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Geant4 Reverse MC

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OUTLINE

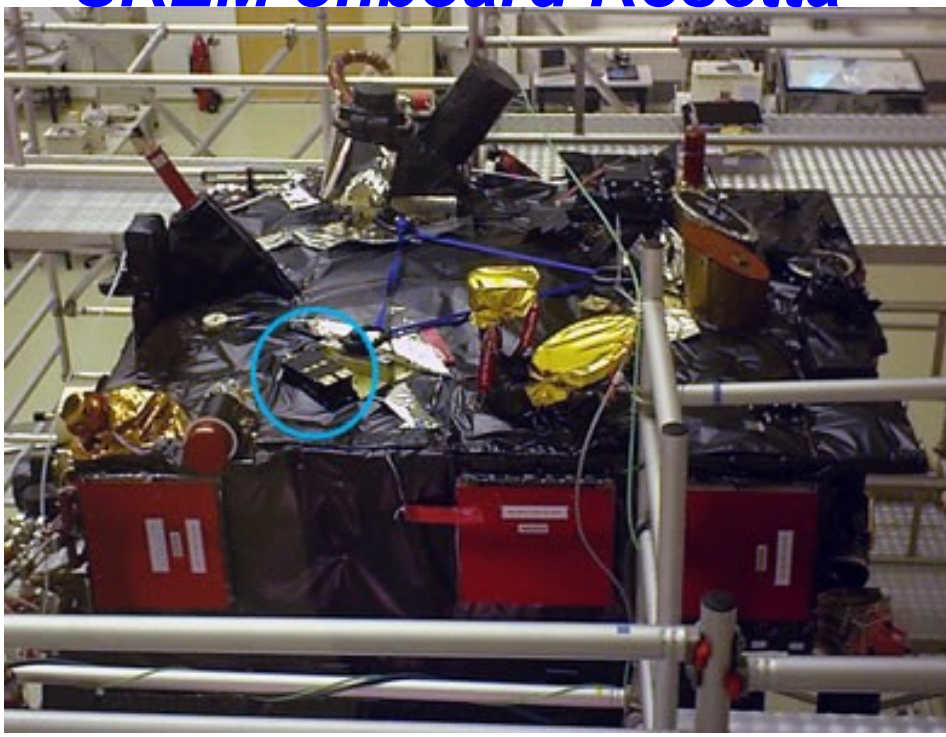
- Reverse Monte Carlo in Geant4 and GRAS
- Some problems for Juice mission simulation with G4RMC
- Some Improvements of the code
- New tests

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

SREM onboard Rosetta

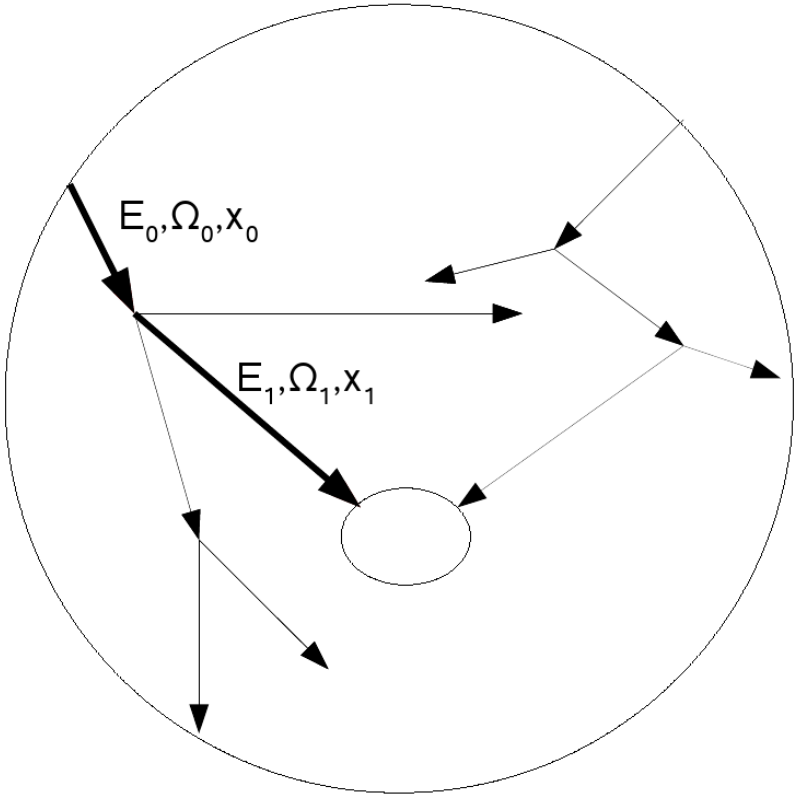


- Reverse Monte Carlo is advantageous when:
  - The region where radiation analysis is computed is small compared to the rest of the geometry
  - The external source of primary particles is extended

