Geant4 Applications for Astroparticle and Rare-Event Physics

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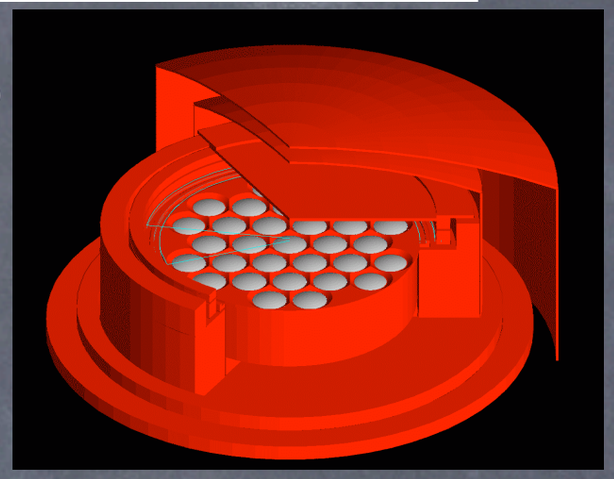
Imperial College London

Outline

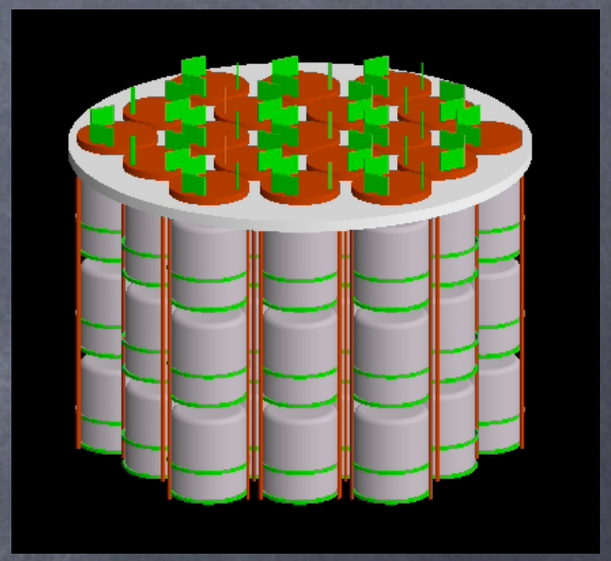
- Geant4 in the Astroparticle and Rare-Event physics community
- Critical issues for underground experiments
  - Muon-induced neutrons
  - Low-energy neutron propagation
  - Radioactivity (decays, small BR, (α,n), etc.)
  - Very-low-energy electromagnetic interactions
- Updates on requirements

Astroparticle & Rare-event physics

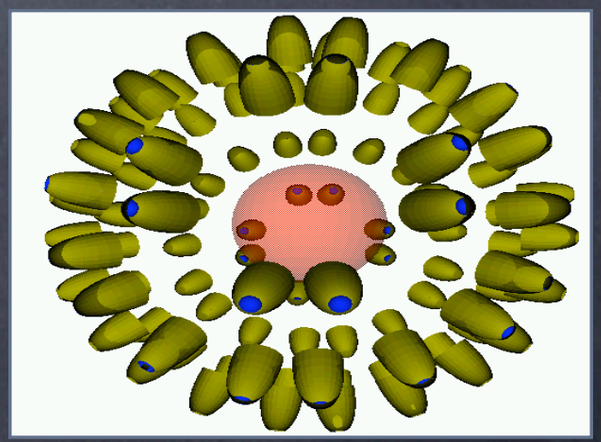
- Direct Dark Matter detection experiments
  - ArDM, (Super-)CDMS, CRESST, DRIFT, EDELWEISS, EURECA, LUX, WARP, XENON, ZEPLIN, etc. (no claim to be complete)



- Neutrinoless double-β decay experiments
  - COBRA, CUORE, GERDA, MAJORANA, etc.



- Solar neutrinos
  - Borexino, KamLAND, etc.

