The Multi-layer THGEM (M-THGEM): Operational Principles and Properties

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Outline

-) Introduction and Motivations
-) AT-TPC readout: operation in pure elemental gas (H_2, D_2, He, …)
-) Multi-layer THGEM
-) Summary & Conclusions

Fantastic Nuclei and where to find them

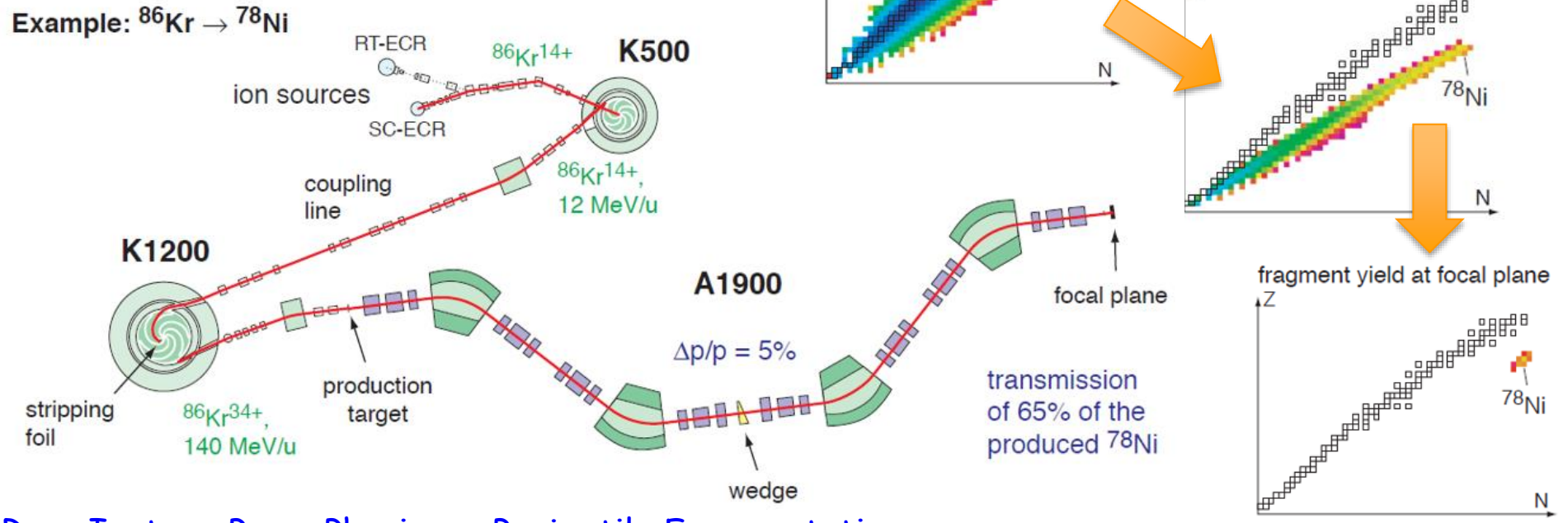
Nuclear Science Challenges addressed by Rare Isotope Beam Physics

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, energy generation in stars, stellar evolution & the resulting compact objects

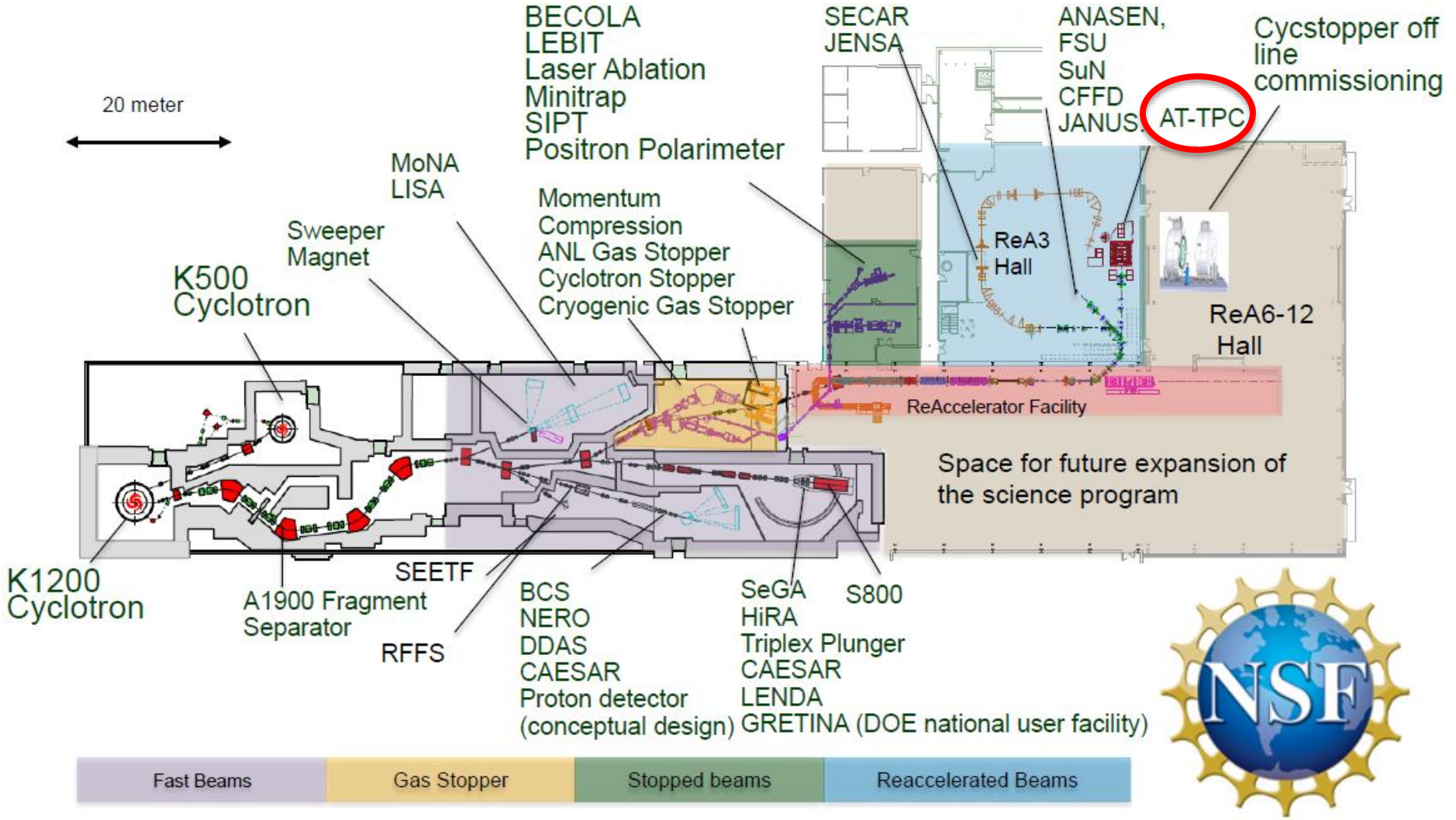
Use atomic nuclei to tests of laws of nature
- Effects of symmetry violations are amplified in certain nuclei

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



Rare Isotope Beam Physics -> Projectile Fragmentation

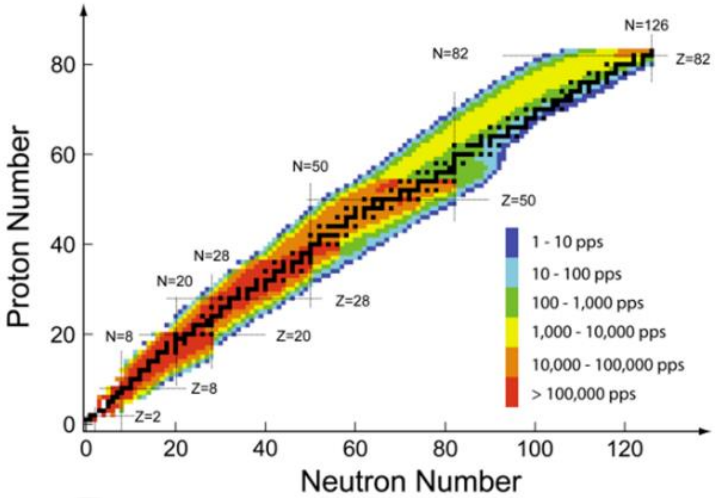
Pre-FRIB Science Opportunities at NSCL
with Fast, Stopped, Reaccelerated Beams



High Luminosity with "slow" radioactive Beams

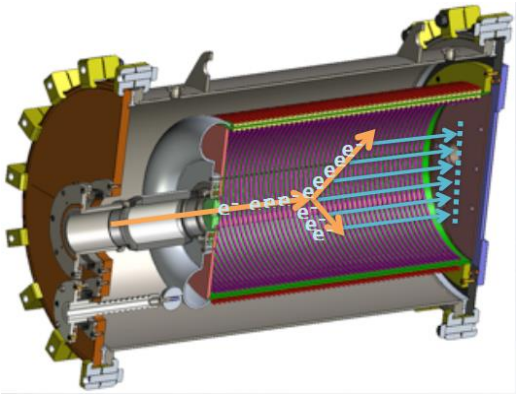
Goal: Study of inverse-kinematic nuclear reactions with resolutions equal to the one achieved in direct kinematics with high-resolution spectrometers + higher efficiency & thicker targets

RIBs → New frontier in Nuclear Science
Cross Sections @ energies < 1 few tens of MeV
The "too thick target" problem
→ Resolution Vs luminosity



