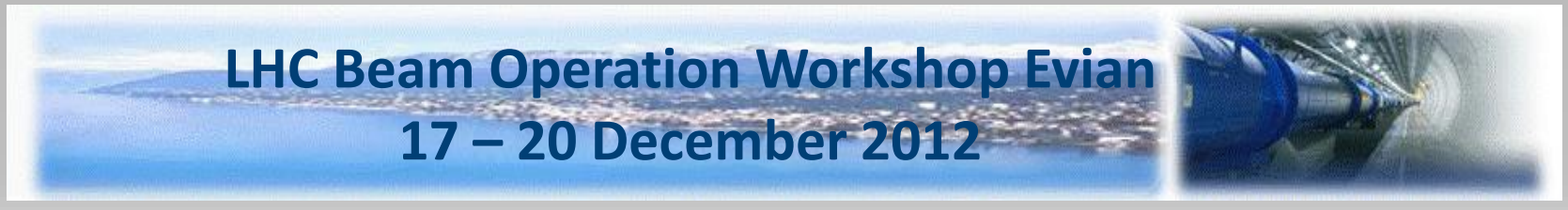


Highlights and conclusions of the LHC operations workshop in Evian

Jan Uythoven

Edited version of presentation given by
Mike Lamont
at the LMC of 6th March 2013

CMAC 14th March 2013

- Three nights immediately after the end-of-run 2012 (2013 still ions and 1.3 GeV protons)
- Fortunately the policy is to encourage presentations by younger members of the team

Workshop outline

- Availability
  - review, availability, R2E, machine protection
- Operational cycle
  - 7 TeV, squeezing colliding, spectrometers
  - optics, emittance growth, beam loss through the cycle
- Systems
  - feedbacks, BI, RF, ADT, injection, beam dump, controls
  - vacuum, cryogenics, collimation, BLMs
- Limitations
  - heating, e-cloud, instabilities, UFOs, cryogenics
- 2015
  - experiments, injectors, plans for restart, potential

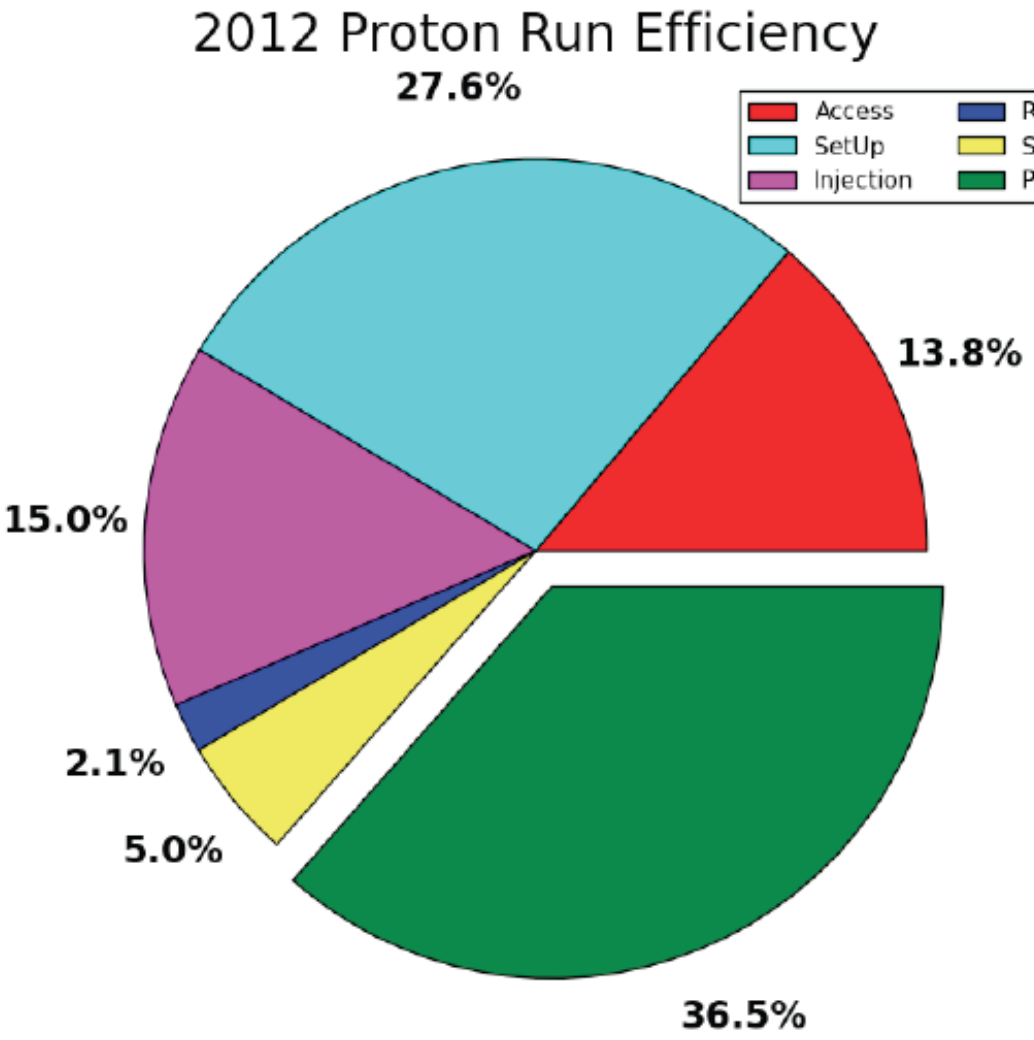
Session 1

Review 2012 - Operational availability and efficiency

2012

- Long year
  - 257 days run
  - ~200 days proton-proton physics
- Technical stops disturb the flow
  - Lose highly optimized conditions across the complex
  - Less technical, more configuration changes (PS extraction, ALICE… etc.)
- Peak luminosity
  - Got close to peak pretty quickly
  - Determined and long running **attempts to improve peak Luminosity** successfully to a certain extent (lots learnt), but with **little effect on integrated rates**

