MULTITURN EXTRACTION BASED ON TRAPPING IN STABLE ISLANDS AT CERN PS: RECENT MEASUREMENT ADVANCES

M. Giovannozzi

and

R. Cappi, S. Gilardoni, M. Martini, E. Métral,
A. Sakumi, R. Steerenberg, CERN
A.-S. Müller, ISS, Forschungszentrum Karlsruhe

Summary:

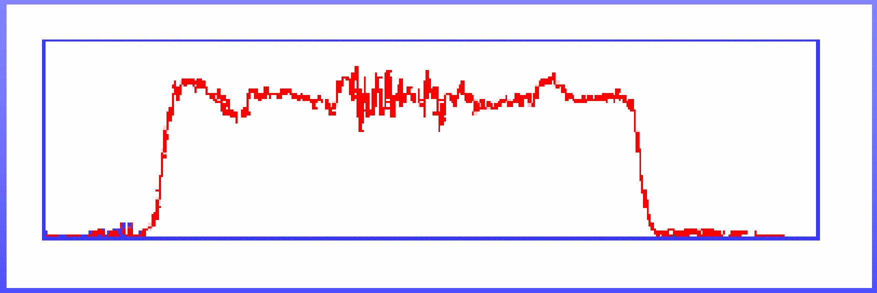
- Present multiturn extraction
- New multiturn extraction
- Measurements: phase space reconstruction
- Measurements: trapping low-intensity beam
- Measurements: trapping high-intensity beam

Introduction: why multiturn extraction?

- The beam has to be "manipulated" to increase the effective length beyond the machine circumference.
- AT CERN this mode is used to transfer the proton beam between PS and SPS. In the SPS the beam is used for
  - Fixed Target physics (broad sense)
  - Neutrino experiments (until 1998)
  - CERN Neutrino to Gran Sasso (CNGS) (from 2006)
- These beams are high-intensity (about 3×10^{13} p in the PS). An intensity upgrade for CNGS is under consideration (about 4.8×10^{13} p in the PS, corresponding to 8 bunches of 6×10^{12} p each).

Present multiturn extraction – I

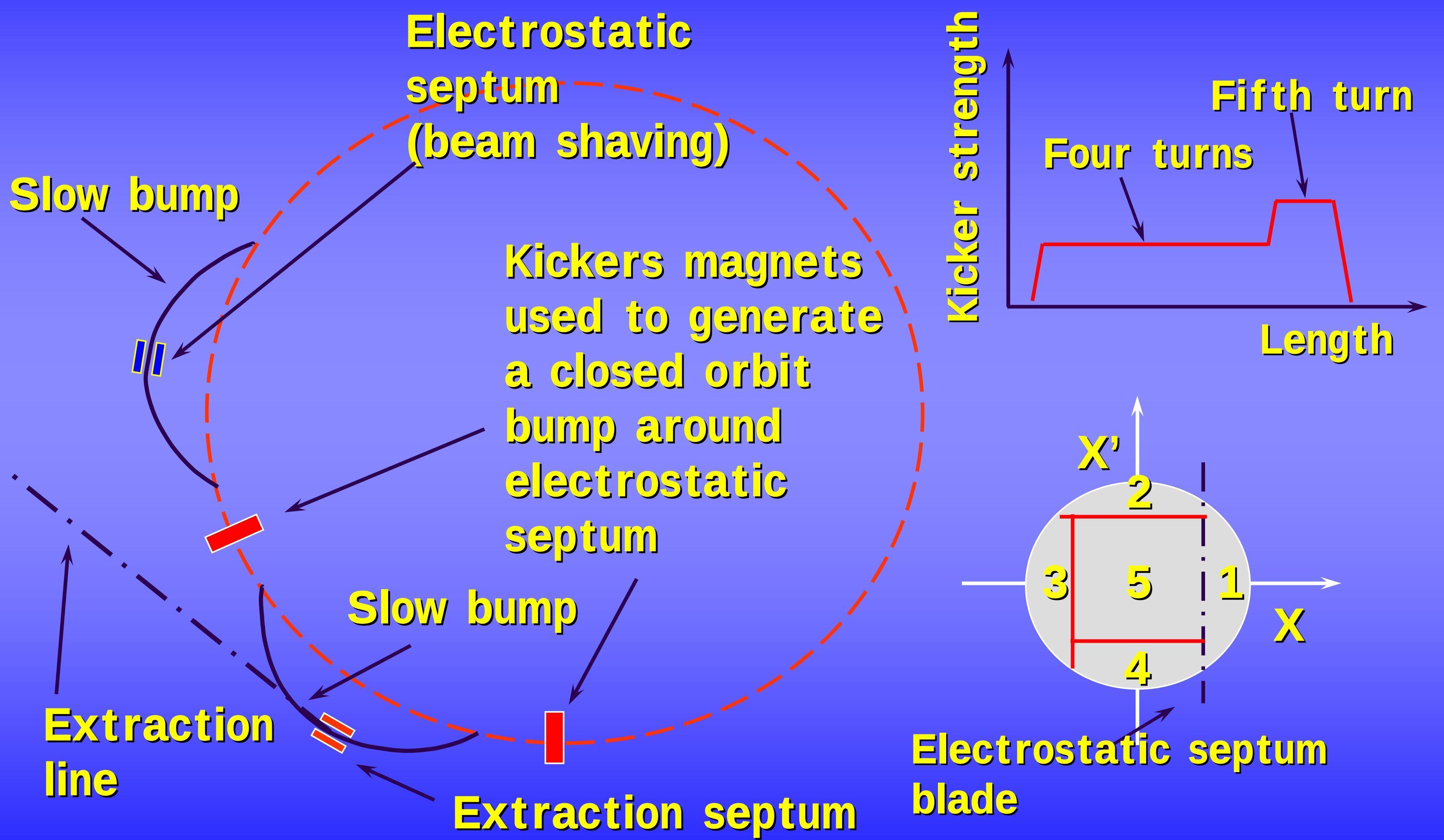
$C_{SPS} = 11\ C_{PS}$



Beam current transformer in the PS/SPS transfer line

1 2 3 4 5 (total spill duration 0.010 ms)

Present multiturn extraction – II



Present multiturn extraction – III

The main drawbacks of the present scheme are:

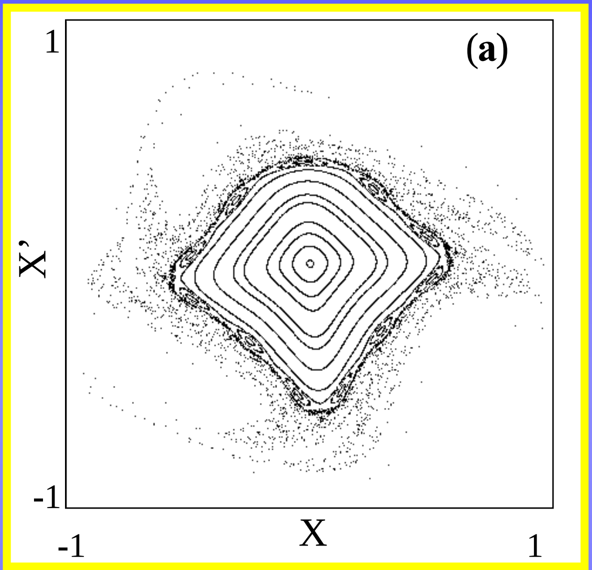
- Losses (about 15% of total intensity) are unavoidable due to the presence of the electrostatic septum used to slice the beam.
- The electrostatic septum is irradiated. This poses problems for hands-on maintenance.
- The phase space matching is not optimal (the various slices have "fancy shapes"), thus inducing betatronic mismatch in the receiving machine, i.e. emittance blow-up.
- The slices have different emittances and optical parameters.

