Status and prospects for MTE

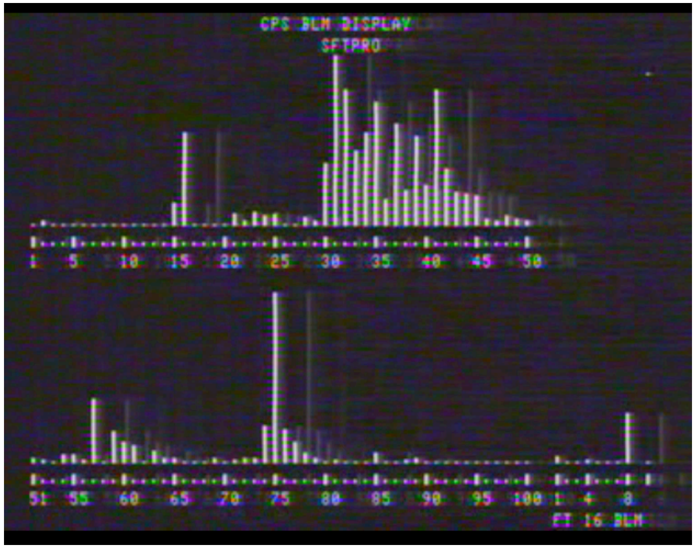
S. Gilardoni, M. Giovannozzi BE/ABP

Thanks to: G. Arduini, E. Benedetto, F. Blas,
M. Chanel, H. Damerau, A. Franchi*, E. Métral, G. Métral,
M. Newman, S. Baird, R. Brown, S. Damjanovic, T. Otto,
M. Widorski, N. Chohan, M. Lazzaroni, M. Poehler,
Transport services, ABT and OP (PS and SPS)

*Now at ESRF

Brief introduction to PS-SPS transfer

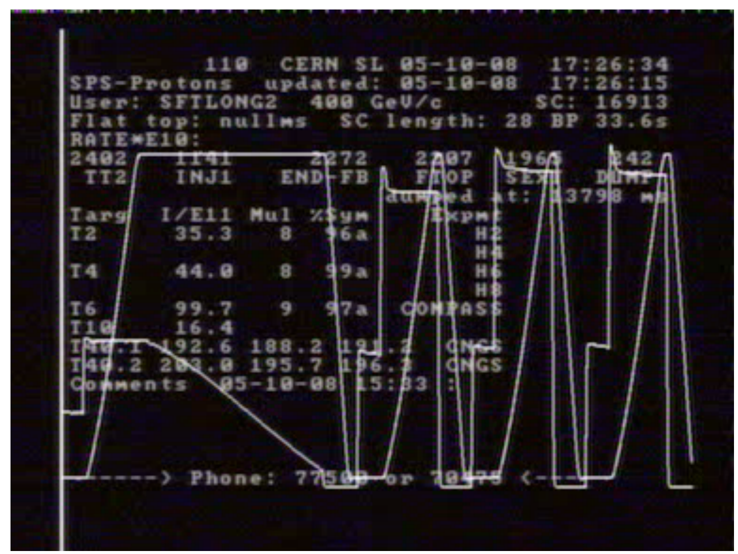
PS Beam loss monitors

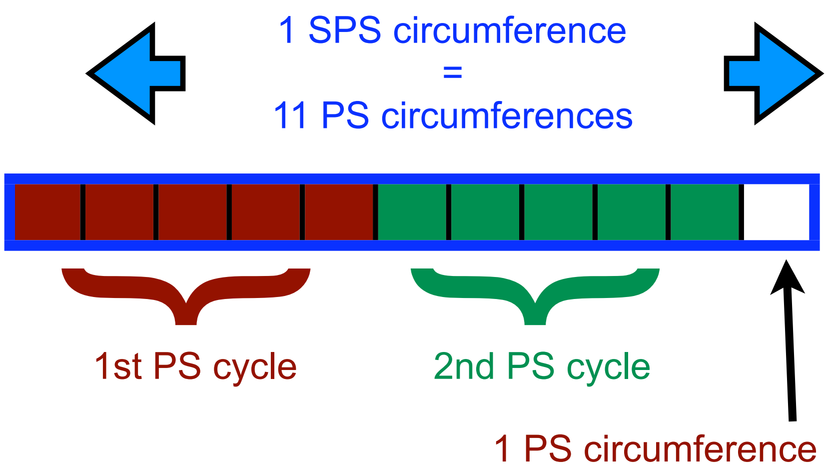


PS cycle

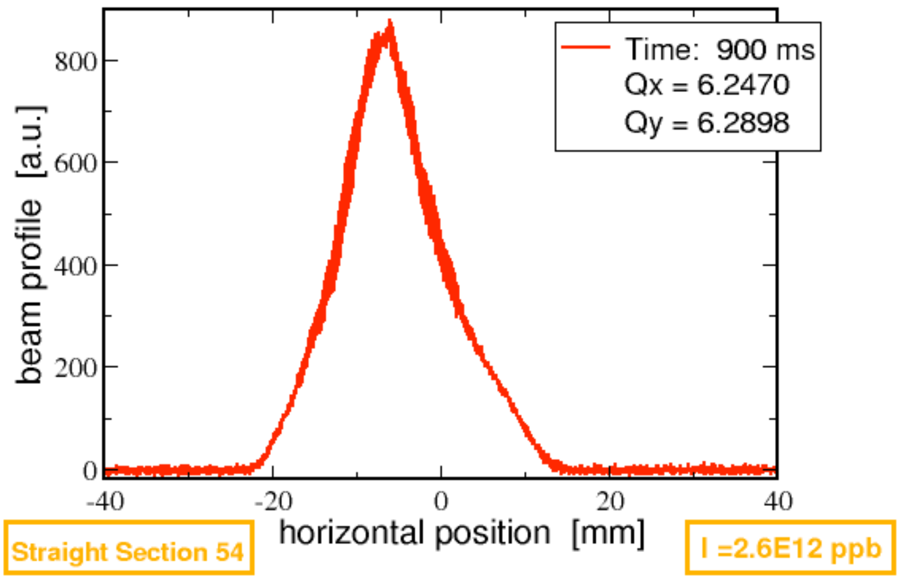
Beam for fixed target physics (CNGS)
at the SPS are extracted from the PS at 14 GeV/c
during five turns repeated on two cycles
with large losses in the PS

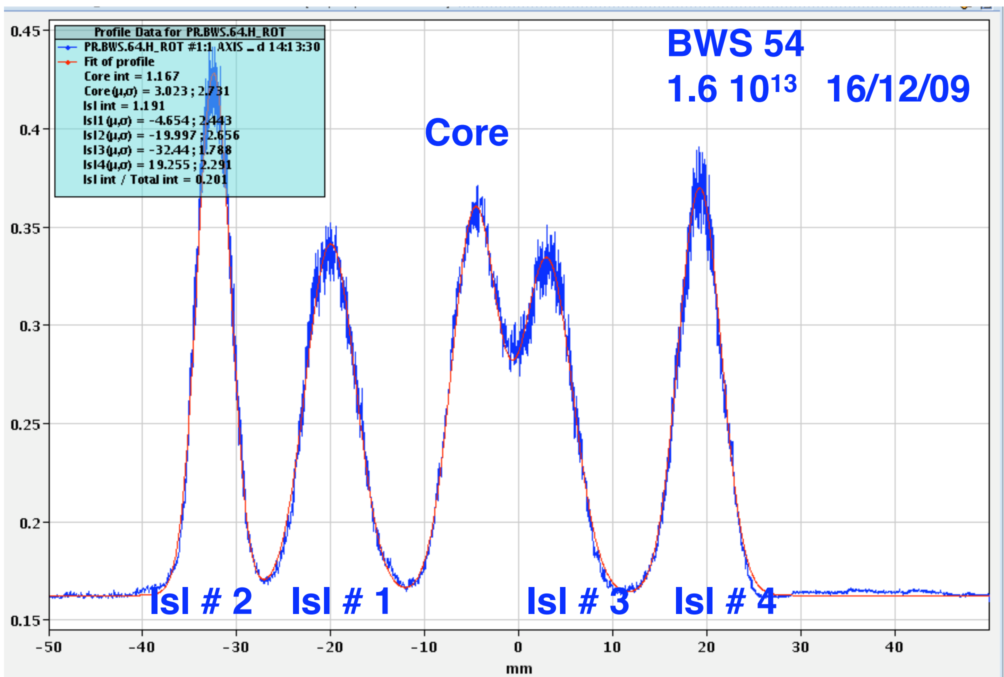
SPS cycle



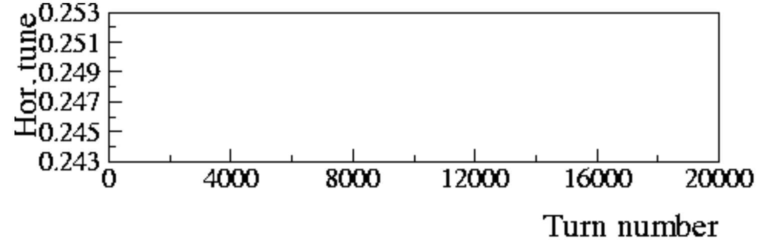


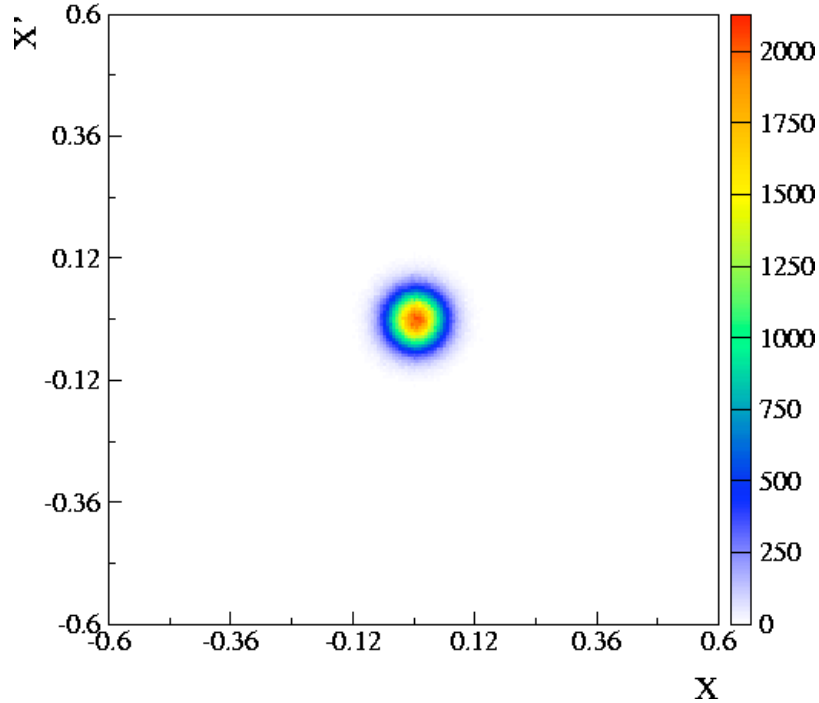
PS Multi-Turn Extraction experiment, 20-11-2006
Depleting the beam core via unstable resonance excitation





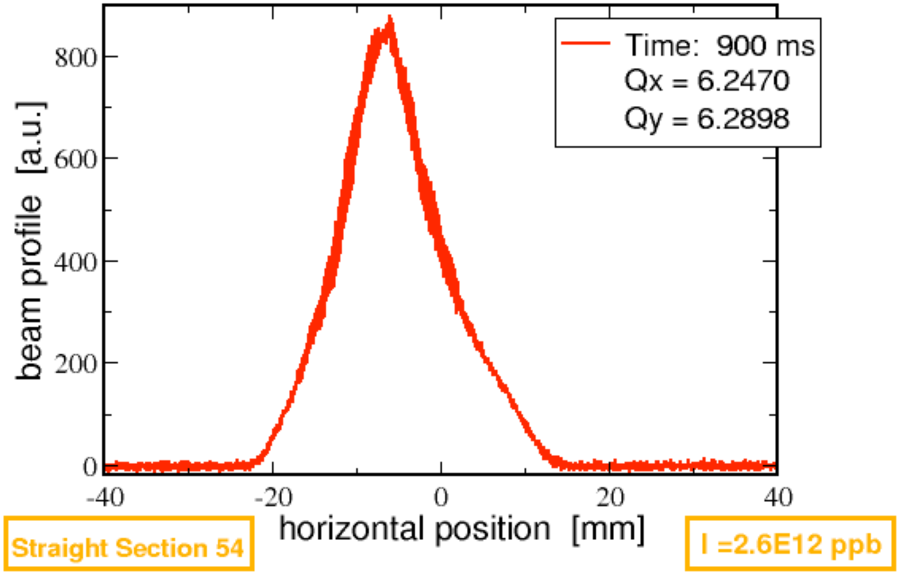
MTE: Multi-Turn extraction

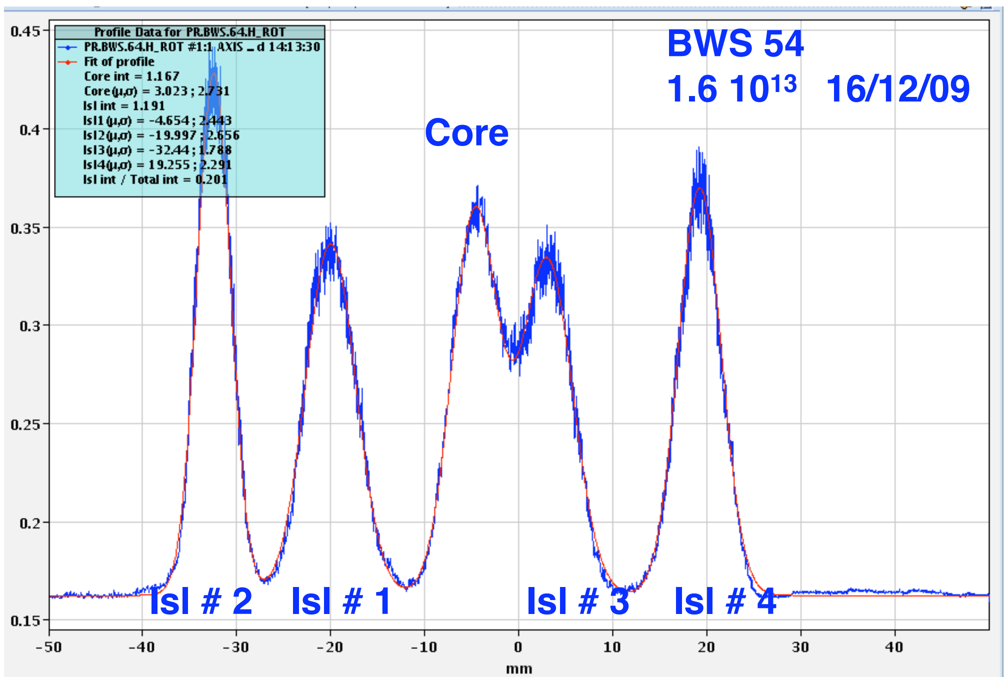


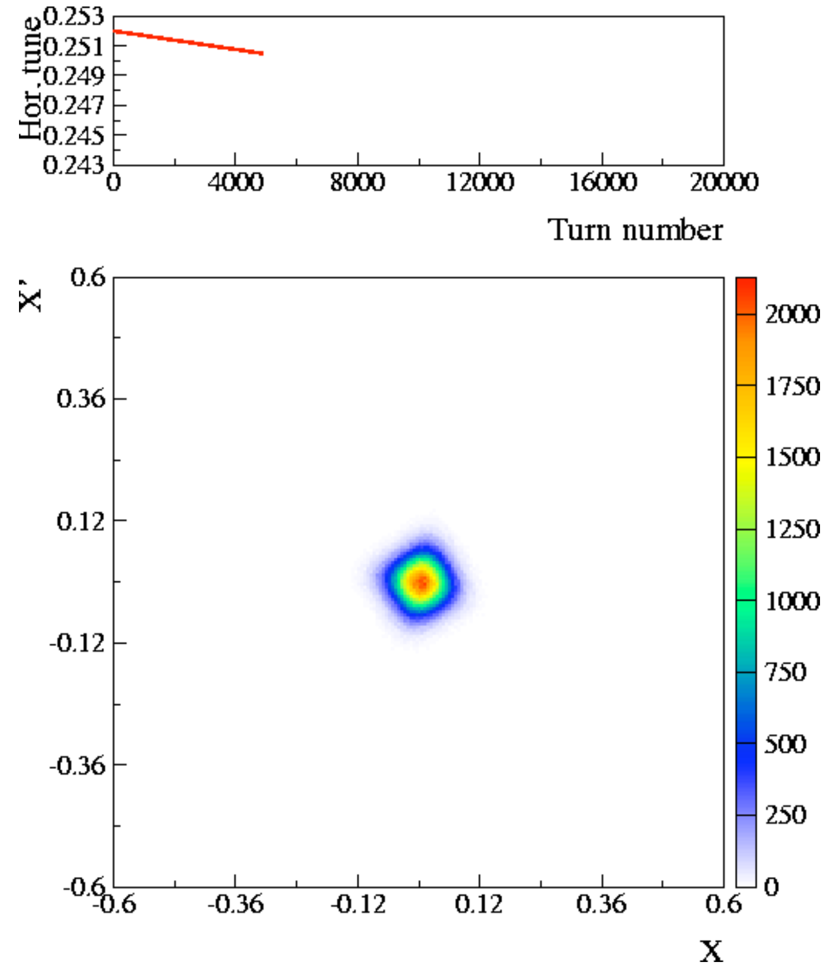


PS Multi-Turn Extraction experiment, 20-11-2006
Depleting the beam core via unstable resonance excitation

MTE: Multi-Turn extraction

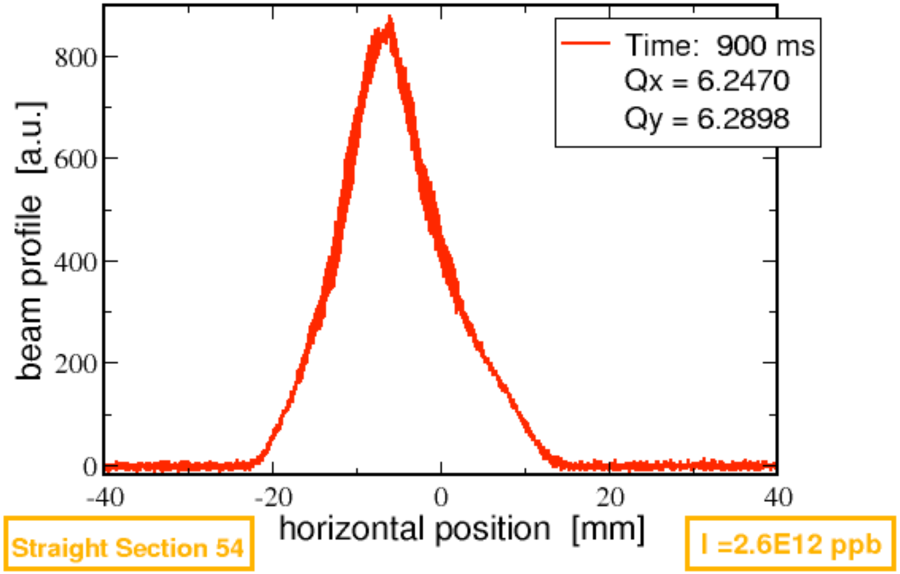


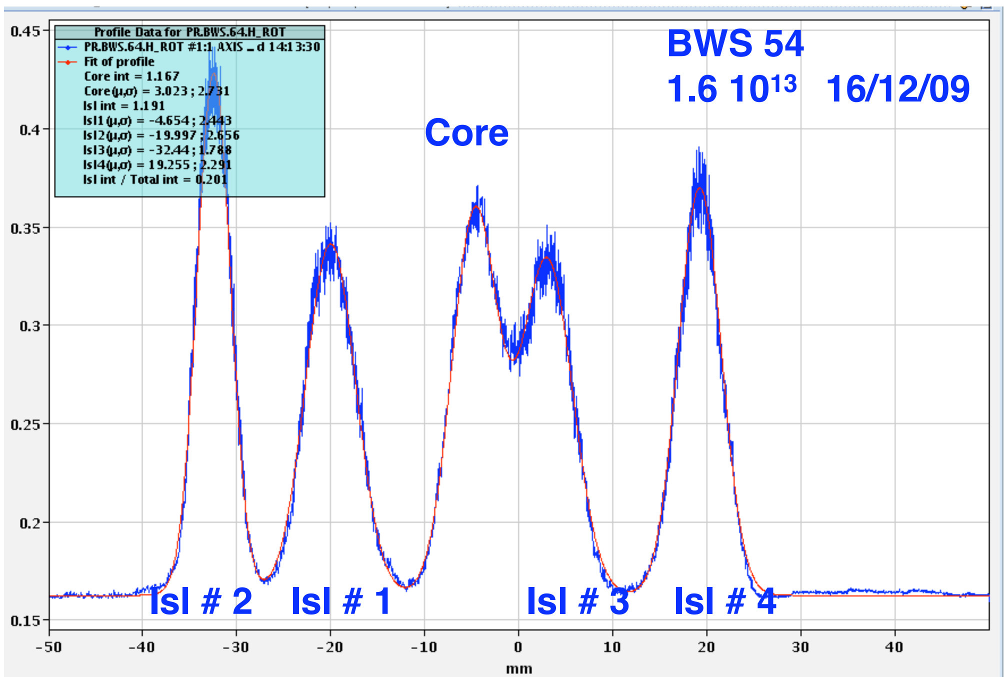




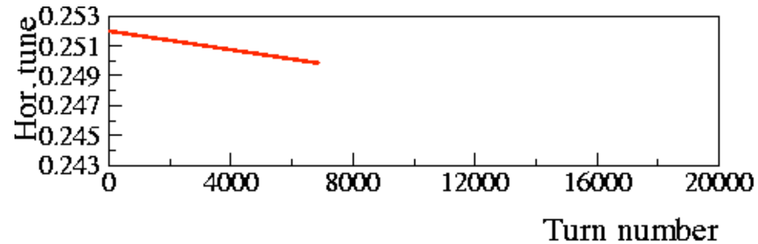
PS Multi-Turn Extraction experiment, 20-11-2006

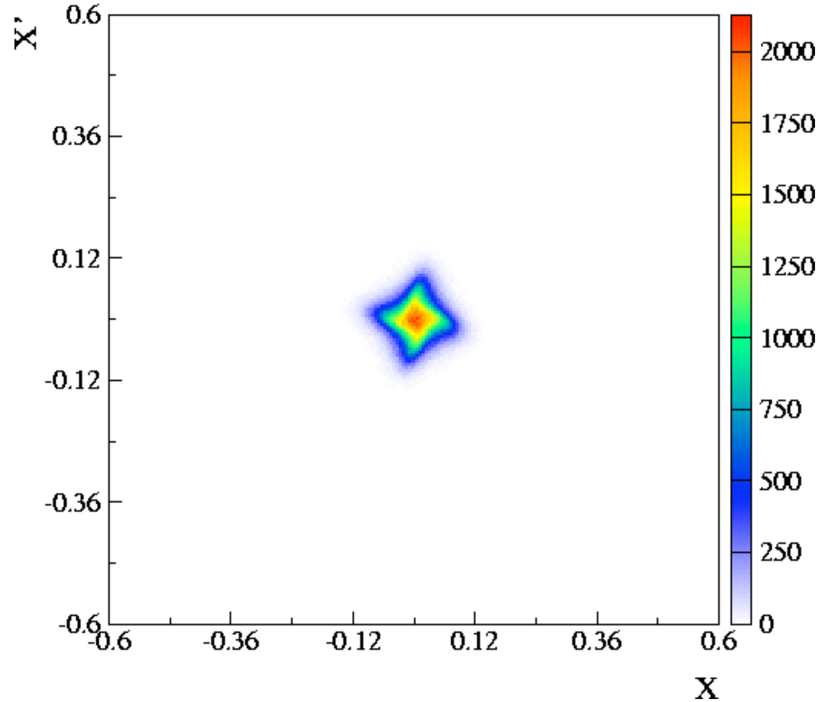
Depleting the beam core via unstable resonance excitation



