GRIDSA

Measuring fs lifetimes with a Ge-detector array.

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People contributing

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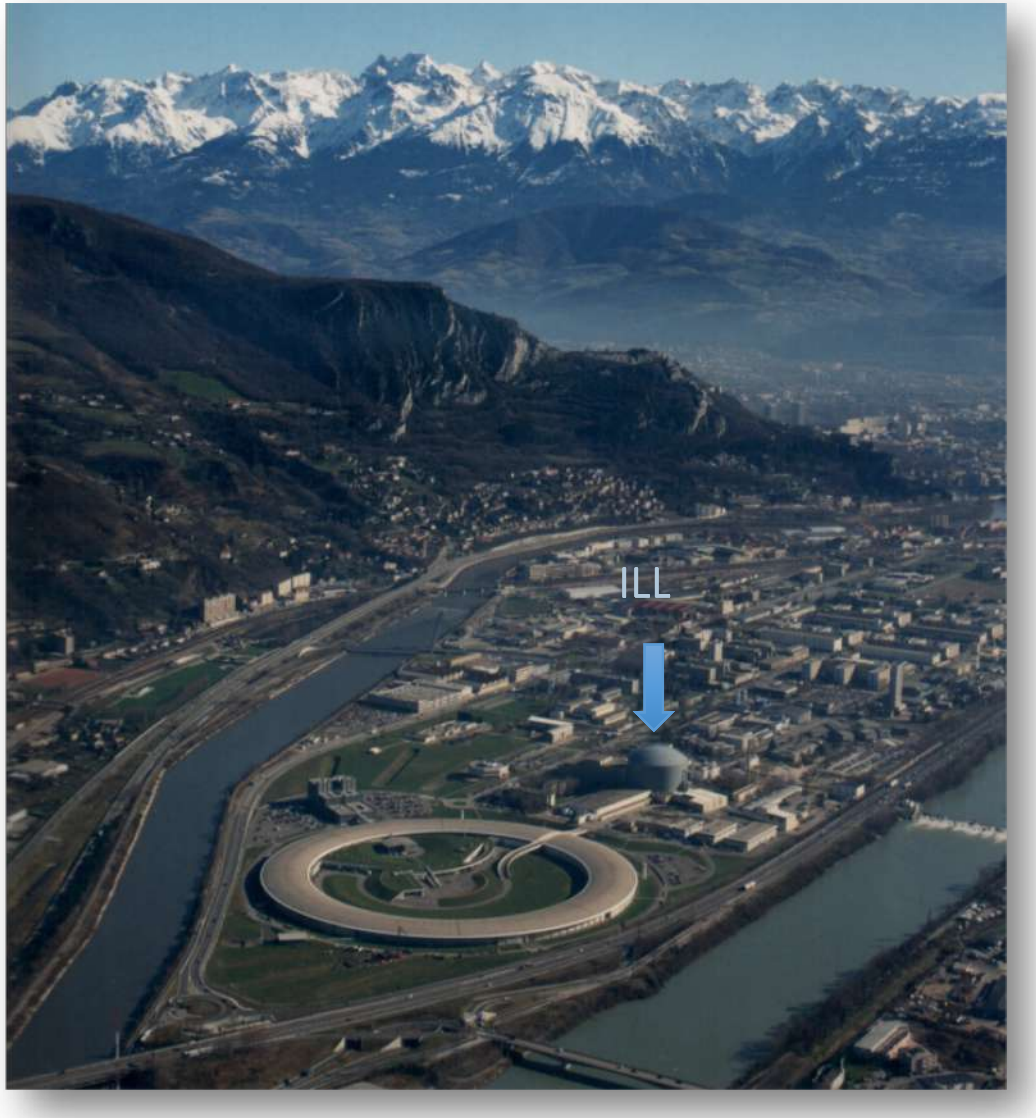


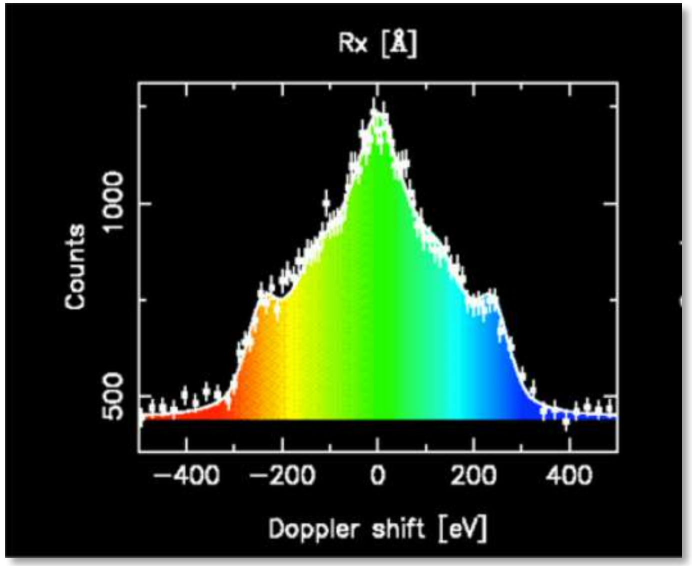
Content

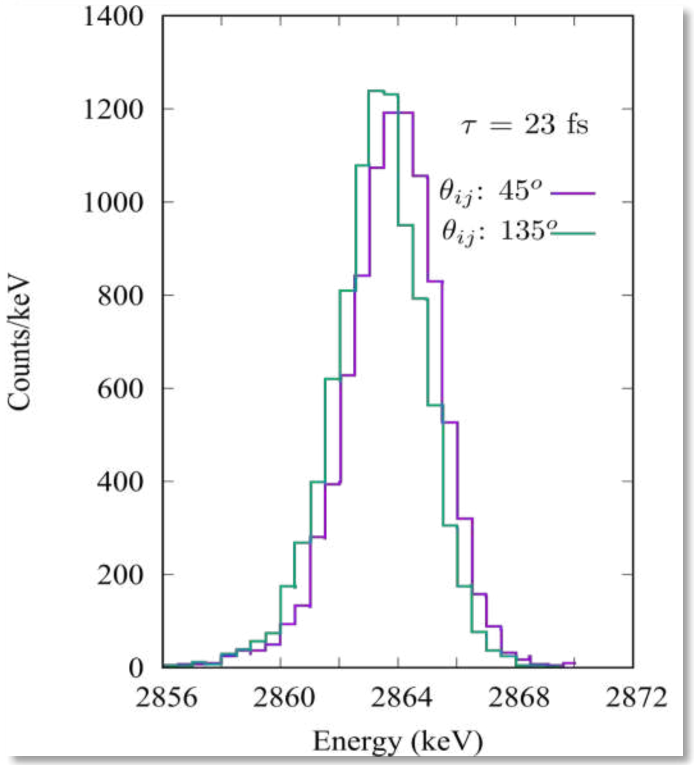
- ILL
- Measuring nucl. Lifetimes (at ILL)

- Gamma ray induced Doppler shift
  - GRID with GAMS
  - GRIDSA with FIPPS

- Results from FIPPS

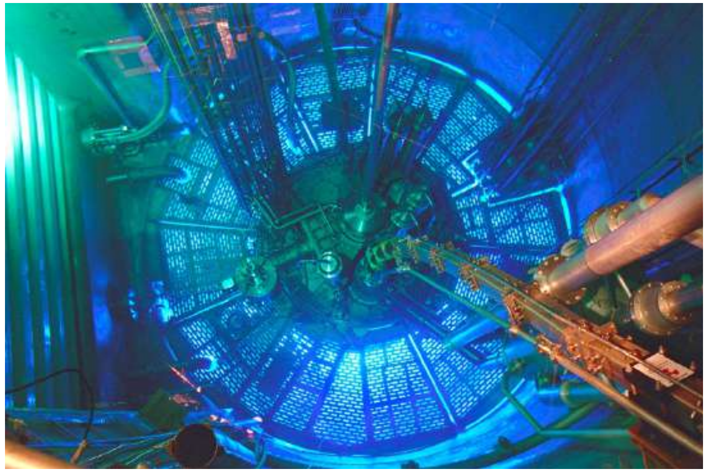
- Future Steps



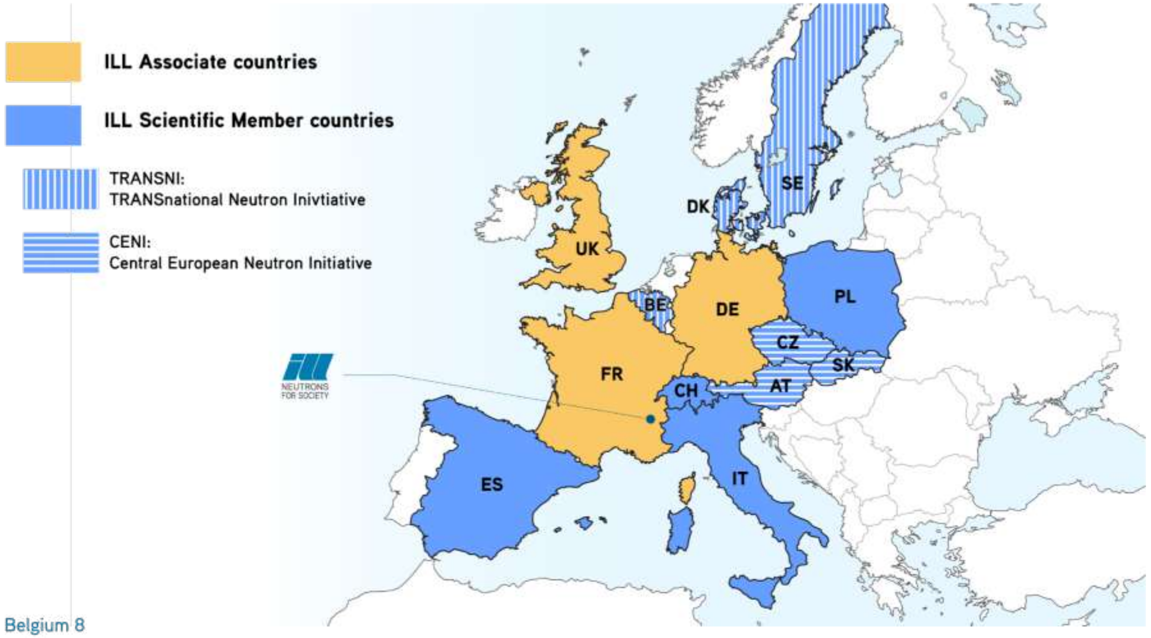


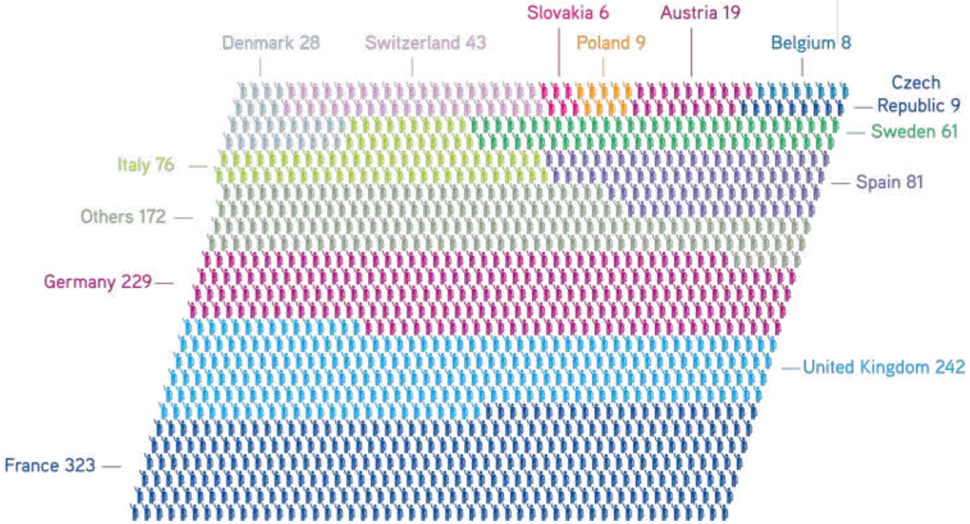
The Institut Laue Langevin

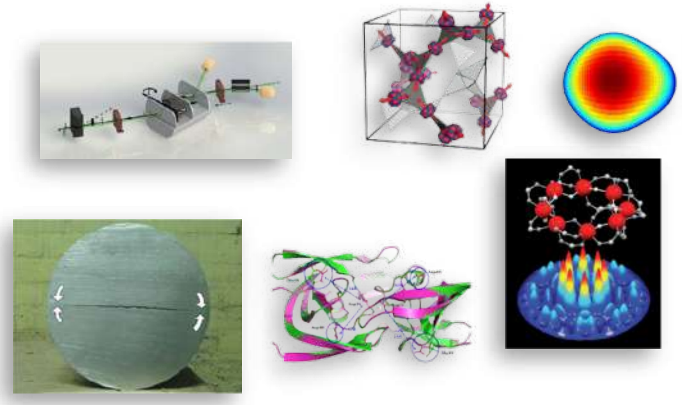
Europes leading neutron source for research



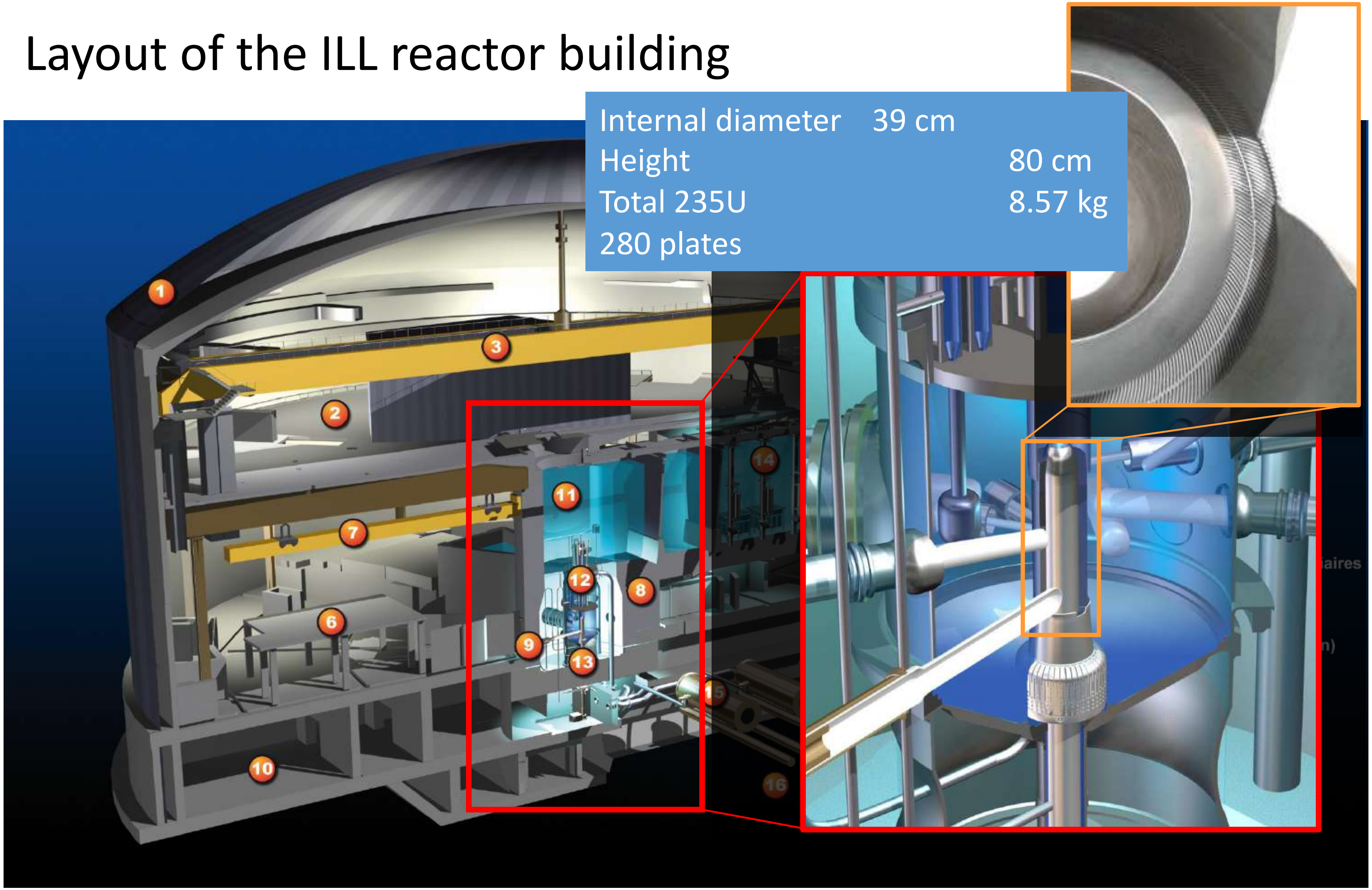
Annual budget: 100 MEuro





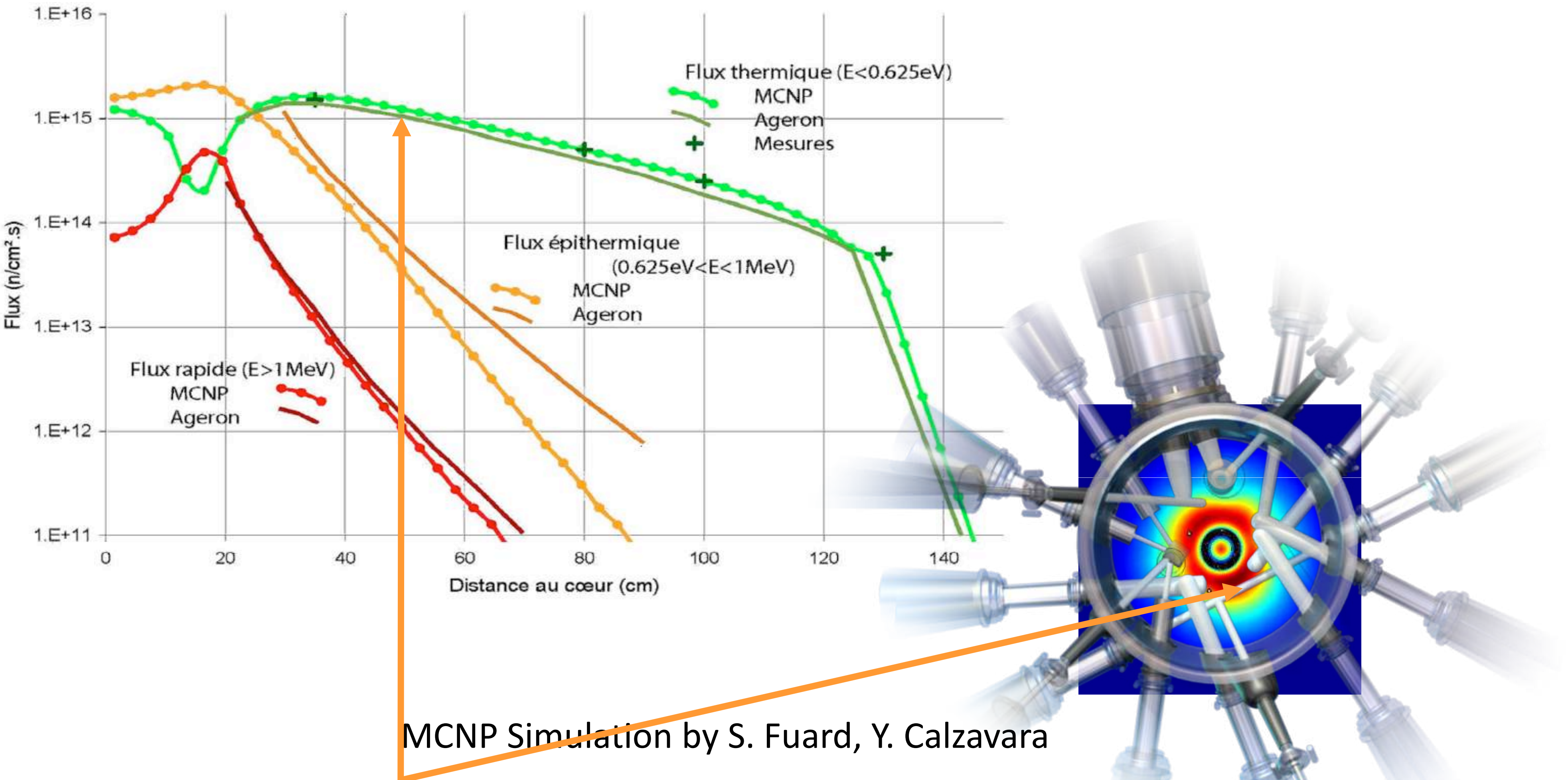


Layout of the ILL reactor building



Internal diameter	39 cm
Height	80 cm
Total 235U	8.57 kg
280 plates	

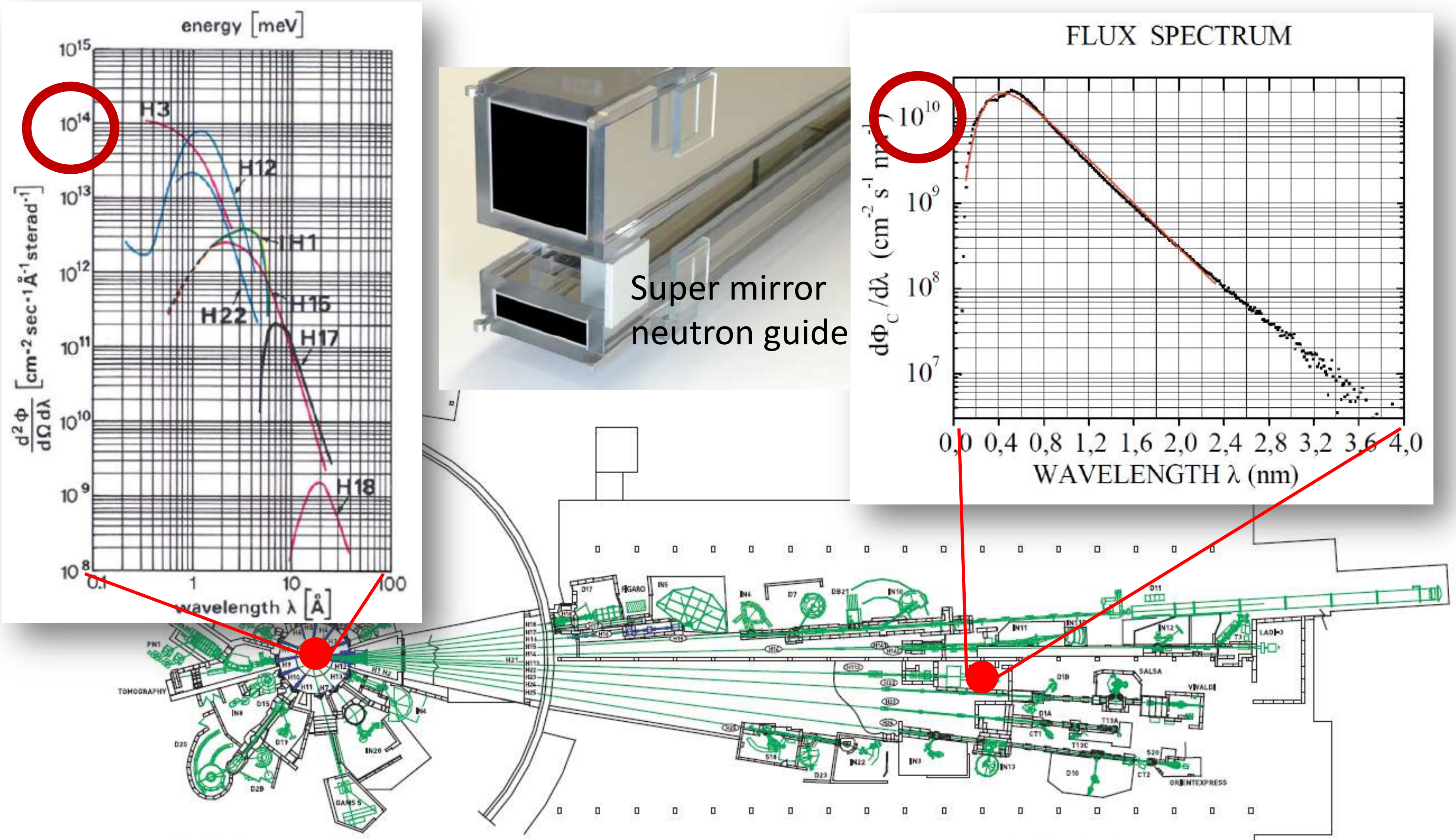
Radial distribution of neutron flux in ILL reactor



