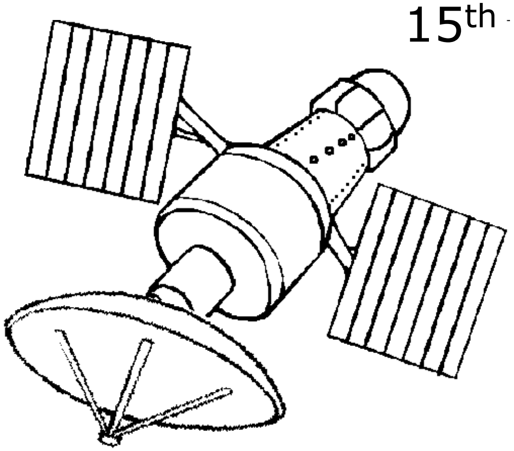

15th Geant4 Collaboration Workshop

ESTEC, 4-8 Oct 2010

Problems and requirements of space users

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European Space Agency

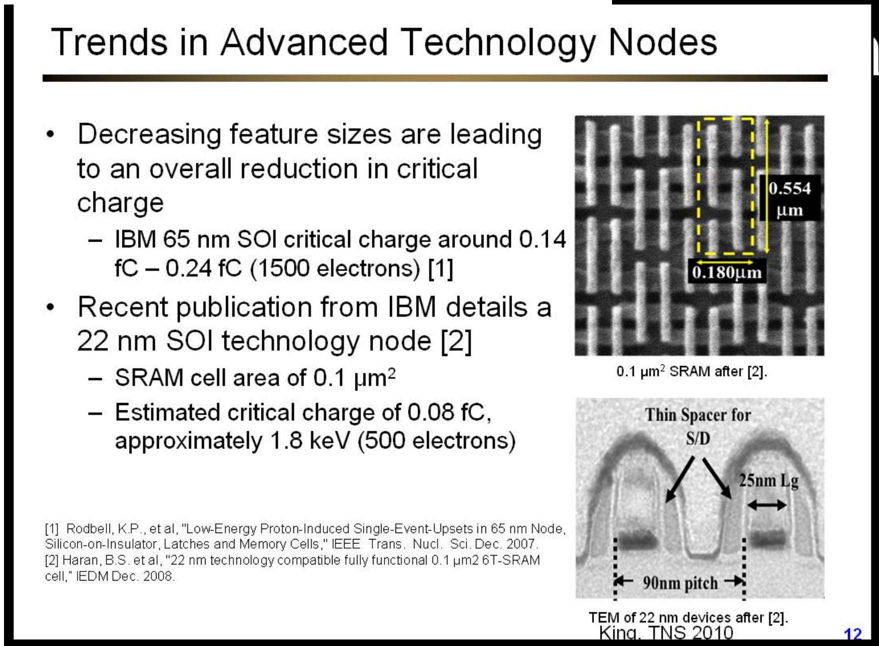
ESTEC

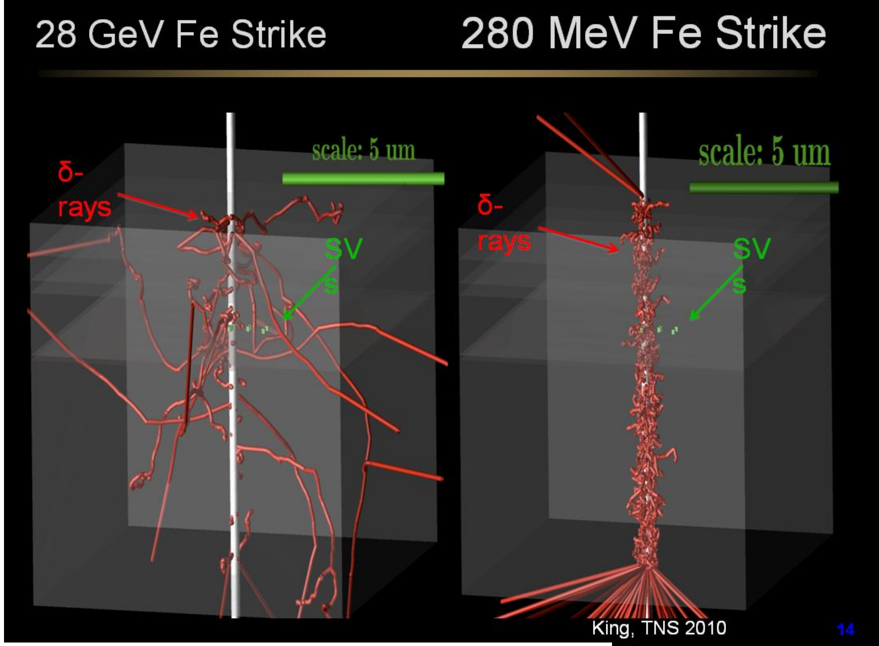
** on loan from RHEA Tech Ltd*

- A personal interpretation of status of electron simulations triggered by
  - Our internal analyses at ESA
  - Recent discussions with people involved in ESA contracts
  - Discussions at space users workshops
- Old ESA internal tests of low energy ion stopping powers
  - Still to be updated with recent releases (my apologies)
- Some other remarks

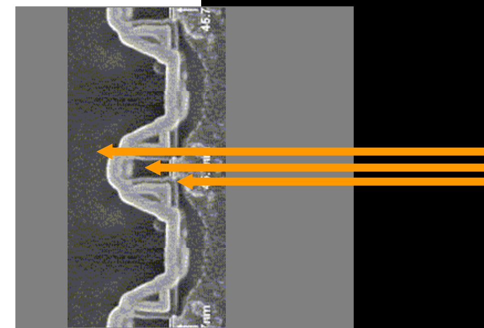
Electrons in Silicon

- Decreasing semiconductor feature sizes, comparable with ion track structure size
  - Detailed description of high density ionisation volume around particle tracks
  - Precise tracking of low energy electrons
  - New models for emission of lower energy delta rays
  - Charge densities?
  - Local temporary electric fields around ion track?
- Single delta rays will cause SEE’s
