Crystal Collimation Workshop, Fermilab – October 29, 2008

G. Robert-Demolaize, A. Drees, BNL

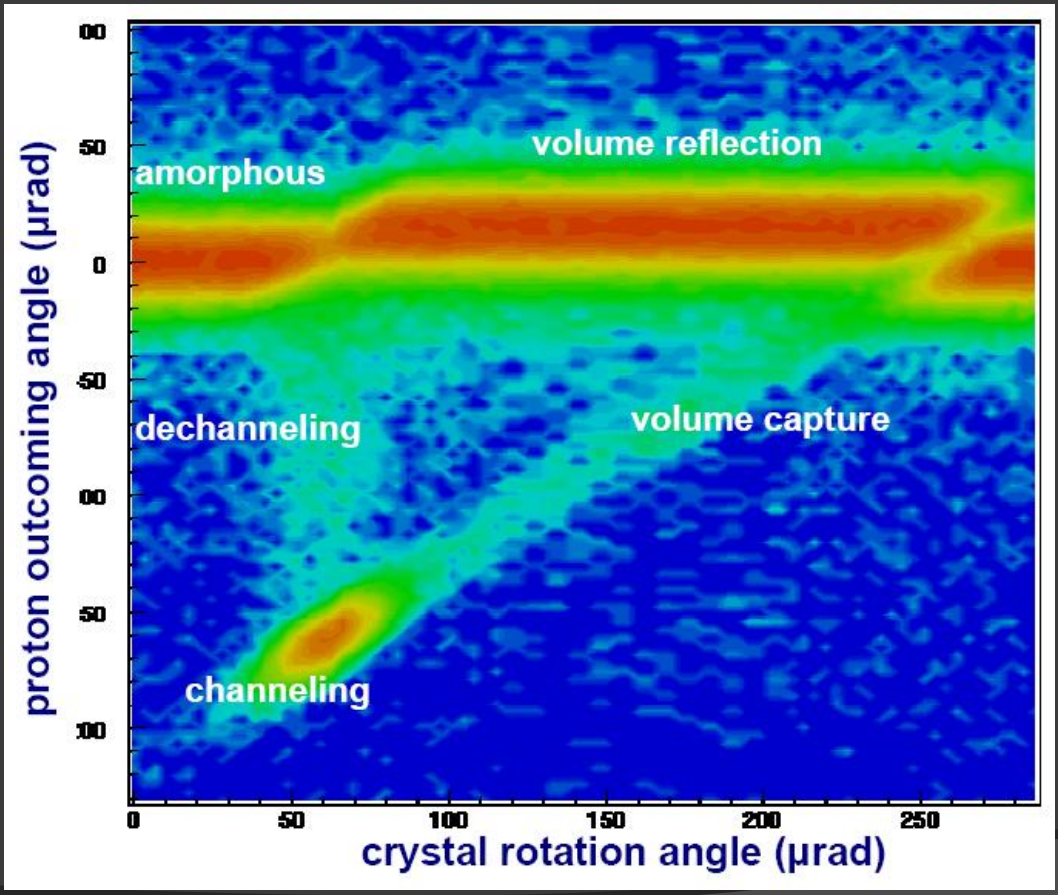
SIMULATIONS AND ANALYSIS FOR UA9

OUTLINE

- I - Motivation – Our goals for UA9
- II - Simulated layout – Crystal model
- III - Preliminary results
- IV - Summary - Outlook

I - MOTIVATION

- Previous SPS experiment in 2006 (H8RD22) featured the first measurement of both channeling and volume reflection processes for a high energy proton beam.



RD22 was a successful single-pass experiment with a bent Si crystal

=> used in a ring as a primary collimator, that crystal will have a different, multi-hit behavior !!

W. Scandale, LTC, 1/30/08

LEARNING FROM THE PAST ??

- The multi-turn physics of a beam passing through a bent crystal has been observed both at FNAL (Tevatron) and BNL (RHIC collimation). However, in all cases, the efficiency of the crystal did not match the prediction from tracking codes.

Run	β^*_{PHENIX}	Channeling Efficiency				
		Design optics	Measured optics	Simulation	Measured width	Channeling data
FY2001	5	59 %			19 ± 2 %	24 ± 3 %
FY2001	2	71 %	39 ± 2 %	37 ± 1 %	9 ± 1 %	28 ± 3 %
FY2001	1	74 %	75 ± 1 %	56 ± 3 %	20 ± 2 %	19 ± 3 %
FY2002	3	79 %			21 ± 2 %	26 ± 3 %
FY2003	2	71 %	52 ± 2 %	50 ± 1 %	26 ± 2 %	26 ± 3 %

A. Drees, CARE-HHH Crystal mini-workshop, CERN, March 2005

OUR GOALS FOR UA9

- It is therefore important to study in details the 6D multi-turn behavior of single particles impacting on a bent crystal, in order to understand and predict the mechanisms of a crystal-based collimation system for any machine conditions (transverse/longitudinal tunes, beam energy, etc…).
- So far, our main concerns are:
  - how the optics (α, β, μ, closed orbit) affect the crystal efficiency (CC/VR acceptance angle), especially the dispersion function and initial angular beam distribution? (see S. Peggs talk)
  - is there a specific multi-turn pattern, i.e. how often does a single particle has to hit the crystal before it reaches the collimator, and over how many turns ?
  - to confirm the energy scaling law for the volume reflection kick in transverse angle.
- Both CRYSTAL (SPS) and T980 (Tevatron) upcoming experiments should allow addressing these issues. This is currently being worked on, with the building and installation of dedicated Roman Pot (RP) stations.
- BNL contribution: data analysis based on fast tracking algorithms, providing output files similar to the ones produced by the detection system.

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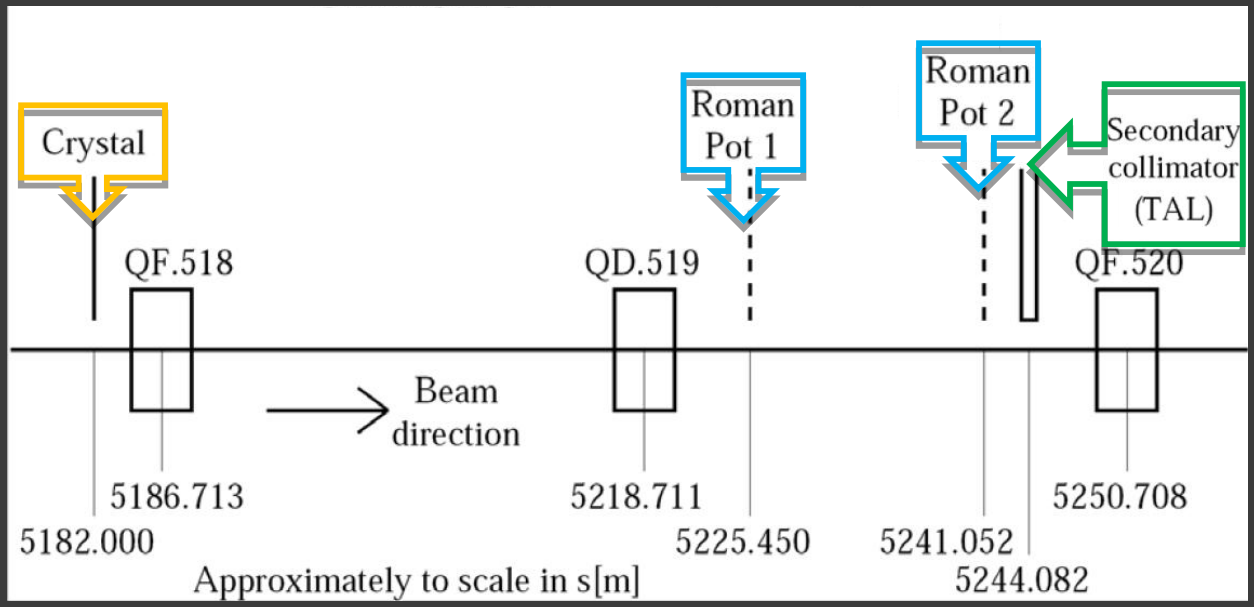
II - SIMULATED LAYOUT

