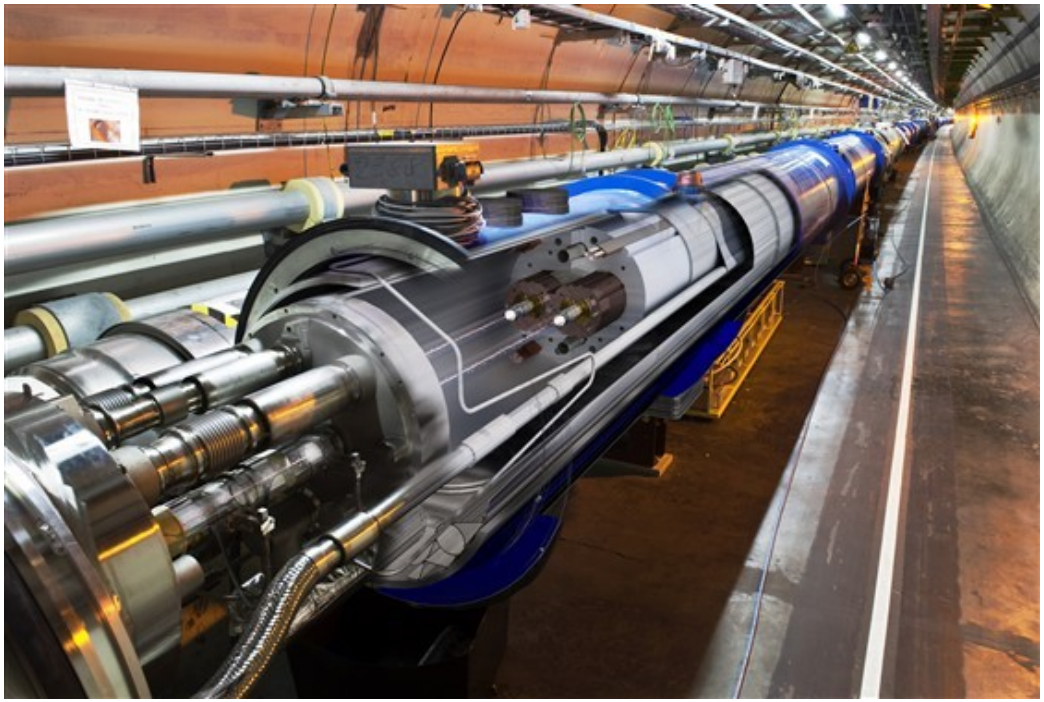
Intensity ramp-up

Mike Lamont

Preamble

$$L = F \frac{N_b N_1 N_2 f_{rev}}{4 \pi \sigma_x \sigma_y}$$

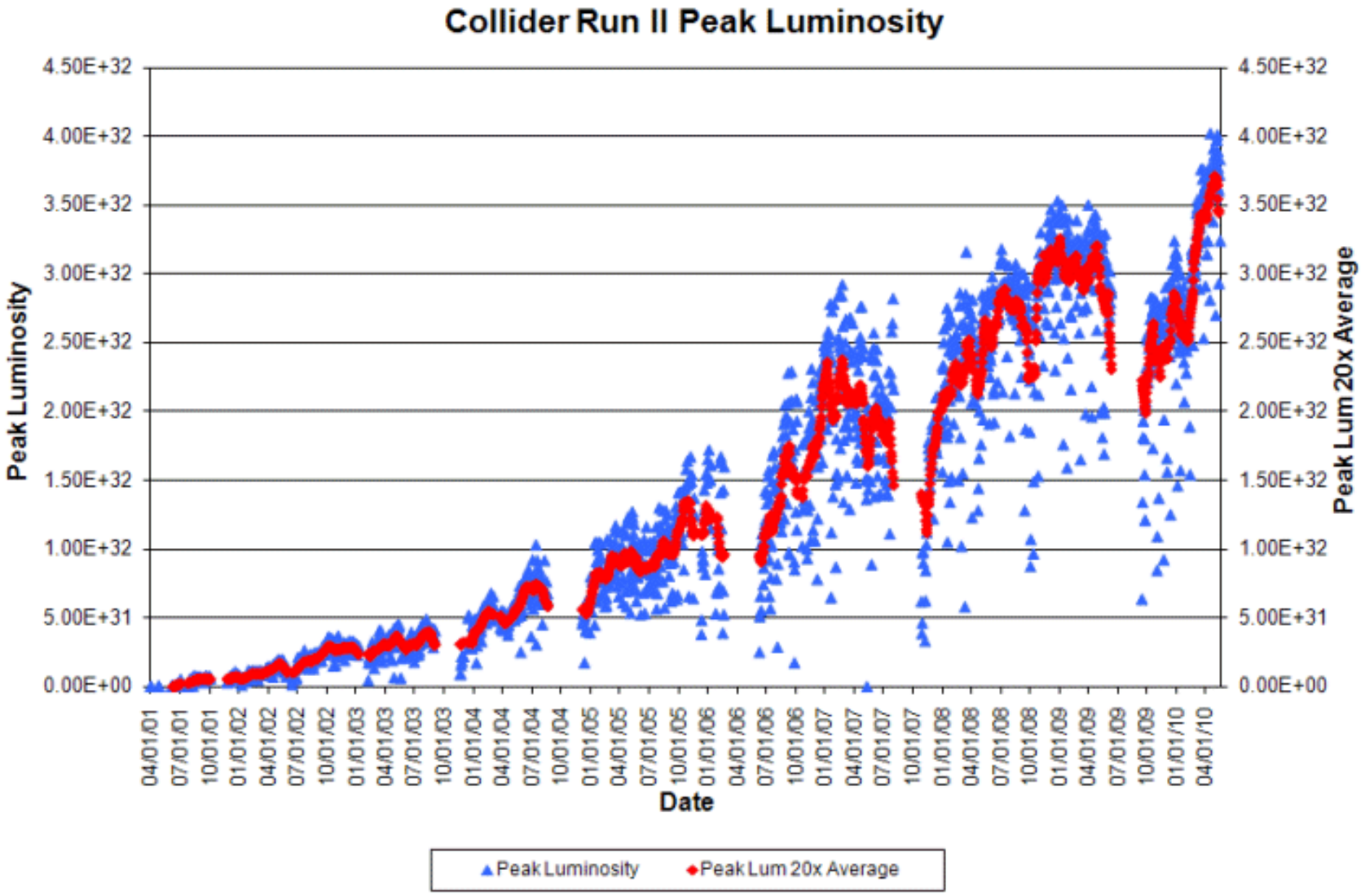
This is an equation. (a)



