CRYM: a channeling emulation program based on the latest experimental data

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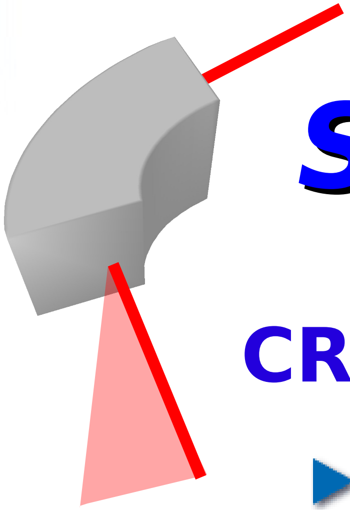


Summary

CRYM stands for Crystal Model

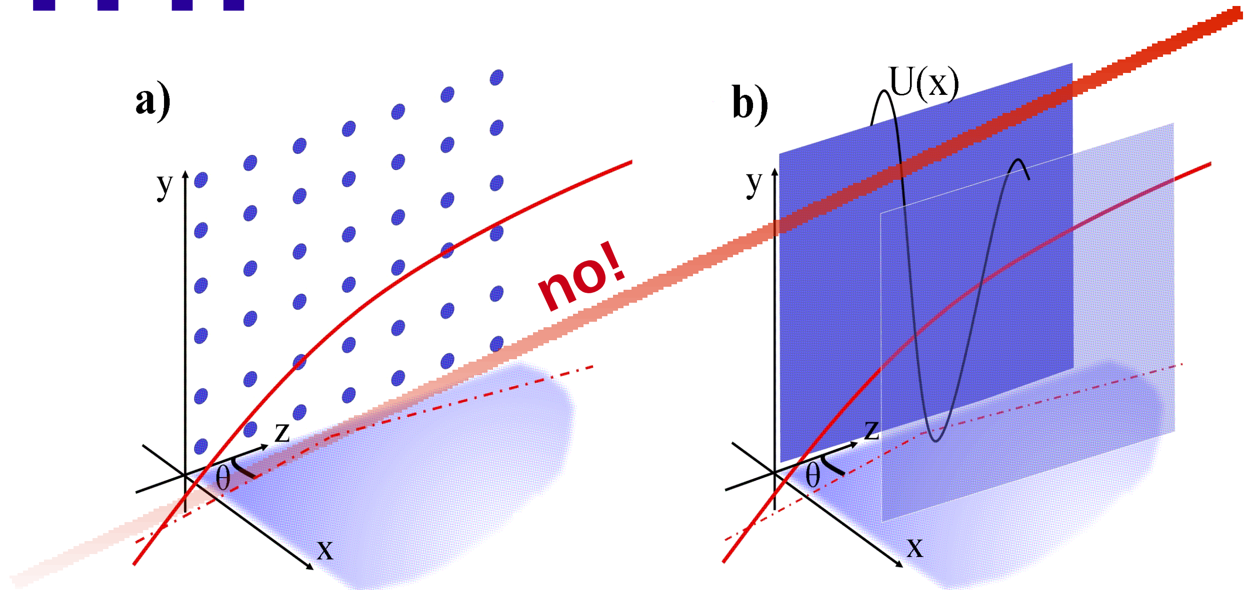
- **What it means**
- **What it is for (pros & cons)**
- ***How it works:***

Crystal ▶ effects
- **Angular acceptance and efficiency**
- **Angular deflection**

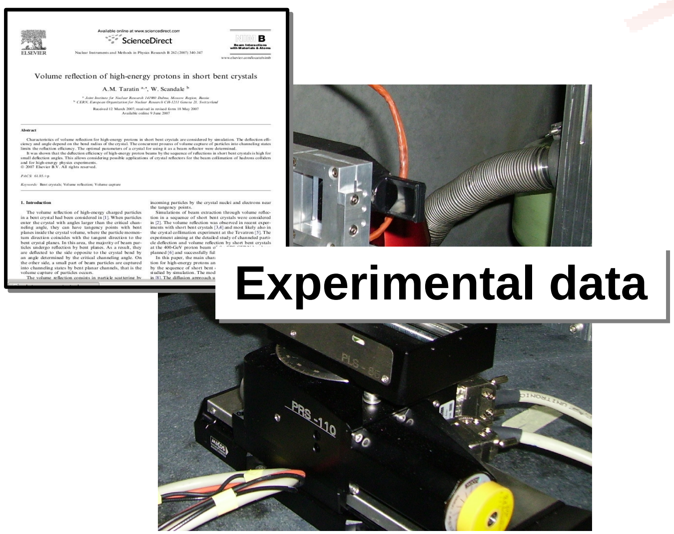
- **A qualitative comparison with data published by the H8RD22 coll.**

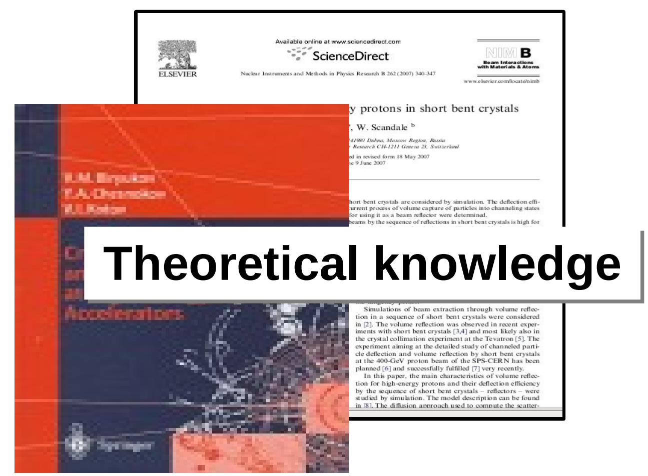
What's CRYM?

- **It is not a Crystal Channeling simulation**



- **It is an emulator!**





It tries to reproduce:

The behavior of short bent crystals in planar condition with heavy high energy particles (hundreds of GeV)

An approach *complementary* to the standard one to:

foresee **and** ***interpret*** **the crystal channeling experiments**

⇩ ⇩

Design and Analysis

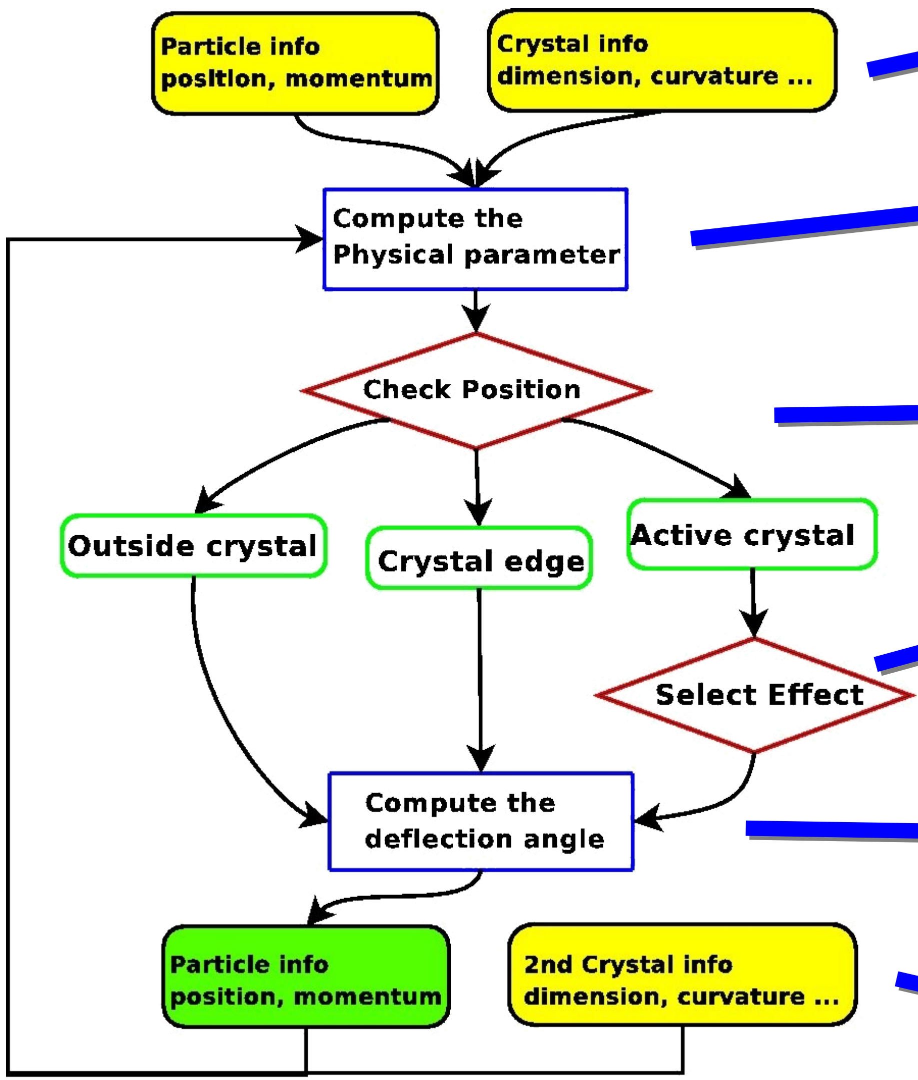
Cons:

- **Unknown (not-measured) effects cannot be included**
- **Possible uncertainties in the emulation of unexplored physical region**

Pros:

- **Easy integration with accelerator and detector simulations:**
  The model reflects our way of thinking
- **Possibility of inserting fine (but maybe important) crystal features (eg. torsion or small spatial misalignment)**
- **It is an attempt to collect all the planar channeling information into coherent model**
- ***It's fast***

How does it work?



Emulation Inputs

Such as critical angle and radius

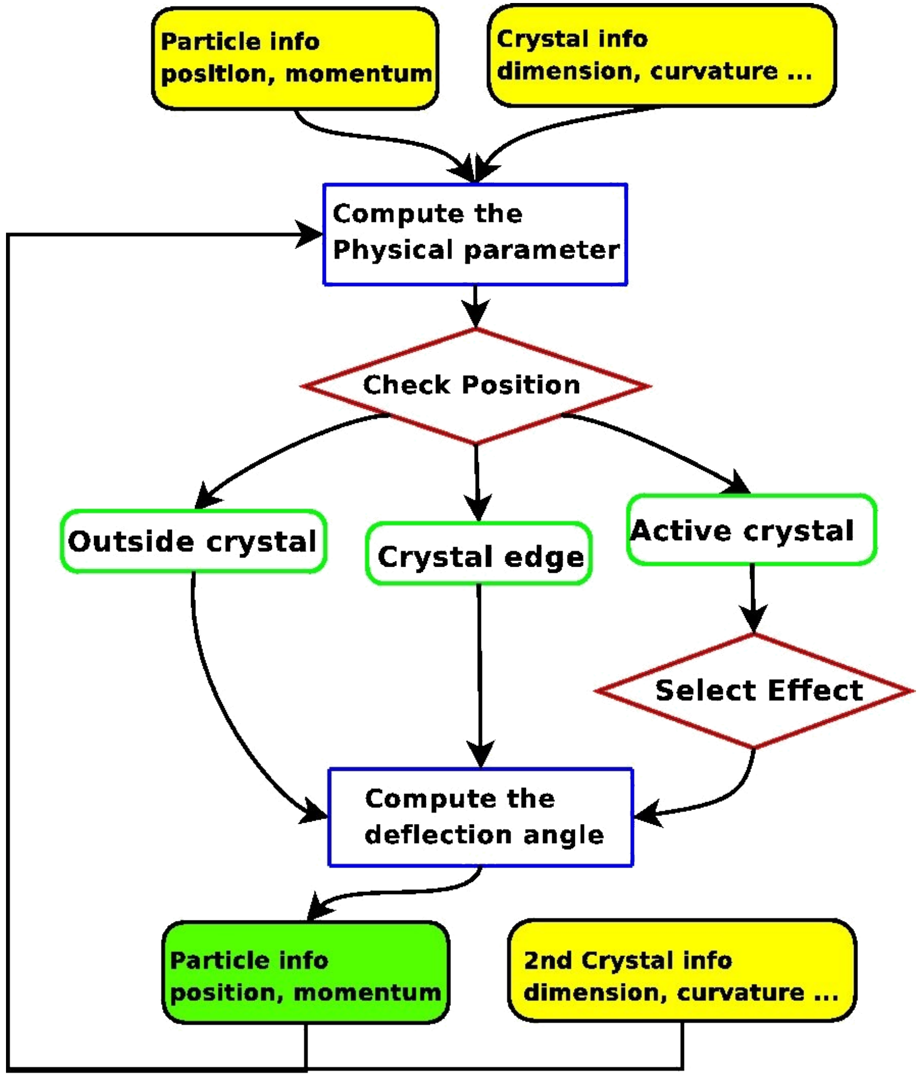
The crystal is inserted in the space

According to angular acceptance and efficiency

Act on the particle trajectory

Multi-crystals easy to be implemented

How does it work?

