Development of new MPGD structures for nuclear physics applications

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Outline

-) Introduction – RIBs experiments & requirements
-) Multi-layer THGEMs (M-THGEM) → exotic-reaction studies
-) Multi-Mesh THGEM (MM-THGEM)
-) New structures (ideas & preliminary results) – TIP-HOLE detector
-) Summary and Conclusions

Fantastic Nuclei and where to find them

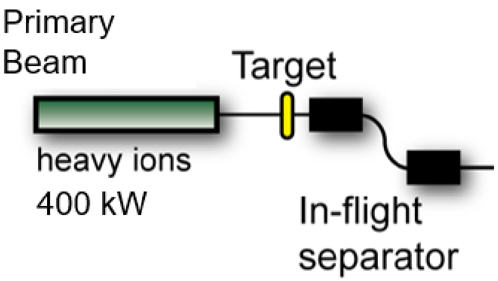
Nuclear Science Challenges addressed by Rare Isotope Beam Physics

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

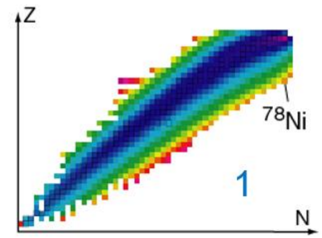
Use atomic nuclei to tests of laws of nature
- Effects of symmetry violations are amplified in certain nuclei

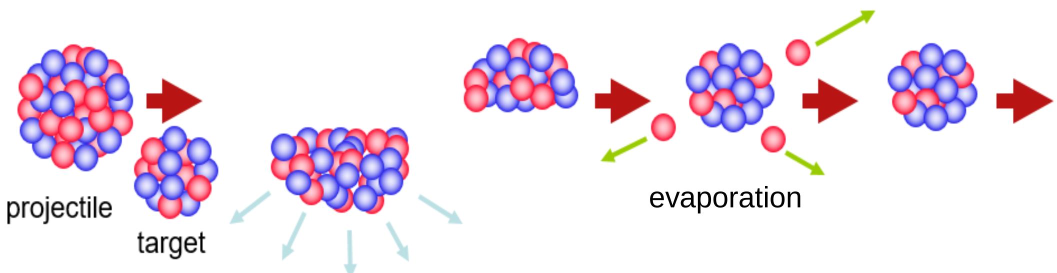
Societal applications and benefits
- Medicine, energy, material sciences, national security, etc. etc.

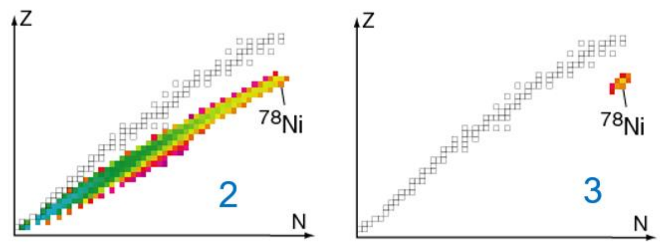


Rare Isotope Beam Physics -> Projectile Fragmentation

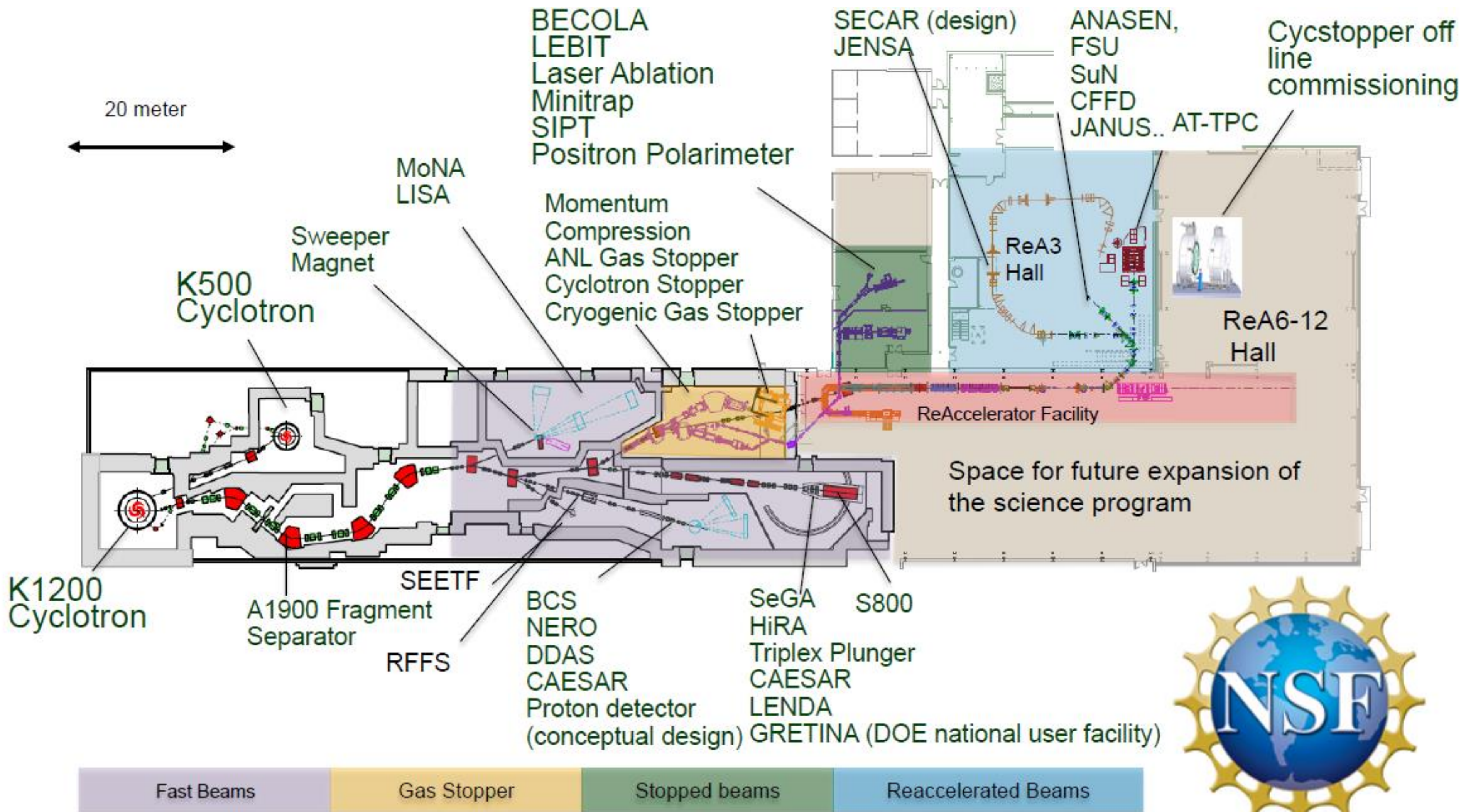
- Production occurs at high energies (~100MeV/u)
- Many isotopes are produced simultaneously







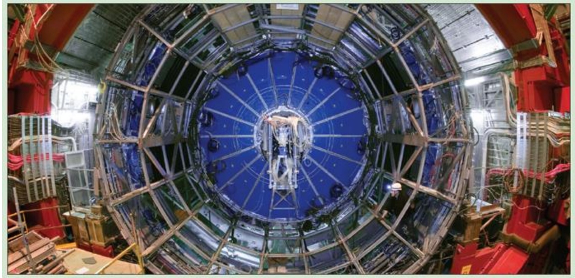
Pre-FRIB Science Opportunities at NSCL
with Fast, Stopped, Reaccelerated Beams

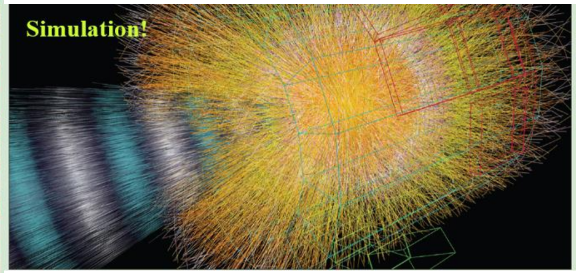


Tracking system for RIBs: requirements

High-E Particle Physics

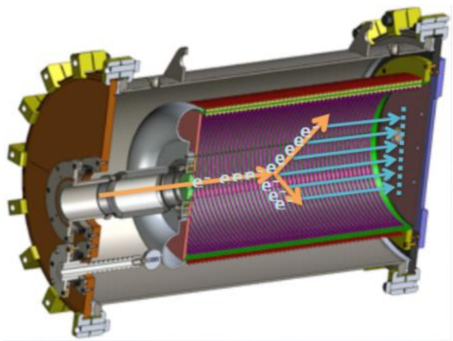
LHC-ALICE ➔ Tens of thousand tracks per event!

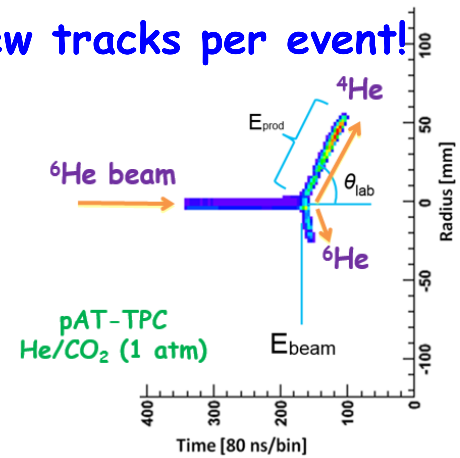




-) High gain (MIPs, Photons, etc.)
-) High Multiplicity
-) Specificity
-) High rate
-) Large & complex
-) IBF → mostly from the gas avalanche readout
-) …

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





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

Low-E Nuclear Physics

-) Modest gain (heavy charged particles)
→ different specific ionization density
-) Low Multiplicity
-) Versatility (one setup many experiments)
→ large dynamic range (different pressure)
→ active target mode (pure elemental gas)
-) Low/moderate rate
-) Small setup, simple
-) IBF → mostly from the beam particles
-) …

Applications: Reaccelerated Beams

Goal: Study of inverse-kinematic nuclear reactions

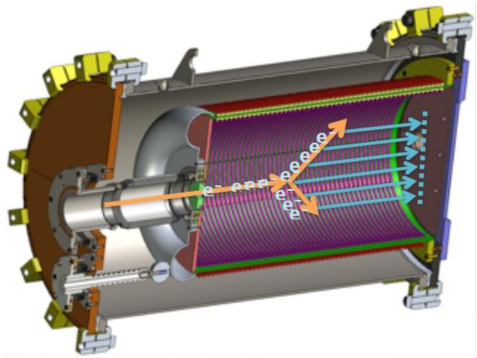
Active-Target Time Projection Chamber (AT-TPC)

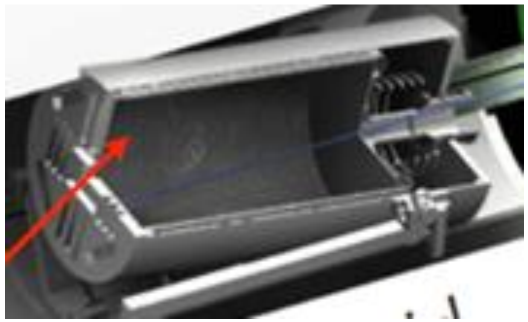
pAT-TPC

- Active volume 25 liters (L = 50 cm, Ø = 25 cm)
- Cylindrical pad plane (1,000 pads)

