

# Investigation of Fission in quasi-free-scattering experiments at R<sup>3</sup>B



**Tobias Jenegger**  
For the R<sup>3</sup>B Collaboration

DPG Mainz  
29.03.2022

Fission via (p,2pf) reaction

R<sup>3</sup>B Setup at GSI

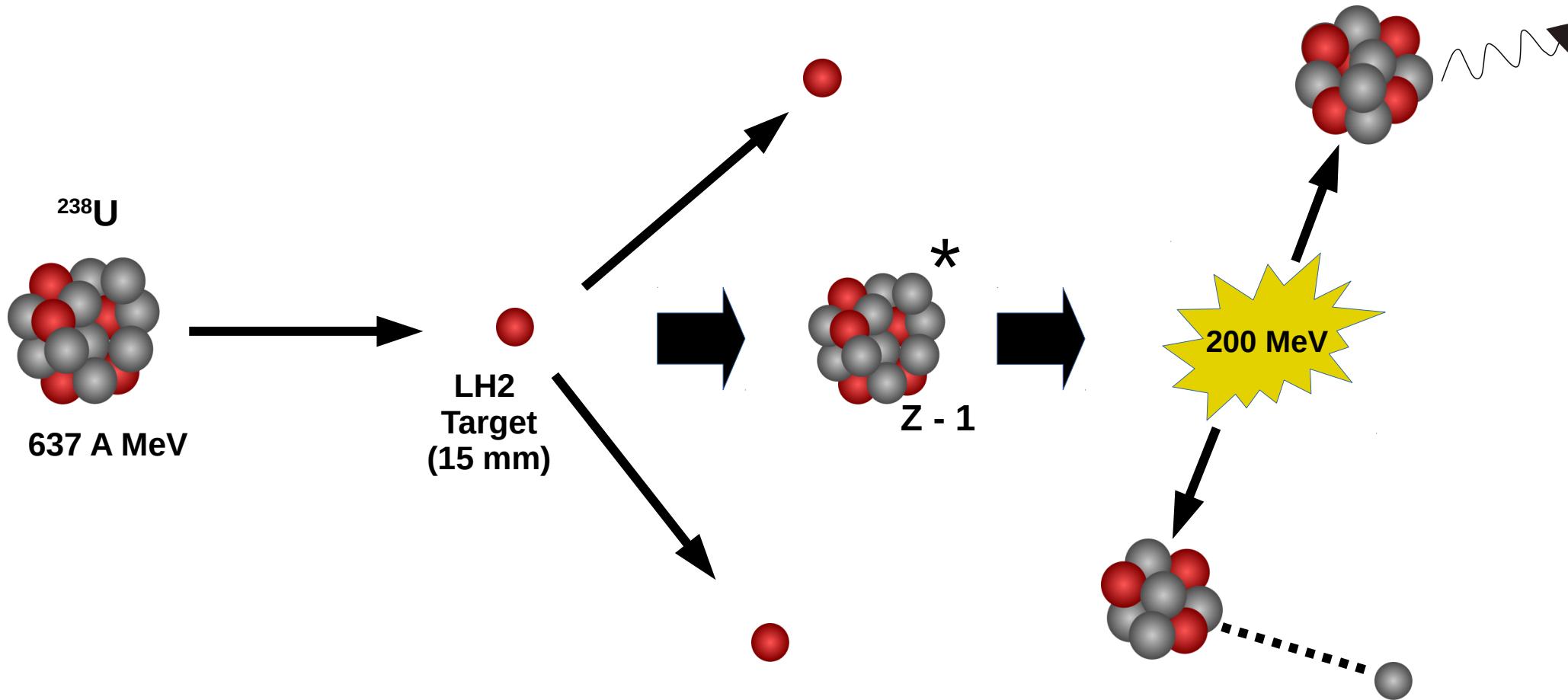
First Analysis Steps

Outlook

TUM Members:  
Roman Gernhäuser, Lukas Ponnath, Philipp Klenze, Tobias Jenegger

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2094 – 390783311, BMBF 05P19WOFN1, 05P21WOFN1 and the FAIR Phase-0 program

# Fission induced by Quasi-Free-Scattering



**S455 Experiment (2021) – Nuclear Fission Studies**

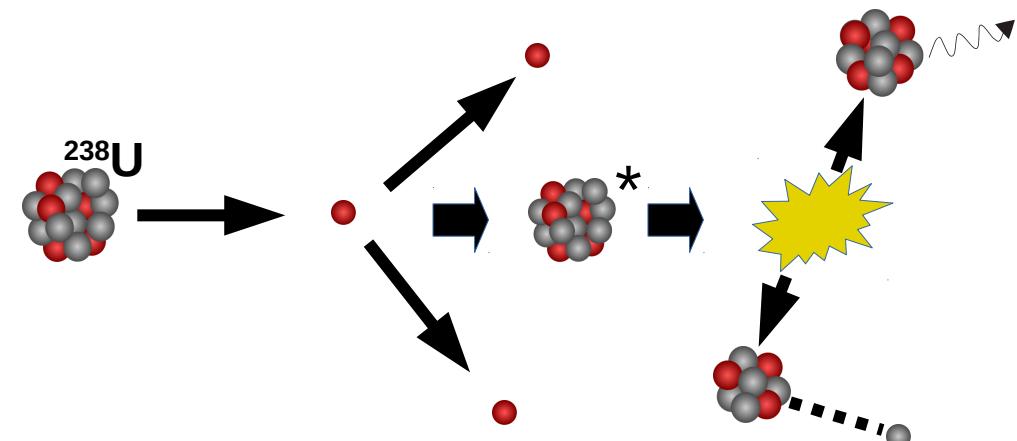
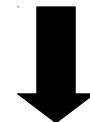
**Spokesperson:** J. Benlliure, Universidade de Santiago de Compostela, Spain

# Why QFS?

- QFS is an excellent method to directly determine the initial excitation energy of the fissile nucleus
- Measurement of the excitation energy on an event-by-event basis
- Unique information about the fission barrier and the dynamics
- Pilot experiment for subsequent exotic beams

What we require:

- Complete characterization of the fissioning system is needed (kinematics, PID)



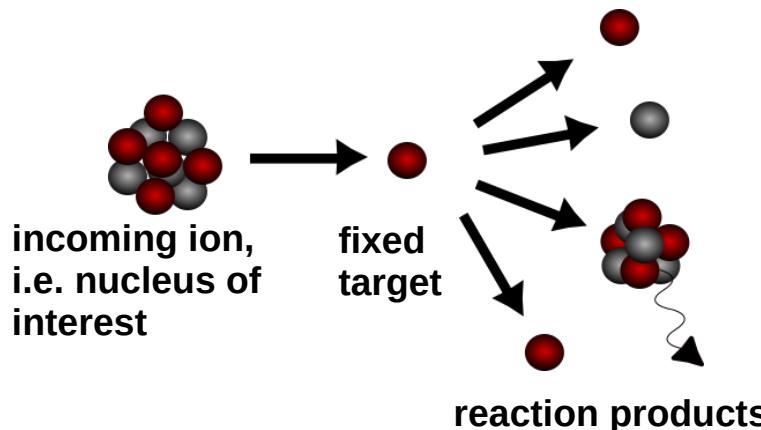
Dedicated experimental setup needed!



