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TUNING OF BEAM AND CRYSTAL IN H8

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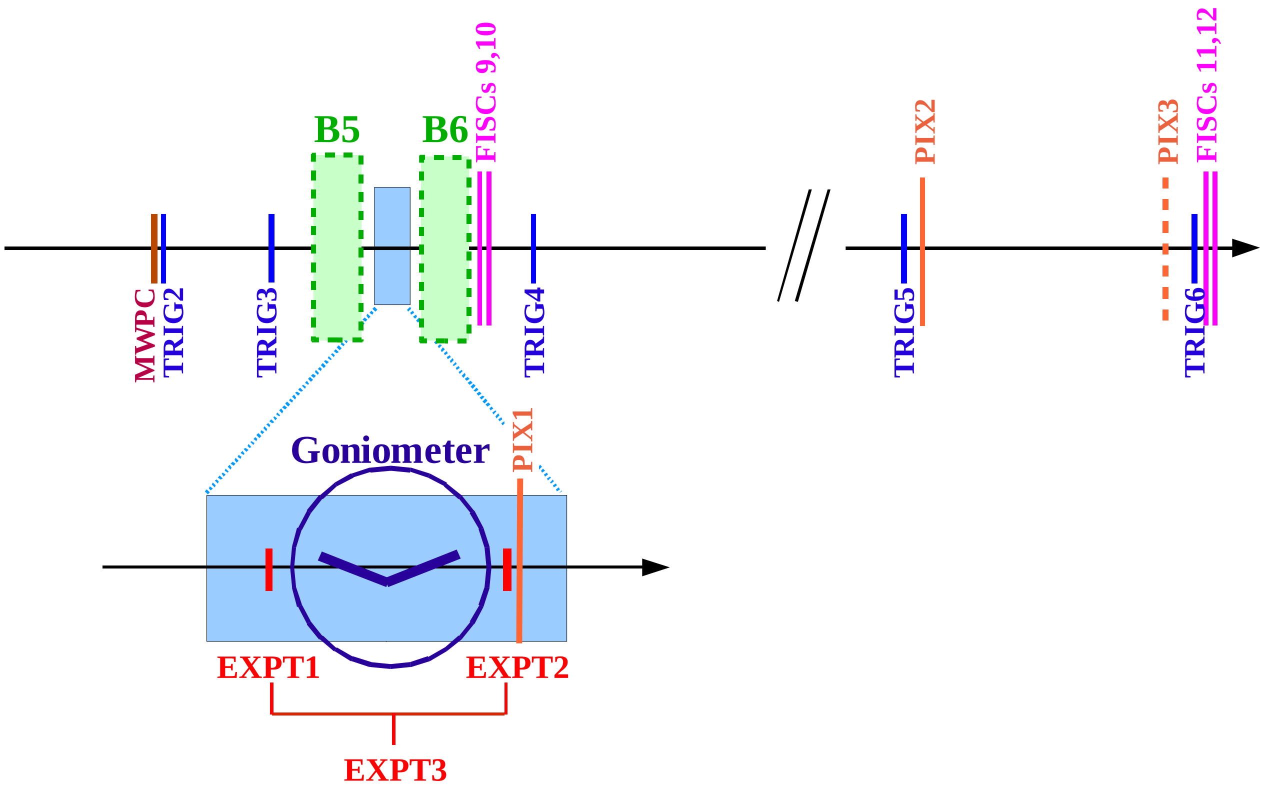
1. The crystal set-up

The crystal is located at postion 414, in between two bending magnets MCAH042412 and 416 (i.e. BEND-5 and BEND-6). Just before BEND-5 there is a 8 cm diameter scintillator (TRIG-3), three collimators ($C7_V$, $C8_H$ and $C9_V$) and a MWPC1,2 + TRIG2 about 10 metres upstream. The downstream magnet is almost immediately followed by a pair of filament scanners, $FISC9_V$ and $FISC10_H$. A second pair of FISCs ($FISC11_V$ and $FISC12_H$) are located at position 476, i.e. about 57 metres downstream. In between there are a number of quadrupoles and correction dipoles (switched off and degaussed during our experiment) and collimators (wide open). An additional scintillator counter, TRIG5, is located at position 463.

