Optics needs for LHC

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AOC workshop

February 5, 2015

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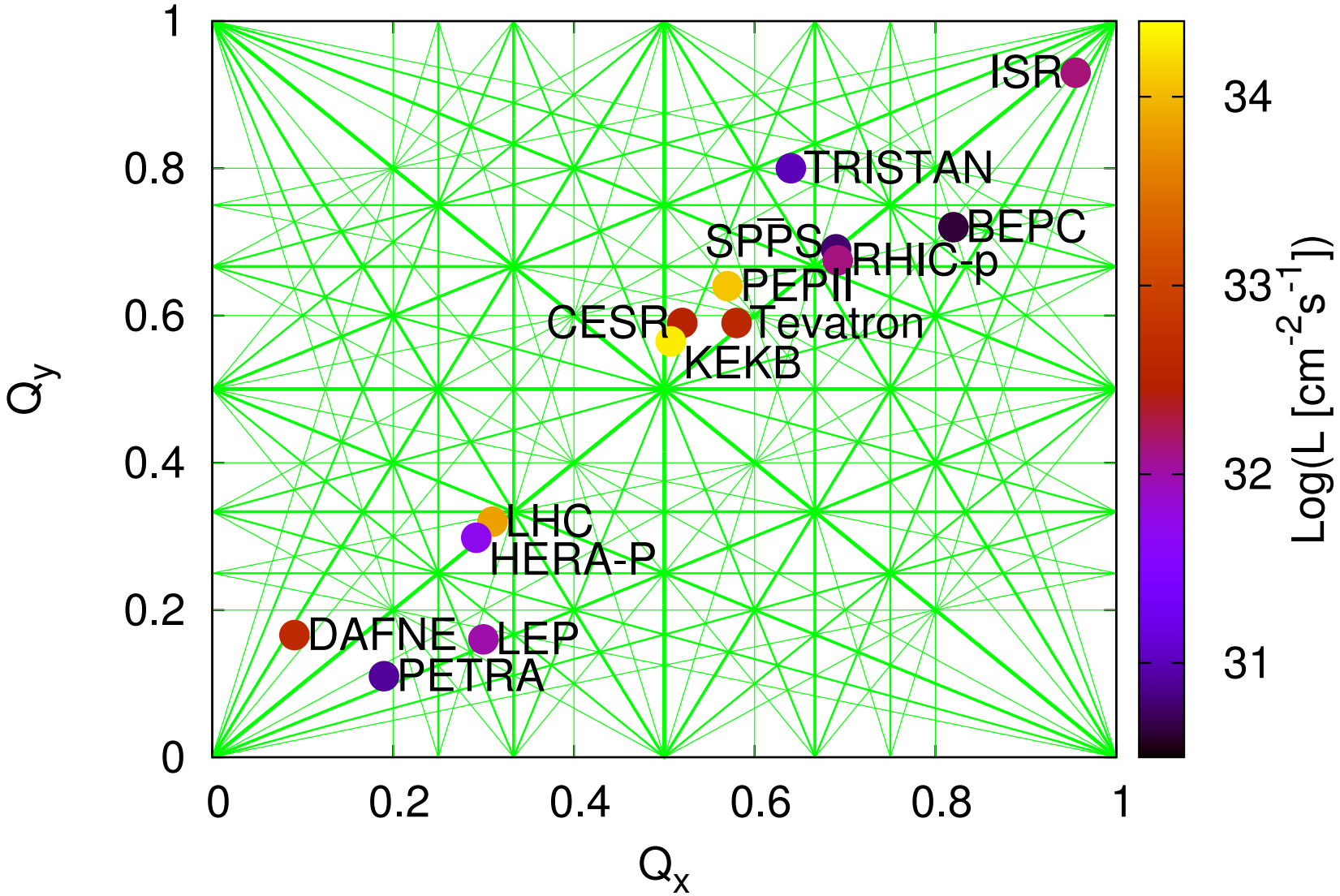
- ★ LHC plans and limits
- ★ Optics control challenges
- ★ 2012 and getting ready for 2015
- ★ The upgrade: HL-LHC

