

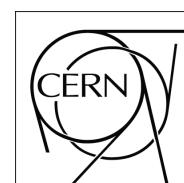
GRAS

Geant4 Radiation Analysis for Space

Geant4 tutorial
Paris, 4-8 June 2007



Giovanni Santin, *ESA / ESTEC and Rhea System SA*
V. Ivantchenko, *CERN*



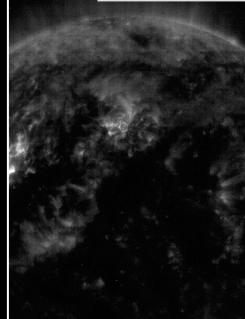
Simulations of the Space Radiation Environment



Sources

(Extra) Galactic and anomalous Cosmic Rays

Protons and ions
 $\langle E \rangle \sim 1 \text{ GeV}$, $E_{\max} > 10^{21} \text{ eV}$
Continuous low intensity



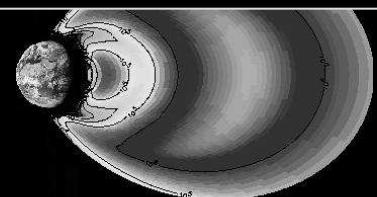
Solar radiation

Protons, some ions, electrons, neutrons, gamma rays, X-rays...
Softer spectrum
Event driven – occasional high fluxes over short periods.



Trapped radiation

Electrons $< 10 \text{ MeV}$
Protons $< 10^2 \text{ MeV}$



Goals

Mission design

Ground tests
Extrapolation to real life in space
Cheaper than accelerator tests

Science analyses

Particle signal extraction
Background
Degradation

Environment models

Simulation of the emission and the propagation of radiation in space

Effects

Effects in components

Single Event Effects
(SE Upset, SE Latchup, ...)
Degradation
(Ionisation, displacement,...)

Effects to science detectors

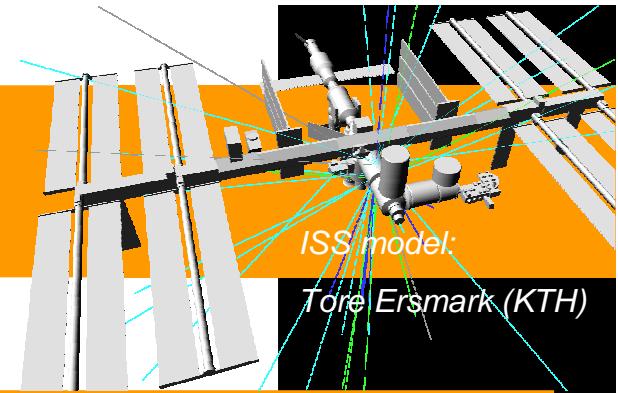
Signal, Background
(Spurious signals, Detector overload,...)
Charging
(internal, interferences, ...)

Threats to life

Dose (dose equivalent) and dose rate in manned space flights
Radiobiological effects

GEANT4-based engineering tools

- Geant4 has been a strategic choice for ESA
 - Advanced physics
 - Extendibility (OO design)
 - Interfaces (Geometry/CAD, visualization, post-processing, analysis)
 - Open source approach
 - Long term support
 - ESA is member of the Geant4 Collaboration since 1997
- Wide range of applications in space, including
 - effects on science payloads
 - doses in telecoms S/C
 - dose mapping in the ISS
 - mapping of primary and secondary radiation on Mars
 - ...

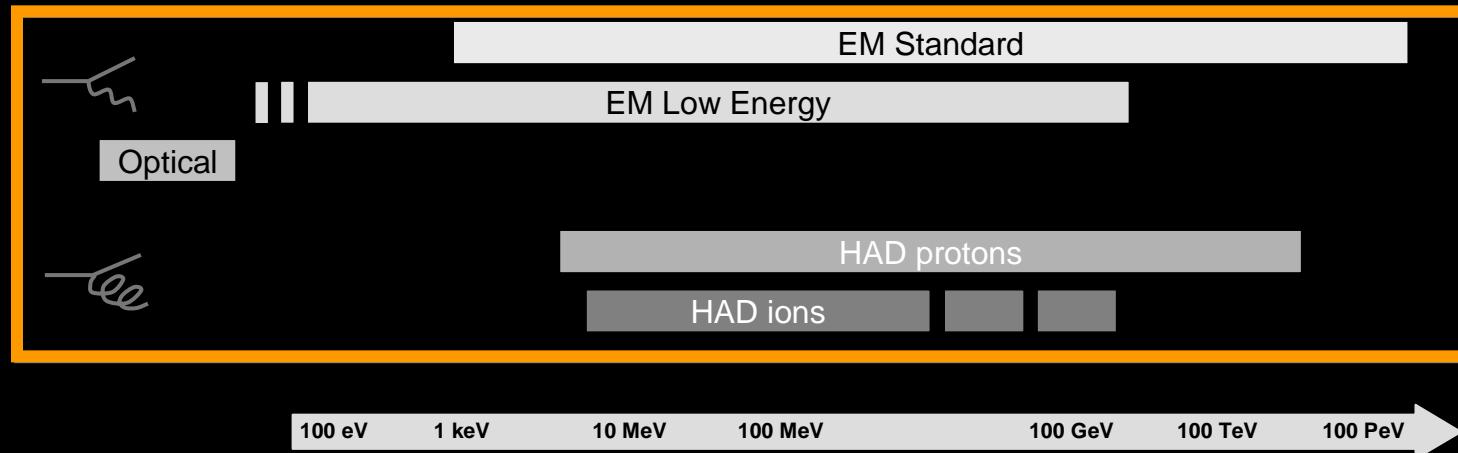


1. Physics models
 - Scientific Exploration,
 - Manned space flight:
 - Low En EM, Ion hadronics
2. Interfaces
 - Materials
 - GDML
 - CAD geometries
 - SPENVIS
3. Engineering tools
 - PlanetoCosmics (mg cut-off)
 - SSAT (Ray-Tracing)
 - MULASSIS (1D shielding)
 - GEMAT (micro-dosimetry)
 - NIEL (Displacement Damage)
 - Reverse MC
 - **GRAS (3D, multi-purpose analysis framework)**

