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Simulations for Crystal (UA9)

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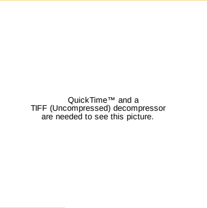
Crystal Workshop 29.10.08

Fermilab

VP 28.10.08



Introduction

- Crystal collimation might be a way to improve cleaning efficiency.
- Studies in AB/ABP group and the LHC collimation project to assess achievable performance in LHC and analyze SPS & Tevatron tests.
- Use the same state-of-the-art beam simulations as used for the LHC design and SPS beam tests for LHC collimators: direct prediction of performance change with crystals!
- Goal of my PhD!
- Work so far:
  - Conceptual studies of crystal collimation.
  - Work with I. Yazinin on crystal simulation routine (phase space match, amorphous layer, general debugging).
  - Implementation of crystal simulation routine into standard LHC tracking tools for collimation (COLLTRACK operational and Sixtrack ongoing).
  - Simulations on LHC and SPS with local loss maps and efficiency.
- Discuss SPS simulations today.

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SPS Crystal experiment: Layout & Optics

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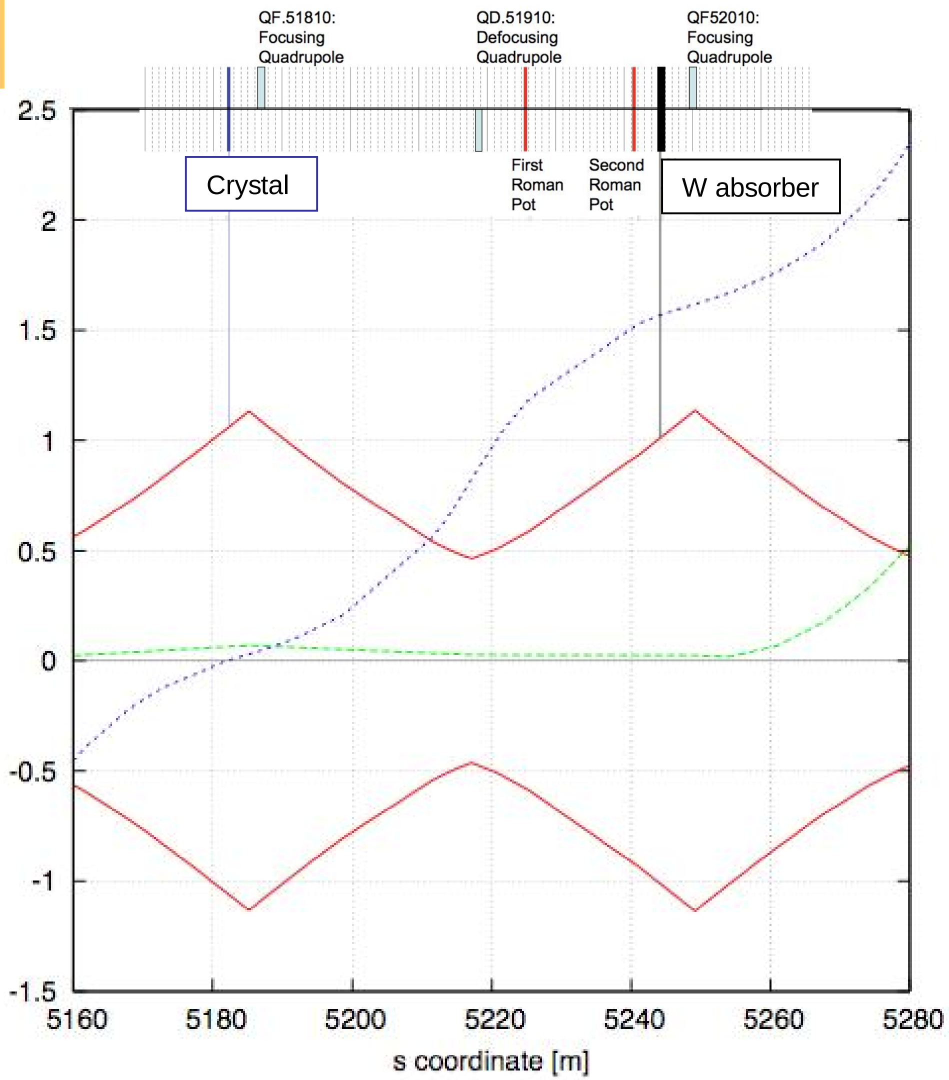
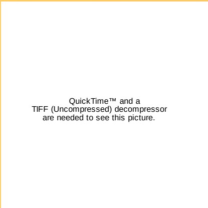


	1 sigma amplitude	1 sigma divergence
crystal	.00106 m	24.28 μrad
rp1	.00060 m	18.51 μrad
rp2	.00094 m	23.78 μrad
tal	.00103 m	24.31 μrad

$\Delta\phi$ rp1=	1.1339 rad=	64.97 degrees
$\Delta\phi$ rp2=	1.4618 rad=	83.76degrees
$\Delta\phi$ tal=	1.5056 rad=	86.26 degrees

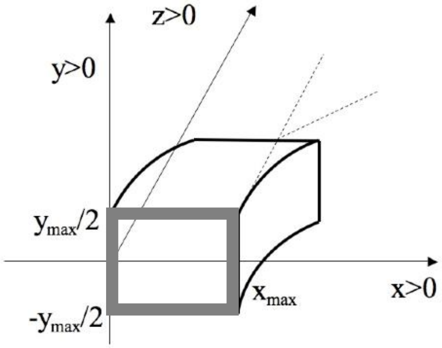
ID	name	material	lenght [m]	aperture [σ]	aperture [mm]
1	CRY.SPS.EXP	Cry-Si (111)	0.001	6	6.367
2	ROMANPOT.1	Steel +Al +Si	~0.03	6+1mm	.4.618
3	ROMANPOT.2	Steel +Al +Si	~0.03	6+1mm	6.651
4	TCLA.TAL.SPS	W	0.66	6+1mm	7.173



SPS experiment

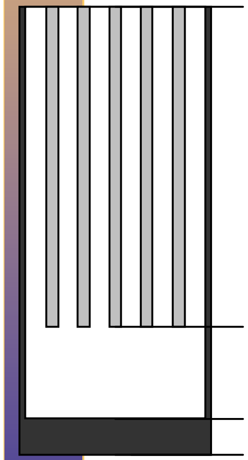
the main elements

- Crystal: Si crystal



R_{curv}	=	6.67 m
$length$	=	1 mm
x_{max}	=	0.5 mm
y_{max}	=	50 mm
$amlayer$	=	$0 \rightarrow$ 0.5 μm

- Roman Pots:



Detector region:
- 3 to 5 Si detector, length 300 μm

- transversal window (Steel); length 2x 200 μm

Dead region, 500 um, length 2x 200 um (Steel)
Border: 150 μm Al, length 3 cm

Represented in code by equivalent thickness in Cu

material	nuclear interaction length [cm]
Cu	15.32
Fe	16.67
Si	46.52
Al	39.70

Detector region:
664 - 882 μm

Dead region:
370 μm

Border region:
1.16 cm

Use 0.75 mm Cu to represent Roman Pot scattering

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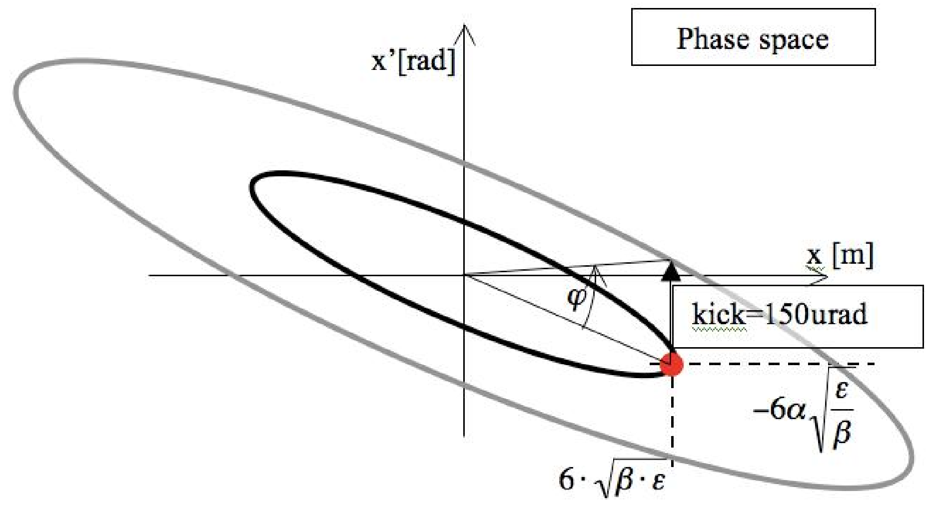
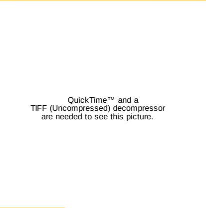
Expected Crystal Effects



