Beam loss studies during the CERN PS CT Extraction

Session 3 - Exploitation and recent* benchmark activities

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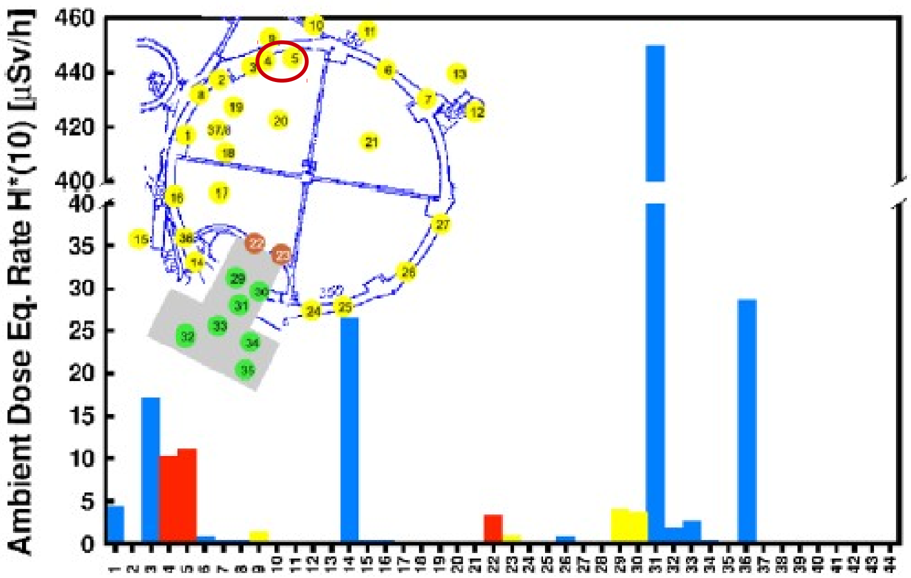
*(Define recent :))

The problem: PS radiation surveys

- During the 2006 survey, two hot areas were identified: the injection region from PS booster (stations 4 to 5) and **building 151** (brown and green stations below).
- The radiation surveys do not specify which specific process is causing the losses. An analysis of BLM measurements during all PS cycles revealed that only during CT extraction the beam is lost in the PS brigde.
- During the CT extraction, large losses are observed in locations where the machine aperture should be large enough. This limits the maximum intensity deliverable due to the induced stray radiation outside the PS tunnel.



Result of the 2006 PS radiation survey in μSv/h for a circulating intensity of 0.8×10^{13} p^+/sec. Color code indicates deviation from guidelines values.

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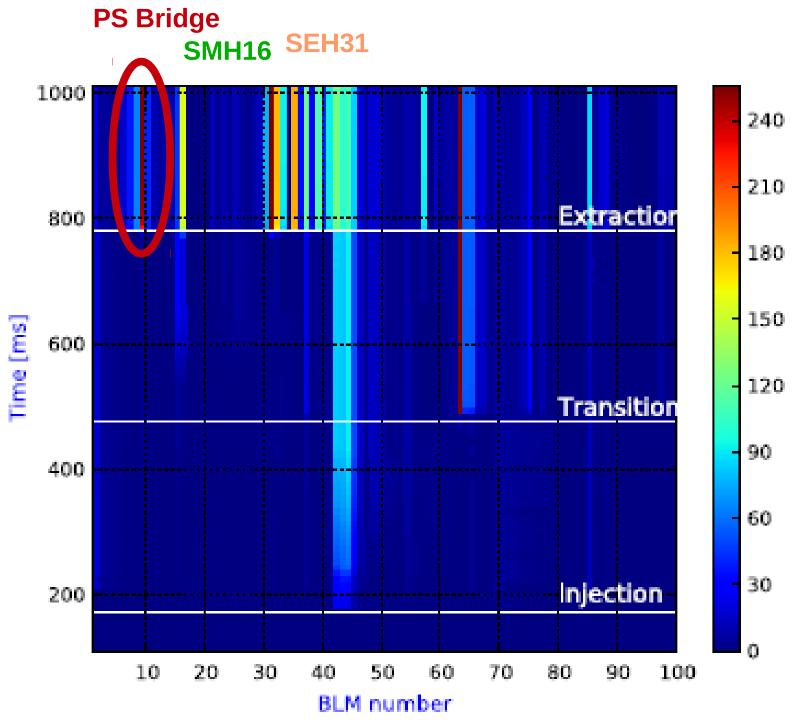
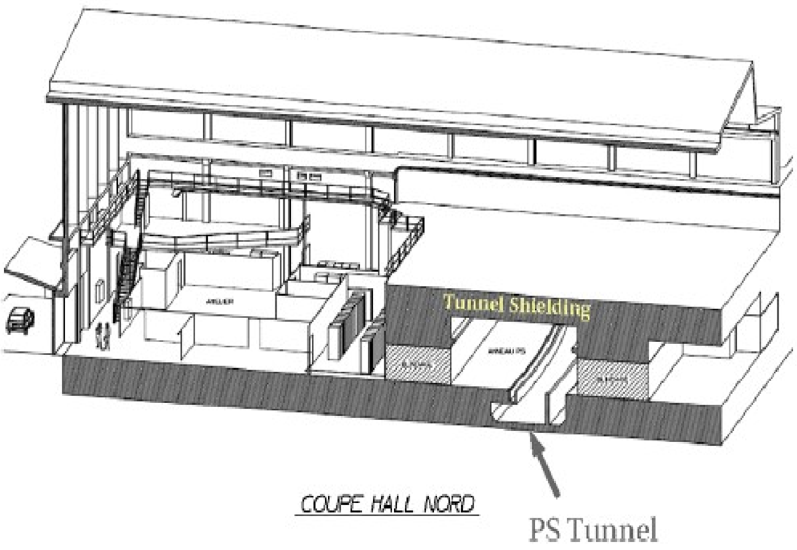


