Summary of TPC2023 Workshop at Texas A&M

Curtis Hunt

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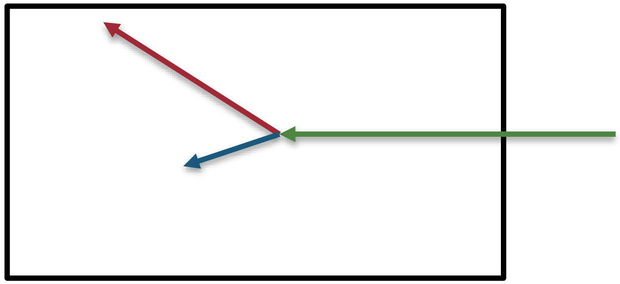
Outline

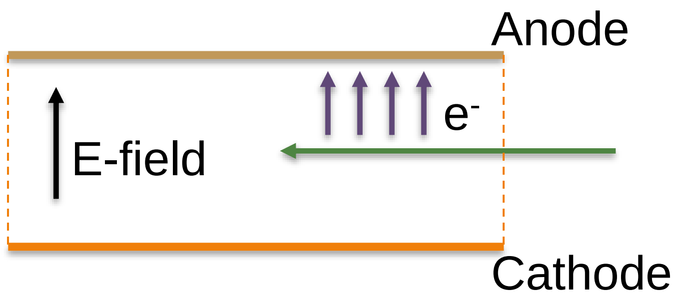
- TPC Basics
  - Basics
  - Gas gain detectors
  - GET
- TPC Detectors
  - SRIT
  - AT-TPC
  - And more …
- Major Discussions
  - New TPC for fast beams at FRIB
  - Electronics
  - Hardware
  - Software
- Discussions Summary

Time Projection Chamber (TPC) Basics

TPCs - Basics

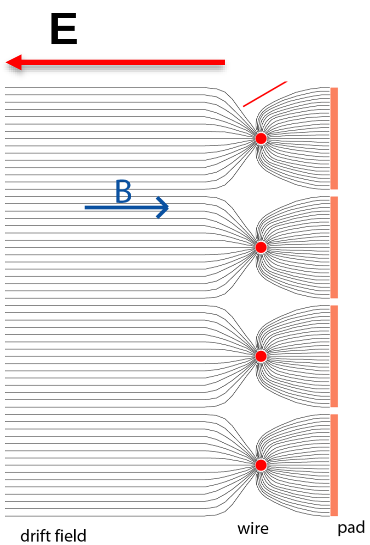
- Particle tracking
  - Particles moving through the active volume ionize the gas
  - Electrons drift in applied electric field toward anode plane
    - » Gas gain detector amplifies signal and reads out charge
    - » More anode segmentation give more position resolution
- Active Target
  - Active Target setups use the detector gas as the target
  - Reactions occur within the gas for good event reconstruction
  - Thick Target Inverse Kinematics (TTIK) method allows for measuring energy over a large energy range with a single beam energy
  - Some limitations on the gas

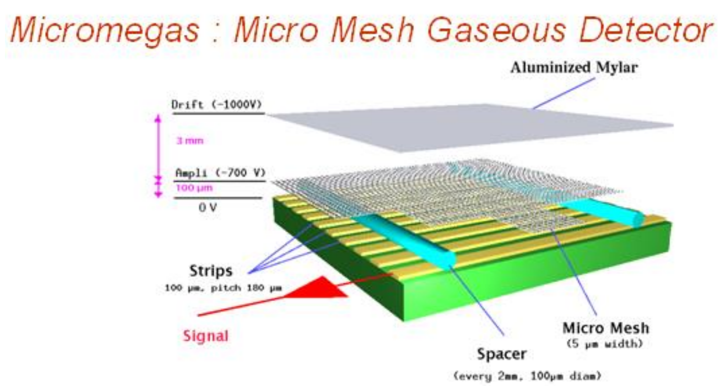


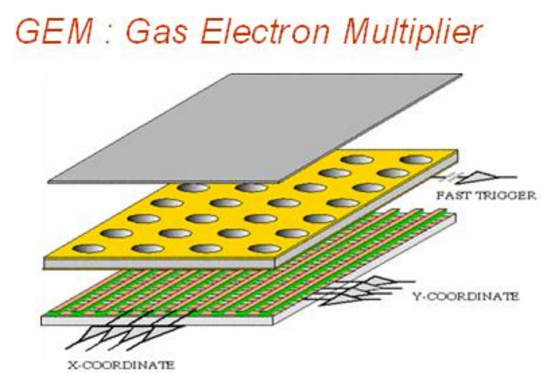


TPCs – Gas Gain Detectors

- Wires – SπRIT
  - Charge attracts to wires; images read by redout anode
- Micromegas – AT-TPC, TexAT,
  - Micromesh on top of readout anode; e^- avalanche created between planes
- GEM – AT-TPC, TexAT,
  - Channels electrons accelerated through holes; amplification from avalanches between sides of GEM

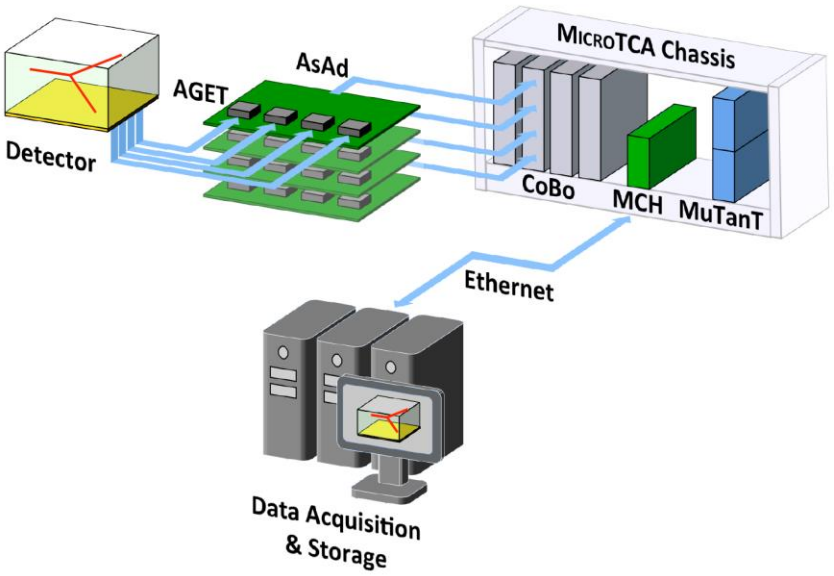






TPCs - GET

- Generic Electronics for TPCs (GET)
  - AGET chips
    - 64 data channels + 4 FPN channels
      - Fixed Pattern Noise (FPN) channels measure the baseline due to electronics
    - Preamplification and Shaping
  - AsAd (ASIC and ADC) boards
    - 4 AGET chips per board
    - Digitizes signal from the AGET
  - CoBo (Concentration Board) Module
    - Up to 4 AsAd per CoBo
  - MuTAnT (Multiplicity, Trigger and Time)
    - Manages the trigger for the connected CoBos

