

#### TexAT/TeBAT

Jack Bishop

TexAT

snapshots

silapsilots

Nuclear structur

Direct fusion

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Transfer

decay

Neutron-induce

#### measurement

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Stiffene

Elev cable

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Channel co

STAGE

Gas handling syster

# TexAT and TeBAT: a multitude of experiments

Jack Bishop Cyclotron Institute Texas A&M University

May 18th 2023



# TexAT overview

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#### TexAT TexAT

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#### TeBAT

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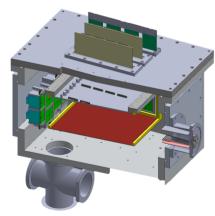
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# TexAT TPC - TEXas Active Target Time Projection Chamber

- 224 (beam) x 245 x 130 (height) mm sensitive volume
- Segmented readout using Micromegas, 1024 channels, pos. res. ≈ 1.5 mm in beam direction
- Gas Electron Multipliers (GEMs) provide additional gain. Low dE/dx particle tracks possible
- MUTANT module (practically essential)
- Ancillary Si+CsI telescope wall



NIM paper: E. Koshchiy et al. - NIMA 957, 163398 (2020)



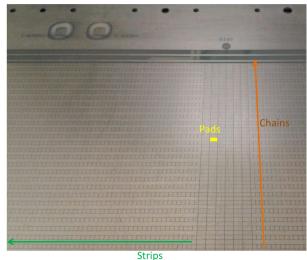
# Micromegas

#### TexAT/TeBAT

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#### TexAT

- $128-\mu \text{m-gap}$
- Central region pads 1.75 x 3.5 mm
- Side regions require multiplexing into 'strips' and 'chains' parallel and perpendicular to beamline
- THGEMs (1.25-mm-thick) and thin GEMs  $(50-\mu m-thick)$





# Ancillary detectors

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#### TexAT

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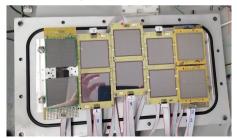
#### TeBAT

Flex cables
Resistive MM
Channel coun

Gas handling system

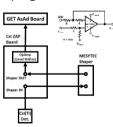
#### Si detectors

- 625-µm-thick "Dubna" detectors
- 1000-μm-thick Micron MSQ25,
   4 junction pads, 1 ohmic
- 0° 500- $\mu$ m-thick W1 DSSD



## Csl detectors

- 40-mm-thick readout by single
   Hamamatsu 20×20 cm<sup>2</sup> S3204 PIN diode
- Max AGET shaping time 1  $\mu$ s  $\Lambda$
- Take Csl signal to external Mesytec MSCF-16 with 8  $\mu$ s shaping-time
- → Fed back into AsAd board with "Gain2Input" option and level-shifter to bypass CSA





# Ancillary detectors: Micromegas Junior

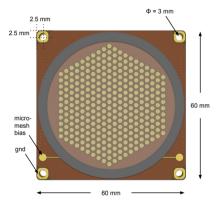
#### TexAT/TeBAT

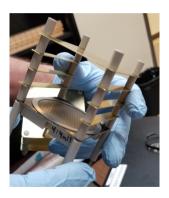
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# TexAT

#### TeRAT

Built by Radiation Detection and Imaging (RDI) - Arizona





Used as a beam monitor  $(dE_{beam})$  from mesh Signal on pads too small for proper reconstruction - need a new design



# Ancillary detectors: Micromegas Junior

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### TexAT

TexAT snapshots

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Overview

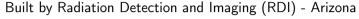
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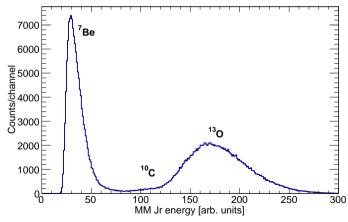
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Mesh signal



# Past experiments

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#### TexAT

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Nuclear structure/exotic nuclei

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 8B(p,p)  $\checkmark$ 

$$\blacksquare$$
 <sup>10</sup>C( $\alpha$ ,  $\alpha$ )

$$\blacksquare$$
 <sup>14</sup>O( $\alpha$ ,  $\alpha$ )  $\checkmark$ 

■ 
$$^{12}$$
Be $(p,p)$  at TRIUMF  $\checkmark$ 

$$\blacksquare$$
 <sup>9</sup>Li( $p,p$ )  $\checkmark$ 

■ 
$$^{9}$$
Li( $p$ ,  $n$ ) TexNeut

Direct fusion measurement

$$^{8}B + ^{40}Ar \checkmark$$

Trojan Horse Method studies

$$\alpha$$
 (20 Ne,  $\alpha$ ) 16 O +  $\alpha$ 

Nuclear astro  $(\alpha, p)$  studies

■  $^{14}O(\alpha, p)$  at RIKEN (CRIB)

Transfer reactions

$$\blacksquare$$
 <sup>12/13</sup>B(*d*, <sup>3</sup>He)

