CERN Machine Advisory Committee, 16.08.2012

2012 LHC MD program and priorities

Giulia Papotti and Frank Zimmermann

acknowledgements

- thanks to all MD teams, machine experts and OP shift crews for the excellent work in preparing and executing the studies, analysing the results, the flexibility and availability.
- here a (probably non-exhaustive) list of all the contributors:
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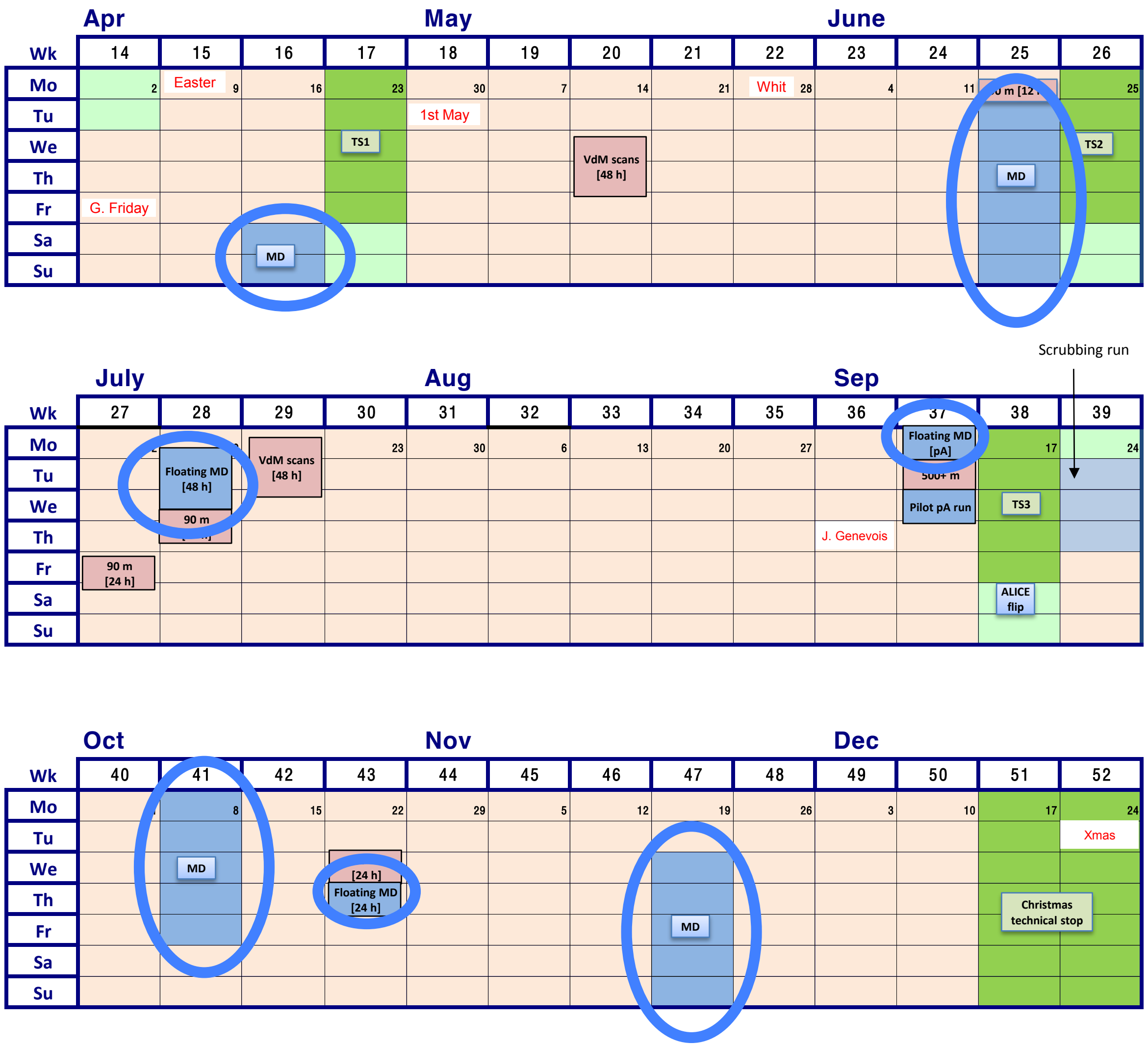
- apologies: later credits are far less thorough

2012 LHC schedule

- 4 categories
  - physics production
    - incl. special runs
  - beam commissioning
  - technical stops
  - MDs
    - 4 long blocks and 4 days floating

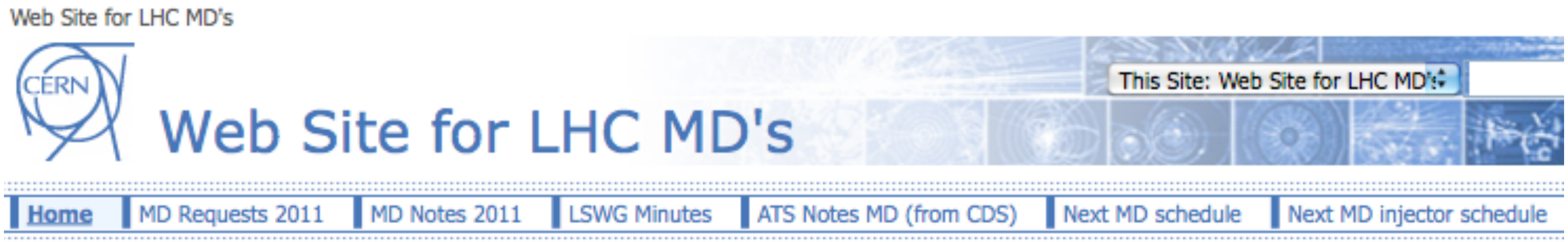


- total 22 d = 420 h
- requests >900 h

the CCC gets crowded

LHC Studies Working Group

- mandate
  - collect MD requests, prioritize them
  - prepare MD schedule, propose it to LMC for approval
- meet for each MD
  - prepare (e.g. Machine Protection classification, beam requests to injectors)
  - review the results (MD notes)
- www.cern.ch/lhc-md
  - holds detailed info, ATS MD notes by the teams, MD requests, LSWG Indico meeting pages and minutes