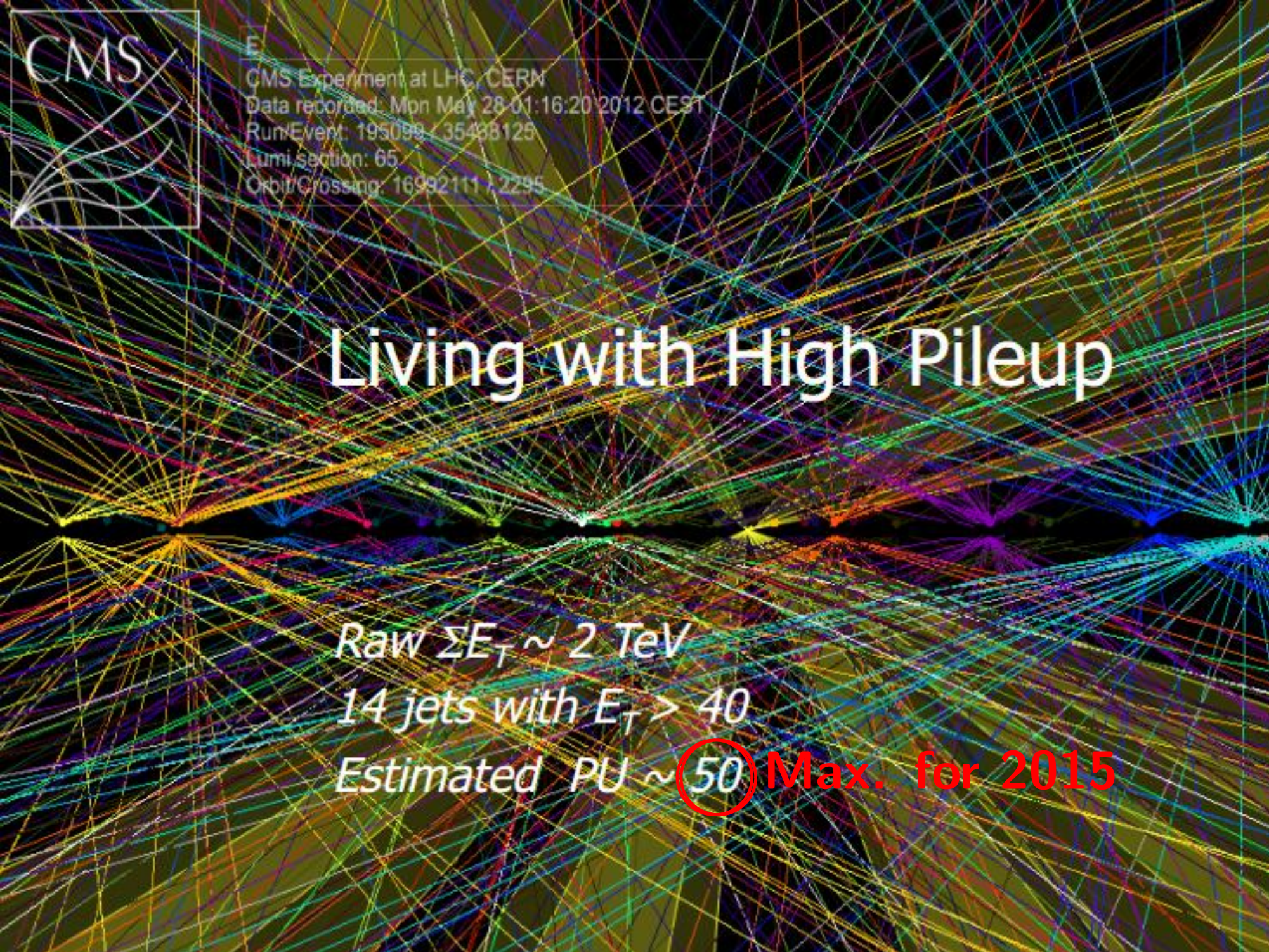
Colliders in the tune space



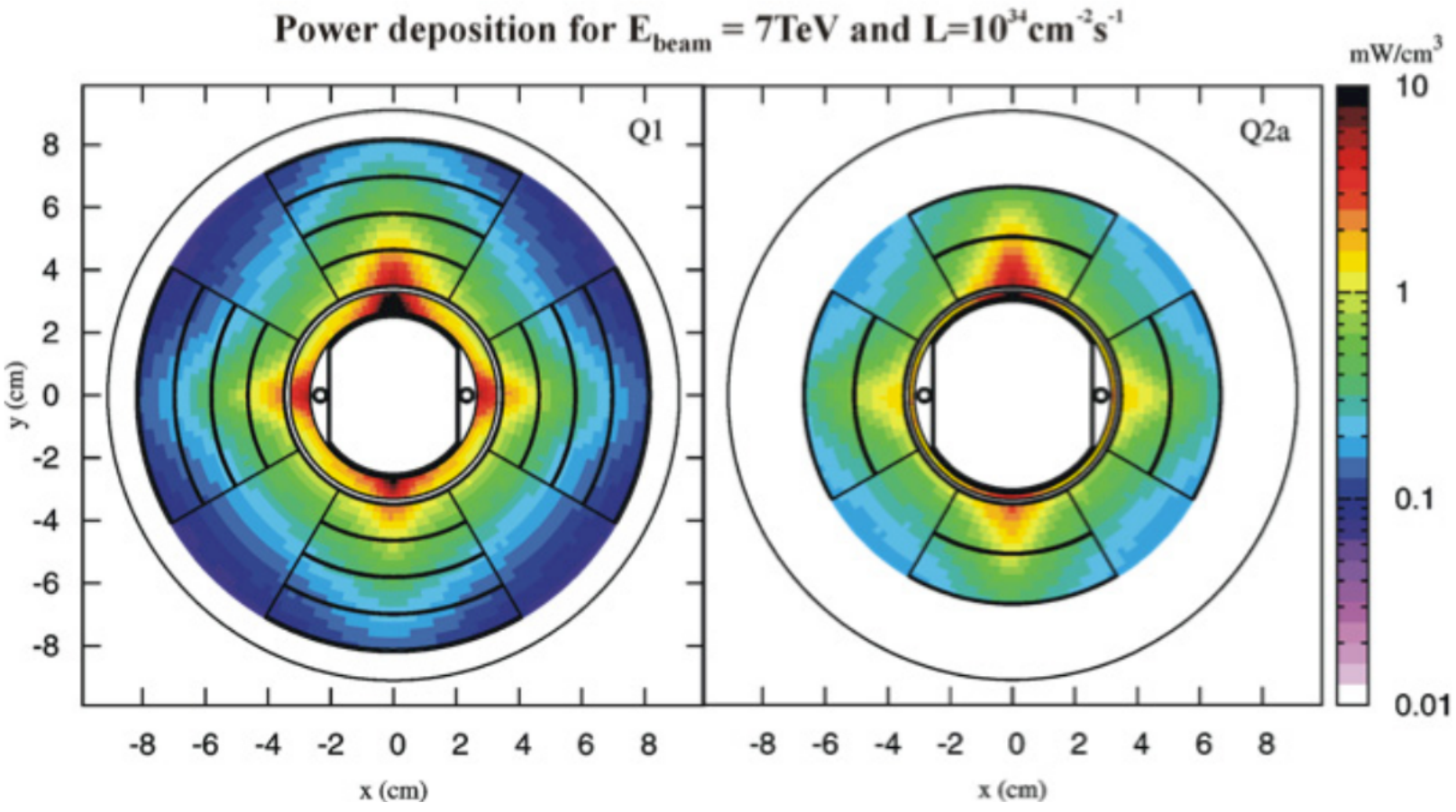
The winner is KEKB with $2.1\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, near $Q_x \approx Q_y \approx 0.5$

Can LHC beat KEKB?

- ★ SuperKEKB might need another 2 years to produce large luminosities (see Sugimoto's talk)
- ★ LHC has a window of opportunity
- ★ **What will limit the LHC performance?**

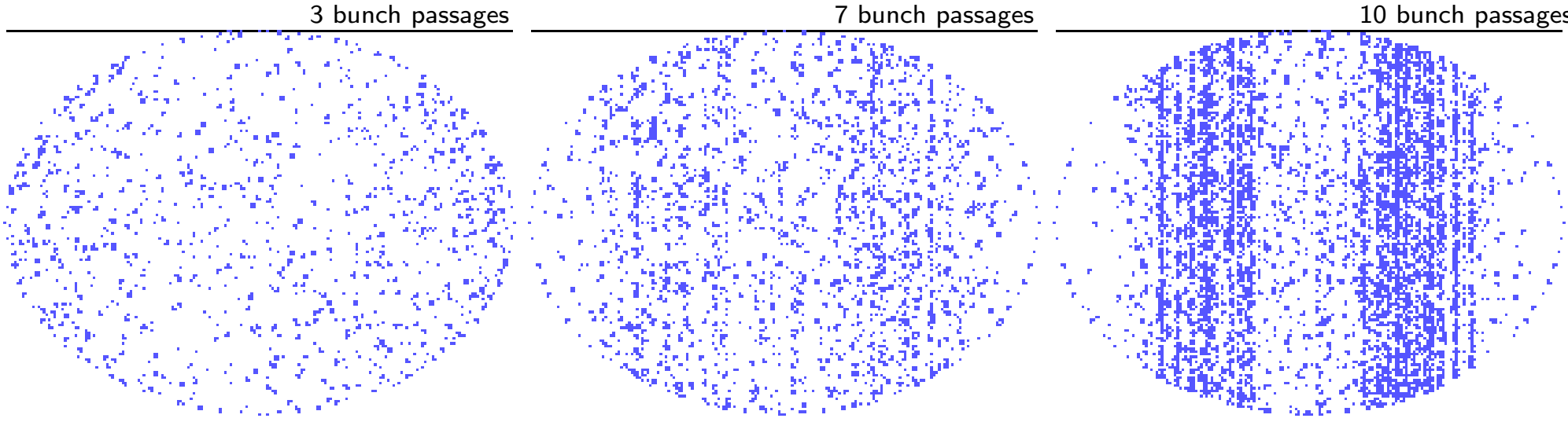

CMS
E
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 354388125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295
Living with High Pileup
Raw ΣE_T ~ 2 TeV
14 jets with E_T > 40
Estimated PU ~ 50
Max. for 2015

Heat load in the triplet quads



- ★ Limitation in the triplet heat exchanger bayonet
- ★ Luminosity $\lesssim 1.75 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$,
- ★ this lumi corresponds to ≈50 PU events!

Electron cloud



- ★ e-cloud heat load and instabilities pose the largest threats for LHC nominal operation
- ★ Fallback solution would be to reduce number of bunches by $\gtrsim$30% increasing bunch charge
- ★ This needs luminosity leveling to limit PU
- ★ and smallest β^* for max integrated luminosity

β^* reach in 2015

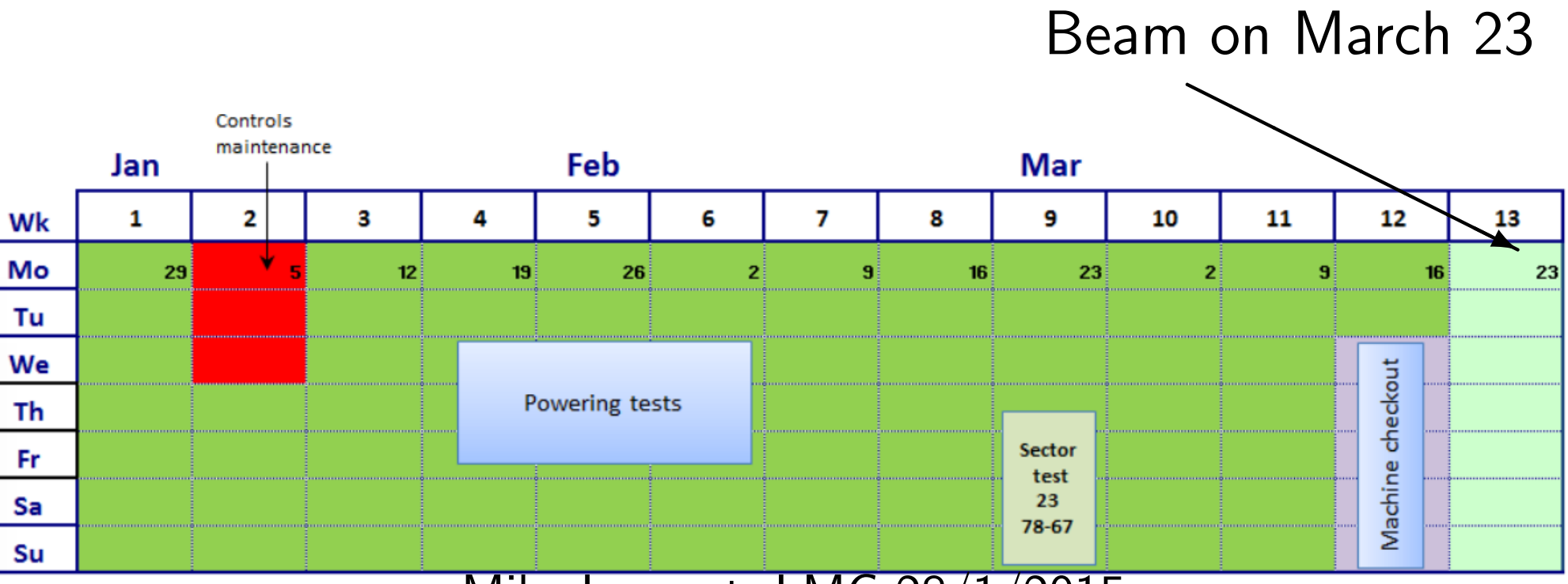
11 σ BB sep, ε =3.75 μm , 1.15×10^11 ppb — Baseline

β* (sep/cross)	Half angle	Aperture	L (10^{34} cm^{-2} s^{-1})	
80/80 cm	145 μrad	13.8 σ	0.65	relaxed start
40/40 cm	205 μrad	9.5 σ	1.0	
30/40 cm	205 μrad	9.5 σ	1.2	

10 σ BB sep, ε =2.5 μm , 1.15×10^11 ppb — Pushed

β* (sep/cross)	Half angle	Aperture	L (10^{34} cm^{-2} s^{-1})	
40/40 cm	150 μrad	11.0 σ	1.6	
31/31 cm	170 μrad	9.0 σ	1.8	*New!*
25/40 cm	150 μrad	9.0 σ	2.0	

When is LHC starting?



