Tri-nucleon cluster structure in A=6 nuclei

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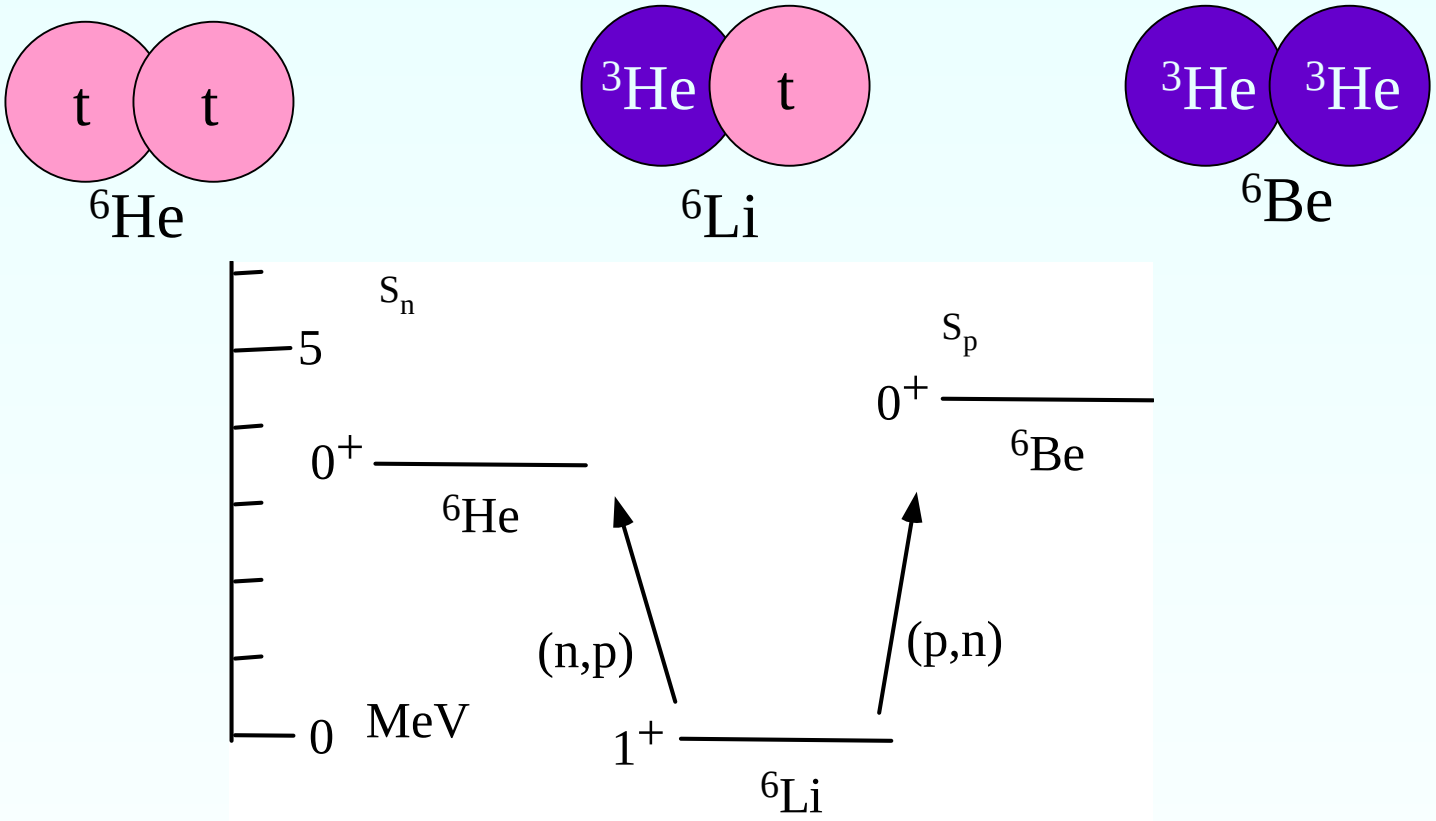
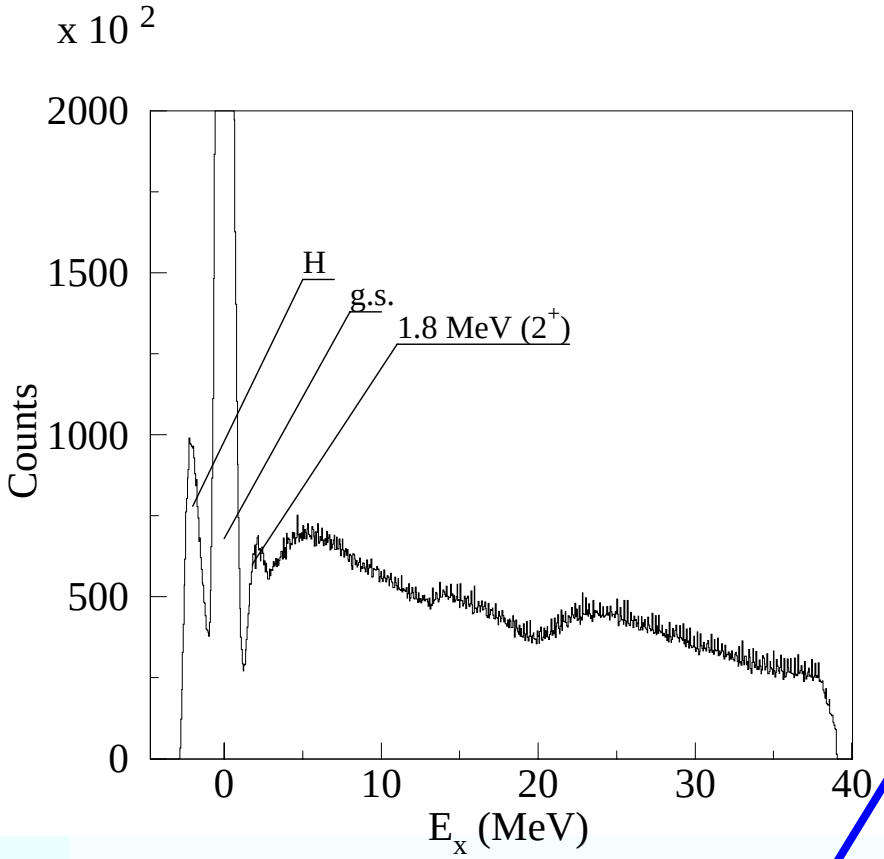
Introduction

