The continuous-angle DSA Method

(sub-) picosecond lifetime measurements with position-sensitive HPGe detector arrays

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- How to facilitate DSAM measurements with position-sensitive HPGe detectors?
- How to perform DSAM measurements with radioactive, relativistic beams?

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Motivation – Value of lifetime measurements

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- **Model-independent access to transition strengths**

$$1/\tau \propto B\left(\mathcal{M}L; J_i^\pi \rightarrow J_f^\pi\right) = \frac{1}{2L+1}\left|\left\langle J_f^\pi \,\|\|\hat{m}L\|\|\, J_i^\pi \right\rangle\right|^2$$

→ probing nuclear wave functions

- **In conjunction with Coulex cross section measurements: Determine nuclear quadrupole moments**

$$\sigma_{Coulex} = f(M_{12}, M_{22})$$

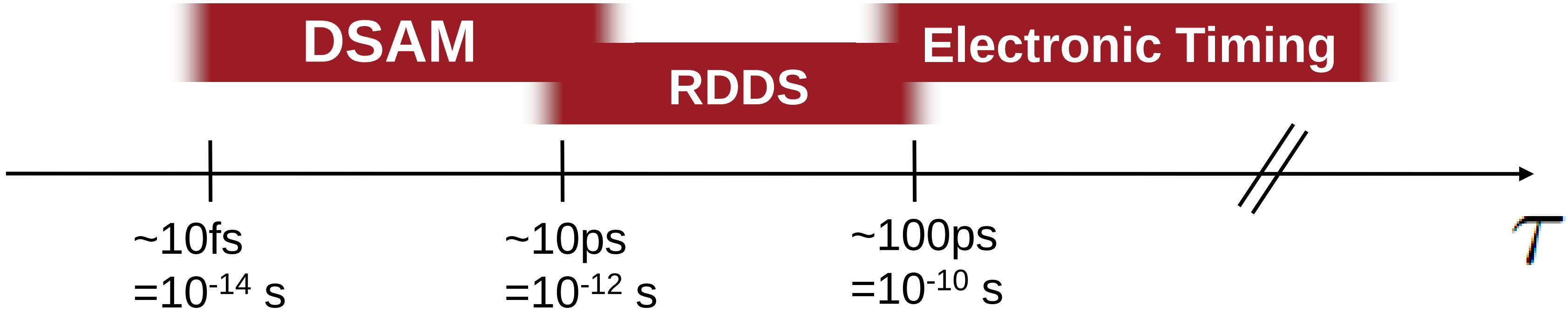
from τ (→ M_{12})

$\propto Q$ (→ M_{22})

→ e.g. C. Bauer *et al.*, PRC **86**, 034310 (2012)

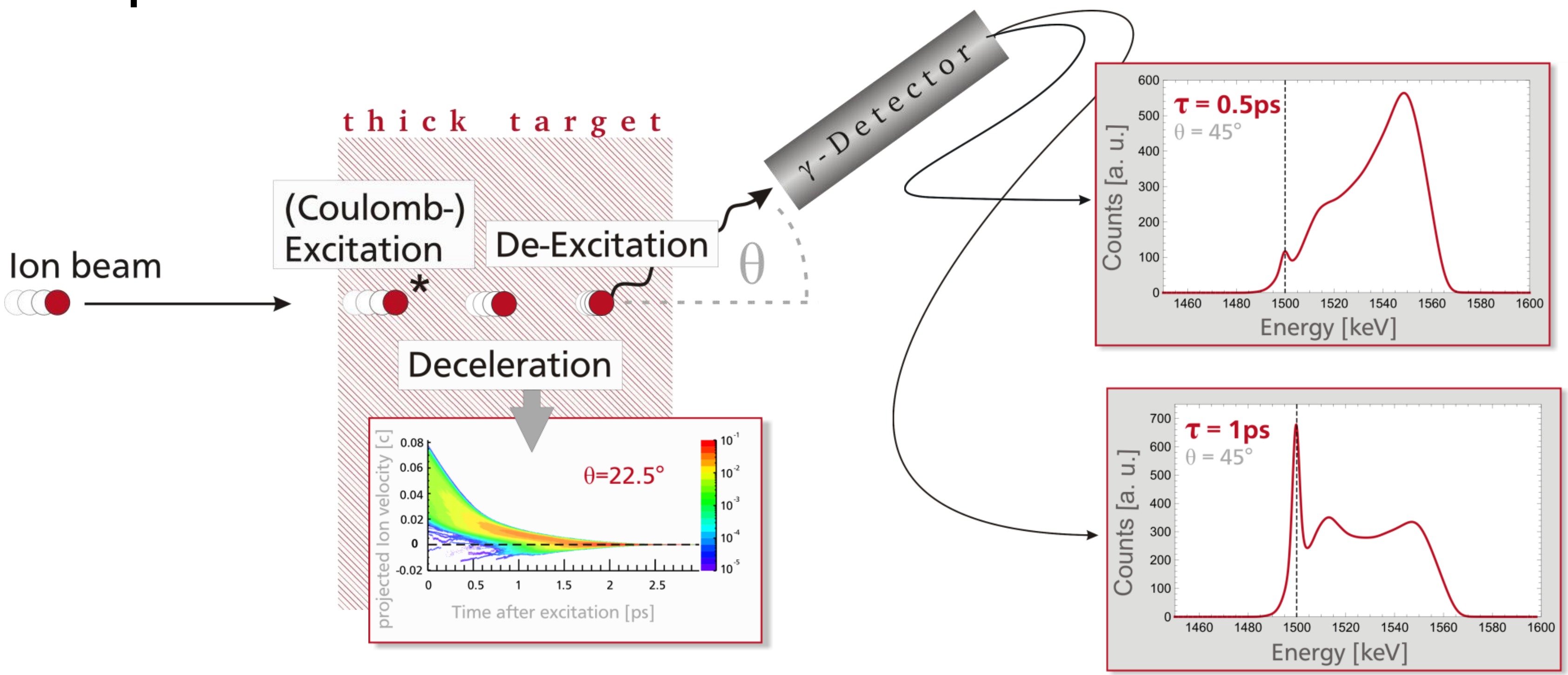
Basics – Doppler-Shift Attenuation Method

- **Lifetime range:**



Basics – Doppler-Shift Attenuation Method

- **Principle:**



Deduce **level lifetimes** from the shape of **Doppler-broadened photo-peaks**

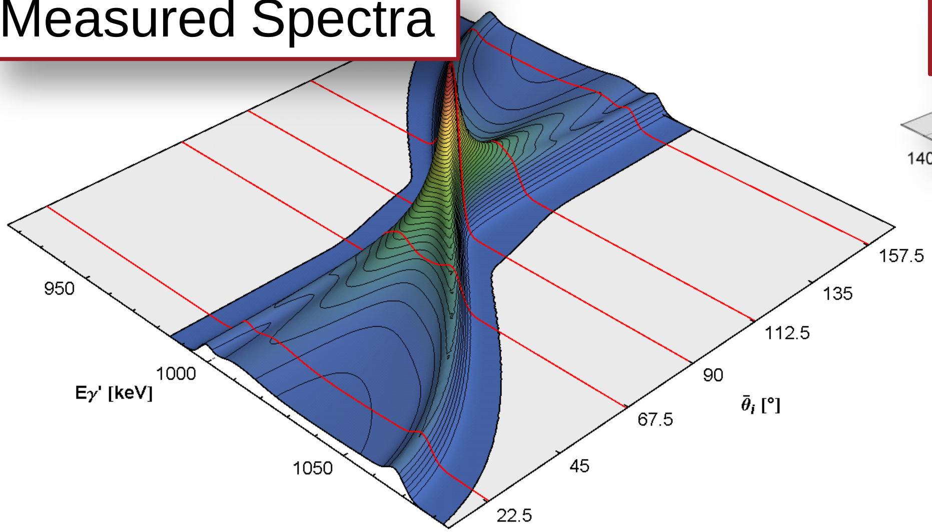
The continuous angle DSA Method

That is done since the 60's. What's new about that?