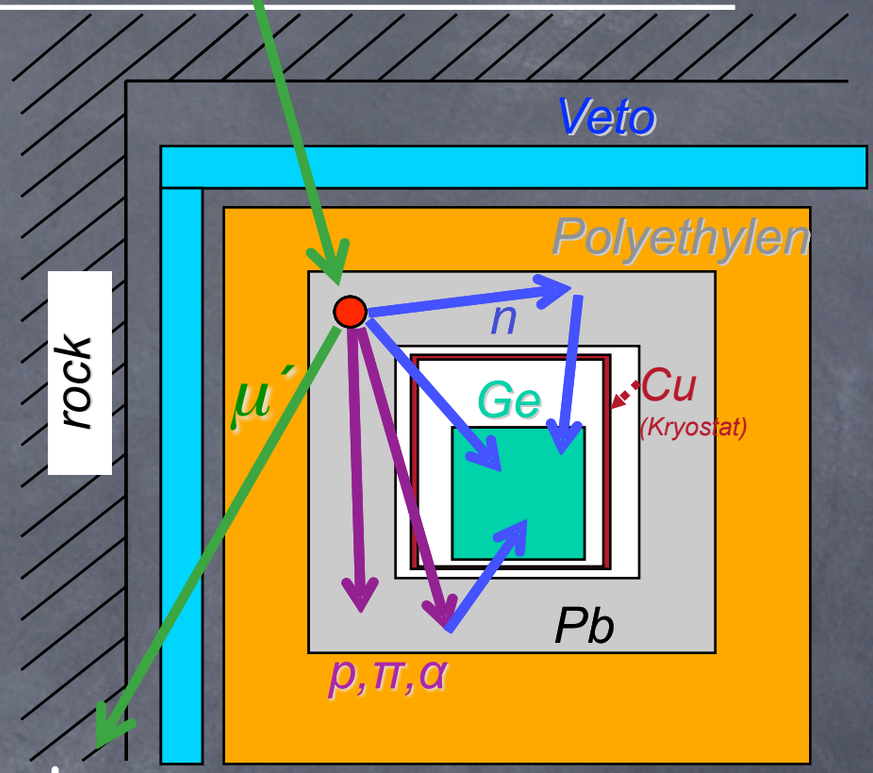


Geant4 applications

- Backgrounds of the experiment
  - internal radioactivity
  - external radioactivity (rock, shielding, etc.)
  - neutron production induced by cosmic muons
  - efficiency of veto systems
- Detector response
  - scintillation, ionisation
  - optics, e.g. photon generation, light collection
- Calibration
  - neutrons and gammas
- Simulated data
  - visualisation, run-time analysis, input to data analysis, etc.