Solutions:
-) Inverse kinematic
-) TPC in active target mode

Ayyad et al. Eur. Phys. J. A (2018) 54: 181

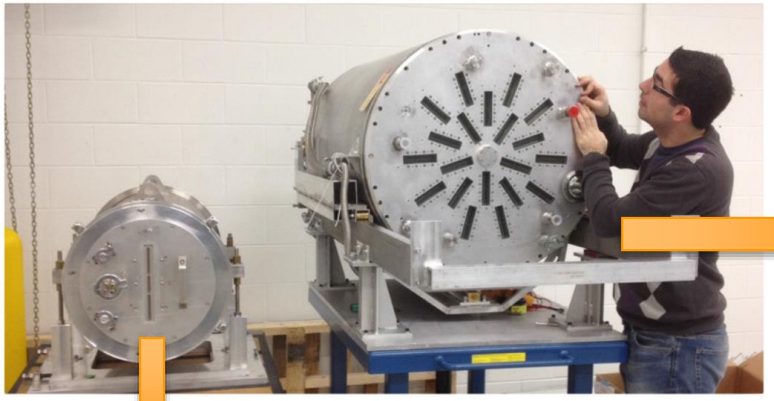


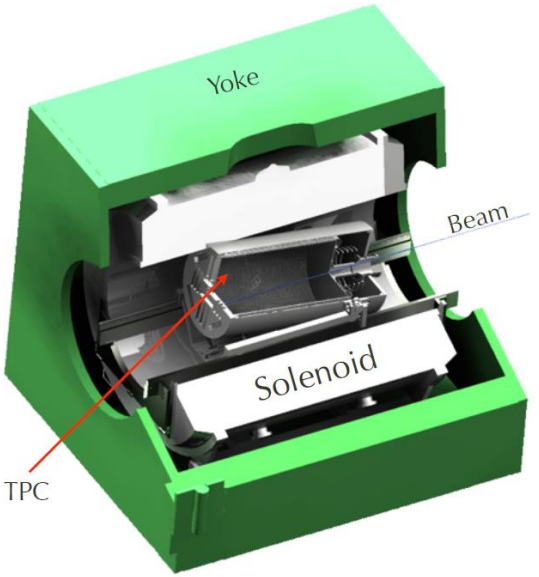
Position-sensitive endcap detector

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

TPC in Active Target mode @ NSCL/FRIB



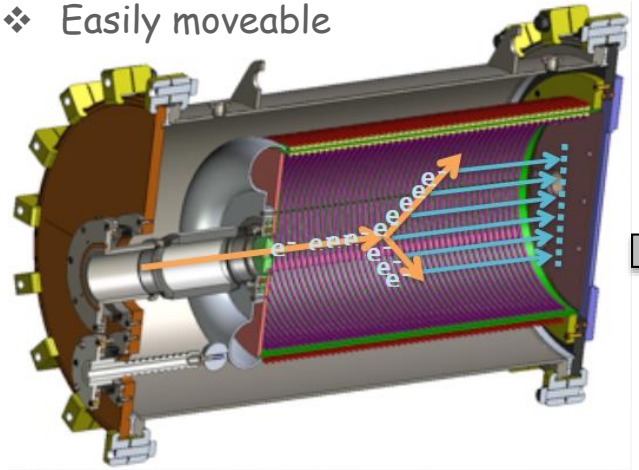


Full scale AT-TPC

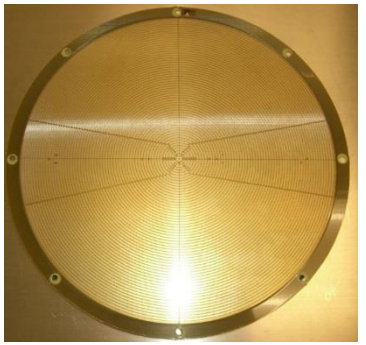
- Active volume 250 liters (L = 100 cm, Ø = 50 cm)
- 10,240 triangular pads
- Placed inside 2 Tesla solenoid

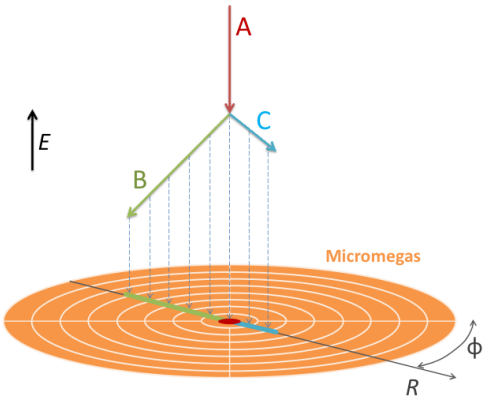
pAT-TPC

- Active volume 125 liters (L = 50 cm, Ø = 25 cm)
- Cylindrical pad plane (253 pads)
- Easily moveable



End-cap readout based on Micromegas

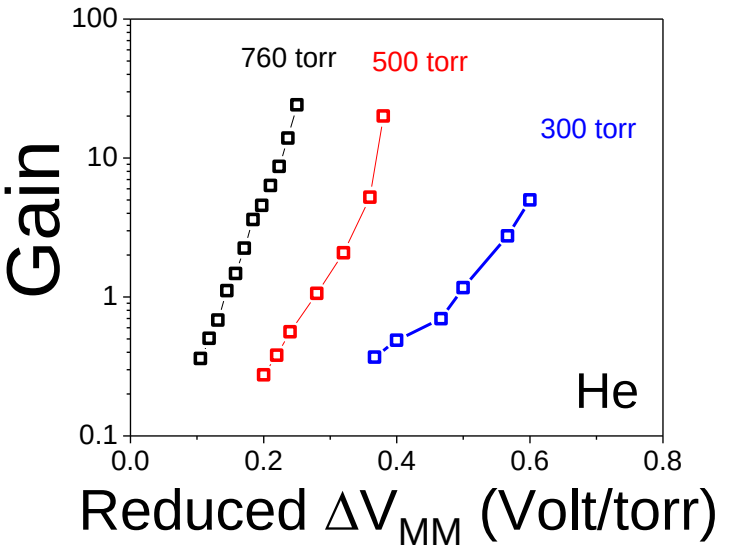




Pure "gaseous" Target for Low-Energy Nuclear Physics Applications

- **H_2 as proton target**
  - 1 neutron pickup (p,d)
  - 2 neutron pickup (p,t)
  - p-scattering
- **D_2 as deuteron target**
  - 1 neutron transfer (d,p)
  - 1 proton pickup (d,^{3}He)
  - Inelastic scattering (d,d')
- **^{3}He**
  - 1 proton transfer (^{3}He,d)
- **^{4}He as alpha-particle target**
  - Inelastic scattering (^{4}He, ^{4}He'),
  - Isoscalar Giant Resonances excitations …
  - Alpha-induced reactions for astrophysical p-process
- **Etc. . .**

AT-TPC Micromegas

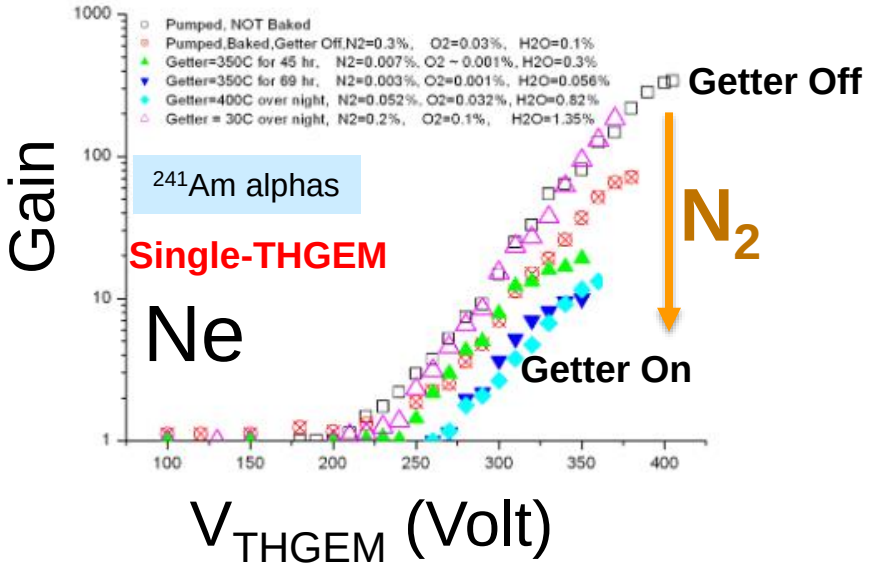


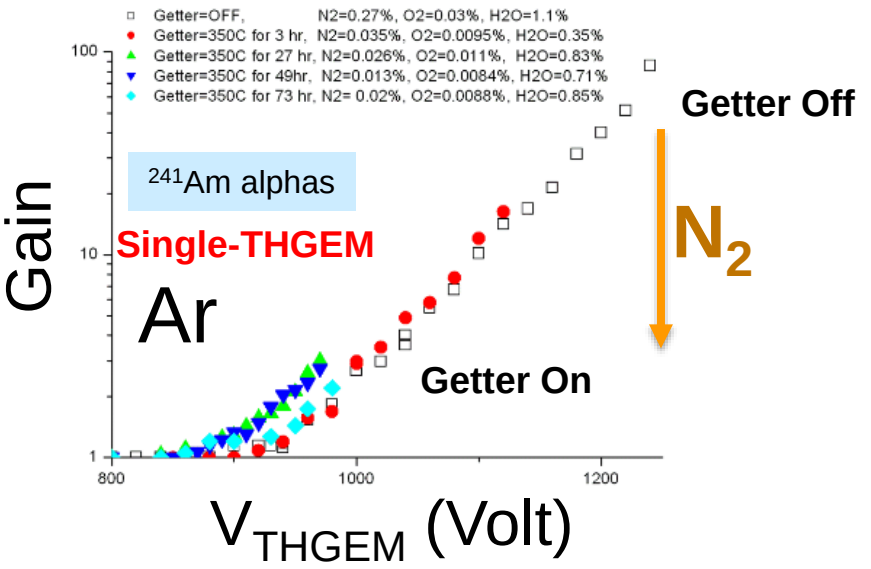
-) Purity (no quencher) → High Reaction Yield
-) Low-Pressure Operation → Large Dynamic Range