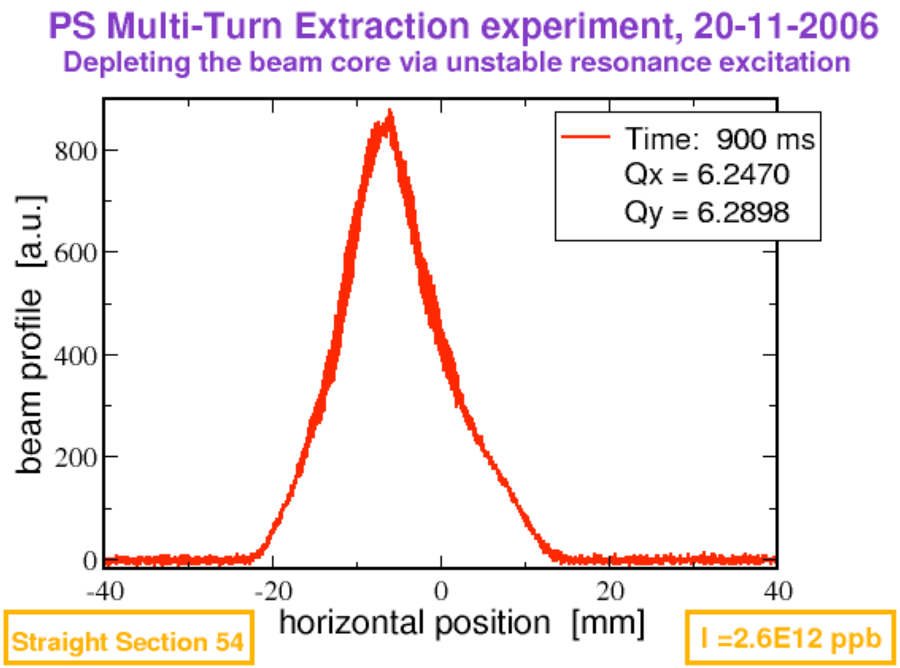


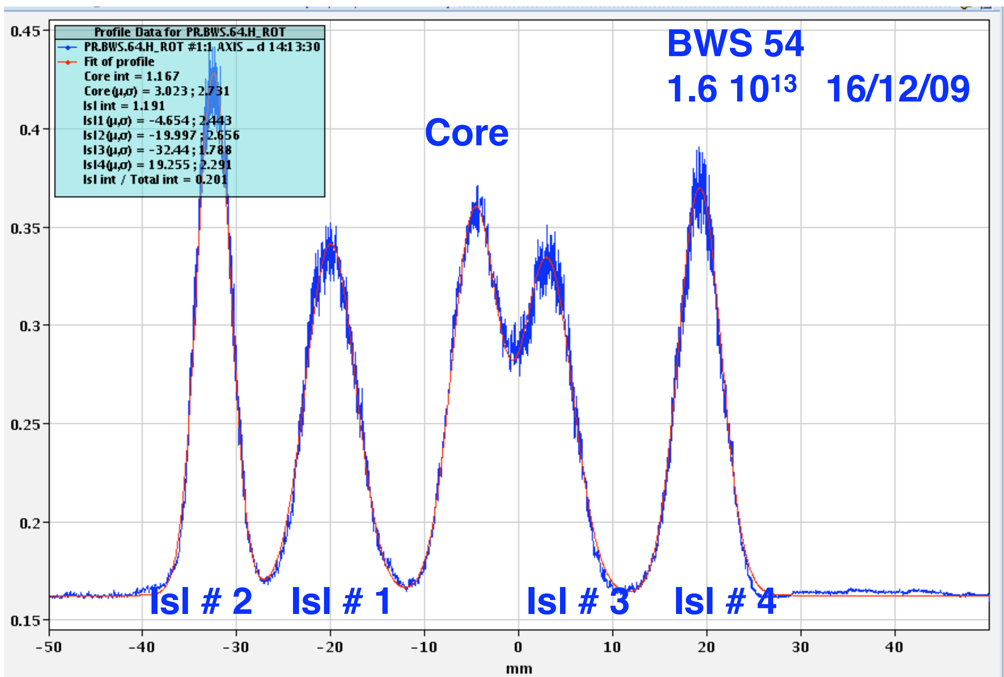
MTE: Multi-Turn extraction

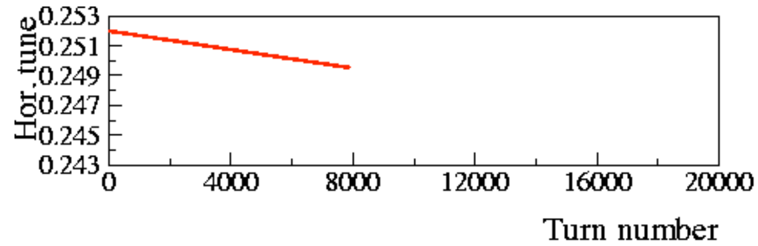


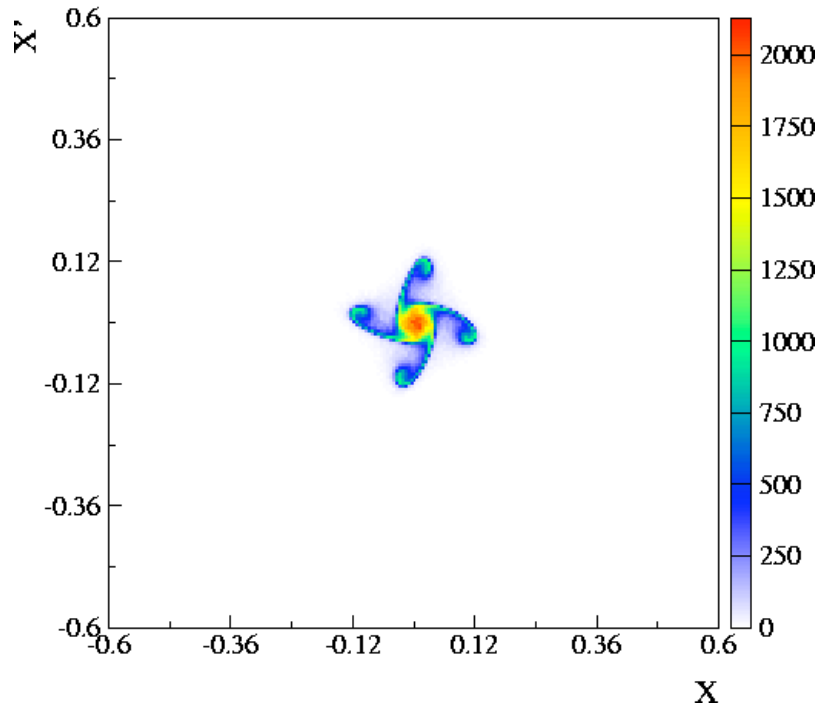


MTE: Multi-Turn extraction



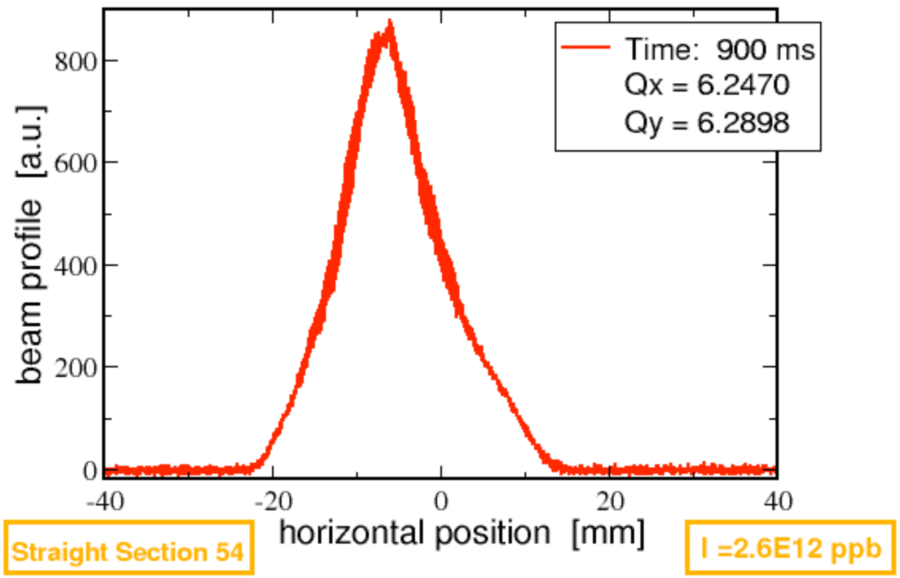


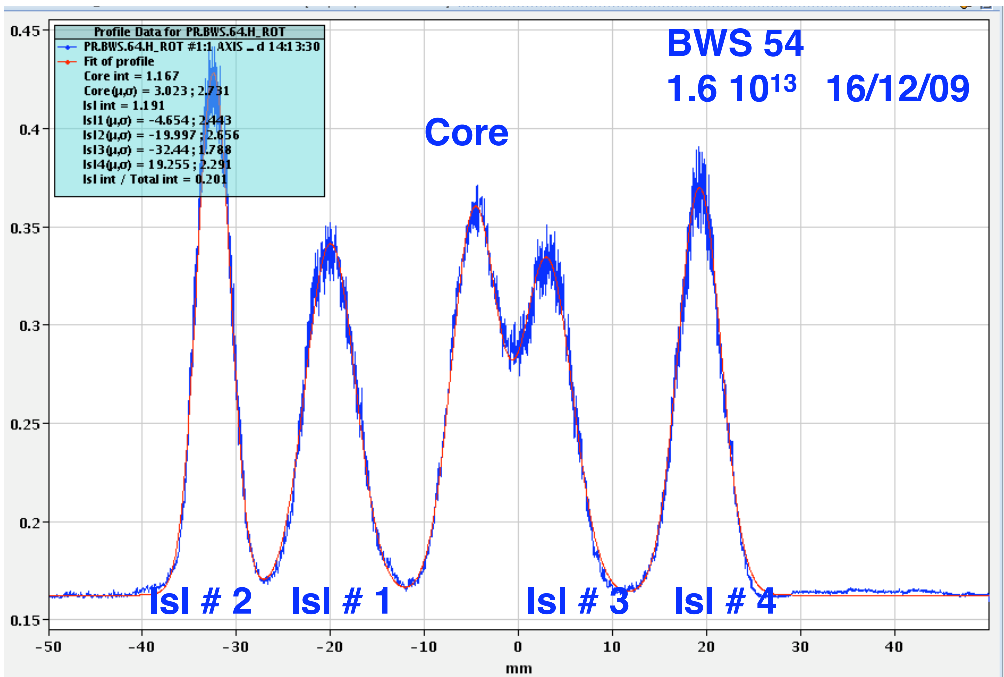


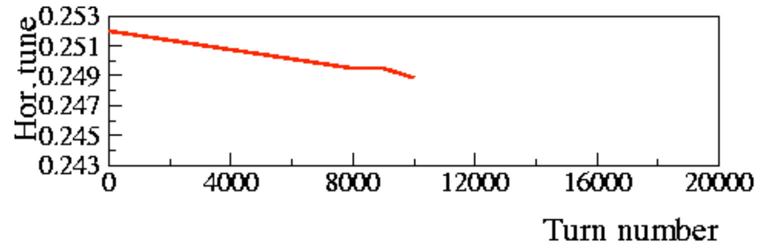


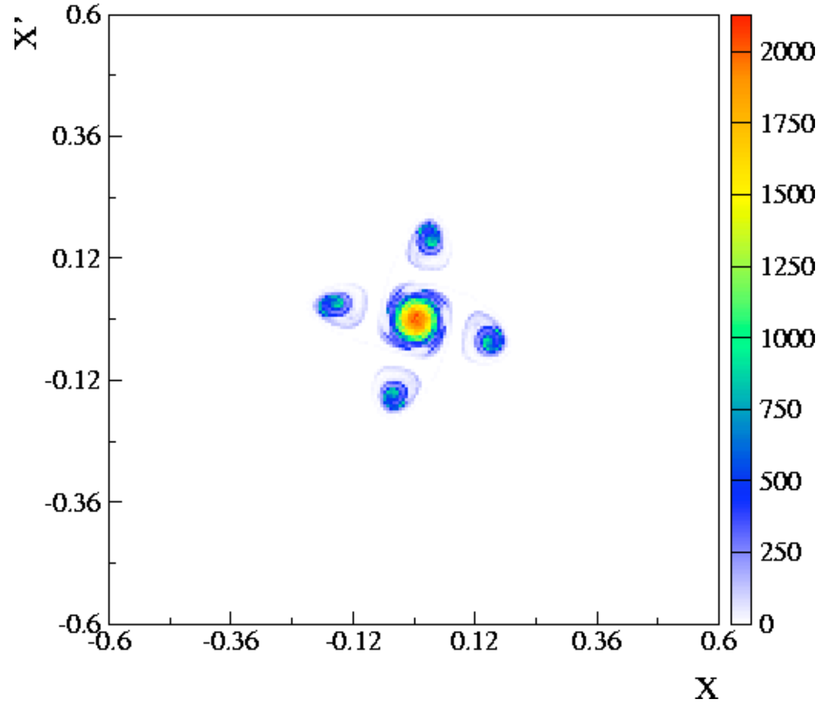
MTE: Multi-Turn extraction

PS Multi-Turn Extraction experiment, 20-11-2006
Depleting the beam core via unstable resonance excitation

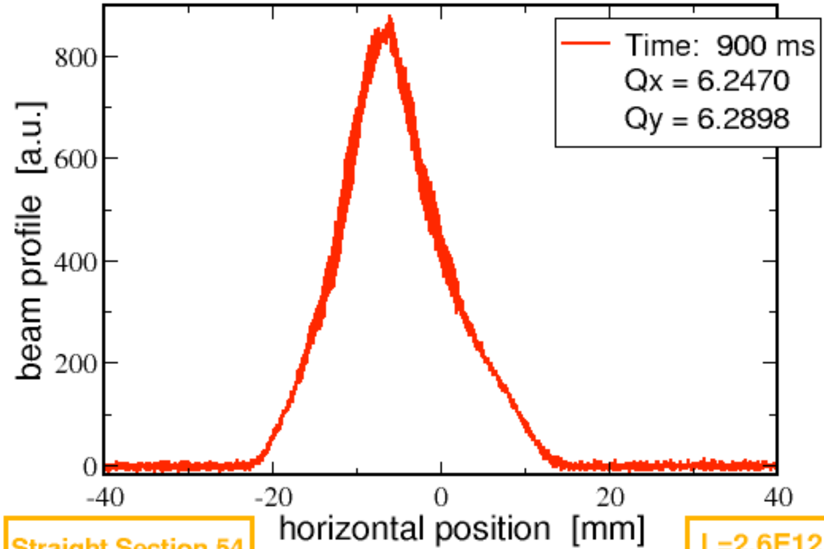


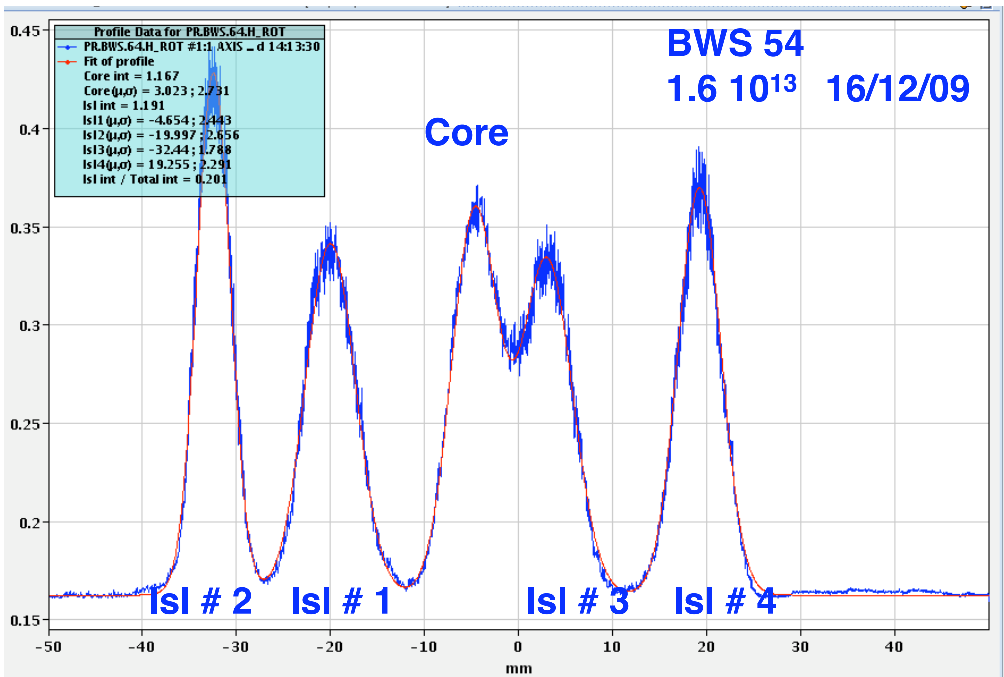




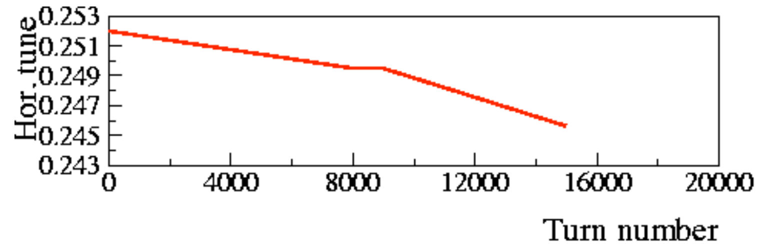


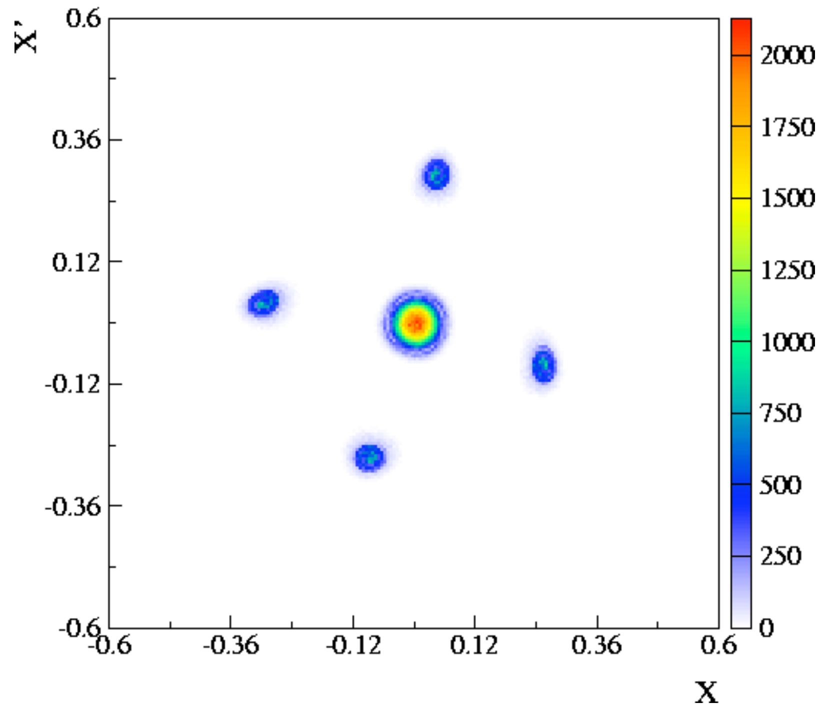
PS Multi-Turn Extraction experiment, 20-11-2006
Depleting the beam core via unstable resonance excitation





MTE: Multi-Turn extraction



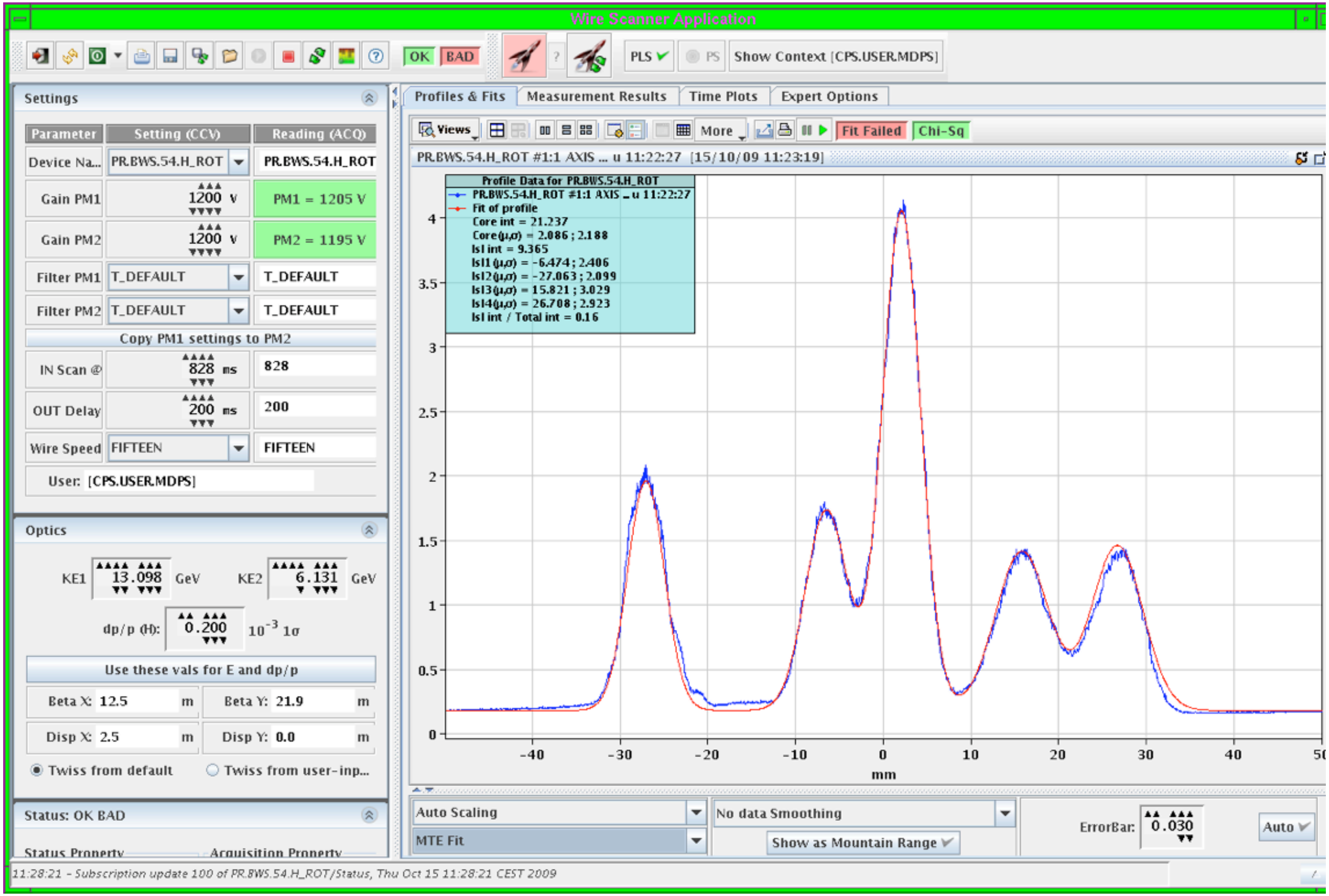


2009 Commissioning phases

- Capture resumed on de-bunched beam in early May
  - first capture with low intensity, about 300e10 p
  - capture efficiency about 14%
- First optimisation of non-linear elements, working point, radial position
  - capture efficiency about 15%
  - full instrumentation available in June-July
- Intensity increased up to 1000e10
  - correction of the drift of the radial position
- Intensity increase to 1600e10
  - First beam to the SPS delivered by the end of August. Beam extracted to the CNGS target to contribute, whenever possible, to the CNGS integrated intensity.
  - First measurements/adjustment of injection trajectories and first attempt to measure optics matching.
- Intensity increased up to 1900e10 in September
  - Correction of the non-linear coupling lead to 17% of capture efficiency
  - Intensity limited to 1500e10 to avoid large losses in the SPS due to the large population of the core
  - Found a microwave instability causing distortion of the momentum distribution
- Last day of operation
  - Capture with bunched beam, de-bunched just prior to extraction.
  - Transverse feed back excitation to reach the 20%.

