Applications of MPGD at FRIB/NSCL

Marco Cortesi
NSCL (Michigan State University)

Outlines

-) Introduction
-) Development of TPC readouts ➔ M-THGEM
-) Heavy-Ions tracking System
-) Proton Detector Project
-) Summaries and Conclusions

Major US Project: Facility for Rare Isotope Beams (FRIB)

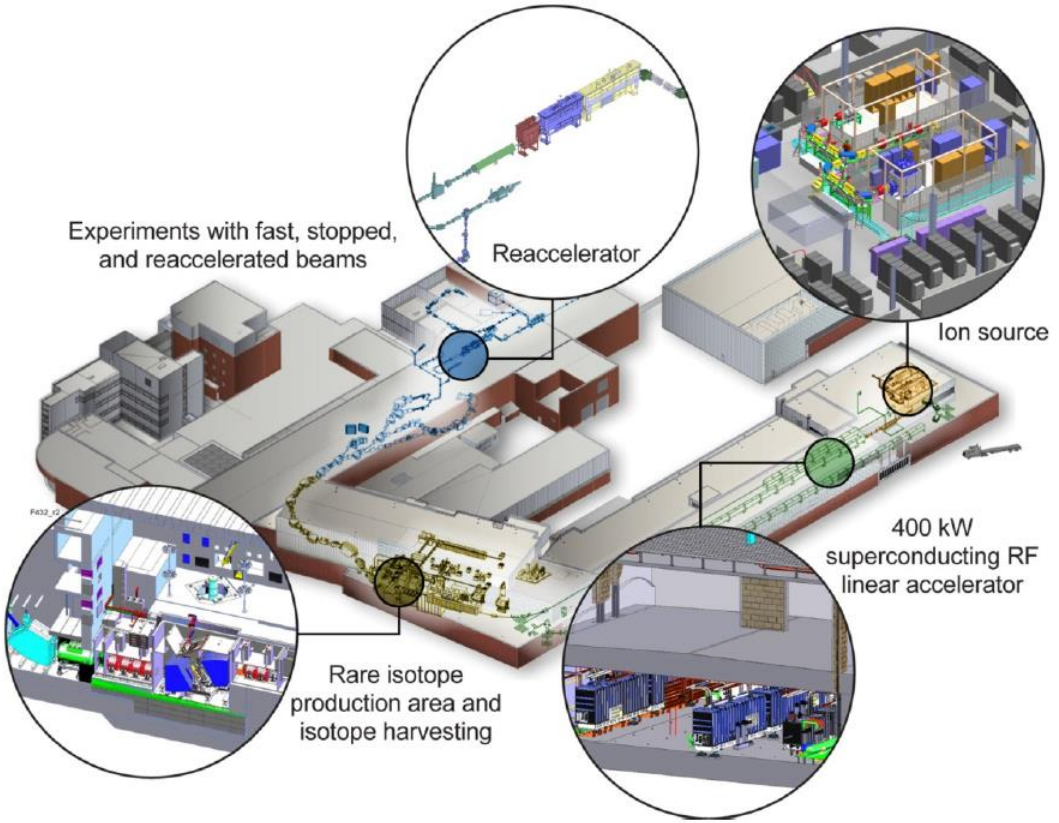
- Funded with financial assistance from DOE Office of Science (DOE-SC) with cost share and contributions from Michigan State University (MSU) & State of Michigan.

- Key features is 200 MeV/u
  400 kW beam power (5×10^{13} ^{238}U/s)
  Tremendous discovery potential:
  80% coverage Z < 82

- Separation of isotopes in-flight

- Science program requires range of energies: Fast, Stopped, & reaccelerated beams

- Upgradable to 400 MeV/u & multi-user



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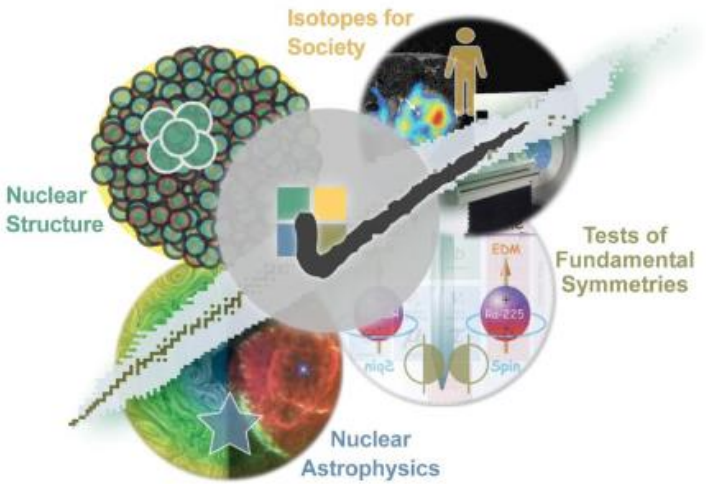
FRIB's Scientific Promise: program

Properties of atomic nuclei
- Study of predictive model of nuclei & their interactions
- Many-body problem & physics of complex system

Astrophysics: Nuclear Processes in the Cosmos
- Origin of the elements, chemical history
- Energy generation in stars, stellar evolution & the resulting compact objects

Tests of laws of nature
- Effects of symmetry violations are amplified in certain nuclei

Societal applications and benefits
- Medicine, energy, material sciences, national security, etc. etc.



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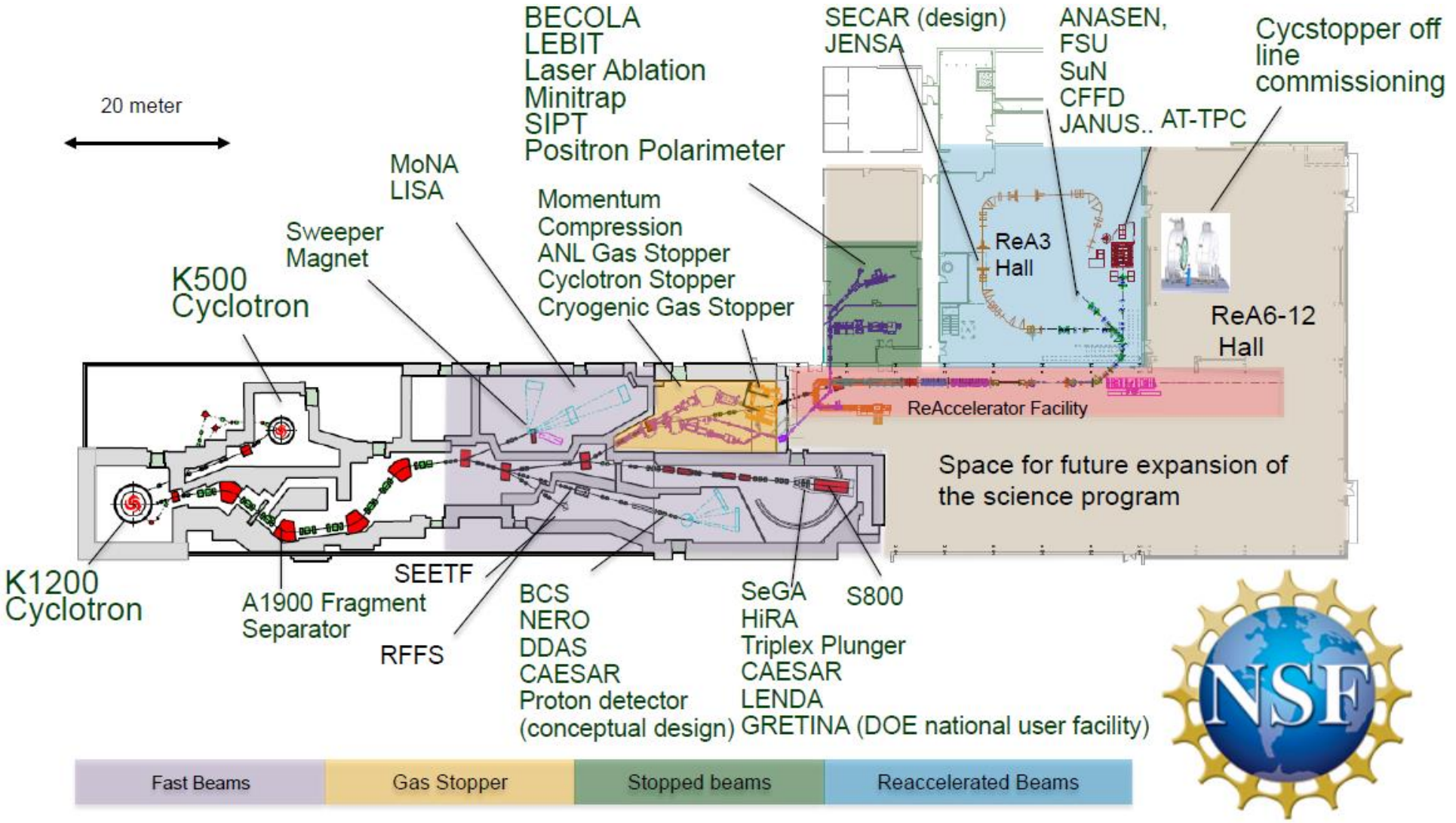
Pre-FRIB Science Opportunities at NSCL
with Fast, Stopped, Reaccelerated Beams



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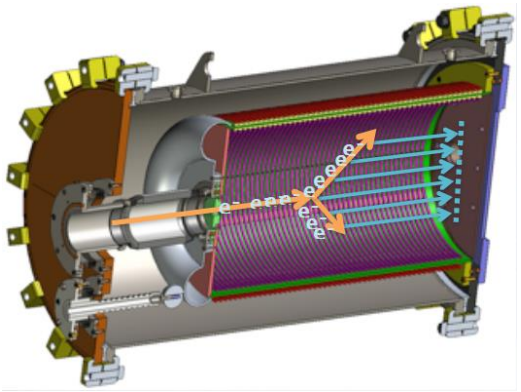
MPGD2017
Temple University, Philadelphia, USA
May 22-26, 2017

Active-Target Time Projection Chamber (AT-TPC)

Goal: Study of inverse-kinematic nuclear reactions with resolutions equal to the one achieved in direct kinematics with high-resolution spectrometers + higher efficiency & thicker targets

Suzuki et al., NIM A, 691 39 (2012)



Position-sensitive endcap detector

Filling Gas/Target

- H_2 as proton target
- D_2 as deuteron target
- ^3He
- ^4He as alpha target
- Others: CF_4, CO_2, etc.

Why Gas-filled AT-TPC?

Gas is both the detector medium & target
4π acceptance of reaction products
Energy loss like thin target = excellent resolution
Very high effective thickness ➔ high luminosity
Detection efficiency ~100% (+ low energy events)
Event-by-event reconstruction in 3 dimensions
Different target pressure ➔ Large dynamic range
Compact, Portable, and Versatile

-) Purity (no quencher) → High Reaction Yield
-) Low-Pressure Operation → Large Dynamic Range

Endcap Detector Performance:
Gas Gain, Energy Resolution, Spatial Resolution,
Counting Rate Capability, Stability etc…

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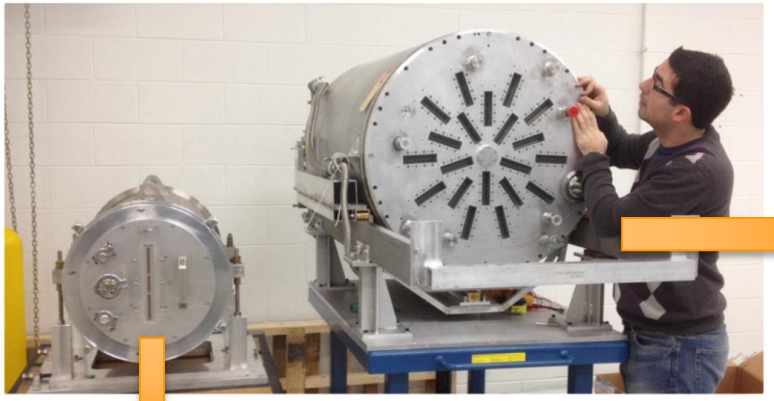
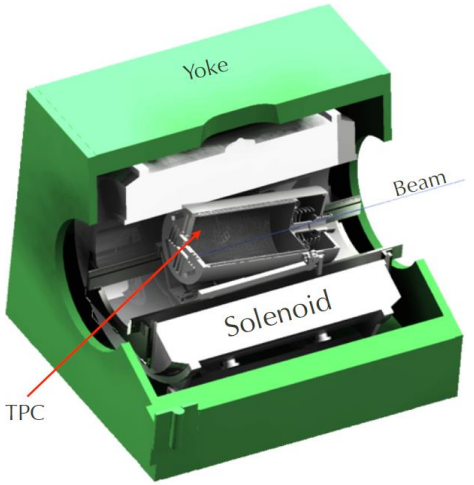
AT-TPC @ NSCL