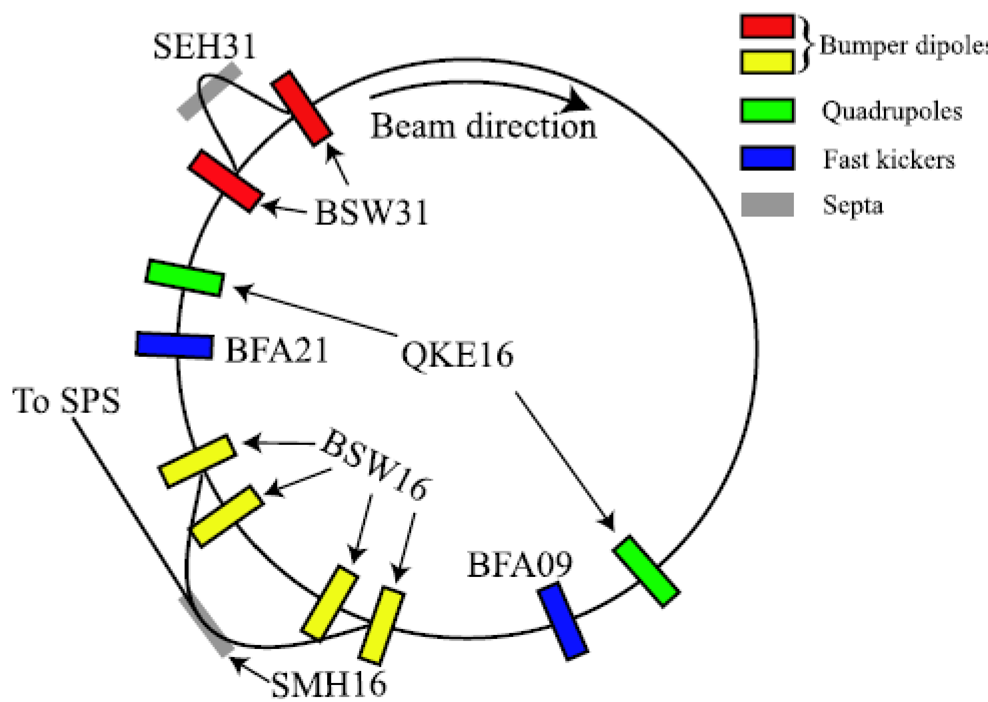
BLMs integrated measurement for the CNGS beam. BLM relates to the 100 SS that the PS is divided into.



Building 151 (or PS bridge) with PS tunnel underneath. Not possible to increase shielding.

Principle of the CT Extraction

- Once the 14 GeV/c flattop is reached the Q_x=6.25 to ensure 90° phase advance/turn.
- Few milliseconds before extraction two slow bumps are powered , BSW31 and BSW16, moving the beam towards the electrostatic septum SEH31 (for slicing) and magnetic SMH16 (for extraction).
- QKE16 circuit enlarge β_x and minimize D_x at SEH31 while the optics remain unchaged at SMH16.
- Two fast magnets (rise time shorter than a revolution period), BFA21 and BFA9 are powered to adjust the relative position between beam and SEH31 blade to obtain equal intensity extraction per turn.
- Extraction to the SPS in 5 turns two times since C_{SPS}=11 x $C_{PS.}$



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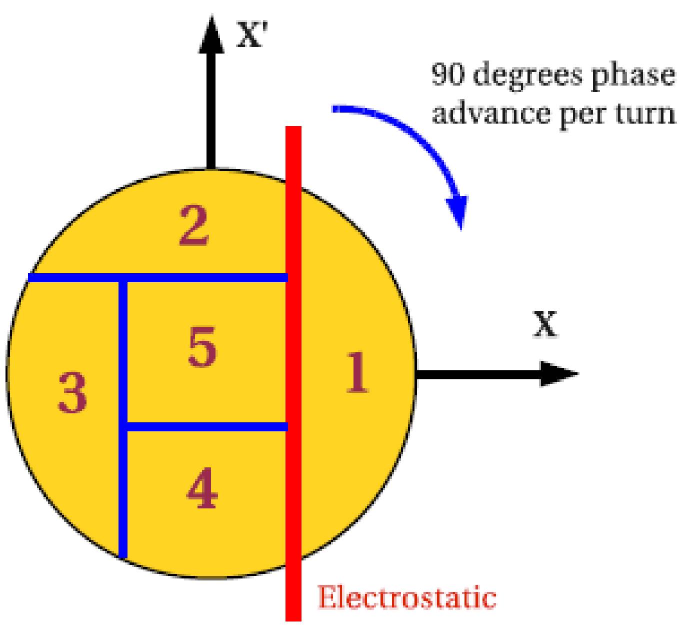