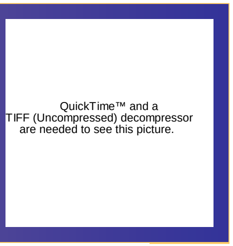
Each kick corresponds an amplitude increase and a phase shift:

- These quantities will determine the particle dynamics after the interaction with the crystal.
- What is the characteristic kick for each process? In theory we know…

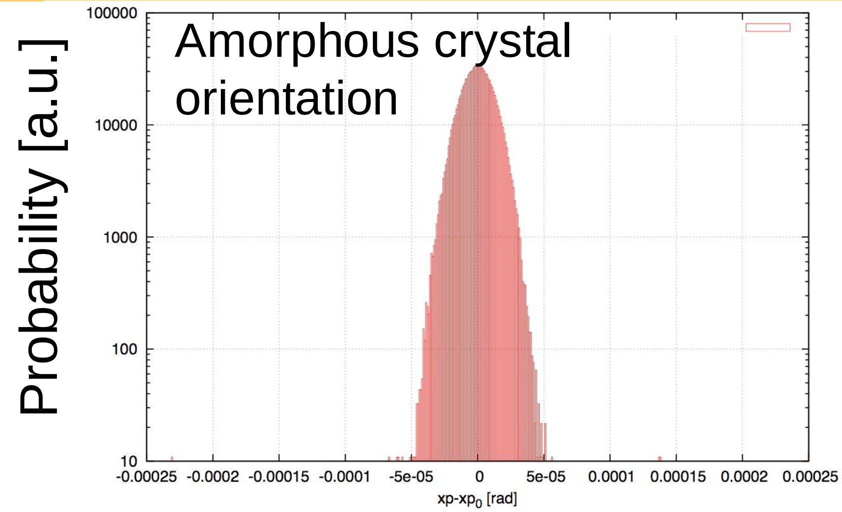
Process	*kick* μrad	*Phase shift* degrees	*New amplitude* σ
Channeling	150	-66.16	14.84
Volume Reflection	-27.03	22.18	6.47
Crystal amorphous	21 (rms)	0 ± 17.57	6 ± 0.29

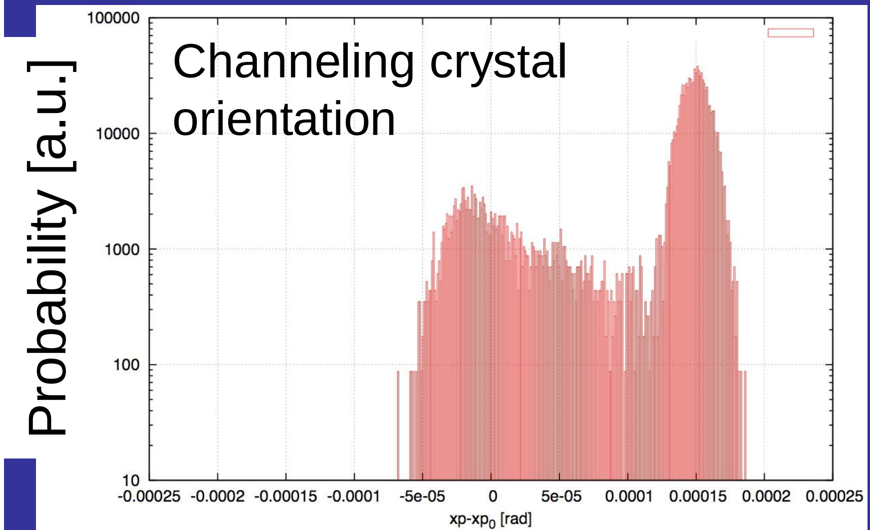


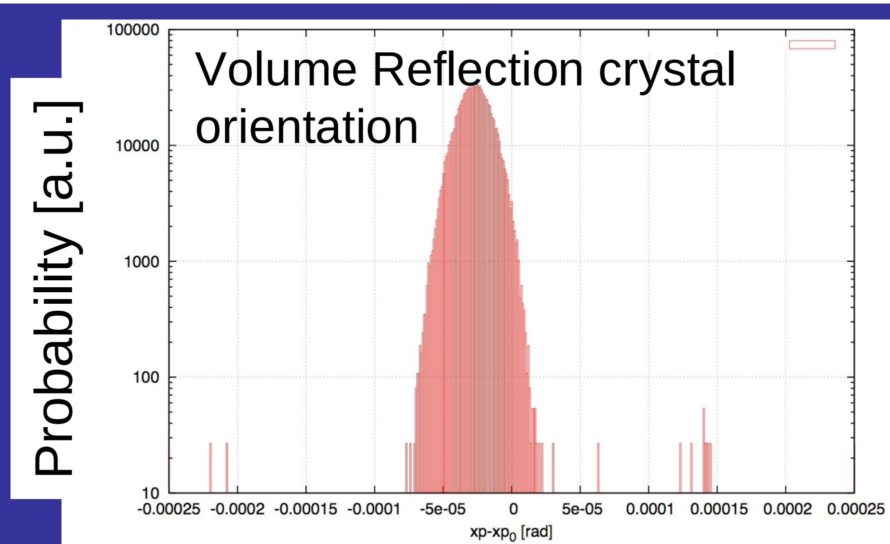
Expected Crystal Effects



- Effect of crystal described by physics cross-sections.
- Monte-Carlo simulation based on probabilities.
- Every interaction can be different!







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Particles of one bunch may have different processes based on their entry condition (offset, angle, energy).

Colltrack simulations

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are needed to see this picture.

What's the output

- Global inefficiency and survival time
- Histogram at the different elements
- Distribution of losses around ring

$N_{part}(n\sigma)/N_{part\_abs}$

$N(t)=1/e\ N_{tot}$

Particle tracks compared with aperture:10 cm accuracy!

Colltrack limitations

- Only on-momentum tracking (all particles are considered at nominal energy - no chromatic effect, synchrotron oscillation, etc… is included)

Next simulations will be performed in 6D with Sixtrack (crystal routine just implemented)

Importance of 6D effects shown in analytical study: S. Peggs and V. Previtali

Colltrack: Simulation Scenarios

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are needed to see this picture.

Different cases presented today (more done):

1. Perfect crystal (no amorphous layer), no diffusion.
2. Perfect crystal, diffusion of 1.2×10^{-4} σ per turn(0.12 μm/turn).
3. Crystal with 0.1 μm amorphous layer, diffusion of 1.2×10^{-4} σ per turn (0.12 μm/turn).
4. Crystal with 0.5 μm amorphous layer, diffusion of 1.2×10^{-4} σ per turn (0.12 μm/turn).

For each case crystal tilt varied from -250 to 100 μrad.

50k halo protons with ≤0.015 σ impact parameter simulated.

Tracked over 250-1000 turns, depending on cleaning time.

Detailed aperture model to locate losses with 10cm spatial resolution.