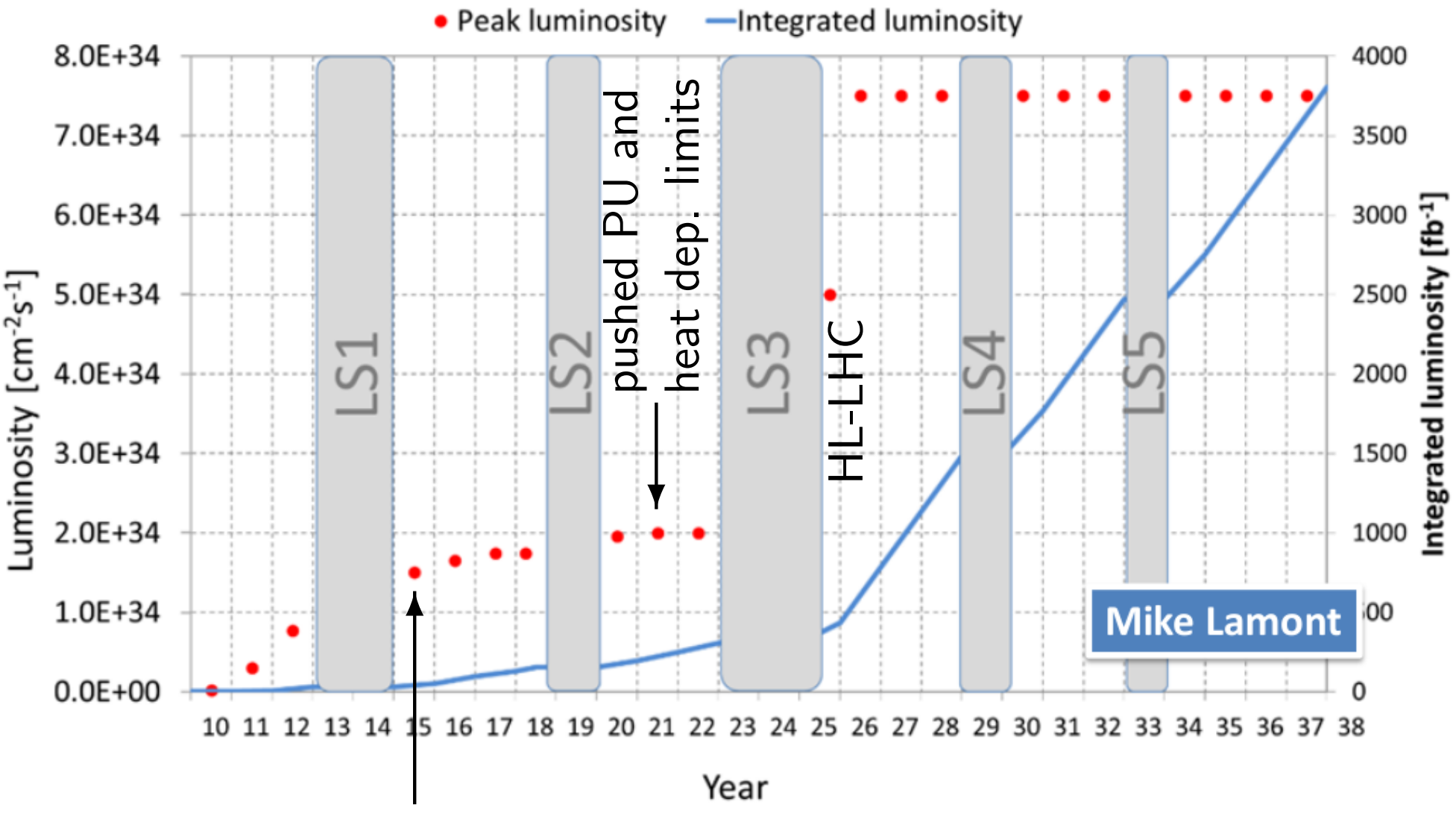
Mike Lamont, LMC 28/1/2015

LHC tasks for 2015

Initial Commissioning	*New optics*	56
Scrubbing (for 50 and 25 ns)		23
Early LHCf/VdM1	*New optics*	5
Proton physics 50 ns		**9 + 19**
Proton physics 25 ns – phase 1		**30**
Change in beta*	*New optics*	**5**
Proton physics phase 2 (including ramp-up)		**48**
Special physics runs (TOTEM/VdM2) Intermediate energy run - to be scheduled	*New optics*	7
MD	*New optics?*	15
Technical stops		15
Technical stop recovery		6
Ion setup/Ion run	*New E, New optics*	4 + 24

Mike Lamont, LMC 28/1/2015

Luminosity predictions

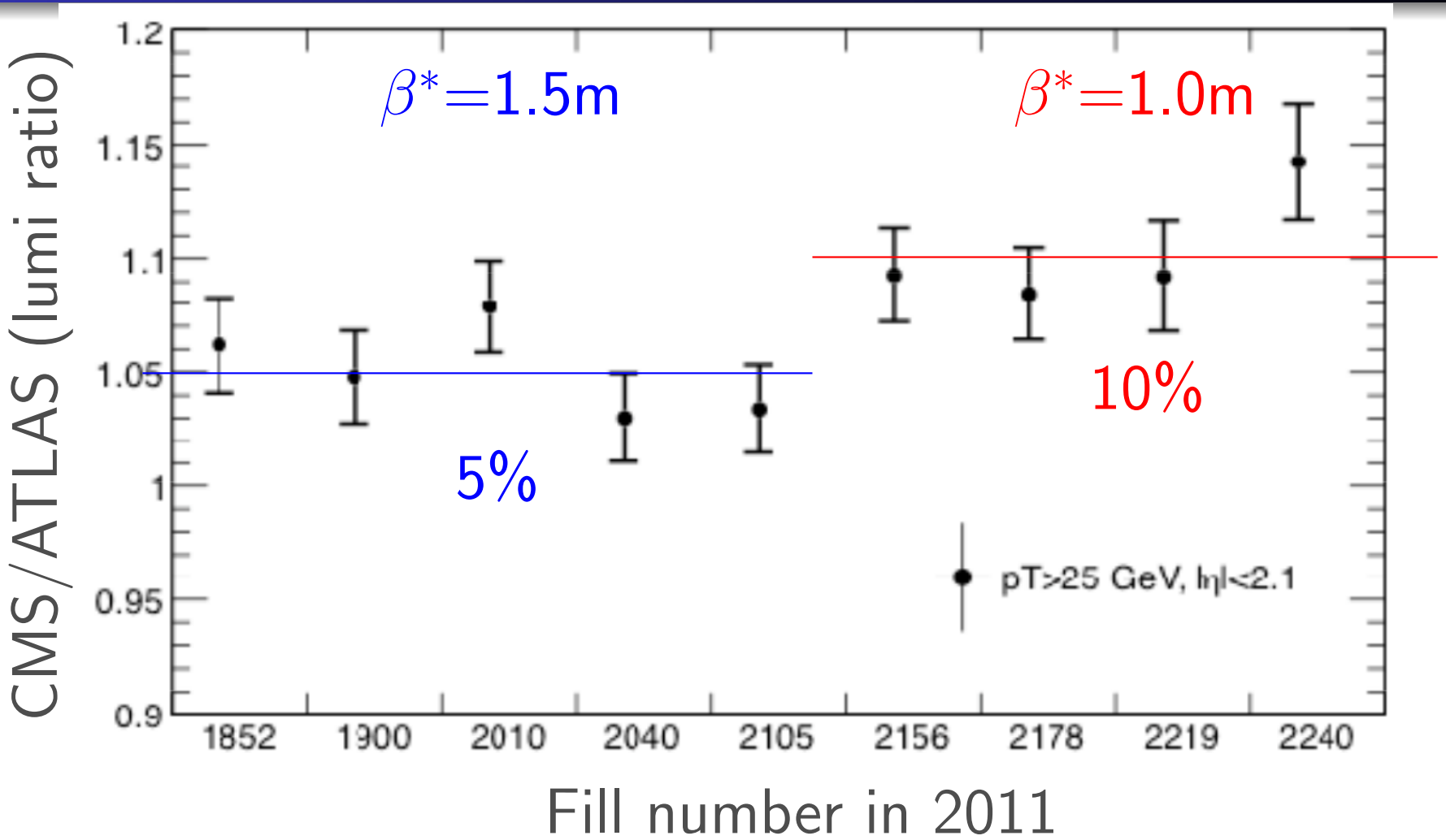


Pushed optics (or large charge) assumed for 2015!

Optics Control challenges

- ★ Optics corrections at low β^*
- ★ Accuracy and resolution
- ★ Dynamic Optics:
  - β^* leveling
  - Combined Ramp & Squeeze
  - Collide & Squeeze
- ★ Non-linear beam dynamics at low β^*

