

Potential performance: pulling it all together

Thanks to Jorg, Gianluigi, Rudiger, Rhodri for their input

Workshop outline

- Availability
- Cycle
 - & optics & emittance & beam loss
- Systems
 - BI, RF, ADT, injection, beam dump
- Systems
 - vacuum, cryogenics, collimation, BLMs
- Limitations
 - heating, e-cloud, instabilities, UFOs
- 2014

Availability

- LHC is a critical asset
 - 5-6 billion capital cost; 300 MCHF/year operating costs
- Effective fault tracking, analysis etc. for targeting weak-points, improvements are mandatory
- Some team (AWG perhaps) need to be give a mandate and resources to put in place an effective, robust solution for the re-start.
 - note other initiatives... operational issue management as part of the **Maintenance Management project**

The future: four points worth considering...

1. Availability should be objective...

+ We need some metrics and rules...

2. information capture should be easier and rigorous...

e.g. eLogbook: tracking and understanding faults is inconsistent.

+ is it the central place to store fault information?

3. Dealing with parallel / hidden / dependent faults should be built in...

+ find one fault, fix it, find another, fix it, ... etc...

+ Is there a way to better predict this? Big Sister? LASER? DIAMON?

4. Information analysis should be easier...

+ better tools needed

+ Simple, easy to use, make benefits obvious

metric for luminosity impact ...

