



## Geant4 Reverse MC

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# OUTLINE

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- Reverse Monte Carlo in Geant4 and GRAS
- Some problems for Juice mission simulation with G4RMC
- Some Improvements of the code
- New tests

# Why Reverse Monte Carlo?

- Radiation effects in tiny components computed with Monte Carlo codes as Geant4 :

Accurate but need a lot of computing time

- Need of biasing methods or approximations to speed up these codes:

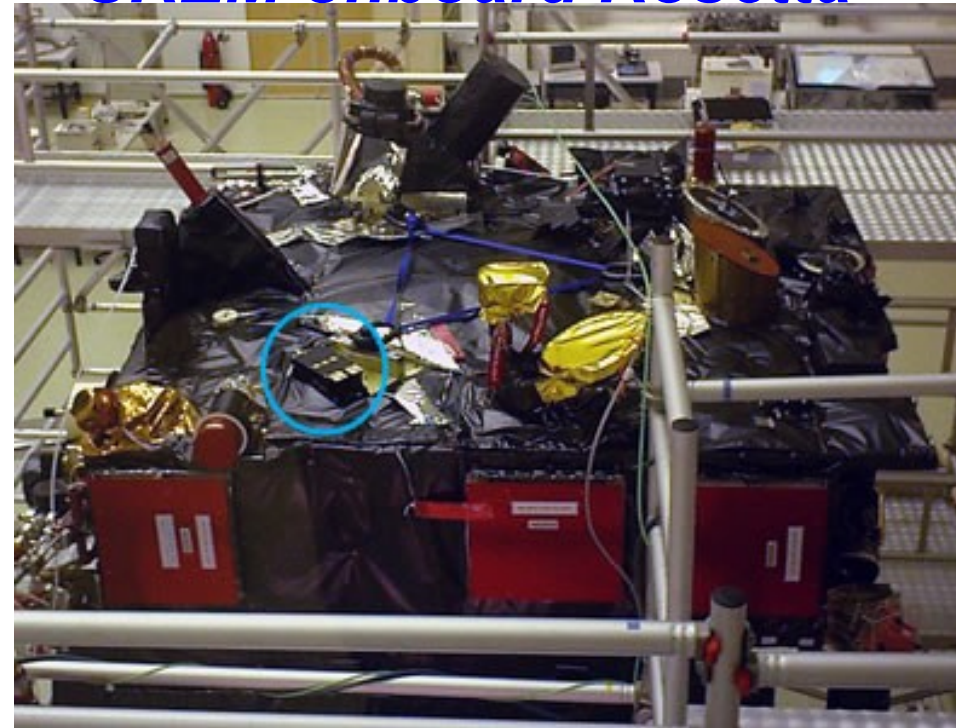
Reverse Monte Carlo method is one of these methods

- Reverse Monte Carlo is advantageous when:

- The region where radiation analysis is computed is small compared to the rest of the geometry
- The external source of primary particles is extended

It is typically the case in space radiation effect modelling

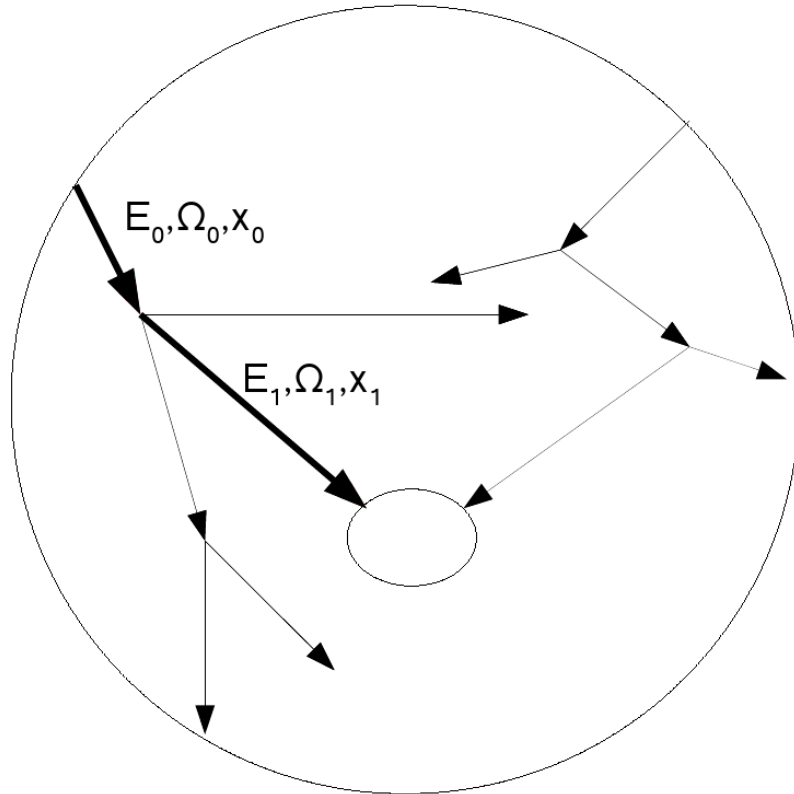
## SREM onboard Rosetta



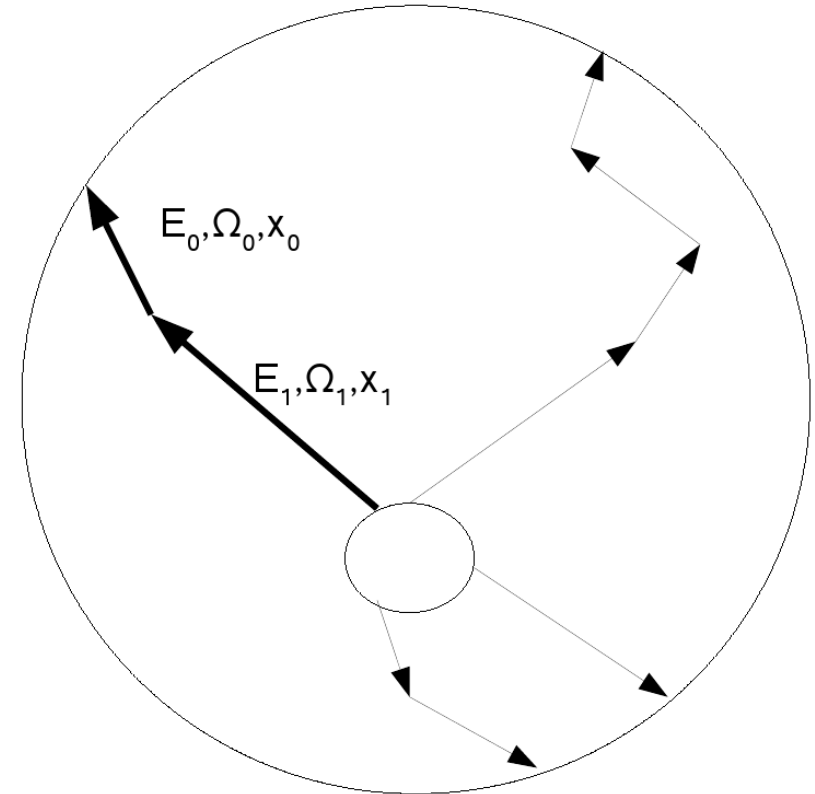
# Reverse Monte Carlo method

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
- Much more rapid as computing time focuses mainly on tracks that reach the sensitive region
- But tricky while all the physics need to be reversed!!!

