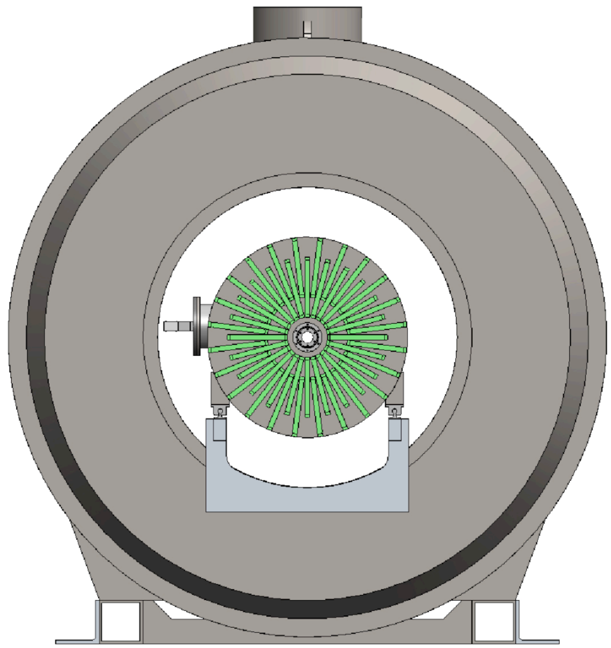
Active Target - Time Projection Chamber Capabilities



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March 18, 2009

NSCL

MICHIGAN STATE UNIVERSITY

Active Target Advantages

- Active Target:
  - Detection medium also serves as target
  - Typically gaseous
  - Thickness critical for low intensity beams & small cross sections
  - Example - $^{32}Mg(d,p)^{33}Mg$
    - Solid Target: CD_2 solid target requires target thickness ~500 μg/cm^2 to reconstruct recoil; 10^{19} atoms D_2 /cm^2
    - Active Target: D_2 active target at 1atm, ~20 μg/cm^2; total target thickness of 1m detector is 10^{21} atoms D_2 /cm^2
- Vertex & Energy Resolution:
  - Solid Target: particles must exit solid target before being tracked
  - Active Target: particle tracking begins immediately
- Efficiency:
  - Solid Target: detector geometry dependent
  - Active Target: 4π geometrical acceptance
- KEY: Active targets allow reactions to be conducted in inverse kinematics without loss of resolution and efficiency due to presence of target material!

Scientific Program

Table 1: Overview of the AT-TPC scientific program.

Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)
Transfer & Resonant Reactions	Nuclear Structure	^{32}Mg(d,p)^{33}Mg ^{26}Ne(p,p)^{26}Ne	3	100
Astrophysical Reactions	Nucleosynthesis	^{25}Al(^{3}He,d)^{26}Si	3	100
Fusion and Breakup	Nuclear Structure	^{8}B+^{40}Ar	3	1000
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 - 200	50,000
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000

- 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
- Detector will make use of the full range of beam energies and intensities available at NSCL

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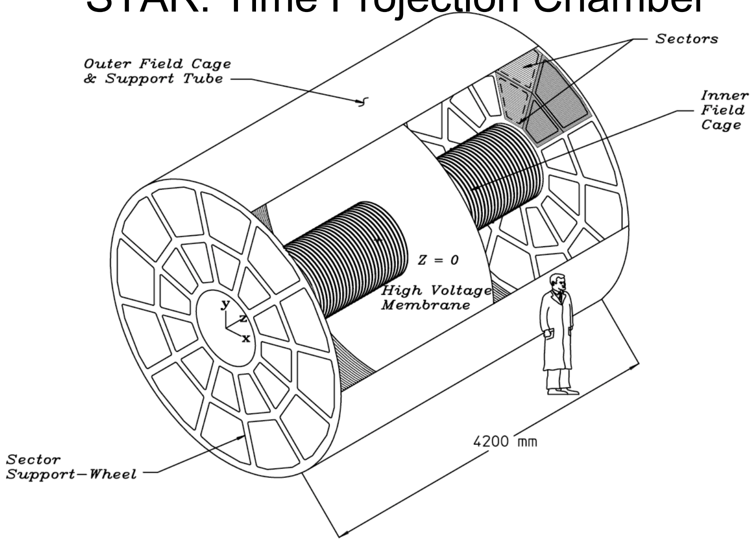
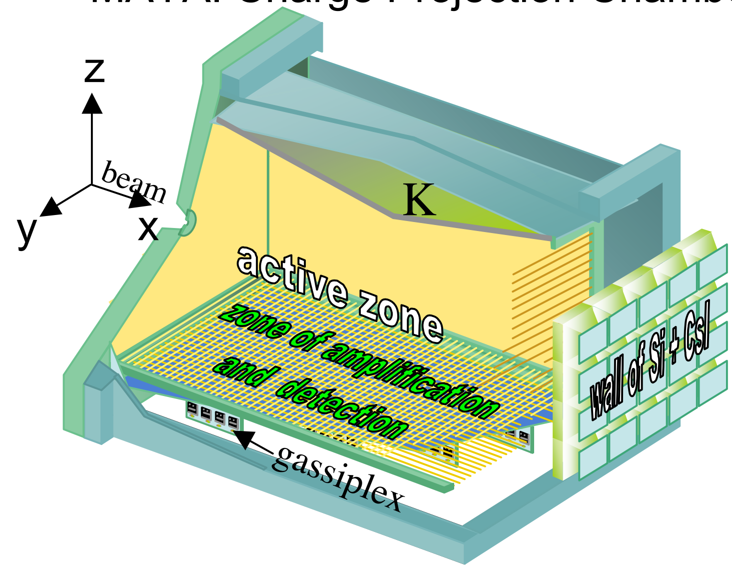
AT-TPC Concept