MD categories and priorities

- operation & physics
- future running
- lower priority / others

- 76 requests for Evian 2011
- now 82 requests
  - RF, ADT and long. dynamics (12)
  - collimation (11)
  - optics (9)
  - impedance (8)
  - beam-beam (7)
  - quenches (6)
  - injection (4)
  - ions or p-Pb (3)
  - …

	title	time [h]	energy	spacing [ns]	current	requestor	theme	MP class	
1	MKI UFO	8	450	25	high	Tobias Baer	after LS1	C	
2	ATS optics	16	4000	NA	low	Stephane Fartoukh	HL-LHC	A	
3	bb limit HO with unequal beams	16	450/4000	NA	medium	Herr / Papotti	HL-LHC	B	
4	bb limit, LR separation	24	4000	25+50	medium+	Herr / Papotti	HL-LHC	C	
5	bb limit, LR intensity	8	4000	50	medium+	Herr / Papotti	after LS1	C	
6	large Piwinski angle	16	450	NA	medium	Fartoukh / Zimmermann	HL-LHC	A	
7	BI MDs	91	450 & 4000	NA	medium	BI team	2012	B (and A)	
8	CaC	8	450	NA	medium	Assmann / Fartoukh	HL-LHC	A	
9	Transverse noide & coh. bb	16	4000	50	medium+	Herr / Papotti	2012	C	
10	bb emittance growth due to transv. noise	16	4000	NA	medium	Buffat et al	HL-LHC	B	
11	Source of transverse emittance blow up	16	450/4000	50	high	Arduini	2012	C	
12	LR beam-beam with flat beams	24	4000	50	medium+	Herr / Papotti	HL-LHC	C	
13	Tune close to 1/2 integer	16	4000	50	medium+	Calaga et al	HL-LHC	C	
14	High pile up	8	4000	NA	medium	Fartoukh	HL-LHC	B	
15	HV passive compensation	16	4000	25+50	medium+	Calaga et al	HL-LHC	C	
16	compensation of IR nonlinearities	12	4000	NA	low	Tomas	2012	A	
17	Quench margin at top energy	16	4000	50	medium+	Redaelli / Wollmann	after LS1	C	
18	Halo scraping	0.5	450/4000	50	high	Wollmann / Burkart	after LS1	C	EOF
19	Transverse emittance blow up at injection	10	450	50	medium+	Metral / Mounet	2012	C	
20	TCBI at flat top and octupole stabilization	20	4000	25+50	medium+	Mounet / Metral	after LS1	B/C?	
21	Impedance budget at injection	6	450	NA	low	Biancacci	2012?	A	
22	Multibunch tune shift at flat top	8	4000	25+50	medium+	Mounet / Metral	2012?	B	
23	Multibunch tune shift at injection	8	450	25+50	medium+	Mounet / Metral	2012?	B	
24	TCBI at flat top and octupole stabilization	1	4000	50	high	Mounet / Metral	after LS1	D	EOF
25	Beam losses at injection	16	450	25	medium+	Bartmann / Bracco	after LS1	B	
26	Probing the single bunch limits in LHC	6	450	NA	medium	Salvant	HL-LHC	B	
27	Quench limit investigation	16	450	NA	low	Bracco et al	2012	C	
28	Asynchronous dump in collimation set up	8	450	NA	low	Rossi / Lari / Cauchi	after LS1	C	
29	Scraping scans for beam shape	8	450/4000	NA	medium	Wollmann / Burkart	after LS1	B	
30	Protection from long devices	16	450/4000	NA	low	Bartmann / Bracco	2012	A	
31	LHC transverse impedance	10	450/4000	NA	medium	Redaelli / Salvant	2012	B	
32	Injection matching and emittance preservation	16	450	NA	low	Kain	2012	B	
33	Impedance and beam heating of long protetion devices	16	450	50	medium+	Goddard	2012	B	
34	LHC transfer line stability	16	450	50	medium+	Kain	2012	B	
35	Wire scanner quench test at flat top	8	4000	50	medium+	Sapinski	2012	C	
36	Optimization of ADT in the ramp	12	450/4000	50	high	Hofle	2012	B	
37	Noise properties of ADT with FB on and off	6	450	25+50	medium+	Hofle	after LS1	A	
38	Residual tune signal in damper signal	6	450	25+50	medium+	Hofle	after LS1	A	
39	ADT Q/Q' diagnostics possibility	[illegible]	450/4000	50	high	Hofle	2012	B	
40	Collimation studies with different settings	24	4000	50	medium+	Assmann	after LS1	B	
41	Quench test at injection energy	8	450	NA	medium	Priebe	2012	A?	
42	Loss maps with transverse damper	8	450/4000	50	medium+	Salvachua	2012	B or C	
43	Collimation with beta*=40 cm	8	4000	NA	medium	Bruce	HL-LHC	B	
44	Fast collimator setup at 3.5 TeV	8	4000	NA	medium	Valentino	2012	B	
45	intensity limitations for 25 ns operation	24	450/4000	25	medium+	Arduini	after LS1	B	
46	Operational development MD	48	450/4000	NA	low	Wenninger	after LS1	A or B	
47	Quench test at nominal energy	8	4000	NA	medium	Priebe	2012	C	
48	Scraping with tune excitation	16	450/4000	NA	medium	Bruce	HL-LHC	A or B	
49	Nonlinear beam dynamics	12	450	NA	low	Giovannozzi et al	HL-LHC	A	
50	Transfer & injection of high brightness bunches w SPS Q20	16	450	50	medium+	Bartmann et al	after LS1	C	
51	Single bunch parameter evolution	?	4000	50	high	Papotti	2012	A	
52	Effective lontiudinal broadband impedance	6	450	NA	medium+	Shaposhnikova	after LS1	B	
53	Movements IT with beam at injection	8	450	NA	low	Wenninger	2012	A	
54	Sensitvity of QPS thresholds to FB systems	8	4000	50	high?	Denz et al	after LS1	A	
55	Loss of Landau damping during ramp	6	4000	NA	medium+	Shaposhnikova	2012	B	
56	Ion collimation loss mitigation	16	4000	100 or 200	medium+	Jowett	2012	C	
57	Proton lead intensity limit	16	450/4000	100 or 200	medium+	Jowett	2012	C	
58	Proton collimation loss mitigation	16	4000	50	medium+	Jowett	after LS1	C	
59	De-squeeze to beta*=500	8	4000	NA	low	Burkhardt	2012	A	
60	Scraping to 1 micron emittance at to energy	8	4000	NA	medium	Burkhardt	2012	A	
61	RF cavity non-linearities	16	450/4000	NA	medium	Calaga	HL-LHC	A	
62	Longitudinal blow up studies	16	450/4000	50	medium+	Baudrenghien	2012	B	
63	RF feedback optimization with circulating beam	4	450/4000	50	medium	Baudrenghien	2012	B	(EOF)
64	Commissioning of longitudinal damper	16	450	50	medium+	Baudrenghien	2012	B	
65	Commissioning of p-Pb rephasing using p	8	450	50	medium+	Baudrenghien	2012	B	
66	Longitudinal stability for batch	16	450	50	medium+	Baudrenghien	after LS1	B	
67	Voltage modulation to minimize klystron power	16	450/4000	50	medium+	Baudrenghien	after LS1	B	
68	Longiudinal stability of batch	16	450	50	medium+	Baudrenghien	after LS1	B	
69	Aperture measurements at 3.5 TeV w ADT blow up	8	4000	NA	medium	Redaelli	2012	B	
70	Collimation cleaning during the ramp w ADT blow up	8	4000	NA	medium	Redaelli	2012	B	
71	Fast beam losses at the collimators	8	450/4000	NA	medium	Redaelli	2012	B	
72	Combined ramp & squeeze	8	450/4000	NA	low	Redaelli	after LS1	A	
73	Luminosity leveling with dynamic beta* change	8	4000	NA	medium	Redaelli	after LS1	C	
74	LHC linear chromaticity	6	450	NA	low	Tomas	2012?	A	

Frank Zimmermann, Evian 2011

from Chamonix 2012

(Ralph Assmann, "MD plans in 2012")