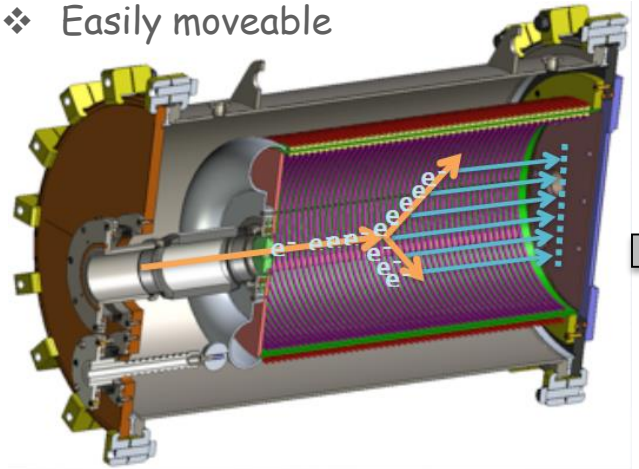


Full scale AT-TPC

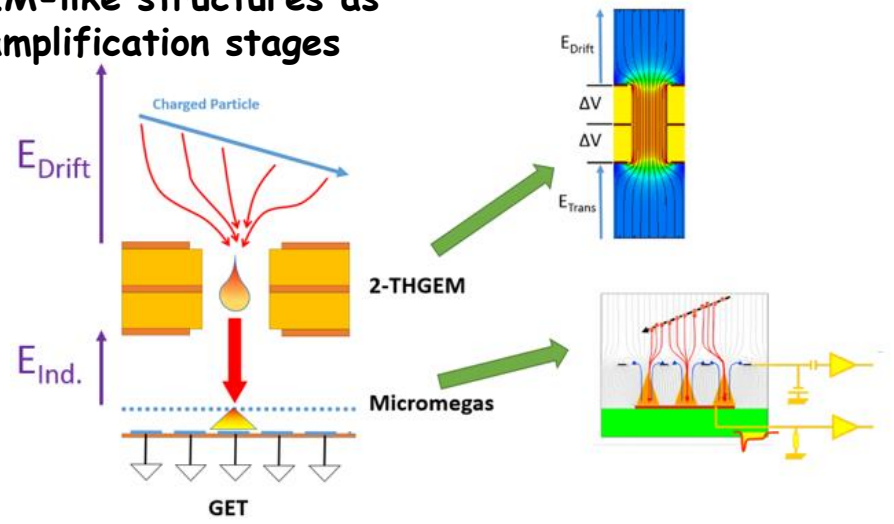
- Active volume 200 liters (L = 100 cm, Ø = 50 cm)
- 10,240 triangular pads
- Placed inside 2 Tesla solenoid

pAT-TPC

- Active volume 25 liters (L = 50 cm, Ø = 25 cm)
- Cylindrical pad plane (253 pads)
- Easily moveable



Position-sensitive MICROMEGAS & THGEM-like structures as pre-amplification stages



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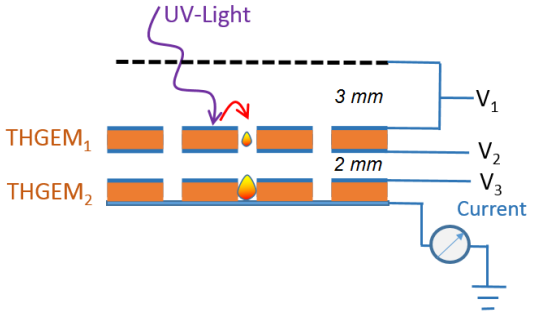
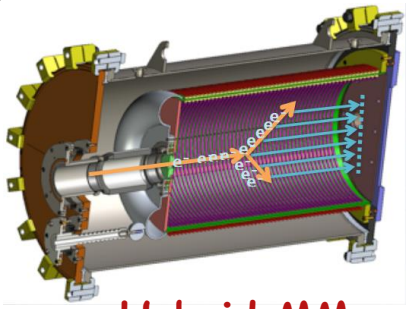
Hybrid MICRMEGAS + THGEM: gain

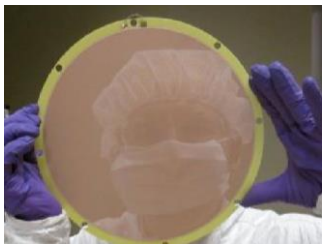
Position-sensitive Micromegas readout +
2-cascade THGEM as pre-amplification stage

THGEM geometry:
-) Thickness = 0.6 mm
-) Hole Ø = 0.5 mm
-) Hole Pitch = 1 mm



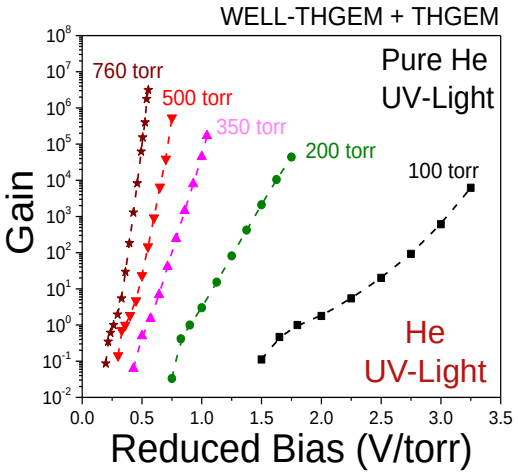
pAT-TPC (NSCL)



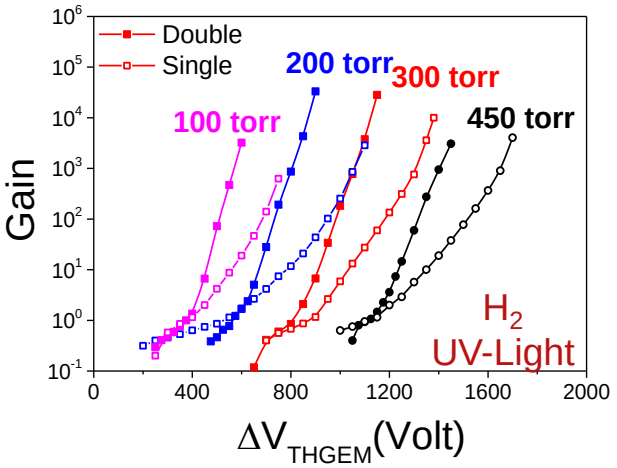


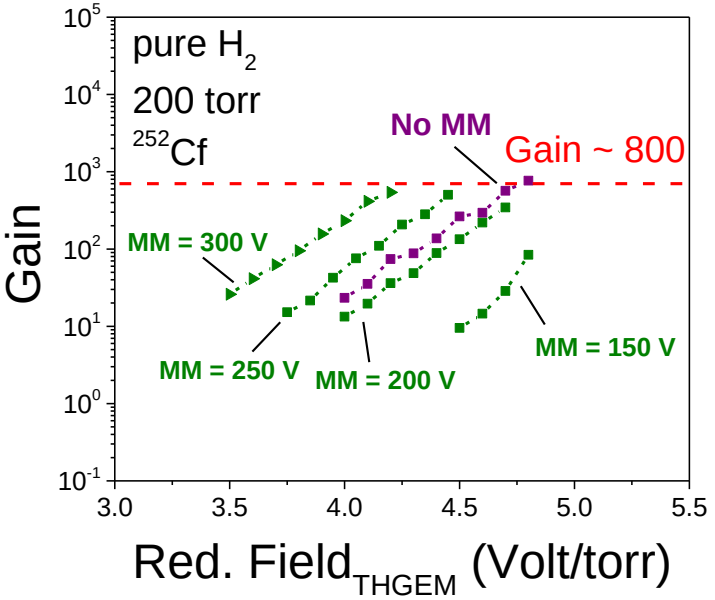
Hybrid MM + double THGEM

Cortesi et al., 2015 JINST P02012



Cortesi et al., 2015 JINST P09020





Cortesi et al., arXiv:1512.07102

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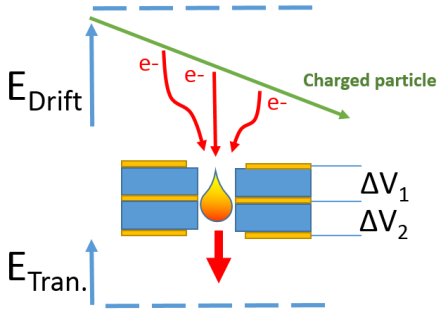
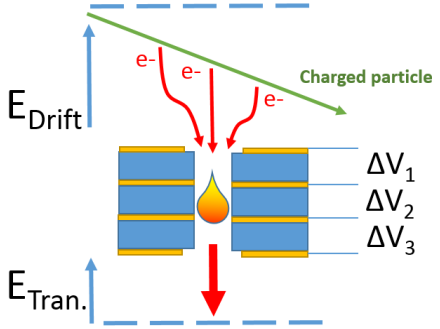
Multi-layer THGEM (M-THGEM)

Manufactured by multi-layer PCB techniques out of FR4/G-10/ceramic substrate



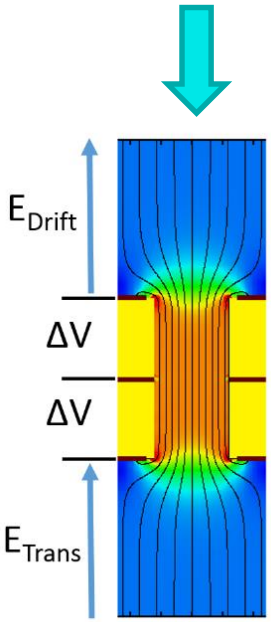
2-Layer M-THGEM

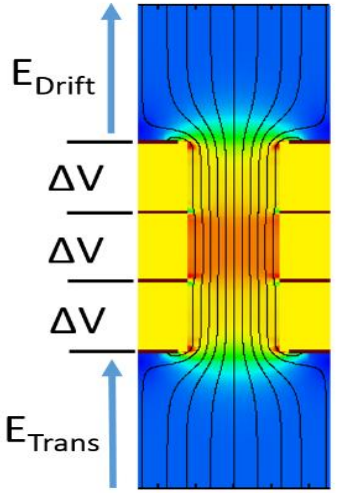


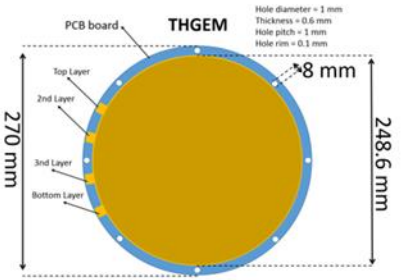
3-Layer M-THGEM

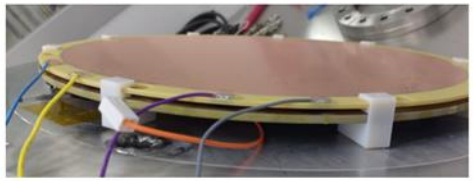
-) No loss of charge ➔ high gain @ low voltage
-) Robust avalanche confinement
➔ lower secondary effects
-) Long avalanche region
➔ high gain @ low pressure

Cortesi et al., Rev. Sci. Ins. 88, 013303 (2017)