Muon induced neutrons

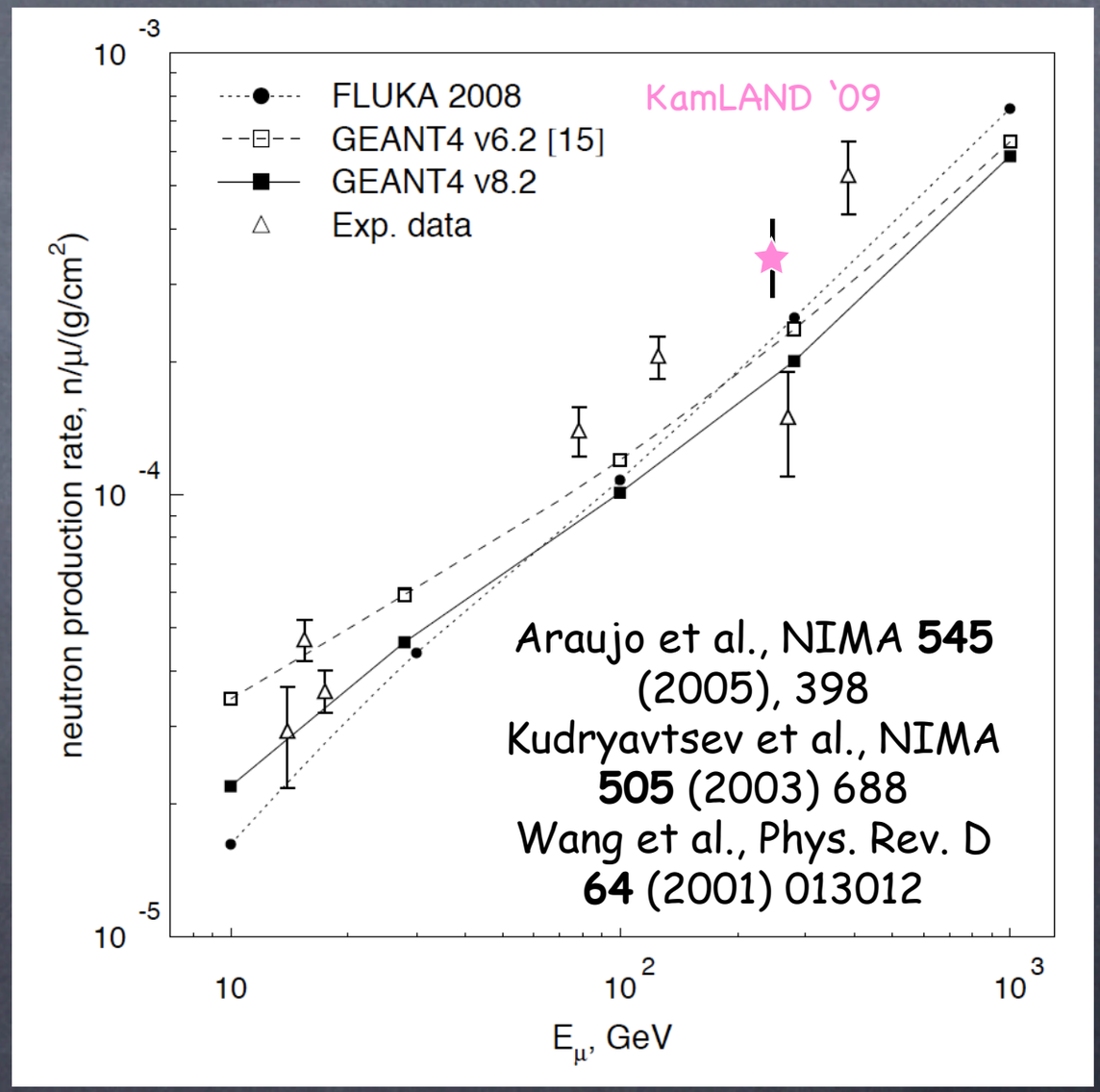
- Muon induced neutrons
  - HE cosmic ray muons (>200GeV) inducing neutrons in surrounding rock or shielding material
  - critical for ALL underground experiments
  - very important for ton-scale next-generation experiments (Dark Matter, 0ν2β, etc.)
  - assessment of new and ongoing multi-experiment underground facilities



Muon induced neutrons (cont. I)

- Differences between Geant4, FLUKA, MUSIC to experimental data remain
  - see Boulby/Zeplin-II report (arXiv:0810.1682) yield in Pb seems lower than Geant4/FLUKA

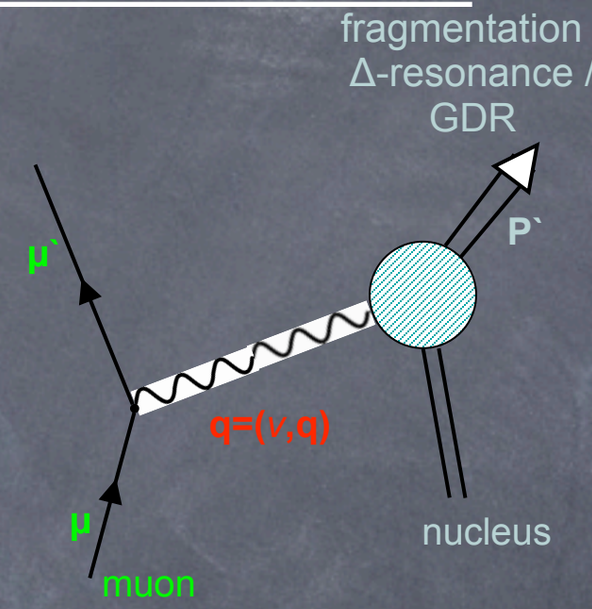
- New data from KamLAND (arXiv:0907.066)
  ➜ see talk I.Shimizu

