Pionic Fusion Study of 3N Clustering in the A=6 System

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Why pionic fusion?

We study the reaction: $^{3}He + {}^{3}He \rightarrow {}^{6}Li + \pi^{+}$

the experiment is sensitive to the high momentum parts of the wave function

$$^{4}He + d \rightarrow {}^{6}Li_{\mathbf{3.56}} + \pi^{0}$$

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

$$d + {}^{4}He \rightarrow {}^{6}He_{\mathbf{g.s}} + \pi^{+}$$

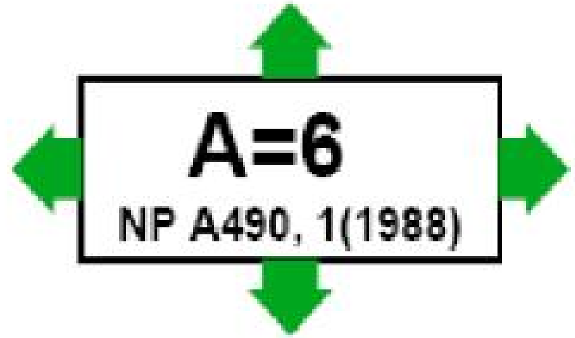
M. Andersson et al. Nuclear Physics A 779 (2006) 47

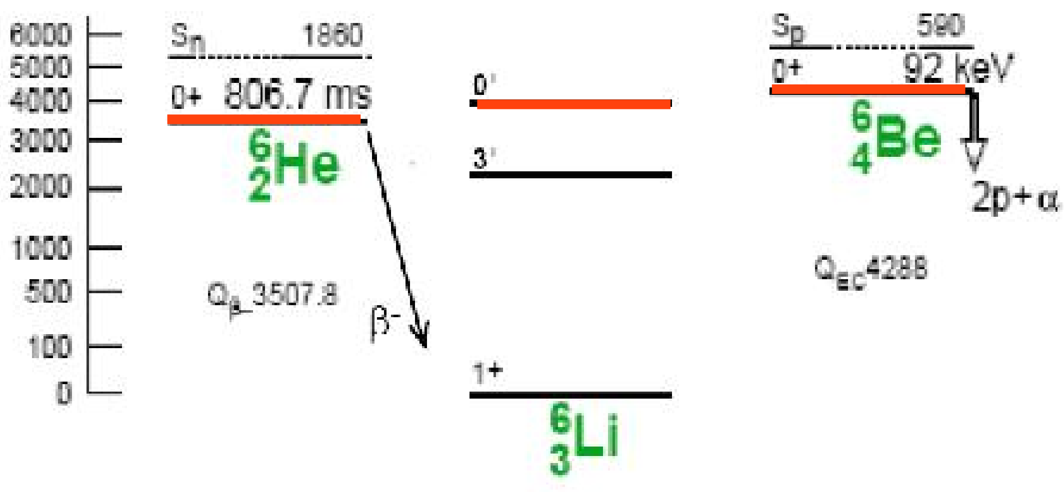
Why $^3He + ^3He$?

- ^6Li can be described as a bound state of $^3He + ^3H$
  Le Bornec et al. PRL 47 (1981) 1870

- In the present experiment we probe the relative wave function between ^3He and ^3H
- In $^4He + d \to {}^6Li_{3.56} + \pi^0$ we probe the relative wave function between ^4He and dineutron.

What are isobaric states?





Why halo nuclei?

1. In 1985 Tanihata discovered abnormally spatially extended nuclei, such as $^{6,8}He$, ^{11}Li, ^{11}Be

2. They are interesting quantum mechanical systems

3. They are also interesting in astrophysical processes and especially in nucleosynthesis

What are halo nuclei ?

A halo nucleus consists of a core that is surrounded by one or more nucleons with wave functions extending far beyond the core (usually neutrons)

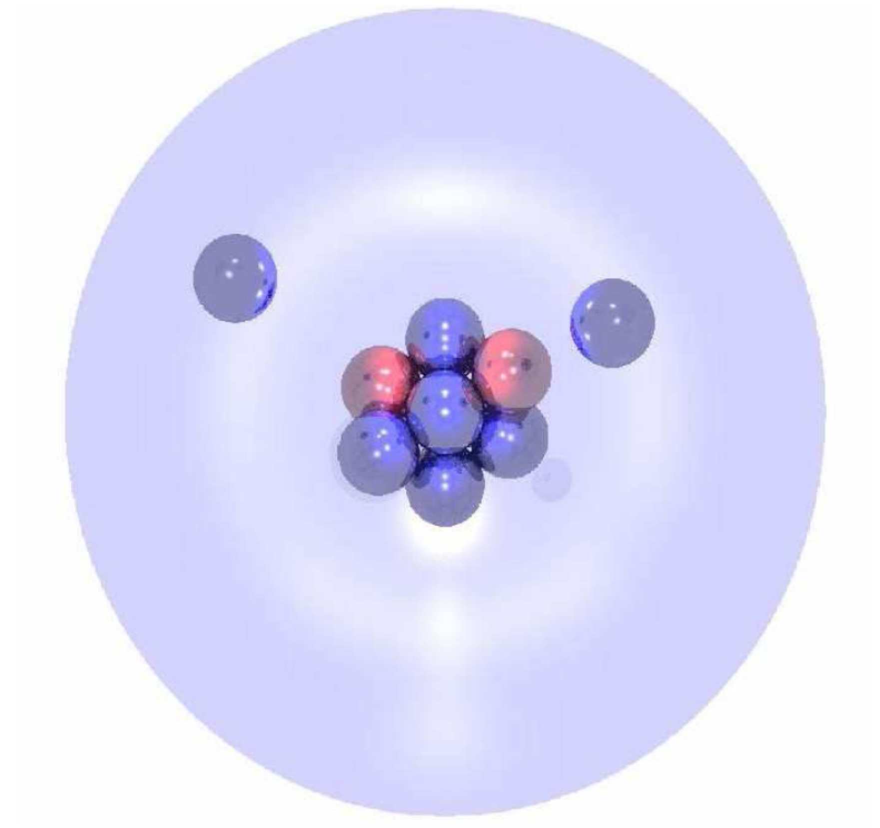
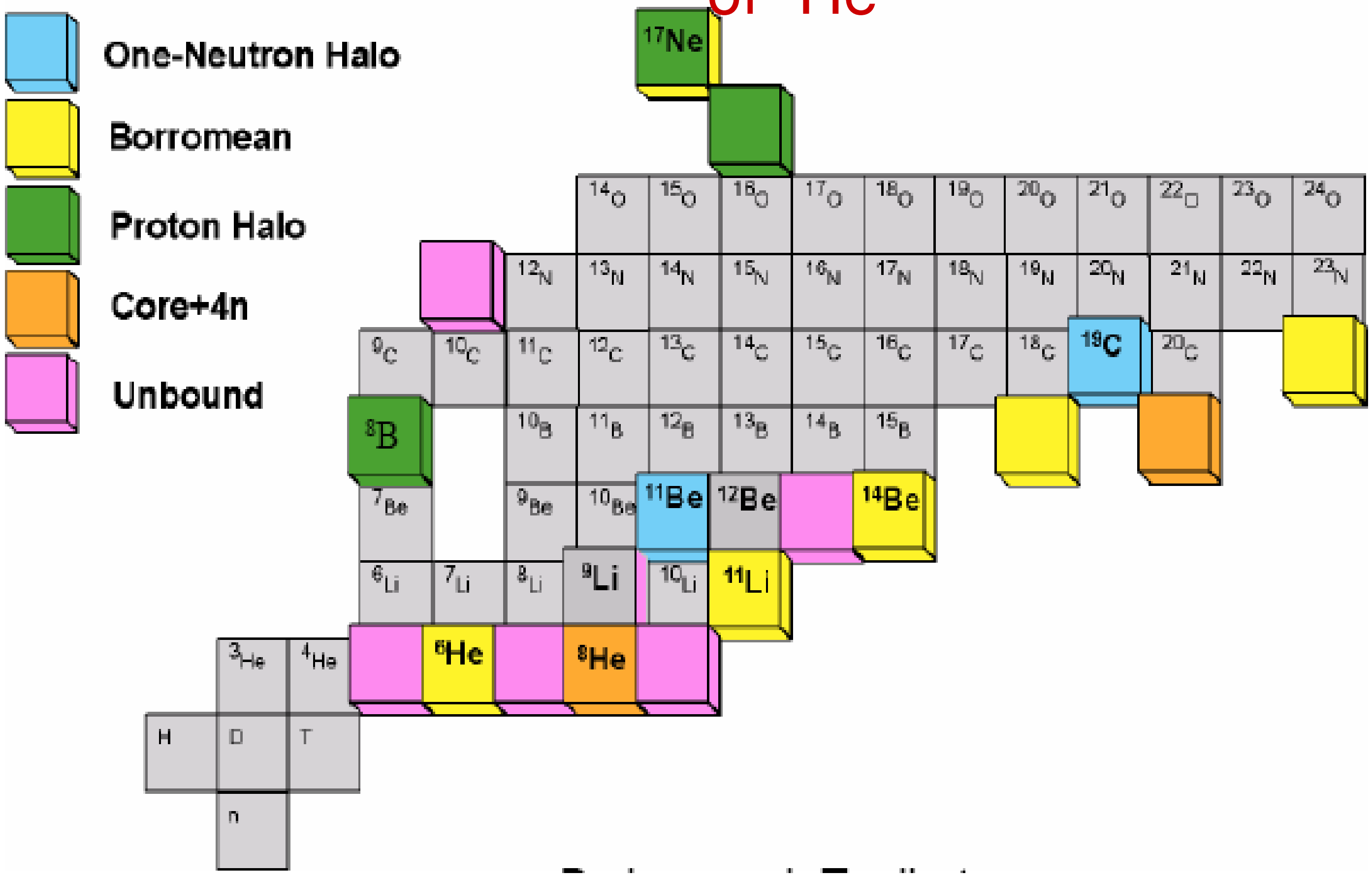