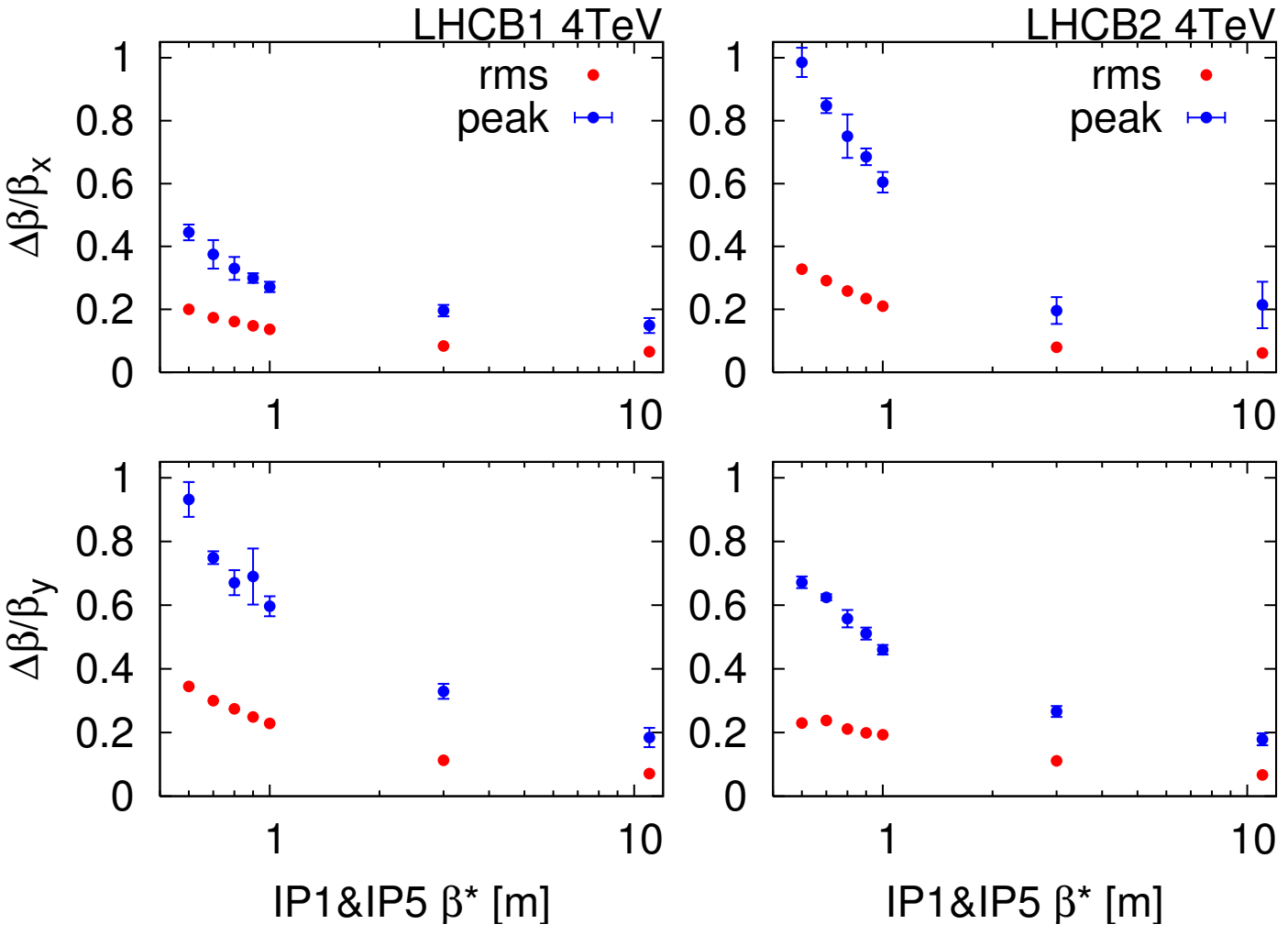
Luminosity imbalance CMS/ATLAS



Corrections only at β^* =1.5m. ATLAS was unhappy to get lower luminosity at β^* =1m

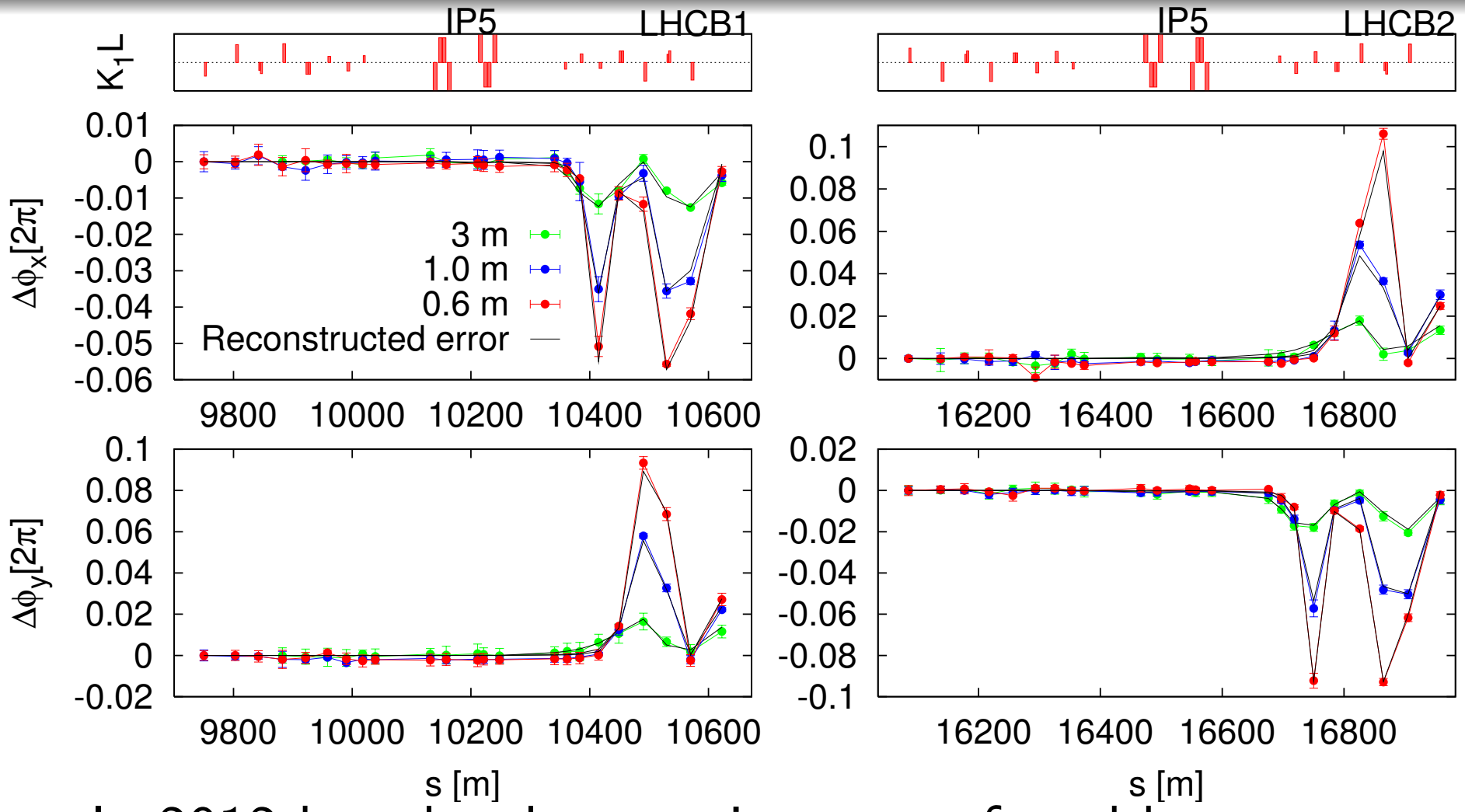
$\rightarrow$ Need optics corrections at all β^*.

Natural β-beating versus β^* in 2012



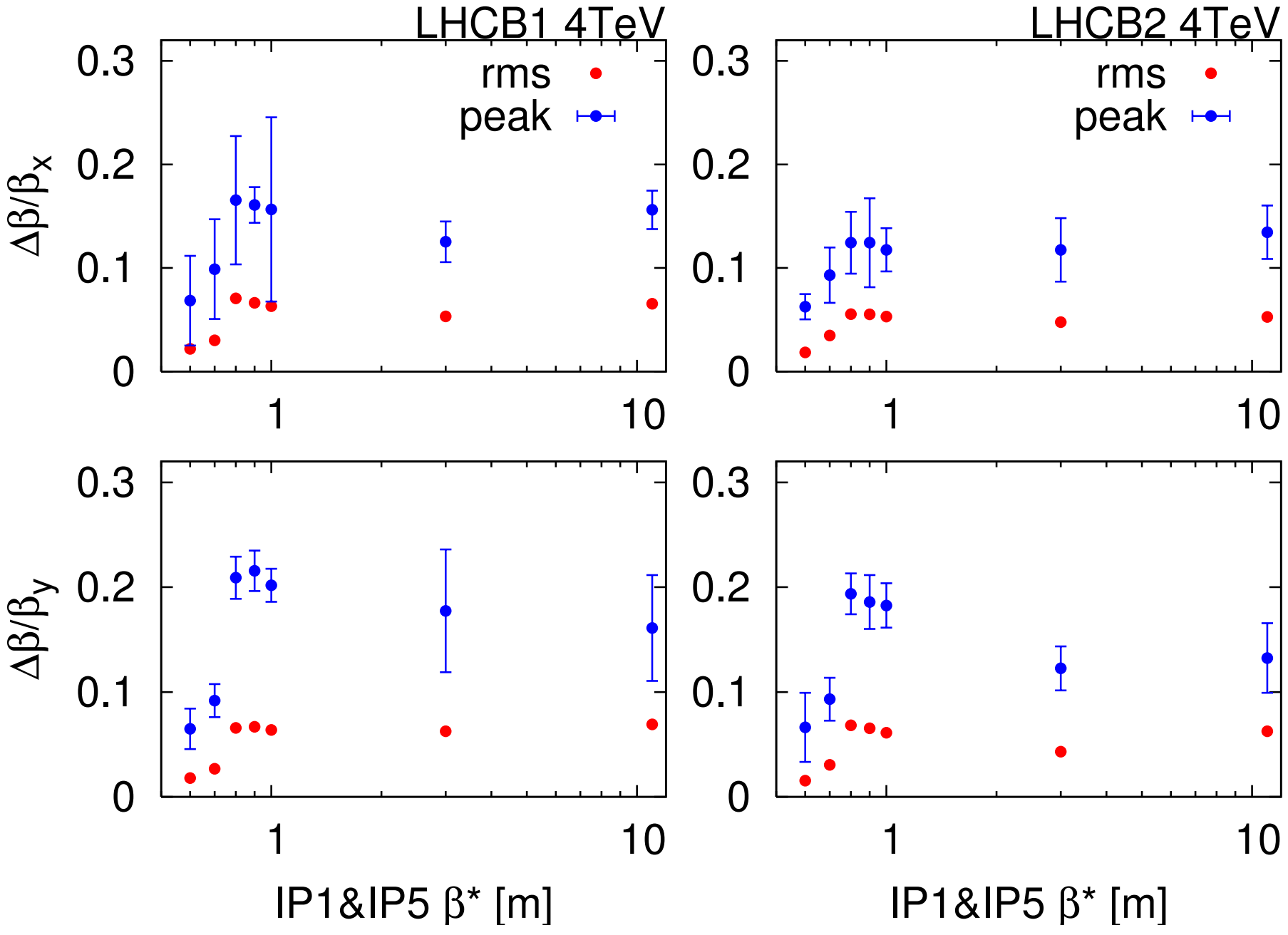
Up to 100% β-beating without corrections!

