# What Can We Conclude from CRYSTAL for Beam Cleaning?

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**CERN/BE**

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Complaints to me (my view and understanding).

All compliments to Chiara, Stefano and especially Valentina!!!

# Introduction

- Crystal collimation is investigated as a possible way to improve collimation efficiency: CRYSTAL collaboration at CERN.
- LHC collimation project members participate in CRYSTAL:
  - Steering (R. Assmann)
  - Simulation (R. Assmann, V. Previtali)
  - Data taking (R. Assmann, C. Bracco, S. Redaelli, V. Previtali)
  - Data analysis (R. Assmann, S. Redaelli, V. Previtali)
  - Strong support…
- Content of this talk:
  - Summary of results for near-crystal losses.
  - Summary of results for far-away losses.
  - General observations and proposals.

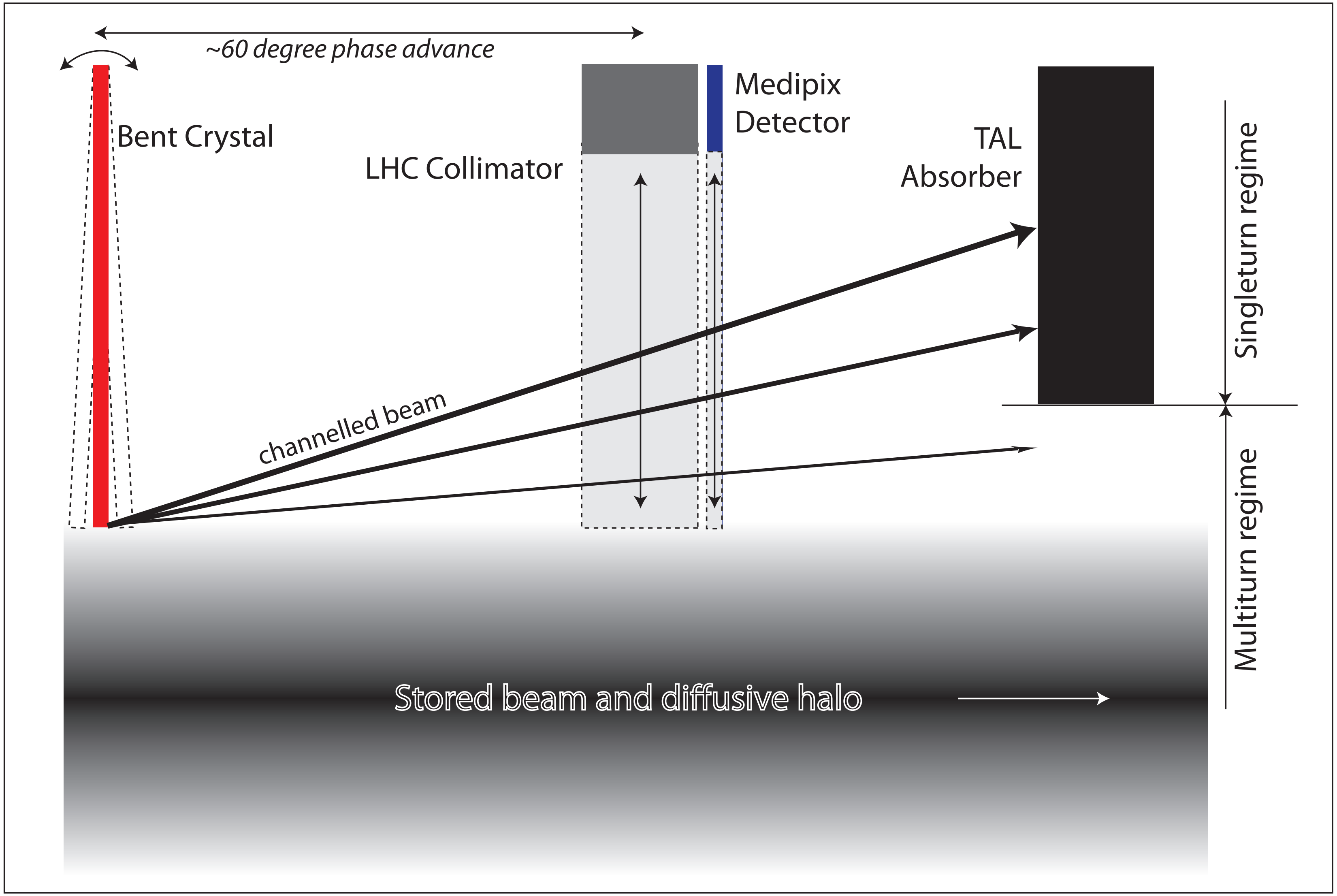
# Near-Crystal and Far-Away Losses

- Near-crystal losses:
  - Losses in region immediately downstream of bent crystal. Fully simulated.
  - Near-crystal losses can locally be much higher than without crystal (e.g. at dump location for channeled beam).
  - Require that measured losses behave as expected and simulated.
  - Should prove that crystal-beam interaction is understood with stored beam.
  - Assessed with collimator scans, medipix data, …
- Far-away losses:
  - Losses in regions far away from the bent crystal. Fully simulated.
  - Far-away losses should be much lower than without crystal.
  - Require that expected reduction is observed at magnets far away.
  - Should prove that cleaning efficiency is improved with crystal collimation.
  - Assessed with beam loss measurements in far away regions (BLM’s).

