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

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For the R³B Collaboration

DPG Mainz
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Fission via (p,2pf) reaction

R³B Setup at GSI

First Analysis Steps

Outlook

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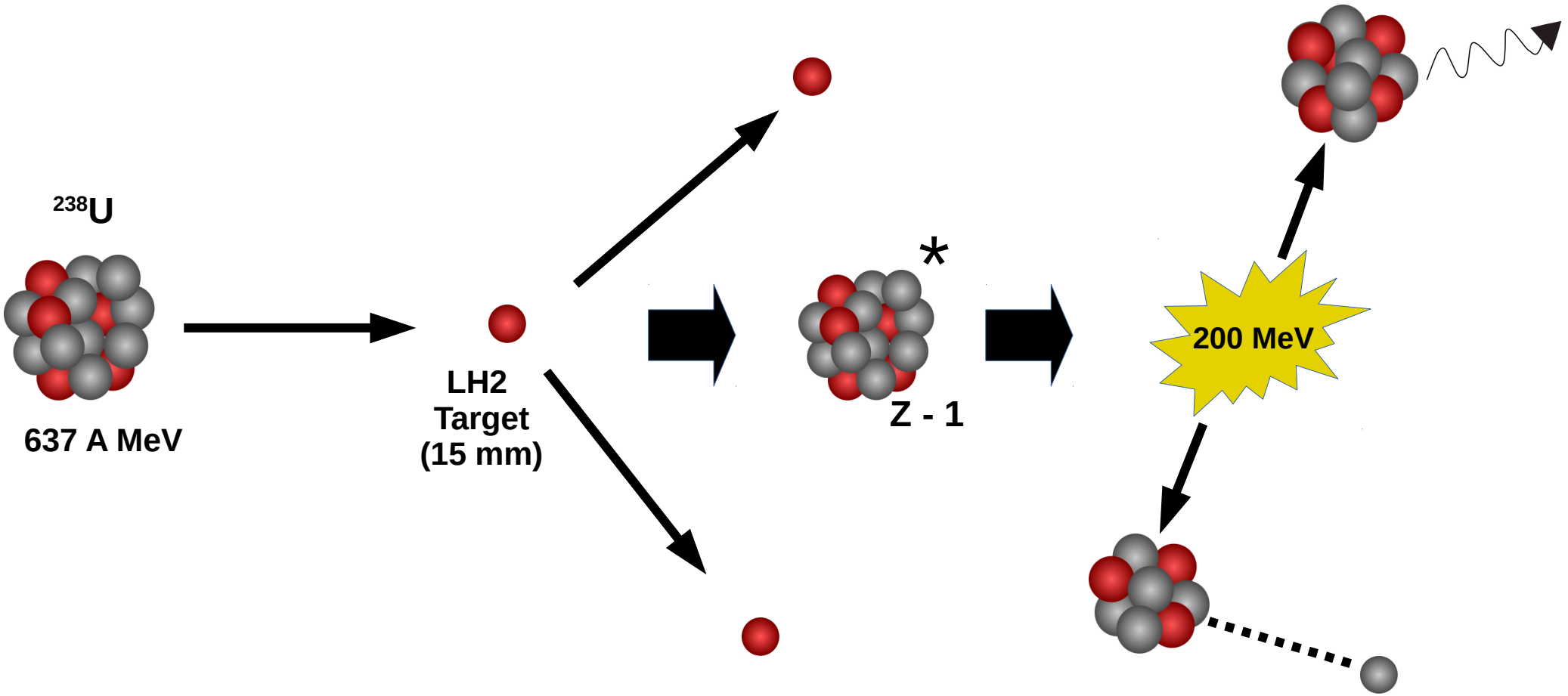
and the FAIR Phase-0 program

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

Fission induced by Quasi-Free-Scattering



S455 Experiment (2021) – Nuclear Fission Studies

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

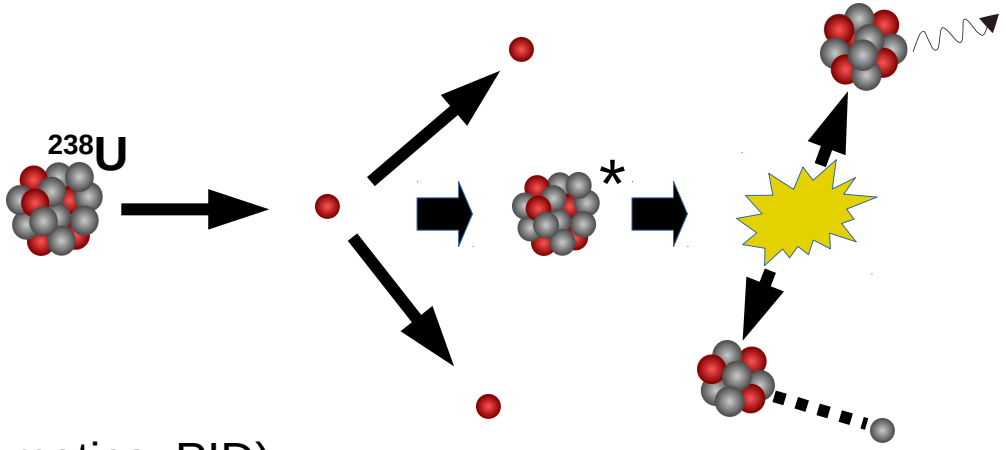
Why QFS?

→ 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



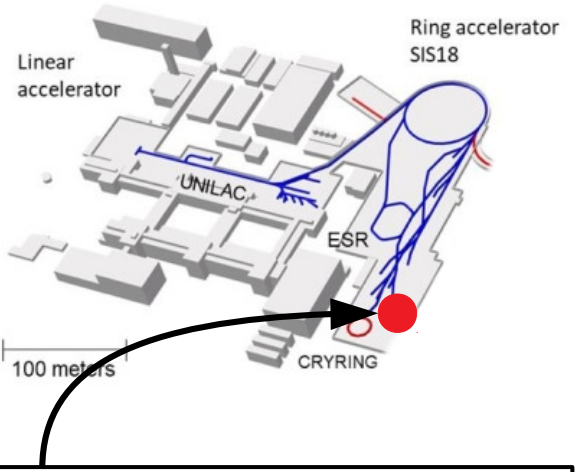
What we require:

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

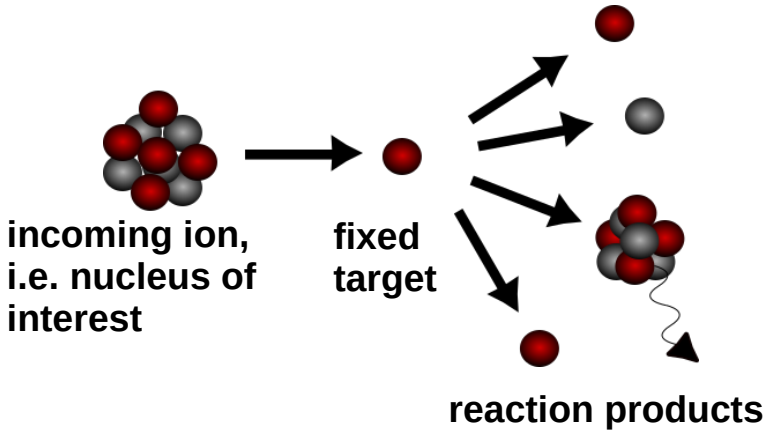
Dedicated experimental setup needed!