Local corrections: segment-by-segment



In 2012 best local corrections were found by analyzing many different optics. Global corrections follow only at β^*=0.6m.

After local & global corrections



LHC optics control made history

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **15**, 091001 (2012)

Record low β beating in the LHC

R. Tomás,* T. Bach, R. Calaga, A. Langner, Y. I. Levinsen, E. H. Maclean, T. H. B. Persson, P. K. Skowronski, M. Strzelczyk, and G. Vanbavinckhove
CERN, CH 1211 Geneva 23, Switzerland

R. Miyamoto
ESS AB, SE-221 00 Lund, Sweden
(Received 12 July 2012; published 28 September 2012)

Lepton Collider	Circumference [km]	Peak $\Delta\beta/\beta$ [%]	Hadron Collider	Circumference [km]	Peak $\Delta\beta/\beta$ [%]
PEP II	2.2	30	HERA-p	6.3	20
LEP	27	20	Tevatron	6.3	20
KEKB	3	20	RHIC	3.8	20
CESR	0.8	7	**LHC**	27	7

CMS and ATLAS luminosities in 2012 got equal!

Phys. Rev. ST Accel. Beams **15**, 091001, 2012

Improving accuracy, resolution and speed

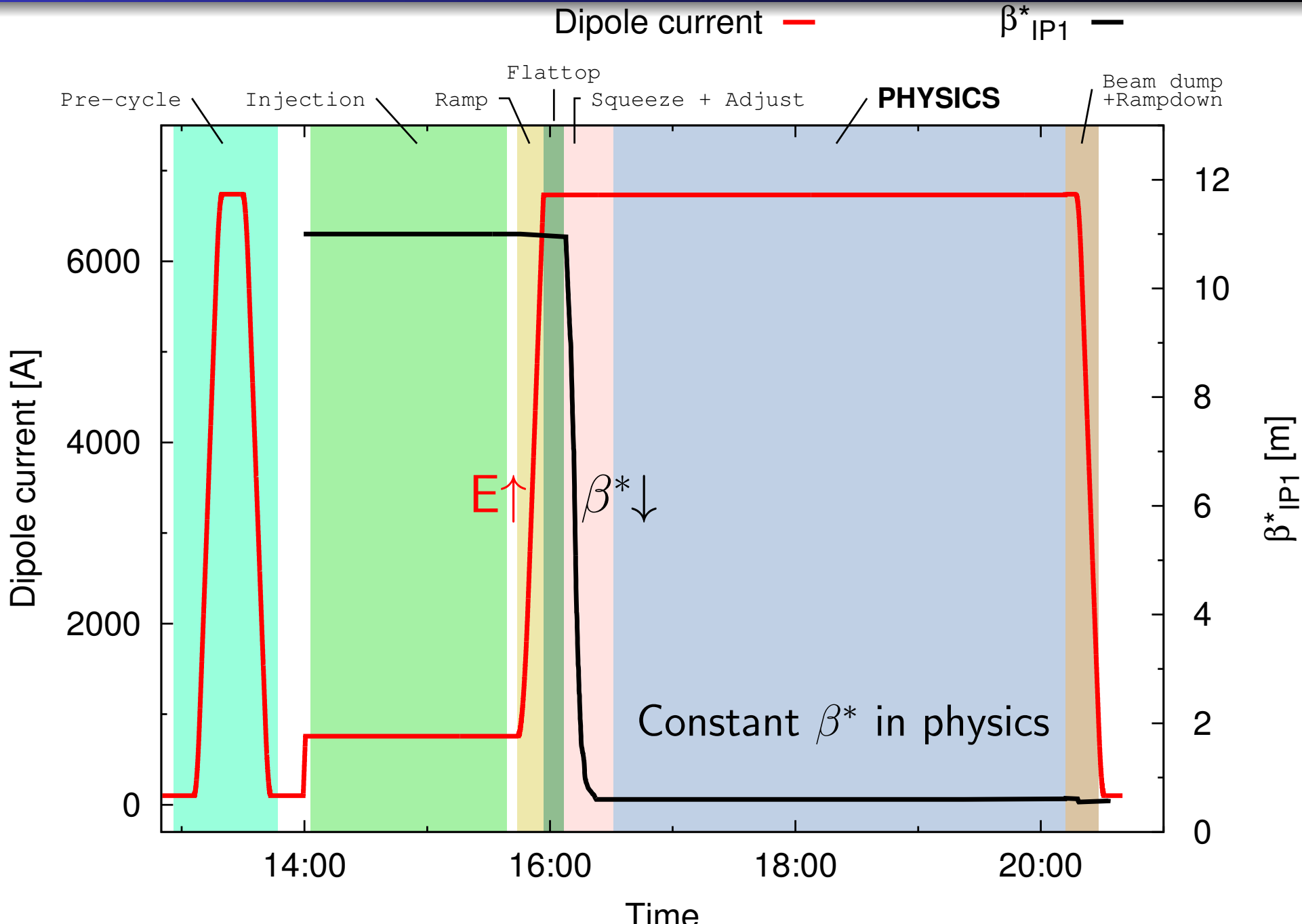
- ★ *N*-BPM method (see Andy's talk)
- ★ Better models
- ★ Coupling feedback (T. Persson et al, PRSTAB **17**, 051004)
- ★ High resolution BPMs: DOROS (see Rhodri's talk)
- ★ Longer AC dipole plateau (N. Magnin) and BPM acquisition (V. Kain)

β^* leveling

- If pushed optics are demonstrated and large charge is available luminosity exceeds limits $\rightarrow$ Need to level luminosity
- Also if e-cloud limits number of bunches PU would exceed 50 events $\rightarrow$ Need to level PU
- β^* leveling is the preferred leveling mechanism

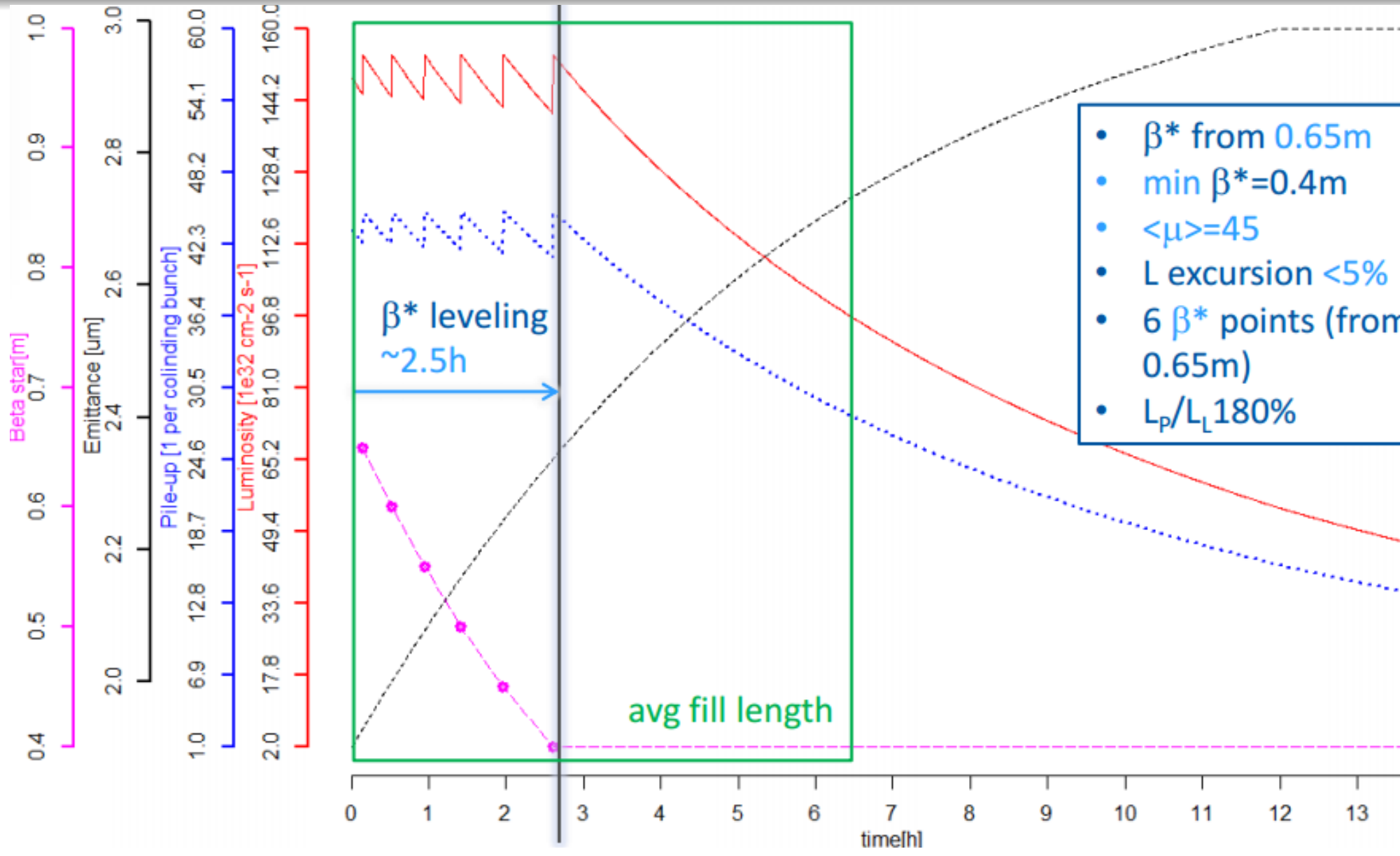
  RHIC just did β^* leveling, see Guillaume's talk
- LHC has no experience with dynamic optics!

