Status of MTE commissioning with beam

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In collaboration with:

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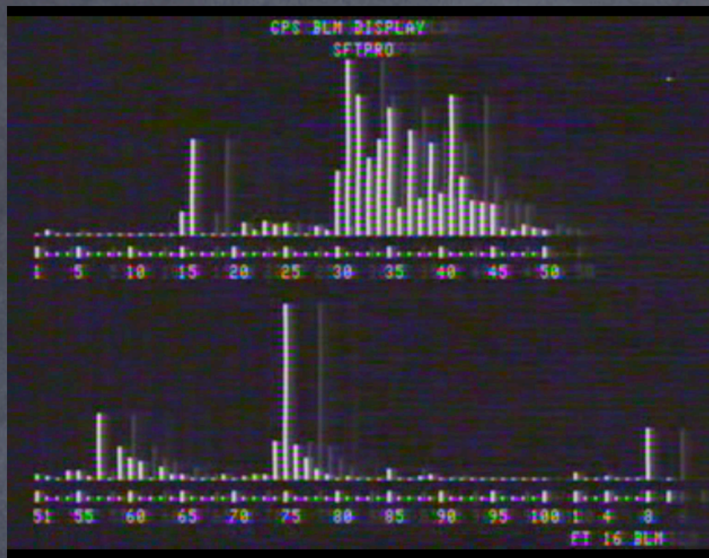
and thanks to

PSB/SPS/PS-OP crews, machine supervisors,
BE/BI, TE/ABT, TE/EPC, BE/CO, BE/RF, TE/MSC, EN/MEF, DGS/RP

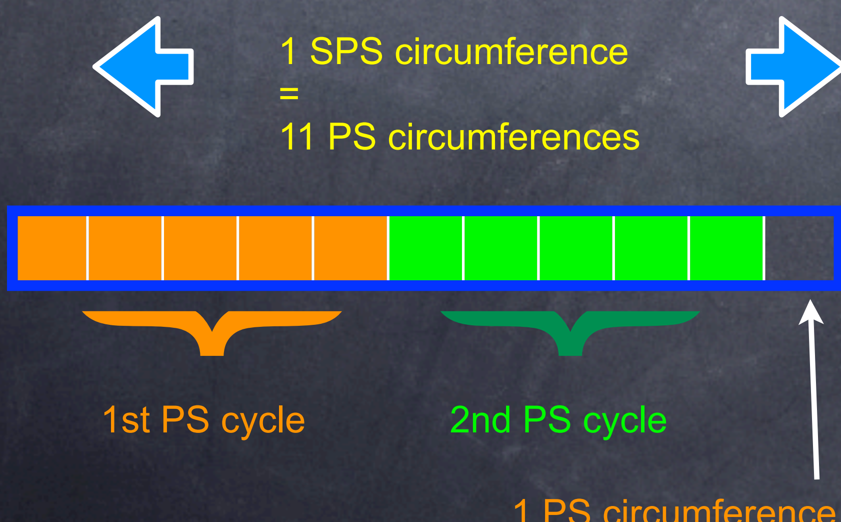
Brief introduction to PS-SPS transfer

PS Beam loss monitors

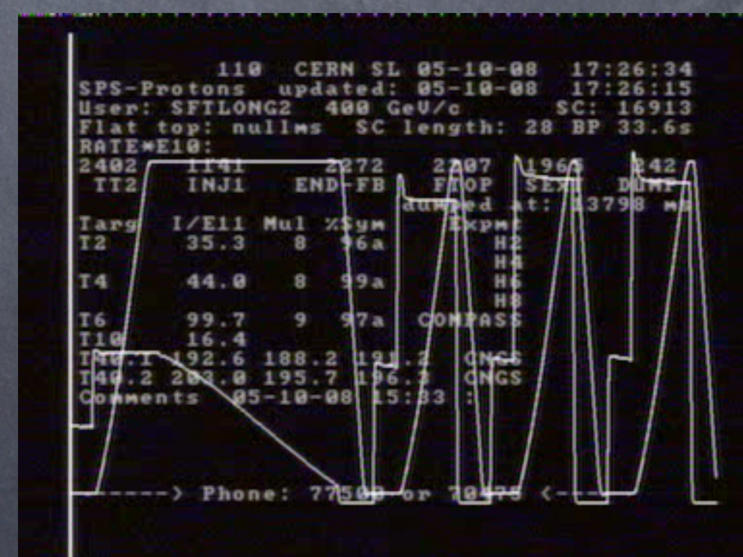


PS cycle

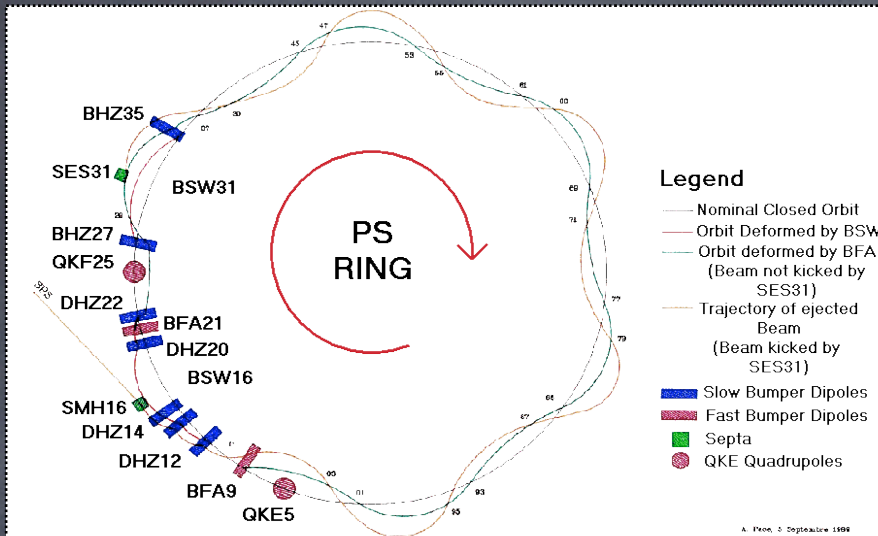
Beam for fixed target physics (CNGS) at the SPS are extracted from the PS at 14 GeV/c during five turns repeated on two cycles **with large losses in the PS**



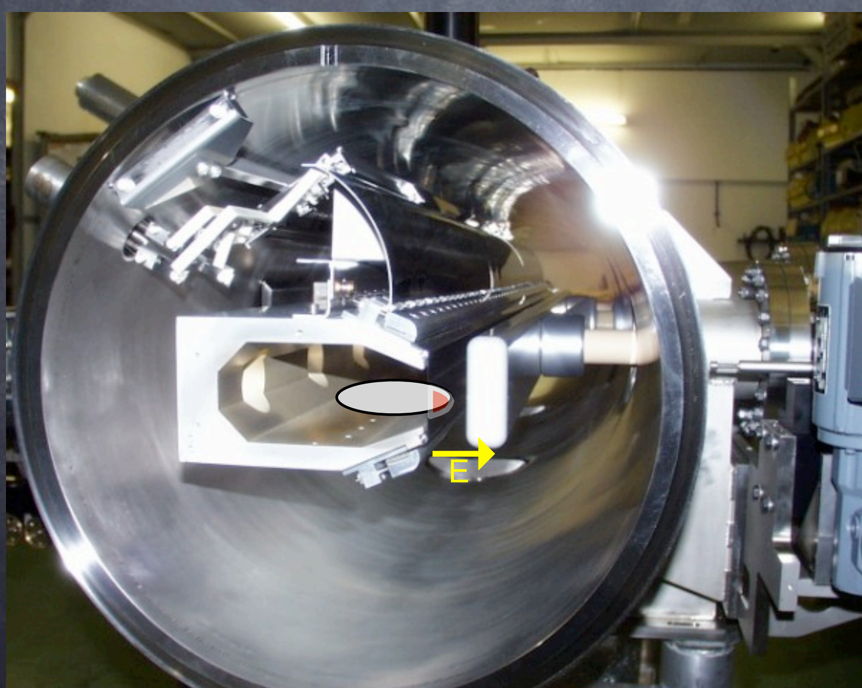
SPS cycle

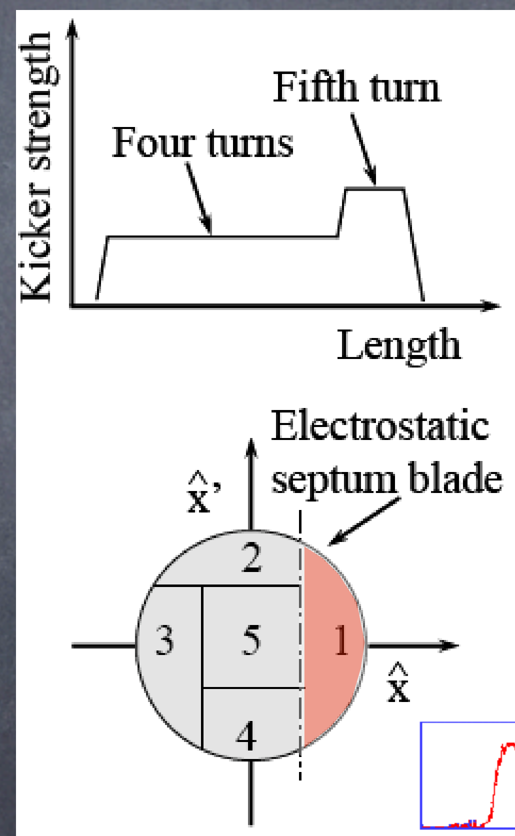


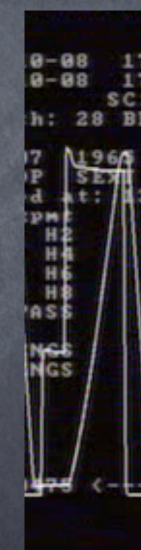
Continuous Extraction (CT, 70s): the principle

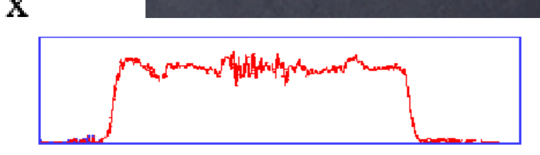


- Horizontal tune set to 6.25 phase advance per turn of 90°.
- A part of the proton beam is pushed by a slow and a fast bumps beyond the blade of an electrostatic septum.
- The sliced beam that receives the kick of the electrostatic septum is extracted during the current machine turn
- The rest is extracted with the same mechanism within the next 4 turns.
- The five beam slices feature the same intensity.



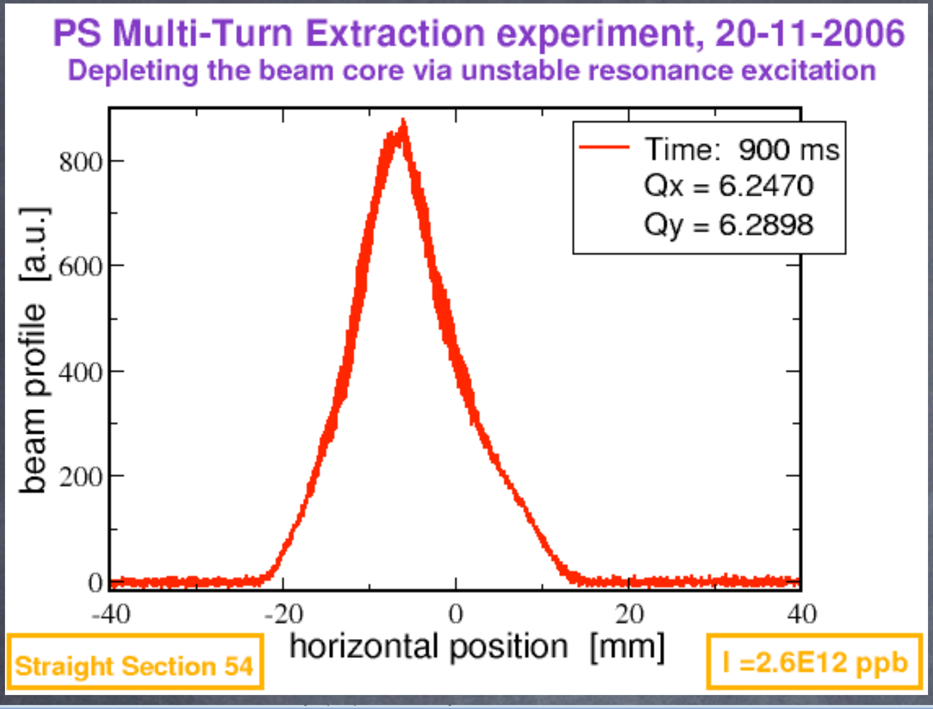


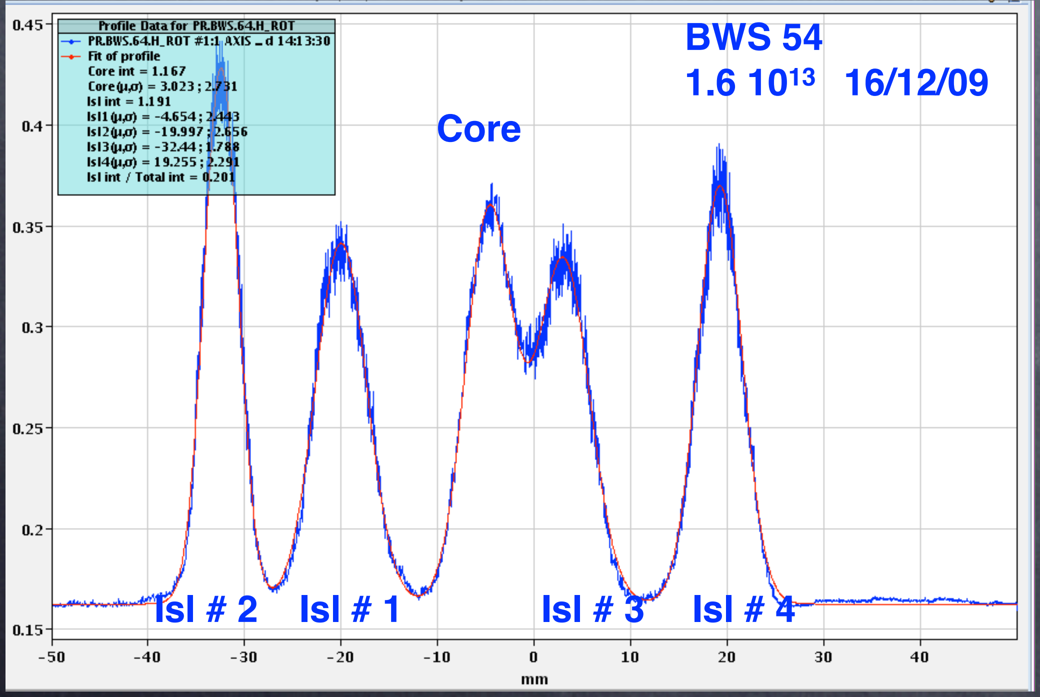


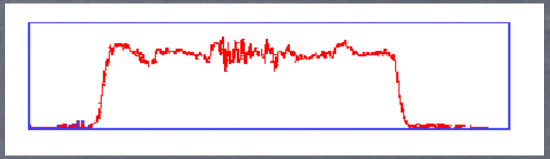


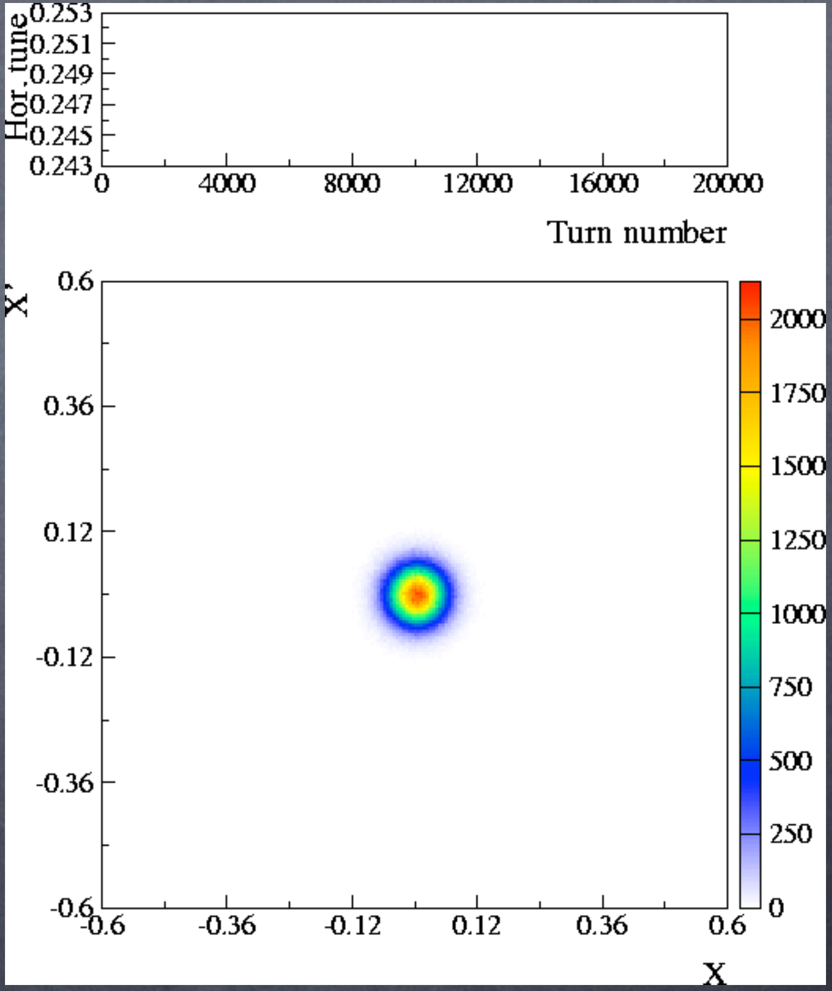
← Five PS turns →

MTE: Multi-Turn extraction









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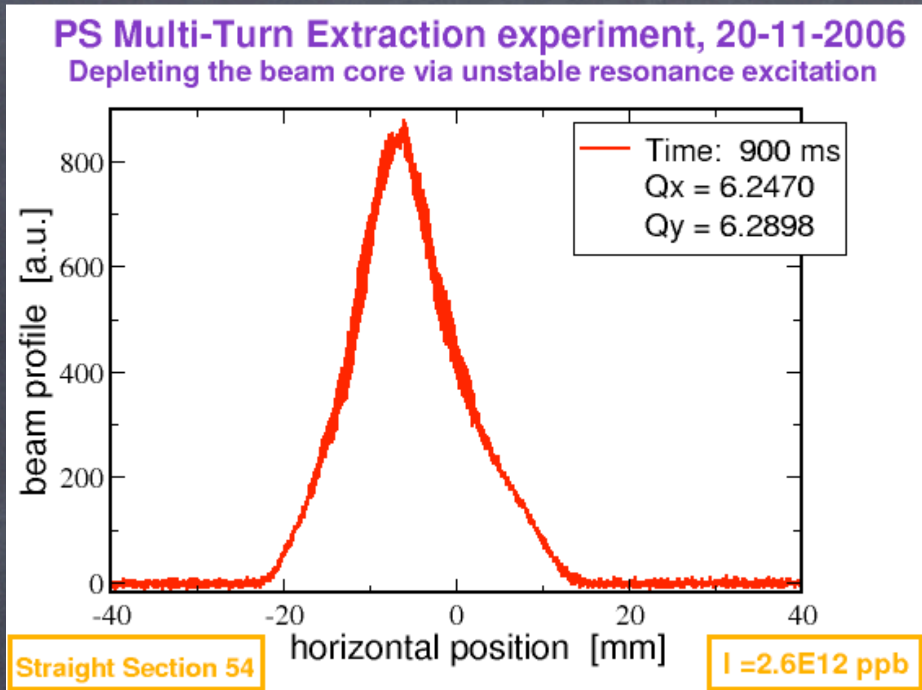