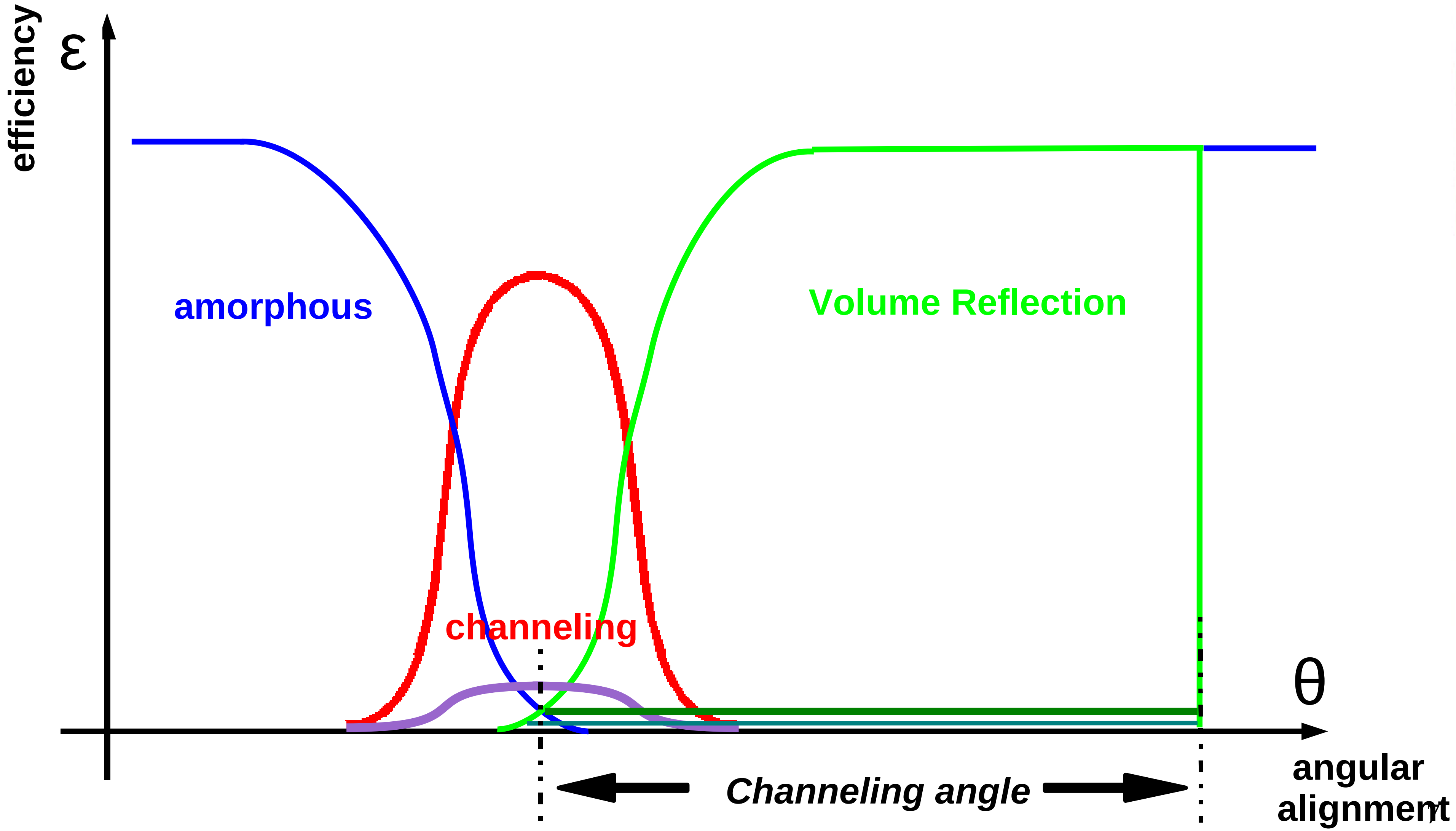


The crystal is described through its effects

Each effect is described mainly by:

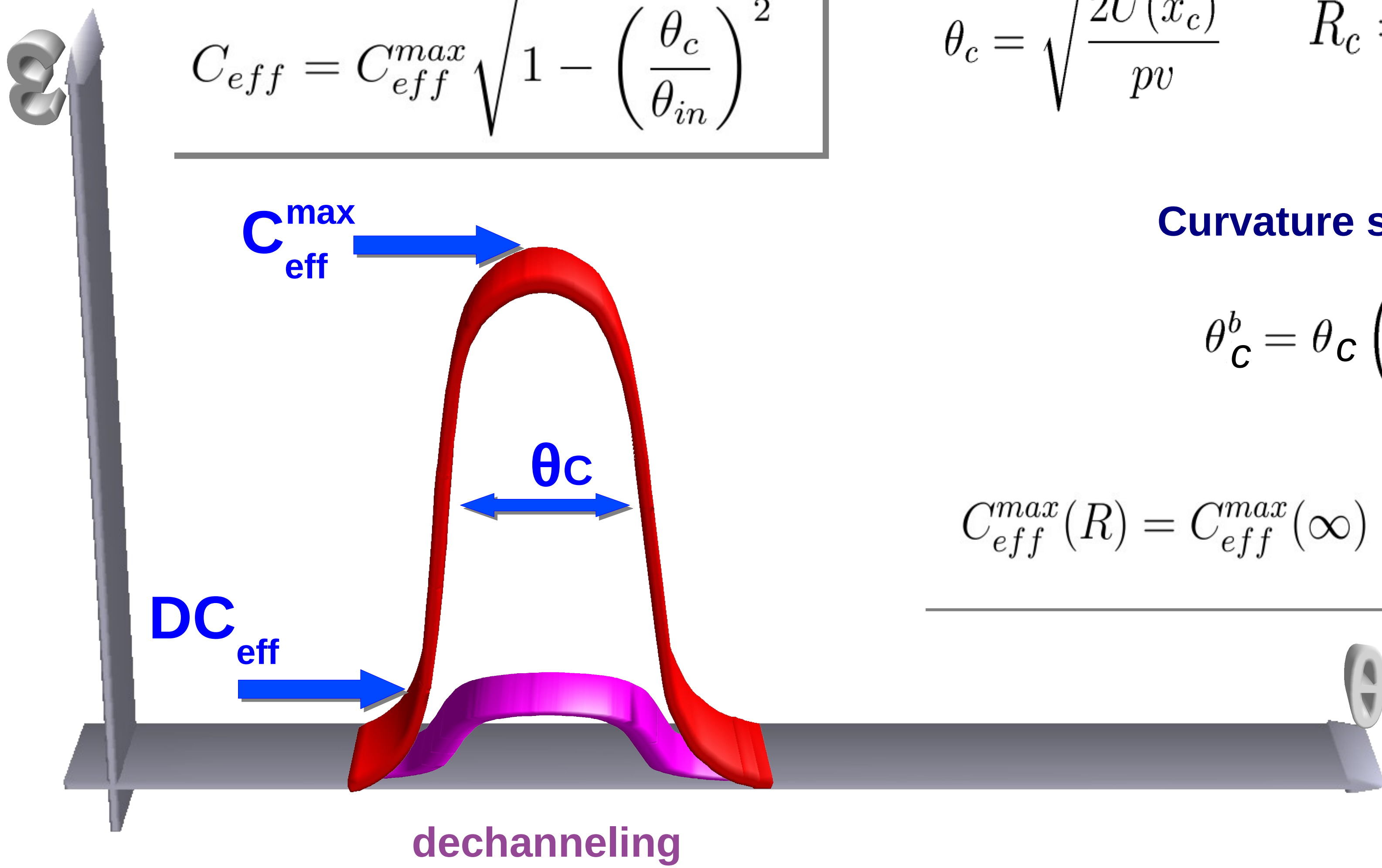
- **Angular acceptance + efficiency**
- **The angular deflection**

Angular acceptance and efficiency



Channeling region

$$C_{eff} = C_{eff}^{max}\sqrt{1-\left(\frac{\theta_c}{\theta_{in}}\right)^2}$$



Energy scaling

$$\theta_c = \sqrt{\frac{2U(x_c)}{pv}} \qquad R_c = \frac{pv}{U'(x_c)}$$

Curvature scaling

$$\theta_c^b = \theta_c\left(1-\frac{R_c^b}{R}\right)$$

$$C_{eff}^{max}(R) = C_{eff}^{max}(\infty)\left(1-\frac{R}{R_c}\right)$$

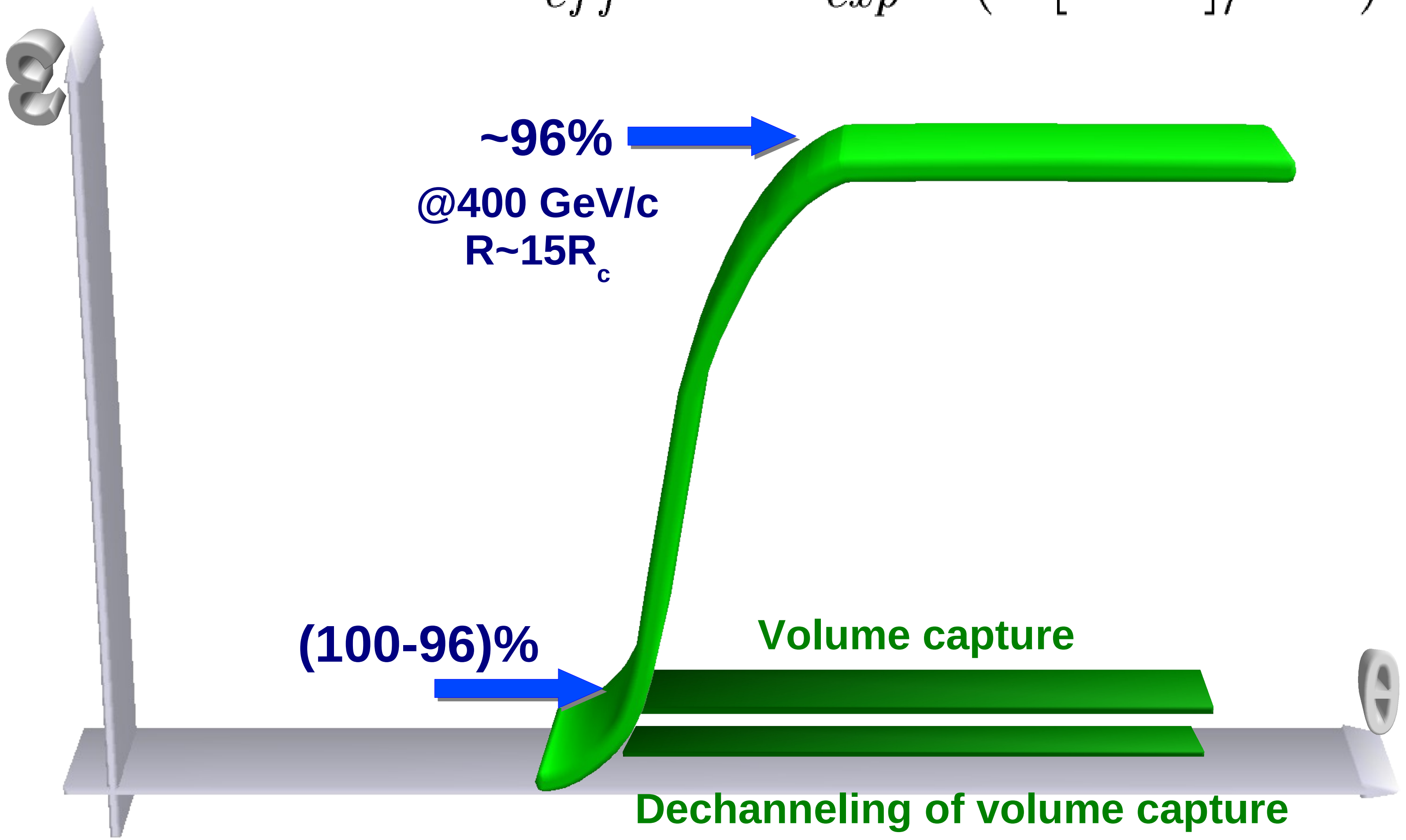
DC_{eff} is defined with respect to the total of initially channeled particles