R³B Experiment @ GSI

Reactions with Radioactive Relativistic Beams



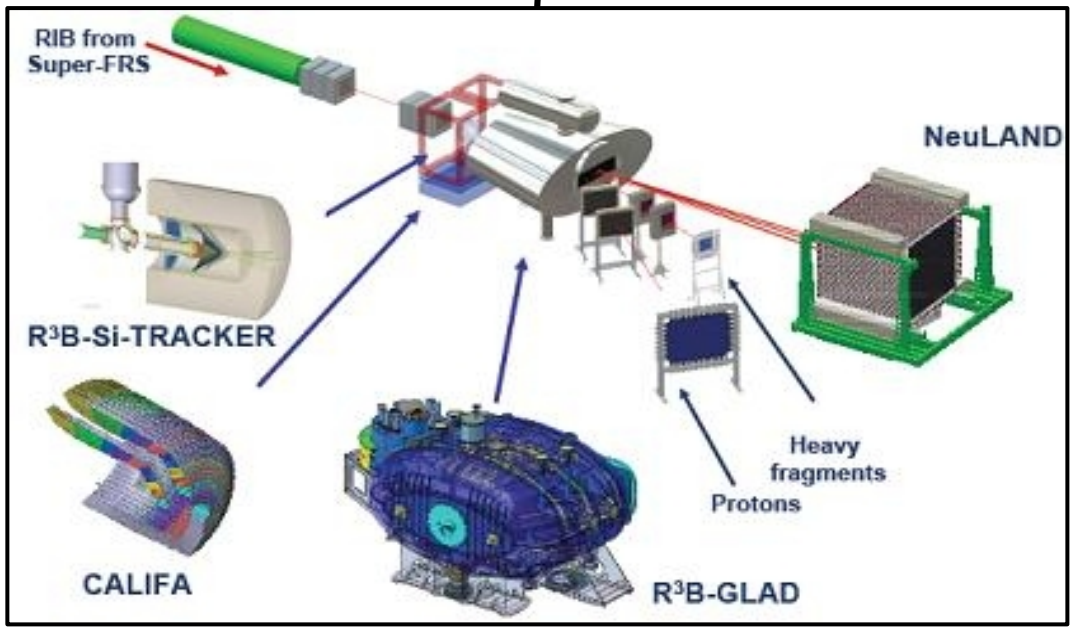
- Physics program on exotic nuclei in inverse kinematics:



- **kinematically complete measurements**

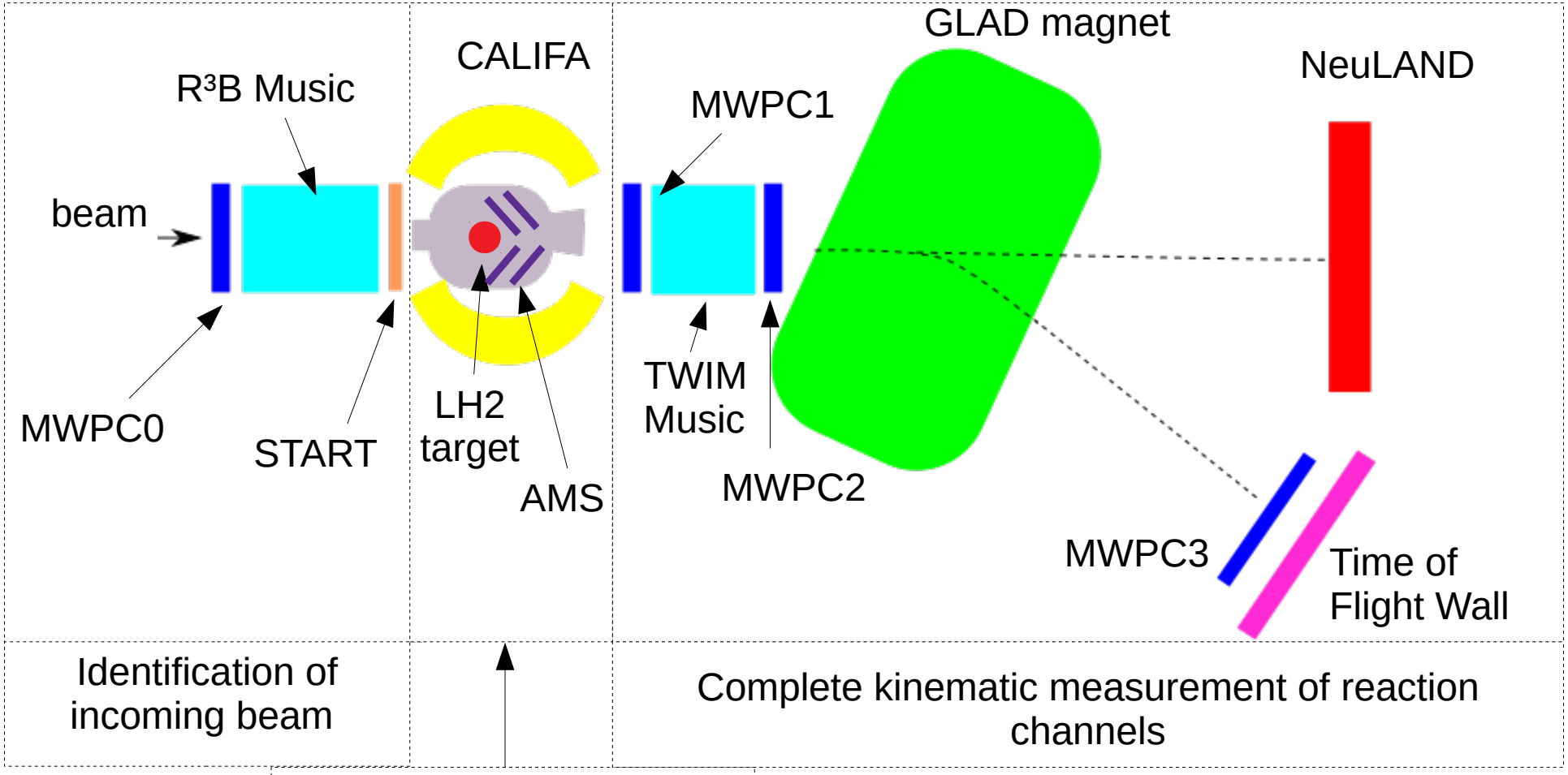
Talk from Lukas Ponnath:

"Total Reaction Cross-Section Measurements in the S444 Commissioning Experiment for R³B" (HK 29.1)

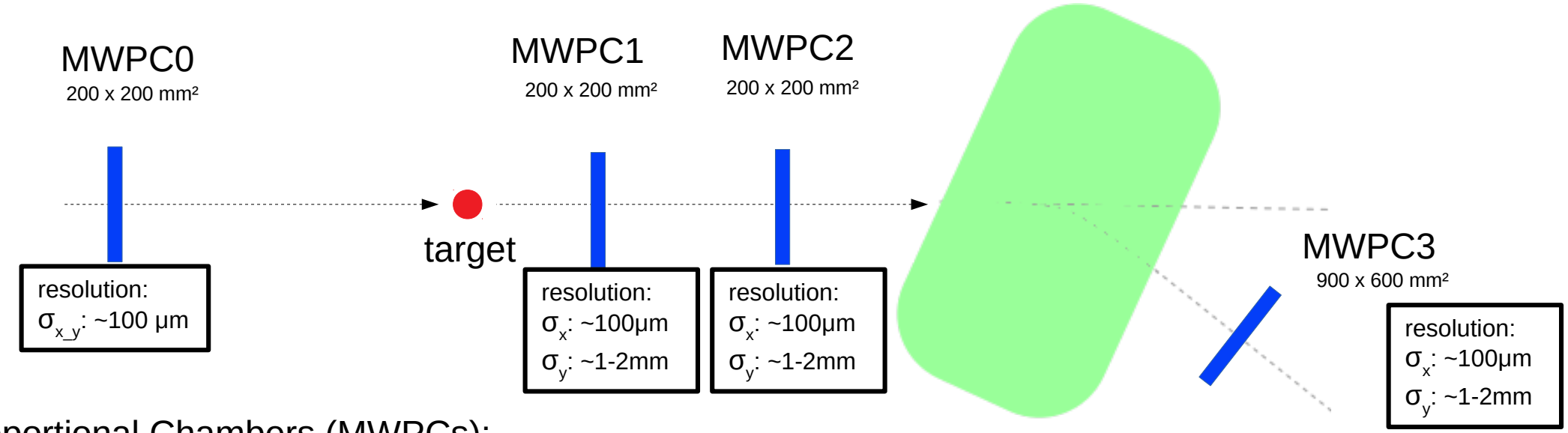


R³B Setup for Pilot Experiments (2021)

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



Tracking with the MWPC



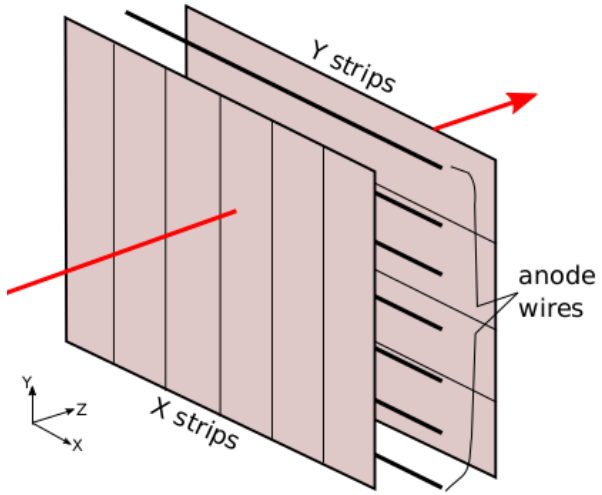
Multi Wire Proportional Chambers (MWPCs):

