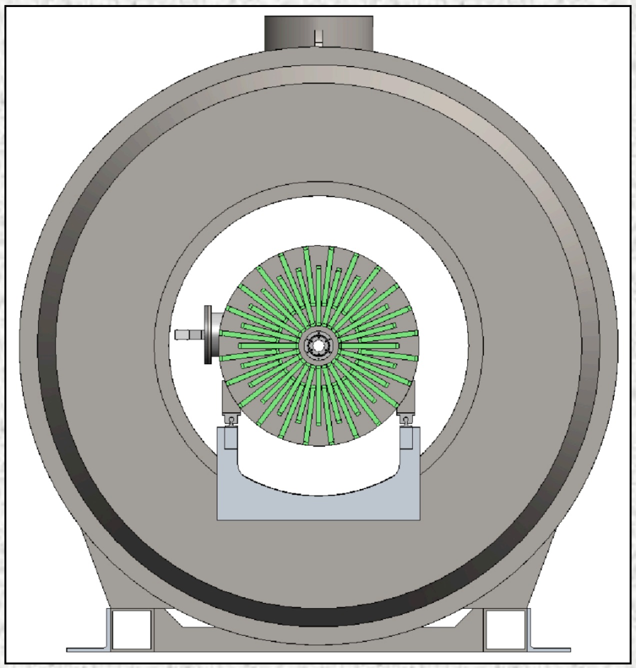
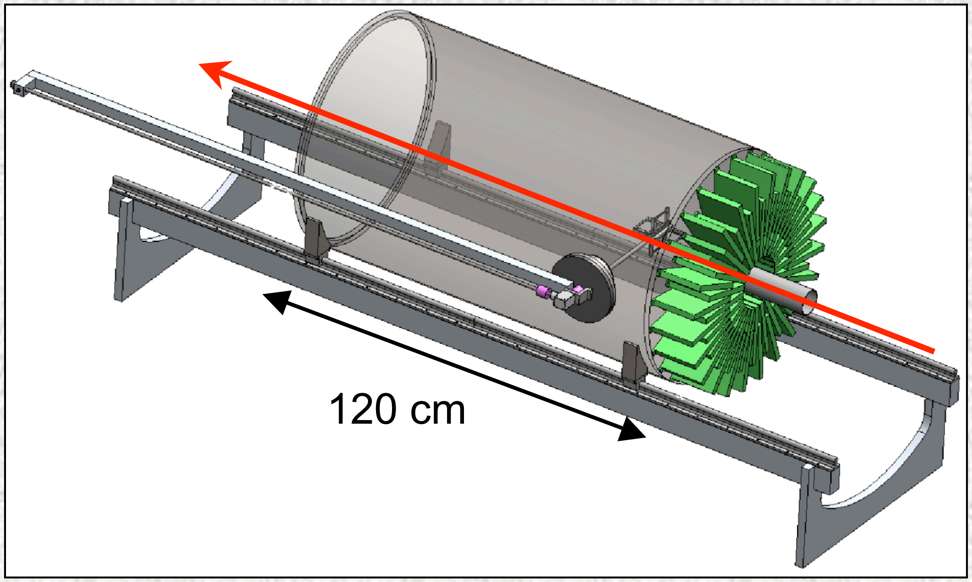
Active Target Time Projection Chamber (AT-TPC)



