Probing ^{11}Be Structure with Transfer Reactions in the AT-TPC

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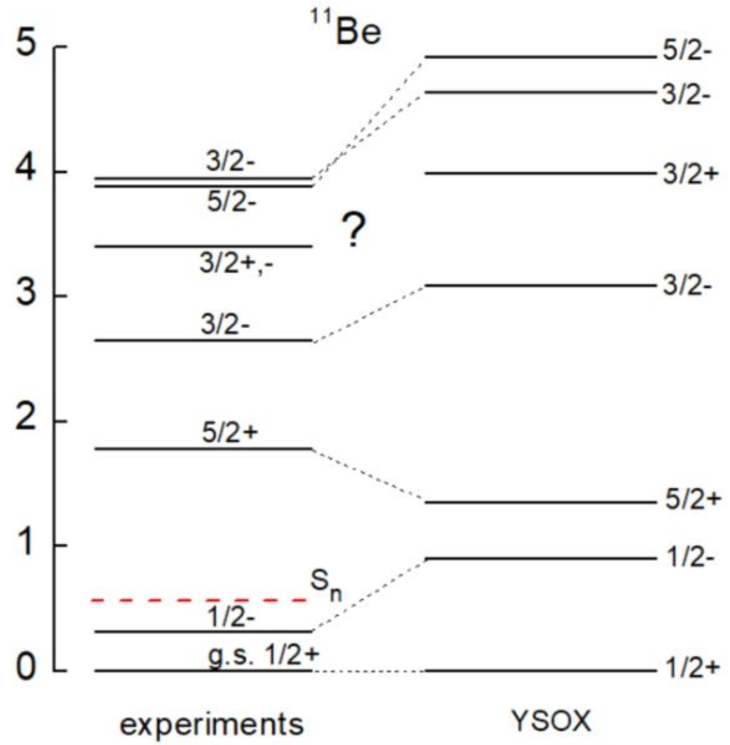
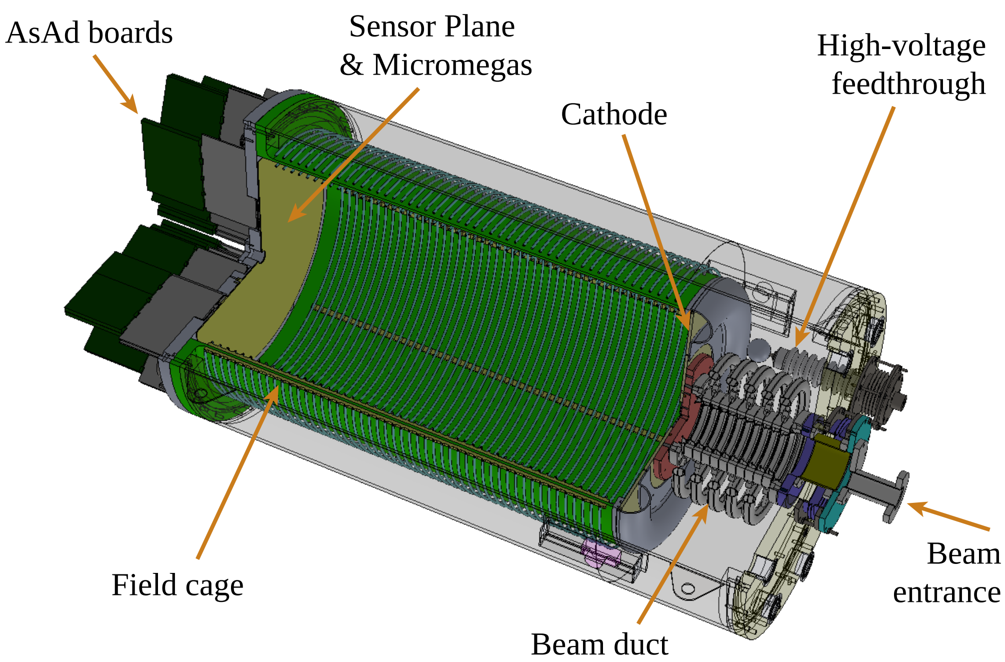
Motivation

- Experiments disagree on parity of fourth excited state with J = 3/2 at 3.40 MeV
- <u>Physics goal</u>: determine the parity of this state from its angular distribution
- <u>Experimental goal</u>: demonstrate capability to measure transfer reactions in inverse kinematics in AT-TPC
  - Have since measured ^{6}C+d, ^{16}C+p, ^{15}C+d, ^{15}C+p, ^{12}Be+p, and ^{7}Be+d at around 12 MeV/u



AT-TPC

- **A**ctive **T**arget – **T**ime **P**rojection **C**hamber
- 250 liters (1 m long by 55 cm wide)
- Oriented on beam axis
- Electrons produced in gas drift towards sensor plane perpendicular to beam
- Central beam region blind from reduced electron gain or hole in pad plane depending on experiment