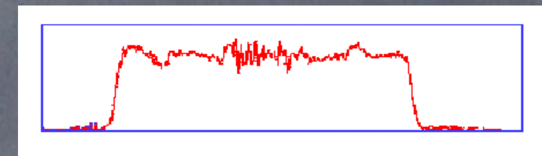

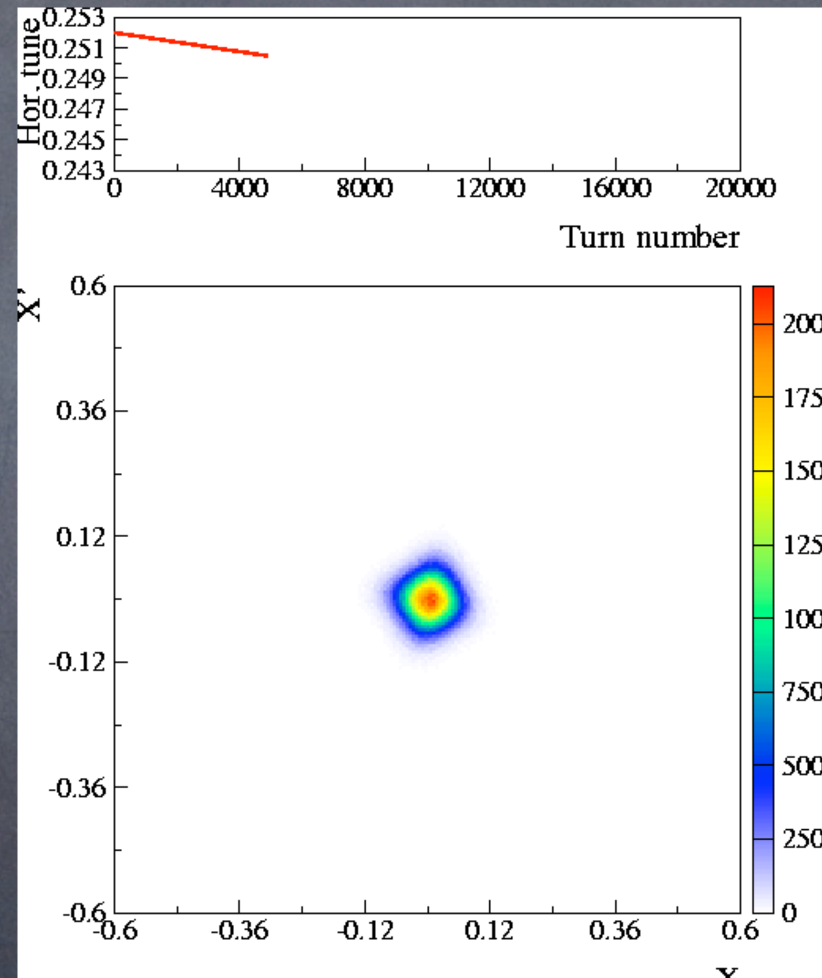

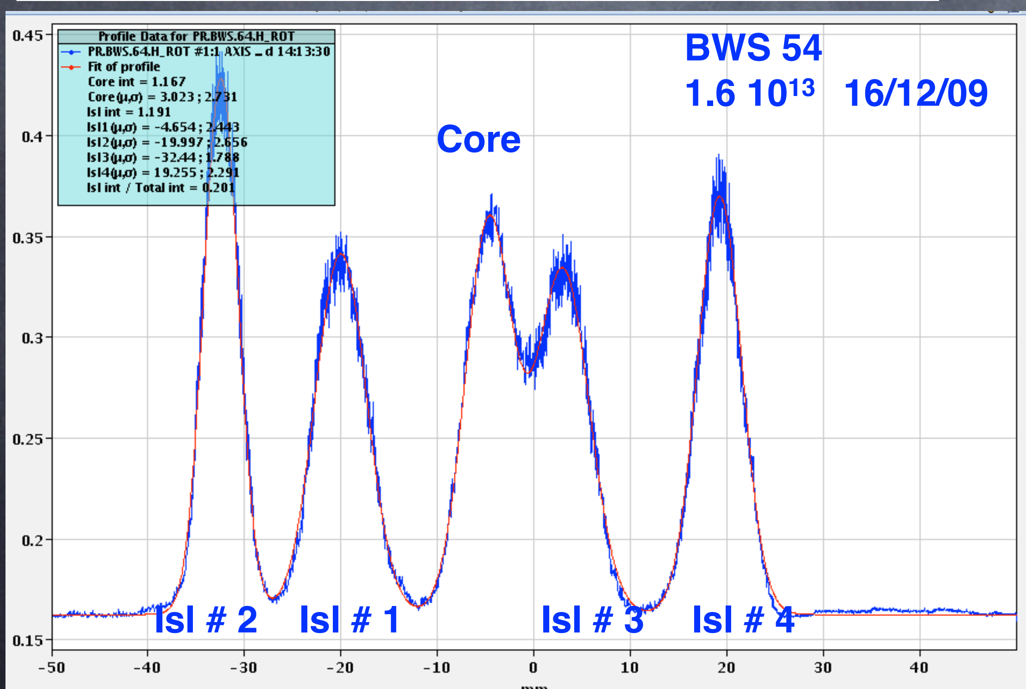

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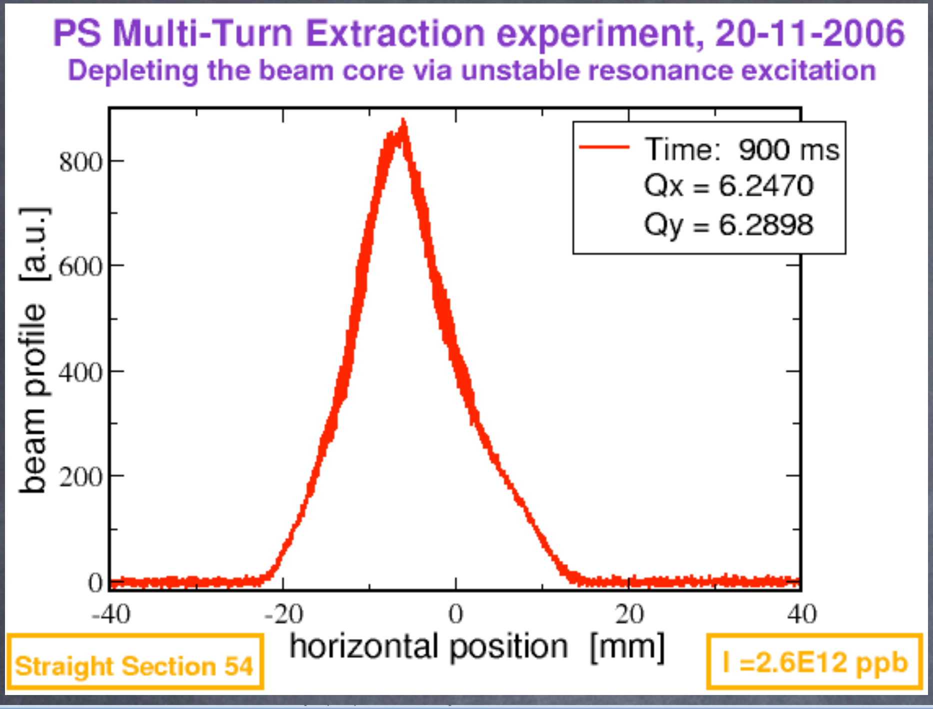

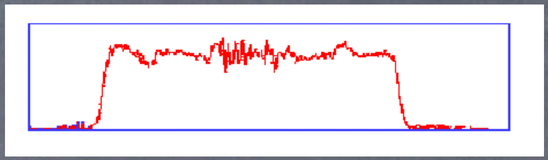

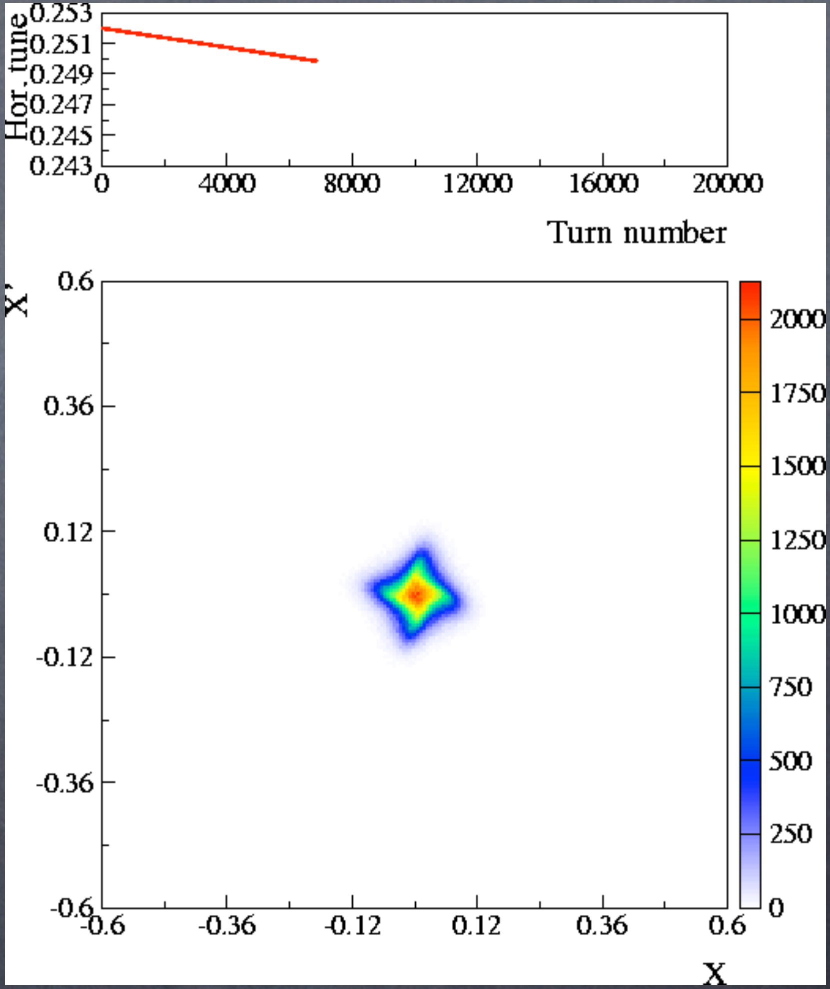

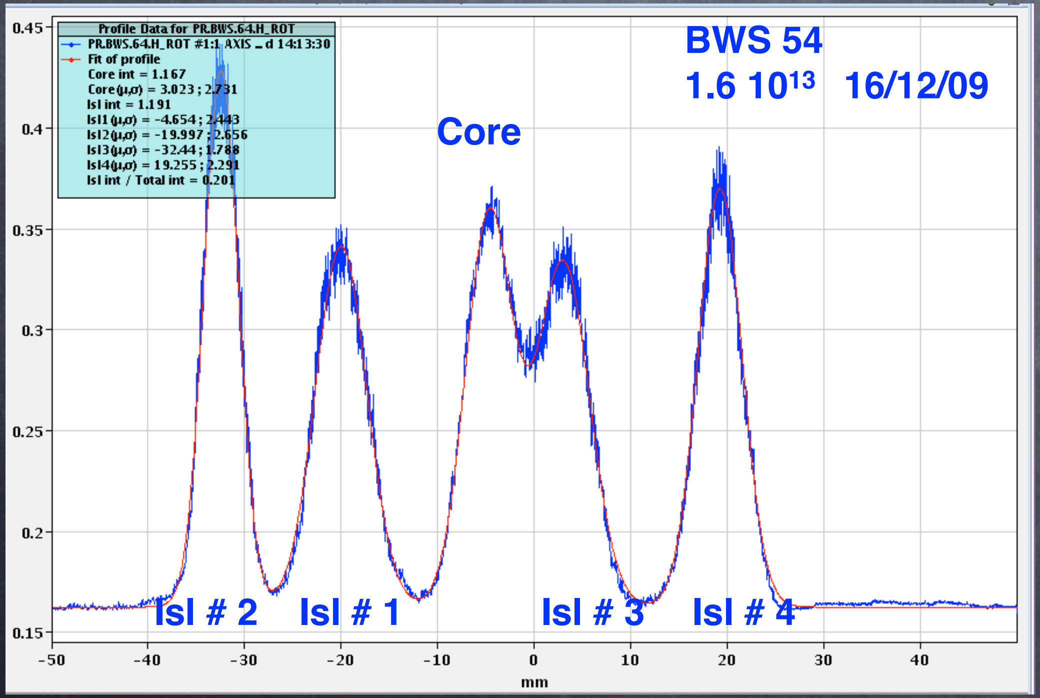

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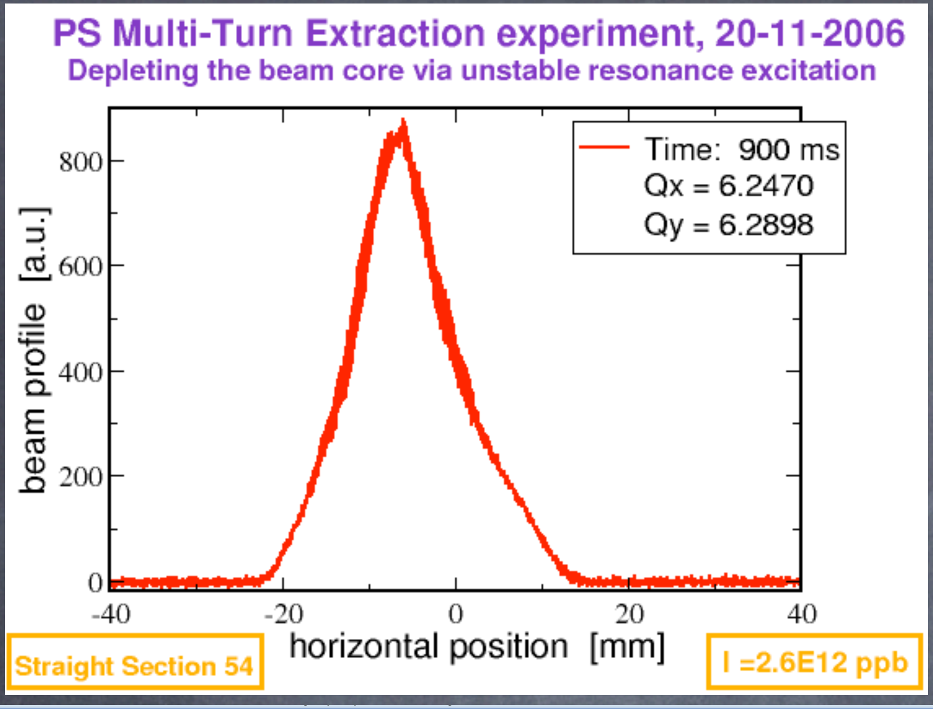

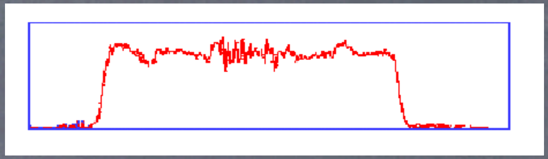

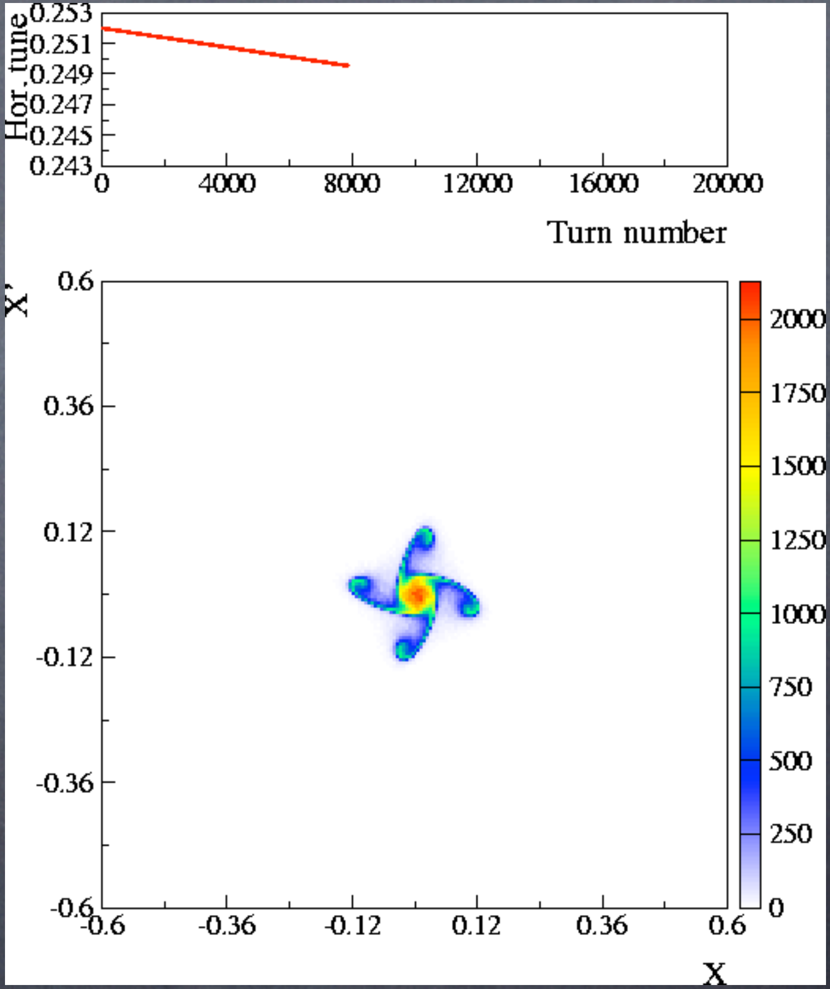

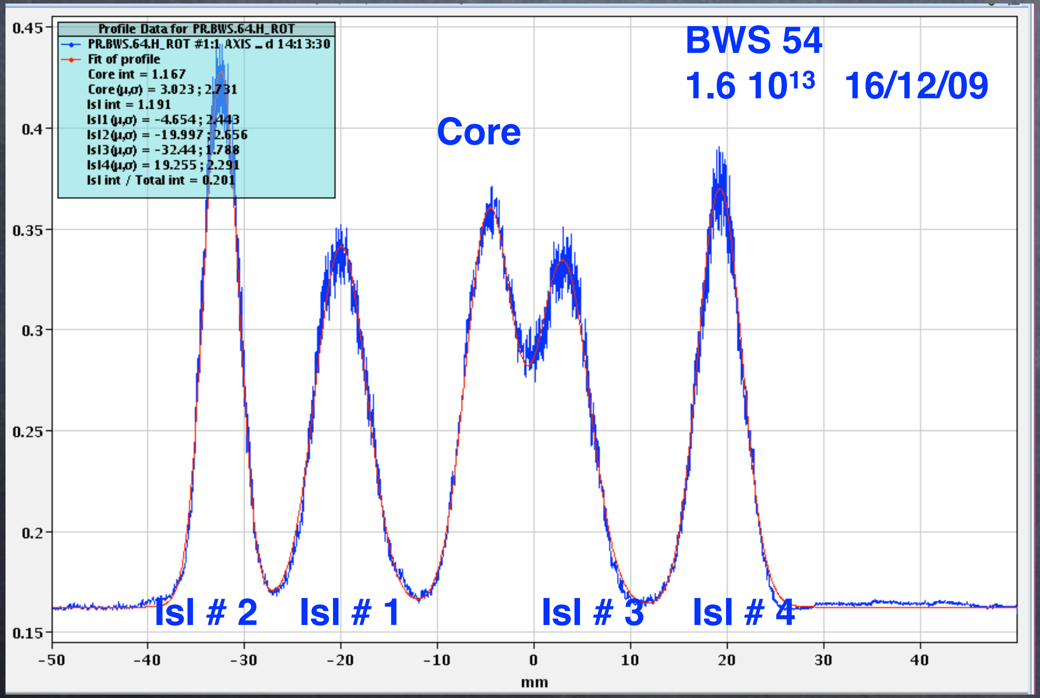

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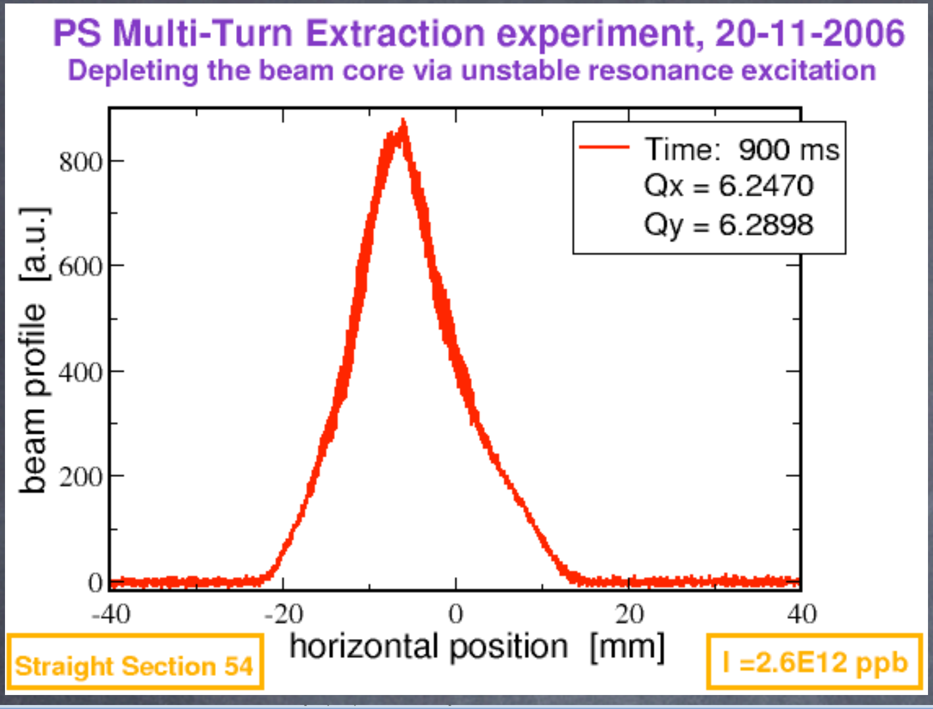