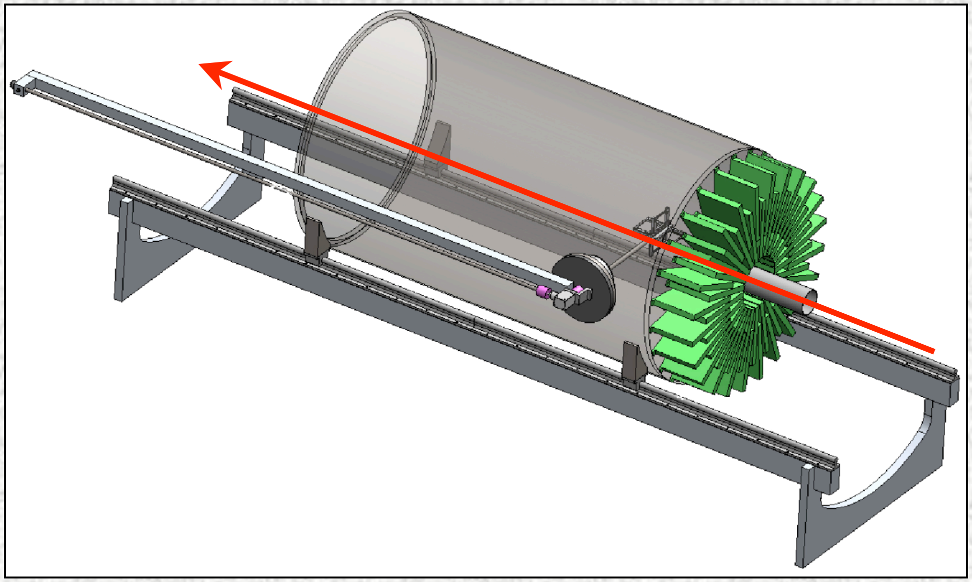
Abigail Bickley
Michigan State University
June 2, 2008

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.

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

- 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 ≤ 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}He,d) and (α,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}Mg(d,p)^{33}Mg reaction
  - With the reaccelerator beam intensities of ~1000pps are expected for ^{32}Mg
- Resonance Reactions:
- Astrophysical Reactions:

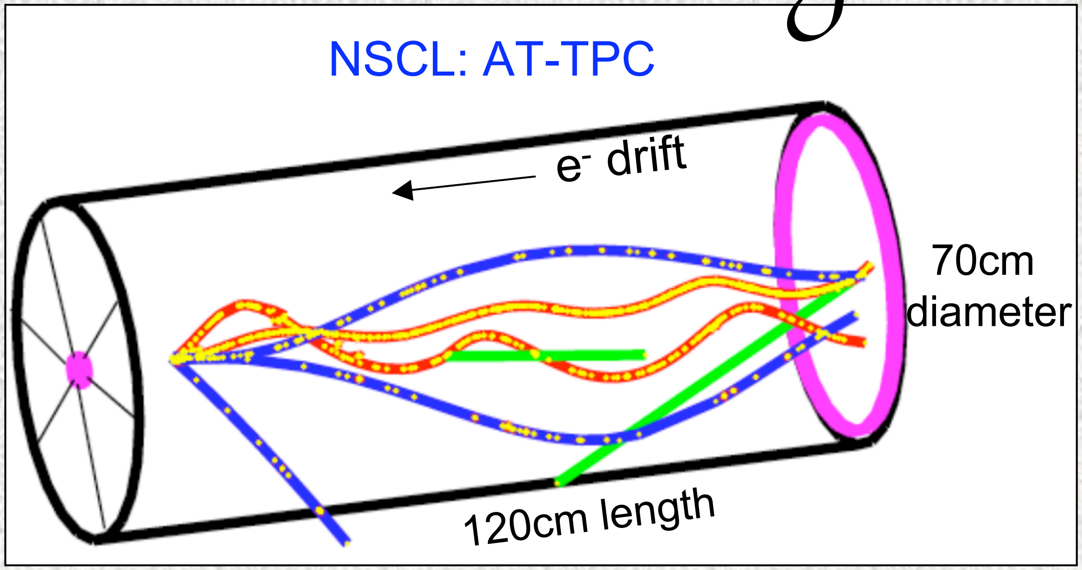
Active Target Experiments

- 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 determines 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^{π}.
  - Backward CoM angles are important => correspond to 0-45° in lab
  - Center-of-mass resolutions of 35 keV expected
  - Reaction example: $^{26}Ne(p,p)$
- Astrophysical Reactions:

Active Target Experiments

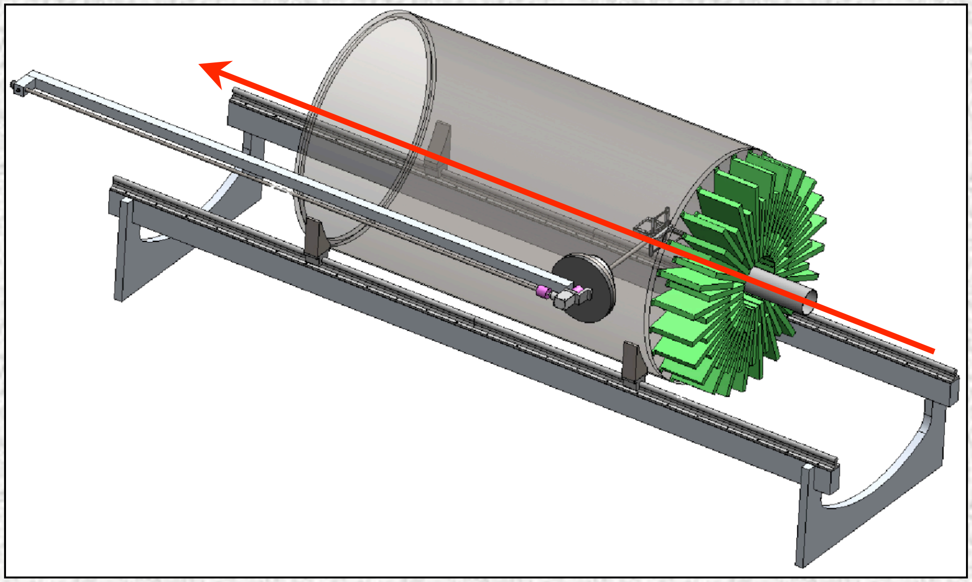
- Transfer Reactions:
- Resonance Reactions:
- Astrophysical Reactions:
  - Study proton reaction rates relevant for hot and explosive stellar environments where nuclei are far from stability
  - Example: Origin of large galactic abundance of ^{26}Al unresolved
  - Proton capture on ^{25}Al followed 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



- 4π 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

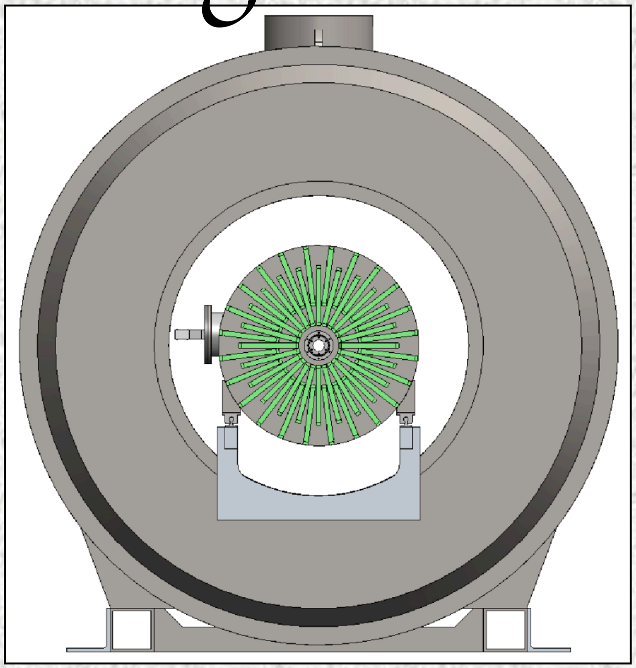
- Cylinder - length 120cm, radius 35cm
- Chamber designed to sustain vacuum
- 2cm radius entrance window
- 33cm radius exit window
- Removable target wheel
- 10,000pads, 0.5cm x 0.5cm
- Testing wire planes, GEMS & Micromegas for electron amplification