Novel multiturn extraction – I

The main ingredients of the novel extraction:

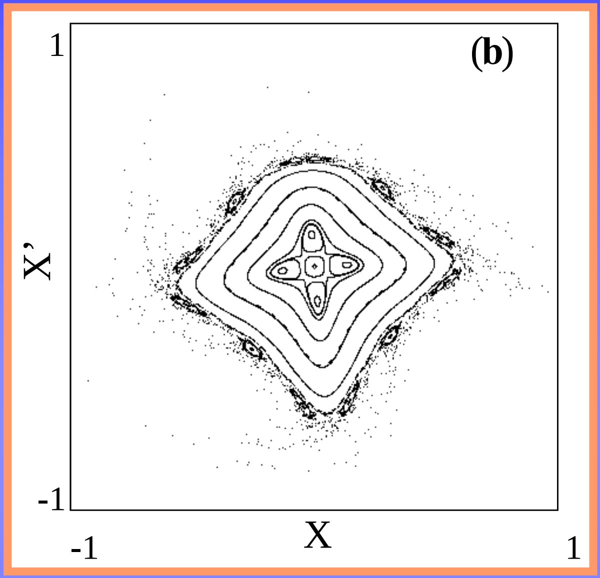
- The beam splitting is not performed using a mechanical device, thus avoiding losses. Indeed, the beam is separated in the transverse phase space using
  - Nonlinear magnetic elements (sextupoles ad octupoles) to create stable islands.
  - Slow (adiabatic) tune-variation to cross an appropriate resonance.
- This approach has the following beneficial effects:
  - Losses are reduced (virtually to zero).
  - The phase space matching is improved with respect to the present situation.
  - The beamlets have the same emittance and optical parameters.

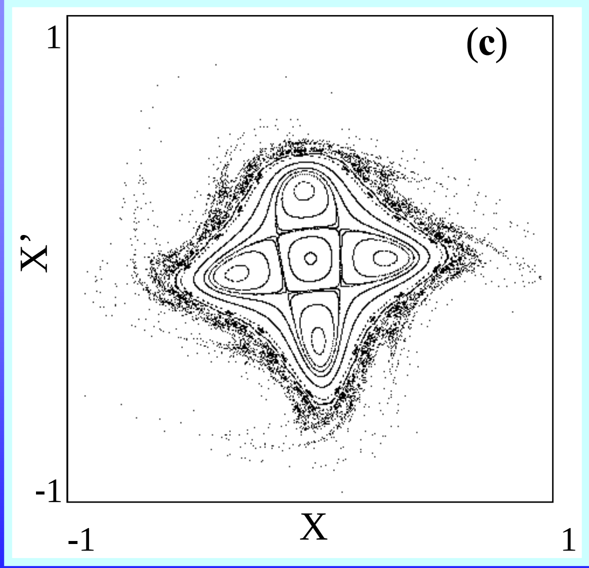
Novel multiturn extraction – II



Left: initial phase space topology. No islands.

Right: intermediate phase space topology. Islands are created near the centre.



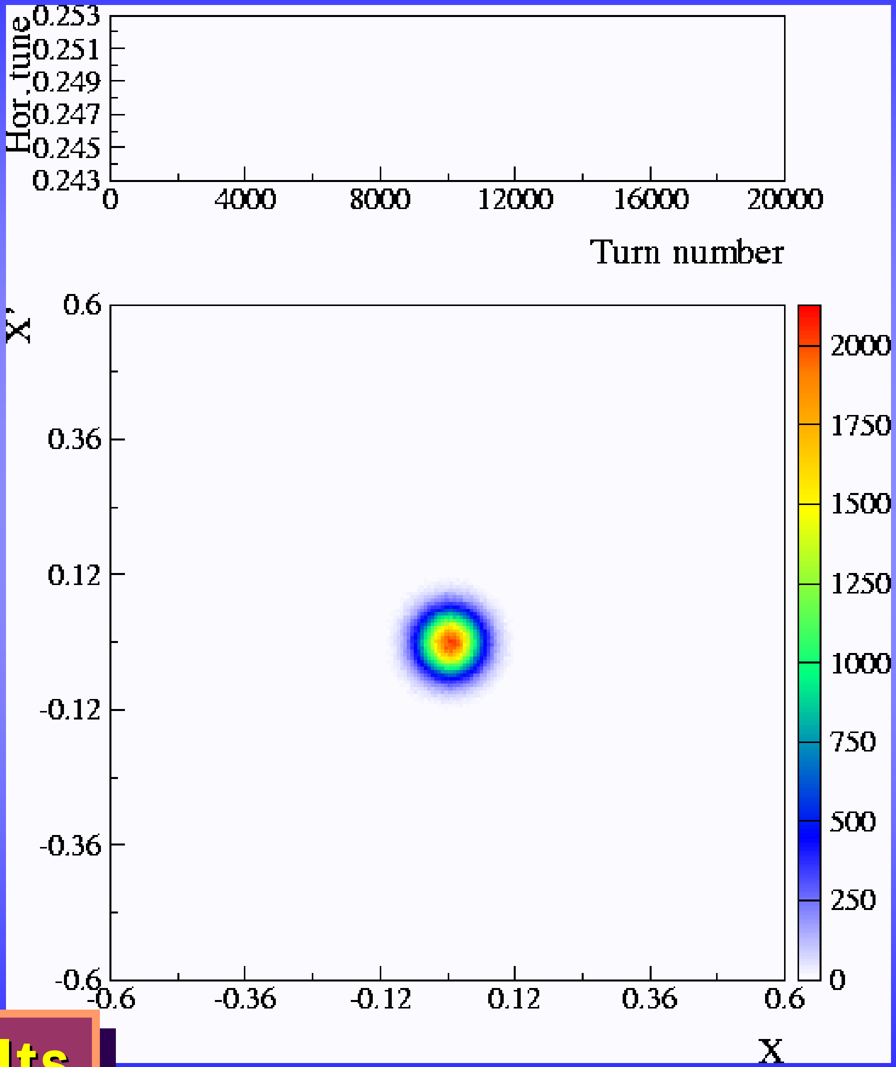


Bottom: final phase space topology. Islands are separated to allow extraction.