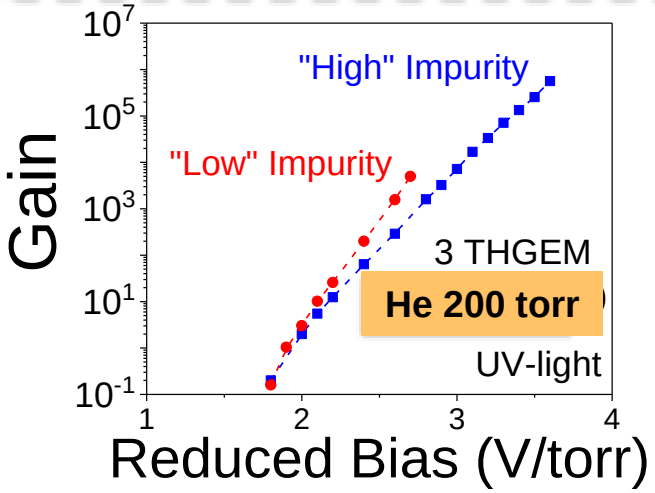
Endcap Detector Performance:
Gas Gain, Energy Resolution, Spatial Resolution, Counting Rate Capability, Stability etc…

Operation of THGEM in Noble Gas

Miyamoto et al. 2010 JINST 5 P05008



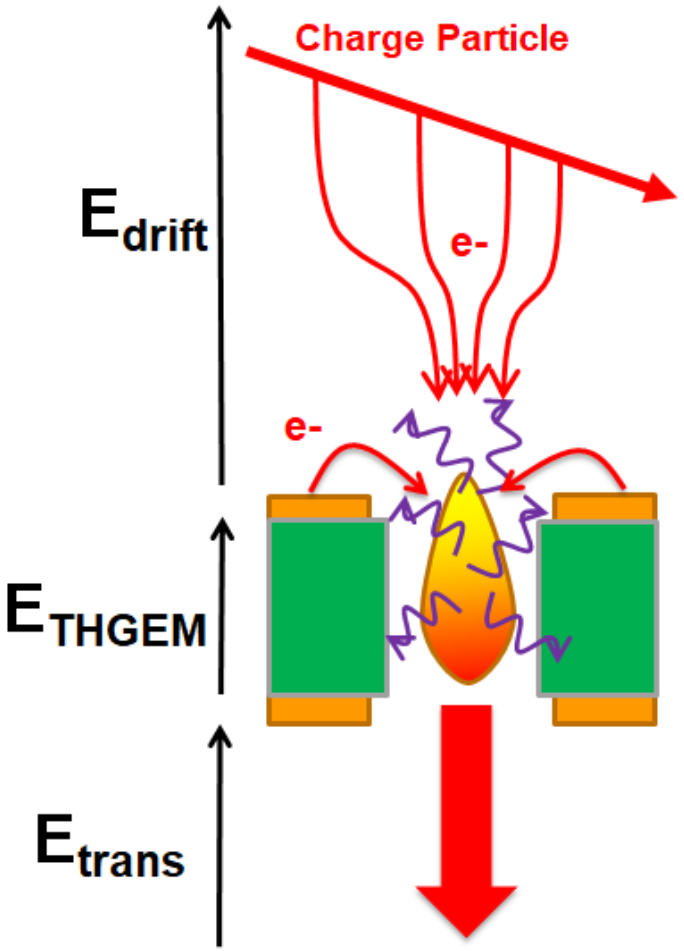




THGEM operation possible in "dirty" **noble gases** due to:
-) Avalanche confinement in holes
-) Impurities (mostly N_2) act as quencher

Low gain for extremely pure gas!

Photo-Mediated Secondary Effects

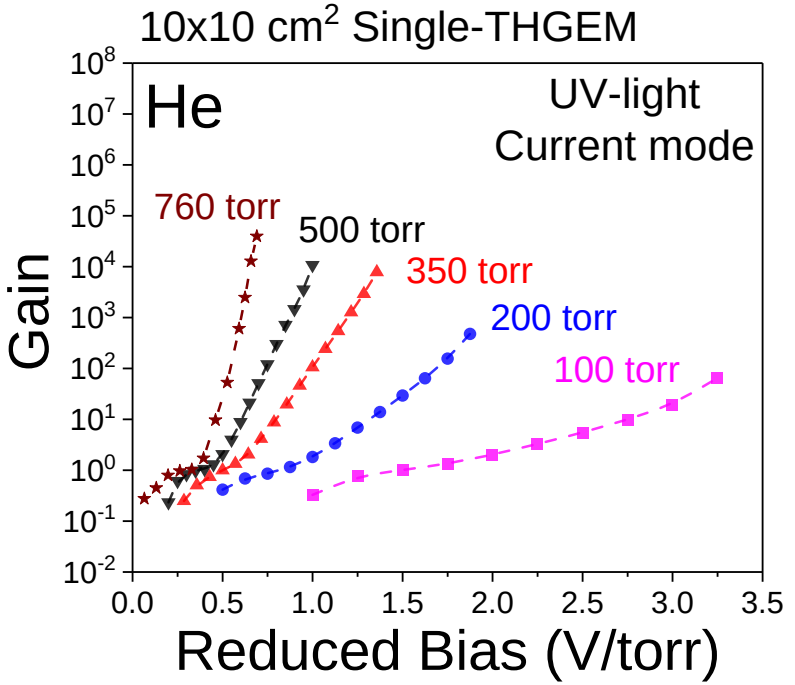


The Problem:

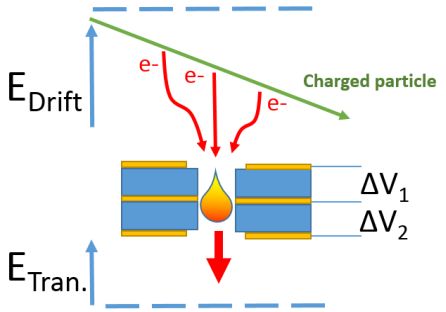
Drop of THGEM max. achievable gain in pure elemental gas

➔ loss of electron avalanche confinement (within the holes) that results in photo-mediated secondary effects

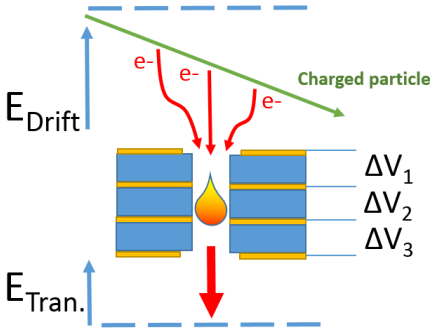
➔ transition from proportional mode to streamer



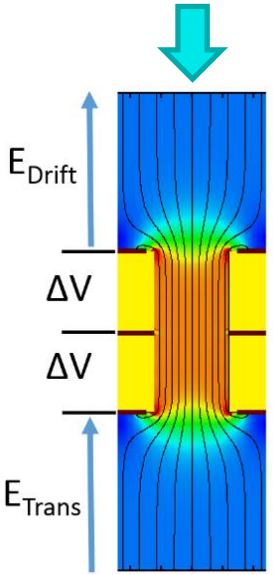
Multi-layer THGEM (M-THGEM)



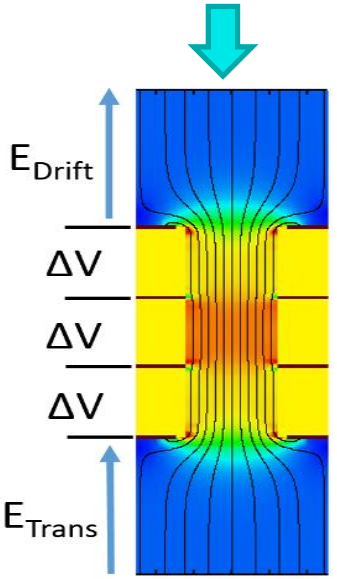
2-Layer M-THGEM



3-Layer M-THGEM



Low pressure applications



AT-TPC & pure gases

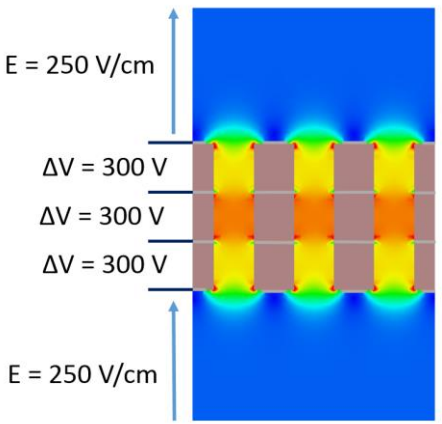
M-THGEM:

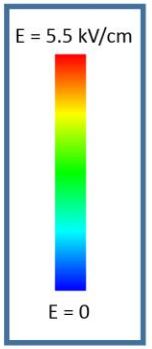
Cascade of THGEM elements with no gas gap.
Manufactured by multi-layer PCB technique out of FR4/G-10/ceramic substrate

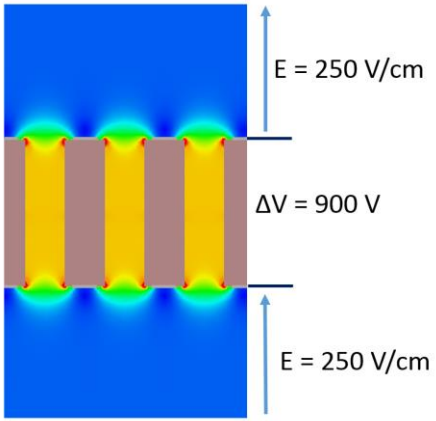
Main features:

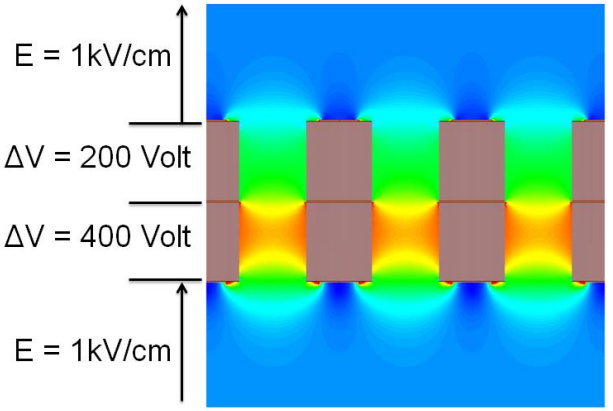
-) No loss of charge ➔ high gain @ low voltage
-) Robust avalanche confinement
➔ lower secondary effects
-) Long avalanche region
➔ high gain @ low pressure
-) Field geometry stabilized by inner electrodes
➔ reduced charging-up

