Heavy hydrogens studied by transfer

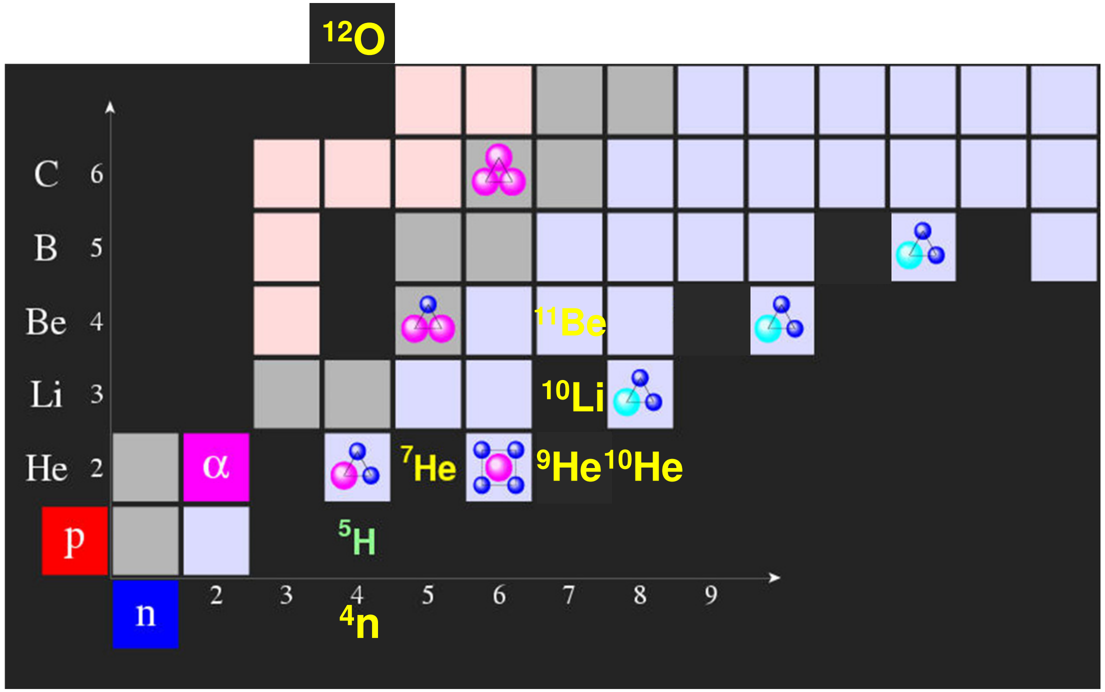
D. Beaumel,
IPN Orsay

ESNT, Saclay Jan 30 – Feb 3, 2017

Transfer studies with light exotic nuclei

Extensive studies could be performed during the last 15 years by our collaboration (IPN Orsay, CEA/Saclay, GANIL)

- **Missing mass - recoil particle detection**
- **Tools : MUST & MUST2**



- **“Critical” region experimentally accessible**
- ***ab initio* calculations**

Recently : ***make use of ab initio overlaps in cross-section calculations***

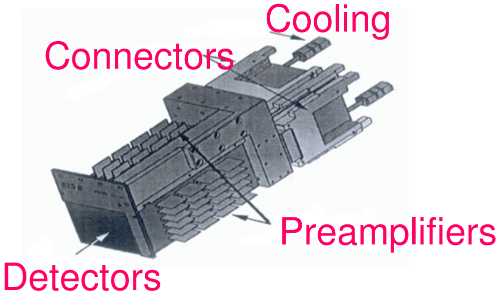
Landscape of Si detectors for DR studies

Light Beams — **Fission fragments**

1997 — 2007 — 2019~

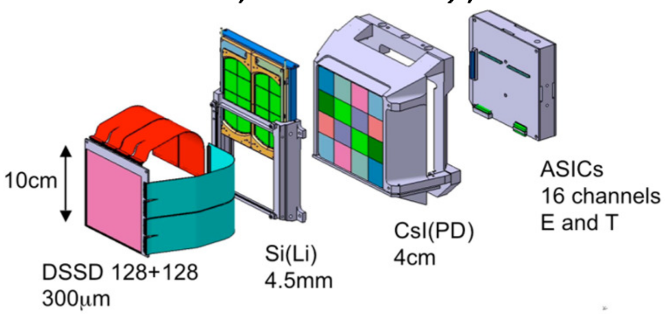
MUST

coll.: IPN,CEA-Saclay, DAM



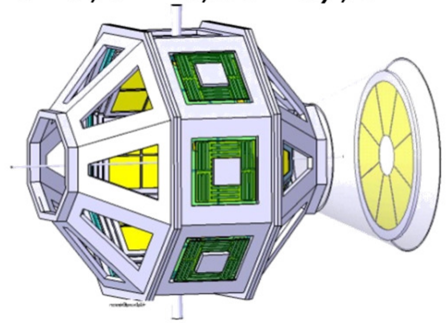
MUST2

coll.: IPN,CEA-Saclay, GANIL



GASPARD-TRACE

coll.: IPN, INFN, BARC
Irfu,Huelva,STFC,Surrey,GANIL

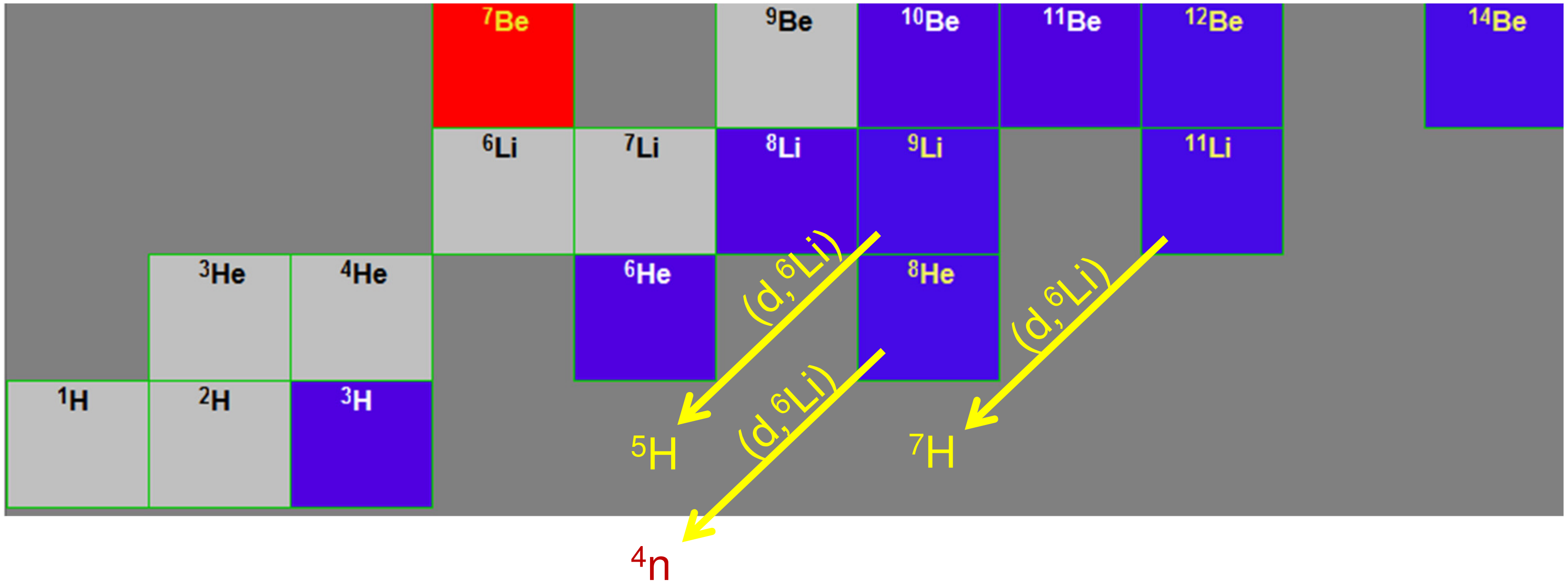


Particle spectrocopy

E_x resolution: ~500keV

Particle-Gamma Spectroscopy

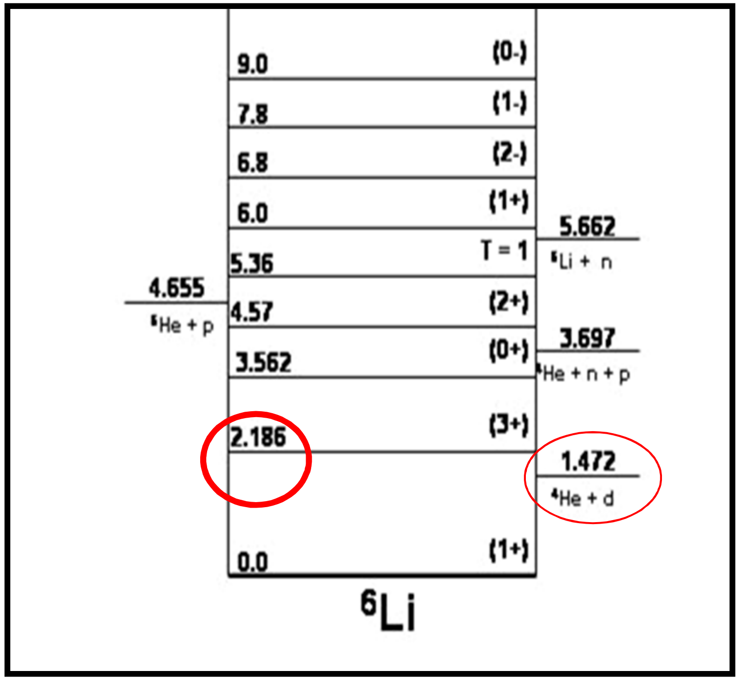
E_x resol.: ~5keV (AGATA case)



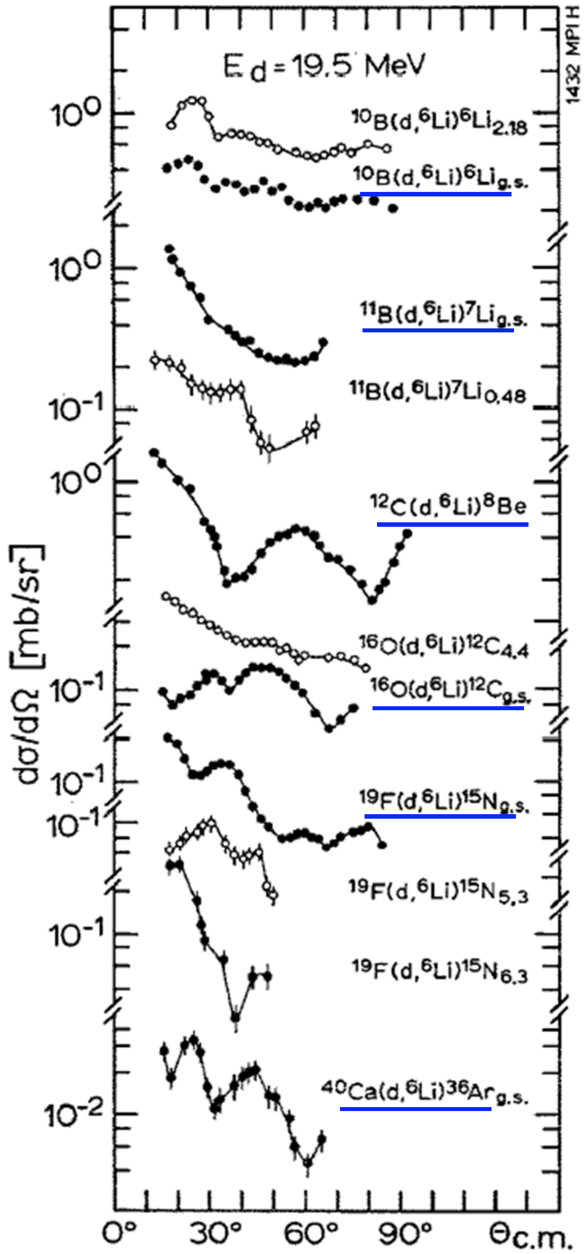
7Be
9Be
10Be
11Be
12Be
14Be
6Li
7Li
8Li
9Li
11Li
3He
4He
6He
8He
1H
2H
3H
(d,6Li)
(d,6Li)
(d,6Li)
5H
7H
4n

