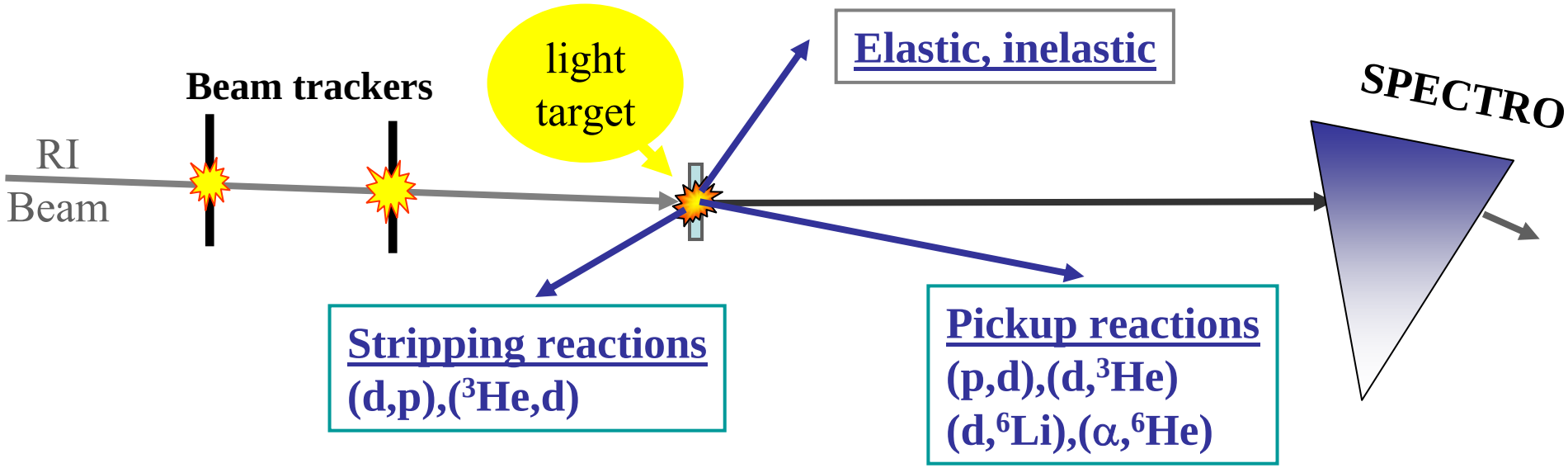
Light neutron-rich nuclei beyond the dripline by means of transfer reactions

D. Beaumel, IPN Orsay

Experimental method using RIBs

- **Exotic Beam + light target (p,d,α,..)**
- **Detect the target- like ejectile with *large solid angle array***

$(E,\Theta)^{LAB} \rightarrow (E^*, \Theta_{CM})$



- ➢ Large solid angle
- ➢ Highly segmented
- ➢ Good E resol

Detector array

→

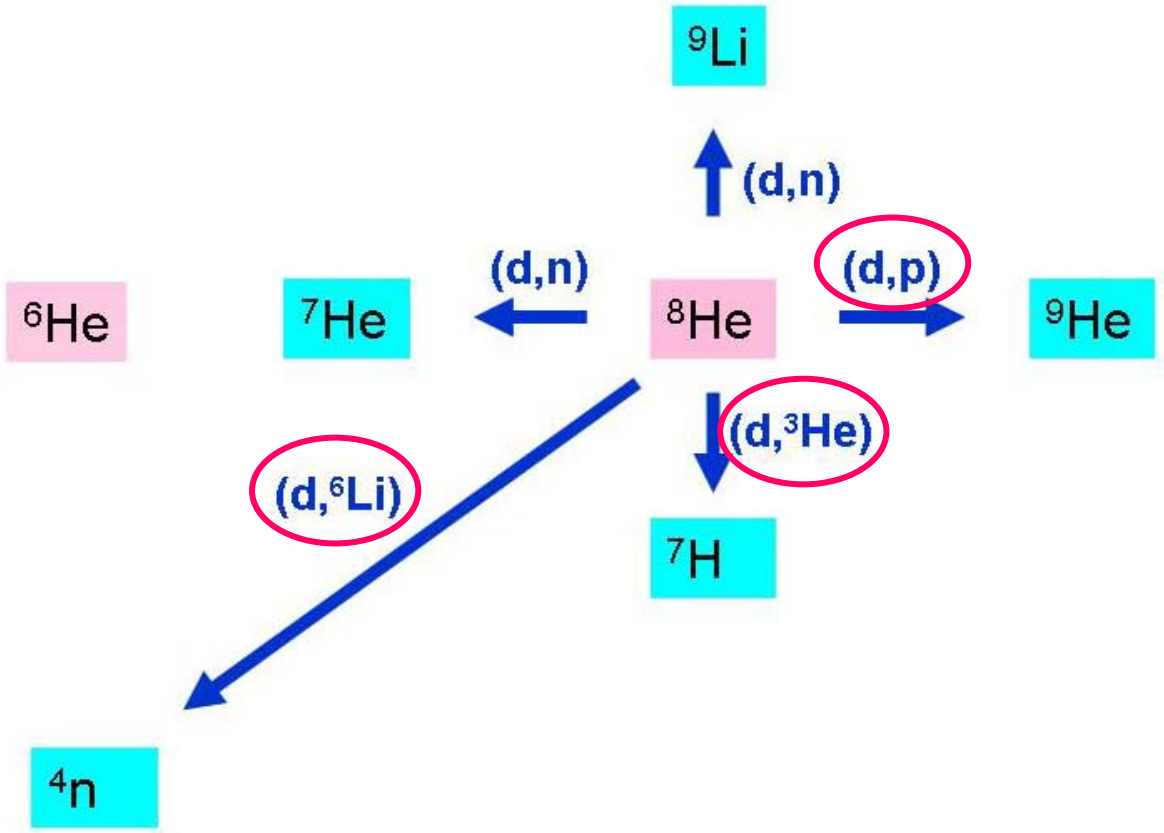
- ✓ Good angular and E* resolution
- ✓ Nice angular distributions !
- ✓ Bound and unbound states on the same footing

Other method: active target

Study of the ^{8}He + d system using the (relatively) intense 15 MeV/u SPIRAL beam

The ^{8}He+d system leads to:

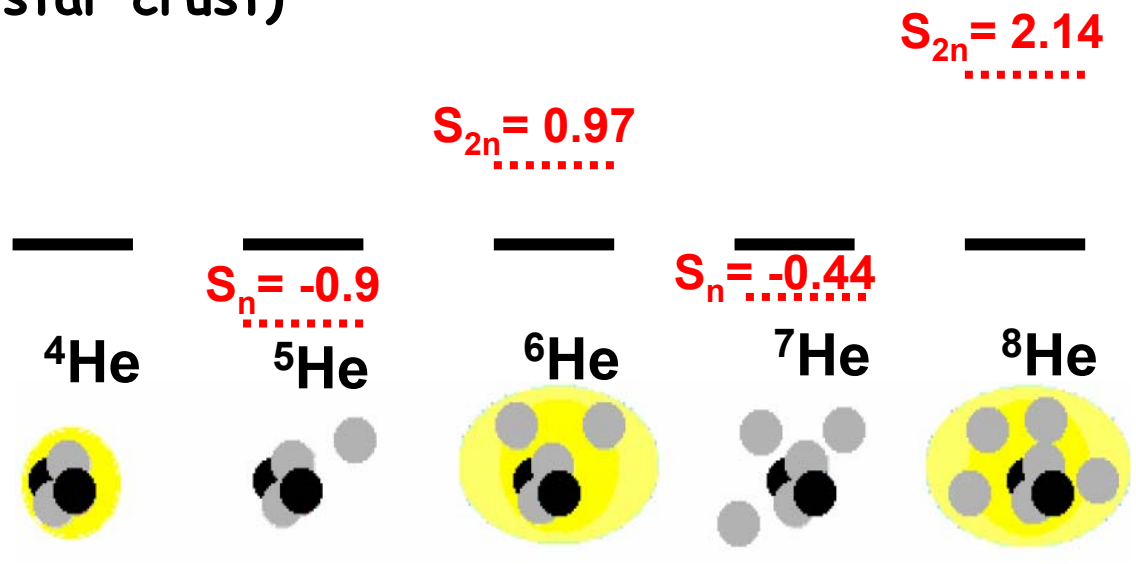
^{9}He: N/Z = 3.5
^{7}H: N/Z = 6
^{4}n: N/Z = ∞



Searching for the heavy hydrogen ^{7}H

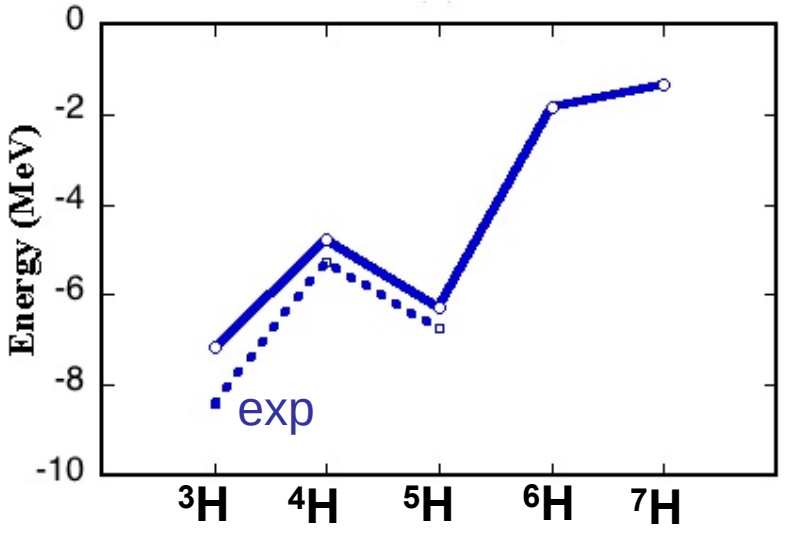
N/Z=6 (similar to neutron star crust)

- The Helium "anomaly"
  - *^{8}He more bound than ^{6}He*
  - *^{7}He less unbound than ^{5}He*