1.9e13 extracted with normal losses (2-3%)

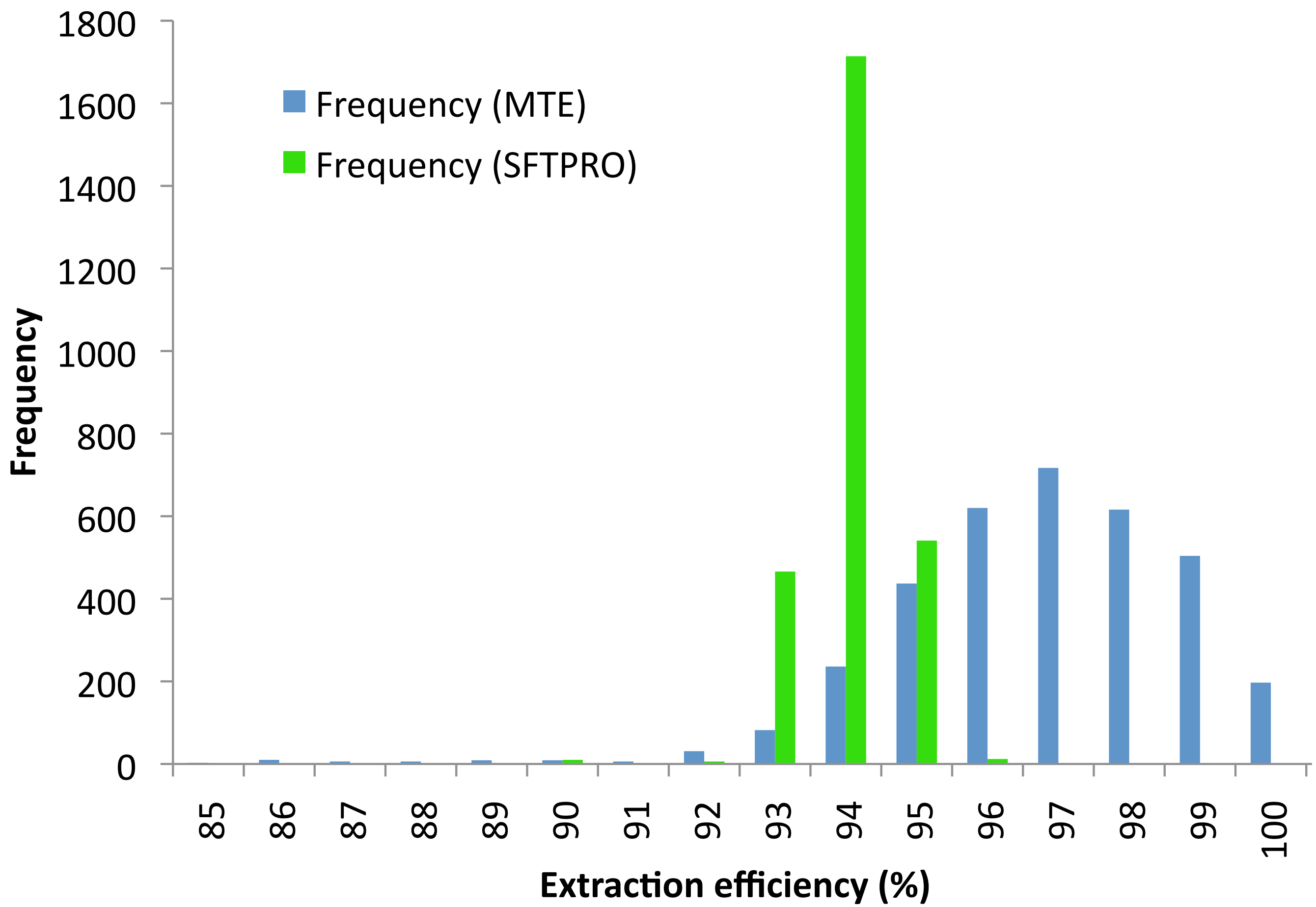
- Intensity increased up 1.9e13 when capture still at 16-17%
- No particular problem observed, apart the necessary adjustment of the extraction bump



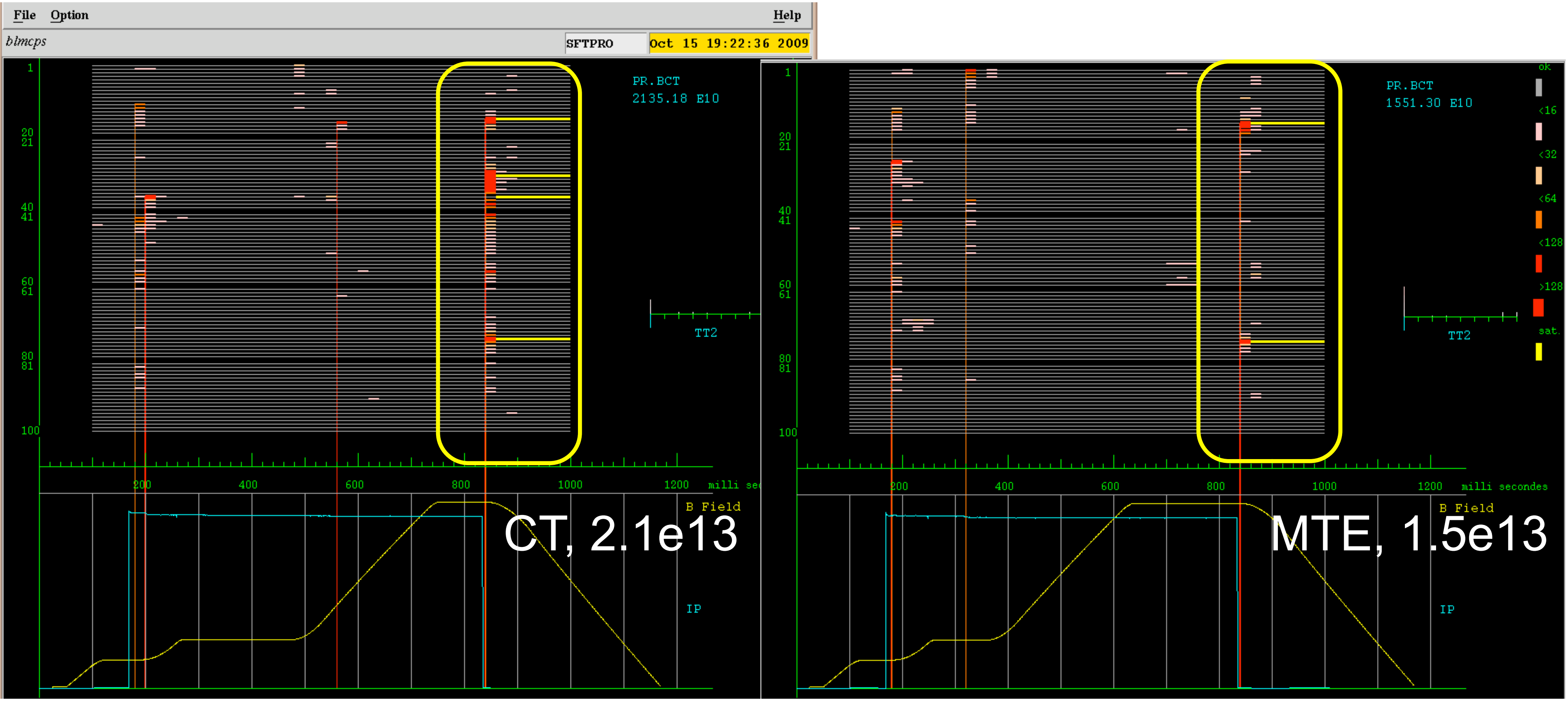
Comparison of extraction losses/efficiencies wrt CT

- Comparison of extraction efficiency between SFTPRO and MTE at 1.6e10^{13}
- Confirmed expected MTE extraction efficiency around 97%.
  Extraction efficiency fluctuations, due probably to longitudinal microwave instability.

  Extraction efficiency on average better than the CT extraction.



Extraction loss pattern



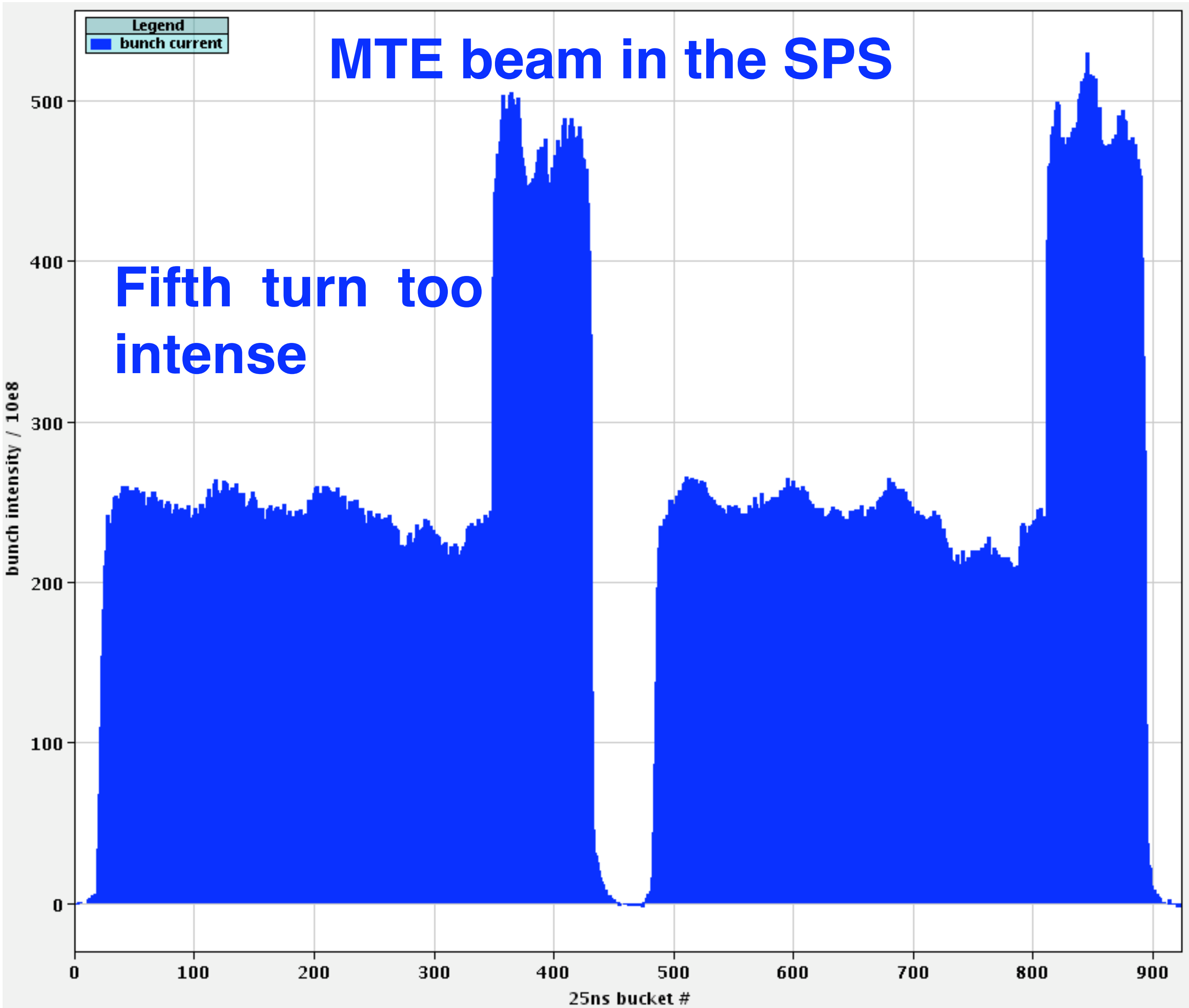
- As expected, MTE losses limited to the extraction septum instead of all around the ring as for the CT
  - kicker rise time + debunched → beam loss pattern will not change by increasing the intensity
  - losses in SS75 to be further studied
  - **with MTE no losses in the injection region,i.e., under route Goward**

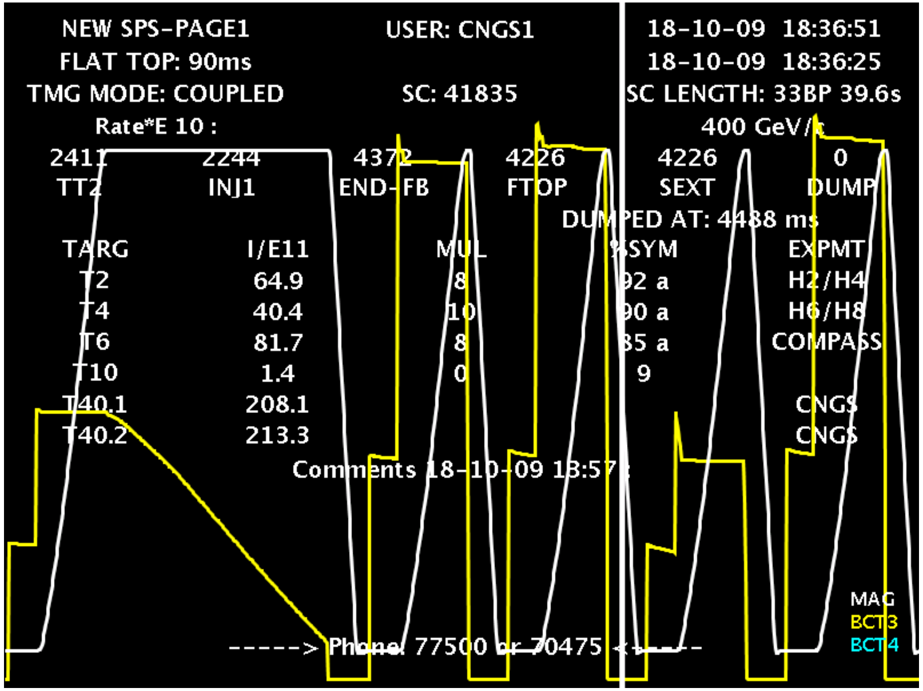
Beam delivered to the SPS on regular basis

Beam delivered on regular basis to the SPS.

Losses during acceleration due to the intensity of the core.

RF setting up optimised, since the peak intensity was corresponding to the CNGS peak intensity





CNGS Larger

Former teletext 111

User: CNGS1

18-Oct-2009 18:37:32

Last update: 1 secs ago

TT2	TT10	%LOSS	INJ	%LOSS
2421	2388	1.4	2257	5.5
2428	2399	1.2	2236	6.8

	I/E10	%LOSS	%TRNS	TIME/ms
INJECT	4493	6.1	94	1210
END FB	4411	1.8	98	1260
20 GeV/c	4333	1.8	96	1470
27 GeV/c	4281	1.2	95	1530
50 GeV/c	4271	0.2	95	1740
400 GeV/c	4243	0.7	94	4200

LOSS @ FB: 2.5%

SFTLONG Larger

Former teletext 113

User: SFTLONG1

18-Oct-2009 18:38:00

Last update: 1 secs ago

TT2	TT10	%LOSS	INJ	%LOSS
1423	1400	1.6	1307	6.6
1414	1395	1.3	1293	7.3

	I/E10	%LOSS	%TRNS	TIME/ms
INJECT	2599	7.0	93	1220
END FB	2585	0.5	99	1260
20 GeV/c	2560	1.0	98	1470
27 GeV/c	2552	0.3	98	1530
50 GeV/c	2550	0.1	98	1740
400 GeV/c	2550	0.0	98	4200

LOSS @ FB: 0.7% LOSS T.L. 17.2

CNGS Larger

Former teletext 111

User: CNGS2

18-Oct-2009 18:38:17

Last update: 0 secs ago

TT2	TT10	%LOSS	INJ	%LOSS
1501	1481	1.3	1340	9.5
1553	1529	1.6	1408	7.9

	I/E10	%LOSS	%TRNS	TIME/ms
INJECT	2749	8.7	91	1210
END FB	2587	5.9	94	1260
20 GeV/c	2285	11.6	83	1470
27 GeV/c	2171	5.0	79	1530
50 GeV/c	2171	0.0	79	1740
400 GeV/c	2168	0.1	79	4200

LOSS @ FB: 6.4%

Beam delivered to the SPS on regular basis - II

- Beam transmission could be improved up to a peak of 94%, more stable settings were giving more ~ 90% transmission (~ 10% gain wrt to the first setting up).

- Clearly the spill modulation was the cause of the losses.

TT10 Top	TT10 Bottom	%Loss	Inj
1,558.5	1,534.7	1.5	1,482.9
1,562.8	1,539.3	1.5	1,440.1

Marker	Energy	Time/ms	Intensity/E10	%Lost	%Trans
Total Inj.	14GeV/c	1210	2922.9978	4.9	95.1
BEF_INJ2	14GeV/c	1180	1,443.3	2.7%	97.3%
END_FB	14GeV/c	1260	2,864.3	2%	98%
FR_PORCH	20GeV/c	1470	2,834.2	1.1%	97%
TRANS	27GeV/c	1530	2,789.8	1.6%	95.4%
RAMP	50GeV/c	1740	2,772.3	0.6%	94.8%
START_FT	400GeV/c	4200	2,766	0.2%	94.6%

2.766e13

94.6%

Open issue until December: fraction of trapped particles

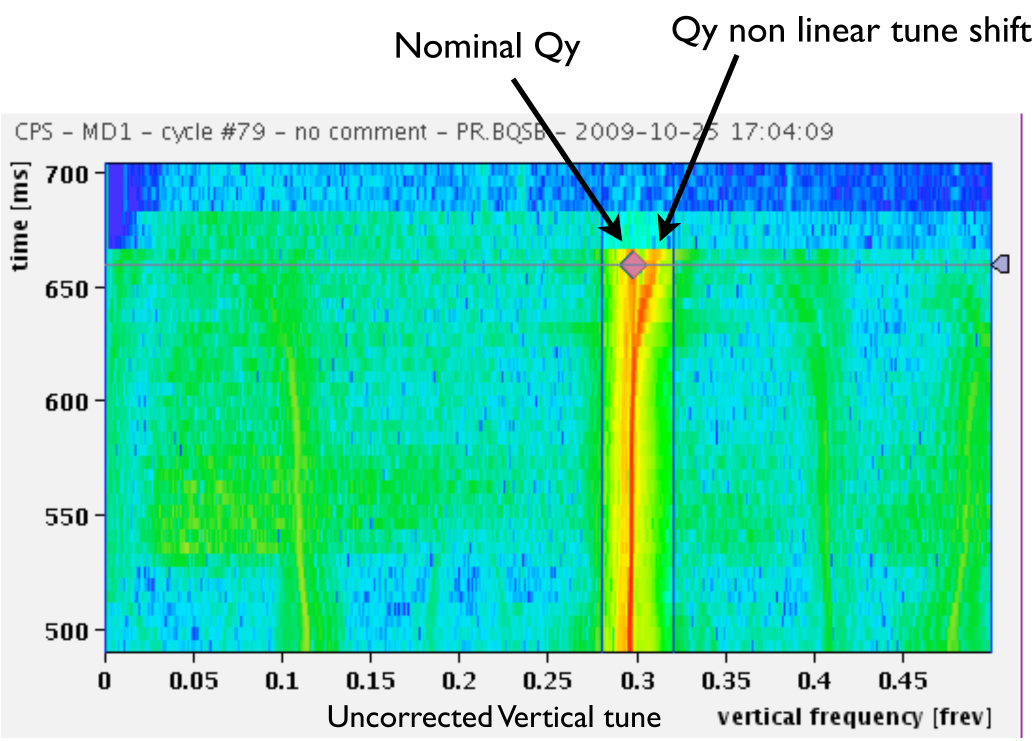
- Optimisation of various parameters done:
  - tune variation vs time
  - octupole and sextupole functions
- Coupling (linear or non-linear) between degrees of freedom could explain the lower-than-nominal fraction of particles trapped.
  - Hor./Ver. non-linear coupling.
  - it is generated by the octupoles used for the islands' creation.
  - It can be corrected using the extra octupole family present in the PS.
  - Tested successfully and used to achieve about 17% sharing.
- Hor./Longitudinal non-linear coupling (Q'').
  - It is also generated by the octupoles use for the islands' creation.
  - It cannot be corrected in the PS.
  - As the coupling term is of the form $\frac{1}{2} Q'' (\Delta p/p)^2$, the only solution consists of minimising $\Delta p/p$.

Non-linear coupling inducing a tune shift.

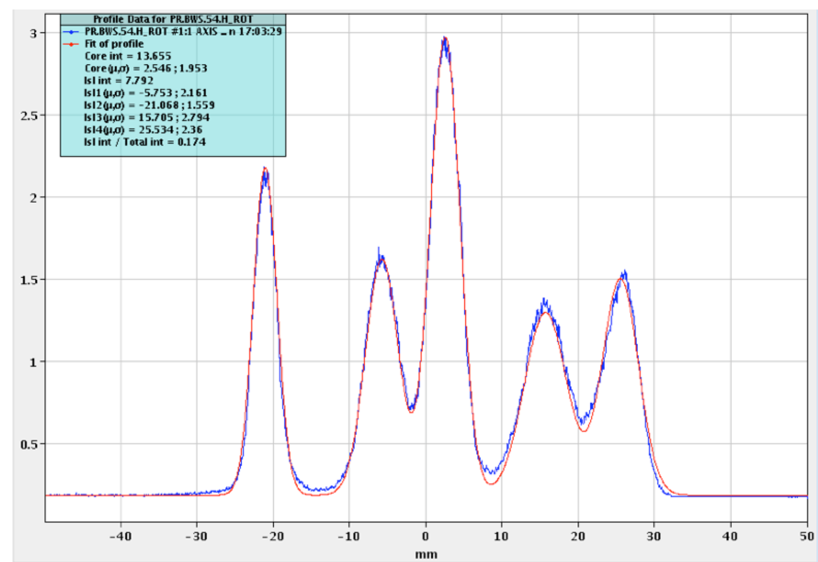
Due to the presence of non-linear fields (octupoles and sextupoles) two particles with different vertical position have a different horizontal tune (or a different horizontal position generates a different vertical tune) → particles with wrong horizontal tune are not captured

from octupoles
$$\Delta Q_x = \sum_i \frac{K_{3,i}}{8} \beta_{x,i} \beta_{y,i}$$

from one sextupole
$$\Delta Q_x = \frac{1}{32} K_2^2 \beta_x \beta_y \left(2\beta_x \cot\frac{\omega_1}{2} + \beta_y \cot\left(\frac{\omega_1}{2} - \omega_2\right) - \beta_y \cot\left(\frac{\omega_1}{2} + \omega_2\right)\right)$$

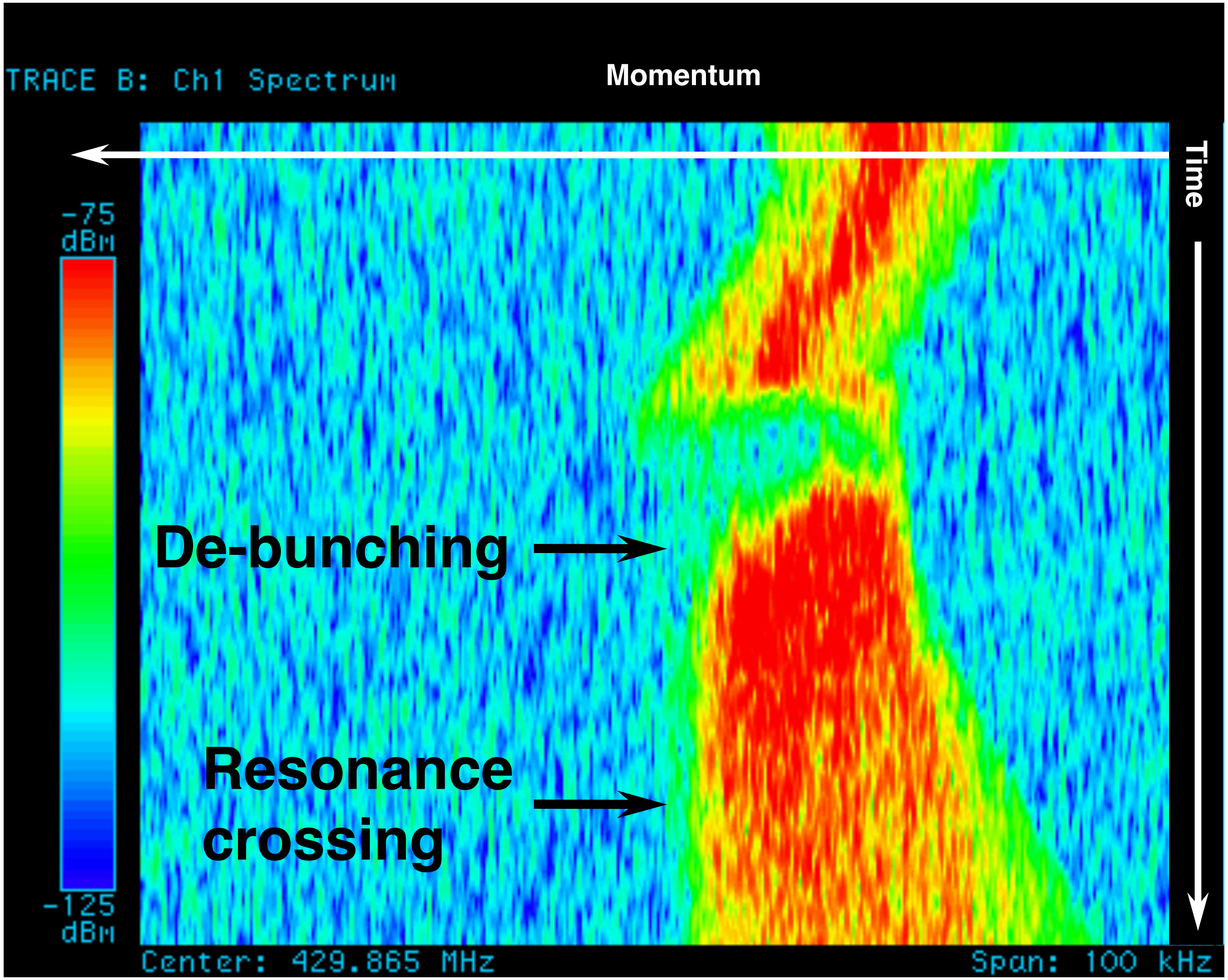


The tune shift can be computed and corrected by an extra family of octupoles
→ increase the capture efficiency to about 17%.