2012 Physics Run: Overall Availability



SB Time: 73.2 days Total Time: 200.5 days

Hubner factor

$H = 11.574 \times L_{Del} / (D \times L_{Peak})$

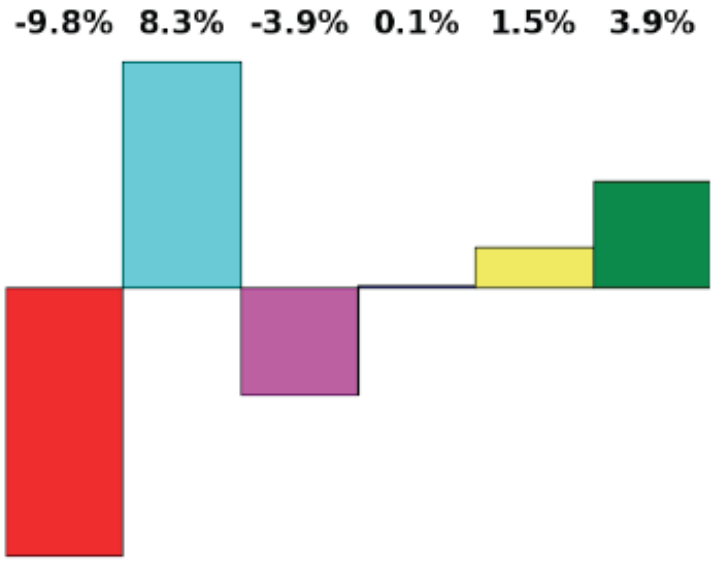
$\Rightarrow$ **H = 0.175**

D = 200.5 days

$L_{Peak} = 7695\ (\mu b.s)^{-1}$

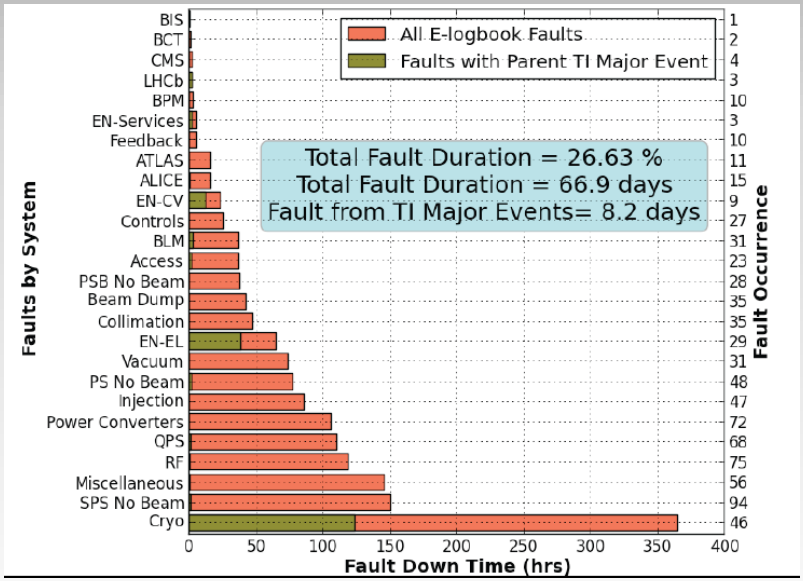
$L_{Del} = 23.269\ fb^{-1}$

H_{2011_LP} = 0.156



2012 Availability Compared to 2011 Production Run

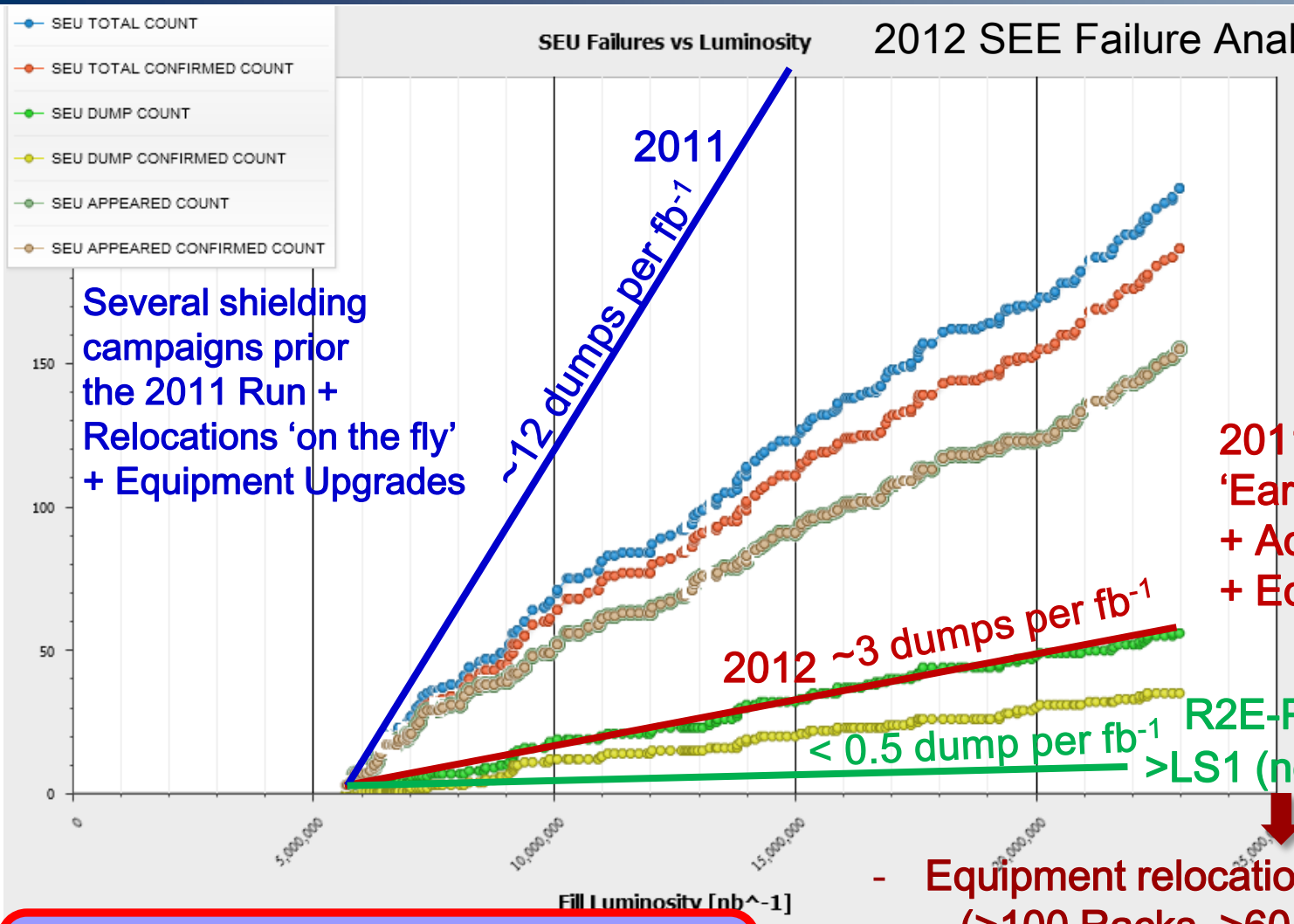
Faults



- Cryo availability improved to 94.4 % (p-p)
- In terms of beam dumps above 450 GeV, **QPS** leads in occurrence and recovery time and SEUs.
- Coherent fault/downtime tracking still to be implemented…

Alick Macpherson

R2E: Past/Present/Future



2011/12 xMasBreak
'Early' Relocation
+ Additional Shielding
+ Equipment Upgrades

R2E-Project aiming for …
>LS1 (nominal -> ultimate)

- Equipment relocations @ 4 LHC Points (>100 Racks, >60 weeks of work)
- Additional shielding
- Critical system upgrades (QPS, FGC)

We owe R2E and the concerned equipment groups a big thank you

Machine protection

worked reliably and efficiently

- ~ 1000 clean beam dumps performed in 2012:
  - 585 beam dumps above 450 GeV
- Some interesting probes of failure space – still learning
  - OFSU
  - LBDS 12V
  - BSRT mirror
  - TL collimators
  - Injecting the wrong beam
- MD enforcement
- Annecy workshop finished yesterday (13/3/2013)
  - Full analysis and follow-up

Session 2

Analysis of the operational cycle (implications of 6.5 TeV, 25ns, higher total I...)

