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# TEST AND CHARACTERISATION OF BENT CRYSTAL PROTOTYPES

**Milan October 4, 2019**

# Outline

- **Introduction**
  - Needs for MDM and EDM measurement
  - Channeling in very long crystals
- **CRYSTALRAD** simulation code & **Geant4**
- **Experimental** and **simulation** results
  - Experimental setup
  - Experimental setup implemented in Geant4
  - Measured and simulated deflection angle distributions

# SELDOM: characterization of bent crystals for the future measurement MDM and EDM

**What we want:**

- To measure **MDM** and **EDM**

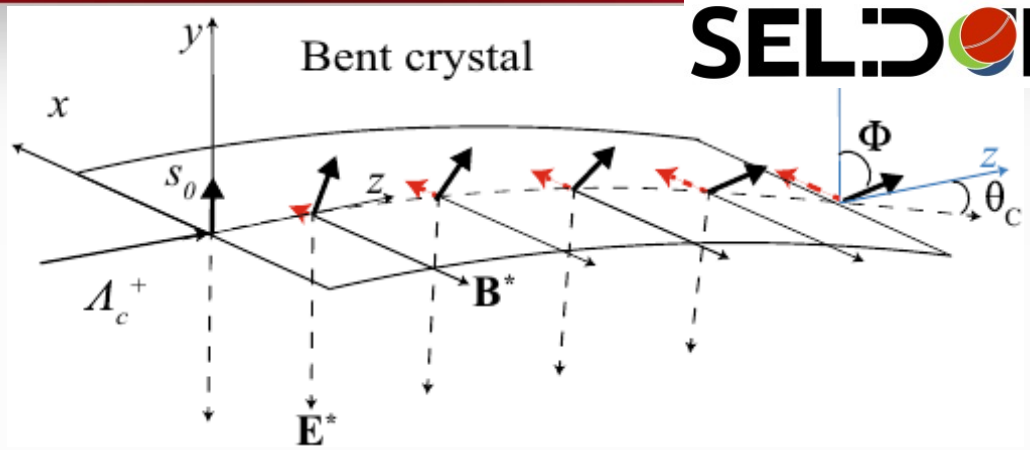
**What we have:**

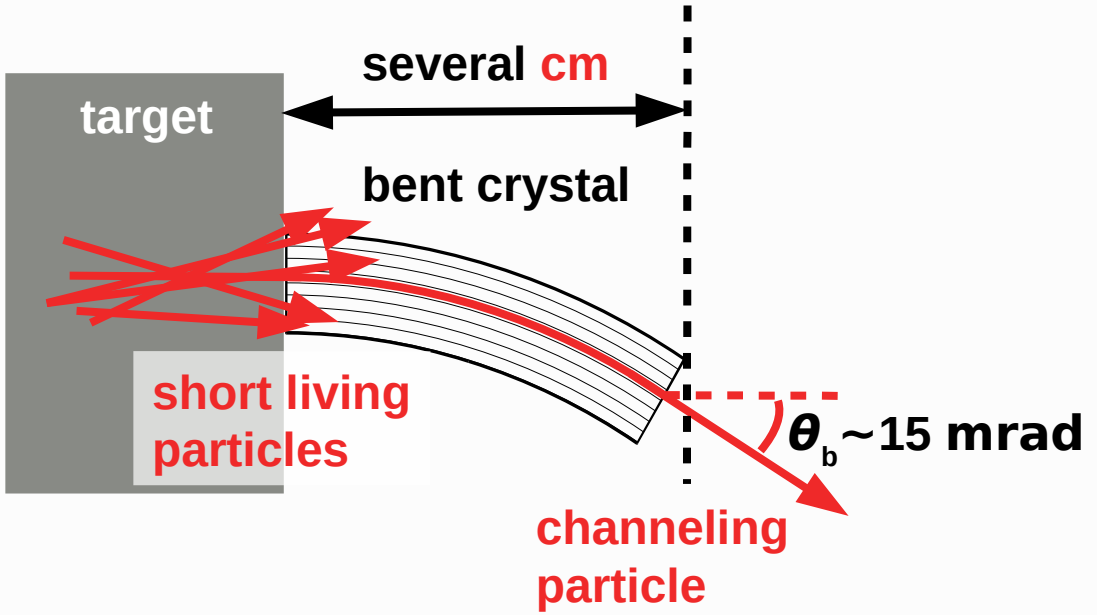
- **Very divergent beam** of short living particles
- **Very short lifetime**

**What we need:**

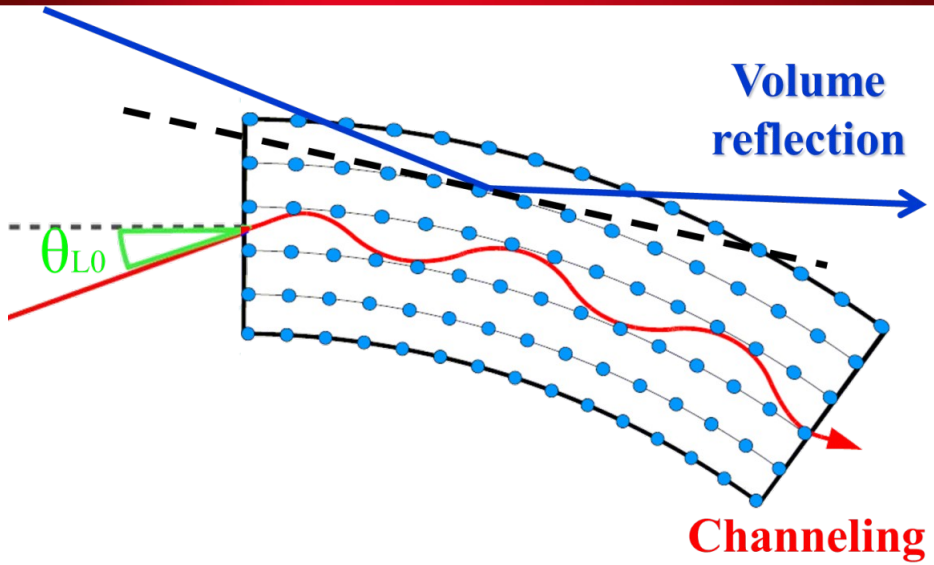
- The **bent crystal** attached to the target
- **Low crystal thickness**
- **High deflection angle**

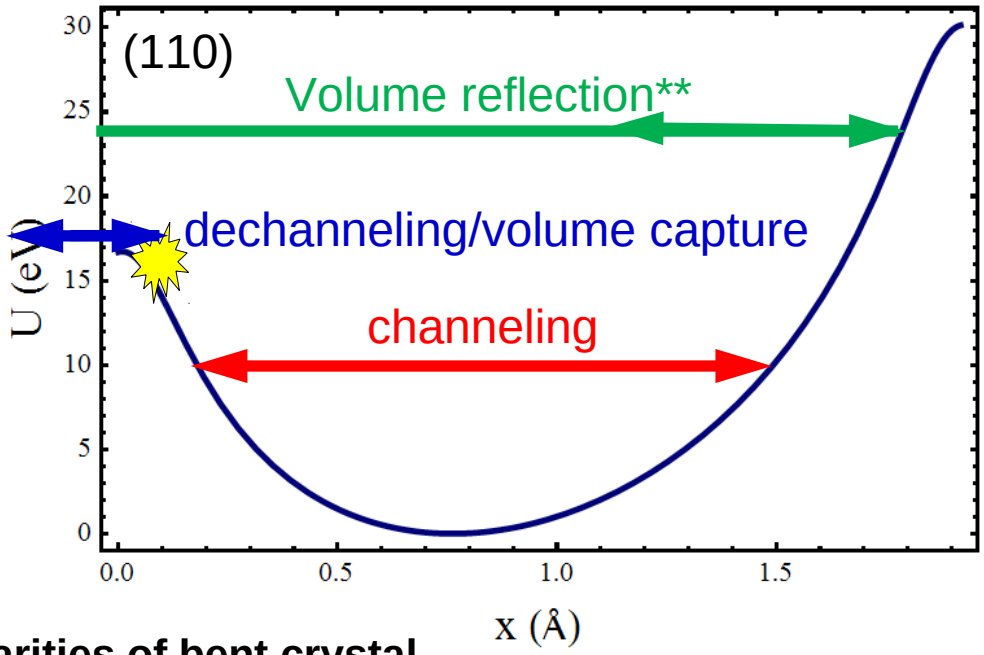
**Crystal thickness** must be **comparable** with the **lifedistance** of the particle