STAR: Time Projection Chamber



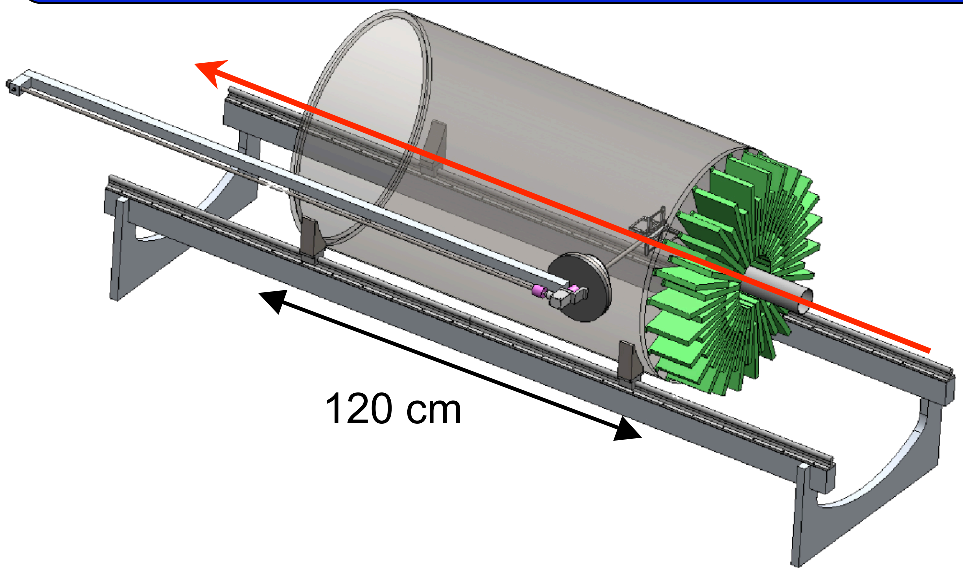
MAYA: Charge Projection Chamber

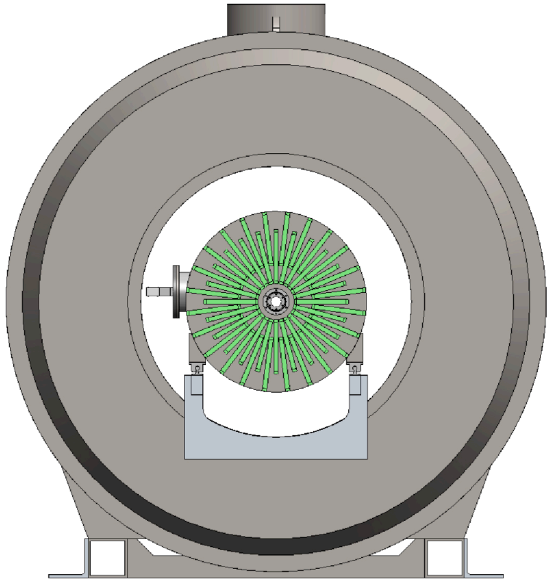


- Time Projection Chambers:
  - Multiple time sampling of pads
  - Allows 3D reconstruction of high multiplicity events
  - External magnetic field results in curved charged particle tracks
  - Particle identification from measurement of dE/dx and p
  - Isotopic resolution for light particles

- Active Targets:
  - 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

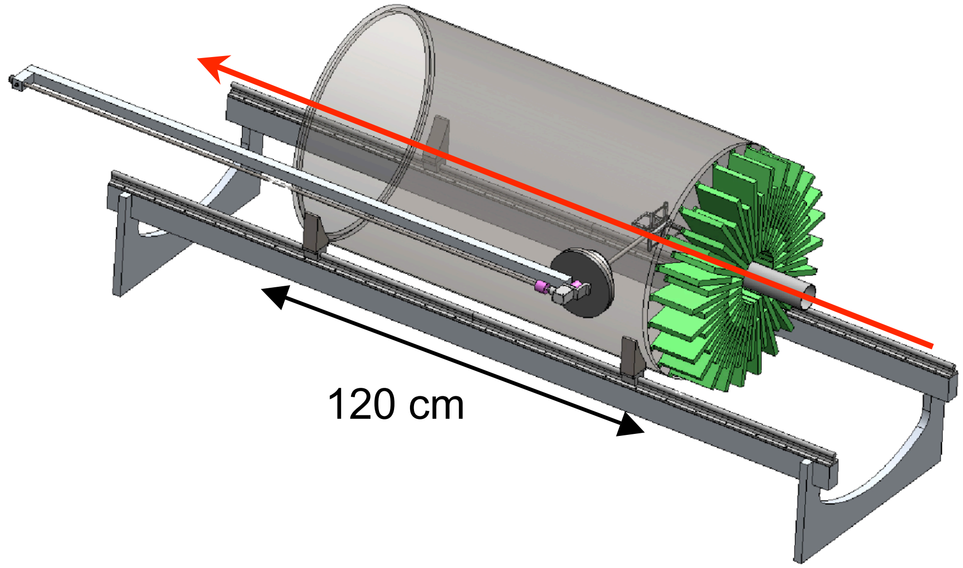
Conceptual Design





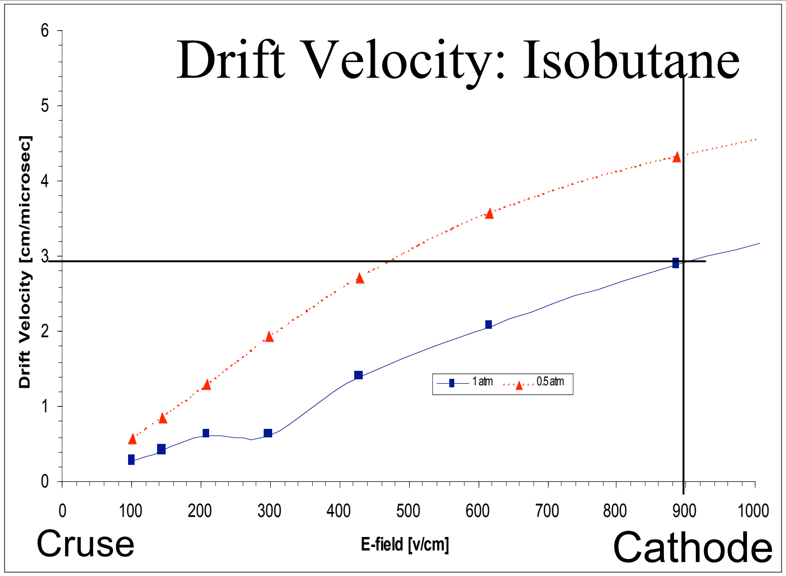
- Active target and time projection chamber functionality in a single device
- Fixed Target Mode:
  - Target wheel installed within the chamber thus gas serves only as a detector
  - Configuration reflects standard TPC conditions (ex: P10 @ 1atm)
- Active Target Mode:
  - Chamber gas acts as both detector and target
  - Gas identity and pressure chosen based on experimental requirements
  - Limitations imposed by low beam intensities addressed by providing a thick target while retaining high resolution and efficiency

