Geant4 Collaboration Meeting 2015

USER REQUIREMENTS – SPACE

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Based also on input from:

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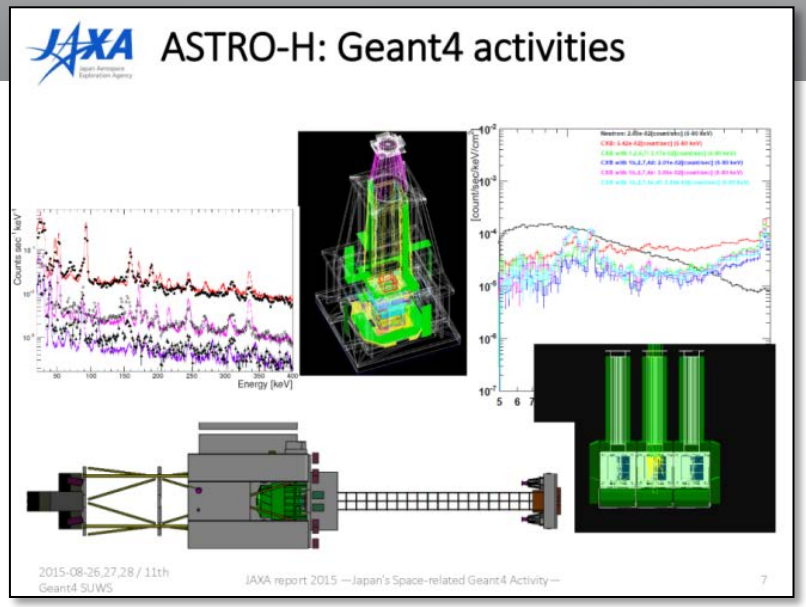
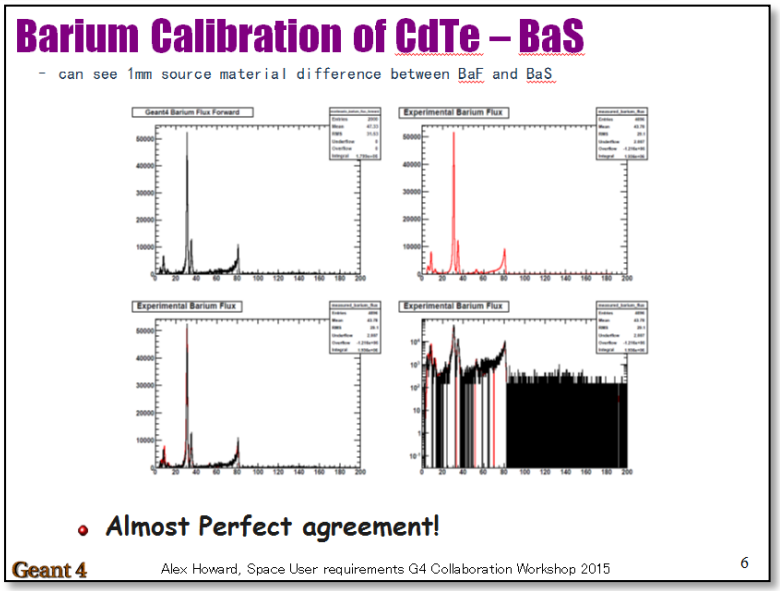
Pete Truscott – Kallisto Consultancy
Martina Giraudo, Marco Vuolo – Thales Alenia Space Italy
Petteri Nieminen – ESA/ESTEC
Robert Weller – Vanderbilt University
Sergio Ibarmia – INTA
John Allison – G4AI
Masanobu Ozaki – ISAS/JAXA

Fermilab
28 September - 3 October 2015

Signal and background for spaceborne experiments

- Science missions / experiments
  - X- and gamma-ray instruments (e.g. JAXA ASTRO-H, ESA: Athina X-ray telescope)
  - Proof-mass charging as in LISA
- Radioactive decay module (RDM)
  - Short and long-term activation induced by Earth proton belt, or Solar proton events, Galactic Cosmic Rays
  - Many happy users
  - Significant effort in past few years in update of DB, bug-fixing, transition to MT, but still some open issues!