Fig.1: Halo nuclei Li11 Source: GSI

Light nuclei

3.56 MeV excited state in ^{6}Li is the analogue state of the g.s of ^{6}He



Previous experiments

- Isospin selective: I = 1 states of the A=6 nuclei selected

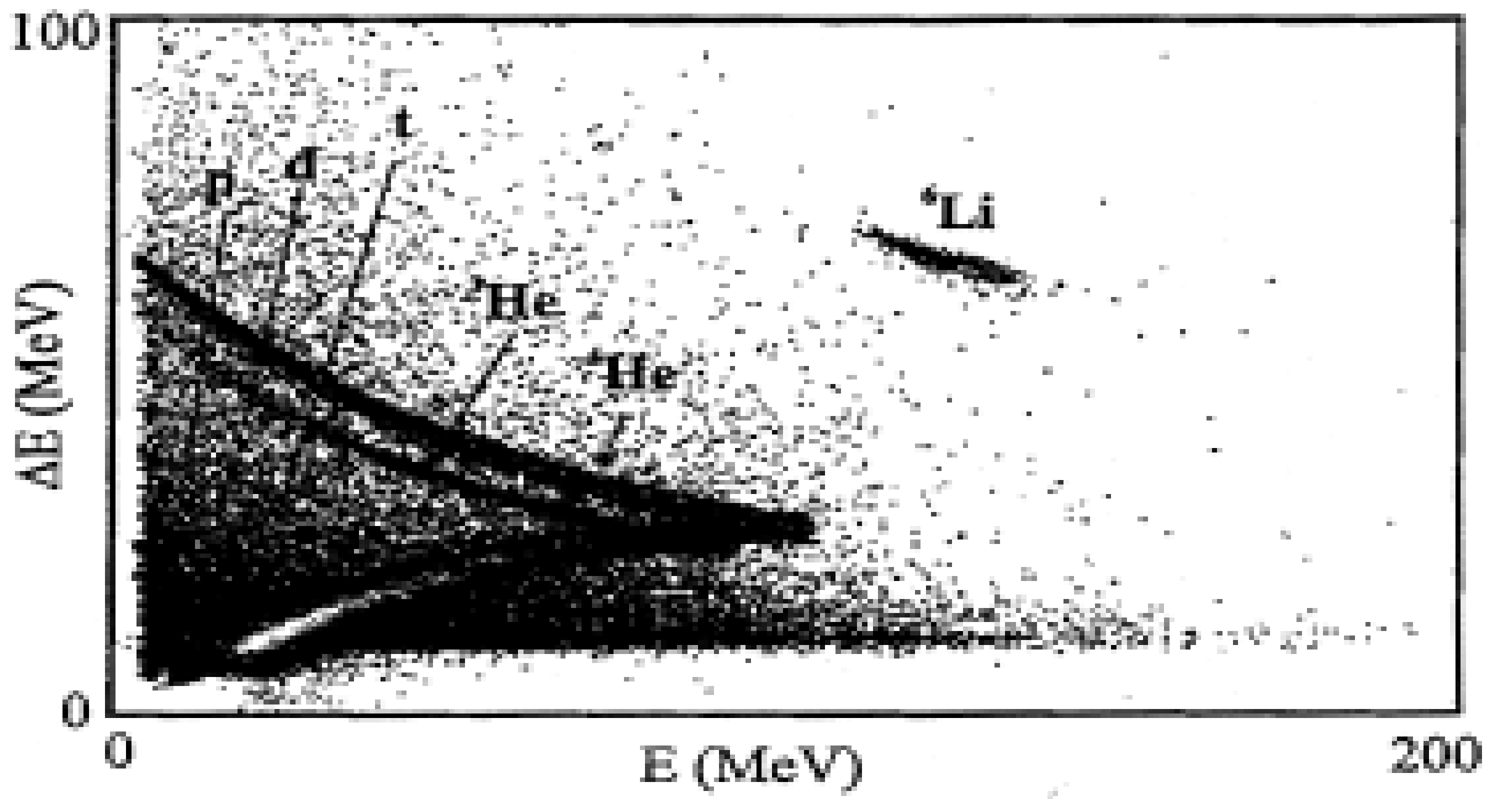
$$^{4}He + d \rightarrow {}^{6}Li_{3.56} + \pi^{0}$$

$$d + {}^{4}He \rightarrow {}^{6}He_{g.s} + \pi^{+}$$

- Isospin non selective, both ground and I = 1 excited states are produced

$$^{3}He + {}^{3}He \rightarrow {}^{6}Li + \pi^{+}$$

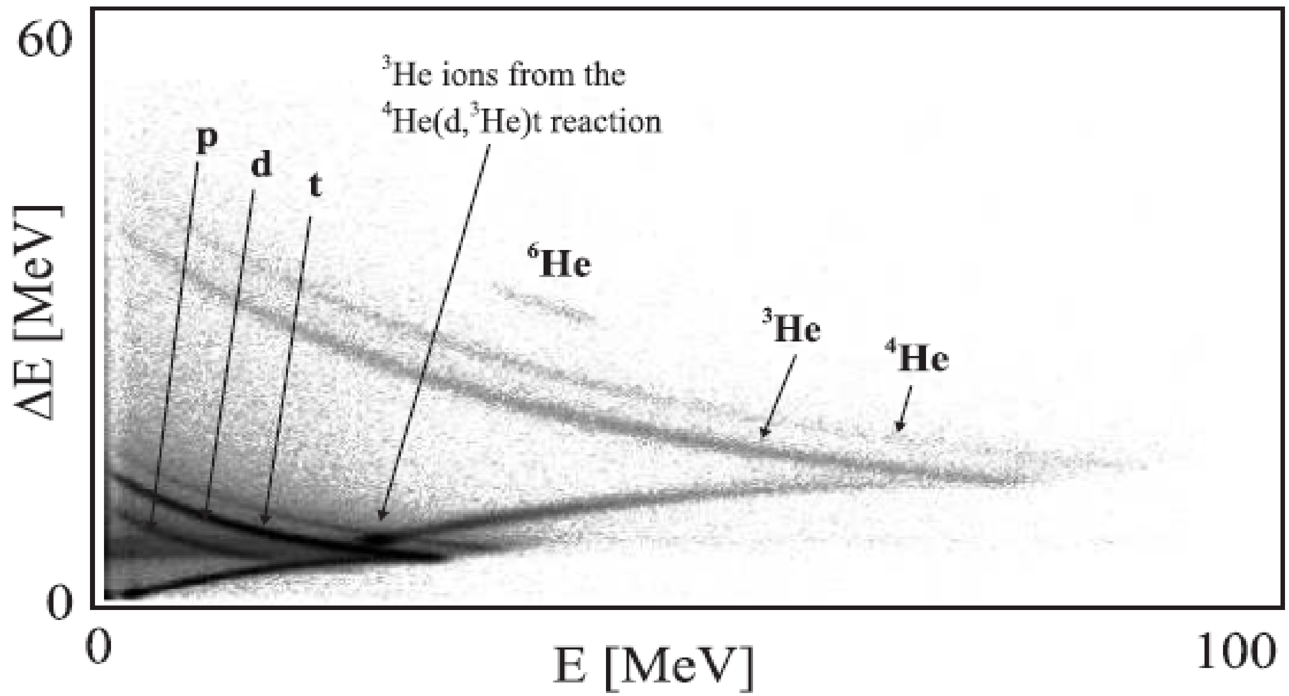
$^4He + d \rightarrow {}^6Li_{3.56} + \pi^0$



$E_{c.m.}$=1.2 MeV above thr. σ=228±6+70 nb

$E_{c.m.}$=1.9 MeV above thr. σ=141±12+42 nb

$d + {}^4He \rightarrow {}^6He + \pi^+$



$E_{c.m.}$ = 0.6 MeV above thr. σ=22±1 nb

$E_{c.m.}$ = 1.2 MeV above thr. σ=38±1 nb

$E_{c.m.}$ = 1.9 MeV above thr . σ=57±1 nb

$$^{3}He + ^{3}He \rightarrow ^{6}Li_{3.56} + \pi^{+}$$

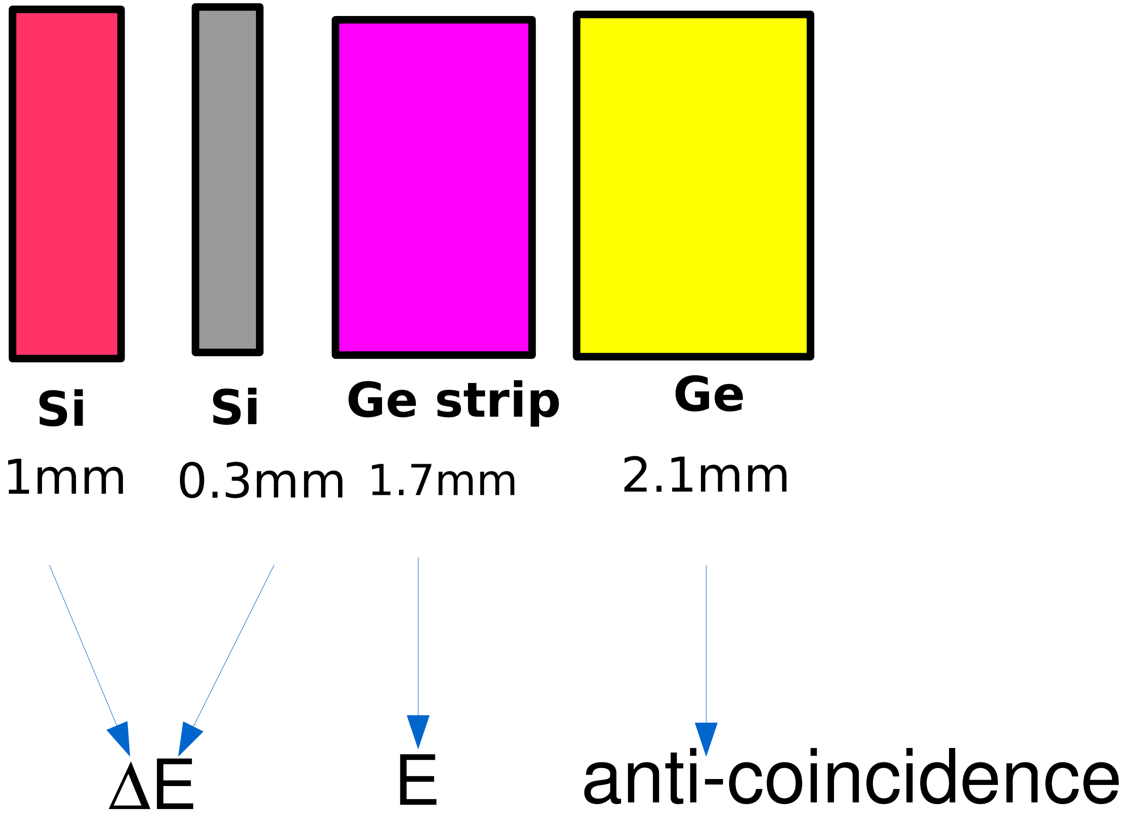
- Aim: to measure the total cross sections at two beam energies- 261.1 and 262.5 MeV (1.2 and 1.9 MeV above the threshold in the center of mass for production of the 3.56 MeV state)