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Global Inefficiency

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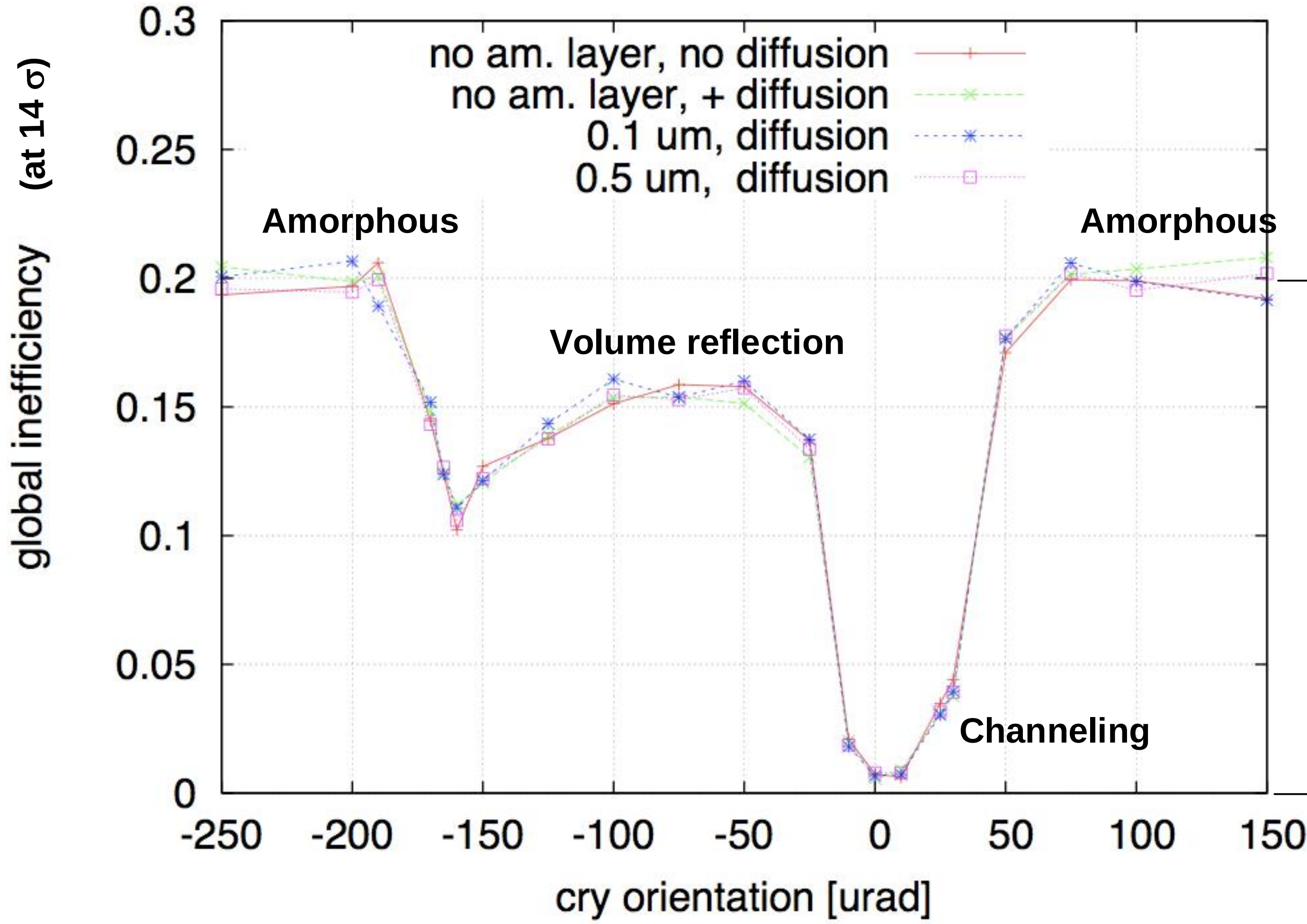
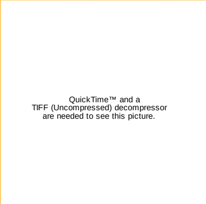


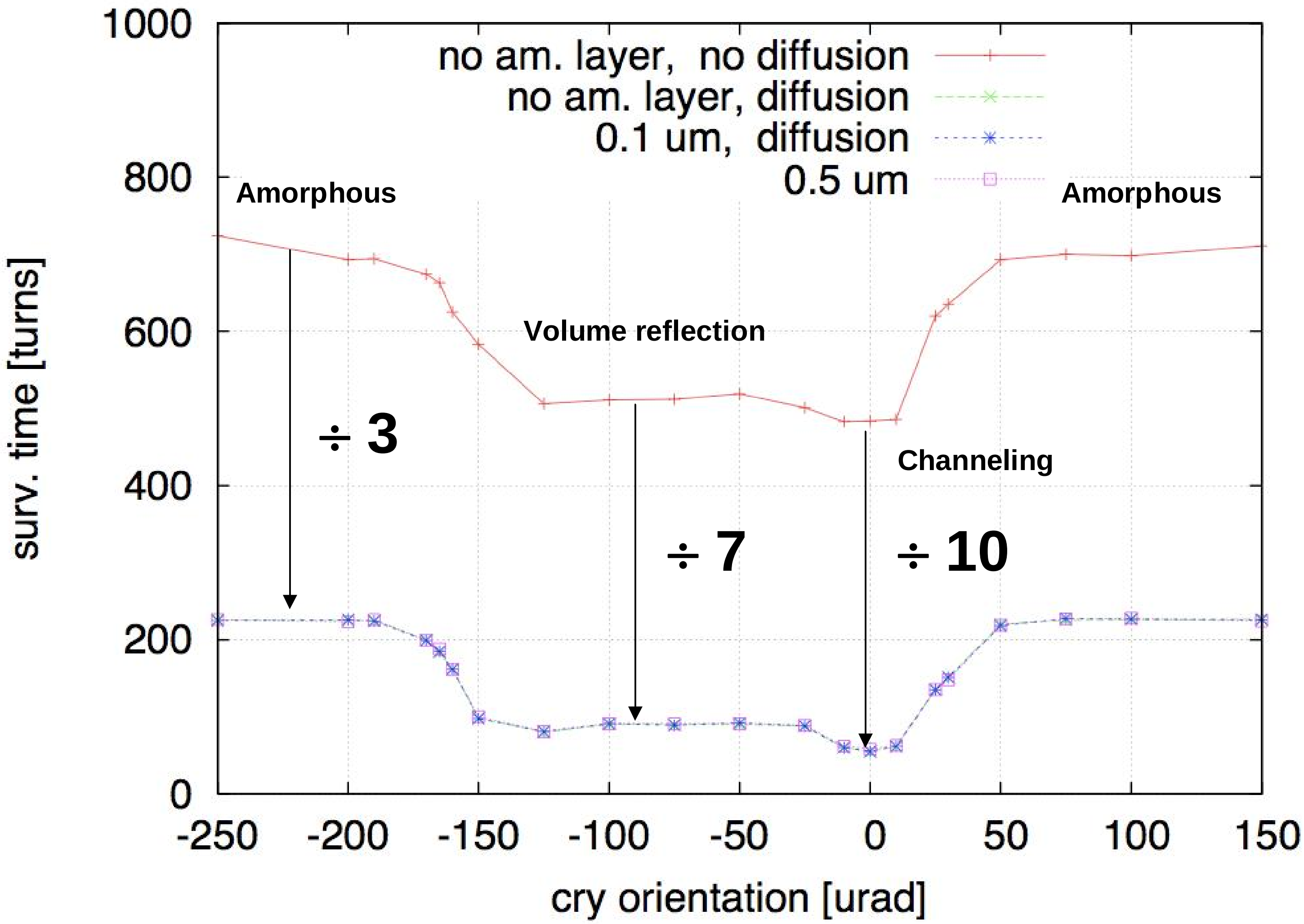
20% leakage

0% leakage best case

No significant changes when adding amorphous layer or adding diffusion for global inefficiency!?



Cleaning Time



The diffusion accelerates the halo cleaning (about 500 turns faster, time required for ~ 60 μm diffusion).

Different improvement factors for various crystal regimes.

To be understood and analyzed in more detail.

