New Results with TECSA: Study of the d(^{26}Al,p)^{27}Al reaction

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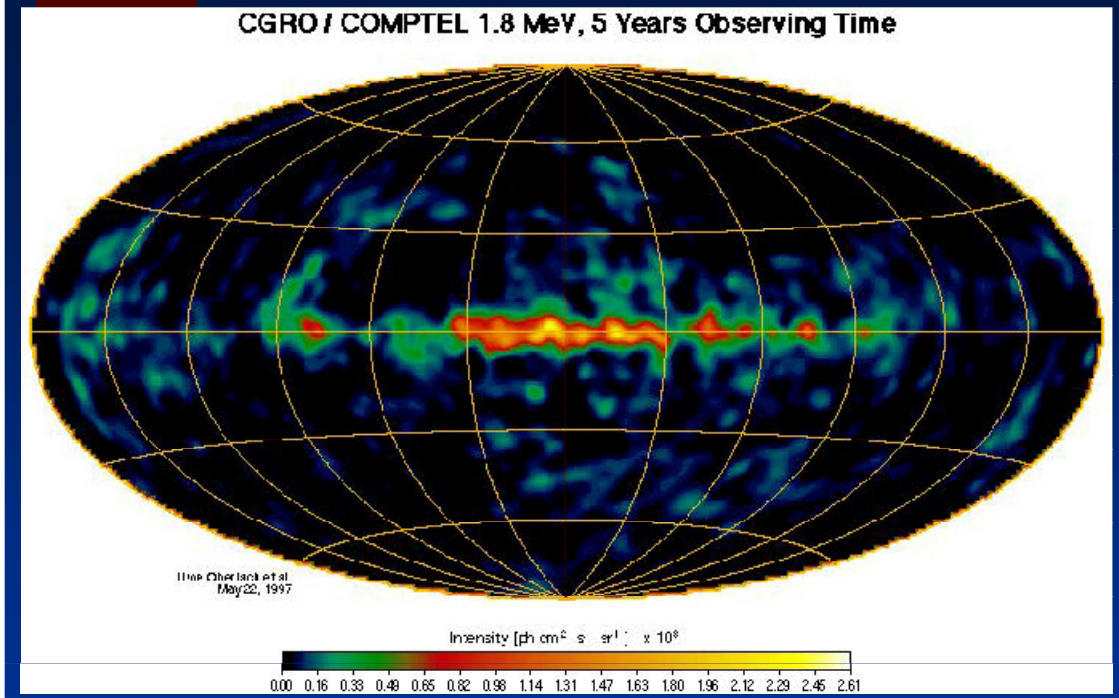
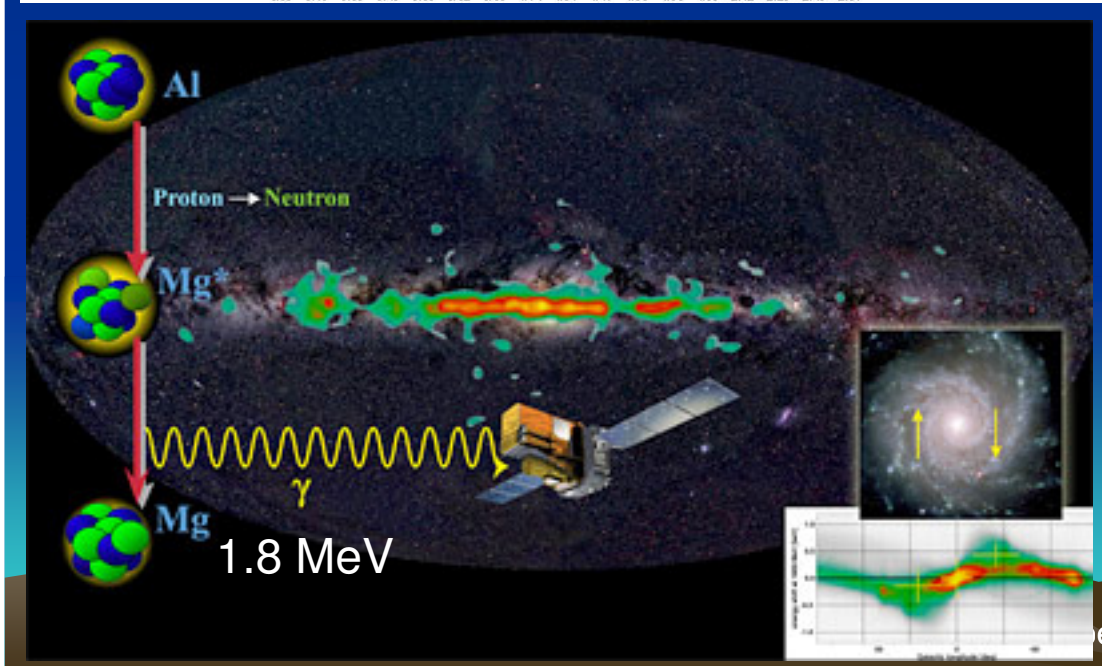
Motivation for TECSA Detector

- TECSA pools existing resources from TAMU (USA), Univ. of Edinburgh (UK), and INFN-LNS (Italy).
- Goal: Build detector suitable for transfer reaction measurements with rare isotope beams.
- The silicon detector array should cover a large solid angle to maximize efficiency while providing needed granularity.
- We use TECSA to develop methods applicable to nuclear astrophysics, nuclear structure and stockpile stewardship such as ANC, TH Method and other surrogate techniques.

Davinson et al. NIM A 454, 350 (2000)
Xu et al. PRL 73, 2027 (1994)
Cherubini et al. Astro J 457, 855 (1996).





Galactic images with Comptel and Integral

- Satellites detect 1.8 MeV gamma ray from $^{26}Al^{g}$ β-decay.
- Lifetime of $^{26}Al^{g}$ is $7.2*10^{5}$ yrs.
- Gives evidence of ongoing Nucleosynthesis in stars in the galaxy.
- Want to understand production and destruction of nuclei like ^{26}Al in stars – maybe $^{26}Al^{m}$ (0^{+}) is important?