  - Detailed tracking of electron ionisation and related fluctuations
- Anisotropic tracking in lattice?





Ion stopping power and fluctuations



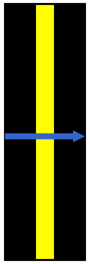
- Ion stopping power and ranges for
  - Low energy (heavy) ion beams for ground testing
  - Recoils and fragments from proton and ion interactions
- Precise local energy deposition of ions
  - In sensitive volume (not at device entry surface)
  - With correct fluctuation (not only nominal, average stopping power)
  - With correct charge (validity of "effective charge" approach?)
- One example: Radiation Effects Facility (RADEF)
  - JYFL Accelerator Laboratory, Jyväskylä, Finland
    One of the ESA's European Component Irradiation Facilities (ECIF)
  - Heavy ion cocktail (7 ion species from N to Xe)
  - Energy of < 9.3 MeV/nuc
  - LET in Si from ~2 to 60 MeV/(mg/cm^2)

Test of ion stopping power and straggling
Simulation setup

- GRAS v2.3 (Geant4 9.1, 09-01-ref-02)
- GRAS v2.4 (Geant4 9.2.p01 and 9.3.b01)
  - No big changes in GRAS w.r.t. v2.3

- Will be repeated with Geant4 9.3 and 9.4

- Geometry: MULASSIS type:
  - Vacuum
  - Silicon: 1μm (thin) or 10μm (thick)
  - Vacuum



