Geant4 11.4.3

Decay, Optical and Channeling Processes

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Geant4 Tutorial at Jefferson Lab

9 December 2026

Outline

- Particle decays
  - decay channels and tables
  - special decays
- Optical photon interactions
- Crystal channeling
  - lattices

Particle Decays

- For all unstable, long-lived particles
  - not used for radioisotopes (G4RadioactiveDecay)
- Decay can happen in flight or at rest
  - decay process is discrete + at-rest (G4VRestDiscreteProcess)

- Different from other physical processes
  - mean free path (λ) for most processes: $1/\lambda = \Sigma = N\rho\sigma/A$
  - for decay in flight (mean free path): $\lambda = \gamma\beta c\tau$
  - for decay at rest (mean life time): $\lambda \rightarrow \tau$
  - at rest processes like decay and capture compete in time

- Same process used for all eligible particles
  - retrieves branching ratios and decay modes from decay table stored for each particle type

Particle Decay Modes Available

- Phase space
  - two-body: $\pi^0 \rightarrow \gamma\gamma$ (~98.8%)
  - three-body: $K^0_L \rightarrow \pi^0 \pi^+ \pi^-$
- Dalitz
  - $\pi^0 \rightarrow l^+ l^- \gamma$
- Muon and tau decay
  - $\mu^- \rightarrow e^- \overline{\nu_e} \nu_\mu$
  - no radiative corrections , mono-energetic neutrinos
- Semi-leptonic K decay
  - $K \rightarrow \pi\, l\, \nu$

Defining Decay Channels

- Geant4 provides decay modes for long-lived particles
  - user can re-define decay channels if necessary

- But decay modes for short-lived (e.g. heavy flavor) particles not provided by Geant4
  - user must “pre-assign” to particle
    - proper lifetime
    - decay modes
    - decay products
  - process can invoke decay handler from external generator
    - must use G4ExtDecayer interface

- Take care that the pre-assigned decays from generators do not overlap with those defined by Geant4 (e.g. K^0_S , τ)

Specialized Particle Decays

- G4DecayWithSpin
  - produces Michel electron/positron spectrum with first order radiative corrections
  - initial muon spin is required
  - propagates spin in magnetic field (precession) over remainder of muon lifetime

- G4UnknownDecay
  - only for not-yet-discovered particles (SUSY, etc.)
  - discrete process – only in-flight decays allowed
  - pre-assigned decay channels must be supplied by user or generator

Optical Processes

- Propagation of optical photons and their interaction with materials is treated separately from regular electromagnetic processes. Why?
  - wavelengths are much larger than atomic spacing
  - they are treated (partially) as waves; no smooth transition to gammas
  - energy/momentum not generally conserved in G4 optics
- Optical photons produced directly by five processes
  - G4Cerenkov, G4QuasiCerenkov
  - G4Scintillation, G4QuasiScintillation
  - G4TransitionRadiation

New Optical Particles, Processes and Models

- Optical processes can now be implemented by models case of x-ray production
  - G4StandardCerenkovModel
  - also a model for scintillation coming soon
  - derived from base class G4VXRayModel

- G4QuasiOpticalPhoton
  - scintillation or Cerenkov processes may produce a large number of photons in a step
  - save time in tracking by clumping them into one G4 particle
  - send G4QuasiOpticalPhoton to deferred process for generation and propagation: G4QuasiScintillation, G4QuasiCerenkov