Cycle

- Operational cycle is well optimized and transfers reasonably well to 7 TeV
  - Ramp, squeeze, collide
  - Magnetic machine well established
  - Excellent understanding of linear and nonlinear optics (including corrections)
- "Aggressive" modifications proposed
  - combined ramp and squeeze
  - partial squeeze with colliding beams and/or beta* levelling
    - Possible implementations have been/need to be explored
    - An effective solution should be in place for post LS1
  - Lower beta* at injection
  - ATS, flat beams
  - Start with a lower ramp rate – ease the impact on Cryo (Serge)
  - Keep collimators out for as long as possible; non-synchronized collisions….

2012 - issues

- Enhanced satellites
  - Luminosity at the ALICE experiment
  - Losses at injection
- LHCb – tilted crossing angle – combined with simultaneous into collisions at all points
- Squeeze – handling of round in/out at matched points
  - Clearly sensitive to beam conditions from injectors with tight collimator settings
- Losses at end ramp as we transit to tight collimator settings
  - How does this translate to 7 TeV? Strategy?

Spectrometers

* ***ALICE*** ***Spectrometer needs polarity switch once per collision mode***
TCT re-alignment needed in all machine procedures
fast procedure established (and already used in 2012) for Pb-Pb / p-Pb runs
vertical deflection does not harm operation

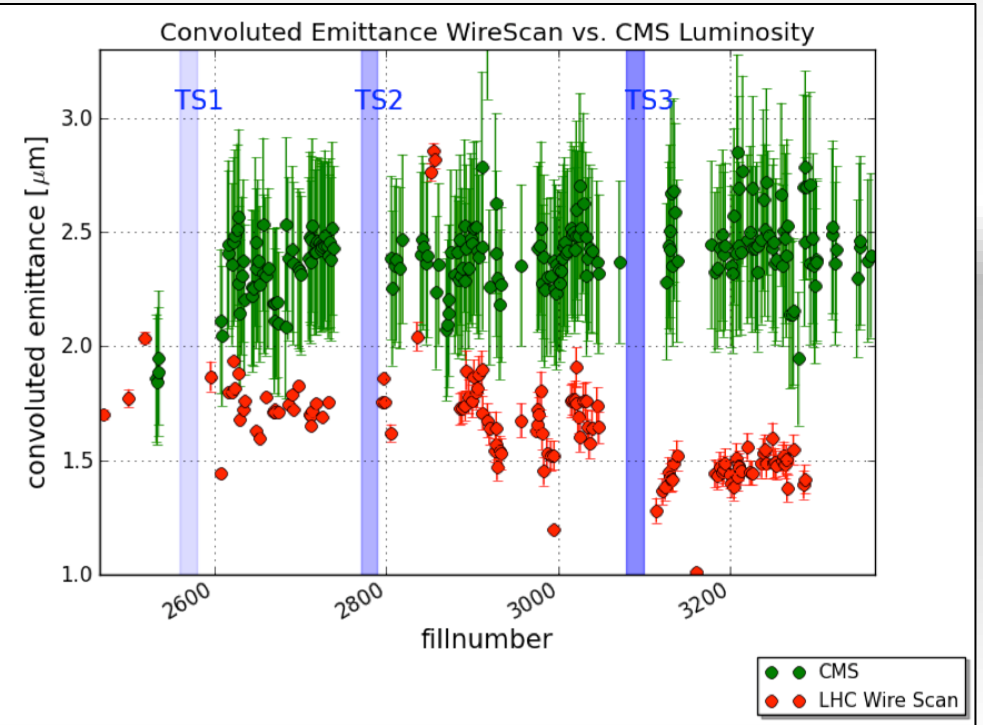
* ***LHCb*** ***Spectrometer needs polarity change every "n" weeks,***
horizontal crossing scheme is not compatible with 25ns bunches
new procedure has been established combining the unavoidable hor. crossing with vertical crossing scheme and a hor. offset.
Problem: Aperture, but seems feasible.

The horizontal crossing angle bump always will have to fight against the bad LHCb polarity. A vertical crossing angle bump does not !

- (Lack of) possibility to rotate beam screen during LS1 to be confirmed..

Emittance blow-up in LHC

- Emittance blow-up situation in 2012 similar to 2011
  - Significant blow-up from injection and ramp. Sometimes at the end of squeeze.



- Q20… end up at the same place - curious
- Sitting on 50 Hz line at 450 and ramp
- WS calibration – issues
- Instrumentation - issues

Session 3

Beam Based Systems and Control: 2012 performance and “2014” outlook (implications of 6.5 TeV, 25ns, higher total intensity ….)

OP - what we want?

Analysis of systems issues from an OP perspective

- Reliable tune measurement, feedback to stay on
- Orbit feedback to stay on through the cycle (21 dumps assigned in 2012)
- Release management and testing
- Better information flow
- Interlocked BPMS…problem low bunch intensities
- Abort gap monitoring to be improved
- Beam size: operational applications in CCC
- Improved instability observation tools
- Reduced time steering lines…
- Ease the wrestling match with the injection kickers (vacuum, temperture)
- RF: interlock diagnostics; phase acquisition per batch; faster BQM; phase/amplitude noise for each klystron…
- ADT settings management – less dependency on experts
- Control System and data management – 3 pages of requirements

Systems: Injection & dump

- Injection
  - Reproducibility: MSE current ripple and flat-top orbit variation in SPS
  - It weren't always the satellites – correct for the right problem - diagnostics
  - Sunglasses OR LICs – follow-up…
  - Injection Kickers – heating and flash-overs etc. etc.
  - TDI – even after refurbishment – does this remain a risk?
- LBDS
  - New TCDQs
  - Common mode failure on 12V line – addressed but worry about increasing probability of asynchronous dump with **new link between BIS and Beam Dump**
  - Higher voltages on switches at 6.5 TeV – increased risk of erratics

