THE ACTIVE TARGET
TIME PROJECTION
CHAMBER
AT NSCL

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Solid targets provide poor luminosity

- Inverse kinematics reactions in solid targets (probe)
- Target-like particle has little energy to leave target material
- Compromise between resolution and number of nuclei in target (resolution goes against luminosity)
Luminosity with slow radioactive beams

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  - **Inverse kinematics reactions in solid targets** *(probe)*
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- **New approach: active target + time projection chamber**
  - **Target no longer inert material, but used also to detect particles**
  - **Gas target ideal for low energies**
  - **Time Projection Chamber tracks particles from the vertex of the reaction** *(no lost energy in inert target)*
Active Target Time Projection Chamber

- A detector tailored to low energy reactions
  - Active gas target and full $4\pi$ angular coverage
  - High luminosity without loss of resolution
  - Beam slowing in gas gives excitation function
Active Target Time Projection Chamber

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- Requirements and restrictions
  - Target gas has to provide good electron amplification (mixtures)
  - Trigger generation: slowing down beam particle ionize the gas
  - Time projection chamber is slow (rate limitation)
Active Target Time Projection Chamber

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- Very well adapted to rare isotope beams!
Principle of operation

Insulator gas volume ($N_2$)

Field shaping rings

Cathode: - 100 kVDC (1kV/cm)

Active gas volume
$\text{He, H}_2, \text{D}_2$...

Pad plane and electron amplification device (Micromegas)

Position $\rightarrow (x, y)$

Drift time $\rightarrow z$
AT-TPC concept

- Straight and tilted (7°) configurations
- Tilt relative to beam axis to increase accuracy for small angles
- Placed inside 2 Tesla solenoid (increase range and measure Brho)
- 250 liters (1 m by 55 cm) active volume
Detector details

- Based on prototype design with few improvements
Detector installation & servicing
Electron amplifier: Micromegas

- Negligible charge spread, sharp images
- Very robust against sparking
- Can operate in different conditions (gases, pressures)
Close-up on Micromegas
10,240 pad plane geometry

- Optimized for detector inclinations from 0° to 7° relative to beam axis
- 4 small triangles in a large one
- Small triangle side = 4.67 mm
- 55 cm diameter disk
Digital Readout Electronics

- Accommodate electronics for the 10,240 pads without cable connections
- 40 front-end cards fit in pentagonal pattern
- Shielding covers electronics cards by pairs
- Only 7,000 channels instrumented (3 receiver cards on loan in France)
GET (General Electronics for TPCs)

- Trigger needs to filter out unreacted beam events
- GET electronics provides discriminators on each pad
- Running multiplicities of each AsAd routed to MuTanT through CoBos
- Trigger configuration can be programmed
- AGET front-end chips provide various gains and shaping times
- GET: CEA-Saclay, CENBG-Bordeaux, GANIL-Caen, NSCL
Example of reconstructed event

- Track from alpha source placed inside the active volume
Example of reconstructed event

- Track from alpha source placed inside the active volume
- 3D plot clearly show time correlation
Example of reconstructed event

- Track from alpha source placed inside the active volume
- 3D plot clearly show time correlation
- Individual traces show difference in amplitude between small and large pads
Trigger generation

- Define pad regions with different trigger attributes
- Example shows configuration for elastic scattering
- More complex pattern triggering configuration can be programmed

- Pad not connected
- Trigger enabled
- Reading if hit
- Trigger disabled
- Reading always
Commissioning on ReA3 linac

- Beam provided: $^4\text{He}$ @ 6 MeV
- Gas target: He (90%) CO$_2$ (10%) 100 Torr
- No magnetic field
- Measure excitation function of ($^4\text{He},^4\text{He}$) elastic scattering
Online event display

- Atypical event shows two scattering events in one shot
- Maximum drift time of 40 µs
- Instantaneous beam rate of ~3 kHz (600 Hz @ 20% duty cycle)
Experimental program with PAT-TPC