SOLARIS solenoid

- AT-TPC placed inside large-bore MRI solenoid
- SOLARIS solenoid can go up to 4 Tesla
- Curve trajectories of scattered particles
  - Increase their trajectory length and measure their range
  - Measure their magnetic rigidity

^{10}Be(*d*,*p*) in the AT-TPC

- ^{10}Be beam from the ReA6 linac
  - Energy of 9.6 MeV/u
  - Rate of ≈ 1-2k Hz
  - Contamination of ^{10}B and ^{15}N
- AT-TPC filled with 600 Torr of pure deuterium gas
- SOLARIS solenoid set to 3 Tesla
- Small ion chamber placed upstream of the AT-TPC
- Trigger set on mesh signal with signal suppression in beam region
- Ran for 120 hours

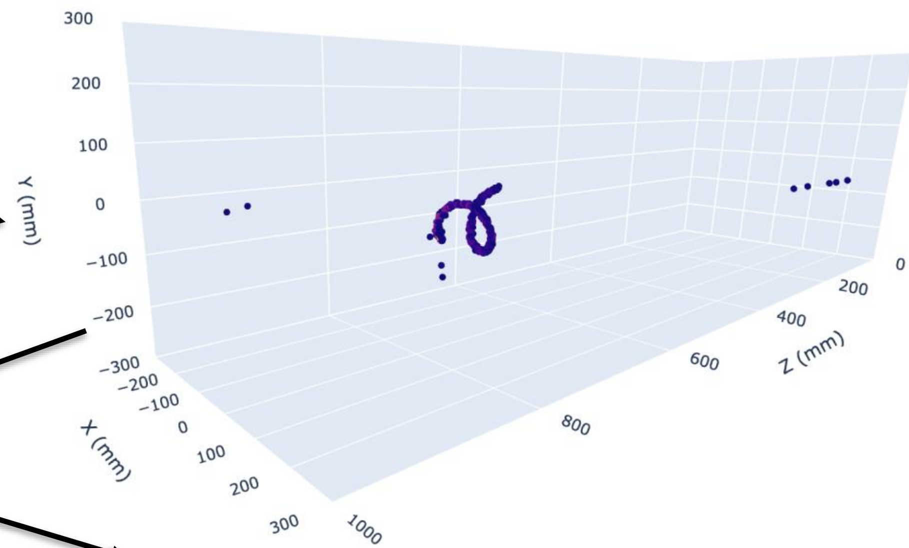
AT-TPC analysis with Spyral

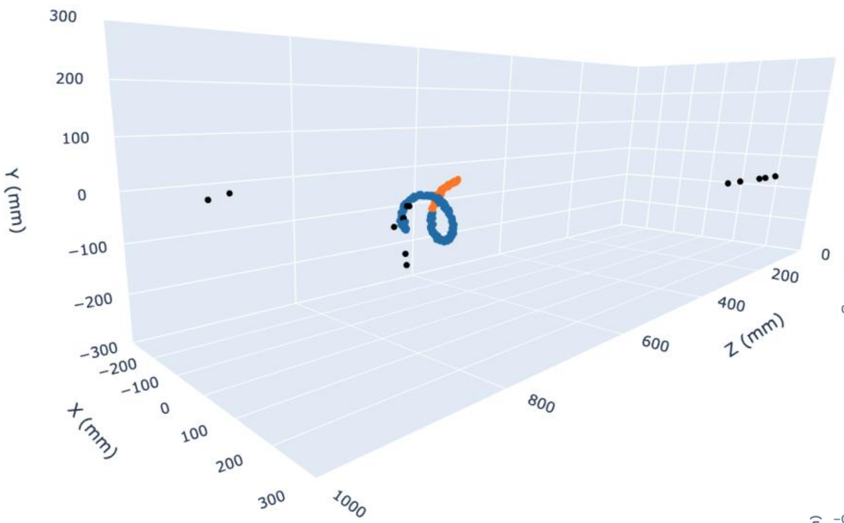
- Newly developed Python AT-TPC analysis package
  - Designed by local FRIB AT-TPC group, spearheaded by postdoc Gordon McCann
- Highlights:
  - Installable Python package
  - Flexible pipeline design
  - Cross-platform
  - Parallelized to analyze large datasets
  - Comprehensive documentation