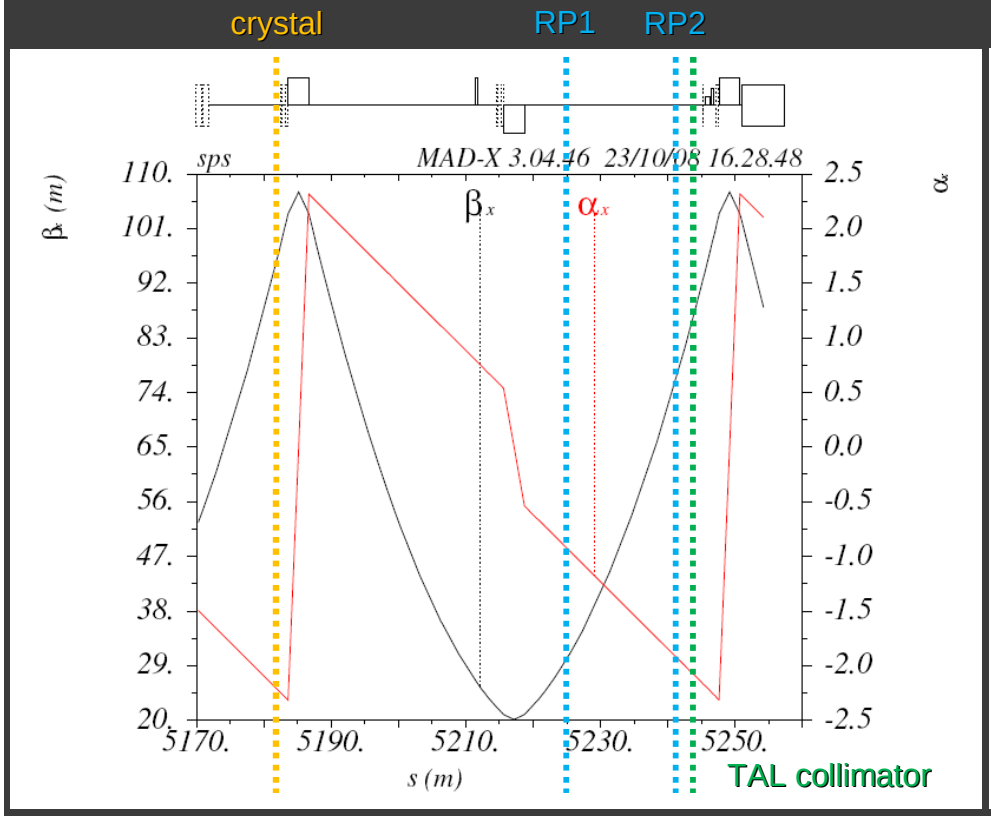
- The CRYSTAL experiment is scheduled for early 2009 along LSS5 in the CERN SPS. The bent Si crystal is placed upstream of QF.518; two locations are foreseen downstream of QD.519 for the installation of RP's.

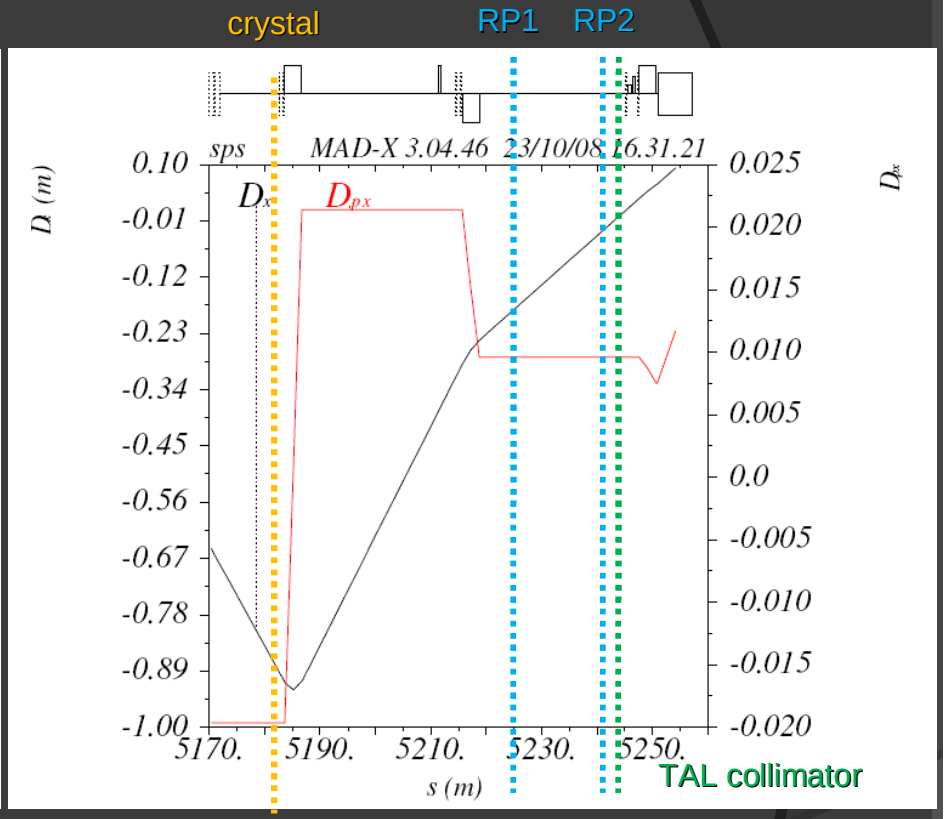


W. Scandale & A. Taratin, CERN/AT 2008-21

- A 60 cm long secondary tungsten absorber (TAL) is located upstream of QF.520. The crystal configuration will aim at channeling particles in the horizontal plane so as to dump them on the TAL; practically, the crystal will only intercept particles with $X > 0$ and give them a transverse angular kick $\Delta X' > 0$.

OPTICS ALONG LSS5





- The crystal will be installed close to a maximum of β_x (GOOD) and an extrema of η_x (BAD). Values of α_x and η'_x are also non negligible…
- For collimation/channeling efficiency studies, the crystal will sit at 6 σ_x from the center of the beam; RP1&2 and TAL at $\approx$ 6.83 σ_x.