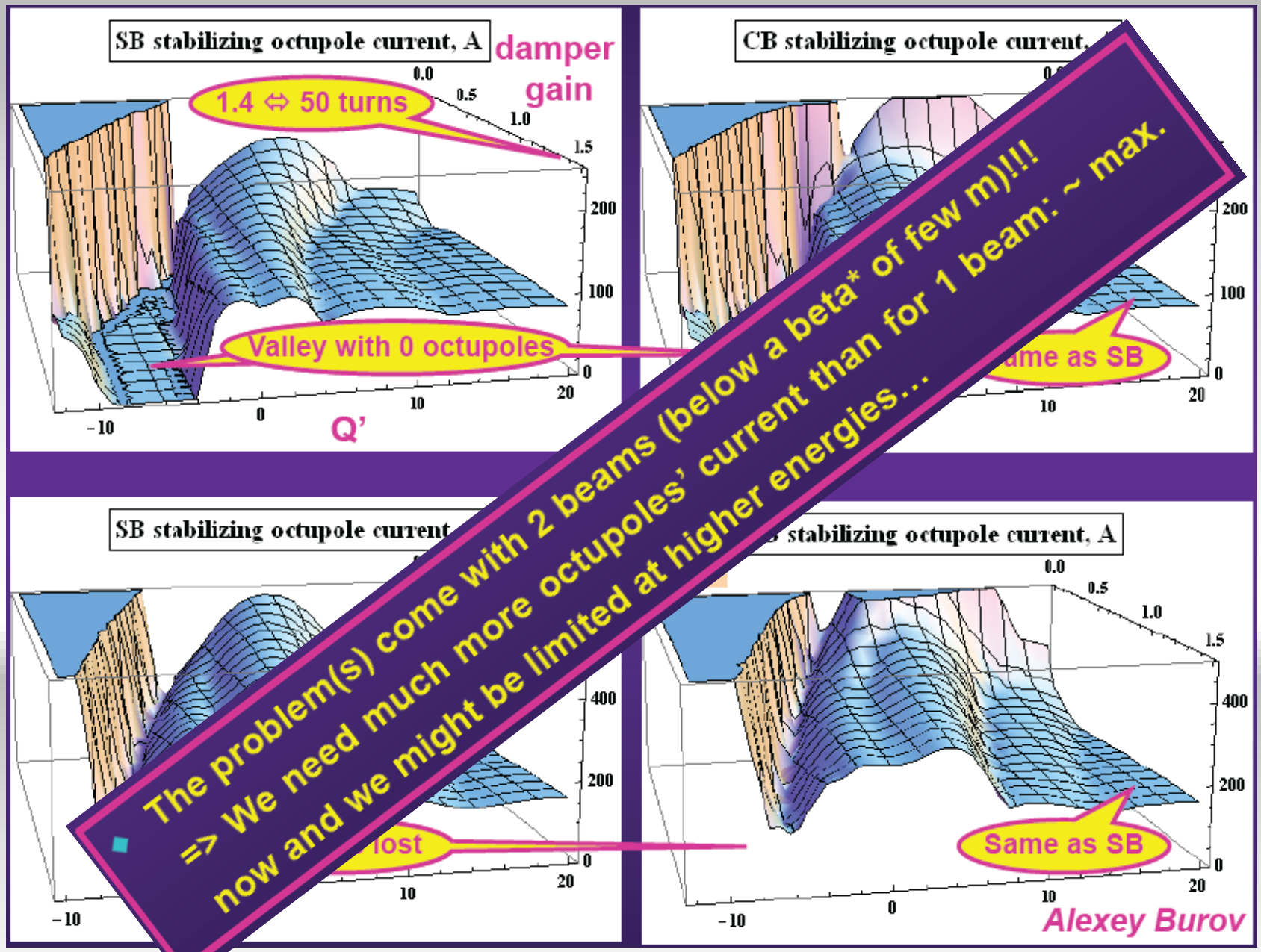
Session 4

Performance limitations: 2012 review and "2014" outlook (6.5 TeV, 25ns, higher total I...)

13 talks !

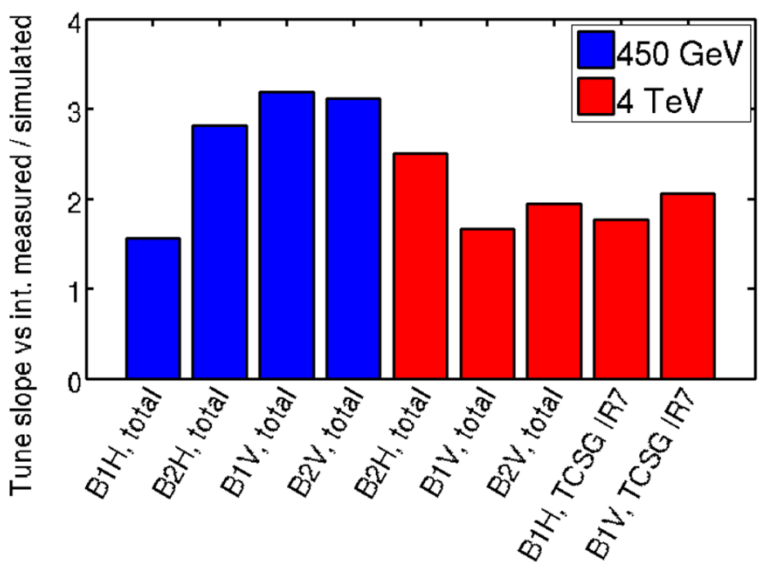
Instabilities

- Saved the beam at end of squeeze and going into collision by (ab)using
  - Chromaticities (high)
  - Octupoles (max / polarity changed)
  - Transverse damper gain (high)
- End of squeeze
  - Flipped octupole sign – instability moved to B1V

