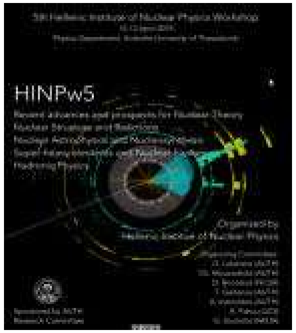
HINPw5 workshop

Thessaloniki-Macedonia

12-13 April 2019



The breakup of ^{9}Be on a proton target at 5.67 MeV/nucleon

athena pakou

Lay out

- Introduction-motivation
- Previous studies
- Present study-the ^{9}Be breakup
- The Data and Results
- Probing the signature of ^{9}Be clustering modes

The motivation:

- **Weakly bound nuclei together with** extra-scale computing power offer unique possibilities for obtaining more insight into many body problem
- Borromean nuclei good candidates
- ^{9}Be is an excellent example of nuclei to be described by clustering theories, while has attracted also a vivid interest in astrophysical problems (r-process)

The goal

Study breakup and other reactions involved for a global understanding of Coupling channel and clustering effects at near barrier energies

Use of weakly bound nuclei on proton targets Inverse kinematics approach @MAGNEX detecting heavy ejectile

GLOBAL UNDERSTANDING of the reactions ^{6,7}Li + p

In a CDCC approach at low beam energies

elastic scattering at 3 to 6 x Cb

Breakup at ~ 5 to 6 x Cb

Other reactions : ^{6}Li(p, ^{3}He)^{4}He - ^{7}Li(p, ^{4}He)^{4}He - ^{7}Li(p, n)^{7}Be at ~ 5 to 6 x Cb

Soukeras et al. PRC91,057601(2015); PRC95,054614(2017)

Pakou et al. : PRC 94, 014601(2016); PRC95, 044615(2017); PRC96, -34615(2017)

Sgouros, Soukeras, Pakou : EPJA 53, 165 (2017).

Betsou et al., Eur. Phys. Journal A51, 86(2015)

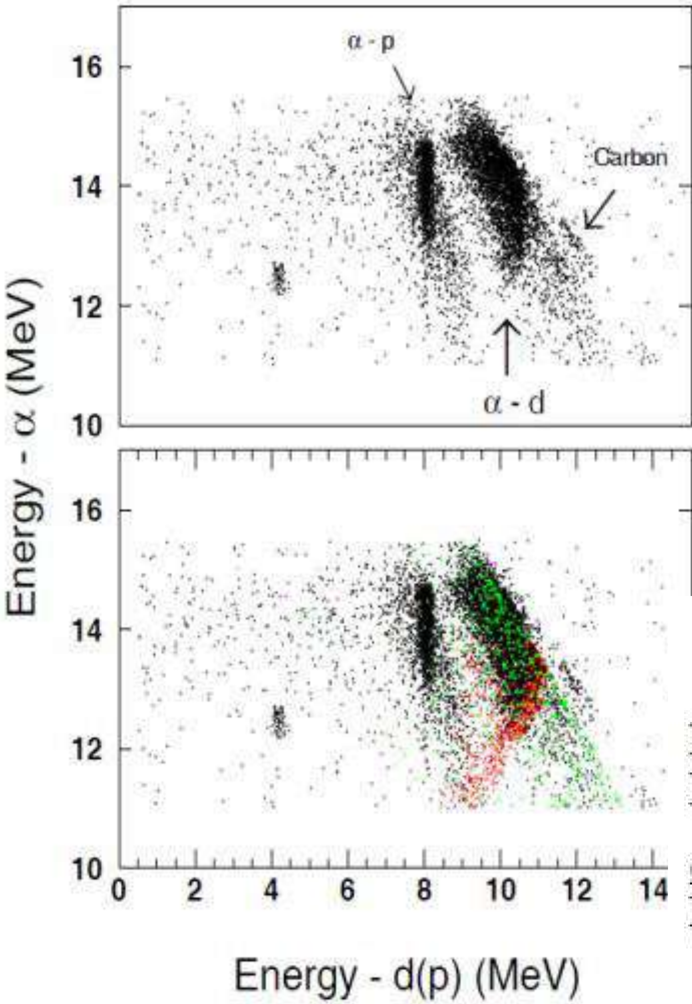
^{6}Li+p

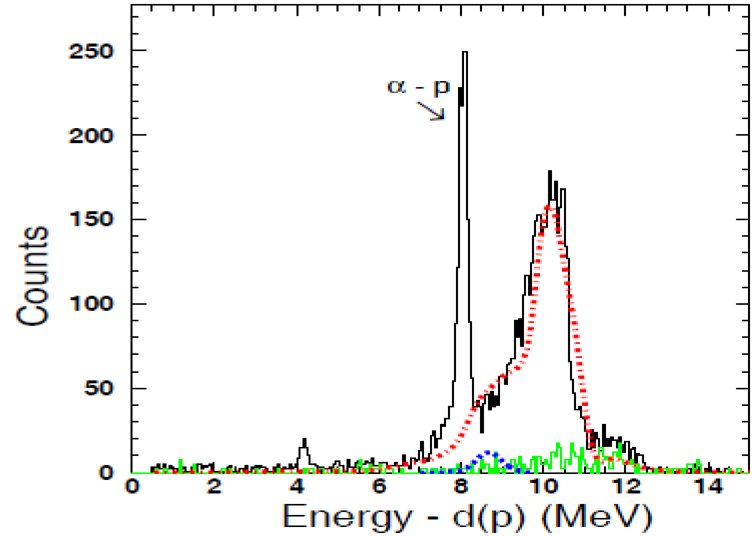
E (MeV)	σ_{br} (mb)	σ_{br}^{C} (mb)	σ_{abs}^{C} (mb)	σ_{abs} (mb)
29	370 ± 64	269.4(143.3)	109.5	95 ± 2
25	235 ± 46	200.0(117.0)	133.0	131 ± 6
20		102.9(37.5)	162.0	140 ± 8
16		69.7(0.03)	130.7	111 ± 2

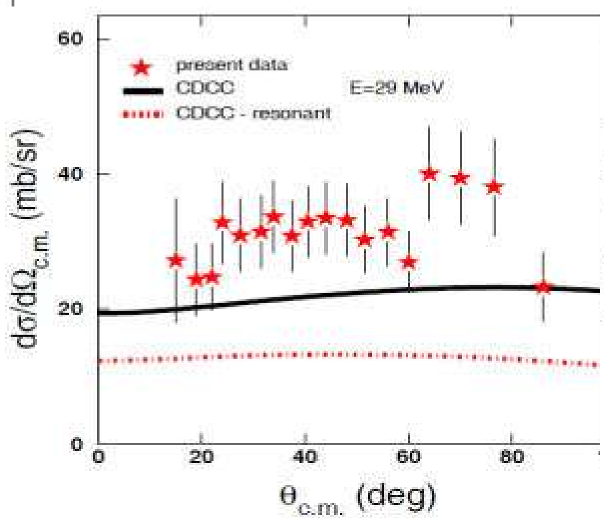
^{7}Li+p

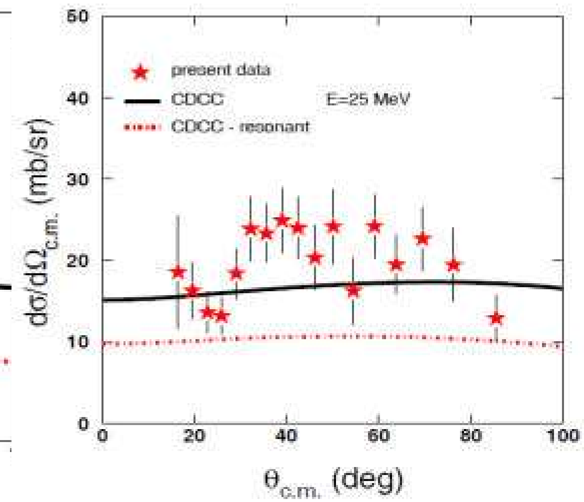
Reaction	σ_{exp} (mb)	σ_{CDCC} (mb)
$^{7}\mathrm{Li} + p \rightarrow {}^{7}\mathrm{Li}^{*} + p$	65 ± 12	47
$^{7}\mathrm{Li} + p \rightarrow {}^{7}\mathrm{Be} + n$	361 ± 39	
$^{7}\mathrm{Li} + p \rightarrow {}^{7}\mathrm{Be}^{*} + n$	61 ± 10	$\left.\right\}$500
$^{7}\mathrm{Li} + p \rightarrow {}^{4}\mathrm{He} + {}^{4}\mathrm{He}$	27 ± 3	
$^{7}\mathrm{Li} + p \rightarrow {}^{4}\mathrm{He} + {}^{3}\mathrm{H} + p$	72 ± 11	66

