Imperial College London

BACKGROUND SIMULATIONS WITH GEANT4

Overview & status of GEANT4 developments for the underground physics community

with thanks to Luciano Pandola, Vitaly Kudryavtsev,
GEANT4 collaboration, ZEPLIN-III collaboration

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LRT-2010, SNOLAB 28-29 August 2010

GEANT4

- GEANT4: GEometry ANd Tracking - http://geant4.cern.ch/
  “Monte Carlo simulation of passage of particles through matter”

- Member institutes: CERN, ESA, Fermilab, Helsinki IOP, IN2P3, INFN, KEK, Lebedev institute, LIP, SLAC, TRIUMF, STFC

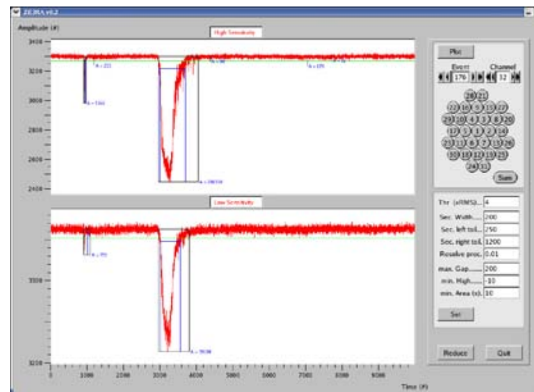
- Many areas of application
  - particle physics, space, medical, accelerator, underground physics,…

- Agostinelli *et al.* NIM A 506 (2003) 250
  - 2000 citation mark this week! (but that does not mean it’s right…)

- Disclaimer: I do not speak for the GEANT4 collaboration
  Luciano Pandola and I have been liaising with G4 on behalf of the (European) low-background community

ZEPLIN-III

- Some examples from ZEPLIN-III dark matter experiment (Boulby, UK)
- Two-phase xenon detector (TPC with scintillation & ionisation readout)
- End-to-end simulation framework (well ahead of detector deployment)
  - Backgrounds (electron and nuclear recoil)
  - Signal development (S1 and S2)
  - Calibration (yields, efficiencies)
  - Analysis (position reconstruction)
  - Flexibility

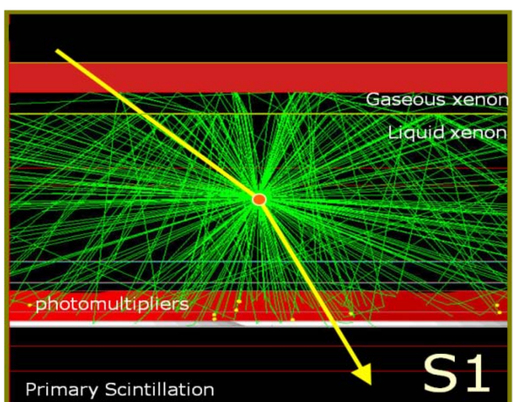


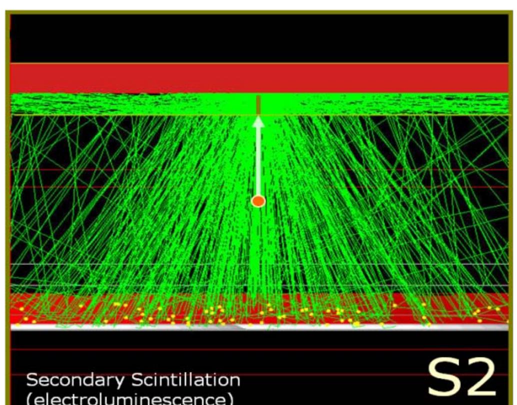
H.Araújo *et al.*, Astropart. Phys. 26: 140 (2006)

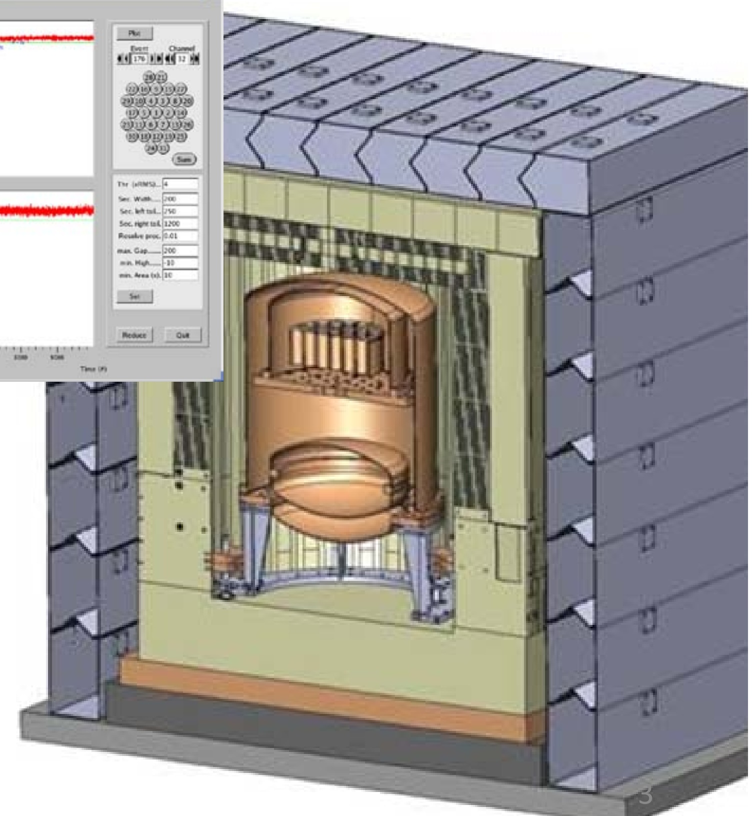
D. Akimov *et al*., Astropart. Phys. 27: 46 (2007)