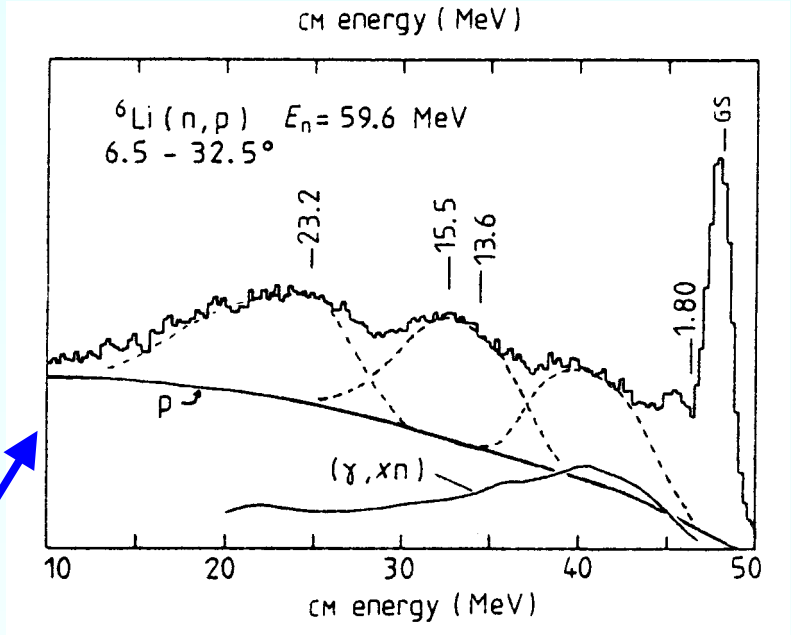
- Question: Are there tri-nucleon clusters in A=6 nuclei?



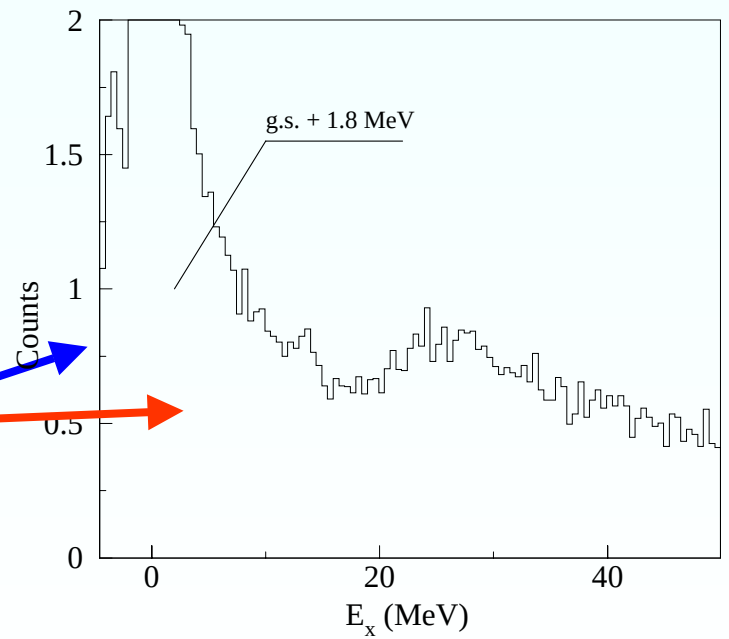
- ^{6}He is well known as neutron-halo nucleus (2n+ **α** System)

$^{6}Li(^{7}Li,^{7}Be)$ Reaction and Other Reactions





- $^{6}Li(n,p)$ at E_n=60 MeV
  - F.P. Brady et al. (JP G10 (1984), 363)
- $^{6}Li(p,n)$ Reaction at E_p=300 MeV
  - T. Wakasa et al. (private communication)

