GEANT4 simulations of detectors

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A quick outline……

I will not give you an introduction of the GEANT4 full physics, but just an idea on what you can do with it…

1) SHORT introduction to the MONTECARLO method in physics and General architecture of GEANT4
2) Practical architecture of GEANT4
3) OK, but in practice what should I do?
4) …… and what can I simulate?
5) Simulation and reality: what is better?
6) Some FAQ from neutron-lovers

«The road to the knowledge (of the full physics of GEANT4) is as long as 10000 lives…»

The MONTECARLO method in physics

Problem: radiation interaction with matter is not always «deterministic».

For instance, you do not know what a single, specific neutron will do when interacting in your sample/detector.

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- *Coherent elastic scattering*
- *Coherent inelastic scattering*
- *Incoherent scattering*
- *Resonant absorption*
- *Off-resonance absorption*
- *Nuclear reactions*

All of these interactions have their own cross-section, i. e. **PROBABILITY** to occour

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The MONTECARLO method in physics

Transport of radiation (particles) in matter

Local rules of particles transport are expressed as probability distributions which describe the **step size** of particle movement and interactions.

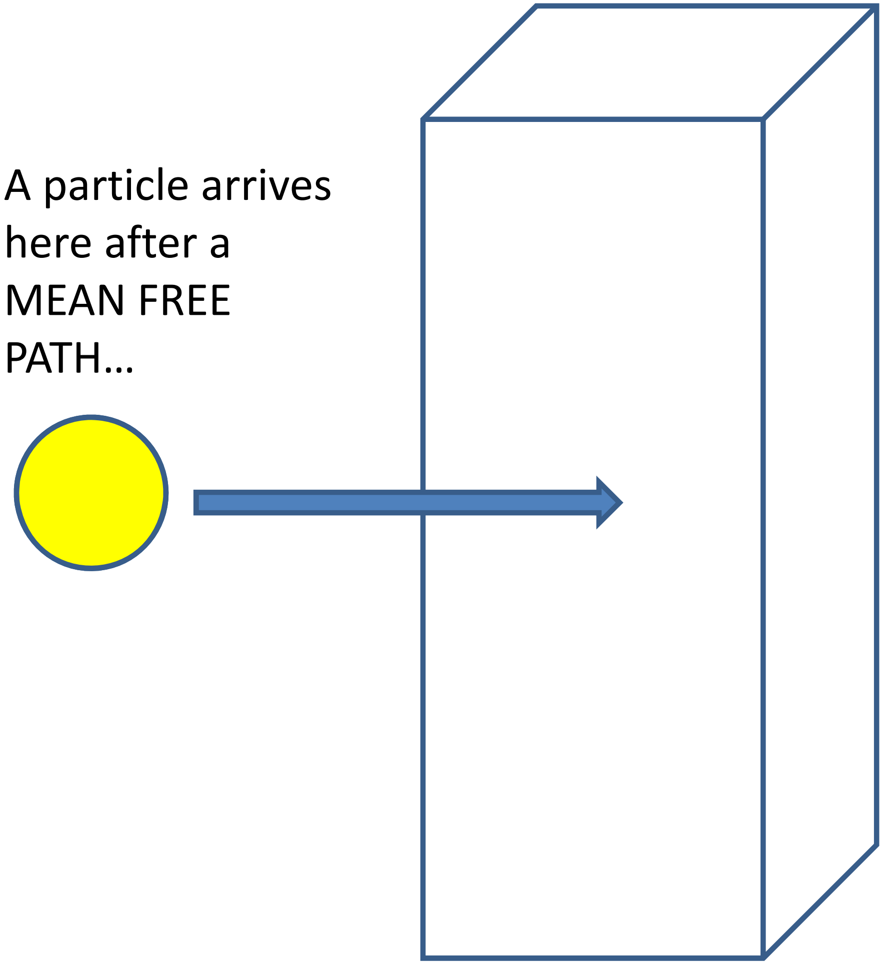
Interactions and further steps are selected via repeated random* sampling.

In particle physics, most interaction probabilities are expressed in terms of CROSS-SECTIONS.

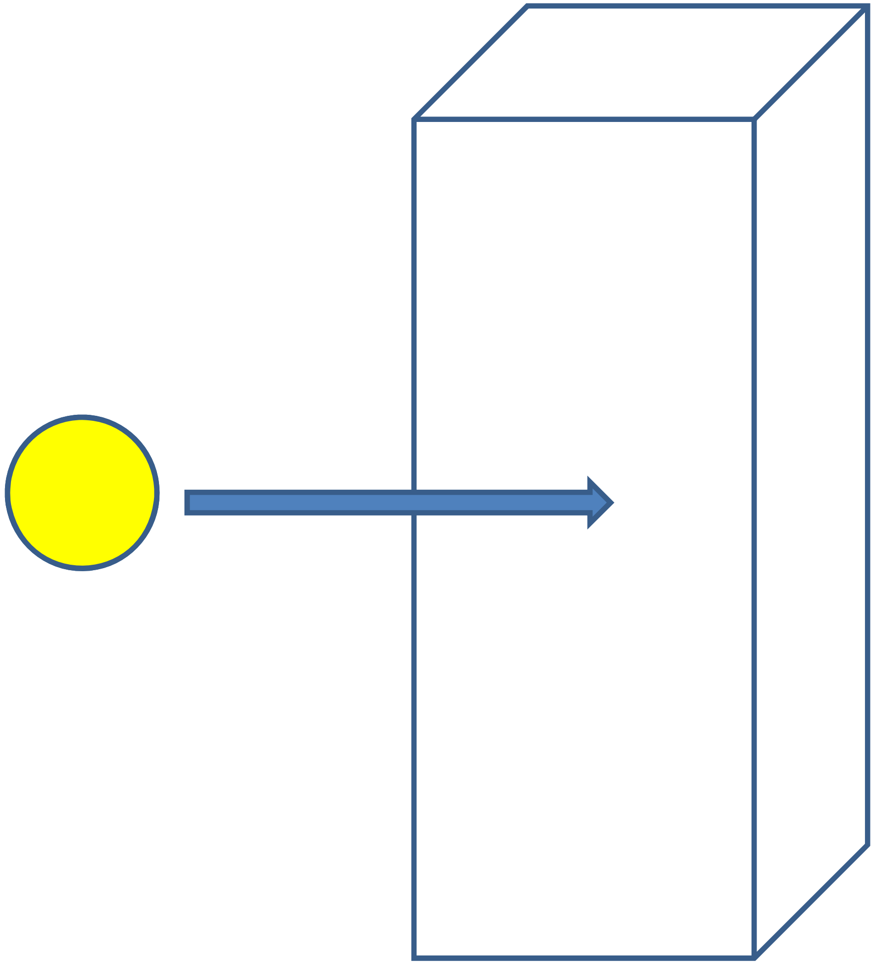
** OK, let us say «pseudo-random»……*

The MONTECARLO method in GEANT4: work in **steps**……

A particle arrives here after a MEAN FREE PATH…

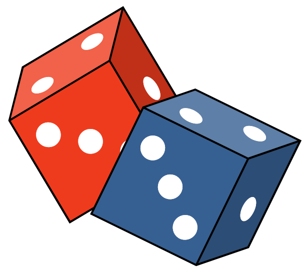


The MONTECARLO method in GEANT4: work in steps……



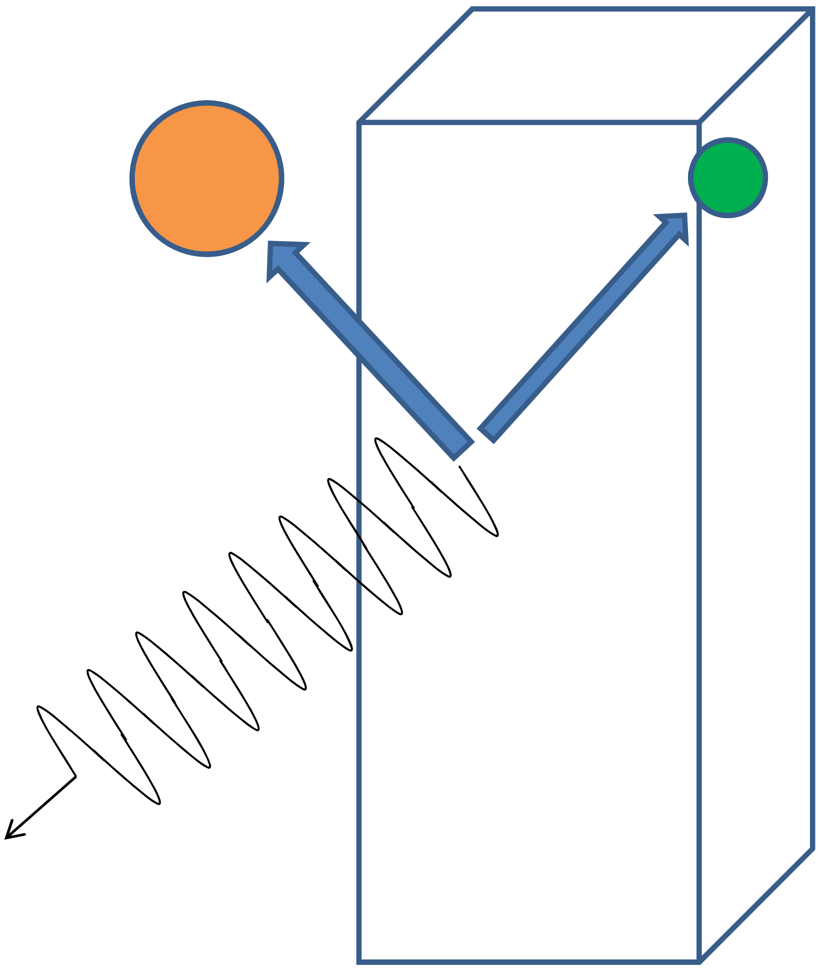
Does it happen something to the particle?

- Scattering ?
- Absorption?
- Annihilation?
- …….?



Random selection WEIGHTED on the cross sections

The MONTECARLO method in GEANT4: work in steps…..