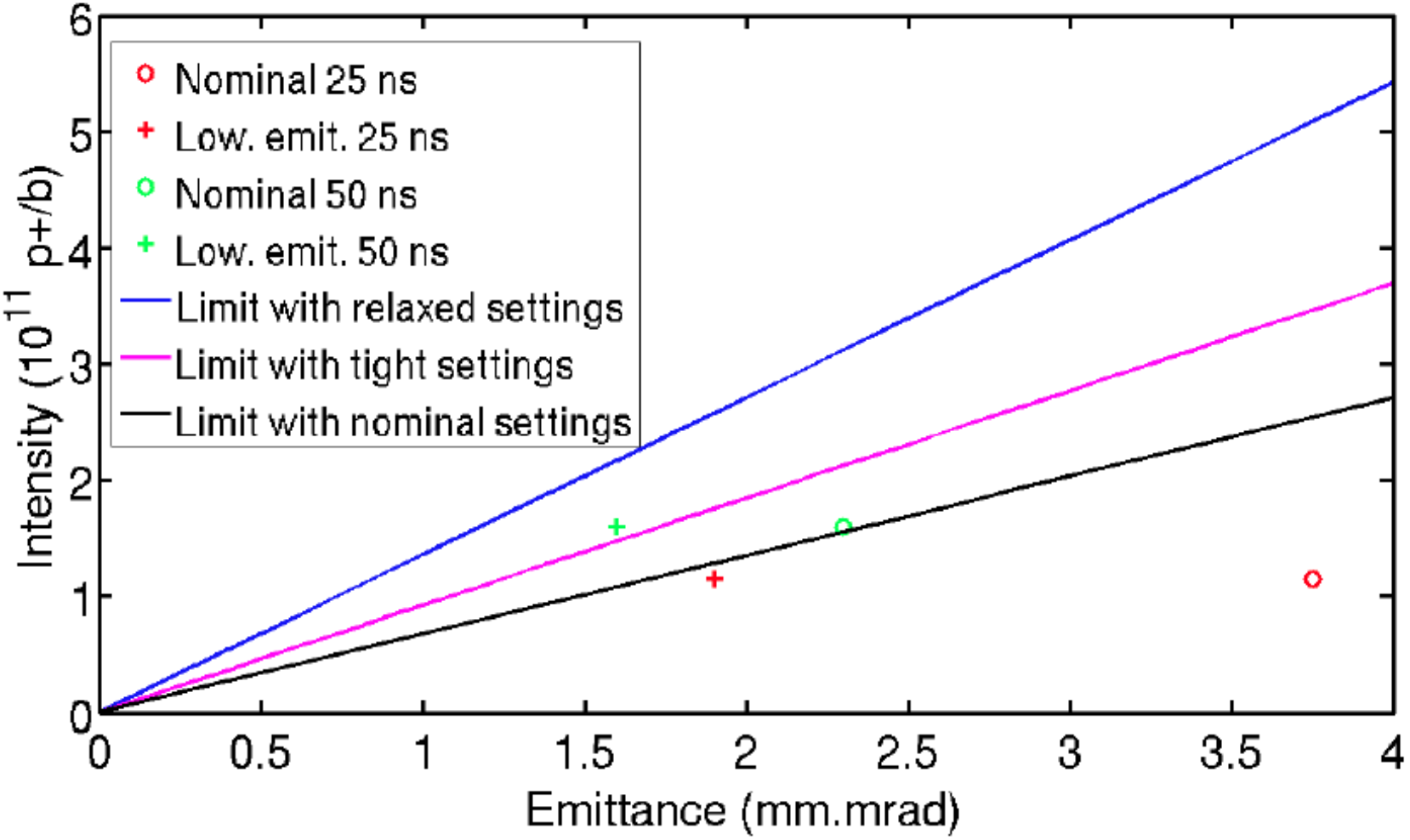

SB stabilizing octupole current, A
damper gain
1.4 ⇔ 50 turns
Valley with 0 octupoles
Q'
CB stabilizing octupole current,
Same as SB
SB stabilizing octupole current
lost
stabilizing octupole current, A
Same as SB
Alexey Burov
The problem(s) come with 2 beams (below a beta* of few m)!!!
=> We need much more octupoles' current than for 1 beam: ~ max.
now and we might be limited at higher energies…

Impedance

- ~3 times more than expected at 450 GeV
- ~2 times more than expected at 4 TeV
- For post LS1 operation, can sacrifice performance if required, impedance dependence on collimators:
  - Nominal +50%
  - Tight +10%
  - Relaxed – 25%



Beam parameter space with separated beams post-LS1



We are close or above the limit for 50ns beam parameters in post-LS1 operation (depending on collimators), and fine with 25ns parameters.

Beam induced heating

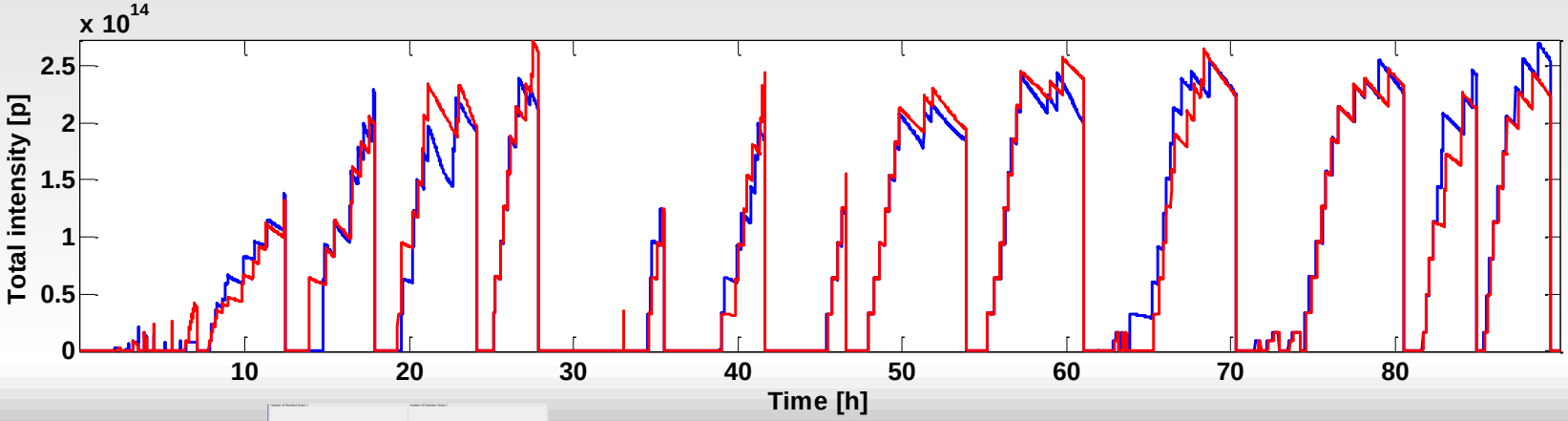
- Heating will remain an issue
  - in particular the upgrade of TDI should be pursued
- Maximum bunch length should be pursued compatible with maximum extension of the luminous region
  - 1.35/1.4 ns seems to be within reach

equipment	Problem	2011	2012	Hopes after LS1
VMTSA	Damage		replaced	removed
TDI	Damage			Beam screen reinforced, and?
MKI	Delay		(+ MKI8C high temperatures)	Beam screen and tank emissivity upgrade
TCP_B6L7_B1	Few dumps		Interlock increased	Cooling system checked
TCTVB	Few dumps		Interlock increased	removed
Beam screen Q6R5	Regulation at the limit		Since TS3, correlation with TOTEM?	Upgrade of the valves + TOTEM check
ALFA	Risk of damage		Due to Intensity increase	New design + cooling
BSRT	Deformation suspected			New design + cooling

The 2012 scrubbing run

3.5 days of scrubbing with 25ns beams at 450GeV (6 - 9 Dec. 2012):