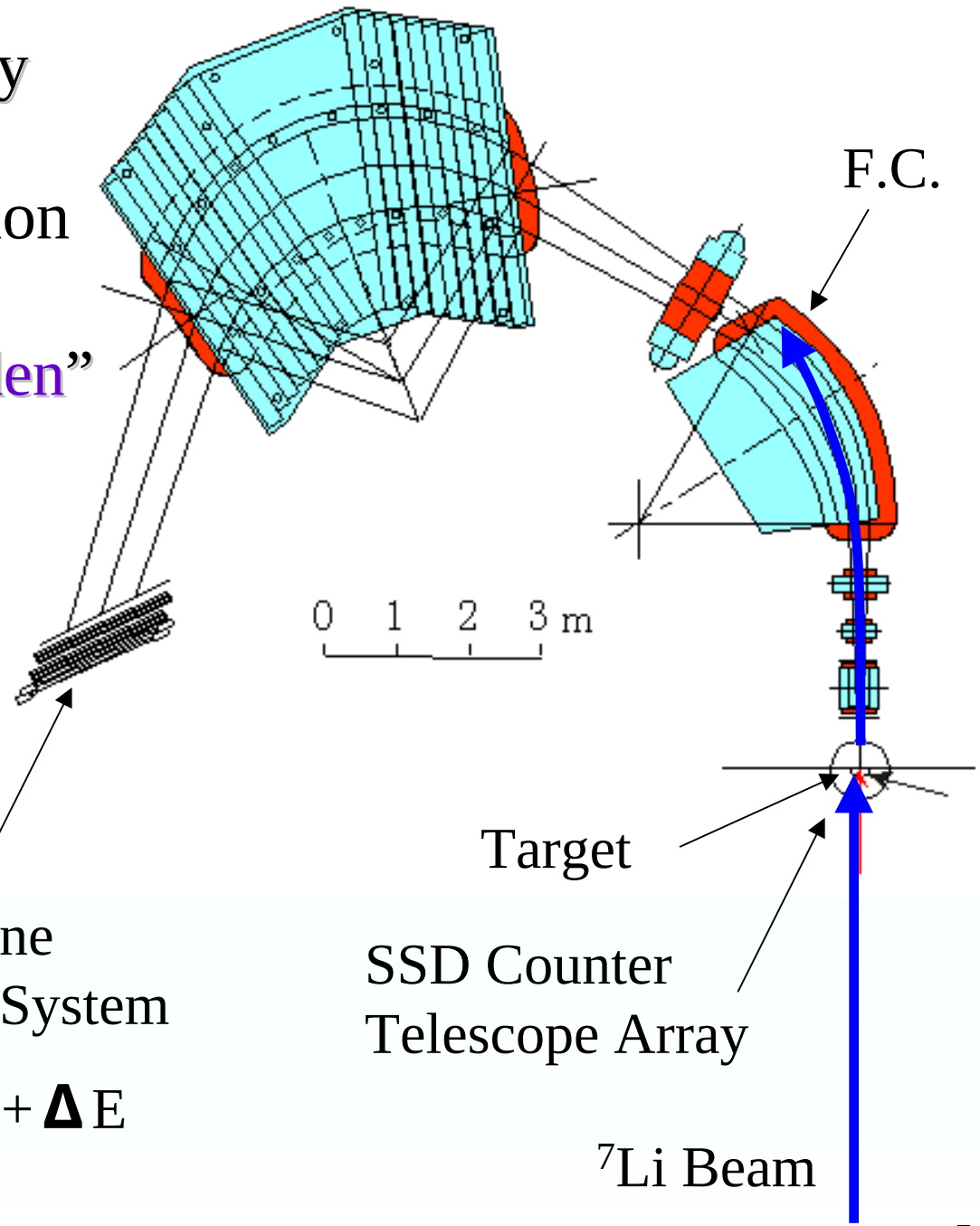


^{6}Li(^{7}Li,^{7}Be) Reaction at 65 MeV/A

- (^{7}Li,^{7}Be) reaction
  - (n,p) type reaction
  - Excite both Spin-flip and Non-Spin-flip excitation
  - Single step excitation is dominant
- Bumps at high excitation region in ^{6}He
  - 4, 8, ~15, ~23MeV
    - Tri-nucleon cluster feature
      - ^{6}Li: ^{6}Li(**γ** ,t)
      - RGM predicts ^{3}P states in ^{6}He, ^{6}Li and ^{6}Be
    - **α** culster feature
      - Neutron Halo structure in ^{6}He
      - ^{6}He: 4 MeV Soft Dipole Resonance
      - ^{6}He: 23 MeV Dipole excitation of **α** in ^{6}Li
    - 8 MeV: Analog of GDR and SDR in ^{6}Li
- 15 MeV?
- Detection of decay particles
  - Direct information on cluster structure

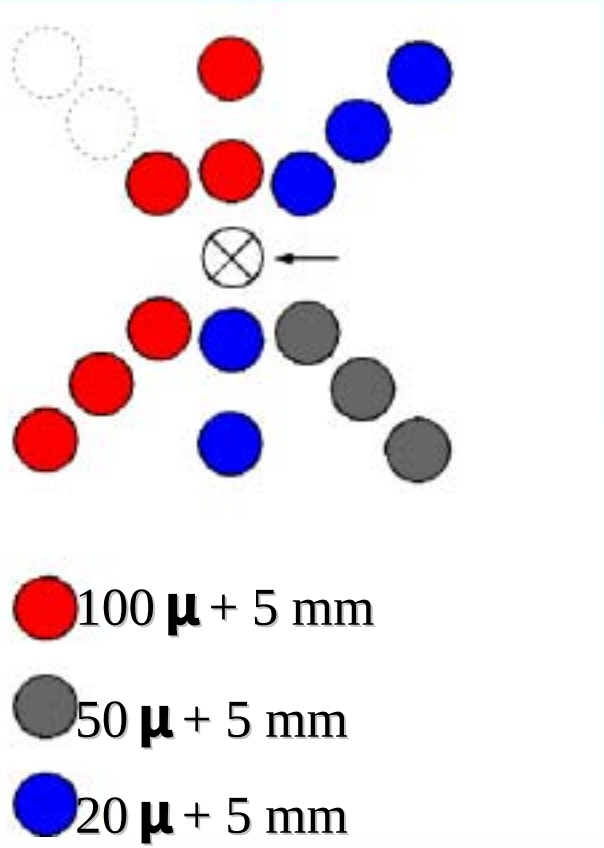
Experiment

- RCNP Ring Cyclotron Facility
- Charged particle decay following $^{6}Li(^{7}Li,^{7}Be)$ reaction
- $(^{7}Li,^{7}Be)$ reaction:
  - Spectrograph "Grand Raiden"
  - E_{7Li} = 455 MeV
    - 65 MeV/A
  - $\Theta_{lab} = 0°$
- Detection of decay particles:
  - SSD Counter telescopes
    - 4% of 4π



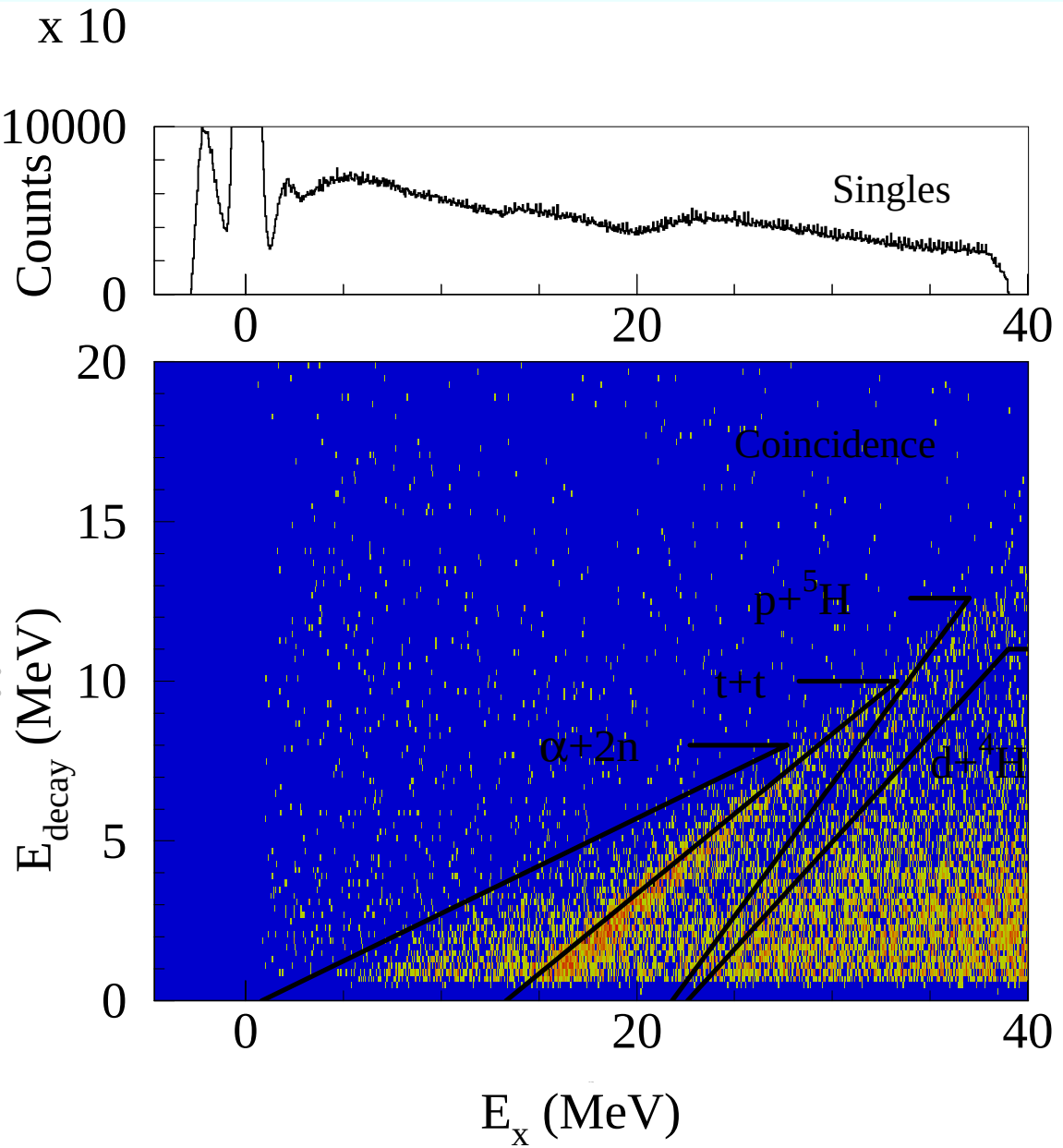
SSD Counter Telescope Array (SSD Ball)

