Development of a Simulation Toolkit for Lifetime Studies Based on Doppler-Shift Methods

Thomas Braunroth

Thursday, 25th April 2019

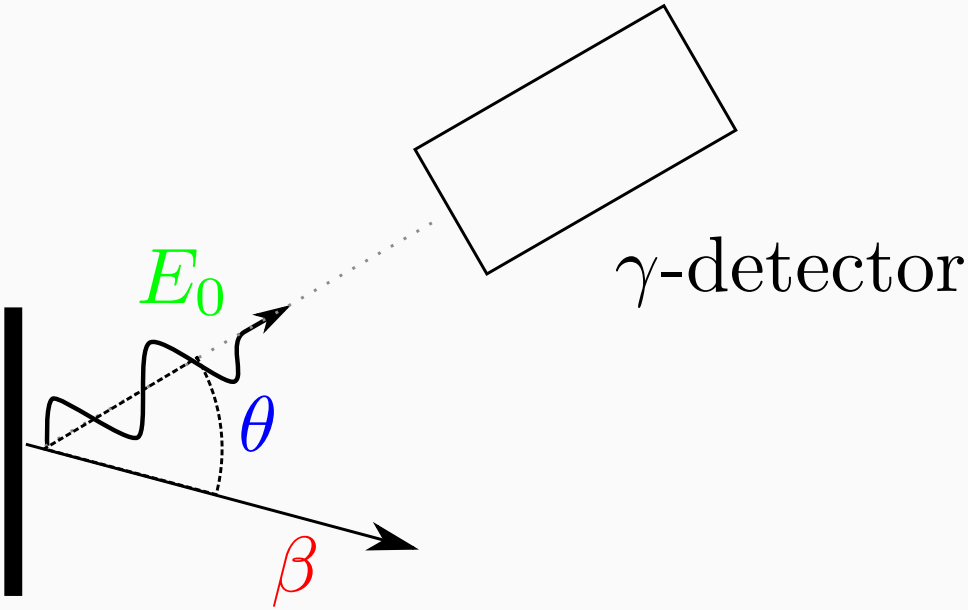
Physikalisch-Technische Bundesanstalt Braunschweig und Berlin, Bruinswick (Germany)

Part 1

–

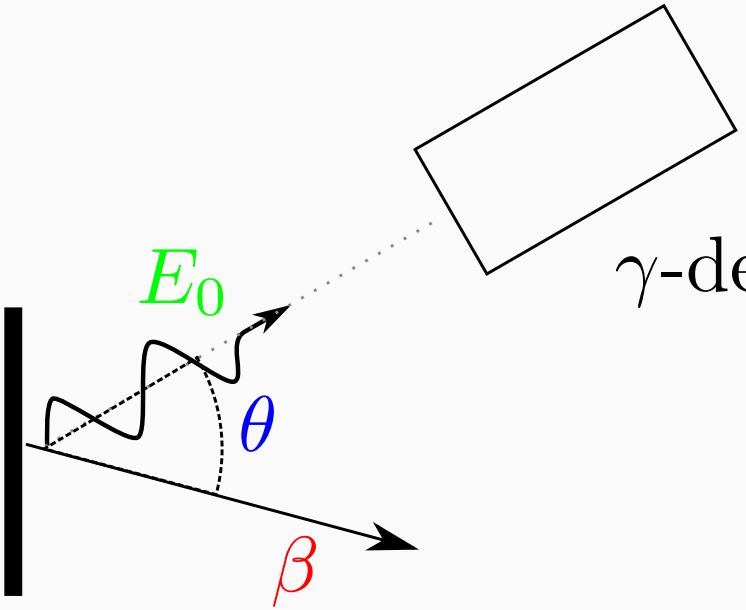
Introduction

The Electromagnetic Doppler-Shift



$$E_{\mathrm{ds}} = E_0 \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

The Electromagnetic Doppler-Shift



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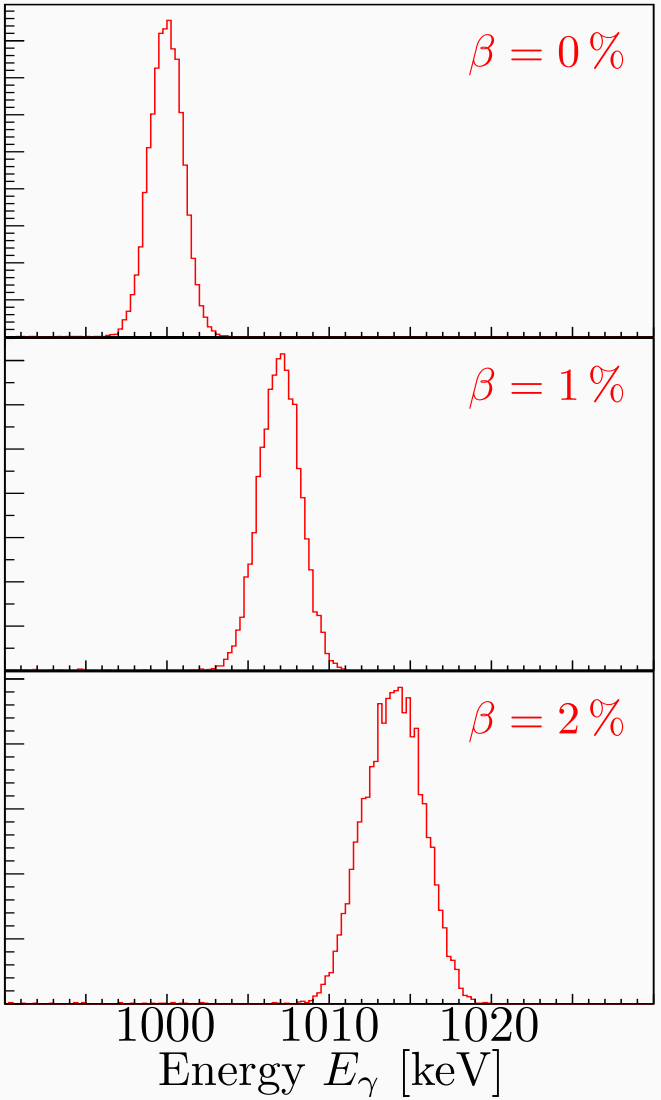
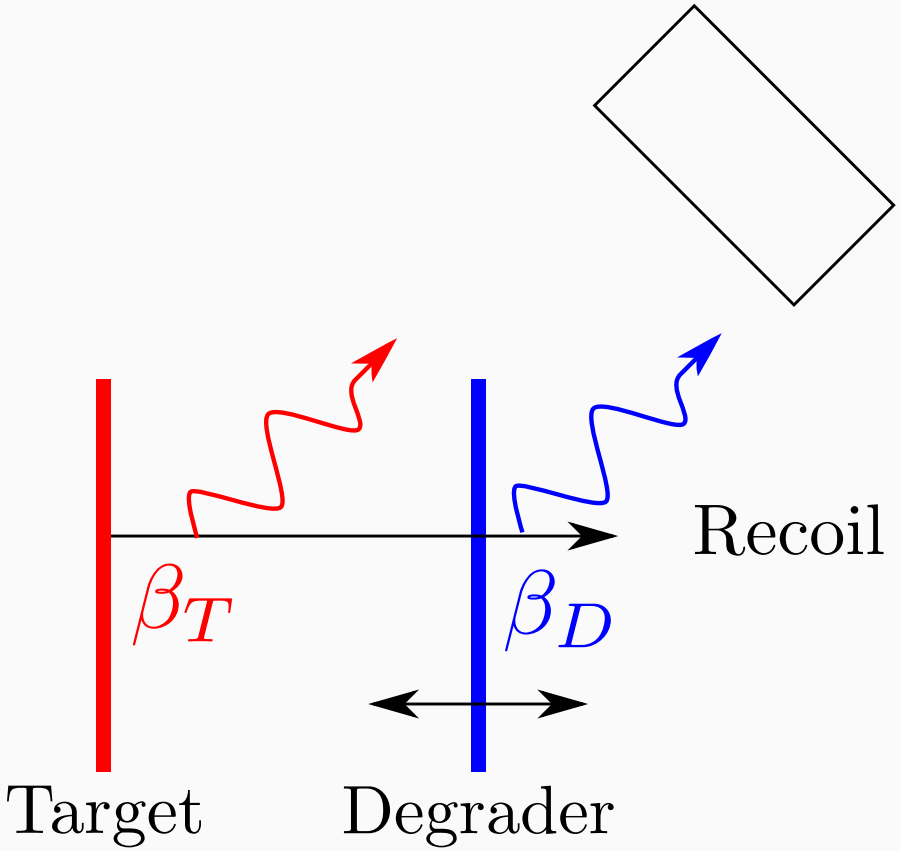
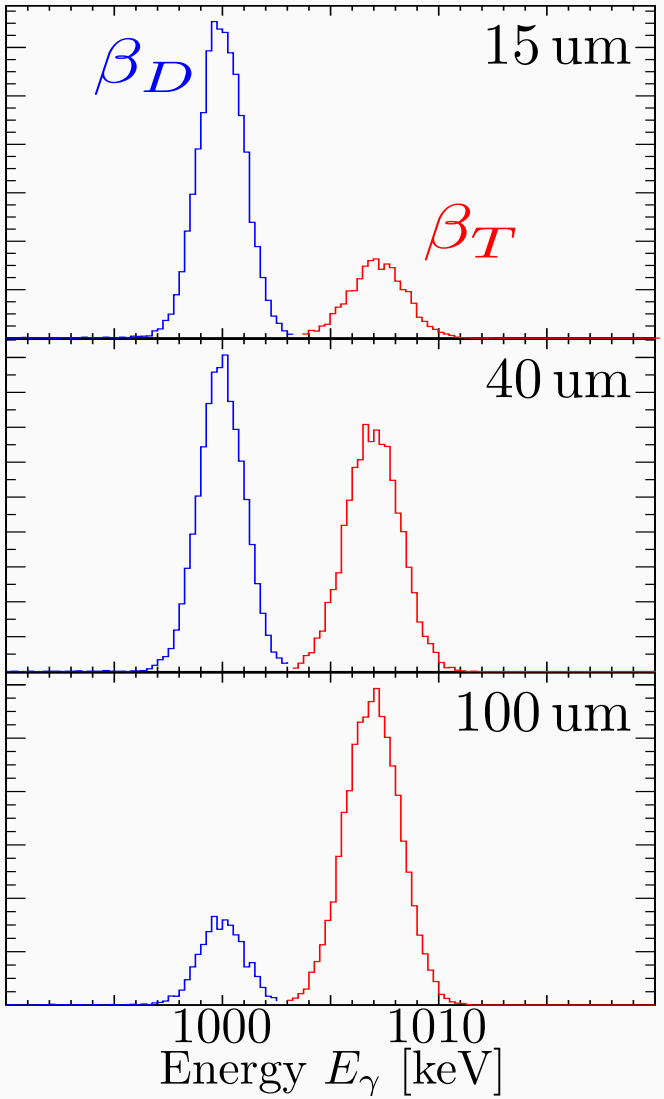


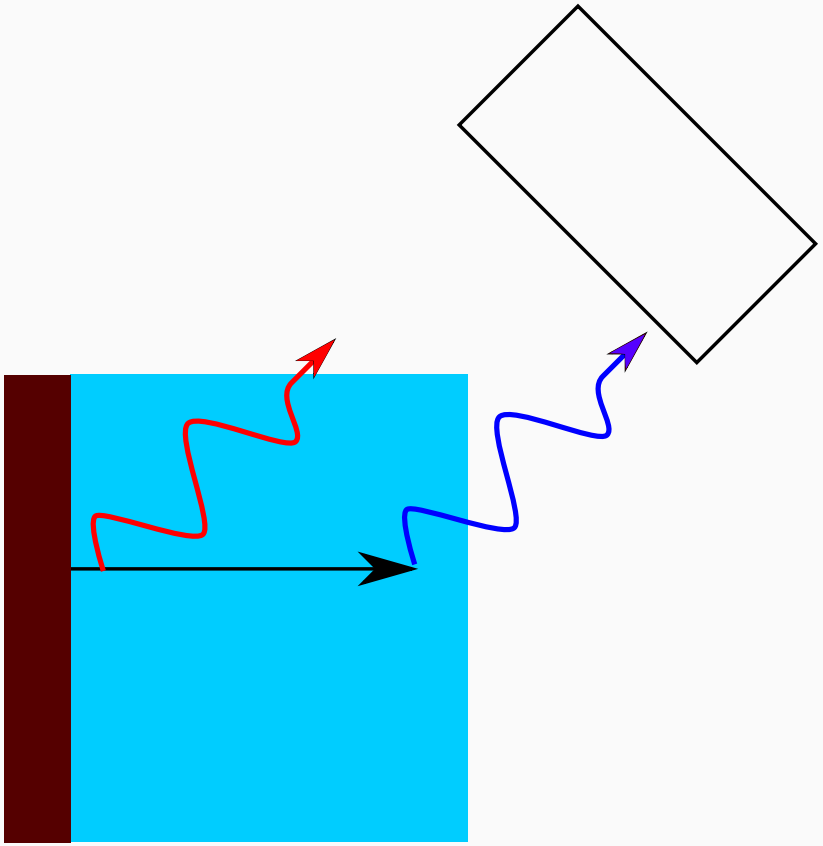
The Recoil Distance Doppler-Shift Technique



Suitable method for $1\,\text{ps} \lesssim \tau \lesssim 1\,\text{ns}$

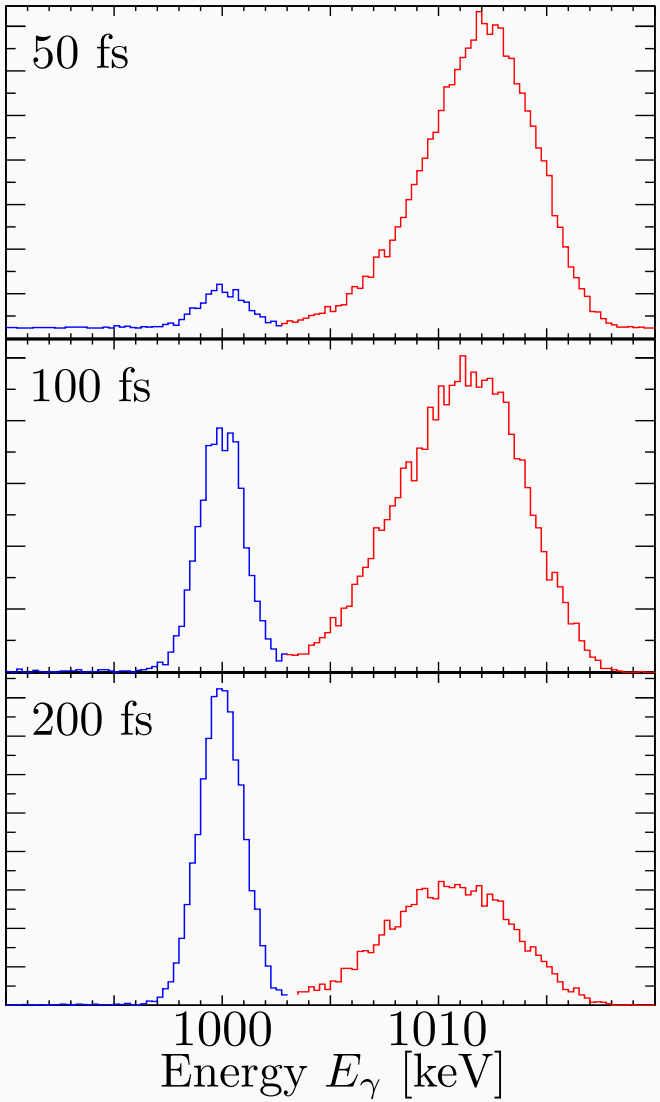


The Doppler-Shift Attenuation Method

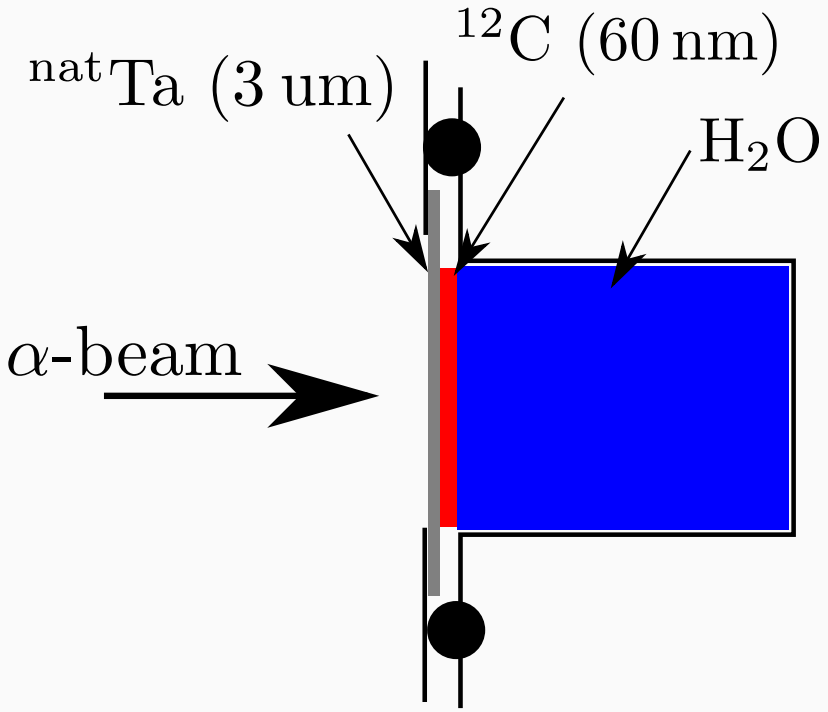


Target Stopper

Suitable method for 1 fs $\lesssim \tau \lesssim$ 10 ps



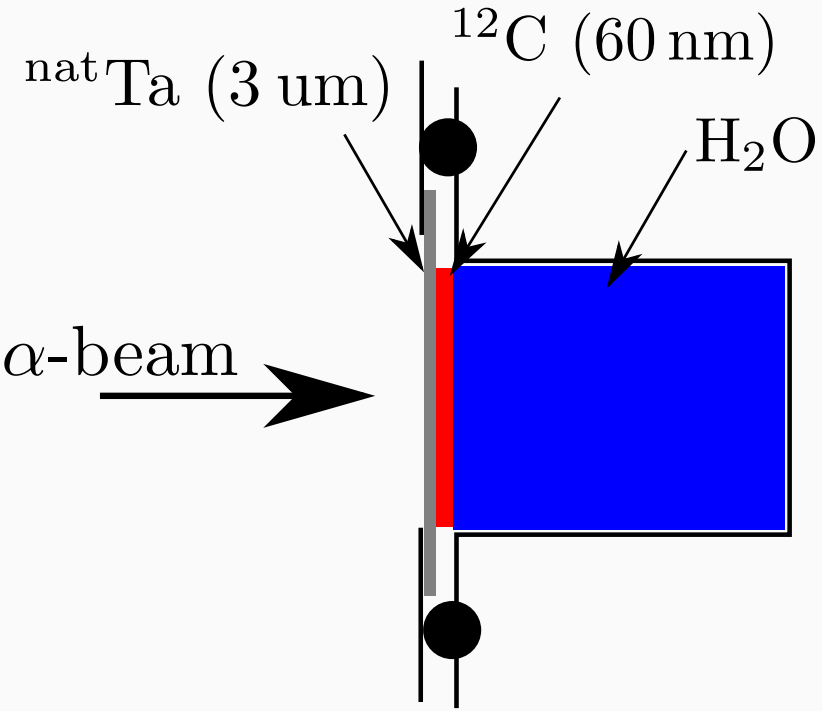
Our Experiment: Stopping Power of H_2O for ^{12}C



Reaction:

$^{12}C(\alpha, \alpha')^{12}C^*$, $E_\alpha = 15\,\text{MeV}$

Our Experiment: Stopping Power of H_2O for ^{12}C



Reaction:

$^{12}C(\alpha, \alpha')^{12}C^*$, $E_\alpha = 15\,\text{MeV}$

What's already on the Market?

Lots of stuff! But often:

- ...Optimised (setups, reactions)
- ...Problematic maintenance
- ...Restricted to "closed" communities

$\rightarrow$ **Idea**

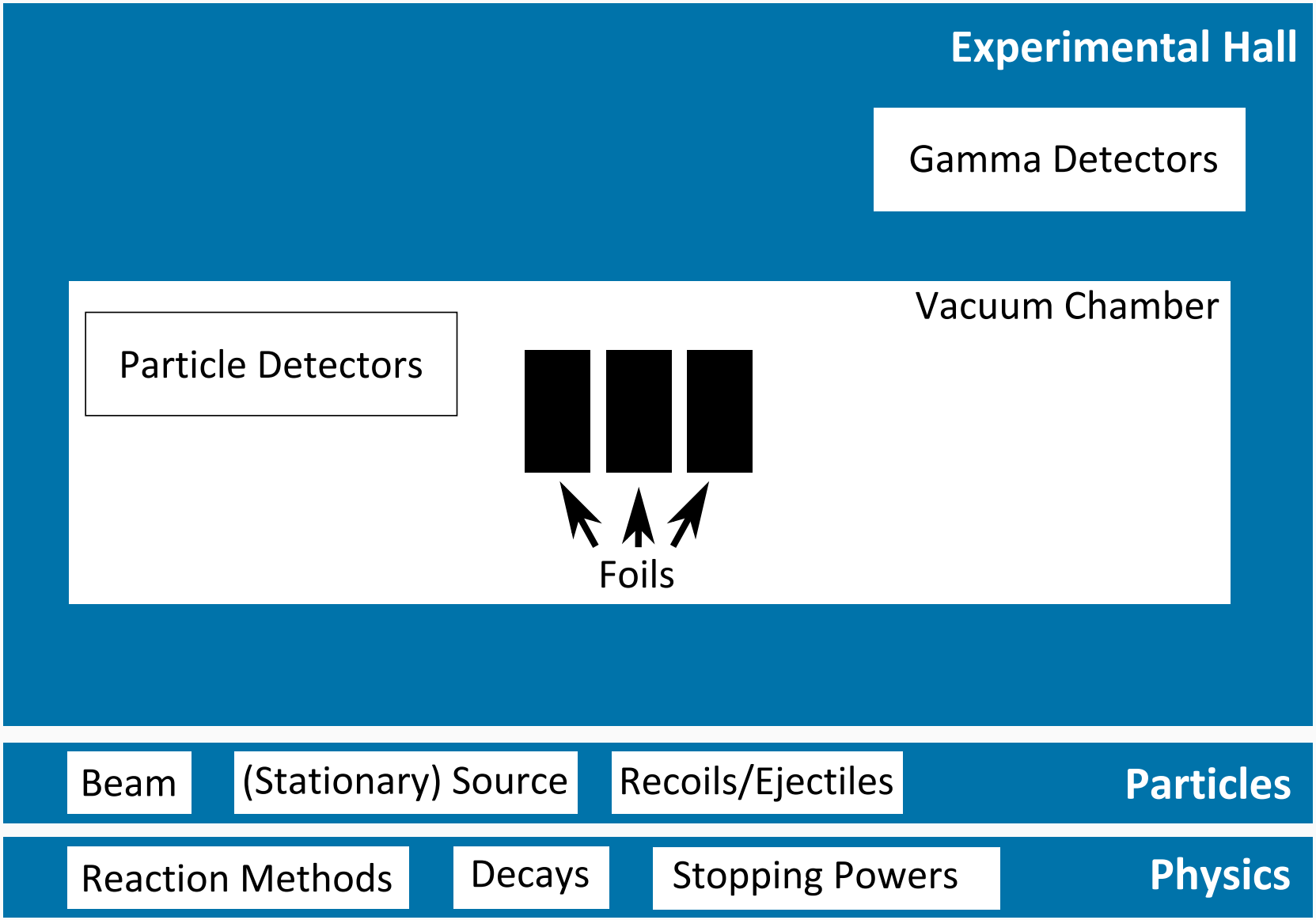
- Versatility (RDDS and DSAM)
- Treatment of γ-singles and (γ, γ) / (particle,γ) coincidences
- Easy adaptability (Messenger)
- Allow a simple implementation of new objects
- Store event-information in ROOT containers

Part 2

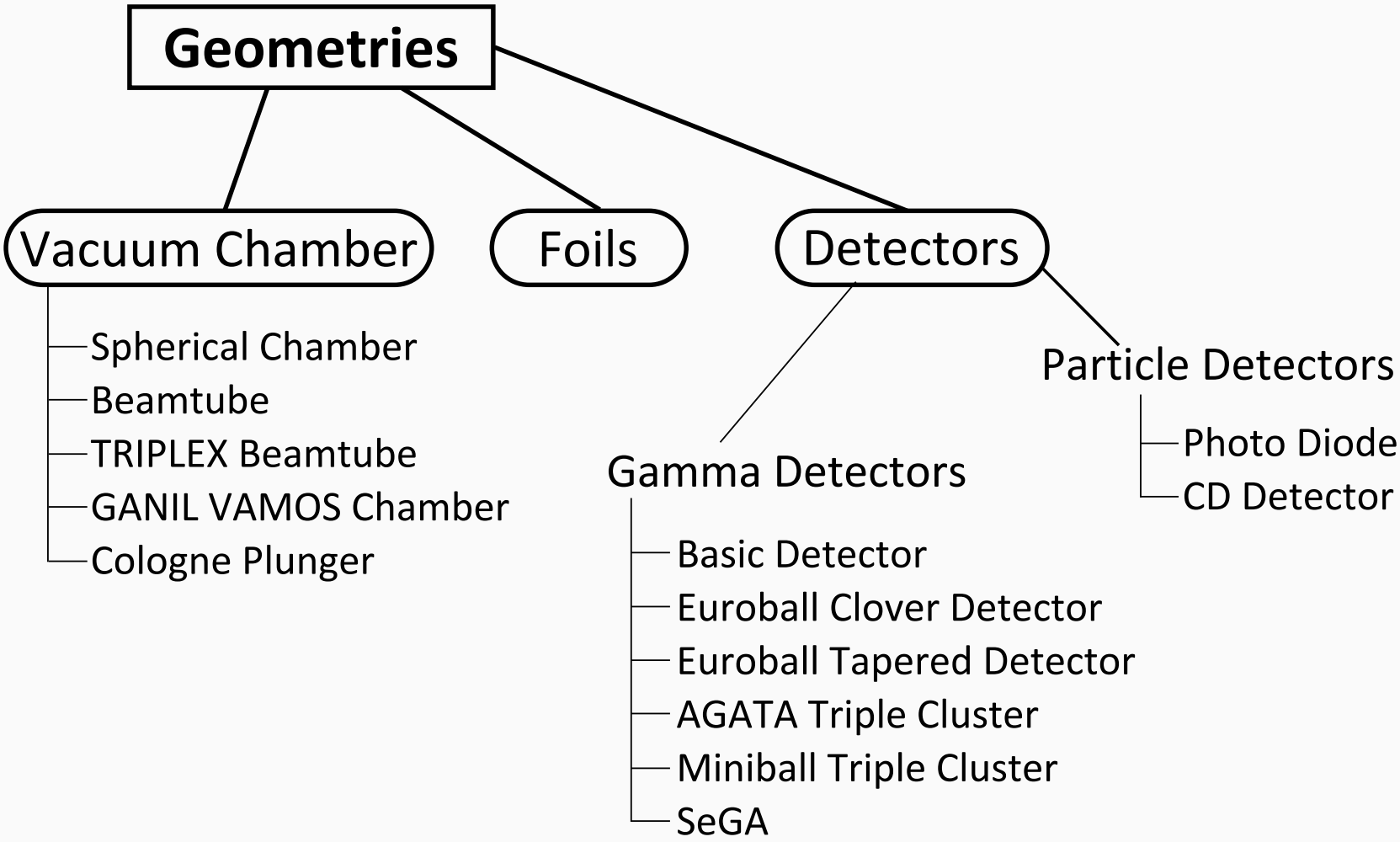
-

Basic Properties

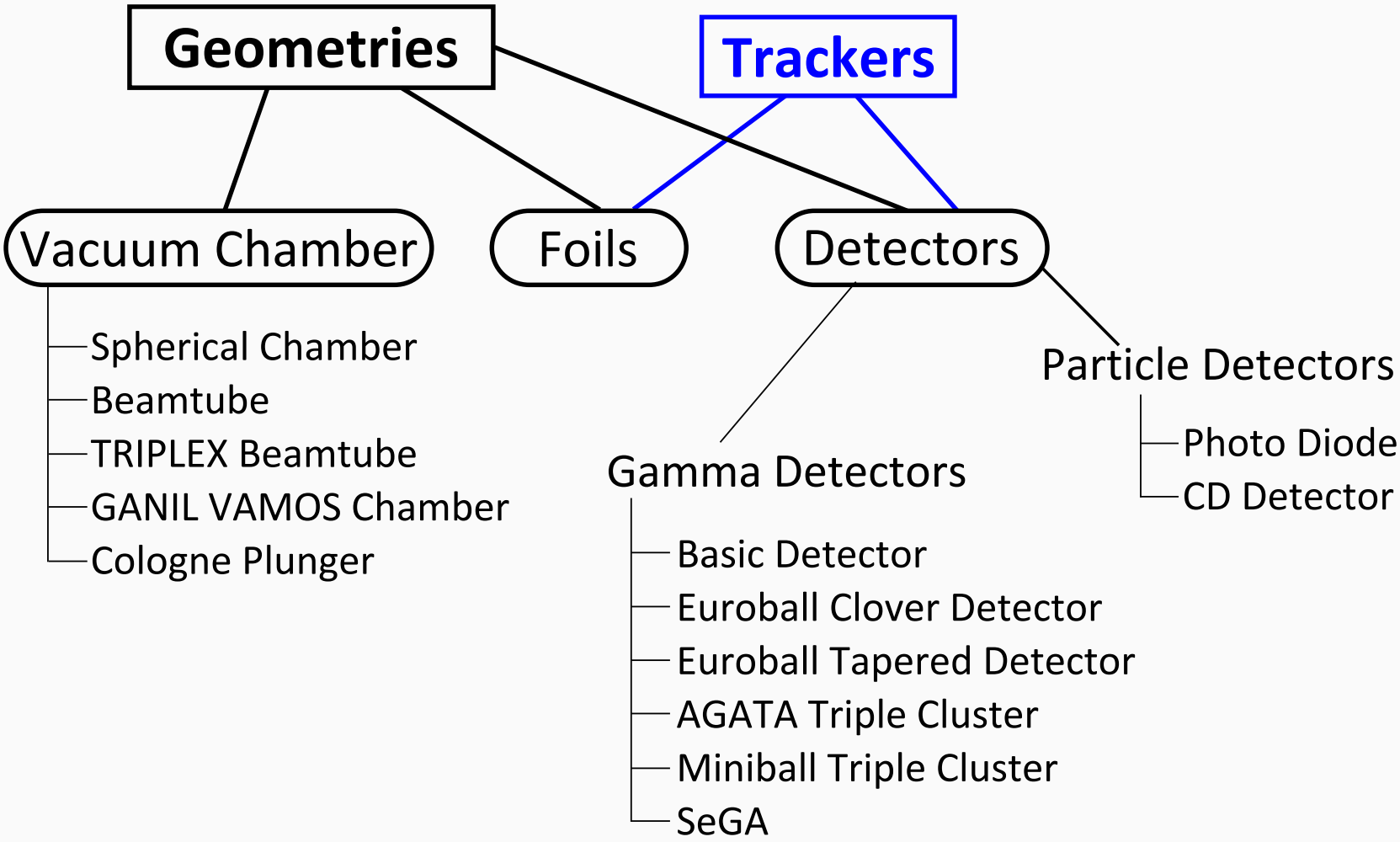
Think in Terms of Modules



Geometries


Geometries
Vacuum Chamber
Foils
Detectors
Spherical Chamber
Beamtube
TRIPLEX Beamtube
GANIL VAMOS Chamber
Cologne Plunger
Gamma Detectors
Basic Detector
Euroball Clover Detector
Euroball Tapered Detector
AGATA Triple Cluster
Miniball Triple Cluster
SeGA
Particle Detectors
Photo Diode
CD Detector

Geometries


Geometries
Trackers
Vacuum Chamber
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Particle Detectors
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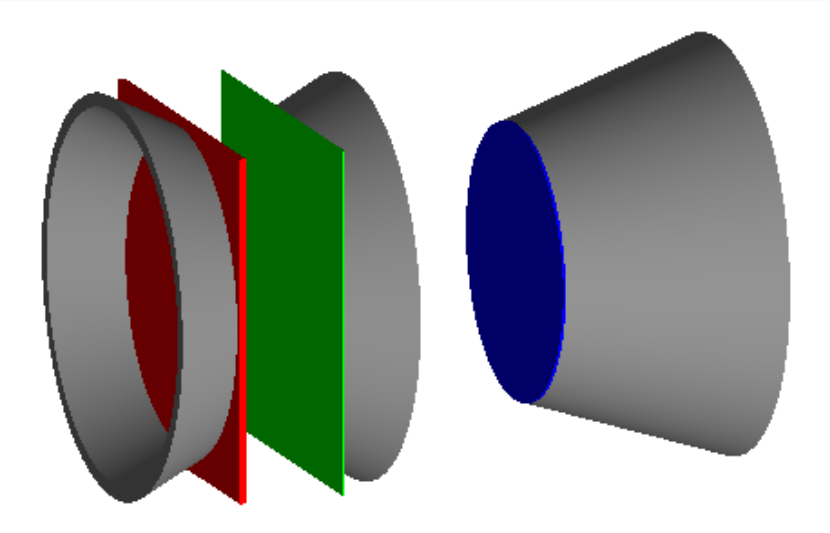
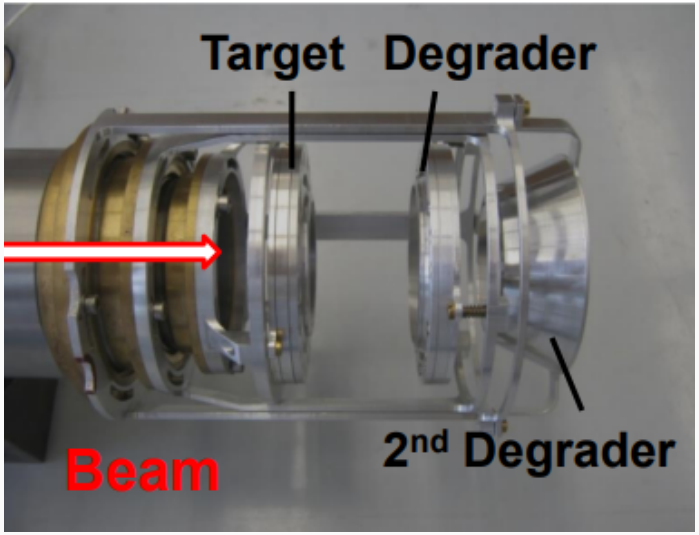
CD Detector
Gamma Detectors
Basic Detector
Euroball Clover Detector
Euroball Tapered Detector
AGATA Triple Cluster
Miniball Triple Cluster
SeGA

Foils with Holders

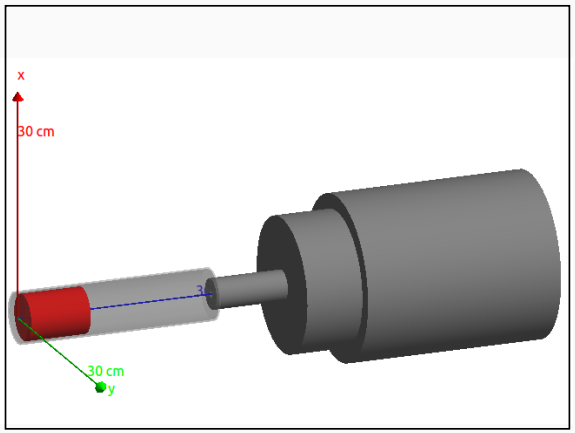
```
/ExperimentalSetup/SetNrOfFoils 3
/ExperimentalSetup/Foil/0/Material G4_Be
/ExperimentalSetup/Foil/0/UseSquare TRUE
/ExperimentalSetup/Foil/0/Thickness 200 um
/ExperimetnalSetup/Foil/0/Width 5 mm
/ExperimentalSetup/Foil/0/CenterPos 0 0 -5 mm
/ExperimentalSetup/Foil/0/SetSteps 20
/ExperimetnalSetup/Foil/0/UseTRIPLEXTargetHolder TRUE
/ExperimentalSetup/Foil/0/HolderOrientation -1 # upstream
/ExperimentalSetup/Foil/0/Construct
```



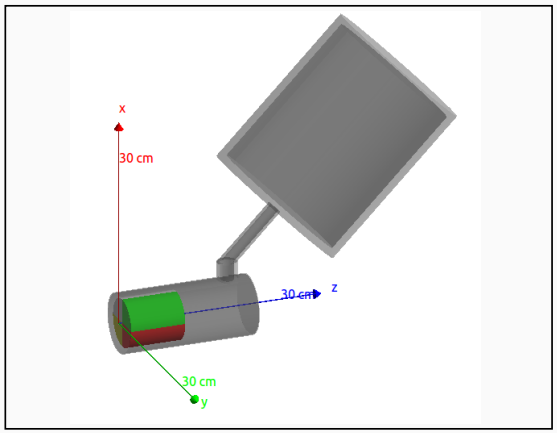


Germanium Detectors - Included Geometries

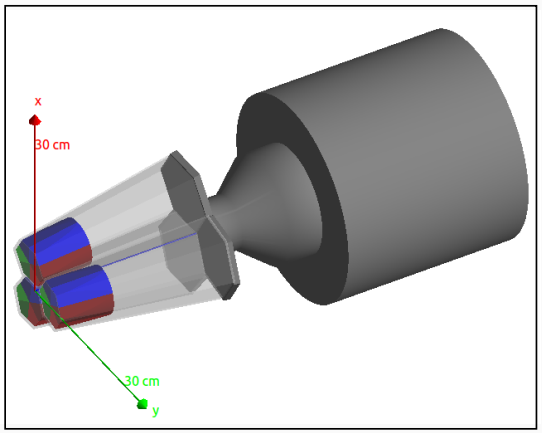
IKP Cologne

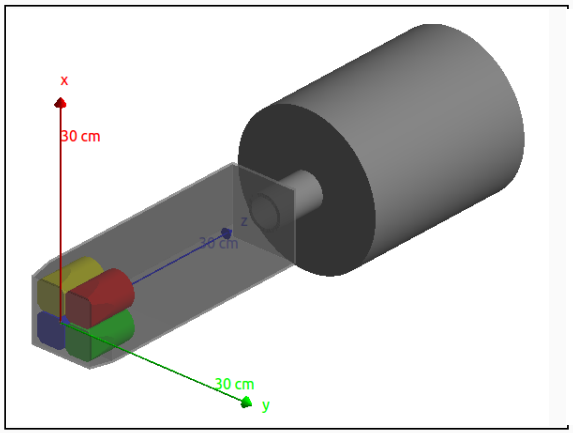


NSCL, MSU

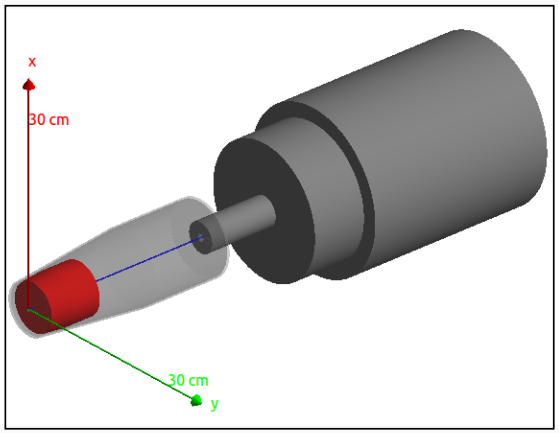


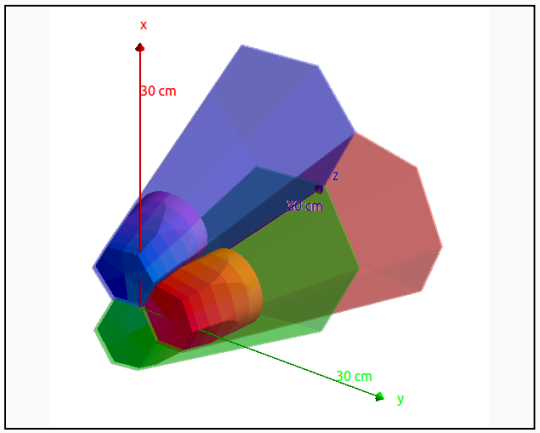
REX ISOLDE, RIKEN





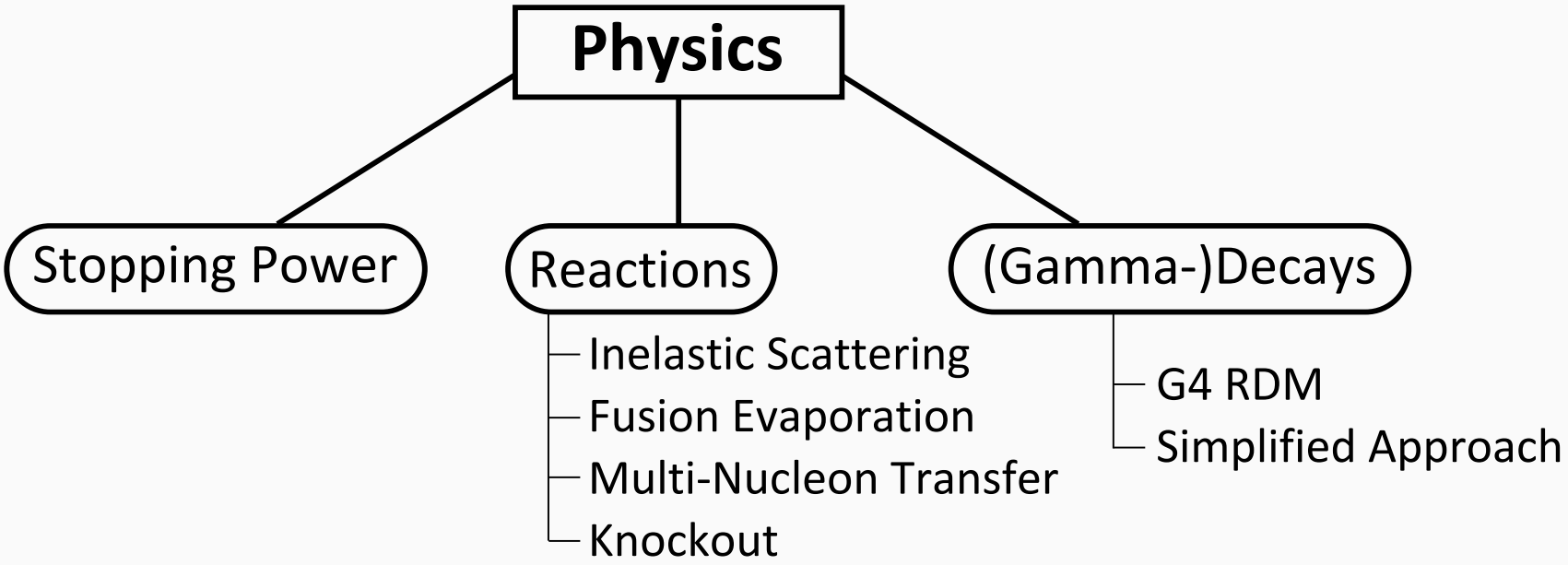
JYFL Jyväskla (Gamma Pool)





GANIL

Overview


Physics
Stopping Power
Reactions
(Gamma-)Decays
Inelastic Scattering
Fusion Evaporation
Multi-Nucleon Transfer
Knockout
G4 RDM
Simplified Approach

Stopping Powers

```
#PhysicsList.cc
if ( particleName == "GenericIon") {
   [...]
   Ionisation = new G4ionIonisation();
   Model = new G4IonParametrisedLossModel();
   Ionisation->SetEmModel(Model);
   ph->RegisterProcess(Ionisation, particle);
   ph->RegisterProcess(new G4NuclearStopping(), particle);
   [...]
}
```

Stopping Powers

```
#PhysicsList.cc
if ( particleName == "GenericIon") {
   [...]
   Ionisation = new G4ionIonisation();
   Model = new G4IonParametrisedLossModel();
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   ph->RegisterProcess(Ionisation, particle);
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   [...]
}
```

Information on electronic stopping power is taken from directory:

```
$G4LEDATA/ion_stopping_data/icru73/
```

Stopping Powers

```
#PhysicsList.cc
if ( particleName == "GenericIon") {
   [...]
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   [...]
}
```

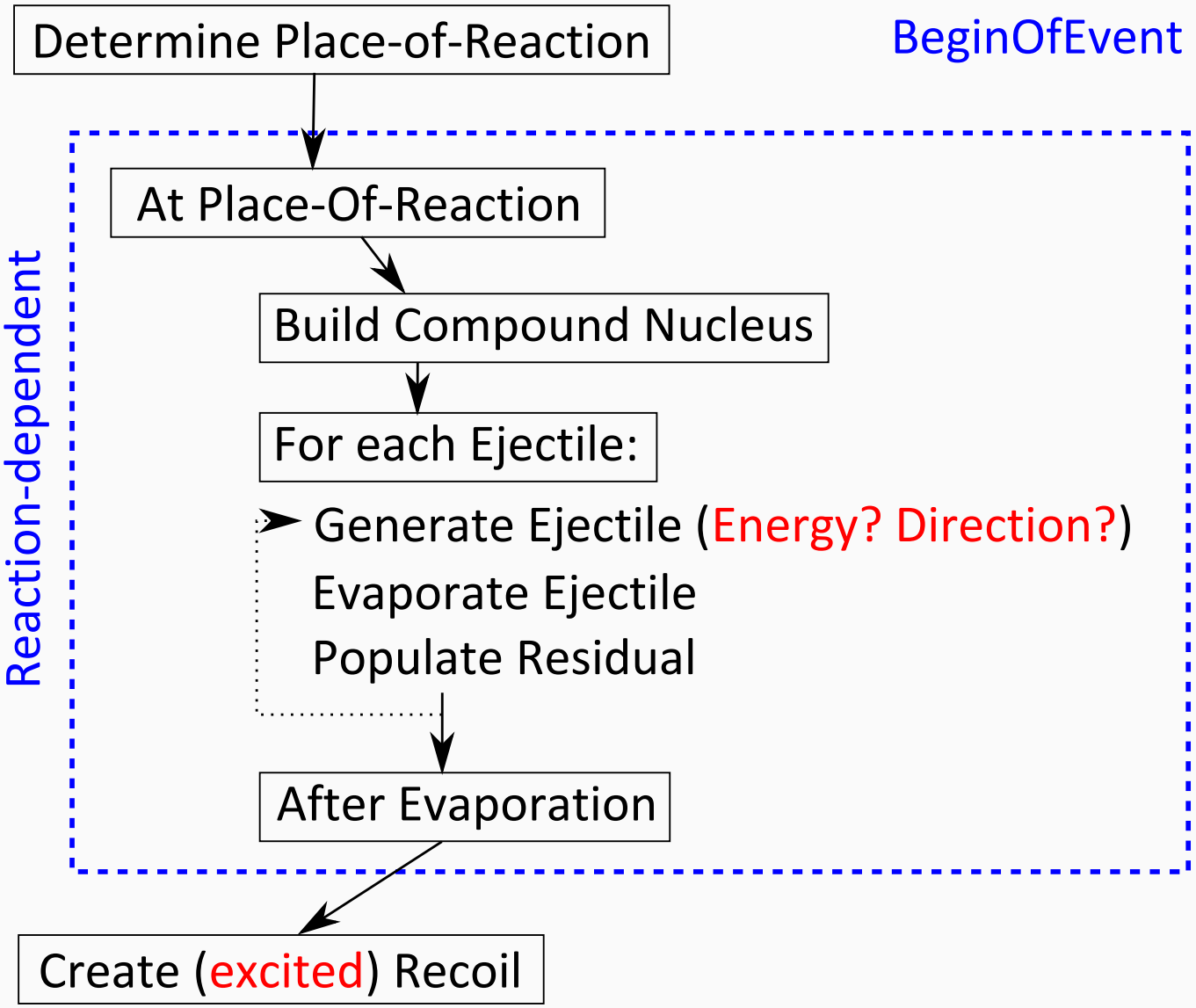
Information on electronic stopping power is taken from directory:

```
$G4LEDATA/ion_stopping_data/icru73/
```

→ G4IonParametrisedLossModel was modified and allows to take tables from a specified directory:

```
/PhysicsList/AddDEDXFromDirectory ./StoppingPowerTables/
```

Simplified Process for Fusion-Evaporation Reactions



Initial Populations and Gamma-Decays (Simplified Model)

- Provide file with information on excited levels

```
/Reaction/0/UseSimplifiedRDModule TRUE
/Reaction/0/SetLSFile LSFile.dat
```

```
#LSFile.dat
0    0     0       0.0   +1   0.0
1    6094  0.005   1.0   -1   0.5
2    6589  4.2     0.0   +1   0.5
```

Represent each level with a G4ParticleDefinition (G4IonTable), set (PDG)Lifetime accordingly and add a decaytable to the particle.

Initial Populations and Gamma-Decays (Simplified Model)

- Provide file with levels

```
#LSFile.dat
0    0      0        0.0   +1   0.0
1    6094   0.005    1.0   -1   0.5
2    6589   4.2      0.0   +1   0.5
```

- Provide file with possible γ-transitions

```
/Reaction/0/UseSimplifiedRDModule TRUE
/Reaction/0/SetTransitionsFile Transitions.dat
```

```
#Transitions
1    0    1.0    0
2    1    0.999  0
2    0    0.001  0
```

Add γ's (modified GammaDecayChannel class) to the decay tables.

Disadvantage: Outdated approach?!

Initial Populations and Gamma-Decays (Geant4 RDM)

```
/PhysicsList/AddRDM TRUE
/Reaction/0/UseG4RDModule TRUE
/Reaction/0/SetN0File N0File.dat
```

```
#N0File.dat
6093.8 0.5
6589.4 0.5
```

- Given level energies must be listed in ENSDFSTATE.DAT (directory: $G4ENSDFSTATEDATA) with the correct τ.
- Information on γ-ray transitions are extracted from files in directory $G4LEVELGAMMADATA. Adjustable:

```
/grdm/setPhotoEvaporationFile 6 14 MyC14EvapFile.dat
```

Q: Why not just the EvaporationFile?

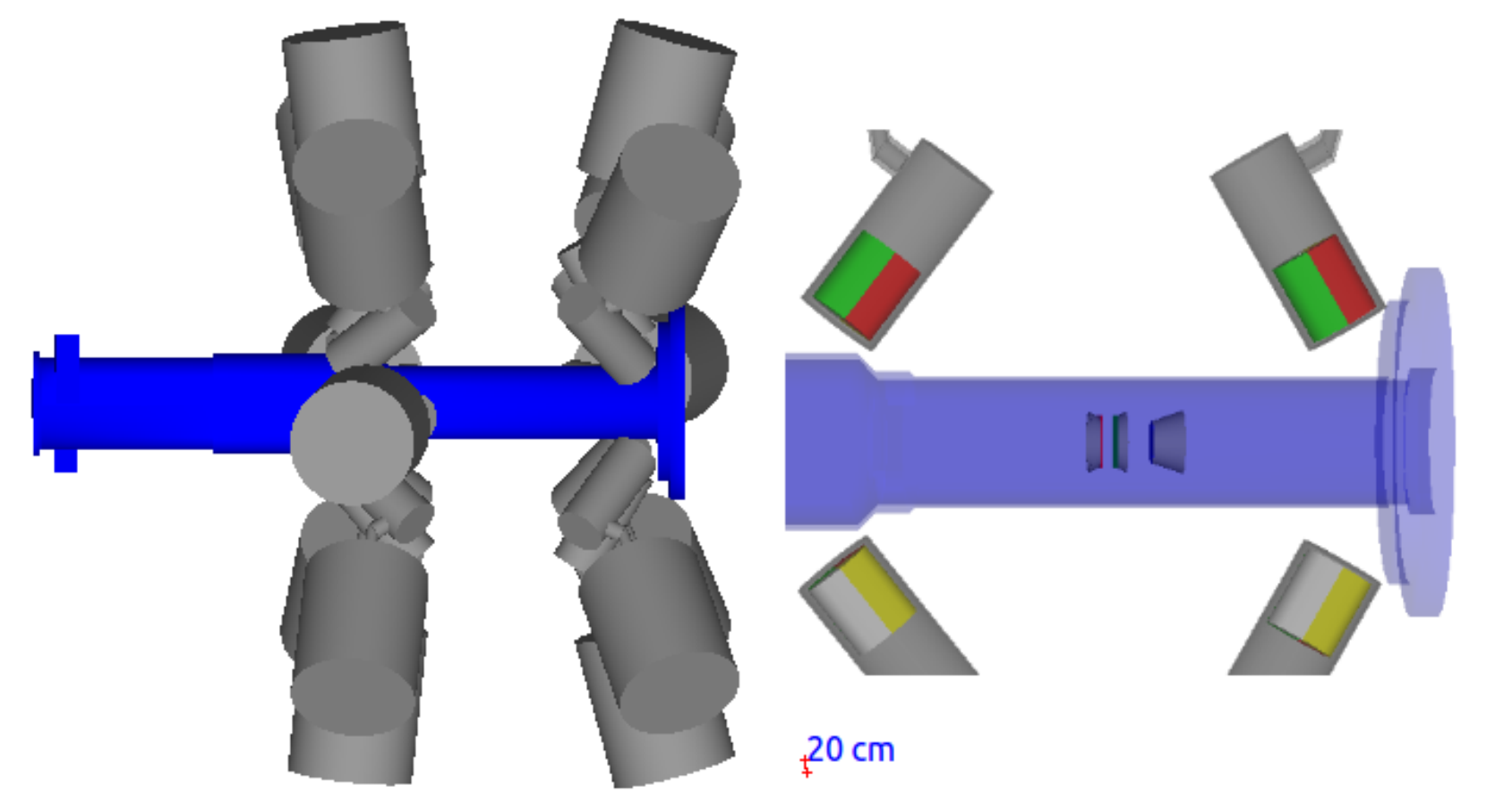
Part 3

-

Applications and Outlook

Applications

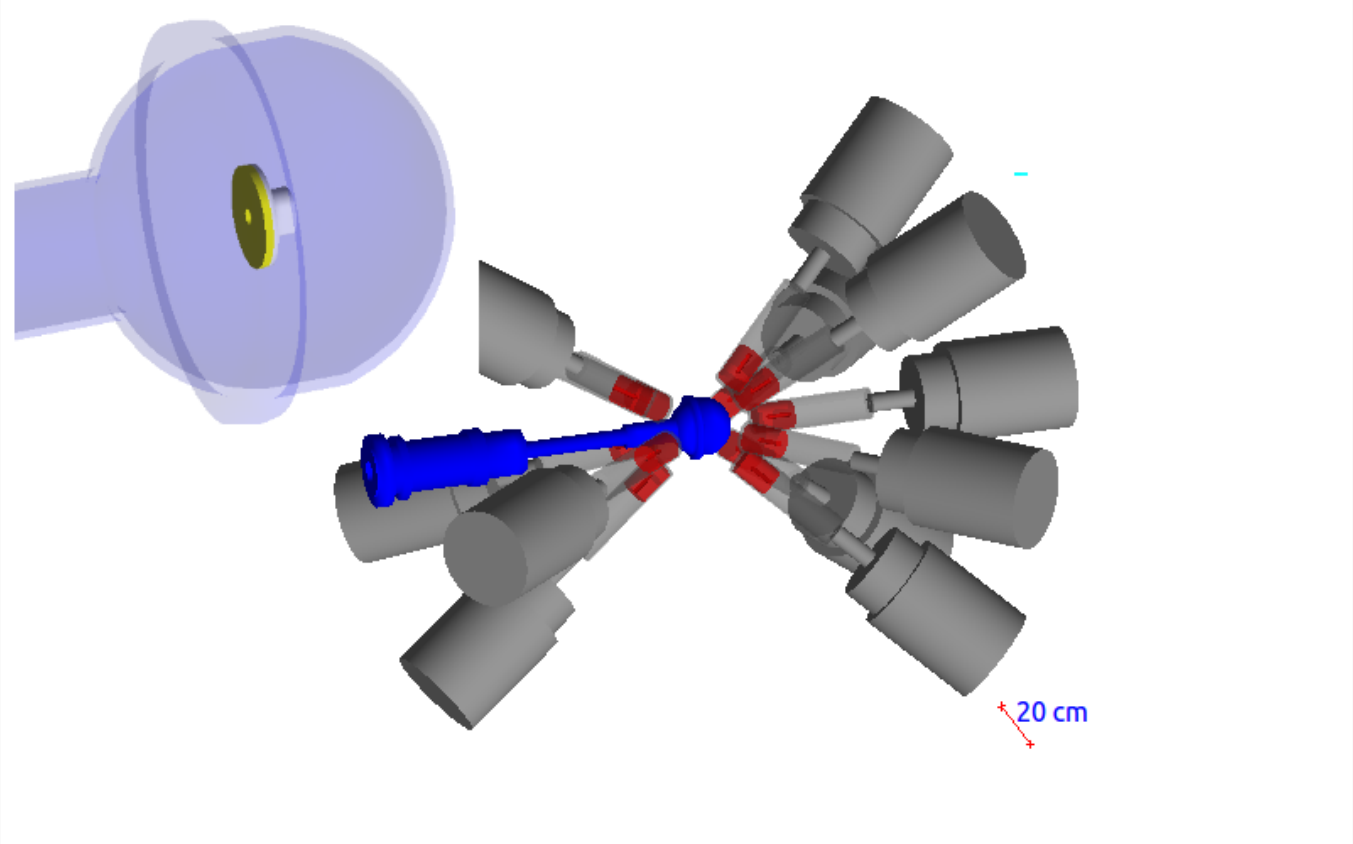
- Preparation of experiments / feasibility studies



SeGA setup at NSCL (S800 vault)

Applications

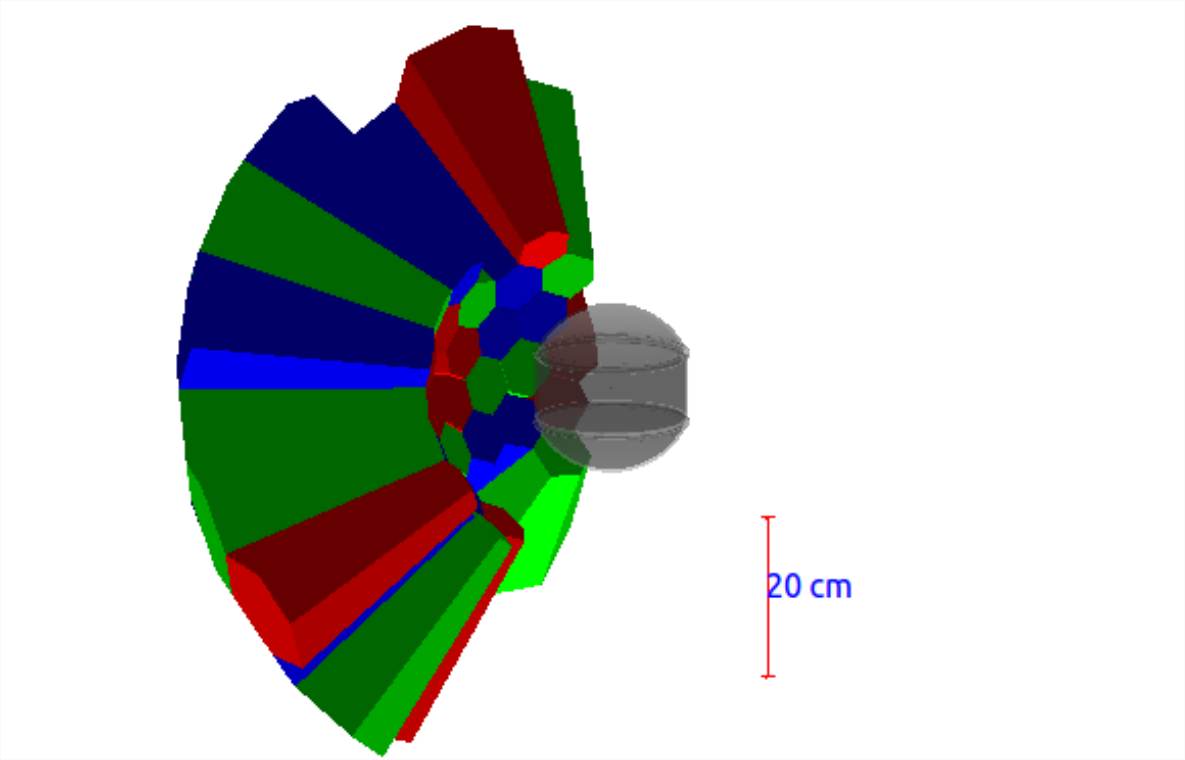
- Preparation of experiments / feasibility studies
- Analysis of experimental data



Lifetime setup at IKP Cologne

Applications

- Preparation of experiments / feasibility studies
- Analysis of experimental data
- Investigation of systematic effects



AGATA at VAMOS

Application: Investigation of Velocity Distributions in RDDS

Exponential Decay Law: $N(t) = N_0 \exp(-t/\tau)$

But: RDDS depends on separations d

$\rightarrow$ For a fixed β:

$N(t) \rightarrow N(d[\mu\text{m}]) = N_0 \exp(-d[\mu\text{m}]/3 \cdot \beta[\%] \cdot \tau[\text{ps}])$

Problem arises in case of broad velocity distributions.

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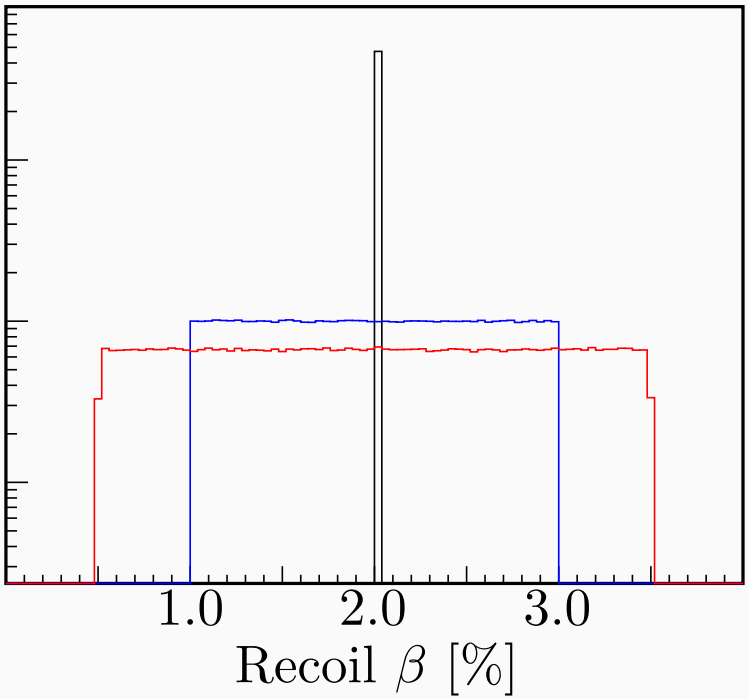
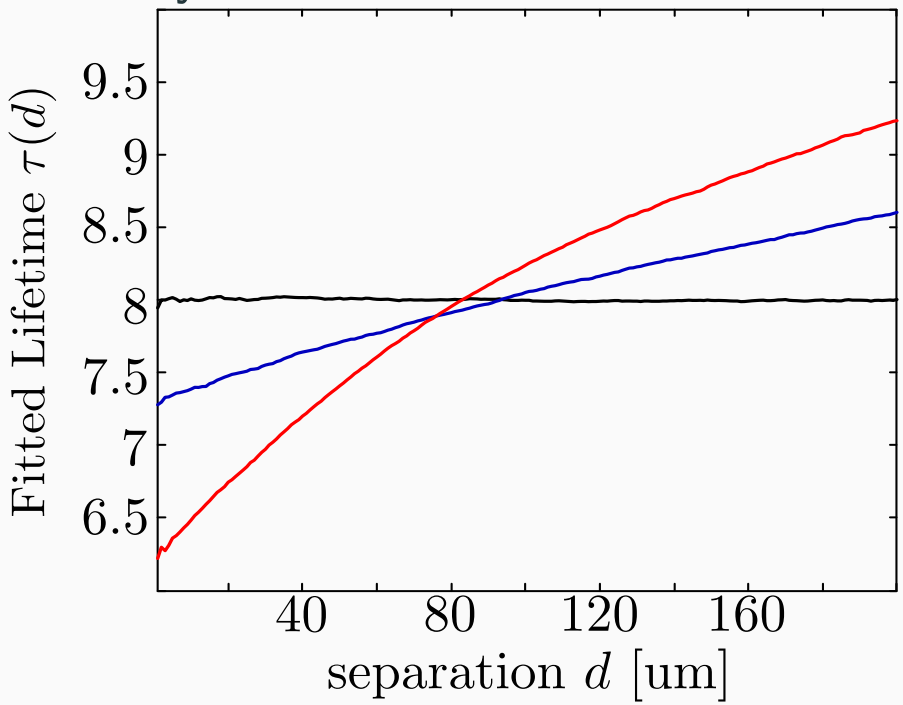
Problem arises in case of broad velocity distributions.





Outlook

Almost done:

- Code (will be published soon (git))
- Manual
- Publication

Afterwards:

- Refinements and improvements (Reactions, Angular Correlations,..)
- Implementation of new geometries (in collaboration?)

End

Development of a Monte Carlo code for lifetime studies

- For RDDS and DSAM experiments
- Modular concept, high flexibility
- Easy to use
- Easy to extend

contact: Thomas Braunroth, thomas.braunroth@ptb.de

Thanks for your attention

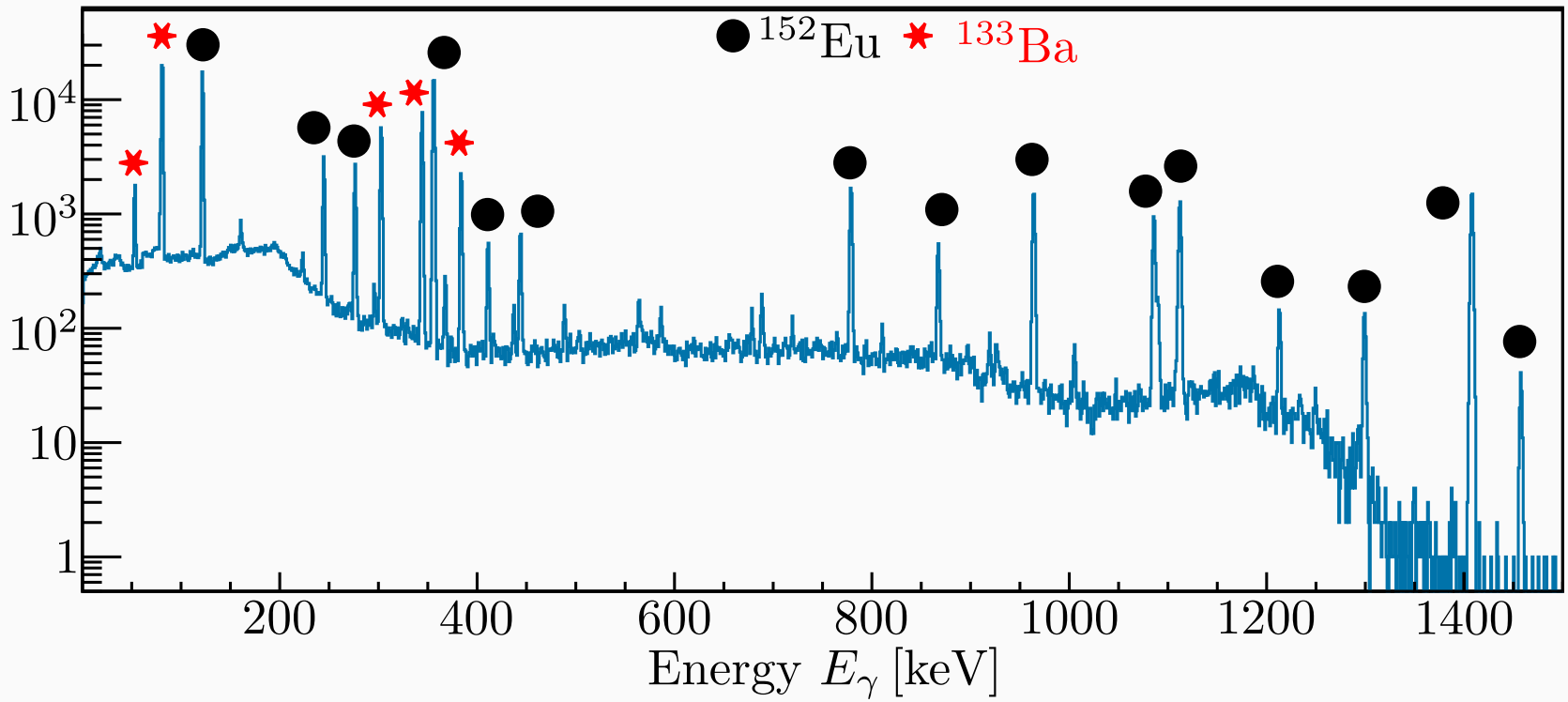
This work is supported by the DFG, contract number: 311 099 672

Backup

Primaries - Stationary Source

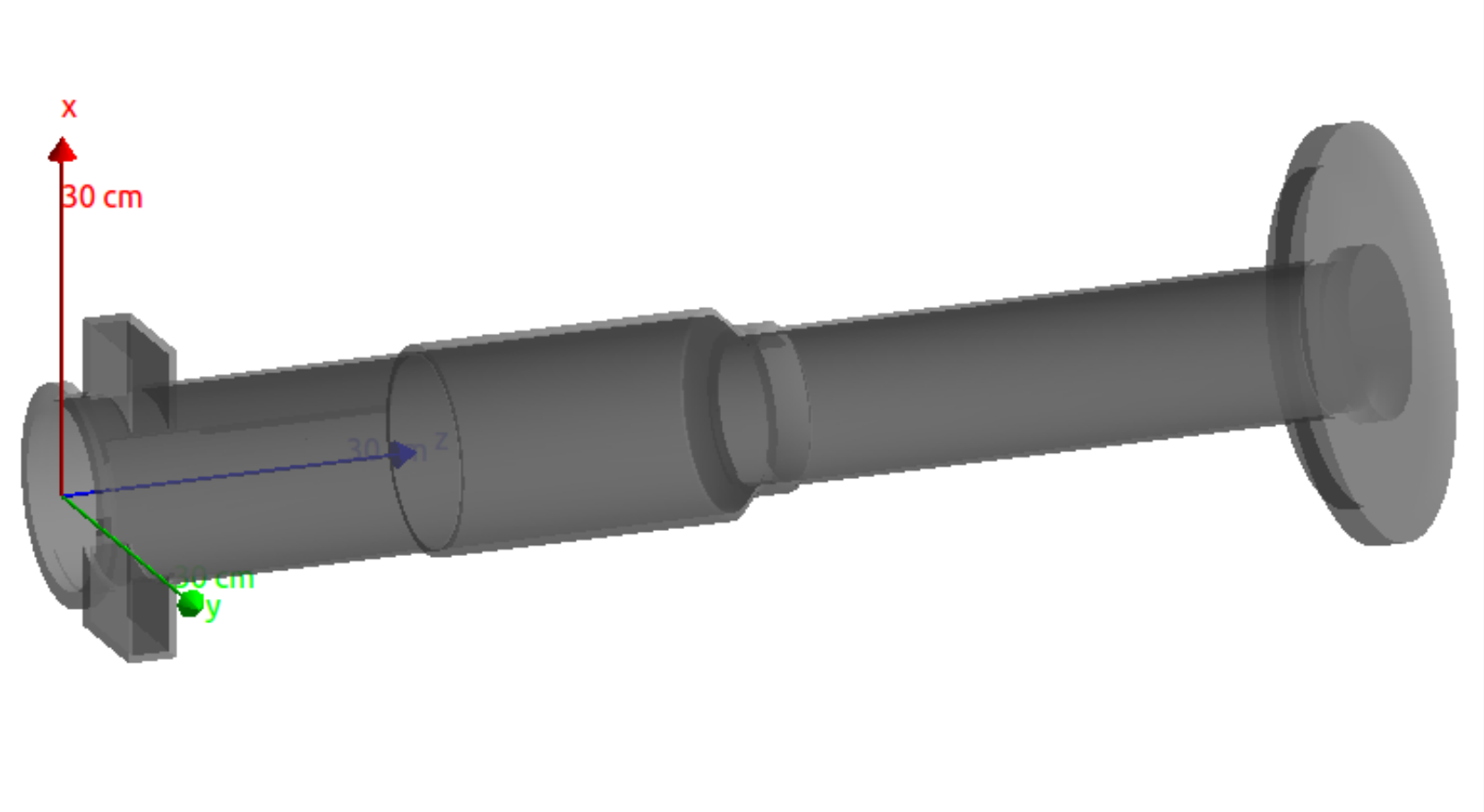
- Based on the radioactive decay module

```
/Experiment/UseSource TRUE
/Experiment/Source/AddMaterial 0.5 152 63 # 50% Eu-152
/Experiment/Source/AddMaterial 0.5 133 56 # 50% Ba-133
```



Vacuum Chamber: TRIPLEX Tube

```
/ExperimentalSetup/UseTRIPLEXTube TRUE
/ExperimentalSetup/SetOffset 0 0 -40 cm
/ExperimentalSetup/SetRotationZ -25 deg
/experimentalSetup/Construct
```



Foils

Handling of an arbitrary number of foils.