Destruction of ^{26}Al

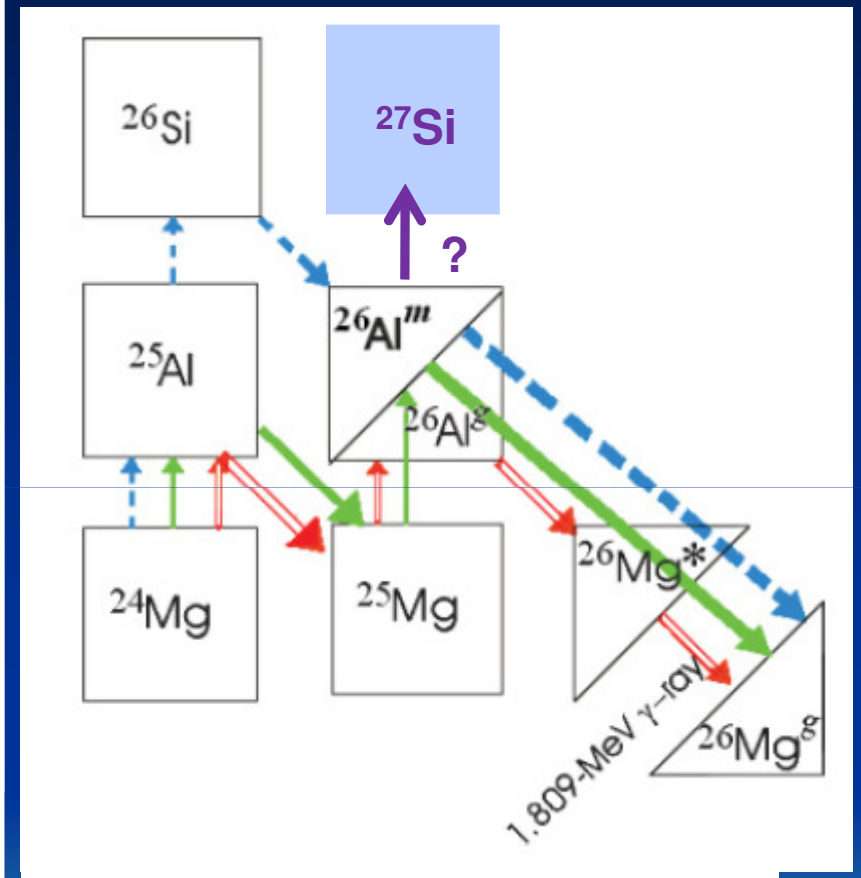
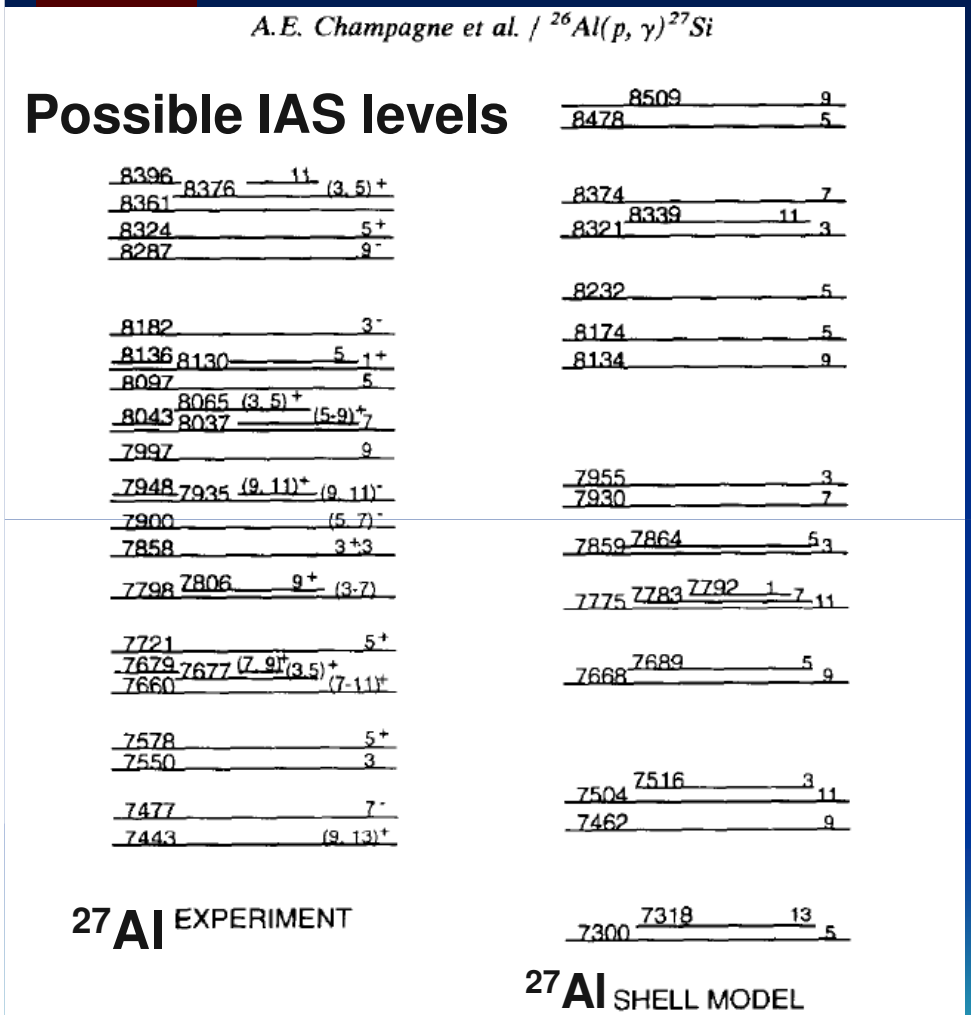
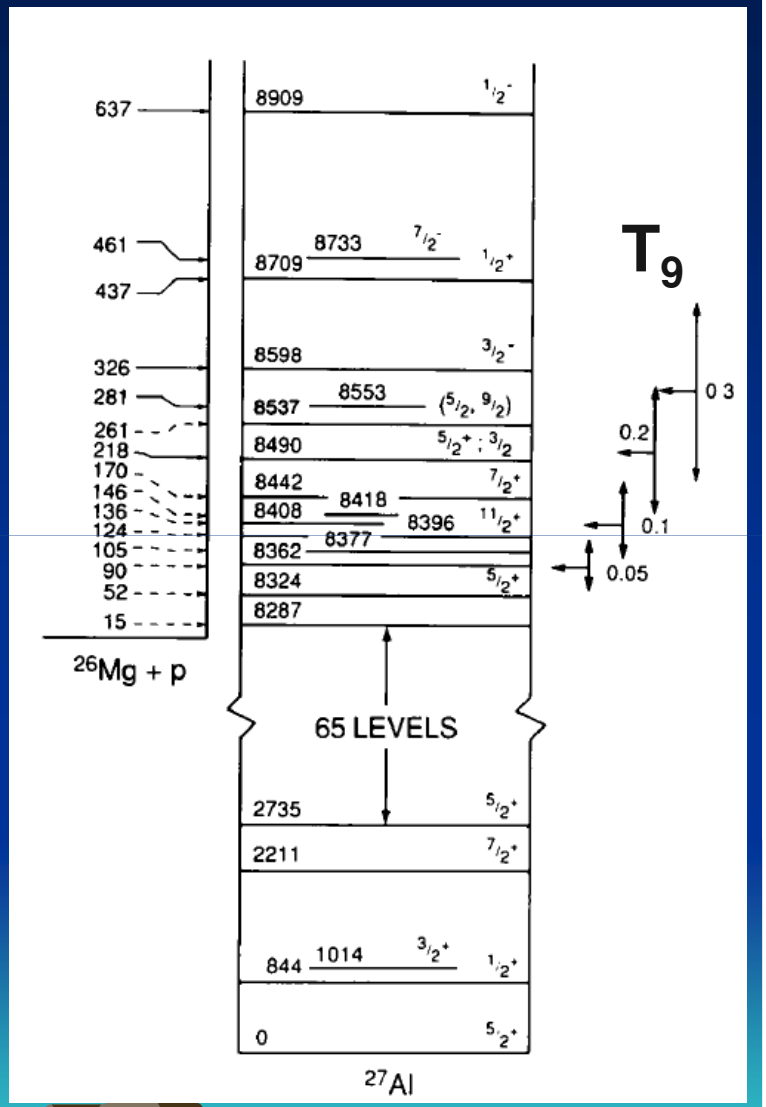


Figure: C.M. Deibel et al. PRC 80

- Satellites detect less 1.8 MeV γ-rays than expected.
- In astrophysical environment (0.1 GK < T < 0.4 GK → 100 keV < E_{CM} < 600 keV) ^{26}Al can also be destroyed by ^{26}Al(p,γ).
- Try to investigate levels of interest for ^{26}Al^{m}(p,γ) and ^{26}Al^{g}(p,γ) by studying IAS states in ^{27}Al with ^{26}Al(d,p) reaction.