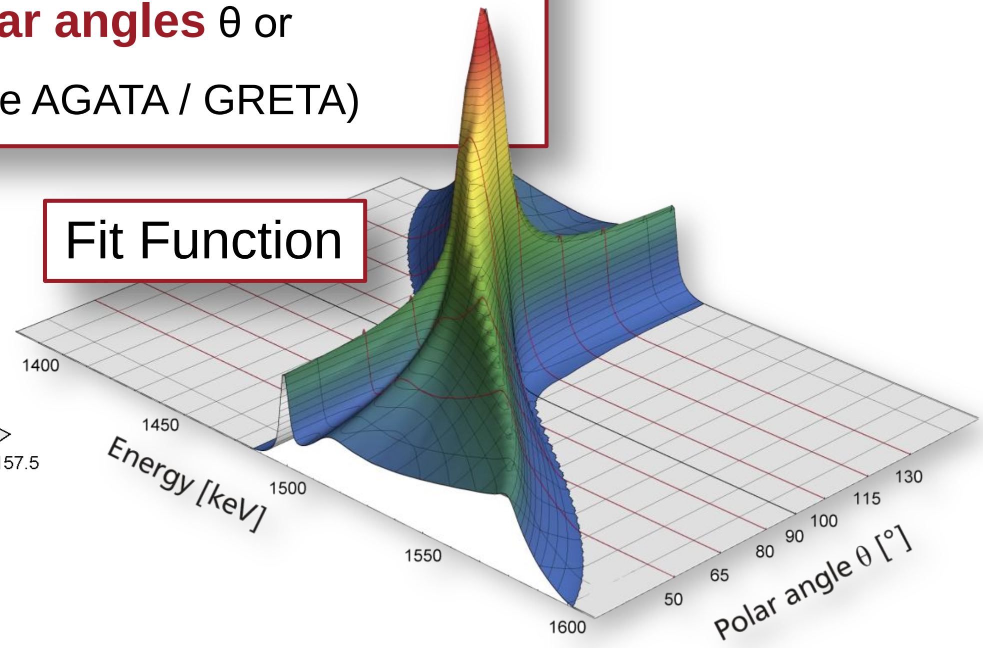
Newly developed **analysis software**

Designed for the **simultaneous fit** to spectra taken with **many detectors** under **many polar angles** θ or **position sensitive detectors** (like AGATA / GRETA)

Measured Spectra



Fit Function



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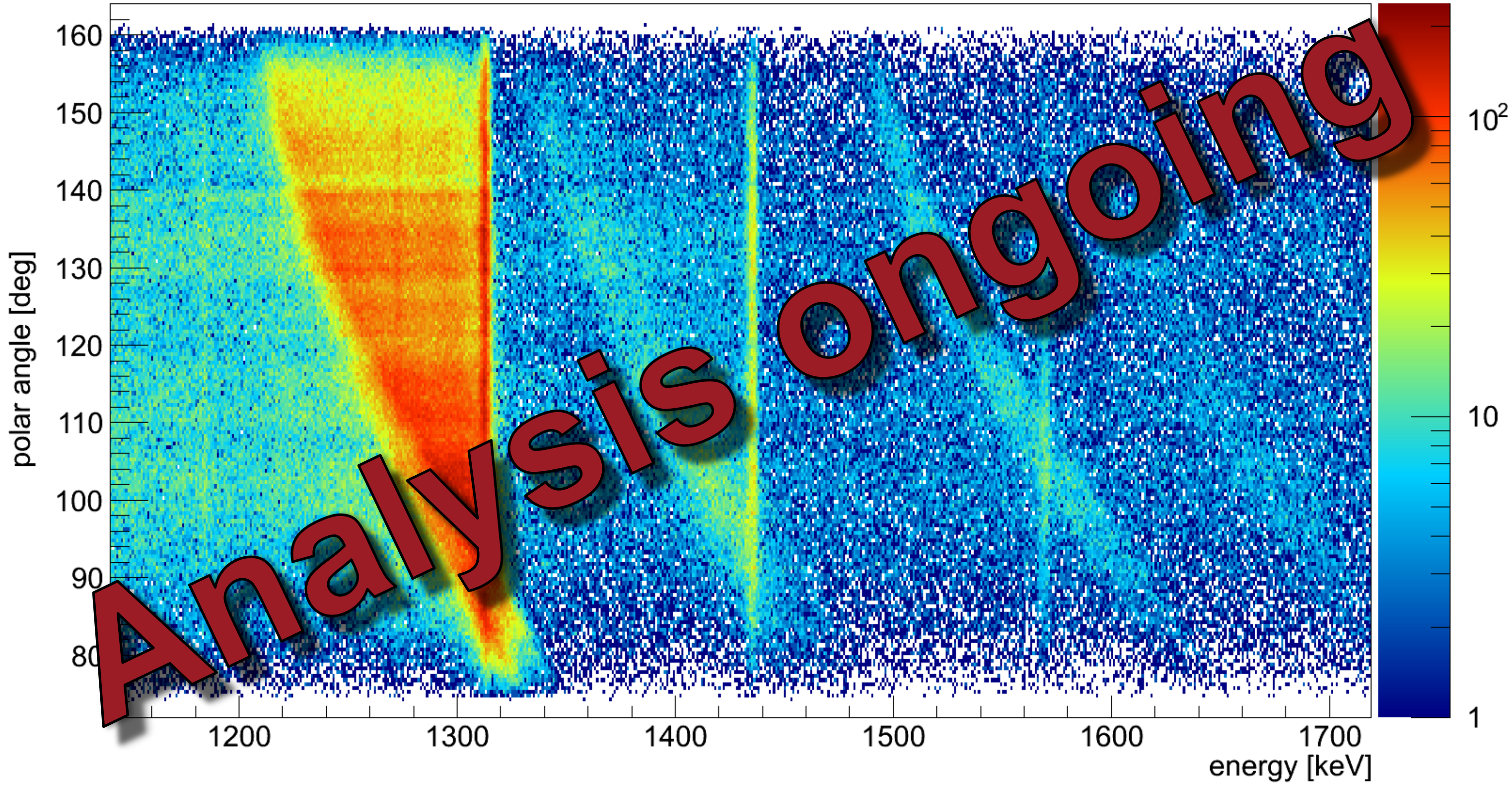
The continuous angle DSA Method