# Channeling and volume reflection in a bent crystal*




**Critical channeling angle (Lindhard angle)**

$$\theta_L = \sqrt{\frac{2U_0}{pv}}$$

**Critical channeling radius**

$$R_{cr} = \frac{pv}{E_0}$$

**Pecularities of bent crystal in SELDOM experiment:**

- Very thick bent crystals ~ **several cm**
- Very high deflection angle ~ **15 mrad**

→ **Low deflection efficiency**

**No channeling data either for 180 GeV or for 1 TeV for such crystals**

***E.N. Tsyganov, Fermilab TM-682 (1976)**

****A.M. Taratin, S.A. Vorobiev, NIM B 26, 512 (1987)**

# CRYSTALRAD simulation code*

**Main conception** – tracking of charged particles in a crystal in averaged atomic potential

**Program modes:**

- **1D** model – particle motion in an interplanar potential
- **2D** model – particle motion in an interaxial potential

**Simulation of the different physical processes:**

- Multiple and single **Coulomb scattering** on nuclei and electrons.
- **Nuclear scattering**
- **Ionization energy losses**
- **Crystal geometry**

**New**: unification of **CRYSTAL**** and **RADCHARM++***** simulation codes into the **CRYSTALRAD** code to simulate the radiation spectra by Baier-Katkov formula

**Advantages:**

- High calculation speed
- **MPI** parallelization for high performance computing

**Project VELOCE special for SELDOM simulations. MARCONI: 320 kh**

**What have we been granted by (2016-2019)?**

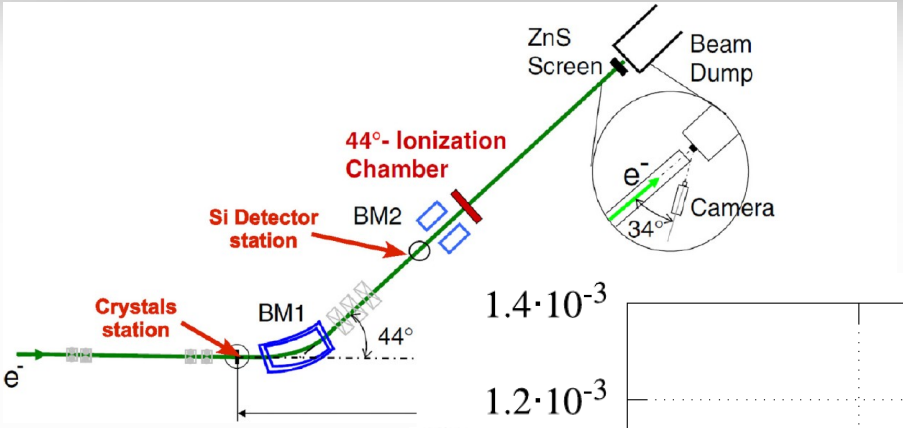
- **FERMI: 200 kh**
- **GALILEO: 100 kh**
- **MARCONI: 900 kh**

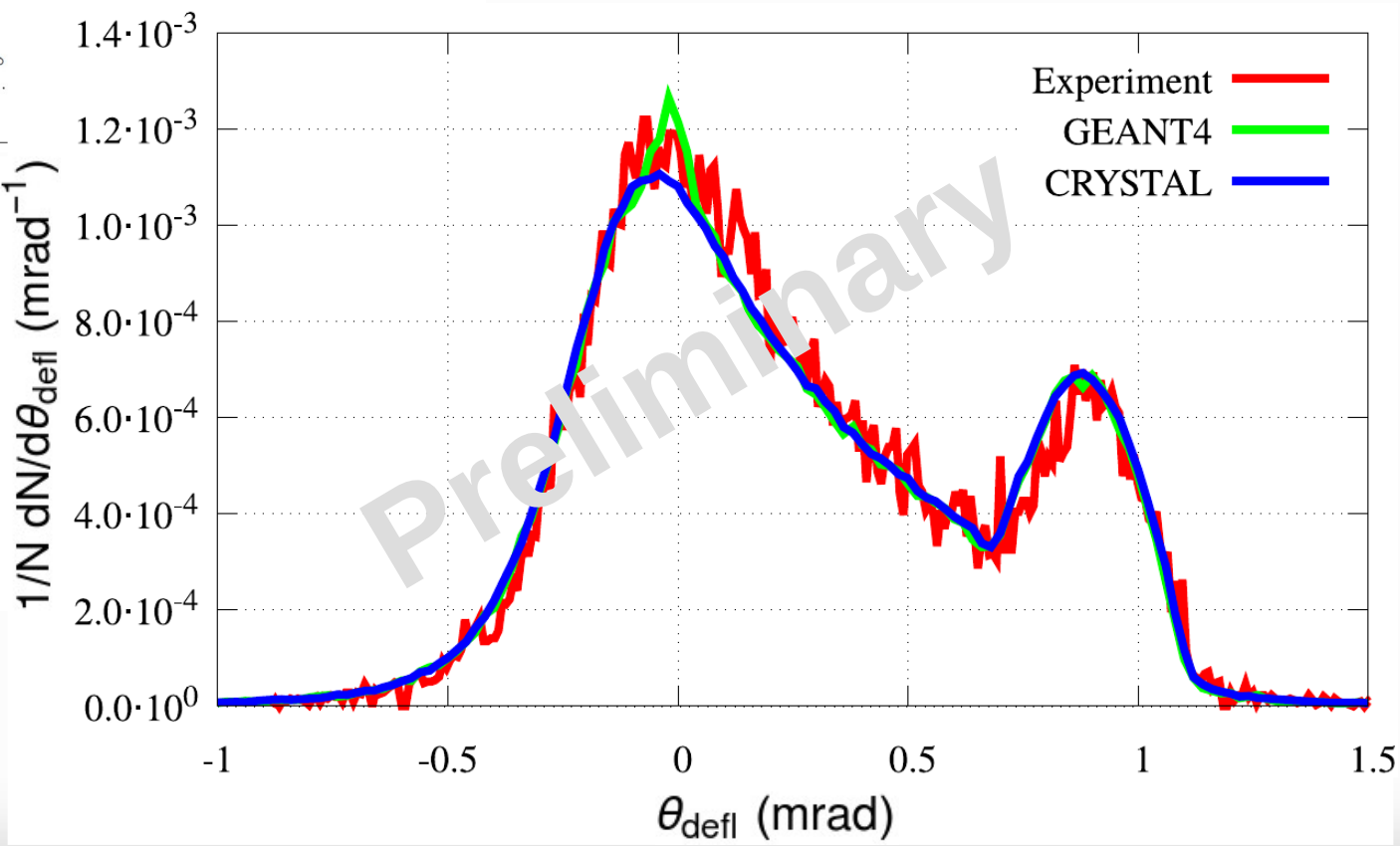
****A.I. Sytov, V.V. Tikhomirov. NIM B 355 (2015) 383–386.**