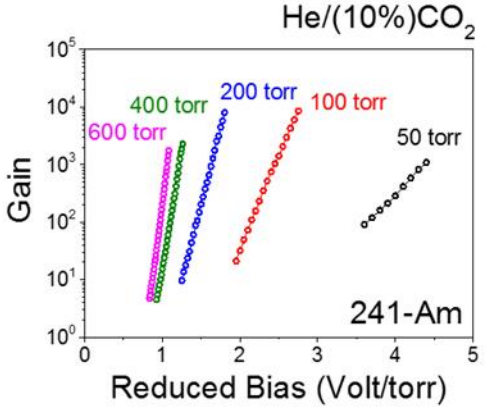


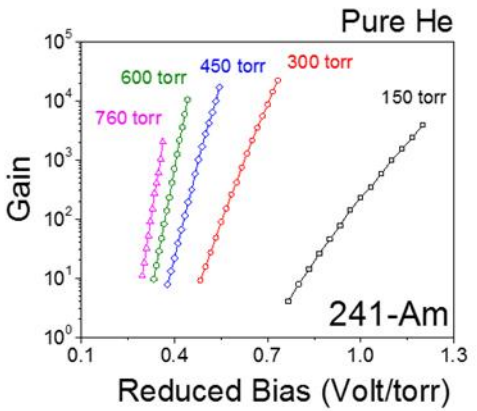






Single 3-layer M-THGEM





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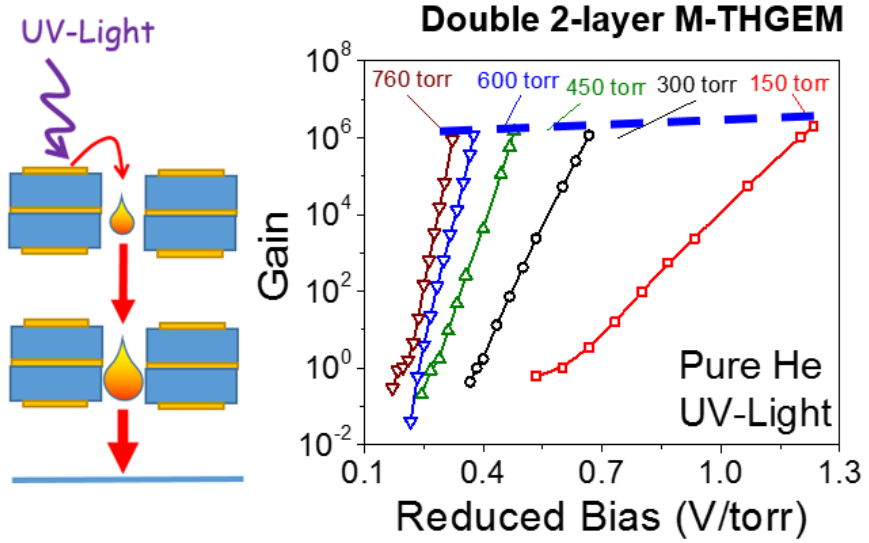
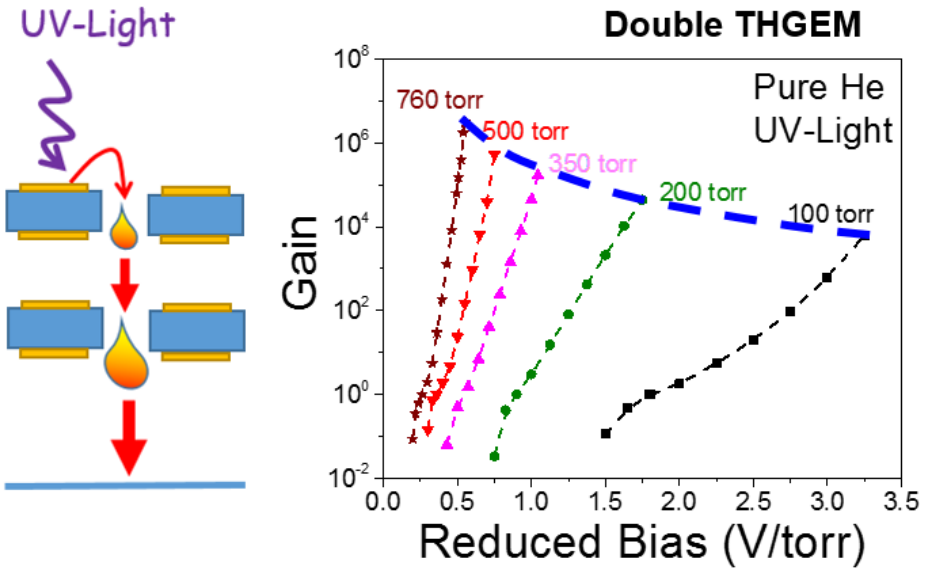
M-THGEM: performance

Cortesi et al. Rev. Sci. Instrum. 88, 013303 (2017);

10x10cm² M-THGEM
(thickness = 1.2 mm, hole = 0.5 mm, pitch = 1 mm)



10x10cm² THGEM
(thickness = 0.6 mm, hole = 0.5 mm, pitch = 1 mm)



Higher Maximum Achievable gain at low pressure due to lower secondary effects

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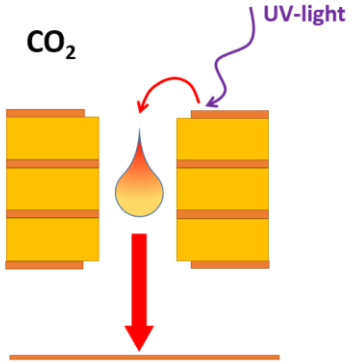
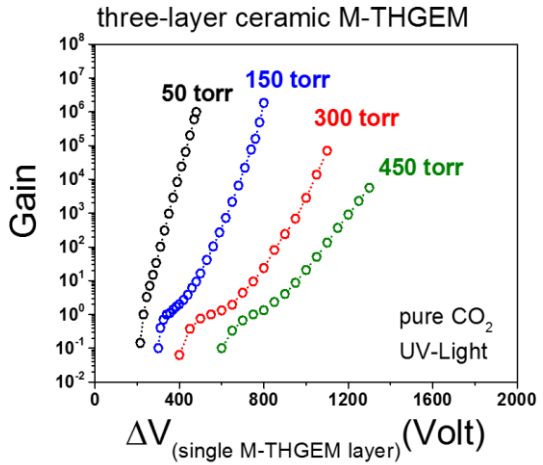
Operation of THGEM-like detector in CO_2

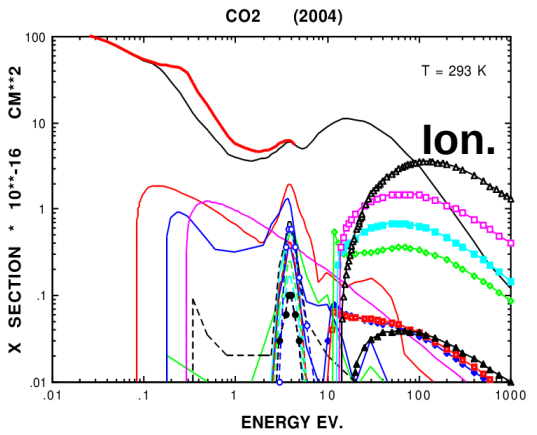
Ayyad et al. accepted for publication in JINST

High-gain operation at low pressure



Ceramic M-THGEM
10x10 cm²





Many elastic, rotational, vibrational, excitation modes competing with ionization process

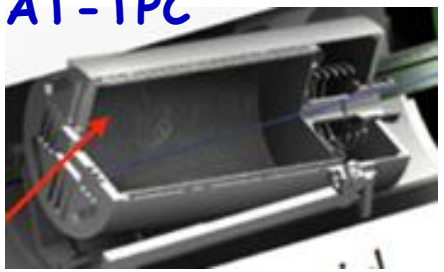
High operational reduced field

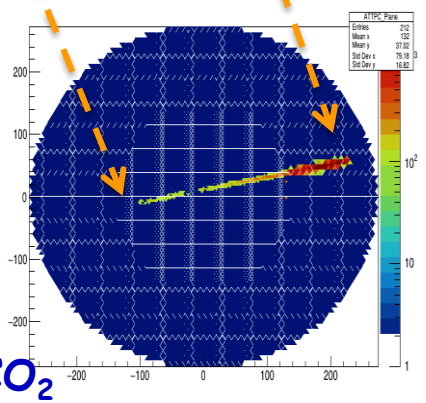
6.1 MeV α-track

Hybrid MM + 2*THGEM

AT-TPC

252-Cf

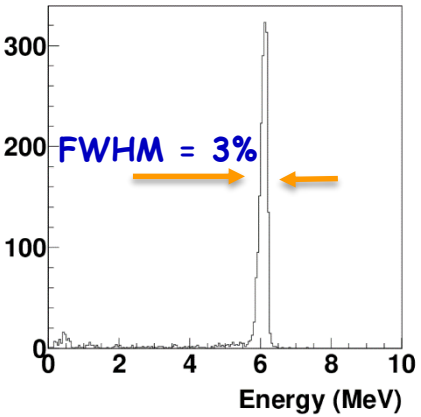




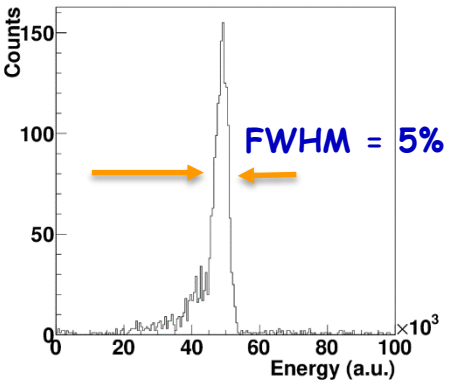
50 torr Pure CO_2

Energy resolution

Range



Collected Charge



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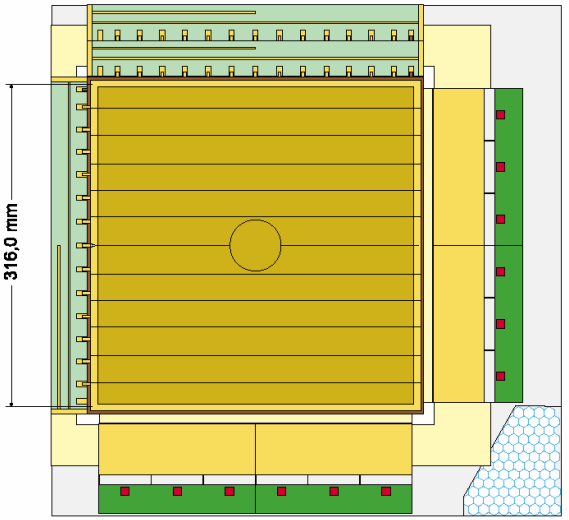
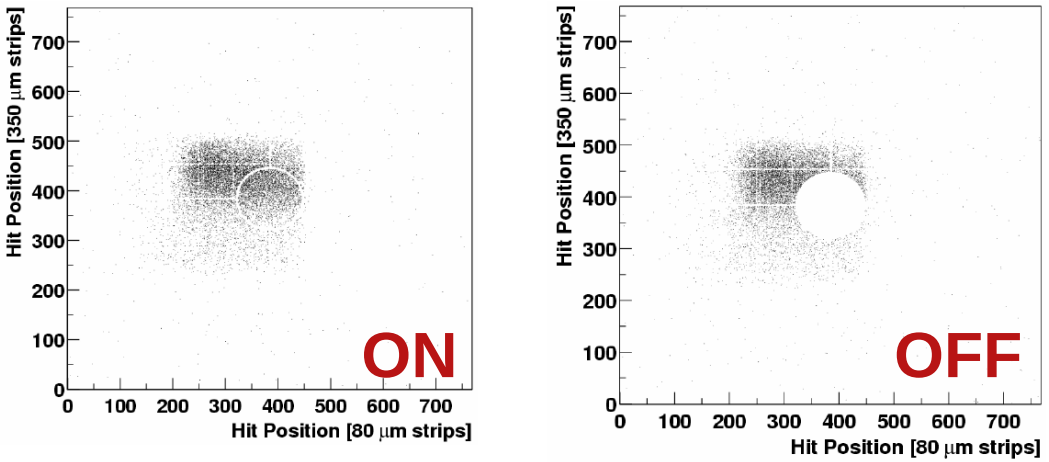
How to kill the beam (when the beams move)

COMPASS Triple GEM

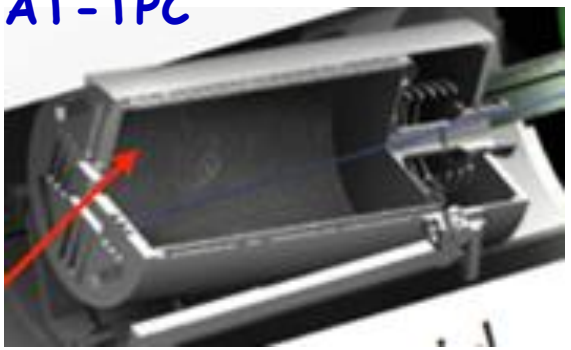


The central beam area can be remotely activated for calibrations and alignments, and disabled during high intensity runs.