^{6}Li+p - The breakup

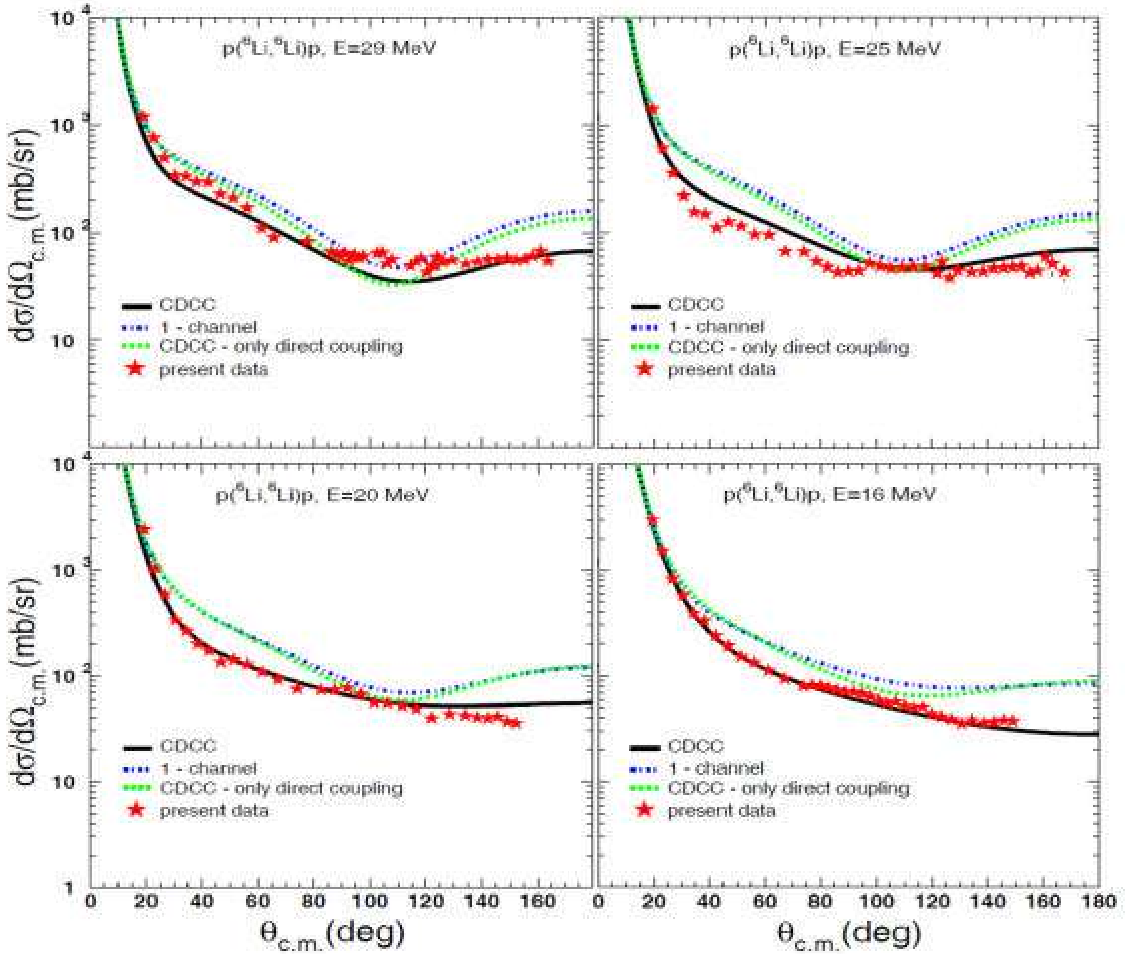




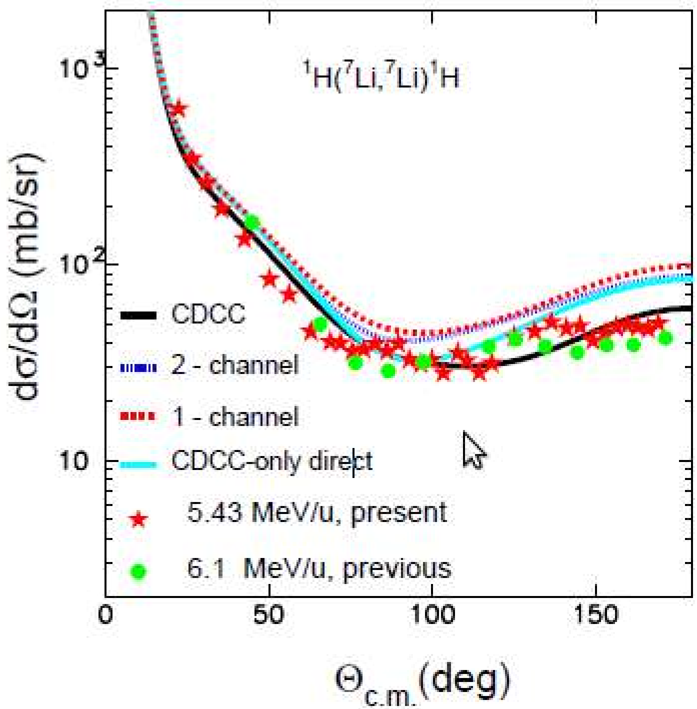




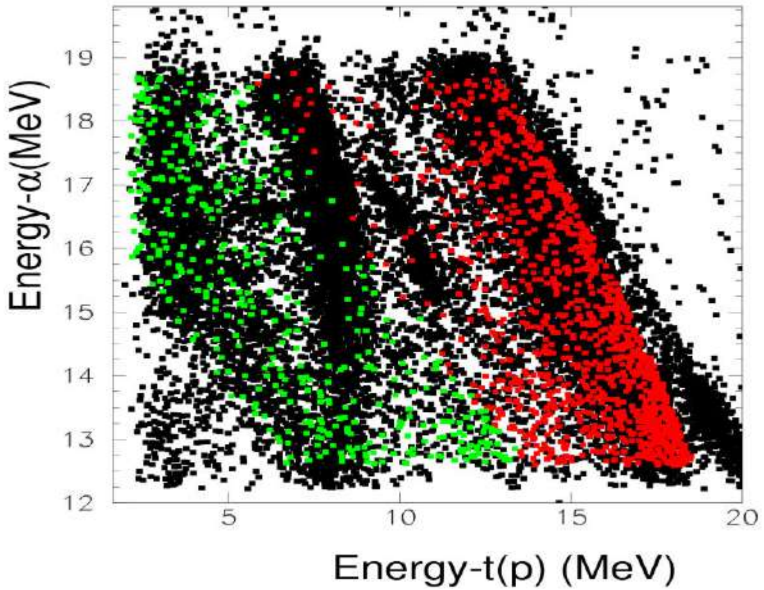
$^{6}Li+p$ - The elastic scattering

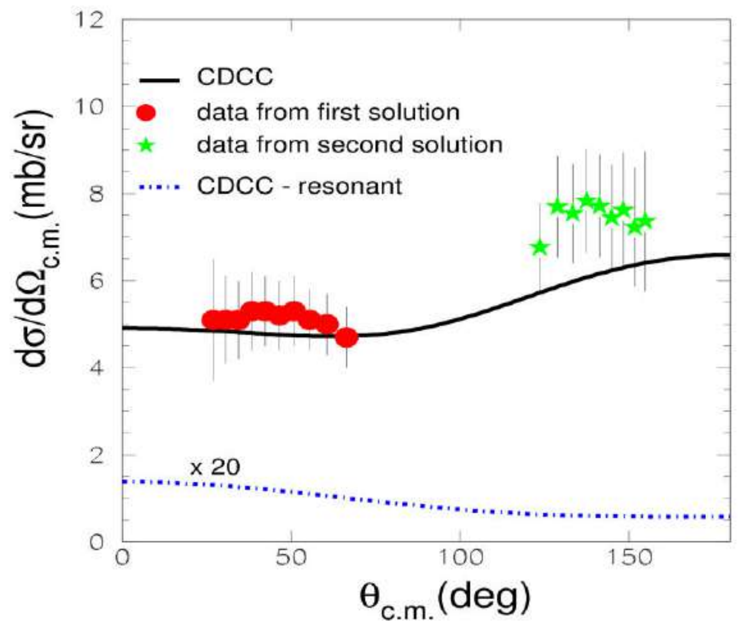


^{7}Li+p - The elastic scattering

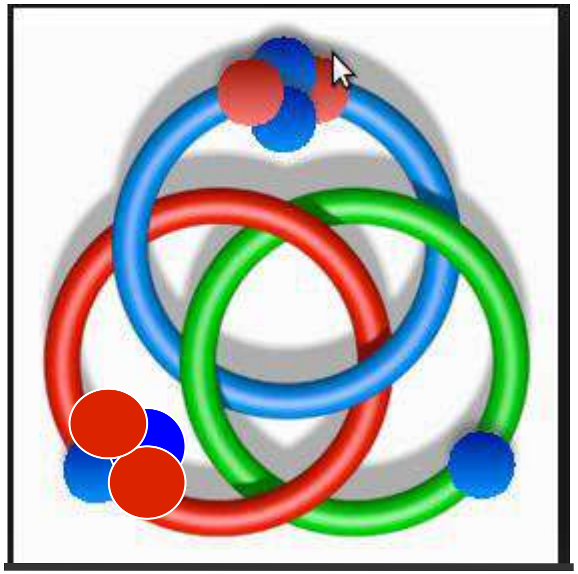