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Local Beam Loss vs Global Efficiency

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- Remember: LHC problem is local loss of protons after collimation regions in super-conducting magnets.
- What matters, are losses in magnets far downstream of collimators, crystals, etc.
- We want to measure beam loss distributions after crystals and compare with predictions for cleaning and collimation for magnets.
- Was done in SPS for LHC prototype collimator in 2004 and 2007.
- Reference paper:
  - "Comparison between measured and simulated beam loss patterns in the CERN SPS." S. Redaelli, G. Arduini, R. Assmann, G. Robert-Demolaize (CERN) . CERN-LHC-PROJECT-REPORT-938.
- Results show power of beam loss measurements (BLM) in the SPS and cross-checking with beam loss simulations (Sixtrack with collimator routines).
- Tracking codes fully qualified by beam tests.

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SPS Beam Loss Response: Measured and Simulated Full Ring

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SPS Beam Loss Response: Measured and Simulated

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1.2 km Downstream of Collimator

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TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

SPS Beam Loss Response: Measured and Simulated

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

2.3 km Downstream of Collimator

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are needed to see this picture.

Measurement Approach for CRYSTAL

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- Use the benchmarking method as used for LHC collimators and beam loss simulations in the SPS also for crystal collimation studies.
- Approach:
  - For each crystal and beam setup simulate the losses around the full SPS ring.
  - For every crystal and beam setup measure the losses around the full SPS ring.
  - Compare measurement and simulation to demonstrate reduction of beam losses in magnets with a crystal.
  - Successful benchmarking in the SPS will then verify predictions of cleaning efficiency with crystals for the LHC (not reported here but existing).
  - Use same method also for benchmarking in Tevatron crystal experiments.
- Next slides: Report loss predictions for SPS with crystals.

Where are leaking protons lost?
Movie of beam loss vs crystal tilt

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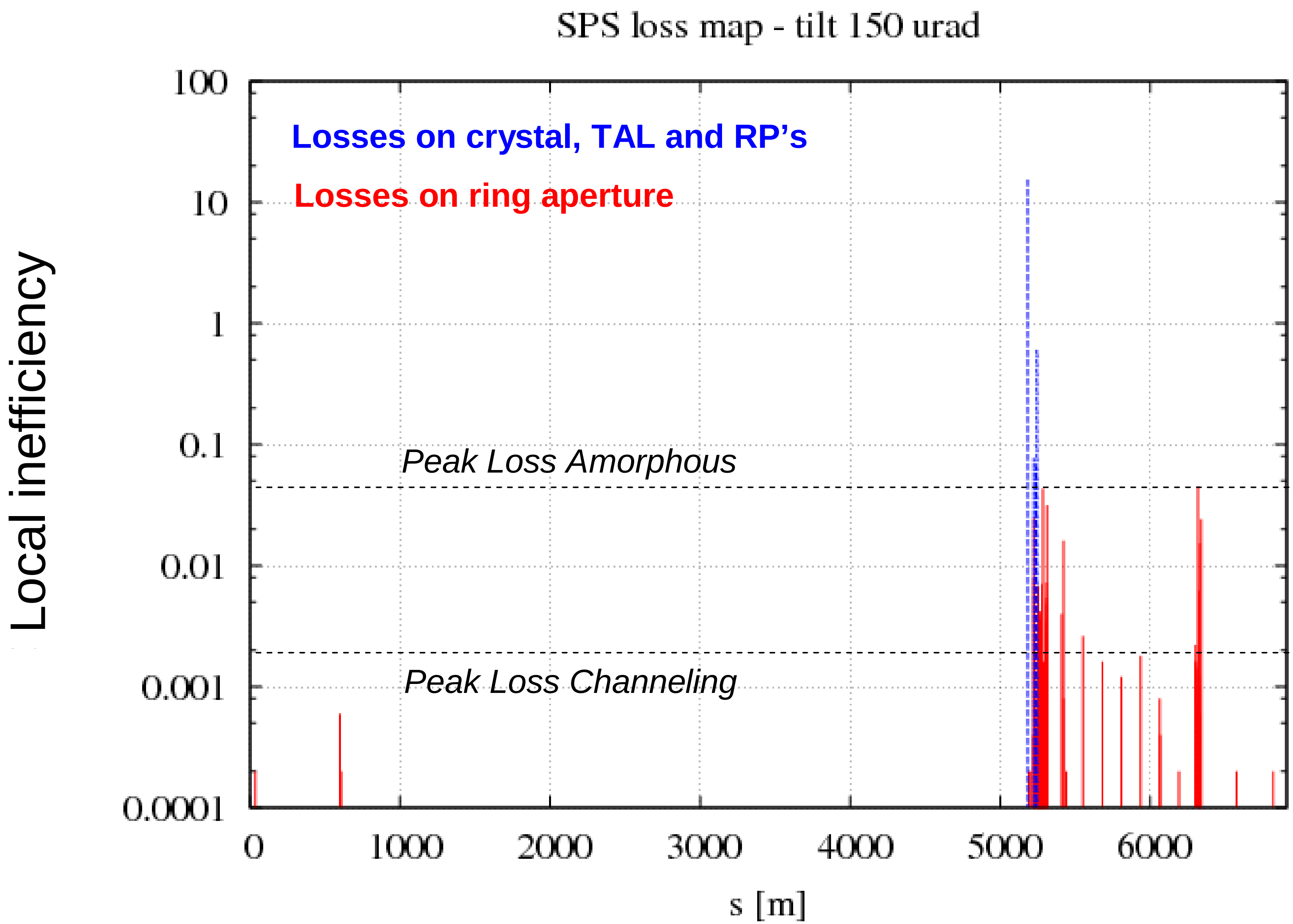

