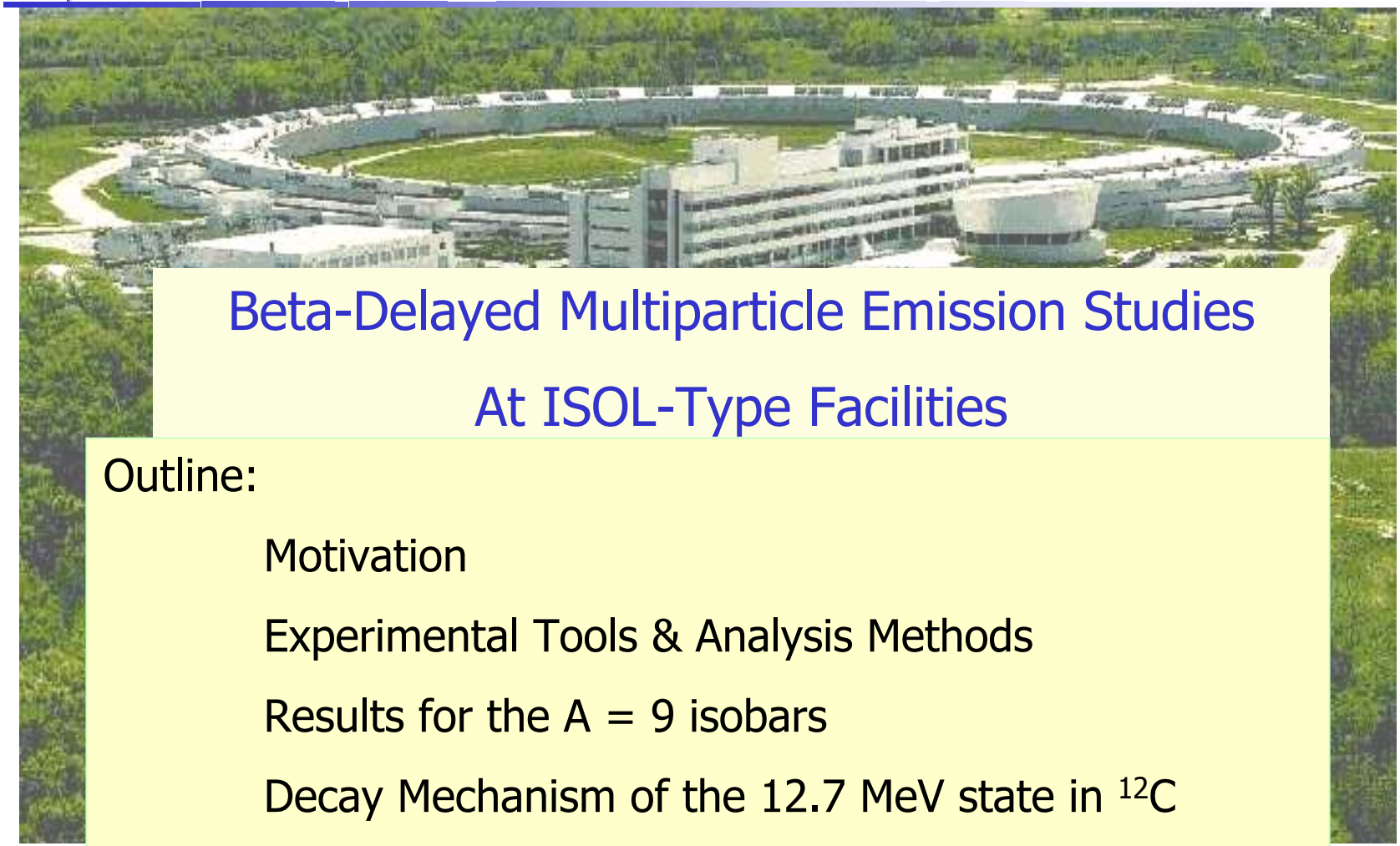
Radioactive Nuclear Beams 6



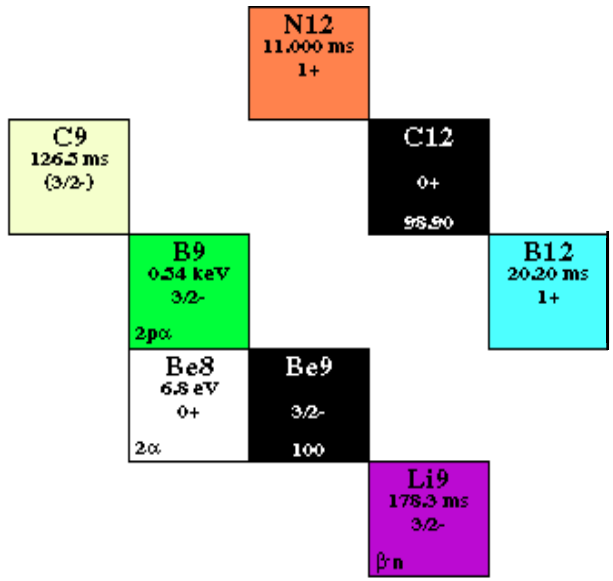
Beta-Delayed Multiparticle Emission Studies At ISOL-Type Facilities

Outline:

- Motivation