Experimental Set-up

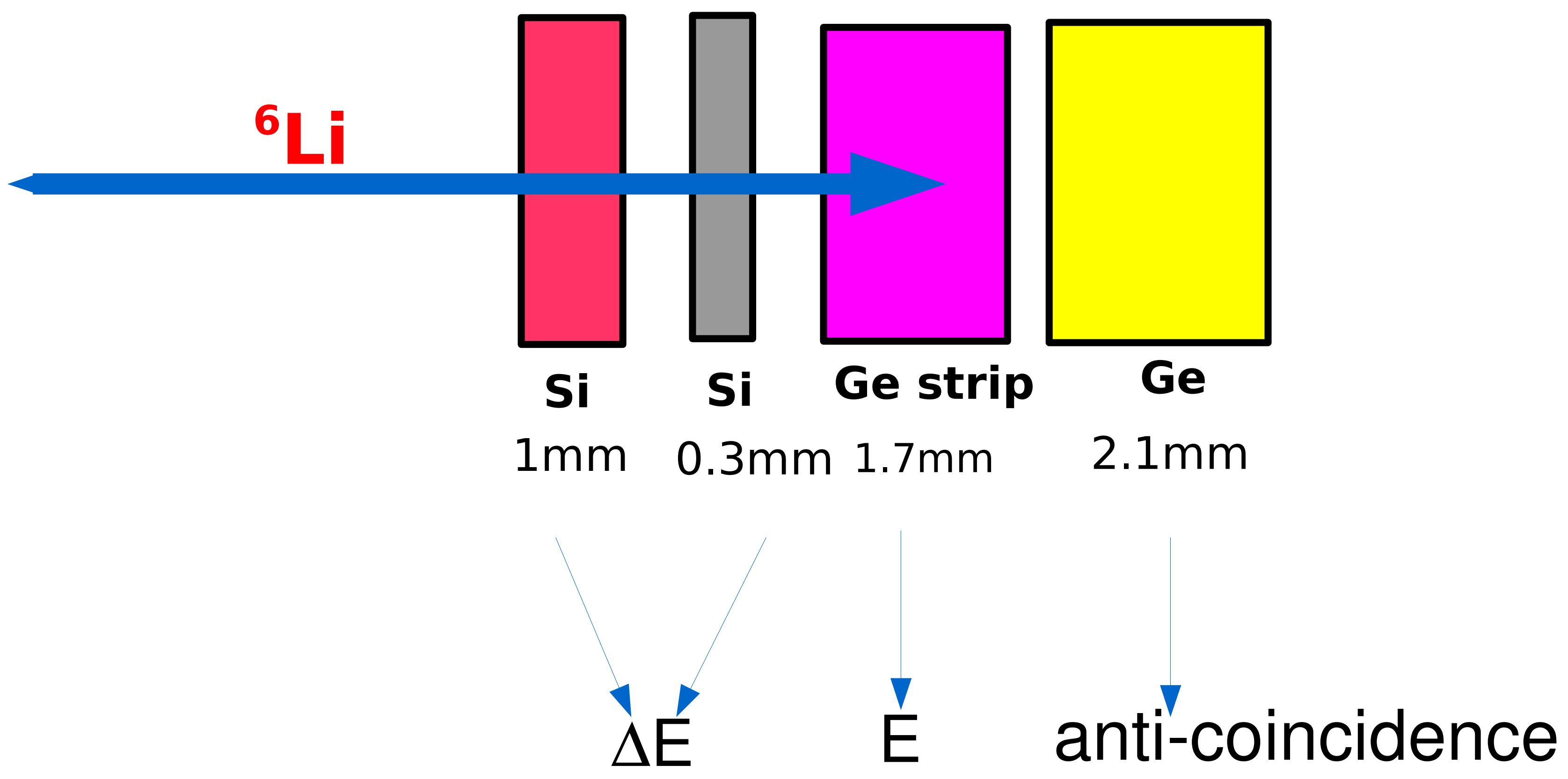
- Performed in Uppsala at CELSIUS storage ring
- Used electron cooled beam of ^{3}He
- Cluster-jet target of ^{3}He. *Known problem: The ^{3}He target gas does not cluster well so we have to face the problem of an extended target*

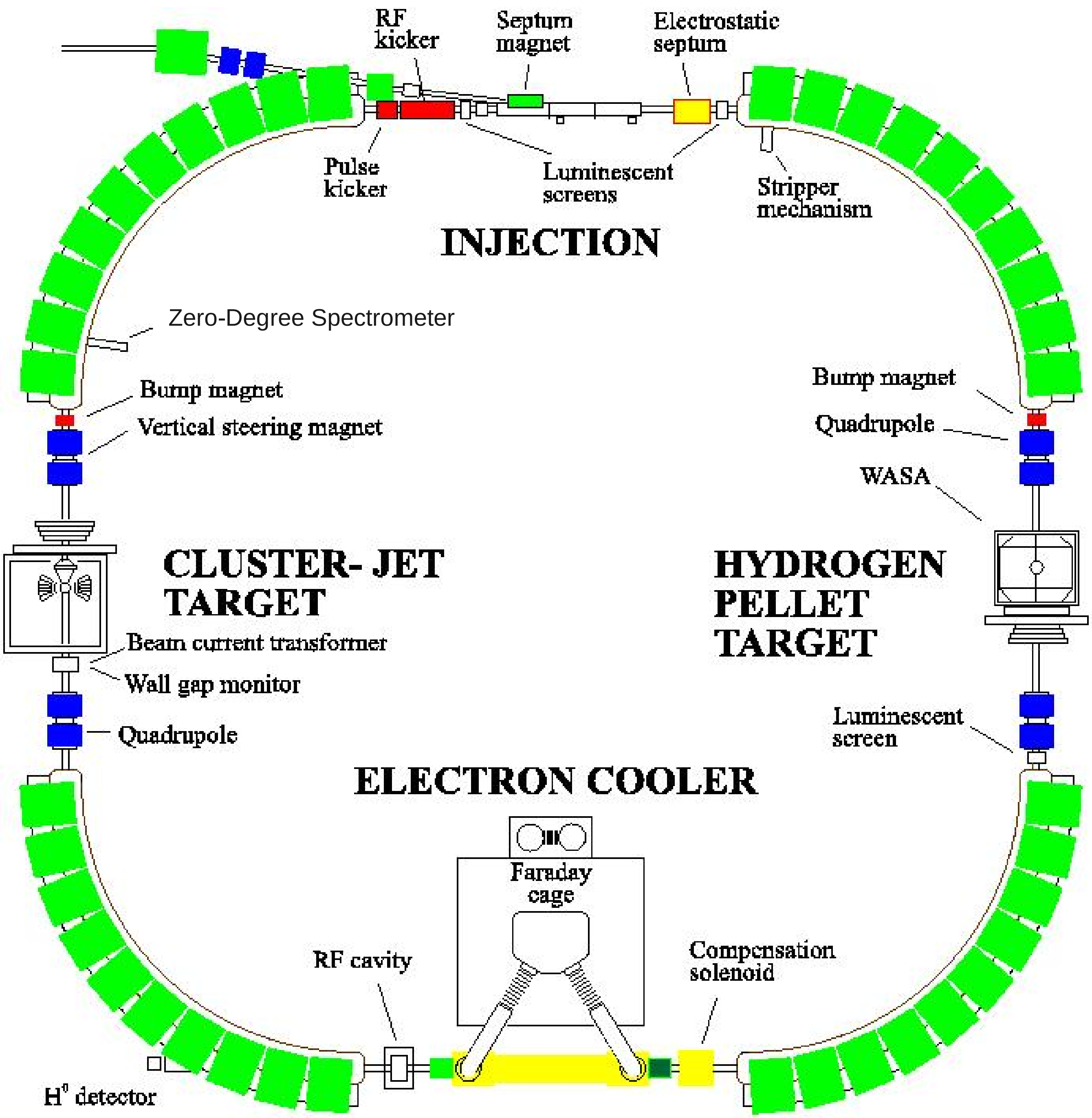
- We detect ^{6}Li
- Zero-degree spectrometer
- Telescope comprising of 4 detectors: two thin Si transmission detectors, a strip Ge detector and a forth detector made of Ge