^{136}Xe-ions Coulomb excited on 0.5mg/cm² Carbon, stopped in 30mg/cm² Tantalum



LNL-experiment 09.08, ^{136}Xe at 546 MeV, recoiling carbon ions detected by a DSSSD
AGATA Demonstrator with 5 TC at backward angles

The continuous angle DSA Method

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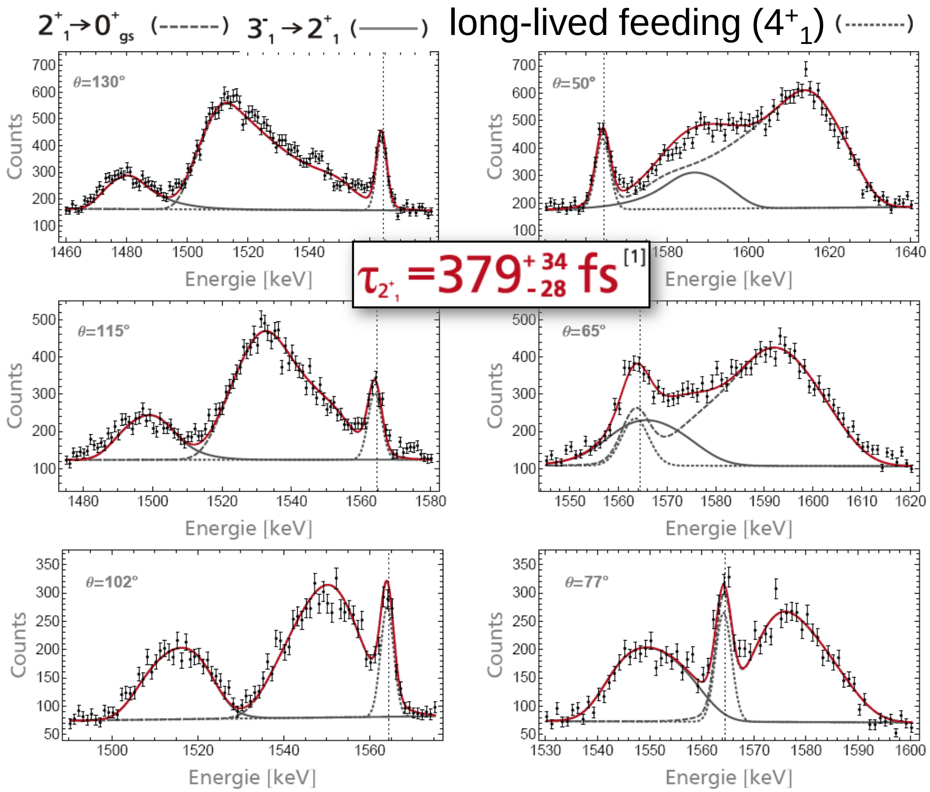
- **Effective use of the full statistics and resolution**
- **Good chances to disentangle overlapping transitions**



GSI-Experiment U246 (10/2010)

^{86}Kr @ 2.91AMeV

Coulomb-excited on a 0.33mg/cm² ^{nat}C layer

stopped in a multilayer-target (Gd, Ta and Cu)

γ-rays detected by 4 EUROBALL cluster detectors.

recoiling carbon ions detected by 4 PIN diodes

Overlapping $2^+_1 \to$gs and $3^-_1 \to 2^+_1$ transitions

[1] C. Stahl, Master Thesis, TU Darmstadt, 2011

- **Also applicable to position in-sensitive HPGe arrays (Miniball, Gammasphere, …)**

The continuous angle DSA Method

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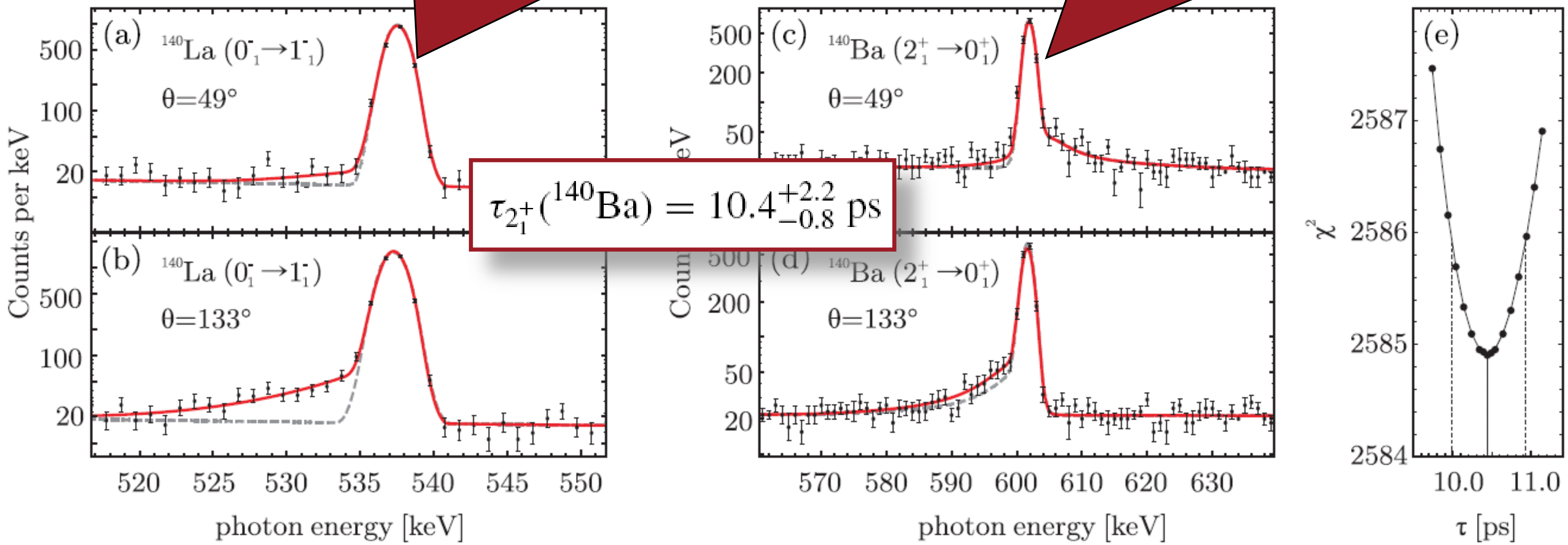
- **Long lifetime, asymmetric detector response (neutron damage)**

„stopped“ peaks from the β-decay of ^{140}Ba

Doppler-broadened peaks (lifetime effect)



$$\tau_{2_1^+}(^{140}\text{Ba}) = 10.4^{+2.2}_{-0.8}\ \text{ps}$$

C. Bauer *et al.*, PRC **86**, 034310 (2012)
Coulomb-excitation of ^{140}Ba on a thick Copper target
REX-ISOLDE / MINIBALL