^{27}Si – ^{27}Al - IAS Levels

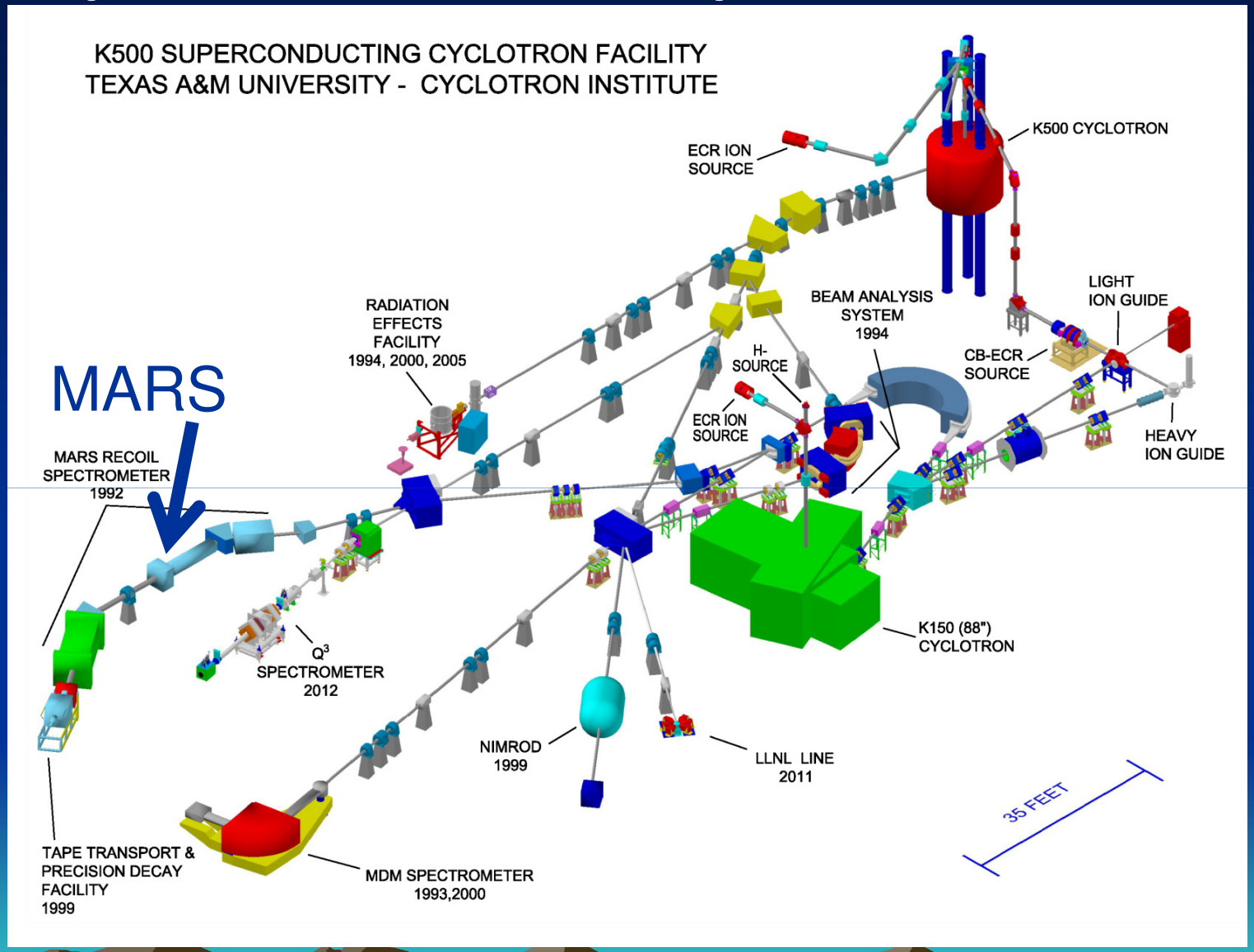




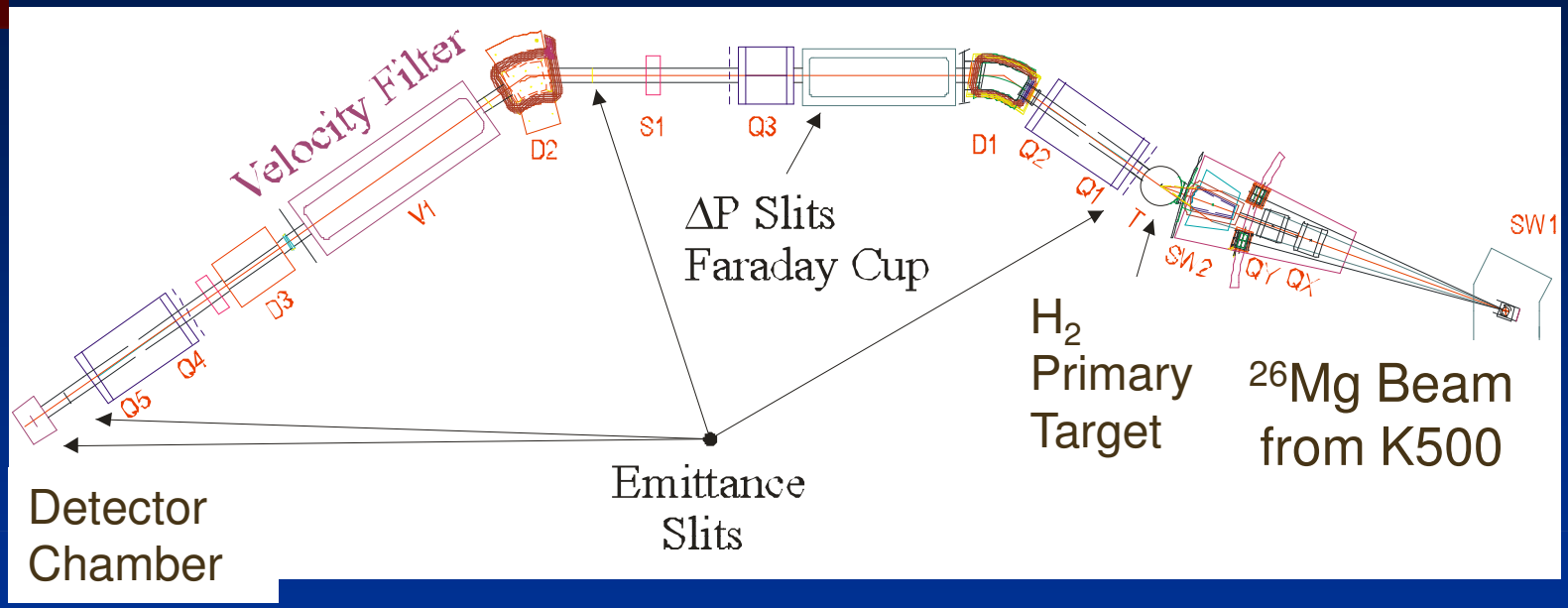
A.E. Champagne, et al., NPA 512 (1990) 317-332

A.E. Champagne, B.A. Brown, et al., NPA 556 (1993) 123-135

Layout of TAMU – Cyclotron Institute

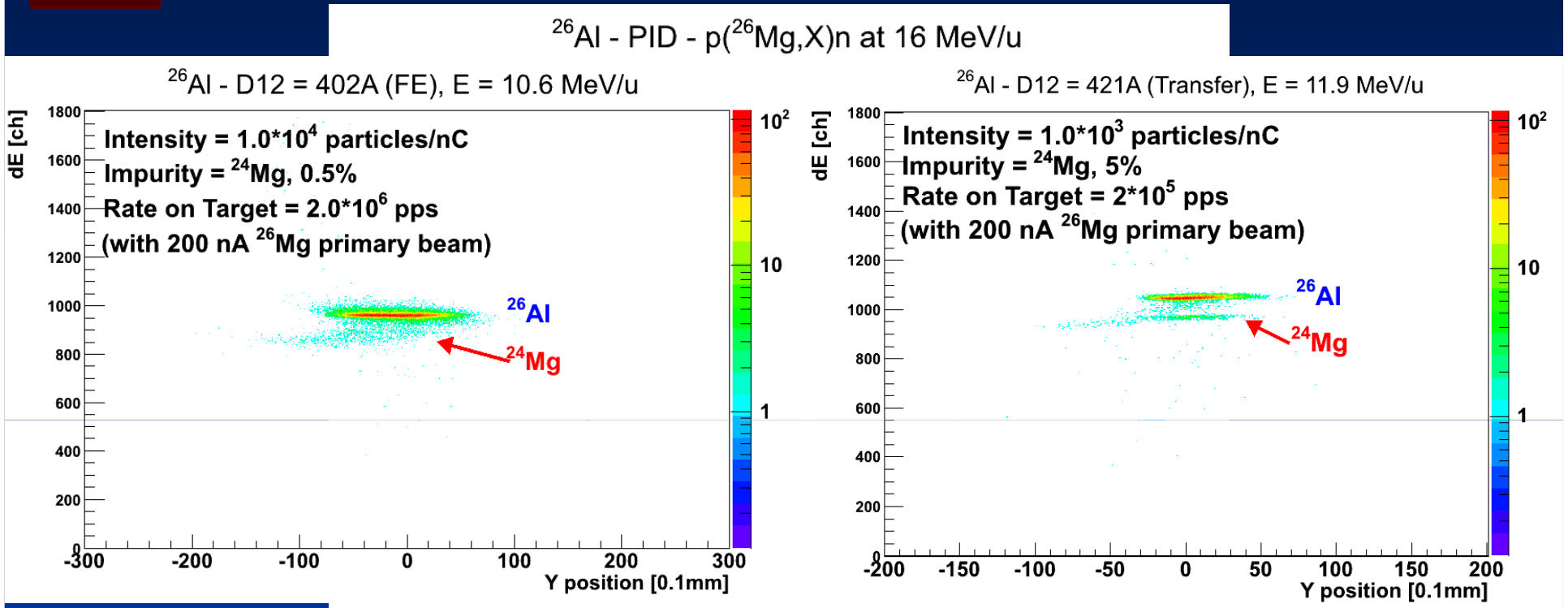


MARS spectrograph



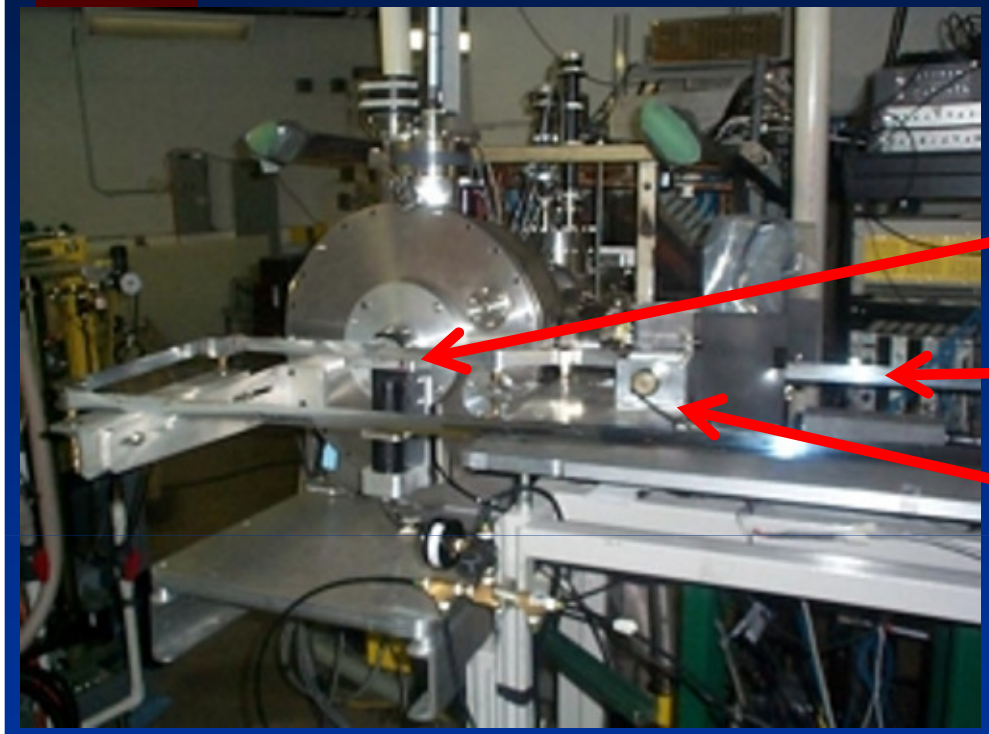
- ^{26}Mg primary beam from K500 at 16 MeV/u.
- Produce ^{26}Al beam with ^{26}Mg(p,n) reaction.
- Refocus Beam in detector chamber on CD_2 target.