# I) Near-Crystal Losses: Collimator Scan Method

- A bent crystal “CRY” is closest to beam and intercepts primary beam halo (acts as primary collimator).
- An absorber “TAL” at retracted setting intercepts the extracted beam halo.
- All relative positions are precisely calibrated by touching the primary beam halo.
- In between the crystal and the absorber sits an LHC prototype collimator “COLL” which is precisely moved to sample the beam distribution downstream of the crystal. So-called “collimator scan”.
- Directly downstream of the collimator sit beam loss monitors (“BLM’s”) that provide a signal that is proportional to the amount of beam hitting the crystal.
- Process can be fully simulated, including beam-matter interaction and multi-turn effects.

# Sketch of Layout



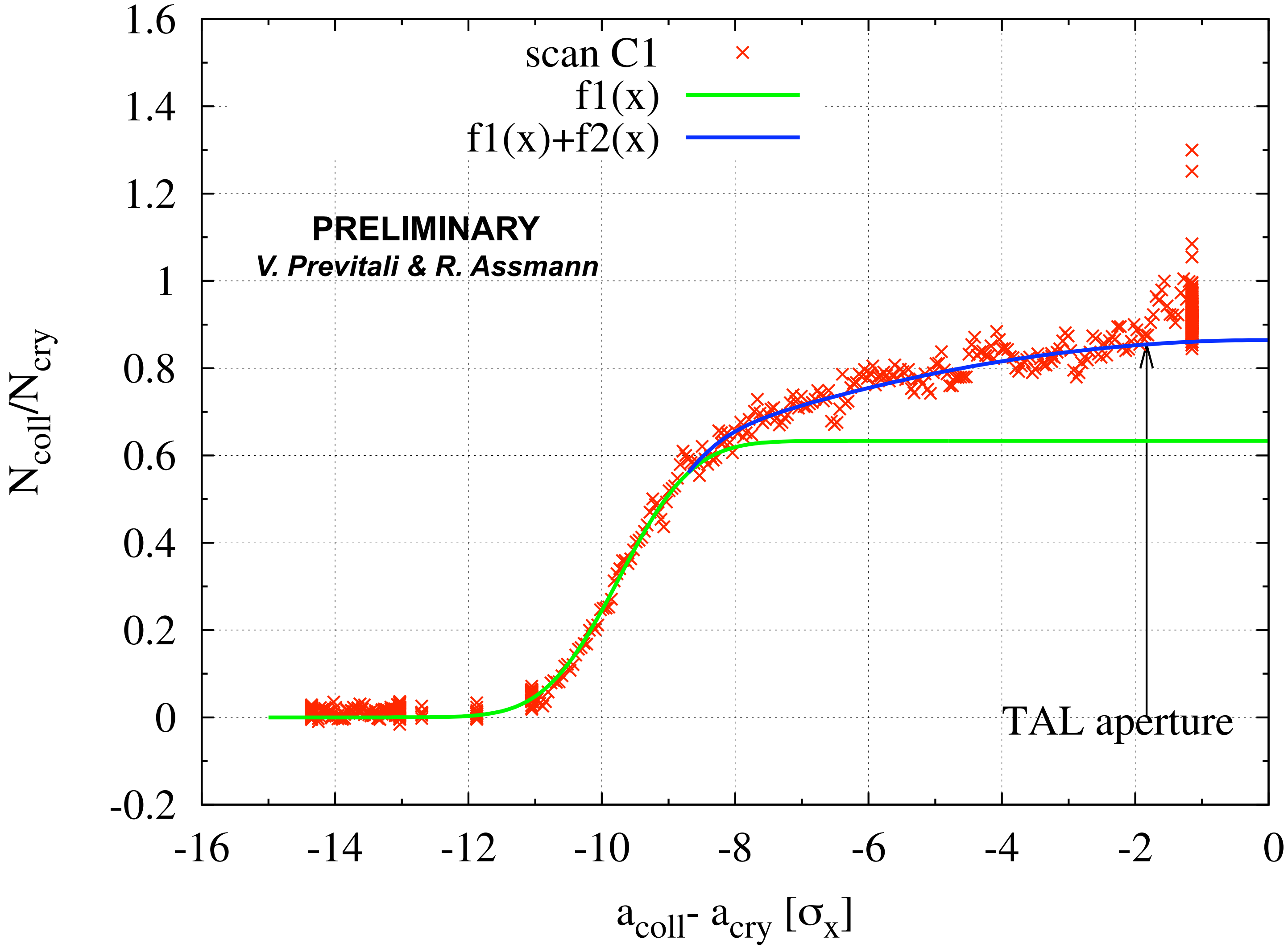
# Quantitative Method

(R. Assmann & V. Previtali)