So far *one thing at a time*

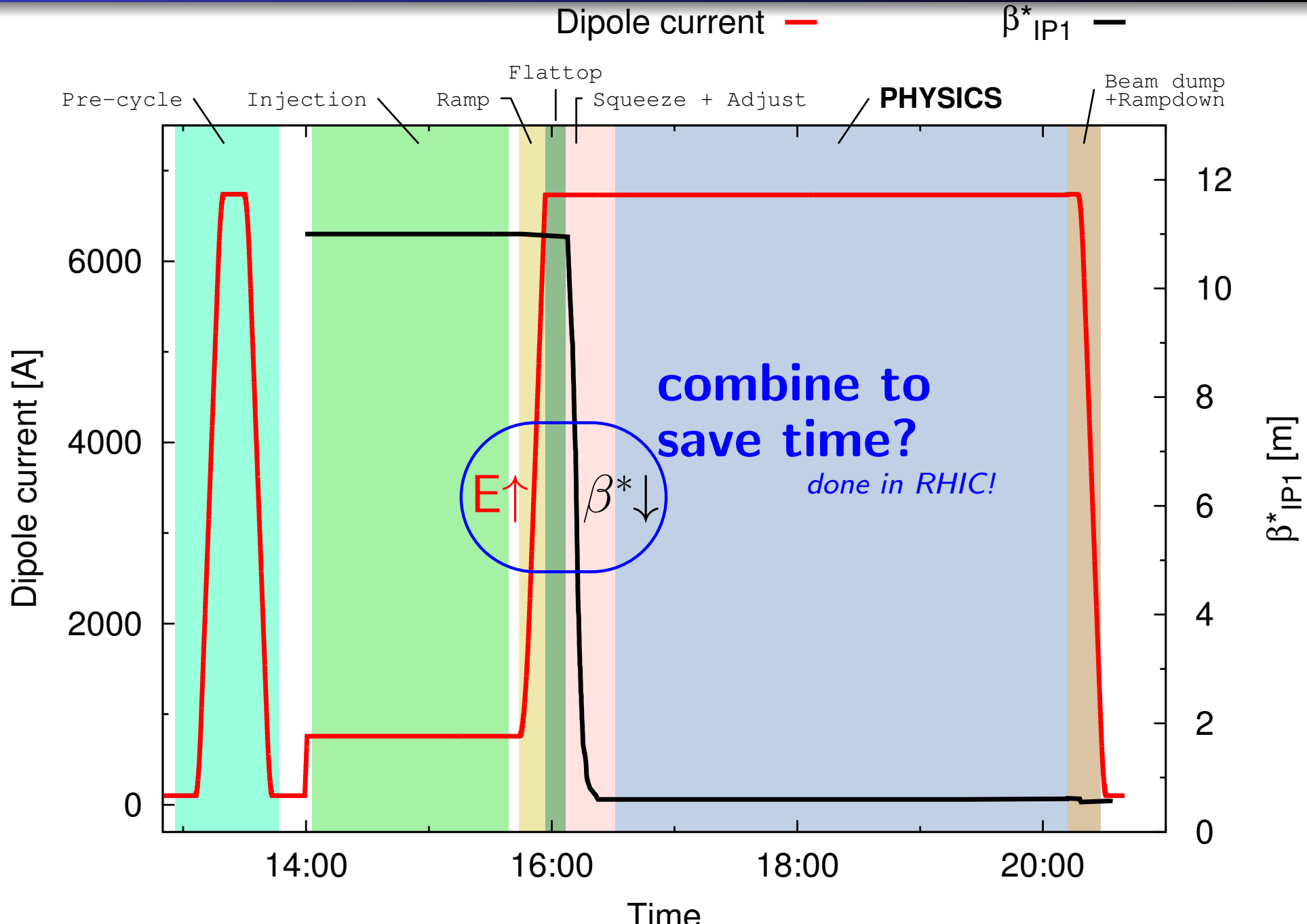


β^* leveling example

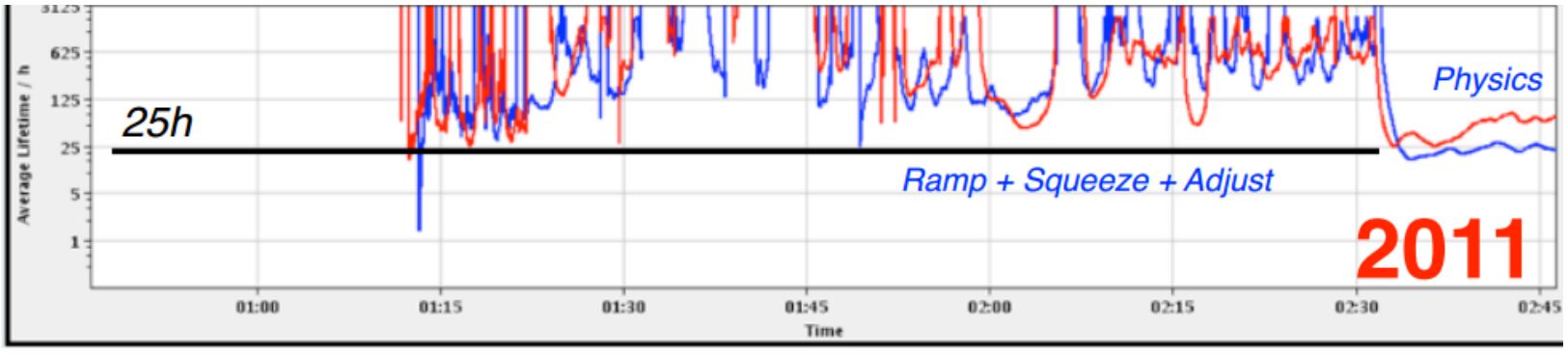
A. Gorzawski

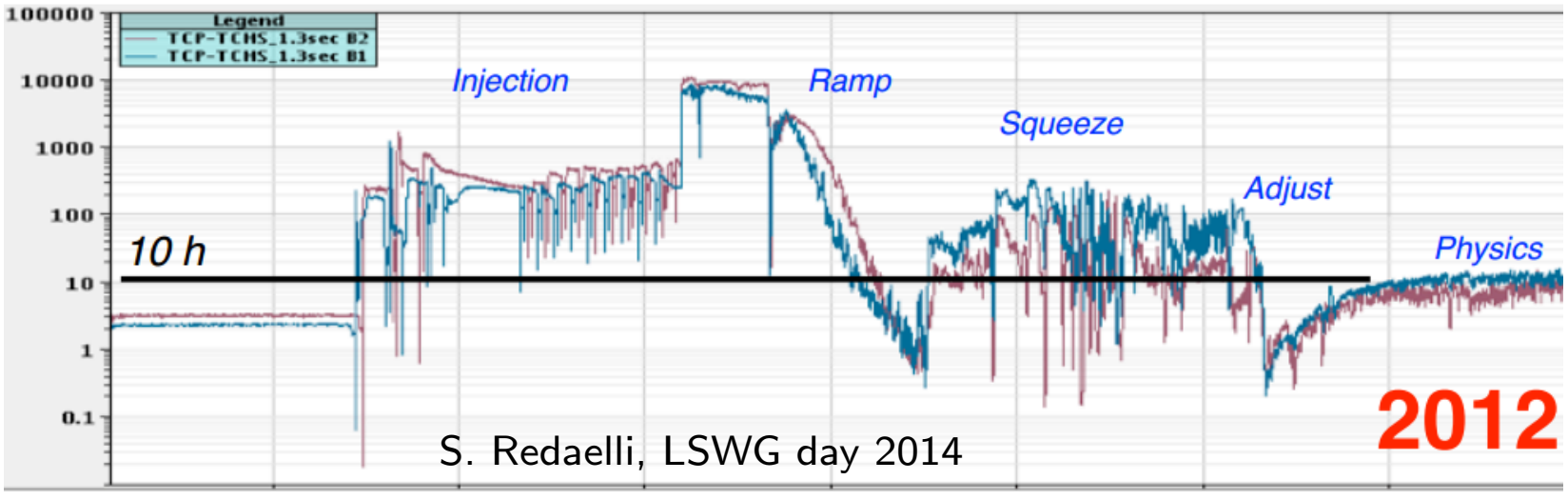


Combined Ramp & Squeeze for 2015?