*****L. Bandiera, et al., Nucl. Instrum. Methods Phys. Res., Sect. B 355, 44 (2015)**

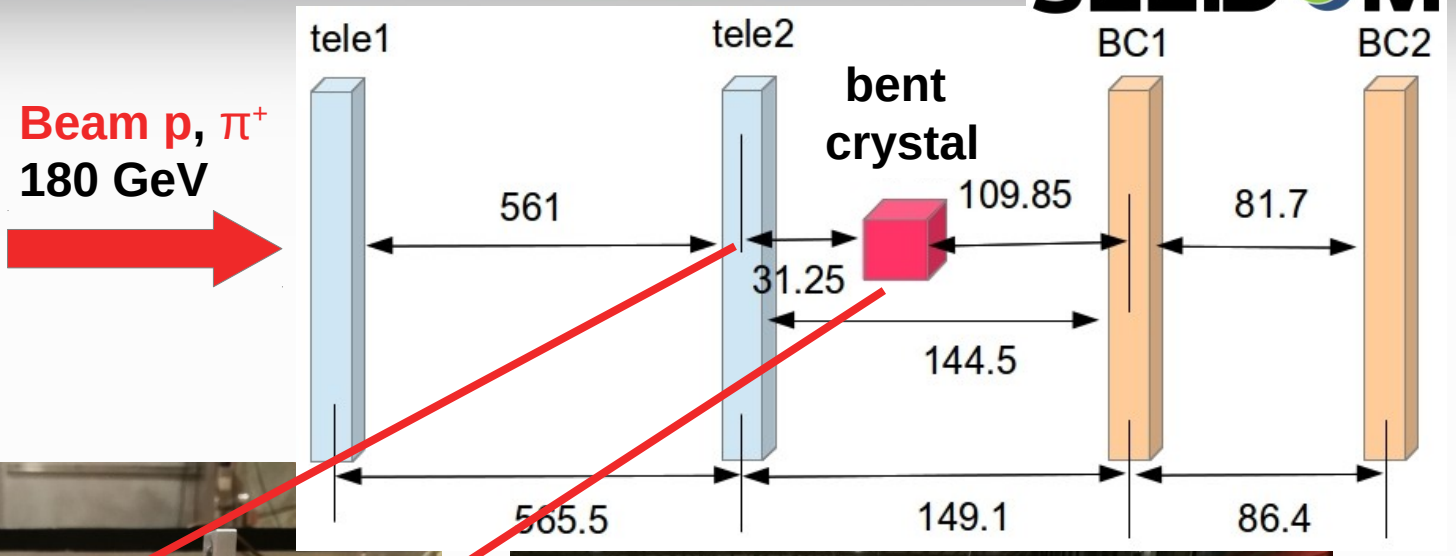
***A. I. Sytov, V. V. Tikhomirov, and L. Bandiera Phys. Rev. Acc. Beams 22, 064601 (2019)**

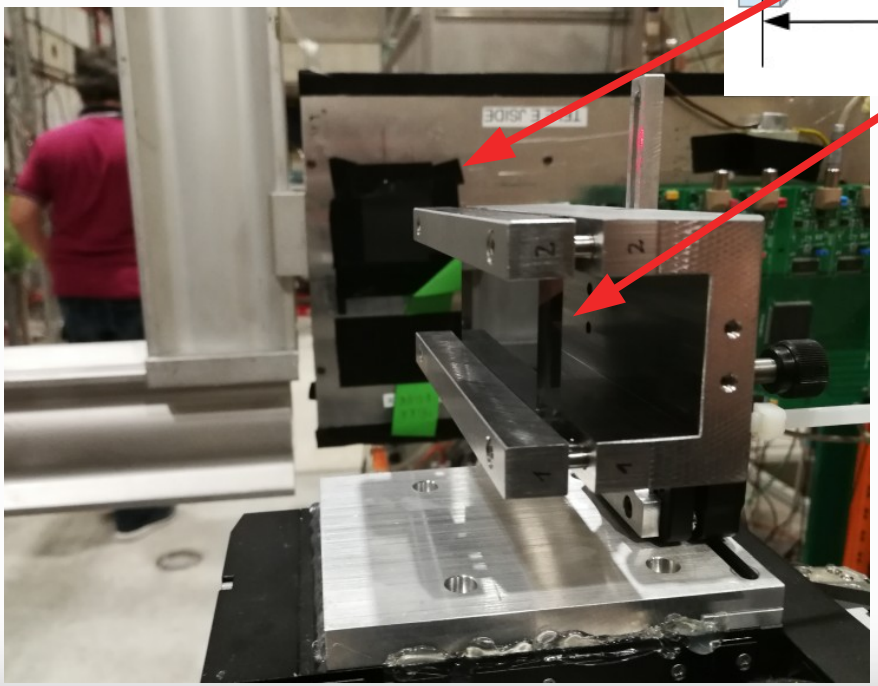
# Insertion of CRYSTAL routing inside Geant4: validation on channeling of 855 MeV electrons at Mainz Mikrotron MAMI

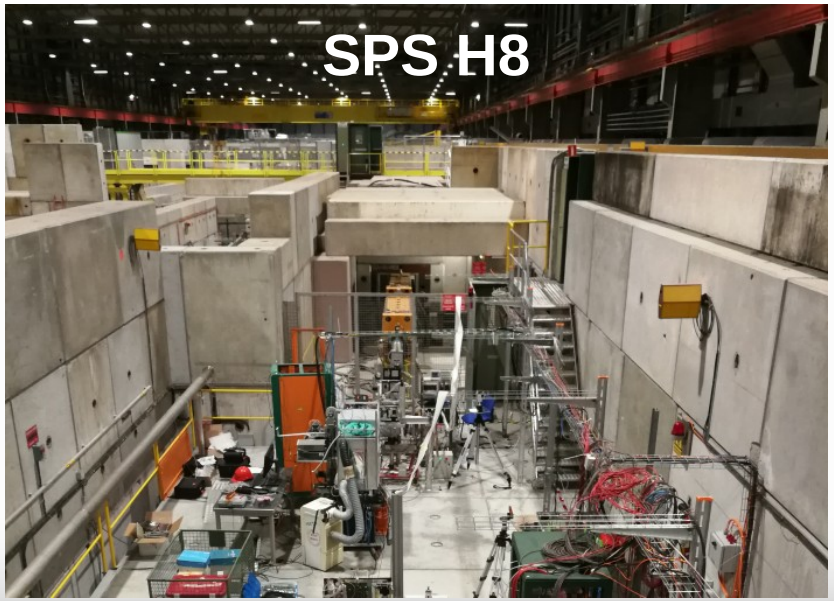


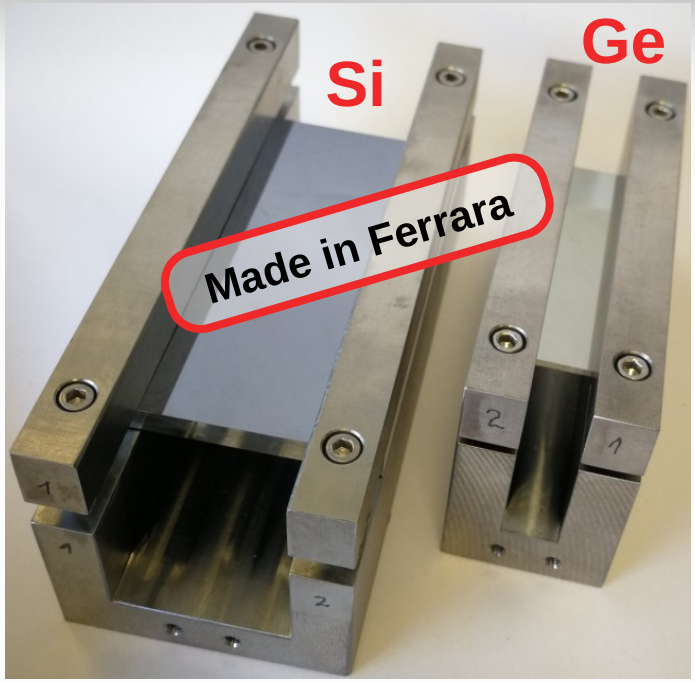
# SELDOM setup in experiment at CERN SPS H8