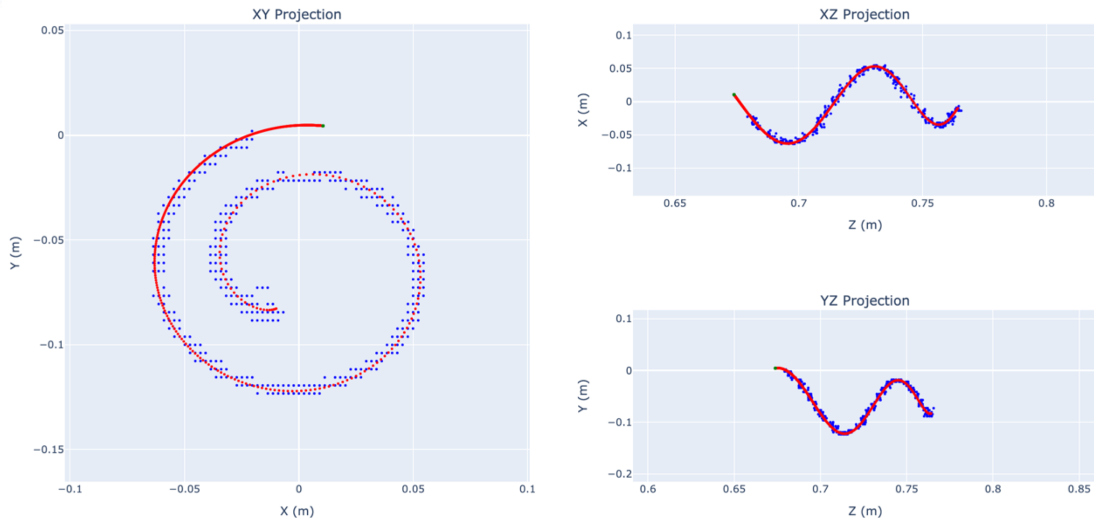
https://github.com/ATTPC/Spyral

AT-TPC analysis with Spyral

1298	324	407	404	401	405	406
1834	307	374	377	378	377	377
446	310	355	354	357	356	358
150	246	297	294	297	297	299
738	341	395	389	390	389	391
3074	379	465	468	470	461	460
3071	262	348	348	350	346	347
2599	269	342	341	339	343	339
1839	235	303	302	299	301	303
149	311	355	356	359	357	355