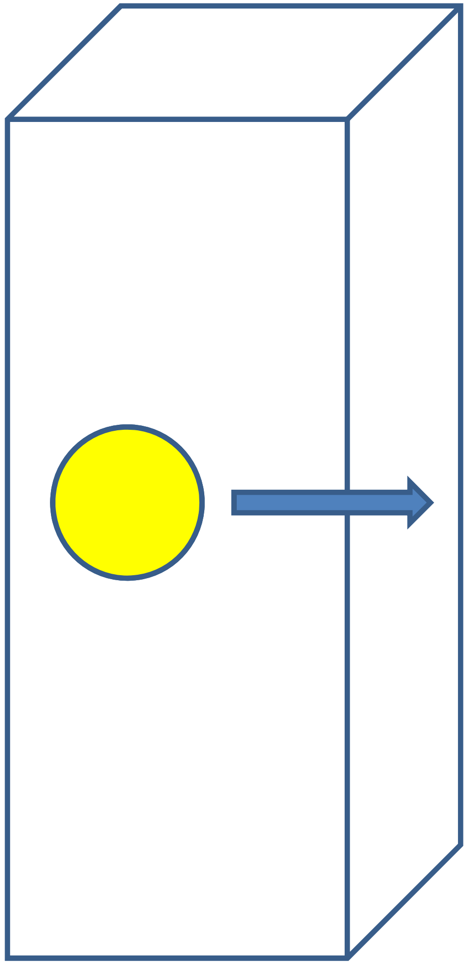


Does it happen something to the particle?

- Scattering ?
- Absorption?
- Annihilation?
- …….?

If YES, thus the new characteristics of the track (direction, energy, mfp etc.) are calculated on the base of Physics.

The MONTECARLO method in GEANT4: work in steps that give you a track



If NO, a new mean free path is calculated for the particle…..

Basics of GEometry ANd Tracking 4

GEANT4 is a simulation toolkit for interaction of radiation in matter

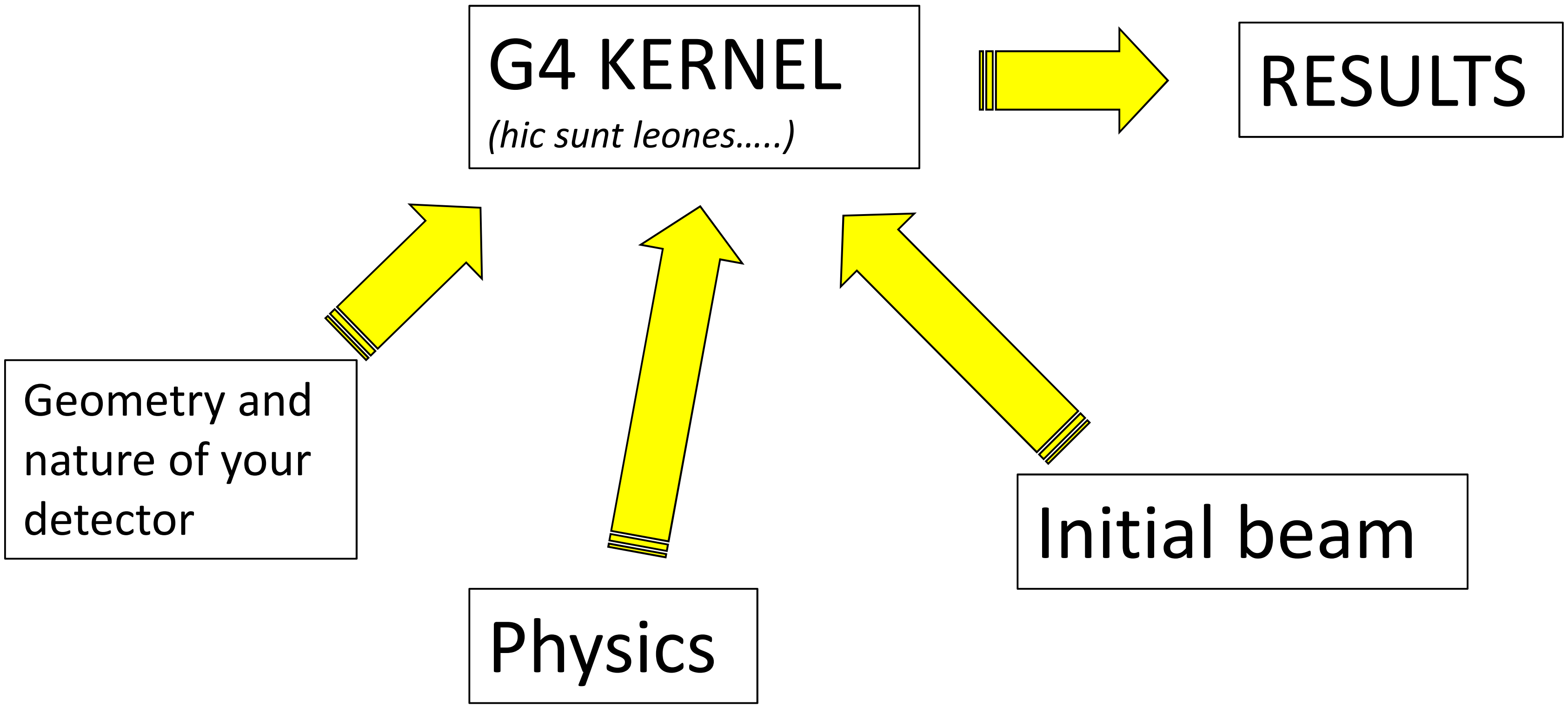
- C++ based / Object orientated
- Developed and used by CERN
- Born to be used with HIGH ENERGY PHYSICS
- Free source

The present version is 9.5 and frequently updated.

All you want to know about the releases, patches etc., at

www. geant4.cern.ch

Basics of GEometry ANd Tracking 4



Geometry and nature of your detector:

Dimensions and position in space, material, density, etc. Local cross sections are determined for every part of your detector.

```
G4double density = 0.92*g/cm3;
G4Material* Poly = new G4Material(name = "Poly" , density,
ncomponents=2);
Poly->AddElement(C, natoms=1);
Poly->AddElement(H, natoms=2);
```

Defining a material in GEANT4

Geometry and nature of your detector:
Dimensions and position in space, material, density, etc. Local cross sections are determined for every part of your detector.

```
G4double Cathode_x = 50.0*mm;
G4double Cathode_y = 50.0*mm;
G4double Cathode_y = 2.0*mm;

G4Box* Cathode = new G4Box("Cathode_box" , Cathode_x,
Cathode_y, Cathode_z);
```

Defining a shape in GEANT4

```
G4double Cathode_x = 50.0*mm;
G4double Cathode_y = 50.0*mm;
G4double Cathode_y = 2.0*mm;

G4Box* Cathode = new G4Box("Cathode_box" , Cathode_x,
Cathode_y, Cathode_z);

//*******************************************************

Cathode_log= new G4LogicalVolume(Cathode_box,Aluminium,
"Cathode.log");

//*******************************************************

Cathode_phys = new
G4PVPlacement(0,G4ThreeVector(0.,0.,0.05*mm),Cathode_log,
"Cathode",experimentalHall_log,false,0);
```

Defining a physical volume in GEANT4

Initial beam or source:

Position of the source, direction of the beam, isotropy/anysotropy, energetic distribution etc. The INTENSITY of the has no meaning: it is the NUMBER OF INITIAL EVENTS.

```
G4ThreeVector Direction = (0.0, 0.0, 1.0);
particleGun->SetParticleMomentumDirection(Direction);
```

Defining a unidirectional beam in GEANT4

```
G4double Estart = 12.0*MeV;
particleGun->SetParticleEnergy(Estart);

//**********************************************************

G4double Estart = GetOne_on_EEnergy();
particleGun->SetParticleEnergy(Estart);

G4double GEMPrimaryGeneratorAction::GetOne_on_EEnergy()
     {
     G4double r, x, mean;
     r = G4UniformRand();
     mean = 10.0;

     x = 5.0 * (100.0 / log (2.0))/log (r+1.0);

     return x;
     }
```

Defining particle energies in GEANT4

Physics:
«Physics lists» in GEANT4 contain models for every particle and their interactions.

Physics lists can be selected based on the characteristics of your simulated experiment and your interest: for instance, if you only have gammas with energy < 1022 keV, you can ignore positrons. If you do not have neutrons, you can ignore neutron cross sections (very heavy).

The less physics you put in, the fastest your simulation, but……… *Be Smart*!

Many validated physics lists are available on
geant4.web.cern.ch/geant4/support/proc_mod_catalog/physics_lists/referencePL.shtml
with suggested uses.

Results:

Typically you associate to your detector elements a «sensitive detector»: a class in which information on the track and/or event and/or step are copied. All this information or a part of it can be extracted to give your output file.

```
int n_hit = DetectorHC->entries();

G4double totE, tottime;
G4string name;

for (int i=0;i<n_hit;i++)
    {
    totE += (*DetectorHC[i])->GetEdep();
    name = (*DetectorHC[i])->GetParticleName;
    }

logFile << "1" << " " << totE/eV << " " <<  name << " " <<
endl;
```

Results:

Typically you associate to your detector elements a «sensitive detector»: a class in which information on the track and/or event and/or step are copied. All this information or a part of it can be extracted to give your output file.

```
1 5256.23 proton
1 6868.08 proton
1 142853 proton
1 64631.2 proton
2 60665.1 alpha
1 5355.13 proton
1 1848.82 proton
1 1758.31 proton
1 489481 Al27[0.0]
1 66358.2 proton
......
```

The output text file from the code in the previous slide

Multi-parametric, list-mode output files like this can be easely transformed in spectra offline.

OK, but in practice what should I do?

GEANT4 releases offer a list of EXAMPLE source files that include basic geometry, creation of detectors and particles, physics lists.

Thus, the best is to start from an example and modify only a few things at a time, until you have your own experiment.

OK, but in practice what should I do?

This you MUST modify.....

`MyWonderfulExperiment_DectectorConstruction.cc`

`MyWonderfulExperiment_SD.cc`

`MyWonderfulExperiment_PrimaryGeneratorAction.cc`

`MyWonderfulExperiment_EventAction.cc`

These files are specific of your experiment: they answer the questions:

- How is my detector?
- How is my source?
- Which results do I want?

OK, but in practice what should I do?

This you MAY WANT to modify…..

`MyWonderfulExperiment_PhysicsList.cc`

`MyWonderfulExperiment_RunAction.cc`

`MyWonderfulExperiment.cc`

The latter file is the «main» of the whole process: you can optimize your simulation in terms of time, used memory, verbosity etc.

OK, but in practice what should I do?