Composition of the ^{26}Al beam



- Tune MARS to select 2 different reaction mechanisms.
- Expect "Transfer" solution to have more 0^+ isomer than the "Fusion-Evaporation (FE)" solution. How do we check?

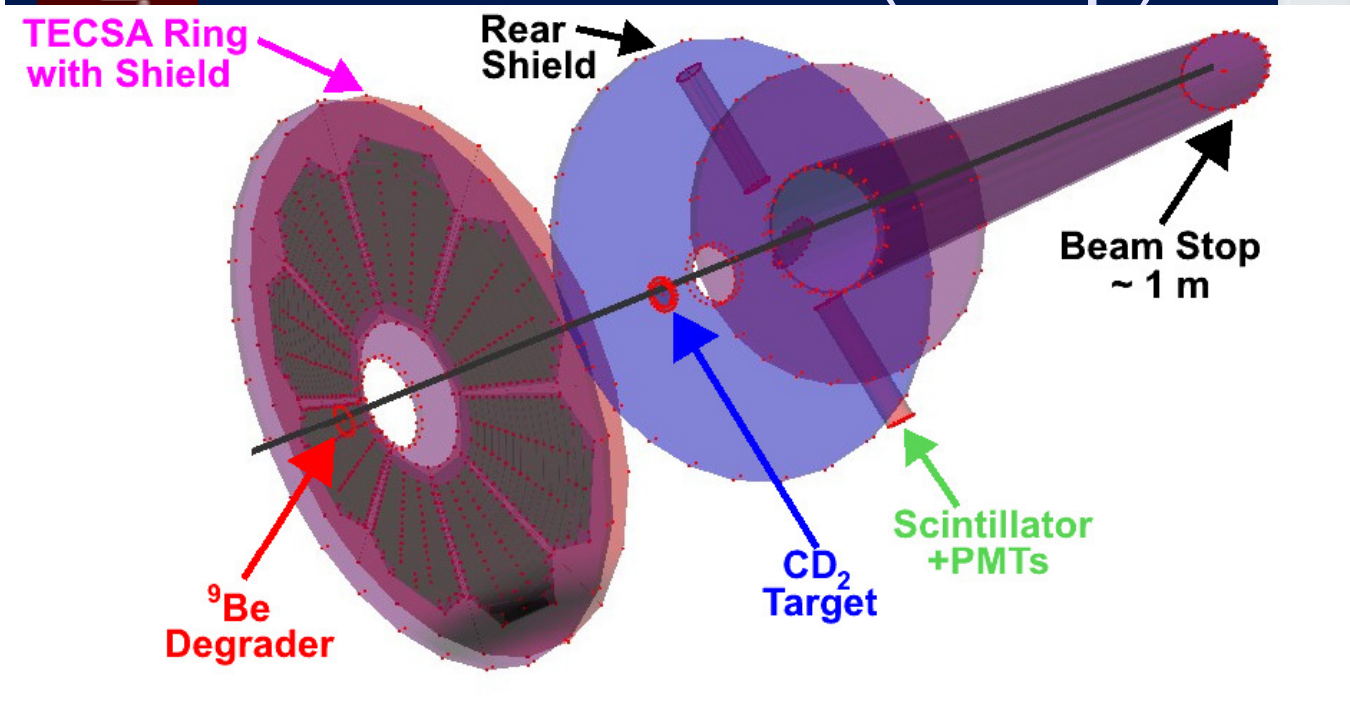
β-decay measurement of isomer ratio



Setup:
V.E. Iacob et al., PRC 82, 035502 (2010)

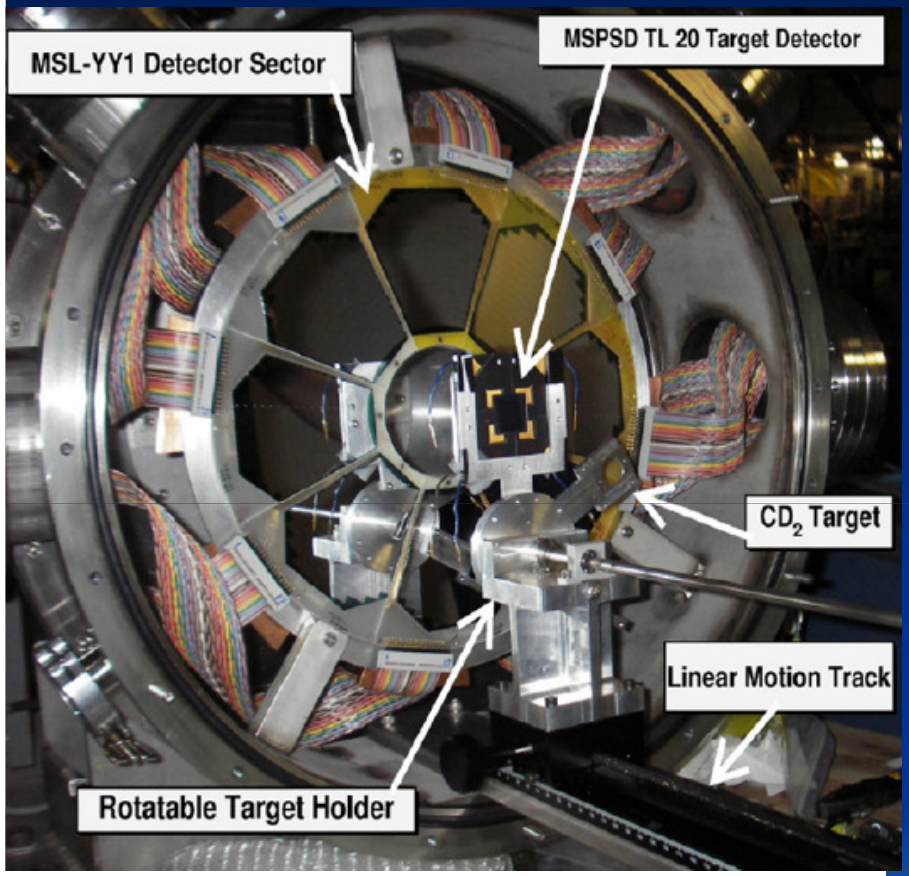
- $^{26}Al^{m}$ $T_{1/2}$ = 6.35 s
- Determine ratio with #β-decays / #^{26}Al total
- "Transfer" solution – 66% 0^+, 34% 5^+
- "Fusion-Evaporation (FE)" solution – 36% 0^+, 64% 5^+

Overview of d(^{26}Al,p)^{27}Al setup



- TECSA – 16-ring annular array at back angles.
- 451 μg/cm^2 CD$_2$ target.
- Energy degraded to 5 MeV/u and 3 MeV/u with 152 μm ^{9}Be foil.
- Scintillator+PMT at back of chamber for timing measurements.
- Beam stop to reduce β-background from beam.