# R<sup>3</sup>B Experiment @ GSI

## Reactions with Radioactive Relativistic Beams

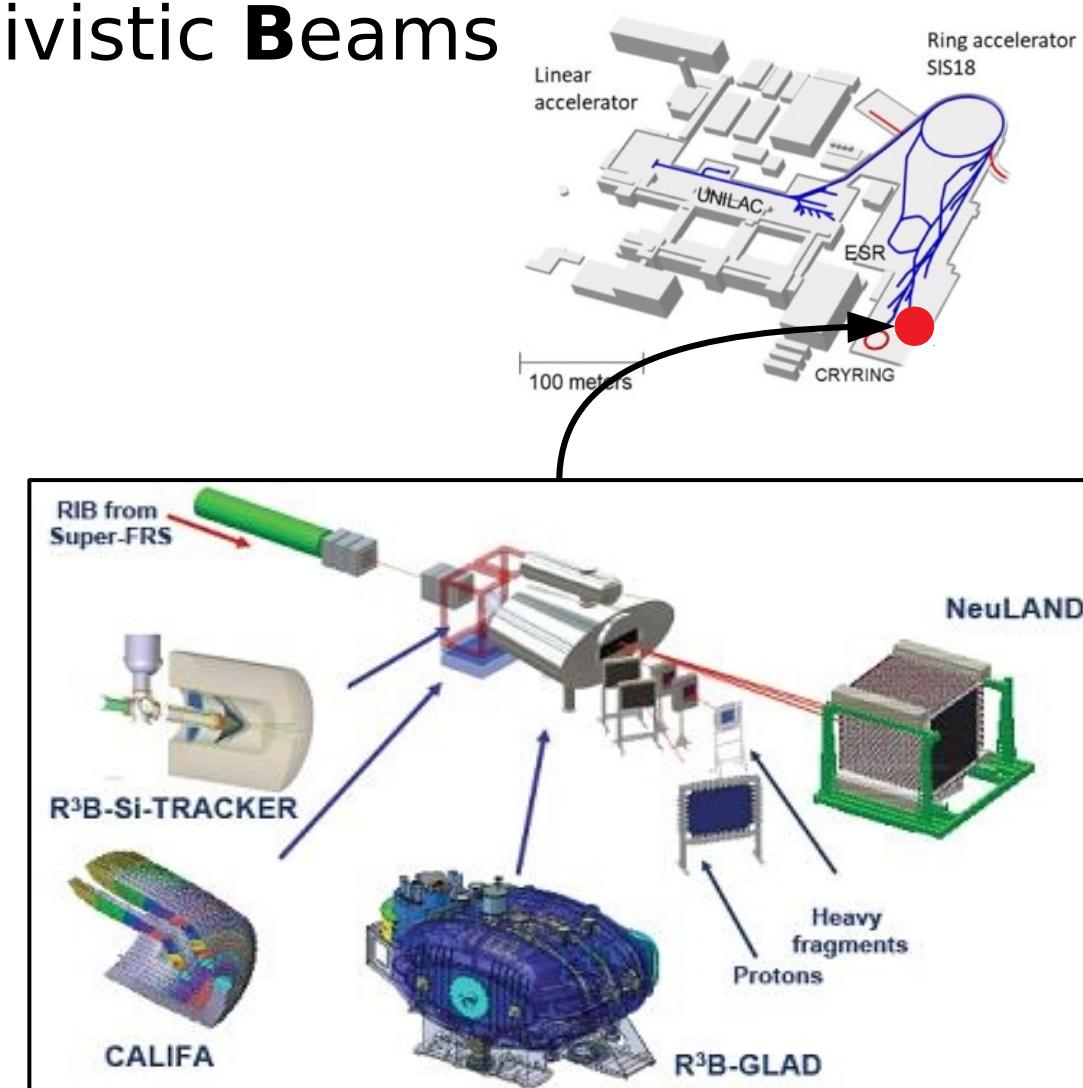
- Physics program on exotic nuclei in inverse kinematics:



- kinematically complete measurements**

Talk from Lukas Ponnath:

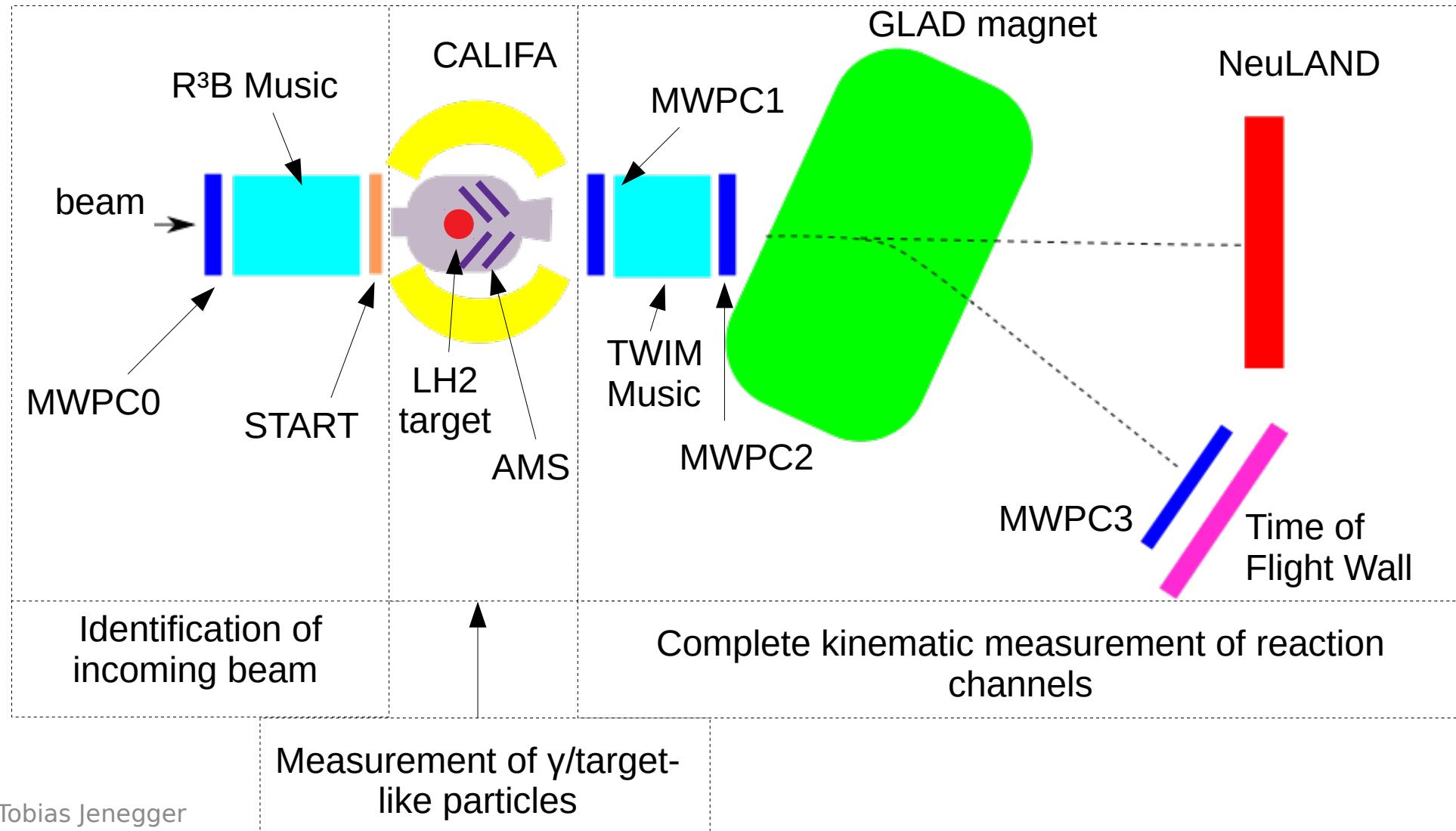
*"Total Reaction Cross-Section Measurements in the S444 Commissioning Experiment for R<sup>3</sup>B"* (HK 29.1)



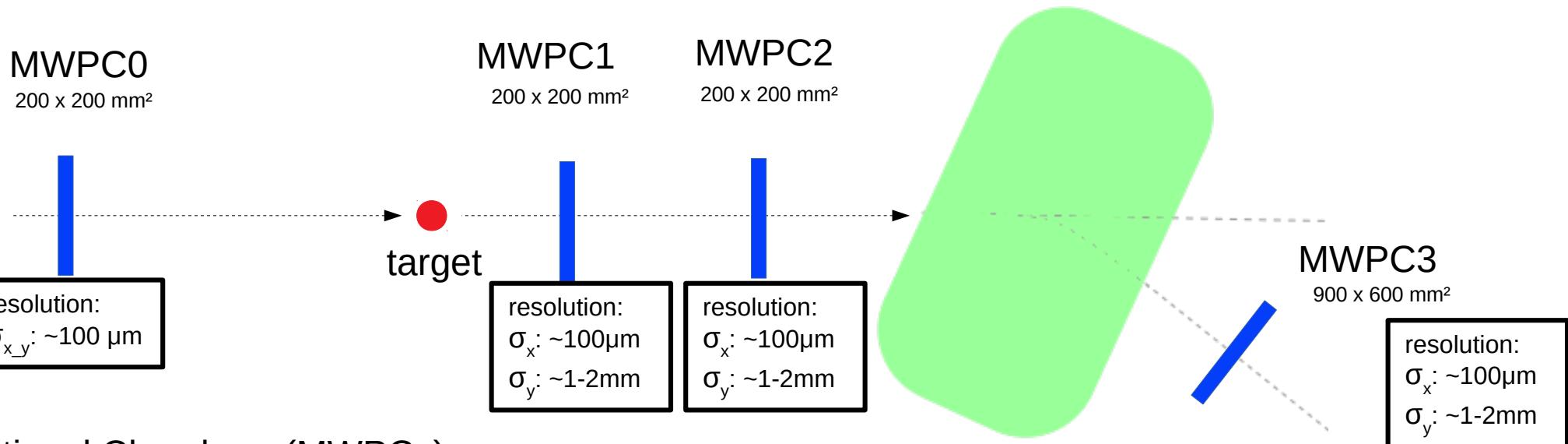
# R<sup>3</sup>B Setup for Pilot Experiments (2021)