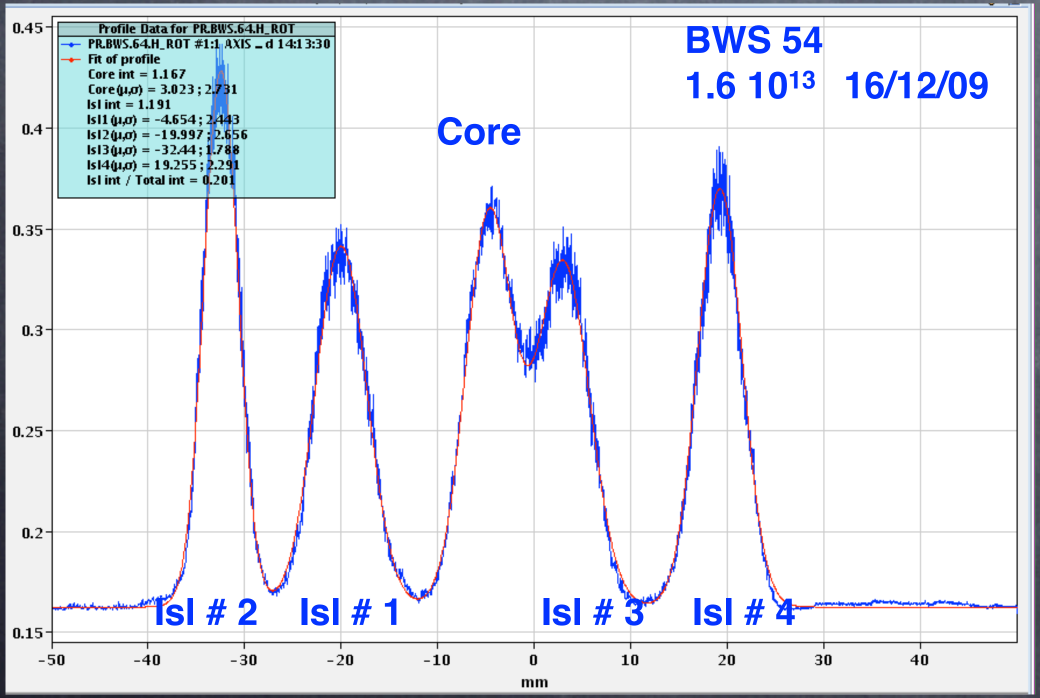

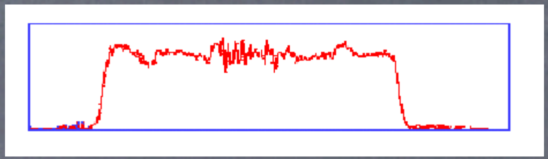

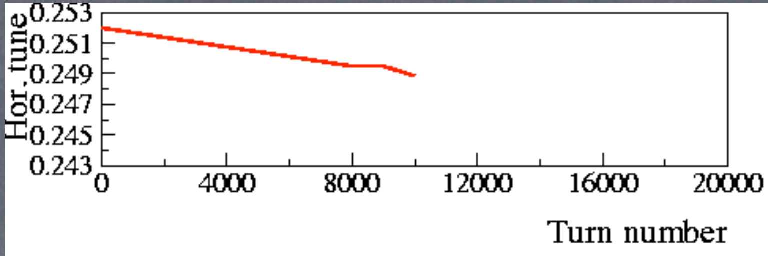

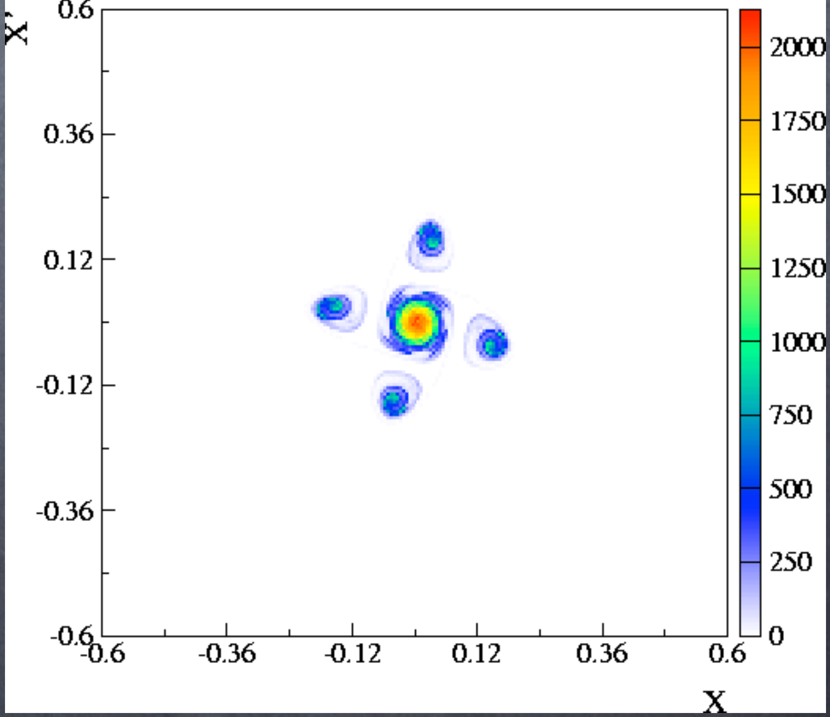

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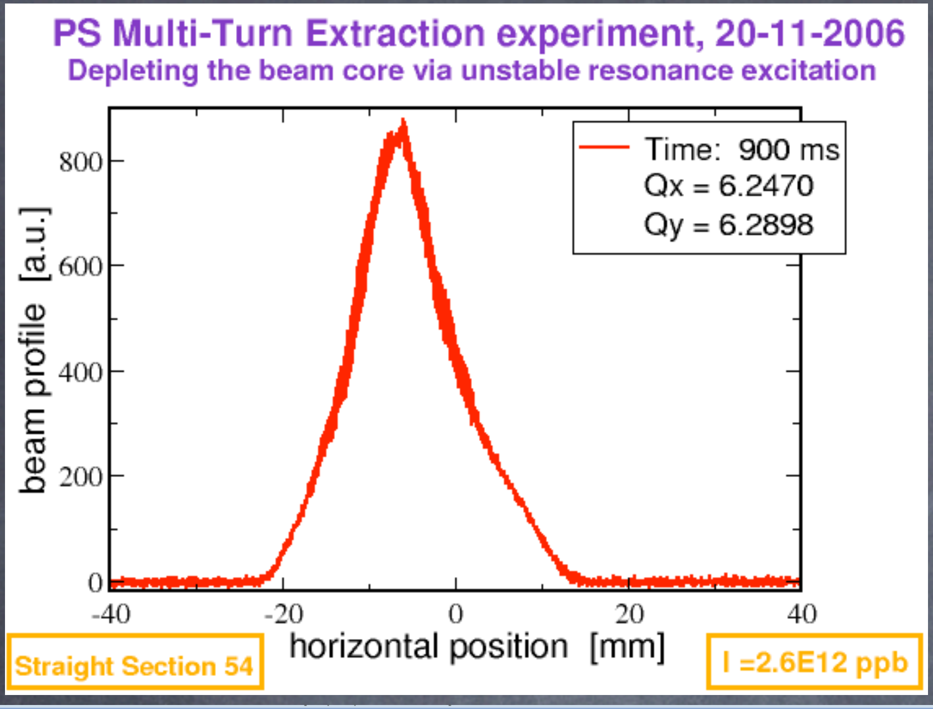
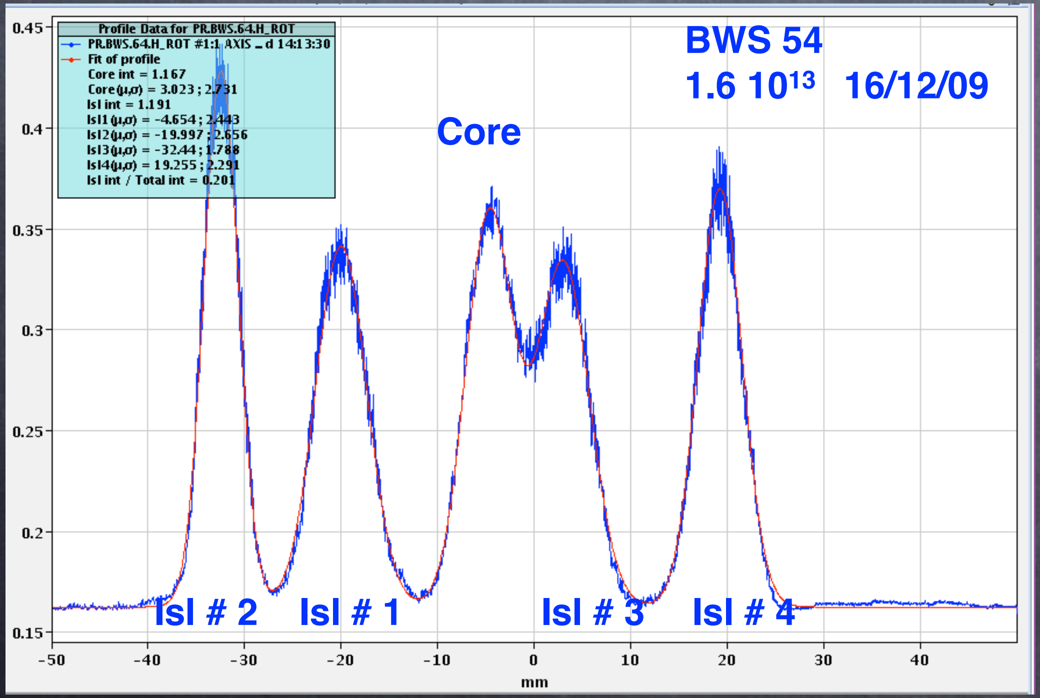
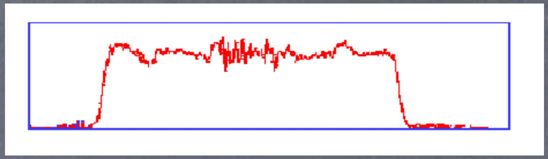
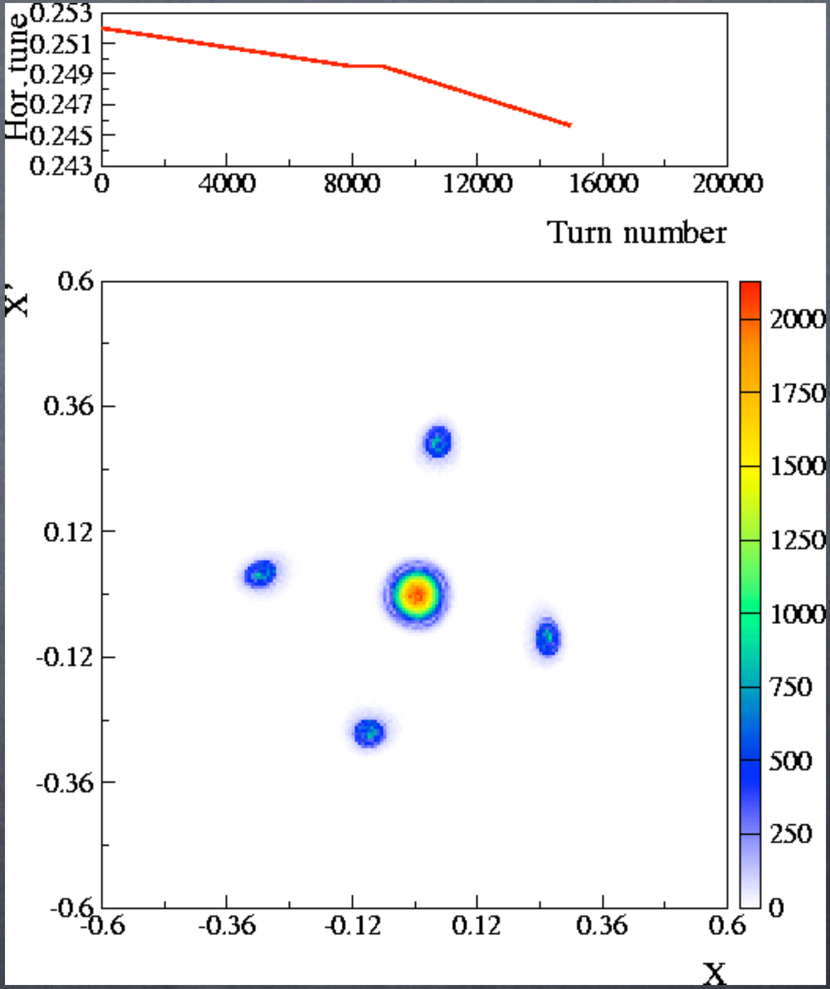
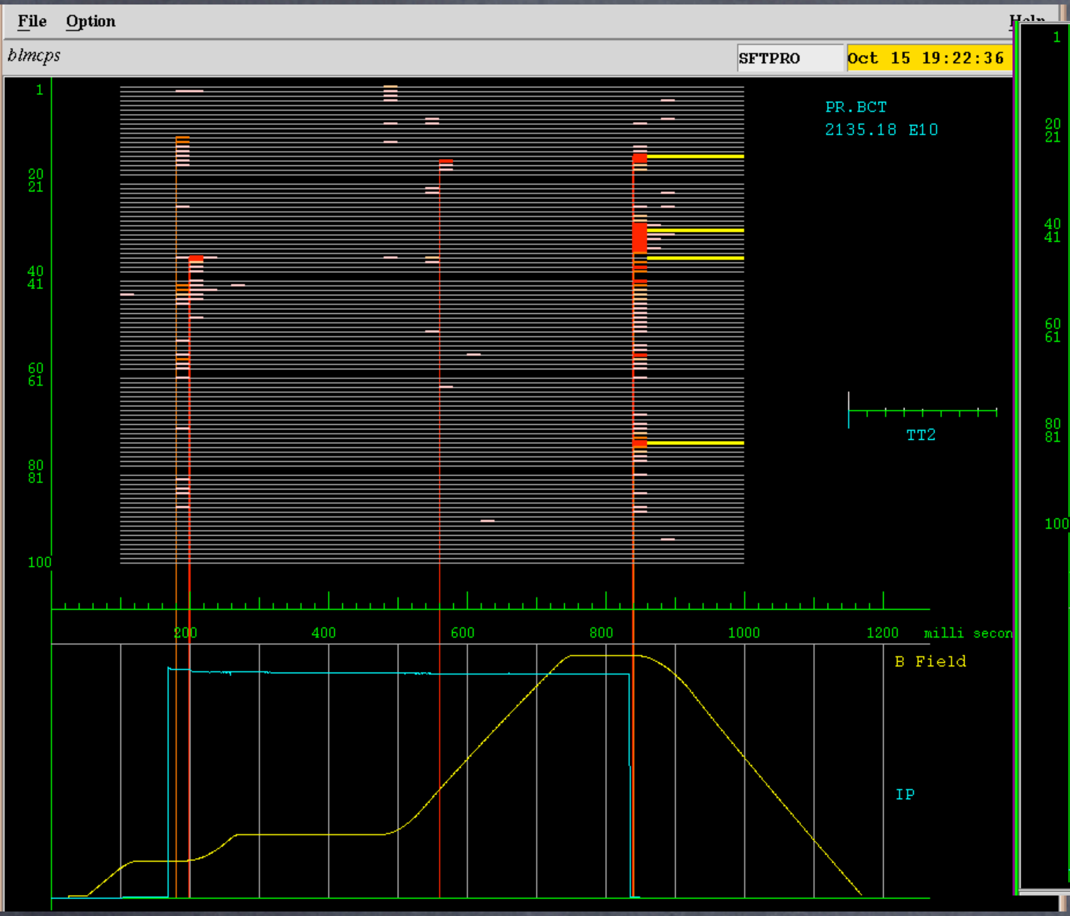


