Commissioning of the Gas Ionizing Reactions Array for Fission Fragments Experiments (GIRAFFE) at FRIB

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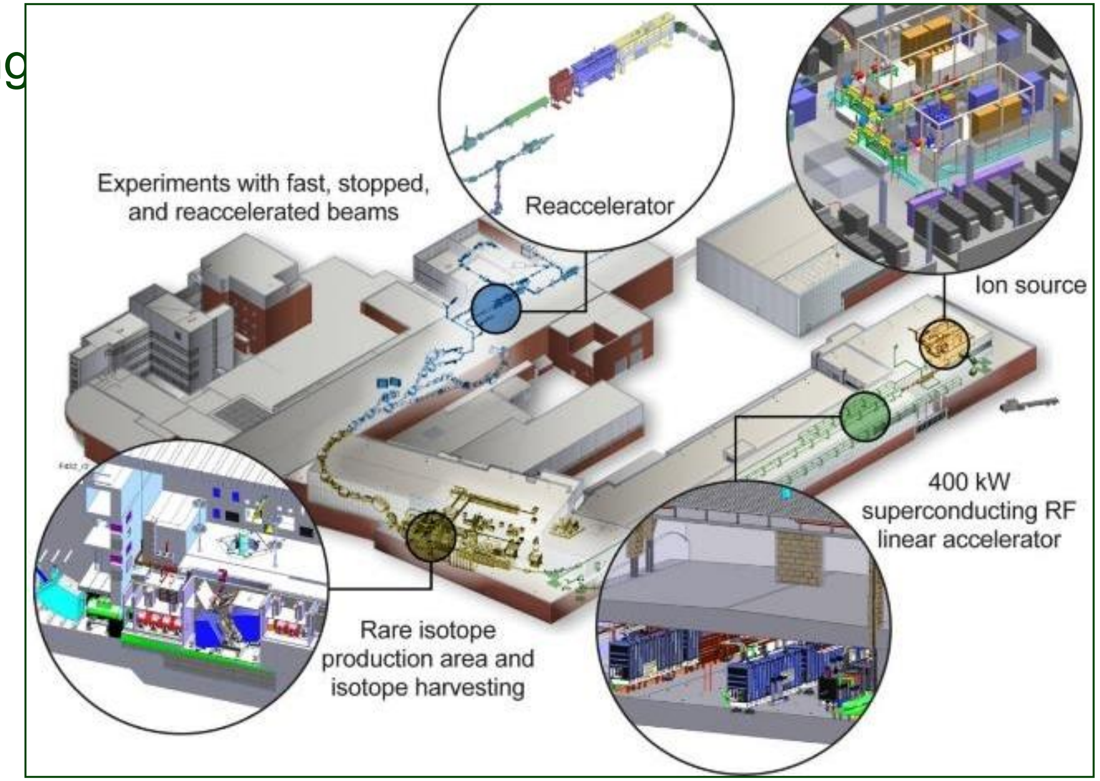
Outline

- Introduction to the Facility for Rare Isotope Beams (FRIB) on Michigan State University campus
- Fission Studies for Super Heavy Elements insight at FRIB
- Micro Pattern Gas Detectors and The Multi-Mesh THGEM for low energy Nuclear Science
  - Development of a prototype detector for Fission Fragment measurements
  - Development and Implementation of a large-area Fission-Fragment position sensitive Detector System
  - Commissioning of the System in the Reaccelerated Beam (Rea6) facility of FRIB
  - First Science Case – preliminary results
- Summary and Conclusions

Facility for Rare Isotope Beams: Low Energy Nuclear Physics

- FRIB: US DOE Office of Science scientific user facility (one of 28) intended to provide beams of rare isotopes
- FRIB's key feature is 400 kW beam power (Currently operating at 20kW with a demonstrated power of 30 kW)
- Experiments with fast (200 MeV/u), stopped (trapped), and reaccelerated beams (0.6 to 10 MeV/u)
- Separation of isotopes in-flight provides *access > 80% of all atoms predicted to exist in nature*

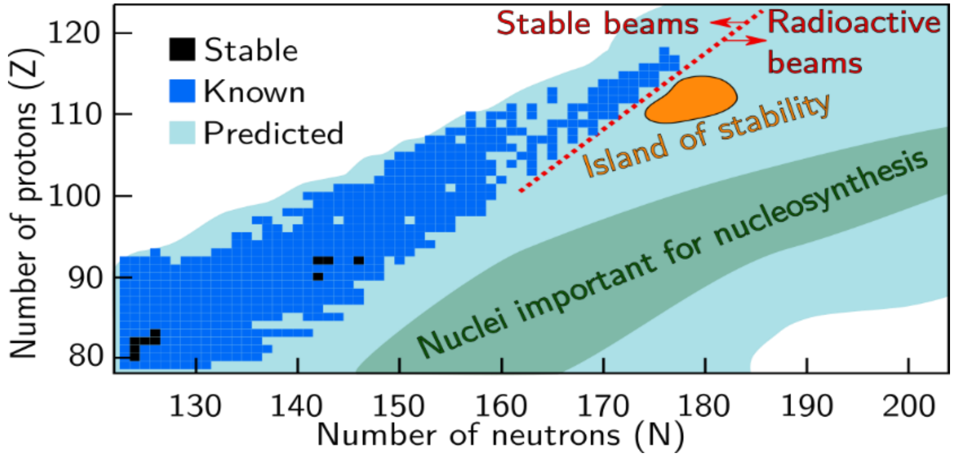
Facility For Rare Isotope Beams – FRIB, MSU

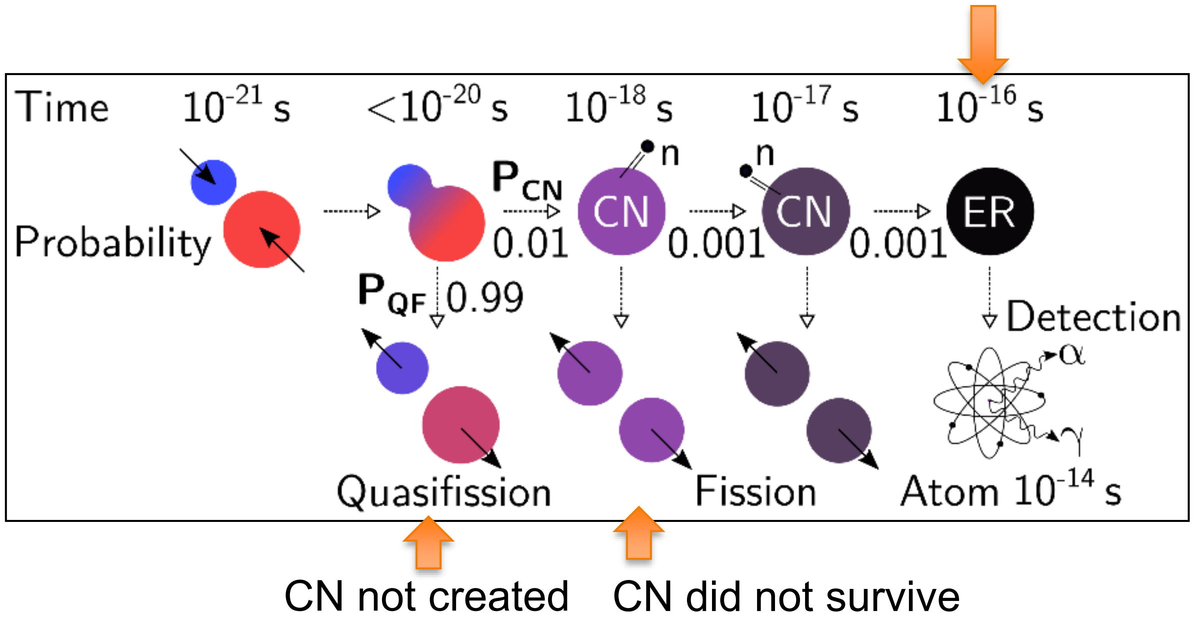


FRIB Science Drivers
- Nuclear Structure and Reactions
- Nuclear Astrophysics
- Fundamental Symmetries
- Societal Benefits and Applications

Synthesis of Heavy and Super Heavy Elements (SHE): The impact of fusion-fission and quasifission on reaction outcomes

- **Goal:** Assess the impact of entrance channels on Fusion-Fission (FF) and Quasi-Fission (QF) probabilities, in particular the N/Z asymmetry (neutron-richness) and magicity of the projectile vs target.
- **Experiment:** Investigate FF/QF in heavy ion reactions, utilizing the capabilities of FRIB to study novel reactions pair by measuring fragment kinematic observables.