It is typically the case in space radiation effect modelling

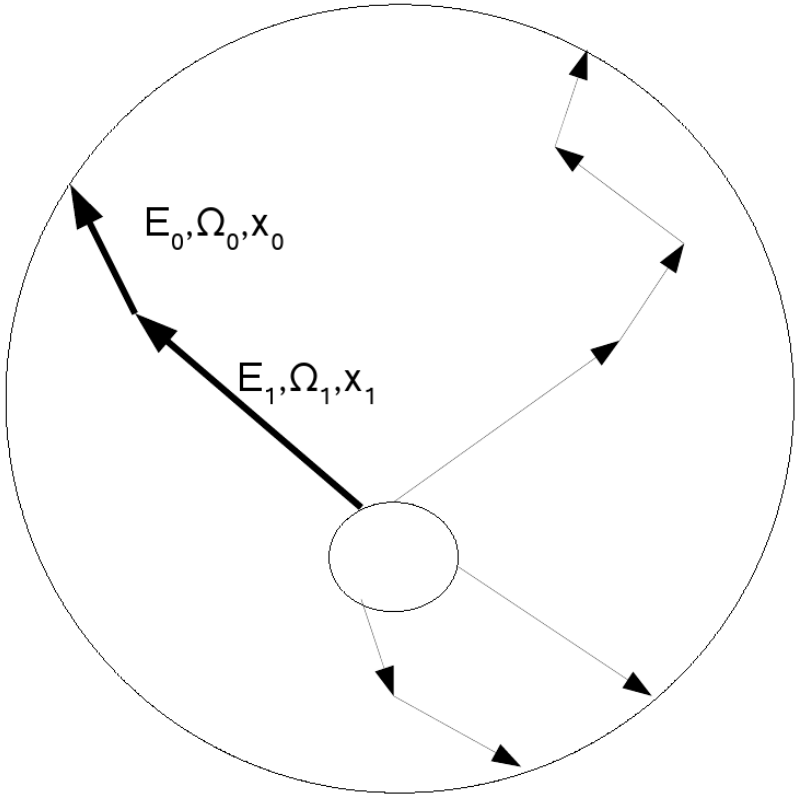
Reverse Monte Carlo method

Forward MC Mode



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

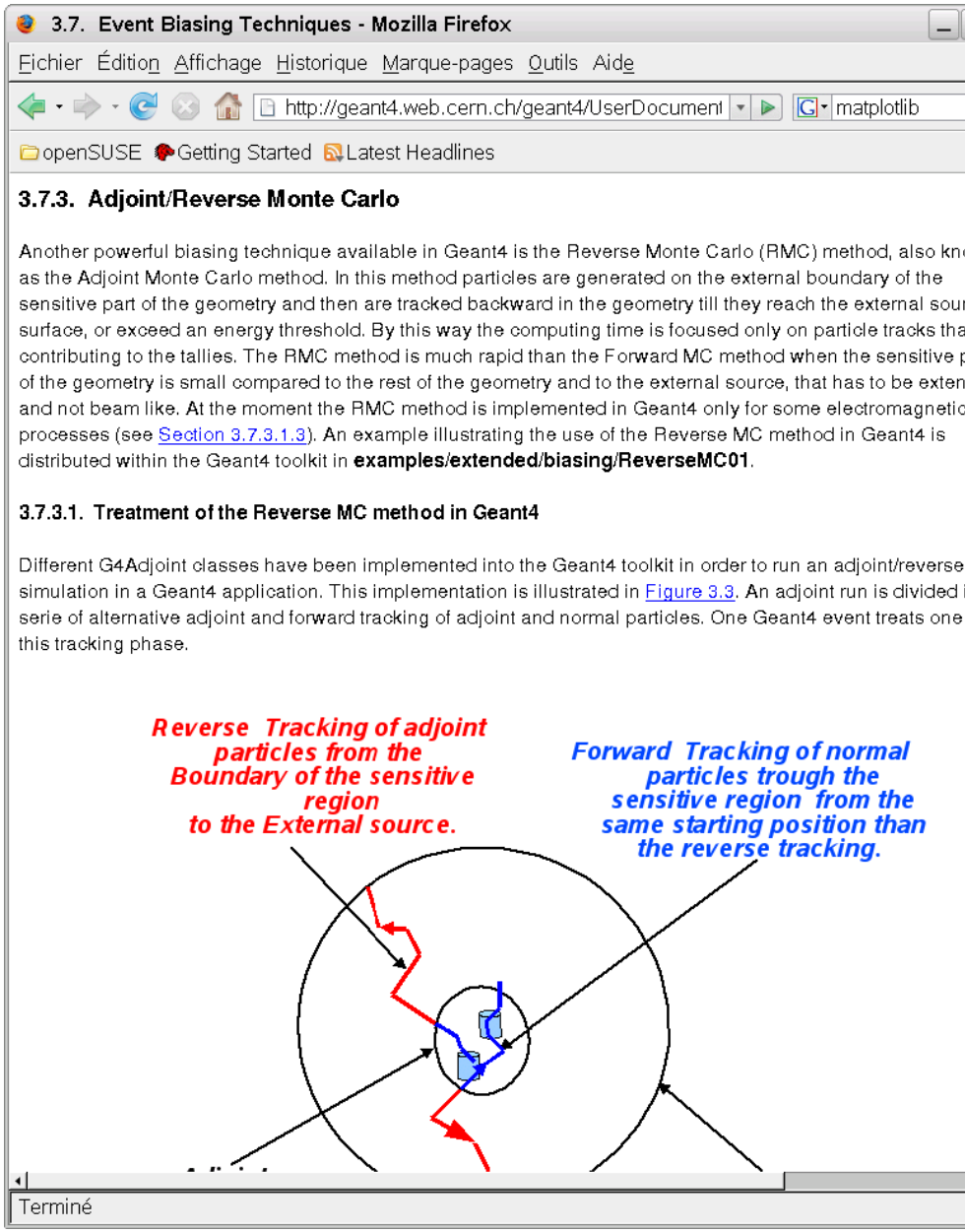
Adjoint/Reverse MC Mode



- 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!!!

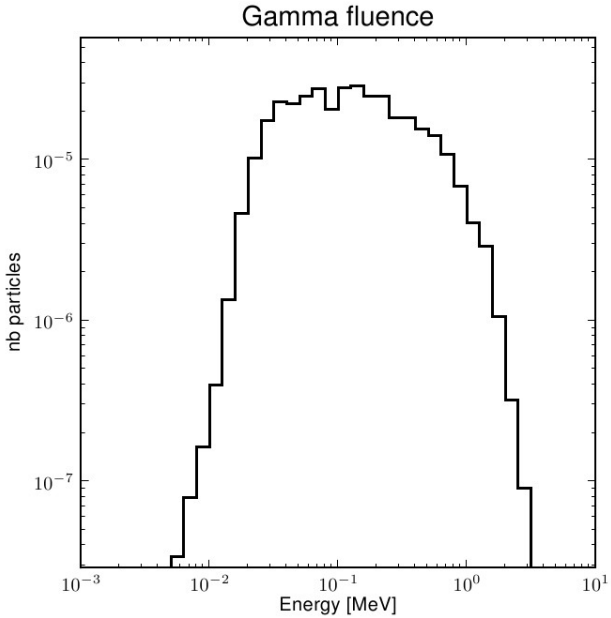
RMC in Geant4 since the version 4.9.3

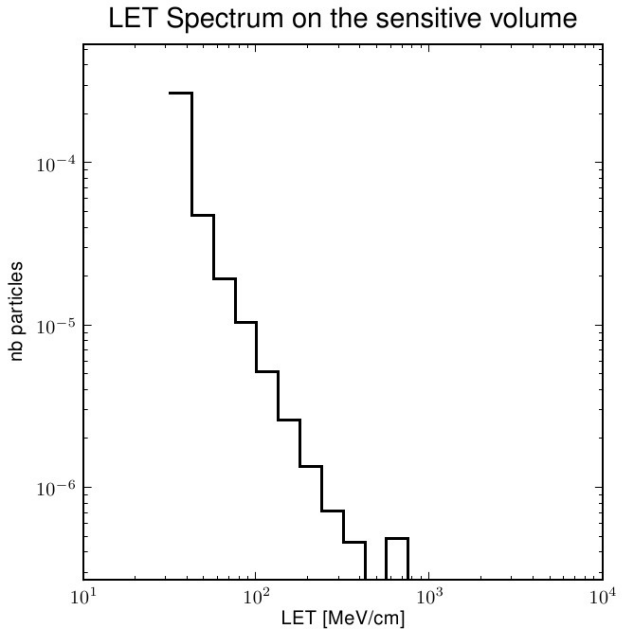
- Base adjoint classes and reverse processes distributed in the G4 toolkit
- Extended/biasing G4 example to illustrate the use of the RMC method in Geant4
- Reverse processes implemented
  - e-, p Ionisation
  - Bremsstrahlung
  - Compton
  - Photo electric effect