# RMC in Geant4 since the version 4.9.3

- 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
- Reverse processes implemented
  - e-, p Ionisation
  - Bremsstrahlung
  - Compton
  - Photo electric effect

3.7. Event Biasing Techniques - Mozilla Firefox

Fichier Édition Affichage Historique Marque-pages Outils Aide

http://geant4.web.cern.ch/geant4/UserDocument matplotlib

openSUSE Getting Started Latest Headlines

### 3.7.3. Adjoint/Reverse Monte Carlo

Another powerful biasing technique available in Geant4 is the Reverse Monte Carlo (PMC) method, also known as the Adjoint Monte Carlo method. In this method particles are generated on the external boundary of the sensitive part of the geometry and then are tracked backward in the geometry till they reach the external source surface, or exceed an energy threshold. By this way the computing time is focused only on particle tracks that contribute to the tallies. The RMC method is much rapid than the Forward MC method when the sensitive part of the geometry is small compared to the rest of the geometry and to the external source, that has to be extended and not beam like. At the moment the RMC method is implemented in Geant4 only for some electromagnetic processes (see [Section 3.7.3.1.3](#)). An example illustrating the use of the Reverse MC method in Geant4 is distributed within the Geant4 toolkit in `examples/extended/biasing/ReverseMC01`.

#### 3.7.3.1. Treatment of the Reverse MC method in Geant4

Different G4Adjoint classes have been implemented into the Geant4 toolkit in order to run an adjoint/reverse simulation in a Geant4 application. This implementation is illustrated in [Figure 3.3](#). An adjoint run is divided in a series of alternative adjoint and forward tracking of adjoint and normal particles. One Geant4 event treats one of this tracking phase.

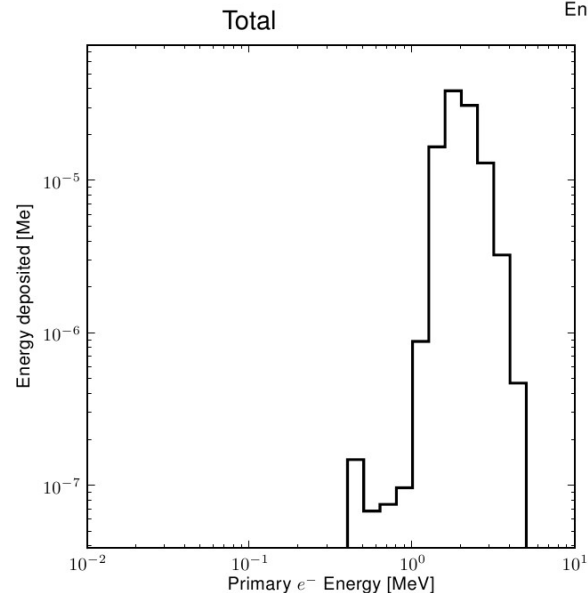
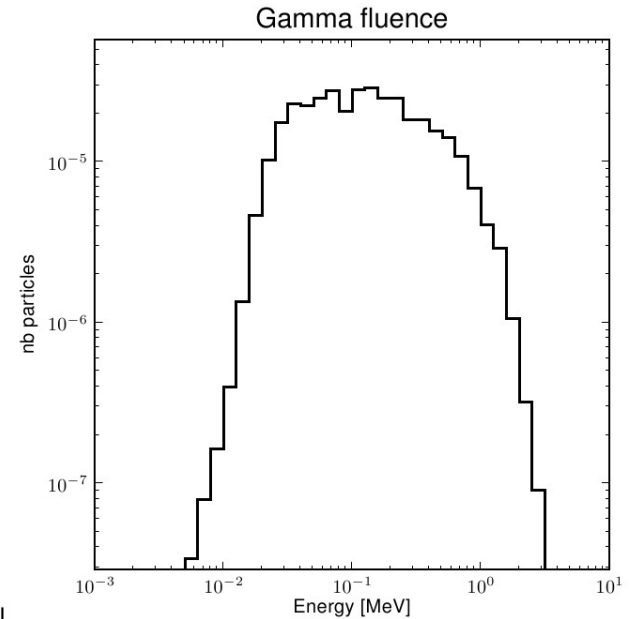
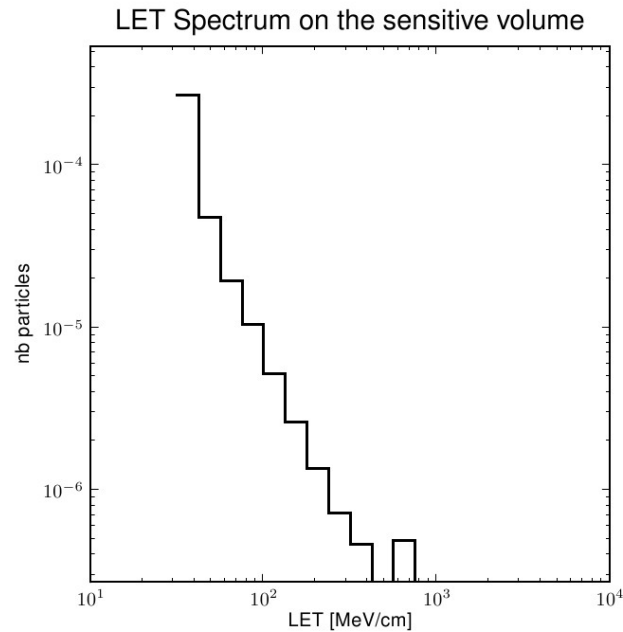
Reverse Tracking of adjoint particles from the Boundary of the sensitive region to the External source.

Forward Tracking of normal particles through the sensitive region from the same starting position than the reverse tracking.

Terminé

# Reverse MC is implemented in GRAS

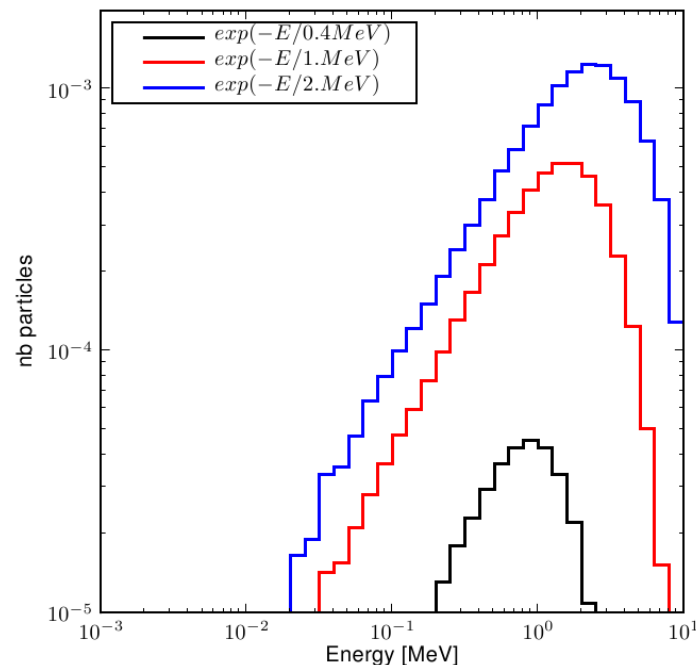
- Same geometry definition
- Same definition of analysis modules
  - TID in sensitive volumes
  - Particle spectra
  - LET spectra
  - NIEL



