ACTAR TPC
Nuclear structure through transfer reactions

Past: structure of nuclei close to stability in direct kinematics, use of magnetic spectrograph

- Good resolution (few keV)
- High beam intensity
- Stuck with stable isotopes from which a target can be made

J.E. Spencer and H.A. Enge, NIM 49, 181 (1967)
Now: structure of exotic nuclei in inverse kinematics

- Study of nuclei with short half-life
- Low beam intensity
- Resolution strongly depends on target thickness

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J.S. Thomas et al., PRC 71, 012302 (2005)

Detector(s)

\[ {}^{29}\text{Si} \rightarrow {}^{28}\text{Si} + p \]

\[ {}^{83}\text{Ge} \rightarrow {}^{82}\text{Ge} + p \]

100 keV FWHM
80 \( \mu \)g/cm\(^2\)

J.C. Lighthall et al., NIM A 622, 97 (2010)

300 keV FWHM
430 \( \mu \)g/cm\(^2\)

J.S. Thomas et al., PRC 71, 012302 (2005)

Need thick targets and excellent resolution
Now: ACTIVE TARGETS

- Study of nuclei with short half-life, produced with small intensity
- Use of thick target without loss of resolution
- Detection of very low energy recoils

Active target: (Gaseous) detector in which the atoms of the gas are used as a target
Gas-filled active target and time projection chamber
- Gas = detector AND target
- Vertexing = resolution similar to thin solid target
- High effective thickness = up to $10^3$ higher

Major advantages over conventional approaches
- Detection efficiency close to $4\pi$
- Detection of low energy recoils (that stop inside the target)
- Event-by-event 3D reconstruction
- Compact, portable and versatile detector

Physics programs
- Resonant scattering
- Inelastic scattering and giant resonances
- Transfer reactions
- Rare and exotic decays ($2p$, $\beta 2p$, …)
- Transfer-induced fission, …

Detection challenge:
- Choice of the gas driven by the physics case
- High detection dynamics (up to 1000)
ACTAR TPC : Design

- Drift region
- Amplification region
- Segmented pad plane
- Electronics
- Auxiliary detectors
Drift region: principle

- Particles ionize the gas along their trajectories
- Ionization electrons drift to pad plane under a homogeneous electric field
- Transparent to particles on 4 sides
  → Wire field cage
- Homogeneous vertical drift electric field
  → Double wire field cage: 2 mm pitch (outside), 1 mm pitch (inside)
  → Optical transparency = 98 %
Drift region

Amplification region: principle
- Micro Pattern Gaseous Detectors: bulk micromegas (CERN PCB workshop)
- Operate at \( P = 75 \text{ mbar} - 1 \text{ bar} \): gap = 220 \( \mu \text{m} \). Homogeneity measured with \(^{55}\text{Fe}\) source scan
- Local gain reduction via pad polarization: detection dynamic range > 300

\[ T. \text{Roger et al.}, \text{NIM A}895, \text{126 (2018)} \]

\[ B. \text{Mauss et al.}, \text{EPJ Web Conference 174, 01010 (2018)} \]
ACTAR TPC : Design

✓ Drift region
✓ Amplification region: principle
✓ Segmented pad plane
  • Micromegas (CERN PCB WS) → transverse multiplicity ≈ electron straggling: 2x2 mm² pads
  • 16384 pads with very high density: connectics challenge!
  • + pad plane makes the vacuum / atmosphere interface

Multi-layer PCB routing solution :
P. Gangnant/M. Blaizot-GANIL
JST Connectors, 0.5 mm pitch

FAKIR solution : J. Pibernat-CENBG

J. Giovinazzo et al., NIM A892, 114 (2018)
ACTAR TPC : Design

✓ Drift region
✓ Amplification region: principle
✓ Segmented pad plane

Multi-layer PCB routing solution : P. Gangnant/M. Blaizot-GANIL
✓ nominal sparking voltage
✓ no leak
✗ 5 % pads grounded (PCB problem)

FAKIR solution : J. Pibernat-CENBG
✓ 100 % pads OK
✗ air leaks detected, problems with 3M connectors soldering (need vacuum soldering)
✗ sparking voltage too low

Courtesy J. Giovinazzo

Courtesy O. Pizzirusso
ACTAR TPC: Design

- Drift region
- Amplification region: principle
- Segmented pad plane
- Electronics
  - Very front end sparking protection circuit: ZAP boards, kapton flex circuit
  - Pads equipped with GET electronics:
    - 512 samples ADC readout depth x 16384 pads = volume sampling in 8 Mega voxels
    - adjustable gain, peaking time, individual trigger: pad per pad

E.C. Pollacco et al., NIM A887, 81 (2018) - design
J. Giovinazzo et al., NIM A840, 15 (2016) - analysis
ACTAR TPC : Design

$^{18}\text{O} (\text{beam}) + ^{12}\text{C} (\text{iC}_4\text{H}_{10} \text{ target gas})$
ACTAR TPC : Design

✓ Drift region
✓ Amplification region: principle
✓ Segmented pad plane
✓ Electronics
✓ Auxiliary detectors
  • Configurable flange design
ACTAR TPC : Design
✓ Commissioning of the 128x128 pad full detector

$^{18}$O(p,p) and $^{18}$O(p,\(\alpha\)) excitation functions: → 3.2\(A\) MeV $^{18}$O beam in 100 mbar iC$_4$H$_{10}$

✓ Resolution in c.m. energy determination: 38 keV (FWHM): dominated by the angular straggling of the ions

✓ 20 kHz beam

✓ Detection dynamics > 100

B. Mauss, et al., submitted to NIM A
ACTAR TPC : First experiments

✓ Study of the Giant Monopole Resonance in the Ni chain (April 2019)

\[^{58,68}\text{Ni}(\alpha,\alpha') \rightarrow 49A\text{ MeV}^{58,68}\text{Ni} \text{ beams in } 400\text{ mbar He(98%) + CF}_4(2%)\]

- Helium gas
- 50 kHz beam
- Observation of 200 keV \(\alpha\)

Courtesy B. Mauss & M. Vandebruuck
Proton-decay branches from the $10^+$ isomer in $^{54}\text{Ni}$ (May 2019)

$^{54}\text{Ni}$ implantation – proton decay: $\rightarrow 10\,\text{MeV}^\ast\text{Ni beam in 900 mbar Ar(95\%) + CF}_4(5\%)$

- Implantation of fragmentation beam
- Simultaneous observation of Ni track ($6\,\text{MeV/pad}$) and proton tracks ($60\,\text{keV/pad}$)
Conclusion

✓ ACTAR TPC is a versatile and portable device for nuclear physics studies
   → can be operated with a large variety of gases and a large range of pressure

✓ Few problems identified on the pad plane
   → technical solutions exist (for both multi layer PCB & FAKIR solutions)
   and will be applied in the near future

✓ The detector was successfully commissioned and was used for 2 nuclear physics experiments this year

✓ It will be upgraded to extend its capabilities (use of higher intensity beams, detection of electrons, ...)

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