Reverse Monte Carlo in Geant4 and GRAS

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Overview

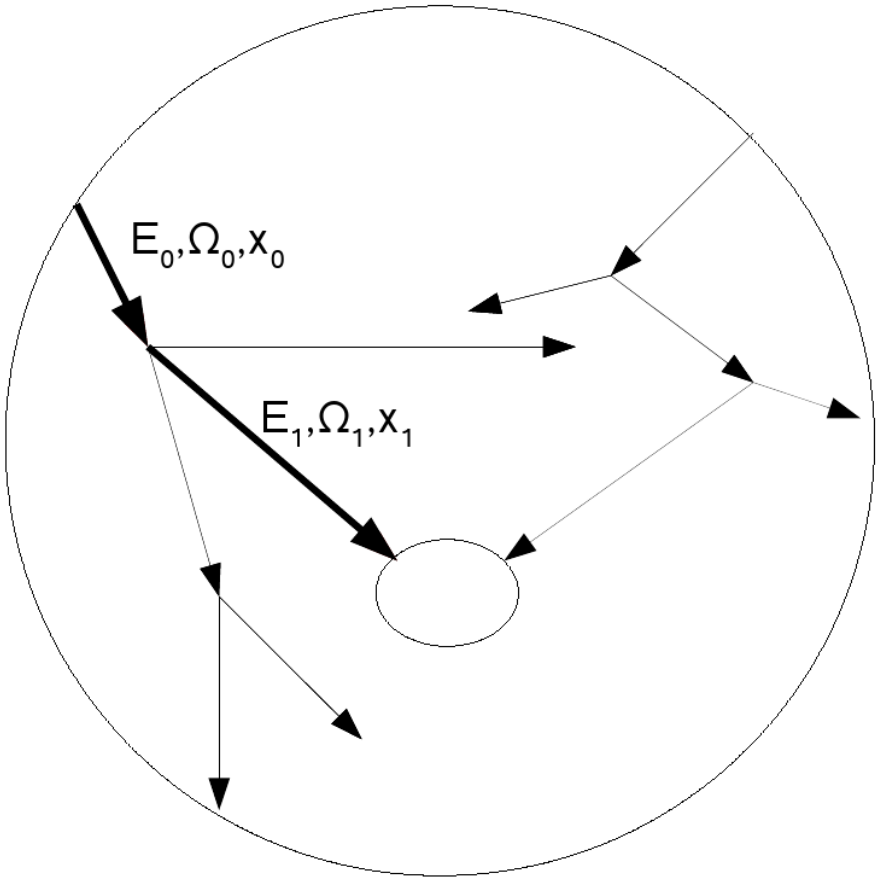
- **Motivations**
- **Definition of Reverse/Adjoint Monte Carlo(RMC) method**
- **RMC method in the Geant4 toolkit**
- **G4 example extended/biasing/ReverseMC01**
- **RMC method in GRAS with example**
- **Conclusions**

Motivations

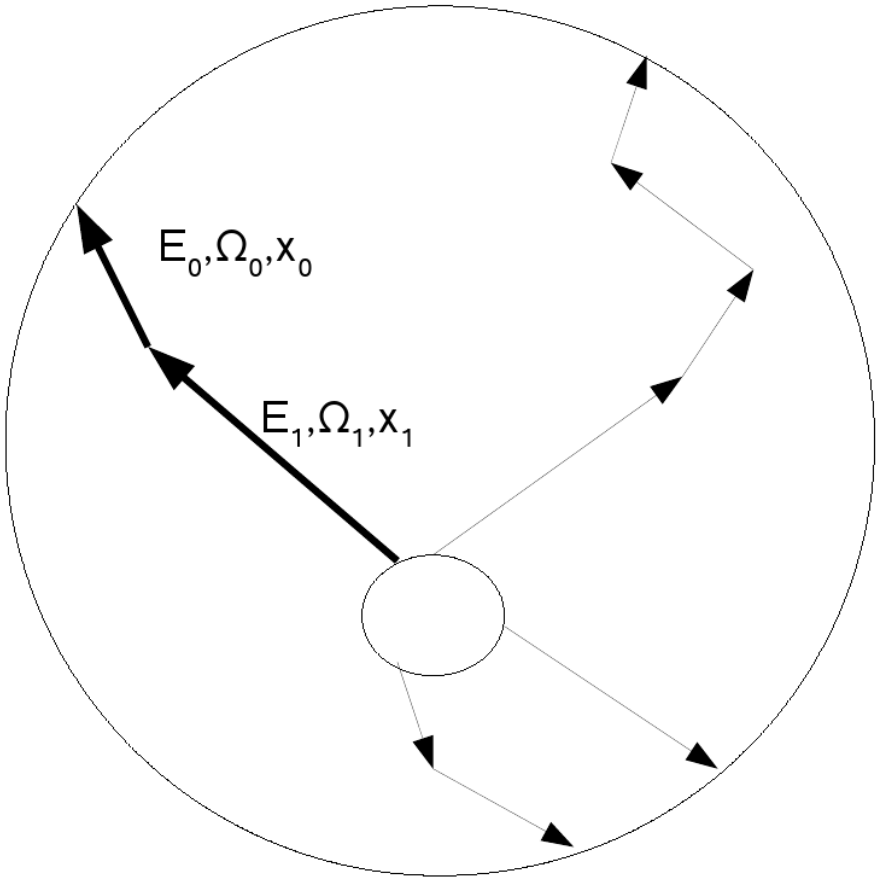
- Monte Carlo codes as Geant4 are accurate but very computing time consuming
- Need of biasing methods or approximations to speed up these codes
- Reverse Monte Carlo is one of these biasing methods
- The Reverse Monte Carlo method has been implemented in Geant4 and GRAS

Reverse Monte Carlo method

Forward MC Mode



Adjoint/Reverse MC Mode

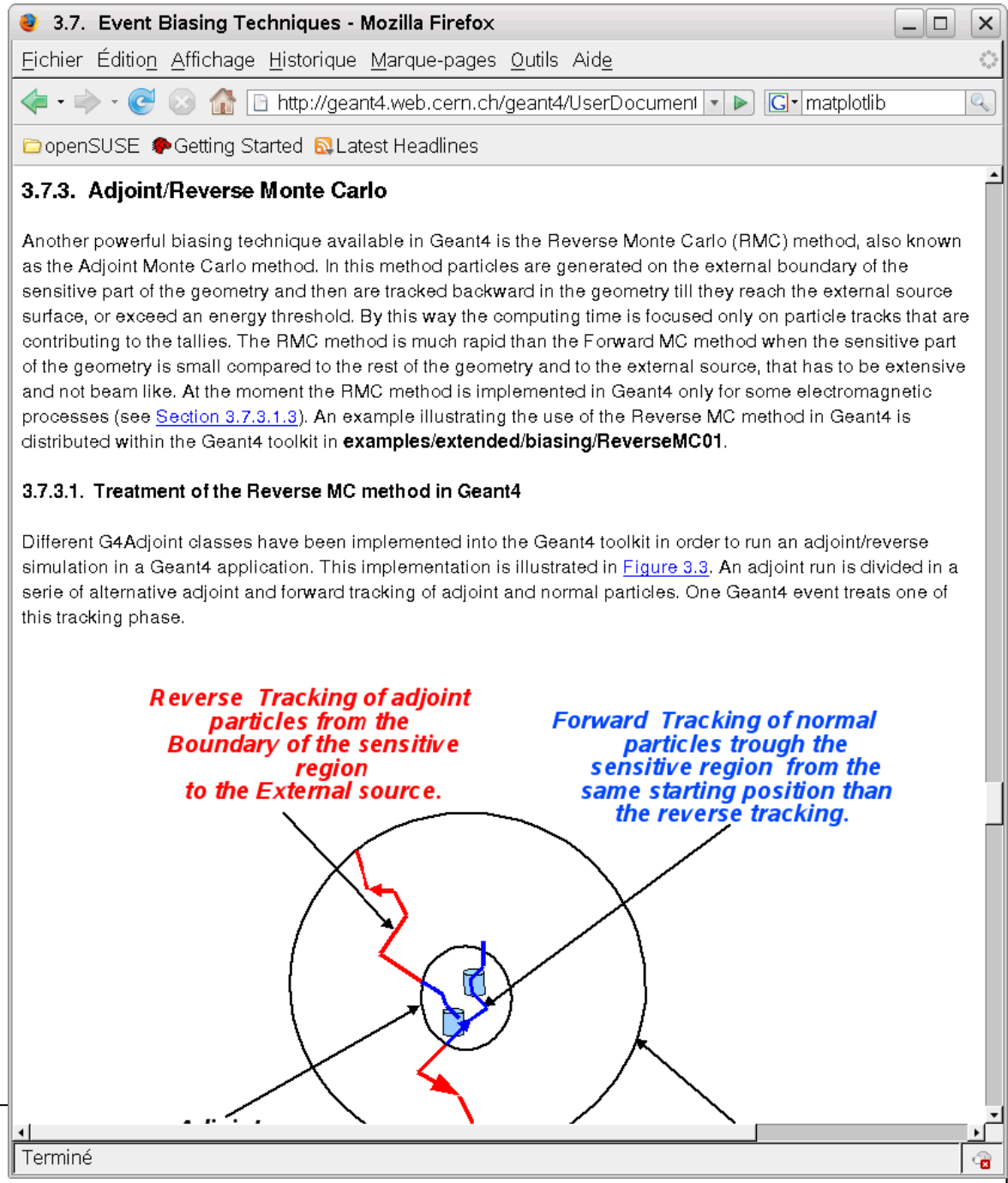


- ***Start from the external source***
- ***Wasted Computing time for tracks that do not reach the sensitive region***