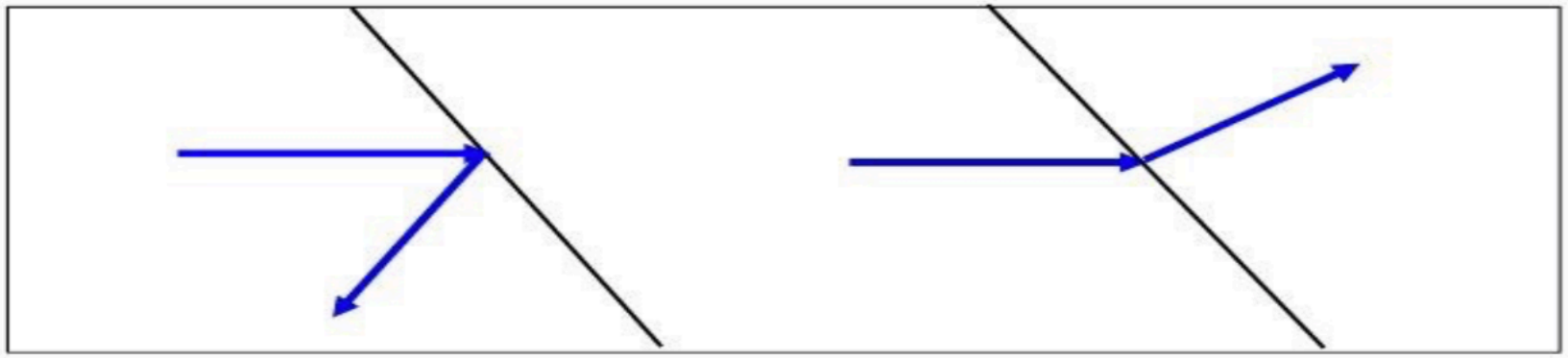
Optical Photon Transport

- Refraction and reflection at boundaries
- Wavelength shifting
- Bulk absorption
- Rayleigh scattering

- Geant4 keeps track of polarization
  - but not overall phase, so no interference
- Optical properties attached to G4Material (by user code)
  - reflectivity, transmission efficiency, dielectric constants, surface properties, including binned wavelength/energy dependences
- Photon spectrum attached to G4Material (by user code)
  - scintillation yield, time structure (fast, slow components)

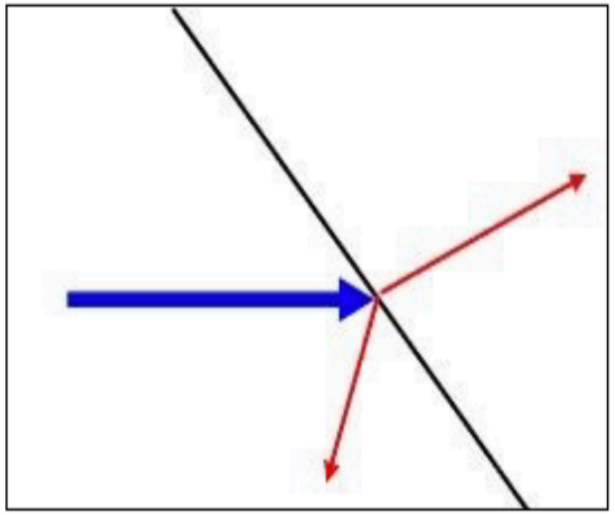
Optical Boundary Processes

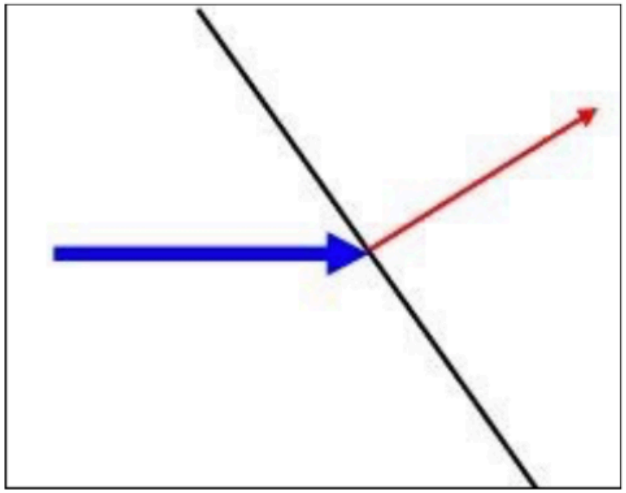
- G4OpBoundaryProcess
  - refraction
  - reflection
- User must supply surface properties using G4OpticalSurfaceModel
- Boundary properties
  - dielectric-dielectric
  - dielectric-metal
  - …
- Surface properties
  - polished
  - ground
  - front- or back-painted
  - …