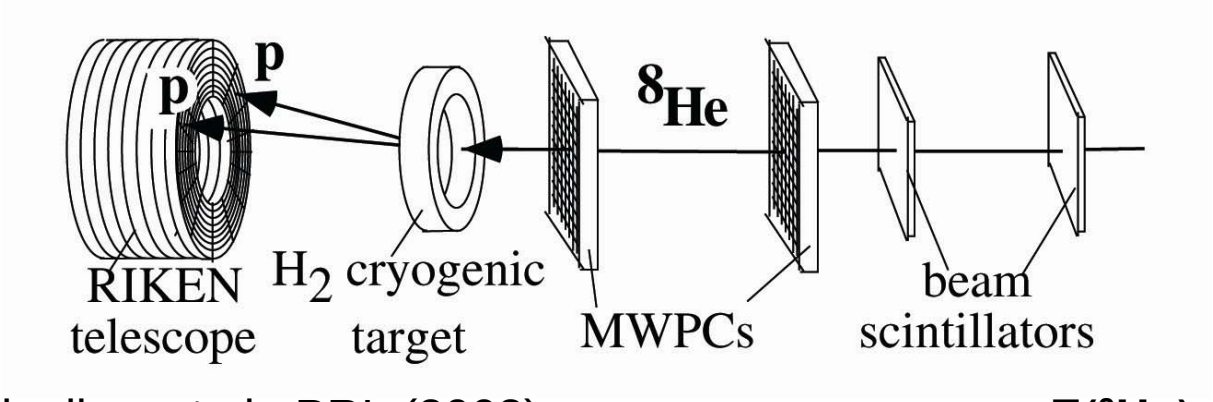


- How about the hydrogens ?
  - *More controversial experimentally*
  - If same trend, possible state above the t+4n threshold

- Theory:
  - *Broad range of predicted energies*
  - HSFM : ~ 1 MeV
    (N.K.Timofeyuk, PRC 2002)
  - AMD : ~ 7 MeV
    (Aoyama&Itagaki, NPA 2004)

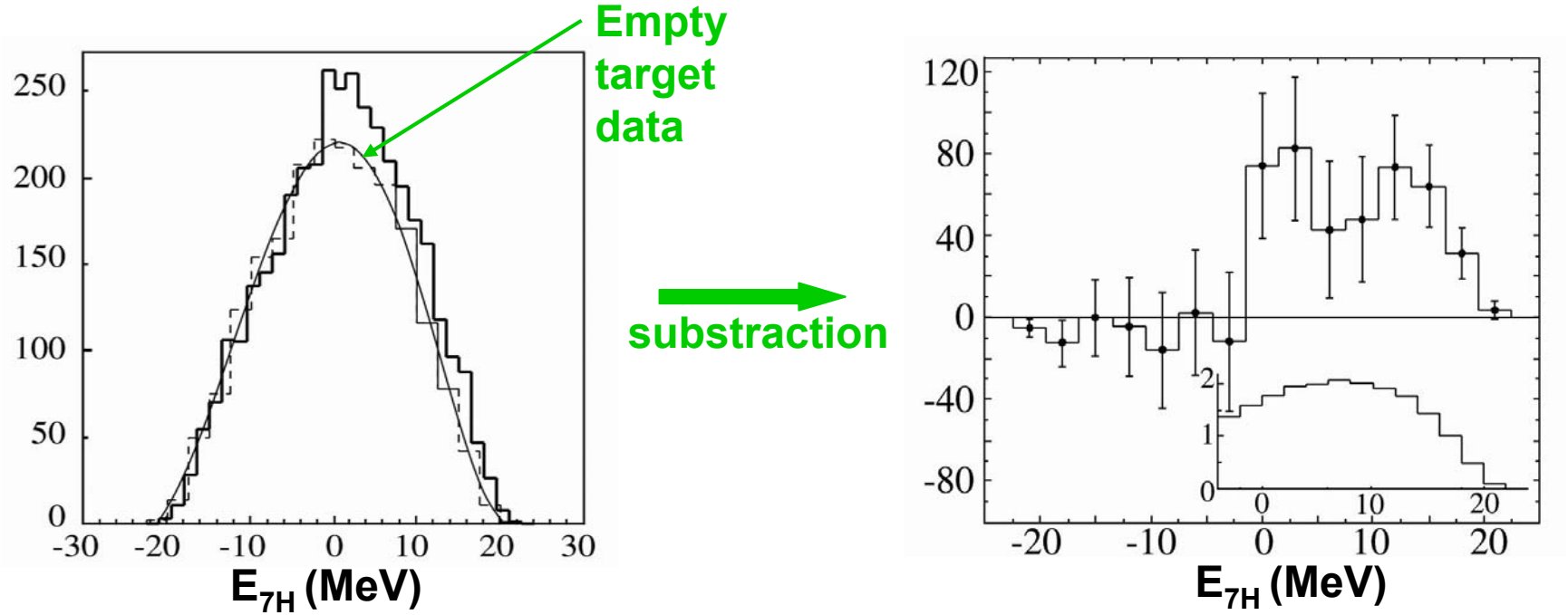


Riken experiment: $^{8}He(p,2p)^{7}H$



A.A. Korsheninnikov et al., PRL (2003)