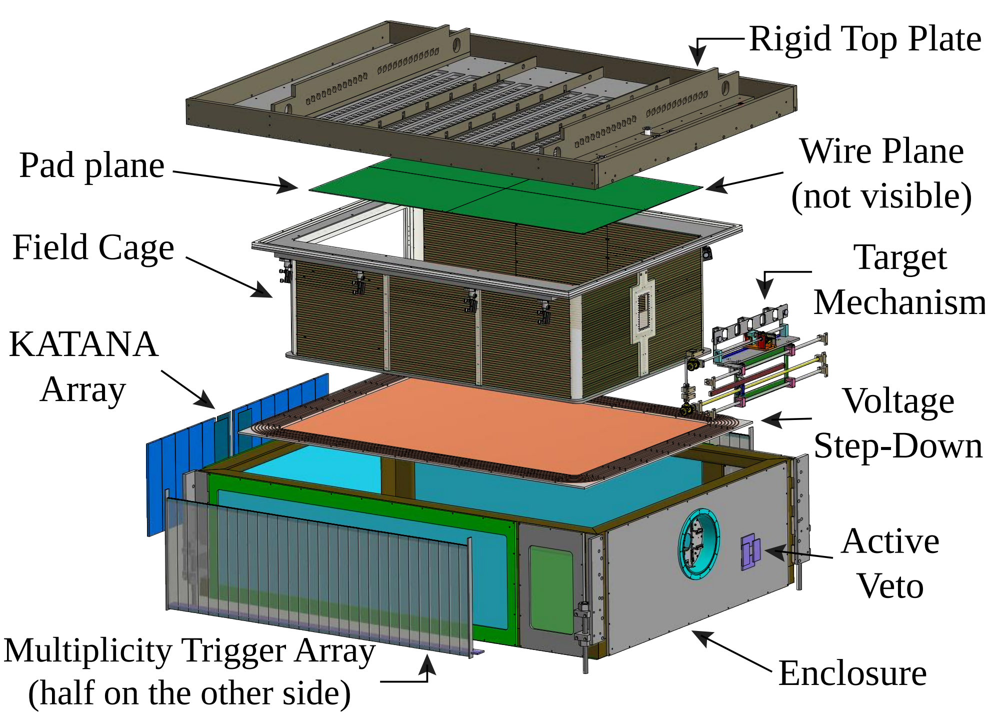


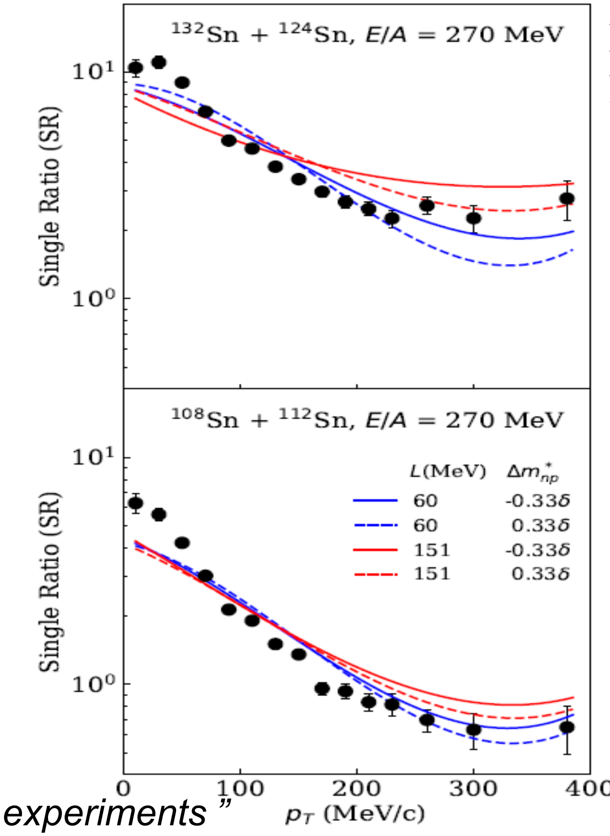
E.C. Pollacco et al. NIMA **887** (2018) 81-93

More on this topic later!!

TPC Detectors

SπRIT





Estee et al, PRL **126**, 162701 (2021)

William Lynch *“Results from SπRIT-Time Projection Chamber experiments ”*

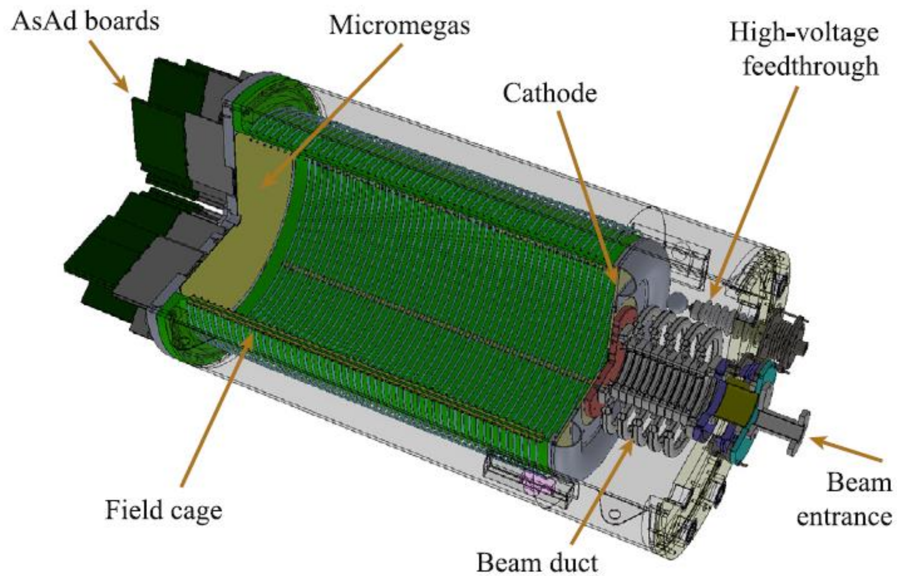
Tadaaki Isobe *“The SPiRIT TPC for heavy ion collision experiments at RIKEN-RIBF ”*

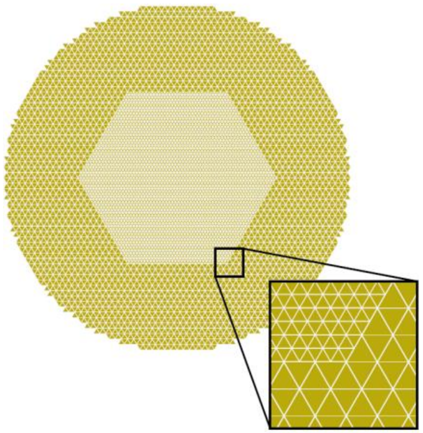
SπRIT Collaboration

NSCL · RIKEN NiSHiNA CENTER · KYOTO UNIVERSITY FOUNDED 1897 · A|M · KOREA UNIVERSITY · TSINGHUA UNIVERSITY

AT-TPC - Overview

- AT-TPC (Active Target Time Projection Chamber)
  - At FRIB
- 1000 mm long x 250 mm radius cylindrical active volume
- 10240 micromegas pads
  - Perpendicular to beam direction
  - Highly segmented inner region
  - Option for use with GEMs
  - New pad plane allows AT-TPC to be used in reverse
- Cylindrical design allows for use in magnetic field
  - SOLARIS
  - HELIOS





