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40th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

VIRTUAL CONFERENCE

Future prospective for bent crystals in accelerators

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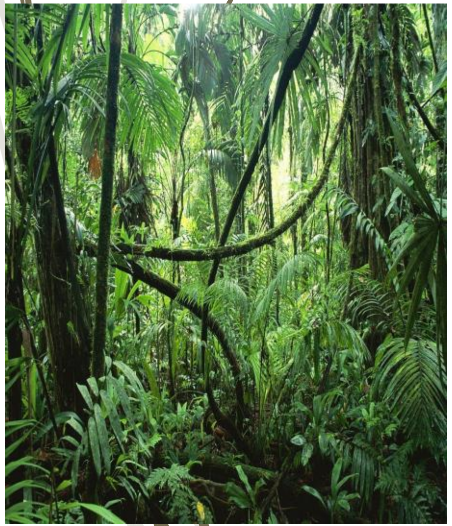
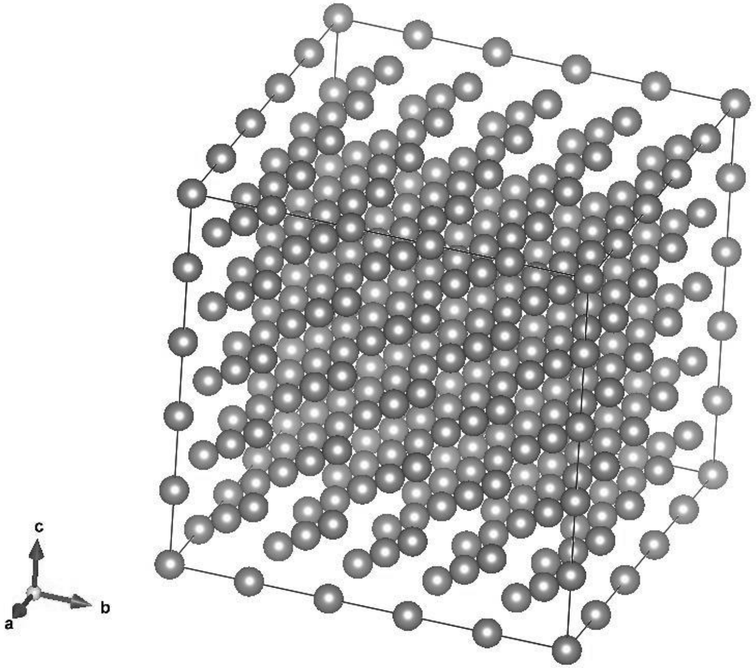
Coherent interaction in crystals

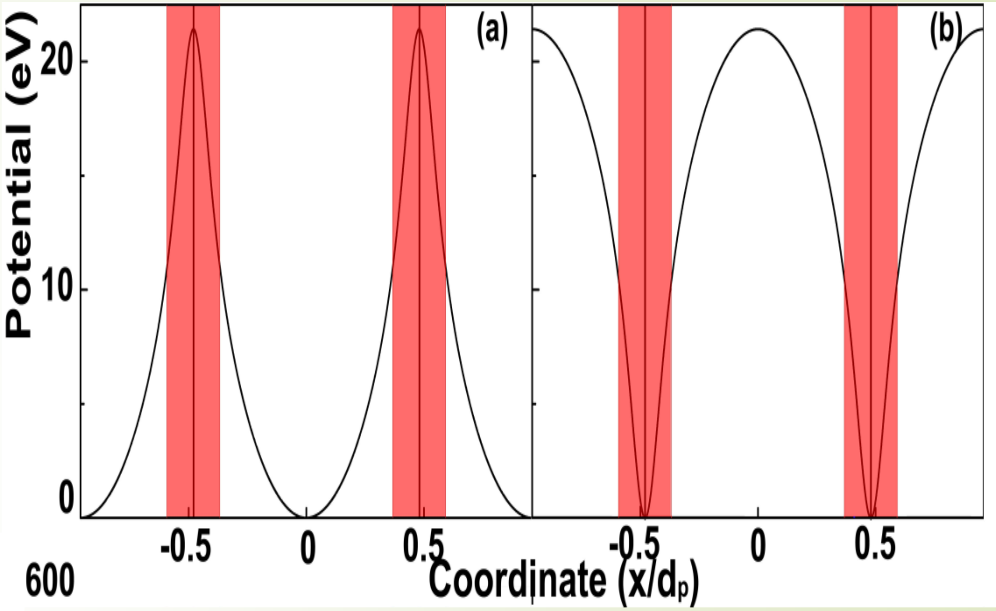
- Atoms in crystal medium are arranged in a precise and periodic lattice structure
- Planes/rows of aligned atoms are observed from specific point of view
- Incoming particles along such trajectories behaves significantly differently than in an amorphous medium