+16 more angles used for the fit

“Differential” DSAM

Application of the DSA Method with relativistic, radioactive ion beams

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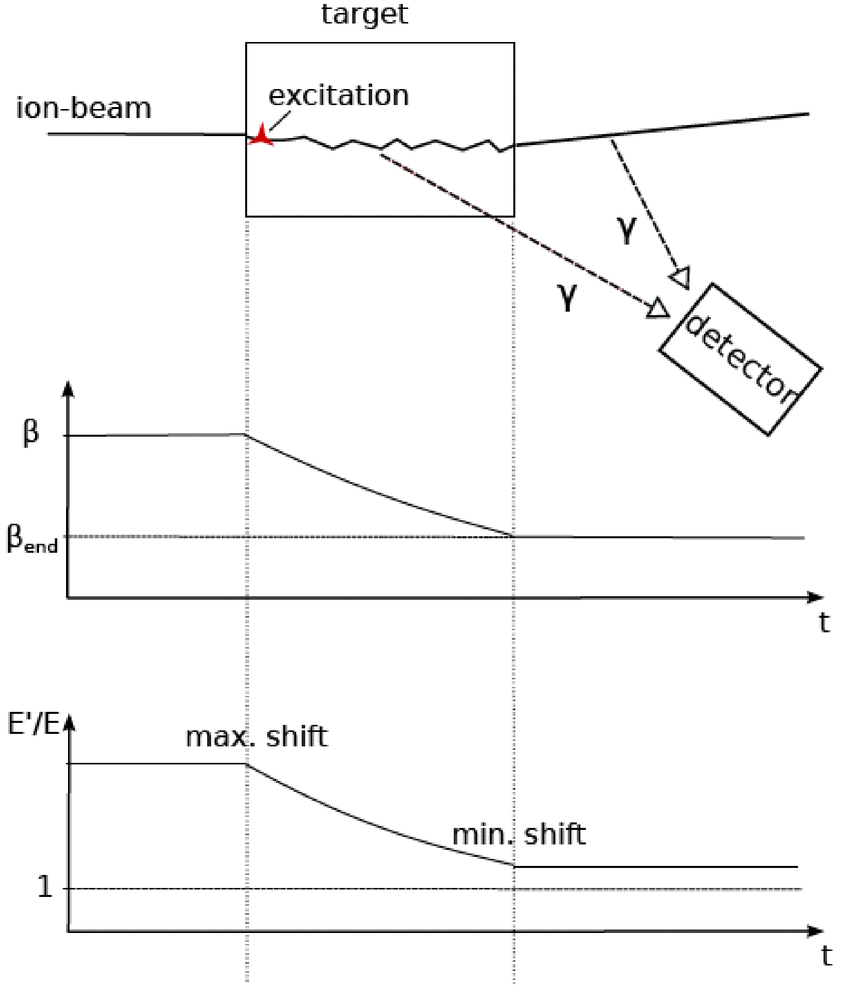
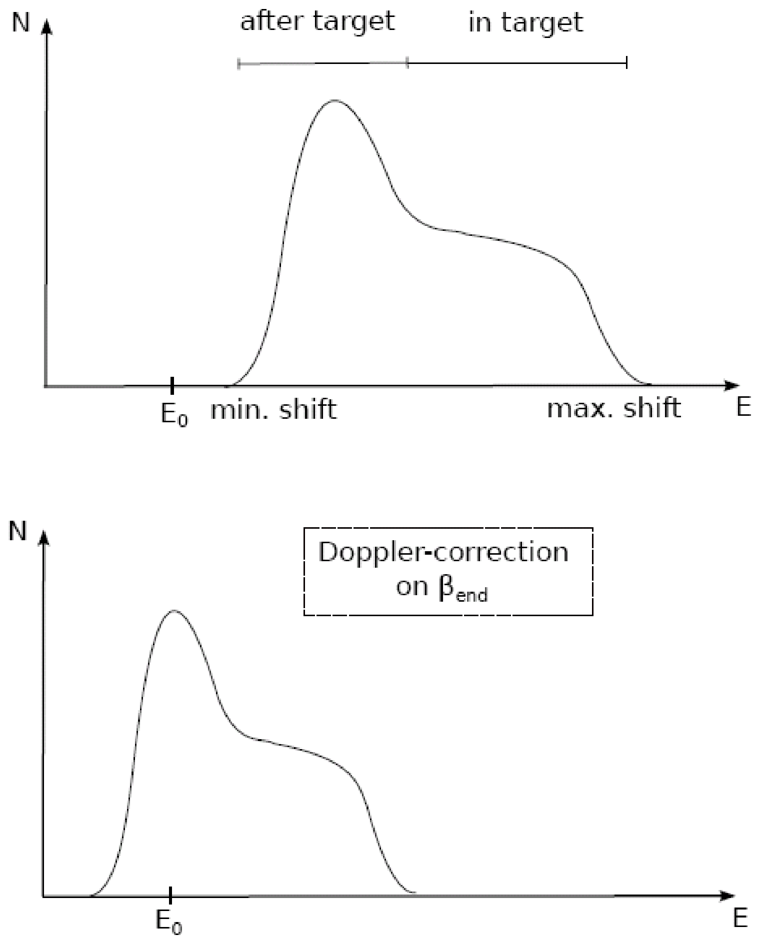
- **Example: PreSPEC / HISPEC**
- **Need to identify ions behind the target (cocktail beams)**
- **No accumulation of activity at the target position**
- **Relativistic beams**

“Differential” DSAM

Application of the DSA Method with relativistic, radioactive ion beams





“Differential” DSAM

Application of the DSA Method with relativistic, radioactive ion beams

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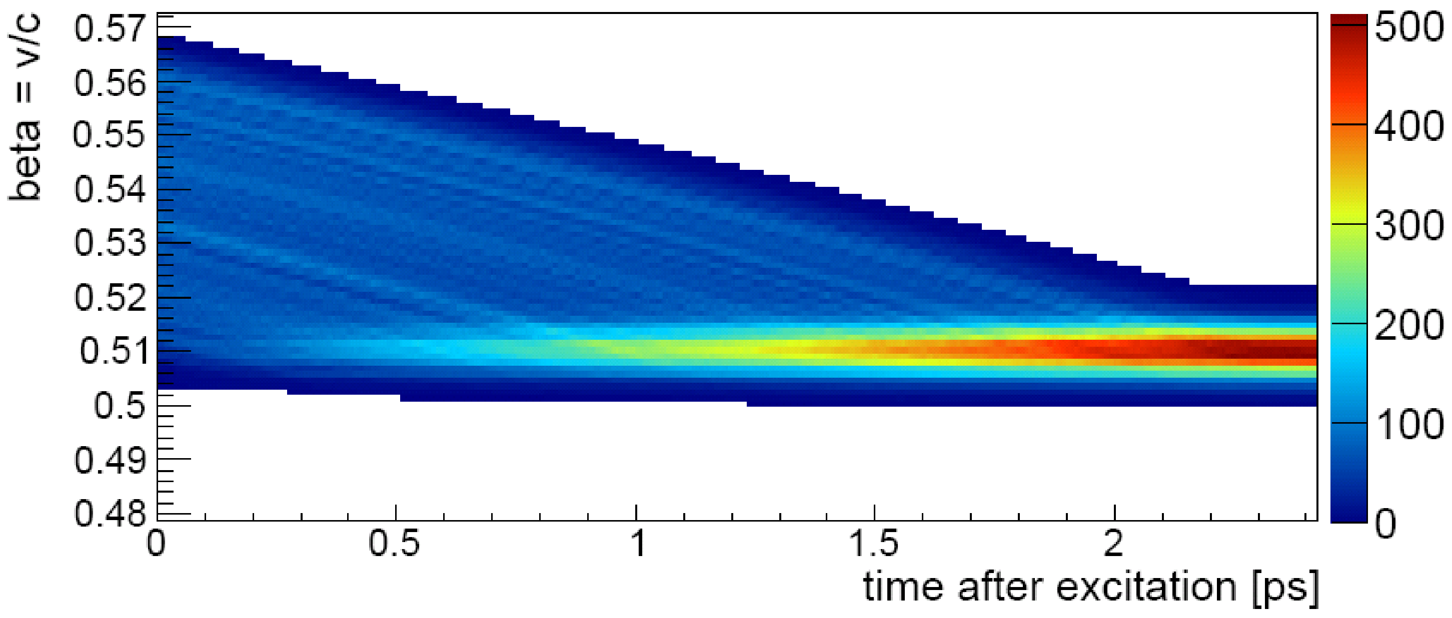
- **Example application: Lifetime of the 2^+_1 level in ^{106}Sn**
  measured with the PreSPEC setup after Coulomb-Excitation