E(^{8}He) =61.3 A.MeV

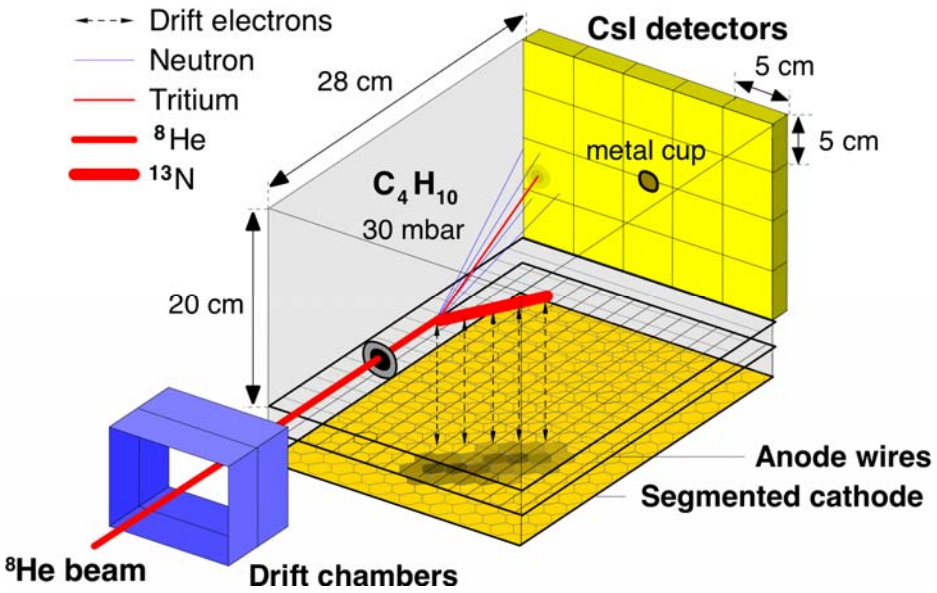


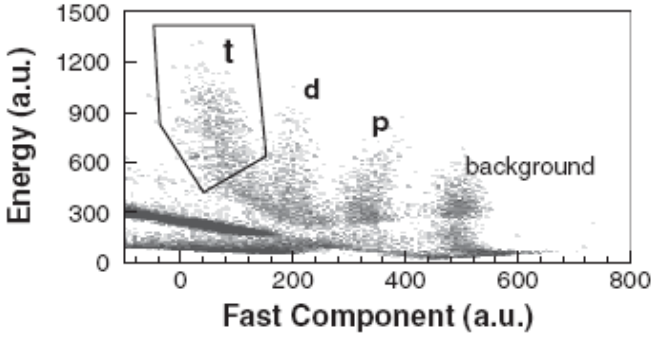
Sharp increase near t+4n threshold

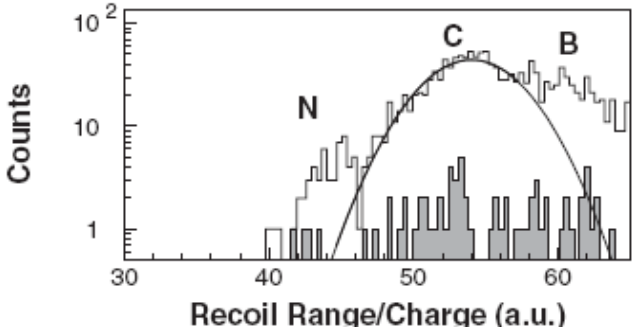
No resonance parameters

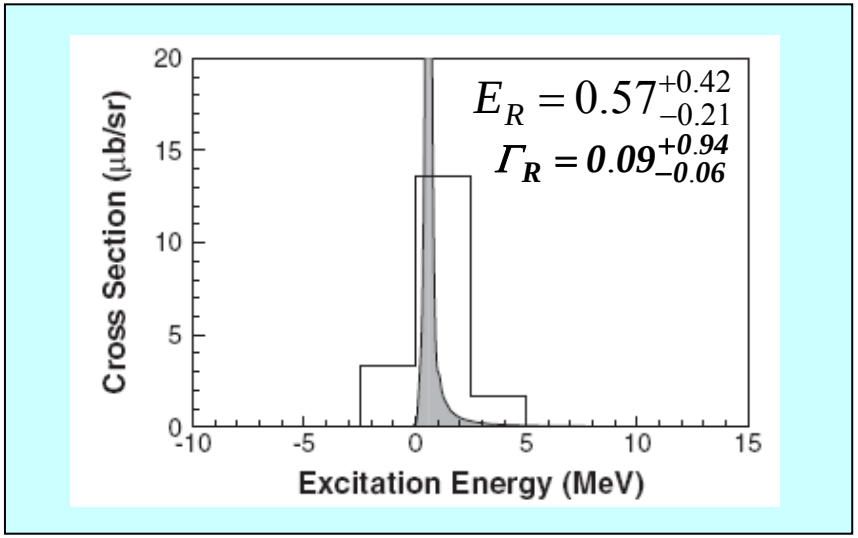
Search of ^{7}H with the MAYA detector

^{8}He(^{12}C,^{13}N)^{7}H → ^{3}H+4n





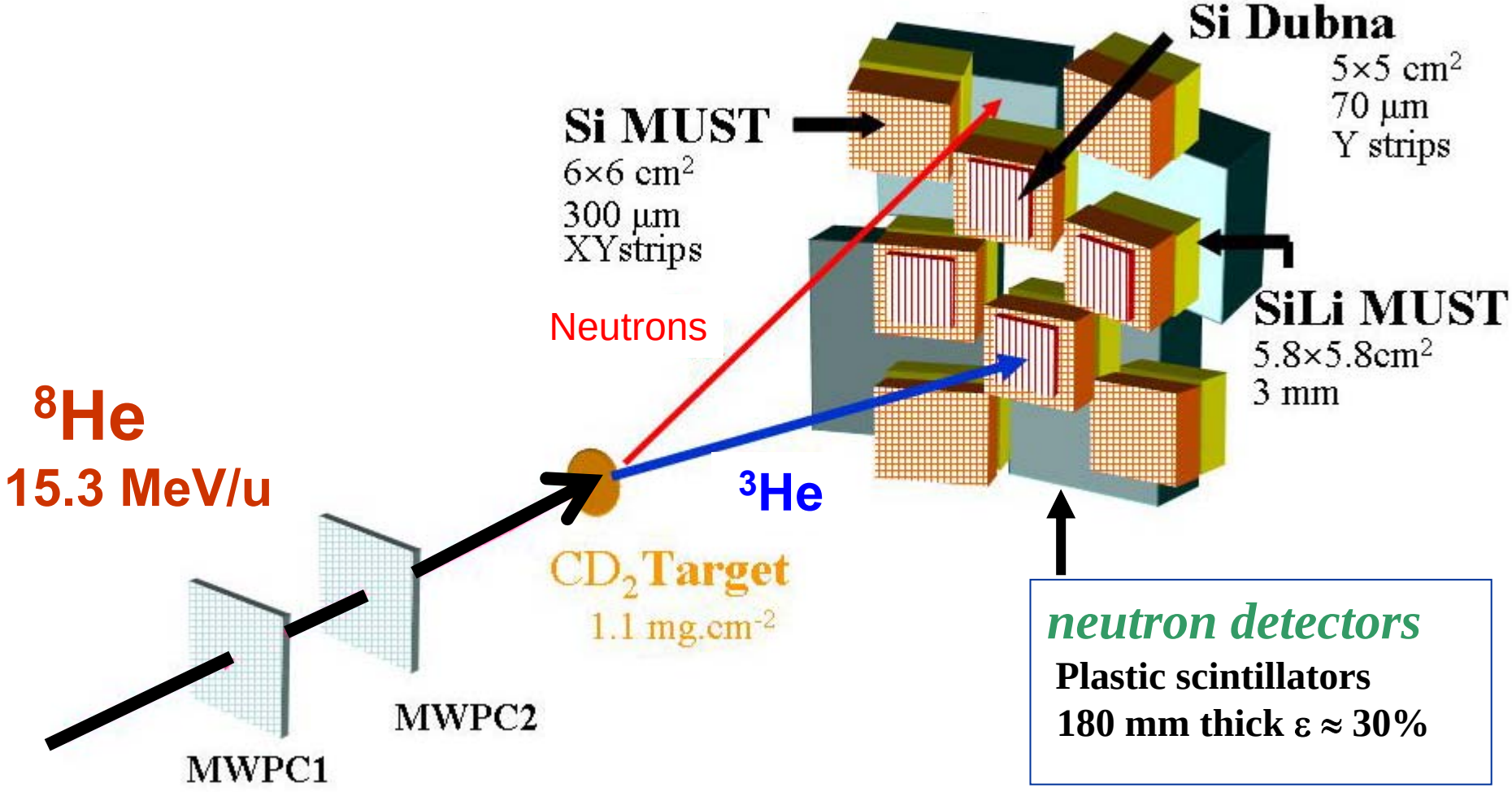




M. Caamaño et al., PRL 99 (2007)

Study of the ^{8}He + d system using the SPIRAL ^{8}He beam

^{8}He(d, ^{3}He)^{7}H



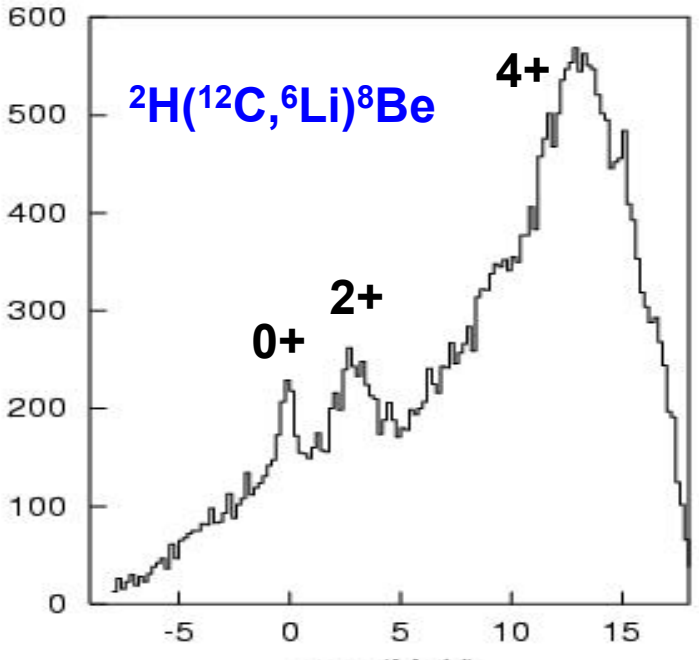
neutron detectors

Plastic scintillators
180 mm thick ε ≈ 30%

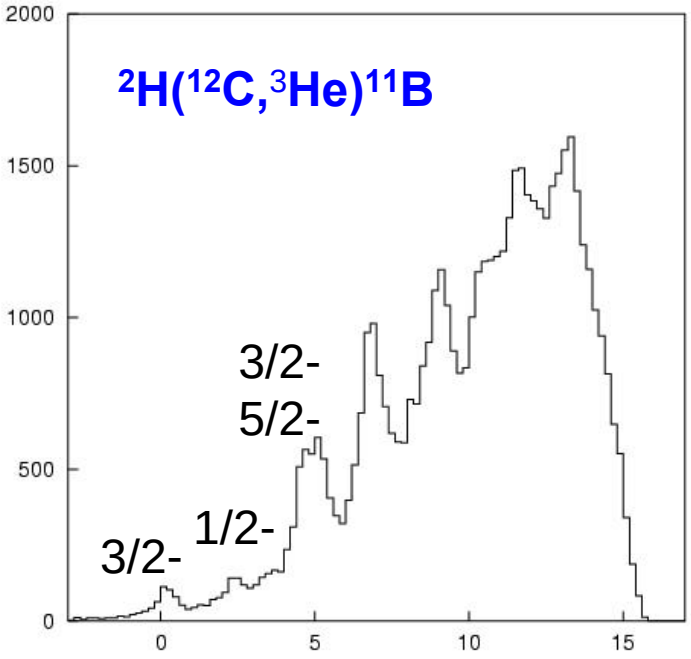
- Missing mass measurement :
  - ⇒ **Energy of the states**
  - ⇒ **Bound** and **resonant** states on the **same footing**

needs good control of
- ✓ ***Angle determination***
- ✓ ***Energy calibration***
- ✓ ***Energy losses in target, etc …***

CHECK C.M. ENERGY DETERMINATION
In a preliminary run with ^{12}C beam



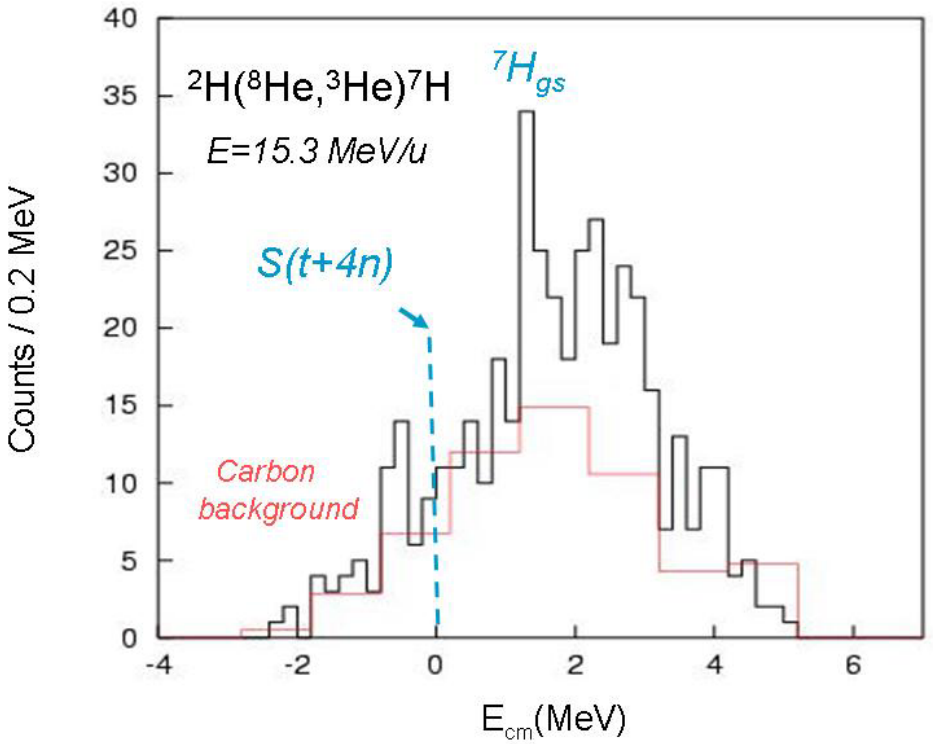
$E_{cm}(^8Be)$ in MeV



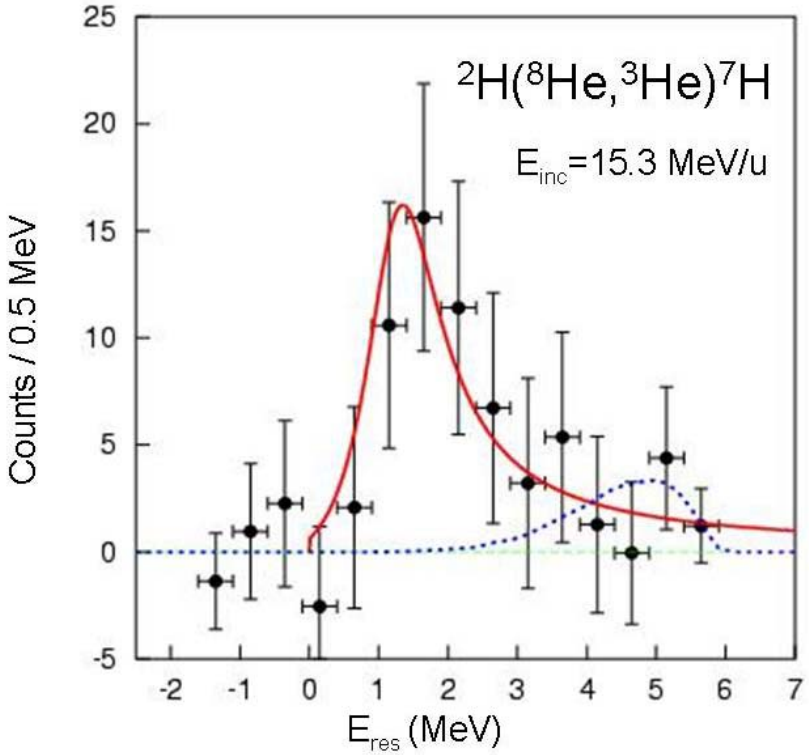
$E_x(^{11}B)$ in MeV

Results for ^{7}H

singles spectrum



after background subtraction



Fit by Breit-Wigner function

$\Gamma=\Gamma_0\sqrt{(E/E_r)}$

$E=1.56 \pm 0.27$ MeV

$\Gamma_0=1.74 \pm 0.72$ MeV

- **^{7}H seems to exist as a resonance close to t+4n threshold**
- **Resonance parameters still ambiguous**
- **New riken data coming soon (same reaction at higher energy)**