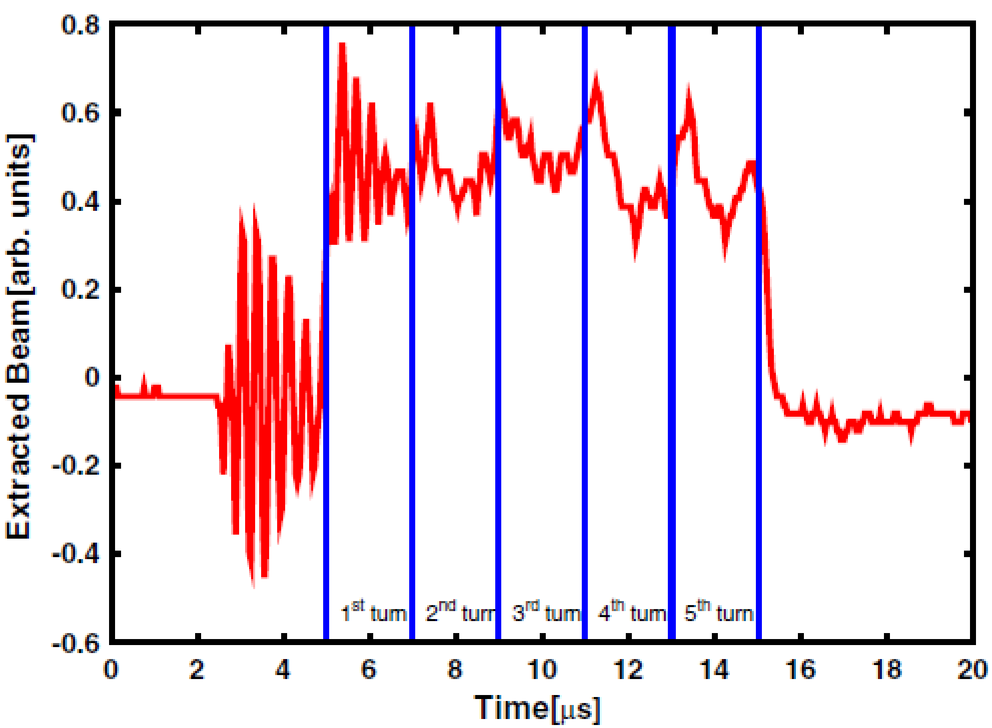

Five turn spill structure measured by a current transformer in the transfer line between the PS and the SPS. Almost equal intensity per turn extraction.

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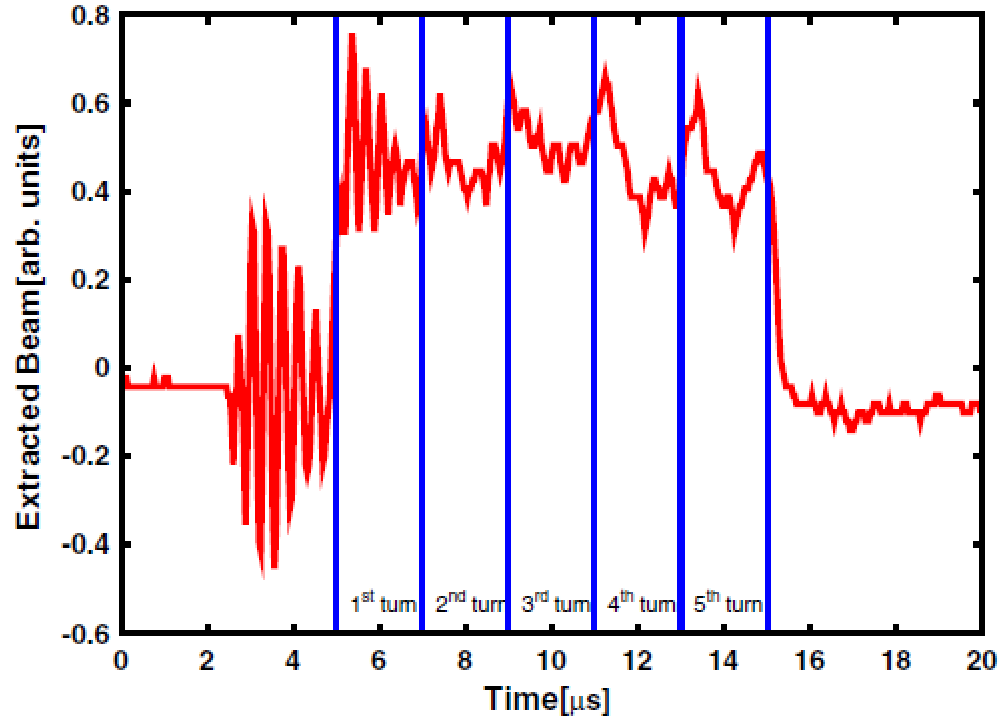
Turn	Beam Extracted (%)
1st	18.1
2nd	18.5
3rd	20.5
4th	18.1
5th	17.8

Overall mesaured extraction efficiency ~93%



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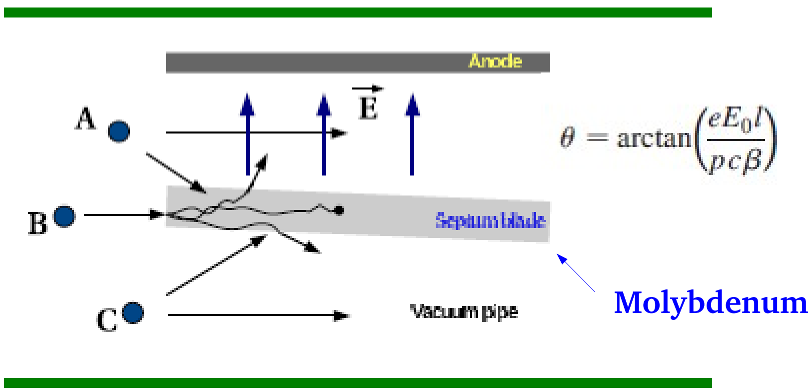
Looking for a solution

- Since these losses were **unavoidable** due the beam shaving process (waiting for the MTE) and the shielding in building 151 could not be increased. Solution adopted was to displace the losses to a better shielded region.
- In order to understand and later on test possible solution we needed to produce a detailed model of the process itself: aperture model, tracking with turn-by-turn closed orbit, interaction with the septum blade, etc…
- At that time SixTrack (with colltrack) was the only available tool at CERN that could let us simulate something close.
- However there were some limitations. K2 scattering routines were developed LHC oriented, i.e. few materials added plus E>450 GeV. SixTrack was not routinely used (never?) with the PS (no thin lens lattice available). No septum element present. So some effort was actually needed.