The (d,^{6}Li) reaction

- Well-established as alpha-transfer reaction
- Simple α-transfer process DWBA
  suitable for e.g. clustering studies
- Peripheral
- ^{6}Li overlaps well with α+d (low E_{sep} , e^{-} scattering)
  Sizeable cross-sections
- Mainly GS and 3^{+} of ^{6}Li are populated

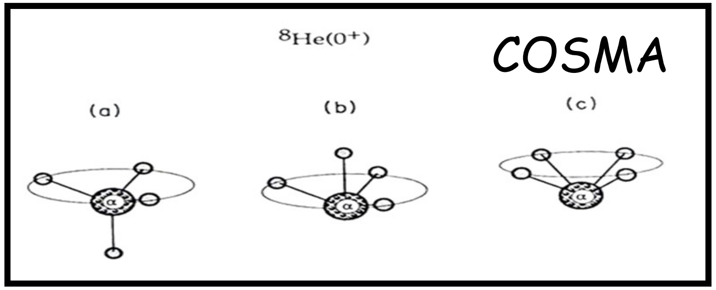


Gutbrod et al., NPA (1971)



Search for tetraneutron via α transfer @ GANIL: $^{8}He(d,^{6}Li)$

$$^{6}Li_{gs} = \alpha + d$$
$$^{8}He_{gs} = \alpha + 4\,n$$
$$= \alpha + {}^{4}n + \ldots$$

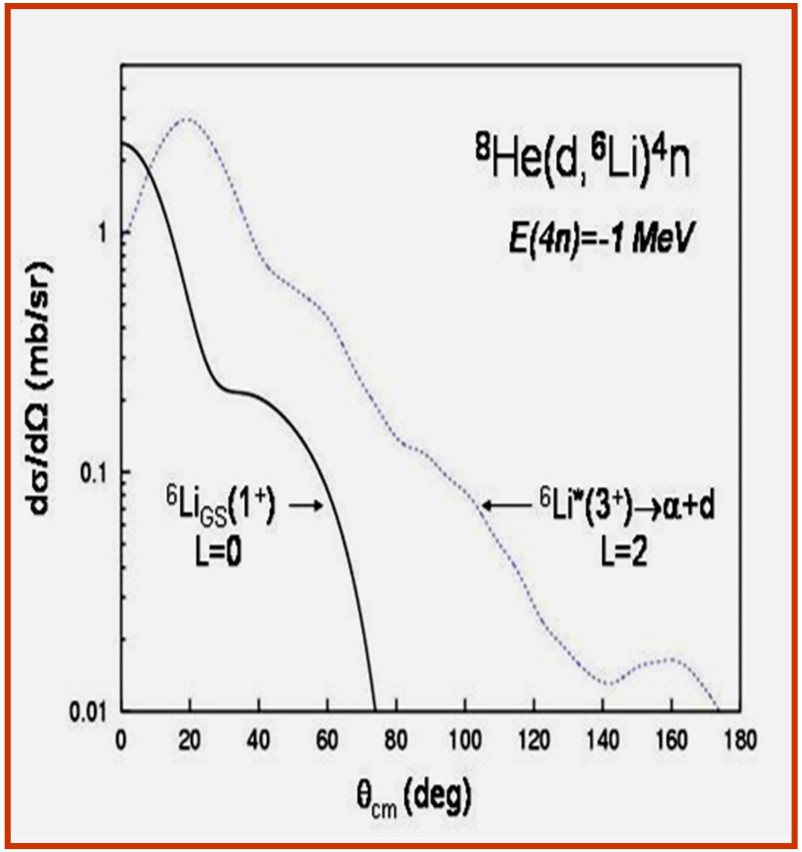


M.V. Zhukov et al, PRC 50 (1994)

for bound tetraneutron

$E_{cm} \approx 0$ $\theta_{cm}<50^o$	⟺	$\theta_{LAB}<22^o$ $E(^{6}Li)$=22-40 MeV