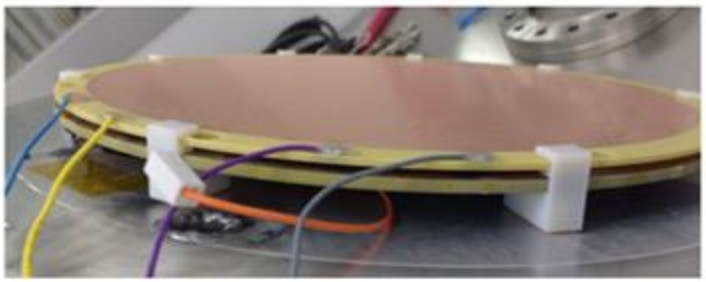
Full scale AT-TPC

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





Hybrid readout: Micromegas + THGEM-like structures



Filling Gas/Target

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

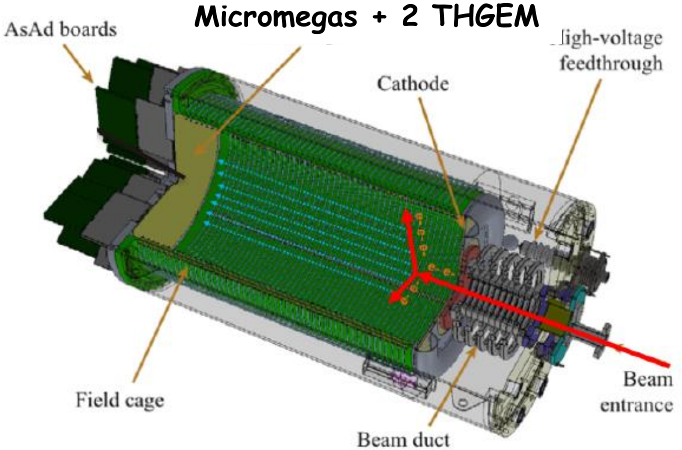
-) Purity (no quencher)
→ High Reaction Yield
-) Low-Pressure Operation
→ Large Dynamic Range

Gas Gain, Energy Resolution, Spatial Resolution, Counting Rate Capability, Stability etc…

Cortesi et. al. EPJ Web of Conferences 174, 01007 (2018)
Ayyad et al. Eur. Phys. J. A (2018) 54: 181

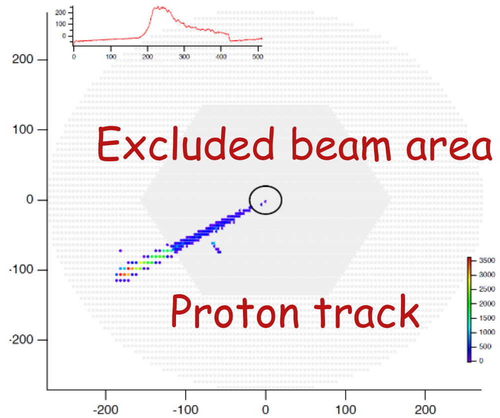
AT-TPC with Reaccelerated Beams

Full-Scale AT-TPC



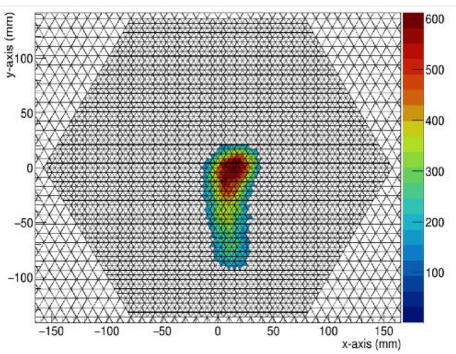
Why Gas-filled AT-TPC for low-energy nuclear physics?

- -) 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
- -) Full excitation function with mono-energetic beam

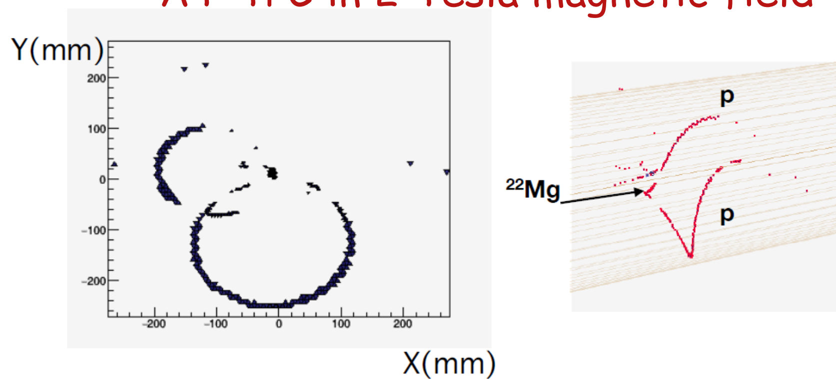


$^{40}Ar(p,p)$ in pure H_2
Spokeperson: D. Bazin

$^{46}K+^{208}Pb$ Fusion-Fission
in 100 Torr P10
Spokeperson: N. Watwood



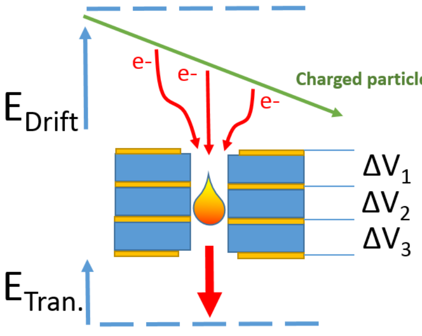
AT-TPC in 2 Tesla magnetic field



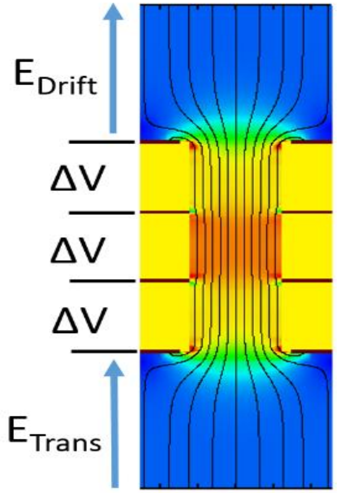
$^{22}Mg(\alpha,2p\ \alpha)$ in $He:CO_2(10\%)$
Spokeperson: Y. Ayyad

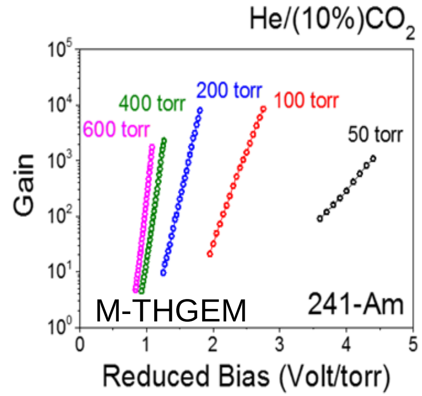
Multi-layer THGEM (M-THGEM)

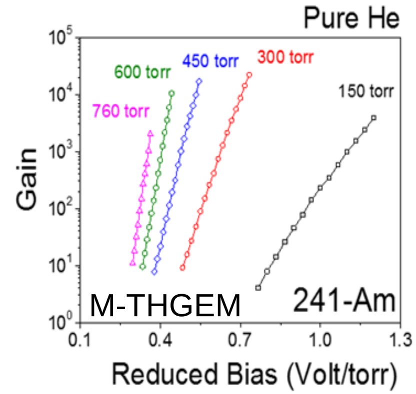
Cortesi et al. Rev. Sci. Instrum. 88, 013303 (2017);



3-layer THGEM

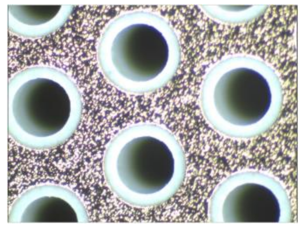


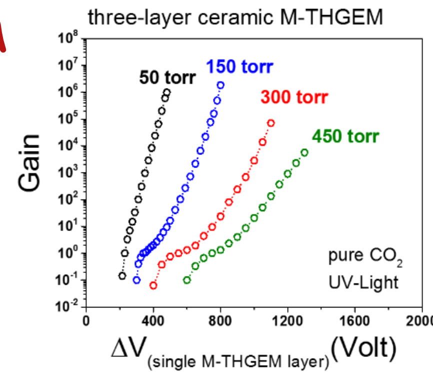




- -) No loss of charge ➔ <u>high gain @ low voltage</u>
- -) Robust avalanche confinement
  ➔ <u>low photon-mediated secondary effects</u>
- -) Long avalanche region
  ➔ <u>high gain @ low pressure</u>

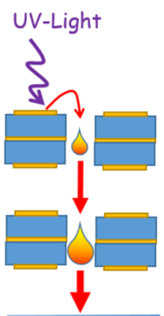
Ceramic M-THGEM

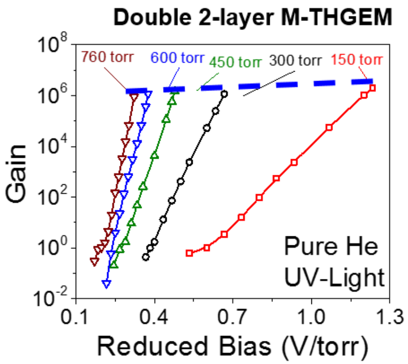


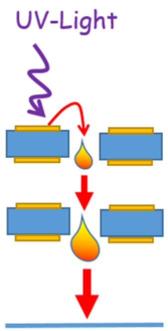


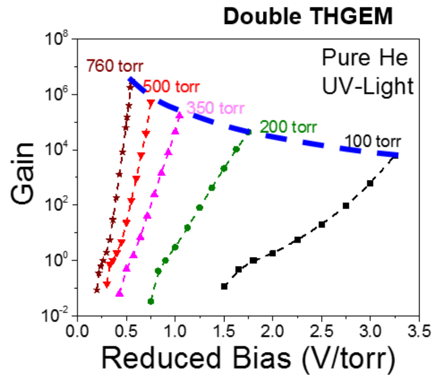
<u>10x10cm² M-THGEM</u>
(thickness = 1.2 mm, hole = 0.5 mm, pitch = 1 mm)

<u>10x10cm² THGEM</u>
(thickness = 0.6 mm, hole = 0.5 mm, pitch = 1 mm)







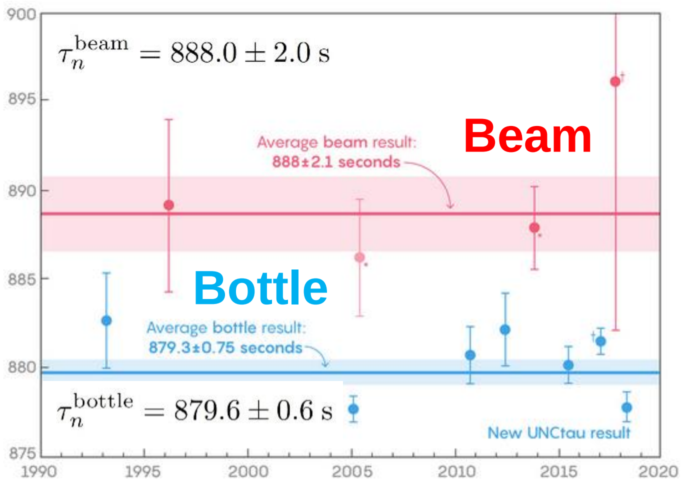


Higher maximum achievable gain @ low pressure due to lower photo-mediated secondary effects

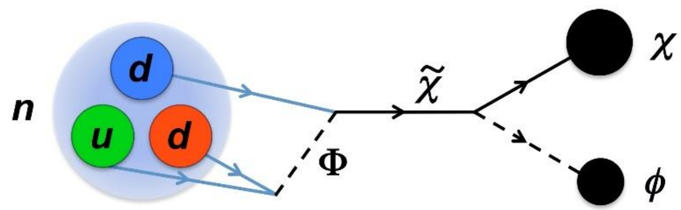
Applications: Stopped Beams

Neutron lifetime puzzle & Dark decay

Free neutron lifetime measured in beam and in bottle are ~4σ away!
Different observables measuring different decay modes?