Longitudinal instability: Schottky signal

Microwave instability for a MTE beam de-bunched before transverse splitting (1.7×10^{13} p) observed in November



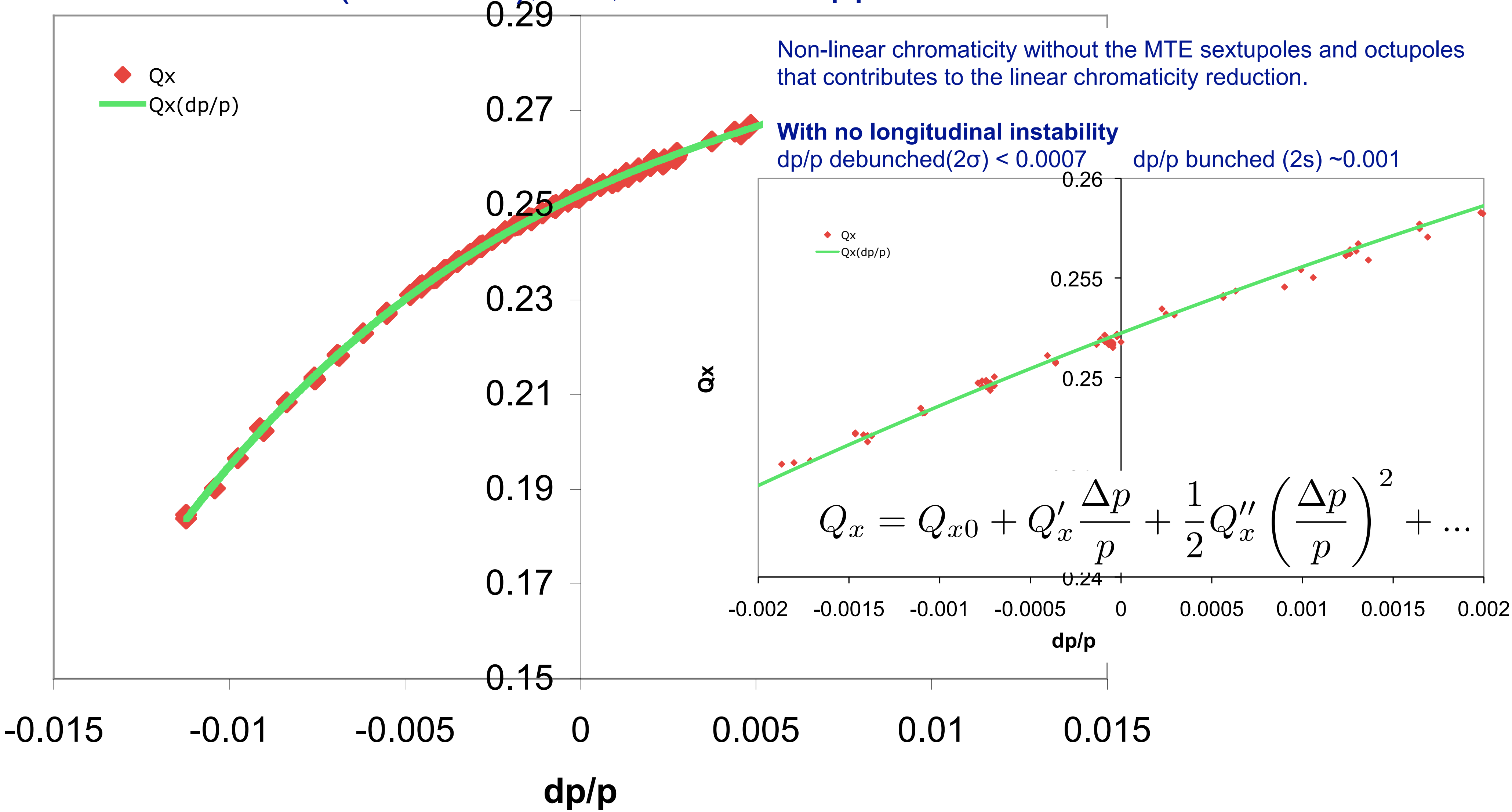
After debunching a fraction of the beam looses energy due to the coupling with the longitudinal impedance.

Not crossing the resonance due to non linear-chromaticiy

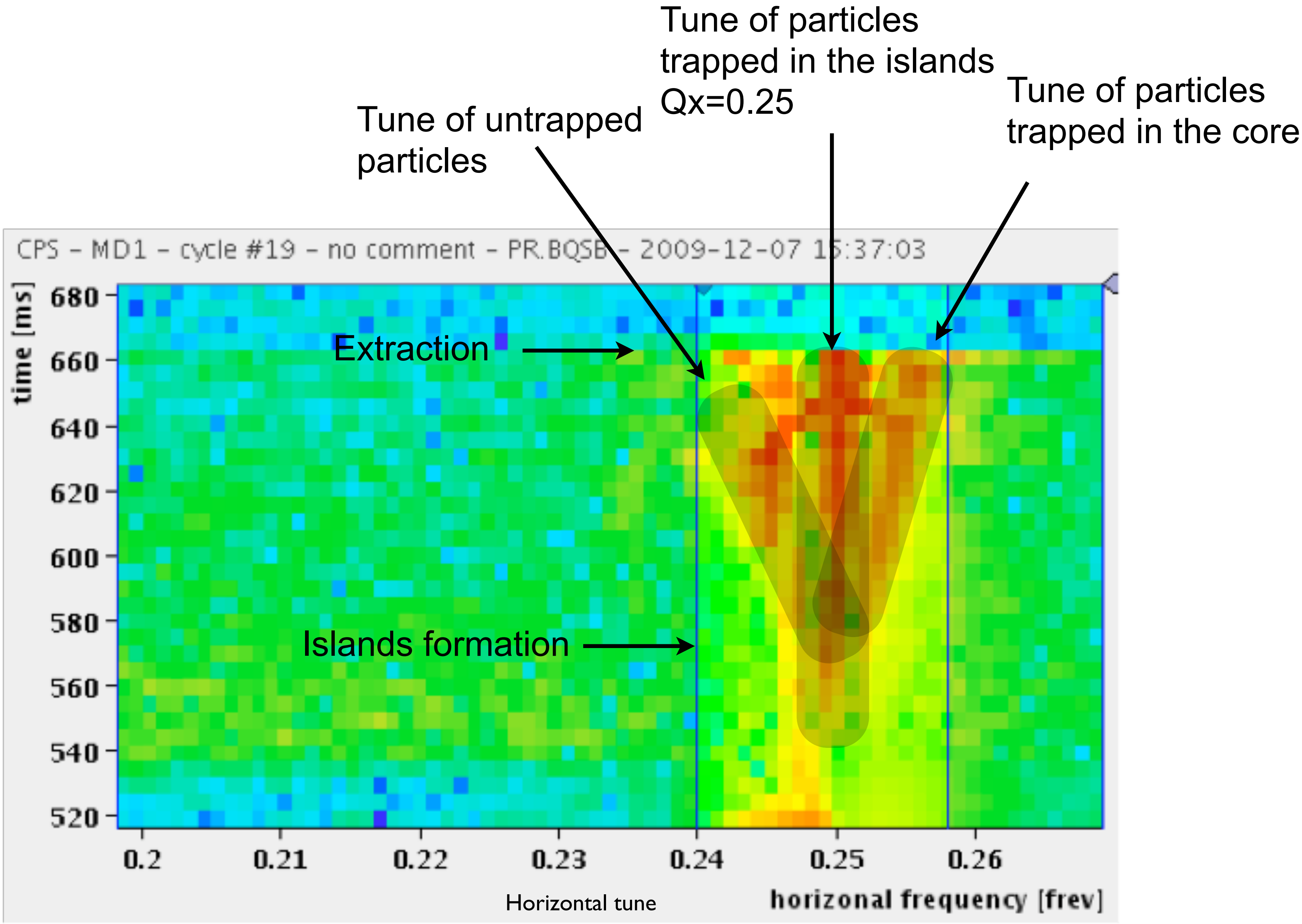
Not possible to determine the fraction of particles from Schottky meas.

Particle with wrong momentum do not cross the resonance

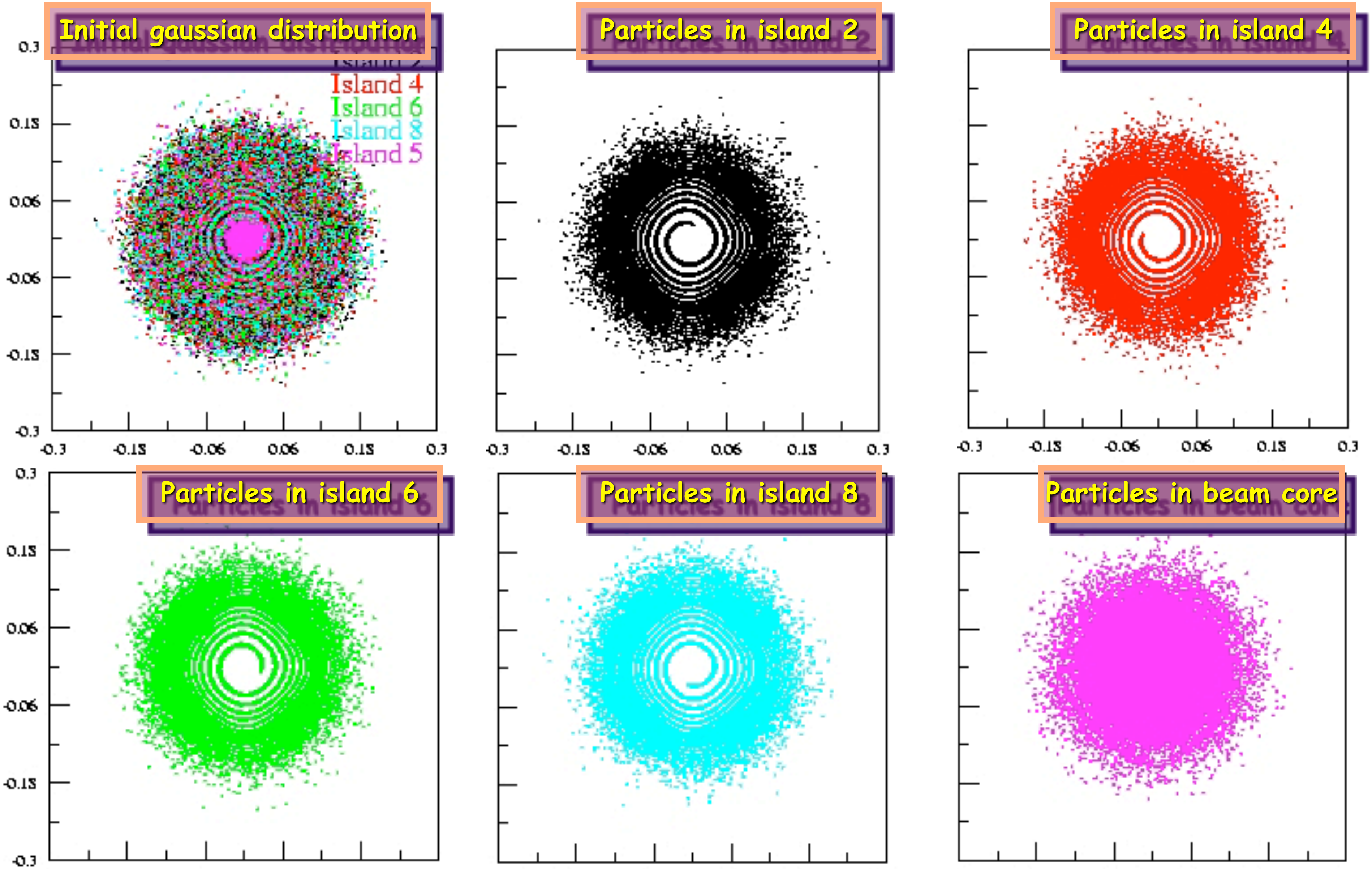
Particles with too small momentum have always a tune too low to cross the resonance (Qx=0.25), i.e., are not trapped in the islands



Horizontal tune analysis



Particles with too small amplitude are not captured

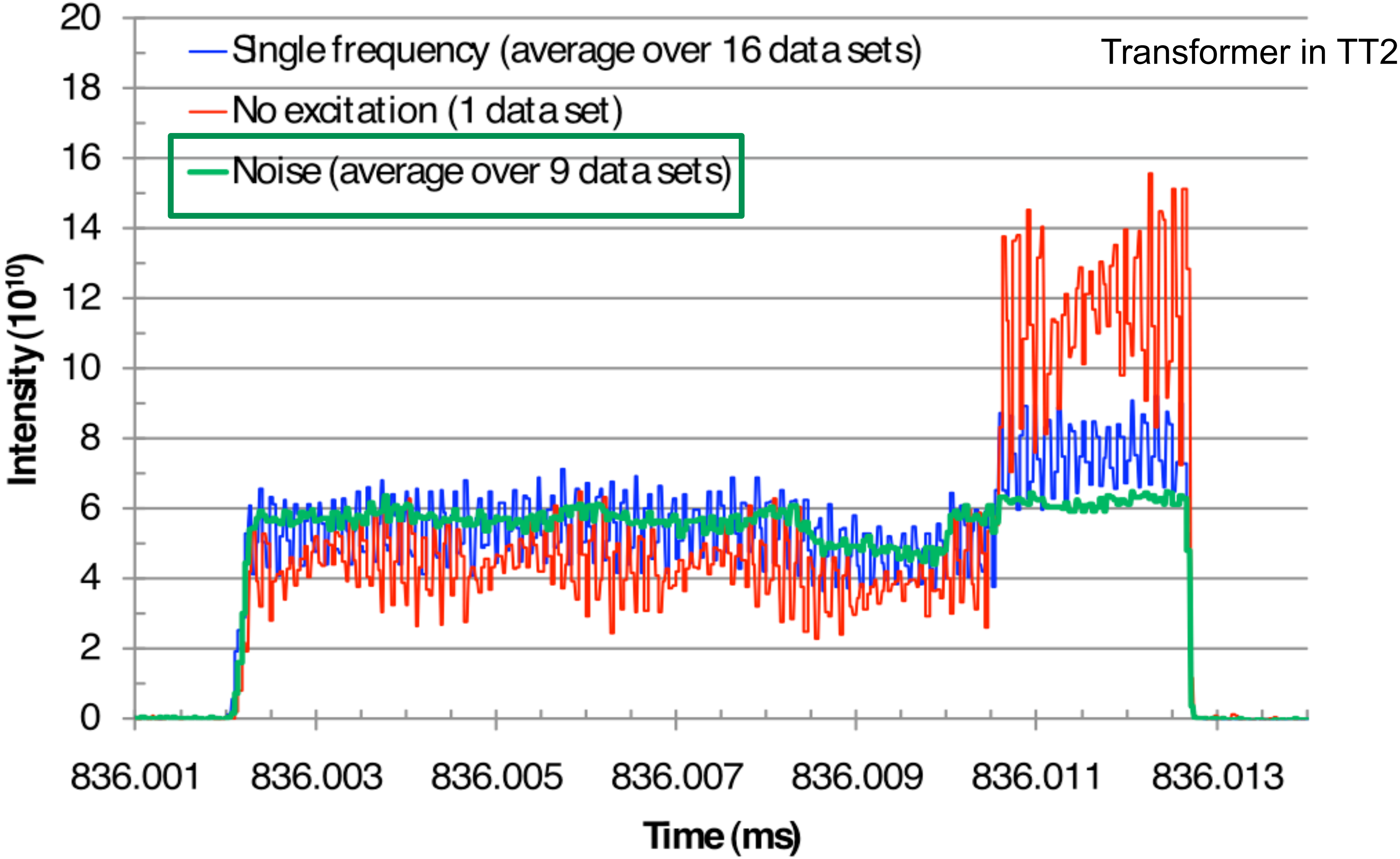


Studies with transverse damper

- Aim: Increase the trapping by changing the beam distribution (increase density towards higher amplitudes, where islands are bigger) to capture particles with the right momentum but with the wrong amplitude
- Due to longitudinal instability, beam kept bunched until extraction and debunched as for the nominal CNGS.
- Blow-up tests done at the end of the 2008 run using the “chirp” option of the Qmetre application.
  - 20% sharing obtained, but a huge emittance blow-up was observed, due probably to wrong linear chromaticity
- Tried again by the end of 2009 with direct control of the transverse damper.
- Two types of excitations tried:
  - Single frequency (tune line)
  - Noise around single frequency

Spill in TT2 during the tests with damper excitation - I

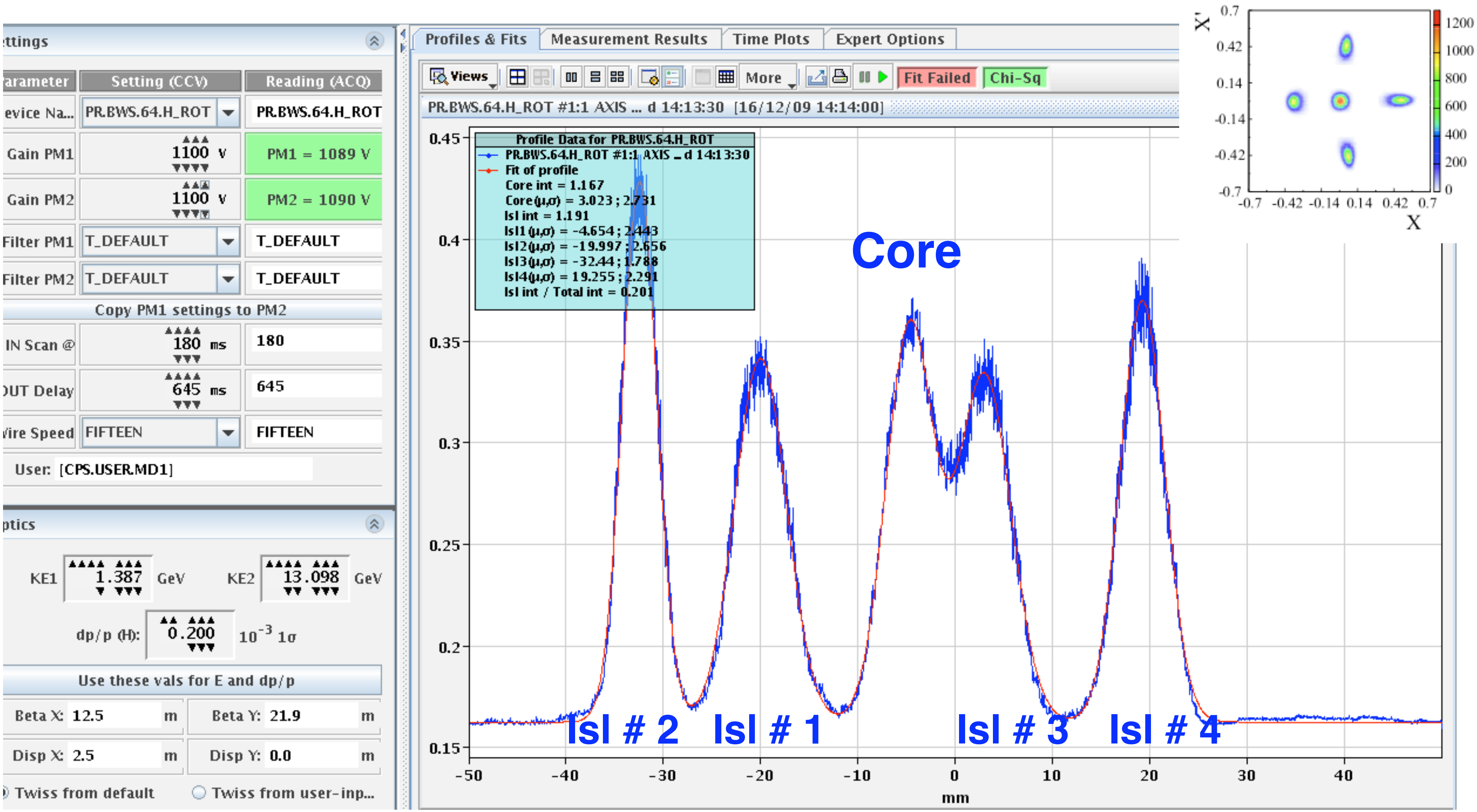
A flat spill on 5 turns means about 20% per islands



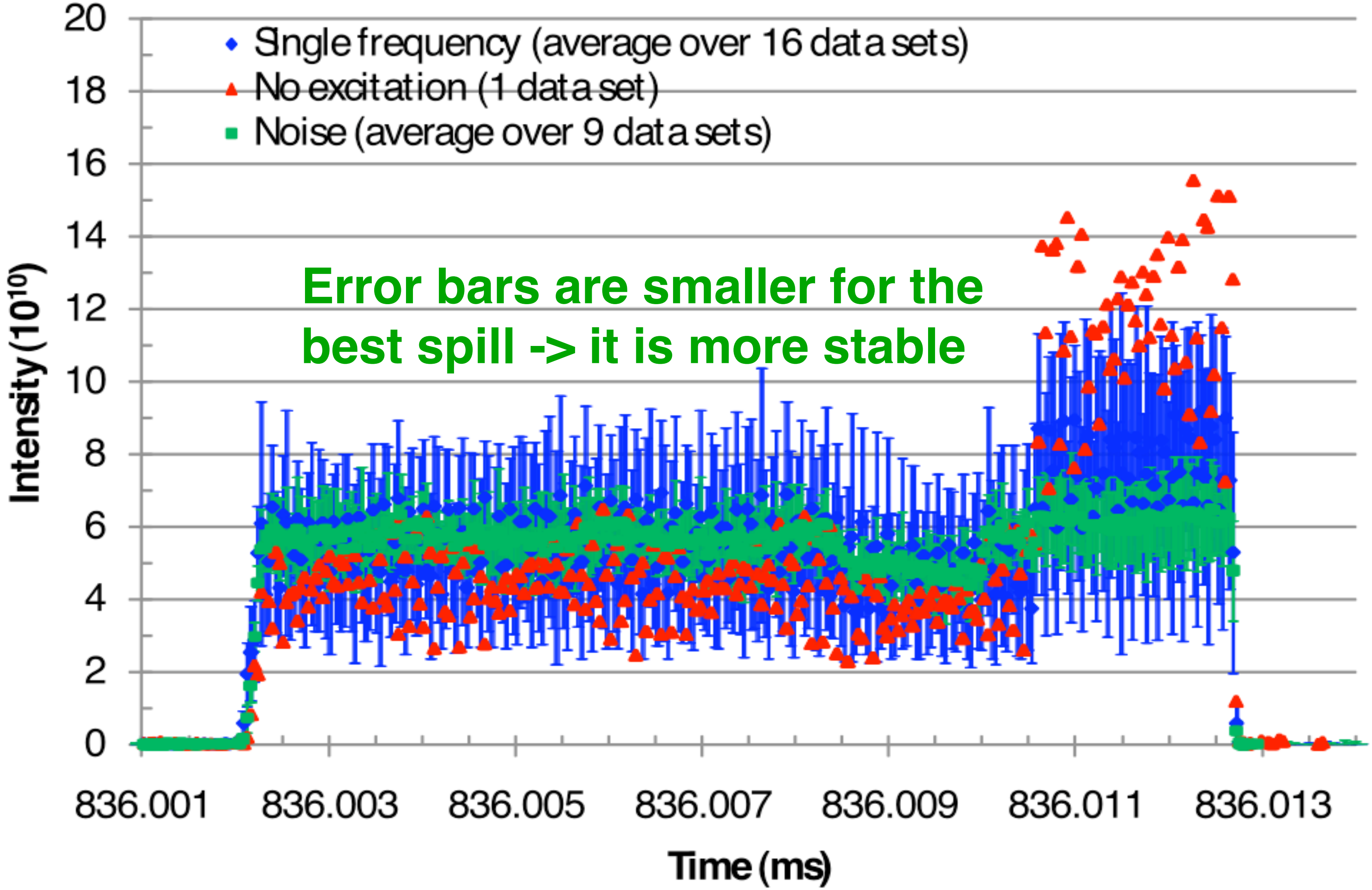
Typical transverse profile with good capture