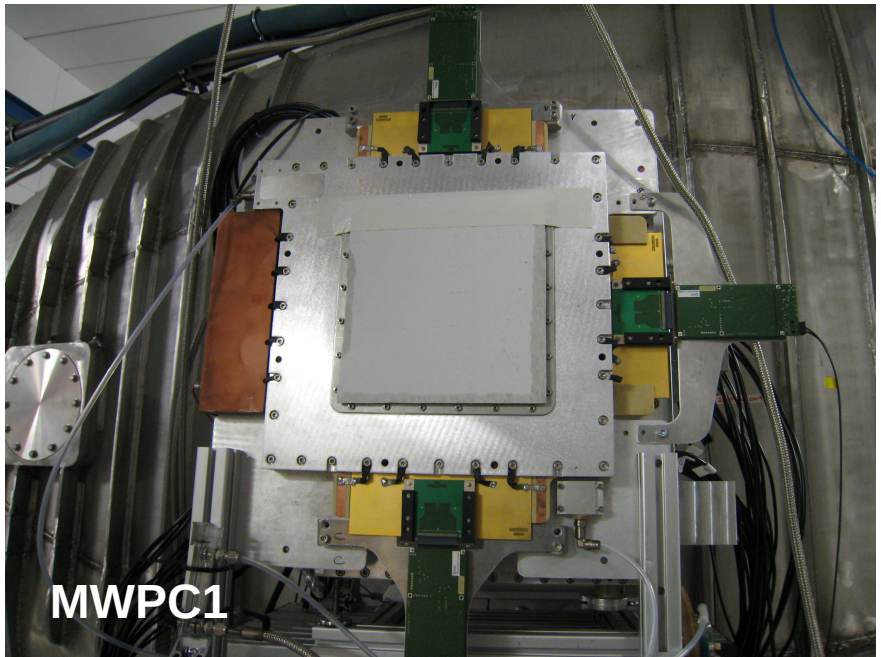
→ horizontal wires: 50 µm diameter, 2.5 mm spacing

→ vertical/horizontal pads:
Al-deposited on a 12 µm Mylar foil,
5/3.125 mm width (vertical/horizontal)

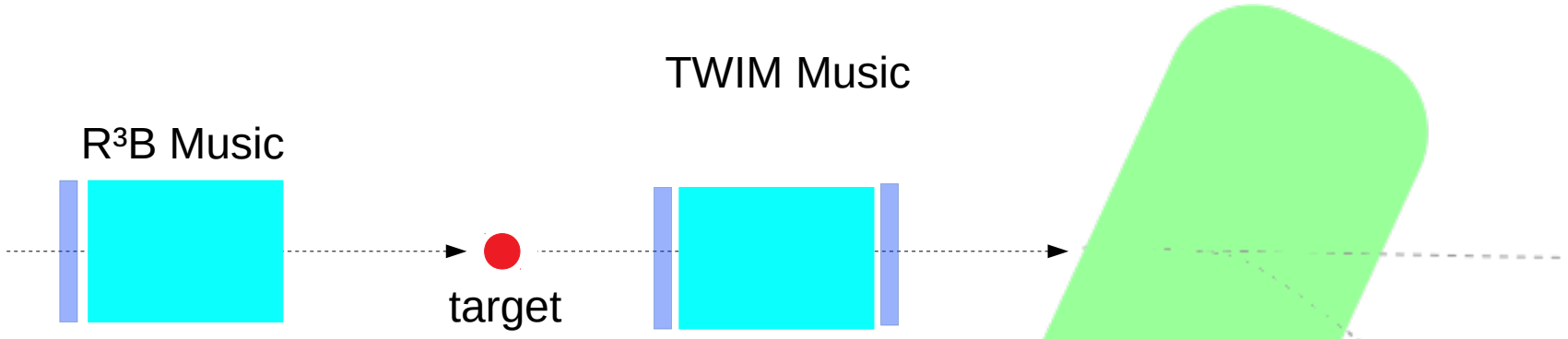
→ gas mixture: 84% Ar, 16% CO2

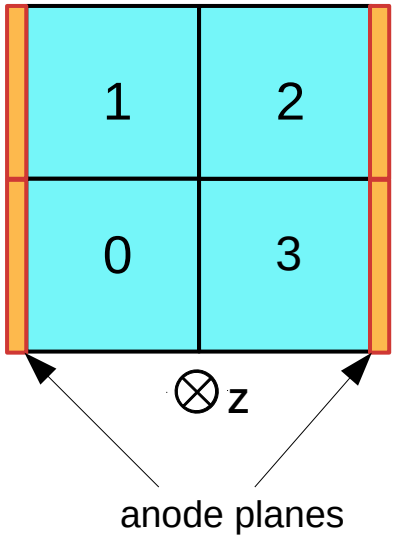
→ pad readout





Charge Measurement – Ionization Chambers





TWIM MUSIC

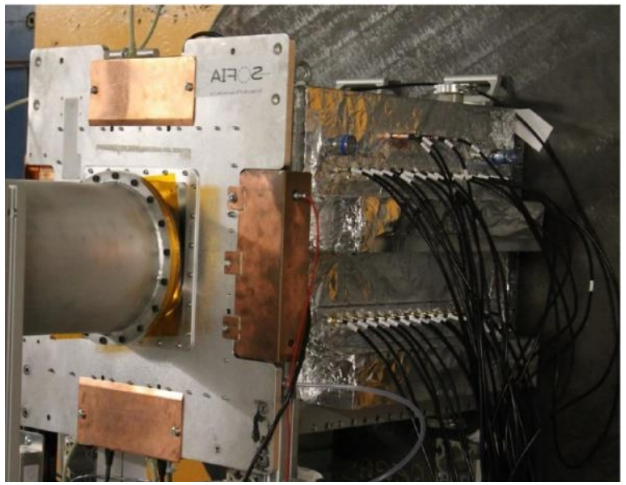
SOFIA Collaboration

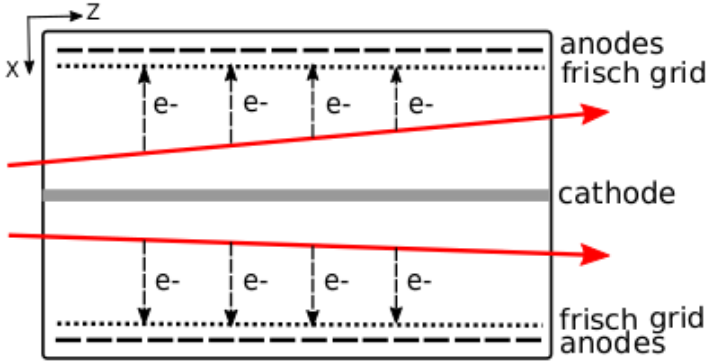
43 x 48 x 55 cm³

Double ionization chamber:

→ central cathode

→ 4 sections, each 16 readout anodes



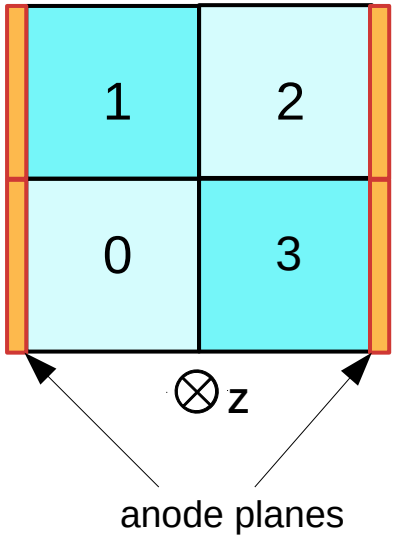


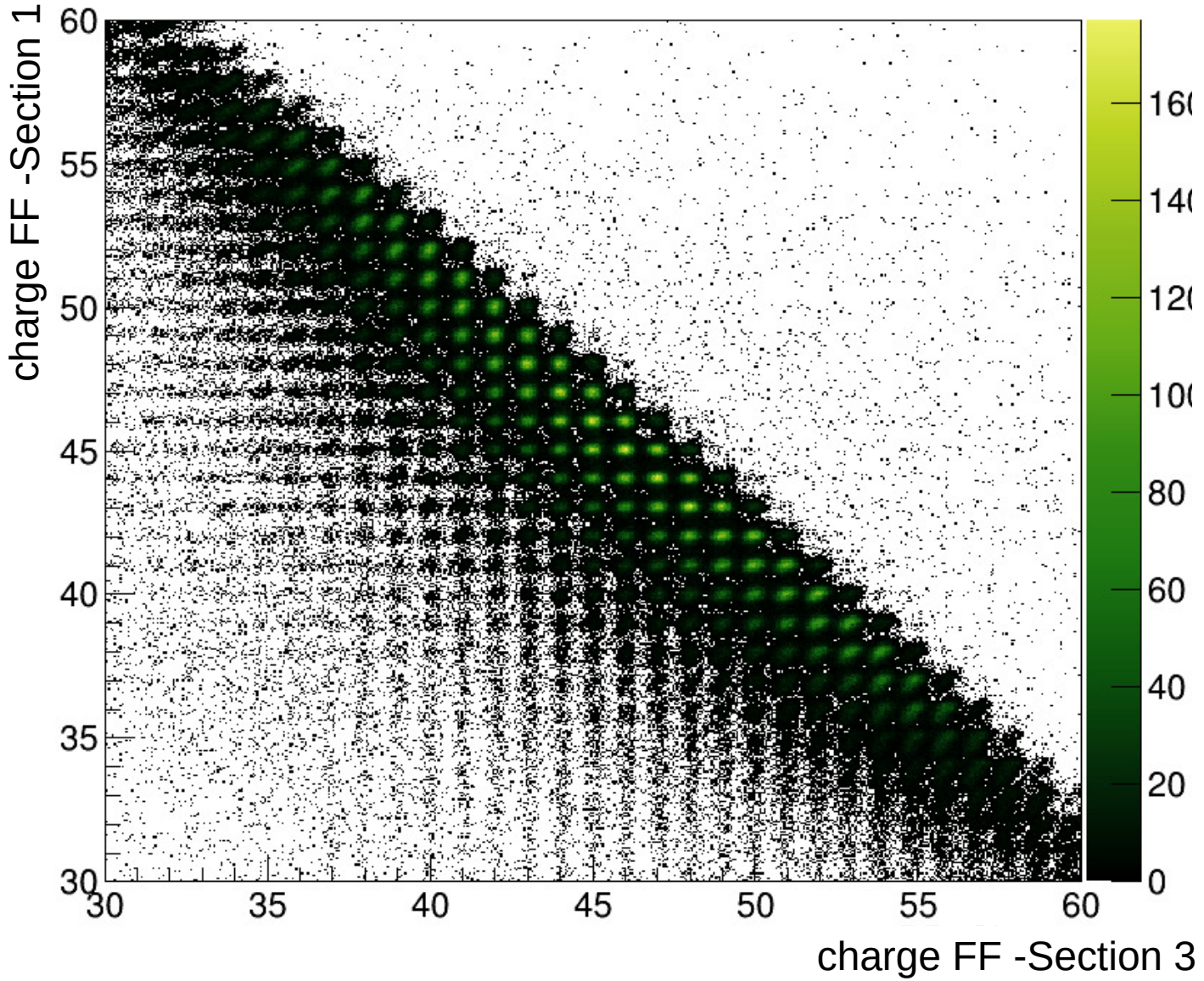
TWIM MUSIC signal information:

→ energy loss in the detector: charge information (ΔZ = 0.35 charge unit FWHM)

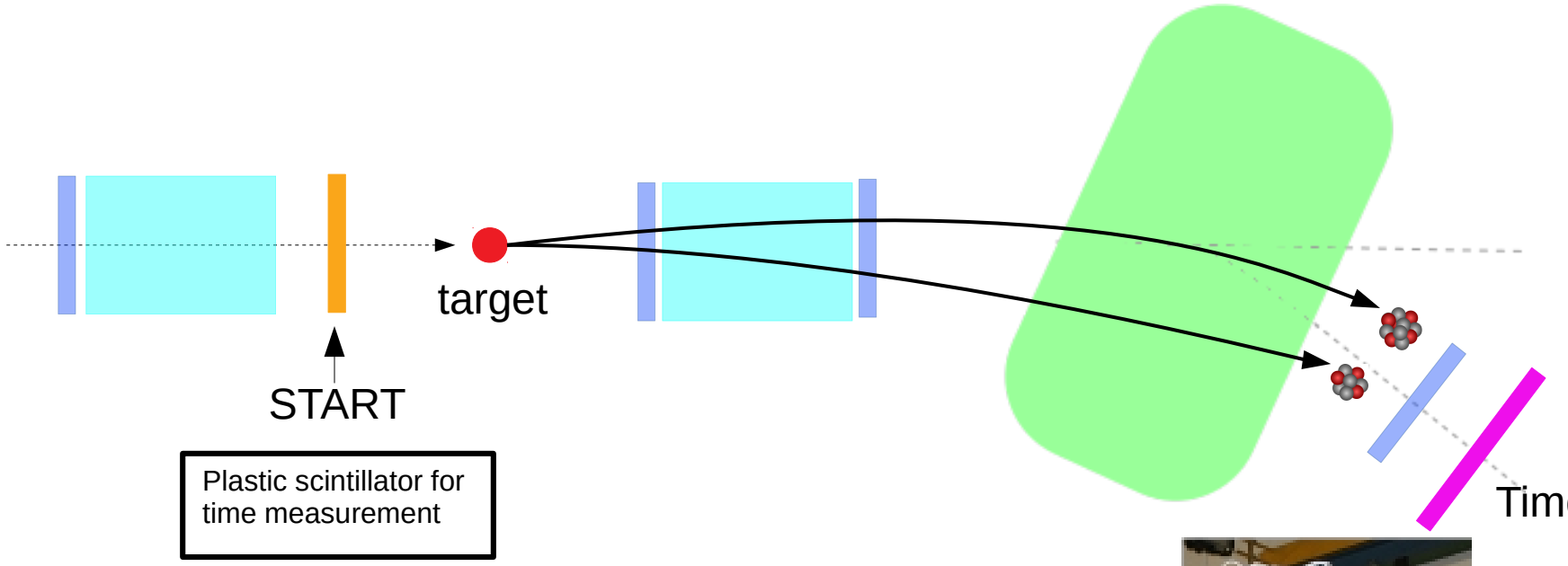
→ time of arrival of the e^- cloud: horizontal position of the fragment's flight path (ΔX = 40 µm)

Charge Measurement of Fission Fragments





Time Measurement – START & TOFW



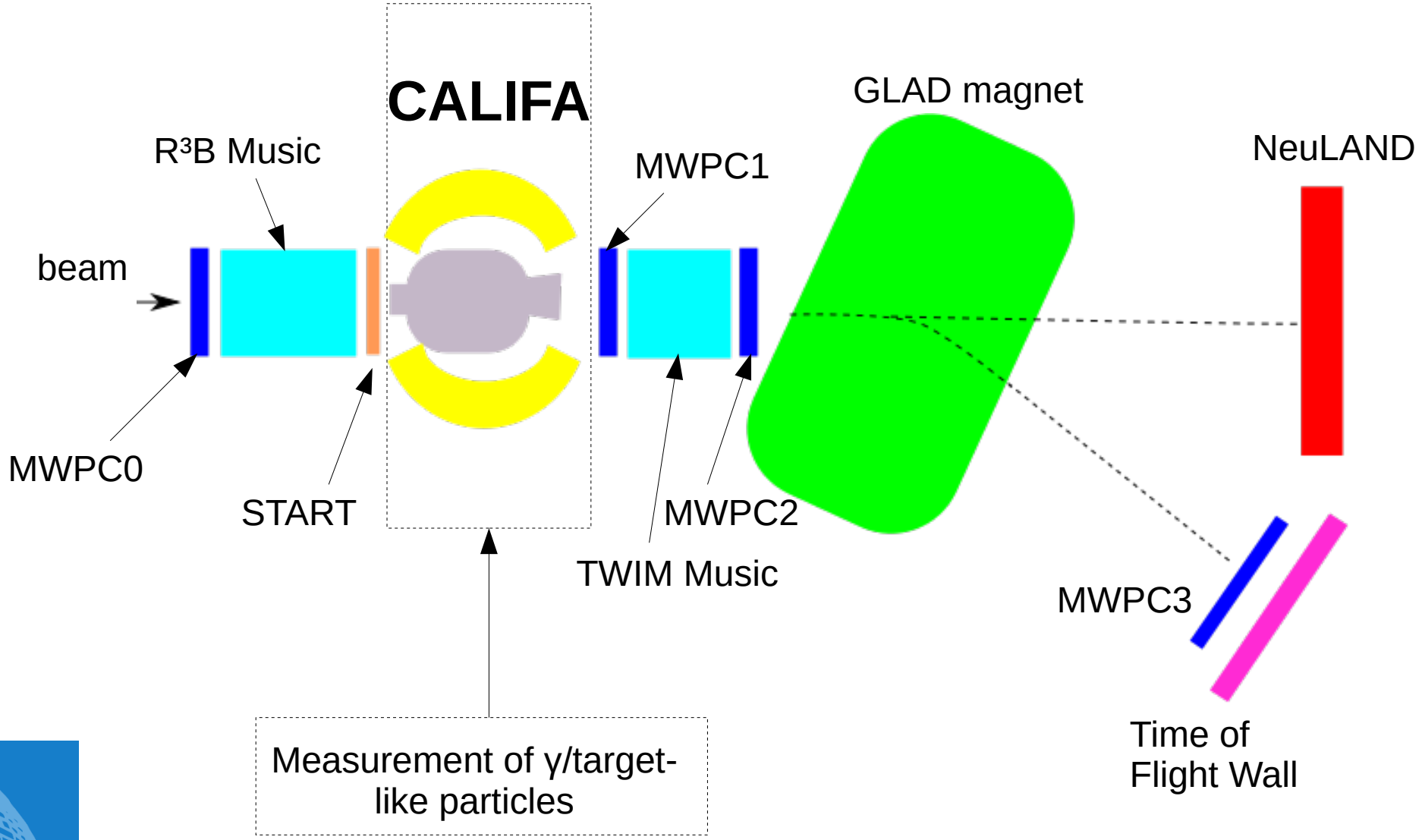
→ ToF measurement: START to TOFW
→ flight-path reconstruction: tracking detectors
→ charge measurement: TWIM MUSIC