DC_{eff} ~20% *(experimental value)*

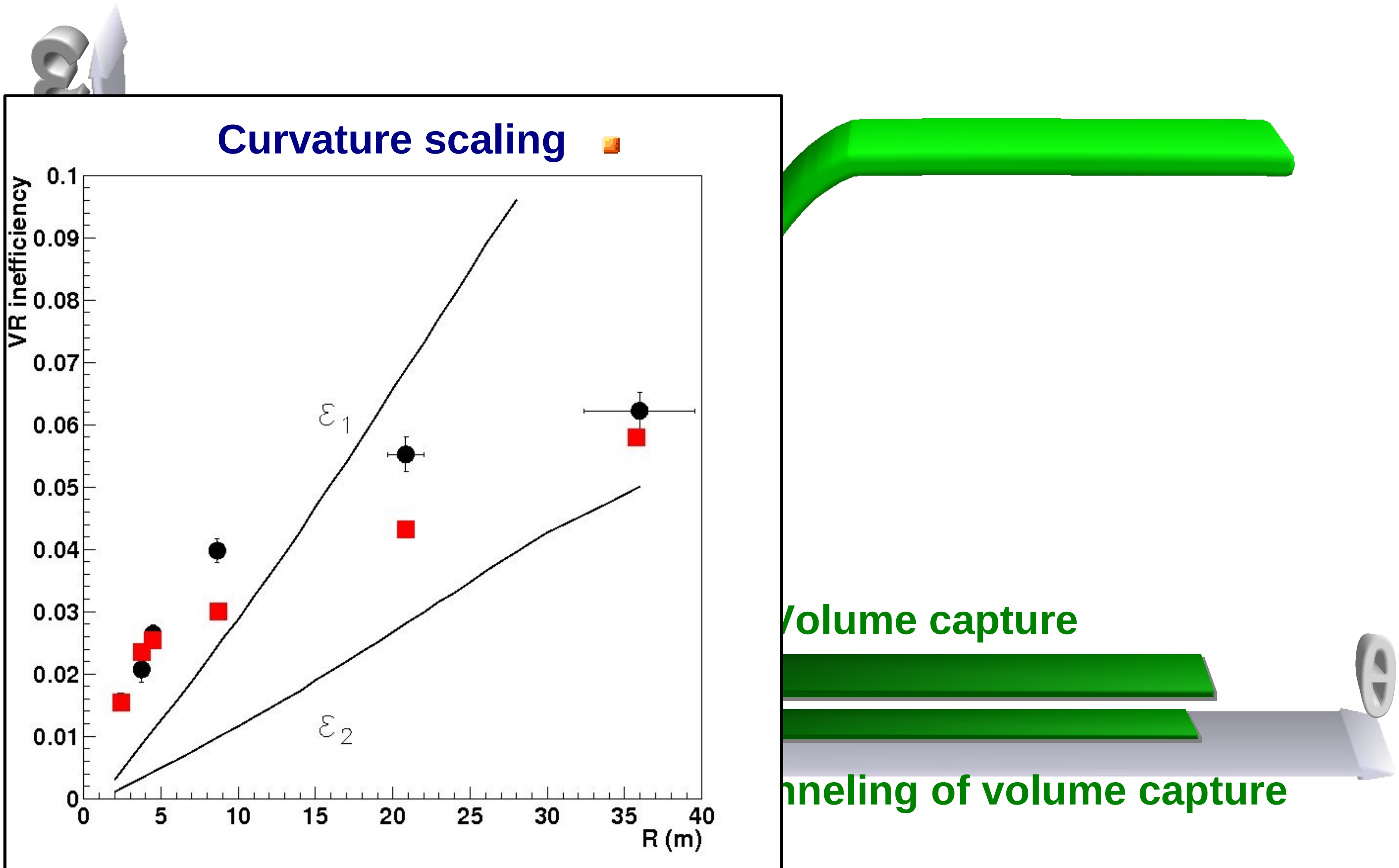
Reflection region

Energy scaling

$$VR_{eff} = VR_{exp} * (E[\mathrm{GeV}]/400)^{3/2}$$

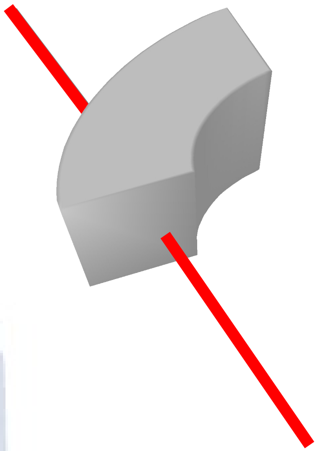


Reflection region

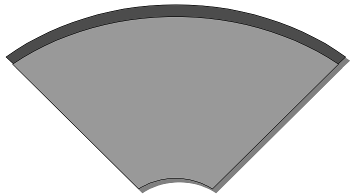


- W. Scandale et al.,“Volume reflection dependence of 400 GeV/c protons on the bent crystal curvature”, Phys. Rev. Lett.

“effects” produce deflection



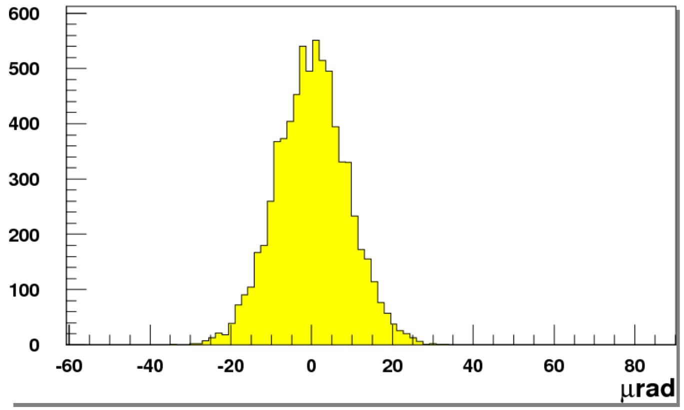
Amorphous orientation and amorphous layer

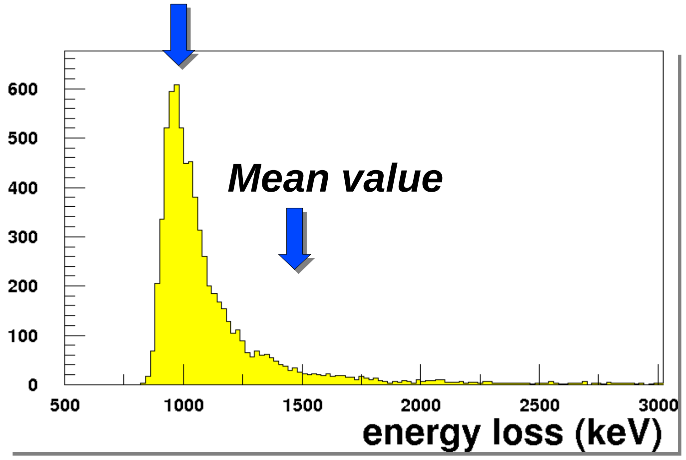


Gaussian distribution with σ:

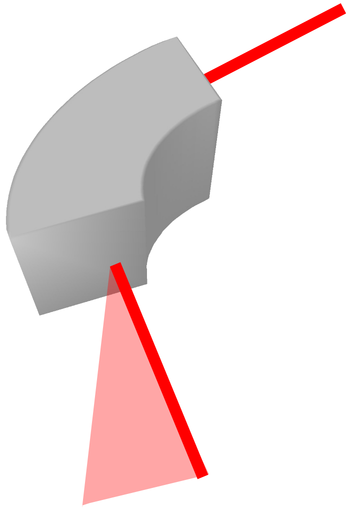
$$\theta_m = \frac{13.6\ \mathrm{MeV}}{\beta c p} z_p \sqrt{x/X_0}\left(1 + 0.038(x_c/X_0)\right)$$

Beam divergence: 7μrad
Design: strip
Dimension (h x w x l): (7cm x 1mm x 3mm)



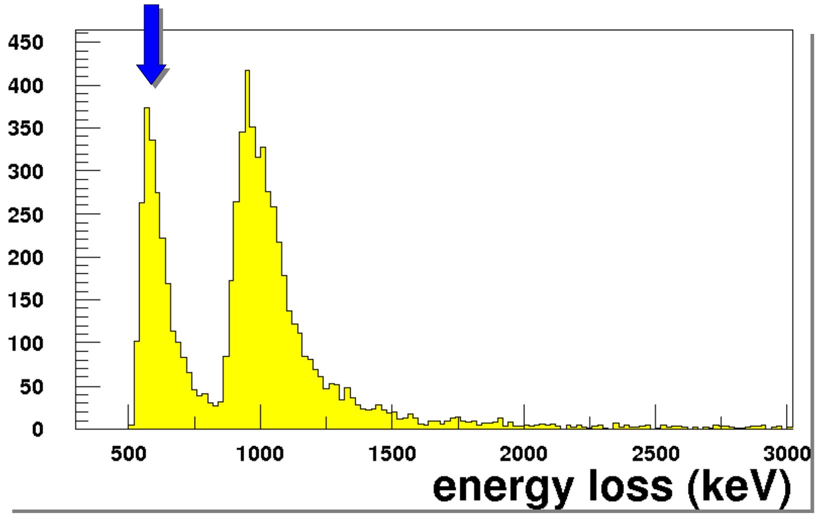


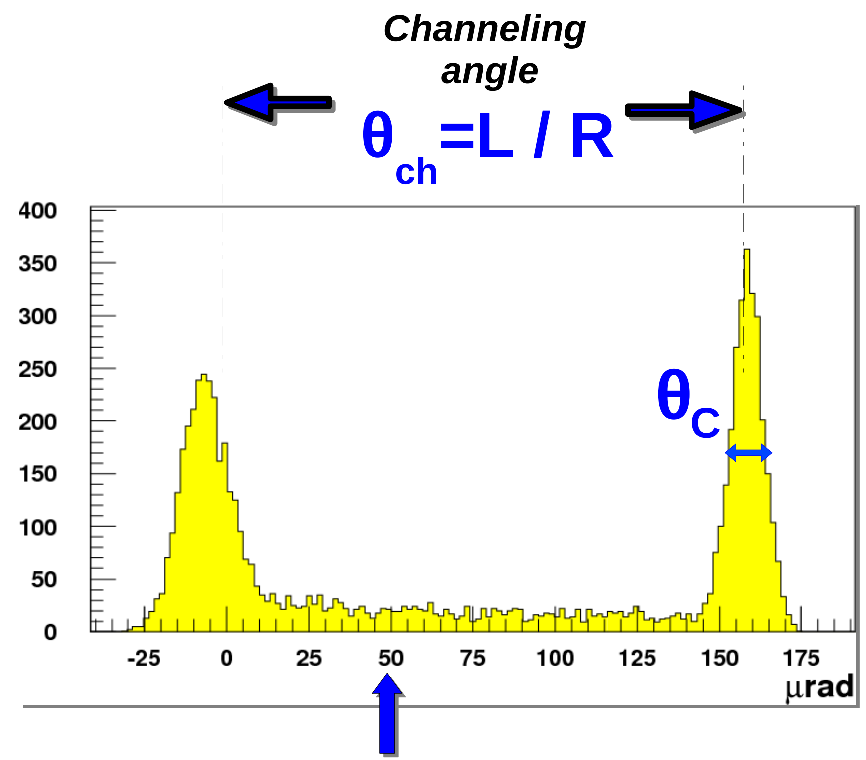
“effects” produce deflection



Channeling and dechanneling

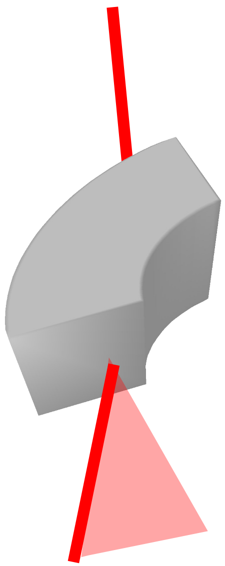
Channeled particles lose less energy, ~60% of the amorphous one



