



Investigation of Fission in quasi-free-scattering experiments at R³B



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DPG Mainz
29.03.2022

Fission via (p,2pf) reaction

R³B Setup at GSI

First Analysis Steps

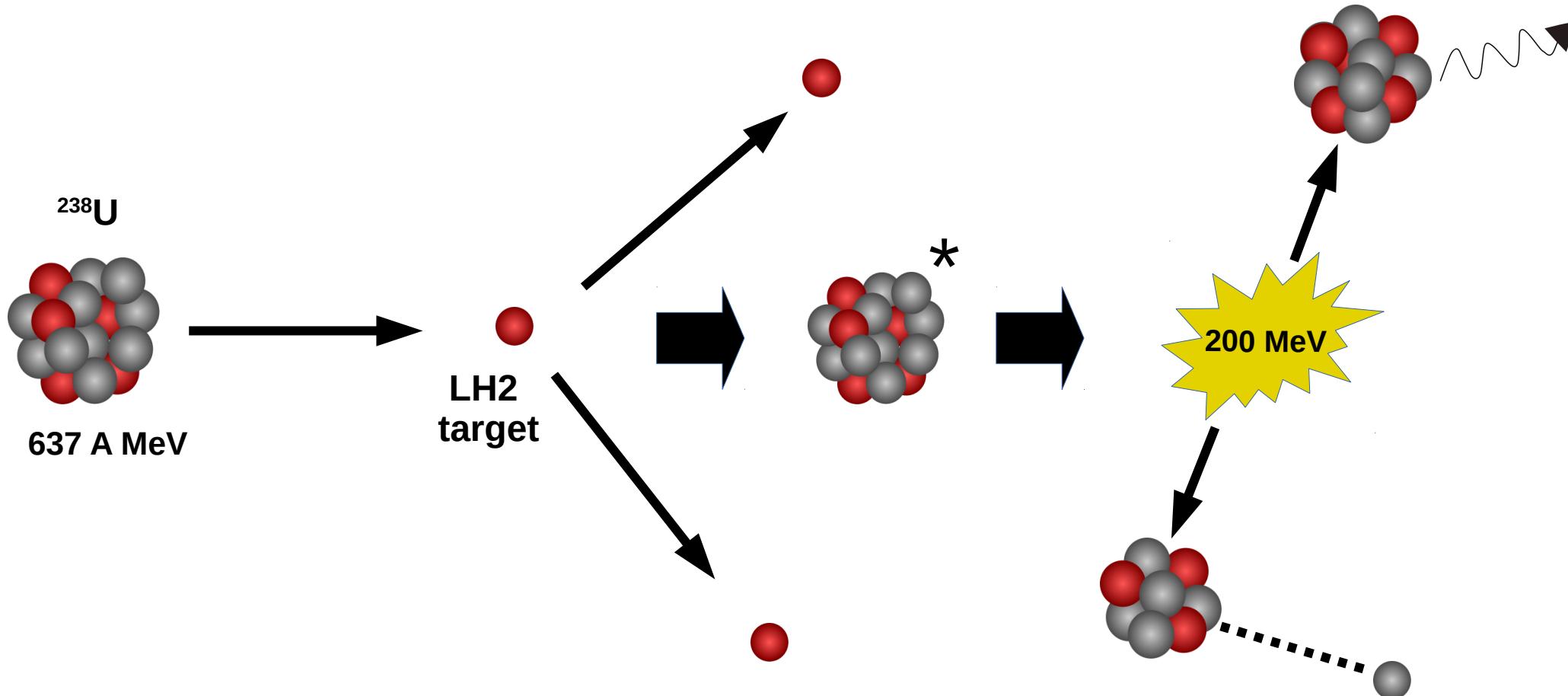
Outlook

TUM Members:
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GEFÖRDERT VOM

Fission induced by Quasi-Free-Scattering



Beam: ^{238}U beam, 637 AMeV beam energy

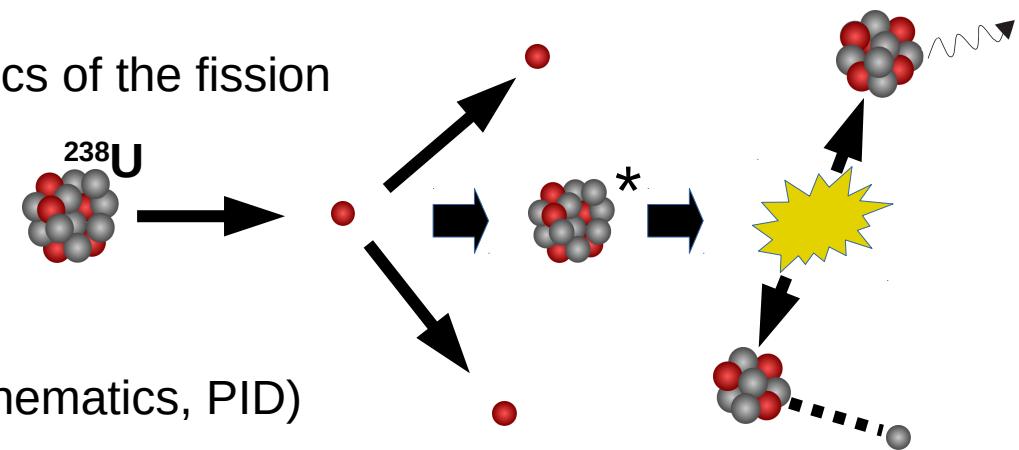
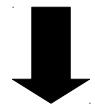
Intensity: $\sim 5\text{E}4$ particles/s

Expected $^{238}\text{U}(p,2pf)$ cross section: $\sim 20 \text{ mb}$

- 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 possible
- Provides unique information about the fission barrier, the dynamics of the fission process and the underlying shell structure

What we require:

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

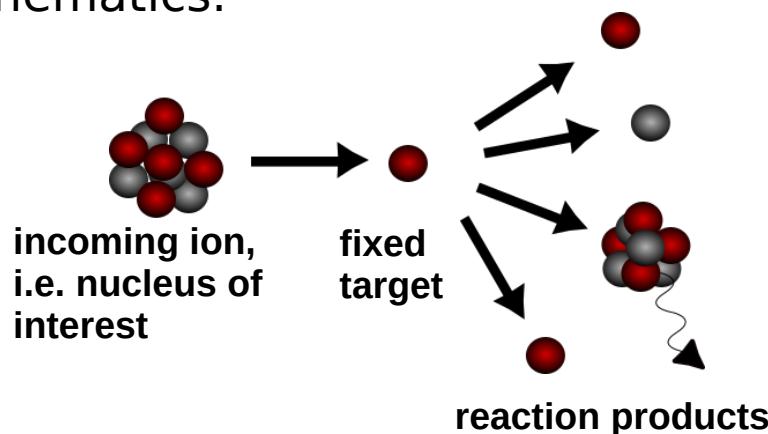


Dedicated experimental setup needed!