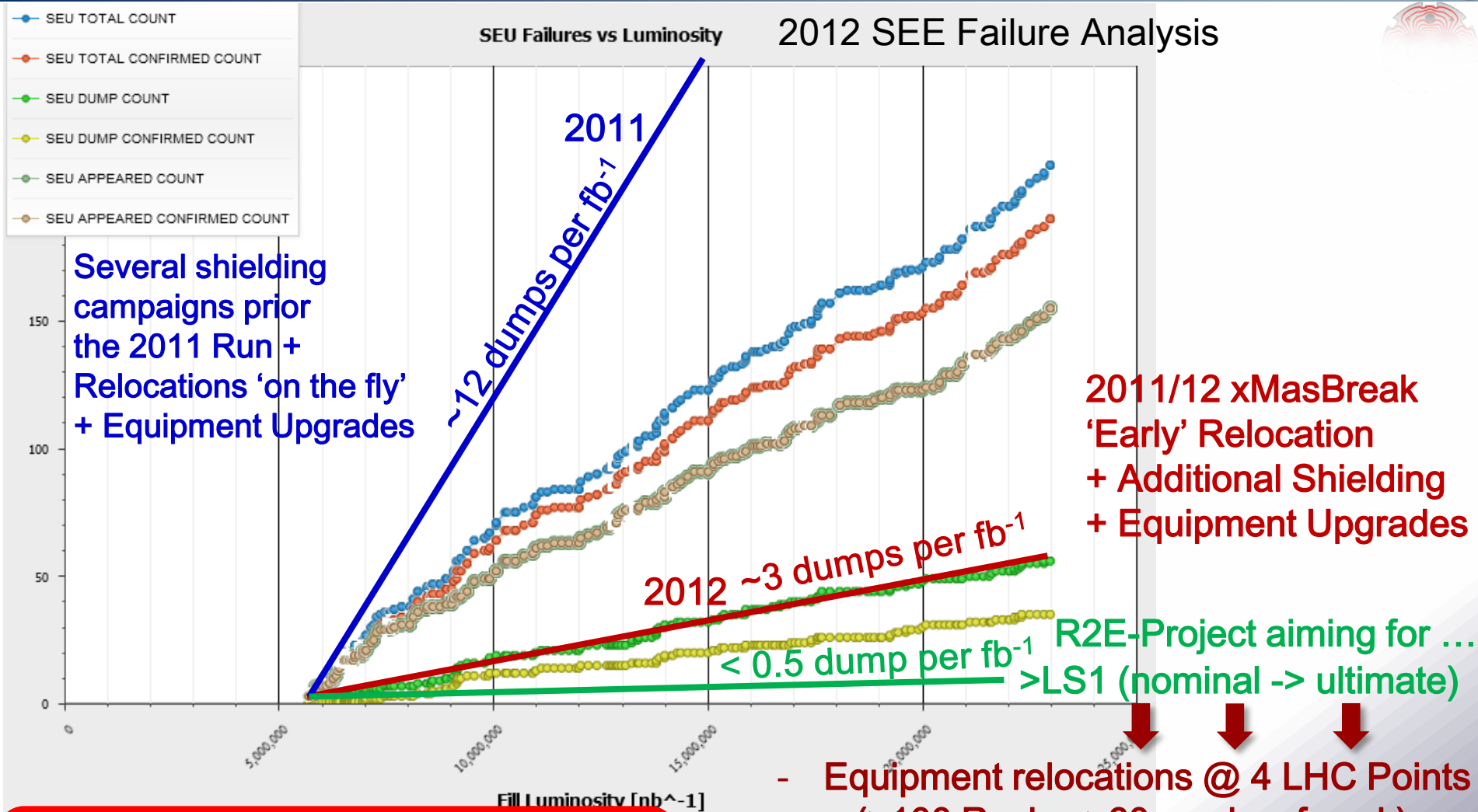
A. Apollonio – HL-LHC – IPAC

better metric for complexity...

TE/MPE & AWG – student 2013



R2E: Past/Present/Future



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

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

Machine protection

- Some interesting probes of failure space this – still learning
 - OFSU
 - LBDS 12V
 - BSRT mirror
 - TL collimators
 - Injecting H9
- MD enforcement
- Workshop....



Cycle

- Operational cycle is well optimized and transfers reasonably to 7 TeV
- “Aggressive” modifications
 - precycle non MB to less than 7 TeV
 - combined ramp and squeeze
 - partial squeeze with colliding beams
 - beta* levelling
 - Options for these two and possible implementations need to be explored
 - An effective solution should be in place for post LS1
- Operational robustness – first priority
 - personally I wouldn't rely completely on reproducibility
- Start up with conservative cycle, then become more aggressive when the dust has settled.

Spectrometers

- Switch crossing angle in point 8 to vertical at injection, while being elegant solution, **implies global change of aperture limit to point 8 – implications to be fully explored**
- (Lack of) possibility to rotate beam screen during LS1 to be confirmed..

Systems

- Delphine
 - Iron fist in a velvet glove

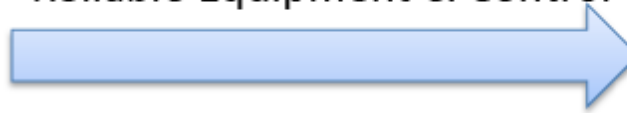


Conclusion

- Issues, weakness and possible improvement for beam based system and control have been presented

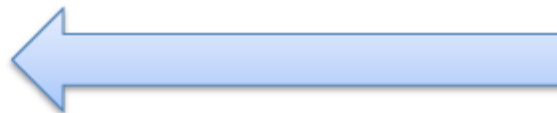
It shows that the success of this year did not come without struggle

Reliable Equipment & Control



Huge work from the equipment and control teams

LHC operation efficiency



Equipment & controls teams

Now, experts of each mentioned system are going to present what is foreseen during LS1 to be prepared for 2015, and realize **all** our wishes...

Systems

- Systems (BI, RF, ADT, Injection, LBDS)
 - in general very good performance
 - mature systems – issues identified – improvements planned
 - imagine these coming back post LS1 in good shape
 - with appropriate time dedicated to re-commissioning and tests

Systems

- BI
 - DOROS looking very encouraging – certainly address IR requirements – triplet BPMs thus equipped could certainly help lumi stability in beta* levelling
 - Interlocked BPMS should not dump the beam when the bunch intensity drops below Ne10
 - Orbit feedback review incoming
 - High intensity test for BSRT required in the New Year
 - Abort gap monitoring from an MP perspective...
- RF
 - importance of cavity voltage set-point modulation for 25 ns
 - cryo module 1B2 to be replaced
 - Heating/bunch length – distribution is key

Systems

- Injection
 - MSE current ripple
 - flat-top orbit variation in SPS
 - It weren't always the satellites – correct for the right problem - diagnostics
 - 288b looks good
 - Sunglasses LICs – follow-up, follow-up....
 - 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 additional interlocks
 - Higher voltages on switches at 6.5 TeV – increased risk of erratics

ADT

- ADT
 - it's good, it's mature and getting better
 - operational rigour identified as a possible issue in expert setting management
 - Do we keep the witness bunches?
 - Yes – any objections?
 - ADT2 post LS2 will require some concerted recommissioning

ADT Settings management

- Why not yet automatic?