# Added functionalities of GRAS RMC compare to GRAS forward

- Direct normalisation
- Different primary particles and spectra can be specified
- File registering the convergence of the simulation results
- Automatic stop after a “user defined” precision of the calculation is reached

Secondary Electron fluence  
for different Primary  $e^-$  Spectra

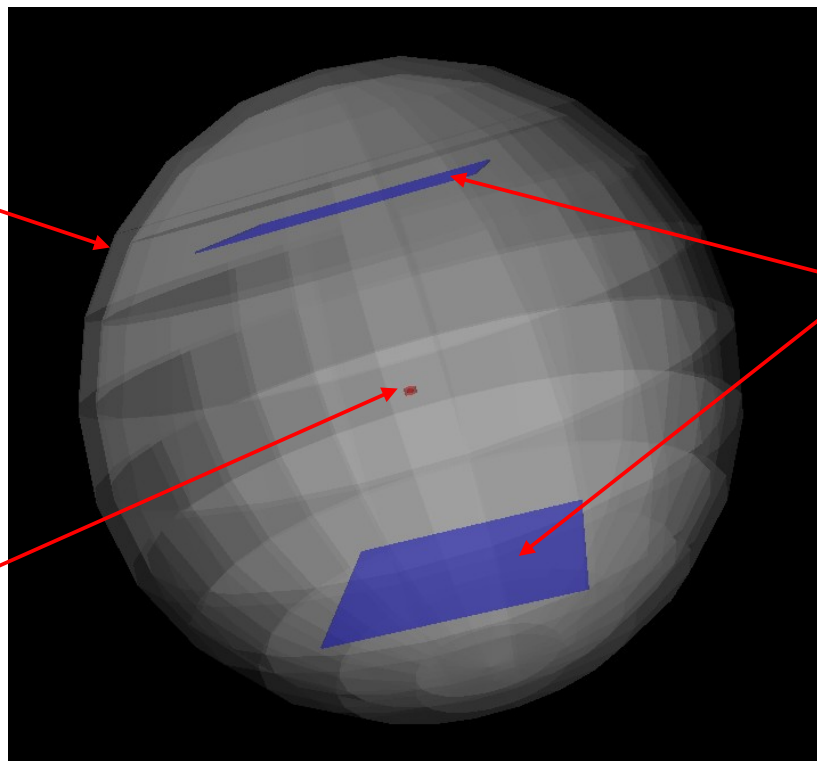


Edep [MeV]	error [MeV]	precision [%]	computing_time [s]
1.269958e-04	3.040472e-05	2.394151e+01	7.100000e-01
1.273392e-04	2.015732e-05	1.582962e+01	1.410000e+00
1.095371e-04	1.475086e-05	1.346654e+01	2.120000e+00
1.076673e-04	1.240530e-05	1.152188e+01	2.830000e+00
1.110131e-04	1.109077e-05	9.990506e+00	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

***Simple Example : Energy deposited  
by e- and protons in a small  
sensitive Cylinder surrounded  
by a large aluminum shielding***

Spherical Al shielding  
Radius 10 cm  
Thickness 2 mm

Small Si Sensitive  
Cylinder  
Radius 1mm  
Height 1 mm

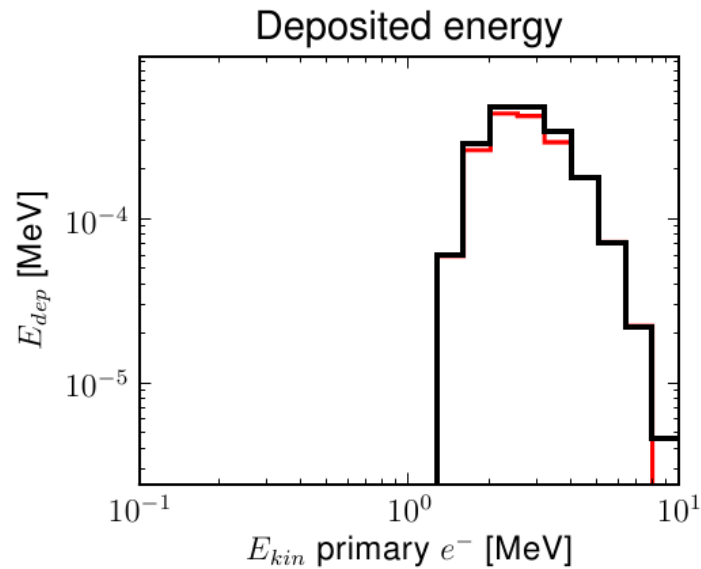
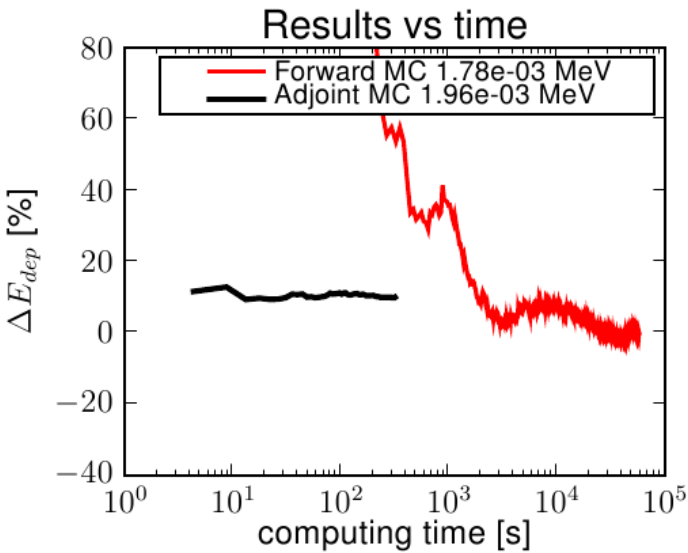