- Alpha cluster structure of neutron-rich nuclei
  - Resonant scattering: $^6\text{He} + ^4\text{He}$, $^{10}\text{Be} + ^4\text{He}$, $^8\text{He} + ^4\text{He}$ (not yet): TWINSOL @ U. of Notre-Dame, ISAC @ TRIUMF (not yet)

- Fusion cross section studies
  - $^6\text{He} + ^{40}\text{Ar}$ sub-barrier fusion cross sections: TWINSOL @ U. of Notre-Dame

- Isobaric analog proton scattering
  - Test on $^{124}\text{Sn} + p$, experiment on $^{132}\text{Sn} + p$ (not yet): ATLAS @ Argonne National Laboratory

- $3\alpha$ decay mode of Hoyle state in $^{12}\text{C}$
  - $\beta$-decay of $^{12}\text{B}$ implanted in PAT-TPC: TWINSOL @ U. of Notre-Dame

6He + 4He scattering

- Missing mass reconstruction
- $E_x$ from TKE, scattering angle of $^4$He and energy of $^6$He
- Energy of $^6$He before reaction known from vertex determination
- $E_x^\theta$ from angles only
- $2^+$ scatter in $E_x^\theta$ from $^6$He($^4$He,2n)$^8$Be channel

Excitation functions & Angular distributions

- Elastic and inelastic scattering measured between 2 and 6 MeV
- Angular distributions measured between 40° and 130°
- Peak at 2.56 MeV corresponds to 9.98(15) MeV resonance in \(^{10}\)Be, identified as \(4^+\)
- Deduced partial width \(\Gamma_\alpha/\Gamma\) of 0.49(5) indicate highly developed \(\alpha\) structure

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Original AT-TPC scientific program

- National Science Foundation funding of $688k
- Exciting physics program planned and to develop!

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

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<th>Measurement</th>
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<th>Beam Examples</th>
<th>Beam Energy (A MeV)</th>
<th>Min Beam (pps)</th>
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<td>Transfer &amp; Resonant Reactions</td>
<td>Nuclear Structure</td>
<td>$^{25}$Mg($d,p$)$^{25}$Mg, $^{26}$Ne($p,p$)$^{26}$Ne, $^{66}_{68-70}$Ni($p,p$)</td>
<td>3</td>
<td>100</td>
<td>Kanungo</td>
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<tr>
<td>Astrophysical Reactions</td>
<td>Nucleosynthesis</td>
<td>$^{25}$Al($^{3}$He,$d$)$^{26}$Si</td>
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<td>Fusion and Breakup</td>
<td>Nuclear Structure</td>
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<td>Transfer</td>
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<td>5-19</td>
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<td>Fission Barriers</td>
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<td>Giant Resonances</td>
<td>Nuclear EOS, Nuclear Astro.</td>
<td>$^{54}$Ni-$^{106}$Sn, $^{127}$Sn</td>
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<td>Garg</td>
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<td>Heavy Ion Reactions</td>
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<td>$^{106}$Sn - $^{120}$Sn, $^{37}$Ca - $^{49}$Ca</td>
<td>50-200</td>
<td>50,000</td>
<td>Lynch</td>
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</table>
AT-TPC team and collaboration

- NSCL team of 10 people
  - Faculty: D. Bazin, W. Mittig, B. Lynch
  - Engineers: N. Usher, F. Abu-Nimeh
  - Post-docs: D. Suzuki (until 2012), T. Ahn, S. Beceiro-Novio
  - Ph.D. students: A. Fritsch, J. Bradt

- Outside collaborators
  - J. Kolata, U. Garg (U. of Notre-Dame)
  - F. Bechetti (U. of Michigan)
  - R. Kanungo (Saint Mary’s U.)
  - M. Heffner (LLNL)
  - I-Yang Lee, L. Phair (LBL)