■ 
$${}^{1}\text{H}({}^{6}\text{He}, t^{\star})$$
 ✓

 $\beta$ -delayed particle decay

$$(^{12}N, \beta 3\alpha) \checkmark$$

$$(^{13}O, \beta 3\alpha p) \checkmark$$

Neutron-induced measurements

■ 
$$^{12}C(n, n_2)3\alpha$$
 ✓

■ 
$$^{12}$$
C( $n, \alpha_0$ ),  $^{16}$ O( $n, \alpha_0$ )  $\checkmark$ 



#### TexAT/TeBAT

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TexAT

# TexAT snapshots

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#### TeBA

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# TexAT snapshots



# $^{12}$ Be(p,p) - Curtis Hunt's thesis work



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TexAT TexAT snapshots

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# TeBAT

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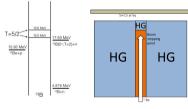
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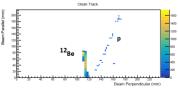
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Gas handling syster

## TRIUMF experiment: July 2019 - 2 weeks setup

- Populate T=5/2 IAS of <sup>13</sup>Be g.s. in <sup>13</sup>B
- 6 MeV/u <sup>12</sup>Be beam 500 pps
- 260 Torr iC<sub>4</sub>H<sub>10</sub> to stop beam 7/8<sup>th</sup> into the MM: TTIK
- Trigger on Si (m=1)
- Proton track in side region and last 1/8<sup>th</sup> (HG) - gain not quite good enough for reliable p/d/t separation
- Lesson learnt 260 Torr → 210 Torr enough for high-enough gain. Not enough experience with GEMs yet







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Direct fusion

TeRAT

Direct fusion studies

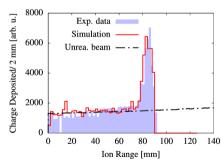
TexAT/TeBAT

Measure <sup>8</sup>B+<sup>40</sup>Ar fusion directly - weakly-bound proton-halo nucleus

No model dependency based on evaporation yields

5.1 MeV/u  $^{8}$ B 1000 pps into P5 ( $^{40}$ Ar (95%) + CH<sub>4</sub> (5%)) at 150 Torr

150 Torr P. 196 mm active region 83 mm Window 8B 49 MeV 270 mm Silicon detector Veto region



Trigger here on the ion counter (external), veto trigger with Si and MM last 1/8<sup>th</sup>

- → L0 trigger with MUTANT for interacting beams only
- J. Zamora++ Phys. Lett. B 816, 136256



# Select example highlighting possibilities of TPCs

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Neutron-indu measurement

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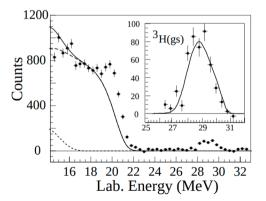
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Gas handling syste

t 85% (7000 pps),  $^9\text{Li}$  10% (800 pps),  $^6\text{He}$  5% (400 pps) 260 Torr iC<sub>4</sub>H<sub>10</sub> measuring  $^6\text{He}(p,t^\star)\alpha$  Excited state of tritium? Measure missing mass spectrum from  $\alpha\text{-particles}$ 



Peak from  $\alpha$ -spectrum at  $E_x = 6.8$  MeV Or possibly a final state interaction? Re-do with range of beam energies and with greater sensitivity of TPC Can also observe the breakup of any excited state



# $^6$ He(p,t\*) $\alpha$



#### TexAT/TeBAT

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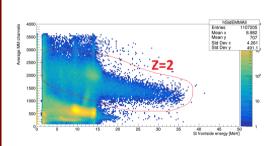
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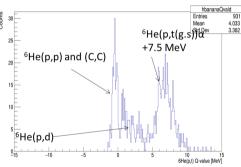
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Gas handling syste





Peaks seen for  $^{6}\text{He}(p,t(g.s))$ ,  $^{6}\text{He}(p,p)$  and  $^{6}\text{He}(p,d)$ 

No peak seen for  $t^{\star}$  and missing momentum distribution not consistent with  $t^{\star}$ 



# 2p-mode: $(^{13}O, \beta 3\alpha p)$

 $\mathsf{Te}{\times}\mathsf{AT}/\mathsf{Te}\mathsf{BAT}$ 

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Transfer

β-delayed particle decay

Neutron-induce measurements

measurement

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2p-mode: L1A and L1B trigger
30 ms timeout between L1A and L1B



# d2p: decay-time measurement

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measuremen

#### TeBAT

Overview

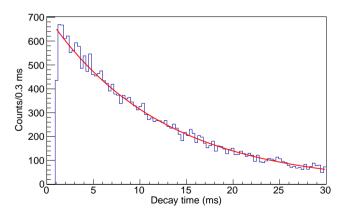
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Correlate implant and decay location



Backgroundless  $t_{1/2}$ =8.55±0.09 (stat.) ms c.f. adopted value of 8.58±0.05 ms



# New decay modes

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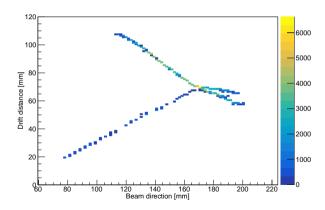
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STAGE Gas handling systen Highly-sensitive - new decay modes:  $\beta 3\alpha p$ . Recently accepted in PRL - arxiv:2302.14111



0.078(6)% branching ratio from few pps beam. Thank you 2p-mode!