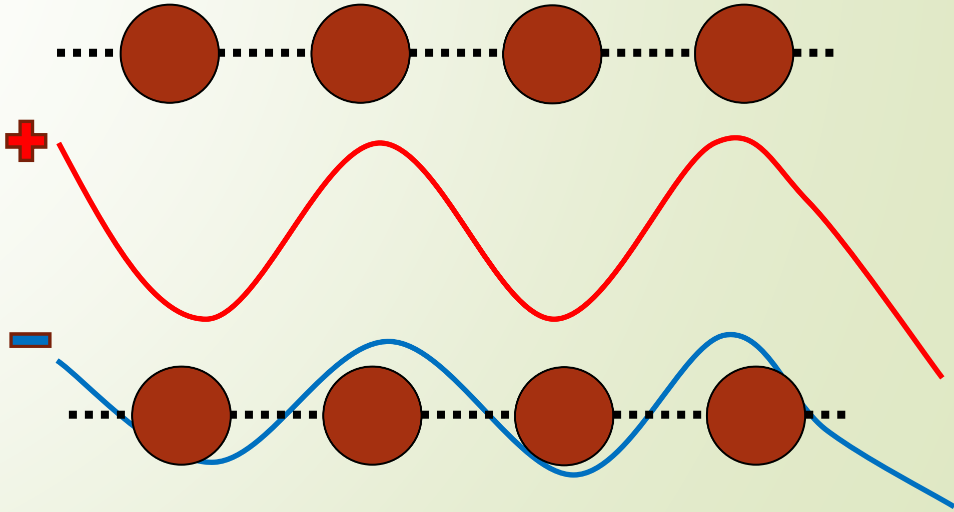




Planar Channeling

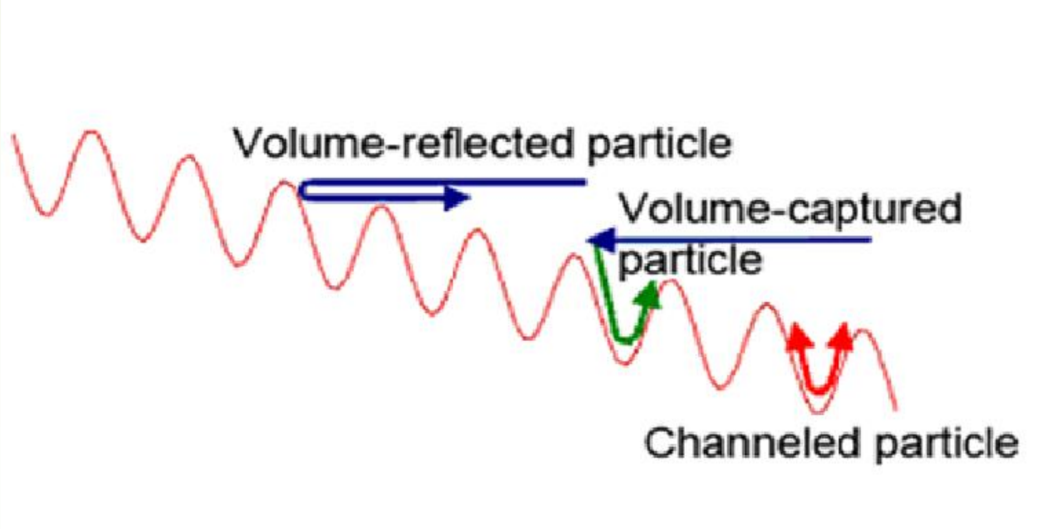
- Particles aligned with atomic planes perceive a continuous potential with wells and barriers
- Particles within a critic angle $\sqrt{(2U_0)/(pv)}$ can be bound to potential:
  - Between adjacent planes if positively charged
  - Into plane if negatively charged
- Scattering is strongly different in two cases:
  - Reduction of inelastic collision with nuclei
  - Increased inelastic collision with nuclei





Bent crystals

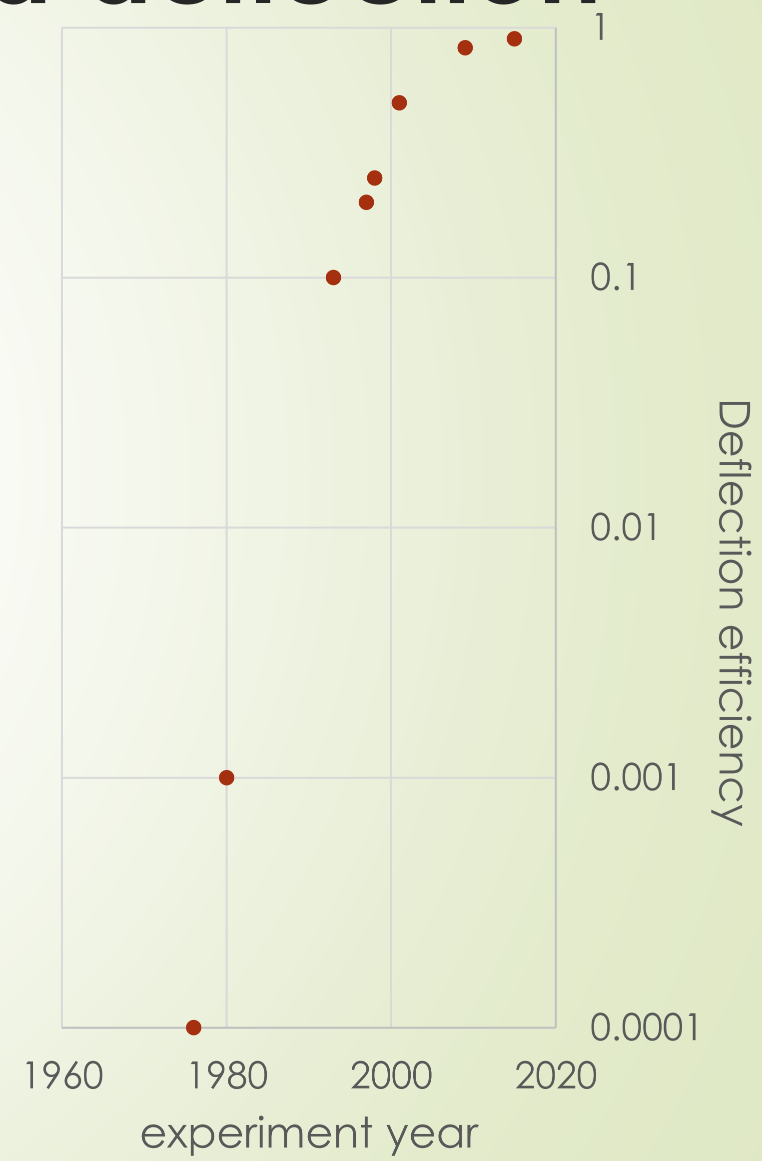
- Being channeled particles trajectory confined along planes, bent crystals can act like waveguide
- Positive particles at high energy can travel long distance in crystal with large efficiency
- Steering power equivalent to hundreds tesla magnetic dipole achievable in compact (few mm) object with zero energy consumption



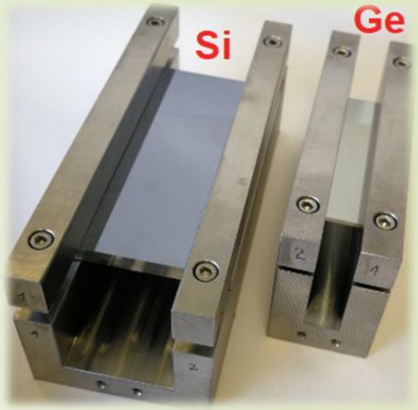
Beam Energy	Crystal length	Beam deflection	Equivalent Dipole	Application
1 TeV	50 mm	17 mrad	1133 Tesla	Λ_C spin precession
6.5 TeV	4 mm	50 µrad	292 Tesla	LHC collimation

Evolution of crystal-assisted deflection

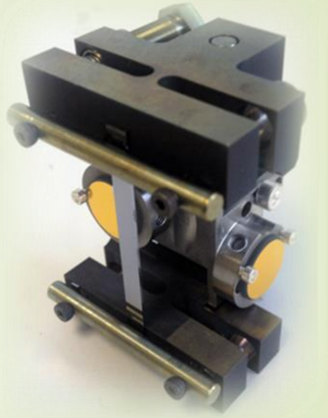
- First theorized in 1976 by Tsyganov
- First experiment achieved small efficiency (~10-4) but demonstrated the effect
- Numerous experiment followed, performed in Russia (U-70), Europe (CERN) and USA (Fermilab)
- For increase of efficiency critical
  - Simulation for optimal bending and length
  - Technological precision in crystal shaping and preservation of perfect lattice quality