Operation & Physics: 9 major MD goals proposed

1. Understand **beam heating** effects around the LHC ring
2. Understand & optimize **transverse emittance growth**
3. Demonstrate RF setup for **proton-lead physics**
4. Establish an LHC optics with a **beta* of 500 m**
5. Understand and optimize **longitudinal beam dynamics** in LHC
6. Establish **automatic and very fast collimator setup**
7. Calibrate and optimize LHC **beam instrumentation**
8. Compatibility **tune and ADT**
9. **Equalize beta*** in ATLAS and CMS

Future running: 7 major MD goals proposed

1. Characterize future **operation with 25ns**
2. Quantify required tolerances for **non-linearities** in LHC
3. Show feasibility **very small beta* / very high pile-up**
4. Verify and check the **transverse impedance** limits of the LHC
5. Show feasibility of **flat beam optics** in the LHC
6. Establish benefits of the **½ integer tune working point**
7. Study and improve LHC **injection limitations**

Plus recommendation from the discussion: "…machine studies and tests related to UFOs and quench levels; a detailed proposal should come from the Machine Protection team"

from Chamonix 2012

(Ralph Assmann, "MD plans in 2012")

- done
- ongoing

Operation & Physics: 9 major MD goals proposed

1. Understand **beam heating** effects around the LHC ring
2. (ongoing) Understand & optimize **transverse emittance growth**
3. (ongoing) Demonstrate RF setup for **proton-lead physics**
4. (done) Establish an LHC optics with a **beta* of 500 m**
5. (done) Understand and optimize **longitudinal beam dynamics** in LHC
6. (done) Establish **automatic and very fast collimator setup**
7. (ongoing) Calibrate and optimize LHC **beam instrumentation**
8. (ongoing) Compatibility **tune and ADT**
9. **Equalize beta*** in ATLAS and CMS

Future running: 7 major MD goals proposed

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a few 2012 MD highlights

- some records in numbers
  - beta* from 10 cm (ATS) to 1 km (de-squeeze)
  - pile-up up to ~70
  - stored high brightness beams: 3e11 ppb in 2.2 um
  - large Piwinski angle: $\phi_{piw} = 1.1$

- others
  - achieved nominal collimation 7 TeV settings (in mm) and measured collimator impedance
  - many improvements on different beam instrumentation
    - e.g. transverse emittance measurements
  - instability thresholds versus chromaticity, octupoles etc
  - luminosity levelling with β^*
  - dynamic aperture found in agreement with prediction
  - first measurement of chromaticity dependence on octupole currents

a list of all MDs scheduled so far

- MD 1 (2 days – before ICHEP)
  - instrumentation & emittance calibration
  - ADT: check damping times, commission batch-by-batch gain modulation, compatibility with Q measurement
  - RF batch-by-batch blow up
  - longitudinal impedance
  - collimation: test of new software for BPM interpolated alignment
  - aperture checks for measurement systematics

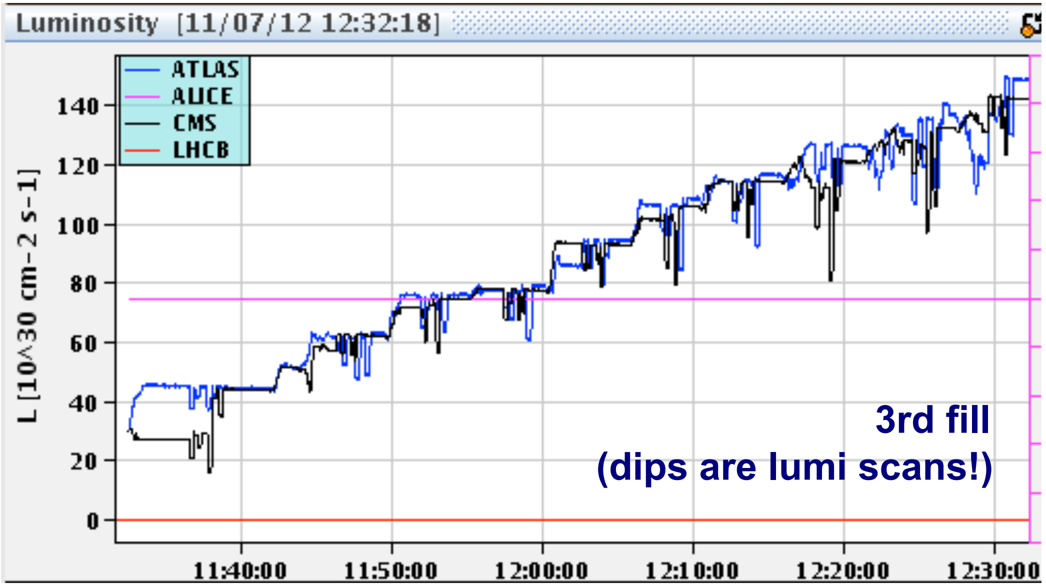
- floating MD (2 days)
  - luminosity leveling with β*
  - high pile-up with SPS Q20
  - Achromatic Telescopic Squeeze
  - 25 ns injection tests
    - injected up to 288-b for beam 1 and 144-b for beam 2 (weak MKI)

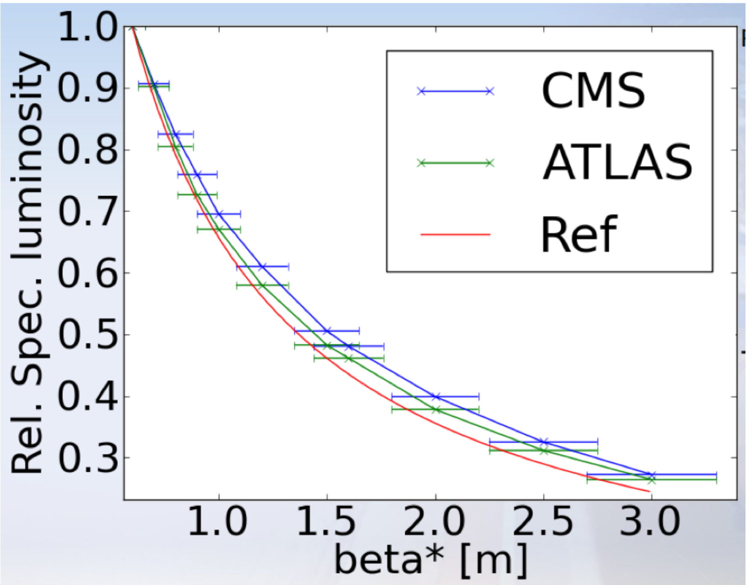
- MD 2 (6 days – after ICHEP)
  - LPA
  - chromaticity vs octupole current
  - stability with different chromas, octupoles, ADT
  - longitudinal dynamics (loss of Landau damping)
  - luminosity levelling with beta*
  - long-range bb with 1.7e11 and 1.1e11 ppb
    - losses at ~ half the crossing angle
  - high beta* (500 m - 1000 m)
  - UFOs
  - scraping diffusion and repopulation
  - injection and store of SPS Q20 single bunches
  - RF cavity phase modulation
    - RF limit on total intensity removed, can go beyond nominal
  - measurement of collimator-induced impedance
    - tune shift as expected
  - established feasibility of 7 TeV collimation settings
  - fast losses with ADT
  - BI and emittance calibration
  - dynamic aperture

luminosity levelling with beta*

J. Wenninger,
S. Redaelli,
X. Buffat et al.

- motivation:
  - alternative to levelling by transverse offset for IP1&5 for post LS1 or HL-LHC
    - levelling by transverse offset is operational but has drawbacks
  - allows profiting from stabilization by head-on beam-beam earlier in the cycle
- 2 fills with single bunches for settings
- 1 fill with 36-b trains to validate procedure
- no show stoppers found, more work required to make it operational