**Beam:**  $^{238}\text{U}$  beam, 637 AMeV beam energy

**Target:** liquid hydrogen

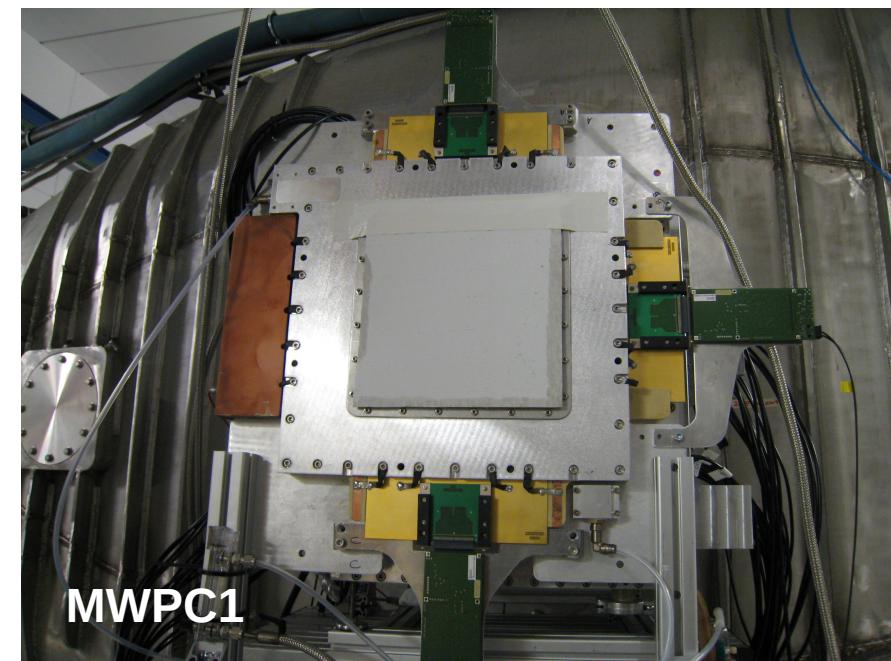
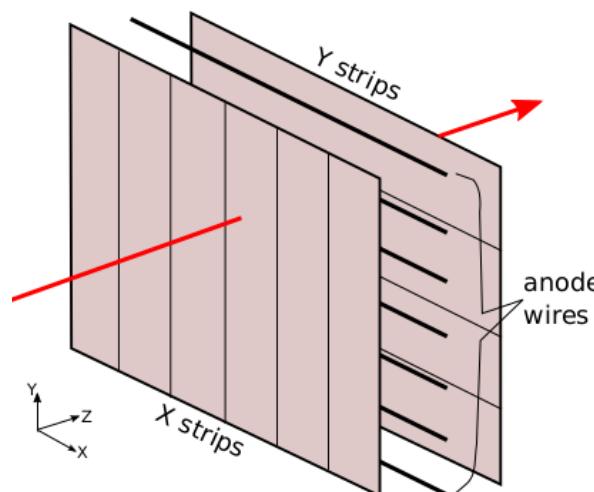


# Tracking with the MWPC



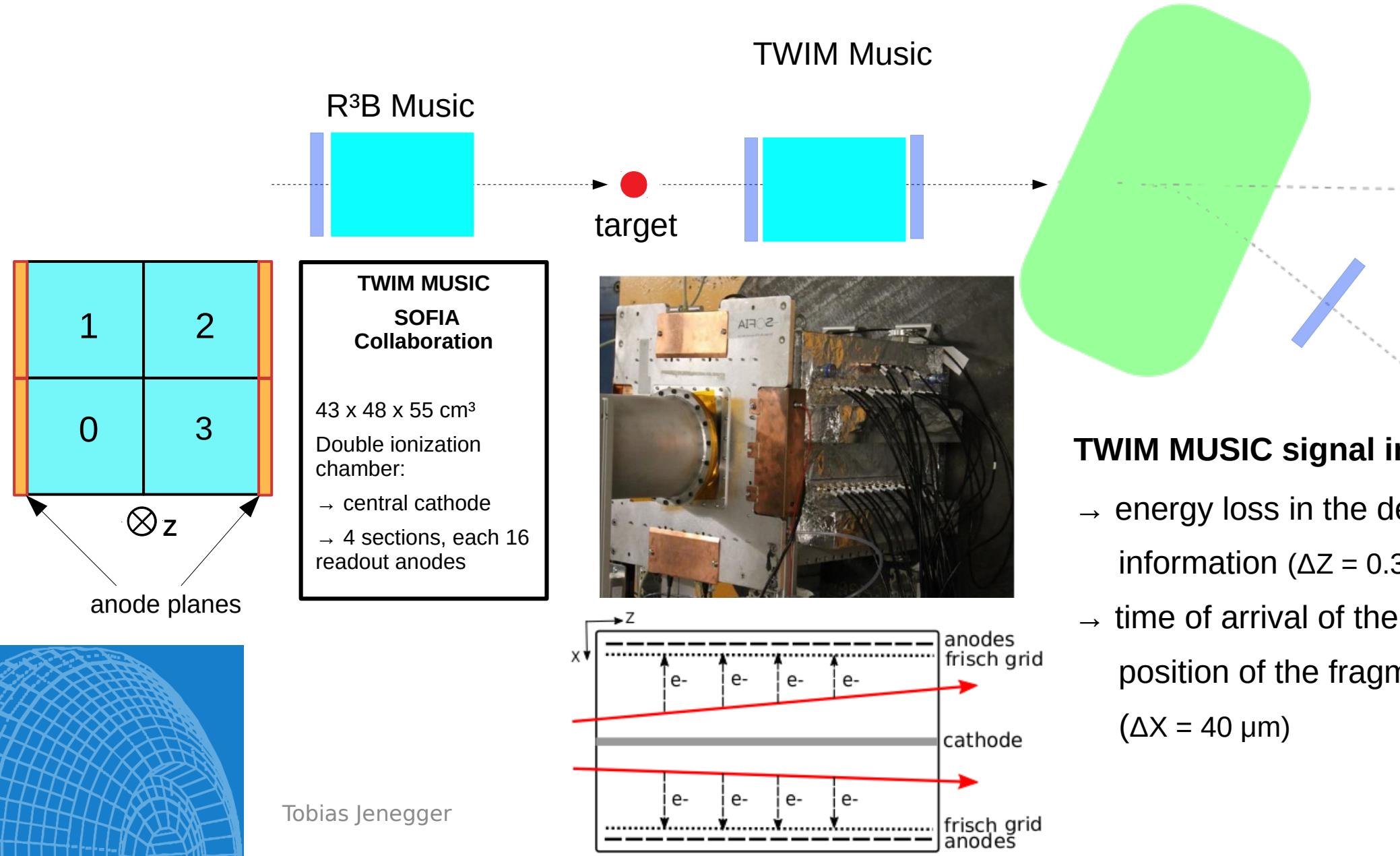
Multi Wire Proportional Chambers (MWPCs):

- horizontal wires: 50  $\mu\text{m}$  diameter, 2.5 mm spacing
- vertical/horizontal pads:  
Al-deposited on a 12  $\mu\text{m}$  Mylar foil,  
5/3.125 mm width (vertical/horizontal)
- gas mixture: 84% Ar, 16% CO<sub>2</sub>
- pad readout

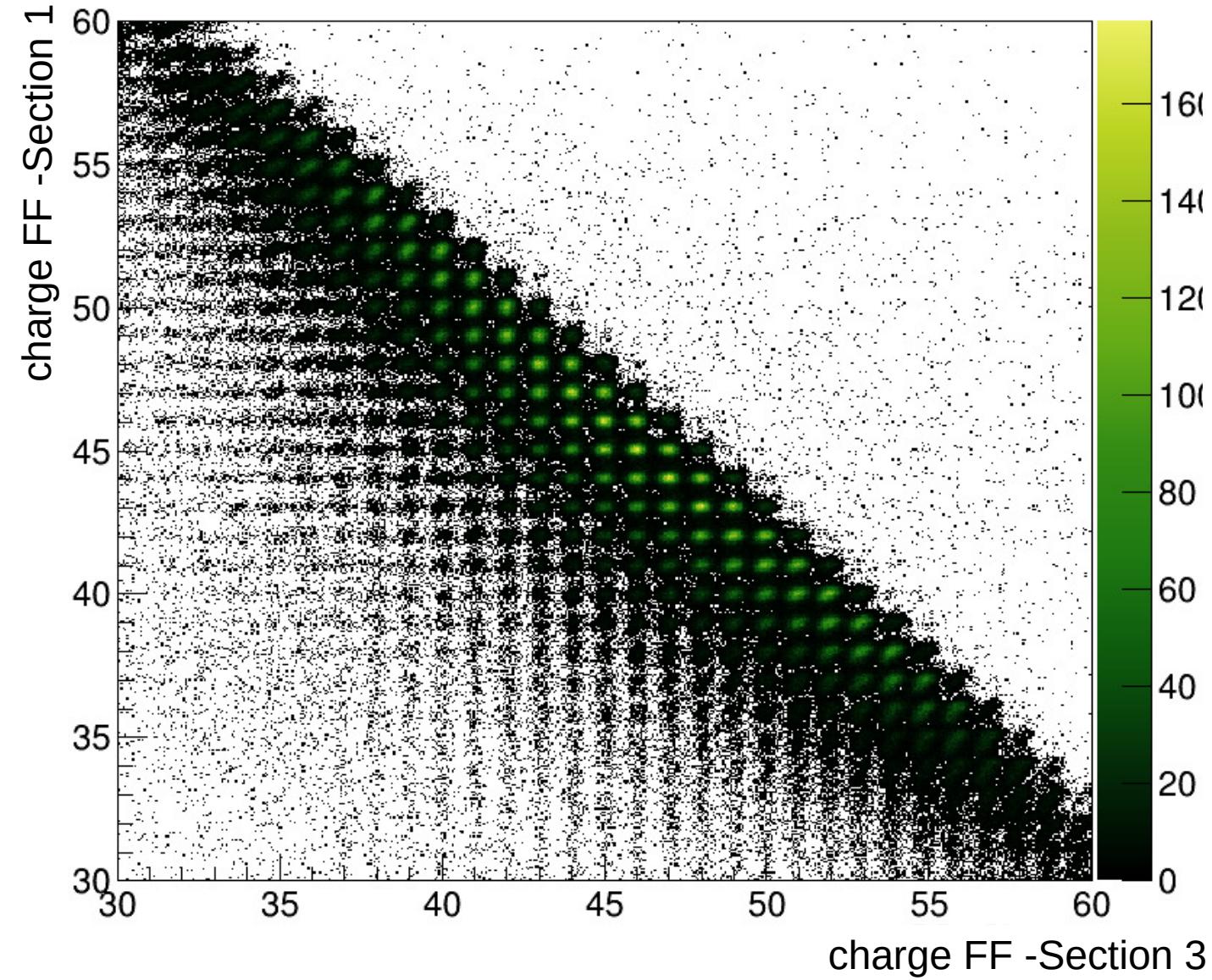
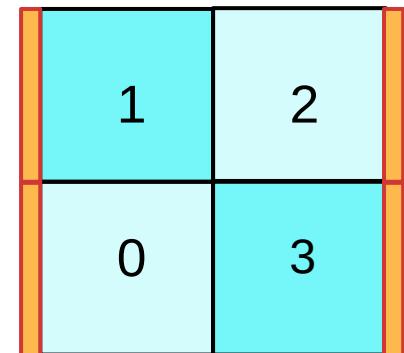