V. Lebedenko *et al.*, PRD 80: 052010 (2009)

V. Lebedenko *et al.*, PRL 103: 151302 (2009)



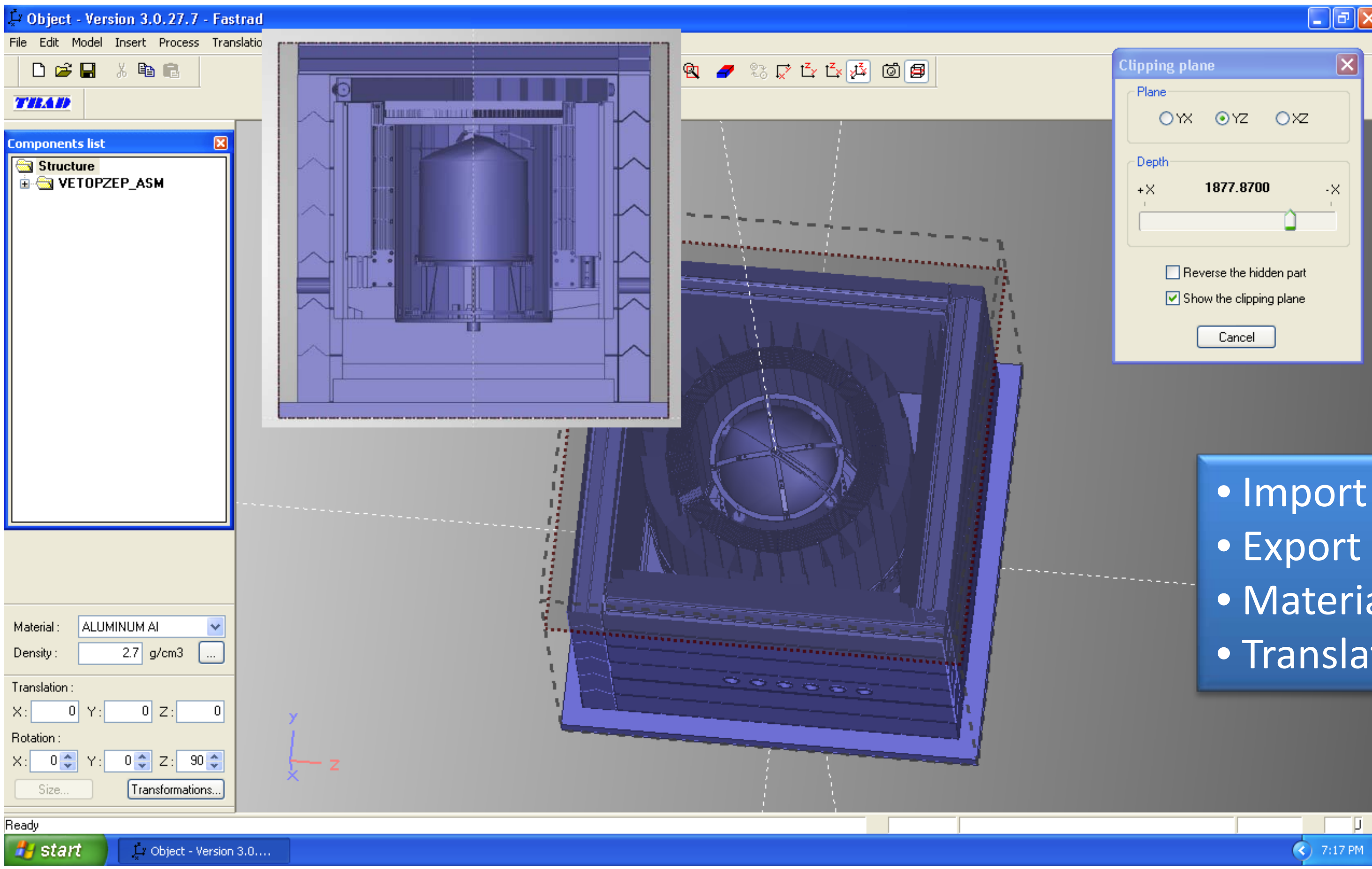




Geometry implementation
FASTRAD – Translating CAD into G4

http://www.fastrad.net/

ST-Viewer is (more expensive) alternative

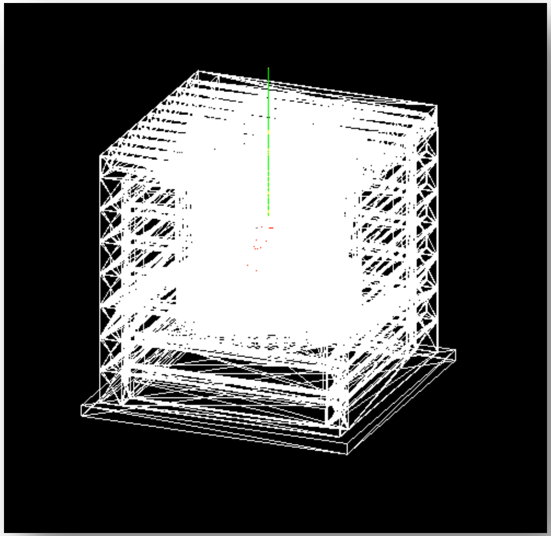


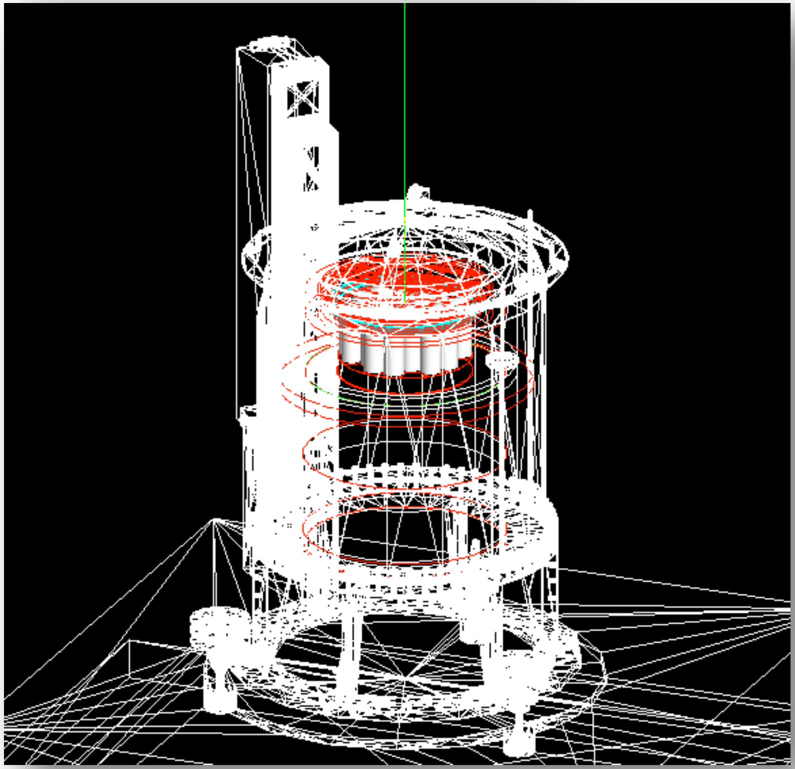
- Import STEP
- Export GDML or C++
- Materials
- Translations/rotations

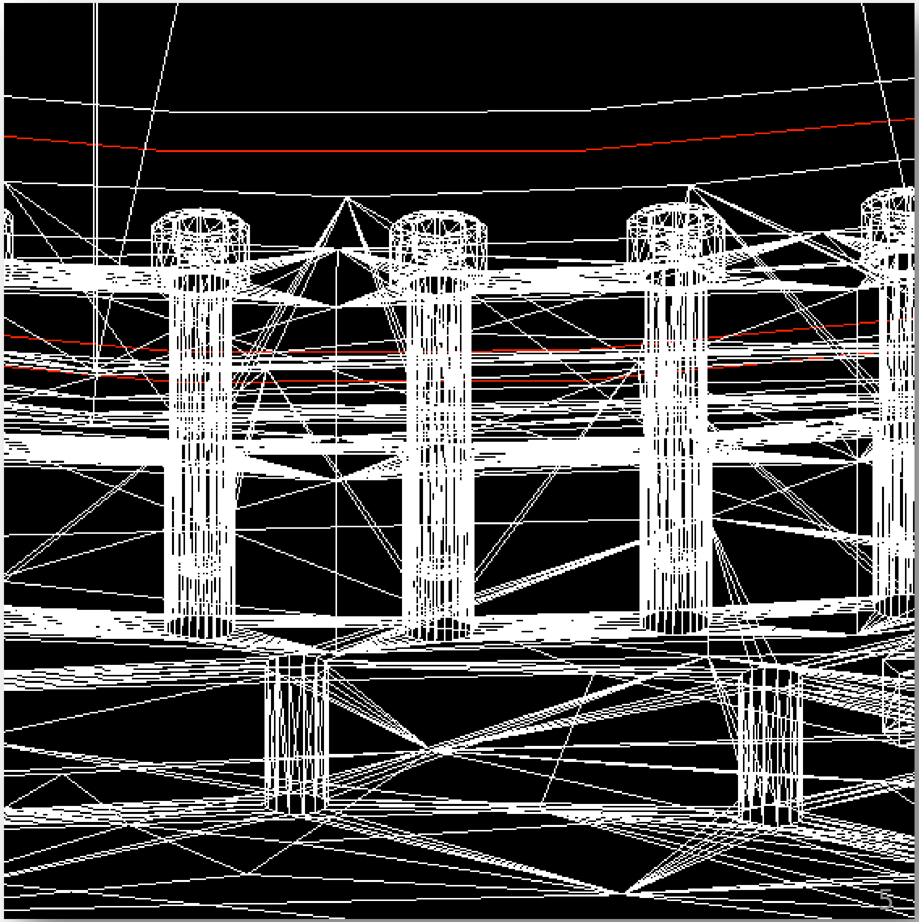
ZEPLIN-III SHIELD & ANTI-COINCIDENCE VETO (L. Reichhart, Un. Edinburgh)

