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 (e.g., torsion or small spatial misalignment)
- It is an attempt to collect all the planar channeling information into a 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

efficiency $\varepsilon$

- amorphous
- channeling
- Volume Reflection

$\theta$

Channeling angle
Channeling region

Energy scaling

\[ \theta_c = \sqrt{\frac{2U(x_c)}{pv}} \]
\[ R_c = \frac{pv}{U'(x_c)} \]

Curvature scaling

\[ \theta_c^b = \theta_c \left(1 - \frac{R_c^b}{R}\right) \]
\[ C_{eff}^{\max}(R) = C_{eff}^{\max}(\infty) \left(1 - \frac{R}{R_c}\right) \]

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

\[ D_{C_{eff}} \text{ is defined with respect to the total of initially channeled particles} \]

\[ D_{C_{eff}} \approx 20\% \text{ (experimental value)} \]
Reflection region

Energy scaling

\[ VR_{\text{eff}} = VR_{\text{exp}} \times \left( \frac{E[\text{GeV}]}{400} \right)^{3/2} \]

\( \sim 96\% \)

@400 GeV/c
R~15R

(100-96)\%

Volume capture

Dechanneling of volume capture
Reflection region

Curvature scaling

“effects” produce deflection

Amorphous orientation and amorphous layer

Gaussian distribution with \( \sigma \):

\[
\theta_m = \frac{13.6 \text{ MeV}}{\beta_c p} z_p \sqrt{x/X_0} (1 + 0.038(x_c/X_0))
\]

Beam divergence: 7\(\mu\)rad
Design: strip
Dimension (h \( \times \) w \( \times \) l): (7cm \( \times \) 1mm \( \times \) 3mm)

![Graph of Gaussian distribution with data points showing most probable and mean values.]
“effects” produce deflection

Channeling and dechanneling

Channeling and dechanneling events are
exponentially distributed

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

The dechanneling events are
exponentially distributed

Channeling angle

\[ \theta_{ch} = \frac{L}{R} \]
“effects” produce deflection

Volume reflection and volume capture

\[ \sigma_{e} = \sigma_{vr} + \sigma_{am} \]

“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)

**Emulation of the ST4 crystal**

Multi-crystals emulation is easy

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

Emulated by CRYM

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

Multi-crystals

Amorphous layer

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 \( \sim 10 \mu \text{rad/mm} \) 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

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

Hypothetic crystal:
- Design: strip (110)
- Dimension \((h \times w \times l)\): \((7\text{cm} \times 0.5\text{cm} \times 1\text{mm})\)
- Bending radius: 4m
- Torsion: 0 urad/mm

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**400GeV**

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**120GeV**
Energy scaling

Hypothetic crystal:

- Design: strip (110)
- Dimension (h × w × l): (7cm × 0.5cm × 1mm)
- Bending radius: 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.
Thank you for your attention!
Backup slide 1

Channeling and dechanneling angular acceptance (and efficiency)

The agreement with the theoretical function which describes 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.

C_{eff}(4.47m) = 77%
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

It depends on the alignment
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