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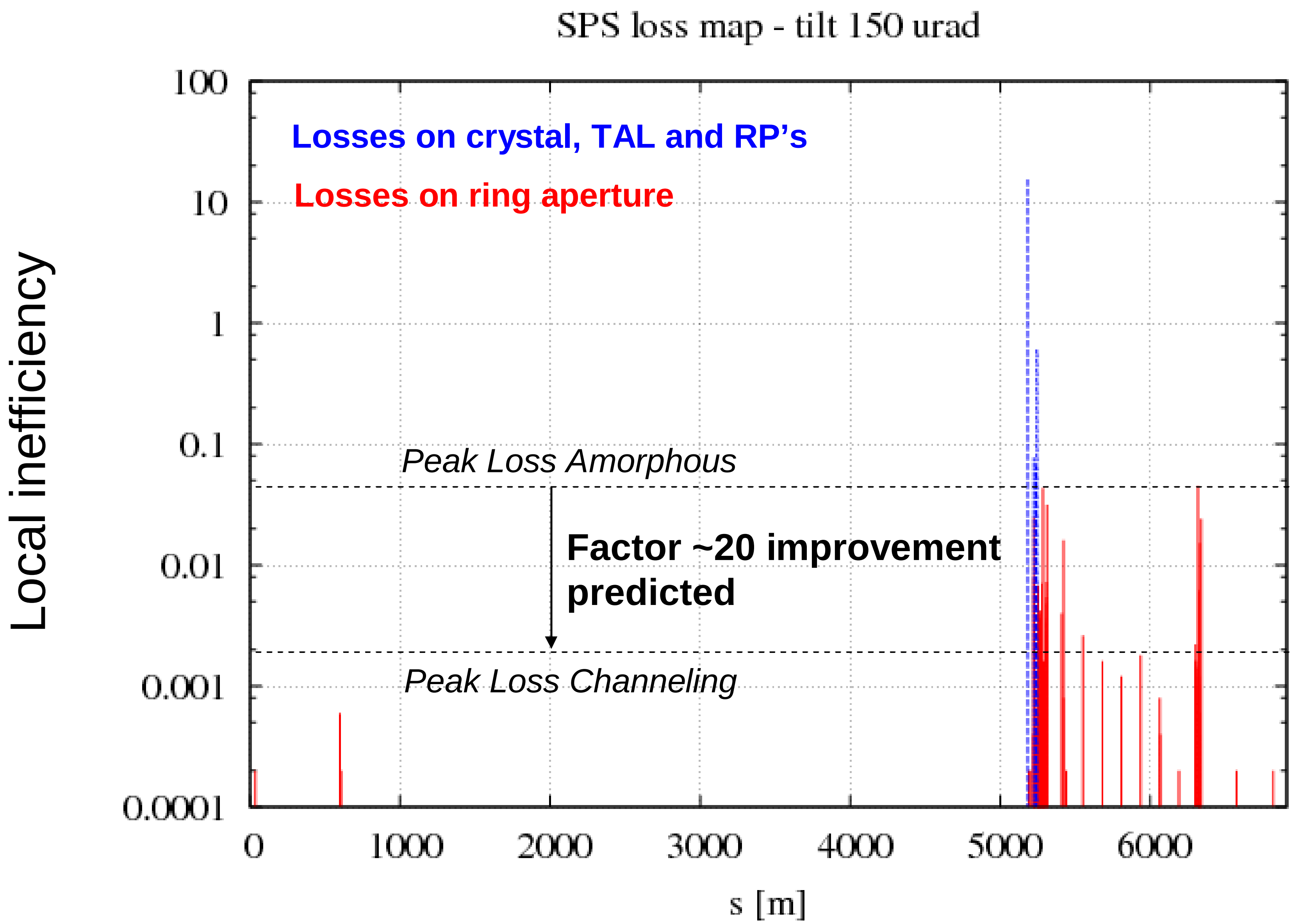
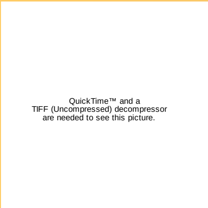
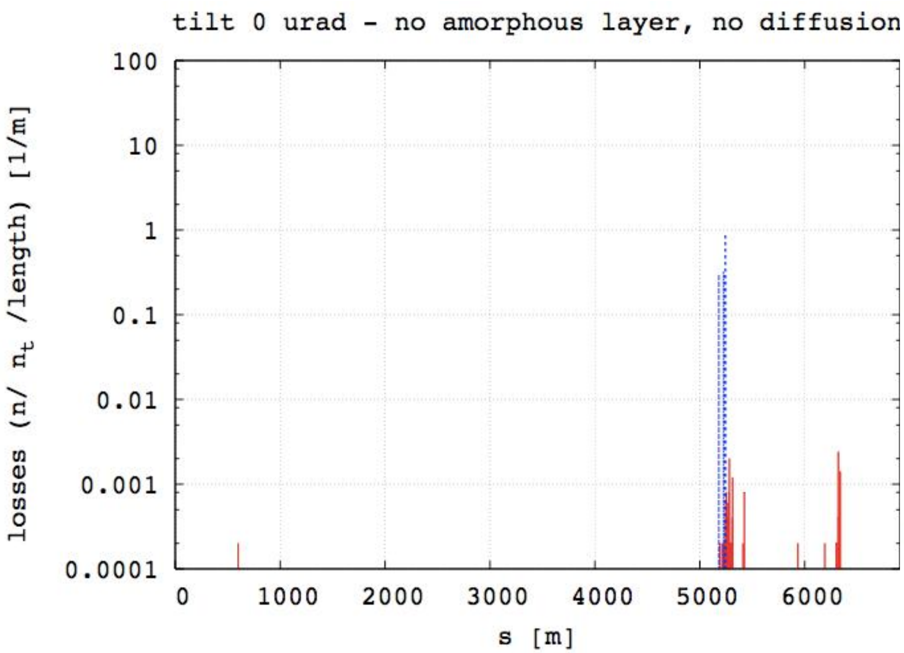
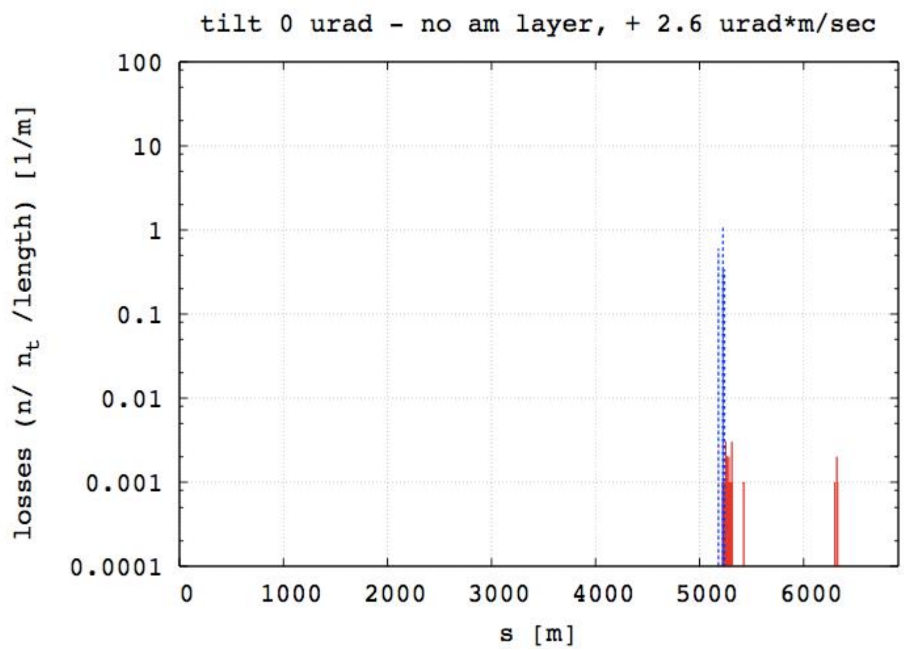




More Loss Maps:

effect of diffusion speed





- Case no amorphous layer, **channeling** position
- Losses between crystal and TAL are much lower (=0 with our statistic, 50K particles) if diffusion is activated
- Losses immediately downstream the crystal are higher in case of diffusion

More loss maps amorphous layer…

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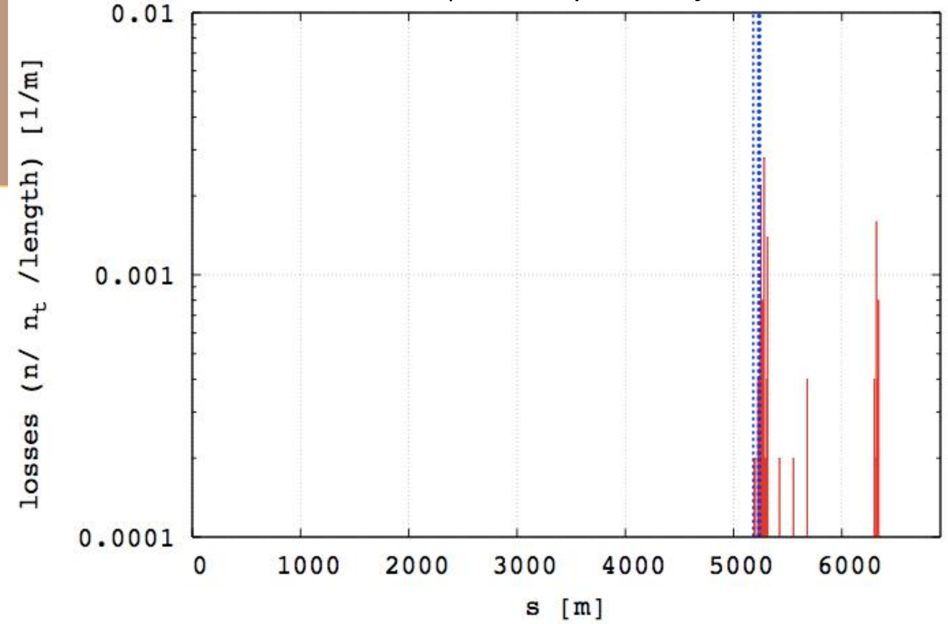
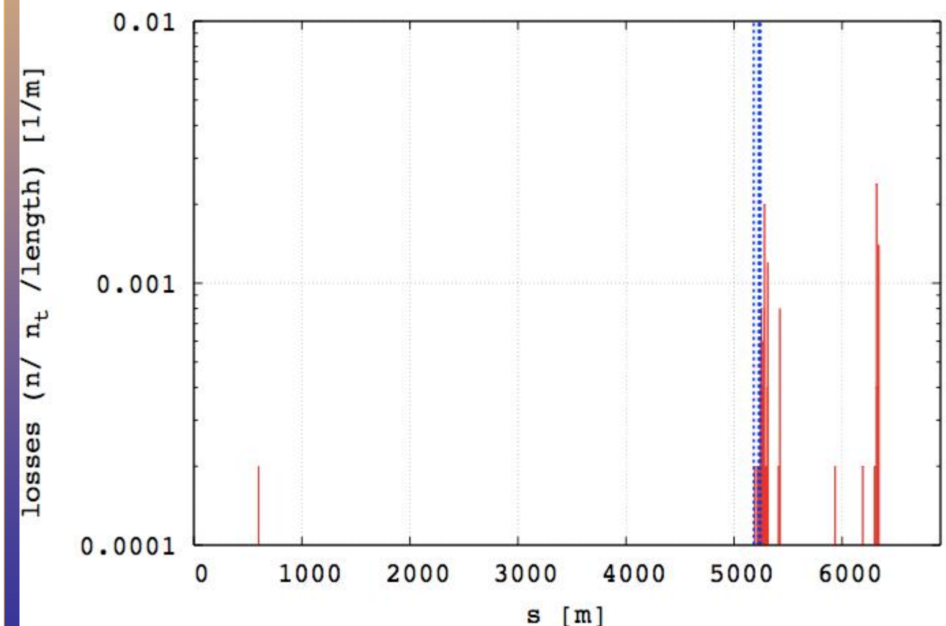
Zoom in on the beam loss maps for different values of amorphous layer.

