

Pionic fusion study of the halo nucleus  ${}^6\text{He}$   
in the reaction  
 $d+{}^4\text{He} \rightarrow {}^6\text{He}+\pi^+$  at Celsius

M. Andersson  
Chr. Bargholtz  
Kj. Fransson  
E. Fumero  
L. Gerén  
L. Holmberg

K. Lindh  
L. Mårtensson  
I. Sitnikova  
P.-E. Tegnér  
G. Weiss  
K. Wilhelmsen Rolander



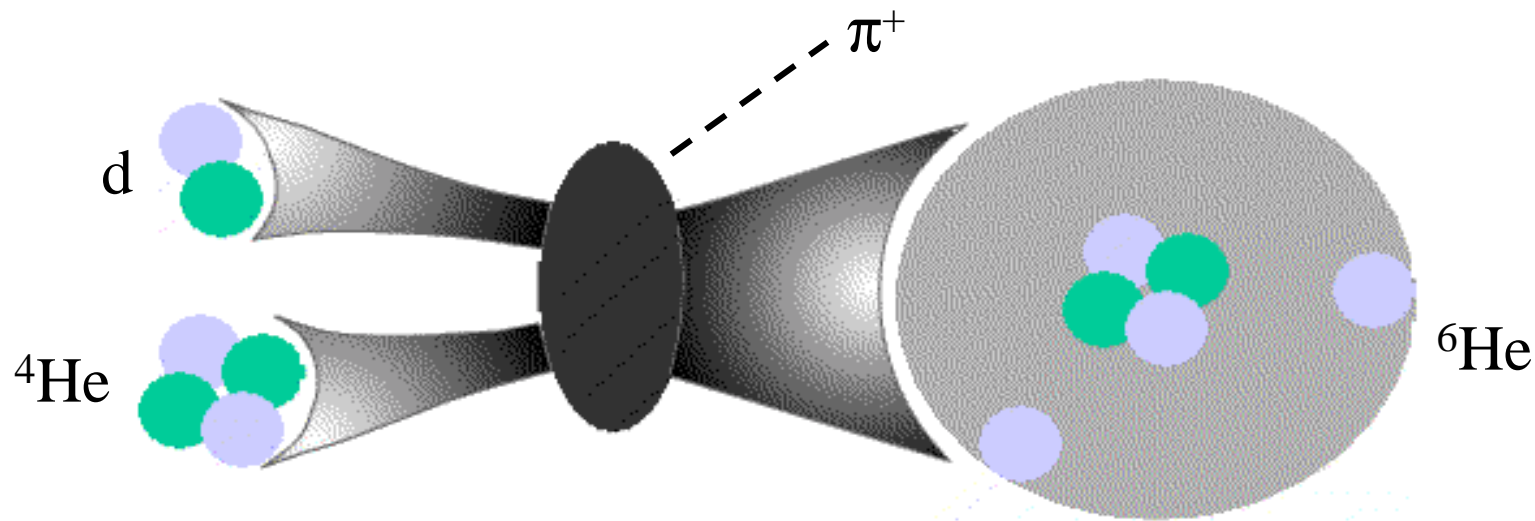
**Linda Gerén, [geren@physto.se](mailto:geren@physto.se)**  
Department of Physics  
University of Stockholm  
Sweden

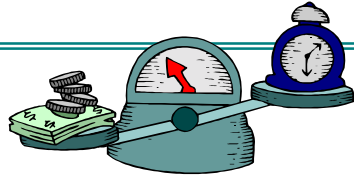


# Idea of experiment

## Cluster Structure of ${}^6\text{He}$

- Measure total and differential cross-section of  $d + {}^4\text{He} \rightarrow {}^6\text{He} + \pi^+$  close to threshold
- Large momentum transfer
- Cross-section sensitive to cluster structure in the  ${}^6\text{He}$  wave function