Some DWBA predictions…

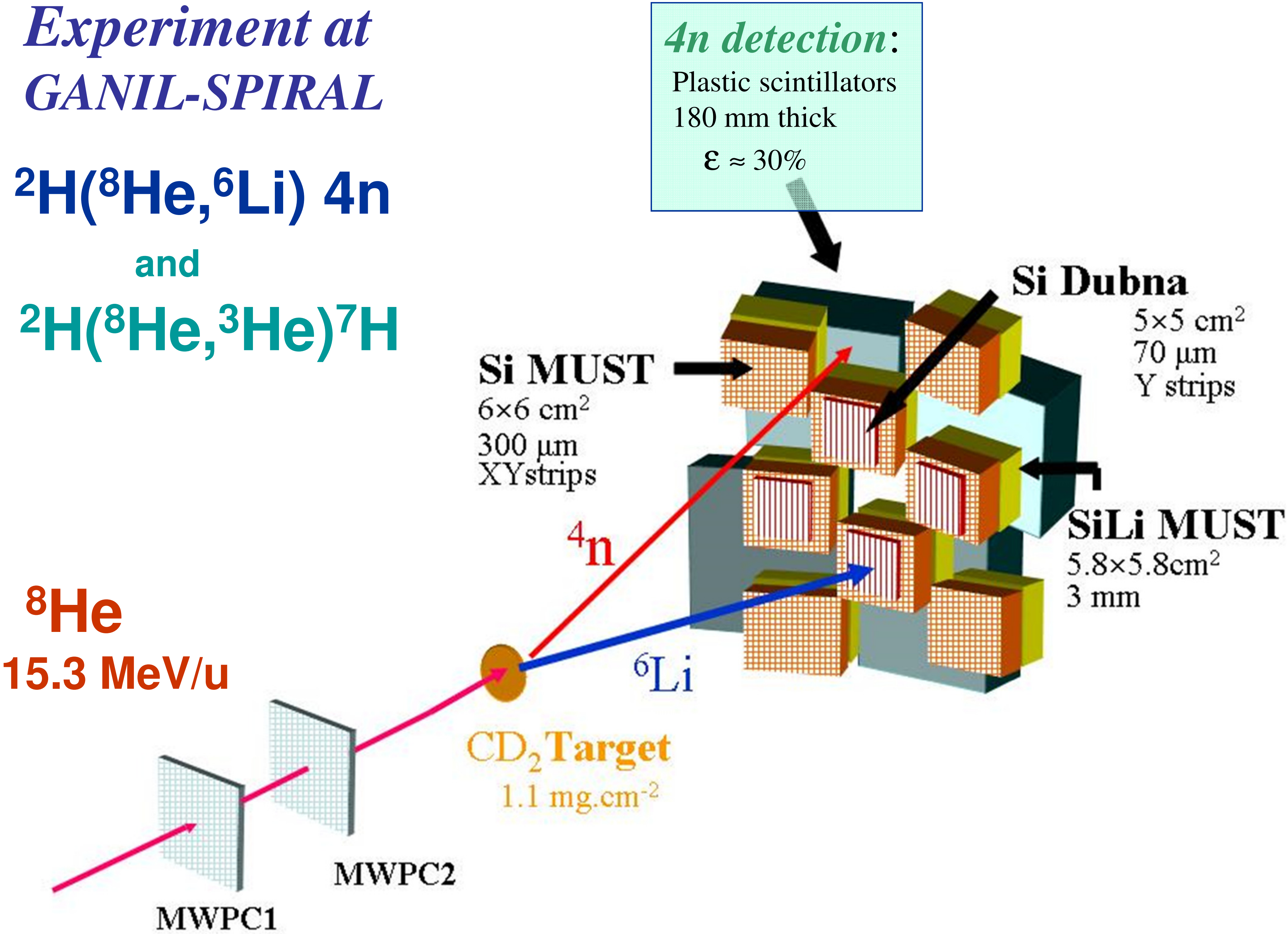


Experiment at GANIL-SPIRAL

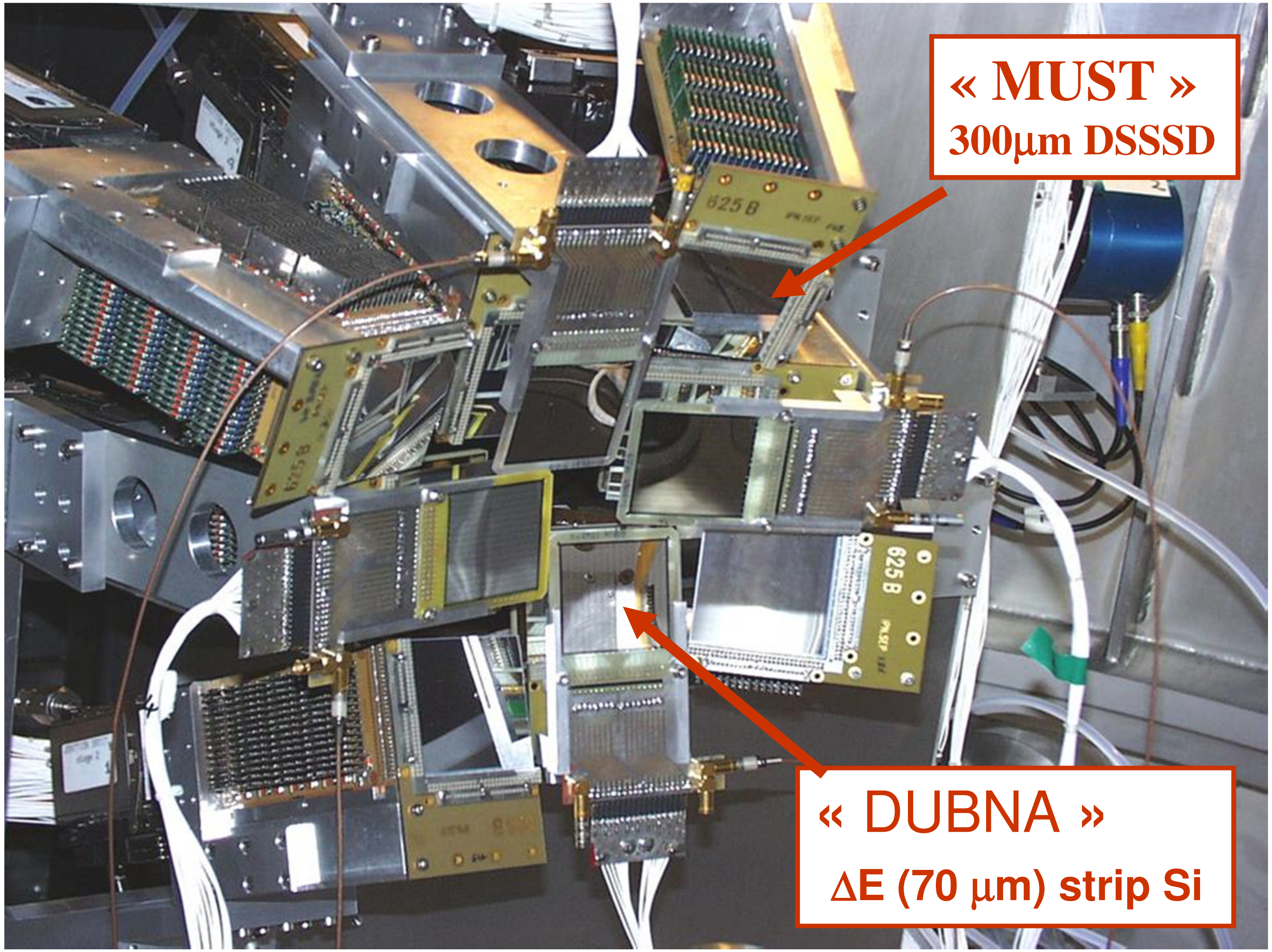
$^{2}H(^{8}He,^{6}Li)$ 4n

and

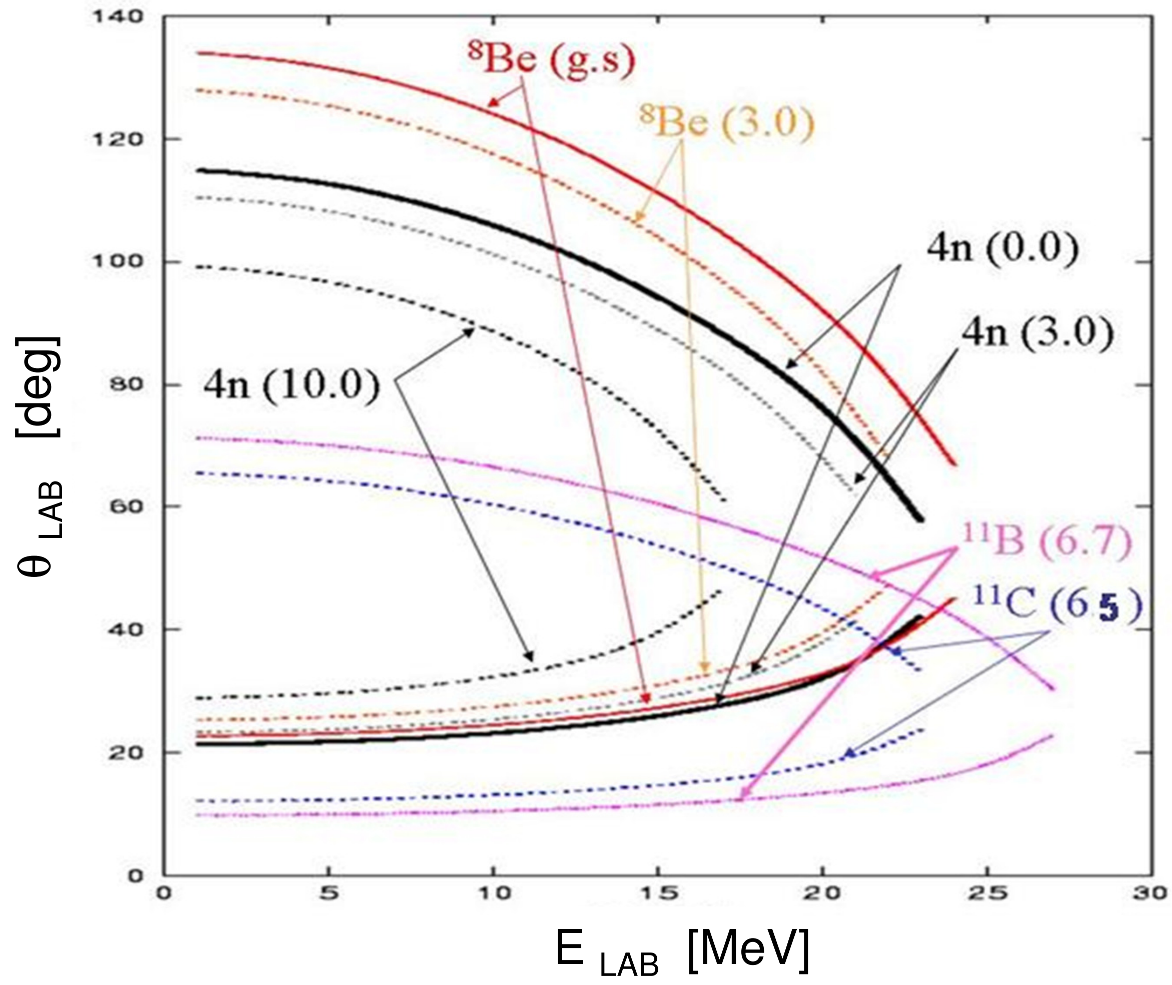
$^{2}H(^{8}He,^{3}He)^{7}H$



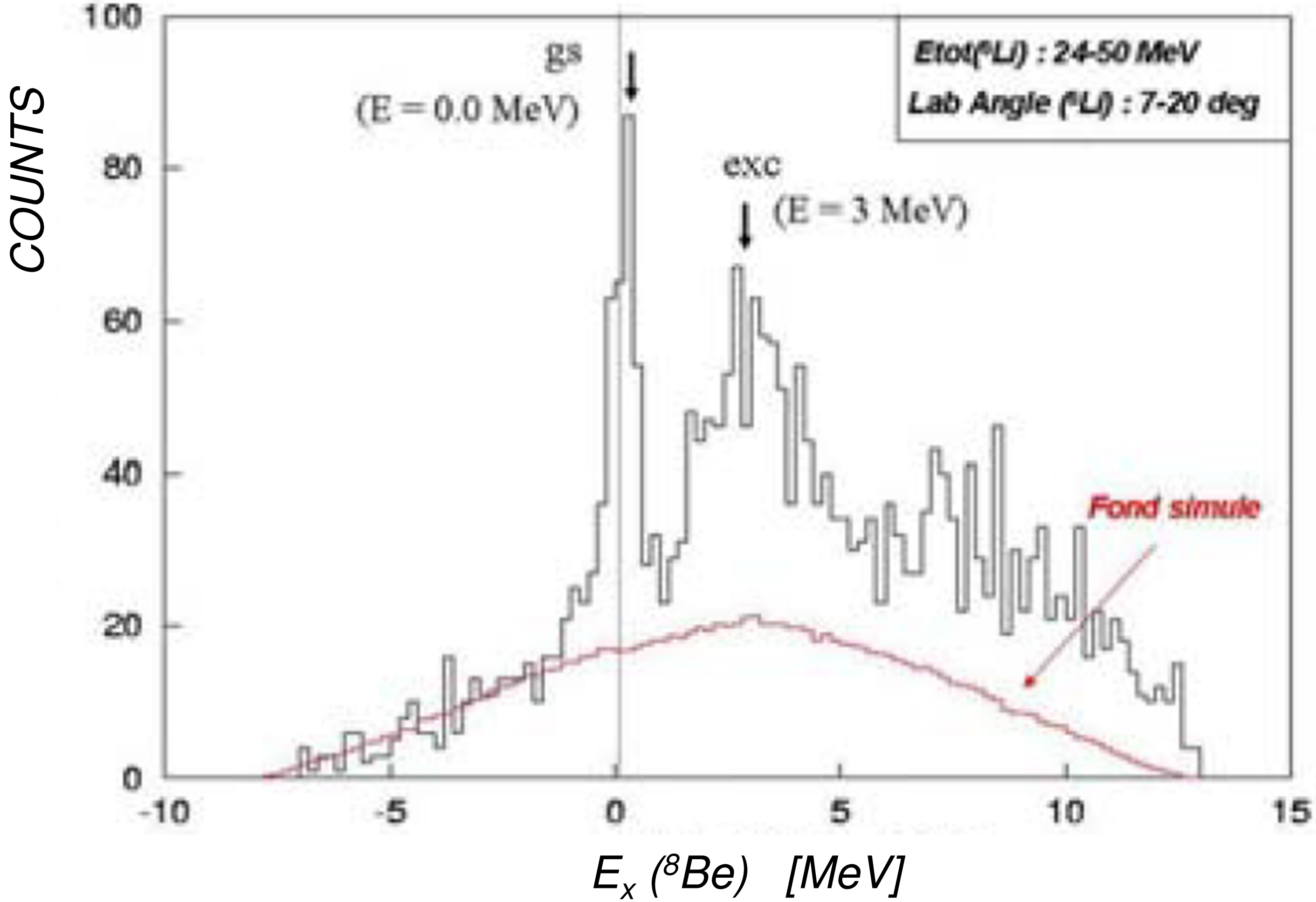
study of the ^{8}He+d system



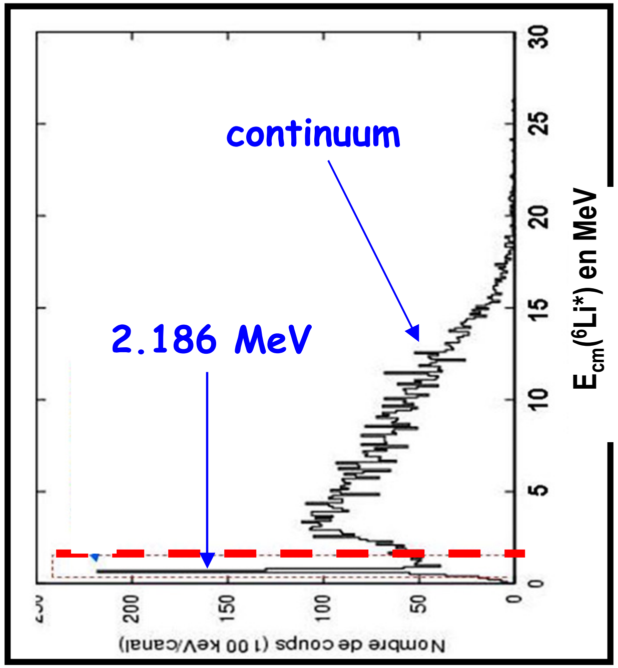
Kinematical plot of reactions induced by ^{12}C and ^{8}He beams