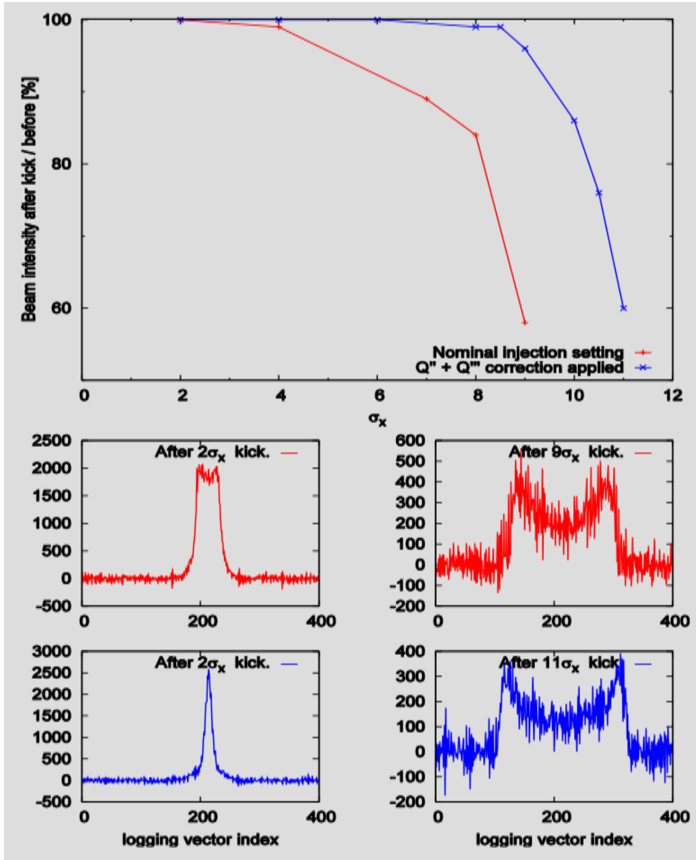




dynamic aperture

F. Schmidt,
M. Giovannozzi,
R. de Maria et al.

- large kicks with the aperture kicker for:
  - I: LHC as is and in particular the standard MO settings.
  - II: same machine except that the MO have been switched off and a full Q'' and Q''' (albeit we have to deduce this from the cancellation of the decoherence)
- demonstrate difference between the 2 cases:
  - I: **Large detuning with amplitudes and a DA due to a combined driving of the 4Qx and 3Qy resonances.** Large nonlinear coupling observed. Kicks up to 9 sigma.
  - II: **Detuning with amplitude very small ~1e-3 even for large kicks**, 12 sigma kicks in H, V and H&V variation of amplitude. Limited by collimation/ injection protection. Confidence that we can disentangle losses from scraping and slow particle losses due to the DA.
- estimate of the DA between **10 and 12 sigma**

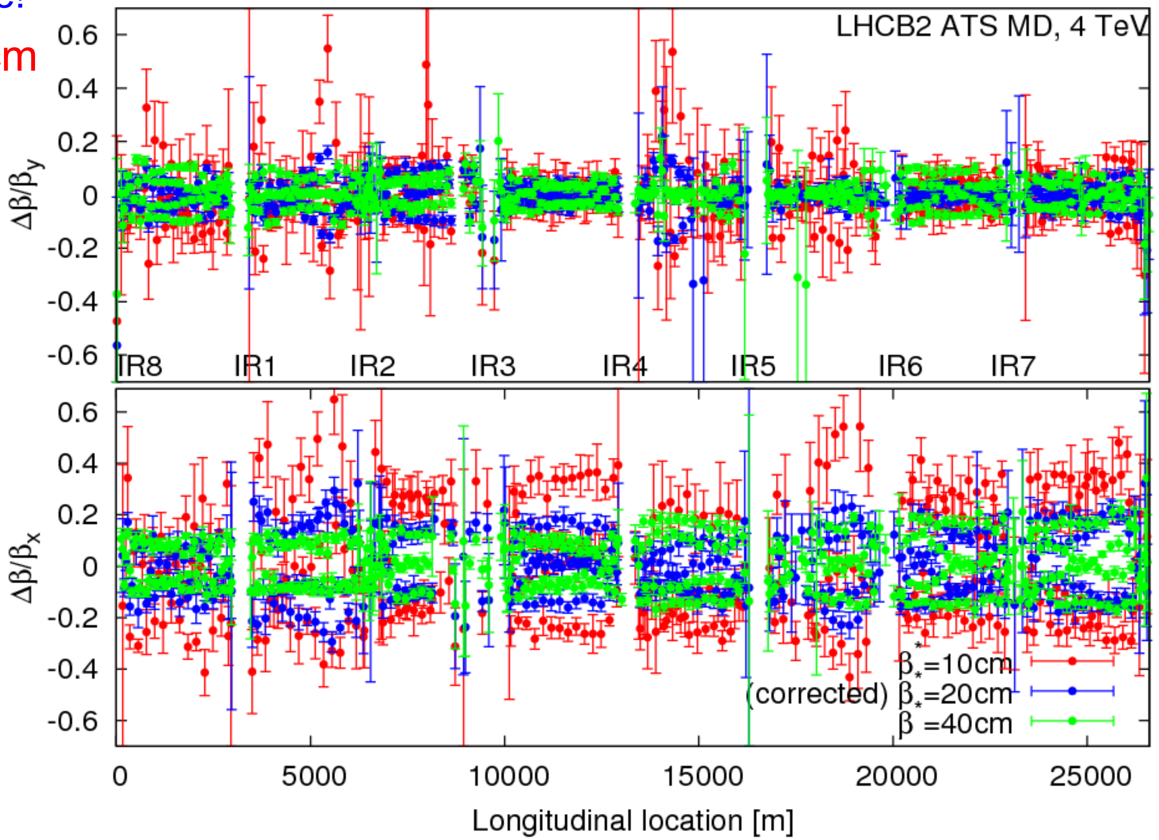


- in parallel on the other beam: studies on intensity evolution of blown up bunches for different decapole and octupole strengths