▶ Could be made automatic, but it requires stringent control of the process from the OP side!

50ns_1092b+1small_1042_35_1008_144bpi	4727	50	36	4	144	100	0	4727	50	36	4	144	100	0
50ns_1092b_1051_0_1032_108bpi12inj	7727	50	36	2	72	100	0	7727	50	36	2	72	100	0
50ns_1093b+1small_1042_35_1008_108bpi_ob	9597	50	36	4	144	100	0	9597	50	36	4	144	100	0
50ns_109b_85_69_72_24bpi6inj	13067	50	36	4	144	100	0	13067	50	36	4	144	100	0
50ns_109b_91_12_90_12bpi10inj	16667	50	36	2	72	100	0	16667	50	36	2	72	100	0
50ns_1104b+1small_1042_35_1008_108bpi_ob	18537	50	36	4	144	100	0	18537	50	36	4	144	100	0
50ns_1200b_36x3bpi_13inj_scrub	22007	50	36	4	144	100	0	22007	50	36	4	144	100	0
50ns_1236b+1small_1180_37_1152_144bpi	25487	50	36	2	72	100	0	25487	50	36	2	72	100	0
50ns_1374_1368_0_1262_144bpi12inj	27357	50	36	4	144	100	0	27357	50	36	4	144	100	0
50ns_1374_1368_0_1262_144bpi12inj_V2	30827	50	36	4	144	100	0	30827	50	36	4	144	100	0
50ns_1380b+1small_1318_39_1296_144bpi														
50ns_1380b_1331_0_1320_144bpi12inj														
50ns_1380b_1377_0_1274_144bpi12inj														
50ns_1380b_1377_0_1274_144bpi12inj_swap														
50ns_1380b_1380_0_1274_144bpi12inj														
50ns_18b_6bnonCollid_6bpi														
50ns_205b_169_24_168_24bpi10inj														
50ns_228b+1small_214_12_180_36bpi_8inj														
50ns_262b_256_0_120_120bpi3inj														

According to this we are injecting precisely 1e11 ppb since 2008...

refresh

save as csv file

18:22:40 - head-on and long range collisions displayed

Controls

- Major infrastructure upgrades planned – commissioning time required
 - don't forget requirements of ongoing TI monitoring etc.
- Timing/cycle management – improvements required and incoming – coherent approach required
- Data analysis tools – yes, yes, yes
- We've learnt a lot, we know how to operate the machine – “Can we do it better?”
 - Note for Operations!!!!
 - ergonomics and software coherency in the CCC is barely acceptable