- For charged particle detection (p, d, t, α…)
- Solid angle: 4% of 4π
- Backward angles
  - Θ_{lab} = 113°, 135°, 158°
  - Reduce contributions from direct reactions
    - such as breakup, Q.F.
- ΔE+E Counter Telescope for PI
  - 100 μ + 5 mm × 6 sets
  - 50 μ + 5 mm × 3 sets
  - 20 μ + 5 mm × 5 sets
- Cooling System
  - Noise reduction
  - Improve resolution



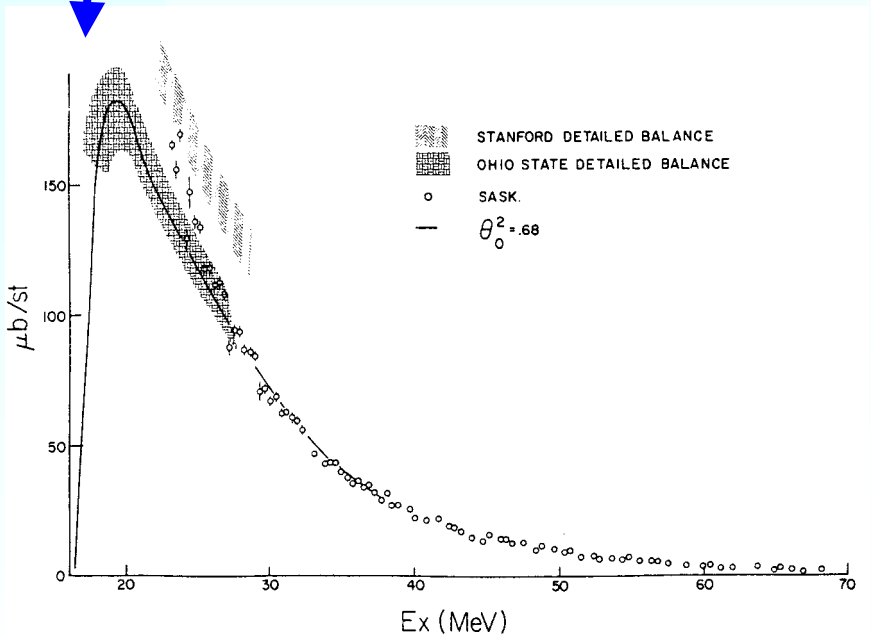
Experimental Results

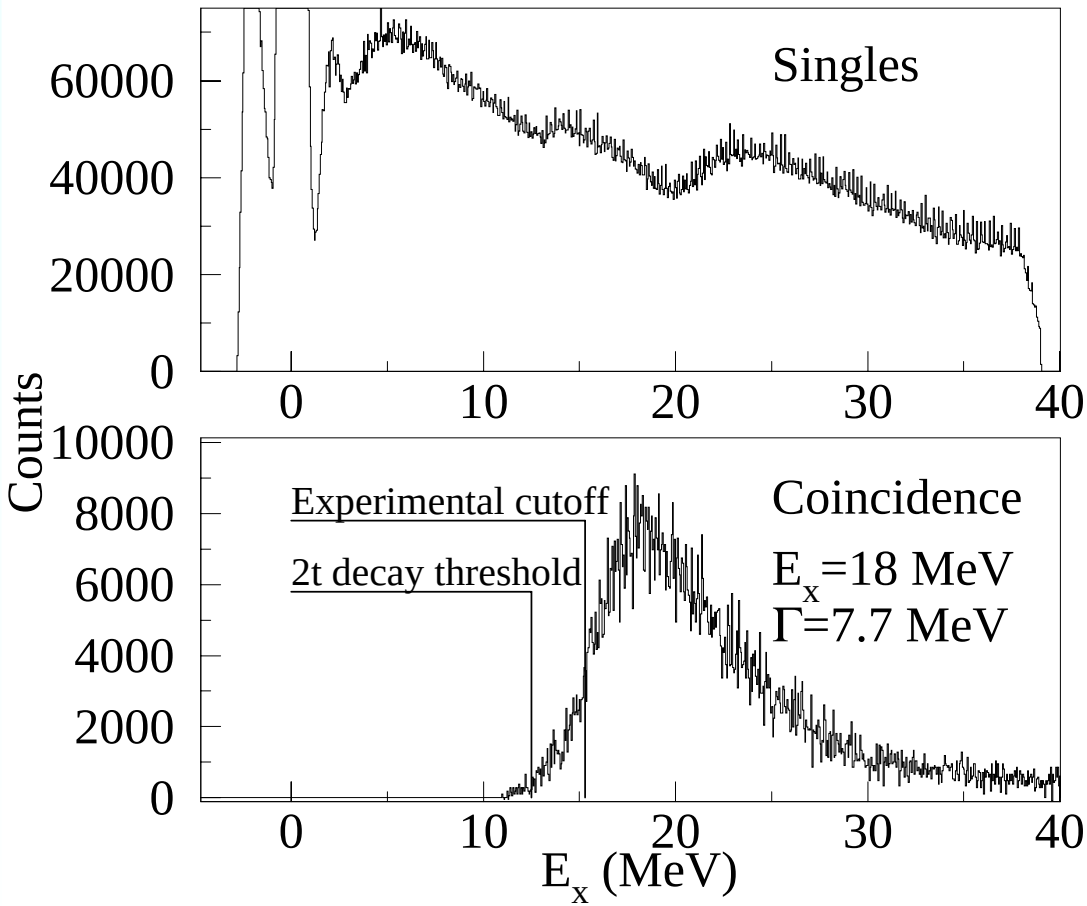
- ^{6}Li(^{7}Li,^{7}Be) ^{6}He -> charged particles
- E_x in ^{6}He V.S. E of all charged particles (p,d,t, α)
- Above 2t decay threshold:
  - 2t decay mode is dominant
  - α +2n mode is suppressed
  - ^{6}He -> 2t is two body decay: locus