- Experimental Tools & Analysis Methods
- Results for the A = 9 isobars
- Decay Mechanism of the 12.7 MeV state in ^{12}C determined
- Summary and Outlook

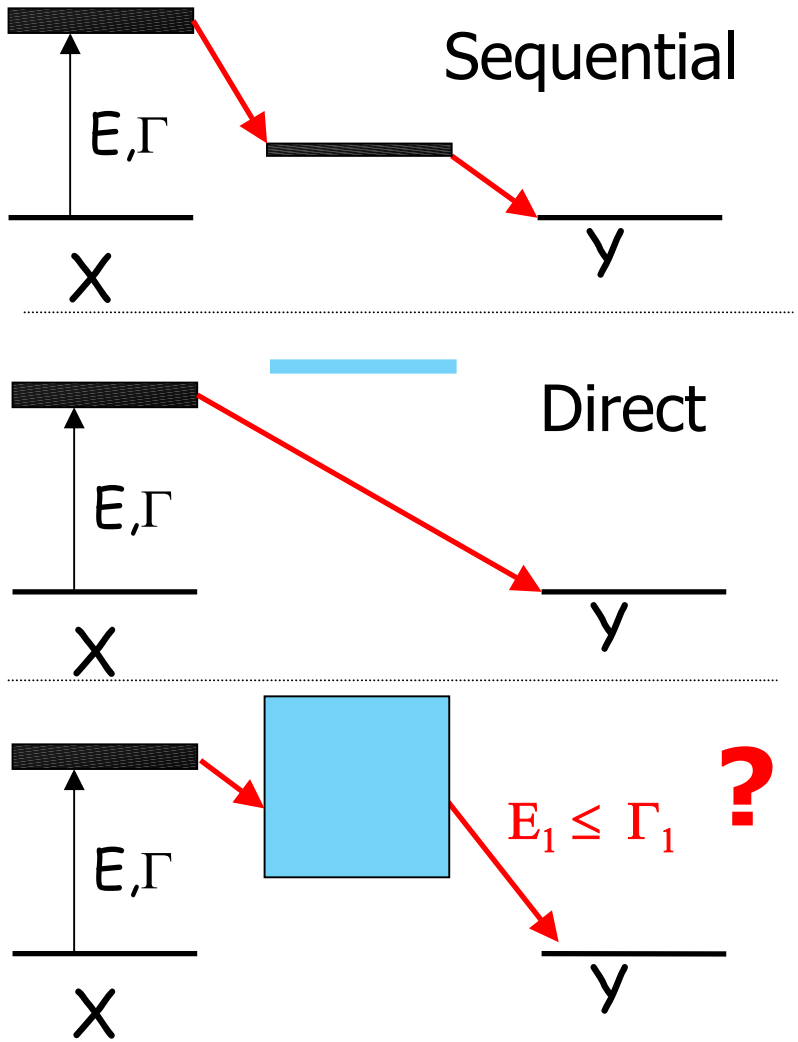
Why study β-decay of Light Nuclei ?

