Crystal Assisted Slow Extraction at SPS: an update

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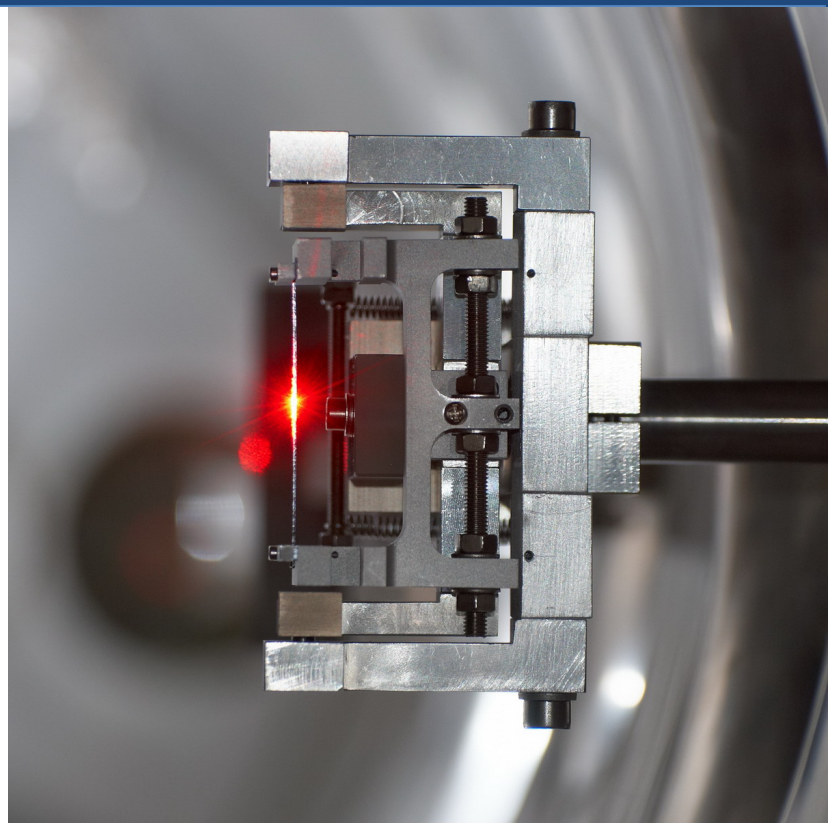
Ferrara – February 13th 2018



Motivation

- Future Fixed Target experiments at SPS, and in particular the proposed Beam Dump Facility (BDF - SHiP), will require much higher intensity extracted beams (up to 4 x 10^{19} PoT/year, ~4 x as today)

- The present slow extraction system from the SPS to North Experimental Area (NA) is intrinsically affected by local beam losses of about 1% due to particles impinging on the Electrostatic Septum (ES) wires (BDF show stopper from machine side).
  - The irradiated wires tend to spark and may be damaged at the highest beam intensities
  - the secondary particle showers strongly activate the area downstream and can also affect the high voltage performance of the ES.

- The ABT group is exploring several strategies to reduce the losses at the electrostatic septum by a factor 4 at least, some of them making use of bent crystals.

- After the proposal from the UA9 collaboration together with the ABT group, and following the request by the CERN Accelerator Directorate,

  since 2016 some members the UA9 Collaboration are putting their expertise at support of the CERN TE/ABT group in the study of the beam loss mitigation scenarios involving beam manipulation via bent crystals.

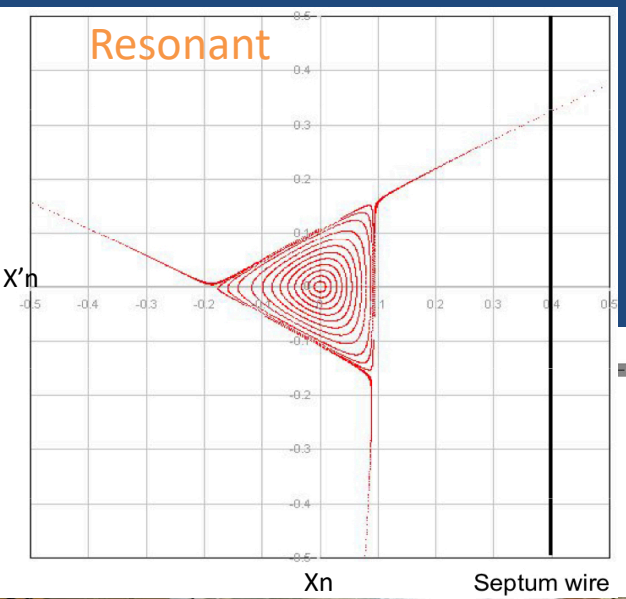
Slow extraction basics

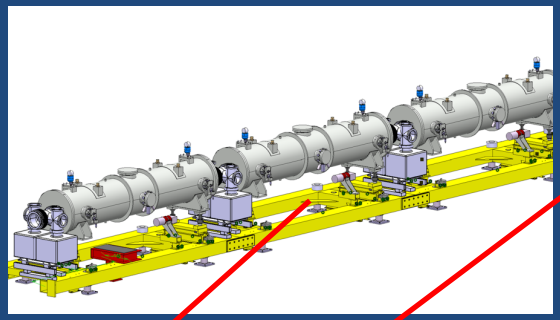
Fixed target experiments normally need an uniform long spill of particles.

1. Particles in a synchrotron move slowly towards the beam periphery, being driven by some instability mechanism:
   a. Tune-shift towards betatron resonance by quadrupole excitation (CERN SPS)
   b. Transverse stochastic excitation by some noisy electromagnetic device (IHEP Protvino U-70)

2. Outer particles are trapped in a bending device that deflects them into the extraction line:
   a. Typically an electromagnetic septum
   b. Alternatively: a crystal ...

