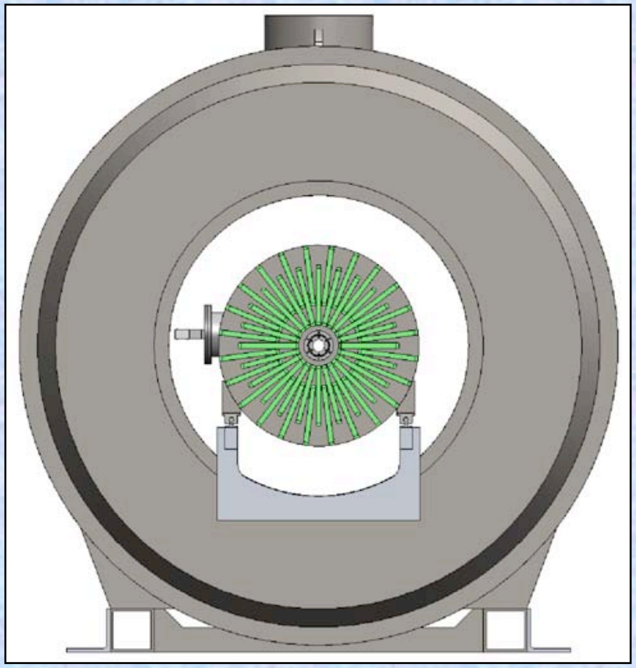
Active Target - Time Projection Chamber



Abigail Bickley

Michigan State University

March 10, 2009

AT-TPC Scientific Program

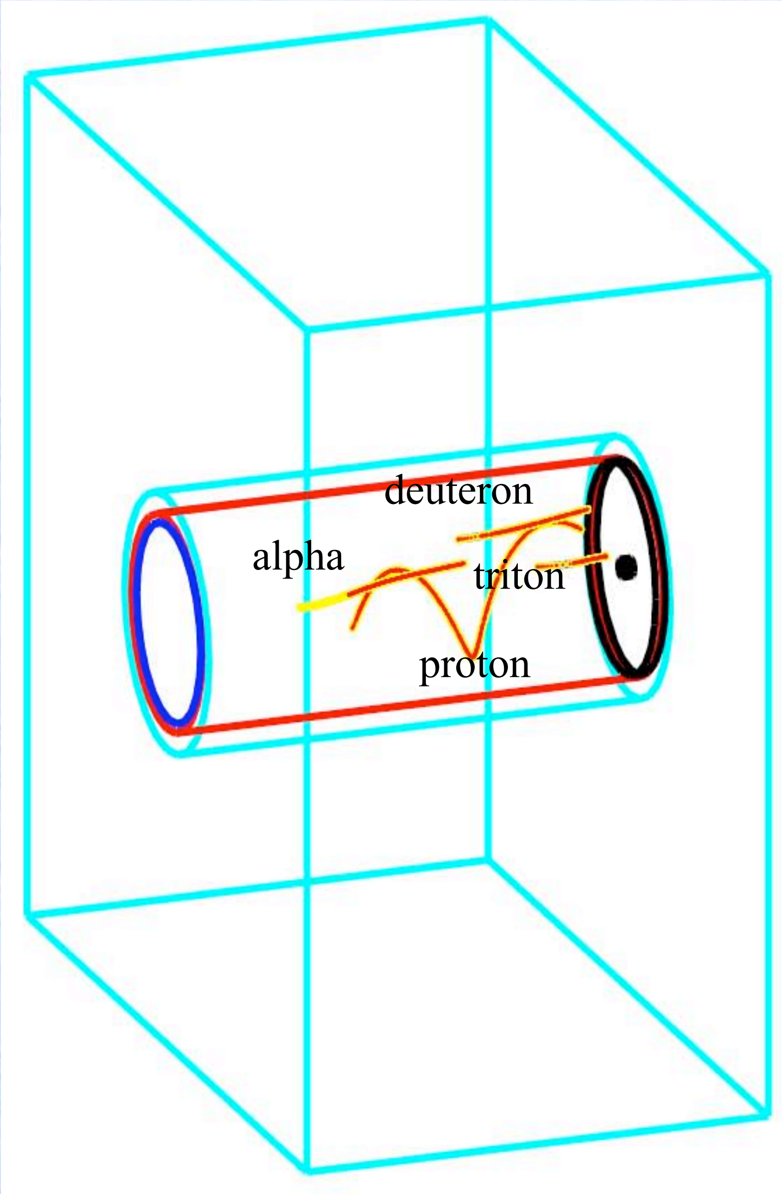
Table 1: Overview of the AT-TPC scientific program.

Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)	Scientific Leader
Transfer & Resonant Reactions	Nuclear Structure	$^{32}Mg(d,p)^{33}Mg$ $^{26}Ne(p,p)^{26}Ne$	3	100	Kanungo
Astrophysical Reactions	Nucleosynthesis	$^{25}Al(^{3}He,d)^{26}Si$	3	100	Famiano
Fusion and Breakup	Nuclear Structure	$^{8}B+^{40}Ar$	3	1000	Kolata
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000	Phair
Giant Resonances	Nuclear EOS, Nuclear Astro.	^{54}Ni-^{70}Ni, ^{106}Sn-^{127}Sn	50 - 200	50,000	Garg
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000	Bickley

- 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

Scientific Program: Transfer Reactions

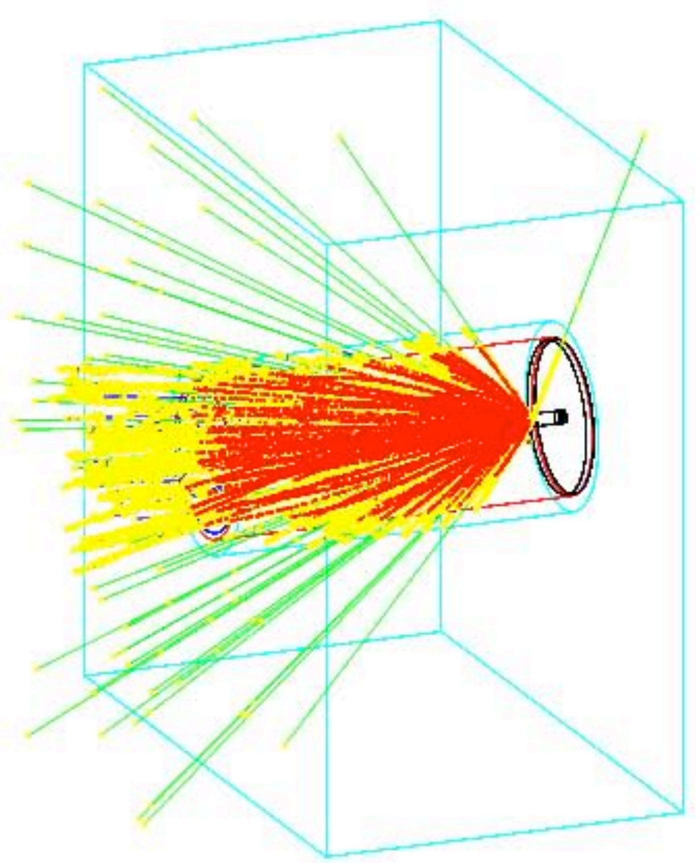
- Objective:
  - Study (d,p), (^{3}He,d) and (α,t) in inverse kinematics in the vicinity of closed shells
  - Probe shell closures far from stability
  - Study reaction rates important for astrophysics
- Beams of Interest:
  - Examples: ^{32}Mg(d,p)^{33}Mg, ^{25}Al(^{3}He,d)^{26}Si
  - Energies: 1-3 A MeV
  - Intensities: ≥ 100pps
- Reaction Characteristics:
  - Low collision multiplicities
  - Measurement of low energy products requires reduced pressure chamber gas
  - Good collision vertex reconstruction
  - Internal triggering of detector
  - Track reconstruction with good angular resolution



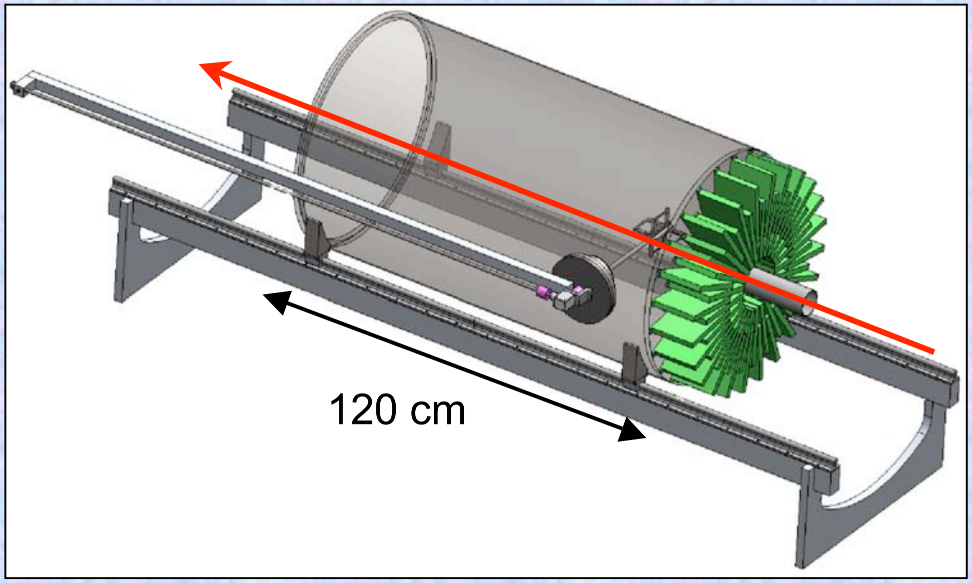
Scientific Program: Heavy Ion Reactions

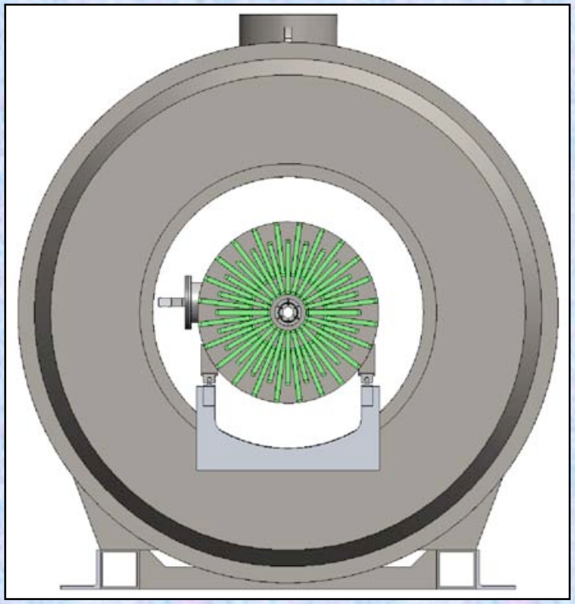
- Objective:
  - Use reaction observables to constrain the nuclear equation of state for isospin asymmetric matter exposed to densities both above and below ρ_0
  - $\rho > \rho_0$: charged pion production, nucleon squeezeout, nucleon elliptical flow
- Beams of Interest:
  - Species: ^{40}Ca, ^{48}Ca, ^{112}Sn, ^{124}Sn
  - Energies: 50 - 150 A MeV
  - Intensities: 5×10^4 pps, limited by ionization of chamber gas
- Reaction Characteristics:
  - High multiplicity ~100 collision products
  - Relatively high energy products $\therefore$ will exit chamber
  - Need full event characterization
  - Rare probes