Space environment and Physics models

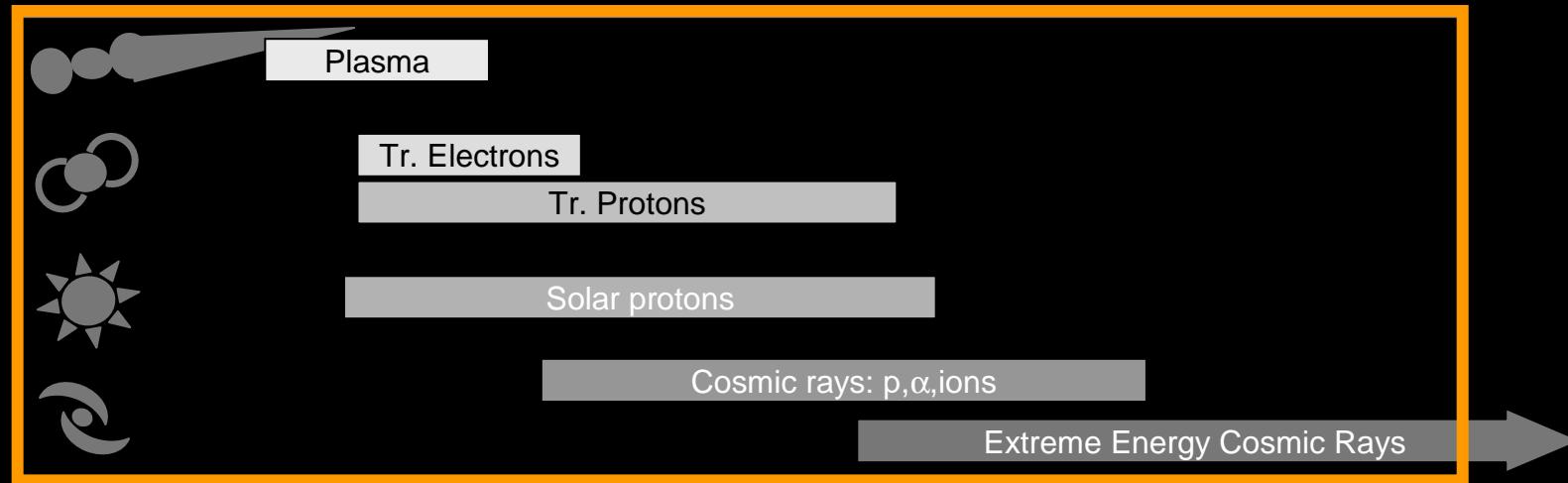


Geant4 models



100 eV 1 keV 10 MeV 100 MeV 100 GeV 100 TeV 100 PeV

Space environment

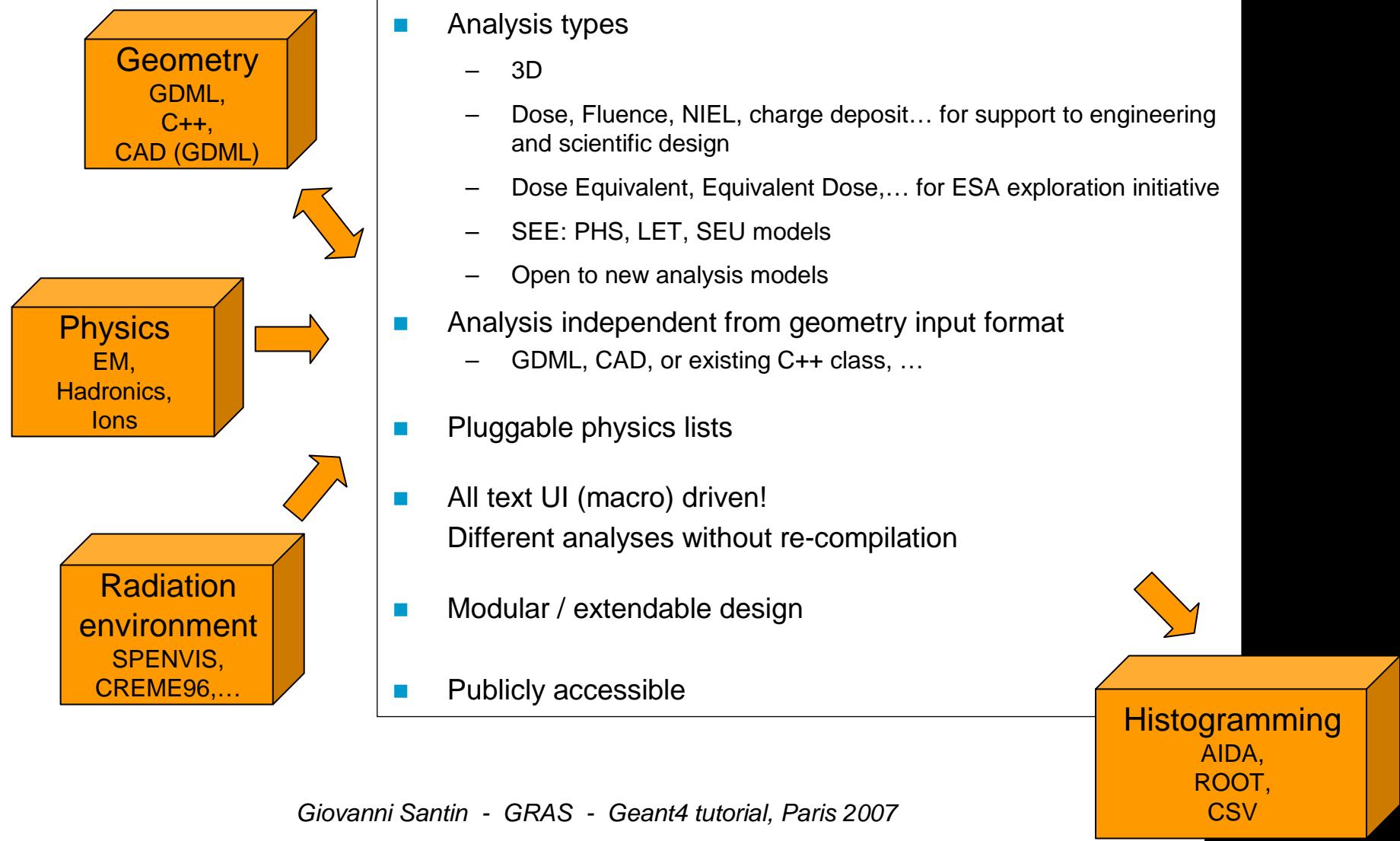


GRAS: motivation

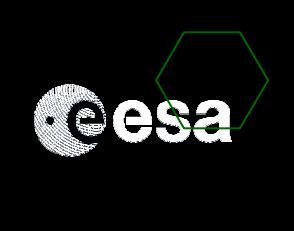
- Wide application of Geant4 models
 - Astronomy (GAIA, JWST, Herschel,...)
 - Planetary (Bepicolombo, Jupiter,...)
 - Earth observation (Aeolus,...)
 - Manned space-flight (ISS, Lunar Exploration, Man2Mars, ...)
 - Similarity in engineering analyses
 - Internal ESA support to projects / support to industry
→ avoid re-writing of similar C++ applications
 - Need of convergence of physics sound models and usability requirements for engineering application
 - Advanced output for scientific analysis (not only for space!)
 - Standard results for engineering requirements
- Offer standard advanced ready-to-use simulation tool