Chamber Design

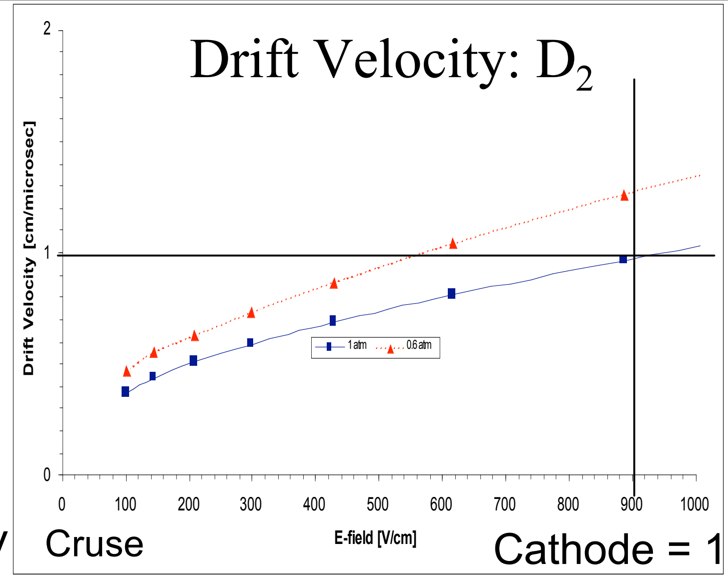


- Cylinder - length 120cm, radius 35cm
  - Constrained to center of solenoid where field is most uniform
  - Clearance retained for outer radial detector
  - Designed to sustain vacuum
- Entrance Window - 1cm radius
  - Thickness dependent on gas pressure
  - Radius minimized to improve tracking efficiency
- Exit Window - 33cm radius
  - Maximize acceptance for downstream ancillary detectors
- Port for removable target wheel
- Mounted on rails within solenoid

Targets



Cathode = 108kV
Drift = 40μs

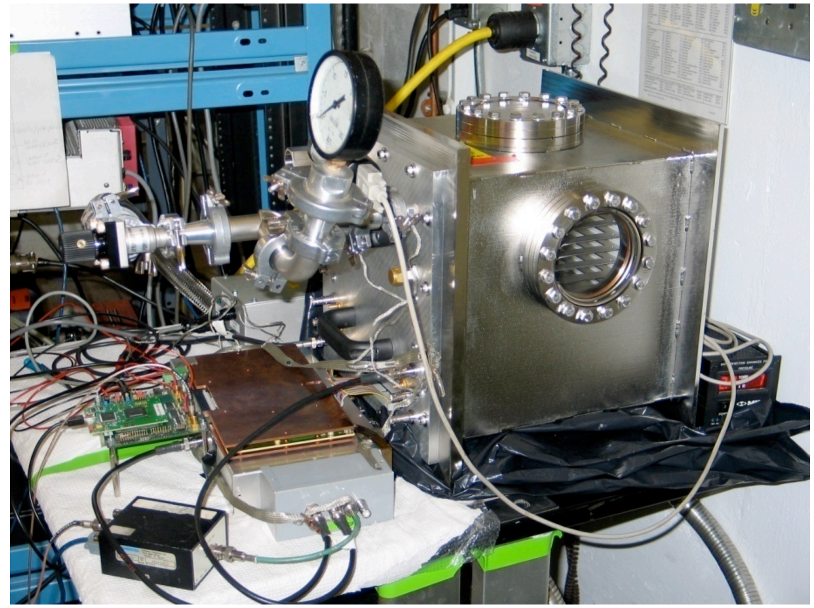


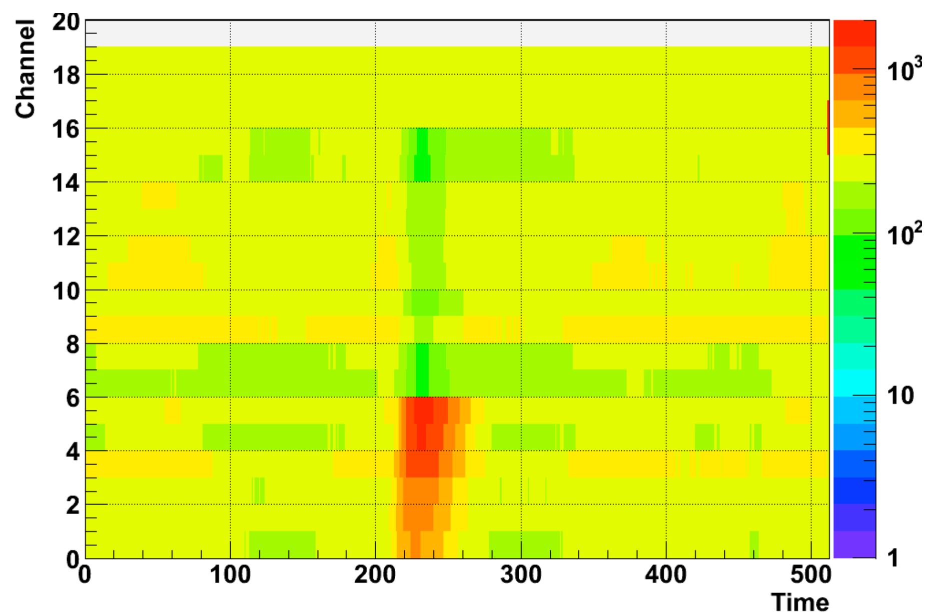
Cathode = 108kV
Drift = 120μs

- Fixed Target Mode:
  - Device must not interfere with uniform E-field produced by equipotential field cage along the beam axis
- Active Target Mode:
  - Identity and pressure of gas used to fill the detector will be dependent upon experimental requirements.
  - H_2, D_2, ^3He, Ne, Ar, Isobutane
  - Pressures ranging from 0.2-1.0 atm
  - Ionization & e- drift depend on physical properties of gases
  - Low pressure gases must sustain required HV without breakdown