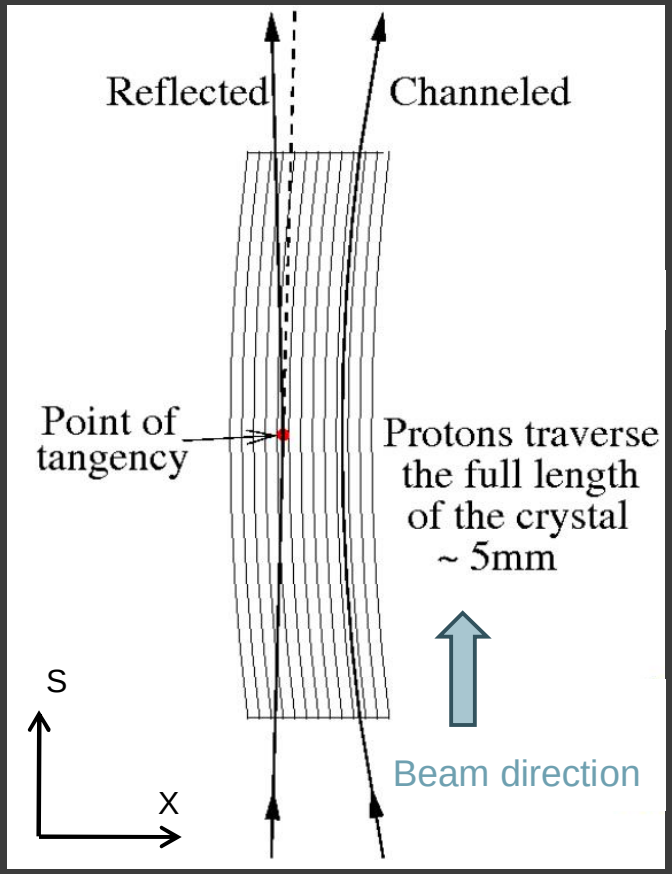
BEAM PARAMETERS

	High energy	Unbunched	Bunched
Momentum P [GeV/c]	270	120	120
Tune Qx	26.13	26.13	26.13
Tune Qy	26.18	26.18	26.18
Tune Qs	0.0021	0	0.004
Normalized emittance (at 1 σ) [mm mrad]	1.5	1.5	1.5
Transverse radius (RMS) [mm]	0.67	1	1
Momentum spread (RMS) $\Delta p/p$	2 to 3×10^{-4}	2 to 3×10^{-4}	4×10^{-4}
Longitudinal emittance [eV-s]	0.4	$\leq$0.4	0.4
RF Voltage [MV]	1.5	0	1.5

- Scenario considered in this presentation: 120 GeV bunched beam with N_{part} ~ 1e11.
- At the location of the crystal: 1 σ_x = 1.058 mm , 1 σ_p = | η_x * $\Delta p/p$ | = 0.351 mm !!!
- From W. Scandale & A. Taratin, CERN/AT 2008-21: halo flux will range between 1e2 and 1e4 particles per turn, synchronous to the bunch structure => limit for single particles experiment: can it be reduced ?? Does the instrumentation then still work ??

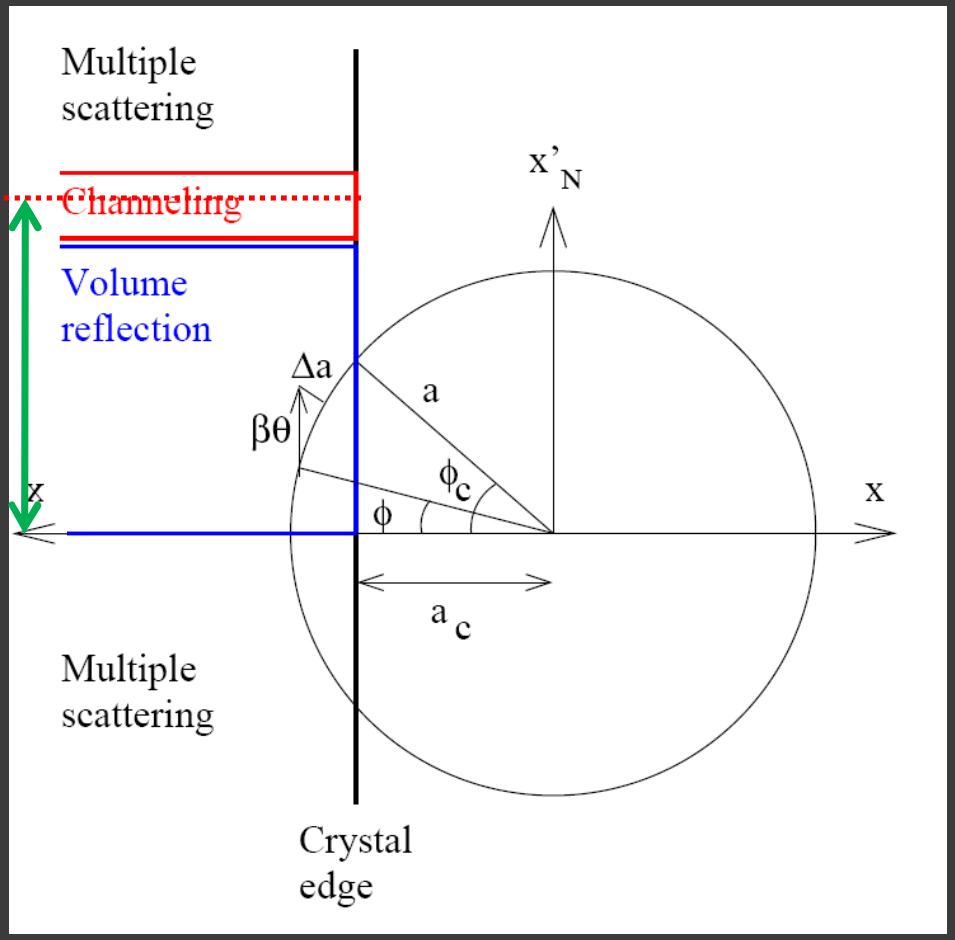
CRYSTAL MODEL (1/2)

- For data analysis, it is sufficient to represent the Si bent crystal using SCM (Short Crystal Model, presented by S. Peggs et al. @ FNAL Crystal Meeting, 12/6/2007).



- Only a few parameters are therefore required to describe on the first order the various processes applied to single particles hitting the crystal:
  - channeling (CC) angle Ω of the crystal,
  - volume reflection (VR) kick in angle θ_{VR},
  - RMS kick in angle from Coulomb scattering θ_{RMS},
  - channeling acceptance angle α_{cc} ,
  - CC and VR efficiencies λ_{CC}, λ_{VR}.
- The corresponding values are obtained from established crystal tracking code like CATCH; in current (preliminary) version of the fast algorithms, there is no spread in the kick given to the particles.

