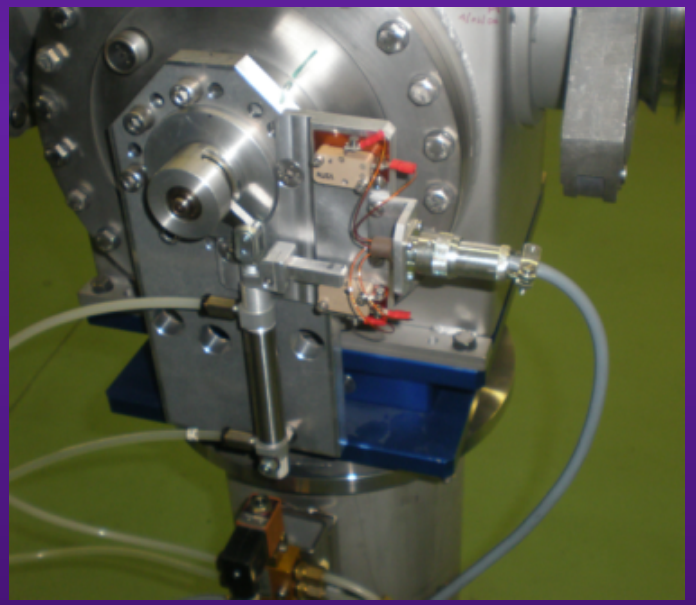
HOW CAN THESE 4 CASES BE PRODUCED RELIABLY IN THE INJECTORS? (1/4)

- CASE 1 = Nominal beam => OK
- CASE 4 = "Classical" BCMS beam => Need to interlock the # of SPS bunches sent to the LHC (could be done with the total intensity in SPS => See next talk)
- CASES 2 and 3 = BCMS beams with decreased brightness => Need to increase the transverse emittance… Should be easy… BUT there are several constraints
  - Controlled way
  - Reliability
  - Core-emittance blow-up (i.e. not increasing the tails)
  - With a method which can be interlocked => It is difficult if this should rely on a transverse emittance measurement

HOW CAN THESE 4 CASES BE PRODUCED RELIABLY IN THE INJECTORS? (2/4)

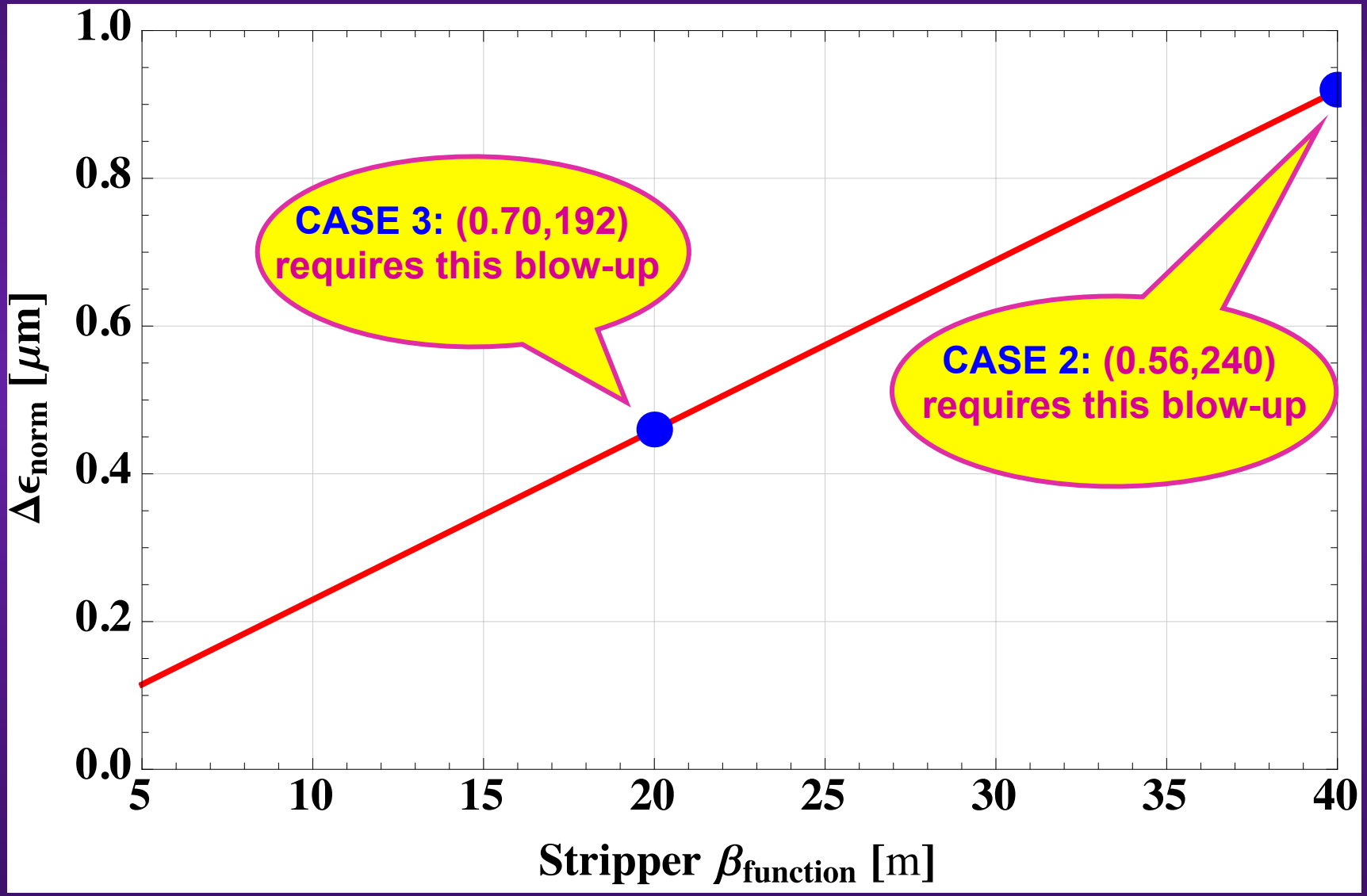
=> Proposition from M. Giovannozzi: use the current TT2 ion stripper (i.e. an Al foil of 0.8 mm thickness)

