SPS slow-extraction: Challenges and possibilities for improvement

Physics Beyond Colliders Kick-off Workshop
6 – 7th September 2016

Matthew Fraser and B. Goddard, TE-ABT

On behalf of B. Balhan, J. Borburgh, K. Cornelis, V. Kain, L. Stoel, F. Velotti

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- Slow-extraction is used to deliver a **constant flux of particles** to Fixed Target experiments over many seconds from a synchrotron:
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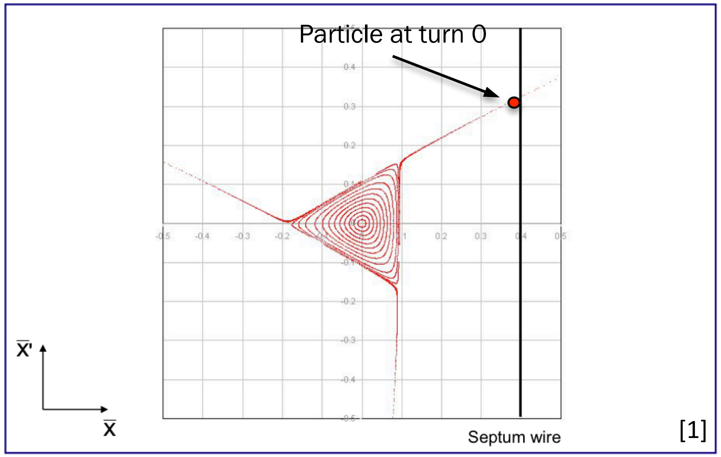
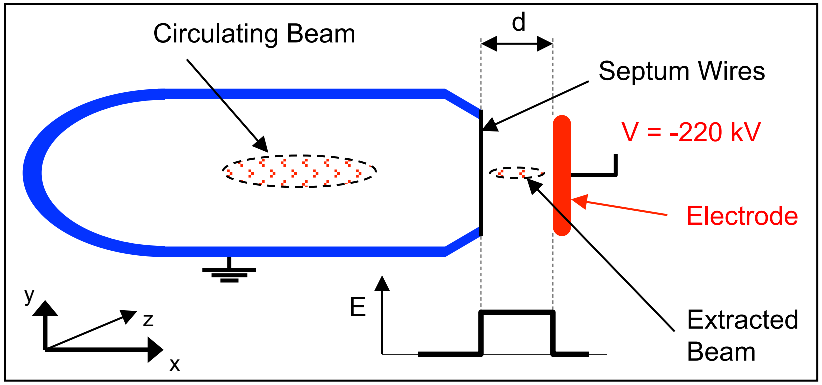
  - We cannot (yet!) create a clear temporal or spatial separation in the beam to extract cleanly
  - In fact, most FT experiments **don't want temporal structure** in the beam!
- Beam loss from slow-extraction is **unavoidable**, and has to be **controlled** and **optimized**:
  - Induced activation in Long Straight Section 2 (LSS2) increases in direct proportion to the beam loss on the septum

The slow-extraction scheme

- Beam deliberately excited using a **third-order resonance** and large amplitude particles extracted with a thin **electrostatic septum** [ES]:





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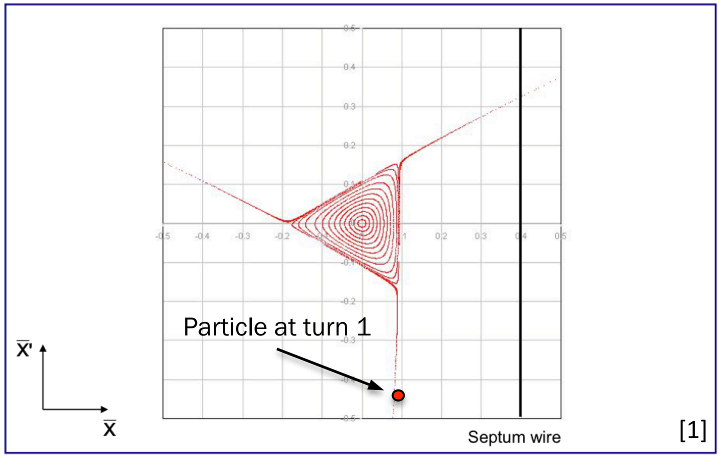

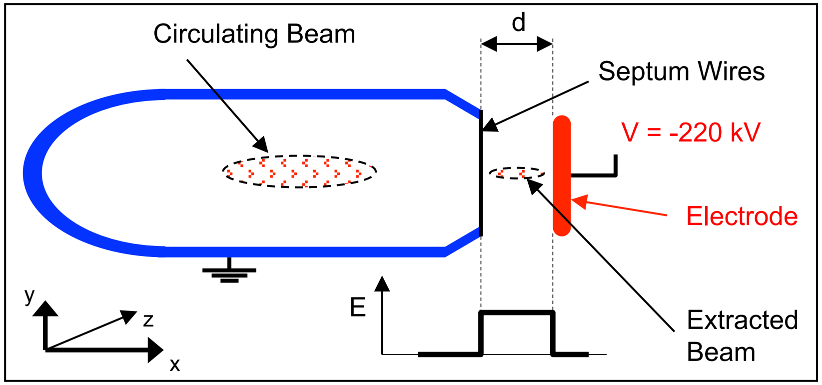

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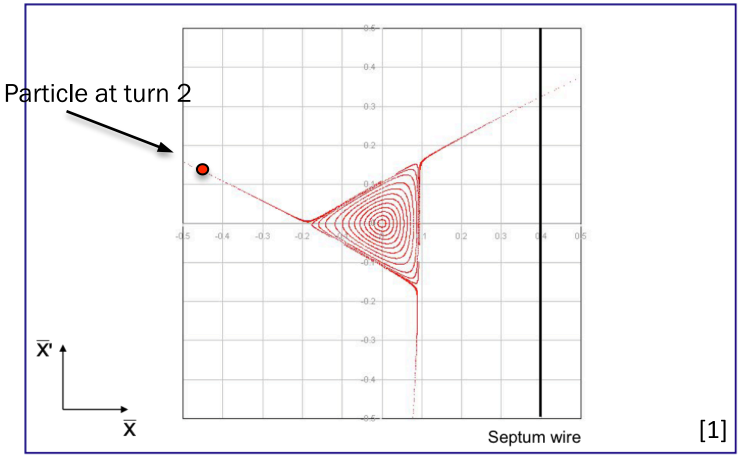

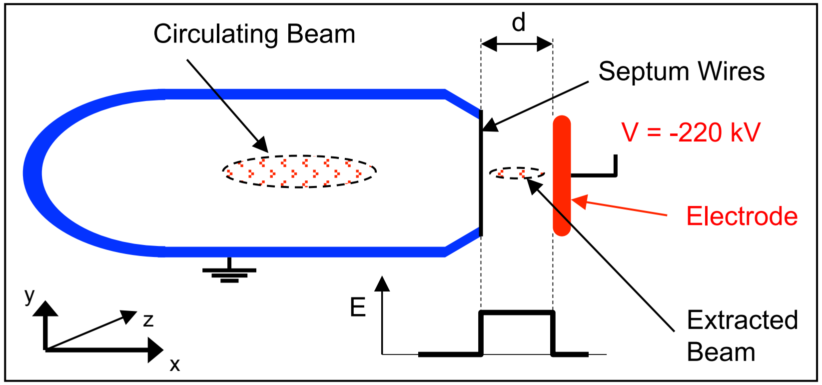

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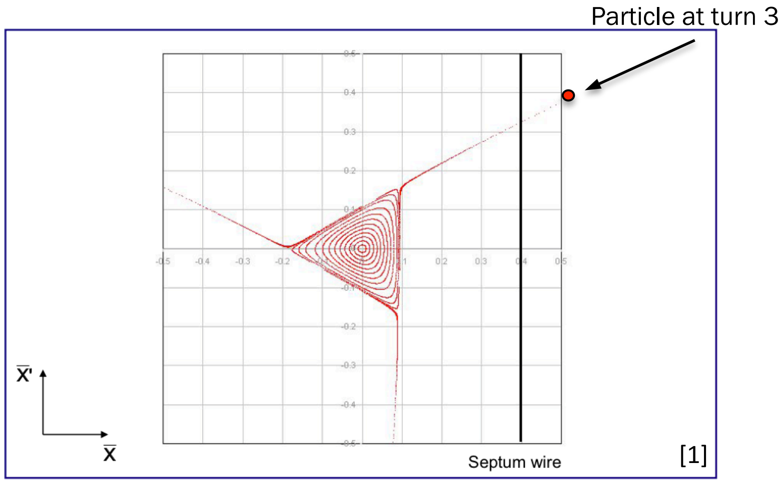

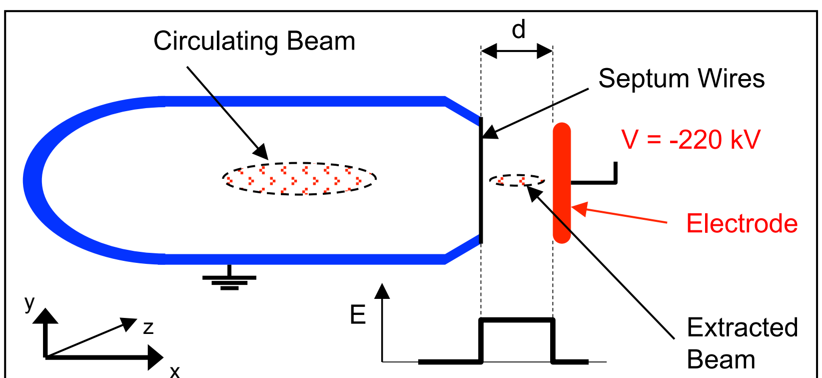

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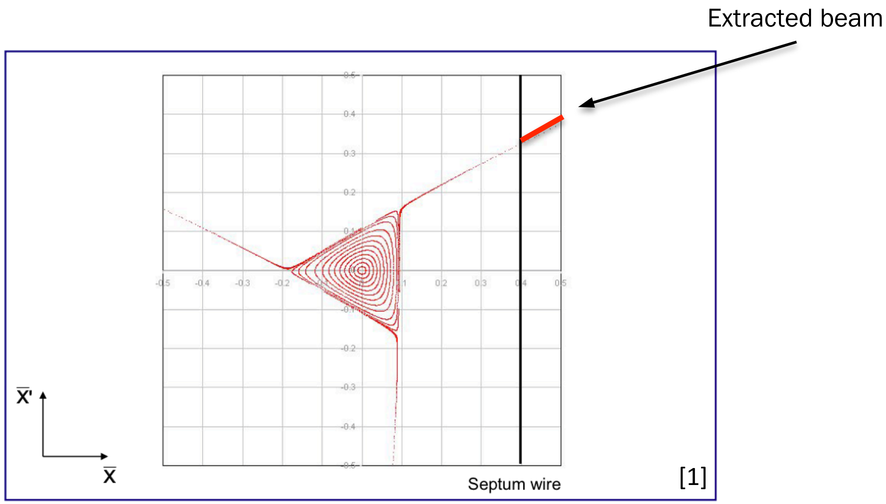

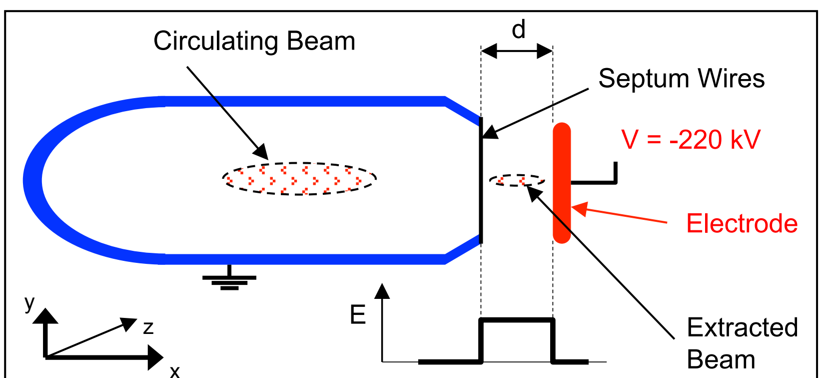

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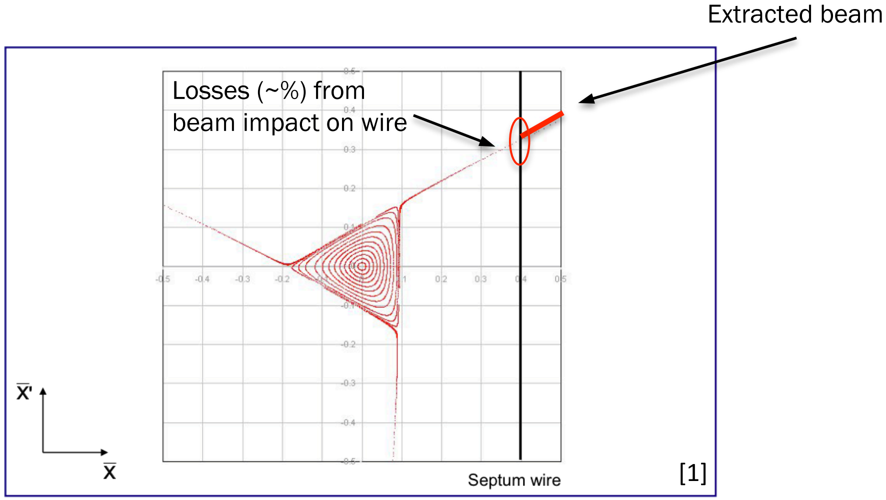