CRYSTAL MODEL (2/2)

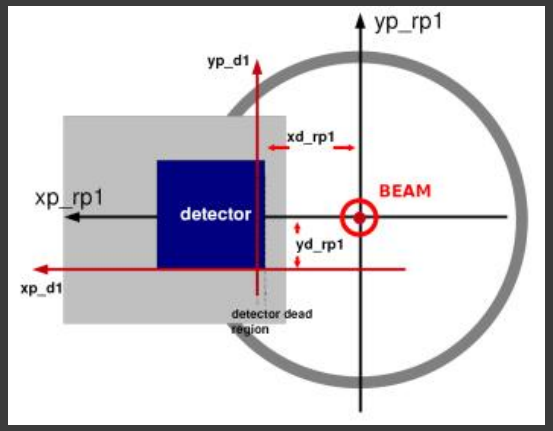


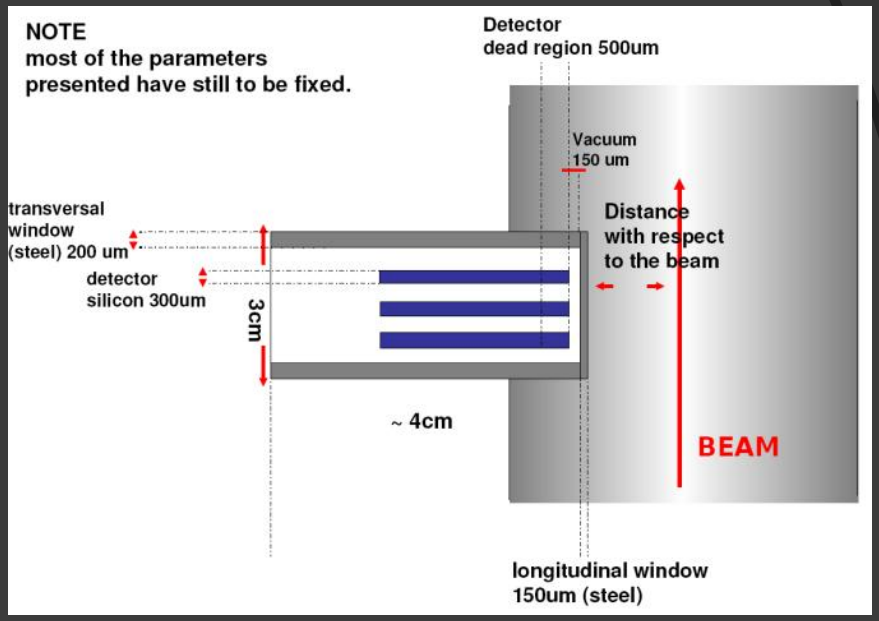
S. Peggs et al.

- In the results presented in the next slides, the following values were used (from W. Scandale & A. Taratin, CERN/AT 2008-21):
  - Ω = 150 μrad,
  - θ_{VR} = 22 μrad,
  - θ_{RMS} = 10 μrad,
  - α_{cc} = 20.4 μrad,
  - λ_{CC} = 56%, λ_{VR} = 95 % (taken from RD22).
- The crystal is set up so that channeling is the favored mechanism for the impacting distribution. VR and MCS can also occur.

ROMAN POTS LAYOUT

S. Hasan et al.





- Total detector dead zone for each RP is equivalent to:
  - @ RP1: 0.8 mm = 1.329 σ_x => particles invisible until they reach 8.155 σ_x !!
  - @ RP2: 0.8 mm = 0.802 σ_x => particles invisible until they reach 7.628 σ_x !!
- Dead zone is included in the fast algorithms; dE/dx and RMS kicks from passage through RP material is not, but is foreseen in later versions for full treatment.

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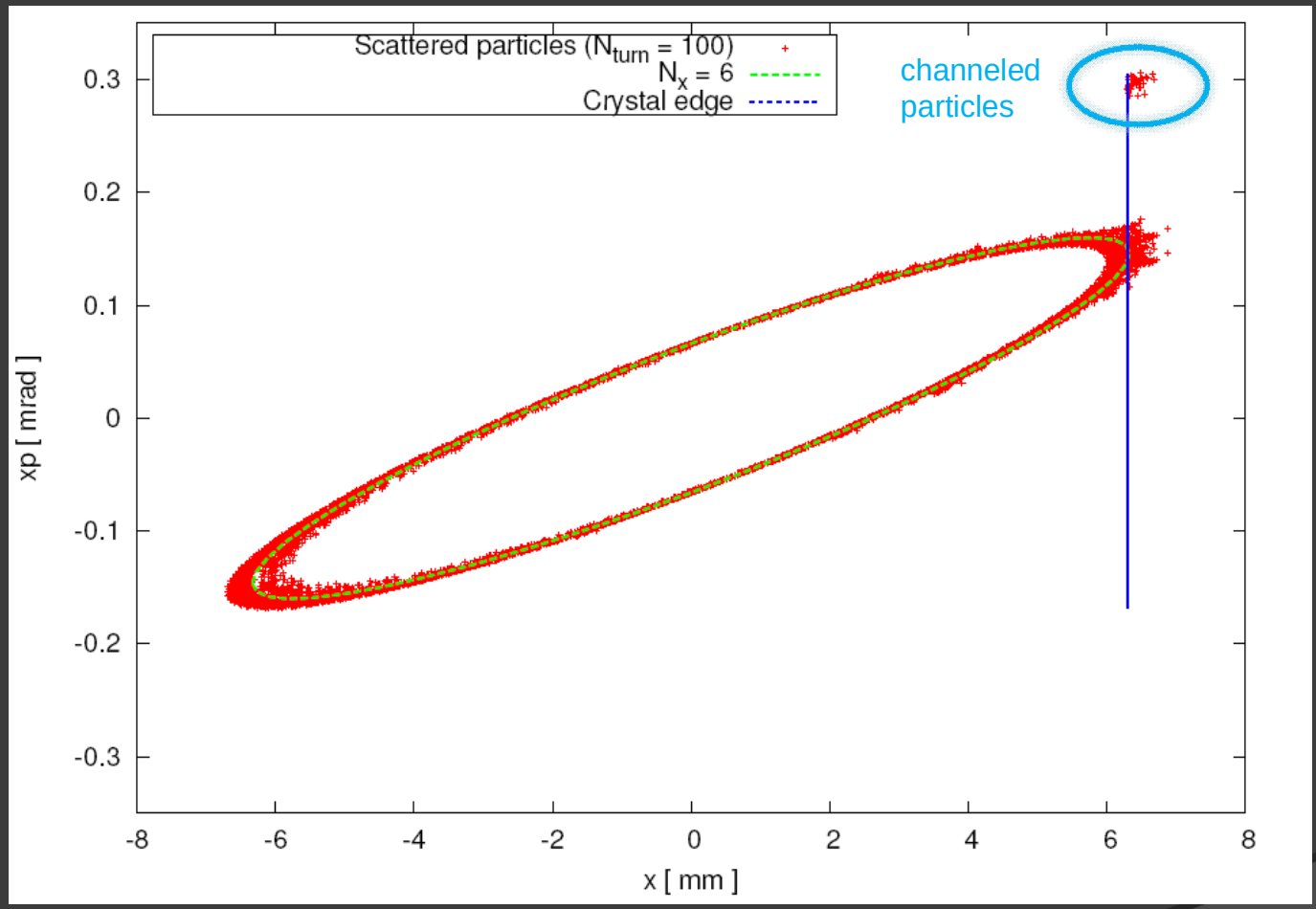
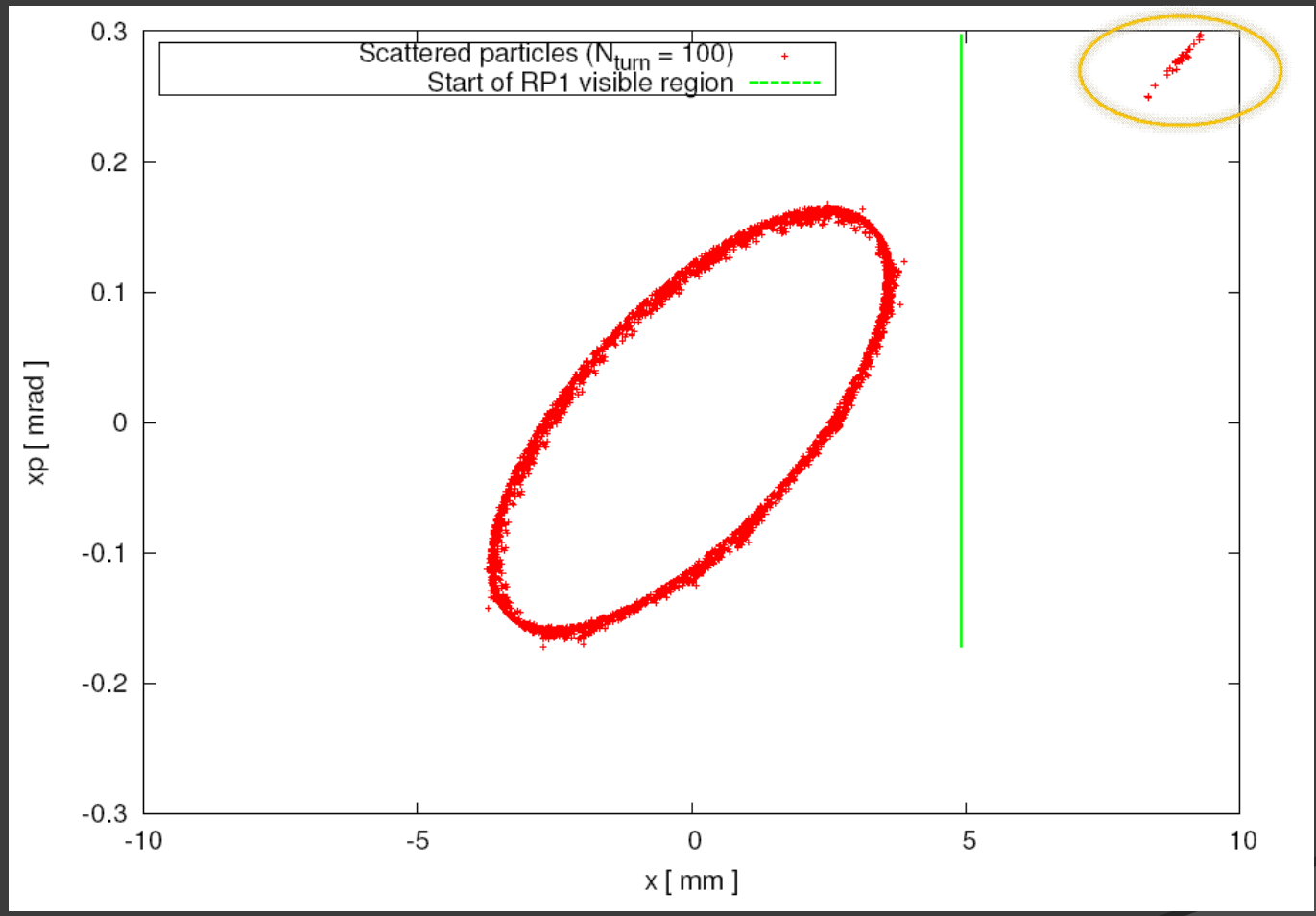
III - PRELIMINARY RESULTS