- Input:
  - **Measured BLM data versus time.**
  - **Collimator jaw position versus time.**
  - **Calibration of relative positions for crystal, TAL and collimator.**
  - **Offset of BLM, obtained at large collimator gaps.**
- Assumptions:
  - *BLM signal is proportional to the number of protons that have an inelastic interaction in the collimator jaw (verified to large extent in SPS measurements).*
  - *95% of the protons that hit the crystal have inelastic interactions in the collimator when its setting is close to the crystal setting (other protons pass through or get a negative deflection away from the crystal – number taken from simulations).*
  - *The beam-based calibration of the relative positions is constant during the experiment. Should be quite true, as only affected by hardware stability.*
  - *Movements of the collimator jaw are well known (true to the 20 $\mu$m level – precision of stepping motors).*
  - *BLM readings for collimator positions far out of the channeled beam define the offset of the BLM that can be subtracted).*
- Result:
  - **Channeling efficiency, angle, width, probabilities for other processes.**

# Quantitative Analysis

Crystal #1 – Main Channeling Position




**f1 – Error function fit to describe channel peak (primary fit)**

**f2 – Parabola**

**Fitting used to assess relative probabilities for various regimes. Simple estimates can provide similar results!**

# Quantitative Results (July 1$^{st}$ data)

| Parameter | Unit | Expected | Simulated | Experiment |
|---|---|---|---|---|
| Channeling angle | μrad | **150** | **149 ± 0.4** | **176 ± 0.7** |
| Width of channel | $\sigma_x$ | **0.9** | **0.86 ± 0.02** | **0.87 ± 0.07** |
| Channel efficiency | % | **n/a** | **92 ± 1.4** | **62 ± 2.0** |
| Probability for intermediate angles (e.g. dechanneling) | % | **n/a** | **1.3 ± 0.4** | **23 ± 2.0** |
| Probability for small angles (e.g. amorphous/VR) | % | **n/a** | **6.7 ± 1.0** | **15 ± 2.0** |

*Notes:* *Simulations include multi-turn processes, full crystal model, interaction in all materials.*

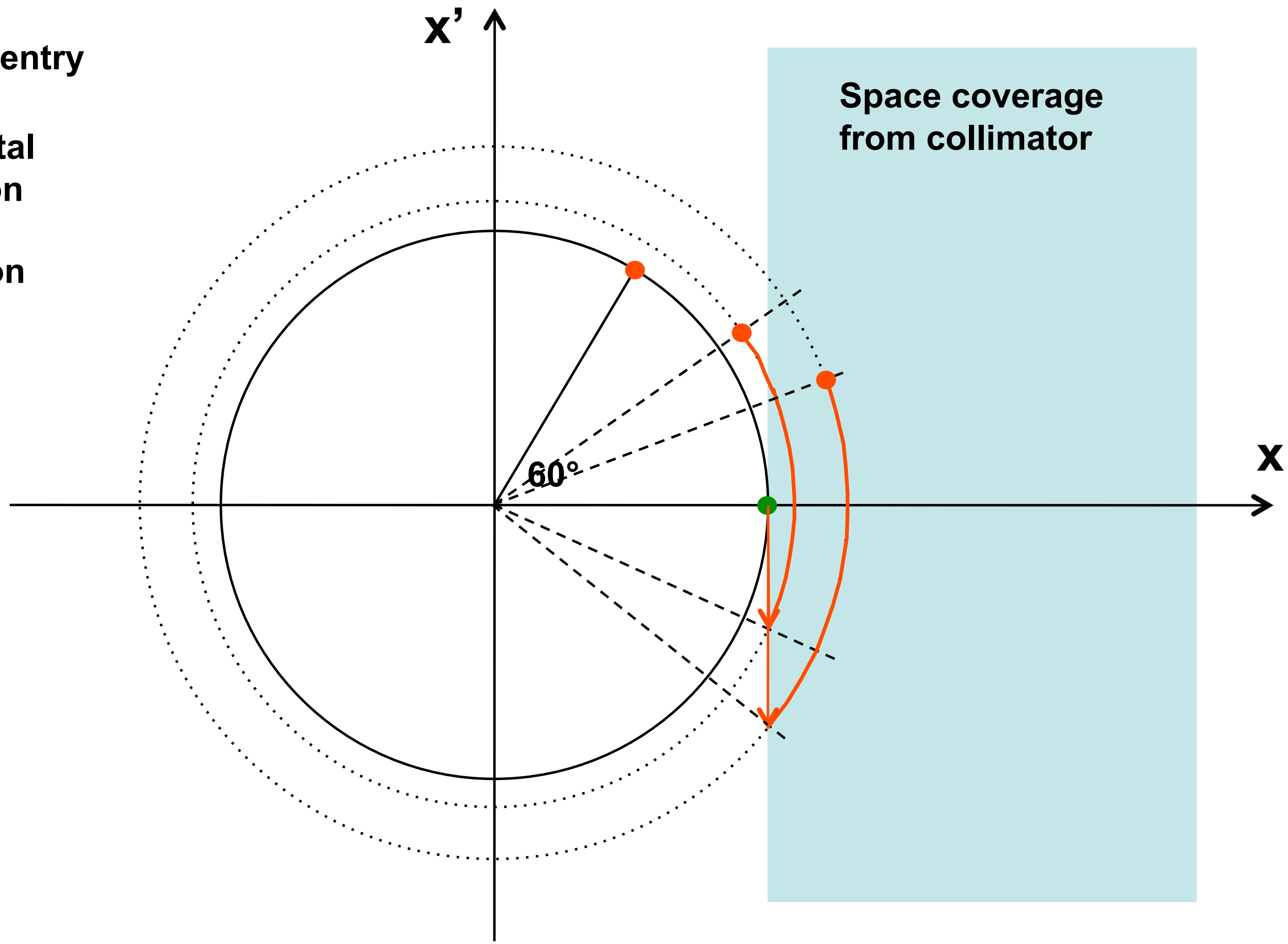
*Errors only include statistics and fit errors, no systematic errors.*