MCNP Simulation by S. Fuard, Y. Calzavara

At 50 cm from core we have thermal neutronflux of 10^{15} n s^{-1} cm^{-2}

Inpile vs. Neutron beam

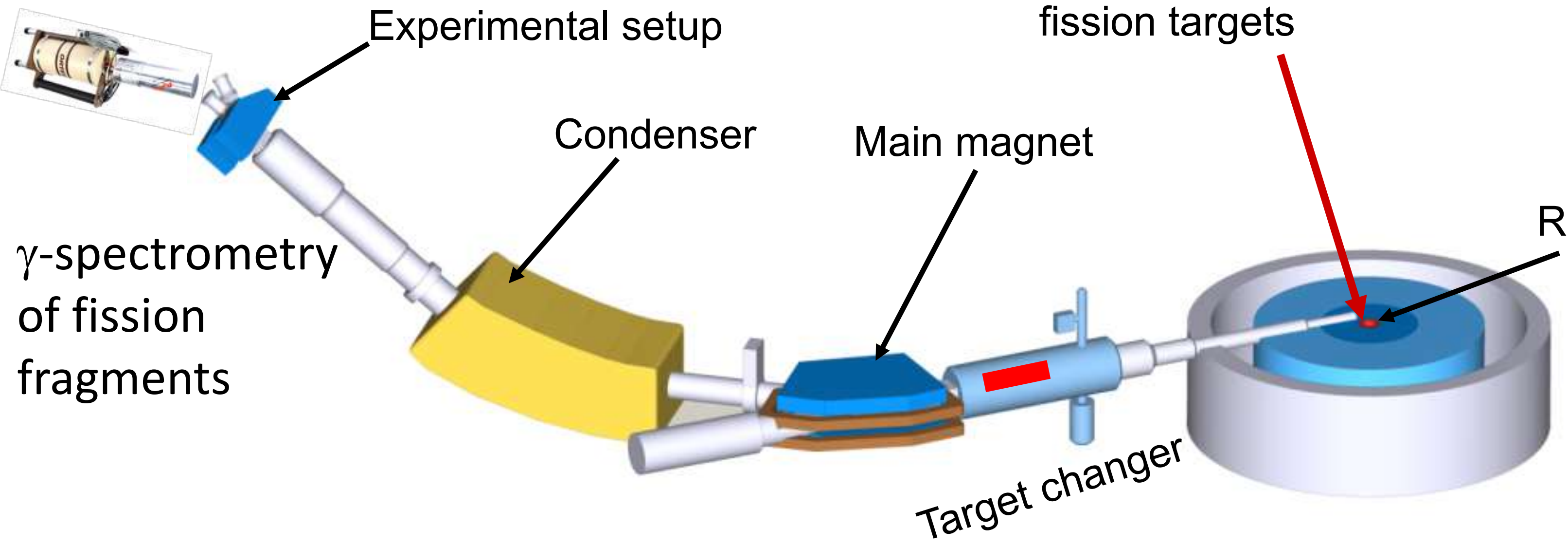


reactor in pile:
5×10^{14} n cm^{-2} s^{-1} ,
7 m to target
10^{-6} – 10^{-5} solid angle

neutron guide :
2×10^{10} n cm^{-2} s^{-1}
0.1 m to target
10^{-1} solid angle

Gamma Spectroscopy @ In-Pile Instruments

For Fission: Lohengrin (PN1)



Experimental setup

Condenser

Main magnet

Target position for fission targets

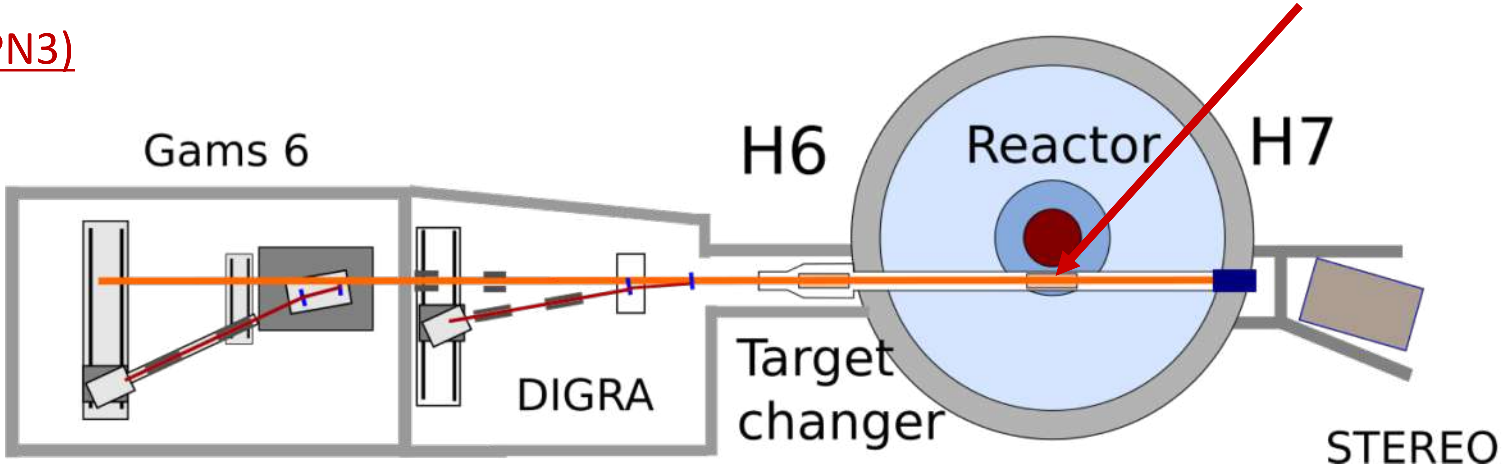
Reactor core

Target changer

Target position for (n,γ)

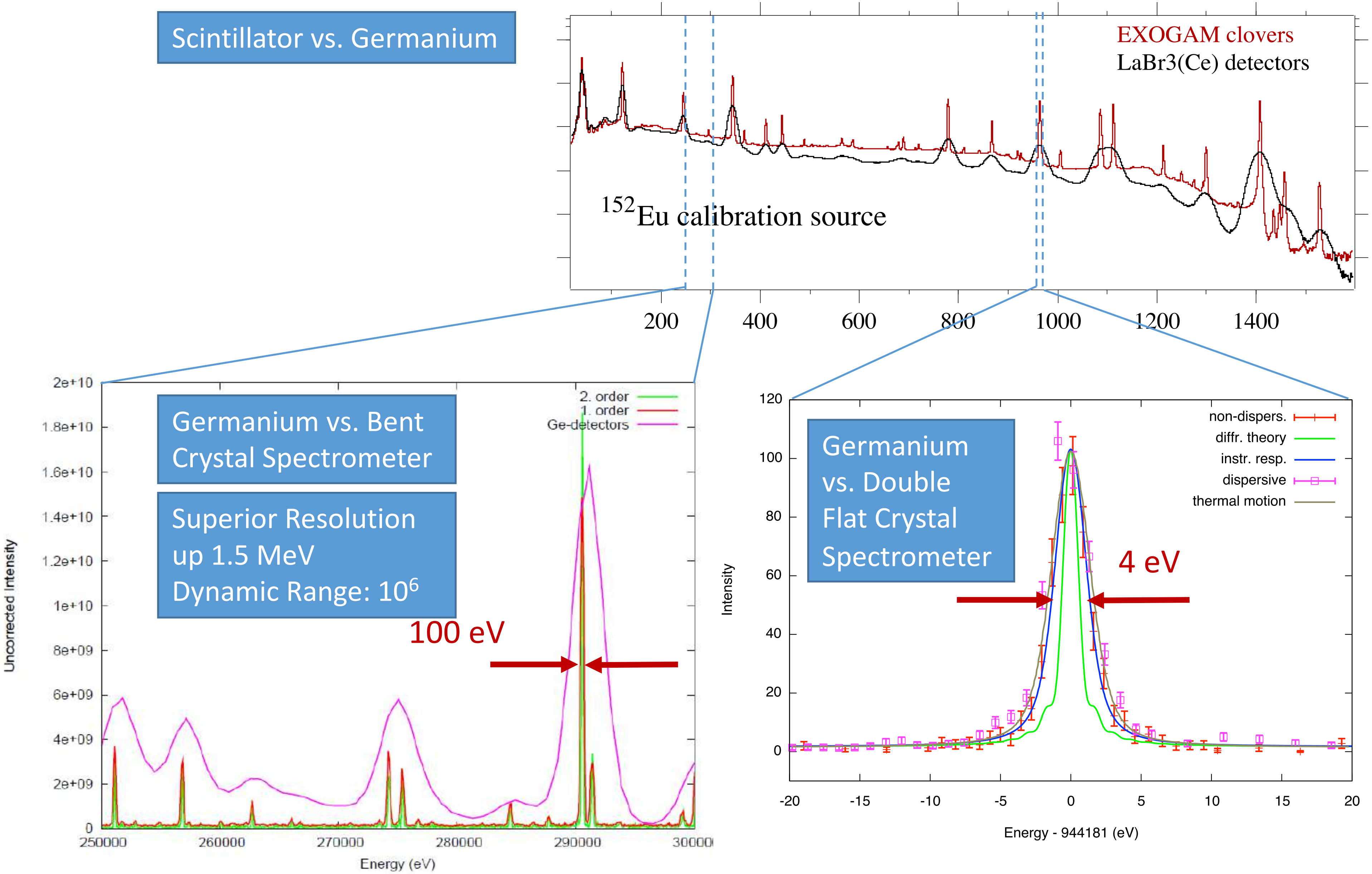
γ-spectrometry of fission fragments

For (n,γ): GAMS (PN3)



Comparing Resolutions:

Scintillator vs Ge-Detector vs Bent Crystal vs Double Flat Crystal



Scintillator vs. Germanium

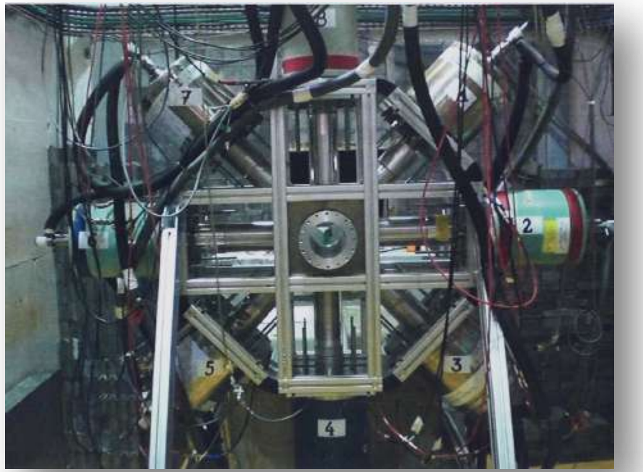
Germanium vs. Bent Crystal Spectrometer

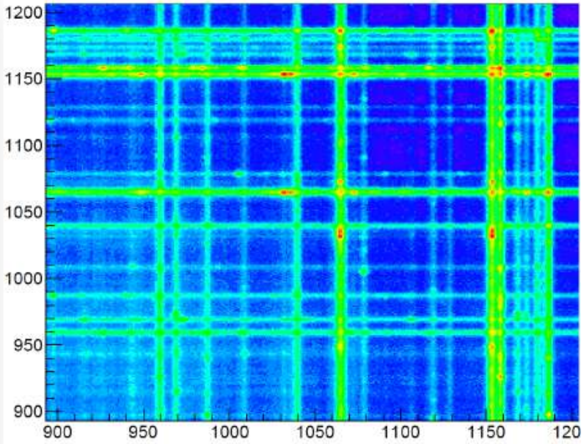
Superior Resolution up 1.5 MeV
Dynamic Range: 10^6

Germanium vs. Double Flat Crystal Spectrometer

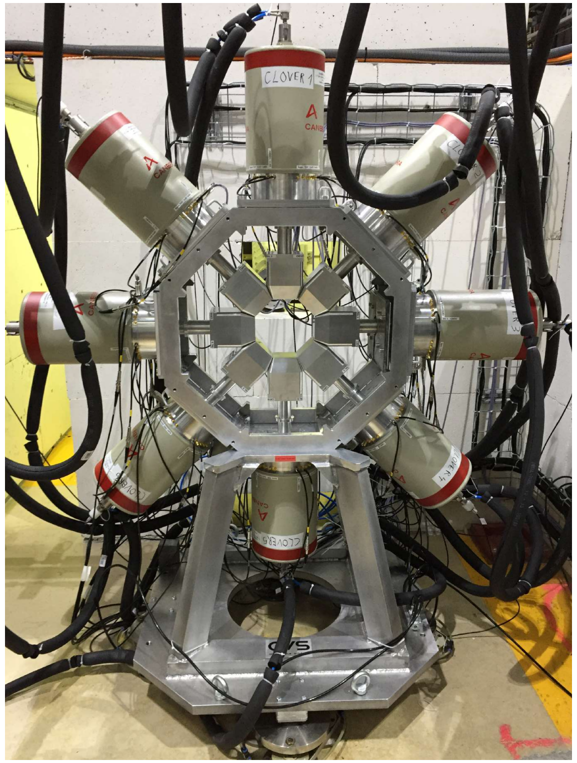
Gamma Ray spectroscopy at a neutron beam

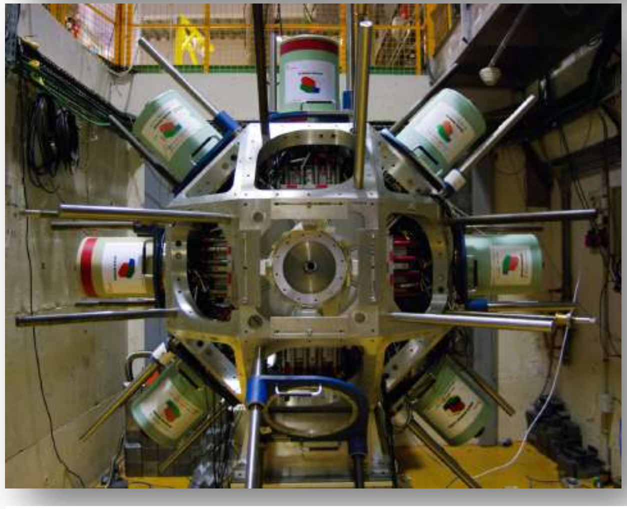
2010 First Test: 8 Horus detectors 80% rel. eff. (from IKP Cologne)

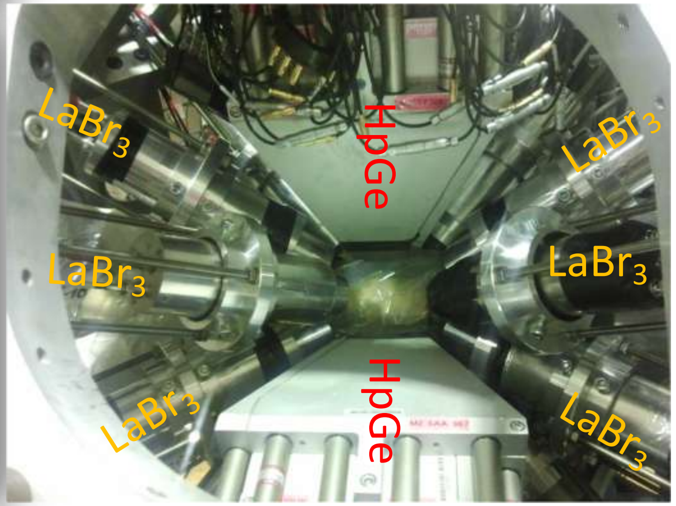




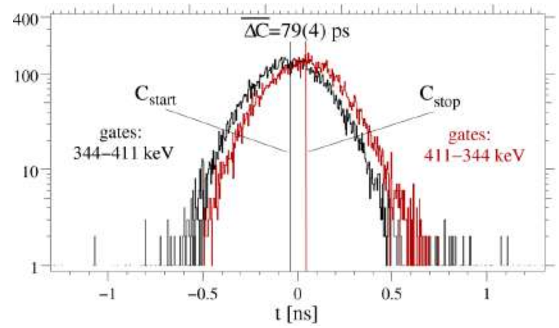
Since 2017 dedicated ILL Instrument: FIPPS





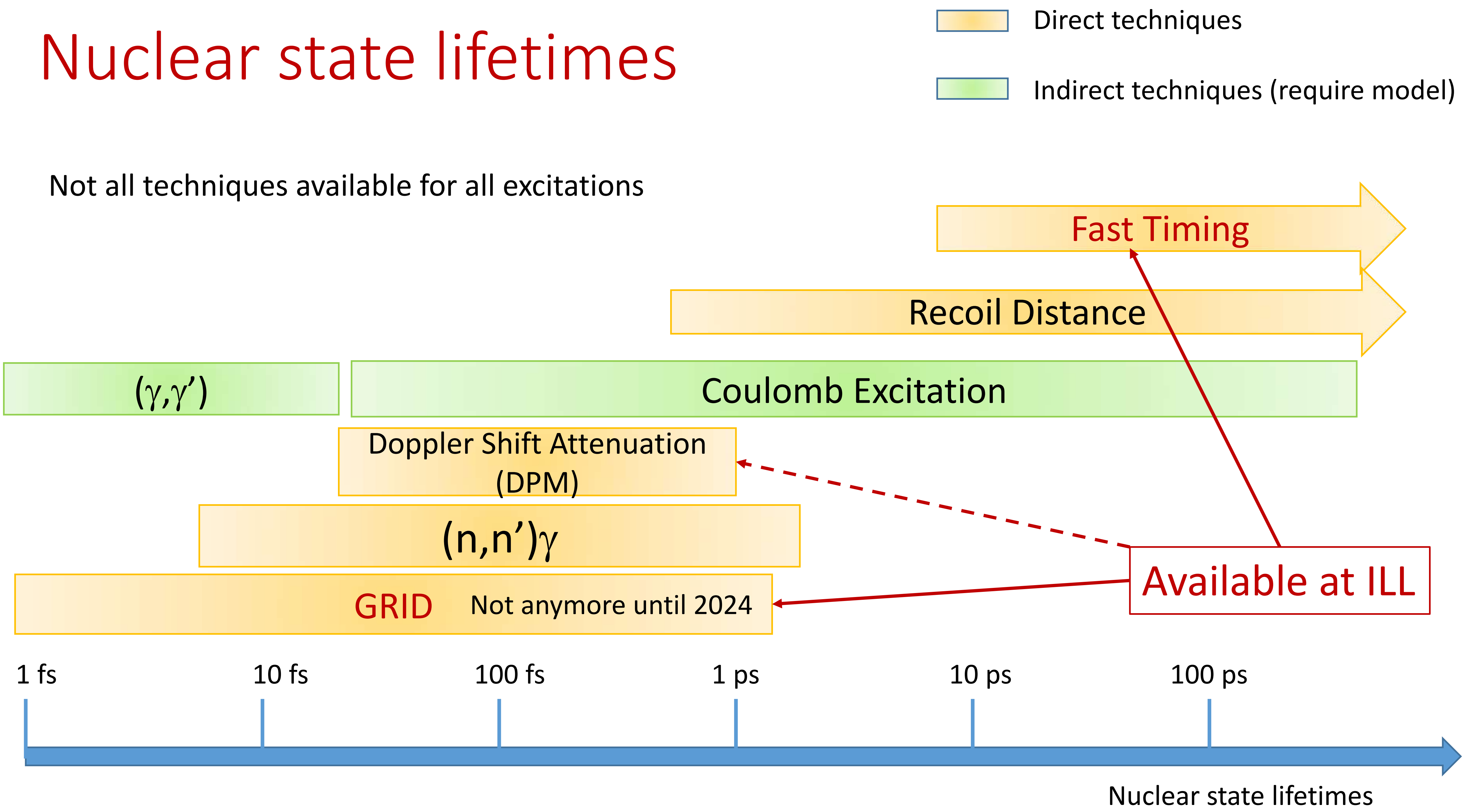


2012/13, 10 EXOGAM clovers + 6 GASP, + 16 LaBr$_3$(from GANIL, LINEARO, FATIMA collaboration)



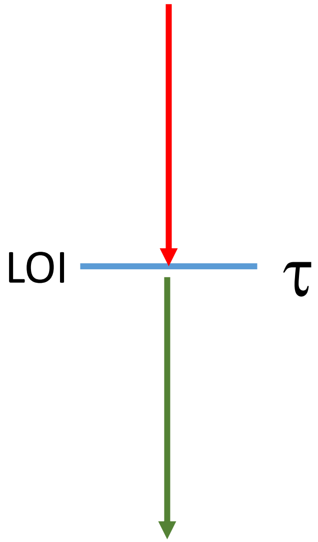
Nuclear state lifetimes

Not all techniques available for all excitations

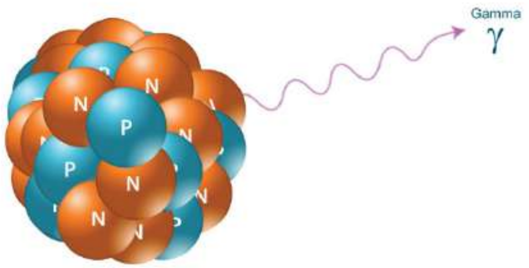


What is needed in direct technique?