The SixTrack model

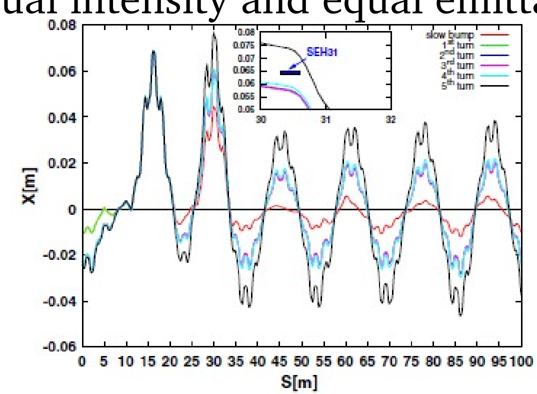
- Produced a thin lens version of the PS lattice.
- Introduced a electrostatic septum as new element in SixTrack (input parameters in fort.3). Based on the one jaw collimator option existing in SixTrack. 3 in 1 tracking element.



Parameter	Value	Unit
Electrode length	1850	mm
Septum length	2293	mm
Septum half gap	65	mm
Blade nominal thickness	0.1	mm
Operative gap width	27	mm
Angle with respect to beam	−0.0006	rad
Voltage (DC)	170	kV

- K2 scattering routines updated for Molybdenum @ 14 GeV/c (multiple Coulomb scattering, ionization energy loss, and nuclear interactions).
- Introduced turn-by-turn fast dipoles (new fort.3 block created) matched to produce equal intensity slices (not possible to have at the same time equal intensity and equal emittance)

Turn	Relative Position	Kick BFA21	Kick BFA9
1st	0.84	−0.5225	−0.5070
2nd	0.67	−0.4793	−0.4638
3rd	0.62	−0.4953	−0.4798
4th	0.32	−0.5864	−0.5709
5th	···	−1.0236	−1.0081



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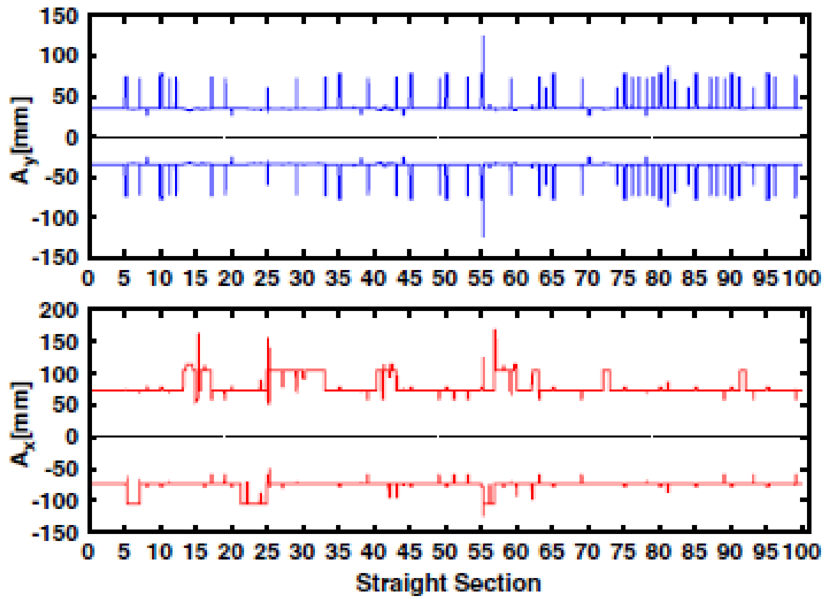
- PS detailed apeture model (courtesy O. Berrig)



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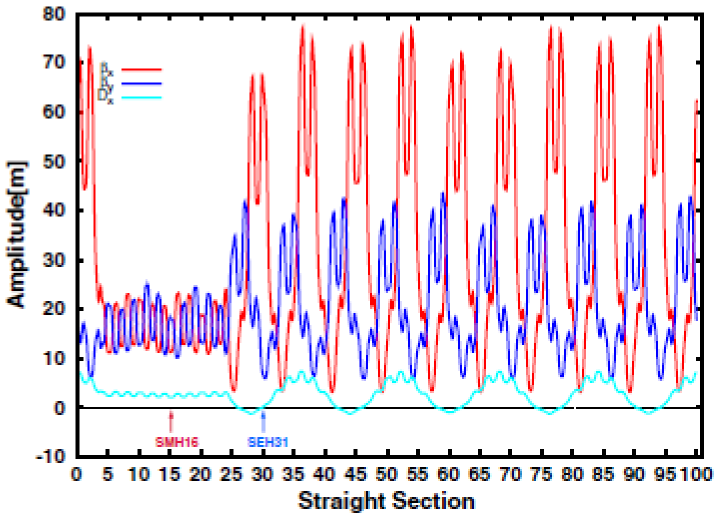
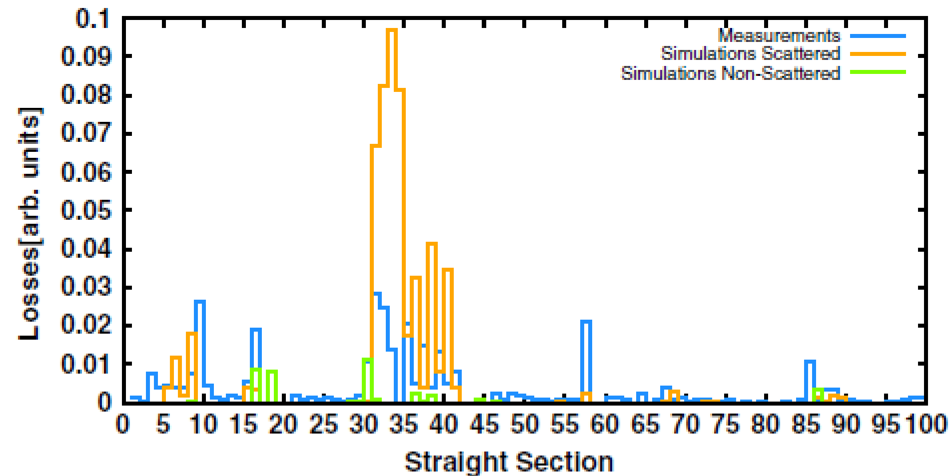
All together allowed single simulations (7 turns) plus beam loss location post-processing.