Test Chamber

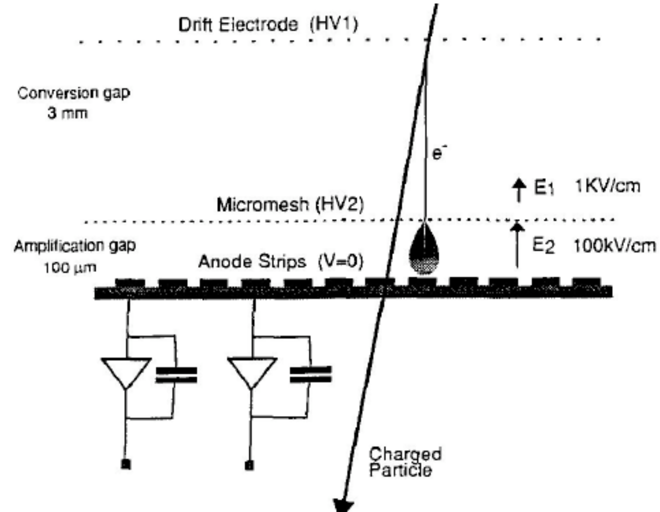
- Current Setup:
  - μmega
  - 10% Isobutane, 90% Ar
  - T2K electronics and daq
  - α source
- Optimize
  - Gas mixture
  - Pressure range
  - Gain
  - Position resolution
  - Pad plane geometry
  - Electron amplification
- Electronics Testing



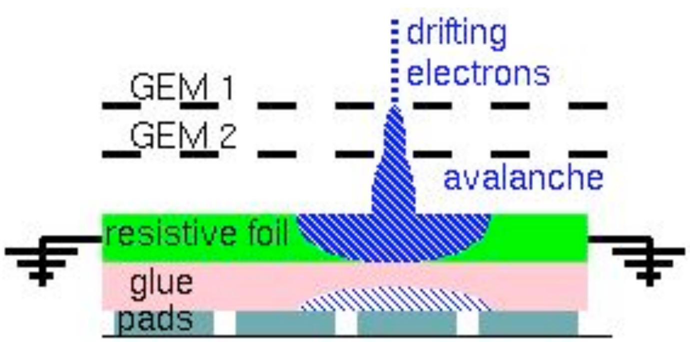


Electron Amplification

- Micropattern Gas Detectors
  - Operating Principle:
    - High E-field gradient directs electrons from direct ionization through holes/mesh
    - Electron avalanche occurs
    - Direct charge measured on anode plane
  - Advantage
    - High gains achieved
    - Signal comes directly from electron cascade
    - Low +ion feedback into chamber
  - Disadvantage
    - Sparking results in permanent GEM damage
    - Sensitive to cleanliness of environment
    - Localized e^- cloud



Giomataris, NIMA376, 29 (1996)



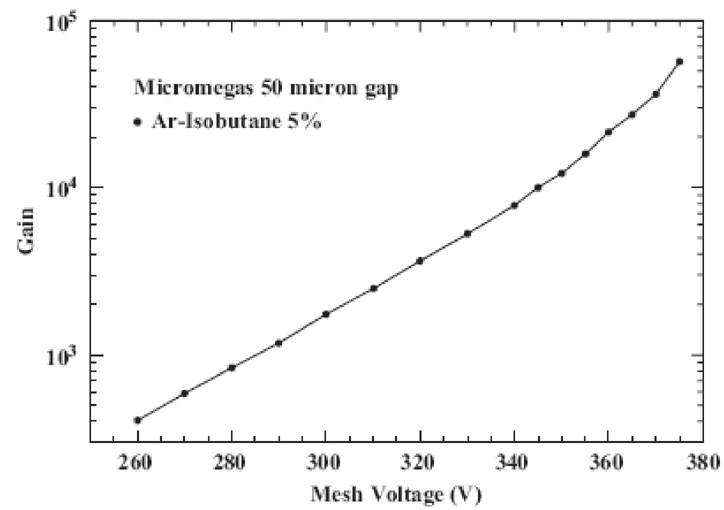
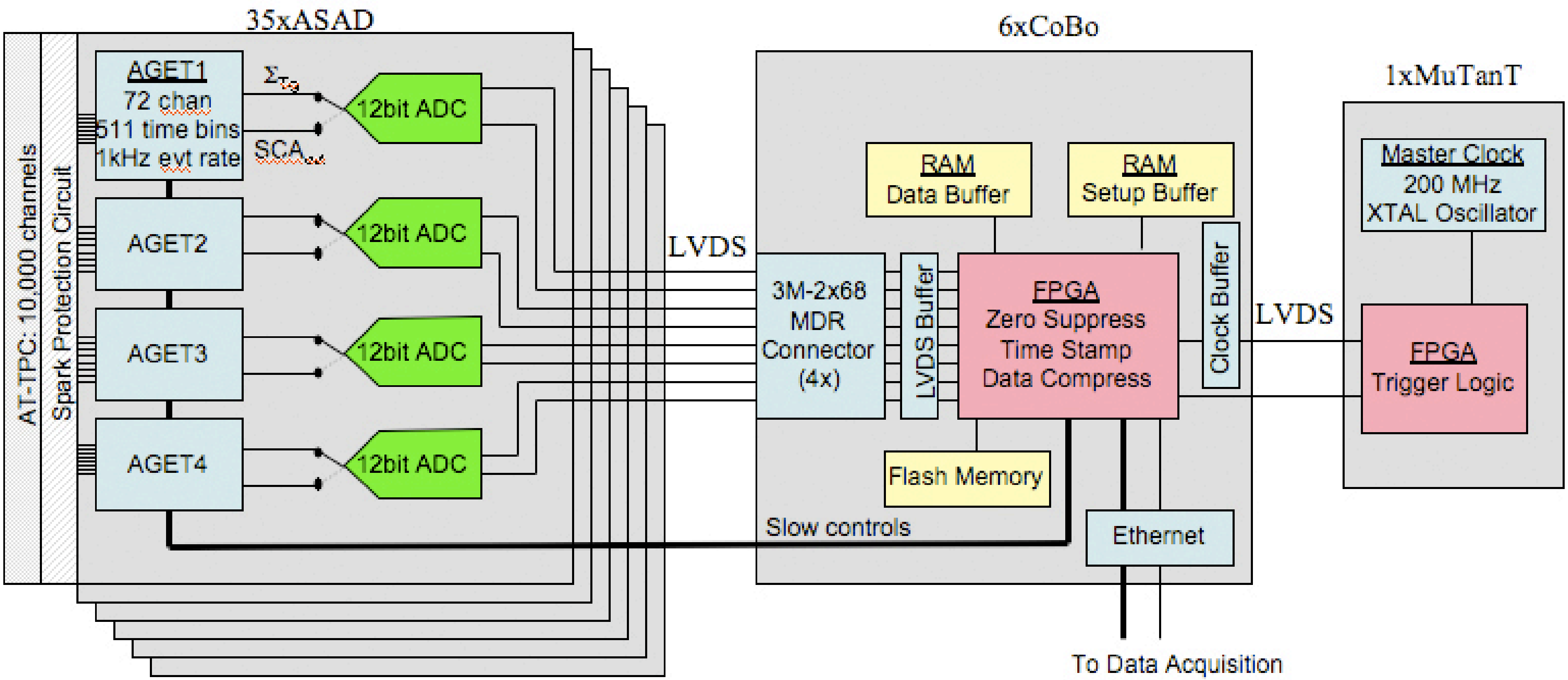