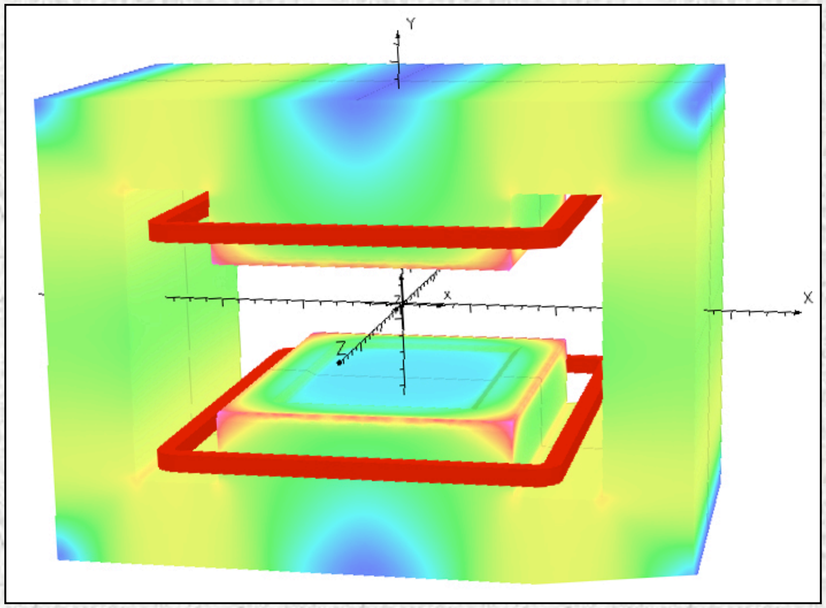
Sub - Systems

- 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.
    - H_2, D_2, ^3He, Ne, Ar, Isobutane and P10(90% Ar + 10% CH_4)
    - 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