Three-Layer M-THGEM vs Single-layer THGEM

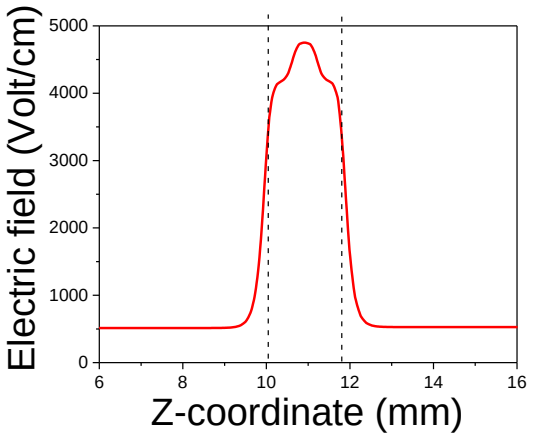




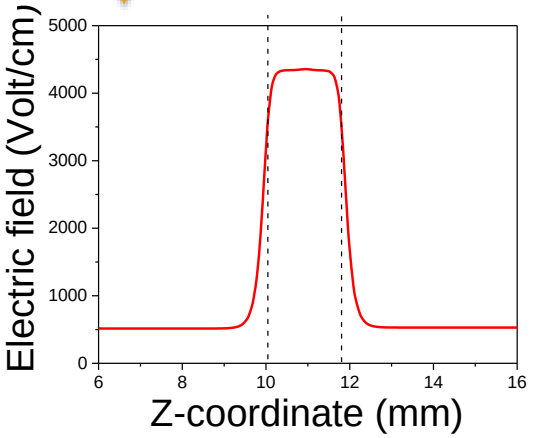




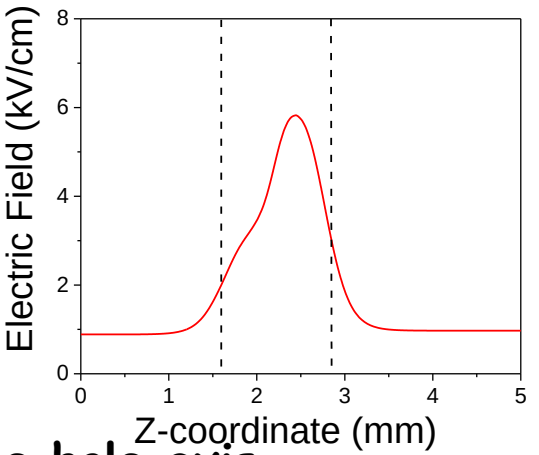
3M-THGEM hole



THGEM hole

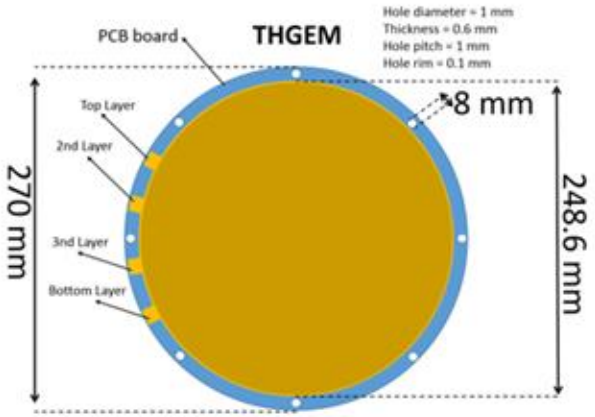


2M-THGEM hole

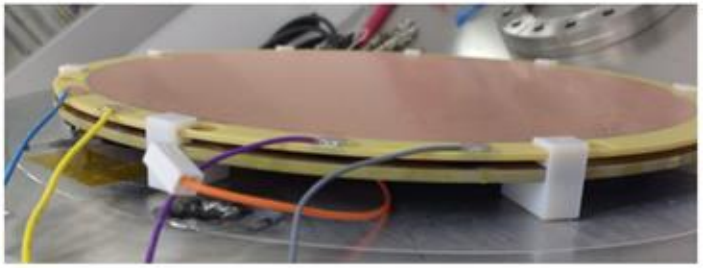


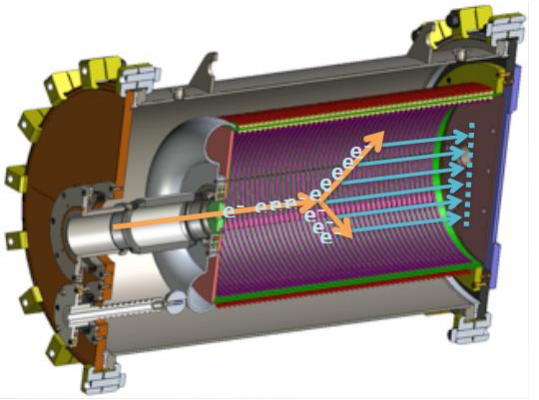
E-field strength computed along the hole axis

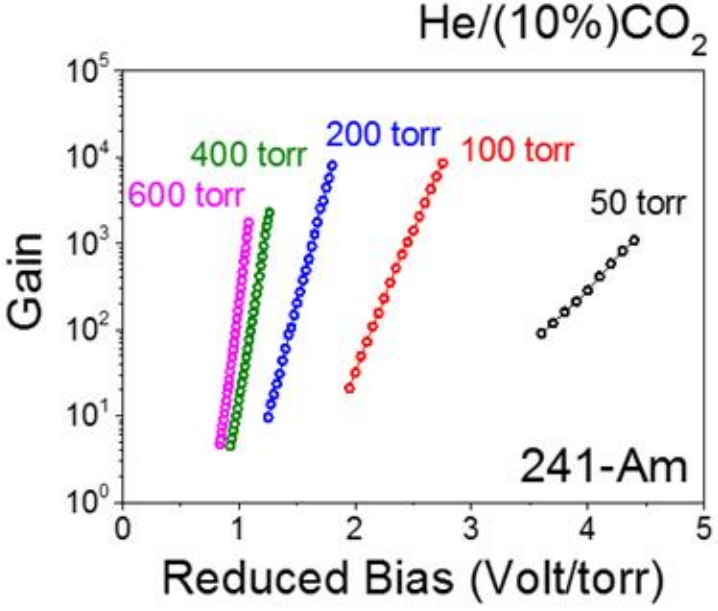
M-THGEM: performance (1)

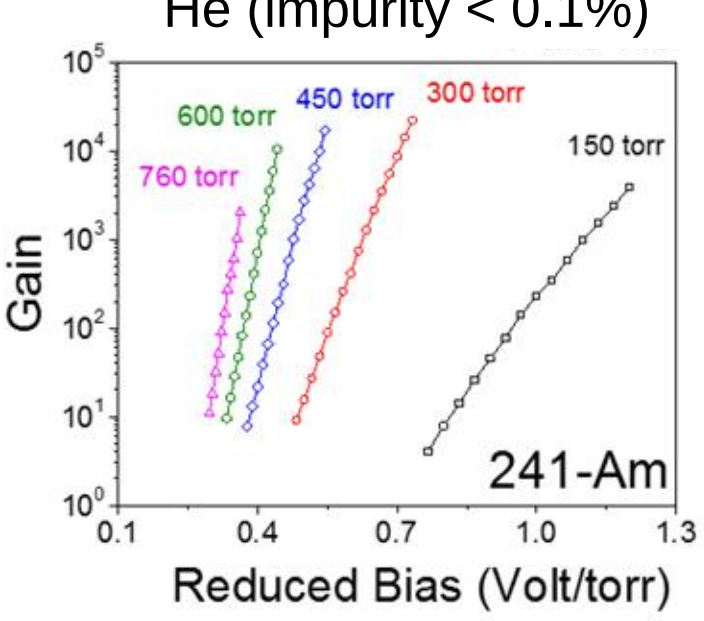


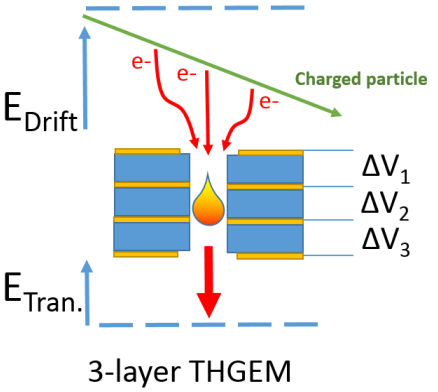
pAT-TPC









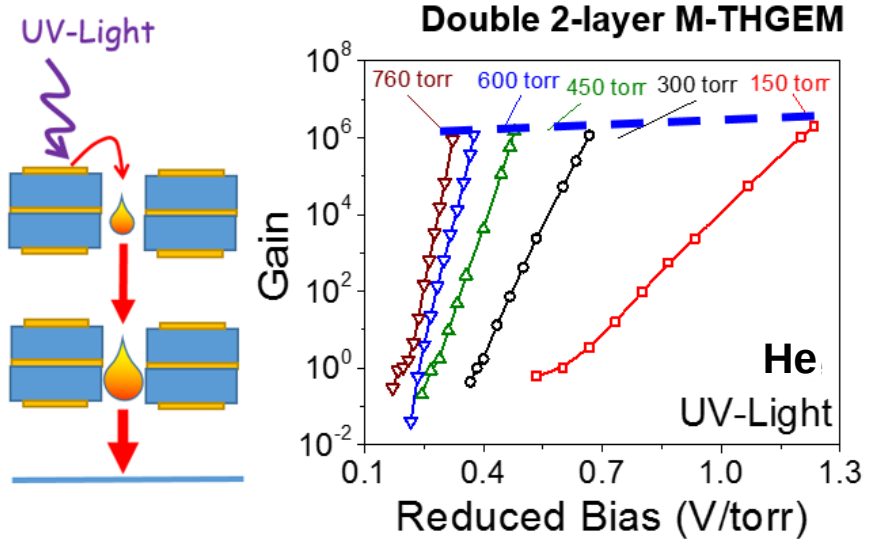


3-layer THGEM

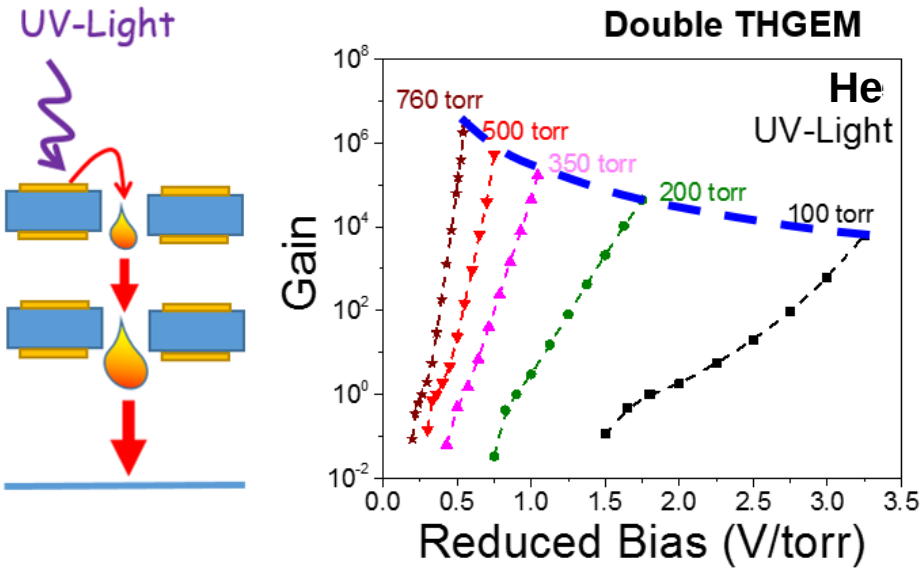
M-THGEM: performance (2)