Future upgrades and improvements of AT-TPC

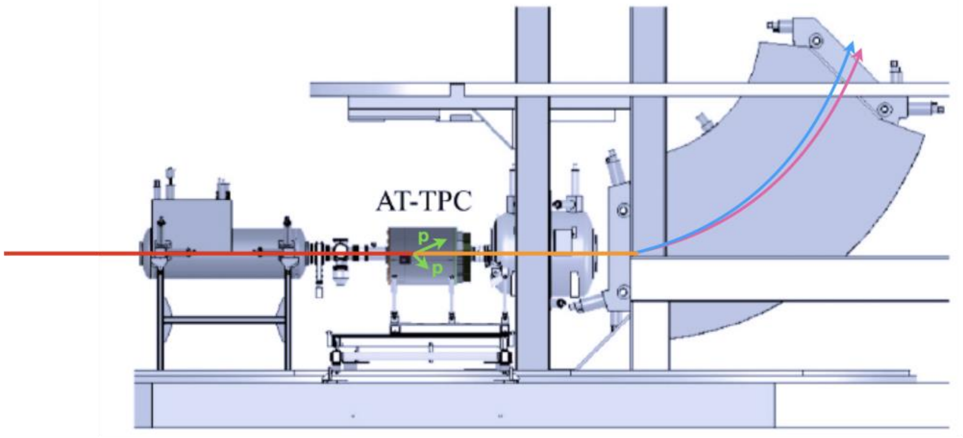
- New CoBo board (ZCoBo)
  - First 2 prototypes received, ongoing preliminary tests
  - SoM from Trenz arriving this month - first full tests
  - Firmware from U. Of Warsaw via NDA with MSU
- Inner beam region tube with gas recovery system
  - Use of expensive gases such as ^{3}He
  - Recovery system built and tested, inner tube being designed
- Heavy recoil detectors at small angles
  - Transmission mode: beam injected through hole in pad plane
  - Pair of DSSSD (10x10 cm2) placed outside exit flange
  - Detectors ordered, design started

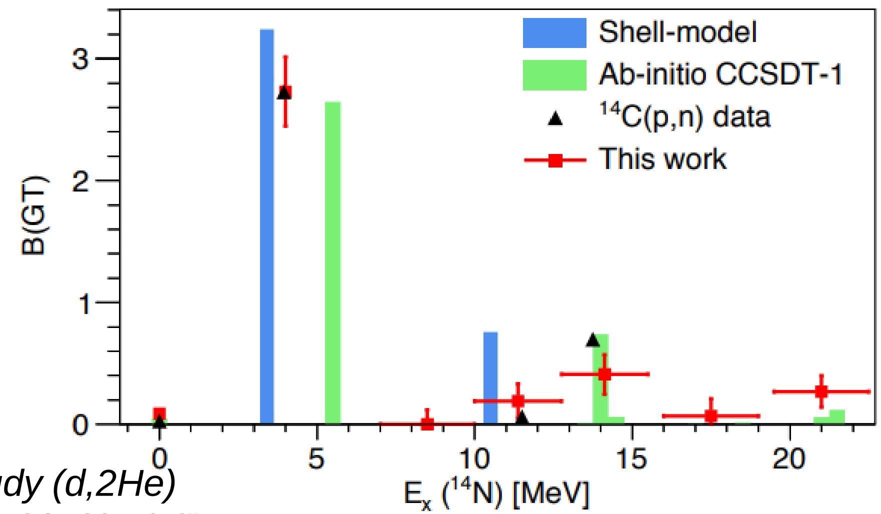
Daniel Bazin *"The Active Target Time Projection Chamber"*

NSCL FRIB
U.S. Department of Energy Office of Science
National Science Foundation
Michigan State University

Charge exchange study in AT-TPC

- $^{14}O(d,^{2}He)$
- AT-TPC used in the configuration where beam comes in through pad plane
- The S800 Spectrometer is Used for Time Verification and Obtaining Signals
- B(GT) for 3.95 MeV 1+ state in agreement with decay and $^{14}C(p,n)$ results for states > 10 MeV.

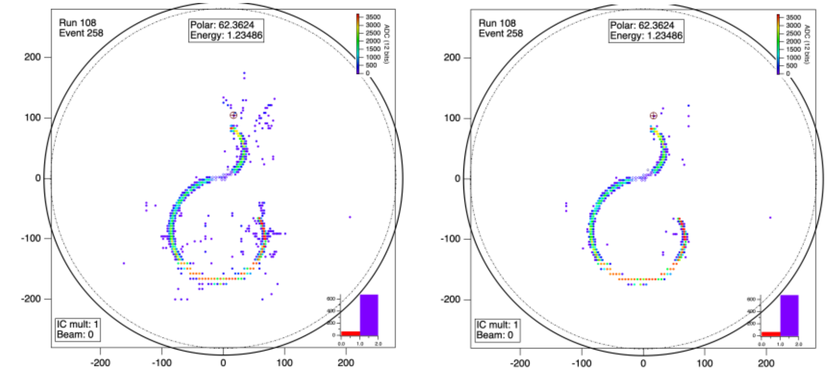


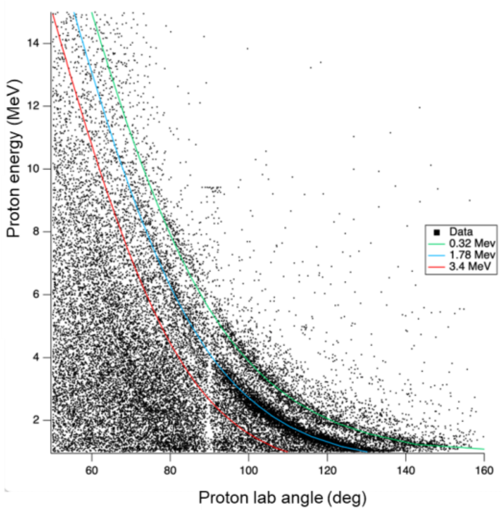


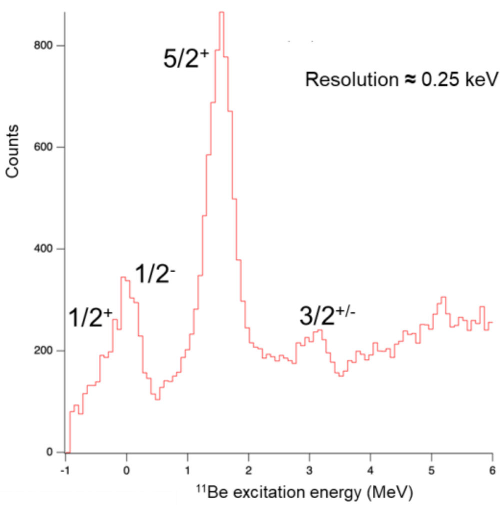
Zarif Mubassir Rahman *"Using AT-TPC to Study (d,2He) Reaction in Inverse Kinematics to Study Unstable Nuclei"*

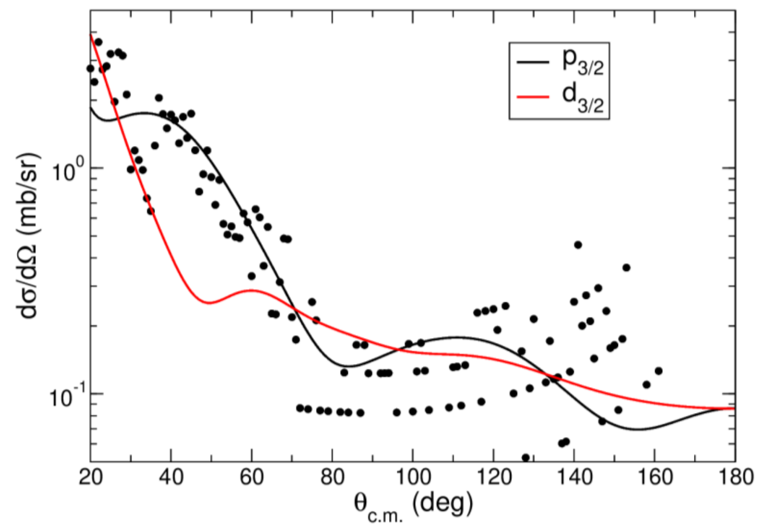
Analysis of 11Be excited states via the 10Be(d,p) reaction

- ^{10}Be(d,p) experiment performed at NSCL during summer 2021 with AT-TPC in SOLARIS solenoid
  - Data analysis ongoing
- Detailed issues and solution for cross-talk in GET
- Showed preliminary results