MWPC1

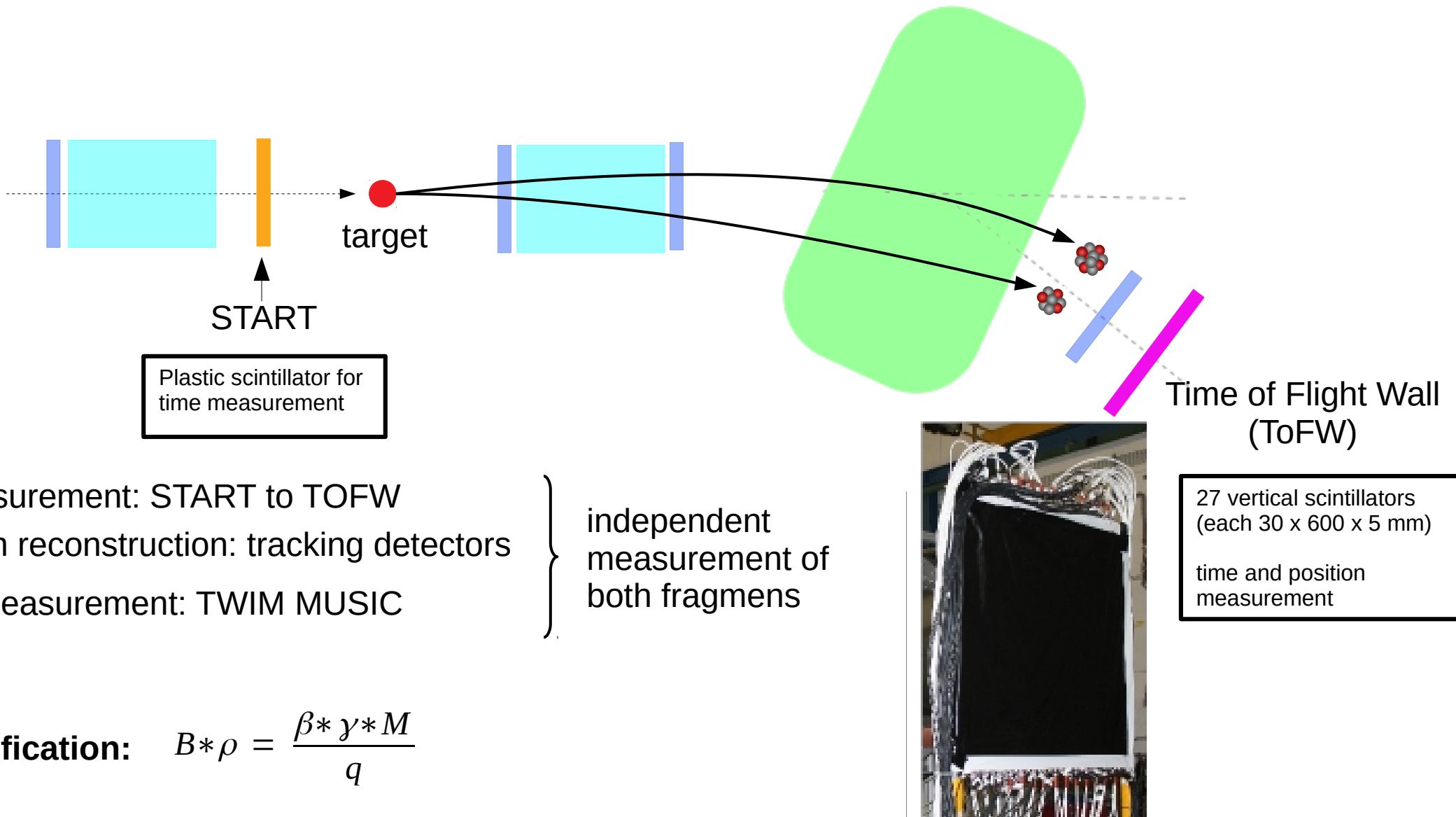
# Charge Measurement – Ionization Chambers

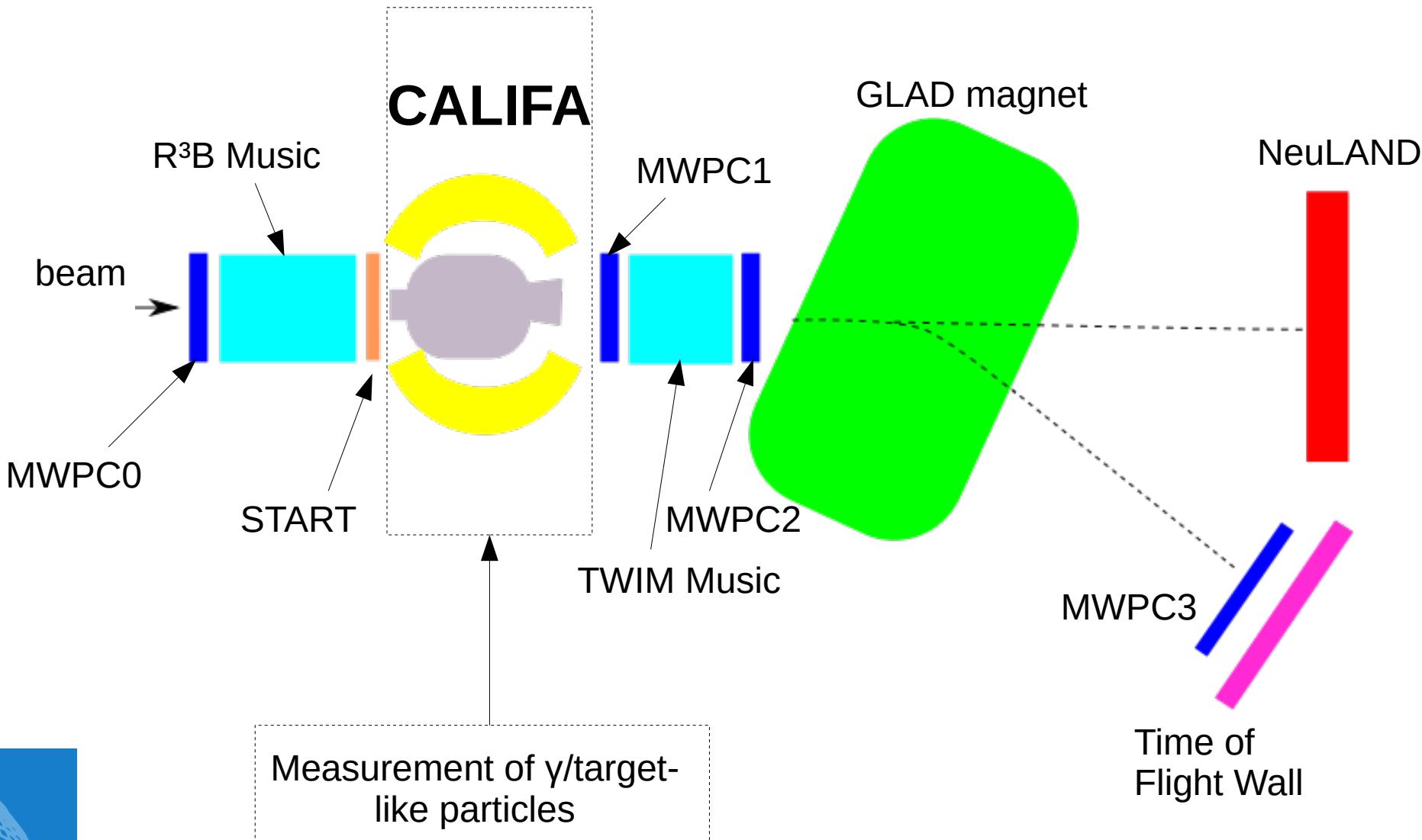


# Charge Measurement of Fission Fragments



## Time Measurement – START &amp; TOFW





# CALIFA Detector @ R<sup>3</sup>B

CALorimeter for the In Flight detection of  $\gamma$ -rays and light charged pArticles