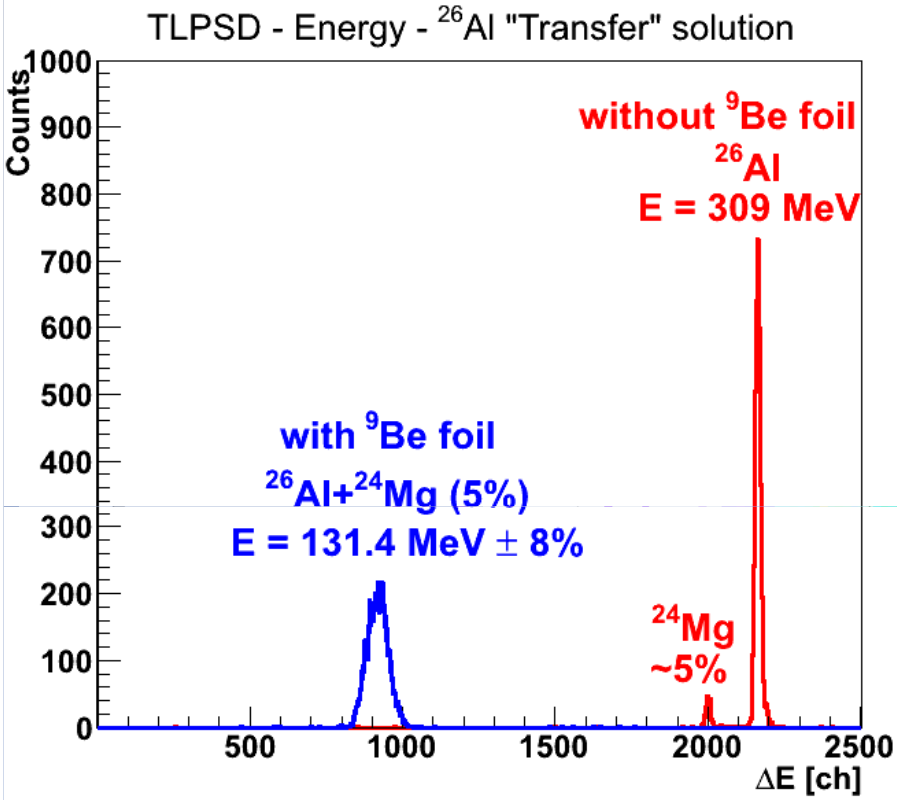
Details of the TECSA setup

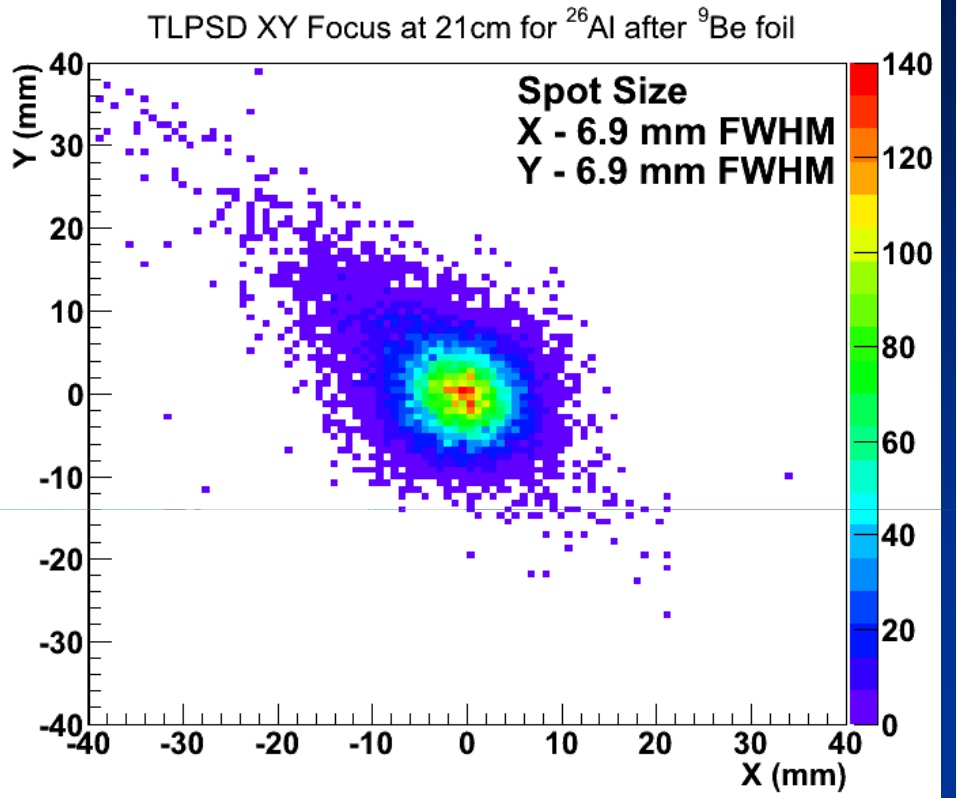


B.T. Roeder et al., Nucl. Instr. and Meth. A 634, 71–76 (2011).

- MSL type-YY1 Si detectors, single-sided, 16 strips each
- 8 detectors form a 16-ring annular array with128 strips
- Movable (Z-axis) and rotatable target holder.
- Measured at 21cm and 12 cm distance, Covered θ_{cm} 5°-25°.
- PSD for focusing the beam.

Focusing and Energy Degradation



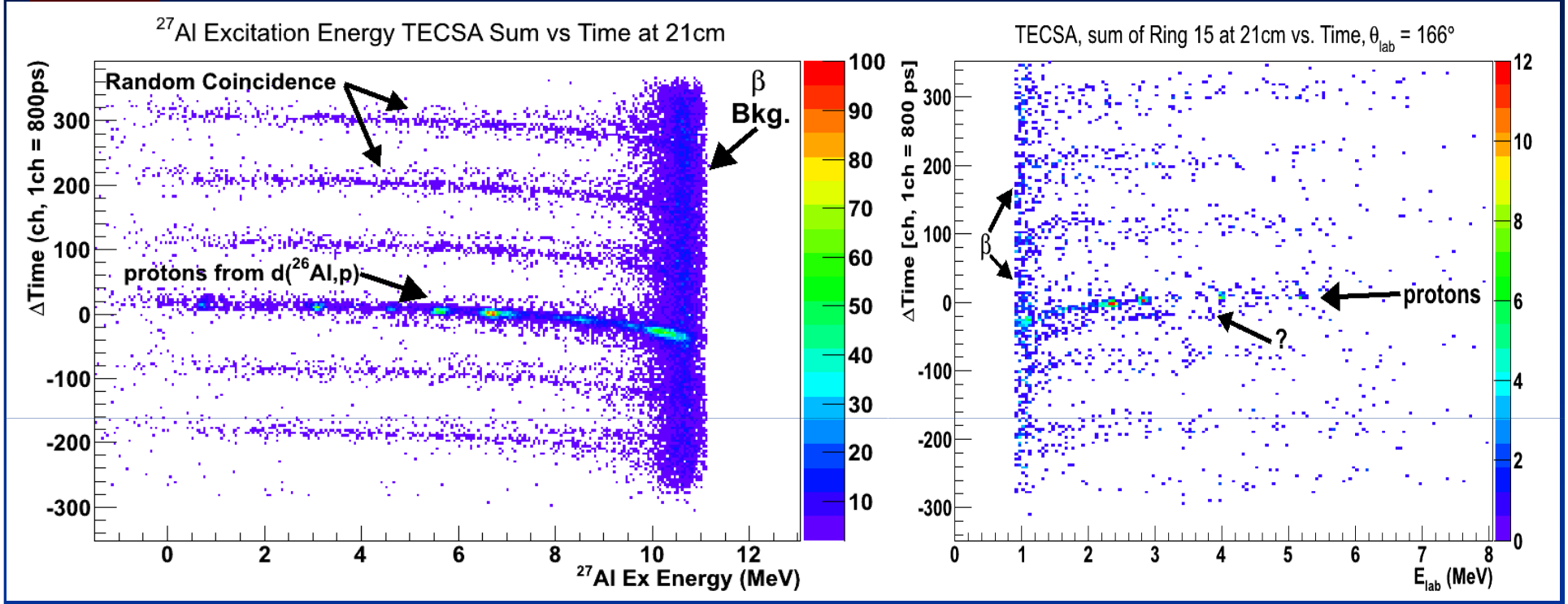


Target diameter = 15.8 mm

Final Energies after ^{9}Be foil

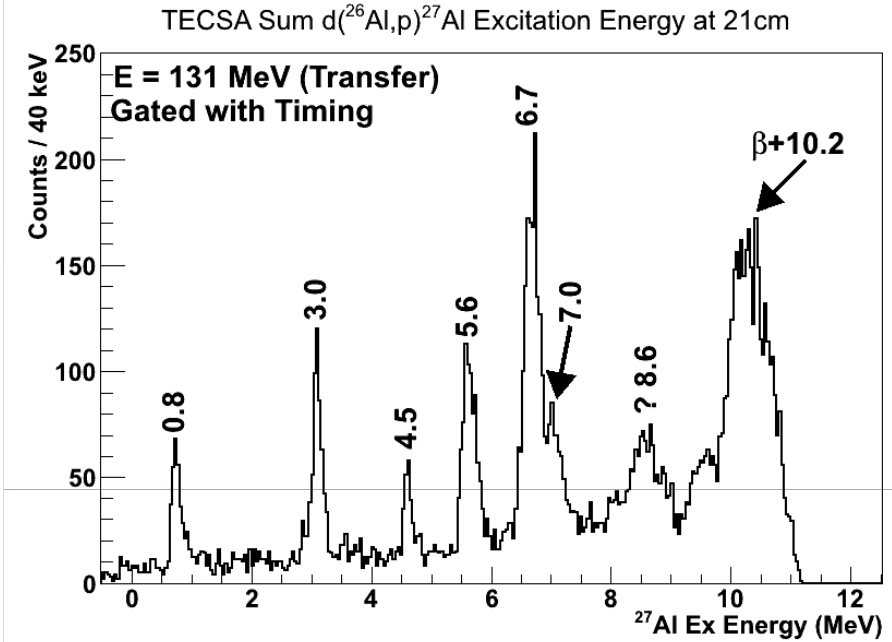
- D12 = 421 A ("Transfer") – 131.4 ± 8% MeV
- D12 = 402 A ("Fusion-Evaporation") – 77 ± 9 % MeV

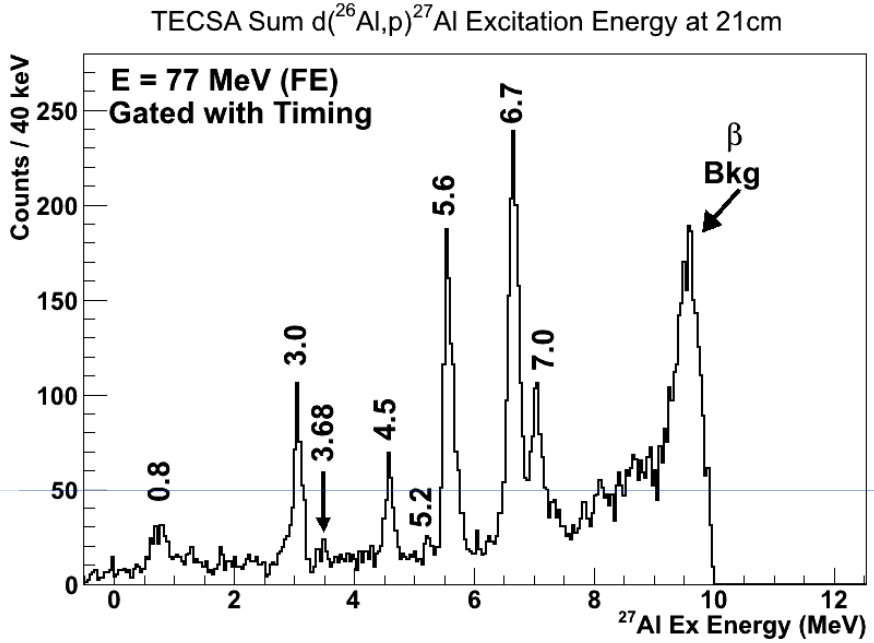
Data analysis and background



- Timing difference between TECSA and scintillator allows separation of coincidence data from random background.
- Primary beam from cyclotron is coming in RF pulses from cyclotron every 76 ns (13.1 MHz).