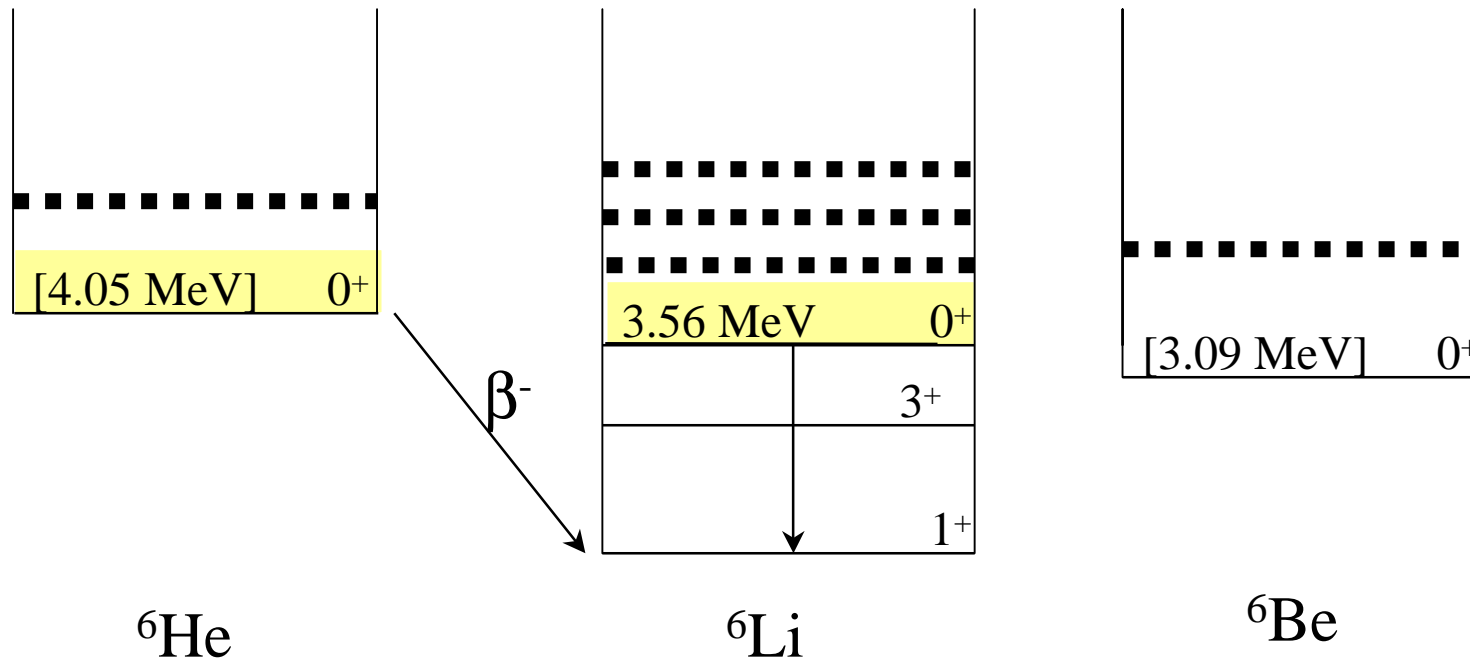




# Mass 6 nuclei

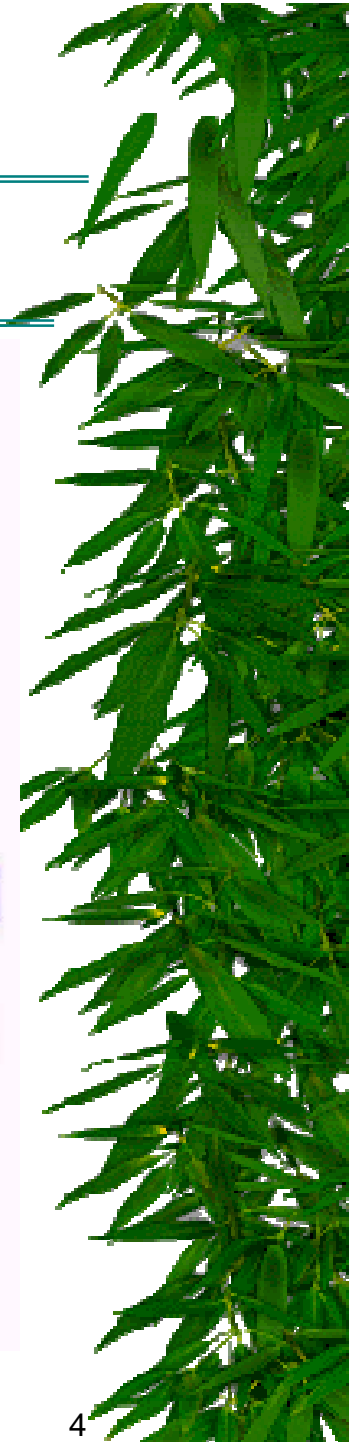
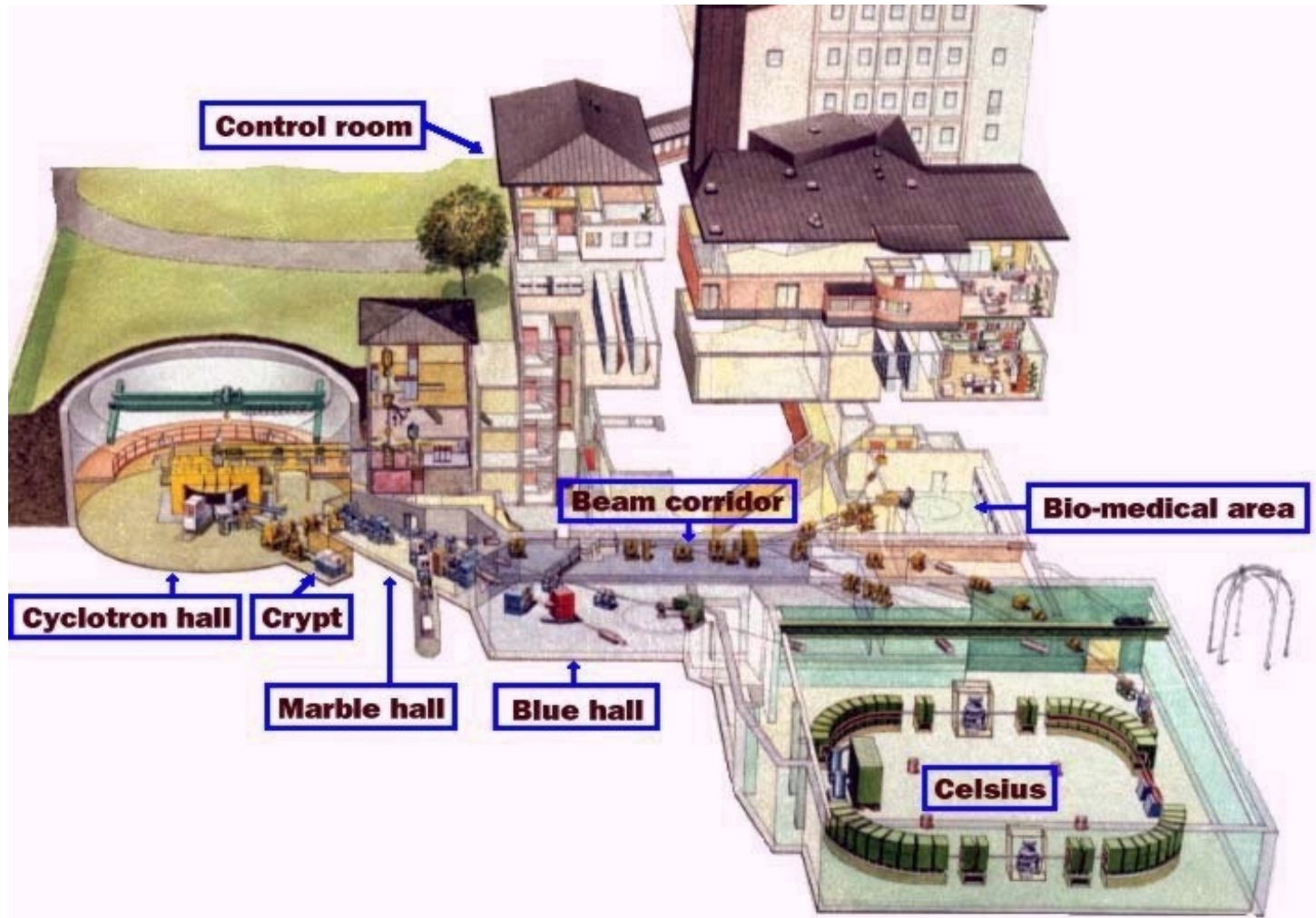
This experiment:  $d + {}^4\text{He} \rightarrow {}^6\text{He} + \pi^+$

Earlier experiment:  $\alpha + d \rightarrow {}^6\text{Li}^* + \pi^0$  where  ${}^6\text{Li}^*$  at 3.56 MeV is the isobaric analogue state of the ground state of  ${}^6\text{He}$