The properties of a foil can be set independent of each other:

- Material
- Geometry (Base area and thickness)
- Placement (Position and Orientation)
- Attached holding structure

Each foil is a sensitive volume and allows particle tracking

Germanium Detectors - Input

- General information

```
/ExperimentalSetup/GammaDetector/DetectorFile Ge.dat
```

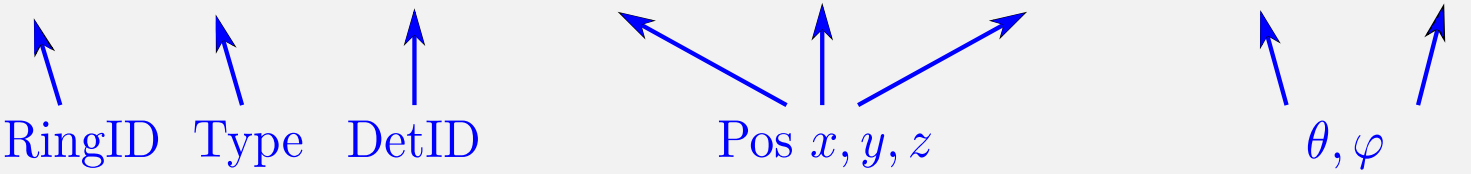
```
#Ge.dat
0        6        1        15        0        15        45        0
```

Germanium Detectors - Input

- General information

```
/ExperimentalSetup/GammaDetector/DetectorFile Ge.dat
```

```
# Ge.dat
0 6 1 15 0 15 45 0
```



Germanium Detectors - Input

- General information
- Resolution parameter (optional)

```
/ExperimentalSetup/GammaDetector/ResolutionFile  Res.dat
```

```
# Res.dat
1          0          2          1          0
1          1          4          2          0
1          2          2          1          0          2          1
```

Germanium Detectors - Input

- General information
- Resolution parameter (optional)

```
/ExperimentalSetup/GammaDetector/ResolutionFile  Res.dat
```

```
# Res.dat
1          0          2          1          0
1          1          4          2          0
1          2          2          1          0          2          1
```

DetID CrystalID Resolution (A,B,C) Tailing (α, β)

Germanium Detectors - Input

- General information
- Resolution parameter (optional)
- CFD Cut-Off (optional)

```
/ExperimentalSetup/GammaDetector/CFDFile CFD.dat
```

```
#CFD.dat
1          0          100        20
1          1          0          0
1          2          70         50
```

Germanium Detectors - Input

- General information
- Resolution parameter (optional)
- CFD Cut-Off (optional)

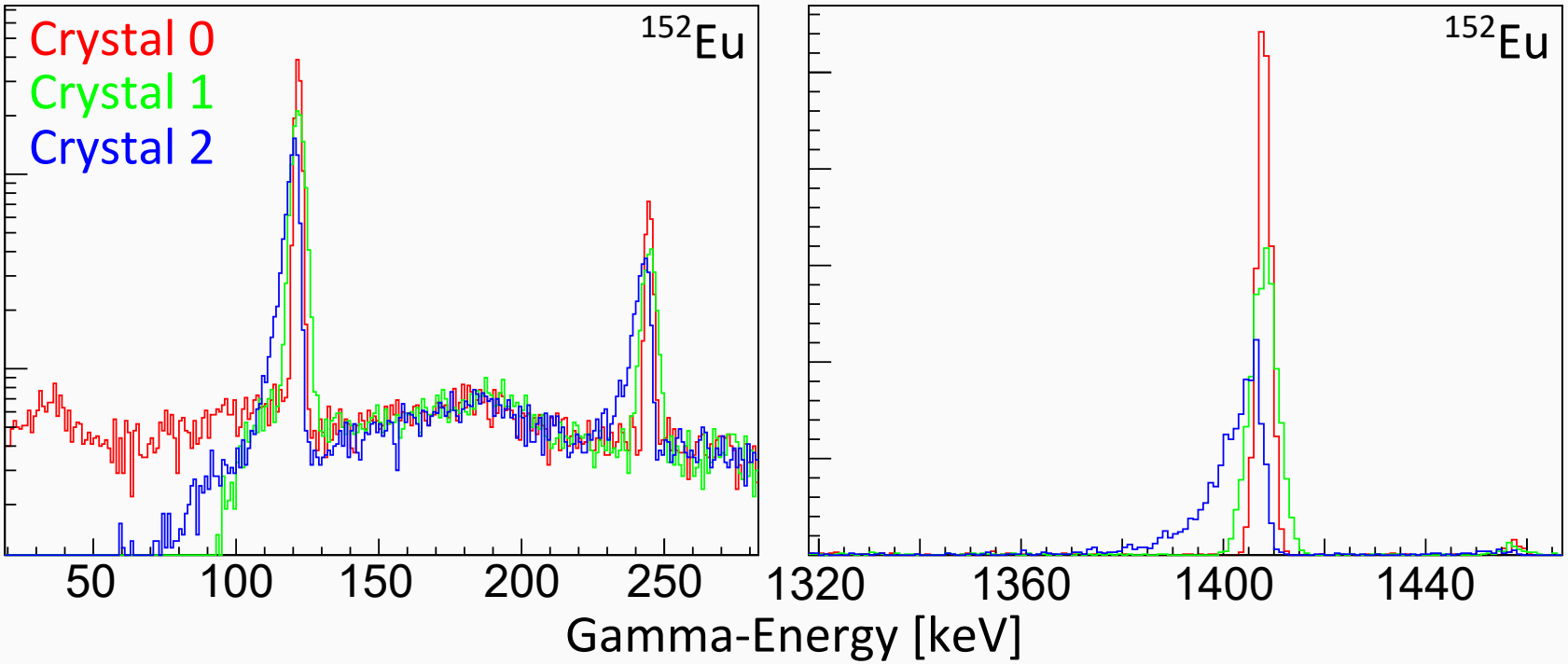
```
/ExperimentalSetup/GammaDetector/CFDFile CFD.dat
```

```
#CFD.dat
1          0          100        20
1          1          0          0
1          2          70         50
```

DetID CrystID $\overline{E}$ σ

Germanium Detectors - Input

- General information
- Resolution parameter (optional)
- CFD Cut-Off (optional)

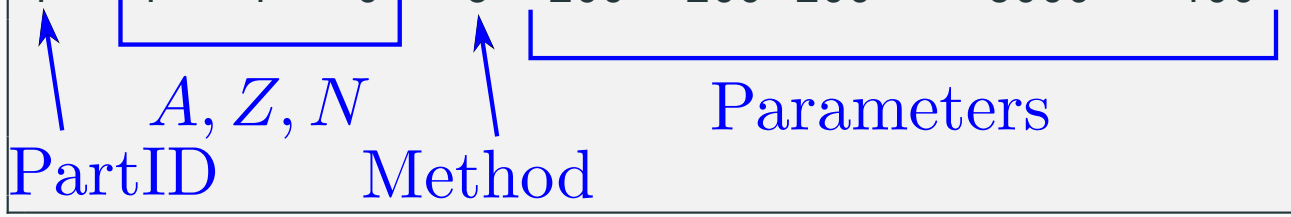


Ejectile Properties (Fusion Evaporation)

- Energy (in the cm system)

```
/Reaction/0/UseFusionEvaporation TRUE
/Reaction/0/SetEvaporationFile Evap.dat
```

```
#Evap.dat
0   1   0   1   2   200   0   1000   100
1   1   1   0   3   200   200 200    5000   100
```



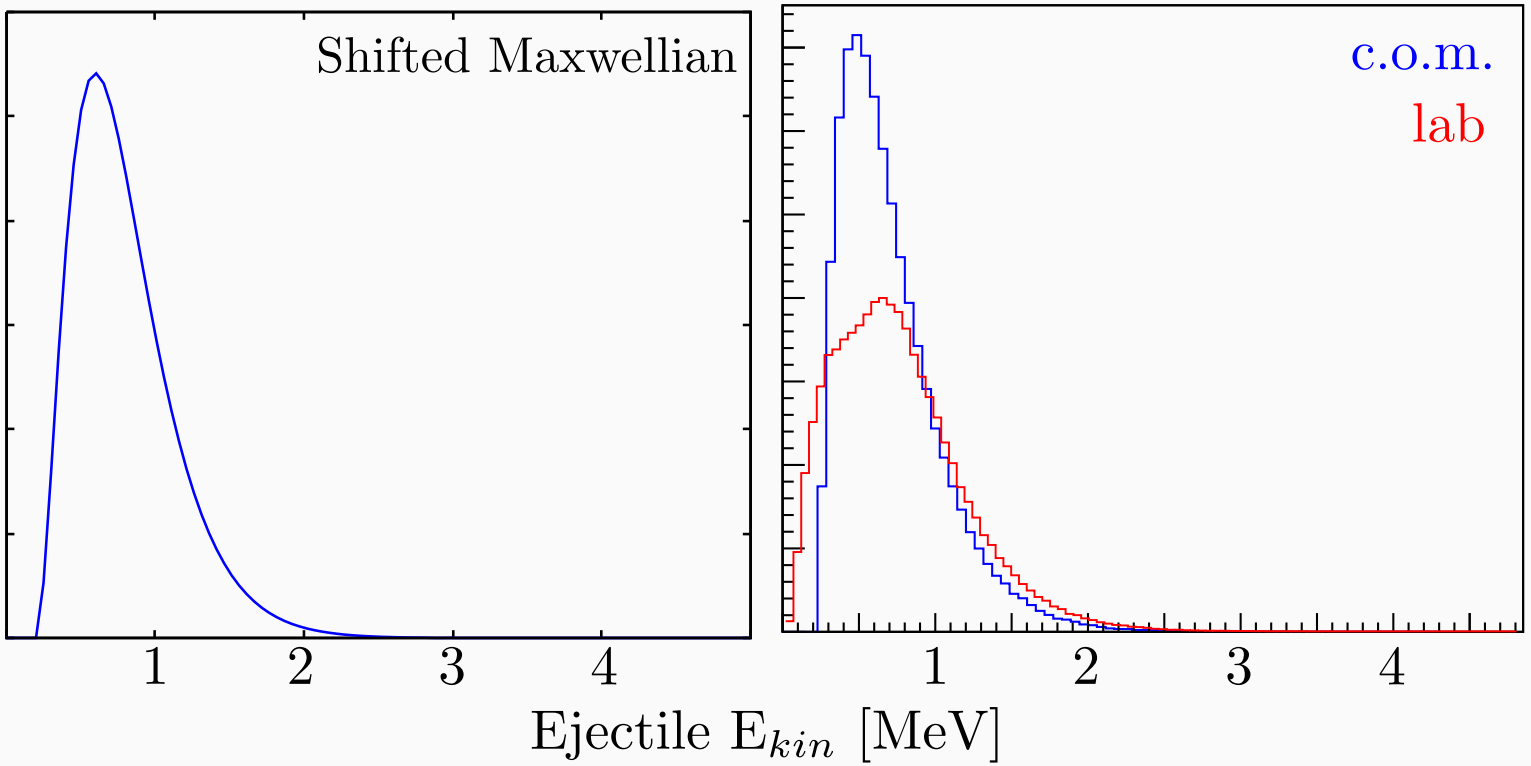
→ Several methods: fixed energy, Gaussian distribution, Maxwellian distribution, shifted Maxwellian distribution,...

Ejectile Properties (Fusion Evaporation)

- Energy (in the cm system)

```
/Reaction/0/UseFusionEvaporation TRUE
/Reaction/0/SetEvaporationFile Evap.dat
```

```
#Evap.dat
0    1    0    1    2    200   0    1000    100
1    1    1    0    3    200   200  200     5000    100
```



Ejectile Properties (Fusion Evaporation)

- Energy (in the cm system)
- Direction

```
/Reaction/0/SetEvaporationThetaFile EvapTheta.dat
```