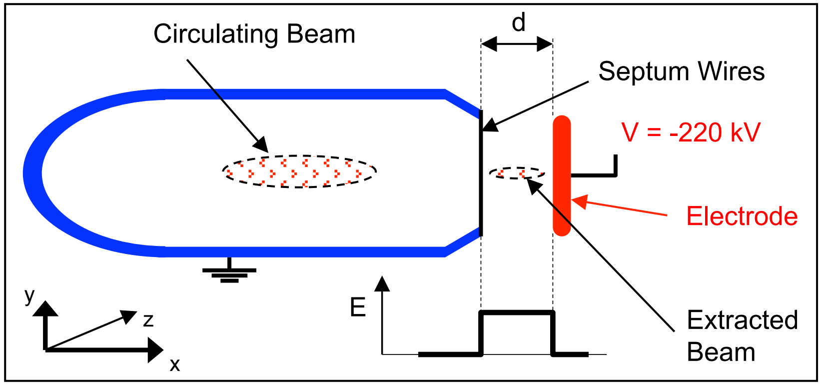

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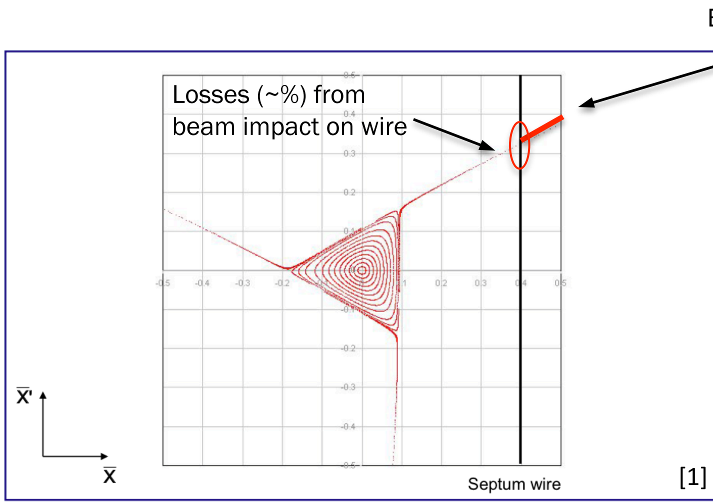
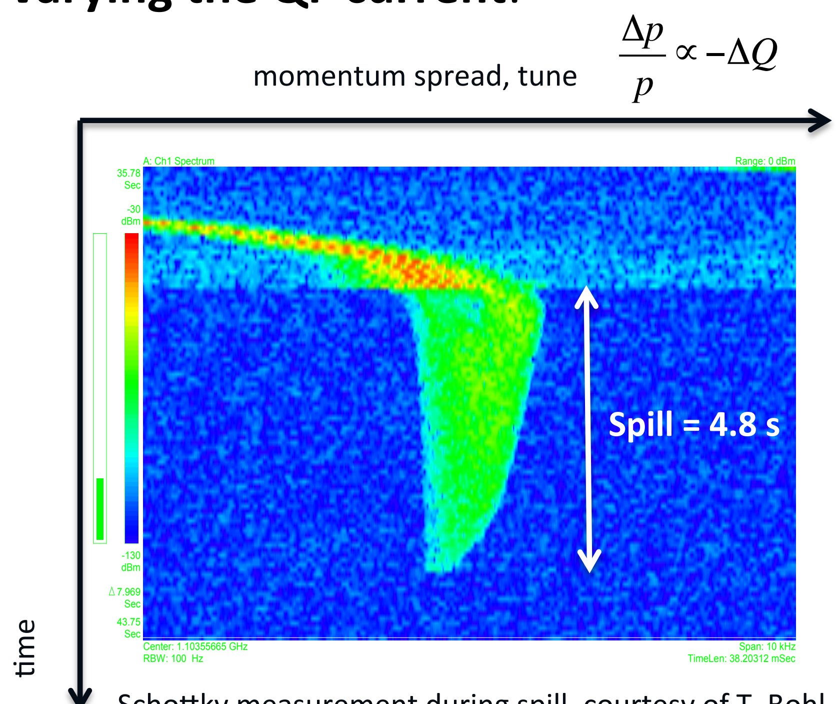
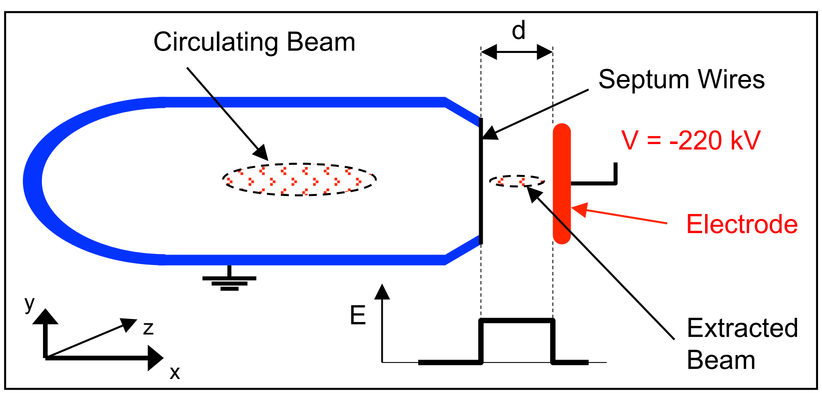


- Resonant tune [Q = 26.666…] swept across the tune spread of the beam by **varying the QF current**:



Schottky measurement during spill, courtesy of T. Bohl



The slow-extraction scheme: LSS2

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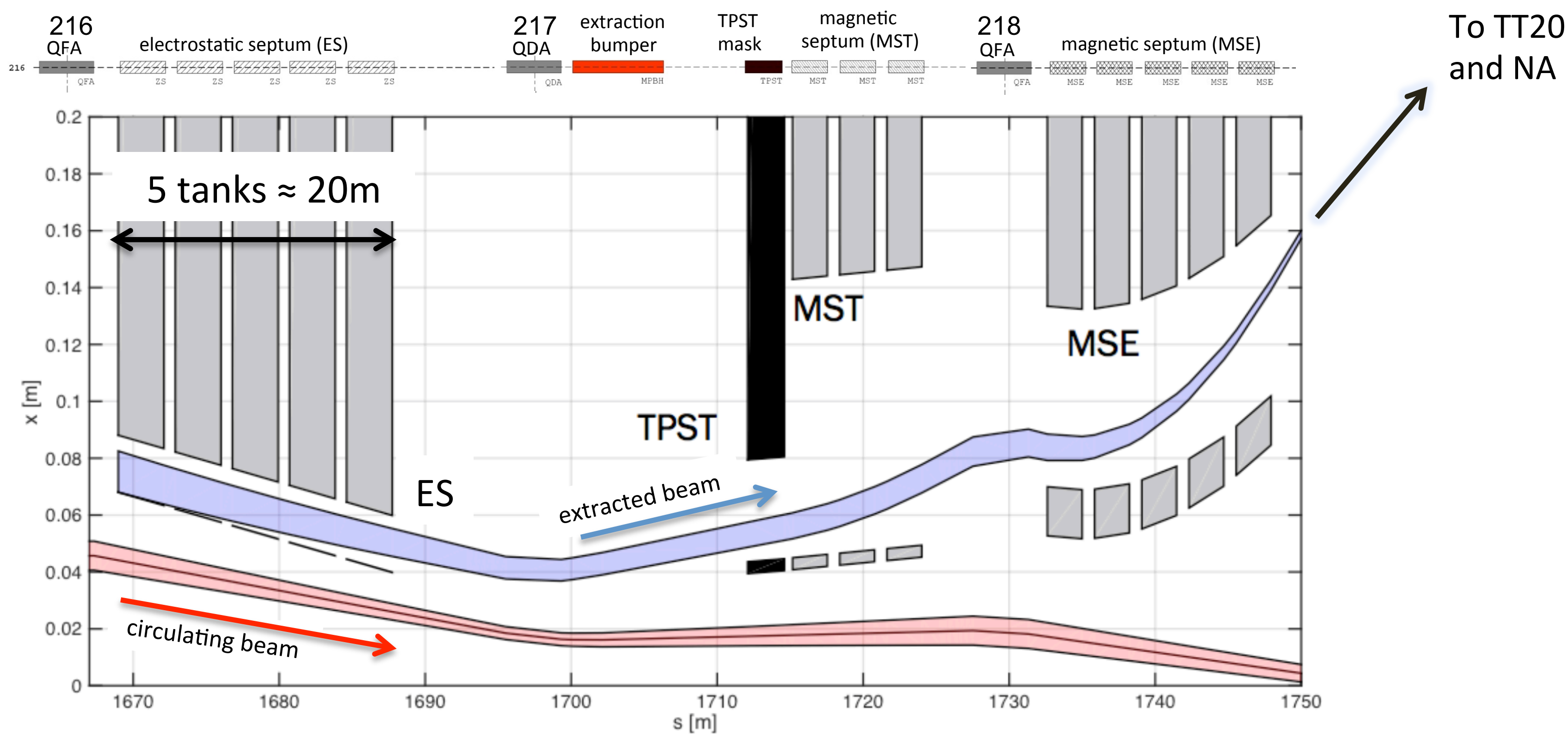

Trajectories for third-integer resonant slow extraction in LSS2 (Q26.666…)

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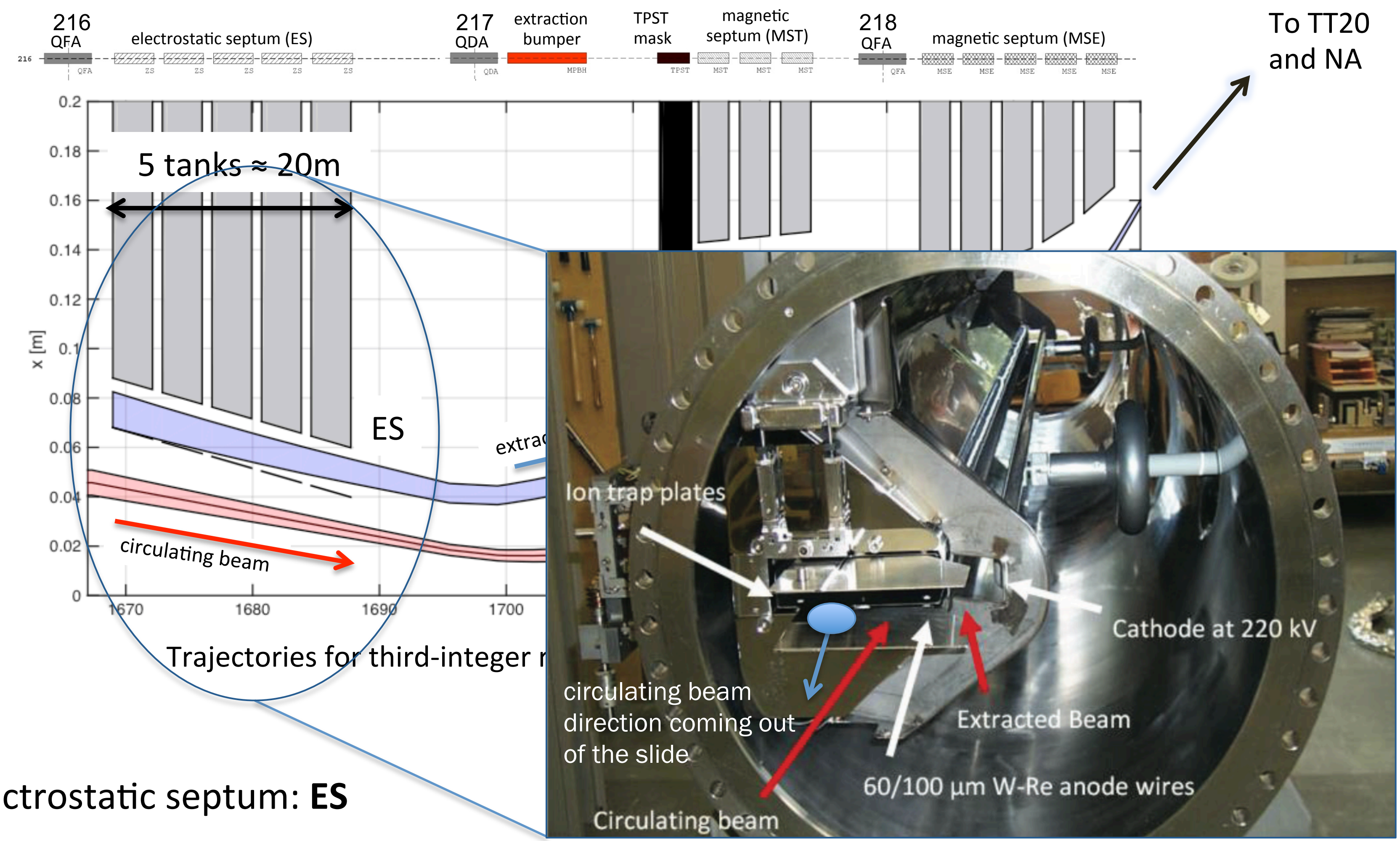