Reflection or Refraction

- Geant4 events support “particle-like” behavior – no “splitting” of tracks
- Each event has either a reflected or refracted photon, chosen randomly from user-input efficiencies





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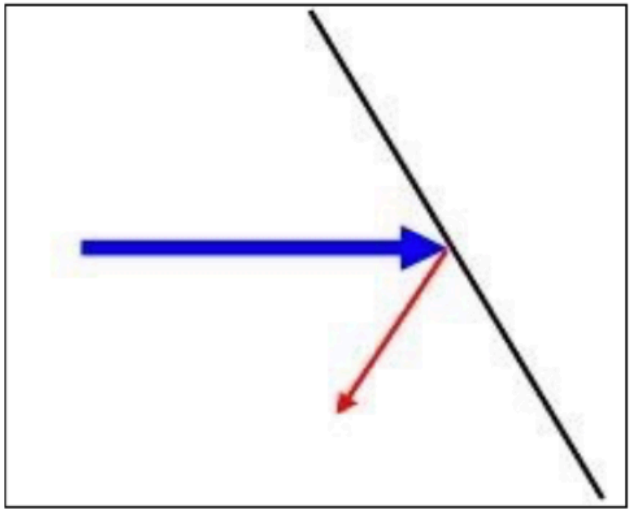
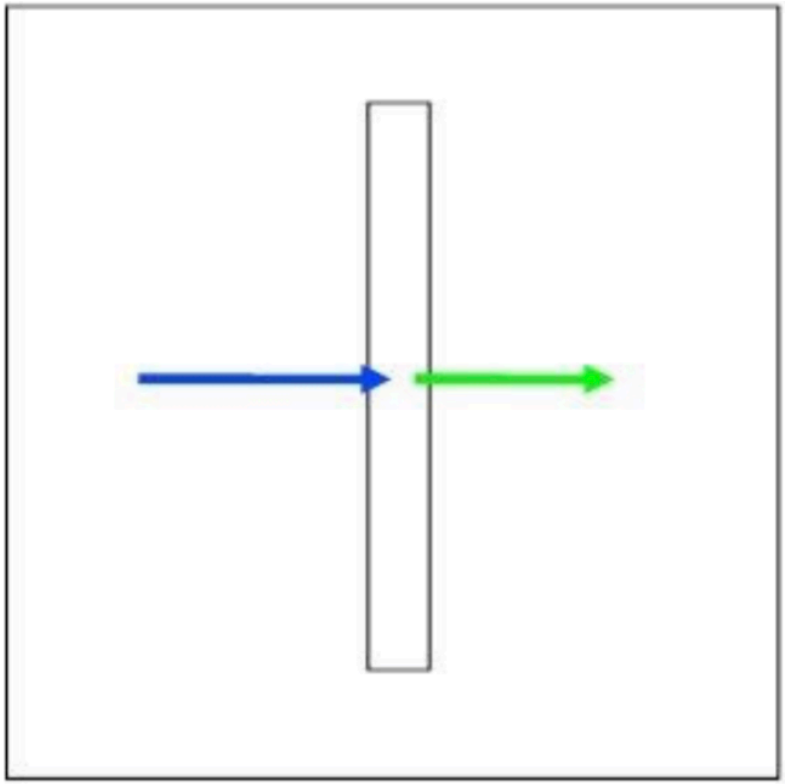


Optical Processes: Wavelength Shifting

- Handled by G4OpWLS
  - initial photon is killed, one with new wavelength is created
  - gets mean free path from physics table
- User must supply:
  - absorption length as function of photon energy
  - emission spectra parameters as function of energy
  - time delay between absorption and re-emission