Novel multiturn extraction - III

Tune variation

Phase space portrait



2D polynomial mapping representing a FODO cell with sextupole and octupole

Simulation results

Measurement Campaign

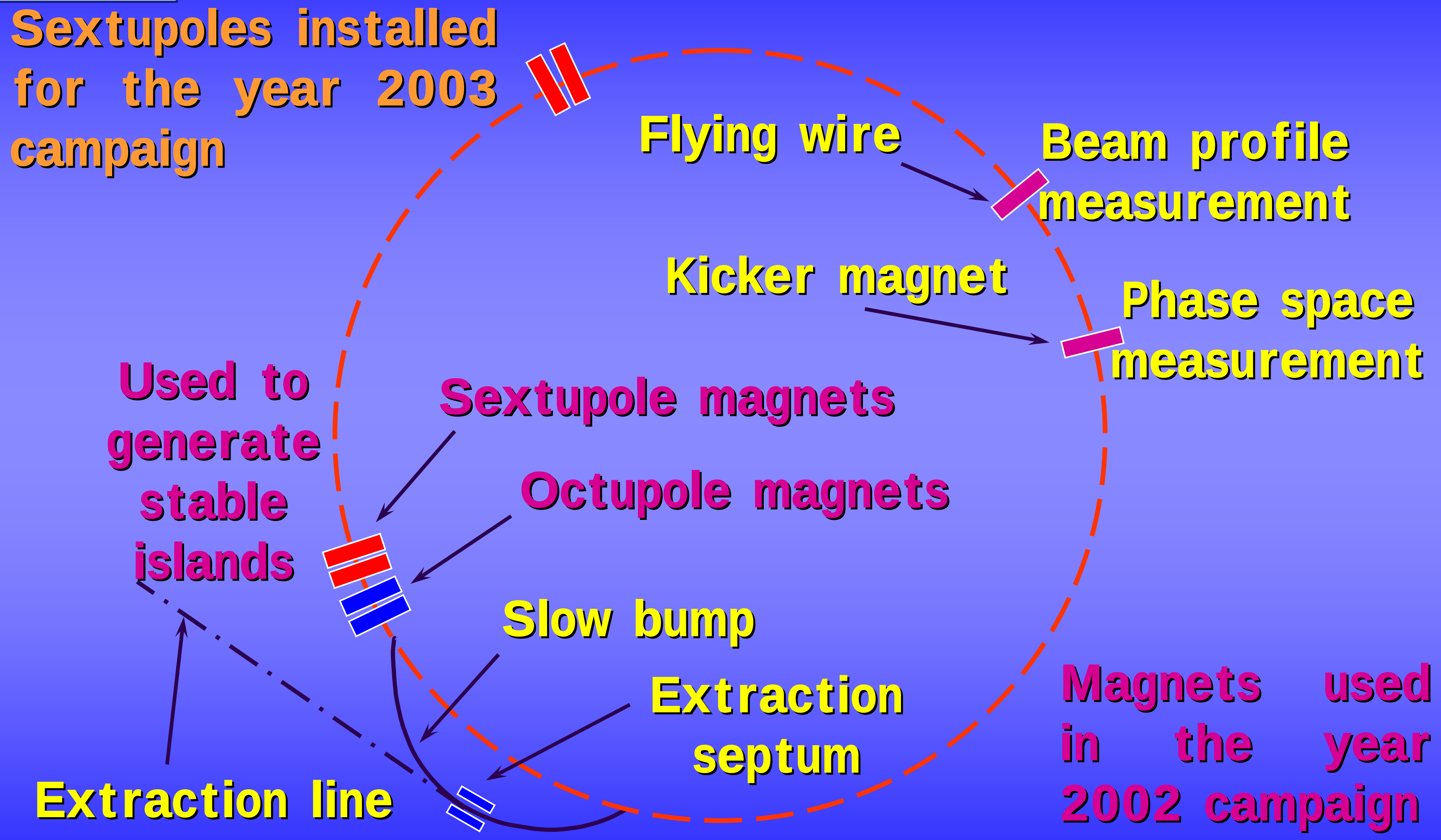
Efforts were devoted to the experimental proof of the proposed extraction:

- **2002: proof of principle using a single-bunch, low-intensity beam.**
- **2003: proof of splitting in realistic conditions, i.e. using a single-bunch, high-intensity beam.**

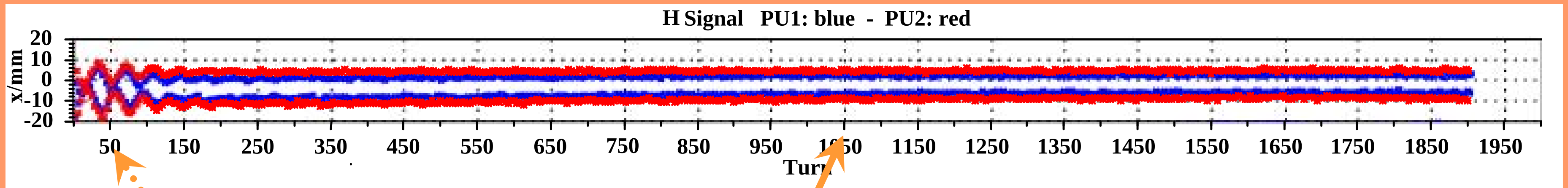
Type of measurements:

- **Phase space reconstruction to ensure the presence of islands: based on turn-by-turn beam position acquisition.**
- **Beam profile measurement to visualise splitting: based on wire scanners.**

Instrumentation and hardware

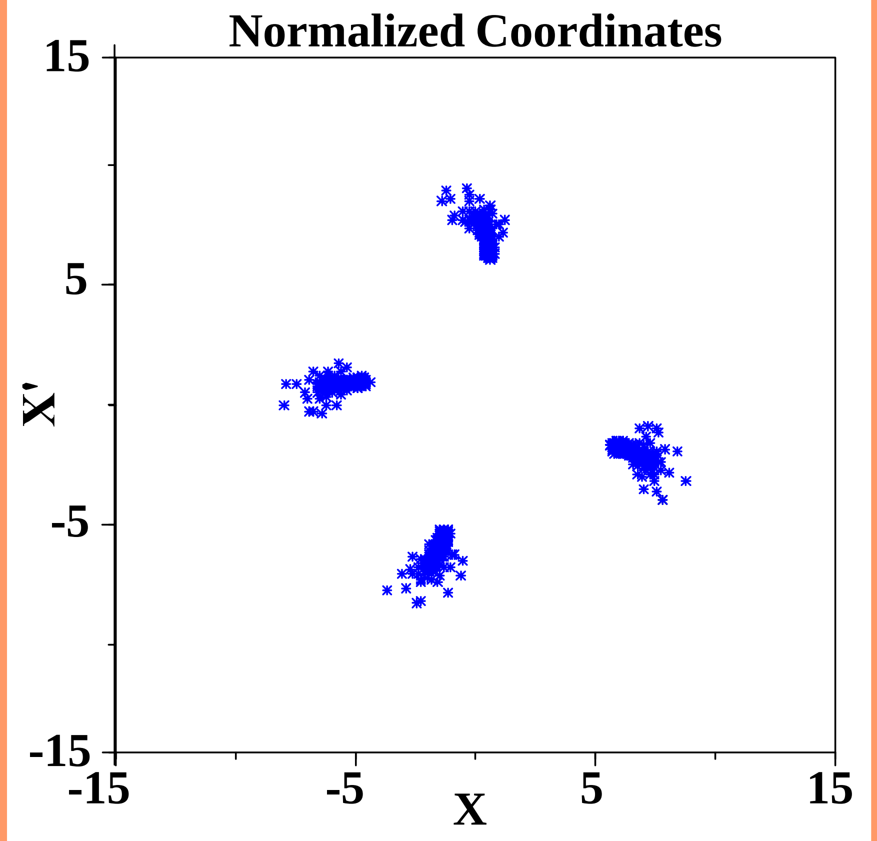


Phase space reconstruction



The pencil beam is kicked into the islands: this produces a strong coherent signal (filamentation is completely suppressed).

Initial wiggles represent beam oscillations around the islands' centre (damped by filamentation).