It is a lot easier to inject lots of high intensity bunches into a than it is b

This is a particle accelerator. (b)

Tevatron


Collider Run II Peak Luminosity
Peak Luminosity
Peak Lum 20x Average
Date
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4.00E+32
3.50E+32
3.00E+32
2.50E+32
2.00E+32
1.50E+32
1.00E+32
5.00E+31
0.00E+00
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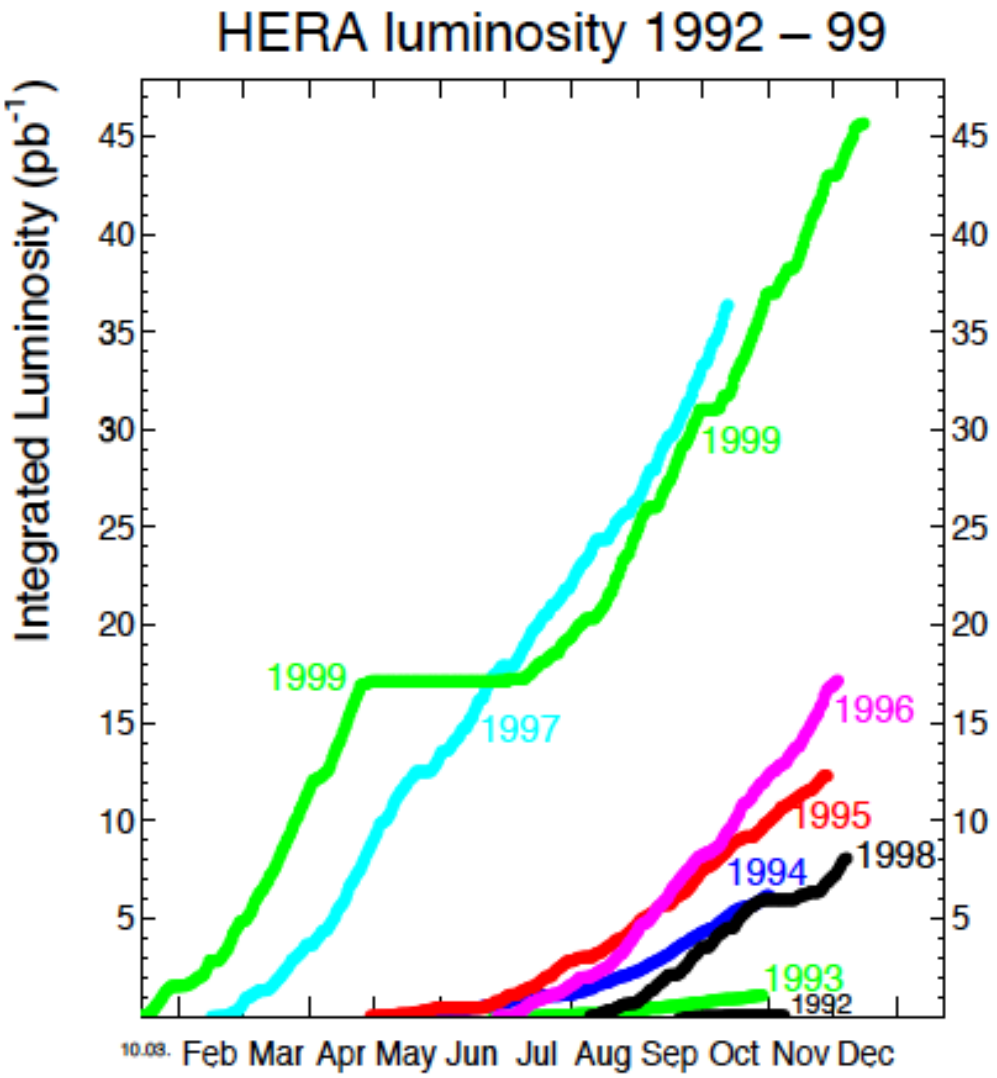
Peak Luminosity
Peak Lum 20x Average