} independent measurement of both fragmens

27 vertical scintillators (each 30 x 600 x 5 mm)

time and position measurement

Mass Identification: $B*\rho = \frac{\beta * \gamma * M}{q}$


CALIFA
GLAD magnet
R³B Music
MWPC1
NeuLAND
beam
MWPC0
START
MWPC2
TWIM Music
MWPC3
Time of
Flight Wall
Measurement of γ/target-
like particles

CALIFA Detector @ R³B

CALorimeter for the **I**n **F**light detection of γ-rays and light charged p**A**rticles

Endcap:

iPhos:

512 CsI(Tl) crystals

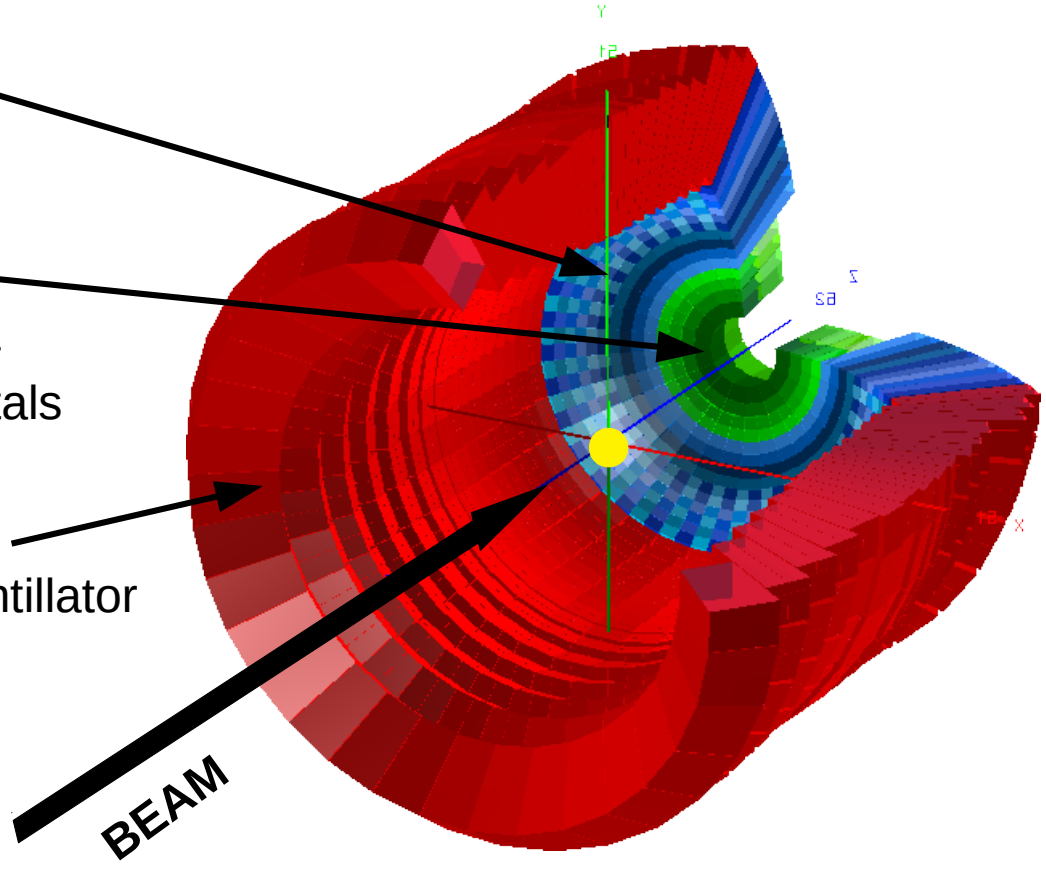
CEPA:

96 LaBr3 &

LaCl3 crystals

Barrel:

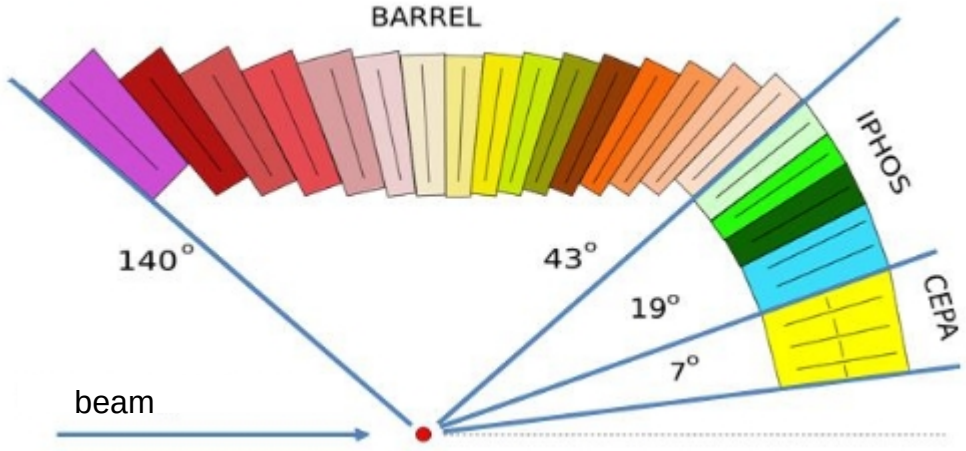
1952 CsI(Tl) scintillator crystals

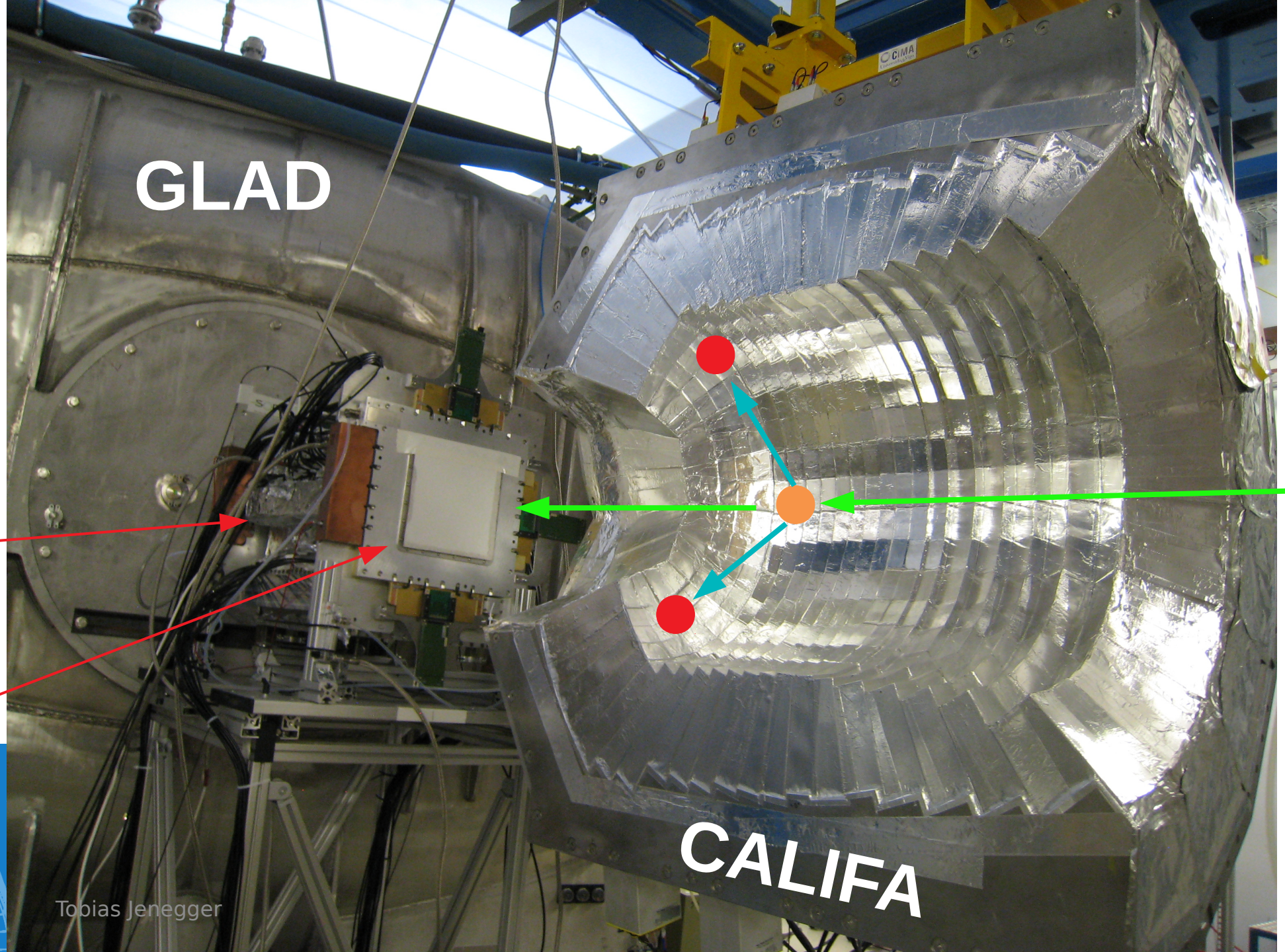


Highly segmented detector:

→ Angular reconstruction

→ Doppler correction




GLAD
CALIFA
TWIM
MUSIC
MWPC 1

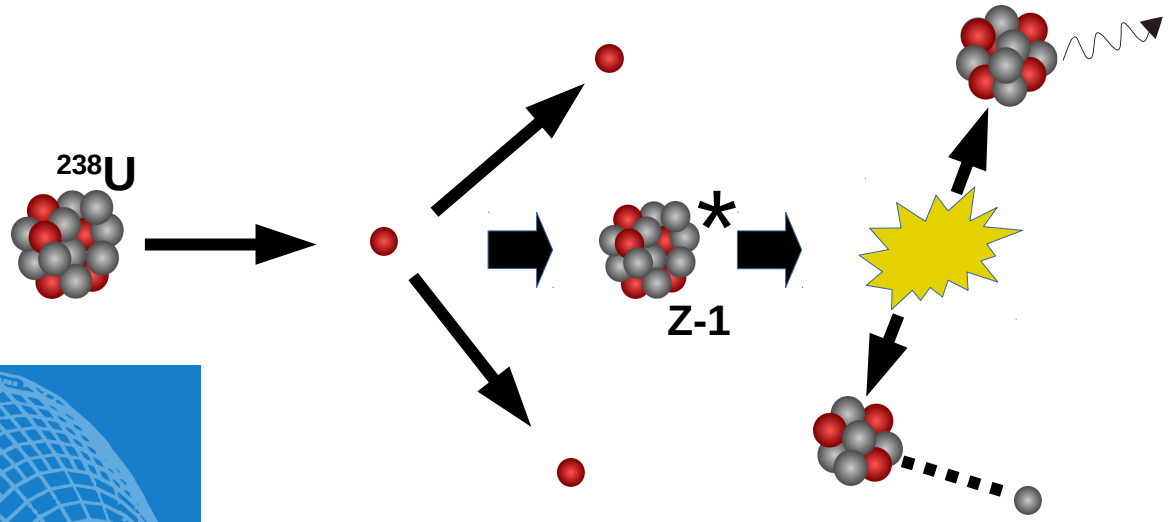
Identification of Fission Process

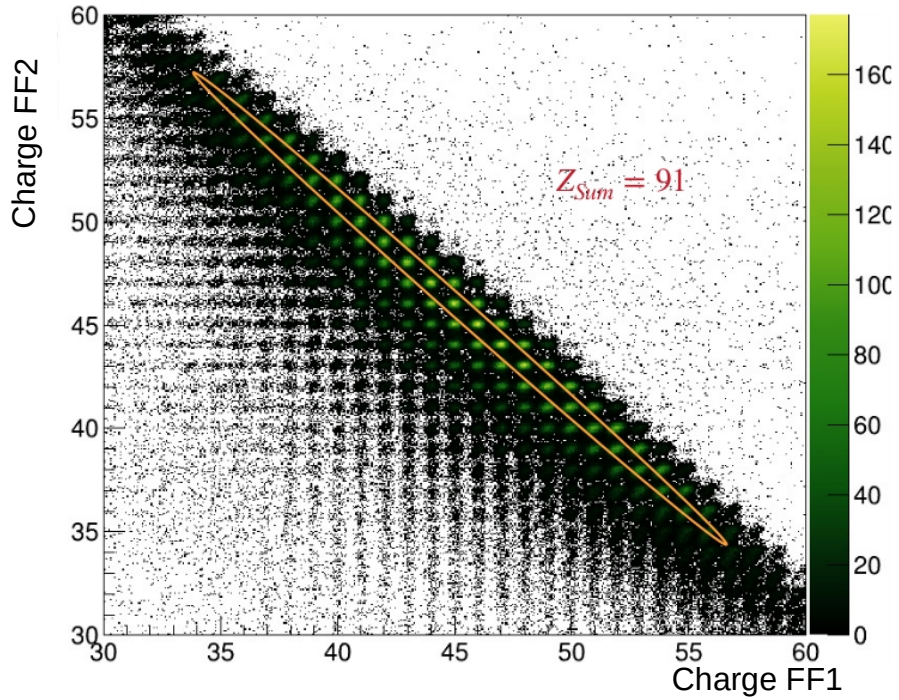
TWIM MUSIC Charge Identification:

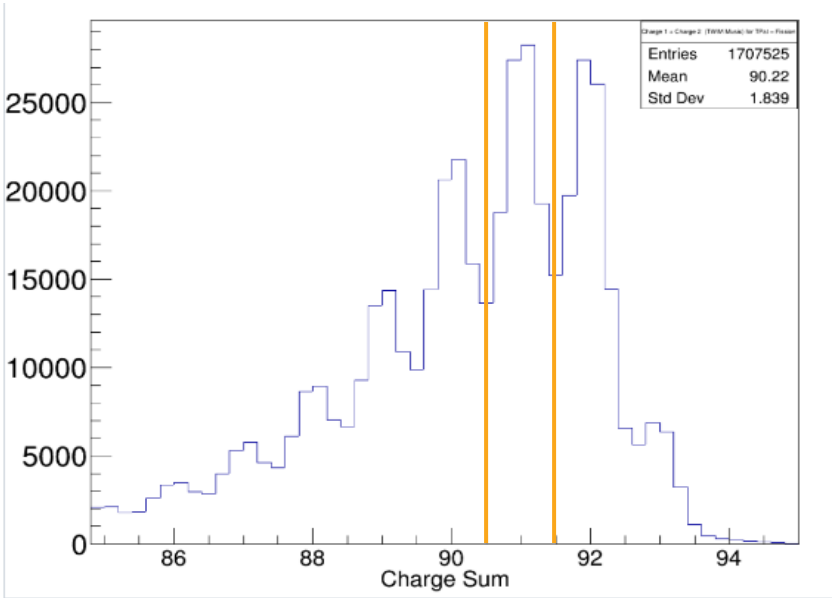
→ two fission fragments (FF)