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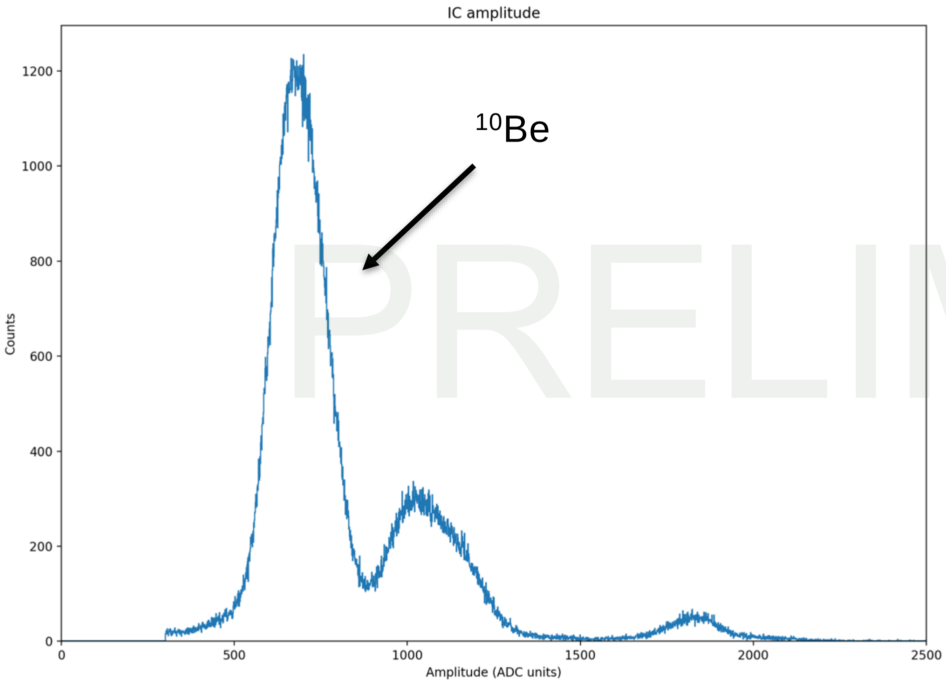
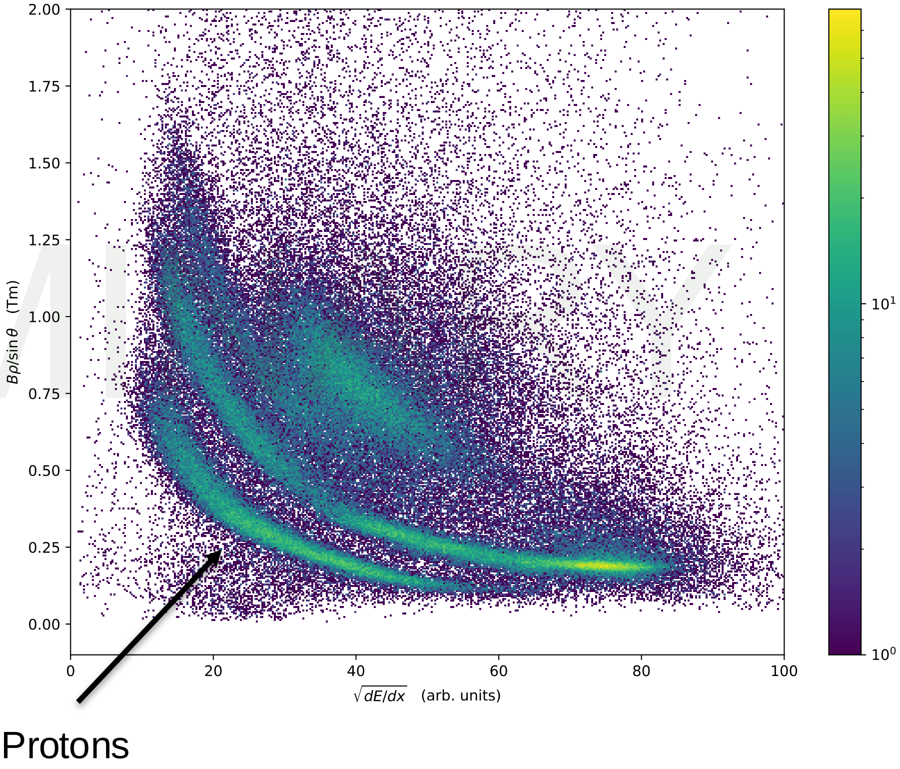
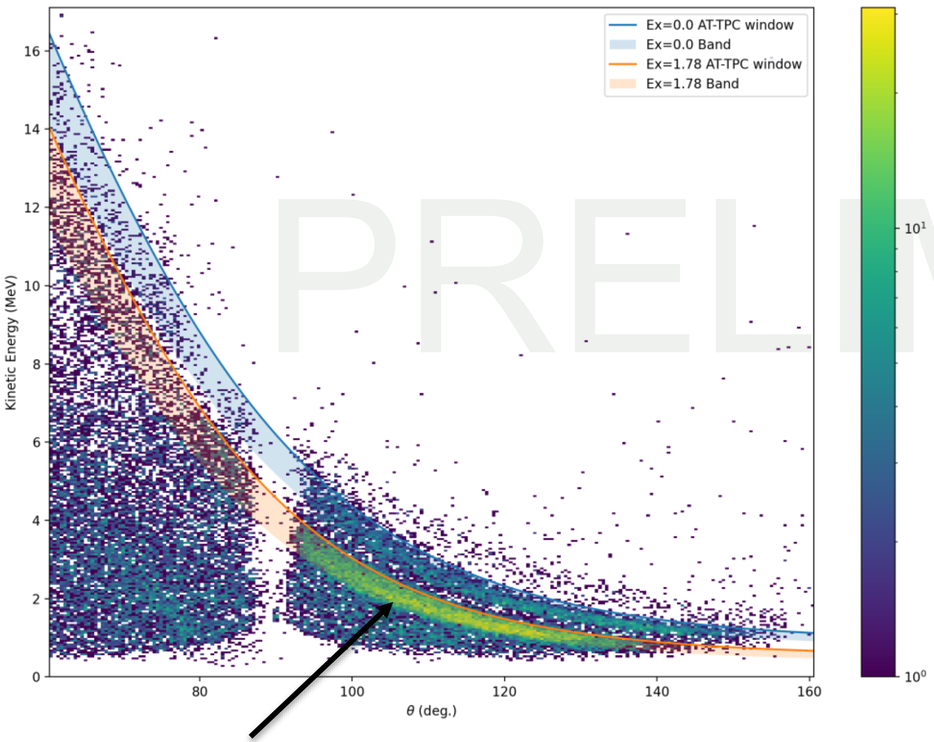
Reaction channel selection