Surface of the Gaussian profiles about the same: 20% per islands

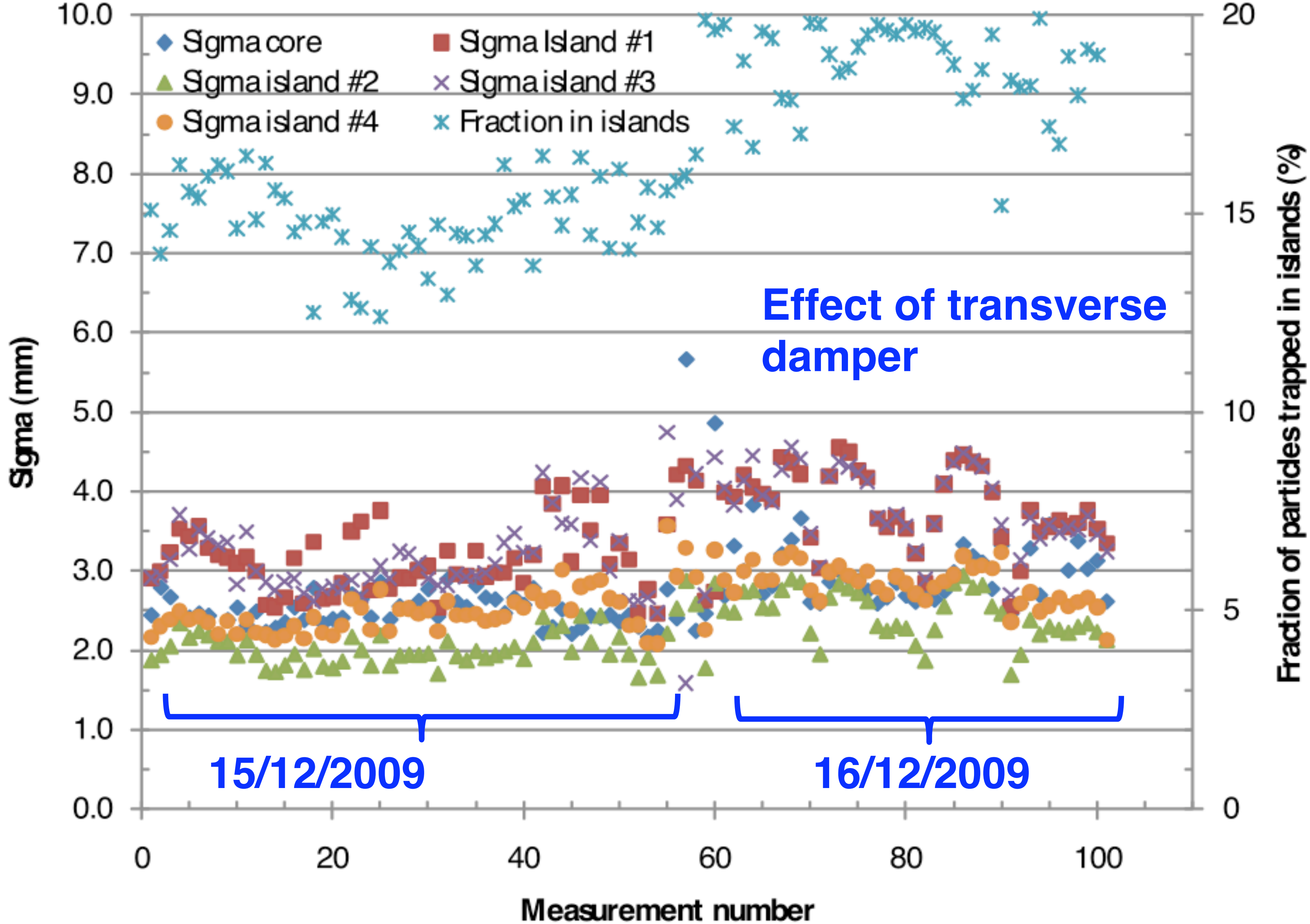
Different sigma per island due to the projection of the phase space on the x axis



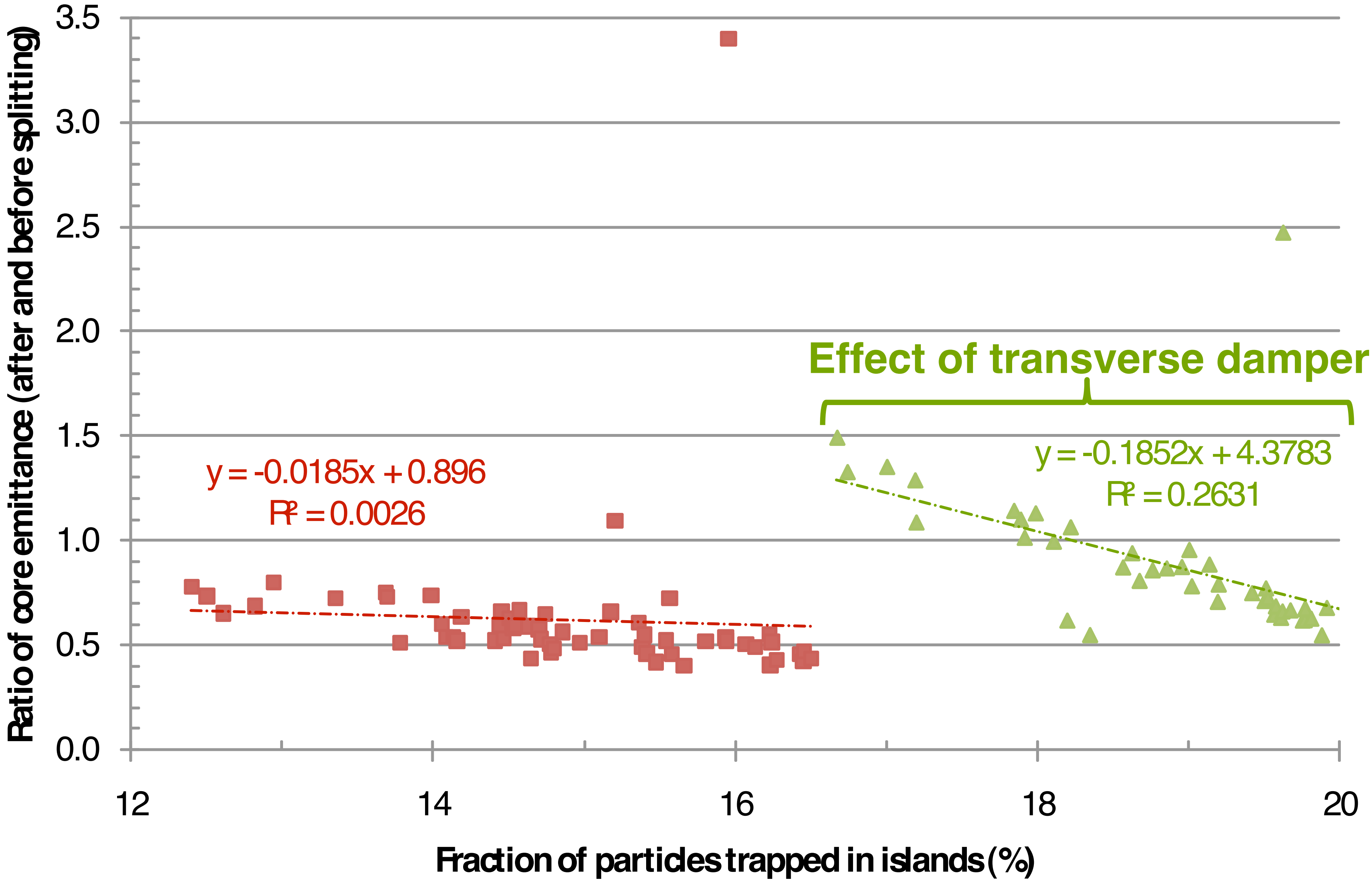
Spill in TT2 during the tests with damper excitation - II



Evolution of beamlets' parameters during last two days of 2009 run



Evolution of beamlets' parameters during last two days of 2009 run



Summary of last part of the commissioning

- About 20% capture efficiency realised thanks to the transverse damper without core blow-up
  - HW installation ongoing to use the damper for the resonance excitation remotely, i.e., from the CCC
- Analysis of the longitudinal plane:
  - de-bunching before transverse splitting:
    - Blow-up of momentum distribution and re-bunching due to micro-wave instability.
    - It is not possible to quantify the fraction of particles with increased momentum spread from the Schottky spectrum.
    - Those particles will not cross the resonance due to a negative tune shift given by the term ½ Q'' $\Delta p/p^2$.
  - de-bunching just prior to extraction:
    - Beam unstable due to coupled bunch instability (quadrupolar mode).
    - No possibility to cure the instability with feedback (as it is done for the LHC beam).
    - Controlled momentum distribution.

➡ The de-bunching prior to extraction was finally preferred.

- Studies will be done in the SPS to check if the dp/p of the particles in the core is different than the dp/p of the islands

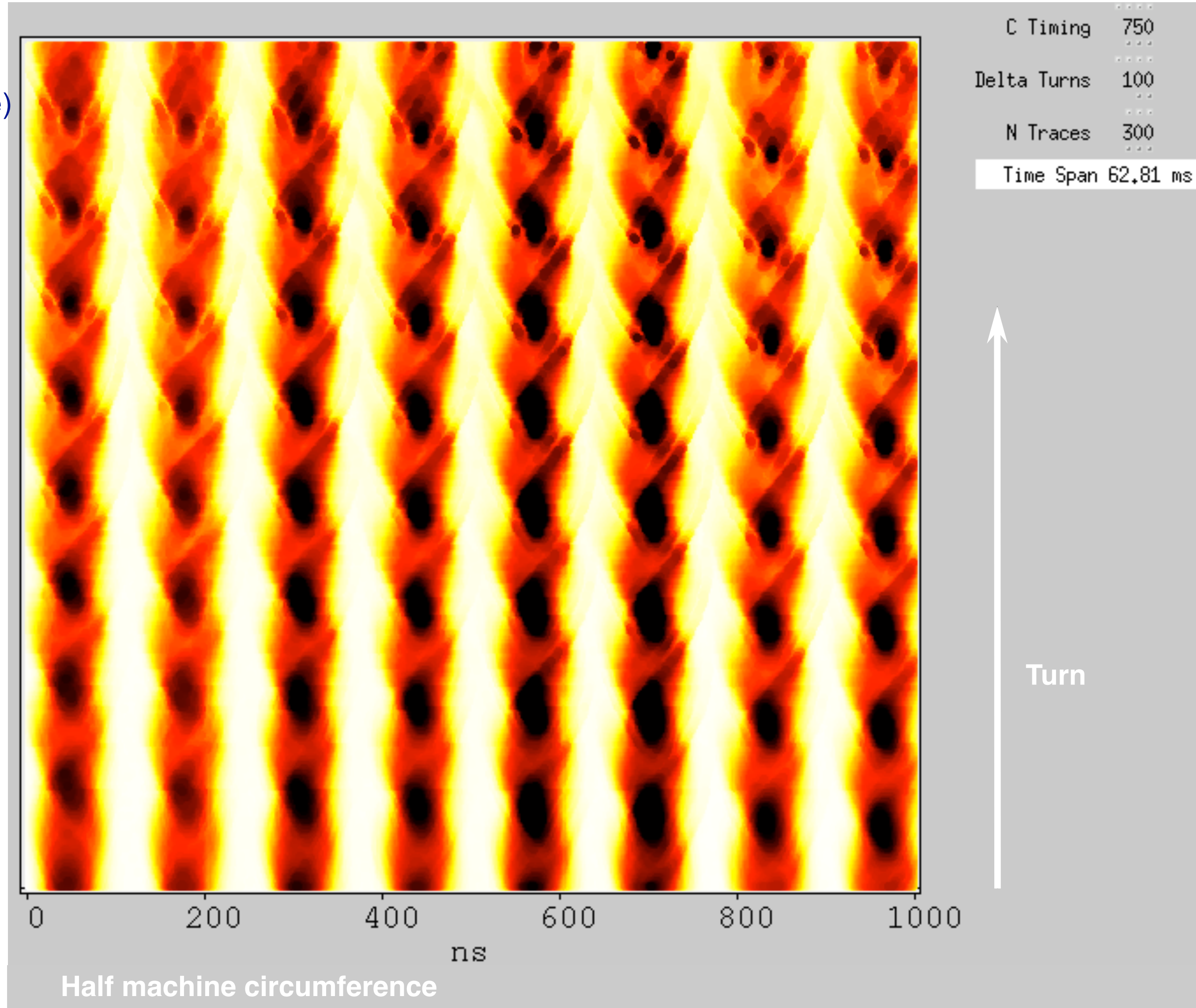
NB: also the CT beam (CNGS) is longitudinally unstable

Longitudinal instability: bunched beam

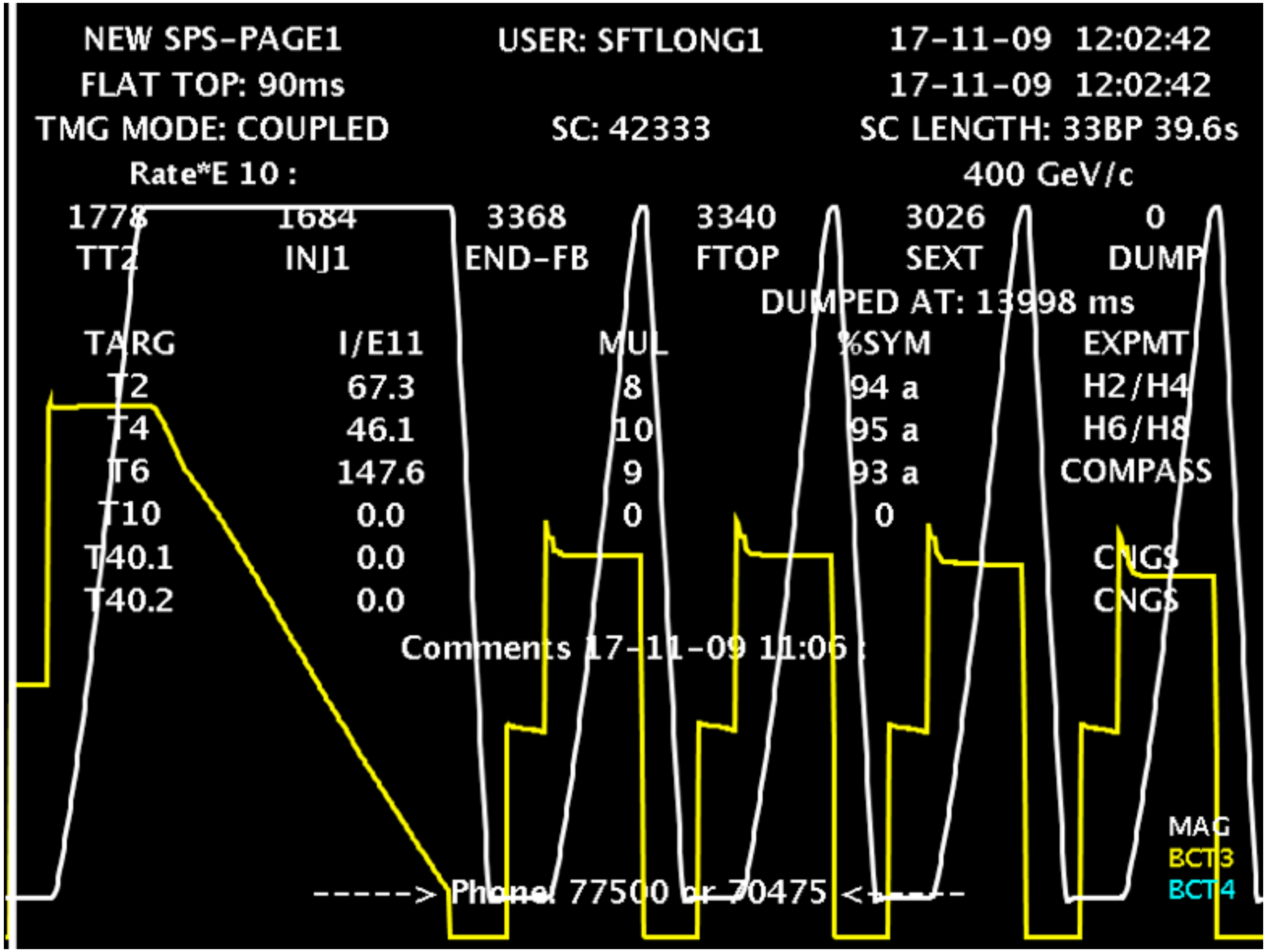
Coupled bunch instability (quadrupolar mode) for a MTE beam kept bunched during transverse splitting and de-bunched only prior to extraction (1.7× 10^{13} p).

Currently this instability is not spoiling the capture, but further studies needed to improve instability understanding.

RF studies will be done in parallel.



MTE for CNGS



For about an entire shift (~ 8 hours) the CNGS has been delivered from the PS by MTE to:

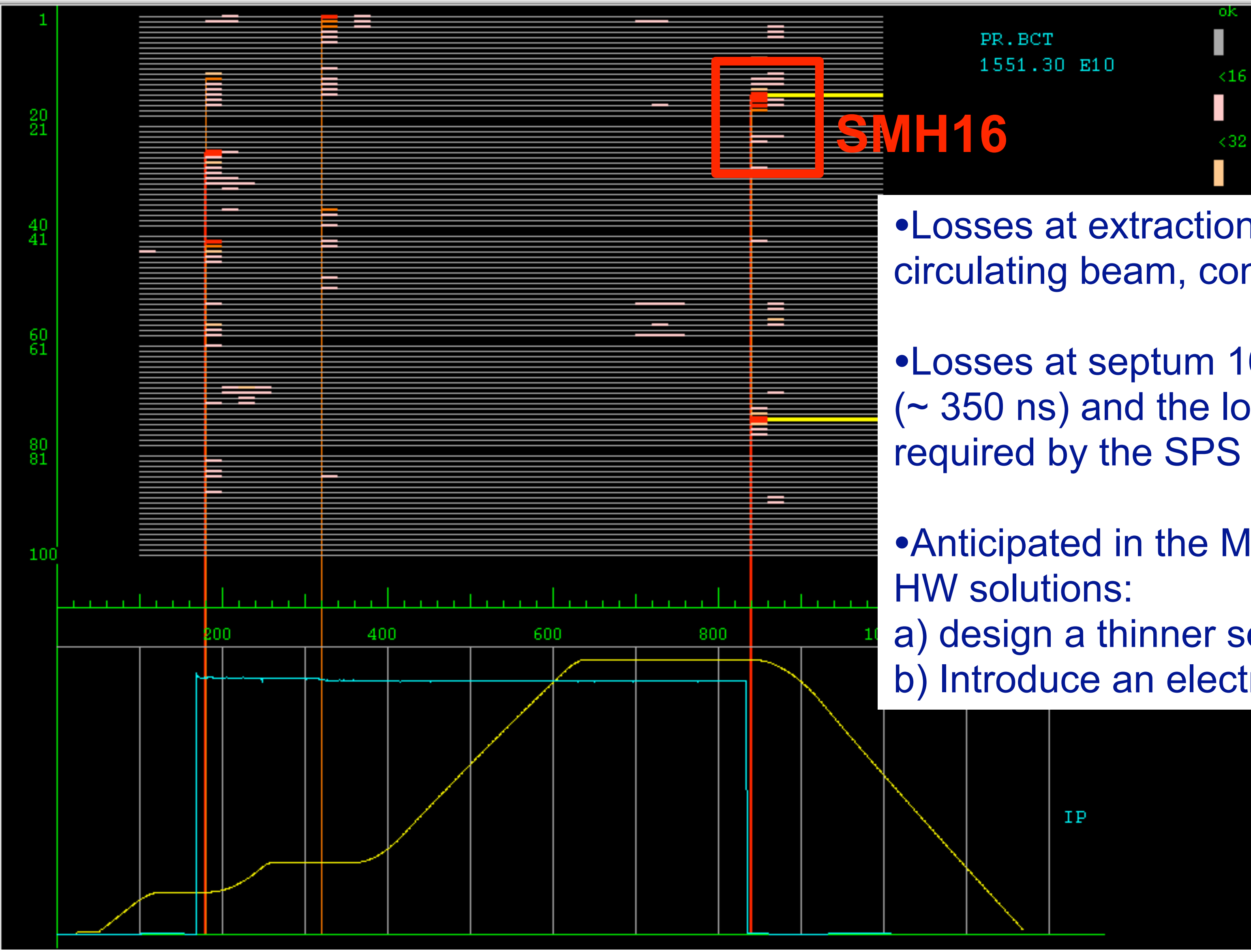
a) allow a radiation survey in the critical areas of the PS (PS-Linac3 shielding)

b) full test of all the equipments for a long time

c) leave the extraction to OP in operational conditions

a) Losses at PS extraction as expected, even if 15 minutes fluctuation in losses have been observed and not yet understood (30% fluctuation on the 2-3% losses).
b) Operation without any particular problem or trimming required.
c) **Identified a shortcoming in the radiation shielding between the PS and the Linac3.**

MTE losses at extraction



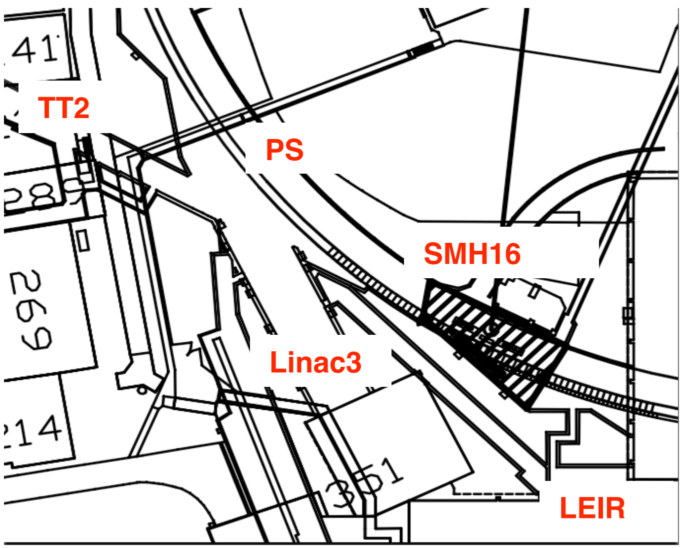
- Losses at extraction, about 2-3% of circulating beam, concentrated in 2 points.

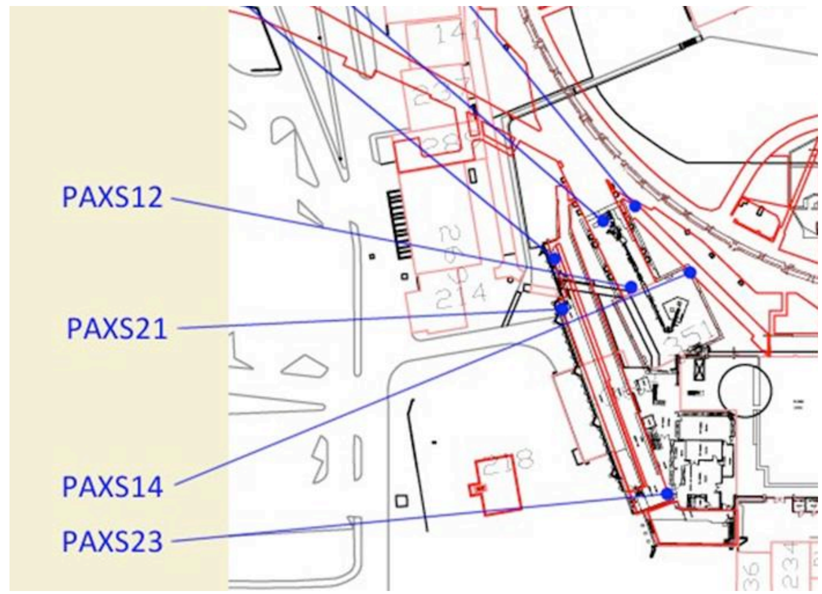
- Losses at septum 16 due to kicker rise time (~ 350 ns) and the longitudinal structure required by the SPS (de-bunched beam).