For channeling position, the presence of an amorphous layer up to 500 nm does not noticeably affect the losses distribution along the ring.

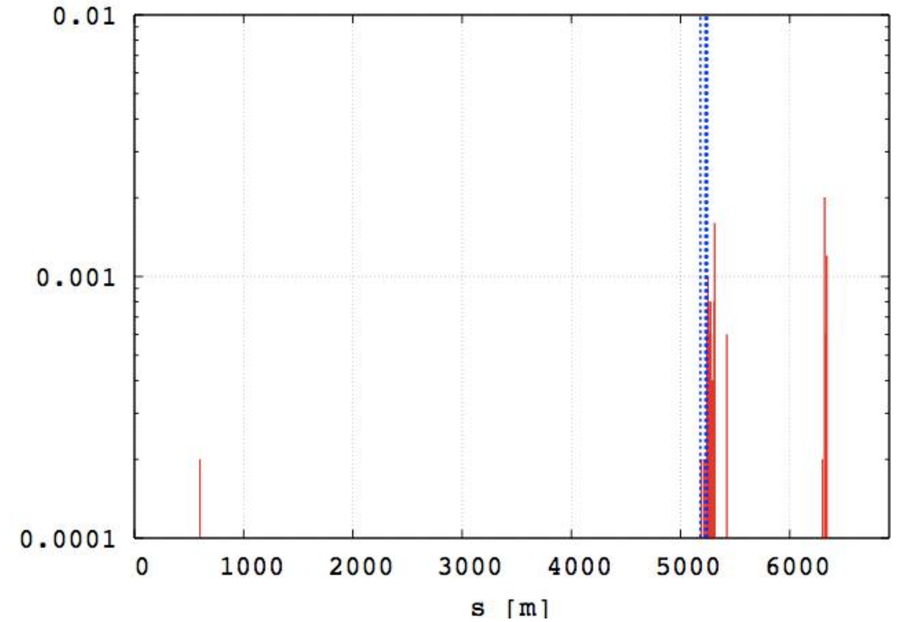
0.5 μm amorphous layer



no amorphous layer



0.1 μm amorphous layer



Looking Element by Element

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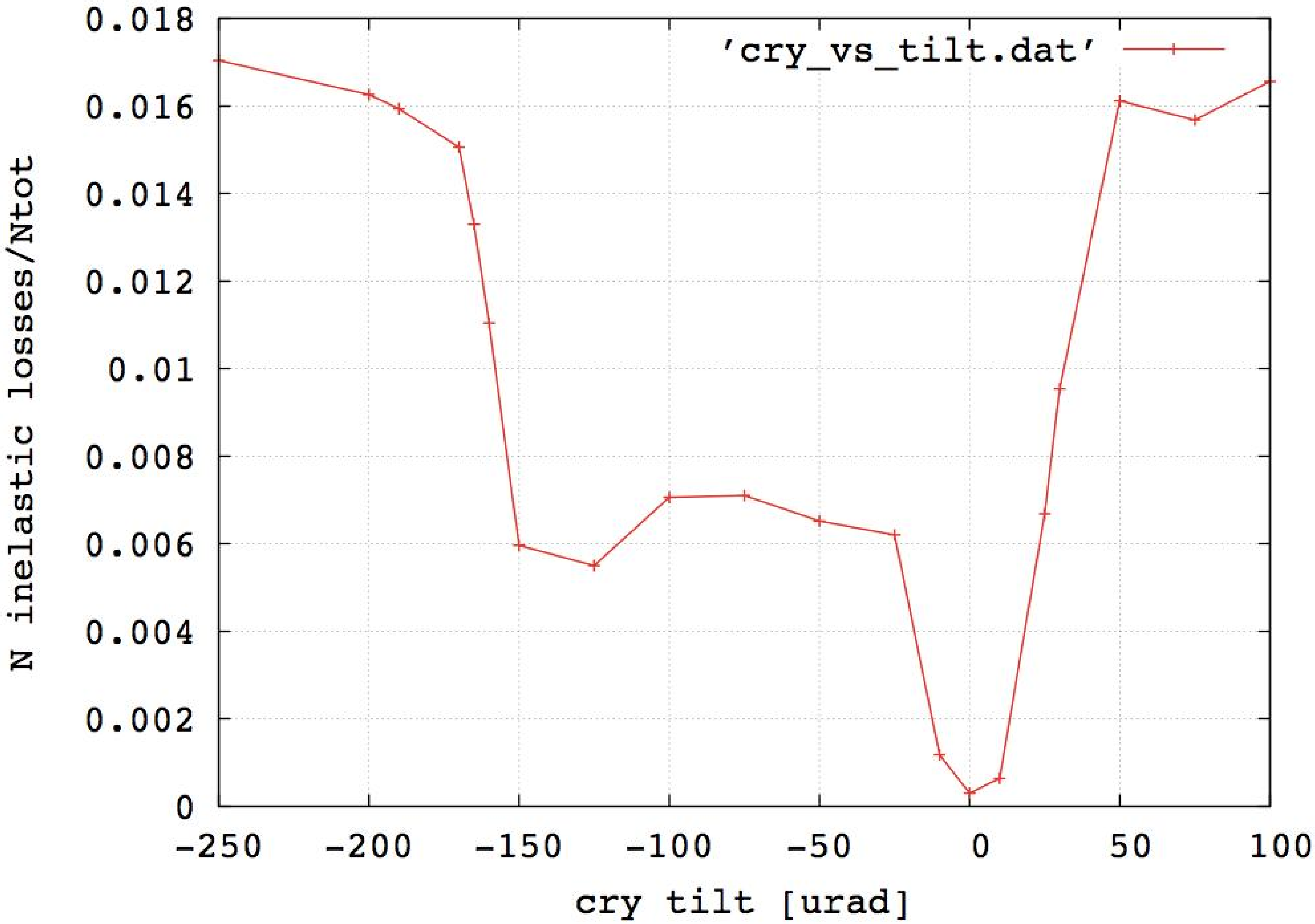
- Previous results show SPS loss maps along the accelerator length.
- Simulations allow to consider losses separately for each element in the model.
- Next slides:
  - Show number of inelastic interactions (losses) at each element integrated over the full length of the element.
  - Plot this versus the orientation of the crystal.
  - Shows the number of local interactions in the various crystal regimes. Each inelastic interaction induces a particle shower.
  - Could be used to analyze local losses for specific magnets in more detail (e.g. including installation of additional BLM's, possibly LHC-type as used for SPS collimator tests).