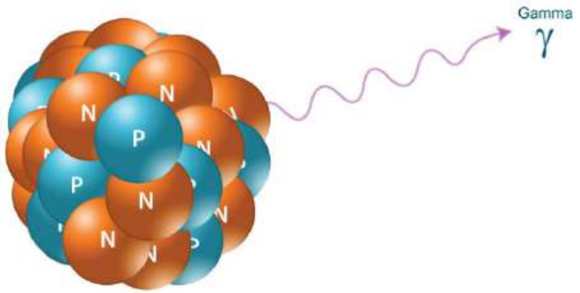
Different clocks: different lifetime ranges



START signal when level of interest (LOI) is populated

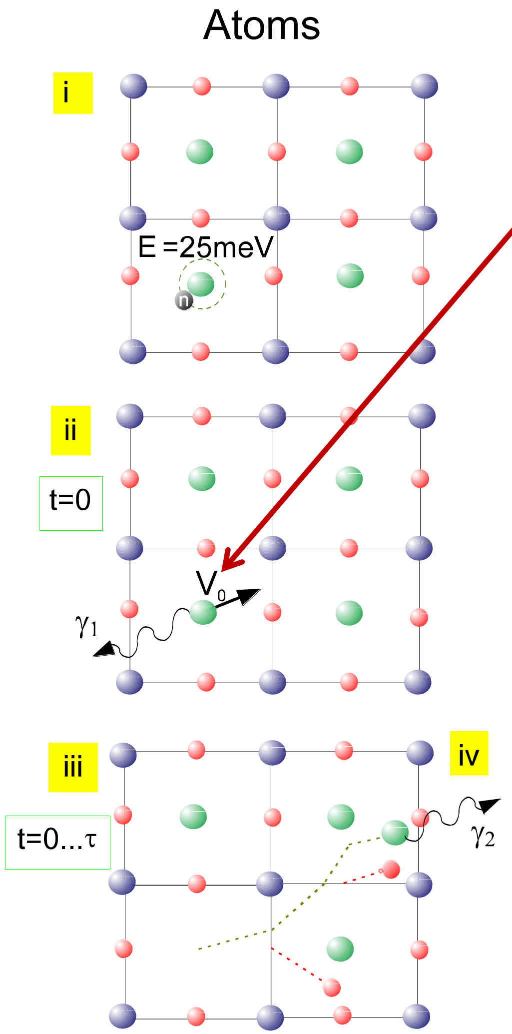


STOP signal when level of interest is depopulated



- START/STOP need to be synchronized to nuclear decay
- START/STOP signal carry information of nuclear clock

Example (direct technique): Gamma Ray Induced Doppler Broadening



Emission of γ_1 starts two clocks:

Atomic clock:

- collision sequence
- sensitive to atomic interaction

Nuclear clock:

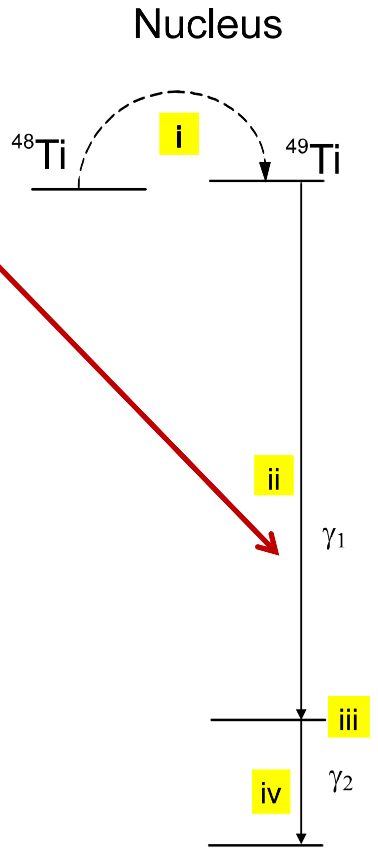
- Emission probability of γ_2

Doppler broadening of γ_2 = convolution of the two clocks

GRID – technique for lifetime measurements

Important Ingredients:

- Computer simulation of slowing down for extracting lifetime
- Feeding of LOI to know initial velocity



Gamma Ray Induced…what?

Atomic recoil after gamma emission:

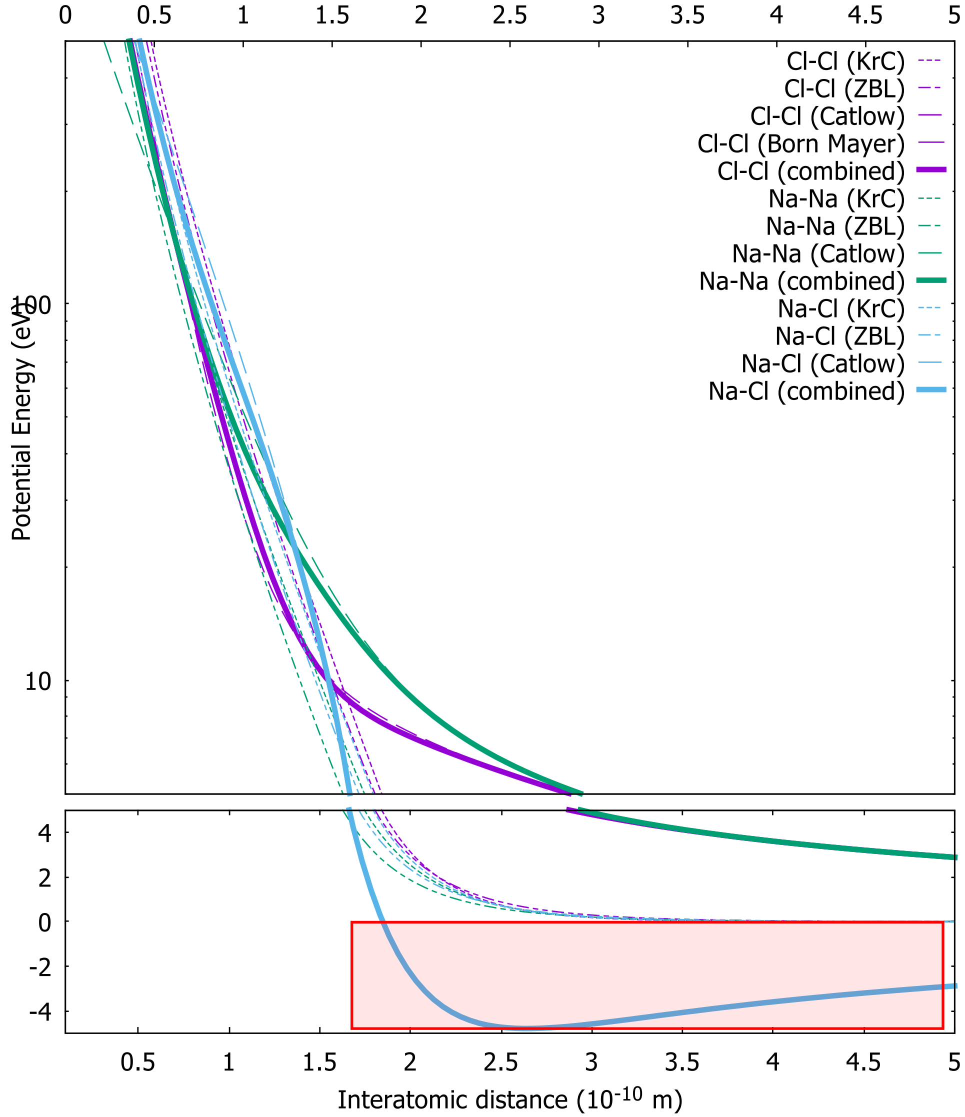
$$\frac{v_R}{c} = \frac{E_{\gamma_1}}{Mc^2} \simeq 10^{-5} \dots 10^{-4}$$

$$\mathrm{E_{kin}} = \frac{\mathrm{M}v_R^2}{2} = \frac{\mathrm{Mc}^2 v_R^2}{2c^2} = \frac{E_{\gamma_1}^2}{2Mc^2} \simeq \underbrace{10\ -500\ \text{eV}}$$

Recoil will kick atom out of its lattice site

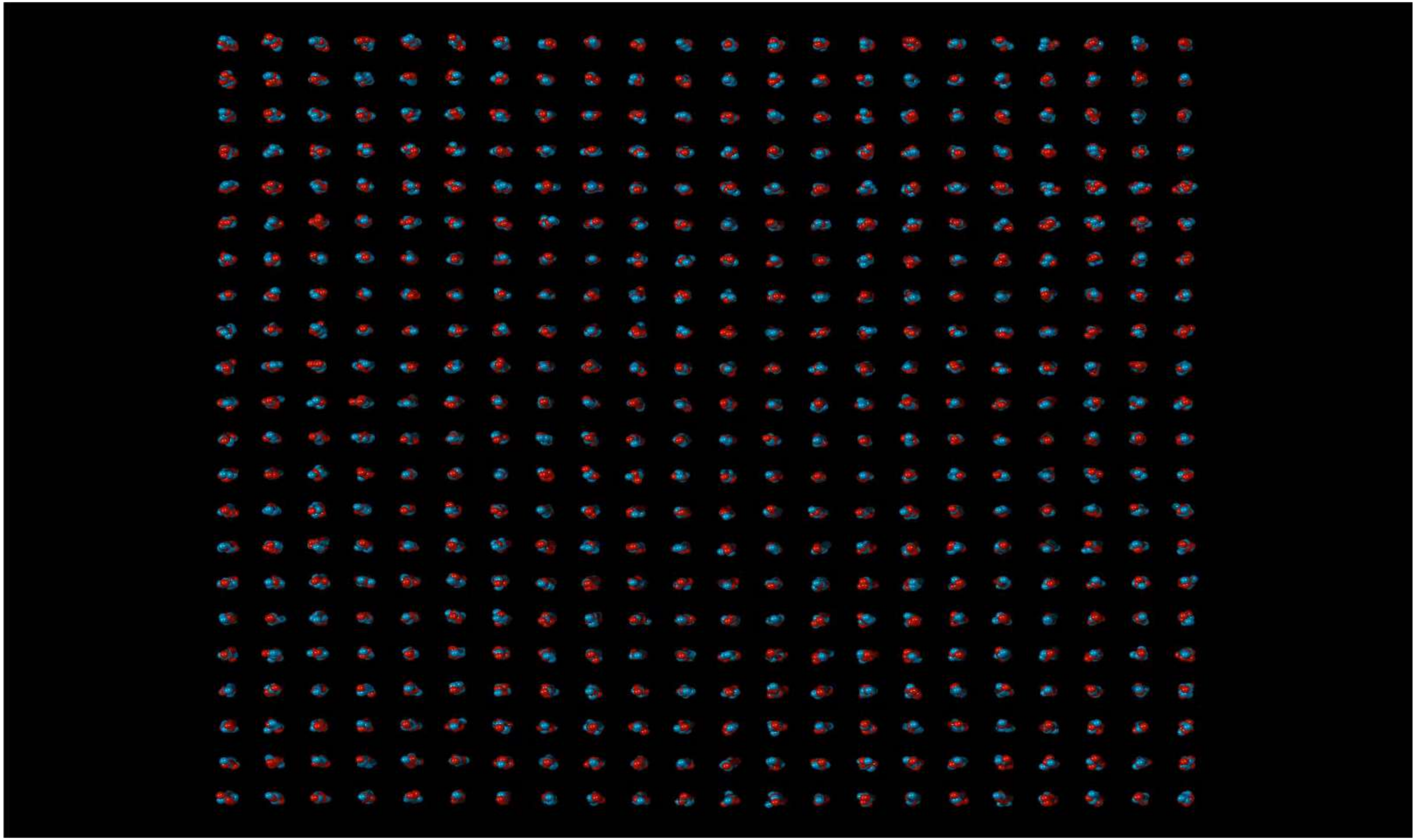
$$\overbrace{\text{Binding Energy: ~5 eV}}$$

We will have a sequence of collision during which the recoiling atom is losing its velocity



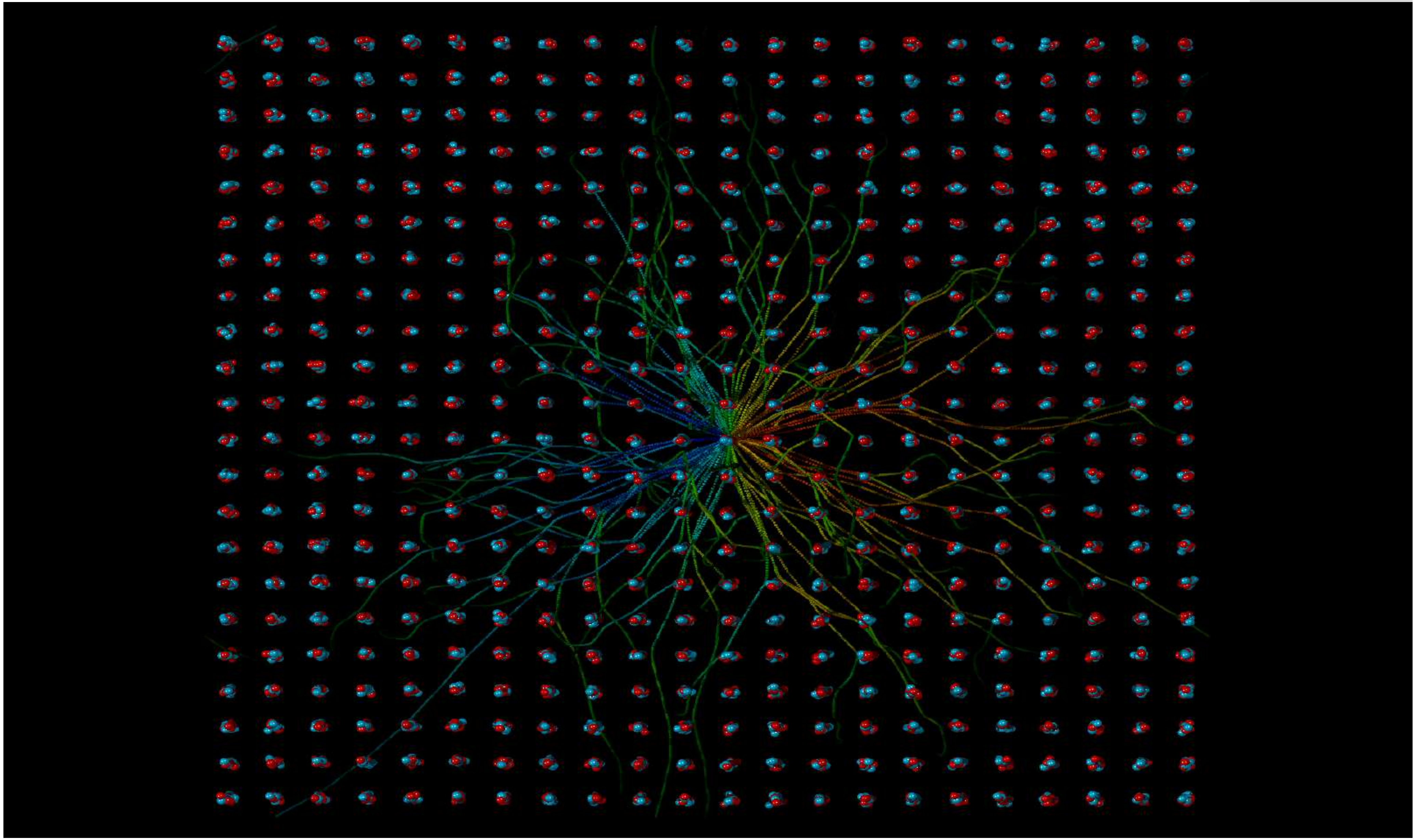
Atomic Clock: recoil of ^{36}Cl atoms in a NaCl lattice due to γ_1-emission

First 400 fs

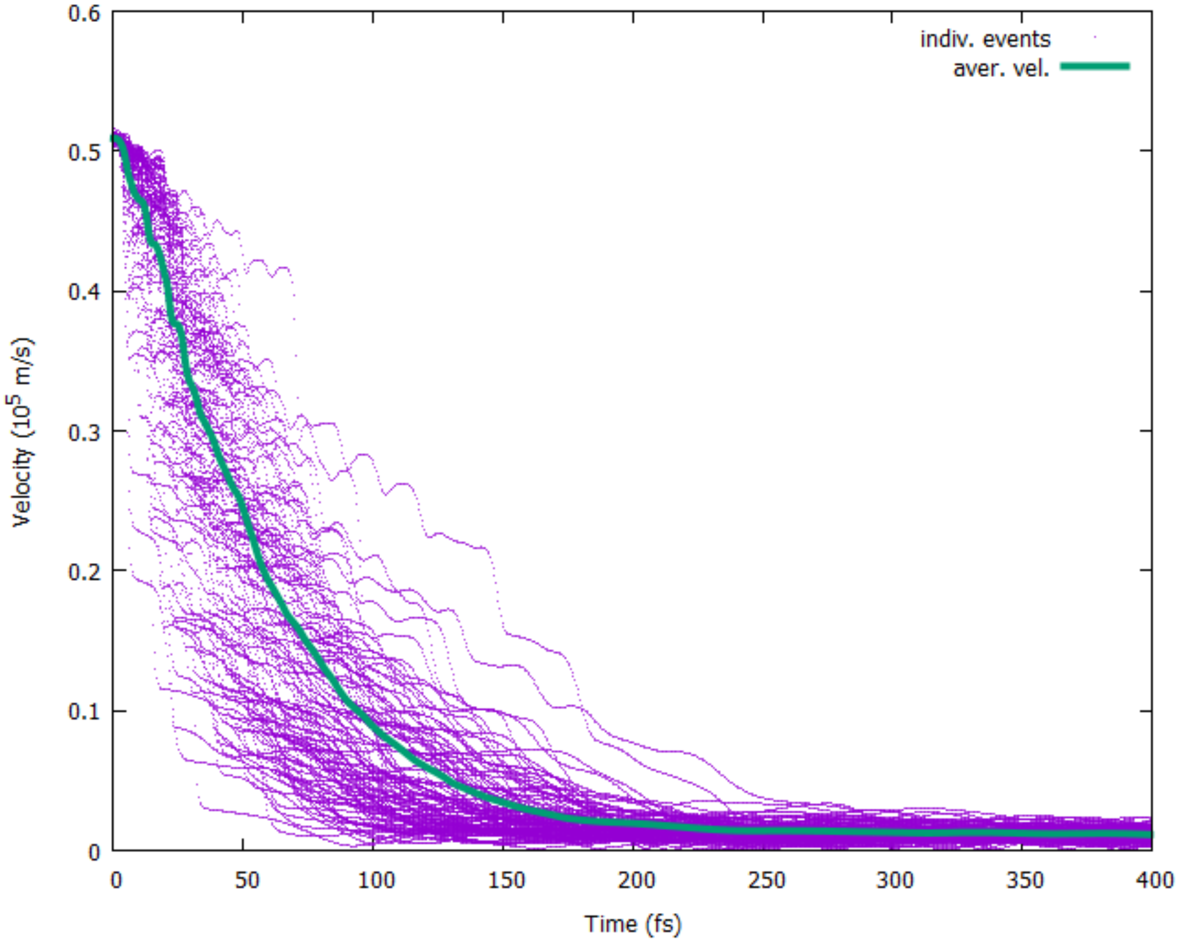


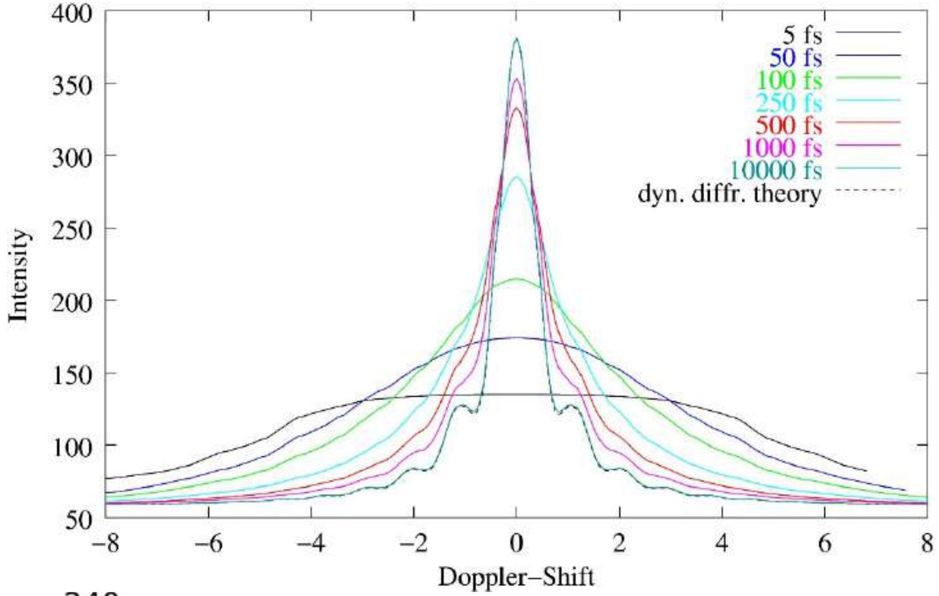
Simulation: color = Doppler Shift of $E\gamma_2$, Intensity = emission probability γ_2

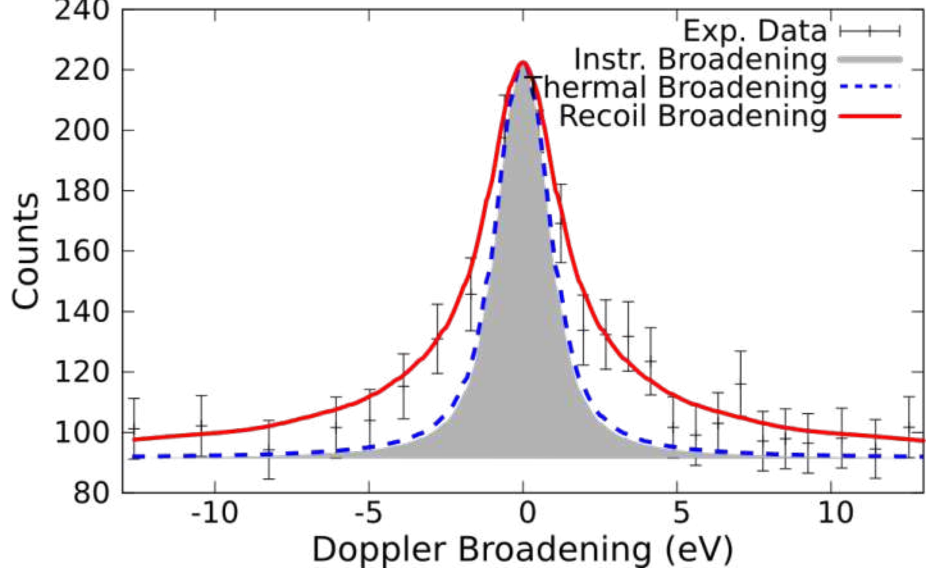
τ= 20 fs



How does this show up in GRID measurement?