^{7}Li+p - The breakup





The borromean nucleus ^{9}Be

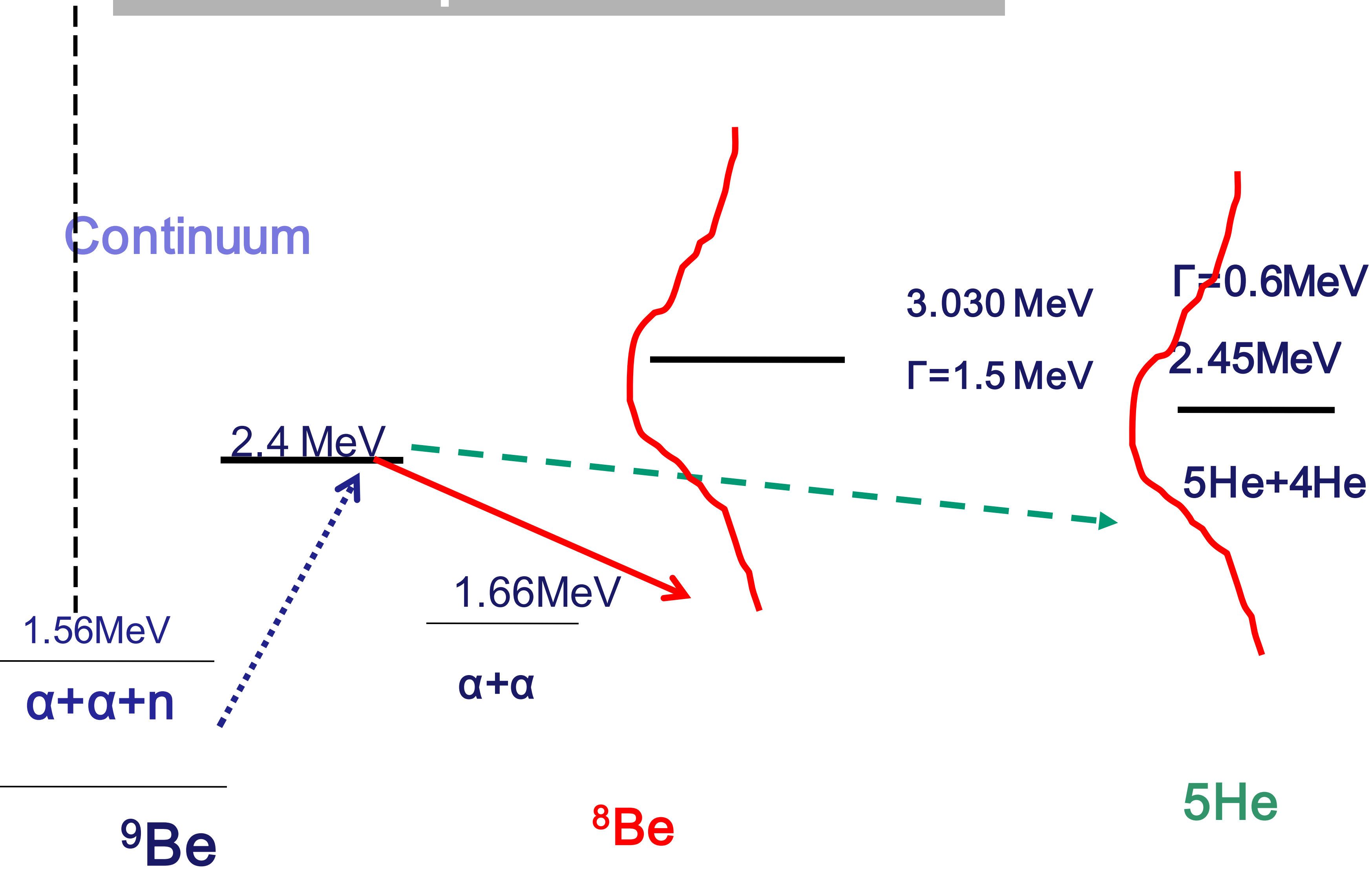


$^{9}Be \rightarrow {}^{8}Be + n$ (Q=1.665MeV)

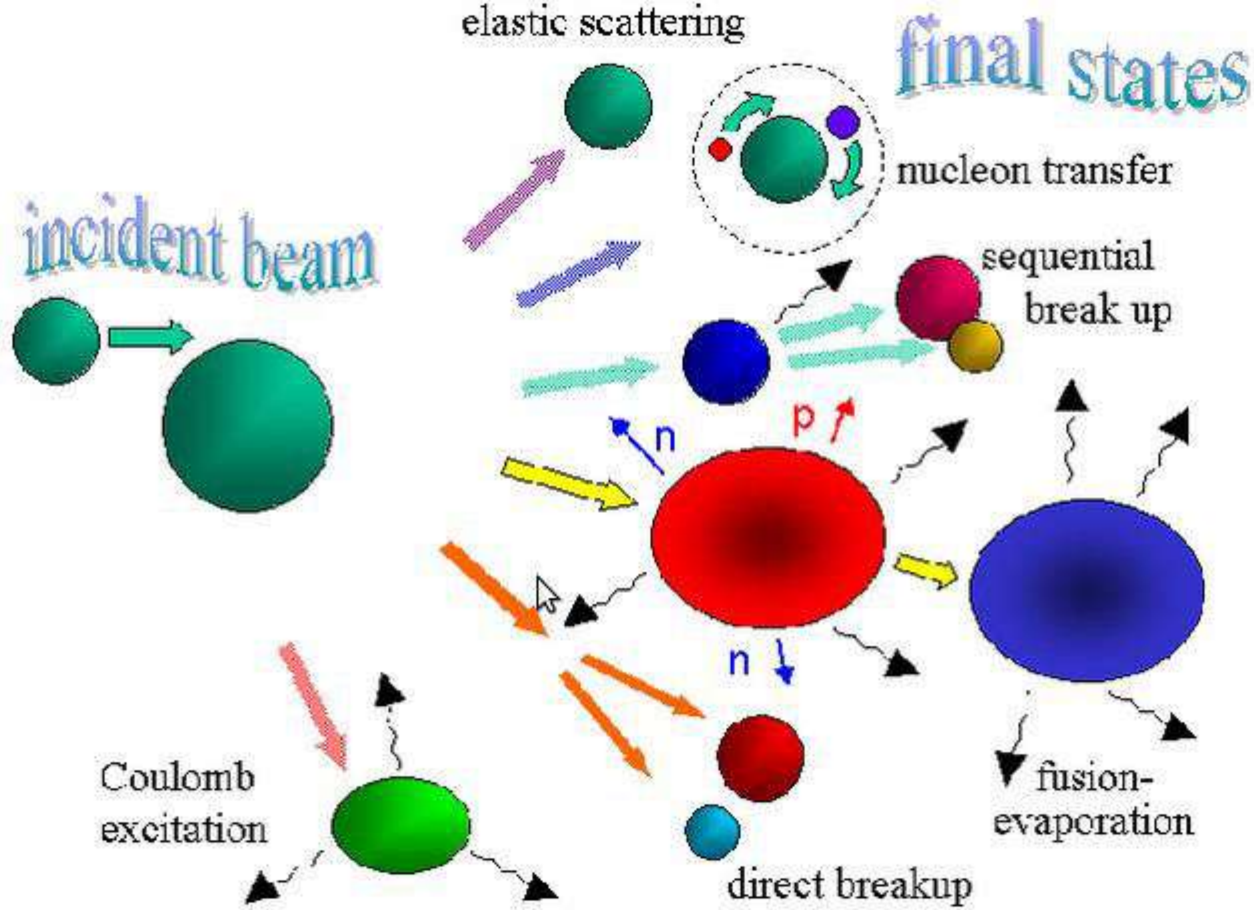
$^{9}Be \rightarrow {}^{5}He + {}^{4}He$ (Q=2.41MeV)

$^{9}Be \rightarrow \alpha + \alpha + n$ (Q=1.57 MeV)