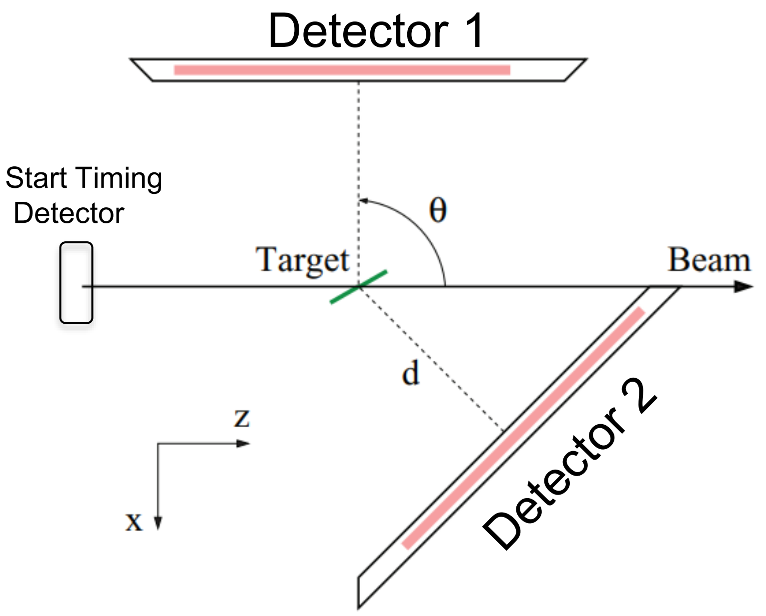




- **Signatures of Fusion-Fission and QuasiFission:**
  - **Reaction time Scale → No way to measure (Theoretical model dependent)**
  - **Mass distribution of Binary Fragments → Derived from coincident time of flight measurement**
  - **Angular correlations of the Binary Fragments → Derived from the position measurements (emission angles)**

Understanding SHE synthesis: The path forward at FRIB

- New beams available for neutron rich SHE production investigations:
  - Investigate the impact of Magicity and larger N/Z ratio
  - Study the Shell effects in FF and QF outcomes
  - What reactions have higher capture cross section? And higher CN survival probabilities?



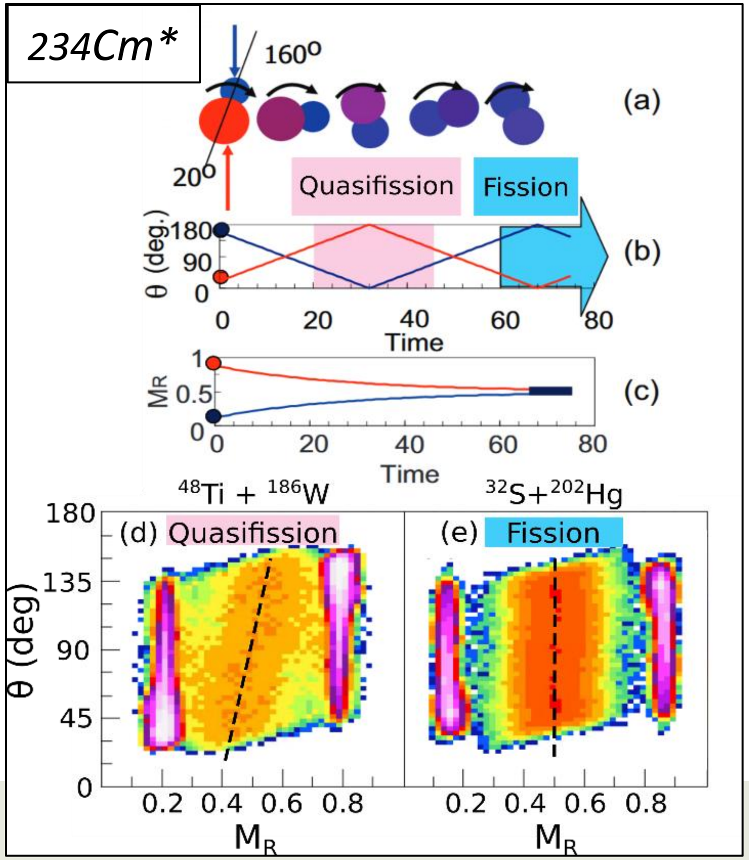
Typical detector system for binary fragment measurements

- Binary Fragments Mass ratio is derived from the measured velocities (i.e. v = d/ToF)

$$M_R = \frac{M_2}{M_1 + M_2} = \frac{V_1}{V_1 + V_2}$$

- Correlation of the MR with emission angle → signatures of FF vs QF

R. du Rietz et al. *Phys. Rev. C* 88, 054618 (2013)

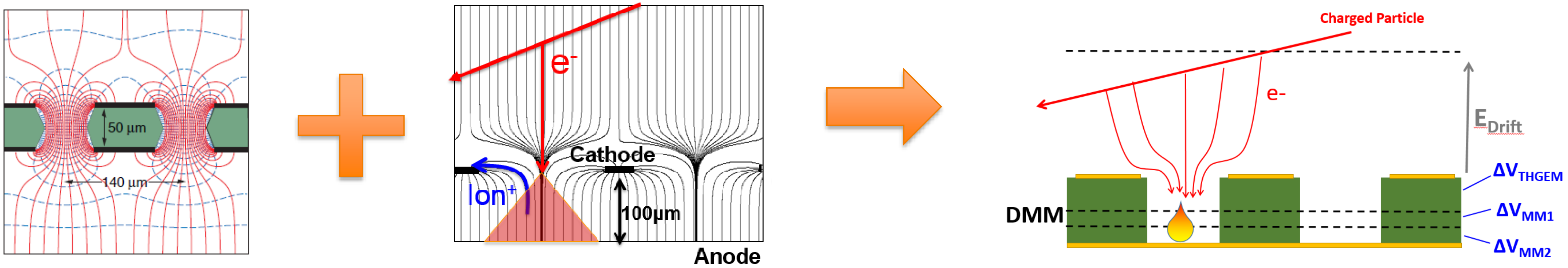


An MPGD for Low-Energy Nuclear Physics: Requirements

- General features
  - Detection efficiency ~100% (high sensitivity to low energy events)
  - Can operate in low gas pressure (with enough gas gain)
  - Versatile: readout with different geometry and front-end electronics
  - Position resolution   ~ 1 mm
- Fission Fragment Detectors based on MPGDs
  - Large angular coverage
  - Low-pressure operation (<15 Torr) ➔ thin windows
  - Good time resolution (< 1 ns)
  - Good position resolution (< 1 mm)

The Multi-Mesh Thick Gas Electron Multiplier (MM-THGEM)

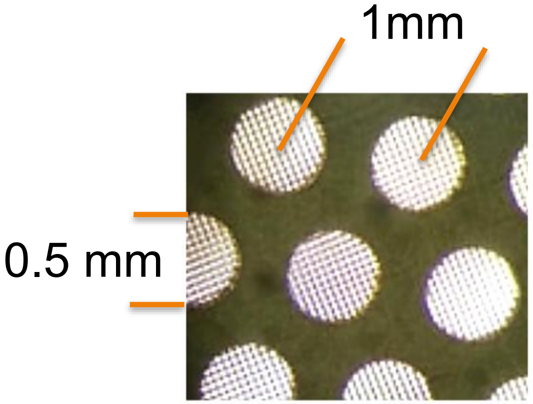
- Concept: Double Micromegas (MM) embedded in hole-type structure as mechanical support



R. De Oliveira and M. Cortesi, 2018 JINST 13 P06019

General features:

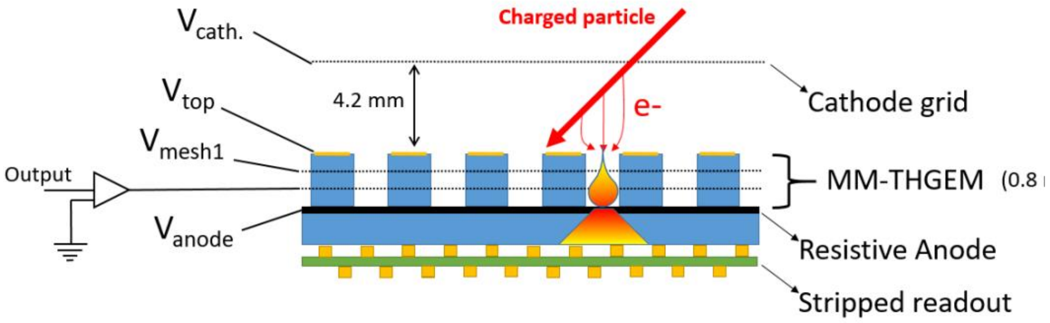
- Geometry:
  - Hole → diam = 0.3-0.7 mm, pitch = 1-1.2 mm, rim < 0.1 mm
  - Thickness (single FR4), like in THGEM (0.2-1 mm)
- Large area double MM over large area (40x30 cm^2 used in this work)
- Multiple amplification stage (uniform field geometry)
- Expected excellent ion backflow suppression
- Mechanically robust
- Can be coupled to reflective photocathode if needed (on top of the THGEM)
- Good performance as Negative-ion TPC readout



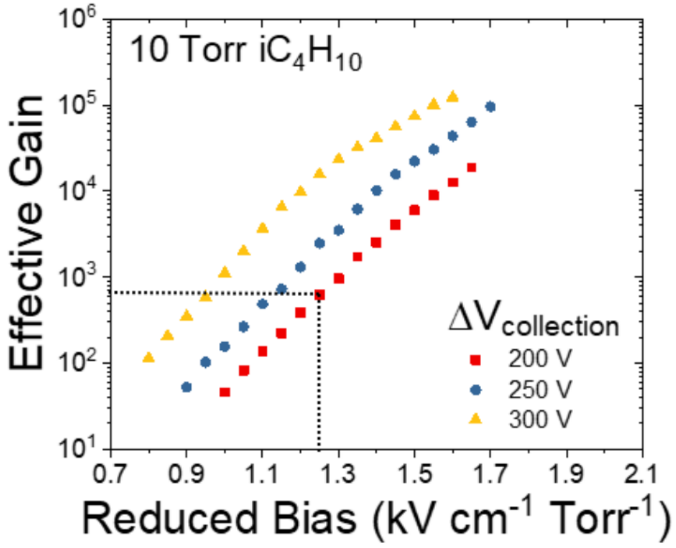
Multi-Mesh THGEM

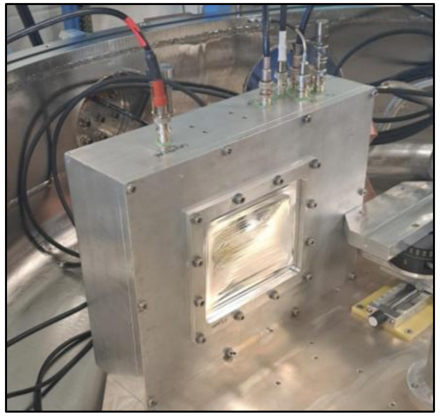
Development of a 10x10 cm^2 Fission Detector Prototype: Gas gain, stability and position resolution

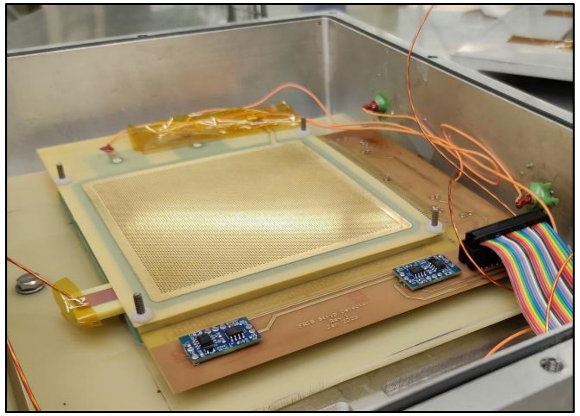
- Detector: 10x10 cm^2 active area, equipped with a resistive readout (DLC. 10 MΩ/☐) + 2D delay-line readout
- MM-THGEM: Hole diam. = 0.5 mm, Hole pitch 1 mm, rim = 0.05 mm,
  FR4 layers: 0.4 mm, 0.2 mm, 0.2 mm.

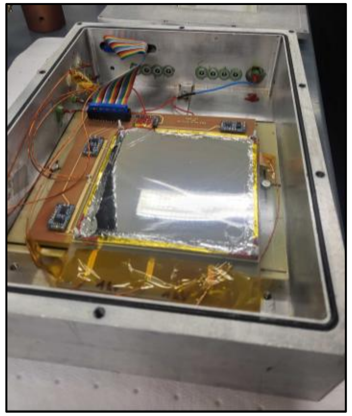


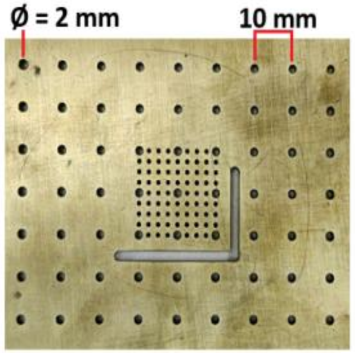
Stable operation at about 10^3 gas gain for FF and position resolution of about 0.5 mm (σ)

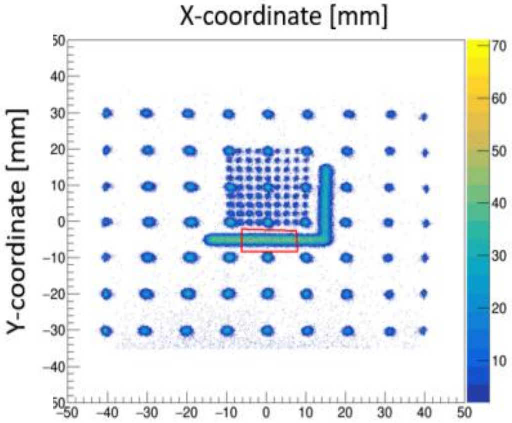










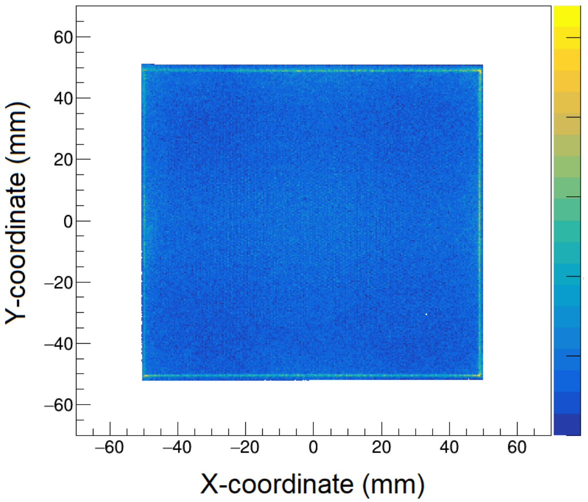


Development of a 10x10 cm² Fission Detector Prototype: ToF and Mass Reconstruction of Fission Fragments

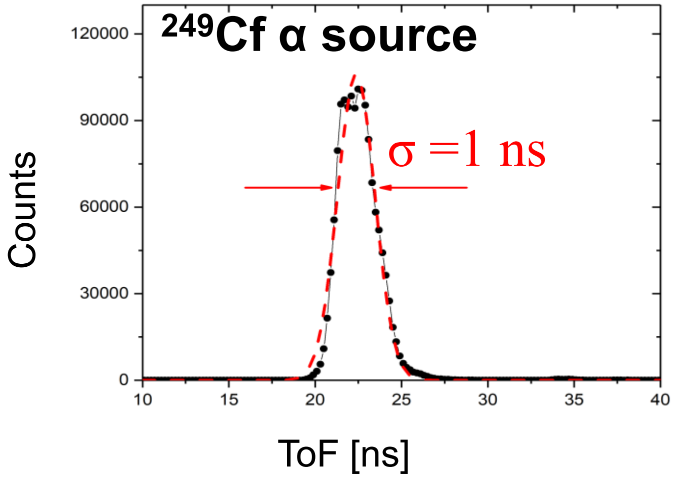
Summary Performance:

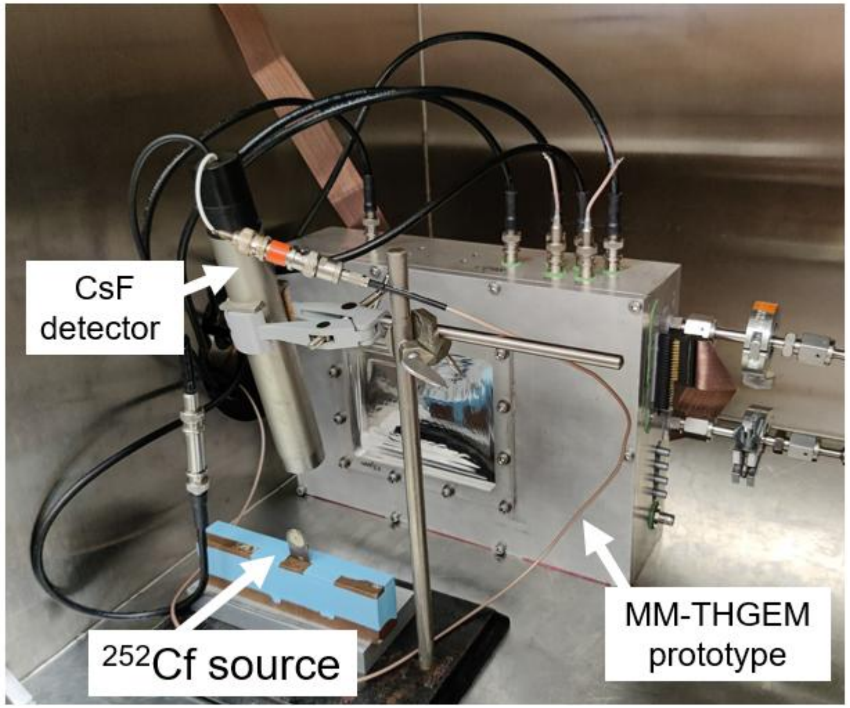
- Stable operation in < 10 Torr iC_4H_{10}
- Uniform gain (>10^3) across the effective area
- Time resolution (ToF) ≈ 1 ns (σ)
- Position Resolution ≈ 0.5 mm (σ)

Good FF detection efficiency Across MM-THGEM area

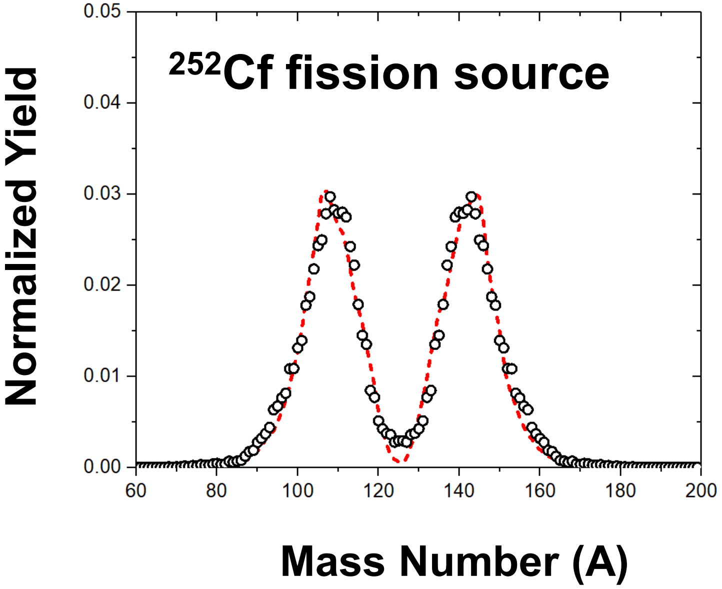


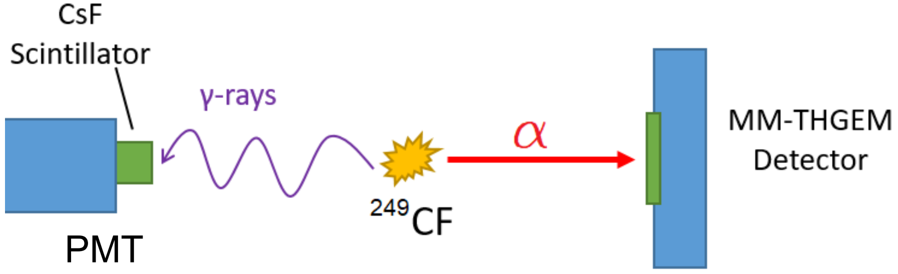
Time Resolution ≈ 1 ns (σ)





The extrapolated mass resolution computed by ToF is 2.3 amu (FWHM) (A≈100-140)





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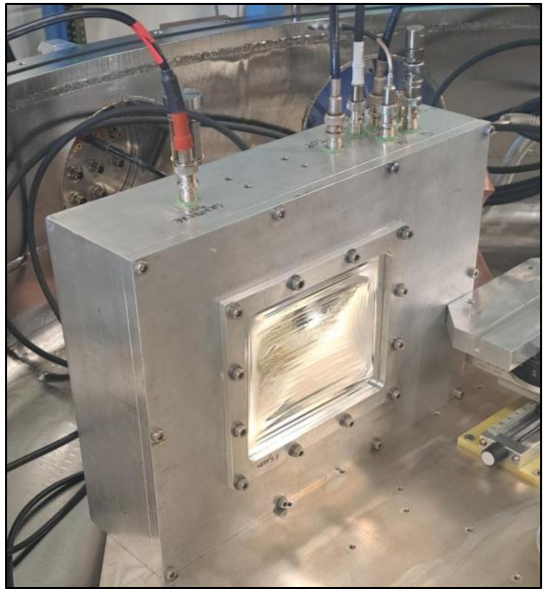
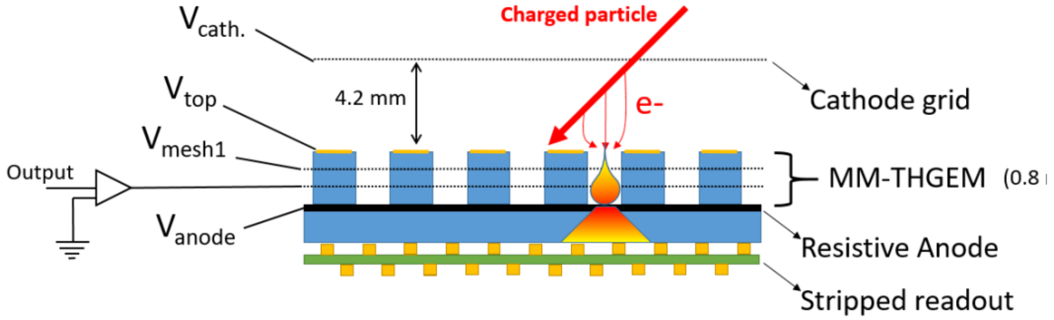
Scale the Prototype to a Large-Area Detector

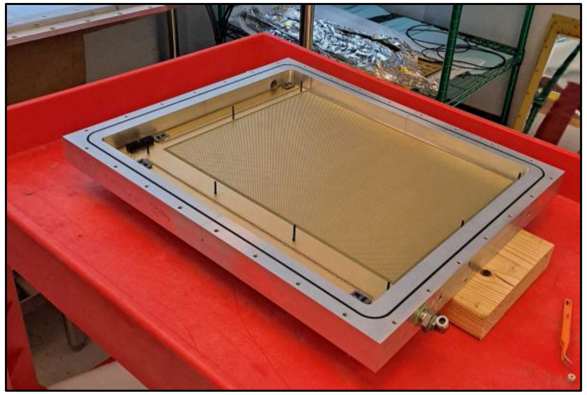
- Scale up the prototype (10x10 cm^2) for Fission-Fragment Imaging Study (40x30 cm^2)