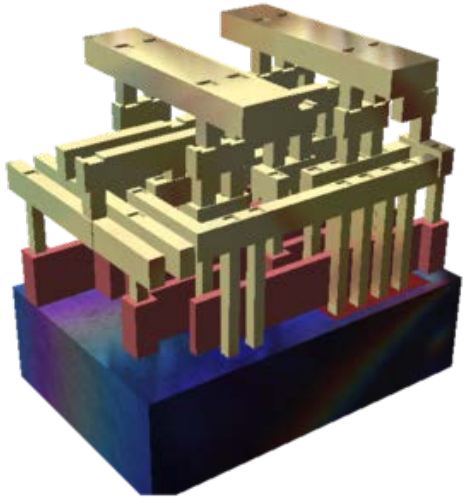
(Single Event) Effects in microelectronics

- Recent years:
  - ground applications of space-originated studies
  - Proton-, muon- and e- induced Single Effects
- Interfaces to TCAD geometry formats
  - E.g. GDS-II
- Physics lists with high accuracy
  - Double differential XS @ < 50 MeV/nuc
  - Hints to inaccuracy of Geant4 hadronics also from recent memory SEE testing at ~1GeV/nuc (low LET)
  - MRED interfacing to PENELOPE 2008 for electrons (Geant4 MSC unsuitable for nm-scale structures) and CEM03 and LAQGSM for hadronics
  - Input from Bob Weller:

"1) get the nuclear reactions right, and 2) take the standard electromagnetic physics as low in energy as possible (and physically sensible for a binary collision code), and 3) make it possible to handle volumes that are on the general order of the size of modern transistors. That, of course, is just a few nm."

"Getting the EM physics down to the point where a different kind of code would be necessary, one that is aware of band structure, permits collisions between moving particles, etc. would be high on my priority list and probably at the top of it"

https://en.wikipedia.org/wiki/GDSII



Radiation shielding effectiveness Protons

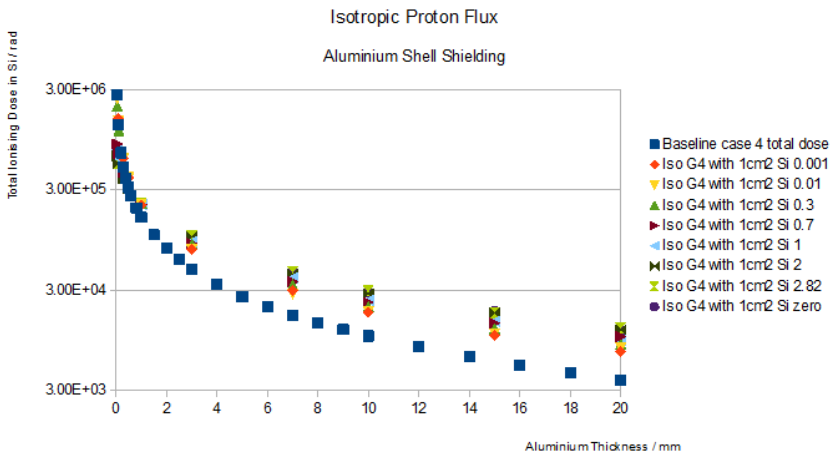
- **Proton** MC dose results generally in good agreement (10-20%) with Continuous slowing down, Straight-ahead approximation

  → less critical, and ray-tracing sector shielding provide reasonable first-order "engineering "answer

- Alex reports significant differences for TID in thicker targets after shielding

- Comparison of TID / TNID predictions from different techniques for protons and electrons in upcoming ESA study

STIX – Total Ionising Dose



- For hadrons (protons/ions) the thin shield 1-D approximation (sector analysis) significantly underestimates the dose
- Explained by build-up/showering. Quite different to gammas/e-
- ESA tool?

