Analysis of long crystal channelling efficiency from hadron beam test data

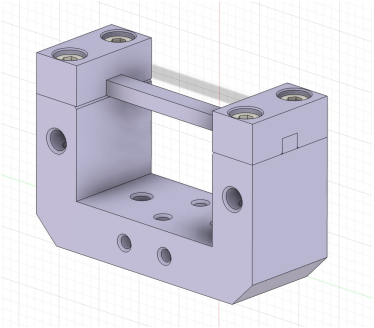
SARA CESARE

3° WORKSHOP ON ELECTROMAGNETIC DIPOLE MOMENTS OF UNSTABLE PARTICLES – 11/12/2023

1. SHORT CRYSTAL

Crystal properties:

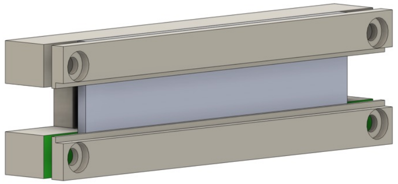
Length	4 mm
Material	Silicon
Bend radius	80.0 m
X dimension	2 mm
Y dimension	35 mm



2. LONG CRYSTAL

Crystal properties:

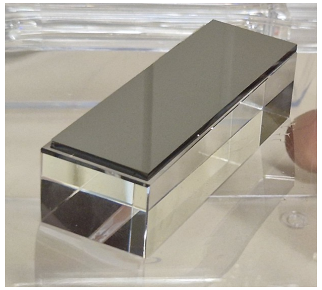
Length	70 mm
Material	Silicon
Bend radius	10.0 m
X dimension	2 mm
Y dimension	8 mm



3. ANODIC-BONDED

Crystal properties:

Length	70.5 mm
Material	Silicon
Bend radius	5.3 m
X dimension	2 mm
Y dimension	22.5 mm



ANALISYIS PROCEDURE SHORT CRYSTAL

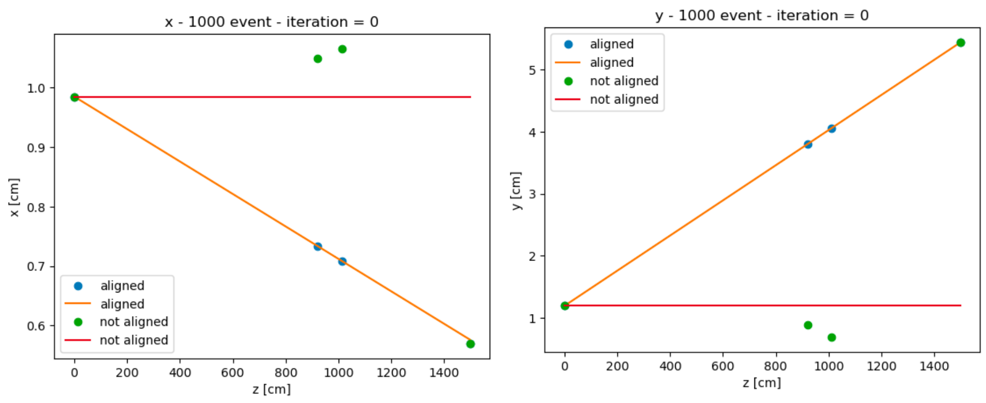
1. Alignment
2. Crystal position estimation
3. Channelling window estimation
4. Channelling efficiency estimation:
    a. Double gaussian estimation
    b. Right-sided single gaussian estimation

ANALISYIS PROCEDURE LONG +ANODIC CRYSTAL

1. Alignment
2. Crystal position estimation
3. Channelling window estimation
4. Channelling efficiency estimation:
    a. Wide crystal face
    b. Wide crystal face + angular scan
    c. Small (x,y) bins +angular scan
    d. Wide crystal face after correction map

ALIGNMENT

Alignment algorithm developed by A. Merli



First station is fixed and z coordinate is fixed for all the planes

Alignment performed for all the crystals since the apparatus changed in between the data taking.

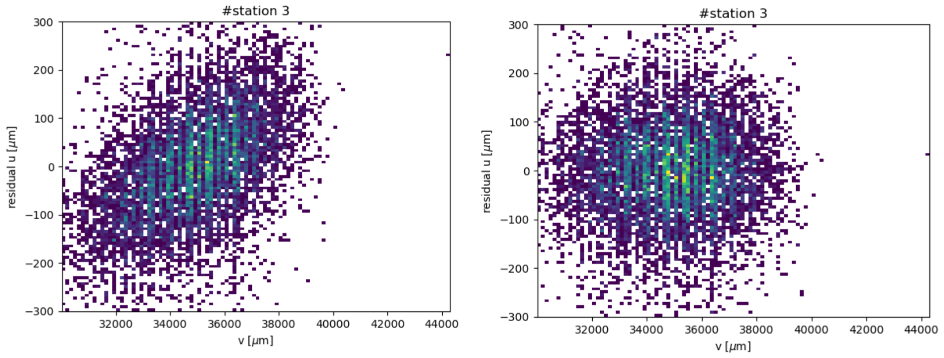
Rotations must be taken into account especially for the short crystal.