This you MAY WANT to modify…..

```
MyWonderfulExperiment_PhysicsList.cc

MyWonderfulExperiment_RunAction.cc

MyWonderfulExperiment.cc
```

The latter file is the «main» of the whole process: you can optimize your simulation in terms of time, used memory, verbosity etc.

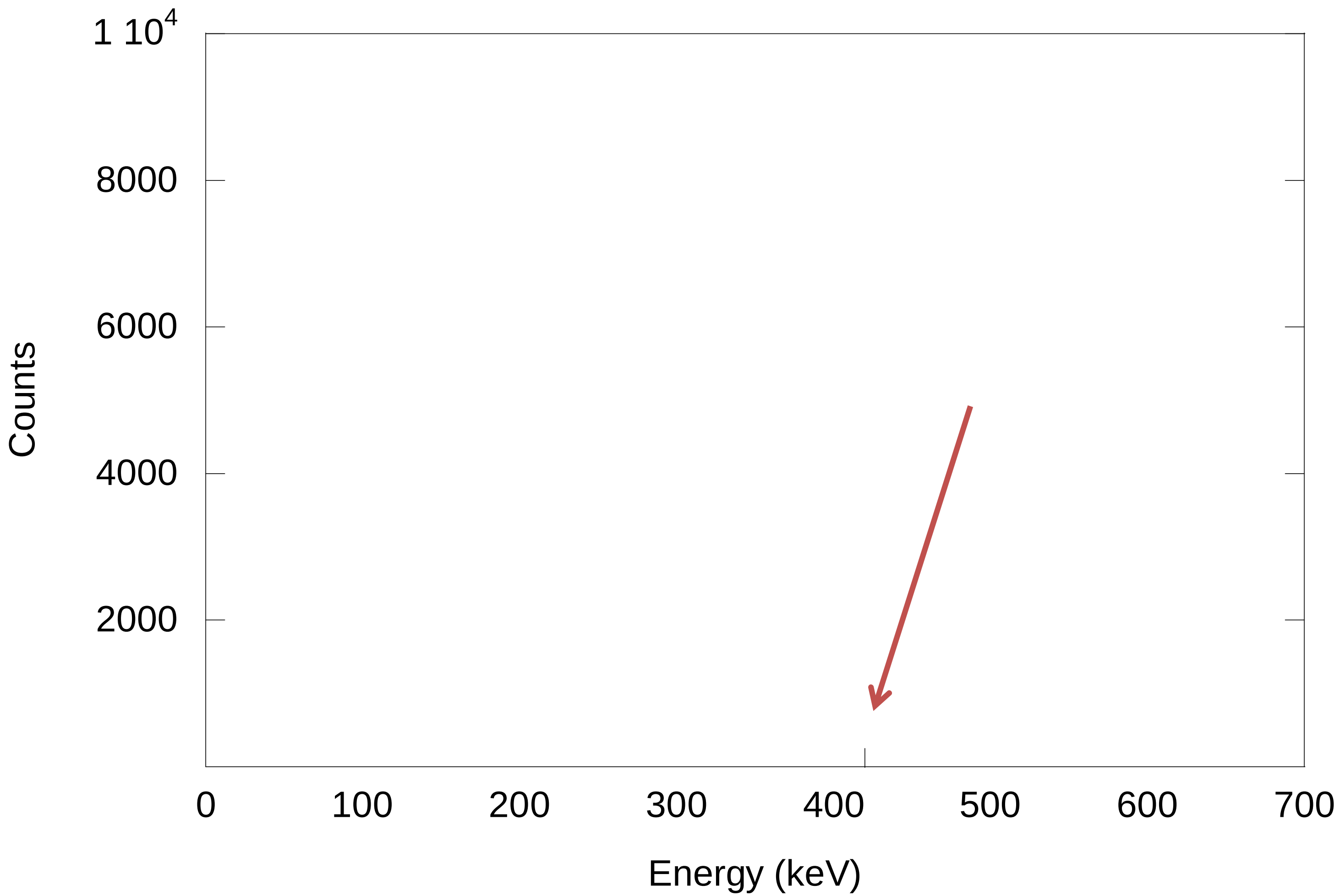
All the rest is better to keep your hands off….

…… and what can I simulate?

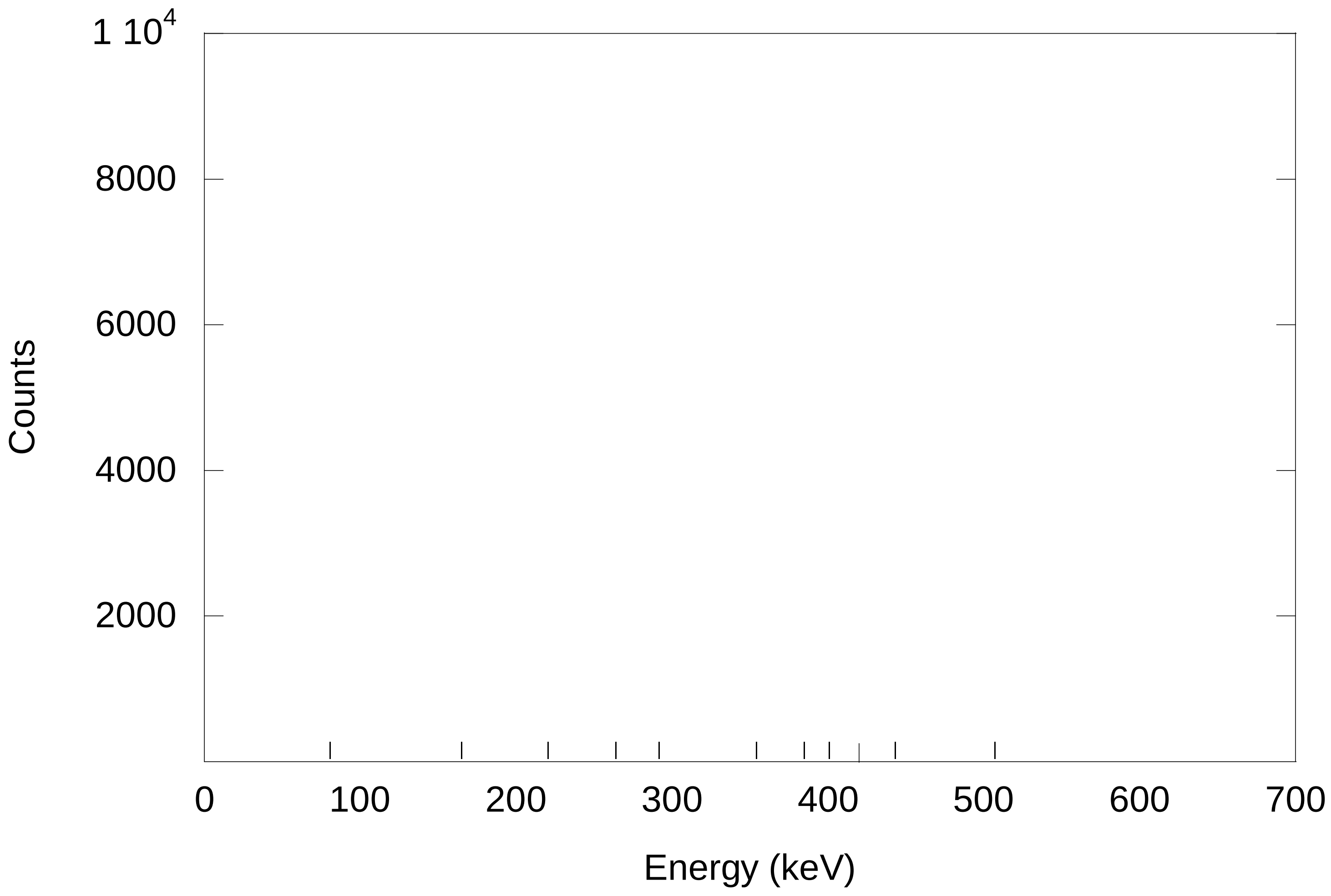
Simulations can help you to solve ACCUMULATION PROBLEMS, i. e. they help to determine the mean behaviour of radiation interacting with the physical part of your experiment.

In many cases only the ACCUMULATION of many particles/radiations is representative of the behaviour of your experiment.

…… and what can I simulate?



…… and what can I simulate?