Just a case study..

^{106}Sn ions at 150 MeV/u impinging a 0.75 g/cm² Au target



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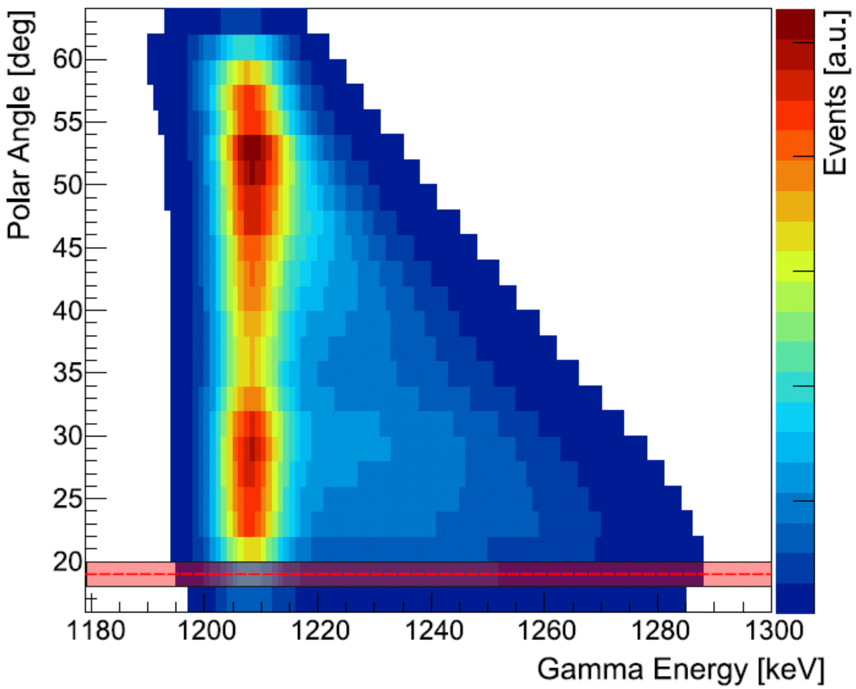

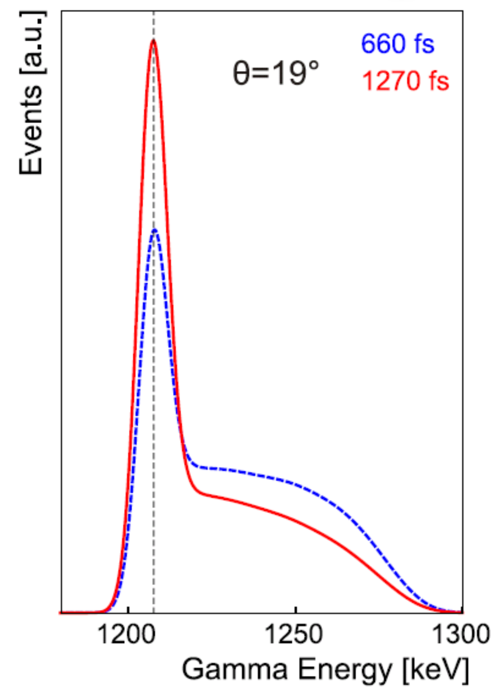

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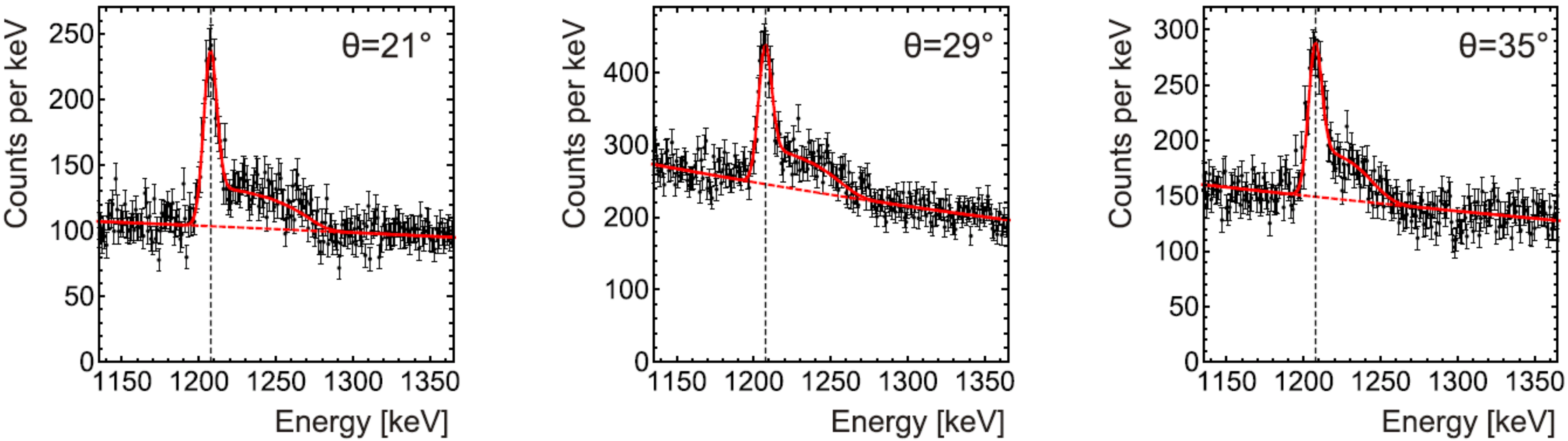
- **Example application: Lifetime of the 2^+_1 level in ^{106}Sn**
  measured with the PreSPEC setup after Coulomb-Excitation
- **Feasibility and Accuracy:**

Just a case study..



Simulated spectra for 100h beam on target with 1.8×10^4 pps, 2° polar angle bins

“Differential” DSAM

Application of the DSA Method with relativistic, radioactive ion beams

- **Example application: Lifetime of the 2^+_1 level in ^{106}Sn**
  measured with the PreSPEC setup after Coulomb-Excitation

Just a case study..

