



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

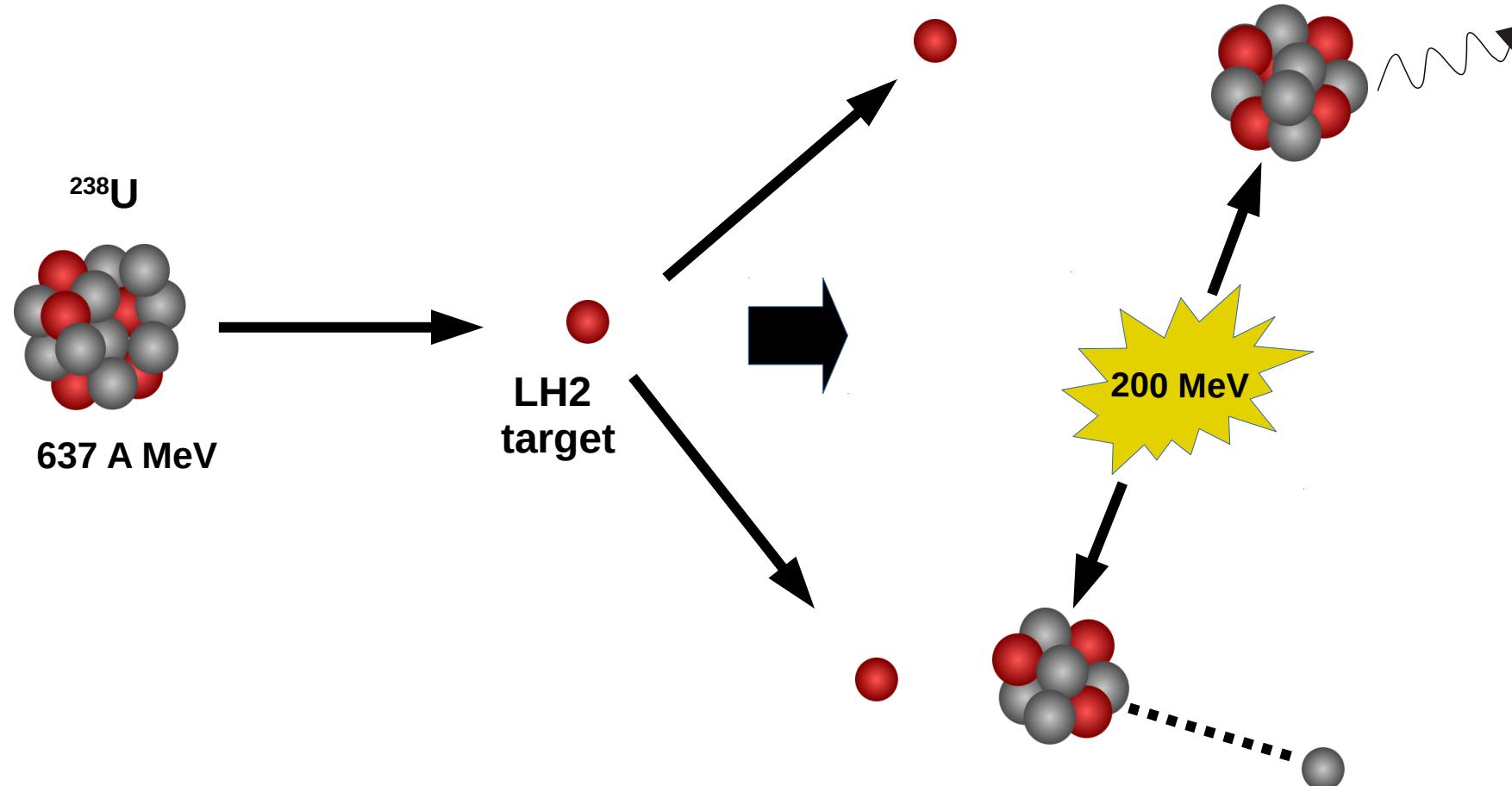
Outlook

TUM Members:
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GEFÖRDERT VOM

Fission induced by Quasi-Free-Scattering



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

Intensity: ~ 5E4 particles/s

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

Total Beamtime: ~ 9 hours

→ ~ 8E5 $^{238}\text{U}(p,2pf)$ events expected

- 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:

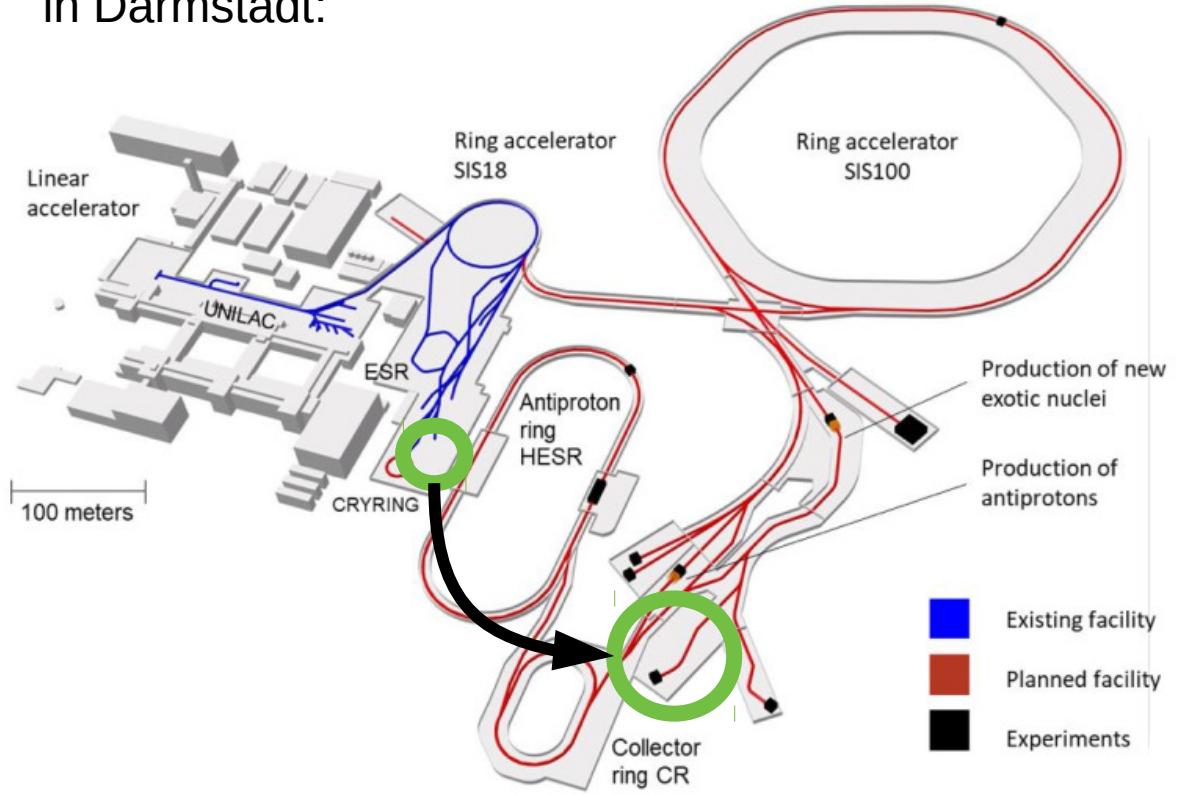
- Complete characterization of the fissioning system is needed (kinematics, PID)



Dedicated experimental setup needed!