Problems with GRID

Needs ultra high resolution $\frac{\Delta E}{E} \simeq 10^{-6}$ => GAMS

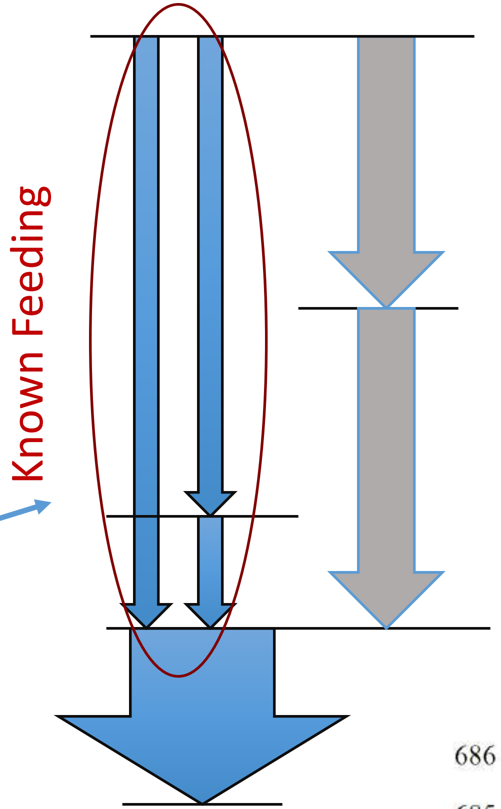
Solid Angle of GAMS: $\Omega \simeq 10^{-11}$

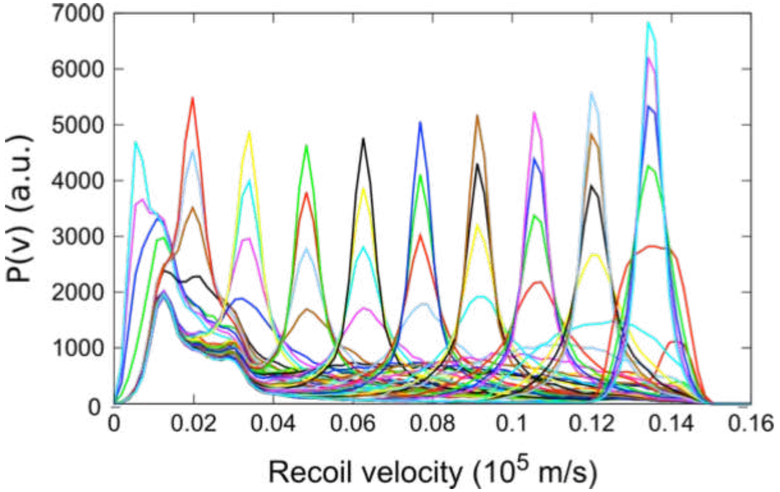
- No Coincidences
- Only γ_2 is measured
- Not clear how LOI is populated

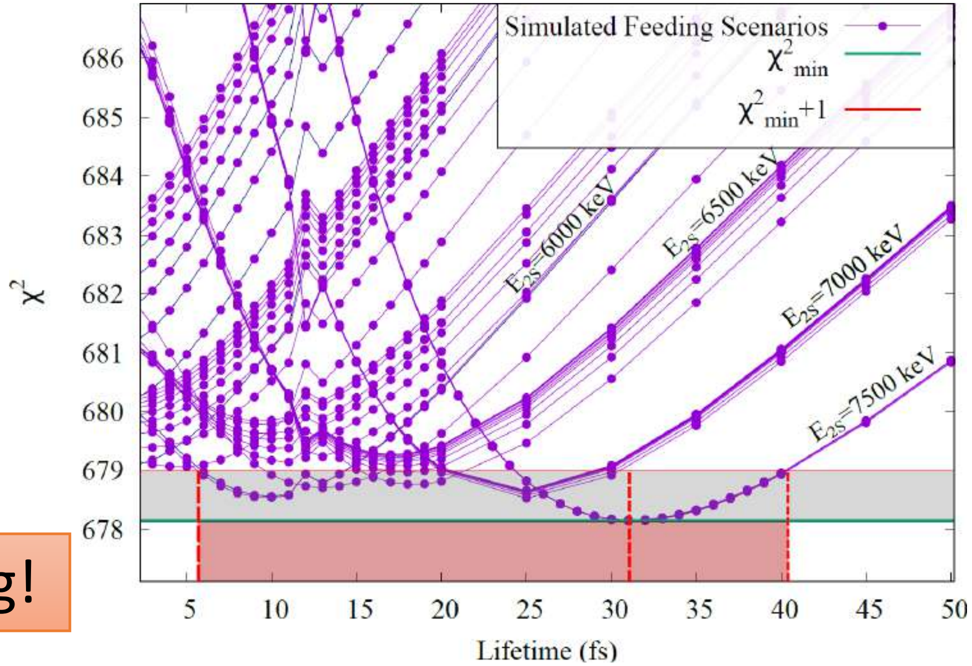
Targets for GAMS in double flat crystal mode:

- Only massive targets (1 - 10 g)
- Only stable targets
- Only targets compatible with H6/H7
- Only strongest transition

Rigth now: No H6/H7 => No Measurements with GAMS

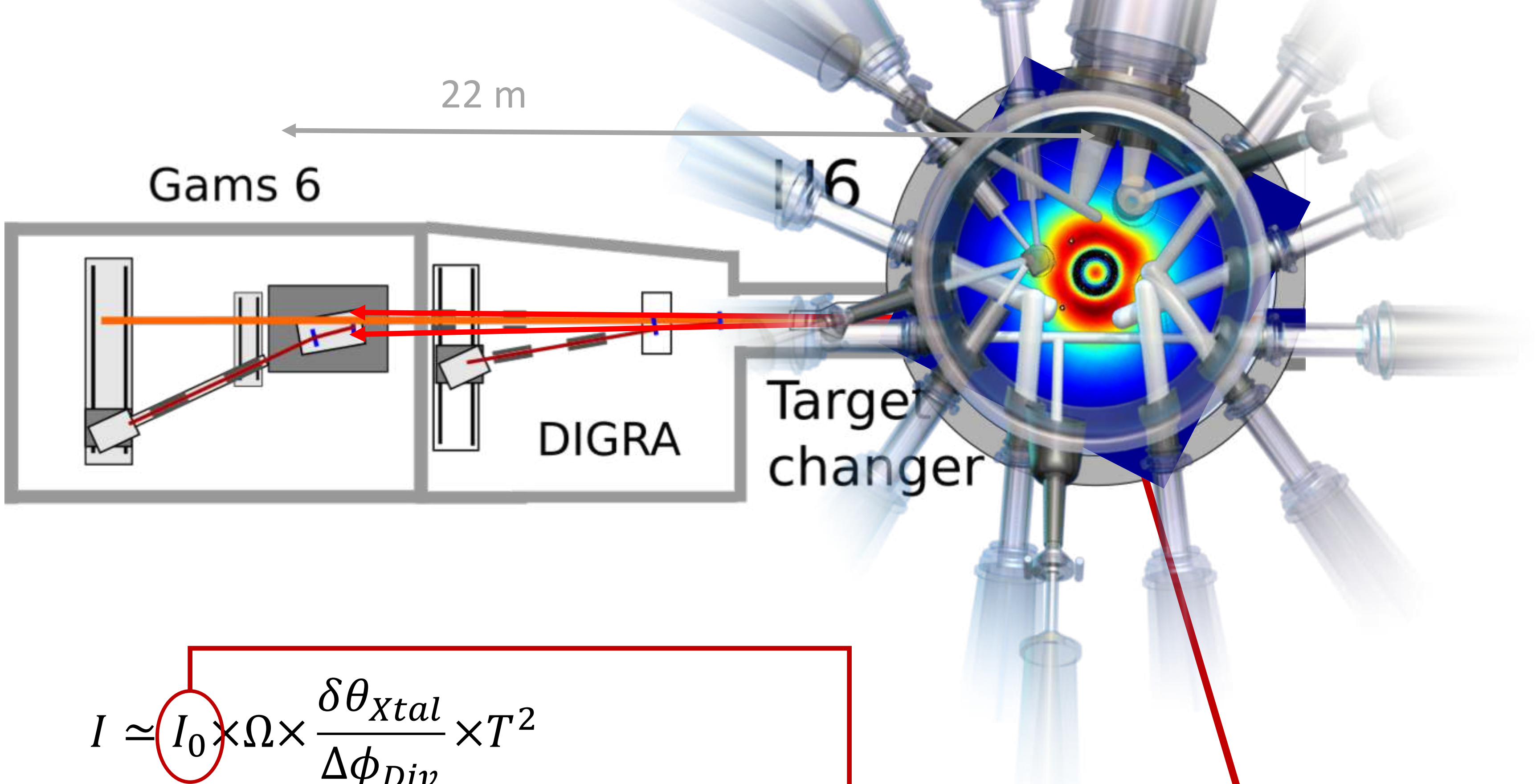






It would be cool if we could gate on one feeding!

Inpile Gamma Ray Spectroscopy with Crystal Spectrometers



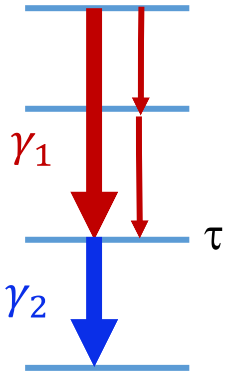
$$I \simeq I_0 \times \underbrace{\Omega}_{} \times \underbrace{\frac{\delta\theta_{Xtal}}{\Delta\phi_{Div}}}_{} \times \underbrace{T^2}_{}$$

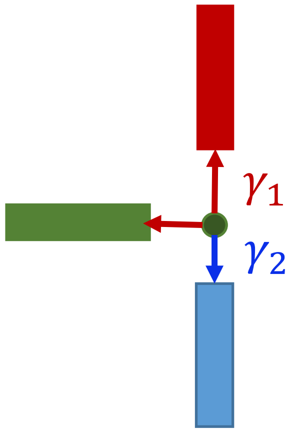
	Ω	$\frac{\delta\theta_{Xtal}}{\Delta\phi_{Div}}$	T^2		Source:
Double flat xtal:	10^{-6}	10^{-3}	10^{-2}	$= 10^{-11}$	2-10 g
Single bent xtal:	10^{-6}	1	10^{-1}	$= 10^{-7}$	20-40 mg

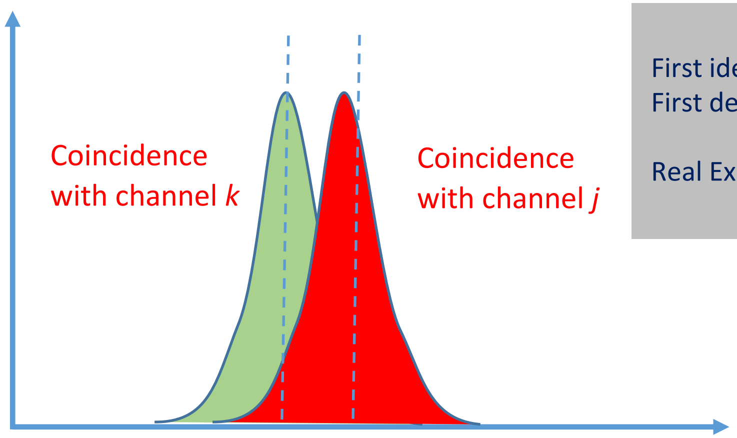
In-pile target position
- 5×10^{14} neutrons $cm^{-2}\,s^{-1}$
- Capture rate: $<10^{16}\,s^{-1}$
- Gamma emission rate $<10^{16}\,s^{-1}$
- $\Delta E/E$ ~10^{-6}

How to do GRID without GAMS?

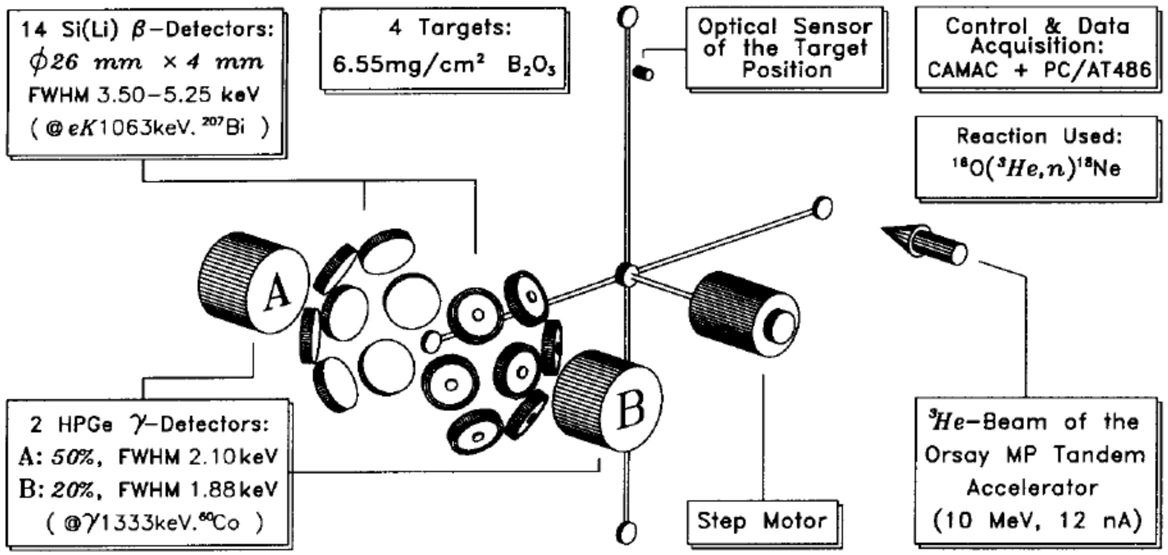
Instead measuring Lineshape look for Doppler-Shift: **G**amma **R**ay **I**nduced **D**oppler **S**hift **A**ttenuation





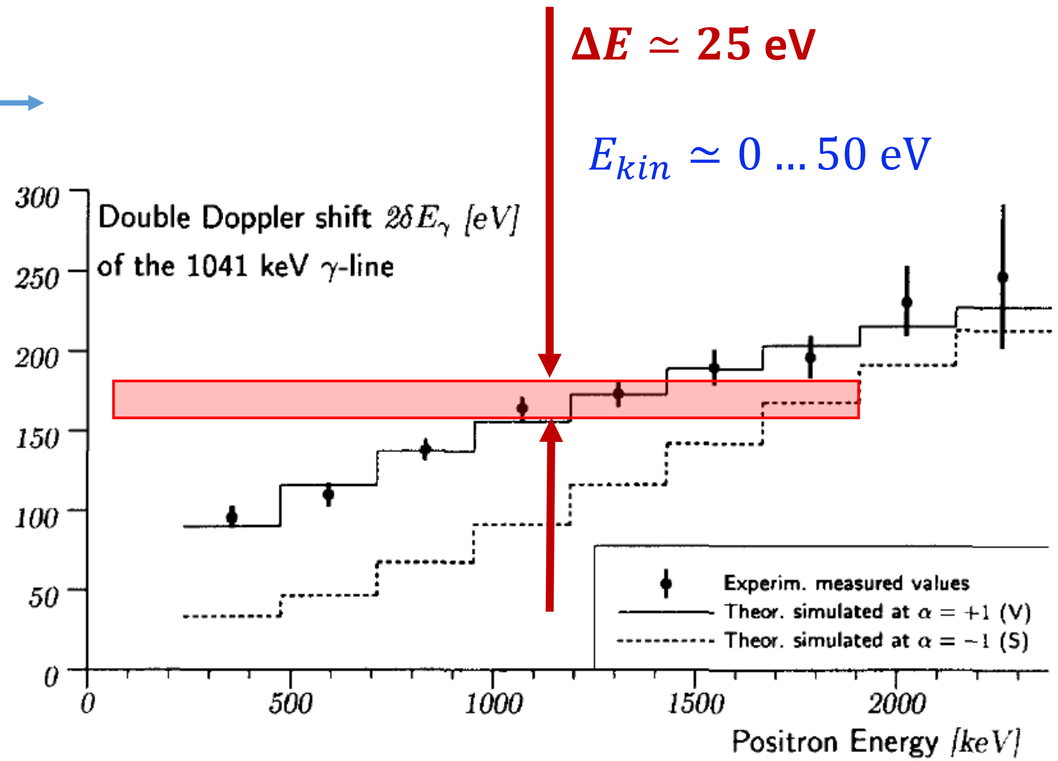


First idea:	V.T. Kupryashkin et al., AN SSSR, Ser. Fiz vol. 53, (1989) 2
First demo with (n,γ):	T. Kahn, T. von Egidy, F.J. Hartmanna, J. Ott, M. Jentschel Nucl. Instr. Meth. A 385 (1997) 100-107
Real Experiment with (β,γ):	V. Egorov et al., Nucl. Phys. A (1997) 745-753