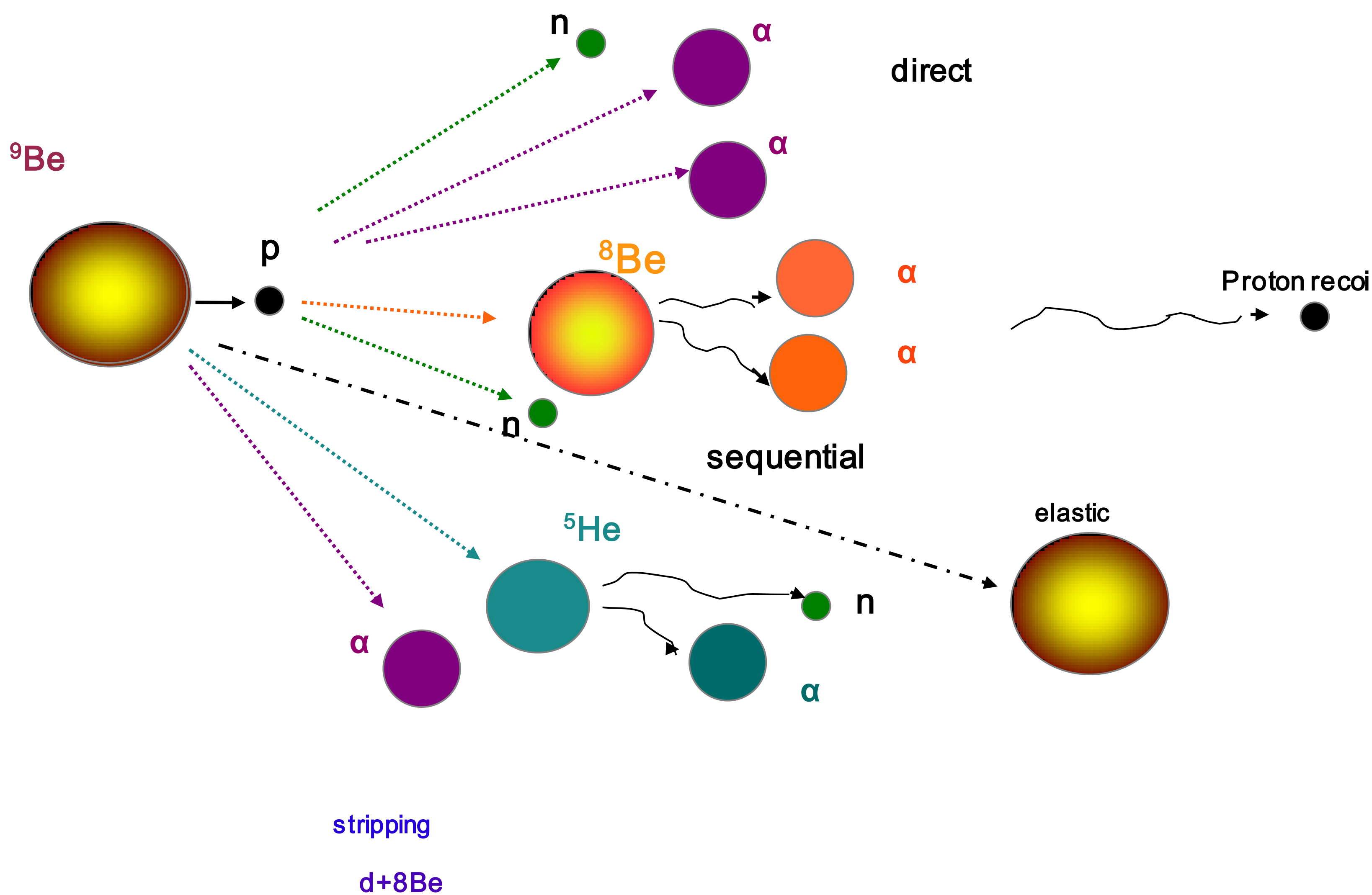
Breakup modes of ^{9}Be



Breakup of a nucleus



Breakup of ^{9}Be on a proton target



The experiment

- Perform exclusive measurements in a full kinematic approach
- Observe three of the four particles –

  two fragments and the proton recoil in coincidence

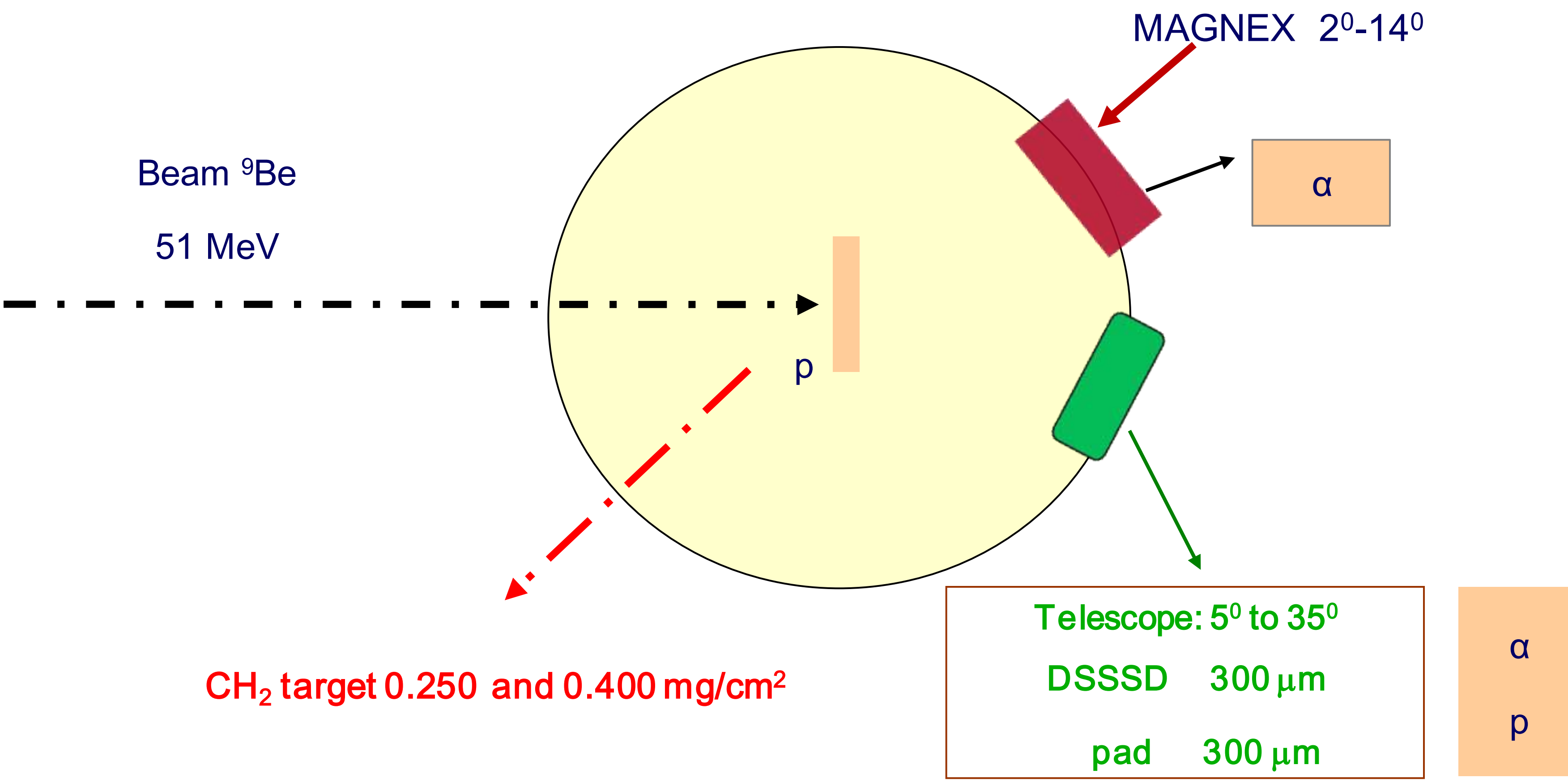
- tag energy and momentum
- Reconstruct energy, relative energy and angular spectra for