**Endcap:**

**iPhos:**

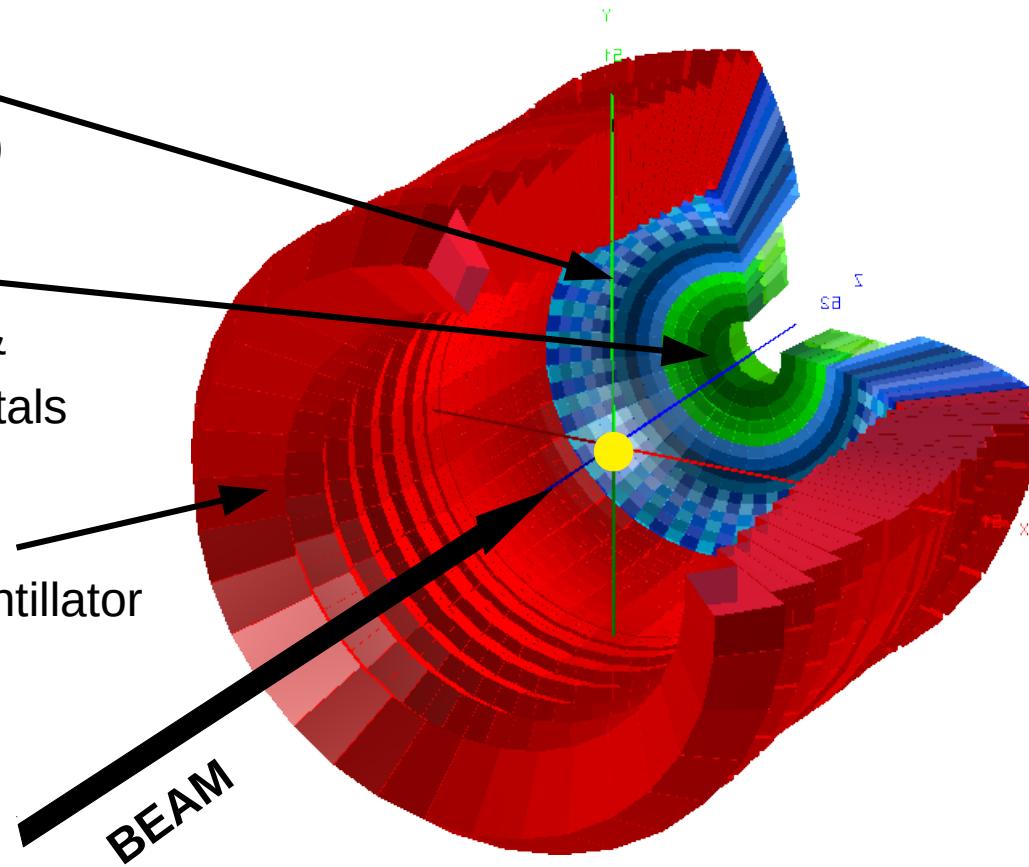
512 CsI(Tl)  
crystals

**CEPA:**

96 LaBr<sub>3</sub> &  
LaCl<sub>3</sub> crystals

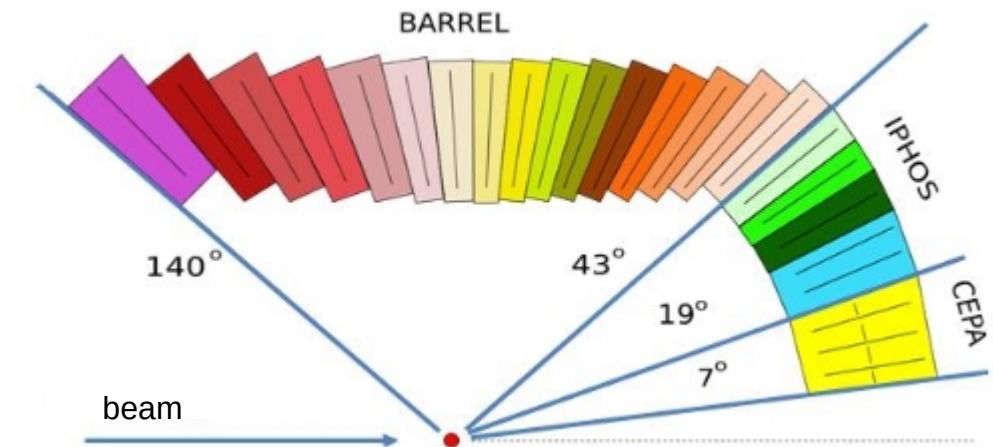
**Barrel:**

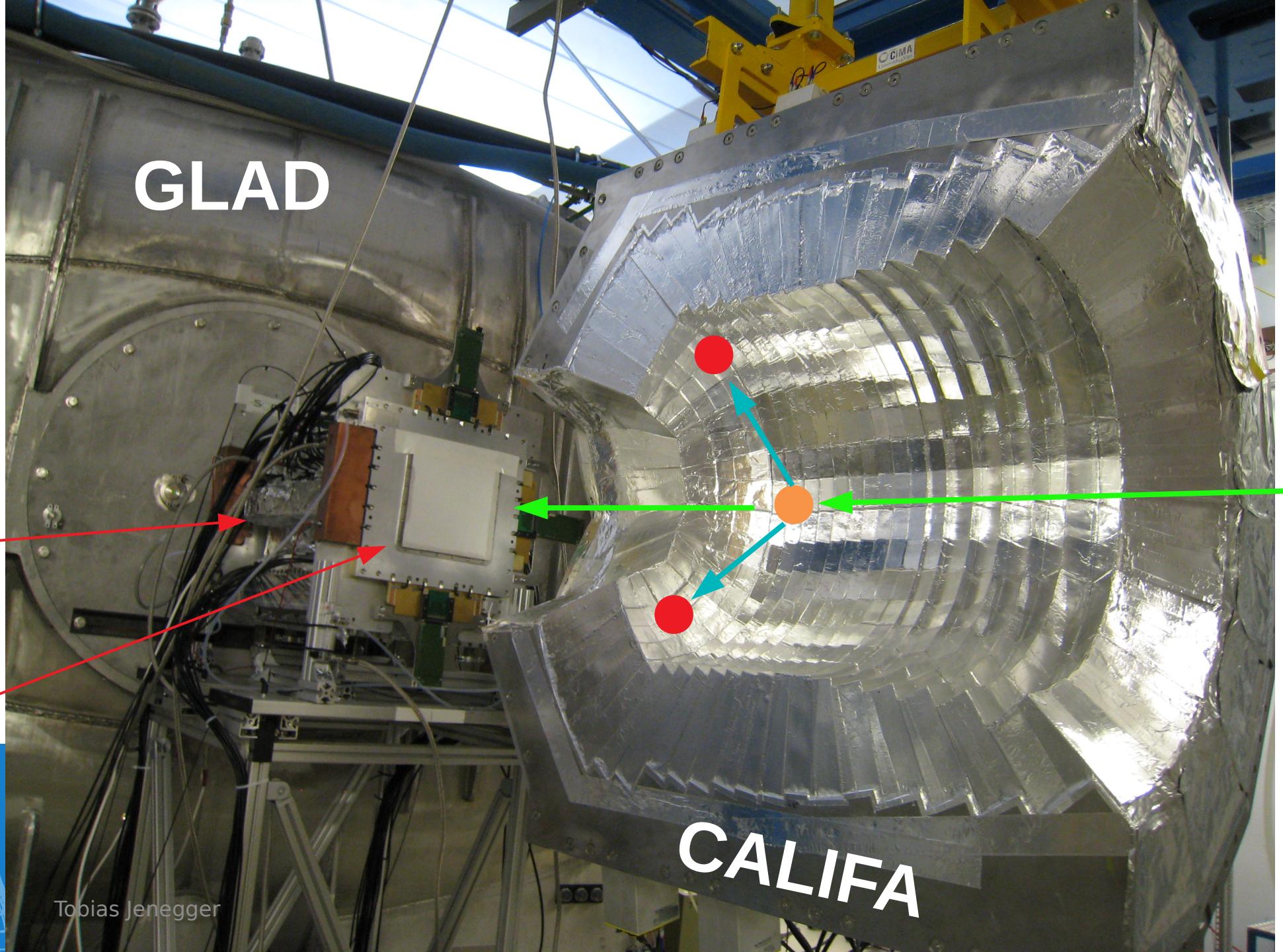
1952 CsI(Tl) scintillator  
crystals



**Highly segmented detector:**

- Angular reconstruction