- **Actuation system => Position sensors for the foil have been moved outside of the tank**



S. Mataguez and R. Folch

HOW CAN THESE 4 CASES BE PRODUCED RELIABLY IN THE INJECTORS? (3/4)



HOW CAN THESE 4 CASES BE PRODUCED RELIABLY IN THE INJECTORS? (4/4)

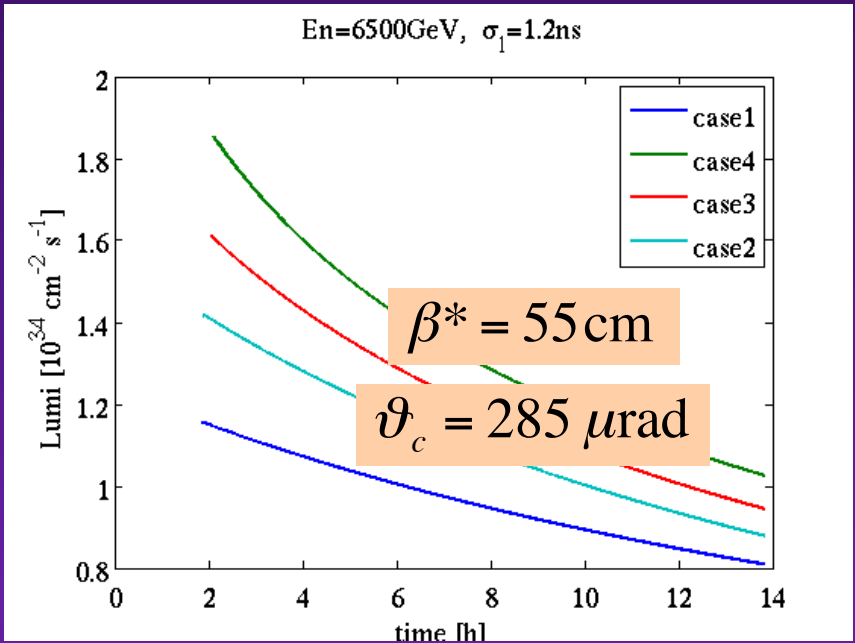
- **The optics solutions corresponding to the 2 proposed β-functions have been found compatibly with aperture and quadrupole strengths for the present stripper (O. Berrig and E. Benedetto)**
- **Preliminary results of the thermo-mechanical analysis (by EN/STI - R. Folch et al.) show a safe margin under the specified proton beam conditions => See EDMS 1460247**
- **Activation was also checked and found to be OK (V. Vlachoudis)**
- ***Note that the injection mismatch option (betatron mismatch or injection offset or dispersion mismatch) has also been studied by E. Benedetto. The SPS transverse damper was also discussed***

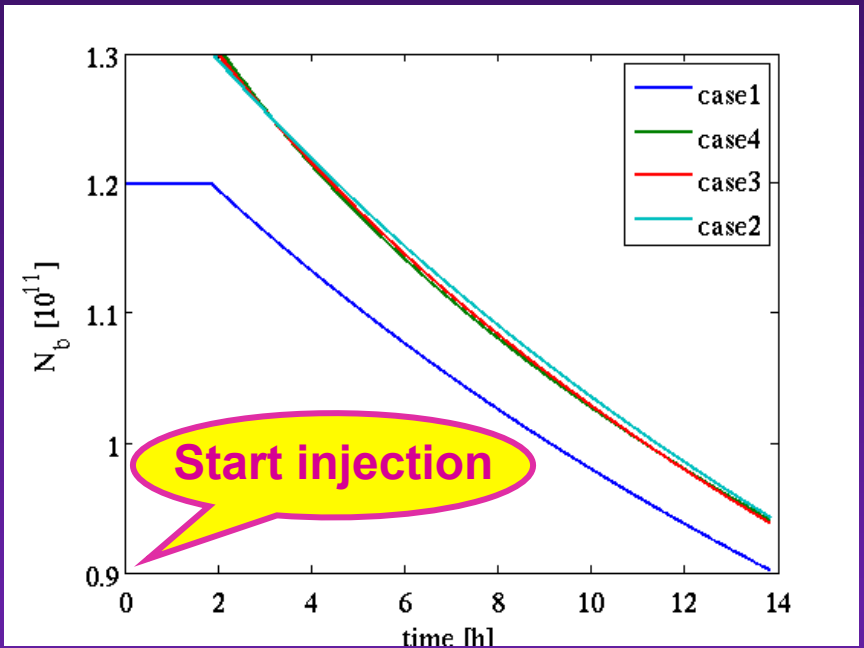
LUMINOSITY COMPUTATIONS (IBS and SR) & PILE-UP (1/3)

Case	N_b [10^{11}]	ε_n [μm-rad]	N_b/ε_n [10^{11}/μm]	n_b	# PS batches	bunches /train	# inject.
" Std25 " (case1)	1.2	2.6	0.46	2640	6	288	11
BCMS25 (case 2)	1.3	2.32	0.56	2592	5	240	12
BCMS25 (case 3)	1.3	1.86	0.70	2544	4	192	15
BCMS25 (case4)	1.3	1.4	0.93	2448	3	144	18

