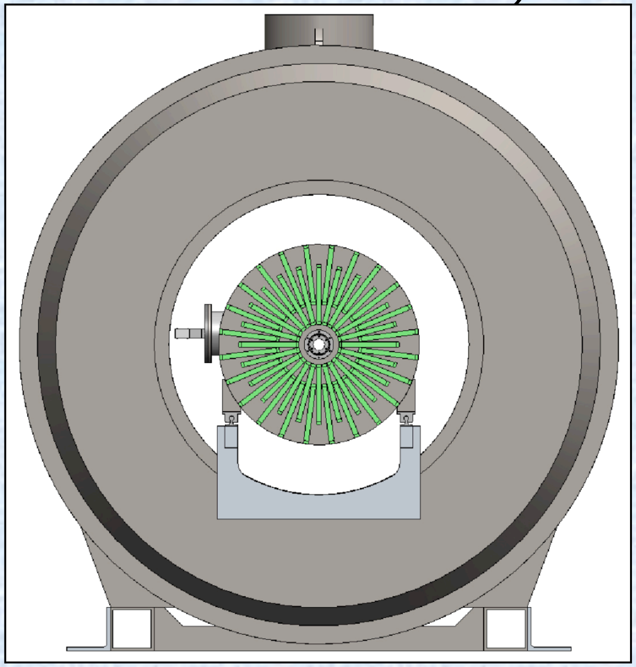
An Active Target Time Projection Chamber for Nuclear Structure and Reactions Experiments



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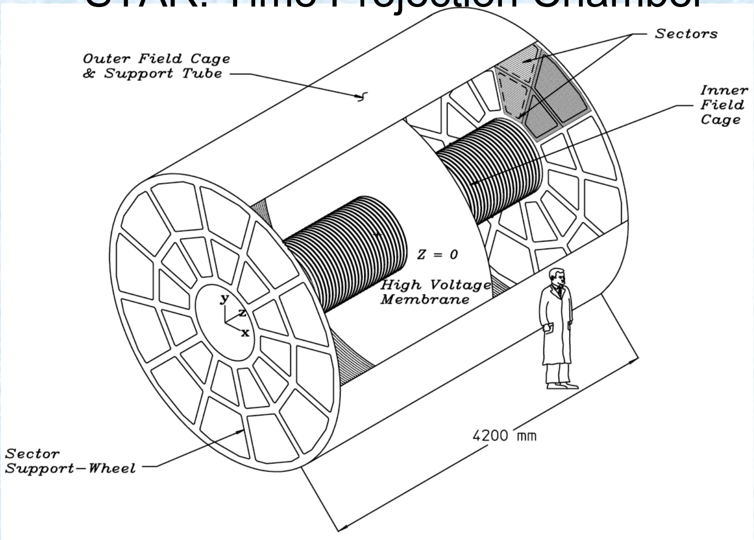
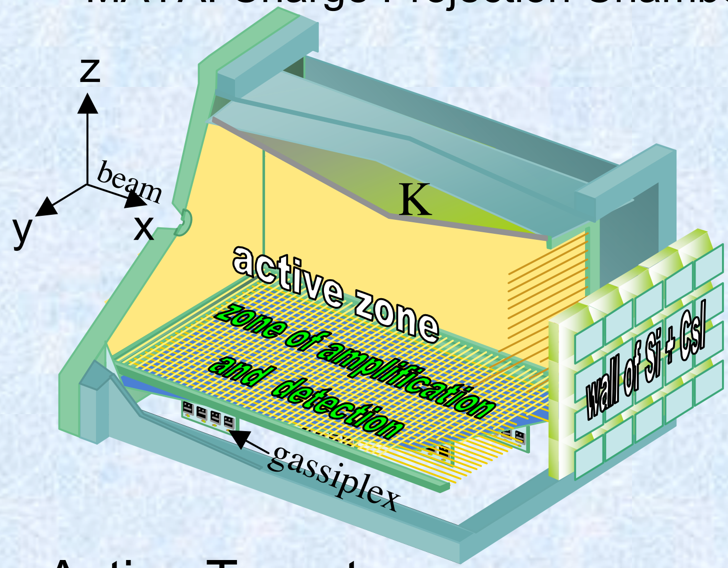
Merging Concepts