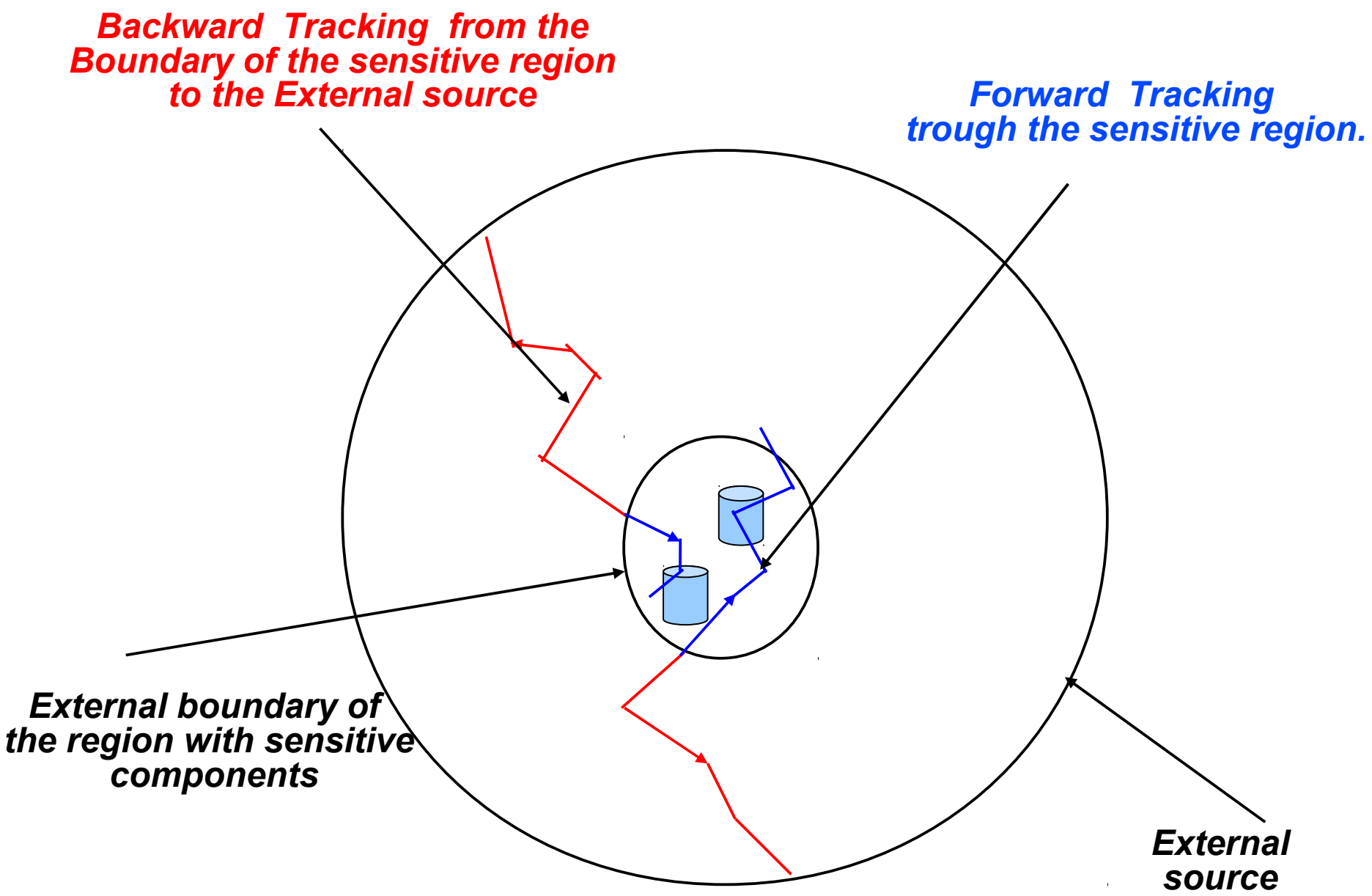
- ***Start from the sensitive region and compute reverse tracks till the external source***
- ***Computing time focuses mainly on tracks that reach the sensitive region***
- ***Much more rapid than forward MC for example to compute e-dose in tiny electronic components***
- ***But tricky while all the physics (cross section, kinematic,..) need to be reversed!!!***

RMC method is available in Geant4 since the version G4.9.3

- Base adjoint classes and reverse processes distributed in the G4 toolkit
- Extended/biasing G4 example to illustrate the use of the RMC method in Geant4
- Documentation in the G4 user guide for application developer
- Publication in NIMA
  Desorgher et al., 2010

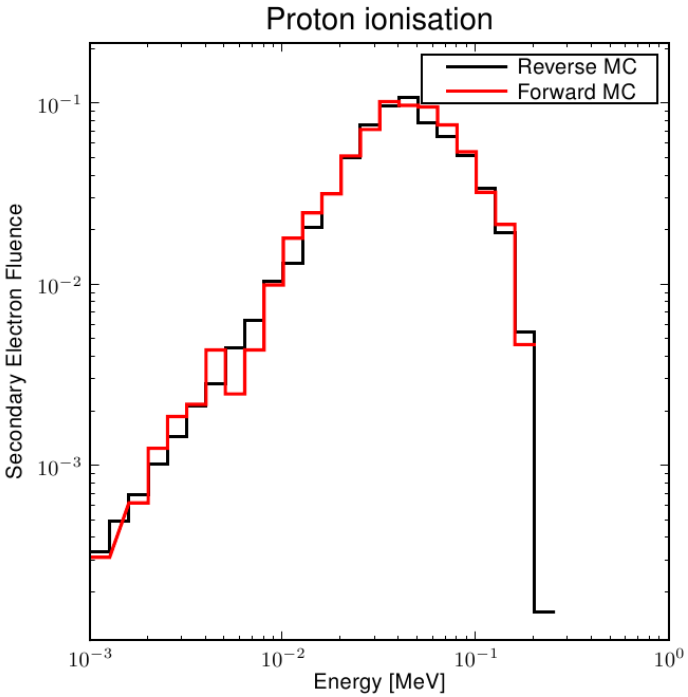


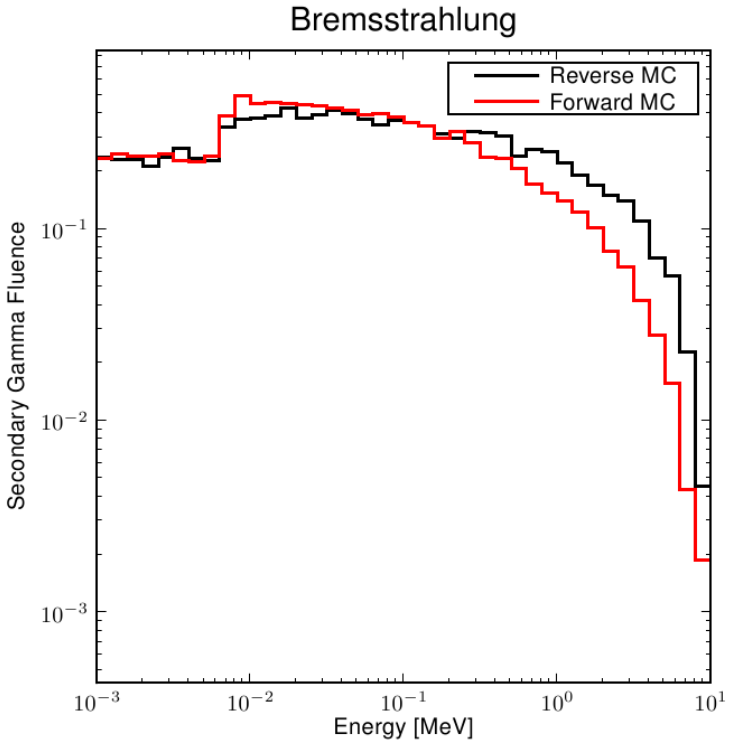
A reverse/adjoint run in Geant4 is a succession of reverse and forward trackings