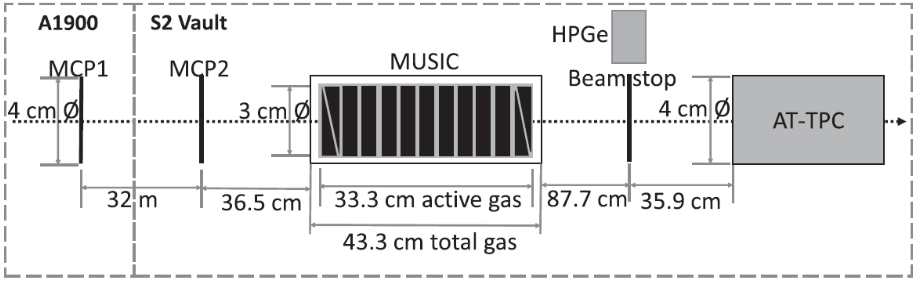


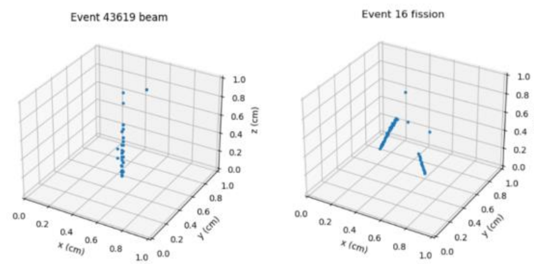


Zach Serikow *"Analysis of 11Be excited states via the 10Be(d,p) reaction"*

Fission in AT-TPC

- Probe of nuclear structure in unexpected region of asymmetry in mass yields near ^{180}Hg and ^{198}Pb
- Challenges Solved
  - Beam particle identification
    - » HEavy ISotope Tagger (HEIST)
  - Identifying Fission Events
    - » Use a combination of algorithmic and machine learning methods
  - Space Charge
    - » Solved Longevin equation to correct fission tracks
  - Signal Processing
    - » Deconvolution for accurate dQ/dt (related to dE/dx)

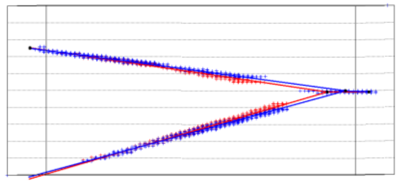




From 70-85% of fission events identified to 94-97% w/ ML!

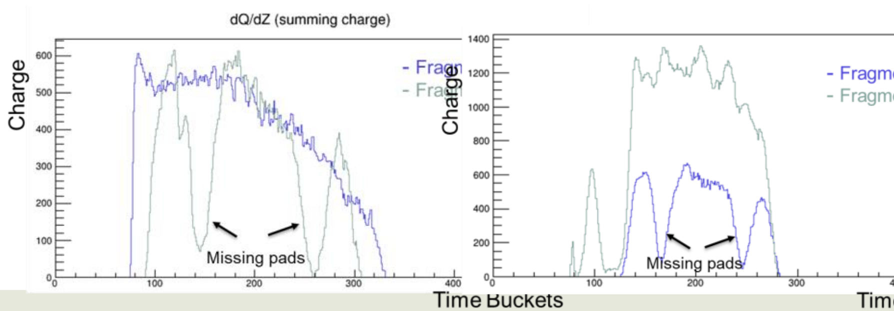
ALPhA DAVIDSON COLLEGE

Example Corrected Event



RED = Before correction

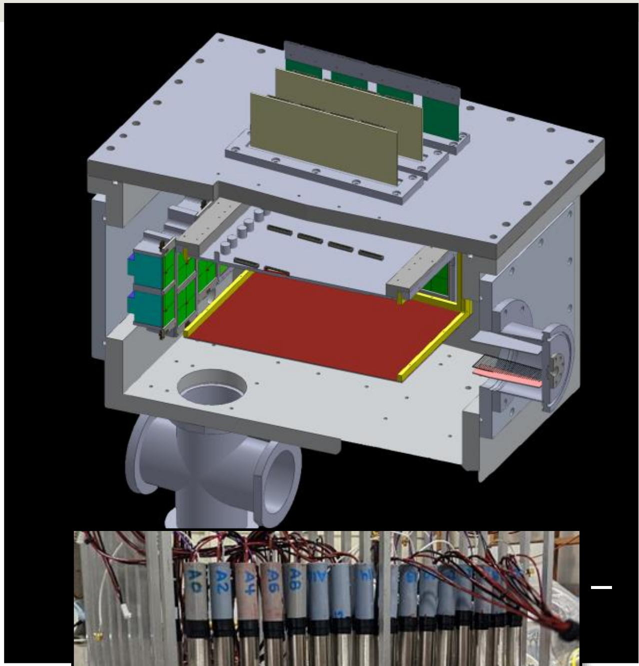
BLUE = After correction

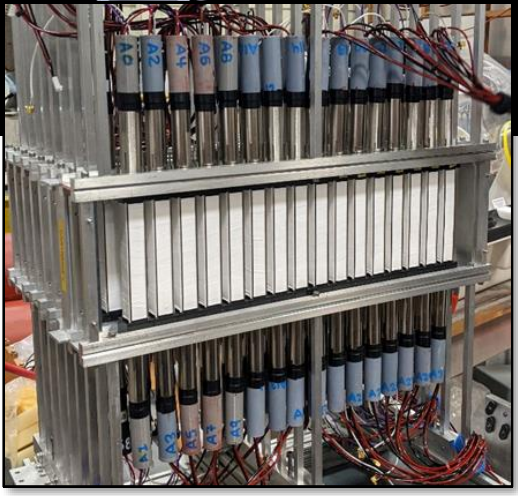


Curtis Hunt *"Studying Fission near ^{198}Pb with AT-TPC at FRIB"*

TexAT/TeBAT

- TexAT TPC - TEXas Active Target Time Projection Chamber
  - Cyclotron Institute at Texas A&M
- 224 (beam) x 245 x 130 (height) mm sensitive volume
- Segmented Micromegas, 1024 channels, pos. res. ≈ 1.5 mm in beam direction
- GEMs provide additional gain. Low dE/dx particle tracks possible
- Ancillary Si+CsI telescope wall
- New TexNeut neutron detector for (p,n)
- New TeBAT with Birmingham University will use resistive Micromegas





Jack Bishop *"TexAT and TeBAT: a multitude of experiments"*
Dustin Scriven *"TexAT-TPC and a Neutron Detector Array, TexNeut"*