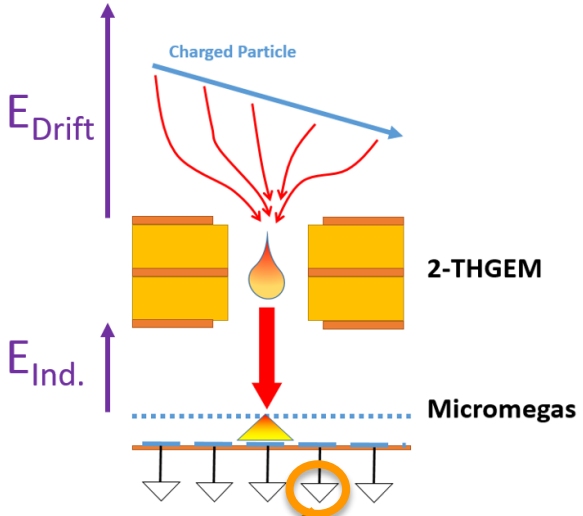
Altunbas et al. NIMA 490 (2002), 177-203

AT-TPC

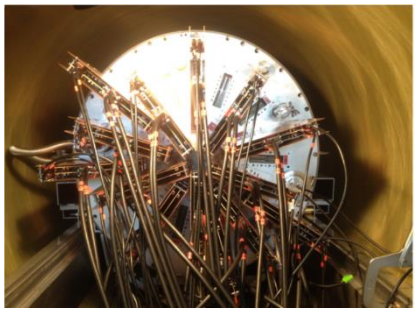


Segmentation does not work
if the same device is used for
different beams with different rigidities

How to kill the beam (when the beams move)



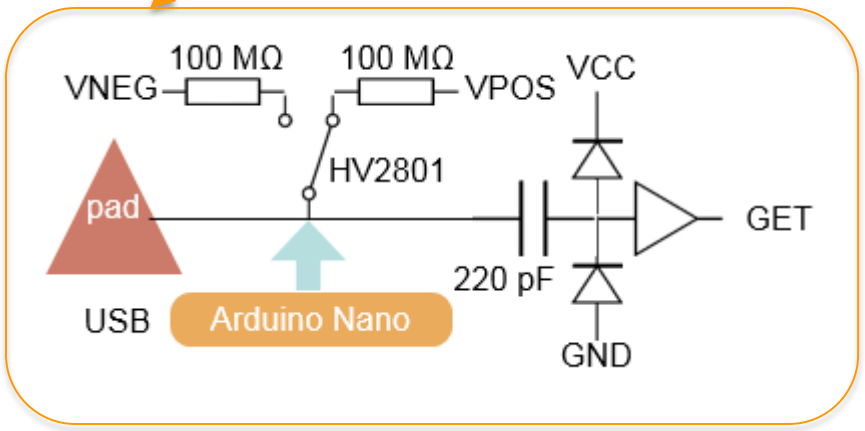
10,240 pad plane geometry



SmartZap Features:

- Pads can be connected to two high voltage inputs (VNEG or VPOS)
- Maximum voltage difference between VNEG and VPOS is ~ 200 V
- Pads can also be disconnected to either inputs (floating)

SmartZap



D. Bazin @ NSCL

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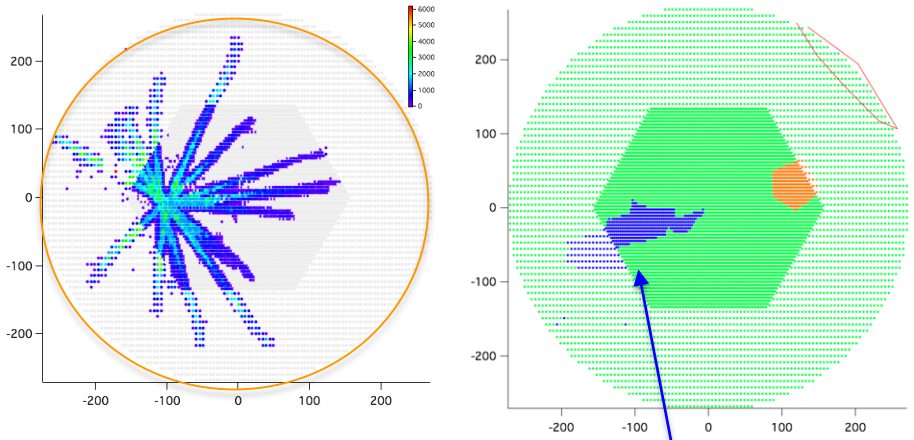
Test with ^{252}Cf fission fragments

AT-TPC filled with 200 Torr of He (90%) + CO_2 (10%)

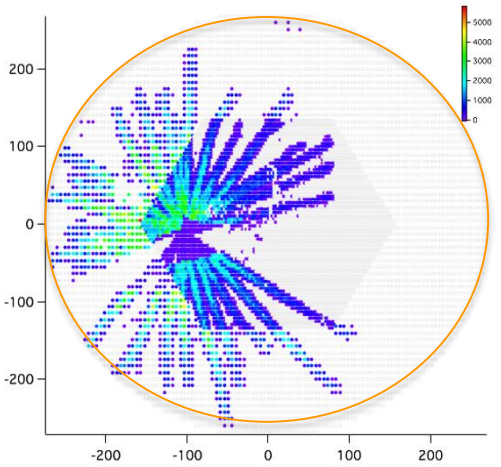
ON - ON



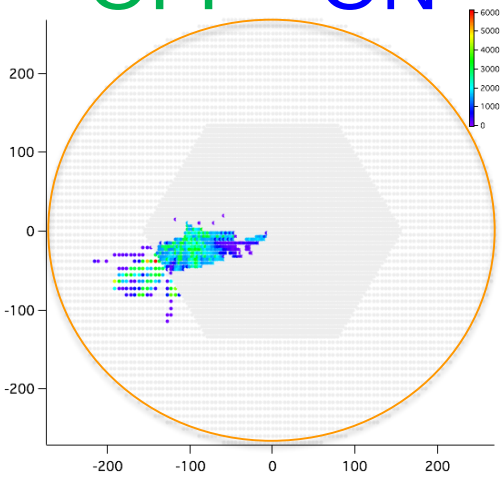
Cumulated tracks clearly shows location of source on the cathode

Pads' voltage controlled by the SmartZap

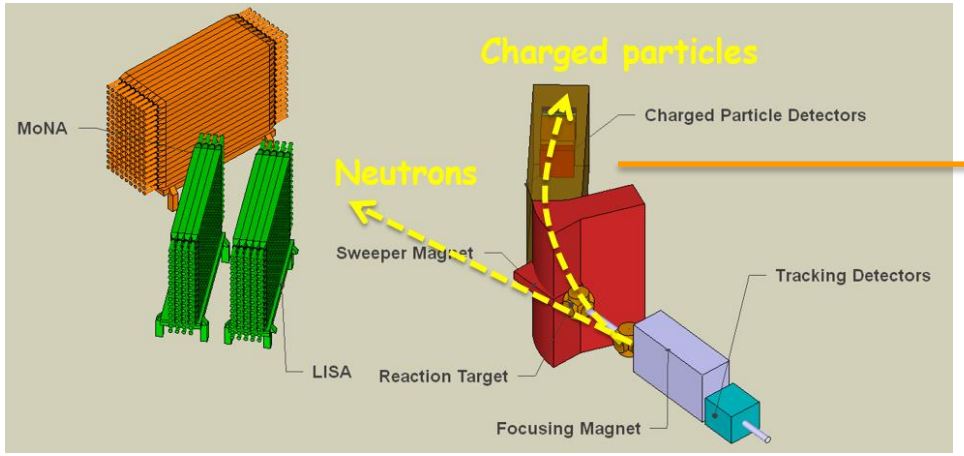
ON - OFF

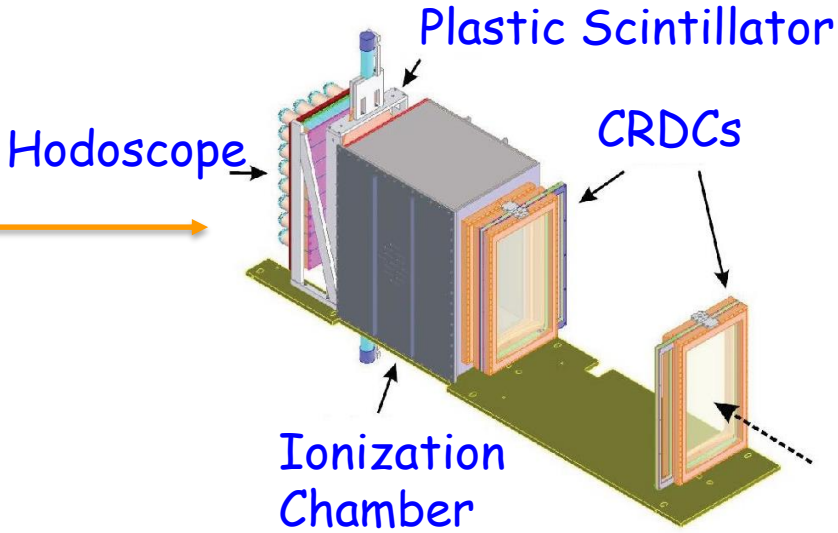


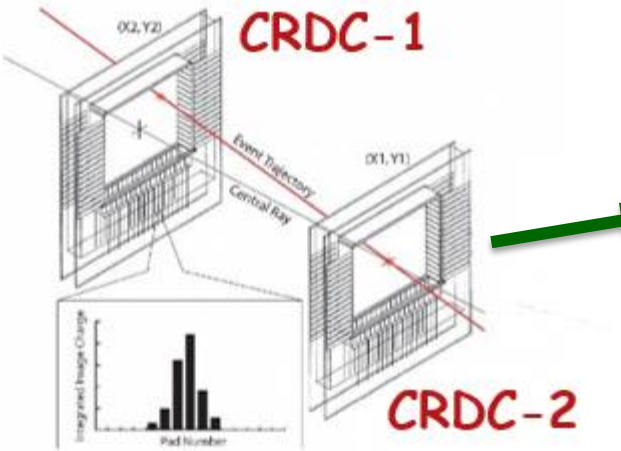
OFF - ON

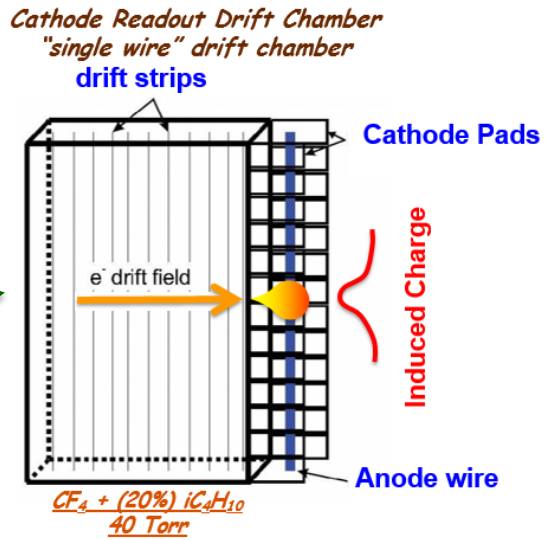


Upgrade of Focal-Plane Detector Systems









S800 Focal Plane

- Positions and angles:
  two CRDCs separated by 1 m
- ΔE: Ion Chamber (50 cm long)
- Time: 1 mm thick plastic scintillator
- TKE and/or decay:
  hodoscope array of 32 CsI crystals