Present SPS Slow Extraction

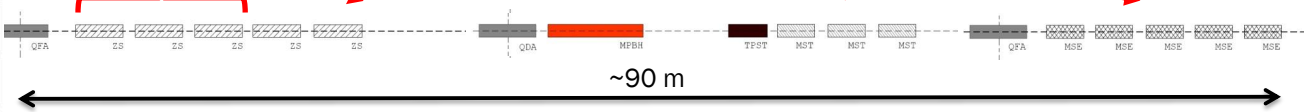




5 Electromagnetic septa mounted on the same support
θ_{ZS} = 72.66 µrad

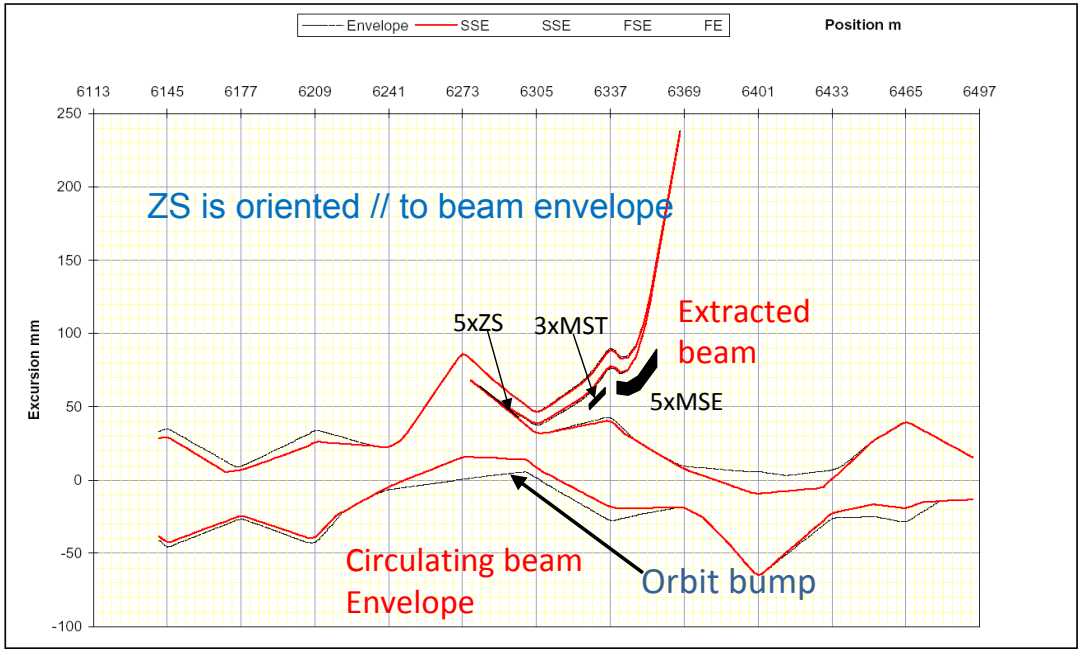
3 Thin magnetic septa

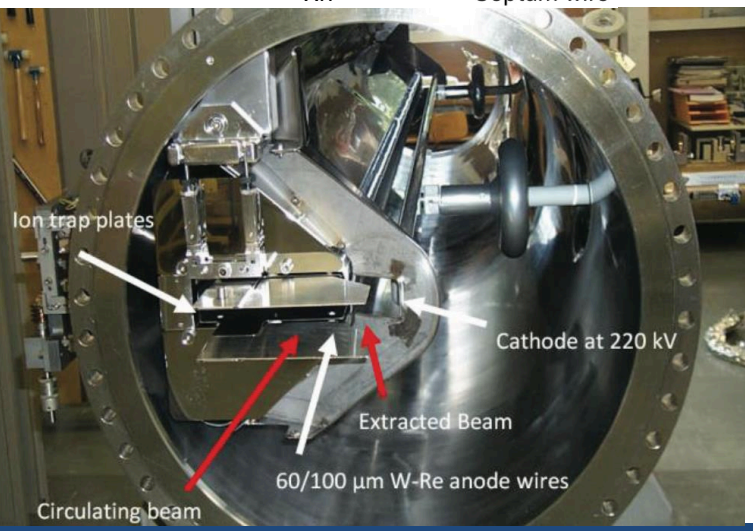
5 magnetic septa



~90 m

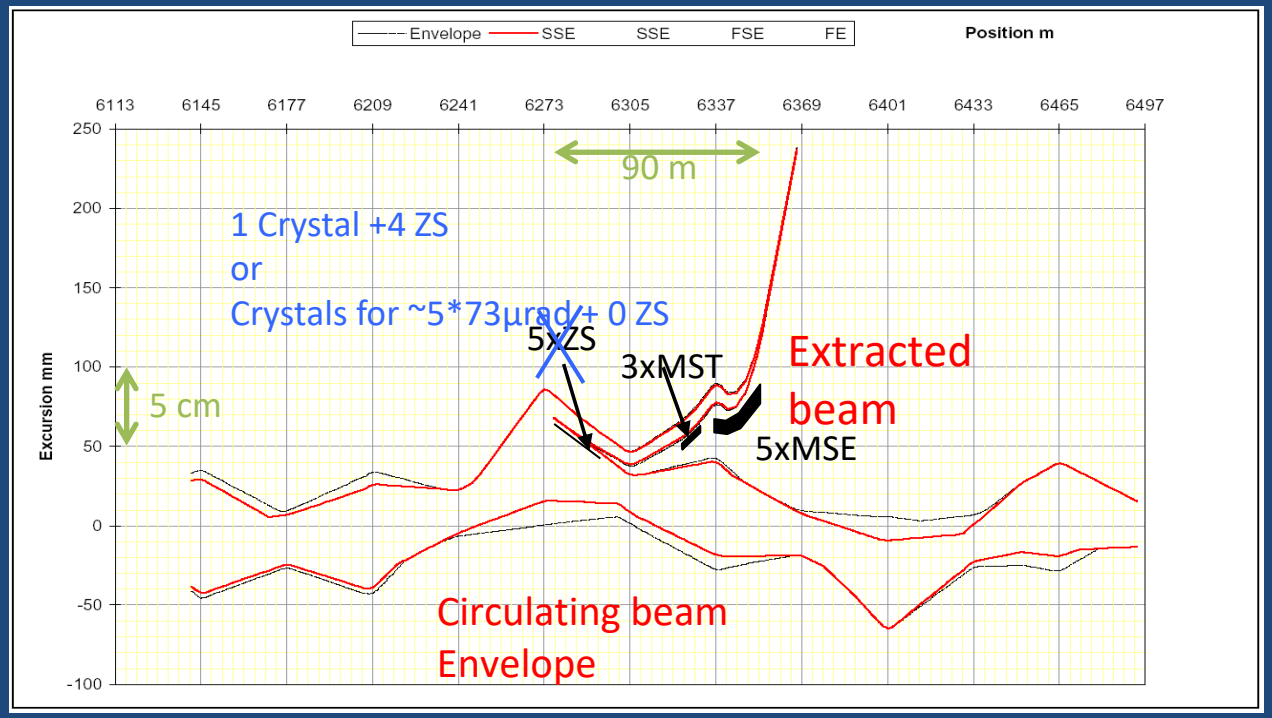
LSS2





Crystal assisted extraction: Septum replacement

Bent crystals may intercept the unstable particles to be extracted, deflecting them into the extraction channel by a similar angle as either the whole ES, or a single element of it would do, thus allowing extraction without one or all of the electrostatic septa.