STAR: Time Projection Chamber



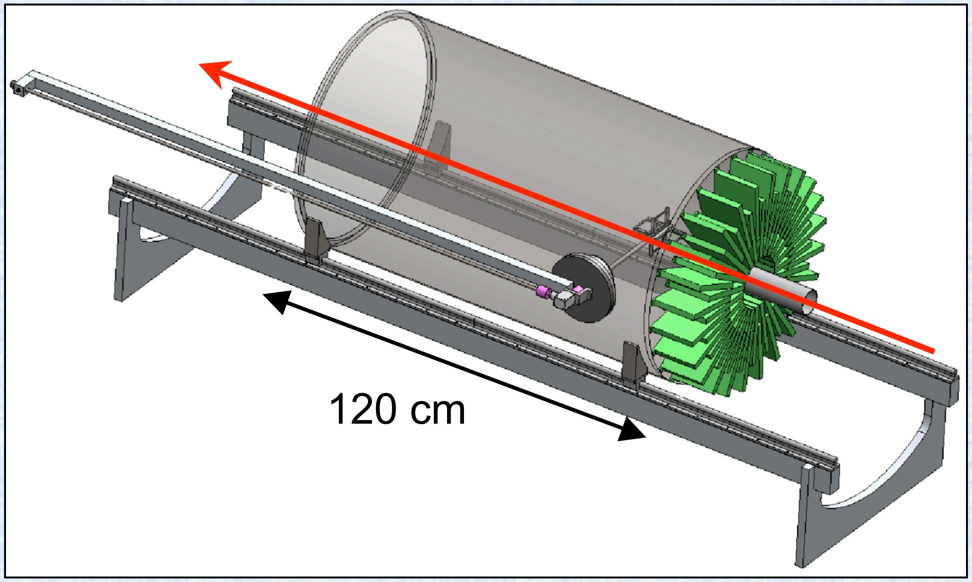
MAYA: Charge Projection Chamber

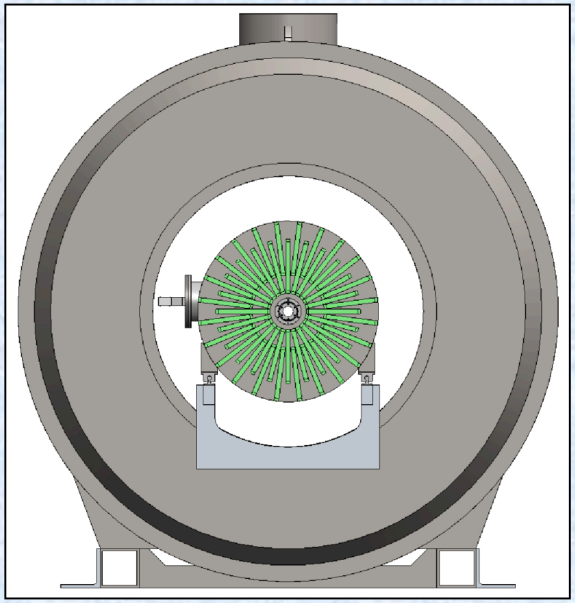


- Time Projection Chambers:
  - Traditionally used for high(er) energy collider or fixed target experiments
  - Multiple time sampling of pads
  - Allows 3D reconstruction of high multiplicity events
  - External magnetic field results in curved charged particle tracks
  - Particle identification from 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 <u>gas identity</u> and <u>pressure</u> chosen to study the reaction of interest in inverse kinematics
  - Thick target possible without loss of energy resolution
  - Measure low energy recoil particles

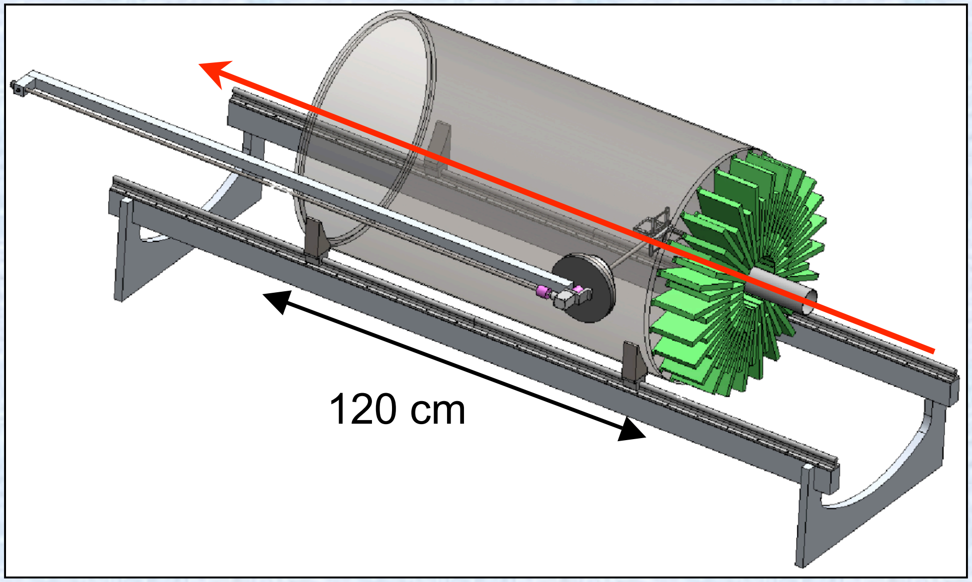
AT-TPC Introduction

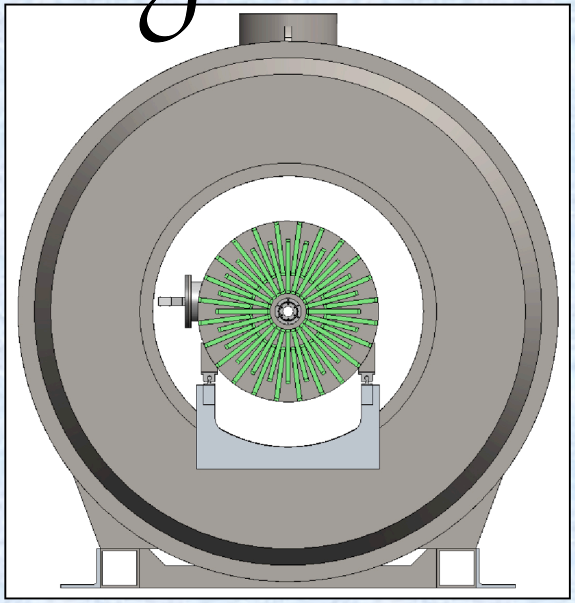




- Combines in a single device both active target and time projection chamber functionality
- Fixed Target Mode:
  - A target wheel will be installed within the chamber thus the gas will serve only as a detector
  - Configuration will reflect standard TPC conditions (ex: P10 @ 1atm)
- Active Target Mode:
  - The chamber gas will act as both detector and target
  - <u>Gas identity</u> and <u>pressure</u> 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