TexAT Experiments Overview

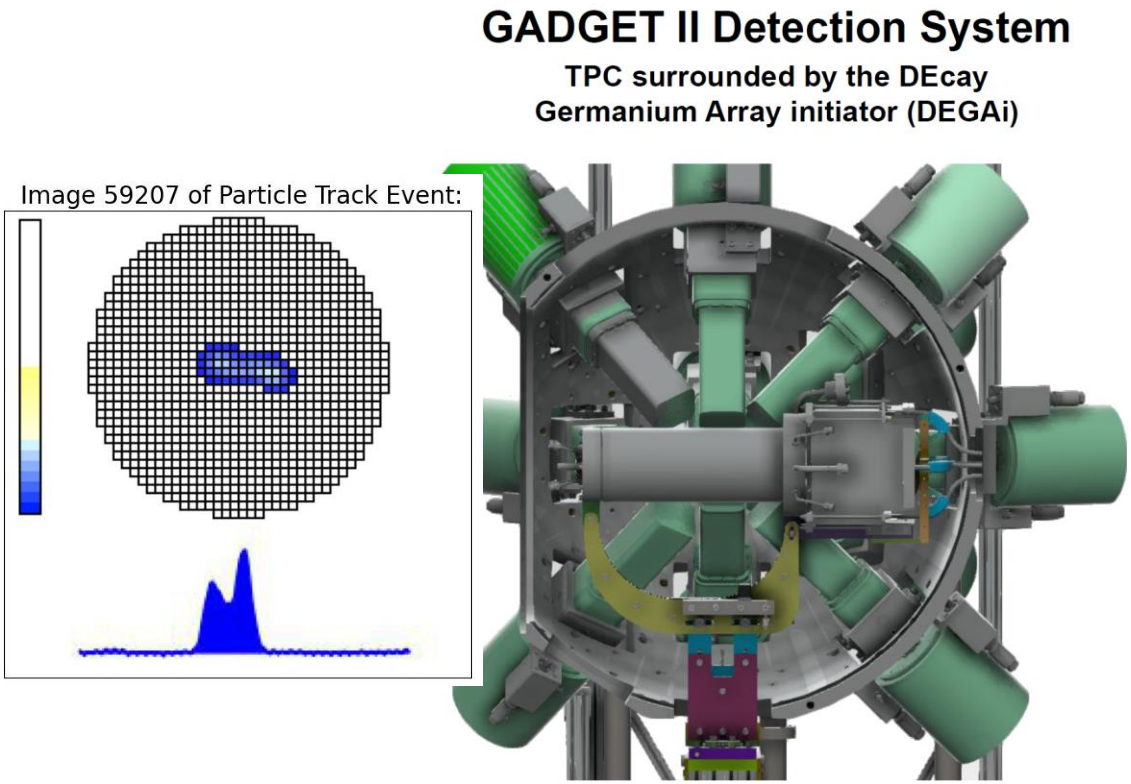
- Nuclear structure/exotic nuclei
  - $^{8}B(p,p)$ ♦
  - $^{10}C(\alpha,\alpha)$
  - $^{14}O(\alpha,\alpha)$ ♦
  - $^{12}Be(p,p)$ at TRIUMF ♦
  - $^{9}Li(p,p)$ ♦
  - $^{9}Li(p,n)$ TexNeut
- Direct fusion measurement
  - $^{8}B+^{40}Ar$ ♦
- Trojan Horse Method studies
  - $\alpha(^{20}Ne,\alpha)^{16}O+\alpha$
- Nuclear astro (α,p) studies
  - $^{14}O(\alpha,p)$ at RIKEN (CRIB)
- Transfer reactions
  - $^{12/13}B(d, ^{3}He)$
  - $^{1}H(^{6}He, t^{*})$ ♦
- β-delayed particle decay
  - $(^{12}N,\beta 3\alpha)$ ♦
  - $(^{13}O,\beta 3\alpha p)$ ♦
- Neutron-induced measurements
  - $^{12}C(n,n_2)3^{\alpha}$ ♦
  - $^{12}C(n,\alpha_0)$, $^{16}O(n,\alpha_0)$ ♦

♦ Published; ♦ Analysis completed

Jack Bishop *"TexAT and TeBAT: a multitude of experiments"*

GADGET II

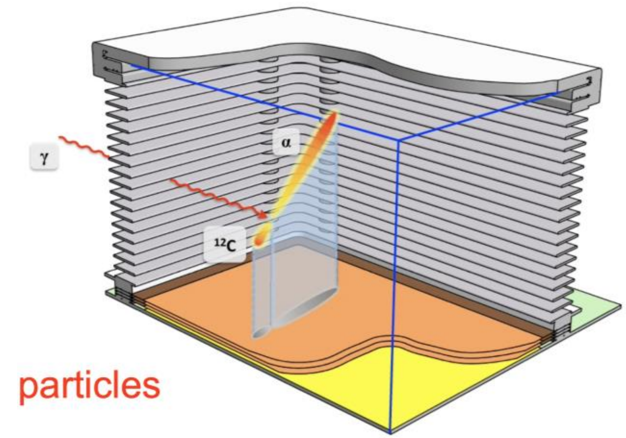
- GADGET II
  - Upgraded Proton Detector to TPC operation to measure ^{20}Mg($\beta p\alpha$)^{15}O through 4.03-MeV ^{15}O(α,γ)^{19}Ne resonance to determine Γ_α/Γ.
  - Segmented Micromegas pad plane
  - For use is DEGAi for gamma ray detection
  - Machine learning used on 2D plots of the 3D+charge information
  - ATTPCROOT for simulation
  - Recent ^{20}Mg($\beta p\alpha$)^{15}O experiment completed at FRIB

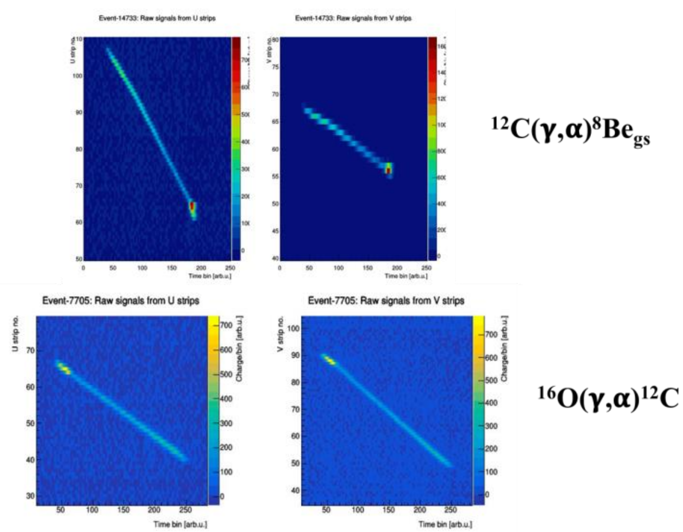


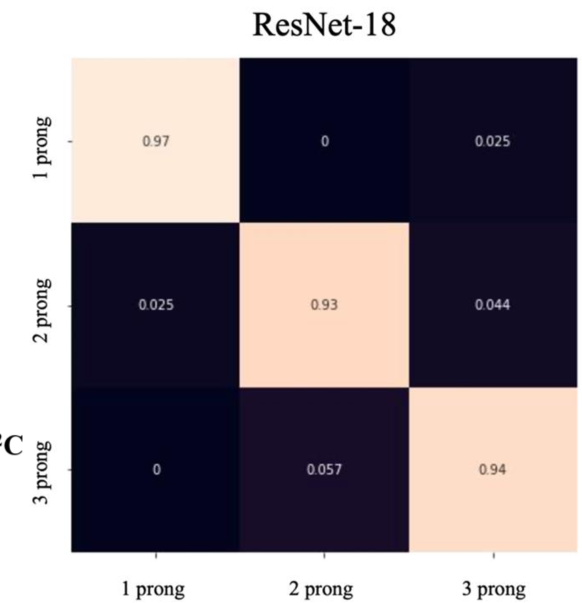
Chris Wrede *"Development of GADGET II"*

Machine Learning with TPCs

- Warsaw TPC
  - Active volume
    - » 33 x 20 cm2 (readout) x 20 cm (drift)
  - Charge amplification
    - » Gas Electron Multiplier (GEM) structures
    - » Readout with planar, 3-coordinate, redundant strip arrays, ~1000 channels







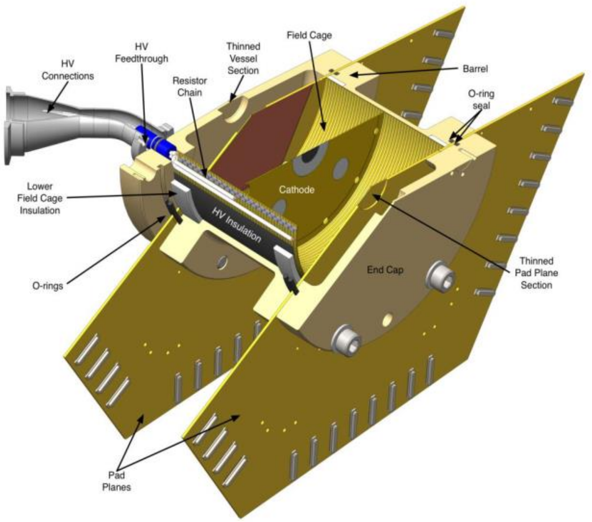
- 12C(γ,3α)
  - Many other types of events occurred
  - Used Machine learning to filter out types of events down to 3 prong events
  - Lots of hand labelling to obtain sufficient samples