Fornal and Grisntein
PRL 120, 191801(2018)

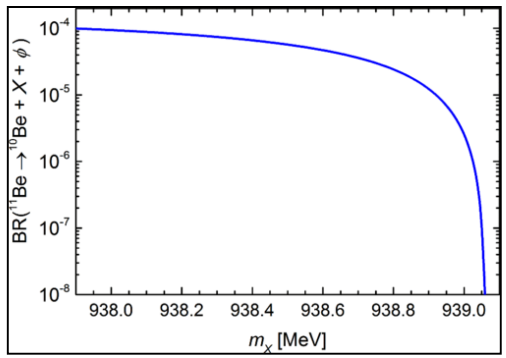


-) Fornal and Grisntein suggested that the n could decay to a dark matter particle
-) A branching ratio of ~1% would explain the n lifetime puzzle

Suggestion: **Dark decay also possible in halo nuclei (weakly bound n) ➔ S_n<1.572 MeV**

Possible candidates: ^{6}He, ^{11}Li, ^{11}**Be**, ^{15}C, and ^{17}C → branching ratio upper limit of 10^{-4} depending on the dark particle mass.

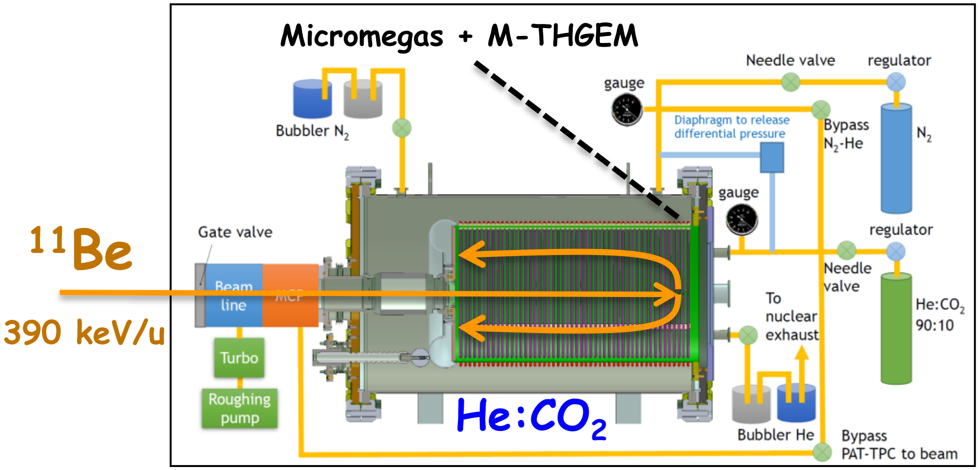
^{11}Be → ^{10}Be (β-delay proton emission + dark decay) measured using AMS with a branching ratio of 8.3(9) ·10^{-6}



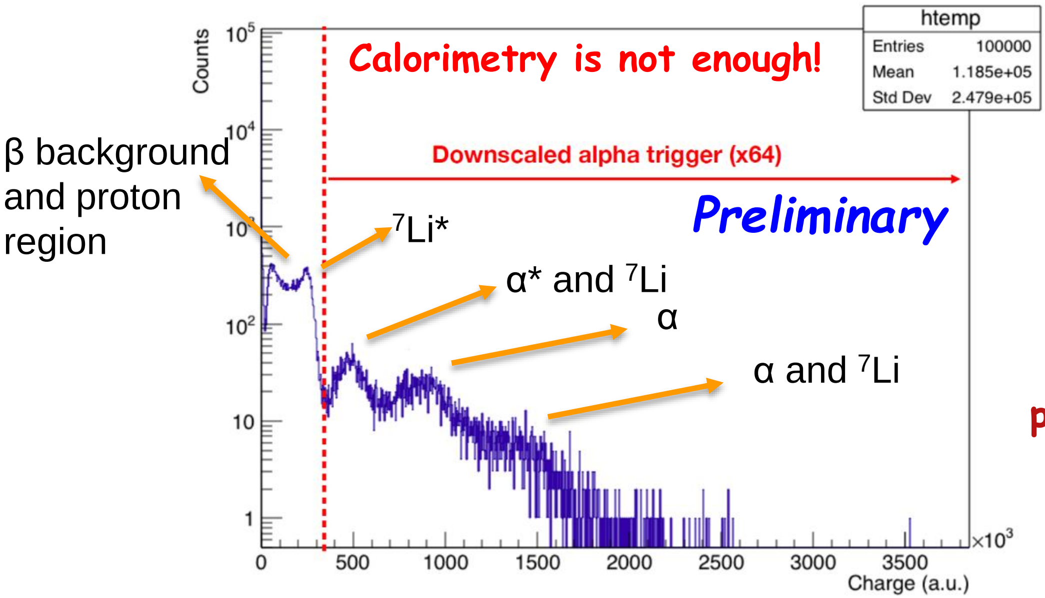
Pfutzner, PRC 97, 042501 (2018)

Experimental setup & preliminary results

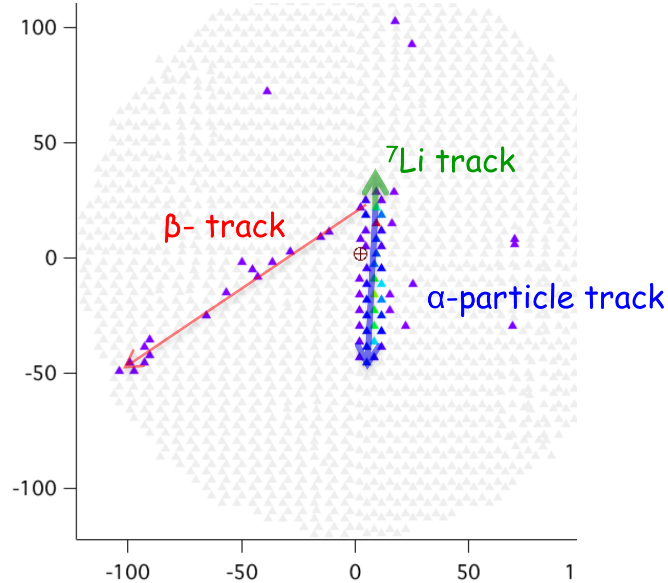
First observation of a β⁻ delay proton emission!



PIs: Y. Ayyad (NSCL) & B. Olaizola (TRIUMF)



Example of tracks from a beta(minus)-delay alpha emission

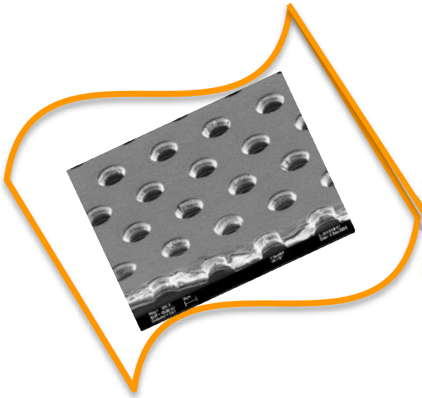


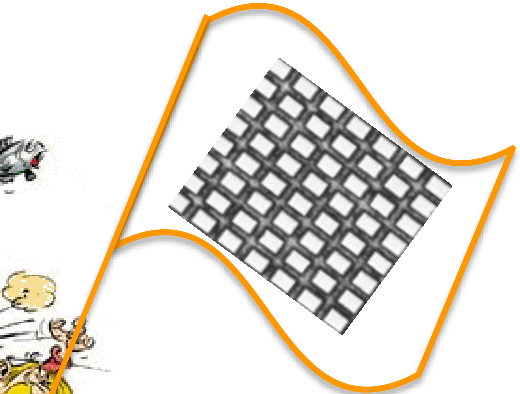
pAT-TPC → tracking of particles with two order of magnitude difference in specific ionization density

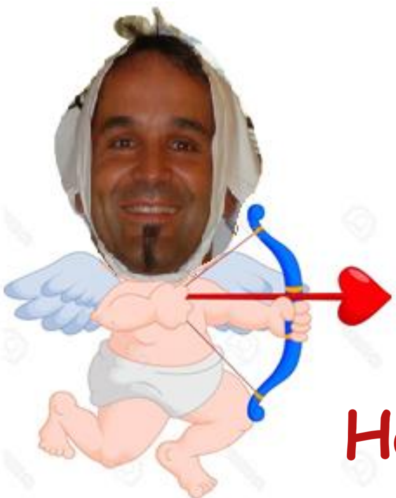
Preliminary (^{11}Be → ^{10}Be + p) branching ratio results (10^{-5}- 10^{-6}) compatible with AMS ^{11}Be → ^{10}Be value ($8.3 \cdot 10^{-6}$).

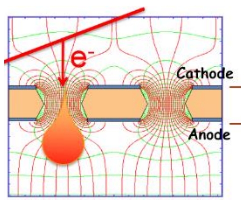
The Battle for the Throne

The Battle for the Throne

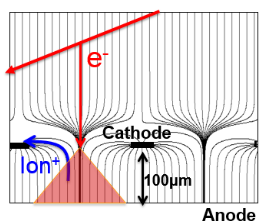




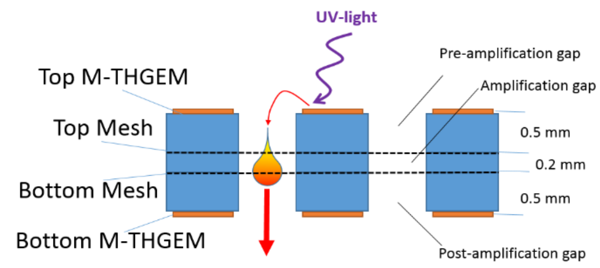




Hole-like



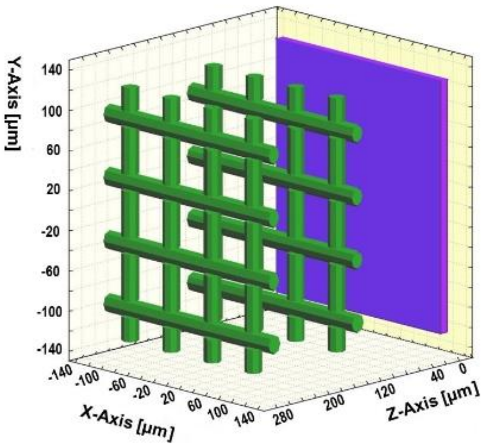
Meshes

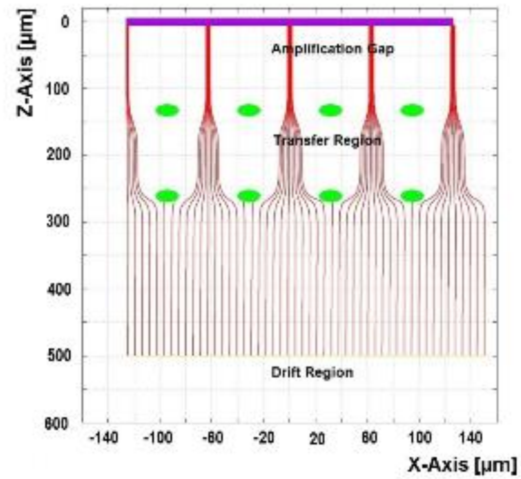


Multi-Mesh THGEM

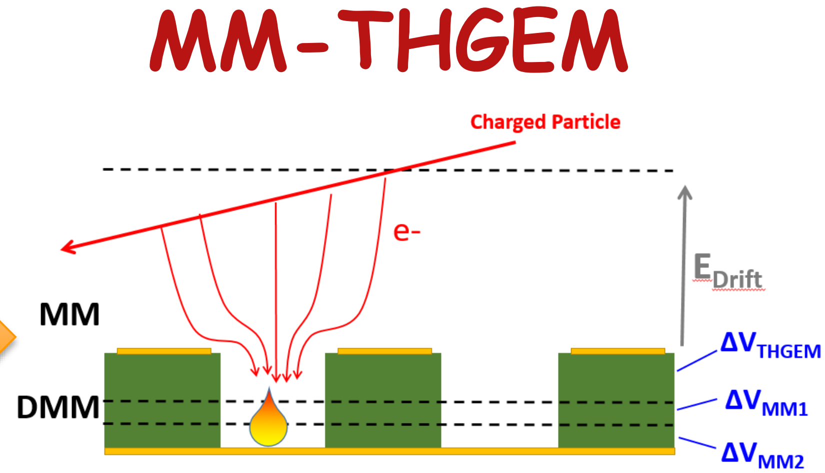
The idea: M-THGEM as support for the Double MicroMegas

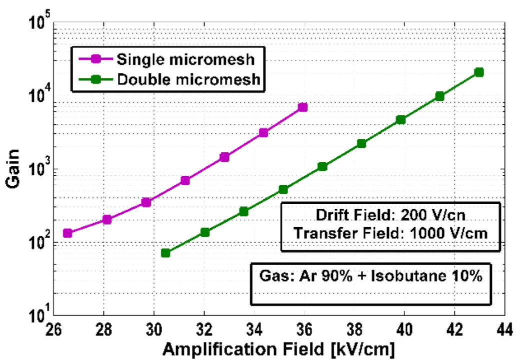
P. Bhattacharya et al 2015 JINST10 P09017

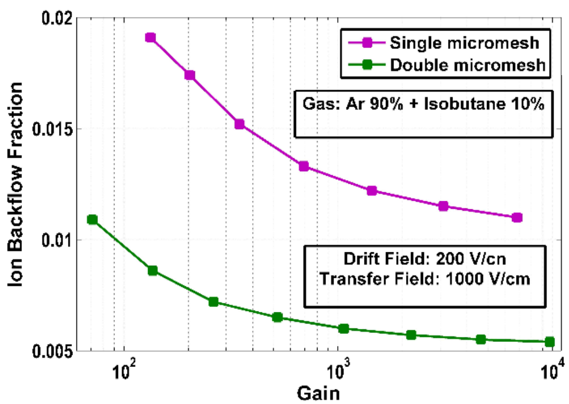




DMM → larger gain, lower IBF
Mechanical stability of DMM over large area?