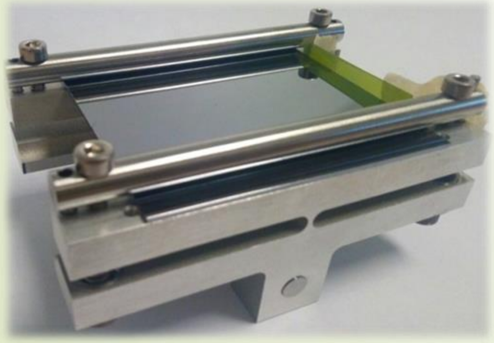


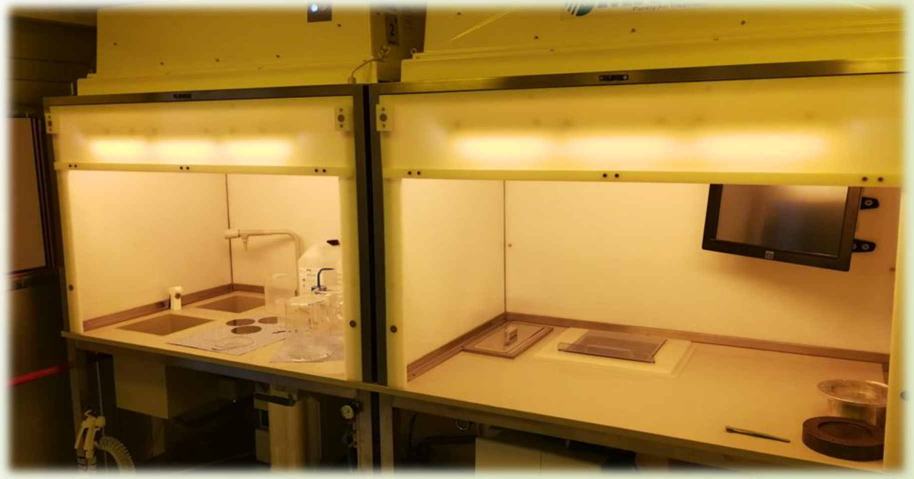
Ferrara Laboratories



- During last decade acquired in simulation and bent crystal samples production
- Collaboration with international collaboration (UA9 @CERN, Crysbeam & Seldom ERC projects)
- Large Clean Room facility for samples production in controlled environment

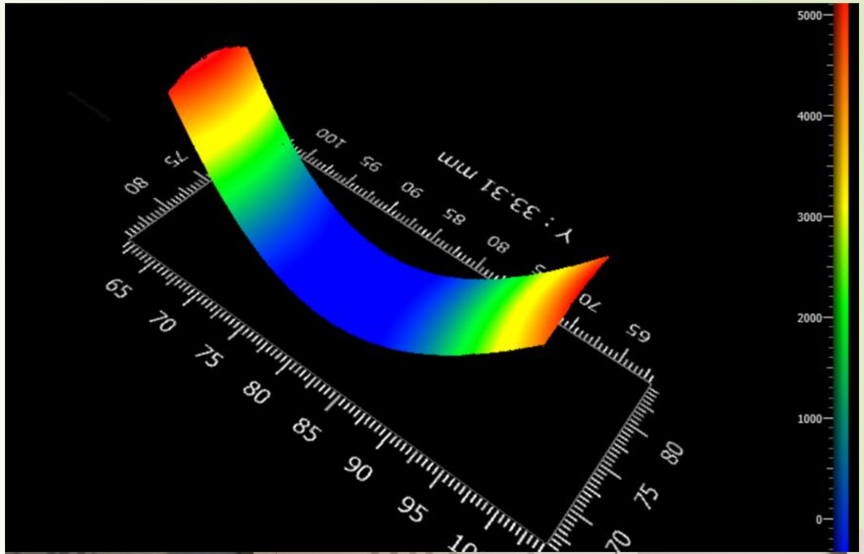


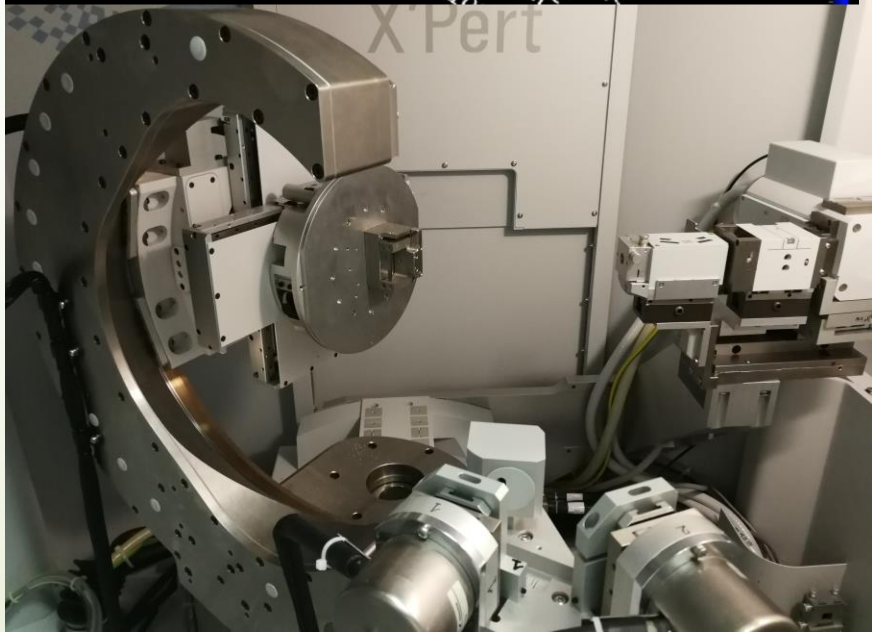




Characterization techniques

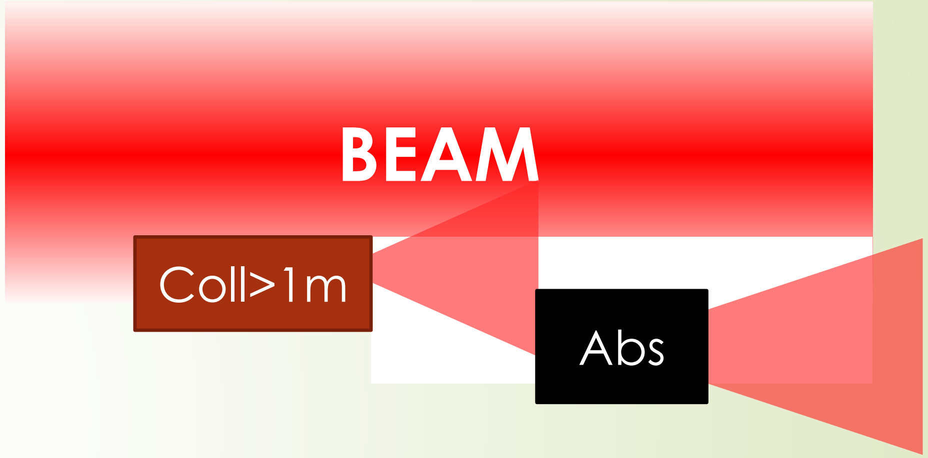
- Laser interferometer Zygo Verifire HDX:
  - large field of view (150 ø mm),
  - max lateral resolution 0.044mm,
  - max vertical resolution <1nm
- HRXRD with monochromatic 8.14 KeV beam (Cu Kα_1). 7 axis handling. Goniometer with angular resolution 1.7 μrad
- Beam test with bent crystal at accelerator facilities (CERN SPS extracted beamlines, Mainz MAMI and SLAC)