- Regularly filling the ring with up to **2748b.** per beam (up to **2.7×10^{14} p**)
- Overall **very good efficiency:** injection rate determined by MKI vacuum interlocks (in the beginning) and by time required by the cryogenic system to adapt to the increasing heat load (mainly in stand alones)

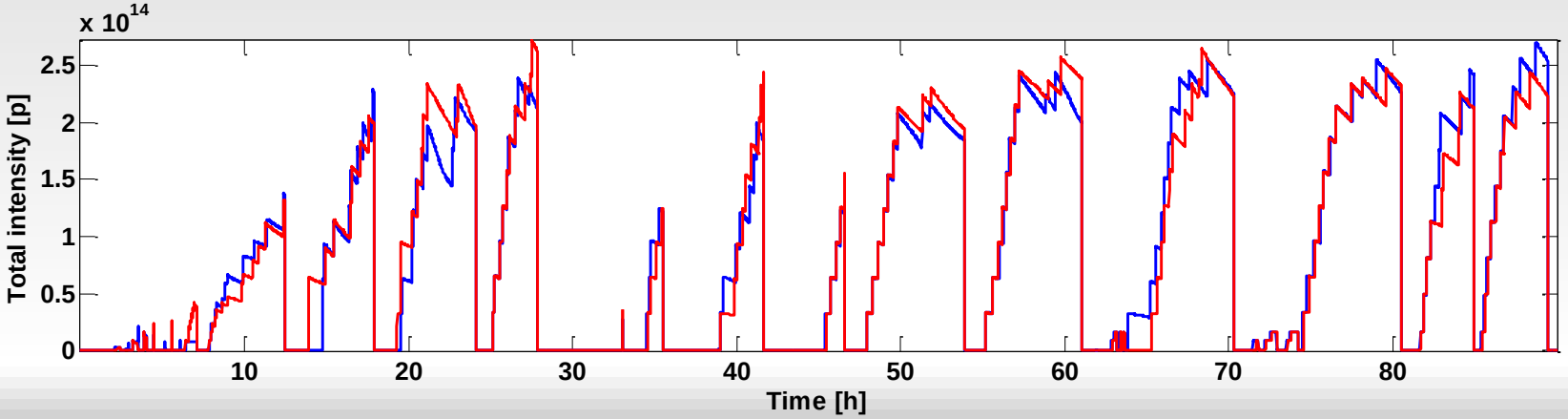


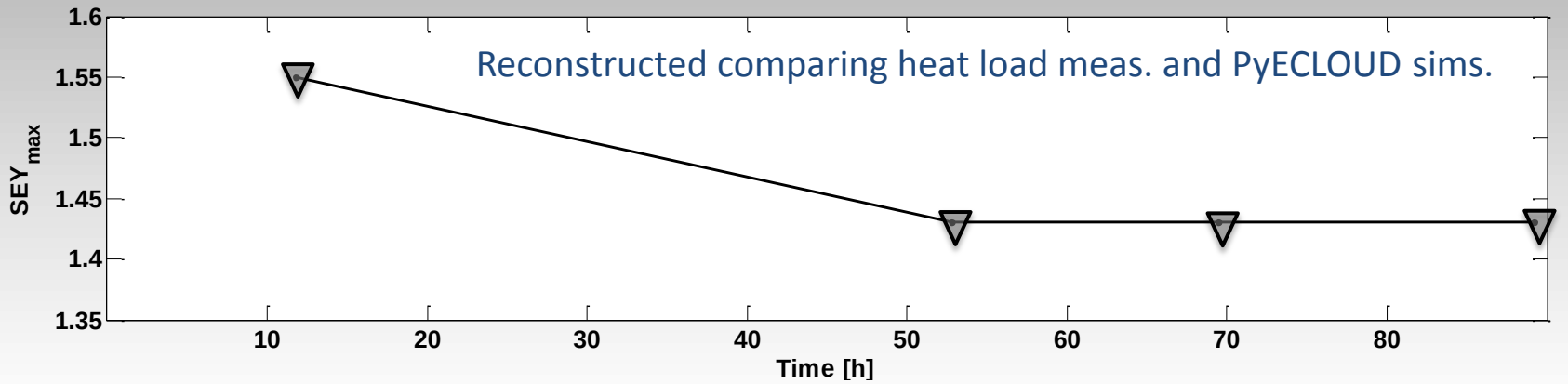
Giovanni Iadarola and team

Giovanni Iadarola and team

Scrubbing effects in the arcs:

- Quite **rapid conditioning observed in the first stages**
- The **SEY evolution significantly slows down** during the last scrubbing fills (more than expected by estimates from lab. measurements and simulations)





25 ns & electron cloud

- There is a change of mode of operation with 25 ns. Electron cloud free environment after scrubbing at 450 GeV seems not be reachable in acceptable time.
- Operation with high heat load and electron cloud density (with blow-up) seems to be unavoidable with a corresponding slow intensity ramp-up.
- 2015: SEY etc. will be reset - initial conditioning required
  - Will need to start with 50 ns and only later to move to 25 ns to recover vacuum, cryogenics, UFOs conditions we were used in 2012

Gianluigi Arduini

Cryogenics

- 25-ns beam scrubbing run in Dec'12 has identified or confirmed:
  - A tricky transient…
  - A discrepancy (factor 2) between the cryogenic heat load measurement (typically 20 kW) and the RF power (typically 40 kW)…

- **Triplet cryogenic limit on luminosity**
  - **1.7e34 $cm^{-2}s^{-1}$ (+/- 20%)**

Laurent Tavian

BLM thresholds - past experience.

- Modified BLM layout is essential – otherwise thresholds to prevent quenches from UFOs in dipole magnets are too low
  - Risk of magnet quenching must be accepted at the start
- We need to plan for beam induced quenches !
  - BLM thresholds in arc to be set above expected quench threshold (as propose in Chamonix 2012 for 2012, but not done)
- Can we use different algorithms to detect UFOs from BLMs?
  - E.g. validation time as for QPS?
- Quench tests will gave more insight – we seem to have more margin

Cleaning and collimator operation – outlook,

- Excellent performance and fast setting up and validation
  - TCL collimators reduced luminosity debris
- Improvement expected with buttons
- Move only primary collimators (very) close to the beam to limit impedance?
- Different scenarios for collimation settings proposed
- Pessimistic scenario (larger emittance)
  - $\beta^* = 70$cm at 25ns
  - $\beta^* = 57$cm at 50ns
- Optimistic scenario (H9 emittance)
  - $\beta^* = 37$cm at 25ns
  - $\beta^* = 30$cm at 50ns
- Quench tests will provide more input