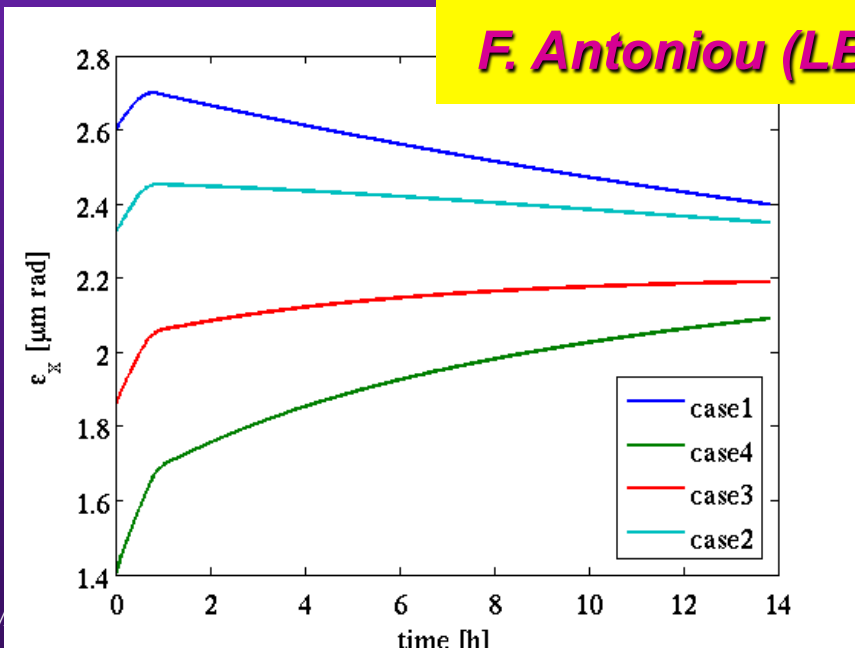
Instead of 2736
=> ~ 4% less bunches

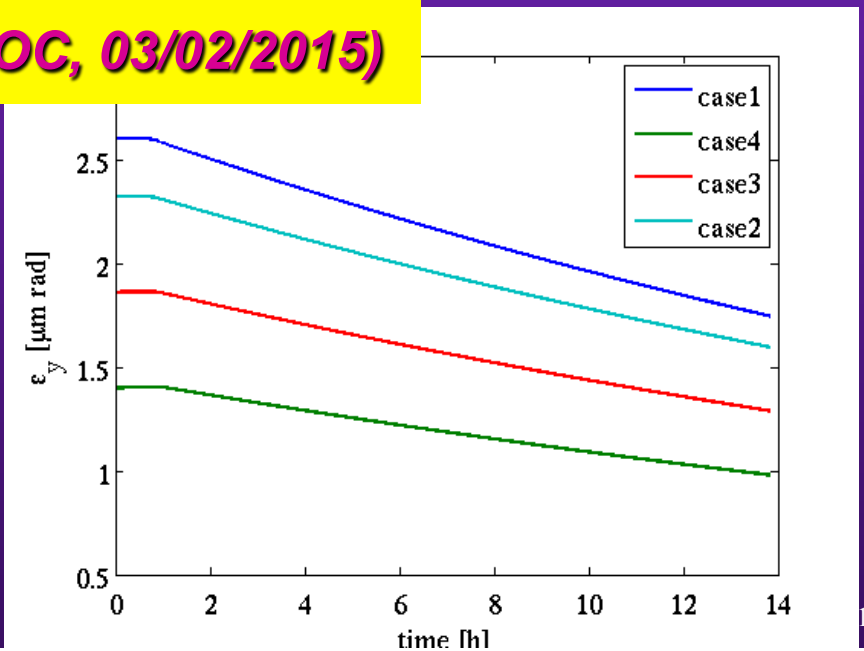
LUMINOSITY COMPUTATIONS (IBS and SR) & PILE-UP (2/3)





F. Antoniou (LBOC, 03/02/2015)





LUMINOSITY COMPUTATIONS (IBS and SR) & PILE-UP (3/3)

	Case1	Case2	Case3	Case4
Integrated Lumi per day [fb^{-1}/day]	0.88	1.04	1.15	1.27
Increase in Brightness [%]	Ref	22	52	102
Gain in Lumi [%]	Ref	18	30	43