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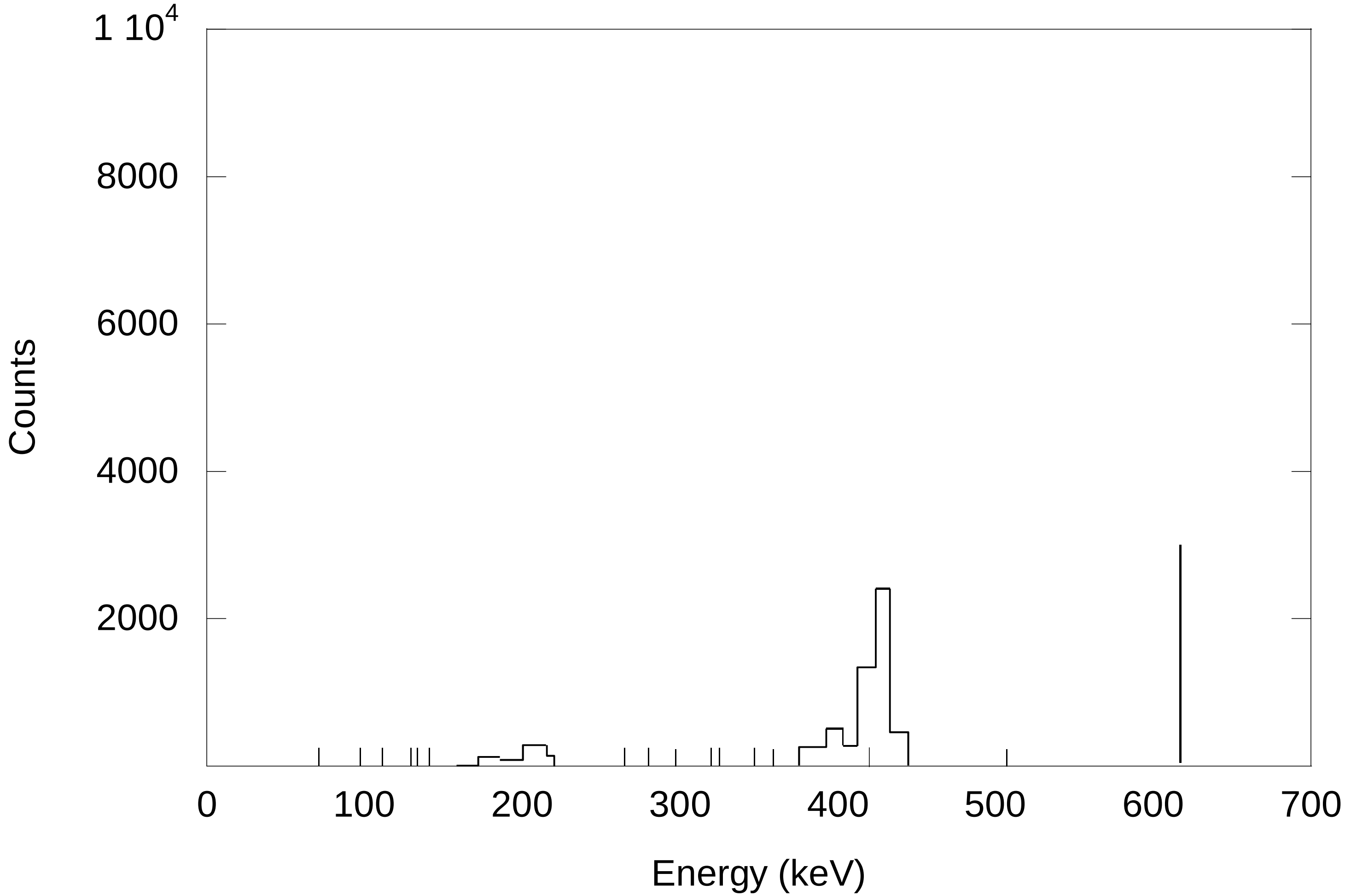
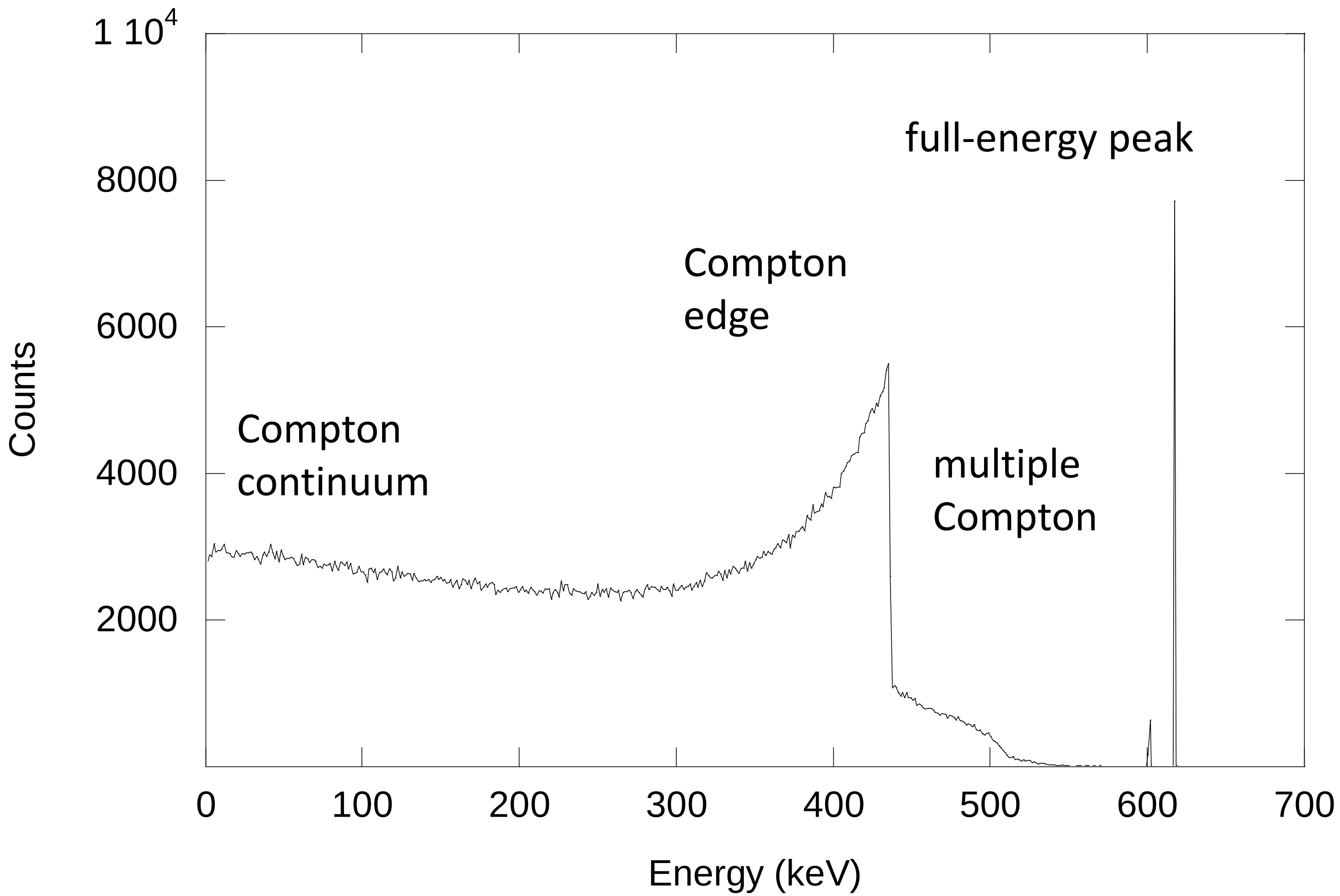


…… and what can I simulate?

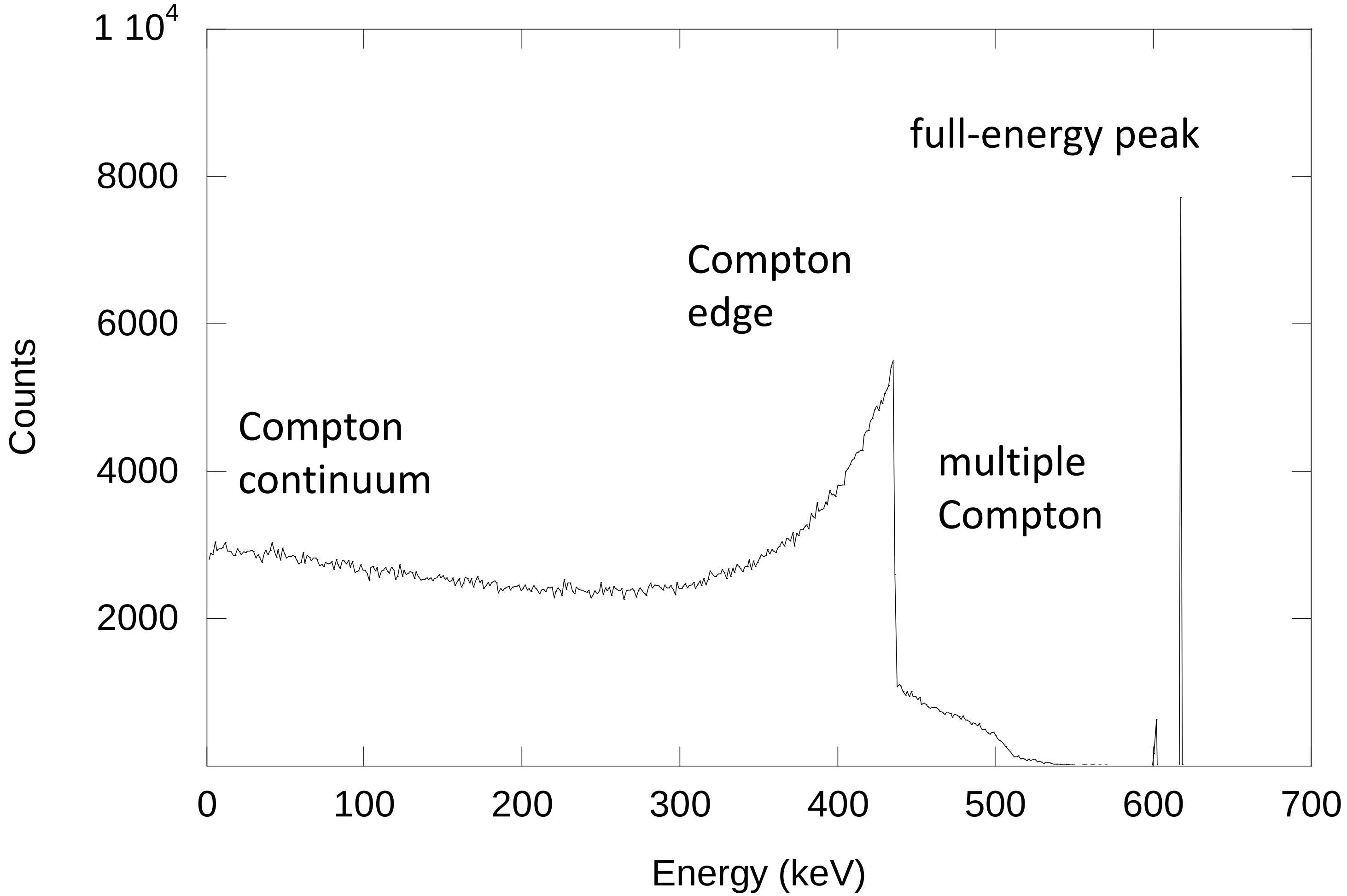
Only when you have accumulated events enough you can say something about your experiment



…… and what can I simulate?

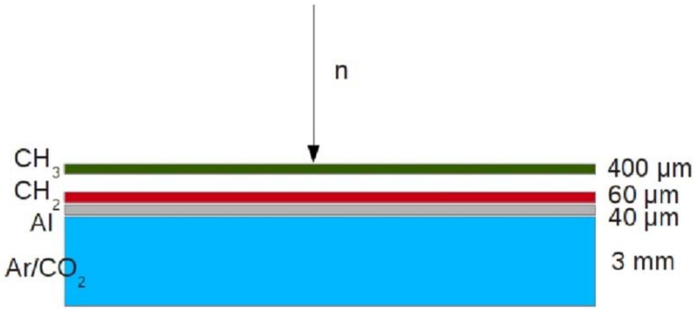
You can estimate the RESPONSE FUNCTION of a detector.