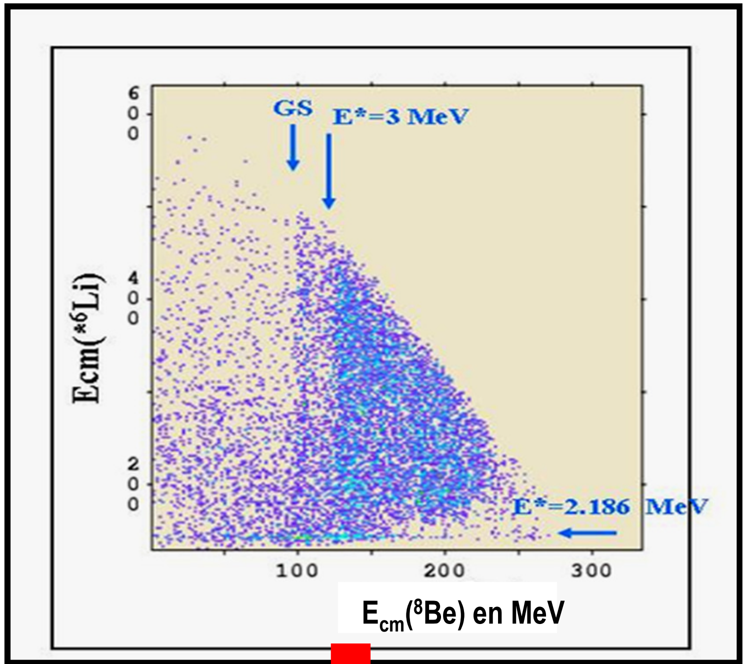


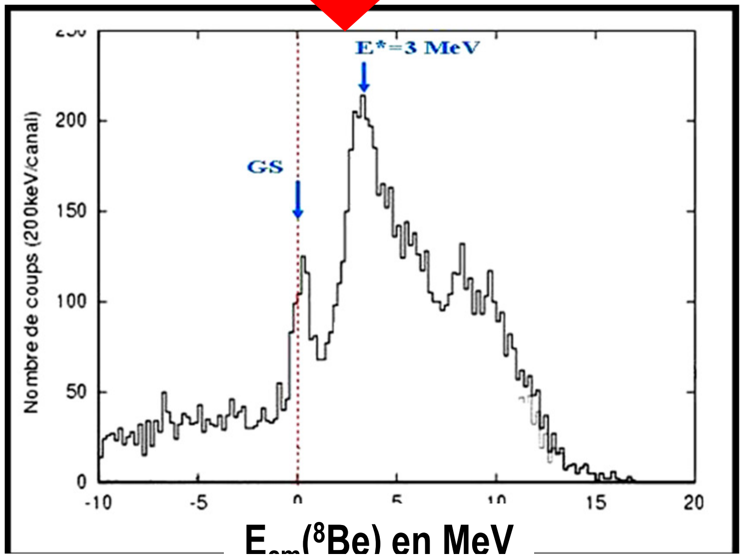
Results for $^{12}C(d,^{6}Li_{gs})$



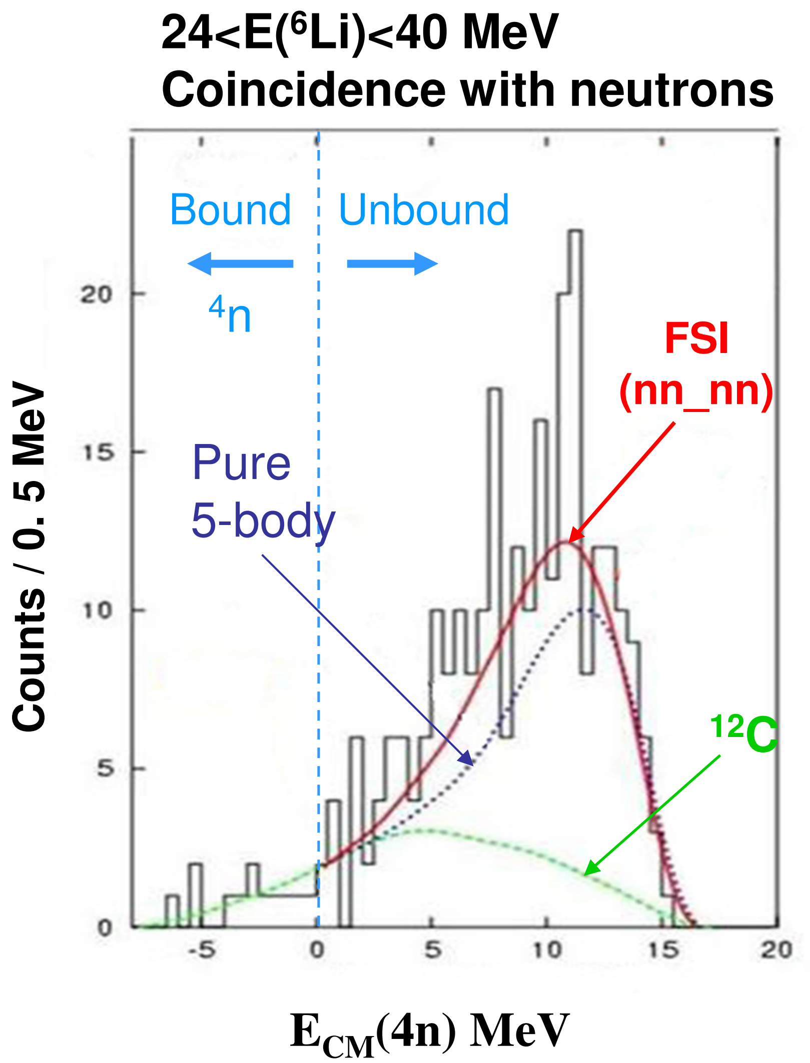
Results for $^{12}C(d,^{6}Li^{*})$







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



Monte-Carlo simulations:

Background from C in CD2
(normalized to data from C target

+5-body phase-space
(normalized to H.E.part)

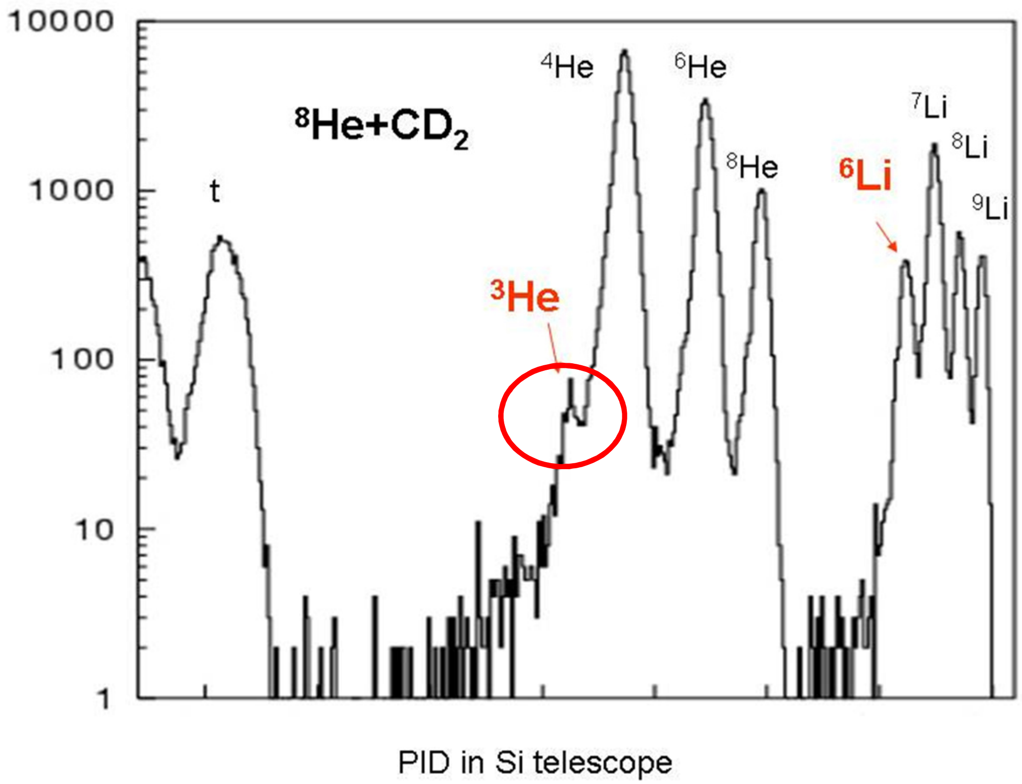
+ 5-body phase-space with nn-nn FSI
(Analytic shape from Stepantsov)

- **Bound ^{4}n not observed**
- *σ<35 μb*
- Spectrum consistent with **nn-nn correlations** in final state

S.Fortier et al., NPA 805 (1998)