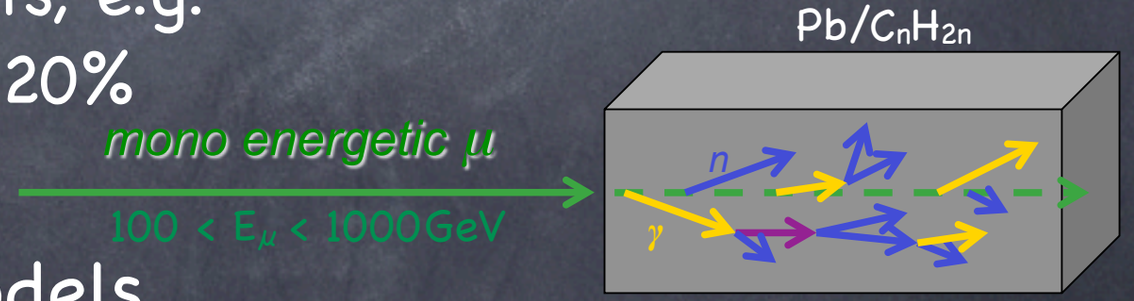


Muon induced neutrons (cont. II)

User requests & Geant4 updates

- Continue development & validation of muon-nucleus interaction models
  - QCollision and QCaptureAtRest
    - ✔ changes for large nuclear excitation in Q models
    - ✔ improvement to fragmentation > 10GeV
  - Validate inelastic cross-sections
  - Validate underground muon spectra, depth intensity relations, etc.
- Dedicated neutron yield test for each release
  - Disseminate validation results, e.g. neutron yield increased by 20% from Geant4 9.0 to 9.2
- Hadron and Ion cascade models, e.g. CHIPS-based models, BiC, Bertini, etc.





Neutron propagation

- Precise tracking of fast (~MeV) neutrons down to thermal energies very important
- Geant4:
  Data-driven approach of NeutronHP models, databases for elastic & inelastic scattering, capture and fission
  - currently ENDF/B-VI, FENDL, JENDL, etc.
  - update to ENDF/B-VII (elastic only)
  - translation to LLNL-ENDL database ongoing

Neutron propagation (cont. I)

- Energy and momentum conservation (event-by-event) in NeutronHPInelastic

  ✔ significant improvements been made, 2-body

  ✔ 3+-body improved, but not solved (yet)