Singles and Coincidence Spectra

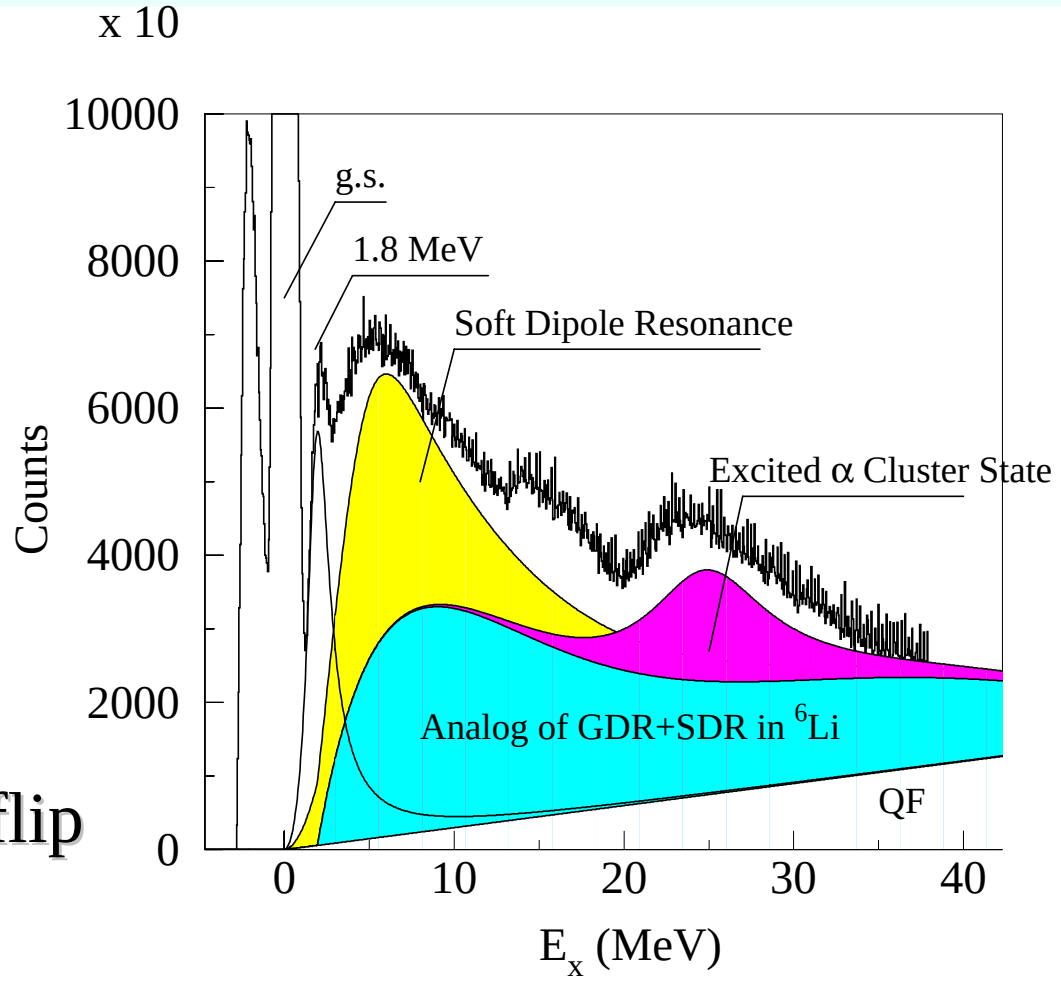
- ^{6}He excitation spectrum gating on 2t decay
- Prominent peak at Ex=18 MeV
  - Dose not appear in singles spectrum
  - Similar to ^{6}Li(**γ** ,t) spectrum
    - Y.M. Shin et al. PLB 55B (1975), 297
  - Common to A=6 System





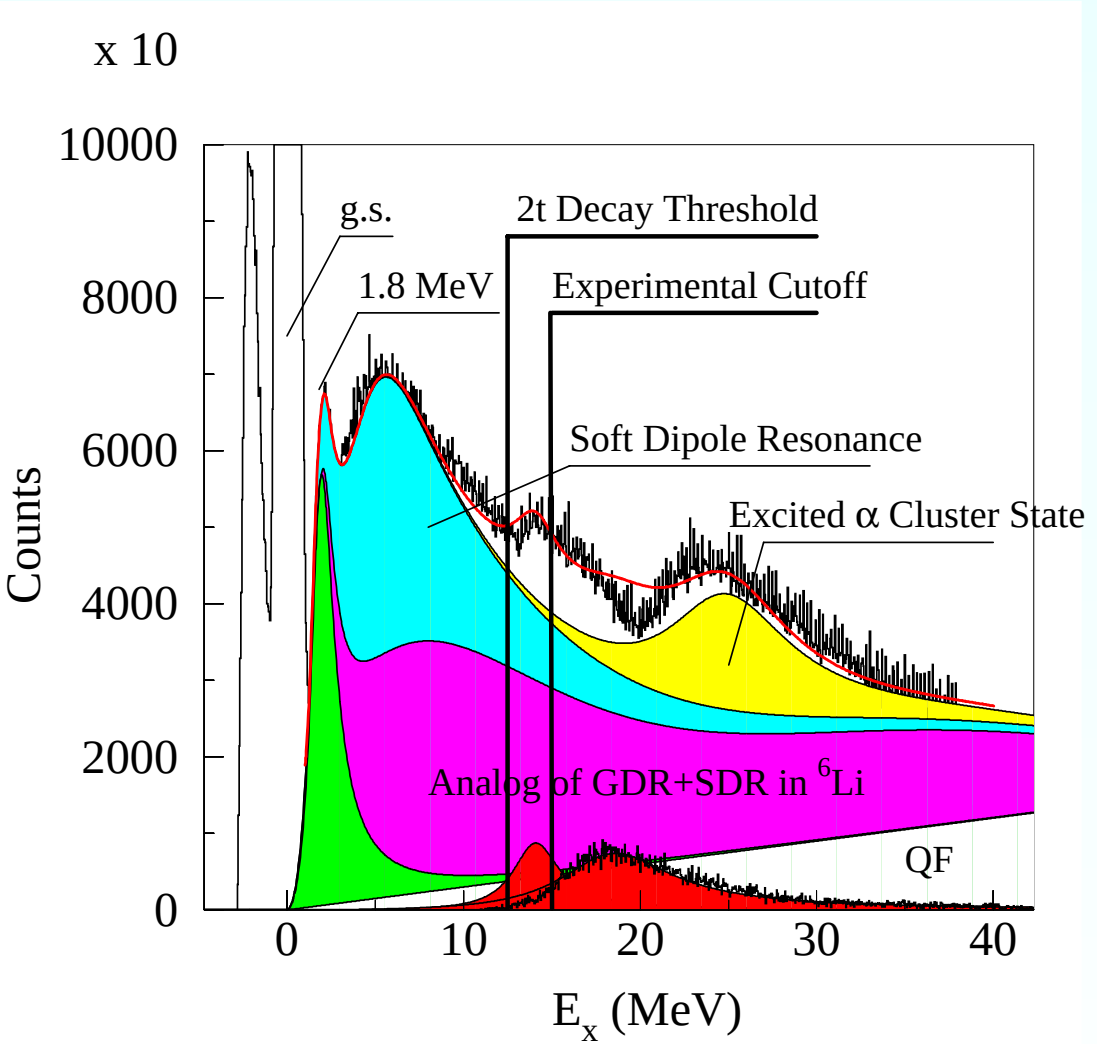
Peak Fitting Procedure for ^{6}He Singles Spectrum