Distribution of particles at the location of the Si crystal; statistics over 100 turns.

WHAT THE ROMAN POTS SEE



how many times does the same particle hits ?

Distribution of particles at the location of Roman Pot 1; statistics over 100 turns.

STATISTICS AT ROMAN POTS

Turn number	Channeled @ crystal (particle ID)	Seen @ RP1 (particle ID)	Seen @ RP2 (particle ID)	Lost @ TAL (particle ID)
2	71	71	71	71
3	15, 35, 100	15, 35, 100	15, 35, 100	15, 35, 100
…	…	…	…	…
18	51, 54, 56	51, 54, 56	51, 54, 56	51, 54, 56
…				
44	1, 19, 46	1, 19, 46	1, 19, 46	1, 19, 46
…	…	…	…	…

- Only channeled particles are seen at the RP's !!
- Channeled particles are absorbed the same turn they are seen !!
- Out of 186 single particle hits on the crystal (over 100 turns), 83 were in the channeling acceptance (45%), 85 in the VR acceptance (45%) and 18 particles went through the amorphous region (10%).

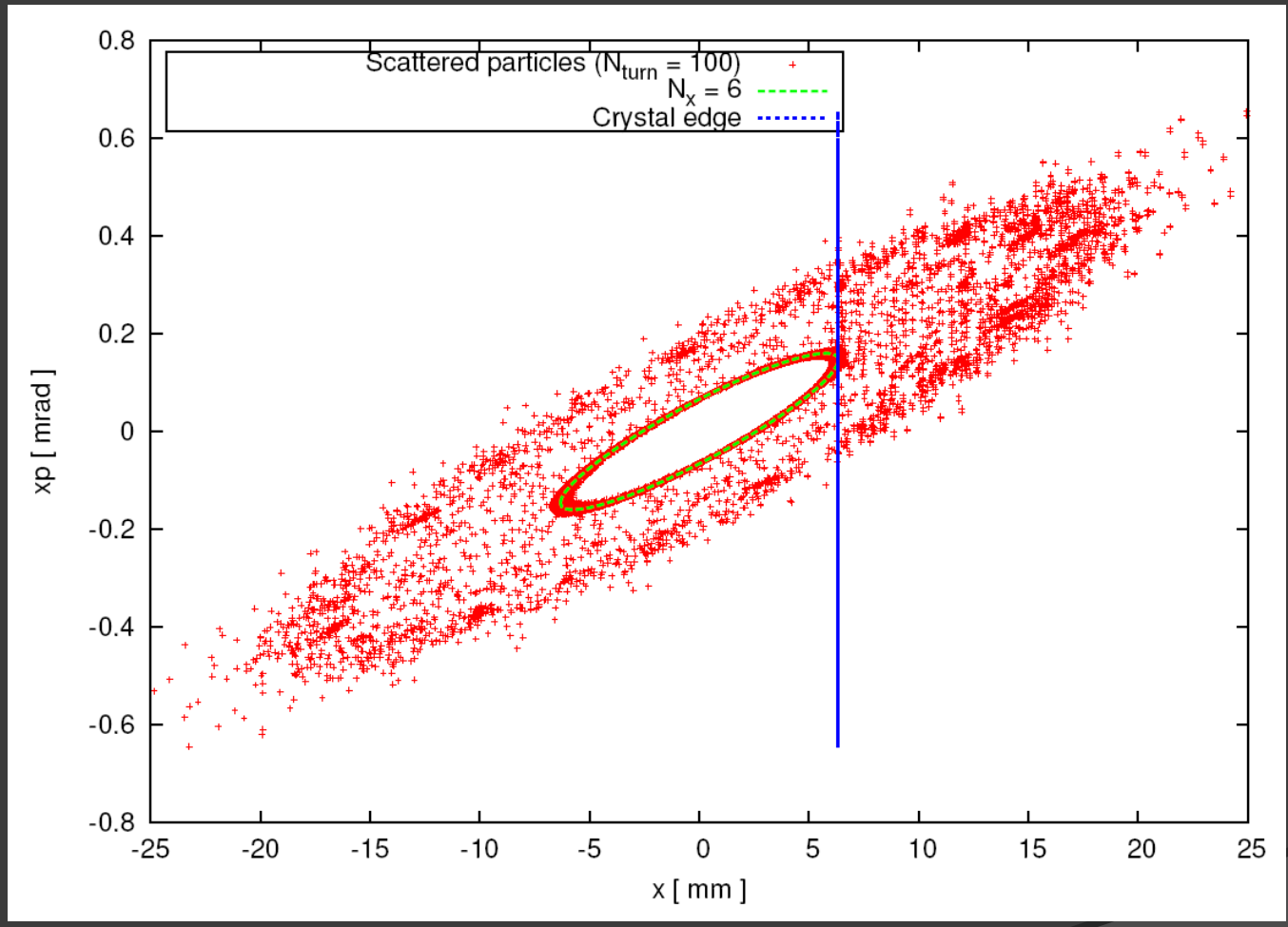
FOOD FOR THOUGHTS…

- The experiment described in CERN/AT 2008-21 is designed to test the efficiency of using a bent crystal to channel particles for collimation purposes; its configuration does not allow single particles, multi-turn data analysis from the Roman Pots !!

- The dead zones would actually force to reduce the opening of RP1 and RP2; in the case of RP1, that would imply sending the front edge of the detector about 1.3 σ_x further in => not in the beam halo anymore !!

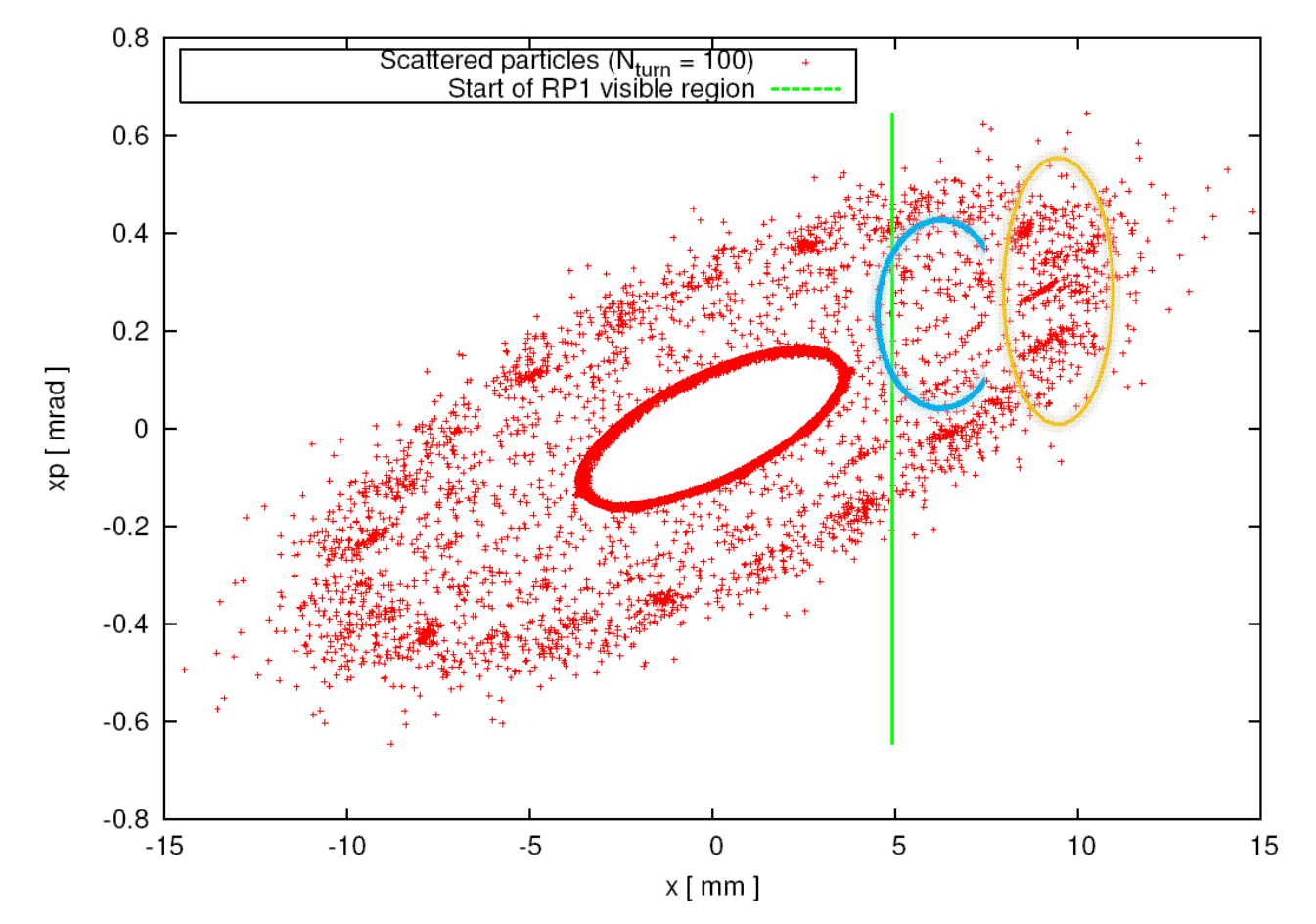
- In the following, the TAL collimator is therefore considered fully retracted, and RP1 and RP2 are left at the openings listed in CERN/AT 2008-21. The initial particle distribution is still generated with $N_x^{init} = 5.95\ \sigma_x$ using the nominal RMS momentum spread $\Delta p/p = 4e\text{-}4$.

RESULTS WITHOUT TAL



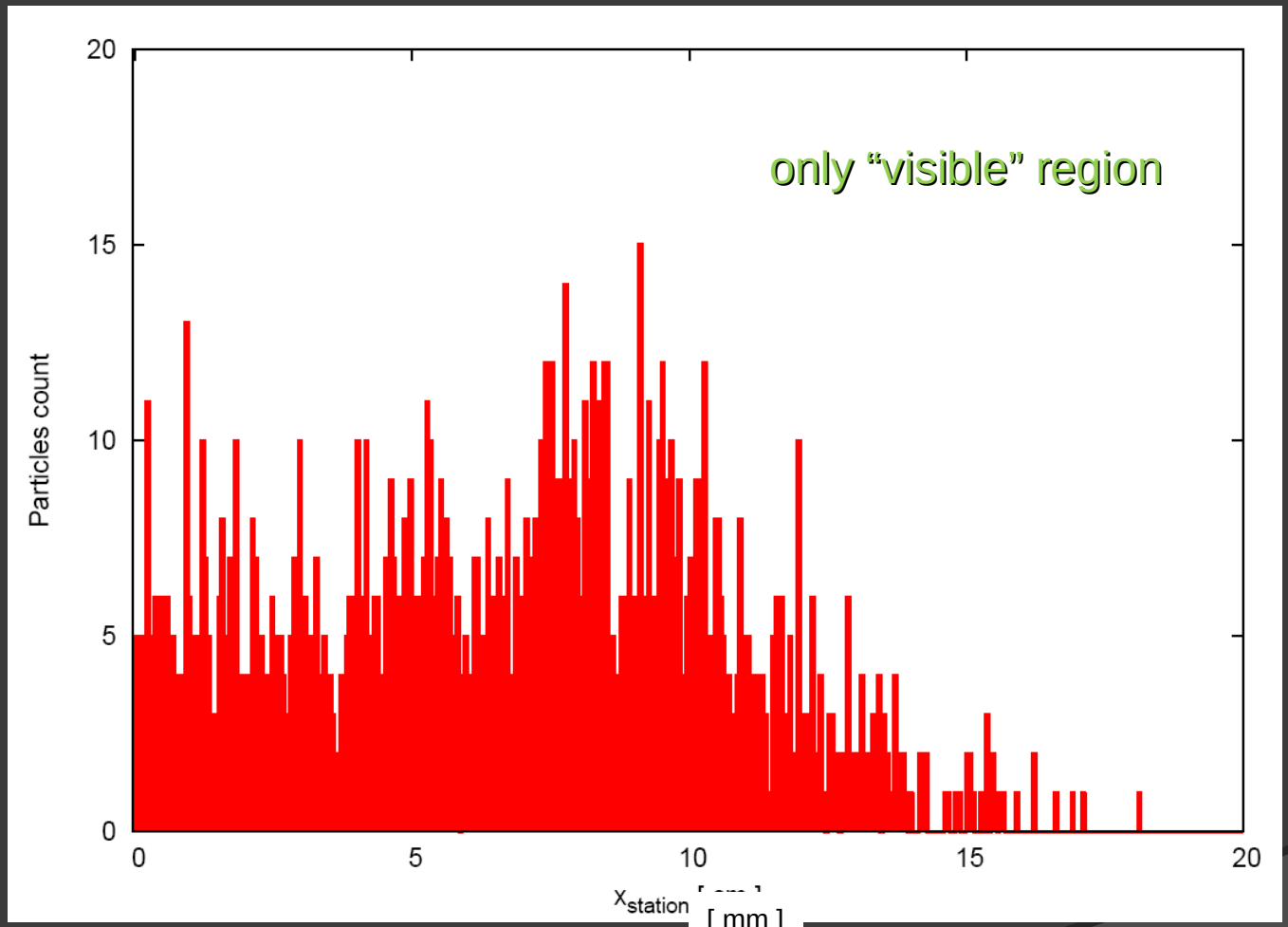
Distribution of particles at the location of the Si crystal; statistics over 100 turns.

ROMAN POTS READINGS WITHOUT TAL

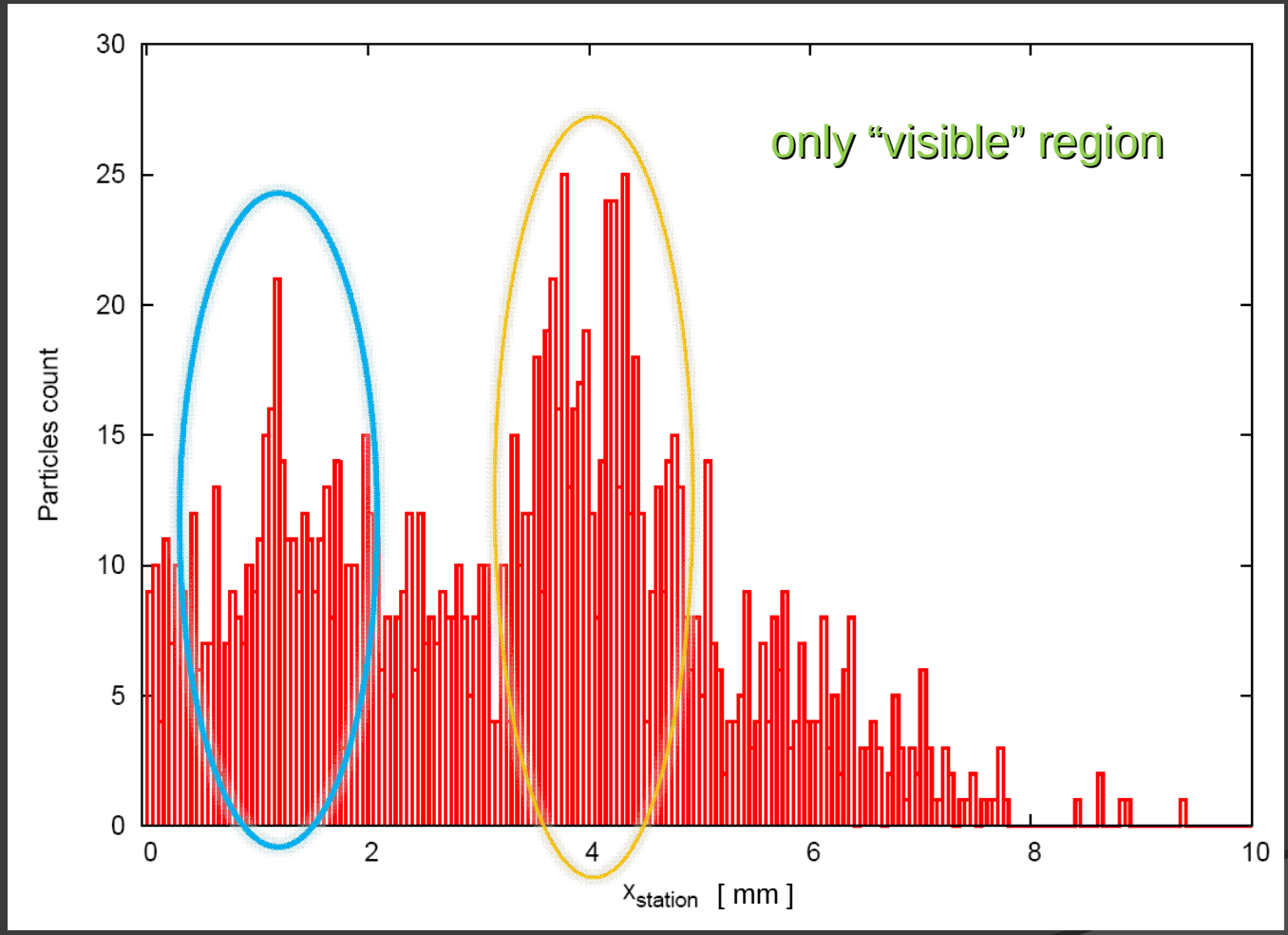


Distribution of particles at the location of Roman Pot 1; statistics over 100 turns.