Extraction mechanisms:

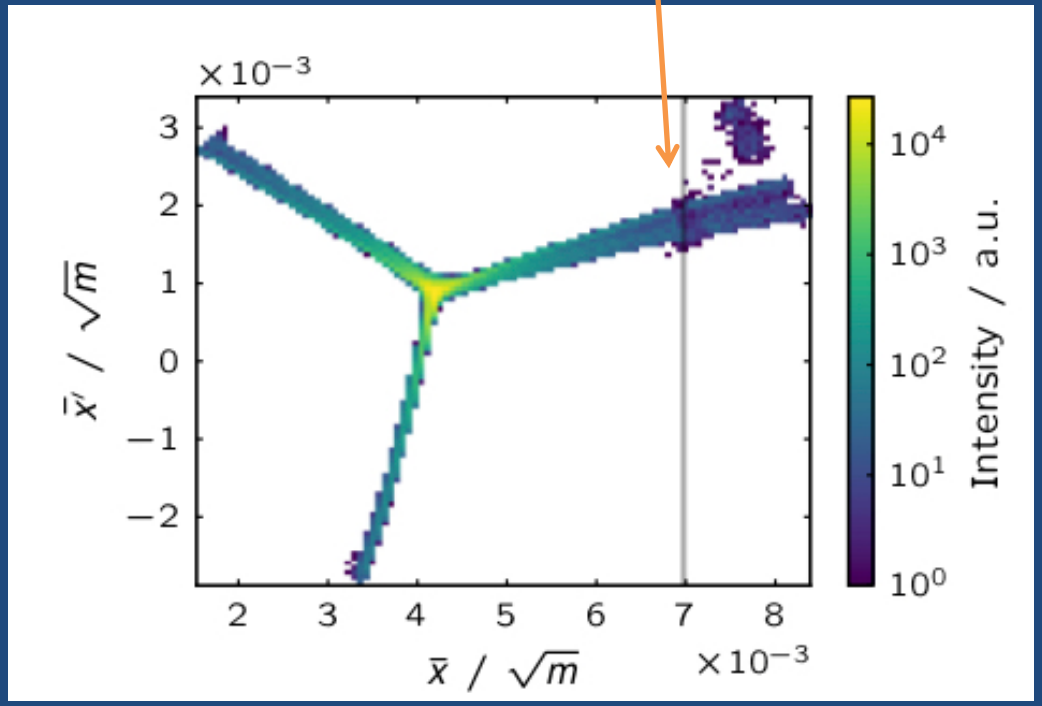
a. 3rd Order Resonance

b. Stochastic Excitation

The possibility of suppressing the ES septum in the extraction channel may drastically reduce the complexity and cost of the extraction system at the highest energies.
(in a standard electromagnetic bending device $\theta \propto 1/E$)

Crystal assisted extraction: Septum shadowing

A bent crystal with the appropriate phase advance from the first septum (i.e. non-local) could shape a gap along the separatrix.



- This would avoid particles in the separatrix hitting the wires of the electrostatic septum (ES) and to shorten its lifetime.
- The local beam loss and the debris produced by ES wires would be reduced, and shifted in a safer area of the accelerator.
- Simulations for an optimized layout account for a factor 4 less particles impinging of the septum. (Velotti PhD Th.)

2016 crystal-aided non-resonant extraction experiment

We set-up a non-local stochastic extraction experiment that could be performed without modifying the hardware in the ring, making use of the equipment specific to the UA9 experiment: goniometers with crystals, absorbers, detectors + TT20 CpFM detector.

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MOPIK048

Non-local → Long Straight Section (LSS) 5 to LSS2 in 1.5 turns
Stochastic → particle diffusion from the beam core was enhanced by means of the Transverse Adiabatic Damper (ADT, random transverse kicks) →different ADT excitation = different extraction rate

Machine tune Qx= 26.62 → appropriate phase advance

Beam energy = 270 GeV (typical UA9)
1 bunch in storage mode as there are not strong enough bumpers in LSS5

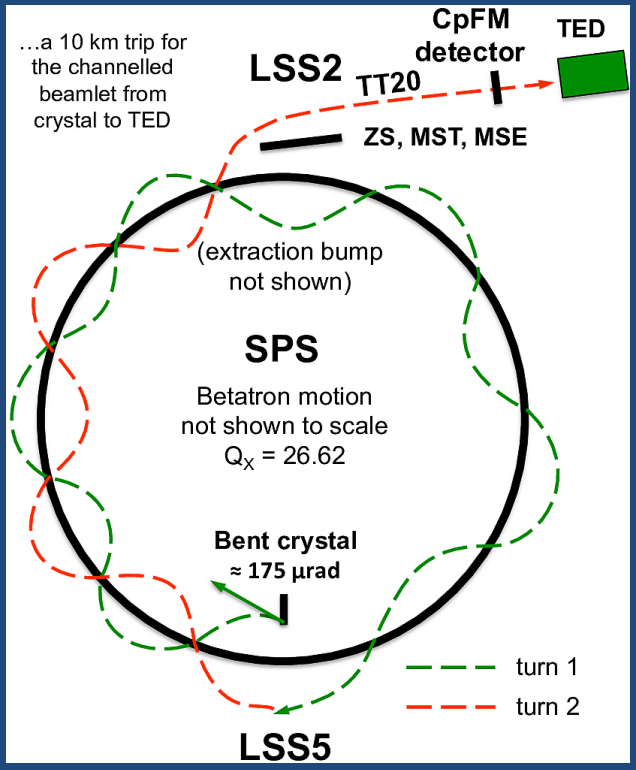
Beam charge = 1.6 x 10^{10} (1 LHC pilot bunch)

Closed orbit bumpers to move channeled beamlet towards electrostatic septum with the right angle to cross the extraction line

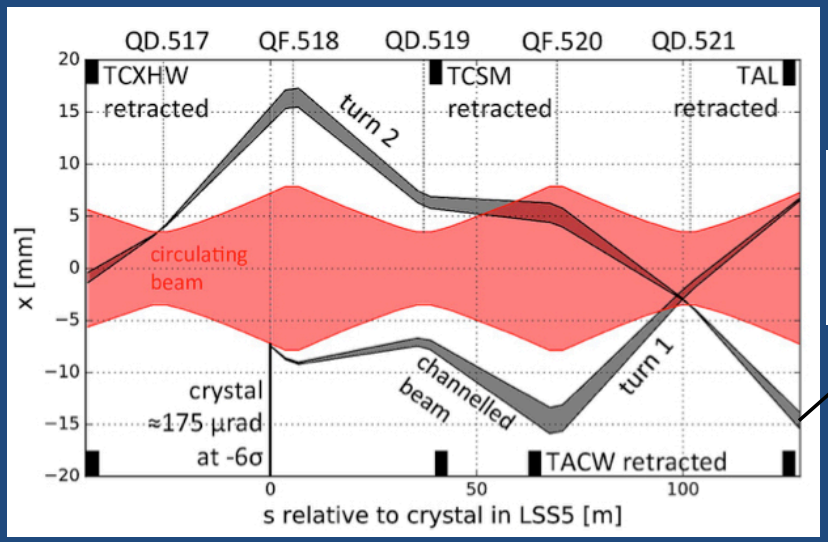
Septa ON and in standard place

Absorbers and scrapers to evidence the presence/absence of the beam at certain locations