- 1.8 MeV 2^{+}
- E_x~ 4 MeV
  - Soft Dipole Resonance
    - S. Nakayama et al. PRL 85 (2000), 262
- E_x~ 8 MeV
  - Analog of GDR+SDR in ^{6}Li
    - ^{6}Li(**γ** ,n) reaction
- E_x~ 15 MeV
  - ??
  - Assigned to be 1^{-} or 2^{-} Spin-flip resonance state
    - J. Janeke et al. PRC 54 (1996), 1070
- E_x~ 23 MeV
  - Excited **α** Cluster Resonance
    - S. Nakayama et al. PRL 87 (2001), 122502



Peak Fitting with Coincidence Spectrum

- Branching ratio for 2t decay is ~100%
- Ex = 18 MeV
  - Higher than the bump at 15 MeV in singles spectrum

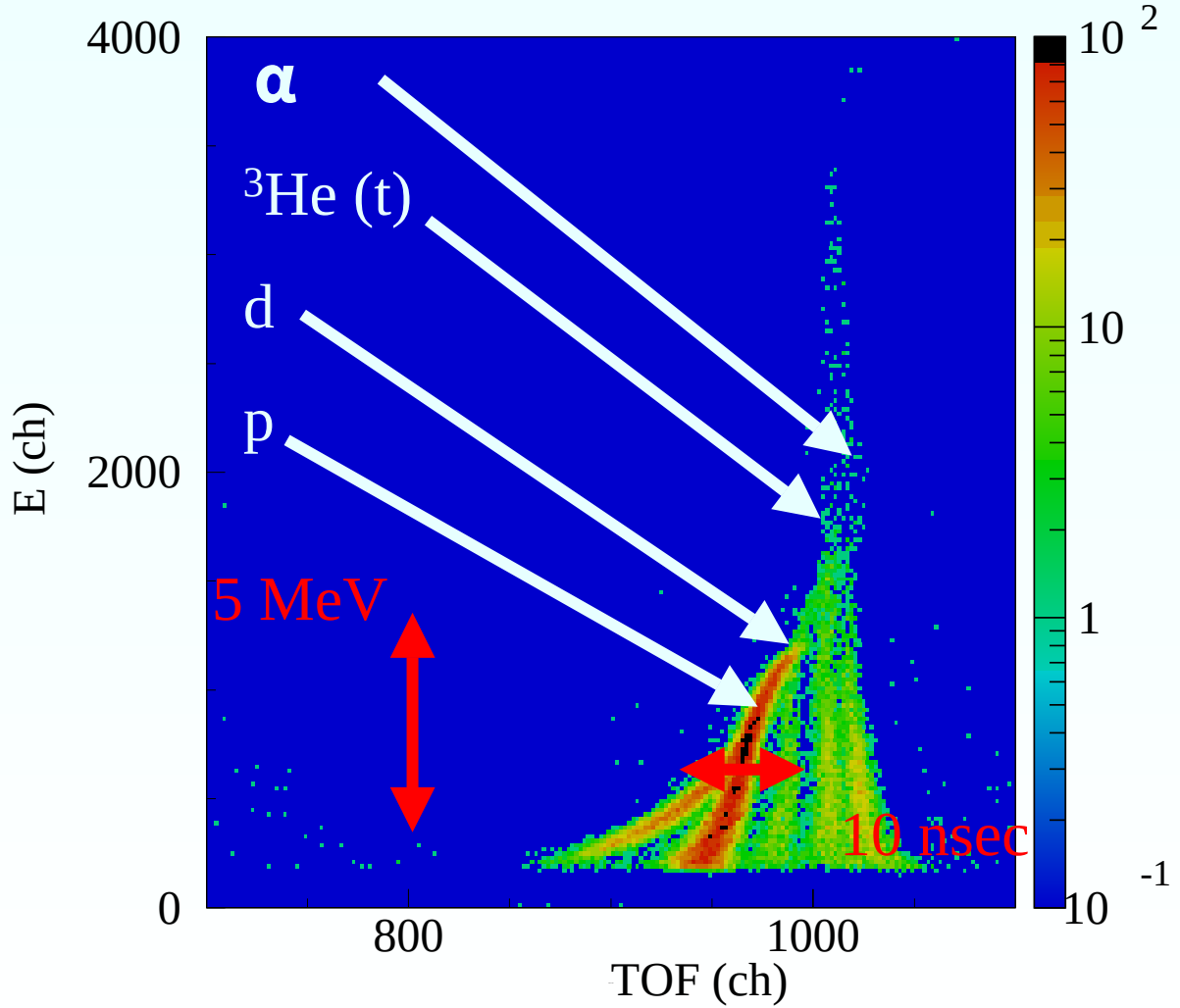


^{6}Li(^{3}He,t+X) Reaction at 150 MeV/A

- Search for ^{3}He+^{3}He molecular structure in ^{6}Be
- Similar setup with ^{6}Li(^{7}Li,^{7}Be) experiment
- ^{6}Be is proton rich nucleus:
  - Many charged particle decay modes:
    - (p, d, t, ^{3}He, **α**)
    - -> Particle Identification is needed