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)

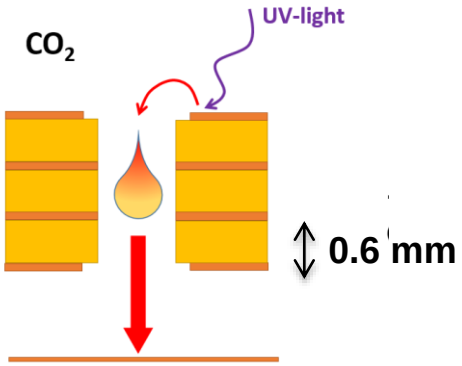


Higher Maximum Achievable gain at low pressure due to lower secondary effects

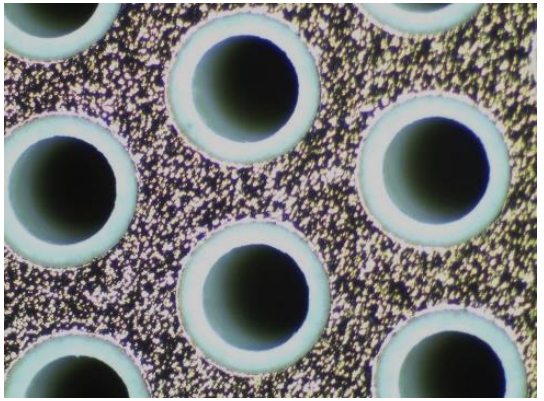
Ceramic M-THGEM

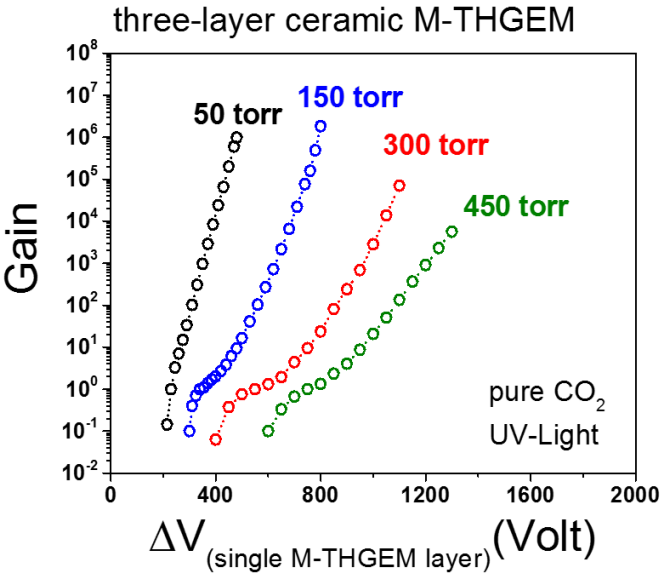
Ayyad et al. 2017 JINST 12 P06003

High-gain operation @ low pressure



Ceramic M-THGEM
10x10 cm²



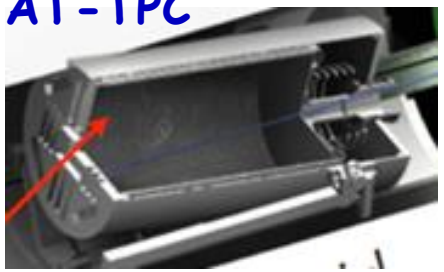


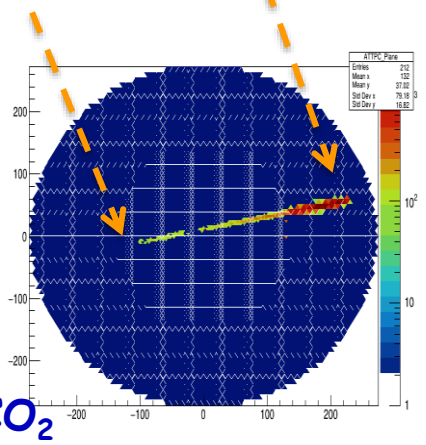
6.1 MeV α-track

Hybrid MM + M-THGEM

252-Cf

AT-TPC

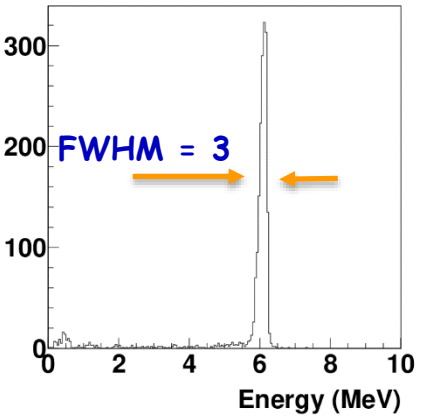




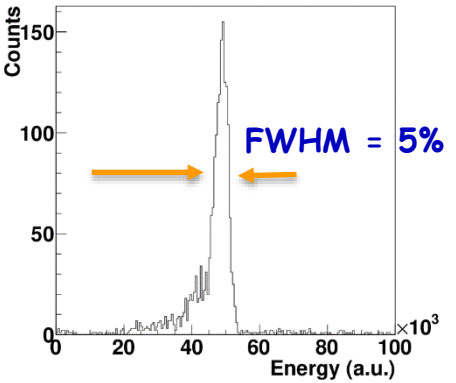
50 torr Pure CO_2

Energy resolution

Range

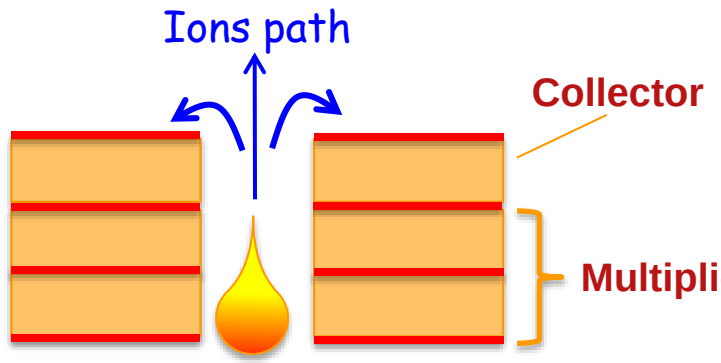


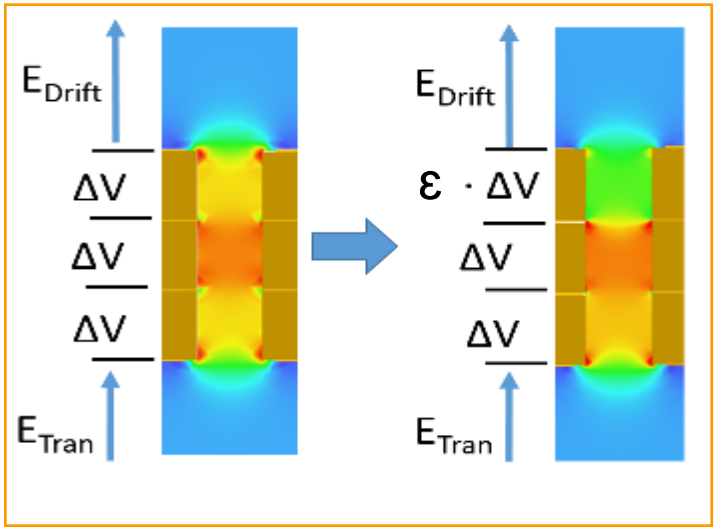
Collected Charge



Ion Backflow: M-THGEM Asymmetric bias mode

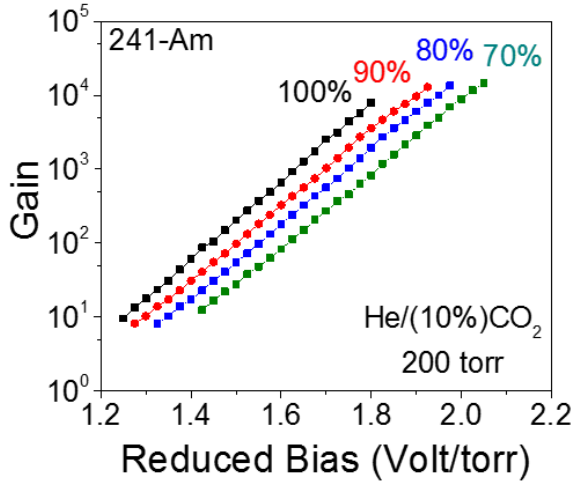
3-layer M-THGEM



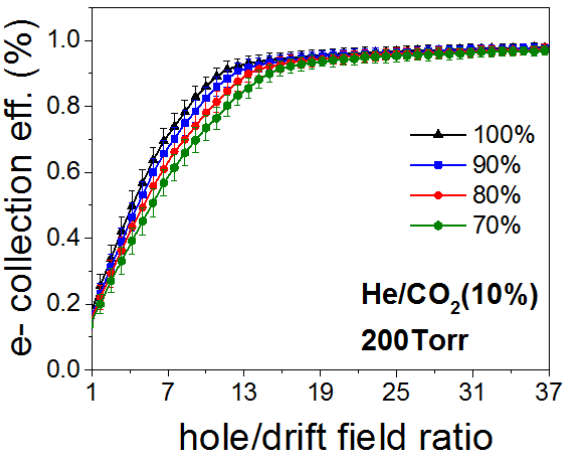


Strategy ➔ Stop ions in asymmetric setup
Problems: energy resolution? Effective gain?