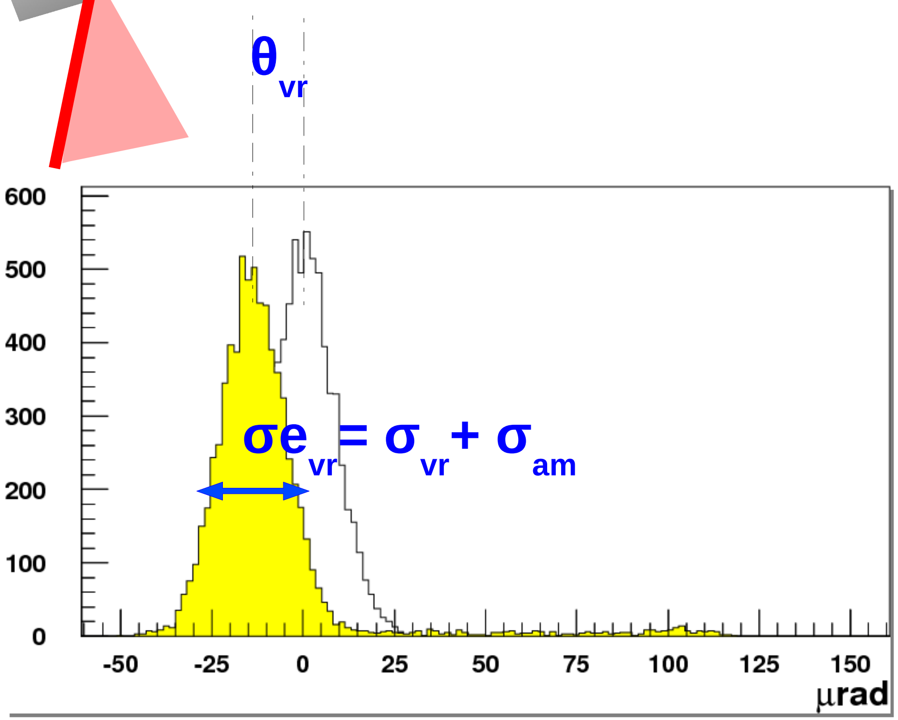


The dechanneling events are exponentially distributed

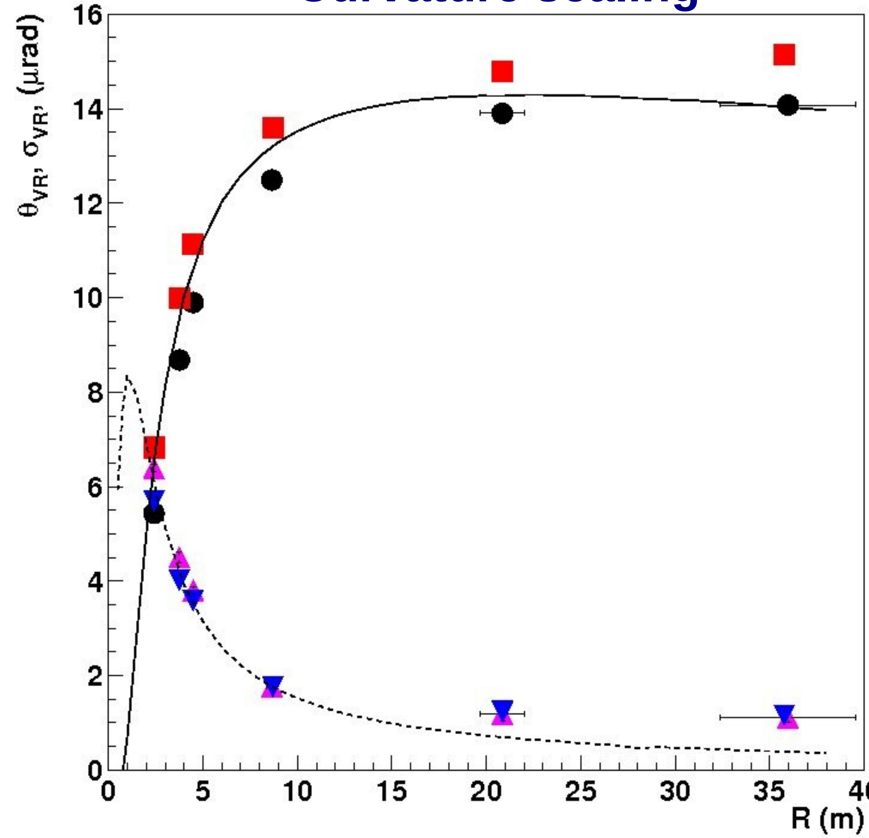
“effects” produce deflection



Volume reflection and volume capture



- Curvature scaling



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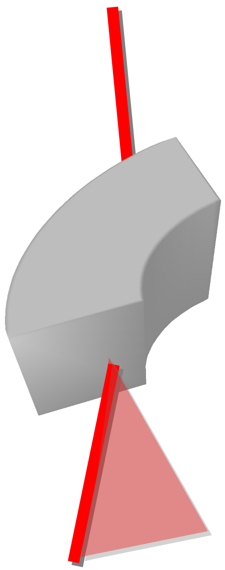
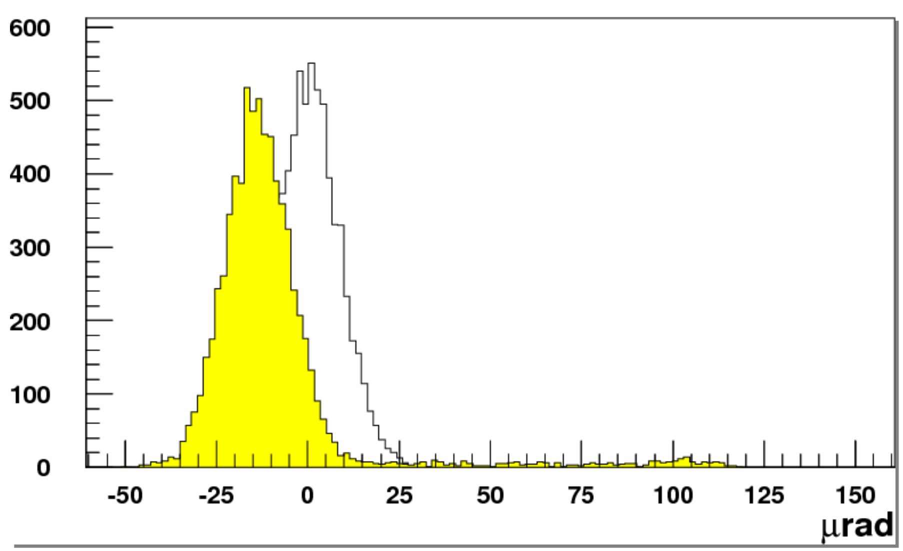
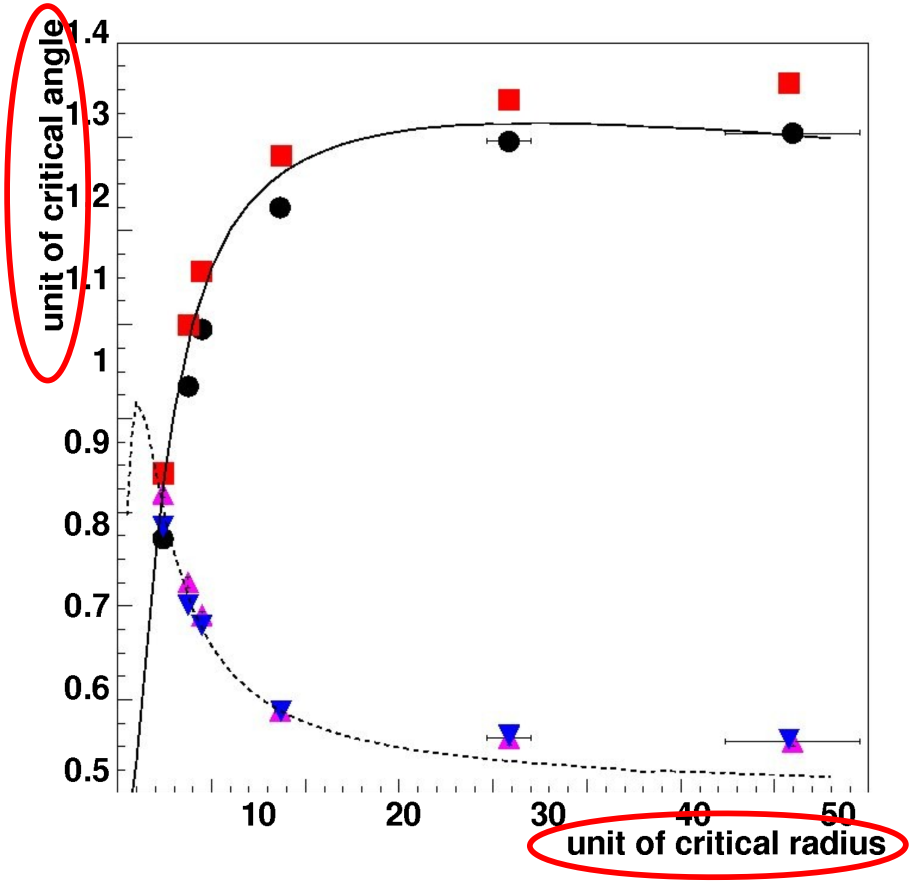
"effects" produce deflection



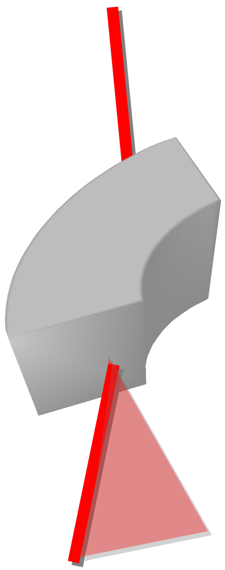
Volume reflection and volume capture

Considering the bending radius dependence in terms of critical parameter a non trivial **energy dependence** occurs