Start with a relaxed approach

UFOs – see talk later

- UFOs: showstopper for 25 ns and 6.5 TeV?
  - 10x increase and harder UFOs
  - (but no increase in low intensity fills)
- UFO "scrubbing": does it work? What parameters?
  - 91 arc UFOs in 2012 would have lead to a dump at 7 TeV
  - Deconditioning to be expected after LS1
- Operational scenario to be developed:
  - start with lower energy and/or 50 ns beam for UFO conditioning?
  - Increase BLM thresholds, optimize BLM distribution
  - Interesting results from quench tests

Tobias Baer

Session 5

Scenario for “2014”

“It’s going to be like after a war”

Serge Claudet

Physics post LS1

- **25 ns pp operation is a strong request of all the experiments**
  - Cleaner environment for precision physics (trigger and reconstruction efficiencies, resolutions)
  - Less demanding in terms of resources (online and offline computing)
- 50 ns is an option only in case of major showstoppers
- Optimization of other parameters (bunch length, crossing angles) as needed
  - Clear demand for stable conditions
- Experiments accept that the commissioning period for 25ns operation may be longer than usual
- ALICE pp operation @ 25ns needs further studies
- Special runs program (RP, hi-b*, LHCf) similar to 2012
- Heavy Ion in 2015: PbPb @ 13Z TeV

Run II – parameters

free interpretation by Mike

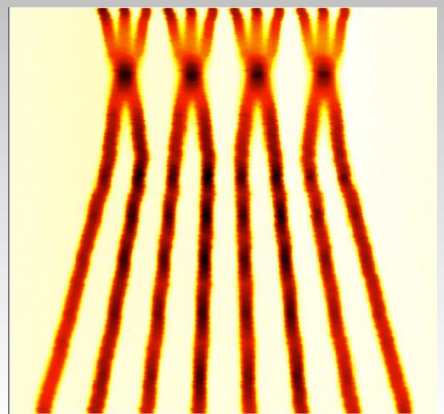
Energy	6.5 TeV
Bunch spacing	25 or 50 ns
Transfer line collimators	4.5 sigma
Injection tunes	0.31/0.32 (=physics tunes, tbc)
Injection beta*	7 m (tbc)
Optics	flat ATS (tbc)
Beta*	I didn't see less than 30 cm
Beta beating	3%
Chromaticity	10 - 20
Collimators	nominal +50% (impedance) tight +10% relaxed -25%
Octupole current	Between +550 and -550 A
Damper gain	To the max

Beam from injectors LS1 to LS2

		Bunch intensity [10^{11} p/b]	Emittance [mm.mrad] Exit SPS	Into collisions
25 ns ~nominal	2760	1.15	2.8	3.75
25 ns BCMS	2520	1.15	1.4	1.9
50 ns	1380	1.65	1.7	2.3
50 ns BCMS	1260	1.6	1.2	1.6

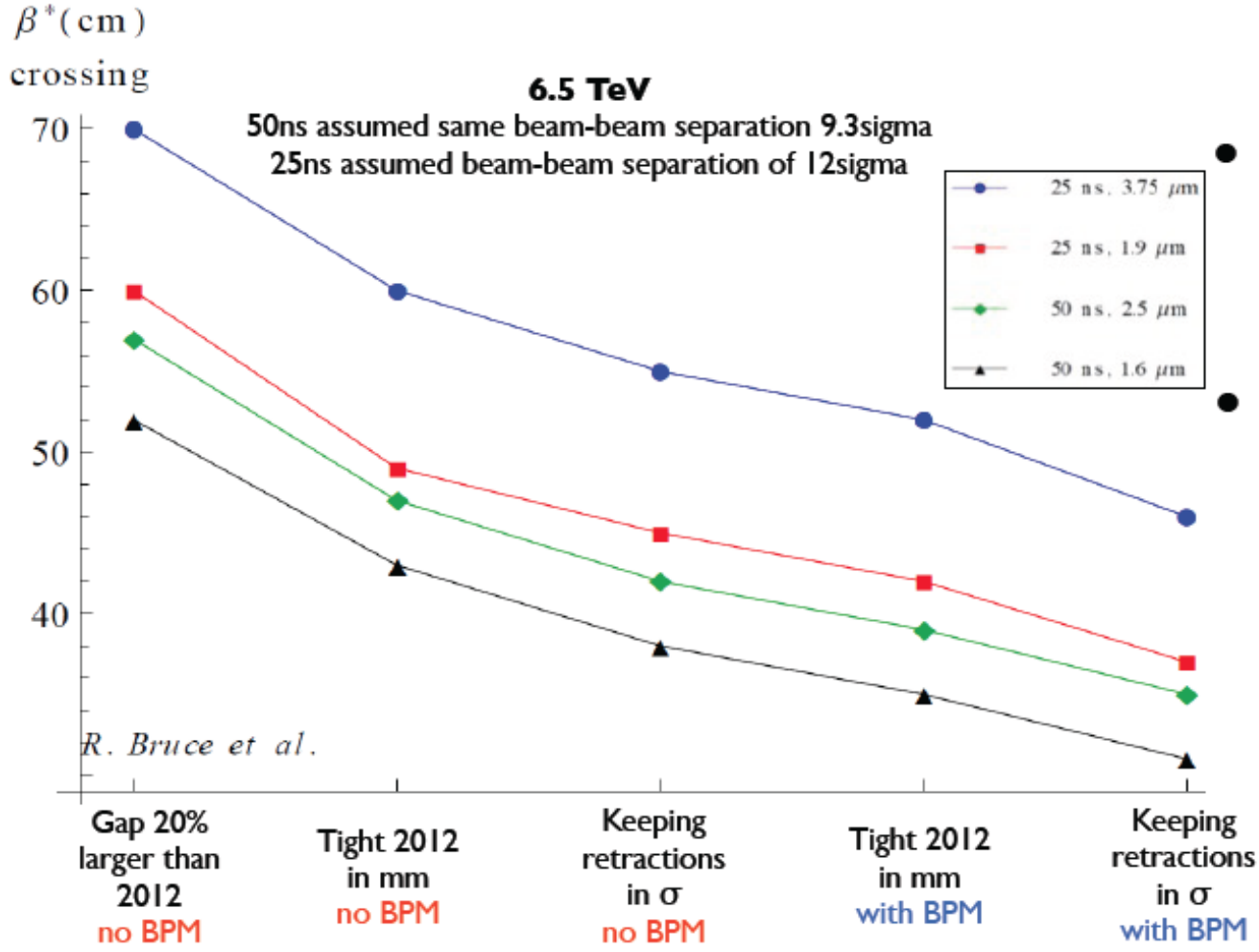
BCMS = Batch Compression and (bunch) Merging and (bunch) Splittings

Rende Steerenberg, Gianluigi Arduini, Theodoros Argyropoulos, Hannes Bartosik, Thomas Bohl, Karel Cornelis, Heiko Damerau, Alan Findlay, Roland Garoby, Brennan Goddard, Simone Gilardoni, Steve Hancock, Klaus Hanke, Wolfgang Höfle, Giovanni Iadarola, Elias Metral, Bettina Mikulec, Yannis Papaphilippou, Giovanni Rumolo, Elena Shaposhnikova,…