ALIGNMENT ALGORITHM

Unbiased fit of the alignment parameters

(2 translation + 1 rotation) x 3 planes — **GLOBAL PARAMETER**

event track parameters (intercept + slope) — **LOCAL PARAMETER**



Residual of the last station before and after including the rotation around z

CRYSTAL POSITION ESTIMATION

1. SHORT CRYSTAL

Selected window

x [1, 1.2] cm

y [1.25 , 1.75] cm

$\theta_L = 13.3$ µrad

2. LONG CRYSTAL

Selected window

x [0.88, 1.4] cm

y [1.9 , 2.19] cm

$\theta_L = 12.9$ µrad

3. ANODIC-BONDED

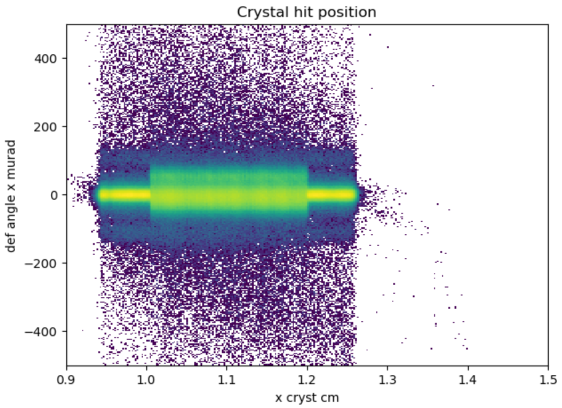
Selected window

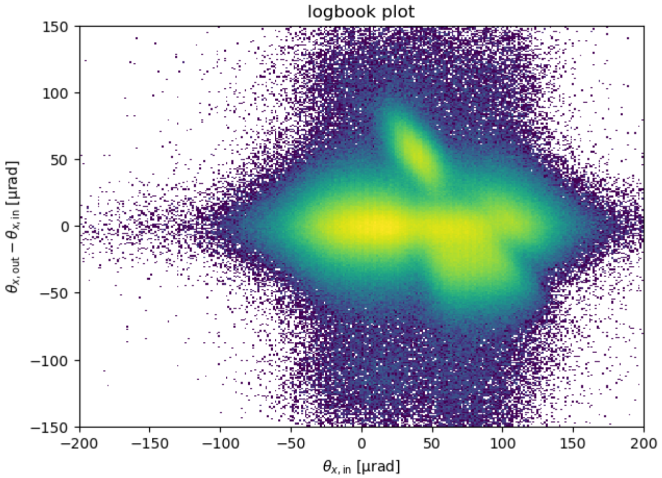
x [0.86 , 0.95] cm

y [1.8 , 2.3] cm

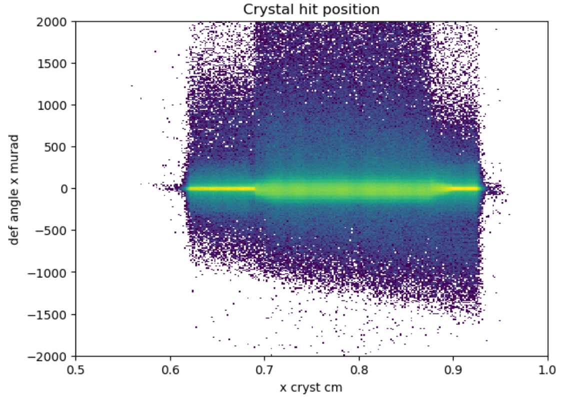
$\theta_L = 12.5$ µrad

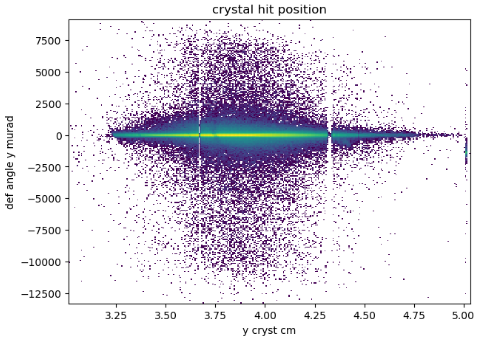
SHORT CRYSTAL

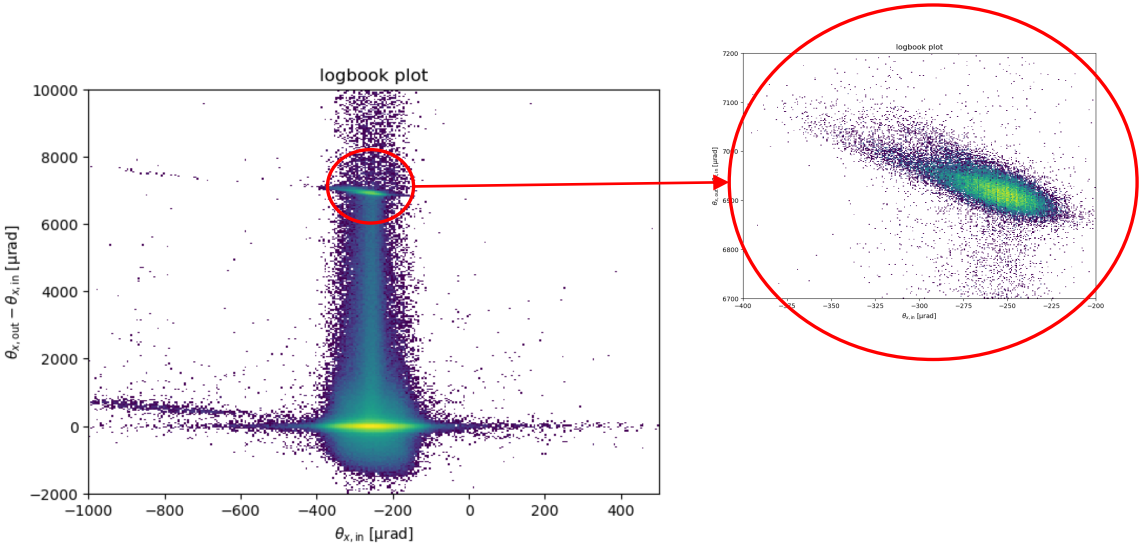




LONG CRYSTAL







CHANNELING EFFICIENCY: first estimate

1. SHORT CRYSTAL

Selected window

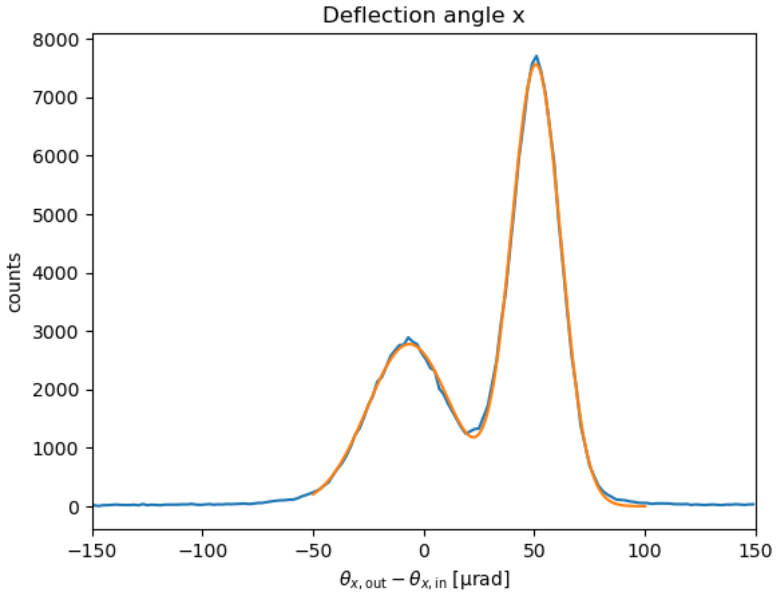
x [1, 1.2] cm

y [1.25 , 1.75] cm

$\theta_L = 13.3$ µrad

θ_{in} angular cut $42 \pm 0.5 * \theta_L$ µrad

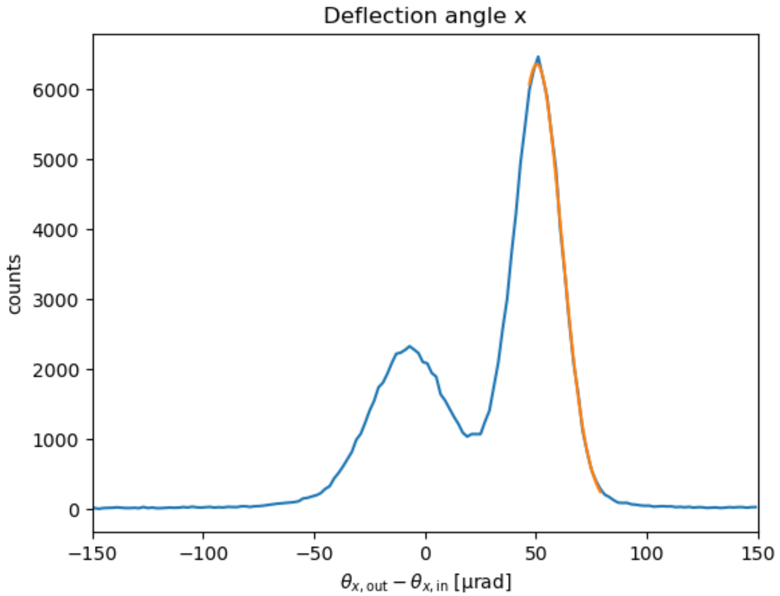
$$\varepsilon_{ch} = \frac{\text{number of channeled particles from gaussian fit}}{\text{n. particles with } \theta_{In} < 0.5 * \theta_L}$$



METHOD 1

Double gaussian fit

$\varepsilon_{ch} = 61.7 \pm 0.3$ %



METHOD 2

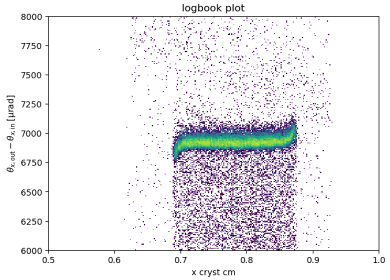
FIT RANGE: $\theta_{out} - \theta_{in} \in [45, 80]$ µrad

$\varepsilon_{ch} = 61.0 \pm 0.2$ %

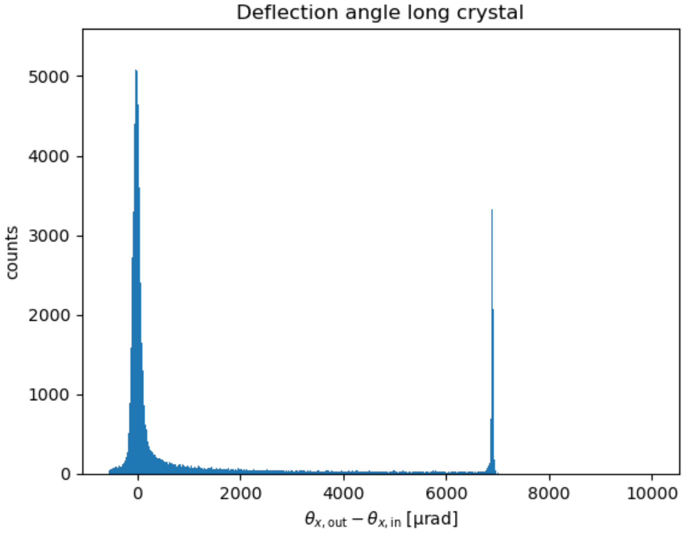
2. LONG CRYSTAL

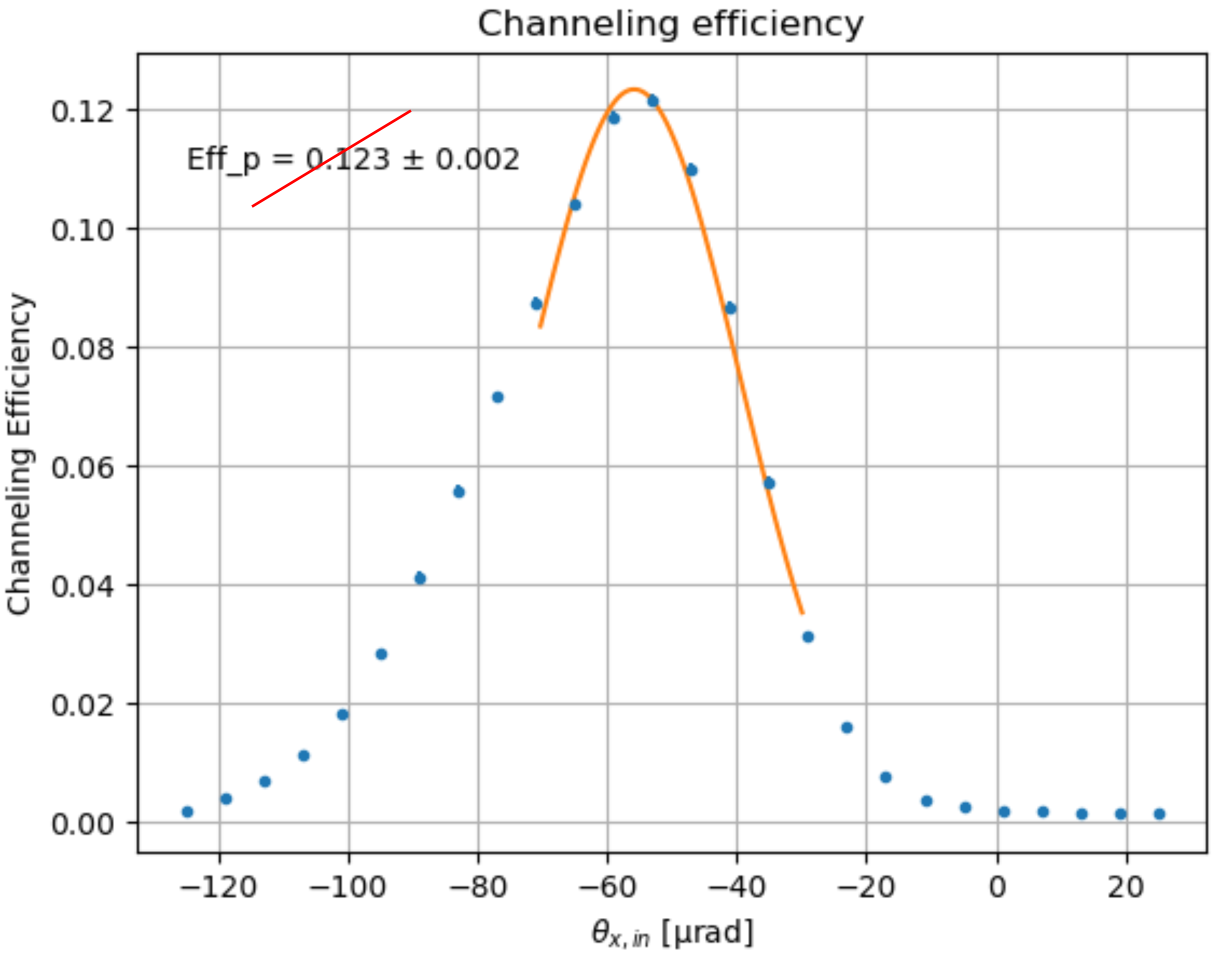
Selected window
x [0.88, 1.4] cm
y [1.9 , 2.19] cm

$\theta_L = 12.9$ µrad



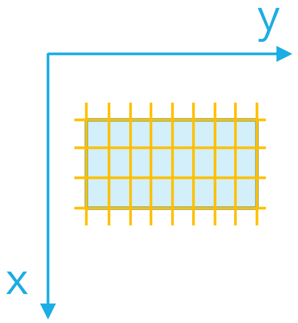
ANGULAR SCAN: 5.9 µrad step $\pm 0.5 * \theta_L$