R³B as part of the
Facility for Antiproton and Ion Research (FAIR)
in Darmstadt:



Haik Simon – FAIR & Super-FRS – EPS 20190930



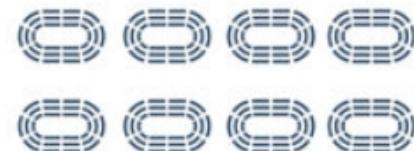
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- 2 mio. m³ of earth excavated
- 600,000 m³ of concrete
- 65,000 tons of steel



5,000 single family homes



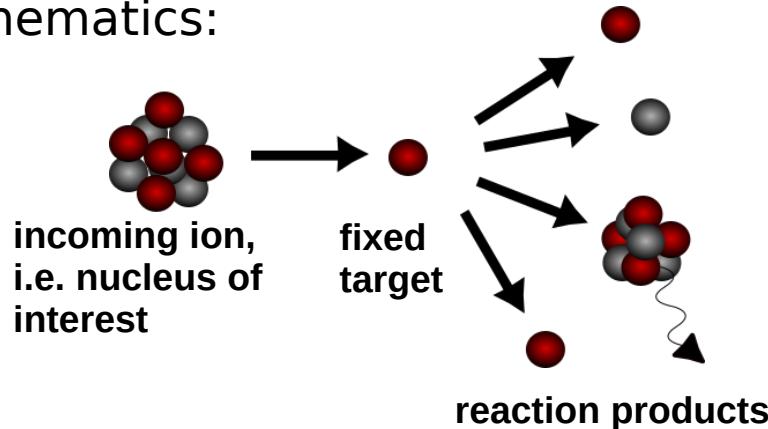
eight Frankfurt soccer stadiums



nine Eiffel Towers

Reactions with Radioactive Relativistic Beams

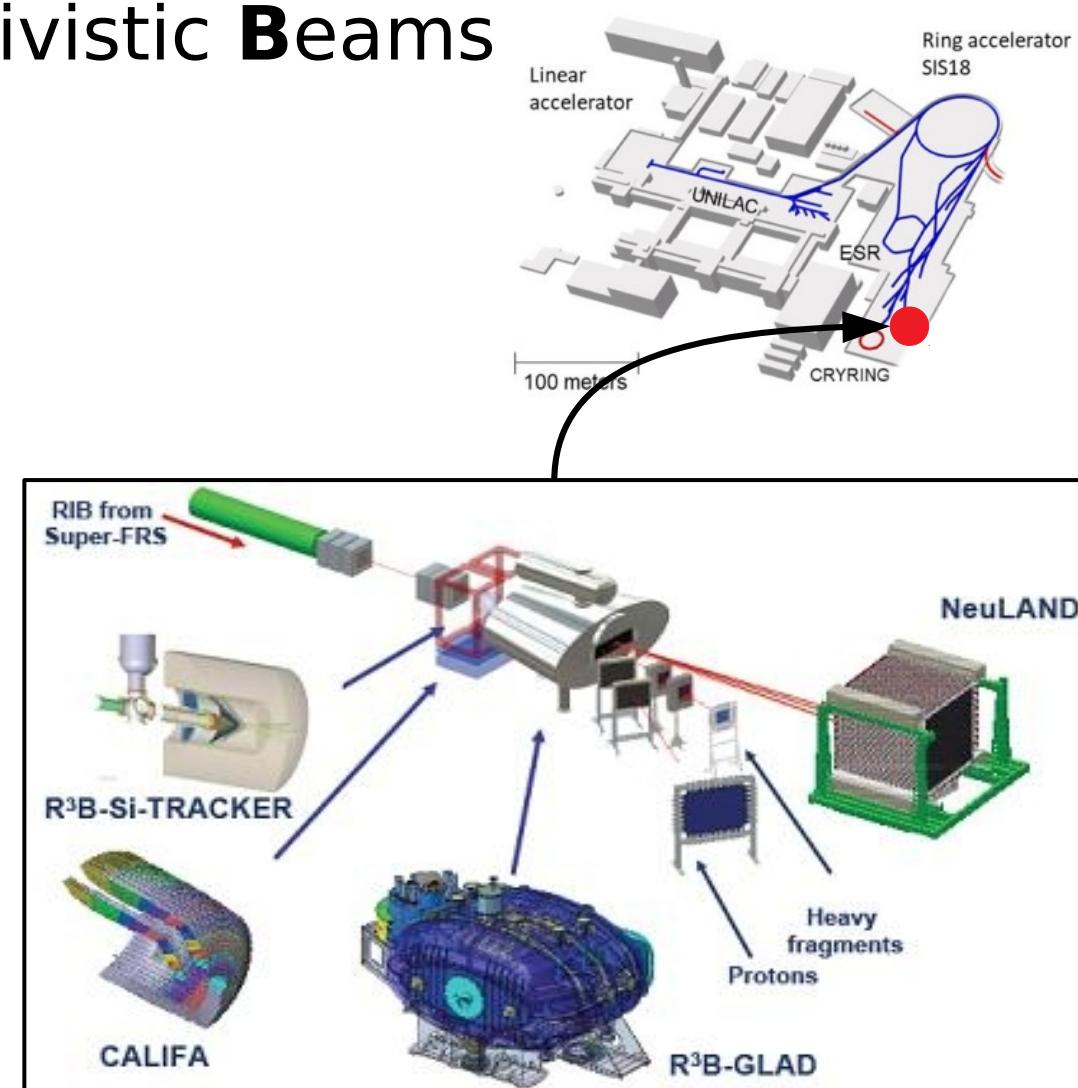
- Physics program on exotic nuclei in inverse kinematics:



- In flight production of exotic nuclei from fragment separator Super-FRS
- kinematically complete measurements**
- Flexible setup, extensive physics schedule
(despite pandemic restrictions)



