Report from Low Background Experiments

Geant4 Collaboration Workshop
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Low Background Experiments Using Geant4

- Quick survey shows > 12 experiments that use it to some degree
- SuperCDMS, Edelweiss II (Ge DM)
- Xenon, LUX, ZEPLIN III (Xe DM)
- CoGeNT, DAMA, CRESST (low mass DM)
- EXO, Majorana, GERDA (ν-less double β decay)
- Ice Cube
- and more

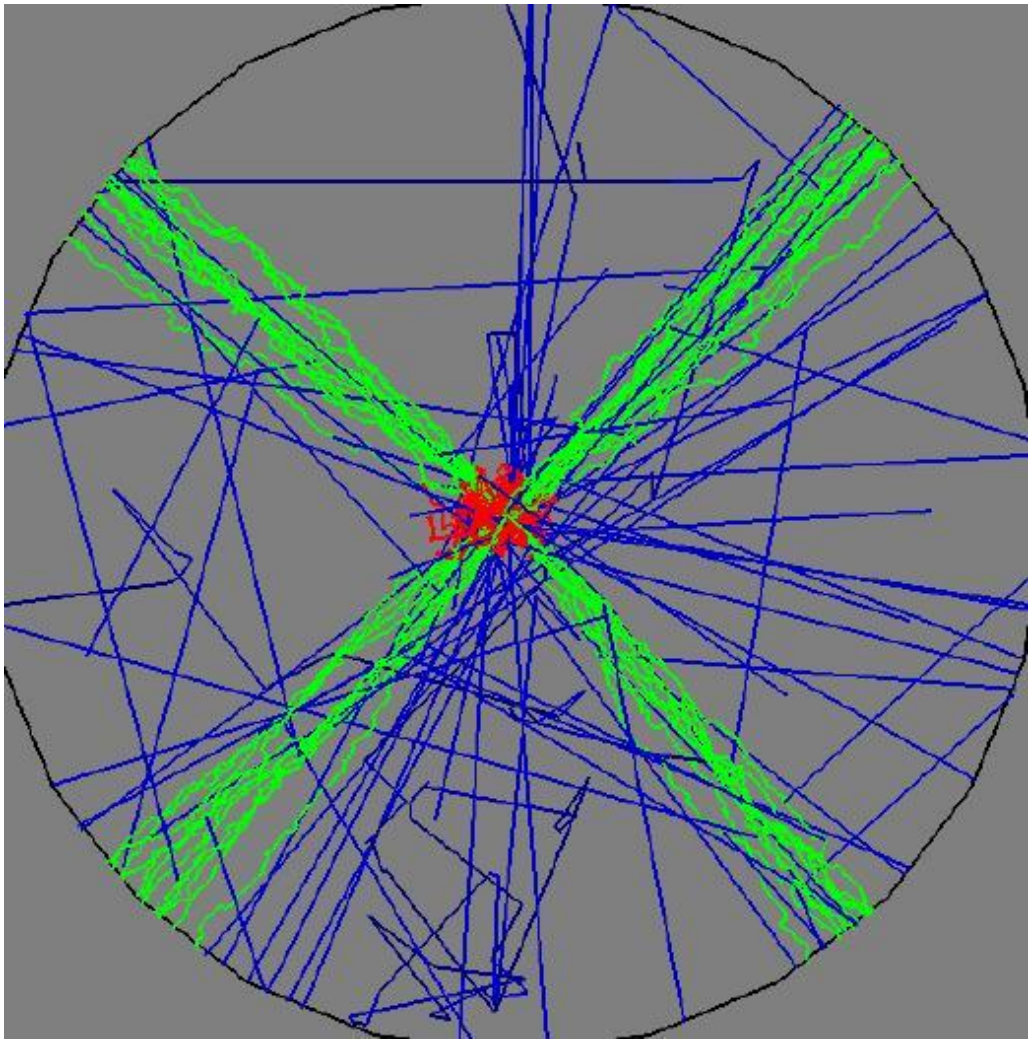
How Geant4 is Used (1)