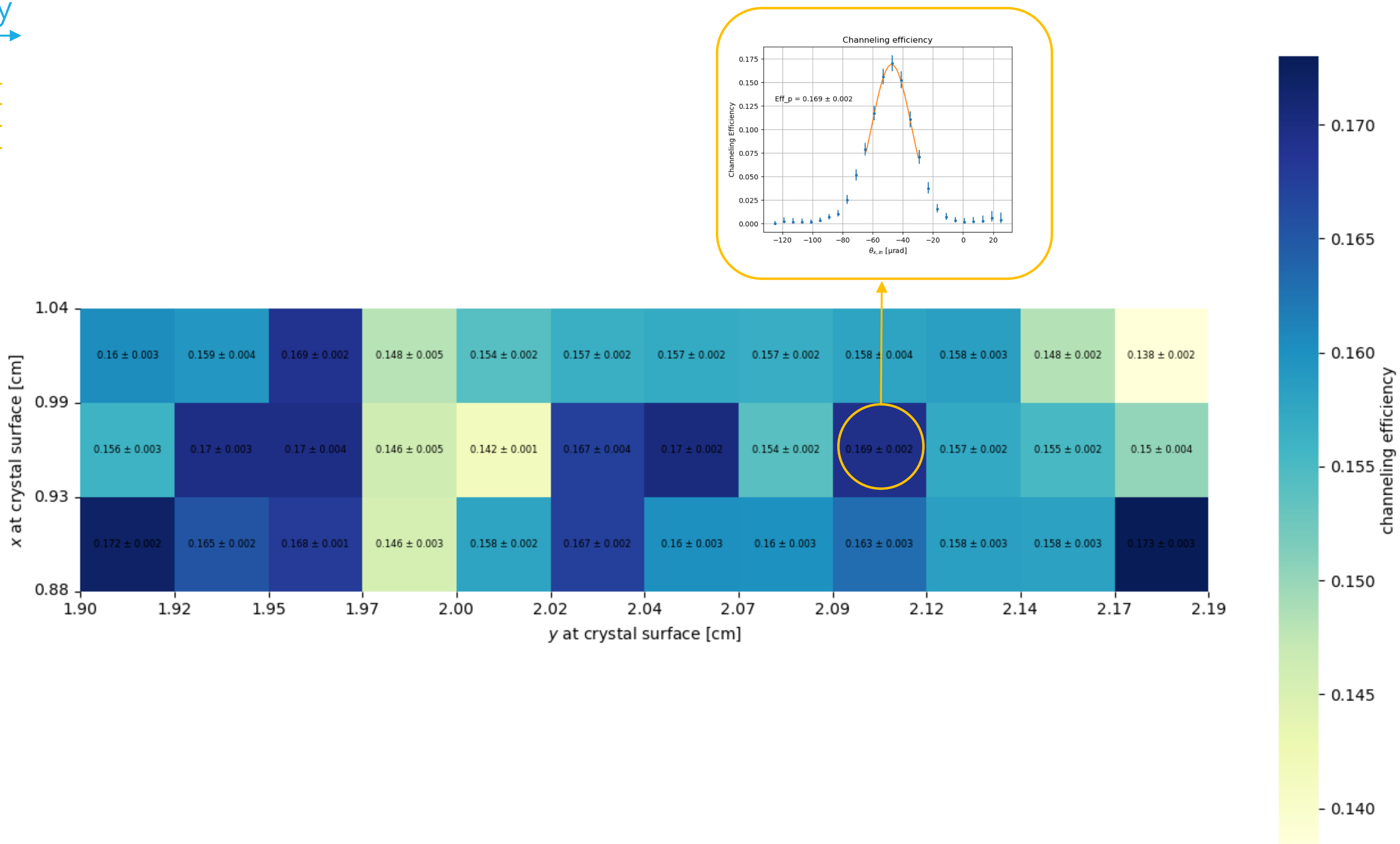




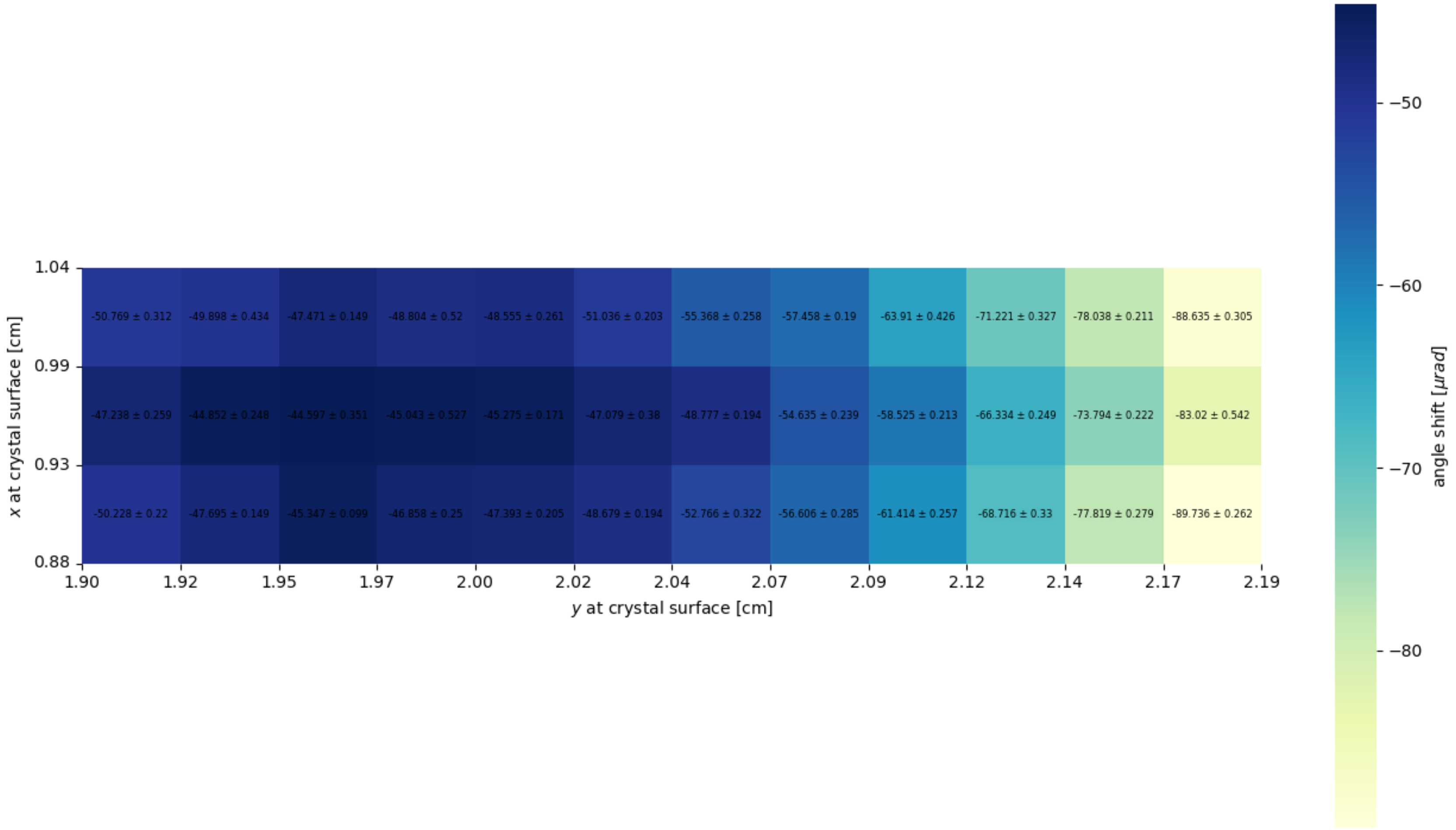
Asymmetry due to torsion effect

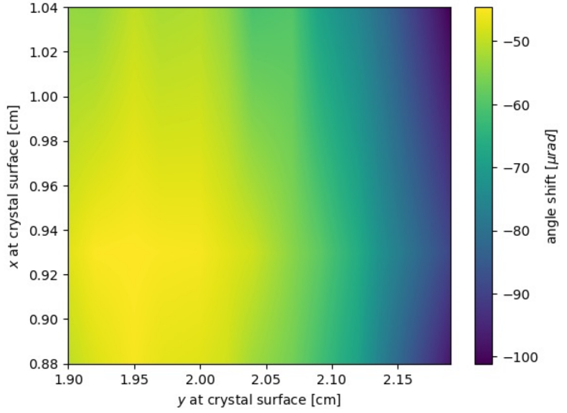
LONG CRYSTAL : efficiency map



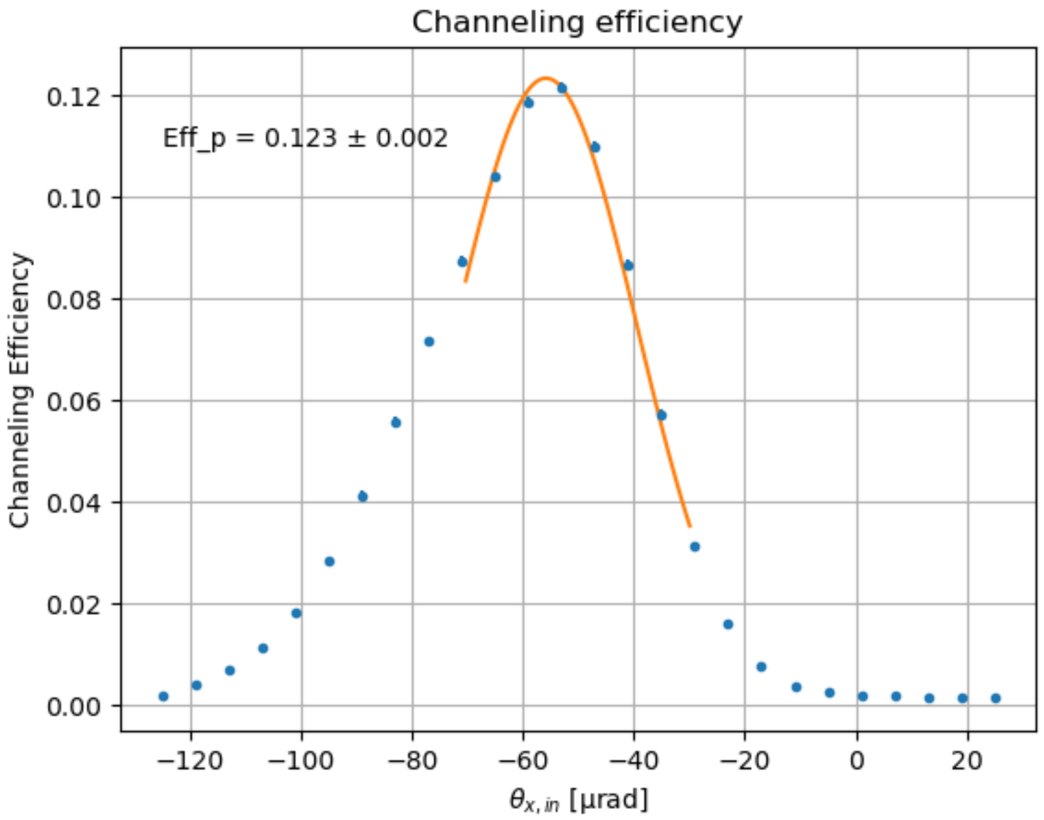


LONG CRYSTAL : torsion map

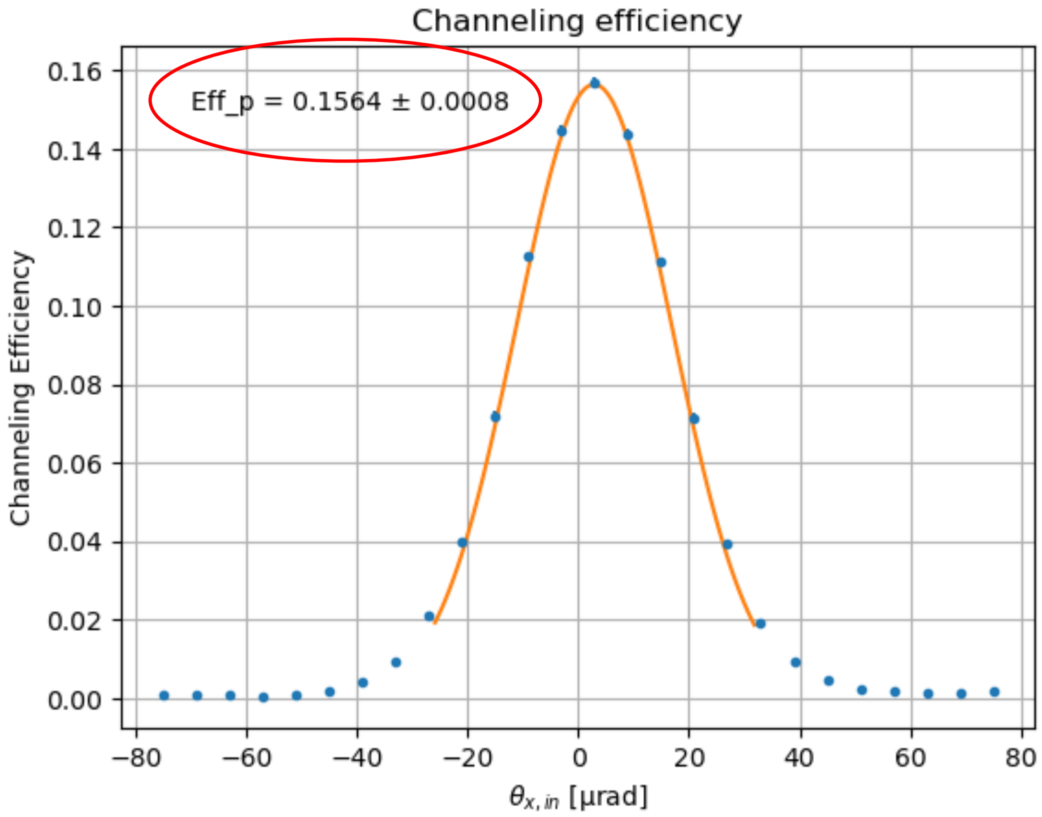




CHANNELLING EFFICIENCY



BEFORE TORSION CORRECTION