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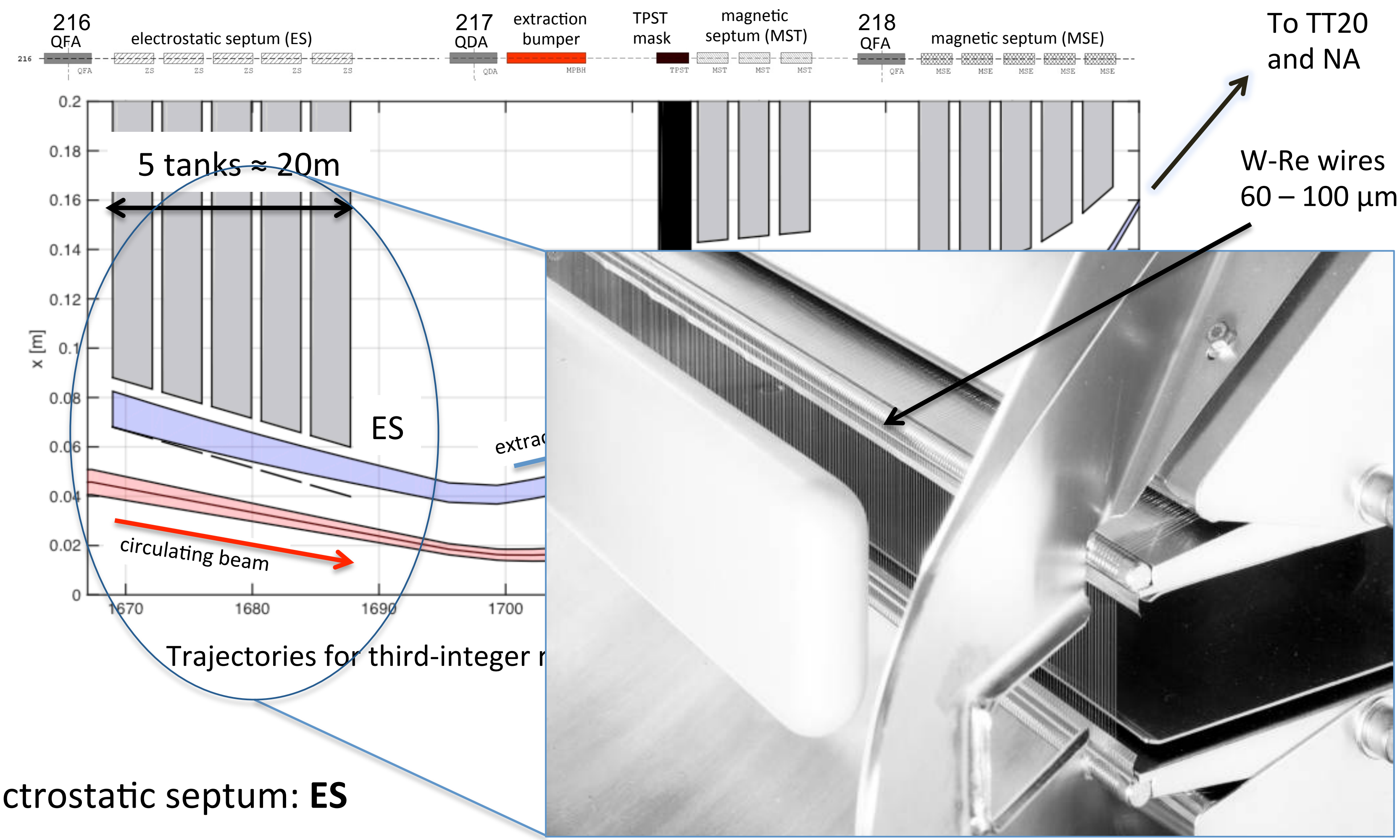

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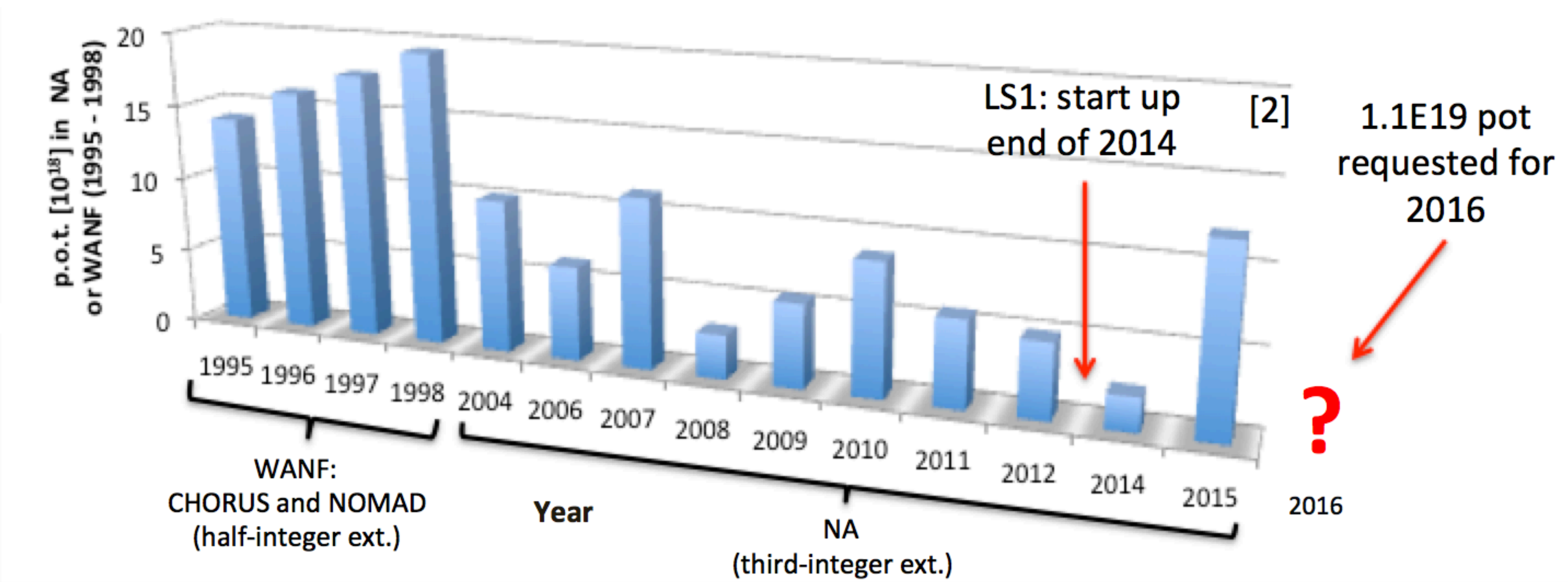
POT delivered and requested

- Since restarting after LS1 some of the highest proton (p) fluxes have been extracted to the North Area in ≈10 years



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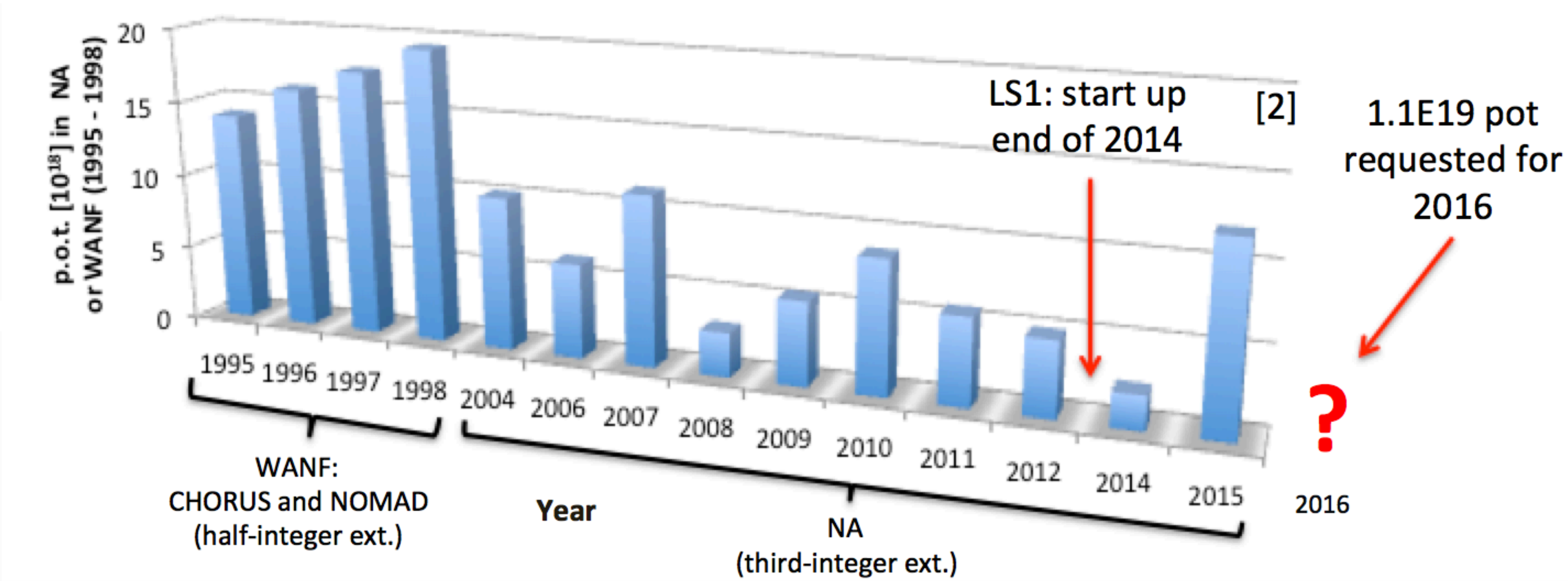