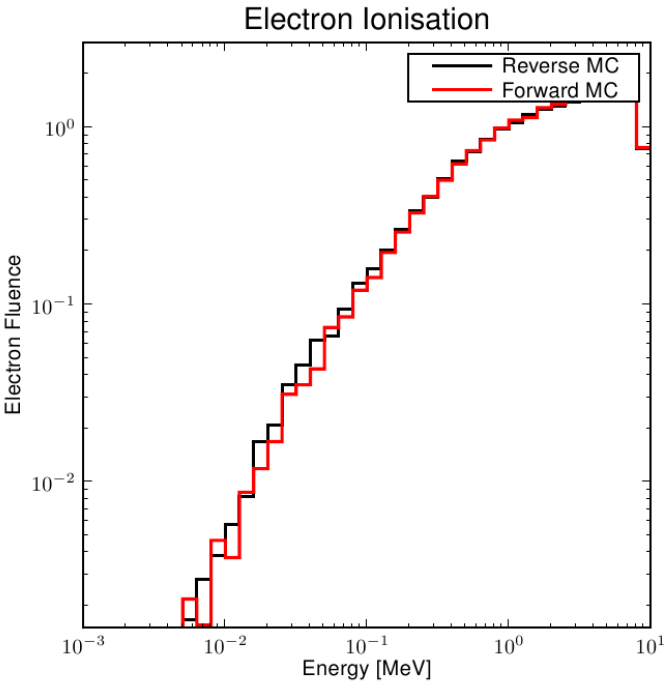


Implemented Reverse processes in Geant4

- ionisation (discrete and continuous) for e-, proton and ion
- multiple scattering
- bremsstrahlung
- Compton scattering
- photo-electric effect







How to update a G4 application to use the Reverse MC method

- Create an instance of G4AdjointSimManager in the main code

- Add adjoint particles and adjoint processes in the physics list
  - See physics list in extended G4 example biasing/ReverseMC01

- Normalisation of tallies computed in the forward phase
  - Weight of the last adjoint track computed by the G4 adjoint machinery

    w = theAdjointSimManager->GetWeightAtEndOfLastAdjoinTrack()
  - tallies computed by your code during the forward phase

    T
  - Differential, directional primary flux

    f
  - Normalised tallies for response functions to register vs primary e_{kin}, *direction, ...*

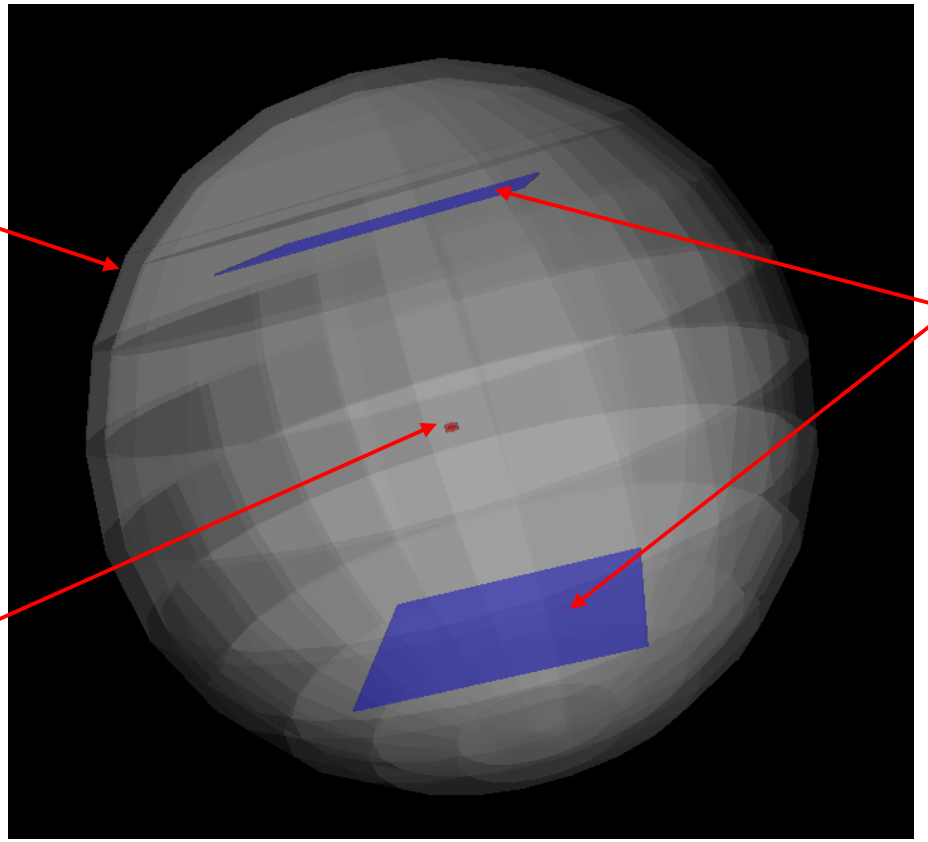
    $R_m = w.T$
  - Normalisation of tallies to external flux

    $T_{norm} = w.T.f$

For more informations look at the
advanced G4 example biasing/ReverseMC01

Geant4 example extended/biasing/ReverseMC1

Spherical Al shielding
Radius 10 cm
User defined
Thickness



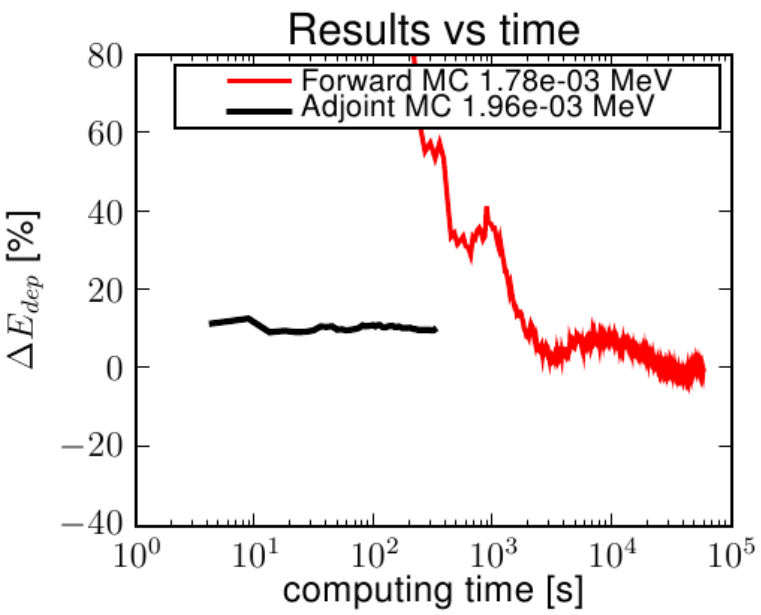
Tantalum plates
0.5mm Thick

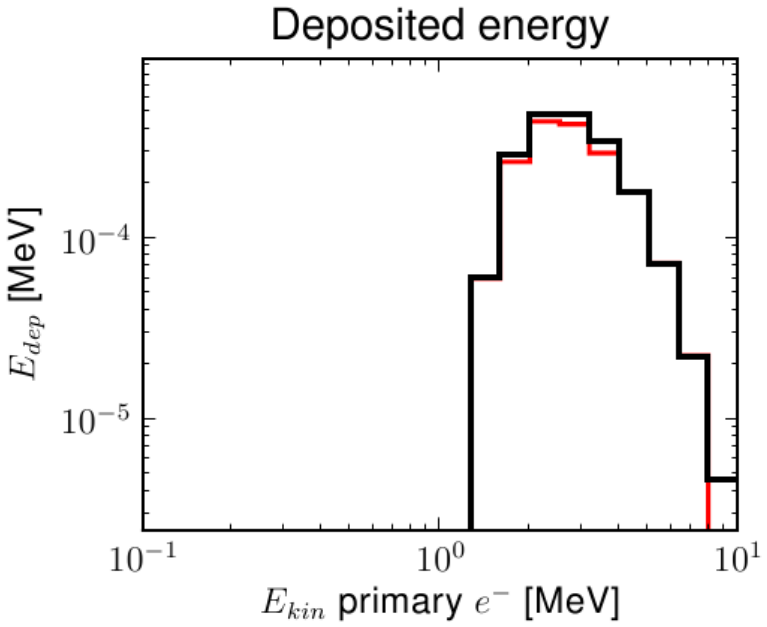
Energy deposited
In Small Si Sensitive
Cylinder
With variable size