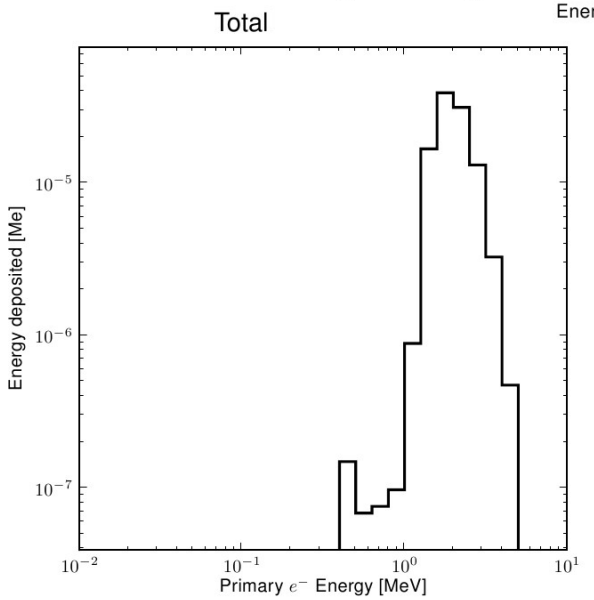


Reverse MC is implemented in GRAS

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



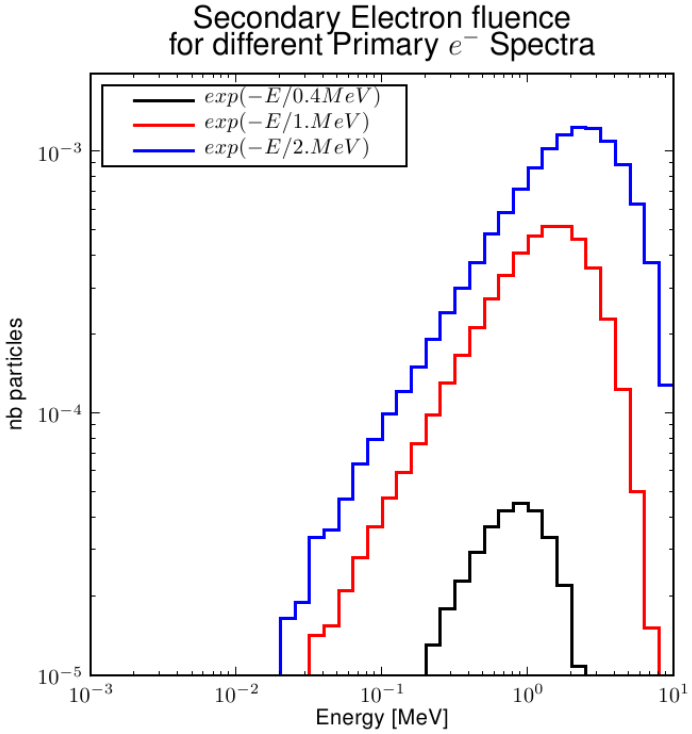




Added fonctionalities of GRAS RMC compare to GRAS forward

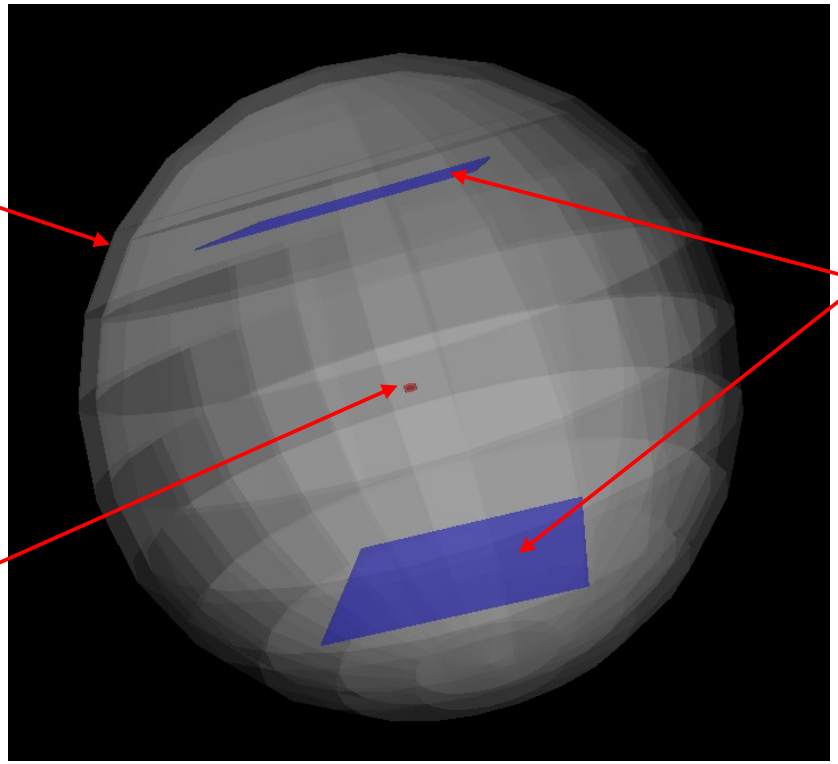
- Direct normalisation
- Different primary particles and spectra can be specified
- File registering the convergence of the simulation results
- Automatic stop after a “user defined” precision of the calculation is reached