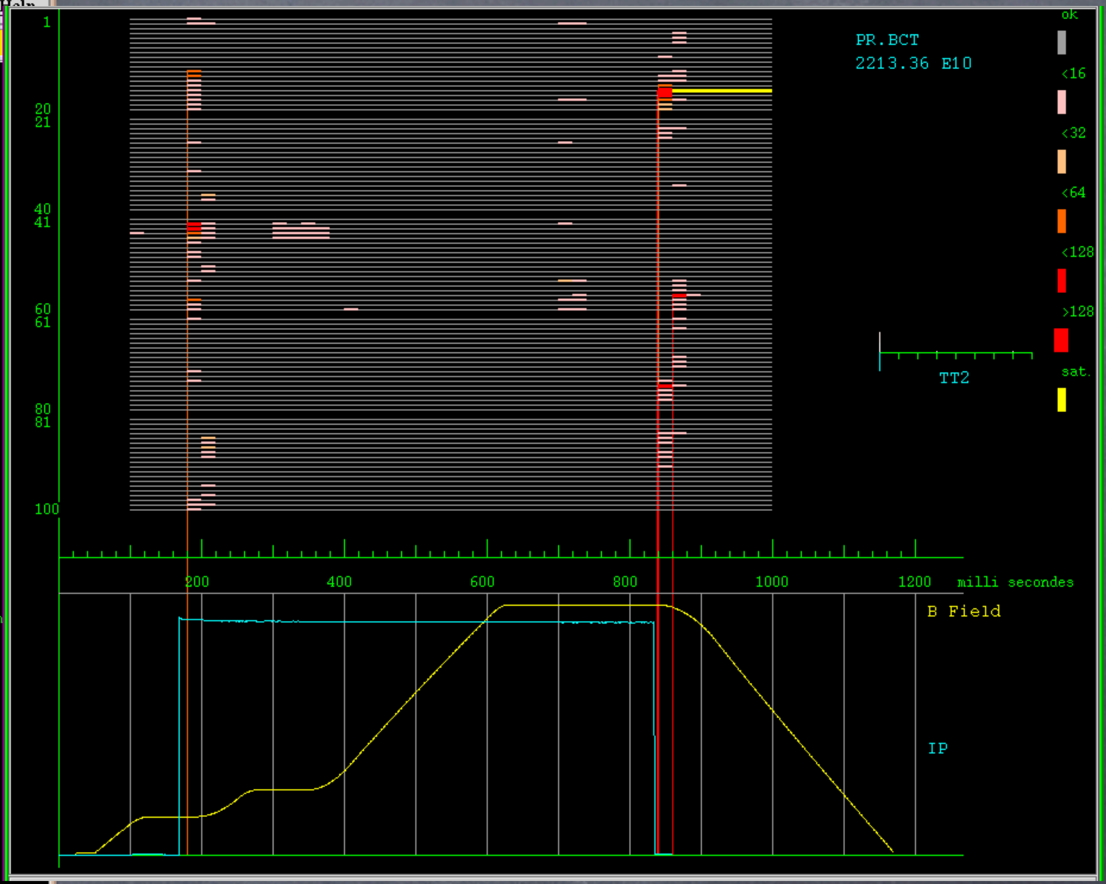






CT vs MTE for same intensity



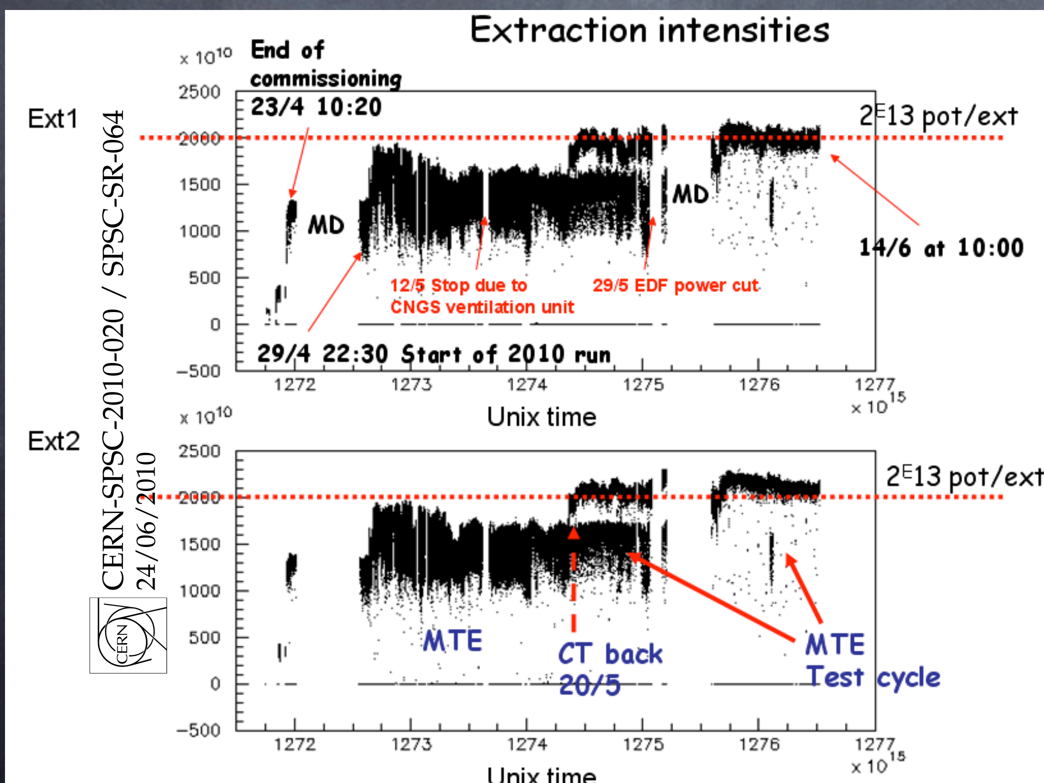


For same extracted intensity, CT extraction has more losses, about the double, compared to MTE

CT losses are spread around the ring whereas MTE losses are concentrated on the SMH16

MTE beam for CNGS

- MTE beam @ 2.2-2.3E13 regularly delivered to the SPS for the CNGS start-up.
- Best capture efficiencies @ 20% as required
- About 11 days of CNGS physics delivered exclusively with the MTE extraction. Then some mixed operation.
  Some SFTPRO also delivered with MTE.
- The CNGS started up without delays even with MTE.



So why we stopped to use MTE for CNGS/SFTPRO operation?

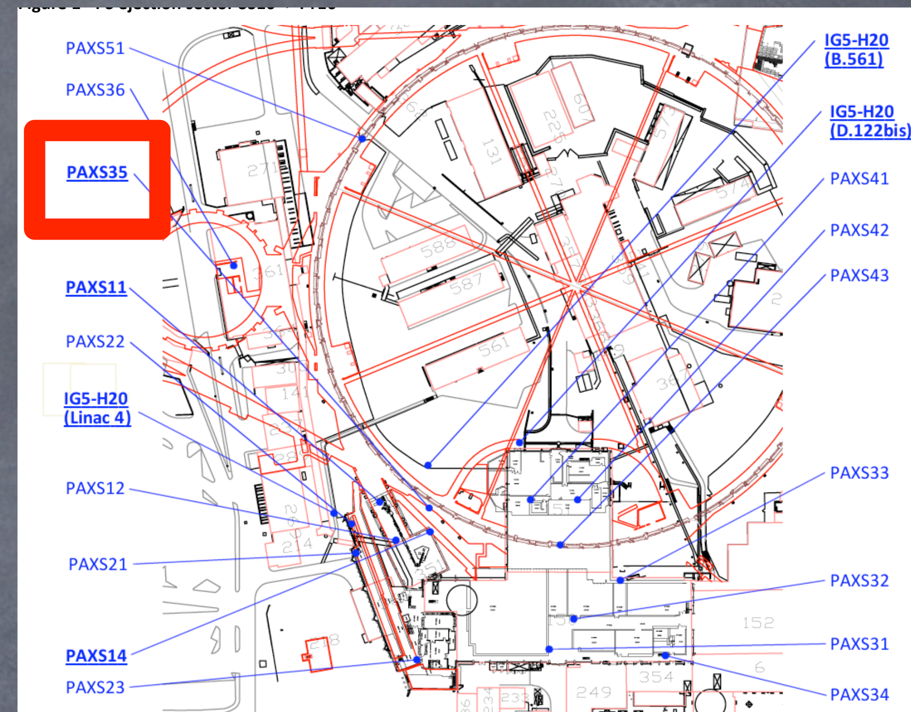
Why we stopped (I/II)?

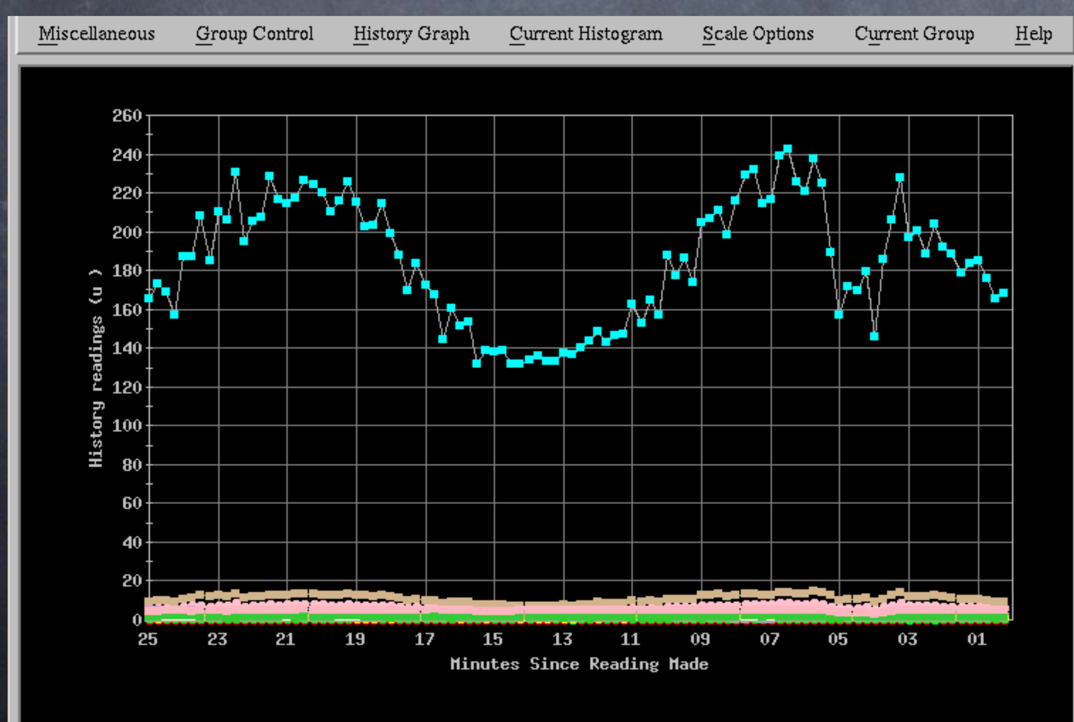
Since last year, a fluctuation has been observed in the capture efficiency, capture drops to 16-17%

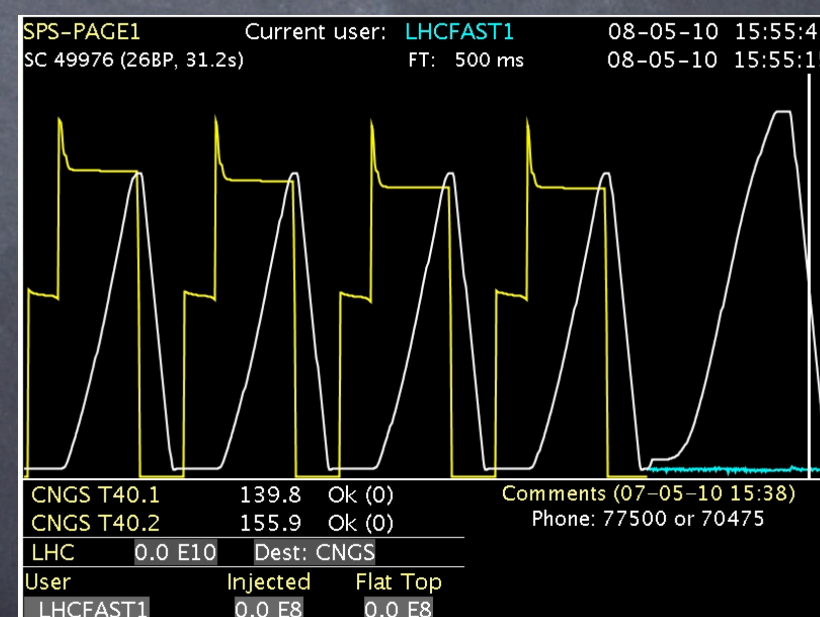
This causes:
a) extra losses at extraction in the PS. (See PAXS35)
About 4% losses instead of 2% losses. More SMH16 activation than in the past.

b) extra losses during acceleration in the SPS.
Large losses in particular at transition.

Reason not found so far (see Massimo's slides)







MTE/CNGS early performances

Outside the bad periods and when the spill was of good quality, the transmission efficiency was up to 94%, practically as a CT beam in the SPS at the start of the run (Carel dixit).

MTE in MAY (old inj. optics)

CNGS Larger | User: CNGS2 | 01-May-2010 10:56:24
Former teletext 111 | Last update: 1 secs ago

TT2	TT10	%LOSS	INJ	%LOSS
2248	2167	3.6	2035	6.1
2160	2082	3.6	1997	4.1

	I/E10	%LOSS	%TRNS	TIME/ms
INJECT	3985	5.1	95	1210
END_FB	3950	2.0	98	1260
20 GeV/c	3834	2.9	95	1470
27 GeV/c	3782	1.4	94	1530
50 GeV/c	3752	0.8	93	1740
400 GeV/c	3743	0.3	93	4200

SC: 28750 LOSS @ FB: 2.3%

CNGS/CT on Wednesday

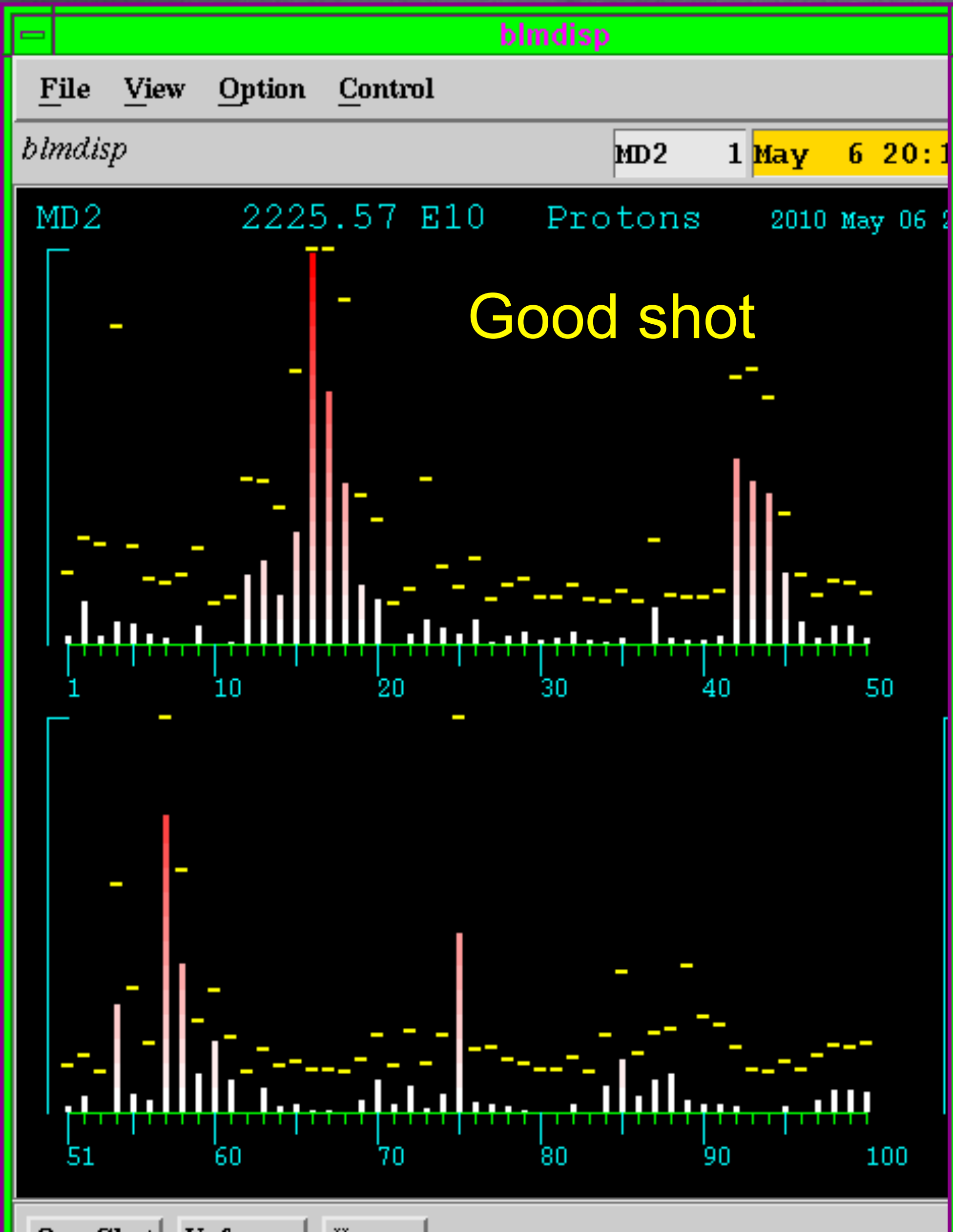
CNGS Larger | User: CNGS1 | 22-Sep-2010 16:27:38
Former teletext 111 | Last update: 20 secs ago

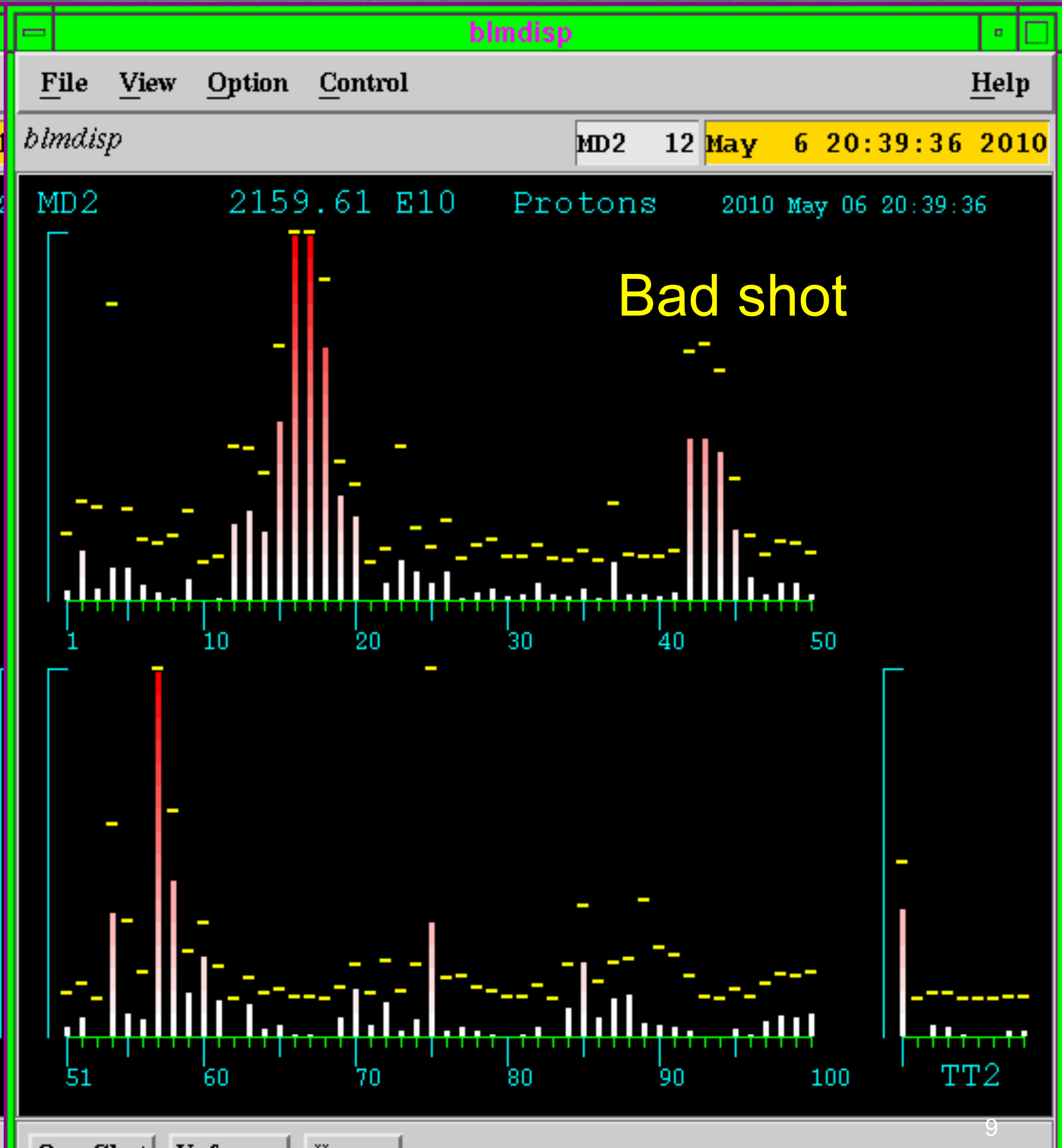
TT2	TT10	%LOSS	INJ	%LOSS
2235	2223	0.5	2160	2.8
2253	2240	0.6	2171	3.1

	I/E10	%LOSS	%TRNS	TIME/ms
INJECT	4311	2.9	97	1210
END_FB	4302	0.7	99	1260
20 GeV/c	4252	1.2	98	1470
27 GeV/c	4209	1.0	97	1530
50 GeV/c	4203	0.1	97	1740
400 GeV/c	4193	0.2	97	4200