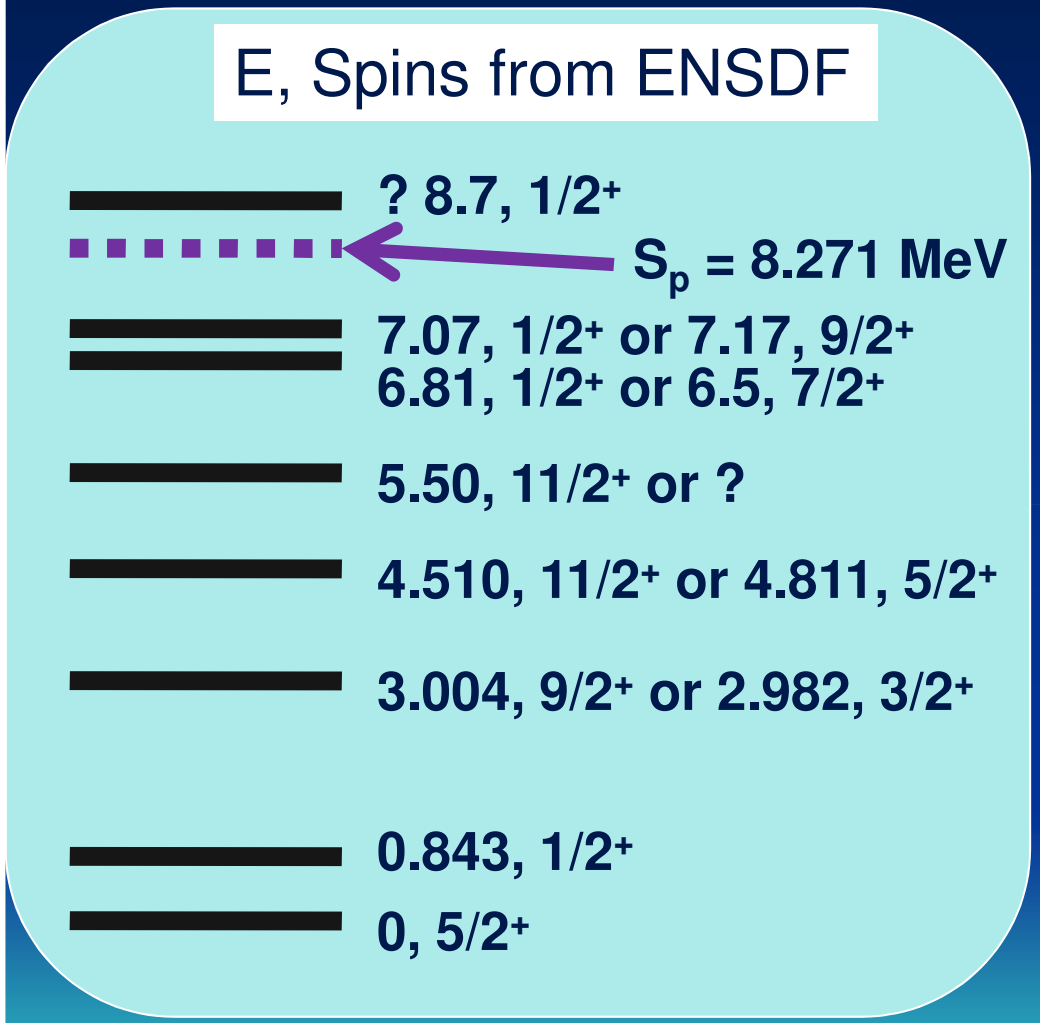
Preliminary Results – d(^{26}Al,p)^{27}Al





- Similar states are populated in the 2 cases
  - 131 MeV data had 66% ^{26}Al^{m}, 34% ^{26}Al^{g}
  - 77 MeV data had 36% ^{26}Al^{m}, 64% ^{26}Al^{g}
- Can the structure of the states be distinguished?

Structure of ^{27}Al

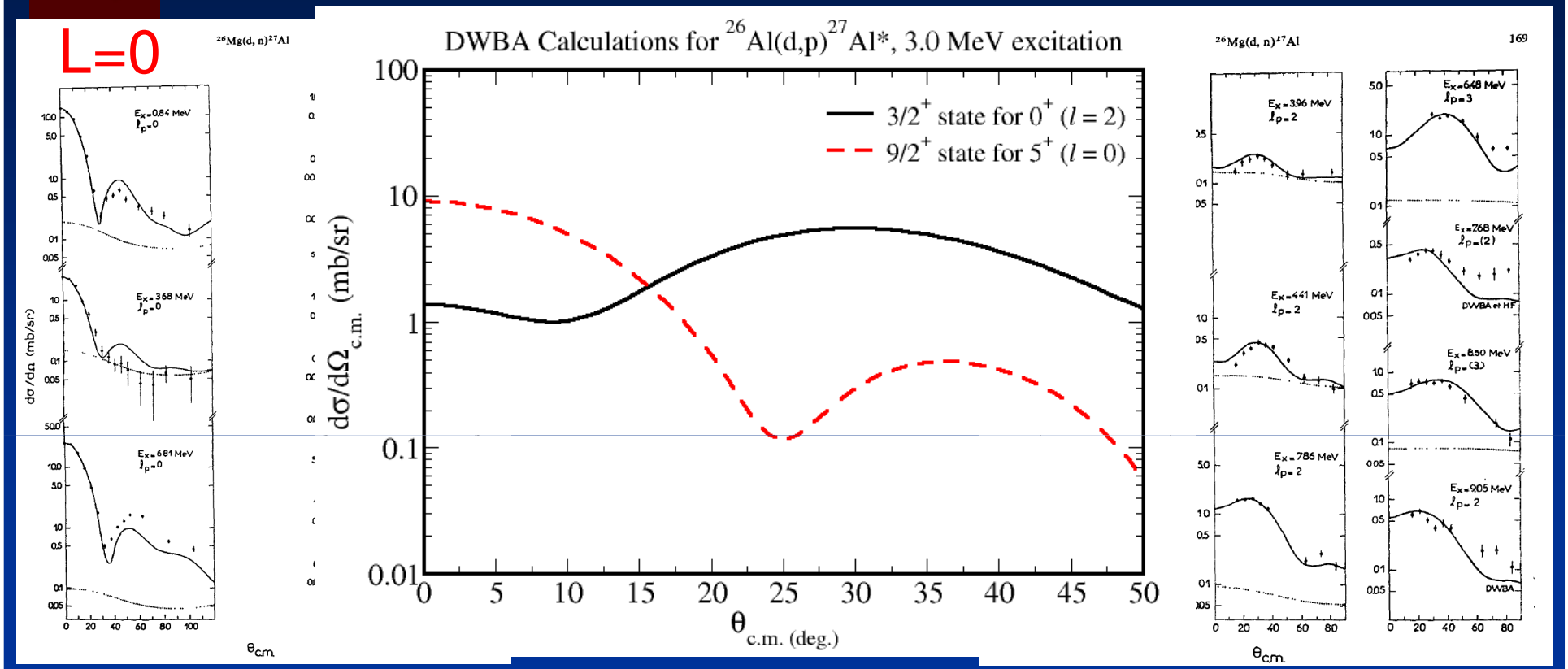


N.B. - Unpopulated states not shown…

- ^{27}Al density of states is high, often there are at least 2 single-particle structure choices within ~300 keV.
- Investigate differences with cross sections and DWBA , (L-values).