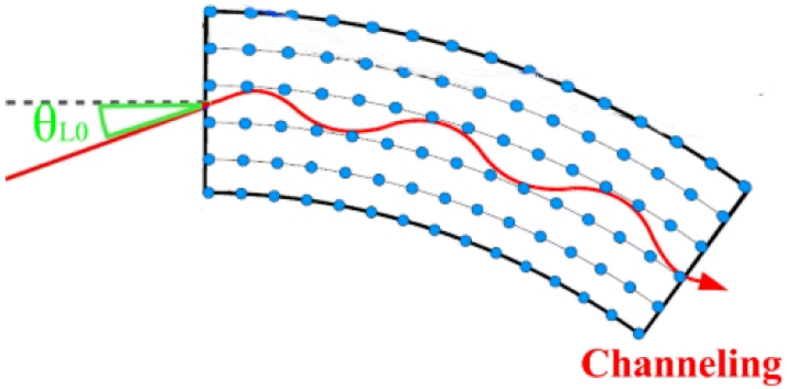
Optical Bulk Processes

- G4OpAbsorption
  - uses photon attenuation length from material properties to get mean free path
  - photon is simply killed after a selected path length

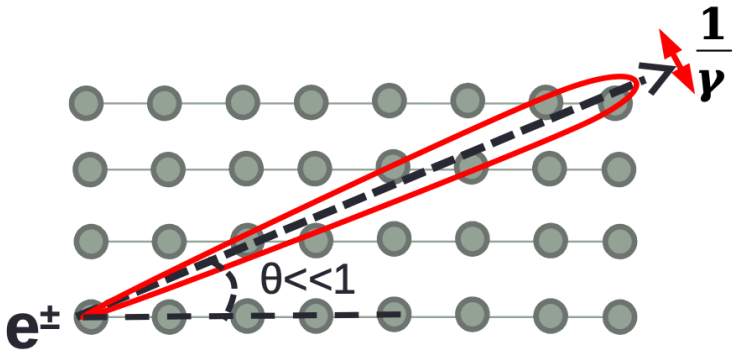
- G4OpRayleigh
  - elastic scattering including polarization of initial and final photons
  - builds its own physics table (for mean free path) using G4MaterialTable
  - may only be used for optical photons (a different process provided for gammas)