Fig. 4. Gas gain as a function of the mesh voltage.

Arogancia *et al*, NIMA602, 403 (2009).

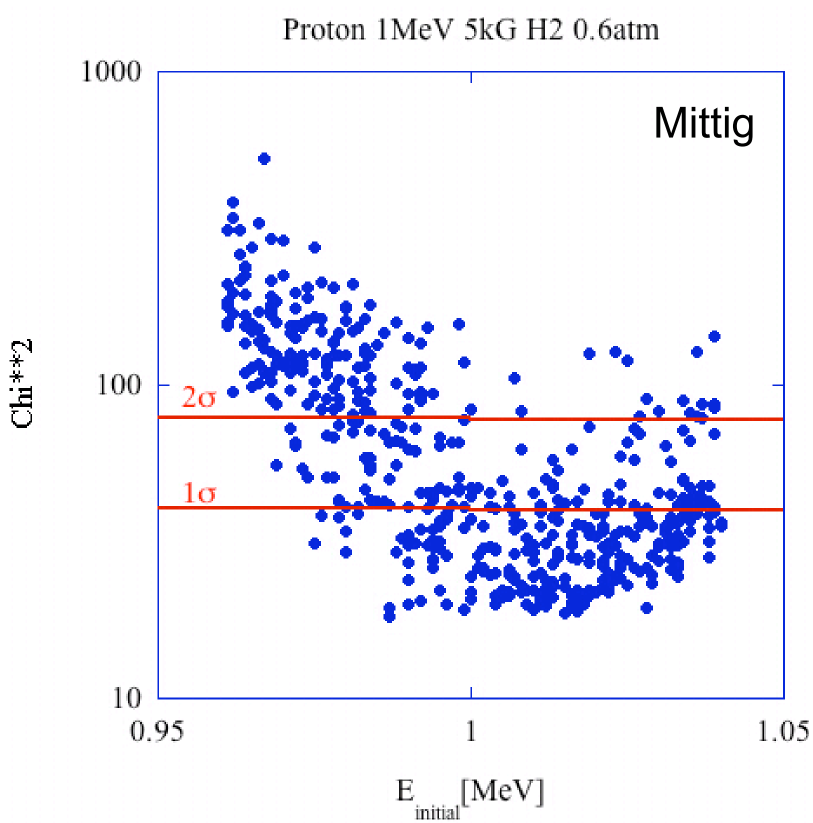
Triggering & Electronics

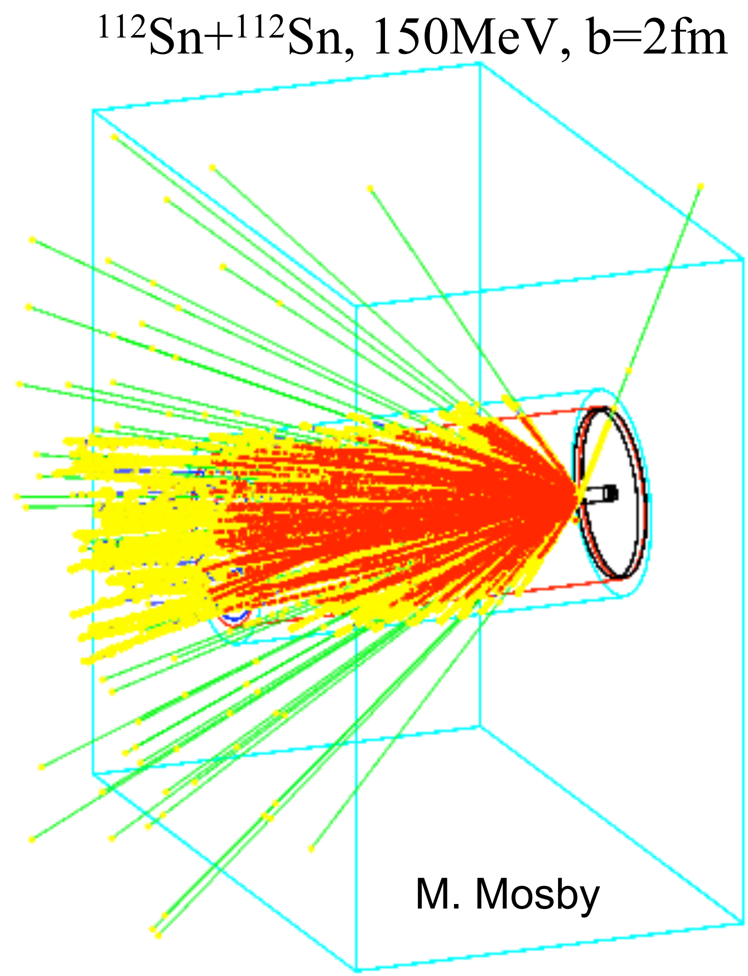
(GET Collaboration = Bordeaux, Ganil, MSU, Riken, Saclay)