SC: 18294 LOSS @ FB: 0.9%

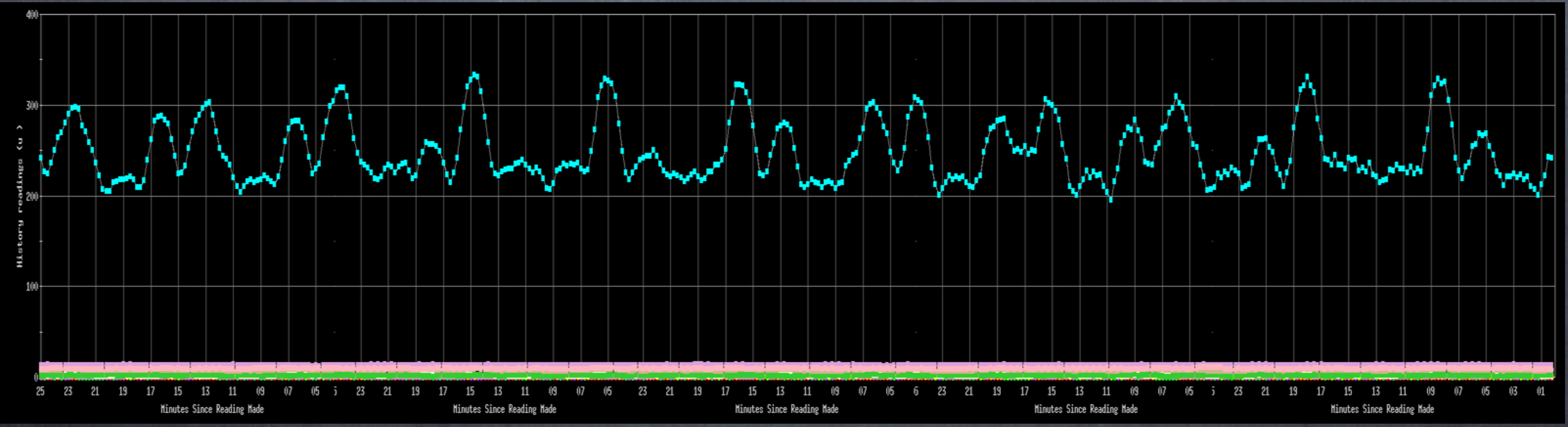
Few minutes fluctuation spoiling the capture efficiency





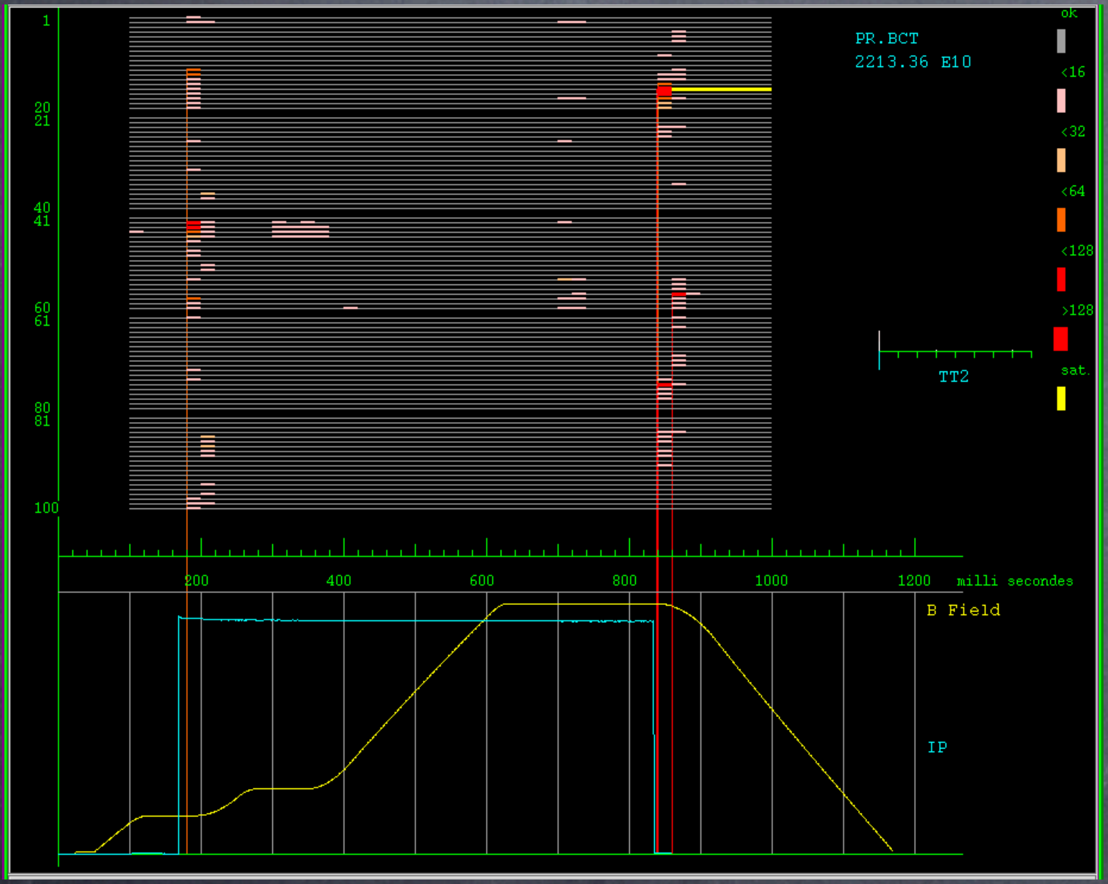
Few minutes fluctuation spoiling the capture efficiency

- Over a longer time scale, the fluctuation is clearly more visible on the radiation monitor (about 1 h total time span)
- See talk of Massimo for investigations/analysis.



➡ Investigation are progressing since beginning of the run

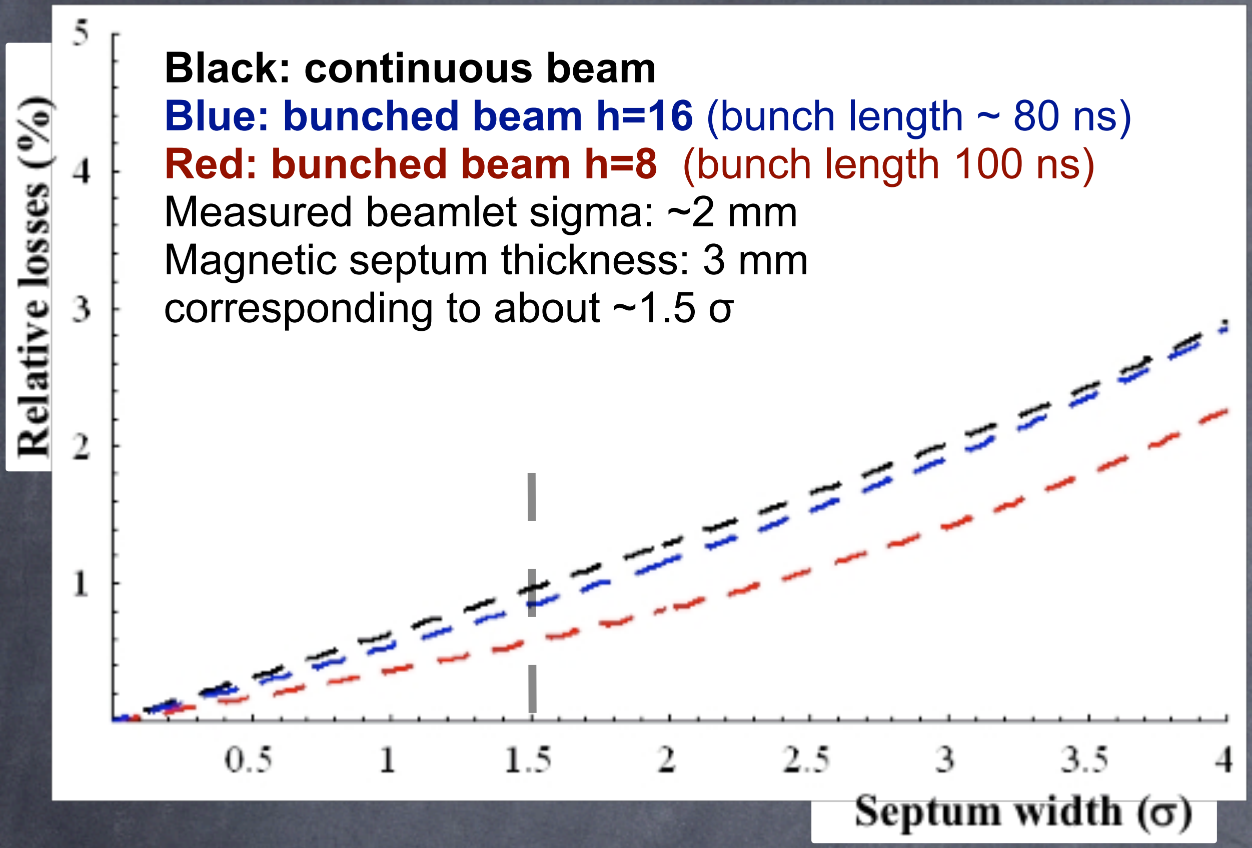
Why we stopped (II/II)?



Losses are concentrated on the extraction septum of the order of 2-4% of the extracted beam.

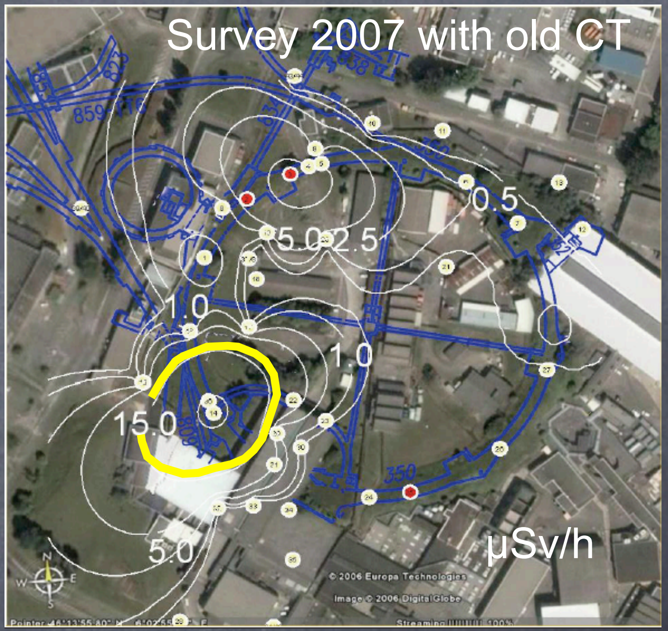
This was predicted in the design: during the rise time of the kickers a fraction of the beam lands of the septum.

Losses vs longitudinal structure



Losses on the septum 16 depends on :

a) septum thickness - 2 mm
b) fast kicker rise time - 350 ns
c) bunch structure - bunched/debunched



Loss diff. between h16 and debunched is only marginal.

Simulated

	Beam losses (%)		
	Continuous	Bunched (h=16)	Bunched (h=8)
Nominal configuration	1	0.9	0.6
Total (capture+extraction)	3–4	2.9–3.9	2.6–3.6
Improved kickers (faster rise time)	0.6	0.5	< 0.1
Total (capture+extraction)	2.6–3.6	2.5–3.5	2.1–3.1
Reduced thickness of magnetic septum	0.6	0.5	0.3
Total (capture+extraction)	2.6–3.6	2.5–3.5	2.3–3.3

Why we stopped (II/II)?

Decision to stop to provide all the CNGS beams with MTE since the dose at the septum extrapolated to a long period of run would have been too large (see next slide).

A septum failure late in the run would have caused a too long waiting time before an intervention would be possible.

This is clearly not compatible with a safe operation of the PS as LHC injector.

Decisions:

a) put back all SFTPRO/CNGS with CT operation. Users prepared in advance. No loss of time for physics due to the change.

b) leave one CNGS with MTE in the SPS for tests.
Judged after a while not really useful since some studies in PS were dedicated for MTE user.

In this way minimised dose to the SPS and to the PS during the search for the spill oscillation.

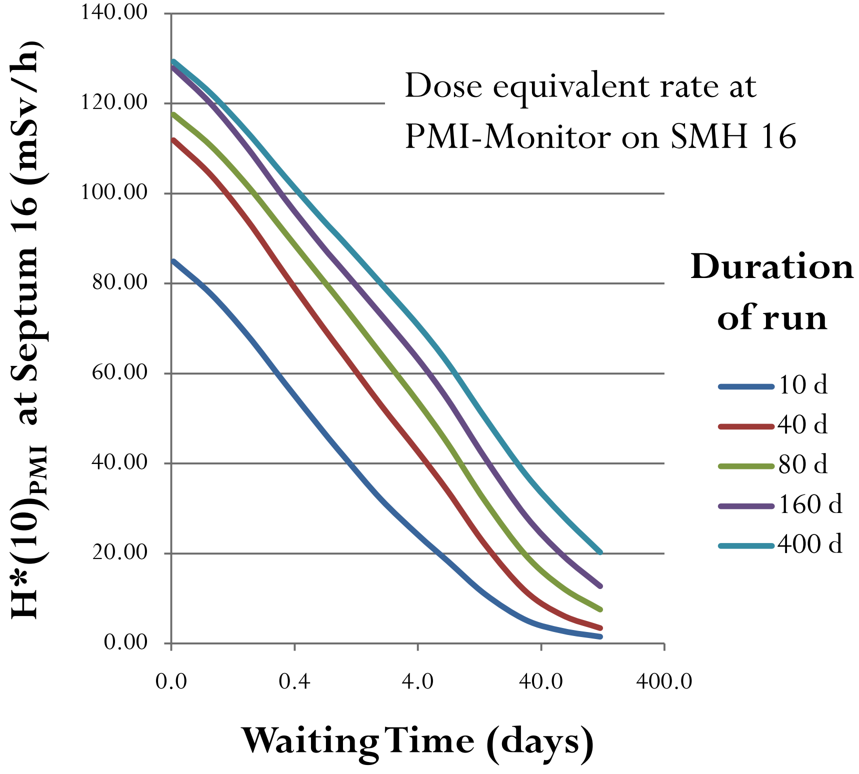
Why we stopped (II/II)? (From T. Otto)

Activation: Septum SMH16

Crucial element of MTE

- Loss of (2-4) % of beam on septum blade

Estimate of ambient dose equivalent rate *H**(10)



Why we stopped (II/II)? (From T. Otto)

Intervention on SMH 16

Experience from previous septum exchanges

- Experienced equipe in TE-ABT
  - $H^*(10)_{PMI} = 3.0$ mSv h^{-1}:
  - $H_{coll} = 1.1$ person-mSv
  - $H_{p,max} = 0.2$ mSv
- In a planned intervention, personal dose for an individual shall not exceed 2 mSv
- => Before an intervention:
  - $H^*(10)_{PMI} < 30$ mSv h^{-1}

Consequence for availability

- After operation with 2 % loss, the necessary decay time would be
  - 8 days after 40 days run
  - 15 days after 80 days run
  - 30 days after 160 days run
  - …
- The intervention would cost $H_{coll} = 11$ person-mSv

Why we stopped (II/II)? (From T. Otto)

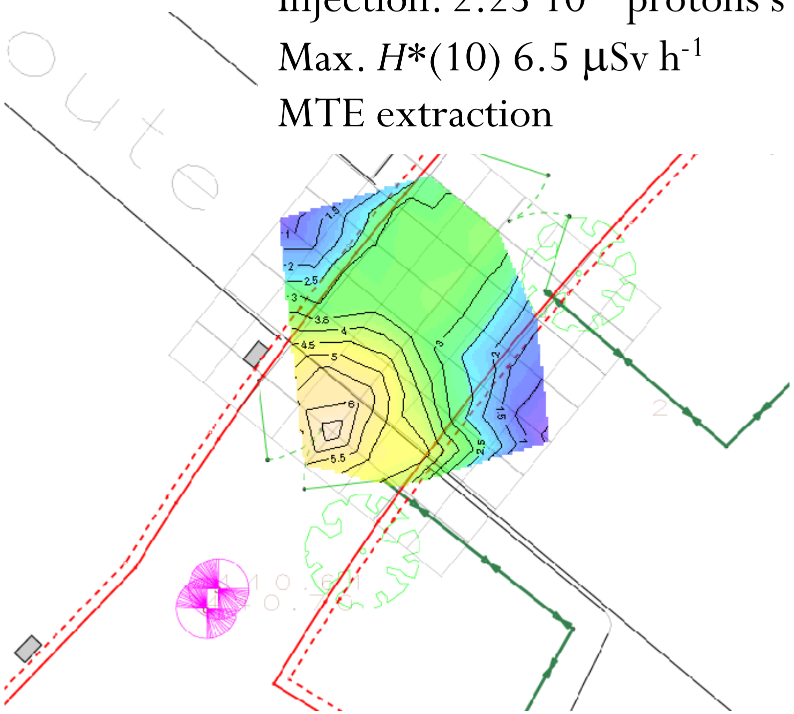
Stray radiation on Route Goward

Observations

- If MTE is used, ambient dose equivalent rate may attain $H^*(10) = 25\ \mu Sv\ h^{-1}$
- (Use of CT could double this number !)
- Need to reduce $H^*(10)$ by more than a factor of 10
- Conventional wisdom suggests 1 m of concrete

Measurement

Injection: $2.25\ 10^{12}$ protons s^{-1}
Max. $H^*(10)$ 6.5 $\mu Sv\ h^{-1}$
MTE extraction



Issues encountered during the setting-up

Different studies were done to:

a) optimise the extraction losses, i.e. minimise them as much as possible

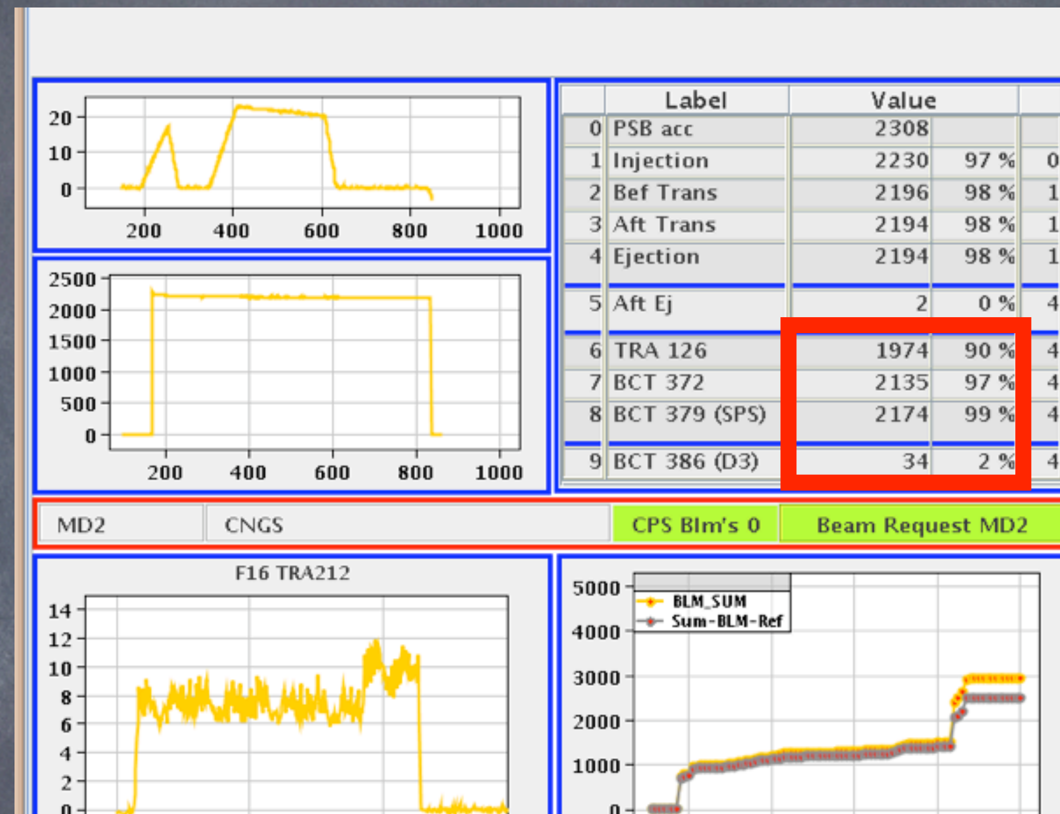
b) improve spill stability to have regularly 20% per island

c) Once different optimisation done, re-inject the beam in the SPS to:

- a) understand if the realised spill stability is sufficient
- b) determine if the emittances are sufficiently small
- c) change the optics: old matched the core, new one the islands

But we had few problems to approach... first

Extraction efficiency evaluation



- Not evident to evaluate precisely the extraction efficiencies seen the lack of cross calibration between the different transformers in TT2.

- Even the absolute calibration was quite doubtful

BCT precision and calibration

a) Calibration of old electronics in TT2 was a clear problem (common to all the beams, included LHC-type ones):

- a) BI made available first a new TRIC card for one transformer
- b) all the TT2 transformers received a TRIC card

b) Triggered discussion on the precision of the trasformer

- a) lead to a recalibration of the ring transformer (PSB and PS), not done due to luck of time during the last Xmas technical stop
- b) anyhow 2% extraction inefficiencies cannot be measured with sufficient precision with the existing hardware.

c) Still the cross calibration between different TT2 transformer is under discussion.