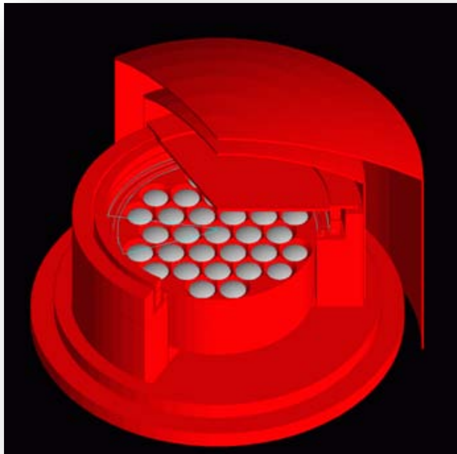
ZEPLIN-III veto/shield model

- Expect inefficient navigation: 2–5x penalty
- Expect geometry conflicts: overlapping volumes
- *The devil makes work for idle thumbs…*









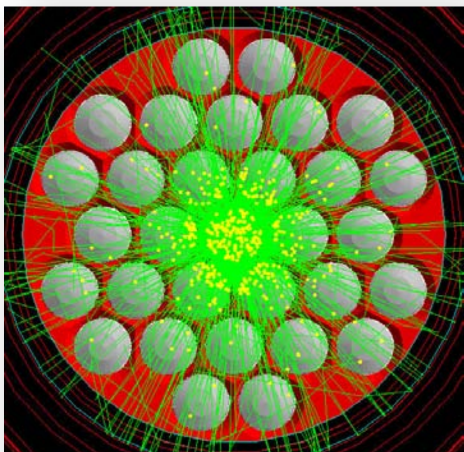
End-to-end simulation

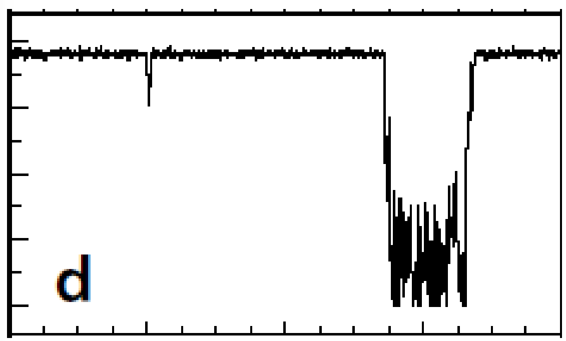
Scintillation (S1) and electroluminescence (S2) response models

S1: particle tracking > scintillation > photon tracking > *electrical signal*

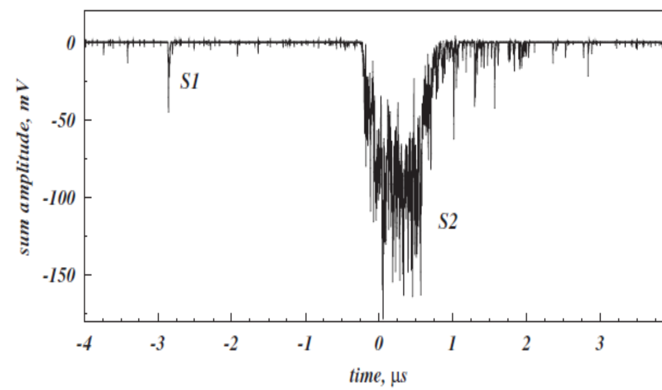
S2: particle tracking > ionisation > drift in field > emission to gas > electroluminescence > photon tracking > *electrical signal*

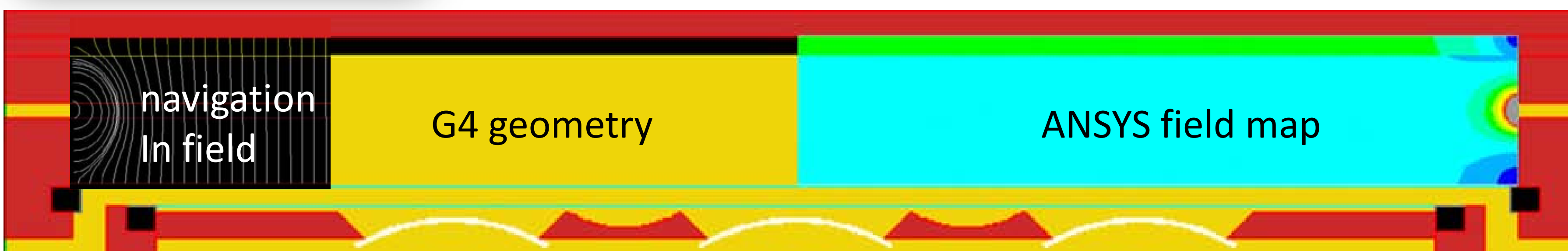
- Design stage: DAQ & electronics design; fake datasets
- Data analysis: detector characterisation; vertex reconstruction





PHYSICAL REVIEW D **80,** 052010 (2009)