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



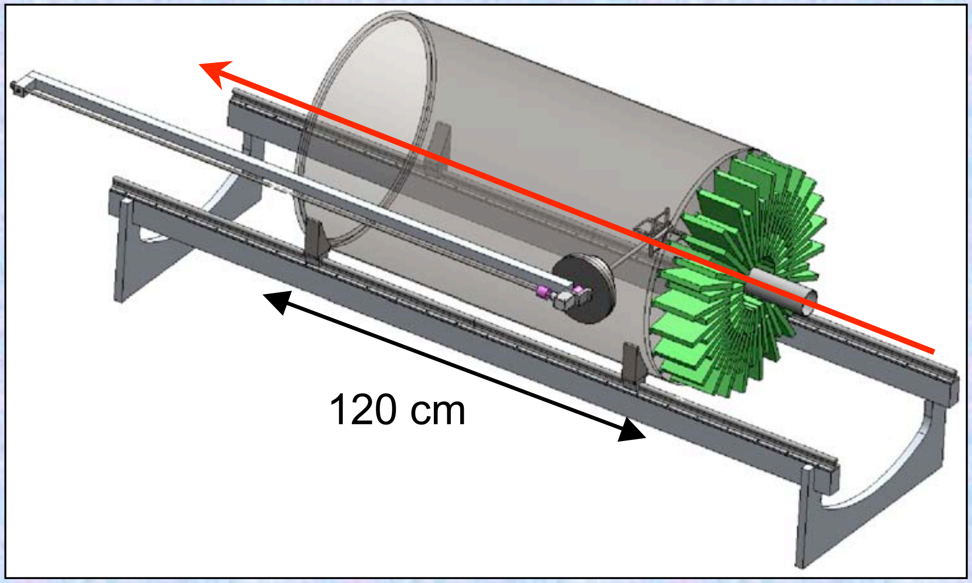
AT-TPC Introduction

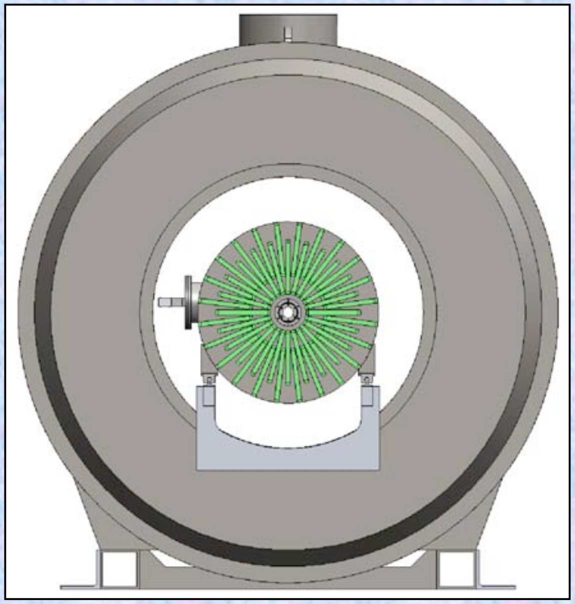




- Fixed Target Mode:
  - A target wheel will be installed within the chamber thus the gas will serve only as a detector
  - Configuration will reflect standard TPC conditions (ex: P10 @ 1atm)
- Active Target Mode:
  - The chamber gas will act as both detector and target
  - Gas identity and pressure 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

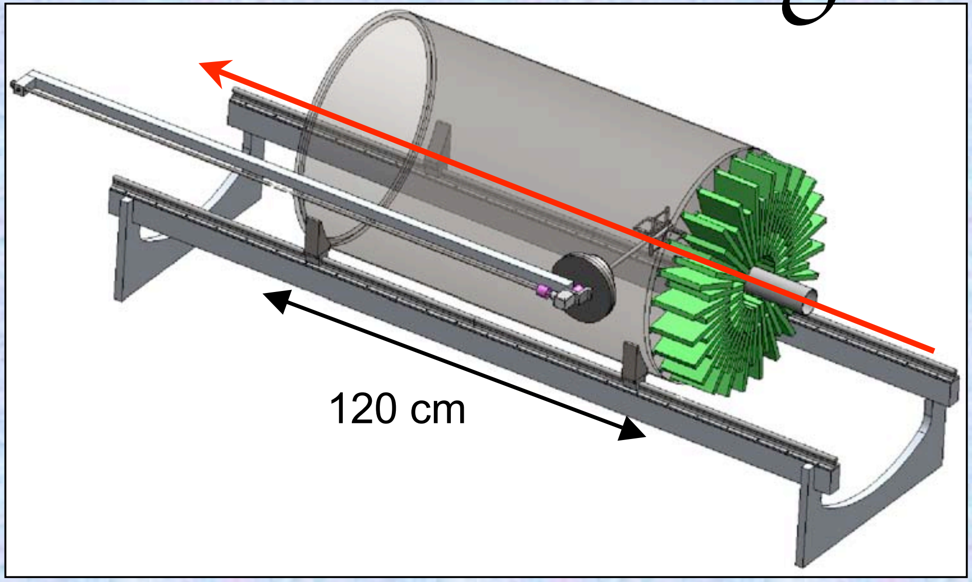
AT-TPC Components





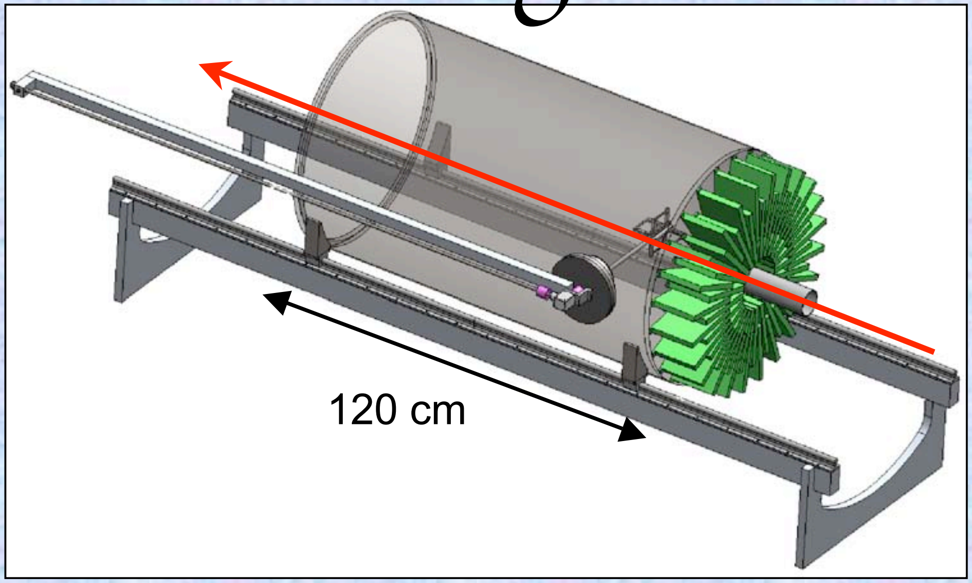
1. Chamber
2. Targets
3. Readout Plane
4. Magnetic Field
5. Triggering
6. Electronics
7. Simulations

1. Chamber Design



- Cylinder - length 120cm, radius 35cm
- Chamber designed to sustain vacuum
- 1-2cm radius entrance window
  - 3-20μm variable thickness mylar
- 33cm radius exit window
- Port for removable target wheel
- Mounted on rails within solenoid
- Can be coupled with ancillary systems

2. Targets

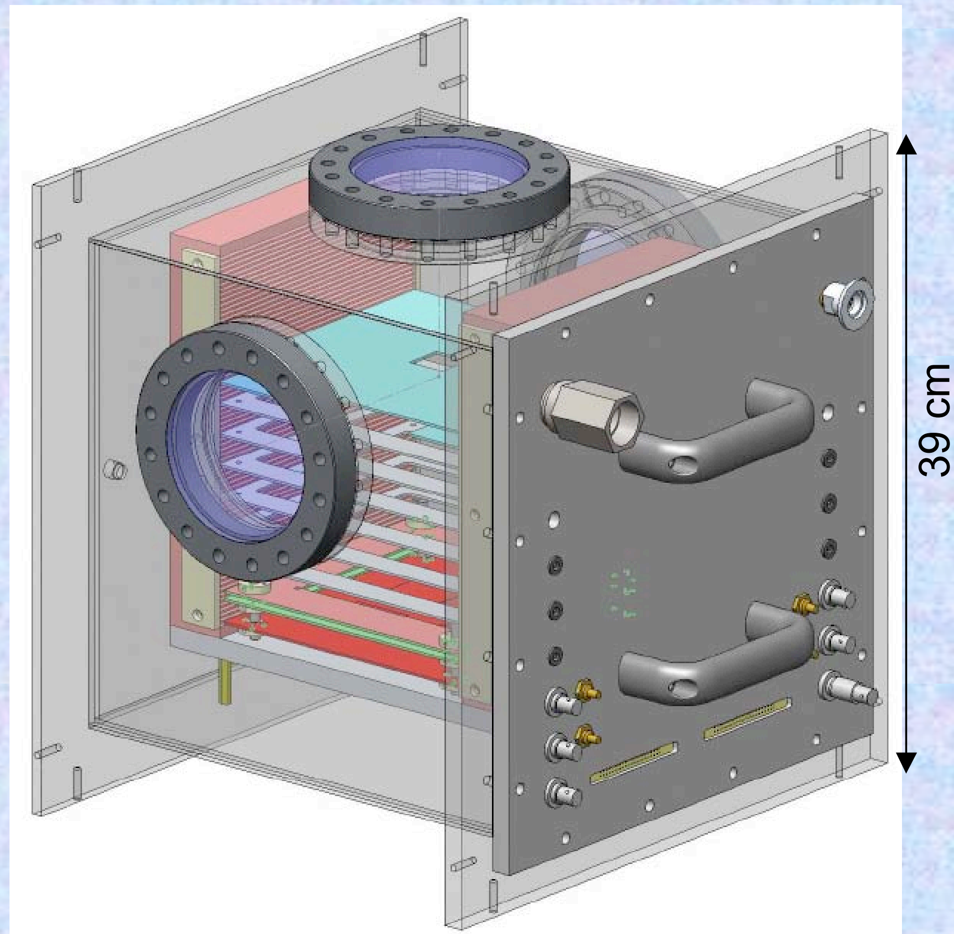


- Fixed Target Mode:
  - Removable target wheel that accommodates multiple targets
- Active Target Mode:
  - Identity and pressure of the gas used to fill the detector will be dependent upon the experimental requirements.
  - H_2, D_2, ^3He, Ne, Ar, Isobutane
  - Pressures ranging from <0.2-1.0 atm
  - Ionization & e- drift depend on physical properties of gases
    - P10: 5.5cm/μs, 22 /μs total drift length
    - H_2: ~1cm/μs, 120 /μs total drift length

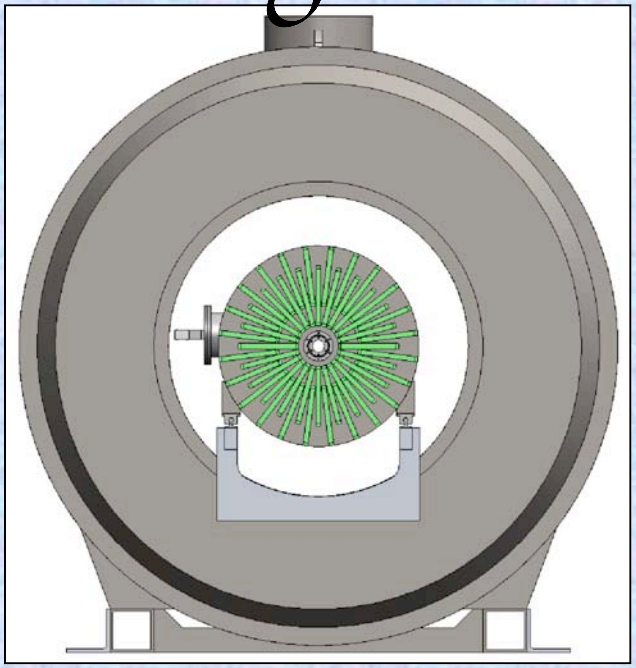
3. Readout Plane

- Physical Features:
  - Covers endcap of chamber with beam entrance window
  - Number of pads: ~10k
  - Pad size: 0.5 x 0.5cm^2
- Composition:
  - Wire Plane
    - ✓ Well known stable behavior,
    - x Reduced resolution
    - x Feedback of +ions into drift region
  - GEMs
    - ✓ High gain
    - ✓ Low +ion feedback
    - x Sensitive to sparking
    - x Localized e$^-$ cloud
  - MicroMegas
    - ✓ High gain
    - ✓ Low +ion feedback
    - x Localized e$^-$ cloud (resistive foil)