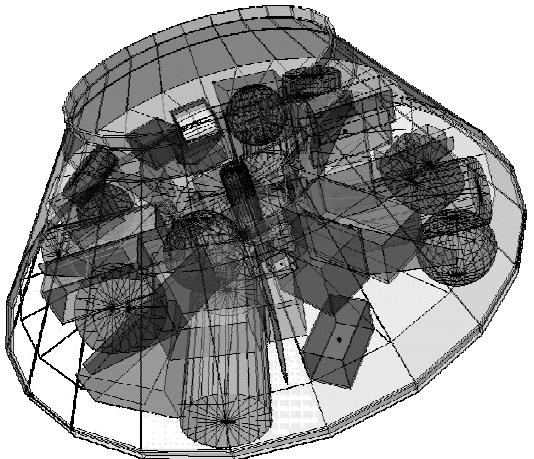
GRAS tool description



GRAS components



1



Geometry

- GDML (Geometry Description Markup Language)
ASCII file, looks similar to HTML
Adopted as exchange format by SPENVIS
- C++ model
- CAD interface via GDML

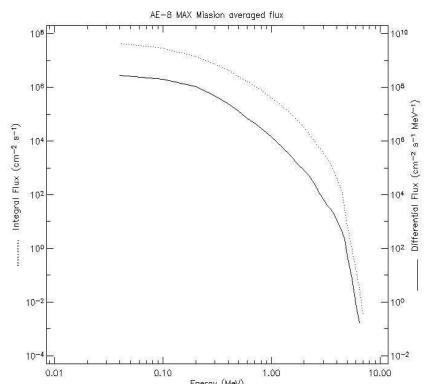
```
/gras/geometry/type gdml  
/gdml/file see.gdml
```

```
<materials>  
  <material name="SiO2"> <D value="2.200"/> ...  
...  
<solids>  
  <box name="solid_World" x="50.0" y="50.0" z="50.0"/>  
...  
<volume name="World">  
  <materialref ref="Vacuum"/>  
  <solidref ref="solid_World"/>  
  <physvol> <volumeref ref="satellite"/> <positionrefref="center"/> ...  
...
```

GRAS components



2 Source RADIATION ENVIRONMENT



```
/gps/pos/type Surface
/gps/pos/shape Sphere
...
/gps/ang/type cos
/gps/particle e-
/gps/ene/type Arb
/gps/hist/type arb
/gps/hist/point    4.000E-02   2.245E+08
...
/gps/hist/point    7.000E+00   0.000E+00
/gps/hist/inter Lin
```

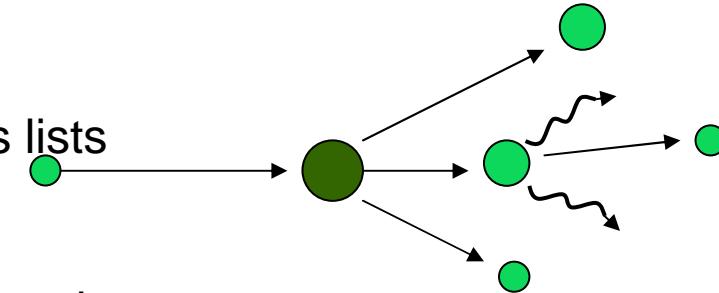
- G4 General Particle Source



3

Physics

Pre-packaged Geant4 physics lists
or single physics models
available through script commands



```
/gras/phys/addPhysics em_standard
/gras/phys/addPhysics binary
/gras/phys/addPhysics binary_ion
/gras/phys/addPhysics gamma_nuc
/gras/phys/addPhysics lowe_neutron
or
/gras/phys/addPhysics em_standard
/gras/phys/addPhysics QGSP

/gras/phys/setCuts 0.1 mm
/gras/phys/region/setRegionCut detectorRegion default 0.01 mm
/gras/phys/stepMax 1.0 mm
/gras/phys/regionStepMax detectorRegion 0.01 mm
```

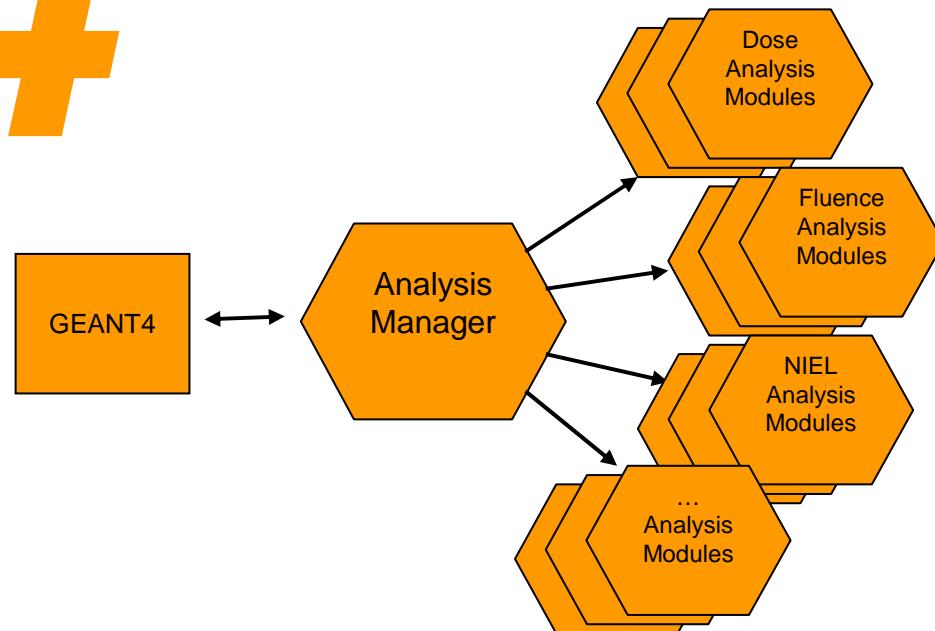
User can use a private C++ Physics List

GRAS components



4

Analysis RADIATION EFFECTS



```
/gras/analysis/dose/addModule doseB12  
/gras/analysis/dose/doseB12/addVolume b1  
/gras/analysis/dose/doseB12/addVolume b2  
/gras/analysis/dose/doseB12/setUnit rad
```