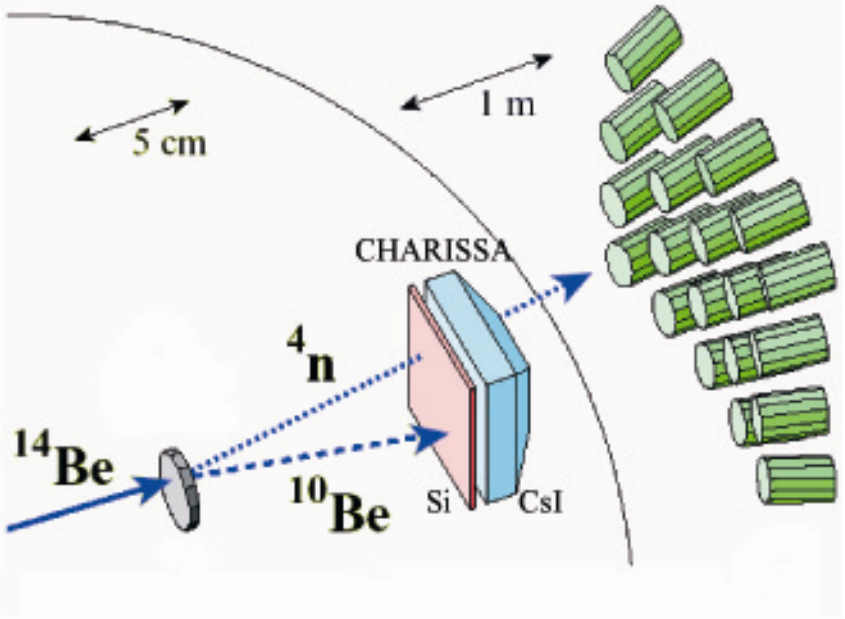
Search for neutron clusters at GANIL/SPIRAL

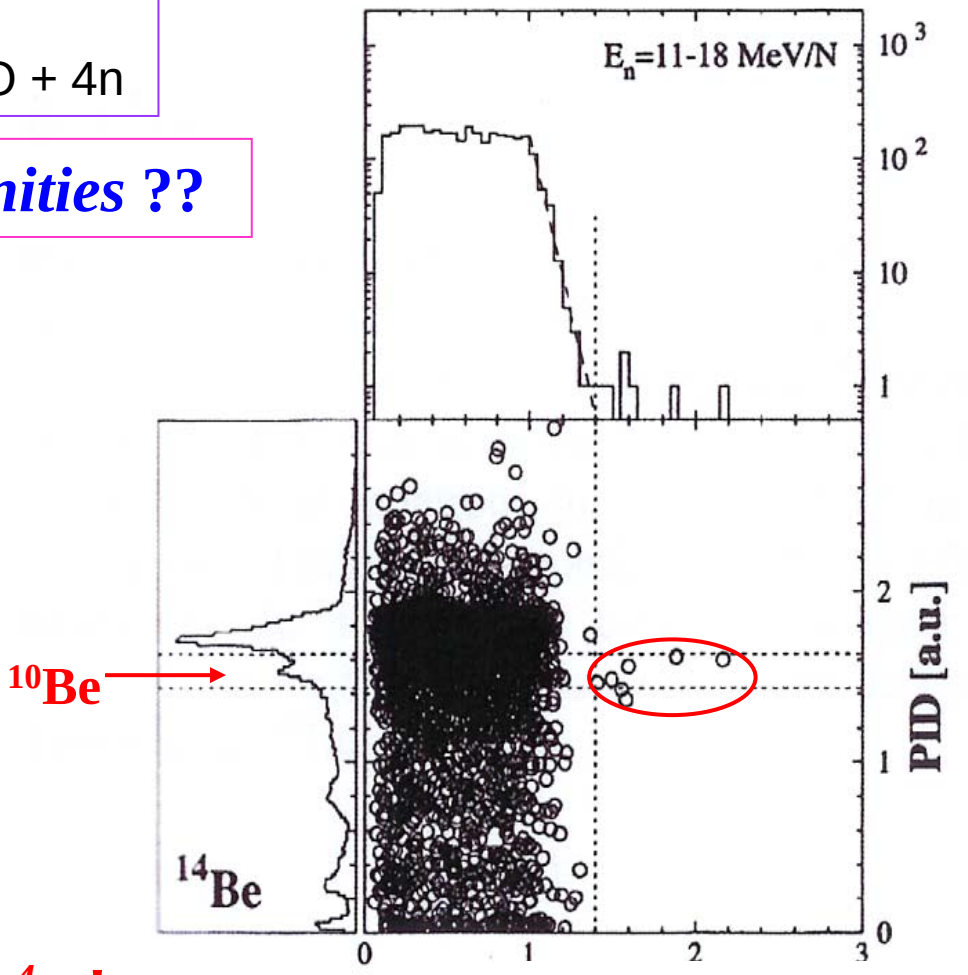
Experimental quest since the 60's

- ✓ Neutron induced fission ^{235}**U(n,^{x}n)**
- ✓ Irradiation by light-ion beams
  - Ex: 24GeV protons + W
- ✓ Double charge exchange ^{4,3}He(π^- ,π^+)^{4,3}n
- ✓ multinucleon transfer **e.g.** ^{7}Li + ^{11}B $\rightarrow$ ^{14}O + 4n

RI Beams : *new opportunities* ??

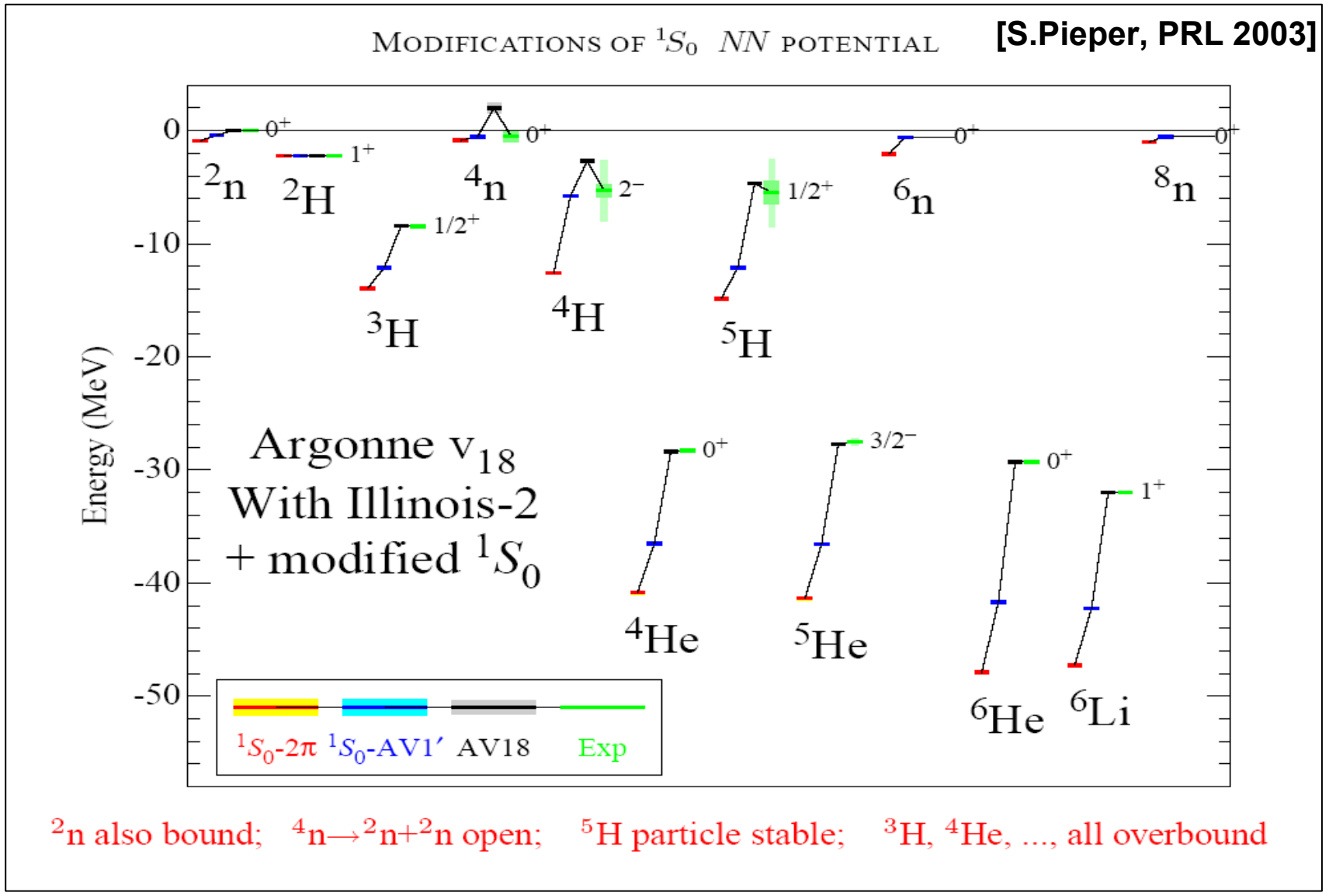
^{14}Be Break-up experiment @ GANIL





6 events compatible with a bound ^{4}n !