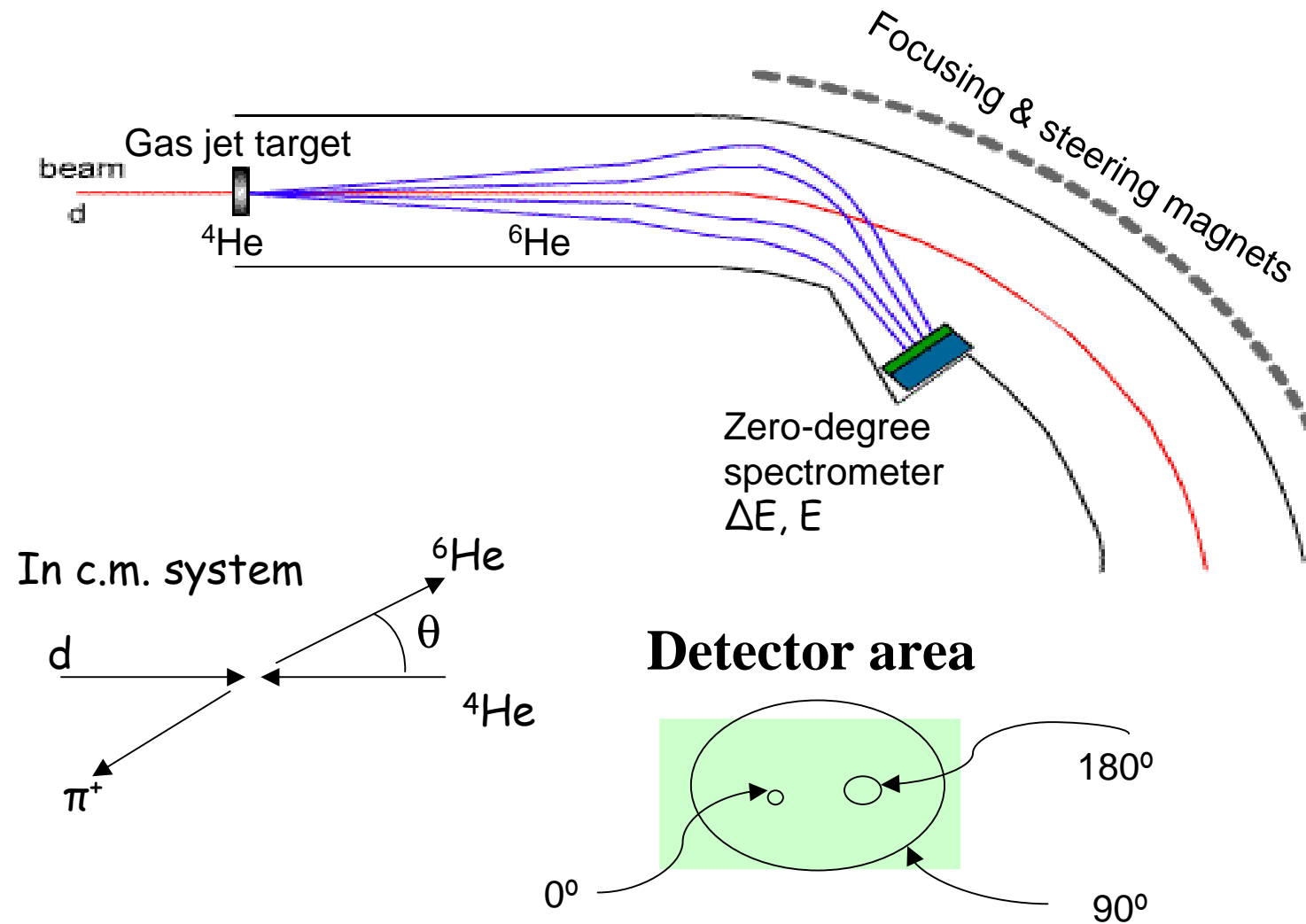


# TSL at Uppsala





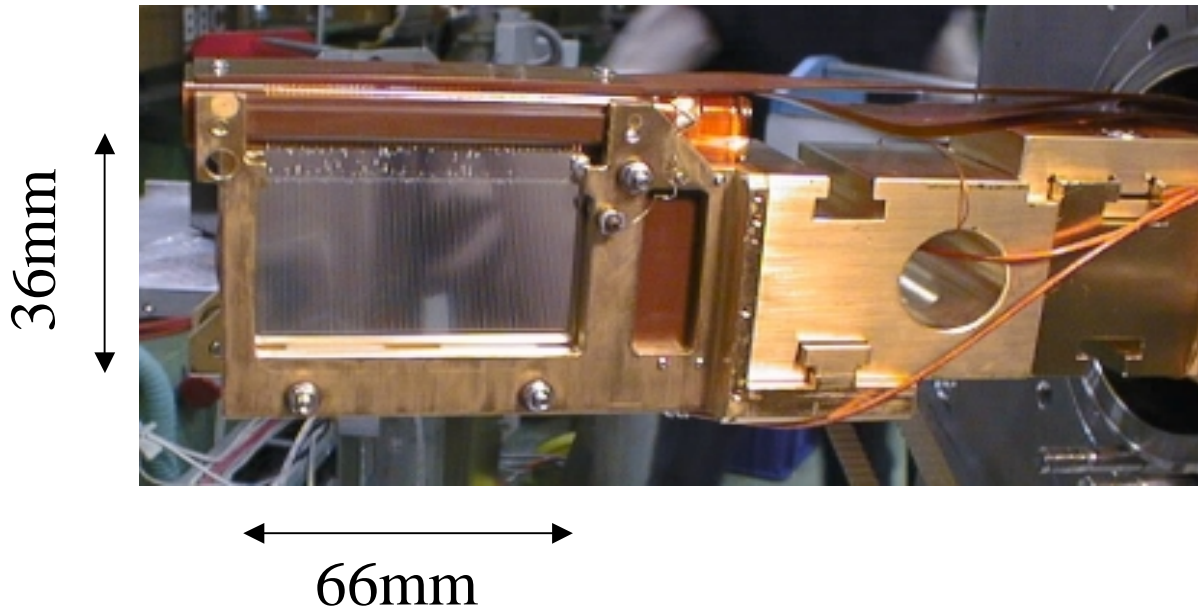
# Detection of ${}^6\text{He}$



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# Zero-degree spectrometer

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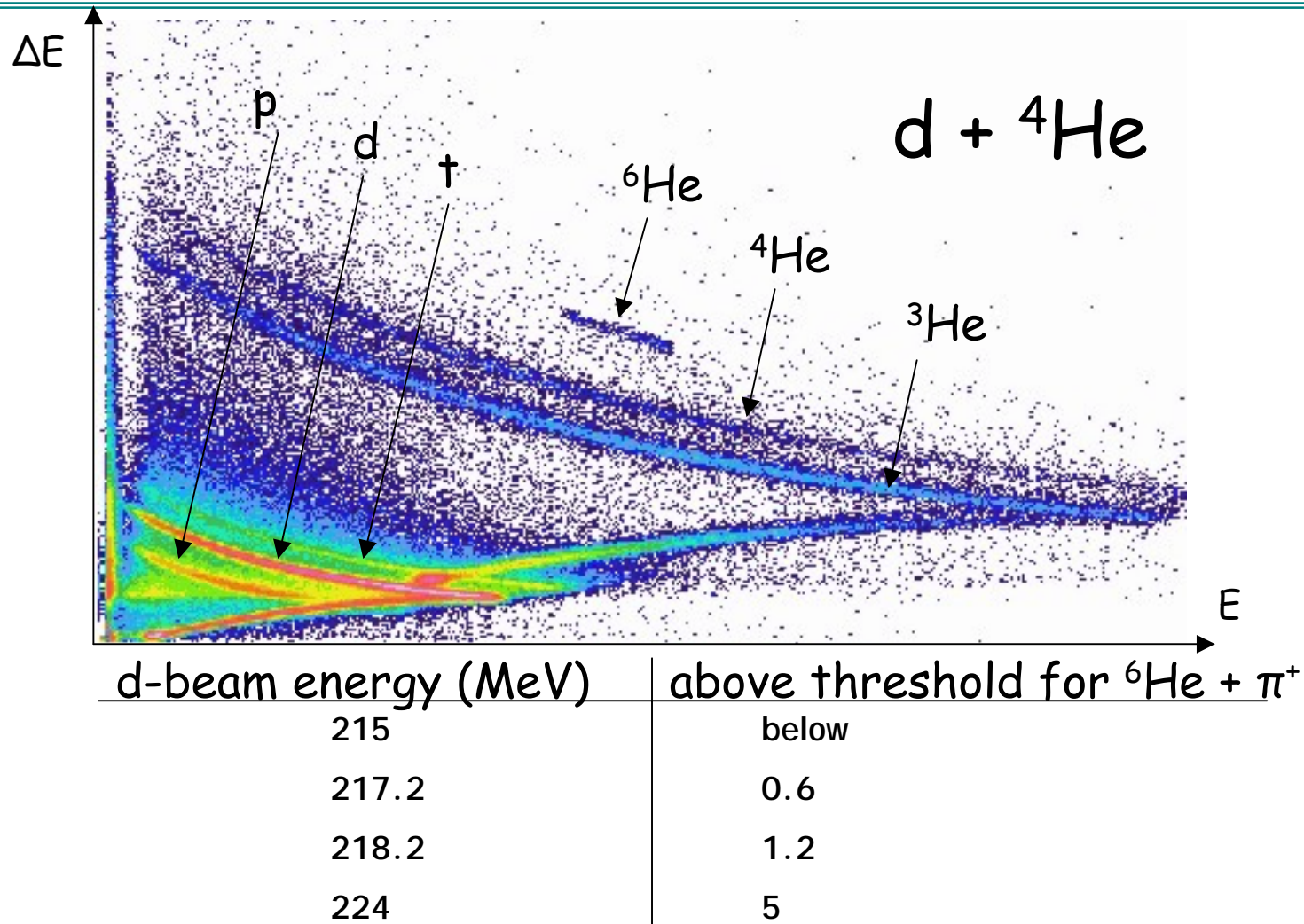


- Consists of two detectors:  
 $\Delta E$ : Si 1.0mm  