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

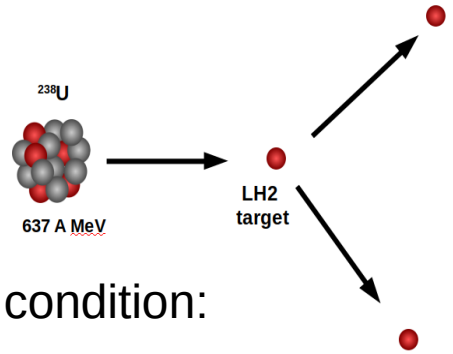
quasi-free scattered proton







Identification of QFS Process



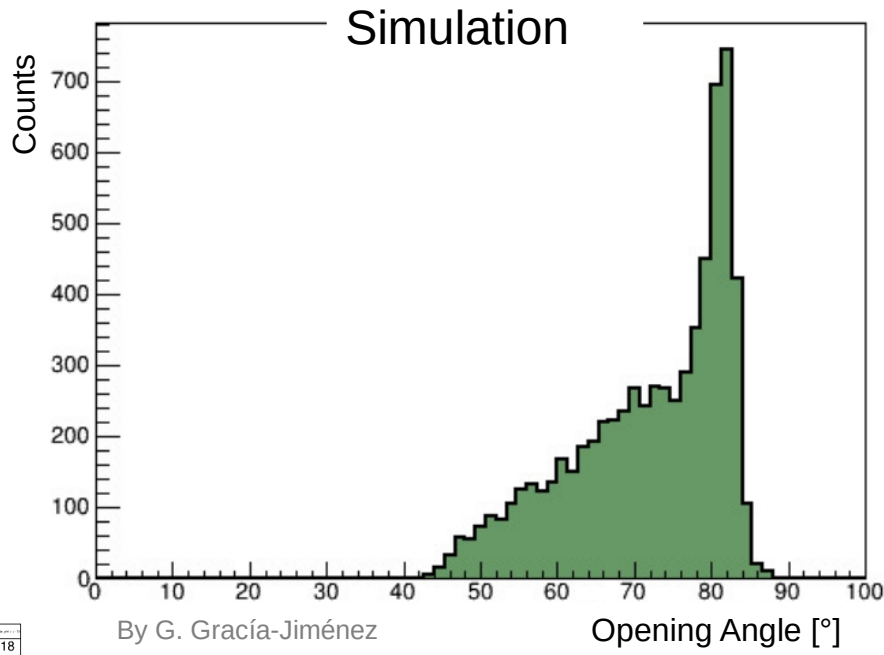
+ Fission Fragments ✓

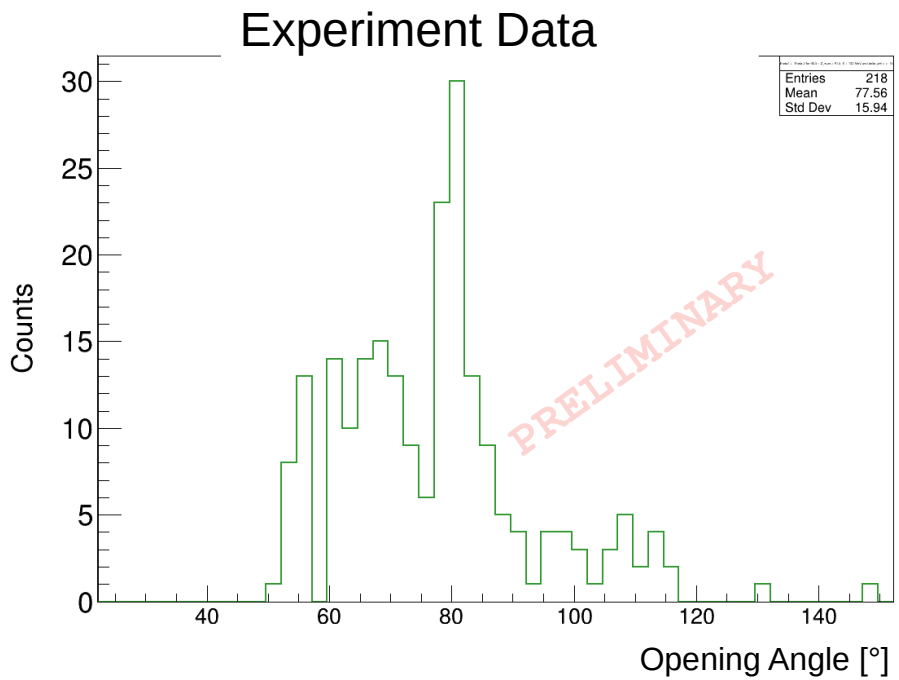
Select events with (p,2p) condition:

→ two hits with E_{p1},E_{p2} > 100 MeV

→ Coplanarity: Δφ = 180° +- 15°

→ 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)

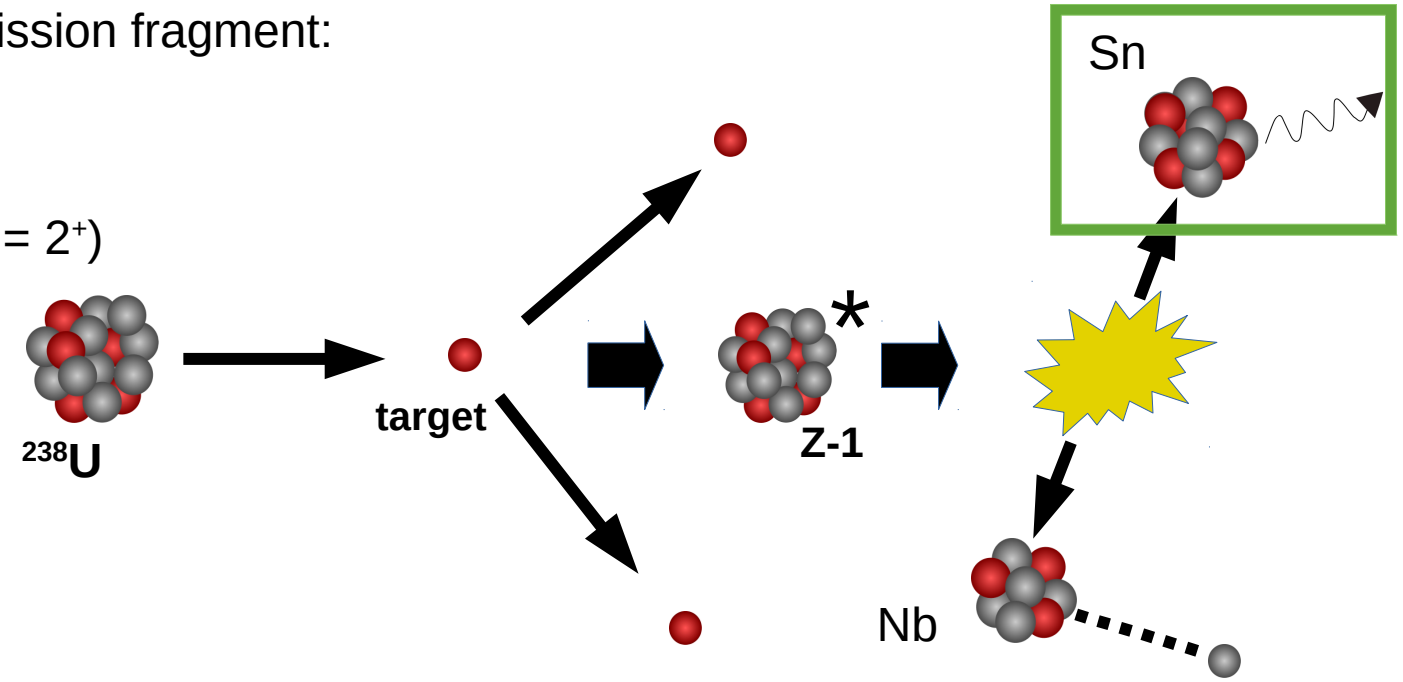
→ analyse energetic states of the fission fragments

→ do we see correlated γ-rays ?