AFTER TORSION CORRECTION

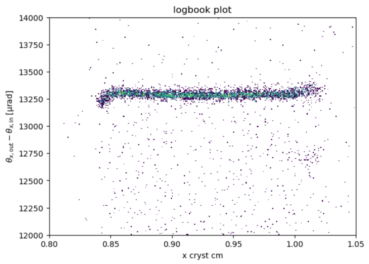
3. ANODIC BONDING

Selected window

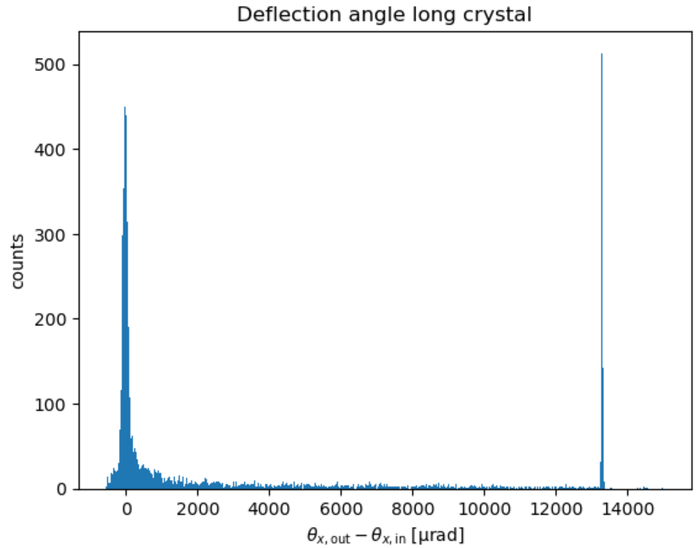
x [0.86 , 0.95] cm

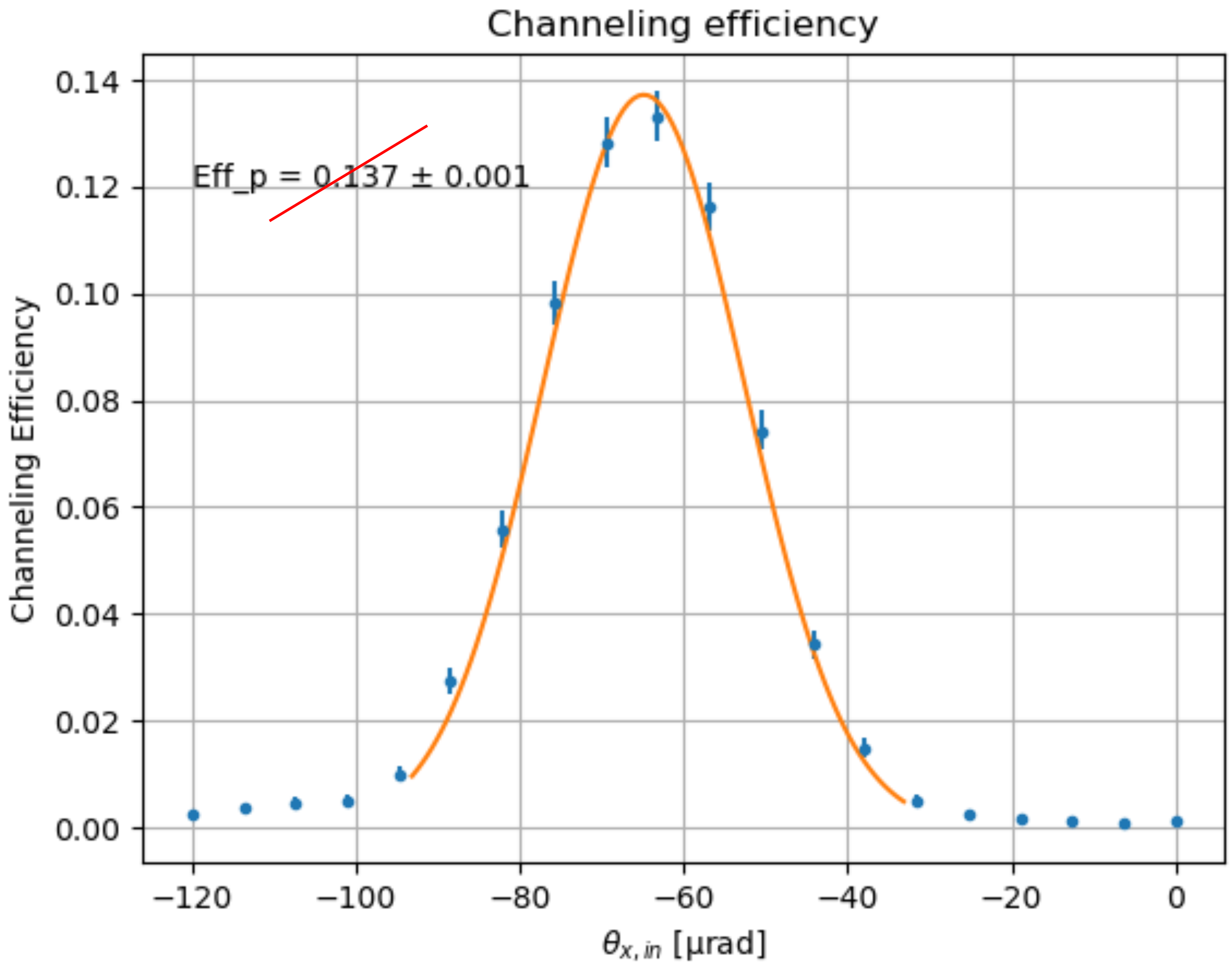
y [1.8 , 2.3] cm

$\theta_L = 12.5$ µrad



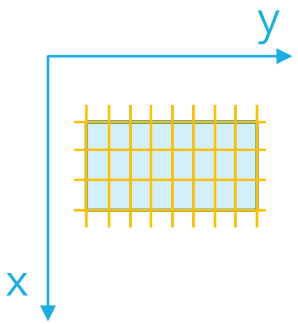
ANGULAR SCAN: 6 µrad step $\pm 0.5 * \theta_L$