Session 4a summary

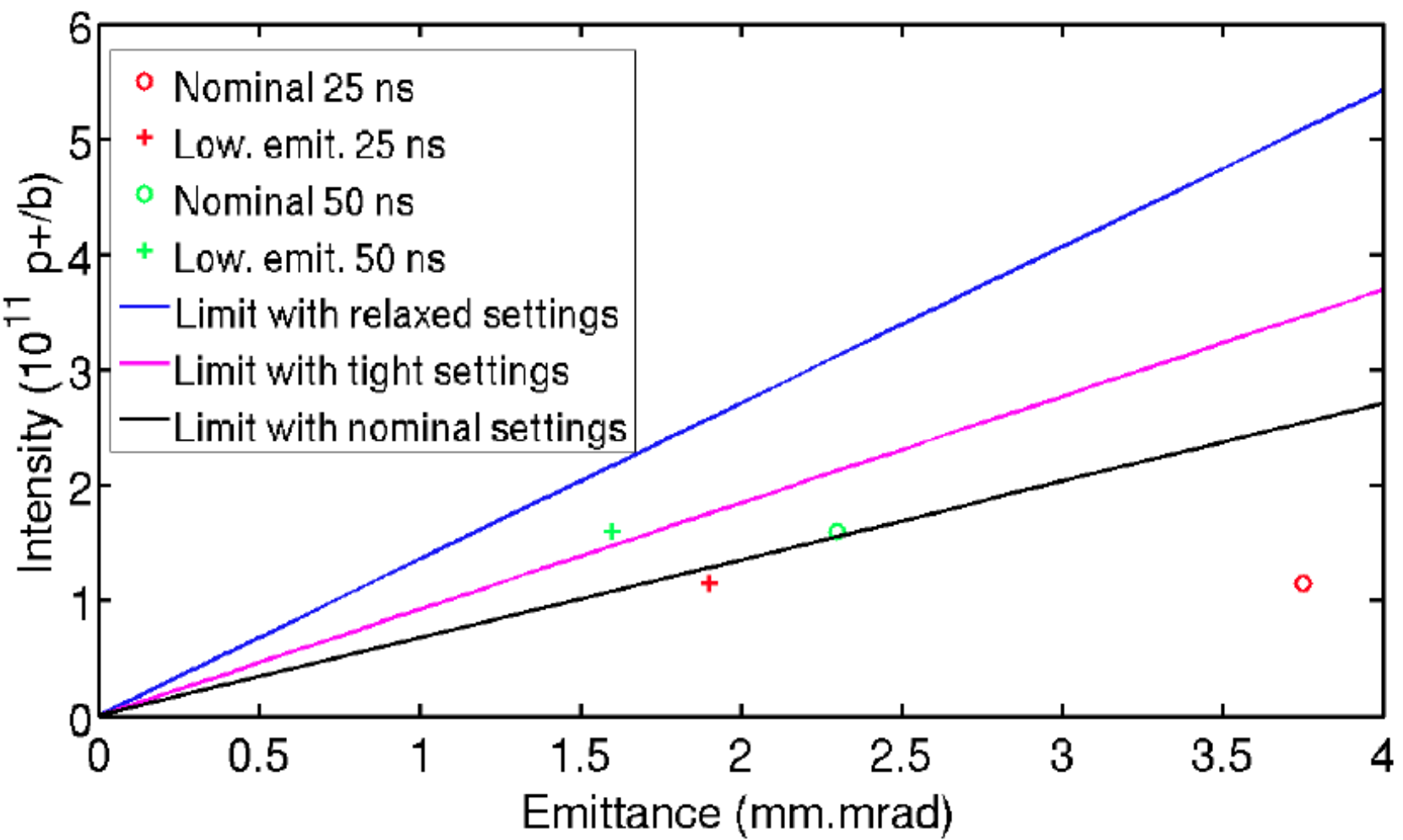
**Performance limitations: 2012 review and
2014 outlook (6.5 TeV, 25ns, higher total
l...)**

Courtesy Gianluigi

Limitations

- Guidelines:
 - Levelling by separation is to be avoided
 - Long range separation of 10 (12) sigmas in IP1/5 for 50(25) ns operation and 15 sigmas in IP2/8
 - Non colliding bunches to be avoided
- 25 ns preferred for single beam instability
- We will have to operate at high octupole current and high damper gain/bandwidth (50 turn damping time).
- Old octupole polarity is preferred for single beam stability
- Schemes for going in collision as fast as possible should be pursued. IP1 and IP5 should be staggered.
 - Go fast – keep it simple

Beam parameter space with separated beams post-LS1



=> No problem with 25 ns, standard 50ns close to limit for nominal coll. settings, but **low emittance 50 ns** can pass only with relaxed settings.

Limitations

- Heating will remain an issue (in particular upgrade of TDI should be pursued).
- Maximum bunch length should be pursued compatibly 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

LS1 will be busy!

25 ns & electron cloud

- There is a change of mode of operation with 25 ns. Electron cloud free environment after scrubbing at 450 GeV seem 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.
- Will start with a new (unconditioned) machine
- 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

25 ns & electron cloud

- Scrubbing in 2012 limited by heat load in the stand alone at 450 GeV and in the arcs at 4 TeV.
- Triplet cryogenic limit on luminosity
 - $1.7e34 \text{ cm}^{-2}\text{s}^{-1}$ (+/- 20%)
- Need to change the valve poppets for sector 34 arcs and stand-alone magnets to increase margin and electron dose rate during scrubbing by up to factor 2.
- Do we need interlocks on temperatures (possibly integrated)?