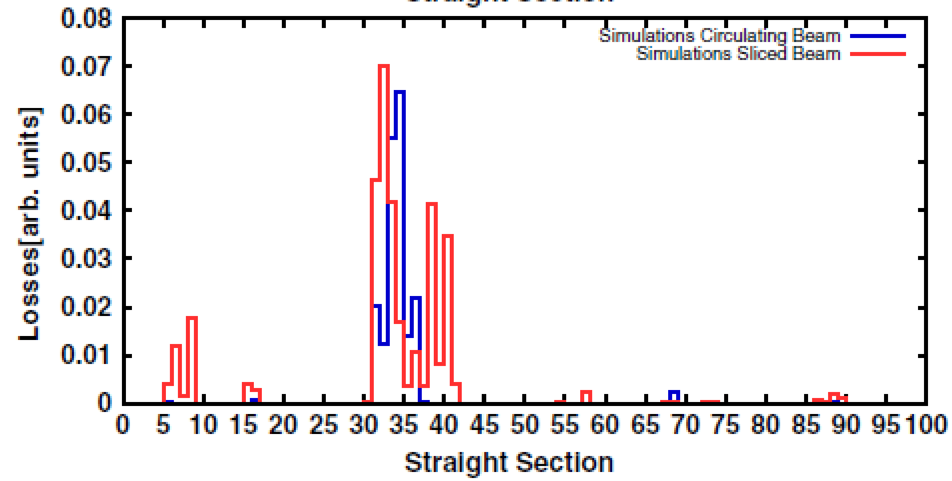
Results



PS Optics distorted by the QKE16.

- Losses in the PS bridge are found to be scattered particles kicked into the aperture by the QKE16.





- Loss pattern agreeing well qualitatively with simulations (not possible to give quantitative values from the ACEM readings) .
- Circulating beam is lost in the sections immediately after SEH31.
- Sliced beam is lost in several locations but in particular in the PS bridge (SS 5-9).
- Model benchmark wrt extraction efficiency turn-by-turn and overall.

Turn	Relative Position	Kick BFA21	Kick BFA9	Beam Extracted [%]
1st	0.84	−0.5225	−0.5070	20.0
2nd	0.67	−0.4793	−0.4638	18.5
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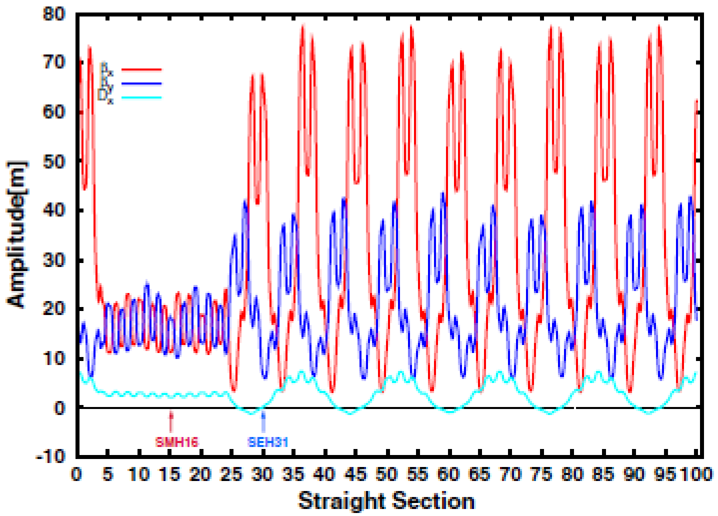

PS Optics distorted by the QKE16.

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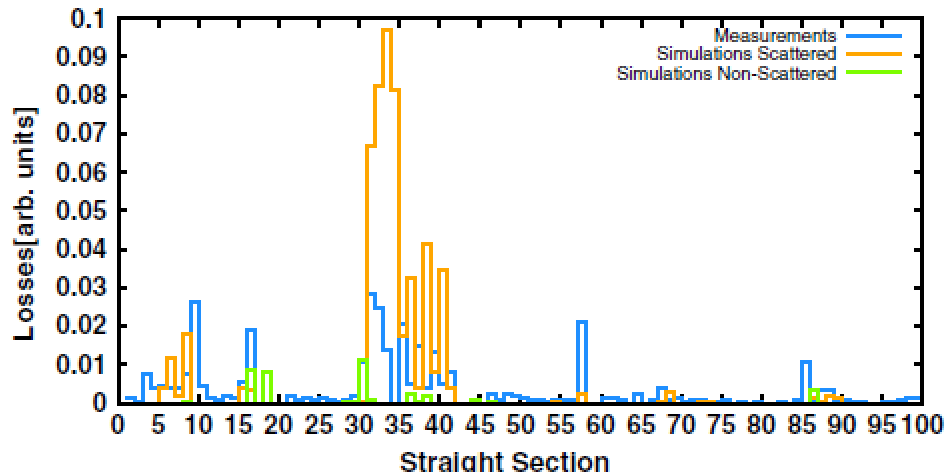