The experiment will install the goniometer on the existing table in position 414. On the same table will be mounted two small counters, one just upstream and one just downstream of the crystal. Let us call those EXPT-1 and EXPT2. The size would be typically 1x2 mm. The crystal is aligned precisely and mechanically on the line between these two counters. Their coincidence is available as EXPT3. These EXPT rates can be provided as NIM signals to the beam control system via a patch panel in the control room. In addition to these small counters, there would be Silicon planes just before (or after) the crystal (PIX1), 40 m from the crystal (PIX2) and possibly one at 50 m from the crystal (PIX3). In position 454 (40 m from the crystal) a finely segmented hodoscope would be useful to see easily and separately the unchanneled, channeled and reflected beams and thus allow to trigger on each of them. This layout is shown schematically in the figure below.



2. Beam tuning

The H8 beam will normally run as an attenuated primary proton beam, with intensities as low as reasonably possible, but not exceeding a few 10^6 ppp. In previous crystal tests the beam has been operating at intensities below 2 10^4 ppp (down to 7 10^3). For a flat top of 4.8 seconds this corresponds to an instantaneous rate of the order of 2-5 kHz. This is achieved by:

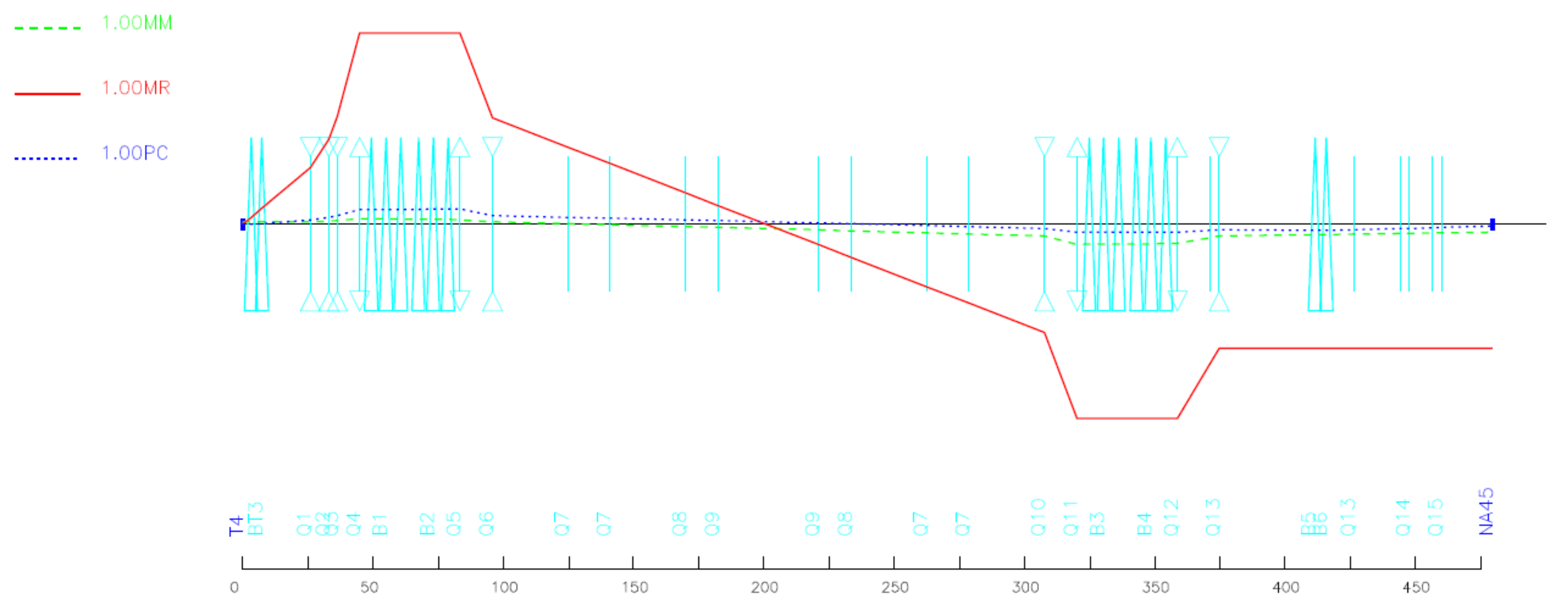
- Selecting a TAX (beam-dump collimator) filled with Beryllium attenuator. The H8 TAXes are equipped with 12 mm diameter rods of 80 cm Beryllium in TAX-1 and 120 cm in TAX-2, thus allowing a total of 2 metres of Beryllium on the beam. This reduces the flux by a factor of e^5=150 due to interactions (interaction length of Bryllium is about 40 cm) and a large additional factor due to multiple Coulomb scattering (> 80 μrad/plane) followed by tight collimation. As the emittance of the beam is redefined in all parameters by collimation, this scattering has no negative impact on the divergence of the beam at the location of the crystal.
- It should be pointed out that an additional attenuation occurs thanks to the presence of the T4 target head in the beam. Ideally a long target is chosen (300 mm Beryllium) for maximum attenuation.
- Installing and closing the H8 micro-collimator, as required for radiation safety anyway. This collimator allows very small apertures, reducing the already attenuated proton rate to fluxes that are hopefully convenient for our tests.