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

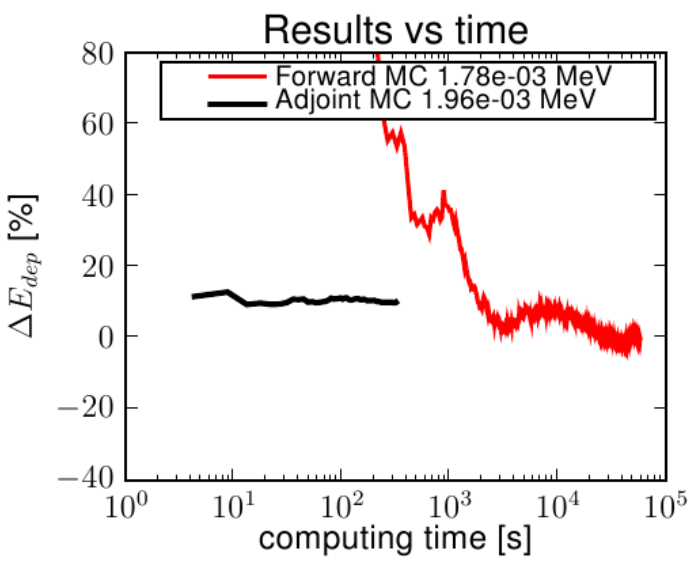


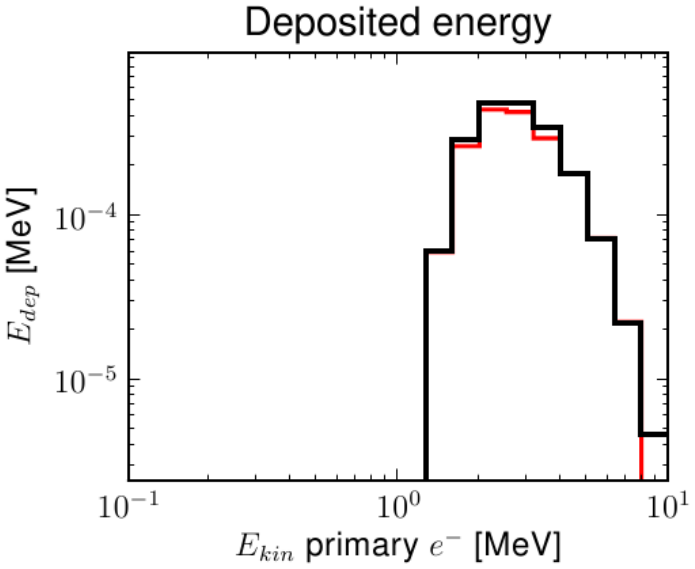
Tantalum plates
0.5mm Thick

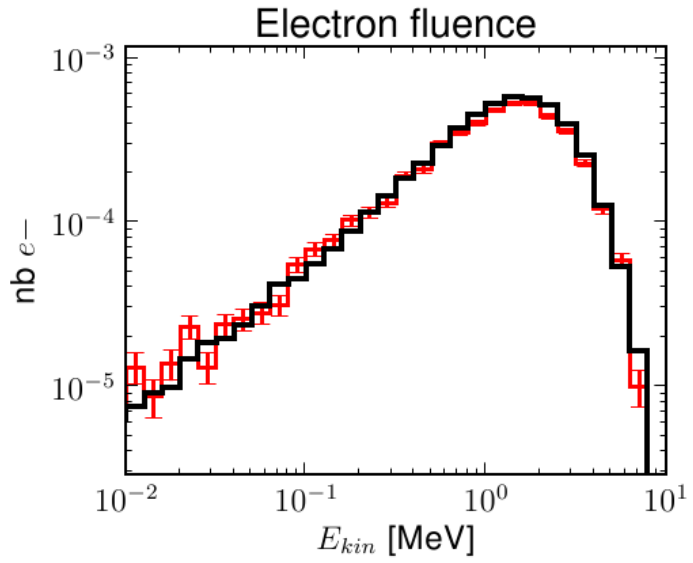
Small Si Sensitive
Cylinder
Radius 1mm
Height 1 mm

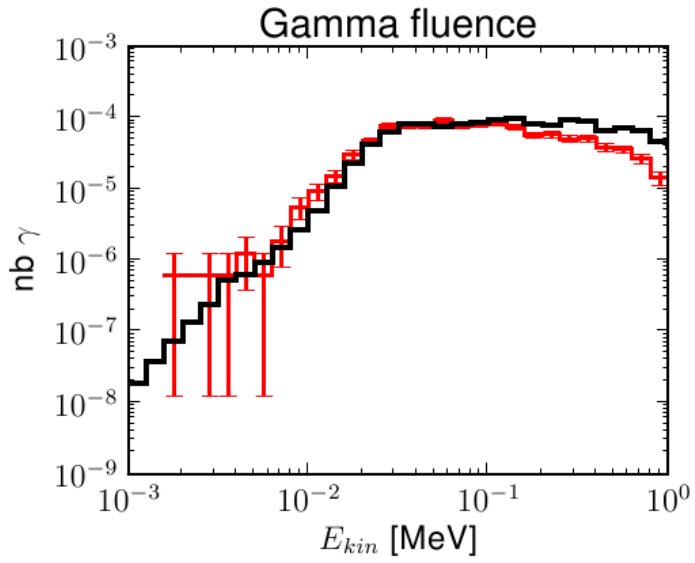
External Spherical source
Radius 10 cm
Primary Particles e-
Isotropic