Achromatic Telescopic Squeeze

S. Fartoukh,
R. de Maria, L. Ponce,
M. Solfaroli et al.

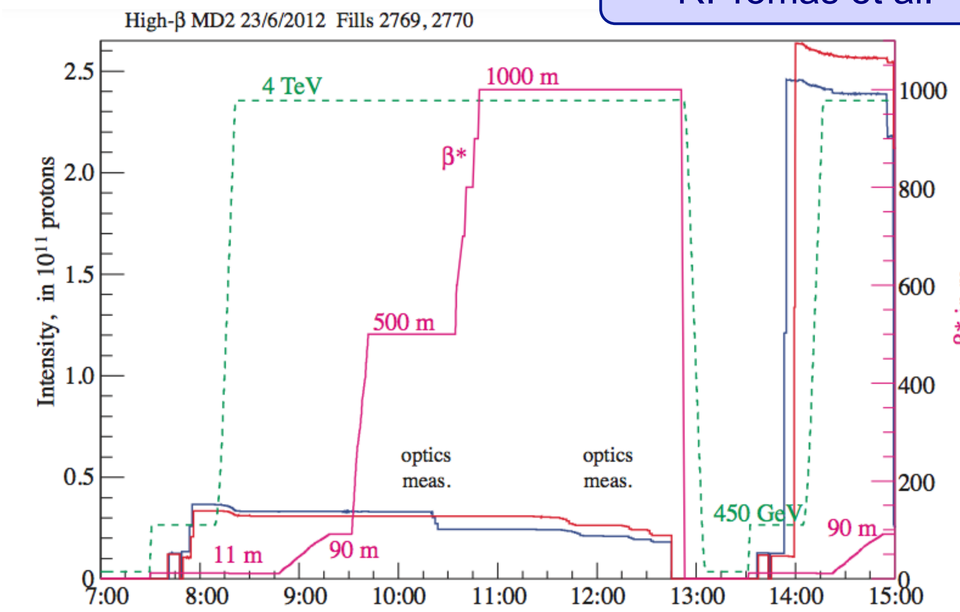
- achieved (with no crossing angle, parallel separation at IP1/5)
  - "pre-squeeze" IR1&5 to β^* = 40 cm
  - squeeze IR1&5 to β^* = 10-15 cm
    - beam 2 reached β^*=10 cm
      - β^*=10 cm → β_{max} = 23.8 km in the triplet (21.1 km for BPMS)
      - "... β^* was probably around 12.5(V)-14.5(H) cm, so still 5mm better than the HL-LHC baseline!"
    - beam 1 lost at β^*=14 cm
      - bad manual trim
- to be redone with corrected beta-beating, coupling
  - plus tune scan to try and improve lifetime

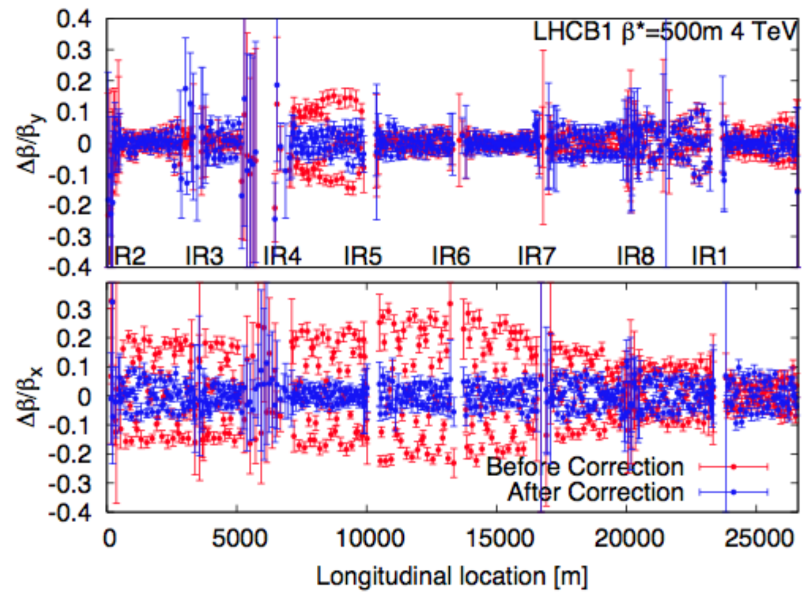


de-squeeze

H. Burkhardt,
S. Cavalier,
R. Tomas et al.

- 3 fills so far
  - de-squeeze 90 -> 500 m flat machine, measure + correct optics, loss-less
  - separation on, re-measure 500 m, first successful attempt to 1000 m done (with optics measurements)
  - started with 2 nominal bunches, ok to 90 m
- next steps in physics time
  - finding collisions, non-trivial at high-β (corrector and aperture limits) requires ~ nominal intensities
  - minimum emittance (~ 1 μm, without scraping)
  - roman pots very close to beam