  all

  reaction products- breakup fragments and proton recoil

  taking into account energy and momentum conservation

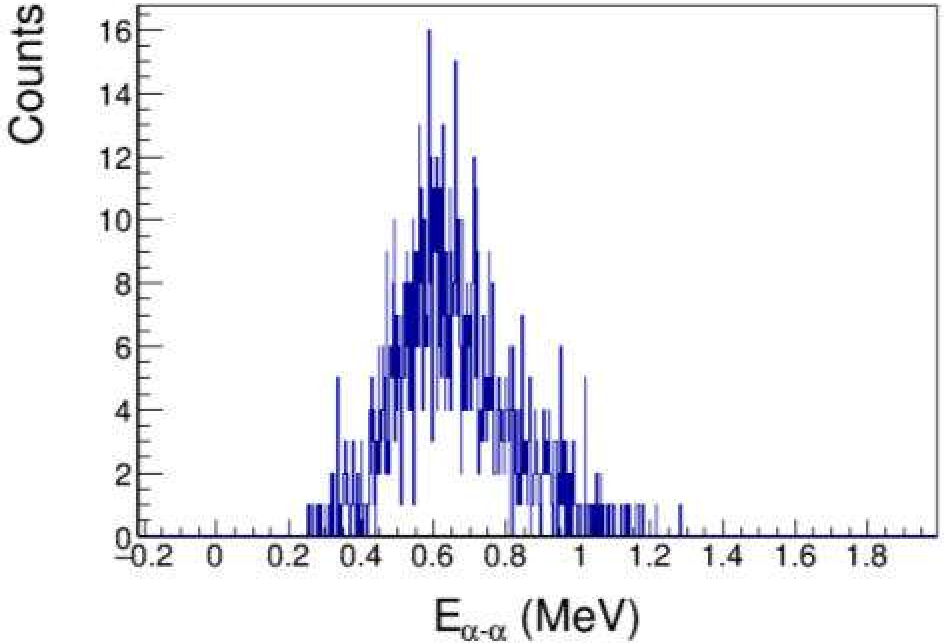
Experimental setup



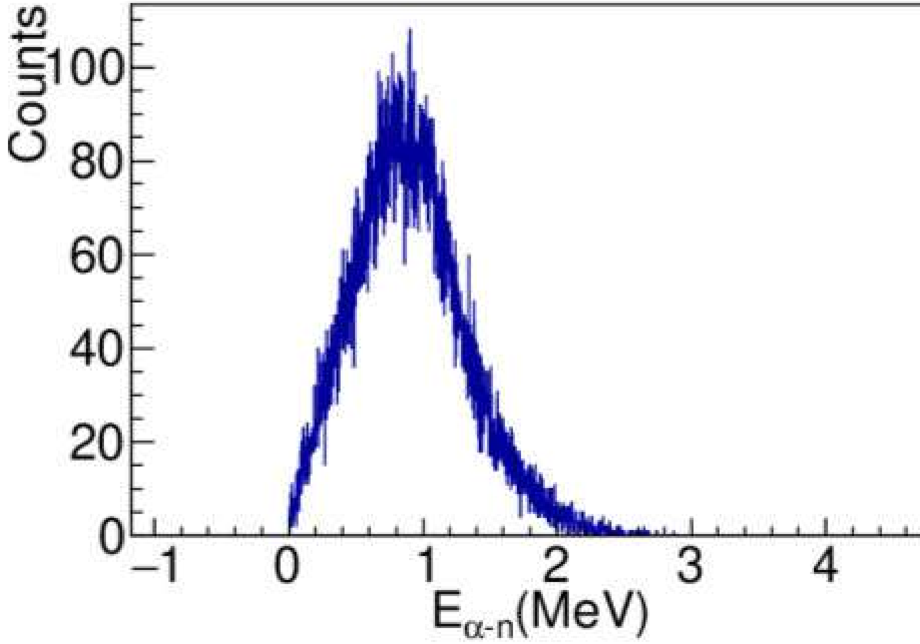
Triple coincidence- reconstruction in a full kinematic approach of energy and angular spectra of all breakup fragments and proton recoil as well as of relative energies between fragments and of Q-value