Batch compression & triple splitting in PS

β* reach at 6.5 TeV



- Pessimistic scenario:
  - ➡ β* = 70cm at 25ns
  - ➡ β* = 57cm at 50ns
- Optimistic scenario:
  - ➡ β* = 37cm at 25ns
  - ➡ β* = 30cm at 50ns

Potential performance

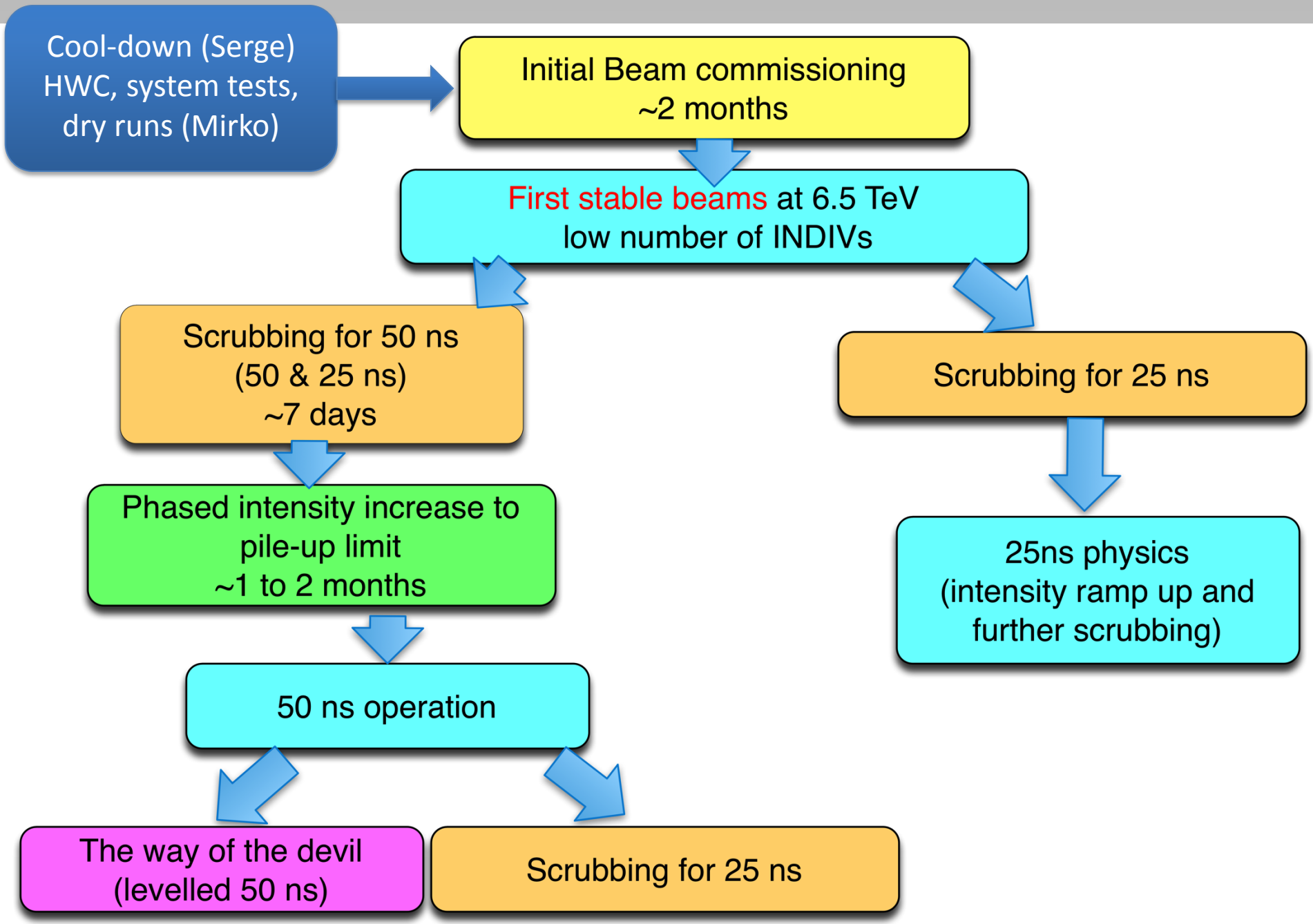
	Number of bunches	Ib LHC FT[1e11]	beta*X-plane beta*sep plane Xangle	Emit LHC [um]	Peak Lumi [cm^{-2}s^{-1}]	~Pile-up	Int. Lumi per year [fb^{-1}]
25 ns	2760	1.15	55/43/189	3.75	9.3e33	25	~24
25 ns low emit	2320	1.15	45/43/149	1.9	1.6e34	52	~41
50 ns	1380	1.6	42/43/136	2.5	1.6e34 level to 0.8e34	87 level to 44	~40*
50 ns low emit	1260	1.6	38/43/115	1.6	2.3e34 level to 0.8e34	138 level to 44	~40*

- 6.5 TeV
- 1.1 ns bunch length
- 150 days proton physics, HF = 0.2
- 85 mb visible cross-section
- * different operational model – caveat - unproven

All numbers approximate

In words

- Nominal 25 ns
  - gives more-or-less nominal luminosity
- BCMS 25 ns
  - gives a healthy 1.6e34
  - peak <mu> around 50
  - 83% nominal intensity
- Nominal 50 ns
  - gives a virtual luminosity of 1.6e34 with a pile-up of over 70
  - levelling mandatory
- BCM 50 ns
  - gives a virtual luminosity of 2.3e34 with a pile-up of over 100
  - levelling even more mandatory


Cool-down (Serge)
HWC, system tests,
dry runs (Mirko)
Initial Beam commissioning
~2 months
First stable beams at 6.5 TeV
low number of INDIVs
Scrubbing for 50 ns
(50 & 25 ns)
~7 days
Scrubbing for 25 ns
Phased intensity increase to
pile-up limit
~1 to 2 months
25ns physics
(intensity ramp up and
further scrubbing)
50 ns operation
The way of the devil
(levelled 50 ns)
Scrubbing for 25 ns

Acknowledgments

- Chairman: Mike Lamont
- Organization: Malika Meddahi, Sylvia Dubourg, Brennan Goddard, Pierre Charrue
- Session chairs
  - Jan Uythoven, Jorg Wenninger, Rhodri Jones, Gianluigi Arduini, Rudiger Schmidt
- Scientific secretaries & speakers
  - Excellent set of talks, for more details please see the originals at the
  - Workshop indico page

- And a big, big thank you for joining us on Wednesday evening:
  - Fabiola Gianotti
  - Paolo Giubellino
  - Joao Varela
  - Simone Giani
  - Pierluigi Campana