The beam optics has been calculated to provide a parallel beam at the crystal – see the optics diagram below. In the table we list the sensitivities at the crystal position to changes of angle at the various steering elements, assuming a proton beam momentum of 400 GeV/c.

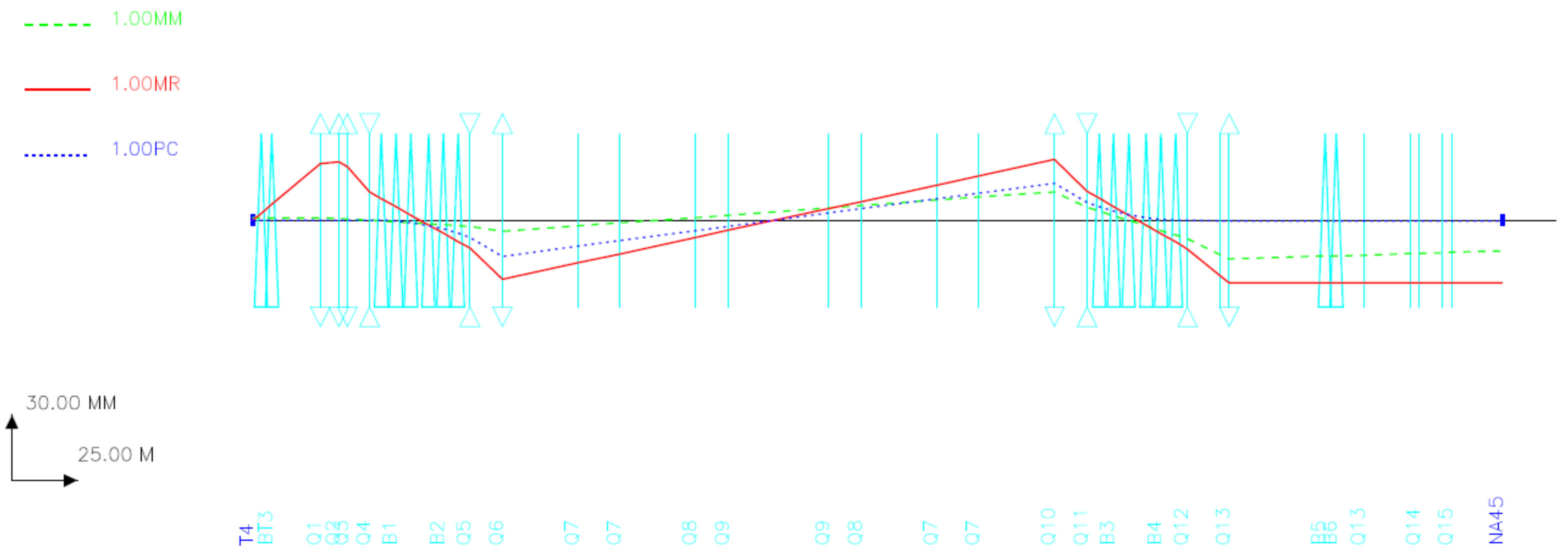
			Effect of 1 mrad kick at crystal location			
Magnet	**Type**	**mrad/Amp**	**ΔX (mm)**	**ΔX' (mr)**	**ΔY (mm)**	**ΔY' (mr)**
TRIM3 - H	MDX 100	0.001687	121.642	0.018		
TRIM5 - H	MDX 100	0.001687	95.119	1.443		
B3+B4 - V	6* MBN	0.023			42.278	0.000
BEND4- V	3* MBN	0.0115			41.386	0.047
TRIM6 - V	MDX 100	0.001687			6.655	1.000
BEND5 - H	MCA	0.00195	2.225	1.000		