Cryogenics

- Scaling with 2015 beam parameters shows sufficient margin with respect to local and global cooling limitations by implementing the following consolidations:
 - Consolidation of the Cu braid configuration on 6/8 IT (planned for LS1)
 - Increase of the maximum flow coefficient of the BS control valve of the standalone magnets (seat and poppet exchange) -> compatible with e-cloud deposition of 1.6 W/m per aperture -> to be planned for LS1

Session 4b summary

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

Courtesy Rudiger

Vacuum, Giulia Lanza

- All RF non-conformities repaired
- Vacuum interlocks with (tight) required for integrity of the vacuum system (e.g. NEG coating)
- Vacuum interventions need a lot of care – to minimize unacceptable conditions after the interventions
- No particular issues for scrubbing
- 2015: SEY etc. will be reset - initial conditioning required – better to start with 50 ns

UFOs

- 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?
- Deconditioning expected after LS1
- Operational scenario to be developed: start with lower energy and/or 50 ns beam,
- What priority from physics: high integrated luminosity versus high energy collisions as soon as possible

BLM thresholds - past experience.

Eduardo Nebot Del Busto

- 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 proposed in Chamomix 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 hopefully give more insight – important for establishing thresholds
- Noise: optimistic that BI will solve this issue
- Triplets: IR8 will be in the shadow of 1 and 5

Cleaning and collimator operation – outlook, Belen Maria Salvachua Ferrando

- 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)
 - $\beta^* = 70\text{cm}$ at 25ns
 - $\beta^* = 57\text{cm}$ at 50ns
- Optimistic scenario (H9 emittance)
 - $\beta^* = 37\text{cm}$ at 25ns
 - $\beta^* = 30\text{cm}$ at 50ns
- Quench tests will provide more input