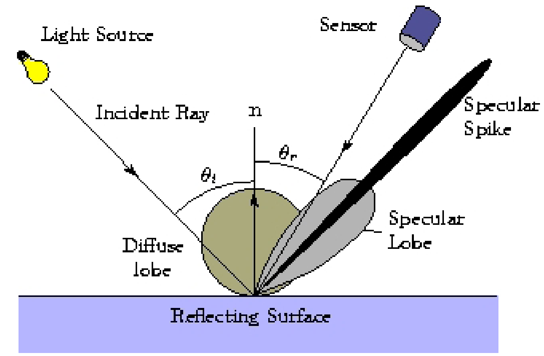
Optical reflection models

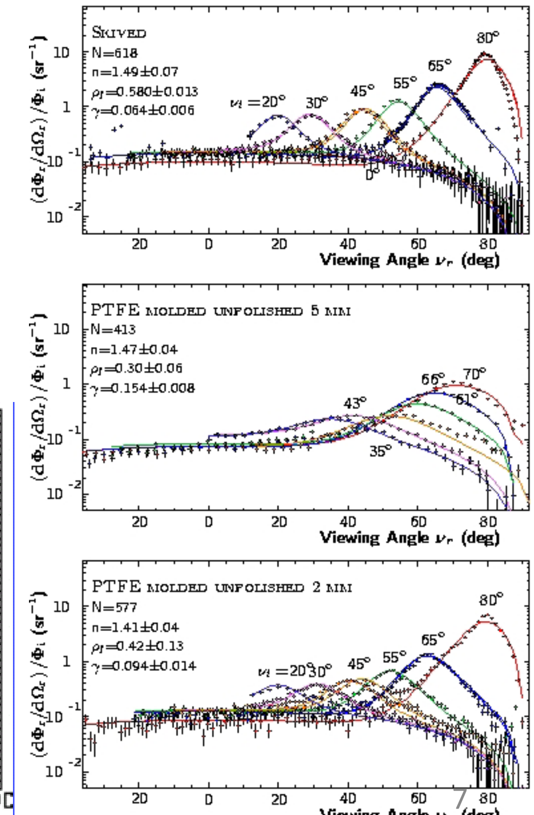
- Tracking of S1 and S2 VUV photons (175 nm)
- Two surface reflection models in GEANT4
  - GLISUR (originally GEANT3), UNIFIED (from DETECT/TRIUMF)
- Lacking data for useful “LXe materials” (Cu, PTFE)

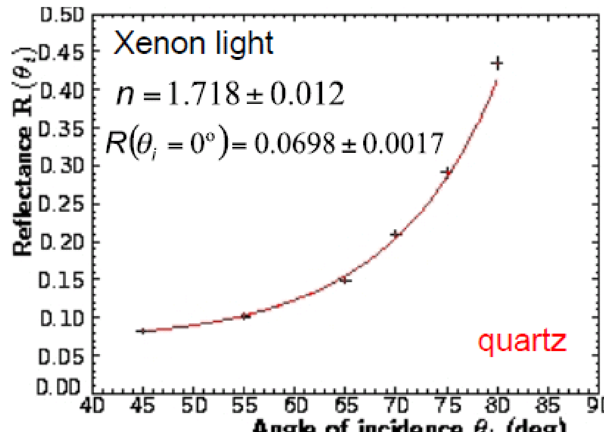
  Models also deserving improvement
- Precision data and model by ZEPLIN-III collaborators
  - Reflectance model for different roughness types with improved implementation of angular dependence of specular spike and lobe
  - New models for diffuse reflection for smooth and rough surfaces
  - Specular reflection models (spike, lobe) also improved
  - Refraction in rough surfaces soon
  - New Coimbra data and model:

    Data for quartz, Au, Cu,

    PTFE (10 varieties)



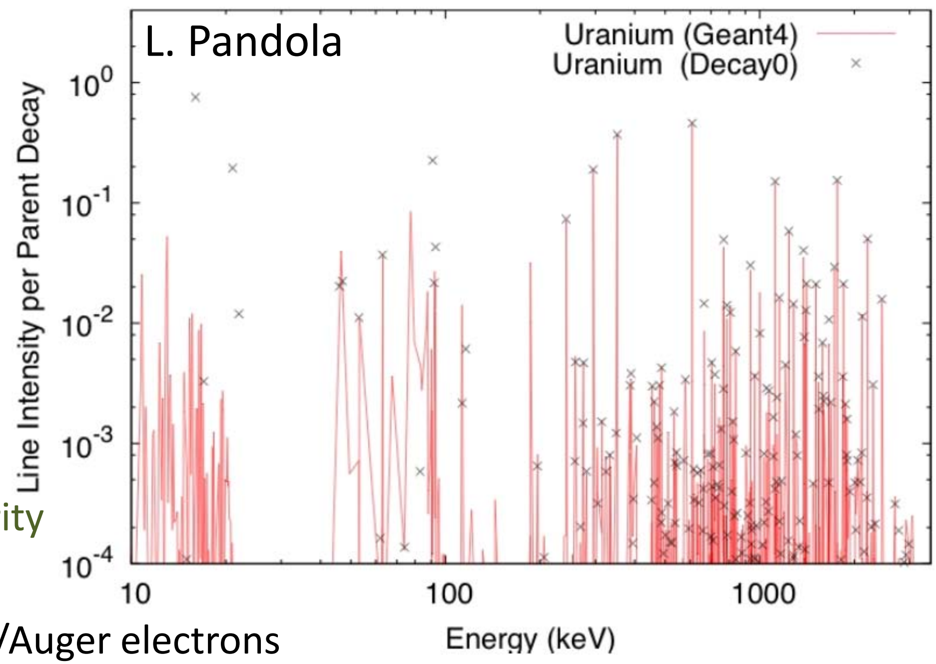




C. Silva et al.,
J. Appl. Phys. 107 (2010) 064902,
NIM A 580 (2007) 322-325
NIM A (In press),

α, β, γ backgrounds with GEANT4

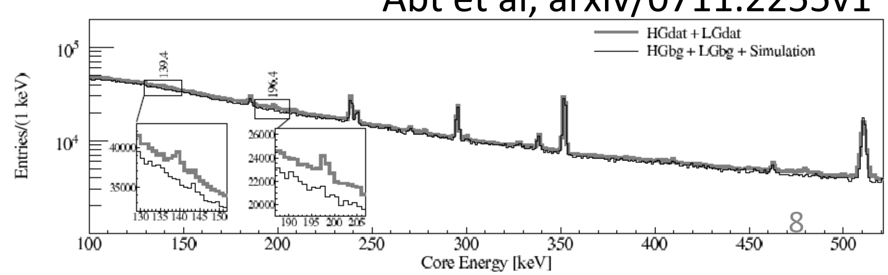
- Standard interface: G4RadioactiveDecayModule & G4GeneralParticleSource
- Alpha decay
    - Fully simulated, with daughter recoil
- Beta decay
    - Coulomb-corrected beta spectrum
    - Forbidden transitions requested (Ar-39)
    - $2\nu\beta\beta$: no plans; event generators exist
- Gammas (U/Th chains)
    - Careful with timing precision!
    - RadScr code (LLNL), Decay0 (Tretyak)
    - Angular correlation in cascades: low priority



– Validate electron yields carefully
    - BR: Gamma/Conversion electrons, X-rays/Auger electrons
    - BUG: energy non-conservation (sub-cut electrons not generated!); known to GEANT4

– Population of metastable states by neutrons
    - G4RDM can decay excited states, but only ground state populated by inelastic/capture (Xe-129m, -131m, Ge-71m, -75m)
    - Under consideration (G4 looking for data)