- Anticipated in the MTE Design Report.
HW solutions:
a) design a thinner septum
b) Introduce an electrostatic septum in SS11

Linac3 issue

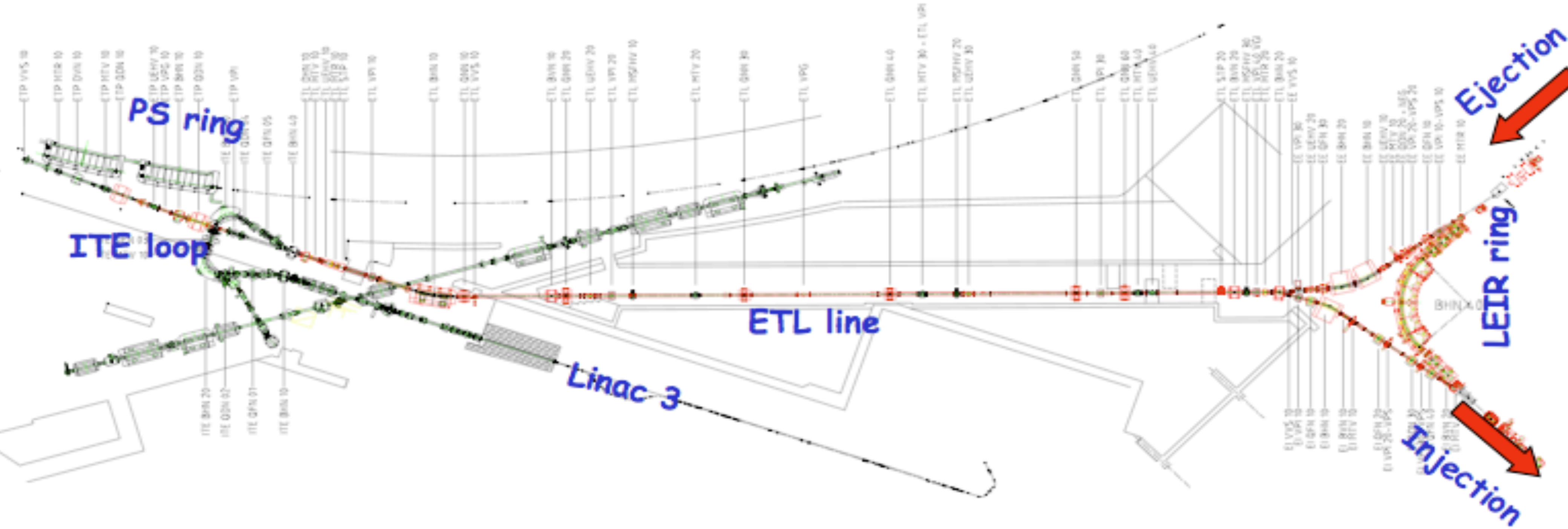
- Due to the (weak) existing shielding, the dose in the Linac3 tunnel would exceed the current area classification during MTE operation with 0.85×10^{13} p/s (typical CNGS operation).
- This result is based on a series of measurements performed in November 2009.
- The dose will be about 13 μSv/h using MTE, whereas the limit is 10 μSv/h.
- With the CNGS based on the CT extraction it was measured about 4 μSv/h.





NB: access to the Linac3 is required for continuous tuning of the Lead source and in particular during the next run for the commissioning of the new source

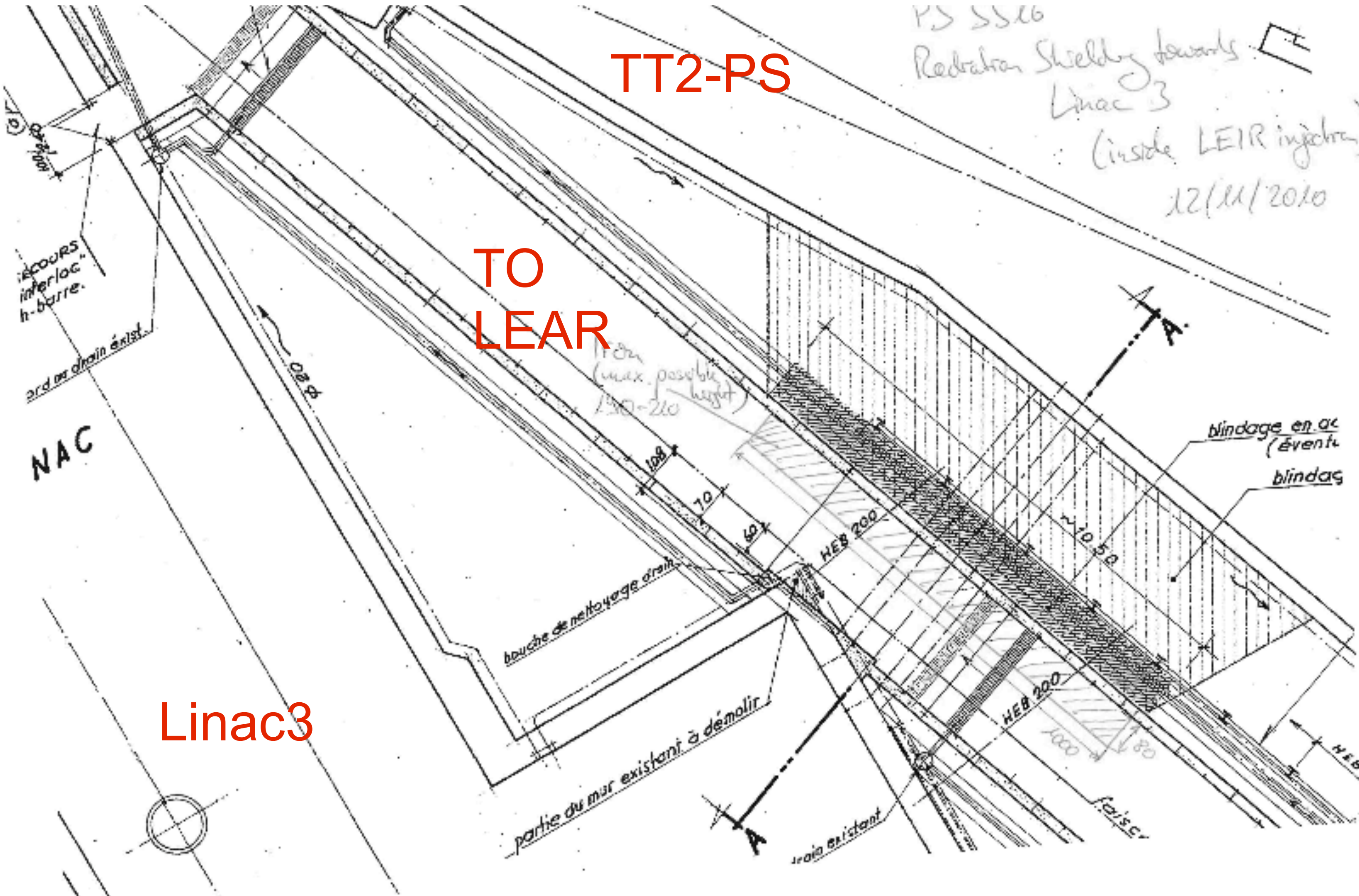
LEIR Layout



Overview of Linac 3, LEIR and PS

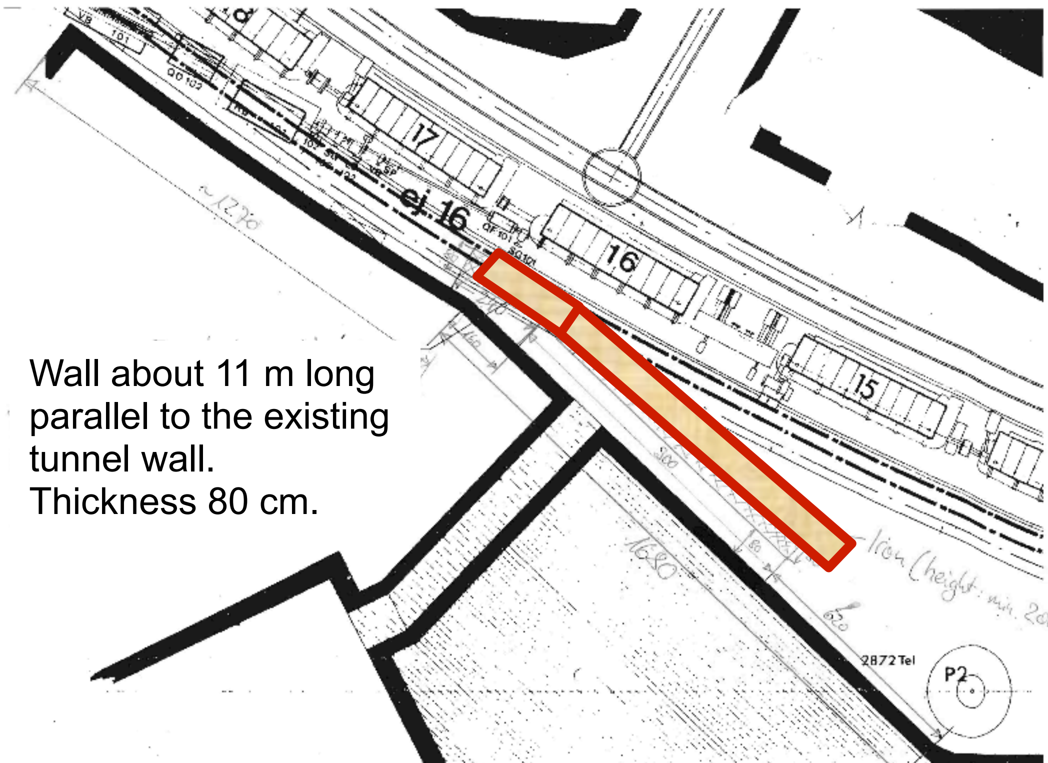
Shielding foreseen during LEAR construction

During LEAR construction, to accommodate injection/extraction line about 2 m of earth shielding removed. Reinforcement of remaining shielding proposed but not realised.



Installation of new shielding

- Install concrete wall shielding in the PS nearby the zone of the septum 16
  - Heavy charge on the floor (about 50 t): impact on structural stability verified.
  - No impact on repairing activities in the area (septum 16, QFO105).
  - High shielding efficiency, studied by FLUKA simulations.
    - Expected dose reduction > factor of 4-5. (desired factor of < 2).



Wall about 11 m long parallel to the existing tunnel wall.
Thickness 80 cm.

Linac3 radiation issue summary

- Linac3 radiation levels turned out to increase due to the MTE losses concentrated at the septum 16. During CNGS operation with exclusively CT extraction larger doses than past years observed. The problem was generated by the choice of not consolidating the shielding between the PS and the LEAR injection/extraction line during the LEAR construction → a concrete has been installed as compensatory measure.

- In case the shielding would turn out to be not sufficient for reasons unknown at the moment, CNGS could be delivered during the day (work ongoing in Linac3) with CT extraction, and during the night with MTE.

- The installation of the wall should be considered as a temporary solution. The current run should be used to look for a better one, for example:

  - Revise the current installation of the Linac3 equipments (radiation mapping of the Linac3 area needed -> detailed measurements to be performed this year)

  - Install shielding on the Linac3 side (if possible)

  - Change the extraction septum (longer time scale)

  - … etc...

- Hopefully the use of MTE in normal operation should also bring a better extraction efficiency thanks to optimisation

Start-up program (Conclusions...)

- It is planned to resume the beam tests as soon as the machines are back in “normal operation”, i.e., after the MPS back in service and the LHC type beams ready (probably next week).
- The effect of the transverse damper giving 20% islands sharing should be reconfirmed with a study of the dependence of the trapping efficiency on the various free parameters (e.g., time of excitation, duration, noise distribution, etc.).
- The intensity should then be increased towards SFTPRO and CNGS nominal values.
- Re-measure the beam instability to verify an eventual effect of the repaired RF bypass.
- The beam should then be delivered as soon as possible to the SPS for additional studies, in particular optics in the transfer line, and for the cycle setting up.
  - Expected before the restart of the nominal CNGS operation at the SPS.
- In collaboration with OP, a number of applications are under development for the MTE normal operation. Amongst other applications, deploying of the LHC on-line model for the PS.

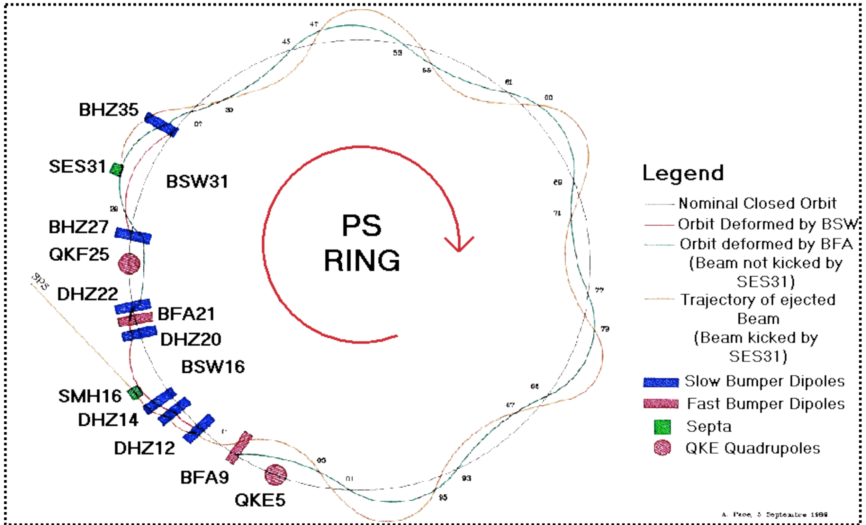
for discussion

Longitudinal structure study results

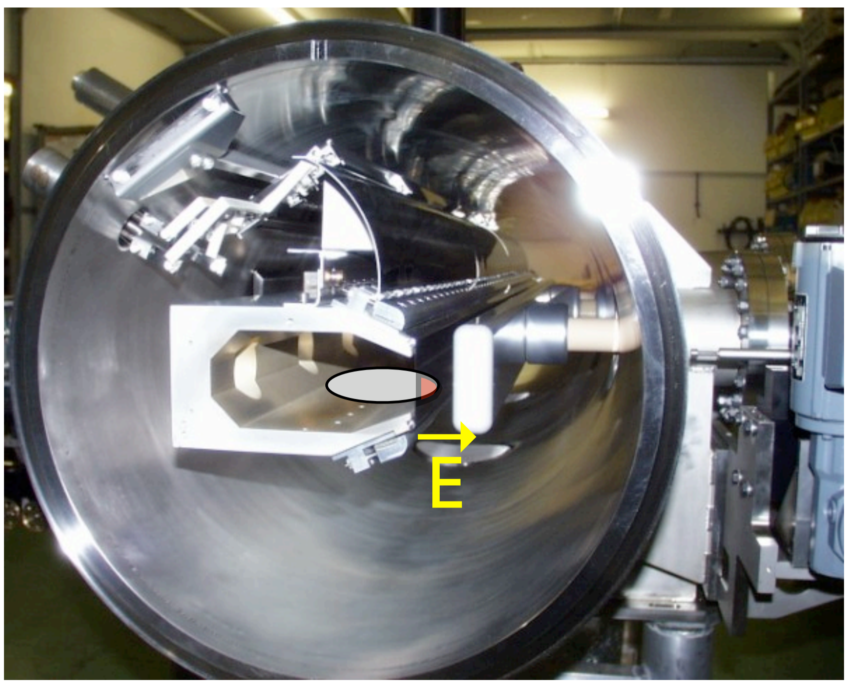
- Study done by injecting in the SPS a CT extracted beam:
  - bunched and synchronised in h8 with different RF voltages
  - bunched and synchronised in h16 with different RF voltages
  - debunched from h8 with same debunching time as for h16
  - debunched from h16, as in normal operation for the CNGS/SFTPRO
- **Results after many iterations** which caused also a change, few times, of the operational CNGS and SFTPRO users and a change of the MTG offset between the PS and SPS
  - Not possible to have a bunch splitting h8-h16 at 14 GeV/c in the PS
  - Not possible to synchronise with less than 40 kV with existing hardware
  - The SPS has minimum losses with two structures: a) debunched from h16; b) bunched h16 with 4 kV in the PS, which is practically a debunched beam and cannot be synchronised
- **Not possible to minimise losses in the PS by using an h8 beam**.
  Further study to reduce the cycle length by debunching from h8.

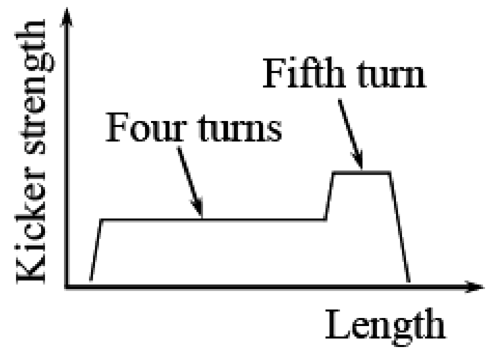
Thanks to G. Metral, T. Bohl, H. Damerau, S. Hancock, K. Cornelis, J. Wenninger, and OP crews

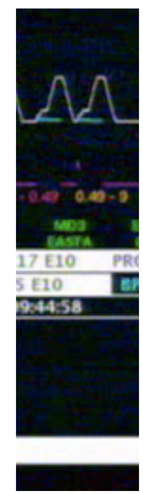
Continuous Extraction (CT, 70s): the principle

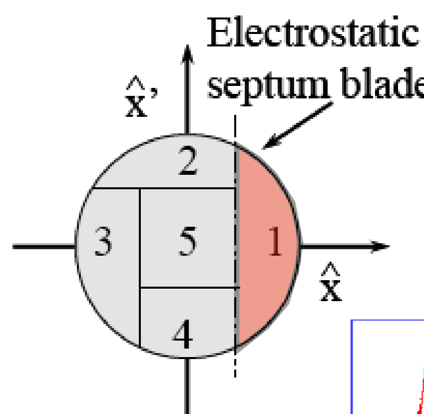


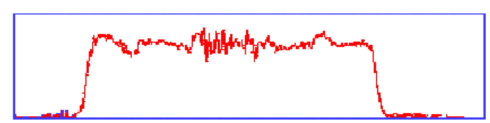
- Horizontal tune set to 6.25 phase advance per turn of 90°.
- A part of the proton beam is pushed by a slow and a fast bumps beyond the blade of an electrostatic septum.
- The sliced beam that receives the kick of the electrostatic septum is extracted during the current machine turn
- The rest is extracted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









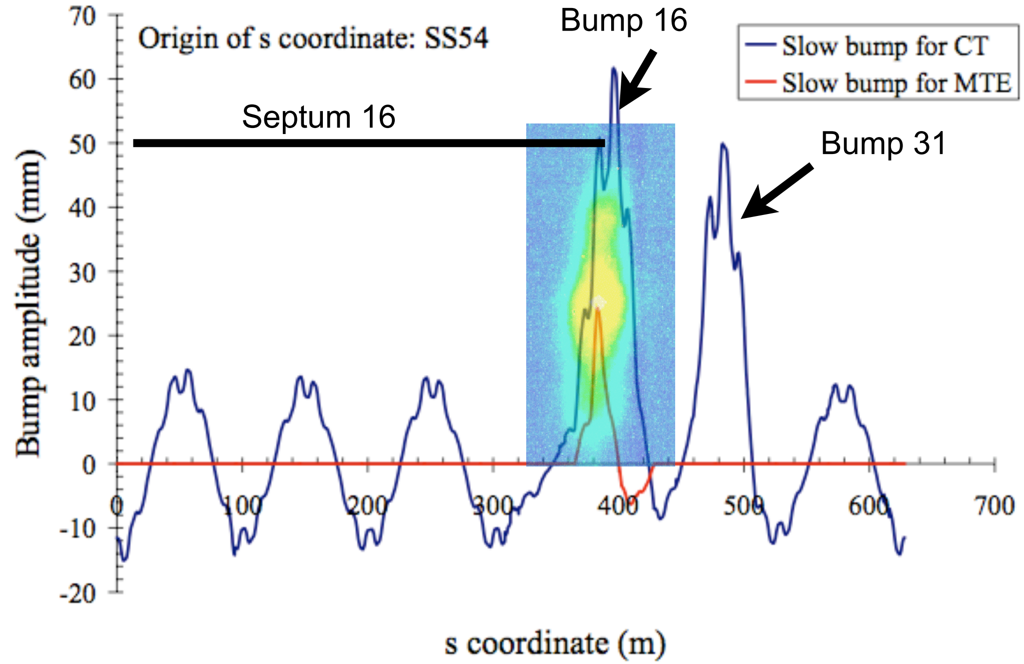


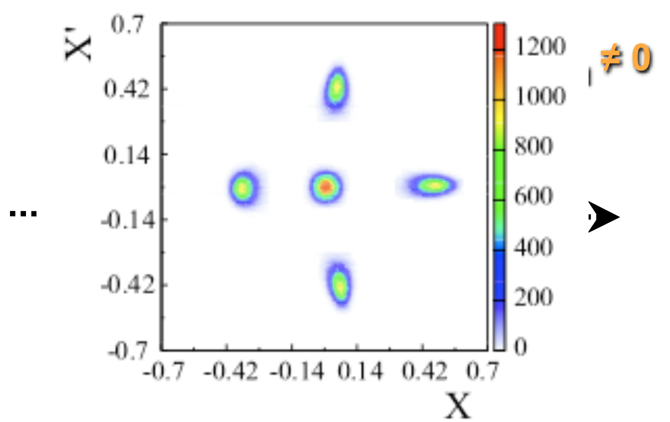
← Five PS turns →

MTE Slow/Fast bumps

New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

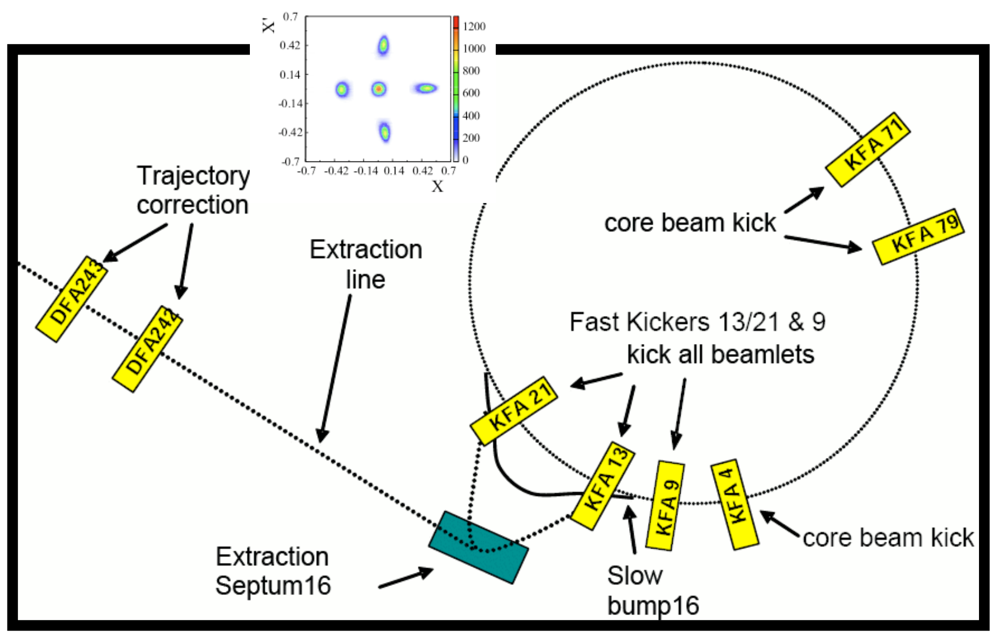
New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns





KFA9, KFA13, KFA21
⇒ 5 turn constant kick

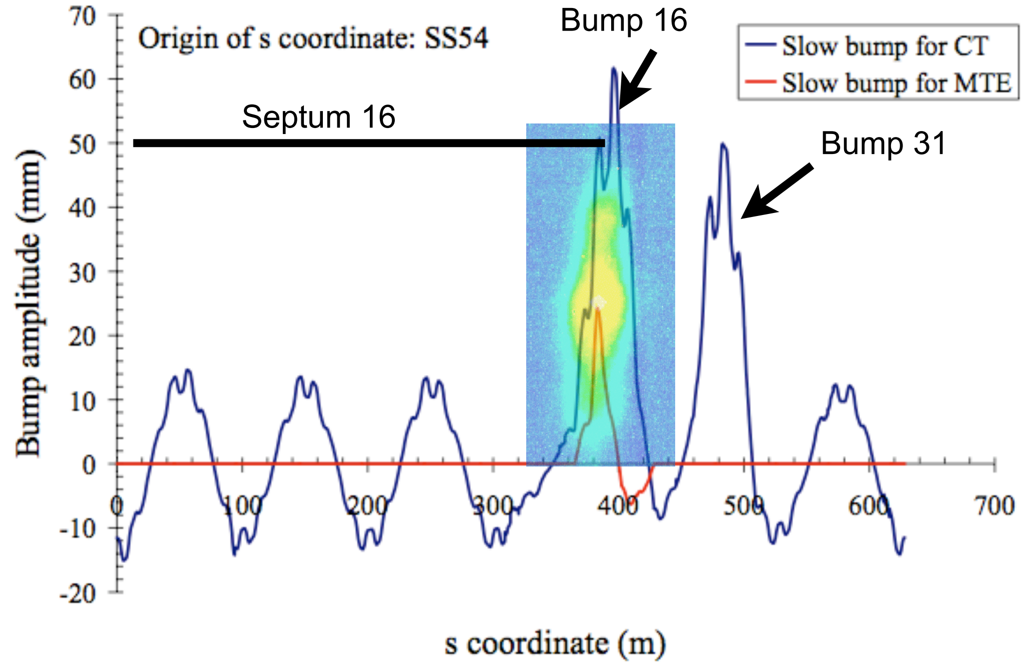
KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction

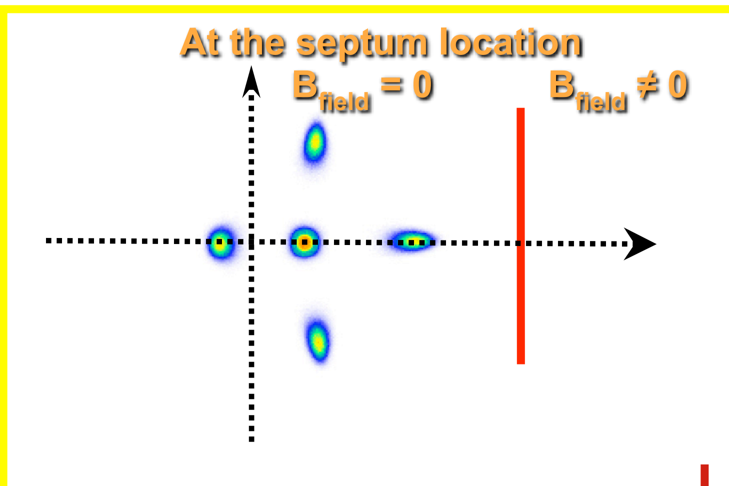


MTE Slow/Fast bumps

New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

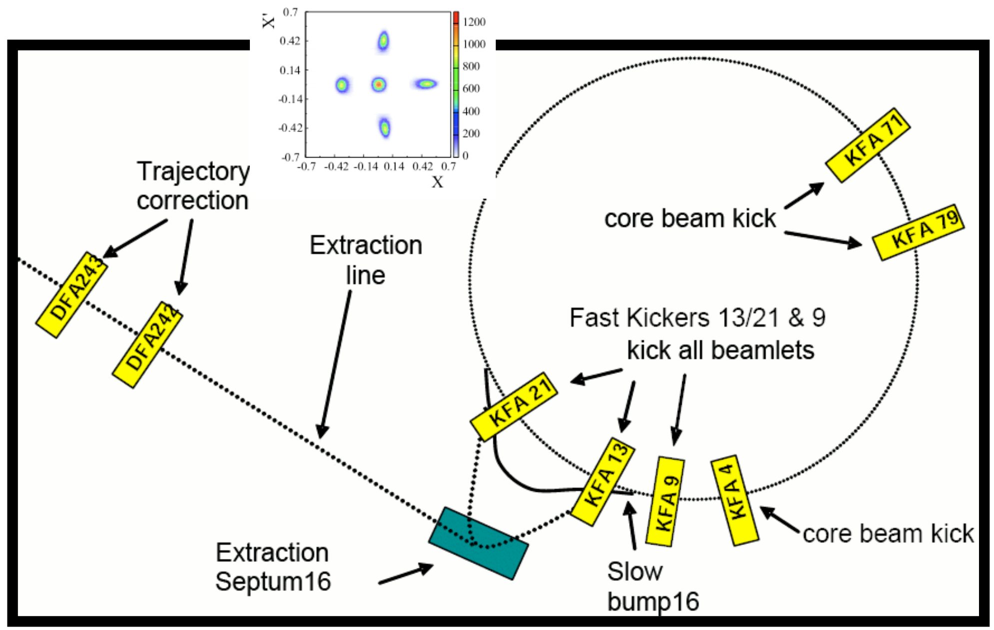
New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns





KFA9, KFA13, KFA21
⇒ 5 turn constant kick

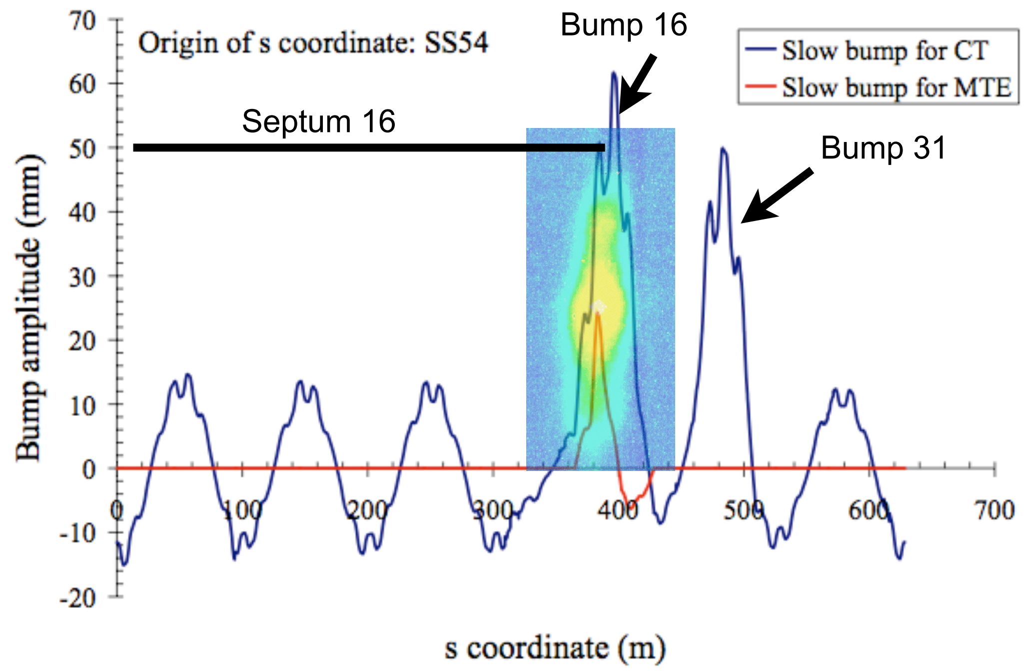
KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction

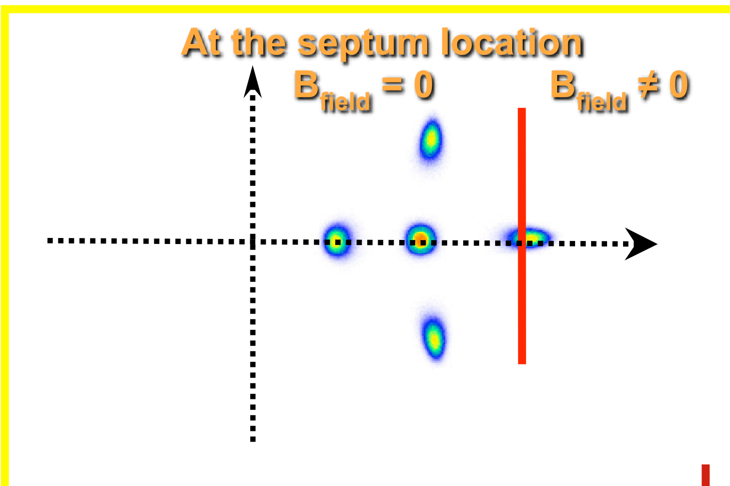


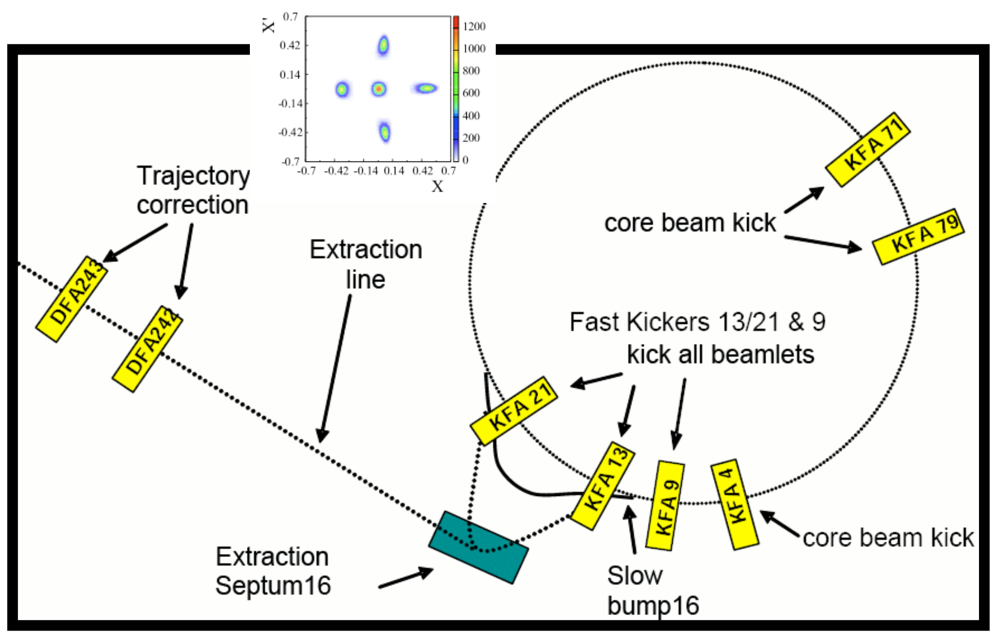
MTE Slow/Fast bumps

New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns







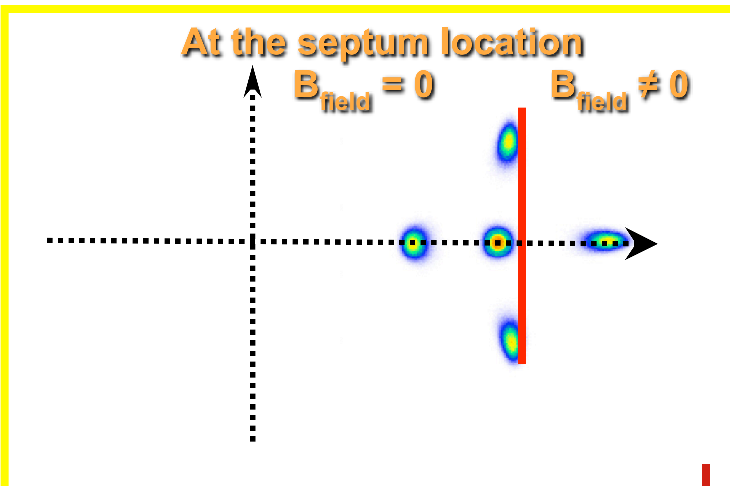
KFA9, KFA13, KFA21
⇒ 5 turn constant kick

KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction

MTE Slow/Fast bumps

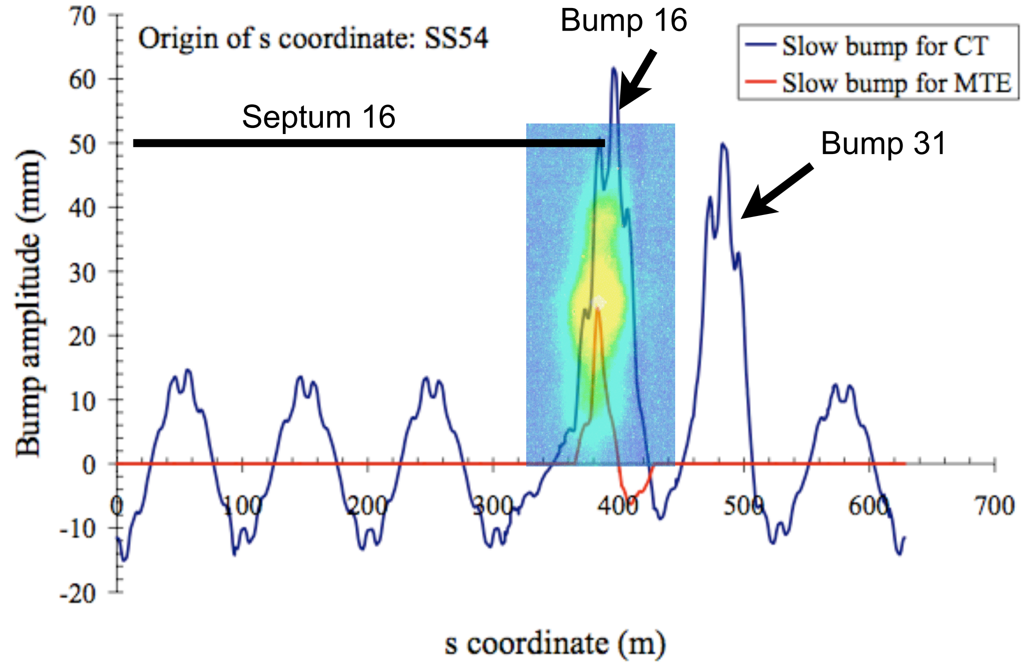
New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

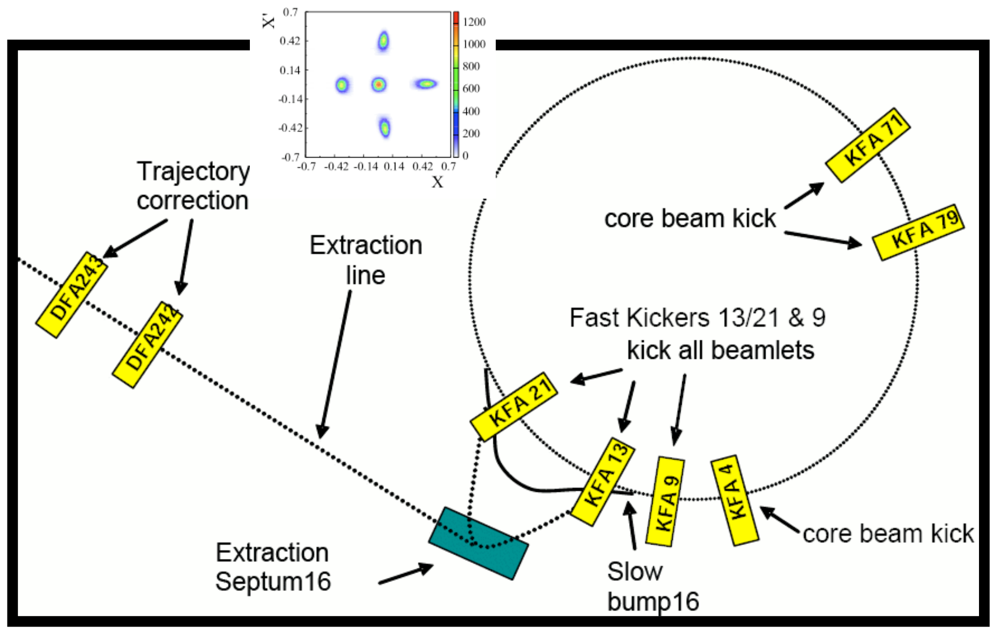
New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns



KFA9, KFA13, KFA21
⇒ 5 turn constant kick

KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction

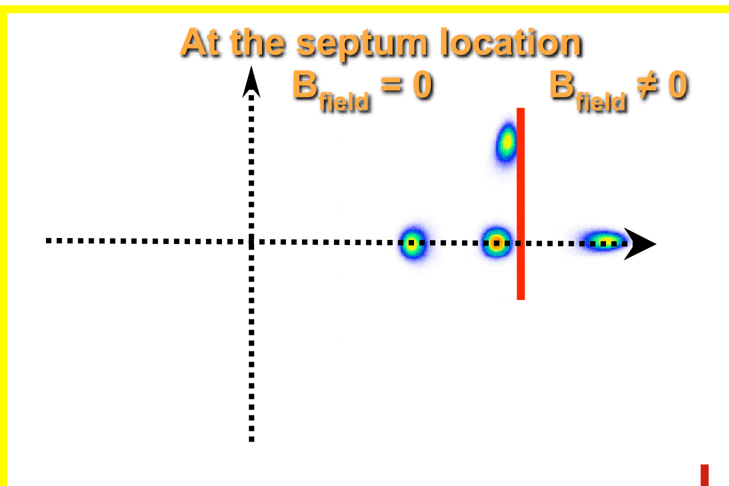




MTE Slow/Fast bumps

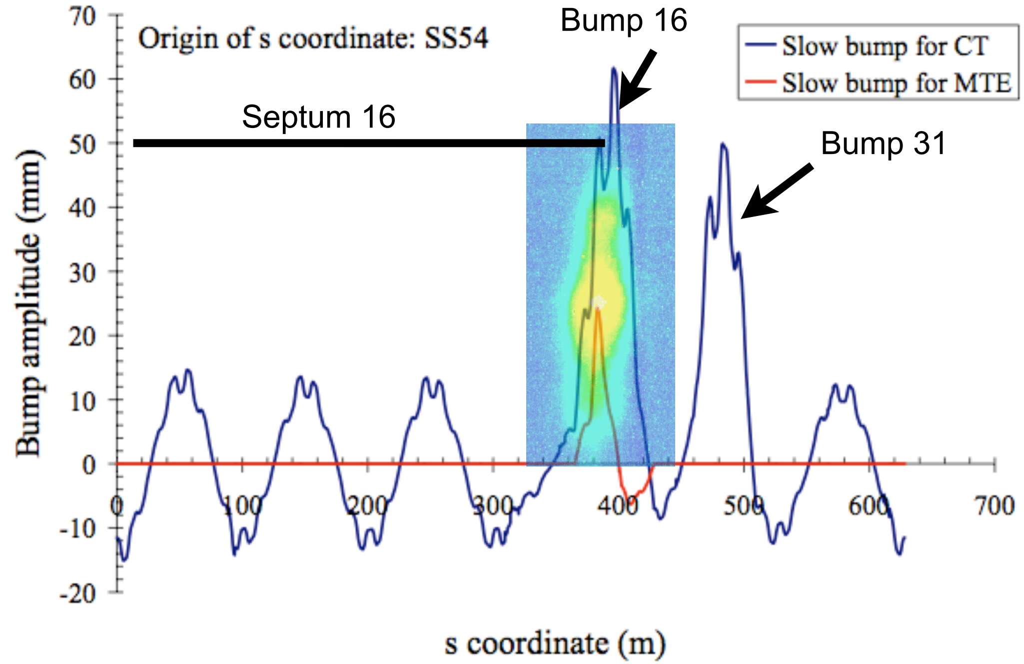
New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

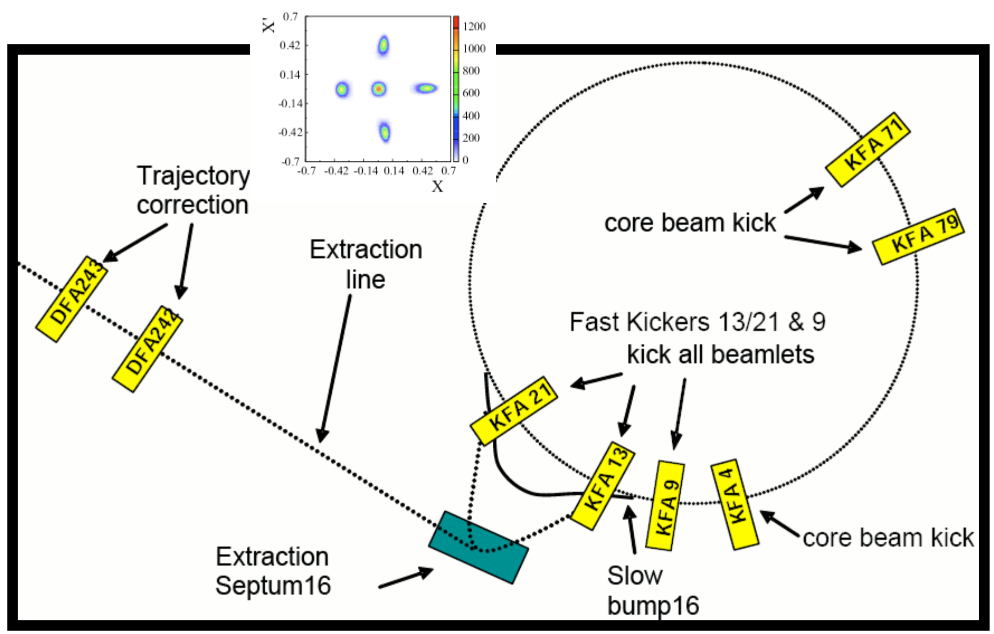
New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns



KFA9, KFA13, KFA21
⇒ 5 turn constant kick

KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction

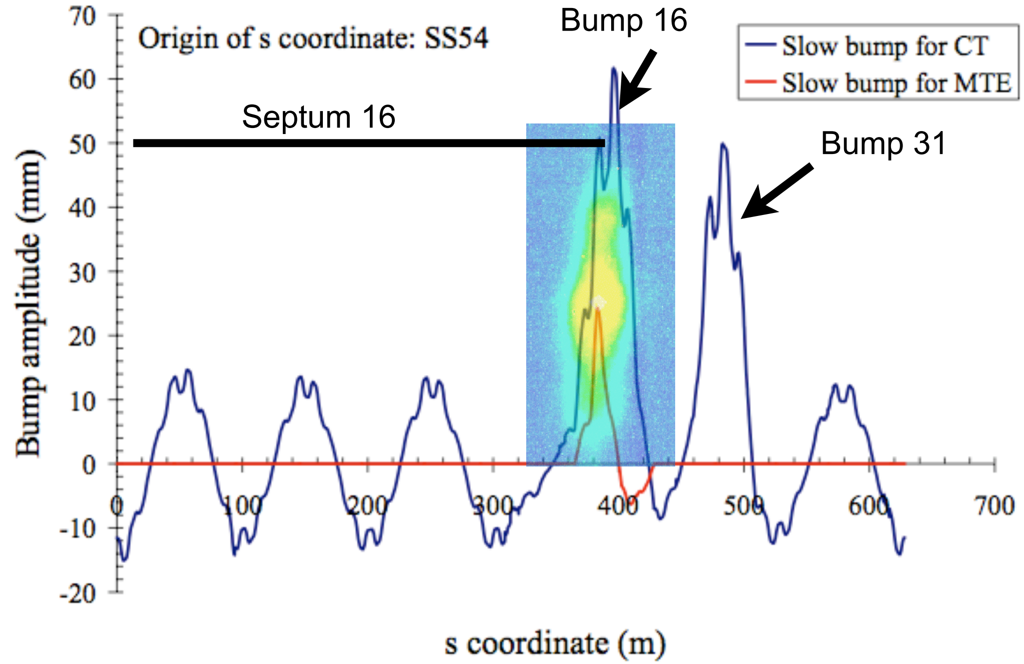


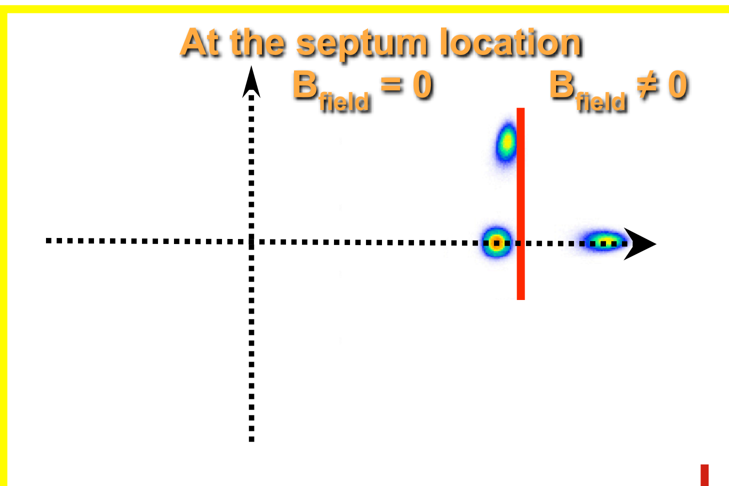


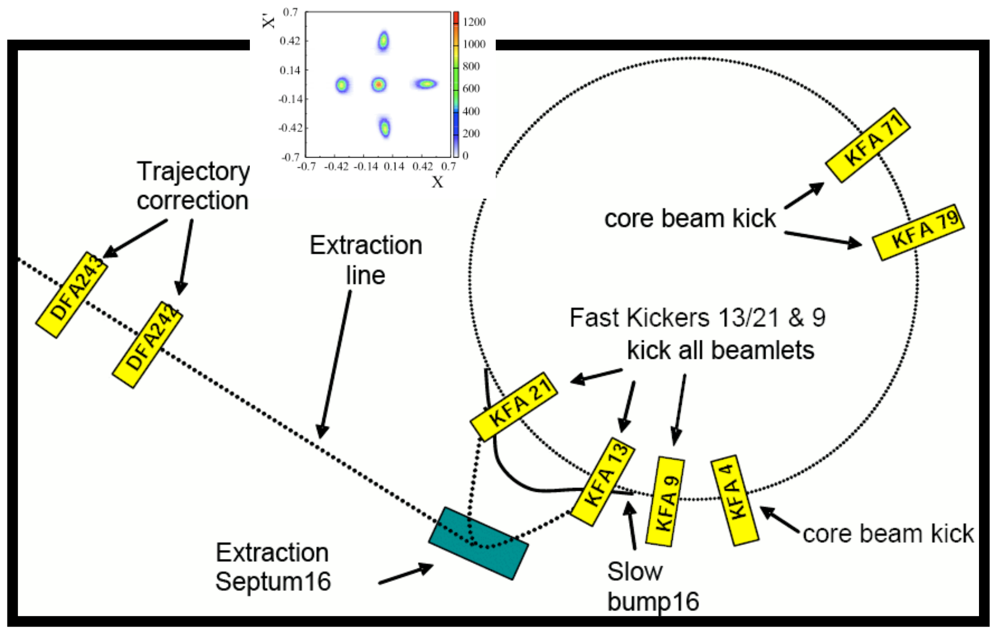
MTE Slow/Fast bumps

New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns







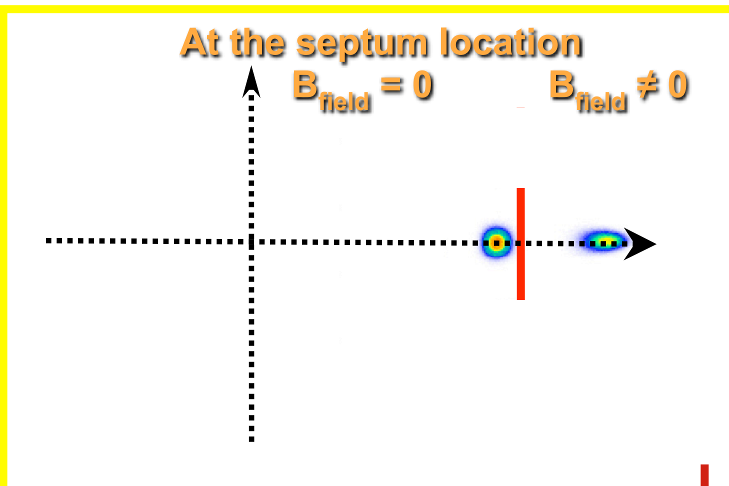
KFA9, KFA13, KFA21
⇒ 5 turn constant kick

KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction

MTE Slow/Fast bumps

New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

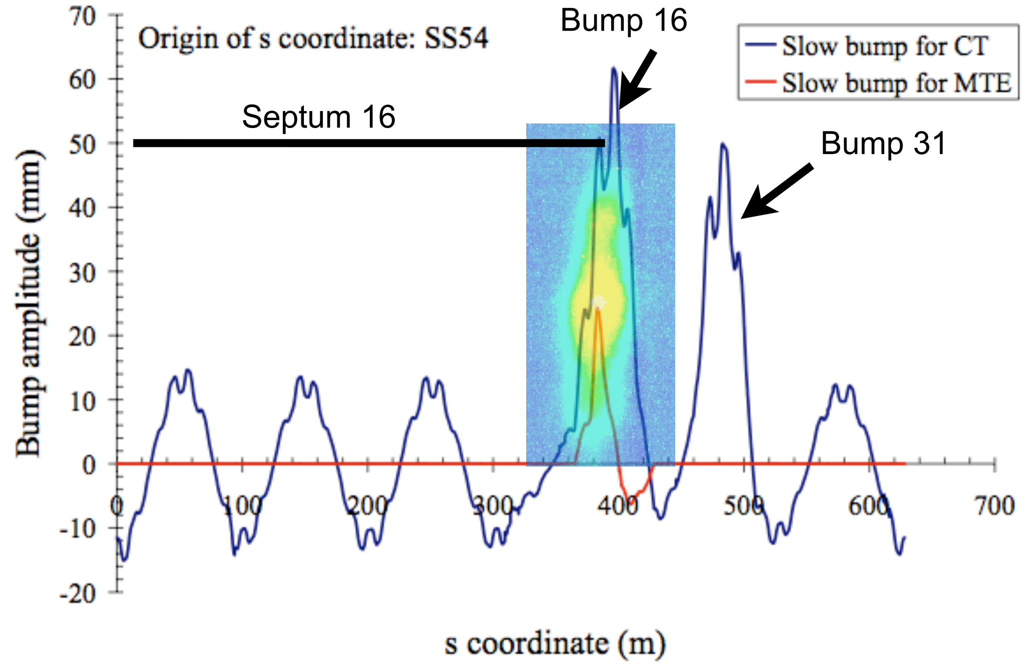
New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns

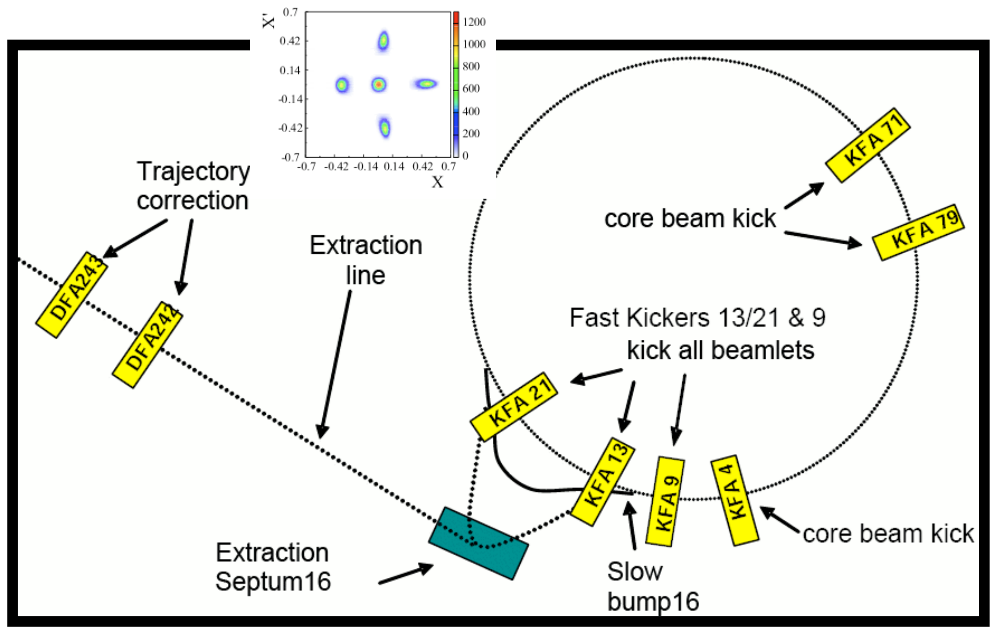


KFA9, KFA13, KFA21
⇒ 5 turn constant kick

KFA71/79, KFA4
⇒ core smaller amplitudes

⇒ extra kick + trajectory correction

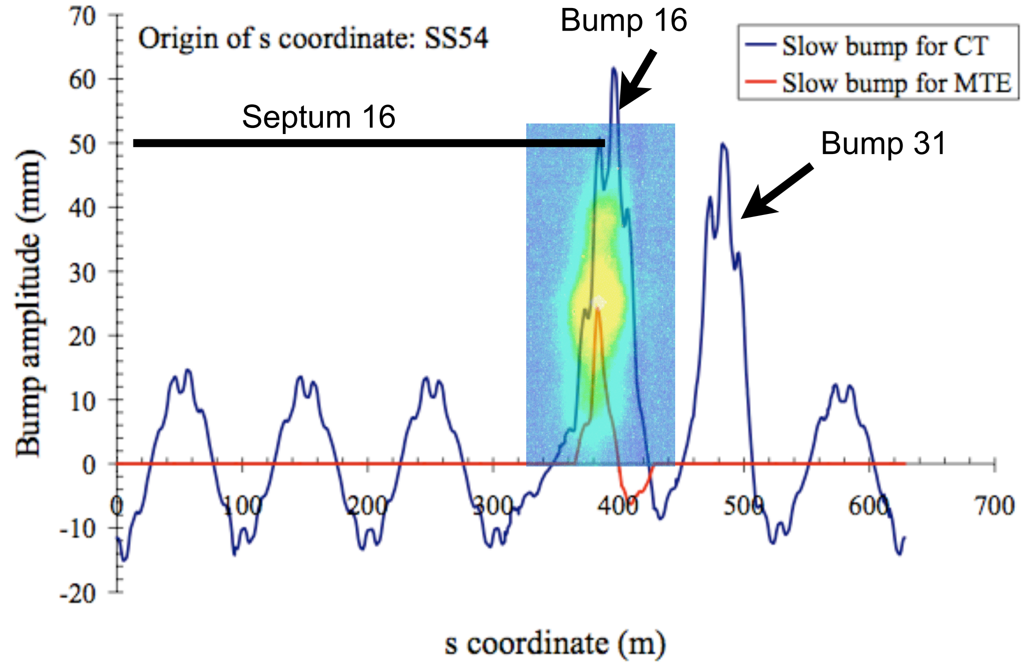


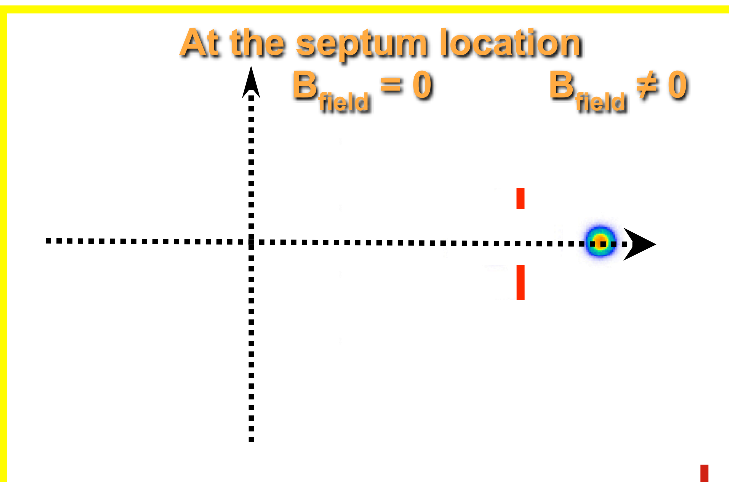


MTE Slow/Fast bumps

New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

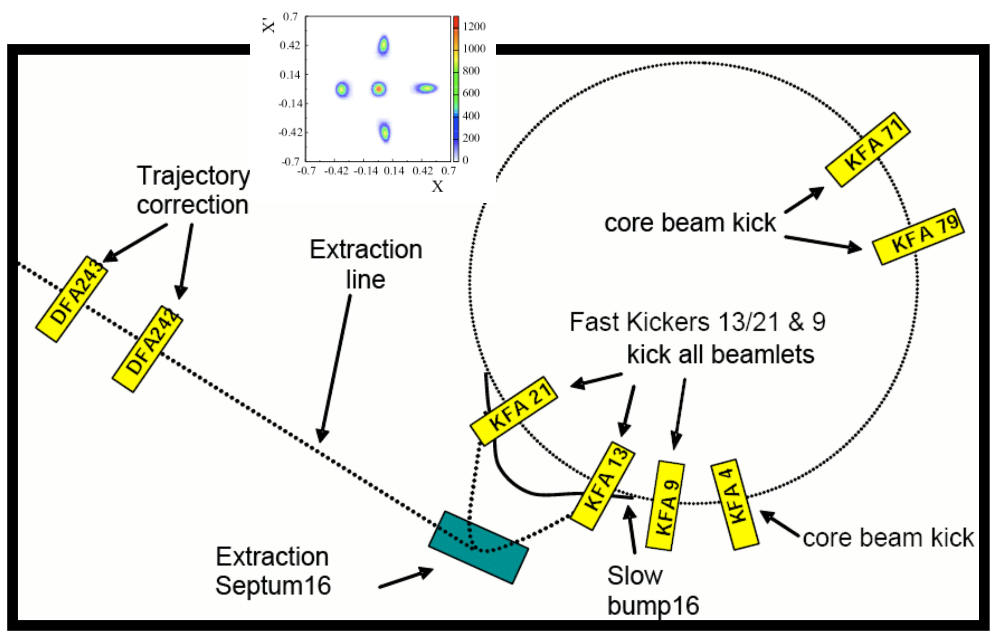
New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns





KFA9, KFA13, KFA21
⇒ 5 turn constant kick

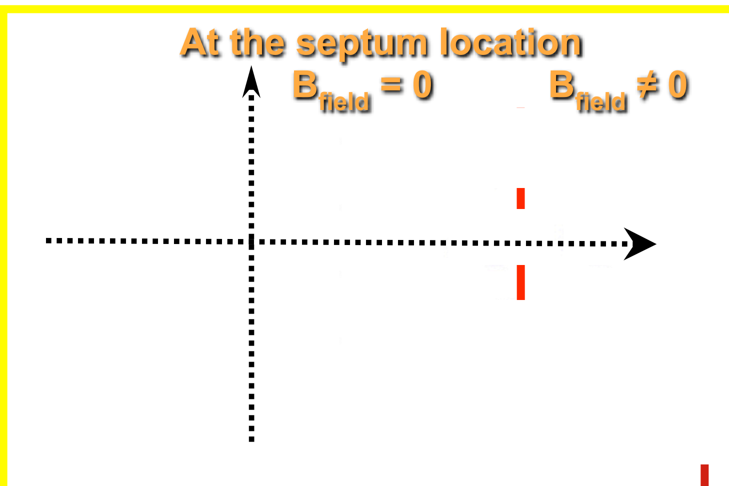
KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction



MTE Slow/Fast bumps

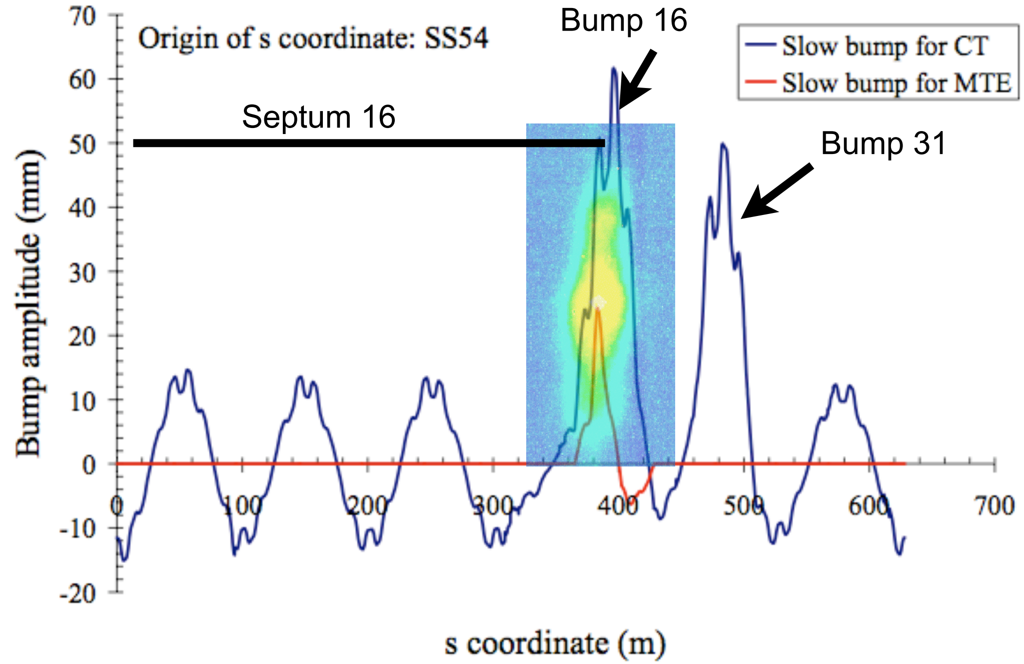
New slow bump composed by 6 independent power converter
⇒ close the slow bump on 7 ms

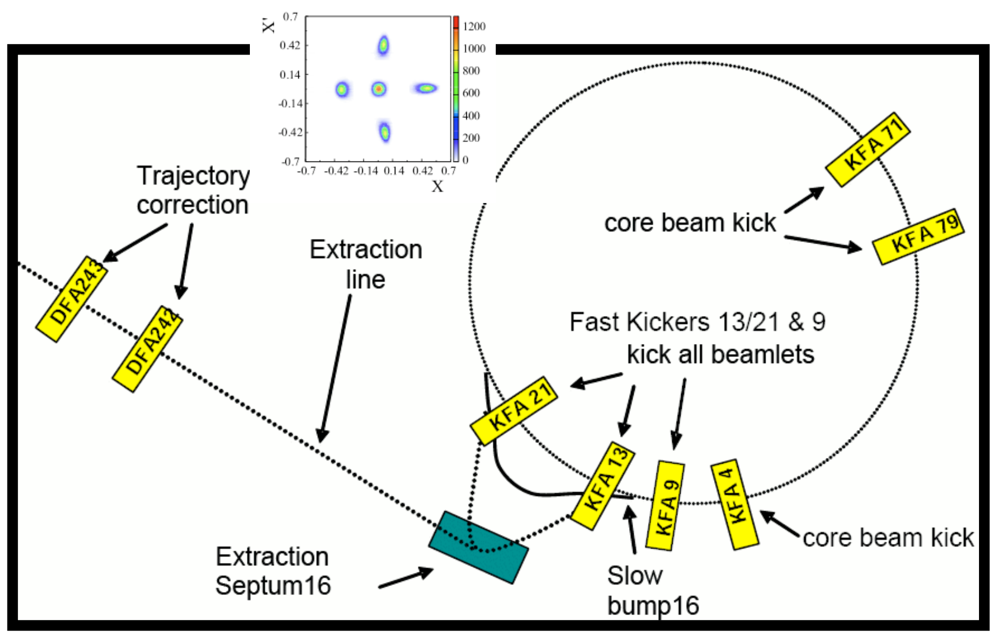
New fast bump composed by 5 independent kickers
⇒ close the fast bump on 5 turns



KFA9, KFA13, KFA21
⇒ 5 turn constant kick

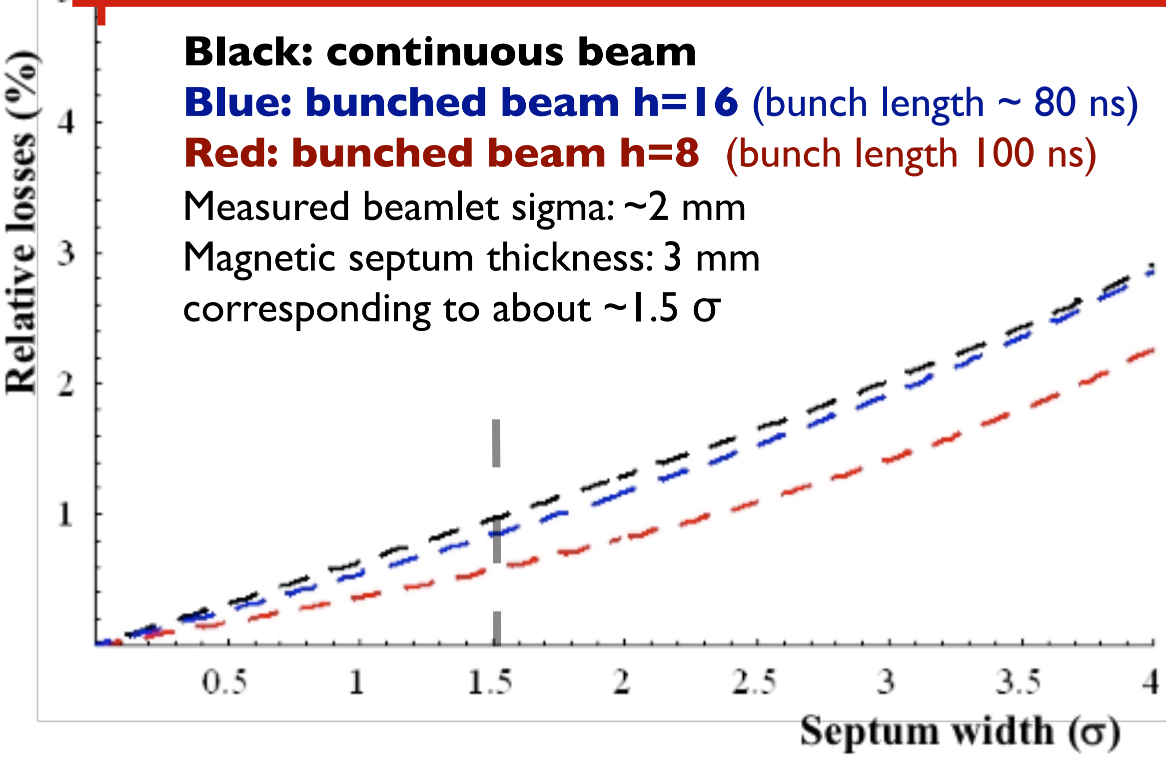
KFA71/79, KFA4
⇒ core smaller amplitudes
⇒ extra kick + trajectory correction





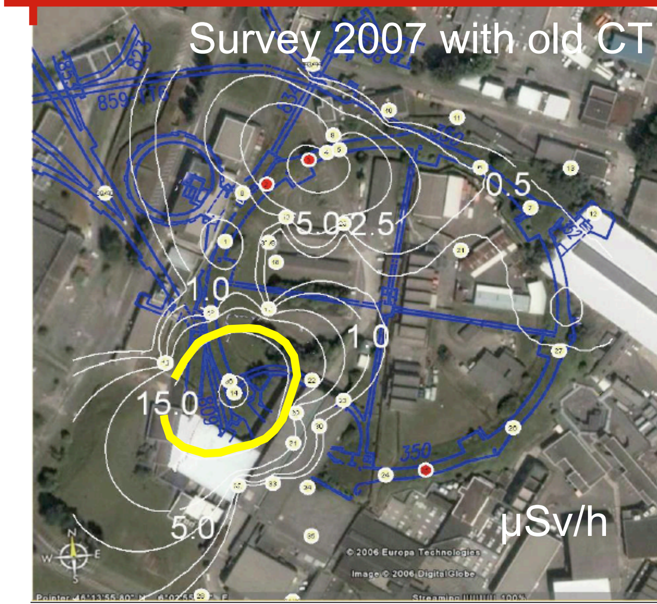
Losses vs longitudinal structure

Losses on the septum 16 depends on septum thickness, fast kicker rise time and on longitudinal bunch structure



Loss diff. between h16 and debunched is only marginal.

MD needed to understand if SPS can accept bunched beam, either h8 or h16. 200 MHz structure always there to allow trajectory measurement in TT2-TT10 - 1st turn in the SPS



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