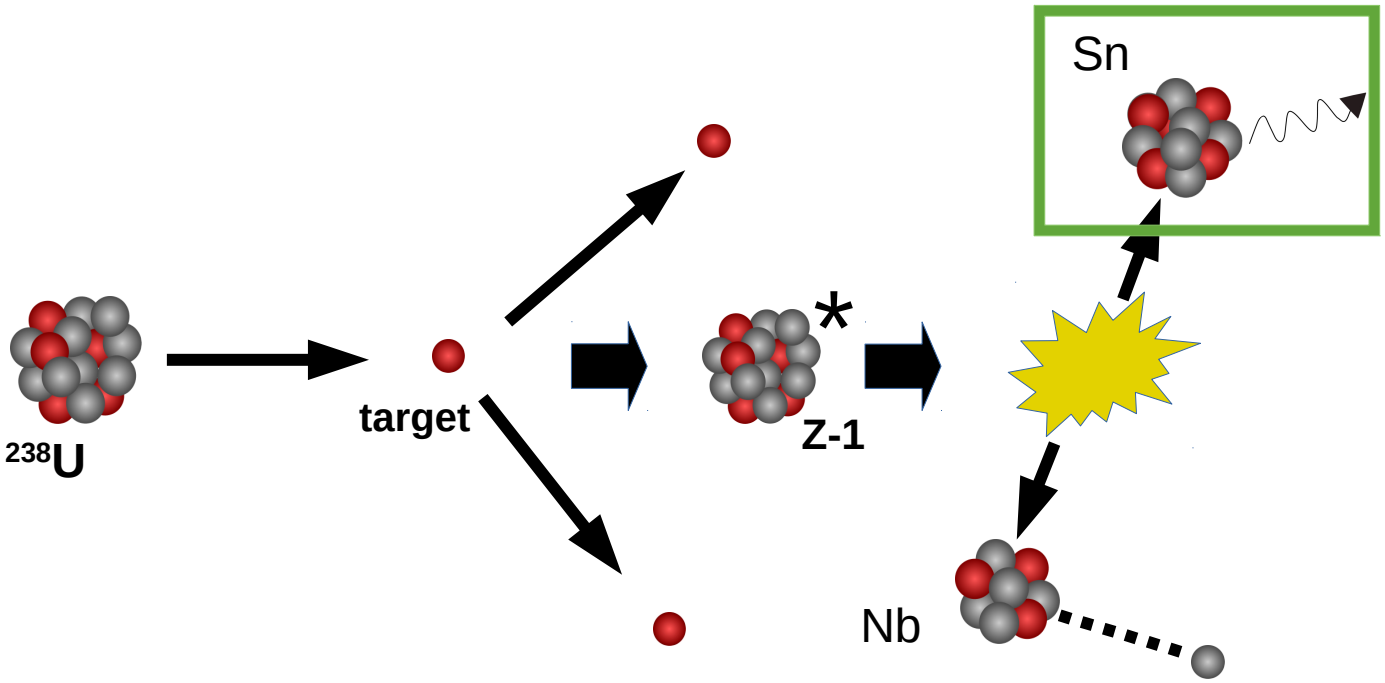
Gamma spectrum of tin (Z= 50) as one fission fragment:

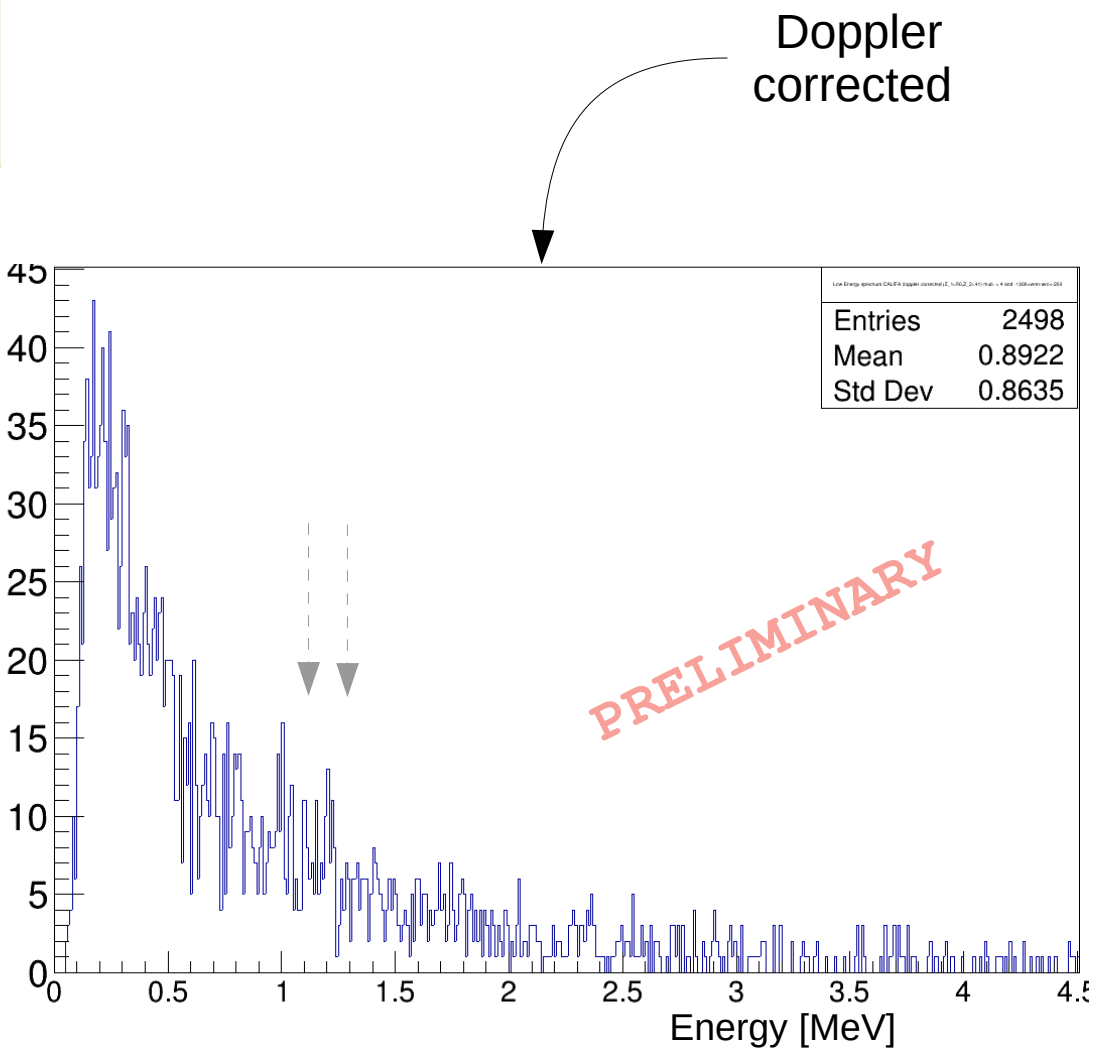
→ gg nuclei with J = 0^+ ground state

→ energy gap ~1-2 MeV (excited state J = 2^+)



Gamma spectrum in CALIFA



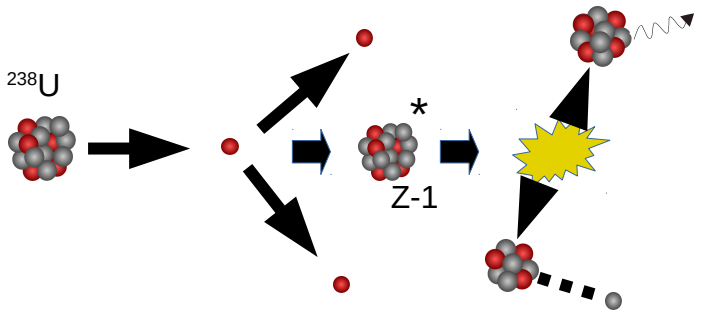


1st excited Sn states of interest:

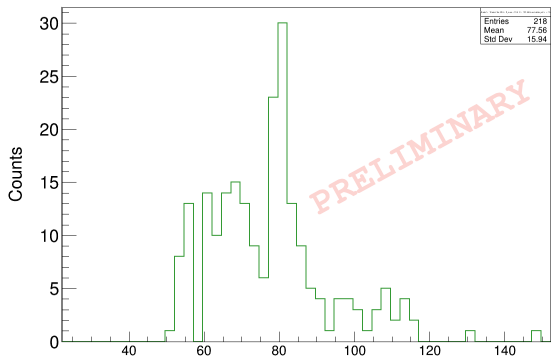
- ^{126}Sn, 1140 keV
- ^{128}Sn, 1169 keV
- ^{130}Sn, 1121 keV
- ^{132}Sn, 4041 keV

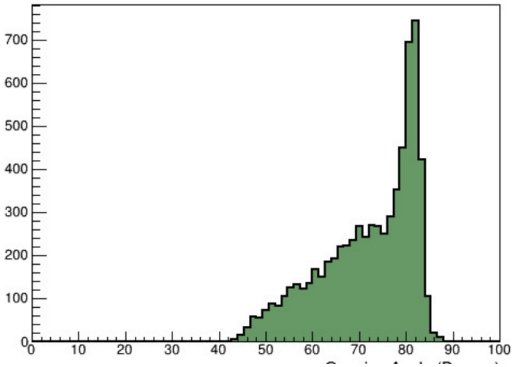
Summary & Outlook

→ 238U(p,2pf) reaction has been identified:

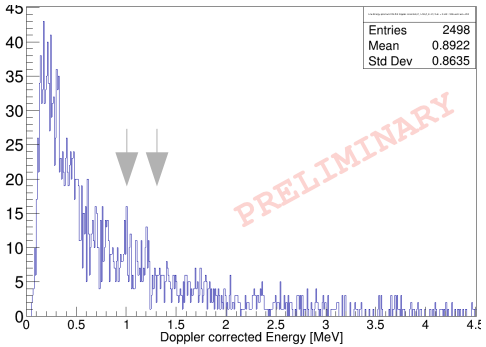


Opening Angle: Experiment-Simulation





→ 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

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung