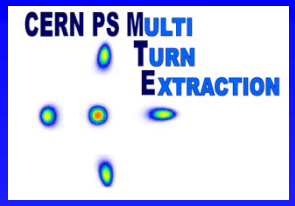


Results from the 2009 Beam Commissioning of the CERN Multi-Turn Extraction

E. Benedetto, A. Blas, T. Bohl, S. Cettour Cave, K. Cornelis, D. Cotte, H. Damerau, M. Delrieux, J. Fleuret, T. Fowler, F. Follin, A. Franchi, P. Freyermuth, H. Genoud, S. Gilardoni, M. Giovannozzi, S. Hancock, O. Hans, Y. Le Borgne, D. Manglunki, E. Matli, E. Métral, G. Métral, M. Newman, L. Pereira, F. Peters, Y. Riva, F. Roncarolo, L. Sermeus, R. Steerenberg, B. Vandorpe, J. Wenninger

Summary:

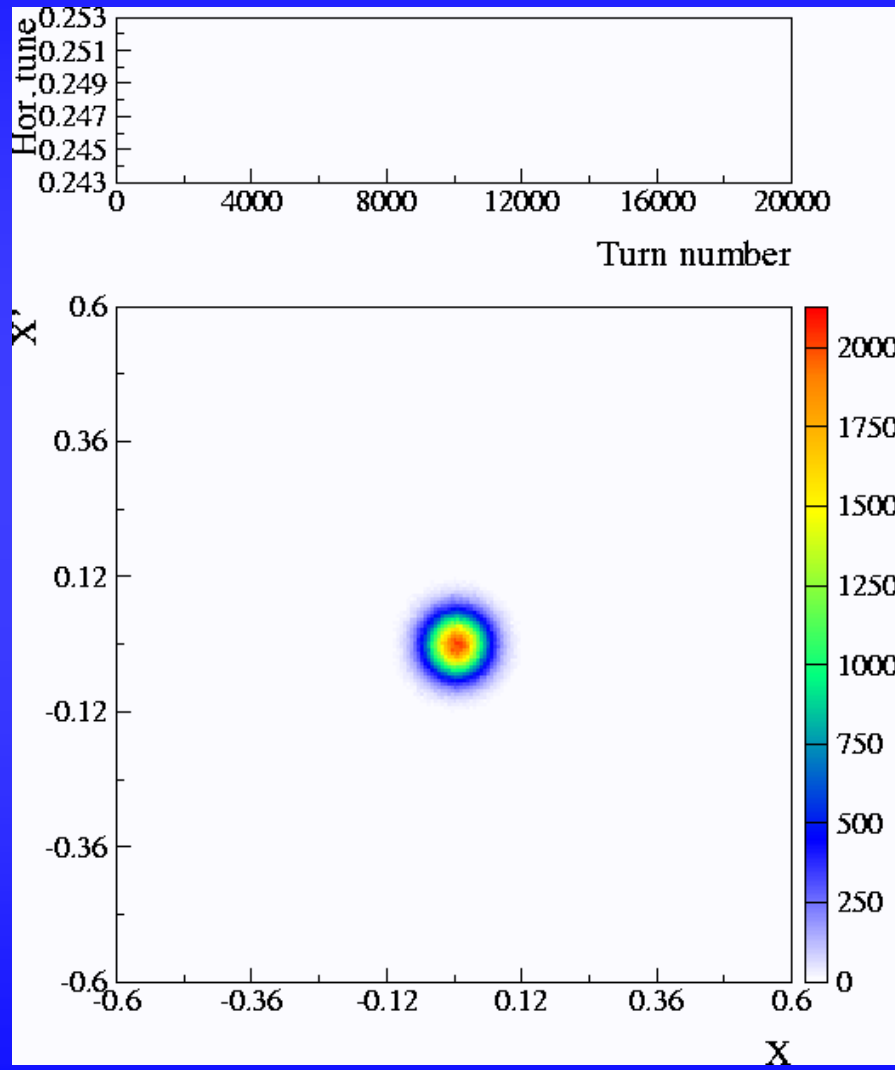
- New multi-turn extraction (MTE)
- Commissioning results 2009/10
- Outlook

CERN PS MULTI TURN EXTRACTION

Multi-turn extraction – I

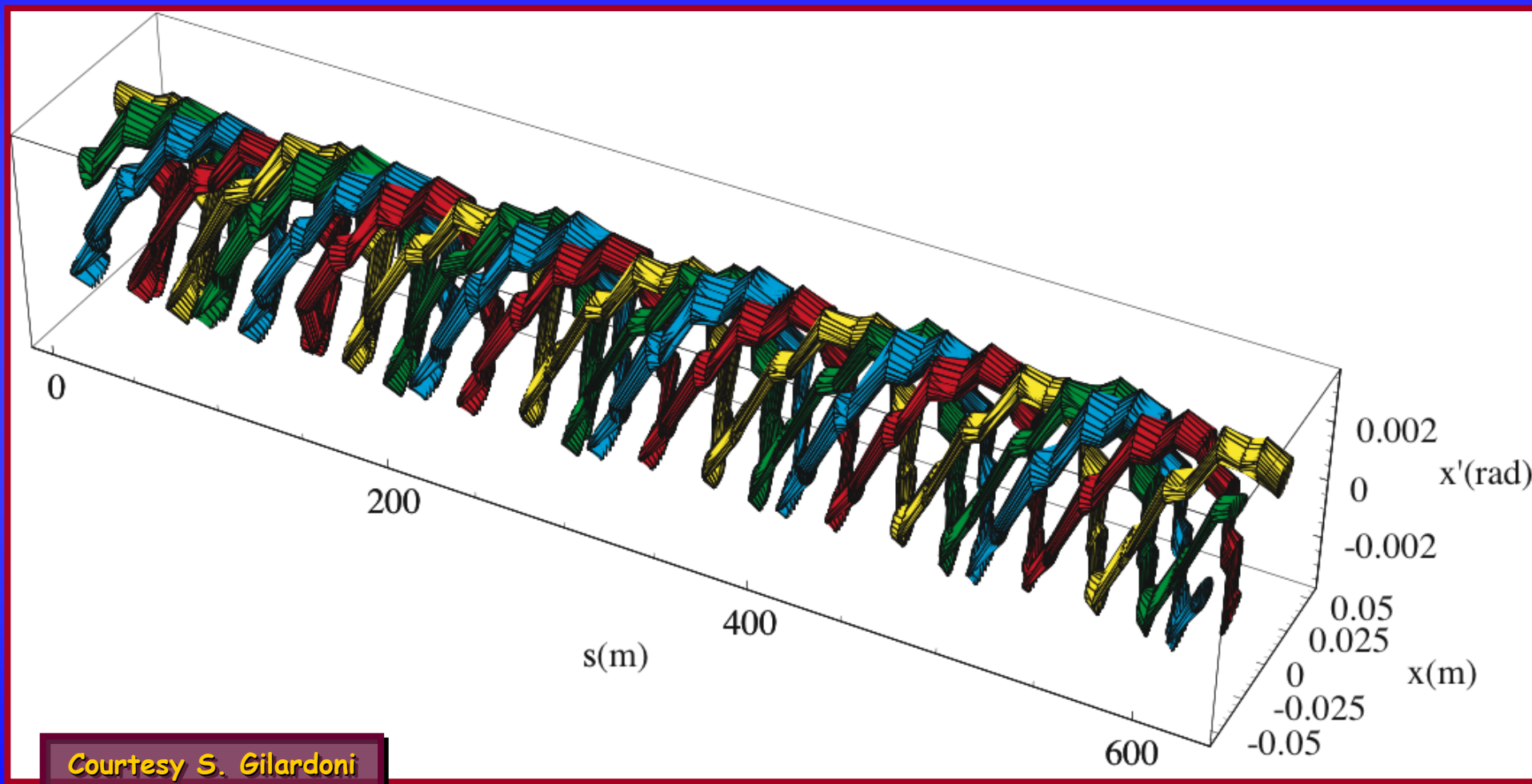
The main ingredients of the novel extraction:

- The beam is separated in the horizontal phase space using
  - Nonlinear magnetic elements (sextupoles ad octupoles) to create stable islands.
  - Slow (adiabatic) horizontal tune variation to cross an appropriate resonance.
- CERN-specific requirements
  - Extraction over five turns -> 4th order resonance
  - Equally populated turns -> (20±1)%



Multi-turn extraction - III

Final stage after 20000 turns (about 42 ms for CERN PS)

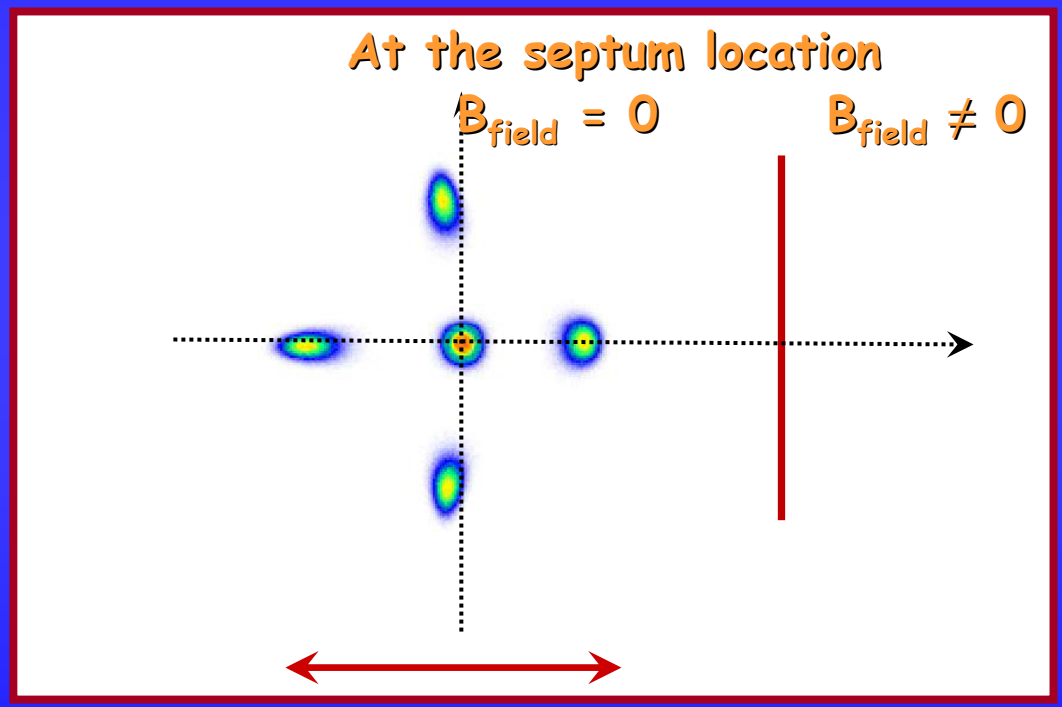


Courtesy S. Gilardoni

CERN PS MULTI TURN EXTRACTION

Multi-turn extraction - III

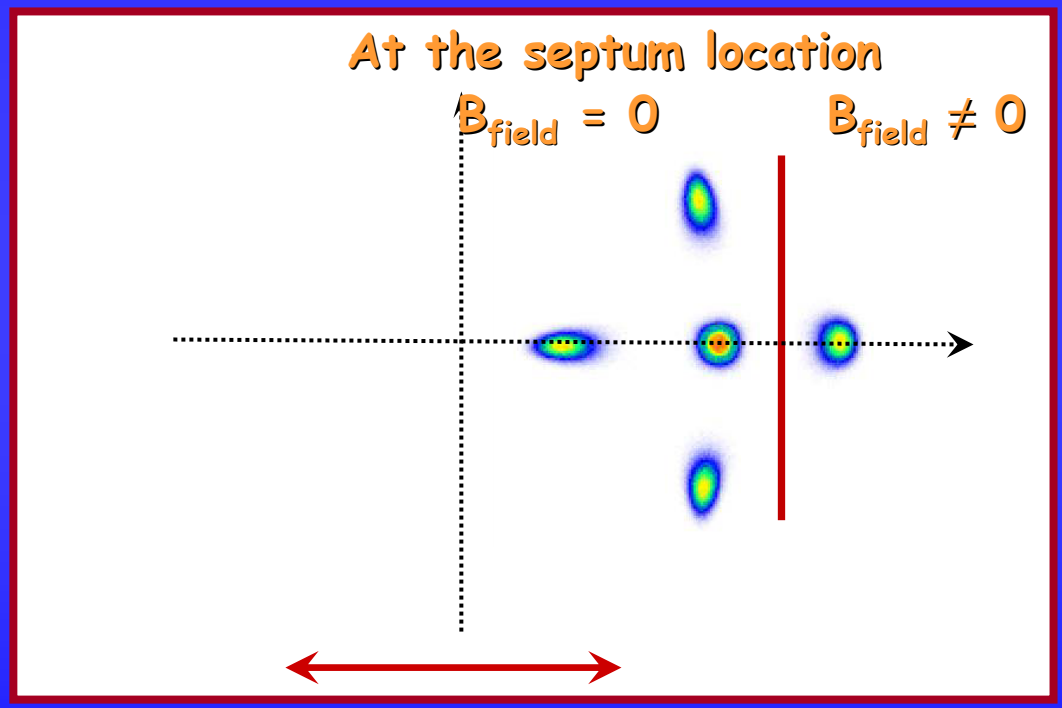
Final stage after 20000 turns (about 42 ms for CERN PS)



About 6 cm in physical space

Multi-turn extraction - III

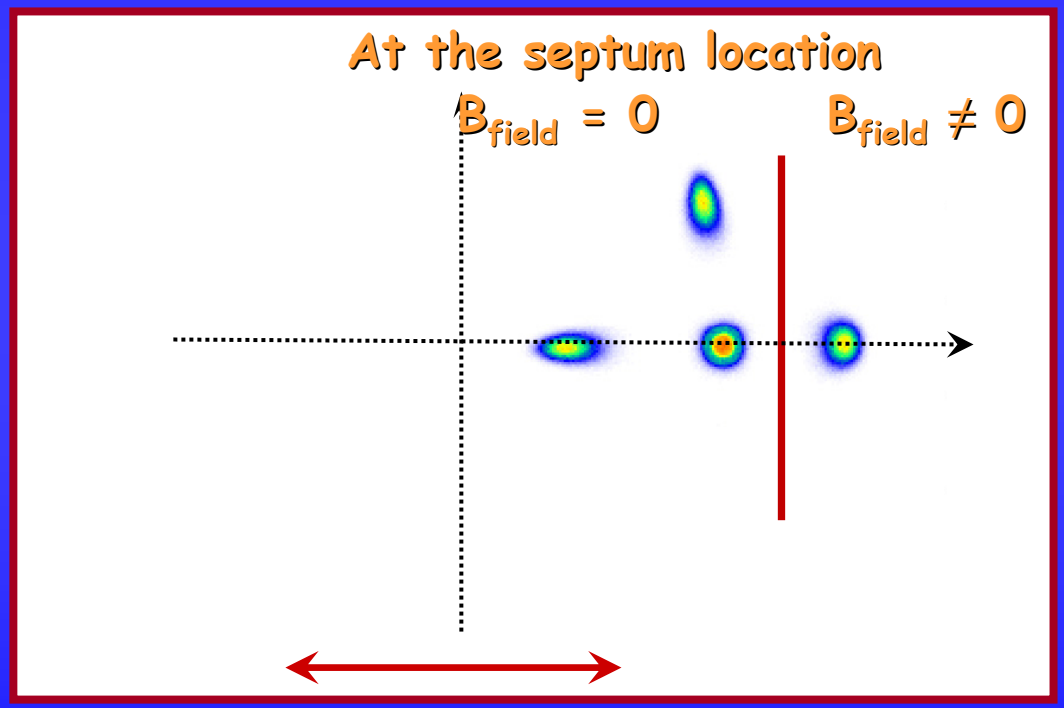
Final stage after 20000 turns (about 42 ms for CERN PS)



About 6 cm in physical space

Multi-turn extraction - III

Final stage after 20000 turns (about 42 ms for CERN PS)

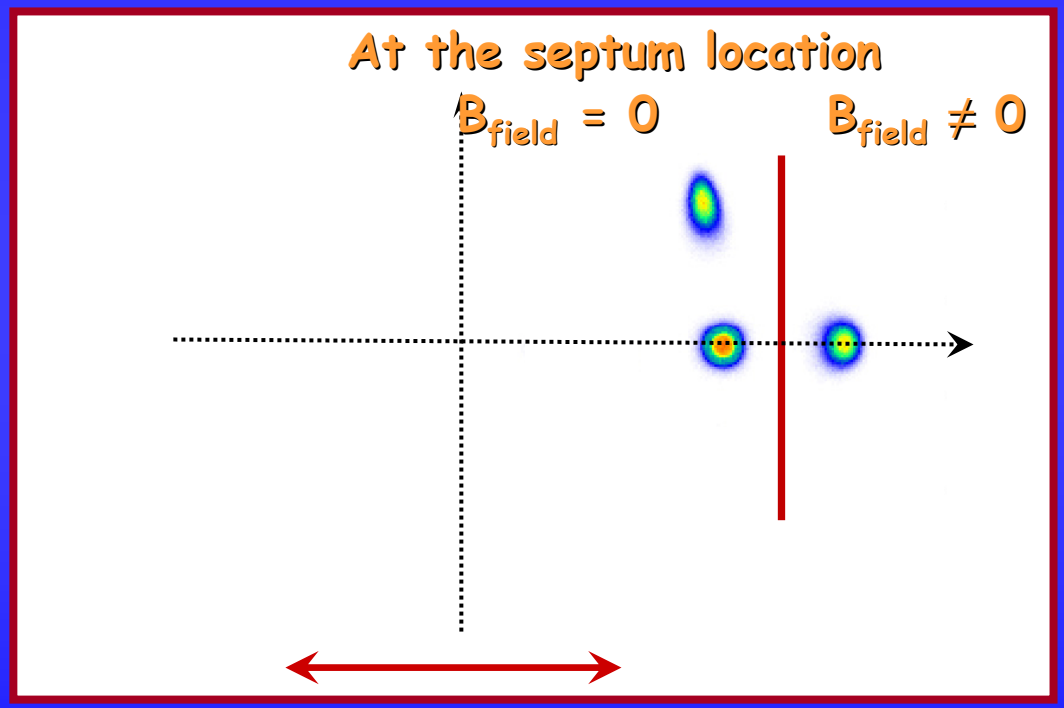


About 6 cm in physical space

CERN PS MULTI TURN EXTRACTION

Multi-turn extraction - III

Final stage after 20000 turns (about 42 ms for CERN PS)

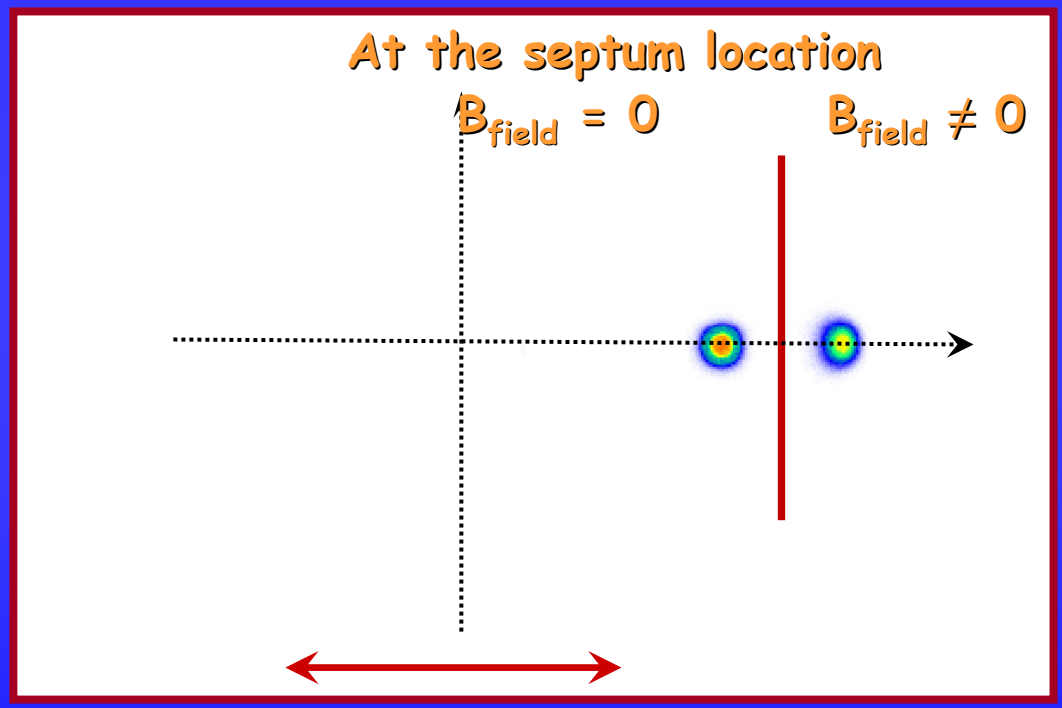


About 6 cm in physical space

CERN PS MULTI TURN EXTRACTION

Multi-turn extraction - III

Final stage after 20000 turns (about 42 ms for CERN PS)