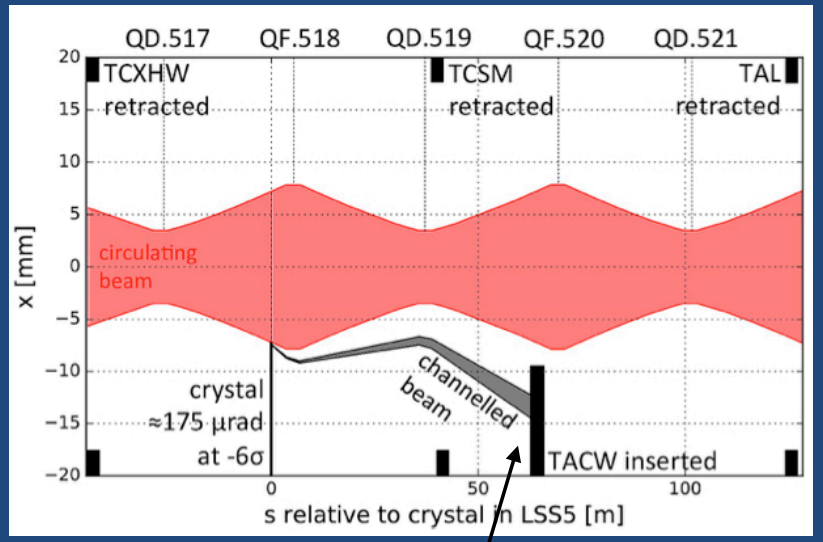
Availability of Timepix and TT20 CpFM detectors was fundamental



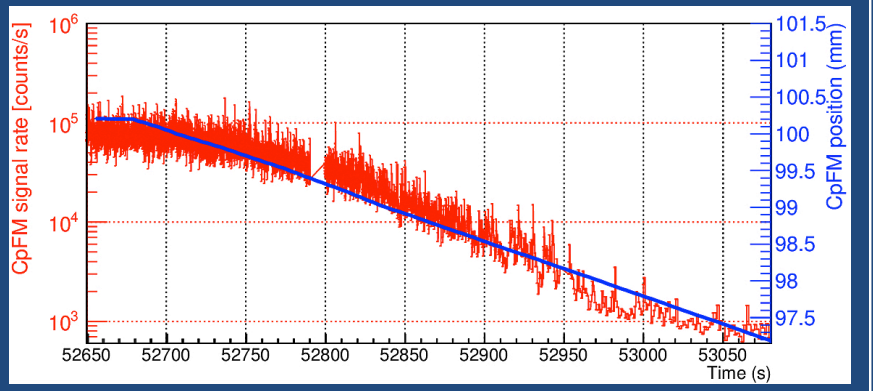
Extracted beam detection by CpFM



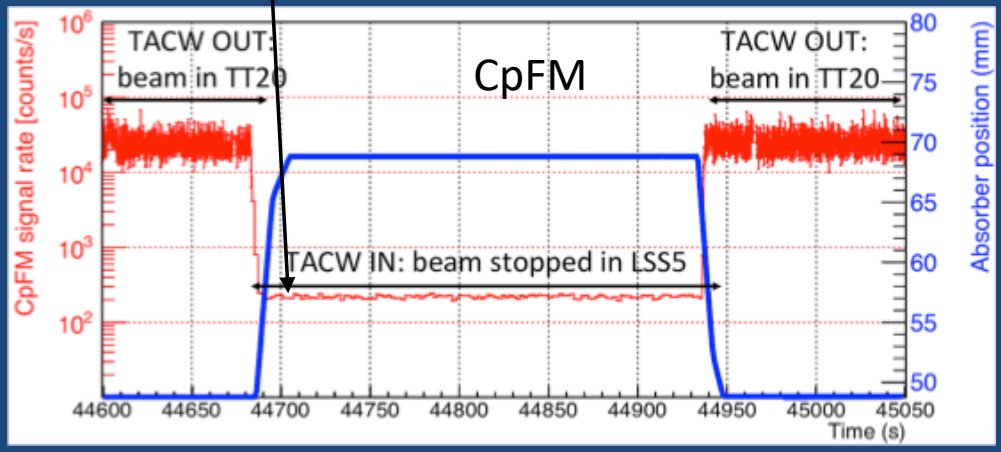
Beam to El. Septum and extraction channel



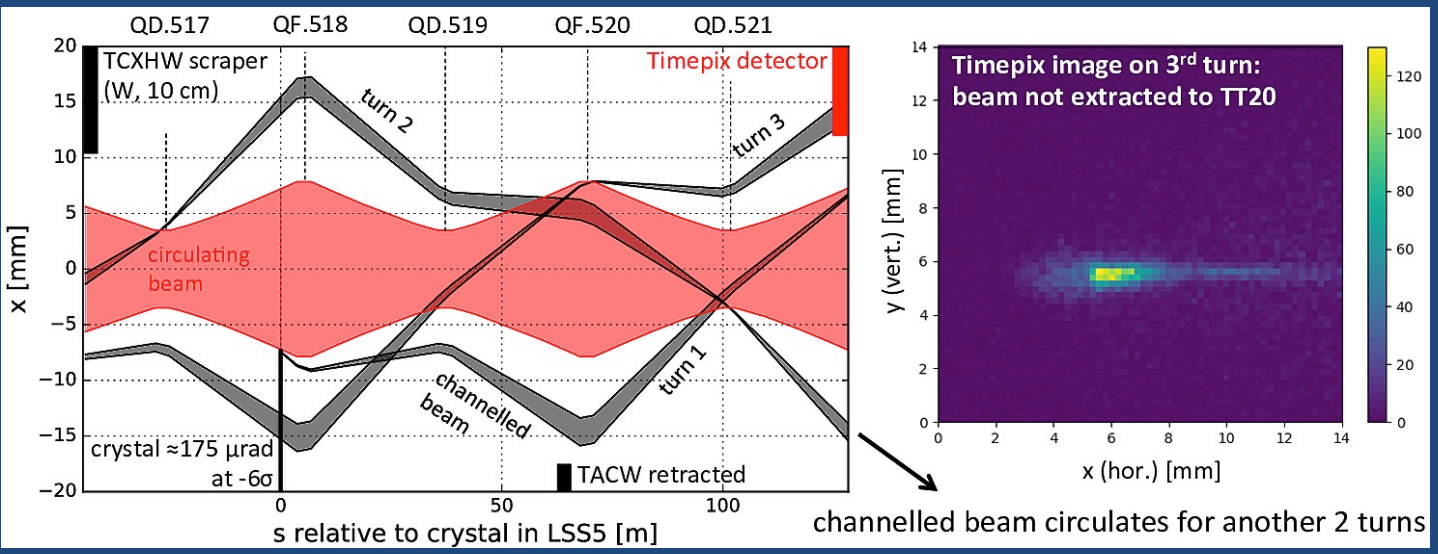
Signal detected by CpFM in the extraction line TT20 disappears when beam is stopped by the TACW absorber