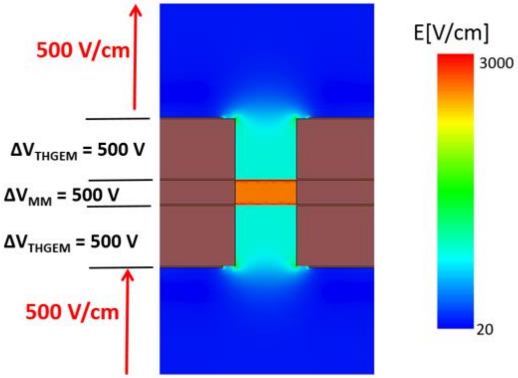


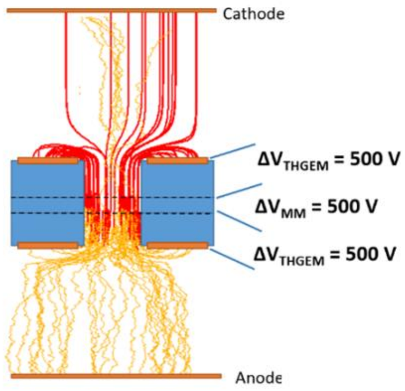


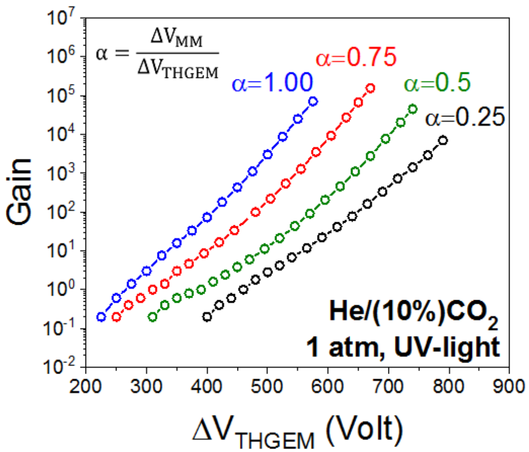
The Multi-Mesh THGEM

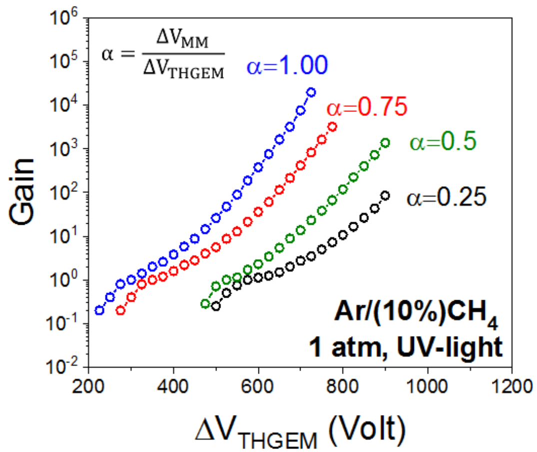
De Olivera & Cortesi 2018 JINST P06019

Maxwell-Garfield Simulations



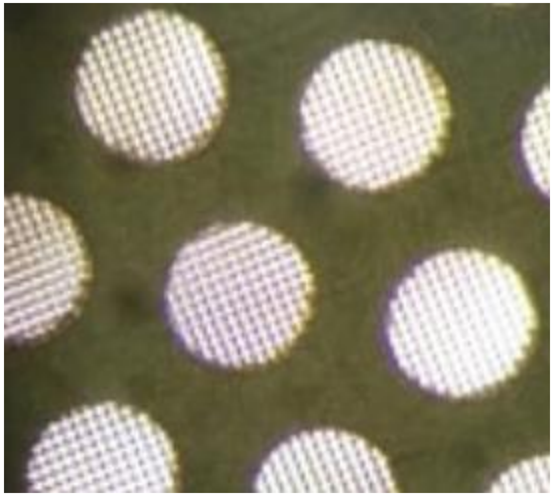






Advantages:
- -) Uniform avalanche field
- -) Lower Ion backflow
- -) Double/Replaceable MM over large area

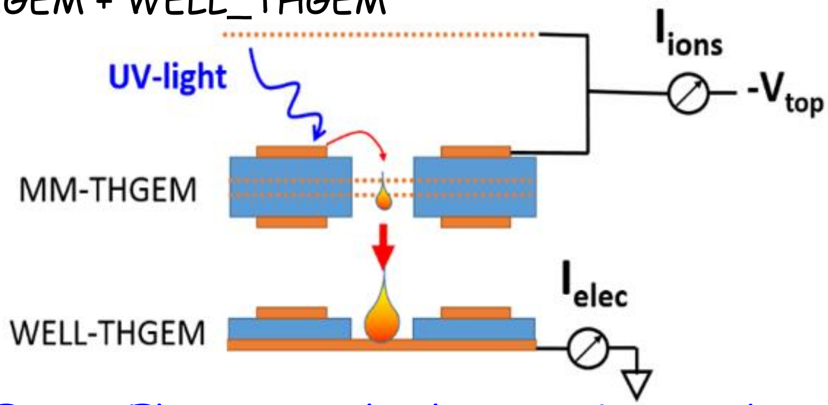
Disadvantages:
- -) Loss due to poor e- transfer efficiency



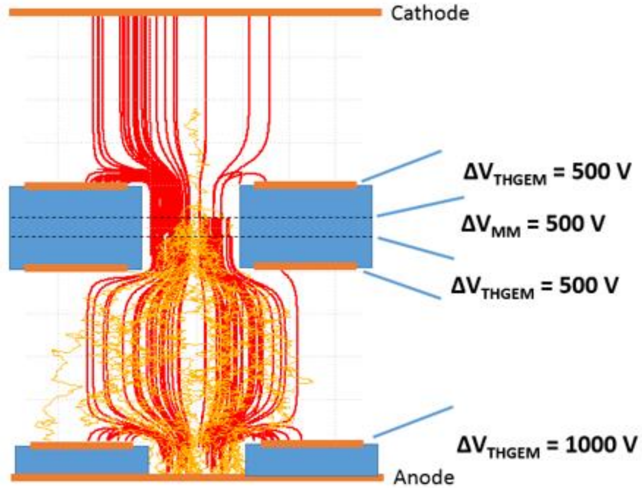
- **-) High effective (single photoelectron) gain (> 10^5) with single element**
- **-) Higher gain with small pre/post avalanche multiplication (α=1)**
- **-) Higher stability and higher max achievable gain at lower operational voltage**

Multi-Mesh THGEM: more results

Two cascade elements
MM-THGEM + WELL_THGEM



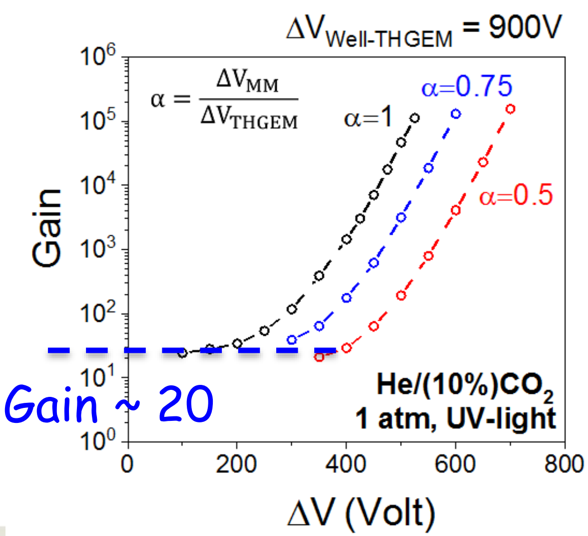
R. De Olivera & M. Cortesi ArXiv:1804.04643

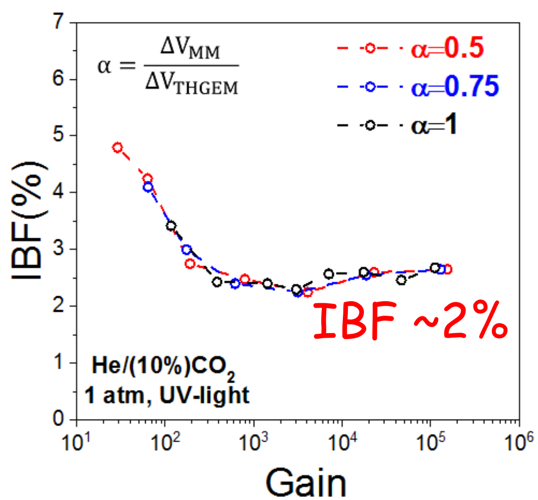


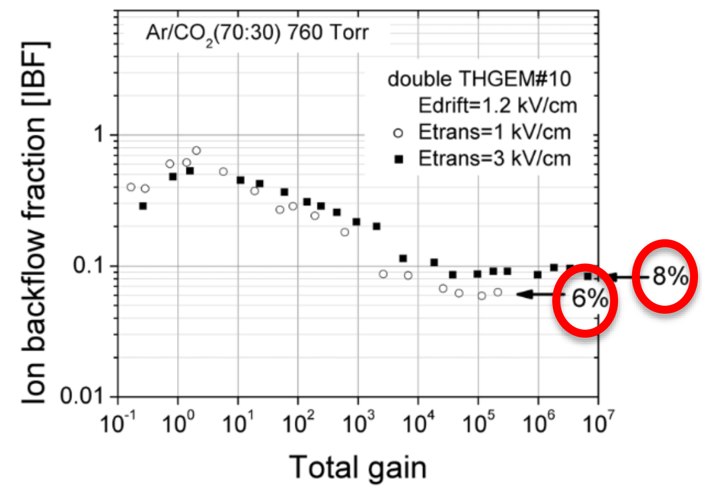
MM-THGEM ➔ Electron multiplication & stop the ions
WELL-THGEM ➔ Extra gain

Double-THGEM

C. Shalem et al. NIM A558 (2006) 475-489





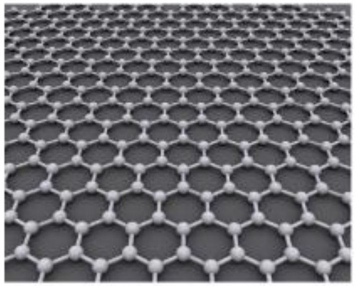


IBF suppression with Graphene

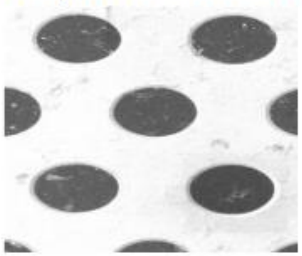
Franchino et al., NIMA 824 (2016) 571–574