LHC - BLMs

LHC-BLMs hoped to be used to evaluate losses at extraction and for optimisation

a) First solution for signal acquisition proposed by BI could not be used since providing only one acquisition per second, i.e. per cycle

b) Second solution: use direct signal connected to OASIS.
Not possible at the beginning due to problem with signal adaptation

c) Third solution: local scope installed to measured direct signal from the chambers

Results (see MSWG) :
a) the chambers are not fast enough to help understanding the losses at extraction

b) the chambers saturate, i.e., the loose linearity already for CT losses @ SMH16, which are smaller than for MTE.

Further steps:
a) In order to help BI in the choice of the future BLM system for the PS, installed a SEM and a PEP-II type detectors.

b) review with BI of the new system

In the meanwhile, losses can be evaluated only with the transformers (see calibration issues...)

CO Issues found during the setting up I

- **Pb during INCA deployment**
  - MD4 user “crashed” immediately after the INCA deployment
    - all settings lost and overwritten more or less randomly without leaving any trace in the INCA db
    - settings restored but only partially and user had to be reconstructed, both for the transverse as for the RF
    - mechanism that crashed the user not clear still today
  - B field set to zero due to the INCAification of the MPS control applications
    - problem understood and common to all the users
  - Unavailability of some application during the migration to INCA
    - control of the working point and MTE trimming
    - with MTE discovered that few applications were bypassing INCA db
    - discovered that some equipments were not logged correctly for the TRIM history
  - User had to be re-defined since badly declared during INCA deployment (same as LHCION as MDION) for the optics change

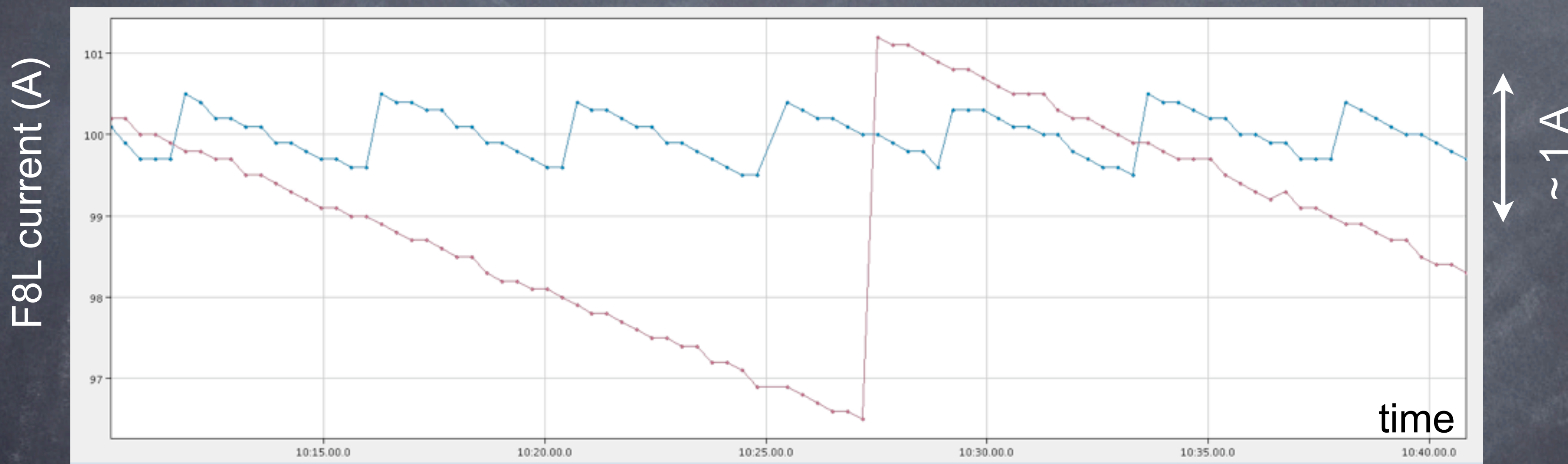
CO Issues found during the setting up II

- User crashed during 6th September PPM copy together with all the 1 bp users
  - full recovery could not be possible due managing of the radial position steering in INCA
  - problem common to all the beams
  - CO/RF/OP investigating now to implement the correct saving of the radial position settings
- Transformer logging in TIMBER
  - fundamental tool to avoid extensive use of the wire scanners to evaluate the capture efficiencies
  - fundamental tool to determine the extraction efficiencies
  - TIMBER logging faults few times due to:
    - unavailability of the data from the transformers
    - sudden change of the units of the transformer published data
    - fault of the server db

Issues found during the setting up III

Discovered asynchronism between AQN of the PFW-F8L and non-linear element power converters and the general ctime. Not possible to determine directly from the CCC the stability in time of the different power converter.

- Difficult to look for oscillation in the spill



- One of two A of the F8L would induce a tune variation compatible with the spill degradation

- Problem understood and modification on the power convert control system done during the before last tech. stop.

Excellent support from all the colleagues for the different issues, however a lot of time has been spent to understand and collaborate solving issues not specific to MTE.

Beam to SPS

- Beam sent to the SPS since about one month ago to:
  - check if the current spill stability is good enough
  - if the new optics that matches the islands is better
- RF setting up done
- Transverse setting up done but for two injections (only one taken)
- Unfortunately
  - desperate need of TT10 trajectory correction to be able to correct the island trajectories and minimise the horiz. transverse emittance
  - activity ongoing but not as fast as hoped

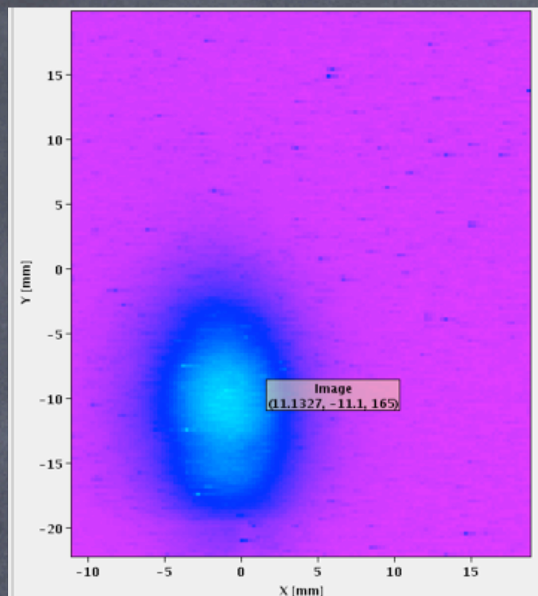
TT10 screens (MTE optics diff. than CNGS/SFTPRO)

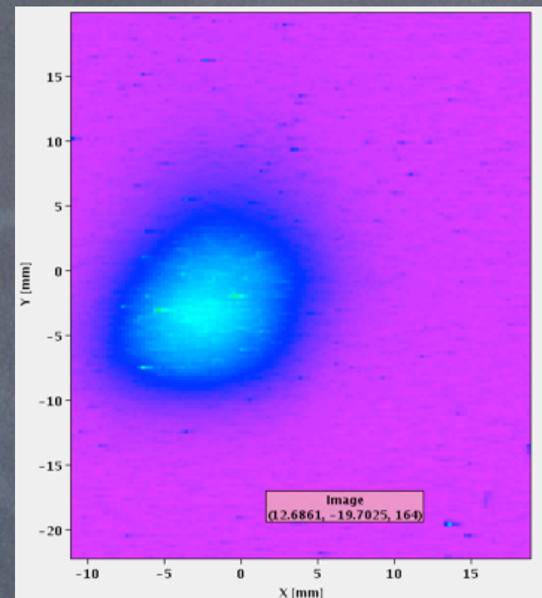
MTE

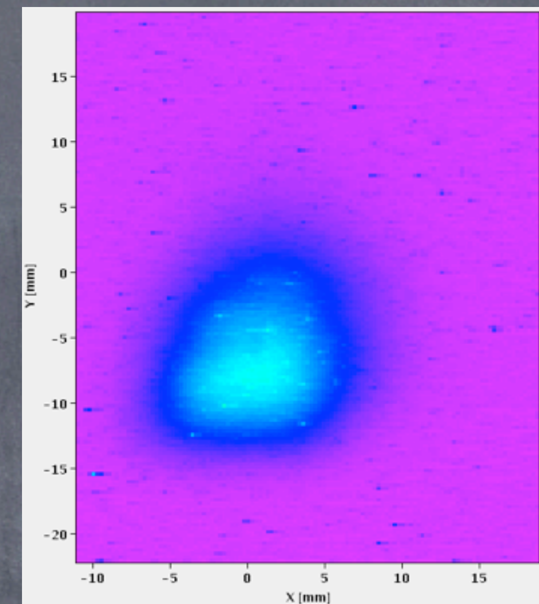
CNGS

SFTPRO

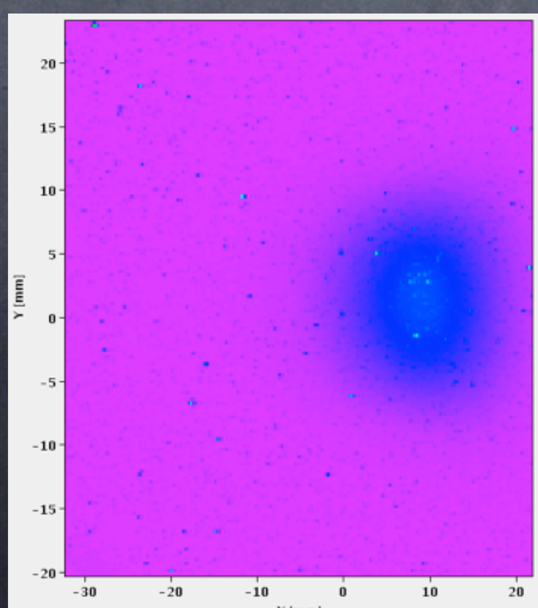
MTV1018

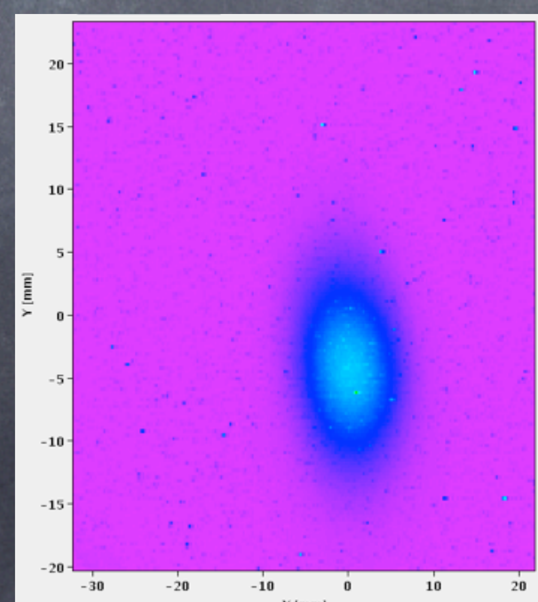


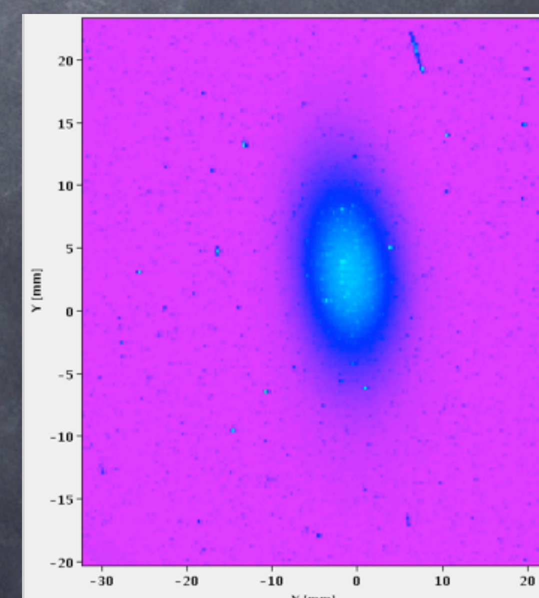




MTV1024

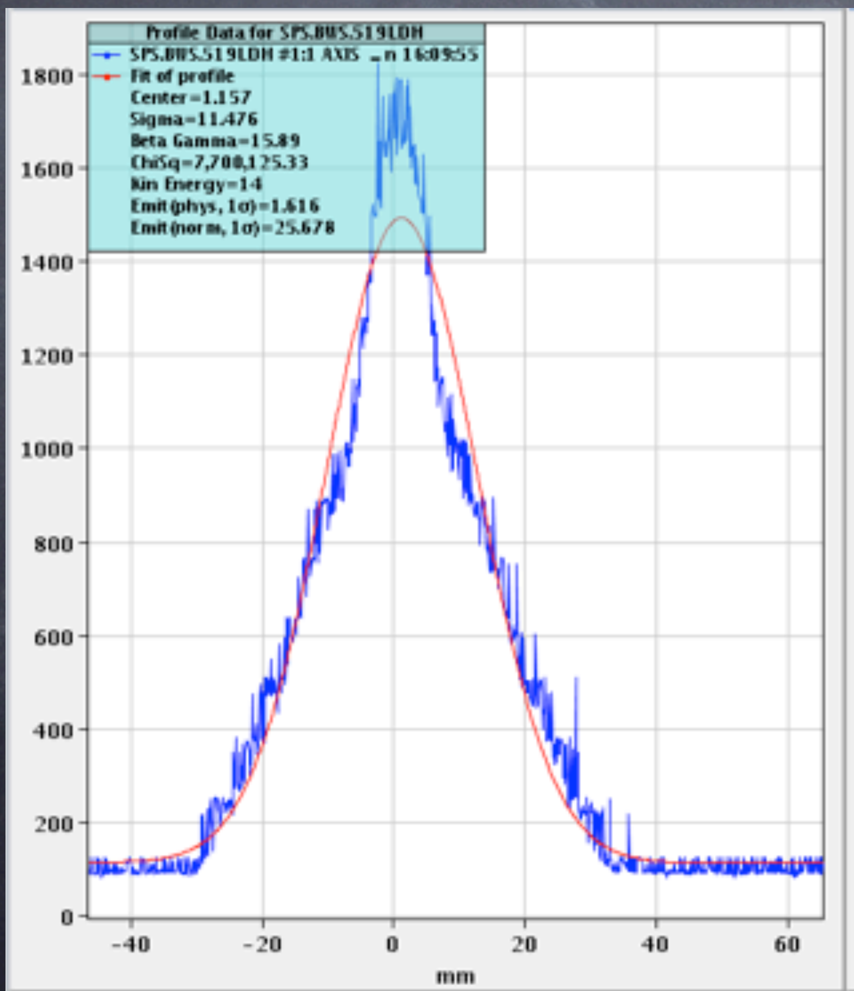




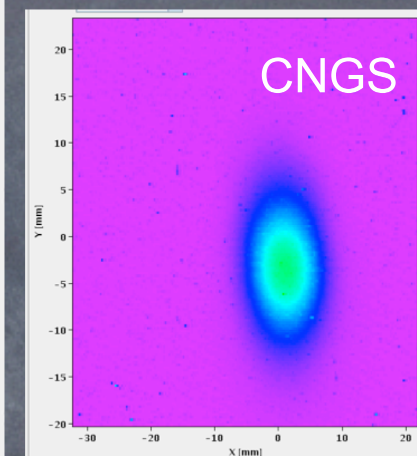


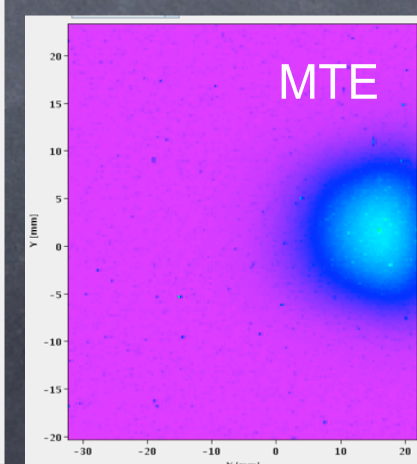
SPS - H emittance

- **H emittance very large due to uncorrected island trajectories at injection.**
- The correction algorithm for the TT2-DFA does not converge correctly probably due to too displaced trajectories in TT10 (see next slides).

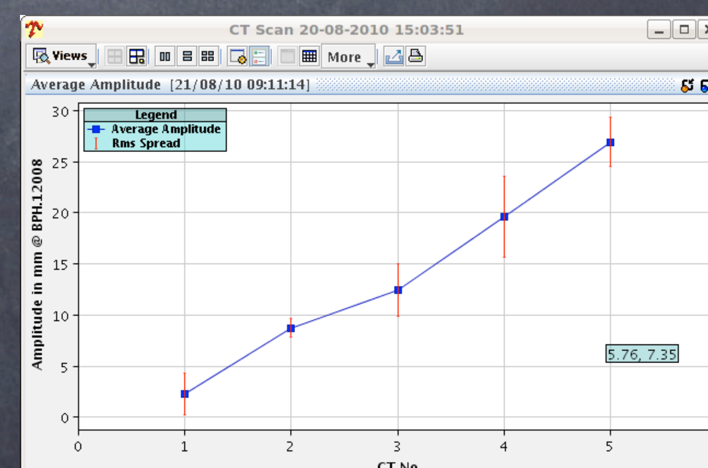


MTV1024

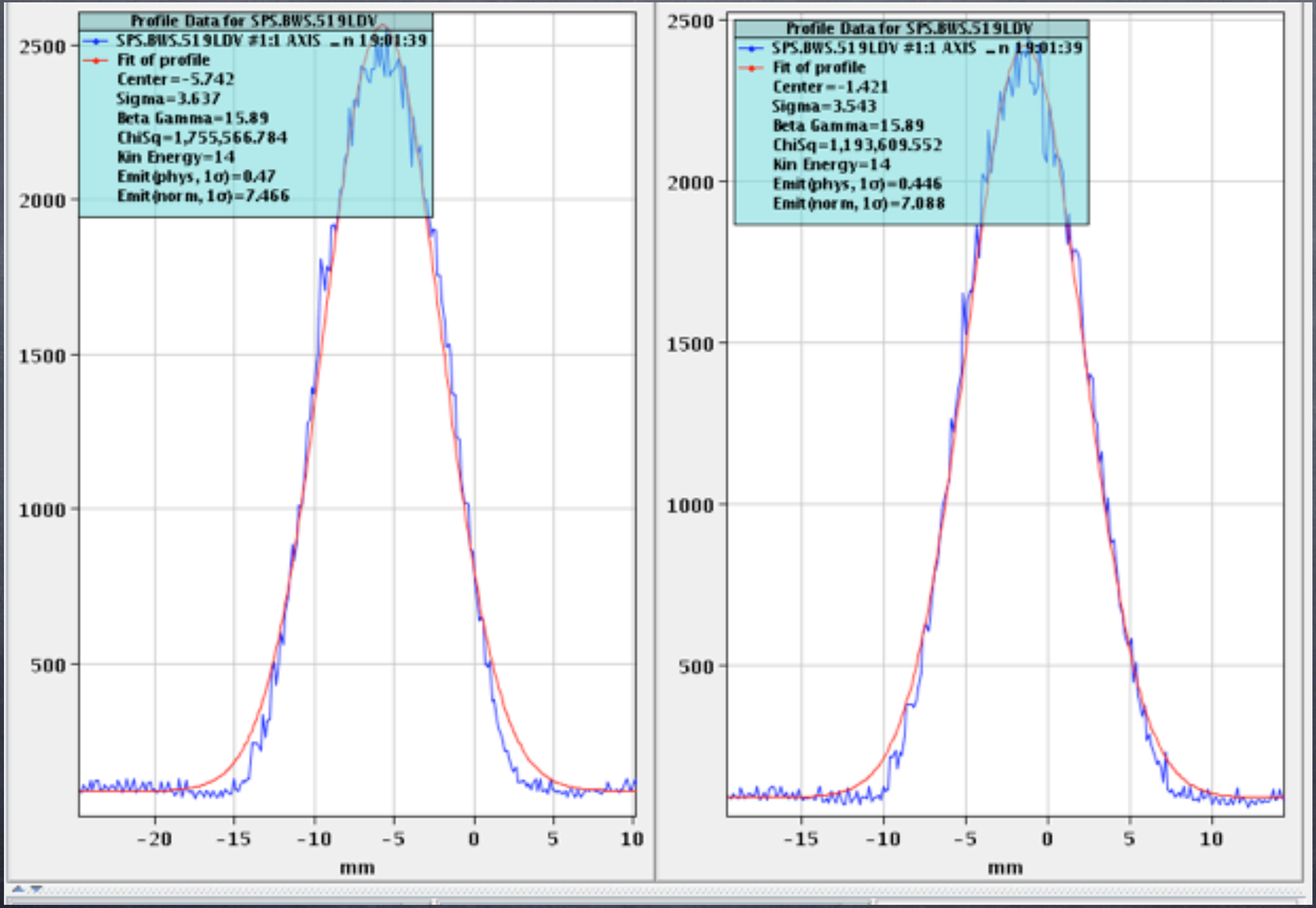




Emit. H used to be about 16 mm in april after first proper trajectory correction. (cfg. logbook 19/04/10)