Reply from theory



Similar conclusions by Timofeyuk (J.Phys.2004) and Lazauskas(PRC2005)

Our alternative approach to B.U. reactions

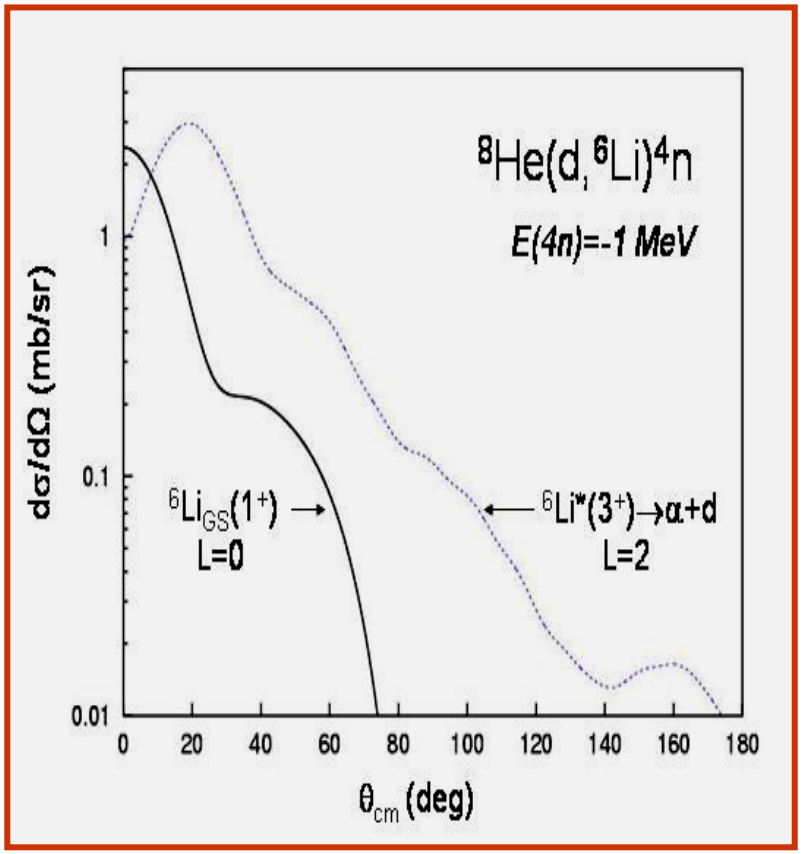
α-transfer reaction *^{8}He(d,^{6}Li)4n using SPIRAL ^{8}He beam*

- **^{8}He very neutron rich**
  large Overlap **< ^{8}He | α ⊗ 4n >**

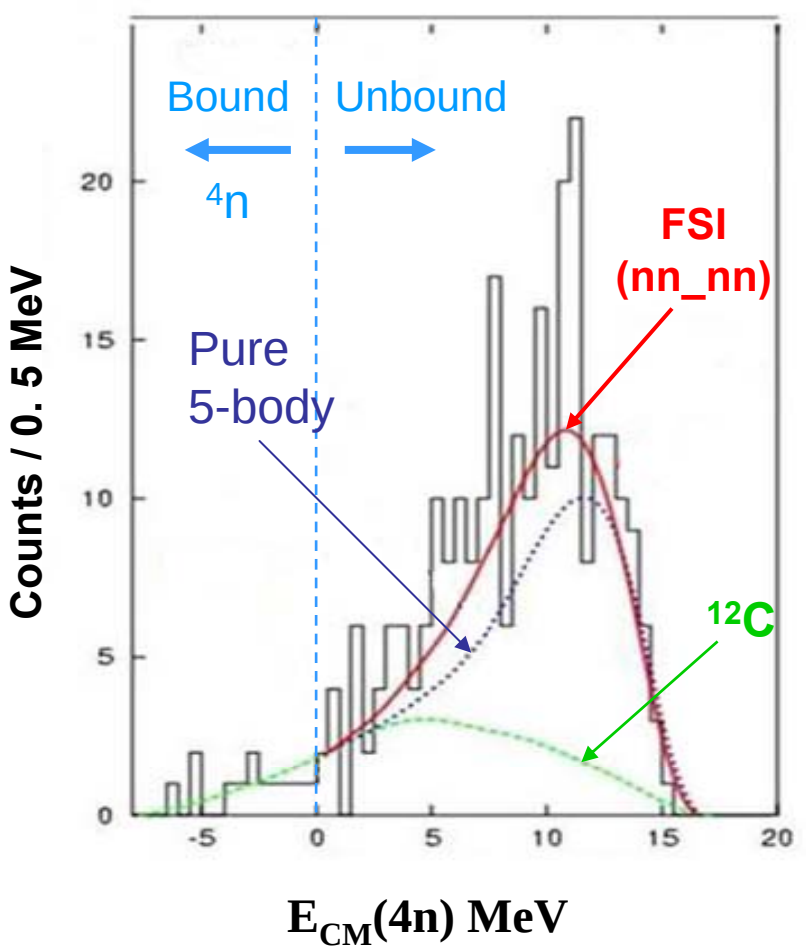
- (d,^{6}Li) well known α–transfer reaction :
  large Overlap **< ^{6}Li | ^{4}He ⊗ d>**
  ⇒ **cross section** ~ few mb/sr

- Missing mass measurement :
  ⇒ **Energy of the states**
  ⇒ **Bound** and **resonant** states
  on the **same footing**

DWBA predictions



Results $^{8}He(d,^{6}Li)4n$



E.Rich, PhD thesis(2005)

24MeV <E(^{6}Li)<40 MeV
Low cm angles

highest cross section for α transfer

coincidence with neutrons (at least 1 hit in PLASTIC) 30% efficiency

reduction of background from C in CD2 target?

CONCLUSIONS

- **Bound ^{4}n not observed**
  $\sigma < 35\ \mu b$
- **Spectrum consistent with nn-nn correlations in final state**

Collaboration

IPN Orsay :
D. Beaumel, E. Becheva, Y. Blumenfeld, F. Delaunay, S. Fortier, N. Frascaria, S. Galès, L. Gaudefroy, J. Gibelin, J. Guillot, F. Hammache, E. Khan, V. Lima, C. Monrozeau, E. Rich, J.-A. Scarpaci, O.Sorlin, E. Tryggestad

INP Cracow/JINR-Dubna
R. Wolski, A.Fomichev, S. Stepantsov

CEA-Saclay
A. Gillibert, V. Lapoux, L. Nalpas, A. Obertelli, E. Pollacco, F. Skaza

GANIL
M. Gelin, P.Roussel-Chomaz

LNS Catania
D. Santonocito

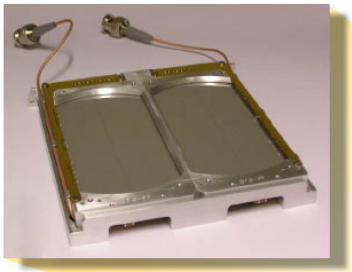
The MUST2 Array

Collaboration: IPN Orsay, SPhN/Saclay, GANIL

MUST2 : a major upgrade of previous MUST 3-stage array

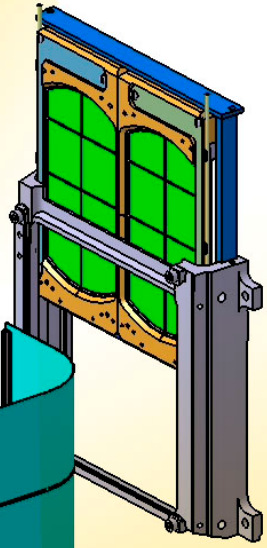
- ***Increase angular coverage***
  - ***Better efficiency***
  - ***Measure several reactions in one shot***
- ***Increase granularity (multiparticle events)***
- ***New electronics to handle the increase of channels***