Comparison Reverse/Forward MC simulation









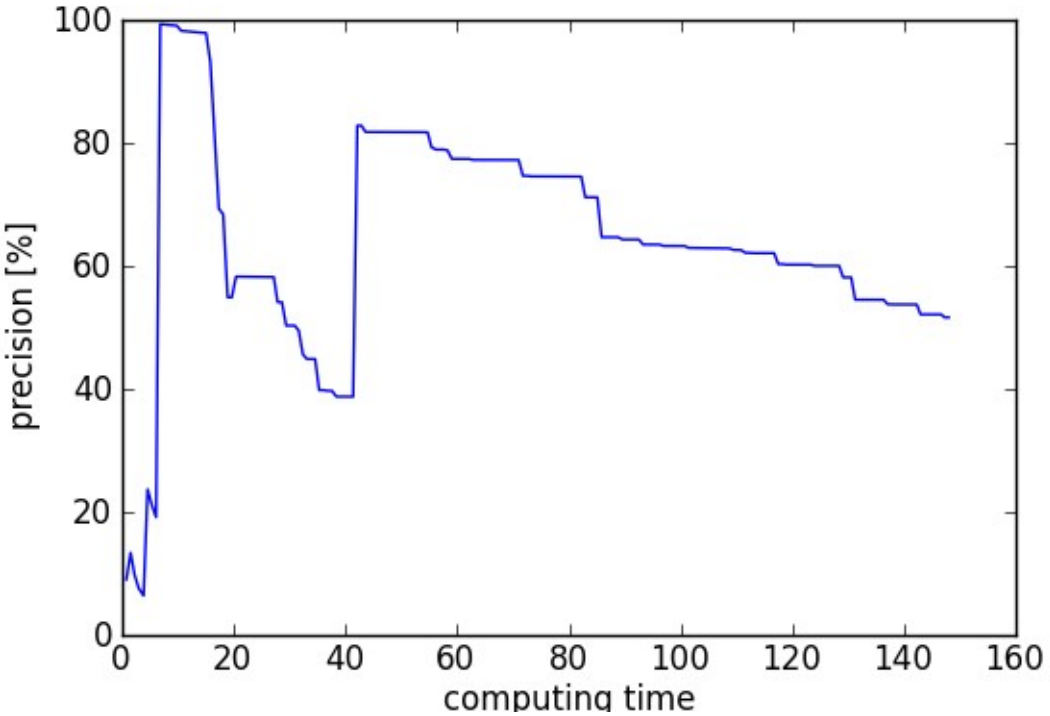
Primary source

- 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

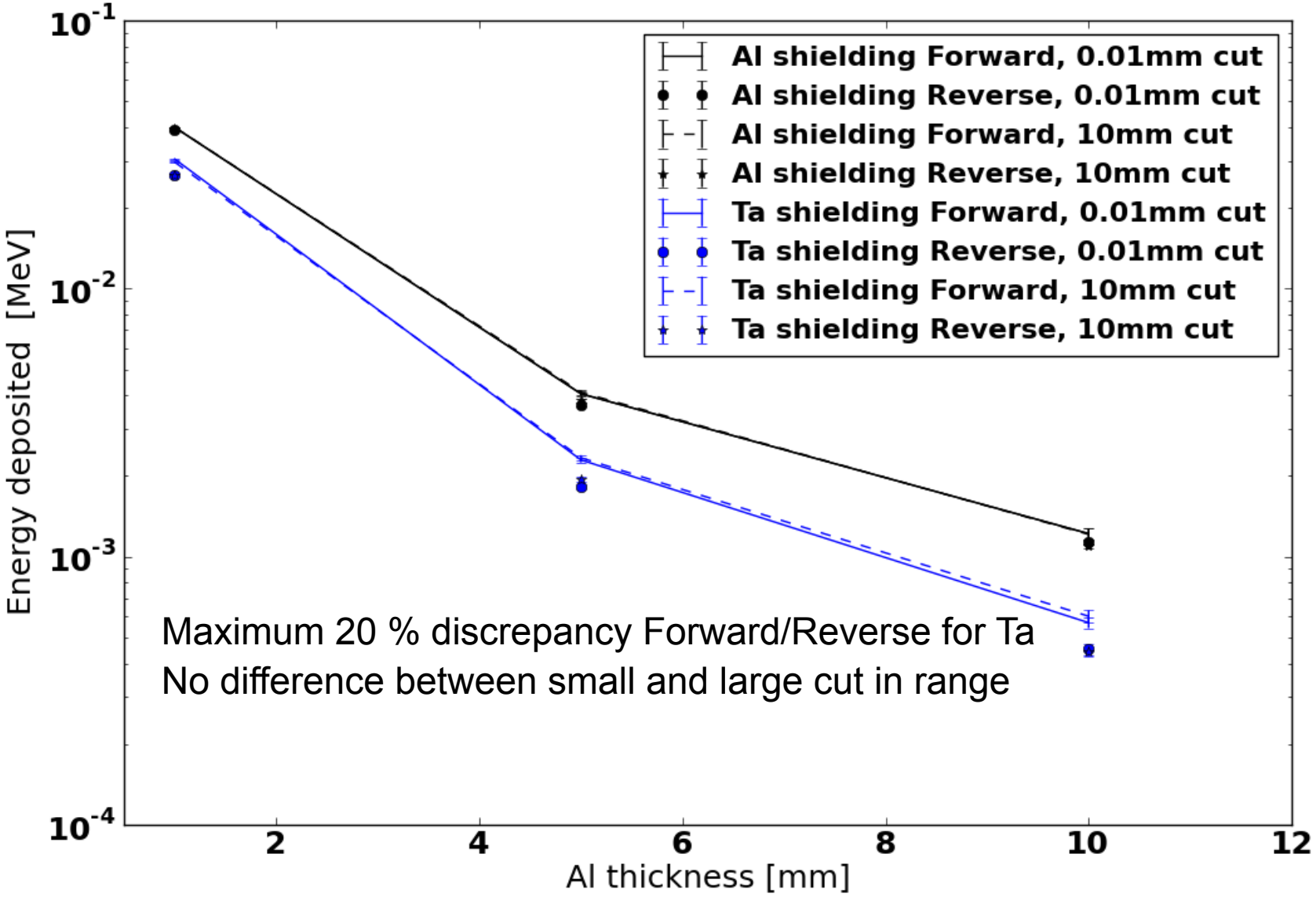
Recent modifications of the code