Our Set -Up

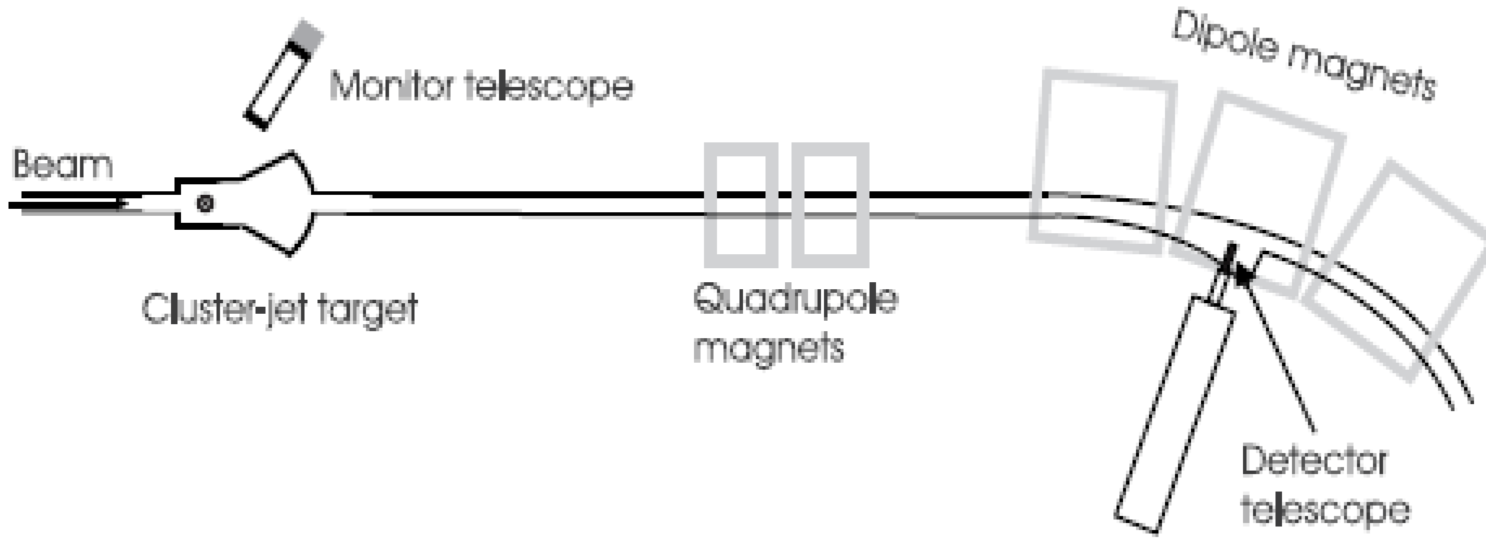


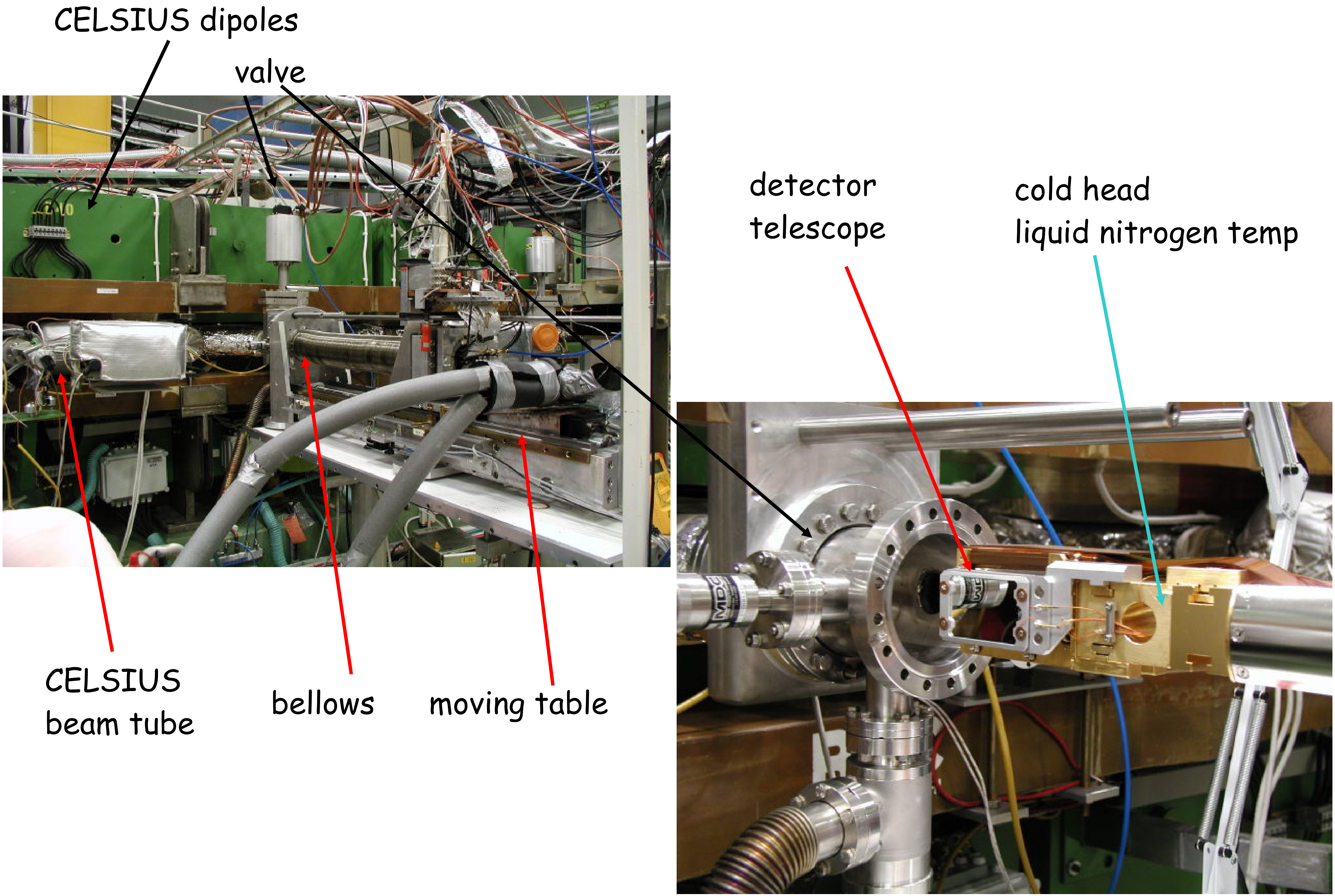
Our Set -Up




RF kicker
Septum magnet
Electrostatic septum
Pulse kicker
Luminescent screens
Stripper mechanism
INJECTION
Zero-Degree Spectrometer
Bump magnet
Vertical steering magnet
Bump magnet
Quadrupole
WASA
CLUSTER- JET TARGET
HYDROGEN PELLET TARGET
Beam current transformer
Wall gap monitor
Quadrupole
Luminescent screen
ELECTRON COOLER
Faraday cage
RF cavity
Compensation solenoid
H⁰ detector

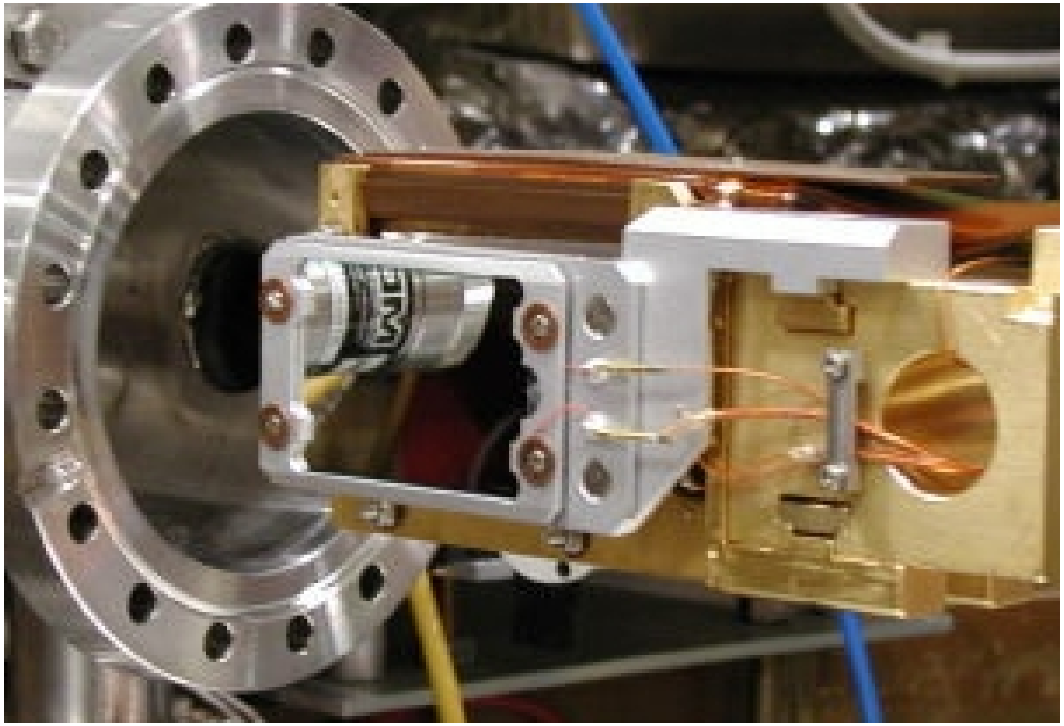
The geometry




CELSIUS dipoles
valve
detector telescope
cold head
liquid nitrogen temp
CELSIUS beam tube
bellows
moving table

Experimental Set-up

Si1 0.91 mm thick
Si2 0.29 mm
Ge 2.30 mm



Experimental Set-up

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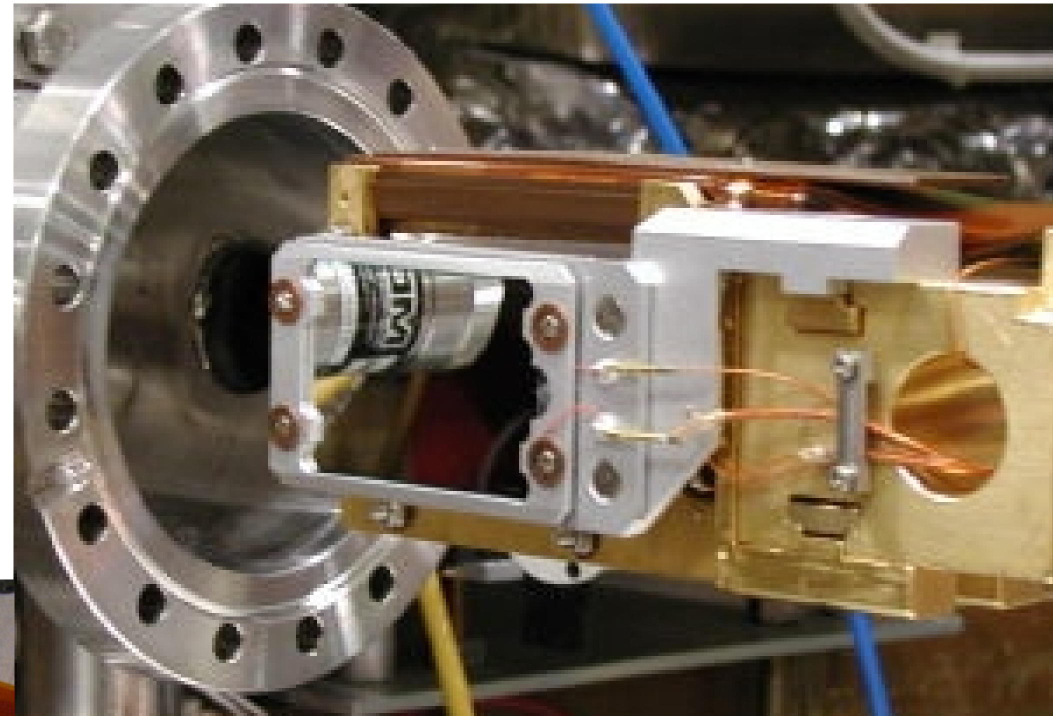
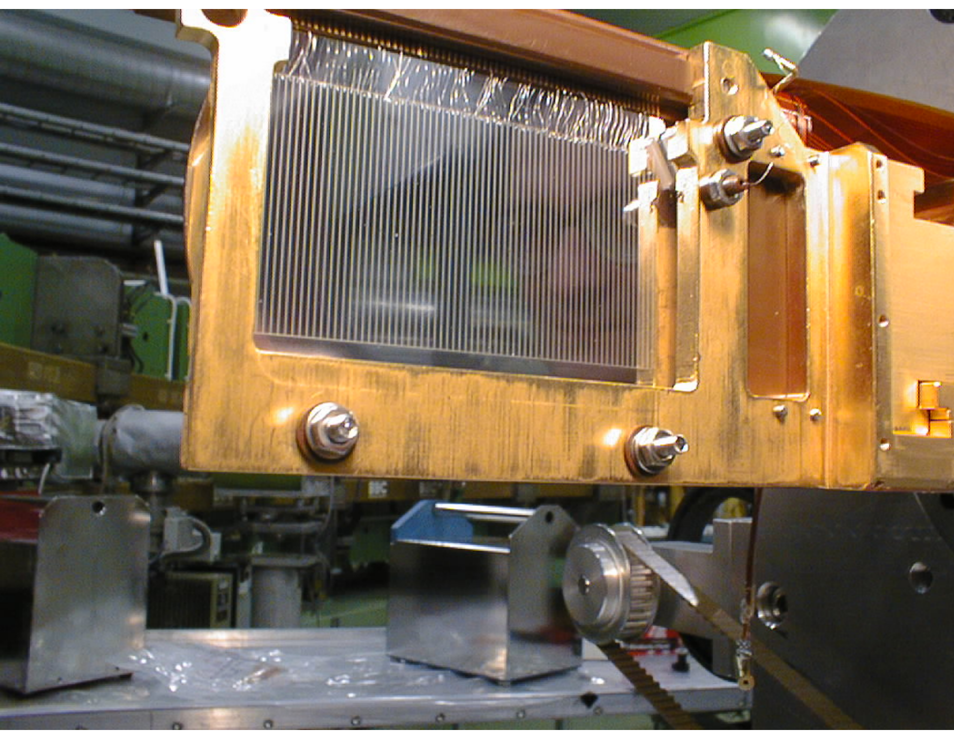




Strip detector :
1.70 mm thick
64 vertical and
16 horizontal strips

Target distribution

- To investigate target distribution and to normalize the luminosity:

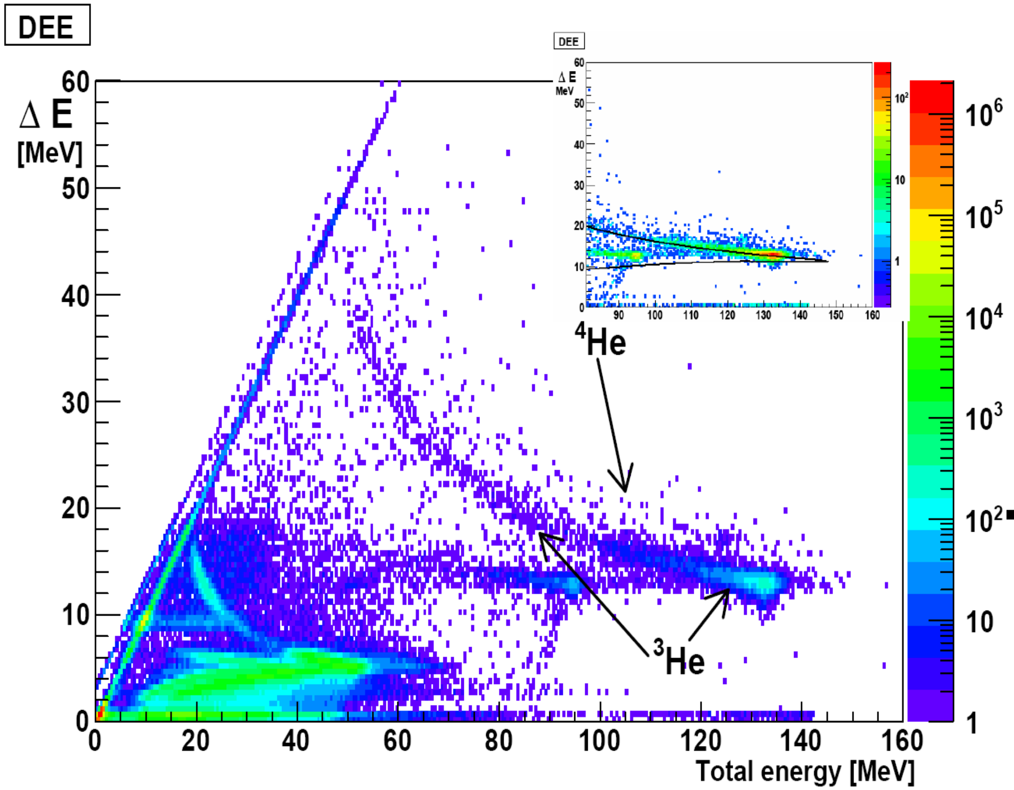
  study the $d+{}^3He$ elastic scattering