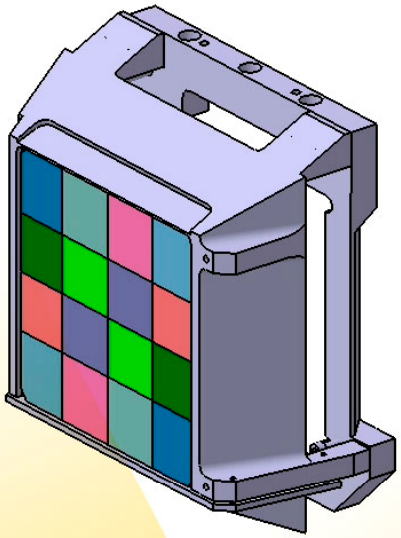
Collaboration: IPNO/SPhN-Saclay/GANIL

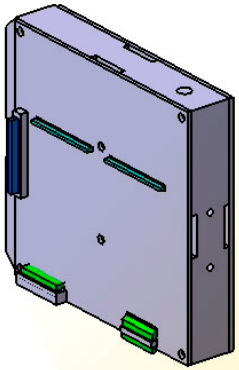


Si(Li) 5mm

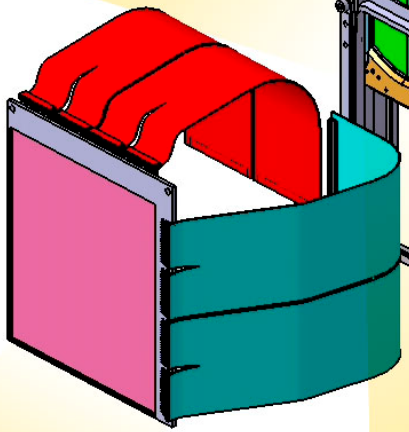
CsI 4cm

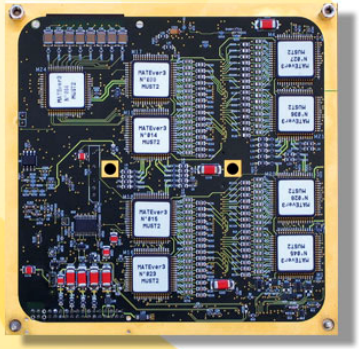


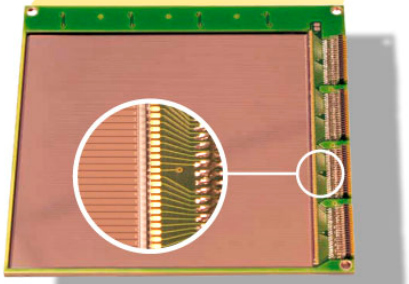


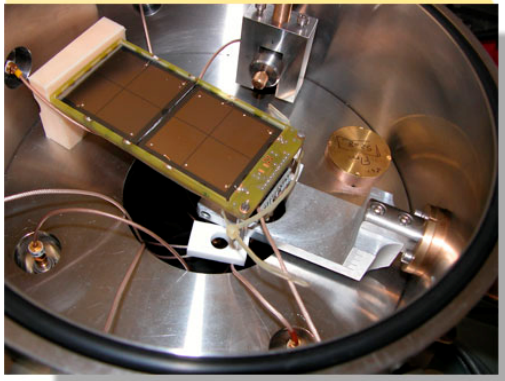


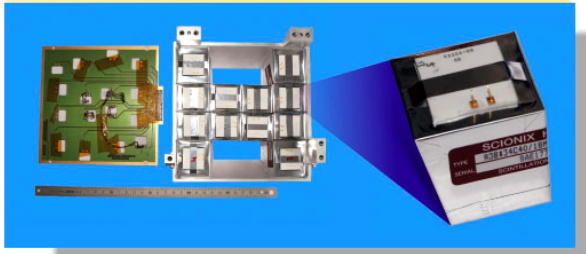
DSSD
10x10cm²
128X+128Y
300μm





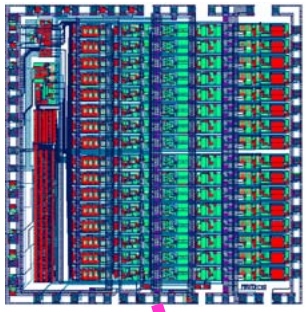






MUST2 electronics

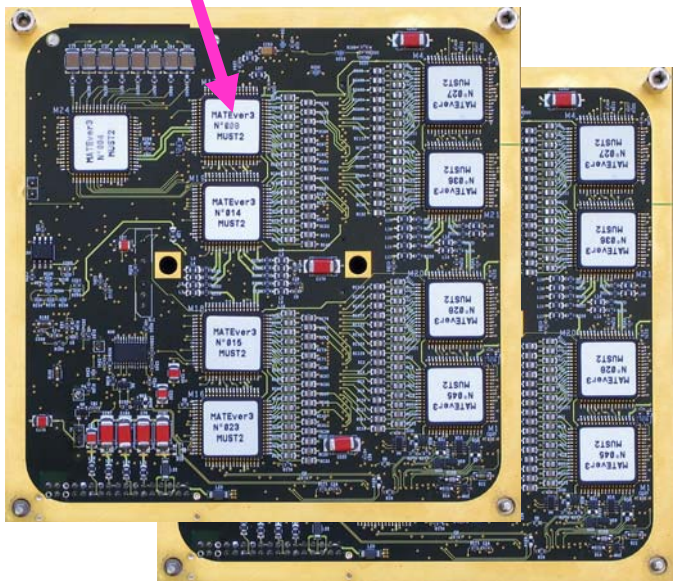
MUST2 ASIC — SACLAY (+IPNO)



- 16 channels 28 mW/ch
- Energy & Time
- Si, Si(Li) and CsI
- Multiplexer
- I2C interface

- High linear. pulser
- T sensor

MOTHER BOARDS (IPNO)



1 telescope

VACUUM | AIR

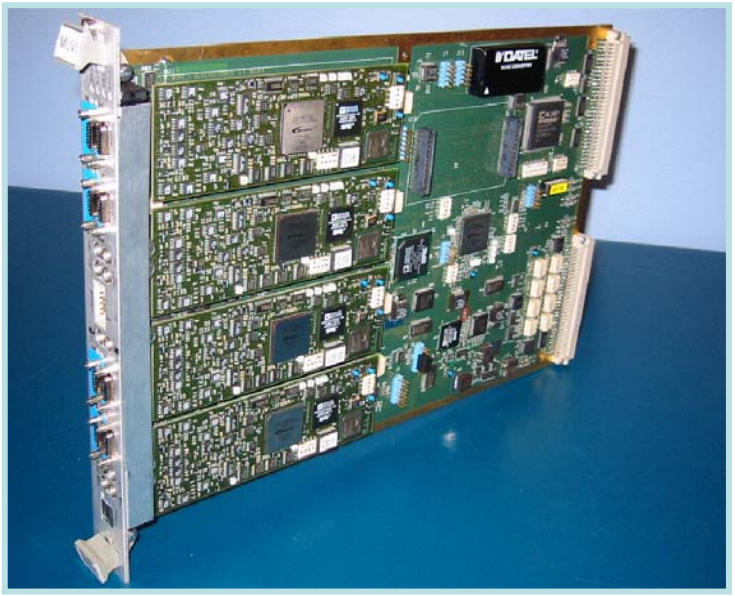
4 analog bus

Control signals

I2C bus

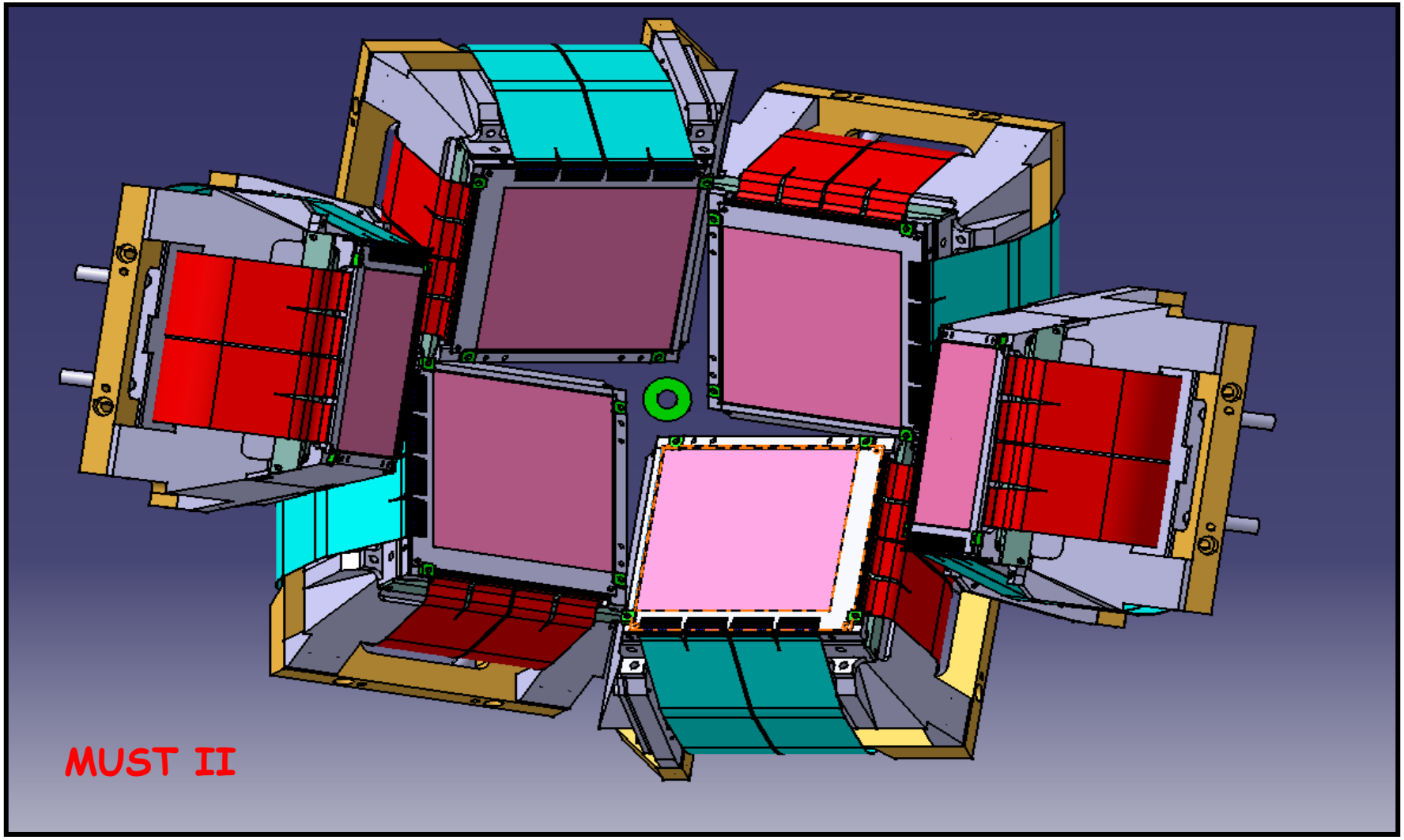
VXI board (GANIL)