- Modifying T2K electronics chain w/ GET Collaboration
- Dynamic range of ADC is key due to wide range of particle species to be simultaneously identified ∴ 12bit AFTER+ chip will be used
- ASIC triggering capability will allow a multiplicity threshold trigger
- Sustainable 1kHz/chan data rate

Simulations





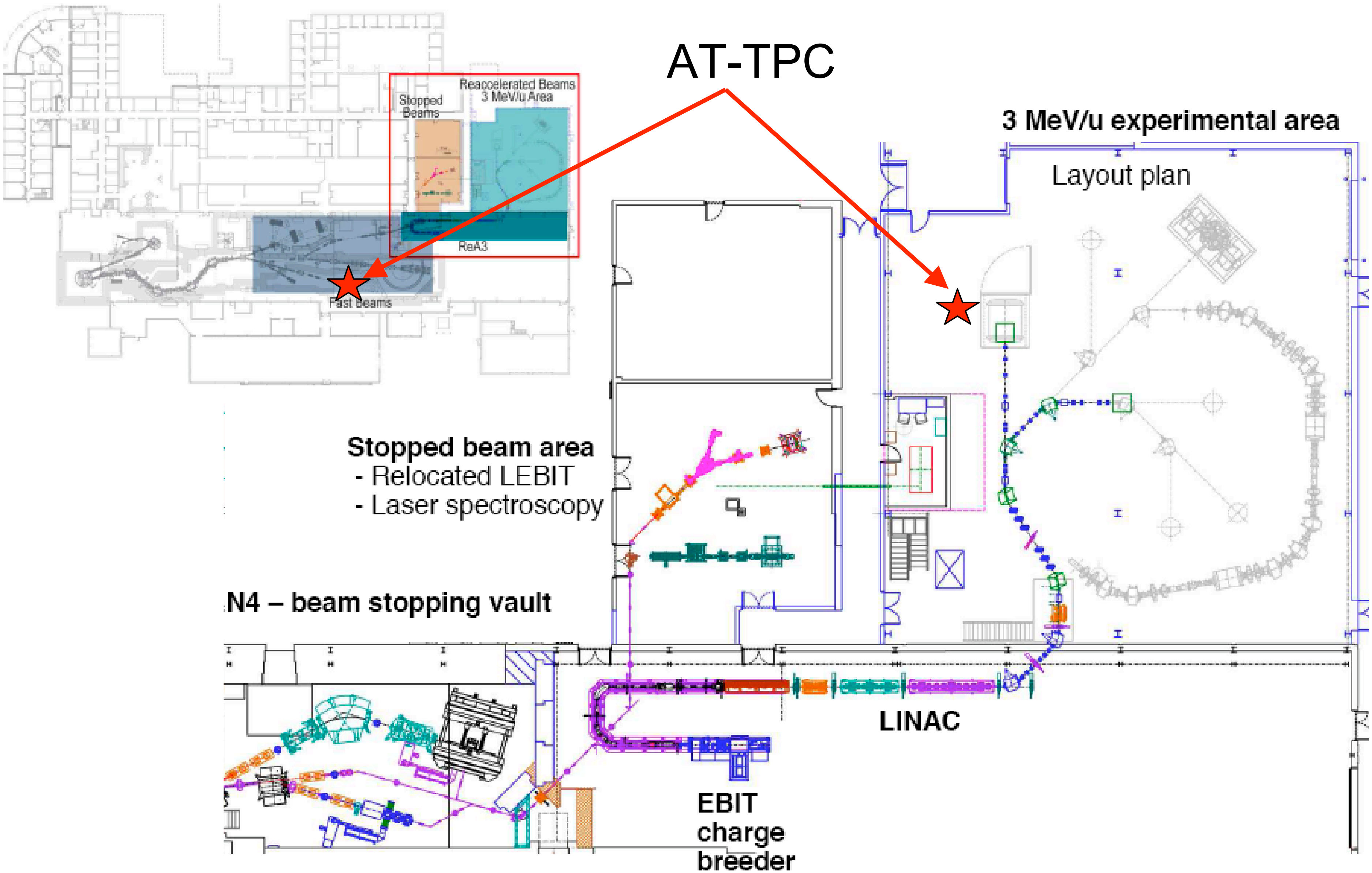
- Includes Fluctuations from:
  - Energy straggling
  - Angular straggling
  - Primary electron number
  - Longitudinal diffusion
  - Transverse diffusion
  - Electronic noise
- χ^2 calculated from known 3D track parameters
- 2σ fit results in resolution of ~100keV

- High collision multiplicity expected
- Results in data volume of :