# SELDOM setup: the bent crystals

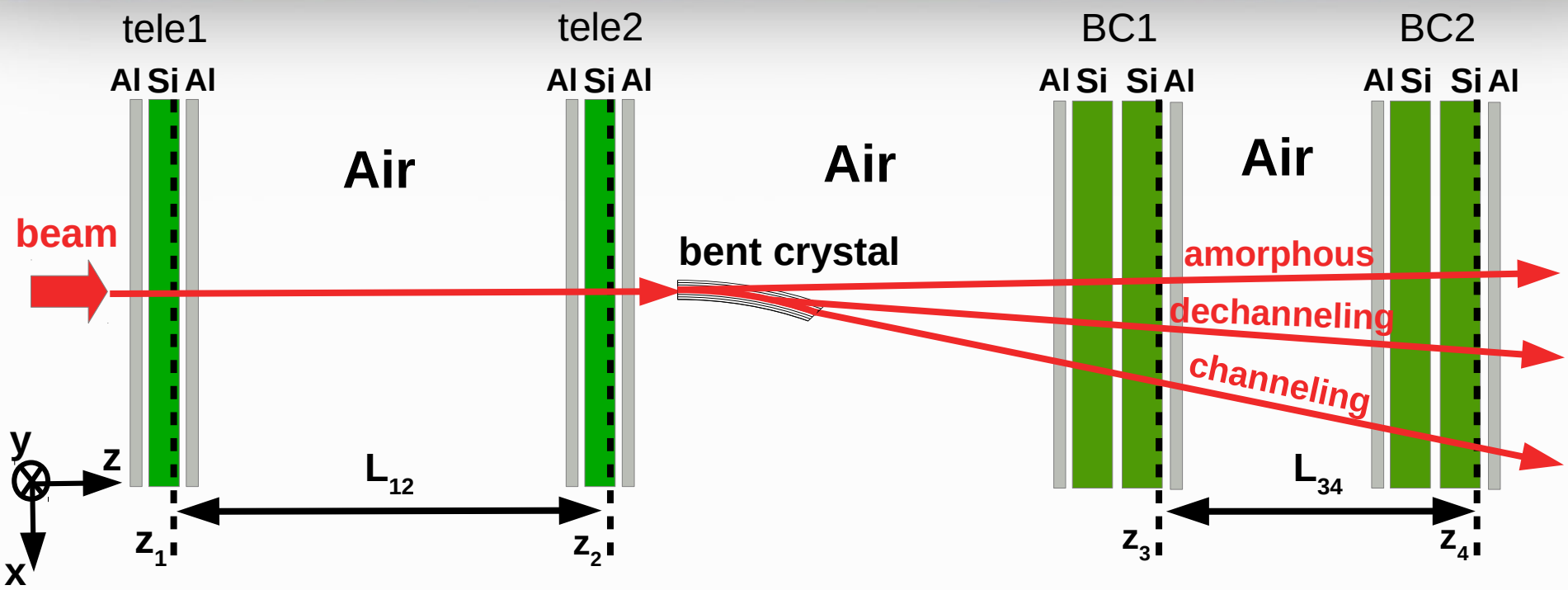



**Si**
- length: **8 cm**
- bending angle: **16 mrad**
- planes: **(111)**

**Ge**
- length: **5.5 cm**
- bending angle: **14.7 mrad**
- planes: **(110)**

**Ge is shorter with a factor 1.5 than Si**


# SELDOM setup in Geant4




**Beam:**

- r.m.s. size: 1 mm
- angular divergence: 24 μrad
- protons 180 GeV: 2/3
- pions $\pi^+$ 180 GeV: 1/3