- "Exact" A-body calculations possible for A≤12
  - Shell-model states
  - Molecular-cluster states
  - Halo states
- Experimentally β-decay provides
  - a clean way to feed unbound states
- Break-up mechanism not fixed by kinematics
  - Test case for ^{2}He emission models (Grigorenko *et al.*)
- Crucial for bridging the
  - A=5 and A=8 gaps in Big Bang and Stellar nuclear synthesis

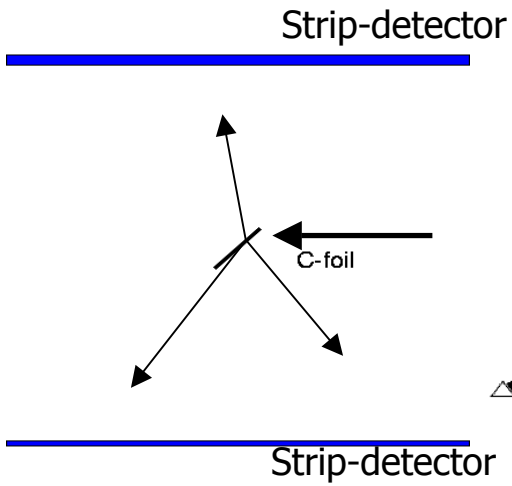


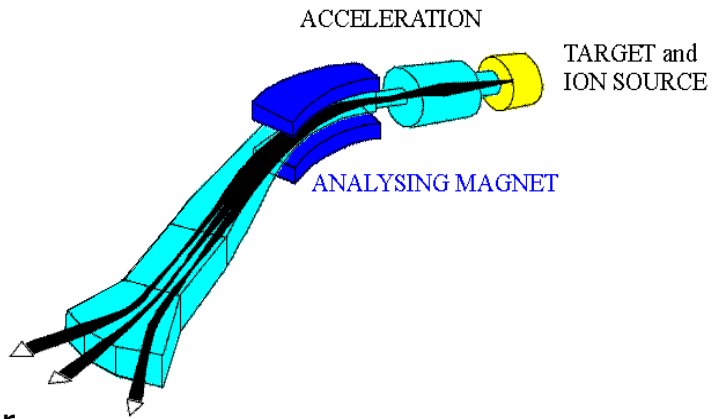
Break-up to multi-particle final states

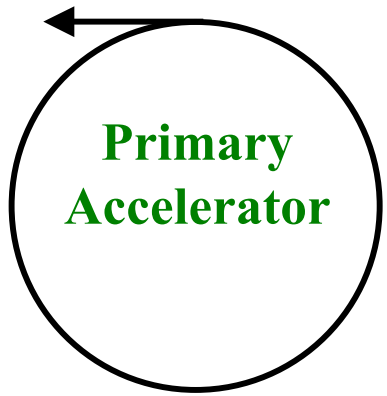
- Characteristics
  - Kinematics **not fixed** by conservation laws
  - The mechanism of X->Y can be studied – **sequential, simultaneous, democratic**...
  - Need **complete kinematics** measurement to fully characterise final state
  - Connection to level structure closer for direct break-up (weak FSI) ?