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

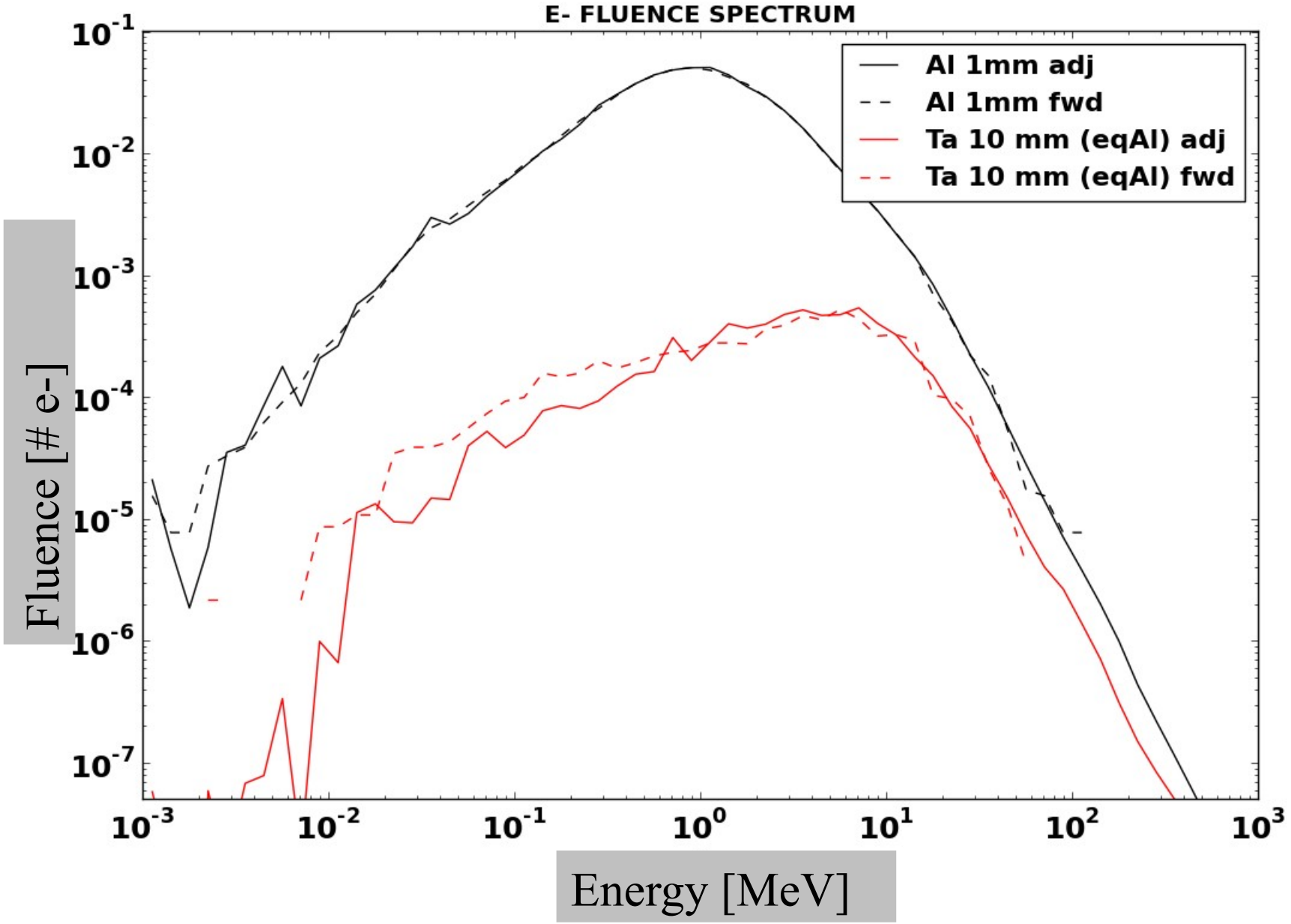
New Tests

- 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 $1/cm^2$

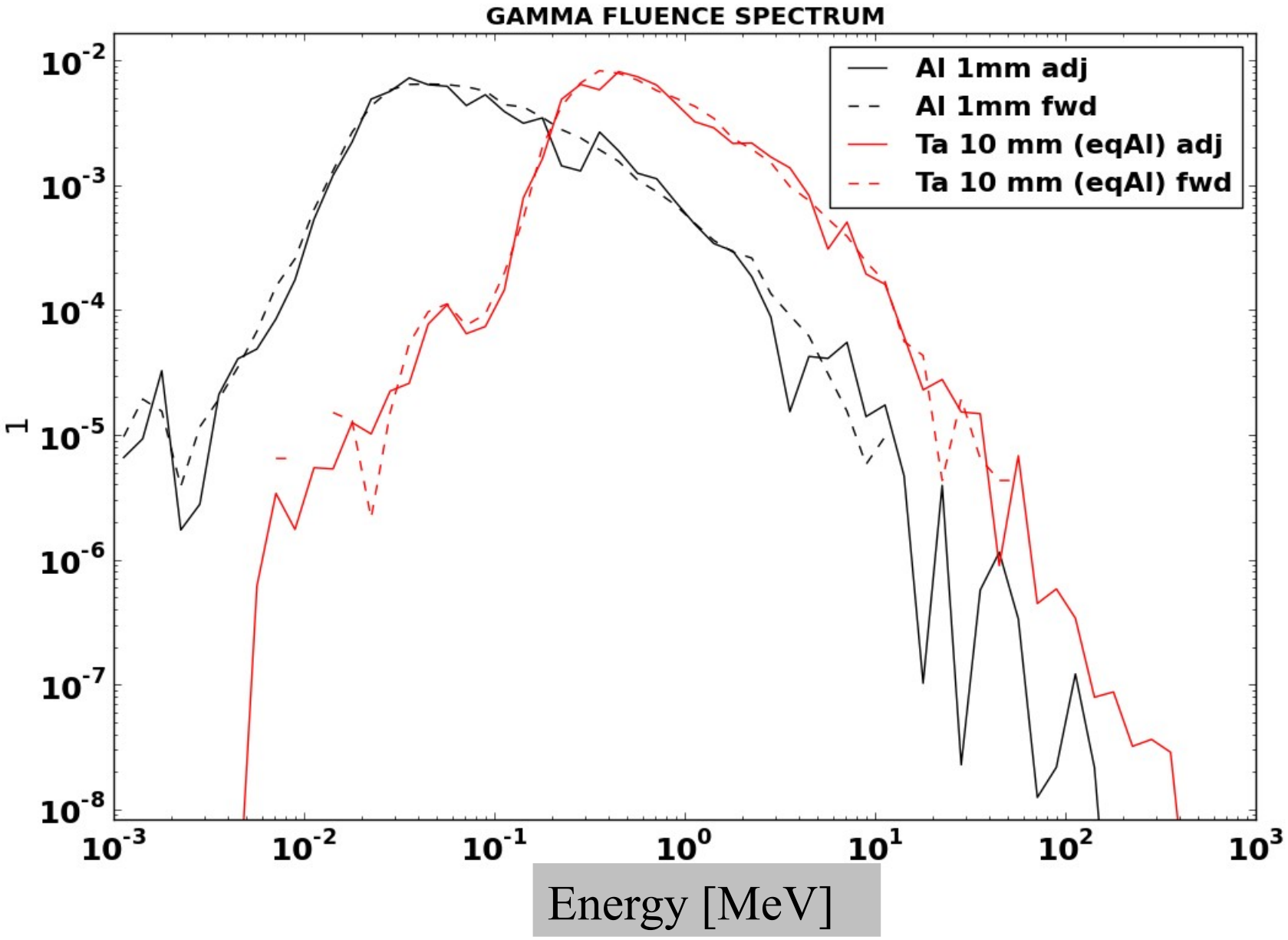
Spherical shielding benchmarking with new code