- * At present:
 - Dose
 - Fluence
 - NIEL
 - Deposited charge
 - Detector

- Dose equivalent
- Equivalent dose

- Path length
- LET
- Pulse Spectrum

- Common
- Source monitoring

Component degradation, background, detectors

Human exploration

Component SEE

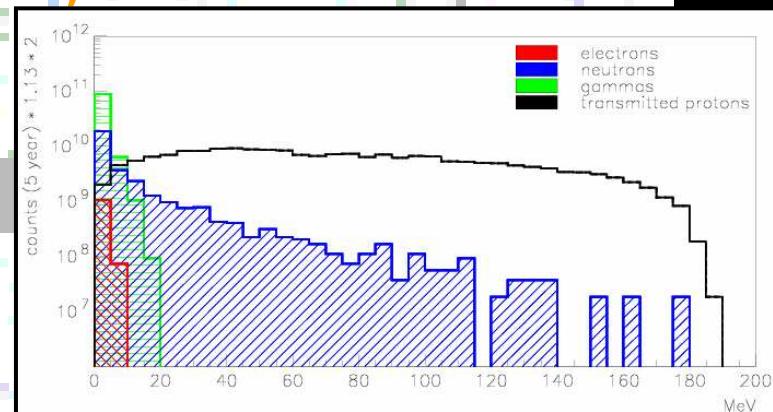
Simulation monitoring

- * Analysis independent from geometry input mode
 - GDML, or existing C++ class, ...
 - Open to future geometry interfaces (CAD,...)

GRAS Analysis modules: Component degradation, Background



- Total Ionizing Dose
 - Gives total accumulated dose
 - Also event **Pulse Height Spectrum**
 - For analysis of induced signal in detectors / el.devices
 - Also per **incoming particle type**, with user choice of interface
 - Units:
 - MeV, rad, Gy



- * FLUENCE
 - Particle type, energy, direction, time at surfaces
 - One/Both ways

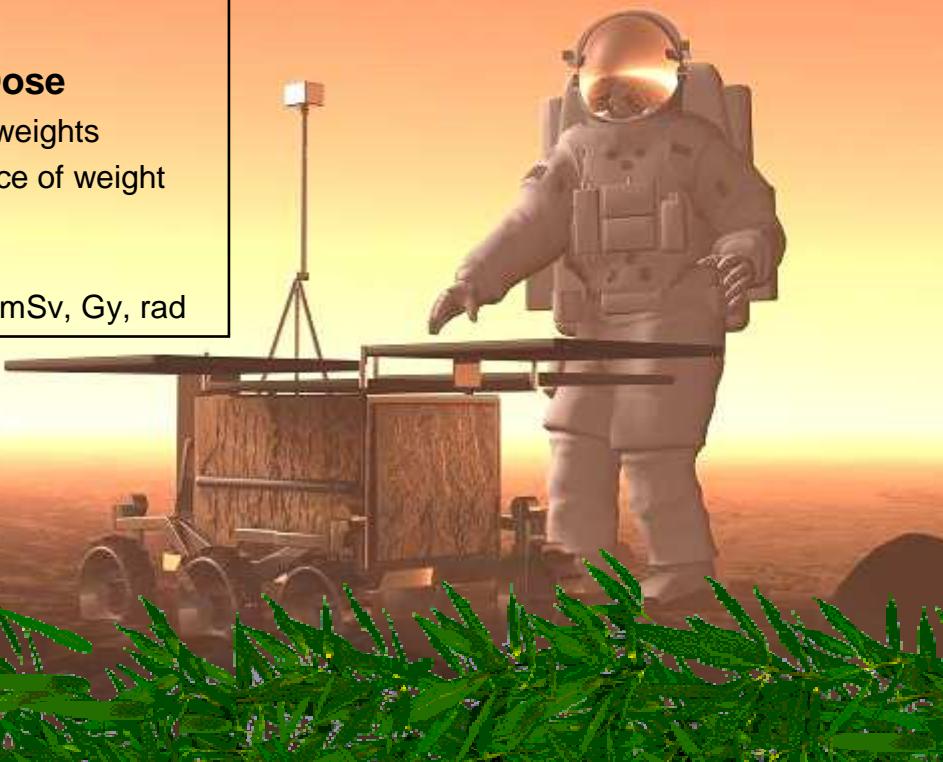
- NIEL
 - Impl. based on NIEL coeff.
 - Easy to add coeff. curves
 - Several curve sets available
 - CERN/ROSE (p, e-, n, pi)
 - SPENVIS/JPL (p)
 - Messenger Si (p, e-)
 - Messenger GaAs (p, e-)
 - Units:
 - 95MeVmb, MeVcm²/g
 - MeVcm²/mg, keVcm²/g

GRAS Analysis modules: Human Exploration Initiatives

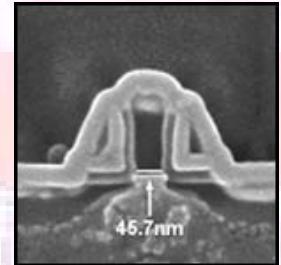
- New user requirements include:
 - planetary models (e.g. scaling of SPE fluence to other planets, magnetic field description, crustal maps)
 - ion physics (electromagnetics / hadronics for HZE)
 - biological effects (macroscopic / microscopic models)

GRAS Biological effects modules

- **Dose equivalent**
 - ICRP-60 and ICRP-92 LET-based coefficients
 - Units:
 - MeV, Sv, mSv, Gy, rad
- **Equivalent Dose**
 - ICRP-60 weights
 - User choice of weight interface
 - Units:
 - MeV, Sv, mSv, Gy, rad