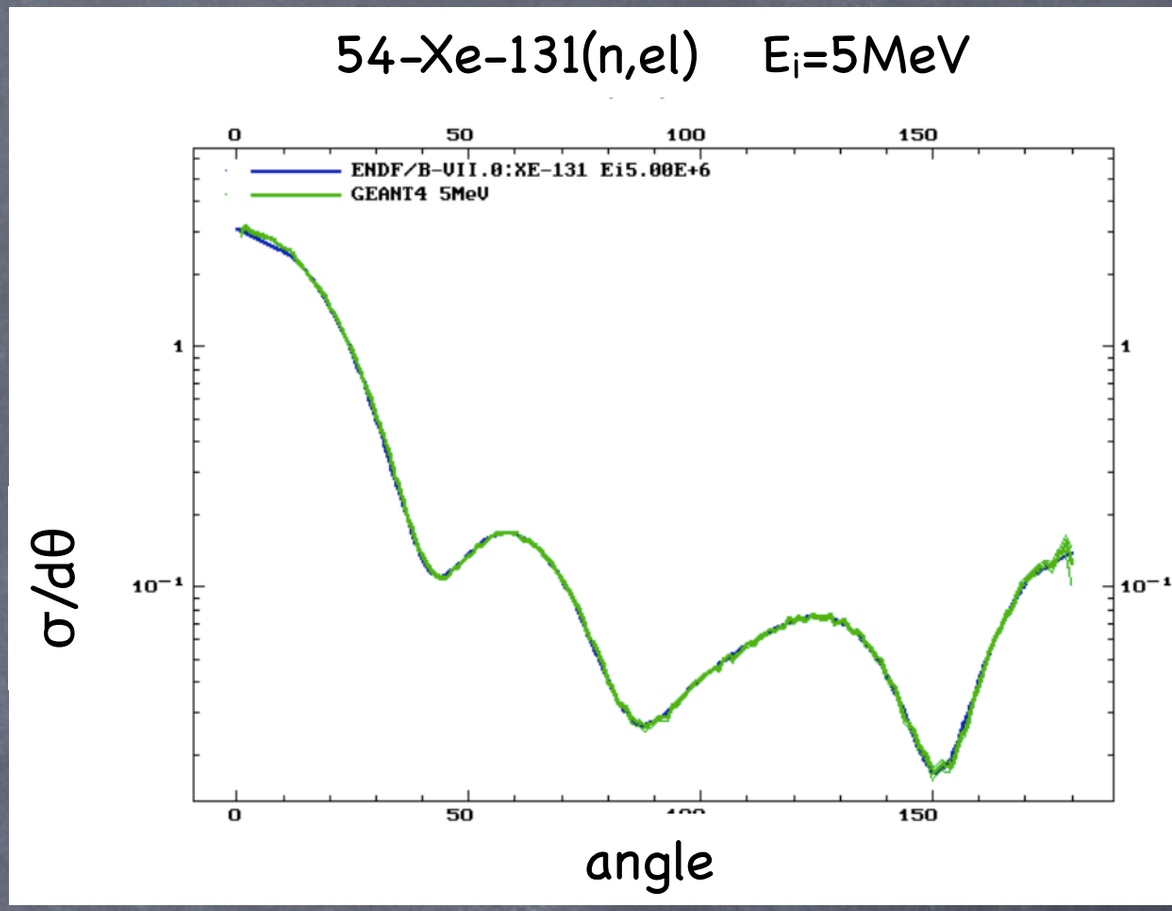
  ✔ missing residual nucleus, e.g. Ge(n,2n)

  ✔ missing γ's in some channels, e.g. (n,α), (n,p)

  - Separation (n,n'γ) to (n,n')+γ remain difficult
  - Angular distribution of recoiling nucleus (n,n'γ) might be relevant for DM applications

Neutron propagation (cont. II)

- Neutron HP database and documentation
  - ✔ ENDF/B-VII.0 elastic cross-sections implemented



- inelastic, capture, fission under development
- Independent database tool available, though needs more materials (only Ar/Xe patches yet)

Radioactivity

- Radioactive decay module needs to be very precise,
  - ✔ atomic de-excitation bugs fixed/patched
  - ➜ see bug report #1001
  - no local energy deposit handled
  - no Auger-electron data loaded for non-detector elements
- some missing X-rays bugs remain, e.g. I-129

Radioactivity (cont. I)

- Small BR decay possibilities (<10^{-8})
  - database needs maintenance and update
- Event generator, non-trivial sources (e.g. 2ν2β)
- Shape of β-spectra for forbidden transitions
- Isotope production
- Metastable states, e.g. Ge-77m, Kr-83m, etc.
  - strong requirement to generate metastable states in radioactive decays and cosmic ray activation

Radioactivity (cont. II)

- (α,n) reactions are the main production mechanism for neutrons in most experiments (background, calibration, etc.)
  - mainly using SOURCES 4A/4C code by LANL
    - data-driven (HP-type) model would be preferred
    - LLNL database? ➜ Problems with licenses
- (angular correlation in gamma cascades)