Geant 4 Alex Howard, Space User requirements G4 Collaboration Workshop 2015 4

Radiation shielding effectiveness
Trapped e^- / GCR ions

- **Electron** scattering make ray-tracing results unreliable (differences with MC factor 2-3)
  → MC essential tool for space industry (relying mainly on NOVICE adjoint MC, by Tom Jordan, EMPC)
  - Validation of shielded spectra / dosimetry including Brem and low-Z / high-Z layered structures
  - Relevant e^- energies in the Van Allen belts
    - Earth : e- ~100 keV to 7 MeV,
    - Jupiter e- ~100 keV to 50 MeV (but extending up to >100 MeV)

- **Galactic Cosmic Rays**:
  - p+ and ions up to at least Z=26 from 100 MeV/n to 100 GeV/n, with peak at a few GeV/n
  - Single Event Effects, human applications, secondaries from fragmentation and spallation important

Human space flight

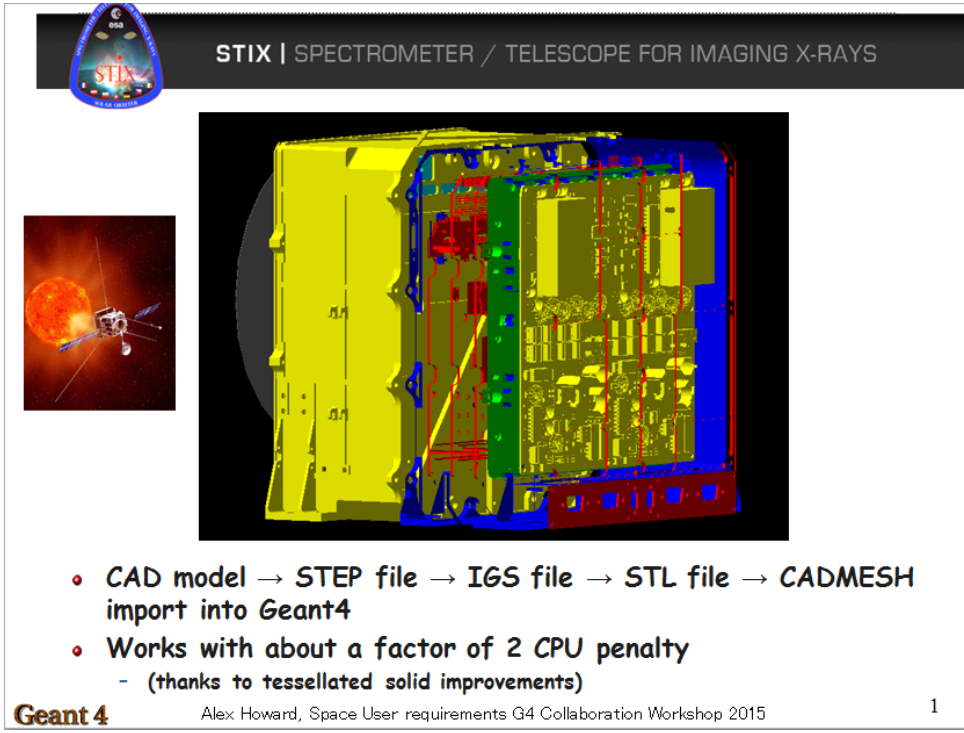
- Proton- and GCR-induced effects
  - Primary proton direct dose deposition
  - Indirect from secondaries including neutrons and activation
- Optimization and trade-off studies for future long-duration interplanetary journeys
  - Recent ESA validation study (ROSSINI2) hints at significant inaccuracy
- Geant4 presence traditionally limited in radiation protection community
  - Reference fluence to dose conversion coeff. computed earlier with FLUKA, now PHITS
- **Low-E extensions with links to chemistry/biological effects** analysis capabilities (e.g. Geant4-DNA)
  - Active community, significant competition with ad-hoc “track structure” models and tools
  - Radiation interactions with biological systems at sub-cellular level
  - Bottom-up approach for understanding basic effects
  - Validation of macroscopic risk models