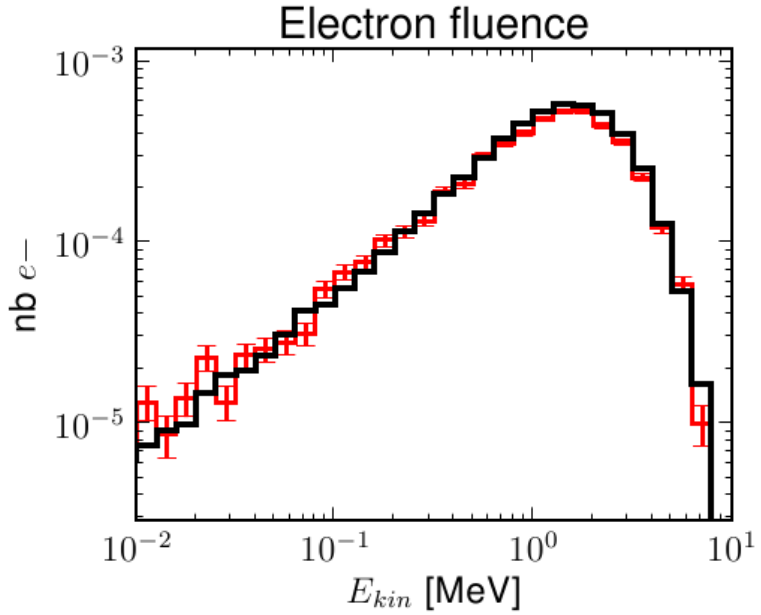
External Spherical source
Radius 10 cm
Primary Particles e- , and proton

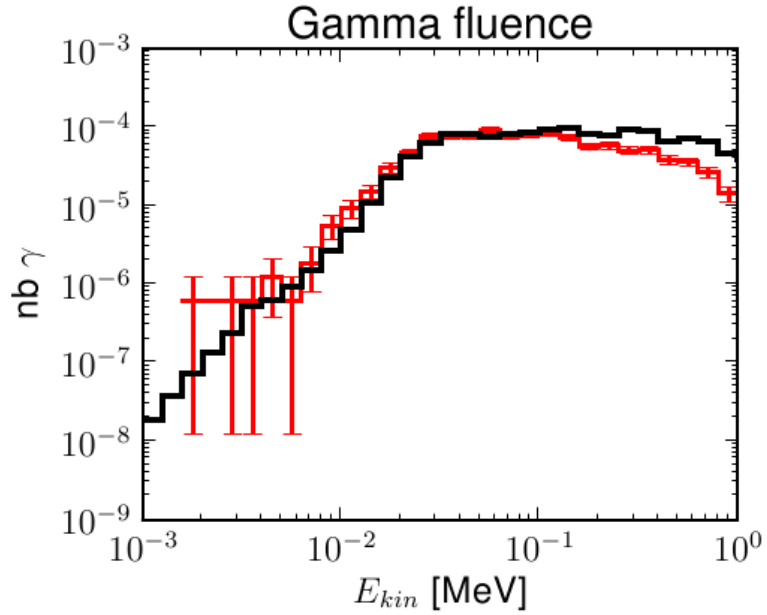
- Comparisons forward and reverse computations
- Illustrates what changes are needed in a G4 application to use the Reverse MC mode
- Introduce the use of few new G4 macro commands relative to adjoint simulation