- In most cases for understanding backgrounds
  - neutrons
  - cosmic rays
  - cavern albedo
  - radioactive decay from sources and contamination
- Also for design
  - detector configuration
  - neutron veto
  - shielding
  - fiducial volume studies, edge effects
  - material selection

How Geant4 is Used (2)

- Precise calibrations (gammas and neutrons)
- Light propagation
- Performance studies
  - thresholds
  - active mass
- In at least two cases (SuperCDMS, ZEPLIN III) signal simulation
  - phonon, electron hole propagation, scintillation

Phonon/Electron/Hole Propagation in CDMS Geant4



Ge crystal simulation
by D. Brandt (SLAC)

blue – phonon
green – electron
red – hole

Electric field
direction into page

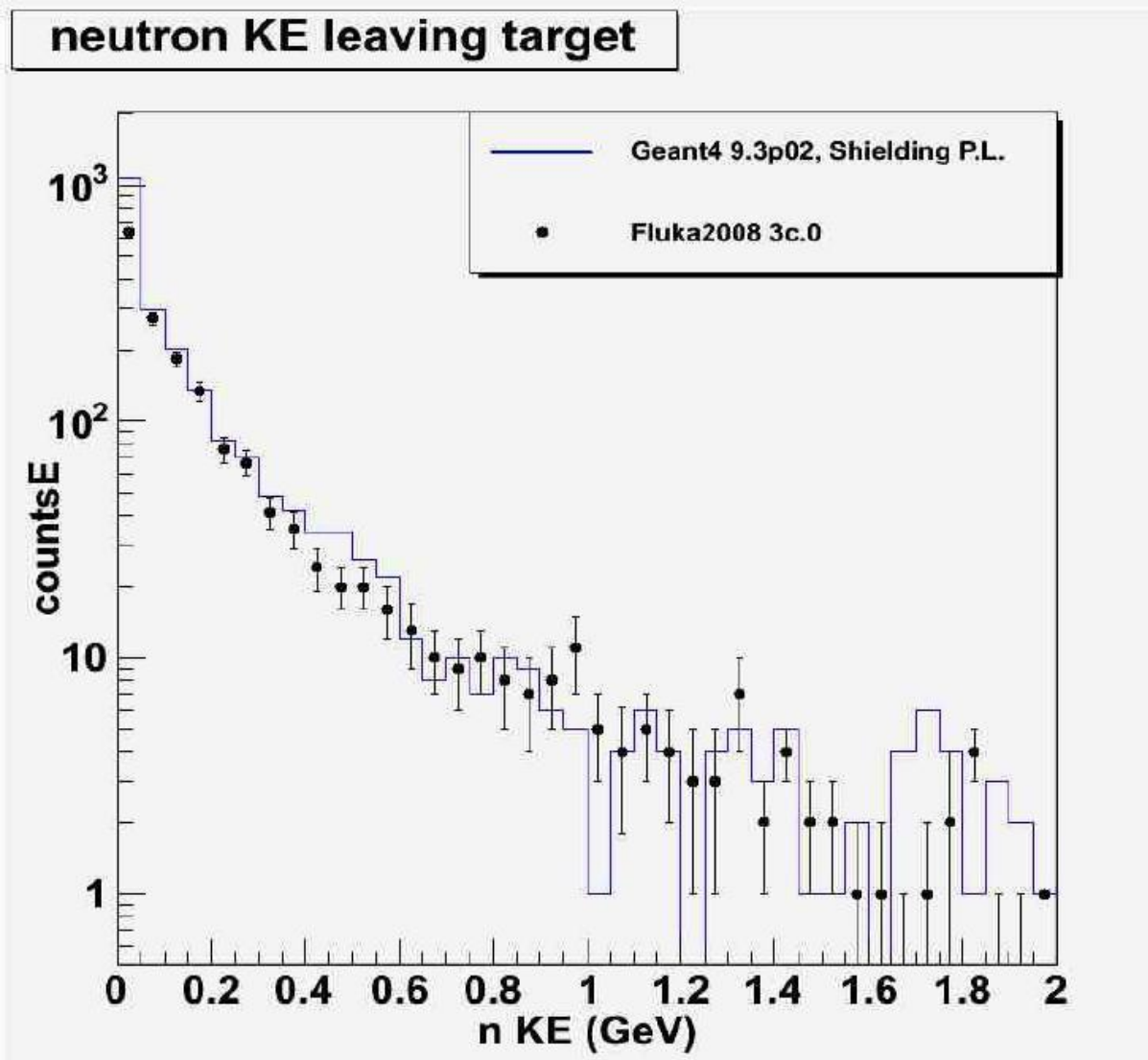
Geant4 Support of LBE

- In 2005 L. Pandola estimated 3 Geant4 members involved in LBE
  - lots of requirements for Geant4 to fulfill
    - low energy EM
    - hadronic and mu-nuclear models
    - radioactive decay
- By 2012 this has doubled to ~6
  - many requirements completed, many more to go

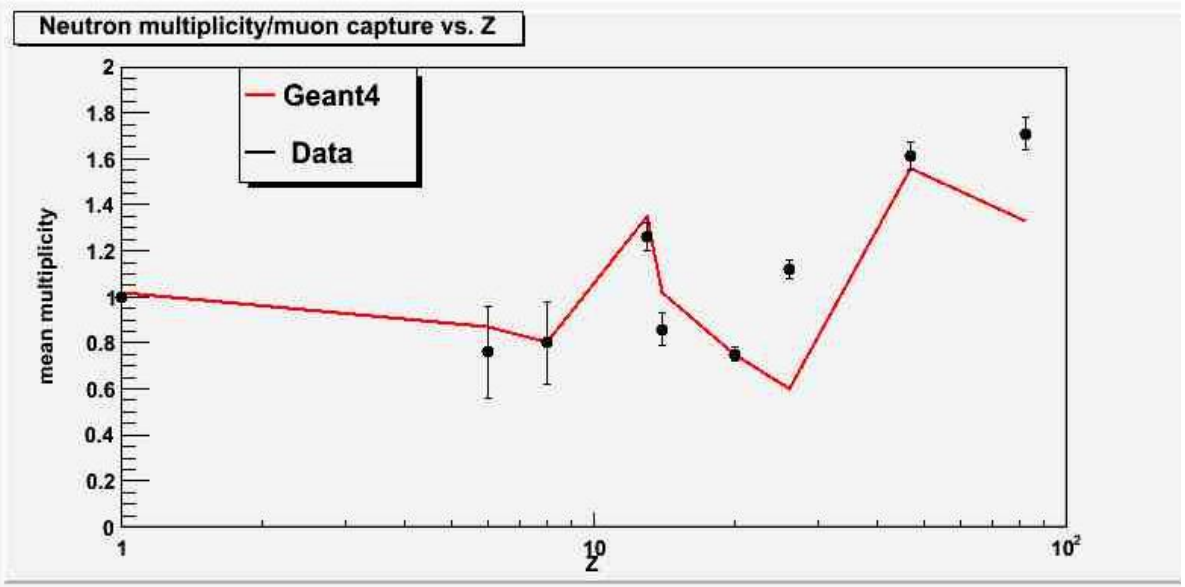
Requirements (1)