E: Ge 1.7 mm

E detector is position sensitive:  
18 horizontal strips  
66 vertical strips



# E - ΔE plot

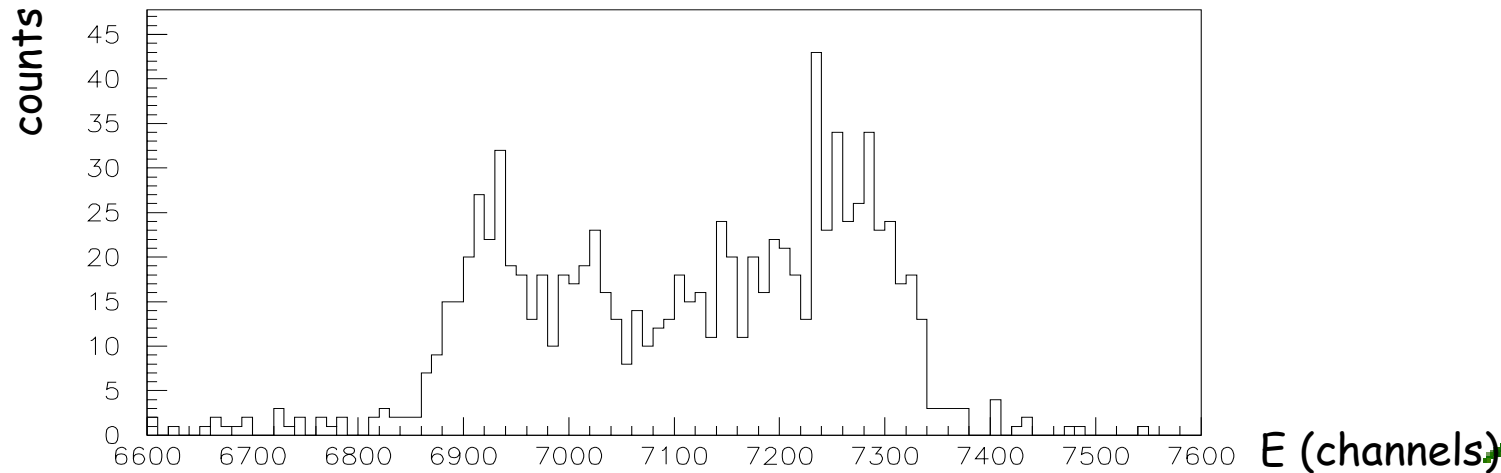




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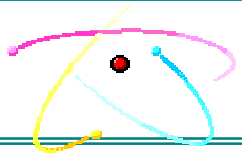
# ${}^6\text{He}$ energy distribution

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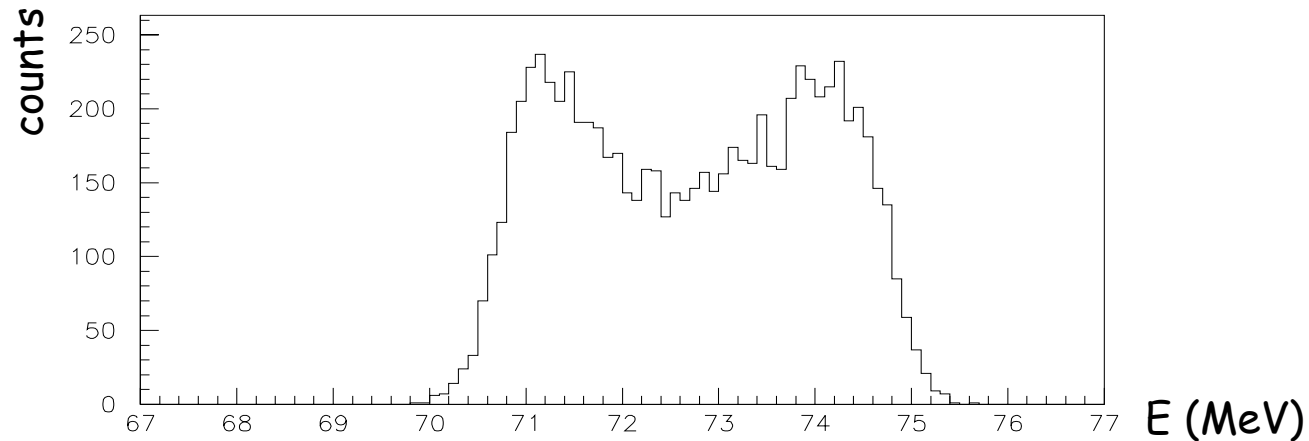