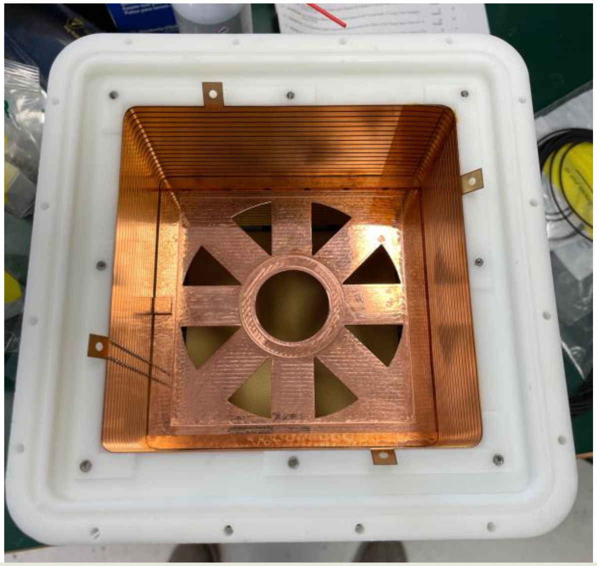
Robin Smith *"Machine Learning TPC analysis for nuclear structure studies using gamma-beams"*

FissionTPC & SREFT
Learning From The Past

- NIFFTE FissionTPC @ LLNL
  - 15+ years old!
  - Micromegas, 5952 hexagonal pads
  - Off the shelf electronics components
    - » Still took development time
  - Did not handle being bombarded with neutrons well
  - Heat was a major problem
  - Difficult to work with

Lucas Snyder *"The NIFFTE fission Time Projection Chamber"*

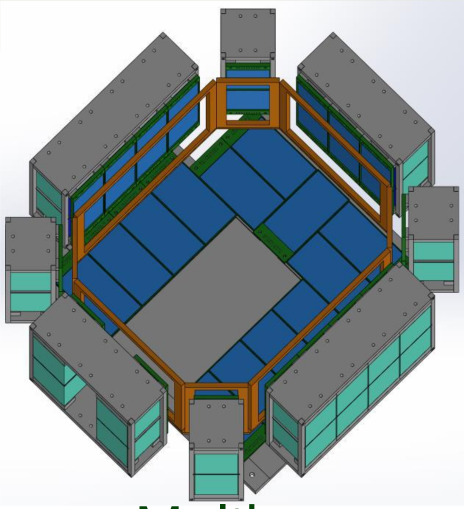




- SREFT @ LANL
  - Rapid prototyping with 3D printing
  - Easily removable cathode
  - Only 180 channels with GEMs and strip anode
  - Off the shelf electronics modules
  - More convenient gas handling systems
  - Simple, but effective

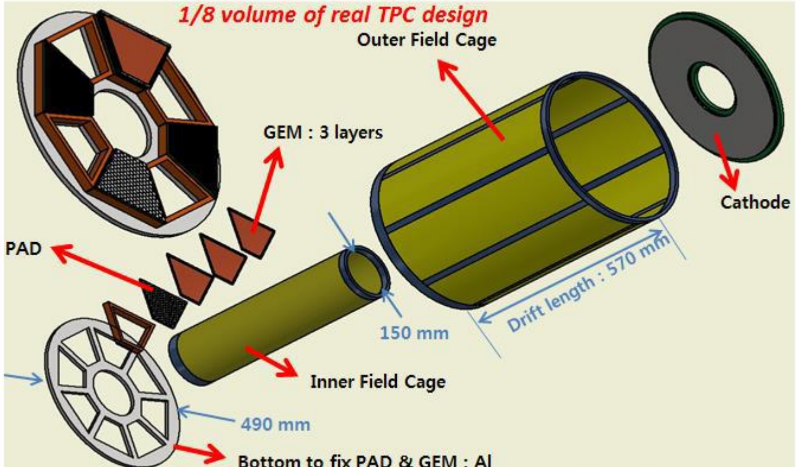
Christopher Prokop *"SREFT (Spatially Resolved Fission Tracker)"*

CENS/IBS



- **ATOM-X:** New Active Target TPC at CENS/IBS
- Active area: 244(X) x 185(Y) x 289(Z) mm3
  - Silicon and CsI detectors wall for total energy of particles
    - » Position sensitive strips on Si. Detector (X6) using resistive layer
  - 5650 channels total

Sunghoon(Tony) Ahn *"TexAT_v2 and AToM-X development at CENS"*



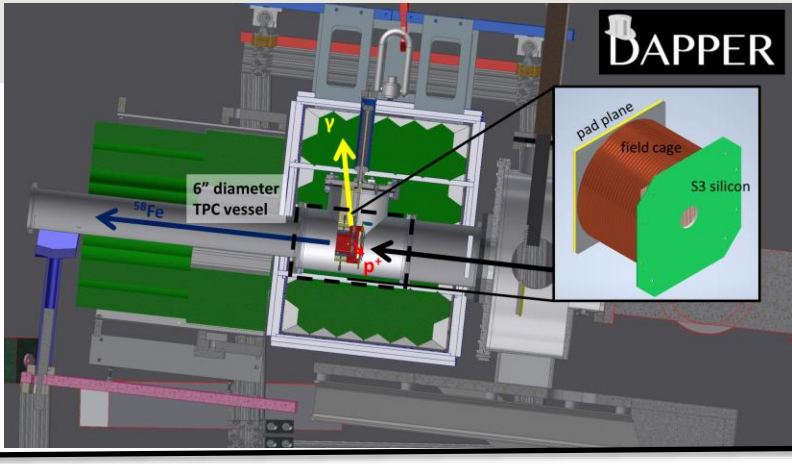
- **LAMPS:** Large Acceptance Multi Purpose Spectrometer
- Made for HIC and EoS studies at IRIS at CENS
- 3 layer GEMs
  - 21,584 channels in total
- Inner field cage shields space charge

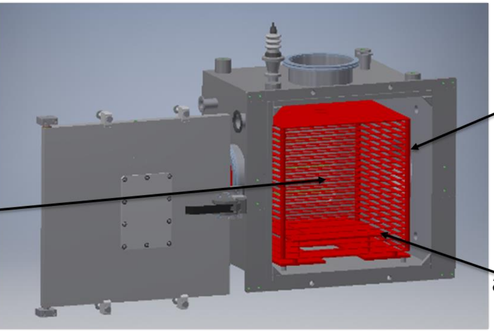
CheongSoo Lee *"Design and Fabrication of LAMPS TPC"*
HyoSang Lee *"R&D and test of LAMPS TPC"*

Others

- **DAPPER TPC:** TPC for use with DAPPER at Cyclotron Institute (TAMU)
- Small TPC in the DAPPER γ-ray detector for improved proton tracking

A.B. McIntosh *"DAPPER TPC"*





- **ND-Cube:** TPC at Notre Dame
- Hexagonal Micromegas plane with 2-layer GEM
- Developed method of using Ne gas with small % of He_2