Test Chamber

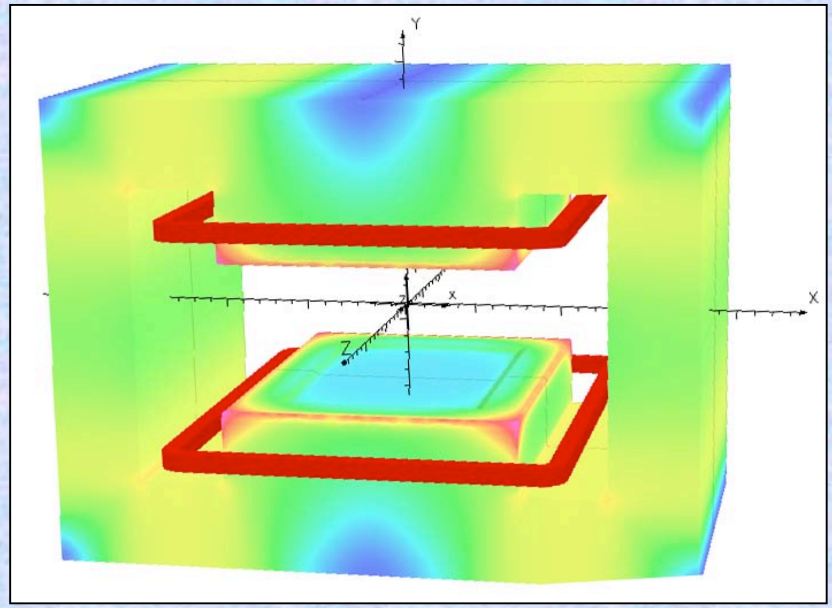


4. Magnetic Field Considerations



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

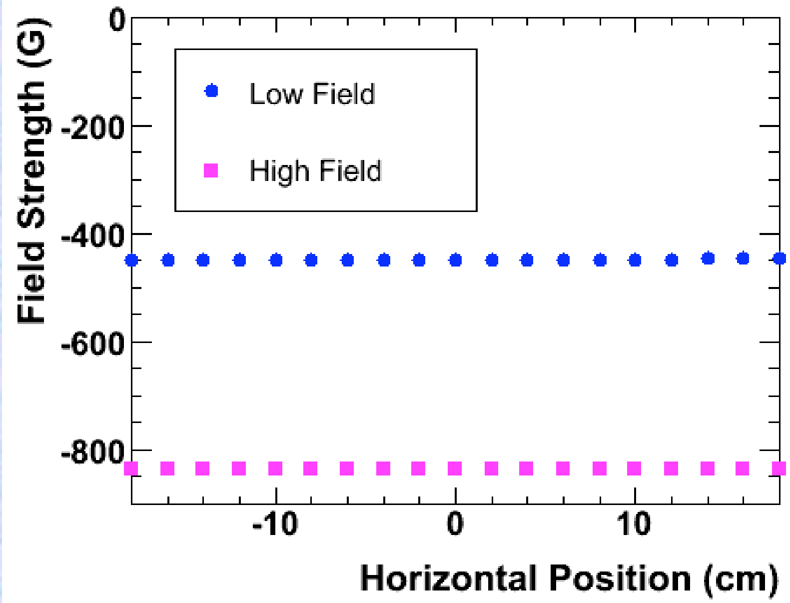
4. TWIST Solenoid at NSCL

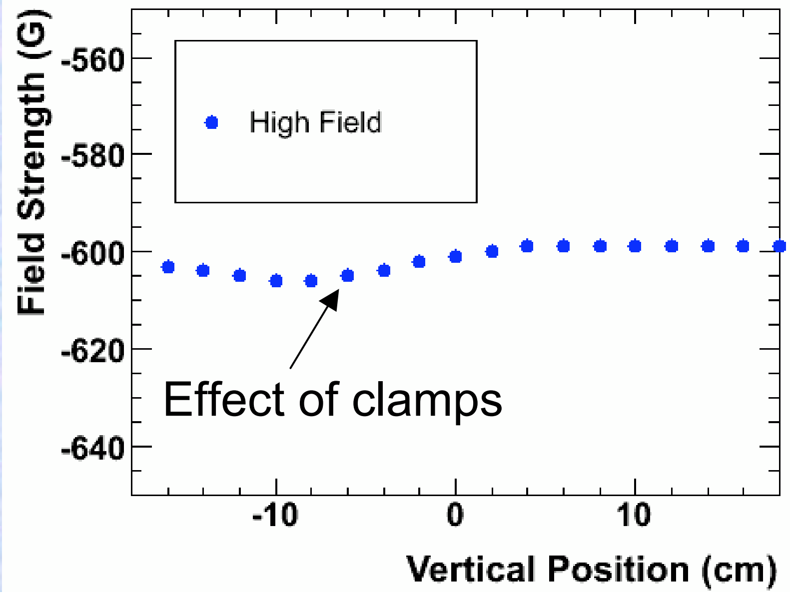
September 22, 2008

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%

4. Field Testing





- ✓ Nov 10: started cooldown
- ✓ Nov 11: LN_2 temperature stabilization
- ✓ Nov 21: LHe temperature stabilization
- ✓ Nov 25 & 26: field ramping & uniformity tests

Cryogen use rate:

LN_2 = 185 L/wk

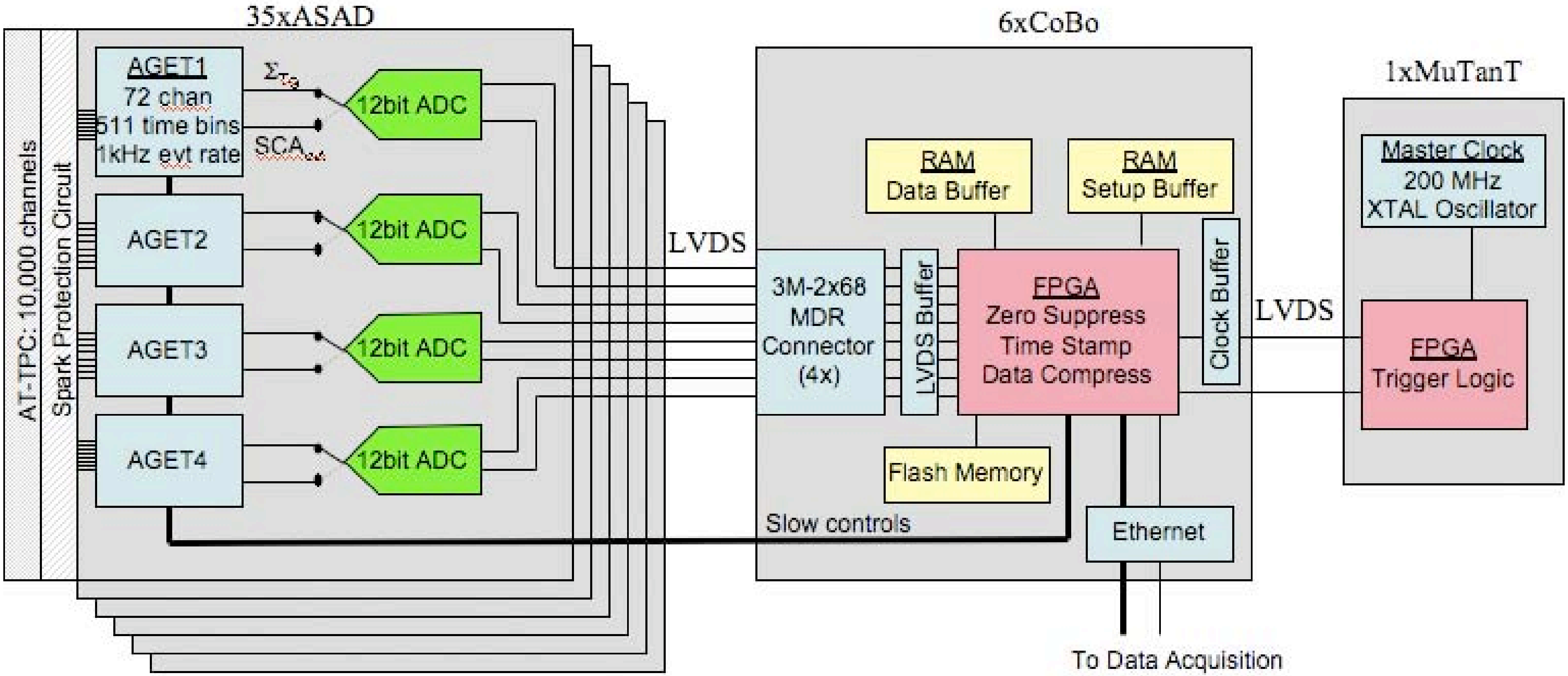
LHe = 41 L/week (not in persistent mode)