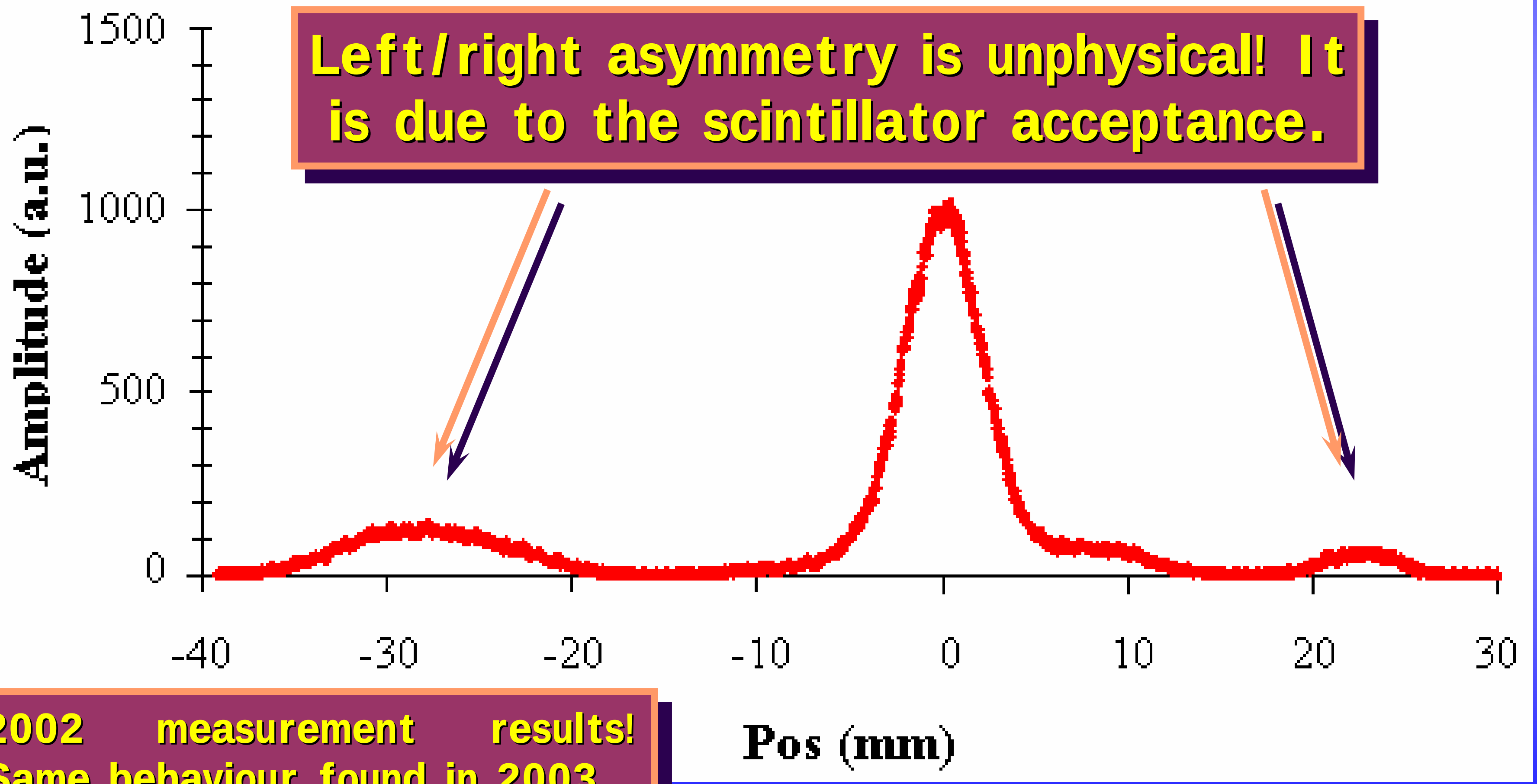


DETAILED ANALYSIS IN POSTER WEPLT018

Trapping low-intensity beam

The horizontal emittance of the low-intensity beam (5×10^{11} p) is artificially increased to simulate the high-intensity beam

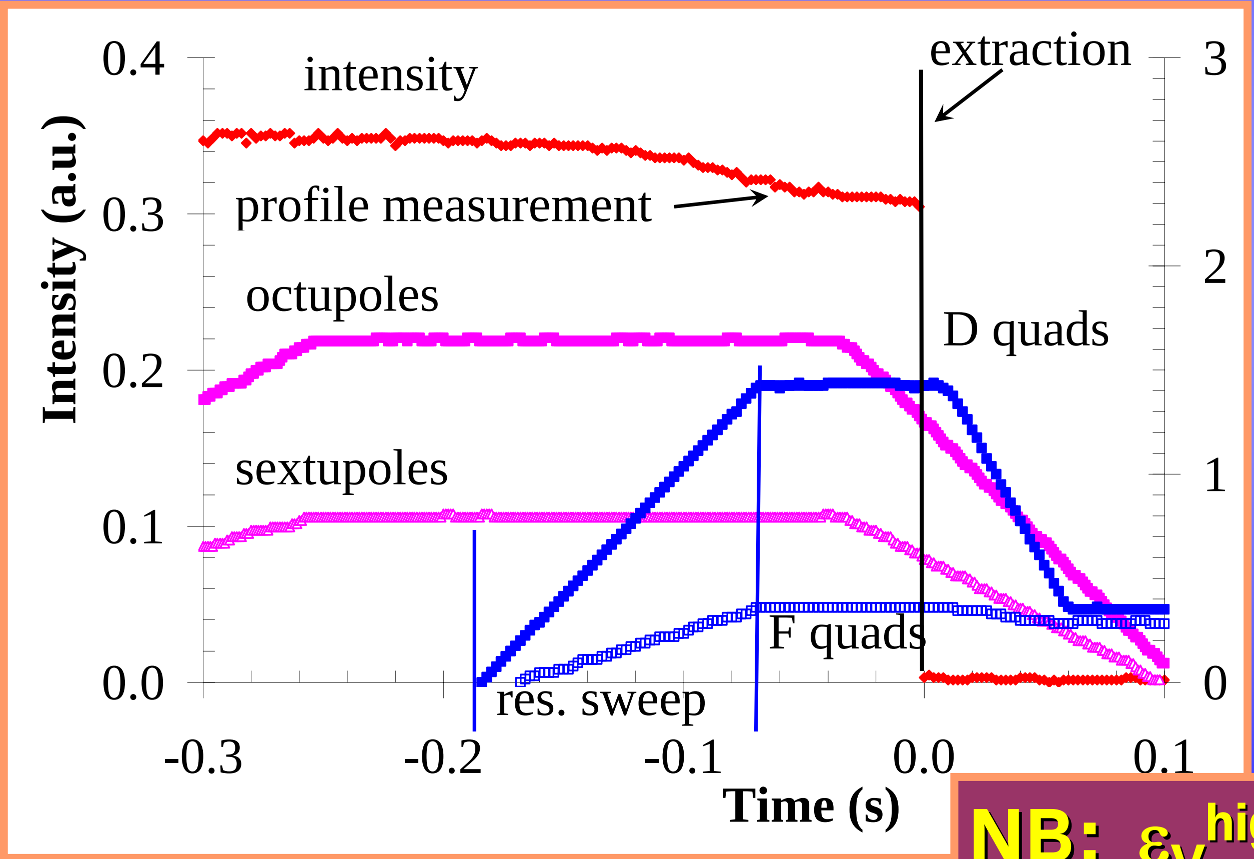
Left/right asymmetry is unphysical! It is due to the scintillator acceptance.



2002 measurement results! Same behaviour found in 2003.