Compare with ^{26}Mg(d,n) from
J. Uzureau et al., NPA 250 (1975) 163

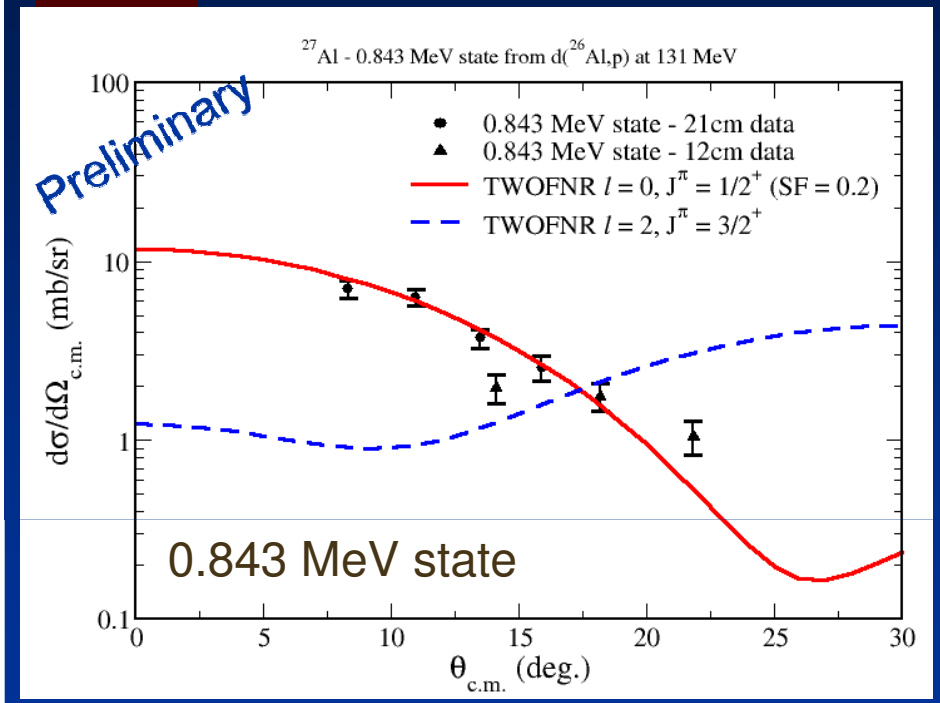
DWBA calculations to check spins

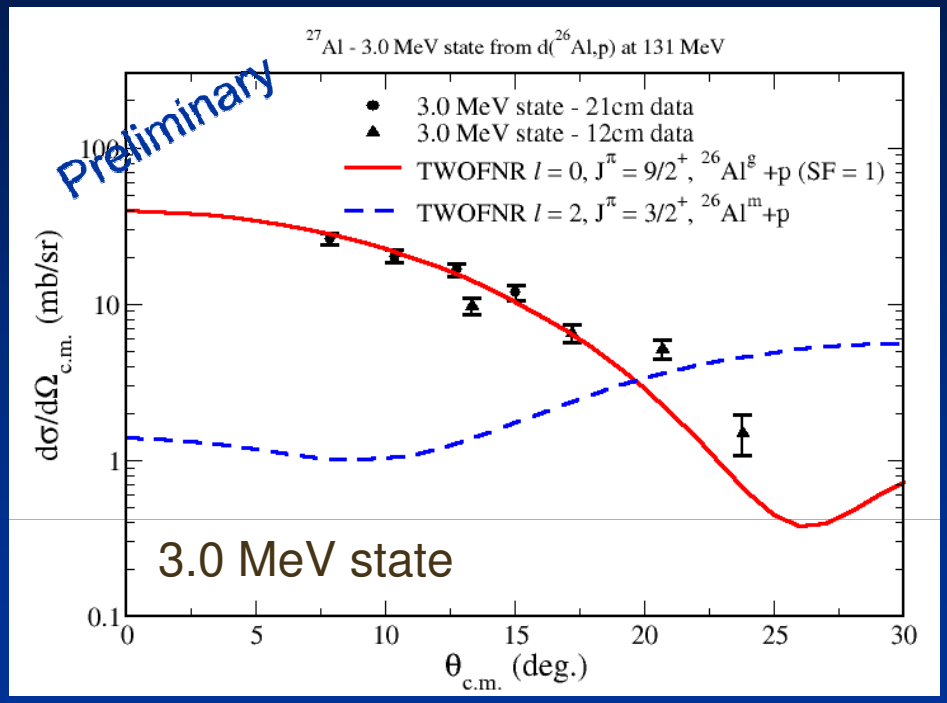


- J. Uzureau et al., noted that for ^{26}Mg(d,n) reaction that L=0 and L=2 angular distributions are distinguishable at forward angles.
- Simple DWBA calculations carried out with program **TWOFNR** using scaled global potentials (Perey&Perey and CH89).

M. Igarashi et al., Surrey Univ. version

Angular Distributions





- Data points are corrected for the measured isomer/g.s. ratio.
- 0.843 MeV state is confirmed as L=0, 1/2^{+}, ^{26}Al^{m}+p
- 3.0 MeV state found to be the L=0, 9/2^{+}, ^{26}Al^{g}+p
- Can tell difference in structure with the calculations.

Summary of Preliminary Results

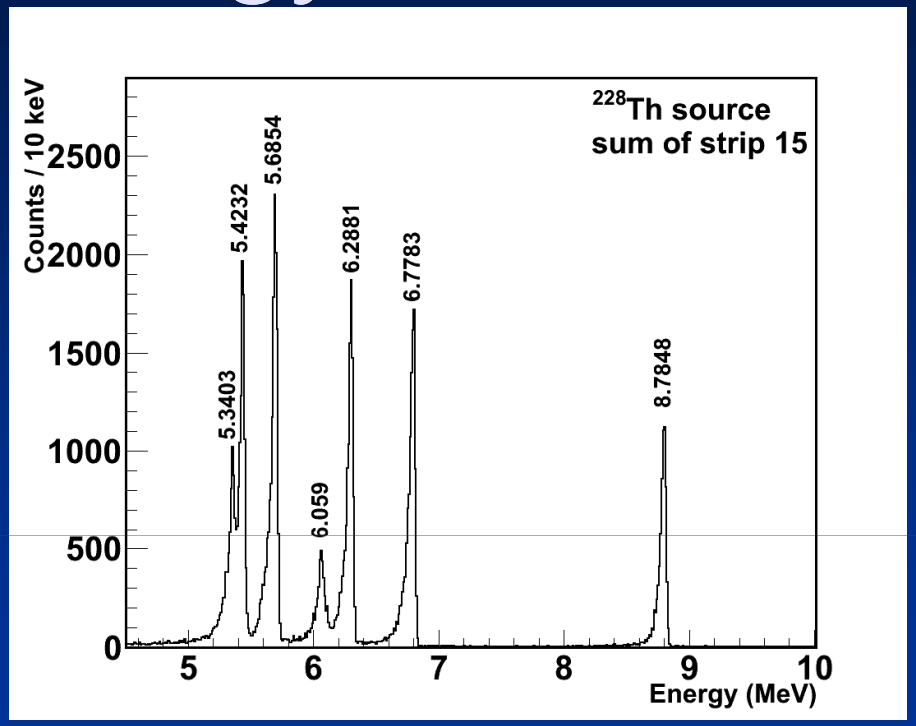
- $d(^{26}Al^{m},p)^{27}Al$ populated:
  - 0.843, $1/2^{+}$ (L=0)
  - 6.7, $1/2^{+}$ (L=0)
  - ? 8.6 MeV state (candidate IAS state)
- $d(^{26}Al^{g},p)^{27}Al$ populated:
  - 3.0 MeV, $9/2^{+}$ (L=0)
  - 4.5 MeV, $11/2^{+}$ (L=0)
  - 5.6 MeV, $11/2^{+}$ (L=0)
- Saw mainly L=0 states. L=2 states have maximums outside of angular range measured.
- Further work needed to verify structure of 8.6 MeV state.

Future Plans

- Continue analysis of current data
  - Identify states of astrophysical relevence (8.6 MeV state ?).
  - Improve DWBA calculations.
- Planning future measurements of relevance to nuclear astrophysics.
  - $d(^{26}Al,p)^{27}Al$ – (more statistics needed)
  - Trojan Horse Method – $^{18}F+p \rightarrow {}^{18}Ne+n$
  - $d(^{30}P,^{31}P)n$