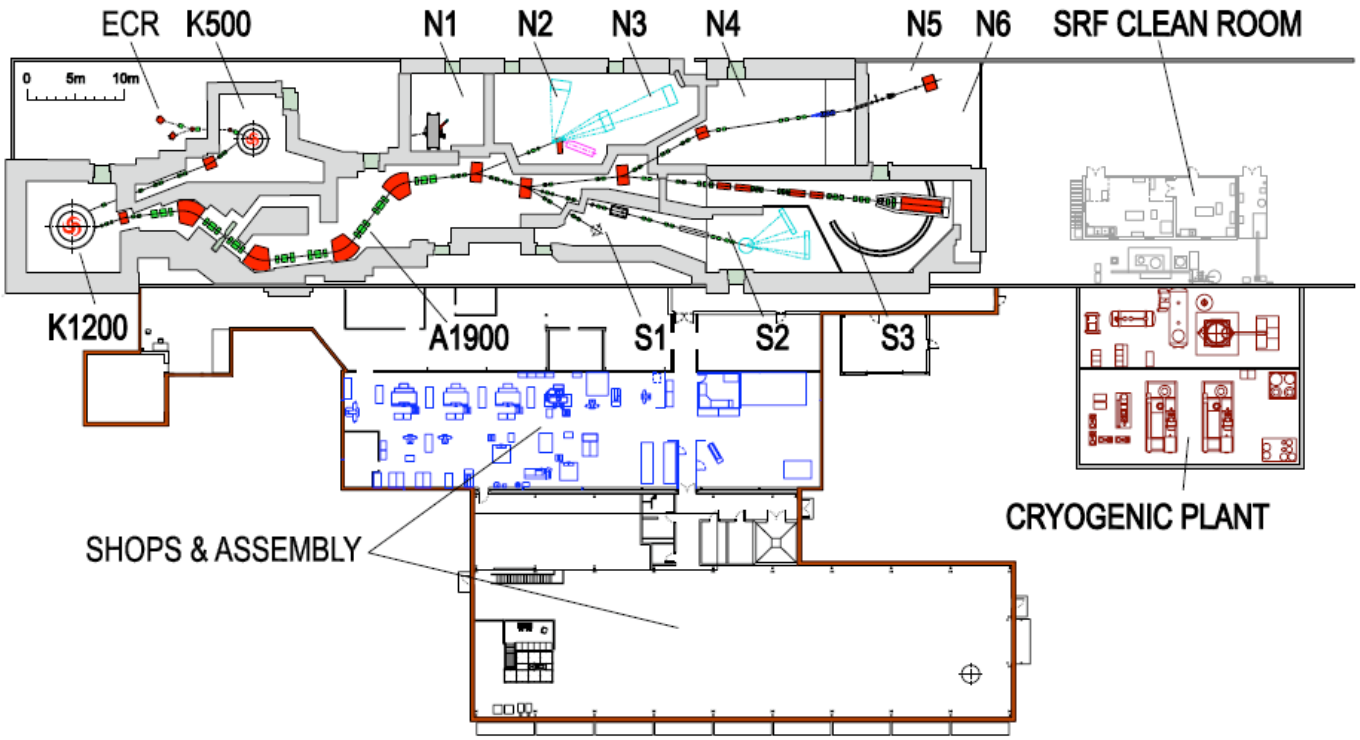




- Combines in a single device both active target and time projection chamber functionality allowing measurements of:
  - Rare processes that require high detection efficiency and large acceptance
  - Low energy processes that are traditionally difficult to measure due to the short range of the reaction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

NSCL: Coupled Cyclotron Facility

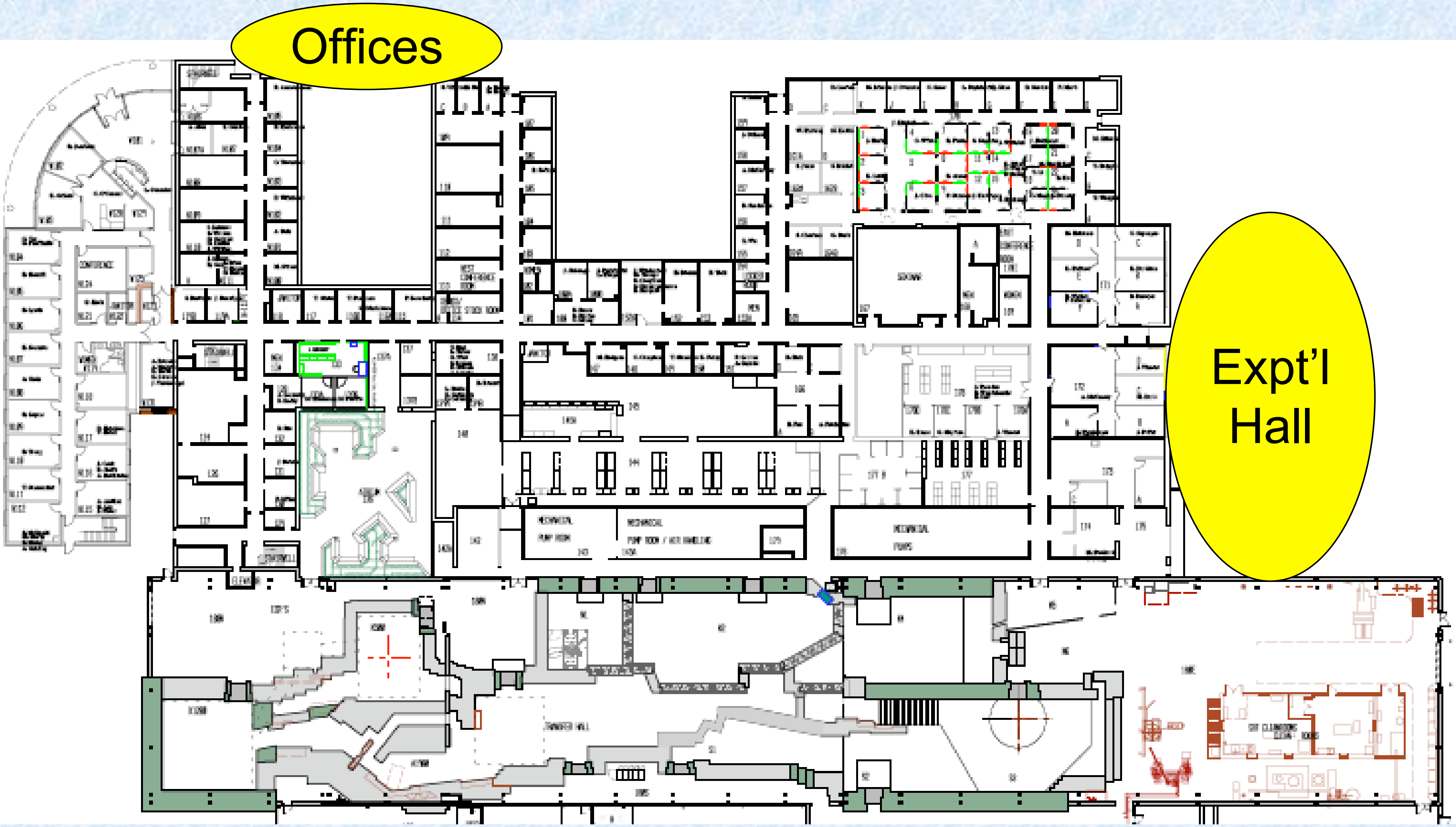
Commissioned in 2001. Vault and beam-line reconfiguration in 2007