- ✗ Yoke will be assembled after the new experimental hall is completed

5. 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

6. GET Electronics



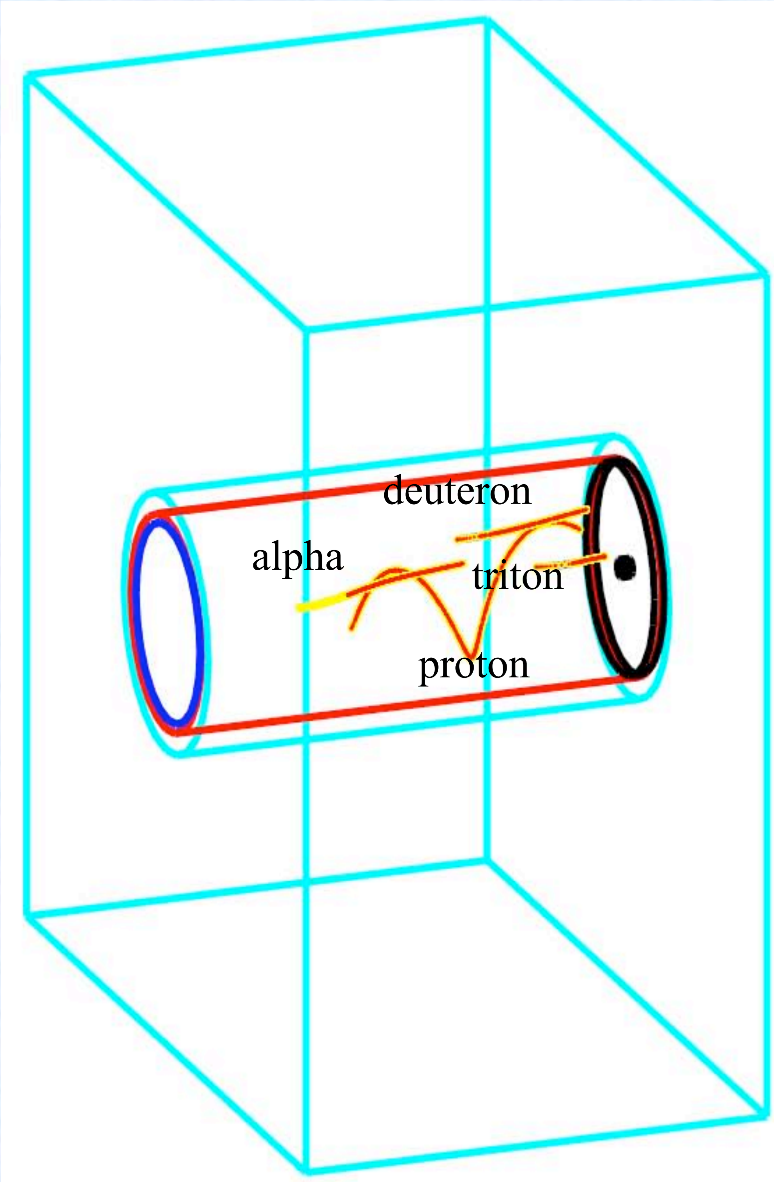
Necessary

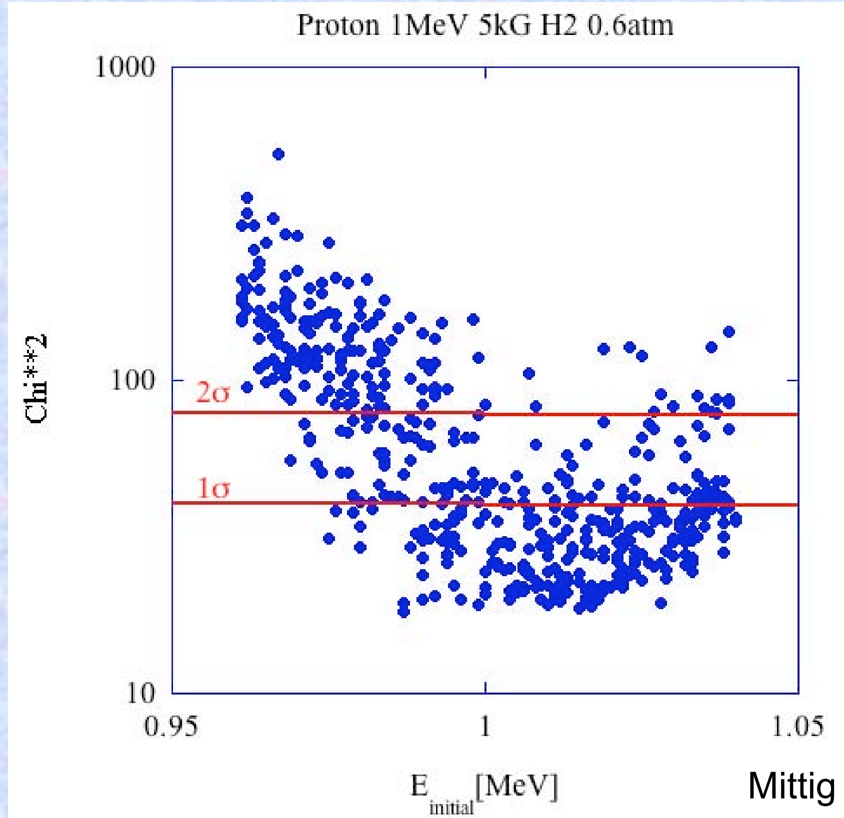
- Large dynamic range
- Internal triggering capability
- 1kHz/chan data rate
- Zero suppression
- Accommodate external trigger

Desired

- 14 bit ADC
- Data compression

7. Reaction Simulations

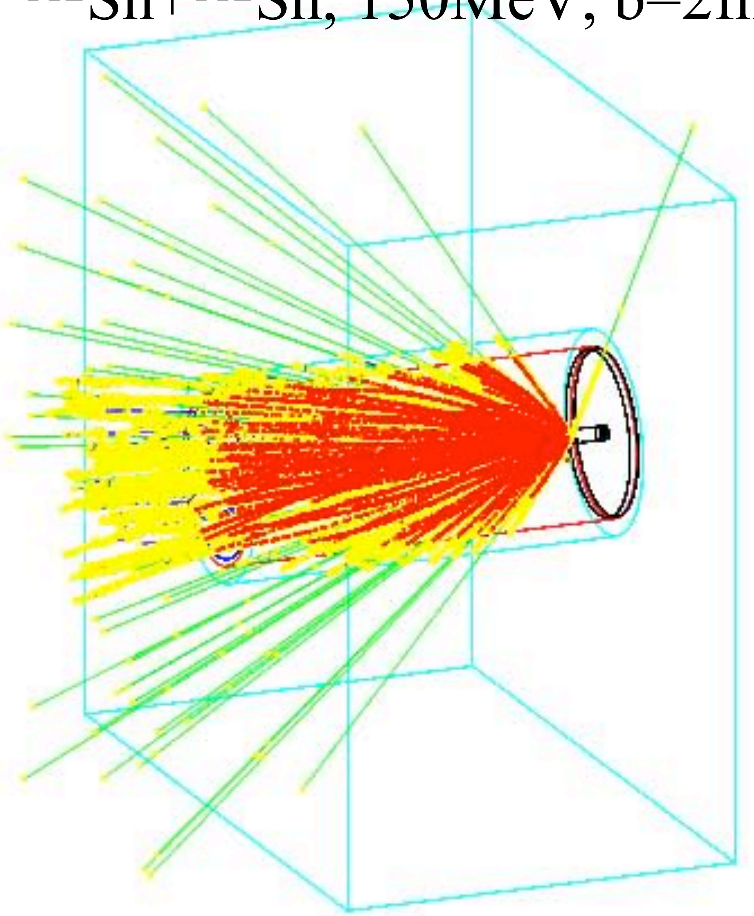




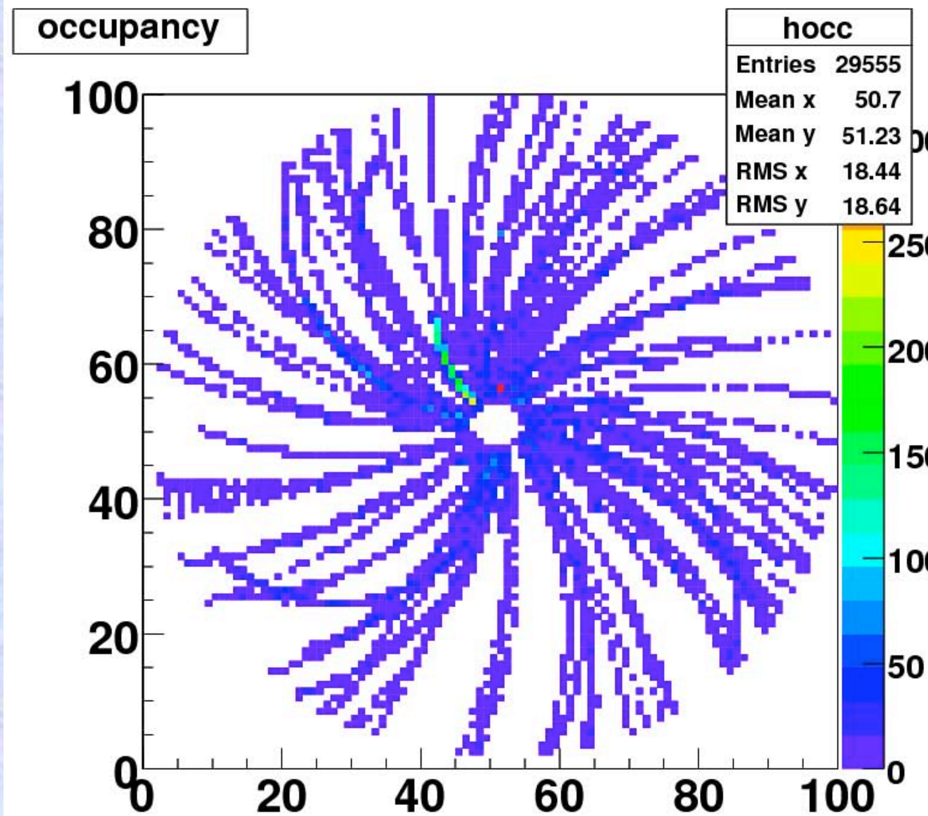
- Includes Fluctuations from:
  - Energy straggling
  - Angular straggling
  - Primary electron number
  - Longitudinal diffusion
  - Transverse diffusion
  - Electronic noise
- χ^2 calculated from known 3D track parameters
- 2σ fit results in resolution of ~100keV

7. Reaction Simulations

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



GEANT Hits, 1evt



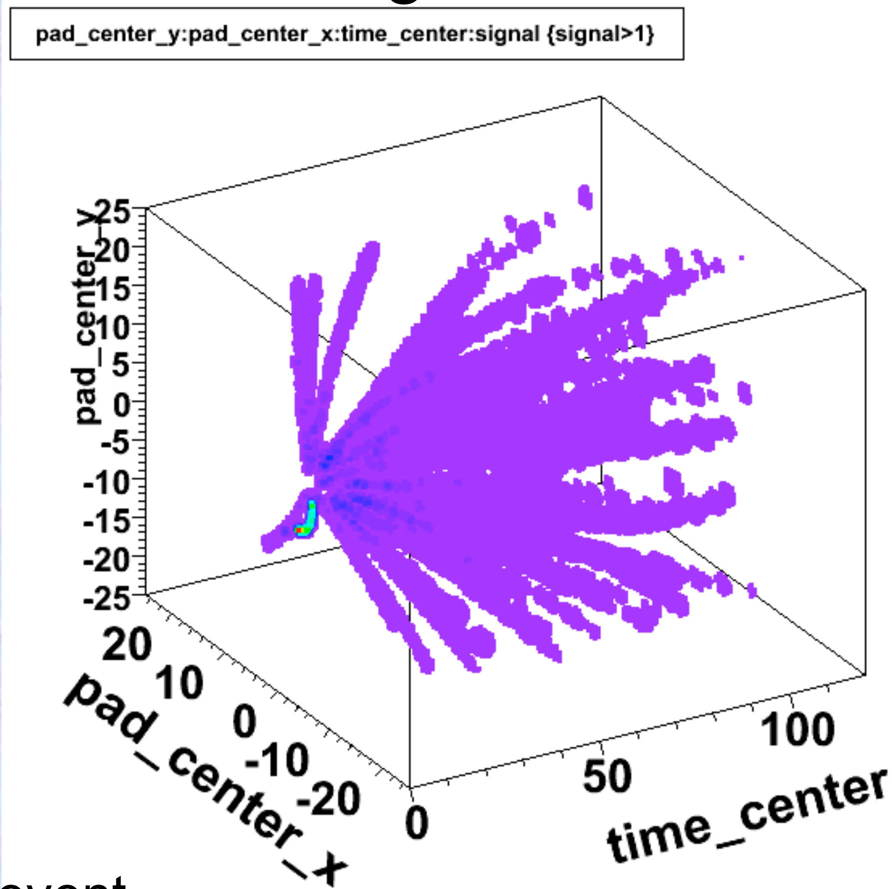
- High collision multiplicity expected
- Results in data volume of :

50 kB/s*chan
500 MB/s } Zero supp, 32bits/sample, 128 time bucket, 10% occup 10k chan, 1 kHz

7. Reaction Simulations

- $^{112}Sn+^{112}Sn$, 150 A MeV, b=2fm
  1) ImQMD →
  2) Gemini →
  3) Fragment Decay →
  4) GEANT4 →
  5) e^- drift →
     - long_diff = 300 μm/cm * drift_distance
     - trans_diff = 145 μm/cm * drift_distance
  6) Pixelization
     - Cut: Signal>1
- Examine # Time Buckets
  - Time Buckets = 511
  - Occupancy = 3%
- Examine detector occupancy per event
- Examine ASAD & CoBo occupancy