Linear scan of TT20 CpFM through the extracted beam

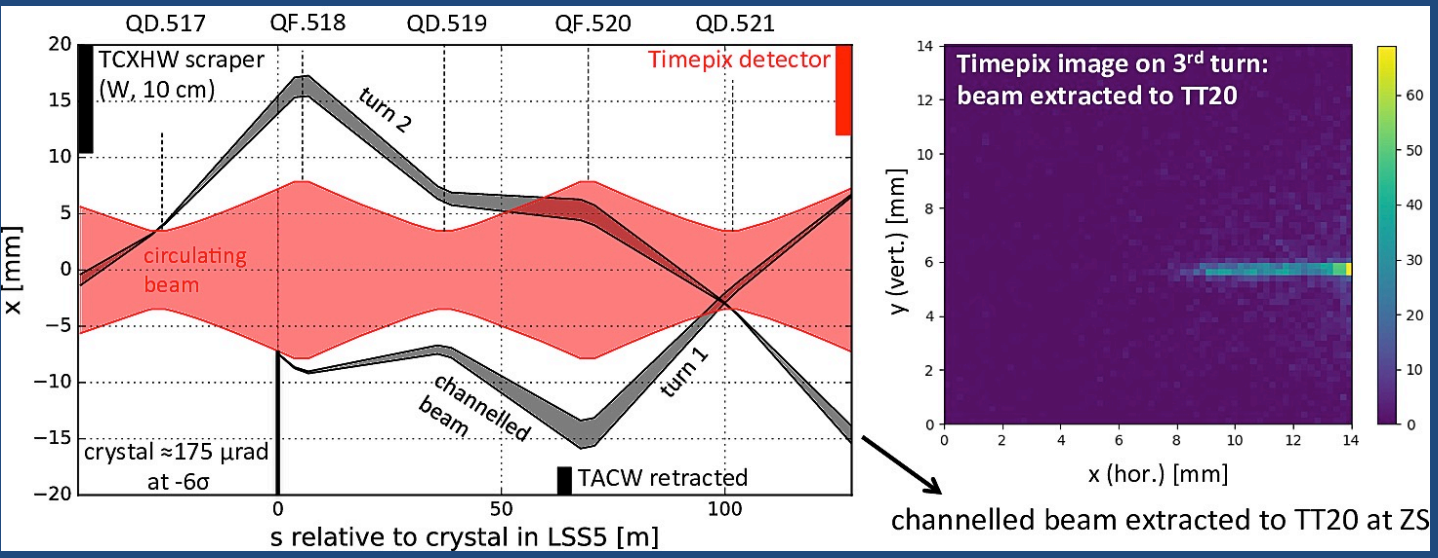


Testing extraction with Timepix



TCXHW inserted to stop the incoming 4th turn

Bump at the electrostatic septum OFF
→ Channeled beam circulates and is detected on Timepix at the 3rd turn.



Bump ON
→ EXTRACTION
→ Channeled beam disappears from Timepix
(plot scales are different!)

2017 slow extraction test

~~4~~ + 10 (effective 4) hours Machine Development (MD)

Aim:

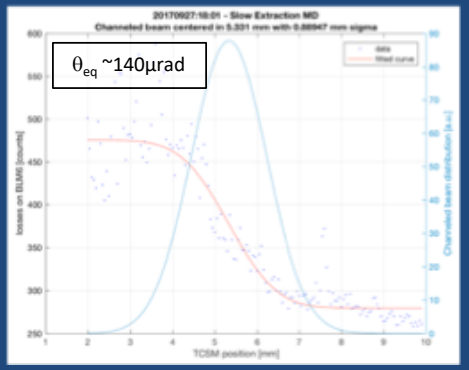
Repeat successful non-resonant extraction to TT20 as in 2016, this time with

- the CpFM synchronized to the extracted beam through an RF trigger signal
  → Allow measuring particle flux
- Medipix with much better developed online analysis software.

All machine settings of 2016 were reproduced and double checked, but we could not extract.

- We bumped the beam closer to the electrostatic septum by 3 mm in steps → still no beam in TT20.
- We verified that the beam was circulating at least up to the 3rd turn.
- The machine people decided not to risk pushing it further (no spare septum available).

Offline analysis shows an 'effective bending angle' of the crystal smaller than expected by 20%.
→ 1 mm bigger bump would have been enough to cross the septum. (!)



Possible causes of the 'effective angle' are under investigation:

- angle in the closed orbit at the crystal (C.O. at 270 GeV is not fully under control)
- too big offset of the closed orbit driving the channeled beam in the non-linear region of the quadrupole field.
- something wrong in one of the 2 quads between Crystal 4 and TACW Absorber.