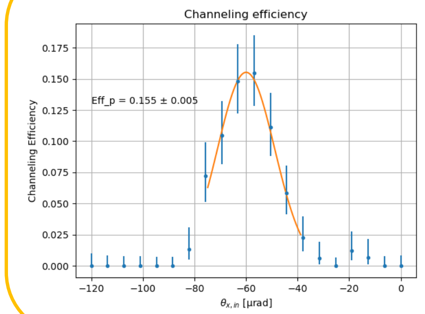


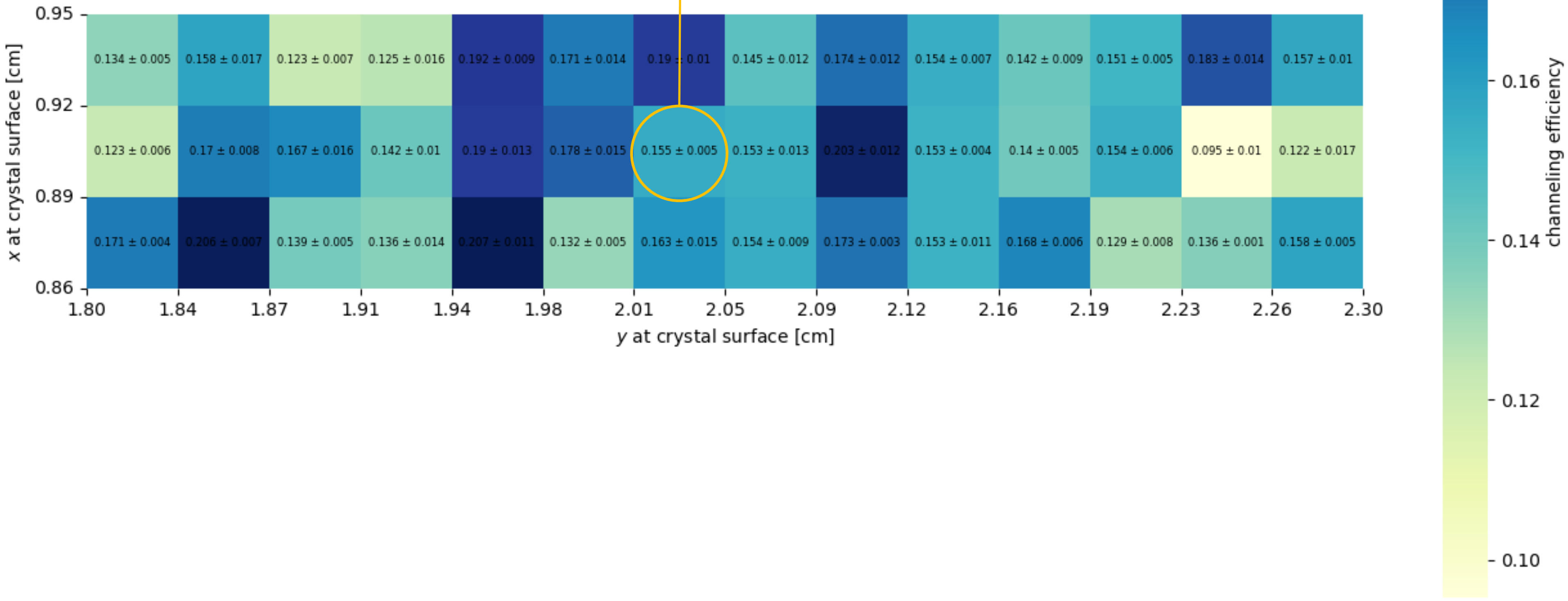


Symmetric already before torsion correction

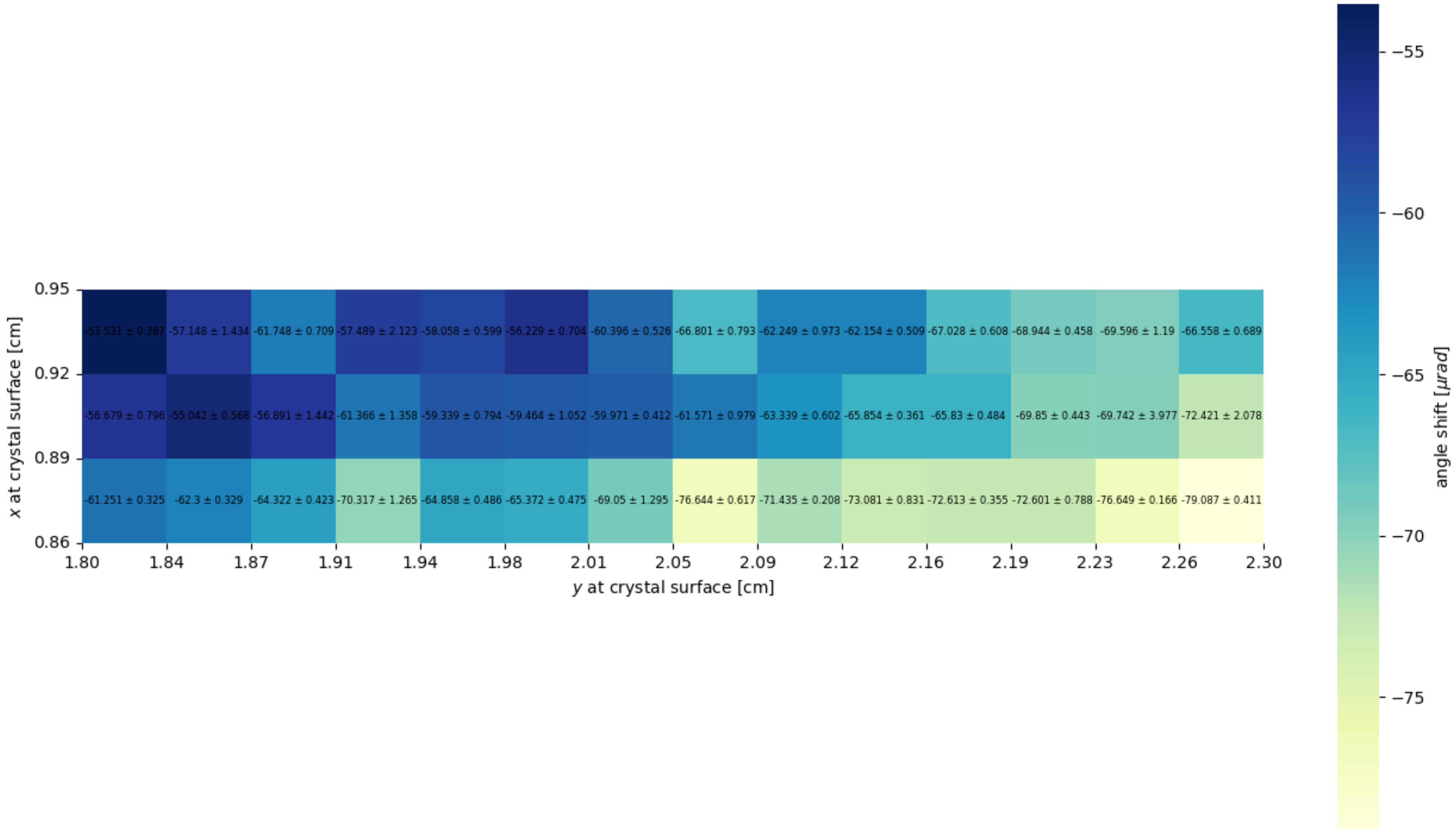
ANODIC BONDING: efficciency map

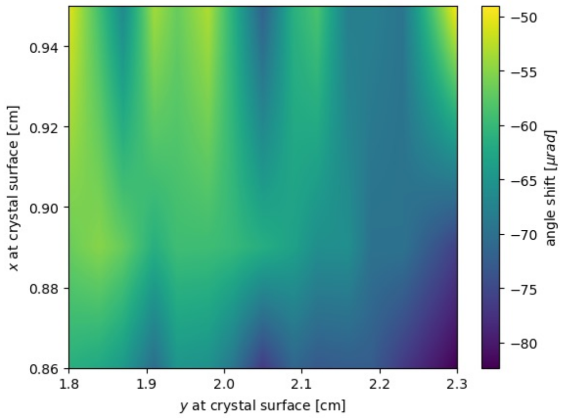






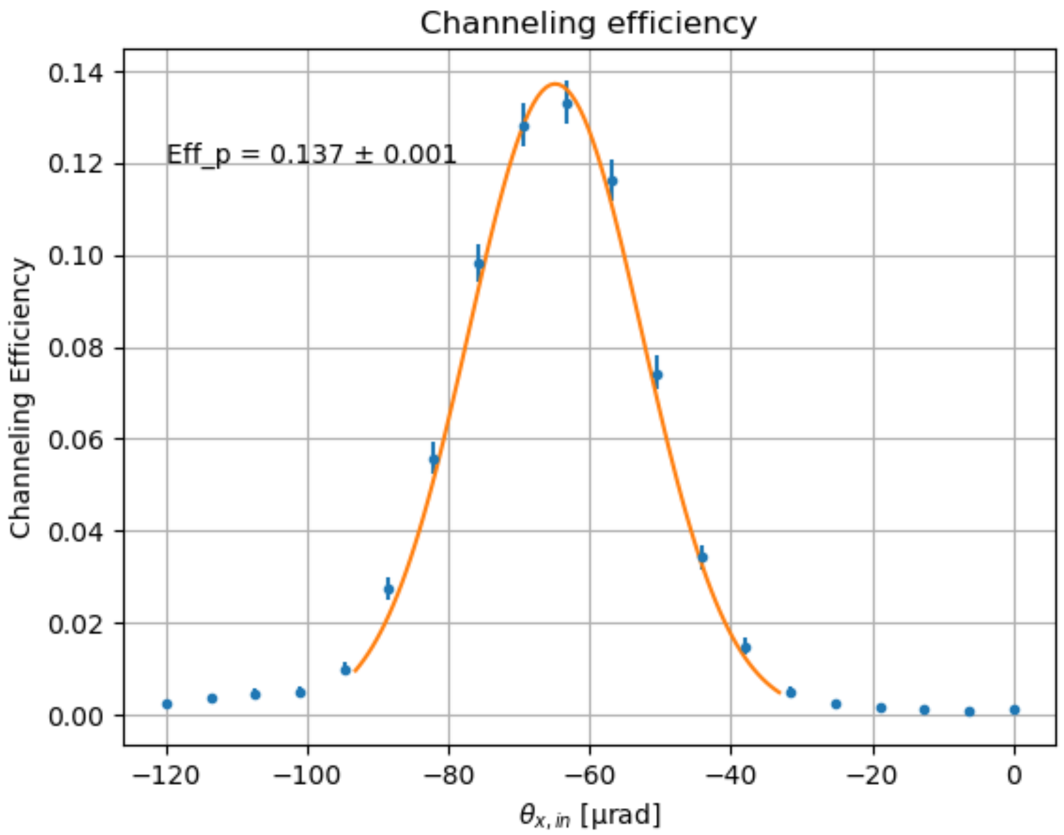
ANODIC BONDING: torsion map

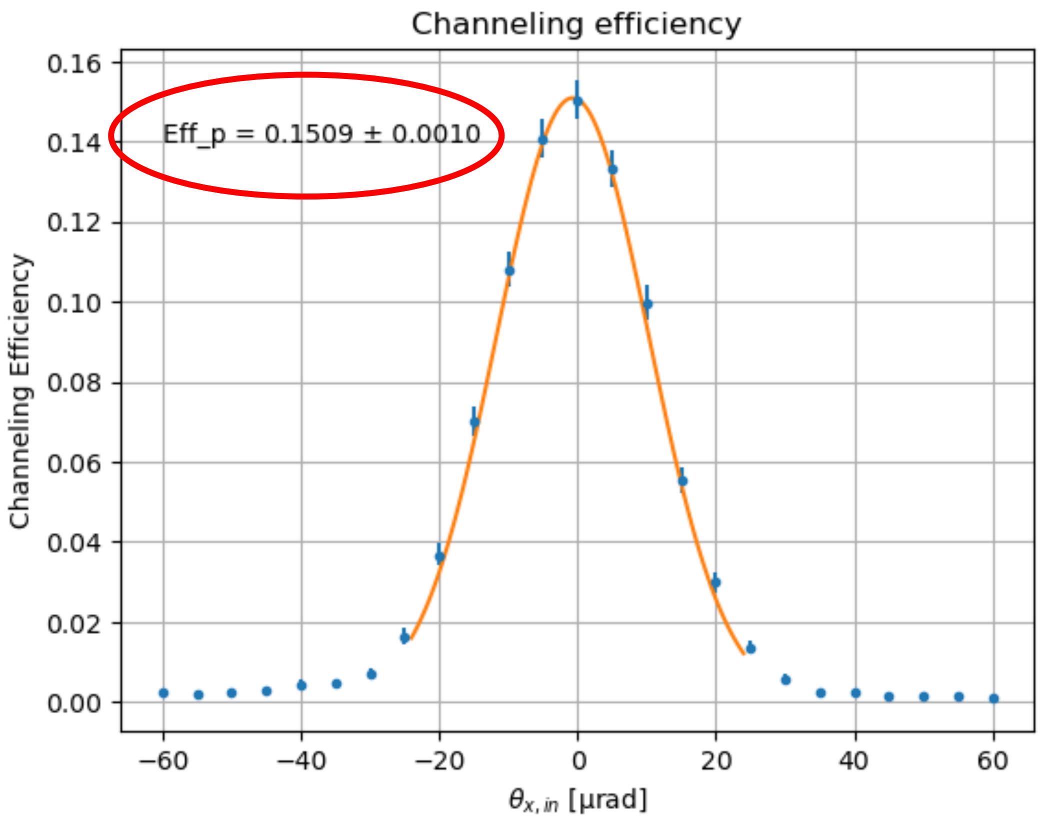




ANODIC BONDING: efficiency after torsion correction

CHANNELLING EFFICIENCY





BEFORE TORSION CORRECTION

AFTER TORSION CORRECTION

SUMMARY

1. SHORT CRYSTAL

ε_{ch1} = 0.617 $\pm$ 0.003

ε_{ch2} = 0.610 $\pm$ 0.002

2. LONG CRYSTAL

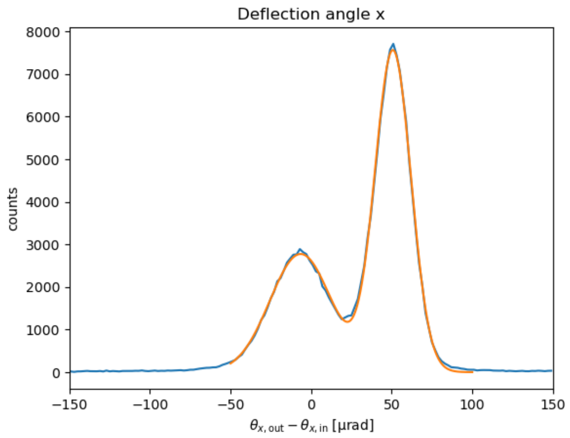
ε_{ch_pre} = 0.123 $\pm$ 0.002

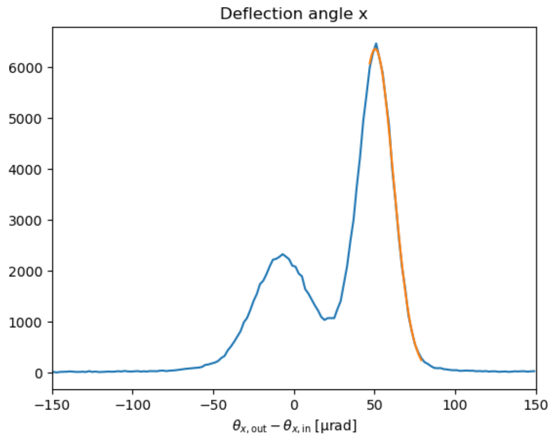
ε_{ch_post} = 0.1568 $\pm$ 0.0007

3. ANODIC-BONDED

ε_{ch_pre} = 0.137 $\pm$ 0.001

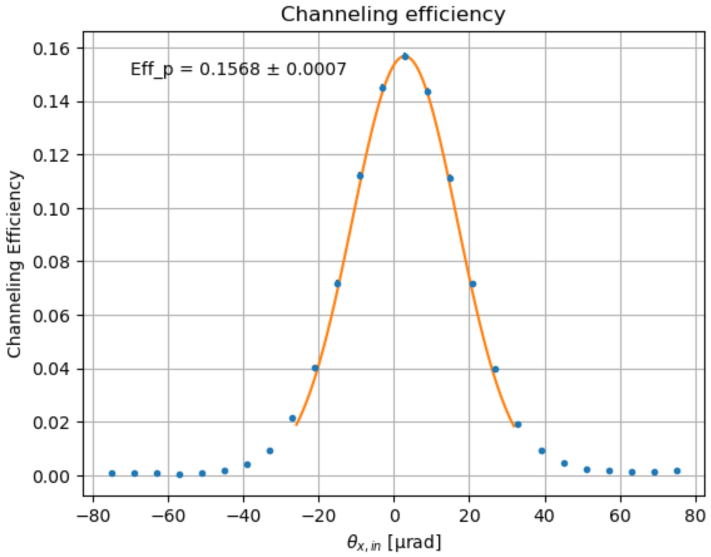
ε_{ch_post} = 0.1509 $\pm$ 0.0010



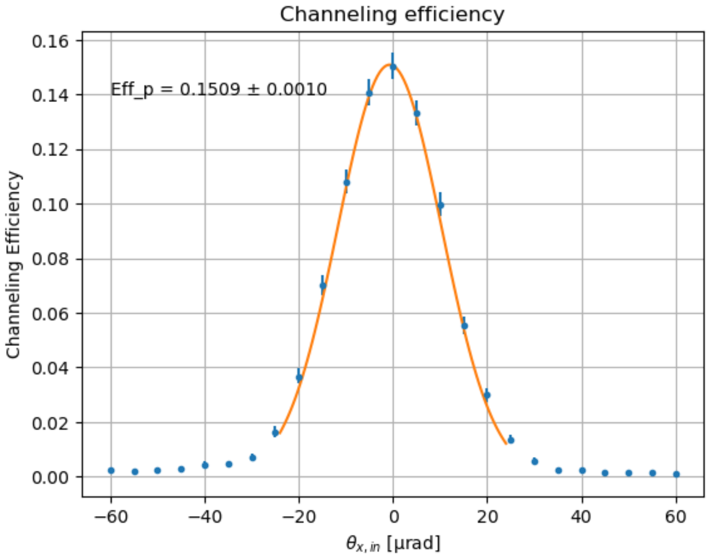


SHORT CRYSTAL

LONG CRYSTAL



ANODIC-BONDED



BACKUPS

Alignment algorithm developed by A. Merli

- Optimisation problem: determine alignment constants that minimise $\chi^2 = \sum_i \frac{(x_i^{pred} - x_i)^2}{\sigma_i^2}$
- $\vec{q}$ local parameters: parameters that describe the single event (tracks slope x/y, track coordinate x/y at 0)
- $\vec{p}$ global parameters: parameters that describe the whole dataset (translation and rotation of sensors)
- Approximate the χ^2 around $\vec{x} = (\vec{p}, \vec{q})$

$$\chi^2(\vec{x} + \Delta\vec{x}) \approx \chi^2(x) + \underbrace{\left(\frac{\partial \chi^2}{\partial \Delta\vec{x}}\right)^T}_{g} \Delta\vec{x} + \frac{1}{2}(\Delta\vec{x})^T \underbrace{\left(\frac{\partial^2 \chi^2}{\partial \Delta\vec{x}\partial\Delta\vec{x}}\right)}_{H} \Delta\vec{x}$$