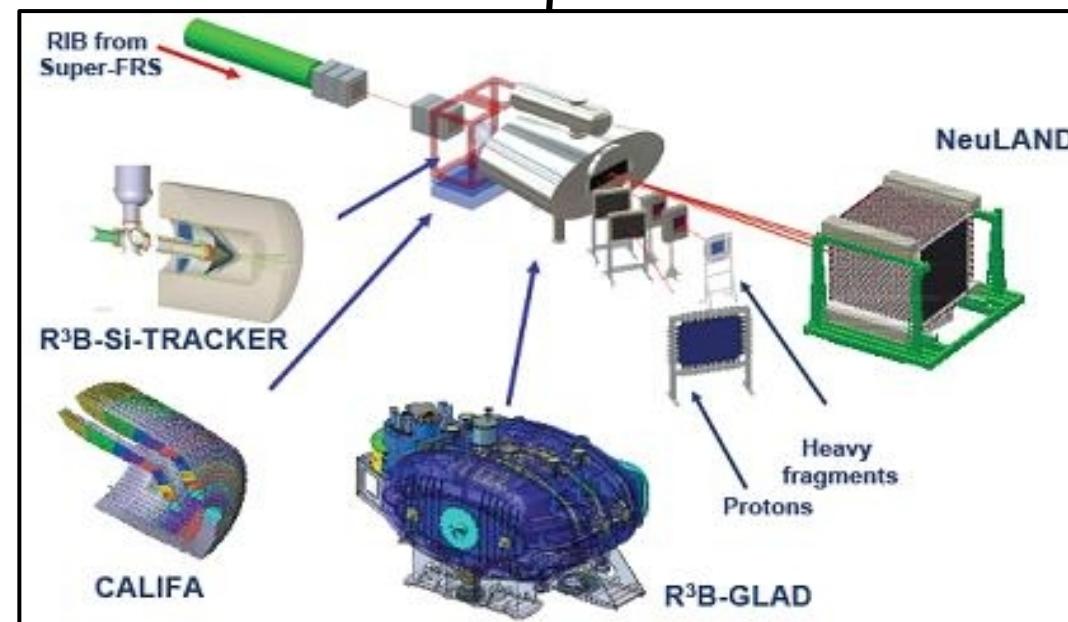
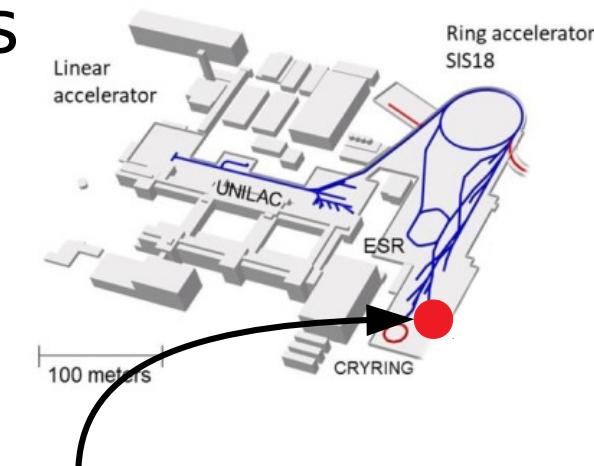


Reactions with Radioactive Relativistic Beams

- Physics program on exotic nuclei in inverse kinematics:



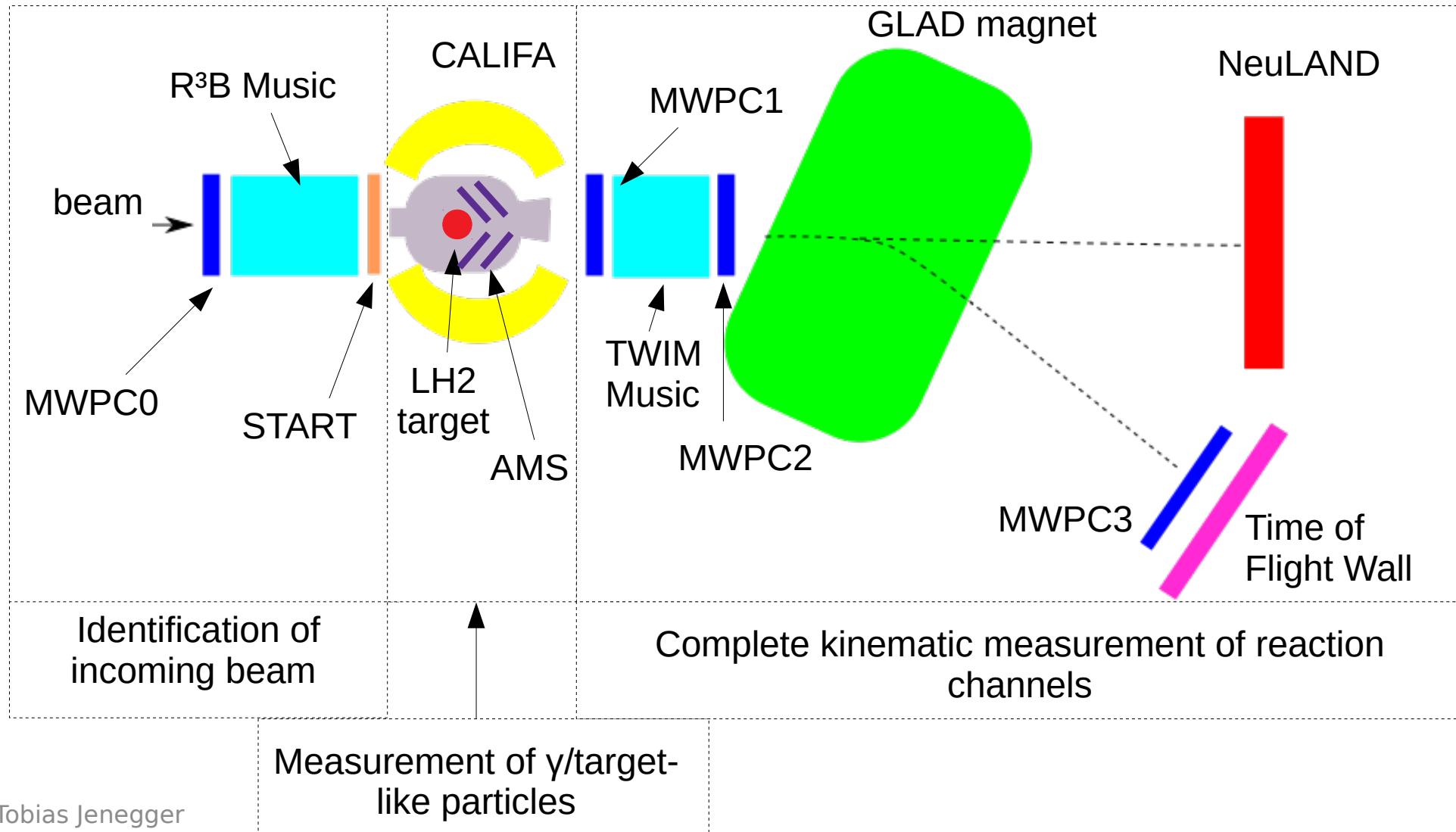
- kinematically complete measurements**
- Flexible setup, extensive physics schedule



R³B Setup for Pilot Experiments (2021)