Trapping high-intensity beam - I

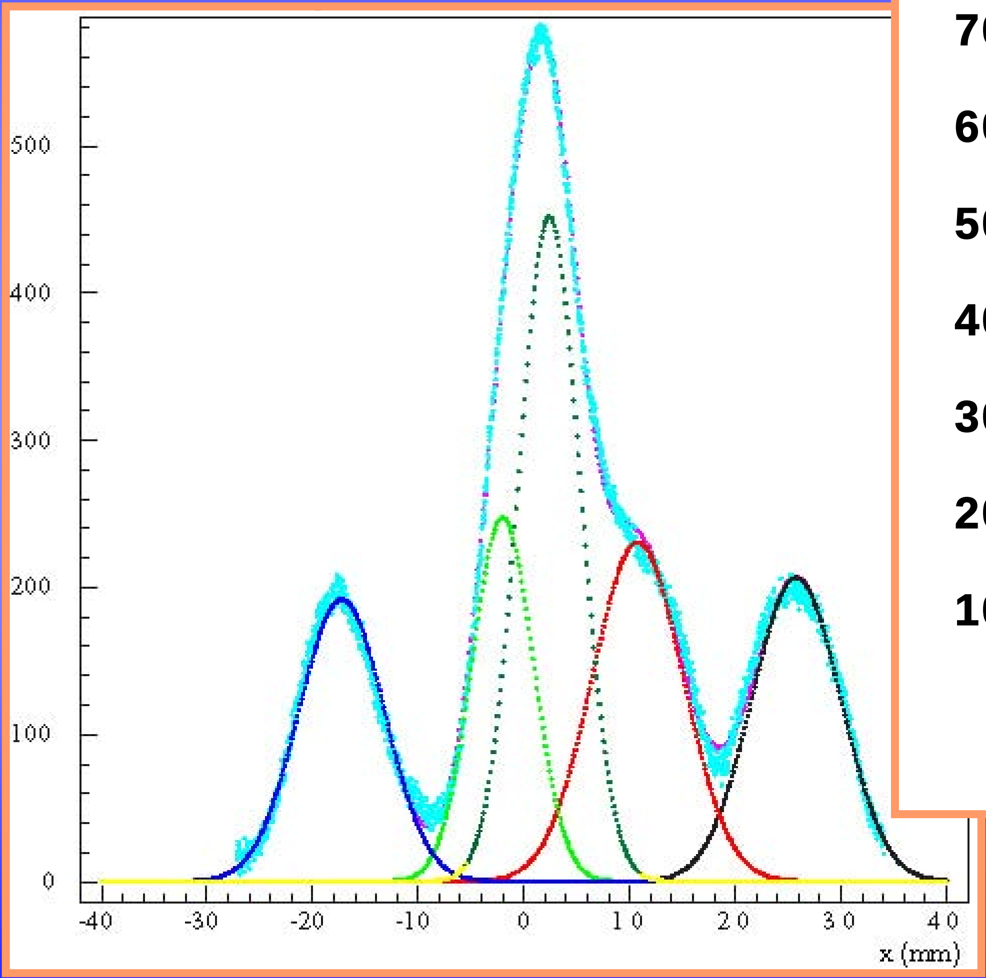
Tests with high-intensity (about 6×10^{12}) beam started in second half of 2003. Losses were observed by the end of the capture process (15-20 %).

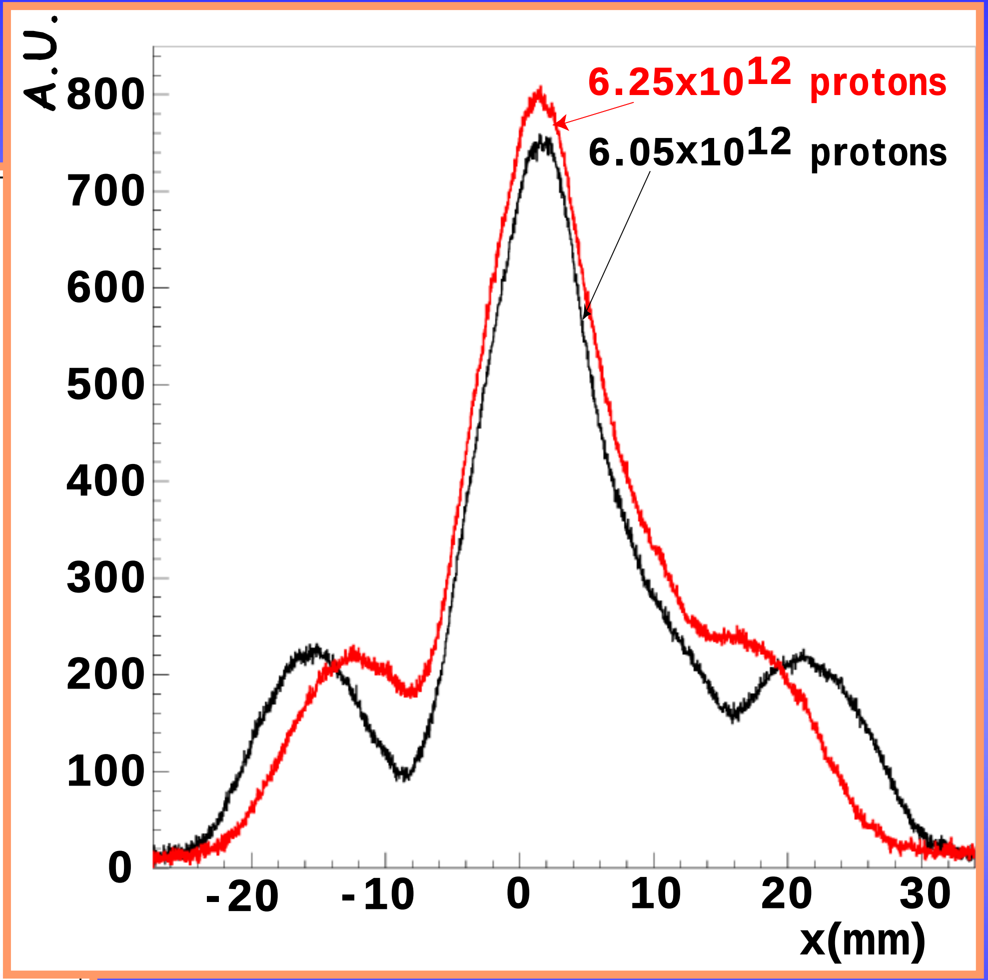


Hint for losses: the octupoles are located in a large-β_V section due to hardware limitations, thus enhancing H/V coupling.