For the combination B3-B4, the effect of 1 Amp is an offset in vertical position of 0.01735 mm and 0 mrad change of angle at the center of B3-B4. This leads however to effects at the crystal location that are too small to be useful. Knowing the characteristics and polarities of each magnet, this can be translated in effects per Amp, as shown in the table below:

Magnet	**Pol.**	**ΔX/Amp (mm)**	**ΔX'/Amp (μr)**	**ΔY/Amp (mm)**	**ΔY'/Amp (μr)**
TRIM3-H	N	0.205	0.0303		
TRIM5-H	N	0.160	2.434		
B3+B4 - V	S			-0.972	0
BEND4-V	S			-0.476	-0.54
TRIM6-V	N			0.0112	1.687
BEND5-H	S	-0.00434	-1.95		



H8 microbeam for Crystal experiment



The beam will first be centered on the crystal by maximising the EXPT1 rate as a function of the currents in $TRIM3_H$ (range ±35 mm) or $TRIM5_H$ (range ±15 mm, limited by passage through the big vertical bends) and B3+B4, respectively TRIM6 in the vertical plane. Once the beam is centered in EXPT1, one tries to center the beam in EXPT2 without upsetting the steering at EXPT1. For this a so-called double scan procedure can be used ('orthogonal steering'). The following combinations can be useful:

Plane	Comb. In BL	Comb. In I	ΔX or ΔY (μm/ A)	ΔX' or ΔY' (μr/A)
H	B5 – 0.0234 TR5	B5 + 0.027 TR5	0	1.884
H	TR3 – 0.012 TR5	TR3 – 0.012 TR5	200	0
V	TR6 – 0.161 B4	TR6 + 0.0235 B4	0	1.67
V	B3 + 1.0 B4	B3 + 1.0 B4	1000	0

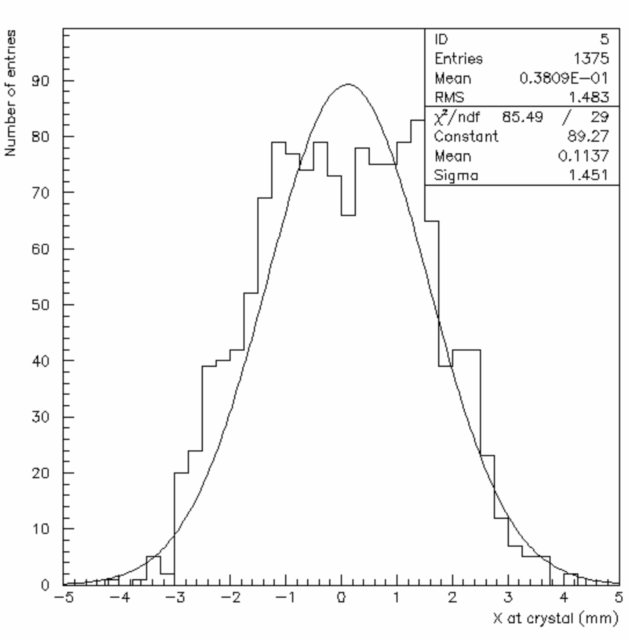
One can see that steps in the 2 microradian range can be achieved. Single scans with $BEND5_H$ and $TRIM6_V$ may be sufficient for small angular variations. A total angular range of ±100 μrad can easily be covered in both planes.
These same scans, respectively double scans can of course also be used to optimise the angle of the beam through the crystal. For this it is useful to get a scaler rate from the channeled or reflected beam in PIX2 and/or PIX3 (or in the hodoscope).