Tantalum plates  
0.5mm Thick

***External Spherical source  
Radius 10 cm  
Primary Particles e-  
Isotropic***

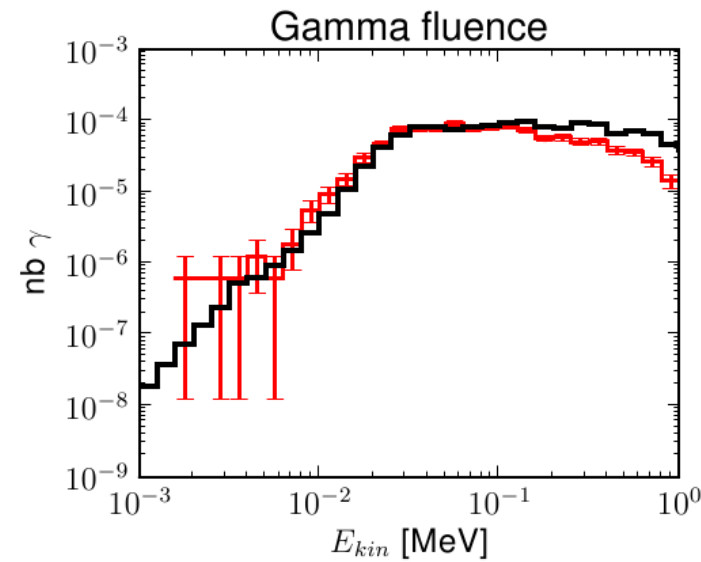
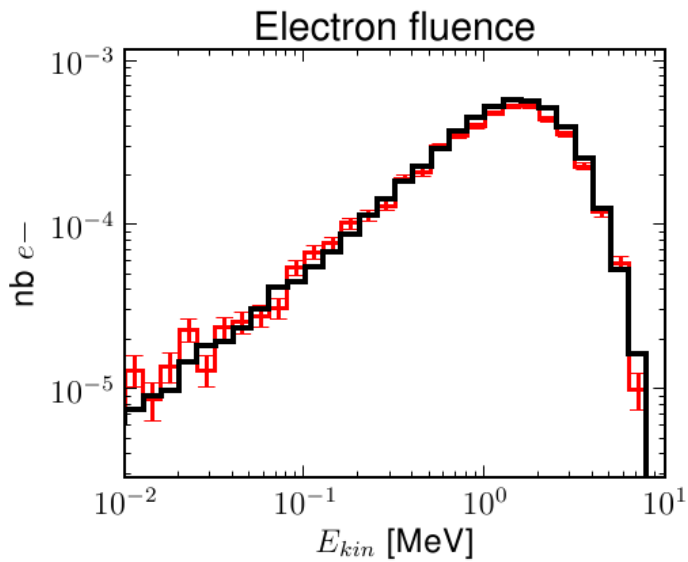


# Comparison Reverse/*Forward* MC simulation



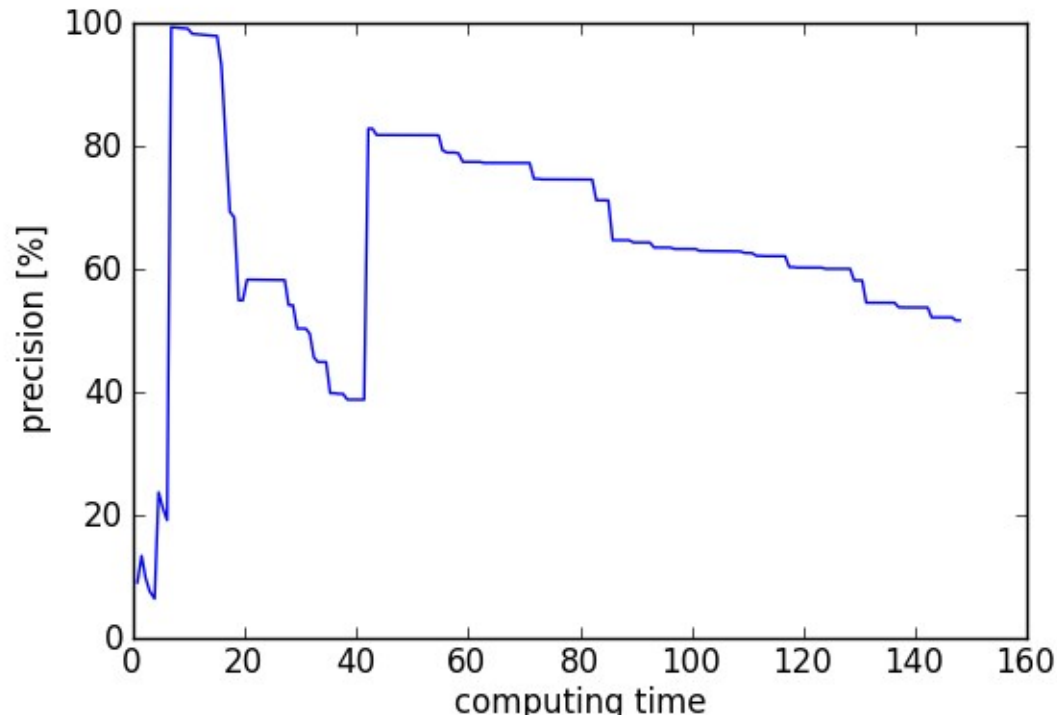
### Primary source

- Electrons
- [1 keV, 10 MeV]
- $\exp(-E/MeV)$



## But problems of G4RMC for some use cases

- Recently important discrepancies (50-100%) between G4 Forward and G4 Reverse MC have been reported for some use cases for Juice mission study
- Problem of convergence for computed dose within G4RMC for Ta shielding



- ESA sponsored study to understand these discrepancies and bring improvement to the code

# Recent modifications of the code

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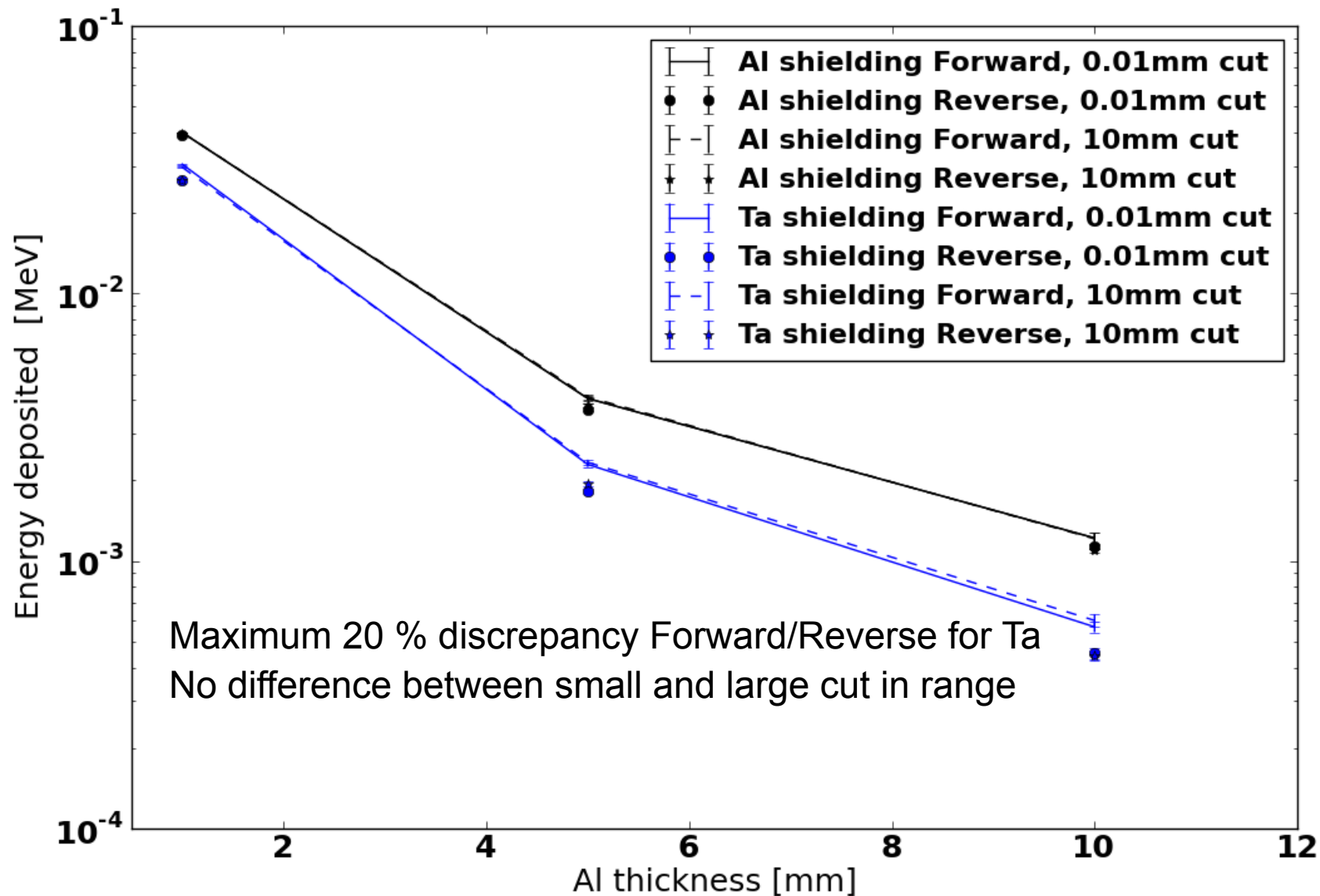
- New model of adjoint bremsstrahlung based on G4SeltzerBergerModel
- Correction of differential CS expression in reverse ionisation
- Fix problem of propagation of weight correction in successive along step actions