# Neutron-induced measurements: ${}^{12}C(n, n_2)3\alpha$

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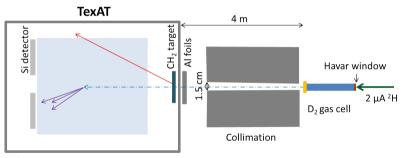
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Gas handling systen

Thin Al entrance flange (3-mm-thick) for 7.2-10 MeV neutrons Edwards Accelerator Lab, Ohio University



Measure  $^{12}$ C( $n, n_2$ )3 $\alpha$  with 50 Torr CO<sub>2</sub> from 5000 pps of neutrons Answered important question of role of neutron-upscattering in the triple-alpha process: JB++ Nat. Comm. 13, 2151 (2022) Plenty of further opportunities for TPCs+neutrons



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# TeBAT



# Next generation - TeBAT

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measurement

#### TeBAT

#### Overview

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## Major changes:

- "External" Micromegas PCB
- Resistive Micromegas
- 1K → 7K channels
- Addition of STAGE chips for Si/Csl
- Additional <sup>3</sup>He gas system



# Flange Micromegas

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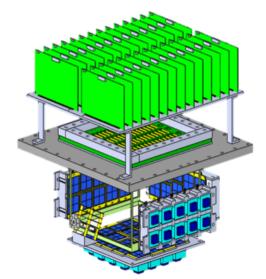
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8K connections - better debug needed Micromegas PCB now a flange - huge pressure differential at vacuum Stainless steel stiffener attached to PCB stops bending



1.2 tons of lead = 1 atm  $300\mu$ m deflection total



# Flex cables

#### TexAT/TeBAT

#### Jack Bishop

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"Flex" cables then connect PCB connectors to ASAD boards High-density cables → capacitance and crosstalk carefully calculated Plugged into "dummy" MM board - no noticeable waveform degradation



# Resistive Micromegas

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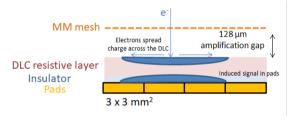
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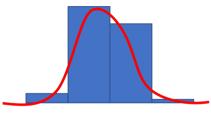
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Gas handling syste





DLC layer deliberately spreads the charge across multiple pads - continuous RC network

ightarrow need to choose the 'best' RC time: want to spread across enough pads to get good position resolution but not too many pads to dilute the signal and increase multiplicity



# RC simulation work

#### $\mathsf{Te}{\times}\mathsf{AT}/\mathsf{Te}\mathsf{BAT}$

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Unshaped charge propagation - then shaped by GET



# RC simulation work

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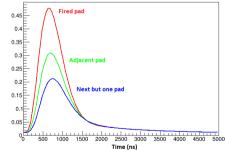
Gas handling syste

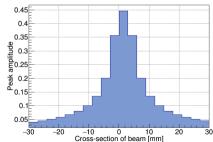
Found that 0.1-2 M $\Omega/\Box$  shows good signal spread

>2 M $\Omega/\Box$  RC time too large - charge hangs around but gives best spark-resistance

1.4 M $\Omega/\Box$  selected (c.f. DESY TPC 0.5 M $\Omega/\Box$ )

Estimated position resolution of 300  $\mu m$  - limited by threshold (gain) and noise





 $RC = 10 \text{ ns/mm}^2$ : 500 ns peaking time



# Increased channel count

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Channel count

New MM, 128  $\mu$ m gap  $84 \times 84$  pads:  $3 \times 3$  mm<sup>2</sup>

- 7056 MM channels (7 CoBos)
- 40 Si front + 10 Si back + 10 Csl (1 CoBo all STAGE)
- 1 spare CoBo

New electronics challenges:

- Data throughput bypass Narval Merger?
- Writing to disk parallel computers/drives?
- Micromegas region triggering tedious xcfg files



# STAGE

#### TexAT/TeBAT

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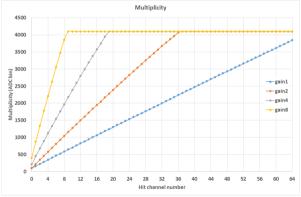
Flex cables

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Gas handling system

Overcome m=1 triggering problems with AGET



Preliminary tests show this works well: 100% triggers regained with 1 chnl firing 8  $\mu$ s shaping time also works well!



# <sup>3</sup>He gas handling system

#### TexAT/TeBAT

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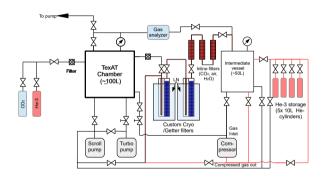
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Channel

STAGE

Gas handling system



 $\approx$  100 L of <sup>3</sup>He - separated from CO<sub>2</sub> and recycled Allows a multitude of new experiments: (<sup>3</sup>He,n), (<sup>3</sup>He,d)...



# The team

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