RESNATI

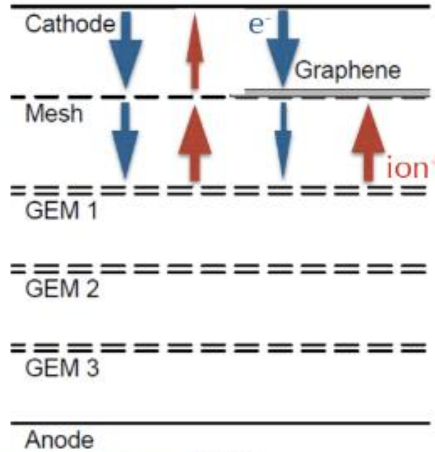
ION BLOCKING w GRAPHENE ON GEM

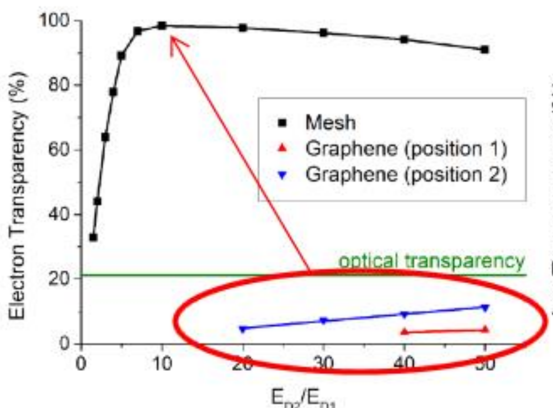


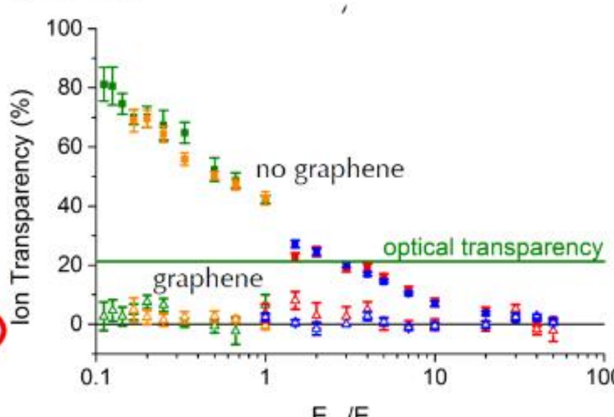
Graphene on “GEM”

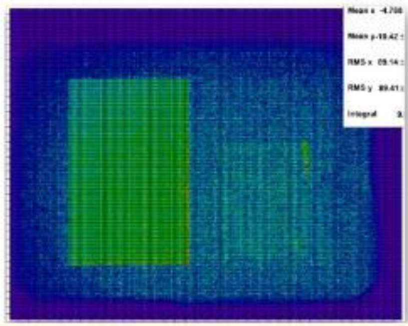


Graphene: opaque to ions and
UNDER SOME CONDITIONS:
transparent to electrons



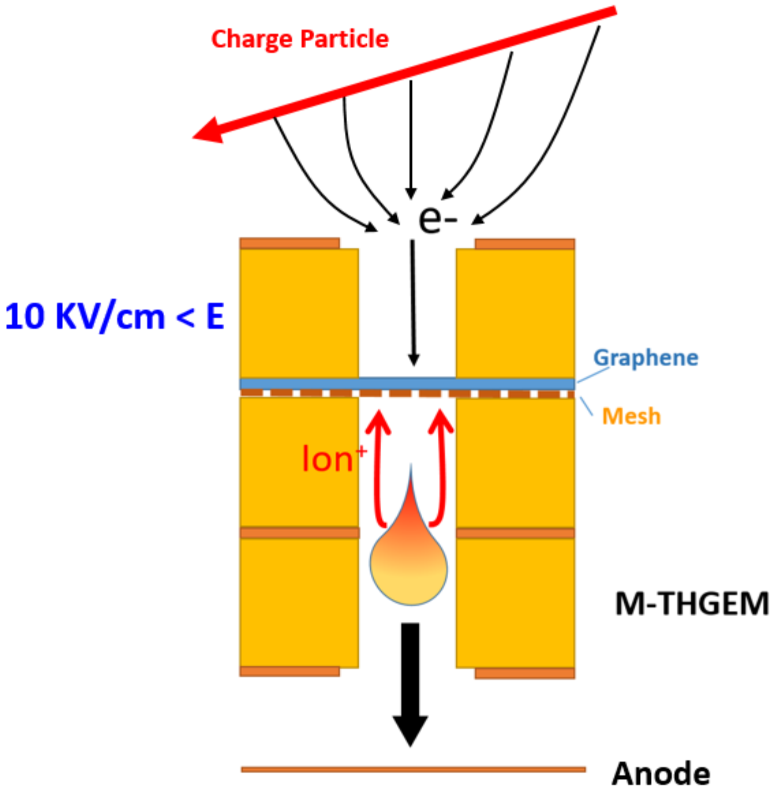






Coating GEM w GRAPHENE: need to increase e- Energy > 10kV/cm. Did not succeed to transmit e- via 3-layer Graphene. Literature: yet unclear (to our community) “directions”

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!

AT-TPC filled with high-stopping-power gas mixture

AT-TPC approved experiments:

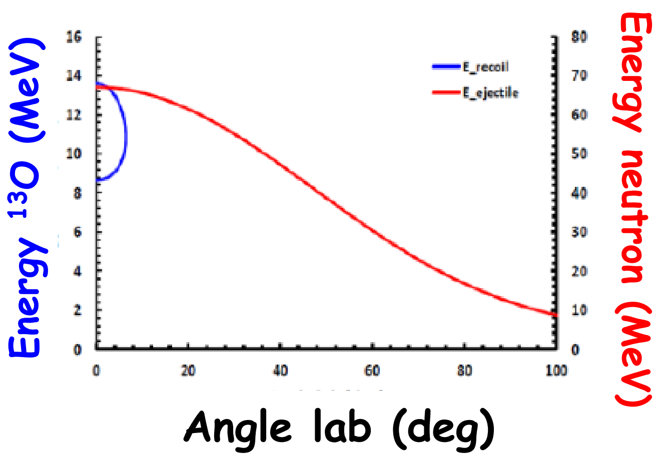
E15328-NSCL:
Measurement of ANC of $^{12}N(p,\gamma)^{13}O$ relevant for the r-process study
Spokesperson: J. Pereira (NSCL).

E534-RCNP:
Spectroscopy of ^{18}C: single-neutron transfer $^{17}C(d,p)$
Spokesperson: B. F. Dominguez (University of Santiago de Compostela).

E535-RCNP:
Study of the $^{13,15}B(d,^{3}He)^{12,14}Be$ transfer reactions
Spokesperson: Augusto Macchiavelli (LBL).

Requirements → ***Deuterium target***
Stop the reaction products in the AT-TPC

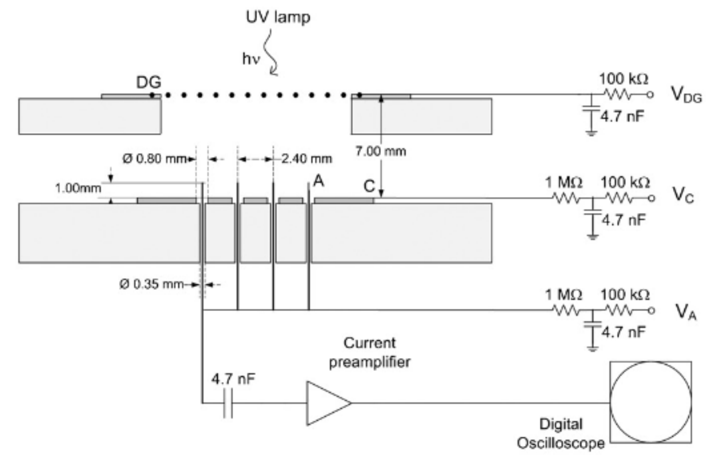
Example: study of $^{12}N(d,n)^{13}O$ reaction to constrain $^{12}N(p,\gamma)^{13}O$ via asymptotic normalization coefficient (ANC) method with 15 MeV/u ^{12}N beam on deuterium or deuterated target.

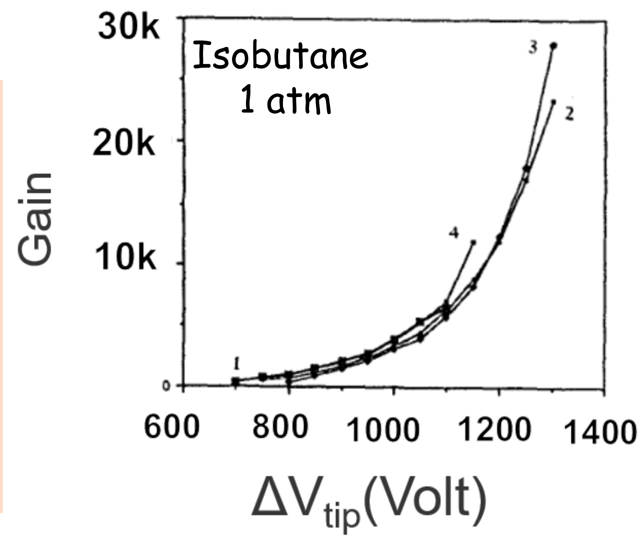


Cannot detect the neutron!
Kinematic variables and PID derived by tracking & stopping the recoiled ^{13}O
➔
AT-TPC operated in iC_4D_{10} @ atmospheric pressure