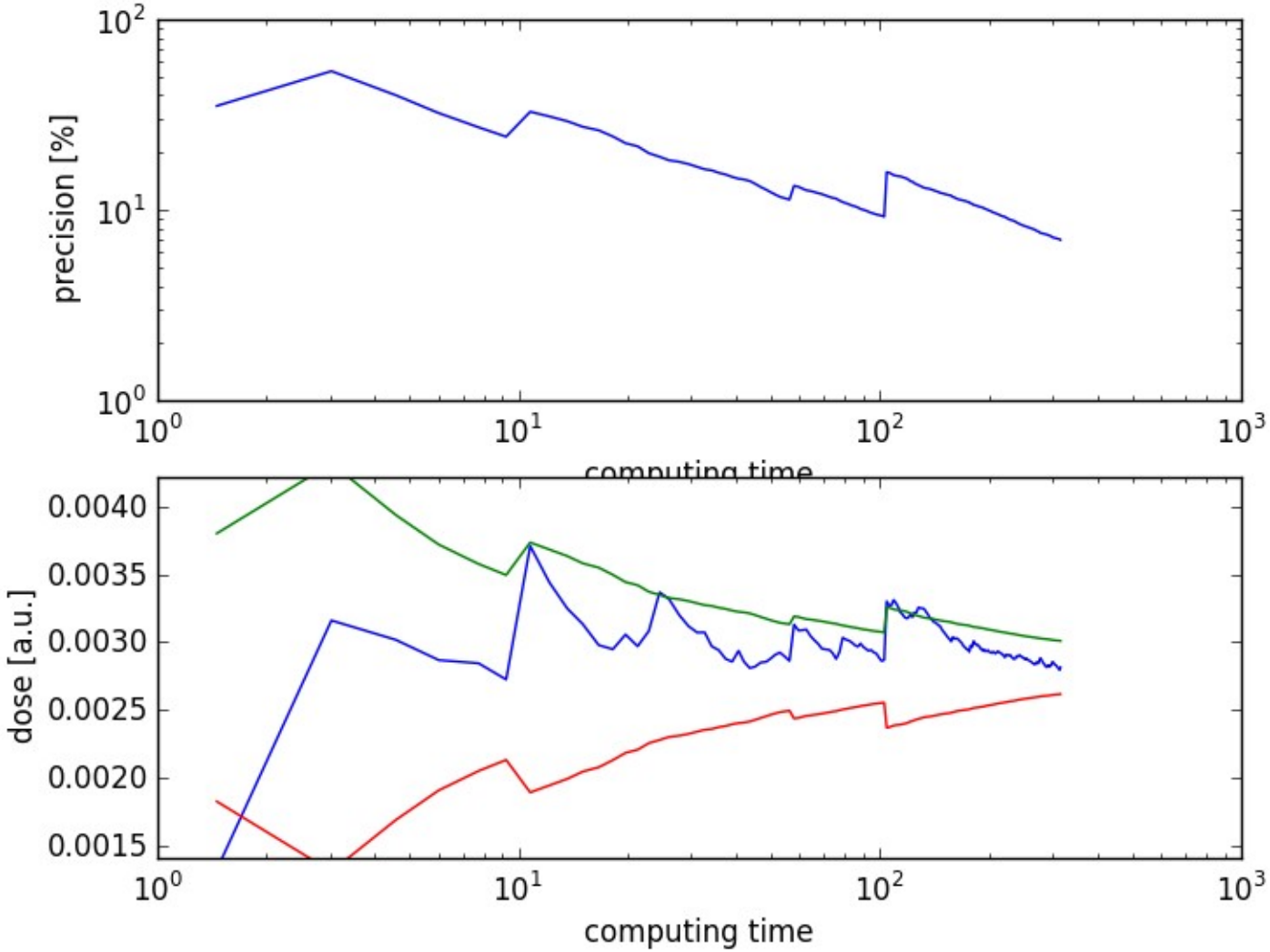
Comparisons e- fluxes



Comparisons gamma fluxes

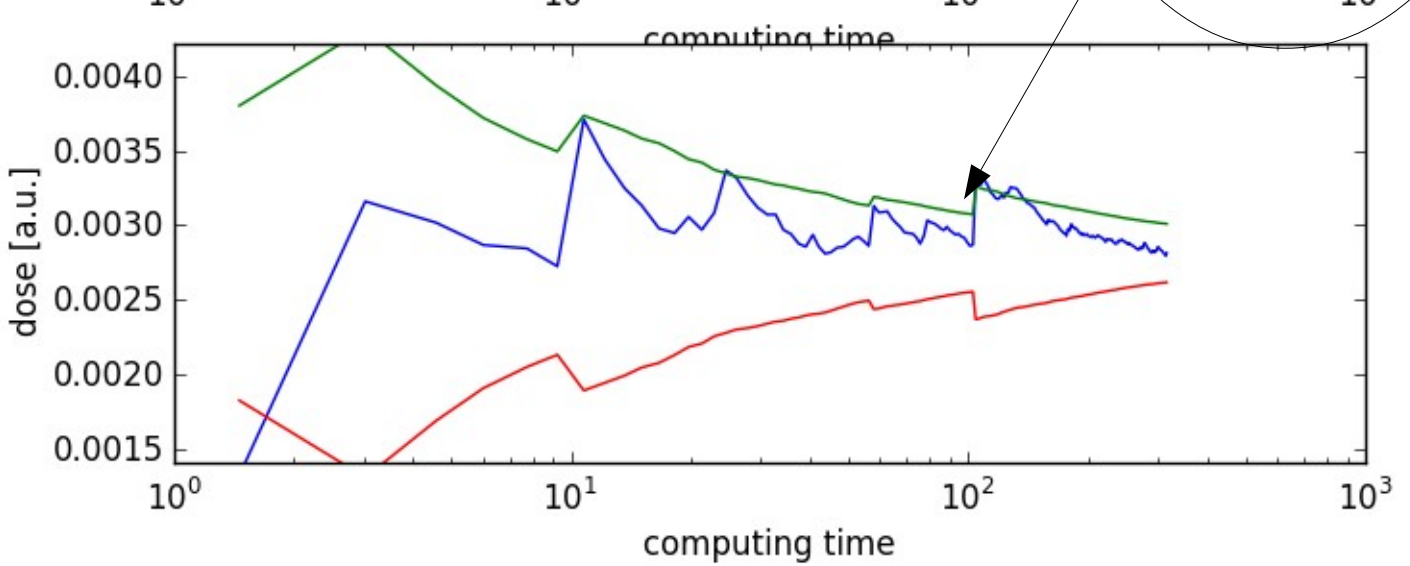


Dose in tiny component in box with Ta shielding



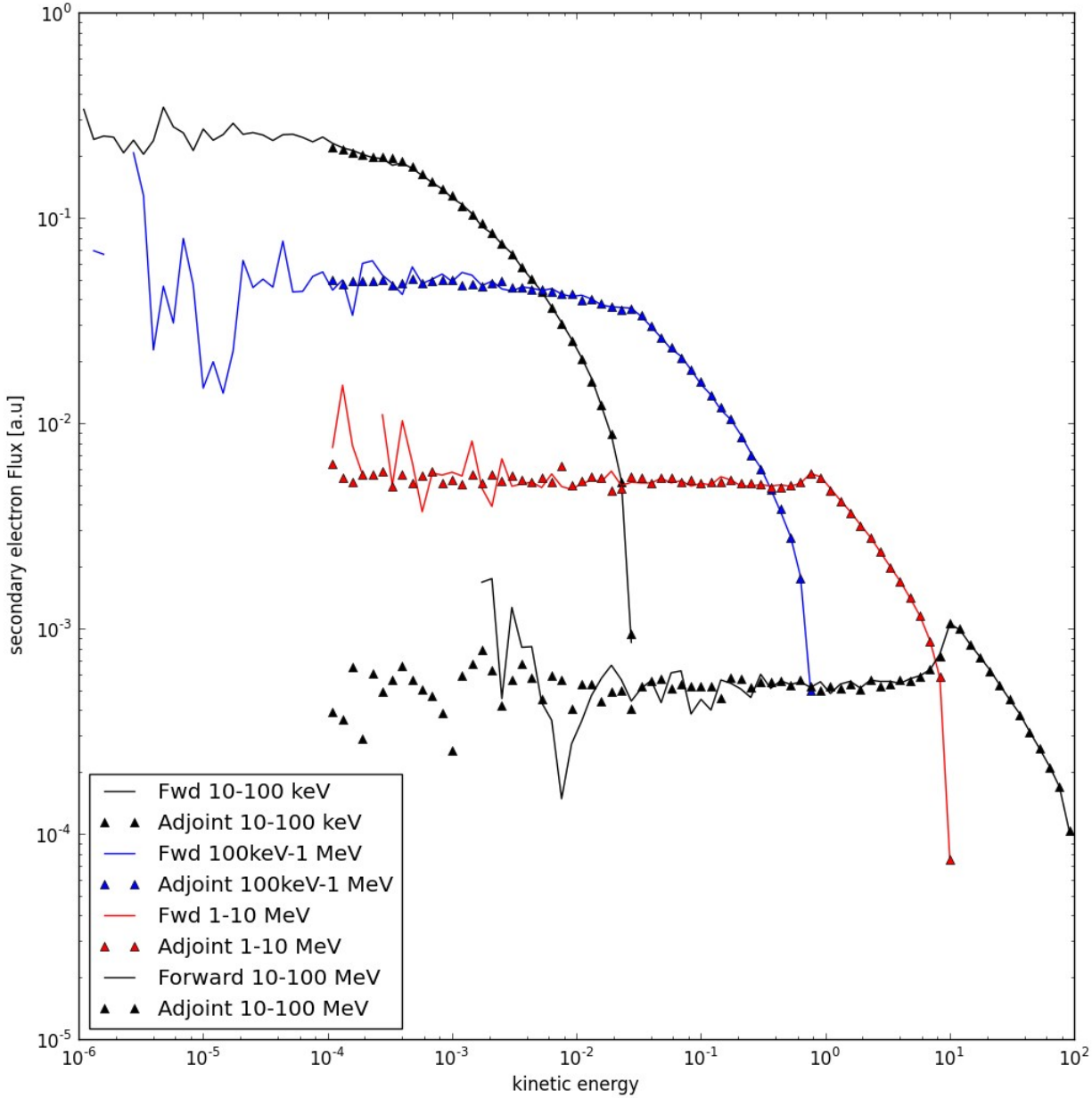
Analysis of adjoint track with peak contribution to the dose