- Peak at higher energy -  ${}^6\text{He}$  emitted in forward direction ( $0^\circ$  in c.m.)
- Peak at lower energy -  ${}^6\text{He}$  at  $180^\circ$  c.m.
- Energy difference between peaks is measure of beam energy





# Simulated energy distribution

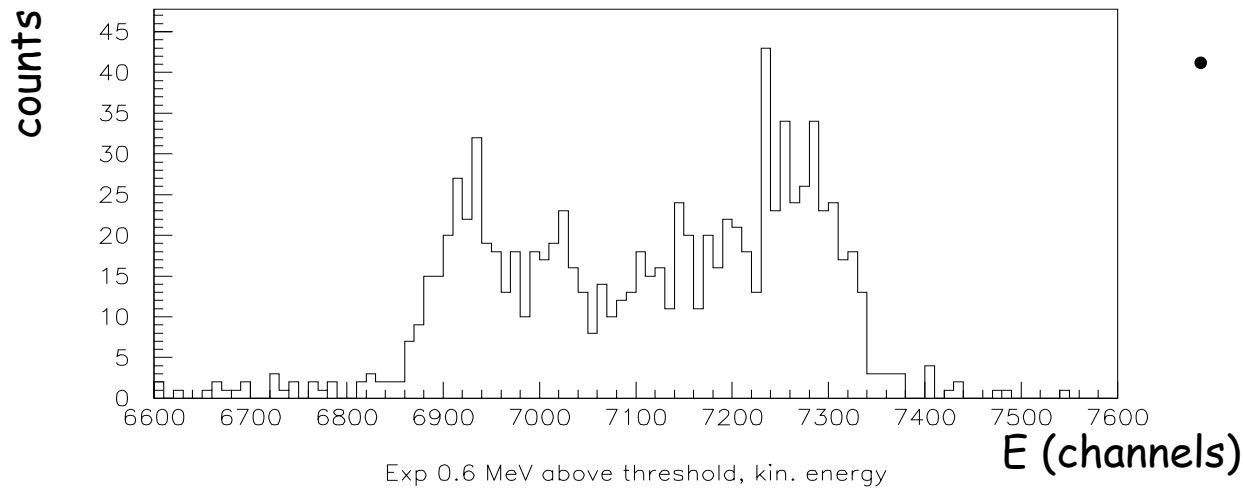


Sim 0.57 MeV above threshold, kin. energy

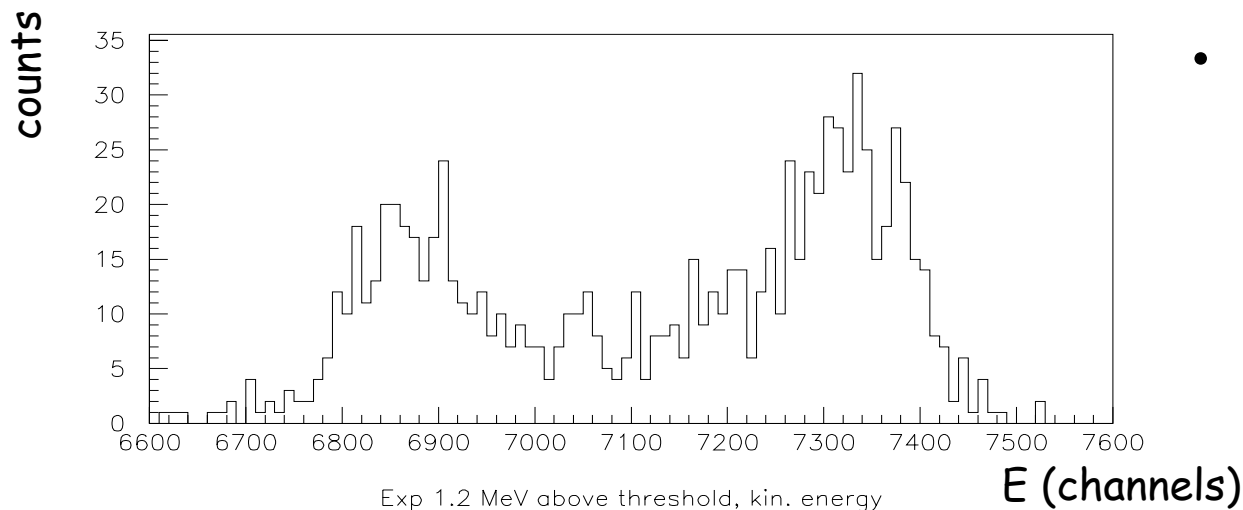
- Monte-Carlo simulations with ray-trace
- Isotropic angular distribution
- d-beam 217.2 MeV, 0.6 MeV above threshold