Lombardi et al. 1996 IEEE Conf. Rec., pg. 603-607

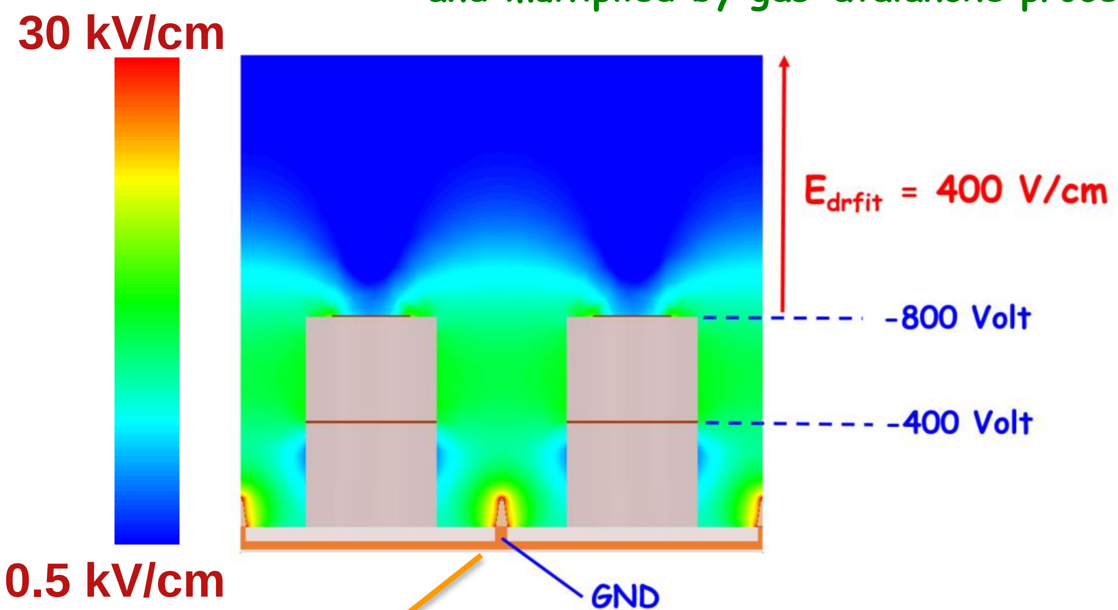
Leak Microstructure

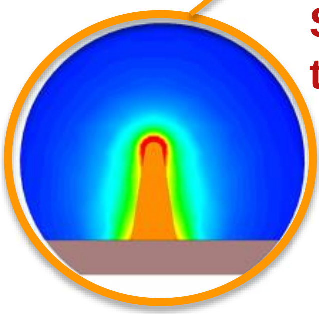




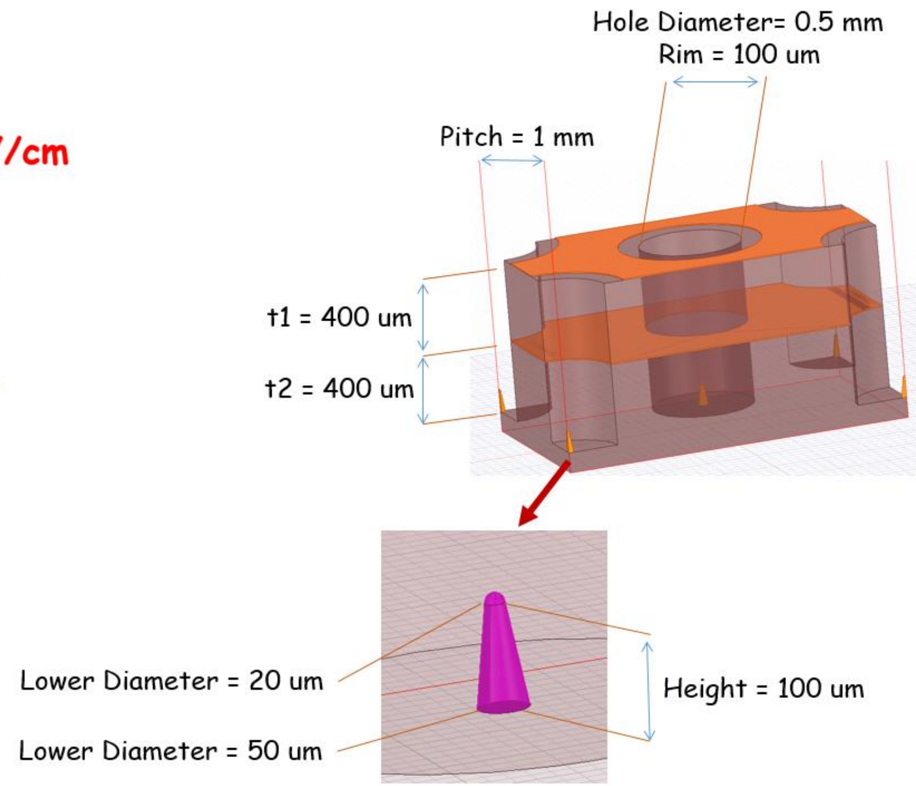
The TIP-HOLE detector

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:

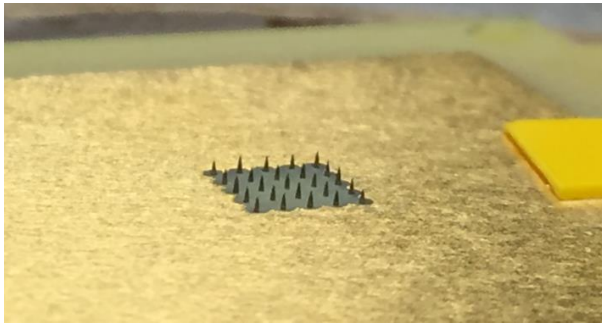
-) Multi-stage amplification ➔ large gain at low pressure

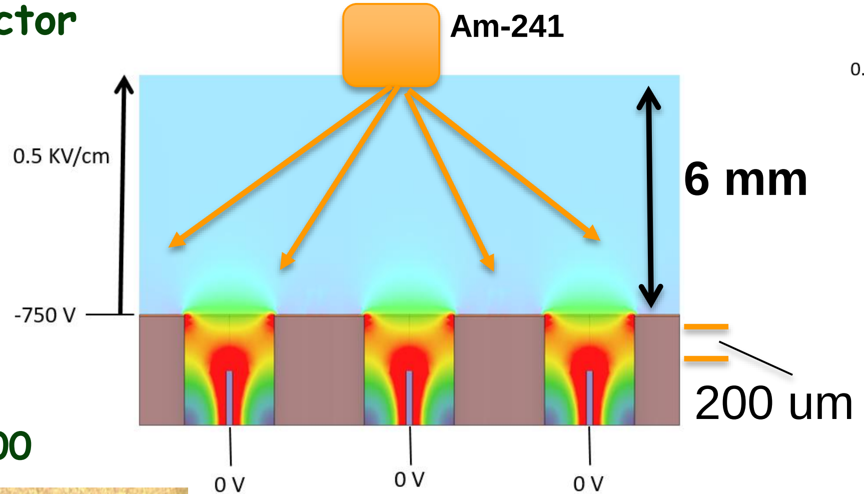
-) High amplification in pure iC_4H_{10}, pure propane … at 1 atm

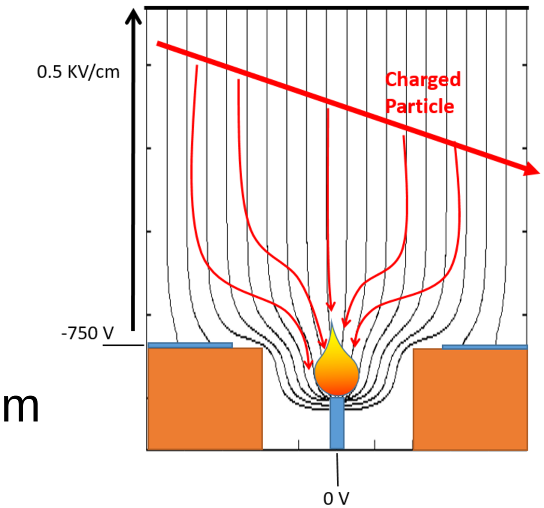
-) Close geometry ➔large versatility

First TIP-HOLE prototype

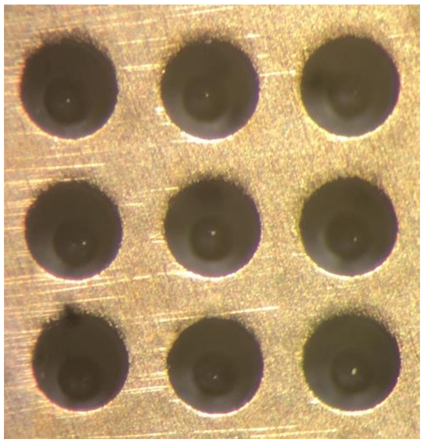
5x5 needles TIP-HOLE detector



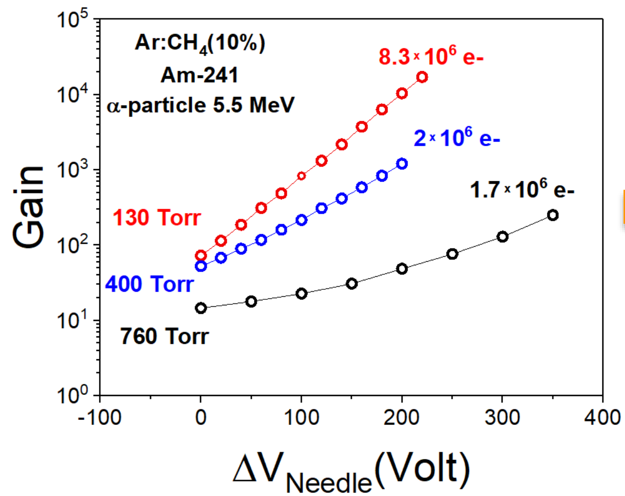




Tattoo Needle (Nickel): Size 00



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



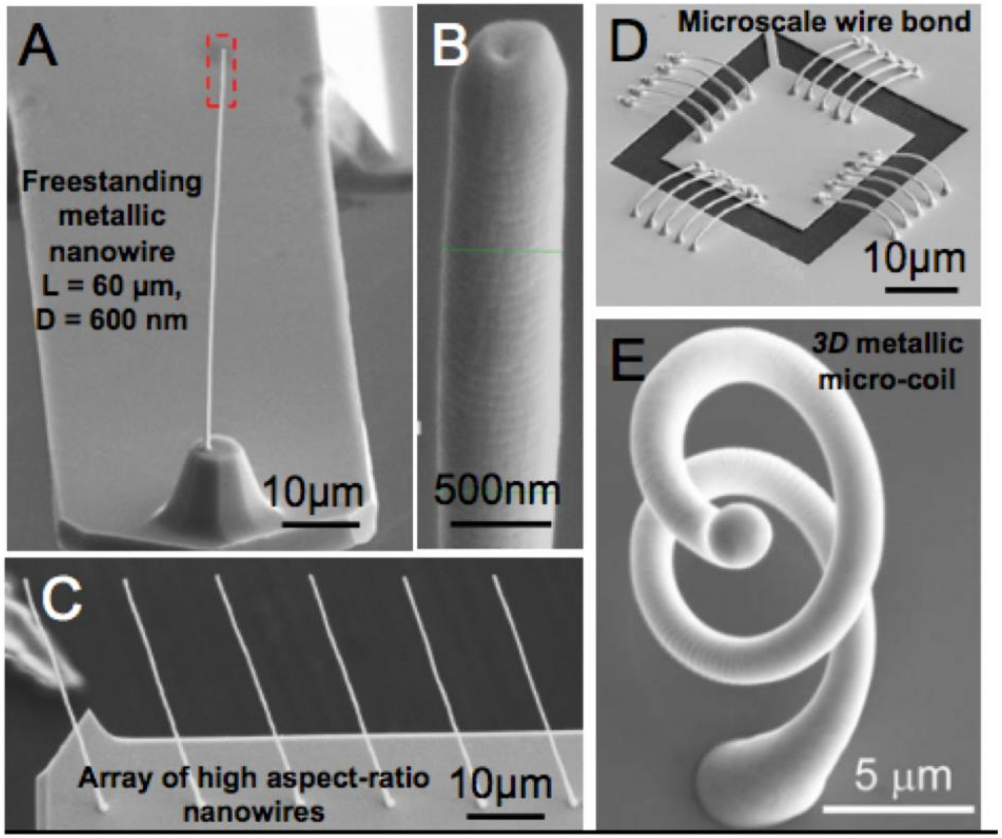
Next step:
Production of “large-area” prototypes

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

-) Exciting New Science from World-Class Equipment with Radioactive Isotope Breams

-) MPGD mostly driven by HEP applications while RIBs experiments have different requirements → new MPGD architectures

-) R&D on new/upgrade of existing detector systems including focal plane tracking upgrade, (AT-)TPC readout, liquid-noble gas technology for neutron detection & focal plane TKE / isomer tagging , …

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

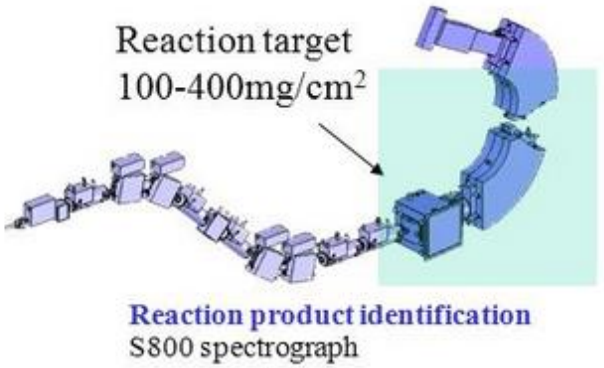
-) Presented preliminary results of new structures (MM-THGEM and TIP-HOLE) derived from the Multi-layer THGEM configuration