Channeling Process

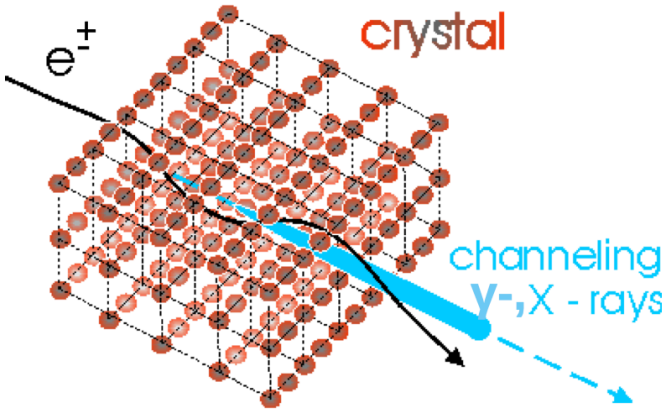
Channeling*



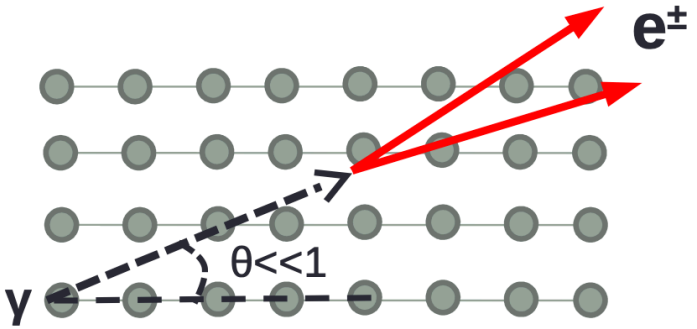
Coherent bremsstrahlung***



Channeling radiation**



Coherent pair production****



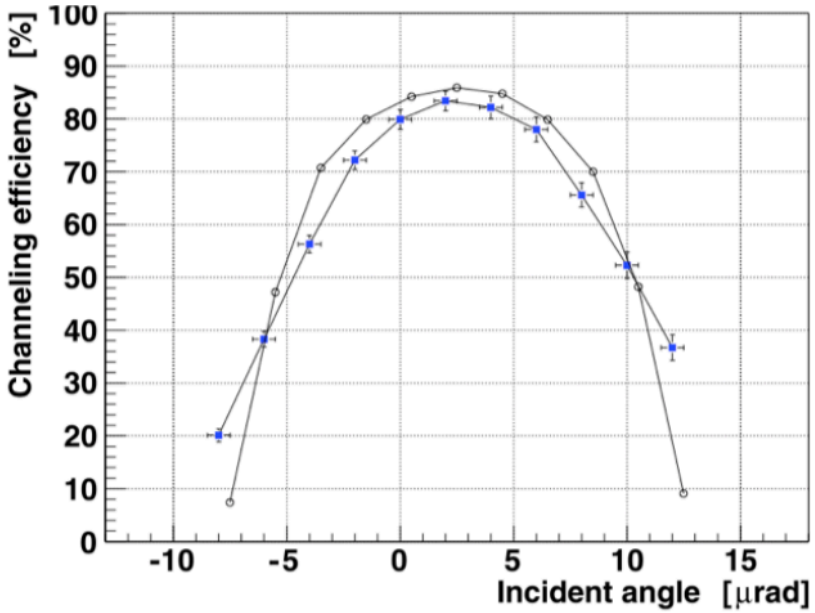
G4Channeling

- A discrete process which transports e^- and e^+ through "valleys" between rows of atoms in crystals
  - Even if valleys are curved (as in bent crystals)
  - No step-by-step transport used (as for G4 multiple, single scattering)
  - Instead, the classical equations of motion of particle in average crystal potential are integrated to get the final state after channeling

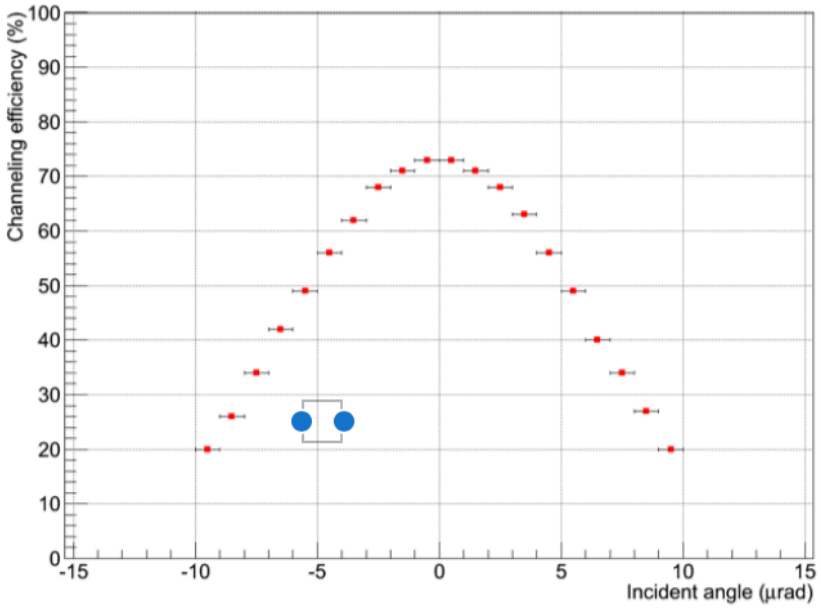
- Requires crystal parameters but actual lattices are not constructed in Geant4 (G4 materials are amorphous)
  - G4LatticeLogical has been introduced as a container to hold parameters and lookup tables
  - G4LatticeManager keeps track of lattices and how they are associated with materials and volumes