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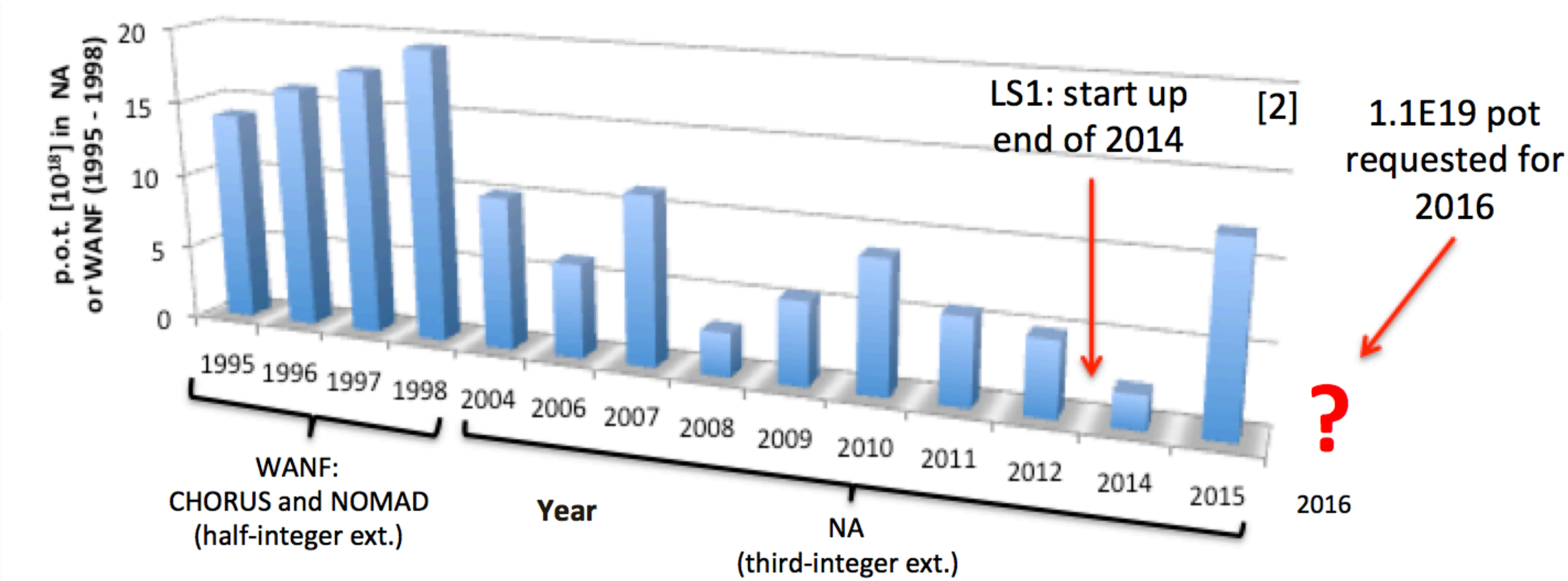
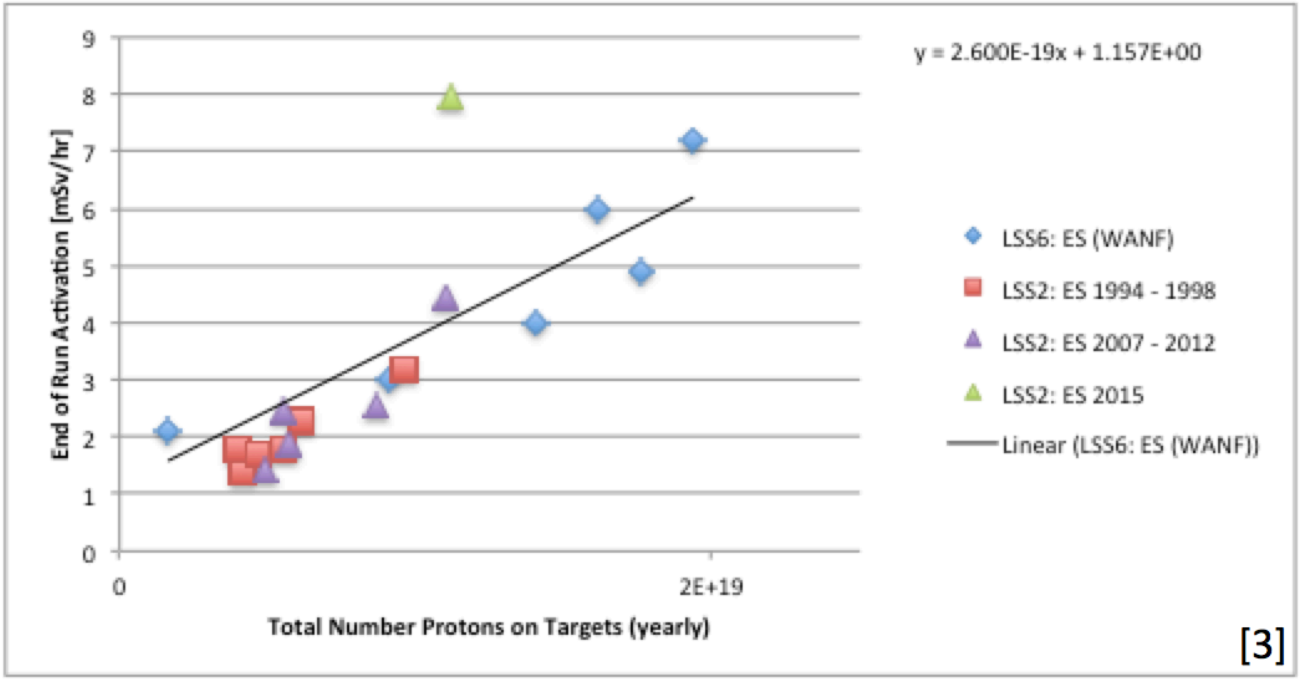
- Future experimental proposals request as much as 4E19 p/yr over 5 years:
  - Same as delivered to CNGS (so OK for SPS) but a fast and almost loss-free extraction process was used (2x 10.5 μs spills per 6 s)



Activation induced by slow-extraction

- Rough **rule-of-thumb** for activation since the early 1990's:
  - end of run activation in LSS2 at ES is linear with the p.o.t. delivered that year



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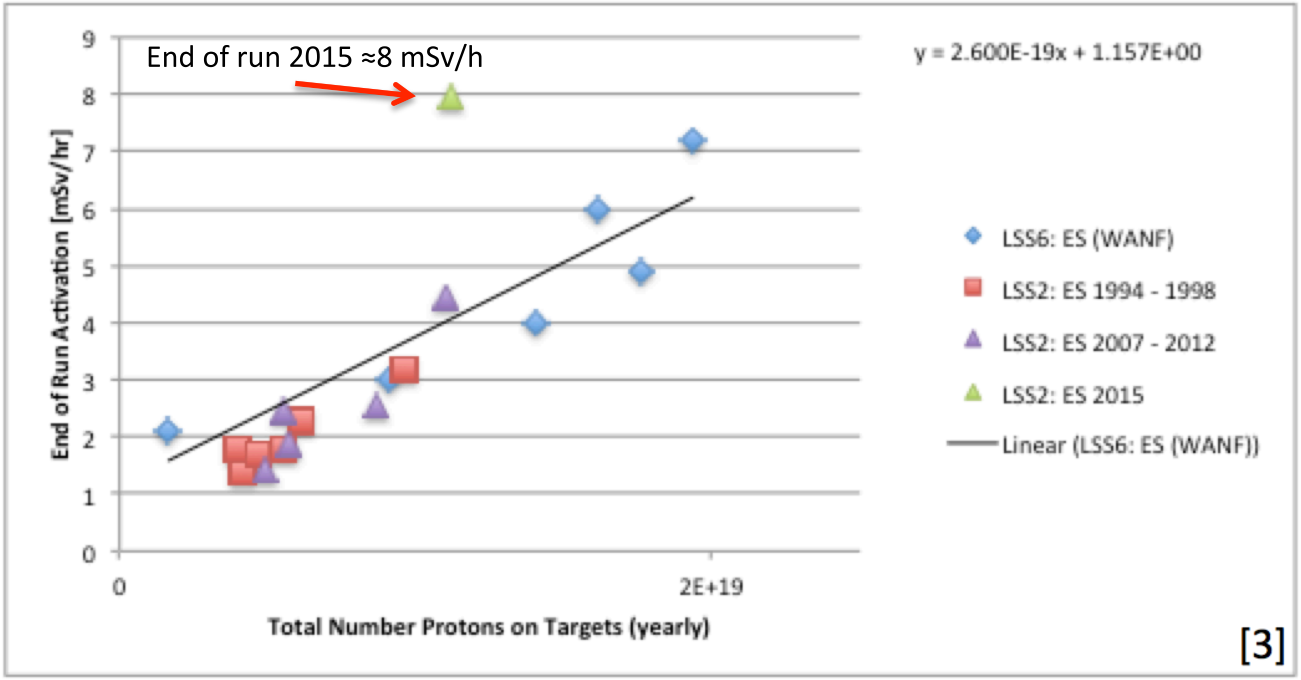

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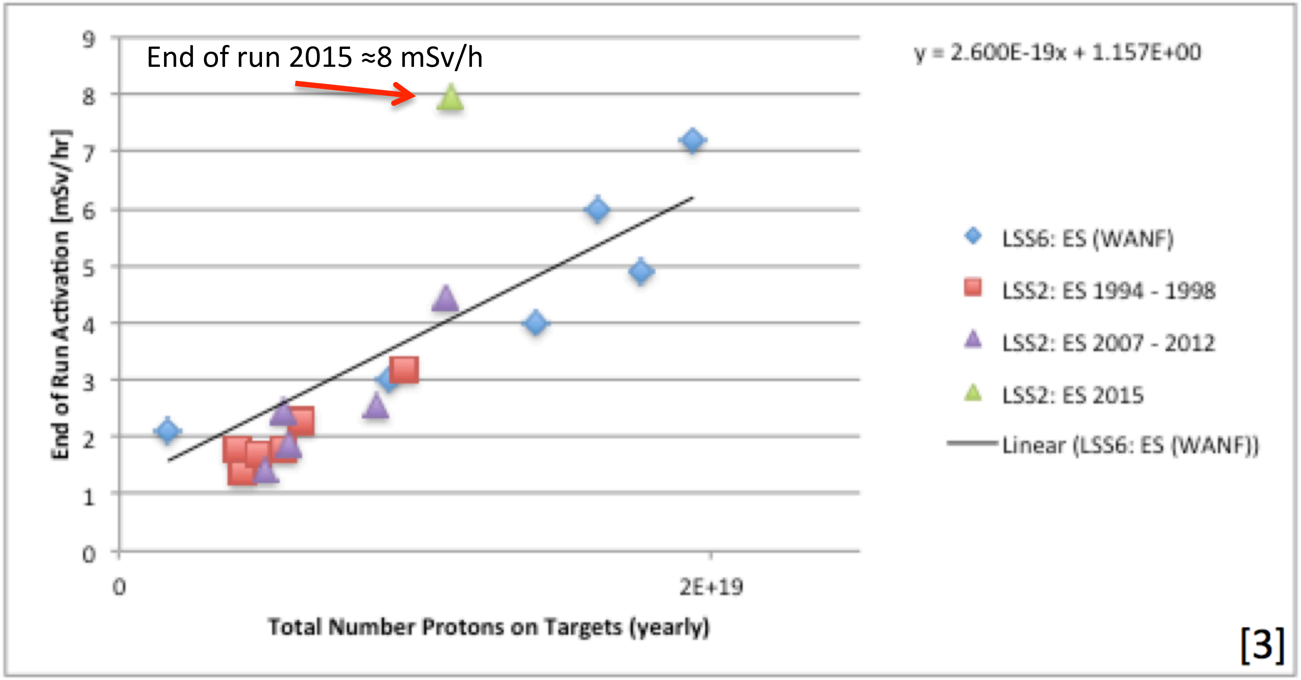

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- **SPS Losses and Activation Working Group (SLAWG)** was formed to investigate and follow-up the increase in activation during 2015

Challenges encountered since LS1

- SPS is becoming a truly **multi-cycling** machine:
  - Frequent super-cycle (SC) changes and dynamic economy cycles induce hysteresis effects that **move the beam alignment with the ES**
  - ES cannot be quickly re-aligned in response to SC changes
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- **Interventions** on extraction hardware in **activated area**