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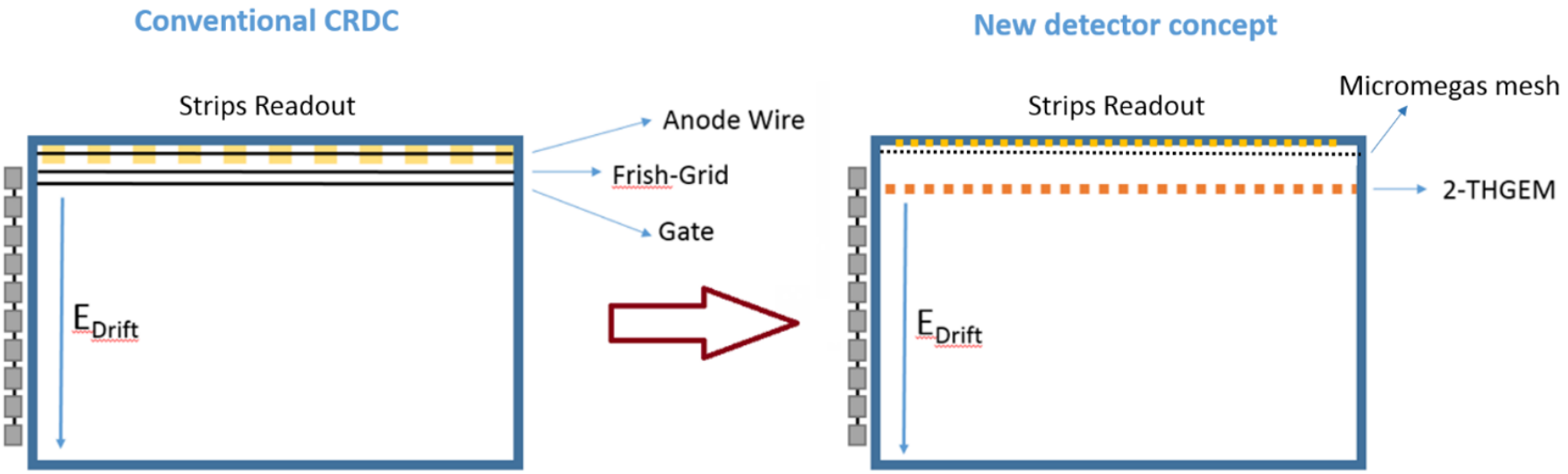
CRDC upgrade

Goal → development of a new readout based on a hybrid MPGD structure, for the upgrade of the Cathode-Readout Drift-Chamber (CRDC) based tracking system



Advantages:

-) Simple (construction) and robust
-) Better ions-backflow suppression
-) Higher detector gain @ low pressure (MM+THGEM)
-) Higher counting rate capability (?) → limited by e^- drift time
-) Higher granularity (all pad are readout individually by GET) ➔ Good (sub-mm) position resolution

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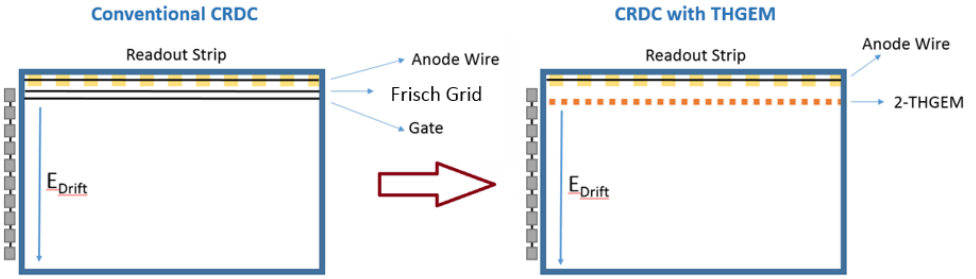
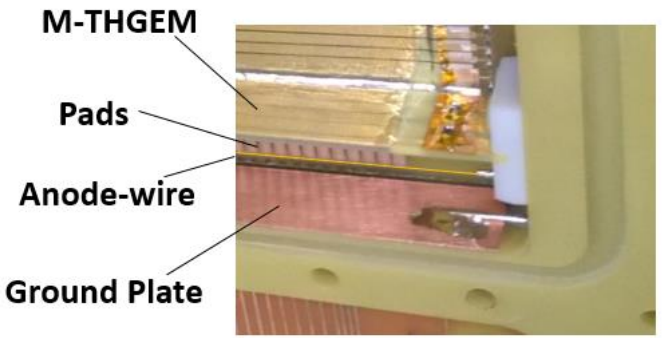
M-THGEM CRDC assembling

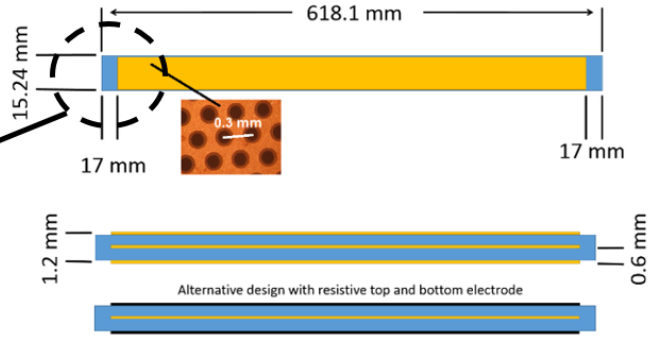
Phase 1:
Replace Frisch grid and gate (wires) by 2-layer M-THGEM
Same wire-based readout and front-end electronics!

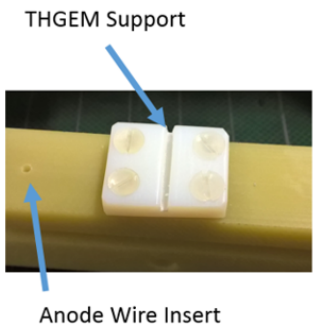


Goals (limited to test the M-THGEM):
-) Selection of the optimal configuration (resistive/not resistive)
-) Maximum achievable gain (alpha particle; 228-Th)
-) Long-term gain stability & homogeneity
-) Maximum achievable drift field
-) Drift time and electron drift velocity measurements
faster gas mixture (?)
-) Overall evaluation and further phase 2 plan

Test of two M-THGEM types (with and without resistive surface)







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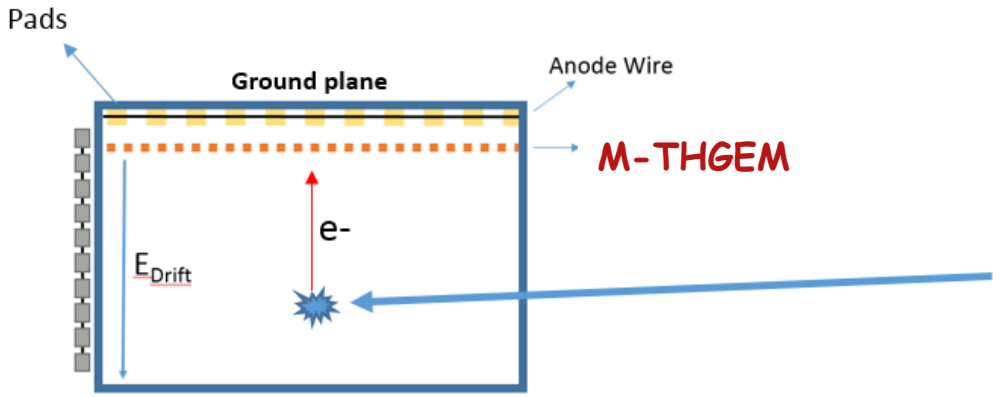
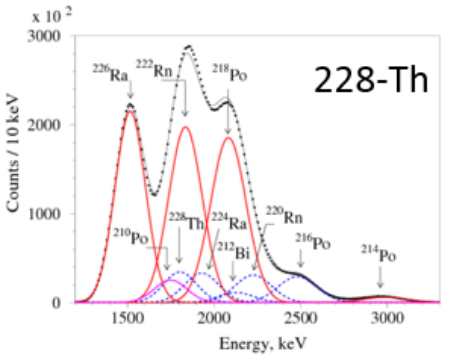
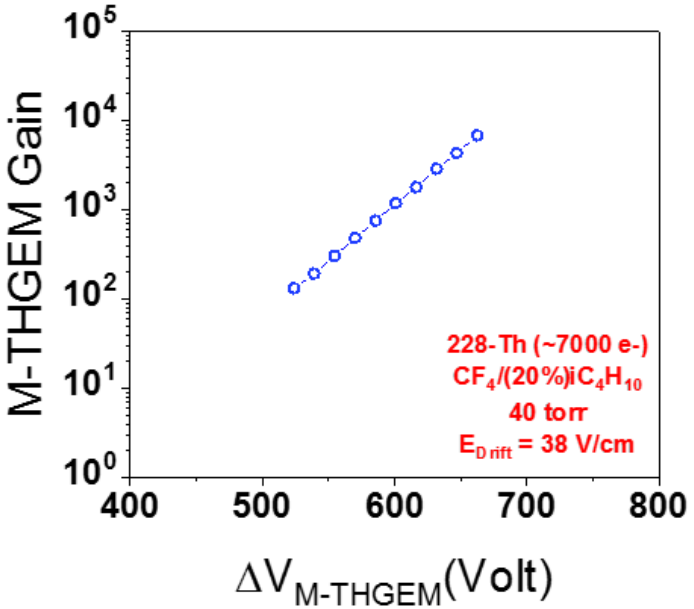
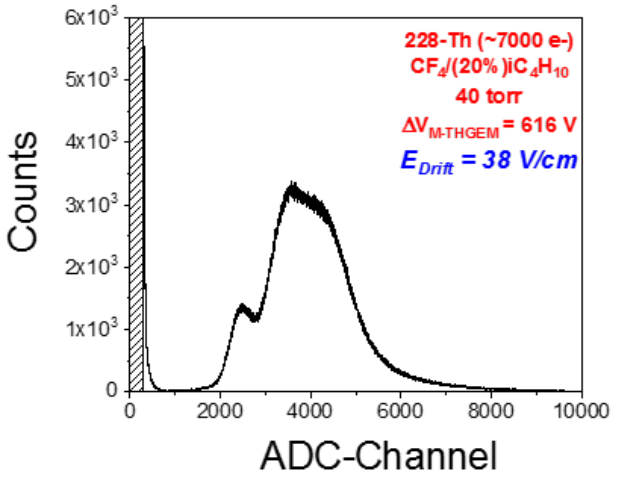
M-THGEM CRDC: preliminary results (1)

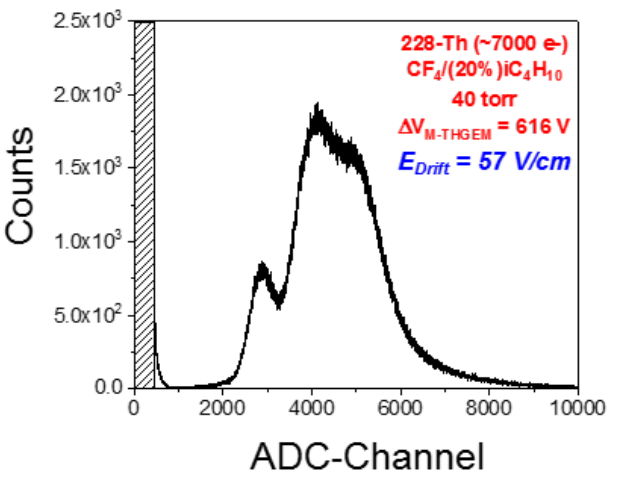




Signals taken form the M-THGEM bottom after avalanche multiplication







-) Maximum Achievable gain ~10^4
-) Good energy resolution
-) Higher drift field ➔ higher e- collection efficiency