Beam: ^{238}U beam, 637 AMeV beam energy

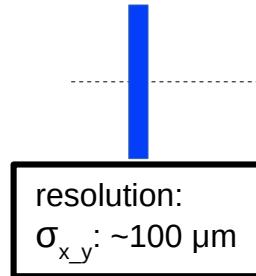
Target: liquid hydrogen



Tracking Detectors

MWPC0

200 x 200 mm²



resolution:
 $\sigma_{x,y}$: ~100 µm

MWPC1

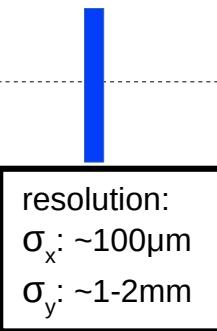
200 x 200 mm²



resolution:
 σ_x : ~100µm
 σ_y : ~1-2mm

MWPC2

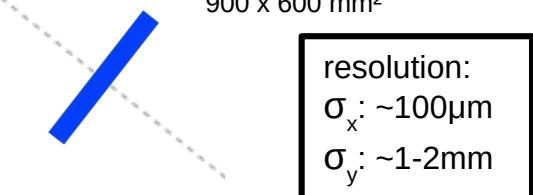
200 x 200 mm²



resolution:
 σ_x : ~100µm
 σ_y : ~1-2mm

MWPC3

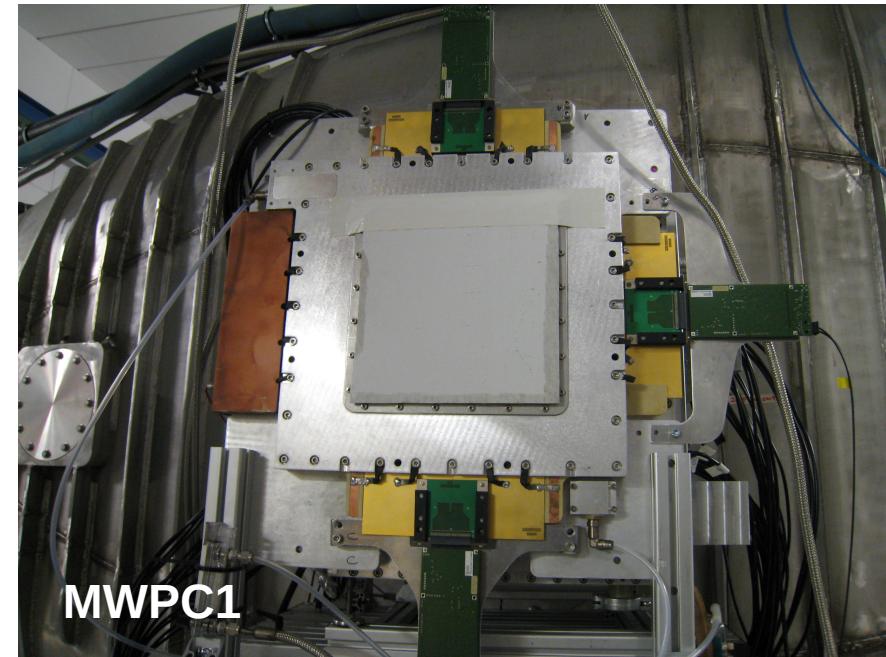
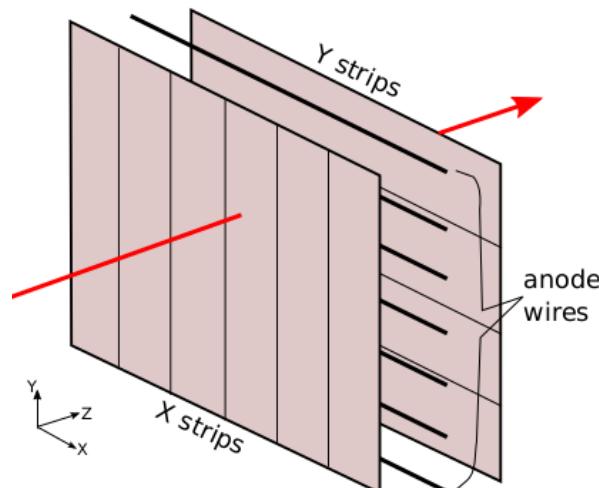
900 x 600 mm²



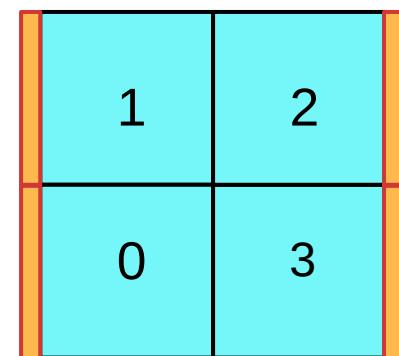
resolution:
 σ_x : ~100µm
 σ_y : ~1-2mm

Multi Wire Proportional Chambers (MWPCs):

- horizontal wires: 50 µm diameter, 2.5 mm spacing
- vertical/horizontal pads: Al-deposited on a 12 µm Mylar foil, 5/3.125 mm width (vertical/horizontal)
- gas mixture: 84% Ar, 16% CO₂
- pad readout



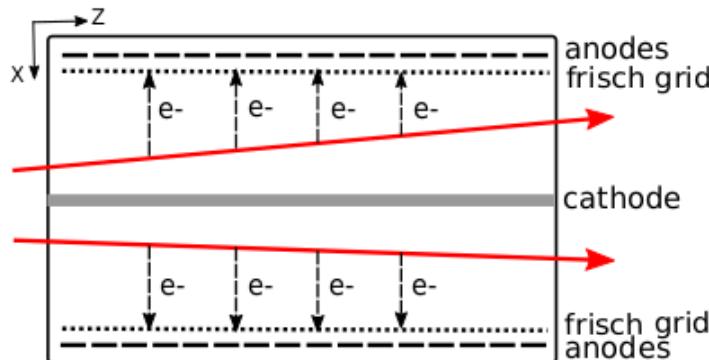
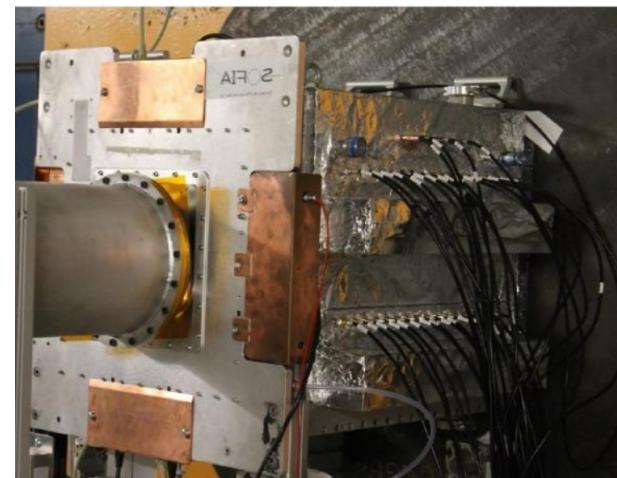
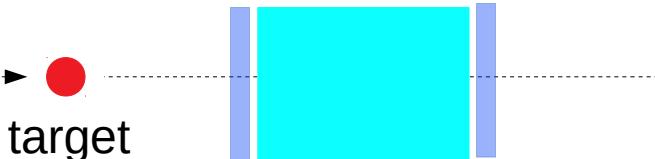
Charge Measurement – Ionization Chambers



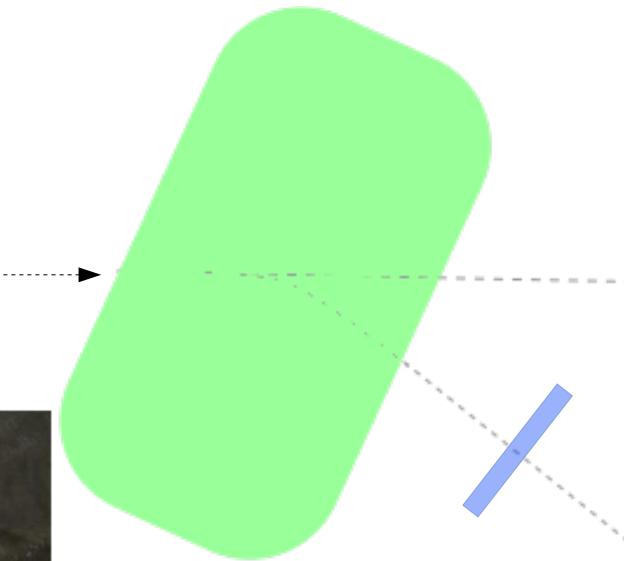
R³B Music

43 x 48 x 55 cm³
Double ionization chamber:
→ central cathode
→ 4 sections, each 16 readout anodes