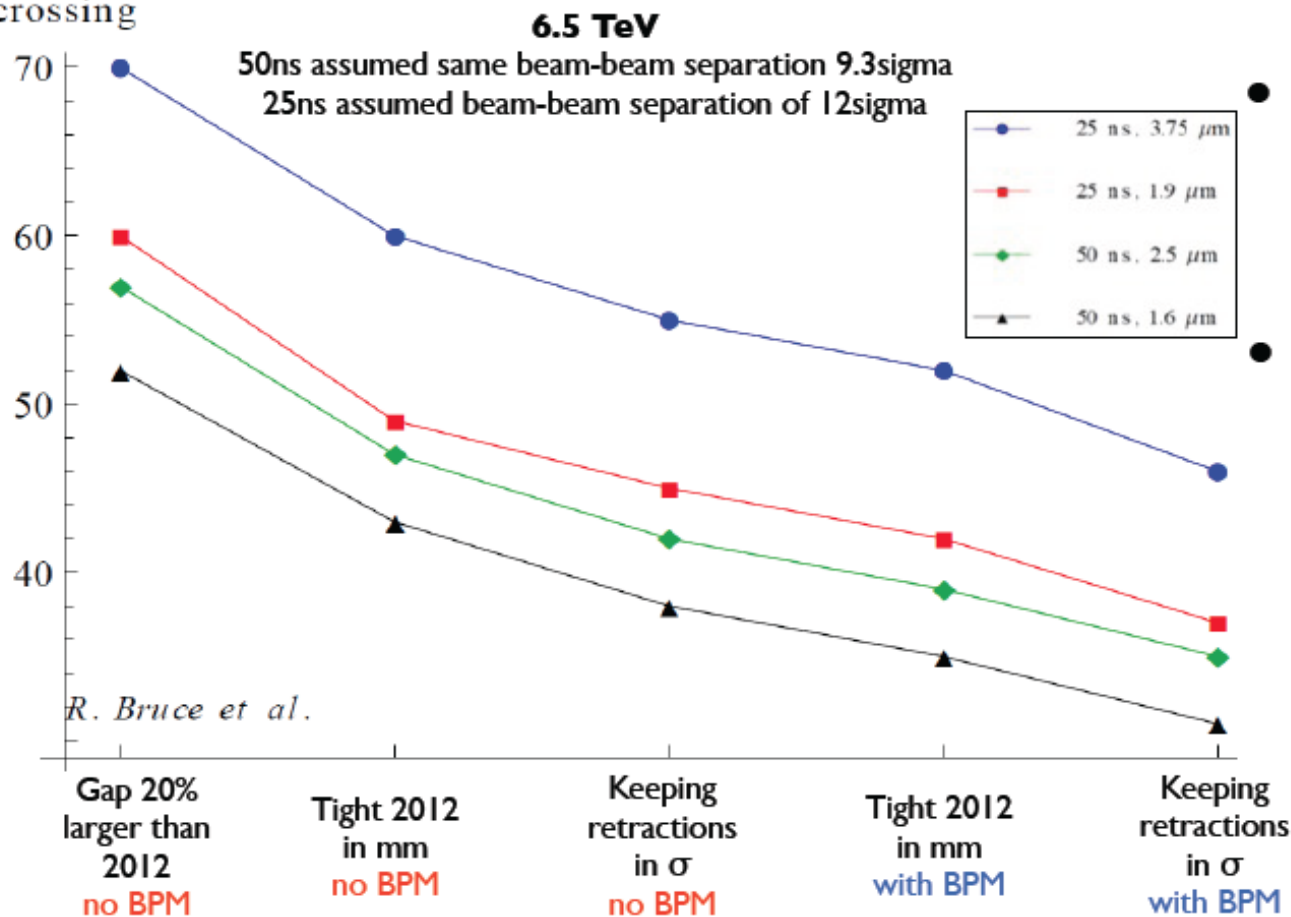
Start with a relaxed approach



β^* reach at 6.5 TeV



β^* (cm)
crossing



- Pessimistic scenario:
 - ➔ $\beta^* = 70\text{cm}$ at 25ns
 - ➔ $\beta^* = 57\text{cm}$ at 50ns
- Optimistic scenario:
 - ➔ $\beta^* = 37\text{cm}$ at 25ns
 - ➔ $\beta^* = 30\text{cm}$ at 50ns

Emittance preservation, Maria Kuhn

- Q20 and Q26 end up the same in physics
- Wire-scanner calibration as an issue:
 - WS ne Lumi etc.
- Sitting on 50 Hz at injection causes blow-up but not in ramp...?
- Blow-up during ramp still not understood

Summary Optics and dynamic aperture at 4 at 6.5 TeV, Rogelio Tomas Garcia

- Excellent understanding of linear and nonlinear optics (including corrections)
- 1% errors in MQY – nice find
- MO, MCO and MCOX can be used to increase Landau damping to an equivalent of 1100 A, but DA is a concern... to be tested
- Beating, injection tunes, injection beta*, optics, luminosity predictions used below used below
- 4 to 10 shifts!



AFTER LS1

Post LS1

- “It’s going to be like after a war”
Serge Claudet
- In what forum do we track, coordinate system tests, cross-system tests, dry runs etc.?

Parameters

Energy	6.5 TeV
Bunch spacing	25 or 50 ns
Transfer line collimators	4.5 sigma
Injection tunes	0.31/0.32 (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% tight +10% relaxed -25%
Octupole current	Between +550 and -550 A
Damper gain	To the max

Cycle

- Inject into collision tunes at beat* = 7 m
- Combined ramp and squeeze
- Ramp, squeeze, collide, squeeze
- Pre-cycle non MB magnets to < 6.5 TeV
- Triplet strengths in 2 & 8 to be brought down at some point
- Staggered collisions

Beam from injectors LS1 to LS2

		Bunch intensity [10^{11} p/b]	Emittance,[mm.mrad]	Into collisions
25 ns ~nominal	2760	1.15	2.8	3.5
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

While recognizing Rende's numbers

50 versus 25 ns

	50 ns	25 ns
GOOD	<ul style="list-style-type: none">• Lower total beam current• Higher bunch intensity• Lower emittance	<ul style="list-style-type: none">• Lower pile-up
BAD	<ul style="list-style-type: none">• High pile-up• Need to level• Pile-up stays high• High bunch intensity – instabilities...	<ul style="list-style-type: none">• More long range collisions: larger crossing angle; higher beta*• Higher emittance• Electron cloud: need for scrubbing; emittance blow-up;• Higher UFO rate• Higher injected bunch train intensity• Higher total beam current

Expect to move to 25 ns because of pile up...