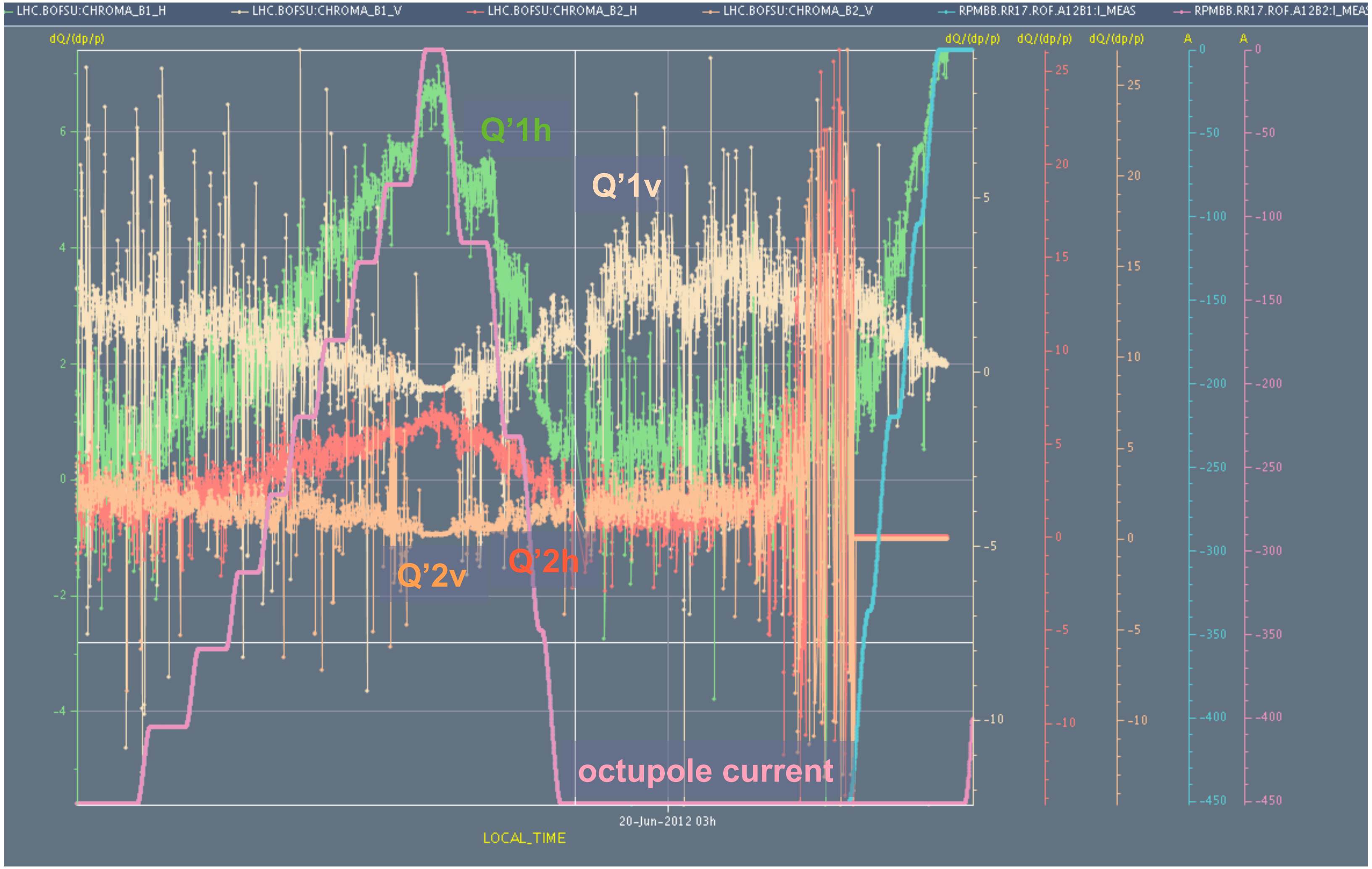




octupole current scans

G. Papotti,
W. Herr,
N. Mounet et al.

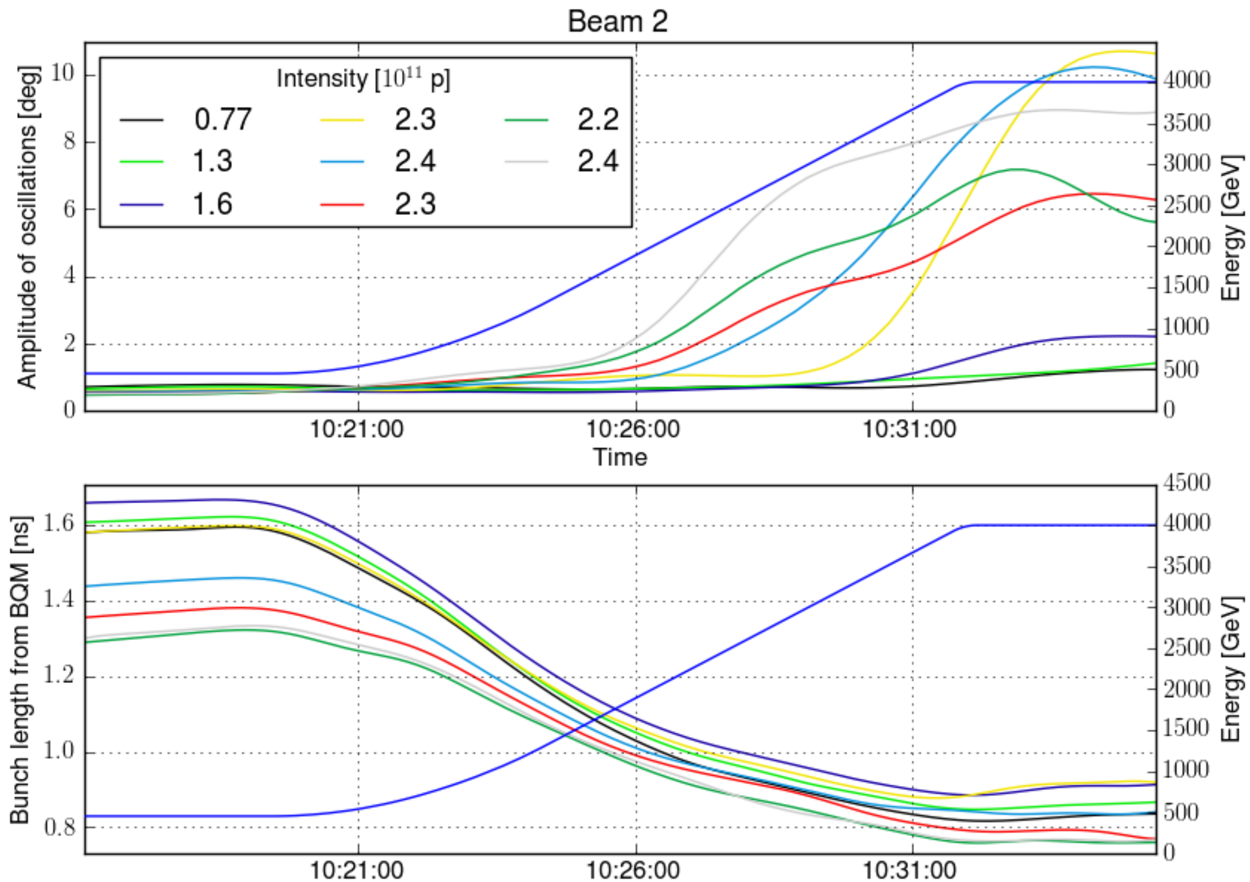
- e.g. first measurement of chroma dependence on octupole current
  - fundamental for studies on stability parameter space
  - up to 5 units in H, 2 units in V



longitudinal dynamics

E. Shaposhnikova,
J. Mueller et al.

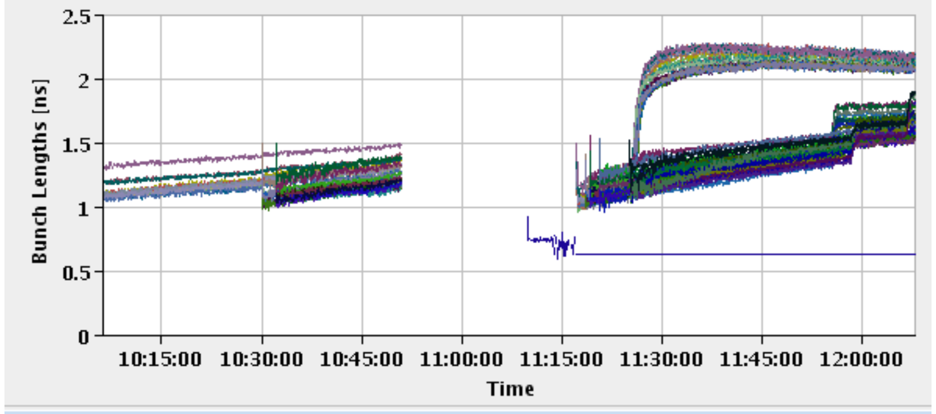
- studies on loss of Landau damping
  - instability threshold dependence on emittance, intensity and energy
  - shorter bunches with higher intensities become unstable earlier in the ramp
- to be continued with more measurements at the flat top

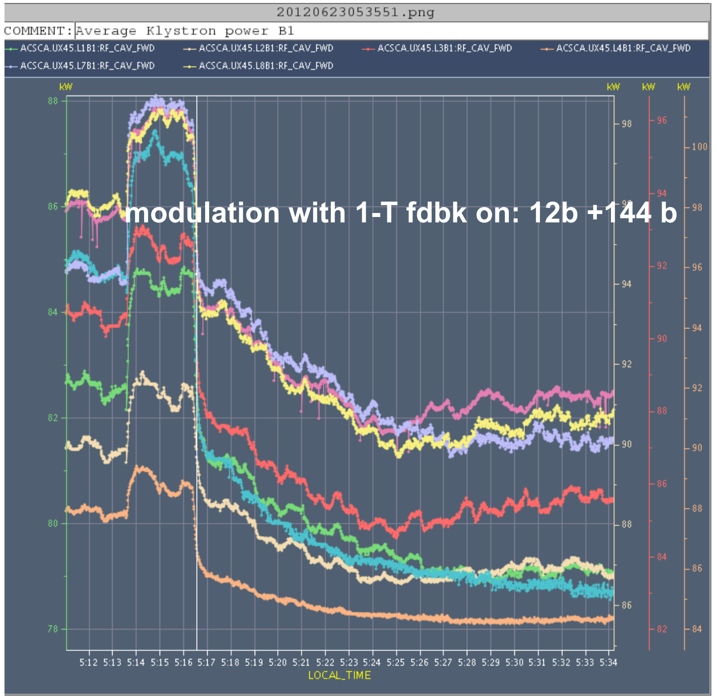


RF development examples

P. Baudrenghien,
M. Jaussi,
T. Mastoridis et al.

- batch-by-batch longitudinal blow up
  - can blow-up the the injected batch without touching the circulating beam
  - possible improvement in luminosity via decreasing the transverse emittance increase due to IBS
  - more developments required to automate the procedure for op