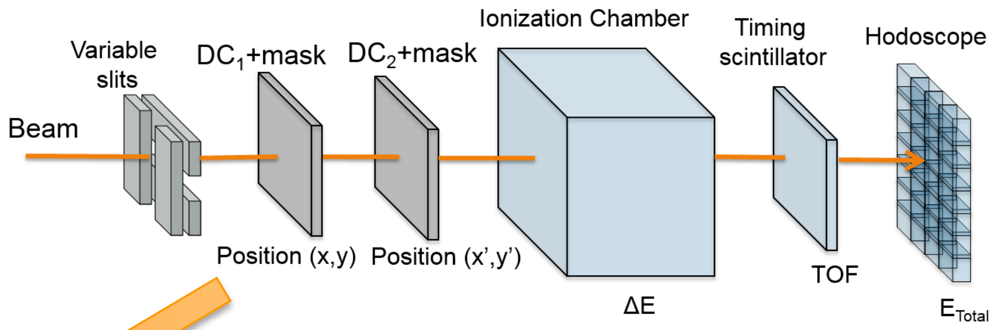
-) Addicting manufacturing technology → new MPGD production technology

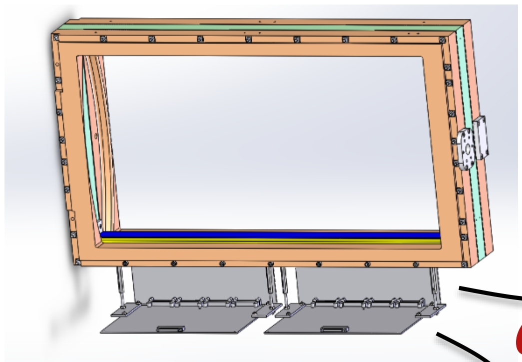
Applications: Fast Beams

Tracking for the S800 spectrometer (and for the future HRS) Focal Plane Detectors System

Focal Plane





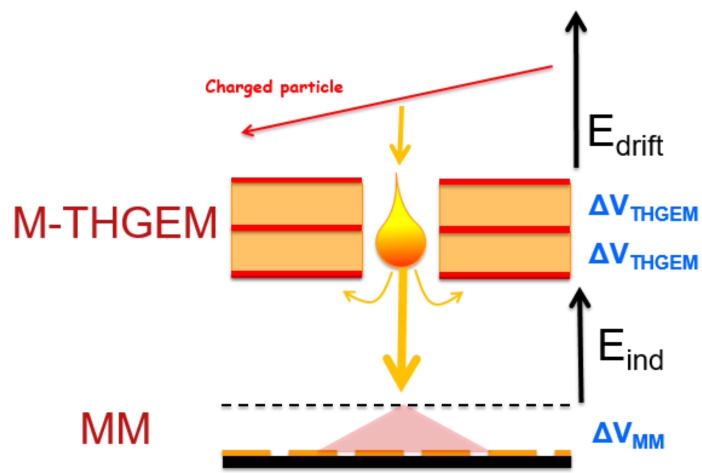


Intermediate Zap board (include protection circuitries for the GET electronics and 16X2 channels reserved for the Ionization chamber signals)

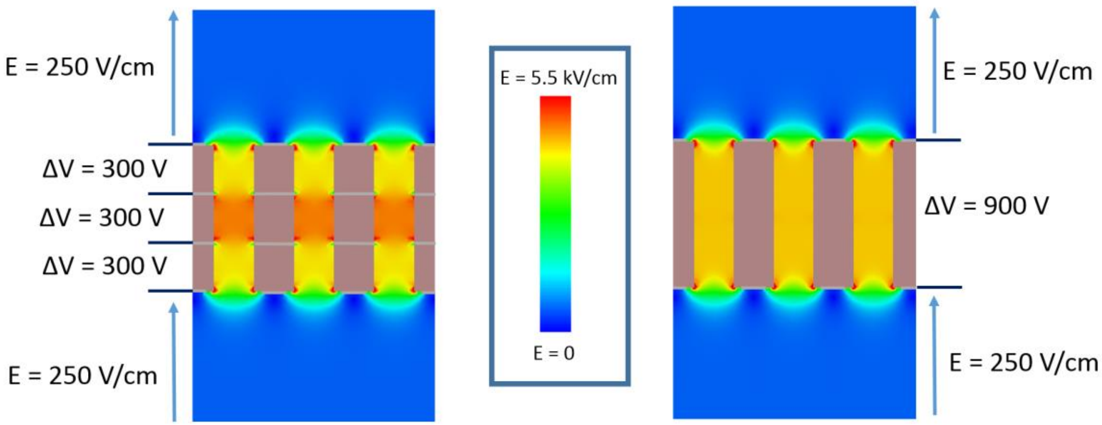
GET electronics

Front end AsAd board
-) 4 AGET per board, 64 channel each ➔ 512 channels
-) 480 channels for the MM-readout

Position-sensitive Micromegas readout + 2L M-THGEM-based pre-amplification stage + GET front-end electronics

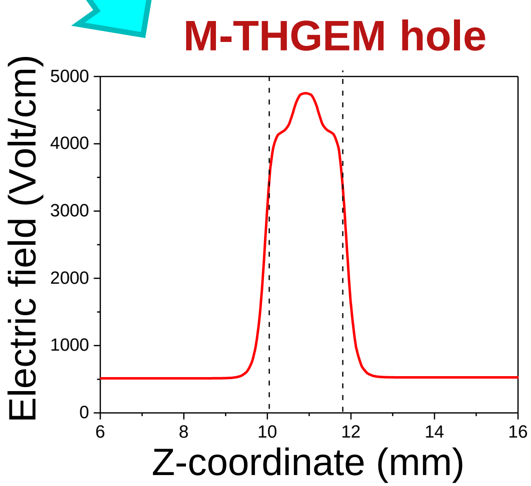


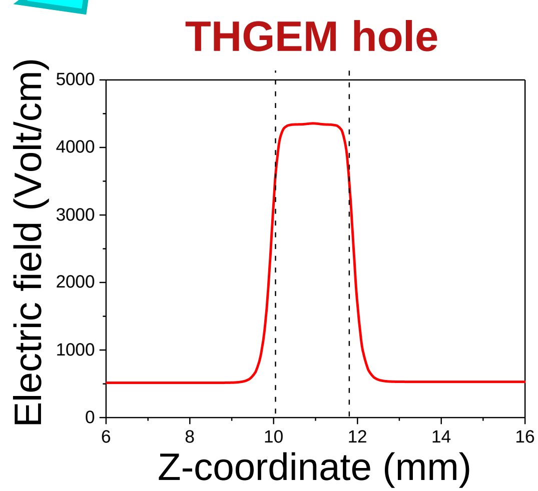
Three-Layer M-THGEM vs Single-layer THGEM



- -) *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

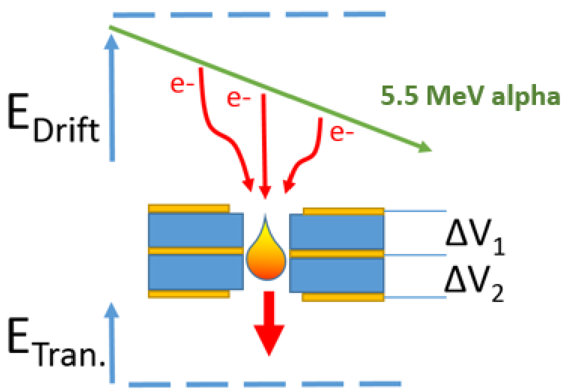




Long-term gain stability of Ceramic M-THGEMs

Two-layer ceramic M-THGEM

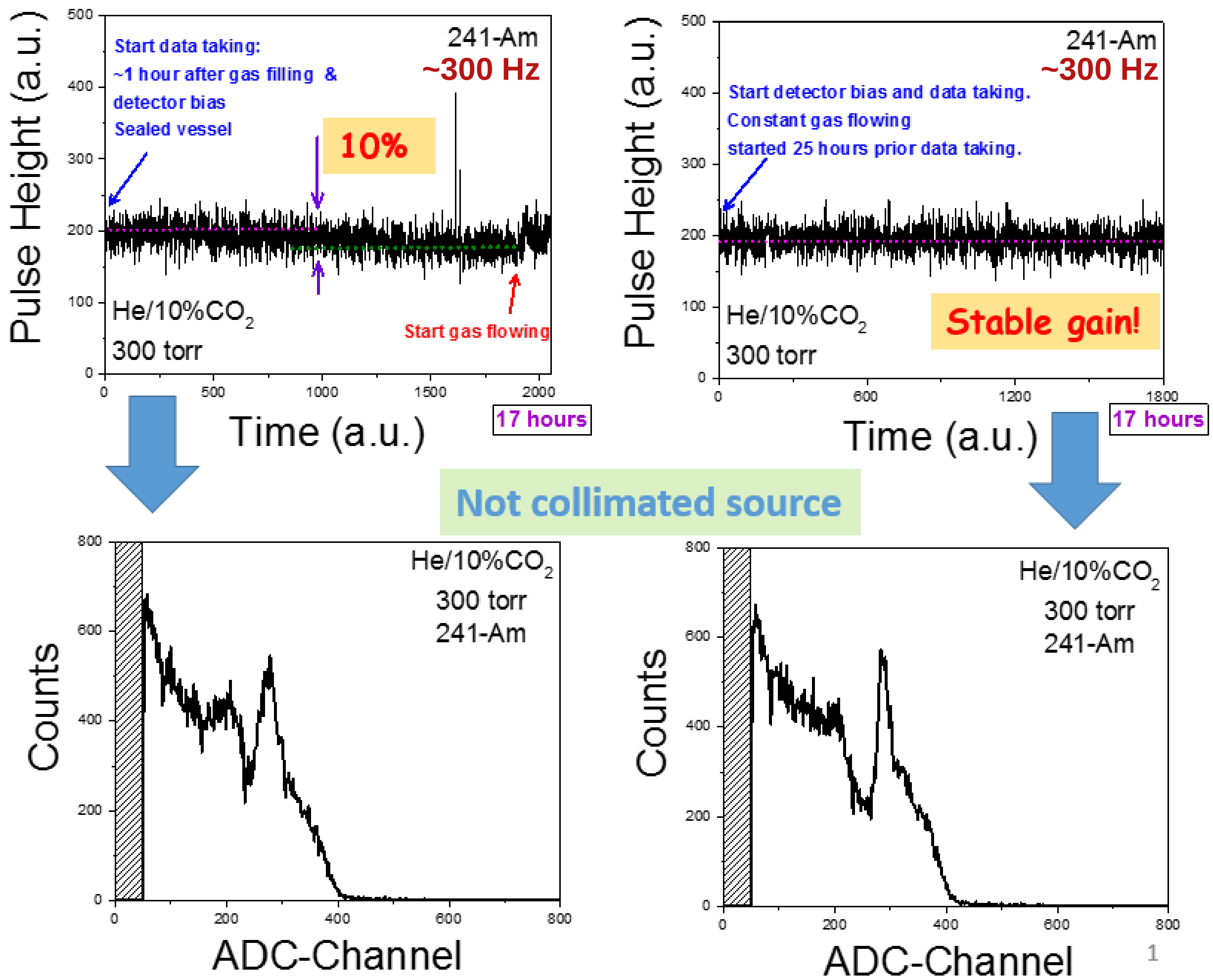
10x10 cm² prototype
12 mm drift ➔ E_{Drift} = 1 kV/cm
3 mm trans. ➔ $E_{trans.}$ = 0.33 kV/cm
$\Delta V_{M\text{-}THGEM}$ = 480 Volt
<u>Counting rate ≈ 700 Hz</u>