**tele1 & tele2:**

- **Si** 0.3 mm thick
- 2 layers of **Al**: each 0.1 mm thick

**World material: G4_AIR**

**BC1 & BC2:**

- 2 layers of **Si**: each 0.41 mm thick
- 2 layers of **Al**: each 0.1 mm thick

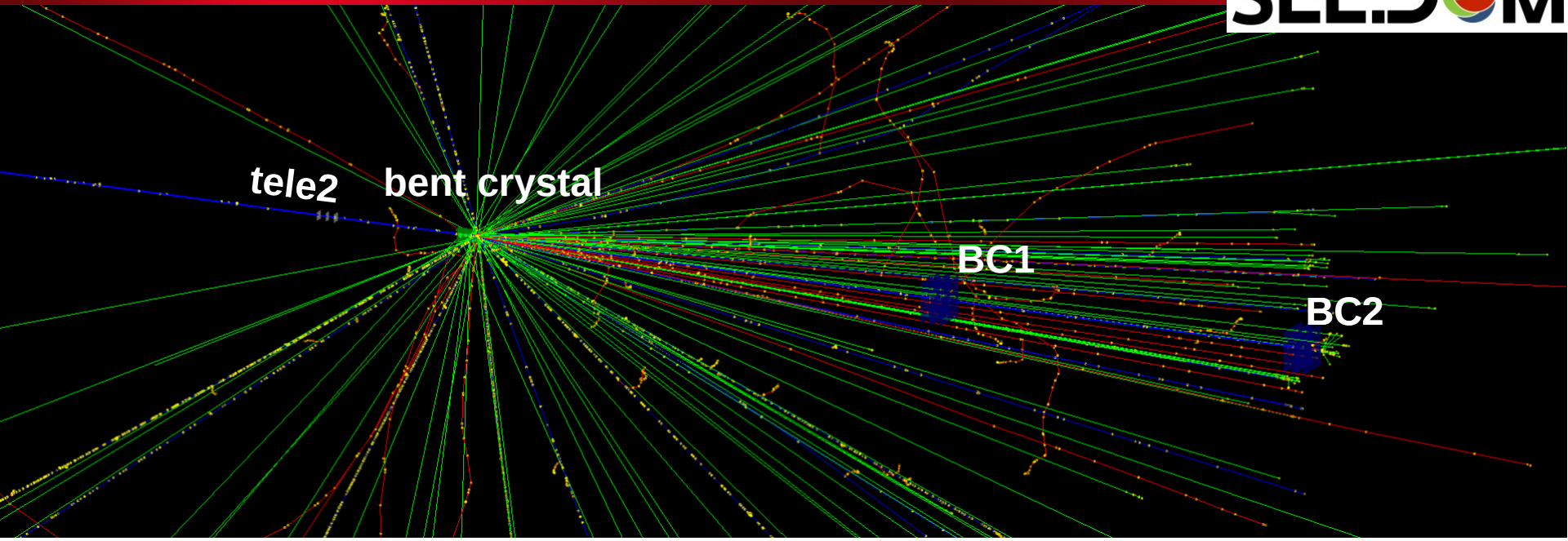
**Definition of angles:**

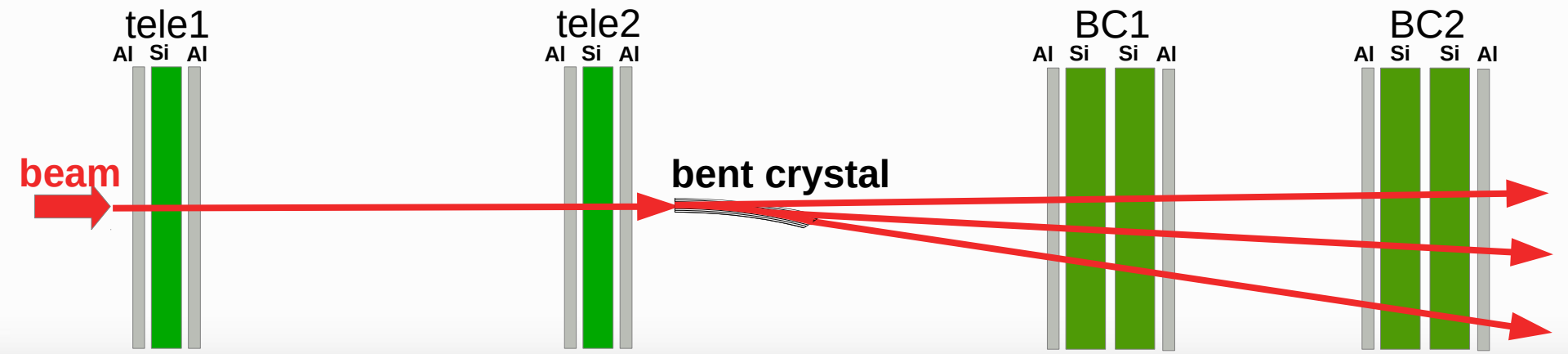
$\theta_{in} = (z_2 - z_1)/L_{12}$

$\theta_{out} = (z_4 - z_3)/L_{34}$

$\theta_{defl} = \theta_{out} - \theta_{in}$

# Visualization of Geant4 simulations: secondary particles

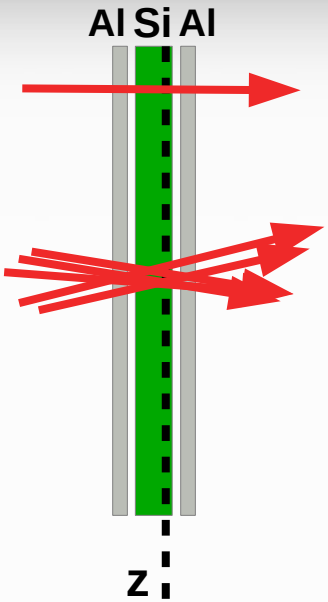


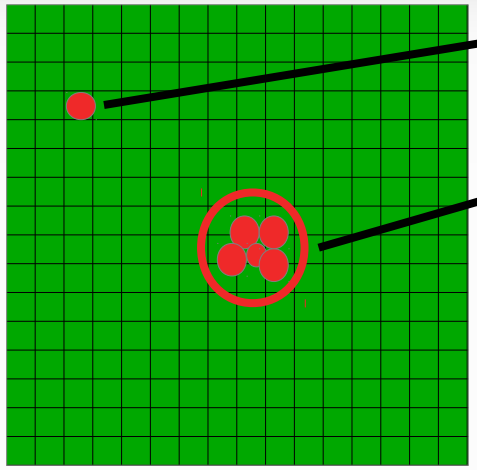



# Strip detectors in Geant4

In each **silicon** layer for **each particle** we score:

- **X, Y positions**
- **$\theta_X$, $\theta_Y$ angles**
- **deposited energy**
- **particle type**



recorded as **one** event

recorded as **one** event

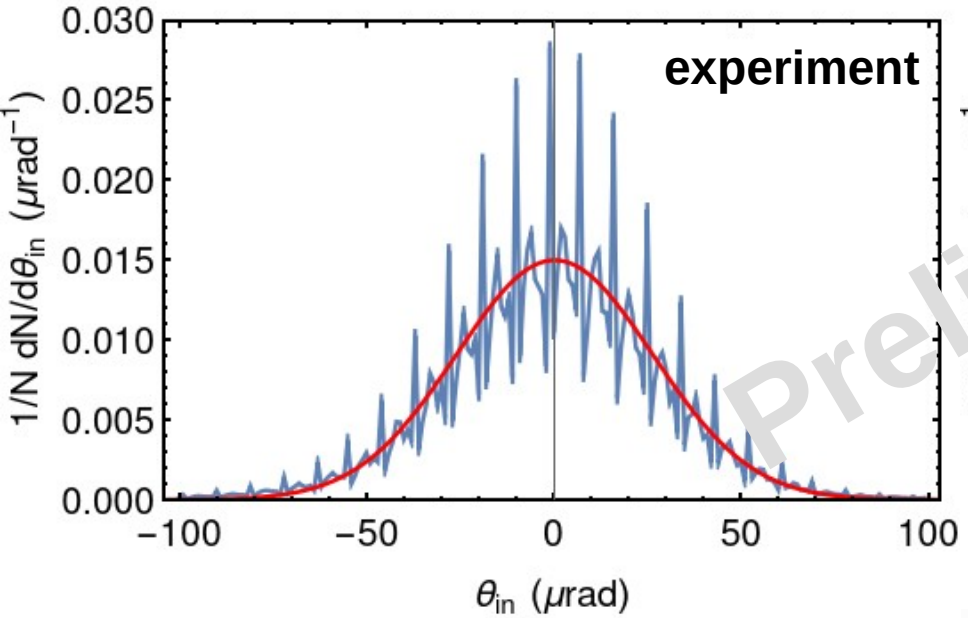
We consider:
**deposited energy ~charge collected**

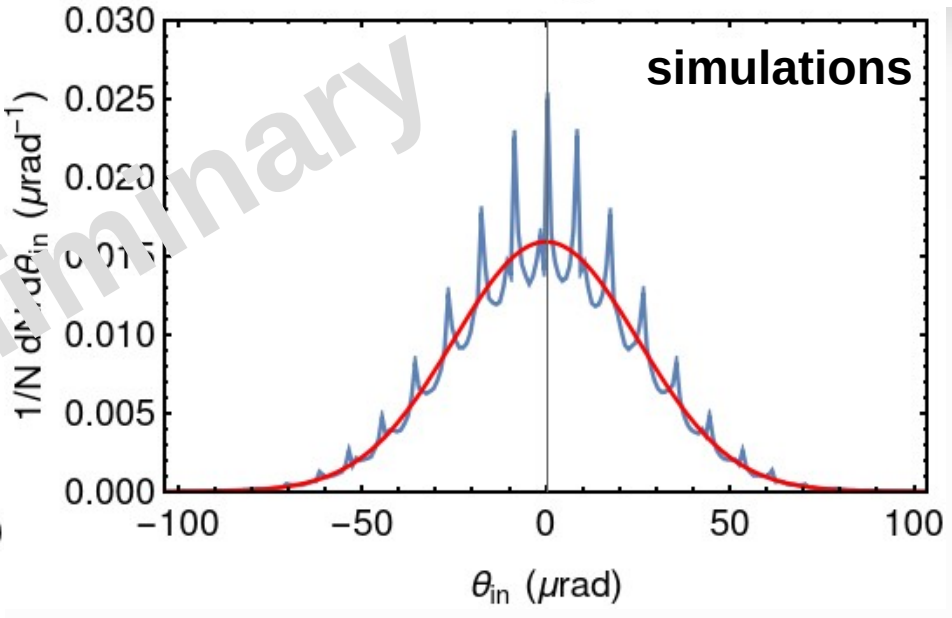
We distinguish single and multiple events

We keep **only single events** (At **all** the strip detectors)

We calculate the initial and deflection angle distribution $\boldsymbol{\theta}_{\mathbf{in}}$ and $\boldsymbol{\theta}_{\mathbf{defl}}$