Comparison Reverse and Forward MC simulation





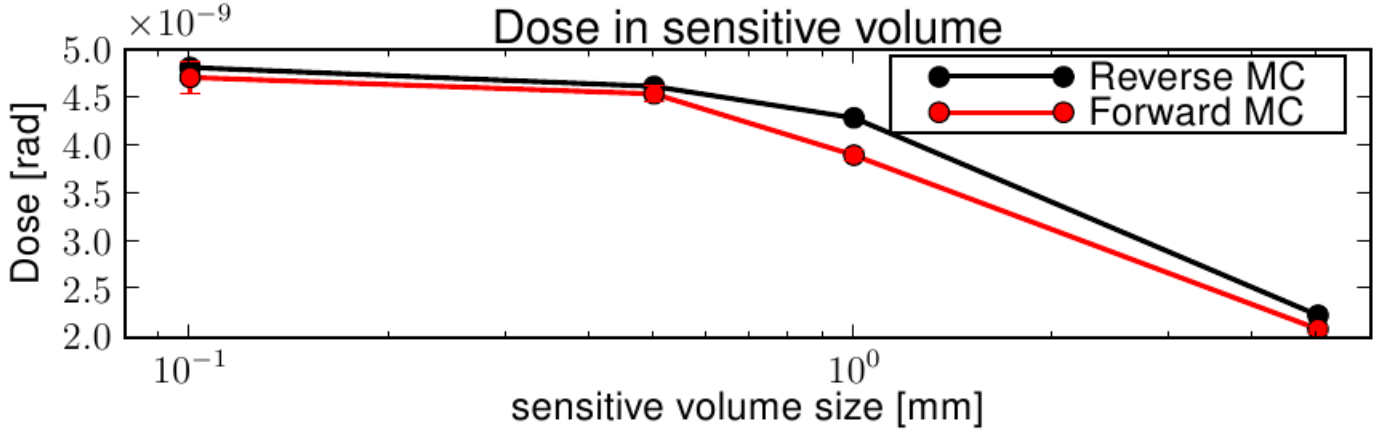


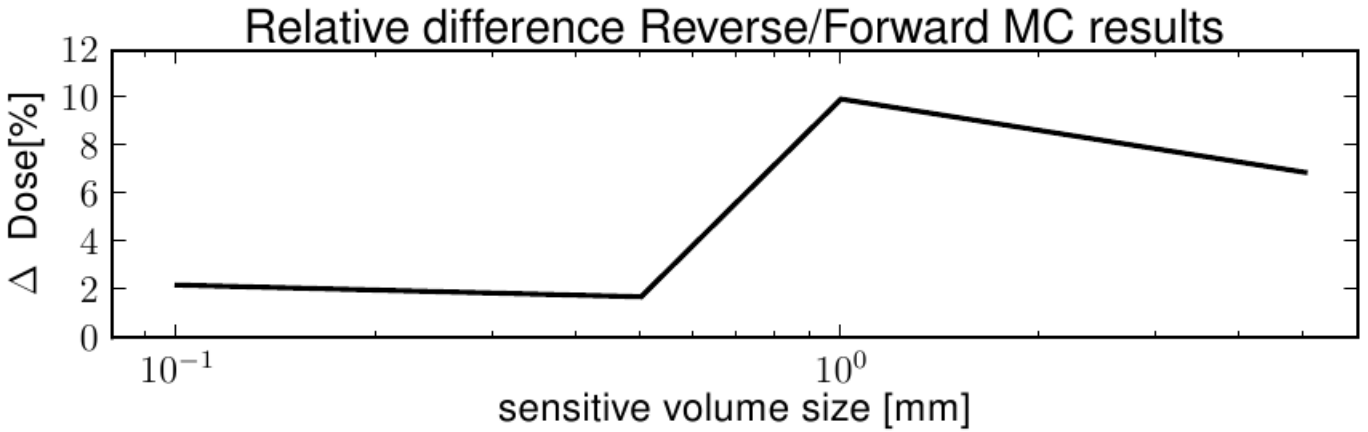


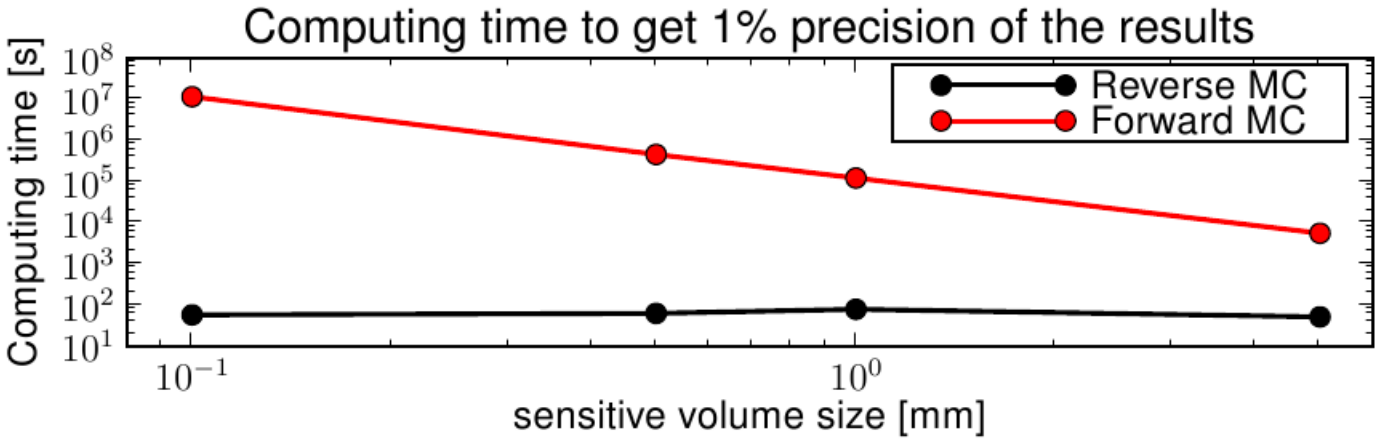
Primary source

- Electrons
- [1 keV, 10 MeV]
- spectrum *exp(-E/MeV)*

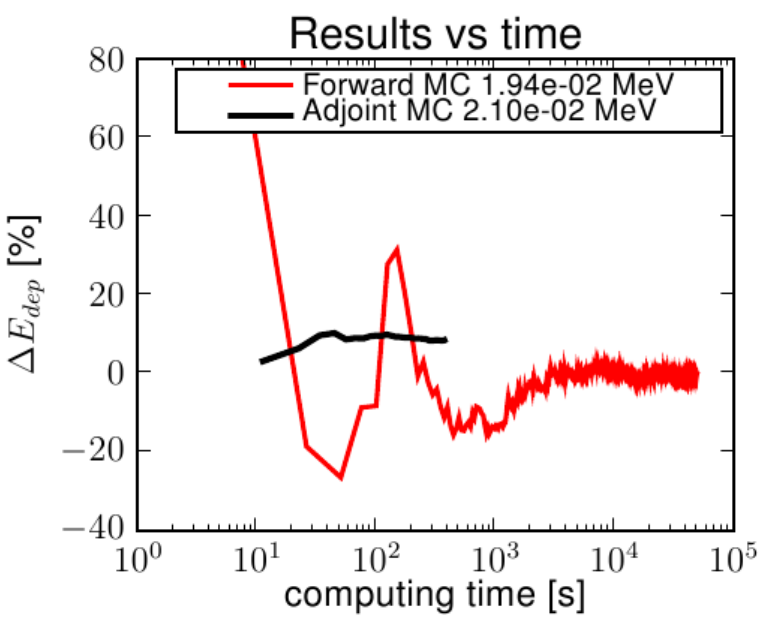
Scaling of the results with the size of the sensitive volume

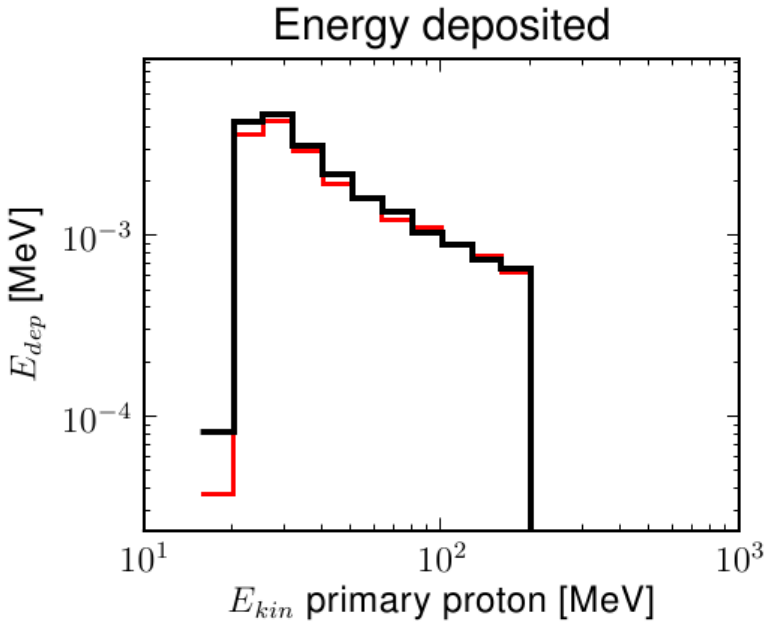


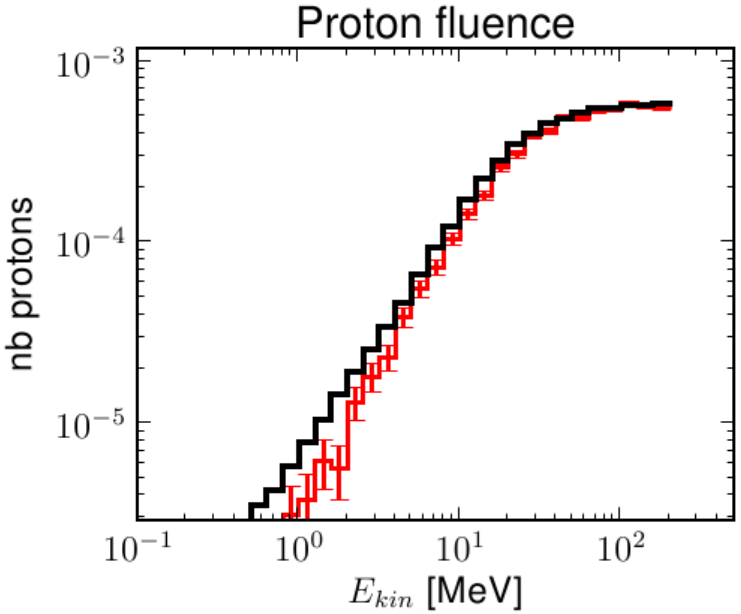


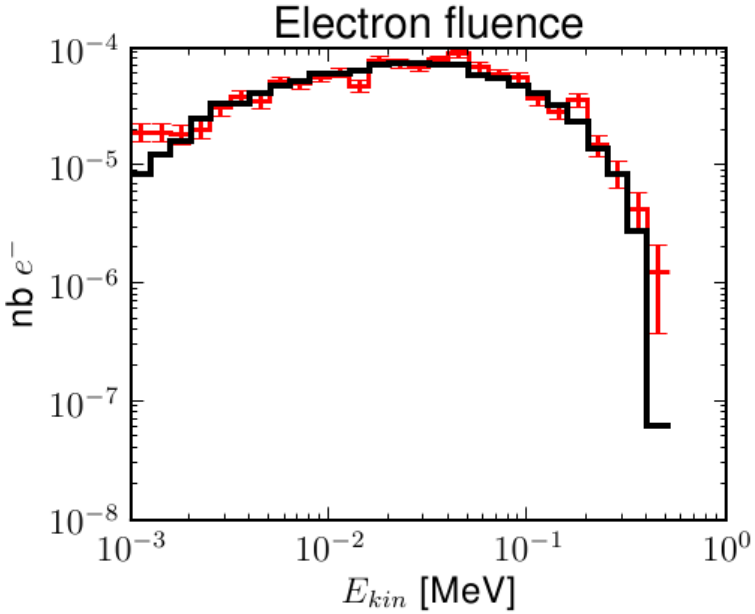


Comparison Reverse and Forward MC simulation









Primary source

- Protons
- [0.1keV, 200MeV]
- spectrum E^{-1}

GRAS and Reverse MC

- GRAS- Geant4 Radiation Analysis for Space
- GRAS Simplifies the access of Geant4 for space radiation analysis
- Availability of analyse modules for common radiation analysis
- GRAS has been updated to use the Reverse MC mode available in Geant4