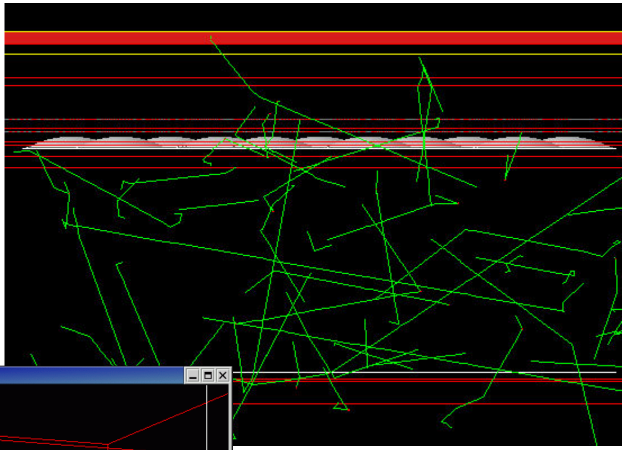
Abt et al, arxiv/0711.2255v1

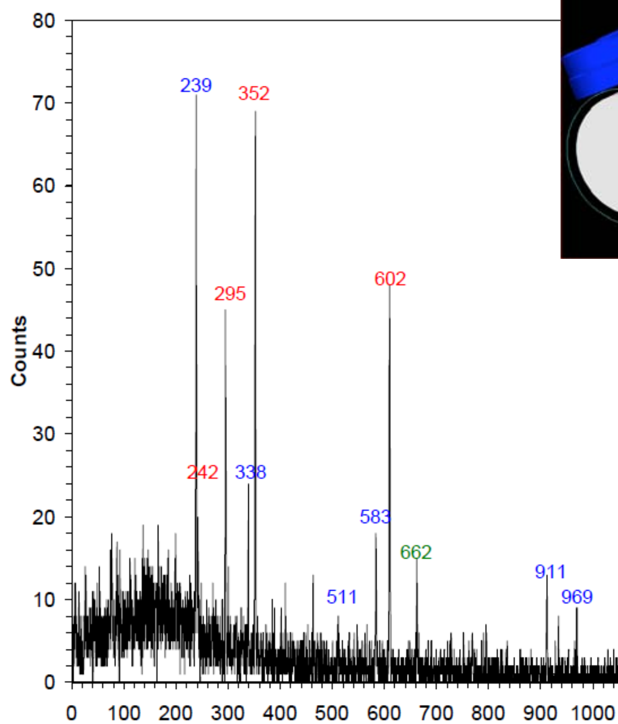


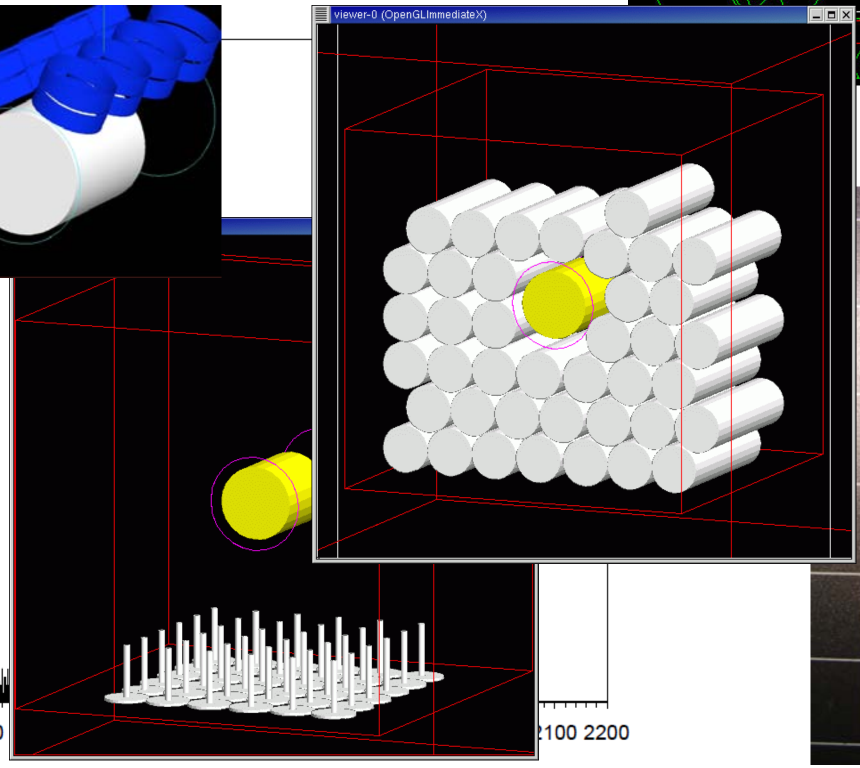
Natural radioactivity: ZEPLIN-III PMTs

1. HPGe component assays
    1. All sub-components tested prior to PMT manufacture
    2. Simulation of gamma-ray detection efficiencies
2. Propagation in experimental geometry

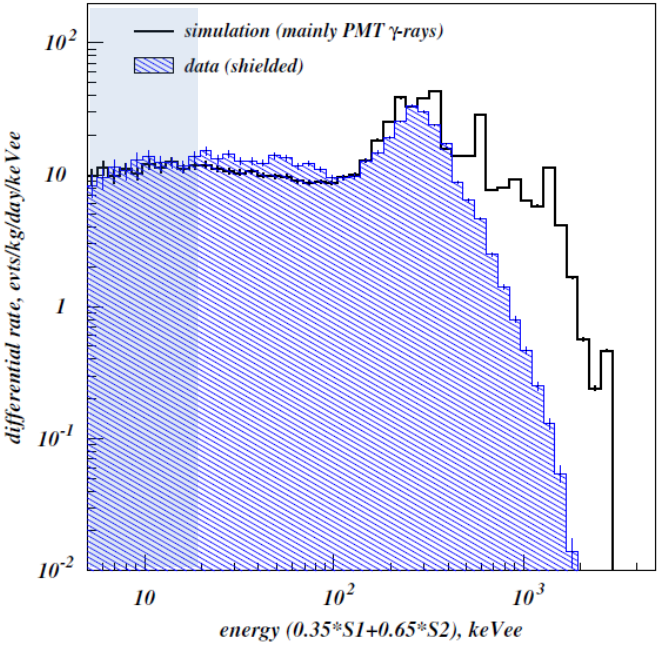
Gammas are often only handle on neutrons







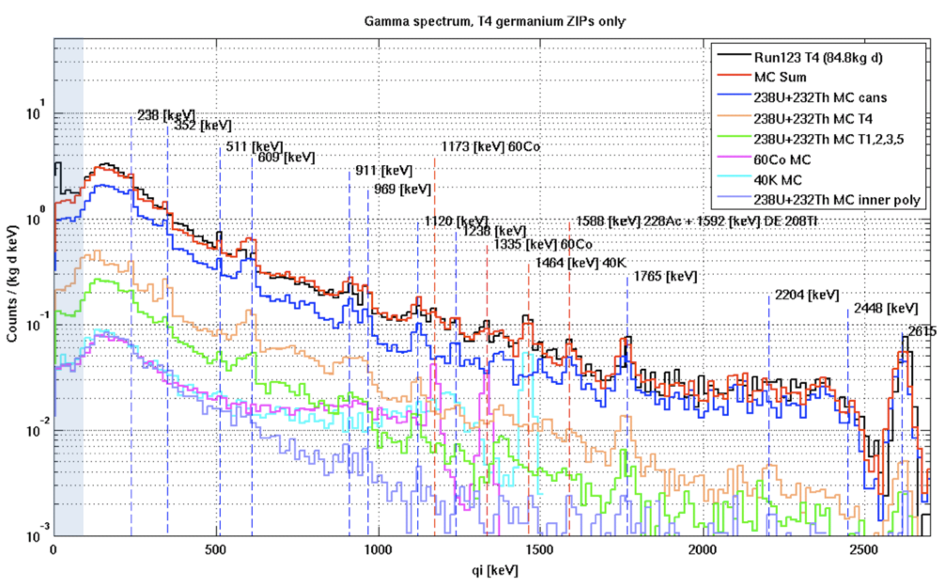
ZEPLIN-III – V. Lebedenko et al, PRD 80: 052010 (2009)