TWIM Music



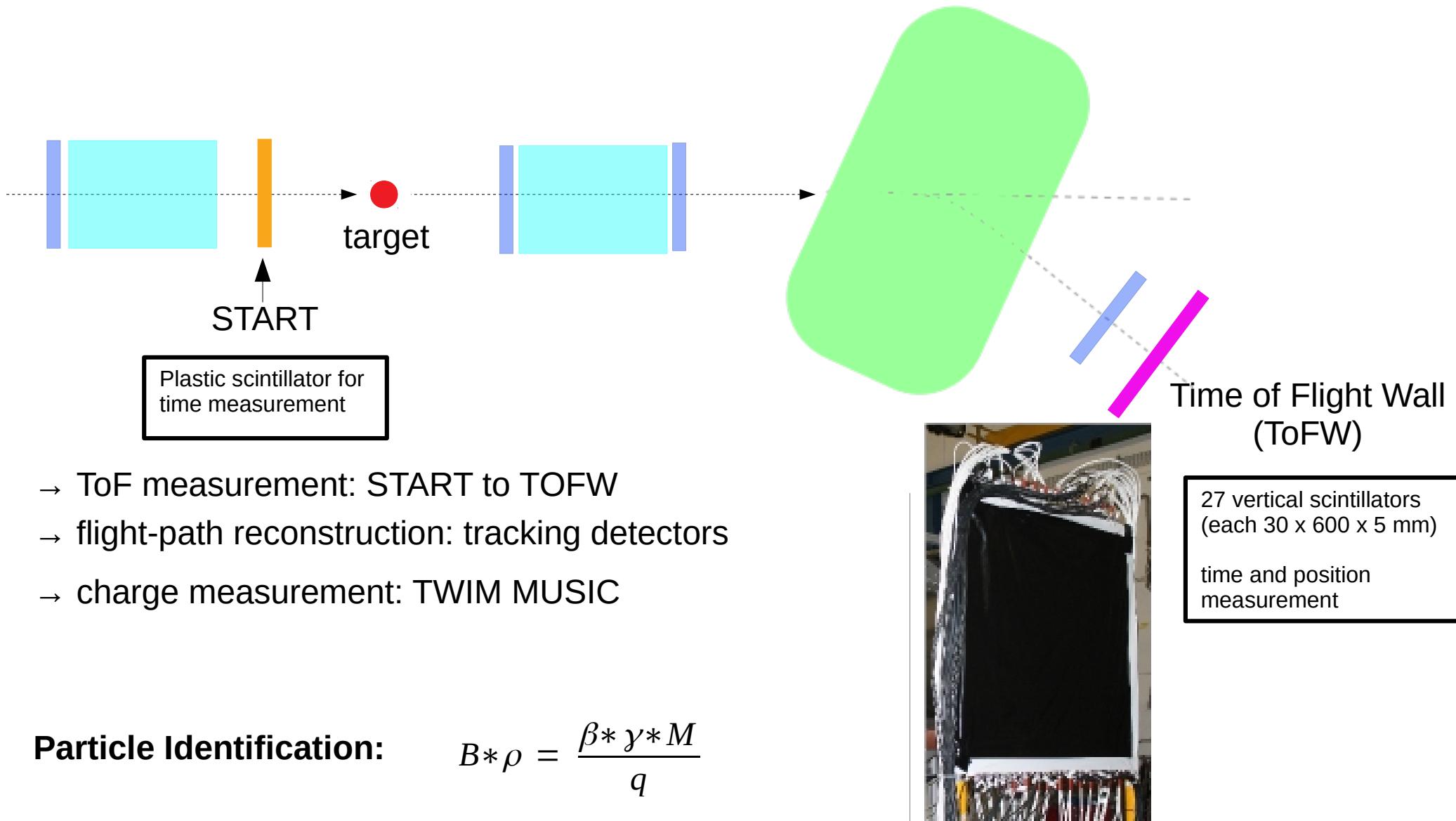
Tobias Jenegger

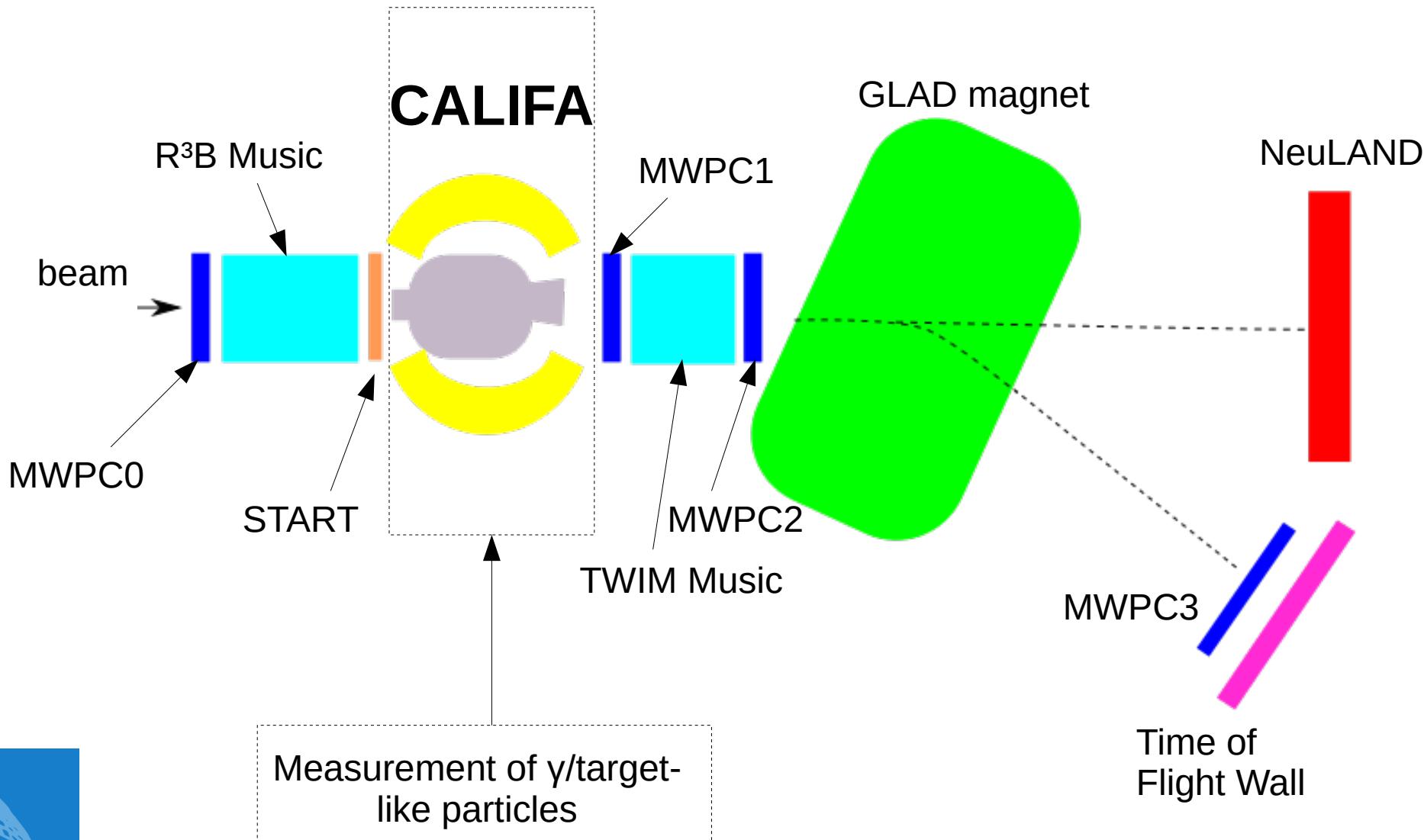


TWIM MUSIC signal information:

- energy loss in the detector = charge & velocity information ($\Delta E/E < 5\% \text{ FWHM}$)
- time of arrival of the e⁻ cloud = horizontal position of the fragment's flight path ($\Delta X = 40 \mu\text{m}$)

Time Measurement – START & TOFW





CALIFA Detector @ R³B

CALorimeter for the In Flight detection of γ -rays and light charged pArticles

Endcap:

iPhos:

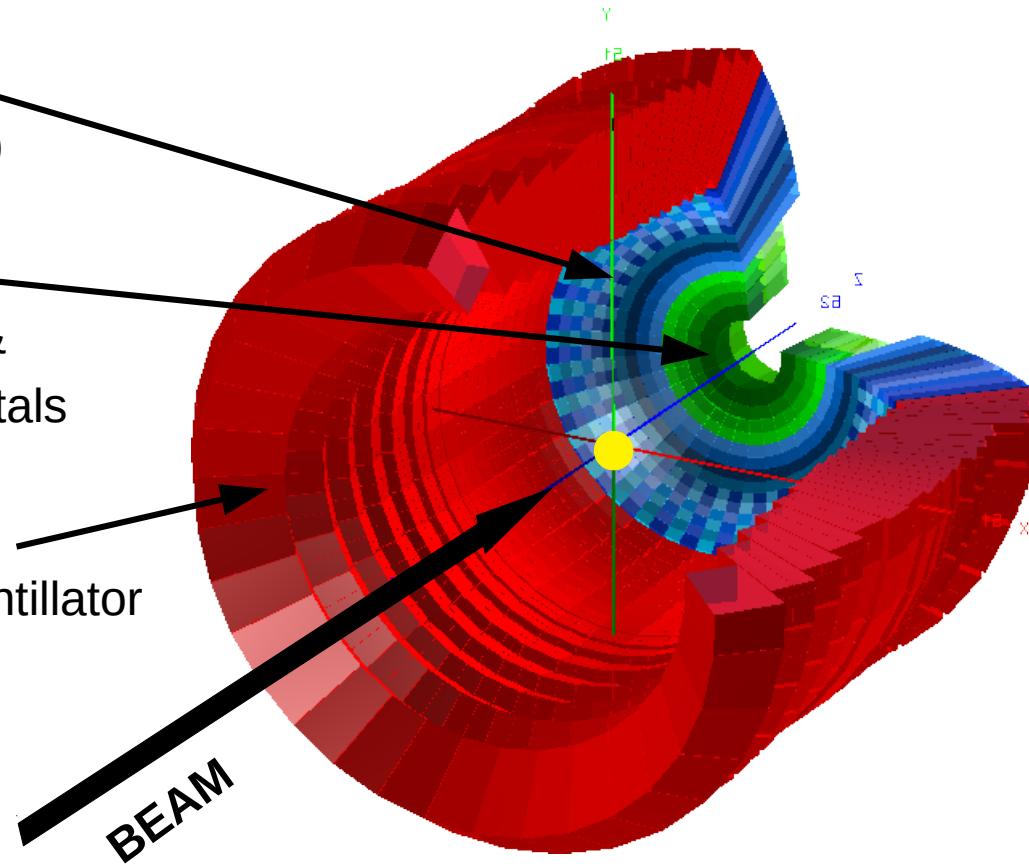
512 CsI(Tl)
crystals

CEPA:

96 LaBr₃ &
LaCl₃ crystals

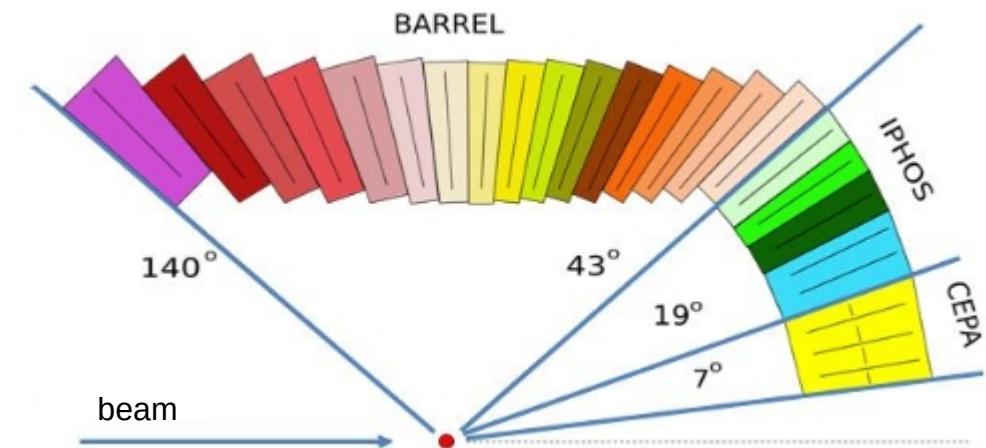
Barrel:

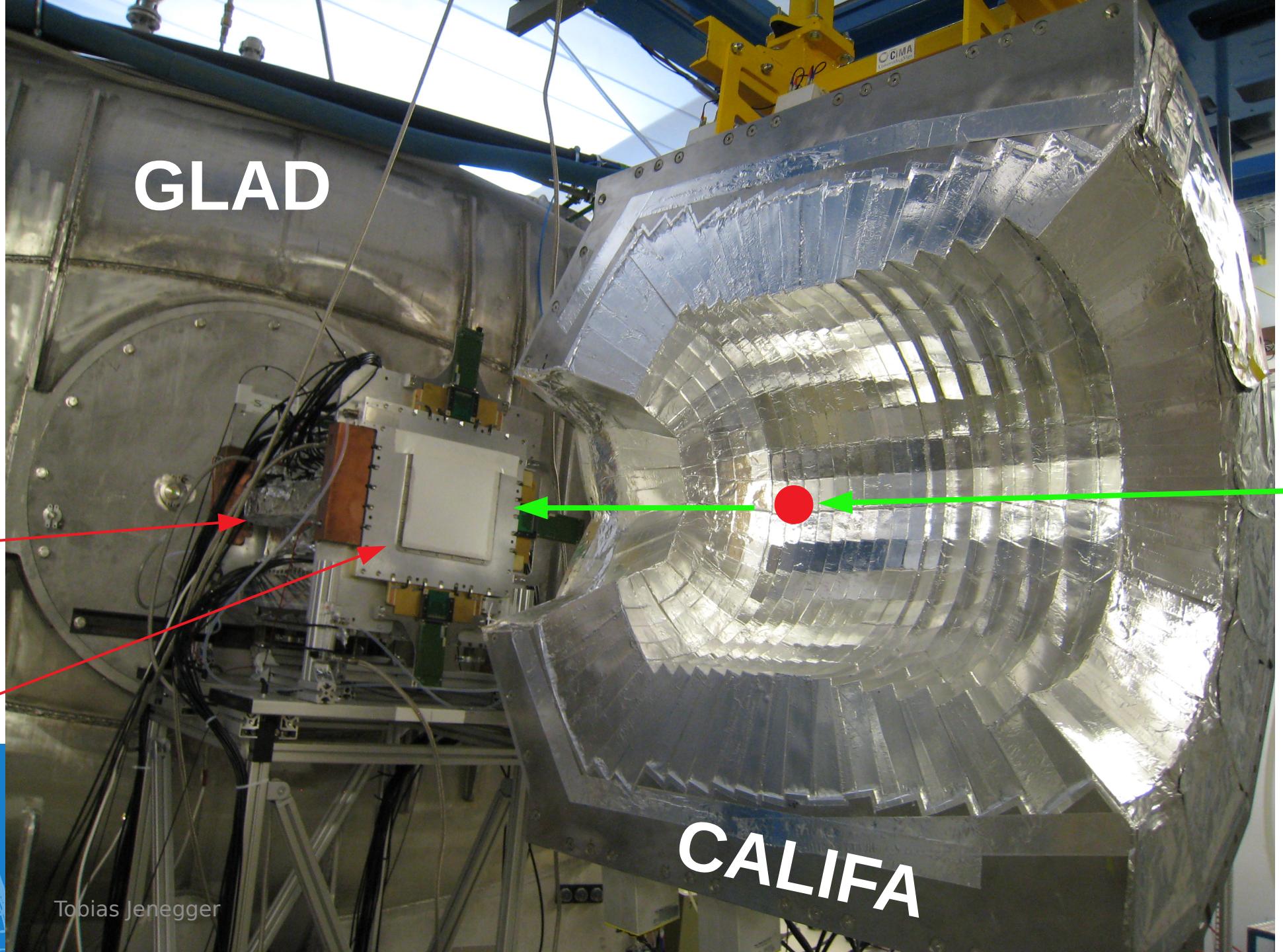
1952 CsI(Tl) scintillator
crystals



Requirements:

- high dynamic range:
100 keV γ -rays – 700 AMeV charged particles
- high efficiency
- high granularity → Doppler correction
- particle identification