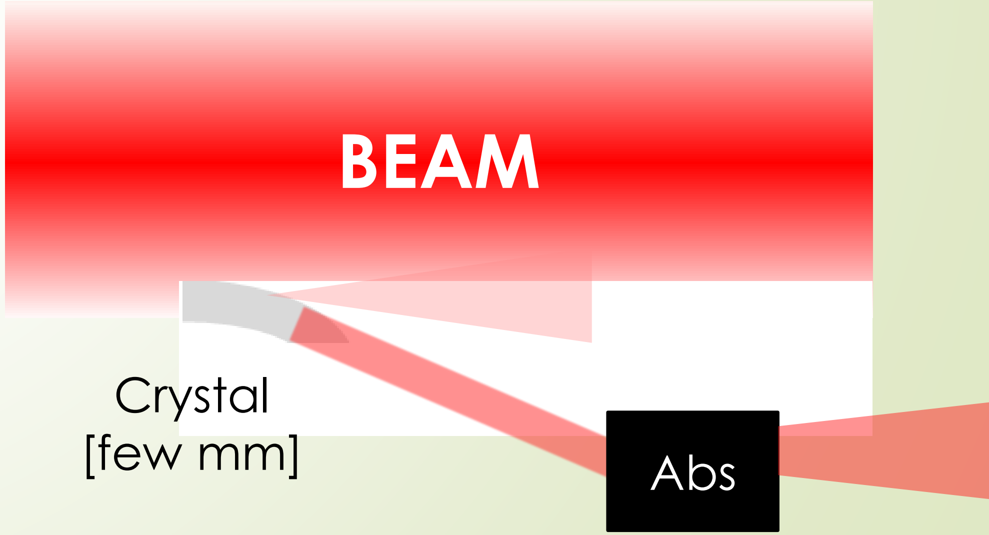




Applications 1: collimation

- Efficiency of beam collimation limits maximum luminosity of an accelerator
- Currently collimation exploit series of target to scatter particles away from beam into absorber
- At TeV scale of energy extremely difficult to deflect
- Bent crystal intercepting beam halo would efficiently steer particles away from beam into absorber:
  - More control over particle trajectory
  - Reduction of secondary particles production near main beam

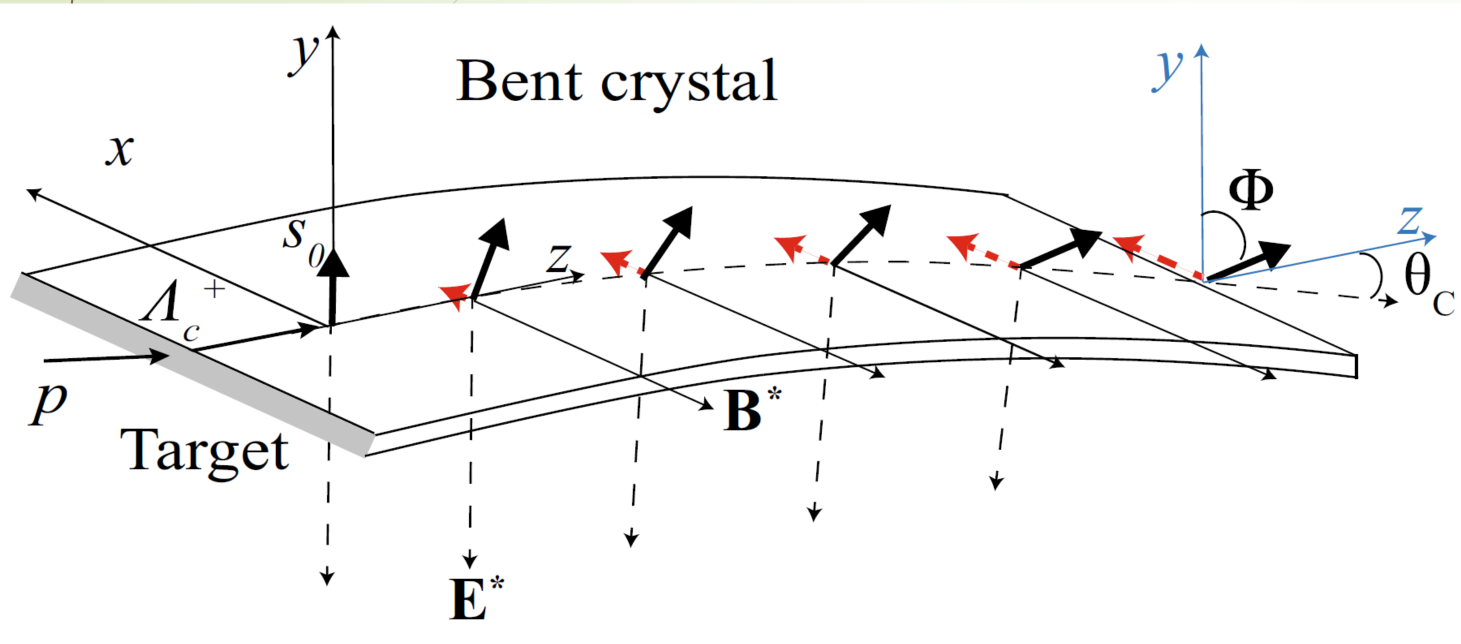




Applications 2: beam extraction

- Beam of steered particles conserve its energy and emittance
- Such particles can be employed for experiment in external beamline
- LHC and future accelerators external beamline could provide unique tool for detector development and fixed target experiments
- Beam halo could be redirected in specific area inside the accelerator, for dedicated experiment

Applications 3: Spin precession



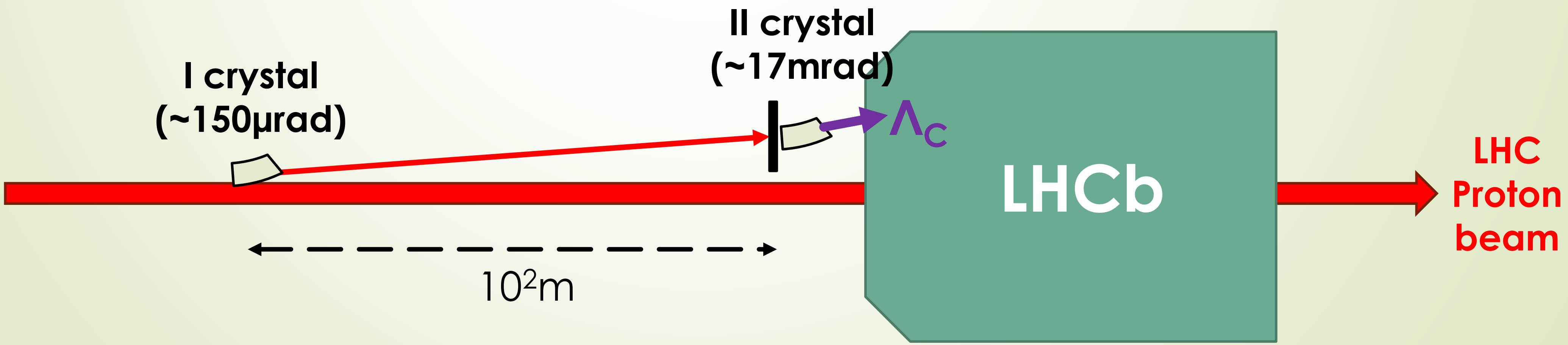
Both electric and magnetic dipole moment (EDM & MDM) can be studied by observing precession of particle spin in external field

- EDM is strongly suppressed: any observation would be clear signal of new physics.
- Baryons MDM precise study can provide confirmation of QCD calculation.