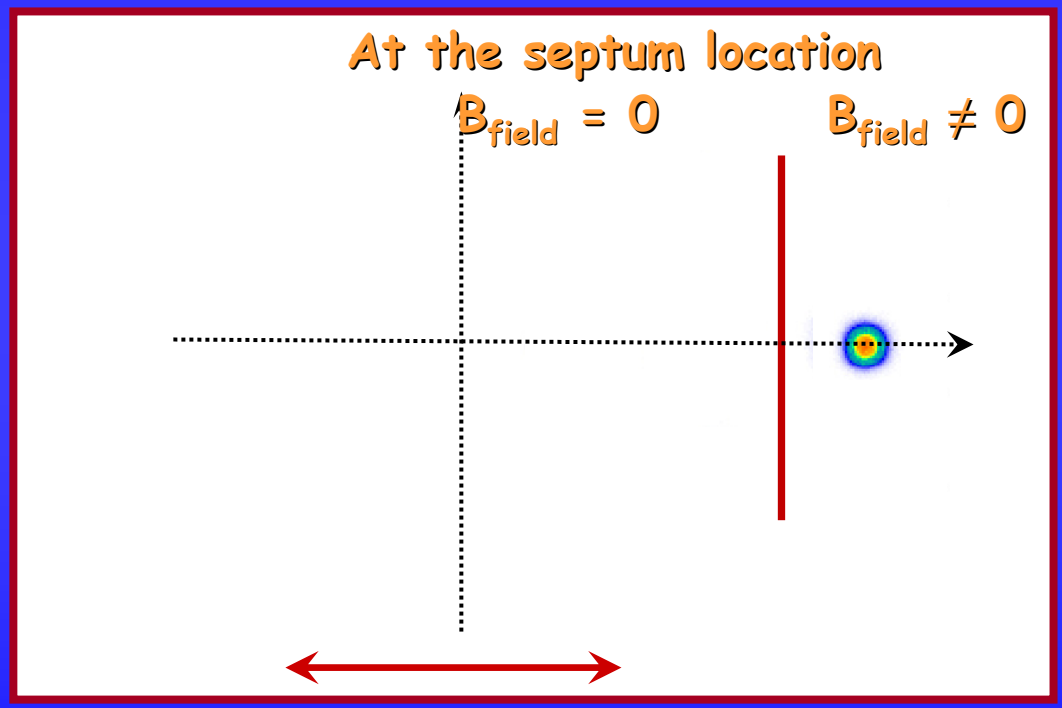


About 6 cm in physical space

CERN PS MULTI TURN EXTRACTION

Multi-turn extraction - III

Final stage after 20000 turns (about 42 ms for CERN PS)

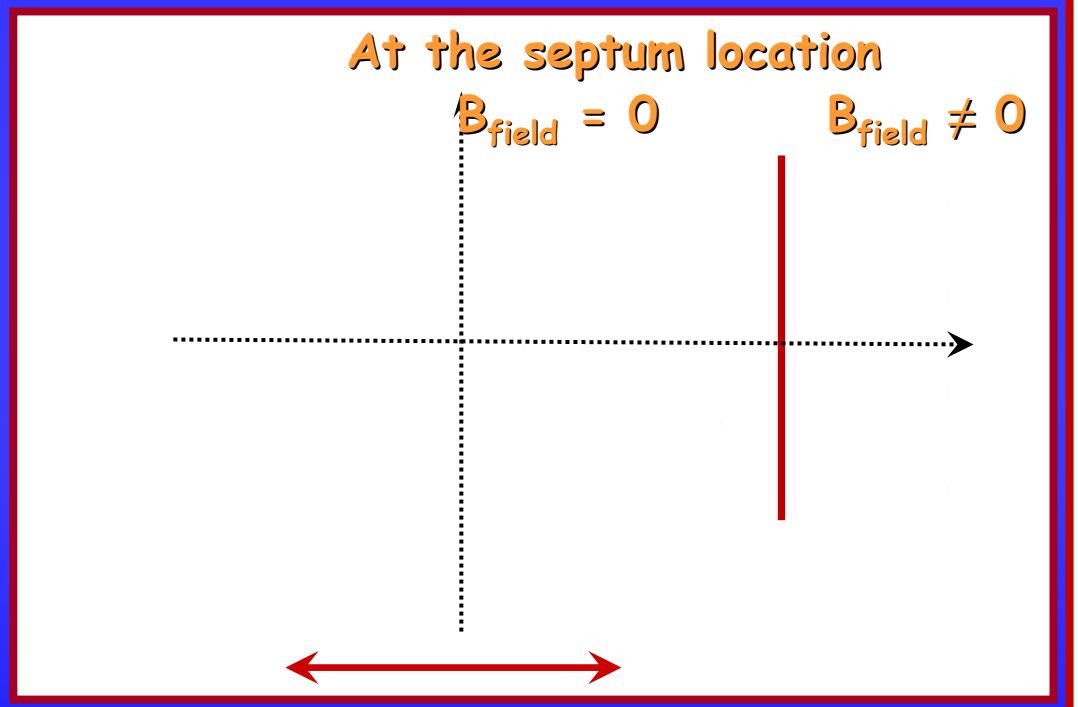


About 6 cm in physical space

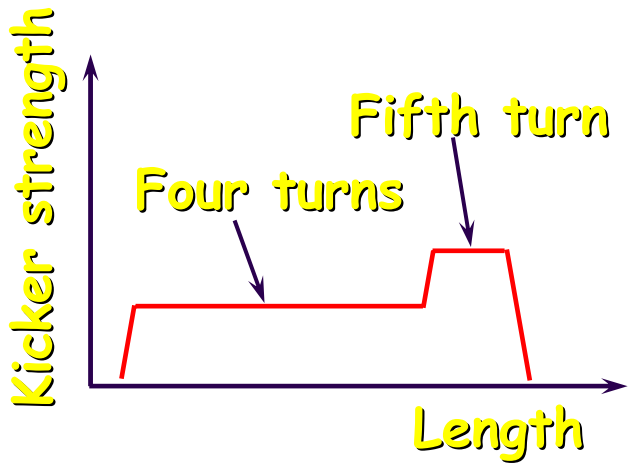
CERN PS MULTI TURN EXTRACTION

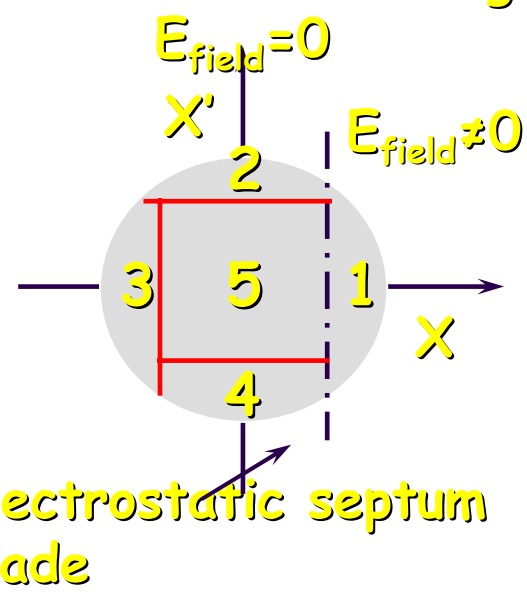
Multi-turn extraction - III

The predecessor of MTE: Continuous Transfer (CT)