Main functionalities of GRAS Reverse MC are the same than in GRAS forward

Same geometry definition

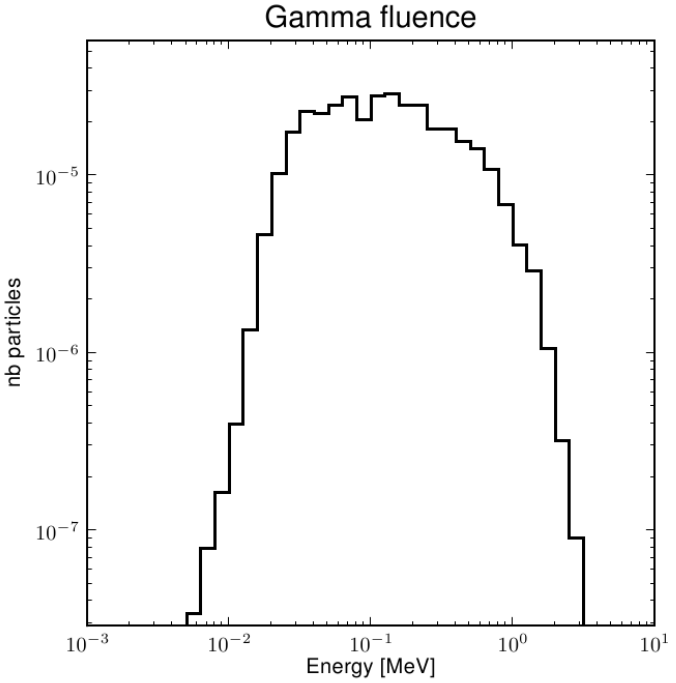
GDML, C++, Mulassis

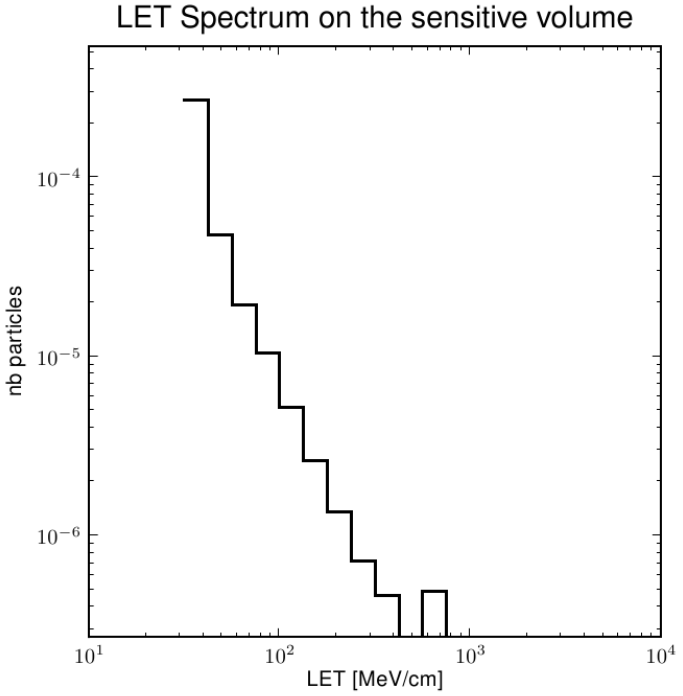
Same definition of analysis modules

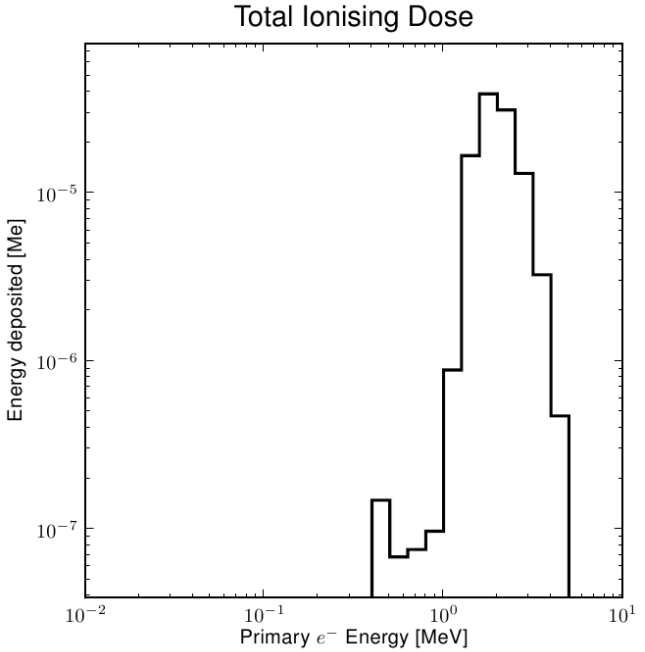
TID, particle spectra, LET, NIEL …

Common Output format

Scalars and 1D Histo in CSV and ROOT



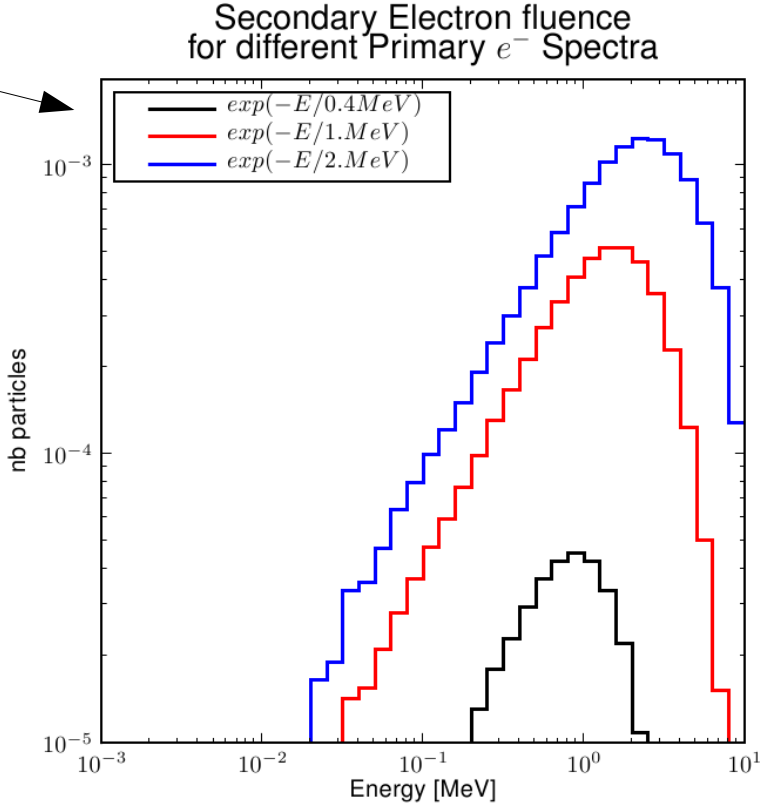




New fonctionalities of GRAS RMC compare to GRAS forward

Direct normalisation to # primary spectra

exponential, power law, histograms



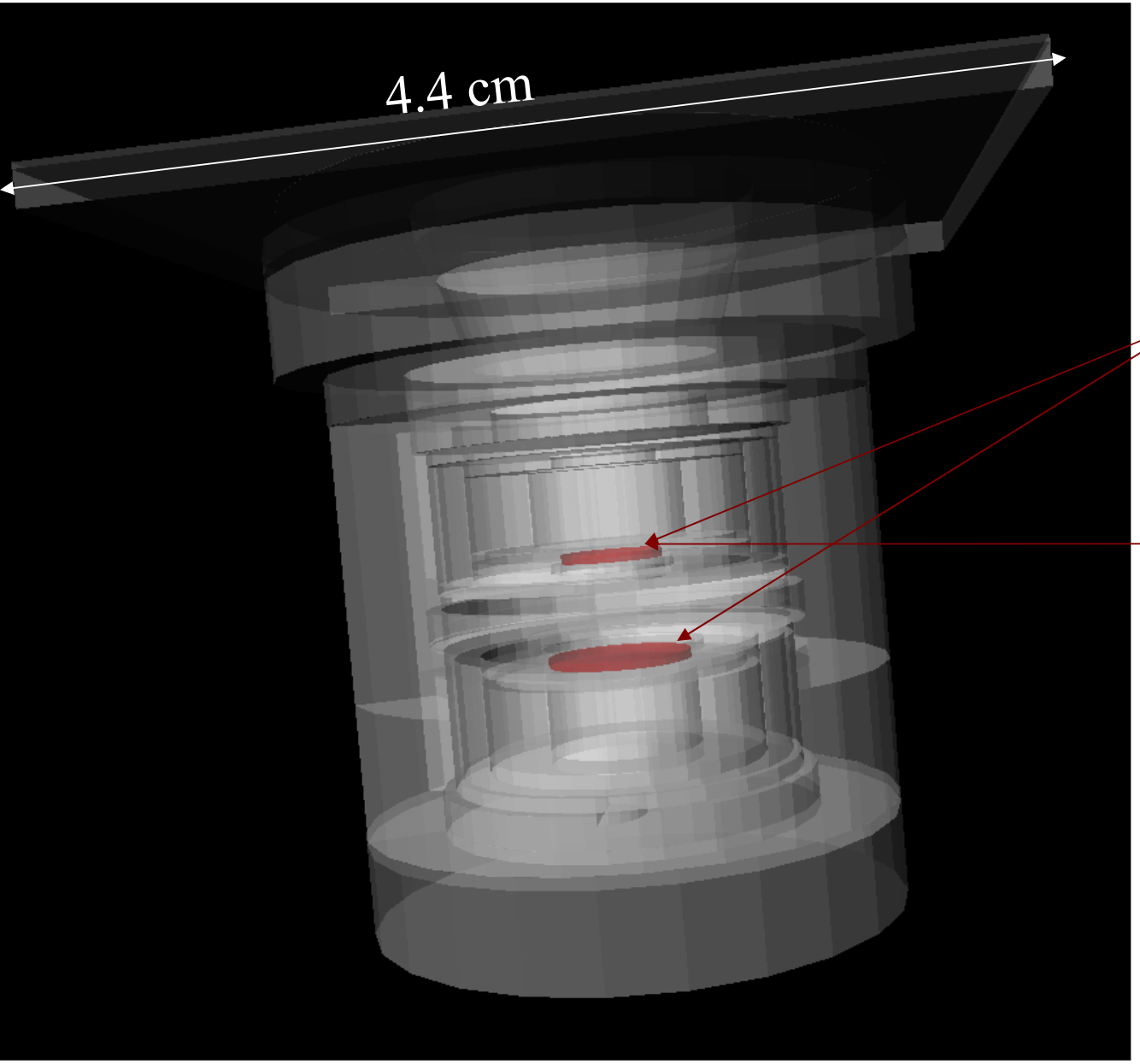
Convergence of simulation results

File registering the computed energy deposited with precision in function of computing time

Edep[MeV]	error[MeV]	precision[%]	computing_time[s]
1.269958e-04	3.040472e-05	2.394151e+01	7.100000e-01
1.273392e-04	2.015732e-05	1.582962e+01	1.410000e+00
1.095371e-04	1.475086e-05	1.346654e+01	2.120000e+00
1.076673e-04	1.240530e-05	1.152188e+01	2.830000e+00
1.110131e-04	1.109077e-05	9.990506e+00	3.530000e+00
1.083752e-04	9.612224e-06	8.869392e+00	4.230000e+00