# ${}^6\text{He}$ events



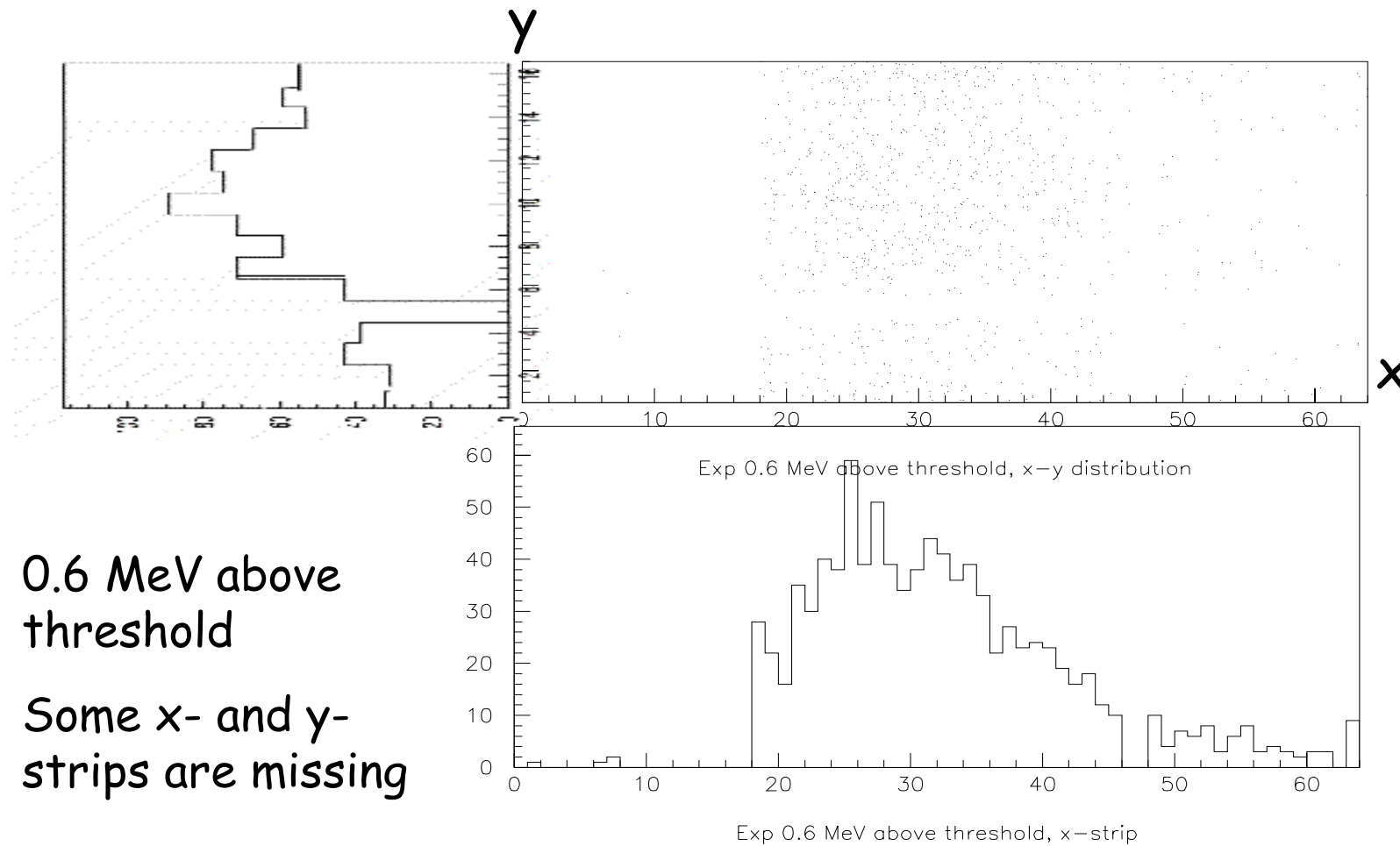
- Beam energy 217.2 MeV, 0.6 MeV above threshold, 941 events



- Beam energy 218.2 MeV, 1.2 MeV above threshold, 921 events



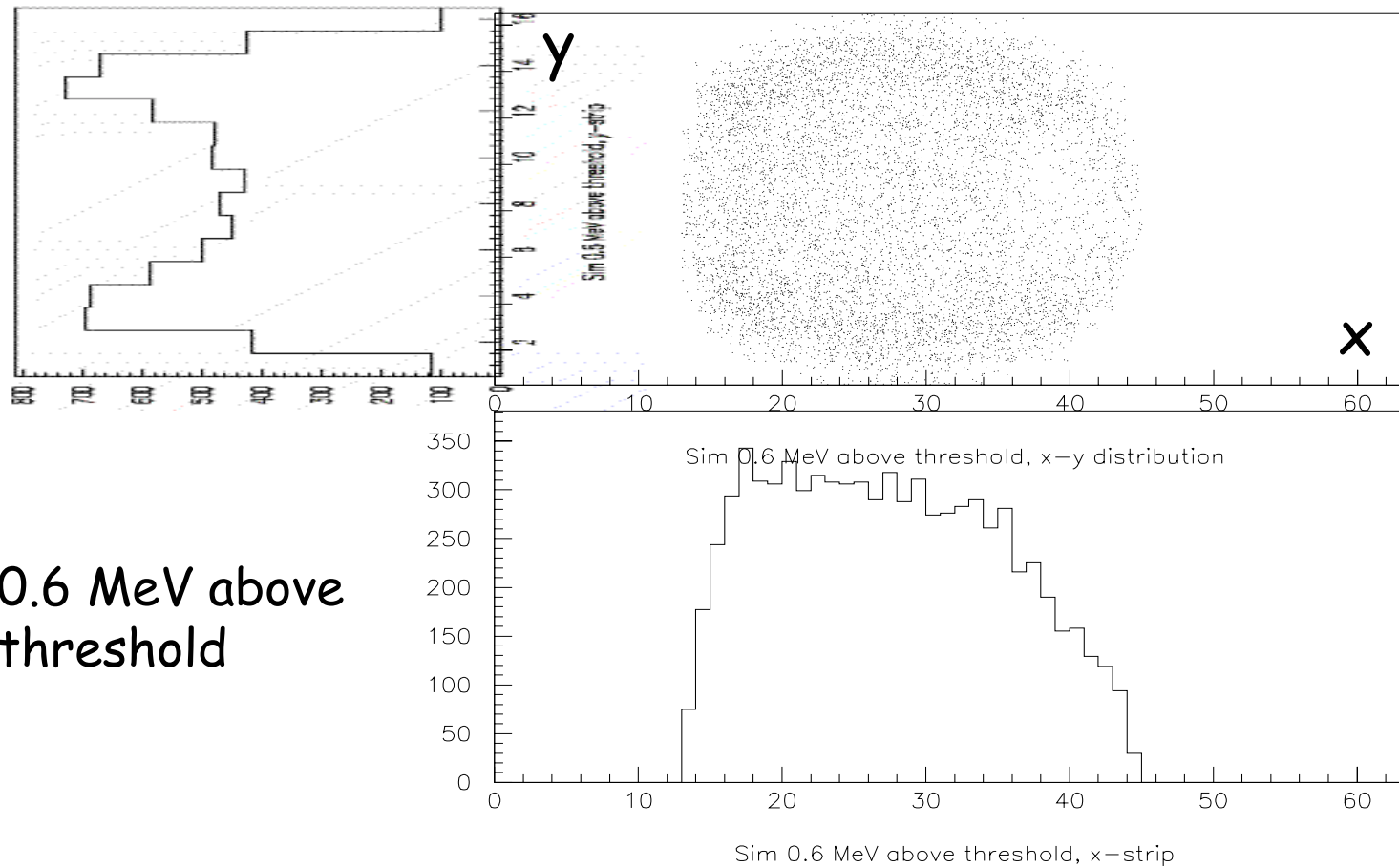
# Experimental x-y distribution of ${}^6\text{He}$