Single Event



7. Reaction Simulations

- $^{112}Sn+^{112}Sn$, 150 A MeV, b=2fm
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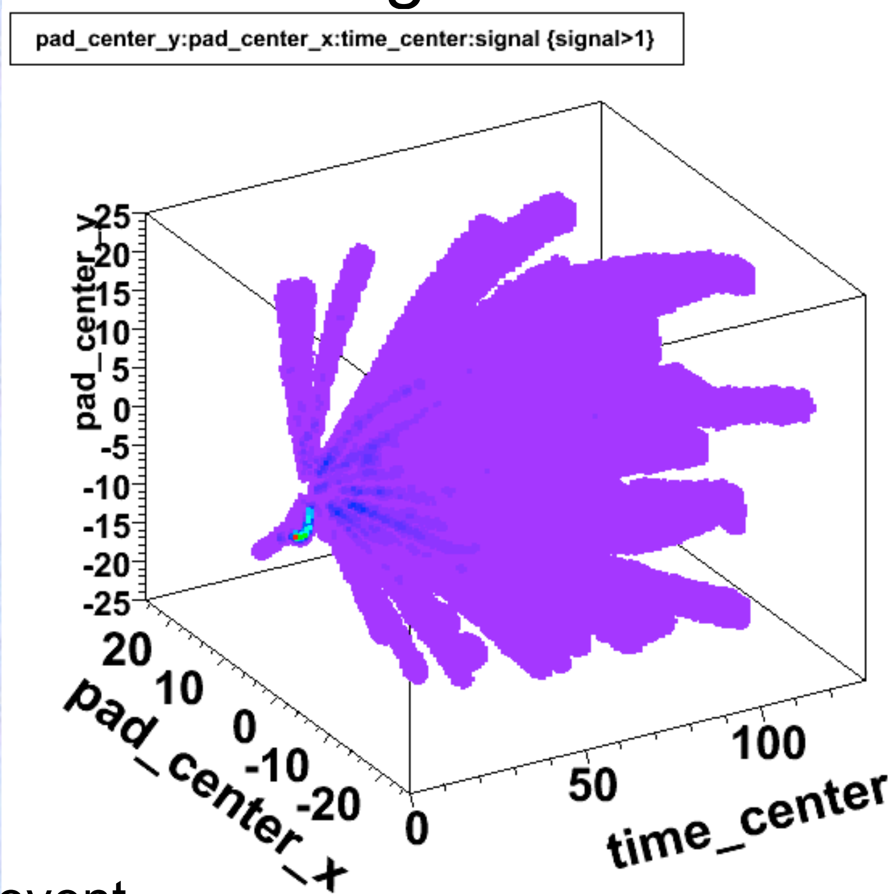
  3) Fragment Decay →
  4) GEANT4 →
  5) e^- drift →
     - long_diff = 300 μm/cm * drift_distance
     - trans_diff = 145 μm/cm * drift_distance
  6) Pixelization
     - Cut: Signal>1
- Examine # Time Buckets
  - Time Buckets = 128
  - Occupancy = 11%
- Examine detector occupancy per event
- Examine ASAD & CoBo occupancy

Single Event



7. Reaction Simulations

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  3) Fragment Decay →
  4) GEANT4 →
  5) e^- drift →
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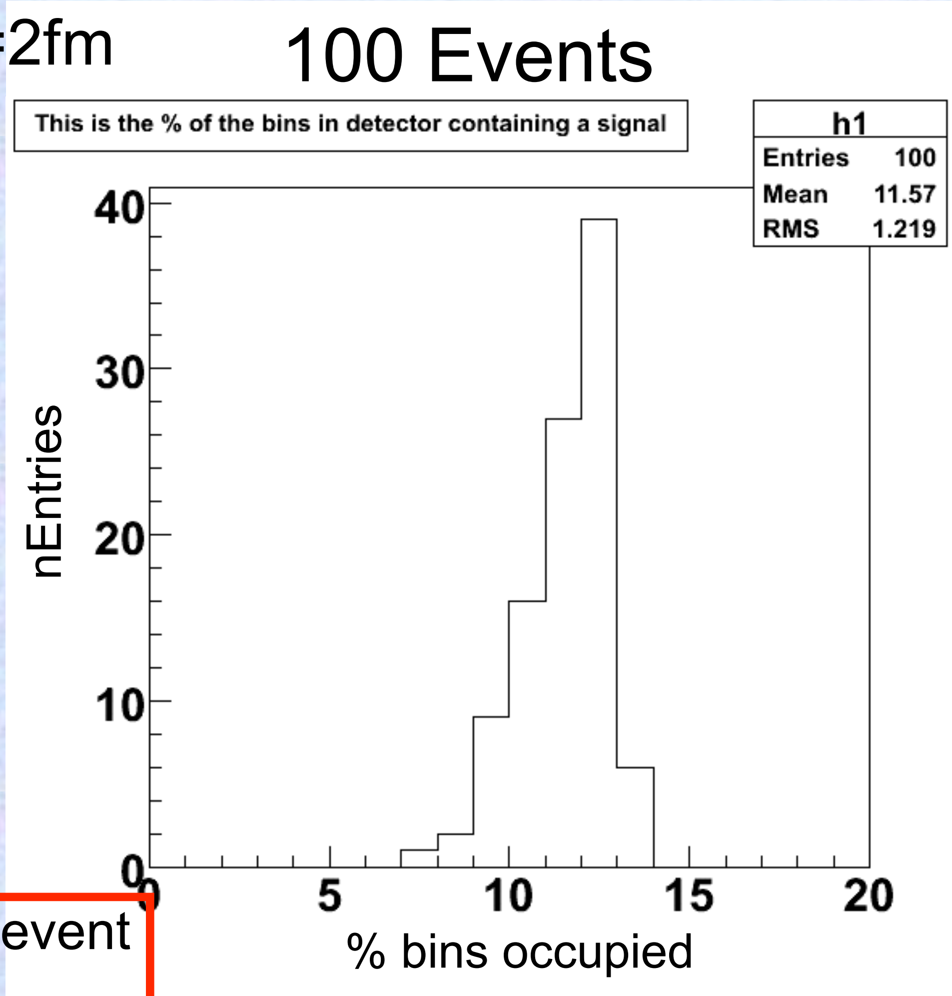
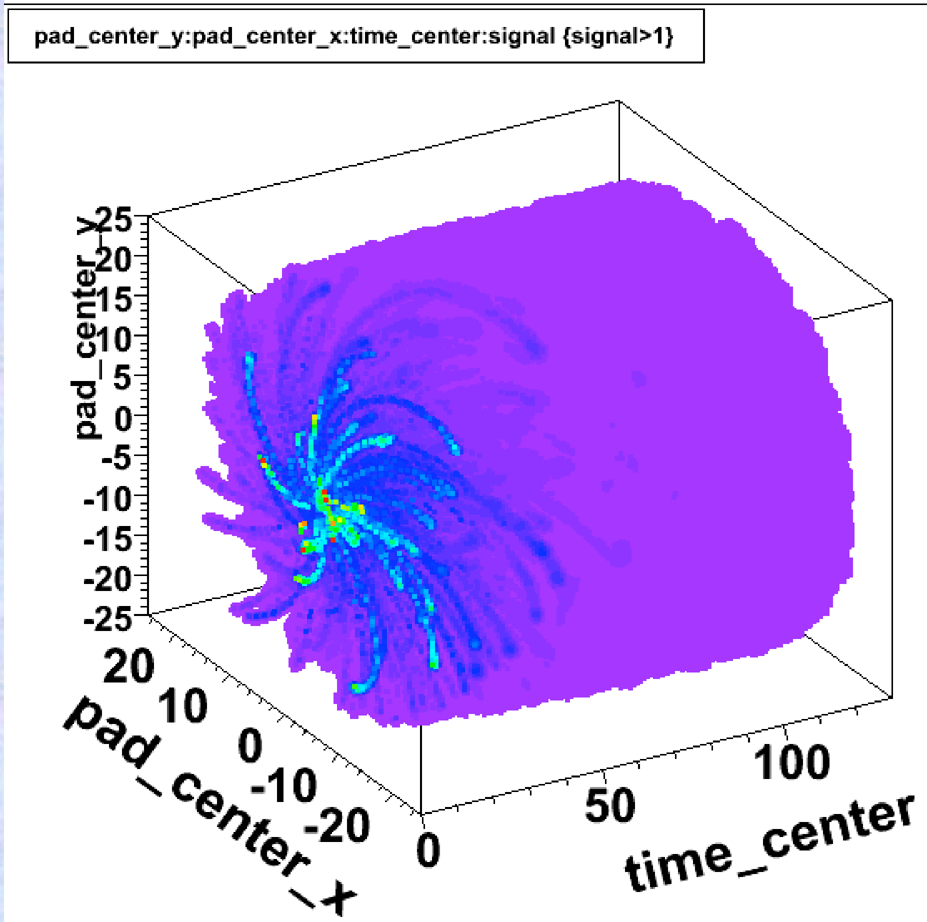
     - trans_diff = 145 μm/cm * drift_distance
  6) Pixelization
     - Cut: Signal>1
- Examine # Time Buckets
  - Time Buckets = 128
- Examine detector occupancy per event
  - Occupancy = 7-14%
- Examine ASAD & CoBo occupancy



7. Reaction Simulations

- $^{112}Sn+^{112}Sn$, 150 A MeV, b=2fm
    1) ImQMD →
    2) Gemini →
    3) Fragment Decay →
    4) GEANT4 →
    5) e^- drift →
        - long_diff = 300 μm/cm * drift_distance
        - trans_diff = 145 μm/cm * drift_distance
    6) Pixelization
        - Cut: Signal>1
        - Time Buckets = 128
- Assign pads to an AsAd
    - 26 identical sectors in φ
    - <AsAd Occupancy> = 1-40%
- Assign AsAds to a CoBo
    - ~ independent of position

100 Events



7. Reaction Simulations

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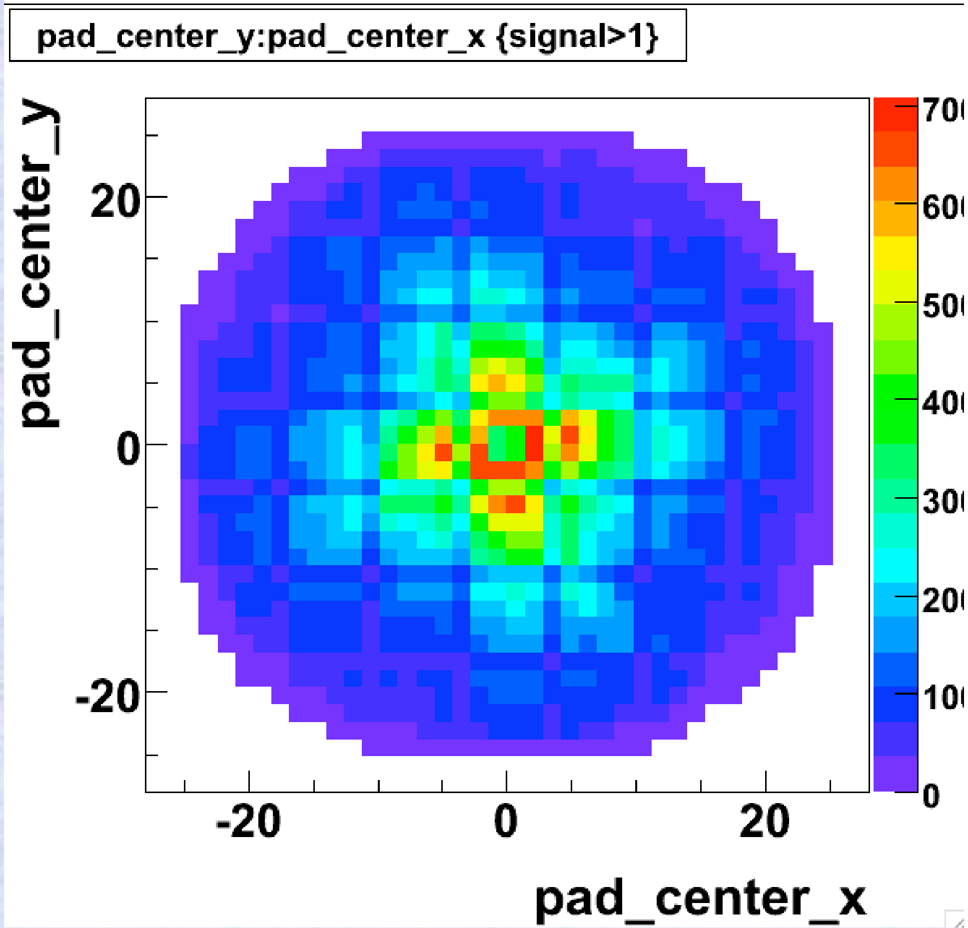