F. Antoniou (LBOC, 03/02/2015)

- **Pile-up:** $$PU = \frac{L \sigma_r}{n_b f_{rev}}$$ **85 mb**

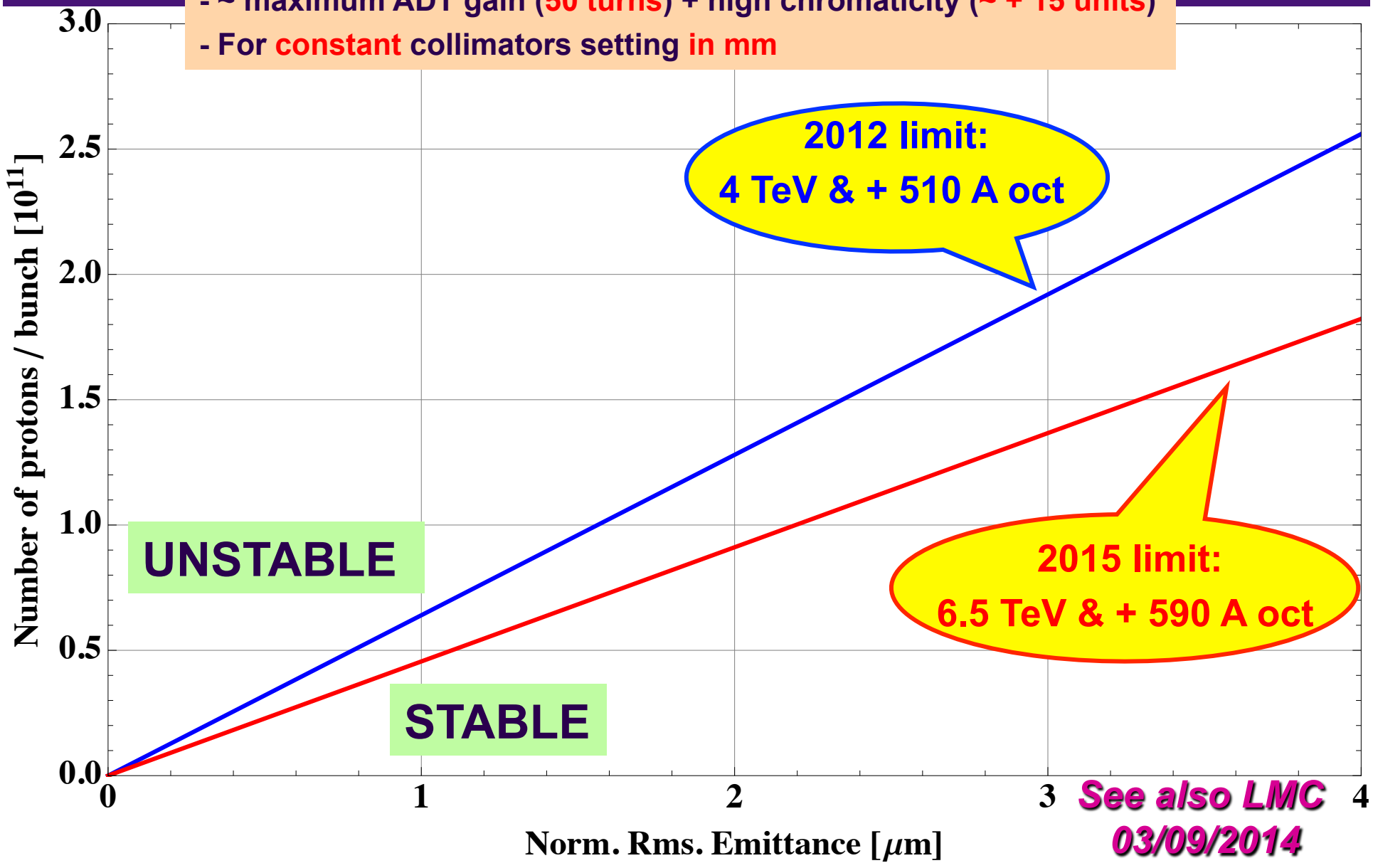
  = ~ 57 / 48 / 41 / 33 for Cases 4 / 3 / 2 / 1

  Some levelling would then be required for Case 4 (but the real Xing angle and β* should be bigger – see later => Should be OK)

- **Reminder: A maximum pile-up of ~ 50 is considered to be acceptable for ATLAS and CMS (see Chamonix2014's talk from EmilioM)**

POTENTIAL TRANSVERSE BEAM STABILITY ISSUES (1/2)

- For LOF > 0 (i.e. positive octupole amplitude detuning)
- ~ maximum ADT gain (50 turns) + high chromaticity (~ + 15 units)
- For constant collimators setting in mm



See also LMC 03/09/2014

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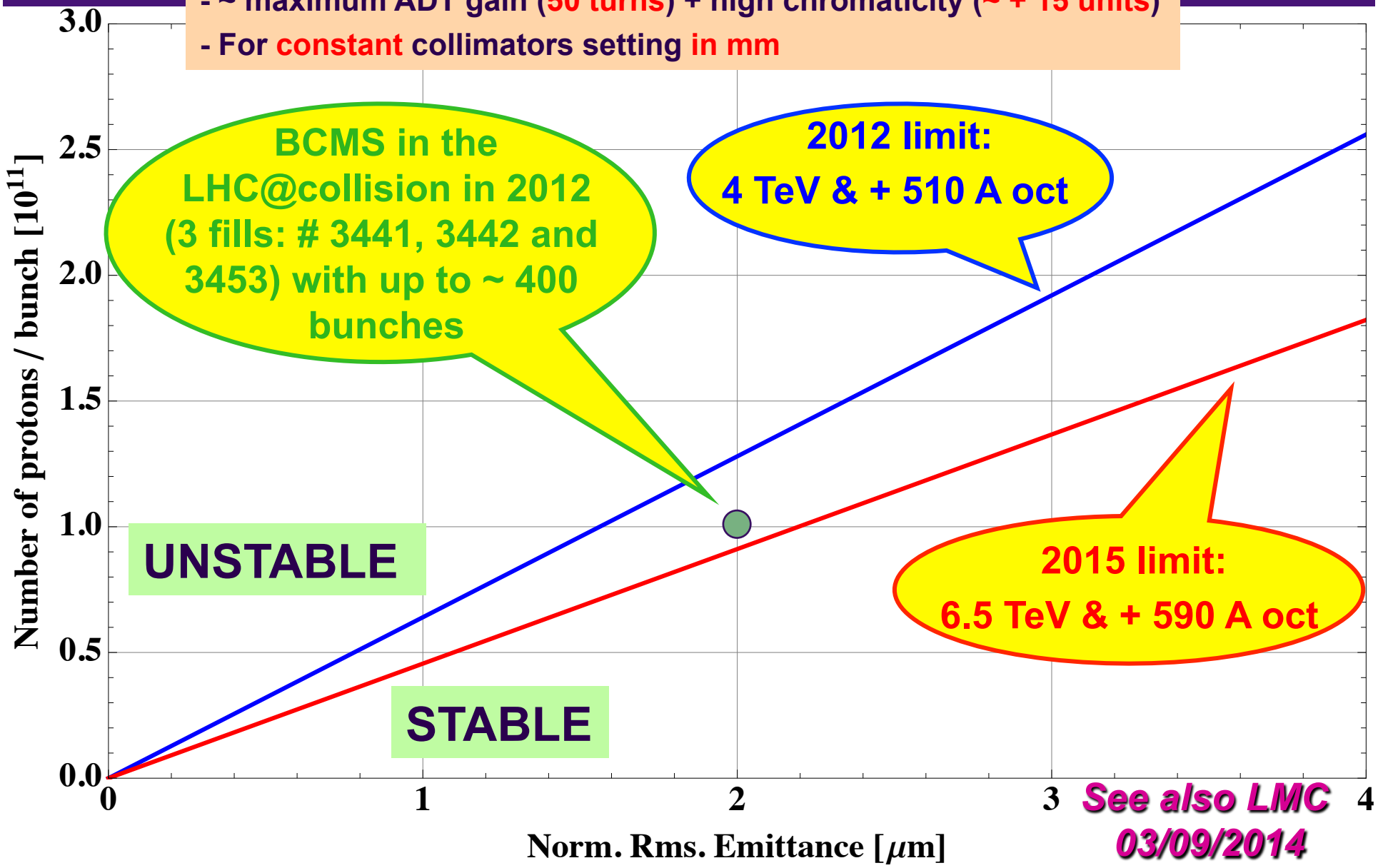