HERA


HERA luminosity 1992 – 99
Integrated Luminosity (pb^{-1})
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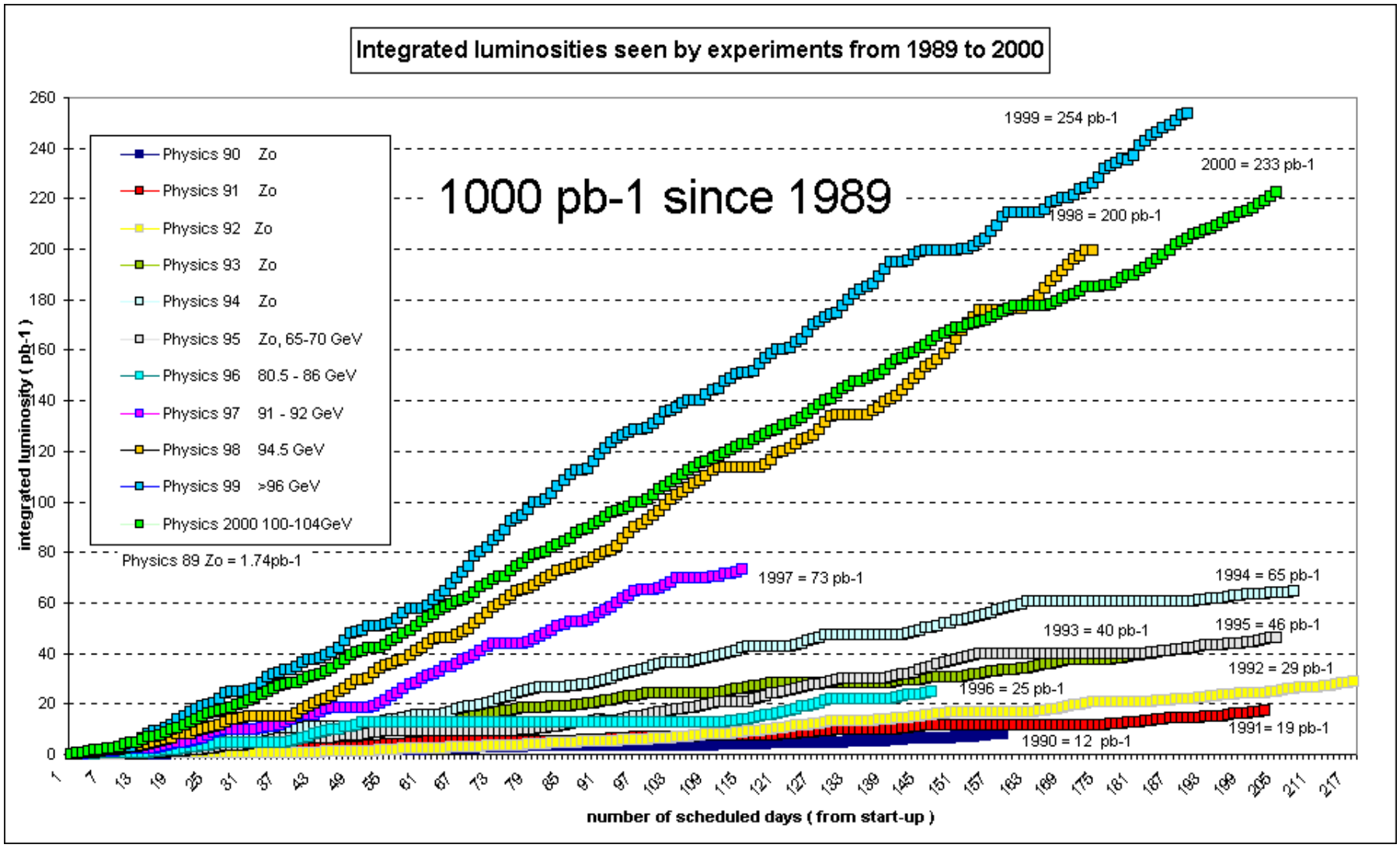
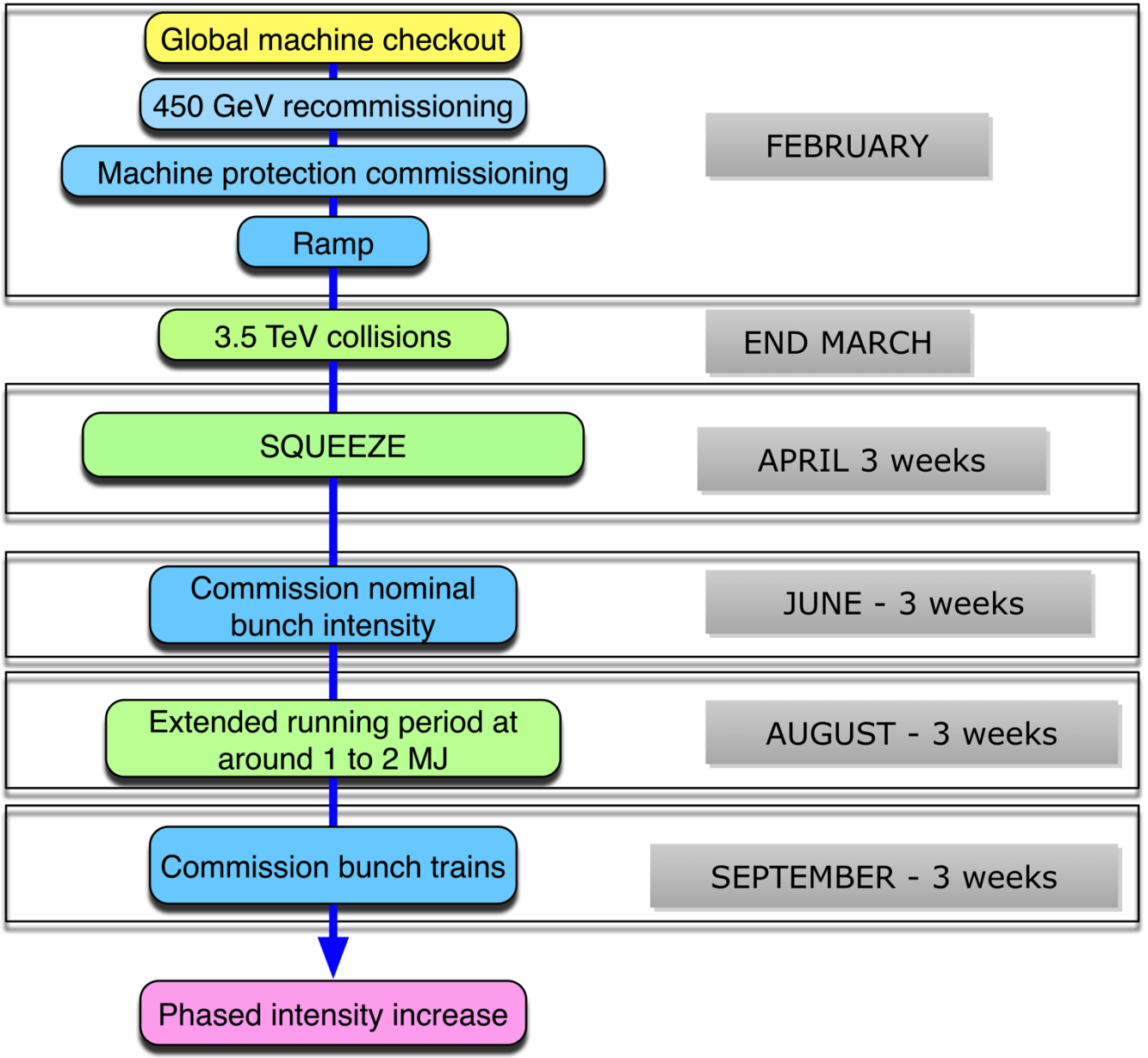
35
30
25
20
15
10
5
1999
1999
1997
1996
1995
1994
1998
1993
1992
10.03. Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

LEP



MESSAGE: IT TAKES TIME!

2010 – main phases



2010 – main phases

March	Initial commissioning leading to first collisions (30/3)
April	Squeeze commissioning leading to first collisions with beta* = 2 m. (24/4)
May	Physics 13 x 2e10 (24/5)
June	Bunch intensity to nominal, beta* = 3.5 m. 3 on 3 nominal bunches (25/6)
July	25 on 25, 16 colliding pairs per experiment, 9e10 per bunch (30/7)
August	25b until 18th August (around 1.5 MJ) 48 on 48 for 2 weeks (2 - 3 MJ)
September	Bunch trains
October	**Intensity ramp up**

Milestones reached 2010 (to August)

Date	Achieved	
Feb 28	Restart with beam.	
Mar 30	First collisions at 7 TeV centre of mass.	Luminosity ~ 2 10^{27} cm^{-2} s^{-1}
Apr 01	Start squeeze commissioning.	Regular physics runs 2 on 2 bunches of 10^{10} Un-squeezed 1 colliding pairs per experiment Rates around 100Hz
Apr 07	Squeeze to 2 m in points 1 and 5.	
Apr 09	Single nominal bunch of 1.1 1011 stable at 450GeV.	
Apr 13	Squeeze to 2 m in point 8.	
Apr 16	Squeeze to 2m in point 2.	
April 24	First stable beams at 7 TeV, 3 on 3, squeeze to 2m.	Luminosity ~ 2 $10^{28}$$cm^{-2}$ s^{-1}
May	Increase bunch intensity to 2 $10^{10,}$ Increase $k_{b.}$	Regular physics runs
May 24	13 on 13, 8 colliding pairs per experiment.	Luminosity ~ 3 $10^{29}$$cm^{-2}$ s^{-1}
June	Increase bunch intensity to nominal, squeeze to 3.5m.	Machine development
June 25	First stable beams at 7 TeV, 3 on 3 nominal bunch.	Luminosity ~ 5 $10^{29}$$cm^{-2}$ s^{-1}
July 15	13 on 13, 8 colliding pairs per experiment, 9 10^{10} / bunch	Luminosity ~ 1.5 $10^{30}$$cm^{-2}$ s^{-1}
July 30	25 on 25, 16 colliding pairs per experiment, 9 10^{10} / bunch	Luminosity ~ 3 $10^{30}$$cm^{-2}$ s^{-1}
Aug 19	48 on 48, 36 colliding pairs 1 5 and 8, 9 10^{10} / bunch	Luminosity ~ 6 $10^{30}$$cm^{-2}$ s^{-1}
Aug	Stable running period to consolidate operation and MP	~2 MJ per beam