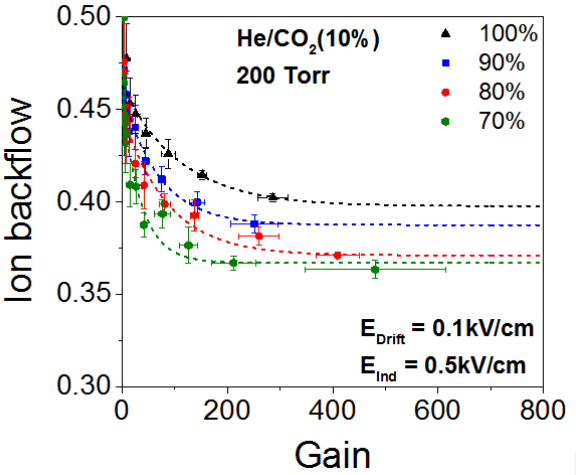
Garfield – Stefan Rost MSc Thesis



Same Max achievable Gain!



No significant loss of e- collection efficiency



Lower ion backflow with cascade configurations

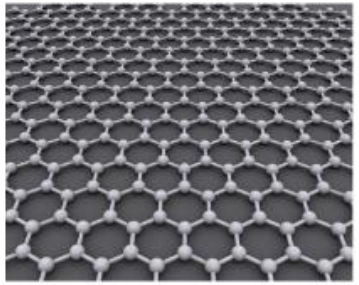
IBF suppression with Graphene

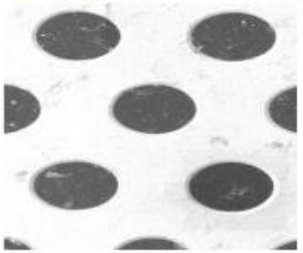
Franchino et al., NIMA 824 (2016) 571-574

RESNATI

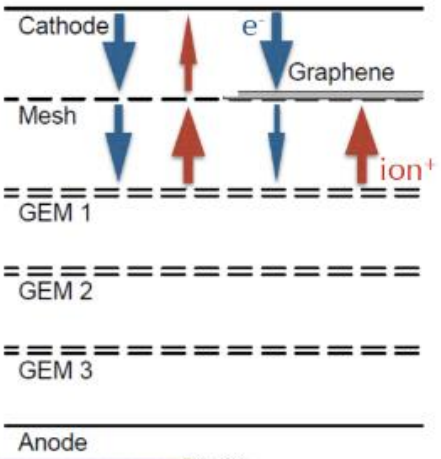
ION BLOCKING w GRAPHENE ON GEM

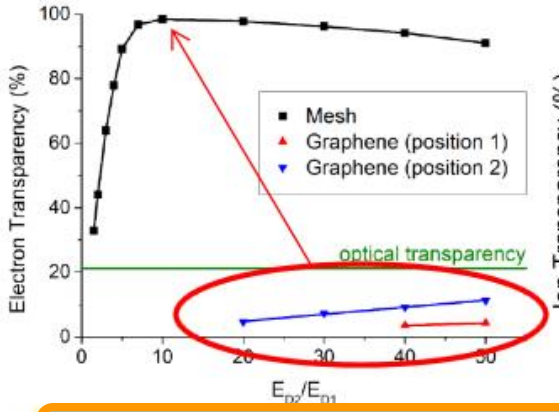
Graphene on "GEM"

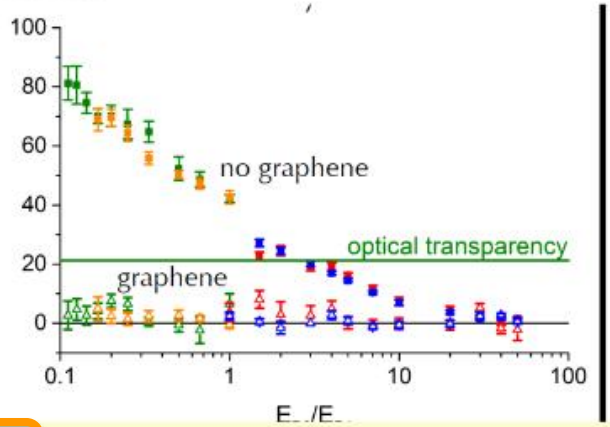


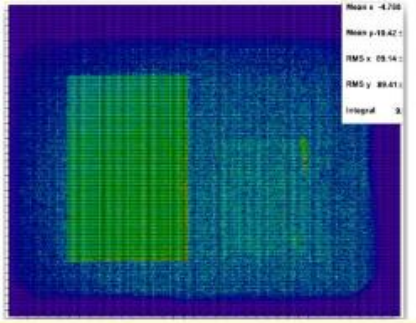


Graphene: opaque to ions and
UNDER SOME CONDITIONS:
transparent to electrons



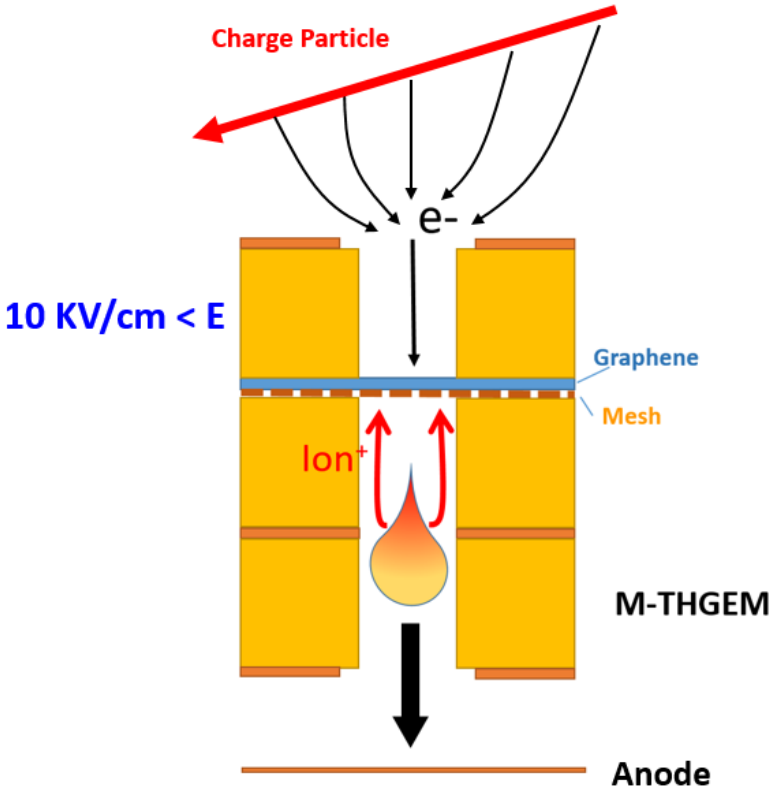






Coating GEM w GRAPHENE: need to increase e- Energy > 10kV/cm. Did not succeed to transmit e- via 3-layer Graphene. Literature: yet unclear (to our community) "directions"

MM-THGEM with inner Graphene electrode



The idea:

sandwich a layer graphene inside the MM-THGEM transparent to the drifting electrons and opaque to ions to suppress the IBF!

-) Hole-type structure
→ e- collection
-) first stage MM-THGEM first stage
→ pre-amplification and mechanical support for the graphene
-) last stages M-THGEM
→ gas avalanche process

Parameters to be estimated:

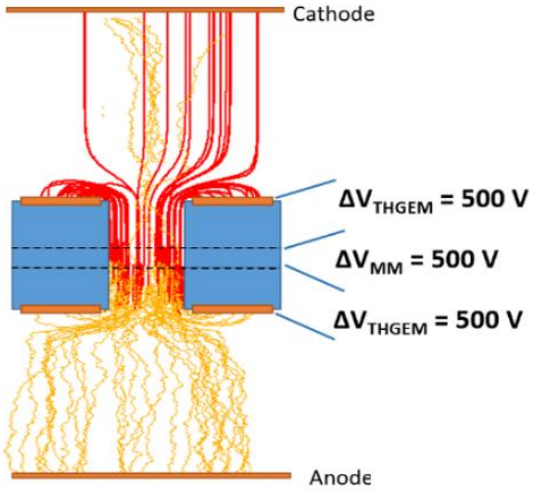
-) Electrons/ions transparency vs gain/bias configuration
-) Homogeneity of the graphene
-) Mechanical Robustness and stability
-) Aging (radiation-induced damages)
-) Production techniques
-) IBF reduction (including cascade geometries)
-) Multi-layer THGEM and possible different configurations (intermediate layers between different electrodes)

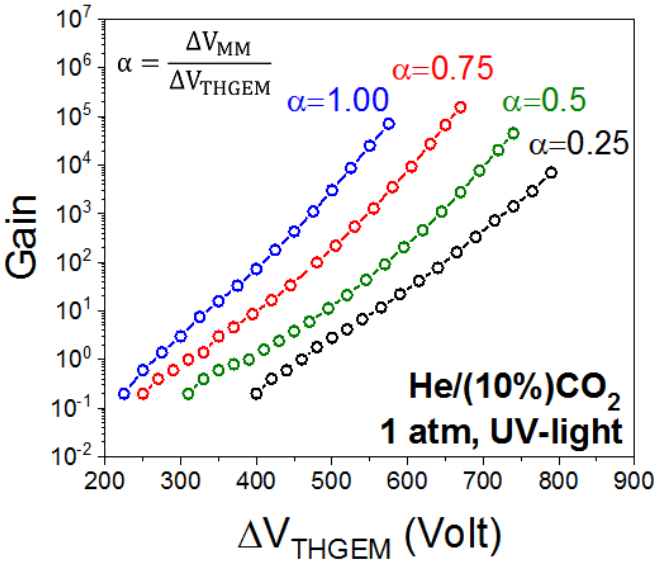
-) First prototype will be ready for evaluation in a few weeks
-) Phase I DOE SBIR/STTR submission in collaboration with a USA company!