# New Tests

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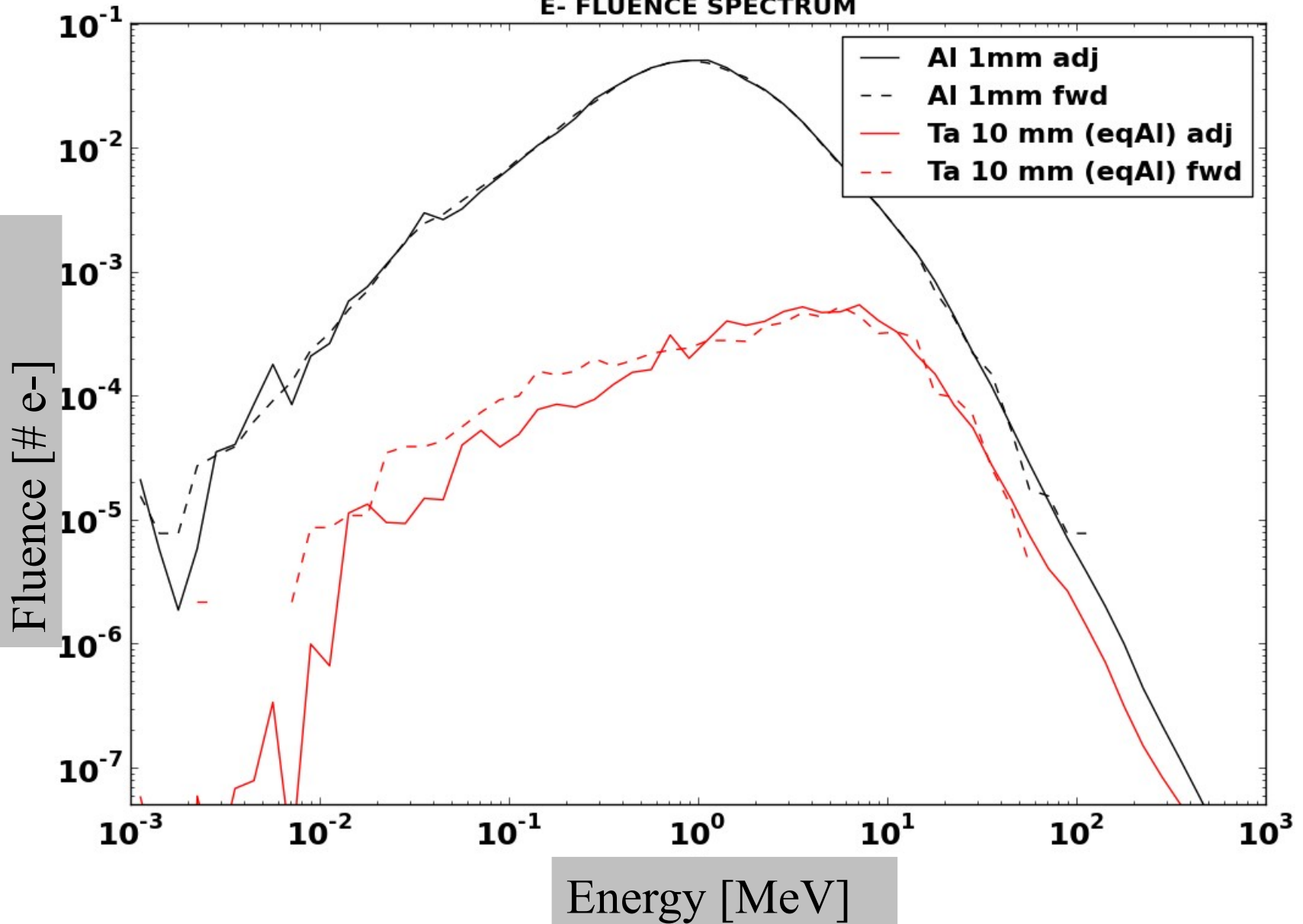
- Test with spherical shielding
  - Benchmarking of total dose simulation
  - Study of dependence of cut in range
  - Comparisons flux of secondary
- Study of problem of convergence in shielded box
- Test of production of secondary by Reverse processes:
  - Test sampling of reverse secondary
  - Test correction of weight in post step do it
- Test with complex geometry ongoing
- For all tests a JUICE e- spectrum is used as given in ESA specification document (normalisation to  $1/\text{cm}^2$ )