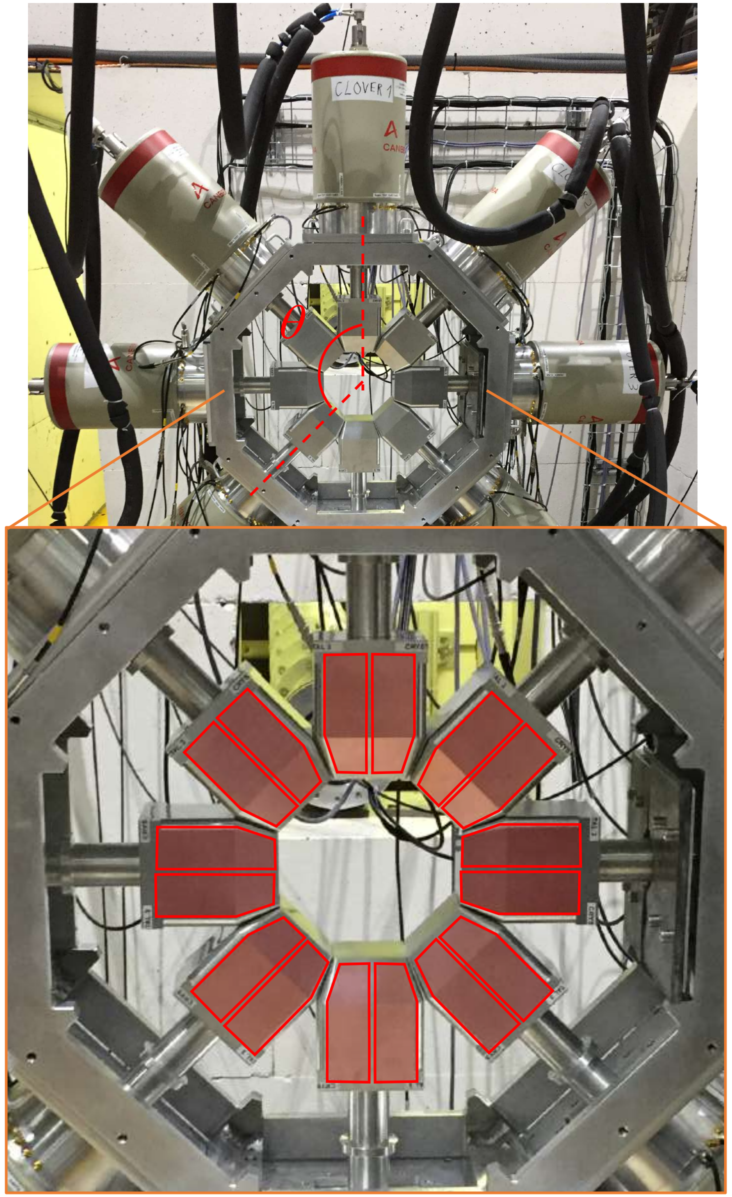


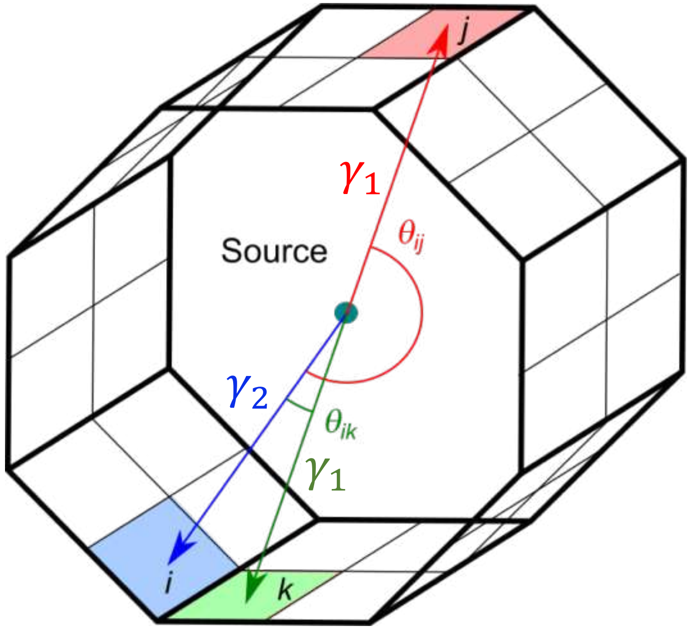
$\Delta E \simeq 25$ eV

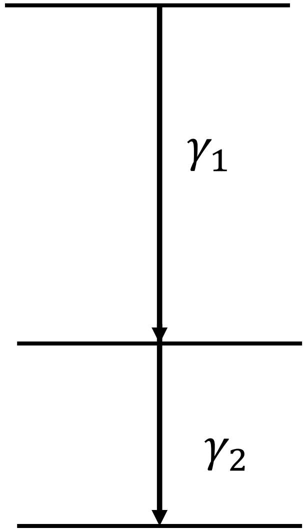
$E_{kin} \simeq 0 \ldots 50$ eV

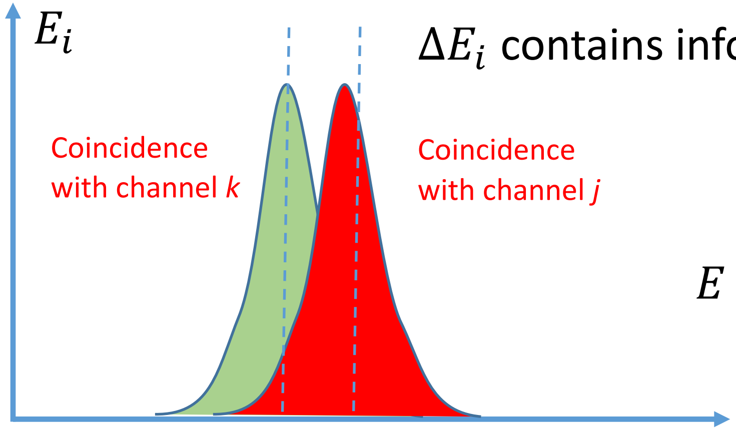


GRIDSA with a Germanium Array @ ILL





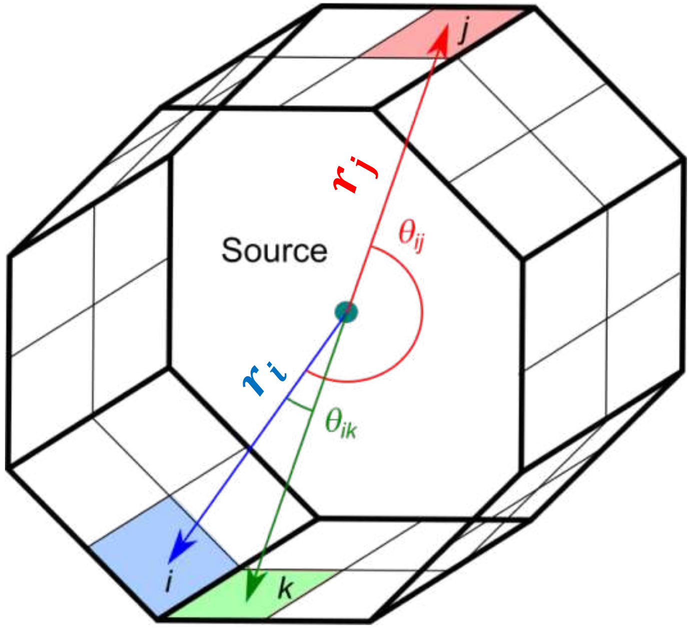




ΔE_i contains information on τ

$$E = E_{\gamma_2}\left(1 + \frac{v(t)}{c}\cos\theta\right)$$

What do we expect (part I)



$$E_{ij} = \frac{1}{\tau}\int_0^\infty \exp\left(-\frac{t}{\tau}\right)\iint E_{\gamma_2}\left(1+\frac{\frac{v(t)}{c}(\boldsymbol{r_i},\boldsymbol{r_j})\epsilon_i(E_{\gamma_2},\boldsymbol{r_i})\epsilon_j(E_{\gamma_1},\boldsymbol{r_j})}{\epsilon_i(E_{\gamma_1})\epsilon_j(E_{\gamma_2})}\right)d\boldsymbol{r_i}\,d\boldsymbol{r_j}\,dt$$

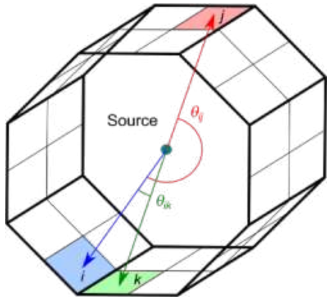
Assumption #1: Each detector can be replaced by a single detection point $\boldsymbol{d_j}$

$$\epsilon_j(E_{\gamma_1},\boldsymbol{r_j}) \simeq \epsilon_j(E_{\gamma_1})\delta(\boldsymbol{r}-\boldsymbol{d_j})$$

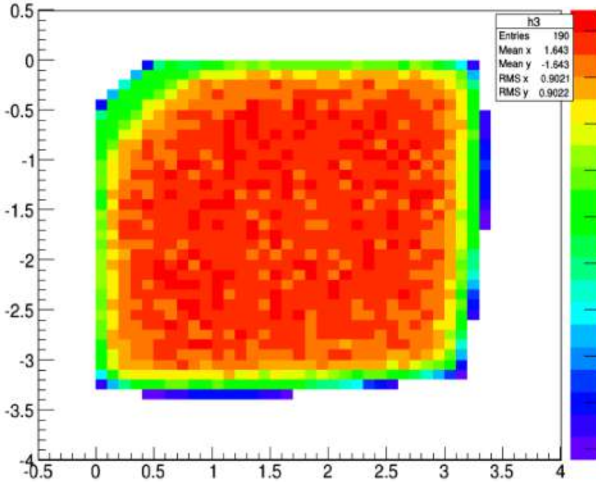
$$E_{ij} = \frac{E_{\gamma_2}}{\tau}\int_0^\infty \exp\left(-\frac{t}{\tau}\right)\left(1+\frac{v(t)}{c}\cos\theta_{ij}\right)dt$$

How reasonable is this assumption?

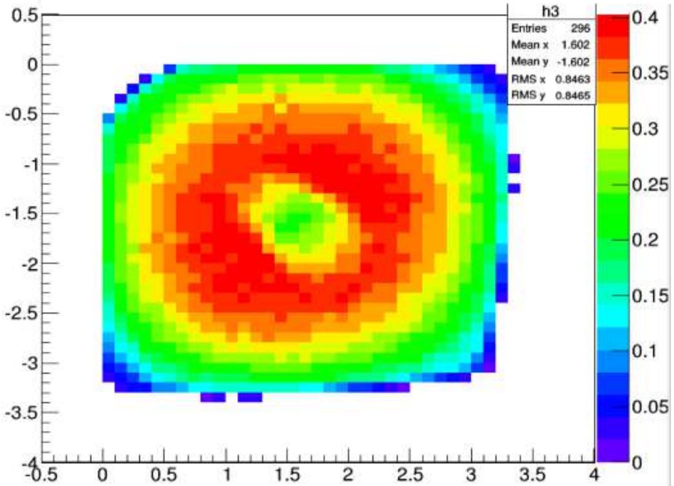
GEANT4 simulations of $\epsilon_j(E, \boldsymbol{r_j})$ by Yung Hee



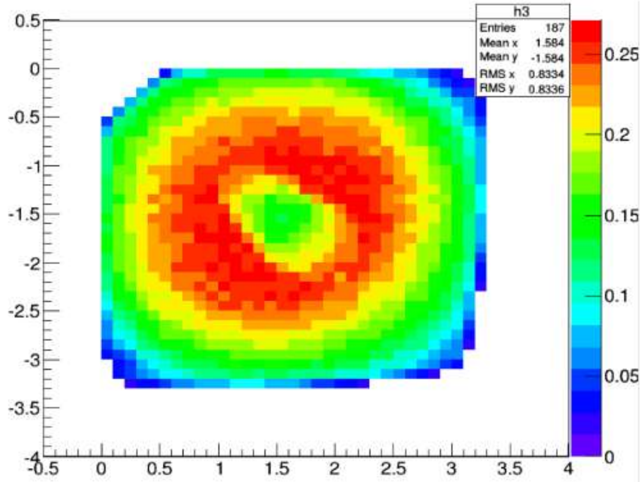
$E = 0.1$ MeV

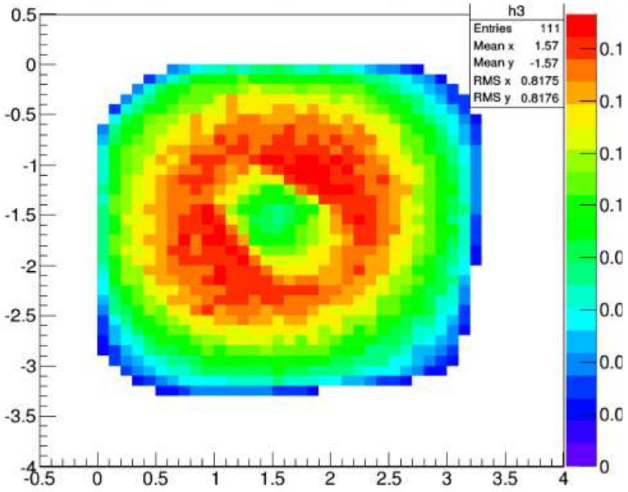


$E = 0.5$ MeV

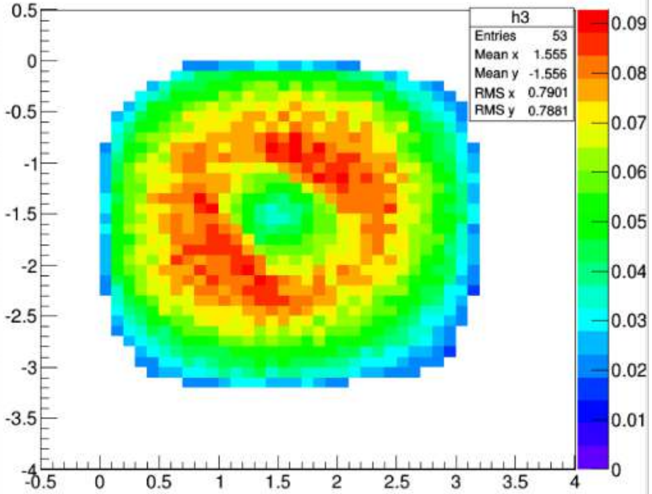


$E = 1.0$ MeV

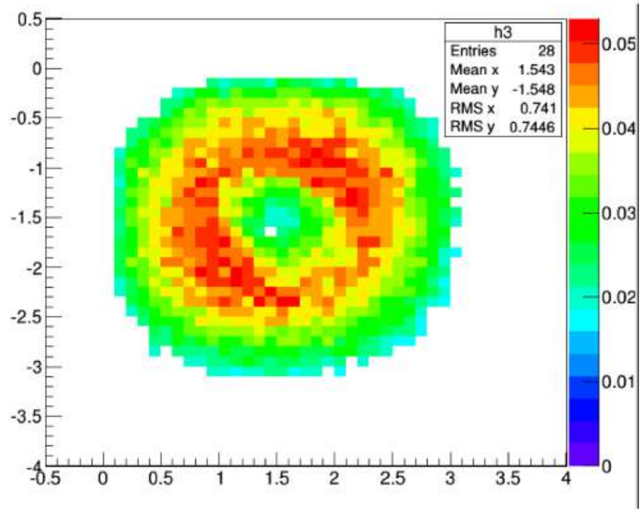




$E = 2.0$ MeV

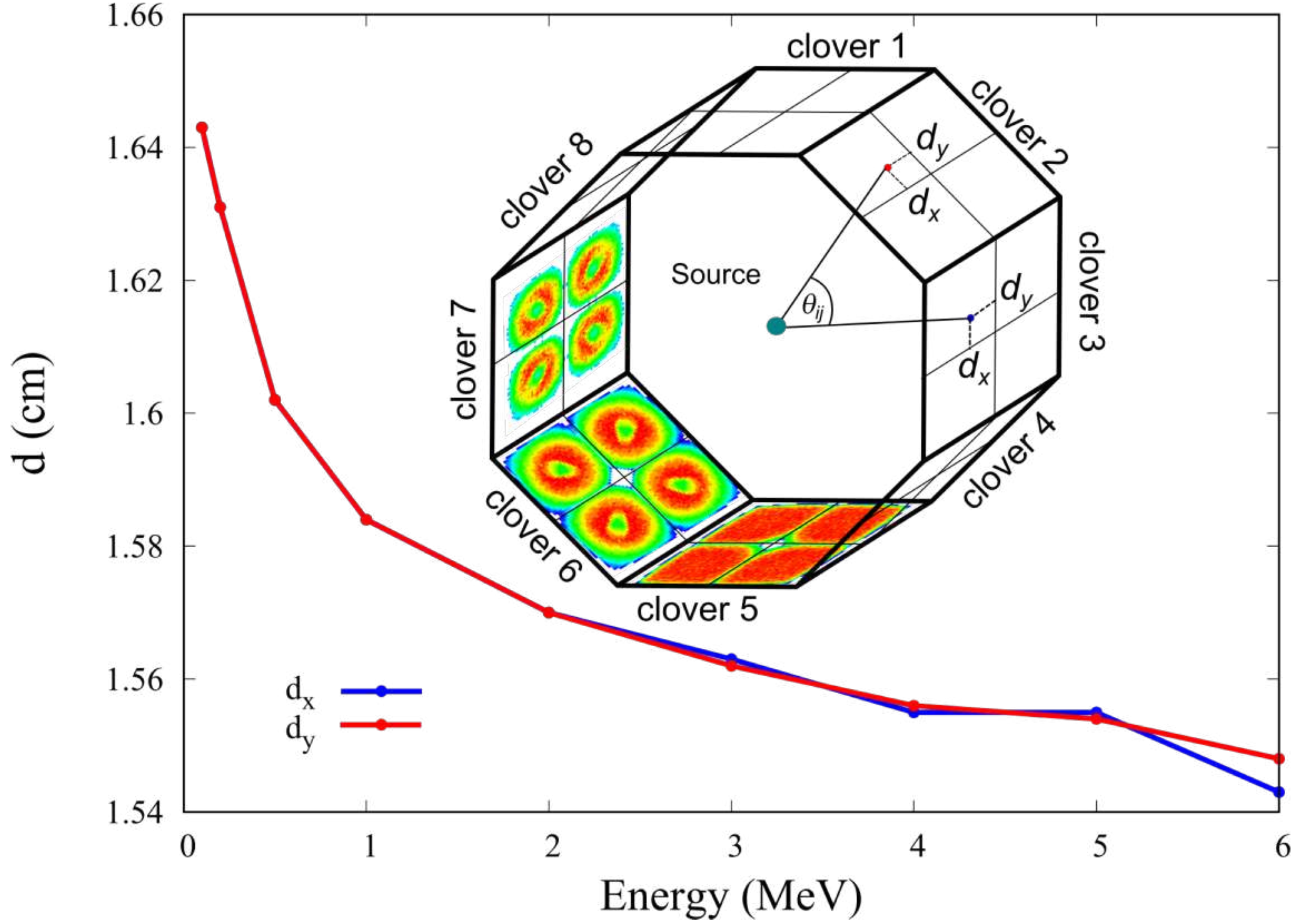


$E = 4.0$ MeV



$E = 6.0$ MeV

Realization of assumption #1



- From simulated $\epsilon(E, \boldsymbol{r_i})$ we calculate $\boldsymbol{d_j}(E)$ as "center of mass"
- Allows for each combination of Energies E_{γ_1} and E_{γ_2} to calculate appropriate θ_{ij}

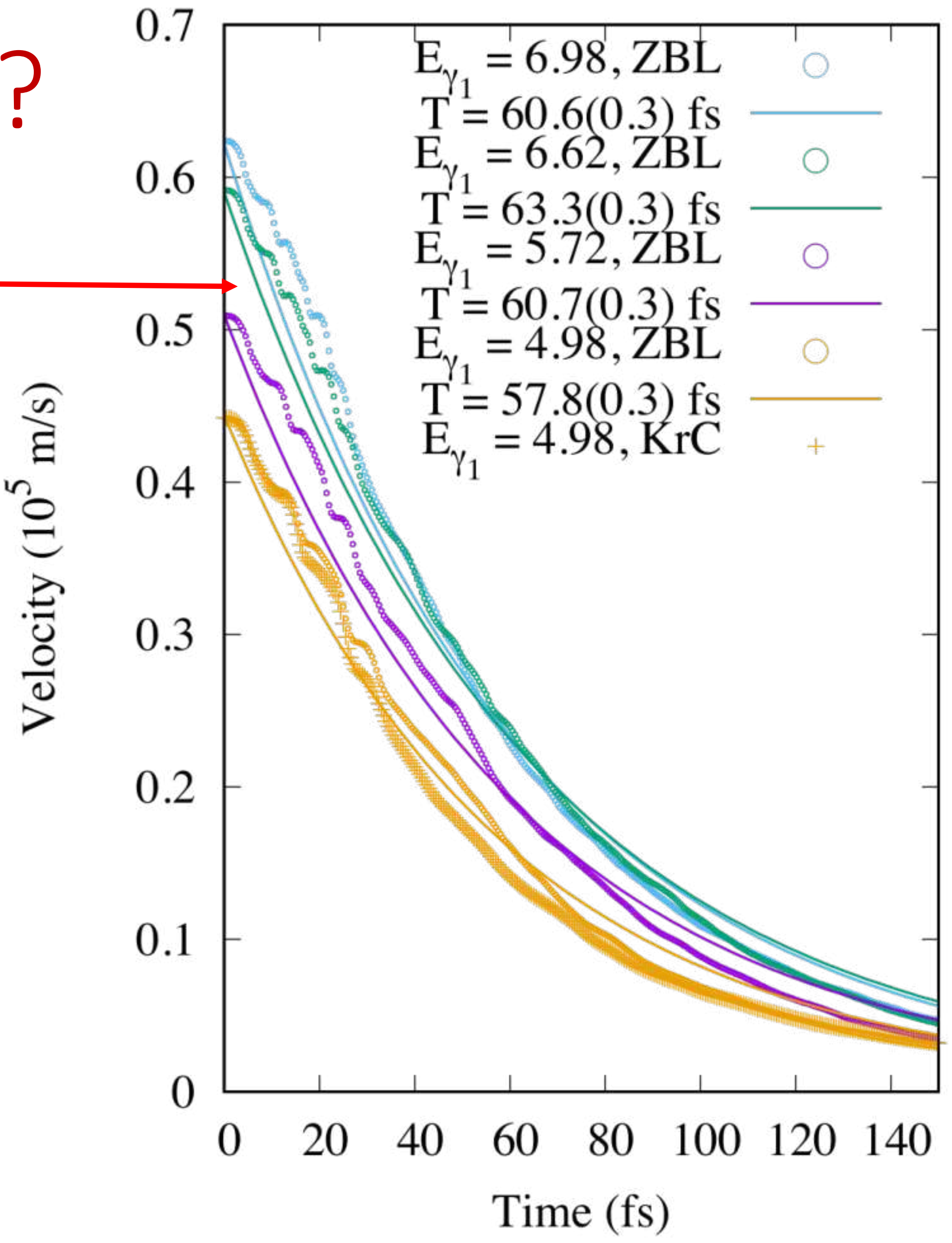
What do we expect (part II)?

$$E_{ij} = \frac{E_{\gamma_2}}{\tau}\int_0^\infty \exp\left(-\frac{t}{\tau}\right)\left(1+\frac{v(t)}{c}\cos\theta_{ij}\right)dt$$

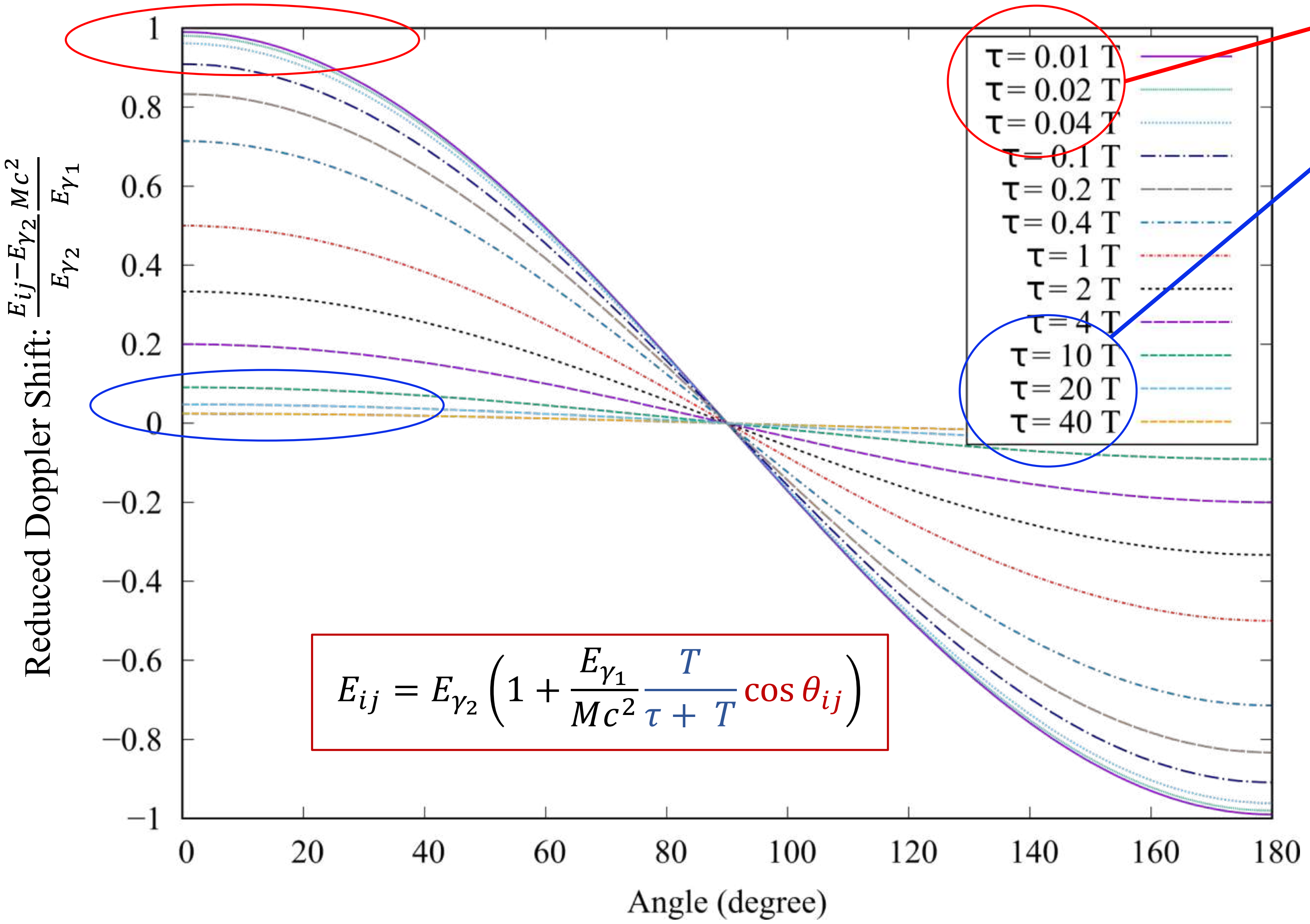
Assumption #2: $v(t) = v_r \exp\left(-\frac{t}{T}\right)$

$$\boxed{E_{ij} = E_{\gamma_2}\left(1+\frac{E_{\gamma_1}}{Mc^2}\frac{T}{\tau+T}\cos\theta_{ij}\right)}$$

$$\frac{v_R}{c} = \frac{E_{\gamma_1}}{Mc^2}$$



What to expect (all together)