- RF cavity phase modulation for 25 ns
  - modulate set point during one turn resulting in constant klystron drive and klystron power independent of current

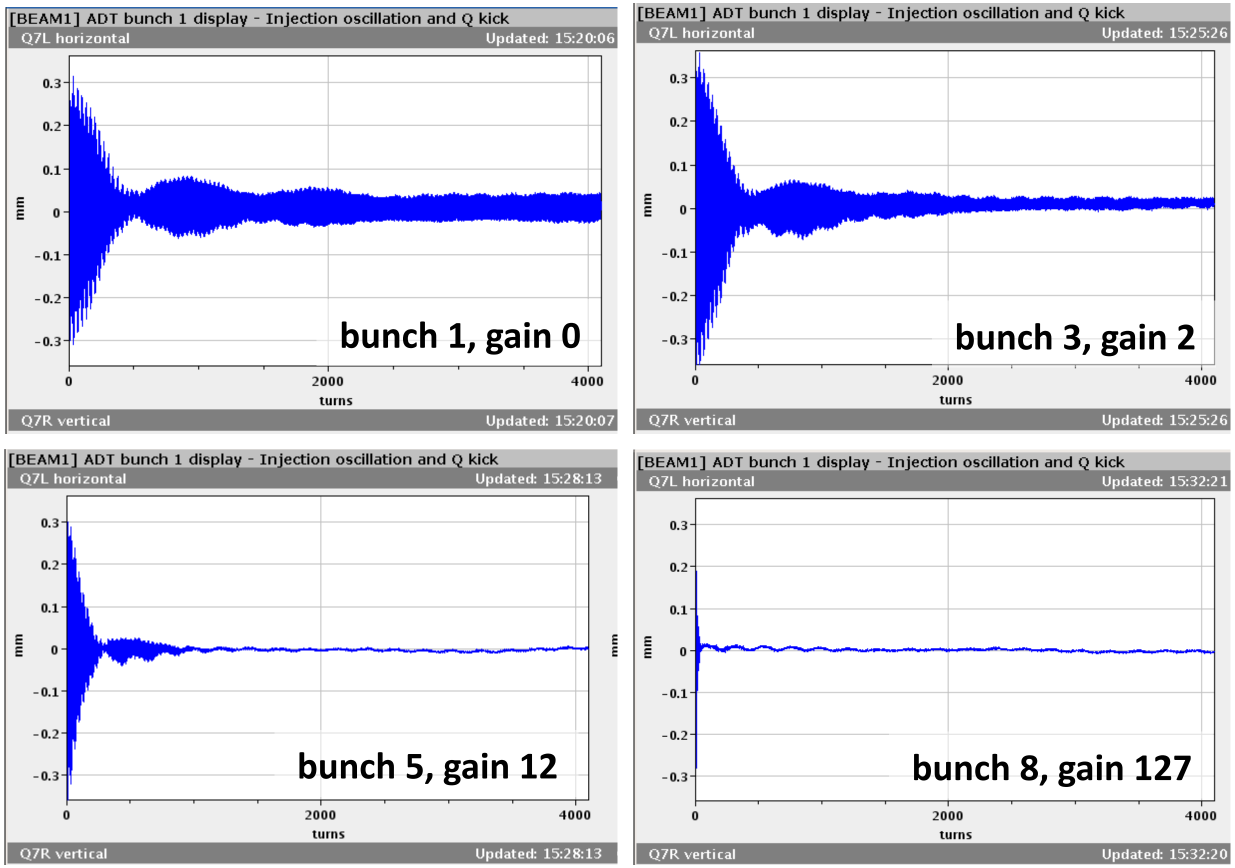
decreasing klystron power as set point is adapted

transverse damper

W. Hofle,
D. Valuch et al.

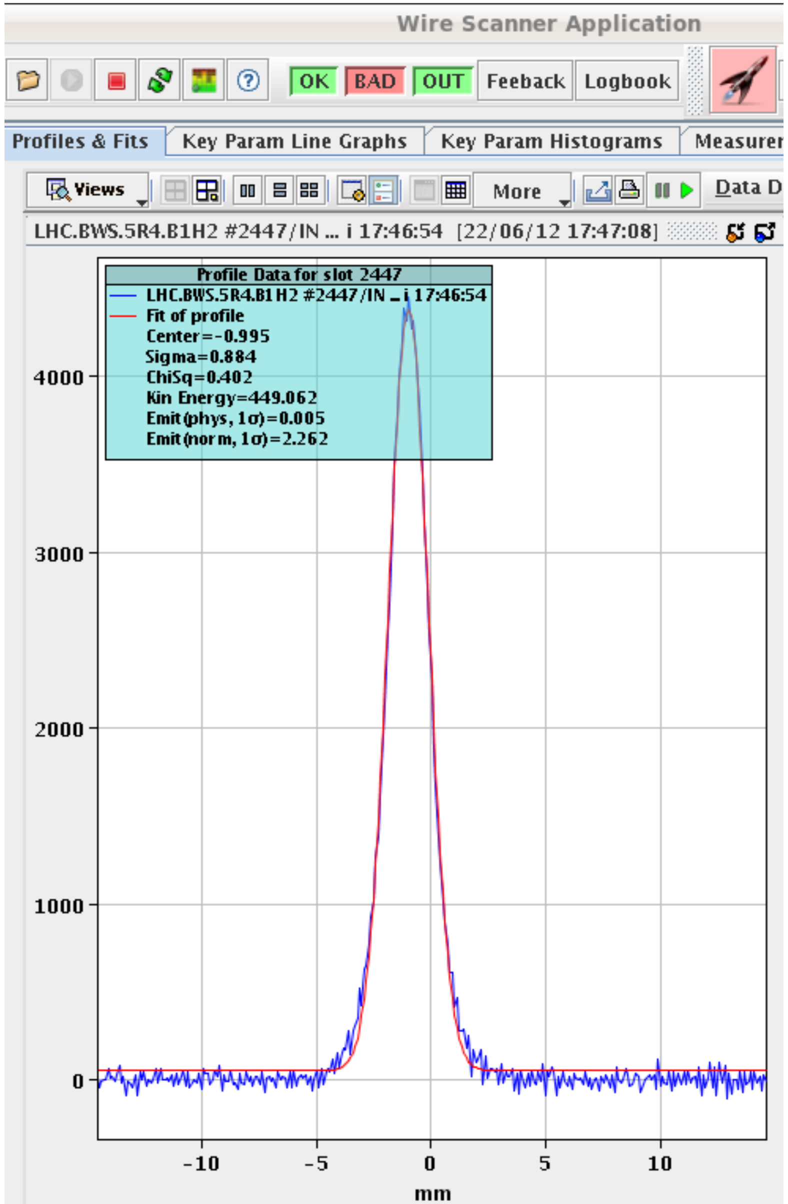
- optimization and new developments:
  - gain normalization and optimization
  - studies of tune measurement compatibility
  - studies for feasibility of tune measurement from damper pickups
    - still ongoing, also as operational developments