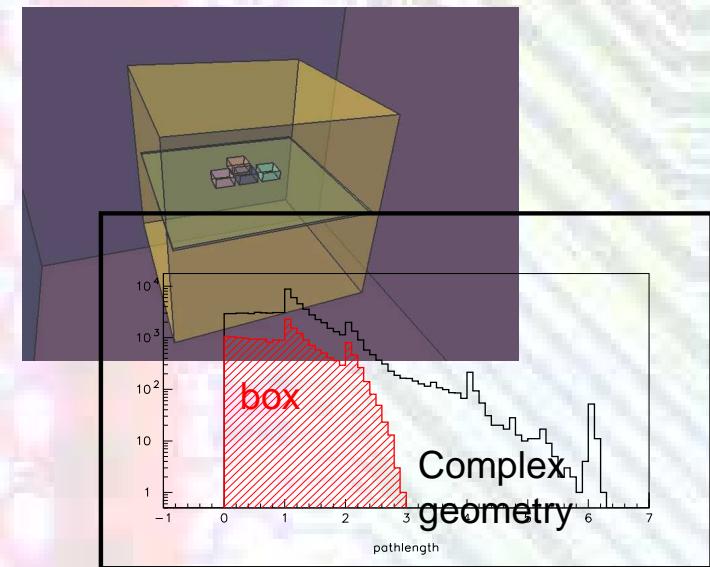


GRAS Analysis modules: SEE in microelectronics



Courtesy Sony/Toshiba

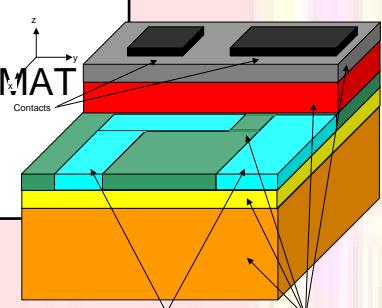
- Path length analysis
 - Event distribution of particle path length in a given set of volumes
 - If used with “geantinos”, it provides the geometrical contribution to the energy deposition pattern change
 - In a 3D model
 - W.r.t. a 1D planar irradiation model



- SEE models
 - Charge threshold simple model
 - Design open to more complex modeling
 - Coupling to TCAD will give device behavior
 - CAD import (on-going) will ease geometry modeling

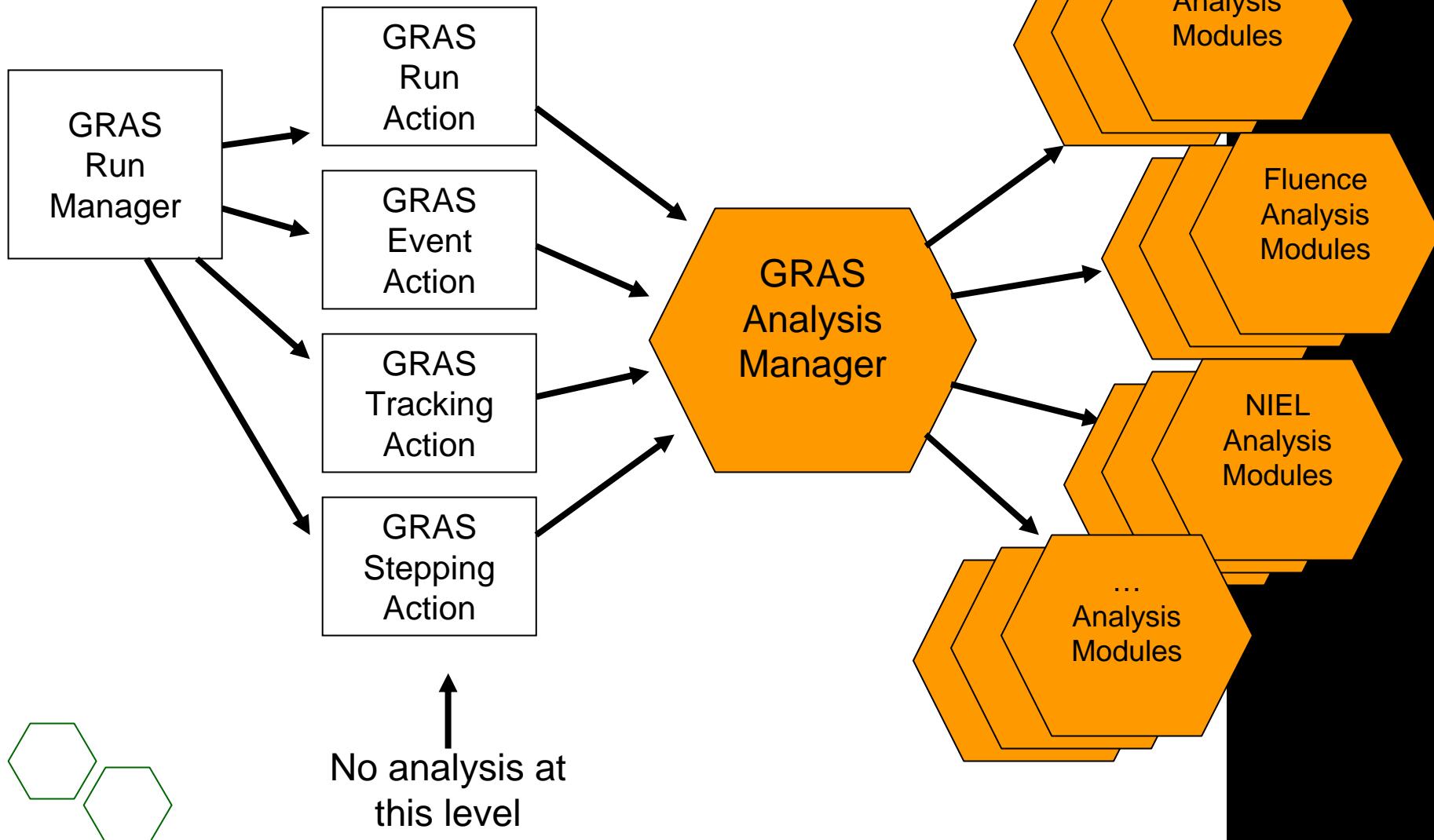
- LET
 - Based on Geant4 dE/dx tables
 - Computed at surface
 - Units:
 - 95MeVmb, MeVcm²/g
 - MeVcm²/mg, keVcm²/g

- CC (Charge Collection)
 - Based on REAC approach
 - QinetiQ development for GEMAT (ESA REAT-MS contract)
 - Available soon