50 kB/s*chan
500 MB/s

} Zero supp, 32bits/sample, 128 time bucket, 10% occup. 10k chan, 1 kHz

AT-TPC @ NSCL

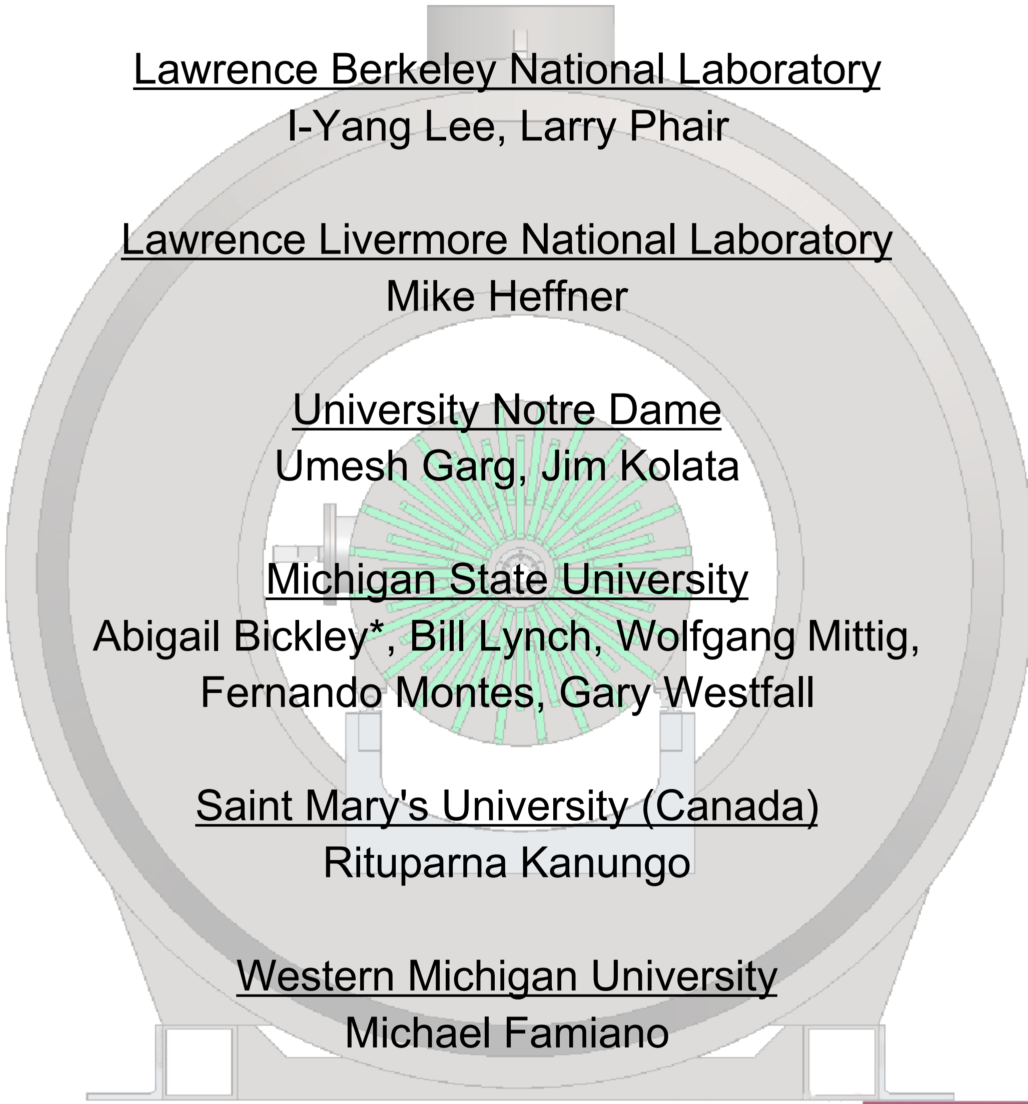


AT-TPC
Reaccelerated Beams 3 MeV/u Area
Stopped Beams
ReA3
Fast Beams
3 MeV/u experimental area
Layout plan
Stopped beam area
- Relocated LEBIT
- Laser spectroscopy
N4 – beam stopping vault
LINAC
EBIT charge breeder

AT-TPC Outlook

- Funded through NSF MRI program
  - FY2010 - design
  - FY2011 - construction
  - FY2012 - assembly & testing
  - FY2014 - commissioning run
- First experiments will be performed with ReA3 beams
  - 4 LOIs submitted to PAC
- Move to fast fragmentation beam vault follows

AT-TPC Collaboration



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Rituparna Kanungo

Western Michigan University
Michael Famiano

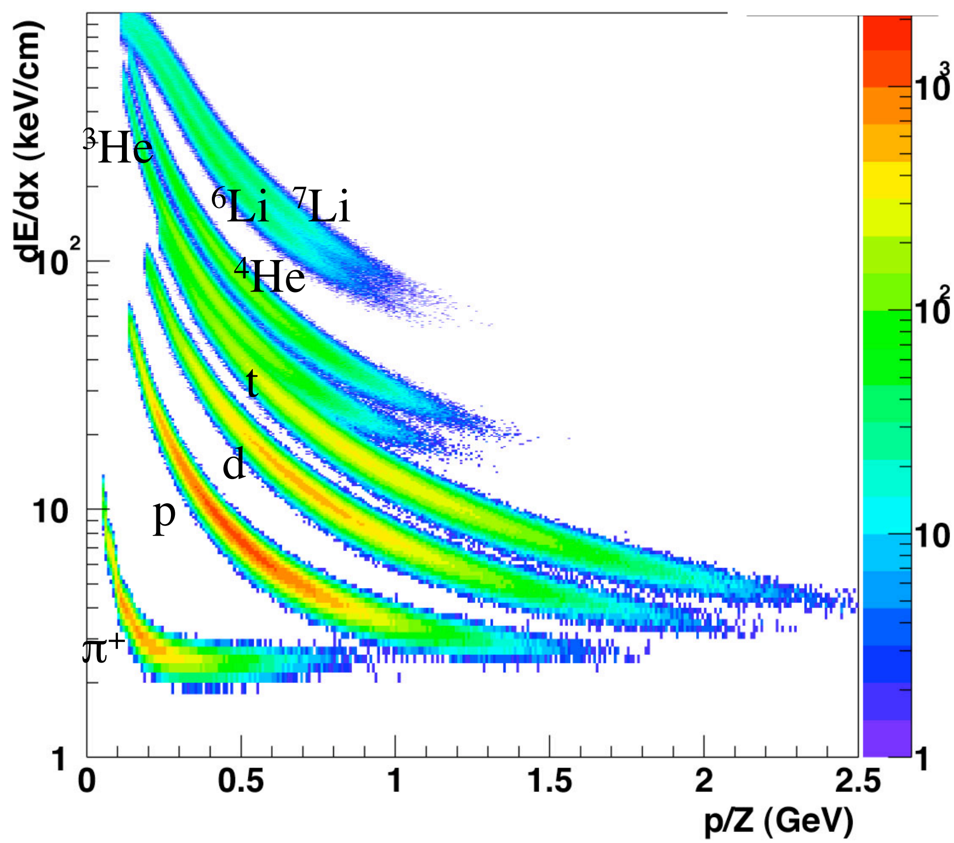
Triggering

- 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

PID & Magnetic Field

- Stopped particles:
  - Identified based on dE/dx vs E_{tot}
  - Total energy determined by range
- Exiting particles:
  - Energy deposition and radius of curvature of each particle species is unique
  - Allows momentum of particle to be determined
  - Particle species and charge state identified
- Dynamic range sufficient to simultaneously measure pions → light isotopes