Operational review

Internal MPP review

External MPP review

REVIEWS

Operational review 1st June

- Are operations' really ready to deal with the real destructive potential of 0.5 – 1 MJ?
- Issues were identified with:
  - Preparation & procedures
  - Injection
  - Collimation
  - Feedbacks
  - Sequencer
  - Controls
  - LSA, settings management etc.
  - XPOC
  - Post mortem
  - Orbit
- **ANSWER: NO!!!**

Internal MPS review 17/18 June 2010

- Beam Interlock System, Bruno Puccio
- SMP, Benjamin TODD
- PIC, WIC and FMCM, Markus Zerlauth
- LBDS, Jan Uythoven
- Collimation, Ralph Assmann
- Transfer and injection, Verena Kain
- Dump protection, Wolfgang Bartmann
- BPM system, Rhodri Jones
- Orbit feedback, Ralph Steinhagen
- RF frequency and power interlocks, Andrew Butterworth
- BLM system, Bernd Dehning
- Software Interlock System, Jorg Wenninger
- Experiments, Massimiliano Ferro-Luzzi
- OP review summary, Mike Lamont
- Post-mortem system, Markus Zerlauth

Internal review 1/2

BIS	Automated connection tests with users
BIS	Beginning of the ramp – operation – Safe Beam Flag to FALSE and unmask all inputs (sequencer)
SMP	Energy distribution check, since there is no redundancy
SMP	Intensity for SBF – No redundant readings
SMP	SBF limit – MPS commissioning / availability
SBF	Now uses the FBCT, too complex for providing a safe system
PIC	After technical stops and interventions the traceability of changes and required testing must be documented –„sloppy‟ as compared to HWC
PIC	PIC configuration: Automated tests of configuration and BIC connection to be performed more regularly

Internal review 2/2

XPOC	Reliability of some beam instrumentation data not good enough
LBDS	Technical stop modifications
LBDS	Interlocked beam position monitors - safety – Threshold and algorithms needs to be addressed
Collimation	Machine stability important, some worries
Collimation	Steady state losses are different from failure transients
BPM	BPM sensitivity settings: Automated and reliable sensitivity switching
Dump protection	Abort gap monitoring and cleaning
BPM	BPM readings dependence on intensity. Need a long term approach for critical location (IR3, IR7, TCT-IR regions).
BPM	Orbit correction strategy
BLM	Threshold management
BPM	Data from “direct dump” BLM
SIS	Most conditions are maskable (independent of SBF)

External MP review 6-8 September

- Clear criteria should be established by which steps and under which conditions the beam intensity will be increased. This includes, among other points,
  - establishing the necessary operational discipline associated with the potential risks in the new regime of stored energy which to a large extent was promoted during the LHC engineering and construction phase,
  - the understanding of the mechanisms populating the abort gap and their scaling as a function of beam intensity,
  - consolidation of the beam position monitoring system,
  - the improvement of a detailed and comprehensive post-mortem analysis, and
  - establishing a robust and rigid set of operating procedures and sequences.

More quotes

- In summary, the Committee feels that the LHC is ready to go beyond 3 MJ. It sees no objection to a relatively fast but successive increase in stored energy. This conclusion is based on what was presented on the machine protection system and its performance. It assumes
  - that the improvements are implemented which have been presented by the LHC project team themselves, including the priorities made by the Committee in addition to further recommendations,
  - that the machine performance is all the time understood as the stored energy increases and that confidence is gained in all the operational phases, and
  - that it is verified that there is no onset of new phenomena affecting the reliability of the machine protection system.

External review - specifics

Human Factor	Discipline, RBAC, back doors
Configuration Control and Requalification	Change management, tests
Sequencer and High-Level Operations Tools	It's a mess guys, get rid of the paper
Abort Gap Monitoring and Cleaning	Monitoring, cleaning
Collimator System	Hierarchy, tests
Beam Position Monitors	drifts
Movable Devices	Totem, VELO, Wire scanners
Beam Loss Monitors	Quench levels, blind spots, diamonds
Beam Current Monitors	BPF
Software Interlock System	Review, put in HW what you can
Specific Procedures	MKI, transfer line colls.

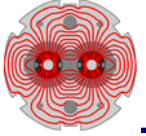
Ramping up

- Halting push through nominal intensity to 1-2 MJ
- Settled on 3 weeks at or around
  - 25 bunches until 17th August
  - 48 bunches until 1st September
  - Timeout for bunch train commissioning
- Could we have gone to 1 – 2 MJ earlier?
- NO!

Timeout for bunch trains

- The importance of hiatus should be stressed
  - Nominal bunch intensity
  - **Commissioning of bunch trains and the endless loss maps provided an opportunity to consolidate and really marked:**
  - the transition to a more rigorous sequence,
  - the reduction of manual actions,
  - and some sense that the sequence was under control.

- Eventually nailed down the sequence, procedures, orbit and settings to a state that could be more or less trusted.
  - Interestingly enough, we changed very little thereafter
  - And the sequence became frozen (until lead)



CRANKING UP BEYOND 2 MJ

Established procedure

- 50 nominal bunches steps (~ 3.2 MJ)
- 3 fills per step (making it into stable beams)
- 20 hours of stable beams
  - Always some debate – critical phases are those before stable beams – some latitude asked for and given
- BPMD test for each new bunch configuration

- Sign off of checklist before step up
- Meeting of rMPP where practicable
- Some step-ups took place at night, and at weekends
-

Why Not Faster?