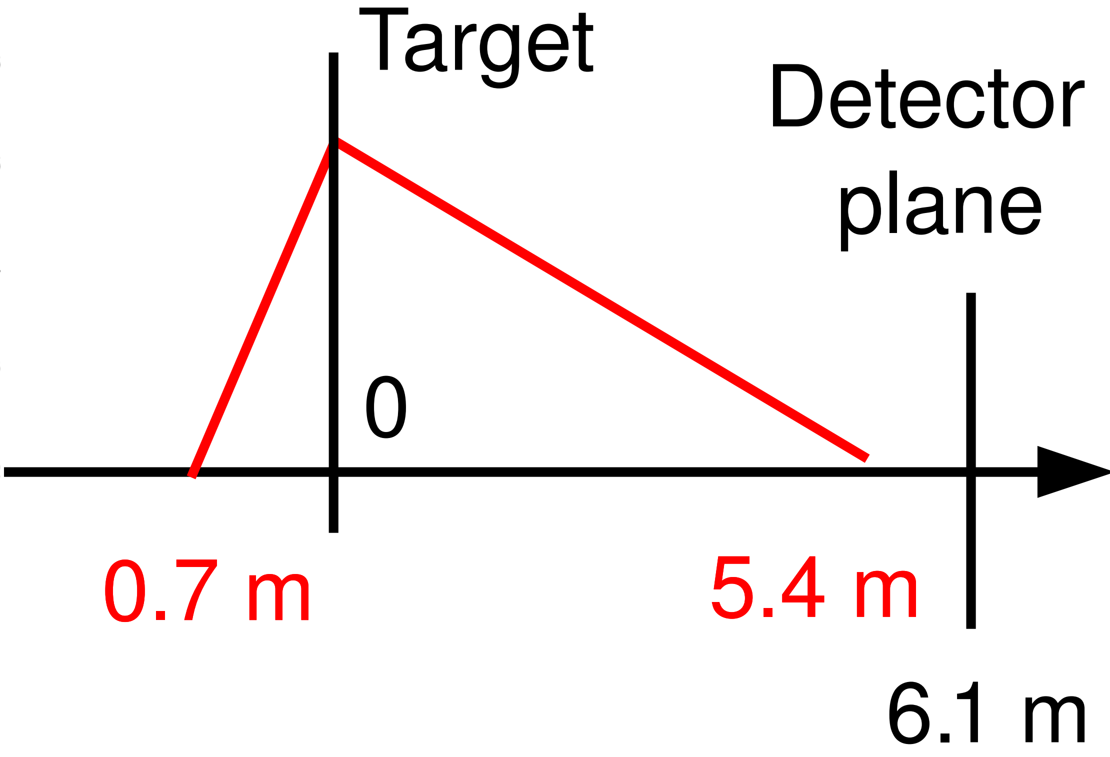
- Deuteron beam energy: 140 MeV

- Known cross section: 16.3(1) mb/sr

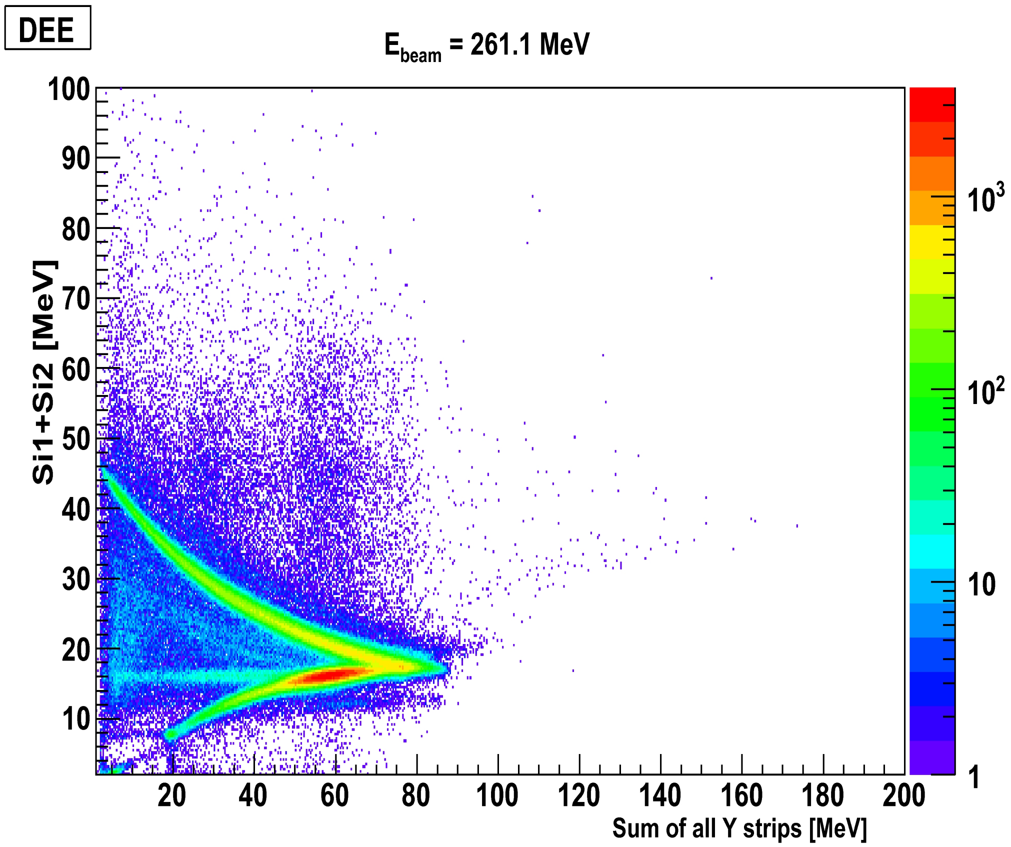
  M. Tanifuji et al. Phys. Rev. C 61 (1999) 024602