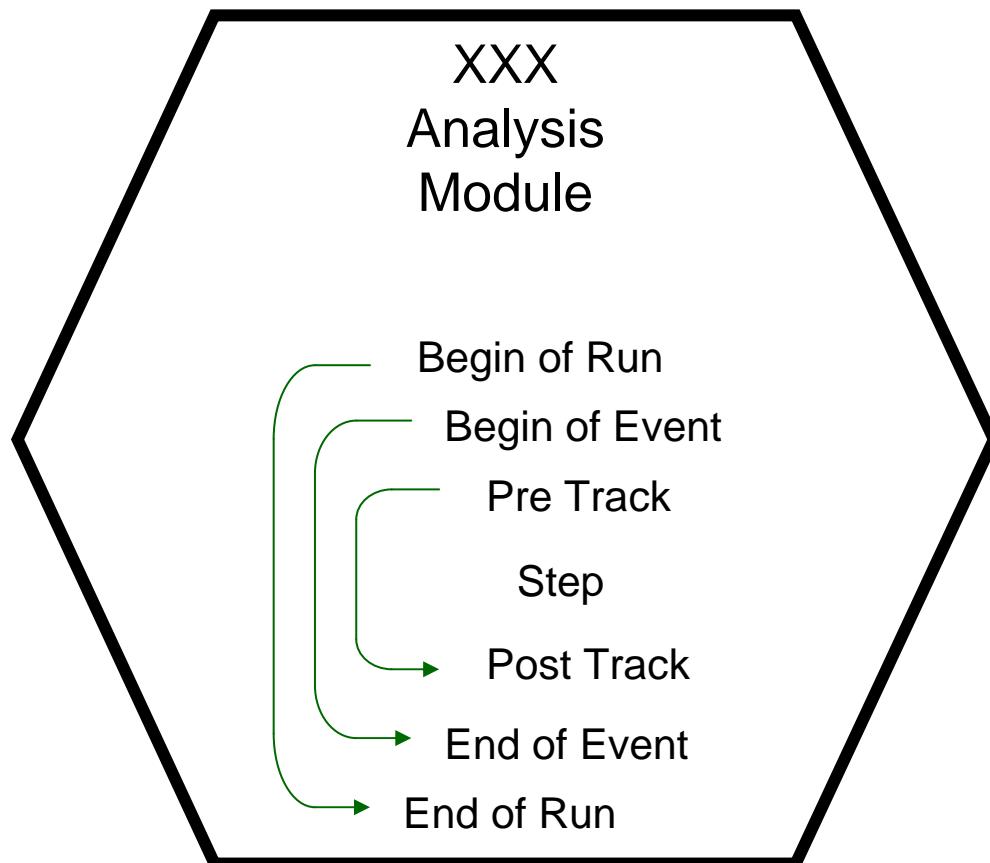
GRAS Analysis

Modular, extendable design

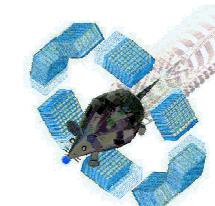




Analysis Module



- Easy to implement:
Self contained analysis element
- One class only to create/derive for new analysis types
- Histogramming “per module”
Internal (CSV text) + AIDA + ROOT
- G4 UI commands “per module”
 - Automatic module UI tree
 - à la GATE

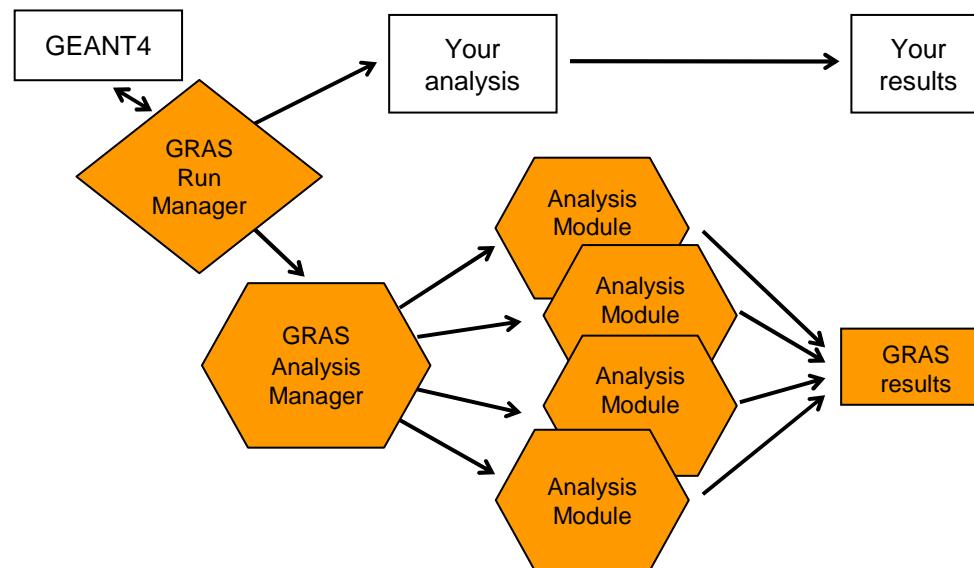


`/gras/analysis/dose/addModule doseCrystal`
`/gras/analysis/dose/doseCrystal/setUnit rad`

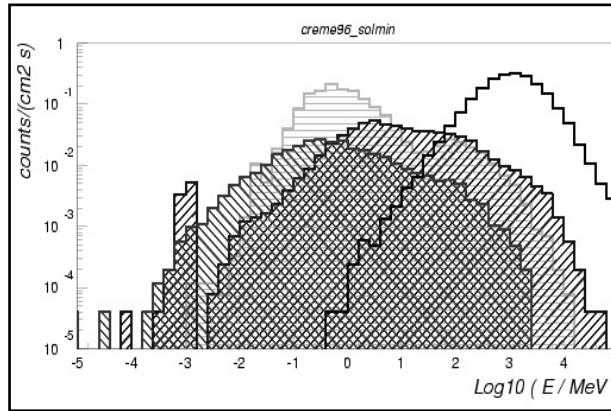
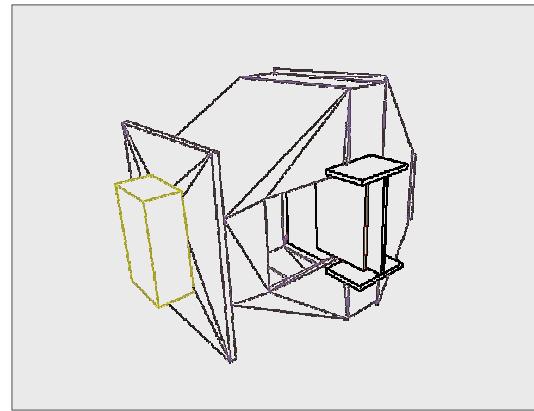
For present Geant4 users GRAS and previous work



- 2 ways of obtaining GRAS output from within your previous Geant4 application
 - A. Inserting C++ Geometry, Physics and/or Primary Generator classes inside GRAS
 - In the main `gras.cc`
 - B. Inserting GRAS into your existing applications
- Which way is the fastest depends on existing work