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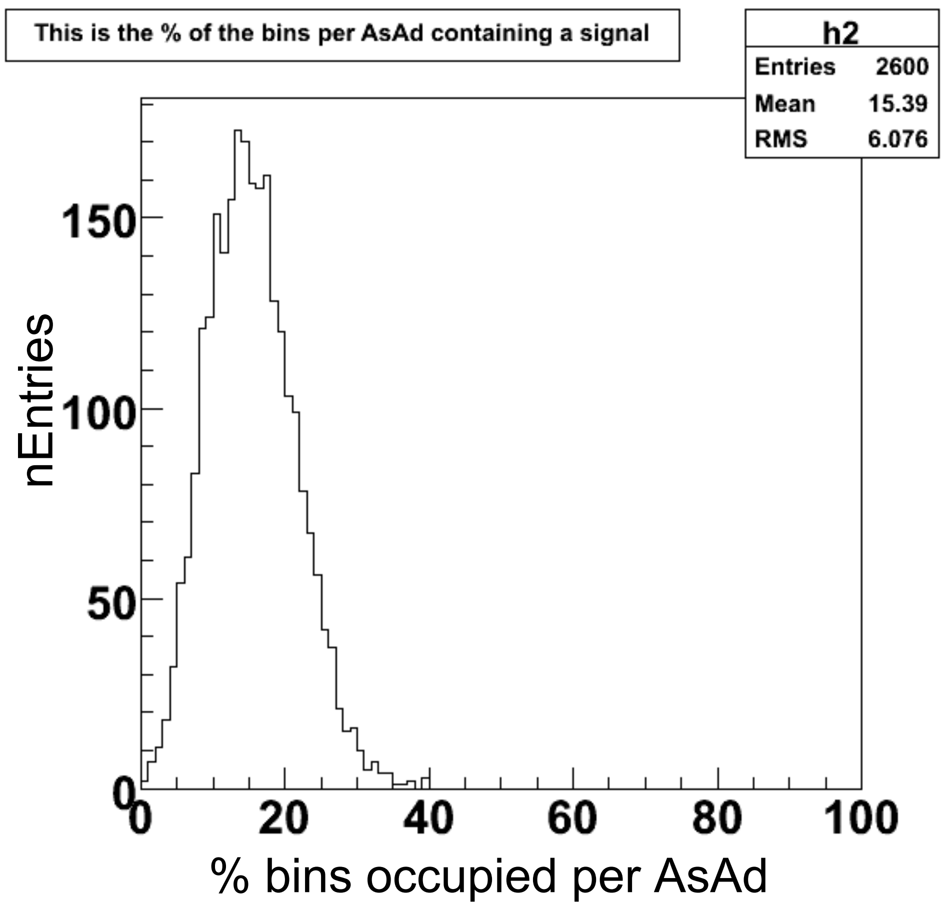
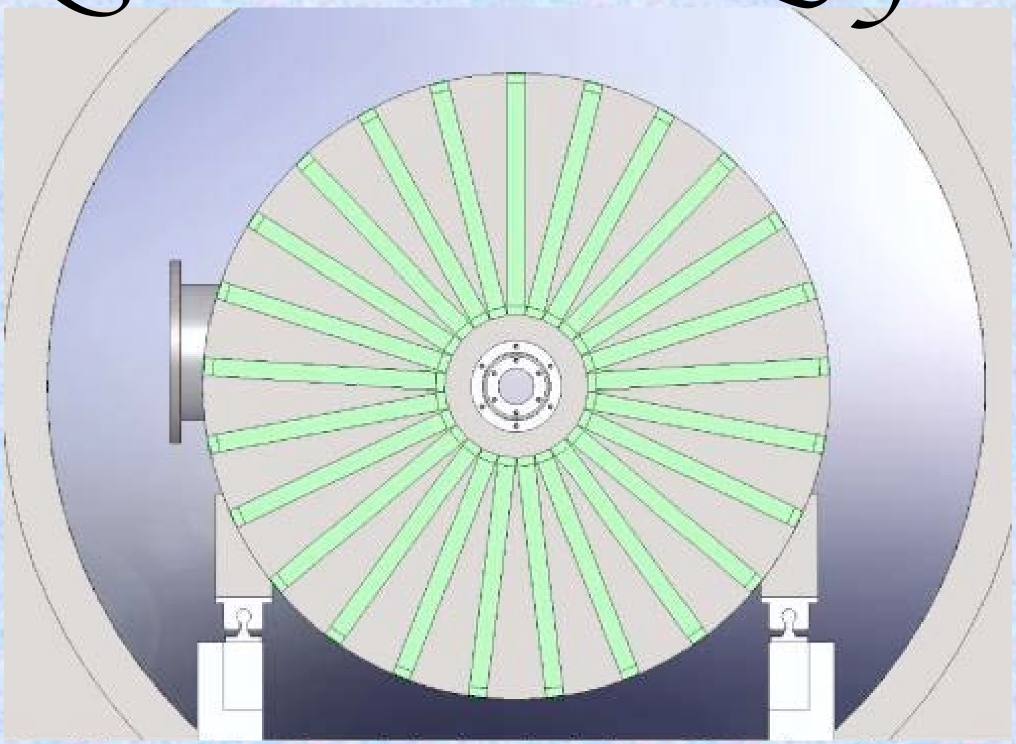
  - ~ independent of position

100 Events

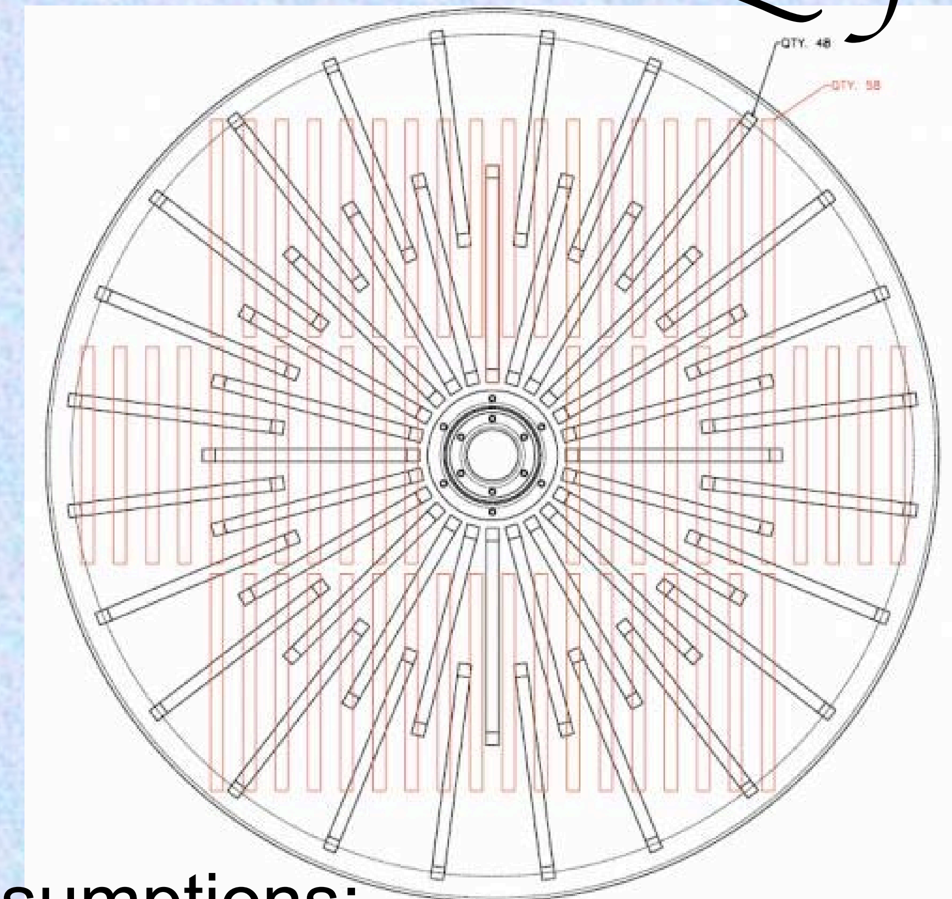


Radial AsAd Layout



- Design assumptions:
  - Based on T2K FEC
  - FEC dimensions = 2.0cm x 14.0cm x 25.0cm
  - Require 26 cards
  - Only 25 fit within geometrical constraints

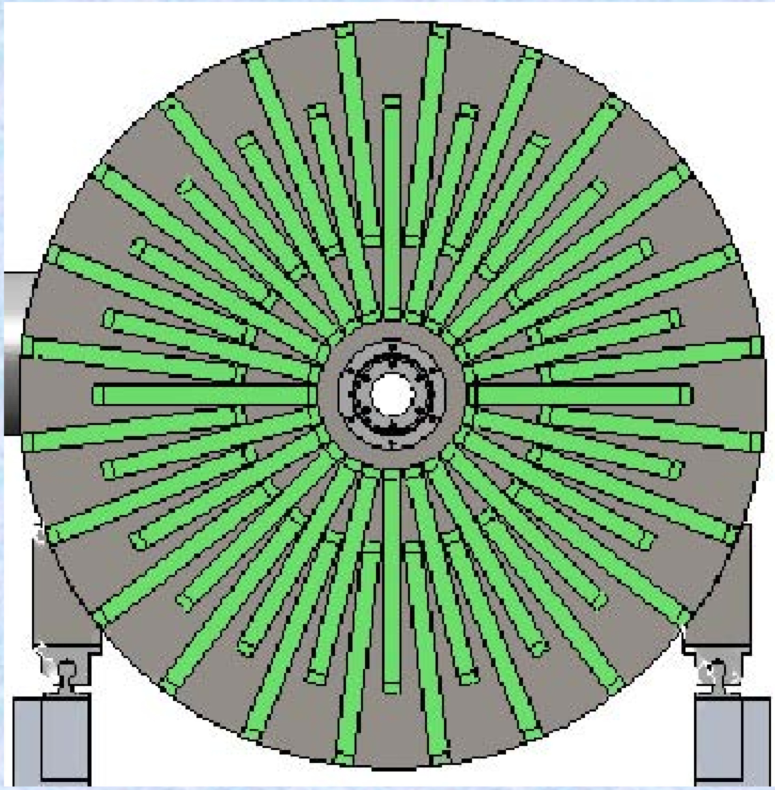
Alternate AsAd Layouts



- Design assumptions:
  - FEC dimensions of 1.0cm x 9.3cm x 17.0cm
  - now known to be too small

Staggered AsAd Layout

- $^{112}Sn+^{112}Sn$, 150 A MeV, b=2fm
  1) ImQMD →
  2) Gemini →
  3) Fragment Decay →
  4) GEANT4 →
  5) e^- drift →
     – long_diff = 300 μm/cm * drift_distance
     – trans_diff = 145 μm/cm * drift_distance
  6) Pixelization
     – Cut: Signal>1
     – Time Buckets = 128



- Assign pads to an AsAd
  – 13 inner sectors in ϕ
  – 13 inner sectors in ϕ
  – <AsAd Occupancy> = 0-60%
- Assign AsAds to a CoBo
  – Must group equal # inner & outer sectors