Target distribution II

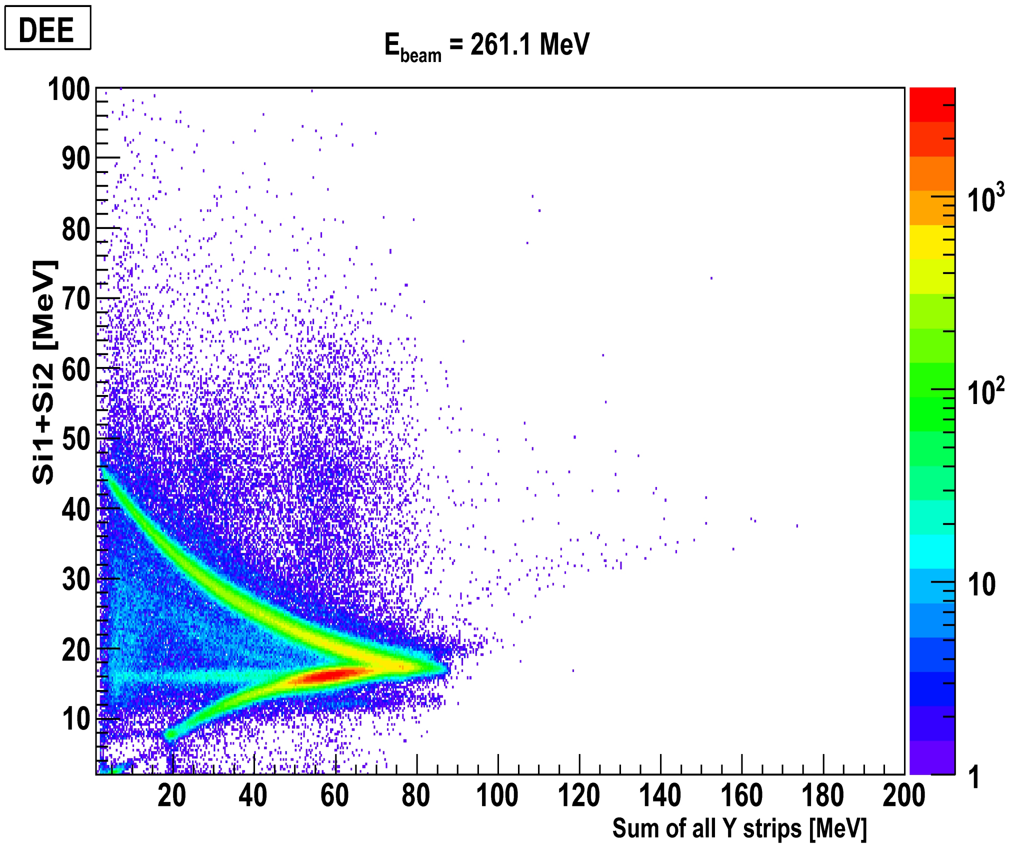


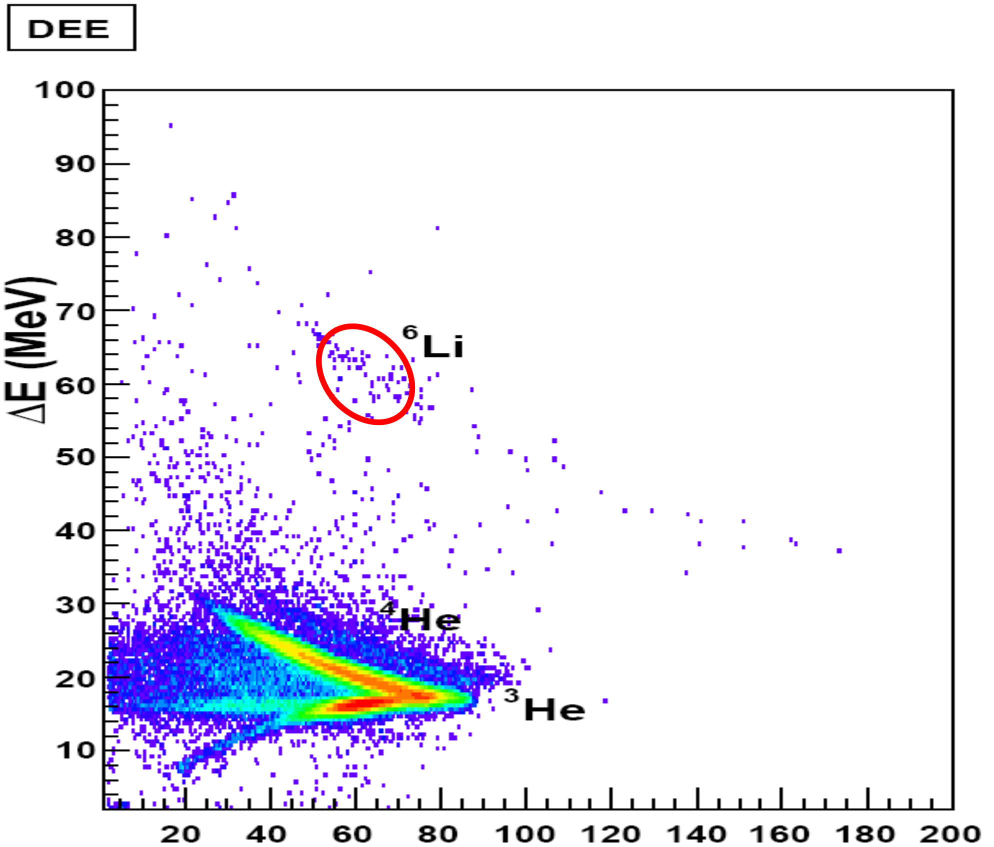


Beam energy 261.1 MeV, selection of events

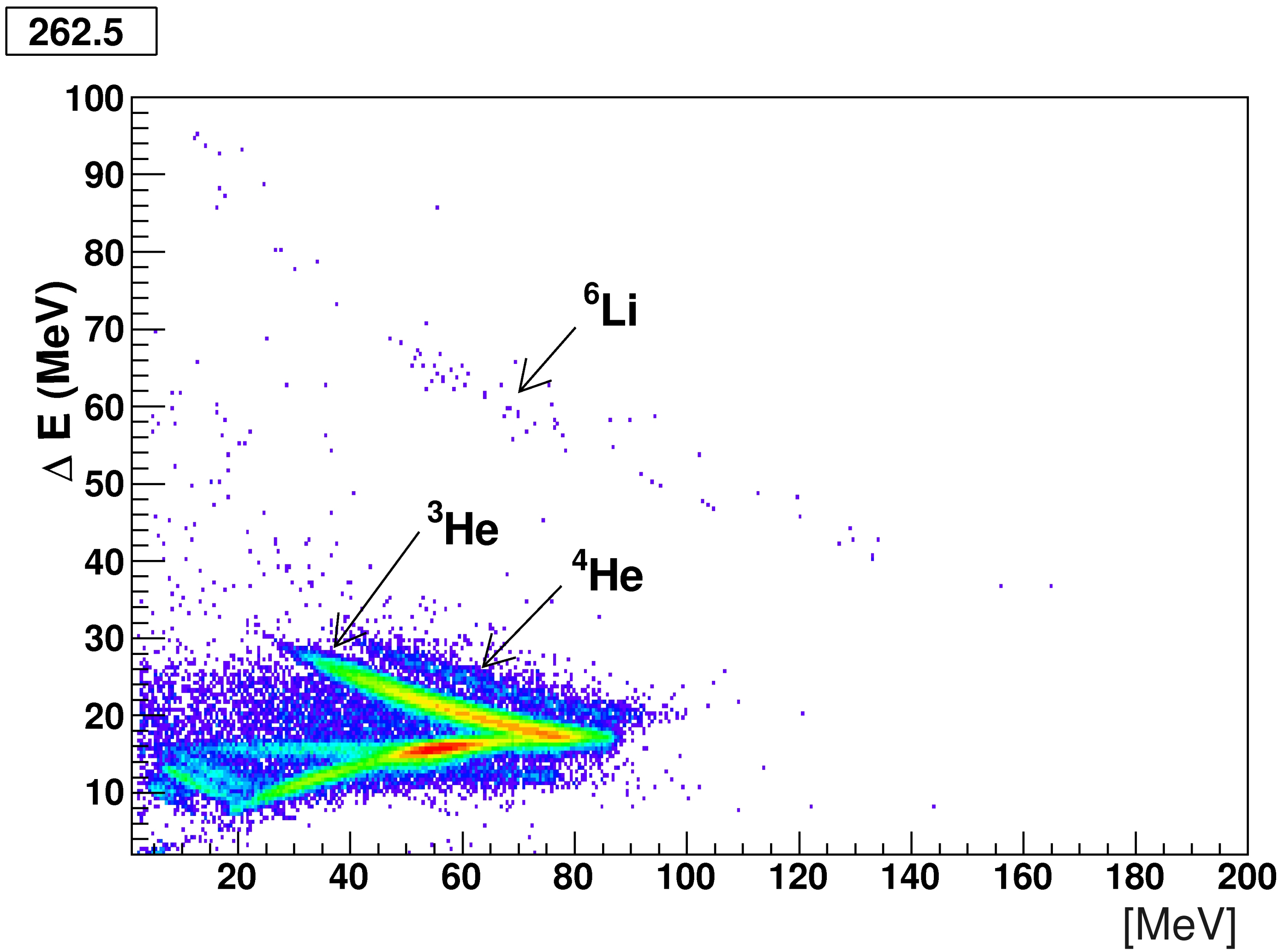


Beam energy 261.1 MeV, selection of events

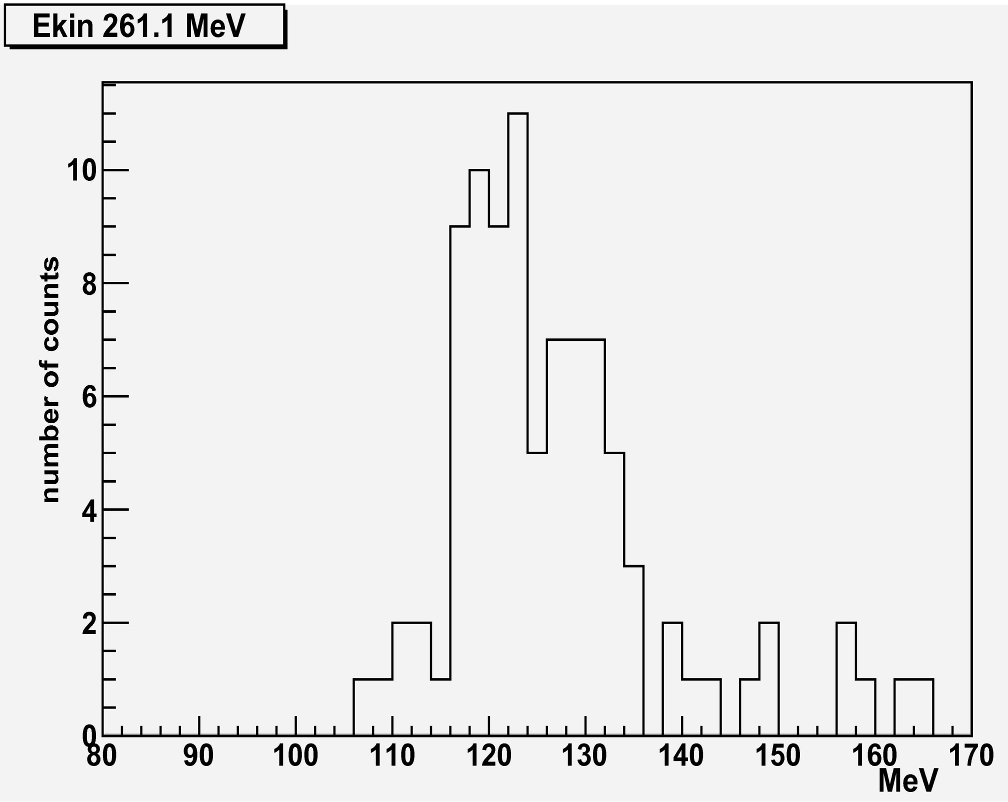


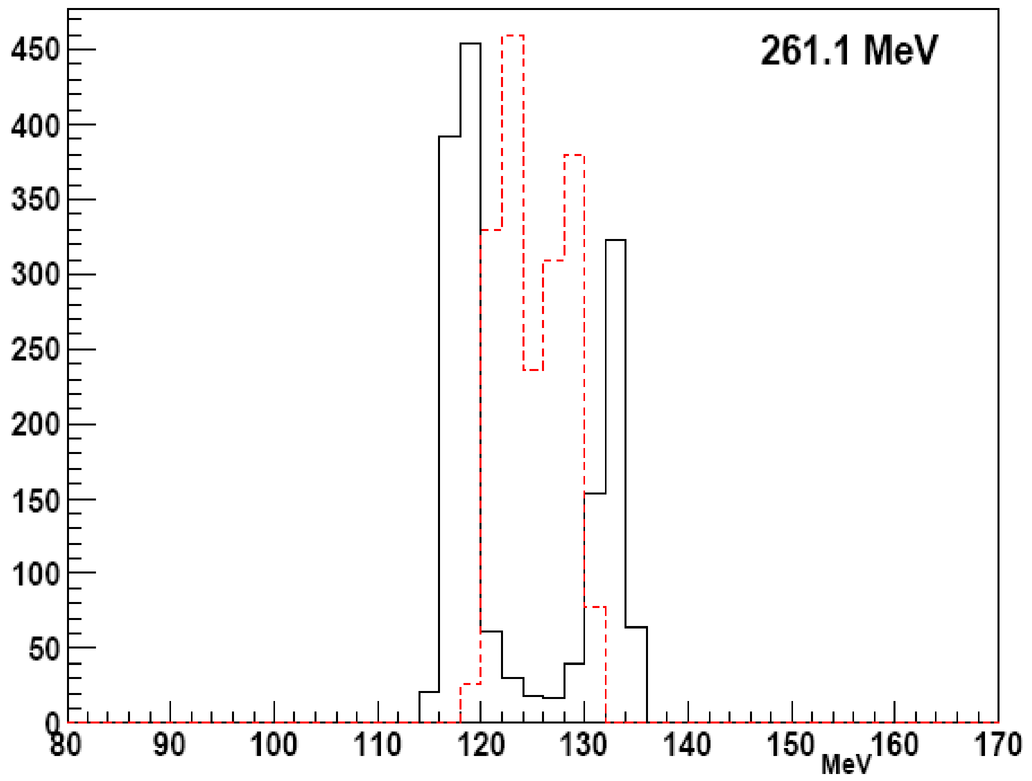


Beam energy 262.5 MeV, selection of events

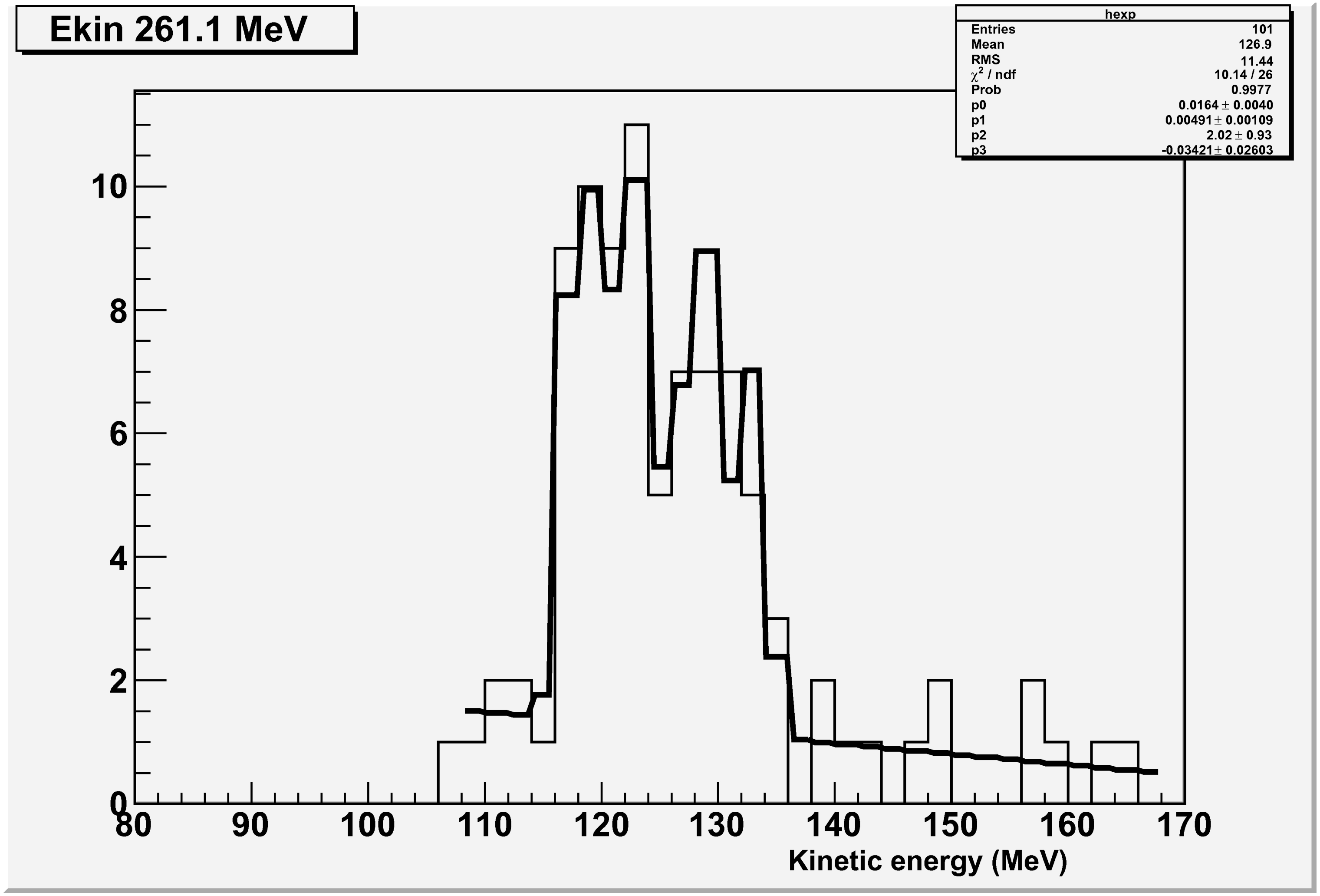


Kinetic energy spectra





Fit of the data for 261.1 MeV



Results

E_{beam} (MeV)	$\sigma^{tot}_{c.m.}$ g.s (nb)	$\sigma^{tot}_{c.m.}$ exc. state (nb)
261.1	347 ± 84 ± 42	104 ± 23 ± 12
262. 5	92 ± 84 ± 11	56 ± 35 ± 7

Results

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261.1	347 ± 84 ± 42	104 ± 23 ± 12
262. 5	92 ± 84 ± 11	56 ± 35 ± 7

E_{beam} (MeV)	$d\sigma/d\Omega_{c.m.}$ g.s (nb/sr) 30 deg c.m.	$d\sigma/d\Omega_{c.m.}$ exc. state (nb/sr) 30 deg c.m.