*We only had one good UA9 collimator scan to use. Ask for more data. Need to move to real edge of primary halo ➔ channeling efficiency can go down!*

*Other known effects of crystal #1 not included: vertical kick, tilt of extracted beam. Can induce additional systematical errors.*

# Limit in Angle Coverage

- Proton at crystal entry
- Proton after crystal induced deflection and transport to collimator location

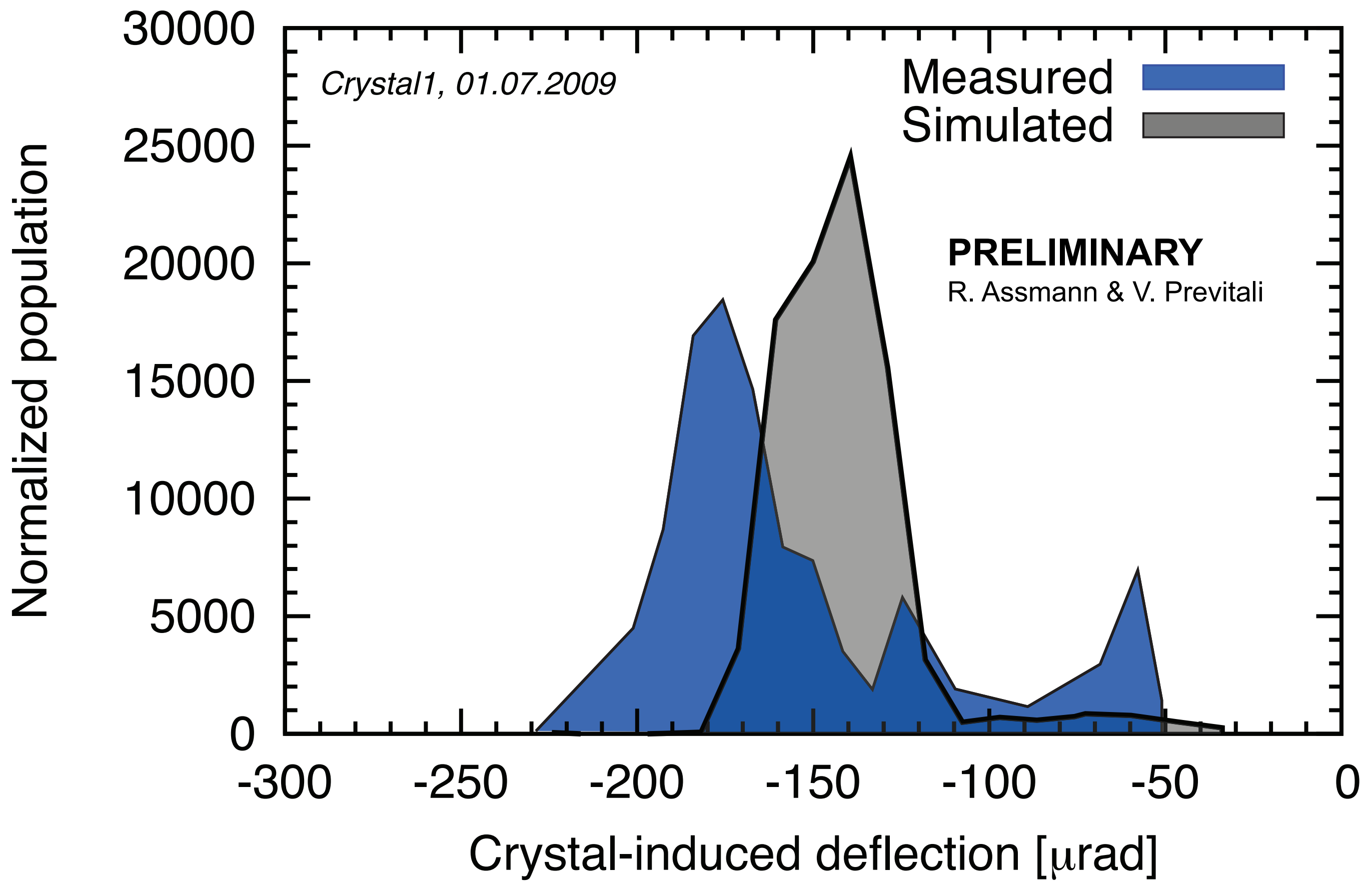



→ **Proton needs to get a minimal deflection in order to be seen at collimator (same for medipix)**