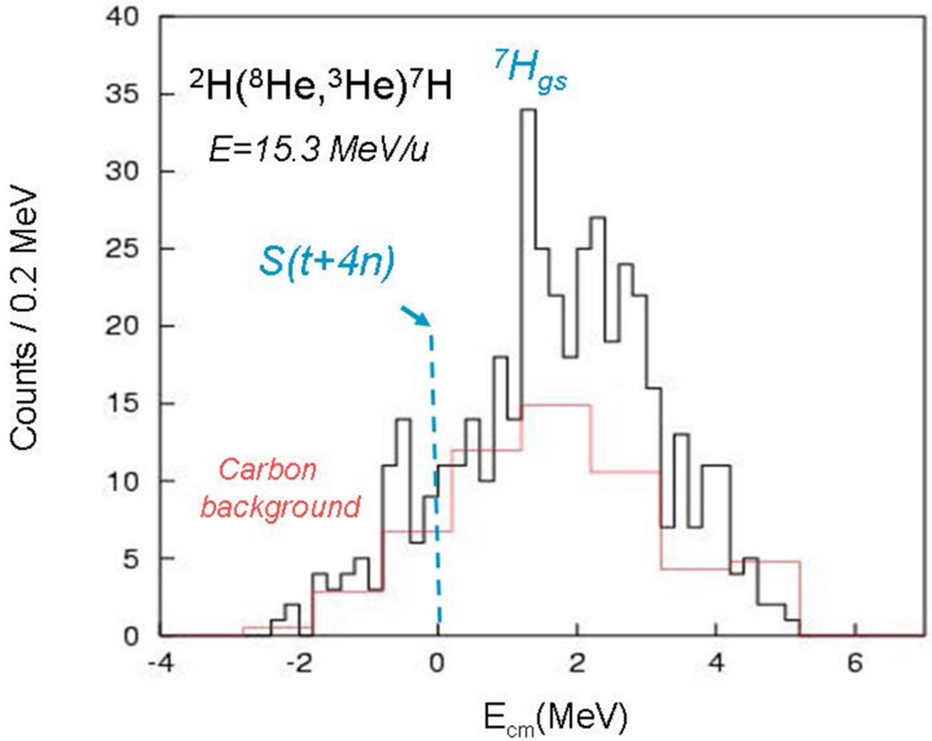
$^{8}He(d,^{3}He)^{7}H$

Identification of ^{3}He

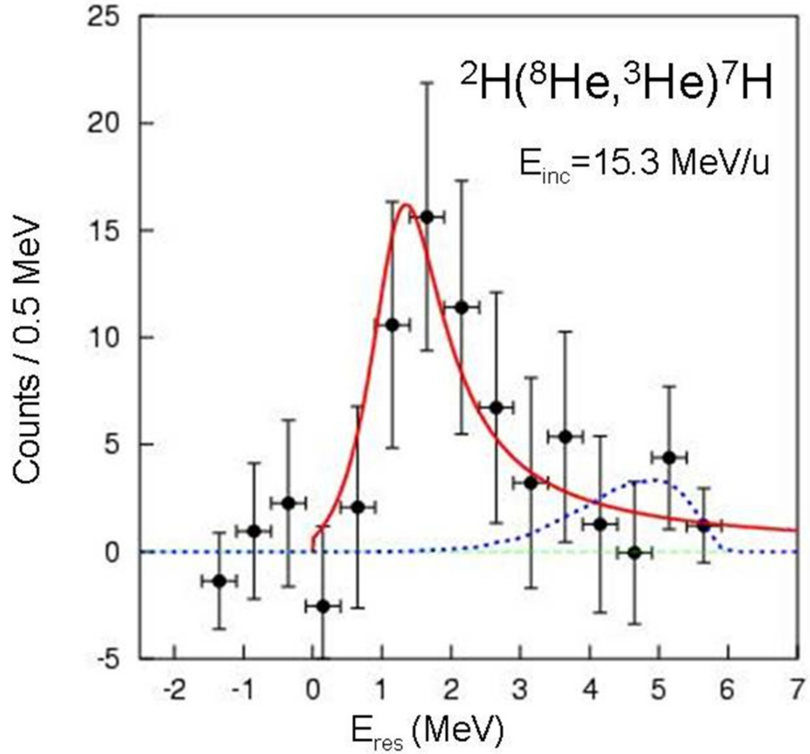


Spectra for ^7H

singles spectrum



after background subtraction



Fit by Breit-Wigner function
$\Gamma=\Gamma_0\sqrt{(E/E_r)}$

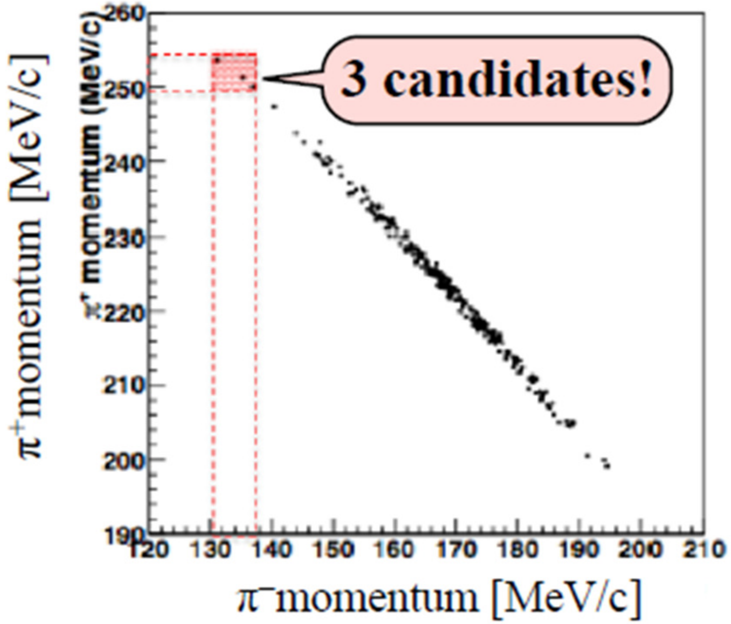
E=1.56 ± 0.27 MeV
Γ_0=1.74 ± 0.72 MeV

- **^7H seems to exist as a resonance close to t+4n threshold**
- **Resonance parameters still ambiguous**

^{5}H and $^{6}_{\Lambda}H$

Experiment

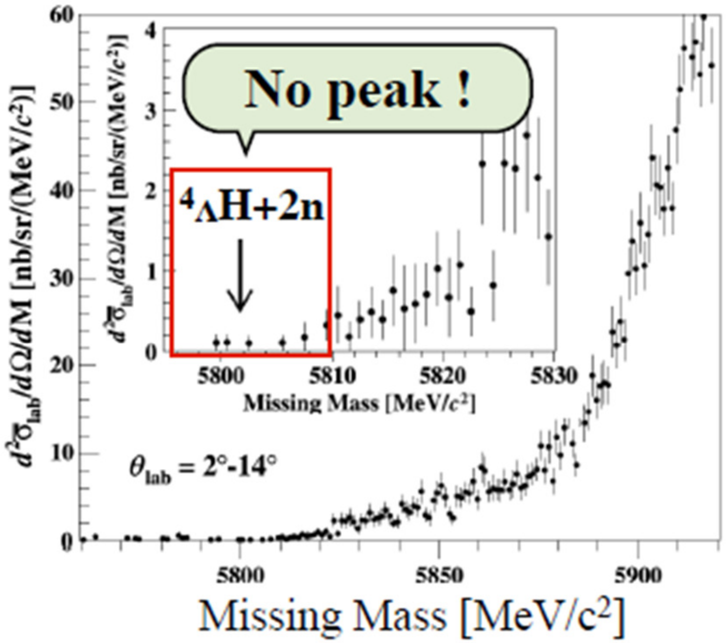
FINUDA $^{6}Li(K^{-},\pi^{+})^{6}_{\Lambda}H$



$B_{\Lambda}(^{6}_{\Lambda}H) = 4.0 \pm 1.1$ MeV from $^{5}H + \Lambda$

M. Agnello, *et. al.*, FINUDA Collaboration, Phys. Rev. Lett. **108** (2012) 042501

J-PARC $^{6}Li(\pi^{-},K^{+})^{6}_{\Lambda}H$



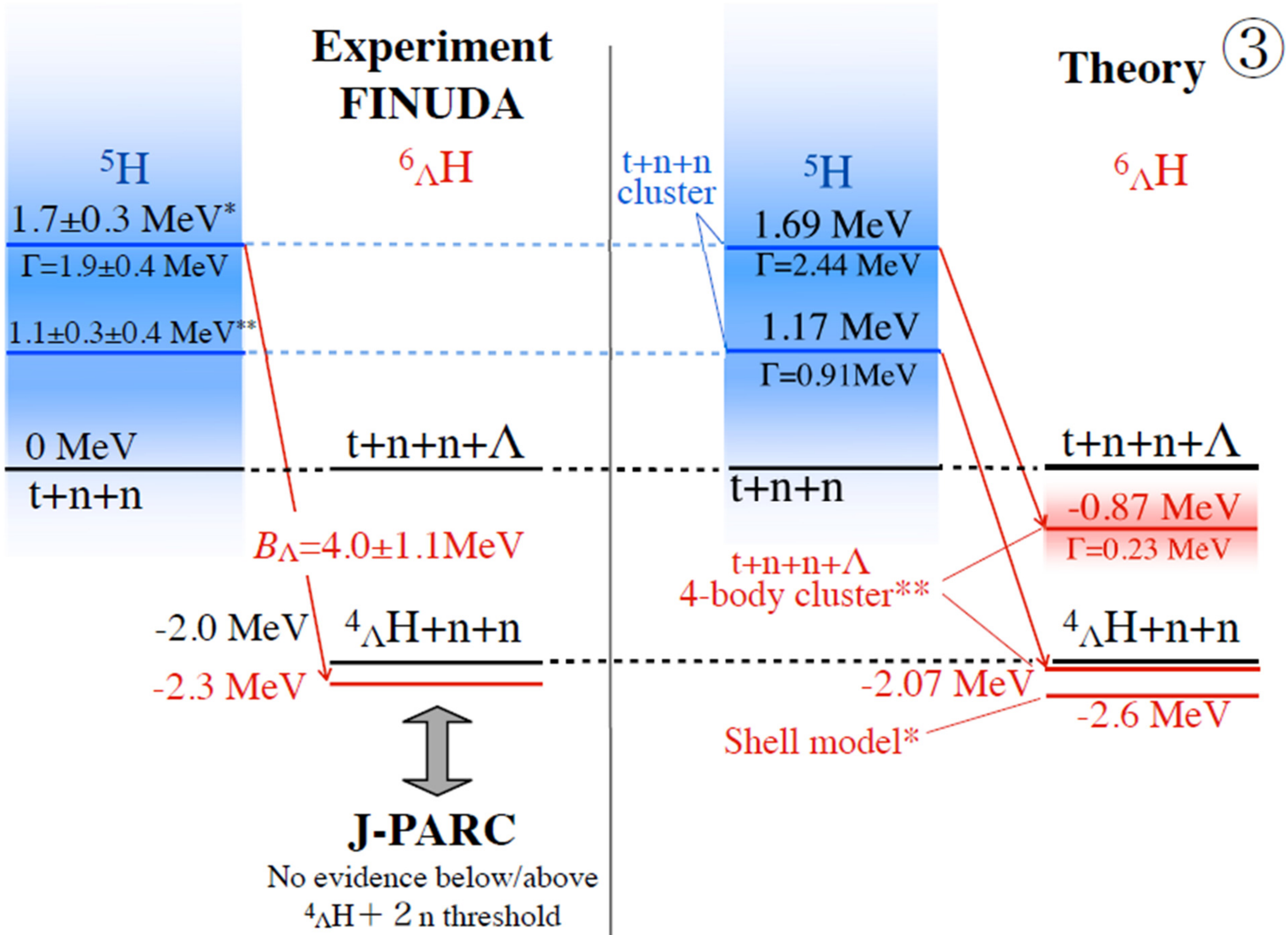
Production Cross Section < 1.2 nb/sr

H. Sugimura, *et. al.*, J-PARC E10 Collaboration, Phys. Lett. B **729** (2014) 39

Theory

Model	$B_{\Lambda}(^{6}_{\Lambda}H)$ [MeV]	State	Ref.
shell model	4.3	**bound**	R. H. Dalitz, et. al. Nuovo Cimento **30** (1963) 489.
$t+n+n+\Lambda$ 4-body cluster model	2.56	**unbound!!**	E. Hiyama, et. al. Nucl Phys. A **908** (2013) 29

From J.Tanaka



* T. Kobayashi, *et. al*. Nucl. Phys. A **616** (1997) 223c

** A. A. Korsheninnkov, *et. al*., Phys. Rev. Lett. **87** (2001) 092501

*R.H. Dalitz, R. Levi-Setti, Nuovo Cimento **30** (1963) 489

** E. Hiyama, *et. al*., Nucl Phys. A **908** (2013) 29

From J.Tanaka

Results on ^{5}H from previous studies

- ✓ **2n transfer on triton**
- ✓ **1p removal from ^{6}He**
- ✓ **pion absorption**