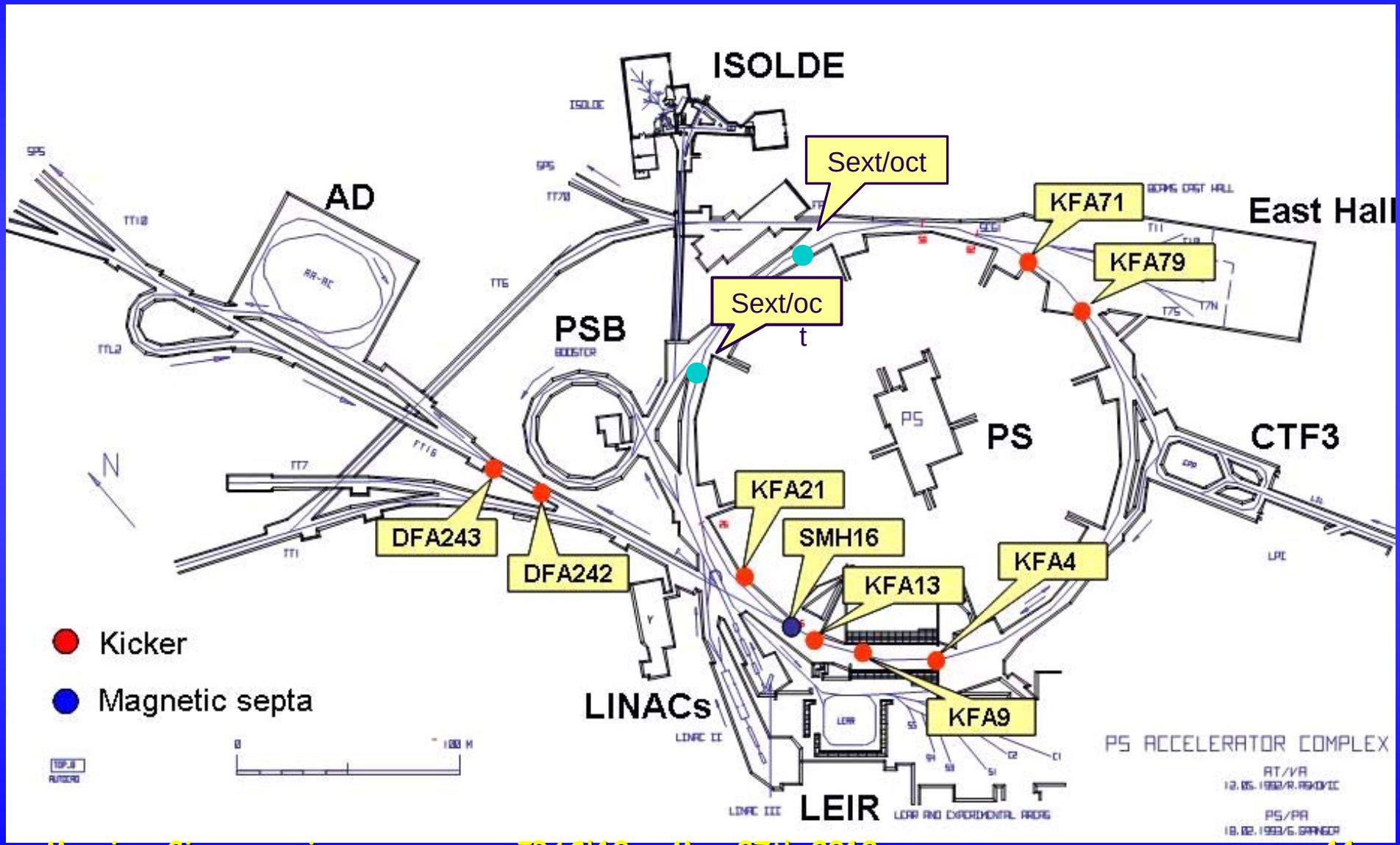
About 6 cm in physical space





CERN PS MULTI TURN EXTRACTION

Implementation of MTE



Transverse dynamics - I

Sextupoles and octupoles are used to

- Generate stable islands
- Control size/position of islands
- Control linear chromaticity
- Control non-linear coupling (using an additional set of octupoles, normally used to combat instabilities)

$$\delta Q_x = h_{2,0} J_x + h_{1,1} J_y$$
$$\delta Q_y = h_{1,1} J_x + h_{0,2} J_y$$

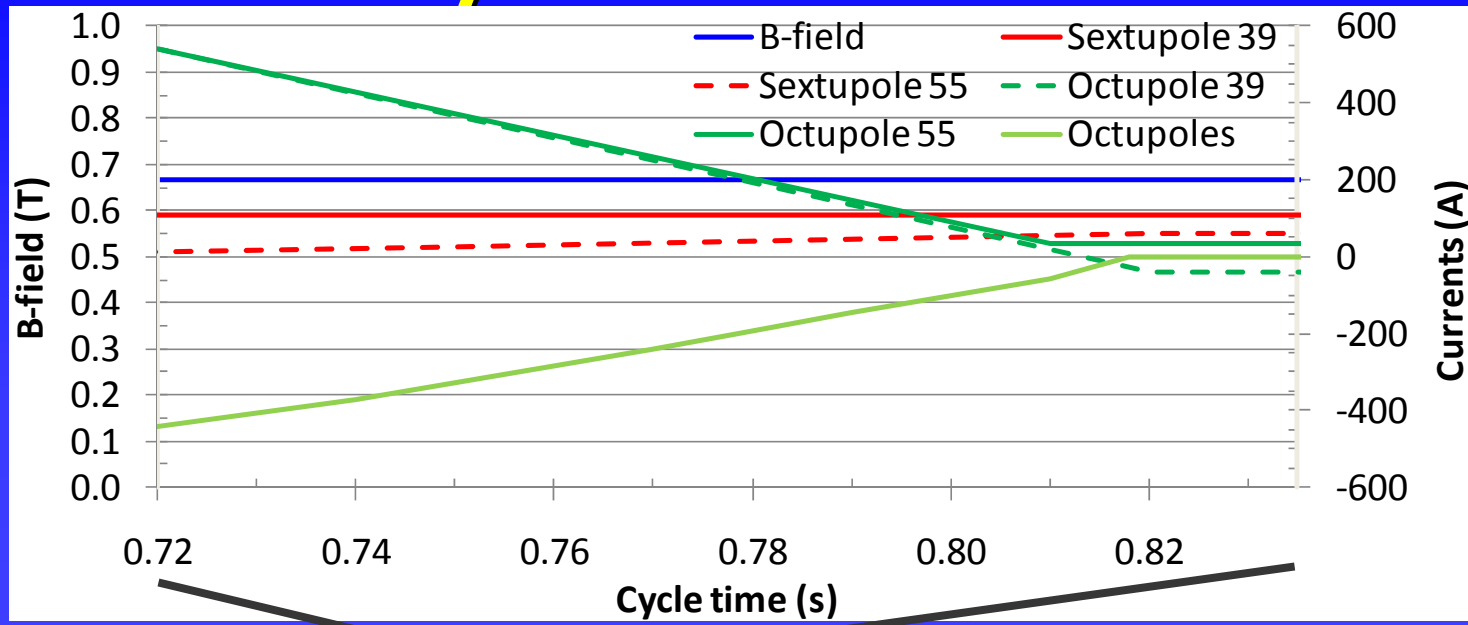
$h_{2,0}$ -> detuning with amplitude (H-plane) -> $\propto \beta_x^2 K_3$

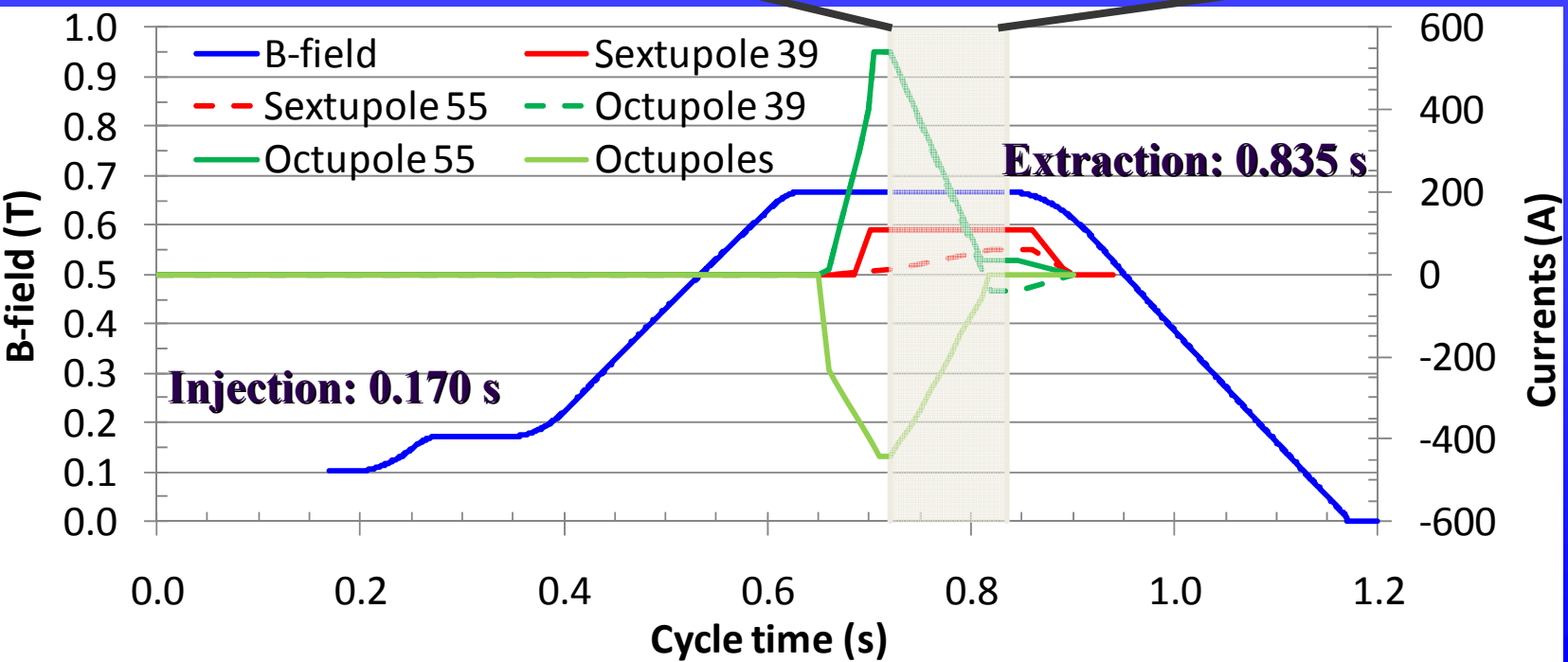
$h_{1,1}$ -> non-linear coupling -> $\propto \beta_x \beta_y K_3$