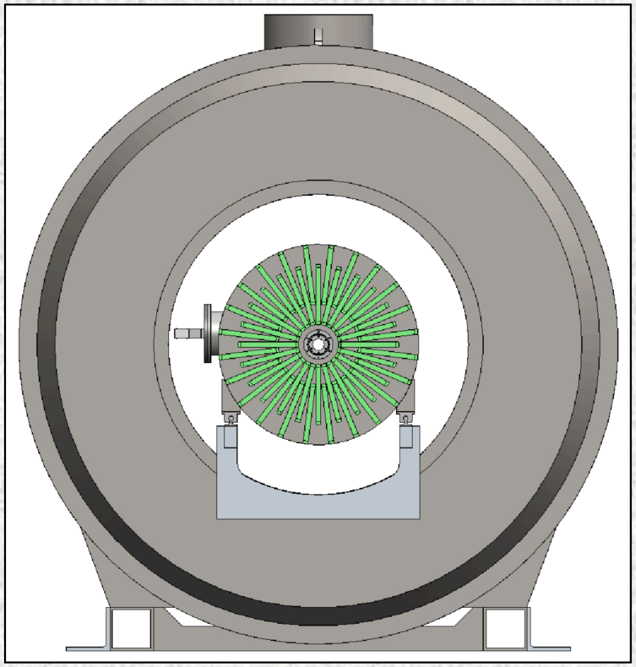
<u>Solenoid</u>

- 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

<u>Dipole</u>

- 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



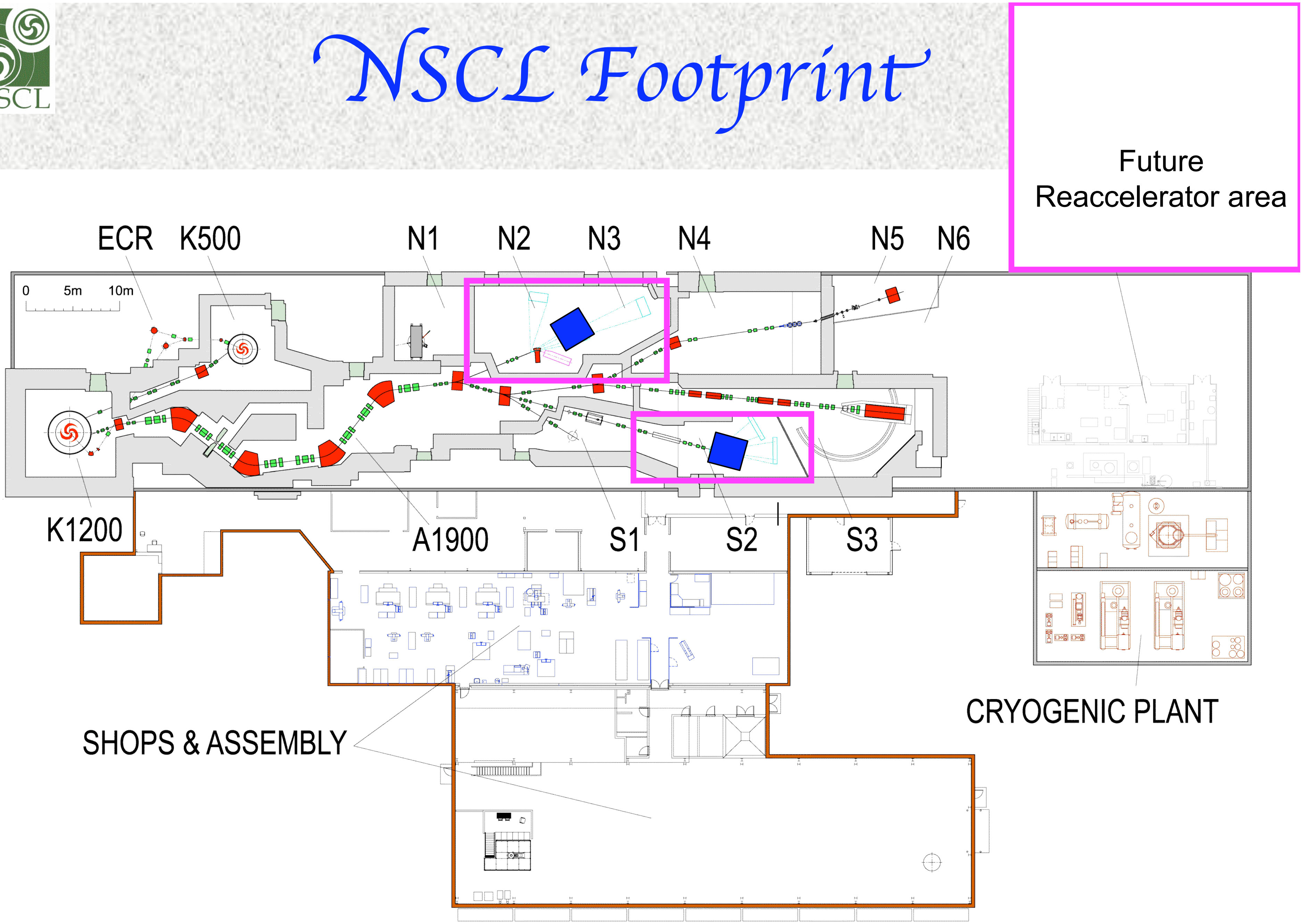
NSCL: AT-TPC

- Superconducting solenoid
- 2 Tesla Field
- Bore Dimensions:
  - ≥ 70 cm diameter
  - ≥ 120 cm length
  - ≤ 125 cm beam height
- Field Non-uniformity: ≤ 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%