Vacuum – Silicon – Vacuum

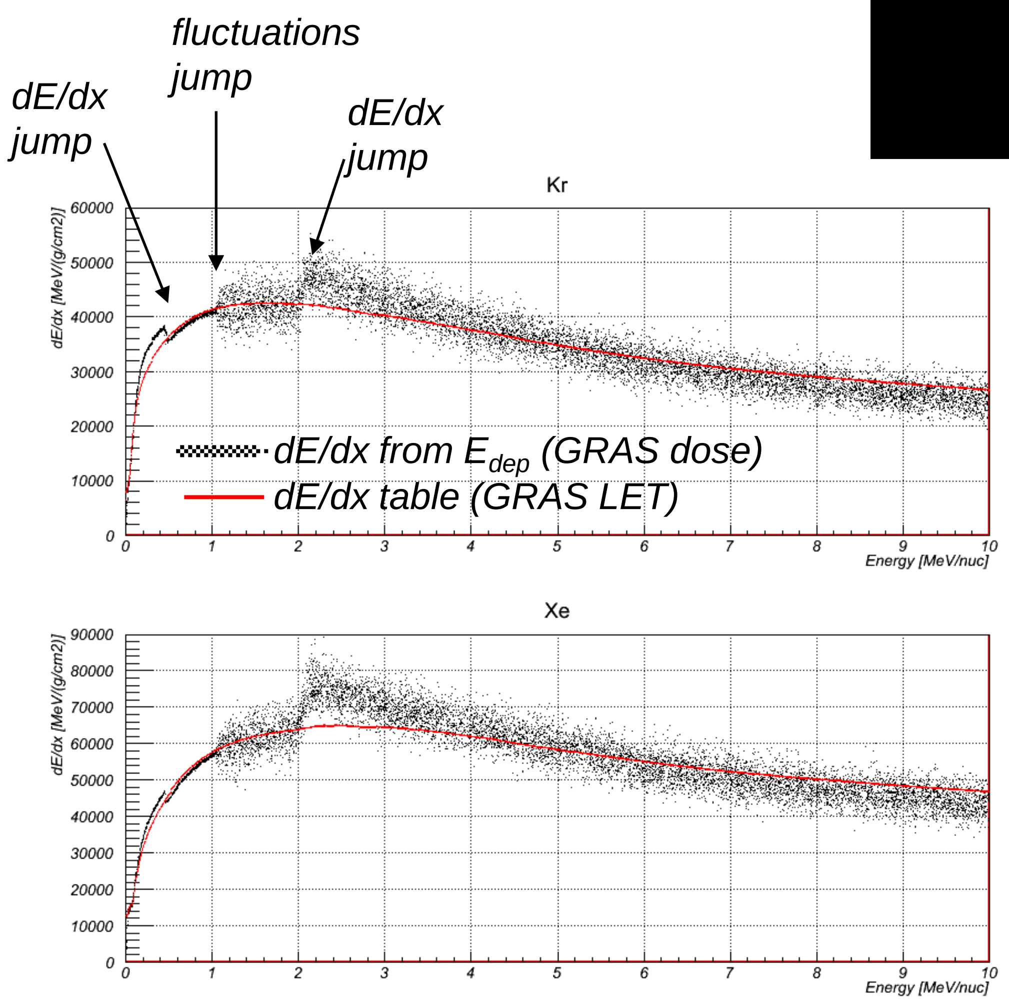
- Source
  - ^{131}Xe and ^{84}Kr, 0→10 MeV/nuc
- Physics
  - em_standard (G4ionIonisation)
  - em_standardICRU73
  - Cuts: 1μm

```
# geometry
/gras/geometry/type mulassis
/geometry/layer/delete  0
/geometry/layer/shape slab
/geometry/layer/add  0 Vacuum   2    10.0 mm
/geometry/layer/add  1 Silicon  8    0.001 mm
/geometry/layer/add  2 Vacuum   2    10.0 mm
/geometry/update

# source
/gps/particle ion
/gps/ion 54 131

# flat spectrum
/gps/ene/type Arb
/gps/hist/type arb
/gps/ene/min    0.  MeV
/gps/ene/max    1310. MeV
/gps/hist/point    0.    1.
/gps/hist/point    1310.   1.
/gps/hist/inter Lin

# physics
/gras/physics/addPhysics  em_standard
/gras/physics/setCuts    0.001 mm
```