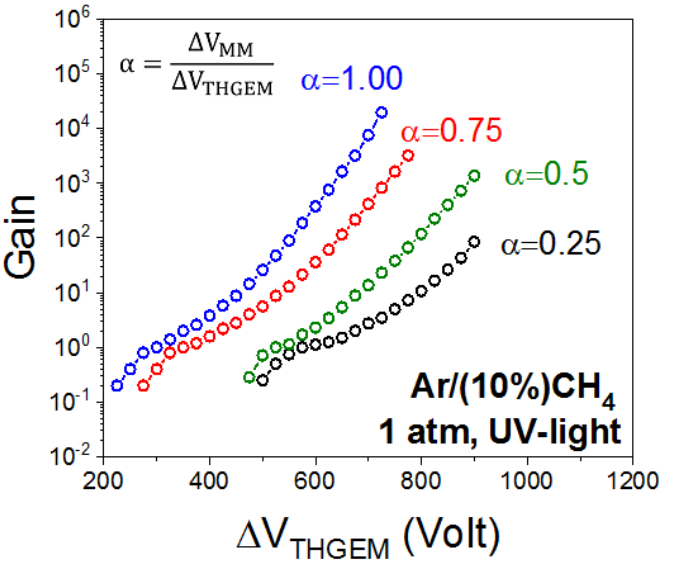
M-THGEM derived Structures: MM-THGEM

Multi-Mesh THGEM (MM-THGEM)

Single MM-THGEM



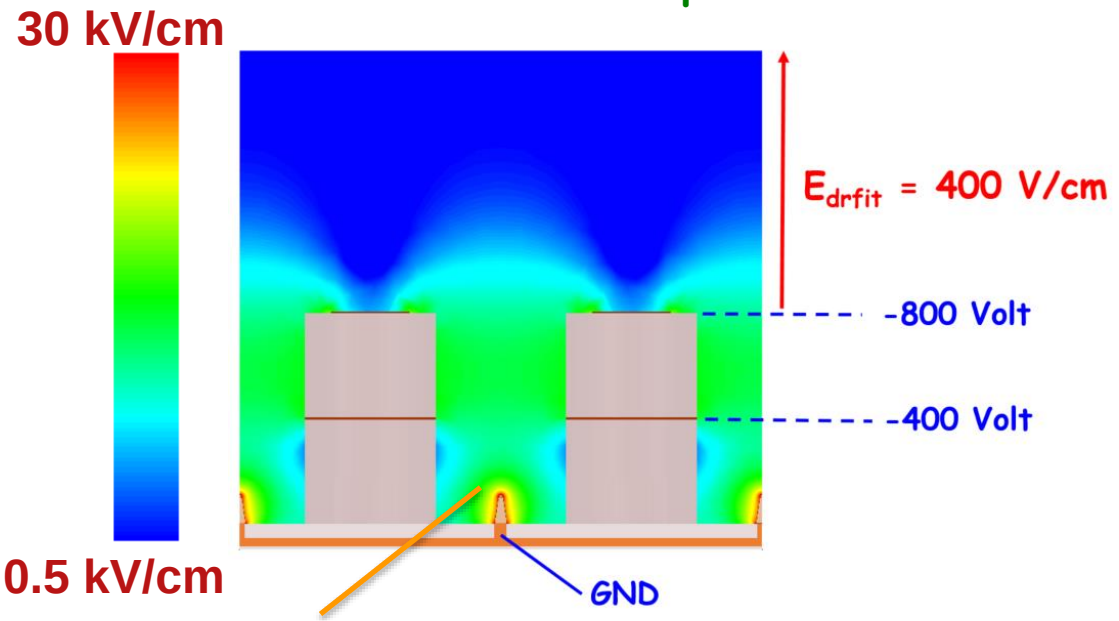


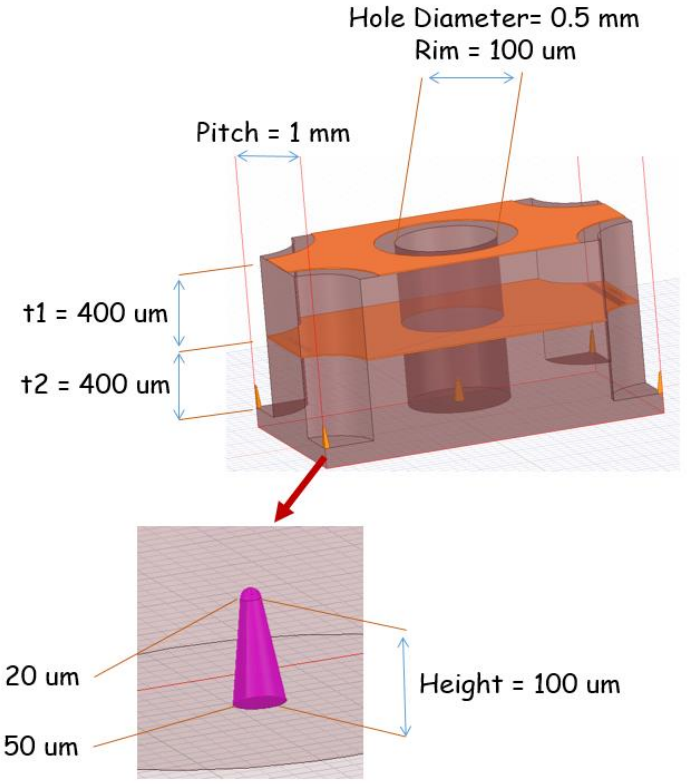


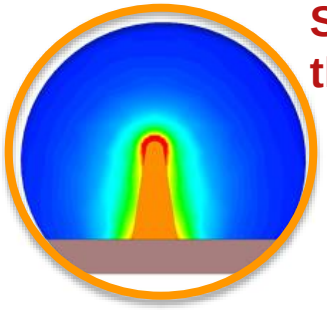
Goal: double Micromegas supported by M-THGEM over large area

M-THGEM derived Structures: TIP-HOLE

New Concept: Electrons focused in the hole-type structure, pre-amplified along the multi-layer THGEM and multiplied by gas-avalanche process in the proximity of the anode tip.







Strong electric field on the tip of the needle

Advantages:

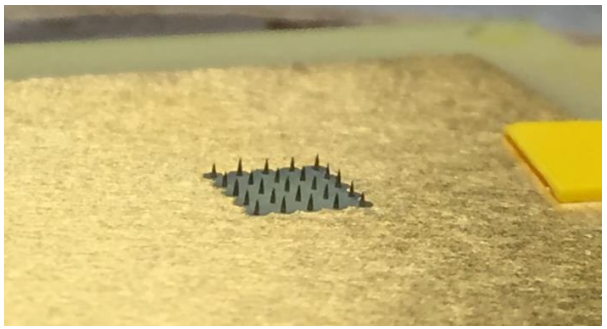
-) Multi-stage amplification ➔ large gain at low pressure

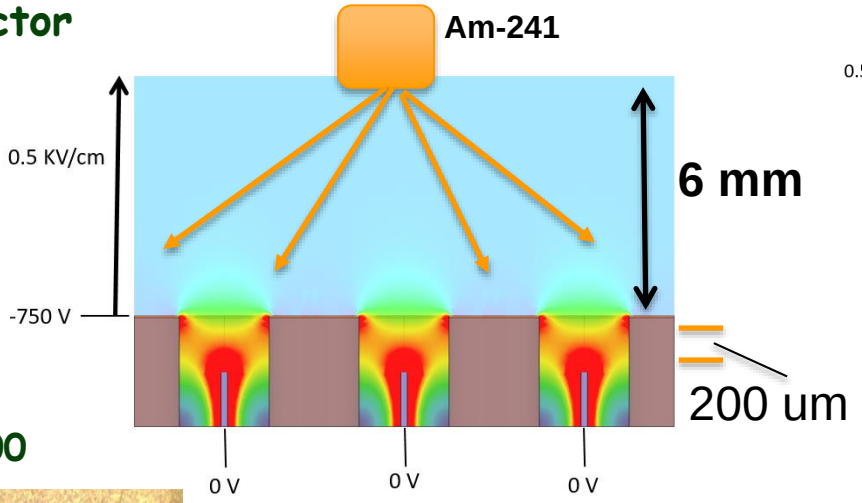
-) High amplification in pure iC_4H_{10}, pure propane … at 1 atm