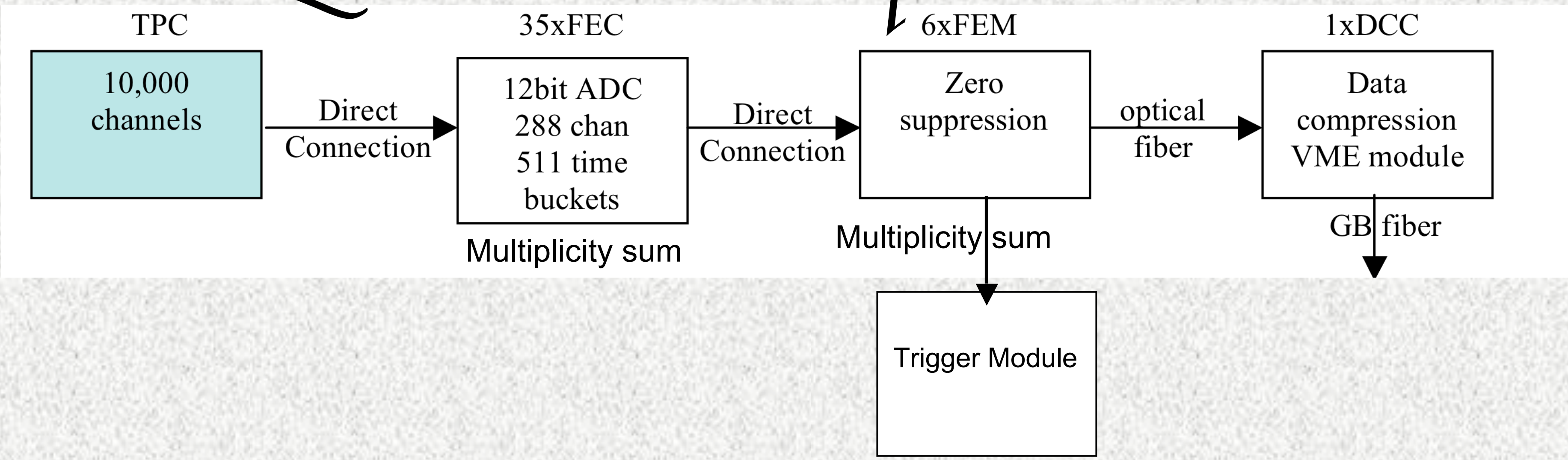
NSCL Footprint



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

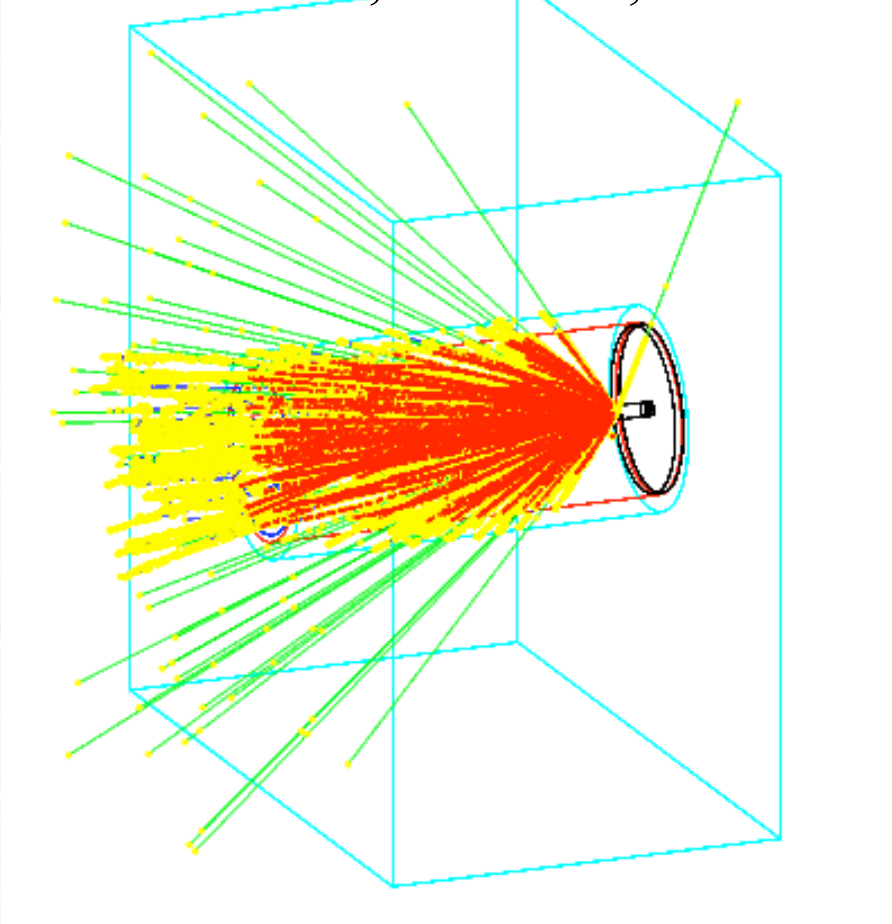
Electronics Requirements

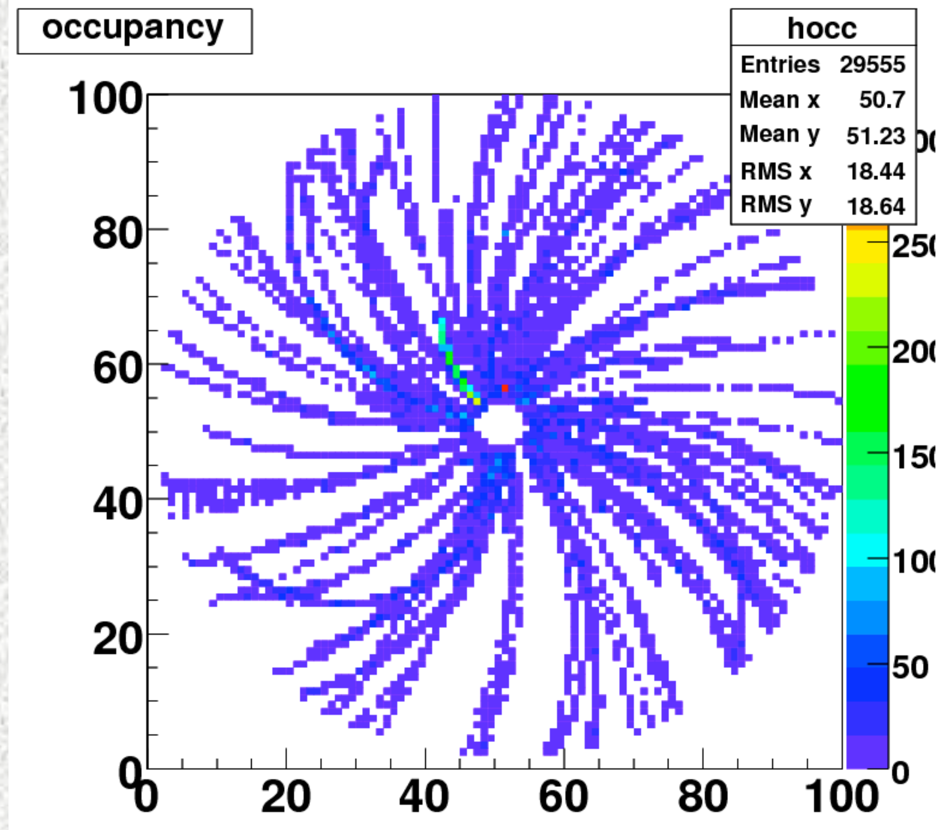


- Investigating opportunities to modify existing T2K electronics chain to accommodate our requirements
- Collaborative effort with the ACTAR working group
- Internal triggering capability will allow low energy reactions to trigger on number of channels above threshold
- Dynamic range of ADC is key due to wide range of particle species to be simultaneously identified ∴ 12bit AFTER+ chip will be used
- Must sustain 1kHz/chan data rate

Data Volume

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





- High collision multiplicity expected
- ~2% channels & time buckets filled
- Results in data volume of :