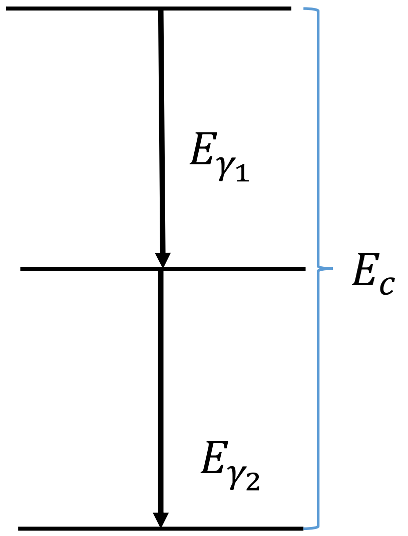
$$E_{ij} = E_{\gamma_2}\left(1 + \frac{E_{\gamma_1}}{Mc^2}\frac{T}{\tau + T}\cos\theta_{ij}\right)$$

- Little sensitivity for τ << T
- Good sensitivity for τ ~ T
- Little sensitivity for τ >> T

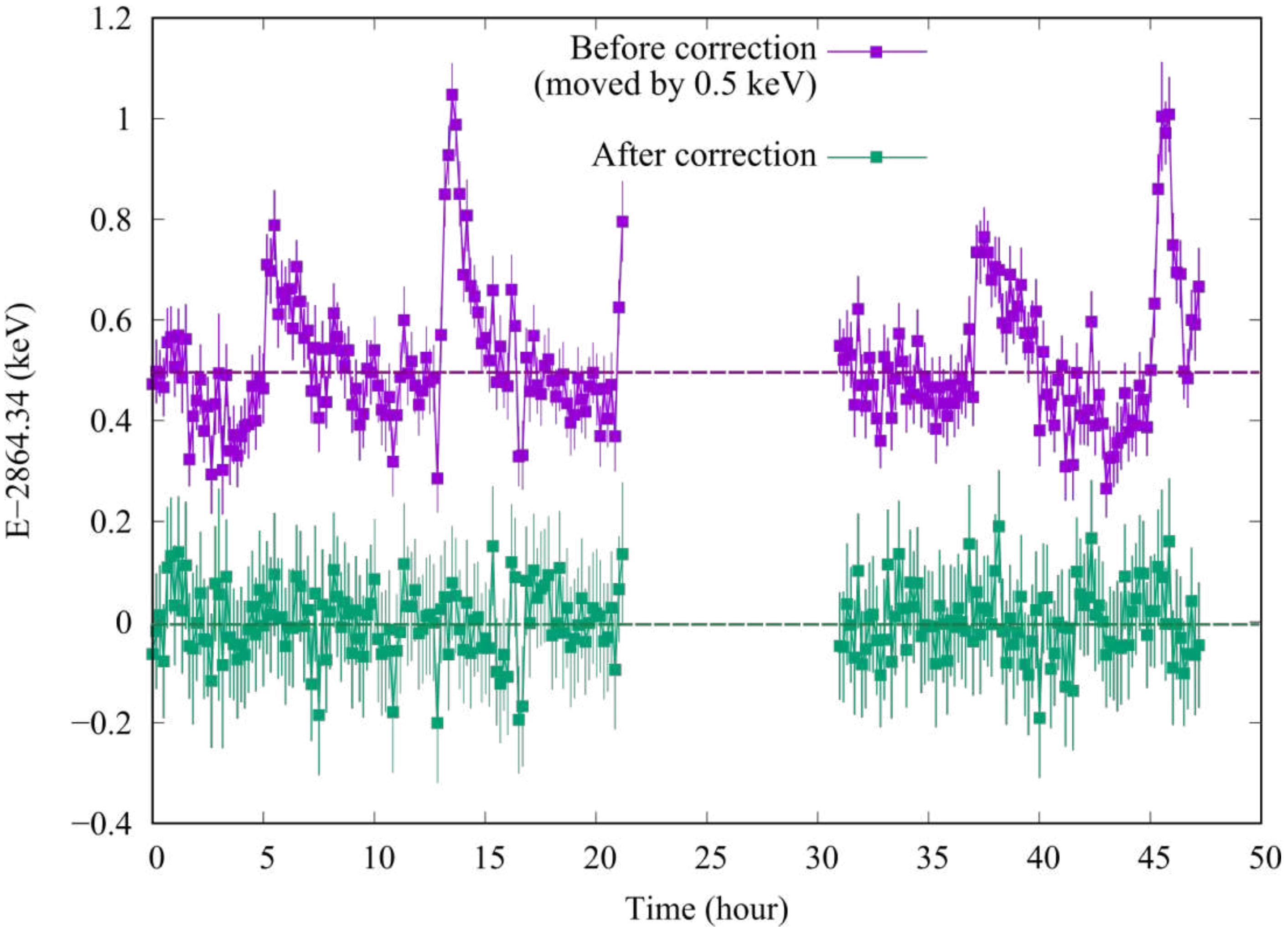
- Doppler shift small for τ >> T

- Doppler shift scales with $1/M$

- Doppler shift is maximum for $E_{\gamma_2} = \frac{1}{2}E_C$



Towards real data

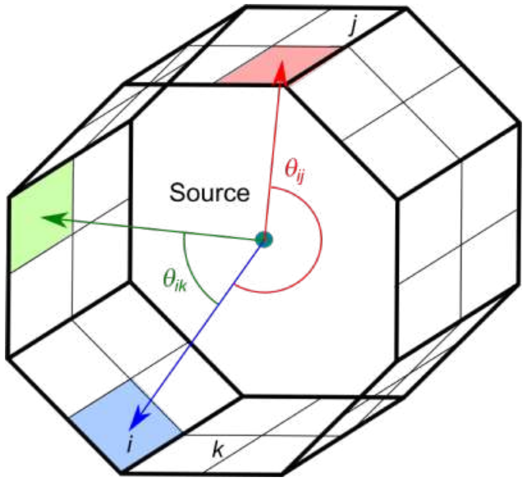


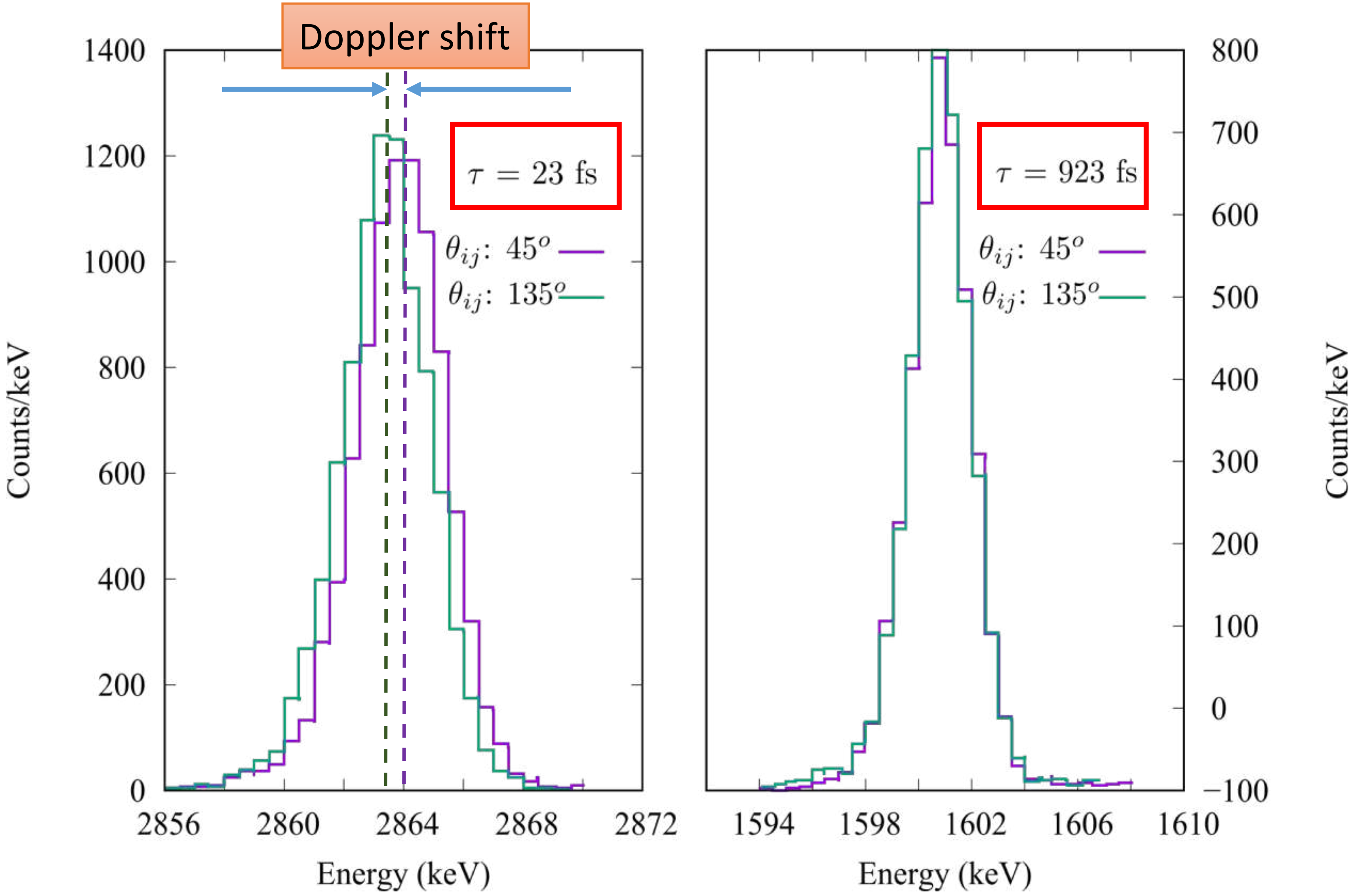
We want to measure small shifts:

- No background subtraction
- Permanent calibration correction
- Start γ-ray: use photo+escape+double escape

Real Data

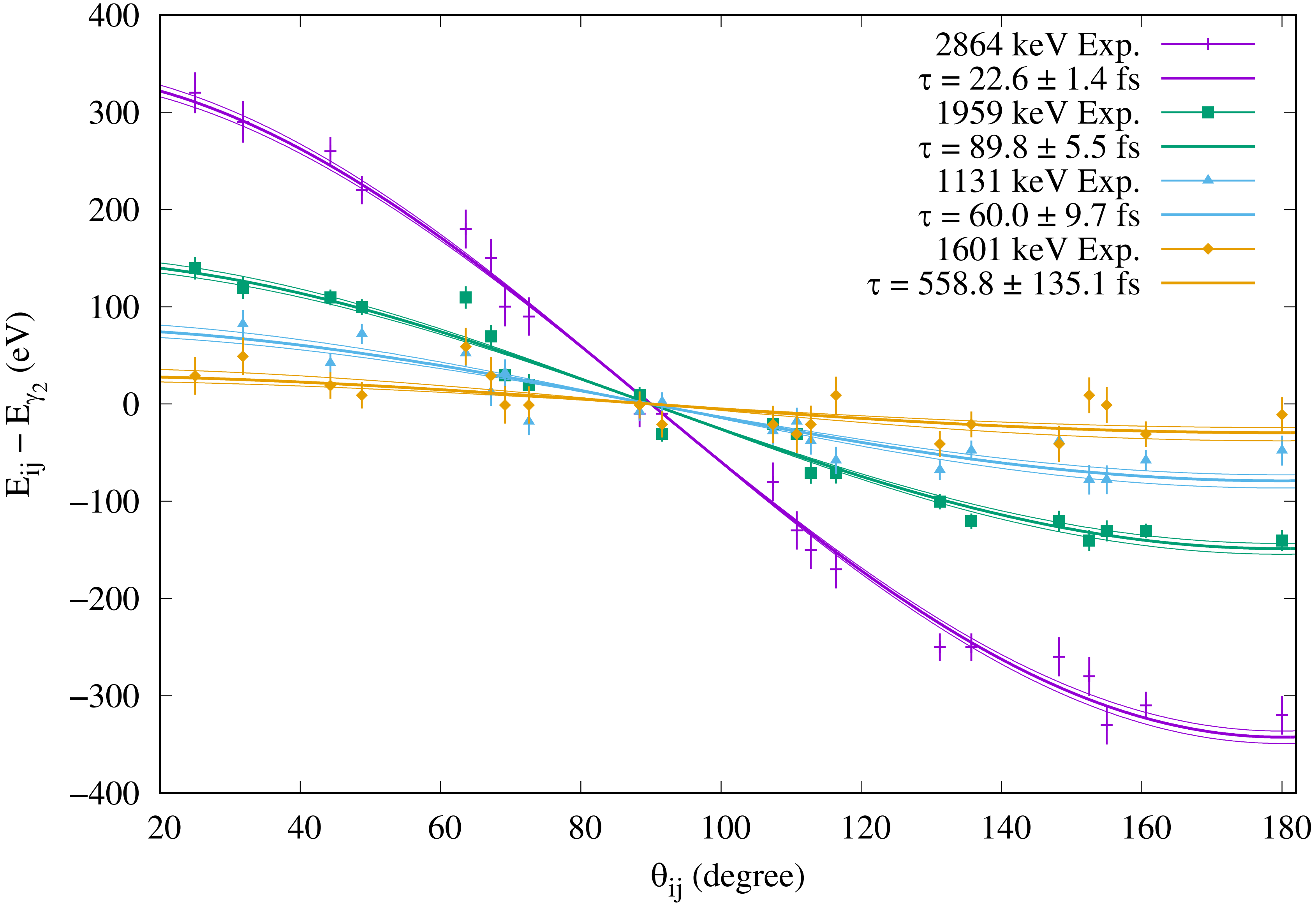
- 38h data taking @ FIPPS
- Sample NaCl
- Reaction $^{35}Cl(n,\gamma)^{36}Cl$





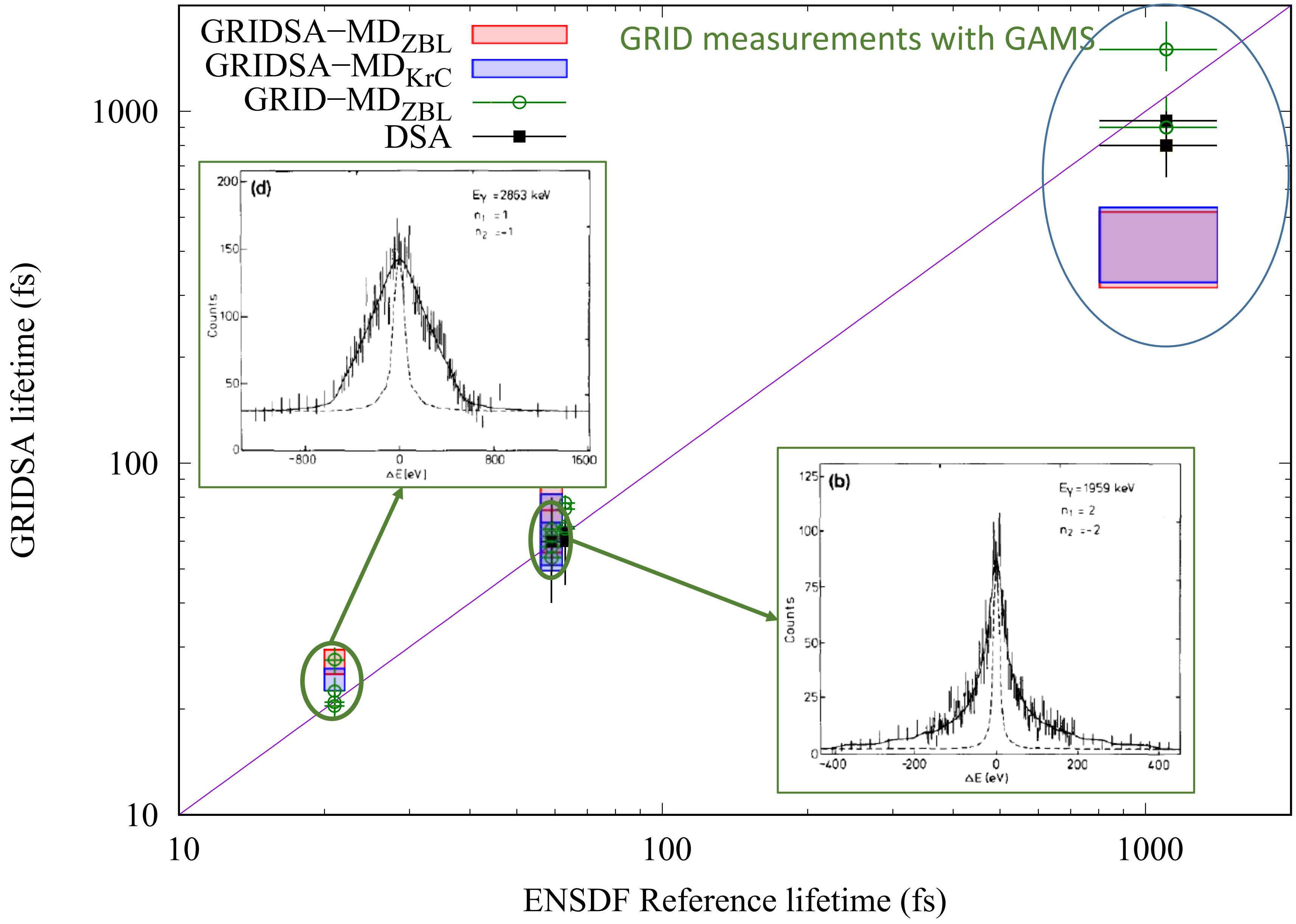
Centroid position determined as barycenter (no difference to Gaussian fit)

Experimental Results for 4 nuclear states in ^{36}Cl (NaCl target)



How does this compare?

