An Active Target Time Projection Chamber for Nuclear Structure and Reactions Experiments

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Merging Concepts

**Time Projection Chambers:**
- Traditionally used for high(er) energy collider or fixed target experiments
- Multiple time sampling of pads
- Allows 3D reconstruction of high multiplicity events
- External magnetic field results in curved charged particle tracks
- Particle identification from measurement of dE/dx and p
- Isotopic resolution for light particles

**Active Targets:**
- Traditionally used for low energy reaction experiments with low detector occupancy
- The chamber gas acts as both detector and target
- Appropriate gas identity and pressure chosen to study the reaction of interest in inverse kinematics
- Thick target possible without loss of energy resolution
- Measure low energy recoil particles
AT-TPC Introduction

- Combines in a single device both active target and time projection chamber functionality
- Fixed Target Mode:
  - A target wheel will be installed within the chamber thus the gas will serve only as a detector
  - Configuration will reflect standard TPC conditions (ex: P10 @ 1atm)
- Active Target Mode:
  - The chamber gas will act as both detector and target
  - Gas identity and pressure chosen based on experimental requirements
  - Limitations imposed by low beam intensities will be addressed by providing a thick target while retaining high resolution and efficiency
AT'-TPC Advantages

• Combines in a single device both active target and time projection chamber functionality allowing measurements of:
  – Rare processes that require high detection efficiency and large acceptance
  – Low energy processes that are traditionally difficult to measure due to the short range of the reaction products in matter
  – High multiplicity reactions that require multi-track reconstruction
  – Global event reconstruction of charged reaction products

120 cm
**NSCL: Coupled Cyclotron Facility**


**Developed Primary Beams**

<table>
<thead>
<tr>
<th>Particle</th>
<th>MeV/A</th>
<th>pnA</th>
</tr>
</thead>
<tbody>
<tr>
<td>16O</td>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>18O</td>
<td>120</td>
<td>125</td>
</tr>
<tr>
<td>22Ne</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>24Mg</td>
<td>170</td>
<td>30</td>
</tr>
<tr>
<td>36Ar</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>40Ar</td>
<td>140</td>
<td>50</td>
</tr>
<tr>
<td>40Ca</td>
<td>140</td>
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<td>90</td>
<td>15</td>
</tr>
<tr>
<td>48Ca</td>
<td>110</td>
<td>15</td>
</tr>
<tr>
<td>48Ca</td>
<td>140</td>
<td>80</td>
</tr>
<tr>
<td>58Ni</td>
<td>140</td>
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<td>140</td>
<td>7</td>
</tr>
<tr>
<td>76Ge</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>78Kr</td>
<td>150</td>
<td>25</td>
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<tr>
<td>86Kr</td>
<td>100</td>
<td>10</td>
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<tr>
<td>86Kr</td>
<td>140</td>
<td>20</td>
</tr>
<tr>
<td>96Zr</td>
<td>120</td>
<td>1.5</td>
</tr>
<tr>
<td>112Sn</td>
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<td>124Xe</td>
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<td>10</td>
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<td>136Xe</td>
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<td>208Pb</td>
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<td>1.5</td>
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<td>209Bi</td>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>238U</td>
<td>80</td>
<td>0.2</td>
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</tbody>
</table>
MSU Construction Projects

Offices

Expt’l Hall
NSCL: Reaccelerator

Re-acceleration (0.3-3.2 MeV/u, 12 MeV/u upgrade)

- Low-energy reactions important for nuclear astrophysics
- Transfer reactions, Coulomb excitation for nuclear structure studies
- See talk by Georg Bollen Thursday
Scientific Program Overview

Table 1: Overview of AT-TPC scientific breadth.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Physics</th>
<th>Beam Examples</th>
<th>Beam Energy</th>
<th>Min Beam Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Reactions</td>
<td>Nuclear Structure</td>
<td>$^{32}\text{Mg}(d,p)^{33}\text{Mg}$</td>
<td>3 (A MeV)</td>
<td>100 (pps)</td>
</tr>
<tr>
<td>Resonant Reactions</td>
<td>Nuclear Structure</td>
<td>$^{26}\text{Ne}(p,p)^{26}\text{Ne}$</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Astrophysical Reactions</td>
<td>Nucleosynthesis</td>
<td>$^{25}\text{Al}(^{3}\text{He},d)^{26}\text{Si}$</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Fission Barriers</td>
<td>Nuclear Structure</td>
<td>$^{199}\text{Tl},^{192}\text{Pt}$</td>
<td>20 - 60</td>
<td>10,000</td>
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<tr>
<td>Giant Resonances</td>
<td>Nuclear EOS, Nuclear Astro.</td>
<td>$^{54}\text{Ni} - ^{70}\text{Ni},^{106}\text{Sn} - ^{127}\text{Sn}$</td>
<td>50 - 150</td>
<td>50,000</td>
</tr>
<tr>
<td>Heavy Ion Reactions</td>
<td>Nuclear EOS</td>
<td>$^{106}\text{Sn} - ^{126}\text{Sn},^{37}\text{Ca} - ^{49}\text{Ca}$</td>
<td>50 - 150</td>
<td>50,000</td>
</tr>
</tbody>
</table>

- Detector will make use of the full range of beam energies and intensities available at NSCL
- Experiments with rare isotope beams continuously push the limits of low beam intensities and low cross sections
- AT-TPC will address these limitations by providing access to reactions at beam intensities as low as 100pps
**AT-TPC Advantages**