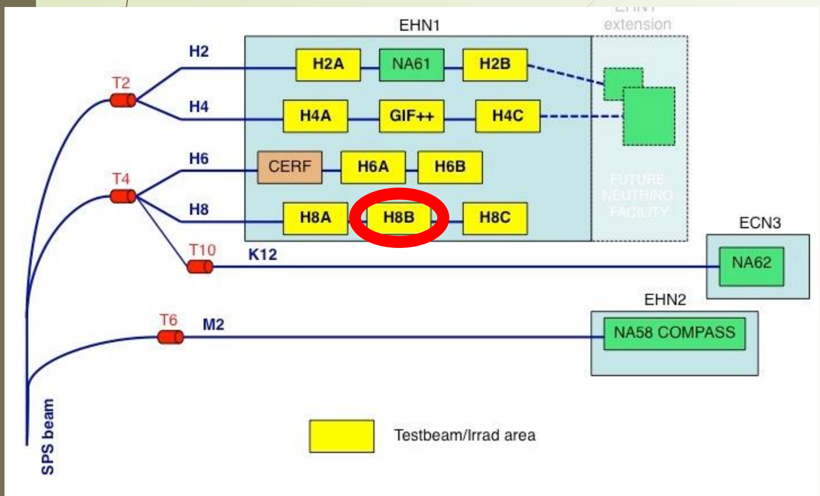
Exploiting channeling in bent crystal instead of artificial magnetic dipole, even short-lived particle like charmed baryon can be studied!

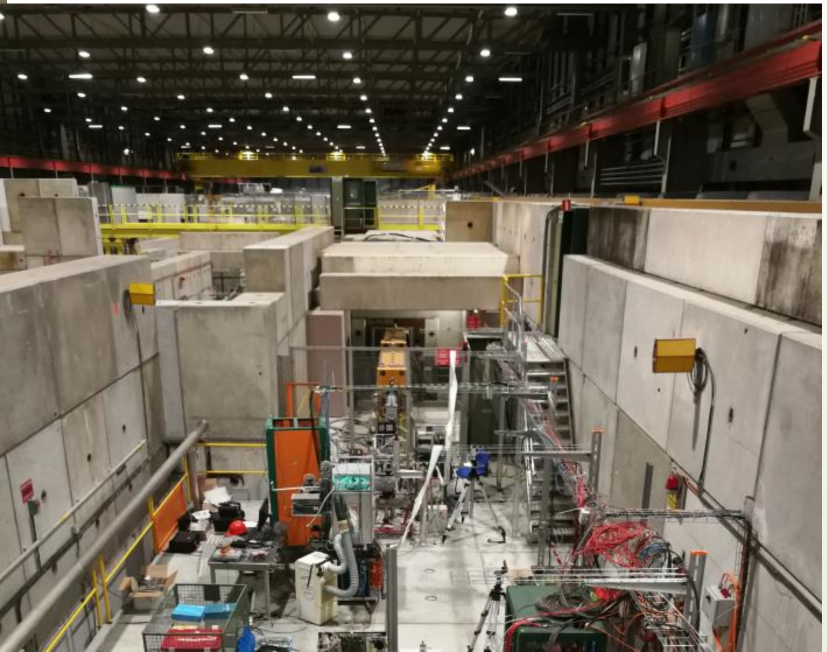
Seldom experiment

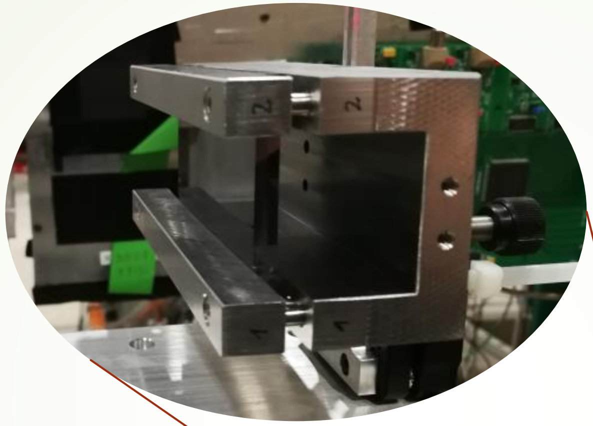
- Seldom proposes an experiment based on bent crystal in order to study EDM and MDM of Λ_C baryons
- A first upstream crystal deflects protons into a target placed before LHCb detectors
- A second crystal after target channels Λ_C produced in target
- Decay of channeled Λ_C is observed with LHCb in order to define its original spin state after precession in the crystal