2018 slow extraction plans

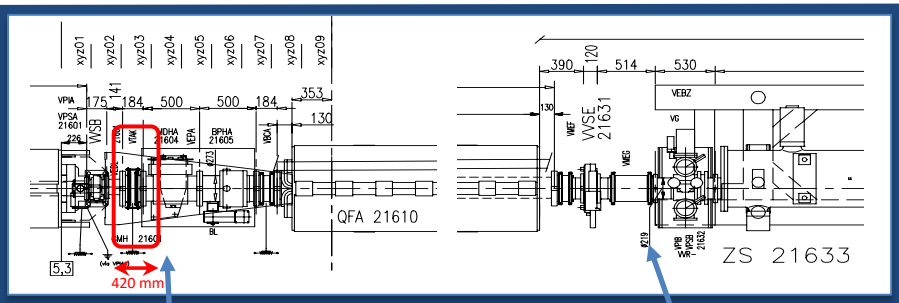
Before September technical stop:

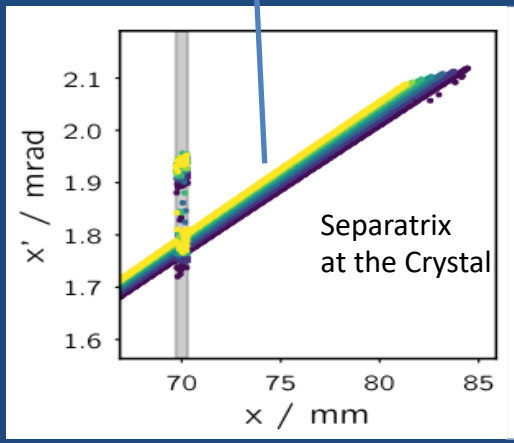
- Same program as 2017 to have CpFM calibrated as counter
  + more beam diagnostics at the septum
  + better flattening of the orbit all around the ring
  + logging of many more machine parameters
  + dare more (!) with the bump at the septum
  + increase the extraction flux

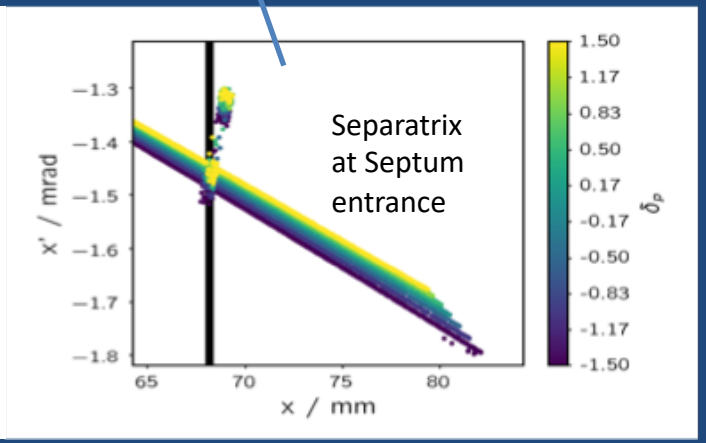
After September technical stop:

- Test of the crystal shadowing scenario

Septum shadowing by bent crystal in resonant slow extraction







September 2018 →

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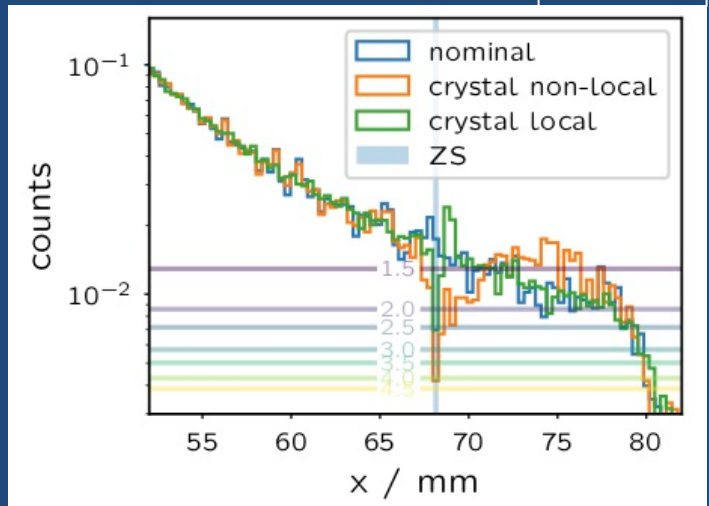


Simulated particle density at the septum

Expected loss reduction ~ 2.5

Setup:

- Resonant extraction cycle, duty cycle as high as possible
- A few 10^{12} particles per spill (will try to have less)
- Beam needs to be bumped towards the crystal
- Alignment of the crystal to the wires in cycle mode will be a challenge → exploring the possibility to add a retractable target just for the alignment.

Aim:

- demonstrate the principle of shadowing
- measure loss reduction and compare with simulations
- Test a dynamic bump to follow the momentum sweep during extraction, thus relaxing the constraints posed by the crystal acceptance
- Understand how the disposal of the channeled particles will need to be addressed for the nominal beam.
- Ultimately gain experience in view of the installation of an optimized non-local system.

Conclusion

The collaboration with CERN for the application of bent crystals for the improvement of the slow extraction efficiency is going on.

The first trial of extracting the beam from SPS by means of a crystal assisted non-local non-resonant mechanism was very successful.

Not so much was the second attempt. Nevertheless we believe we understand the main difference between the two runs and we are ready to continue experimenting in this direction.

Although several systems need to be upgraded in the machine itself before the non-resonant extraction procedure could become operational, like for instance:

- More local setup → shorted distance crystal to septum
- Strong bumpers at the crystal to allow running in cycled mode
- Diagnostics, …

this remains extremely promising because of the possibility of suppressing the ES septum in the extraction channel. If validated, on the long term this setup may drastically reduce the complexity and cost of the extraction systems, resulting in much easier integration scenarios for beam extraction at very high energy, for example for the multi-TeV fixed-target beams in the FCC era.

The shadowing test in preparation is extremely challenging but, if successful, it may bring immediate benefits for the daily SPS operation and ensure a safe extraction scenario for the high intensities required by the Beam Dump Facility.

THANK YOU

FOR

YOUR ATTENTION

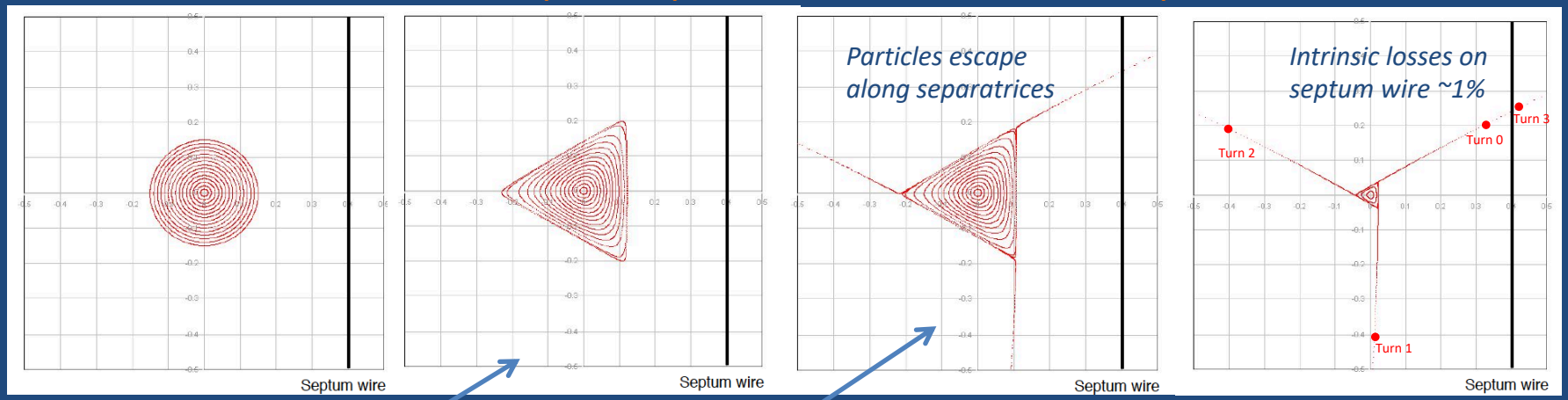
Reminder: Resonant Slow Extraction

- Fixed Target physics experiments generally require a quasi-continuous flux of particles
- A long (few seconds to hours) spill is obtained at SPS by 3rd order resonant extraction