$h_{0,2}$ -> detuning with amplitude (V-plane) -> $\propto \beta_y^2 K_3$

CERN PS MULTI TURN EXTRACTION

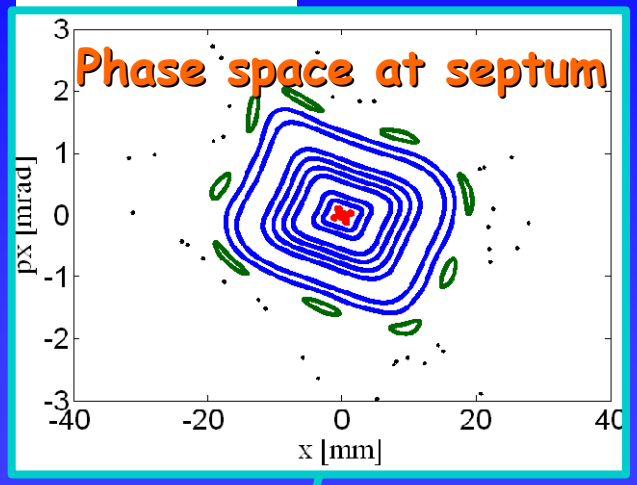
Transverse dynamics - II

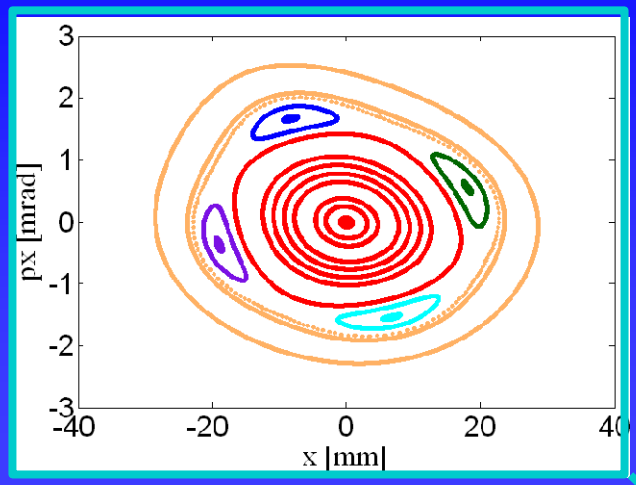


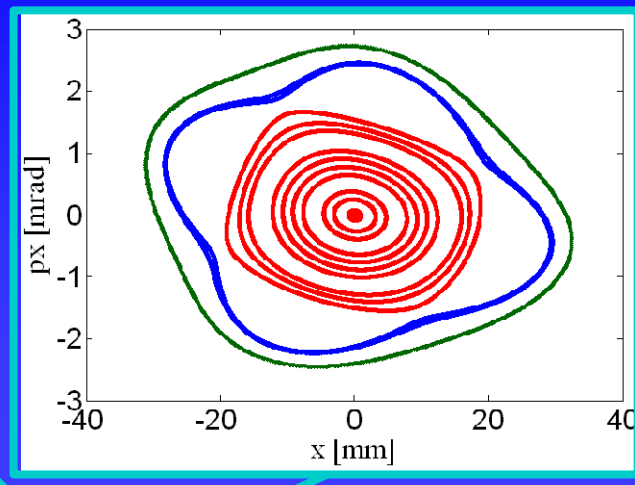


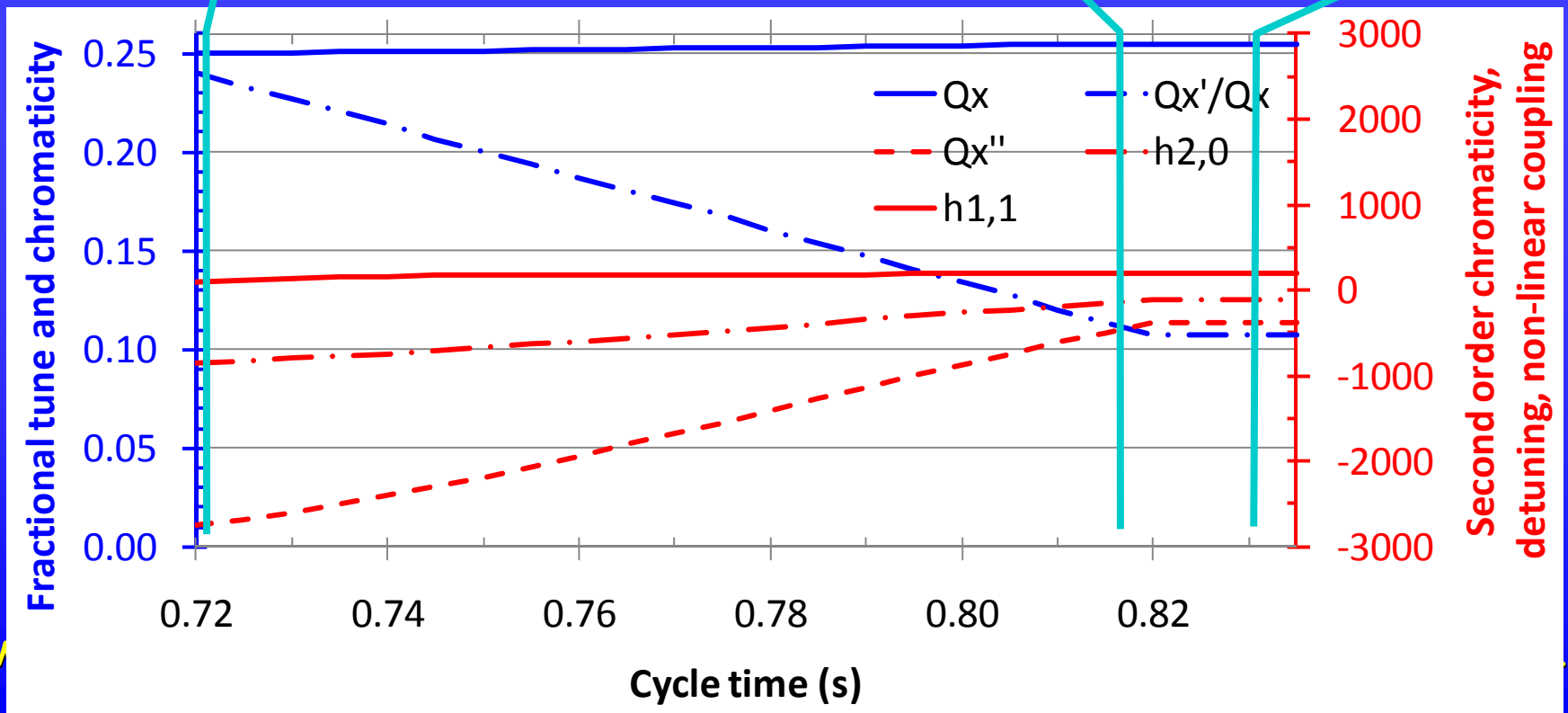
CERN PS MULTI TURN EXTRACTION

Transverse dynamics - III





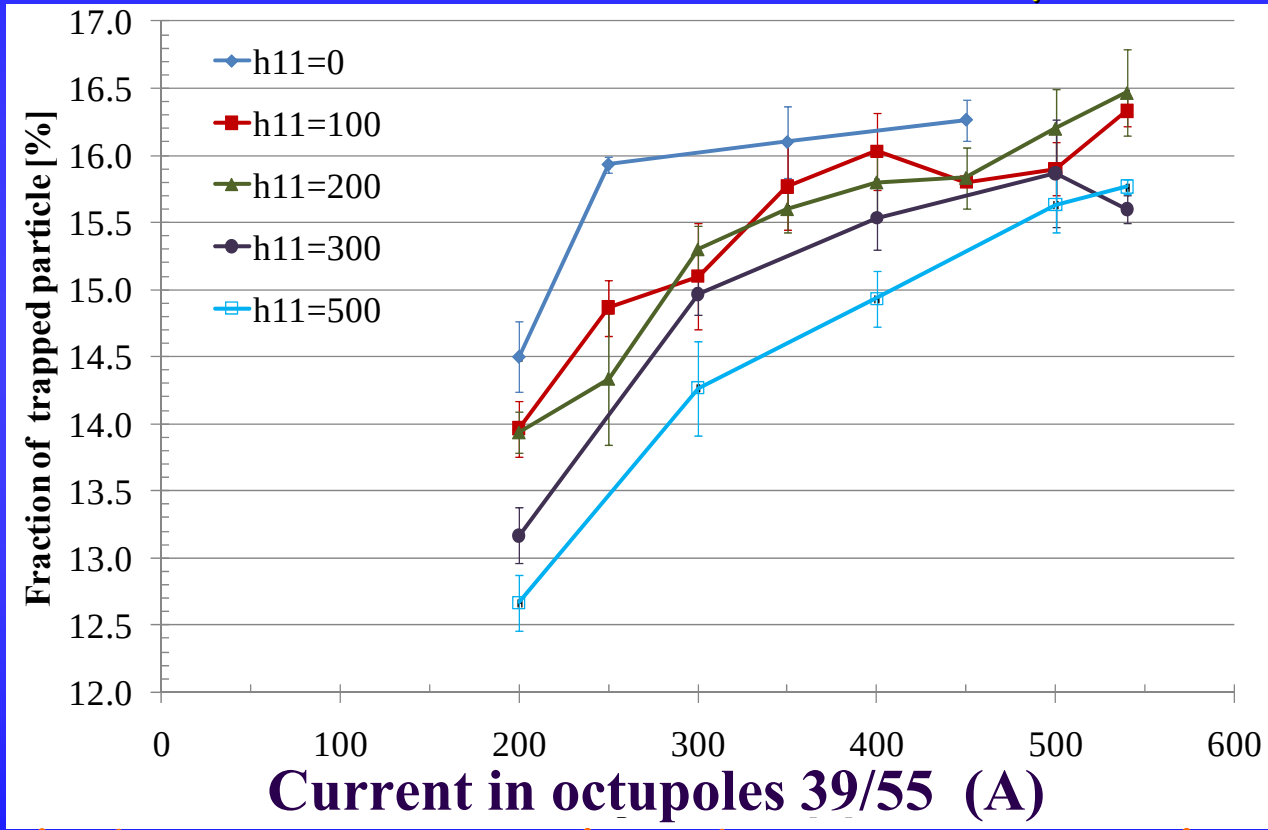




CERN PS MULTI TURN EXTRACTION

Transverse dynamics - IV

- To achieve good sharing of beam intensity between islands and core various parameters optimised ($h_{1,1}$ is rather crucial).



- Last bit achieved by exciting the beam using the transverse damper.

CERN PS MULTI TURN EXTRACTION

Improving capture: beam excitation

$$x'(t) = A\sin\left[\left(16+0.25\right) f_{rev}\, t + N(t)\right]\delta_p\left(T_{rev}\right)$$

Noise component

Effect of transverse excitation

y = -0.0185x + 0.896
R² = 0.0026

y = -0.1852x + 4.3783
R² = 0.2631

Ratio of core emittance (after and before splitting)