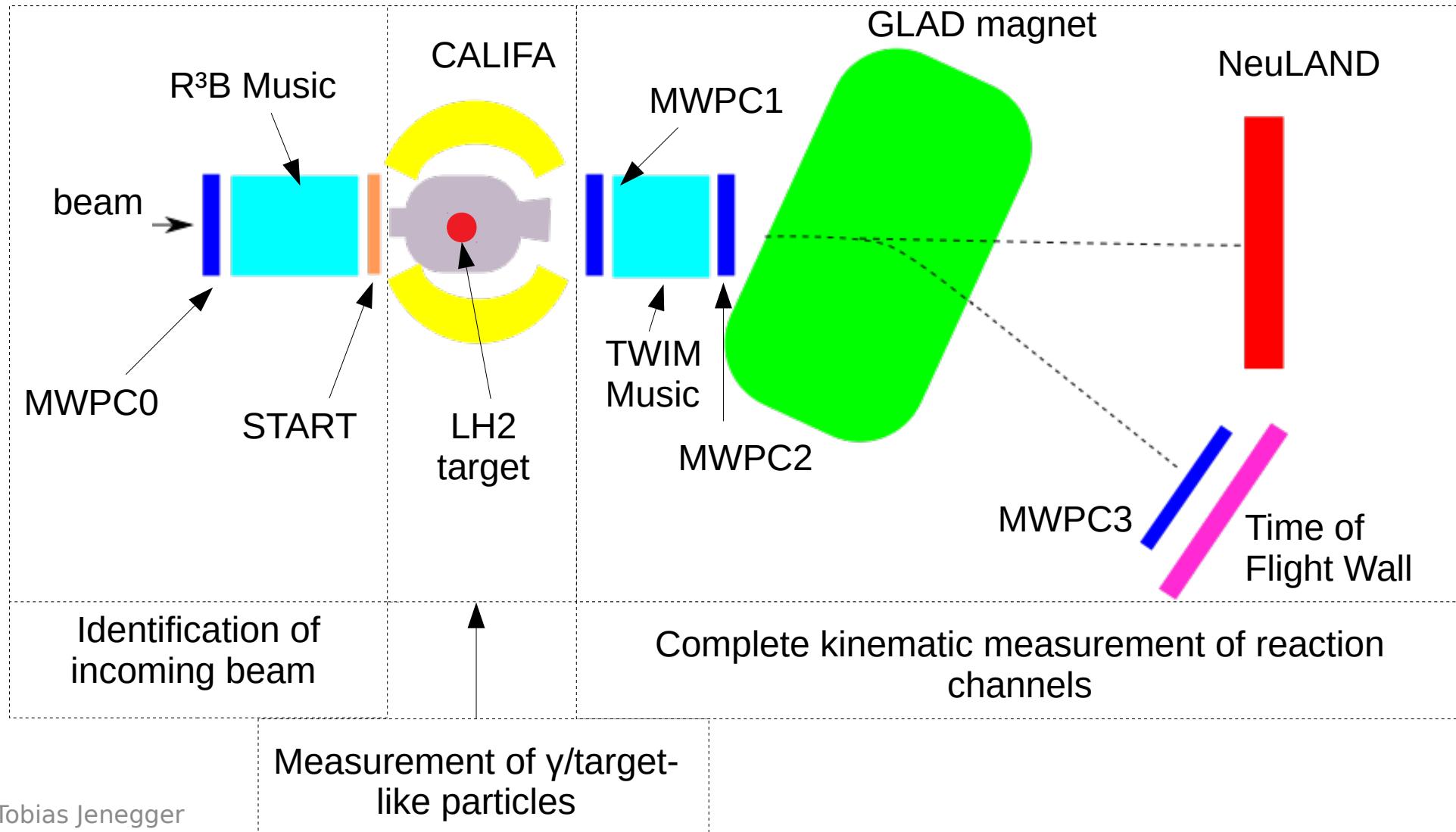
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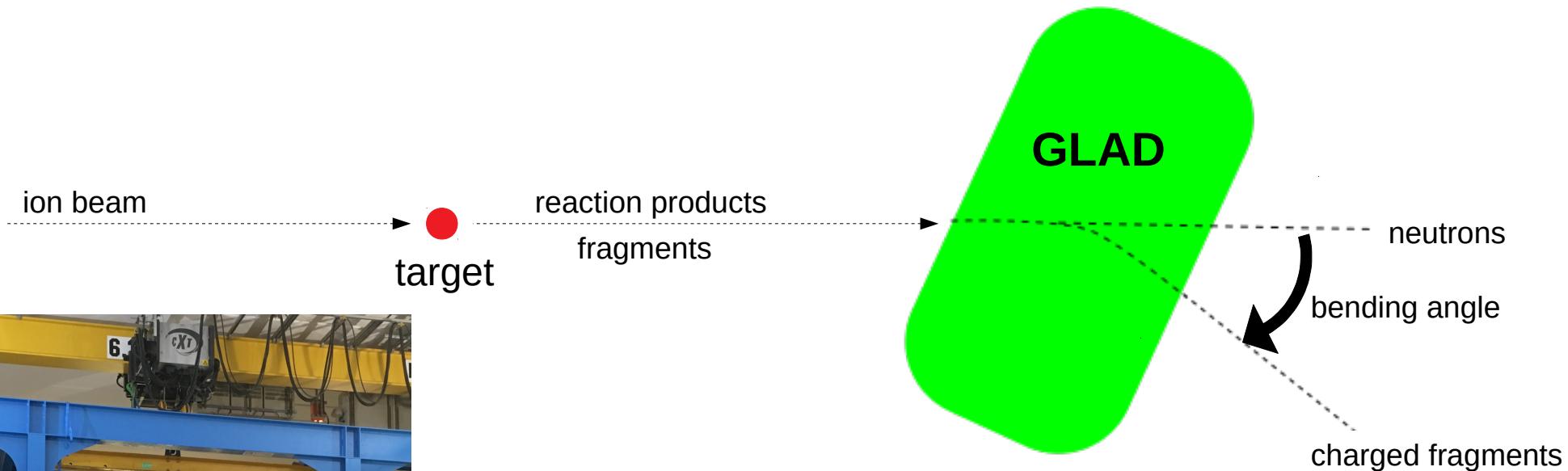
R³B Setup for Pilot Experiments (2021)