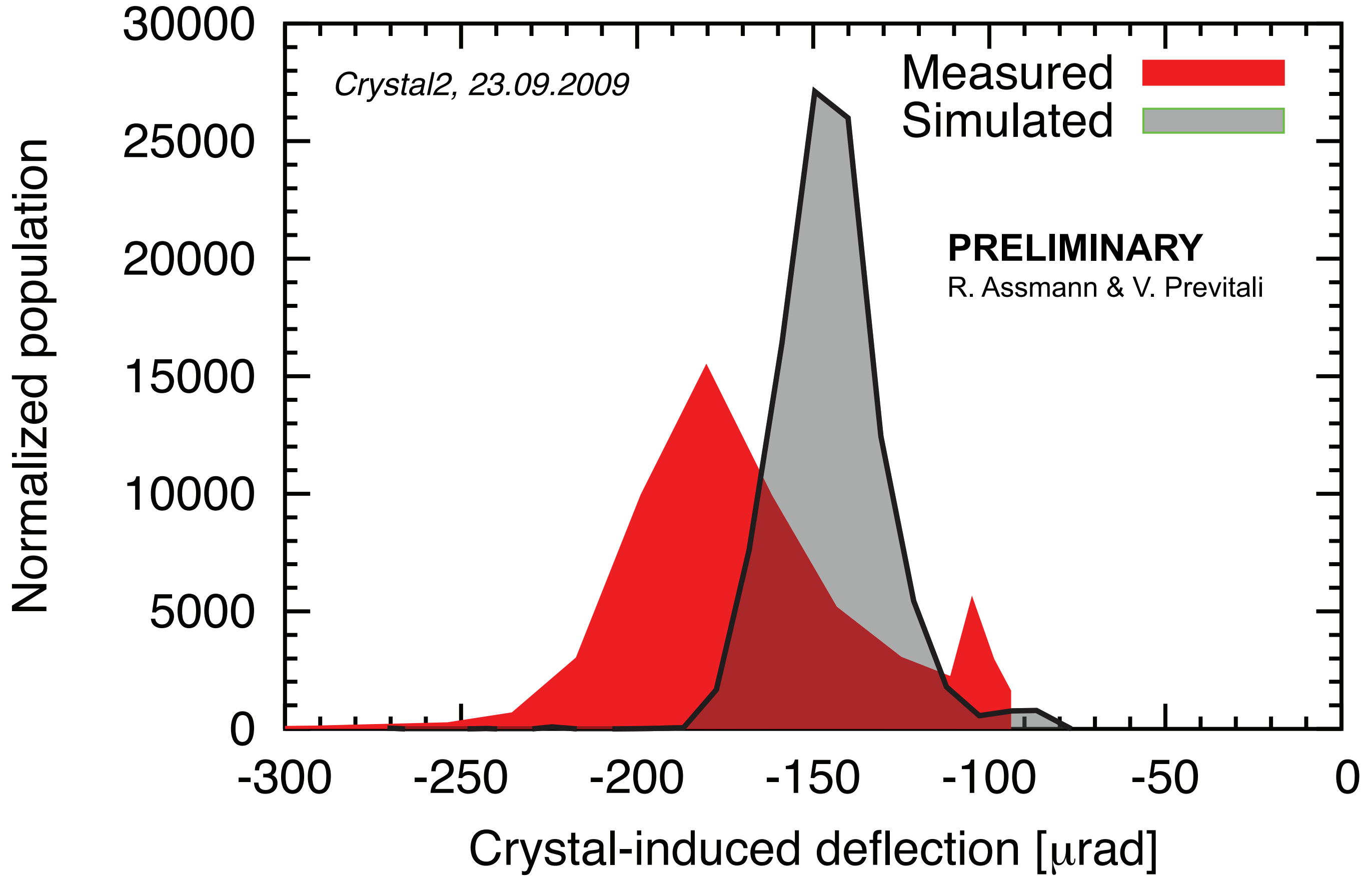
# Limited Observation of Near Crystal Losses

- Experimental layout prevents to observe protons that received in the same turn a deflection from the crystal below ~50-100 μrad.
- This is true both for collimator scans and medipix pictures ➔ results include only large angle protons.
- The protons that are not seen, are either lost during the same turn elsewhere in the SPS or come back and can receive another crystal-induced deflection (multi-turn process).
- From simulations we expect that about 5% of protons are not seen by the collimator. This is assumed for the following.
- BEWARE: If there is any much bigger fraction of particles in the low angle regime, then results for efficiency must be scaled down (e.g. 50% of protons in the low angle regime would require reducing efficiencies by factor ~2.

# Best Crystal 1 Result



# Best Crystal 2 Result



# Result Summary

## (Simplified Analysis – No Fit for Intermediate Angles)

**PRELIMINARY**

V. Previtali & R. Assmann

| Scan | Date | Intensity | Efficiency measured | Efficiency simulated | Efficiency meas/sim | Width measured | Width simulated | Width meas/sim | Angle measured | Angle expected | Angle meas/exp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [p] | | | | urad | | | urad | | |
| SPS crystal 1 | 1.7.09 | 2.00E+10 | 74.00% | 91.40% | 0.81 | 16.6 | 13.2 | 1.26 | 172.8 | 170 | 1.02 |
| SPS crystal 1 | 22.9.09 | 1.00E+10 | 58.80% | 92.50% | 0.64 | 35.3 | 13.5 | 2.61 | 200.6 | 170 | 1.18 |
| SPS crystal 1 | 23.9.09 | 1.00E+10 | 55.60% | 92.50% | 0.60 | 35.3 | 13.5 | 2.61 | 201.6 | 170 | 1.19 |
| SPS crystal 2 | 23.9.09 | 2.00E+12 | 77.40% | 91.60% | 0.84 | 19.5 | 14.1 | 1.38 | 180.9 | 150 | 1.21 |
| Tevatron | 20.11.08 | ??? | 66.60% | | | 13.3 | | | 296 | 410 | 0.72 |

Note all the conditions and assumptions for arriving at these results. BEWARE!