Developed Primary Beams

Particle	MeV/A	pnA
16O	150	125
18O	120	125
22Ne	120	80
24Mg	170	30
36Ar	150	50
40Ar	140	50
40Ca	140	22
48Ca	90	15
48Ca	110	15
48Ca	140	80
58Ni	140	5
58Ni	160	20
64Ni	140	7
76Ge	13	20
78Kr	150	25
86Kr	100	10
86Kr	140	20
96Zr	120	1.5
112Sn	120	3
118Sn	120	1.5
124Sn	120	1.5
124Xe	140	10
136Xe	120	2
208Pb	85	1.5
209Bi	80	1
238U	80	0.2

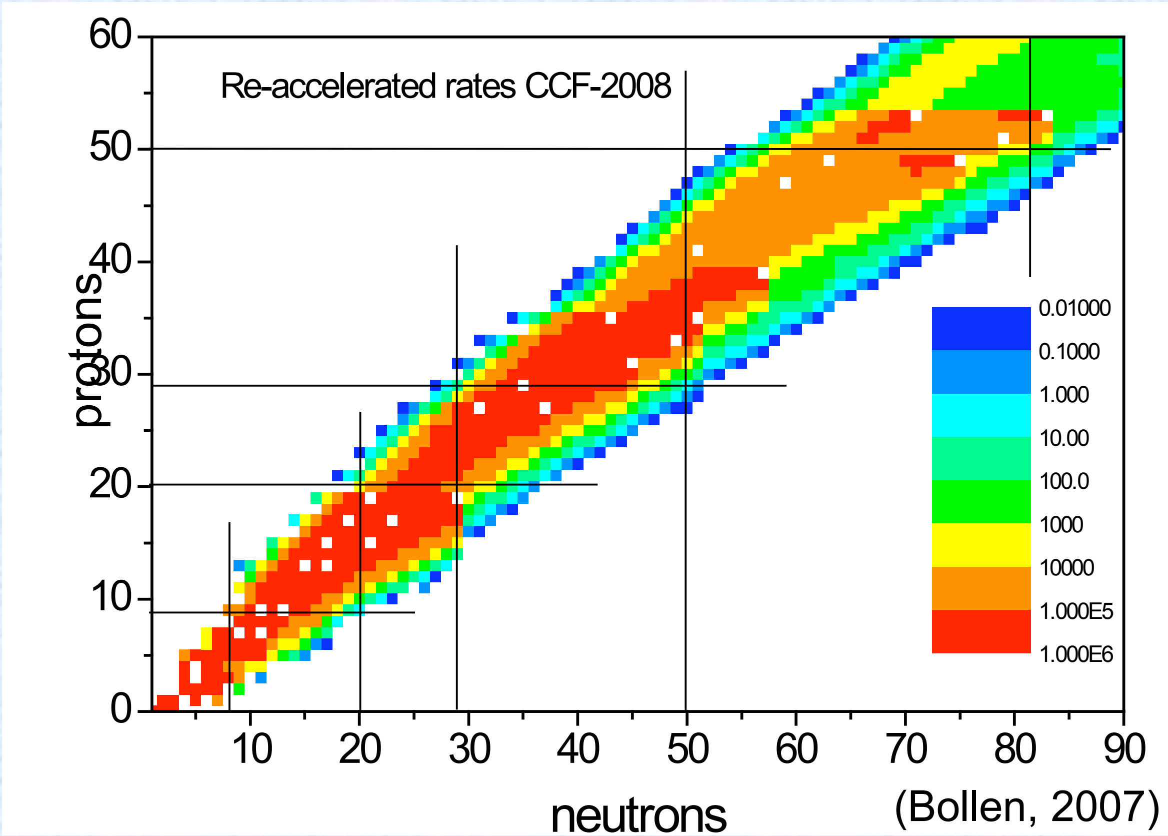
MSU Construction Projects



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



(Bollen, 2007)