- Doppler correction





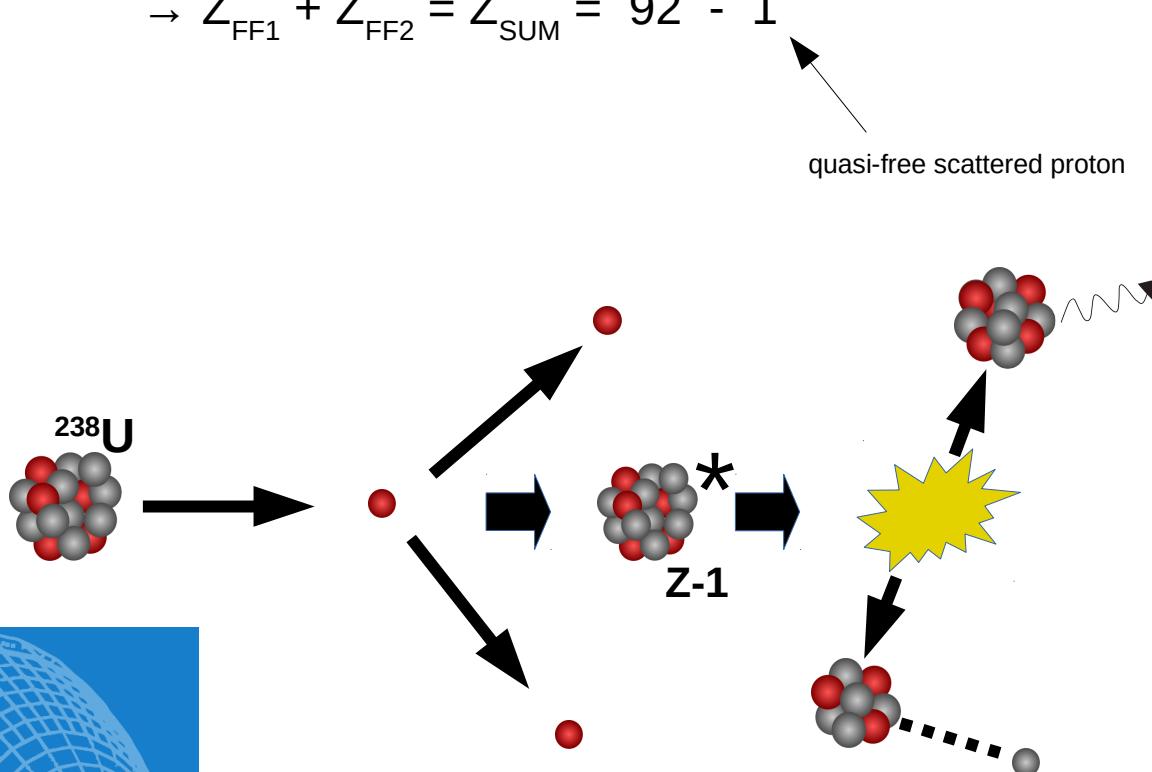
Tobias Jenegger

# Identification of Fission Process

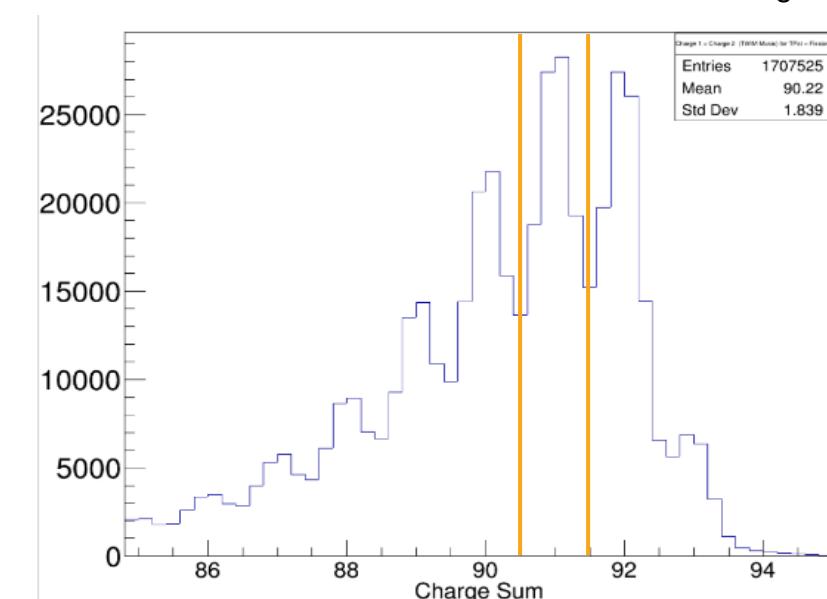
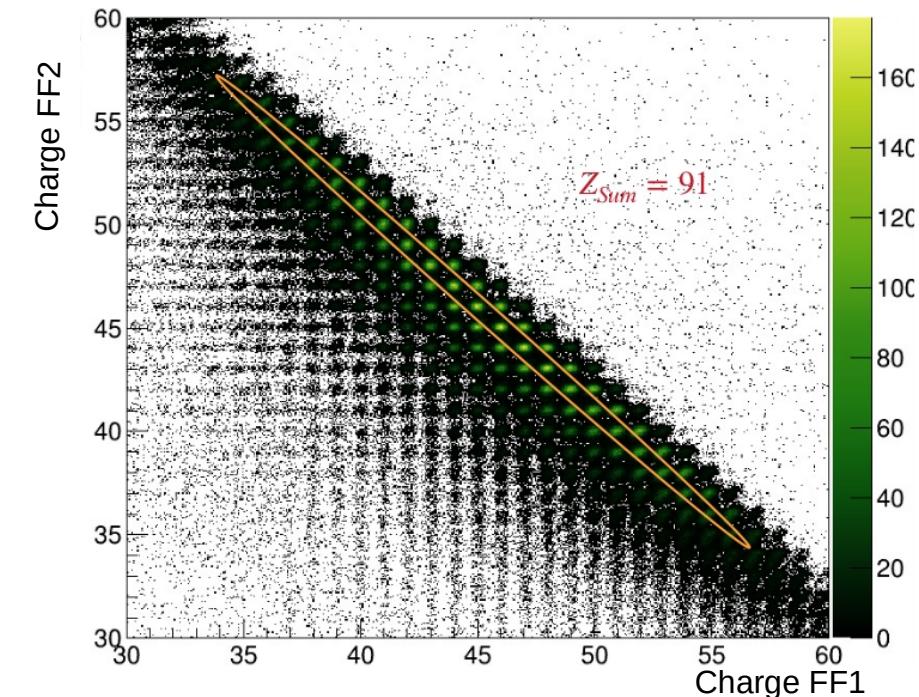
TWIM MUSIC Charge Identification:

→ two fission fragments (FF)

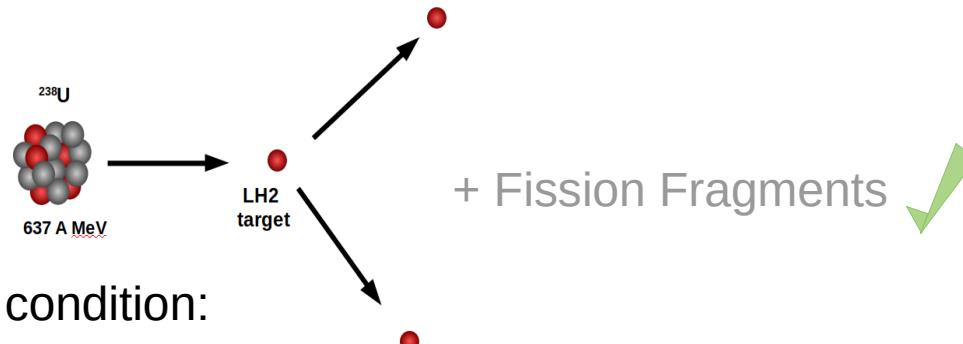
$$\rightarrow Z_{FF1} + Z_{FF2} = Z_{SUM} = 92 - 1$$