In a circular accelerator, the slow extraction is a resonant process that brings circulating particles into an extraction channel.

An electrostatic septum (ES) is used to cut and bend a slice of the resonant beam separatrices, directing it into the extraction channel for removal from the ring.

Normalized phase space evolution at extraction point



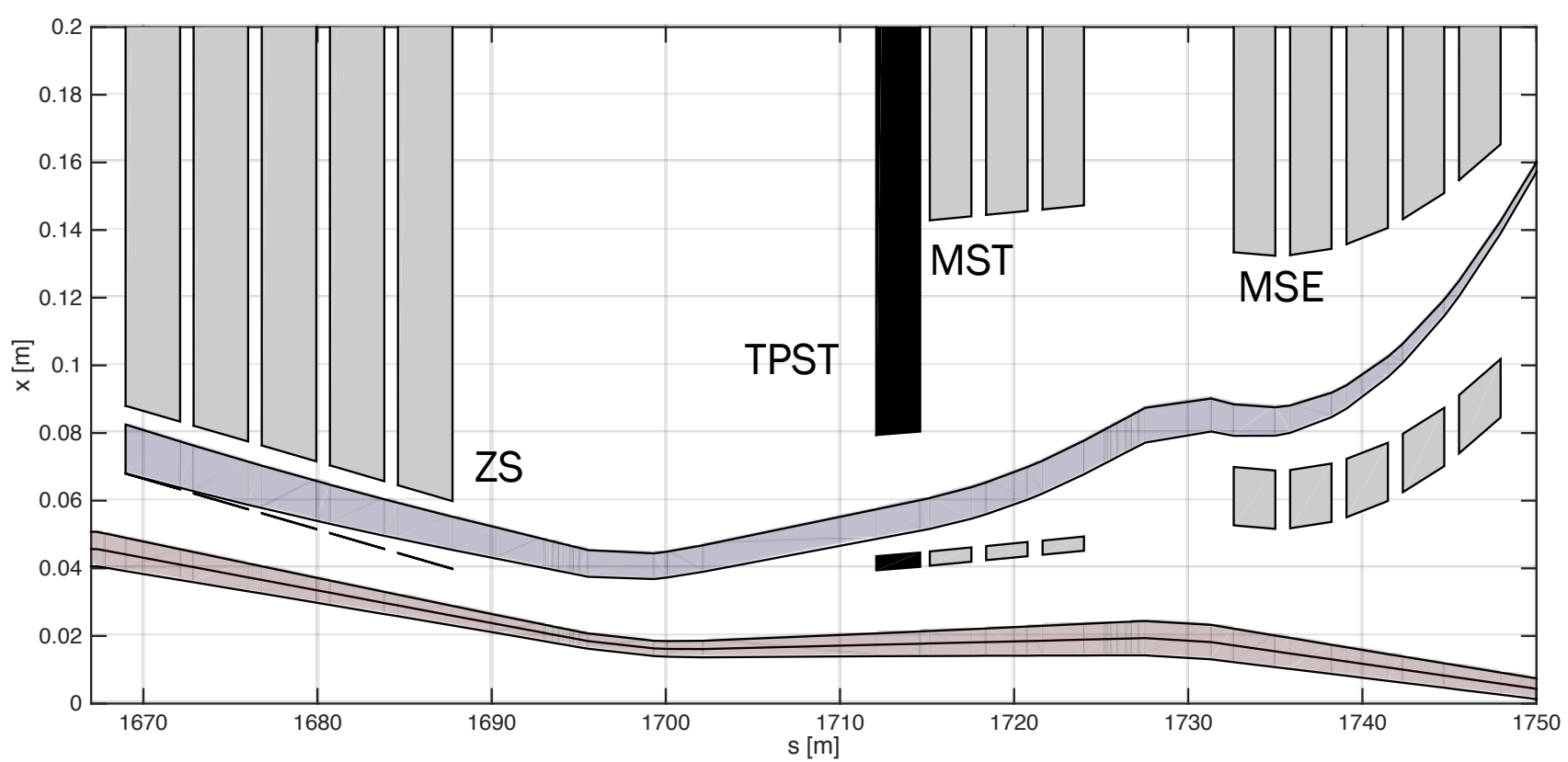
B. Goddard, CAS, Frascati, 2008

Sextupole magnets deform phase space stable area

Changing tune towards 3rd ord. resonance makes stable area shrink

Extraction by the Electrostatic septum

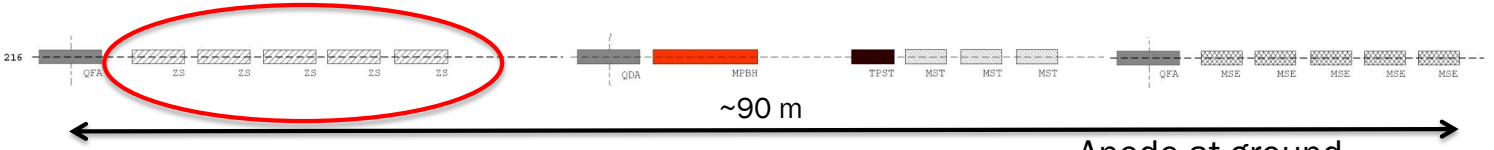
Extracted beam at SPS septa



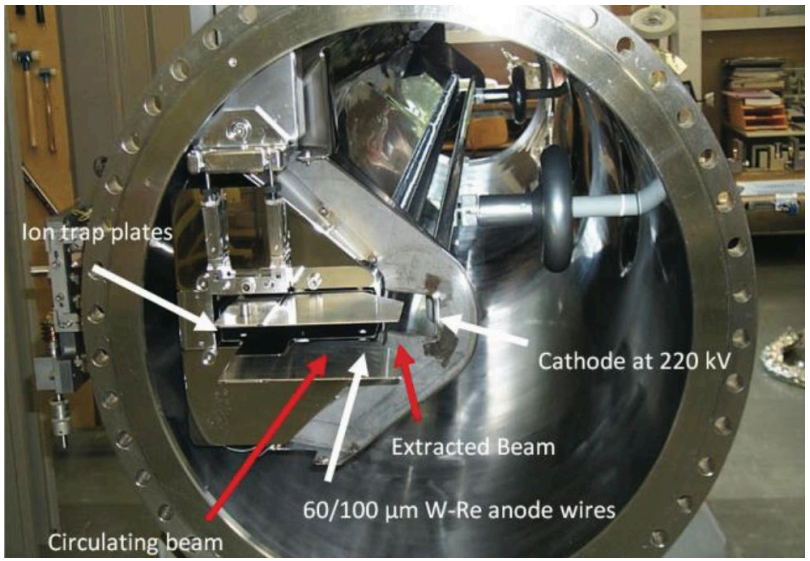
ZS detailed view