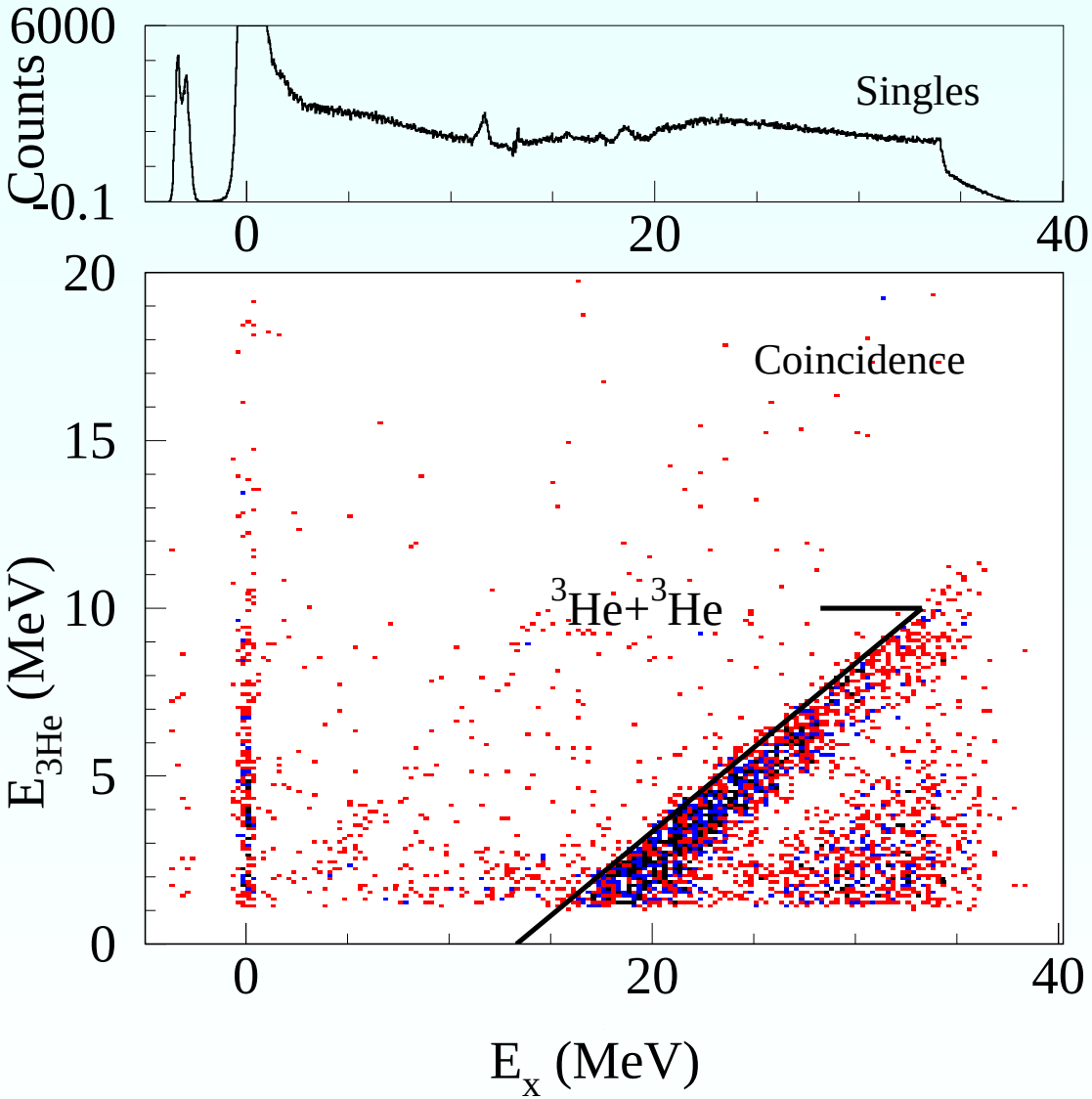
Particle Identification for Decay Particles

- Energy and Time of Flight
  - Between RF signal and Trigger
- Thin (500 μm) Surface burrier type SSD's
- Time resolution:
  - 1.5 nsec
  - Up to 20 MeV



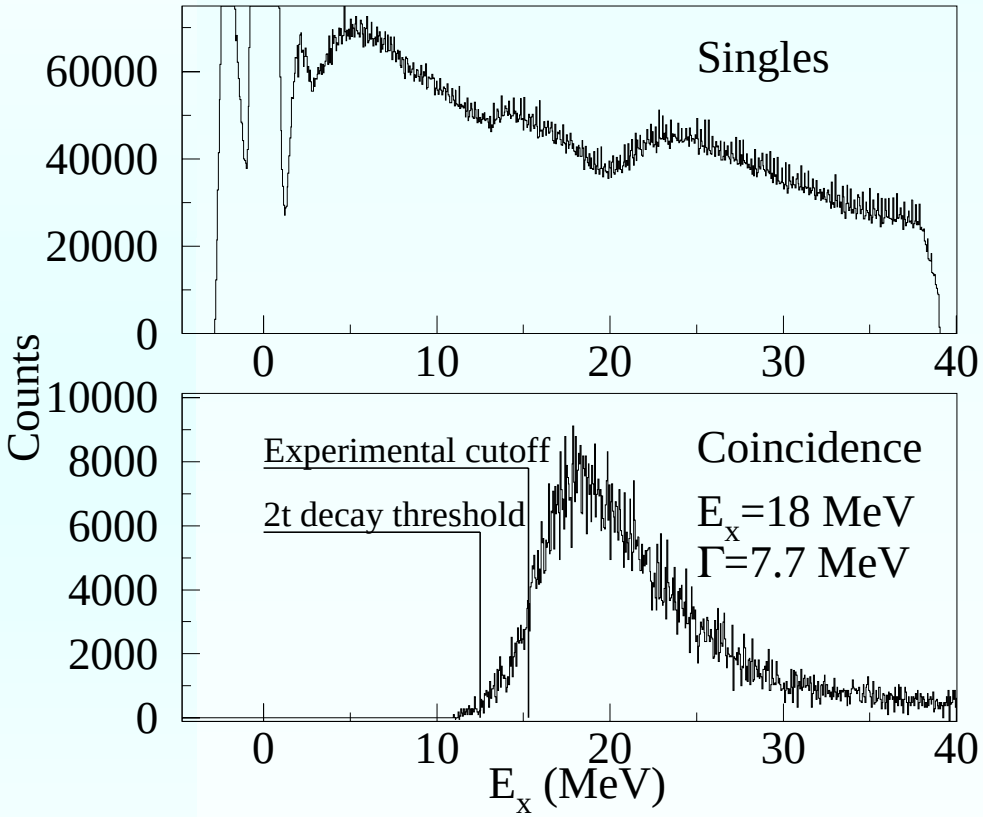
Singles and Coincidence Spectra

- ^{6}Li(^{3}He,t) ^{6}Be ->
- charged particles
- E_x in ^{6}Be V.S. E of ^{3}He
- Above 2^{3}He decay threshold:
  - ^{6}Be -> 2^{3}He is two body decay: locus



