Active Target Time Projection Chamber (AT-TPC)

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What is the AT-TPC?

• Active Target Mode:
  – The chamber gas will act as both detector and target
  – Appropriate gas identity and pressure will be chosen to study the reaction of interest in inverse kinematics
  – Limitations imposed by low beam intensities will be addressed by providing a thick target while retaining high resolution and efficiency
• 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)
What is the AT-TPC?

- The AT-TPC combines time projection and active target 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
### 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>
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<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>
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<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>
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<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>
</tr>
<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 beam continuously push the limits of low beam intensities and low cross sections
- AT-TPC will allow access to measurements of rare processes that require high detection efficiency and large acceptance
Active Target Experiments

• Transfer Reactions:
  – Beam energy $\leq 3$ AMeV; Minimum beam intensity 100pps
  – Study Coulomb dominated transfer reactions to extract asymptotic normalisation coefficients that are needed for astrophysical reaction rate calculations
  – Experimentally must measure the energy dependence of the cross section to find the angular momentum of the state of interest
  – Many transfer reaction cross sections are highest at energies of $1 – 2$ A MeV due to excellent velocity matching between the initial and final states
  – Study $(d,p)$, $(^3\text{He},d)$ and $(\alpha,t)$ transfer reactions in the vicinity of closed shells in inverse kinematics
  – An example of interest for understanding shell closures far from stability that will be possible with the AT-TPC is the $^{32}\text{Mg}(d,p)^{33}\text{Mg}$ reaction
  – With the reaccelerator beam intensities of $\sim 1000$pps are expected for $^{32}\text{Mg}$

• Resonance Reactions:

• Astrophysical Reactions:
Active Target Experiments

• Transfer Reactions:

• Resonance Reactions:
  – Beam energy ≤ 3 AMeV; Minimum beam intensity 100pps
  – Study the production and decay of isobaric analog resonance states in both elastic and inelastic scattering using $^A Z(p,p)$, to determine the properties of the nucleus $^{A+1}Z$.
  – The gas pressure of the AT-TPC will be adjusted to stop the beam in the detector, allowing continuous excitation functions to be measured between beam energy and zero energy.
  – Large cross-sections are typical for this reaction where the interference between the potential and the resonant amplitudes determines $J^\pi$.
  – Backward CoM angles are important => correspond to 0-45° in lab
  – Center-of-mass resolutions of 35 keV expected
  – Reaction example: $^{26}\text{Ne}(p,p)$

• Astrophysical Reactions:
Active Target Experiments

• Transfer Reactions:
• Resonance Reactions:
• Astrophysical Reactions:
  – Study proton reaction rates relevant for hot and explosive stellar environments where nuclei are far from stability
  – Example: Origin of large galactic abundance of $^{26}$Al unresolved
  – Proton capture on $^{25}$Al followed by $^{26}$Si beta decay could be the mechanism, but depends on the capture cross section and the structure of high lying levels in $^{26}$Si
  – Use indirect ANC to measure the $^{25}$Al($^3$He,d)$^{26}$Si transfer reaction
  – Very good energy resolution is needed due to the high level density in $^{26}$Si.
  – Due to the low deuteron energy (0.4-1.0MeV), a conventional target would need to be extremely thin
  – Beam energy $\leq 3$ AMeV; Minimum beam intensity 100pps
**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
AT-TPC Chamber Design

NSCL: AT-TPC

- Cylinder - length 120cm, radius 35cm
- Chamber designed to sustain vacuum
- 2cm radius entrance window
- 33cm radius exit window
- Removable target wheel
- 10,000 pads, 0.5cm x 0.5cm
- Testing wire planes, GEMS & Micromegas for electron amplification
Sub - Systems

• Gas Mixing System:
  – Monitors & maintains chamber pressure and gas purity
  – Identity and pressure of the gas used to fill the detector will be dependent upon the experimental requirements.
    • H₂, D₂, ³He, Ne, Ar, Isobutane and P10(90% Ar + 10% CH₄)
    • Pressures ranging from 0.2-1.0 atm

• Laser Calibration System:
  – Calibration based on drift rate of laser induced ionization
  – Compensates for changing environmental conditions and static non-uniformities in the magnetic and electric fields
  – A predefined fraction of the event rate will be laser triggered allowing the electron drift rate to be continuously sampled
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:
  - $\geq 70 \text{ cm}$ diameter
  - $\geq 120 \text{ cm}$ length
  - $\leq 125 \text{ cm}$ beam height
- Field Non-uniformity: $\leq 10\%$
- Consistent with a medical MRI solenoid

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

Future Reaccelerator area
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
  - External trigger -
    • Downstream calorimeter to measure Z of leading particle
    • Not incorporated in plan for reaccelerated beam experiments; primarily for high energy reactions
• Investigating opportunities to modify existing T2K electronics chain to accommodate our requirements
• Collaborative effort with the ACTAR working group
• *Internal triggering capability will allow low energy reactions to trigger on number of channels above threshold*
• Dynamic range of ADC is key due to wide range of particle species to be simultaneously identified \( \therefore \) 12bit AFTER+ chip will be used
• 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:
  - $5\text{ kB/s*chan}$
  - $50\text{MB/s}$
  - Zero suppressed
Figure 1: Overview of data flow. The shaded items will be developed at NSCL while the FEC, FEM, and DCC will be adapted from the T2K experiment.
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
- 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
Summary

• The AT-TPC is 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.

• 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.