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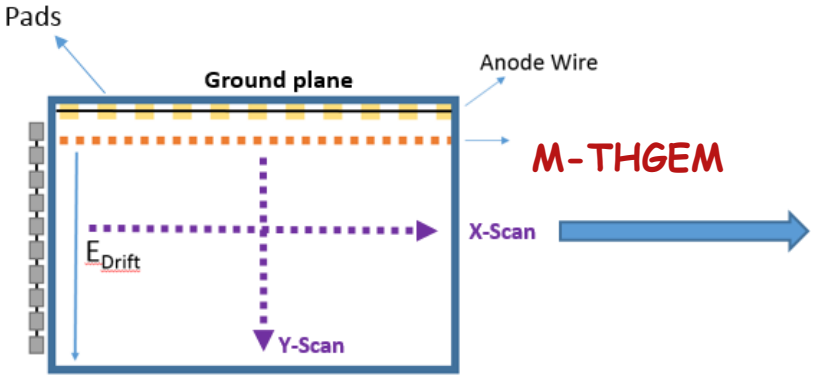
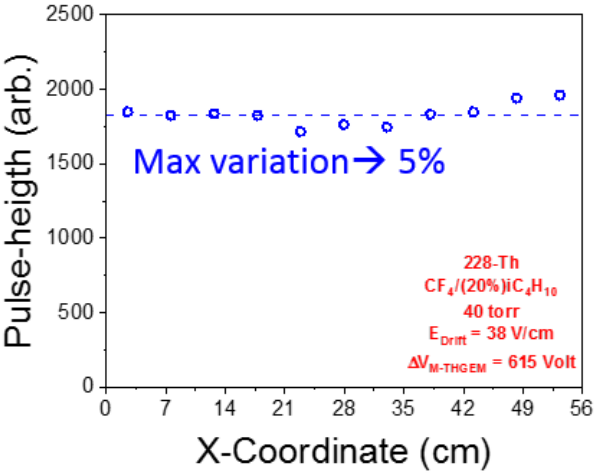
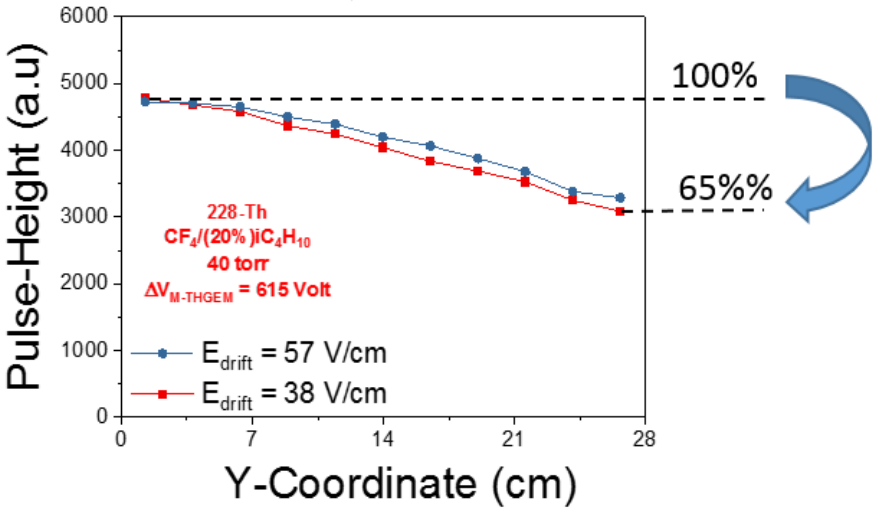
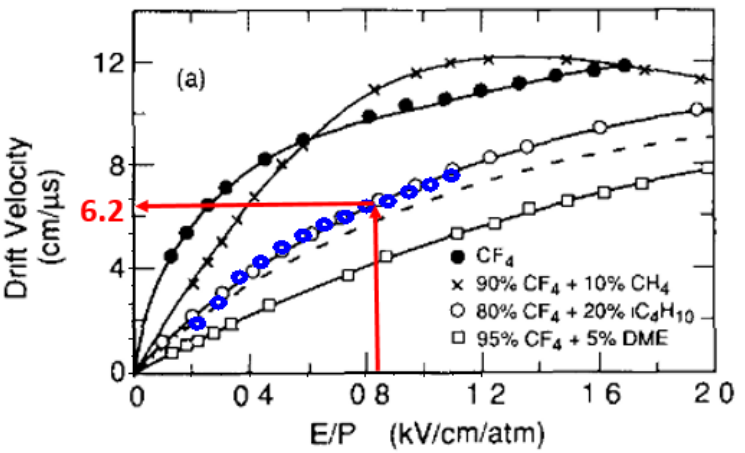
M-THGEM CRDC: preliminary results (2)







J. Va'vra et al., NIMA 324 (1993), pp. 113-123



M-THGEM CRDC CRDC

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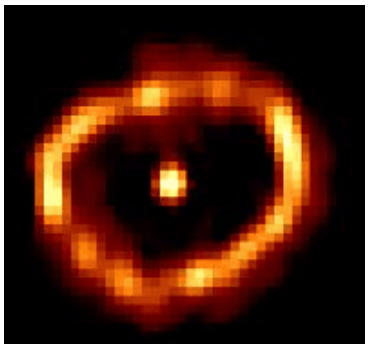
Proton Detector for Nuclear Astrophysics

Chris Wrede Group (MSU dep. Physics and Astronomy)

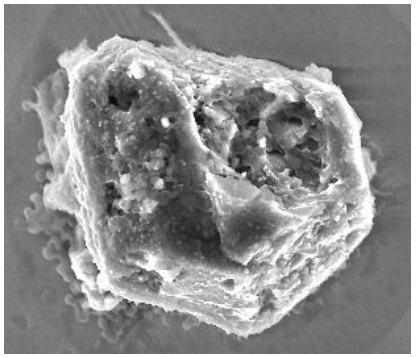
Goal: measured weak low-energy beta delayed protons branches with fast beam

Phase 1

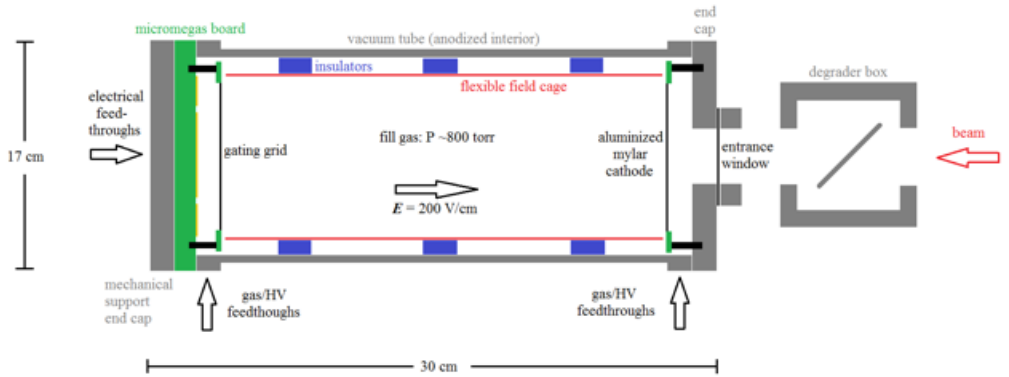
The $^{30}P(p,\gamma)^{31}S$ reaction rate is needed to identify pre-solar grains from classical novae in primitive meteorites



Nova Cygni 1992
NASA, ESA, HST

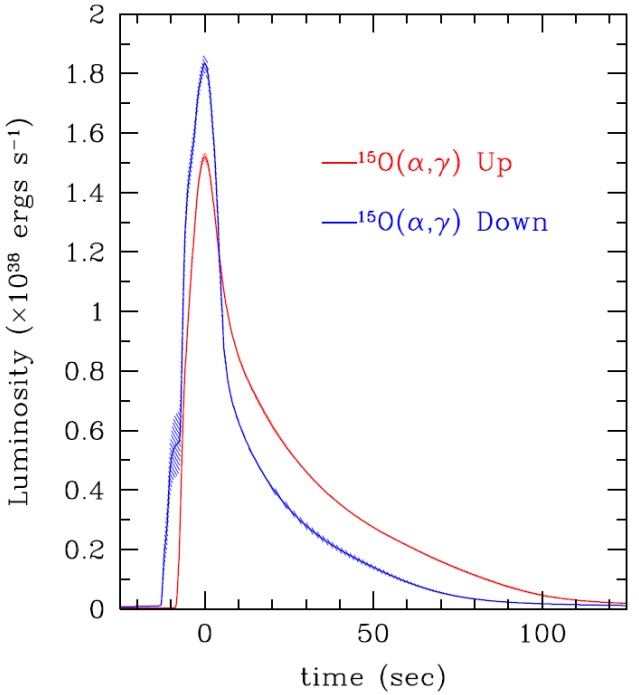


www.dtm.ciw.edu/users/lrn/psg/types.html



Phase 2

R. Cyburt *et al.*, Astrophys. J. 830, 55 (2016)



The $^{15}O(\alpha,\gamma)^{19}Ne$ reaction rate has the greatest affect on the modeling of type I X-ray burst light curves

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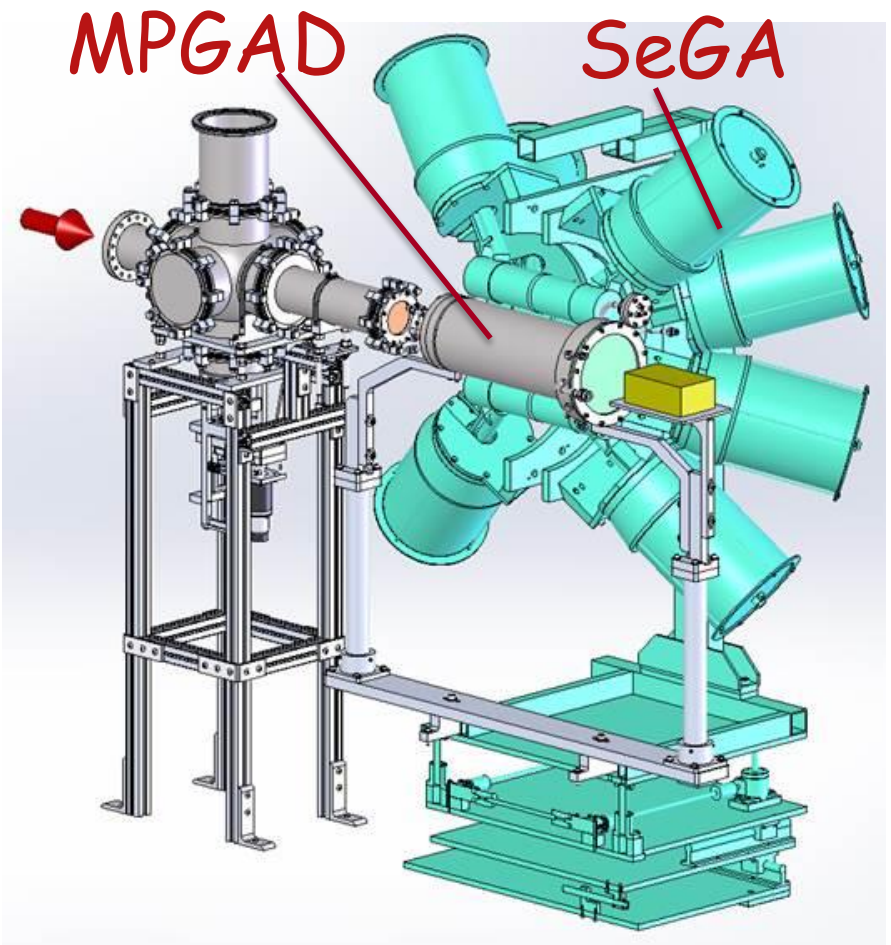
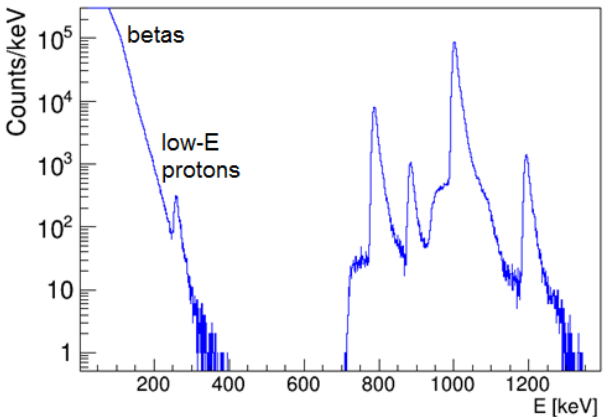
Design & simulations

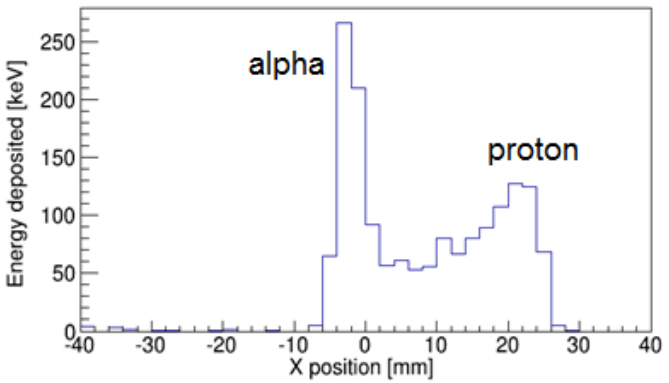


Cylindrical chamber with MPGAD stops fragmented NSCL RIB and detects β delayed charged particles. Surrounded by SeGA HPGe array to detect γ rays.