Tan Ahn *"Using Neon for Active-Target TPCs: Development Using the ND-Cube"*

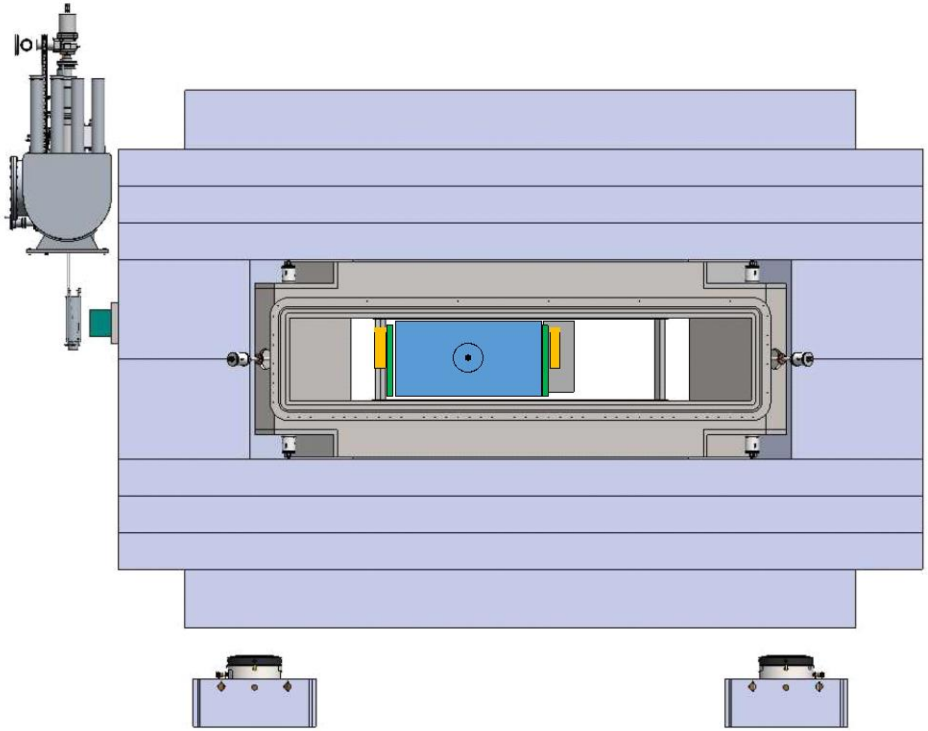
- **MUSIC:** Argonne National Lab
- Several published and in progress results from MUSIC in Active Target mode

C. Fougères *"Capture reactions with the active target MUSIC"*

Main Discussions

New TPC at FRIB

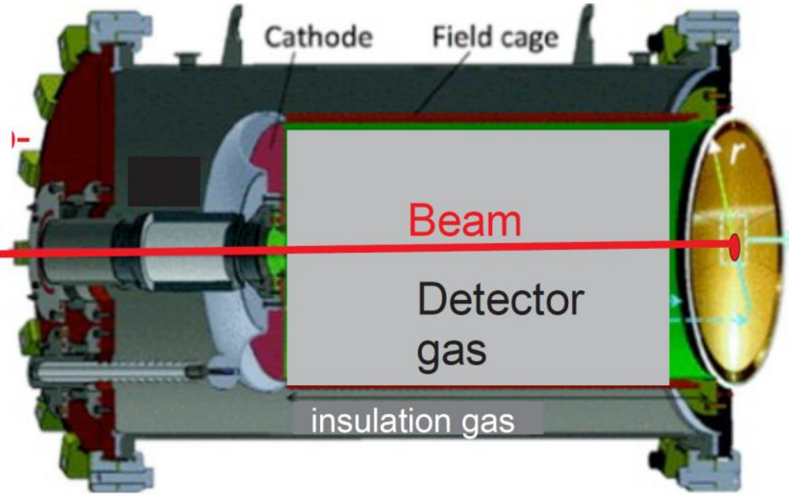
- The SπRIT TPC could be modified to fit into the High Rigidity Spectrometer or a similar detector could be built with modern improvements
- Needs to fit in 60 cm gap of D1
- Can be coupled with LANA or upgraded neutron walls
- Fitting the TPC in at HRS:
  - Moving GET electronics off of the top and reducing support structure (replace GET with something else)
  - Requires R&D for preamps
  - Reduction of a bit more than 10 cm
  - Small reduction of the drift cage

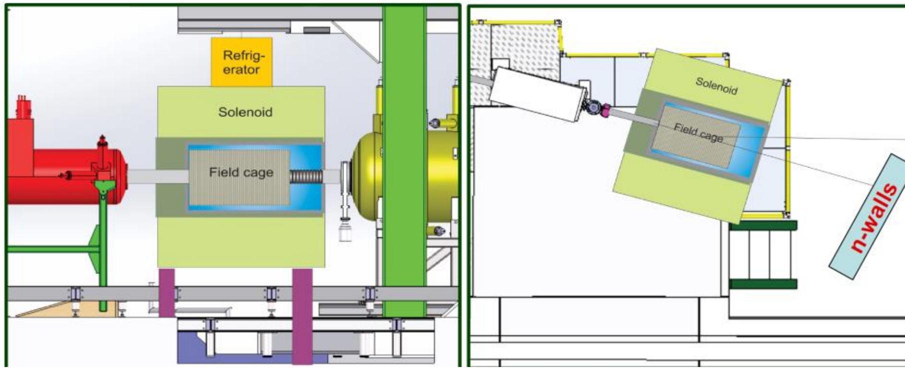


Kyle W. Brown *"Outlook for an Equation of State TPC with the High Rigidity Spectrometer"*

New TPC at FRIB

- A new AT-TPC style detector for fast beams at FRIB
- More portable solenoid required
  - Desired use at many locations of FRIB
- Include existing AT-TPC modifications
- Add new improvements
  - Inner beam region tube to shield from space charge
  - Option thin cathode for additional downstream detectors
  - Option for internal solid target (for EoS studies, for example)





Zbigniew Chajęcki *"An active target time projection chamber for fast rare isotope beam experiments"*

Electronics - GET

- GET
  - No more MUTANTs
    - » Only about a dozen around the world between USA, Japan, and Korea
    - » Possibility of an electronics pool to ensure availability of electronics for the short term
      - New Electronics system > 5 years to develop
  - New chips give new capabilities
    - » STAGE
      - Longer shaping time
      - Good for Si and CsI detectors
    - » Streaming chips
      - SAMPA
      - SALSA
  - ZCoBo
    - » Next generation CoBo
    - » More accessible components
    - » Trigger and Timing without MUTANT
    - » Backward compatible with MUTANT

Electronics – The Future

- Commercial
  - CAEN - FERS system
    - » Could be made compatible with existing and future chips
    - » Current configuration is not usable in magnetic fields
    - » ~100 USD/channel
    - » Timeline for development is unknown
  - Commercial is expensive but has longevity and support that specialized systems such as GET lack
- New GET like system
  - Cost would be lower (though some cost hidden)
  - Long term sustainability is a concern
- SBIR
  - Potential for a startup with government funding to handle development and production
  - Possible alternative to the commercial route to have long term support but cheaper

Hardware

- New CoBo boards difficult to obtain
  - FPGA chips no longer available
  - ZCoBo could alleviate this
    - » Plan to make IP available to expand production options
- AsAd boards currently only manufactured in one place
  - Possibility to IP to be released so more options can be explored independently by members of the TPC community
- Gas gain detectors currently primarily produced at CERN
  - Investigate more places for manufacture
  - Need a lab to take lead
    - » Need sufficient buy in for new manufacturing initiative

Need more options for obtaining hardware and manufacture within the TPC community

Software - DAQ

- FRIBDAQ (formerly NSCLDAQ)
  - Containers
    - » A container consists of apps, libraries, binaries, and config files ("userland") ALL bundled in one package.
    - » It includes only what is needed.
    - » - One machine can run multiple
    - » containerized applications.
    - » - Essentially no overhead.
    - » - Instant booting
    - » - Modularity (micro-service approach).