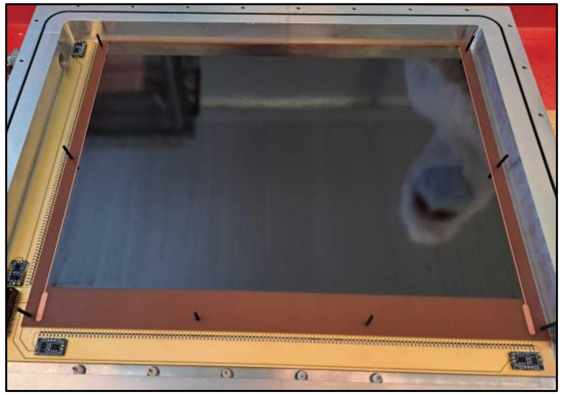
MM-THGEM:
Hole diam. = 0.5 mm
Hole pitch = 1 mm
Hole rim = 0.05 mm
FR4 layers: 0.4 mm, 0.2 mm, 0.2 mm



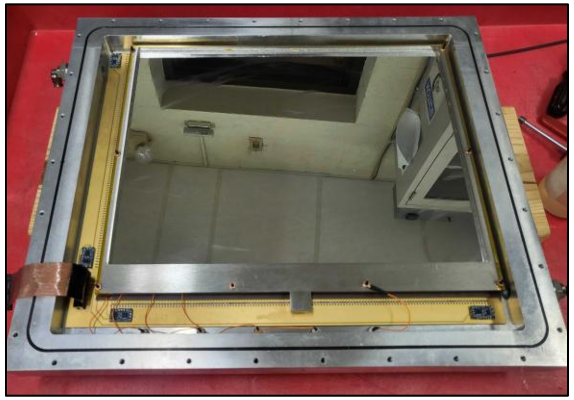
Delay-line Readout



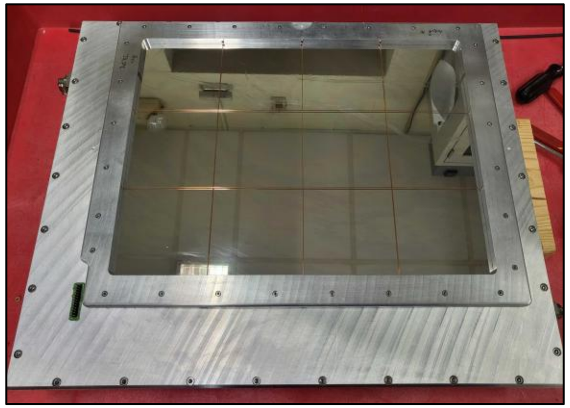
DLC Resistive Anode (10 MΩ/□)



Thin metalized cathode foil



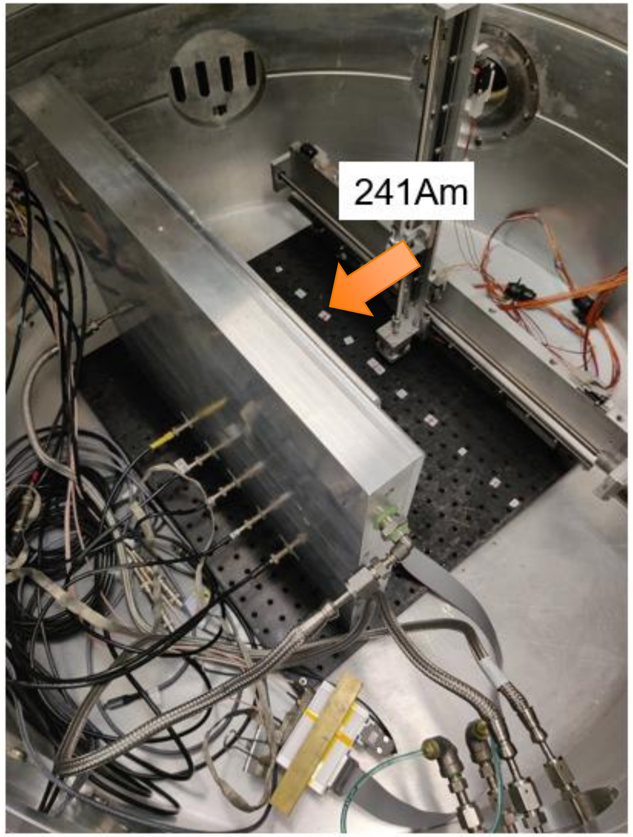
Full Assembly

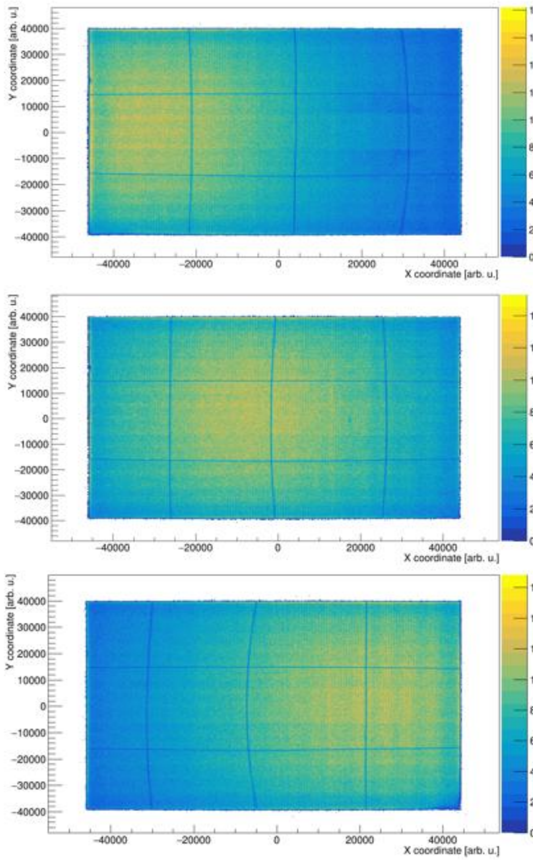


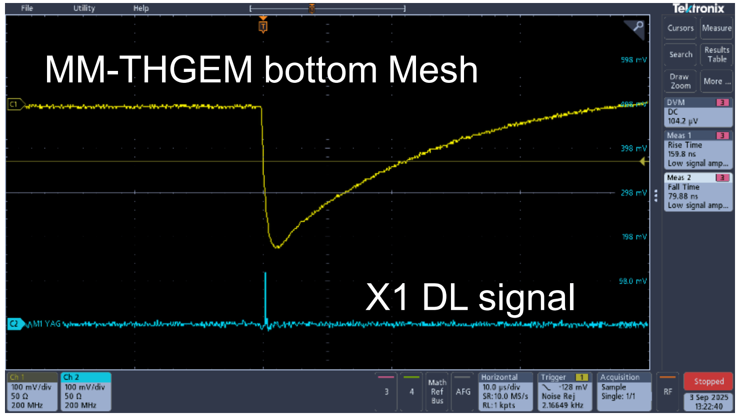
Performance Evaluation with α-Particle Source: Uniformity and Stability

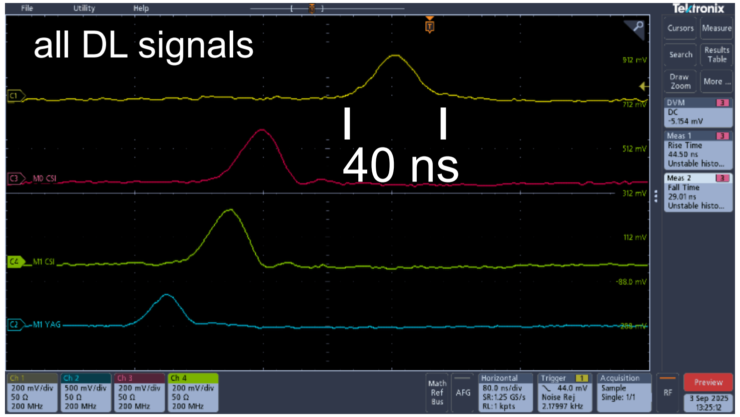
- Large MM-THGEM based detector show performance similar to the small-scale prototype