First Analysis Steps



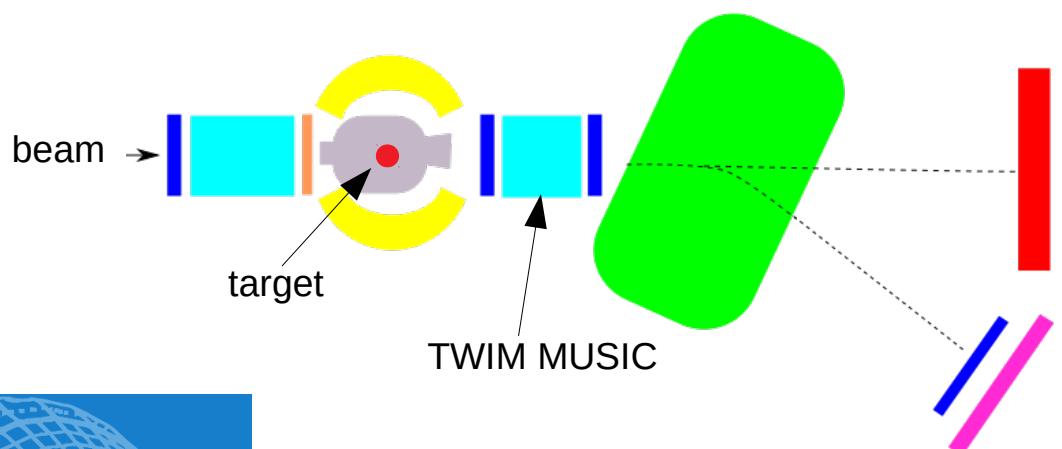
Identification of Fission Process

TWIM MUSIC Charge Identification:

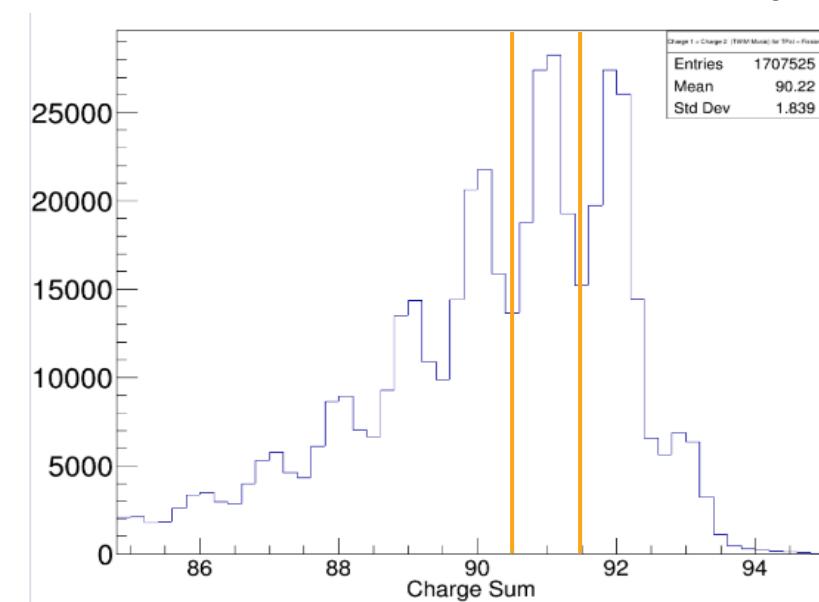
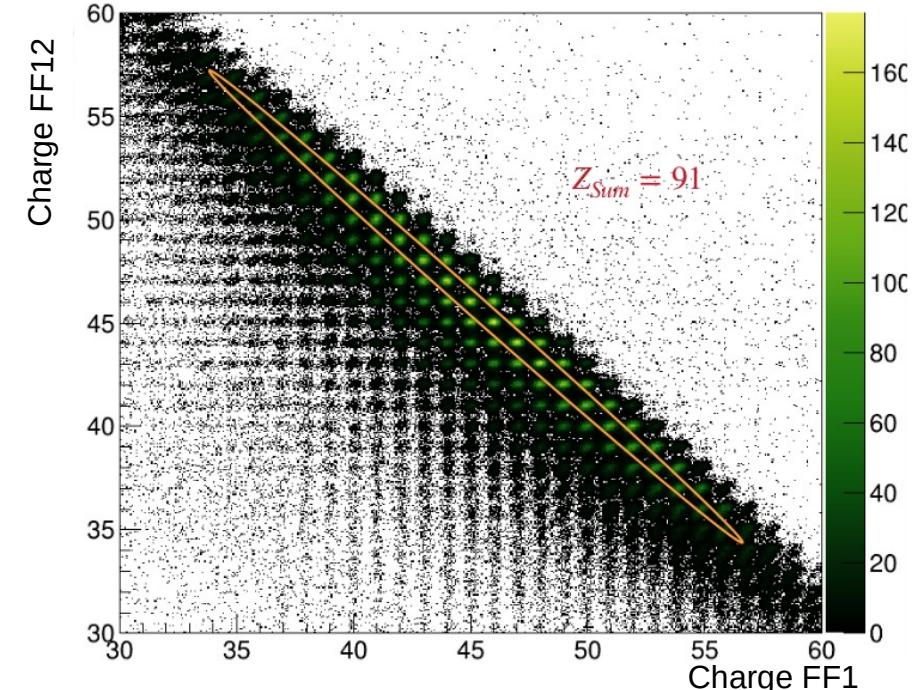
→ two fission fragments (FF)