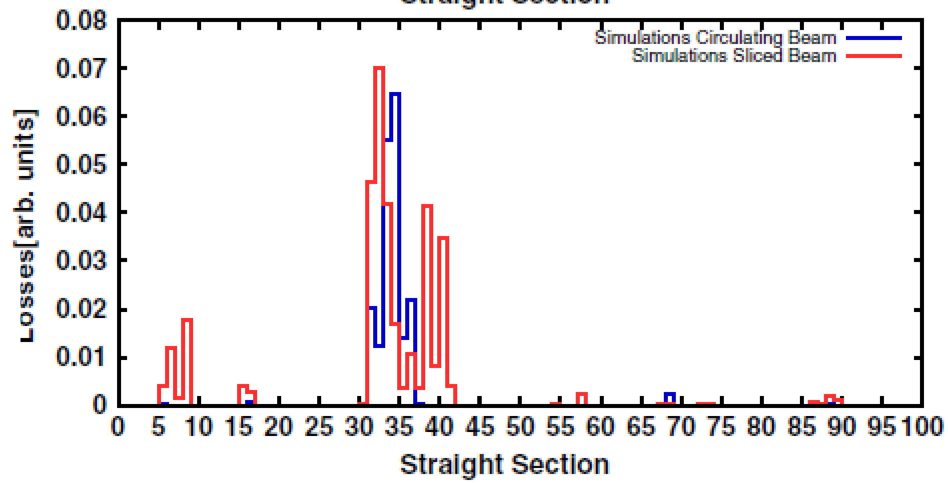

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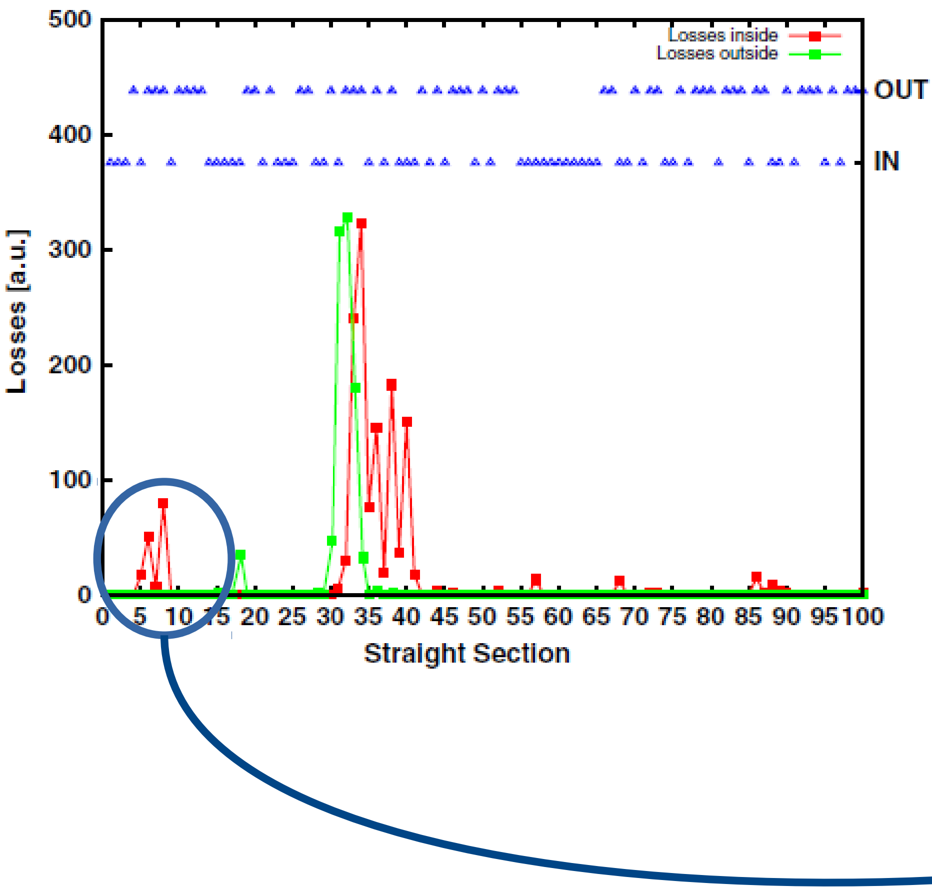
- Model benchmark wrt extraction efficiency turn-by-turn and overall.

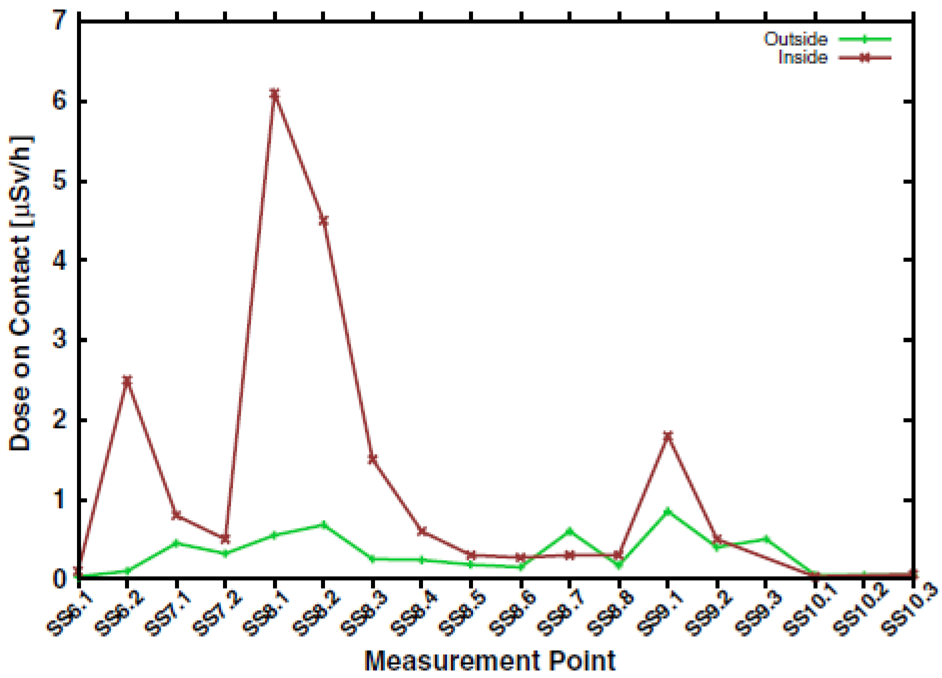
Angle [rad] \ Width [mm]	0.1	0.2	0.3
−0.0002	96.1	94.5	93.4
−0.0006	96.3	95.3	94.2
−0.001	95.0	94.0	92.6