Operational condition = 10 Torr iC_4H_{10}





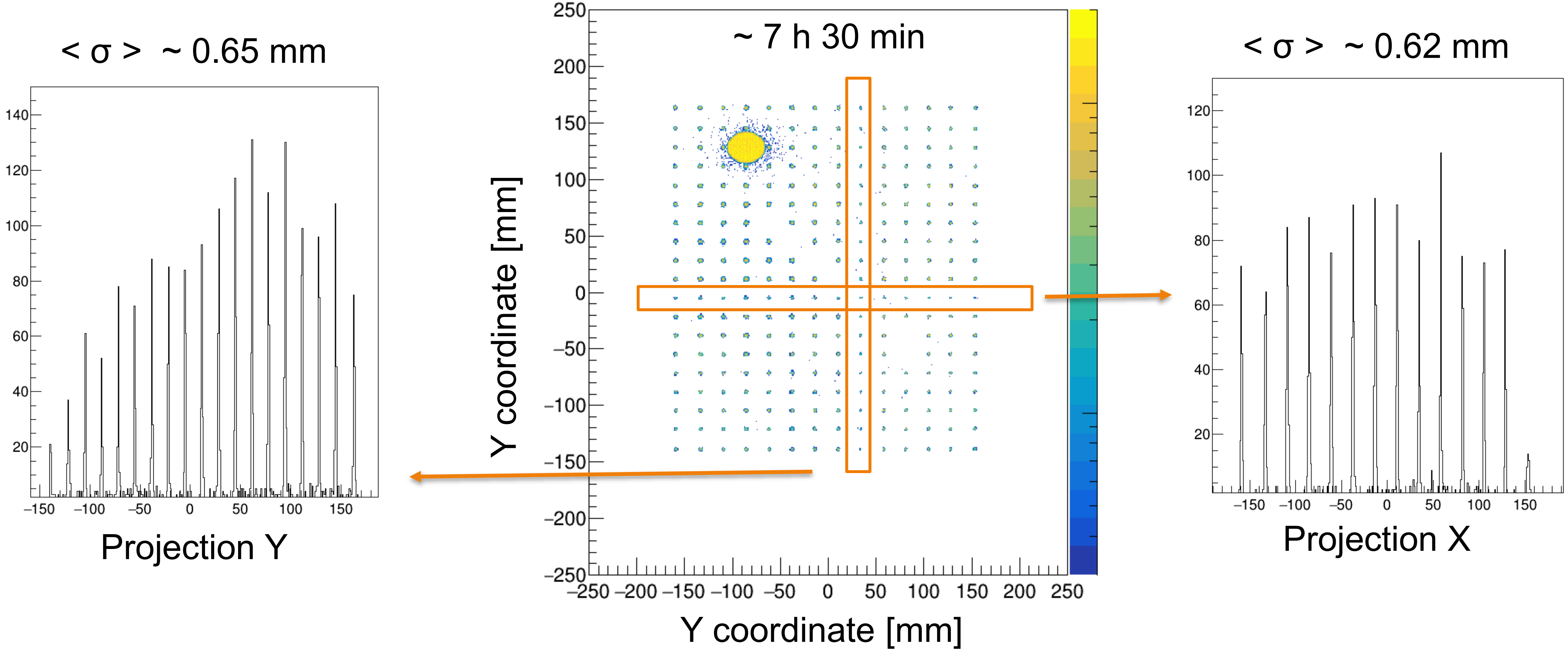




Typical Bias Configuration:
gas-gain ~ 10^3

Layer	Bias applied
Drift Foil	-800 V
Top M-THGEM	-470 V
Mid Mesh	-170 V
Bottom Mesh	Grounded
Resistive Anode	+220 V

Large-area MM-THGEM Detector: Position Resolution



Measured position resolution across the effective area ≈ 0.63 mm (σ)

➔ Expected coincidence angular resolution of the system ≈ 4.5 mrad (σ)

FRIB

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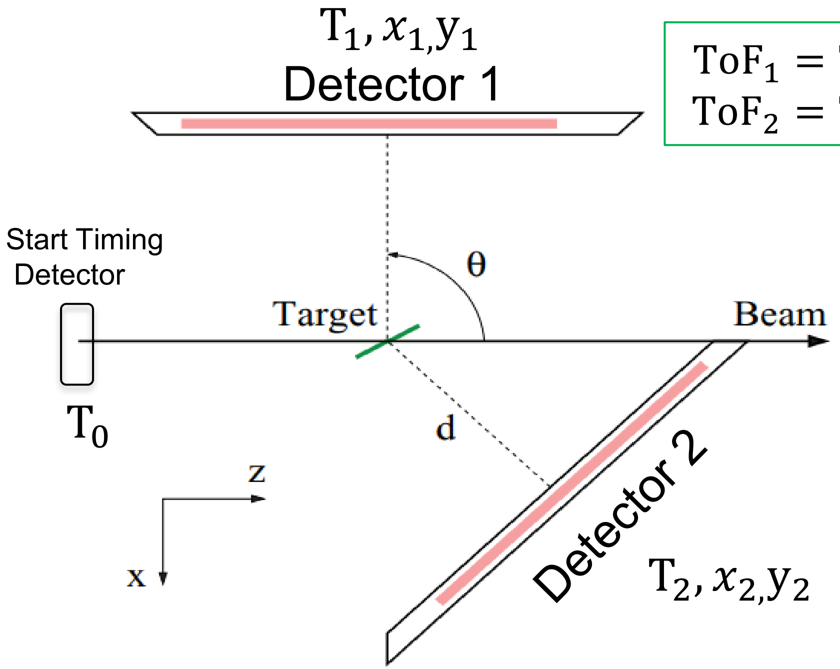
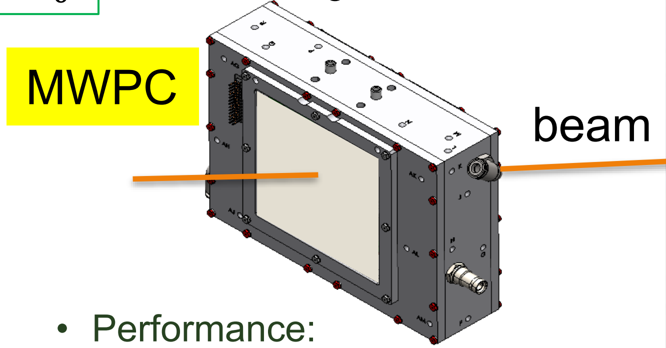
GIRAFFE: The new Gas Ionizing Reactions Array for Fission Fragments Experiments

- Two large-area position-sensitive MM-THGEM detectors around the target → cover complementary θ ranges for binary fragment detection
- One start detector installed at zero degrees upstream (provides the start timing signal T_0 for the Time-of-Flight measurement)
- Kinematic coincidence method used to reconstruct fragment mass ratio (M_R) and center-of-mass angle (θ) from position and timing information
- Two SBS detector are used for beam monitoring and cross section normalization
- Target ladder allows target changes in the vacuum chamber



$$\mathrm{ToF}_1 = \mathrm{T}_1 - \mathrm{T}_0$$
$$\mathrm{ToF}_2 = \mathrm{T}_2 - \mathrm{T}_0$$

DL Multi Wire Proportional Chamber (MWPC)
As a Timing start detector



- Performance:
  - Position → 0.5 mm (σ)
  - Time → 200 ps (σ)
  - Rate → up to 300k pps