5 kB/s*chan
50MB/s
} Zero suppressed

Data Management

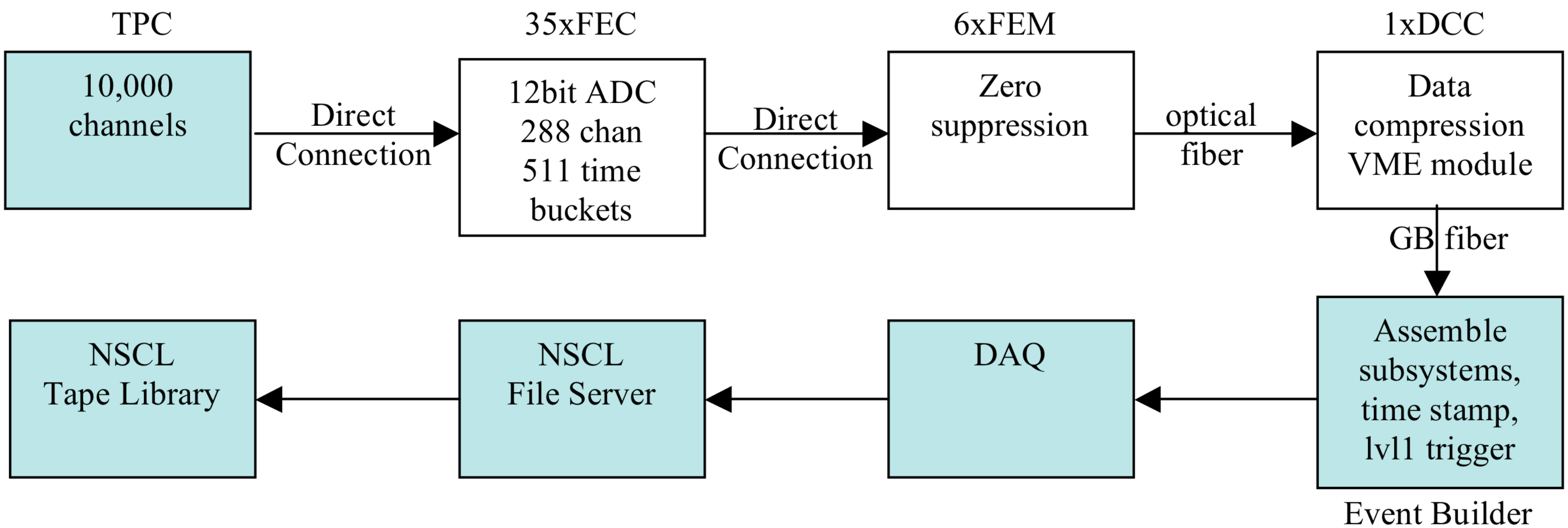


Figure 1: Overview of data flow. The shaded items will be developed at NSCL while the FEC, FEM, and DCC will be adapted from the T2K experiment.

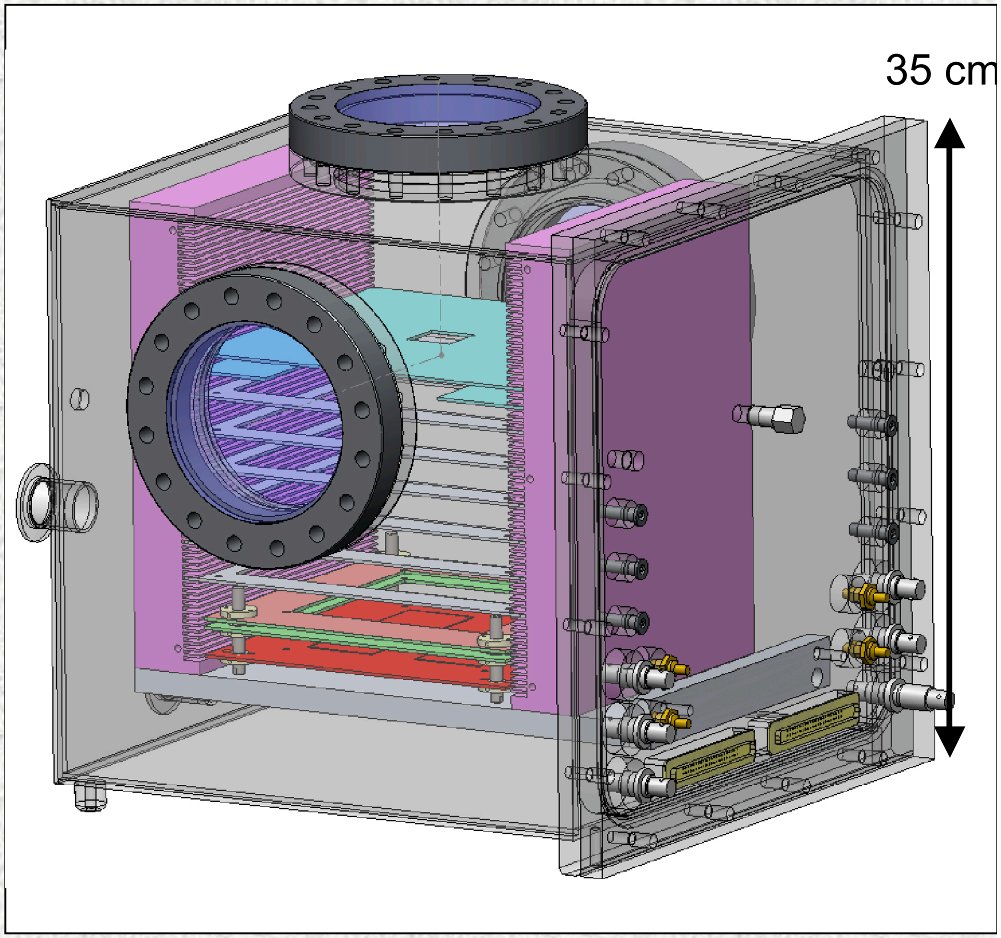
Timeline & Funding

- 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



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

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.