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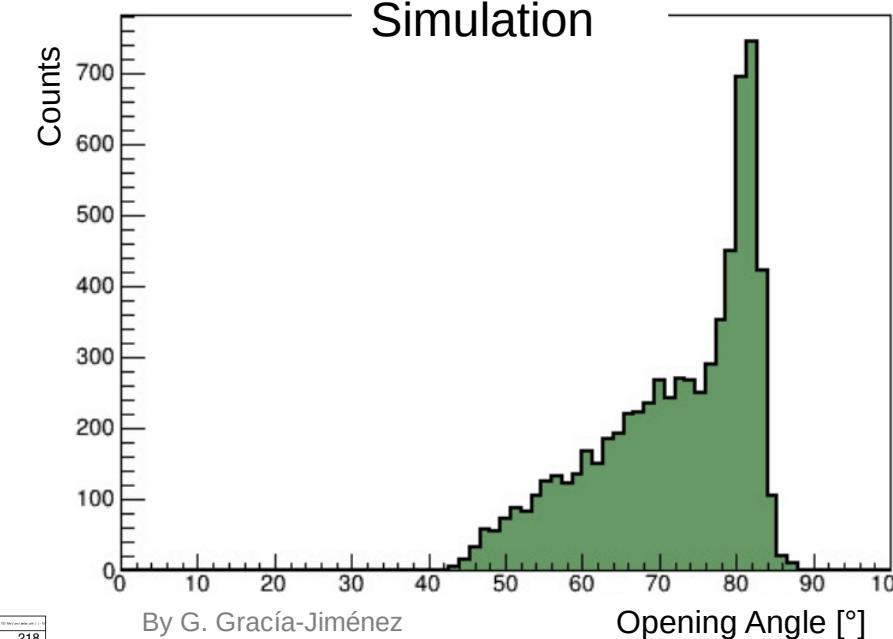
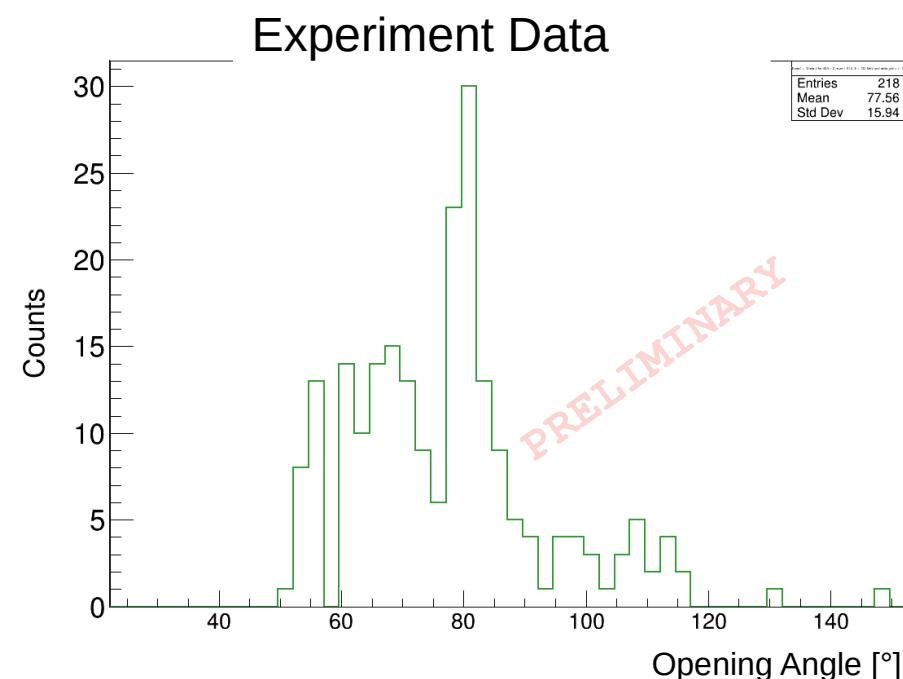


# Identification of QFS Process



Select events with ( $p, 2p$ ) condition:

- two hits with  $E_{p1}, E_{p2} > 100 \text{ MeV}$
- Coplanarity:  $\Delta\phi = 180^\circ \pm 15^\circ$
- reasonable number of crystal hits



- method works!
- FSI is not dominating



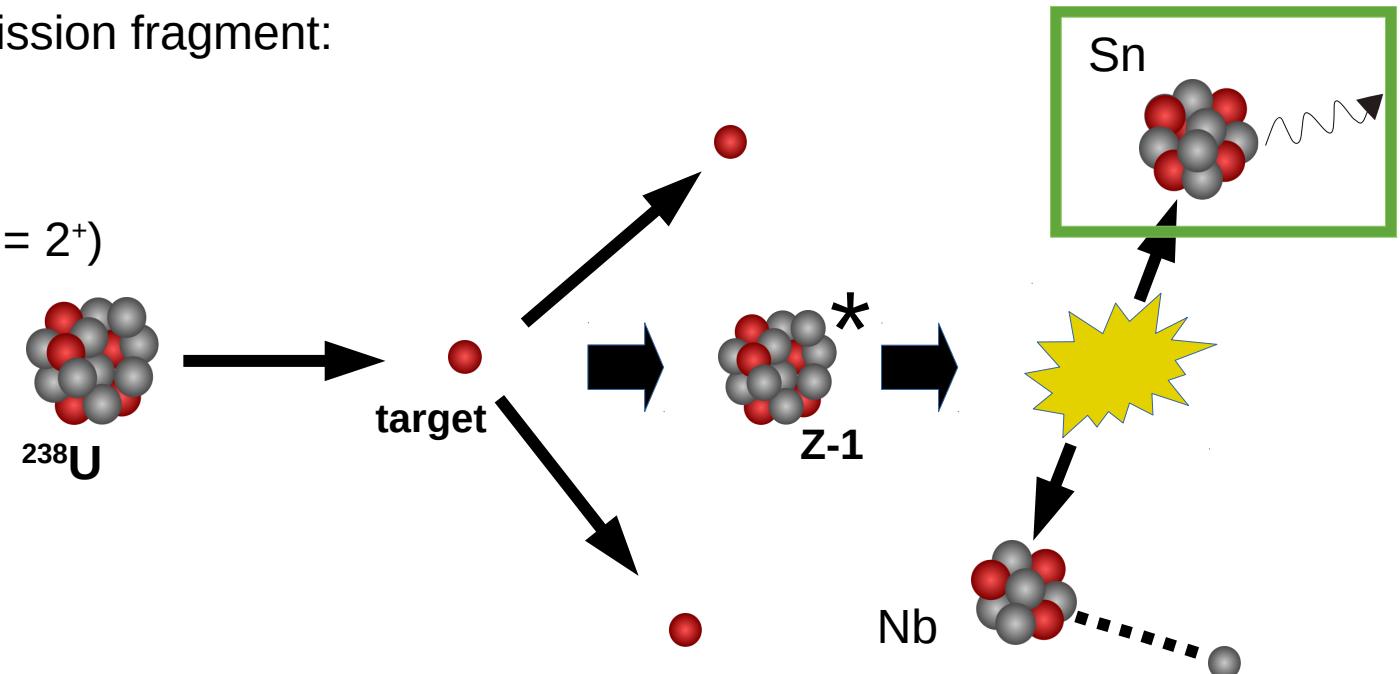
# Gamma spectrum in CALIFA

As intermediate step of the analysis:  
(calibration for mass identification not finished yet)

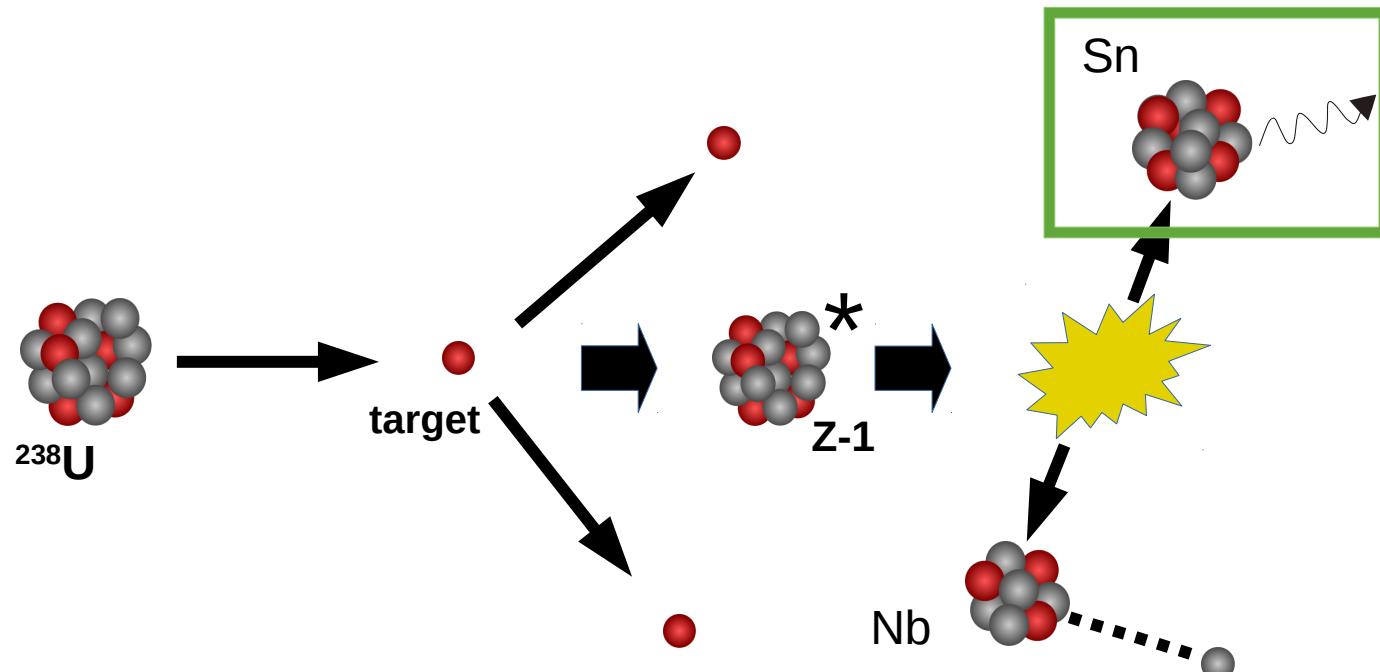
- analyse energetic states of the fission fragments
- do we see correlated  $\gamma$ -rays ?