- This would already be very fast: ~6 MJ per week. Still needs to be agreed.
- Remember that we **passed beyond Tevatron and HERA record stored energy in as little as 6 months**.
- We did this very safely! Not even a quench → good sign!
- Now we would add 3 record Tevatron or HERA beams every week!
- Both of these colliders had damaging events. Could end the LHC run for a few weeks or months of repair.
- Very thorough testing program ongoing to verify protection against all foreseeable problems.
- The constantly collected experience will define the ramp up of beam intensity!

Ralph Assmann

Criteria for passage 1/5

LHC intensity increase – check list

Version 0.2 - 5-Dec-10

Bunch pattern / intensity	368 nominal bunches
Start date	24.10.2010
Fill numbers	1440, 1441, 1442, 1444
Next intensity	424 nominal bunches
Comment	

Fill	Int B1/B2 [1E12]	Emittance [um]	Stable beams (h)	Dump reason
1440	43.0/43.0	~2.3	12	TCP scan triggered dump on collimator limit.
1441	43.0/43.0		0	UFO Q17.L4 on flat top
1442	43.0/43.0	~2.4	2.3	UFO MBA.Q8L7
1444	42.0/42.0	~2.6	8.5	OP dump

Criteria for passage 2/5

Check list

Non-conform points: the intensity increase is put on hold pending a satisfactory understanding / resolution of the issue.

Magnet powering	**Status**	**Who**
No unexplained IPOC failure in Post Mortem for FMCM and PIC	OK	JW
No magnet quench after beam dump in RQ4.R/L6	OK	JW
No unexplained quench of a magnet	OK	JW
No unexplained abort of the 3 previous fills by magnet powering system	OK	JW
No problems with loss of QPS_OK for main circuits following injection process	OK	JW
Comments:		

Beam interlocks	**Status**	**Who**
No unexplained IPOC failure in Post Mortem for BIC	OK	JW/MZ
No unexplained false beam dump from beam interlock system	OK	JW/MZ
No failure of BIS pre-operational check	OK	JW
Comments:		

Criteria for passage 3/5

BLM	Status	Who
Internal test (sanity checks) results must be true	OK	JW/BD
Rise time (10 to 90%) of fast losses must be larger then 200 us	OK	JW/BD
No unexplained BLM check failures	OK	JW/BD
Expected losses for the to be injected beam must be 30 % below threshold level	n/a	BD
BLM system modification (ECRs) have to be agreed on, EDMS: notified persons signature is needed	n/a	BD
No nonconformities in the energy transmission to the BLM crates	OK	BD
Comments:		

Loss maps not performed at each step. Frequently enough?

~~Collimation~~	~~Status~~	~~Who~~
Betatron loss map	OK	Coll. Team
Off-momentum loss map	OK?	Coll. Team
No observed violation of cleaning hierarchy	Seems OK	OP
~~Comments:~~		

Criteria for passage 4/5

Post-mortem	Status	Who
Loss leakage to TCTs below 0.5% during beam dump	OK	JW
UFO occurrences	2	JW
No unexplained PM event above 450 GeV	OK	JW
Comments:		

Orbit	Status	Who
Global orbit in tolerance in stable beams (< 0.2 mm rms)	OK	JW
Orbit IR3/IR7 collimators within ± 0.2 mm in stable beams	OK	JW
Check that orbit is correctly measured	OK	JW
BPM IP6 (interlock BPM) during first beam with higher intensity and different bunch pattern	OK	ABT
Orbit at TCTs in tolerance in stable beams (≤ 1 sigma)	OK	JW
Comments:		

Feedbacks & operation	Status	Who
OFB operational status / no anomalies	OK (1)	JW
QFB operational status / no anomalies	~OK(2)	JW/OP
Comments:		
1. OFB OK, but one fill dumped after incorrect OFB changes before the squeeze. 2. Short FB outages during the ramp for one fill, else OK.		

Criteria for passage 5/5

Beam dump	Status	Who
Asynchronous dumps understood? Protection worked correctly?	OK	BG
Parasitic asynchronous dump data show no loss of protection	OK	BG
No positioning errors on TCSG/TCDQ	OK	BG
No settings or thresholds mistakes/wrong sequences/unexplained faults on TCSG/TCDQ	OK	BG
No unexplained MKD, MKB kicker, TSU or BETS faults	OK	BG
No potentially dangerous XPOC or IPOC failure on MKD or MKB	OK	BG
No unexplained synchronization problem with TSU	OK	BG
Pressure and temperature rise in TDE block within tolerances	OK	BG
Requalification passed OK at 450 GeV and 3.5 TeV with pilot in case of any important component exchange	OK	
Comments:		

Injection	Status	Who
Injection oscillations within tolerance for all injections	OK	BG
No unexplained large beam loss on TCDIs	OK	BG
No issues in injection procedure, settings or tolerances	OK	BG
Orbit in injection region in tolerance wrt reference (tolerance <0.5 mm)	OK	BG
Resetting of TL trajectories and TCDIs done when needed	OK	BG
No increased rate of MKI flashovers	OK	BG
No increased rate of MKI switch erratics or missings	OK	BG
No unexplained MKI vacuum or temperature activity	OK	BG
No machine-protection related injection system failures	OK	BG
Comments:		