# Tracker to measure the incidence angle





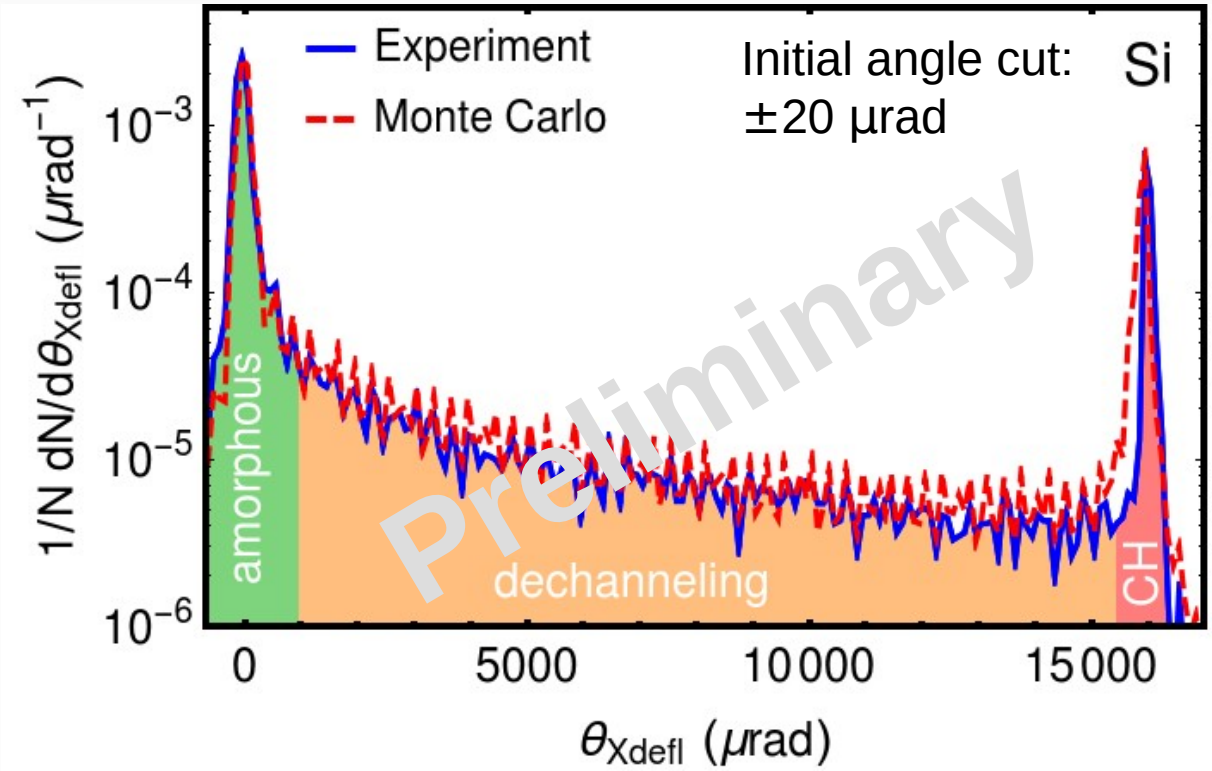

**Non zero resolution reasons:**

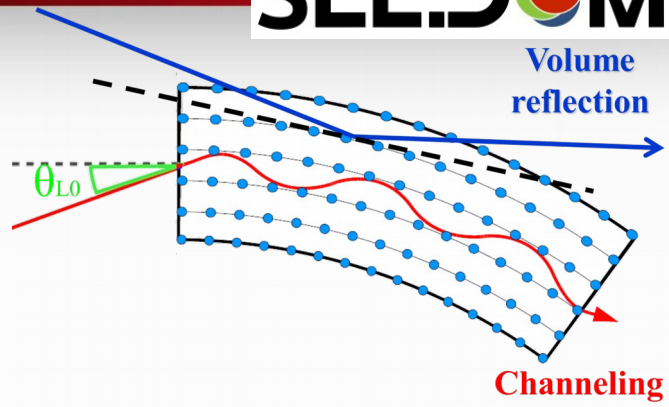
- **Scattering** on **Si** and **Al**
- **Scattering** on **air** in and after the tracker
- Space charge distribution and **strip size**
- Multiple events

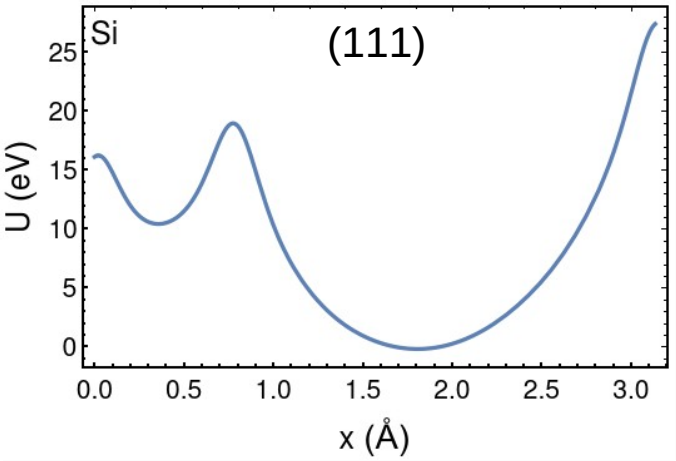
**These factors were considered in simulations**

Angular **uncertainty** of **initial angle** estimated by Geant4 simulations:
**~7 µrad**