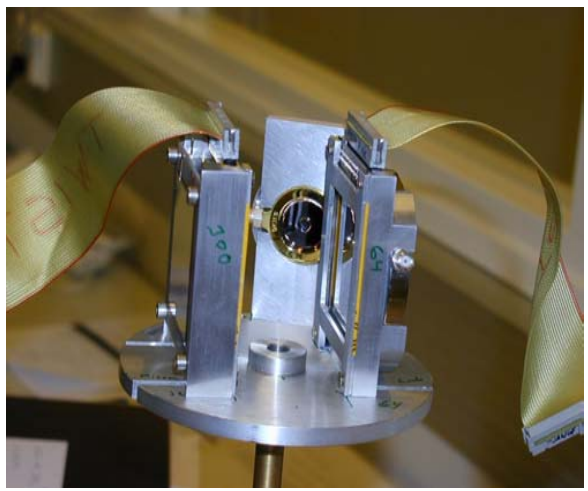
Experimental technique for multiparticle detection







- **ISOL method**
- **β-decay to populate state of interest**
  - **clean and selective**
- **Use DSSSDs for complete kinematics**
  - **Large solid angle (rare events)**
  - **High Segmentation (avoid summing)**
  - **Effective Readout**



Analysis Method

❖Precise determination of the source position

❖The radioactive beam is completely stopped in the thin carbon foil
→ it decays at rest → linear momentum conservation

$$\vec{P}_i = \vec{P}_f = \vec{P}_1 + \vec{P}_2 + \vec{P}_3 = \Delta\vec{P}$$

The uncertainties coming from the finite size of the pixel

$$\Delta\vec{P} \neq 0,\ \Delta\vec{P}_{maximum} = 20-30\ \text{MeV/c}$$

Triple coincidences
Identification of particles
Removal of beta-contamination

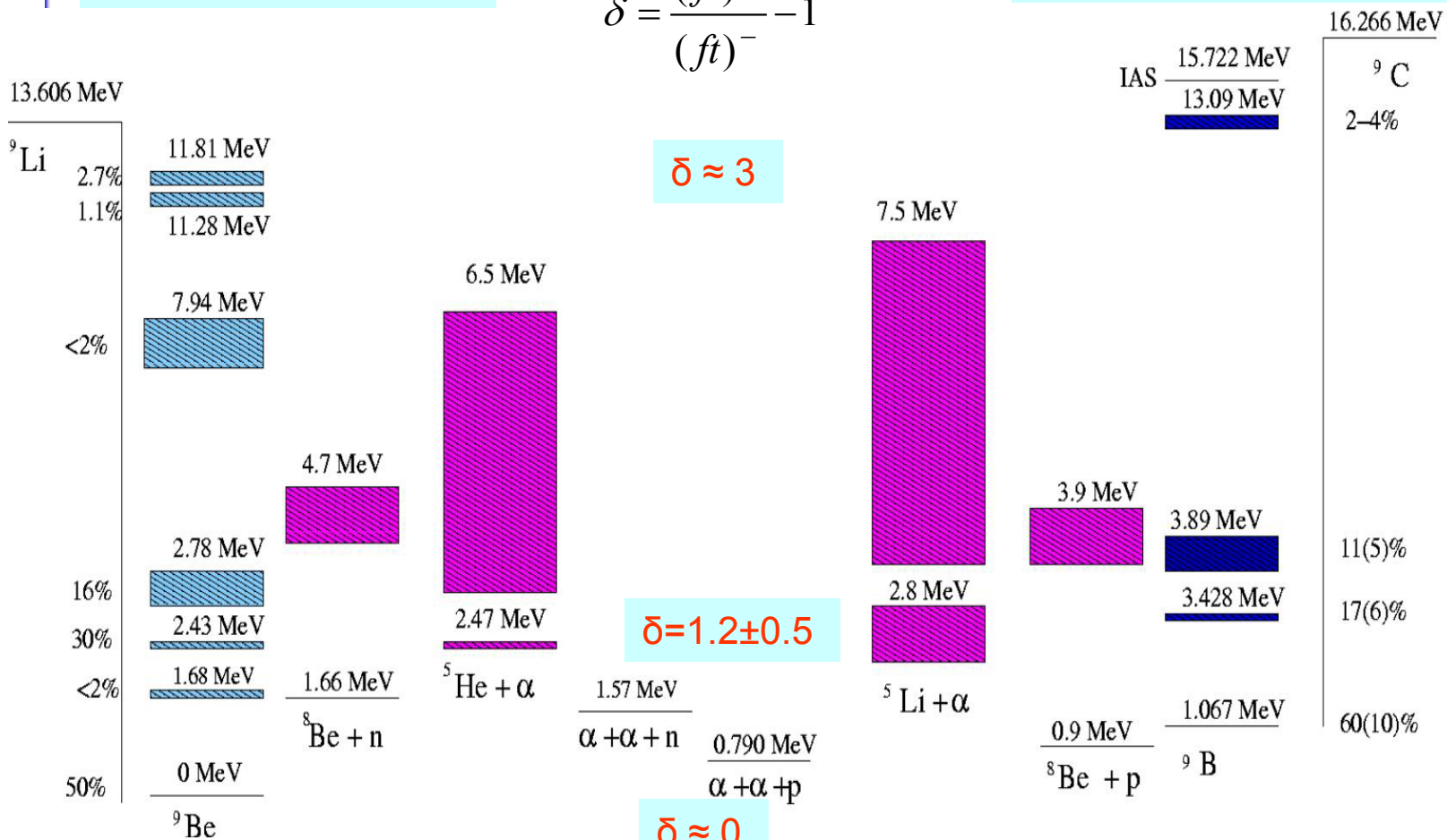
Double coincidences
Reconstruction of the third particle
P1+ P2+ P3=0→ less precise