Geant4 9.1
1 μm target

- Thickness: 1 μm
- Cuts: 1 μm

- These were the first results, with obvious problems, which prompted the discussion at the stdEM meeting, CERN, March 2008

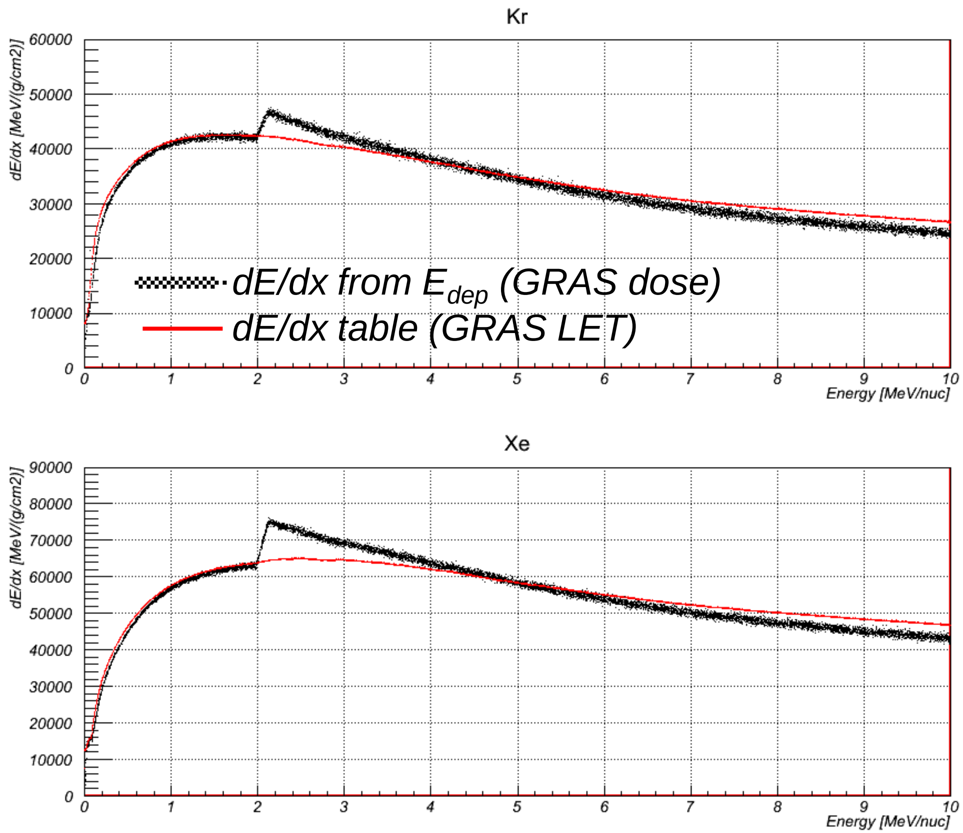


Geant4 09-01-ref-02
1 μm target

- Thickness: 1 μm
- Cuts: 1 μm

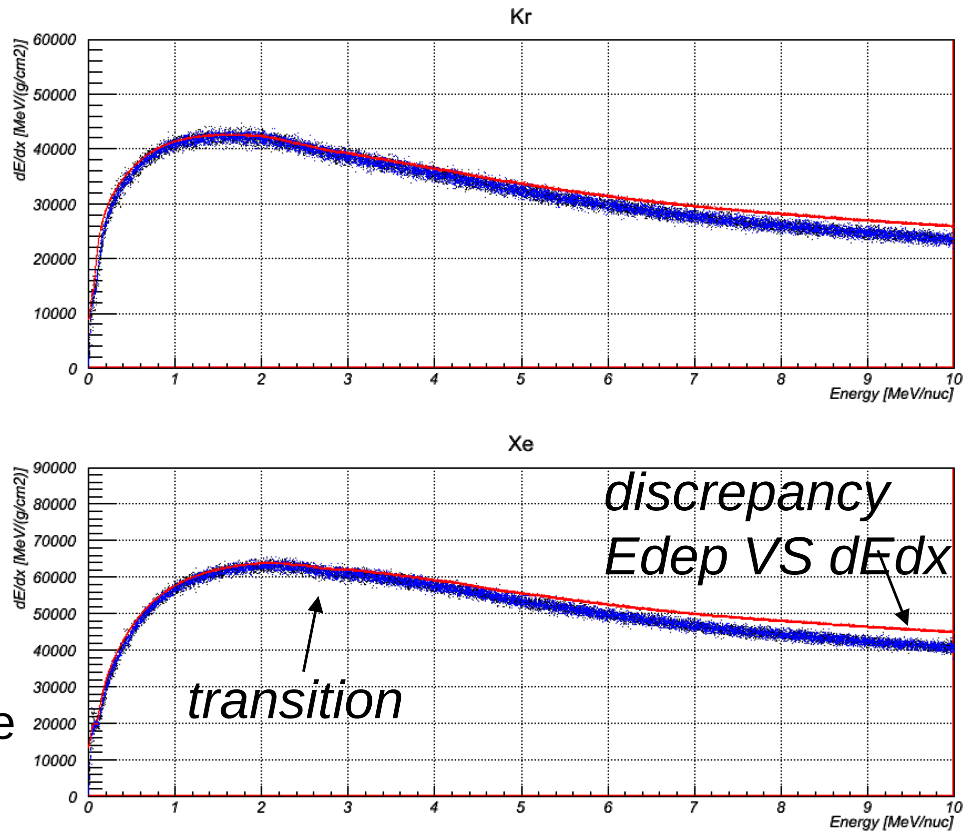