Beamtest for SELDOM at H8



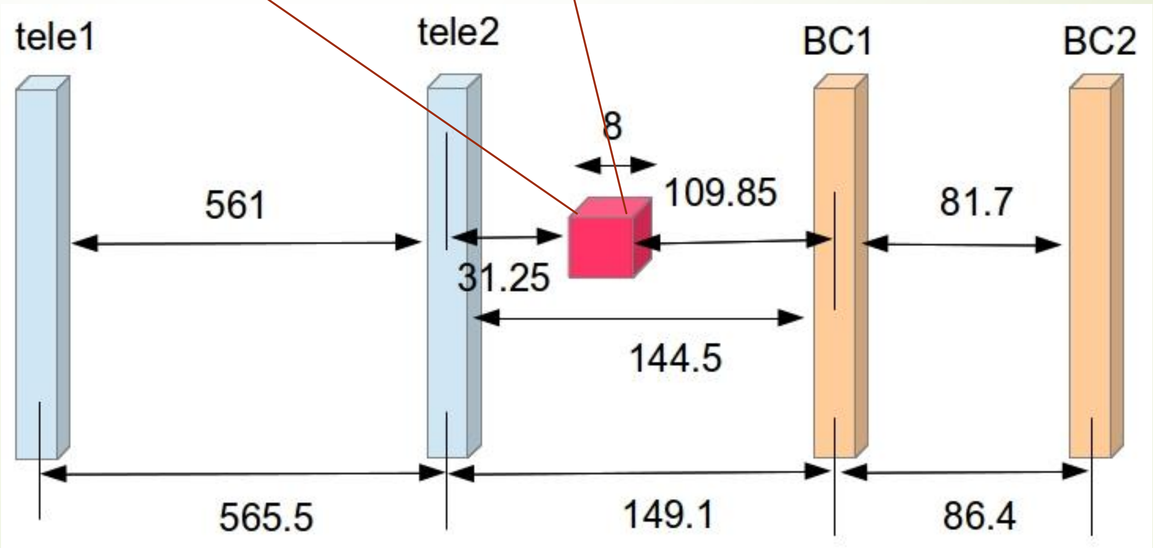




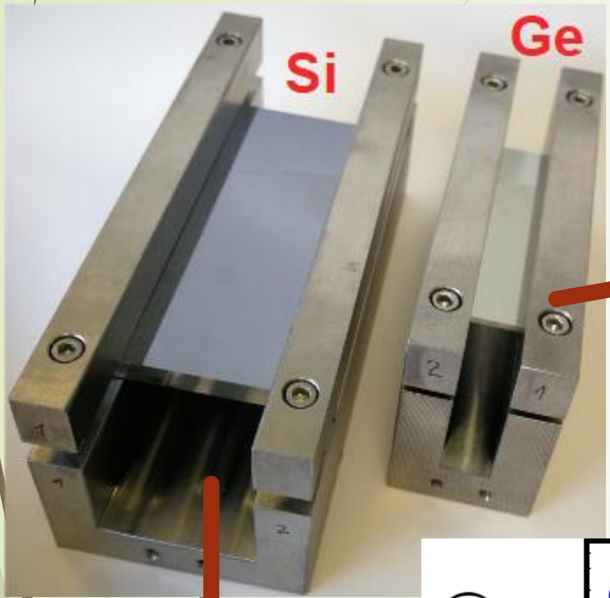
Beam 2/3 p + 1/3 π

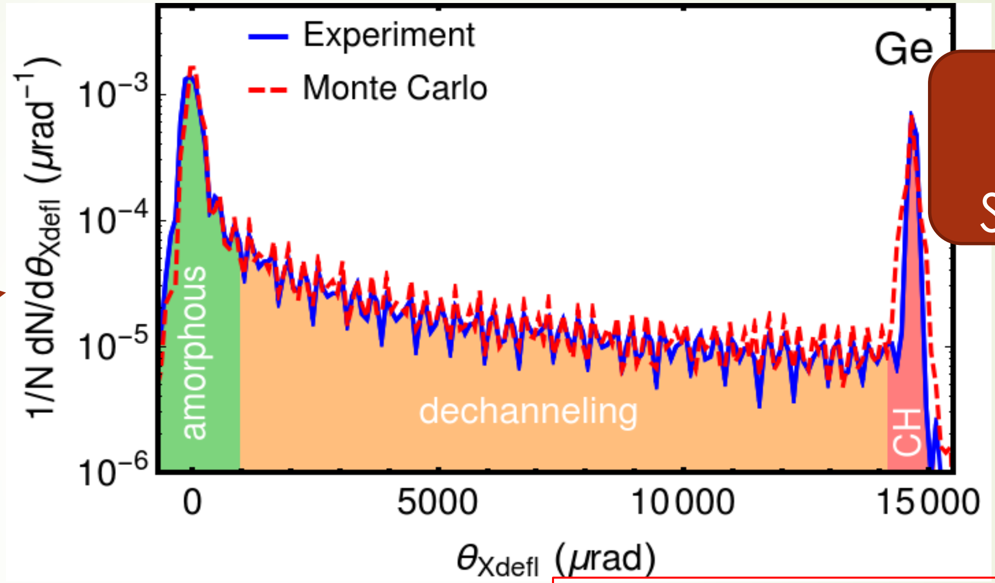
Angular divergence 24μrad

Deflection angle resolution 50 μrad

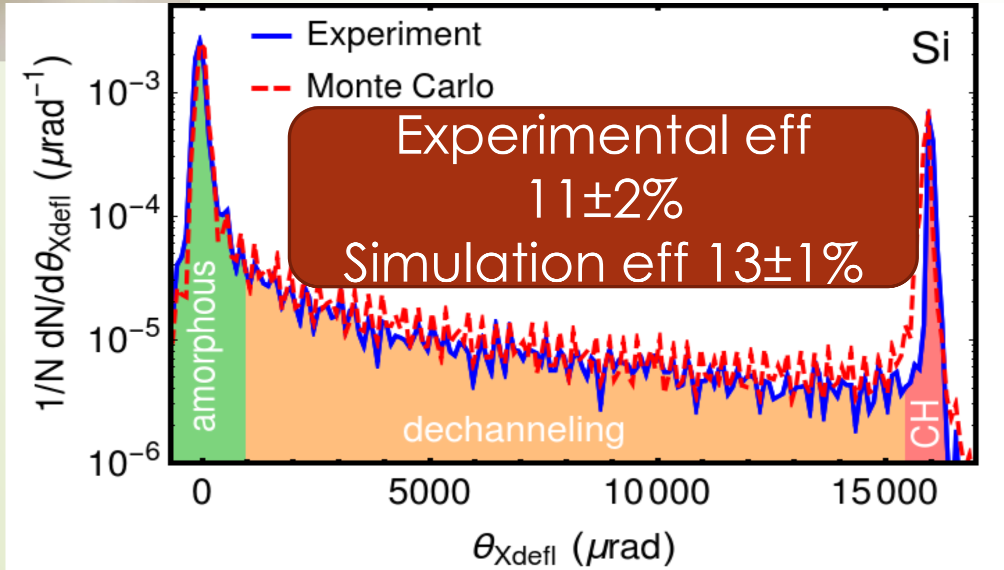


Beamtest results





Experimental eff 13±2%
Simulation eff 15±1%



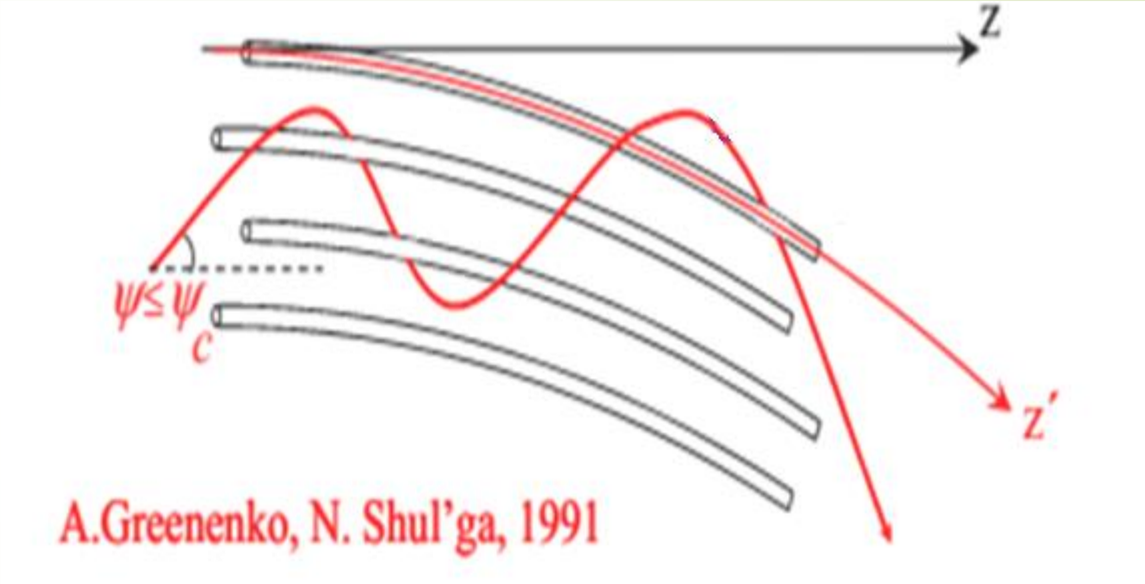
Experimental eff 11±2%
Simulation eff 13±1%