Staggered AsAd Layout

- $^{112}Sn+^{112}Sn$, 150 A MeV, b=2fm
  1) ImQMD →
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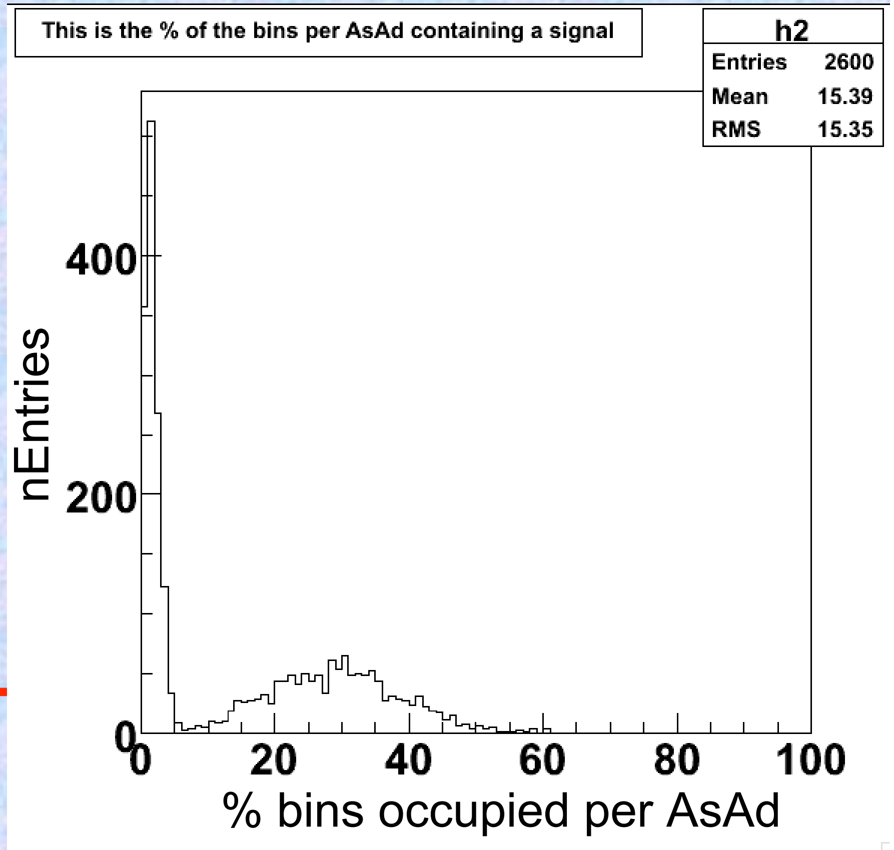

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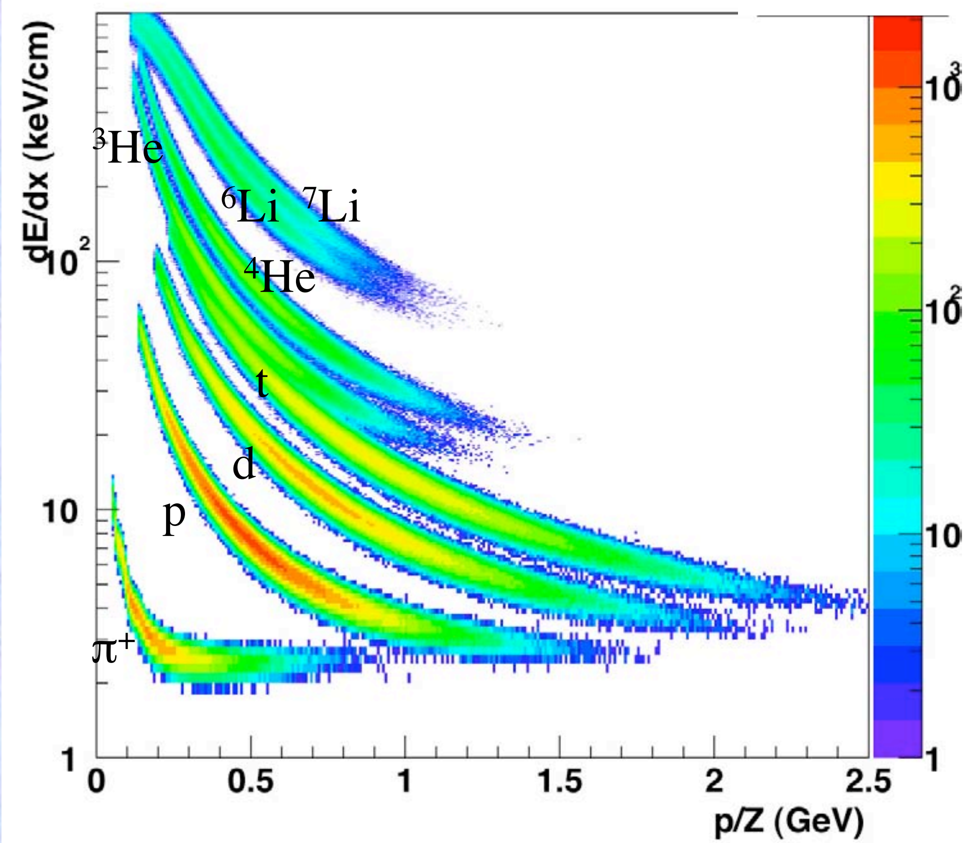
  – 13 inner sectors in ϕ
  – 13 inner sectors in ϕ
  – <AsAd Occupancy> = 0-60%
- Assign AsAds to a CoBo
  – Must group equal # inner & outer sectors

Particle Identification

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

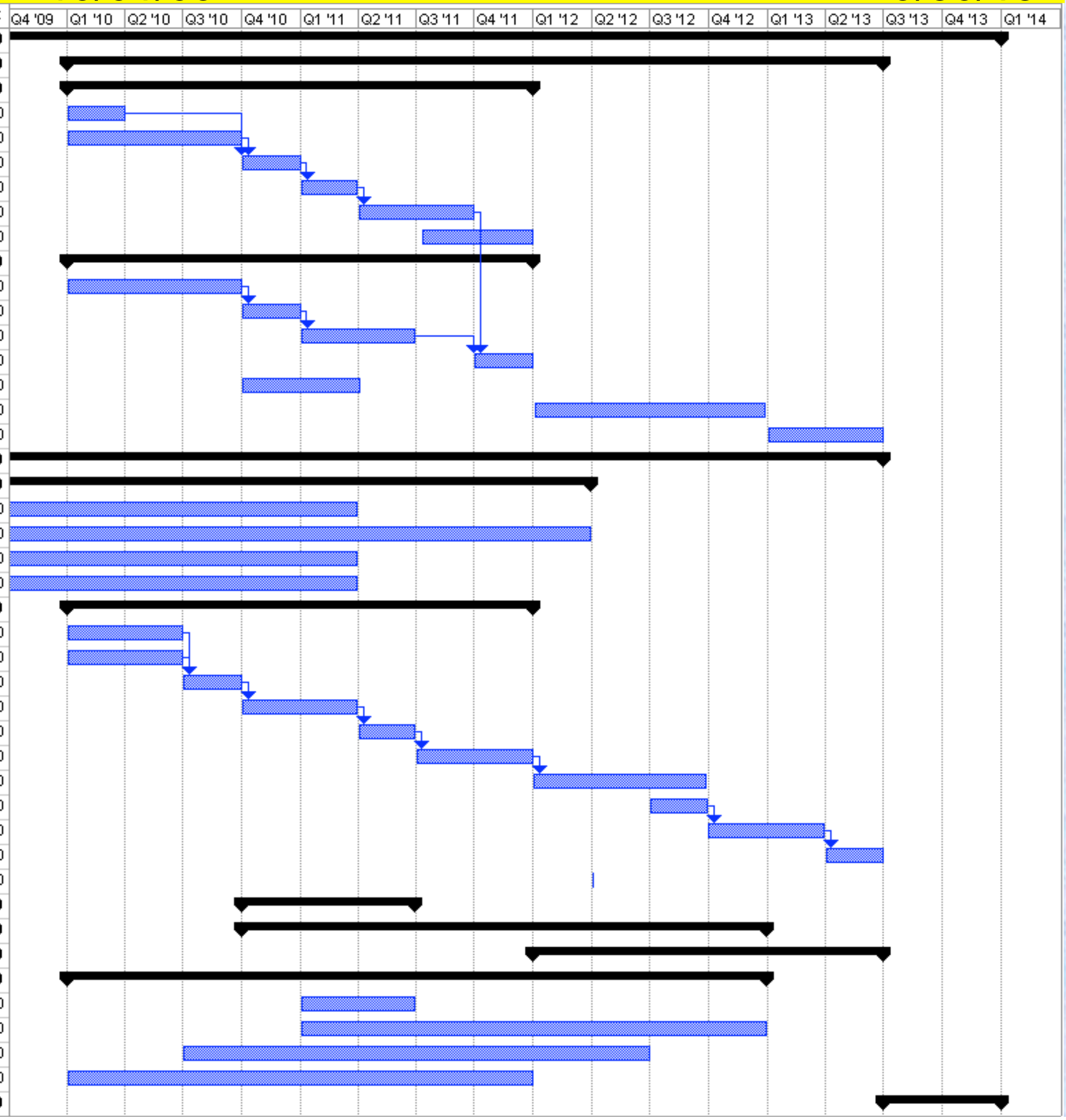
Simulation w/ STAR resolution, scaled to EOS