- Prompt response from V.Ivantchenko, fixes included in reference tag 09-01-ref-02

- Changes w.r.t. Geant4 9.1
  - No jump in fluctuations (OK)
  - Smaller fluctuations (better?)
  - Discrepancy between models at transition (2 MeV) with linear interpolation in small range (2.0-2.5 MeV ?)



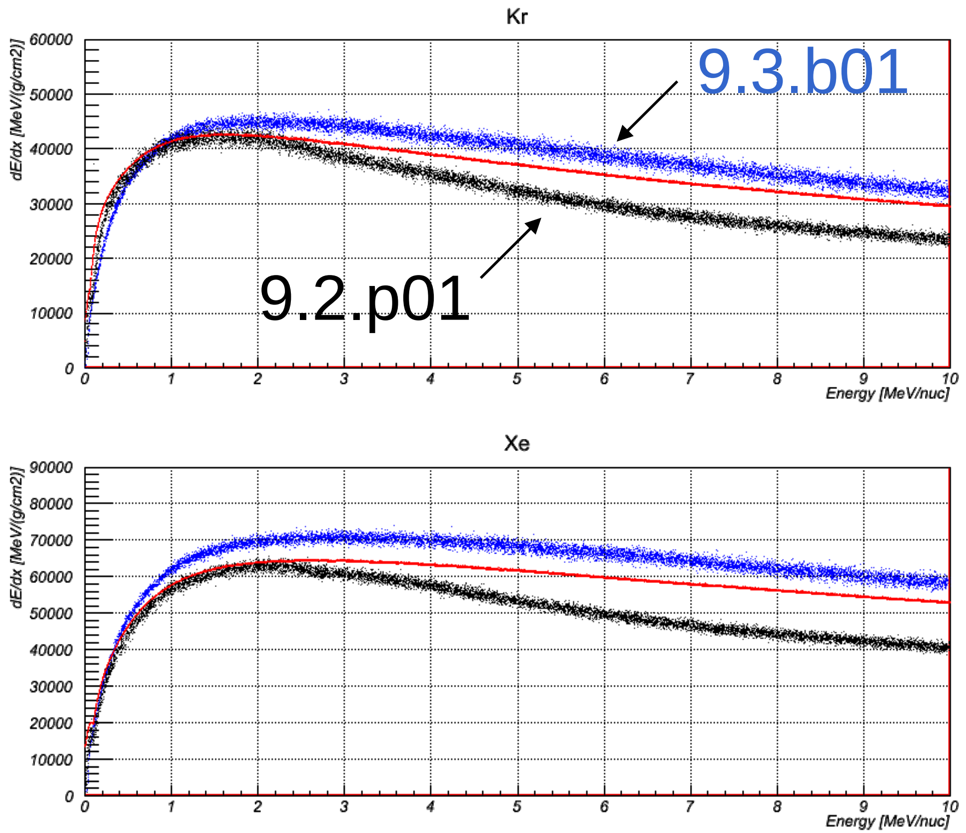
Geant4 9.2.p01 and 9.3.b01
1 μm target
em_standard