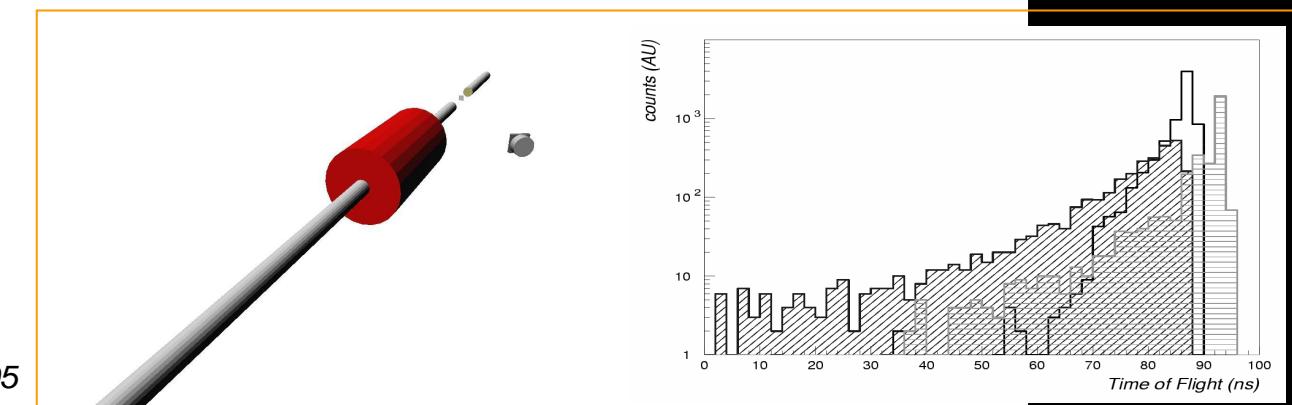
GRAS for James Webb Space Telescope



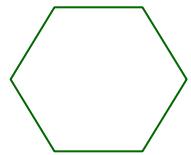
Total Ionizing Dose

Tool, Model	Dose [krad] (11 mm eq. Al)	Dose [krad] (18 mm eq. Al)
SHIELDOSE-2, Spherical Shell,	3.9	1.9
GRAS, Spherical shell	3.5 +/- 0.2	2.3 +/- 0.2
GRAS, Realistic model	2.2 +/- 0.1	1.1 +/- 0.1

- JWST background and TID
- JWST TOF neutron production experiment

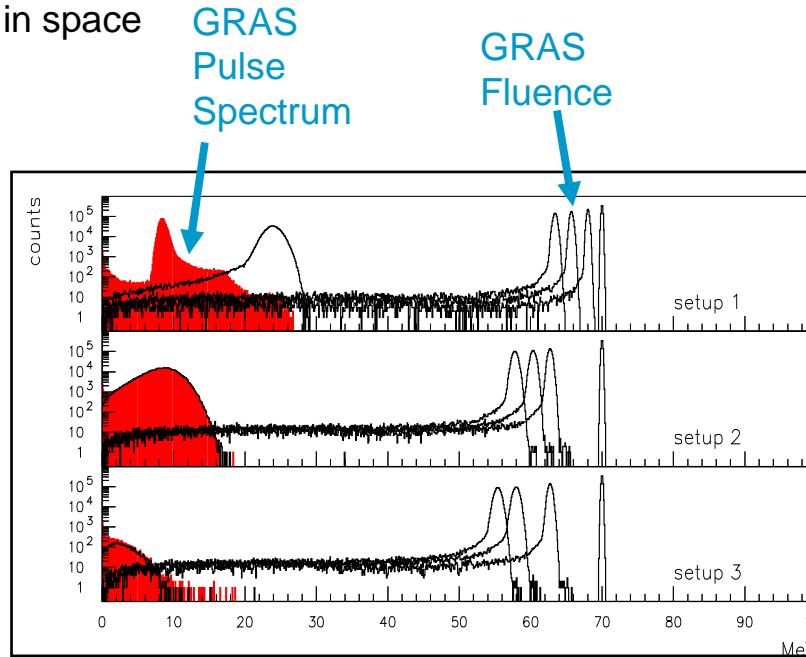
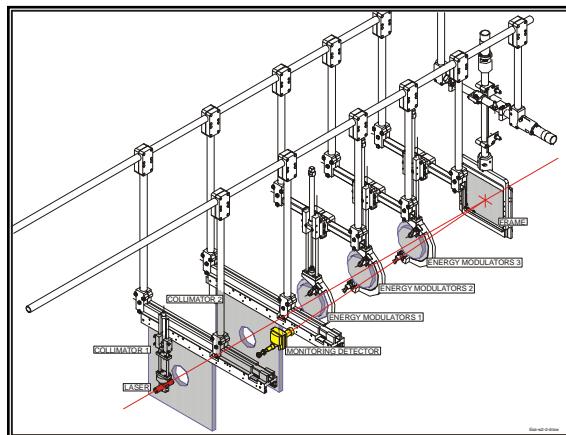


G. Santin et al., IEEE TNS Dec 2005



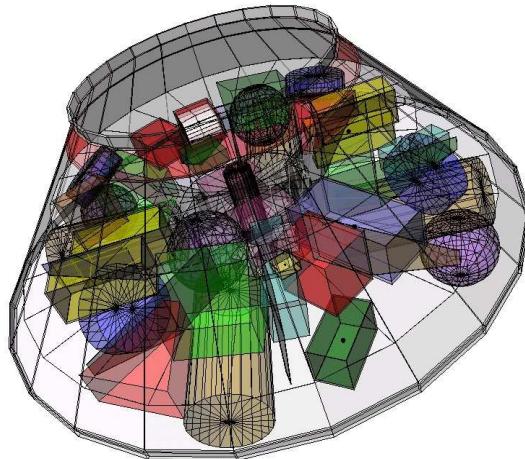
GRAS for HERSCHEL

- Herschel PACS Photoconductor instrument
 - Study and test of the detector to assess glitch rate
 - Impact on science objectives
- Simulation of the proton irradiation at Leuven, Belgium
- Comparison with glitch data on-going
 - Need precise description of energy degraders and beam parameters
 - Extrapolation to detector behavior in space



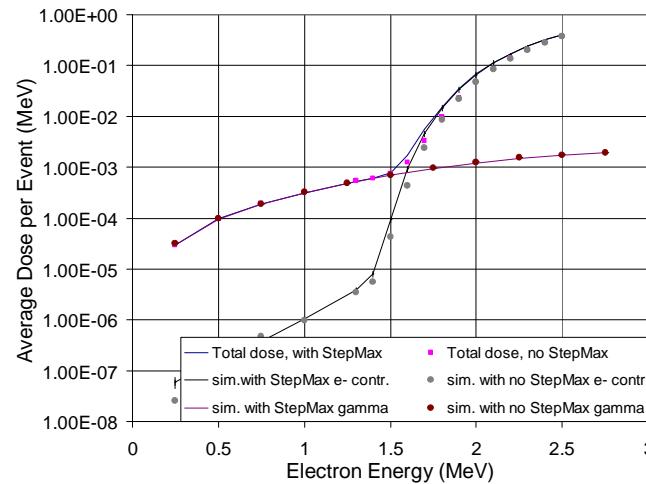
Giovanni Santin - GRAS - Geant4 tutorial, Paris 2007