Mitigation measures implemented

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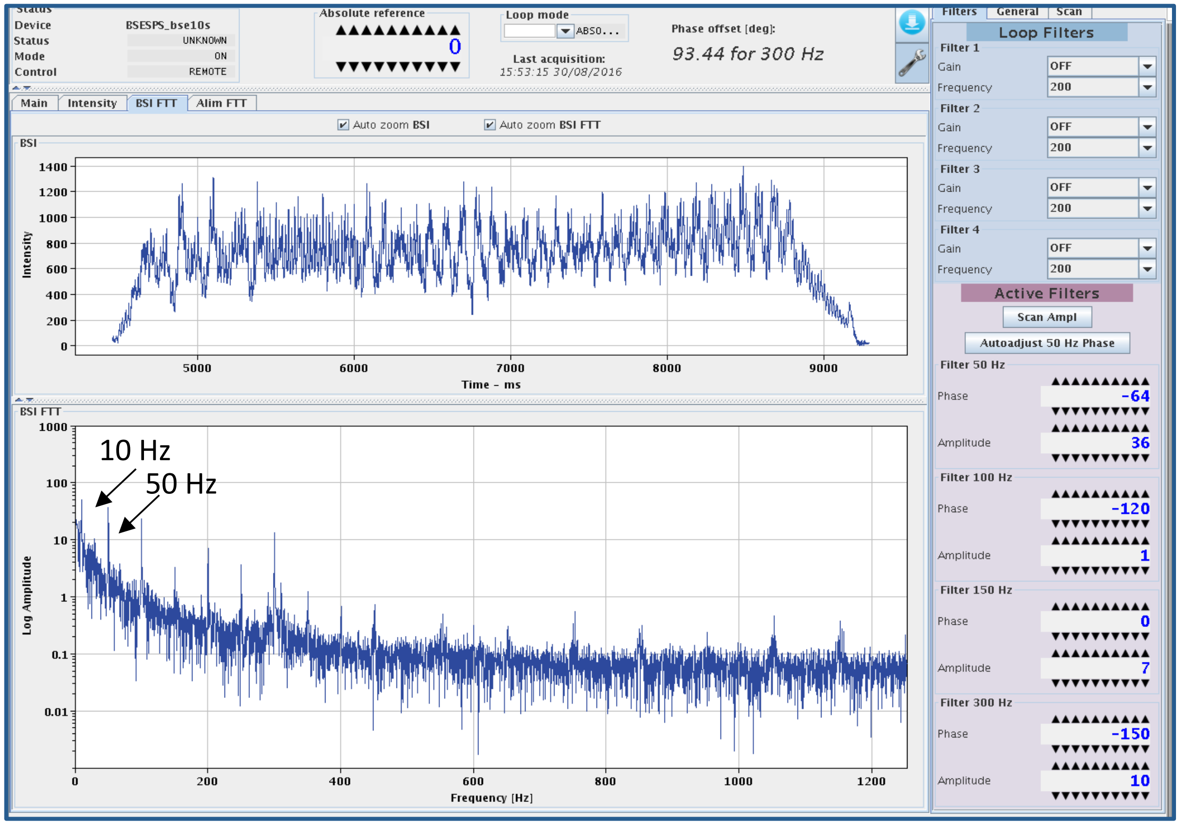
- **Collaboration with UA9** formed to investigate the use of crystals for slow-extraction at the SPS:
  - First MD was successfully carried out in July, with a second planned in October

Spill quality

- Low frequency noise on the QF power supply reduces the effective spill length for experiments:



A recent example of a relatively good spill with large n x 50 Hz components and another noise source at 10 Hz [8]

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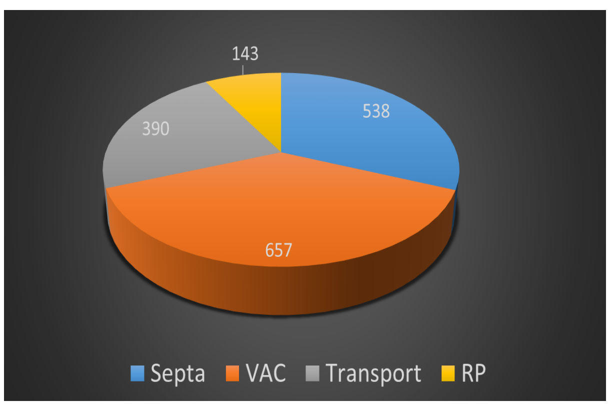
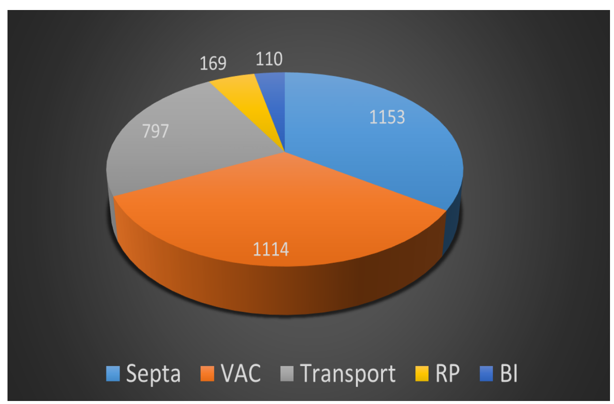
- Interventions in high radiation areas are necessary [9]:
  - **Remote handling:** employed for first time in 2016, has to be the future direction
  - Steep learning curve in 2016: **dose taken reduced by factor 2**
  - Number of interventions is **ultimately limited** by dose taken by trained personnel (< 2 mSv/yr/person) and has to be shared with interventions across CERN complex



ES tank 4 exchange, 9 Feb 2016:
3.3 mSv (collective dose)



ES tank 2 exchange, 19 Feb 2016:
1.7 mSv (collective dose)

Remote handling in LSS2

Impact of future POT requests

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  - As projected by our rule-of-thumb…for a flux of 4E19 p/yr
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- Bear in mind that **during 2015** we would have had to wait **1 month** with the above assumptions:
  – Able to wait 3 months into the YETS, but not to be repeated...!

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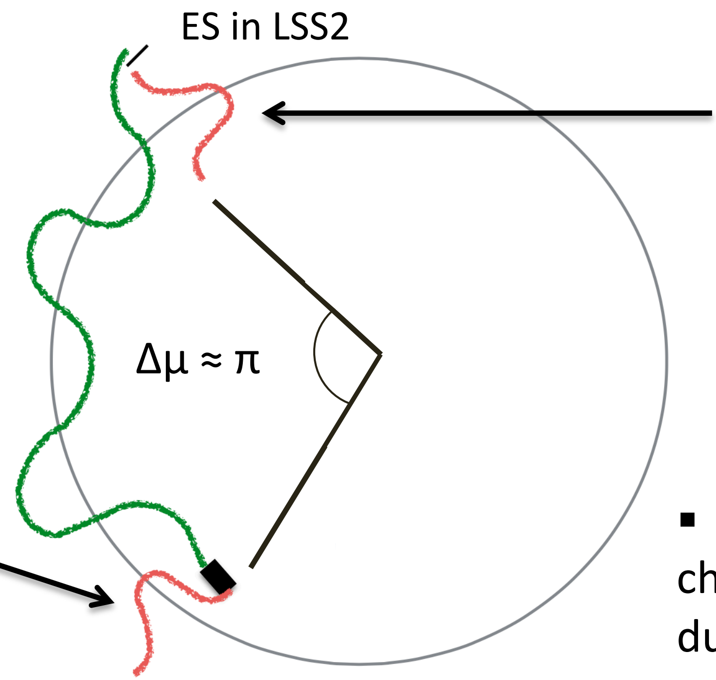
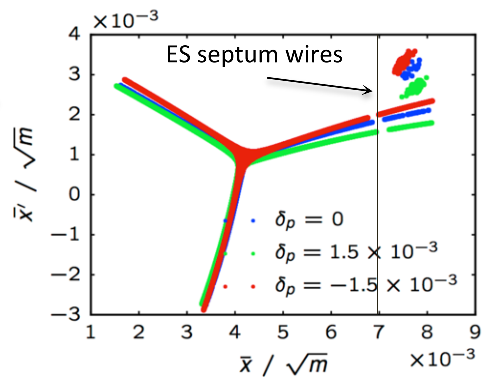
- Doctoral student in TE-ABT since March 2016

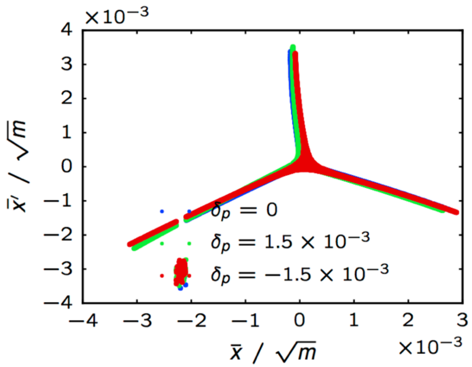
Collaboration between TE-ABT and UA9

- Shadowing the ES septum wires using an upstream crystal to coherently channel particles away from the wires and into the septum gap [11,12]
- First (non-local) tests could made relatively soon (2018?) with a crystal installed in LSS4:





LSS4 crystal location
Identified (extraction bumpers)



- Challenge: transporting channeled beam to target (or dump)

crystal in LSS4 (channeling) ≈1 mm wide, Δx' ≈150 μrad

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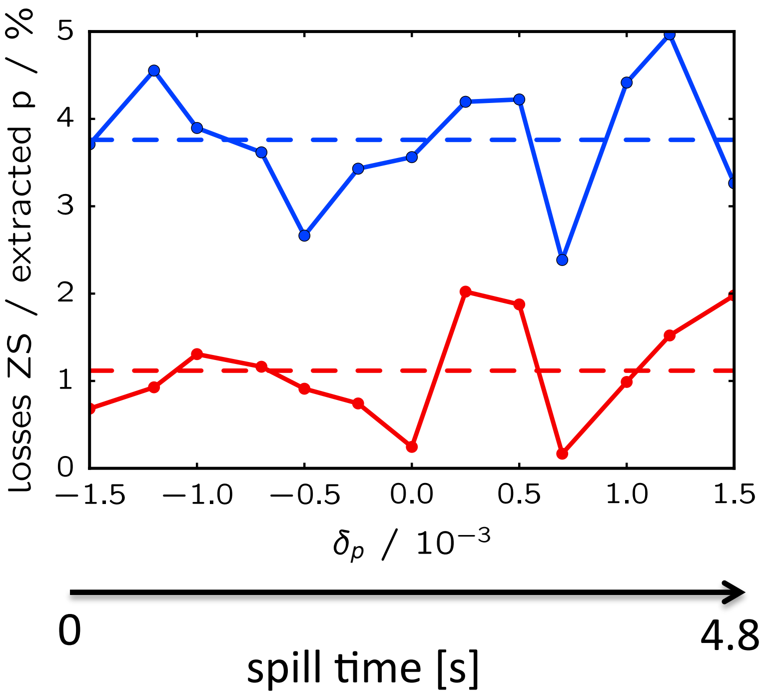
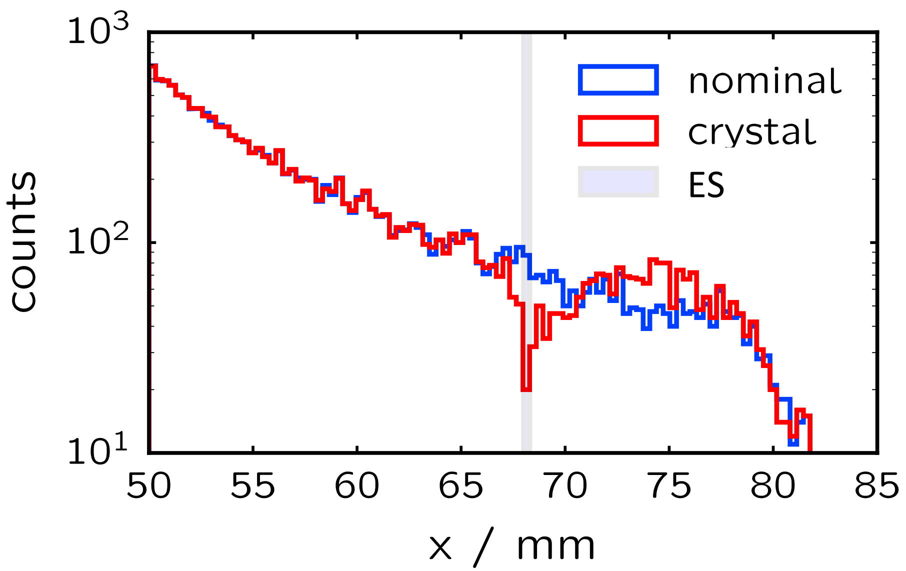
- First (non-local) tests could made relatively soon (2018?) with a crystal installed in LSS4:

Preliminary studies show a promising loss reduction:



Particle density at ES:



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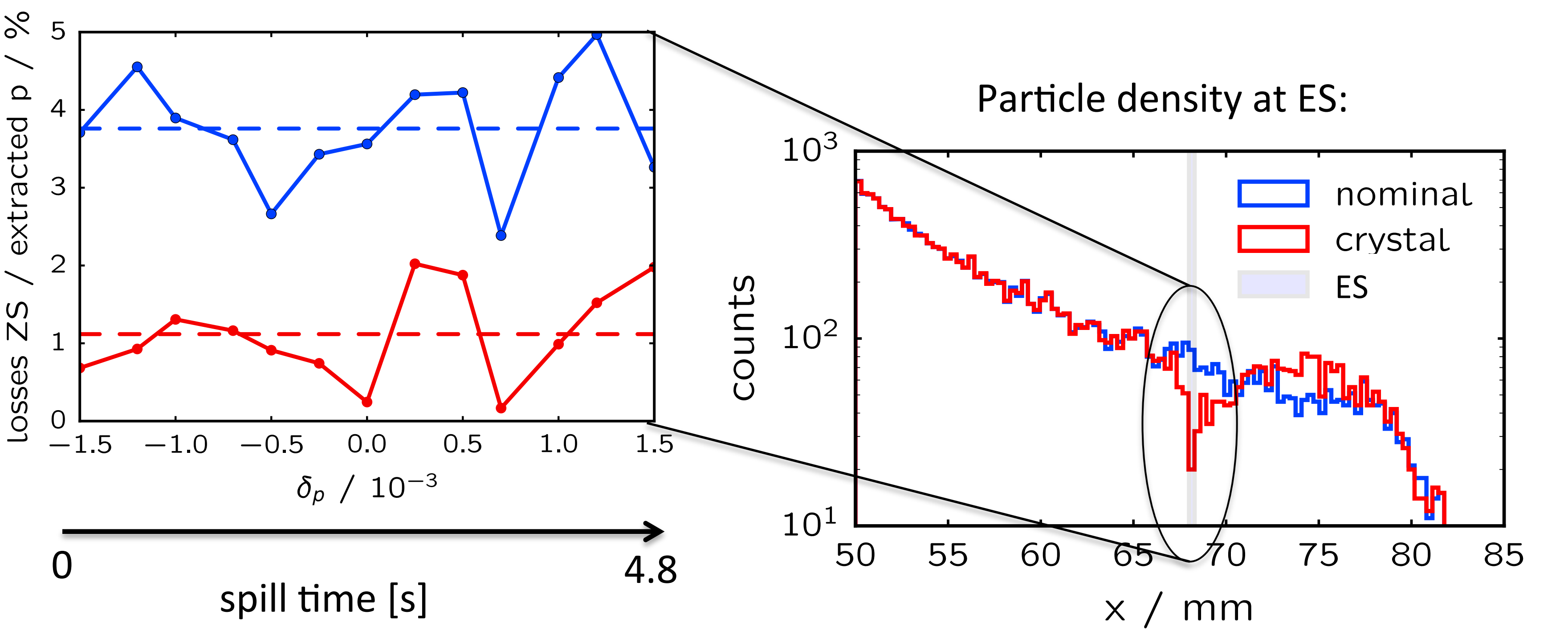


Summary

- Slow extraction is **only way** to give a 1 second spill, but is intrinsically lossy (**few %** of beam)
- Delivering 4E19 pot/yr via LSS2 slow extraction needs **factor 3 - 4 reduction** in local activation
- Working group (**SLAWG**) established in 2016 and actively tackling the issue (already for today's beams)
- **Promising beam loss reduction options exist** and are being actively studied
- SPS instrumentation, stability and reproducibility have to **improve** in parallel

Thank you for your attention!

References

[1] B. Goddard, Introductory CAS Lectures, Frascati, Italy, 2008

[2] M. Fraser, Follow-up on the SPS Activation Levels, 157th IEFC Meeting, CERN, 2015

[3] Extraction and beam transfer for the SHiP facility, EDMS 1495859, CERN, 2015

[4] F. Velotti, Orbit stability during LHC extraction, MSWG Meeting, CERN, 27 May 2016,

[5] C.M. Genton, SPS QF spikes and ripple investigation, 175th IEFC Meeting, CERN, 2016

[6] V. Kain et al., New Spill Control for the Slow Extraction in the Multi-Cycling SPS, IPAC'16, TUPMR051, 2016

[7] B. Goddard, Update on the SPS losses and Activation WG, 179th IEFC Meeting, CERN, 2016

[8] V. Kain, SLAWG Meeting #5, CERN, 1st September 2016

[9] B. Balhan, YETS 2015-16 ZS replacement PM, EDMS 158381, 29 Feb 2016

[10] M. Fraser, Update on SPS LSS2 extraction losses and activation, 168th IEFC Meeting, CERN, 2016

[11] F. Velotti et al., Preliminary studies on non-local resonant crystal assisted slow extraction from SPS, UA9-SE Working Group, 29 March 2016

[12] F. Velotti et al., Slow extraction assisted by bent crystals in the SPS Meeting, 28 July 2016

[13] S. Cettour Cave et al, SPS economy mode, MSWG meeting, CERN, 6 November 2015

[14] W. Scandale, Crystal Extraction, The Slow Extraction Conference, Darmstadt, 1 - 3 June 2016

Extra slides

Mandate of SLAWG

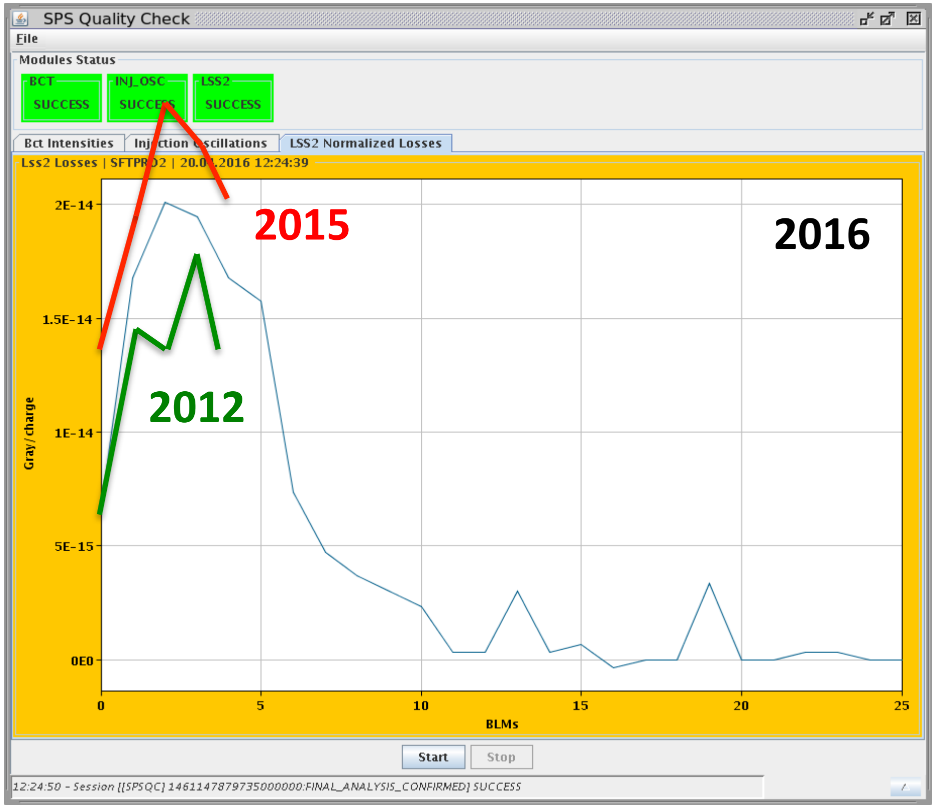
- **Analyse and document** historical and current **beam losses** in SPS and TT20 as a function of beam type and year
- Define key **reference interventions with WDP** and reasonable cool-down times as a function of activation level
- Follow up improvements in SPS **logging and surveillance tools**
- Propose target **interlock** levels for losses per proton for LSS2 slow extraction
- Deploy **surveillance SW to interlock beams** for excessive extraction losses
- Study **short and long-term methods to improve** extraction, transport and splitting losses
- Liaise with **LIU and CONS projects** for common developments/ improvements
- **Analyse required p.o.t.** requests from NA experiments and define implications for SPS operation
- Periodically **report status and results** to IEFC

SPS Quality Check (QC)

- Factor ≈ 2 increase in activation went unnoticed because the per cycle extracted beam intensity was lower, compared to 2012, but the duty factor higher.
- FT cycle now included in SPS QC application:
  - Online monitoring of the per proton extraction losses
  - Interlocked thresholds (SIS)
  - Regular re-alignment of the ZS during dedicated MD

Year	BLM: ZS1 [Gy/10^{14} p^+]	BLM: ZS2 [Gy/10^{14} p^+]	BLM: ZS3 [Gy/10^{14} p^+]	BLM: ZS4 [Gy/10^{14} p^+]	BLM: ZS5 [Gy/10^{14} p^+]
2012	0.7	1.5	1.4	1.8	1.4
2014	1.7	n/a	2.4	2.9	1.8
2015	1.4	2.0	2.5	2.7	2.1
2016	0.7	1.9	2.2	2.1	1.7

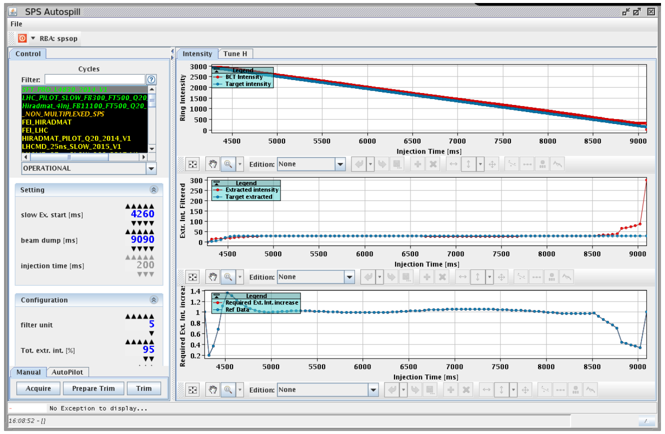
Recent normalised extraction losses (averaged over the year)



SPS QC monitoring application after first ZS alignment in 2016

SPS Autospill [6]

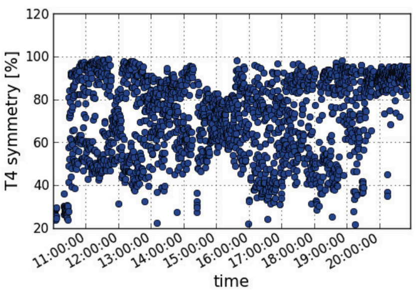
- Servo quad feedback with intensity measured in extraction line disconnected to improve trajectory stability in transfer line:
  - Shot-to-shot orbit variations amplified by servo quad
  - Feedback sensitive to cycle-to-cycle intensity variations
  - Small dimension of NA62 target in 2015 sensitive to steering errors
- Instead, feed-forward on current in main quadrupole (QF) circuit using *Autospill* application:



Autospill application

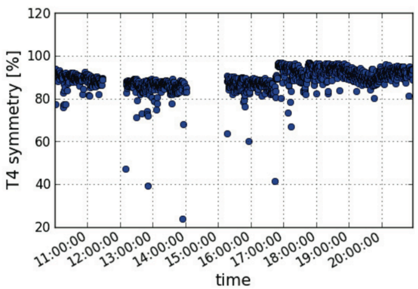
Symmetry measured on T4 target:

servo feedback:



1 Dec 2014

SMQ feed-forward:

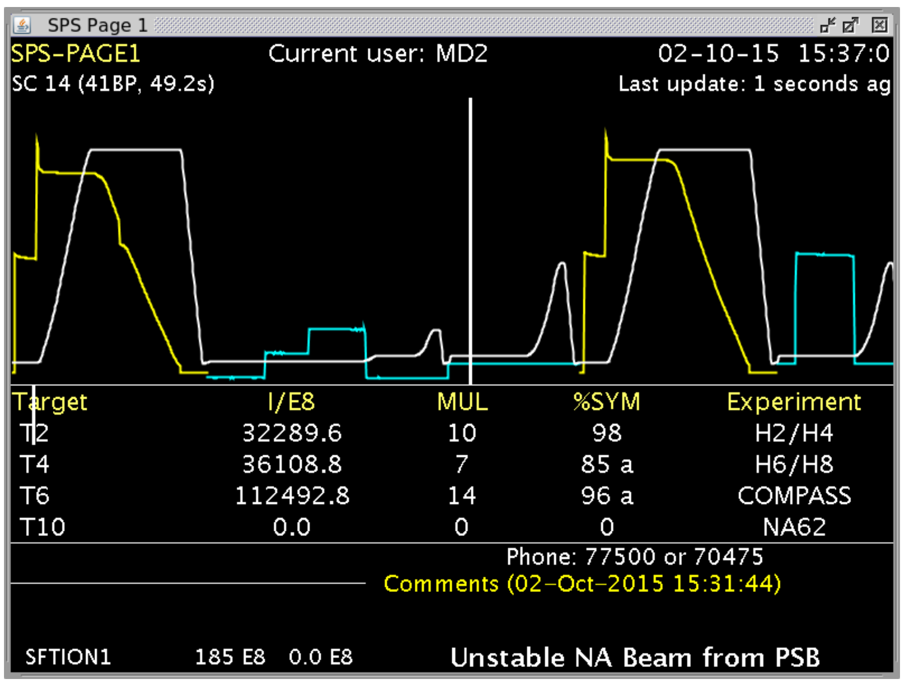


1 Oct 2015

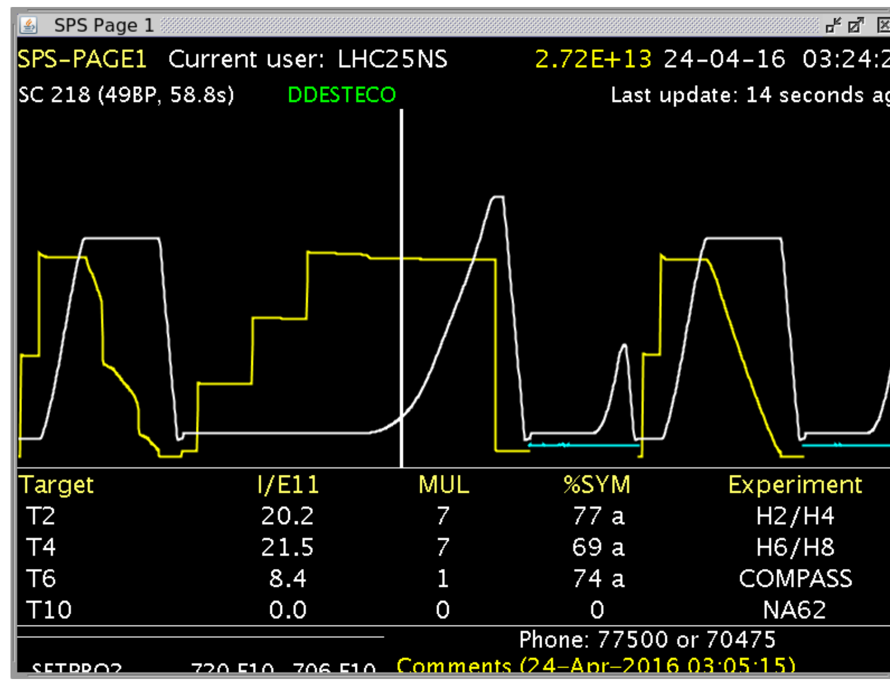
Symmetry (at target): 100% = centred

QF Glitches

- Small current glitches (ΔI ~ 1 in 2000 A) observed recently during slow extraction: sporadic and, to date, without explanation
- Glitches of $\Delta I/I \sim 10^{-3}$ seriously disrupt the slow-extraction



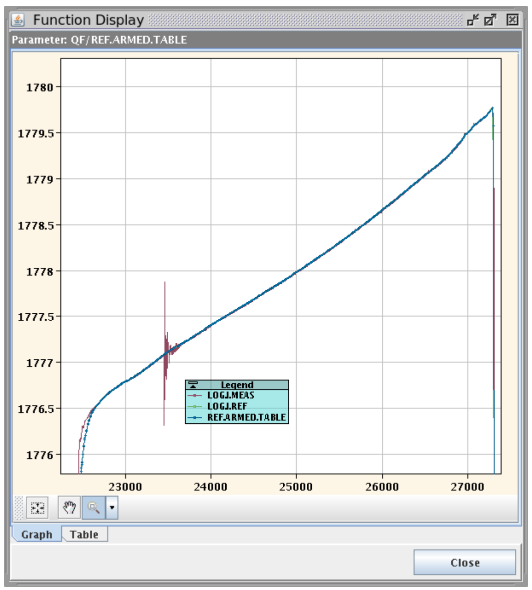
Glitch on 2nd October 2015

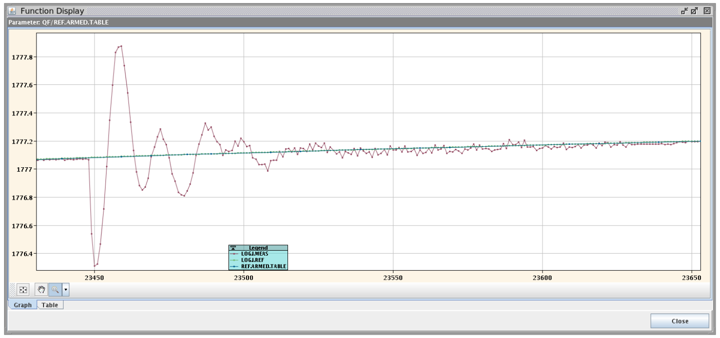


Glitch on 24th April 2016

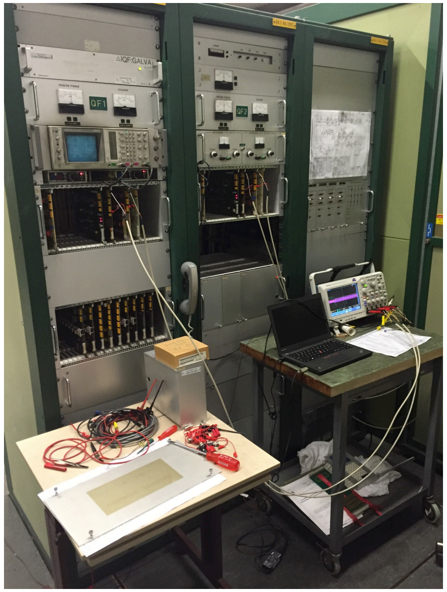
QF Glitches

- Small current glitches (ΔI ~ 1 in 2000 A) observed recently during slow extraction: sporadic and, to date, without explanation
- Glitches of $\Delta I/I \sim 10^{-3}$ seriously disrupt the slow-extraction
- Under investigation!





A classic glitch event on 9th July 2015: current sharply increases before regulation loop kicks in



Scope installed on SMQ to trigger acquisition to diagnose source of glitch

ALARA III (see 88th IEFC, 2013, H. Vincke)

https://edms.cern.ch/document/1296520/1

new

CRITÈRE DE DOSE INDIVIDUELLE **hard limits**

Équivalent de dose prévisionnel individuel (H_i) pour l'intervention, ou pour l'ensemble des interventions de même nature lorsque celles-ci sont répétées plusieurs fois sur une année :

100 µSv | 1 mSv

niveau I | niveau II | niveau III

CRITÈRE DE DOSE COLLECTIVE

Équivalent de dose prévisionnel collective (H_c) pour l'intervention, ou pour l'ensemble des interventions de même nature lorsque celles-ci sont répétées plusieurs fois sur une année :

500 µSv | ~~10 mSv~~ 5 mSv

niveau I | niveau II | niveau III

ALARA III (see 88th IEFC, 2013, H. Vincke)

https://edms.cern.ch/document/1296520/1

- ALARA limits:
  - 5 mSv collective dose per intervention
  - 1 mSv individual dose per intervention
- Hard limit dose to individual is 2 mSv/yr

new

CRITÈRE DE DOSE INDIVIDUELLE **hard limits**

Équivalent de dose prévisionnel individuel (H_i) pour l'intervention, ou pour l'ensemble

…que celles-ci sont répétées plusieurs fois sur

1 mSv

…u II | niveau III

…ve (H_c) pour l'intervention, ou pour l'ensemble

…sque celles-ci sont répétées plusieurs fois sur

5 mSv

~~10 mSv~~

…au II | niveau III

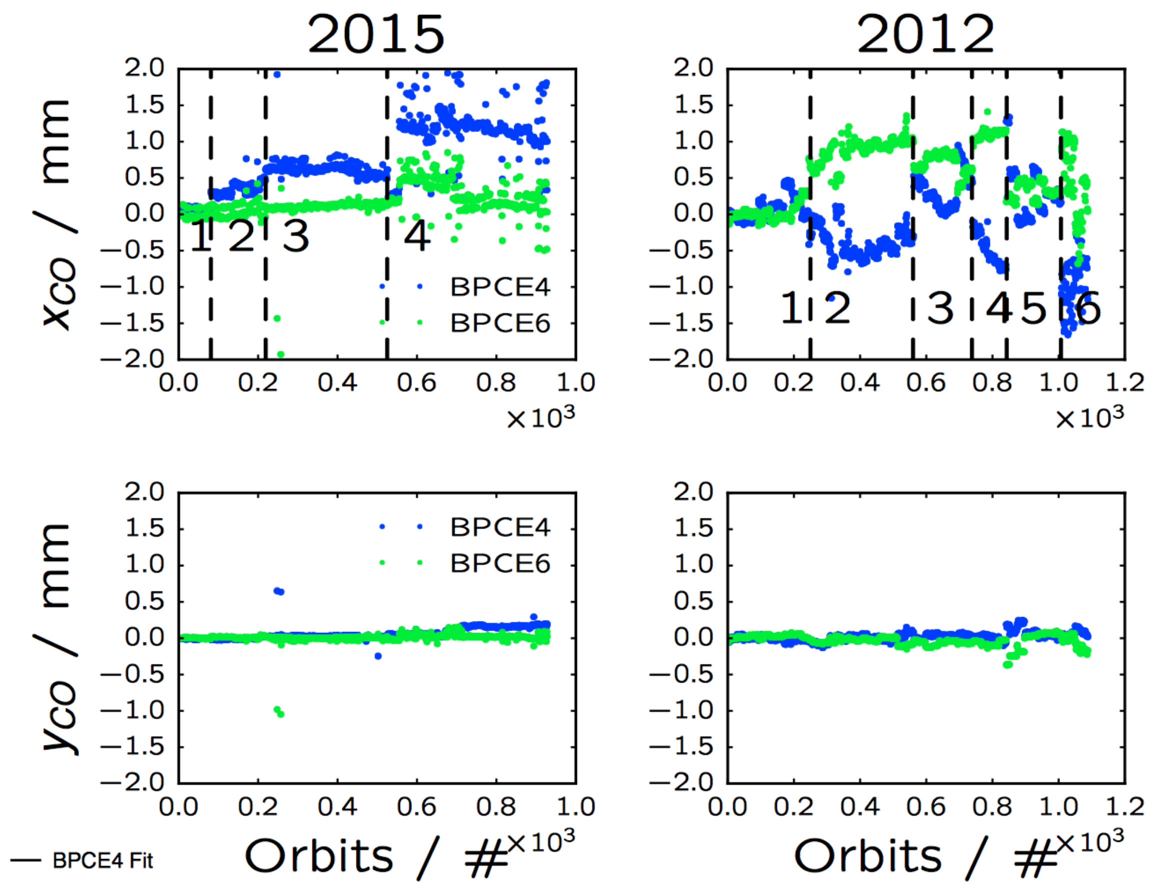
Waiving of the ALARA committee meeting

Circumstances

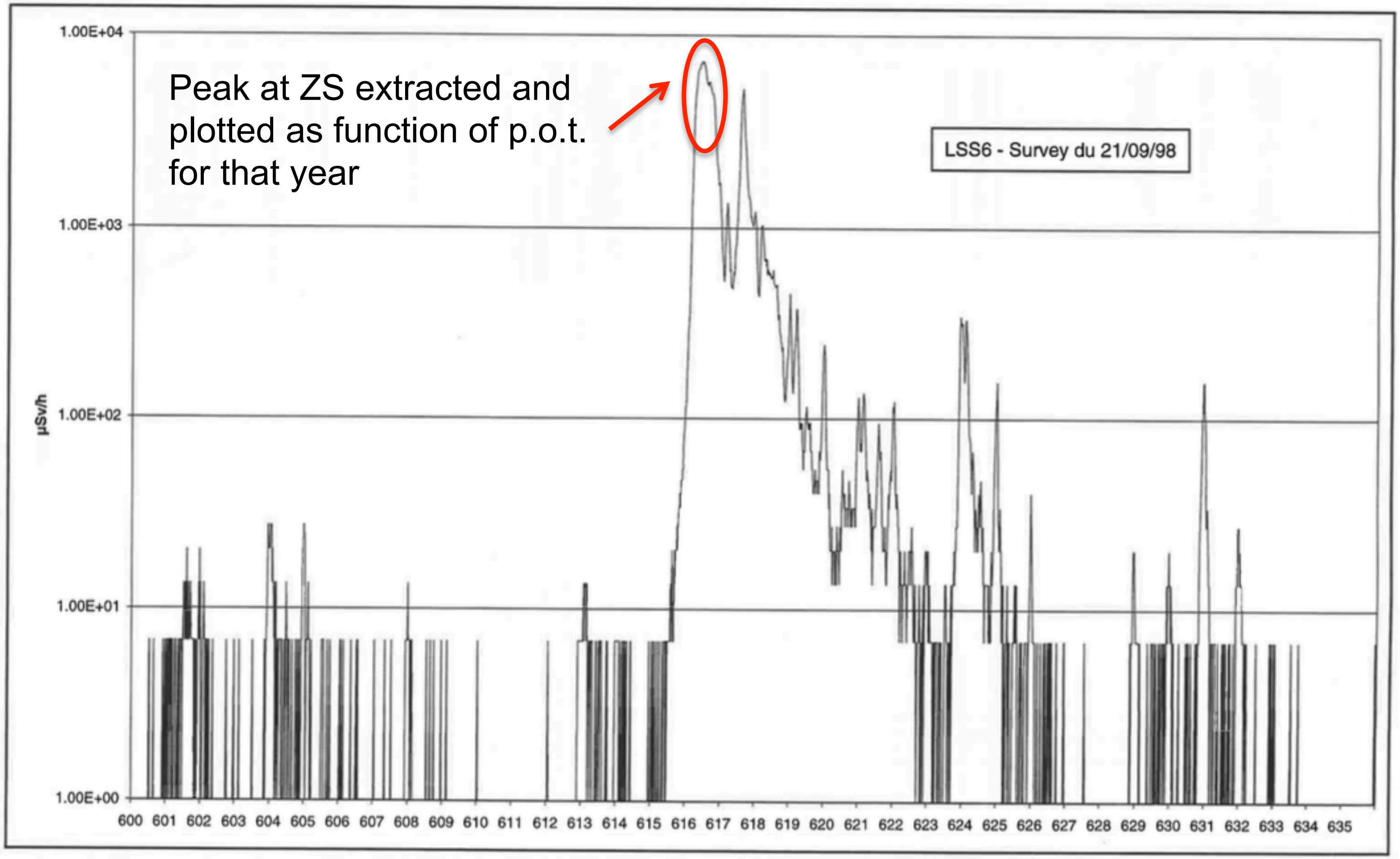
- Repetitive intervention
  - A **procedure** has been worked out under which circumstances a waiving of the ALARA committee meeting could be possible
  - Generic DIMRs should be worked out and approved a priori in an ALARA committee meeting.
- Urgent maintenance/repair
  - 'Urgent ALARA committee' decision
  - No 'formal (physical)' ALARA committee meeting required
  - Generic DIMRs for standard maintenance/repair should be worked out and approved a priori in an ALARA committee meeting.