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

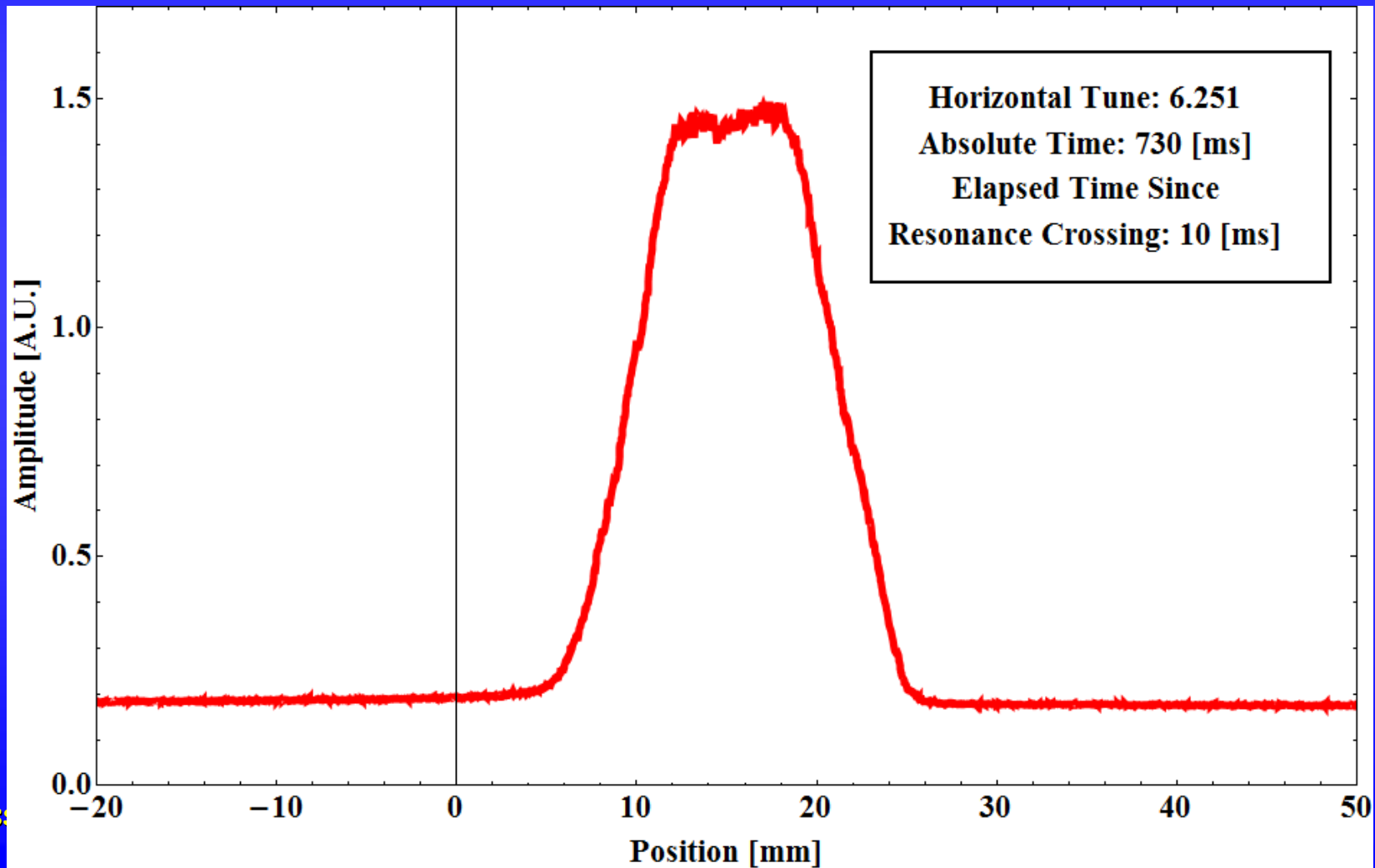
12
14
16
18
20

Fraction of particles trapped in islands (%)

CERN PS MULTI TURN EXTRACTION

Evolution of beam distribution

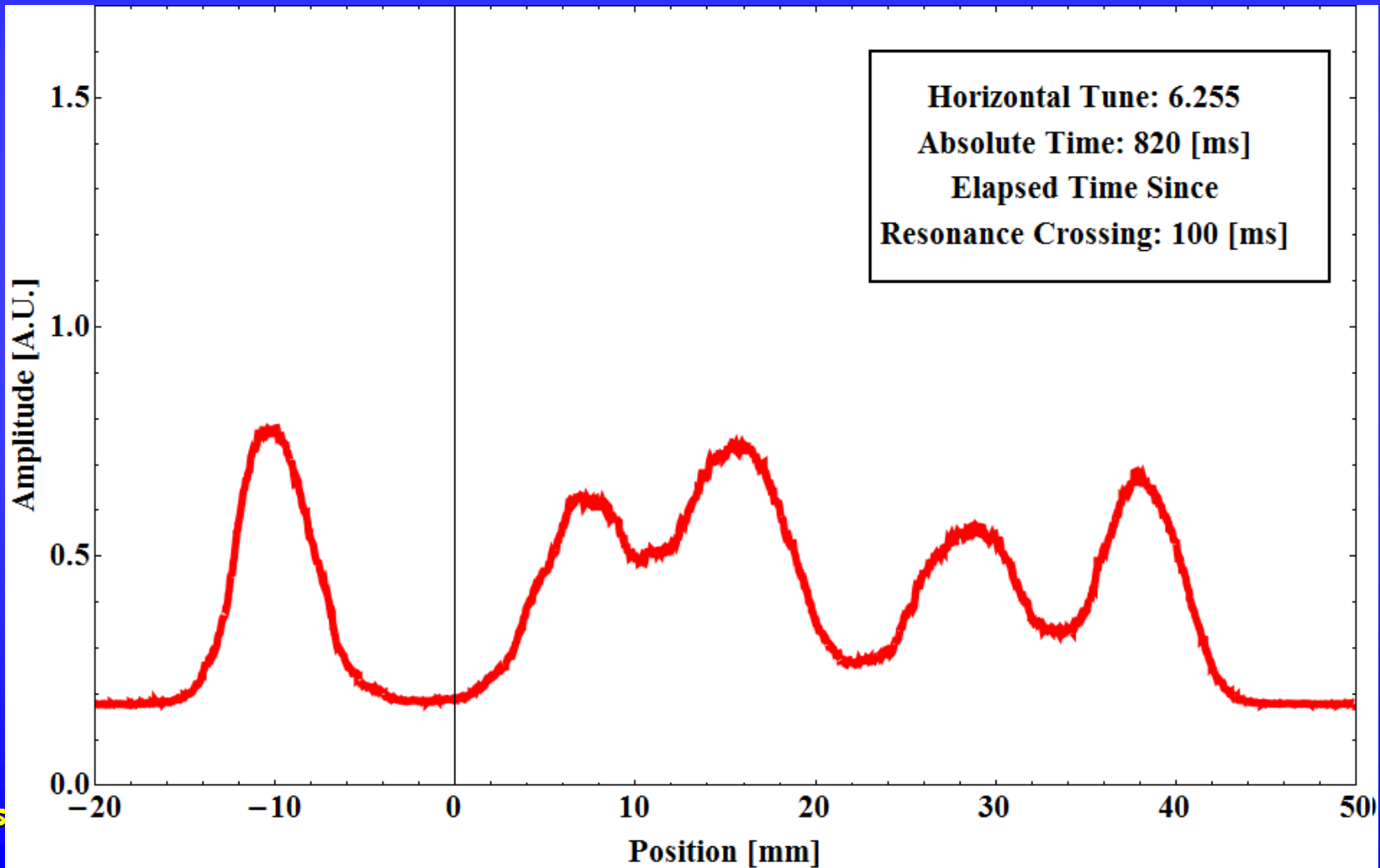
Horizontal beam profiles in section 54 have been taken during the capture process (total intensity ~2.1×10^{13}).



CERN PS MULTI TURN EXTRACTION

Evolution of beam distribution

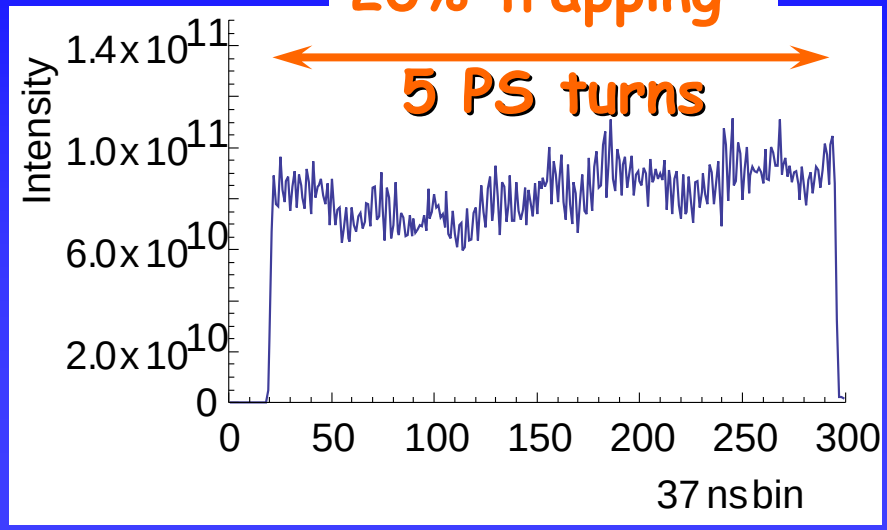
Horizontal beam profiles in section 54 have been taken during the capture process (total intensity ~2.1×10^{13}).