Reaction	Detected	E_R (MeV)	Γ (MeV)	$E_{\rm beam}$ (A MeV)
^{3}H$(t,p)^5$H	p	≈ 1.8	≈ 1.5	7.42
^{6}He$(p,2p)^5$H	$2p$	1.7 ± 0.3	1.9 ± 0.4	36
^{3}H$(t,p)^5$H	t,p,n	1.8 ± 0.1	< 0.5	19.2
^{3}H$(t,p)^5$H	t,p,n	≈ 2	–	19.2
^{3}H$(t,p)^5$H	t,p,n	≈ 2	≈ 1.3	19.2
^{6}He$(^{12}$C$,X+2n)^5$H	$t,2n$	≈ 3	≈ 6	240
^{6}He$(d,^3$He$)^5$H	^{3}He$,t$	1.8 ± 0.1	< 0.6	22
^{6}He$(d,^3$He$)^5$H	^{3}He$,t$	1.8 ± 0.2	1.3 ± 0.5	22
^{6}He$(d,^3$He$)^5$H	^{3}He$,t$	1.7 ± 0.3	≈ 2.5	22
^{9}Be$(\pi^-,pt)^5$H	p,t	5.2 ± 0.3	5.5 ± 0.5	$E_\pi < 30$ MeV
^{9}Be$(\pi^-,dd)^5$H	p,t	6.1 ± 0.4	4.5 ± 1.2	$E_\pi < 30$ MeV

Wuosmaa et al., PRC 95 (2017)

Latest results on $^6He(d,^3He)$

$^6He(d,^3He)^5H$ 55 A.MeV, MSU-HiRA

Wuosmaa et al., PRC 95 (2017)

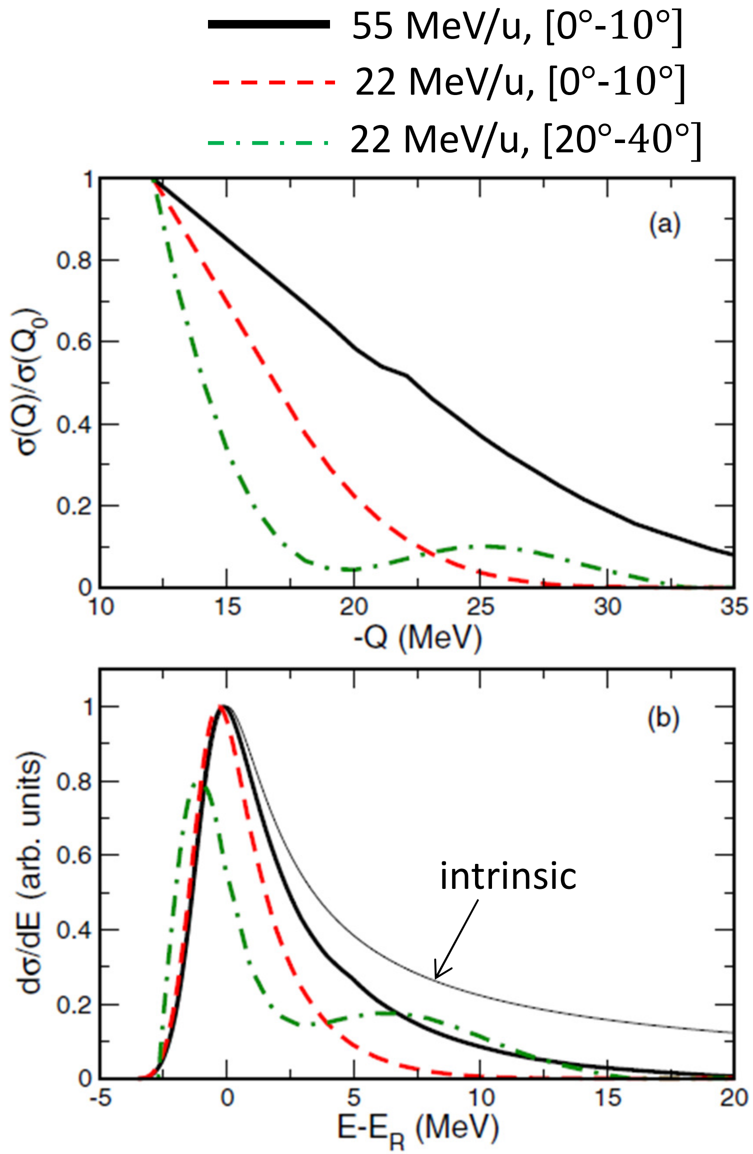
Very negative Q-values
Poorly momentum matched

"intrinsic" lineshape (R-Matrix presciption)

$$\sigma(E) \propto \frac{\Gamma}{(E - E_R)^2 + \Gamma^2/4},$$

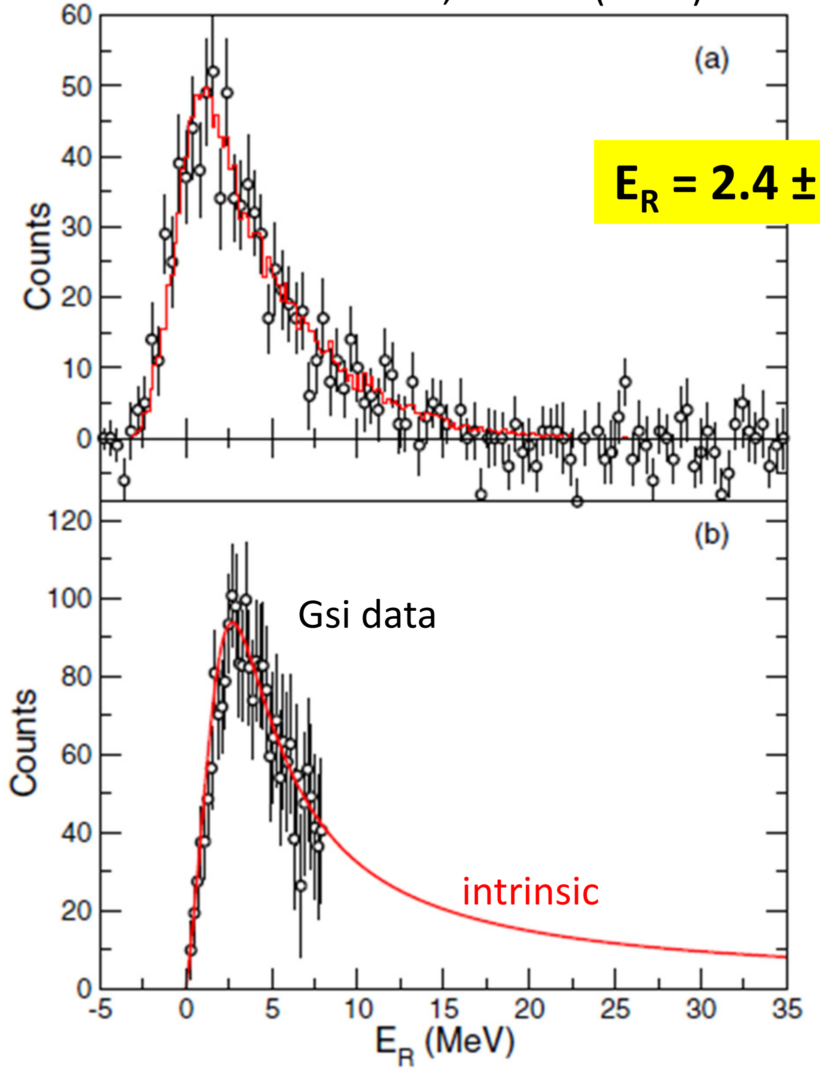
$$\Gamma = 2P_L(E)\gamma^2, \qquad \gamma^2 = S\gamma^2_{s.p.}.$$

- Distorted by Q-value dependence of cross-section
- Simulation of exp setup (decay mode of ^5H, etc…)
- Assume no excited states (small overlap with ^6He GS for both SM and GFMC calc)



Latest results on ^{6}He(d,^{3}He)

Wuosmaa et al., PRC 95 (2017)



E_R = 2.4 ± 0.3 MeV

Discussion:

- “Possibly compatible with some previous data” when taken into account suppression of high energy tail at low bombarding energy
- Only 2.4 MeV above threshold attainable in t(t,p) of Young et al.
- Interferences of states in t(t,p) ?
- Compatible with p-removal at GSI

If confirmed, would plead for an unbound $^6_\Lambda$H

Investigation of ^{10}He through $^{11}Li(d,^{3}He)$ reaction

MUST2 @ RIKEN NISHINA CENTER

Collaboration: IPN Orsay – RIKEN – GANIL - CEA/Saclay - LPC Caen - JINR Dubna – Kurtchatov Institute - Kyushu Univ. – IPNS KEK – Univ. of Tokyo –Tokyo Inst. of Tech., Univ. Huelva, MSU/NSCL, INP Hanoi

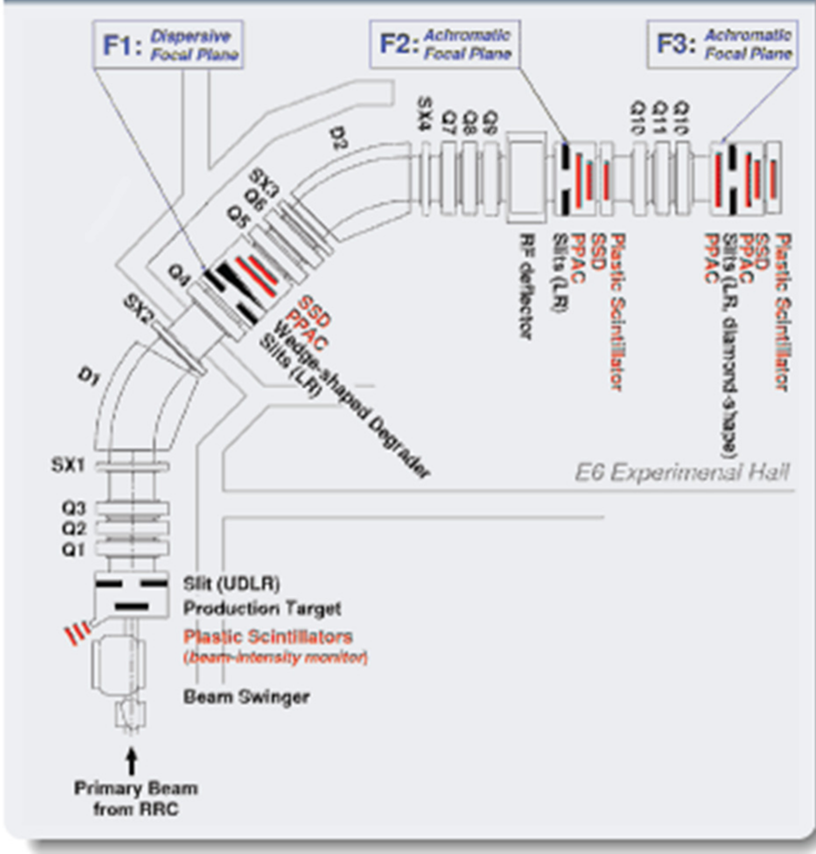
Study of :

- **$^{9}Li(d,^{3}He)$ → $(^{9}Li\,|^{8}He)$**
- **$^{11}Li(d,^{3}He)$ → $(^{11}Li\,|^{10}He)$ "critical" overlap**