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

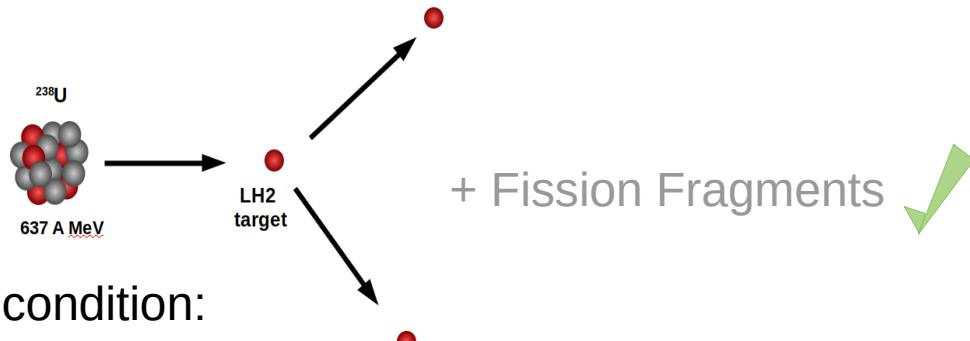
quasi-free scattered proton



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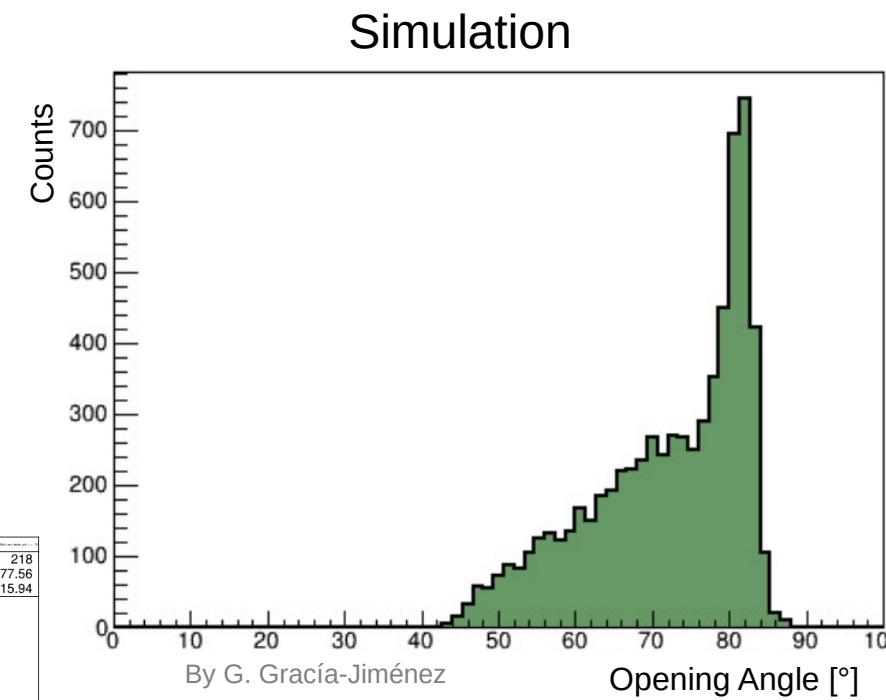
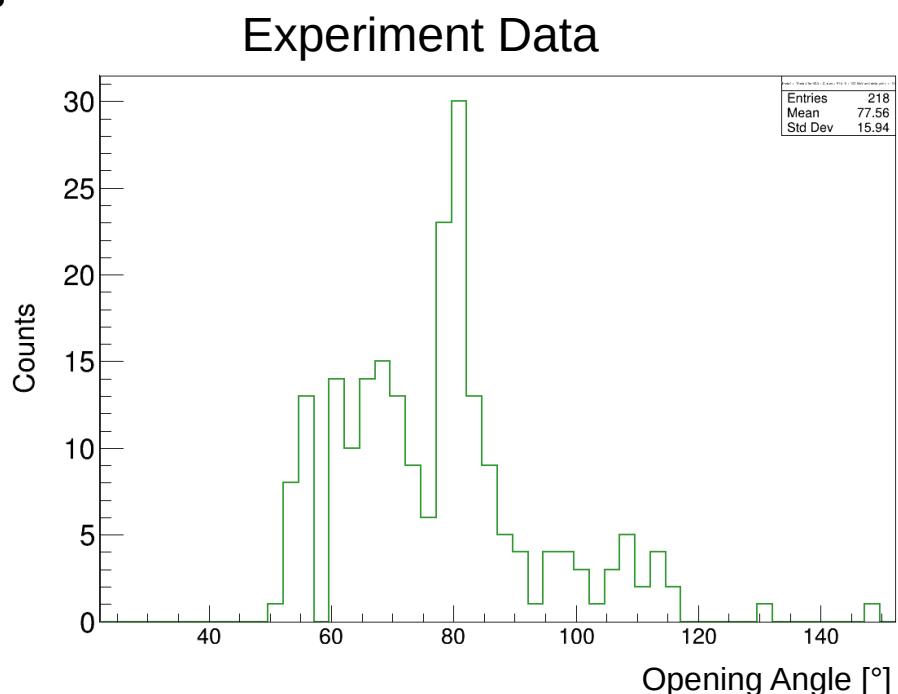


Identification of QFS Process



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

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

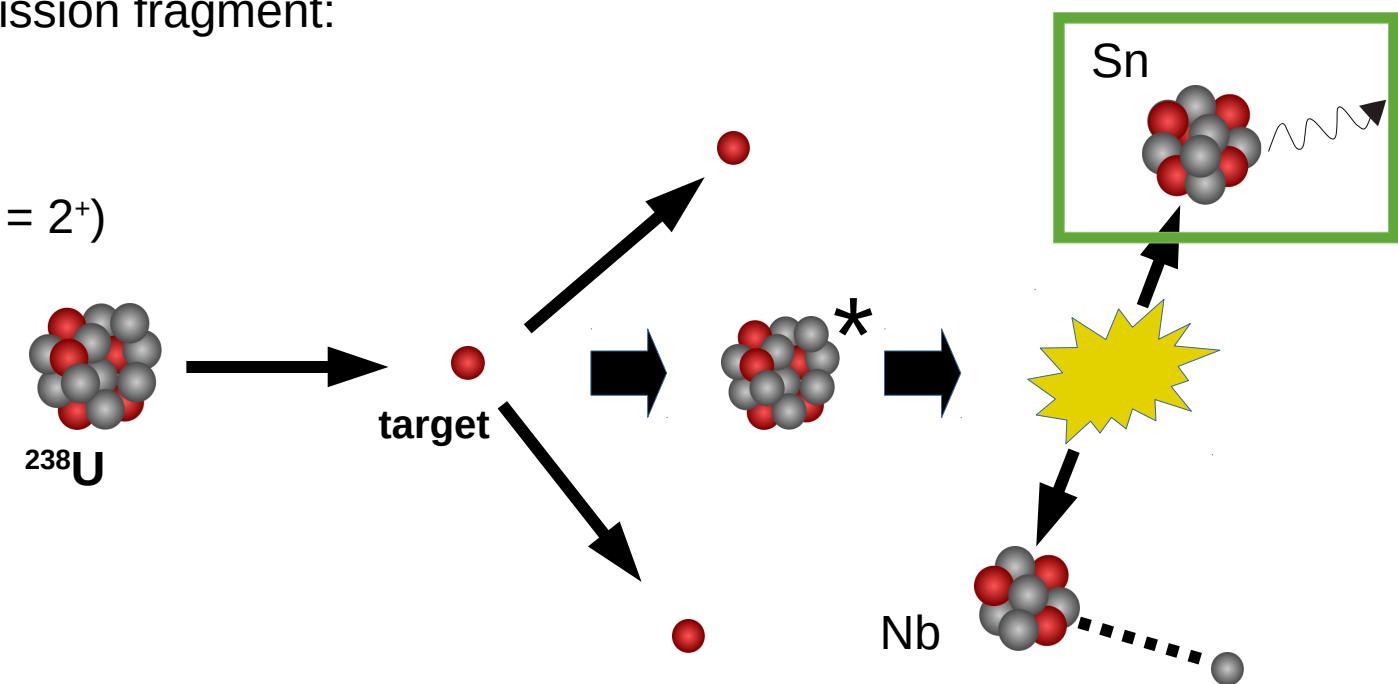


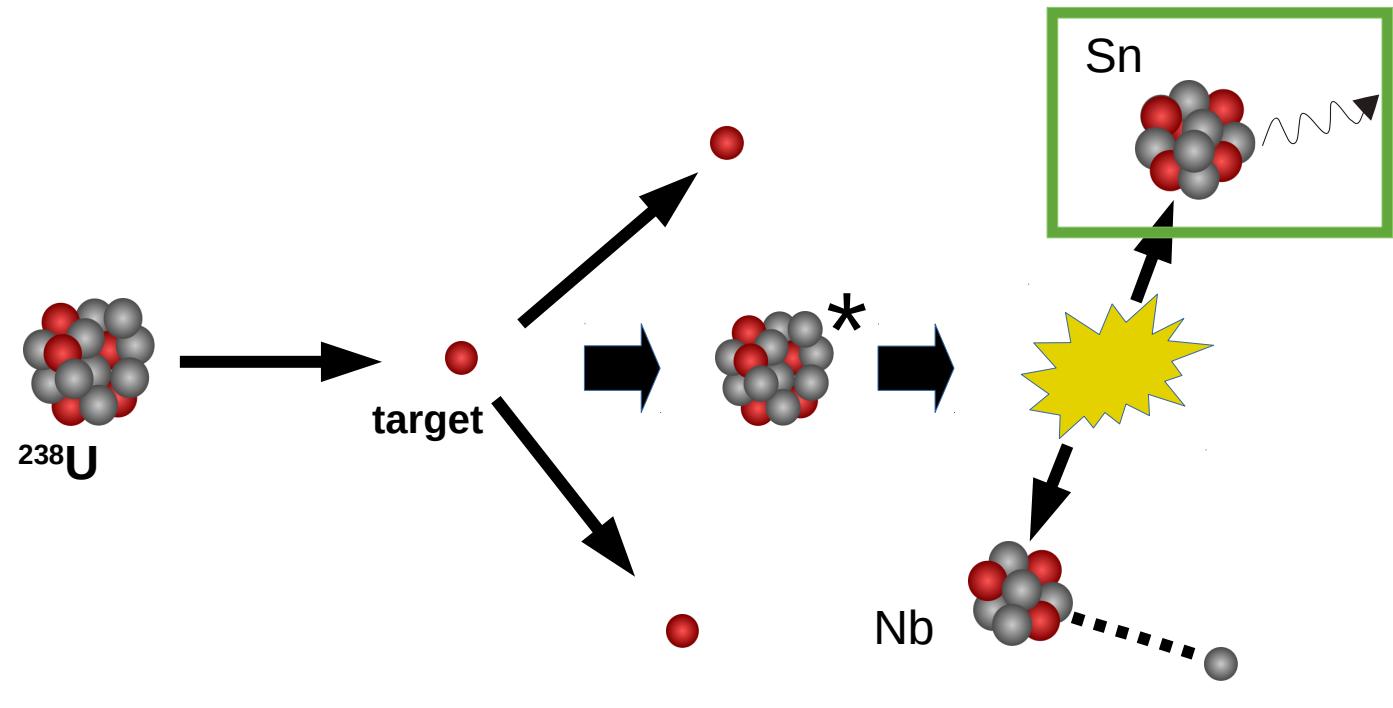
Motivation:

- energetic states of the fission fragments
- information on how the energy dissipated from fission is shared between the two nascent fragments (energy sorting mechanism, shell effects, etc.)