LSS2: BEAMS TO NORTH AREA

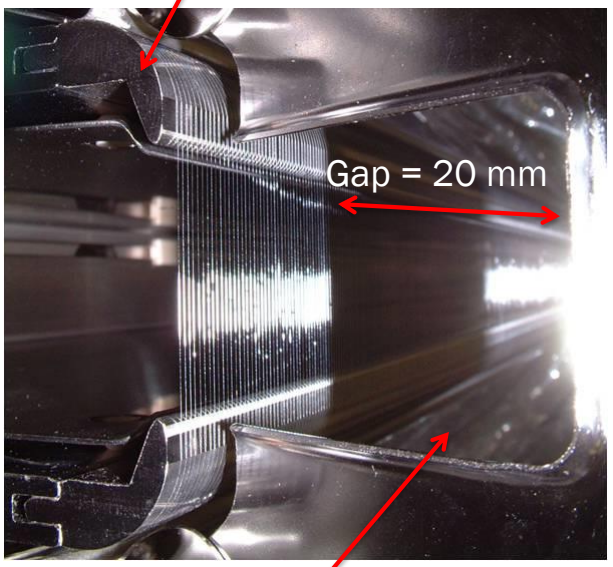
- Long Straight Section 2:



- 5 electrostatic septa [ZS] aligned over ~20 m:

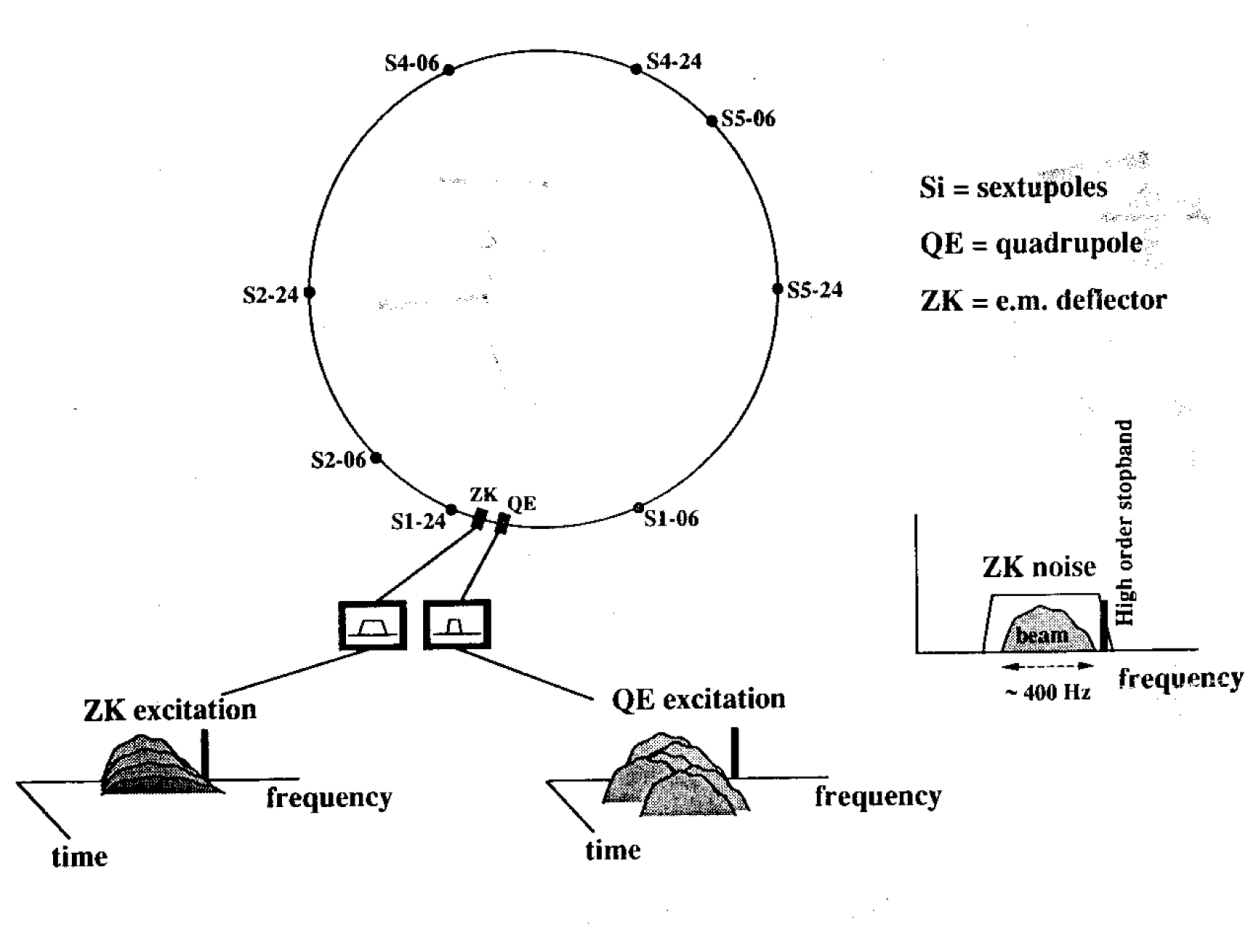


[beam direction coming out of the slide]



M.A. Fraser - UA9-SE WG Meeting, 19th February 2015

Stochastic Beam Excitation



RD-22 Proposal

An electromagnetic device (ZK) could be used to induce random deflections in the circulating beam and to enhance the diffusion speed of the halo population.

By an appropriate shaping of the EM noise, it should be possible to produce a constant spill-out from the beam core.

Then a crystal could shave this halo giving the particles also the appropriate angle to enter the extraction channel.