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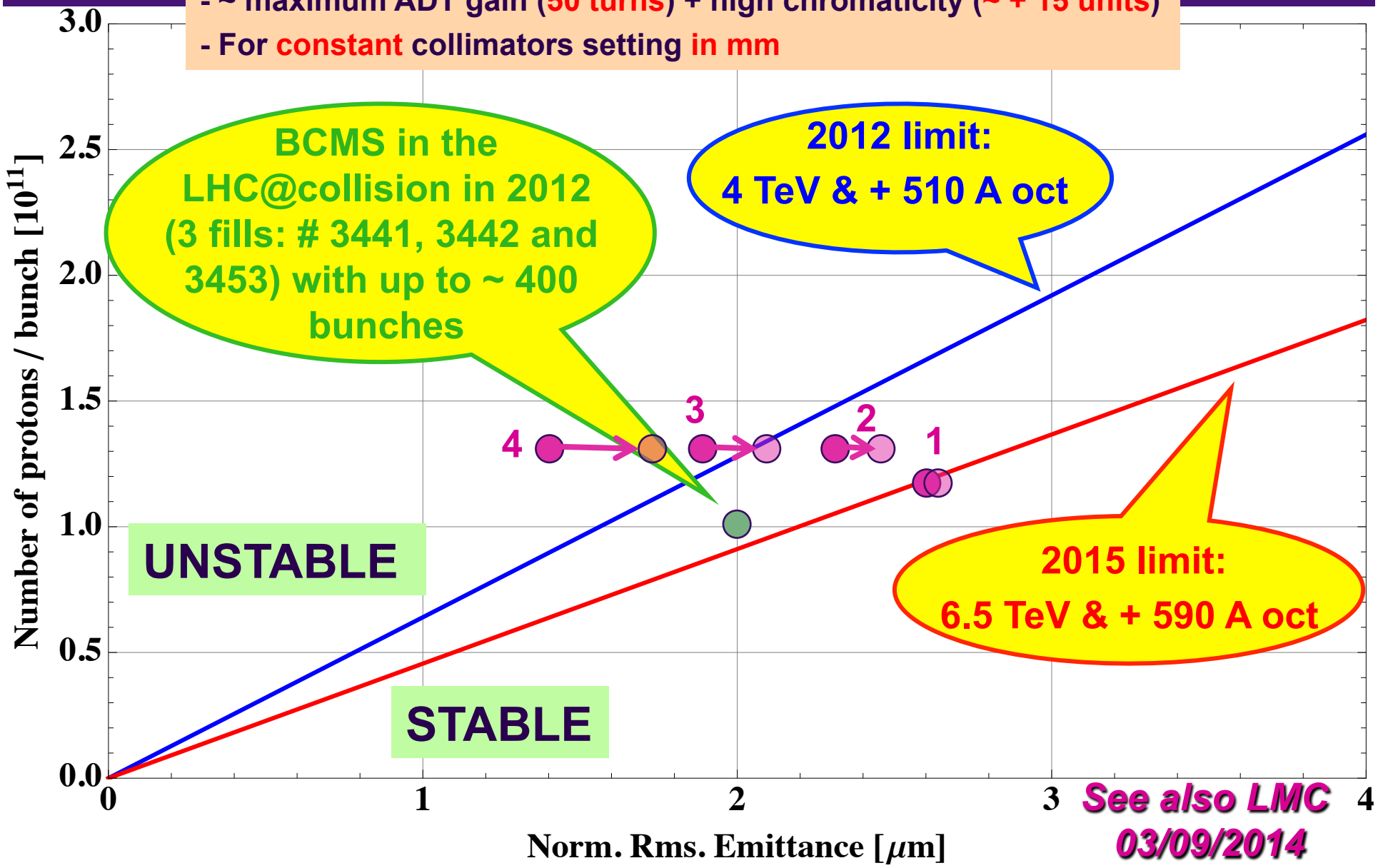
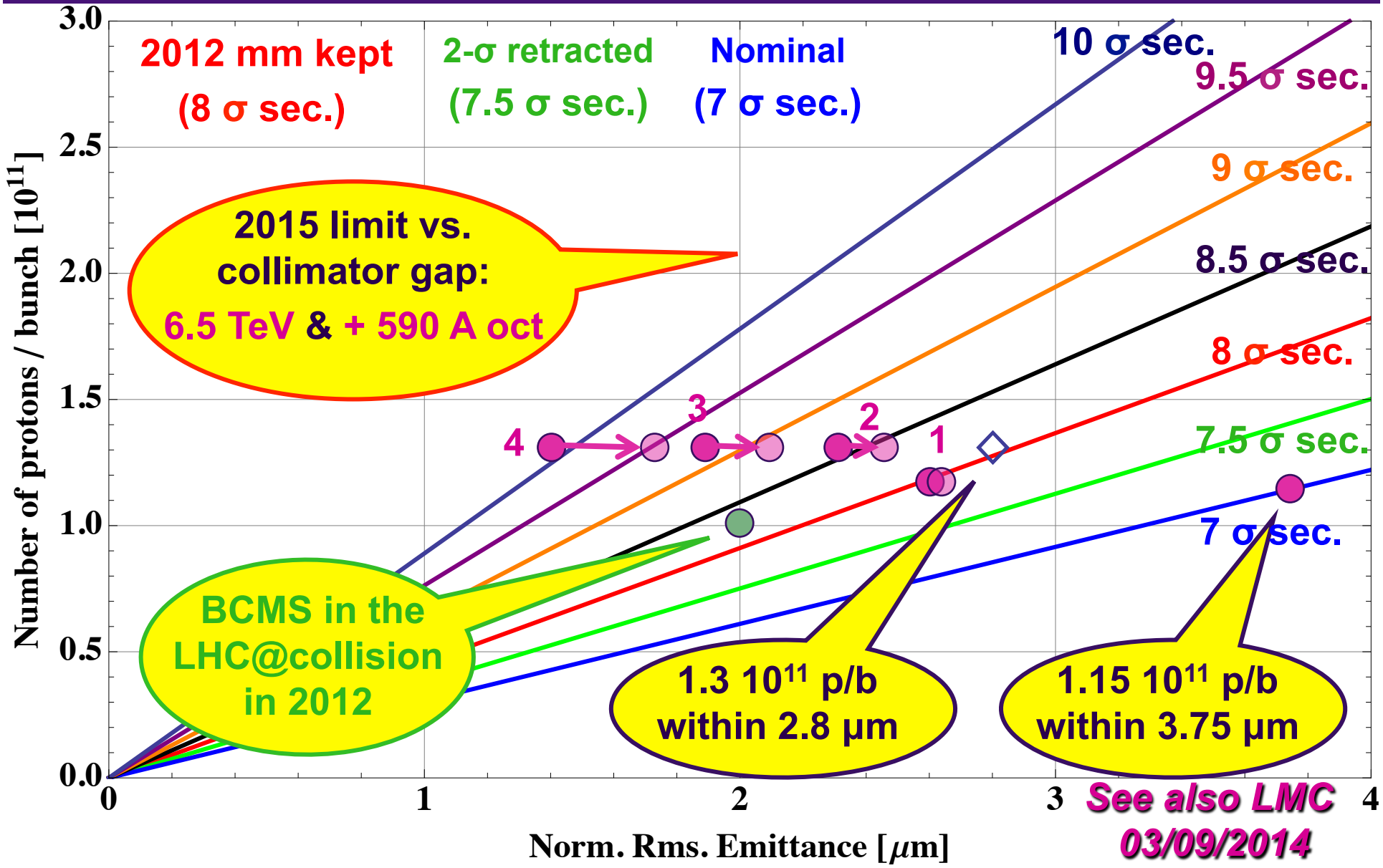