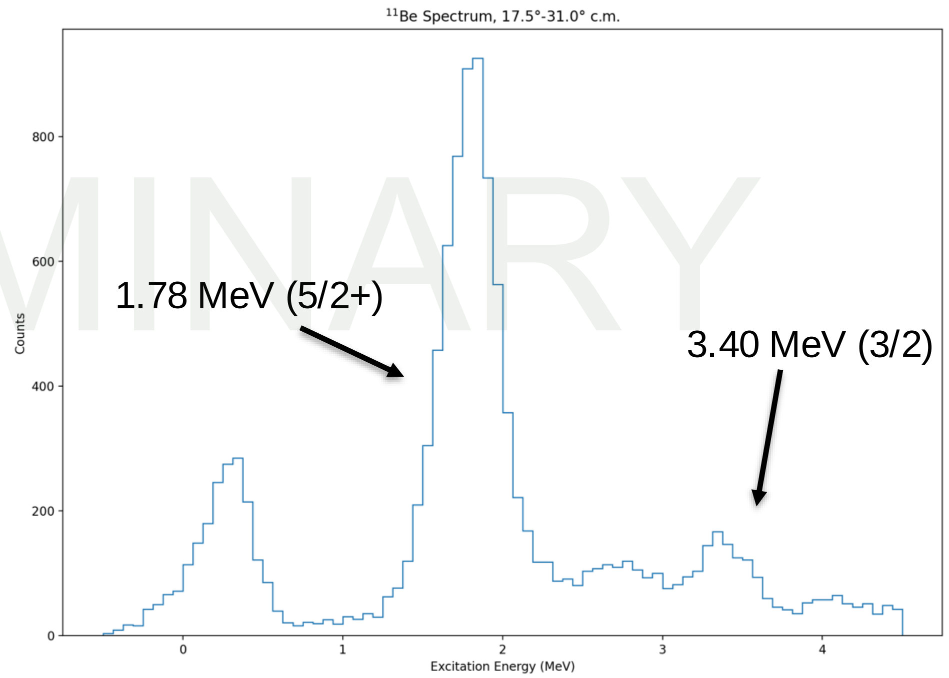
- Based on identification of incoming beam particle from IC
- Identification of target residue using Bρ and energy loss





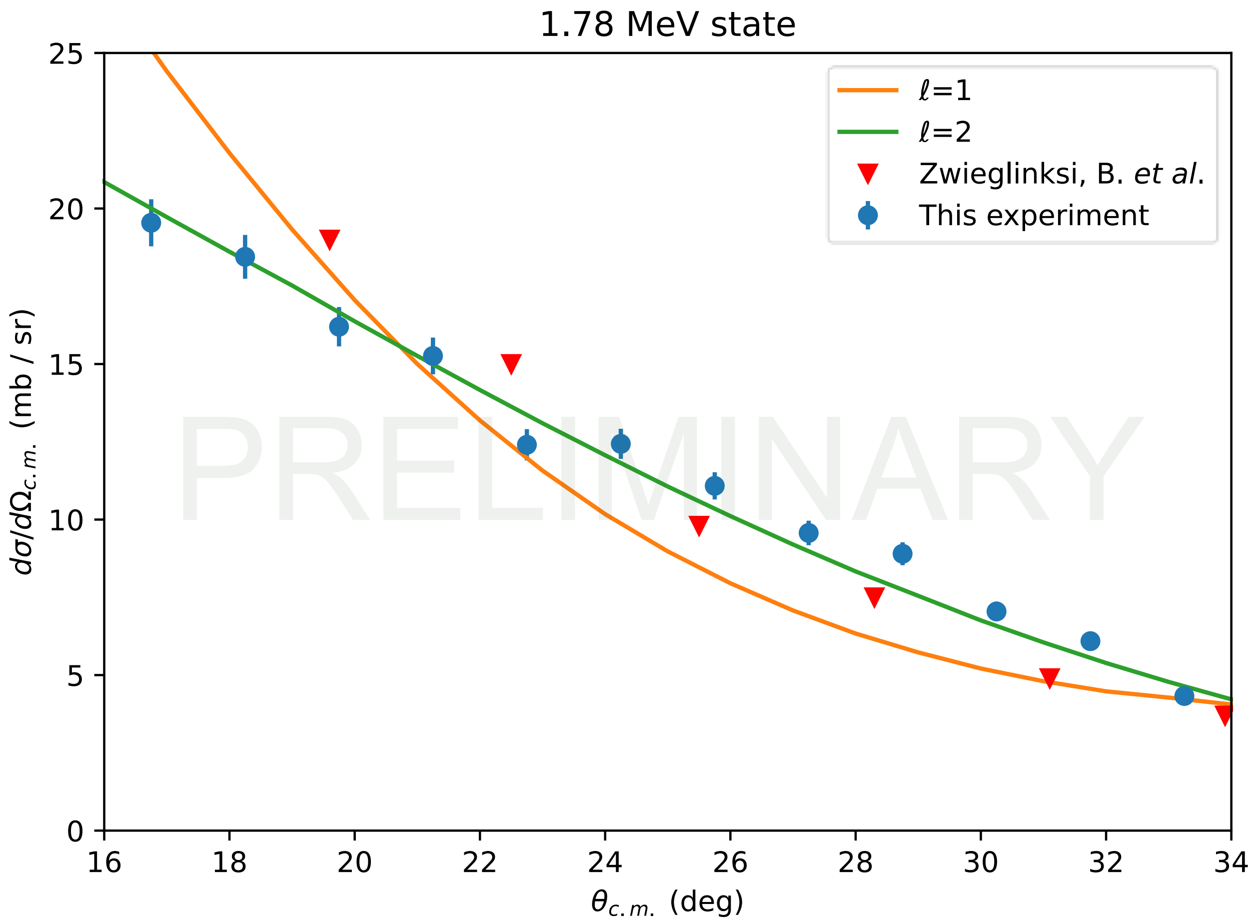
^{10}Be(d,p)