1) Inelastic interactions in crystal

Case no amorphous layer, diffusion



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2) Inelastic interactions in bend MBA52030

Case no amorphous layer, diffusion

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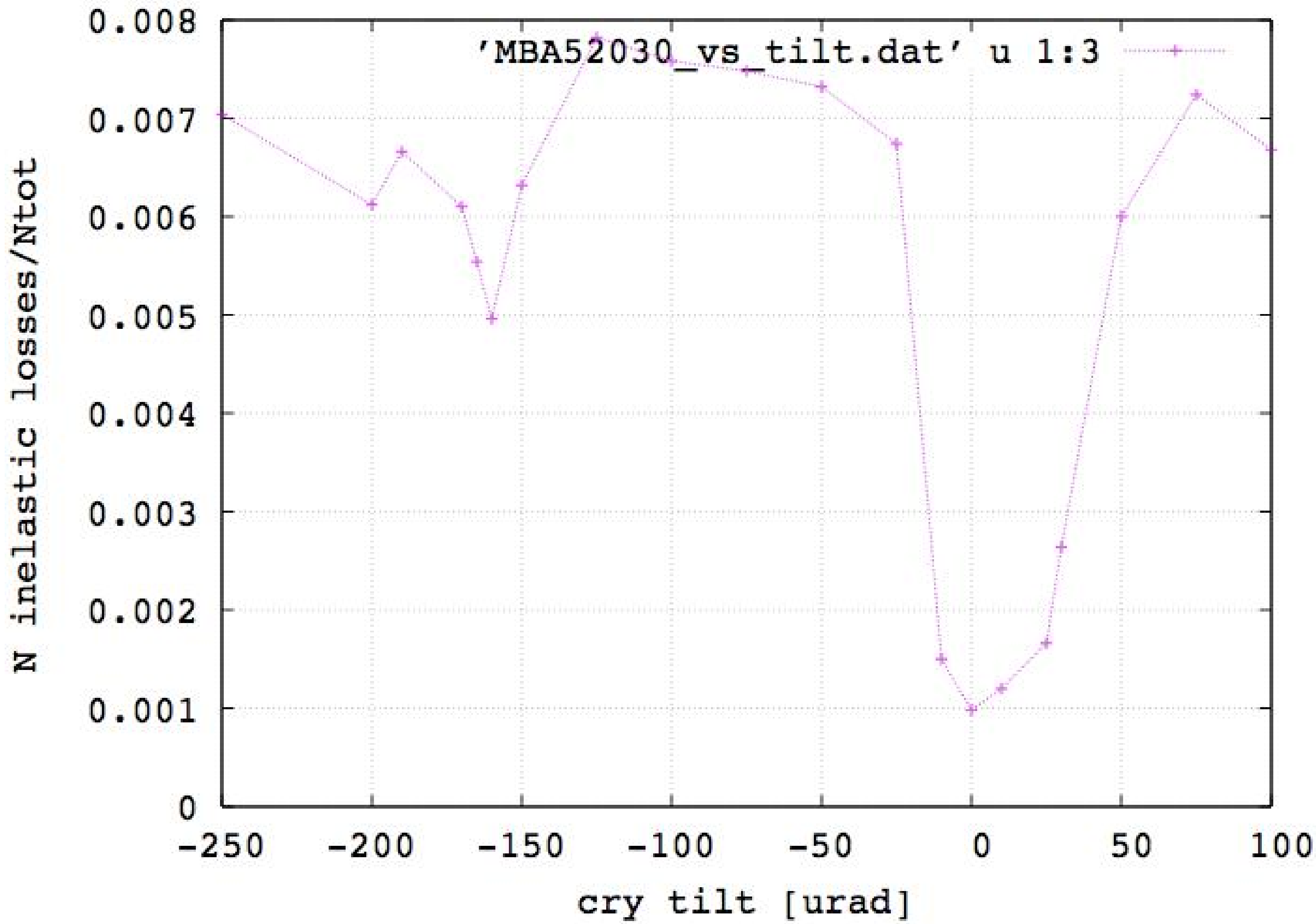

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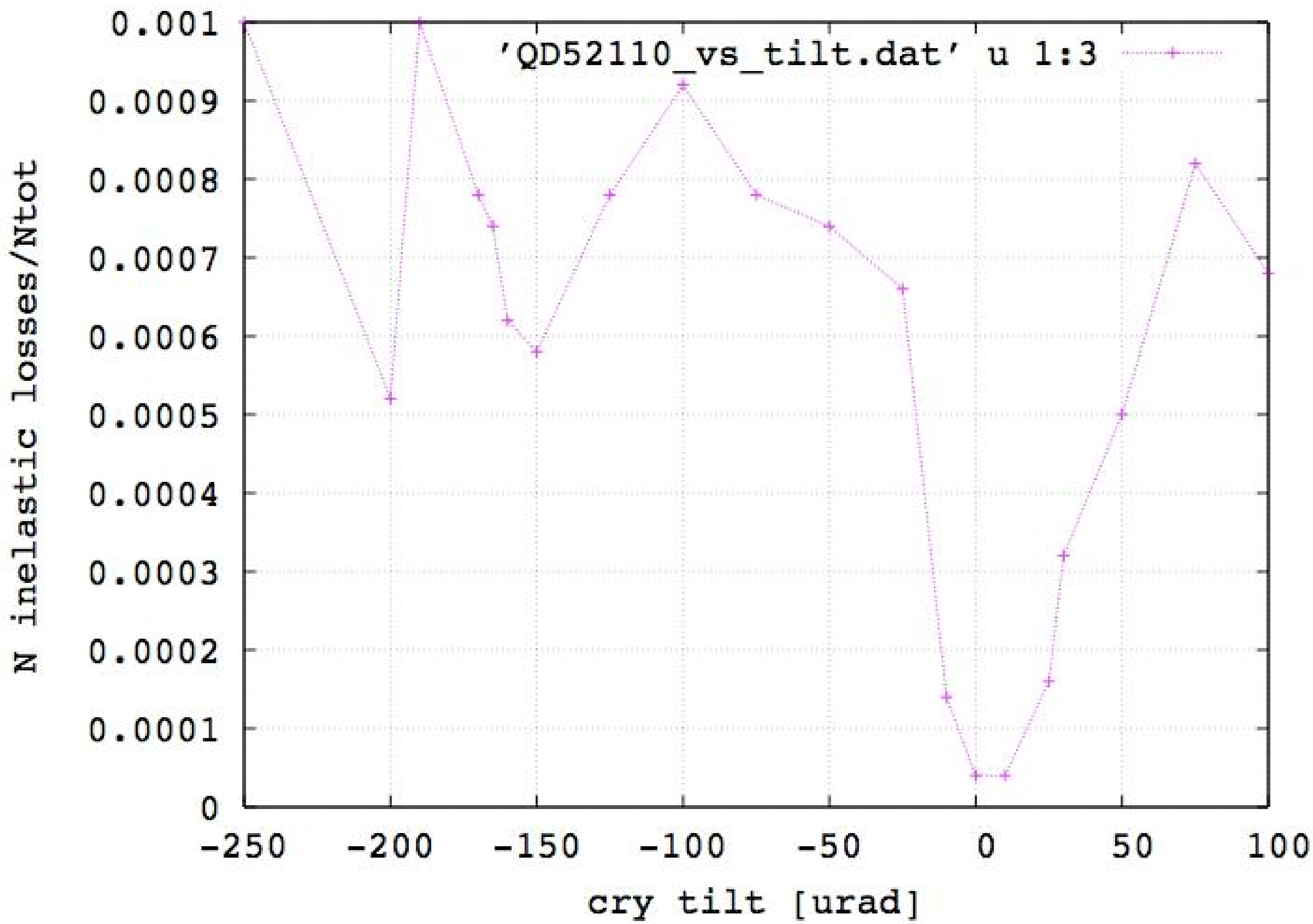
21 m downstream of crystal