See also LMC 03/09/2014

POTENTIAL TRANSVERSE BEAM STABILITY ISSUES (2/2)



See also LMC 03/09/2014

CONCLUSION (1/3)

- **3 BCMS beams could be used to try and push the LHC performance**
  - **Case 4 (max. *B*) => Potential lumi gain (with IBS&SR) of ~ 40%**
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- Cases 2 and 3 could be produced by using the TT2 ion stripper AND limiting the SPS bunches per LHC injection to 240 and 192

CONCLUSION (2/3)

- **However, there are still 2 main issues**
  - **All these beams should be unstable / close to instability (V more critical than H)**
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=> In summary, the maximum expected luminosity gain with the BCMS beam (Case 4), with respect to the nominal 25 ns beam at lowest β^*, should be of the order of ~ 10% => To be checked with beam…

CONCLUSION (3/3)

- In our 2-stage approach for 2015 (starting with a β^* of ~ 75-80 cm), the BCMS beam could be used as an alternative to the 2nd step (instead of decreasing the β^*)

  => In this case, the sec. collimators should be set to ~ 10 σ and a gain of ~ 40% in integrated luminosity could be expected

Integrated lumi [fb^{-1} / day] from IBS&SR only	Case 1	Case 2	Case 3	Case 4
55 cm / 285 µrad	0.88	1.04	1.15	1.27
60 cm / 285 µrad	0.83	0.96	1.05	1.16
75 cm / 285 µrad	0.69	0.80	0.88	0.98
55 cm / 340 µrad	0.82	0.93	1.01	1.11
60 cm / 340 µrad	0.76	0.88	0.95	1.04
75 cm / 340 µrad	0.65	0.74	0.81	0.89

F. Antoniou

NICOLASM'S DETAILED ANALYSIS (e.g. Evian2014) – 4/4

[σ with ε=3.5μm]	Relaxed settings	2012 mm kept	2 σ retraction
TCP IR7	6.7	5.5	5.5
TCSG IR7	9.9	8.0	7.5
TCSG IR6	10.7	9.1	8.3
TCDQ IR6	11.2	9.6	8.8
TCT IR1/5	13.1	11.5	10.7
aperture	14.6	13.4	12.3
β* (m)	**0.75**	**0.65**	**0.55 - 0.6**

Assumtion: 11 σ beam-beam separation for 3.75 μm emittance

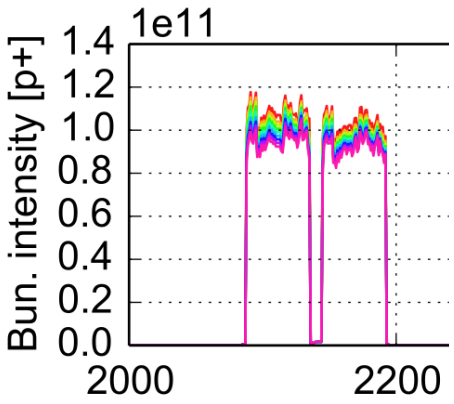
- "2 σ retraction" means TCSG IR7 closer by 0.5 σ
- Nominal (design report) means TCSG IR7 closer by 1 σ (as they are at 7 σ)

RoderikB (Evian2014)

BCMS in the LHC@collision in 2012 (~ 10^{11} p/b within ~ 2 μm at start of collision) => See e.g. Giannil's PHD thesis – chap. 5.3.6 (3 fills in Dec. 15 to 17: # 3441, 3442 and 3453)