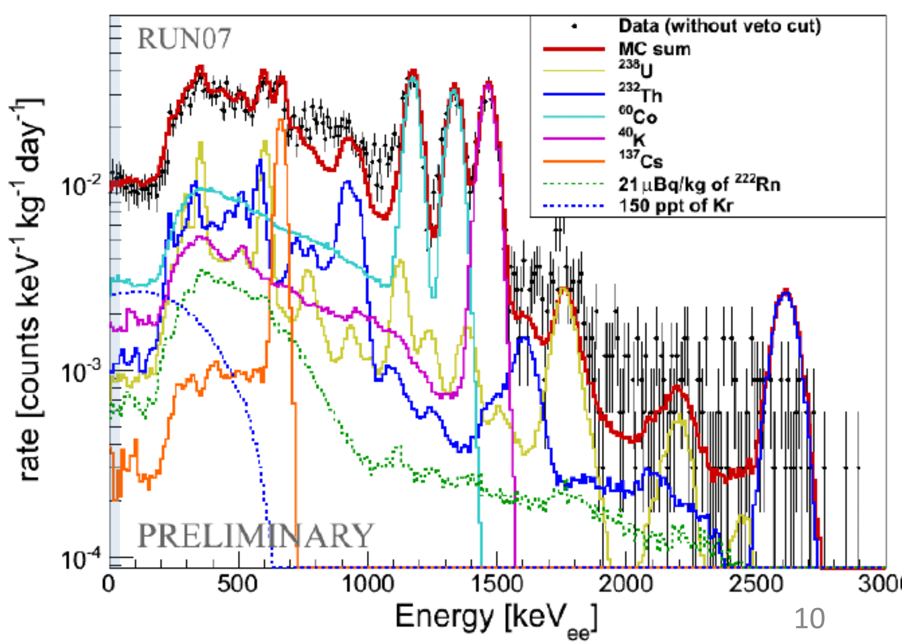
e-recoil backgrounds

- Synthesis: prediction at design stage
- Analysis: dissection of real data
  - Rn-222 chain by β–α delayed coincidences
  - Kr-85 by β-γ delayed coincidences
  - Spatial distribution for particular gamma lines
  - Gamma angular correlation (e.g. in veto)
- ➢ Good (absolute) agreement with simulations

CDMS-II – T. Bruch (U. Zurich); 5th Patras Workshop (2009)



XENON100 – A. Kish (Zurich), DM2010

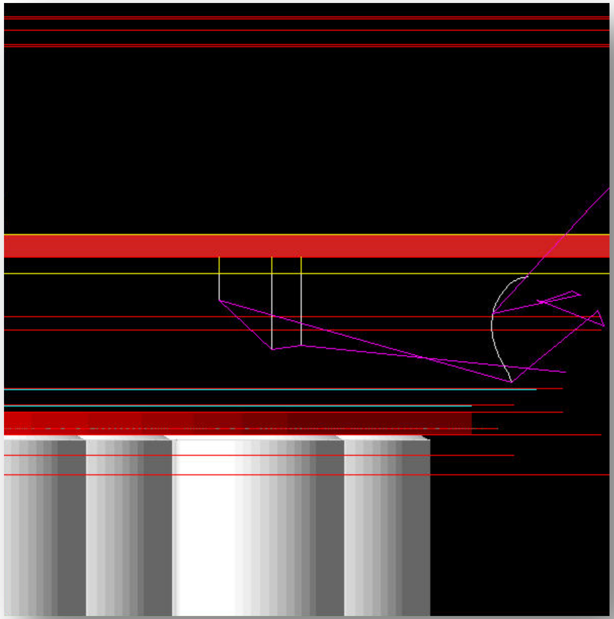


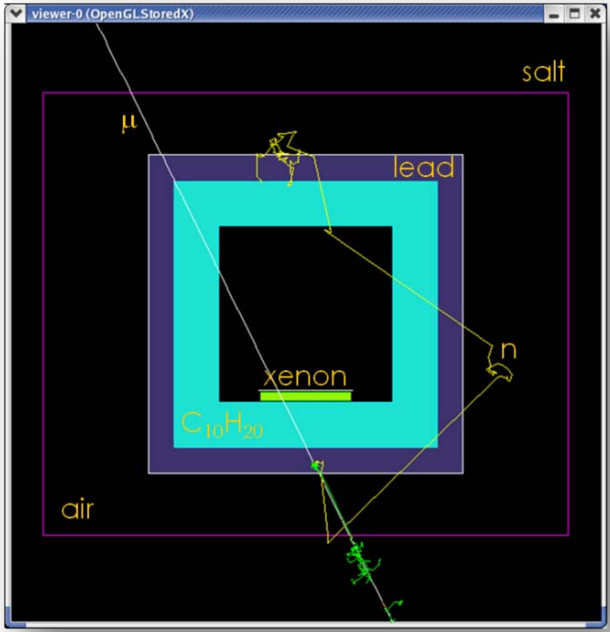
Neutron backgrounds

- Nuclear recoils from neutron elastic scattering are irreducible background (fiducialisation eliminates surface backgrounds)

1. Neutrons from U/Th radioactivity
   - Internal and external components
   - Production, propagation, detection

2. Muon-induced neutrons (see V. Kudryavtsev talk)
   - Main mechanism proto-production in EM cascades
   - Significant simulation effort (GEANT4, FLUKA), but lacking "simulated experiments" (old data exist but difficult to review systematics)
   - Measurements for lead with anti-coincidence vetos
     - ZEPLIN-II, ZEPLIIN-III, EDELWEISS, …





U/Th radioactivity neutrons

- Sources 4A(-4C) (Wilson *et al.*, Tech Rep. LA-13693-MS, 1999)
  - Spontaneous fission and (α,n) reaction from radionuclide decay
  - SF fraction varies widely: negligible for low A, >90% in Cu, ~100% for Pb
  - Careful with (α,n) calculation: mixing and granularity are important!
- "Modified SOURCES" (Carson et al, Astropart. Phys. 21 (2004) 667)
  - XS extended to 10 MeV, some missing target isotopes added
- Extension with EMPIRE XS (V. Tomasello et al**,** NIM A 595 (2008), 431)
  - EMPIRE 2.19, M. Herman *et al.*, NDS 108 (2007) 2655
  - Improved (α, n) XS and BR for transitions to excited states

➢ Neutron yield can increase up to 50% (see V. Kudryavtsev talk)

- Maybe GEANT4 could handle (α,n) with new LLNL models?