Results

- Further benchmark. Since the BLMs were placed at the end of each SS inside or outside depending on the magnet. In the PS bridge region only at SS9 the BPM is located inwards so that's the reason for its saturation.



Dose measurements on contact SS6-10



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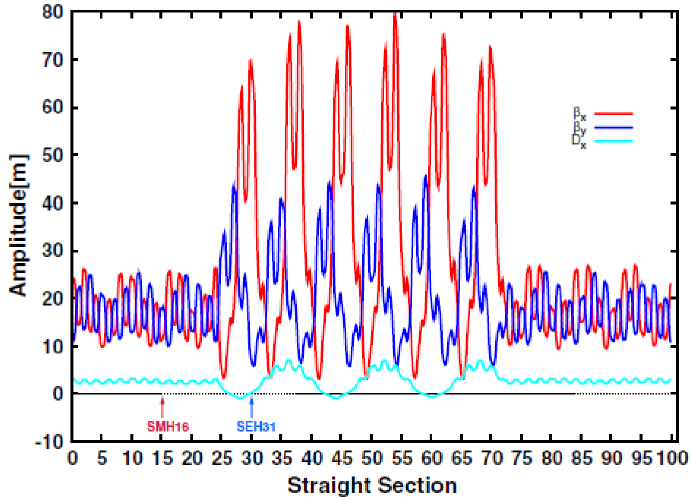
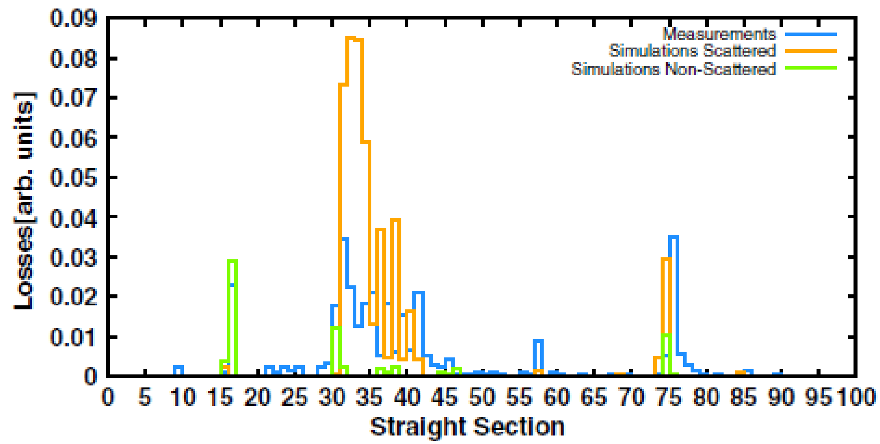
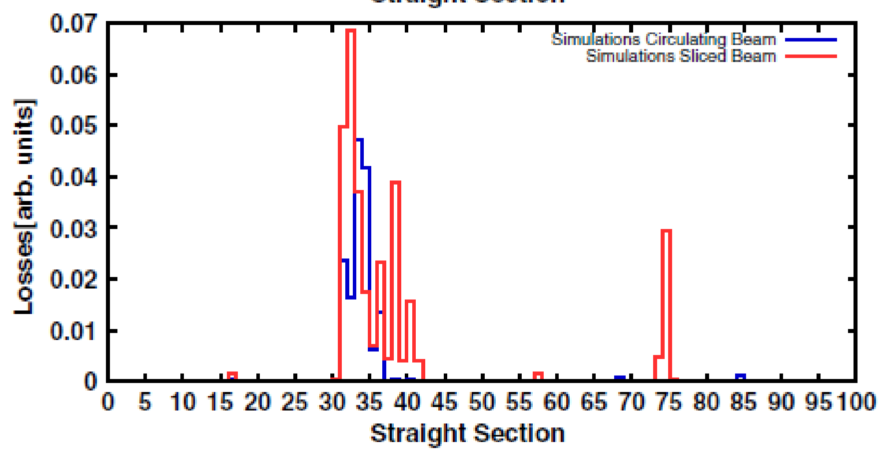
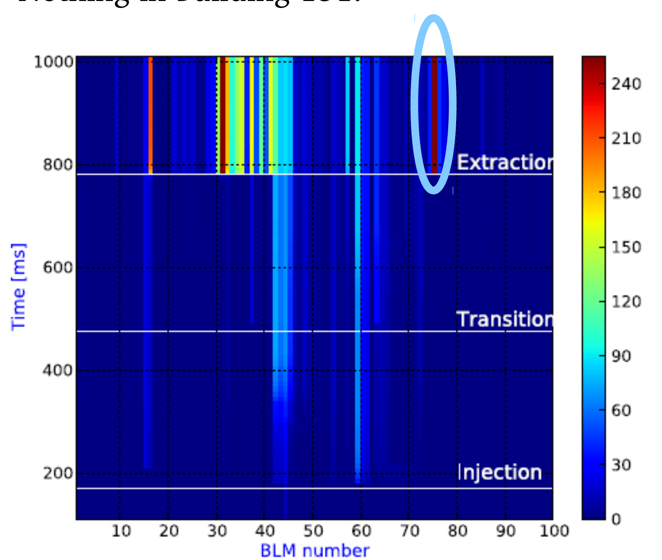


- Proposed solution: displaced losses to SS 73 where shielding is larger by modifying the QKE16 (SS25-SS73)





- Again good qualitatively agreement between measurements and simulations.
- Scattered particles now lost in SS73-SS75 region.
- Nothing in building 151.