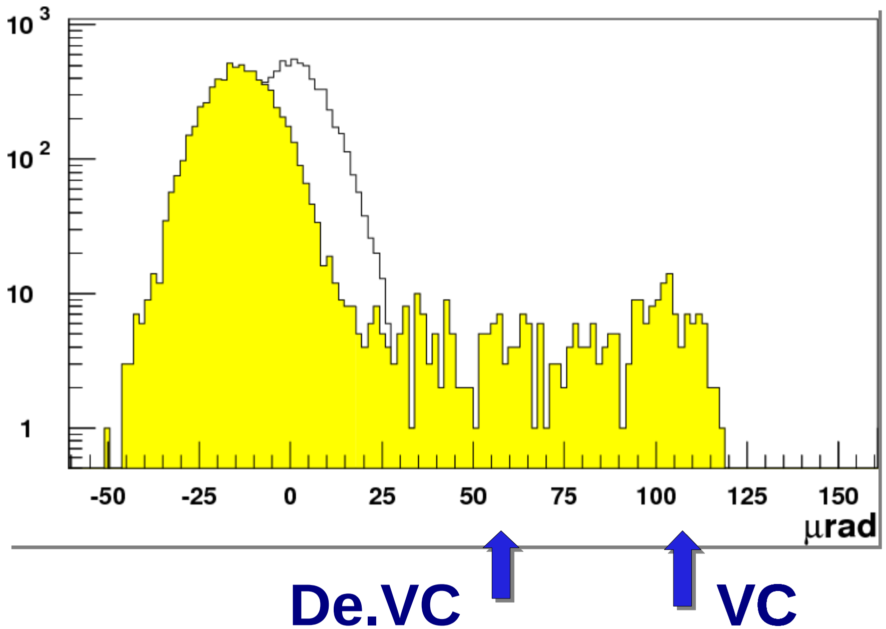


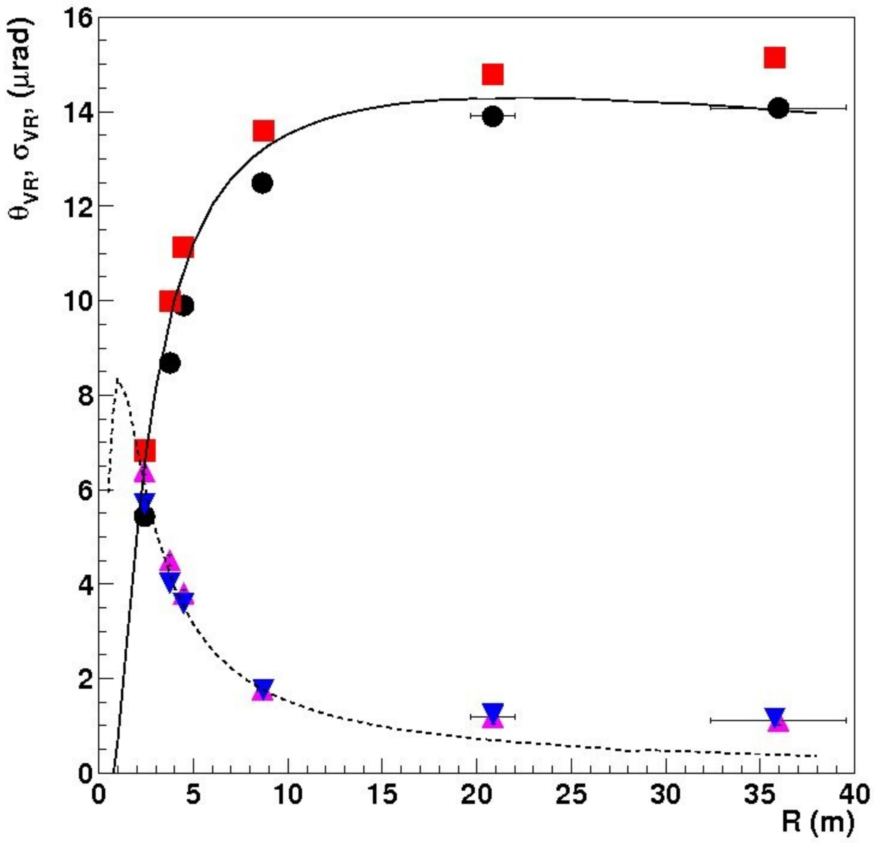
“effects” produce deflection



Volume reflection and volume capture

The VR inefficiency “became” VC or VC dechanneling

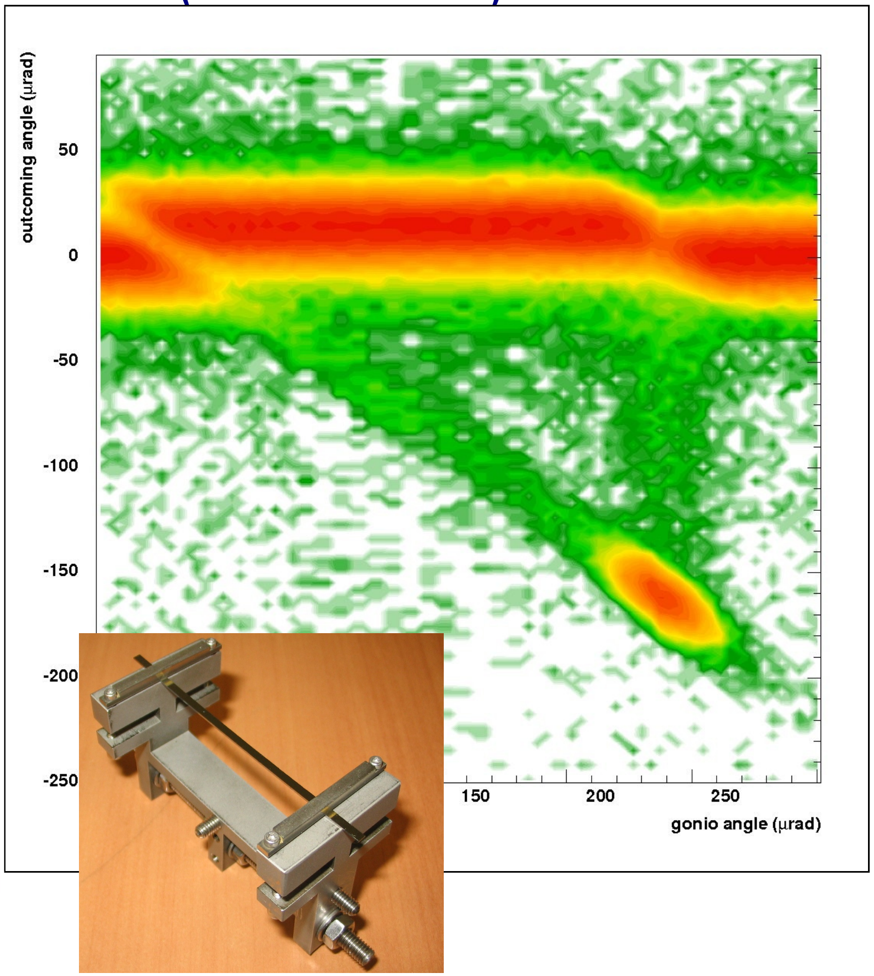


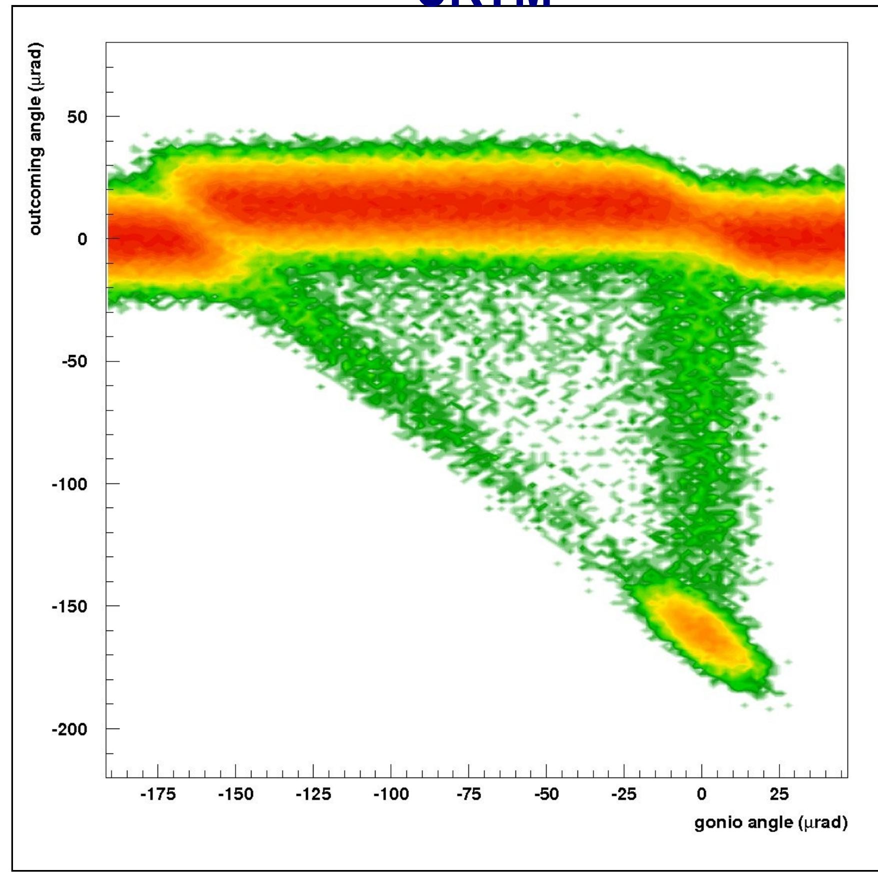


Let's put together the pieces:

- First experimental observation of VR at 400GeV (CERN SPS 2006)

CRYM



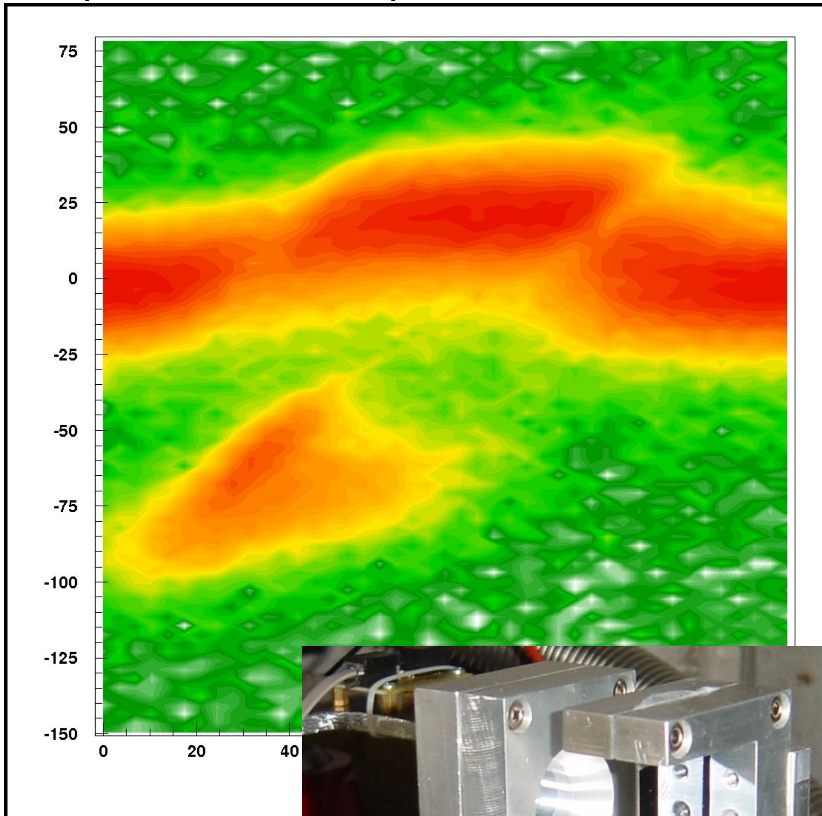


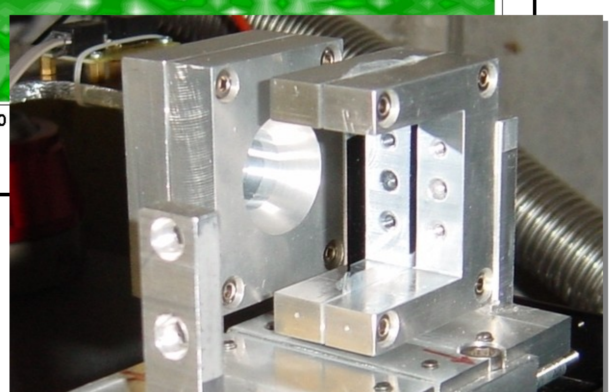
Emulation of the ST4 crystal

- SCANDALE W. *et al.*, *Phys. Rev. Lett.*, **98** (2007) 154801.

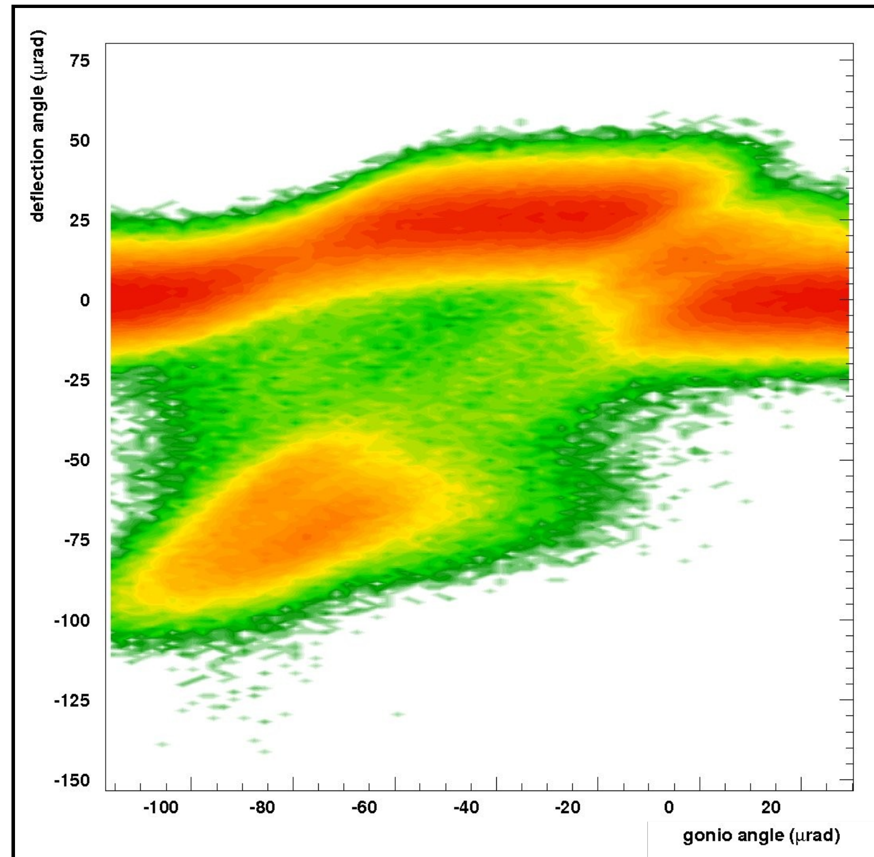
Multi-crystals emulation is easy

- First experimental observation of multi-VR (CERN SPS 2006)