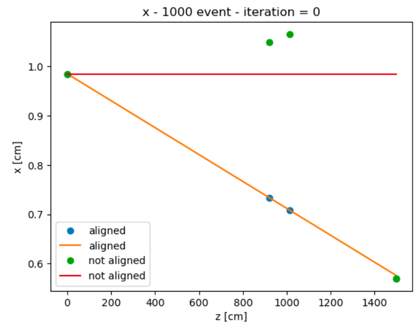
- Solve $\frac{\partial \chi^2}{\partial \Delta\vec{x}}(\Delta\vec{x}^{best}) = 0$ with the Newton method —> $\Delta\vec{x}^{best} = -H^{-1}g$

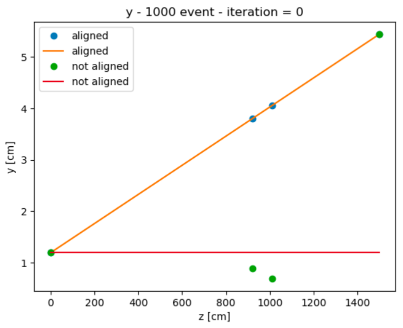
- n_{q_j} local parameters for each track j: 4 x nTracks
- n_p global parameters: (2 translations + 1 rotation) x 3 planes
- The inverse of hessian (dimension = $(n_p + n_{q_j} \times \mathrm{nTracks})^2$) is computational very expensive
  - Solution: Schur complement (https://en.wikipedia.org/wiki/Schur_complement) thanks to the particular structure of the hessian

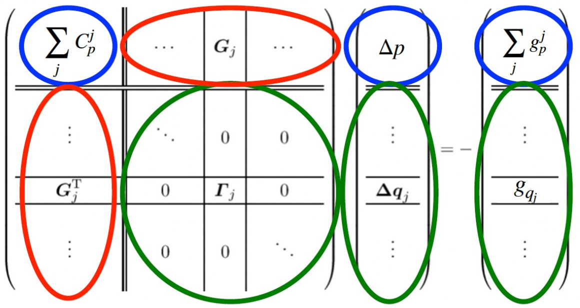
First station is fixed and z coordinate is fixed for all the planes

Alignment performed for all the crystals since the apparatus changed in between the data taking.

Rotations must be taken into account especially for the short crystal.







Hessian Parameters Gradients

Related to global parameters

Related to local parameters

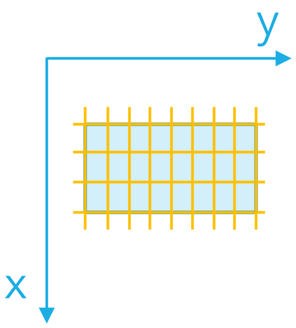
Related to global-local parameters

Schur complement

- The solution only use inverse of nTracks small matrices Γ_j (each with dimension $n_{q_j} \times n_{q_j}$) and $S = \sum_j C_p^j - \sum_j G_j \Gamma_j^{-1} G_j^T$ matrix (dimension $n_p \times n_p$) —> very fast!

$$H^{-1} = \begin{pmatrix} S^{-1} & -S^{-1}G_j\Gamma_j^{-1} \\ -\Gamma_j G_j^T S^{-1} & \Gamma_j^{-1} + \Gamma_j^{-1} G_j^T S^{-1} G_i \Gamma_i^{-1} \end{pmatrix}$$

FIRST ESTIMATION OF THE EFFICIENCY



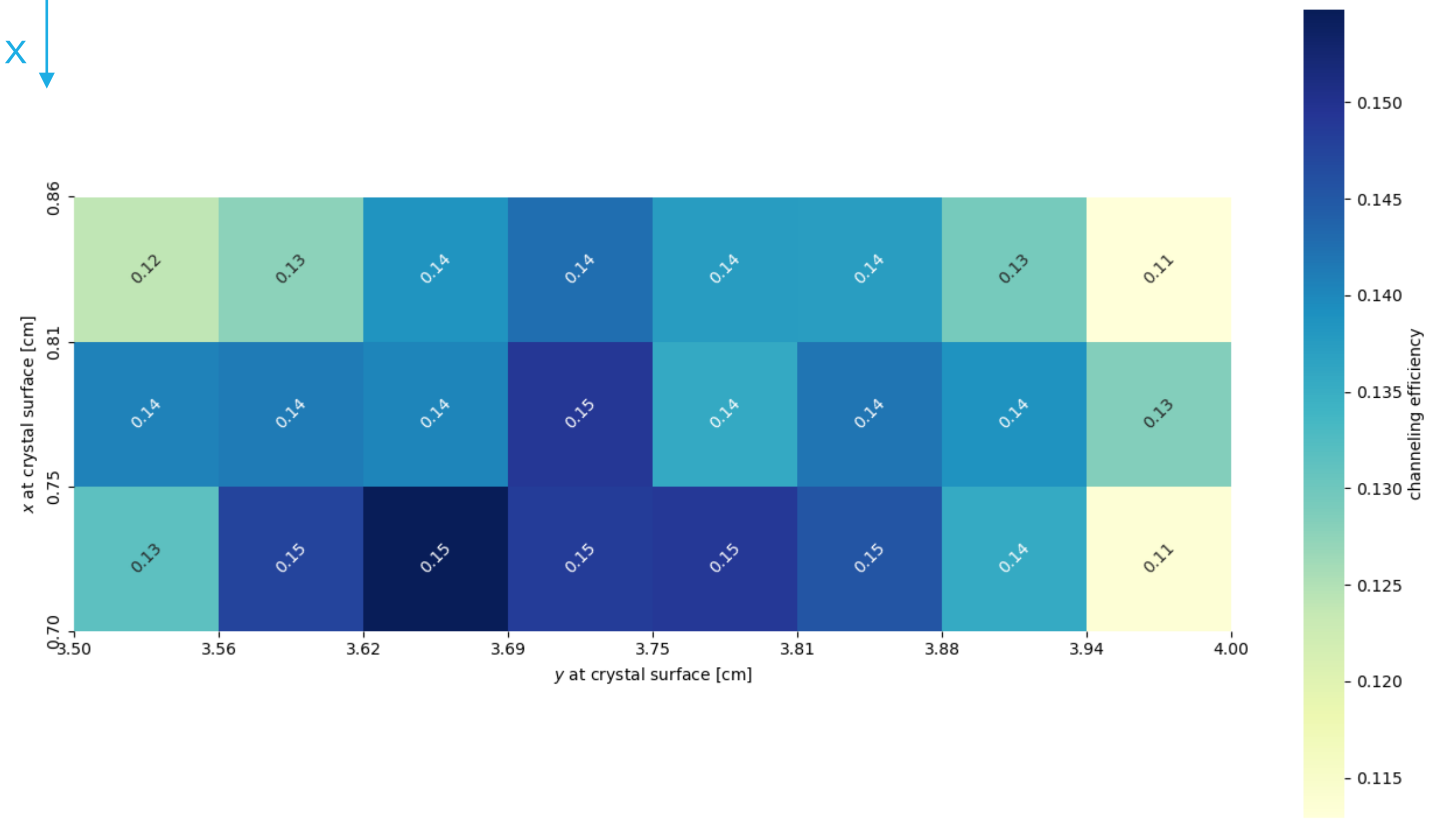
APPLIED CUTS:

- x position on the crystal [0.7, 0.86] cm
- y position on the crystal [3.5, 4.0] cm

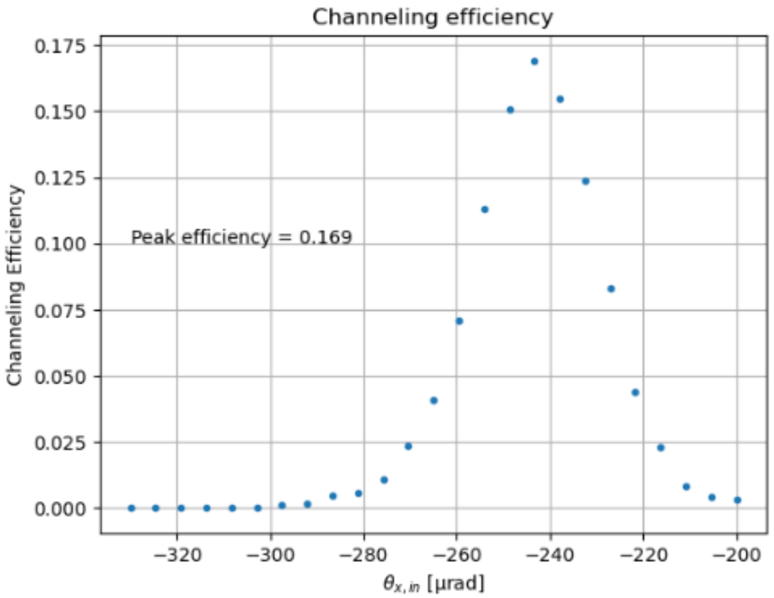
Scan in the hit position at the crystal with 8 bins in the y direction and 3 in the x direction.

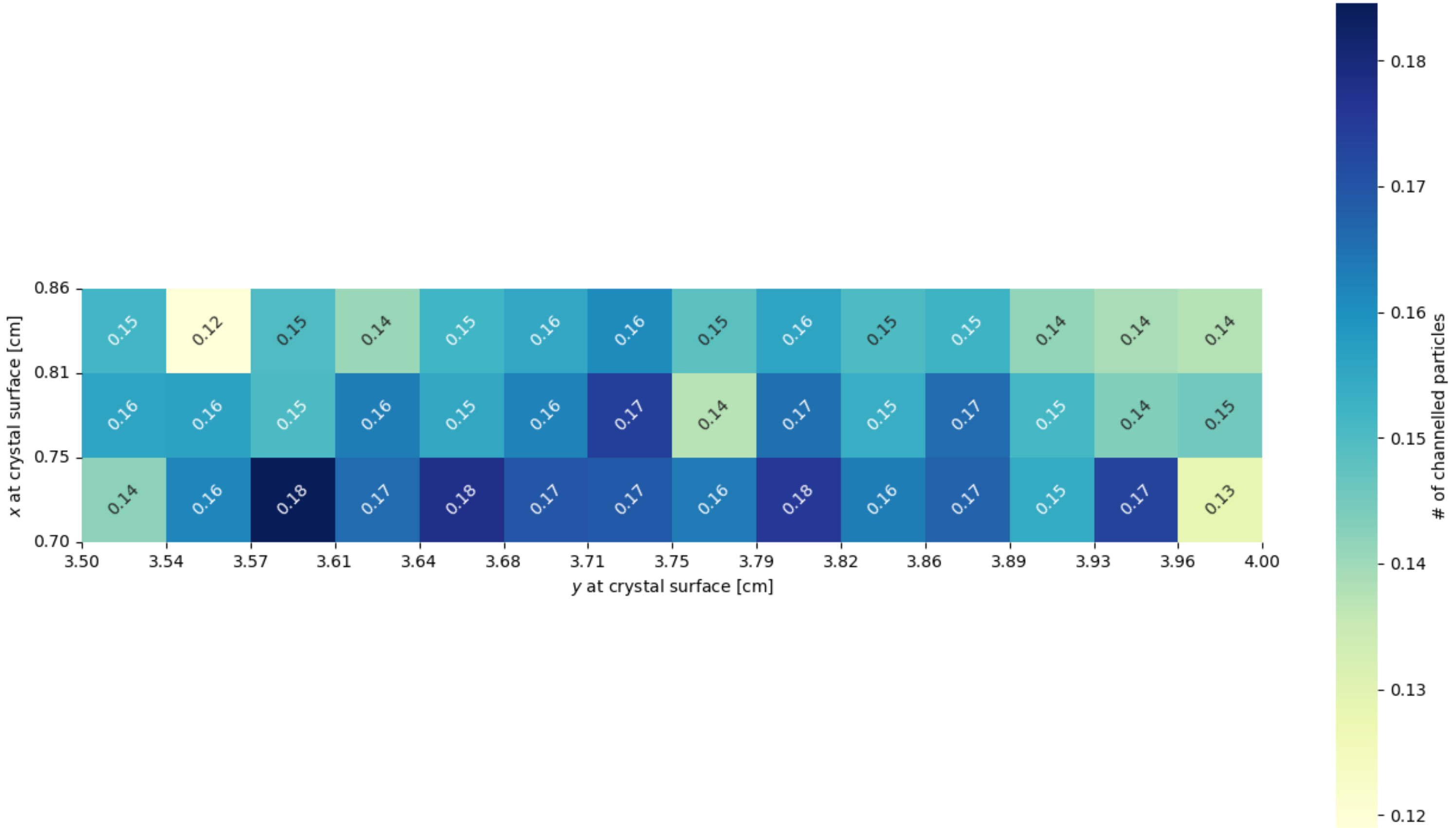
For each step the efficiency was estimated as before within a $\pm\,\theta_L$ window.

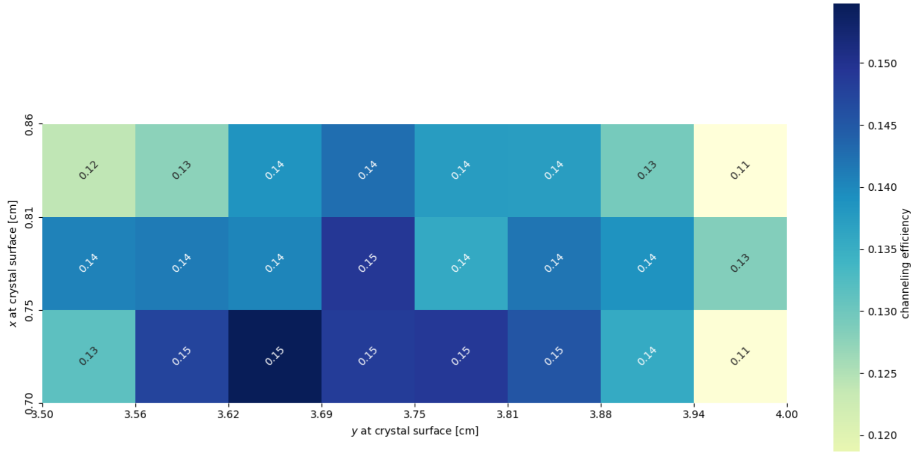
As expected the peak values is higher than before.