Phase I: use as calorimeter to measure ^{31}Cl(β p)^{31}S through E_x = 6390-keV ^{30}P(p,γ)^{31}S resonance and determine Γ_p/Γ



Phase II: upgrade to time projection chamber to measure ^{20}Mg(β p α)^{15}O through E_x = 4033-keV ^{15}O(α,γ)^{19}Ne resonance to determine Γ_α/Γ



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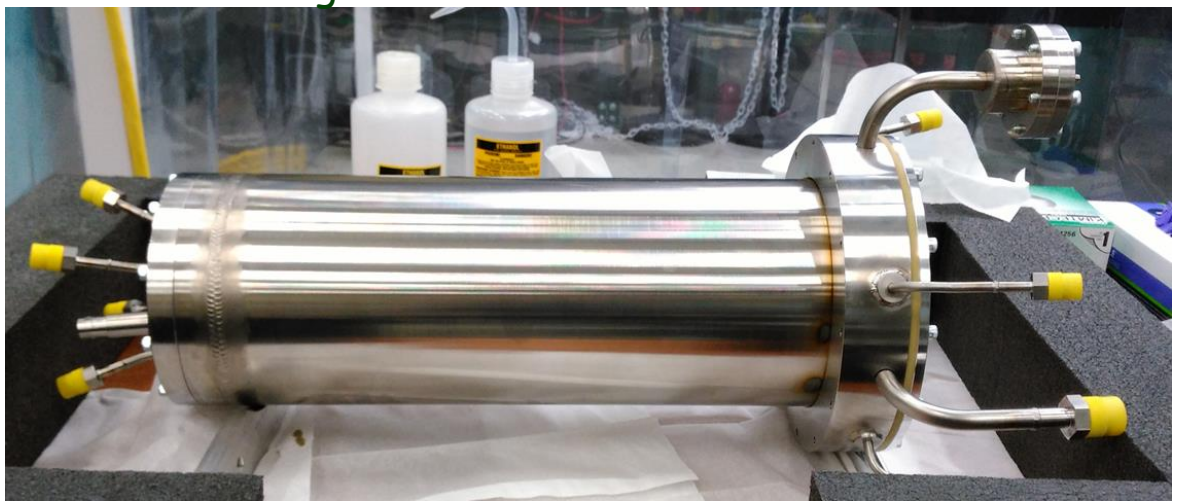
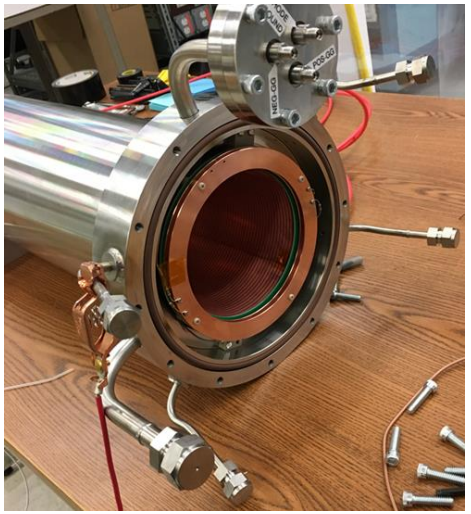
Assembly and tests

Chamber with gas inlets and outlets

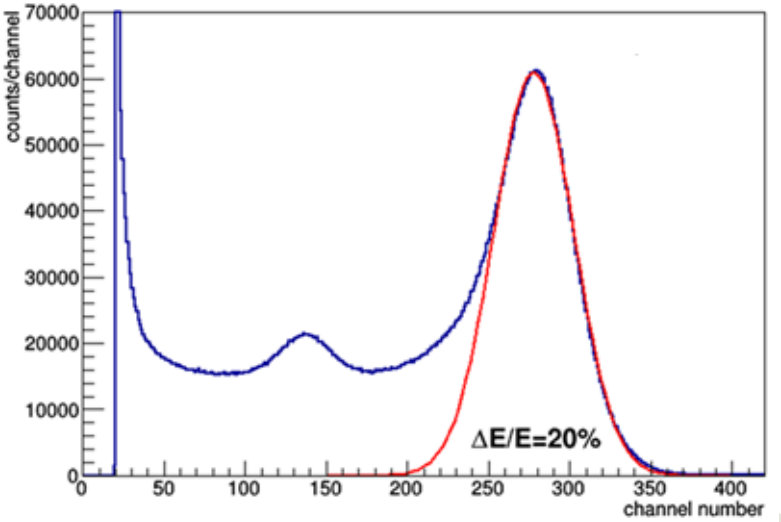


Micromegas from CERN

Field cage inside open chamber



^{55}Fe x-ray spectrum (3 & 6 keV peaks)



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Summary & Conclusions

Exciting New Science from World-Class Equipment

World-class equipment needed to realize FRIB discovery potential
Instruments **enable important new measurements** in *all* FRIB science areas, beam energies and species, experimental halls …

MPGD ➔ R&D on new/upgrade of tracking & TPC readout
including CRDC upgrade, focal plane tracking system, liquid-noble gas readout for neutron detection, …

M-THGEM: first MPGD specifically conceived for applications in Low-E NP
Stable high-gain operation at different pressure in pure elemental gas!

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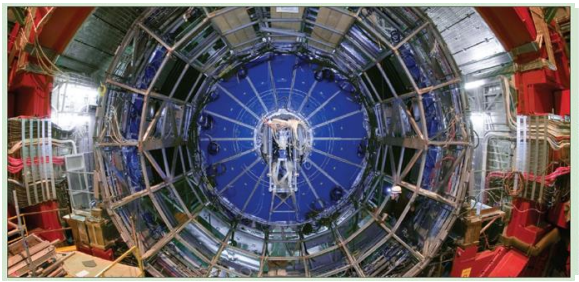
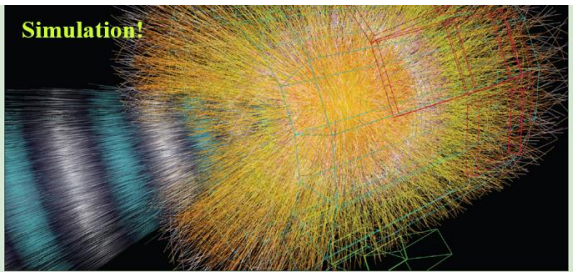
Tracking "Gaseous" Detector: requirements

High-E Physics

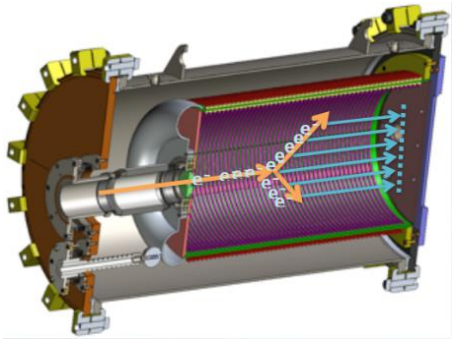
-) High Multiplicity
-) High gain (MIPs, Photons, etc.)
-) Specificity
-) High rate
-) Large & complex
-) …

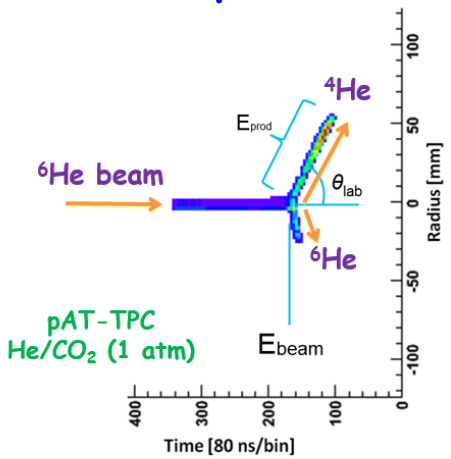
LHC-ALICE ➔ Tens of thousand tracks per event!





pAT-TPC (NSCL) ➔ few tracks per event!





Low-E Nuclear Physics

-) Low Multiplicity
-) Low gain (heavy charged particles)
-) Versatility (one setup many experiments)
-) Low-Moderate rate
-) Small setup, simple
-) large dynamic range (different pressure)
-) …

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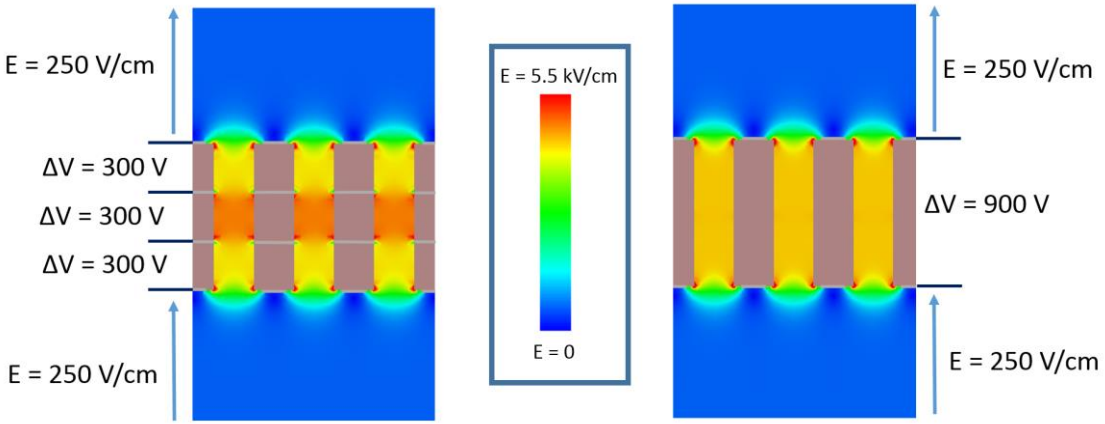
Three-Layer M-THGEM vs Single-layer THGEM

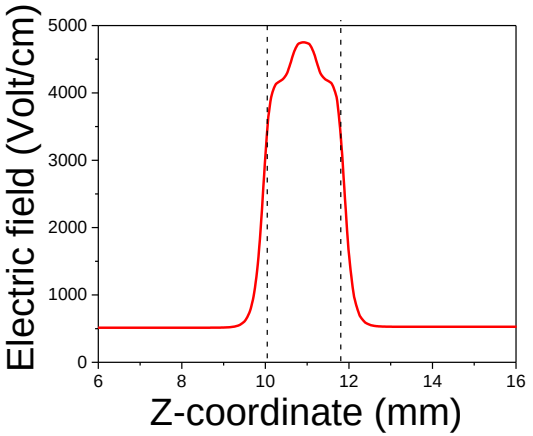


-) Amplification "condensed" in the inner volume of the hole

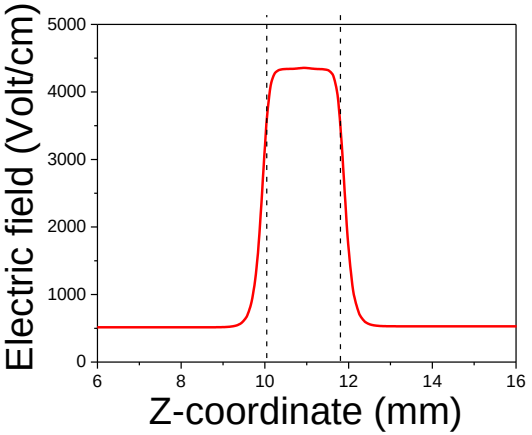
-) Lower energy released during discharges & lower probability to damages

Lower photon-mediated secondary effects in pure elemental gas at low pressure

M-THGEM hole



THGEM hole



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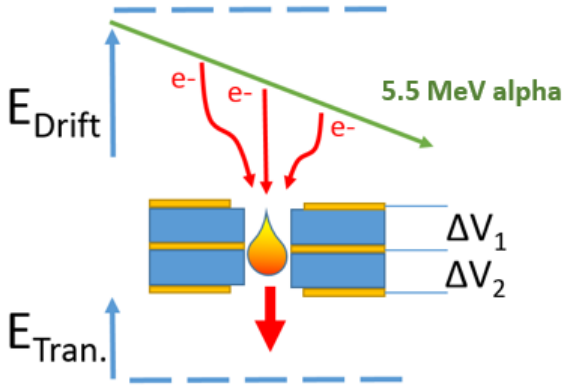
Long-term gain stability of Ceramic M-THGEMs