G4-simulated response function of a scintillator detector to 617 keV photons

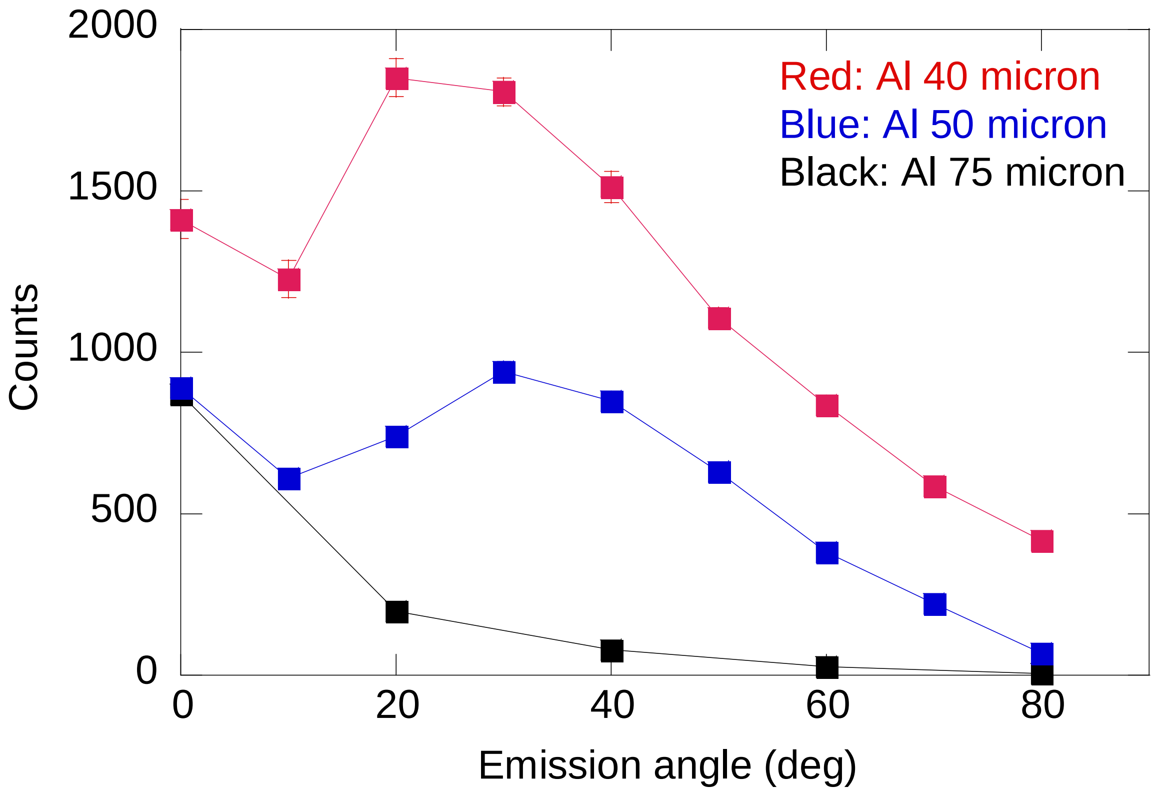


…… and what can I simulate?

You can estimate the RESPONSE FUNCTION of a detector.

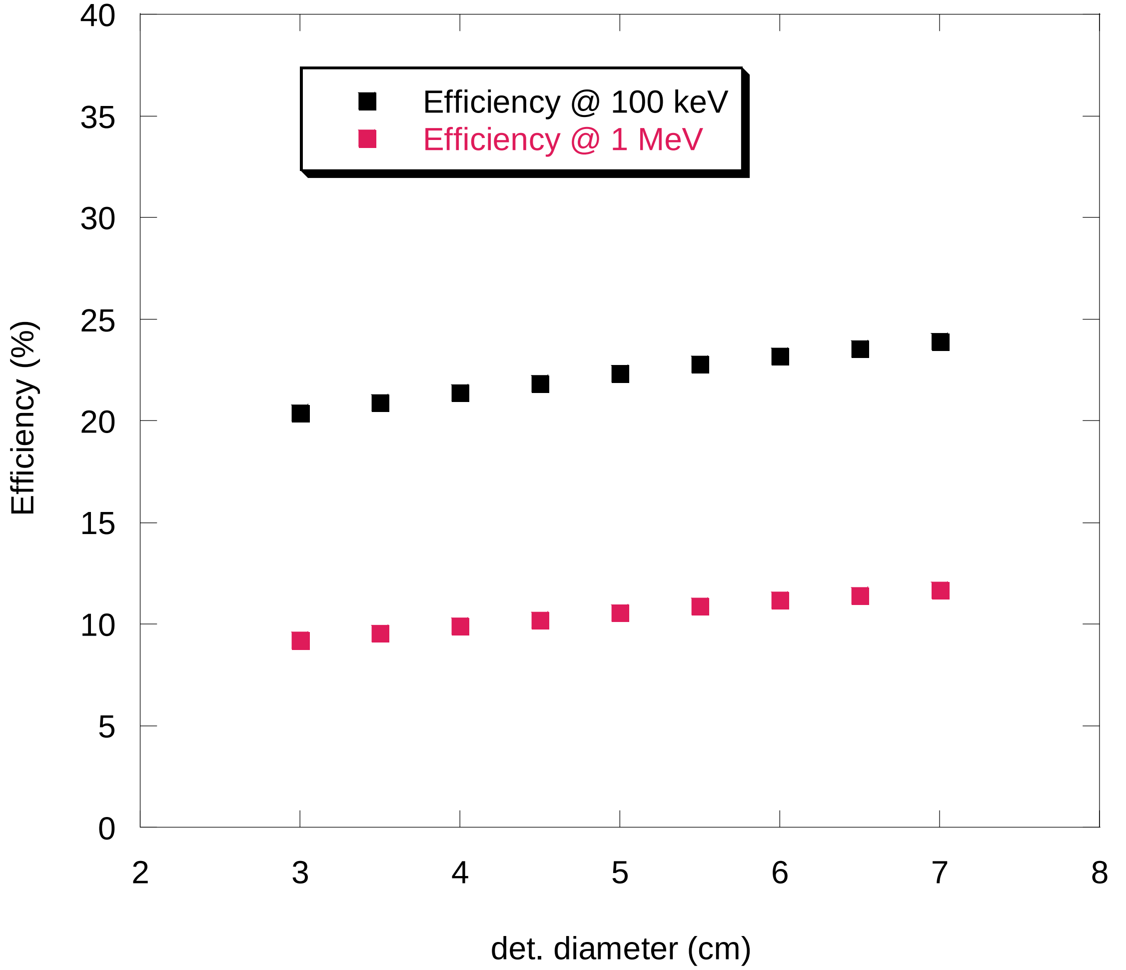


A neutron-GEM detector with G4 simulated response at different angle emission



…… and what can I simulate?

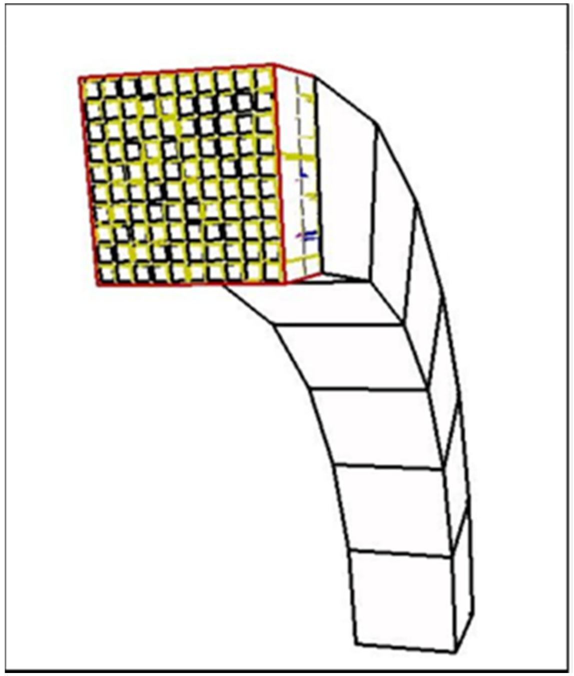
You can estimate the EFFICIENCY of a detector while varying one or more parameters.

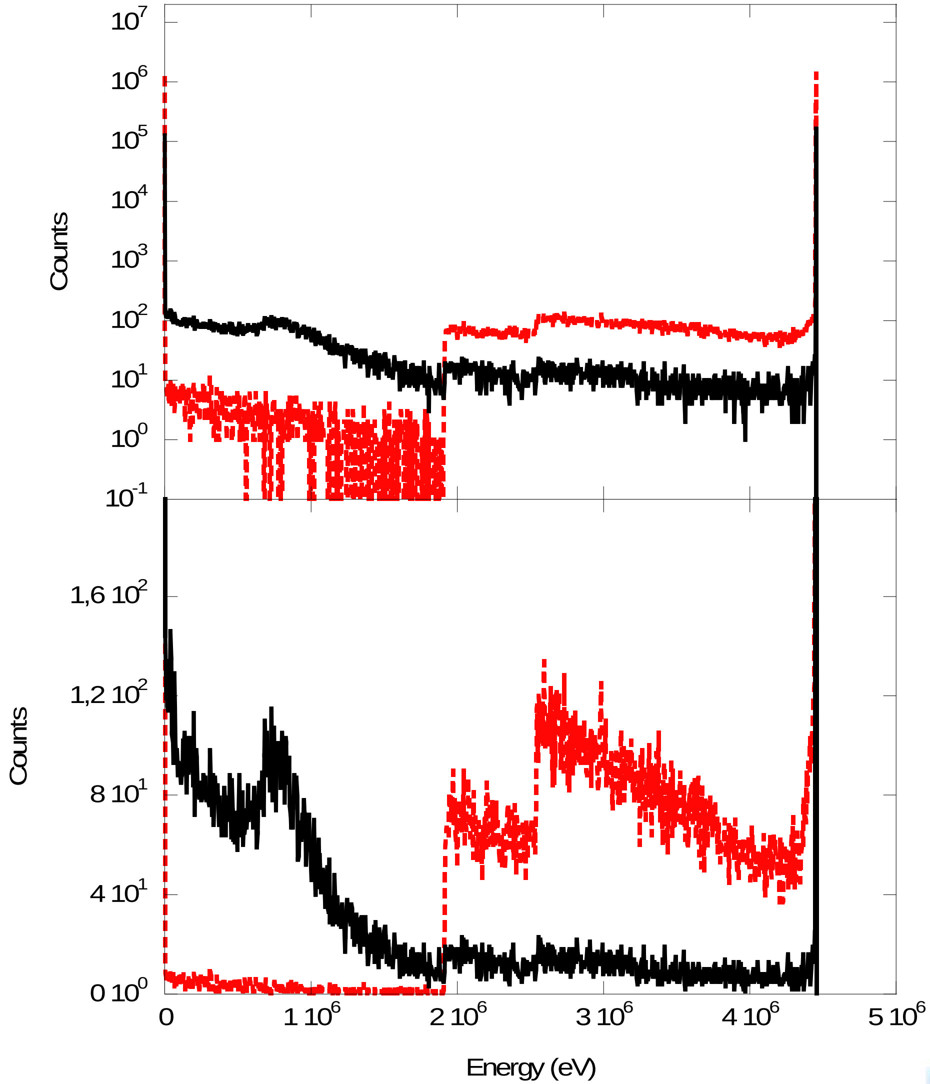


…… and what can I simulate?