Some debate on the way…

12b	Tonight we had two separate incidents injecting, first 4 nominal bunches which we injected onto the TCDQ which we had somehow managed to move to 3.5 TeV settings, and then injecting the pilot with the TCLIA back at the old pre-Xing angle setting. Both of these were because we were pushed for time before the access and got caught out
56b	Alice polarity reversal
56b++	Tune FB switching off in ramp, BBQ saturated
56b	Checklist not completed – pressure from above
	TCDQ wrongly to injection settings, not ramping
	Arc & DS thresholds increased - UFOs
152b	Tune – on and off in ramp & squeeze Vacuum – electron cloud kicks off
	GPS issue which caused the MKI prepulse to arrive too early wrt the BETS window and which then resulted in a kicker missing and the full injected intensity on the TDI (3 times, both beams affected...).
	PM data quality

Observations

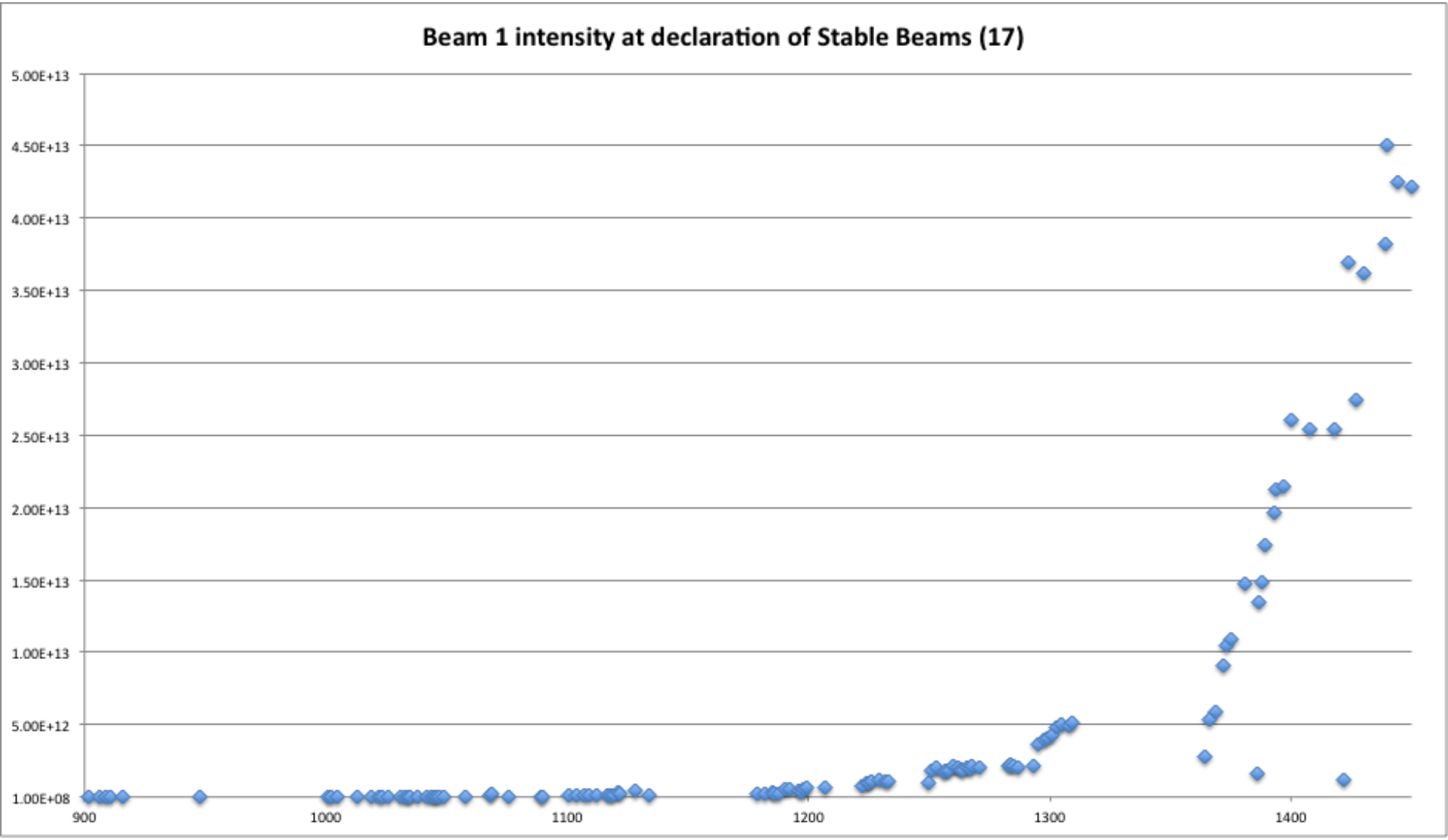
- Circulation to rMPP
  - Good representation of concerned parties
- Limited number of initialees
- Fast turnover (nights, weekends)
- Intrinsic sense among the community that things were OK. Check list not taken too seriously?
- Is MPS coverage assured? Have we checked the checklist? Test sequences?
- No special considerations when coming out of a TS.
- Operational non-conformities were still taking place
  - Intrinsic assumption that BIS & co would pick these up
  - Although some did affect orbit (particularly expt. IRs)
- It wasn't all plain sailing and we indeed topped out at 368 bunches because of issues with 424.