- Notes w.r.t. 09-01-ref-02
  - No big jump in dEdx (OK)
  - Some (really minor) features observable at model transition
  - Still differences w.r.t. nominal dEdx at higher energies
  - Same fluctuations (OK?)
- 9.2.p01 and 9.3.b01 seem indistinguishable
- "Nominal" dEdx from em_calculator (red) is the same

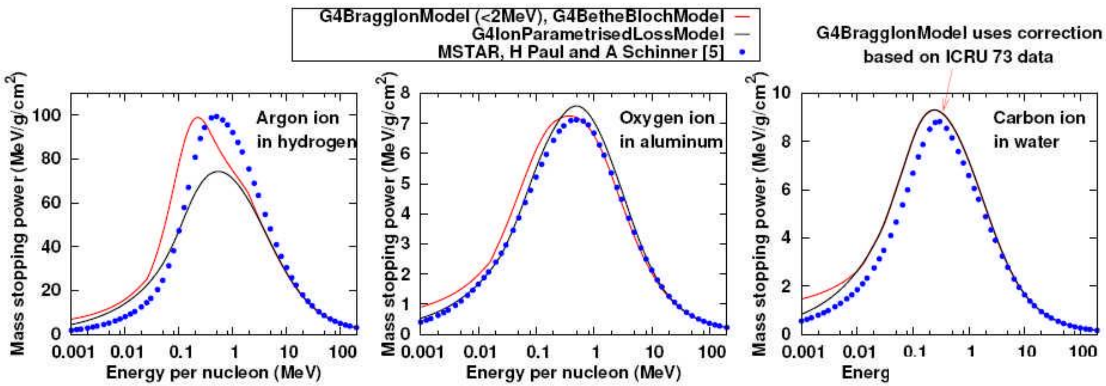


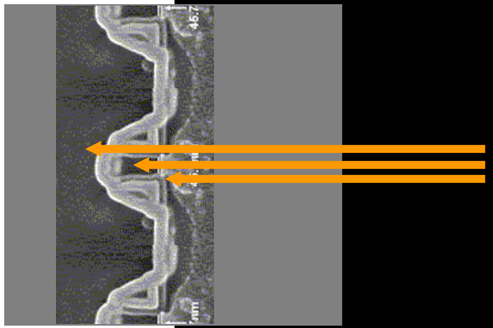
Geant4 9.2.p01 and 9.3.b01
1 μm target
em_standardICRU73

- Significant change of absolute dose deposition in 9.3.b01 w.r.t. 9.2.p01
- "Nominal" dEdx from em_calculator (red) is the same for 9.3.b01 and 9.2.p01, but different w.r.t. em_standard
- The test will be repeated w/ Geant4 9.3 and 9.4