You can estimate the influence of various effects on your detector system,

for instance CROSS TALK

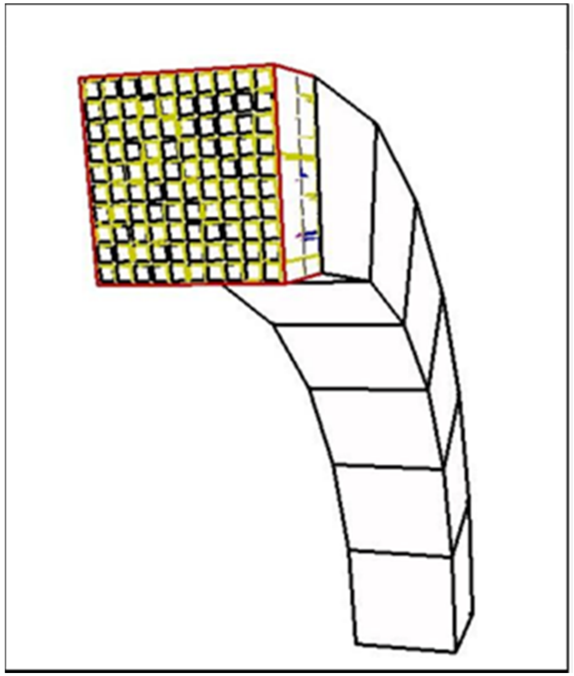




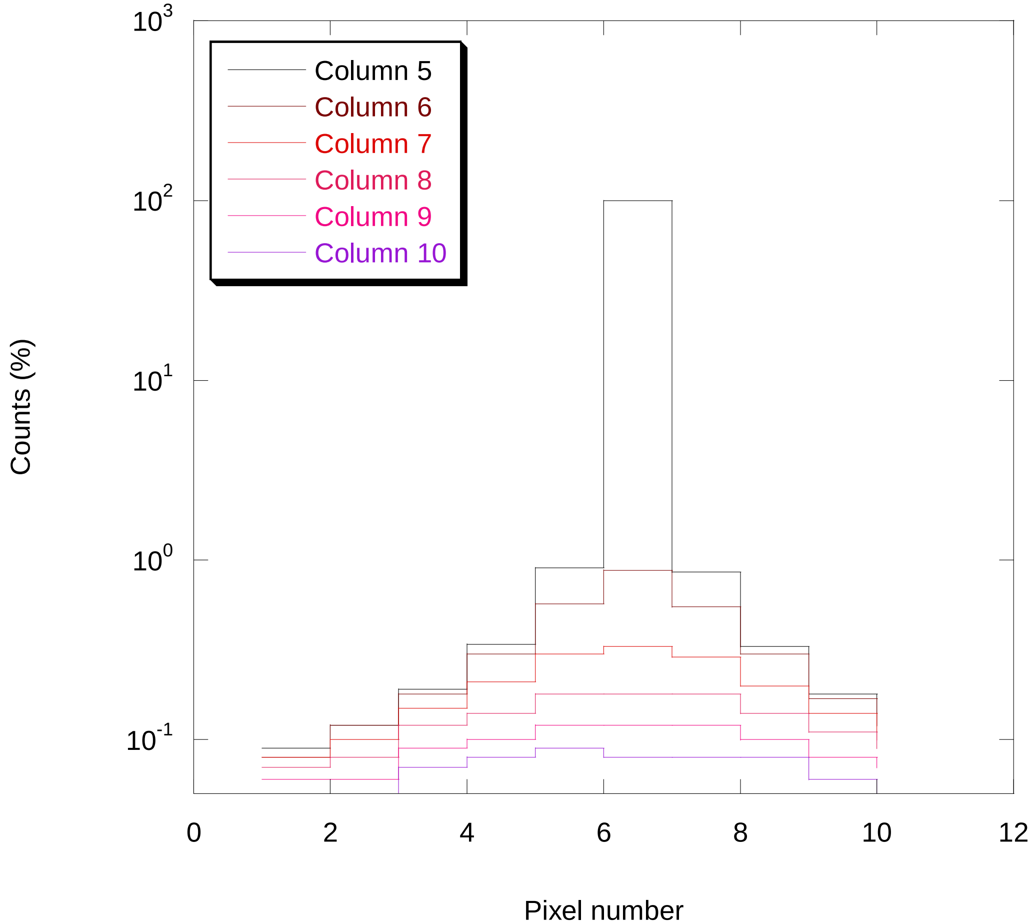
A G4 model of a pixelated neutron detector and the cross-talk spectrum (black) compared with the «good» spectrum

…… and what can I simulate?

You can determine the cross talk effect on the RESOLUTION of your detector

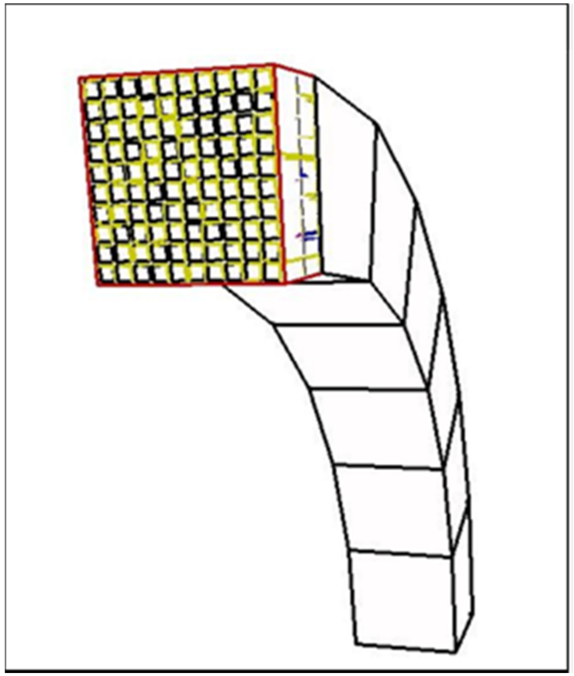


A G4 model of a pixelated neutron detector and estimated spatial resolution.

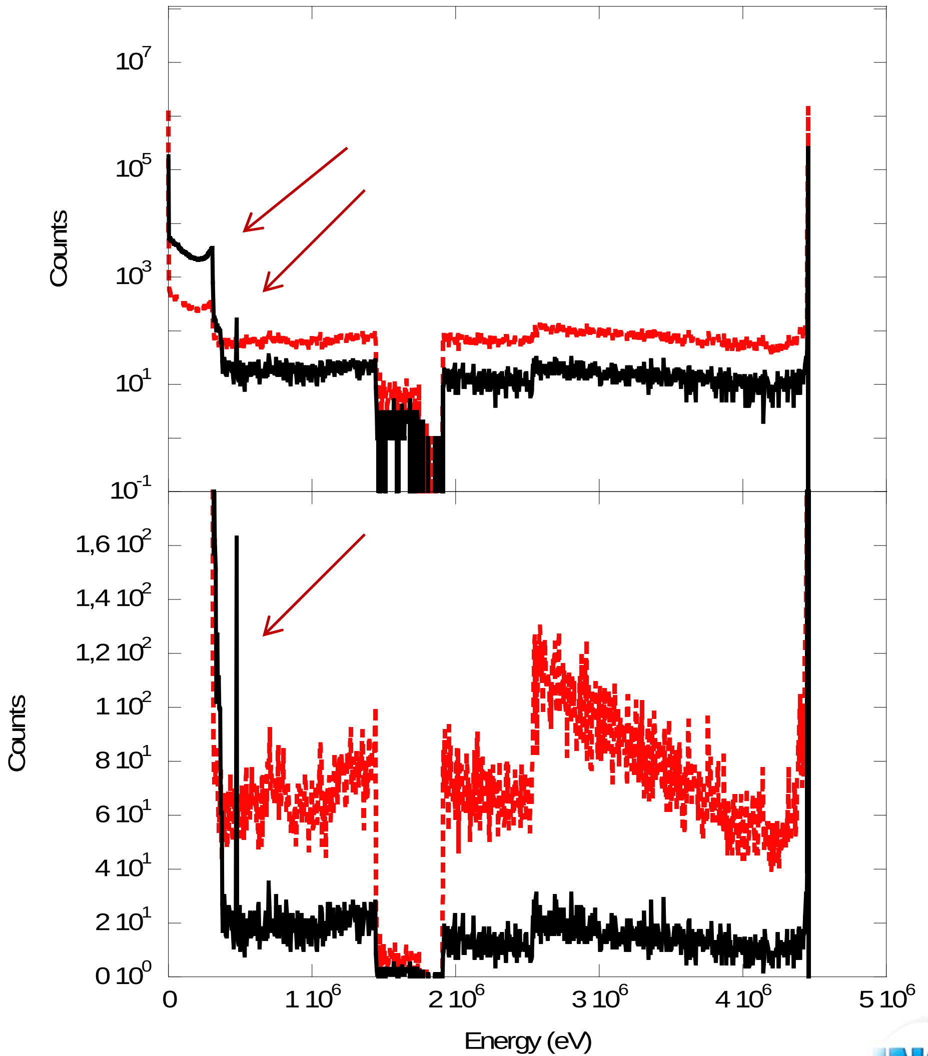


…… and what can I simulate?

You can estimate the effect of changing the composition of one element of your system (for instance the frame of your detector) on the resp. function.