282	24.0 ± 1.7	9.2 ± 2.7
268.5	16.0 ± 1.6	

Le Bornec et al. Phys. Rev. Lett. 47 (1981) 1870

Production cross sections of 3.56 MeV state in ^6Li

	$d(^4He,^6Li)\pi^0$ (nb)	$^3He(^3He,^6Li)\pi^+$ Coulomb corrected (nb)
Q = 1.2 MeV	228 ± 6 + 70	182 ± 40 ± 21
Q = 1.9 MeV	141 ± 12 + 42	88 ± 55 ± 11

Summary

- A study of pionic fusion reaction $^{3}He(^{3}He,^{6}Li)\pi^{+}$ was shown.
- Two previous investigations of the halo nuclei ^{6}He and ^{6}Li were discussed.
- Technical details of the experiment were explained.
- The process of the analysis was shown.
- Results were discussed.

Cross section of 3He(d,3He)d

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Pionic fusion

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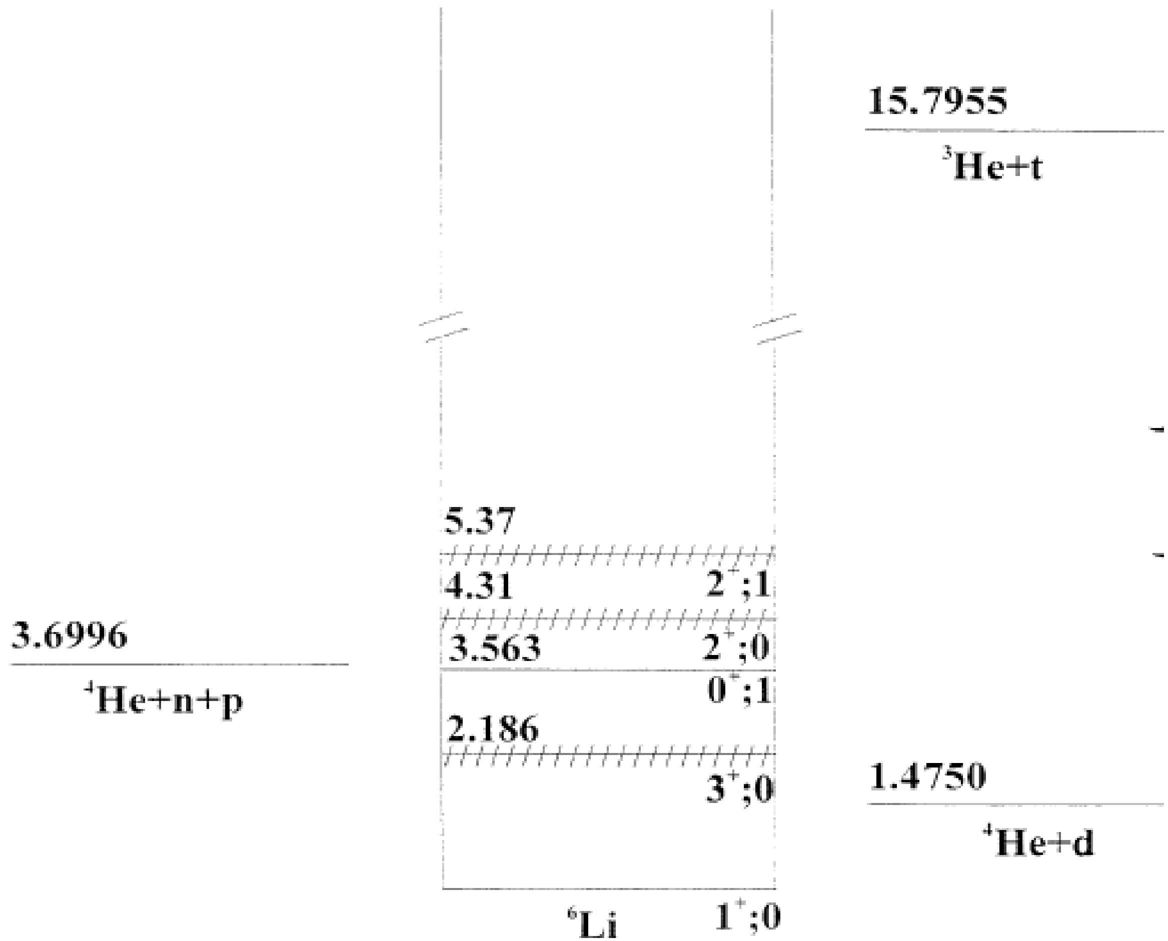
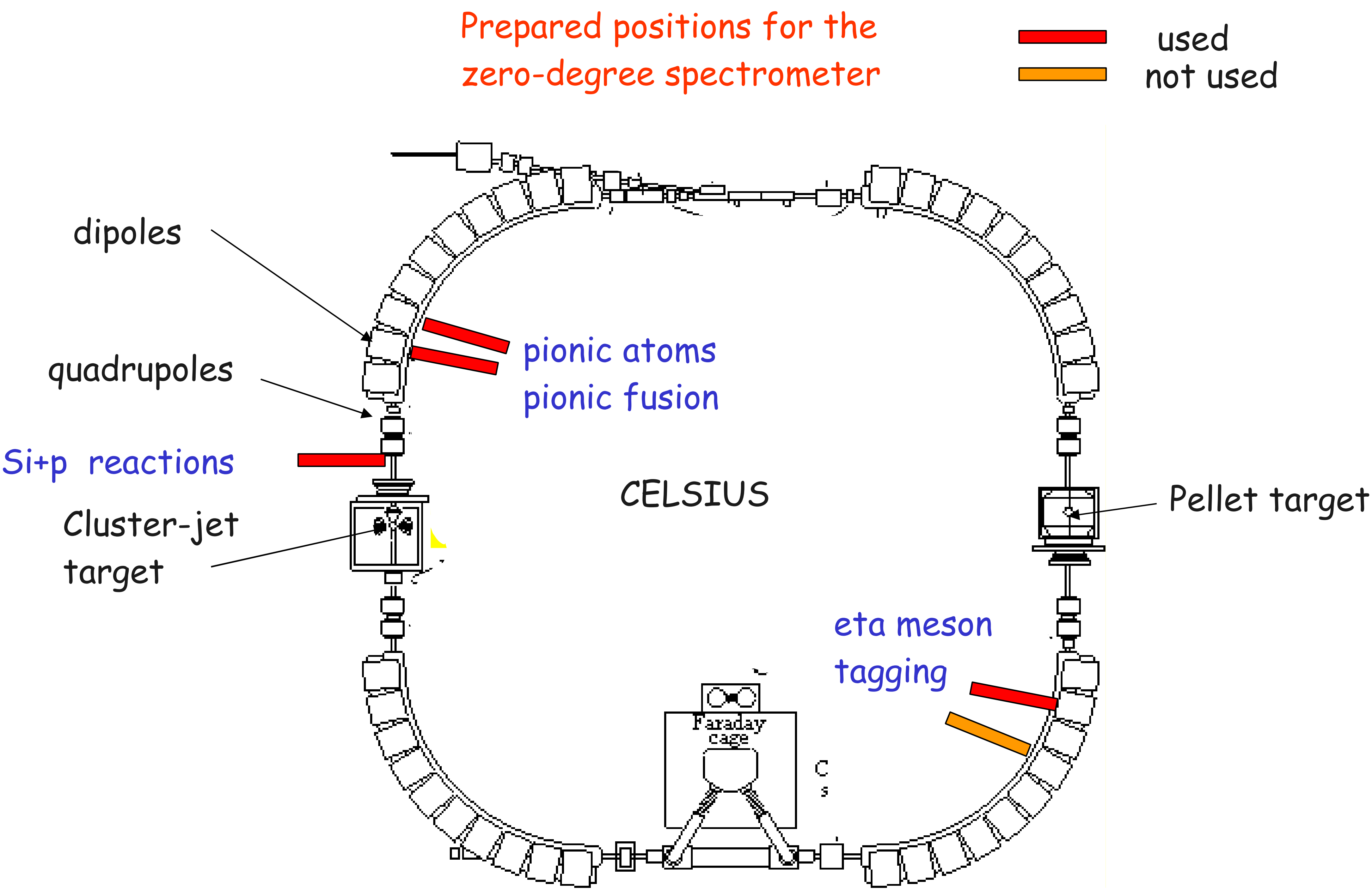
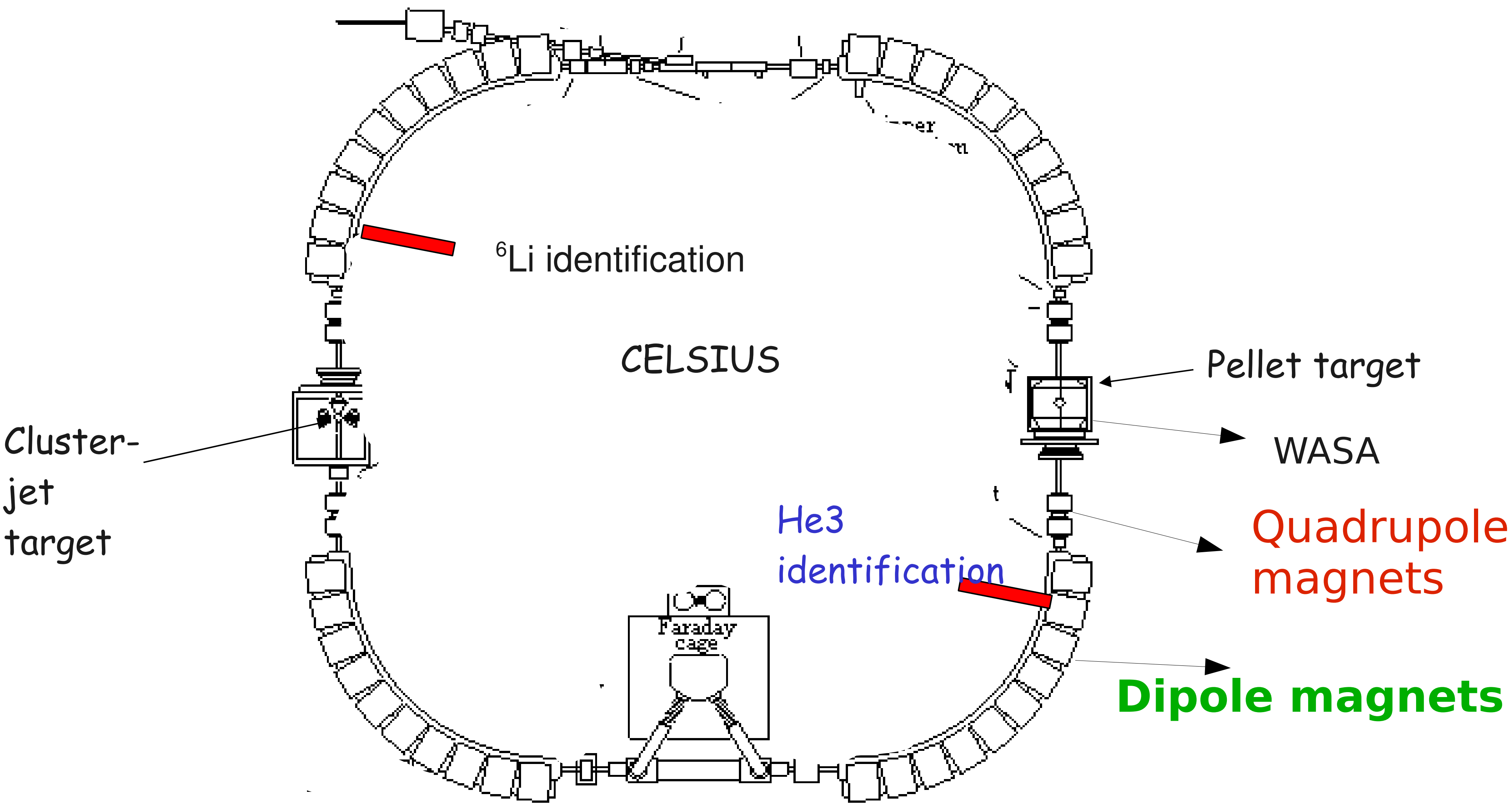