A = 9 Isobar

Large asymmetries

$$\delta = \frac{(ft)^+}{(ft)^-} - 1$$

-Differences in radial w.f
-Binding energies effects



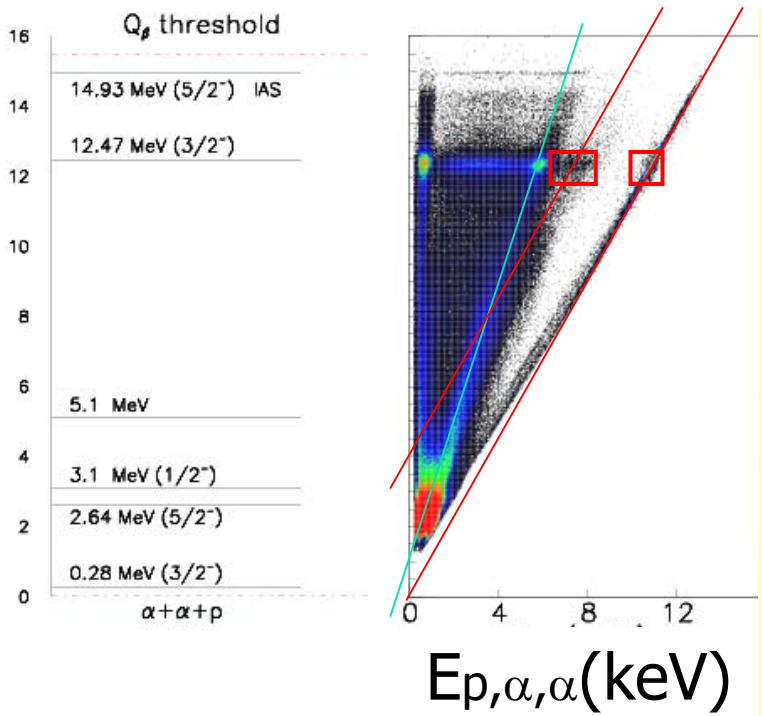
Nyman et al., NPA 510 (1990) 189

Mikolas et al., PRC 37 (1988) 766

F. Ajzenberg-Selove, NPA 490 (1988) 1

^{9}B excitation energy, (Presented in RNB5)

$$E_{sum} = \frac{M_{recoiling} + M_{first}}{M_{recoiling}} E_{first} + x \begin{cases} = 92\ \text{keV}\ (9/8)\ \text{for}\ {}^{8}Be(0^{+}) \\ \approx 2\ \text{MeV}\ (9/5)\ \text{for}\ {}^{5}Li(3/2^{-}) \\ = 3.0\ \text{MeV}\ (9/8)\ \text{for}\ {}^{8}Be(2^{+}) \end{cases}$$