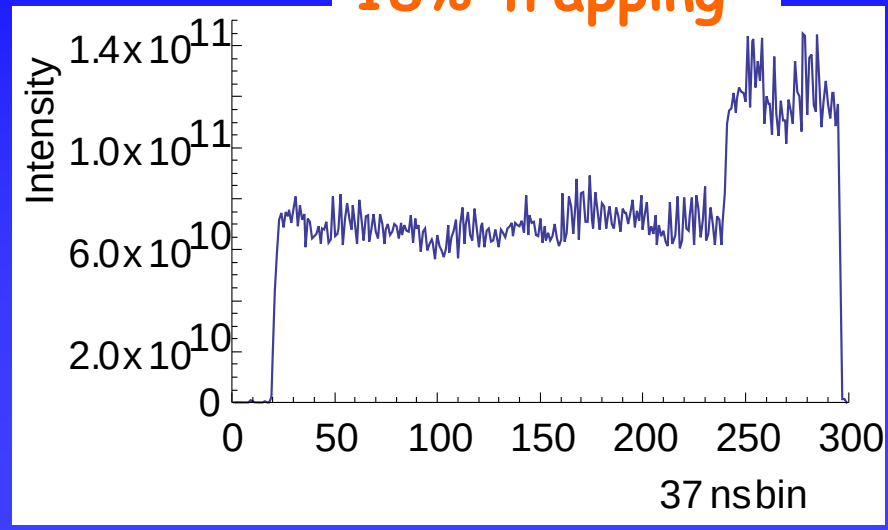
CERN PS MULTI TURN EXTRACTION

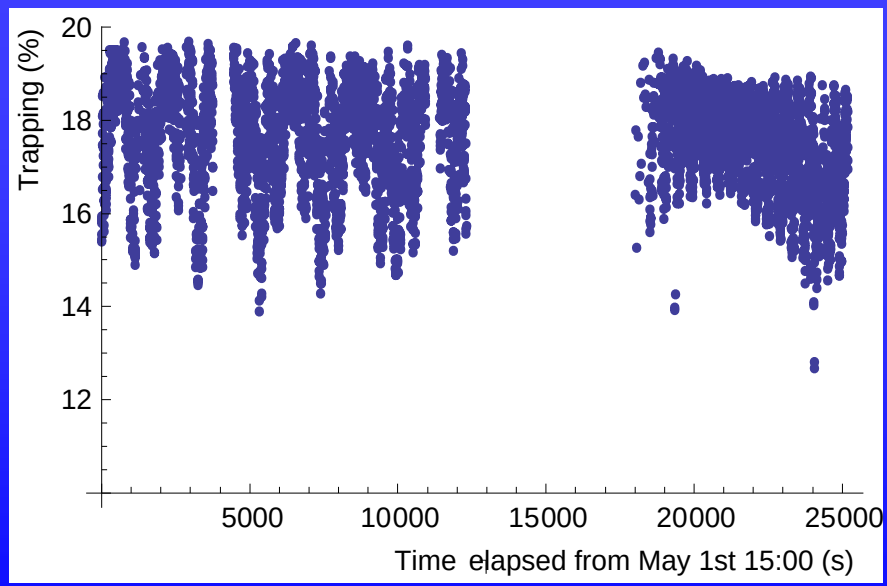
Trapping performance

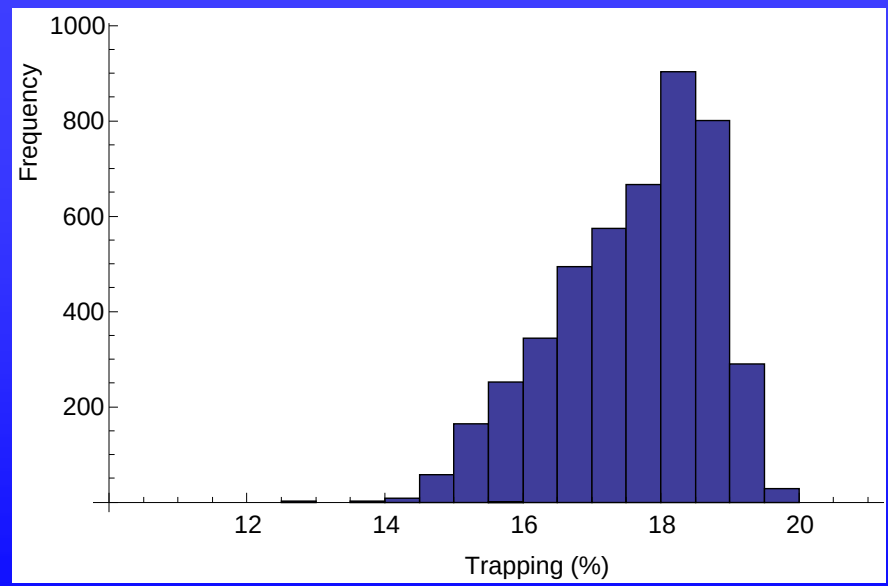
20% trapping



18% trapping



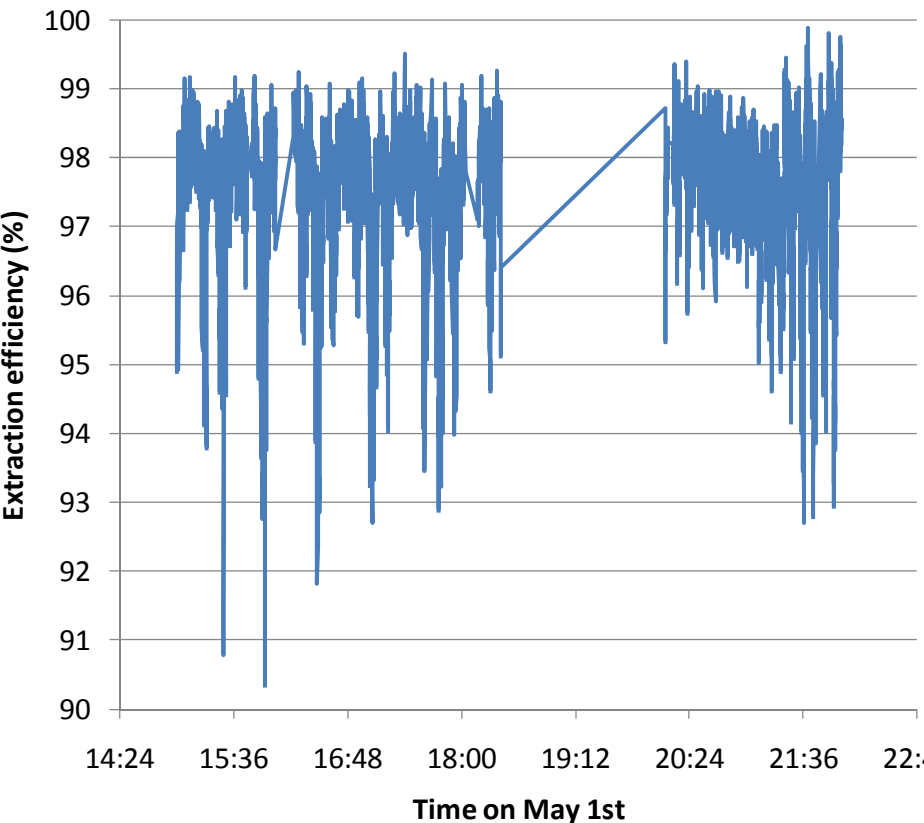


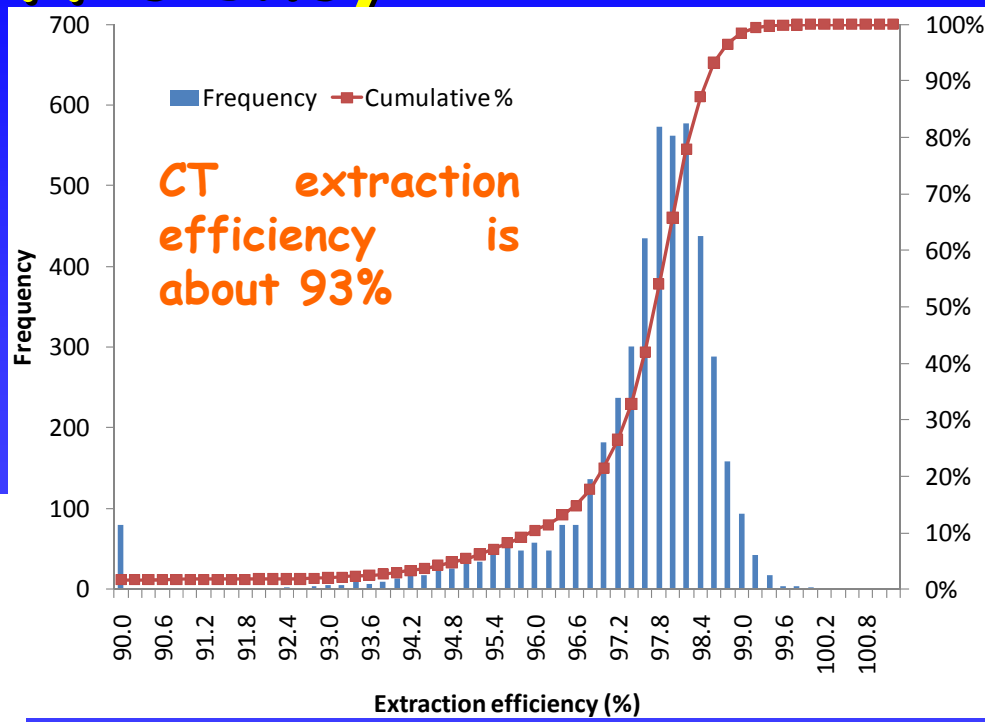


CERN PS MULTI TURN EXTRACTION

Extraction efficiency

Regular fluctuations in the extraction efficiency are also observed and seem well correlated to spill fluctuations.