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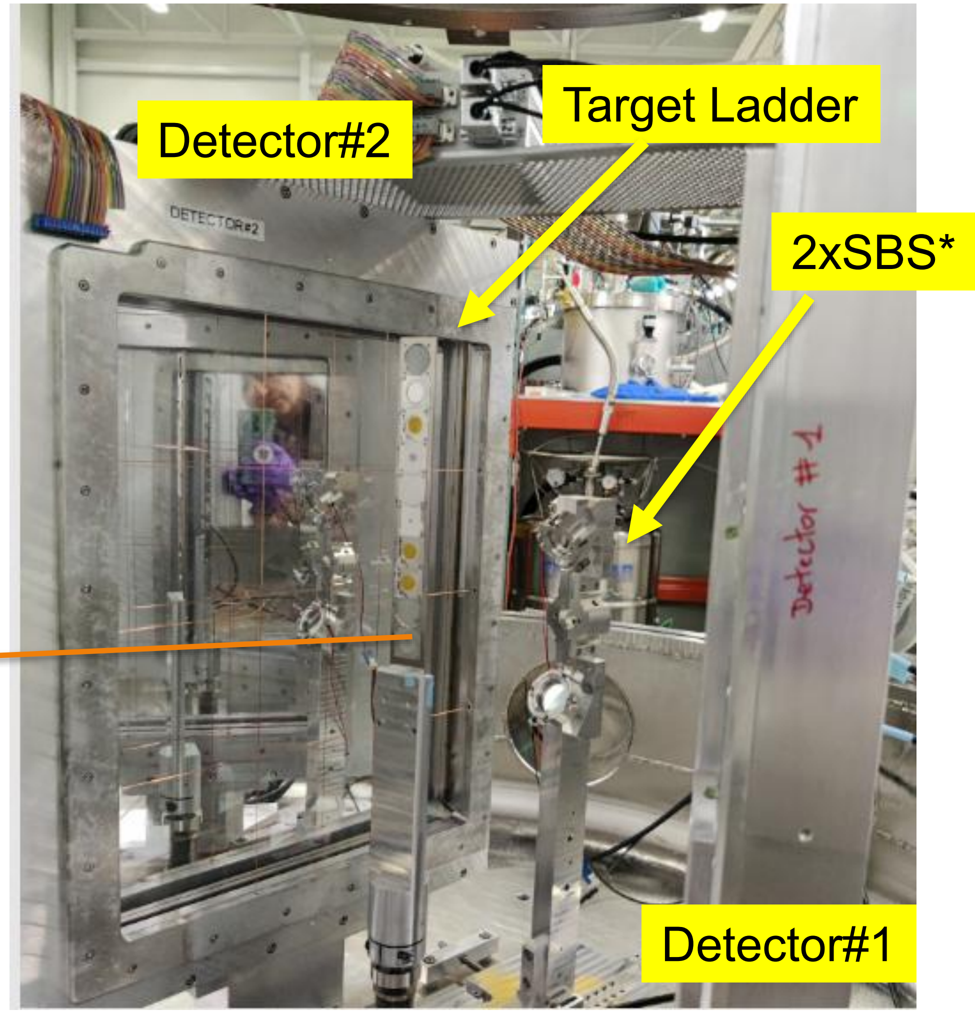
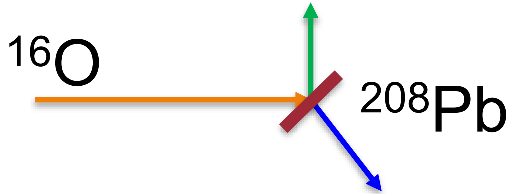
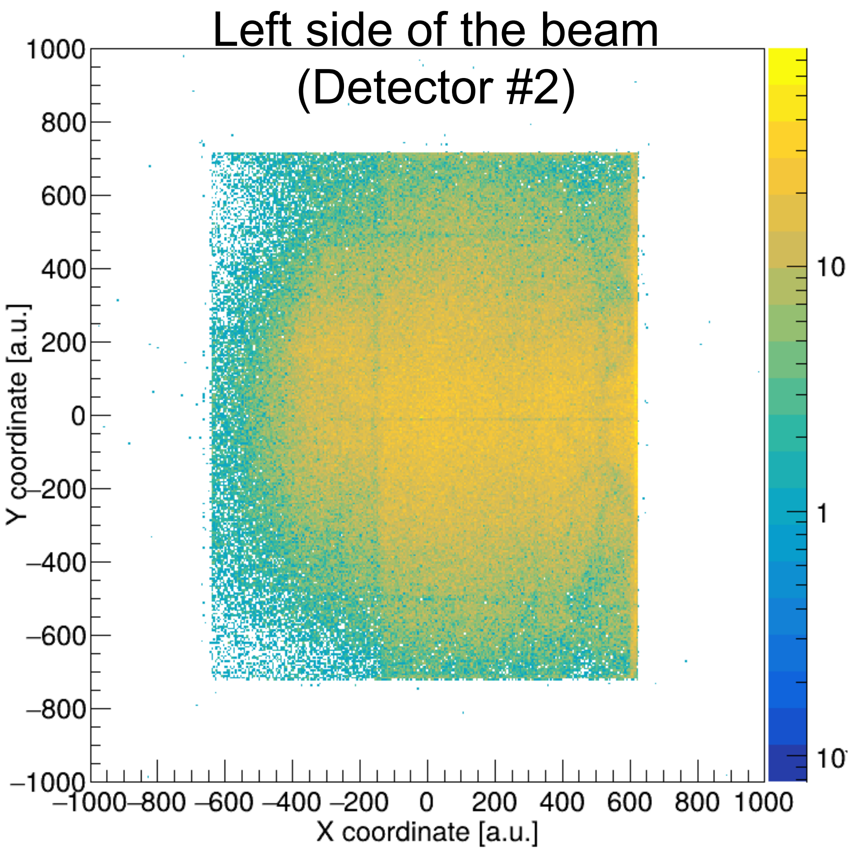


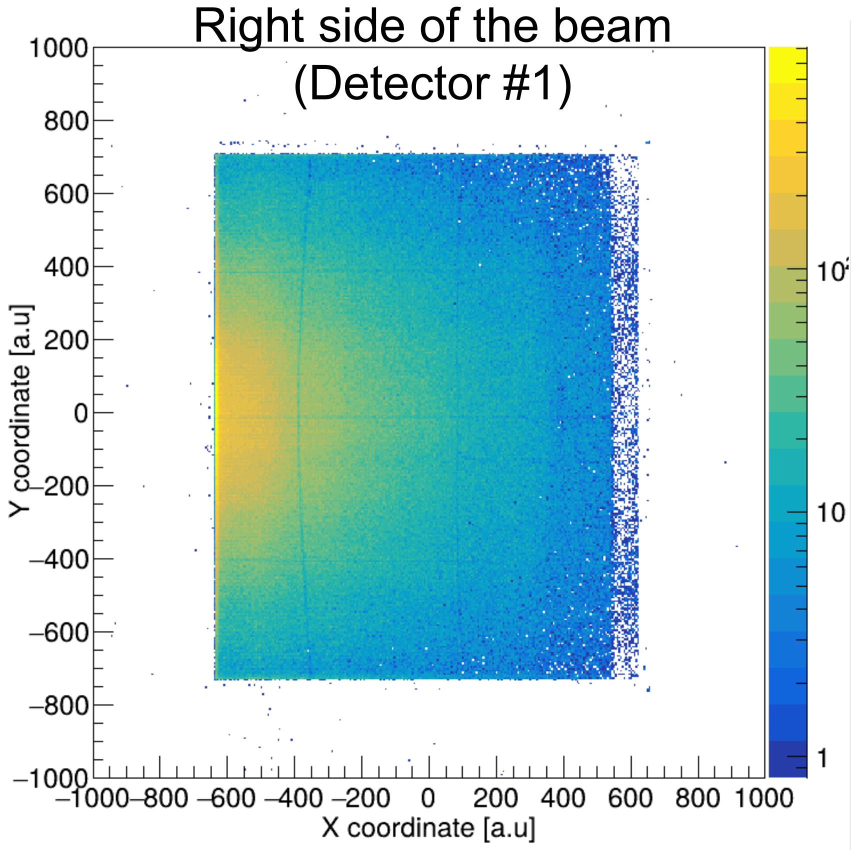
*Surface Barrier Silicon detectors = monitor the Rutherford Scattering events