GRAS for Geostationary orbit electrons

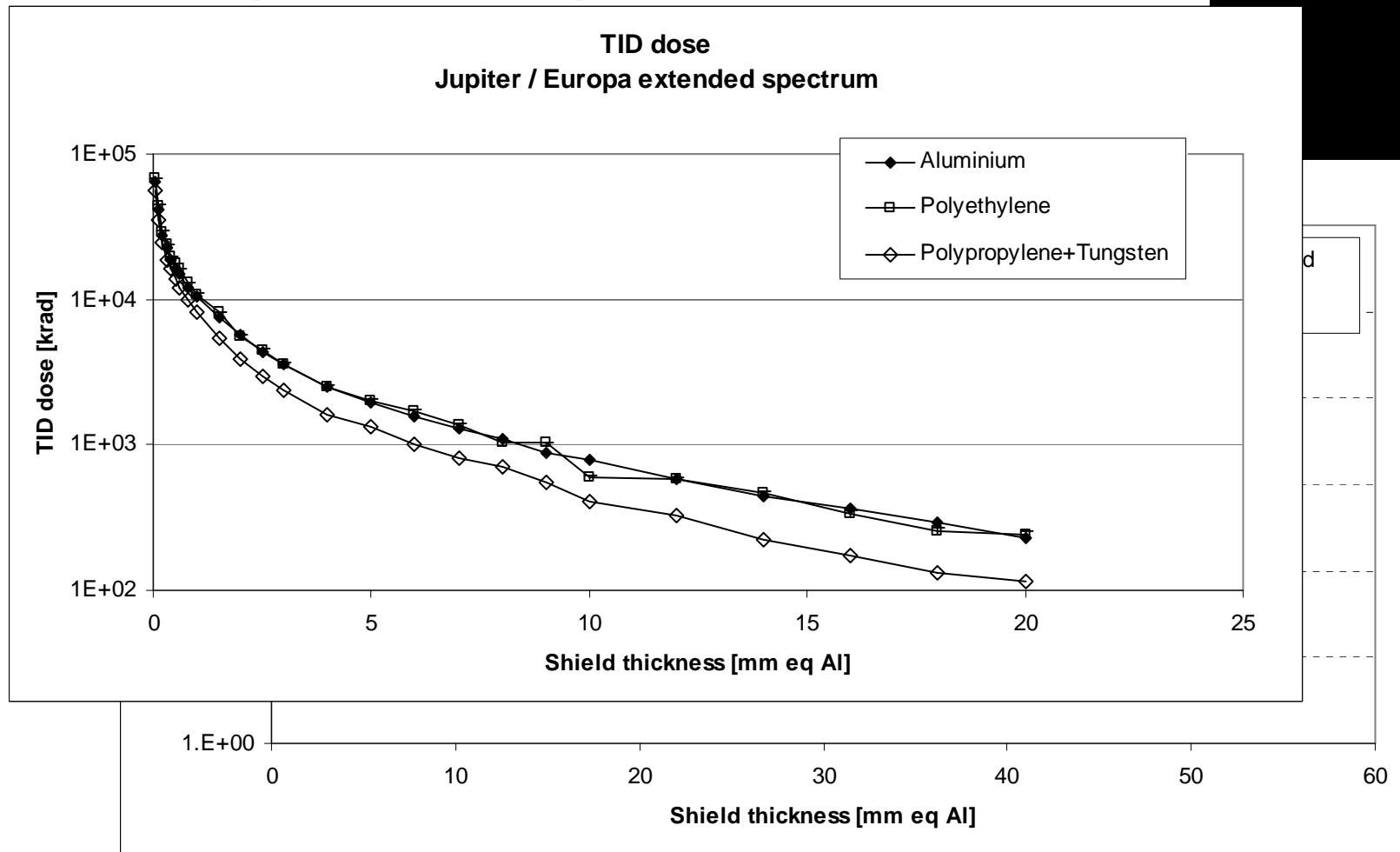


- ConeXpress study
- Electron physics verification
- Separate contribution of electrons and Bremsstrahlung

R. Lindberg et al., IEEE-TNS, Dec 2006



GRAS for Future Jupiter Europa missions



- (Divine-Garrett, GIRE and Salammbo-3D models)

Other applications & work in progress

esa

- GRAS used at INTA (Madrid, Spain) for quasi real-time Space Weather warning system
- MARS exploration
 - Collaboration with Bordeaux (S.Incerti, A. Lepostollec *et al.*)
 - Interface to PLANETOCOSMICS
- Detector test and calibration: SREM

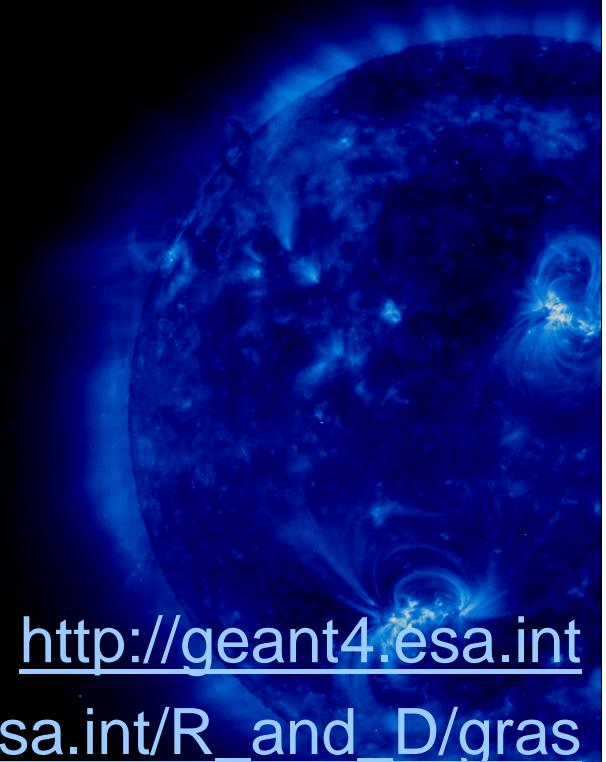
In progress

- SPENVIS (Space Environment information System)
 - GRAS web interface in the new contract
- Charge Collection Analysis module
 - REAT-MS contract (QinetiQ)



GRAS summary

- Modular MC analysis package
- Space users oriented, can be applied to many domains
- Open to comments for upgrades
- Open !
- Already used in the support of a number of space missions and projects
- Feel free to try it and see if it suits your needs:



<http://geant4.esa.int>

http://space-env.esa.int/R_and_D/gras

Giovanni.Santin@esa.int