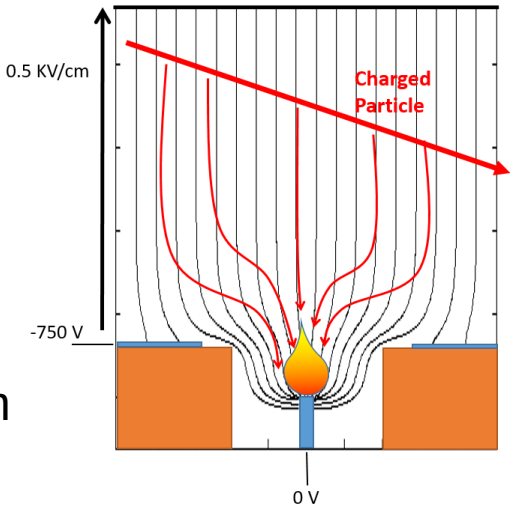
-) Close geometry ➔large versatility

First TIP-HOLE prototype

5x5 needles TIP-HOLE detector

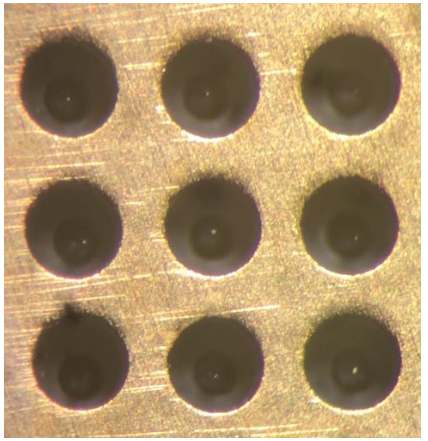


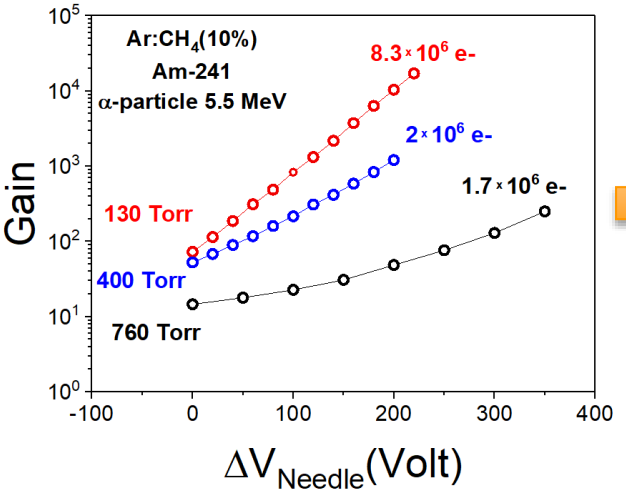




J. Randhawa & AT-TPC (MSU) undergraduate students

Tattoo Needle (Nickel): Size 00





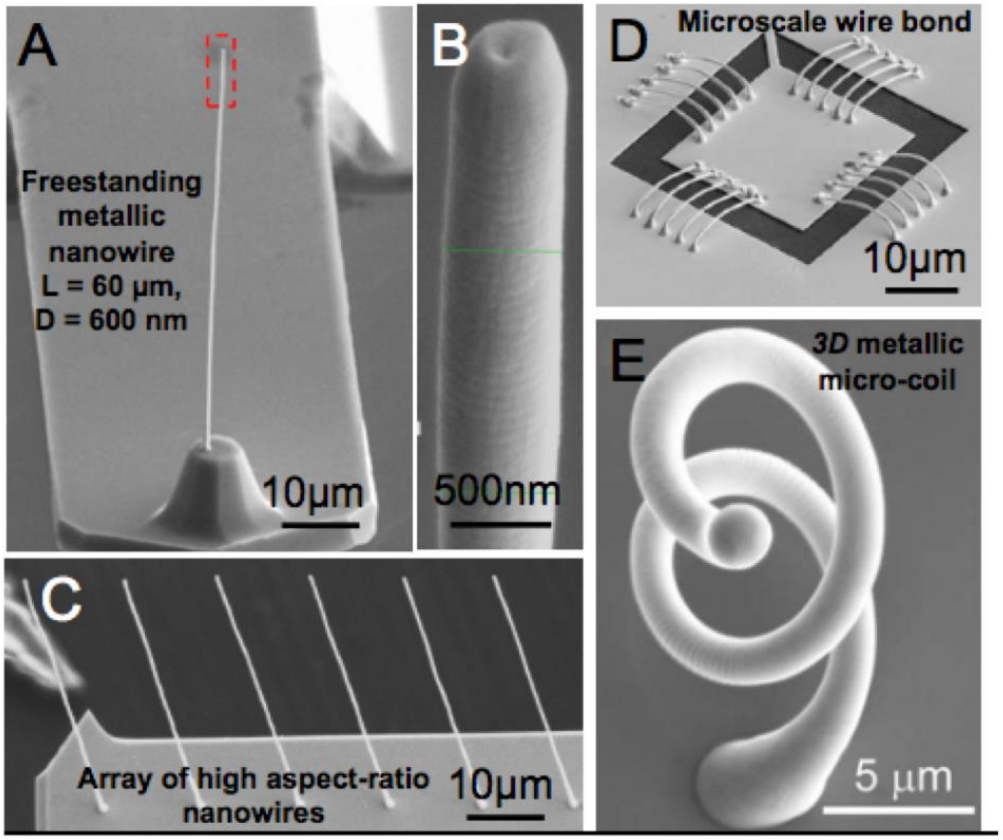
Next step:
Production of "large-area" prototypes

First "homemade" prototype succefully operated in P10 at different pressure

Scalable Additive Manufacturing Technology for Large Area PCBs

NSCL & UHV Technology Inc.

Phase II DOE SBIR/STTR project (DE-SC0017233)



"… room temperature fabrication of high conductivity copper interconnects on 3D printed plastic parts, enabling **for the first time**, printing of metallic and plastic parts in a single low cost 3D printer …"

NSCL team= M. Cortesi, J. Randhawa, W. Mittig

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Award Number DE-SC0017233

U.S. DEPARTMENT OF ENERGY | Office of Science

Summary & Conclusions

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

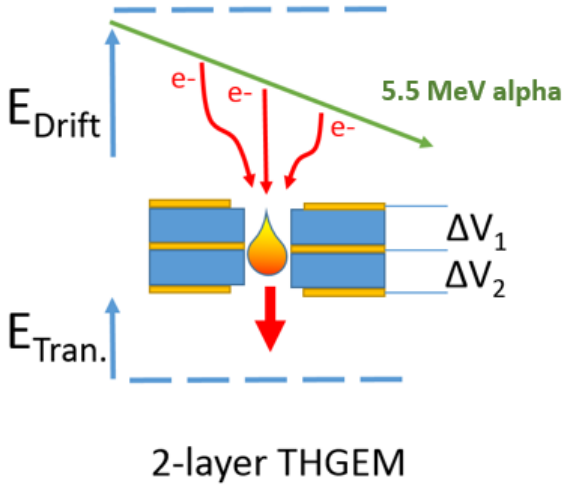
M-THGEM: first MPGD specifically conceived for applications in Low-E NP TPC in pure elemental gas (H_2, D_2, H_3, H_4, etc.) @ different pressure!

➔ Goal: confine electron avalanche volume in a close geometry to reduce photon-mediated secondary effect
- -) Achieved High maximum achievable gain with no quencher
- -) Covered Large Pressure range
- -) New ideas derived from the Multi-layer configuration

Long-term gain stability of Ceramic M-THGEMs

Two-layer ceramic M-THGEM

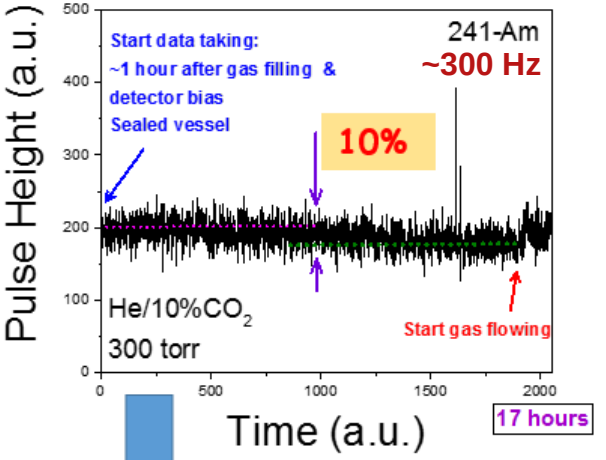
10x10 cm² prototype
12 mm drift ➔ E_{Drift} = 1 kV/cm
3 mm trans. ➔ $E_{trans.}$ = 0.33 kV/cm
$\Delta V_{M\text{-}THGEM}$ = 480 Volt
Counting rate ≈ 700 Hz

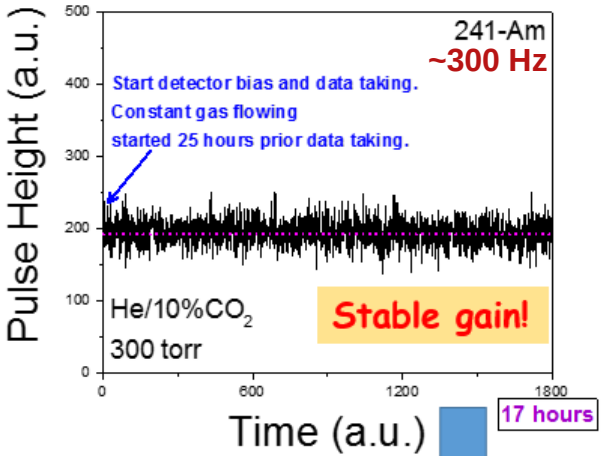


2-layer THGEM

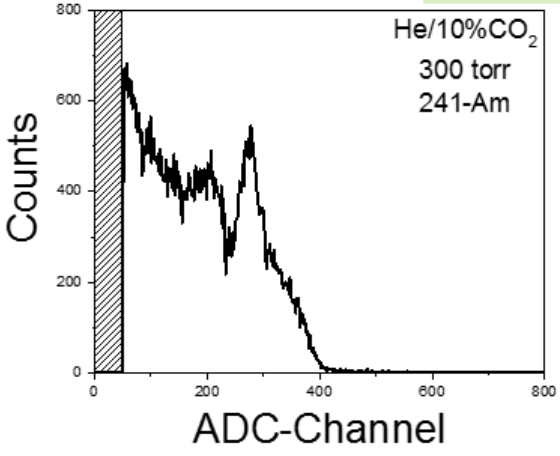
No significant charging up effect at low rate!

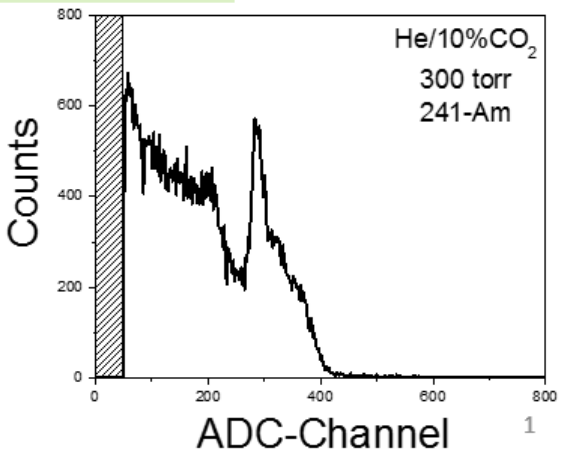
Each point is the average of ≈150 recorded pulse (1 pulse/sec)





Not collimated source





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