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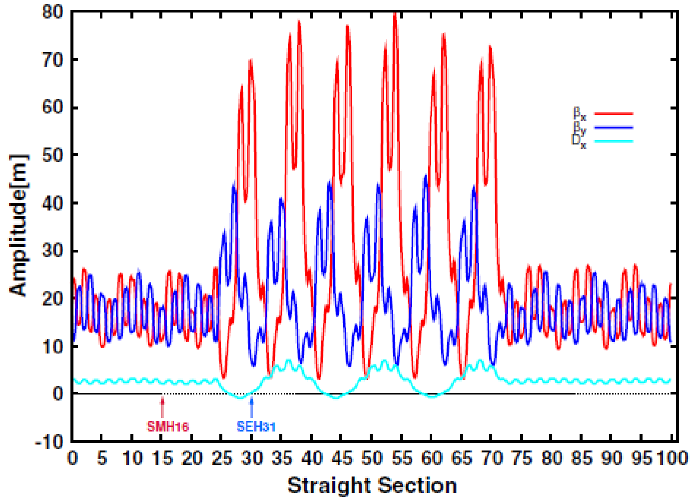

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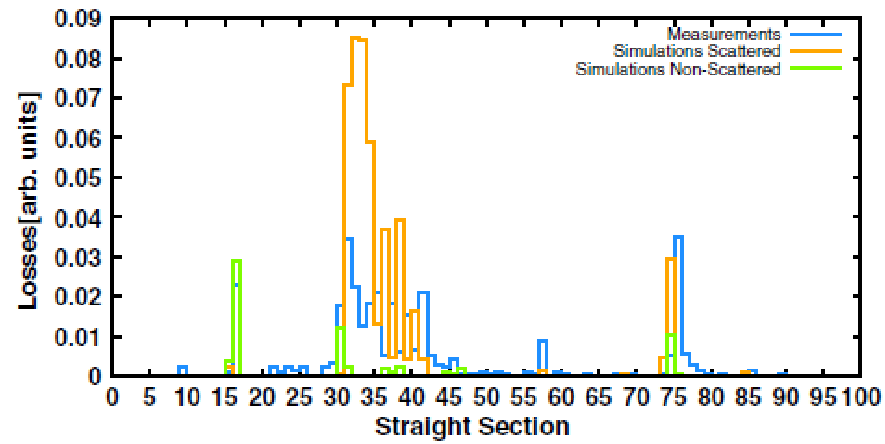

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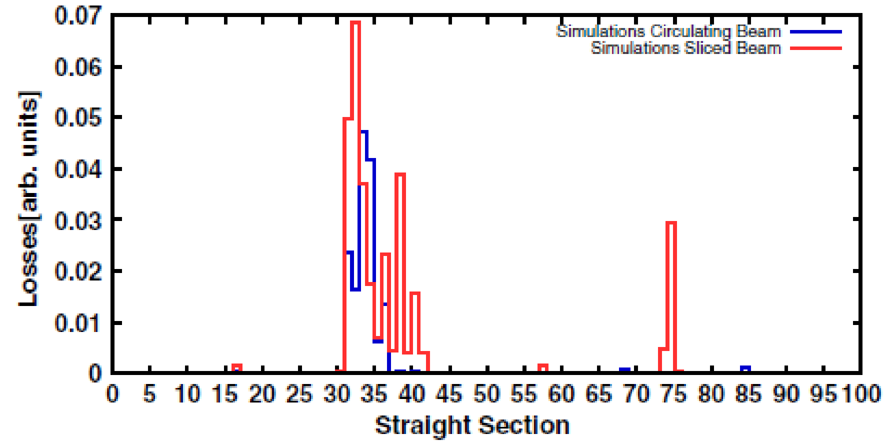

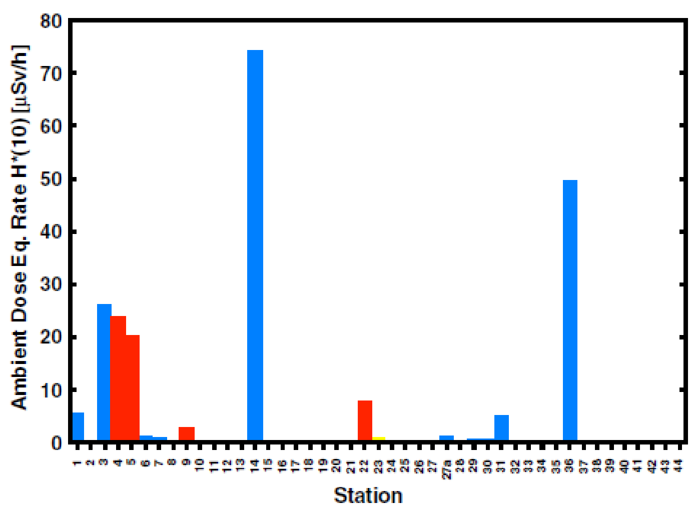

Conclusions

Back in the day

- New optics were proposed to overcome an operational limitation (probably still in use).
- A detailed model was built to understand the details and propose solutions.
- Very good agreement both qualitatively (beam loss location) and quantitative (extraction efficiency)

Now, quite some time after

- It was an *ahead of its time* study due to all features included.

More info
http://journals.aps.org/prstab/pdf/10.1103/PhysRevSTAB.14.030101

THANKS!