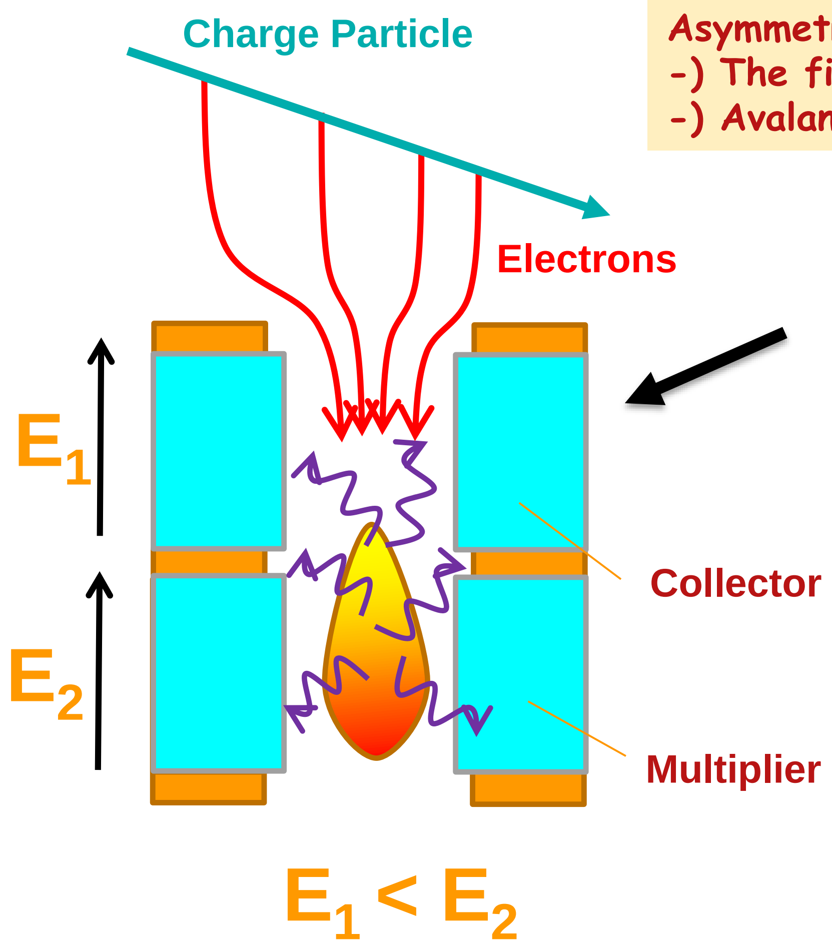
2-layer THGEM

No significant charging up effect at low rate!

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



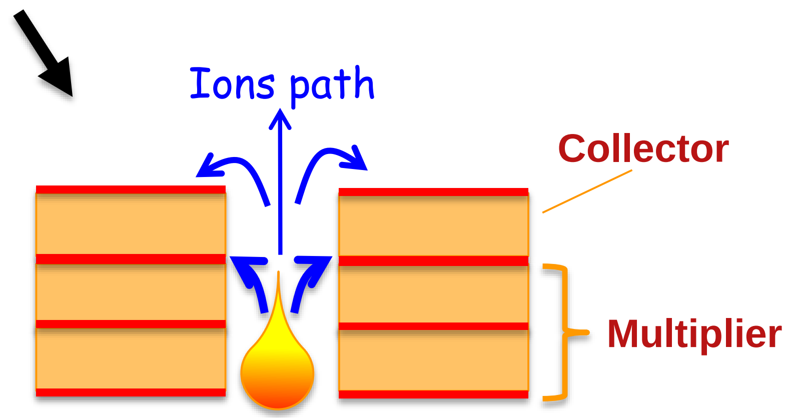
M-THGEM: photo-feedback/ion-backflow reduction



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

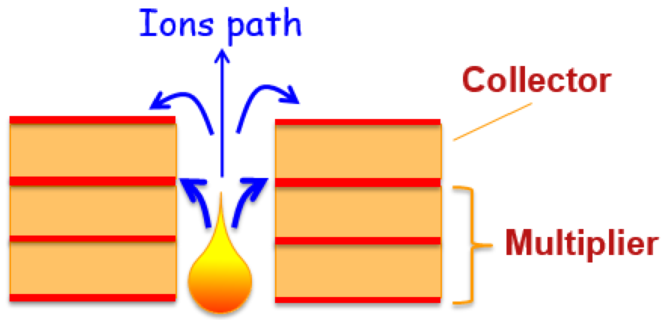
Disadvantages:
Single element ➔ lower spatial resolution (limited to the pitch of the THGEM's)
@ low gain ➔ Lower electron collection efficiency ➔ low energy resolution

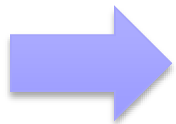
Advantages:
Better reduction of the photo-mediated effects
Slight reduced of the ion backflow

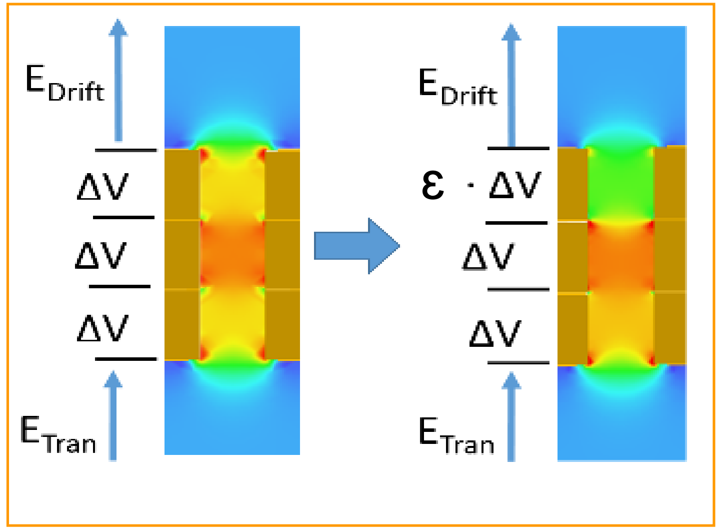


Asymmetric bias mode

3-layer M-THGEM



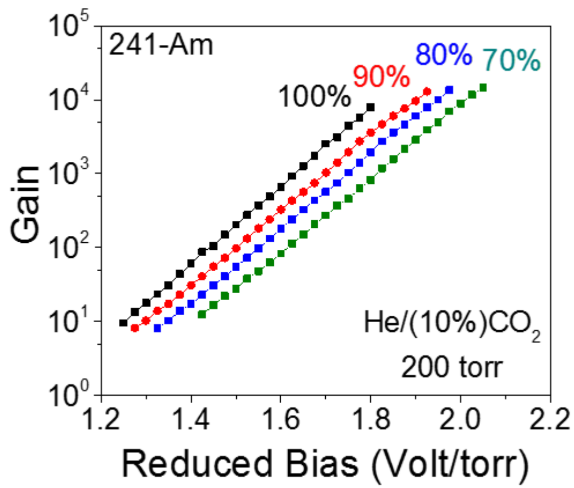




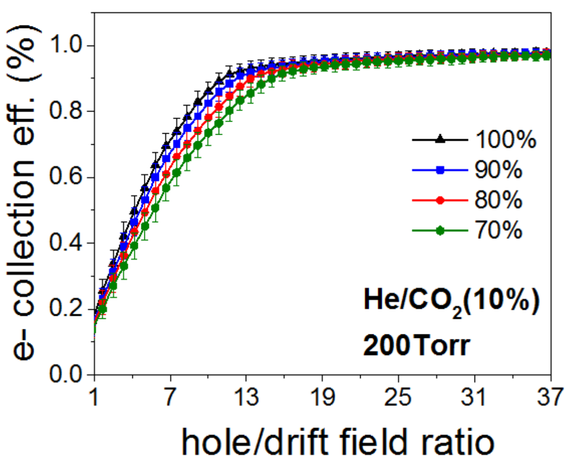
Strategy ➔ Stop ions in asymmetric setup

Problems: energy resolution? Effective gain?

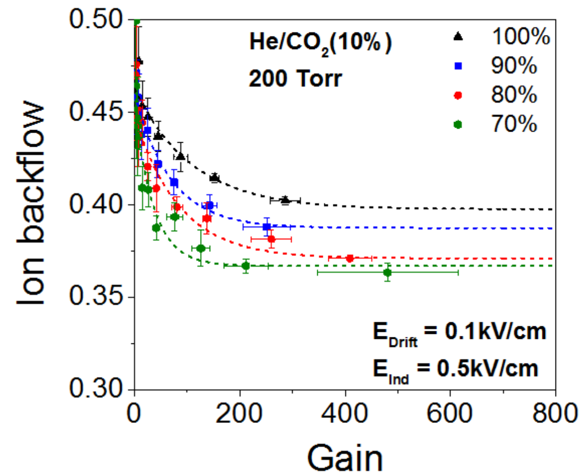
Garfield – Stefan Rost



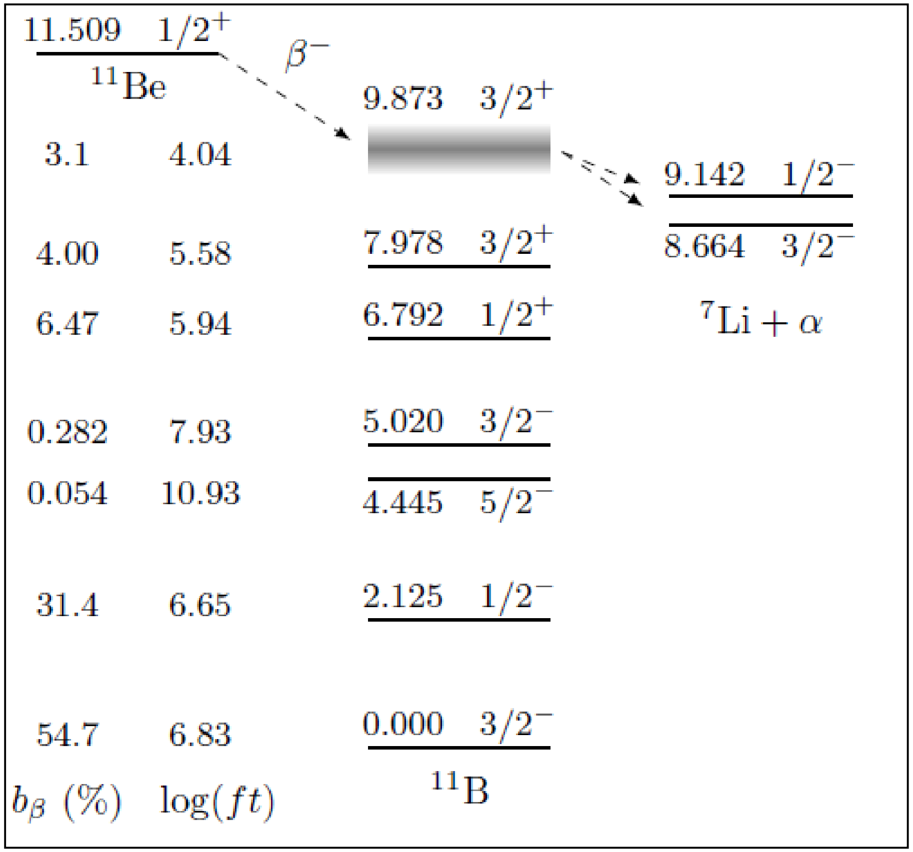
Same Max achievable Gain!



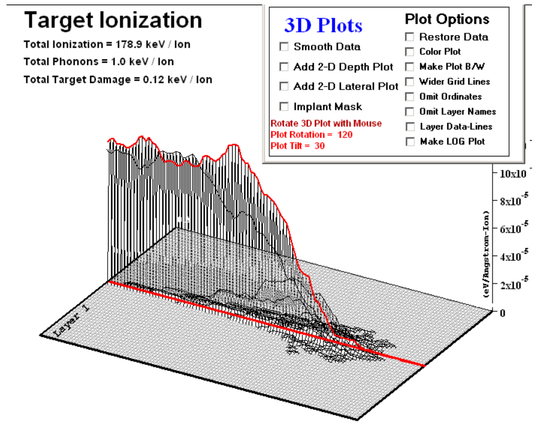
No significant loss of e- collection efficiency



Lower ion backflow with cascade configurations



Typical expected proton (180 keV) track



Typical expected alpha-particle (180 keV) track