First and **crucial** benchmark for SELDOM experiment feasibility: crystal works according to simulations

Germanium crystal achieved same beam deflection of silicon in 3/5 of length

Axial effects: stochastic deflection

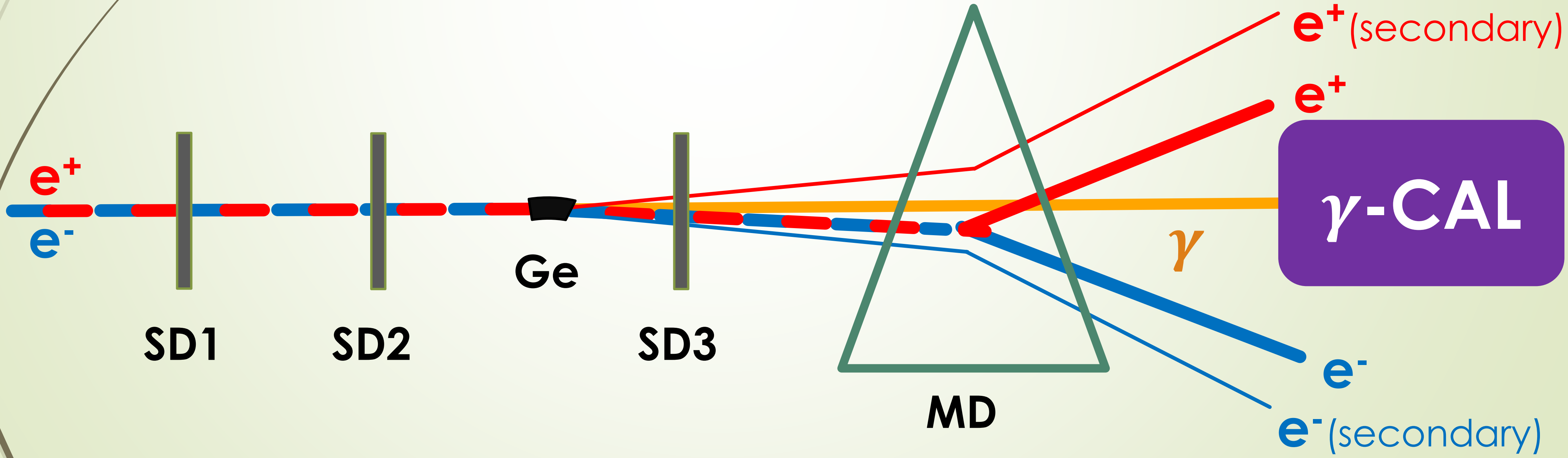
- Significantly different dynamics occur for alignment with lattice atomic rows
- In bent crystals, particle scattering wit atomic rows converges along axis direction, hence deflecting particles along crystal curvature
- “Stochastic deflection” is efficient for both positive and negative charged particles



Large axial fields for light ultrarelativistic particles (e-/e+) overcome linear QED condition $\chi = \gamma E / E_{Schwinger} \geq 1$, resulting in radiative loss of most of the particle momentum

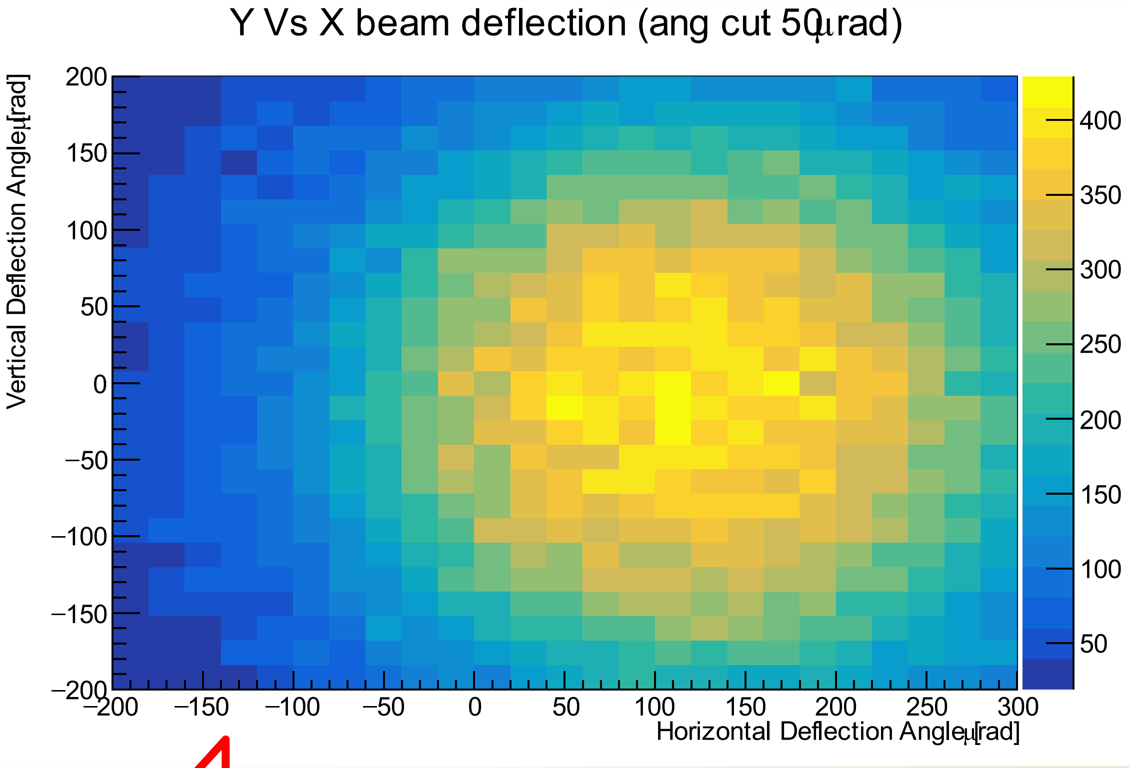
Beamtest for deflection & energy loss at H4