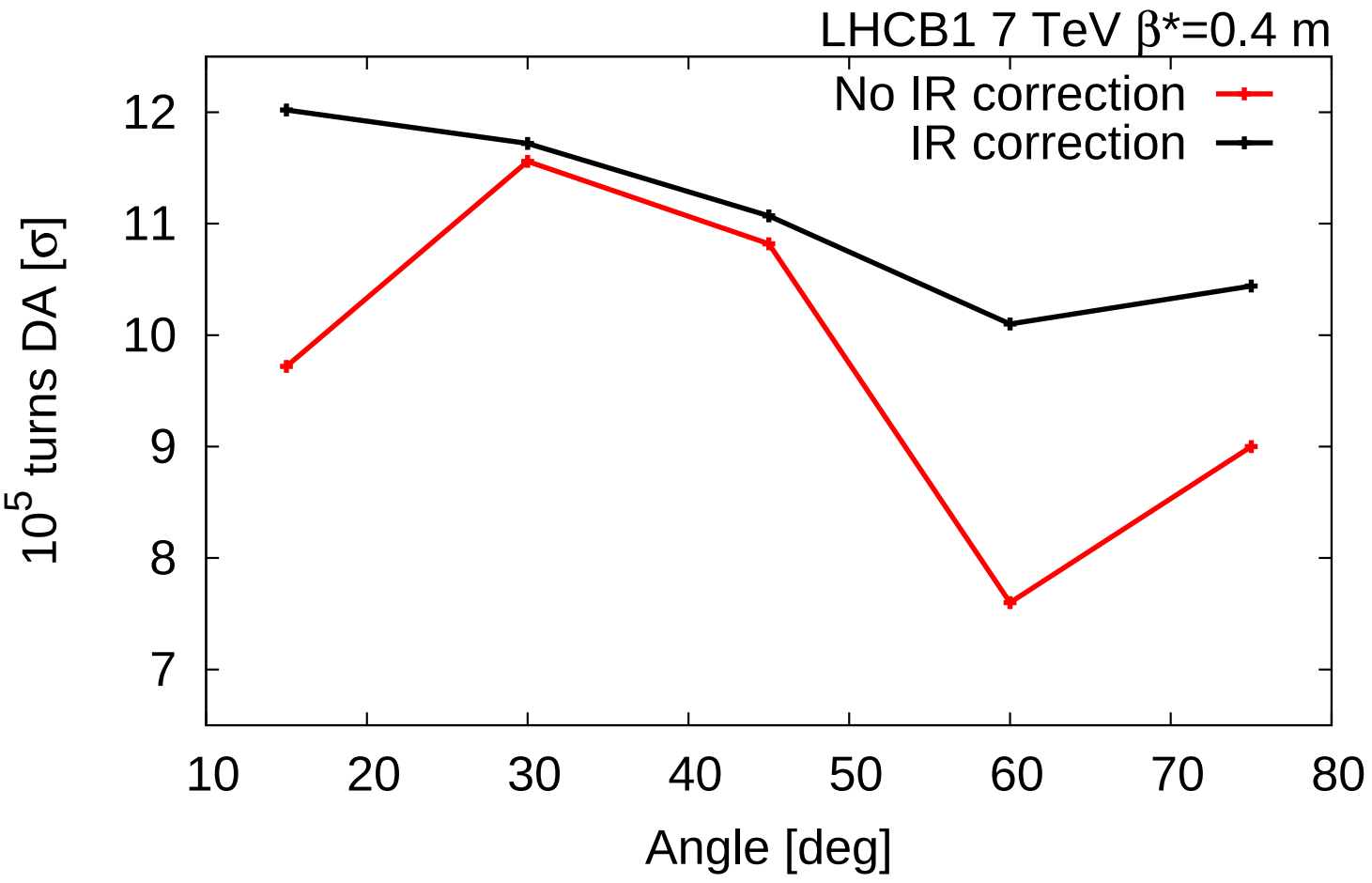
Lifetime 2011 vs 2012





- ★ Lifetime considerably worse in 2012
- ★ What is the role of non-linearities?

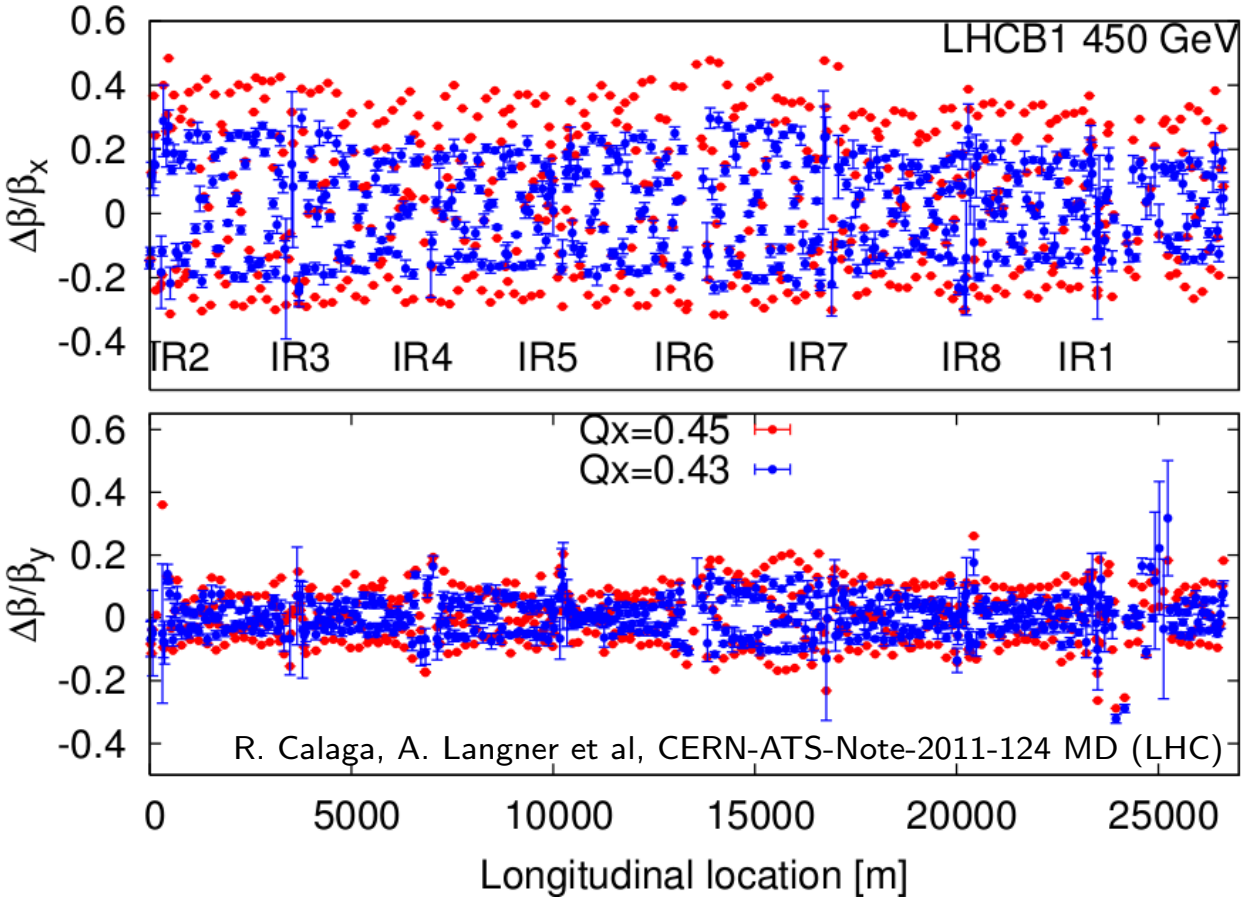
Dynamic Aperture at low β^*



Non-linear IR corrections will be critical at low β^* (see Ewen's talk)

Can LHC operate at $Q_x \approx Q_y \approx 0.5$?

Tevatron did it



- ★ Half integer resonance represents a challenge
- ★ First exploration at injection in 2011 $\rightarrow$ Need further demonstrations