- $4\pi$ geometrical acceptance
- High resolution and efficiency tracking
- Variable pressure and identity of gas
- Internal triggering for low energy particles that stop in the detector gas
- Multiplicity triggering for intermediate energy heavy ion reactions
- Sufficient magnetic field to resolve light fragments in heavy ion reactions
- Large dynamic range for particle detection
- Electronics that can accommodate large data volumes and rates
NSCL: AT-TPC

- Cylinder - length 120cm, radius 35cm
- Chamber designed to sustain vacuum
- 2cm radius entrance window
- 33cm radius exit window
- 10,000 pads, 0.5cm x 0.5cm
- Testing wire planes, GEMS & Micromegas for electron amplification
AT'-TPC Targets

NSCL: AT-TPC

• Fixed Target Mode:
  – Removable target wheel that accommodates multiple targets

• Active Target Mode:
  – Identity and pressure of the gas used to fill the detector will be dependent upon the experimental requirements.
  – $\text{H}_2$, $\text{D}_2$, $^3\text{He}$, Ne, Ar, Isobutane
  – Pressures ranging from 0.2-1.0 atm
Magnetic Field Considerations

Solenoid
- Beam trajectory centered in magnet
- **Beam path independent of beam species & energy**
- Optional field cage can be used to mask beam ionization
- Narrow downstream acceptance
- Limited momentum resolution at very forward angles

Dipole
- Good momentum resolution in forward direction
- Wide downstream acceptance
- Beam trajectory influenced by Bfield
- Beam path dependent upon beam species & energy
- Difficult to mask beam ionization
- Difficult to distinguish +products from beam
Magnetic Field

**NSCL: AT-TPC**
- Superconducting solenoid
- 2 Tesla Field
- Bore Dimensions:
  - $\geq 70$ cm diameter
  - $\geq 120$ cm length
  - $\leq 125$ cm beam height
- Field Non-uniformity: $\leq 10\%$
- Consistent with a medical MRI solenoid

**TWIST Solenoid**
- Superconducting solenoid
- 2 Tesla Field
- Bore Dimensions:
  - $105$ cm diameter
  - $229$ cm length
  - $107$ cm beam height (w/o yoke)
  - $130$ cm beam height (w/ yoke)
- Field Non-uniformity: $< 1\%$
Triggering

• Requirements:
  – Beam trigger -
    • Provided by PPAC & RF-ToF before beam enters chamber
  – Internal trigger -
    • Discriminator incorporated in TPC electronics to be used as a threshold trigger
    • Will allow 3D hit multiplicity threshold cut to be applied online
    • Necessary for experiments with low energy products that do not exit the chamber
    • Will allow online centrality trigger based on collision multiplicity for heavy ion reactions experiments
  – External trigger -
    • Downstream calorimeter to measure Z of leading particle
    • Primarily for heavy ion reactions; not incorporated in plan for reaccelerated beam experiments
• Investigating opportunities to modify existing T2K electronics chain to accommodate our requirements
• Collaborative effort with the ACTAR working group
• Dynamic range of ADC is key due to wide range of particle species to be simultaneously identified \( \therefore \) 12bit AFTER+ chip will be used
• Internal triggering capability will allow a multiplicity threshold trigger
• Must sustain 1kHz/chan data rate
Data Volume

$^{112}\text{Sn}+^{112}\text{Sn}, \ 150\text{MeV}, \ b=2\text{fm}$

- High collision multiplicity expected
- ~2% channels & time buckets filled
- Results in data volume of:
  
  \[ 5 \text{ kB/s*chan} \]
  \[ \rightarrow \ 50\text{MB/s} \]

Zero suppressed
Particle Identification

- Energy deposition and radius of curvature of each particle species is unique
- Allows identification particle species and charge state
- Dynamic range sufficient to simultaneously measure pions $\rightarrow$ light isotopes

Simulation w/ STAR resolution, scaled to EOS
Timeline & Funding

• DOE preapplication accepted
• Total budget:
  – DOE: $660k equipment + $645k manpower + $600k magnet

• 2008 - Prototype testing, Mechanical Design, Electronics Design
• 2009 - Electronics Design & Testing, Magnet, Laser & Gas Systems
• 2010 - Detector Construction & Assembly, (Reaccelerator completed)
• 2011 - System Commissioning & First experiments
Test Chamber

- Designed to allow flexibility to test a variety of amplification techniques
  - GEMs
  - MicroMegas
  - Wire planes
- Optimize
  - Gas mixture
  - Pressure range
  - Gain
  - Position resolution
  - Pad plane geometry
- Electronics Testing

35 cm
Summary

- The AT-TPC provides a powerful tool for studying reactions induced by rare isotope beams.
- The scientific program will exploit the full extent of beam species, energies and intensities currently available with fragmentation and reaccelerated beams.
- Active target reactions will study fusion, isobaric analog states, cluster structure of light nuclei and transfer reactions.
- Fixed target reactions will study heavy ion collisions to probe the nuclear equation of state.
- Scientific program can be conducted with existing rare isotope beams, but requires a high resolution AT-TPC.
- The AT-TPC will allow these measurements to be made prior to the completion of the future rare isotope beam facility.
The AT-TPC Collaboration

- Lawrence Berkeley National Laboratory
  - I-Yang Lee, Larry Phair
- University Notre Dame
  - Umesh Garg
- Michigan State University
  - Abigail Bickley*, Bill Lynch, Wolfgang Mittig, Gary Westfall
- Saint Mary's University (Canada)
  - Rituparna Kanungo
- Western Michigan University
  - Michael Famiano