Simulation w/ STAR resolution, scaled to EOS



TWIST Solenoid at NSCL

September 22, 2008

<u>TWIST Solenoid</u>

- 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%

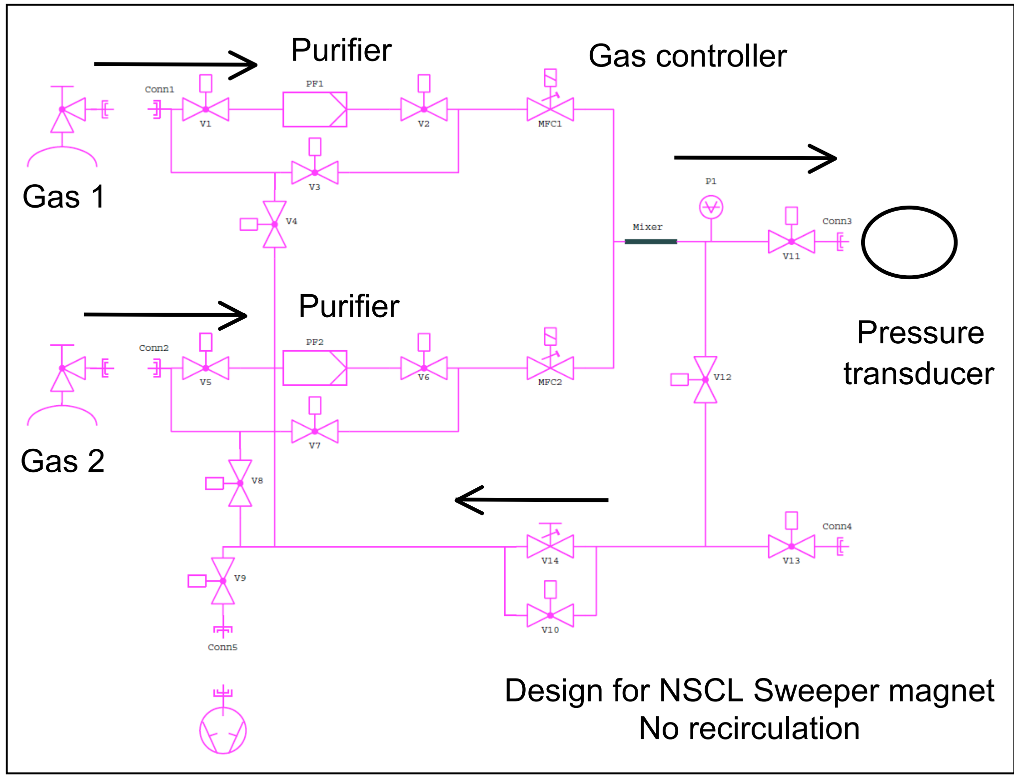
Gas Distribution

Objectives:

- Maintain two component mixtures at pre-defined ratios (^{3}He 90% + CO_2 10%)
- Gas dependant on experimental needs: ^{3}He, ^{40}Ar, ^{58}Ni, D_2, H_2, P10
- Gas pressure: 5-760 Torr

System parameters:

AT-TPC Volume	460 l
Mixtures	$^{3}He + CO_2$
	D_2
Pressure	5-760 Torr
Pressure uncertainty	<1%
O_2 and H_2O contaminants	<20ppm



Considerations:

- Gas recirculation required for $$ gases
- Out gassing of detector components
- Fast flow rate limits buildup of contaminants
- Aging effects of detector materials in H_2 gas
- Flammable gas safety

Calibration

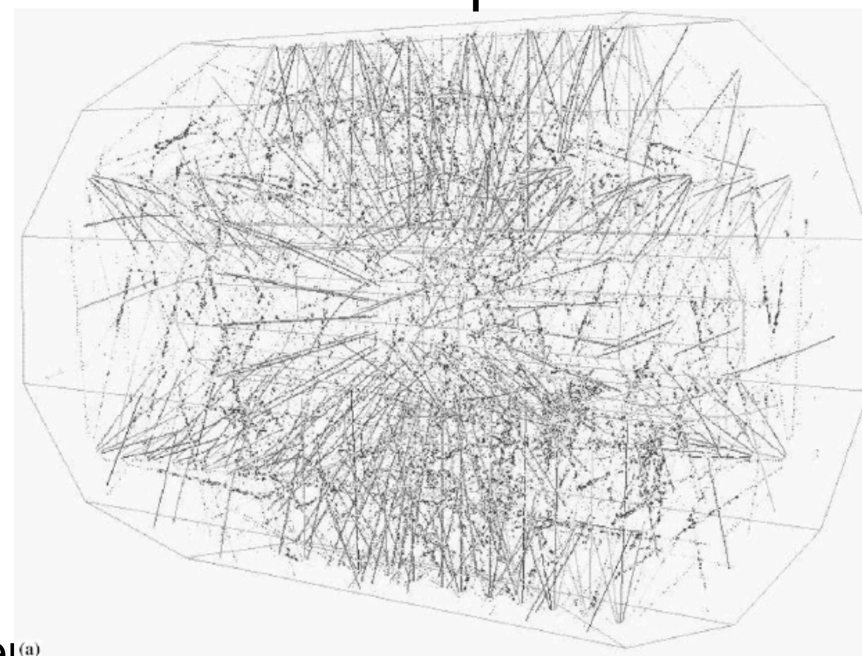
- Goal: Achieve maximum resolution
- Consequence: Must understand all sources of field distortions
  - Variation in drift velocity caused by gas mixture, temperature, pressure and electric field changes
  - ✯ Space charge buildup
  - Radial inhomogenities of E and B fields
  - Misalignment of E and B fields

- Problematic for:
  - High multiplicity expts
  - Beam ionization

Calibration

- Solution: Use narrow UV laser beam to simulate straight charged particle tracks in chamber
  - Independent of multiple scattering
  - Independent of magnetic field
  - Distribute tracks throughout chamber
- UV laser excites two photon ionization in organic contaminants
- Use frequency quadrupled Nd:YAG laser
  - Beam diameter = 30mm
  - Wavelength = 266nm
  - Energy density 1-20μJ/mm^2
  - Pulse length 3ns
- Predefined event fraction dedicated to laser calibration events

STAR Experiment



(Abele, et al., NIMA 499, 692, 2003)