SPS V-emittance as expected, basically as in the PSB



TT10 steering problems

- **PU at the end of TT10 had not clear behavior**
  - expert checked and diagnosis results indicate a HW malfunctioning. Doubts about the diagnosis method. 4 hours long access needed for cross check
  - Response studies showed that PU seems to work correctly for small amplitudes, whereas for |x|>24 mm the signal swap sign
- **YASP steering not correct for the CNGS2 (MTE) user (Carel)**
  - correction computed not sent correctly to the equipments or not correctly computer or not correctly shown
  - investigations ongoing with Jorg to understand the issue
- **Final steering which lead small losses was done finally by:**
  - steering the beam screen-by-screen
  - implementing closed bumps
  - reproducing at the end of the line the CNGS trajectories
  - beam decently re-injected since tuesday

Next step: island trajectories correction

Large H emittance @ SPS injection due to different islands trajectories.
Algorithm to correct for this implemented in the past with tests done for the CT and finally used regularly to correct the CT
Already used for MTE last year and at the beginning of this year

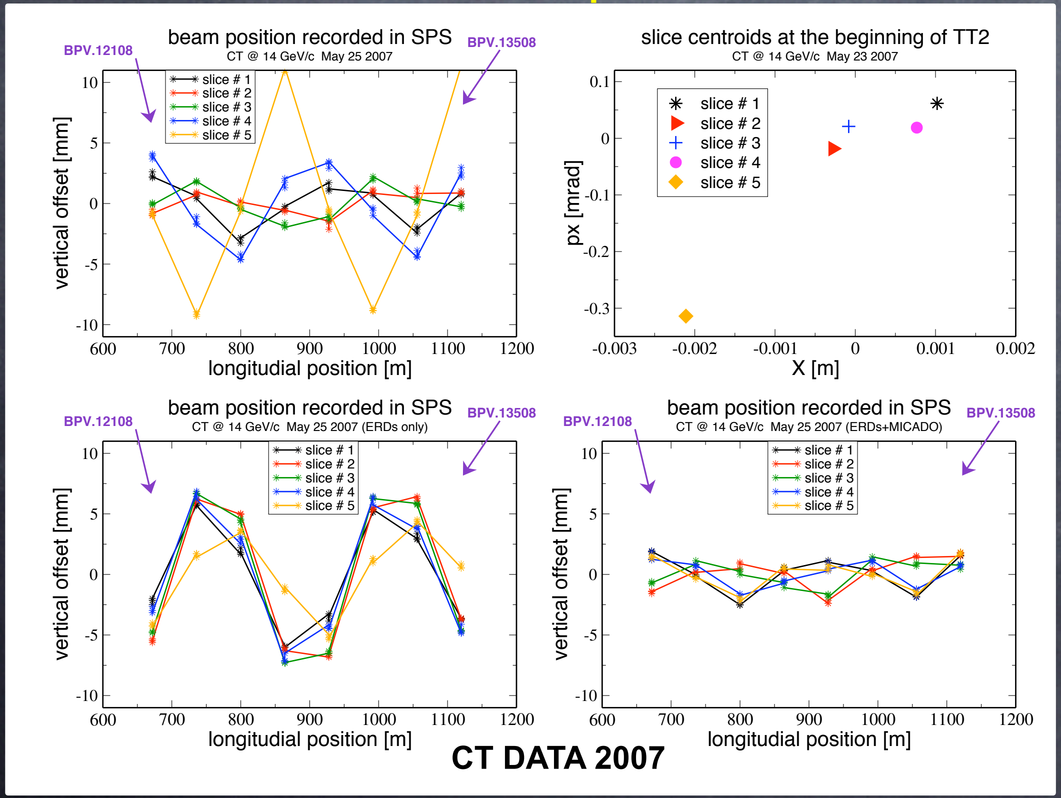
This is step zero before understanding eventual trajectories fluctuation from shot to shot in SPS

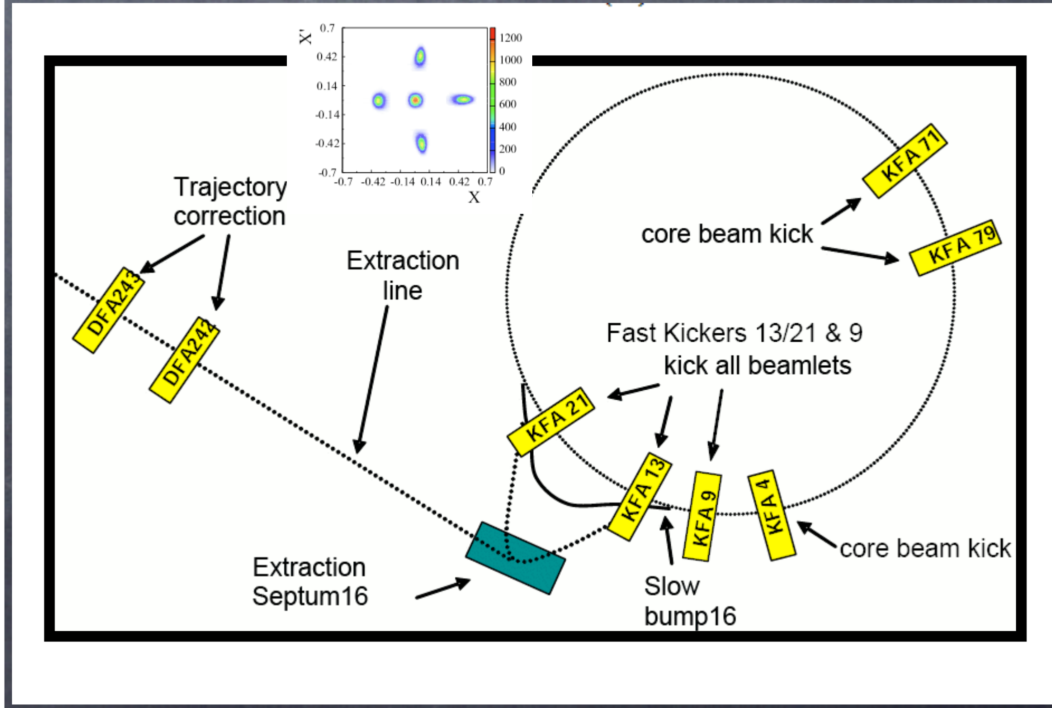
Principle:
a) measure each PS turns in the SPS. PU available to do the same in TT2 but not available yet (see J. J. Gras slides)

b) compute the settings of two TT2 kickers to reduce the spread in beam trajectories at SPS injection

c) Re-steer TT10

This should be done as soon as possible to reduce the 10% losses at SPS injection, this requires PU and YASP Ok.



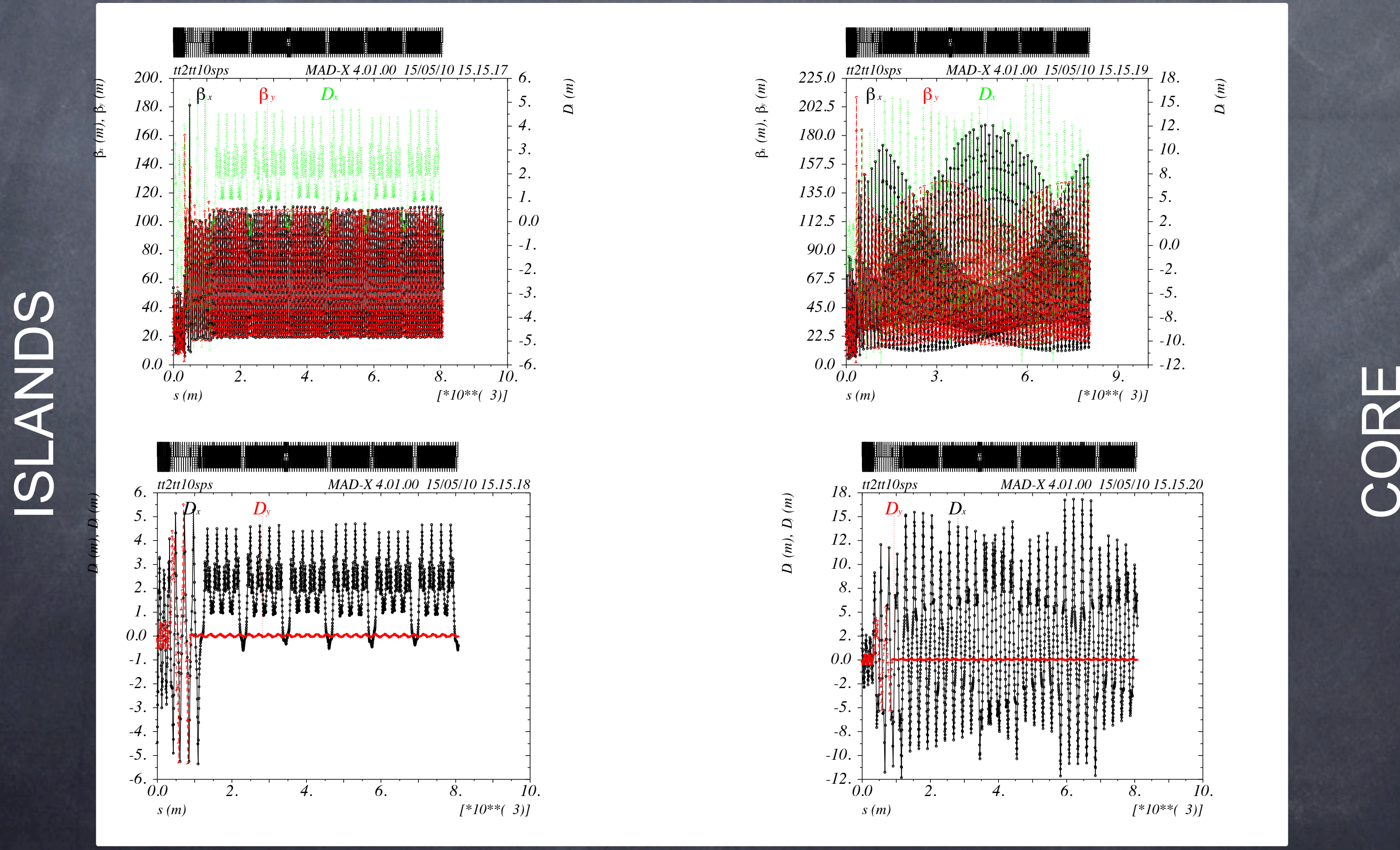


Study new optics

a) Old optics matched the core since most of the intensity was there

b) New optics matches the islands because on average we have >19% capture efficiency. Probably the optimum is between a) and b)

c) First matching measurements shows < 1% mis-match in TT10 for the islands



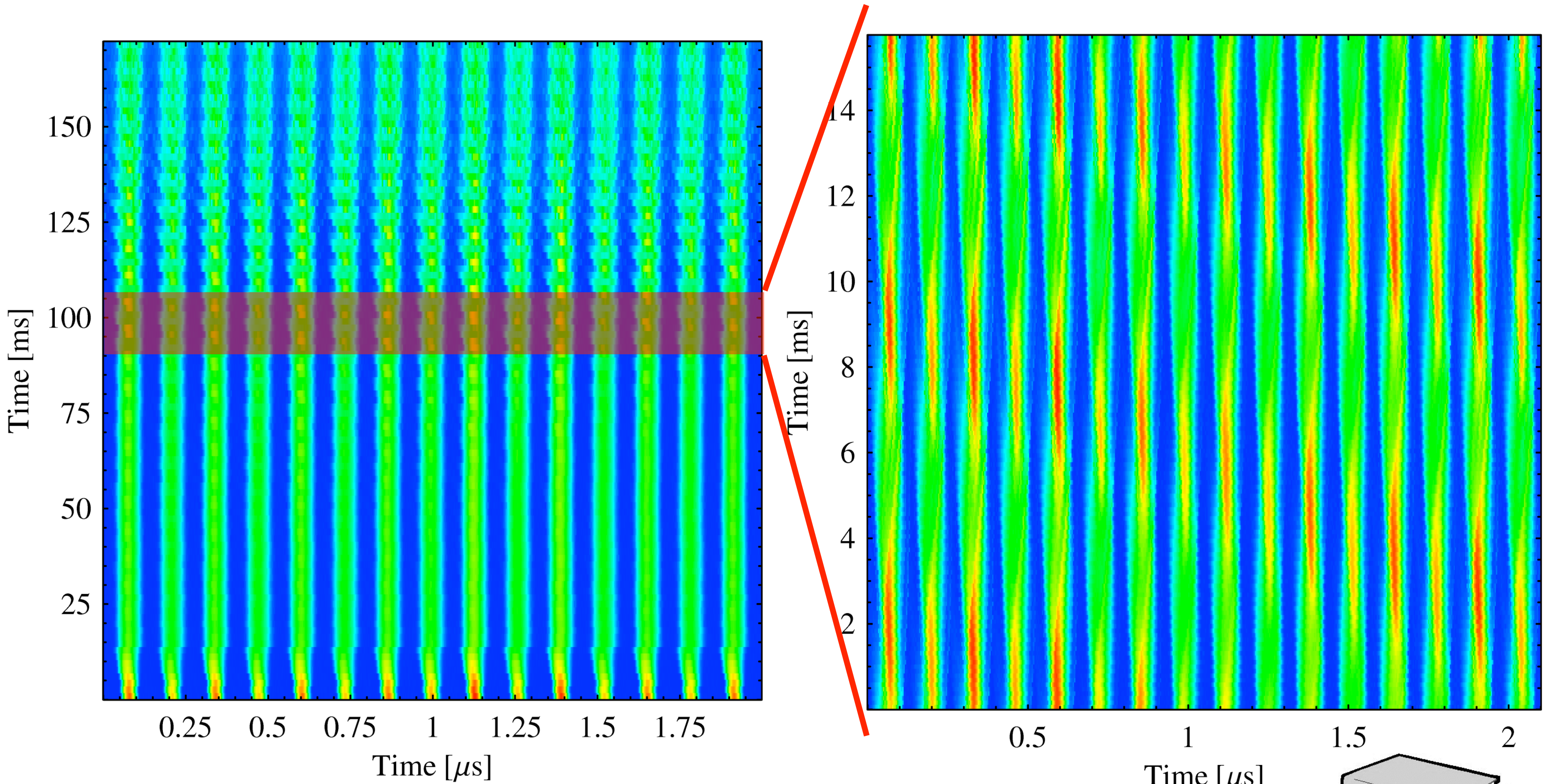
Benefit of MTE on others beams... RF beam LHC improvements

- MTE beam requires low voltage during transition crossing to minimise the dp/p, i.e. minimise the tune spread from the large second order chromaticity but in general from chromaticity effects
- Beam cannot kept de-bunched during resonance crossing due to natural re-bunching, micro-wave instabilities
- With low voltage, coupled bunch instability observed
  - Solution: same feedback used for the LHC-type beam
  - beam on the MHS

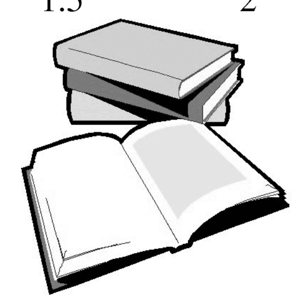
Ack: H. Damerau (BE/RF)
(slides taken from his MSWG presentations)

Observations

- **Beam gets slowly unstable once low RF voltage of 7.6 kV is reached**

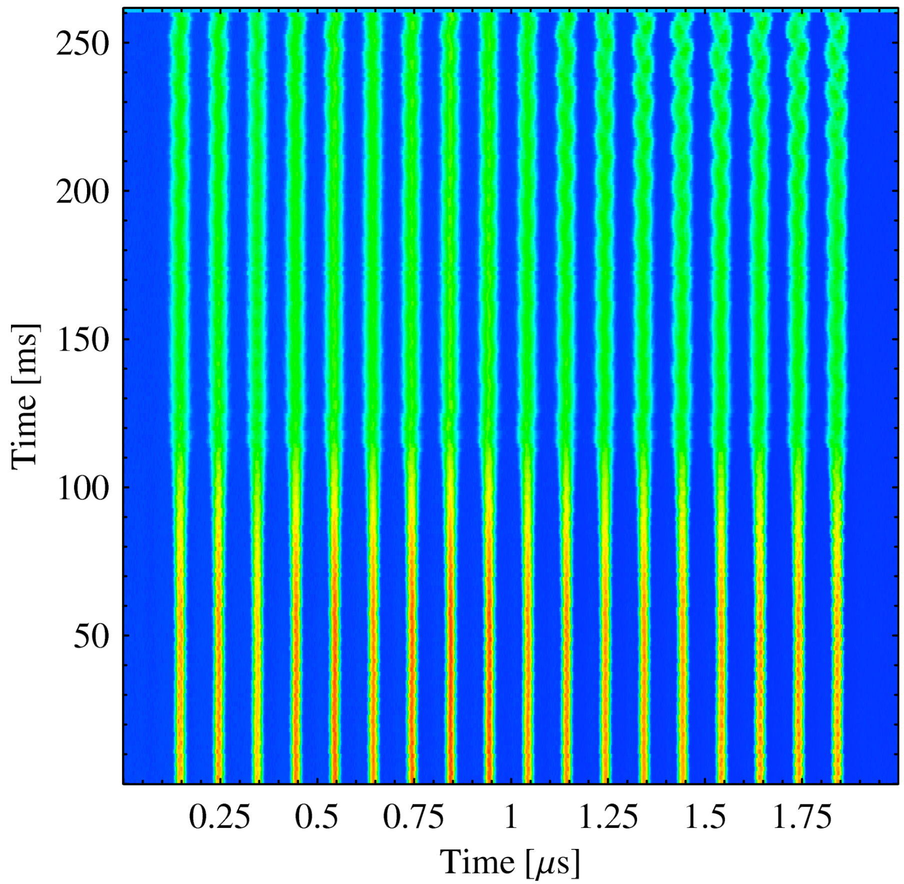


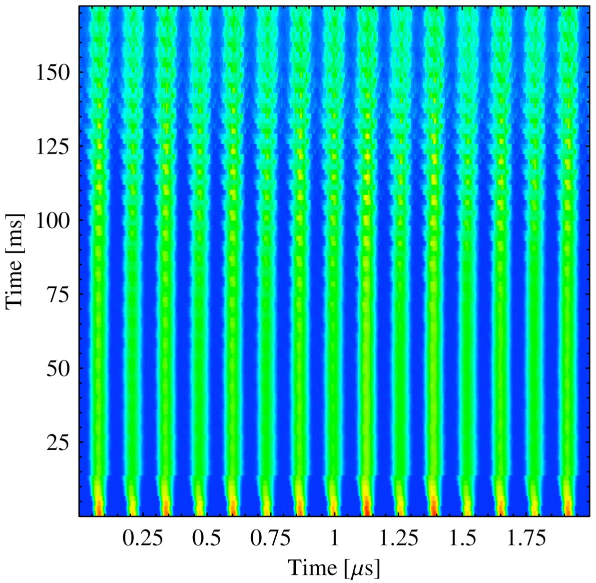
- **Quadrupole, *m* = 2 (only!) mode with a phase advance of Δϕ = 2π/16 per bunch → textbook case**