1.78 MeV (5/2+)

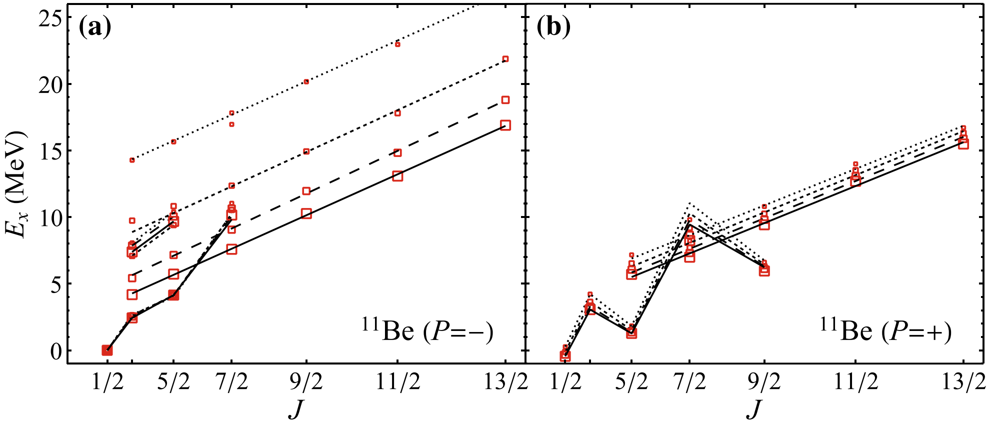
^{10}Be(d,p) angular distributions



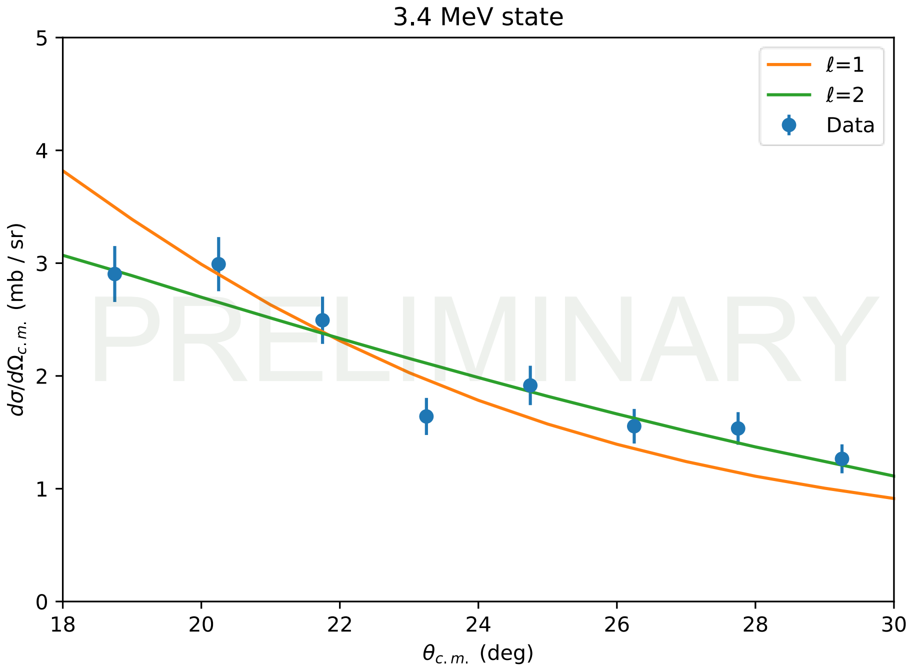
Zwieglinski, B. *et al.* Study of the ^{10}Be(d, p)^{11}Be reaction at 25 MeV. *Nuc. Phys. A* **315**, 124 (1979)

^{10}Be(*d*,*p*) angular distributions

- No-core shell model ab initio calculations of 3.4 MeV state by M. Caprio *et al*. show rotational structure
- If $J^\pi=3/2^-$, predicted to be rotational band head
- If $J^\pi=3/2^+$, predicted to be rotational “halo” band member



Caprio, M. A. *et al.* Probing *ab initio* emergence of nuclear rotation. *Eur. Phys. J. A* **56**, 120 (2020)