15.7955
^{3}He+t
5.37
4.31
2$^+$;1
3.6996
2$^+$;0
3.563
^{4}He+n+p
0$^+$;1
2.186
1.4750
3$^+$;0
^{4}He+d
^{6}Li
1$^+$;0

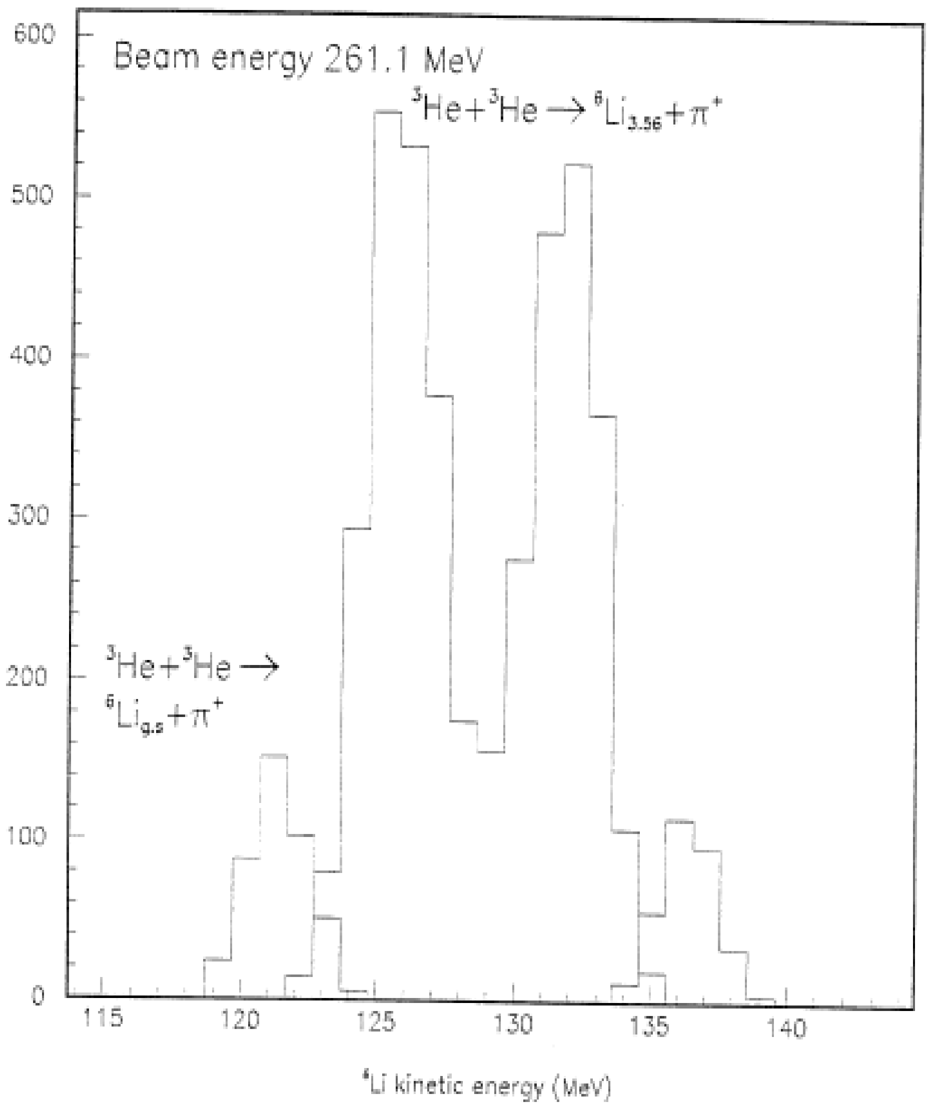
Prepared positions for the zero-degree spectrometer

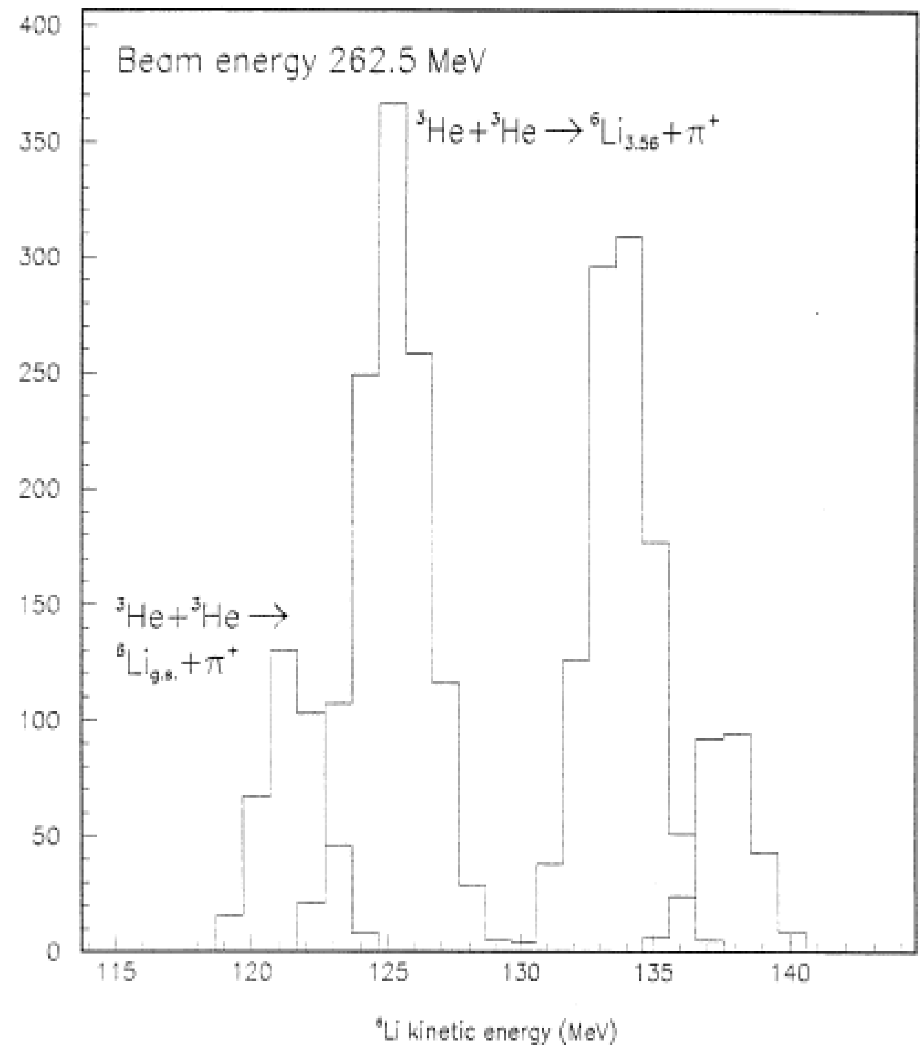


epared Position for the Zero-Degree Spectrometer



Simulations





What are halo nuclei? contd.

$R \approx R_0 \bullet A^{1/3}$

For example: $R_{^{11}Li} \approx R_{^{32}S}$