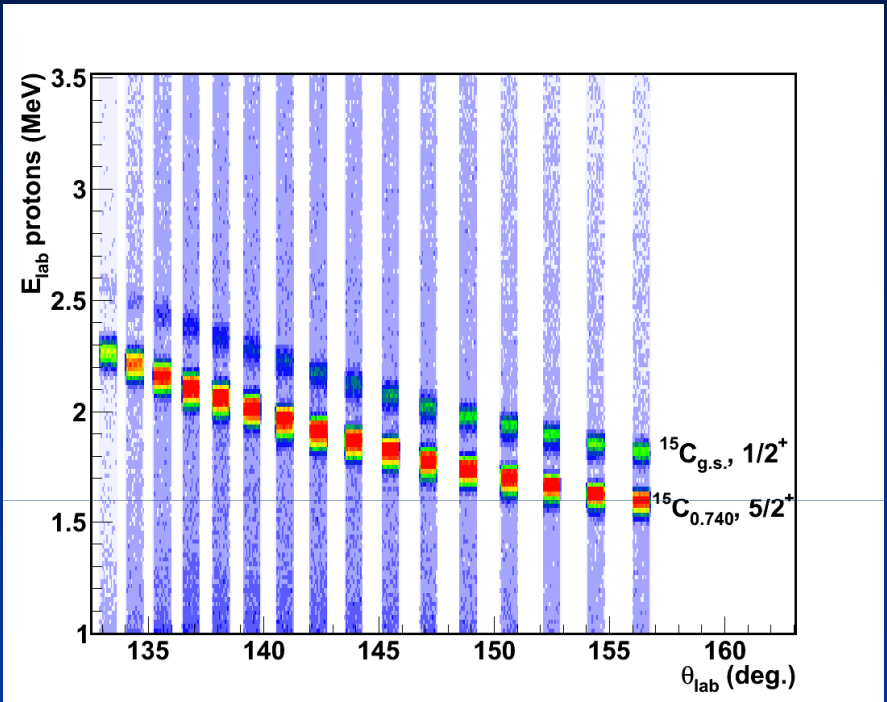
Thank you

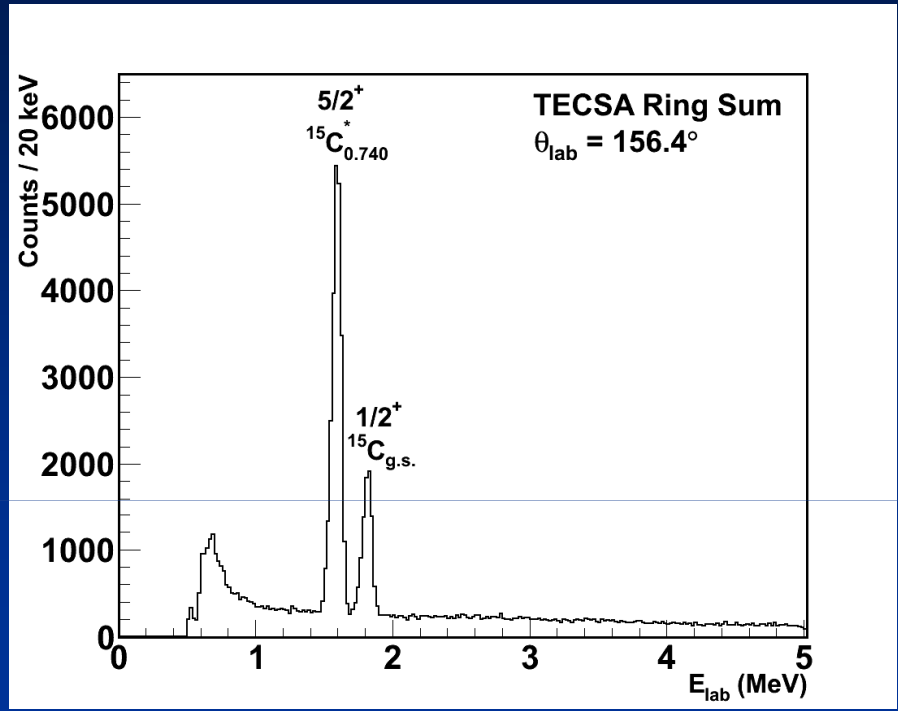
Energy Calibration



- Calibrated with ^{228}Th, ^{241}Am, and ^{148}Gd α-sources.
- Resolution: 40 keV (strip), 50 keV (ring).

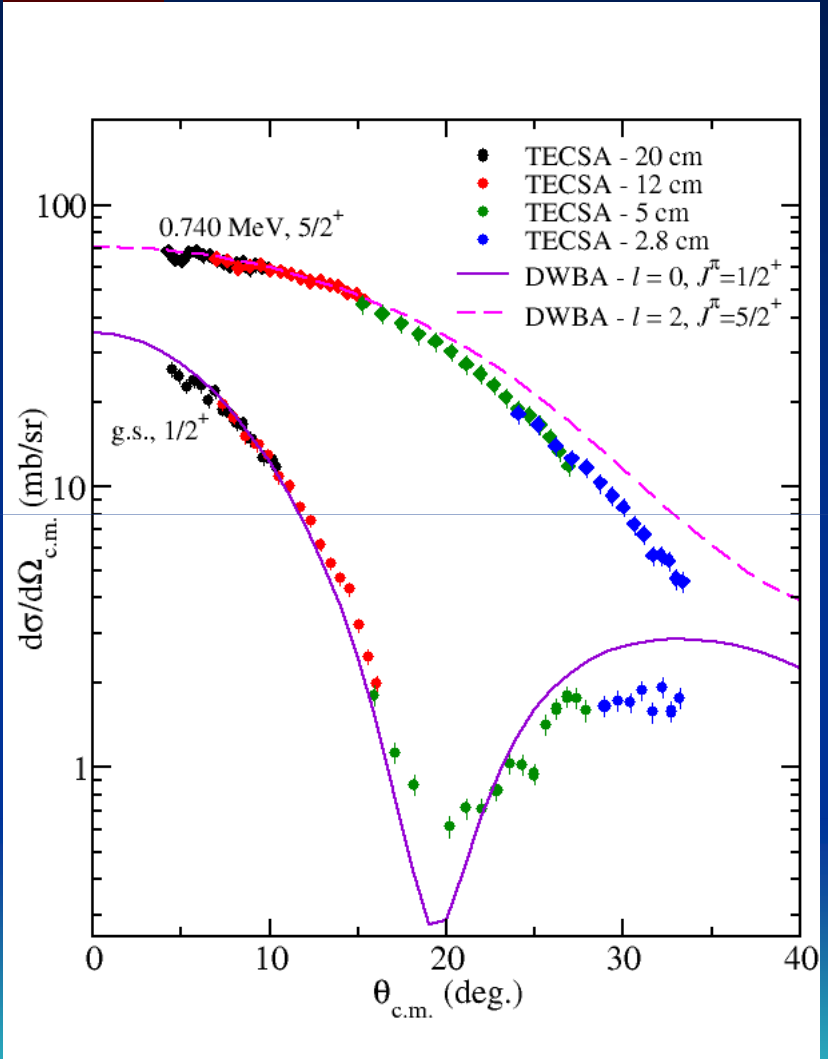
Results - d(^{14}C,p)^{15}C





- Observed protons from ^{15}C g.s. [1/2$^+$] and first excited state [5/2$^+$].
- Resolution was ≈100 keV FWHM.

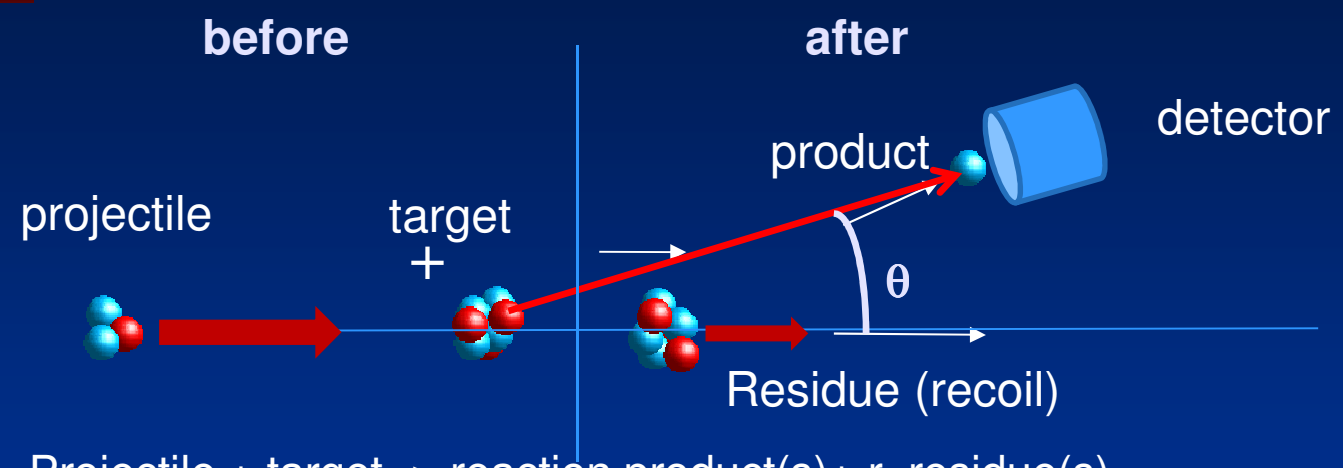
Results d(^{14}C,p)^{15}C



- Angular distributions cover $4° < \theta_{cm} < 34°$
- DWBA calculations with TWOFNR, global potentials.
- Calculations reproduce general features of angular distributions.
- ANC calculated for part of thesis work of M. McCleskey.

B.T. Roeder et al., Nucl. Instr. and Meth. A 634, 71–76 (2011).

Nuclear reactions



- Projectile + target -> reaction product(s)+ r. residue(s)
  - Scattering: 1+2-> 1+2
  - Two-body reactions: 1+2 ->3+4
  - Multi-fragmentation r: 1+2 -> 3+4+5+ …
- Kinematic conditions: incident energy , scattering (react) angle
  - Normal kinematics: Mp<Mt. Inverse kinematics: Mp>Mt
  - E_{lab} -> E_{cm}= (Mt/Mp+Mt)E_{lab} (non-relativistic)
- Measure cross section: σ=nr detected/incident p per area/nr target nuclei
- Angular distributions: dσ/dΩ= f(θ) (info on space charact of inter region)
- Excitation functions: σ=f(E_{inc}) (info on time charact of interaction)
- Momentum distributions