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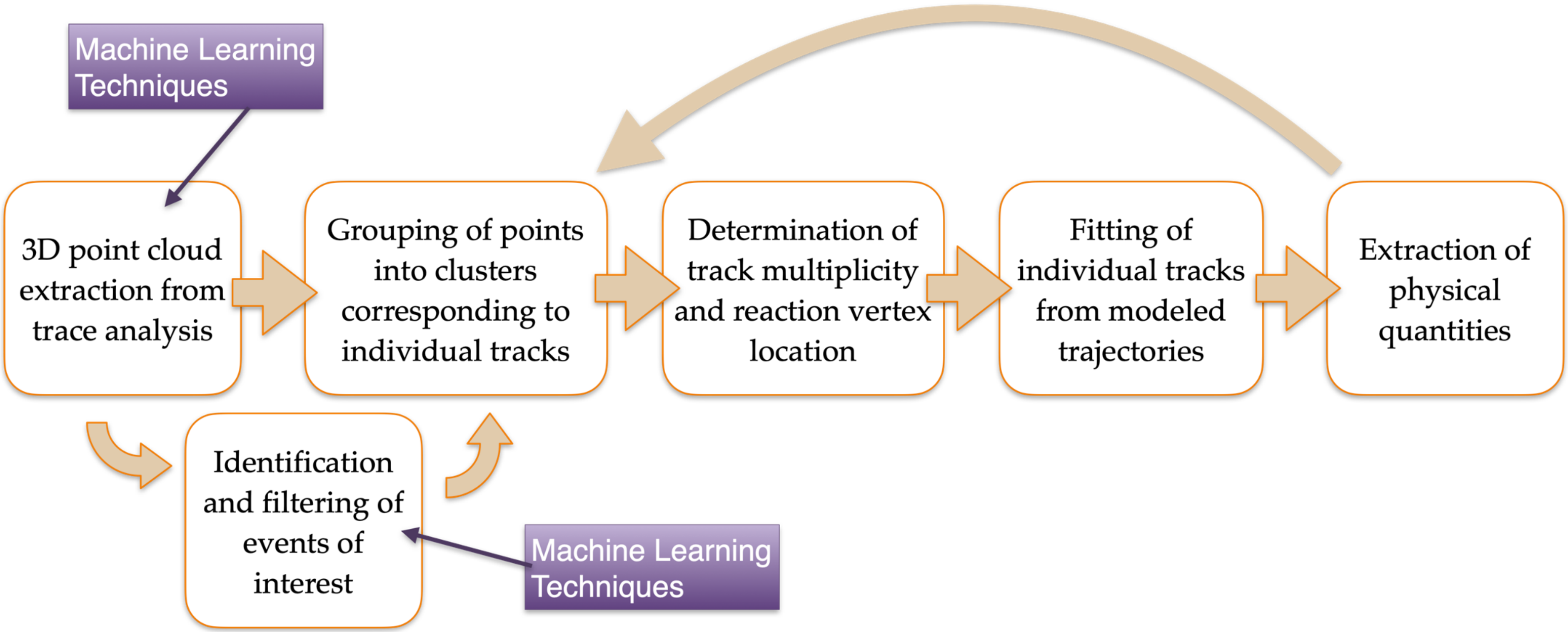
Equations for determining spin/parity