Beta* & crossing angle

Collimation Scheme		Beta* [cm] 25ns	Half X-angle [microrad] 25 ns	Beta* [cm] 50 ns	Half X-angle [microrad] 50 ns
S1	Same in mm	50	190	40	140
S2	Same in sigma	45	200	35	150
S3	1 sigma retraction	40	210	30	160
S4	Low emittance	40	150	40	120

	β^* cross	β^* sep	β^* sep collide&squeeze	$\alpha/2$ urad	BB sep σ
50 ns, 2.5 um	35	33	30	150	9.3
50 ns, 1.6 um	31	33	30	127	9.3
25 ns, 3.75 um	46	33	30	205	12
25 ns, 1.9 um	37	33	30	163	12

50ns H9

β_x^* [m]	β_y^* [m]	θ μrad	Luminosity [$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	Δ [%]
0.5	0.5	201	1.90	
0.4	0.4	225	2.14	13
0.3	0.3	260	2.41	13
0.6	0.4	184	2.08	
0.6	0.3	184	2.40	15
0.6	0.2	184	2.94	23

25 ns H9

β_x^* [m]	β_y^* [m]	θ μrad	Luminosity [$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	Δ [%]
0.5	0.5	282	1.60	
0.45	0.43	298	1.71	7
0.37	0.33	326	1.92	12
0.5	0.33	282	1.97	
0.5	0.23	282	2.36	20

Potential performance

	Number of bunches	Ib LHC FT[1e11]	Collimator scenario	Emit LHC (SPS) [um]	Peak Lumi [cm ⁻² s ⁻¹]	~Pile-up	Int. Lumi [fb ⁻¹]
25 ns	2760	1.15	S1	3.5 (2.8)	9.2e33	21	24
25 ns low emit	2320	1.15	S4	1.9 (1.4)	1.6e34	43	42
50 ns	1380	1.6	S1	2.3 (1.7)	1.7e34 level 0.9e34	76 level 40	~45*
50 ns low emit	1260	1.6	S4	1.6 (1.2)	2.2e34	108	...