# Spherical shielding benchmarking with new code

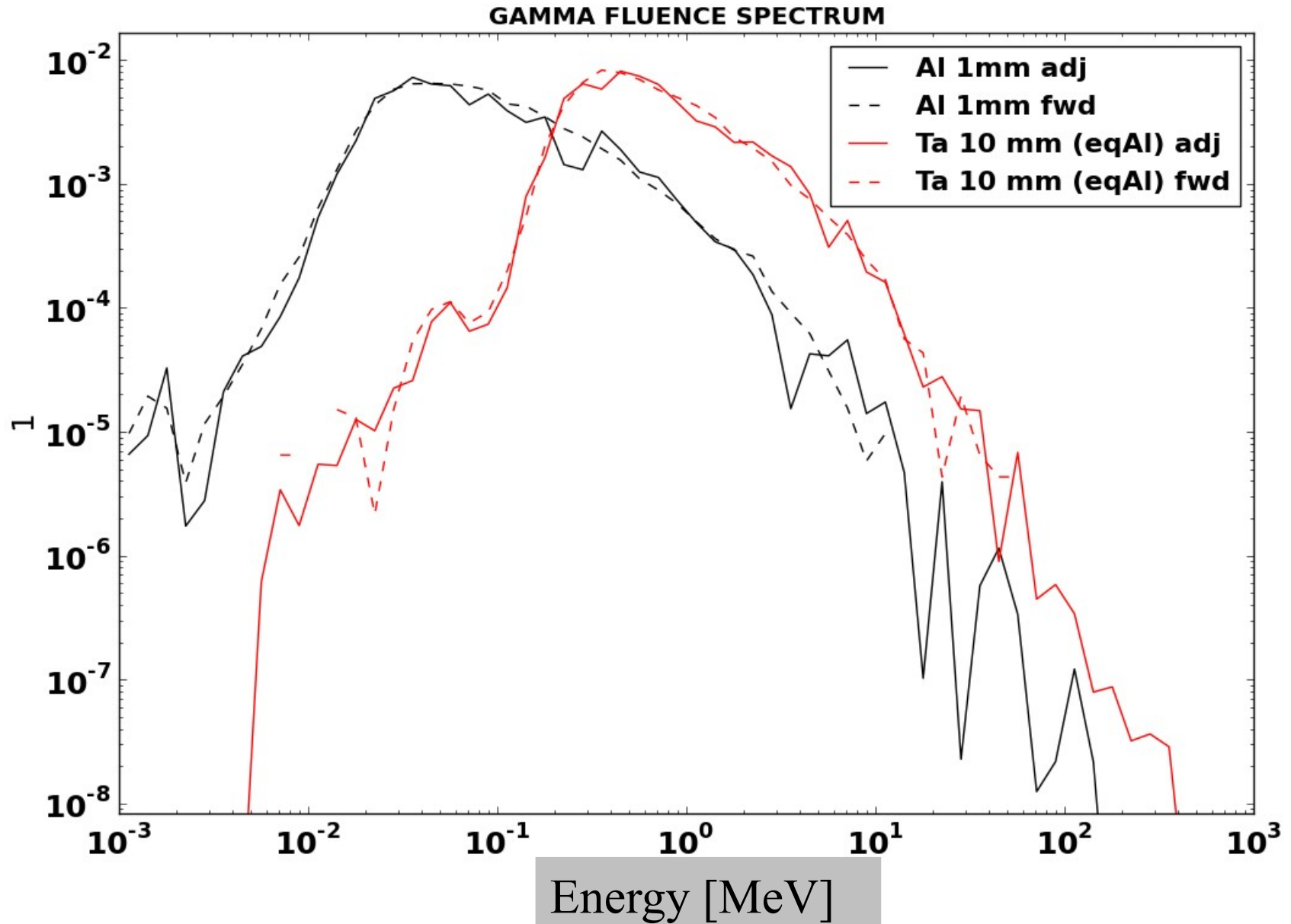


# Comparisons e- fluxes

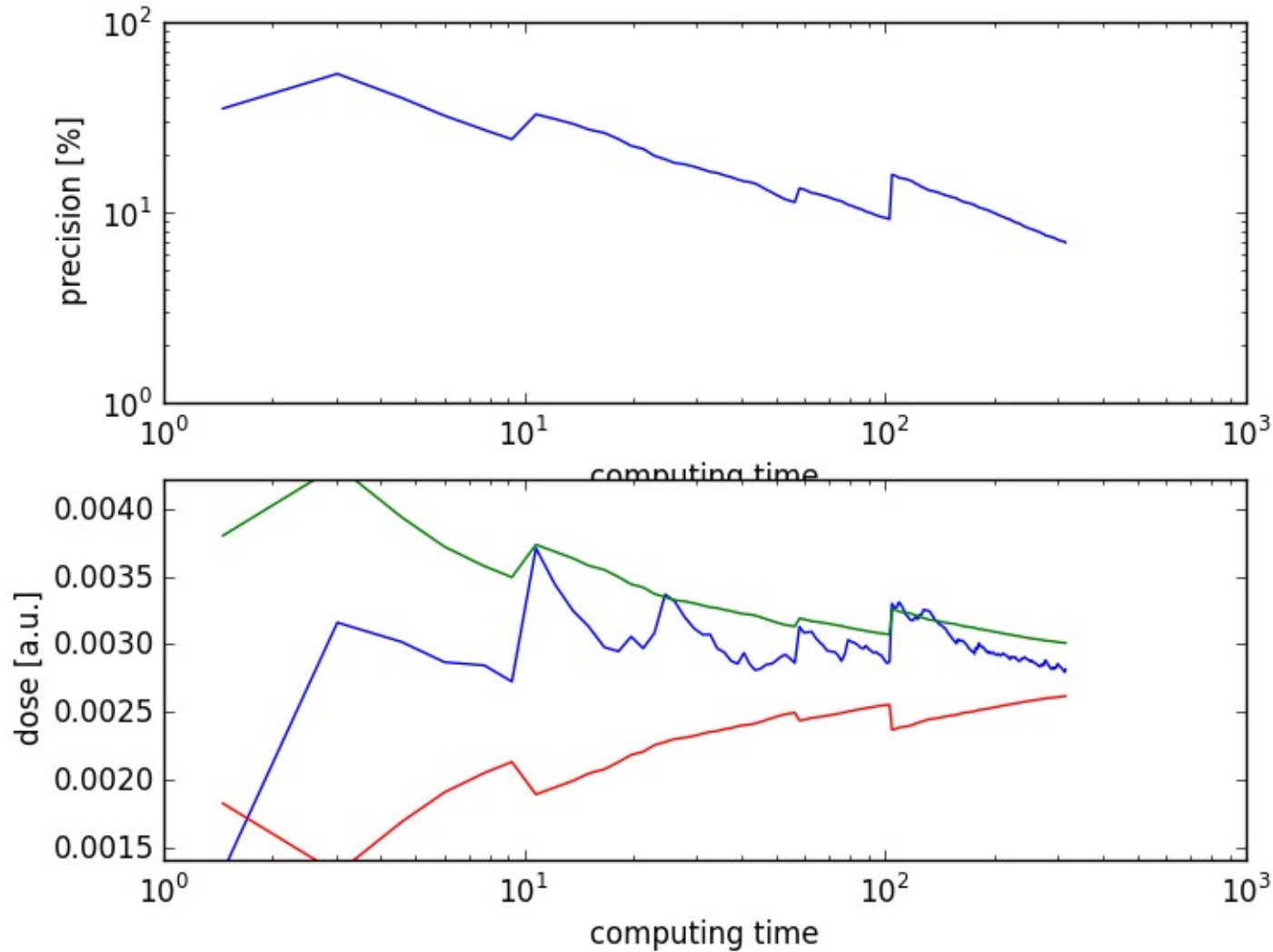
E- FLUENCE SPECTRUM



# Comparisons gamma fluxes



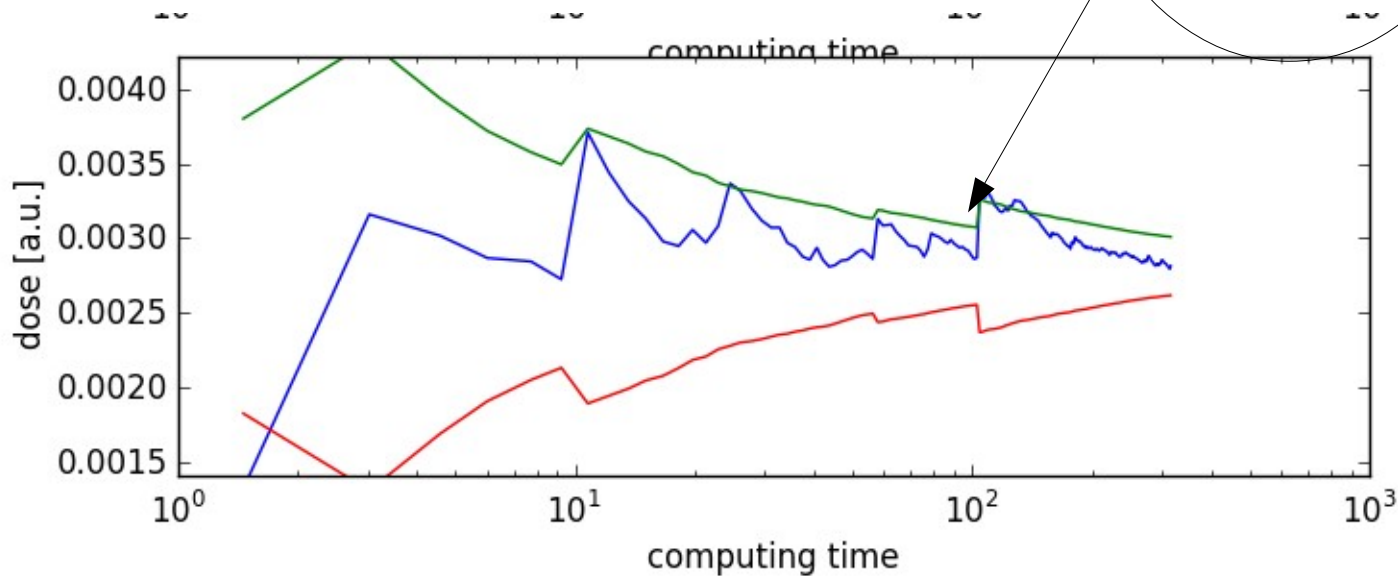
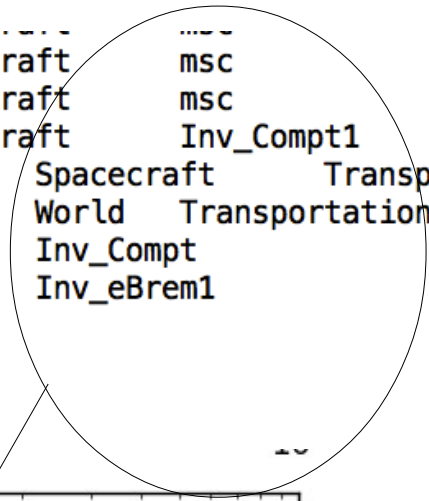
# Dose in tiny component in box with Ta shielding





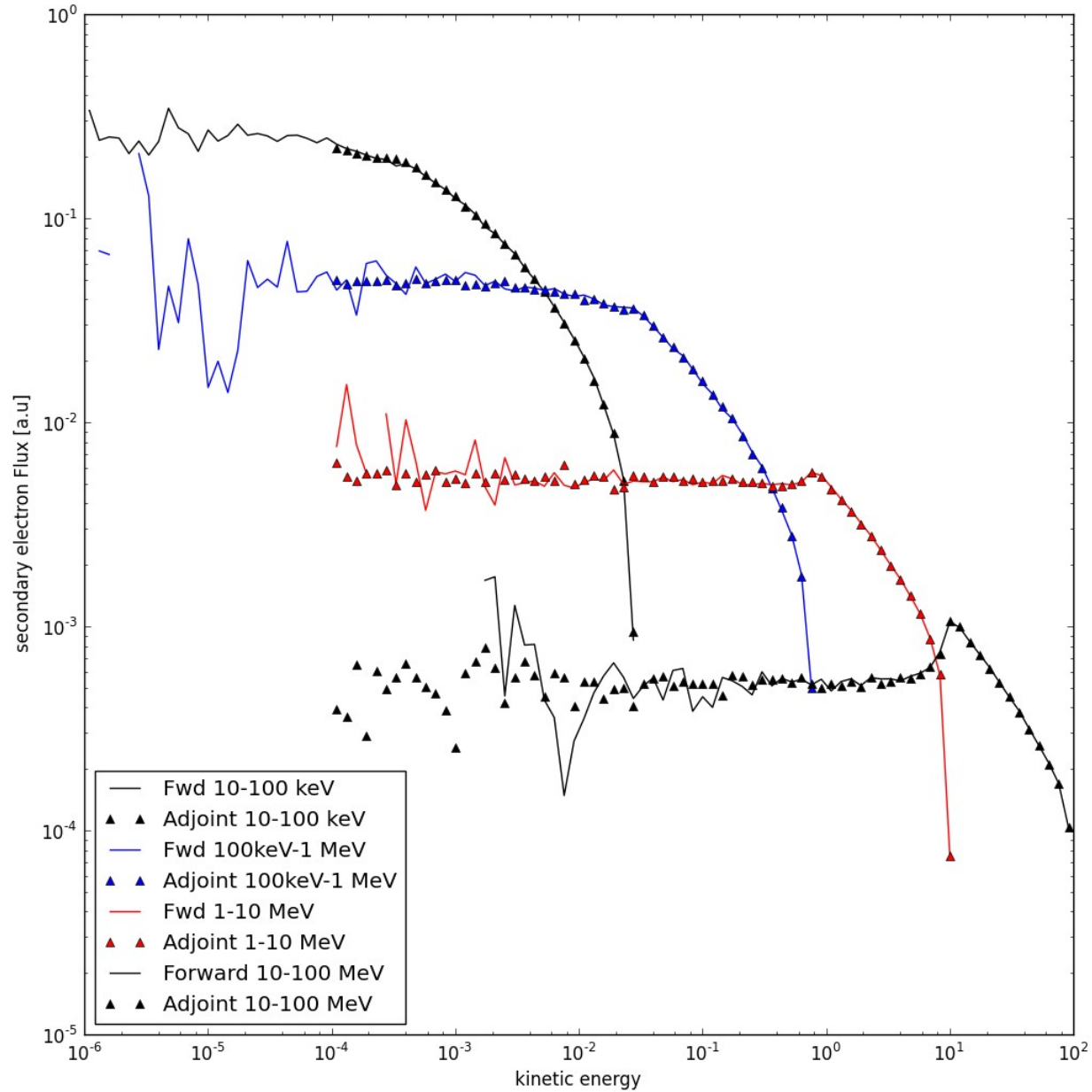
# Analysis of adjoint track with peak contribution to the dose

adj_e-	0.265694	1.64239	0.106786	Spacecraft	msc
adj_e-	0.267789	1.63702	0.111008	Spacecraft	msc
adj_e-	0.270643	1.53869	0.115198	Spacecraft	Inv_Compt1
adj_gamma	0.481096	1.53869	0.126432	Spacecraft	Transportation
adj_gamma	0.481096	1.53869	0.126432	World	Transportation
adj_gamma	1.0649	13.9185	2.44163	Spacecraft	Inv_Compt
adj_gamma	1.0649	128.866	3.66559	Spacecraft	Inv_eBrem1
adj_e-	1.28927	128.202	3.77692	Spacecraft	msc
adj_e-	1.33573	128.014	3.84738	Spacecraft	msc