Especially the uncertainty on population for small and intermediate kicks!

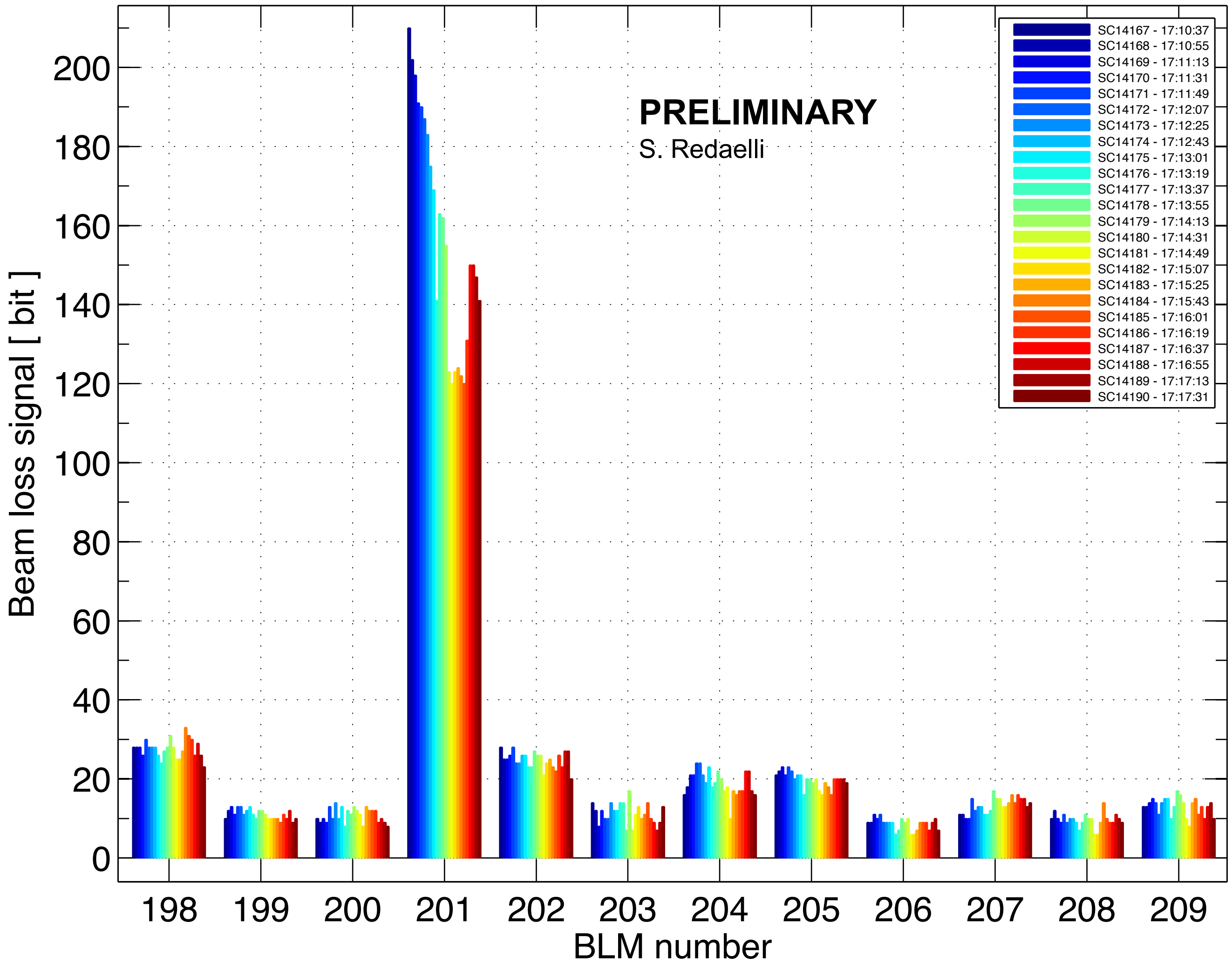
# Summary on Near Crystal Losses

- Crystal efficiency:
  - Maximum channeling efficiency between 56% and 77%, compared to 92% simulated (assuming that 5% of protons are not seen due to small angles).
  - Population of intermediate angles is up to 15 times higher than predicted (e.g. 23% instead of 1.3%).
- Channel width 17 μrad to 35 μrad, compared to 14 μrad expected. Why so much larger?
- Angle 173 μrad to 202 μrad, compared to 150/170 μrad expected.
- Maximum p angle up to 270 μrad ➔ implications for required clearance for halo dump line (need twice the channeling angle).
- Tolerance for crystal-beam alignment: ~ ± 4 μrad.
- Variations not controlled and not fully understood. Different channeling conditions found in various experiments.

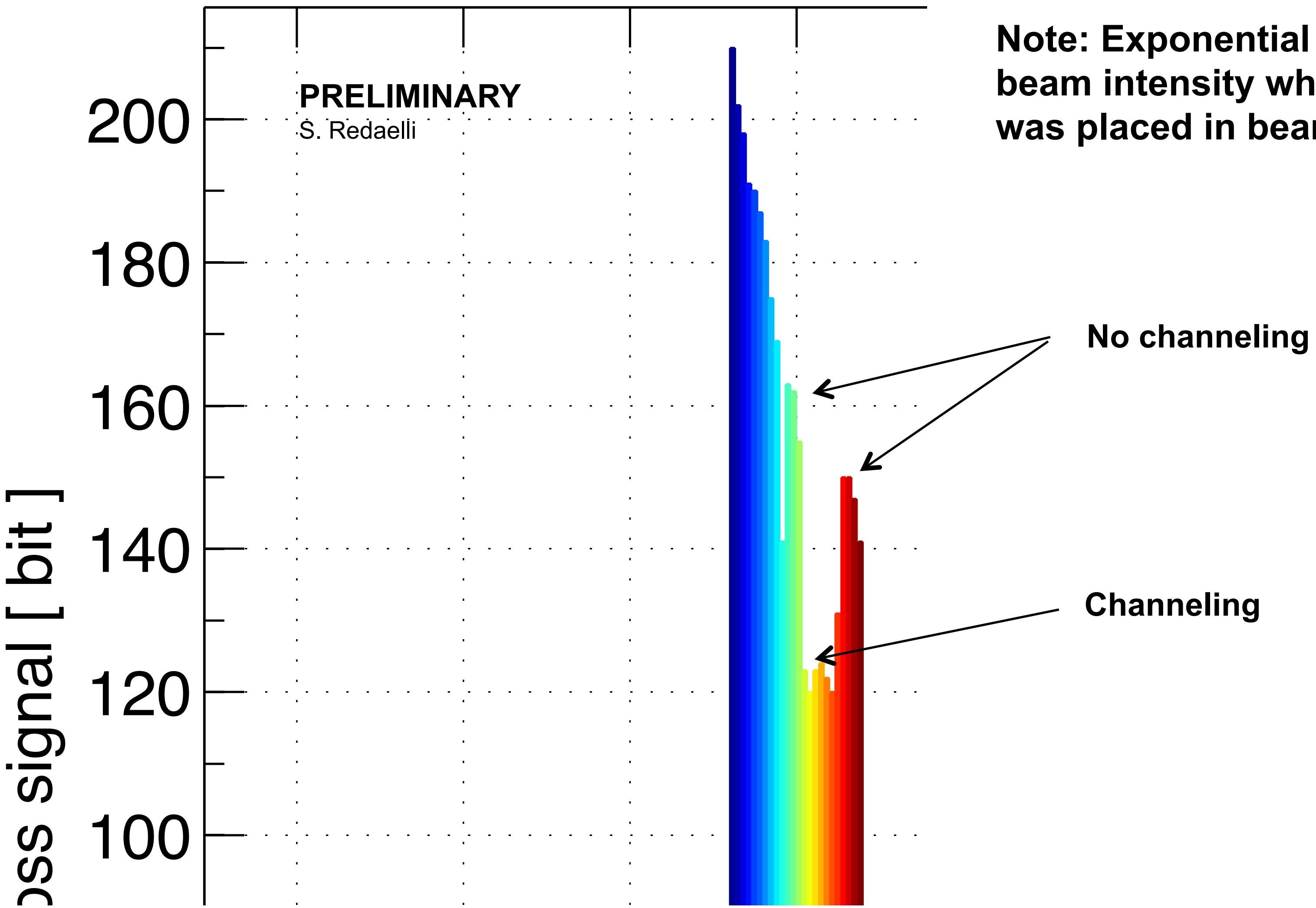
# II) Far-Away Losses: Beam Loss Maps

- Difficult to see any reproducible effect of crystal on beam loss maps around the SPS (except local losses in crystal region).
- Only successful attempt (to my knowledge):
  - August 11, 17h10-17h20.
  - Driving crystal into the core of the SPS beam.
  - Switching from no channel to channel to no channel.
- Reproducible change in far away losses seen.

# Observation LSS6

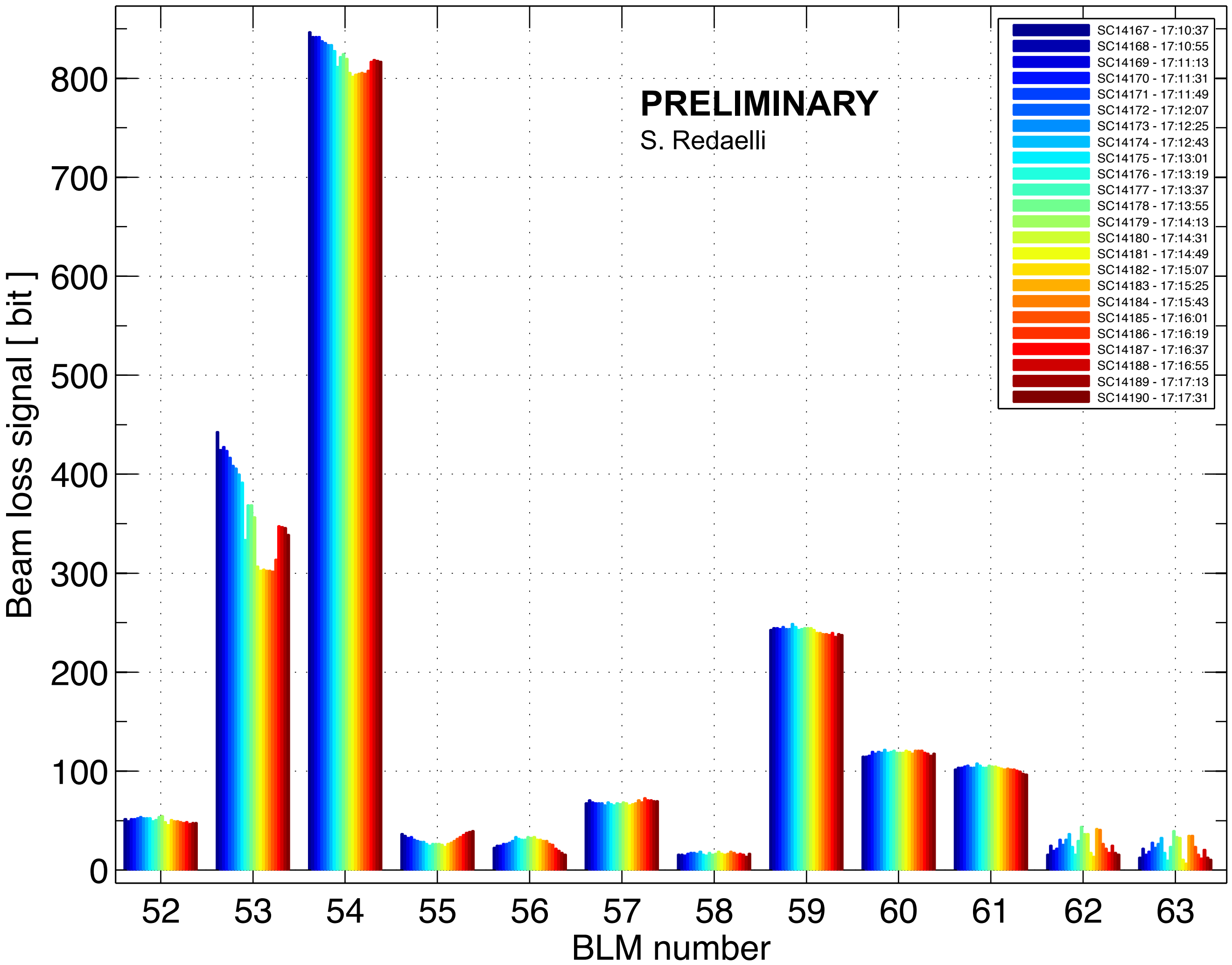


# Observation LSS6




**Note: Exponential decay of beam intensity when crystal was placed in beam core.**

# Observation LSS2



# Observed Gain

- Reduction seen for three BLM's far downstream of the crystal:
  - BLM 53: factor 1.17
  - BLM 54: factor 1.03
  - BLM 201: factor 1.25
- Note that no correction for eventual BLM offsets was applied.
- All other BLM's showed no significant change in loss reading.
- Much less gain than predicted: factor 1.25, compared to factor 20
- Observation:
  - Gain for improved cleaning with crystal collimation has not yet been shown.
  - Effect of increased population for protons with intermediate (and small?) crystal-induced deflections? Is factor 15 higher than predicted…
  - Effect of missing BLM sensitivity? But we see something…

# III) Conclusion & Outlook

- Crystal experiments are interesting and provide a wealth of insights into complicate halo dynamics with single and multi turn issues.
- All comments and input from collaborators very welcome. Things are complicated and our preliminary conclusions need discussion!
- Collimator scans very useful but limited to large angles (like medipix).
- Channeling works with optimistically ~70% of expected efficiency. Intermediate angles have ~15 times higher population than predicted.
- Channeling angle and width are not fully reproducible but depend on crystal alignment angle. Reason not clear to me.
- It seems that angular crystal alignment accuracy should be about ±4 $\mu$rad to arrive at reproducible conditions (see Valentina's talk).
- The halo dump line for the channeled beam should have an acceptance of about twice the channeling angle (implications for LHC). How do we get such large deflections?

# Conclusion & Outlook – Part II

- Best observed gain in cleaning efficiency (far away losses) is factor 1.25, instead of expected factor 20. Problem of BLM system or consequence of higher population for small & intermediate angles?
- Problem of beam induced heating and deformation not addressed: propose temperature sensors connected to crystal for future beam tests.
- SPS results not fully understood and significant discrepancies with simulations/predictions. On the other side, basic channeling works.
- CRYSTAL goal has not yet been achieved, namely to demonstrate for the first time improved cleaning efficiency with crystal-enhanced collimation.
- Same problem as in tests in RHIC and TEVATRON: Channeling works but does not reliably improve cleaning efficiency (far-away losses).
- Additional beam tests in SPS are strongly recommended to either achieve the CRYSTAL goal or to understand why the expected gain is not realized. I would not put a crystal into LHC with present understanding.