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

All numbers approximate

OLD NUMBERS

In words

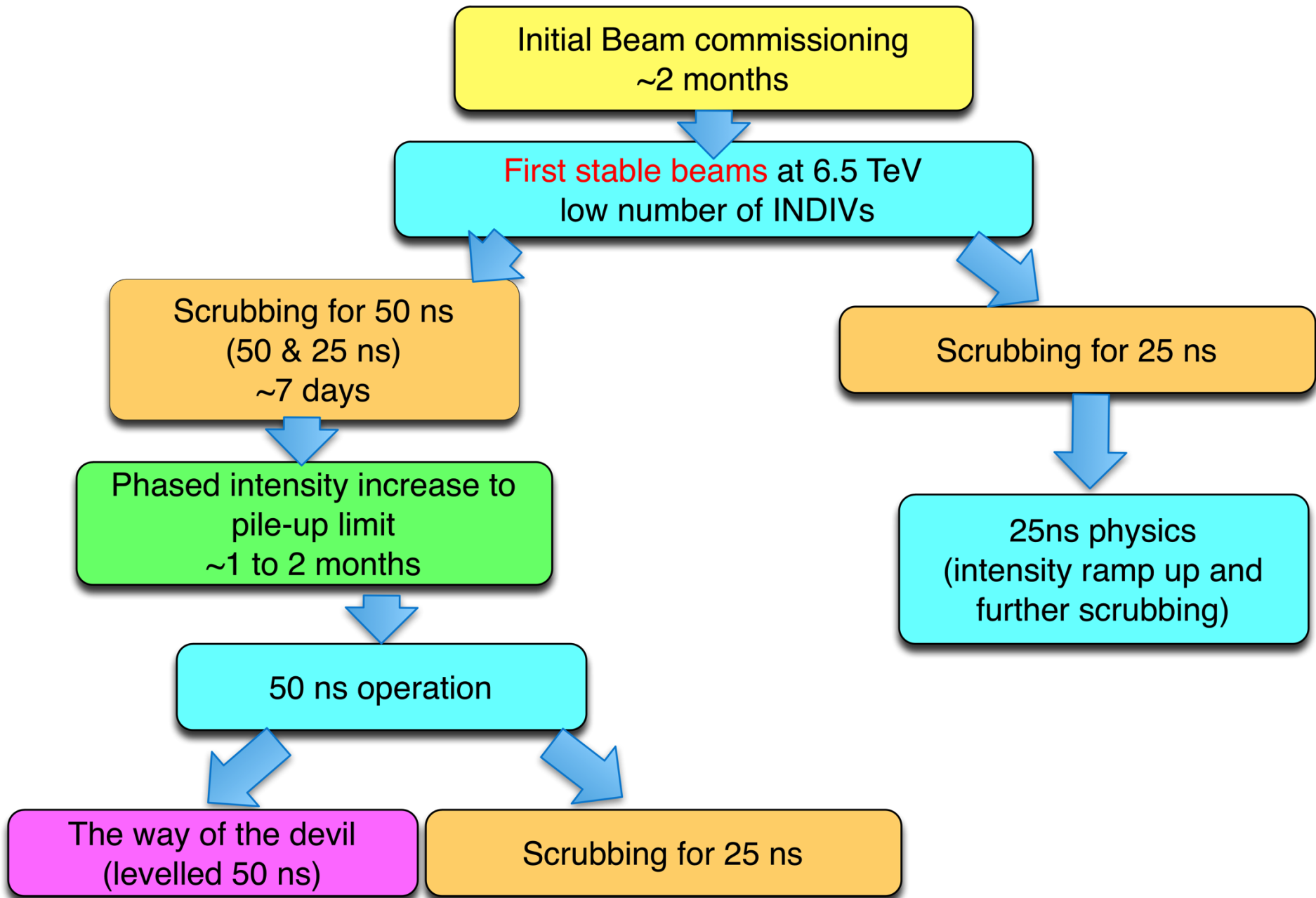
- Nominal 25 ns
 - gives more-or-less nominal luminosity
- BCMS 25 ns
 - gives a healthy $1.6e34$
 - peak $\langle\mu\rangle$ around 40
 - 83% nominal intensity
- Nominal 50 ns
 - gives a virtual luminosity of $1.7e34$ with a pile-up of over 70
 - levelling mandatory
- BCM 50 ns
 - gives a virtual luminosity of $2.2e34$ with a pile-up of over 100
 - levelling even more mandatory

Comments

- 50 ns implies the existence of a robust levelling technique
- A non EC free 25 ns?
 - bench marked very recently...
- The 25 ns will bring issues:
 - UFOs, beam inducing heating, vacuum
- Low emittance 25 ns option is attractive for a number of reasons
 - lower total beam current, performance...

2015 strategy – for discussion

- **Low intensity commissioning of full cycle – 2 months**
 - First pass machine protection commissioning and validation
- **First stable beams – low luminosity**
- **Intensity ramp-up – 1 to 2 months**
 - Commissioning continued: system (instrumentation, RF, TFB etc.), injection, machine protection, instrumentation...
 - Variables: bunch intensity, number of bunches, emittance
 - Pass straight to 50 ns, step up in no. batches
 - Scrubbing for a few days will be required early on
- **50 ns operation (at pile-up limit)**
 - Characterize vacuum, heat load, electron cloud, losses, instabilities, UFOs, impedance
 - Nominal bunch intensity, 40 cm, 2.3 microns gives $9e33 \text{ cm}^{-2}\text{s}^{-1}$ and a pile-up of around 40
- **Options thereafter:**
 - 2 weeks scrubbing for 25 ns, say 1 week to get 25 ns operational (if beta* and crossing angles are changed), intensity ramp up with 25 ns
 - Commission levelling of 50 ns and push bunch intensity up, emittance down...



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

Conclusions

- Magnetically, optically, operationally well understood
- System performance
 - generally good to excellent
 - issues identified and being addressed
- Limitations well studied, well understood and quantified
- 25 ns it is (via 50 ns)
 - but in a non EC free environment at least initially

Misc eternal questions

- Eternal can we minimize or be more flexible with the technical stops