Giordano Cerizza *"From NSCLDAQ to FRIBDAQ: New Solutions for Data Acquisition and Analysis"*

- Notable interest in moving away from Narval DAQ for GET systems from many GET users in the community

Software - Analysis

- Many analysis software packages being developed
  - SPIRITROOT (SπRIT)
  - ATTPCROOT (ATTPC, GADGET II)
  - LILAK (ATOM-X)
  - And others (TexAT/TeBAT, etc)
- Lots of reinventing the wheel for methods
  - Pulse Shape Analysis
  - Track fitting
  - Etc.
- Interest in establishing some community database of methods
  - A website (or wiki) perhaps
  - Browse solutions from others in the community

Discussions Summary

- New TPC at FRIB
  - Significant interest in an AT-TPC like detector for fast beams at FRIB
    - » Mobility and modularity is key
    - » Avoids stretching AT-TPC too thin for experiments
- Electronics
  - GET approaching end of life
    - » International electronics pool could get us by until a new system is developed
  - A new electronics solutions must be developed
    - » GET like system produced by the community would be more affordable but would also lack long term support
    - » Commercial options (CAEN, Mesytec, etc.) would have long term support but would be more expensive
      - Perhaps prohibitively expensive
    - » SBIR could be more affordable and provide long term support
    - » **<u>No consensus yet</u>**
- Hardware
  - Desire for more options for manufacture

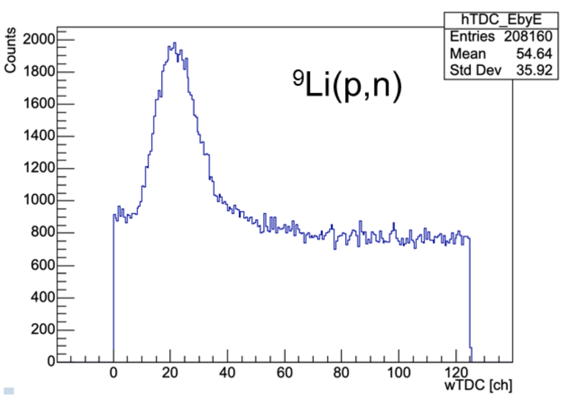
Questions?

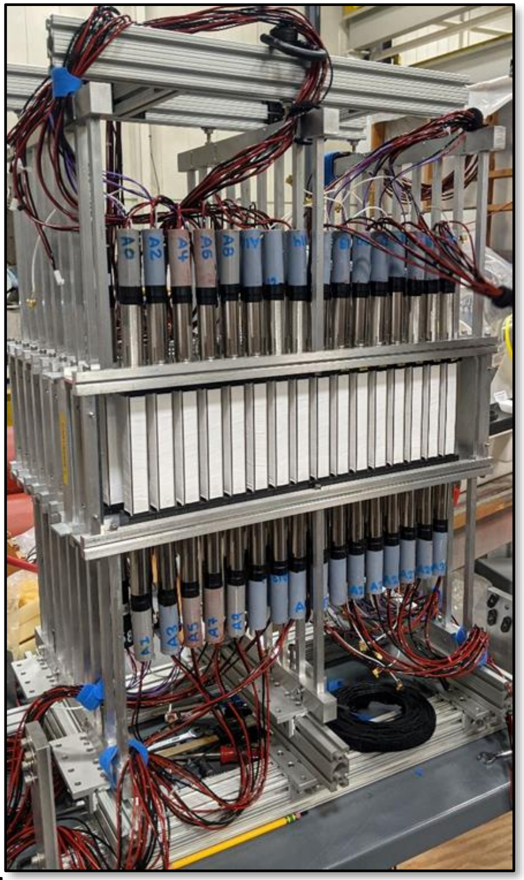
Questions?

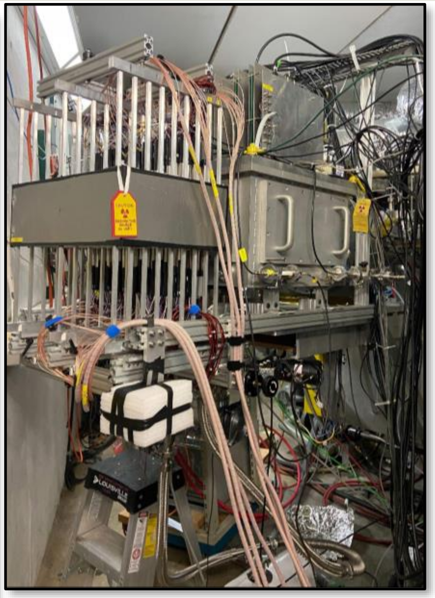
Backup Slides

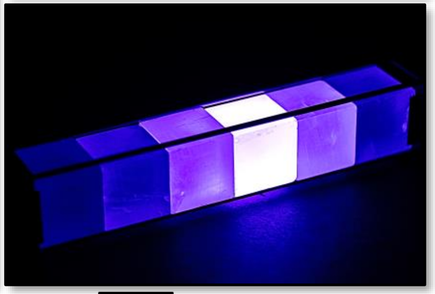
TexAT - TexNeut

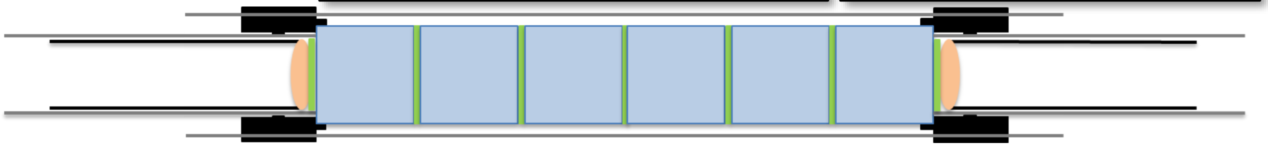
- Neutron detector array for use with TexAT & TeBAT
- Pseudo-bar design
  - 2x2x2 cm3 cubic crystals EJ-560
  - Read out conventionally from both ends by PMTs
- ^{9}Li(p,n) experiment to compliment previous ^{9}Li(p,p) experiment perfomed with TexAT







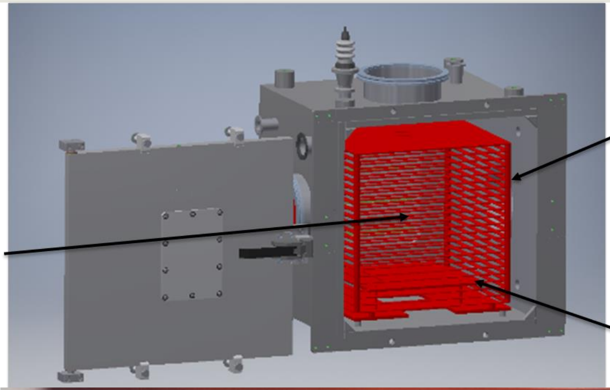




Dustin Scriven *“TexAT-TPC and a Neutron Detector Array, TexNeut”*

ND-Cube Active-Target Detector

- ND- Cube
  - Micromegas Anode pad plane
    - » 1008 anode pads
    - » <1 cm in size
  - Double-layer THGEM (CERN)
    - » Advantages for confining electron amplification to the holes of the THGEMs



- Using Neon for Active-Target TPCs
  - Ne gas is “sparky”
  - It has a lower threshold for discharge
  - H_2 gas as quench gas and Penning mixture
  - Use of Ne:H_2 (95:5) and (98:2) mixture

Tan Ahn *“Using Neon for Active-Target TPCs: Development Using the ND-Cube”*