Gamma spectrum of tin ( $Z=50$ ) as one fission fragment:

- gg nuclei with  $J = 0^+$  ground state
- energy gap  $\sim 1\text{-}2 \text{ MeV}$  (excited state  $J = 2^+$ )



# Gamma spectrum in CALIFA

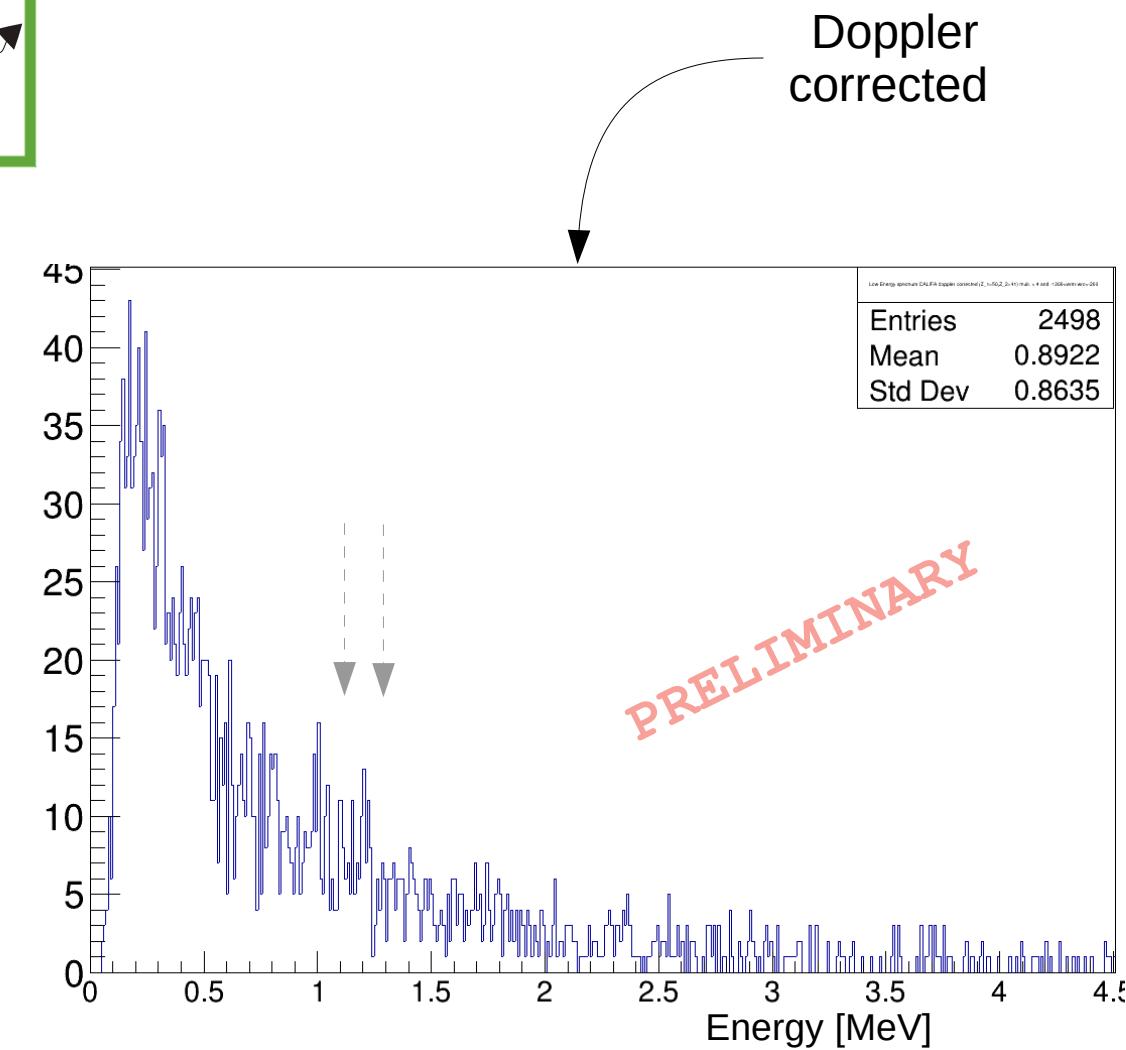


1<sup>st</sup> excited Sn states of interest:

- $^{126}\text{Sn}$ , 1140 keV
- $^{128}\text{Sn}$ , 1169 keV
- $^{130}\text{Sn}$ , 1121 keV
- $^{132}\text{Sn}$ , 4041 keV

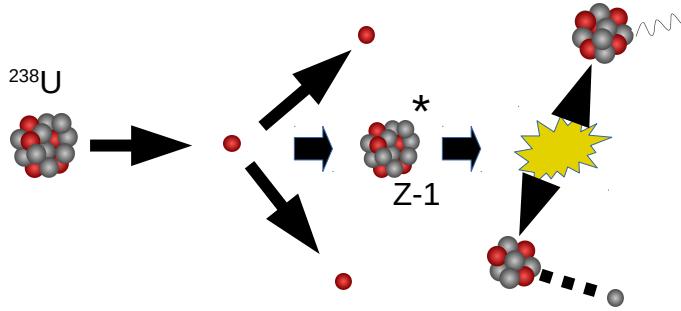


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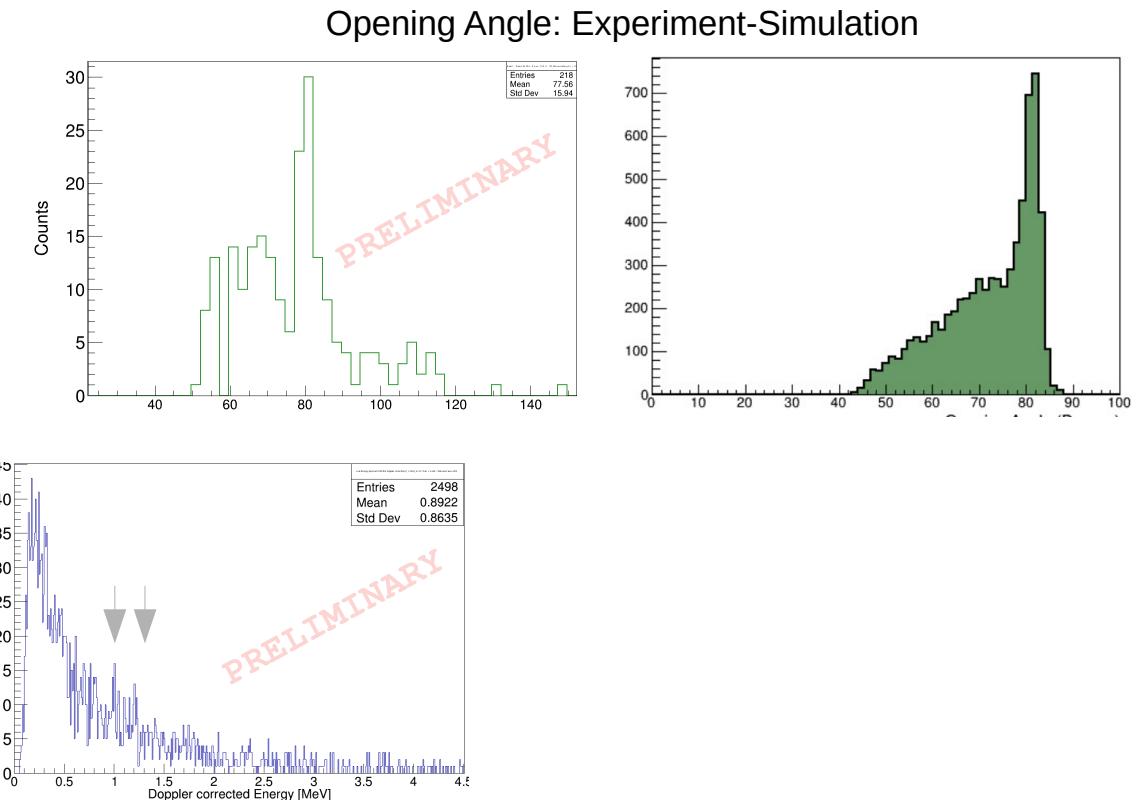


# Summary & Outlook

→  $^{238}\text{U}(\text{p},2\text{pf})$  reaction has been identified:

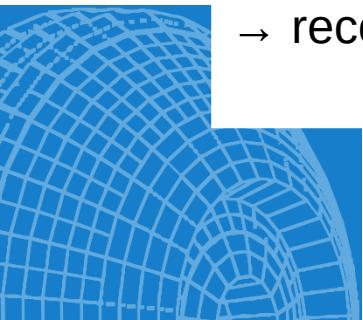


→ gamma spectrum looks promising:



## Next Steps:

- mass identification
- reconstruction of the excitation energy with CALIFA & AMS tracking detectors





# Thank you!

**TODO:** Write  
thanks to all the  
groups

**CALIFA @ Technical University of Munich (TUM)**

Roman Gernhäuser, Lukas Ponnath, Philipp Klenze, Tobias Jenegger



Tobias Jenegger

GEFÖRDERT VOM



Bundesministerium  
für Bildung  
und Forschung