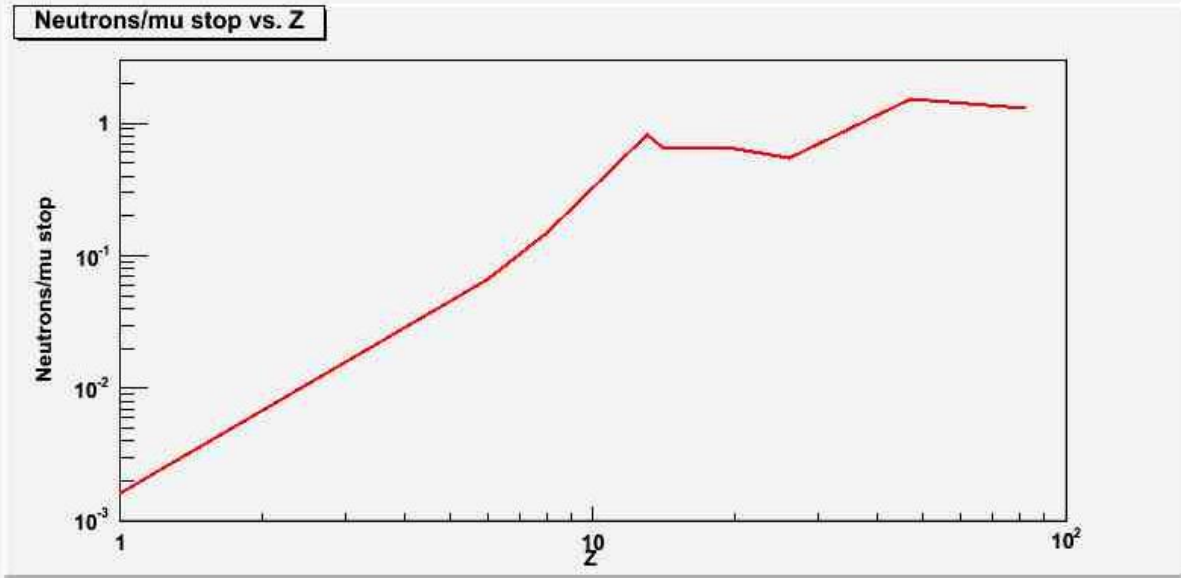
- Improved neutron production in muon-induced showers (SuperCDMS, EDELWEISS II, ZEPLIN III, LUX)
  - improved mu-nuclear model (using Bertini) completed
  - validation underway, see slide 8
- Improved mu-capture (EDELWEISS II, LUX, ZEPLIN III, SuperCDMS)
  - work needed here on both capture process and nuclear de-excitation, see slides 9, 10
  - FNAL is developing new, detailed muon capture code – could be incorporated into Geant4
- Validation of neutron production from muon capture (SuperCDMS, EDELWEISS II)
  - just recently started