1.088696e-04	8.933815e-06	8.205979e+00	4.950000e+00
1.073973e-04	8.099489e-06	7.541612e+00	5.650000e+00
1.049121e-04	7.402633e-06	7.056033e+00	6.360000e+00
1.063614e-04	7.039227e-06	6.618214e+00	7.050000e+00
1.060443e-04	6.864397e-06	6.473142e+00	7.760000e+00
1.051760e-04	6.529784e-06	6.208434e+00	8.460000e+00
1.046732e-04	6.225381e-06	5.947446e+00	9.160000e+00
1.058603e-04	5.944663e-06	5.615575e+00	9.870000e+00
1.067215e-04	5.797705e-06	5.432557e+00	1.056000e+01
1.056946e-04	5.562687e-06	5.262980e+00	1.127000e+01
1.062925e-04	5.409596e-06	5.089349e+00	1.197000e+01
1.062974e-04	5.236012e-06	4.925813e+00	1.268000e+01
1.072061e-04	5.076824e-06	4.735574e+00	1.339000e+01
1.061439e-04	4.886851e-06	4.603985e+00	1.409000e+01

Automatic stop of the simulation when a user defined precision of the computed deposited energy is reached

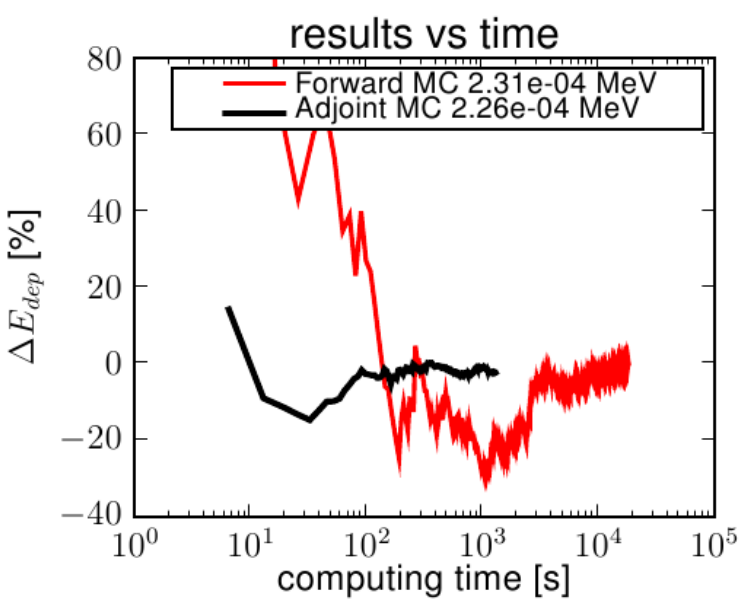
Test of GRAS/RMC with part of the ESA SREM Detector

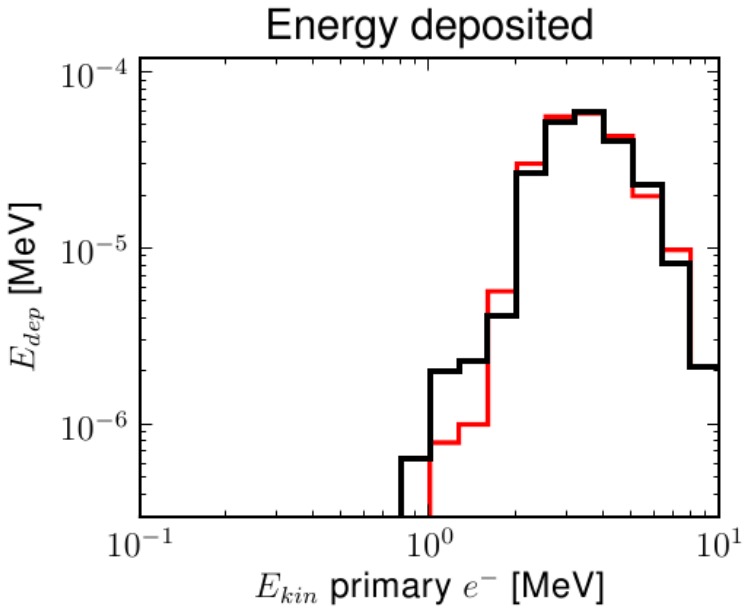


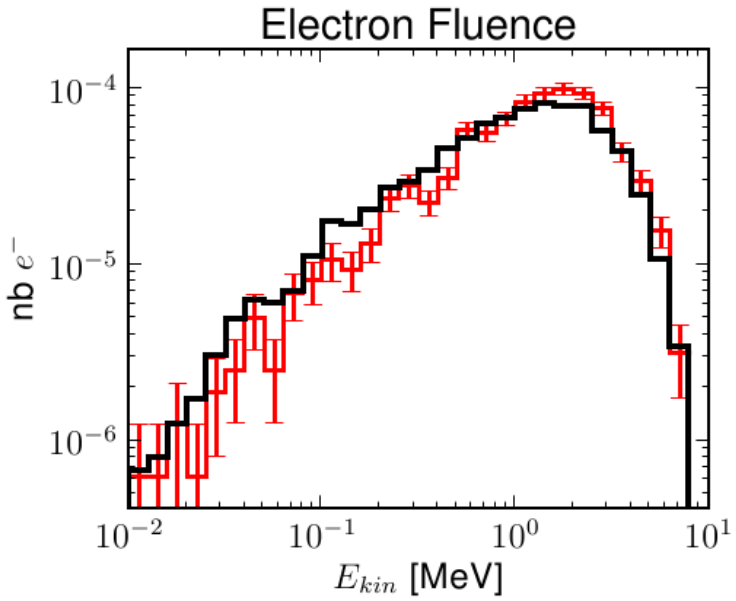
Silicium diodes surrounded by Al and Ta shielding