1. $\pi_i \pi_f = (-1)^l$

2. $|J_i - |l - 1/2|| \leq J_f \leq J_i + l + 1/2$

Analysis pipeline

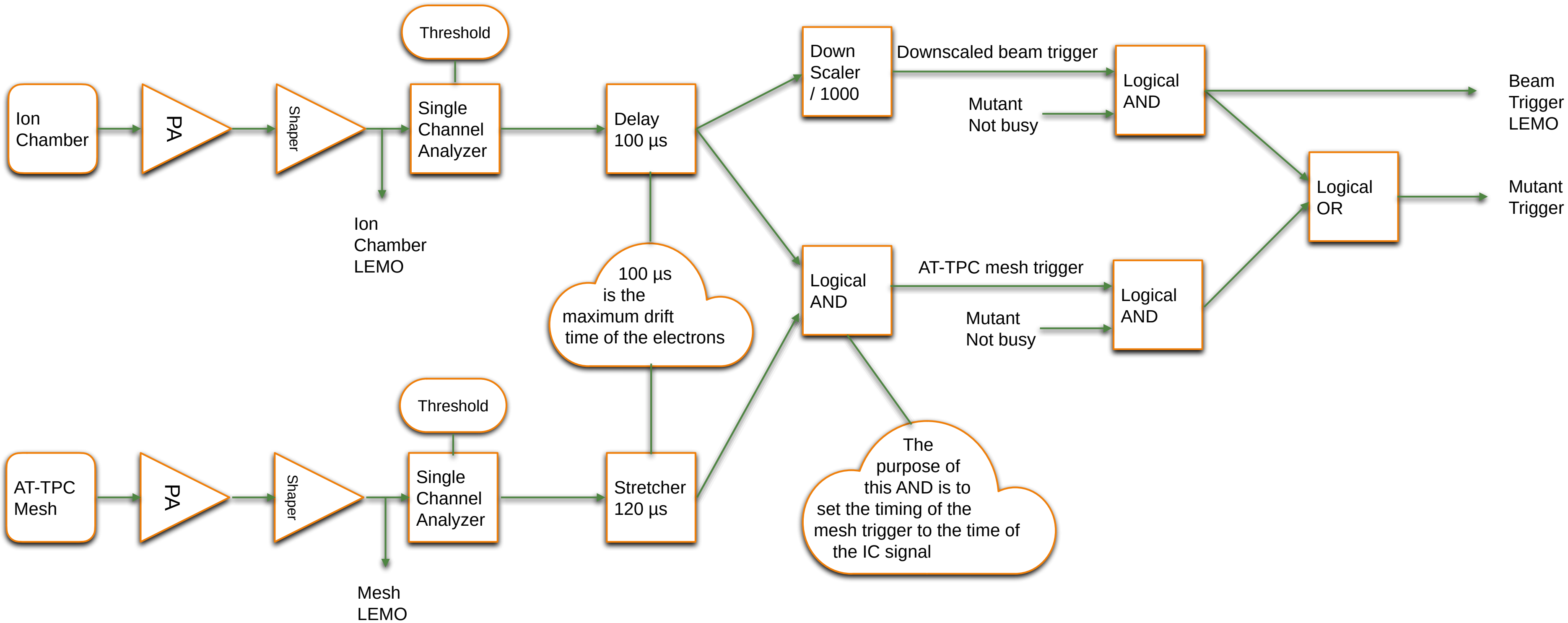


Pros/cons of active targets

- Pros
  - Target thickness and resolution no longer compete as in passive targets
  - Very large solid angle coverage (essentially 4π)
  - Light nuclear probes are naturally gas at room temperature, so they are used in their purest form in active targets
    - p, d, t, ^{3}He, α
- Cons
  - Usually must use low intensity beams
  - Target gas properties are not always great for a detector gas
  - Triggers are tricky
  - Complex data analysis

Slide adapted from "D. Bazin, *Why active targets? What is all the buzz about?*, Personal communication, 2021. Presentation given at ECT 2021 summer school."

E20009 Trigger



Zwieglinksi, B. *et al*. excitation spectrum

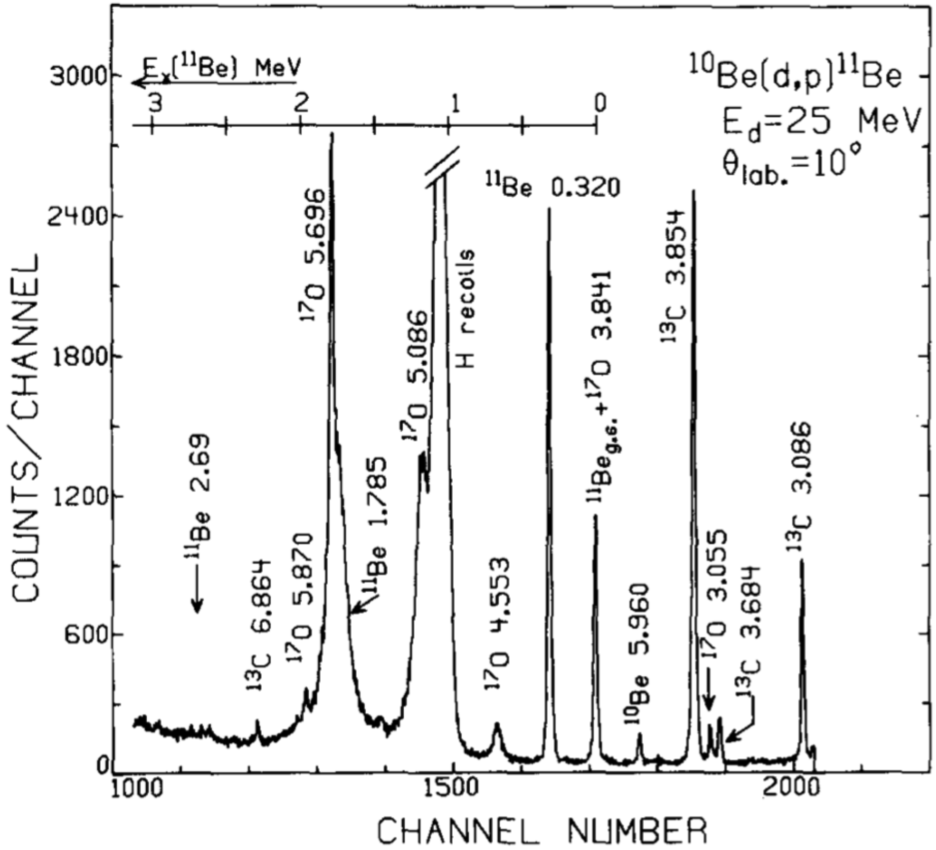


Fig. 1. Spectrum of protons from the ^{10}Be(d, p)^{11}Be reaction at the deuteron energy E_d = 25 MeV and the laboratory angle θ_{lab} = 10°. The arrow marks the expected position of the proton group to the 2.69 MeV state in ^{11}Be.

Fitting spectrum