example:
commissioning of
the batch-by-batch
gain modulation



injection of Q20 single bunches

H. Bartosik,
Y. Papaphilippou,
B. Goddard et al.

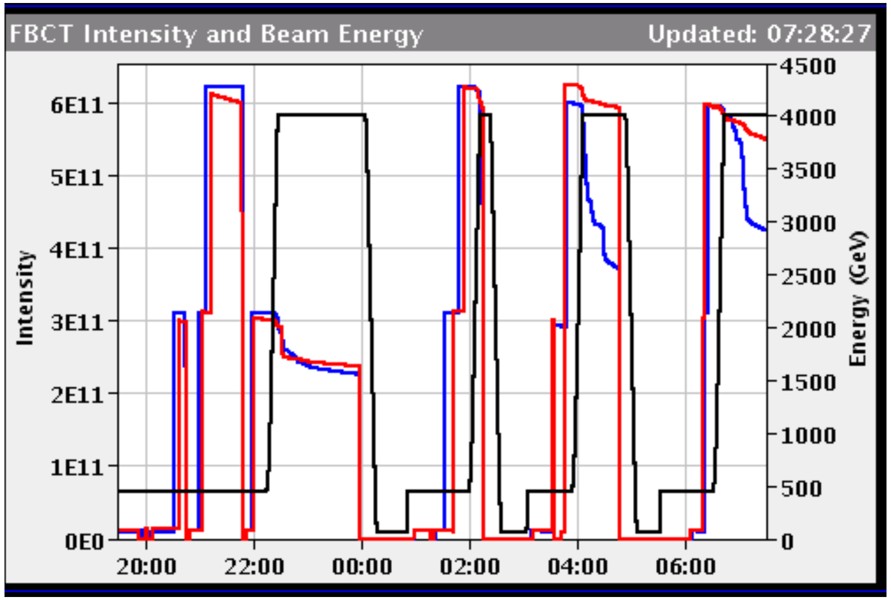


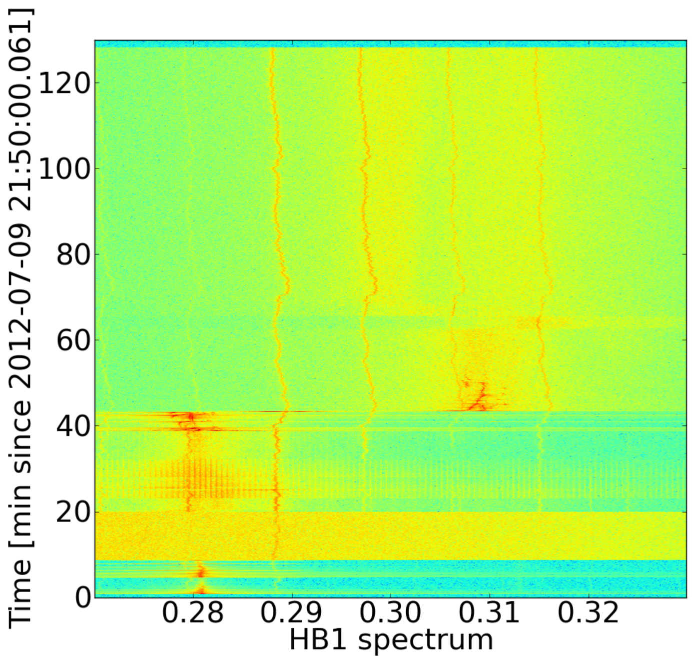
- new SPS Q20 optics allows 3e11 ppb in ~2 um emittances
  - lower γ_t allows bigger margins for instabilities
- in MD: transfer line setup, first injections of single bunches
  - ongoing in operations for bunch trains

high pile-up

R. W. Assmann,
W. Herr,
T. Pieloni et al.

- injected high brightness single bunches from new SPS Q20 optics
  - ~3e11 ppb, 1.5-2 um at injection
- 4 short fills
  - fill 4: achieved pile-up 70 in ATLAS and 65 in CMS





- beams were touchy
  - instabilities and losses observed
  - helped by increase in chroma (+3 units) and in target bunch length (1.4 ns)
  - managed 2.2 um in collisions, losses <5%, beam 2 only
    - feasibility proven! but work needed

other MD results discussed in later talks

- collimation -> *talk by R. Bruce*
  - faster setup, halo repopulation and diffusion, asynchronous dump data, 7 TeV settings feasibility, impedance measurements
- emittance measurement calibration and emittance preservation -> *talk by V. Kain*
  - dedicated ramps in MD1 and MD2
- impedance and instabilities -> *talk by E. Metral*
  - 16h on interplay of chromaticity, octupoles, ADT and instability thresholds, work continued in operations
- beam-beam -> *talk by W. Herr*
  - long-range separation scaling with intensity, luminosity levelling, many observations from operations
- UFOs -> *talk by T. Baer*
  - 10h for dedicated studies, a bit unlucky
- 25 ns -> *talk by G. Rumolo*
  - so far: injection setup and RF klystron voltage modulation
  - more after scrubbing run: long range with 25 ns, UFOs, …

next on the MD list

- understand instability limits and impedance
  - very hot topic, ongoing for present operation; extrapolation to 7 TeV?!
- 25 ns for end of 2012 run and after LS1
  - scrubbing and electron cloud, long range with 25 ns, UFOs, ramp for RF (at least 288b for peak current within 3 μs)
- quench tests: with wire scanners, with orbit bumps, with fast losses with transverse damper, with ions in IR7 dispersion suppressor
- UFOs (especially in the arcs?)
- p-Pb preparation (pilot run, RF cogging), IR2 aperture check
- more beam-beam: high HO-BB with separation in IPs1 & 5 for new octupole polarity, LPA, noise, collisions with flat beams
- collimation: test hierarchy limits, collimator based quench test
  - aperture measurement systematics (measure both sides)
- RF: commissioning of longitudinal damper, transverse damper gain flattening and noise; more longitudinal stability studies
- instrumentation studies (e.g. BSRT at high intensity), IBS at injection
- optics: MOD.A23.B1 coil polarity checks, MQY transfer function, skew sextupoles, ATS optics corrections & lifetime

conclusions

- first two 2012 LHC MDs extremely successful
  - efficient use of beam time, scheduled in agreement with priorities
  - credits to MD teams, the OP crews and the injectors for the results achieved

- 2012 achievements:
  - records: β^* (max. and min.), pile-up, Piwinski angle, brigthness for single bunches
  - feasibility of levelling by β^*, 7 TeV collimator settings, improved understanding of instability thresholds, and hardware systems …

- remaining priorities for this run
  - understanding of instabilities, 25 ns, quench tests, preparation for p-Pb, UFOs, …