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

Target: liquid hydrogen

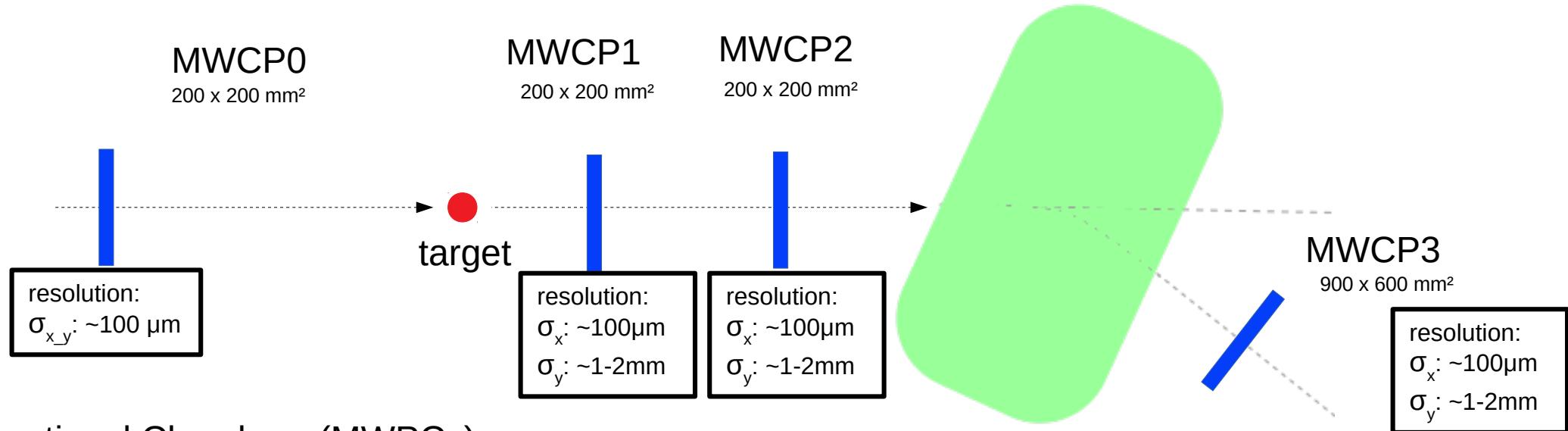


GLAD Superconducting Dipole Magnet



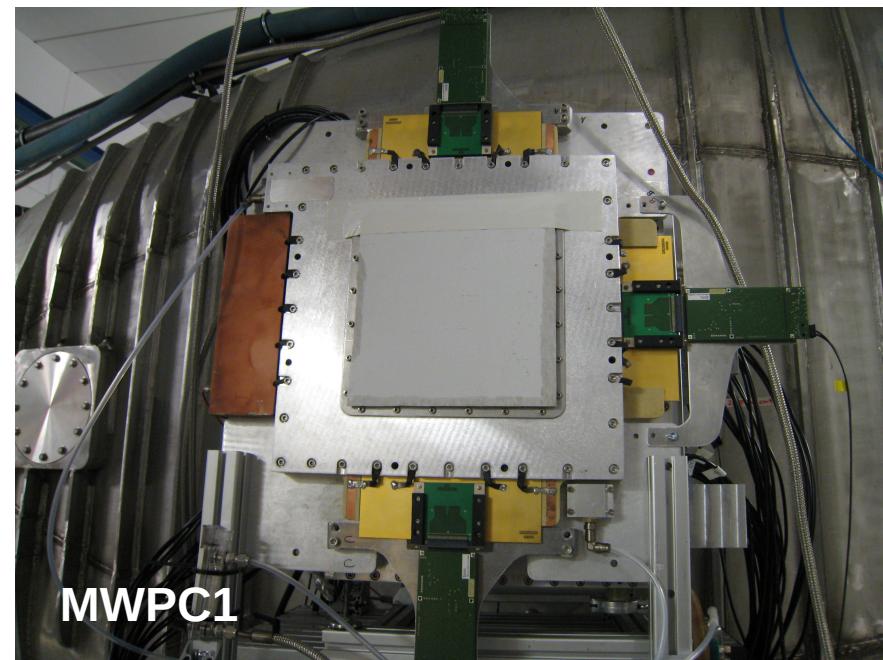
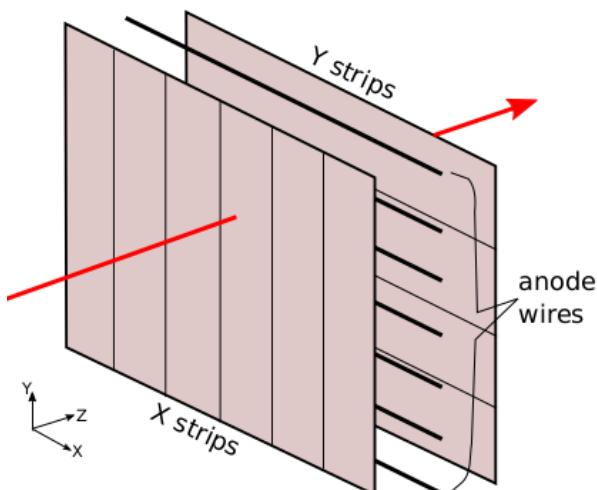
- Mass spectrometer
- large aperture (+-80 mrad) for neutrons
- high bending range from $0^\circ - 40^\circ$
- With tracking detectors: momentum resolution $\Delta p/p$ of around 10^{-3}

Tracking Detectors



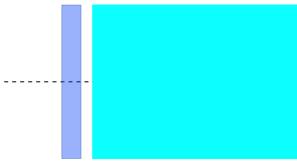
Multi Wire Proportional Chambers (MWPCs):

- 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



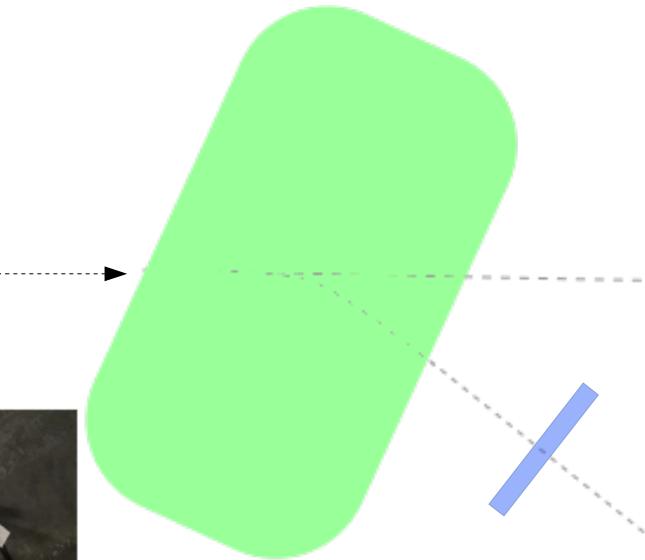
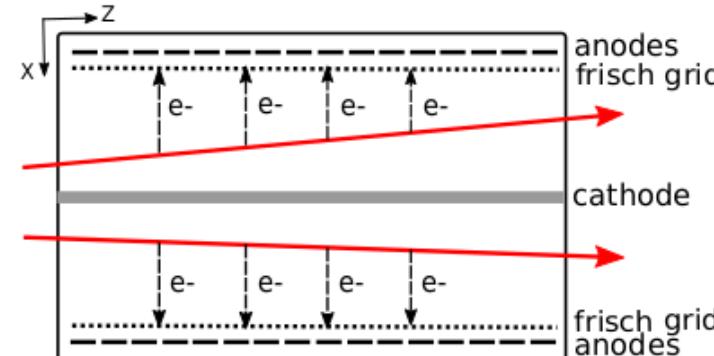
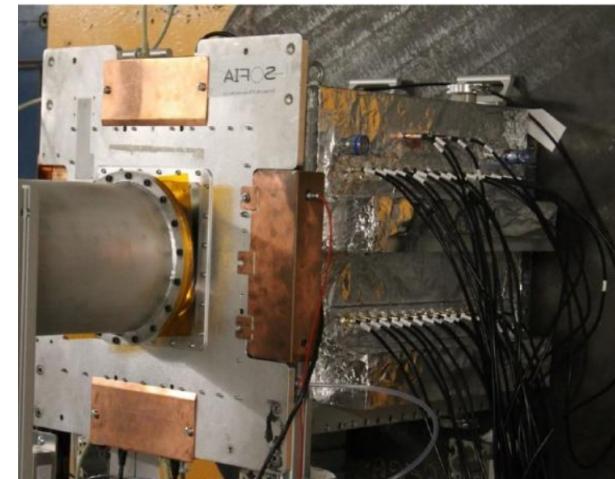
Charge Measurement - Ionization Chambers