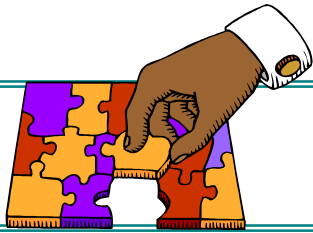


0.6 MeV above threshold

Some x- and y-strips are missing

# Simulated x-y distribution of ${}^6\text{He}$



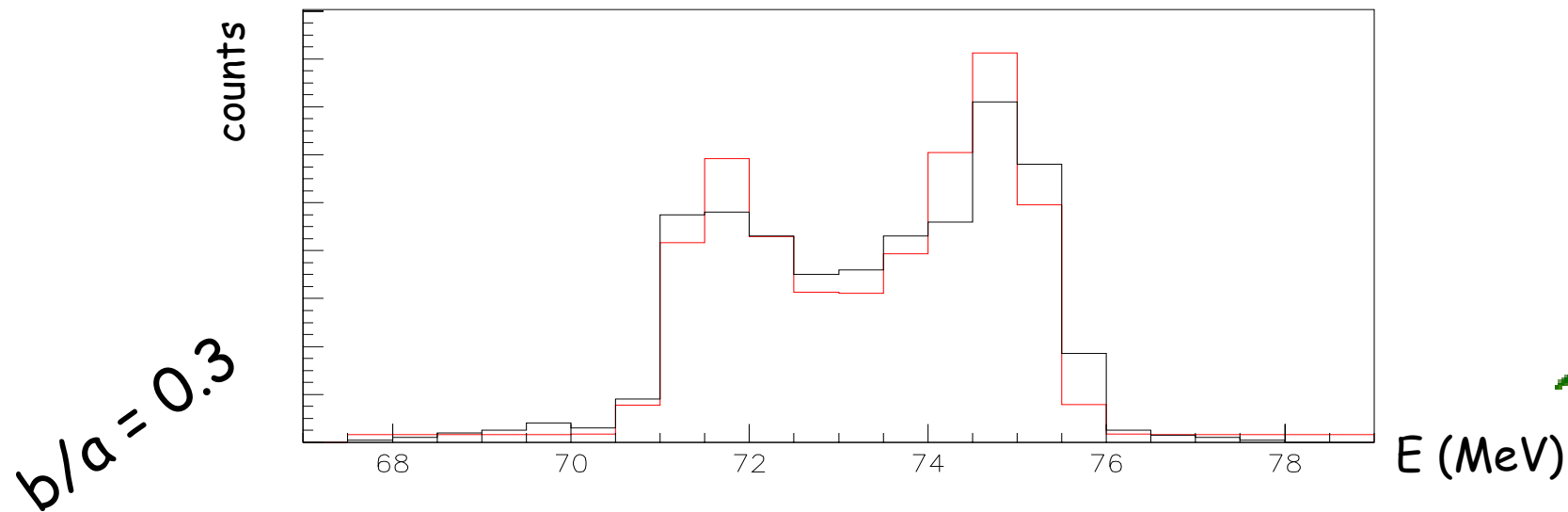


# Fits

- Maximum-Likelihood method
- Simulated data were fitted to experimental using  $f(E,x,y) = a f_1(E,x,y) + b f_2(E,x,y) + c f_3(E,x,y)$  where  $f_1(E,x,y)$  is number of simulated events with energy  $E$ , and coordinates  $(x,y)$  on the detector.
- $f_2(E,x,y)$  represents  $\cos\theta$  distribution
- $f_3(E,x,y)$  represents  $\cos^2\theta$  distribution
- $d\sigma/d\Omega = k(a + b \cos\theta + c \cos^2\theta)$

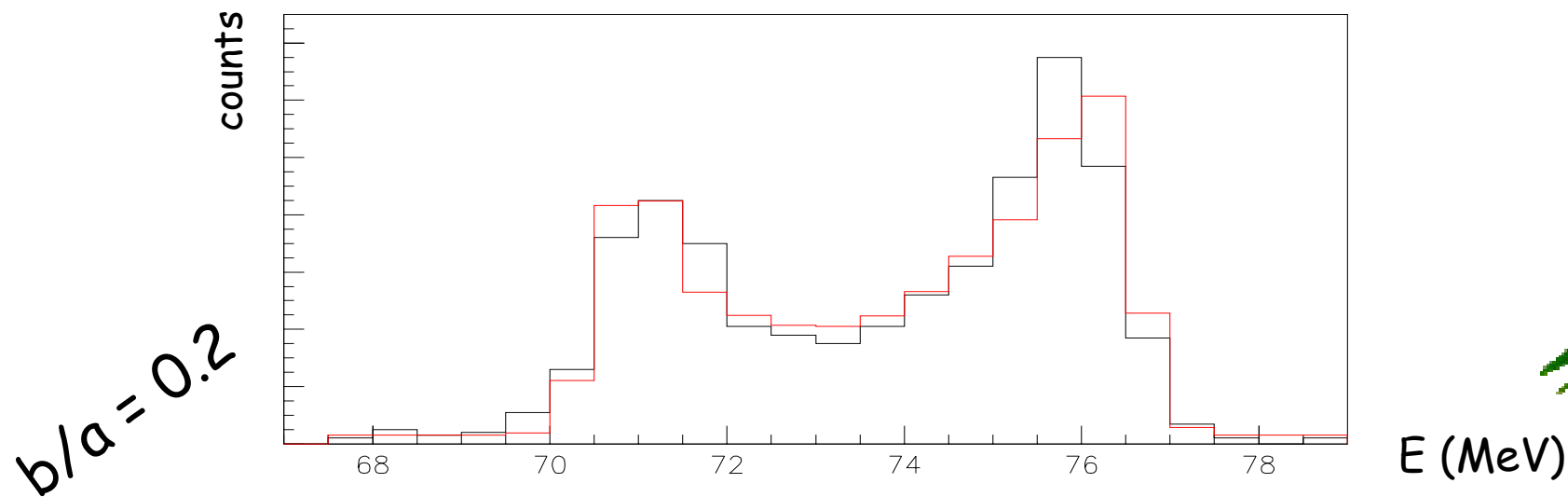


# ${}^6\text{He}$ at 0.6 MeV above threshold



- Preliminary results using energy-information
- Black line is experimental data, red is fit
- Acceptance 78 %
- In  $d\sigma/d\Omega = k(a + b \cos\theta + c \cos^2\theta)$  the coeff. are  $a = 2.7 \pm 0.2$ ,  $b = 0.8 \pm 0.2$ ,  $c = 2.5 \pm 0.5$