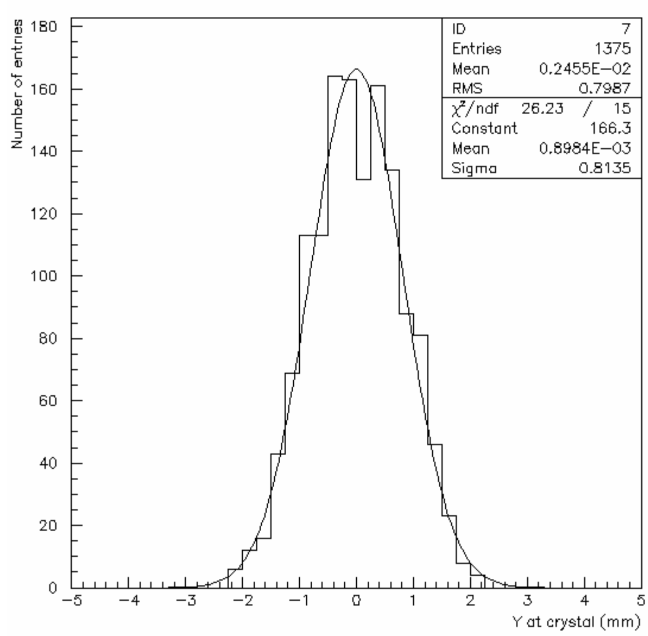
Apart from steering, we must ensure that the beam is sufficiently parallel. The parallellism can be adjusted by varying (linear combinations of) quadrupole currents in e.g. Q12 and Q13. The observation can be made with the FISCs that are permanently installed in the beam line. Fiscs 9 and 10 allow to make vertical, resp horizontal profiles of the beam just downstream of the crystal (that should be moved out the beam during this exercise). Fiscs 11 and 12 can make profiles 56 metres further downstream. The Fiscs are 200 μm wide scimtillators (4 mm thick along the beam), from which the proton induced scimtillation light is collected by the coincidence of two photomultiplier tubes. It is possible to make a profile of FISC11 (resp FISC12) for those particles that have produced a signal in FISC9 (resp FISC 10). For two different positions of the filament in e.g. FISC9 one can compare the distance between the peaks in FISC11. If that distance is not equal to the one in FISC9, tuning of the parallellism is required. The horizontal divergence can be changed by varying Q12-0.219 Q13 (no effect on vertical plane), the vertical divergence with Q12-2.355 Q13. The resolution in angle is of the order of 4 microradians for each quadrupole setting, and by interpolation the optimum can be measured significantly better!

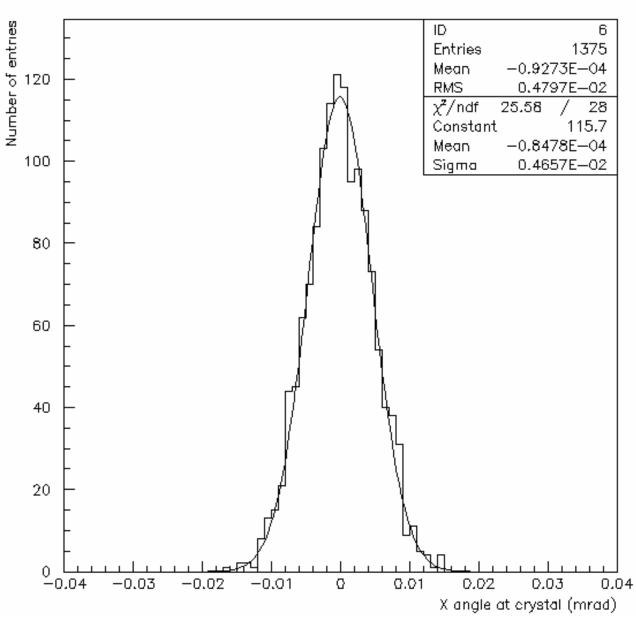
Once the beam is steered and sufficiently parallel, the channeling condition can be found by euther scanning the crystal angle against counting rates in the detectors sensive to channeling or reflection, or by scanning suitable magnets or magnet combinations (see above).

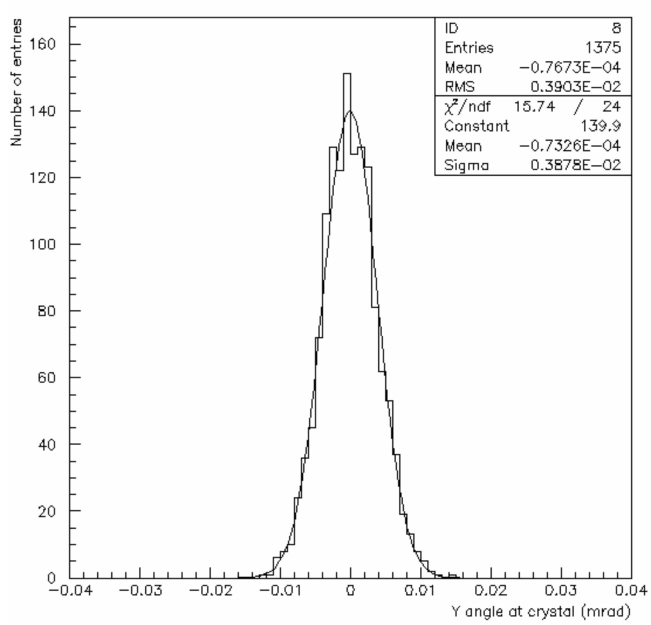
This note is based on the optics used in earlier crystal scans (file **h8microv**). Please note that for this optics to work, quadrupole QNL042371 (Q10B) must be short-circuited!