R³B Music



43 x 48 x 55 cm³
Double ionization chamber
Frisch grid for better signal quality and time resolution
Gas mixture:
Ar 25%, CH4 75%

TWIM Music



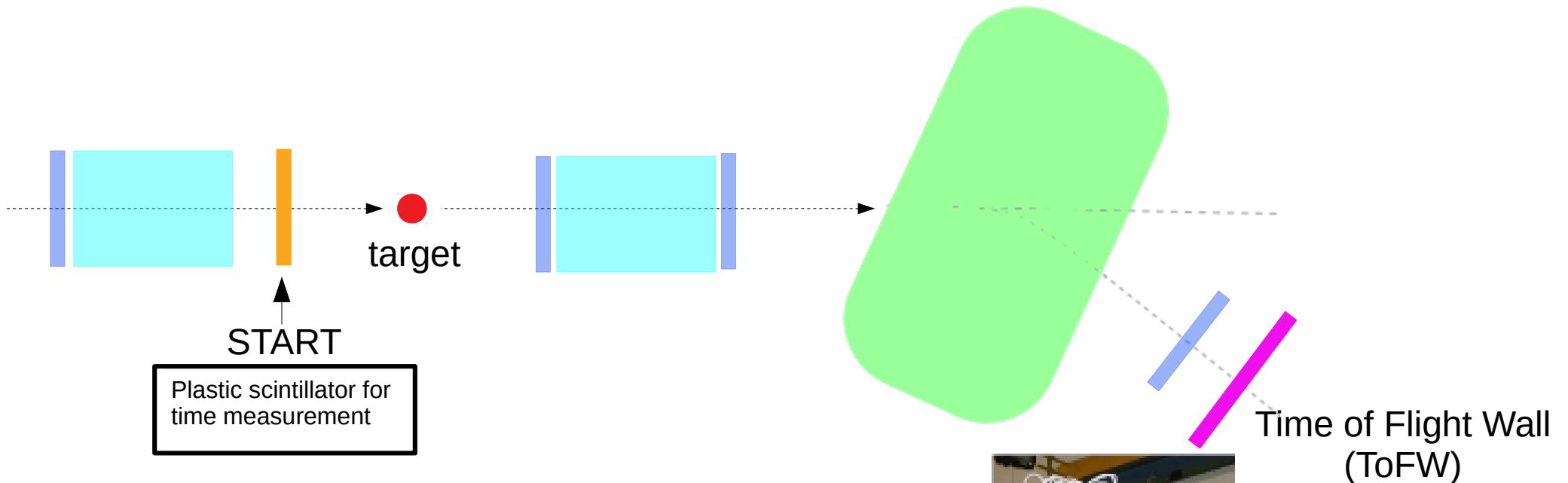
Role of TWIM MUSIC is twofold:

→ charge identification of each FF via energy loss measurement ($\Delta E/E < 5\% \text{ FWHM}$)

→ tracking of the FF ($\Delta X = 40\mu\text{m}$)



Time Measurement – START & TOFW



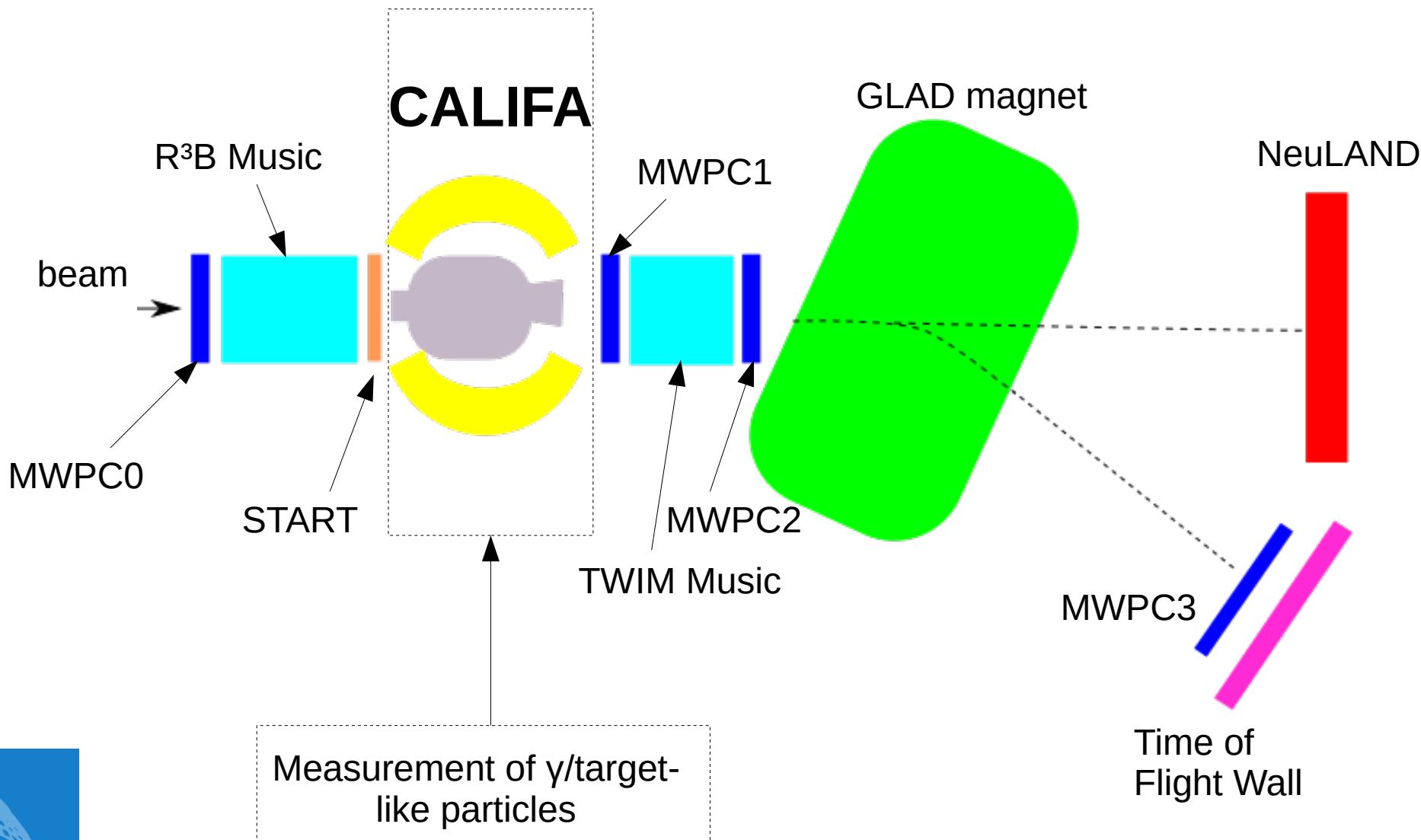
Particle Identification: $B * \rho = \frac{\beta * \gamma * M}{q}$

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



27 vertical scintillators
(each 30 x 600 x 5 mm)
time and position
measurement





CALIFA Detector @ R³B

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

Endcap:

iPhos:

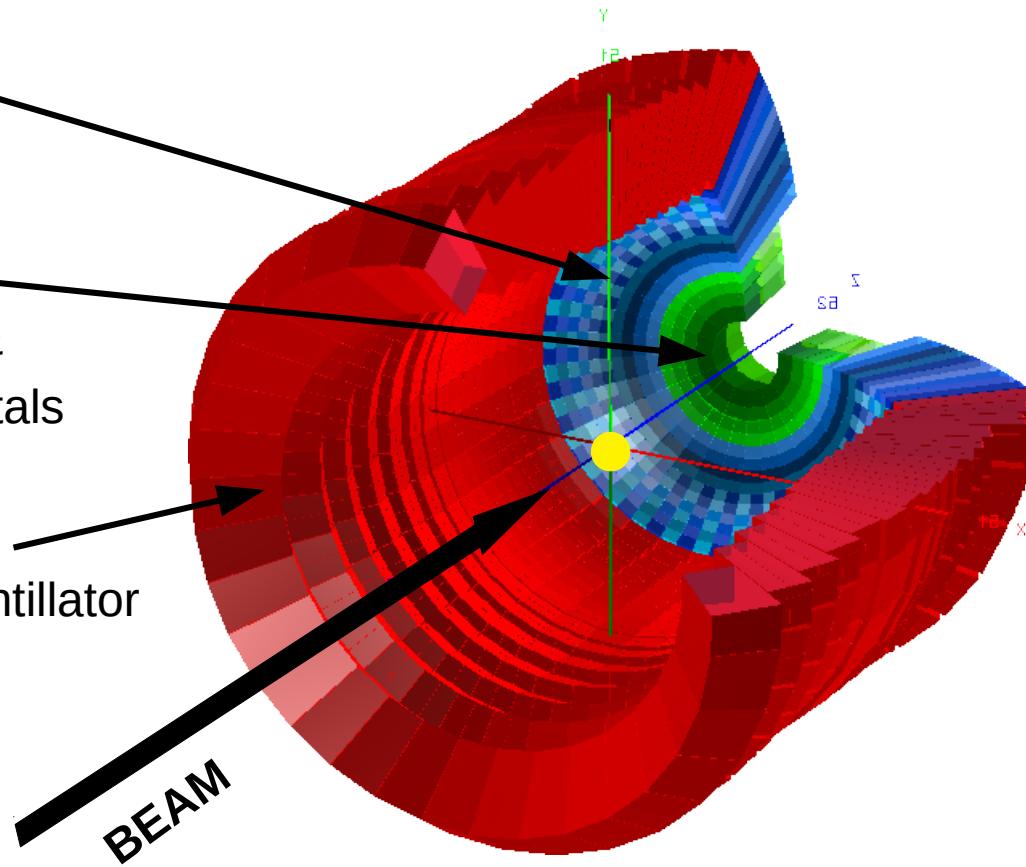
512 CsI(Tl)
crystals

CEPA:

96 LaBr₃ &
LaCl₃ crystals

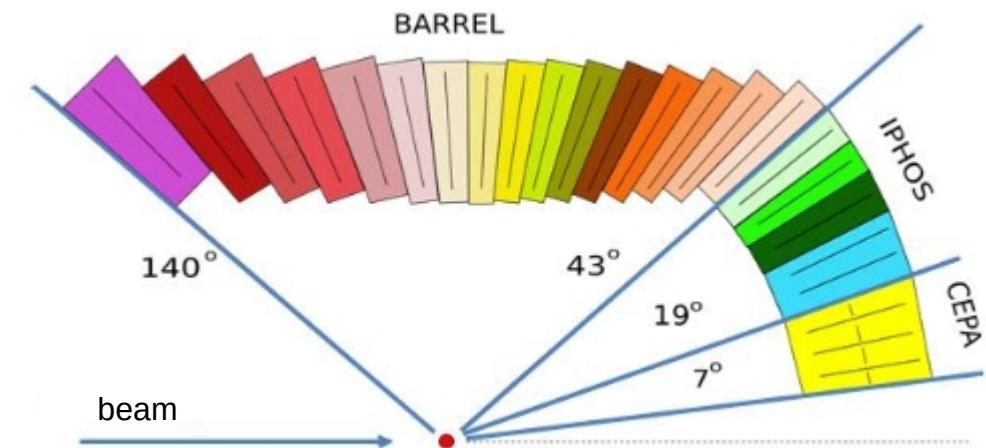
Barrel:

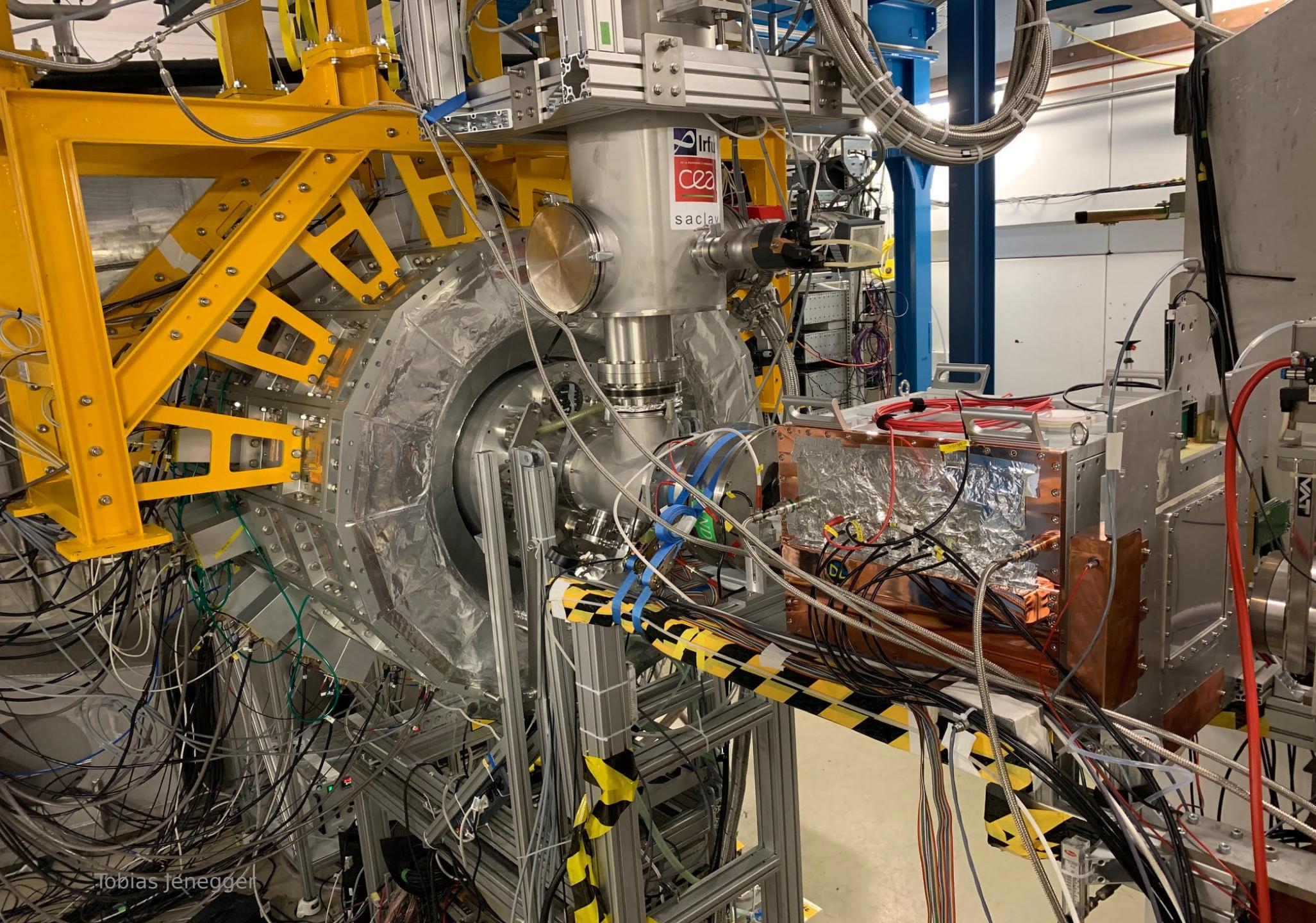
1952 CsI(Tl) scintillator
crystals



Requirements:

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





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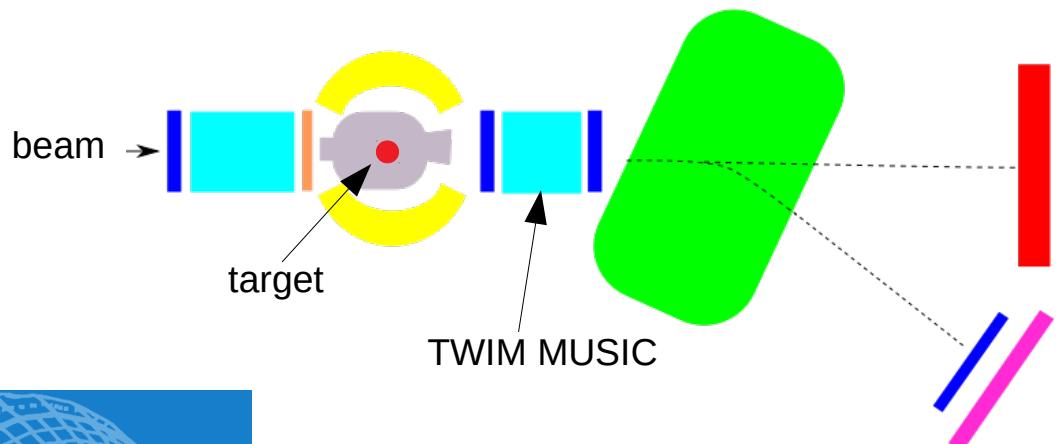
Identification of Fission Process

TWIM MUSIC Charge Identification:

→ two fission fragments (FF)

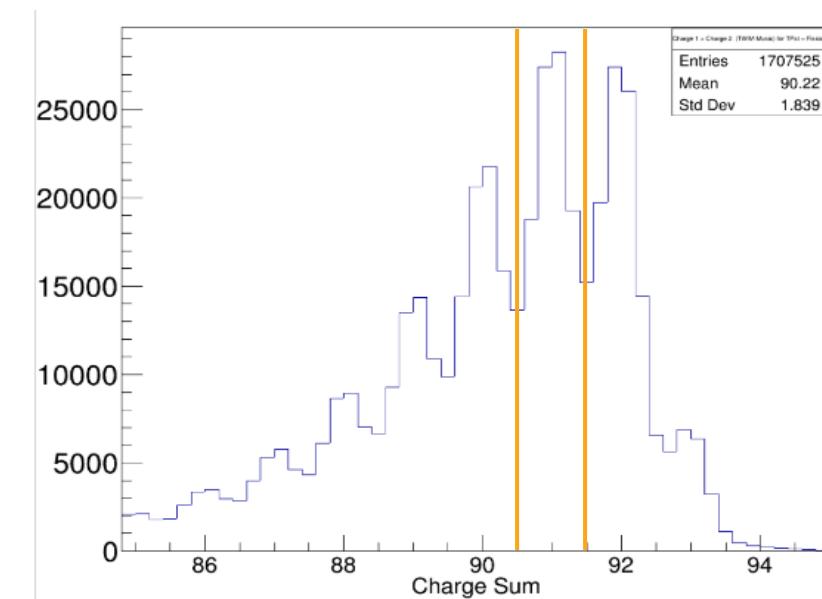
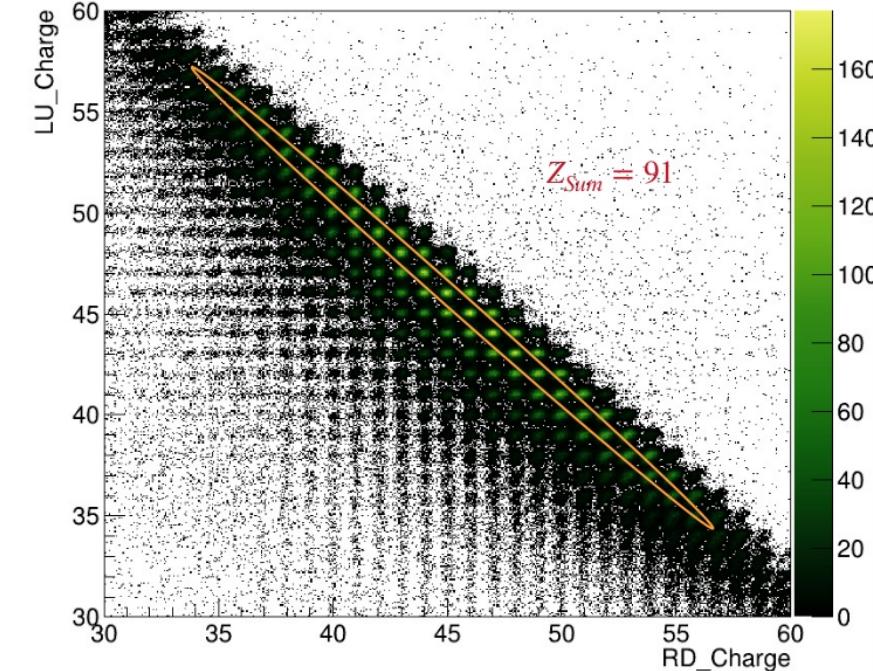
$$\rightarrow Z_{FF1} + Z_{FF2} = Z_{SUM} = 92 - 1$$

quasi-free scattered proton

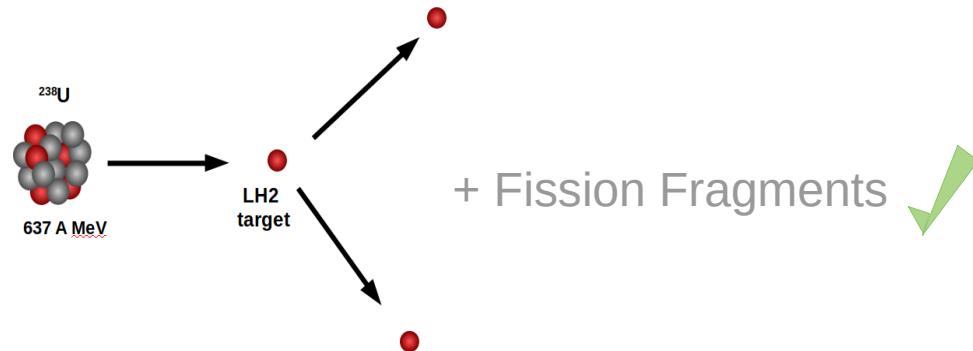


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TWIM: Charge Vs Charge (LU_RD)