Very-low-energy electromagnetics

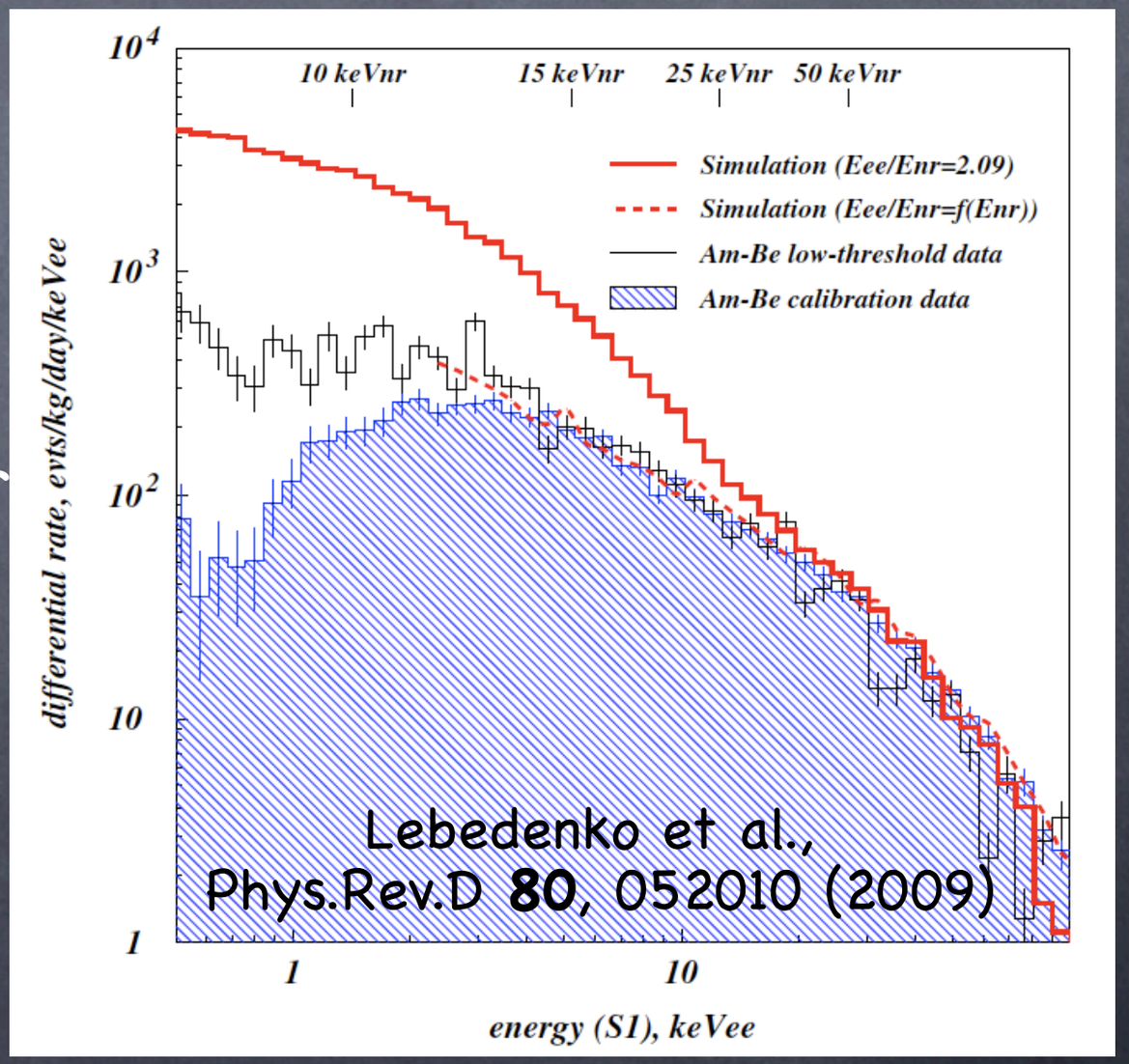
- Precise description of electromagnetic processes of leptons and hadrons down to very low energies is crucial to ALL low background experiments
  - proton/α-particle/nucleus EM processes
    - high spatial precision for α-particles needed
    - simulations of fluorescence X-rays, e.g. in 0ν2β and γ spectroscopy
- Models are continuously tested, maintained and validated, new ones developed

VLE electromagnetics (cont. I)

- Nuclear quenching factor important for ALL DM searches
  QF = E_{nuc}/E_{elec} (ionisation, scintillation, etc.)

- discrepancy between simulation and data
  - either efficiency loss, or
  - non-linear quenching factor
    ➜ new measurement
    LUX/McKinsey (Yale)

- Importance of precise VLE simulations



Conclusions

- Geant4 widely used within our community
- Physics models required cover wide range (from TeV-muons to thermal neutrons)
- Geant4 support/response to community requirements is very well - Thank you!

➜ see also

Parallel Session IV Underground
16:30 - 18:30