Please find below typical examples of beam profiles and divergences that could be expected at H8. From this I would conclude that it is better to bend/reflect the beam in the vertical plane, as the vertical spot is smaller and the divergence possibly slightly smaller as well. However, this may depend on collimator settings.

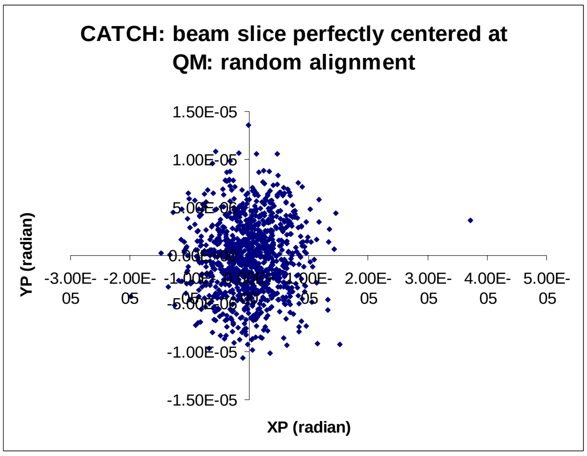






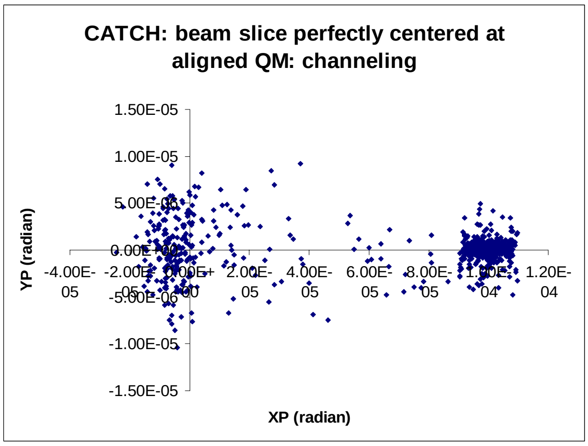


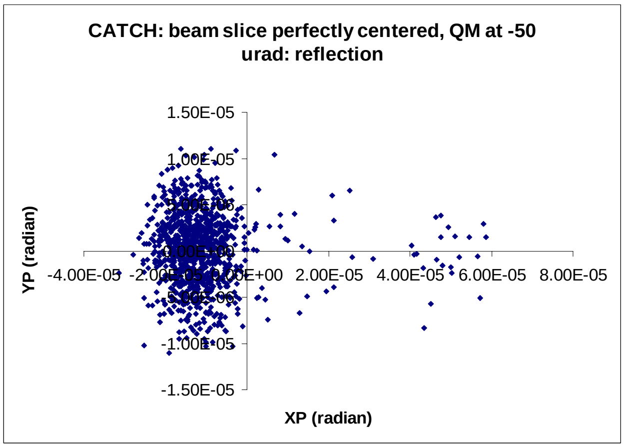
3. The experiment



Biryukov et al have made predictions for the signals to be expected from channeling and reflection in QM crystals. For reference we show at the left hand side the angle of the protons that leave the crystal, if aligned randomly. All incident coordinates are X=Y= 0 mm. If no slicing is made, the effects are not at all visble. The channeling angle is supposed to be 100 µrad. Reflection is therefore expected to happen in the center of the crystal if it is misaligned by exactly 50 µrad.