3) Inelastic interactions in quad QD52110

Case no amorphous layer, diffusion



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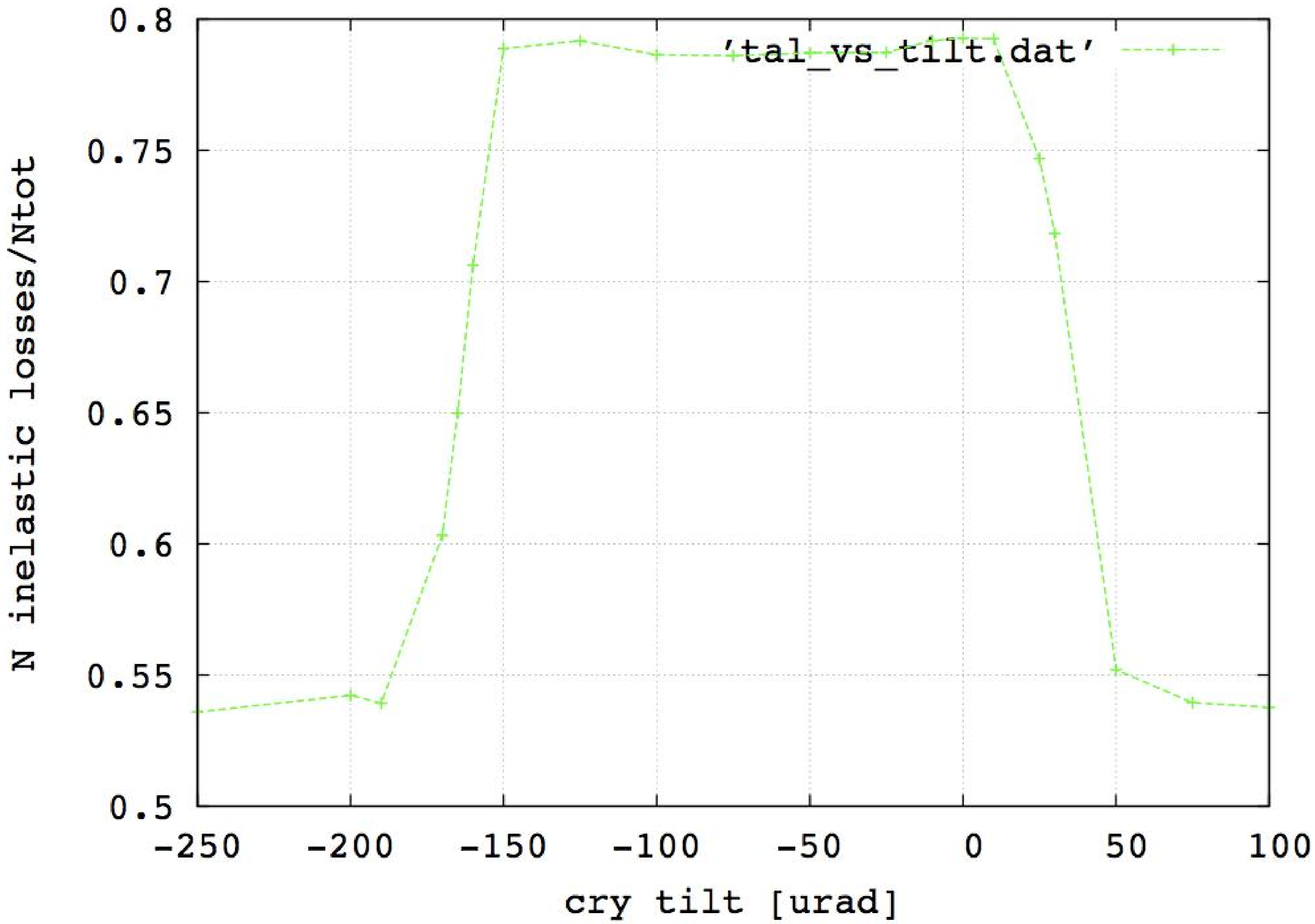
29 m downstream of crystal

4) Inelastic interactions in TAL

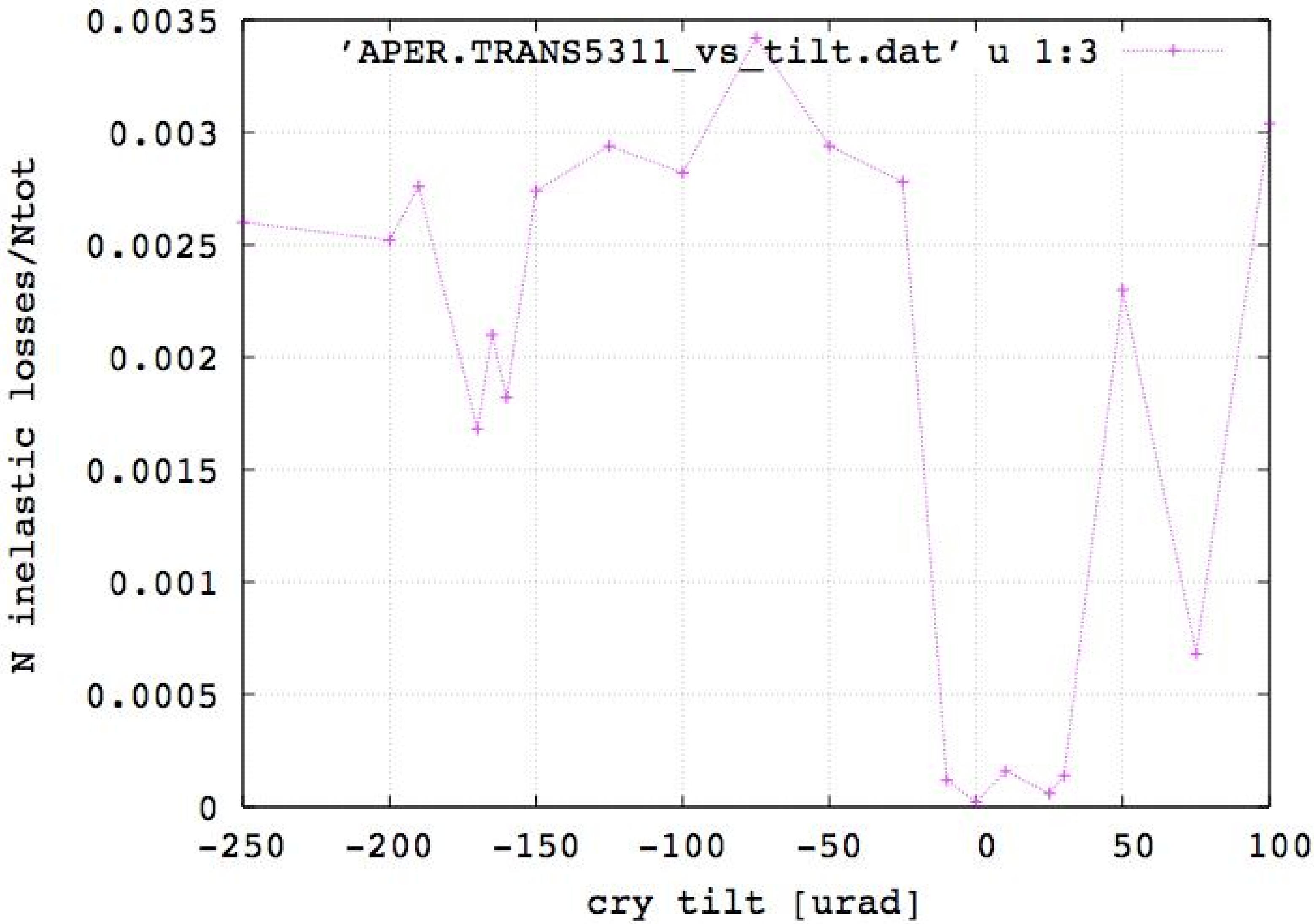
Case no amorphous layer, diffusion



73 m downstream of crystal

5) Inelastic interactions in aperture element

Case no amorphous layer, diffusion



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129 m downstream of crystal

Conclusions

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- Beam loss maps will provide a unique method to validate collimation simulations and measurements (as shown for SPS tests of LHC collimators).
- This relies on distributed beam loss measurement systems as they exist in SPS and Tevatron.
- The LHC state-of-the-art codes for massive tracking have been adapted to include crystal effects (still being finalized for Sixtrack).
- Detailed loss predictions have been prepared for the SPS all around the ring, including magnet losses. Plan to do the same for the Tevatron.
- Measurements for every crystal orientation can be compared to the predictions.
- Once numerical codes have been verified this way, the crystal collimation predictions for the LHC (not shown here) can be trusted.
- Element by element predictions allow focusing on critical elements, maybe equiping them with additional beam loss monitors.
- Work further progressing by moving to full 6D and improving models.