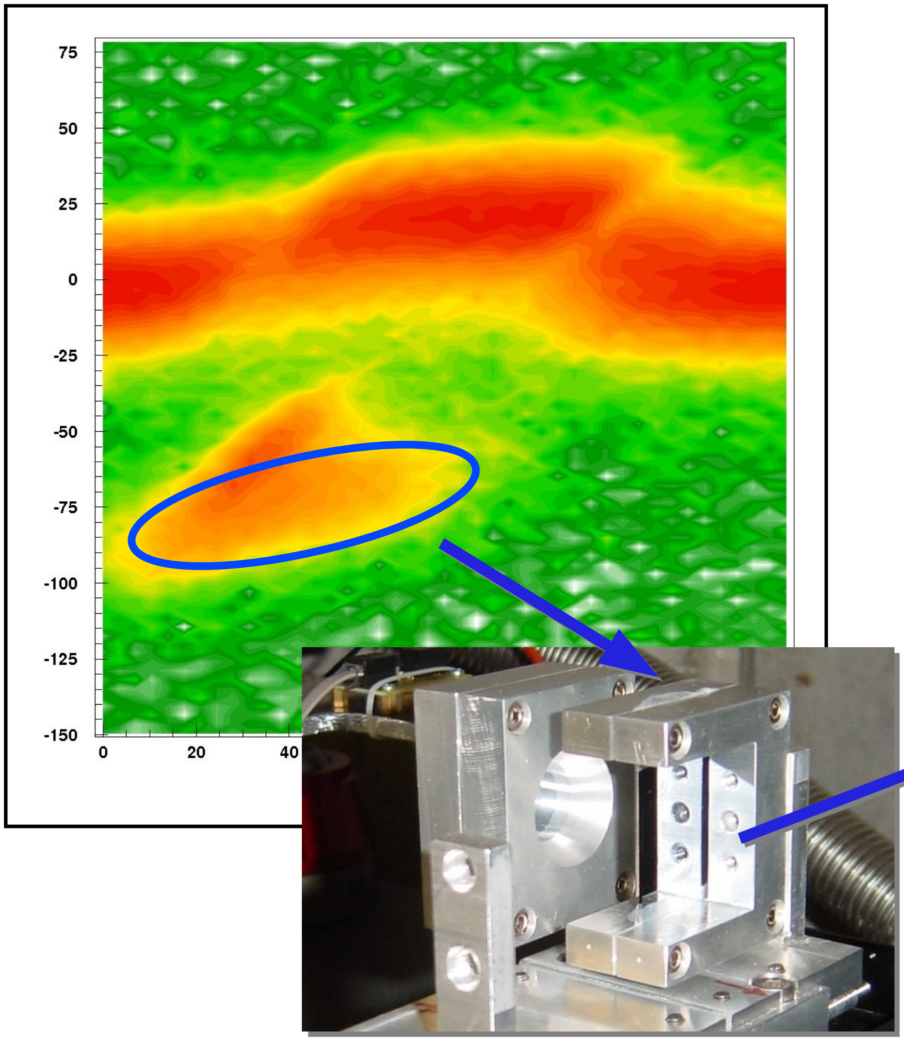


Emulated by CRYM

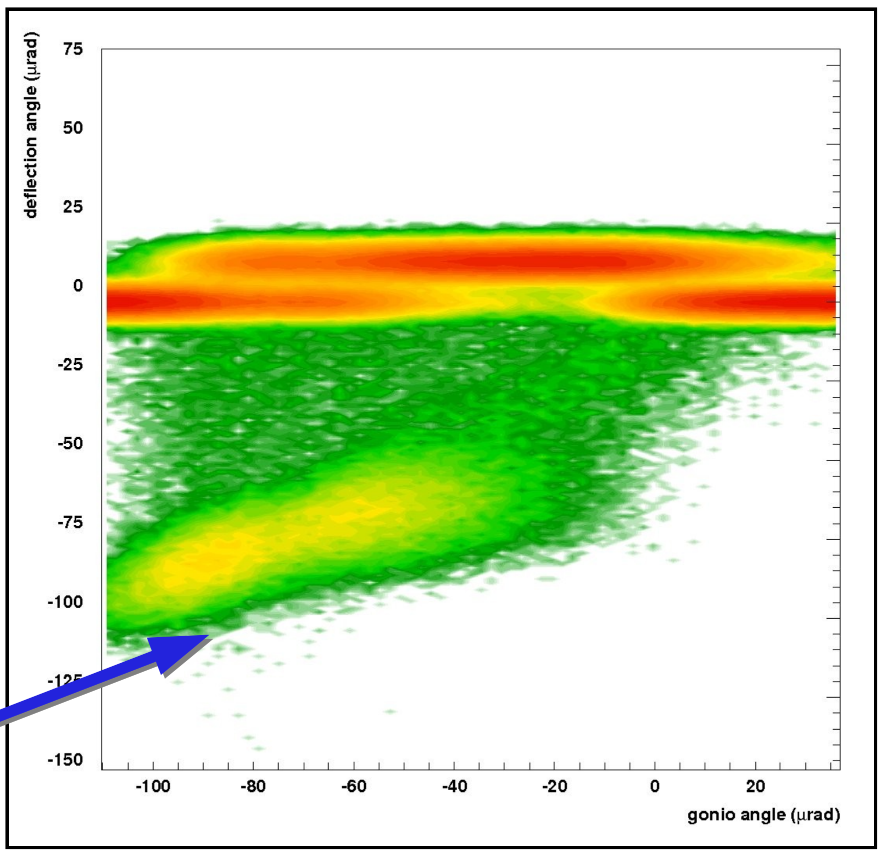


- W. Scandale et al., "Double volume reflection of a proton beam by a sequence of two bent crystals", Phys. Lett. B, Volume 658, Issue 4, Pages 109-111, 2008

Multi-crystals emulation is easy



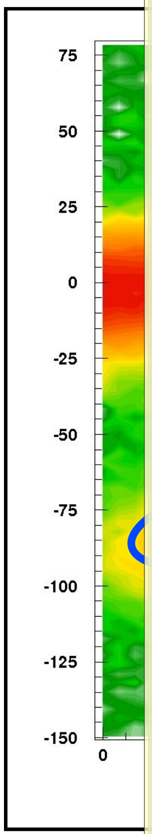
Behavior of the second crystal



Emulated by CRYM

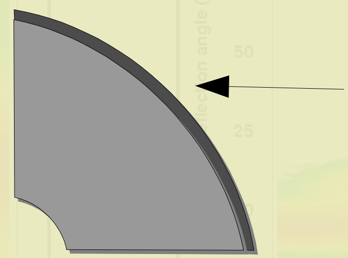
Multi-crystals emulation is easy

Behavior of the second crystal



Edge effect in single and multi-crystals

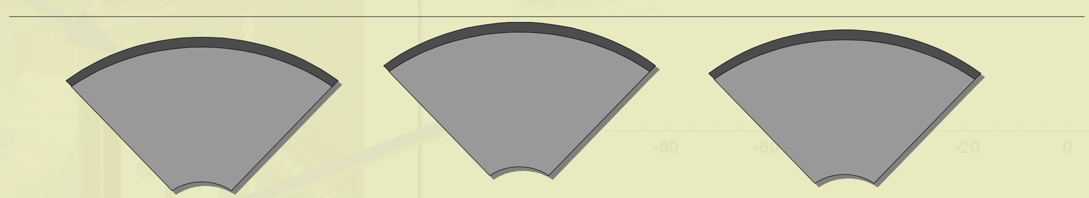
Single crystal

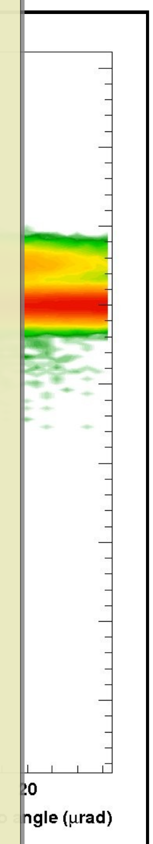


Amorphous layer

Multi-crystals

Beam direction



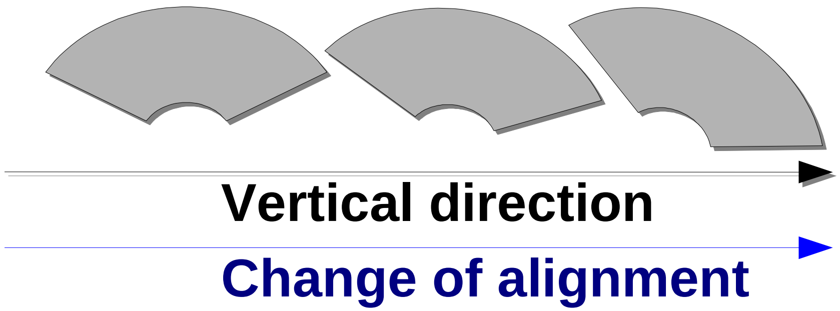


In collimation experiments a small misalignment can be crucial

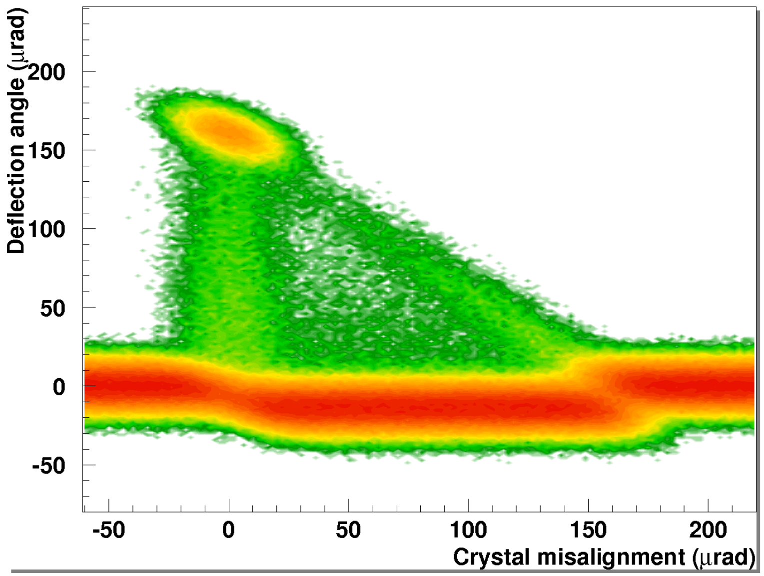
Emulated by CRYM

The "torsion" contribution

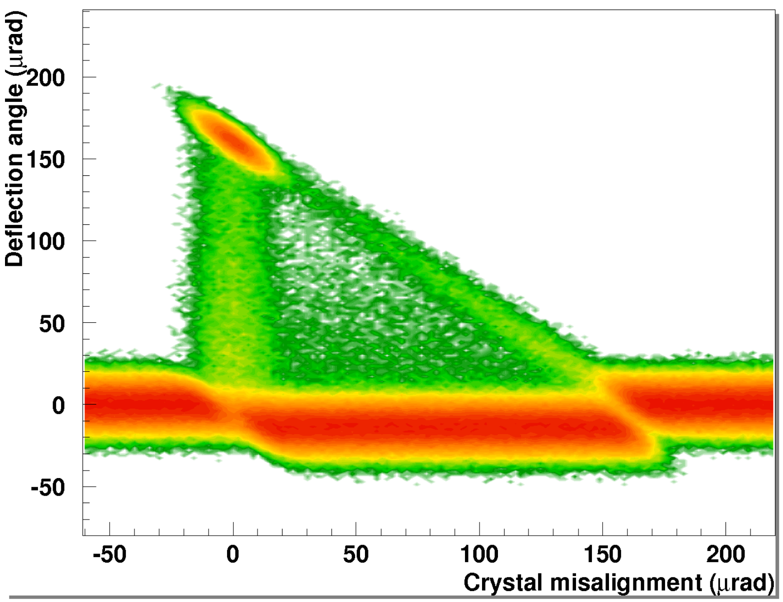
It is experimentally demonstrated that bent crystals are twisted due to mechanical forces