16 ADC14 bits
2.3K parameters
2MHz
Slow Control I2C
Pedestal substraction
DNL correction



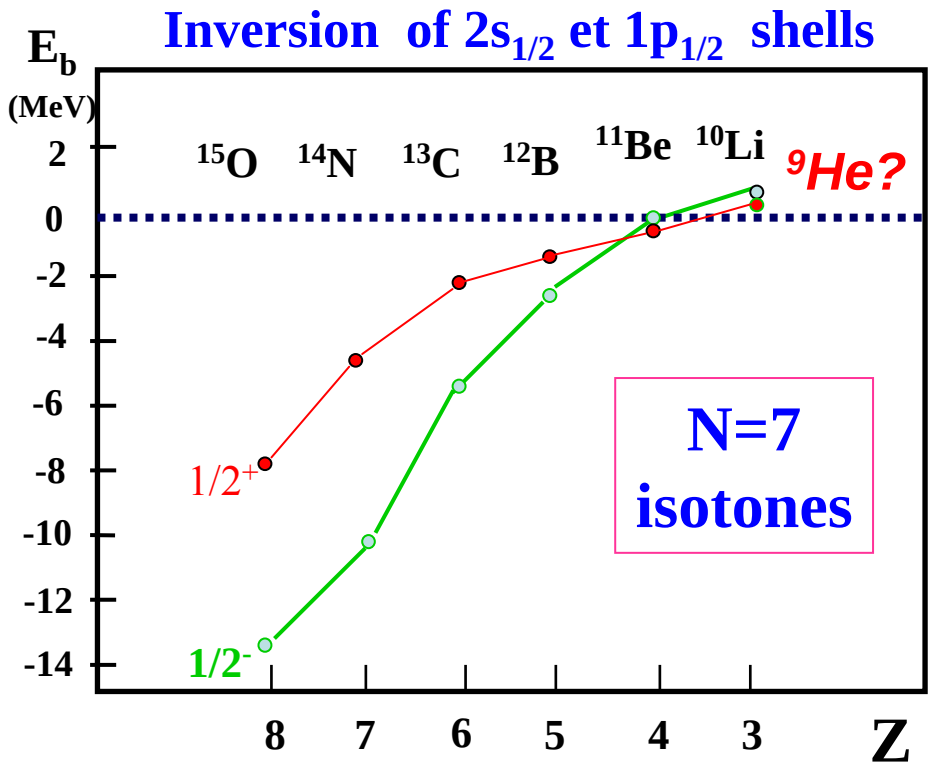
4 telescopes

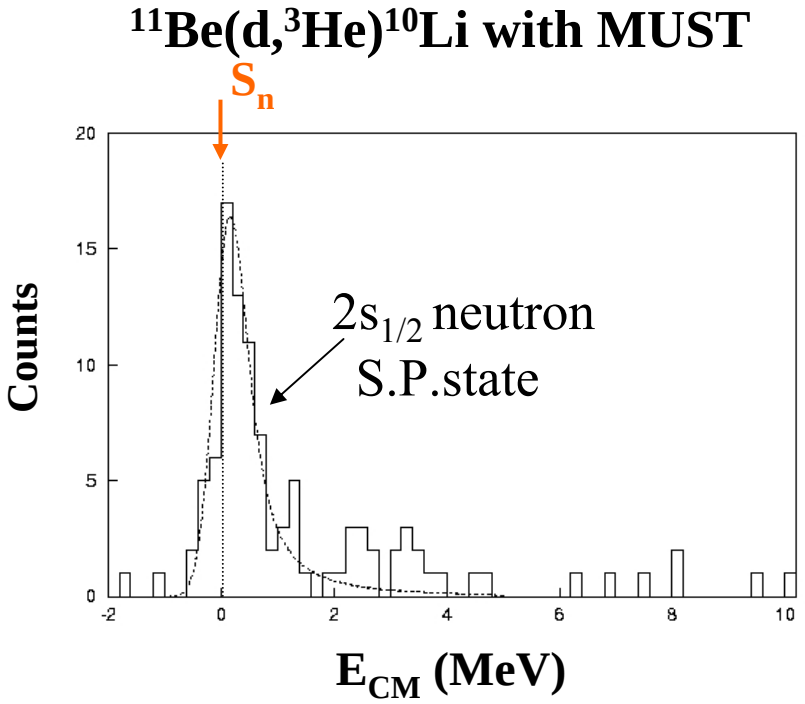
6 telescopes configuration
for e.g. measurement of (d,t) and (d,d) reactions



Study of ^{9}He: parity inversion in N=7 isotones

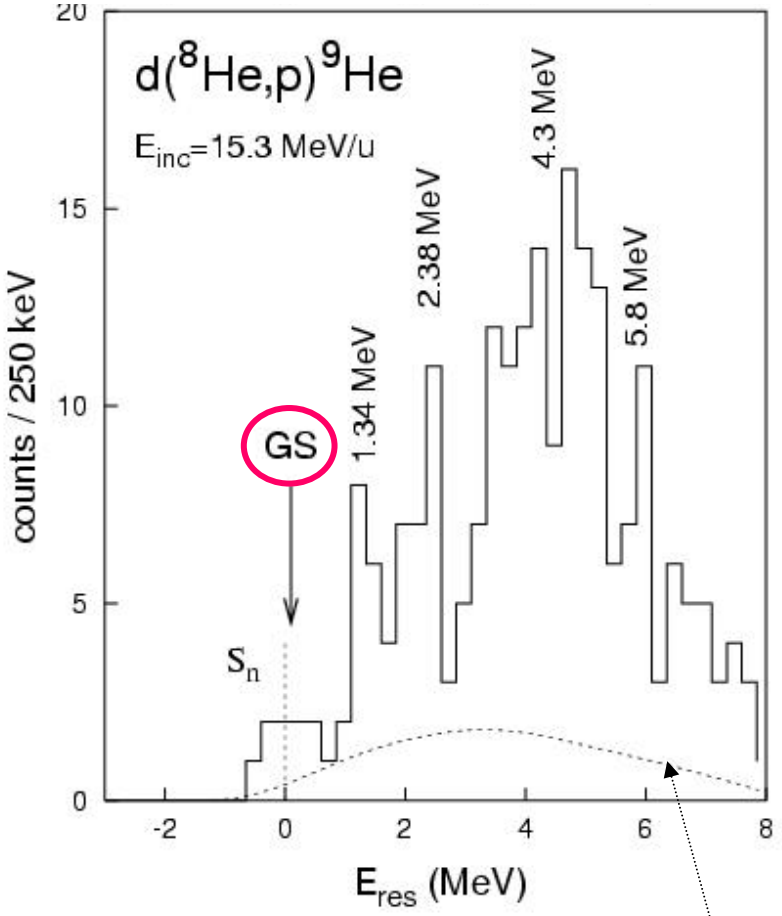
Study of ^{8}He(d,p) with MUST2

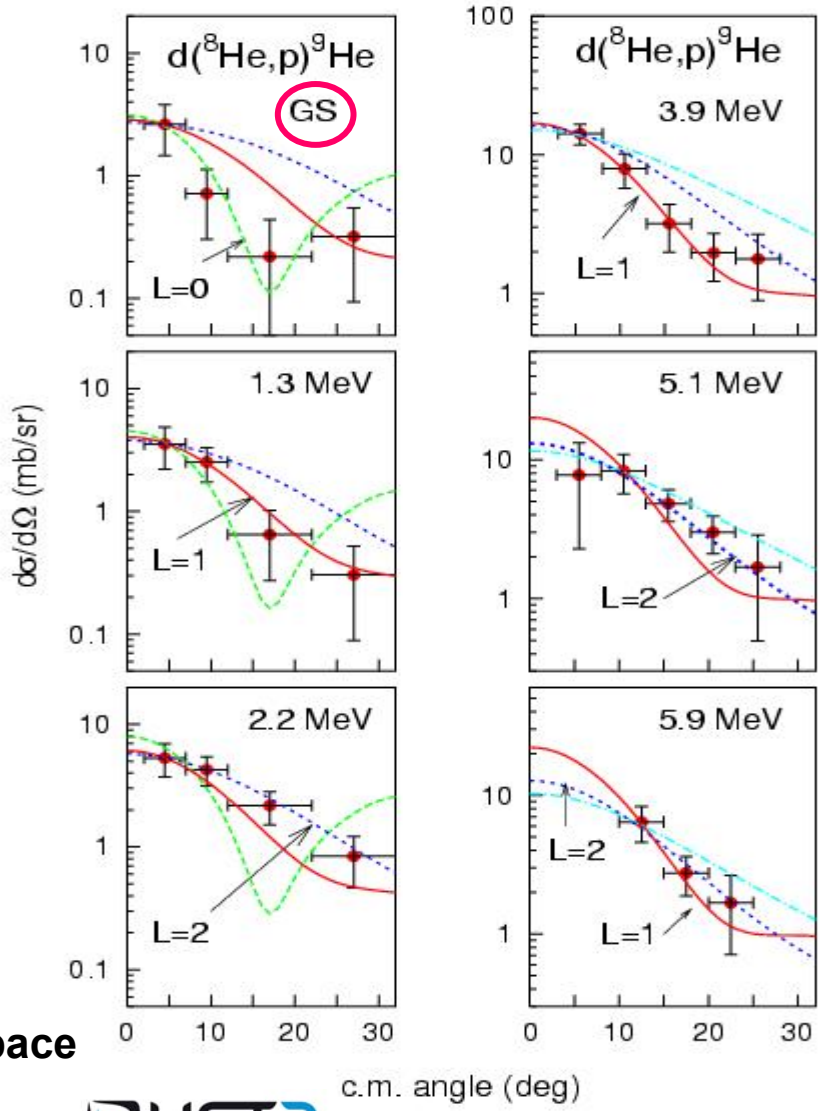




Evidence obtained with MUST1

Excitation energy spectrum in ^{9}He





E.Tryggestad et al.

3-body phase-space

Coming soon: New data obtained with MUST2 (P.Roussel-Chomaz et al.)

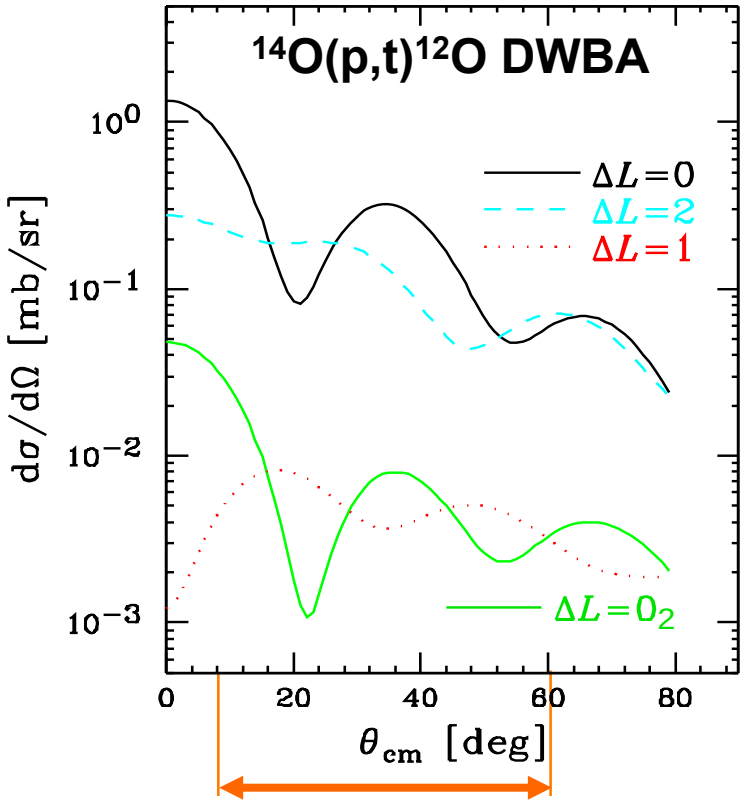
see also Golovkov et al, PRC 76 (2007)