G. Iadarola (PHD thesis)

B2 Fill. 3453 started on Sun,



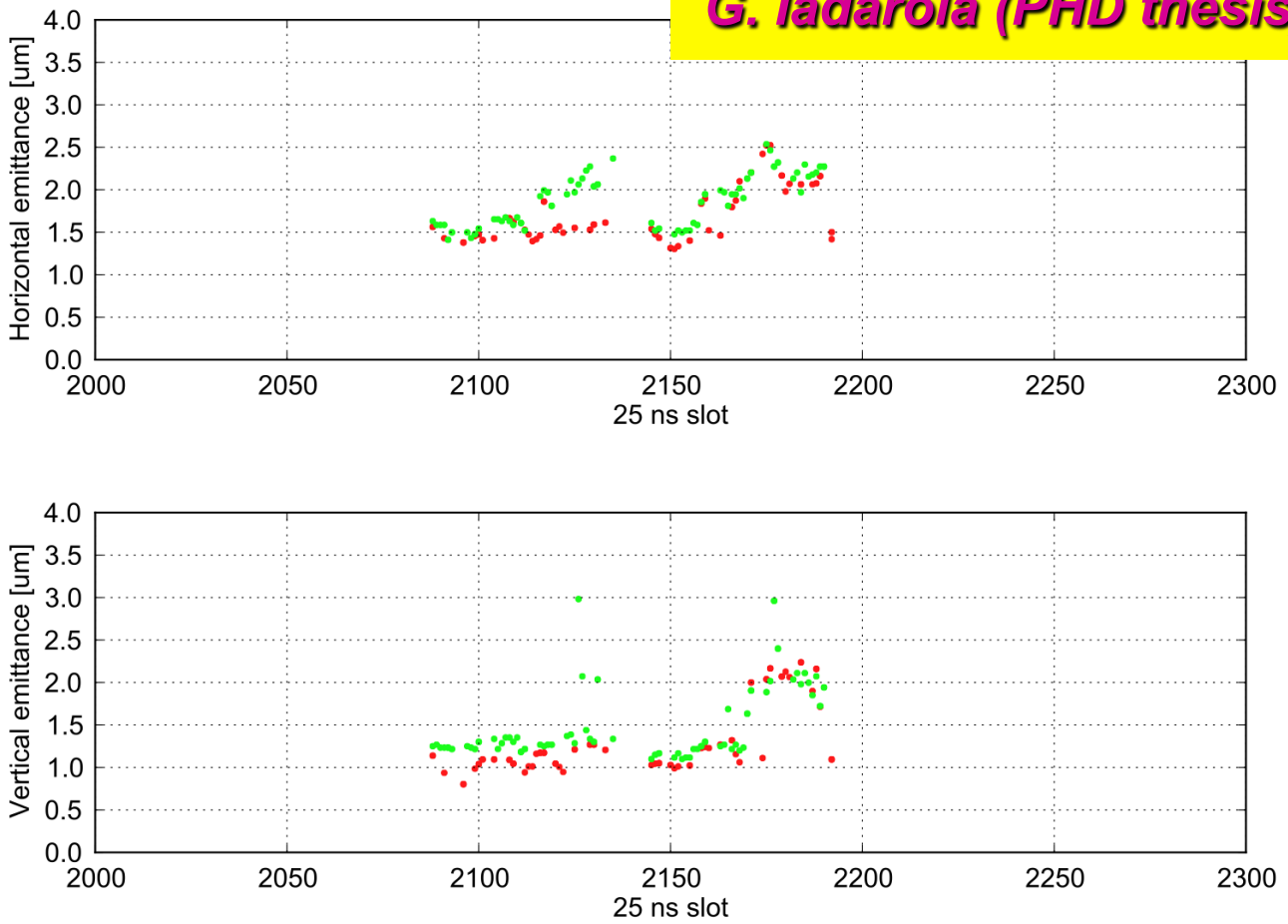
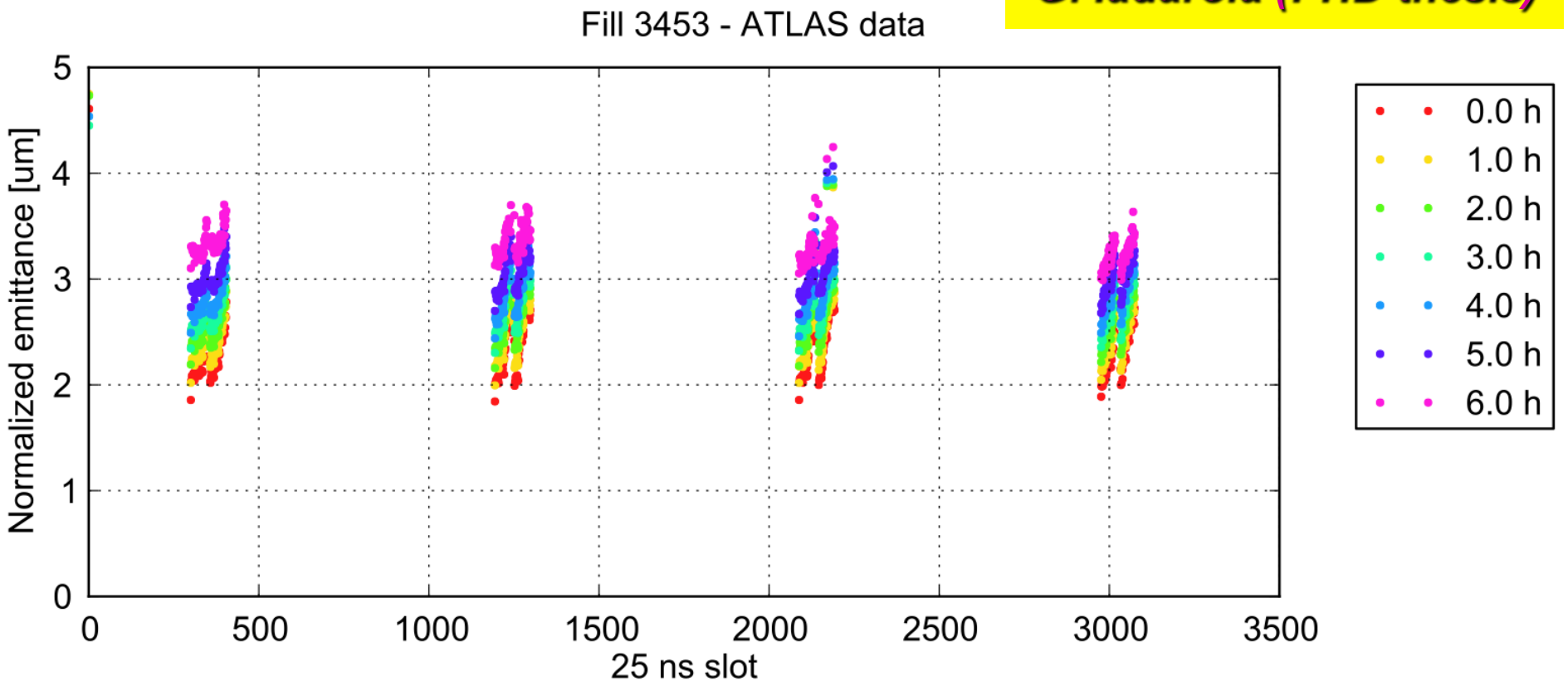
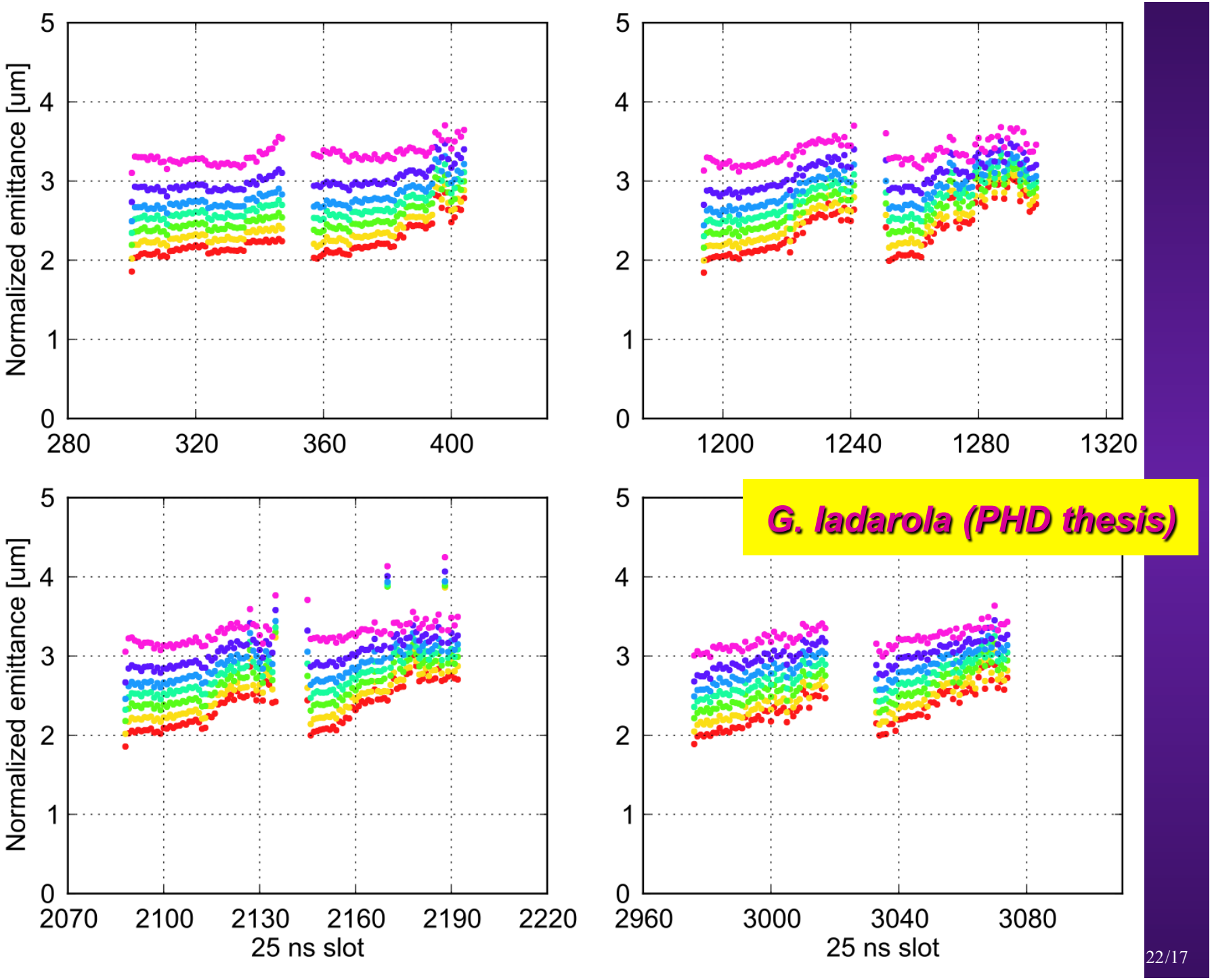


Figure 5.42: Bunch-by-bunch transverse measured by the BSRT before (red) and after (green) the energy ramp of the fill 3453 (the fill with 396 bunches in Fig. 5.31).

G. Iadarola (PHD thesis)




Normalized emittance [um]
0
1
2
3
4
5
280
320
360
400
1200
1240
1280
1320
2070
2100
2130
2160
2190
2220
2960
3000
3040
3080
25 ns slot
G. Iadarola (PHD thesis)