Ease of use – focus on space Industry

- Getting started
  - Installation, graphic UI, clear user manuals and examples
- Interoperability
  - Exchange of geometry and parameters with other tools (e.g. SPENVIS, Deep Dielectric Charging)
- Geometry
  - Exchange, including CAD, TCAD, meshed structures, …
  - (CAD) volume overlaps
  - No-geometry exchange (!) use case (phase-space standard? addressed by ESA GTREFF R&D, and CIRSOS framework)
- Computational speed (mainly for electrons)
  - Reverse MC
  - Other biasing options
- Generic tools / frameworks
  - to be used for multiple missions, for both systematic, parametric and optimization studies, and mission specific detailed investigations (ongoing ESA CIRSOS development tries to address this)

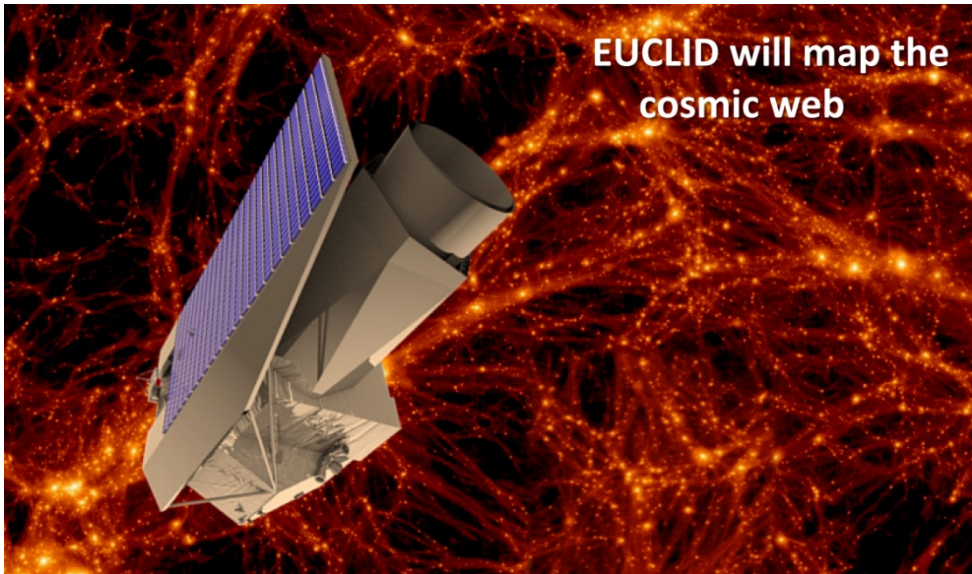
CAD geometry models

- Commercial tools (FASTRAD, ESABASE2) have GDML export, and also limited import
  - FASTRAD is ~4-5k/y, ESABASE2 similar but free for non-commercial use
  - GDML output requires minor tweaks, but works OK
- Positive user experiences with CADMESH
- Even when import is possible, annoying incompatibilities still affect models
  - Manual material input
  - Overlaps
- STEP-SPE includes materials but not used by e.g. CATIA
- What about a Geant4 good/professional geometry modelling tool?



Geant4 accuracy and use in Industry

- Geant4 used at TAS-I for the ESA EUCLID mission
  - Investigation of distance-redshift relationship and the evolution of cosmic structures (2022)
  - Critical analyses of TID and TNID at VIS instrument CCDs (now)
- Geant4 accuracy claim used by Industry to support request to ESA to lower the Radiation Design Margin (RDM)
- Despite no-liability, it remains a big moral responsibility for both Geant4-toolkit and application developers



Other related input from collaborators and space users

- Geant4 modules / features developed under ESA funding
  - Maintenance effort
- Reverse MC
  - not easy to include in user application
  - still some convergence problems
- 2-stage simulations with Phase Space tally at user-defined surface
  - IAEA format limited to a few particle types (?)
  - Add to Geant4 standard tally/generator to/from Phase Space files ?
- Parallel simulations
  - Examples combining MT and MPI would be very useful
  - including analysis merging with g4tools (possible?)
- Physics lists
  - Many options, lack of guidance
  - Choice of EM option (4) to work with hadronics reference physics lists

Thank you

In particular to those who provided input for this presentation:

Fan Lei, Pete Truscott, Martina Giraudo, Marco Vuolo, Petteri Nieminen, Robert Weller,

Sergio Ibarmia, John Allison, Masanobu Ozaki

European Space Agency