In crystal ST4 ~10μrad/mm was measured



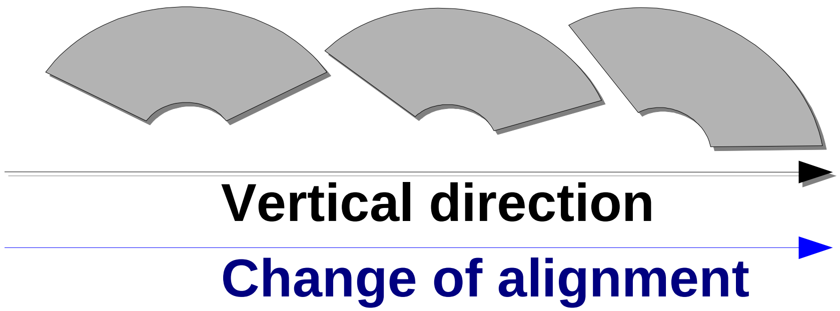
With torsion

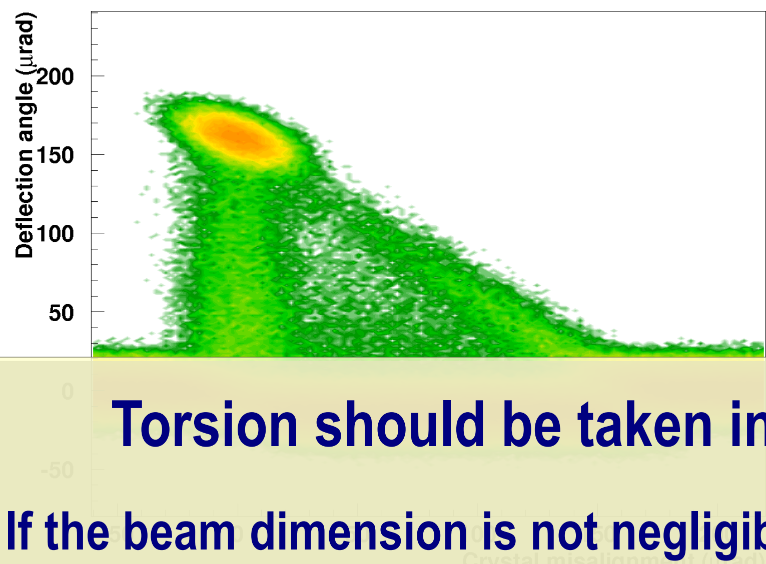


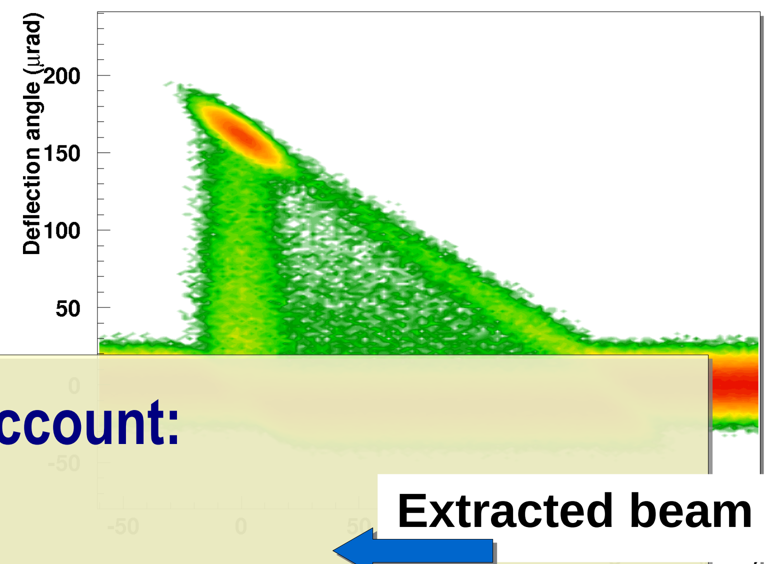
Without torsion

The “torsion” contribution

It is experimentally demonstrated that bent crystal are twisted due to mechanical forces







Torsion should be taken into account:

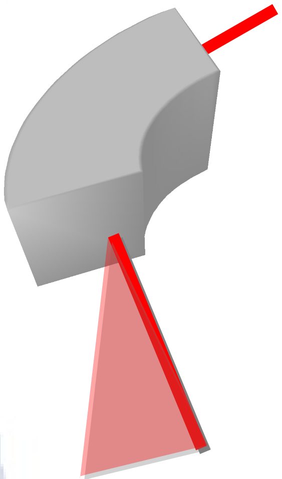
If the beam dimension is not negligible
-> degradation of effective channeling efficiency

Extracted beam

If the beam is not stable
-> degradation of performances especially for multi crystals

circulating beam

Energy scaling



Hypothetic crystal:

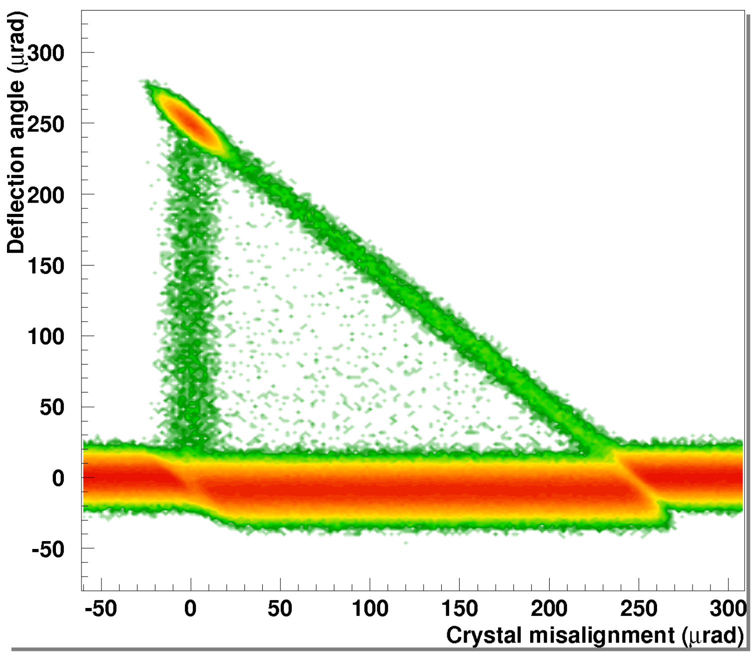
Design: strip (110)

Dimension (h x w x l): (7cm x 0.5cm x 1mm)

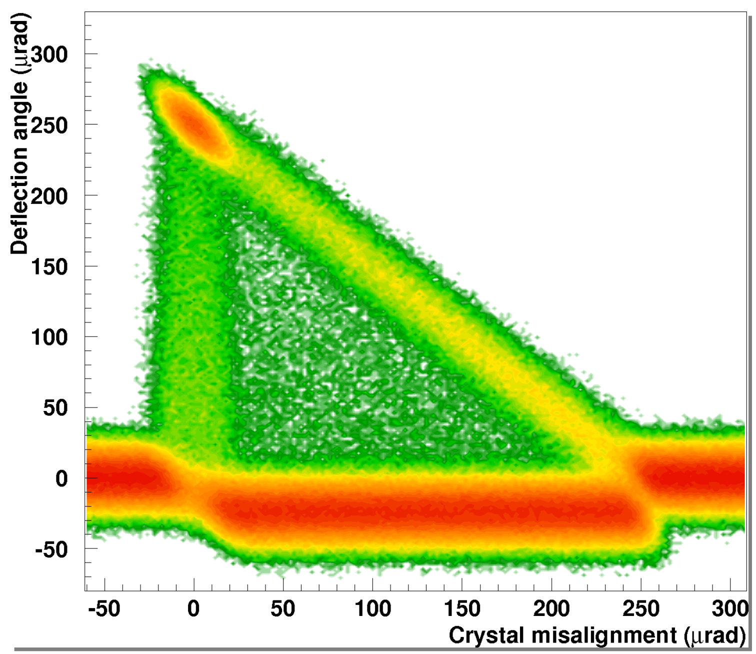
Bending raius: 4m

Torsion: 0 urad/mm

400GeV



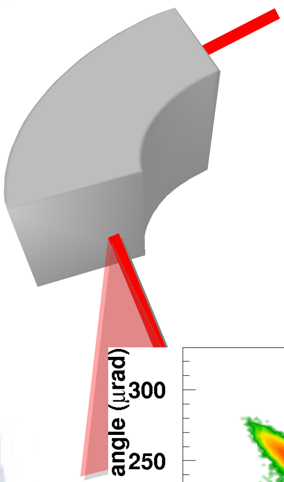
120GeV

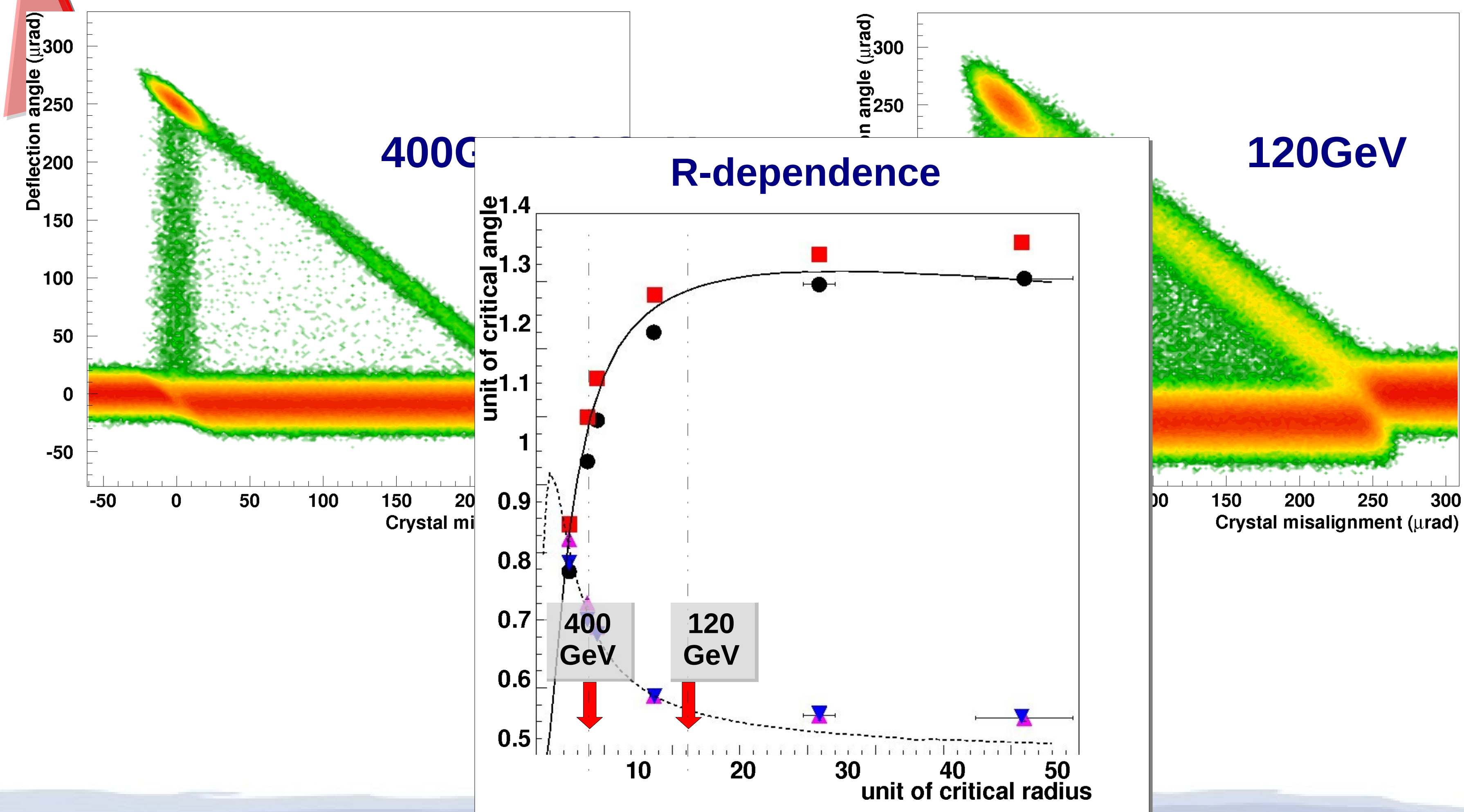


Energy scaling

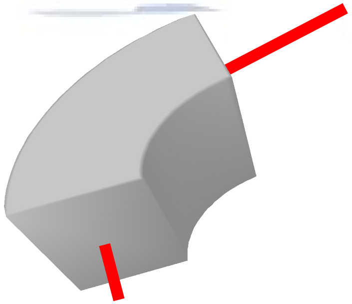
Hypothetic crystal:

Design: strip (110)
Dimension (h x w x l): (7cm x 0.5cm x 1mm)
Bending raius: 4m
Torsion: 0 urad/mm





Conclusions



- **A computer model for the planar channeling phenomena has been developed**
- **The program is designed for the simulation and the analysis of the "accelerator" experiment**
  - **multi-crystals**
  - **torsion**
  - **small misalignment**
- ***NEXT:***
  - **Many details could be added: axial effects and radiation ones**
  - **CRYM is going to be used to simulate the CRYSTAL experiment at CERN**

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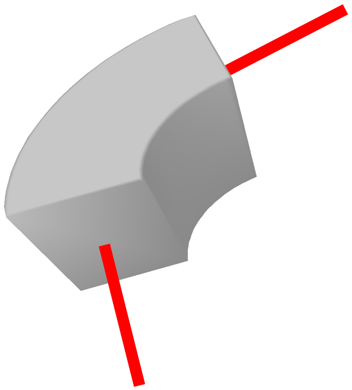

Thank you for your attention!