Identification of QFS Process



Select events with (p,2p) condition:

- two hits with $E_{p1}, E_{p2} > 100 \text{ MeV}$
- $E_{\Sigma} < 600 \text{ MeV}$
- Coplanarity: $\Delta\varphi = 180^\circ \pm 30^\circ$
- Multiplicity ??
- WRTS??

Insert theta distr
exp.

Insert theta distr. sim

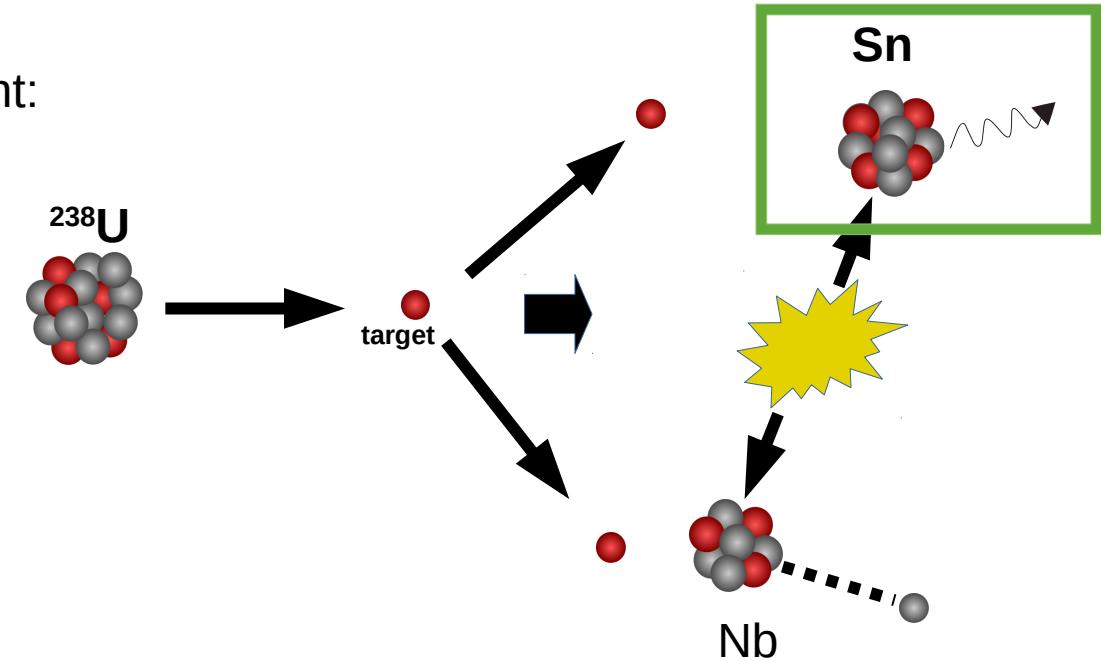


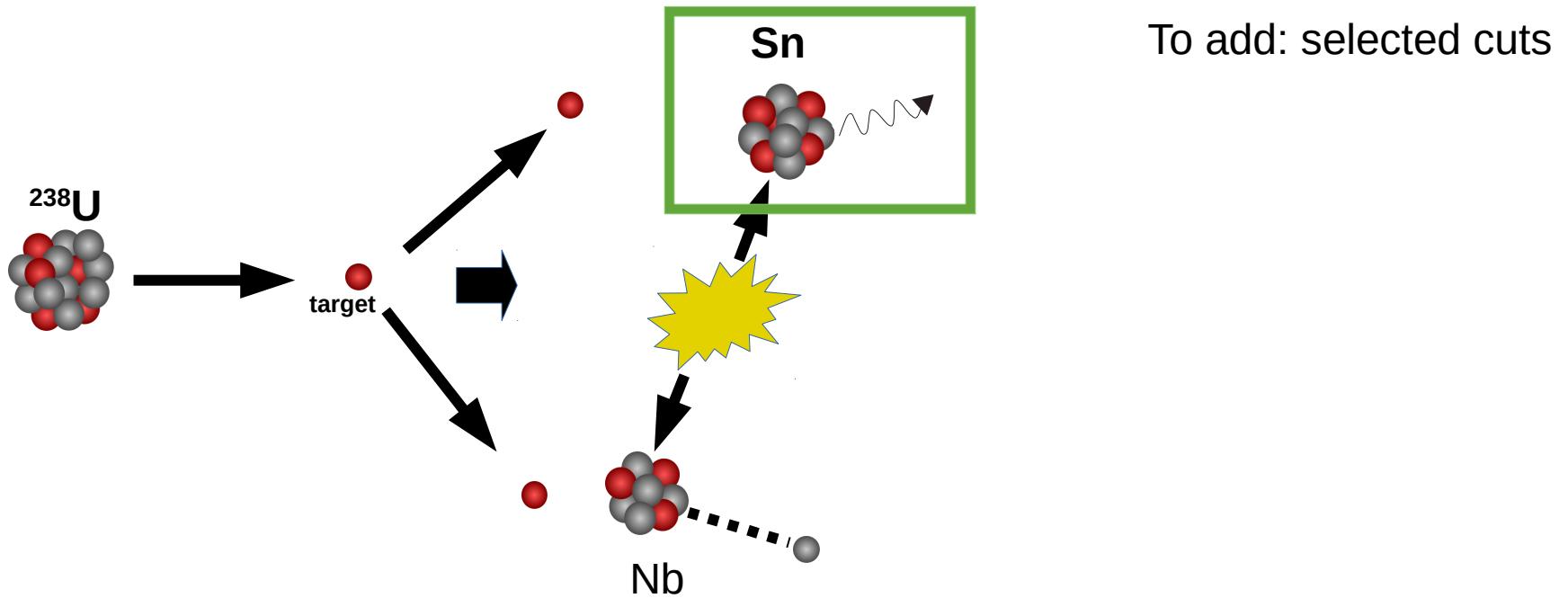
Motivation:

- infer the 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 $J = 2^+$)





Excited Sn states of interest:

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

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





Thank you!

CALIFA @ Technical University of Munich (TUM)

Roman Gernhäuser, Lukas Ponnath, Philipp Klenze, Tobias Jenegger



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GEFÖRDERT VOM



Bundesministerium
für Bildung
und Forschung





Backup