HITS ON THE NEAR CRYSTAL DETECTOR

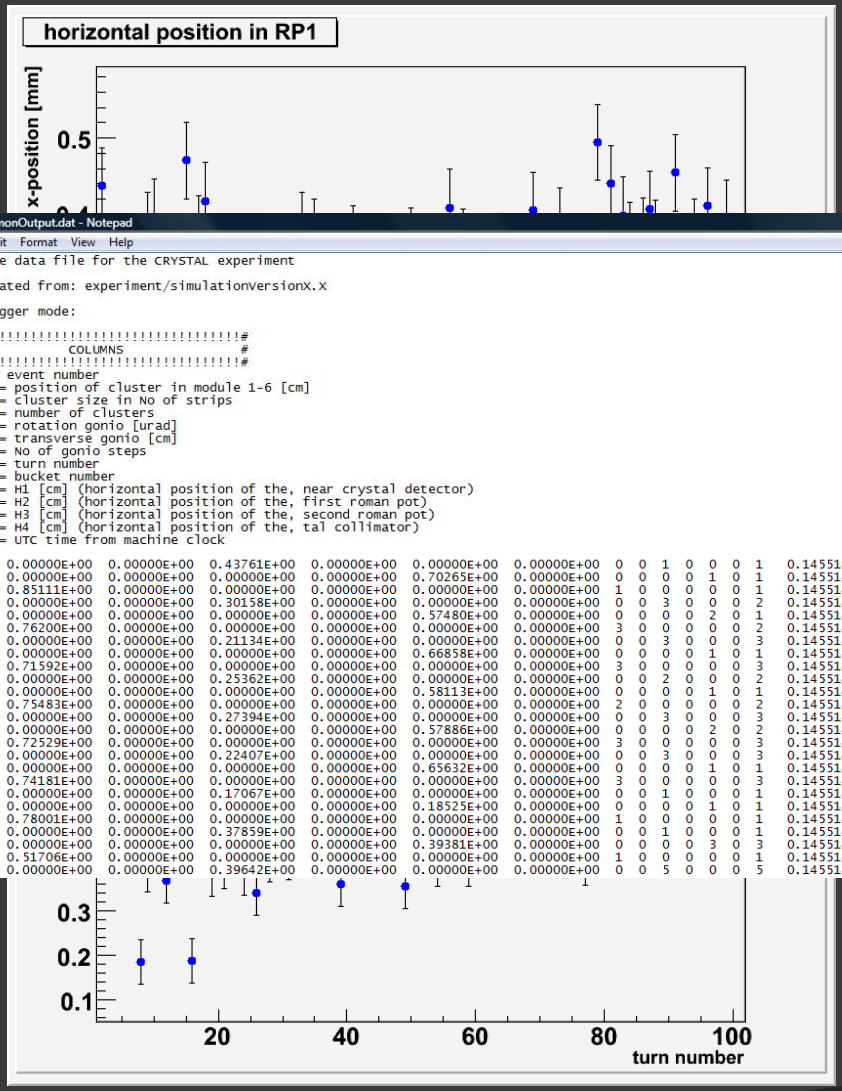


HITS ON RP1



Readout from the detector is one position: which one ??
=> raises the issue of the particle flux !!

FIRST DATA ANALYSIS



CommonOutput.dat - Notepad

File Edit Format View Help

```
#Sample data file for the CRYSTAL experiment
#
#Generated from: experiment/simulationVersionX.X
#
#  trigger mode:
#
#!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!#
#                    COLUMNS                      #
#!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!#
# 1  = event number
#2-7  = position of cluster in module 1-6 [cm]
#8-13 = cluster size in No of strips
# 14  = number of clusters
# 15  = rotation gonio [urad]
# 16  = transverse gonio [cm]
# 17  = No of gonio steps
# 18  = turn number
# 19  = bucket number
# 20  = H1 [cm] (horizontal position of the, near crystal detector)
# 21  = H2 [cm] (horizontal position of the, first roman pot)
# 22  = H3 [cm] (horizontal position of the, second roman pot)
# 23  = H4 [cm] (horizontal position of the, tal collimator)
# 24  = UTC time from machine clock
#
    1  0.00000E+00  0.00000E+00  0.43761E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  1  0  0  0  1   0.14551407E+03   0.63500000E+02    6    2   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    2  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.70265E+00  0.00000E+00  0  0  0  0  1  0  1   0.14551407E+03   0.63500000E+02    6    2   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    3  0.85111E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1  0  0  0  0  0  1   0.14551407E+03   0.63500000E+02    6    3   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    4  0.00000E+00  0.00000E+00  0.30158E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  3  0  0  0  2   0.14551407E+03   0.63500000E+02    6    3   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    5  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.57480E+00  0.00000E+00  0  0  0  0  2  0  1   0.14551407E+03   0.63500000E+02    6    3   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    6  0.76200E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  3  0  0  0  0  0  2   0.14551407E+03   0.63500000E+02    6    4   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    7  0.00000E+00  0.00000E+00  0.21134E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  3  0  0  0  3   0.14551407E+03   0.63500000E+02    6    4   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    8  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.66858E+00  0.00000E+00  0  0  0  0  1  0  1   0.14551407E+03   0.63500000E+02    6    4   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
    9  0.71592E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  3  0  0  0  0  0  3   0.14551407E+03   0.63500000E+02    6    5   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   10  0.00000E+00  0.00000E+00  0.25362E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  2  0  0  0  2   0.14551407E+03   0.63500000E+02    6    5   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   11  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.58113E+00  0.00000E+00  0  0  0  0  1  0  1   0.14551407E+03   0.63500000E+02    6    5   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   12  0.75483E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  2  0  0  0  0  0  2   0.14551407E+03   0.63500000E+02    6    6   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   13  0.00000E+00  0.00000E+00  0.27394E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  3  0  0  0  3   0.14551407E+03   0.63500000E+02    6    6   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   14  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.57886E+00  0.00000E+00  0  0  0  0  2  0  2   0.14551407E+03   0.63500000E+02    6    6   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   15  0.72529E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  3  0  0  0  0  0  3   0.14551407E+03   0.63500000E+02    6    7   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   16  0.00000E+00  0.00000E+00  0.22407E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  3  0  0  0  3   0.14551407E+03   0.63500000E+02    6    7   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   17  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.65632E+00  0.00000E+00  0  0  0  0  1  0  1   0.14551407E+03   0.63500000E+02    6    7   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   18  0.74181E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  3  0  0  0  0  0  3   0.14551407E+03   0.63500000E+02    6    8   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   19  0.00000E+00  0.00000E+00  0.17067E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  1  0  0  0  1   0.14551407E+03   0.63500000E+02    6    8   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   20  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.18525E+00  0.00000E+00  0  0  0  0  1  0  1   0.14551407E+03   0.63500000E+02    6    8   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   21  0.78001E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1  0  0  0  0  0  1   0.14551407E+03   0.63500000E+02    6    9   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   22  0.00000E+00  0.00000E+00  0.37859E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  1  0  0  0  1   0.14551407E+03   0.63500000E+02    6    9   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   23  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.39381E+00  0.00000E+00  0  0  0  0  3  0  3   0.14551407E+03   0.63500000E+02    6    9   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   24  0.51706E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1  0  0  0  0  0  1   0.14551407E+03   0.63500000E+02    6   10   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
   25  0.00000E+00  0.00000E+00  0.39642E+00  0.00000E+00  0.00000E+00  0.00000E+00  0  0  5  0  0  0  5   0.14551407E+03   0.63500000E+02    6   10   7  0.63500E+02  0.41100E+02  0.68100E+02  0.70900E+02      1234567.89
```

- Using the common output format agreed upon with M. Prest et al.,
- Goal of the turn by turn data: recognize hitting patterns of single particles.

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IV – SUMMARY & OUTLOOK

- The successful RD22 experiment opened a gate for more detailed studies of the various physics processes involved in the interaction between a high energy proton beam and a bent crystal.
- UA9 and T980 should allow (in)validating the idea of a collimation system assisted by bent crystal(s); a dedicated detection system must be provided in order to collect all relevant data (impacts, angles, patterns).
- Some beam time must also be dedicated to the understanding of multi-turn single particle physics with a crystal: this is required for the design of future crystal-based collimation systems !
- Both channeling and VR might be of interest for crystal collimation in the LHC; in particular, the energy scaling law of VR has to be tested between UA9 and T980.
- Preliminary results from fast tracking codes should help in deciding the optimal setup for successful UA9 and T980 experiments (RP location + transverse position). ASCII data analysis software is available (root, C++): details should be implemented based on these preliminary results (change of data format required ??).