280 GeV/c mu- on 1 m of H2O

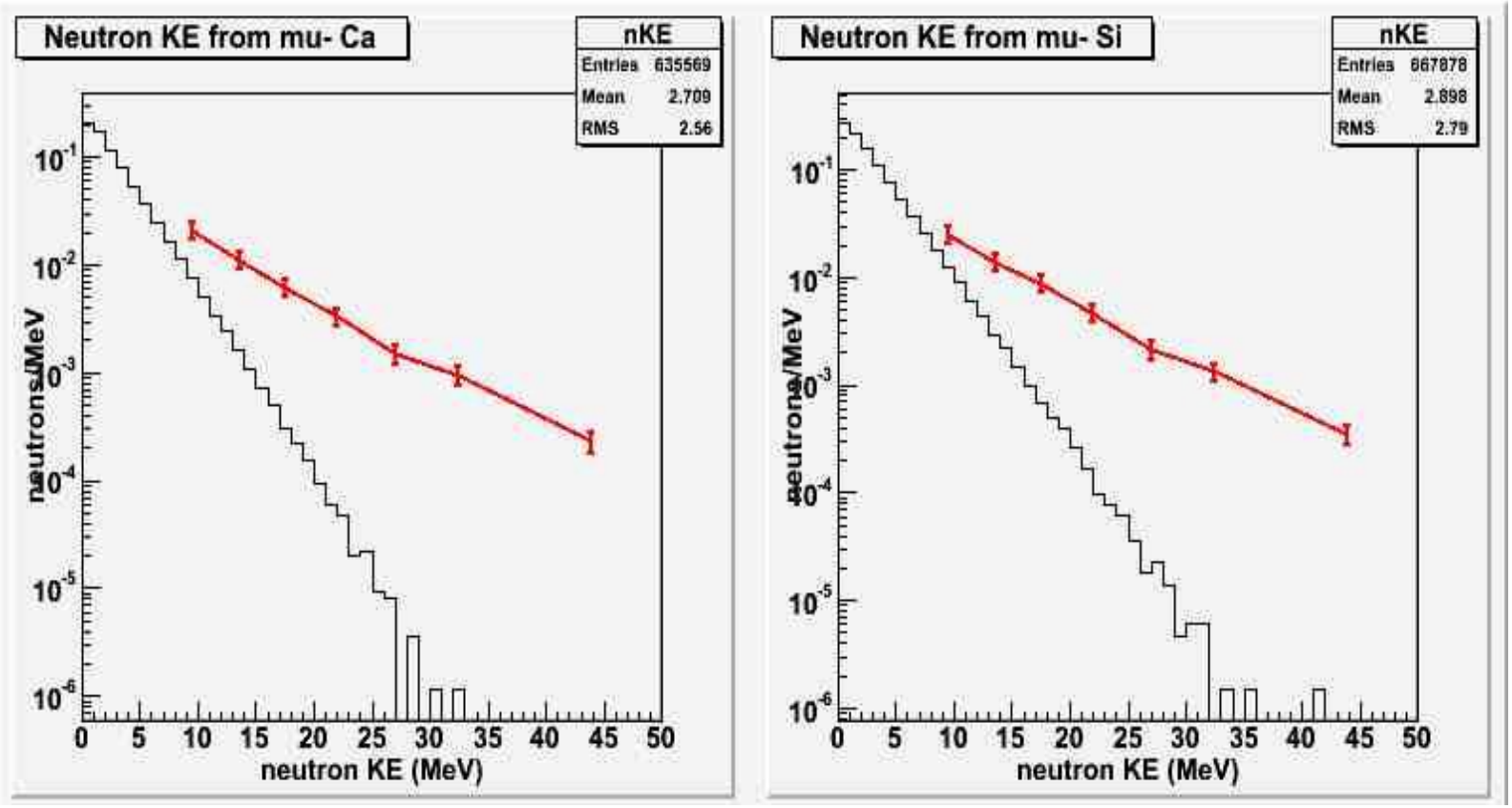


Neutrons from Muon Capture





Neutron Energies from Muon Capture

- 

Requirements (2)

- Improved beta decay (EXO)
  - completed with addition of forbidden decay spectrum shapes
- Fix energy non-conservation for:
  - case when energy is converted to fluorescence
  - internal conversion (e- ejected after interaction with nucleus)
- Precise decay schemes for low branching ratio decays
  - radioactive decay model can now read in user files
- Production of metastable nuclear states (Ge-77m, Kr-83m, etc.)(EXO, Majorana)
  - no progress to date – some redesign of particle classes required
- spontaneous fission (all DM expts.)
  - LLNL model available for some time, only interface to radioactive decay model required

Requirements (3)

- (α,n) reactions (all DM experiments))
  - α s from fission in cavern walls can produce neutrons below ~10 MeV -> significant background
  - data-driven model like HP neutrons or LEND required, prototype model available
- Low energy neutron propagation (all DM experiments)
  - Good progress: G4 HP neutrons and MCNPX agreement now quite good
  - LEND alternative 3X faster, but needs validation
- Improved models for reflection of optical photons at boundaries (ZEPLIN III)
  - angular dependence, wavelength dependence included in 9.5

Low Energy EM (requirements fulfilled)

- Precise tracking of leptons and hadrons (Xenon, DAMA, CRESST)
  - Livermore, Penelope EM models valid down to 250 eV
  - new interface to Penelope2008 extends to 50 eV
  - results < 100 eV are “qualitative” but reasonable (Penelope manual)
- Improved standard EM
  - “standard” EM processes have been improved at their low energy end
  - in many LBE applications standard EM processes are sufficient
- Atomic de-excitation with fluorescence and x-rays (Xenon, DAMA, CRESST)
  - fluorescence activated by default when using Livermore or Penelope
  - x-rays available by turning on PIXE

(Far?) Future Considerations

- “Neutrino wall”
  - nuclear recoils from neutrino interactions will affect sensitivity at some point
  - -> neutrino processes for Geant4?
- Performance
  - large number of simulated events required for high sensitivity experiments
  - related code should be reviewed for efficiency and improved

Summary

- Geant4 seeing increased use in low-background experiments
  - support from Geant4 has also increased
- Many requests fulfilled over last several years
- Things still to do:
  - continued validation of improved muon-nuclear model
  - improvement and validation of mu capture models
  - correct formation and population of metastable states
  - develop and test LEND-based physics list (Shielding has this option)
  - radioactive decay
    - check energy conservation for EC, IC and fluorescence
    - spontaneous fission
  - (a,n) reactions