Relative spectra

α - α



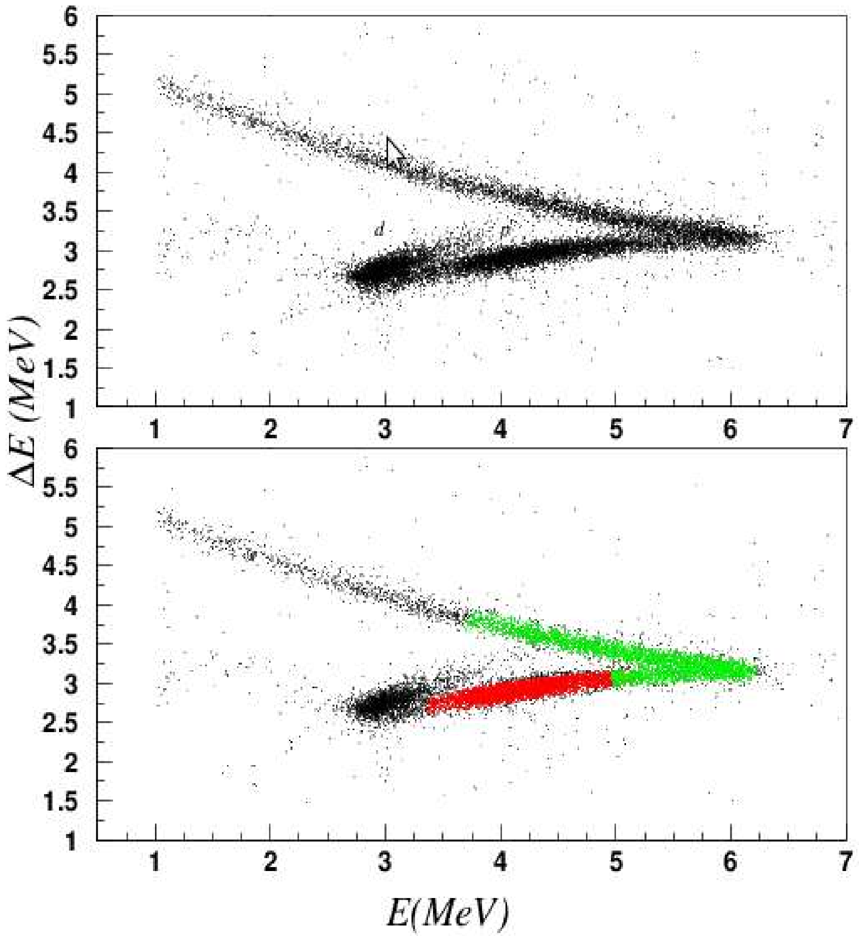
α - n



BREAKUP RESULTS at 51 MeV

Disentangling the three modes

via proton recoil spectra



Intense protons

Correspond to

sequential modes

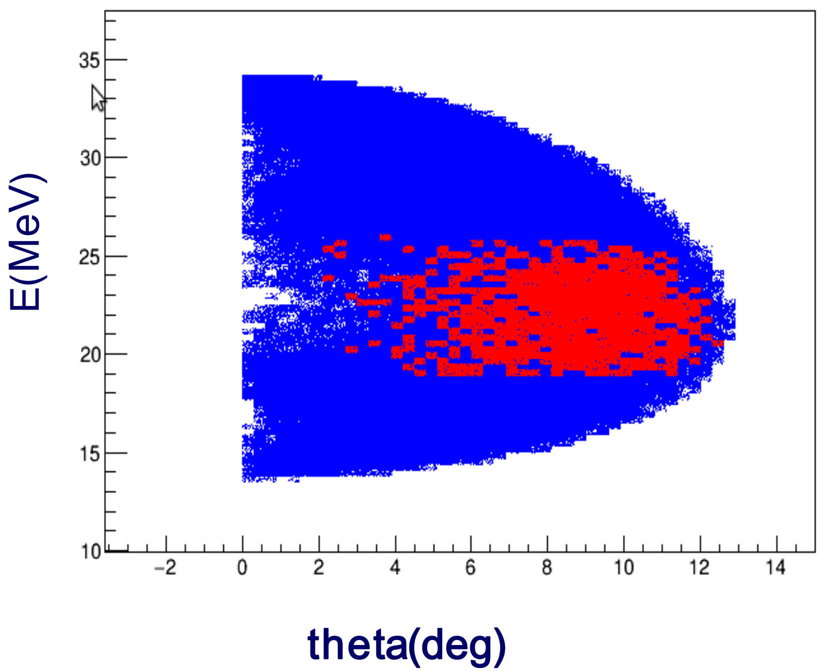
red : $^8Be^* + n$

green: $^5He + ^4He$

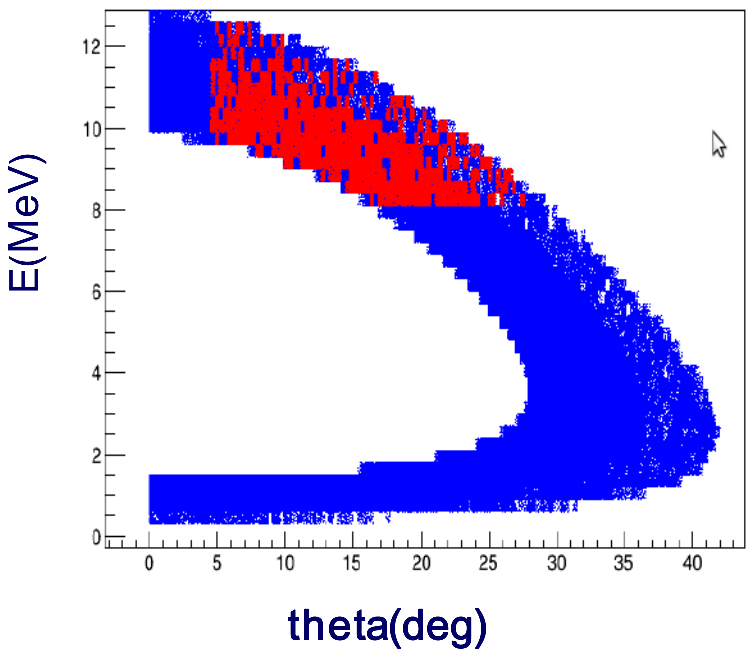
rest : α+α+n

Simulations- the ^{5}He sequential mode

^{5}He



proton recoil

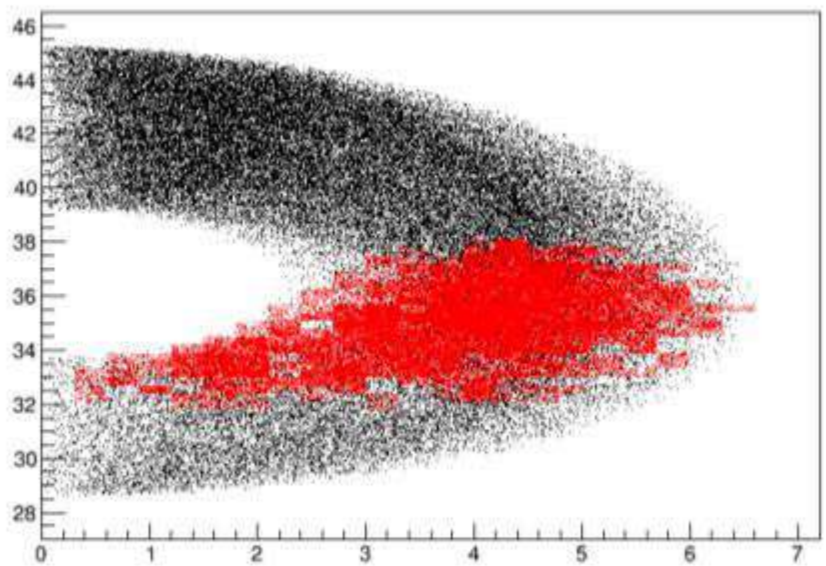


Simulations- the 8Be sequential mode

^8Be

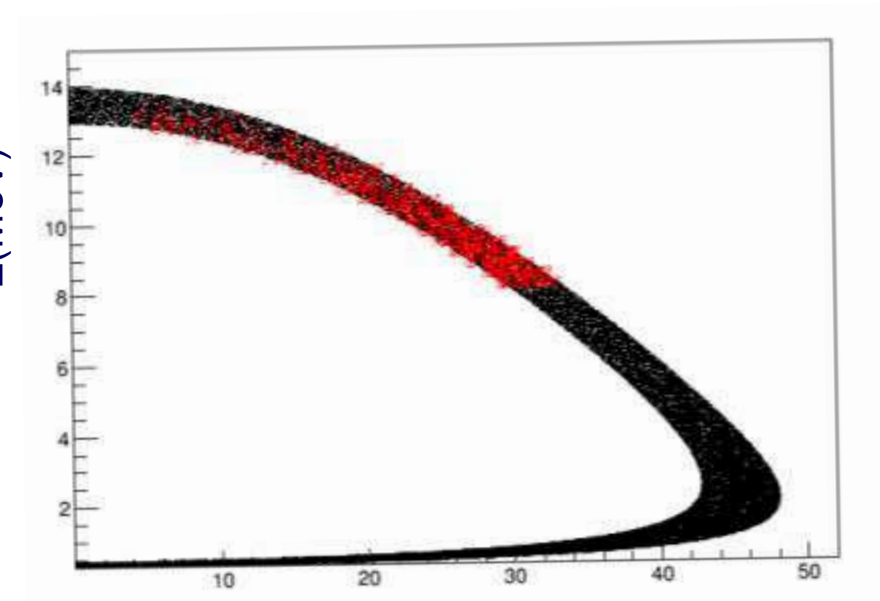
proton recoil

E(MeV)



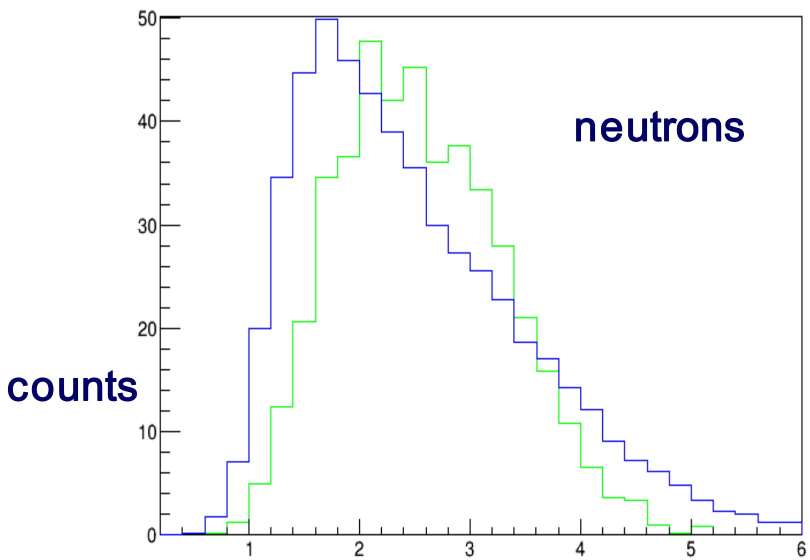
theta(deg)

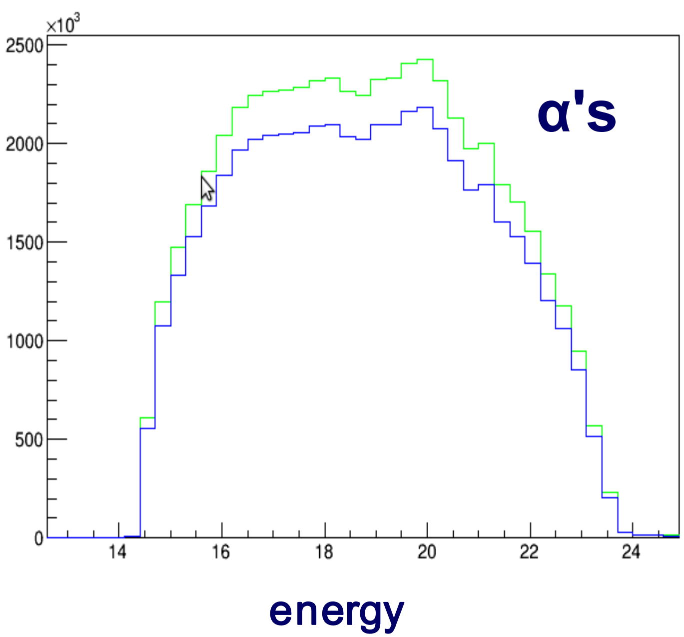
E(MeV)



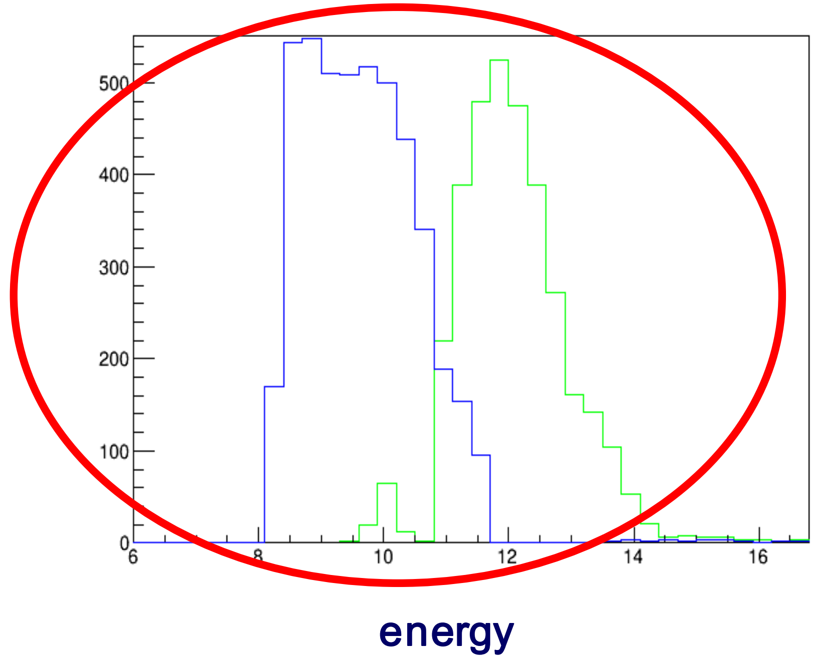
theta(deg)