Low-energy neutron propagation

- G4NDL library (derived mainly from ENDF/B-VI, -VII)
- Missing elements; no longer nat.ab. materials (moved to different database)
- Inelastic scattering not kinematically closed (ENDF not suited for this)
- Database management
  - G4NDL format is difficult (esp. final states) and users want to extend database (e.g. elastic scattering in Xe with ENDF/B-VI and ENDF/B-VII)
  - nTOF (CIEMAT) developed tool to take ENDF format and convert to G4NDL
  - Similar effort at LLNL & SLAC
  - Ar and Xe patches for ENDF-VII data exist, other materials were requested (Ge, Si, Ne, …)
- Replacement of G4NDL format being planned

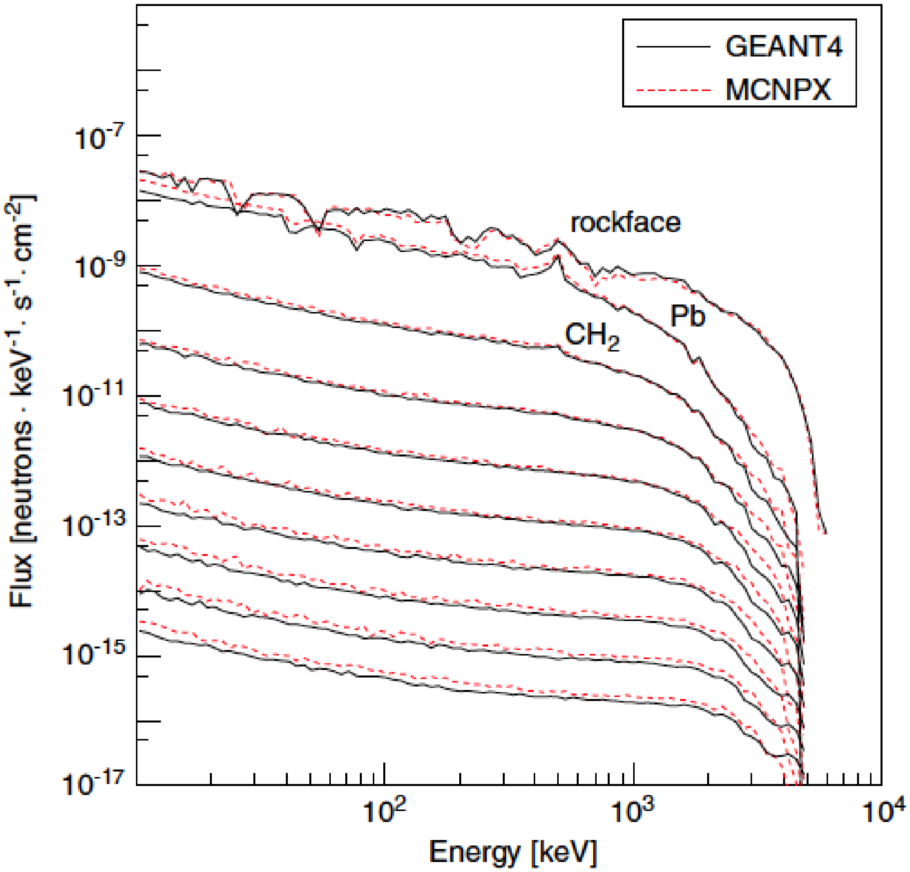
  New approach with LLNL libraries (ENDL instead of ENDF)
  - http://nuclear.llnl.gov/simulation/
  - Final state description is more flexible
  - Elastic model tested; capture, Inelastic and fission models soon
  - Should solve (n,n'γ) case: correct energy-angular correlation for recoil
- US-Geant4 Consortium: multi-year roadmap

  http://www-public.slac.stanford.edu/geant4/papers/USG4-Roadmap-Feb-2009-V2.pdfl

Low-energy neutron propagation

- **Neutron fluxes behind shielding**

  50% higher flux in MCNPX than in GEANT4 after 30 cm of lead and 40 g/cm^2 of CH_2. MCNPX is a reference transport code, so this indicates level of systematic uncertainty



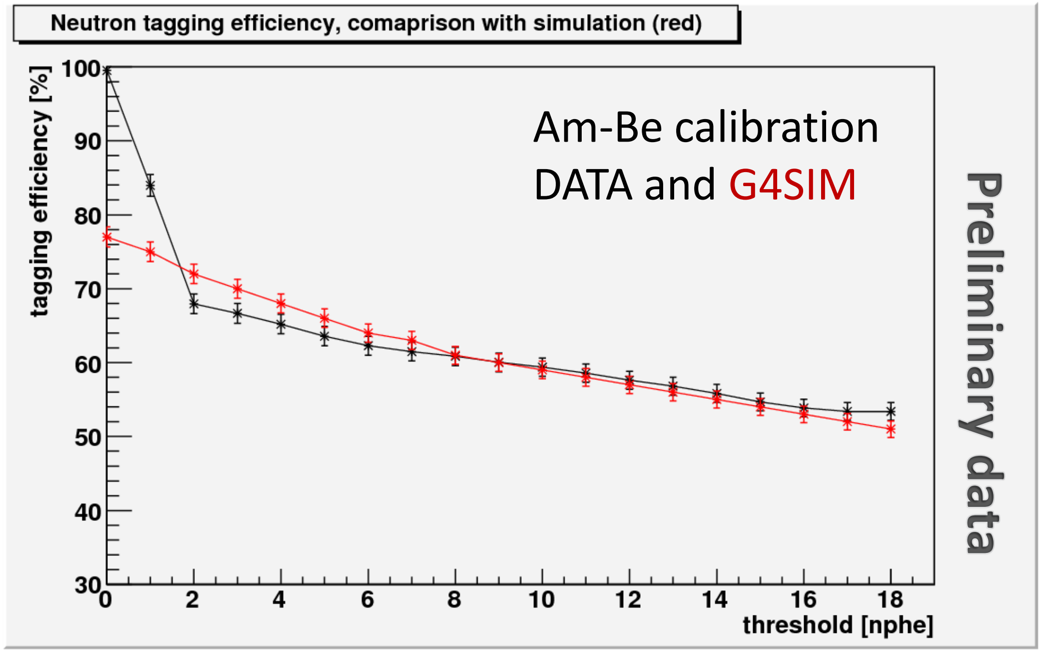
R. Lemrani et al. NIM A 560 (2006) 454
GEANT4.7.0.p01, G4NDL 3.7

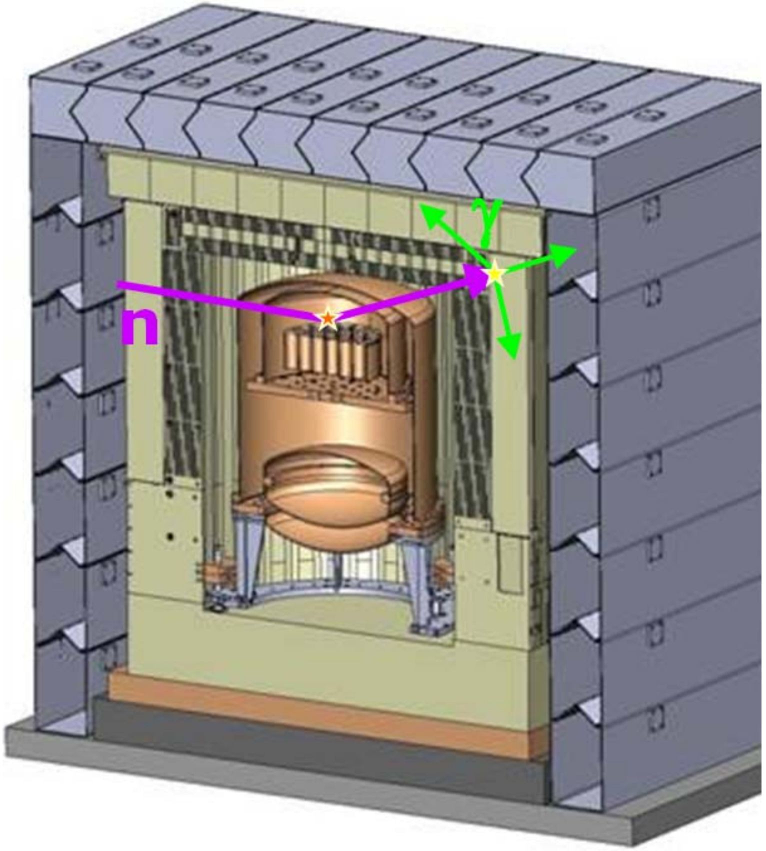
MUST BE REPEATED with recent G4 (presently G4NDL 3.13)