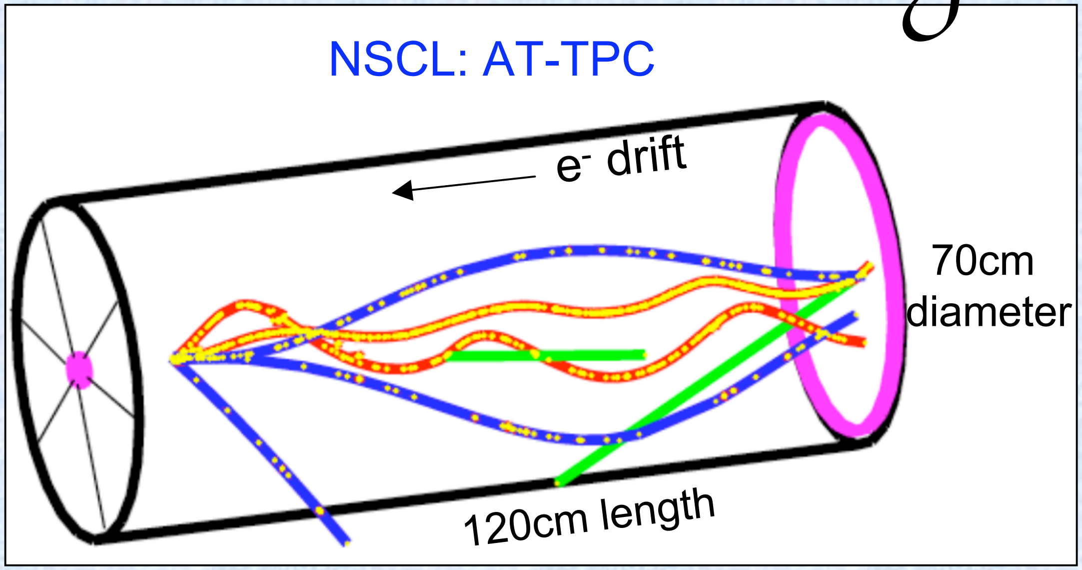
Scientific Program Overview

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

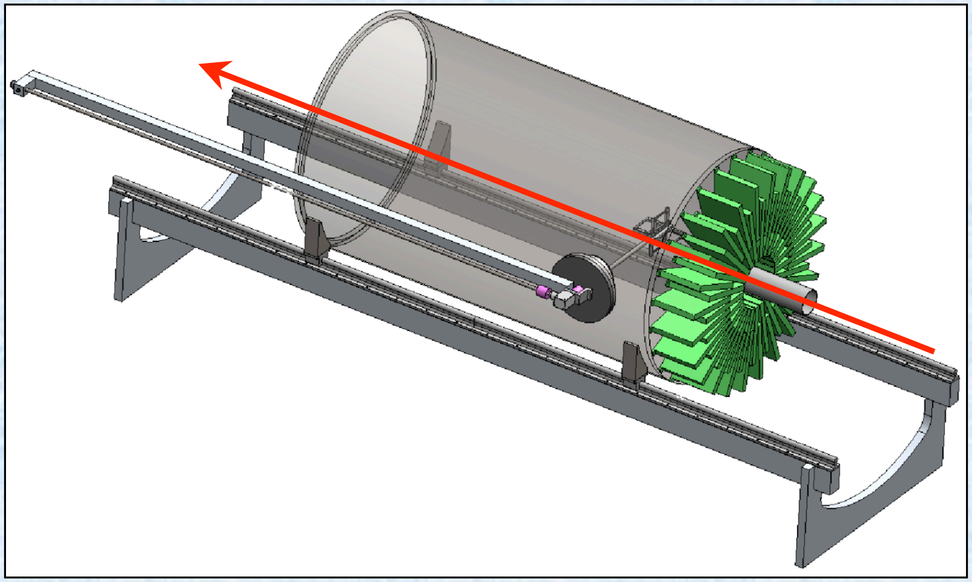
- Detector will make use of the full range of beam energies and intensities available at NSCL
- Experiments with rare isotope beams continuously push the limits of low beam intensities and low cross sections
- AT-TPC will address these limitations by providing access to reactions at beam intensities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

