AT-TPC Tracking Software and Detector Development

Clementine Santamaria (NSCL)

January 17th, 2018
Active Target of 1 m length, 55 cm diameter
- Thick target, good resolution, $4\pi$ detection
- MicroMegas detection pad plane
- 10,240 pads, equilateral triangles
- GET electronics with internal trigger
- Coupling with magnetic field

Resolution capabilities
- Scattering angle = 1° for ($\alpha$, $\alpha'$)
- Energy resolution of 30-40 keV/u in c.m. despite phasing issues
GET ELECTRONICS

★ 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
Define pad regions with different trigger attributes

Example shows configuration for elastic scattering

More complex pattern triggering can be programmed
NSCL
Stable beam commissioning of the AT-TPC (D. Bazin): $\alpha + \alpha$ scattering
Commissioning of the AT-TPC with radioactive beam (D. Bazin): $^{46}$Ar experiment
Capture cross sections and fusion barrier measurements with the AT-TPC (S. Beceiro-Novo)
Fusion with neutron-rich rare isotope beams (S. Beceiro-Novo)
Measurement of the fission barriers for heavy exotic nuclei (Z. Chajecki)
Direct measurement of a key reaction for the rp-process with the AT-TPC (Y. Ayyad)
Spectroscopy of chlorine isotopes at the proton-drip line (R. Kanungo)
Death of first stars. Measurement of ANC of $^{12}$N(p,g)$^{13}$O relevant for the rap process (J. Pereira)

Notre Dame (pAT-TPC)
$^{10}$Be+$\alpha$ (D. Suzuki) + higher energy (3-body analysis)
$^{10}$Be + $^{40}$Ar fusion barrier (J. Kolata)
  F.D. Bechetti et al., NIM B 376, 397 (2016)
$^{12}$C Hoyle state decay
$^{10}$C + $\alpha$, mirror of $^{10}$Be

TRIUMF (pAT-TPC)
Investigation of nuclear forces, nucleon correlation and resonances in $^{8}$He (R. Kanungo)
$^{8}$He+$\alpha$
Search for cluster structures in $^{16}$C through resonant alpha scattering (Y. Ayyad, W. Mittig)

LBNL (pAT-TPC) => Campaign in Spring 2018 ?

RCNP (AT-TPC)
$^{17}$C (d,p) (B. Fernandez Dominguez)
★ Commissioning in December 2014
- Beam: $^4\text{He}$ at 3 MeV/u
- Target: He(90%) + CO2(10%) @ 100 torr
- Magnetic field: 1 Tesla

★ Event displays
- Right: hit pattern on pad plane, **orange region** is trigger exclusion zone
- Top Left: integrated time projection
- Bottom Left: 3D reconstruction of the event
7° tilt angle creates time-position correlation for the beam

Track reconstruction more complex as B and E field not aligned
Two analysis frameworks developed in parallel:
  • ATTPCROOT (C++, ROOT, and FairROOT)
  • pyTPC (Python)

Provides tools for analysis & simulation in the same framework:
  • Merger of raw data taken by GET electronics (hdf5 or ROOT files)
  • Pulse Shape Analysis of signals on pads + calibration (time, charge)
  • Transforms (Hough, RANSAC…) to distinguish tracks & get starting points for the fitting procedure
  • Fitter (MC fitting) to get final parameters for the tracks

Development of cross-platform libraries INDEPENDENT of framework
Maintenance of those libraries by the AT-TPC group, with the availability to use the 2 frameworks (no maintenance for them)
High Energy Physics
- Many tracks
- Tracks leave volume
- Constant curvature

AT-TPC
- Few tracks
- Tracks stop in volume
- Changing curvature
- Tracking protons to fission products
- With & without B field
**FairSoft**

★ All the necessary packages collected to run FairRoot
★ Designed to be installed on both Linux and OS X
★ Included packages:
  ★ gtest, gsl, boost, Pythia6, Pythia8, HepMC, GEANT3, GEANT4, XRootD, Pluto, ROOT, VGM, VMC, Millepede, ZeroMQ, Protocol Buffers, nanomsg
  ★ RAVE, CLHEP, and GENFIT2 packages added for SπRITROOT

**FairRoot**

★ A framework containing base classes for running simulation, reconstruction and analysis

**ATTPCROOT**

★ Based on the SπRIT analysis framework SpiRITROOT
★ A framework containing specific modules for AT-TPC experiment on top of FairRoot
★ Composed of task-based modules, TGeo geometry and steering macro
★ Written by following the structure of FOPIROOT

ATTPCROOT: A TASK BASED MODULE

★ Easy to turn on and off
★ Analysis separated in steps
★ Easy to debug and maintain

Task

In
- ASCII
- GRAW
- ROOT
- An object on memory (TClonesArray*)

Out
- ROOT
- An object on memory (TClonesArray*)

*TClonesArray is a container class provided in ROOT which can be stored in ROOT file.
Experimental Data Flow

Simulation Data Flow

1. MC Generation
2. Digitization
3. Reconstruction
4. Analysis
**Initial fit of tracks**
- Hough transform for lines (without B field) and for circles (with B field)
- RANSAC= RANdom SAmple Consensus algorithm for line detection
- Hierarchical clustering
- 3D Hough Transform
- Neural network ?