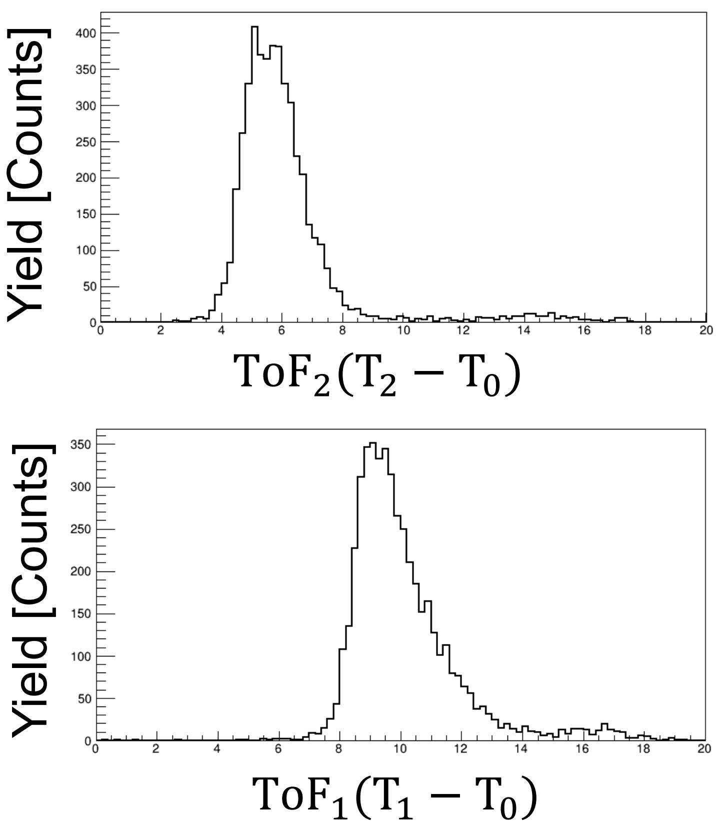
In Beam Commissioning of GIRAFFE: $^{16}O+^{208}Pb$ (E=6.03 MeV/u)

- Verify uniform response of detectors, Check stability over time
- Define coincidence measurement, check DAQ, tweak parameters







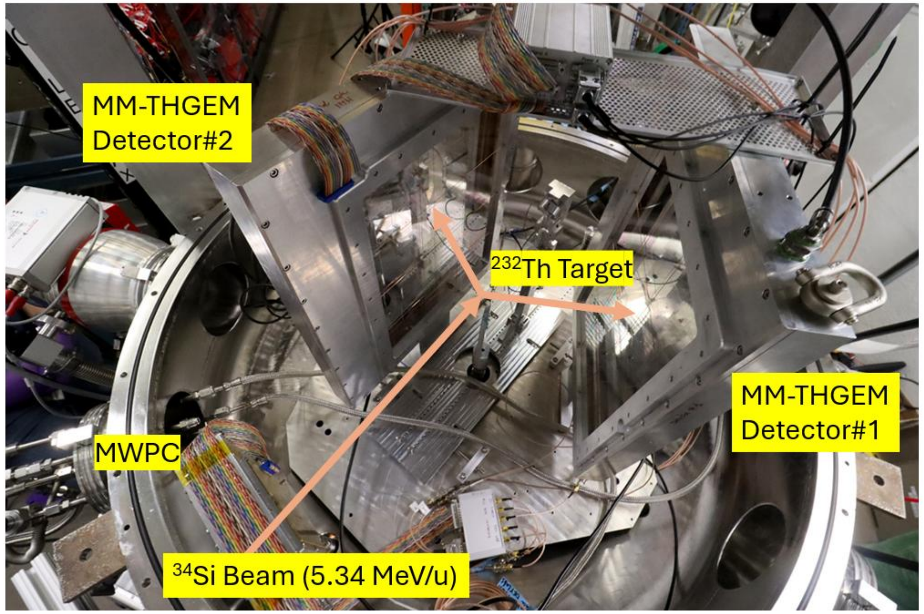


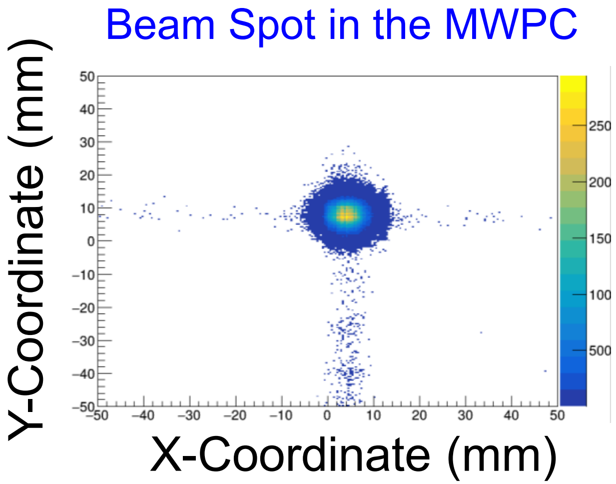
First Science Case: ^{34}Si + ^{232}Th (E=5.43 MeV/u)

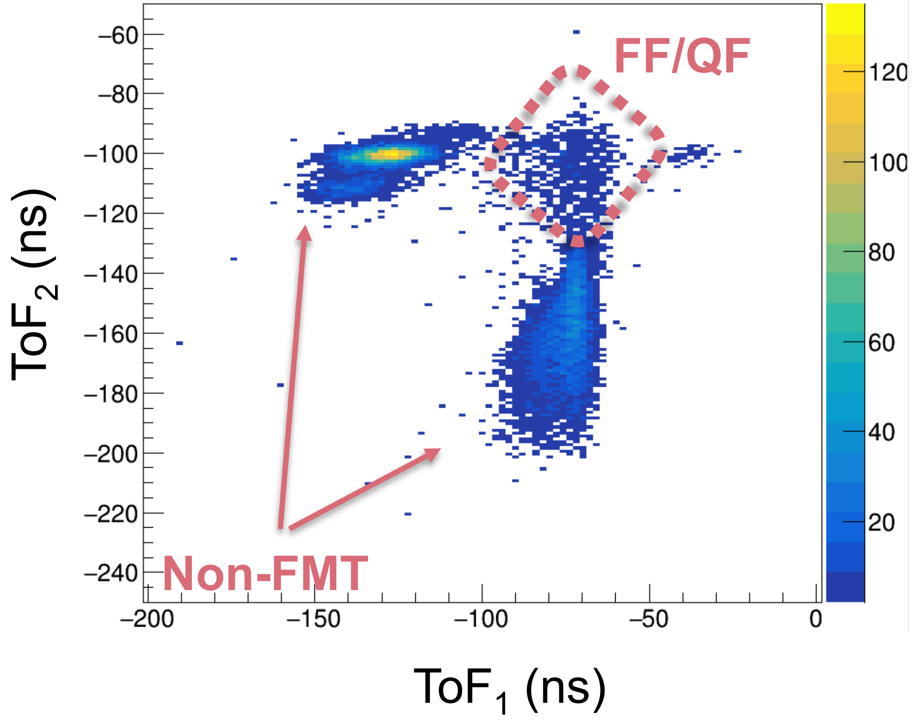
- Reaction identification (Full Momentum Transfer – FMT reactions vs. others) based on coincidence ToF
- Additional mass-angle distribution analysis to disentangle FF from QF reactions.

Preliminary data from ^{34}Si + ^{232}Th → ^{266}Rf* (E* ~68 MeV)
April 2026 run

ToF$_1$: Left MM-THGEM – MWPC
ToF$_2$: Right MM-THGEM – MWPC







Courtesy K. Brown, V. Zerbach (PhD student – Analysis in progress)

Summary

- An MPGD ideal for low energy nuclear physics: the MM-THGEM
  - Double-Micromegas in hole-type support: robust, scalable, multi-stage amplification
  - 10×10 cm² prototype: gain $\sim 10^3$ at <10 Torr iC_4H_{10}, timing ≈1 ns (σ), A resolution ≈ 2.3 amu from ToF
- GIRAFFE: Large-area detector array for fission studies (40×30 cm²)
  - Successful scale-up with DLC + 2D delay-line readout
  - position resolution 0.63 mm (σ), uniform across active area
  - Angular resolution ≈ 4.5 mrad for the coincidence system
- First beam commissioning in ReA6@FRIB: $^{16}O+^{208}Pb$ reaction
- First science case run in ReA6@FRIB: $^{34}Si + ^{232}Th$ reaction
  - FMT/non-FMT separation demonstrated via coincident ToF measurement; FF/QF mass-angle analysis underway

Thank you for your attention!