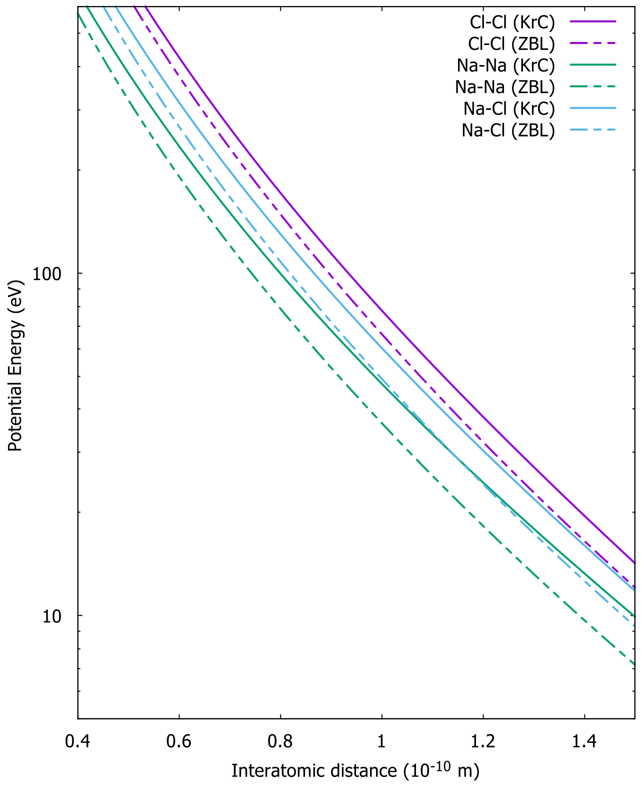
Region, where $\tau >> T$

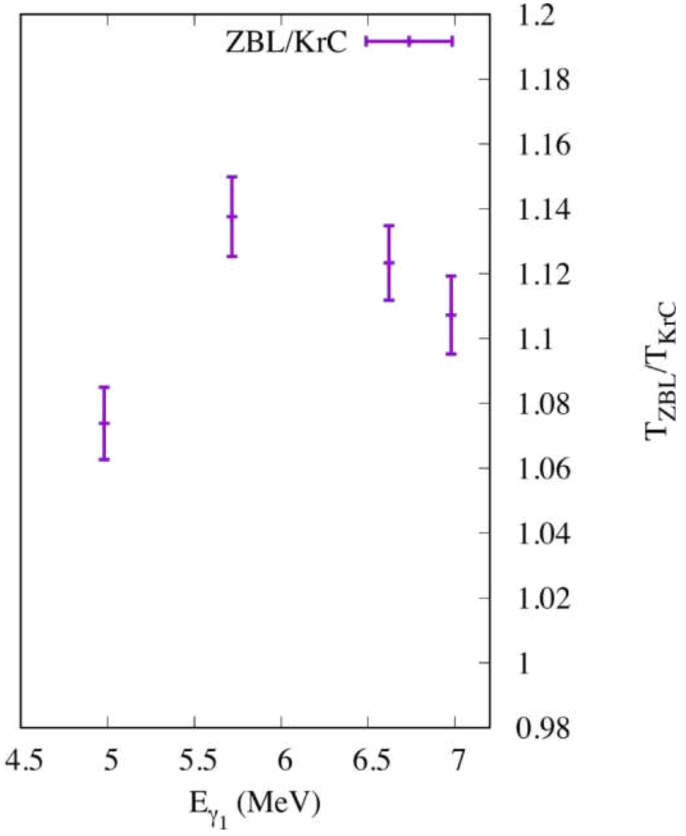


- Rather good agreement for lifetimes up to 500 fs
- Deviation comparable to scattering of different methods
- Very efficient: 4 lifetimes in 38h (GRID: 10 days of beam time)

Difference of ZBL and KrC results: 10% due to unkown atomic interaction

KrC –potential is more repulsive => faster slowing down => $\frac{T_{ZBL}}{T_{KrC}} \simeq 1.1$=> $\tau_{ZBL} > \tau_{KrC}$

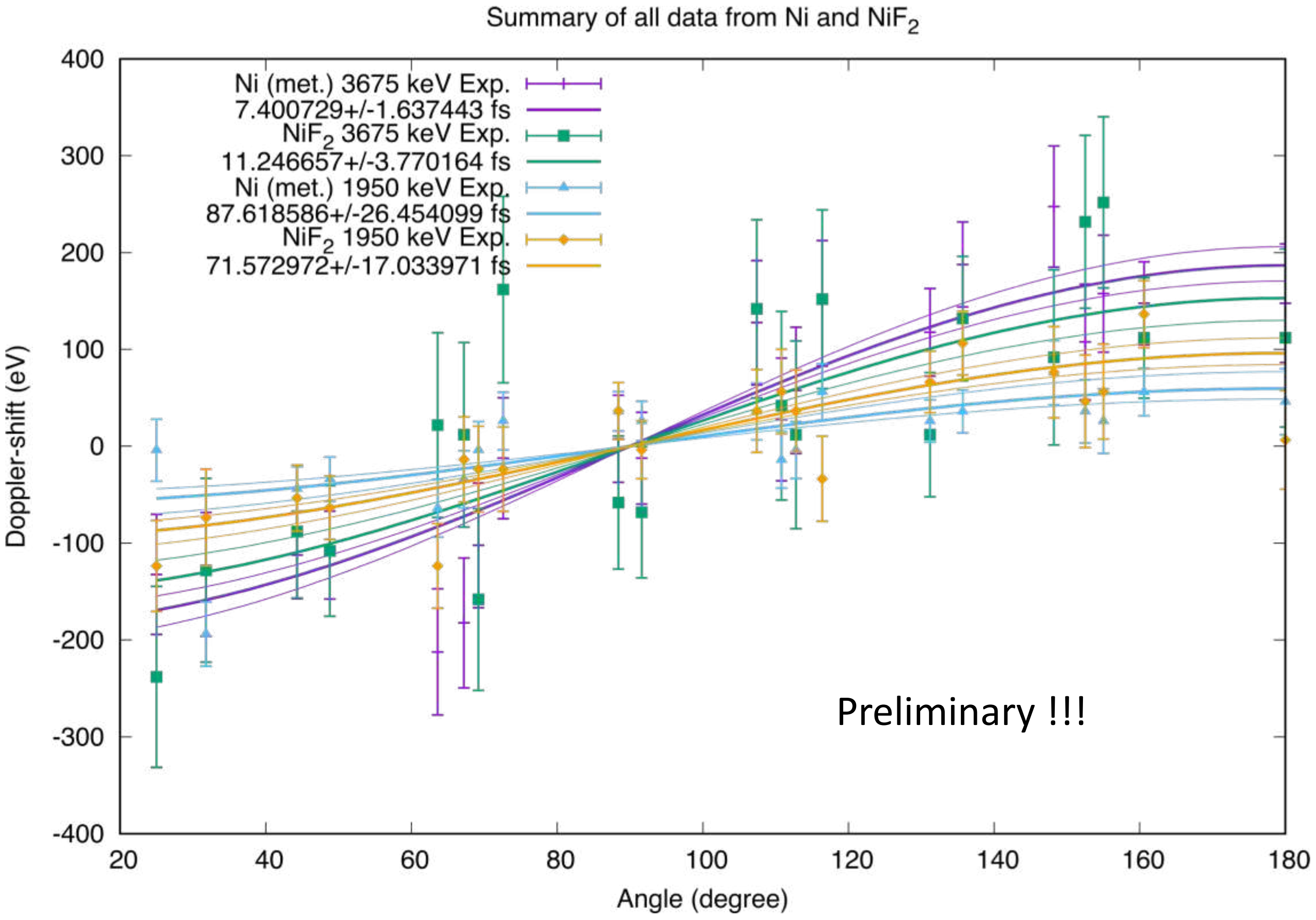




$$E_{ij} = E_{\gamma_2}\left(1 + \frac{E_{\gamma_1}}{Mc^2}\frac{T}{\tau + T}\cos\theta_{ij}\right)$$

$$v(t) = v_r \exp\left(-\frac{t}{T}\right)$$

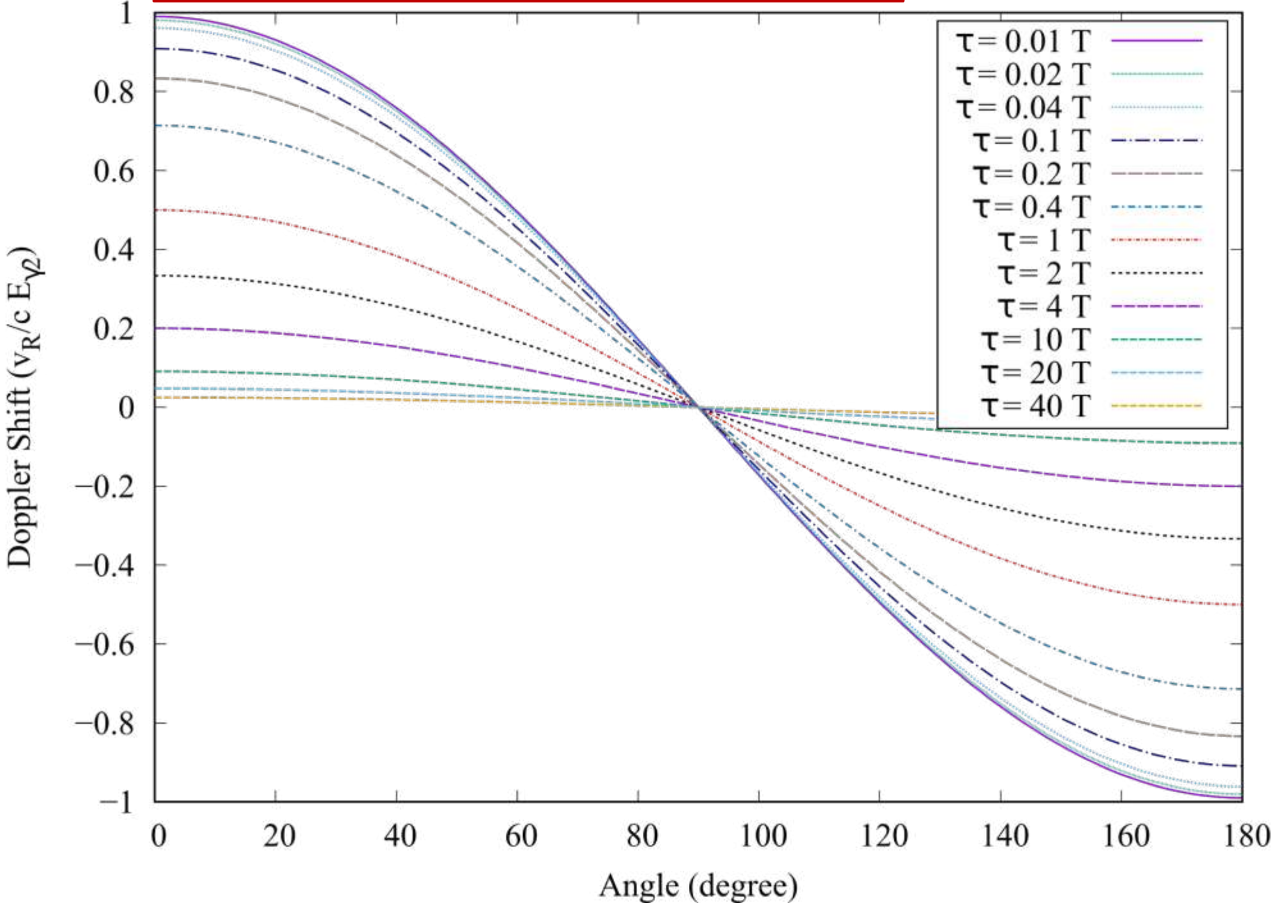
Extending mass range: 59Ni



- Preliminary data, missing drift correction
- Statistics is bad, still results can be extracted

Extending range of sensitivity: Gas target

$$E_{ij} = E_{\gamma_2}\left(1 + \frac{E_{\gamma_1}}{Mc^2}\frac{T}{\tau + T}\cos\theta_{ij}\right)$$



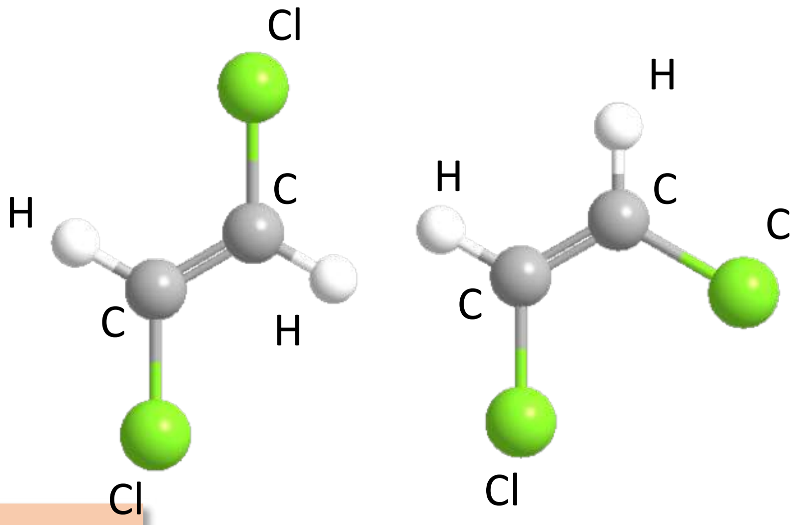
We want to increase T !!!

density of salt $\rho \simeq 2 - 4$ g/cm^3
Density of gas $\rho \simeq 0.002$ g/cm^3

- A factor 1000 lower density = factor 10 larger interatomic distance
- This yields a factor ~10 lower collision frequency
- We expect an increase of factor 10 towards longer lifetimes

Choosing the proper Gas for ^{36}Cl

- Cl_2 gas could work but very toxic, for a test experiment too difficult in terms of safety requirements
- Choice: Dichlorethene
- To avoid neutron scattering: ^{1}H -> ^{2}D
- Is liquid at room temperature, quickly evaporating

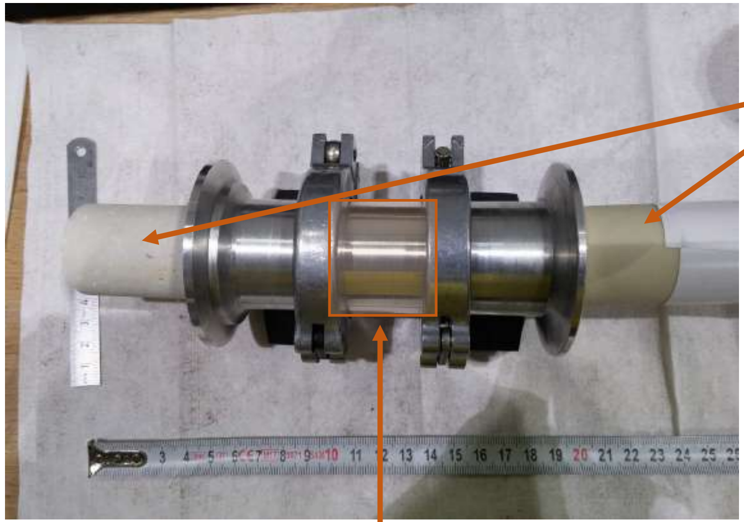


French wikipedia (not in the english)

« Il est surtout utilisé comme solvant de résines, graisses, parfums, colorants, laques, plastiques thermosensibles, phénols, etc., … »

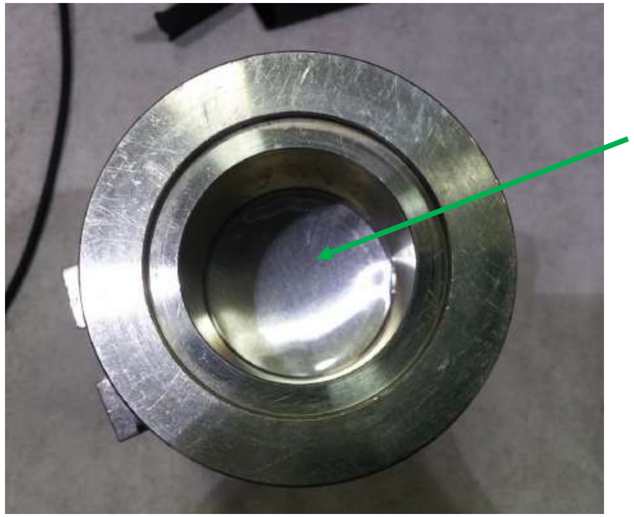
Test (cheap) Experiment with Gas Target @ FIPPS

Wrong seal

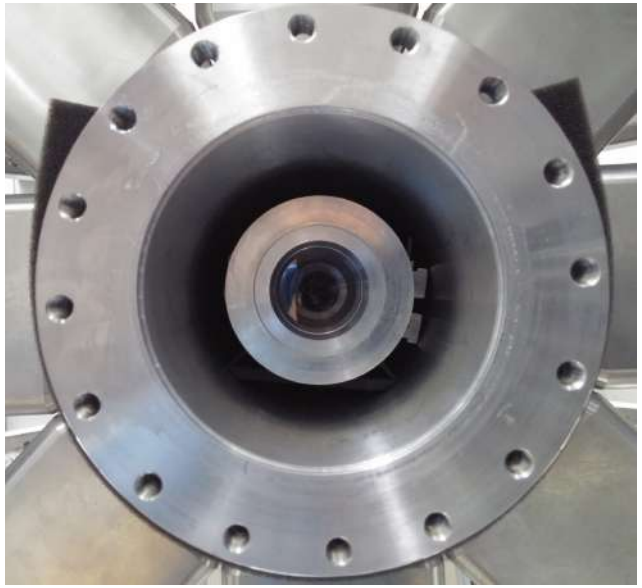


^{6}LiF collimation for neutrons

Gas cell

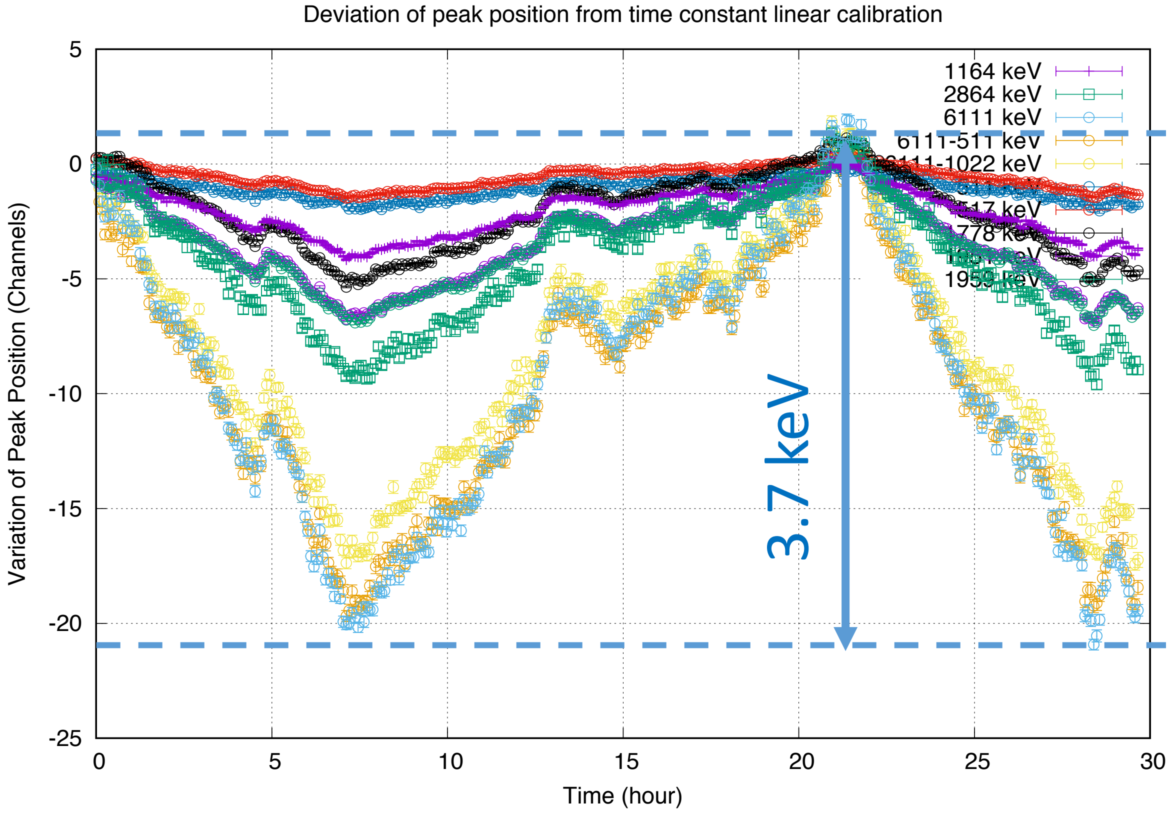


First saphire later
Aluminum window
with Teflon seal



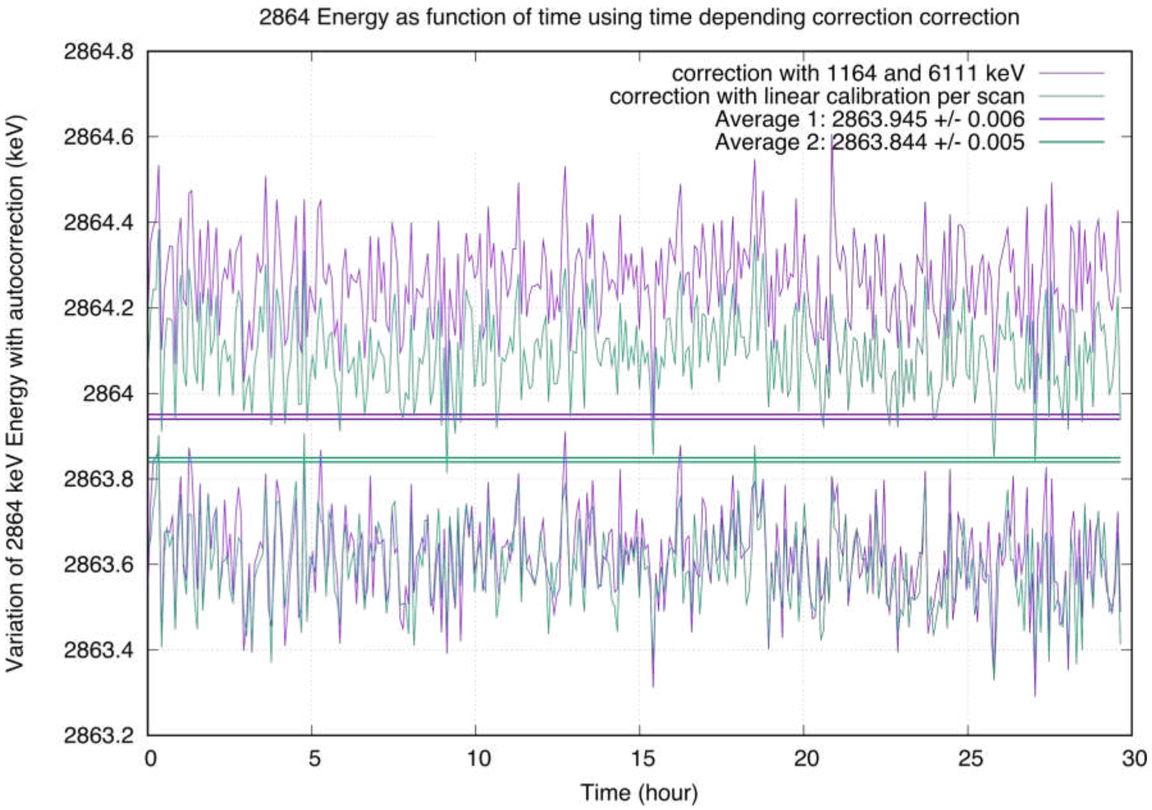
Gas cell placed in
FIPPS target chamber

Bad surprise: drift



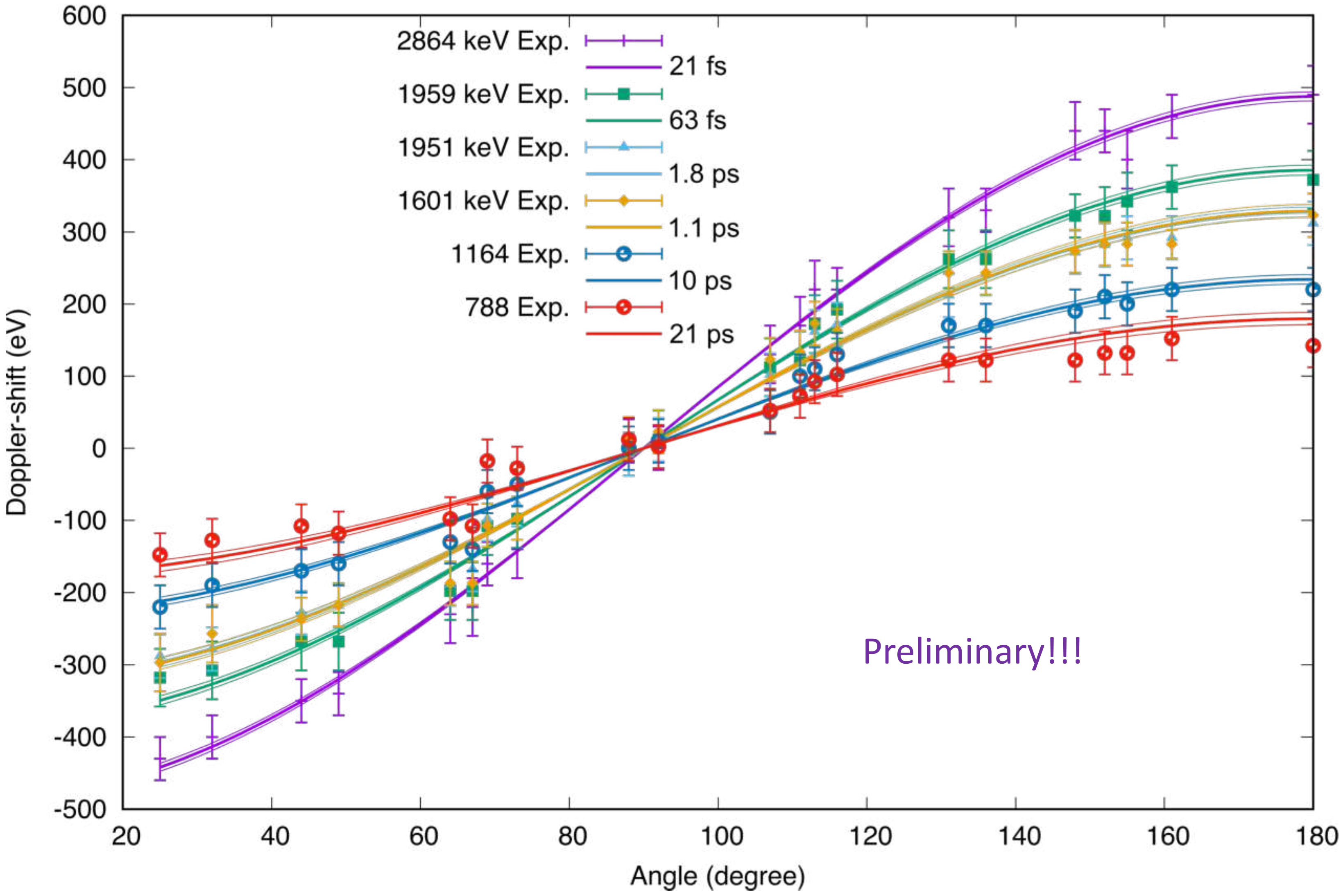
Gas Target

- Due to new acquisition cards we have serious drift of calibration function
- Seem to be related to temperature