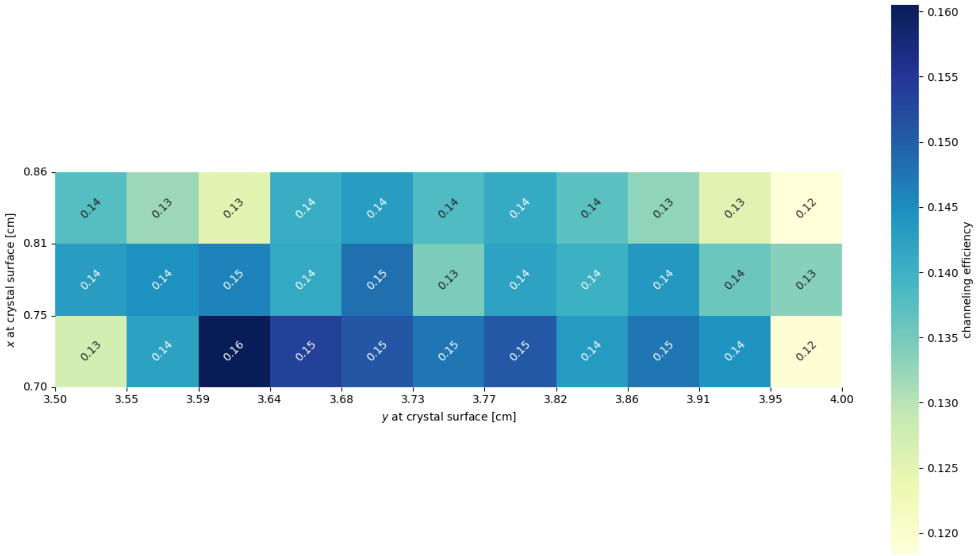


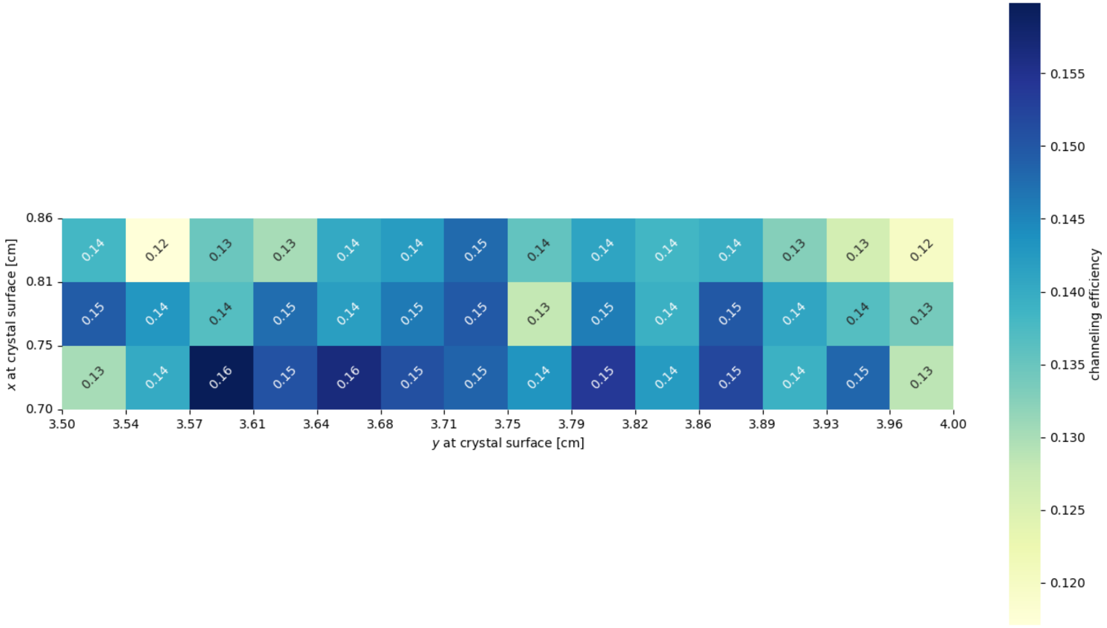
FIRST ESTIMATION OF THE EFFICIENCY






0.12 0.13 0.14 0.14 0.14 0.14 0.13 0.11
0.14 0.14 0.14 0.15 0.14 0.14 0.14 0.13
0.13 0.15 0.15 0.15 0.15 0.15 0.14 0.11
x at crystal surface [cm]
0.86 0.81 0.75 0.70
3.50 3.56 3.62 3.69 3.75 3.81 3.88 3.94 4.00
y at crystal surface [cm]
0.150 0.145 0.140 0.135 0.130 0.125 0.120
channeling efficiency


0.14 0.13 0.13 0.14 0.14 0.14 0.14 0.14 0.13 0.13 0.12
0.14 0.14 0.15 0.14 0.15 0.13 0.14 0.14 0.14 0.14 0.13
0.13 0.14 0.16 0.15 0.15 0.15 0.15 0.14 0.15 0.14 0.12
x at crystal surface [cm]
0.86 0.81 0.75 0.70
3.50 3.55 3.59 3.64 3.68 3.73 3.77 3.82 3.86 3.91 3.95 4.00
y at crystal surface [cm]
0.160 0.155 0.150 0.145 0.140 0.135 0.130 0.125 0.120
channeling efficiency


0.14 0.12 0.13 0.13 0.14 0.14 0.15 0.14 0.14 0.14 0.14 0.13 0.13 0.12
0.15 0.14 0.14 0.15 0.14 0.15 0.15 0.13 0.15 0.14 0.15 0.14 0.14 0.13
0.13 0.14 0.16 0.15 0.16 0.15 0.15 0.14 0.15 0.14 0.15 0.14 0.15 0.13
x at crystal surface [cm]
0.86 0.81 0.75 0.70
3.50 3.54 3.57 3.61 3.64 3.68 3.71 3.75 3.79 3.82 3.86 3.89 3.93 3.96 4.00
y at crystal surface [cm]
0.155 0.150 0.145 0.140 0.135 0.130 0.125 0.120
channeling efficiency

FIRST ESTIMATION OF THE EFFICIENCY

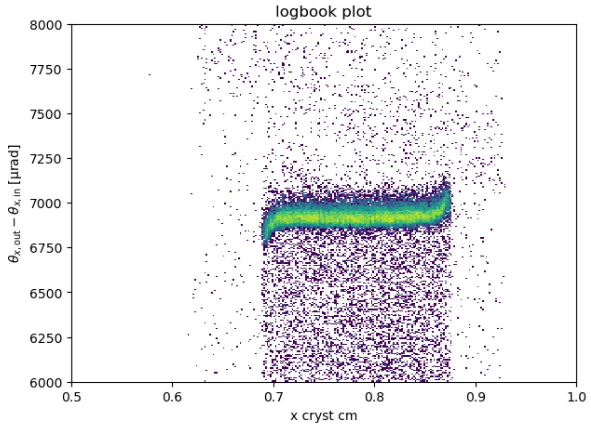
Crystal specifications:

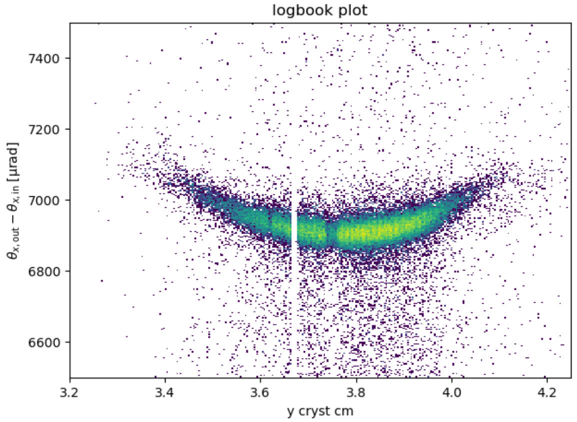
- Dimensions: 2 mm x, 20 mm y, 70 mm z
- Deflection angle: 7 mrad

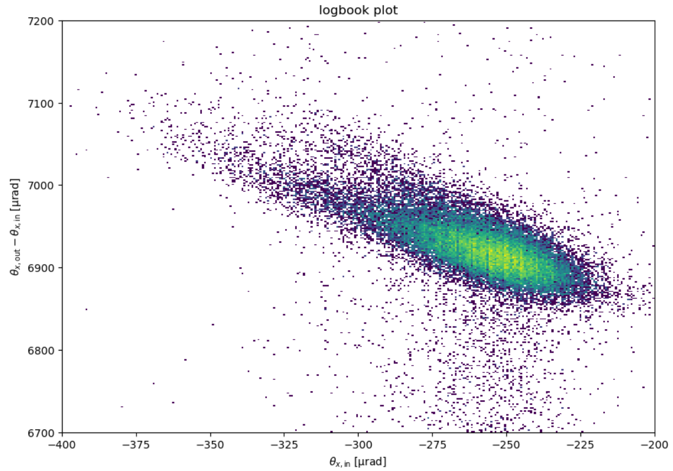
Lindhart Angle: $\theta_L(180GeV) = 12.9\ \mu rad$

Selected run for alignment: 720454

Selected run for channeling: 720462



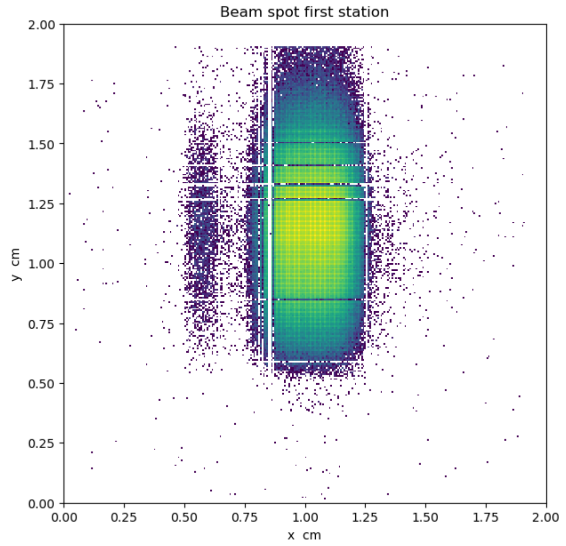


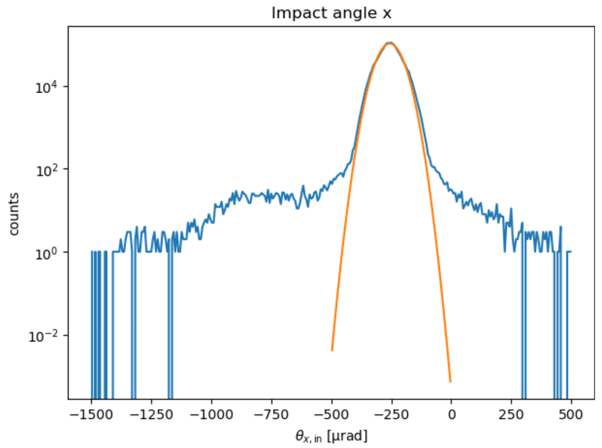


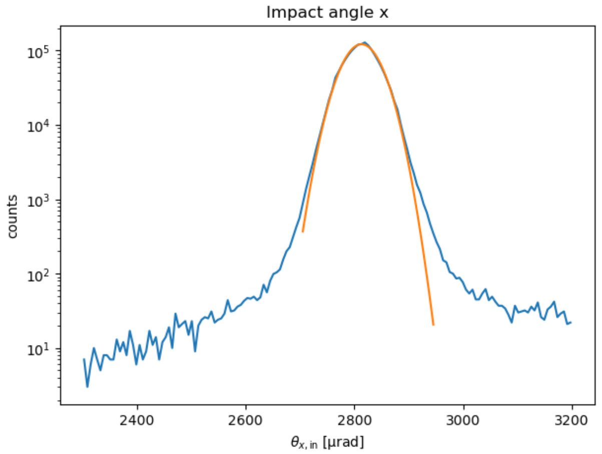
FIRST ESTIMATION OF THE EFFICIENCY

From aligned data, run

```
momentum=180e3,
angular_div_x=41.3e-6,
angular_div_y=31.8e-6,
section_x=5e-3,
section_y=12e-3,
mean_angle_x=-256e-6,
mean_angle_y=2813e-6
```







FIRST ESTIMATION OF THE EFFICIENCY

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# Biryukov et al, Crystal Channeling and Its Application at High-Energy Accelerators, Springer 1997, page 16
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Acceptance for a divergent beam: $\phi = 41\ \mu rad$

$$A(pv/R) = \frac{2x_c}{d_p}\frac{\pi}{4}\frac{\theta_{c,0}}{\Phi}\left(1-\frac{R_c}{R}\right)^2 = A_S\left(1-\frac{R_c}{R}\right)^2 , \qquad (2.12)$$

Taking into account also the dechanneling effect

$$F(\Theta, pv/R) = A_S A_B\left(\frac{pv}{R}\right)\exp\left(-\frac{R\Theta}{L_D}\right) . \qquad (2.19)$$

$$F(\Theta,\rho) = A_S(1-\rho)^2\exp\left(-\frac{\Theta}{\Theta_D\rho(1-\rho)^2}\right) . \qquad (2.20)$$

$$\rho = \frac{R_c}{R}$$

Maximal deflection efficiency = 18.9%

$$\epsilon_{sim} = \epsilon_{max} * \sqrt{1-\theta_{in}^2/\theta_c^2}$$