A G4 model of a pixelated neutron detector and the cross-talk spectrum (black) compared with the «good» spectrum with ^{10}B frame



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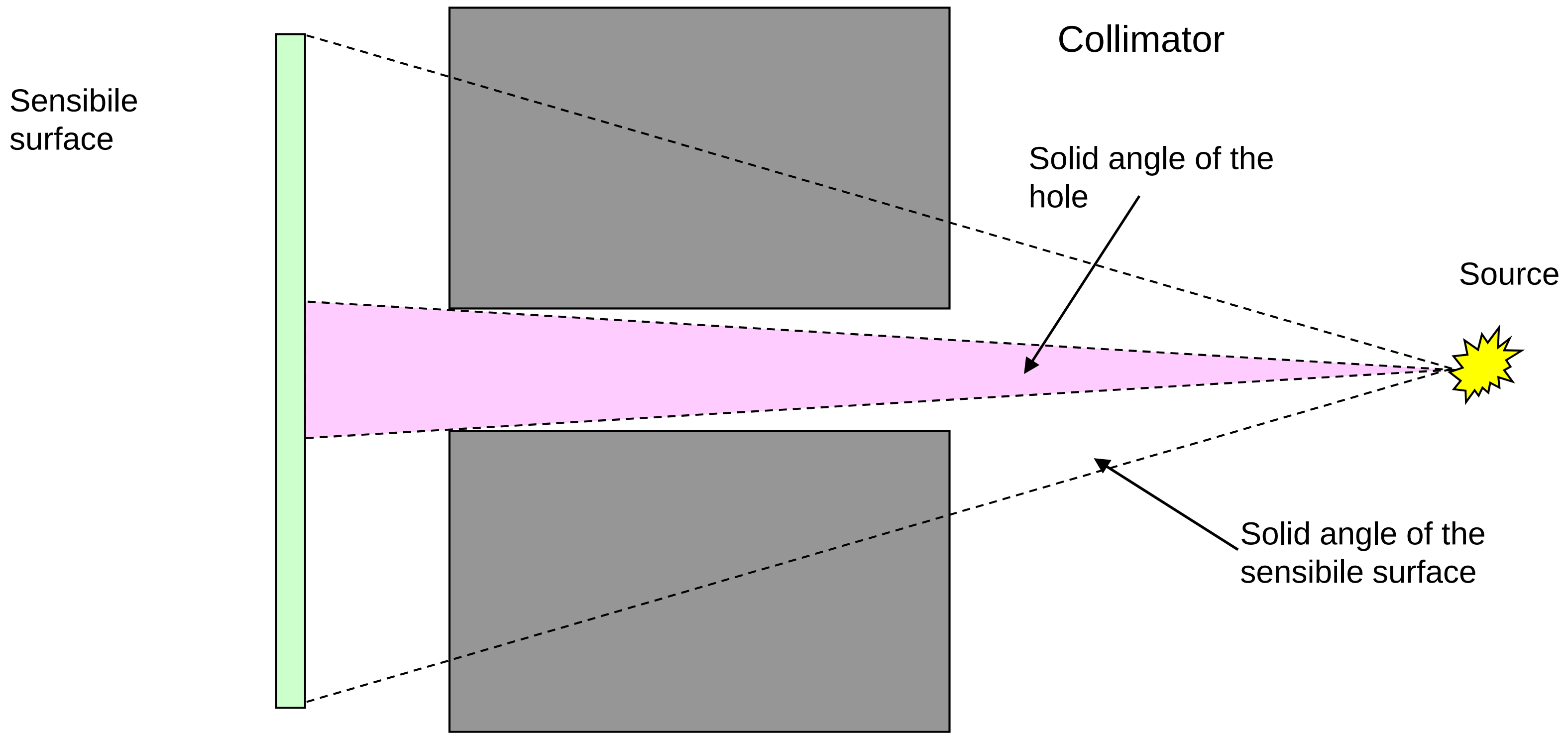
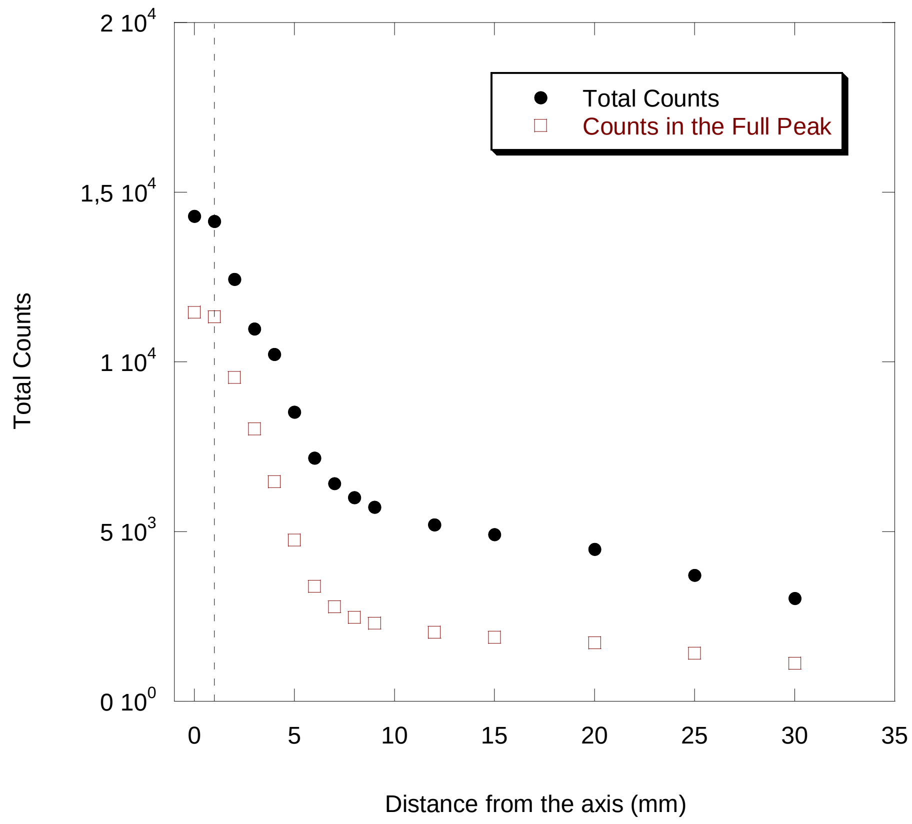
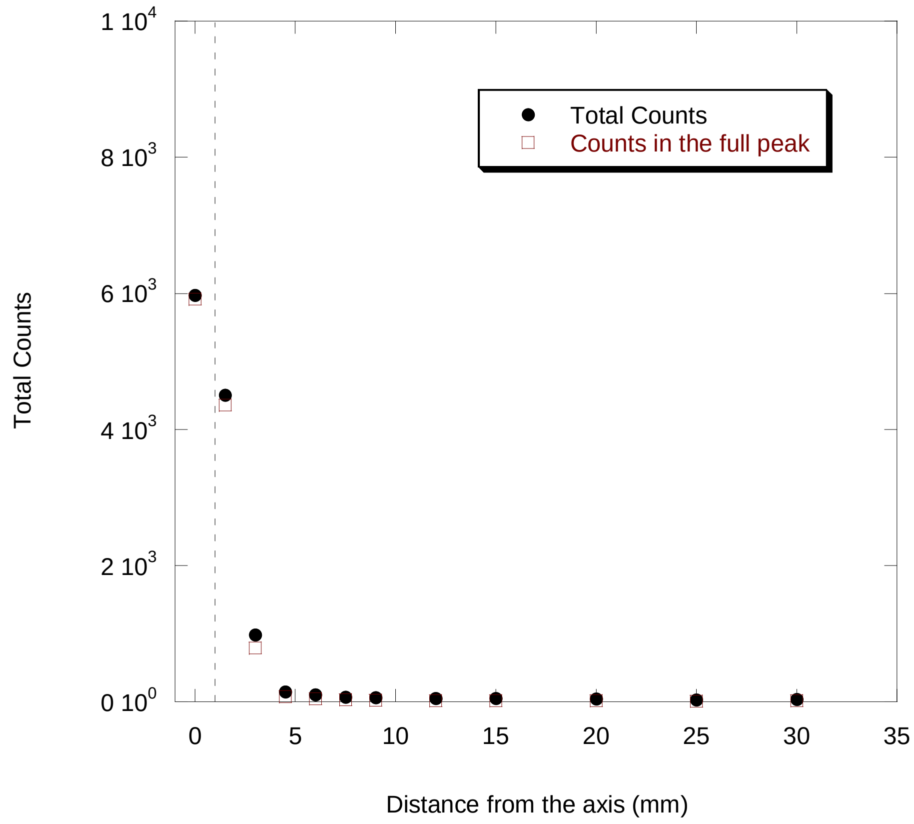


MONTECARLO simulations can be used when ray-tracing is not adequate (for instance energetic gamma rays have non-zero probability of passing through metal collimators).

…… and what can I simulate?