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 $J = 2^+$)



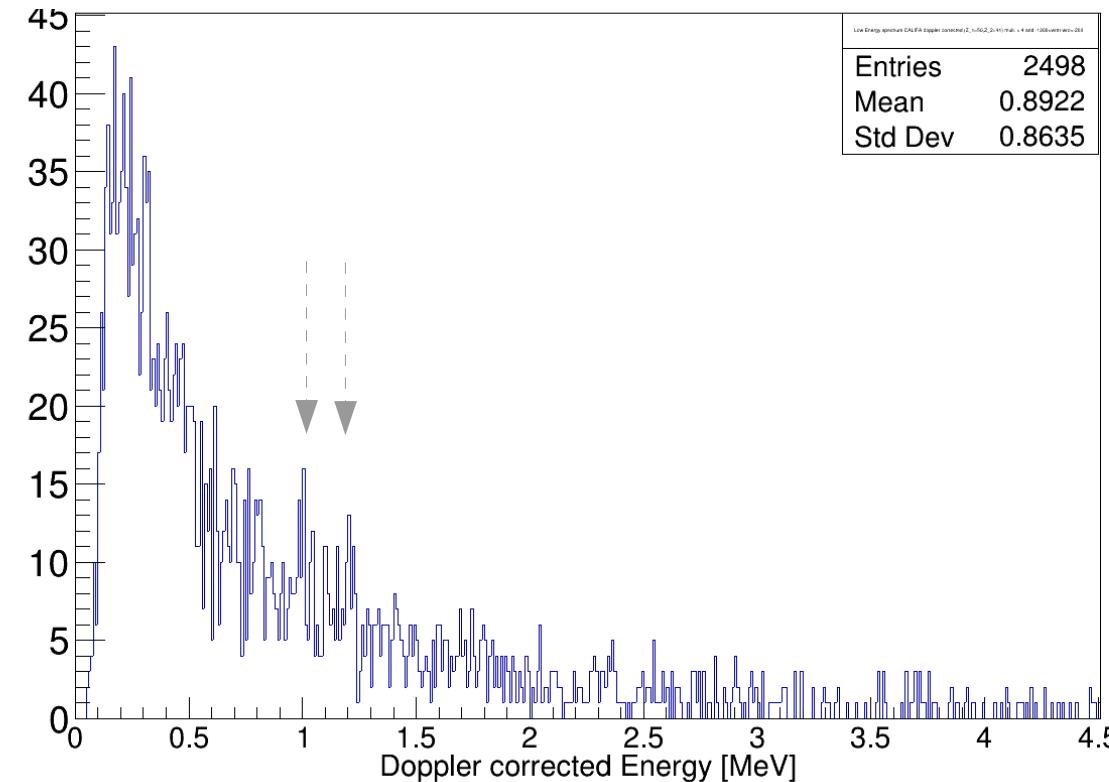


1st excited Sn states of interest:

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

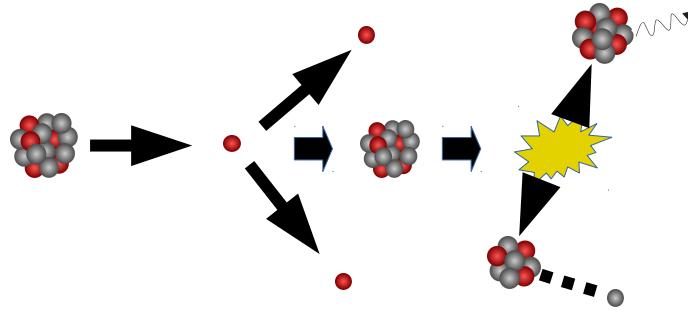


Tobias Jenegger



Outlook

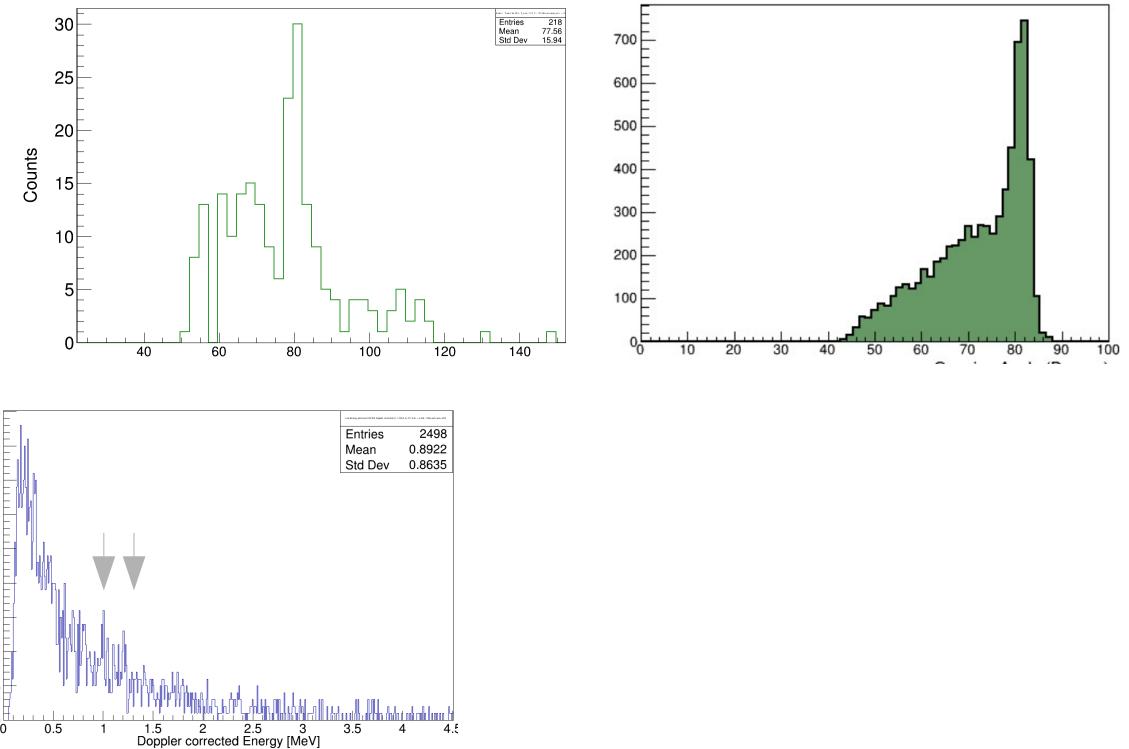
→ $^{238}\text{U}(\text{p},2\text{pf})$ reaction has been identified:



→ gamma spectrum looks promising:

- Fine calibration of TWIM MUSIC
- Time of flight & track reconstruction for exact particle identification
- full energy reconstruction of the fissioning system and the fission fragments
 - fission barriers / spectra of excited fission fragments

Opening Angle: Experiment-Simulation





Thank you!

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GEFÖRDERT VOM



Bundesministerium
für Bildung
und Forschung