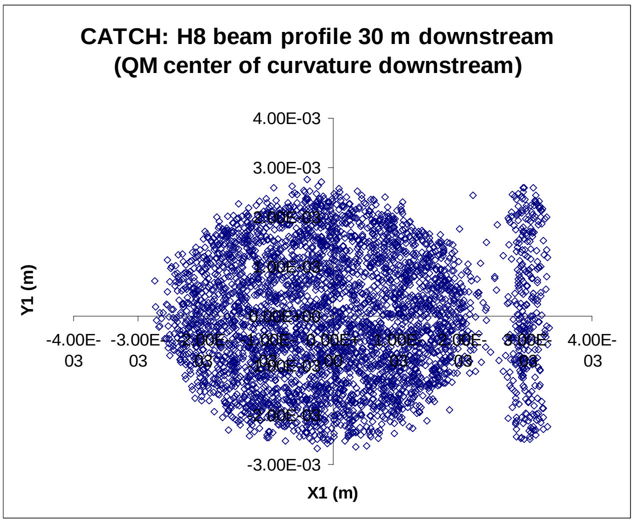
Below we show his results for the protons that hit the central slice of the crystal, in case of an aligned crystal (left hand side) and a crystal misaligned by 50 microradians (right hand side plot).





Both channeled and reflected protons can be seen quite distinctly. In this case, the average exit angle of reflected protons is -10.9 µrad +-0.2 µrad (i.e. reflection by 11 µrad). This is to be compared with the assumed beam divergence of 3 µrad. The center of curvature in this simulation was located upstream of the crystal.

One may also orient the crystal such that the center of curvature is downstream of the crystal. In that case the resulting profiles of the beam 39 m downstream of the crystal are shown on the right hand side. Channeled protons appear at X=+3 mm. In this configuration there is no obvious and easy signal for reflection. However, it has been claimed by Ivanov that a visible signal of reflected protons would exist in case of a misalignment of the crystal by as much as 150 microradians.



Based on these informations I could suggest an approach as described below.

Let us assume a beam spot of 1.5 mm RMS in both planes and 3-4 μrad divergence. We also assume that the beam is parallel to the axis of the goniometer support (defined by EXPT1 and EXPT2 and their coincidence). At the level of PIX2, 40 m downstream of the crystal, the beam spot would extend to ±4 mm, overlapping into the channeled beam. First of all it is therefore important that we can make slices in the incident beam. This can be achieved offline with great precision using PIX1. Much more convenient, particularly for online decisions in the control roomor scanning/triggering is the presence of a small scintillator EXPT1 that covers the central part of the crystal.

Once the beam is steered properly onto EXPT1,2,3 and sufficiently parallel, one would look for a channeling signal as a function of goniometer angle. We know from previous experiments that the width of the channeled beam is of the order of $\pm\Psi_p$, i.e. ±7 μrad. The average deflection is nominally 100 μrad. This means that 40 m after the crystal the channeled beam has a width of 15*40=600 microns and it is displaced from the main beam by about 4 mm. One should therefore scan the goniometer angle against the counting rate in the corresponding part of PIX2. Alternatively one installs a 1-2 mm wide scintillator 4 mm from the axis of the unbent beam and reads it out via a scaler. I think this is extremely convenient. A small scintilator ladder is even better! The relevant counter should of course be put in coincidence with EXPT1.
For this procedure to work it is important that the goniometer step is small enough to hit the channeling condition, i.e. less than $2\Psi_p$= 15 μrad. Once the channeling condition has been found, the resolution can be improved substantially by using magnet scans[1]. Once aligned, the condition for reflection should be easily established by misaligning the goniometer by the known required amount, i.e. ≈50 microradians. Here again it is obviously useful to have goniometer steps that are small compared to those 50 microradians, i.e. of order 10 μrad or better.
Once the conditions for channeling, reflection and random incidence have been established, the information from the pixel planes (and EXPT counters) should be sufficient for offline analysis.

Please note that the total rate of the beam can be well below $2\ 10^4$ particles per spill, assuming the rate incident on the T4 target is below $3\ 10^{12}$ ppp.

For the reding of NIM signals for the detectors, 4 EXPT scalers are available in the control room. Three timing signals are provided as well:

WWE	1 sec before the start of flat top
WE	1 msec before the start of flat top
EE	end of flat top

[1] One may argue that it is sufficient to have a goniometer with a step size that is smaller than the range of the magnet scans. However, this would mean that one has to be very confident that all the geometry is perfect to a few 100 microradians, One would than repeat magnet scans for nominal goniometer settings and for settings ±1, ±2, ±3 steps and so forth. This means many scans and lots of time 'lost'. Previous experience has shown that it is extremely useful to be able to find a channeling peak with the goniometer alone, even if the resoluion is not the final one.