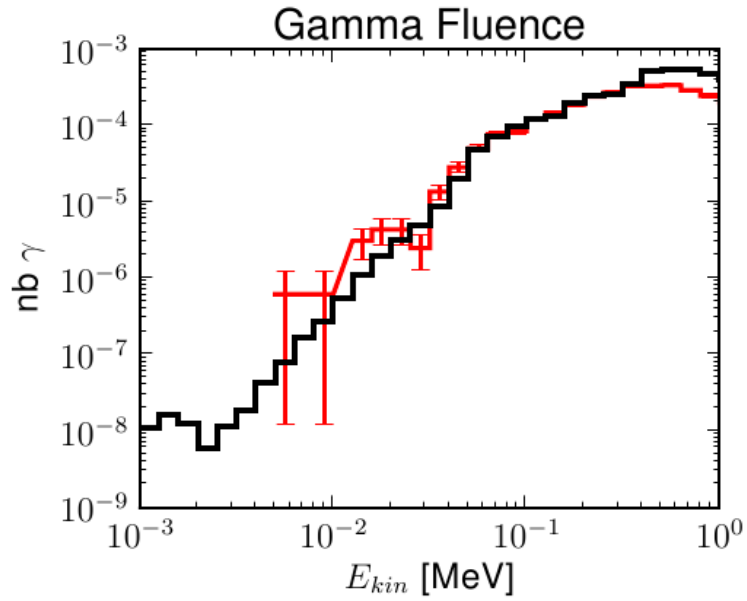
In this example we compute
the dose in the top diode
the flux of secondaries on the top diode

Comparison Reverse and Forward MC simulation





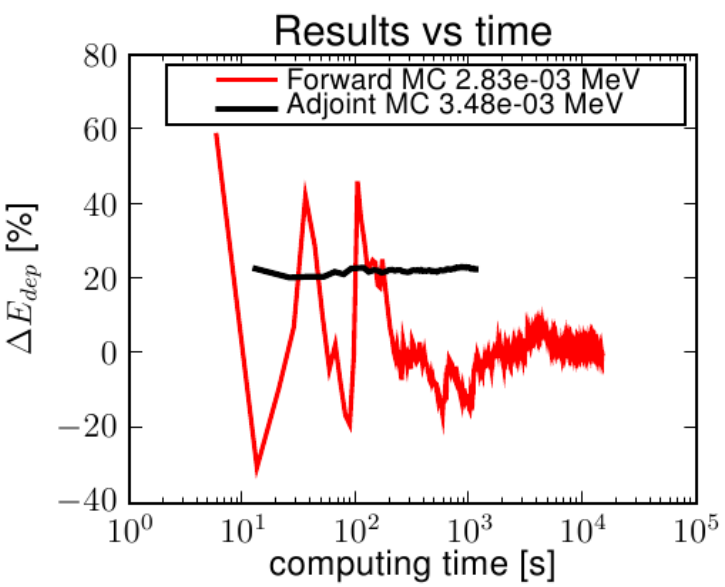


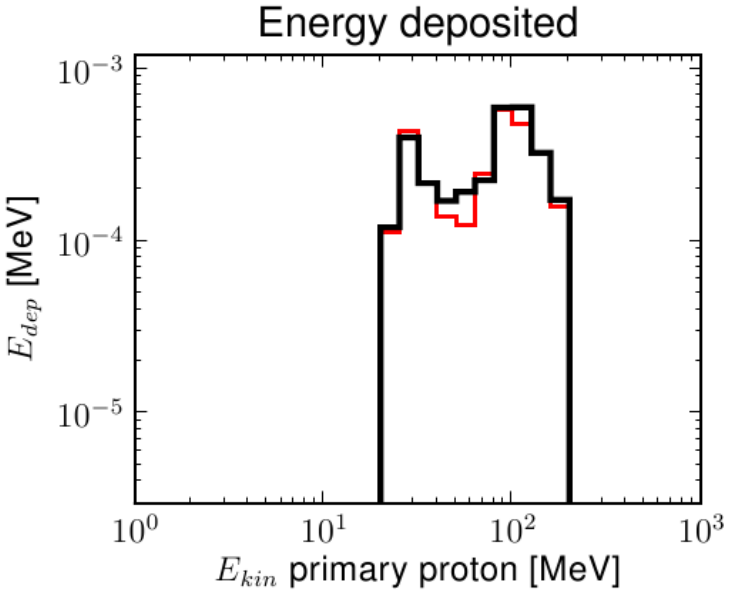


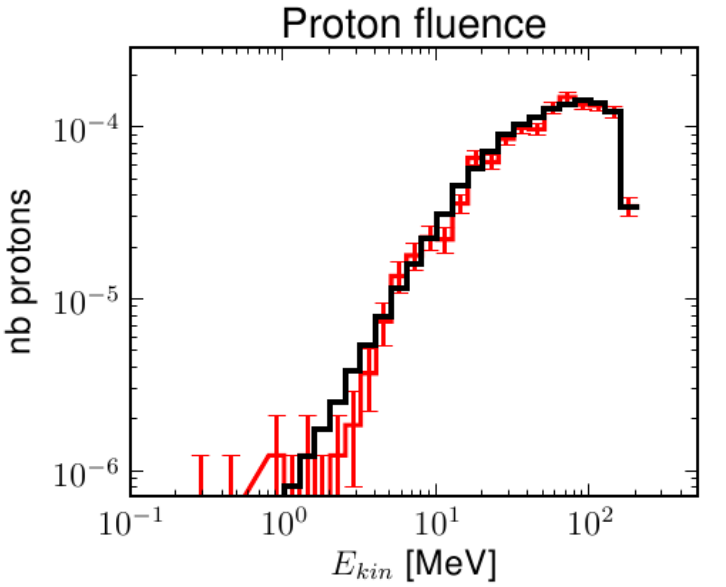
Primary source

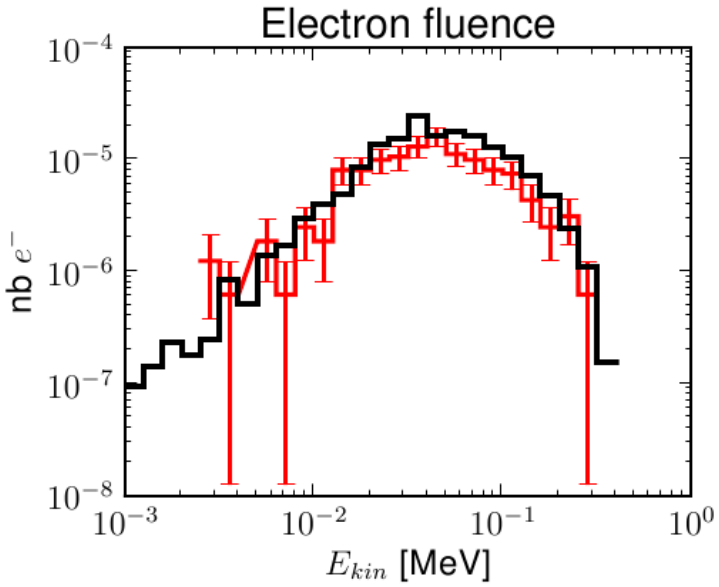
- Electrons
- [1 keV, 10 MeV]
- spectrum *exp(-E/MeV*

Comparison Reverse and Forward MC simulation









Primary source

- Protons
- [0.1keV, 200MeV]
- spectrum E^{-2}

Conclusions and Future work

- The Reverse MC method is available in Geant4 since the 9.3 release

- GRAS has been updated to use the G4 RMC mode. It will be vailable with the next GRAS release.

- The following reverse processes have been considered
  - Ionisation and multiple scattering for e- , protons an ions
  - Bremsstrahlung, Compton and photo-electric effects for e-

- The reverse MC method reaches precise results much more rapidly than the forward MC method

- The maximal discrepancy between the RMC and forward computed total dose is ~ 10-20 %

- Improvement of the bremstrahlung and multiple scattering is under investigation to decrease the discrepancies

- Implementation of point-like detector concept is under development

More informations?

- Documentation in the G4 user guide for application developer. Section 3.7
  http://geant4.web.cern.ch/geant4/UserDocumentation/UsersGuides/ForApplicationDeveloper/html/

- G4 example extended/biasing/ReverseMC01.

- Publication
  Implementation of the reverse/adjoint Monte Carlo method into Geant4,
  L. Desorgher,F. Lei, and G. Santin, NIMA, 621, 1-3, p.247-257
  doi:10.1016/j.nima.2010.06.001

- Feedback and questions to desorgher@spaceit.ch

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V. Ivantchenko, G. Cosmo, Fan Lei,
G Santin, P.Nieminen**

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