fragments





Proton recoil



^{8}Be+n

^{5}He+^{4}He

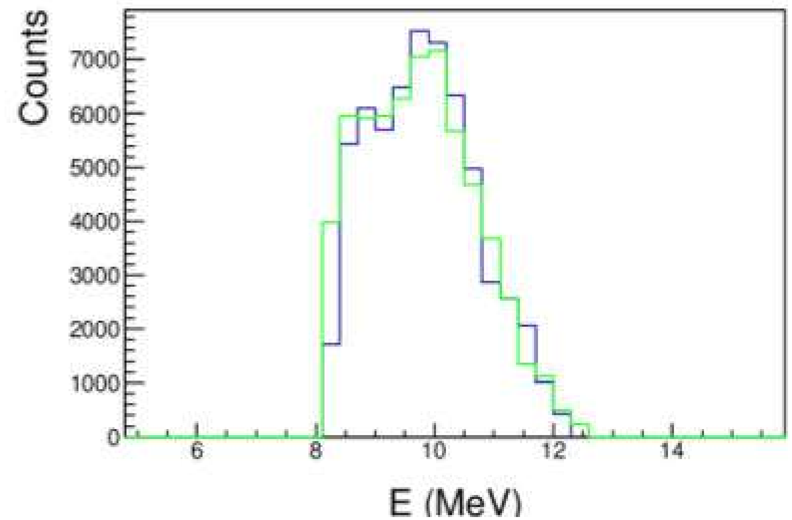
Deconvoluting the three modes:

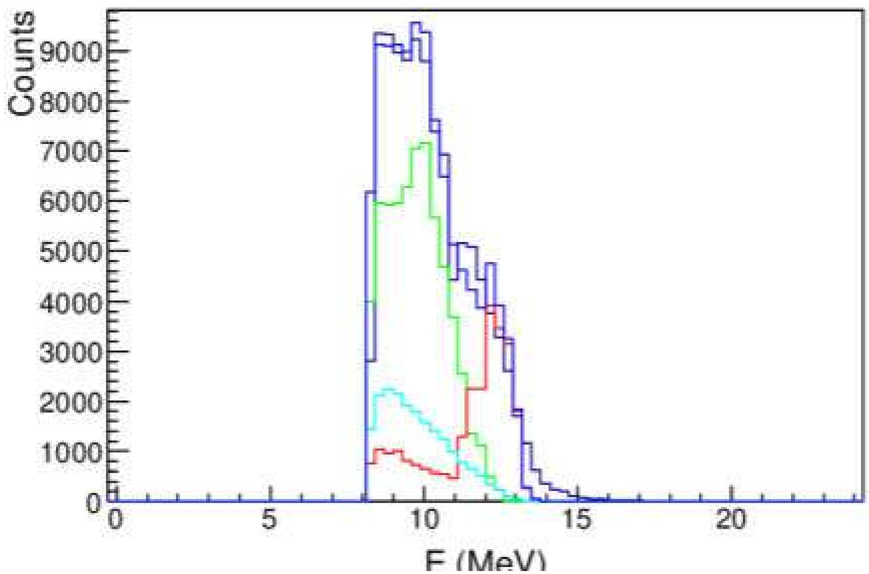
Proton energy spectra with

gate to all protons in triple coincidence

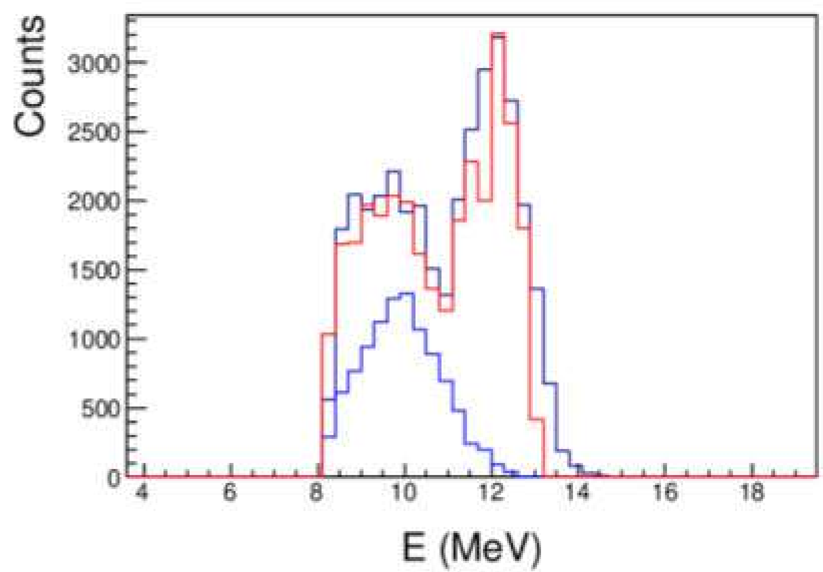
with alphas

$^{5}He+^{4}He$ mode





$^{8}Be+n$ mode



Black: data - sim in blue

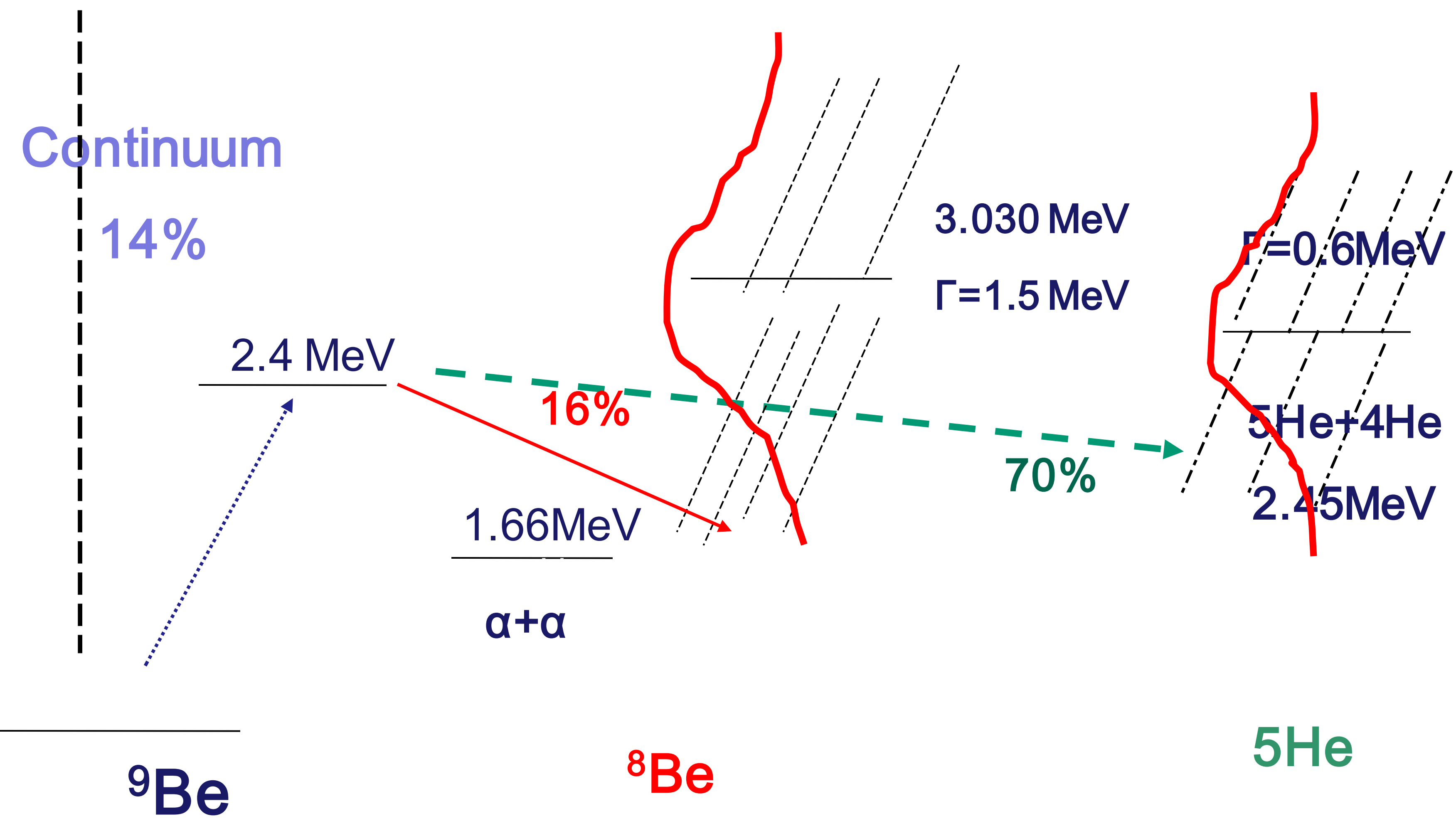
simulation

Ciel : α+α+n

red : 8Be+n

Green : 5He+4He

Decay RATES

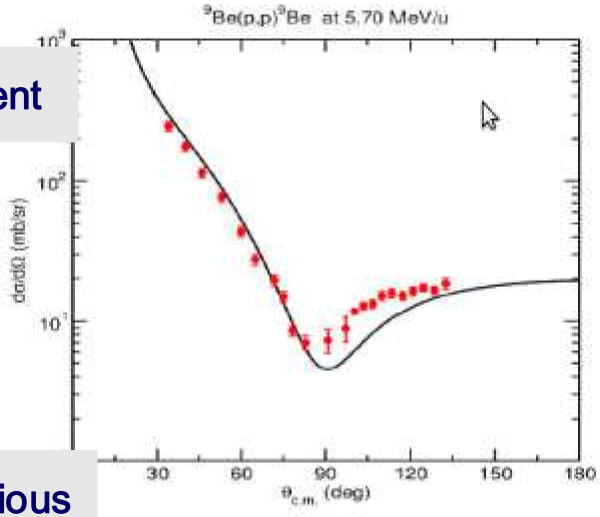

Continuum
14%
2.4 MeV
16%
1.66MeV
α+α
3.030 MeV
Γ=1.5 MeV
70%
Γ=0.6MeV
5He+4He
2.45MeV
9Be
8Be
5He

CONCLUSIONS

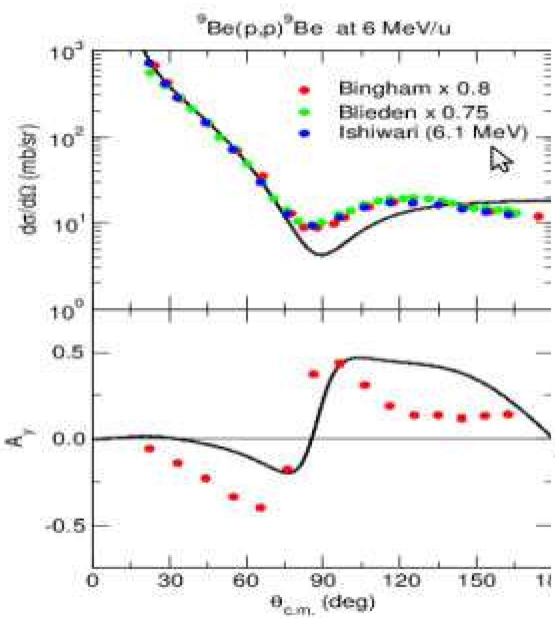
- Measuring breakup of weakly bound nuclei on protons we have a unique possibility to unfold all contributing modes via the kinematics of protons under specific experimental conditions in a full kinematics approach
- In this respect, all three modes were observed and quantified for ^{9}**Be** and this included for the **first time the direct mode**
- Observed decay rates show a predominance of the ^{5}**He +** ^{4}**He** mode which is excited by 70% leaving small space for the other modes equal **to 14 and 16 % for the α+α+n** and ^{8}Be+n respectively

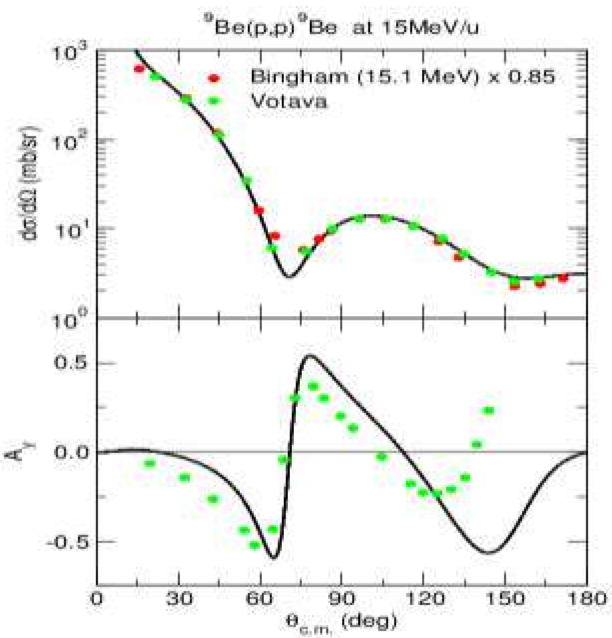
ELASTIC SCATTERING in a CRC approach

present



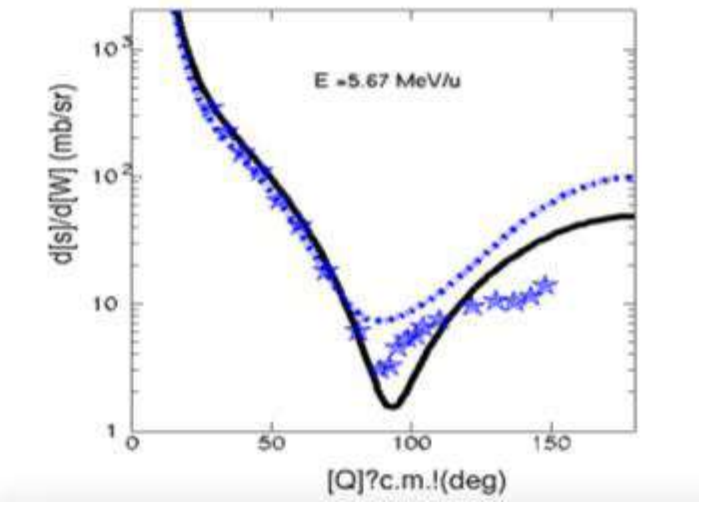
previous





Details of calculation

The calculations include couplings to the 5/2- and 7/2- resonances in 9Be, treated as part of a rotational band and (p,d) pickup to the 0+ and 2+ resonances in 8Be with inelastic coupling treated as member of a rotational band The proton potential is based on the optical potential from Loyd and Haeberli, Nucl. Phys. A 148, 236 (1978) and the exit channel is the DA1p global deuteron potential for p-shell targets, with the parameters readjusted to get the same elastic scattering when the inelastic Coupling between the 8Be 0+ and 2+ is included. The 9Be/8Be spectroscopic factors are from Cohen and Kurath.


E =5.67 MeV/u
d[s]/d[W] (mb/sr)
[Q]?c.m.!(deg)

The first step considers the excitation of 9 Be in continuum, which is discretized in the same way as in a CDCC calculation (Continuum Discretized Coupling Channel) That is it takes into account a ”virtual” reaction 9 Be + p -> 9Be∗ + p leading to an excited state of 9 Be with an angu-lar distribution, determined in a CDCC calculation. 9 Be∗ acquires randomly an excitation energy inside the energy bin as specified in the CDCC framework. Conservation laws in a two body kinematics give the energy of berilium and the recoil in the CM frame to be transformed later in the laboratory.

In a second step, the excited 9 Be breaks in two fragments e.g 9 Be -> 8 Be + n (or 5He + 4 He) withthe one to be emitted randomly with a specific energy and momentum and the second with energy and momentum fulfilling conservation laws in the rest frame of 9 Be for every bin of the 9 Be continuum. The so obtained energy distributions of the 8Be and neutron (or 5 He and 4 He) in the rest frame of 9 Be is transformed to the laboratory system im

posing a Galilean transformation followed by the appropriate rotation.

3d step

In a third step we have the breakup of 8 Be (or 5 He) described in its rest frame. 8 Be breaks up to two particles a+a. The energy for one of the fragment is randomly generated but restricted to a maximum energy equal to the binding energyof 8 Be plus the excitation energy Ex (here fixed to Ex =0.6 as is given in our relative a+a spectra). The polar and azimuthal angles are also randomlygenerated and subsequently the momentum components are defined. Last, the momentum components for the second fragment are determined bymomentum conservation. The last step includes momenta transformation for the two fragments
(or one and a neutron for the case of 5 He) from the system of 8 Be (or 5 He) to laboratory.

Similar procedure is applied for the case of direct breakup. Here after step 1 we proceed with the breakup of 9 Be in its rest frame but in three particles that is

9Be->

a + a + n. The energy for the two fragments is randomly generated but restricted to a maximum energy equal to the binning energy of 9 Be The polar and azimuthal angles are also randomly generated and subsequently the momentum components are defined. Last,the momentum component of the third particle, the neutron, is obtained by applying conservation laws of momentum: Finally we repeat step 3, which includes momenta transformation from system of 9 Be to laboratory appropriate Galilean transformations and rotations