AT-TPC Advantages



- 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

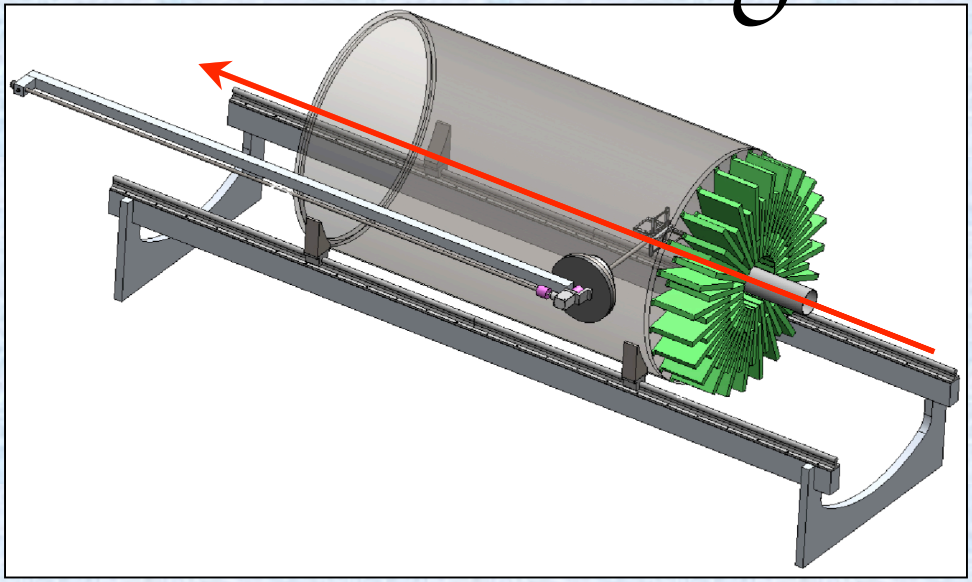
AT-TPC Chamber Design



<u>NSCL: AT-TPC</u>

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

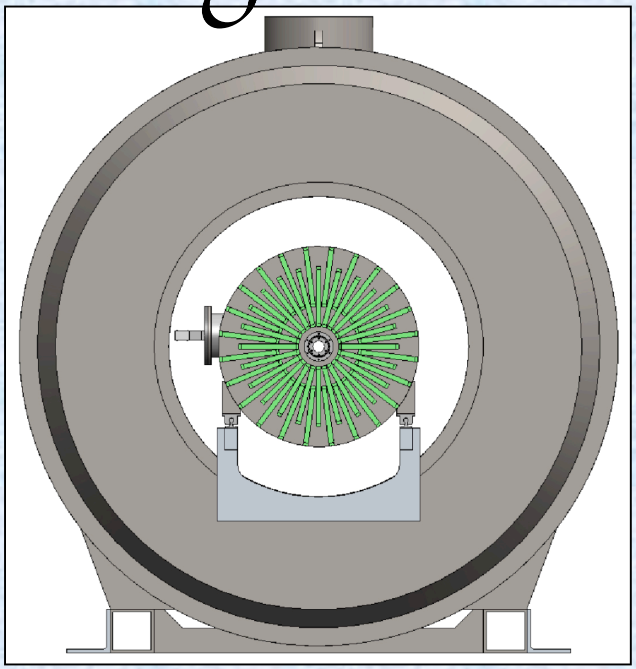
AT-TPC Targets

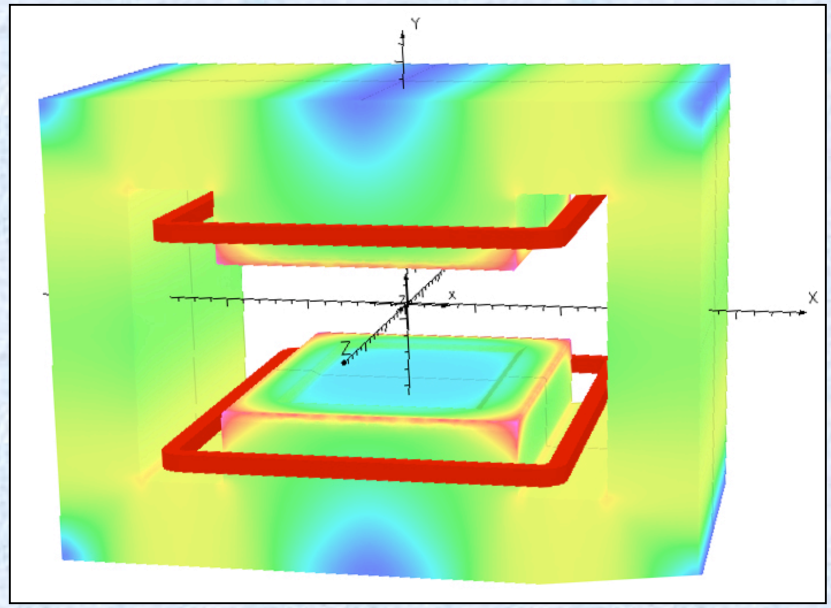


NSCL: AT-TPC

- 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.
  - H_2, D_2, ^3He, Ne, Ar, Isobutane
  - Pressures ranging from 0.2-1.0 atm

Magnetic Field Considerations





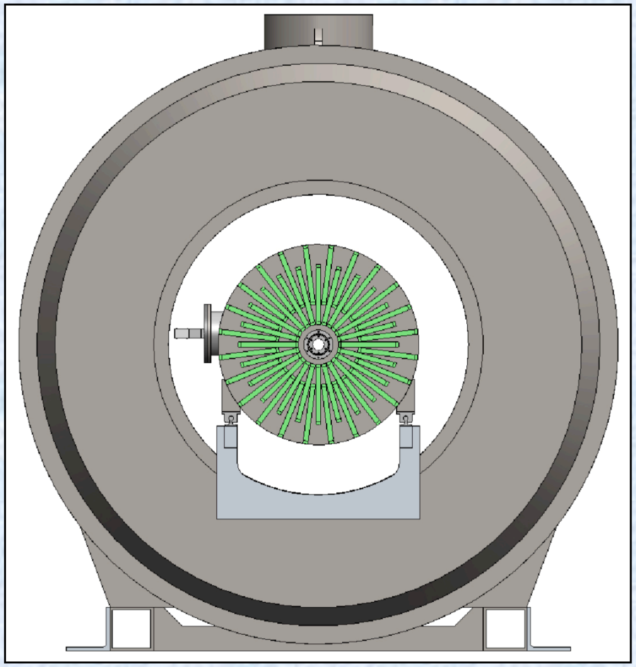
Solenoid

- 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:
  - ≥ 70 cm diameter
  - ≥ 120 cm length
  - ≤ 125 cm beam height
- Field Non-uniformity: ≤ 10%
- Consistent with a medical MRI solenoid