NB: $\varepsilon_V^{\text{high-int.}} \sim 2\ \varepsilon_V^{\text{low-int.}}$

Capture of high-intensity beam - II



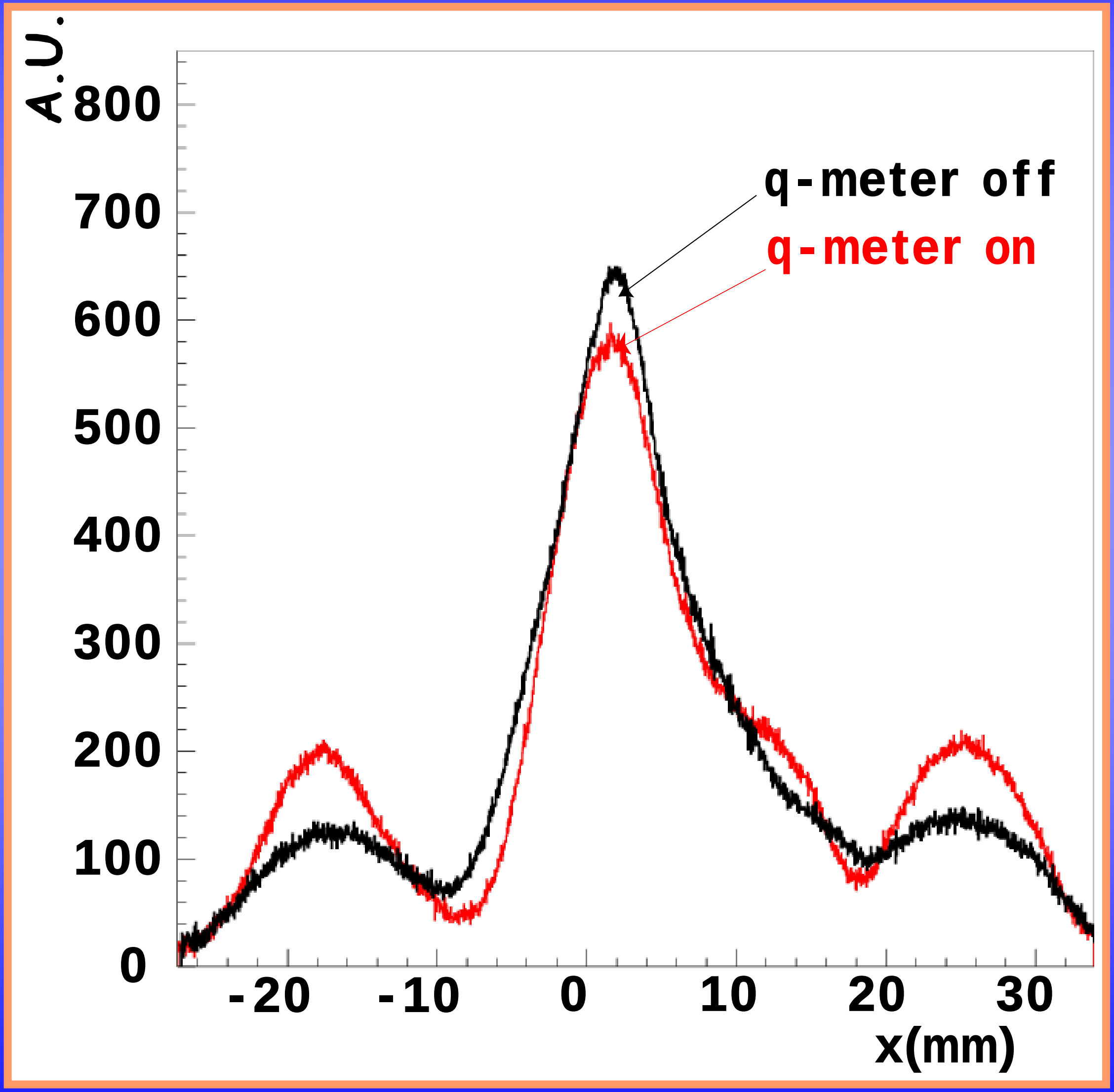


How to increase capture efficiency - I

Two approaches are possible to capture more beam in the islands.

- Increase islands' size. This requires increasing nonlinearities (sextupoles and octupoles). It is a delicate procedure (chromaticity has to be corrected – difficult in CERN PS machine).
- Change beam distribution, e.g. induce core-emittance blow-up. It is much easier than playing with islands' size. No need to increase the strength of nonlinearities (always delicate!). The kicker of the q-metre was used.

How to increase capture efficiency - II



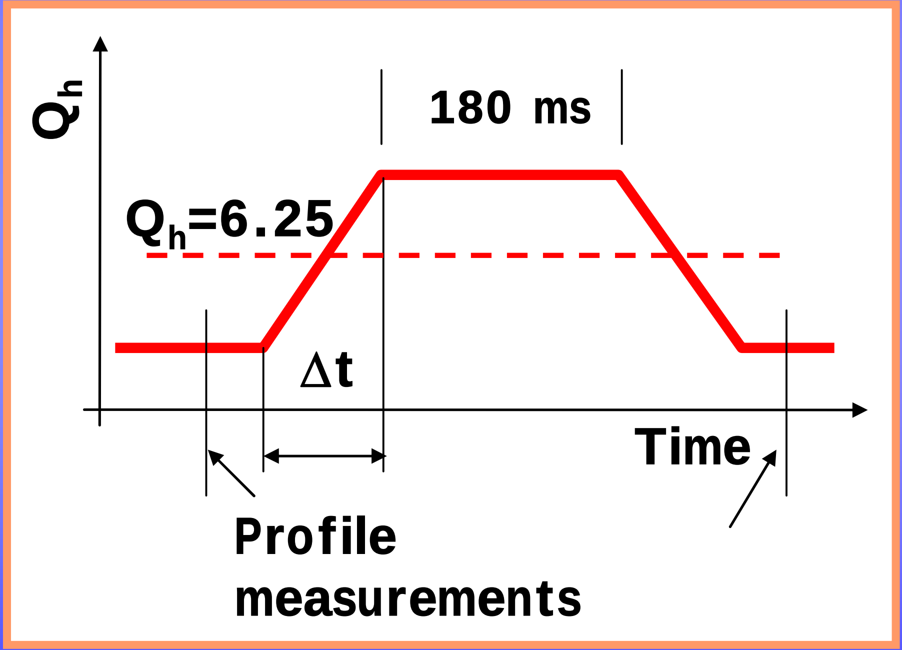
The influence of the q-metre is clearly visible for a high-intensity bunch

- More beam in the islands.
- Less beam in the core.
- The beneficial effect depends of the direction of resonance crossing.

Adiabaticity tests with low-intensity beam - I

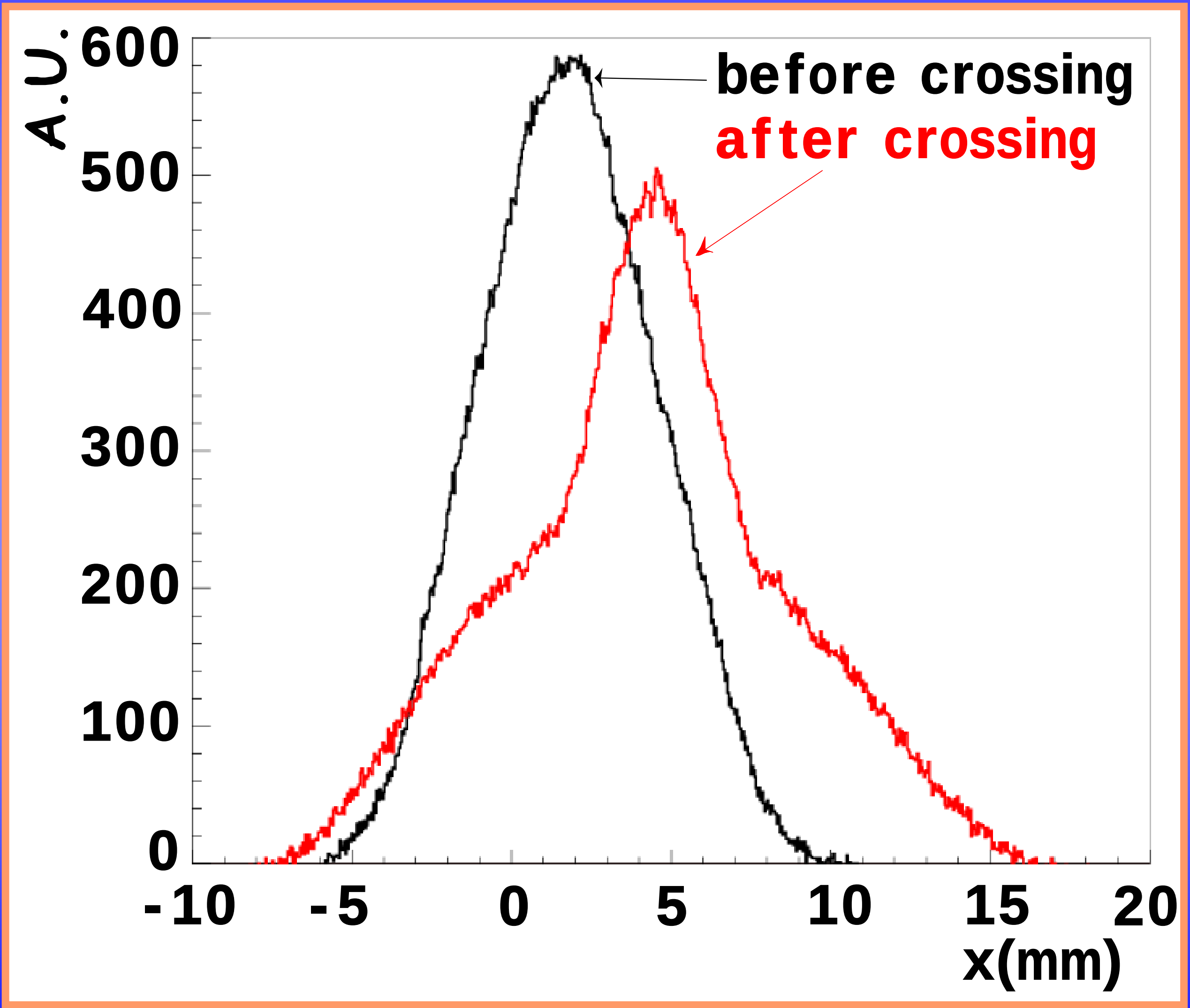
A number of tests were performed by crossing twice the resonance and measuring the profile before and after.