# Experimental vs simulation results for Si bent crystal

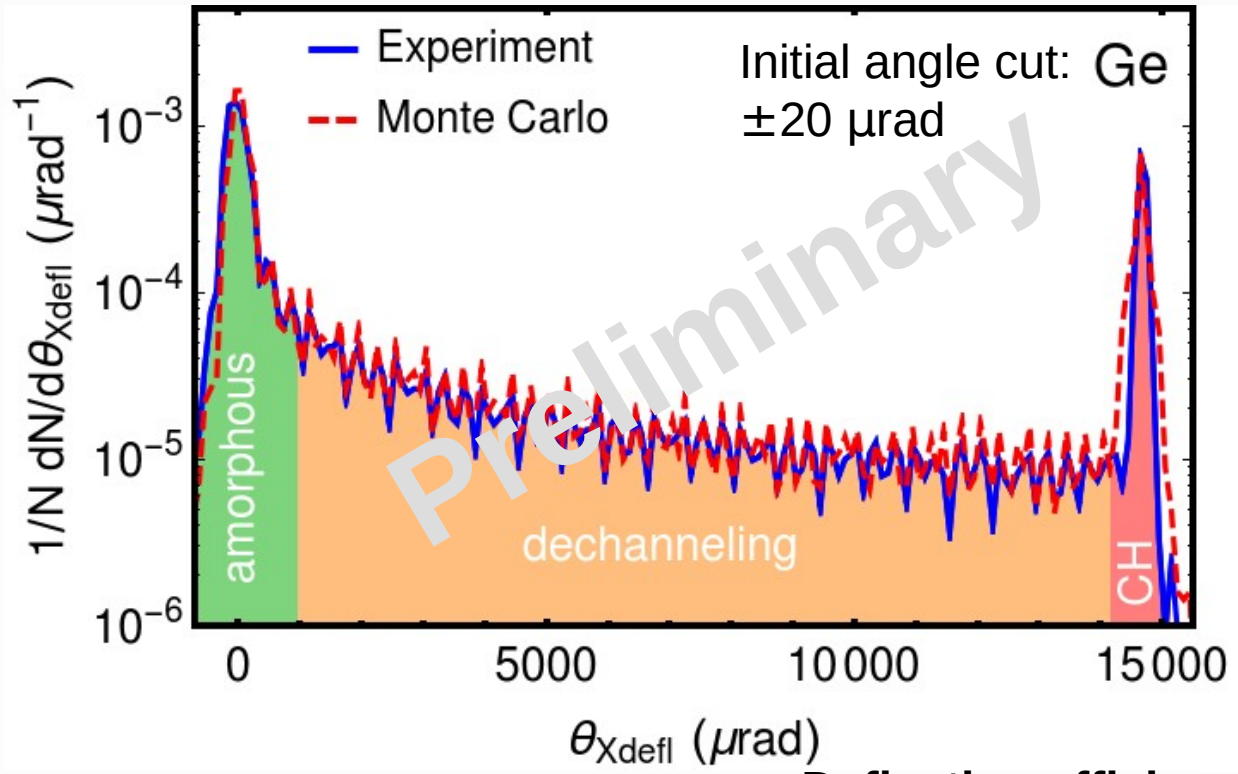


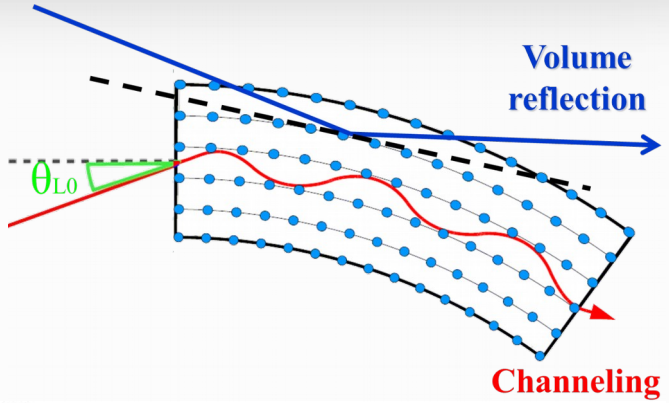



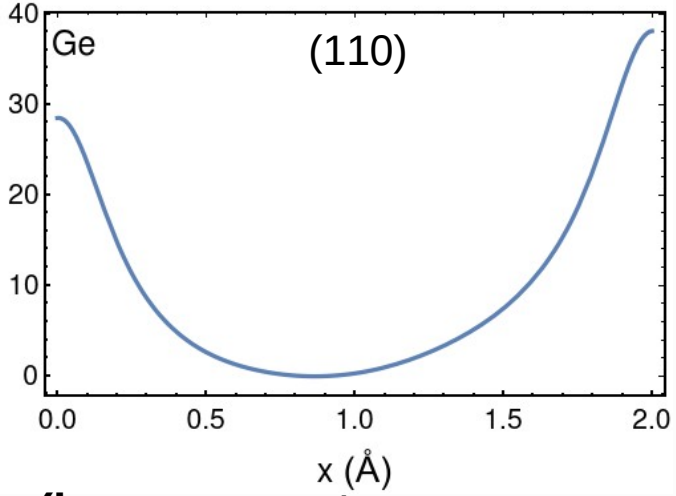




**Deflection efficiency (in agreement with analysis by Milano group):**
Experiment: **11±2 %**
Simulations: **13±1 %**

# Experimental vs simulation results for Ge bent crystal



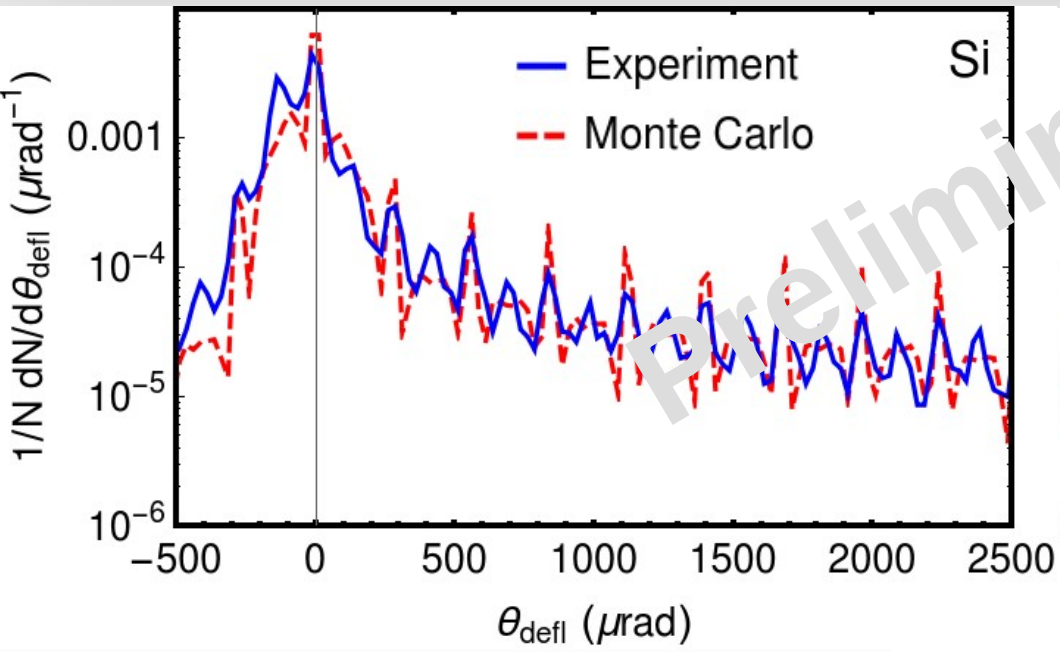

**Ge is thinner but more efficient than Si**

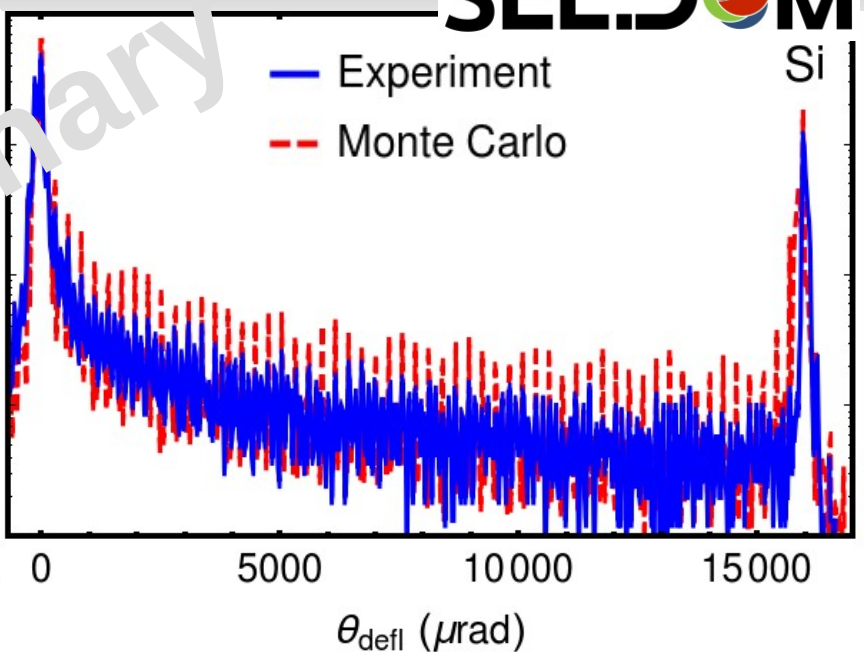
**Deflection efficiency (in agreement with analysis by Milano group):**