Observations

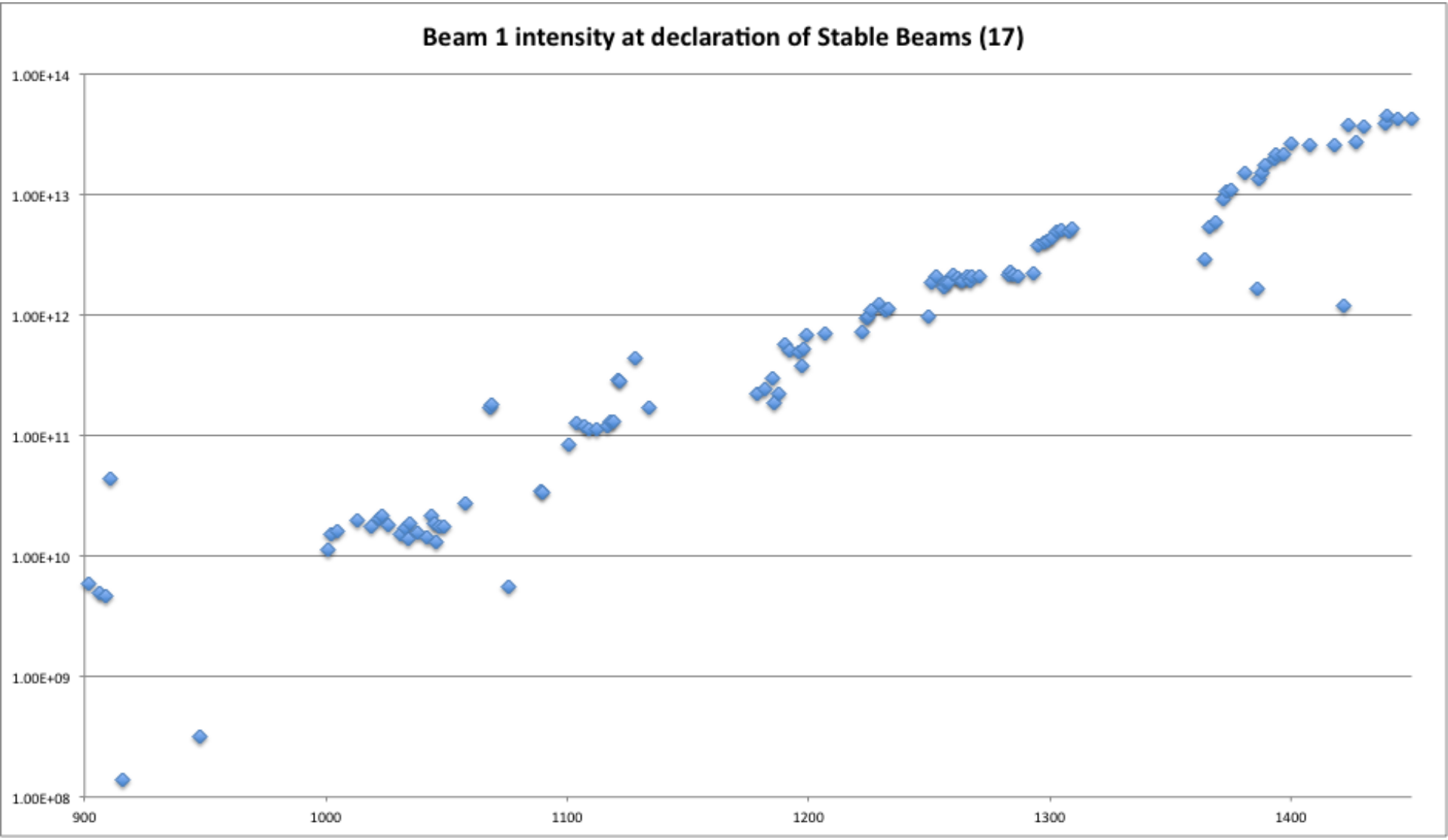
- Strategy was useful in providing a framework for intensity increase.
  - And thus prevented the need for protracted wrangling at each step.
- It did provide a breaking mechanism and ongoing chance to address issues that did arise with increasing intensity.
- The eventual result would seem perfectly acceptable

25th October	368	348	2.07e32
16th October	312	295	1.35e32
14th October	248	233	1e32
8th October	248	233	8.8e31
4th October	204	186	7e31
29th September	152	140	5e31
25th September	104	93	3.5e31
23rd September	56	47	2e31
22nd September	24	16	4.6e30

Intensity versus fill number



Intensity versus fill number



2011: ramping back up – for discussion

- 3 to 4 weeks re-commissioning
  - Virgin set-up, new ramp, new squeeze, new beta*s, orbit, modified parameter space… it will be different
  - Full collimator set-up
  - Full validation (loss maps, asynchronous dumps etc.)
- Back-up to 300b in 50 bunch steps
  - Would imagine starting with 75 ns
  - In 2010 took around 4 days (minimum) per 50 bunch step
    - Machine availability, lost fills (UFOs…)
  - 50 – 100 – 150 – 200 – 250 – 300
  - Around 3 weeks to get back to 300 bunches
- 100 bunch steps thereafter.
  - 400 – 500 – 600 – 700 – 800 – 900
  - Around 3 weeks

Open questions

- Do we need another review?
- Does the procedure need to be modified or extended?
- Does it need to be more formal?
- Extended MPS unit testing?