- **Feasibility and Accuracy:**

Can use thicker targets than for ‘standard’ – Coulex experiments
→ more events per ‘ion on target’

Can do Coulex analysis with the same dataset

Highly charged ions at high velocity:
→ No nuclear stopping
→ Stopping Power precisely known

Case of ^{106}Sn:

Expect (statistical) accuracy for the 2^+_1 level lifetime of **2.5%** after 70h beam on target

- **‘Real’ Application:**
  Method will be used for the analysis of PreSPEC data from experiment S428 (level lifetimes in heavy Zr isotopes), Pietri, Ralet *et al.*

“Differential” DSAM

Application of the DSA Method with relativistic, radioactive ion beams

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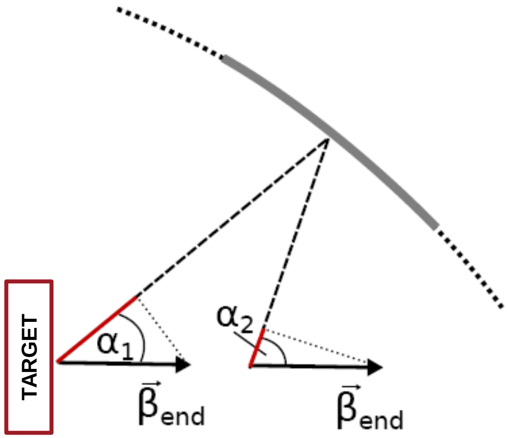
- **Another sensitivity region with “differential DSAM” in the order of 100ps:**

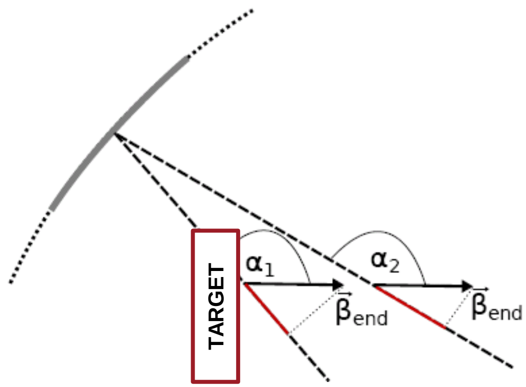
  Doppler-correction on exit velocity “fails”, if decay occurs far behind the target (assumed angle between direction of ion motion and gamma detection is wrong)

  P. Doornenbal et al., NIM A 613 (2010) 218–225; C. Domingo-Pardo et al., NIM A 694 (2012) 297–312

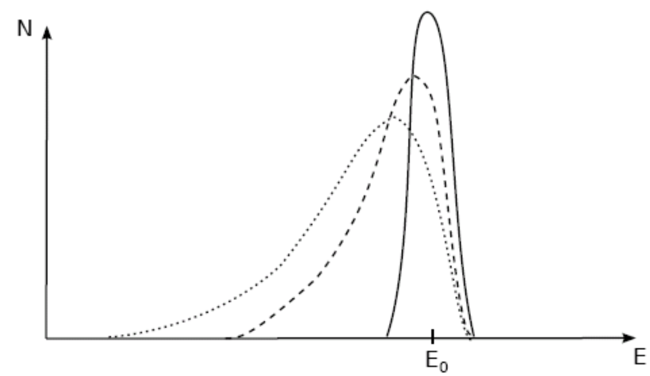
  → **A “continuous Plunger”:**



Detector under forward-angle:
Over-estimation of Doppler-shift



Detector under backward-angle:
Under-estimation of Doppler-shift



Thank you for your attention!

If you are interested in our analysis software,
please contact me!

✉ stahl@ikp.tu-darmstadt.de

It's free! ;-)

Implementation of the continuous angle DSAM in a new Analysis tool

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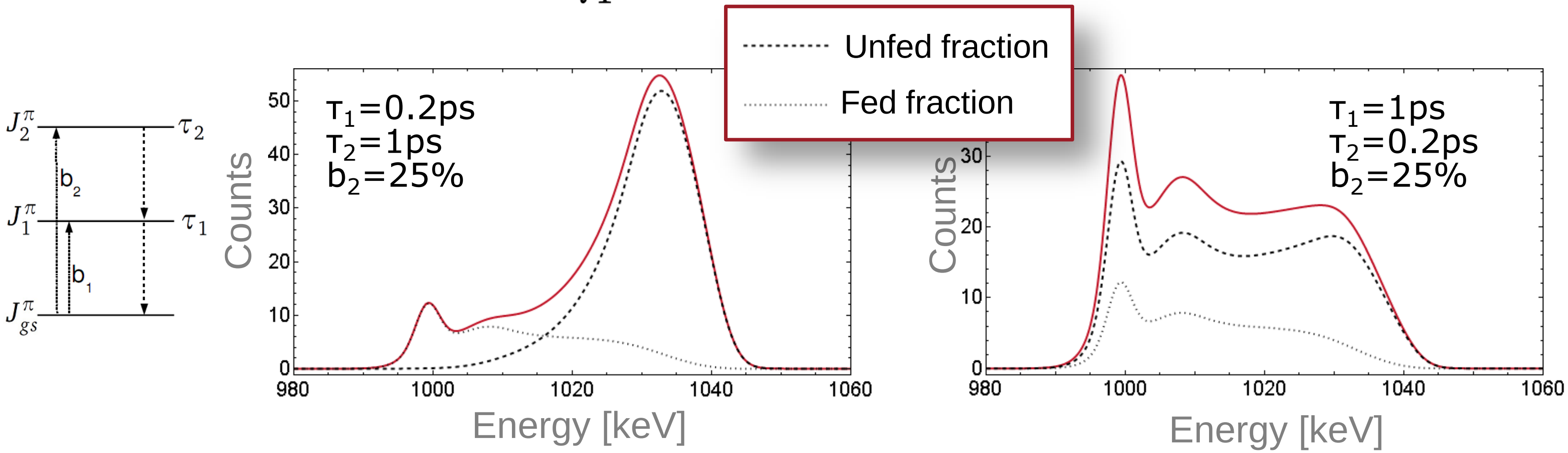
2 major ingredients for the calculation of lineshapes

- *Decay function* $A_1(t) = \frac{1}{\tau 1} N_1(t)$



- Complex feeding schemes
- Decay function from analytical solutions of the Bateman equation
- Simultaneous fit of feeding transitions
- Different angular distributions for fed and unfed fraction

Implementation of the continuous angle DSAM in a new Analysis tool

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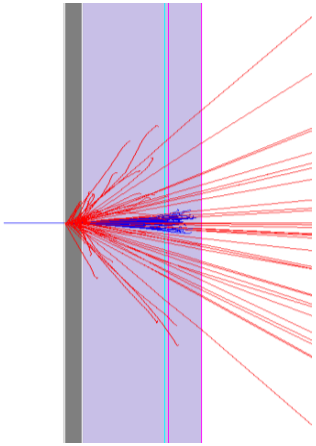
2 major ingredients for the calculation of lineshapes