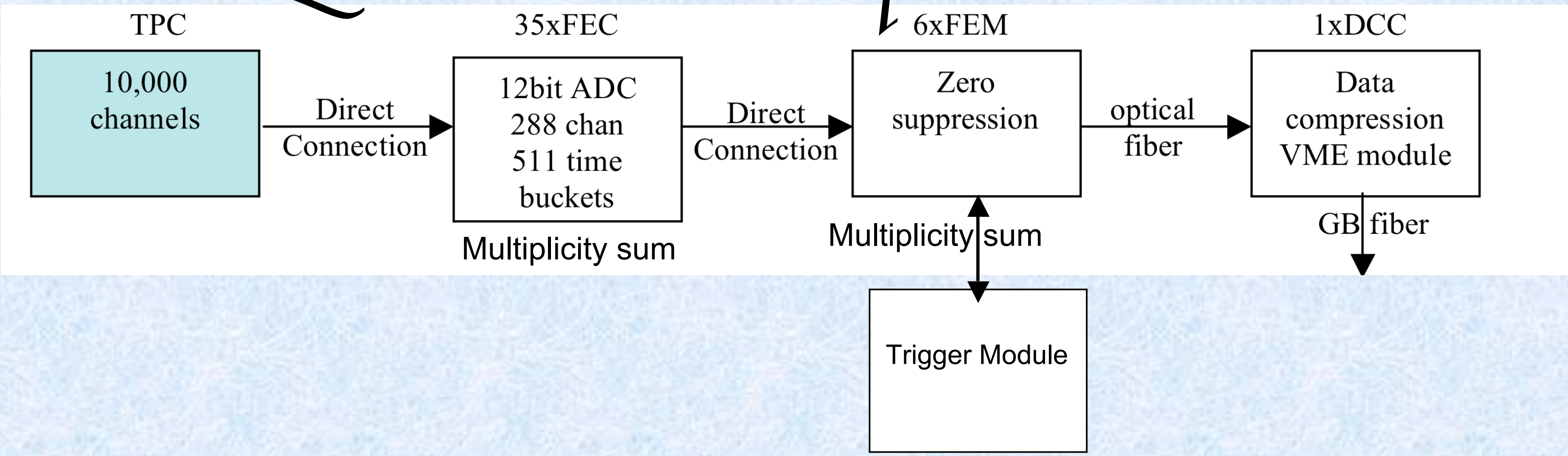
TWIST Solenoid

- 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%

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

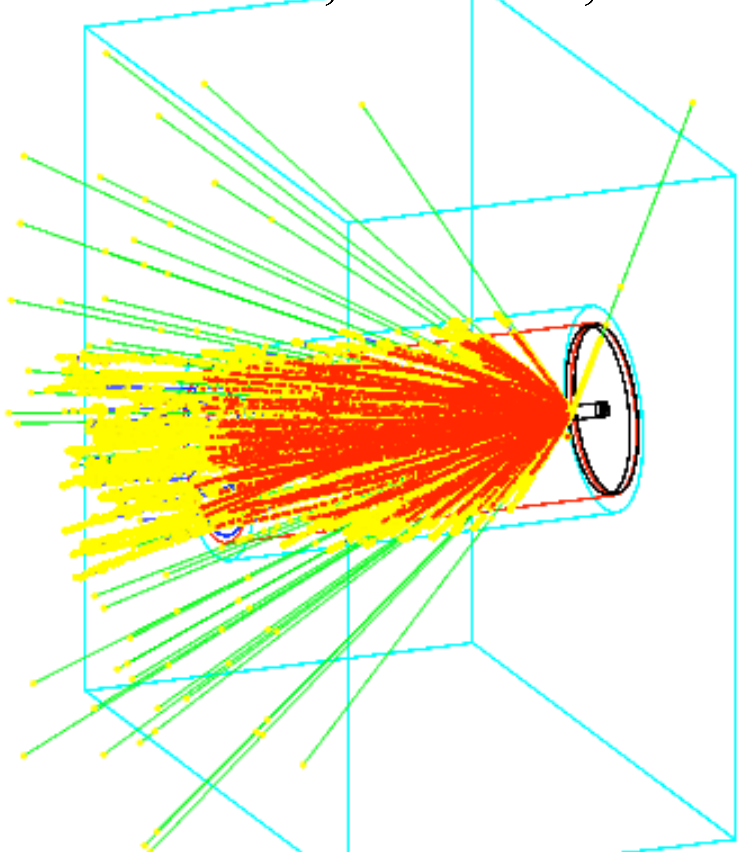
Electronics Requirements

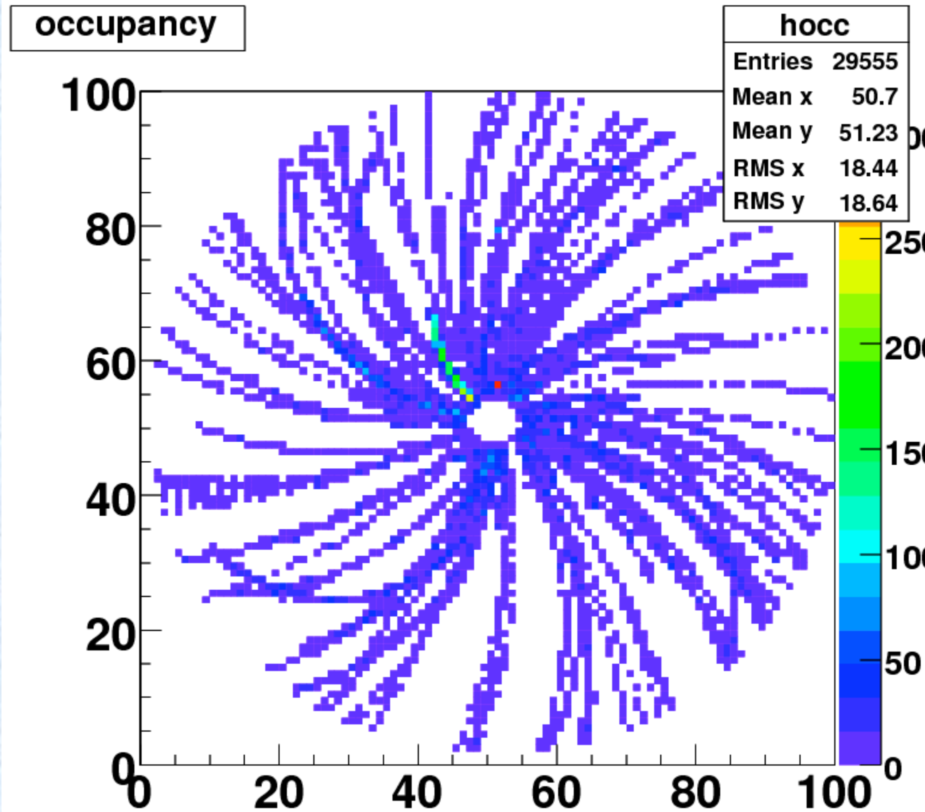


- Investigating opportunities to modify existing T2K electronics chain to accommodate our requirements
- Collaborative effort with the ACTAR working group
- Dynamic range of ADC is key due to wide range of particle species to be simultaneously identified ∴ 12bit AFTER+ chip will be used
- Internal triggering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