Study of ^{9,11}Li(d,^{3}He) @ 50 MeV/u at RIKEN/RIPS

- **Spectroscopy of populated states**
- **Decay pattern (branching ratios)**
- **Cross-sections**

RIPS separator



Primary Beam

^{18}O at 100MeV/A
Production Target :10mm Be

^{9}Li

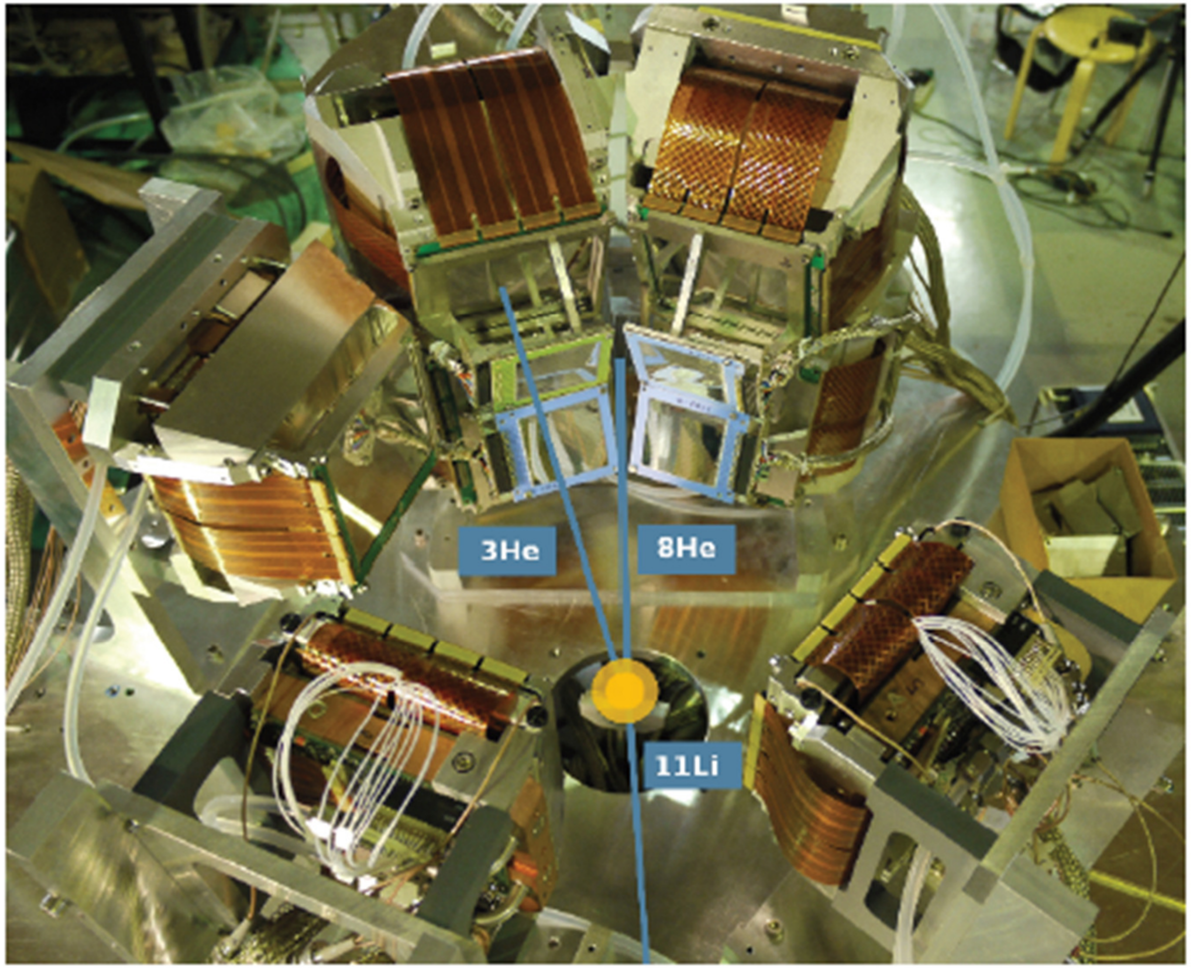
Intensity $= 1.10^5$
Purity≈84% (main contaminant ^{3}H)
Count during 35h

^{11}Li

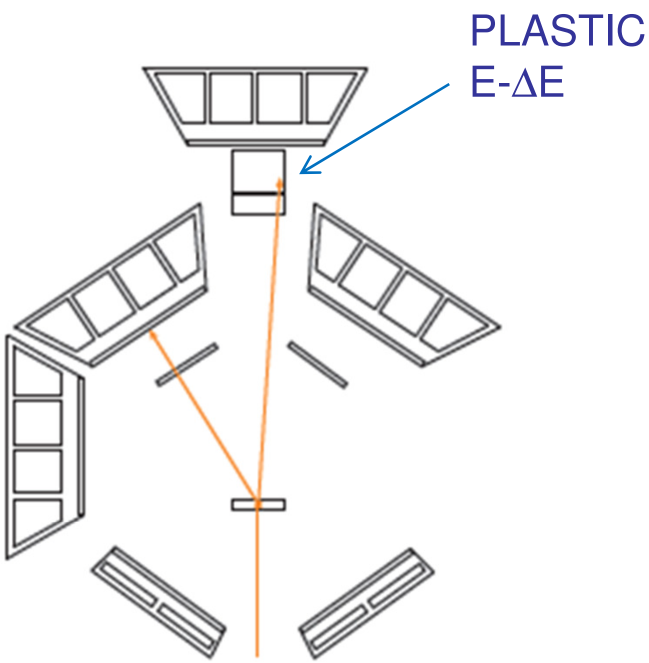
Intensity $= 1.7.10^4$
Purity≈7% (main contaminant ^{15}B)
Count during 140h

Detector's setup

- Beam tracking detectors (PPAC) upstream of CD2 target
- 8 MUST2 telescopes around the CD2 target + thin (20μm) Si layer (fwd)
- Plastic telescope at zero degrees



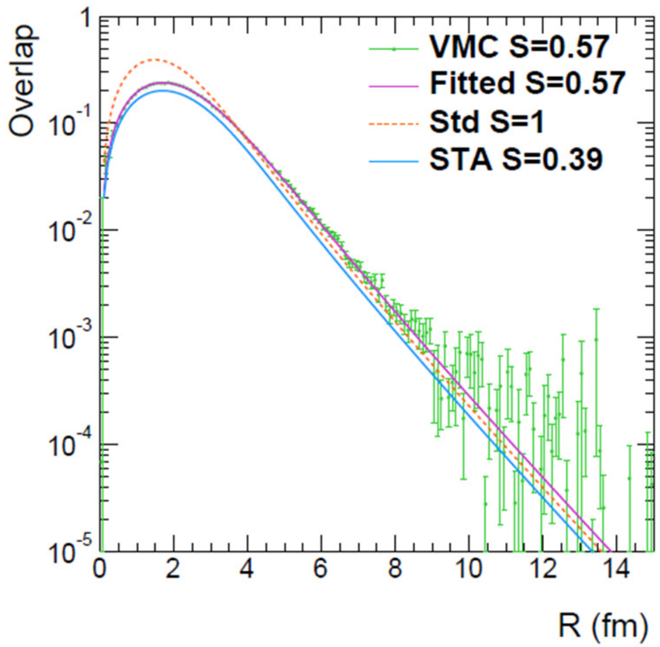
TOP VIEW SCHEME



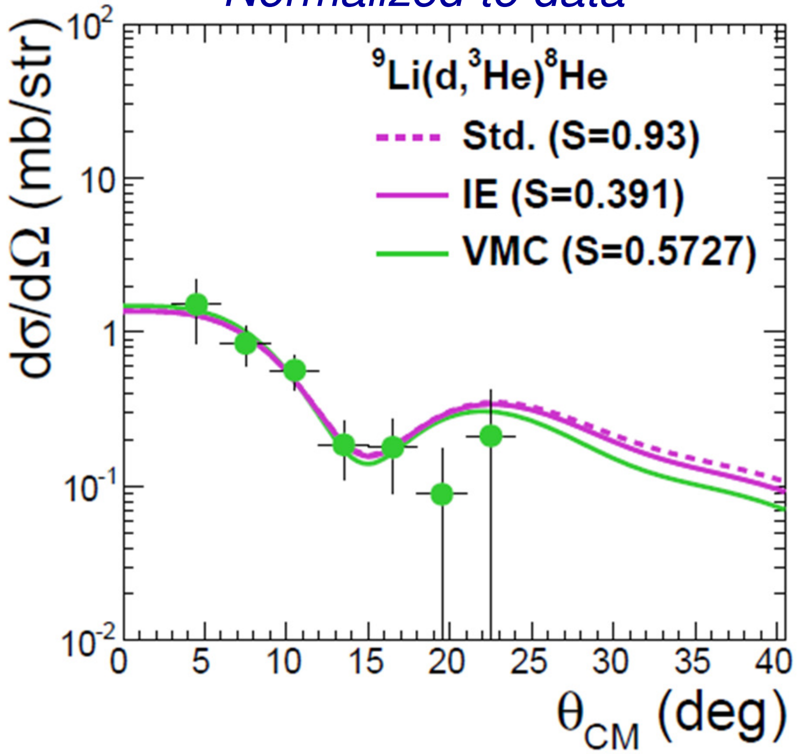
CD2 : 1.9 mg/cm^2

Differential cross-sections

- Full finite range calculations using DWUCK5 (and FRESCO)
- (d|^{3}He) overlap from GFMC (*Brida, Pieper, Wiringa, PRC84 (2011)*)
- Entrance potential : From fit of elastic scattering
- Exit potential : from Global formula
- Overlaps:
  1. Standard (s.p wave function) ($S^{th} = S^{SM} = 0.93$)
  2. Inhomogenous equation ($S^{th} = 0.391$)
  3. VMC ($S^{th} = 0.5727$)



Normalized to data



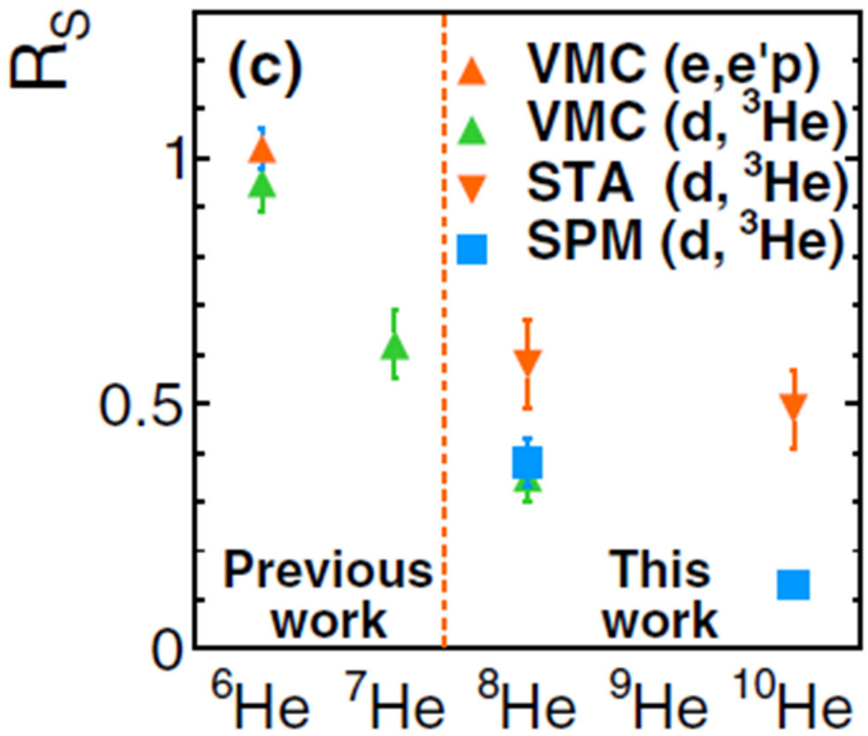
Shape well-reproduced by DWBA calculations (l=1 transfer)