SPS orbit stability (LHC cycle at extraction)

- Drifts of ~ mm observed over months (July to October 2015) [4]



RP survey LSS2: example in 1998



Collaboration with UA9

Edms No. 1509966
7 May 2015

MEMORANDUM

To : Walter Scandale, Chairperson of the UA9 Collaboration

From : Frédérick Bordry, Director for Accelerators and Technology

c.c.: Paul Collier, Head of the Beams Department
José Miguel Jiménez, Head of the Technology Department
Roberto Saban, Head of the Engineering Department
Brennan Goddard, TE-ABT Group Leader

Subject : Slow extraction assisted by bent crystals in the SPS

Following the interest generated by the *Proposal for Investigating Slow Extraction Assisted by Bent Crystals in the SPS,* I would like to ask the support of the UA9 collaboration both for the studies and for the developments of hardware and software which these might entail.

Needless to say, the beam time required for the validation of the concept will be taken from

Dynamic Economy at SPS

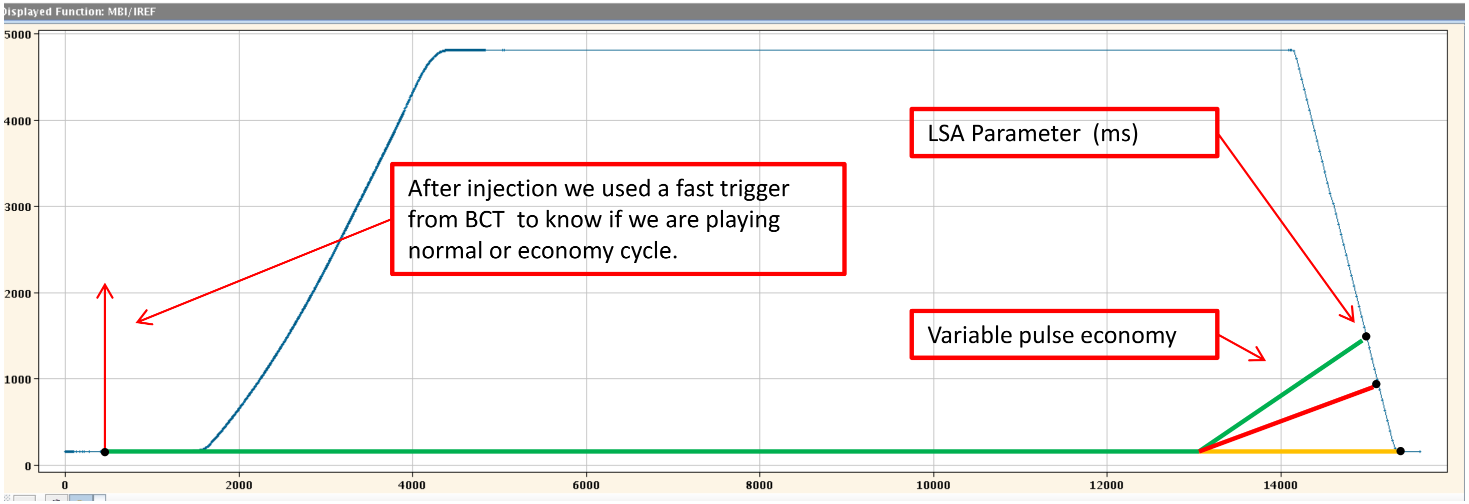
SPS Ring

a) Dynamic economy

The main power supply and RF power will execute a modified (energy saving) function if the BCT does not detect the beam after the first injection.

- MPS staying at injection energy.
- All ring circuits staying at Imin.
- All transfer line circuits without TT10 staying at Imin.

If the FGCs receive a trigger dynamic eco.
The FGCs staying at the injection energy and play a smooth function to reach the last configurable point and to keep the same magnetic history.
We can force the pulse by hand to do some check.

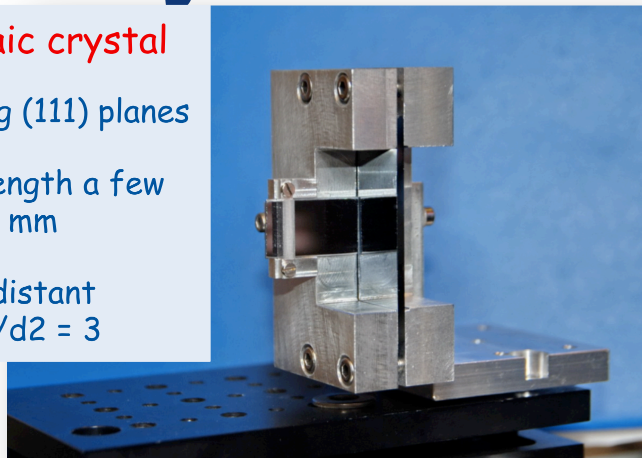


[13] S. Cettour Cave et al, SPS economy mode, MSWG meeting, CERN, 6 November 2015

Bent crystals for UA9

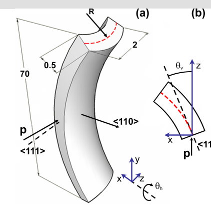
Quasimosaic crystal

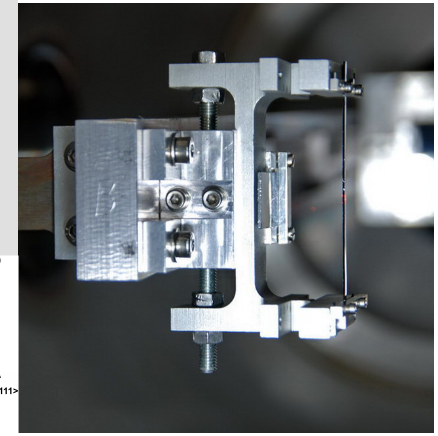
- ❑ Bent along (111) planes
- ❑ Minimal length a few tenths of mm
- ❑ Non-equidistant planes d1/d2 = 3



Strip crystal

- ❑ Bent along (110) planes
- ❑ Minimal length ~ 1 mm
- ❑ Equidistant planes

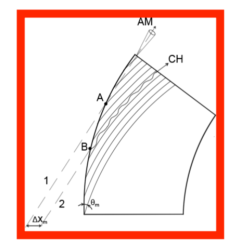




Crystals

- ❑ Dislocation-free silicon crystals plates or strips
- ❑ for optimal channeling efficiency
  - ✓ short length (few mm)
  - ✓ moderate bending radius 45 ÷ 70 m
- ❑ Mechanical holders with large C-shape frame imparting the main crystal curvature
  - ✓ Strip crystal: (110) planes are bent by anticlastic forces
  - ✓ Quasimosaic crystal: (111) planes are bent by 3-D anticlastic forces through the elasticity tensor
- ❑ Expected crystal defects:
  - ✓ Miscut: can be ≈100 μrad, but negligible effect if good orientation is applied
  - ✓ Torsion: can be reduced down to 1 μrad/mm ➔ UA9 data in the SPS North Area
  - ✓ Imperfection of the crystal surface: amorphous layer size ≲ 1 μm

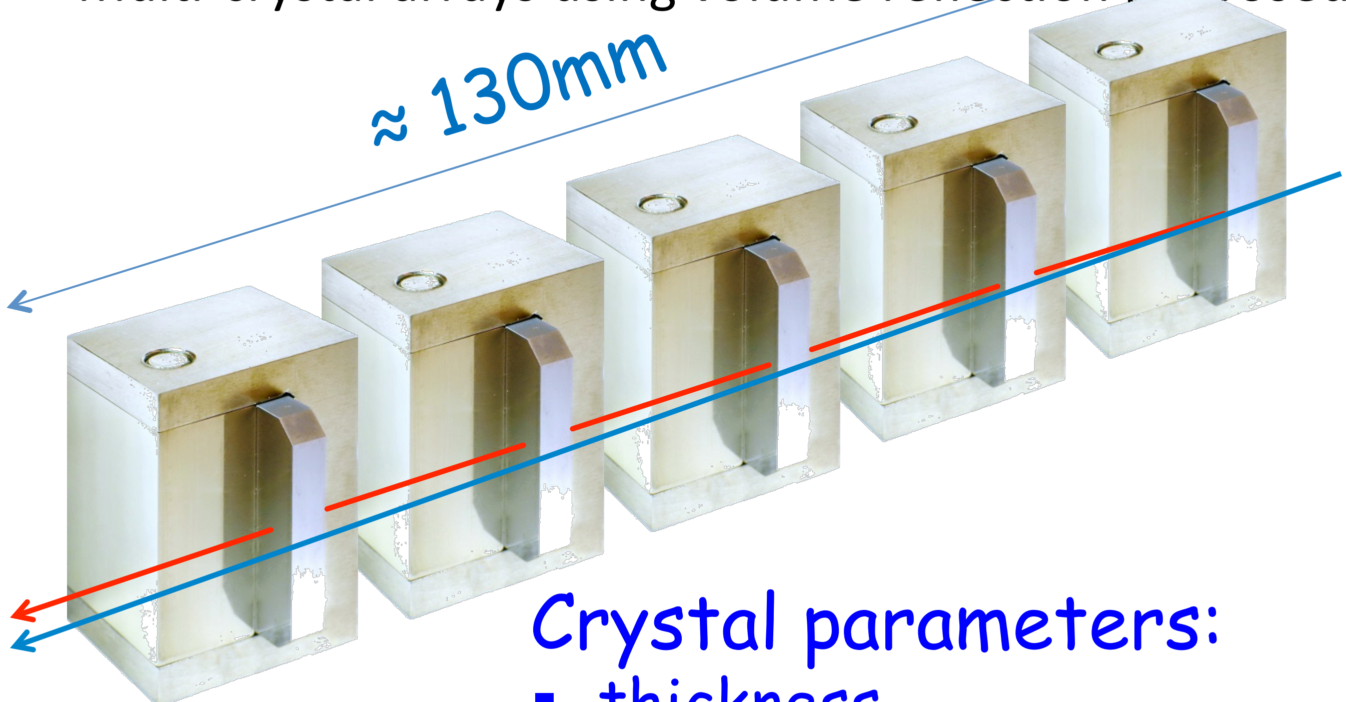
- ❑ SPS at 120÷270 GeV) 1÷2 mm length, 150÷170 μrad angle
- ❑ LHC 3÷5 mm length, 40÷60 μrad angle



[14] W. Scandale, Crystal Extraction, The Slow Extraction Conference, Darmstadt, 1 - 3 June 2016

Multi-crystals as a septum

- Multi-crystal arrays using volume reflection proposed as septa:



Crystal parameters:

▪ thickness	1-4 mm
▪ CH deflection angle	60-150 μrad
▪ MVR deflection angle	≈ 60 μrad
▪ open area	≤ 5 x 20 mm^2

[14] W. Scandale, Crystal Extraction, The Slow Extraction Conference, Darmstadt, 1 - 3 June 2016