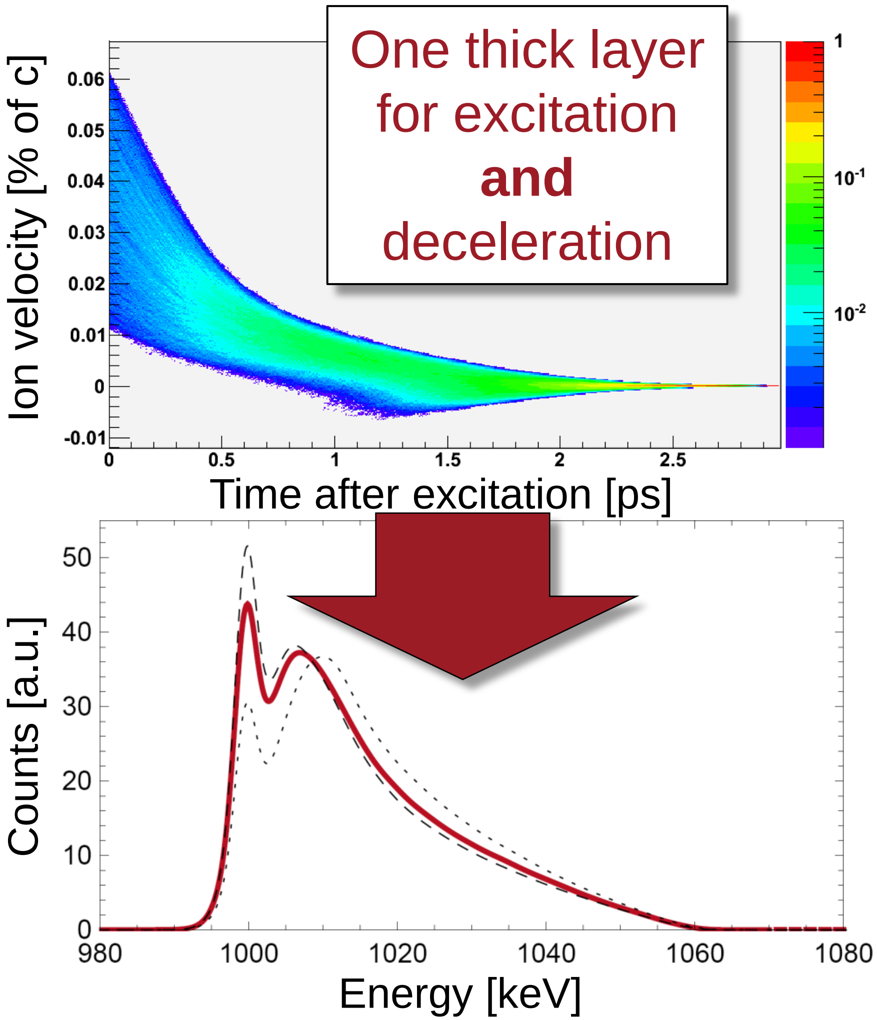
- *Decay function* $A_1(t) = \frac{1}{\tau 1} N_1(t)$
- *Stopping-Matrix* $p\left(\vec{\beta}, t\right)$ from a Monte-Carlo simulation

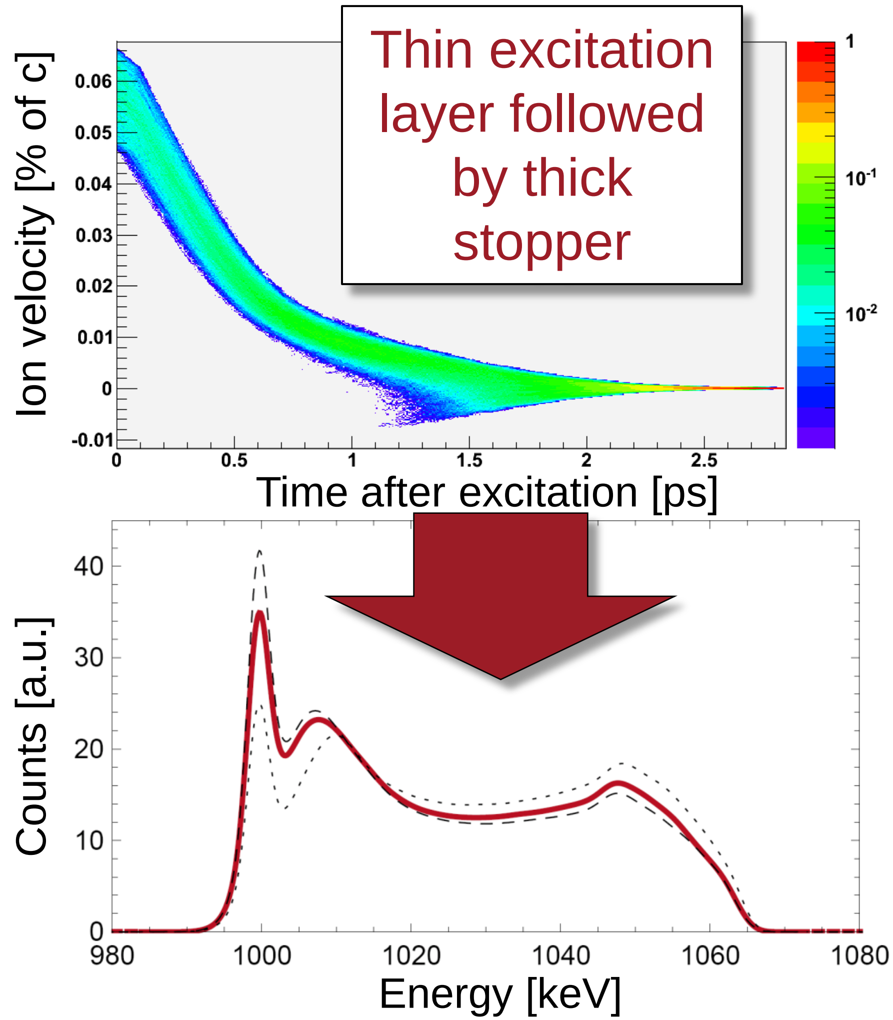
  - Realistic Monte-Carlo Simulation of the **(Coulomb-) excitation** and the **deceleration process** on the Basis of **Geant4**
  - **Transport and energy loss** calculated for **beam and secondary ions**
  - Set **kinematic conditions** in the analysis software to select ion tracks ("particle detectors")
  - Good platform for the implementation of further excitation processes