Neutron detection (capture)

- Good agreement for tagging efficiency for internal neutrons (considering implementation of Gd-157 capture gammas in G4NDL)

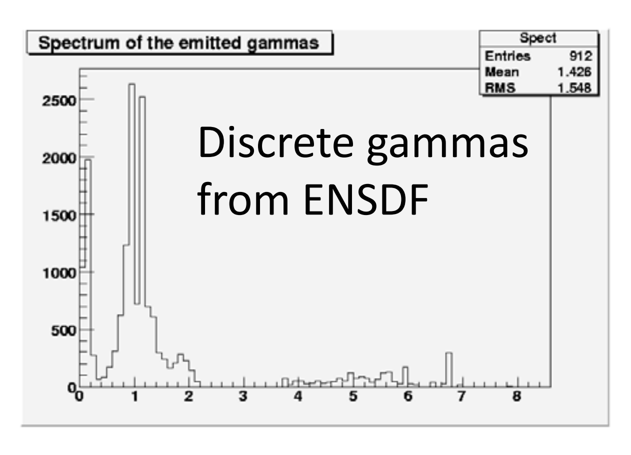
Simulation prediction:
70% efficiency at 4-phe threshold
Ghag *et al.*, Astropart. Phys. 34 (2010) 51

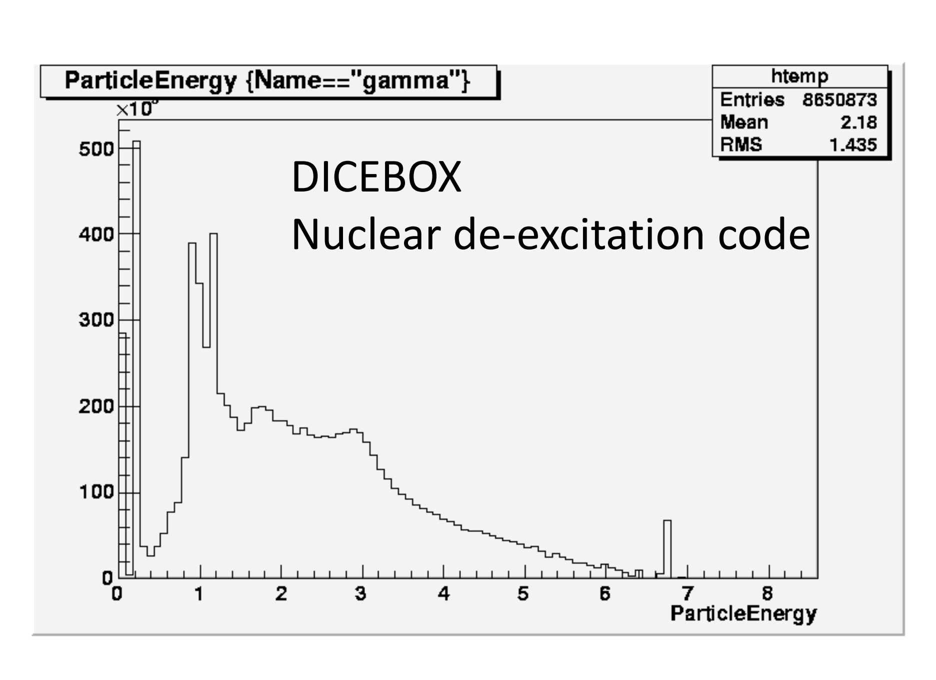


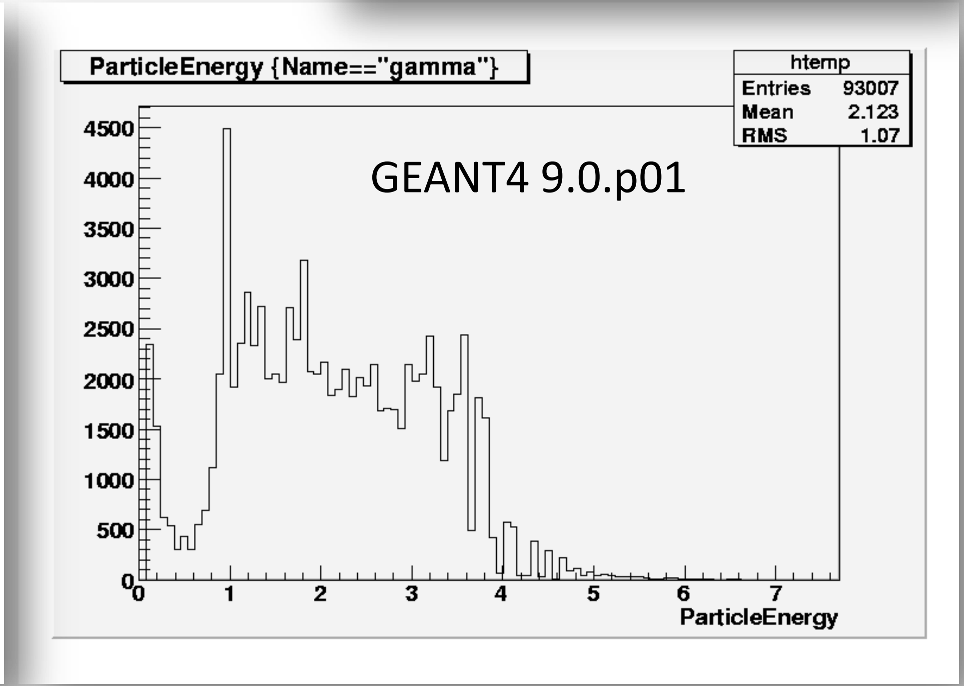


Neutron detection (capture)

- Gd-157 capture gammas: ~8 MeV total energy
  Discrete + continuum components
  (some discrepancy on both)
- Plots from A. Kobyakin (ITEP)
- See also GLG4sim (neutrino.phys.ksu.edu/~GLG4sim/Gd.html)







Conclusions

- GEANT4 has allowed the precise simulation of entire low-background experiments; it is a vital tool in the design of next-generation experiments
- There are several unresolved issues in the simulation of α,β,γ radioactive backgrounds; careful validation is always advisable
- Significant improvement of neutron simulations (production and transport) is possible with the forthcoming ENDL-based libraries; final-state specification should become more flexible
- The GEANT4 collaboration is responsive to our community, but lacks resources in this area; we must support their effort
  - Committing manpower
  - Interacting constructively with the G4 collaboration
    - Technical Forum (next Thursday, Sept 2nd 2010) – passing on user requirements