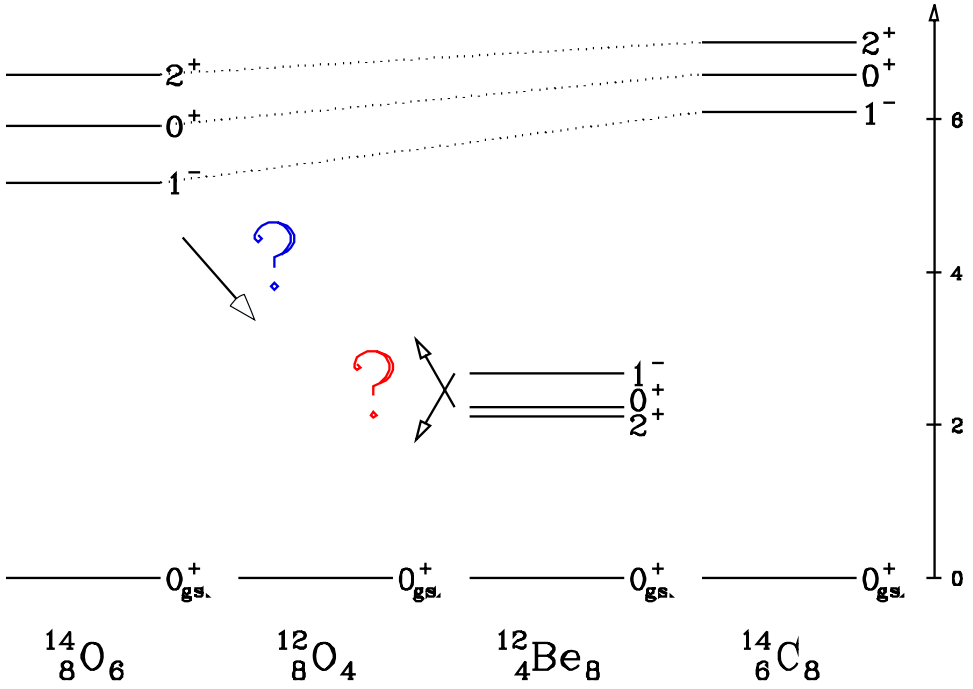
Magicity loss at Z=8 ?

D.Suzuki, H.Iwasaki et al.

Magicity loss at N=8

- **Intruder configurations in GS**
  K.O. reactions at GANIL and MSU
- **Low lying intruder 1- and 0+**
  H.Iwasaki et al, PLB 481(00)7.
  H.Iwasaki et al, PLB 491(00)8.
  S. Shimoura et al, PLB 560(03)31.



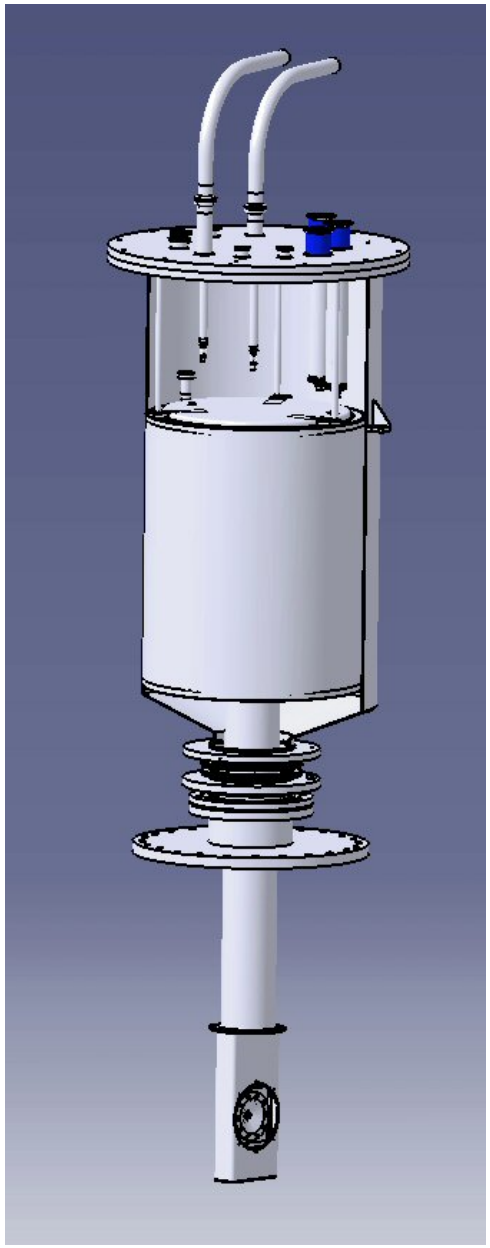


Study of **^{14}O(p,t)^{12}O** at 50 MeV/u at GANIL with MUST2

Data recently taken

Test experiment @ GANIL: $^{22}Ne + \alpha$ at 30 MeV/u

Collaboration: IPNO, Saclay, GANIL

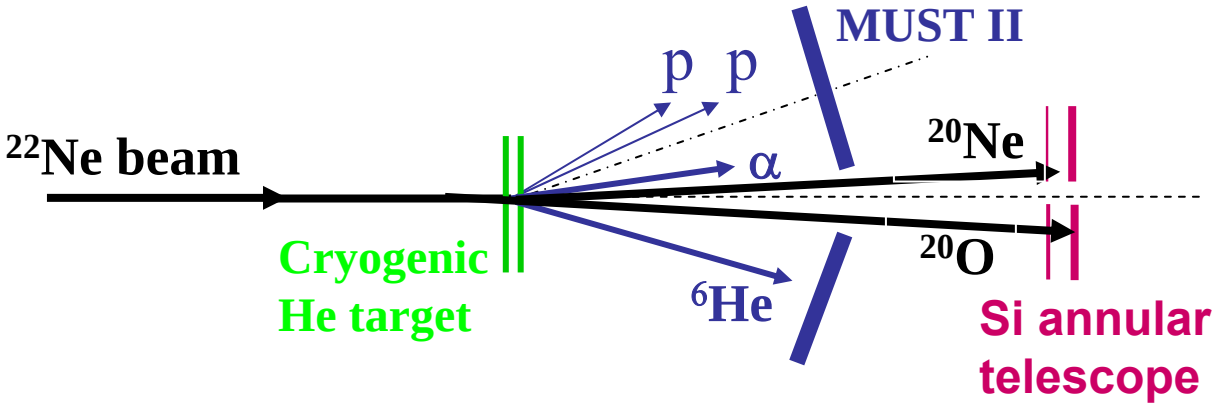


$^{22}Ne(\alpha,^{6}He)^{20}O$ *30 MeV/u*

$^{22}Ne(\alpha,^{6}Be)^{20}O \rightarrow \alpha + p + p$

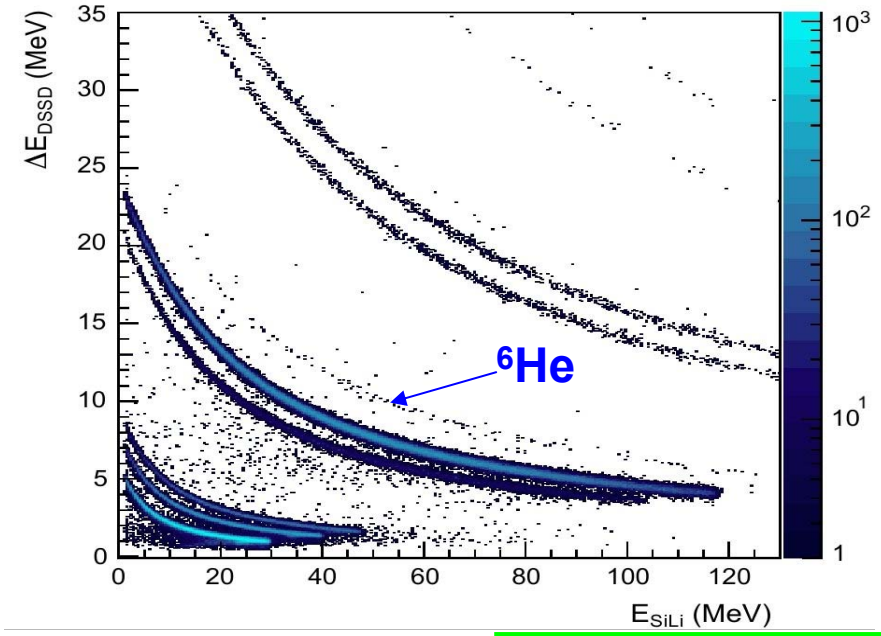
EX: $^{6,8}He(\alpha,^{6}Be)4n,6n$; $^{16}C(\alpha,^{6}Be)^{14}Be$; …

Using cryogenic He <u>gas</u> target made for missing mass measurements

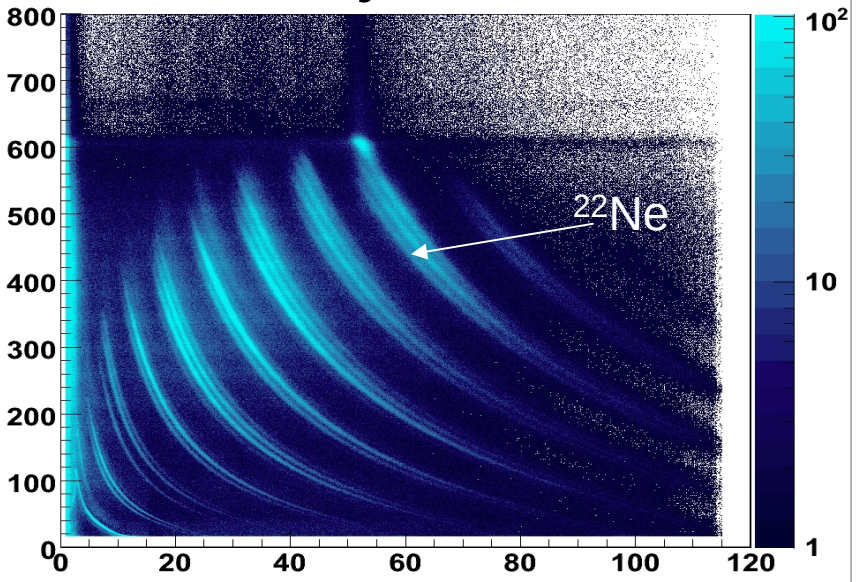


RESULTS - $^{22}Ne(\alpha,^{6}He)$ at 30 MeV/u

Recoil PID



Ejectile PID



15 hours counting
~ 10^6 pps beam