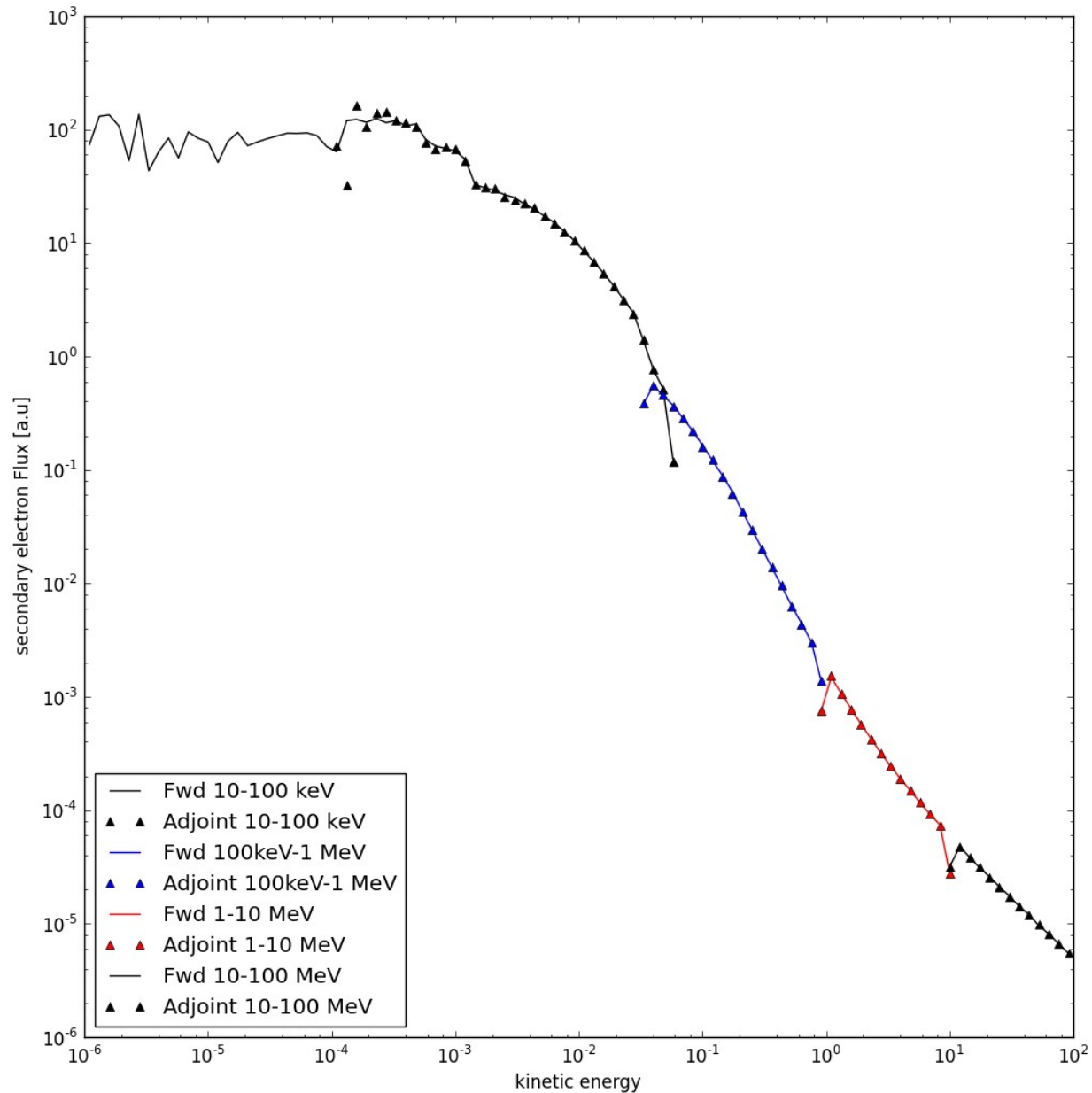


Combination of Reverse Compton or Photo-electric with Reverse Brem

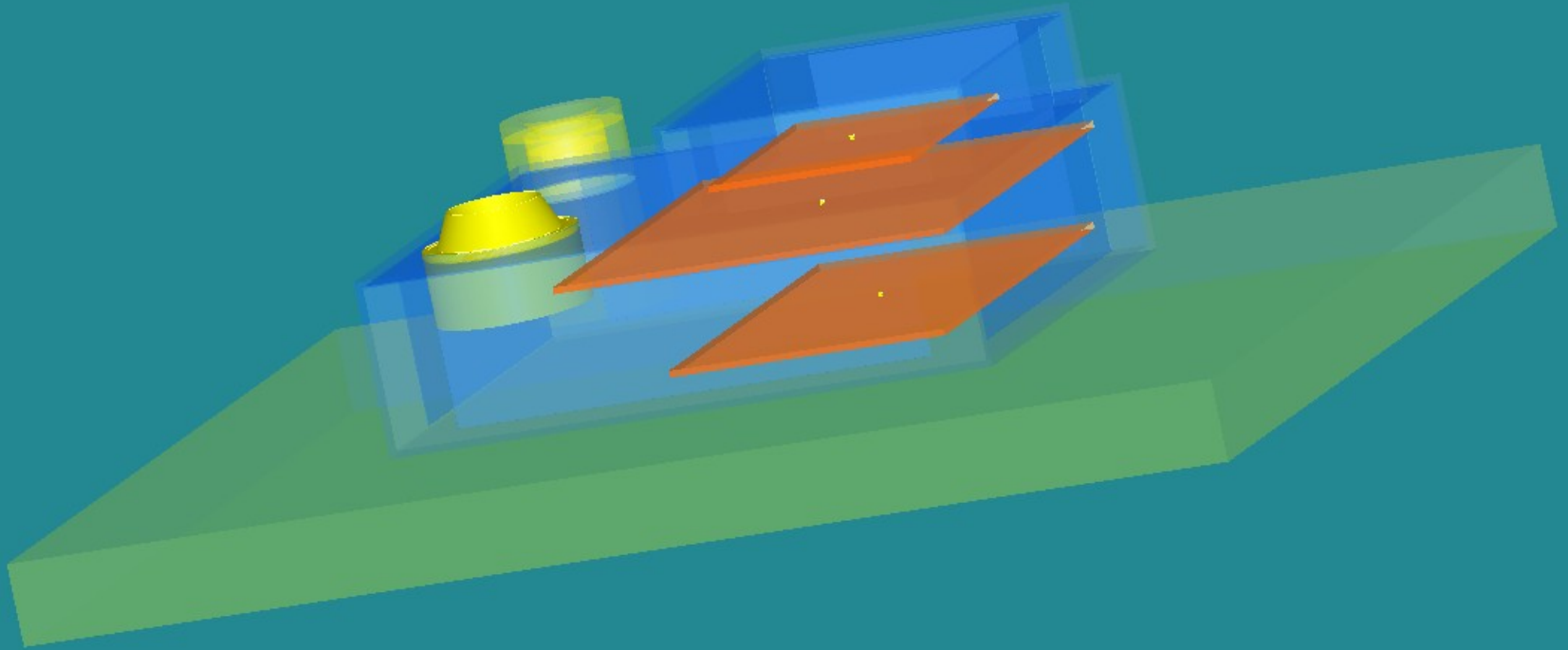
# Test of PostStepDolt for Reverse Compton



# Test of PostStepDolt for Reverse Photo Electric



# Test with NGRM geometry started



## Test of full simulations for 3D geometry

- Parameterized layered housing
- Switch on/off some physical models
- Comparisons of dose and e-, gamma flux on the sensitive volume
- Juice primary spectrum

# Future work / ideas

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- Continue tests with complex geometry
- Increase statistic of some reverse processes
- Implement an automatic technique to remove peak in tallies in order to increase convergence speed
- Better multiple scattering ??? Challenging!