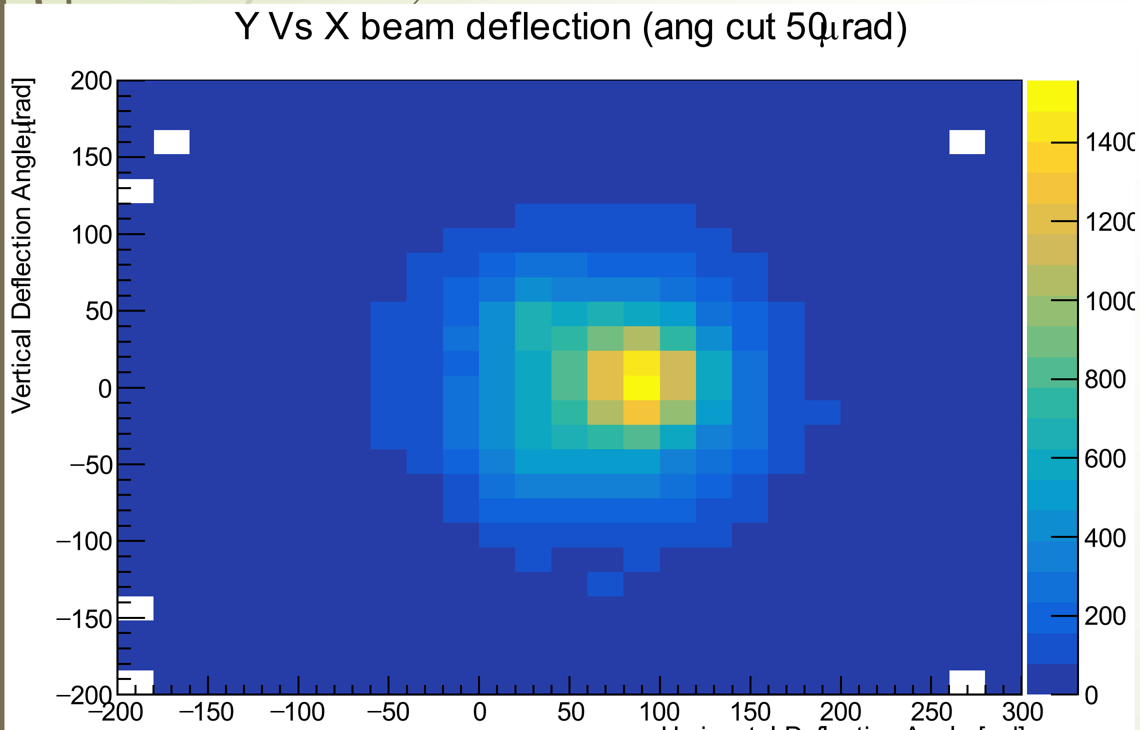
Both deflection efficiency and radiation energy loss were measured for 120 GeV electron beam and positron beam crossing a bent Germanium crystal during axial alignment



Deflection

Electron beam cross the crystal close to atomic rows, undergoing large scattering



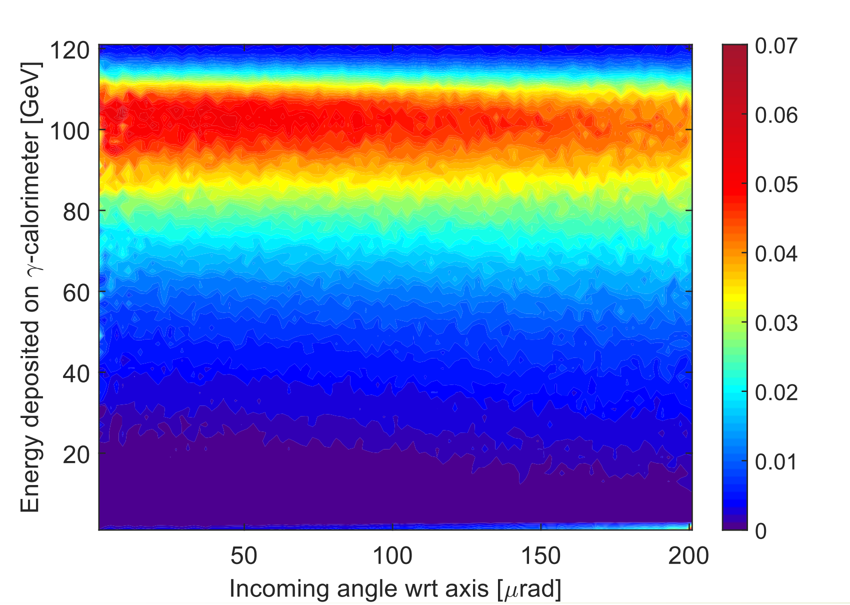


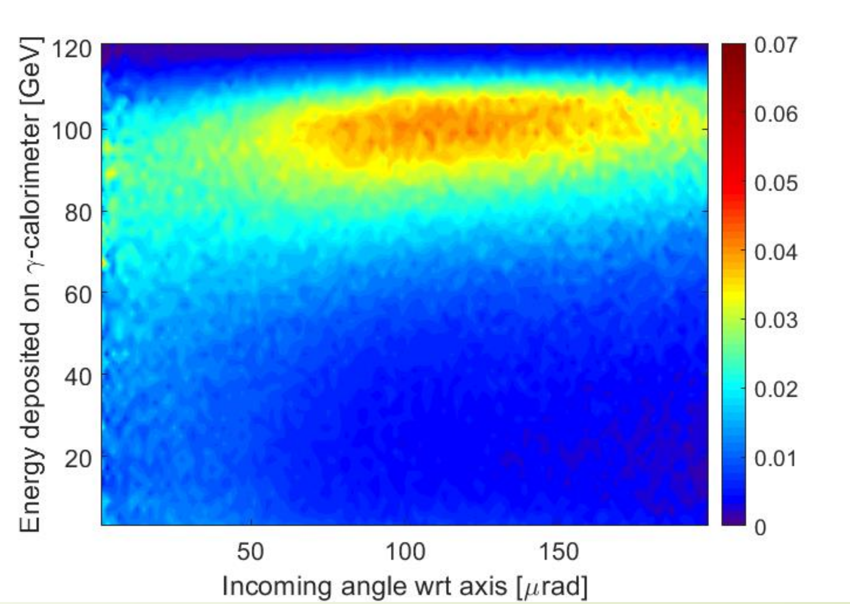
Positrons beam avoids region near atomic rows as crystal is crossed, preserving initial angular divergence

Energy loss

- Electron cross crystal near atomic rows, in region of maximum axial electric fields
- Strong field regime condition $\chi \geq 1$ is always satisfied

- Positron are repelled from atomic rows, thus cross crystal in region with lower electric fields
- Only misaligned particles are effected by strong field regime





Conclusions

- Large steering power is achievable with bent crystals
- Bent crystals enables novel solution for accelerator
  - LHC collimation
  - Beam extraction
  - Fast decaying particles EDM & MDM studies
- Axial effects widen possibilities:
  - Efficient deflection of negative particles as well as positive ones
  - Unique opportunity to study QED non-linear effects
  - Collimation of e+/e- beam is coupled with enhanced radiative energy loss

Thanks for your attention!