Comparison to instabilities with LHC beam

LHC25, 26 GeV | **MTE, 14 GeV**

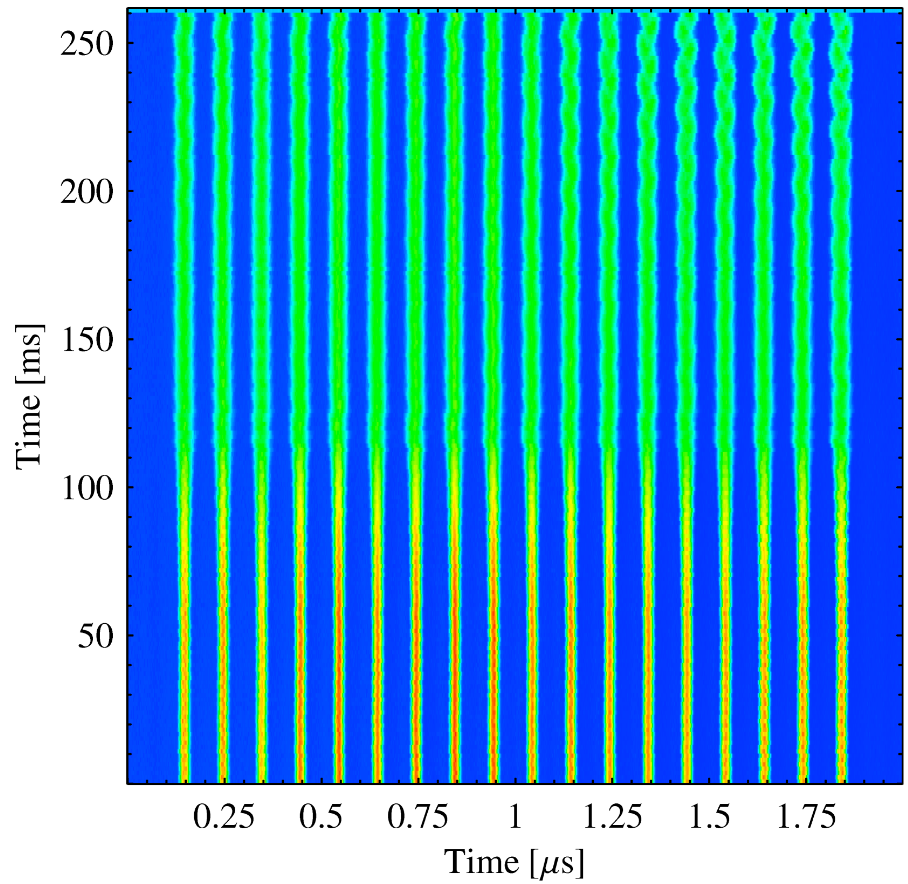




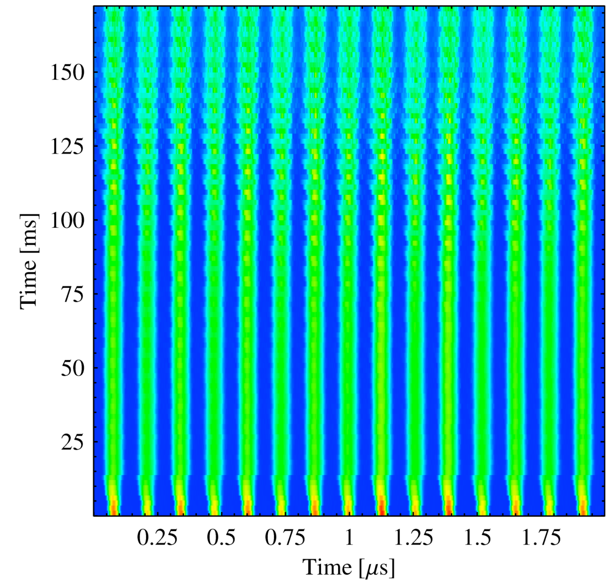
- \+ **Similar growth rates**
- \+ **Oscillation amplitude rises along the batch → points to low *Q* impedance**
- \- **Dipole ($m = 1$) versus quadrupole only mode ($m = 2$)**
- \- **Different mode numbers *n* for MTE and LHC-type beams**

Comparison to instabilities with LHC beam

LHC25, 26 GeV



MTE, 14 GeV



Same source of impedance?

- \+ **Similar growth rates**
- \+ **Oscillation amplitude rises along the batch → points to low *Q* impedance**
- \- **Dipole (*m* = 1) versus quadrupole only mode (*m* = 2)**
- \- **Different mode numbers *n* for MTE and LHC-type beams**

Conclusions

- **High beam intensities of at least up to $2.3 \cdot 10^{13}$ ppp can be accelerated with the MHS system without problems**
- **The 10 MHz cavities are the impedance source causing the instability with the MTE beam**
  - **The existing 1-turn-delay feedback works extremely well to control the instability**
  - **Gap relays less perfect than expected: Parking cavities far away from the RF harmonic helps to stabilize the beam → for free!**

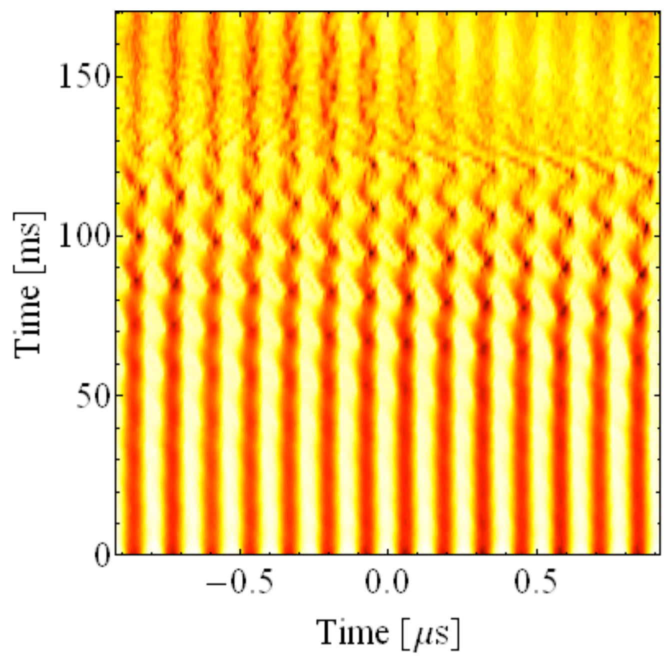
- **Still much work before beam would be operational, if needed**
- **Problems with the old 1-turn-delay feedback used on h8/h16**

Longitudinally stable beam up to present maximum intensity

Park unused 10 MHz cavities

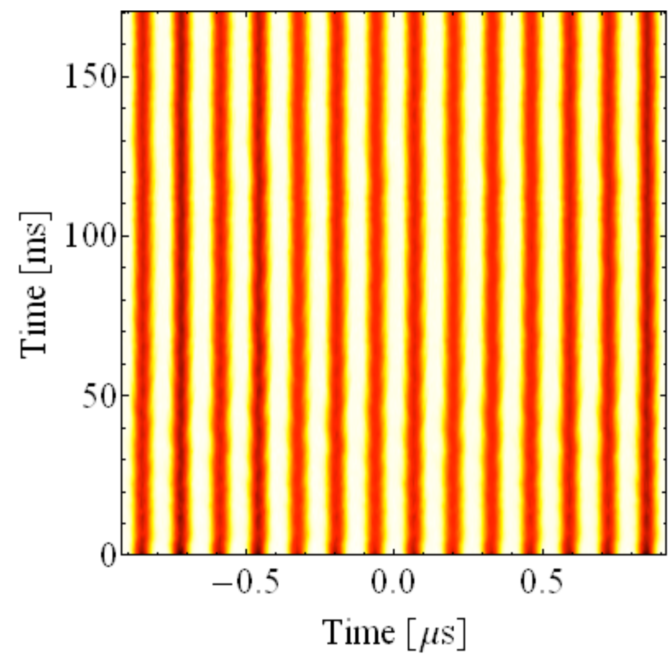
- First lesson learnt from MTE:

1 + 4 cavities open, $h = 16$



$N = 1.5 \cdot 10^{13}$ ppp

…and 4 tuned to $h = 6.5$



- Tuning unused cavities to a parking frequency reduces their impedance, even when the gap relay is closed
- Not implemented on LHC-type beams yet (needs re-shuffling of 10 MHz matrix) and minor hardware modification
- Improvement of stability on flat-top already observed with LHC25 beam (very first test)

Outlook

- **Fully use the lessons learnt with MTE to LHC beams**
  - **Detune all unused 10 MHz cavities to parking frequency**
  - **Evaluate benefits of a second gap relay per 10 MHz cavity**

  → **Expected improvement: Better stability on the flat-top**

- **Implement new 1-turn-delay feedback for 10 MHz cavities**

  → **Expected improvement: Better stability during acc. and flat-top**

- **Implement 1-turn delay (notch) feedback for 40/80 MHz cavities**

  → **Expected improvement: Better stability during acc. and flat-top**

- **Improve coupled-bunch feedback**
  - **Short-term: Variable gain for the existing electronics**
  - **Mid-term: New electronics based on development for 1-turn FB**
  - **Long-term: Wideband kicker cavity covering all modes?**

  → **Expected improvement: Better stability during acceleration**

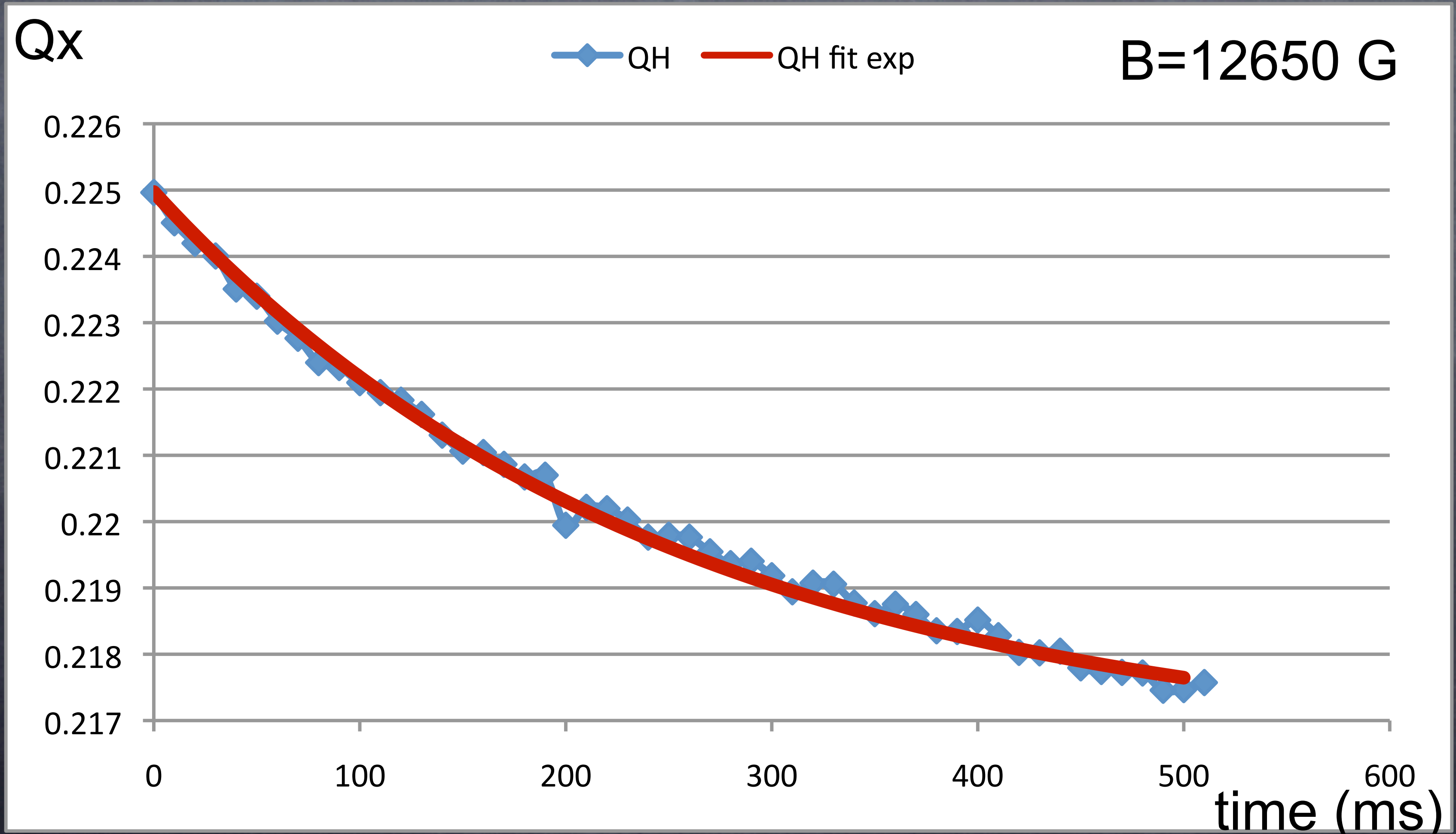
Other issues general to all beam which affect also MTE

Magnetic field at injection and B fluctuations

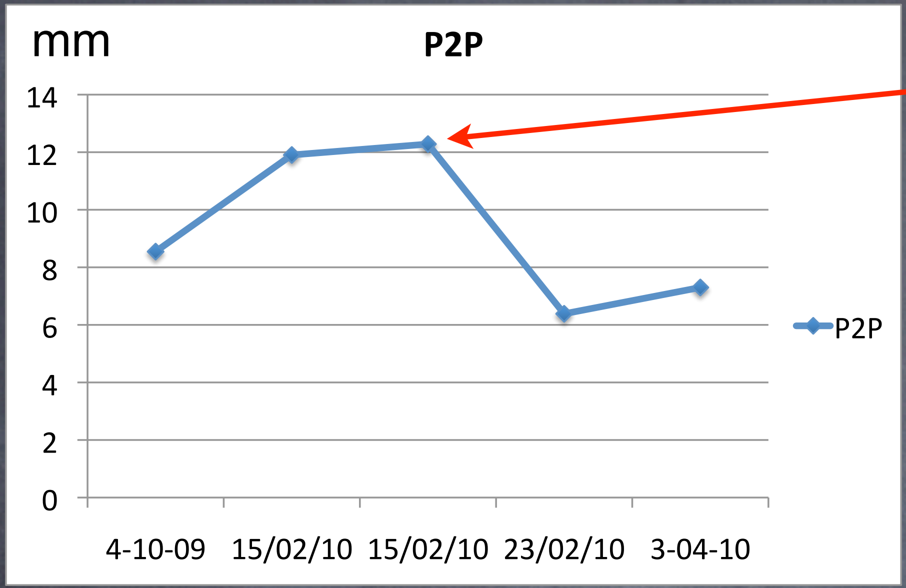
- Observations done already at the beginning of the run:
  - The beam radial position (MRP) at injection
    FOR THE SAME USER, was changing depending on previous user magnetic field.
    Large difference depending on the F8L powering on the previous cycle.
  - Variation of the MRP corresponding to a maximum variation of the B field of about 6 G (few mm, Bfield ~1013 G).
- B field variation detected by the MRP variation not detected by the peaking strip.
- SPS had to adjust regularly the field at injection for the CNGS/SFTPRO of about 2 G.
- **Impact on normal operation:**
  - larger losses at injection for high intensity beams due to different radial position
  - some doubts about the emittances of LHC-beams when multi-cycle SPS filling
- **Impact of MTE: energy modulation at extraction means different beam trajectories due to large islands dispersion.**
- Investigations ongoing with OP/MSC/PO

Tune drift during long flat top at different energy

- Tune data taken at different energies (magnetic fields) with stable conditions, i.e., fixed PFW+F8L and MRP.
- Source not understood, yet. Should check also the chromaticity
- **Impact on MTE: tune drift during resonance crossing/islands separation**



Orbit deformation during the year

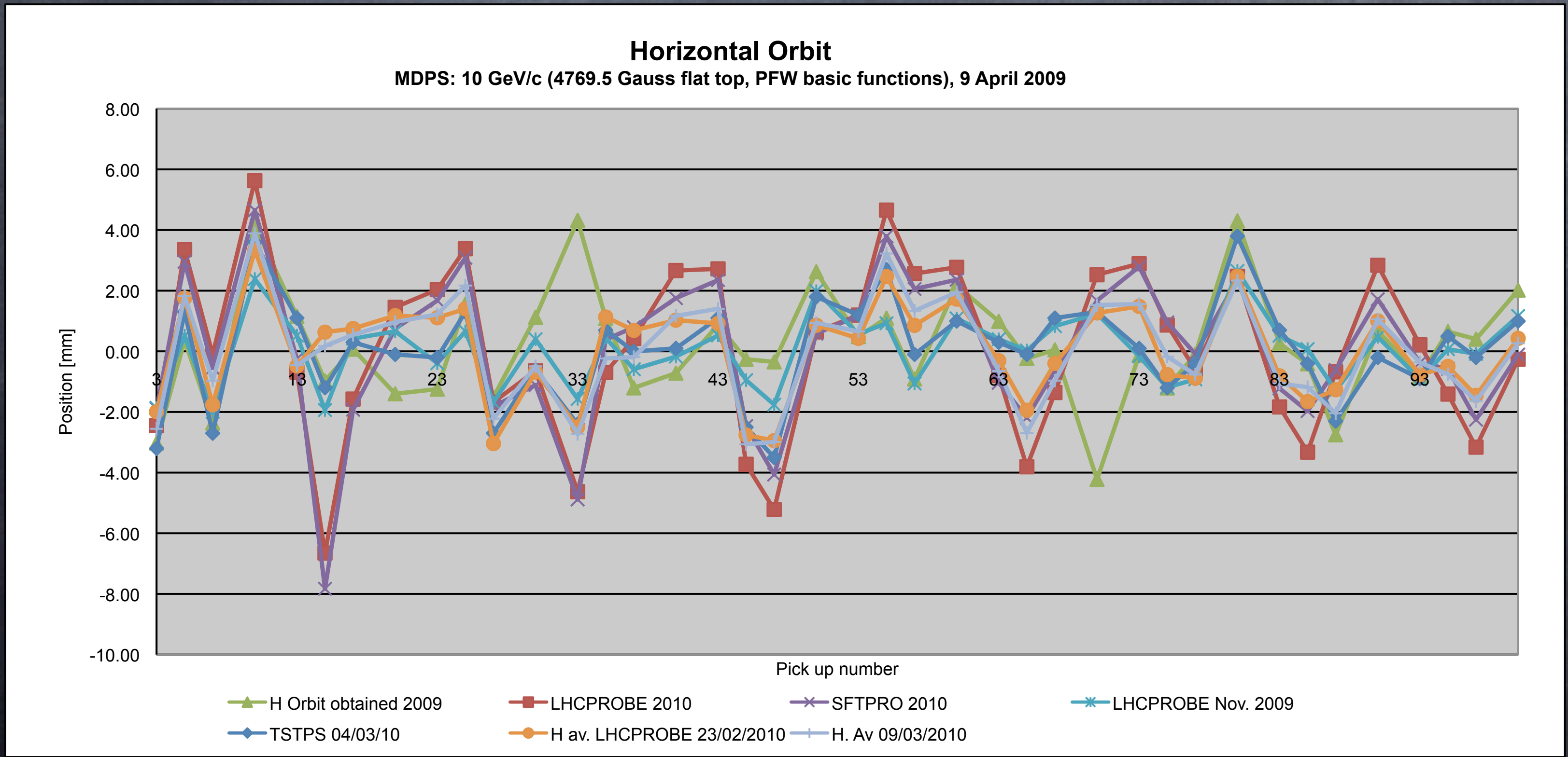


About the same two week ago

Orbit degradation observed wrt last year, disappeared and NOW reappeared

Clearly the magnetic field of the machine is changing

Impact on MTE: if orbit changes, different chromaticity and tune from magnetic feed-down



Program for next months

- Re-inject properly the beam in the SPS:
    - correct the trajectories to reduce losses
    - beam back to the CNGS target if possible
    - study new optics
- Continue investigation on spill instability:
    - cross the resonance from above
    - change the beam longitudinal structure if possible
- Investigate the general machine instabilities:
    - B-field, orbit, tune