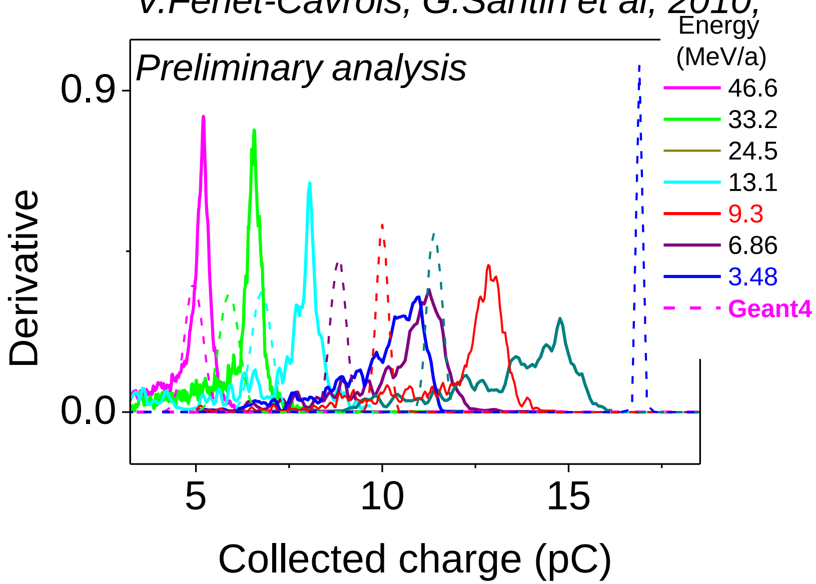


Ion stopping power recent developments





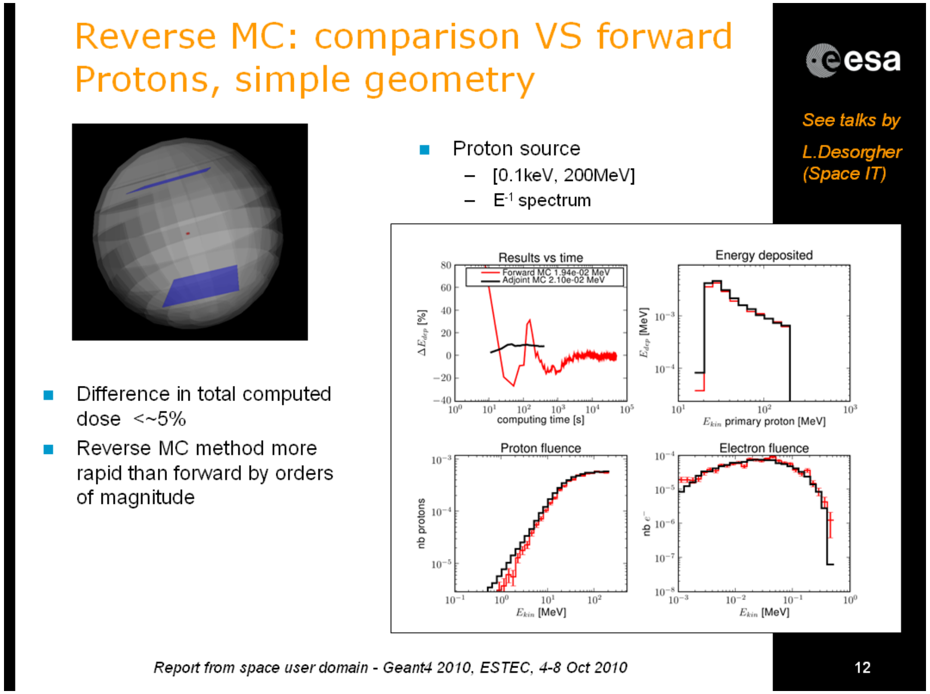
V.Ferlet-Cavrois, G.Santin et al, 2010,



Open questions

- status of ion stopping power after ICRU73 implementation
- status of ion ionisation fluctuation models
- validity of ion and proton ionisation in short steps (thin layers) e.g. for deep sub micron technologies
- theoretical validity, validation and present limitations of ion effective charge approach