Data Volume

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





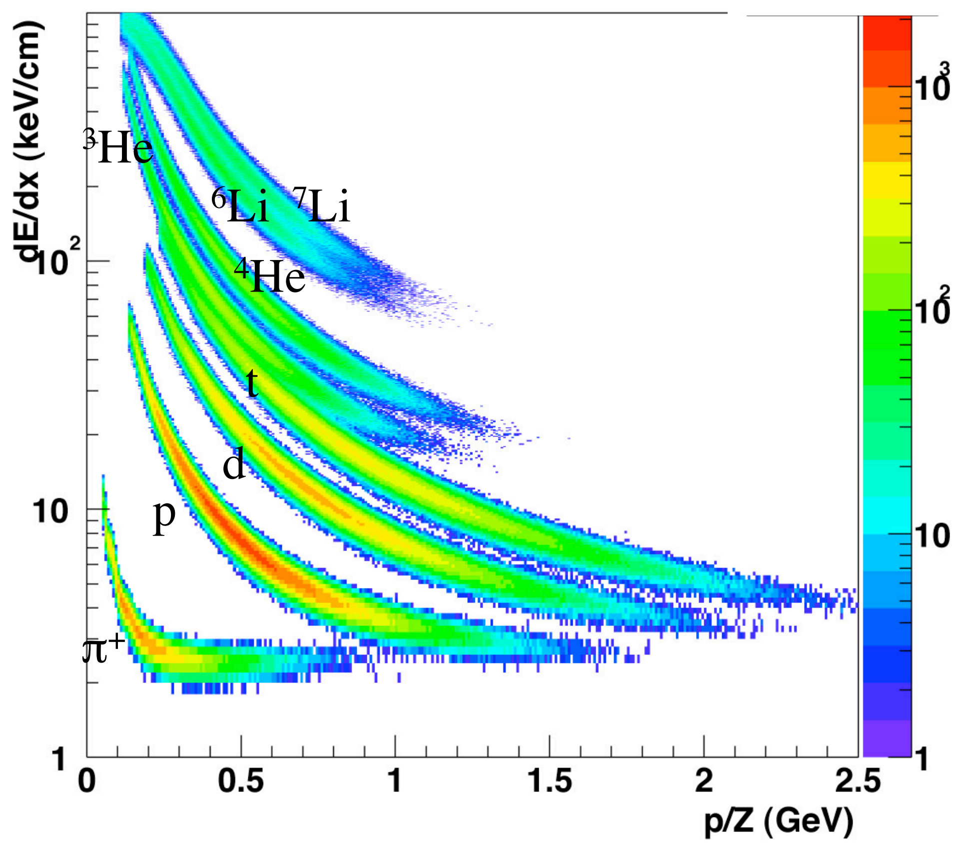
- High collision multiplicity expected
- ~2% channels & time buckets filled
- Results in data volume of :

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

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 → light isotopes

Simulation w/ STAR resolution, scaled to EOS



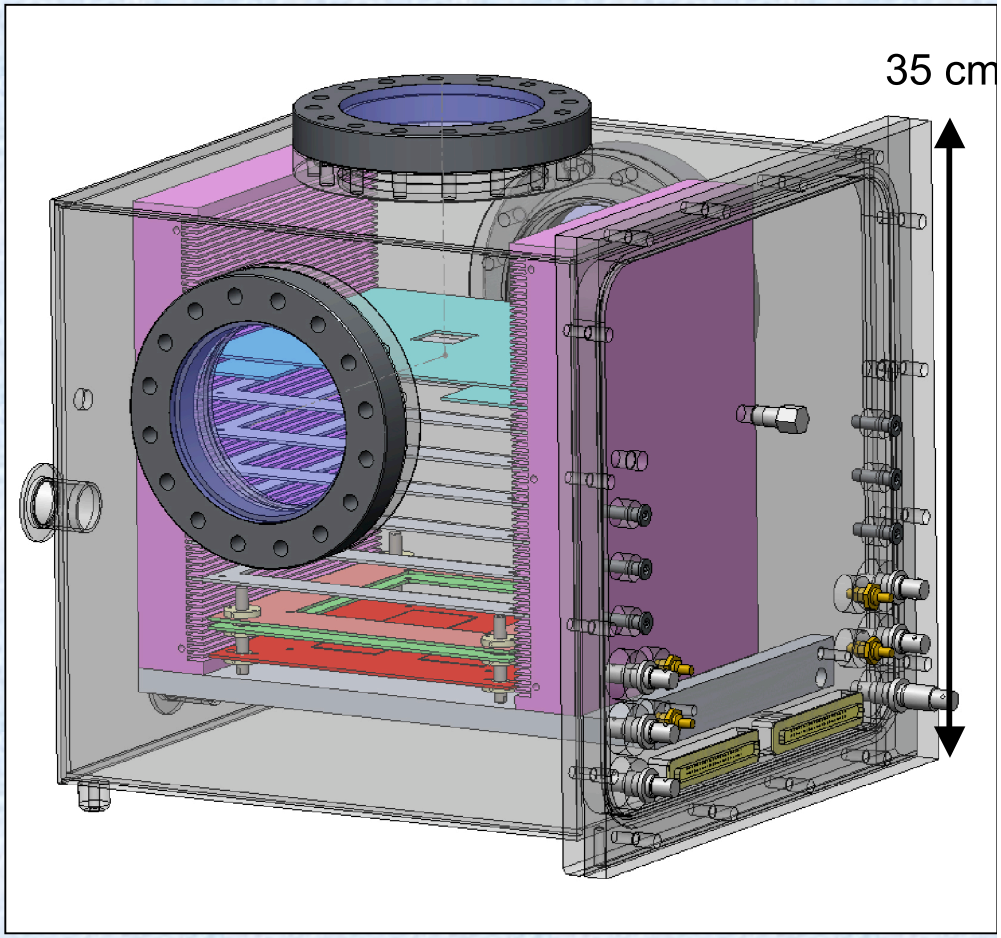
Timeline & Funding

- 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



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.

AT-TPC Collaboration

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