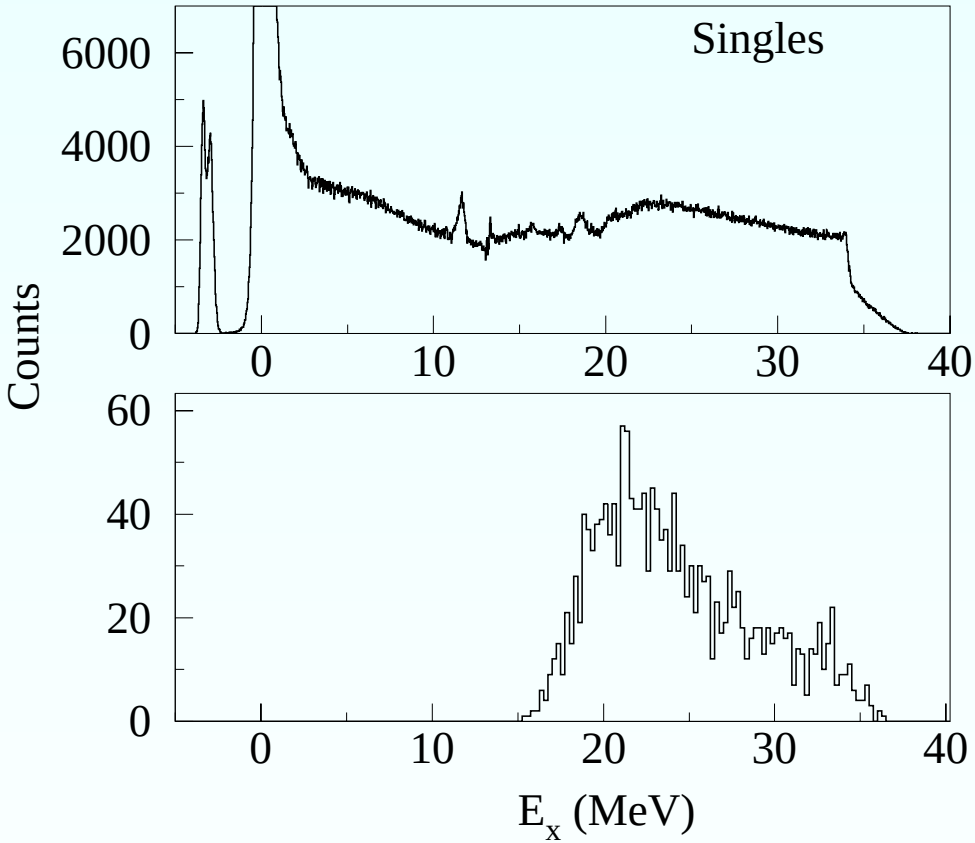
Singles and Coincidence Spectra

- Similar to 6Li(7Li,7Be)



^{6}Li(^{7}Li,^{7}Be) at 65 MeV/A

2t decay

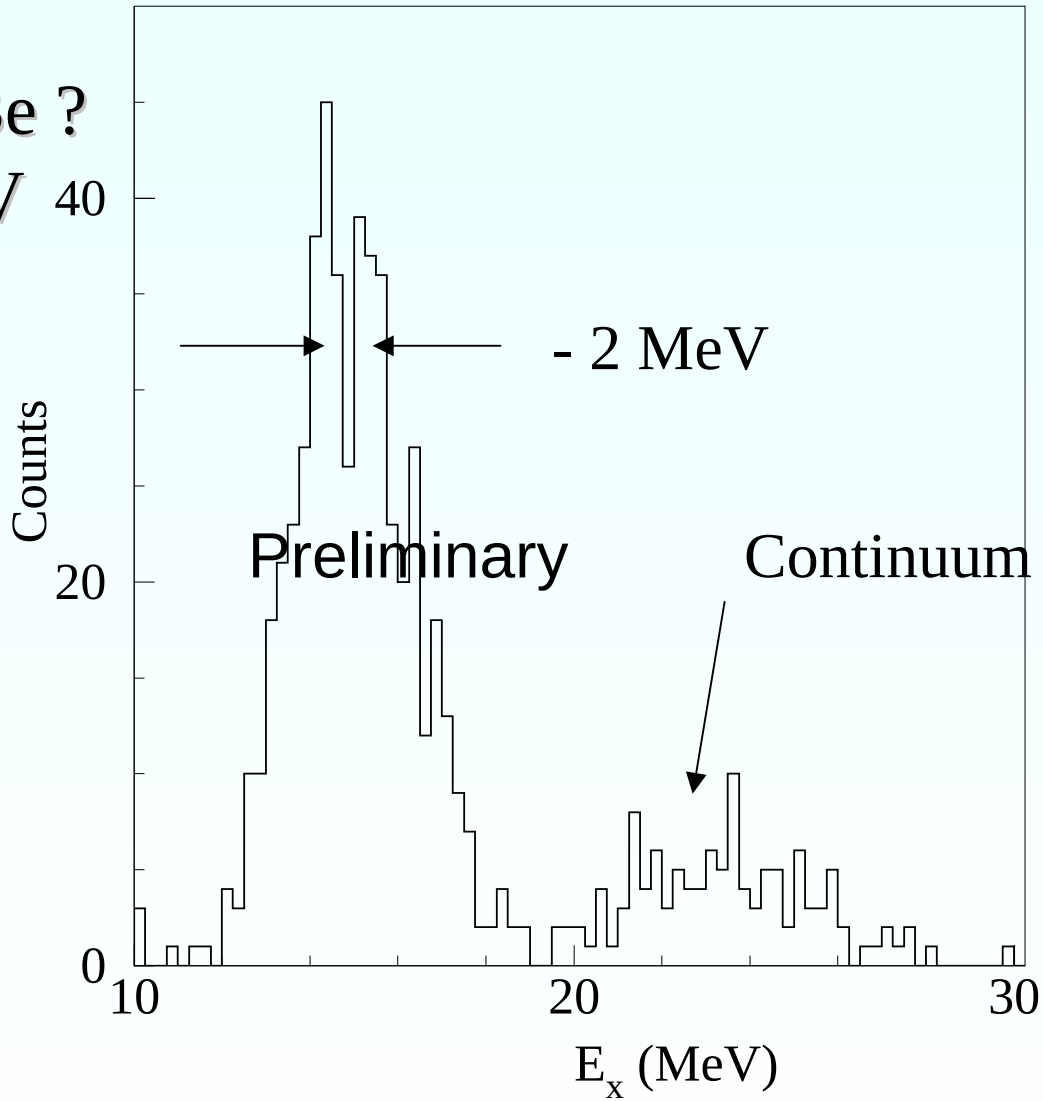


^{6}Li(^{3}He,t) at 150 MeV/A

2^{3}He decay

Excitation energy in ^{6}Be

- Projection to excitation energy in ^{6}Be
- $4 < E_{3He} < 6$ MeV
- Rotational band in
  - 2^{3}He molecular state in ^{6}Be ?
- Energy loss in target: 500 keV
- Recoil energy: 150 keV



Summary

- We found 2t resonance state in ^{6}He via ^{6}Li(^{7}Li,^{7}Be) reaction at $E_{^{7}Li}$=65 MeV/A
- 2t decay branching ratio is ~100%
- E_x =18 MeV Γ = 7.7MeV
- Consistent with:
  - ΔL=1 transition found in other (n,p) type experiments
  - RGM prediction t+t ^{3}P resonance state
  - Tri-nucleon state suggested in ^{6}Li via ^{6}Li(γ ,t) reaction
- Charged particle decay following (p,n) type excitation
  - ^{6}Li(^{3}He,t X) at RCNP