**Final fit of the tracks**
- Monte Carlo iterative procedure to correctly fit the tracks
- Starting point of the parameters from the initial fit
2D Hough transform
Real space line ↔ Hough space (ρ,θ) point

<table>
<thead>
<tr>
<th>ρ</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ₁</td>
<td>θ₁</td>
</tr>
<tr>
<td>ρ₂</td>
<td>θ₂</td>
</tr>
<tr>
<td>ρ₃</td>
<td>θ₃</td>
</tr>
<tr>
<td>ρ₄</td>
<td>θ₄</td>
</tr>
<tr>
<td>ρ₅</td>
<td>θ₅</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ρ</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ₆</td>
<td>θ₆</td>
</tr>
<tr>
<td>ρ₇</td>
<td>θ₇</td>
</tr>
<tr>
<td>ρ₈</td>
<td>θ₈</td>
</tr>
<tr>
<td>ρ₉</td>
<td>θ₉</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ρ</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ₁₀</td>
<td>θ₁₀</td>
</tr>
<tr>
<td>ρ₁₁</td>
<td>θ₁₁</td>
</tr>
<tr>
<td>ρ₁₂</td>
<td>θ₁₂</td>
</tr>
<tr>
<td>ρ₁₃</td>
<td>θ₁₃</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ρ</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ₅</td>
<td>θ₅</td>
</tr>
<tr>
<td>ρ₅</td>
<td>θ₅</td>
</tr>
<tr>
<td>ρ₅</td>
<td>θ₅</td>
</tr>
</tbody>
</table>
Random sample consensus (RANSAC):

- iterative method
- estimate parameters of a mathematical model
- from a set of observed data that contains outliers (noise)

- sample subset chosen at random
- fitting model computed
- algorithm checks which elements are outliers from a threshold applied
**Goal**

find tracks without assumption of particular shape:


**Problem formulation**

Almost a classic clustering problem:

- partition points into tracks (= clusters)
- however:
  - points at collisions belong to more than one track
  - additional cluster “noise” (disjoint from other clusters)

Reformulation as a clustering problem:

① transform points into triplets
  - group of three points representing a line segment
  - points in same triplet approximately collinear
  - one point can belong to several (or no) triplets

② cluster these triplets instead of original points

③ points not in grouped triplets are noise
Rough idea

Triplet idea inspired by Lezama et al., 2017
• devised for 2D locally equidistant point patterns
• searches shortest path in weighted triplet graph

Our algorithm is different and consists of the steps:
① smooth points by averaging
② find somewhat collinear triplets
③ hierarchical clustering
   (parameters: triplet distance & cutoff threshold)
④ remove too small clusters

Lezama et al.: An Unsupervised Algorithm for Detecting Good Continuation in Dot Patterns. IPOL 7 (2017), pp. 81–92
Preliminary results

- every color in visualization represents a detected cluster
- red points have been classified as noise
- Implementation with ATTPCROOT
- Testing of $^4$He+$^4$He scattering data
- Comparison with Hough and RANSAC

Christoph Dalitz, Lukas Aymans, Jens Wilberg
Right: Sample event from $^{46}$Ar run, result of the MC fit with line, proton energy reconstructed at 2.081 MeV with a scattering angle of 63.5° (lab frame)
Bottom Left: Monte Carlo fitted energy for proton track with respect to iteration
Bottom Center: $\chi^2$ energy fit, we can distinguish proton from carbon scattering

★ Single electron detection (delayed decay such as 2p disintegration)

★ Dual gain on pads to measure light particles and heavier nuclei
★ MicroMegas Th-GEM detector for higher gains
★ $^3$He gas, CD$_4$ gas in future TPC experiments
PAT-TPC UPGRADE

- new pad plane
- ~2000 pads
- triangular pads
- better granularity
- smaller radius than AT-TPC
- coupling to other detectors
★ smaller TPC (200 mm diameter)
★ smaller drift time
➡ Higher count rates
★ Exit window possible in the design for higher beam energies
★ Different pad plane orientation for beam tracking
★ Coupling with gamma detection & neutron detection
★ example: (d,n) reactions
SUMMARY

★ ATTPCROOT in development using SpiRITROOT as basis
★ PyROOT development in parallel
★ Independent libraries for cross-platform programming
★ Upgrade of the pAT-TPC
★ New TPC design for the future
★ Physics campaigns at LBNL, NSCL, RCNP => Y. Ayyad