Channeling Efficiency vs. Angle

W. Scandale et al., Phys. Lett. B 680 (2009) 129



Geant4 Channeling



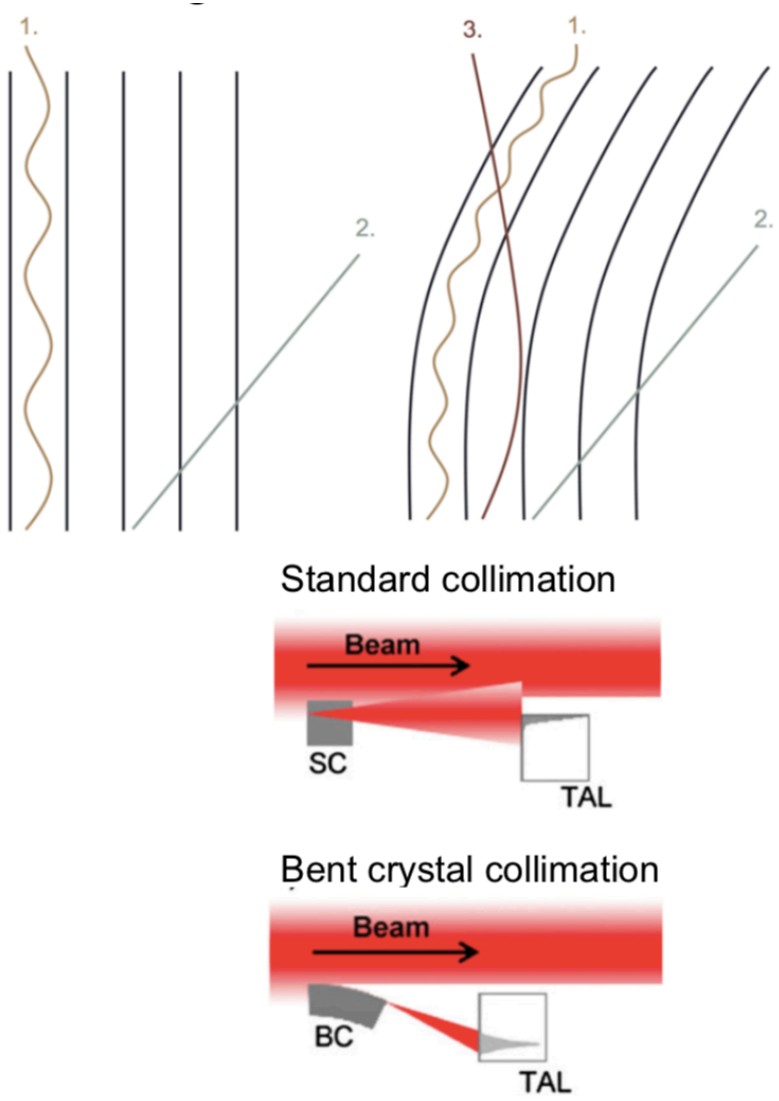
Experimental measurements (a)

UA9 collaboration simulations (a)

Geant4 Simulations (b)

Application: Crystal Collimation

- Particles with directions aligned with crystal planes are channeled (1)
- Crystal can be used as primary collimator to deflect halo particles toward secondary collimator
- Main advantage is the possibility of deflecting halo out and reducing losses