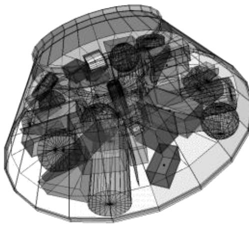
Reverse MC status and upgrades



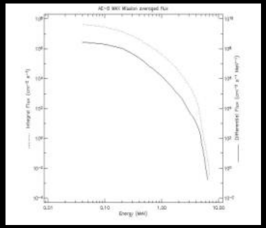
- Reverse MC developments could be made easier by improved Geant4 design / S/W architecture
- Hopefully addressed in new Geant4 architecture studies

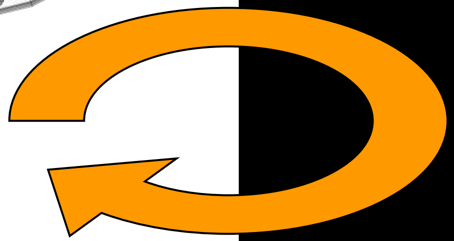
Engineering margins
Confidence in simulation results

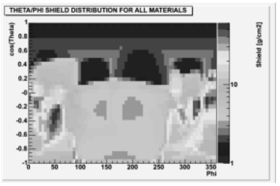
- Typical radiation analysis is iterative process with chain of calculations based on models, each with statistical and systematic uncertainties
  - Engineering margins should account for known and unknown unknowns to ensure mission survival in hostile environments
  - High margins imply extra costs (e.g. from weight of thick shielding, or system redundancy) and are sometimes showstoppers in feasibility studies – need justification, and should be reduced if possible
- 3-D Monte Carlo is assumed to be more precise than approximations based on 1-D calculations or ray tracing.
  - Is it really so? Contribution to the global error from particle transport models? Contribution from mistakes in MC tracking parameters, or misjudged confidence in physics model?
  - Can we quantify the global confidence in our Geant4 engineering calculations?
- Convergence criteria can help in confidence and computational speed

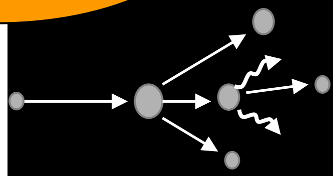


ConeXpress, R.Lindberg, ESA









ELSHIELD
Energetic Electron Shielding, Charging and Radiation Effects and Margins

- Analysis of problem areas in energetic electron penetration and interactions in S/C and P/L
- Tools: improve usability and physics modelling
- Validation of developments (also dedicated testing campaigns)
- Relationships with pre-flight testing and design margins
  Benchmarking and analyses to identify systematic deviations between simulation tools and engineering analysis processes performed as part of radiation hardness assurance and EMC assurance

TAS-E led consortium
G4AI, TRAD, INTA, DHC, ONERA, Artenum, TAS France

Report from space user domain - Geant4 2010, ESTEC, 4-8 Oct 2010 9

Other topics

Smart physics

- Geant4 can (now) deliver high quality output with best settings (?) , but results still show dependence on parameter tuning.
- Ideally: adaptive behaviour, with process and model change during tracking without user intervention
  - Standard behaviour determined by developer's knowledge (by e.g. energy, step length, distance from boundary,…)
  - Optionally responding to additional user requirements (e.g. by region, distance to sensitive volume,…)

Link to materials (point raised by Laurent Desorgher)

- Requirement for point tallies e.g. dose in a point for reverse MC
  - obtained from accessing LET tables in materials not necessarily present at that point nor anywhere in the geometry

NIEL analysis:

- Status of single scattering processes/models for protons and ions
- Status of NIEL calculation with different possible approaches