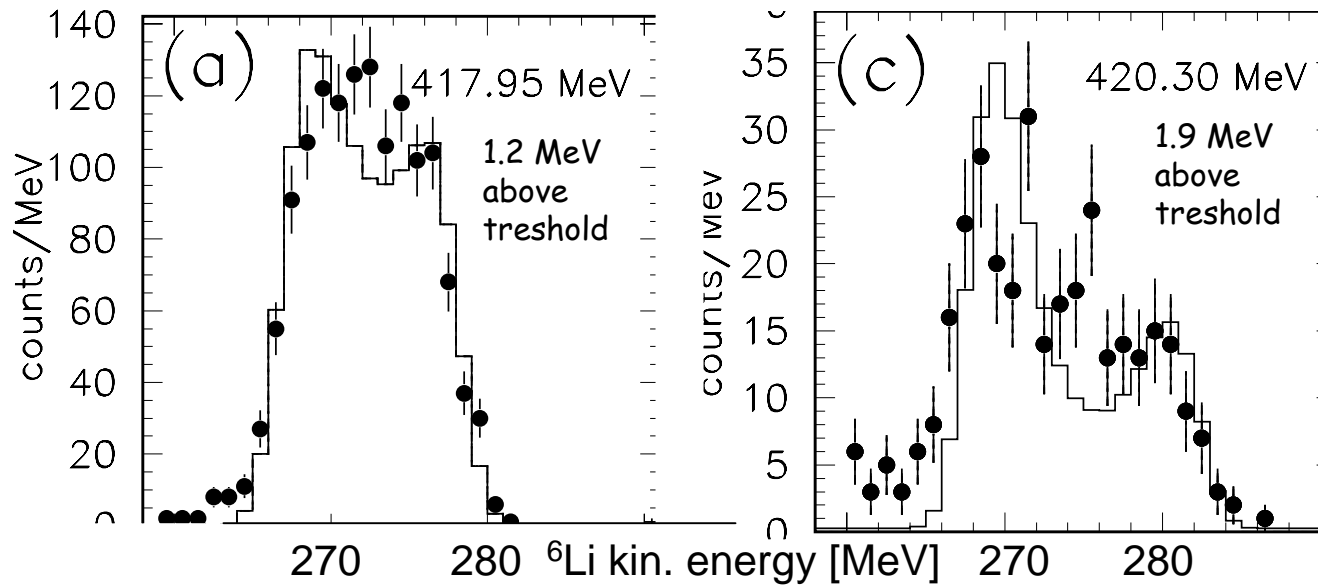
# ${}^6\text{He}$ at 1.2 MeV above threshold



- Preliminary results using energy-information
- Black line is experimental data, red is fit
- Acceptance 49 %
- In  $d\sigma/d\Omega = k(a + b \cos\theta + c \cos^2\theta)$  the coeff. are  $a = 4.6 \pm 0.4$ ,  $b = 0.9 \pm 0.3$ ,  $c = 3.2 \pm 0.7$



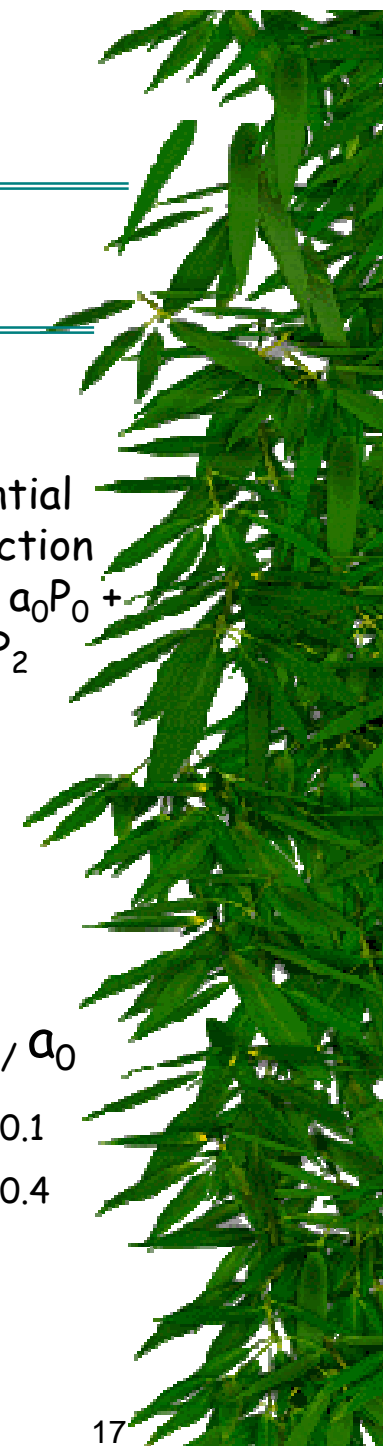
# Results from $\alpha + d \rightarrow {}^6\text{Li}^* + \pi^0$

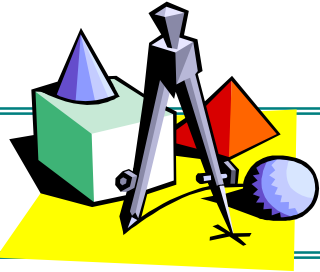


Differential cross section  
 $d\sigma/d\Omega = a_0P_0 + a_1P_1 + a_2P_2$

Beam energy (MeV)	$a_0$ (nb/sr)	$a_1$ (nb/sr)	$a_2$ (nb/sr)	$\sigma$ (nb)	$a_1/a_0$
$417.95 \pm 0.07$	$18.2 \pm 0.8$	$-2.1 \pm 0.8$	$0.2 \pm 1.2$	$228 \pm 10$	-0.1
$420.30 \pm 0.07$	$11.4 \pm 1.3$	$-4.6 \pm 1.0$	$-1.2 \pm 1.5$	$144 \pm 18$	-0.4

From M. Andersson et al., Phys. Lett B. 481 (2000) 165

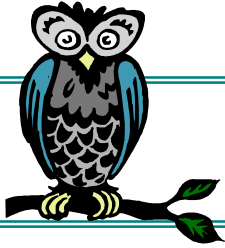




# Comparison

	Q (MeV)	Asymmetry (b/a)	Cross section
This experiment: $d + {}^4\text{He} \rightarrow {}^6\text{He} + \pi^+$	0.6	0.3	$\frac{\sigma(1.2)}{\sigma(0.6)} = 1.6$
	1.2	0.2	
Earlier experiment: $\alpha + d \rightarrow {}^6\text{Li}^* + \pi^0$	1.2	-0.1	$\frac{\sigma(1.9)}{\sigma(1.2)} = 0.63$
	1.9	-0.4	





# Summary

- We have measured pion production in two experiments
- Cross sections:  
 $d + {}^4\text{He} \rightarrow {}^6\text{He} + \pi^+ \Rightarrow \sigma \text{ increases with energy}$   
 $\alpha + d \rightarrow {}^6\text{Li}^* + \pi^0 \Rightarrow \sigma \text{ decreases with energy}$
- Asymmetry with respect to the heavier particle in initial system has the same sign
- Different energy dependences of asymmetry