Normalization factors

$R_S = \sigma^{EXP} / \sigma^{React\ Mod}$

VMC : Variational MC

STA: Source Term Approach
(corrected by geom.
mismatch factor)

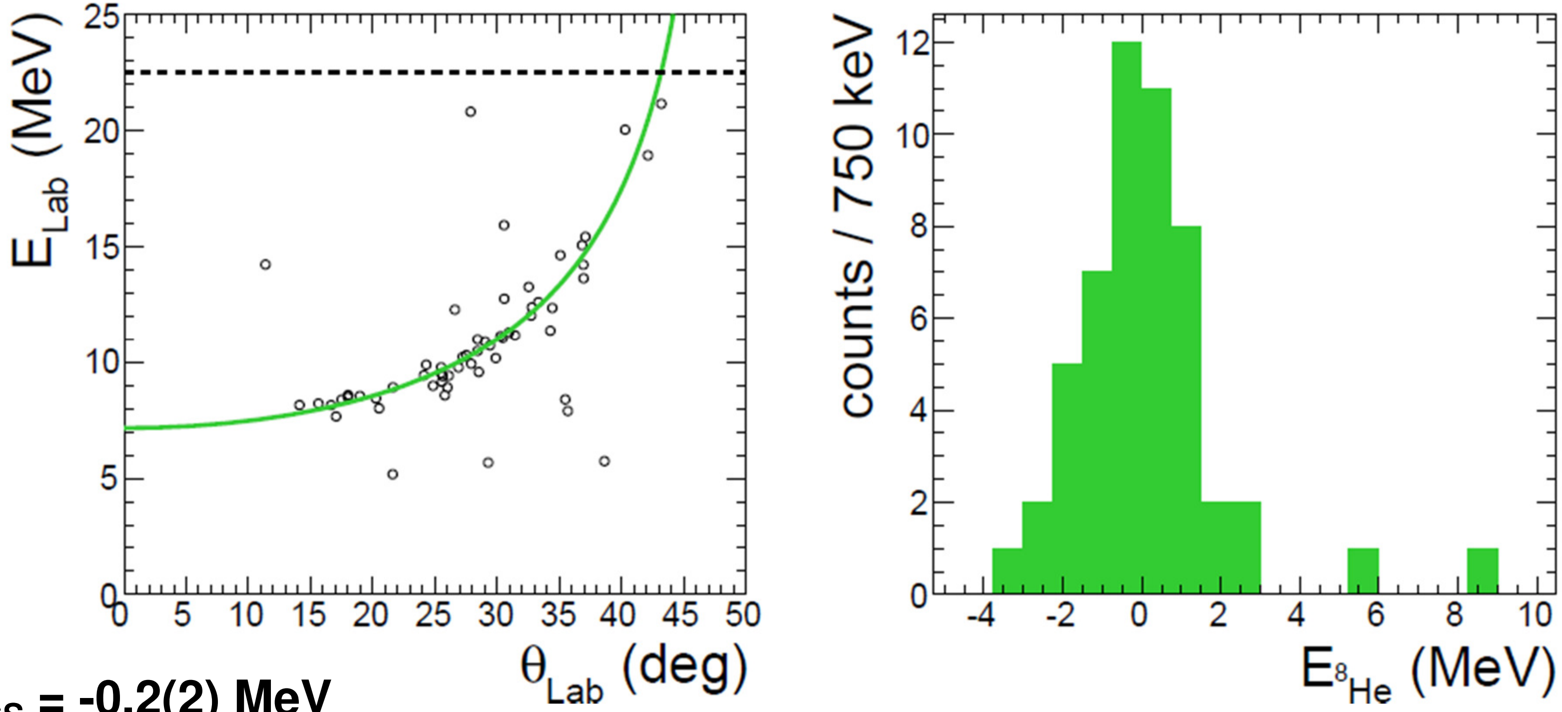


- Decreasing trend of N_f toward the drip line
- N_f = 0.35 for ^{9}Li(d,^{3}He)^{8}He using VMC
  $N_f \approx 1.$ for ^{8}Li(d,p)^{9}Li using VMC
- N_f for ^{11}Li correspond to standard SF of only 0.08

A.Matta et al., PRC 92, 041302(R)(2015)

Spectrum for $^{9}Li(d,^{3}He)$ @ 50 MeV/u

Gated on ^{8}He residues

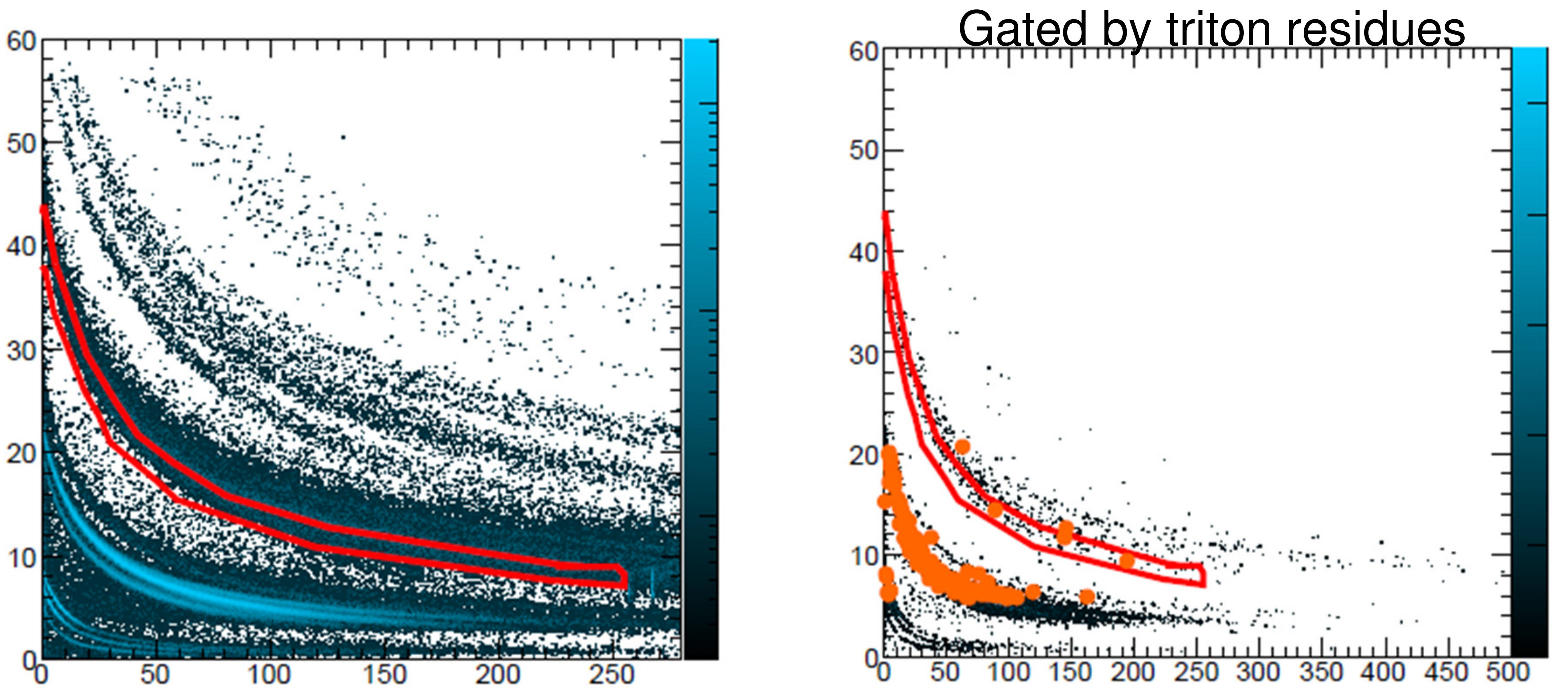


E_{GS} = -0.2(2) MeV
σ_{EXP} = 1.29 MeV
σ_{SIMU} = 1.16 MeV

$^{8}He^{GS}$ energy and width in agreement will full simulation

Spectrum for $^{9}Li(d,^{6}Li)^{5}H$ @ 50 MeV/u

PID of particles in forward MUST2 telescopes



- Statistics seems low (high beam energy)
- Need consider and add-up :
  - Events with residue out of plastic telescope
  - $(d,^{6}Li)$ to $^{6}Li(3^{+})\rightarrow\alpha+d$ channel

  → Optimized experiment proposal
  (beam, target, residue detection…)

Multineutrons with A > 4 ?

Some predictions for 6n system

(Phenomenological) Isomorphic Shell Model

G.S. Anagnostatos, Intern. Journ. of Mod. Phys. E (2008)

Reproduce well the binding energies of states in $^{3,5}H$, $^{4,5}He$, $^{5,6}Li$, ^{6}Be, ^{11}Be

Nuclei	Nucleon average positions Nos.	State configurations	Potential of Ref. 24 ΣV	$\langle T \rangle$	E_B	Potential of Ref. 32 ΣV	$\langle T \rangle$	E_{so}	E_B	Com.	Radii
^{2}n	1–2	$(1s1/2)^2$	6.9	−10.9	−4.0	7.3	−10.9	0.0	−3.6	unst.	1.33
^{4}n	1–2, 7–8	$(1s1/2)^2(1p3/2)^2$	22.4	−20.0	2.4	23.2	−20.0	0.2	2.2	st.	2.11
^{6}n	1–2, 5–8	$(1s1/2)^2(1p3/2)^4$	38.9	−36.6	2.3	40.6	−36.6	0.4	3.7	st.	2.31

- **^{2}n definitely unstable**
- **^{4}n and ^{6}n could be stable or exhibit a L.E. resonance**
- **^{6}n more bound than ^{4}n**

Study of the 6 neutron system

Study of cluster quasifree scattering (p,pα), (p,p^{6}He) reactions on neutron-rich Be isotopes @ RIKEN/RIBF

Collaboration: IPNO, RIKEN, Peking U., Hong-Kong U., LPC Caen, Titech, CEA Saclay RCNP Osaka, Tohoku U., CNS Tokyo U., Kyoto U.

^{14}Be(p,pα) ^{10}He* → α + 6n

- High ^{10,12,14}Be rate at RIBF
- Use SAMURAI for detection of residue