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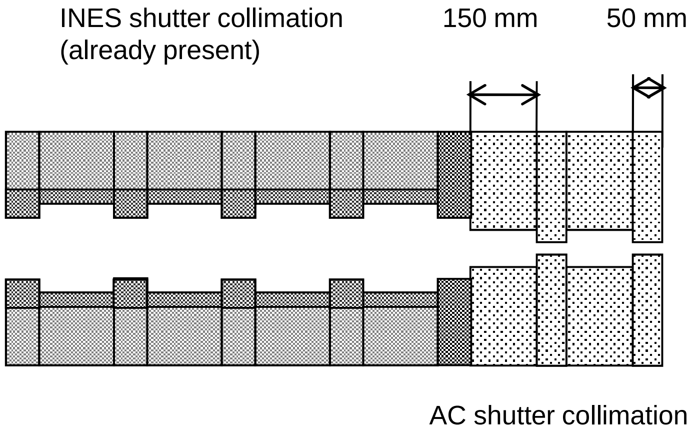
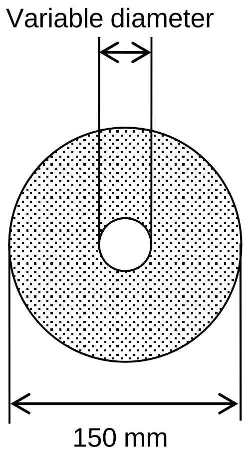
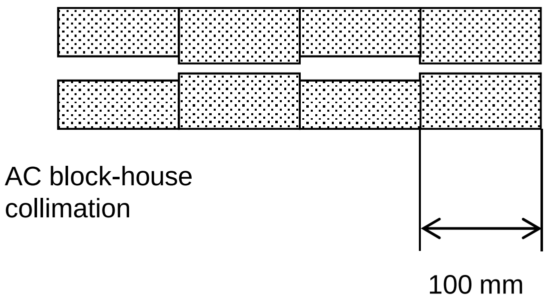
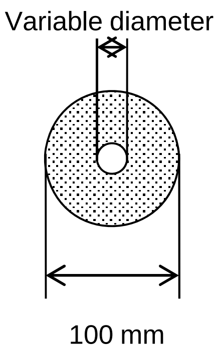




Even more important when you have complicated neutron collimators





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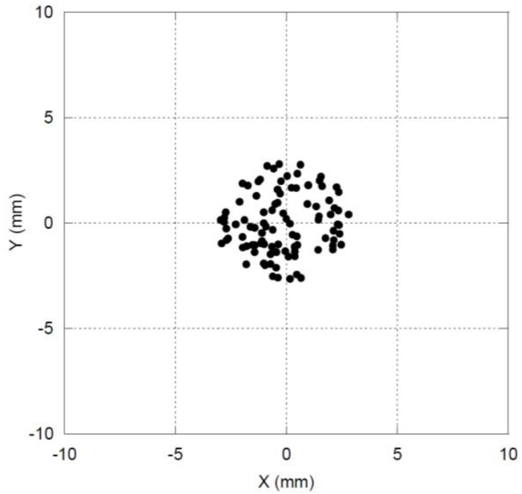

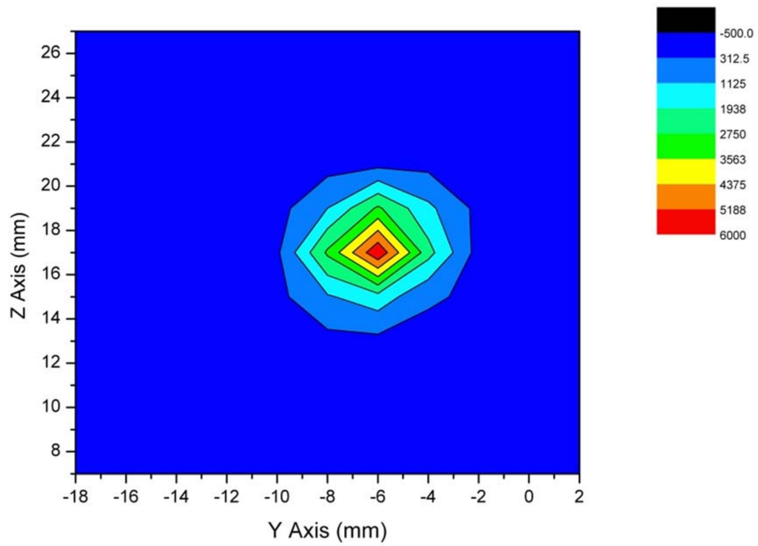

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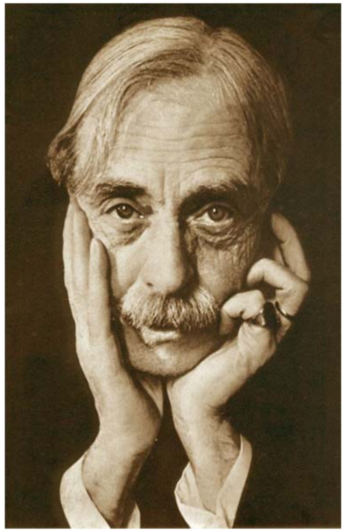
Simulation and reality: what is better?

MONTECARLO simulations help you
to solve ACCUMULATION problems.

Spare time
Spare money

«REALITY is just a special case…..»



P. Valéry (1871 – 1945)

Simulation and reality: what is better?

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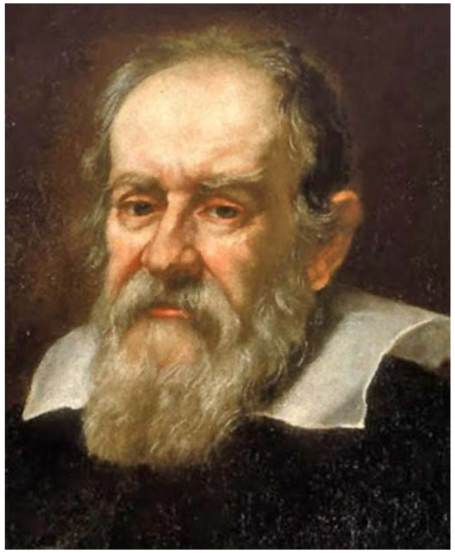
Separate un-separable effects

You can create unrealistic cases to help you better understanding your problem.

«The experiment is the ISOLATION of the quantitative structure of the nature…..»



G. Galilei (1564 – 1642)

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You will not discover «something new».

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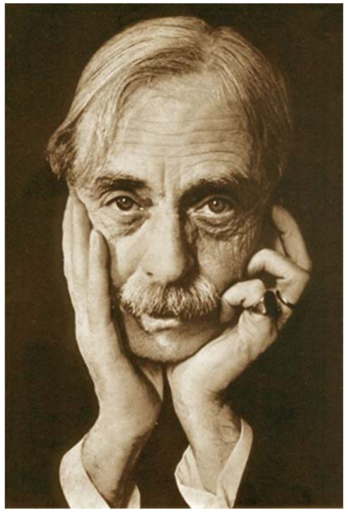
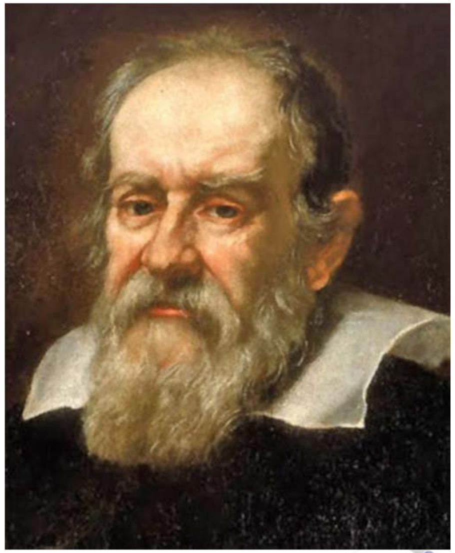


Again….. BE SMART!



Just before the conclusion…. some FAQ from neutron-lovers

Q: Can I simulate neutron diffraction with GEANT4?

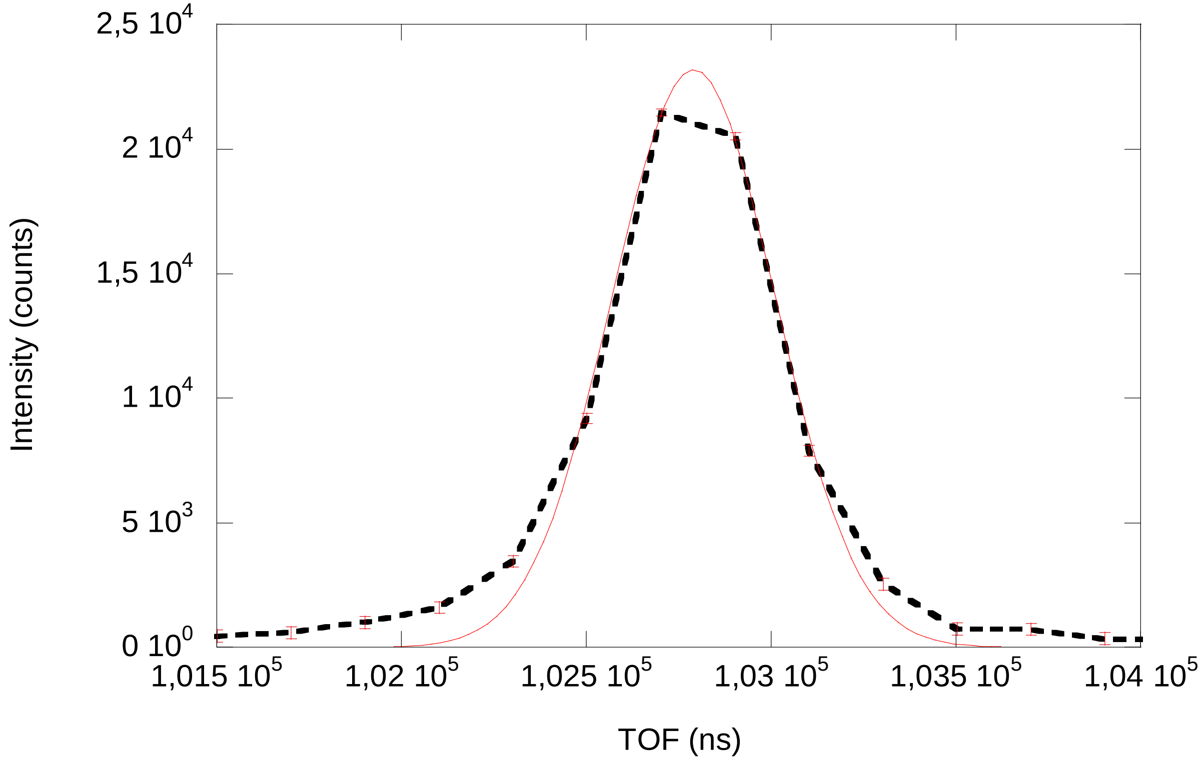
A: Not yet……..

GEANT4 neutron scattering processes are based on a «free gas» approximation.

However, ENDF/VI cross-sections modified to include coherent elastic scattering are being prepared for a limited number of materials, and they can be included in the GEANT4 package.

Just before the conclusion…. some FAQ from neutron-lovers

… but other interesting effects of neutron scatttering can be simulated….



Just before the conclusion…. some FAQ from neutron-lovers

Q: Can I simulate Time-Of-Flight experiments with GEANT4?

A: yes!

```
int n_hit = DetectorHC->entries();

G4double totE, TOF;
G4string name;

for (int i=0;i<n_hit;i++)
    {
    TOF = (*DetectorHC[i])->GetGlobalTime();
    name = (*DetectorHC[i])->GetParticleName;
    }

logFile << "1" << " " << TOF << " " <<  name << " " << endl;
```