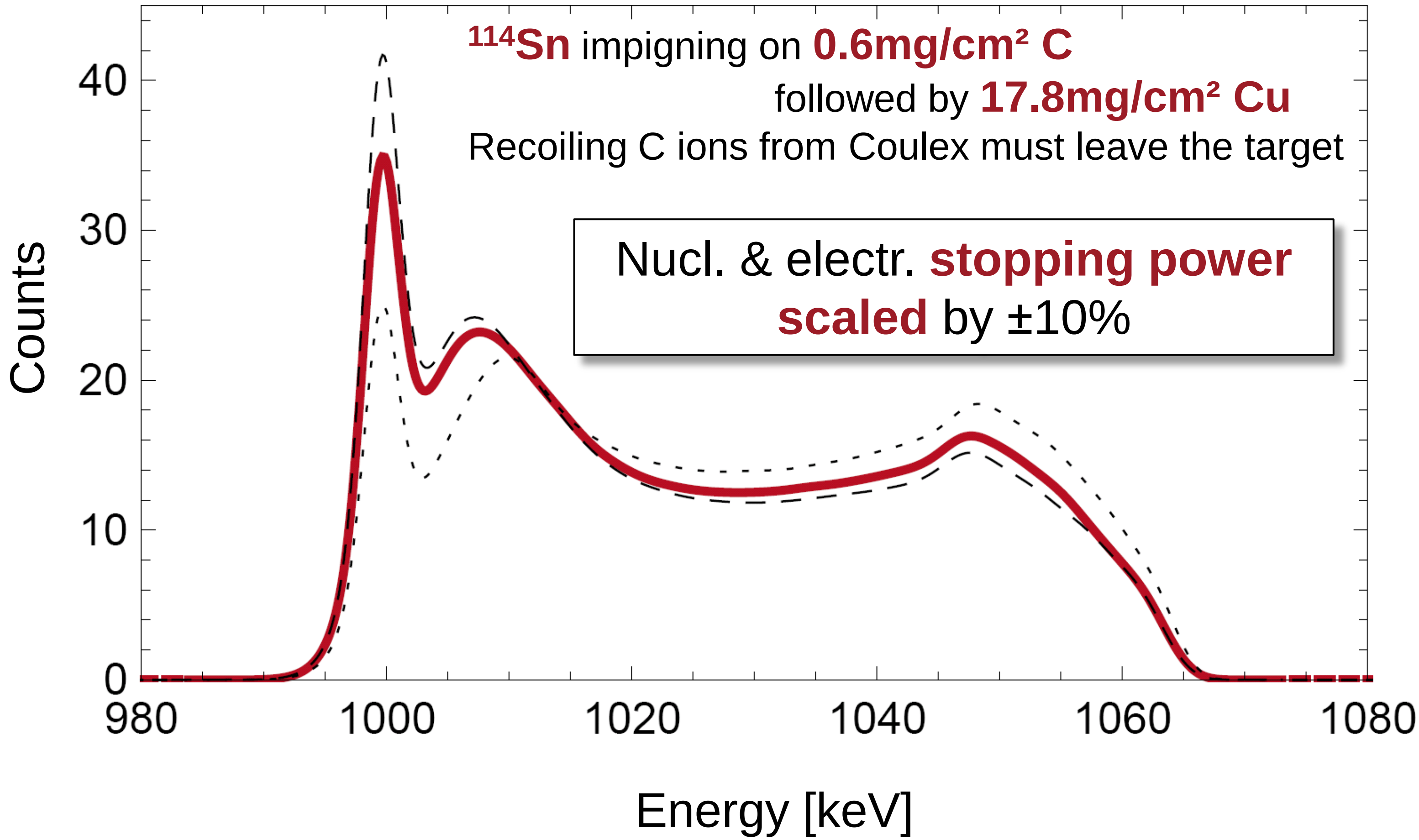
^{86}**Kr ions** Coulomb-excited at a **Carbon layer** and stopped in the following layers, **recoiling Carbon ions** escape from the target

Choice of excitation situation





dE/dx scaling



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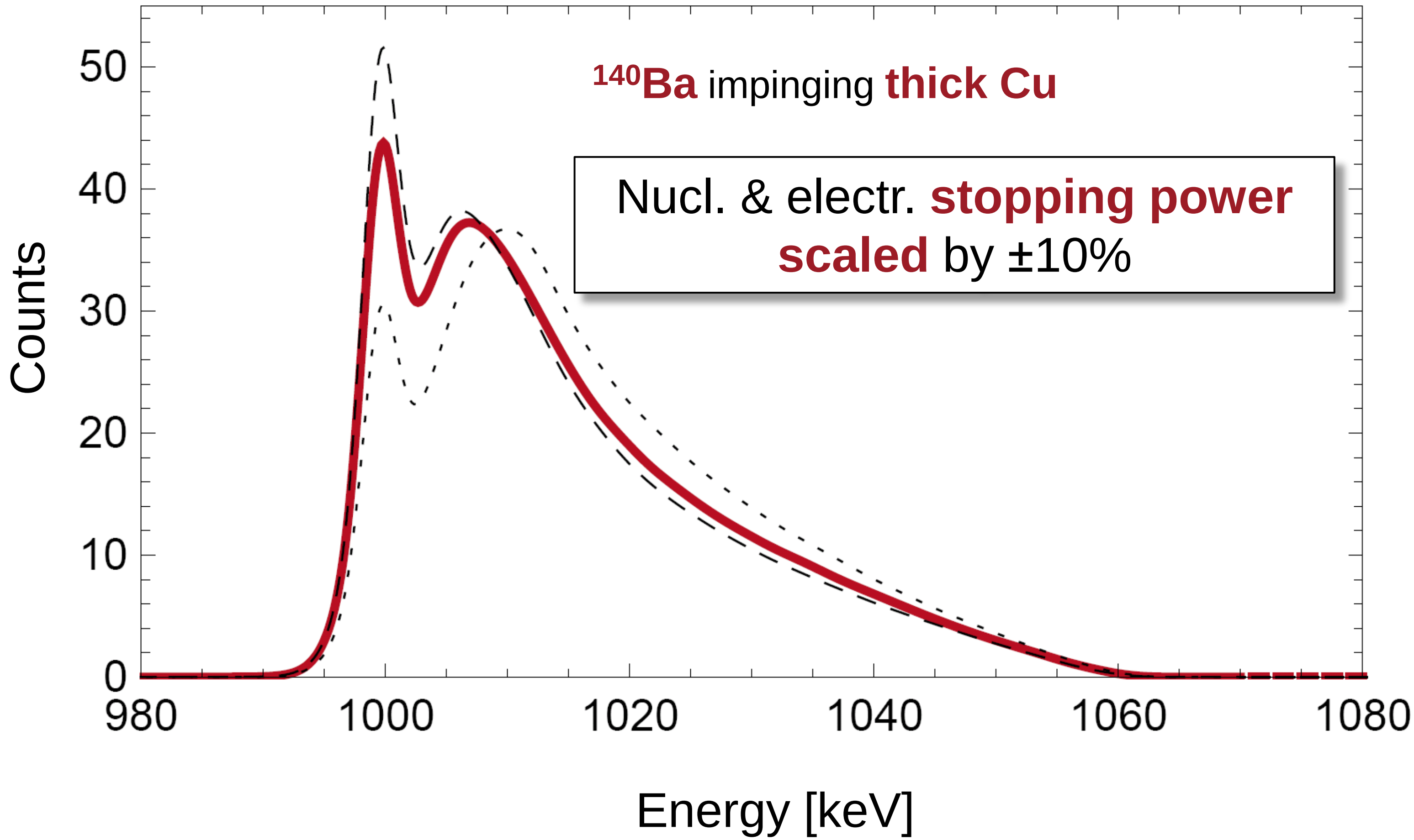

Implementation of the continuous angle DSAM in a new Analysis tool

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Important effects to account for

- Relativistic corrections of the detector **solid angle**
- Transformation of the **angular distribution** from the ion rest frame to the lab frame