Experiment: **13±2 %**

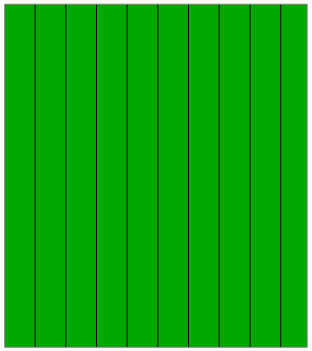
Simulations: **15±1 %**

# Experimental vs simulation results for Si bent crystal: effect ofstrips of the tracker of outcoming angle



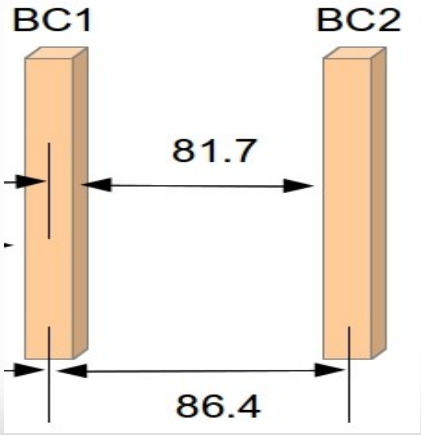


**Peaks** in the deflection angle distribution are **connected with**

- **Strip size**
- The **distance** between strip **detectors**

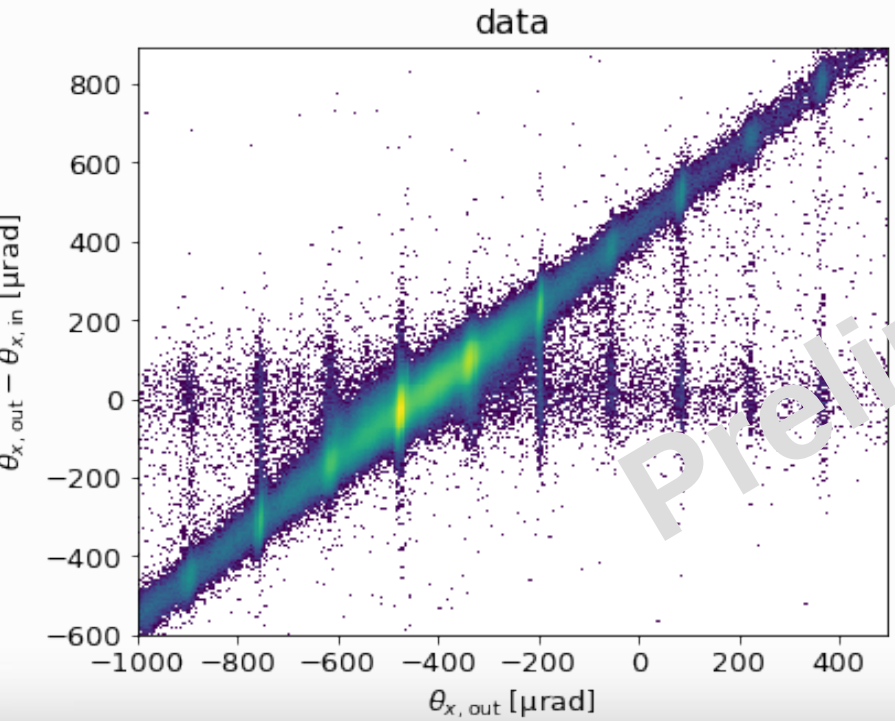
Angular **uncertainty** of outcoming **angle ~50 µrad**

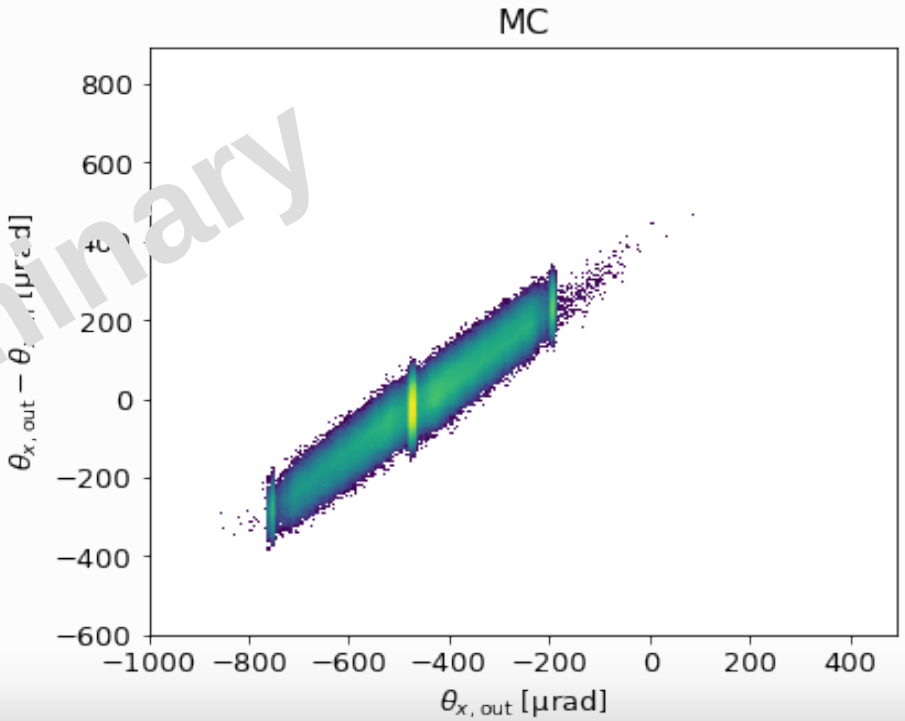


# Important contribution into experimental and simulation results of INFN Milano Group

Deflection angle vs $\theta_{out}$ in xz plane

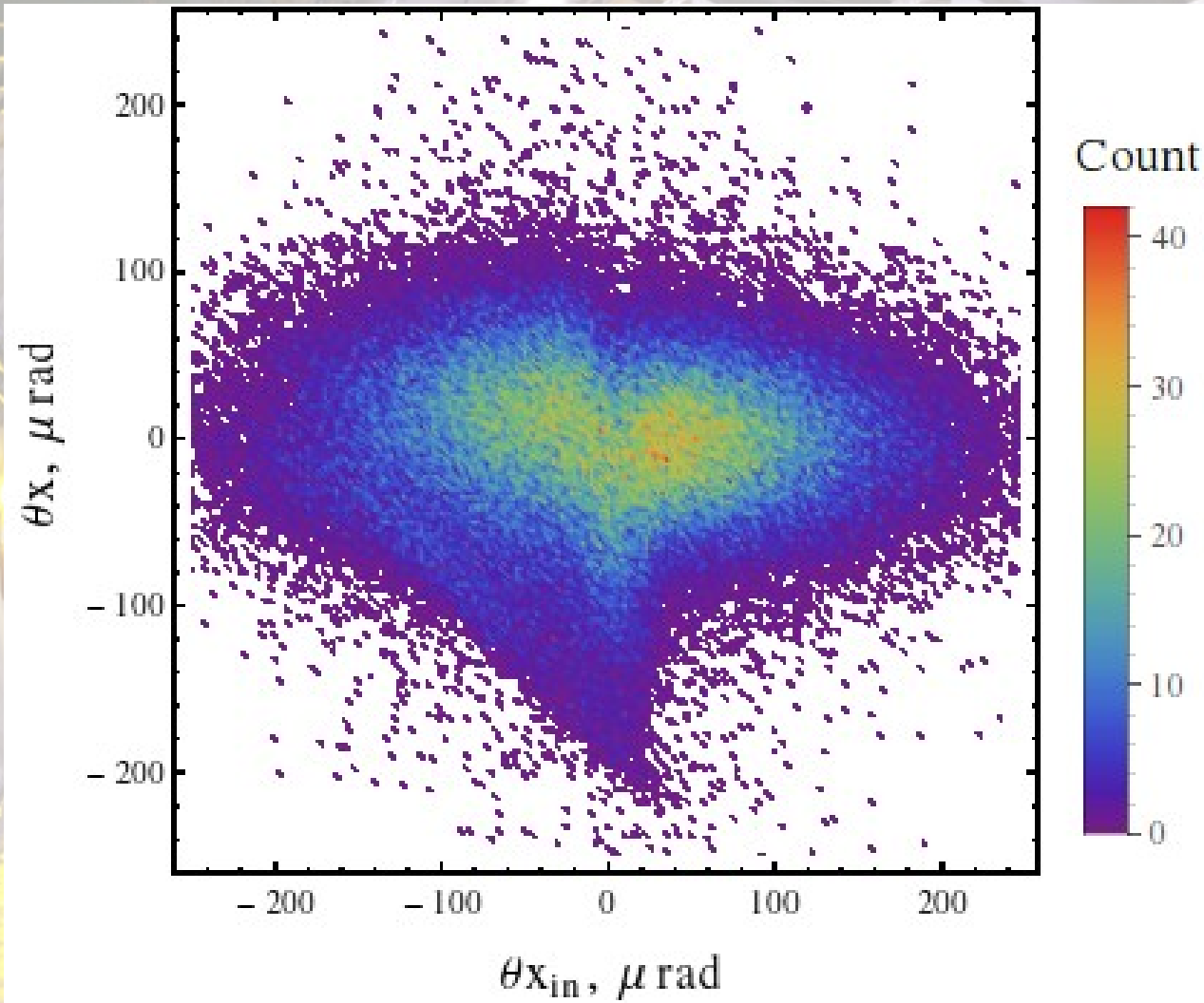
- non-channelled particles



# Conclusions

- **Channeling** of 180 GeV protons and pions in **very long** Si and Ge **bent crystals** was **observed**.
- **Ge** crystal is **more efficient** than the Si one and thinner which is very important for the **MDM** and **EDM** measurements.
- All the **experimental results** were **reproduced** by simulations using **Geant4** with CRYSTAL routine and complete experimental setup implemented
- **Channeling** of **1 TeV exotic baryons** will be less efficient but still **possible** in SELDOM experiment




# Thank you for attention!