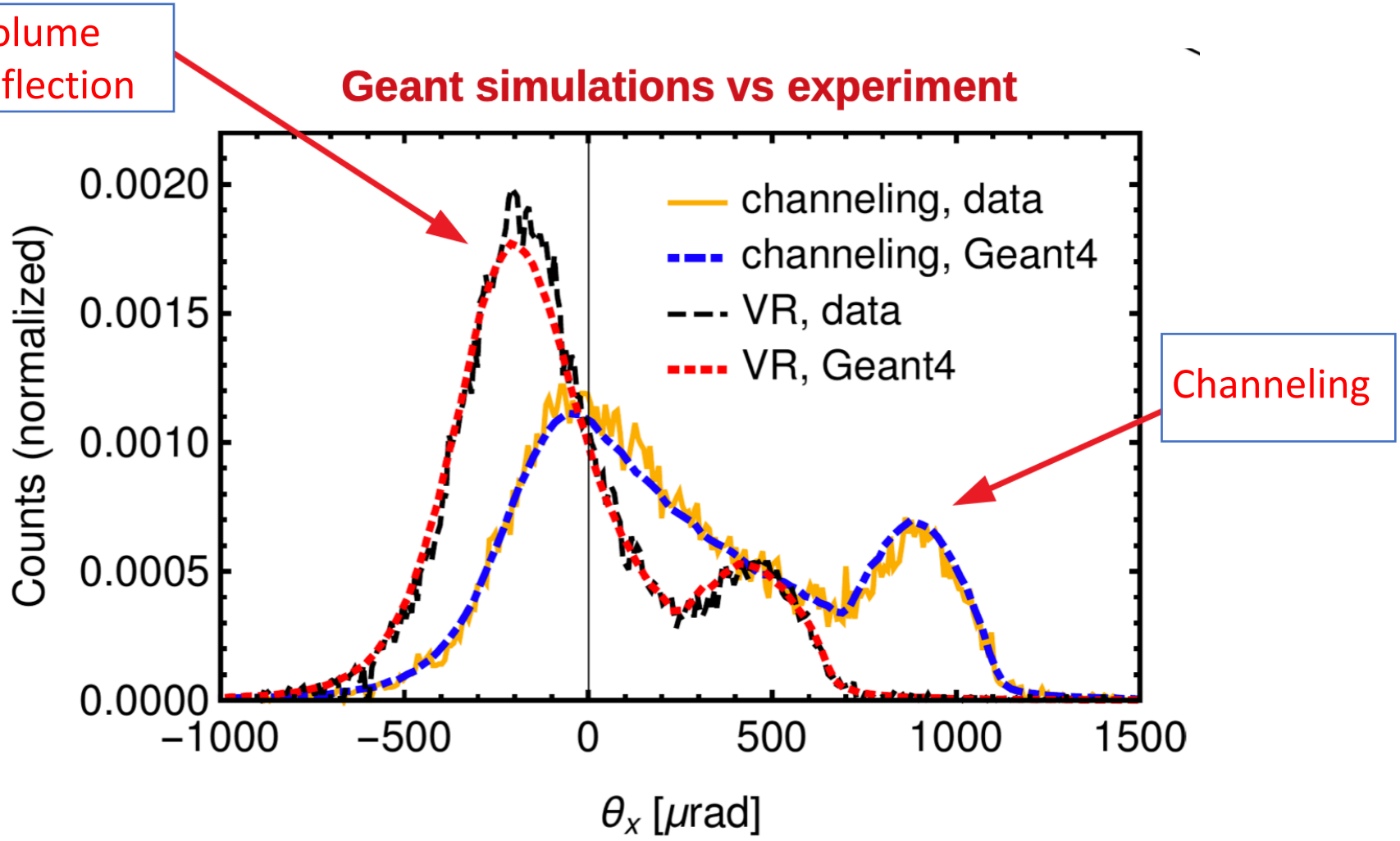


G4ChannelingFastSimModel

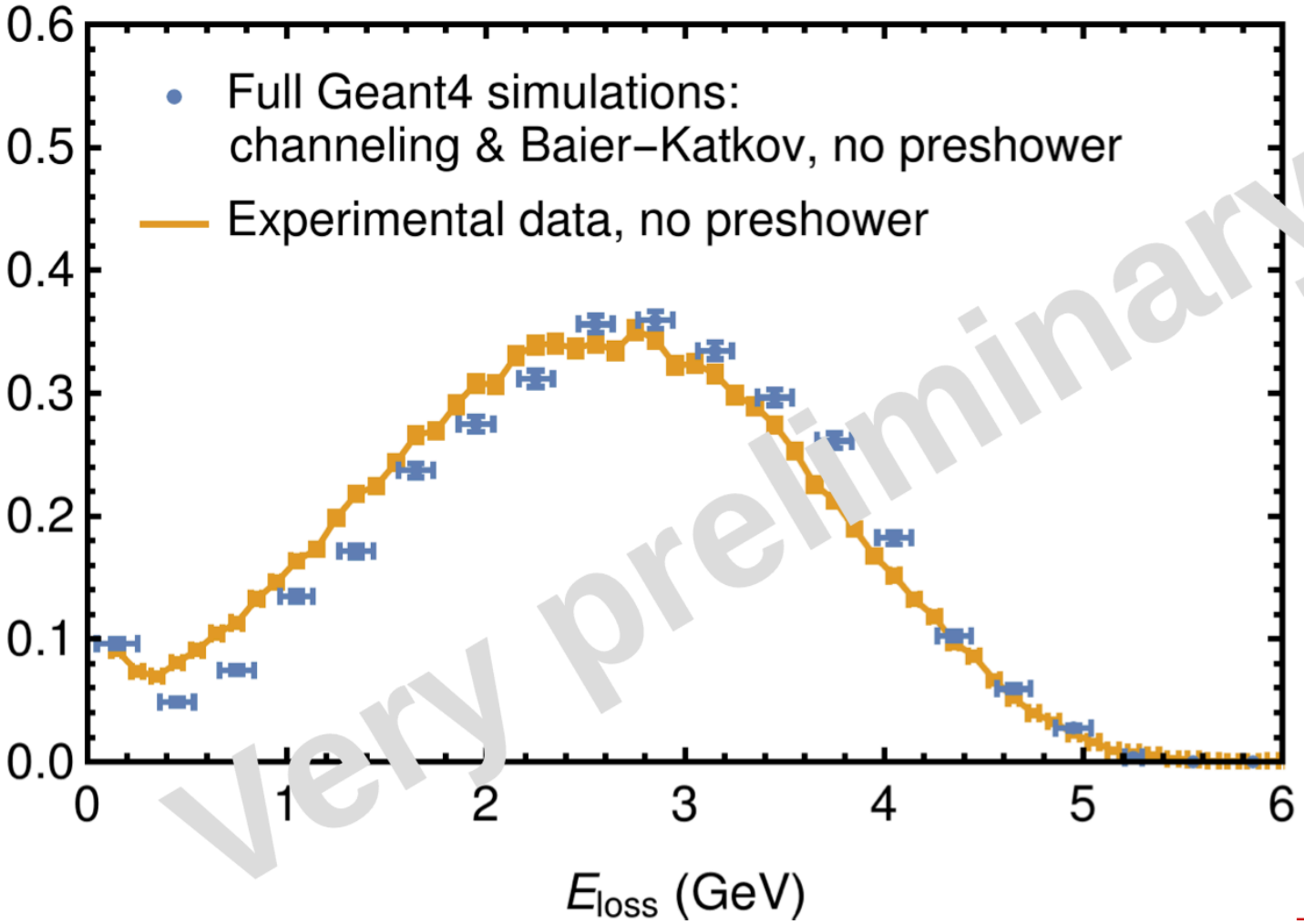
- A parameterized fast simulation model which transports e^-, e^+, p through “valleys” between rows of atoms in crystals
- Similar to G4Channeling (integrates equations of motion) but
  - higher energy incident particles allowed
  - more detailed interactions
  - has its own crystal parameters handling (no G4Lattice, etc.)

- Key physics is in G4BaierKatkov model
  - must be activated within G4DetectorConstruction and used in G4ChannelingFastSimModel
  - does equation of motion integration
  - provides channeling radiation spectrum for single photon mode
  - generates secondary photons

855 MeV Electron Incident on Short Bent Crystal



Comparison for 5.6 GeV e^- at DESY



Summary

- Geant4 provides decay processes for all long-lived elementary particles
  - short-lived and yet-to-be-discovered particles can also be treated with decay files and special classes

- A versatile optical photon package provides all basic low energy photon interactions with volumes and surfaces
  - particle-like approximation to wave-like physics\
  - further details: https://geant4-userdoc.web.cern.ch/UsersGuides/PhysicsReferenceManual/html/electromagnetic/optical_photons/index.html

- Channeling
  - Two options for channeling of charged particle in crystals: G4Channeling process and G4ChannelingFastSimModel