Two-layer ceramic M-THGEM

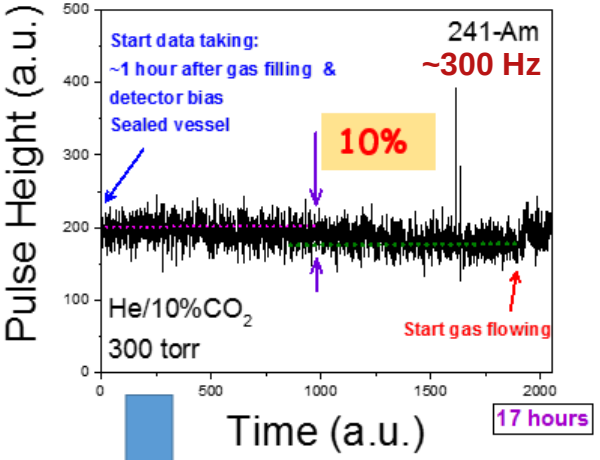
10x10 cm² prototype
12 mm drift ➔ E_{Drift} = 1 kV/cm
3 mm trans. ➔ $E_{trans.}$ = 0.33 kV/cm
$\Delta V_{M\text{-}THGEM}$ = 480 Volt
Counting rate ≈ 700 Hz

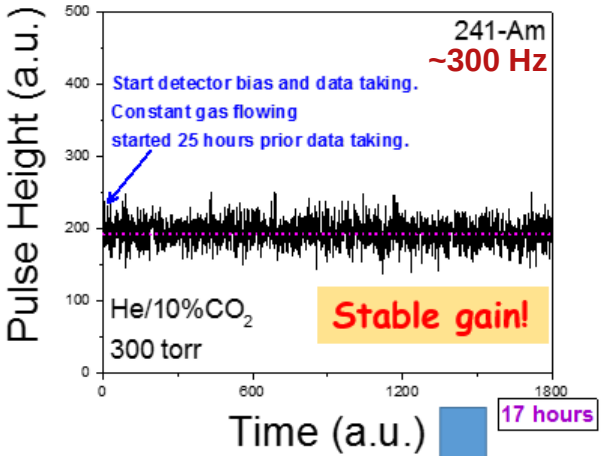


2-layer THGEM

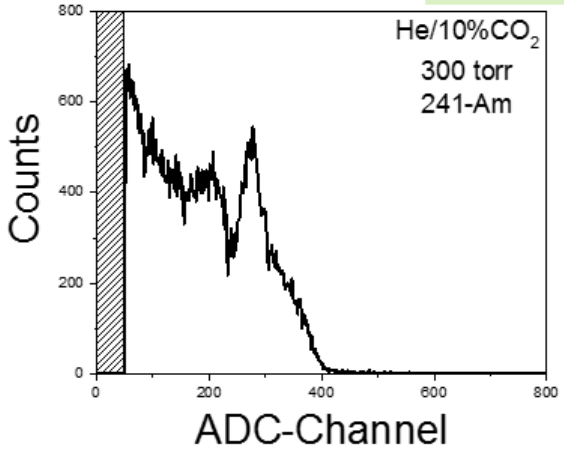
No significant charging up effect at low rate!

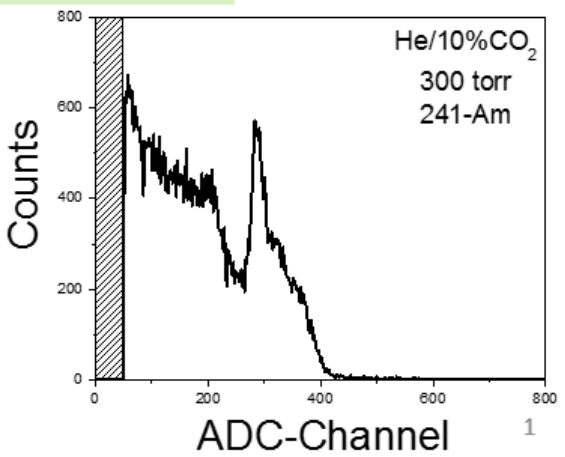
Each point is the average of ≈150 recorded pulse (1 pulse/sec)





Not collimated source





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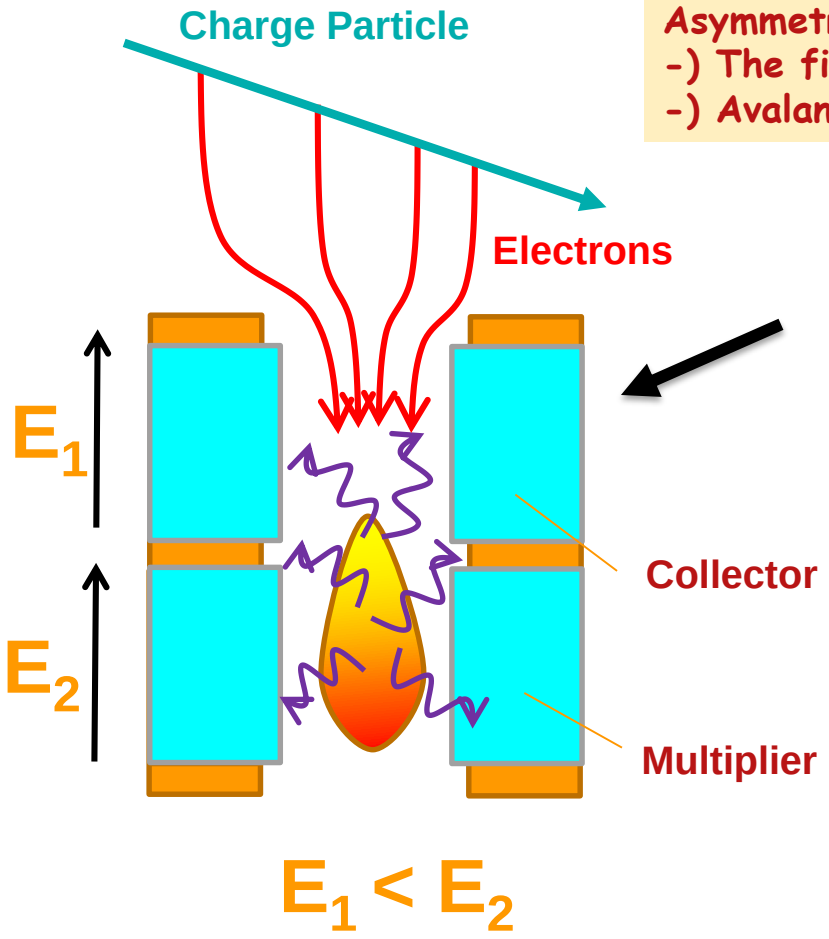
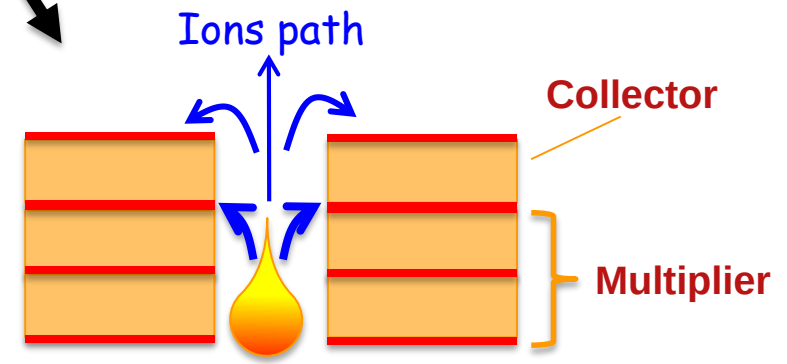
M-THGEM: photo-feedback/ion-backflow reduction



Asymmetric bias "Collection" mode of operation:
-) The first THGEM act as a "collector" – no multiplication
-) Avalanche multiplication occurs in the lower THGEM elements

Disadvantages:
Single element ➔ lower spatial resolution
(limited to the pitch of the THGEM's)
@ low gain ➔ Lower electron collection efficiency
➔ low energy resolution

Advantages:
Better reduction of the photo-mediated effects
Slight reduced of the ion backflow



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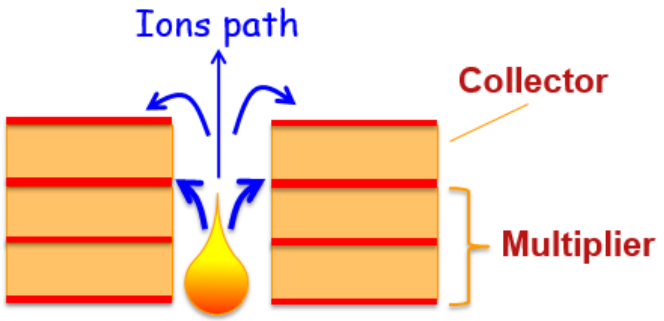
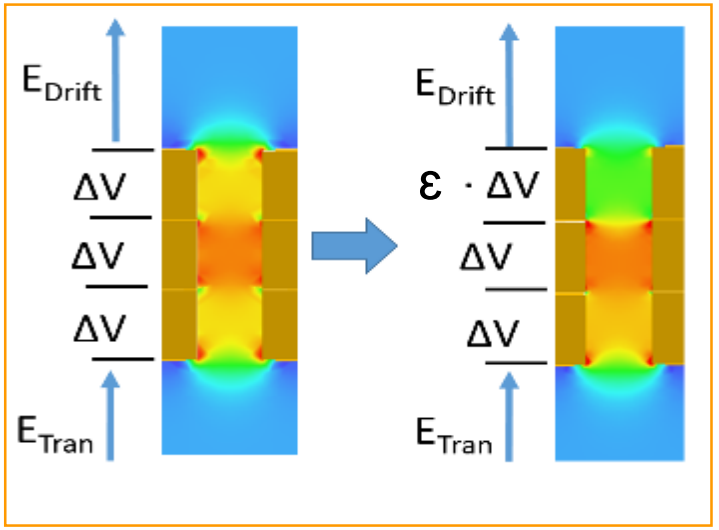
Asymmetric bias mode

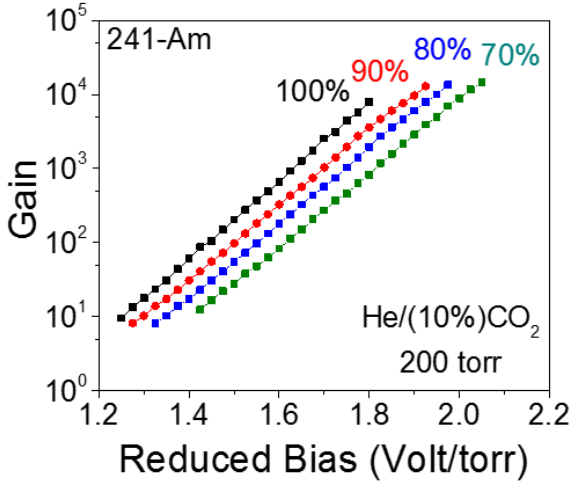
3-layer M-THGEM



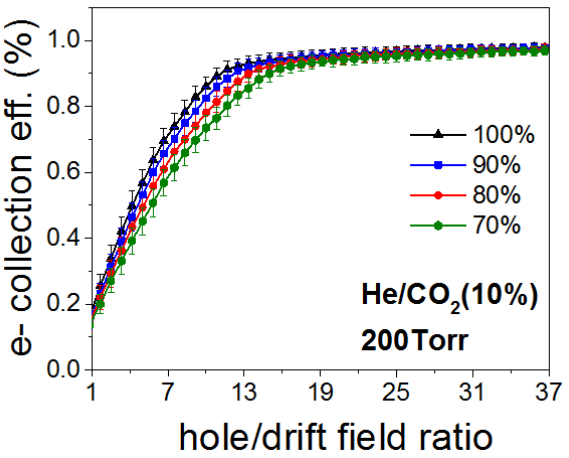


Strategy ➔ Stop ions in asymmetric setup
Problems: energy resolution? Effective gain?

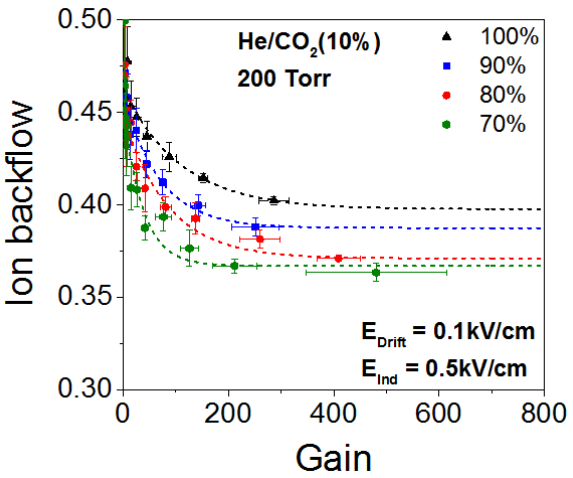
Garfield – Stefan Rost



Same Max achievable Gain!



No significant loss of e- collection efficiency



Lower ion backflow with cascade configurations

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