- A symmetric tune curve is used
- Only Δt is varied
- Very mild dependence on Δt. As long as Δt > few ms no more changes in the final profile



- Measurement results indicate that the process is not reversible!

Adiabaticity tests with low-intensity beam - II



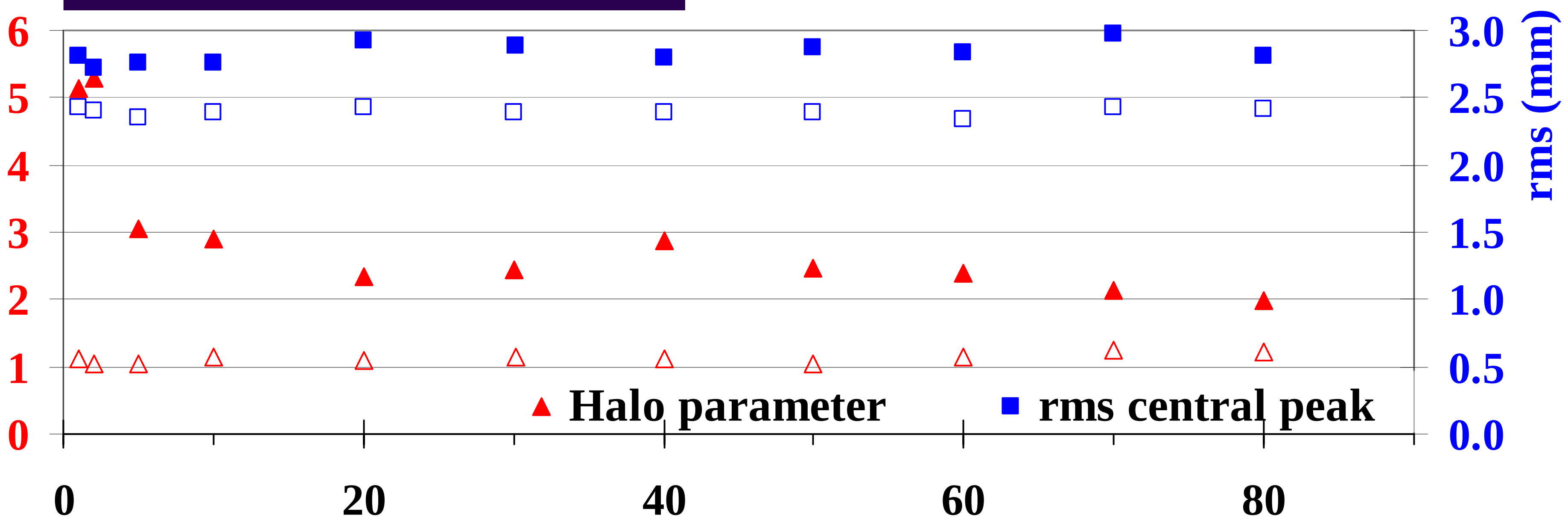
The horizontal beam profile after crossing

- Looks like a superposition of two distributions
- The wider distribution features non-gaussian tails

Adiabaticity tests with low-intensity beam - III

Halo parameter $\rightarrow h = \dfrac{<x^4>}{<x^2>^2} - 2 \begin{cases} h = 0 \text{ uniform} \\ h = 1 \text{ Gaussian} \\ h > 1 \text{ heavy tails} \end{cases}$

Horizontal beam profile



Open markers: before crossing

Solid markers: after double crossing

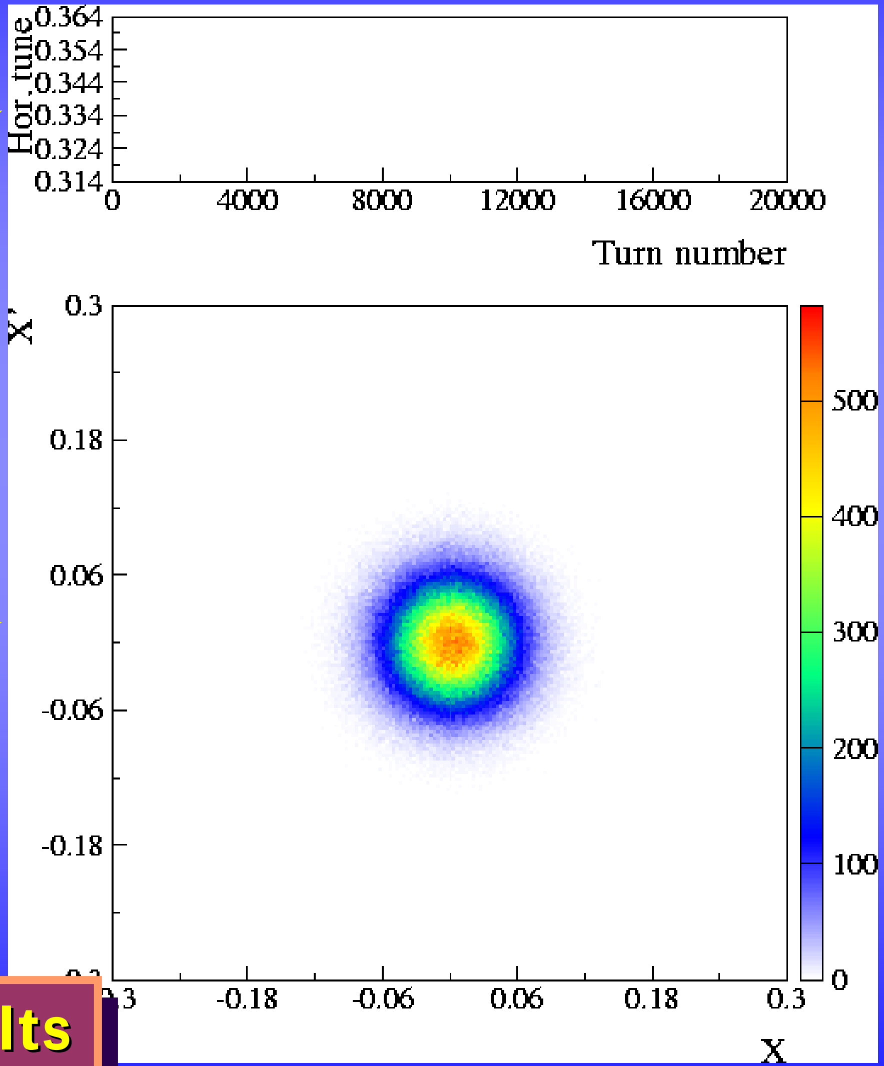
Conclusions and Outlook

- Experimental verification of the proposed approach started in 2002 and continued in 2003. Final results:
  - Capture established for a bunch of up to 6.25×10^{12} protons.
  - Clean capture, i.e. without losses, obtained for the low-intensity beam.
  - Losses still present at the end of capture, i.e. when islands are separated for the high-intensity beam. These losses might be induced by H/V coupling due to location of octupoles at large β_V.
- In the shutdown 2003/2004 octupoles were installed in a small β_V section.
- The year 2004 is crucial for drawing conclusions on the feasibility of this scheme for the CNGS Project (nominal and upgraded intensity).

The novel multiturn extraction works also with other resonances

Tune variation

Phase space portrait

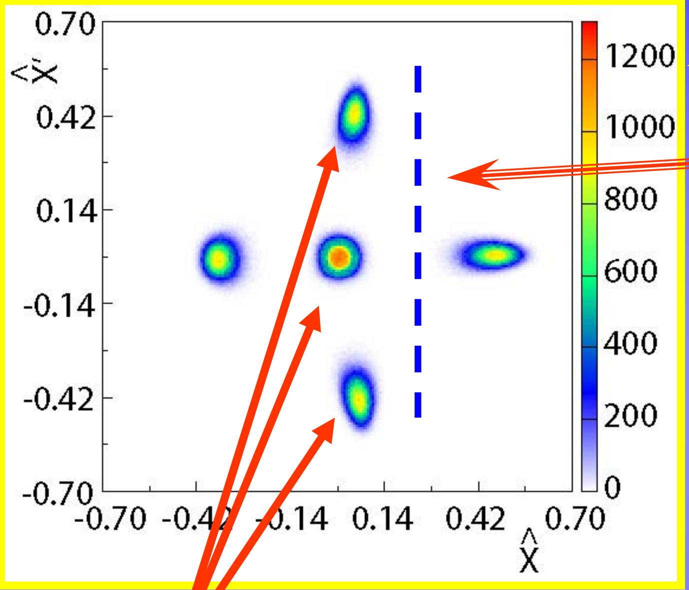


Simulation results

2D polynomial mapping representing a FODO cell with sextupole and octupole

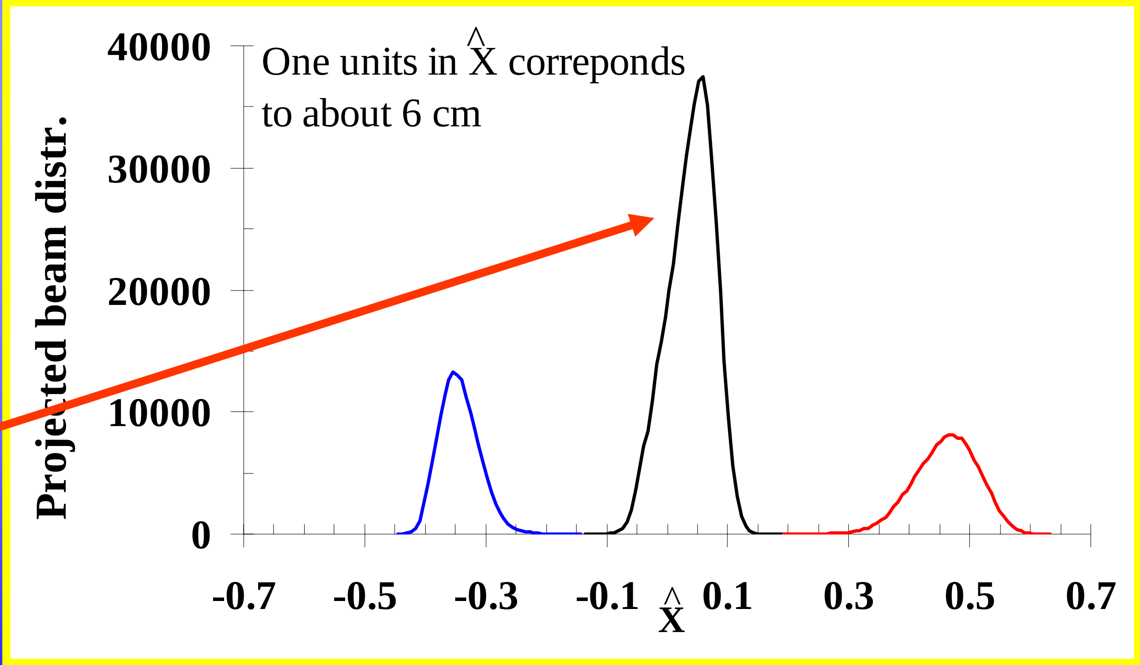
The third-order resonance is used, thus giving a three-turn extraction

Novel multiturn extraction – IV



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

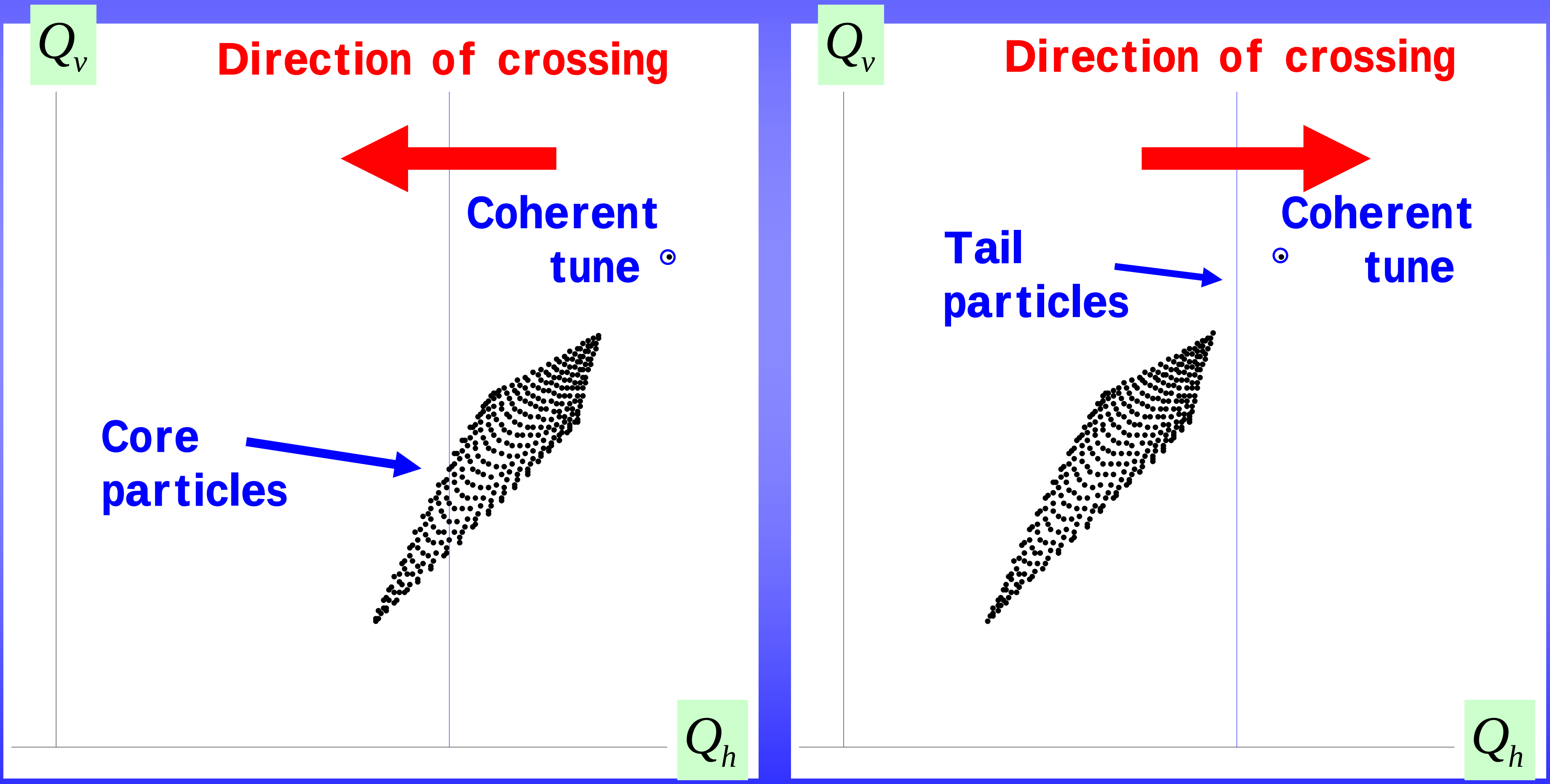
Position of extraction septum after capture



Three beamlets are superimposed in the projections

How to increase capture efficiency - III

Example from low-energy space charge studies



Courtesy E. Métral

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