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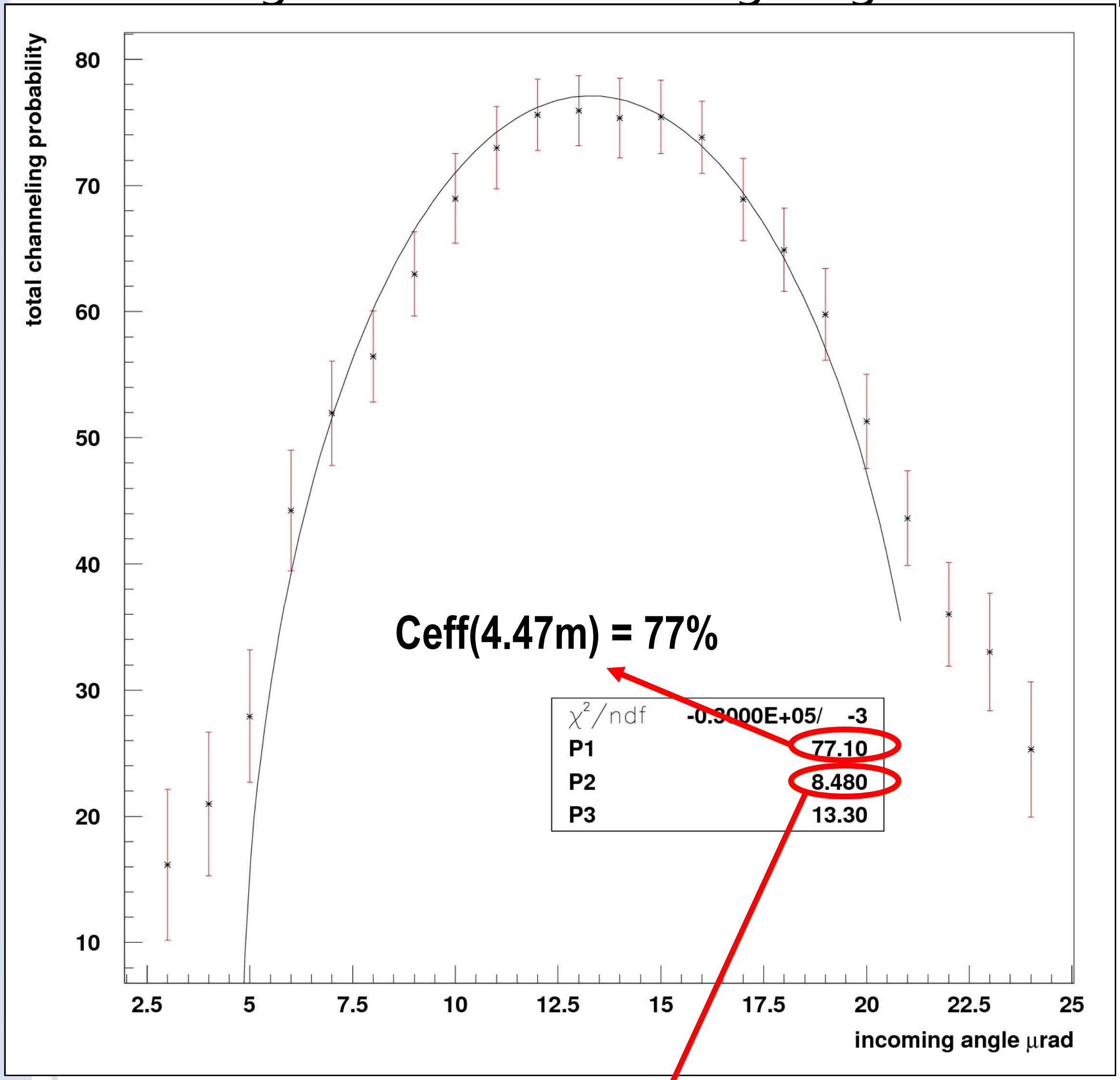
Backup slide 1

Channeling and dechanneling angular acceptance (and efficiency)



The agreement with the theoretical function which describe the channeling acceptance (harmonic potential) approximation is good

$$C_{eff} = C_{eff}^{max} \sqrt{1 - \left(\frac{\theta_c}{\theta_{in}} \right)^2}$$

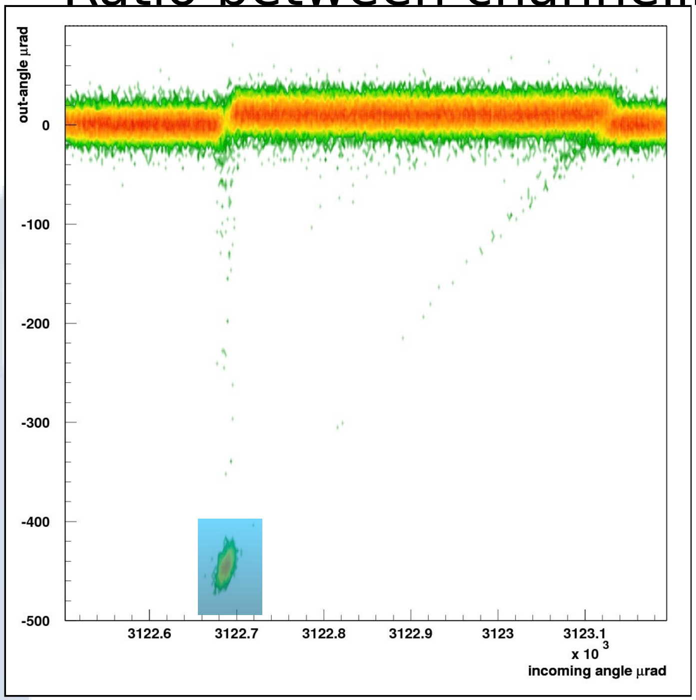
the following scaling law with the bending radius is assumed for CRYM

$$C_{eff}^{max}(R) = C_{eff}^{max}(\infty) \left(1 - \frac{R}{R_c} \right)$$

Critical angle at 400GeV for a bending radius of 4.47m

Backup slide 2

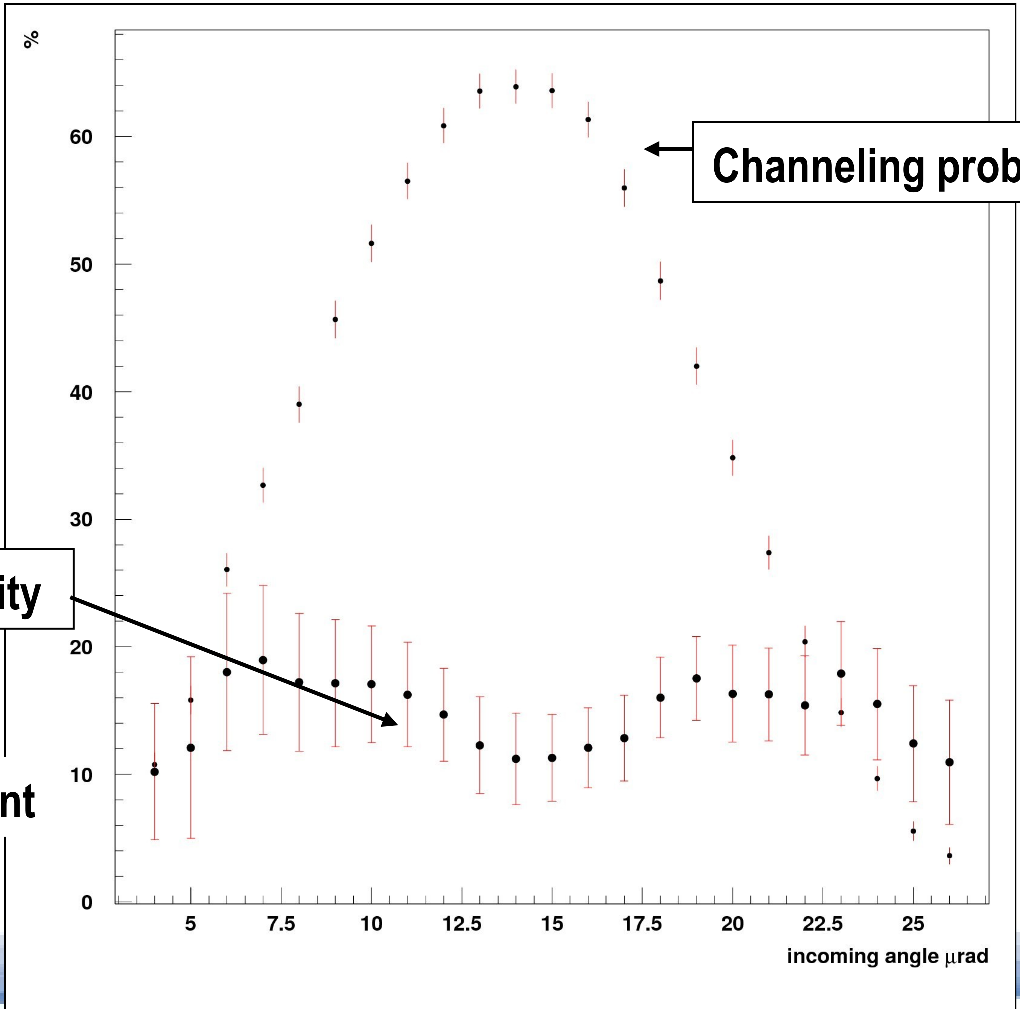
Ratio between channeling and dechanneling yield



Integrating the events in the channeling peak (±3σ) gives:

-The channeling probability

-The dechanneling one subtracting the channeling probability from the previous plot



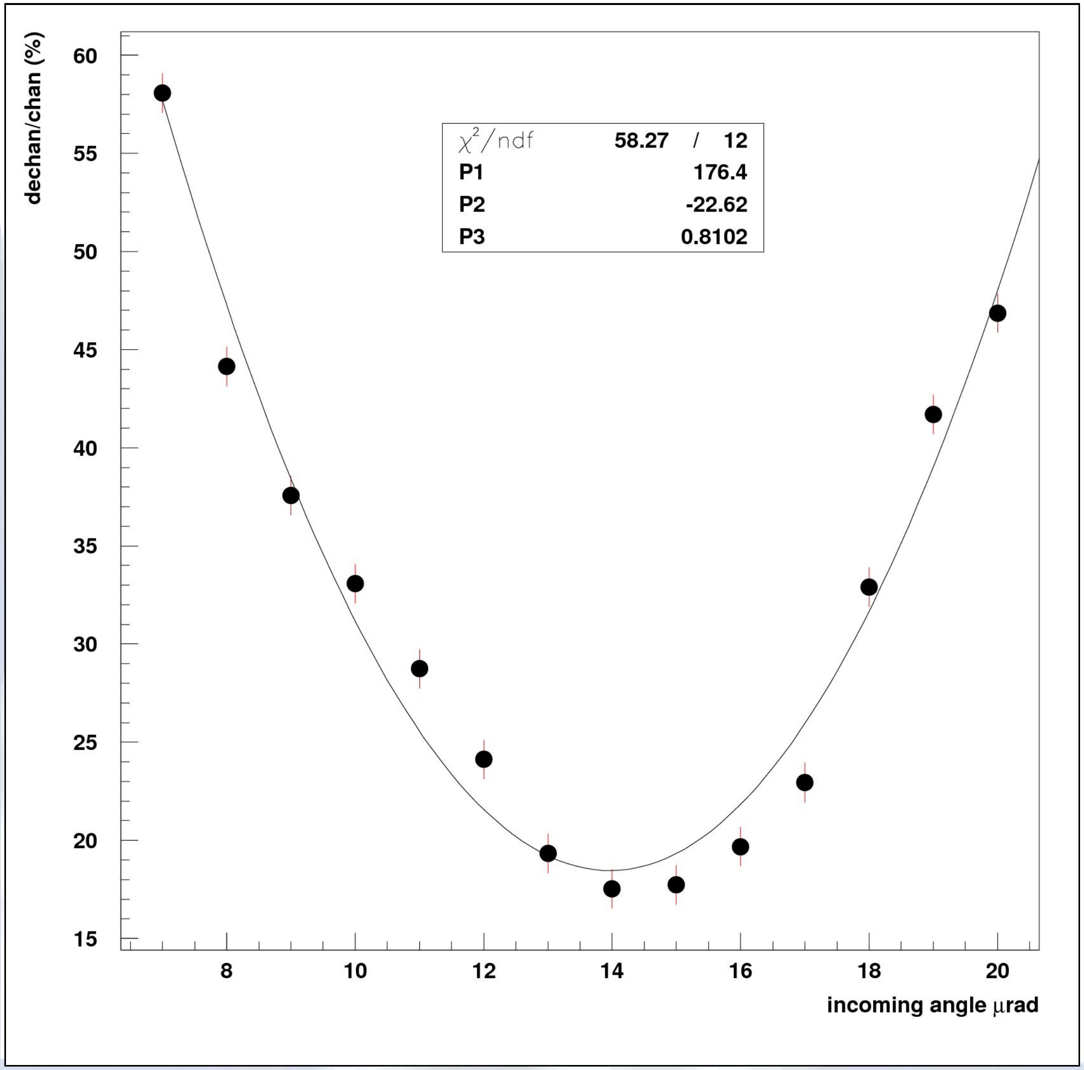
Channeling probability

Dechanneling probability

It depends on the alignment

Backup slide 3

Relative ratio of the two distributions:



It has a parabolic trend as a function of the incoming angle (experimental observation)

The parameters of this function are used in CRYM to compute the dechanneling length as a function of the relative angle between the particle and the crystal

Backup slide 4