- Drift correction without glogal calibration of the array

Preliminary Results from Gas Target

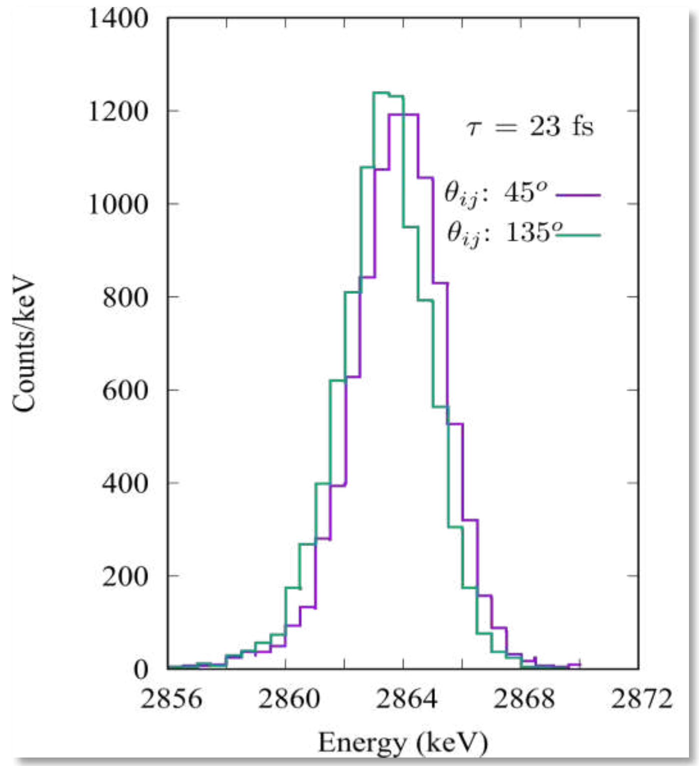


Preliminary!!!

- We now see Doppler shift even for very long lifetimes
- Might open a way to extent technique to ps range
- Needs dedicated slowing down
- Needs geometrical corrections

Next Steps

- Look into existing spectroscopy data up to A ~ 100
- Fingerprint:



- Develop dedicated gas target for FIPPS:
  - Filling / gas circulation during experiment
    - Allows admixing of noble gases during experiment -> variation of T
  - Variable Pressure/Temperature
    - -> allows variation of T by pressure
    - -> allows variation of T by phase transitions

Conclusion

- GRIDSA allows to extract fs lifetimes
    - For the moment considerations limited to two step cascades
    - Fundamentally not limited to (n,γ) reaction
- Does not require dedicated setup, just different way of looking at data
- Very time efficient: all lifetimes are measured at the same time
- If calibration of the system is stable (or can be corrected): lifetime measurements up to A=100 and/or τ<500 fs possible
- Statistics and Resolution is very, very important (if calibration can be maintained)
- Gas target might allow to extent to ps range

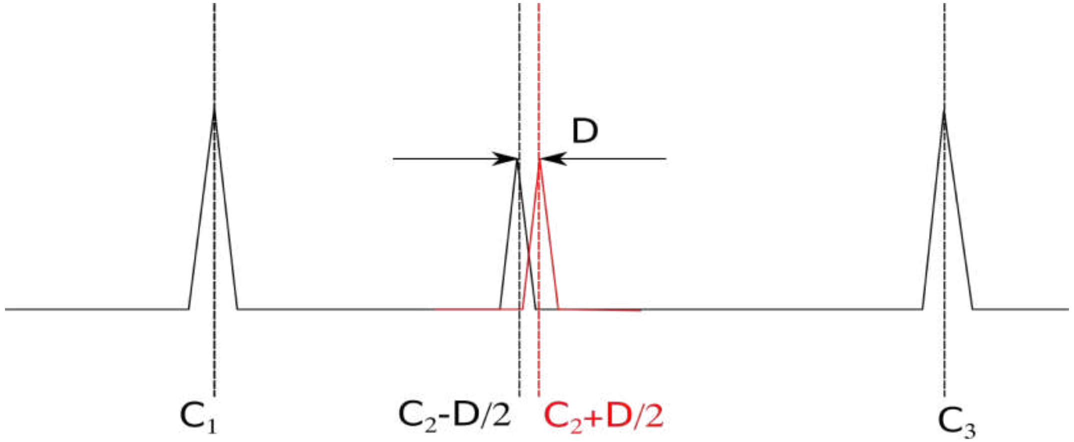
…just another talk on Nuclear Spectroscopy and Lifetimes

Thank you for your Attention

Back Up Slides

Proposal of drift resistant evaluation algorithm

(capital letters: Detector units, small letters: Energy units)



Calibraton function of detector:

$$E_i = a(t) + b(t) \cdot C_i$$

$$C_i = c(t)E_i + e(t), \quad c(t) = \frac{1}{b(t)}, \quad e(t) = -\frac{b(t)}{a(t)}$$

Eliminates $a(t)$ time dependece

d is the Doppler shift measured in eV

Lets introduce the quantities:
(consists of values in Det. units)

$$X^{\pm} = \frac{C_2 \pm \frac{D}{2}}{C_3 - C_1}$$

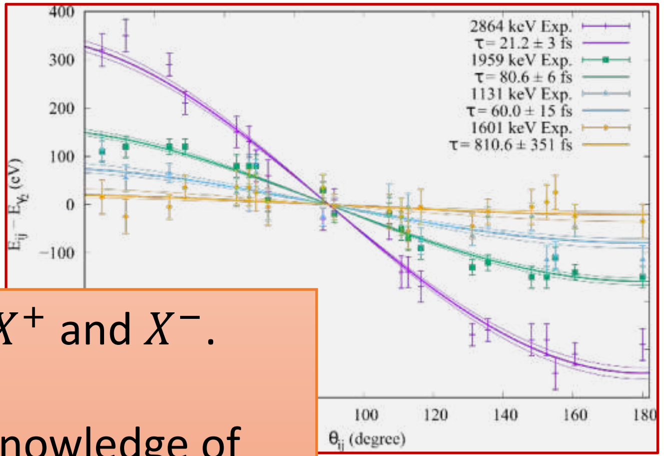
$$X^{\pm} = \frac{E_2 \pm \frac{d}{2}}{E_3 - E_1} + \frac{e(t)}{(E_3 - E_1)c(t)}$$

Here are still time depending via $c(t)$

Now we look at: $\Delta X = X^{+} - X^{-}$

$$\Delta X = \frac{d}{E_3 - E_1}$$

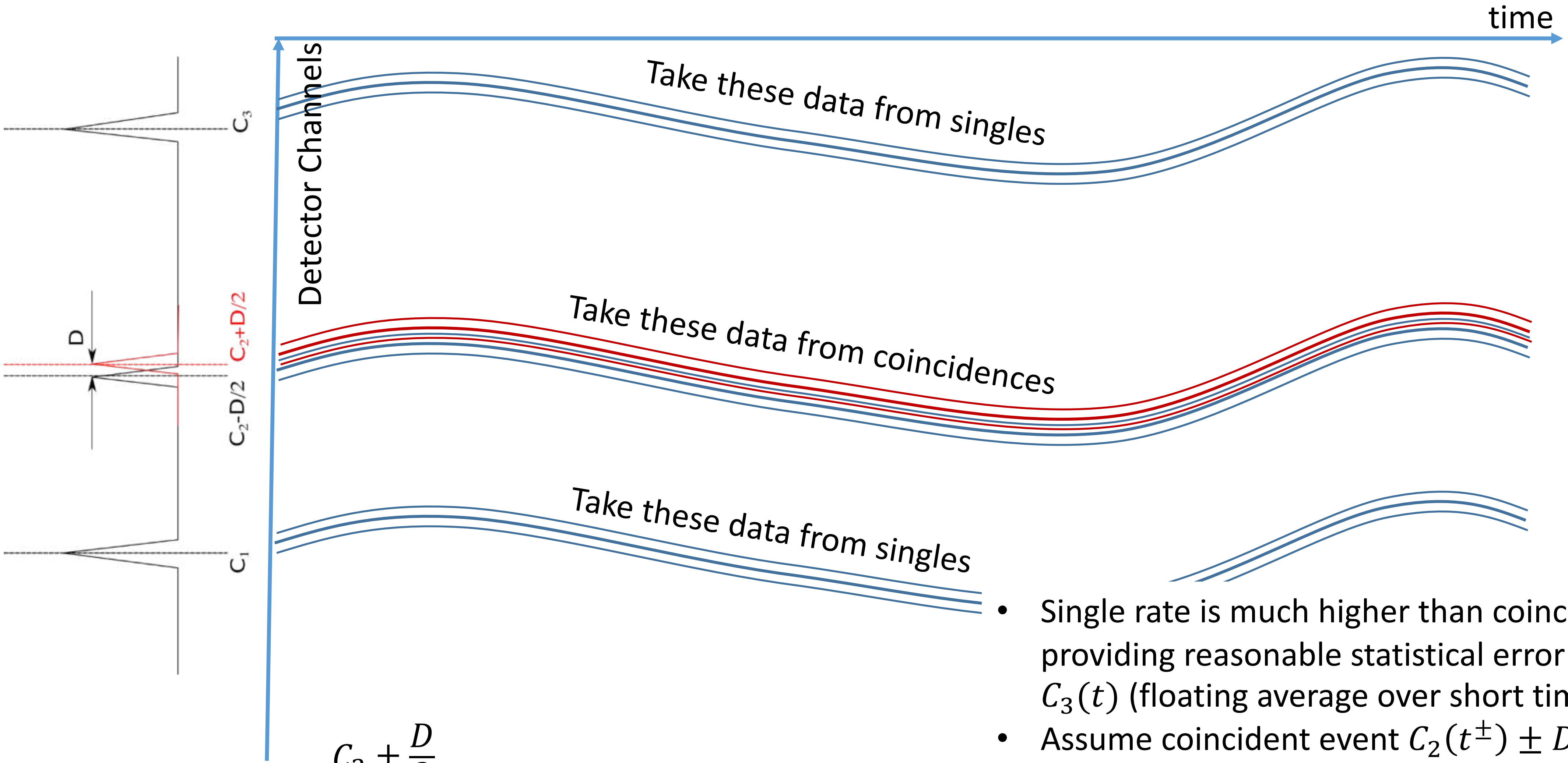
$$\boxed{d = (E_3 - E_1)(X^{+} - X^{-})}$$



We can determine d by knowing the energies E_1 and E_3 and we determine X^{+} and X^{-}.

FOR ALL THIS WE DON'T NEED ANY CALIBRATION FUNCTION! It is all in the knowledge of E_1 and E_3 providing a local linear calibration

How could this be done practically



Take these data from singles

Take these data from coincidences

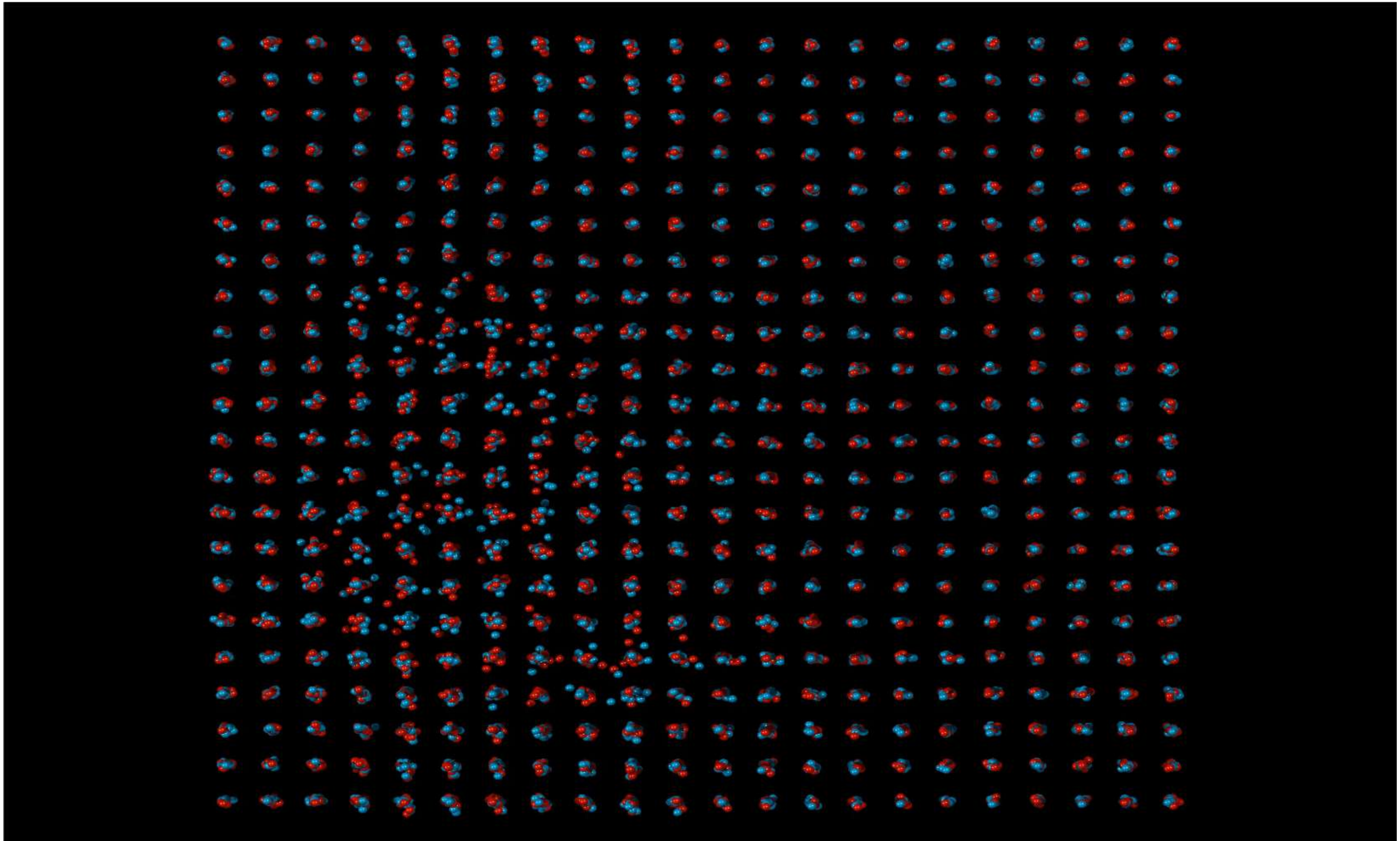
Take these data from singles

$$X^{\pm} = \frac{C_2 \pm \frac{D}{2}}{C_3 - C_1}$$

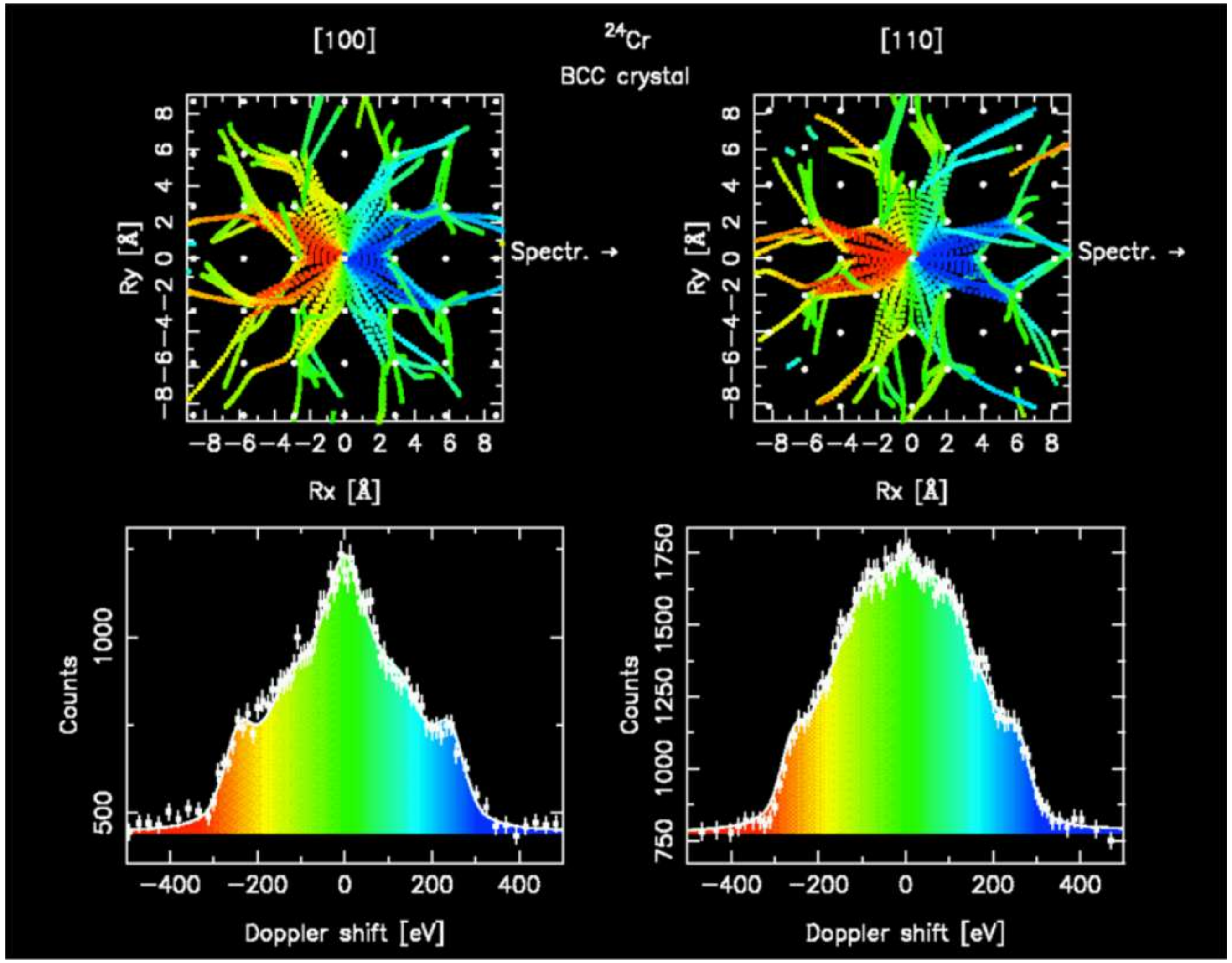
$$\boxed{d = (E_3 - E_1)(X^{+} - X^{-})}$$

- Single rate is much higher than coincidence rate, providing reasonable statistical error for $C_1(t)$ and $C_3(t)$ (floating average over short time interval)
- Assume coincident event $C_2(t^{\pm}) \pm D/2$ we determine $X^{\pm}(t^{\pm})$
- From close combination of $X^{\pm}(t^{\pm})$ we extract $d(t)$

What happens to the target on longer time scales?



If done with single crystals: “Crystal-GRID” allows to study atomic motion



Crystal-GRID:

- Recoil anisotropy not averaged if single crystalline samples
- Several sample orientations increase info on recoil process
- Works for $\tau < 30$ fs

Next Steps

- We still have data from Ni- and Ti-compounds to further tests, however statistics is not as good
  - NiF2, Ni-metal
  - Ti2O3, Ti-metal
- Main reason for problems with statistics: E_{γ_1} is higher => coincidence efficiency lower
- How to improve statistics
  - During current evaluation no add-back, although high energies for coincidence
  - We have a cross talk problem with FIPPS clovers
    - If γ_1 and γ_2 within same clover => artificial shift of E_{γ_2} => fake Doppler shift
    - We exclude coincidences within same detector => less coincidence events
- Actually there are many more targets:

All (n,g) targets used at FIPPS so far !!!
(Probably with even better statistics)

Example of Clocks

Femtoseconds:

- Electromagnetic excitation: CoulEx, (γ,γ')
- Atomic collision sequences: GRID, DSA, $(n,n')\gamma$ (GAMS)
- Laser pulses Synchronization Problematic, FUTURE: laser driven ion acceleration

Picoseconds:

- Scintillation dectectors (incl. PM): Fast Timing (FIPPS, PN1)
- Distance measurement: Recoil Distance

- Nanoseconds:

  - Electronics: Coincidences (time correlations) (FIPPS, PN1)