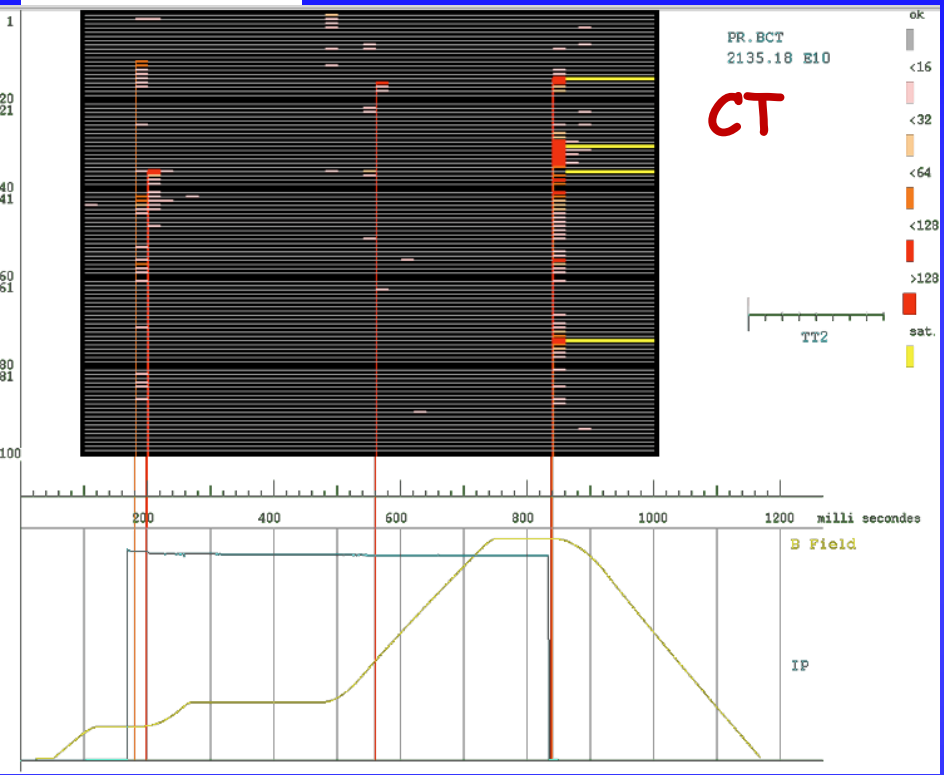


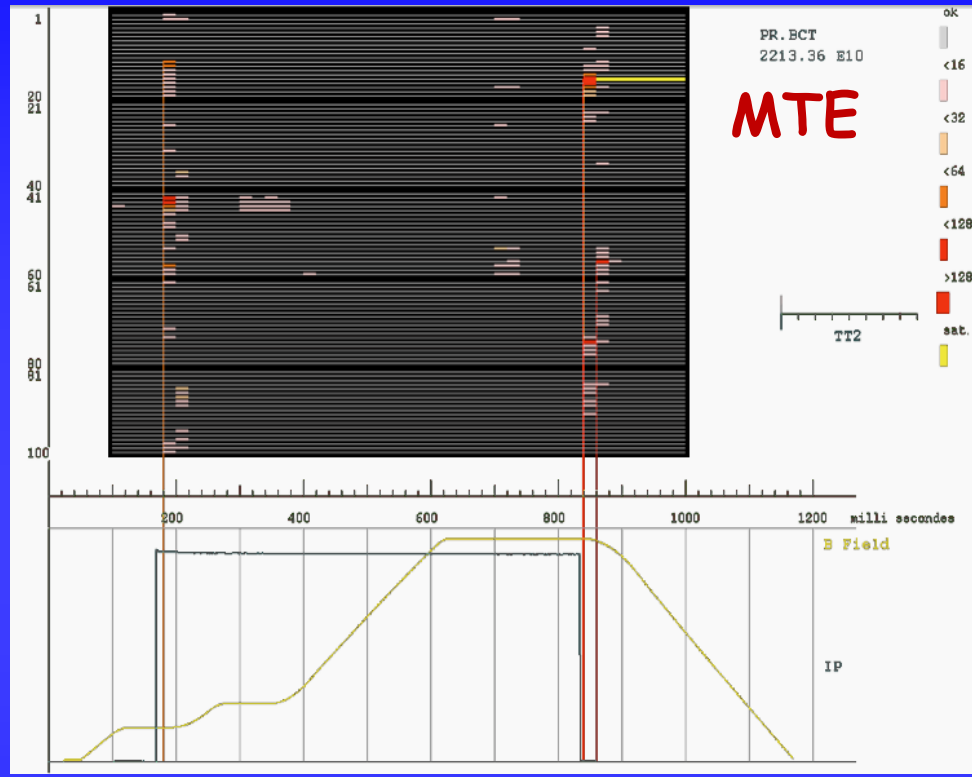


Distribution of extraction efficiency is peaked at about 98% (NB: the beam is debunched at extraction! Unavoidable beam losses are estimated at about 1-2%)

CERN PS MULTI TURN EXTRACTION

CT vs. MTE: extraction losses





- For the same extracted intensity, the CT features more losses, about the double, compared to MTE.
- The CT losses are spread around the ring whereas for MTE the losses are more concentrated on the extraction septum as anticipated in the MTE Design Report.

CERN PS MULTI TURN EXTRACTION

MTE performance in SPS

- 2009: the MTE beam was delivered to SPS as of mid-September. Total intensity delivered was about 3×10^{17} p
- 2010: commissioning activities started as of February. Physics run started with MTE beam instead of CT.
- Lower trapping in islands generates beam loading in the cavities, thus limiting the performance of the SPS.

CNGS Larger
Former teletext 111

User: CNGS2

01-May-2010 10:56:24
Last update: 1 secs ago

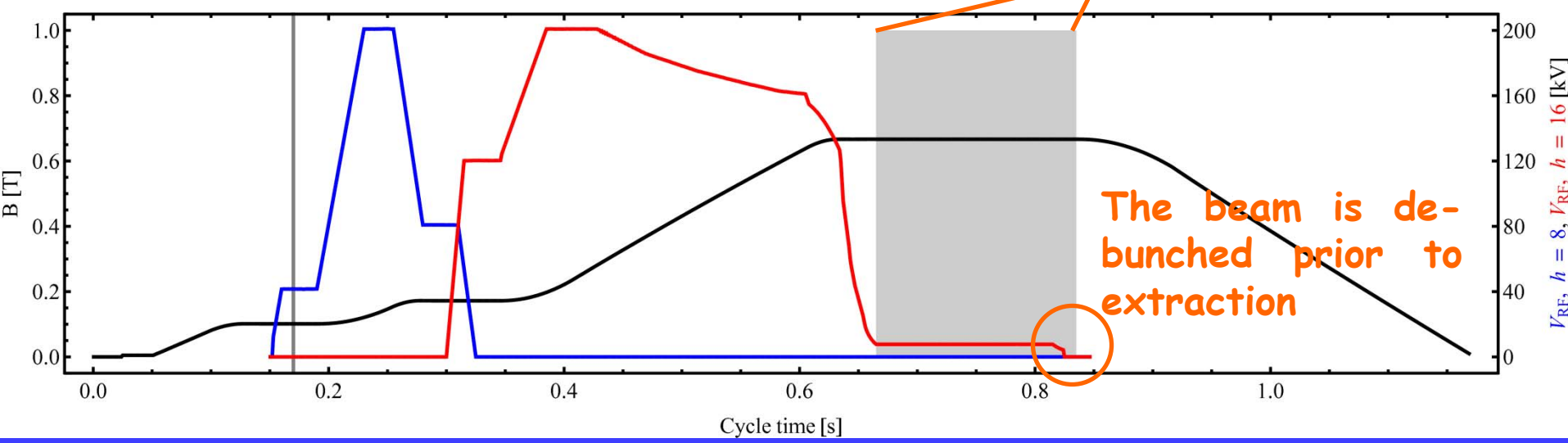
TT2	TT10	%LOSS	INJ	%LOSS
2248	2167	3.6	2035	6.1
2160	2082	3.6	1997	4.1

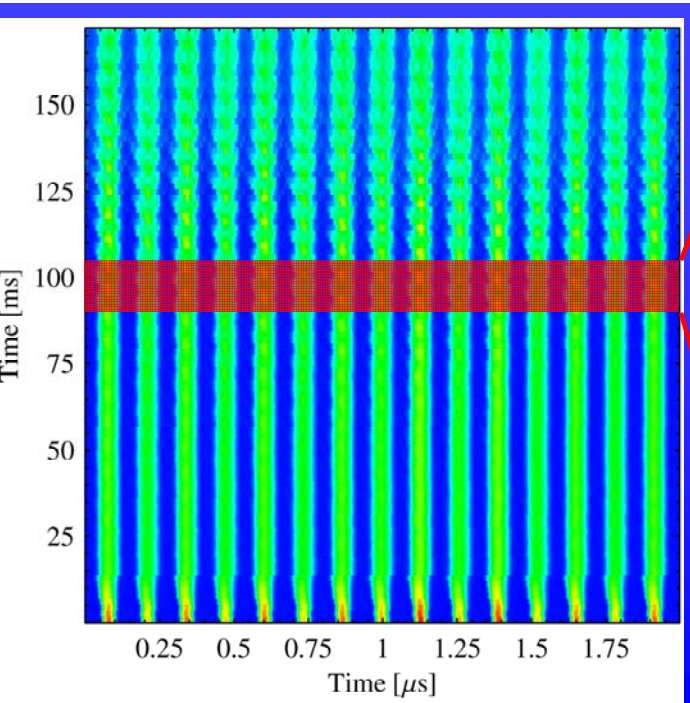
High intensity beam: peak performance

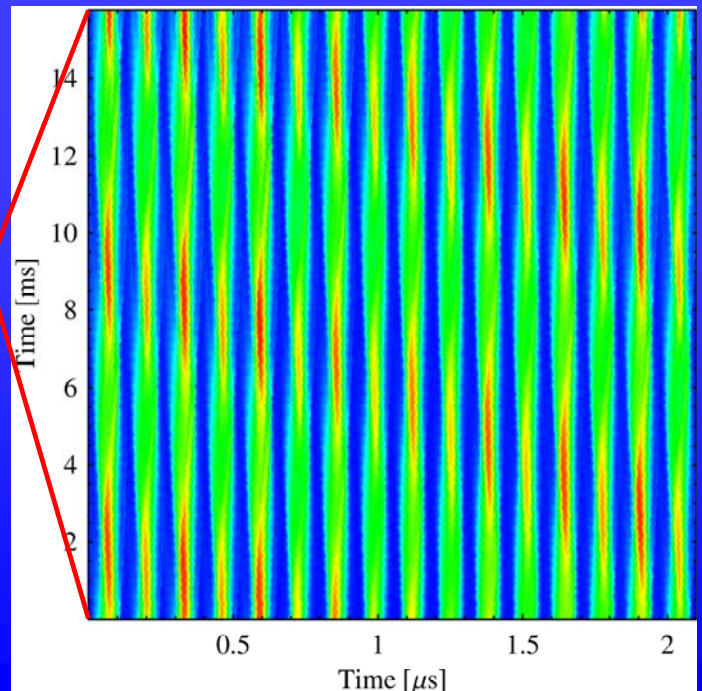
	I/E10	%LOSS	%TRNS	TIME/ms
INJECT	3985	5.1	95	1210
END_FB	3950	2.0	98	1260
20 GeV/c	3834	2.9	95	1470
27 GeV/c	3782	1.4	94	1530
50 GeV/c	3752	0.8	93	1740
400 GeV/c	3743	0.3	93	4200

SC: 28750 LOSS @ FB: 2.3%

Longitudinal dynamics





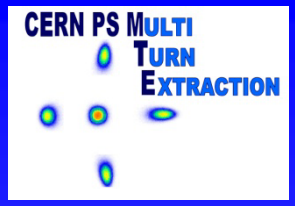


Longitudinal coupled-bunch instability of quadrupolar mode

CERN PS MULTI TURN EXTRACTION

Outlook

- First MTE beam delivered to the SPS by mid-September 2009 (about 1.5×10^{13} p/extraction).
- Equal sharing between islands and core achieved by the end of 2009.
- In February 2010 the commissioning was resumed.
- High intensity beam was extracted (about 2.1×10^{13} p/extraction) with record intensity 2.6×10^{13} p/extraction.
- 2010 physics run at SPS was started using MTE beam.
- Open issues:
  - Periodic variation of the fraction of particles trapped in islands.
  - Activation of extraction septum due to the extraction losses related to the longitudinal structure of the extracted beam (de-bunched as needed by the SPS).



Acknowledgments

- G. Arduini, M. Chanel, K. Hanke, R. Louwerse, J. Tuckmantel, U. Wehrle
- PS-Booster, PS, and SPS operations crew and machine supervisors.
- Beam instrumentation, power converter, kicker experts.
- Radioprotection experts.