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

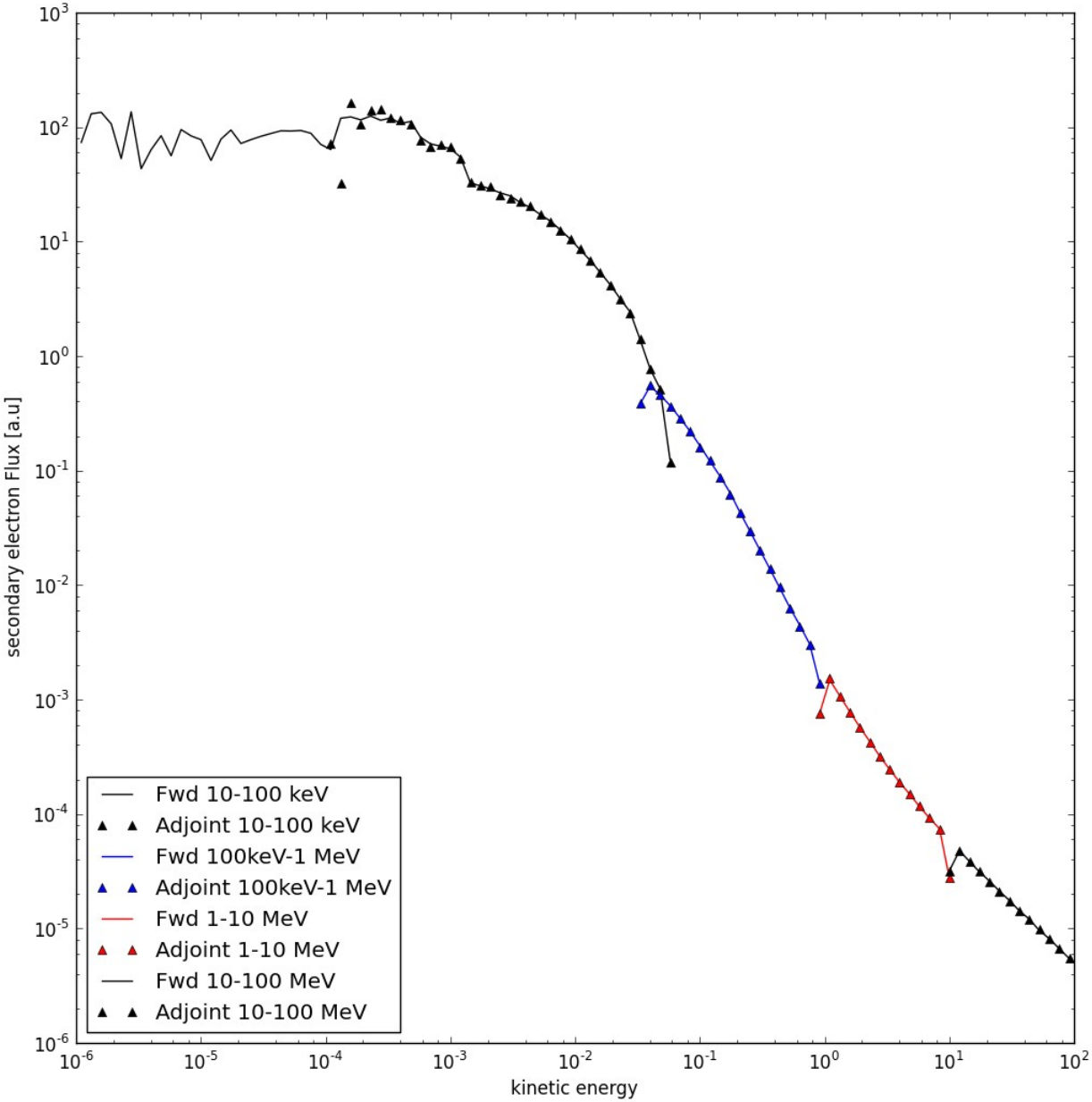


Combination of Reverse Compton or Photo-electric with Reverse Brem

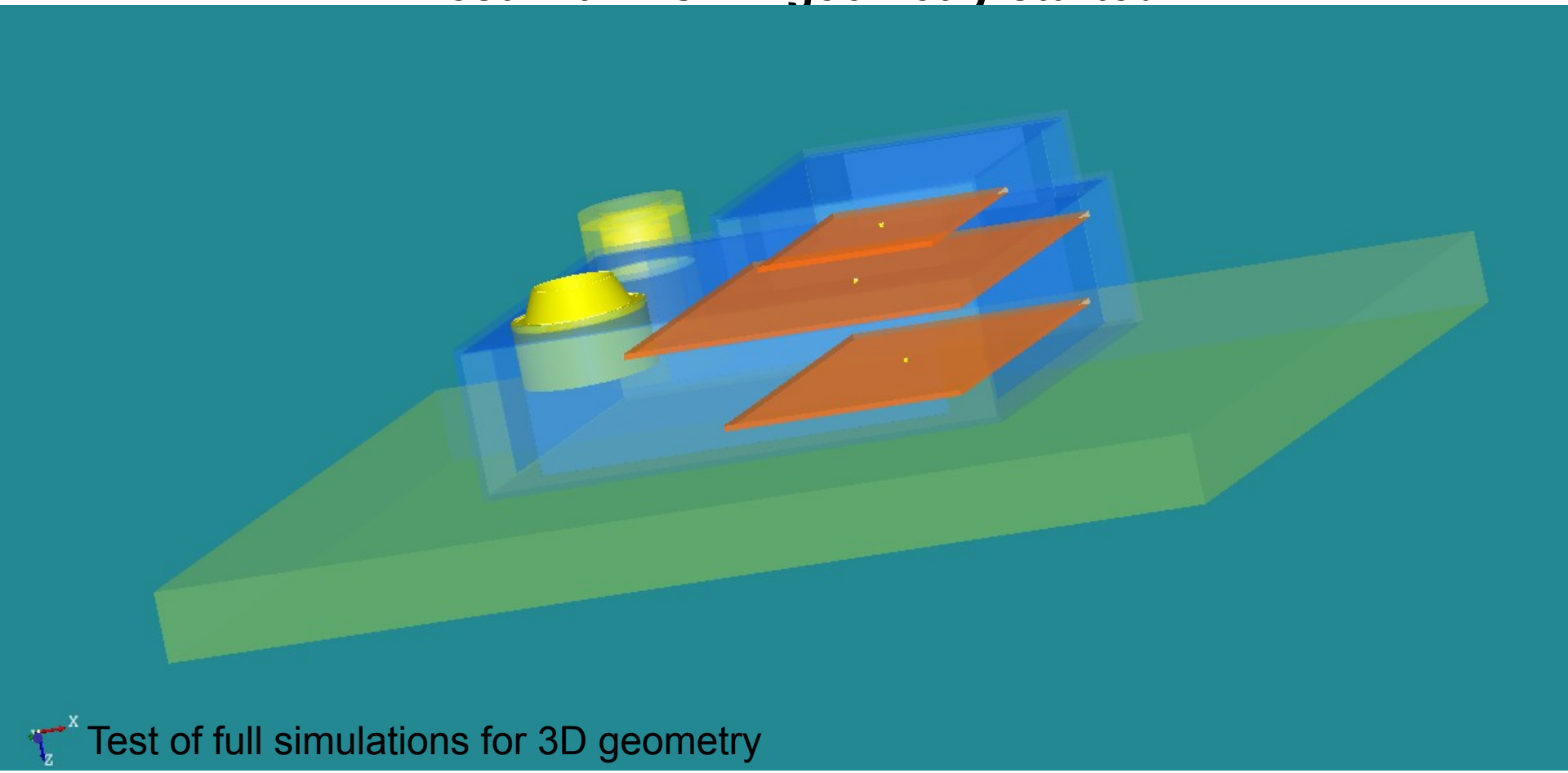
Test of PostStepDoIt for Reverse Compton



Test of PostStepDoIt 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

- 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!