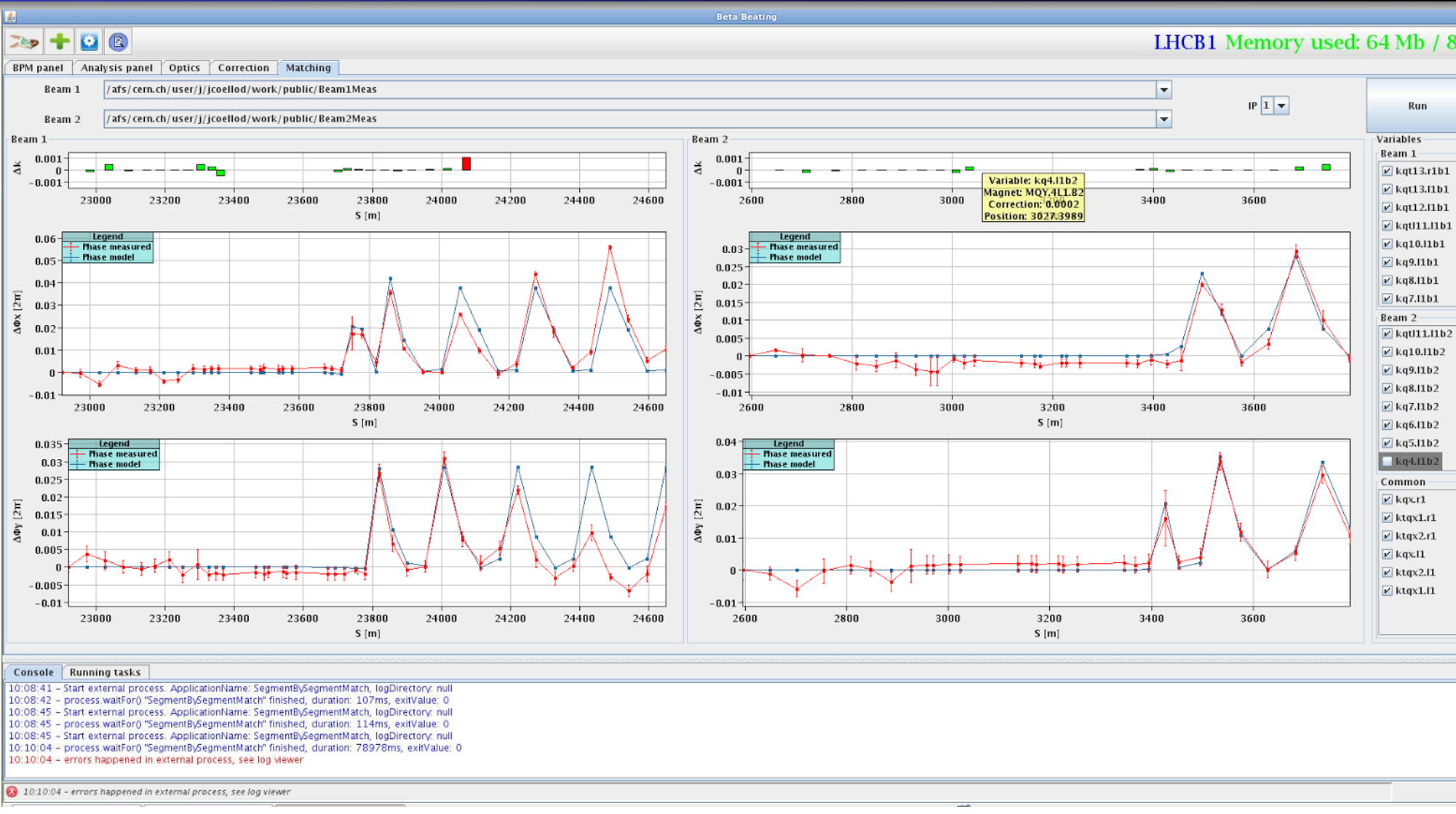
OMC software upgrades

	2013 bad code (physicists)	2014 good code (IT)	2015 new features
Lines of code	331,312	141,195	166,370
Static analysis issues	479,680	165,531	112,227

New functionalities: Automatic 2-beam local corrections (P. Skowronski), chromatic coupling correction, correction tests, amplitude detuning measurement, resonance driving terms, best real-time model, measurement database (D. Jacquet), etc

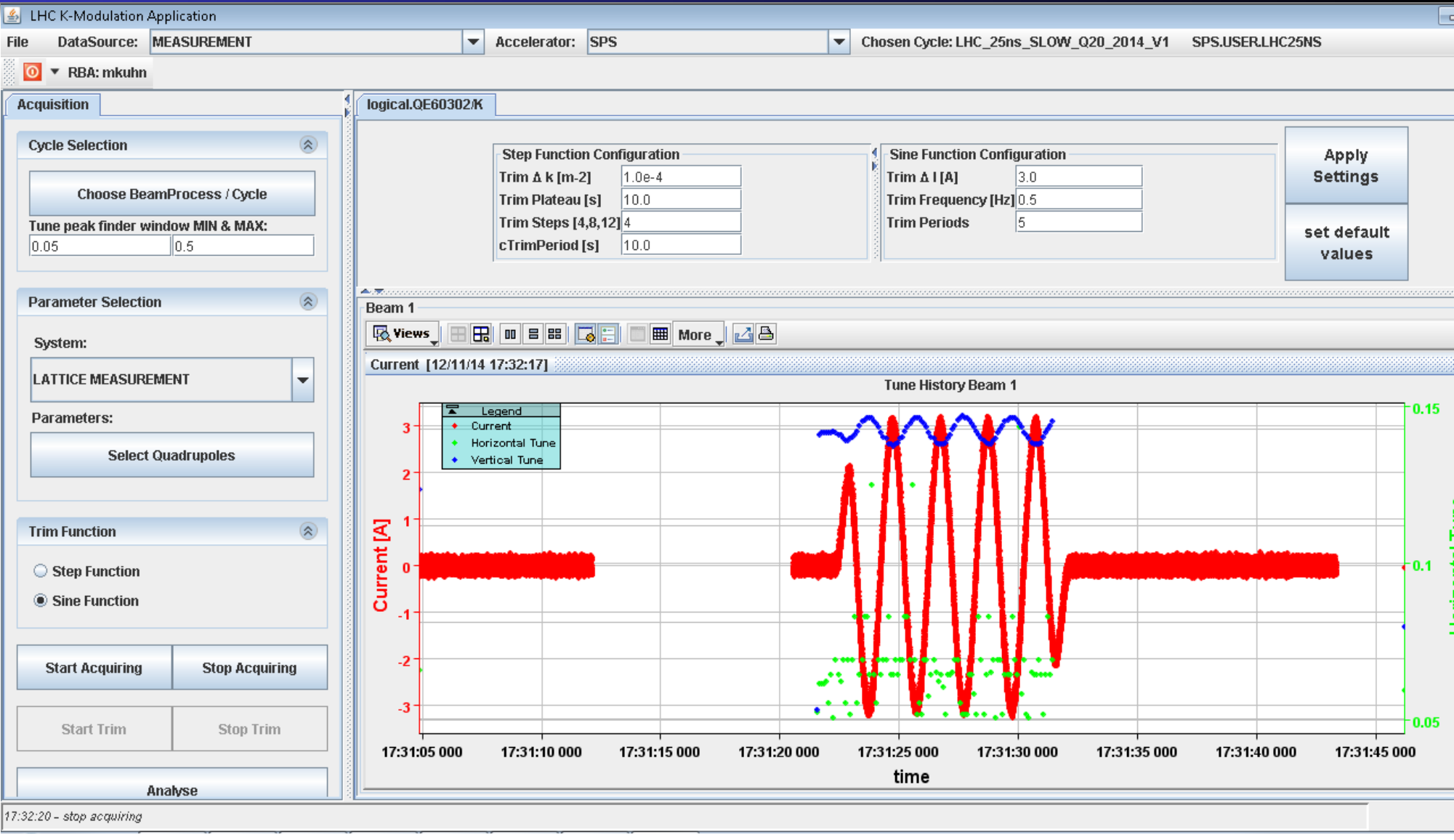
OMC software upgrades

J. Coello



New tools: K-modulation

M. Kuhn



First tests in the SPS with sine modulations as in LEP

The upgrade: HL-HLC

- ★ β^* =15cm, smallest β^* in hadron colliders
- ★ Large Nb_3Sn triplet quadrupoles
- ★ Crab cavities for geometric luminosity factor (1^{st} time in hadron colliders)
- ★ Extreme β^* leveling, $\beta^* \in$ [0.65,0.15]m
- ★ Pushed combined Ramp & Squeeze
- ★ Doubling LHC nominal bunch charge
- ★ PU$\approx$140, ...

Summary

LHC is getting close to its limits,
setting unprecedented demands on *optics control* for its safe exploitation

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setting unprecedented demands on *optics control* for its safe exploitation

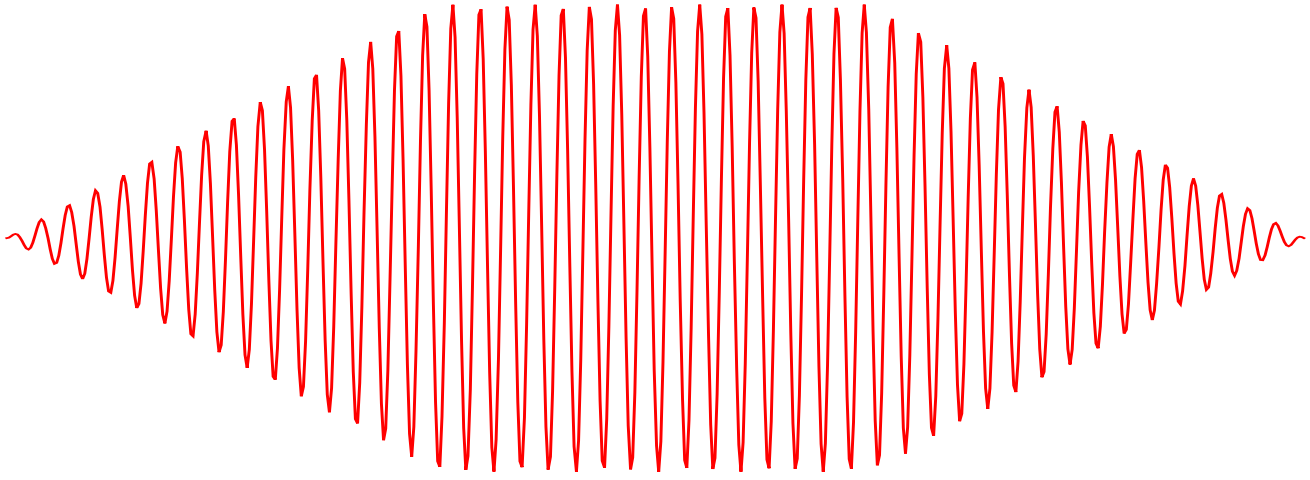
OMC owls waiting for the beam

Thanks!

Extra slides

Forced oscillations with AC dipole

- An AC dipole forces betatron oscillations
- If adiabatically ramped up & down causes no emittance blow up
- Can be used as many times as needed with the same beam



AC dipole for non-linear diagnostics

- ★ Adiabaticy with non-linearities

  "Adiabaticity of the ramping process of an AC dipole" PRSTAB **8** 024401

- ★ Resonace Driving Terms

  "Measurement of global and local resonance terms" PRSTAB **8** 024001

- ★ Coupling & Chromatic coupling

  "Measurement of Coupling Resonance Driving Terms in the LHC with AC Dipoles" IPAC 2011

  "Chromatic coupling correction in the LHC" PRSTAB **16**, 081003

- ★ Amplitude detuning

  "Direct amplitude detuning measurement with AC dipole" PRSTAB **16** 071002

- ★ Impedance measurements N. Biancacci CERN-THESIS-2014-043