Timeline & Funding

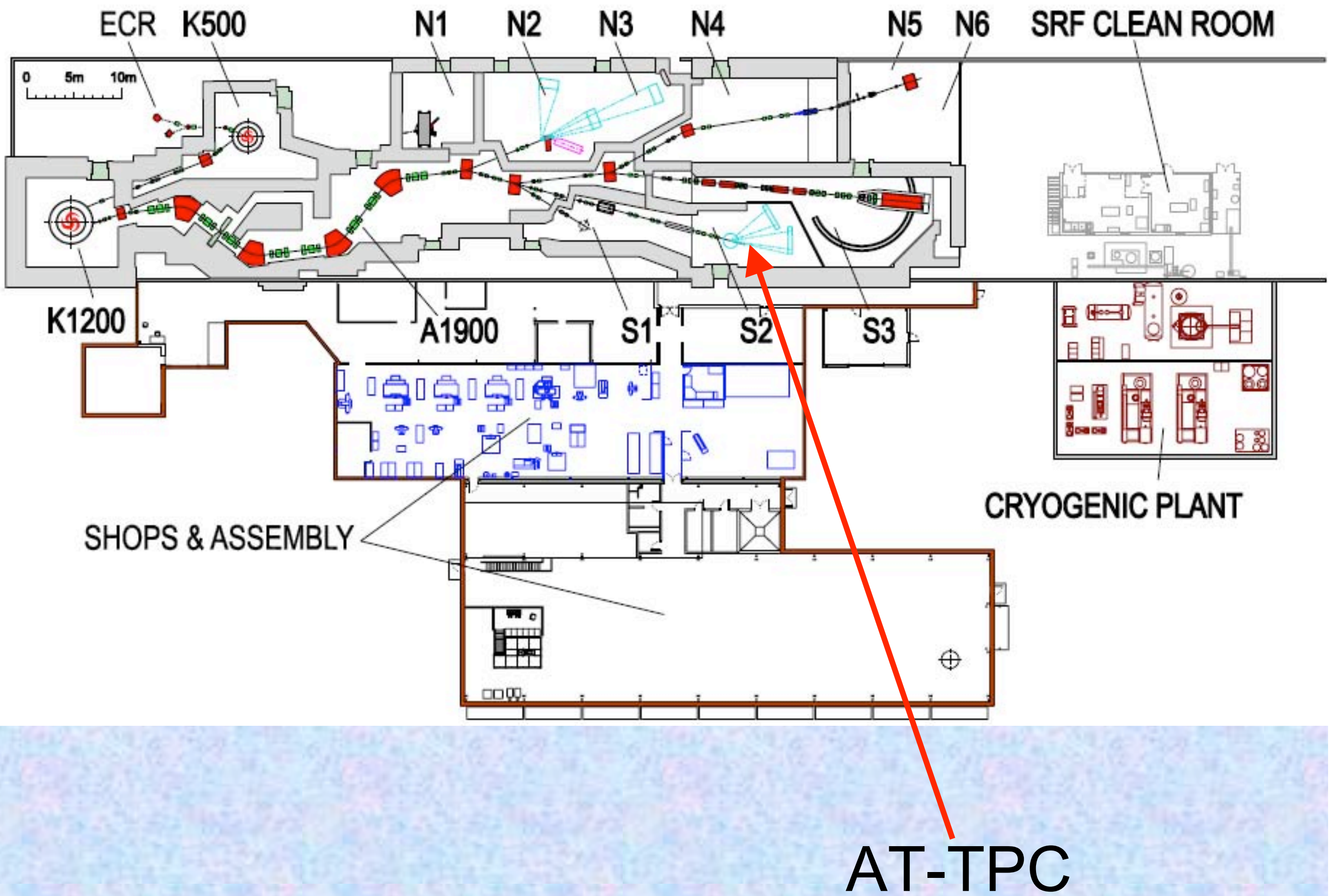
$1018k 10/01/09 9/30/13

ID	Task Name	Procurement Cost
1	**Project Total**	**$629,530.00**
2	**TPC**	**$109,400.00**
3	**Chamber**	**$25,875.00**
4	Design	$0.00
5	Electromechanics	$0.00
6	Procurement	$25,875.00
7	Machining	$0.00
8	Assembly	$0.00
9	Testing	$0.00
10	**Pad Plane**	**$62,100.00**
11	Design	$0.00
12	Procurement	$62,100.00
13	Assembly	$0.00
14	Installation	$0.00
15	High Voltage Supply	$21,425.00
16	Commissioning	$0.00
17	Contingency	$0.00
18	**Electronics**	**$353,315.00**
19	**Development**	**$20,700.00**
20	ASIC - IRFU	$0.00
21	ASAD - CENBG	$0.00
22	Trigger Card - GANIL	$0.00
23	Protection Circuit - IRFU	$0.00
24	**CoBo - NSCL**	**$20,700.00**
25	Board Layout	$0.00
26	FPGA Programming	$0.00
27	Prototype	$20,700.00
28	Prototype Testing	$0.00
29	Production	$0.00
30	Contingency	$0.00
31	System Testing	$0.00
32	Installation	$0.00
33	Commissioning	$0.00
34	Contingency	$0.00
35	Production Costs	$332,615.00
36	**Gas System**	**$20,700.00**
38	**Laser System**	**$55,436.00**
40	**Downstream Trigger**	**$29,692.00**
42	**Computing**	**$60,987.00**
43	DAQ Hardware	$60,987.00
44	DAQ Software	$0.00
45	Tracking Software	$0.00
46	Simulations	$0.00
47	**Project Contingency**	**$0.00**



NSCL: Coupled Cyclotron Facility

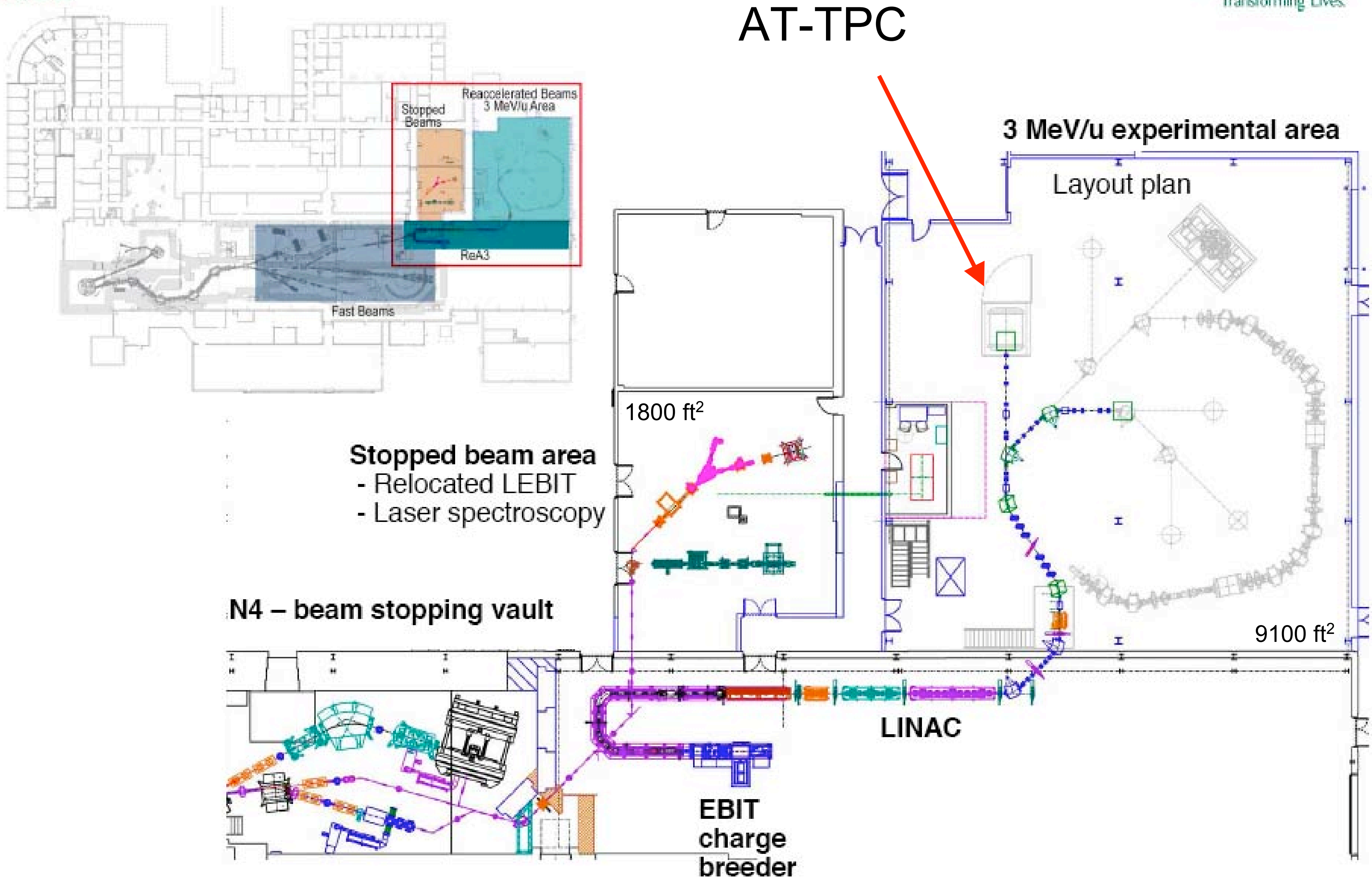
Commissioned in 2001. Vault and beam-line reconfiguration in 2007



Developed Primary Beams

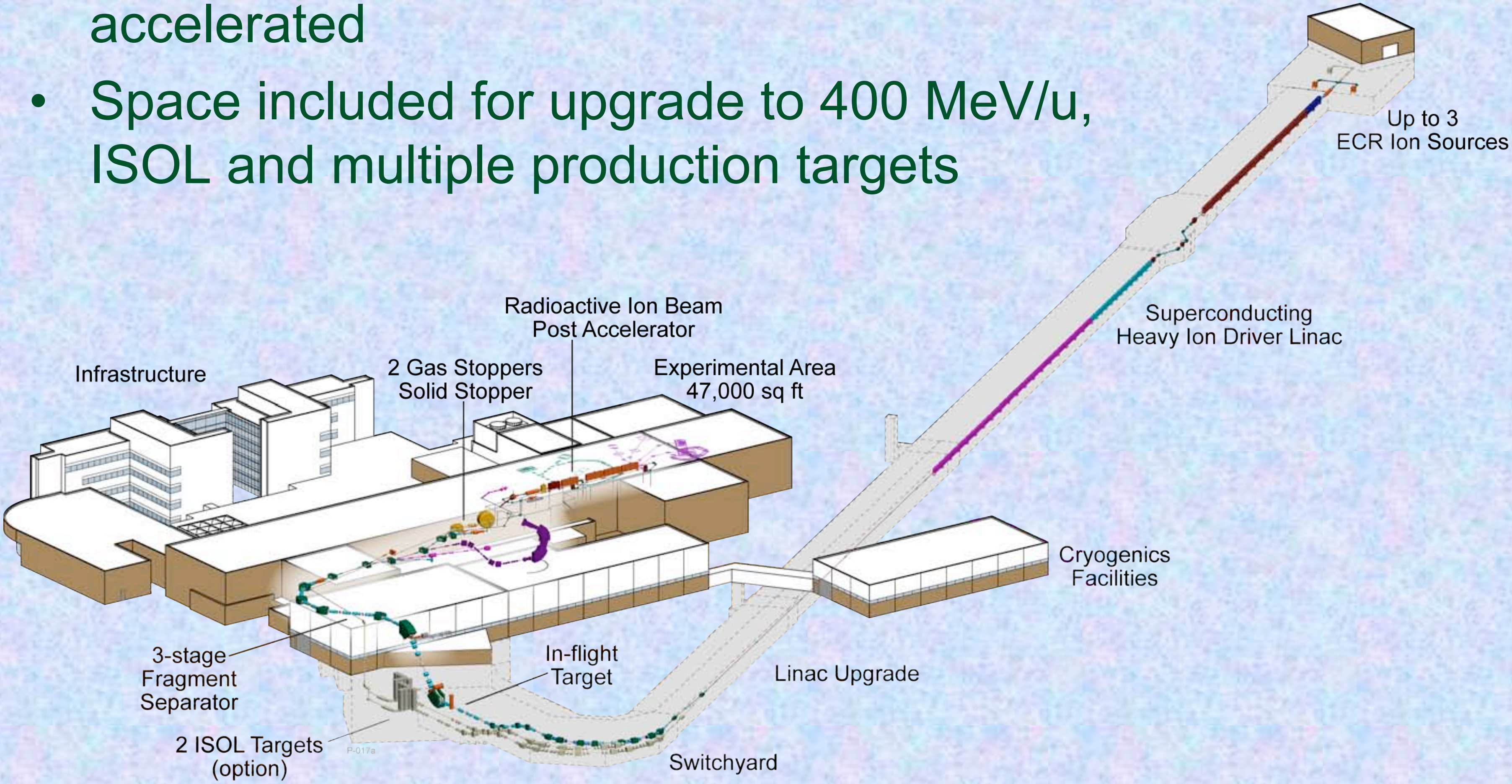
Particle	MeV/A	pnA
16O	150	125
18O	120	125
22Ne	120	80
24Mg	170	30
36Ar	150	50
40Ar	140	50
40Ca	140	22
48Ca	90	15
48Ca	110	15
48Ca	140	80
58Ni	140	5
58Ni	160	20
64Ni	140	7
76Ge	13	20
78Kr	150	25
86Kr	100	10
86Kr	140	20
96Zr	120	1.5
112Sn	120	3
118Sn	120	1.5
124Sn	120	1.5
124Xe	140	10
136Xe	120	2
208Pb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

ReA3 – concept and overview



FRIB General Features

- Driver linac with 400 kW and greater than 200 MeV/u for all ions
- Ions of all elements from protons to uranium accelerated
- Space included for upgrade to 400 MeV/u, ISOL and multiple production targets



AT-TPC Program& Collaborators

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

Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)	Scientific Leader
Transfer & Resonant Reactions	Nuclear Structure	^{32}Mg(d,p)^{33}Mg ^{26}Ne(p,p)^{26}Ne	3	100	Kanungo
Astrophysical Reactions	Nucleosynthesis	^{25}Al(^{3}He,d)^{26}Si	3	100	Famiano
Fusion and Breakup	Nuclear Structure	^{8}B+^{40}Ar	3	1000	Kolata
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000	Phair
Giant Resonances	Nuclear EOS, Nuclear Astro.	^{54}Ni-^{70}Ni, ^{106}Sn-^{127}Sn	50 - 200	50,000	Garg
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000	Bickley

Lawrence Berkeley National Laboratory: I.Y. Lee, L. Phair

Lawrence Livermore National Laboratory: M. Heffner

University of Notre Dame: U. Garg, J. Kolata

Michigan State University: A. Bickley, W. Lynch, W. Mittig, F. Montes, G. Westfall

Saint Mary's University (Canada): R. Kanungo

Western Michigan University: M. Famiano