- Sequential Decay of 12.2 MeV State via ^{8}Be(gs), ^{8}Be(2^{+}), ^{5}Li(gs) and ^{5}Li(1/2)
- R-Matrix-formalism applied.
- MC-simulations to account for efficiencies of each channel
- Results E: 12.19(4) MeV

  Γ: 450(20) keV

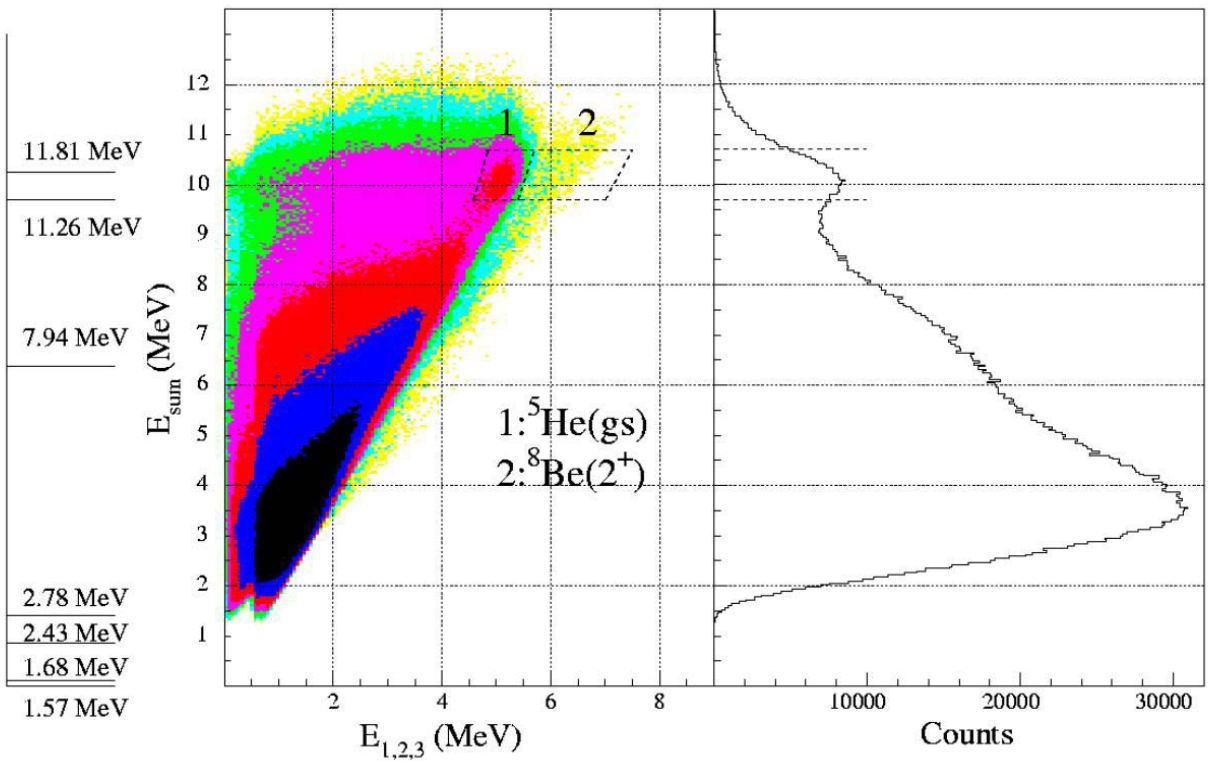
  J: 5/2

  B_{GT}: 1.20(15)

Double coincidences in ^{9}Li decay

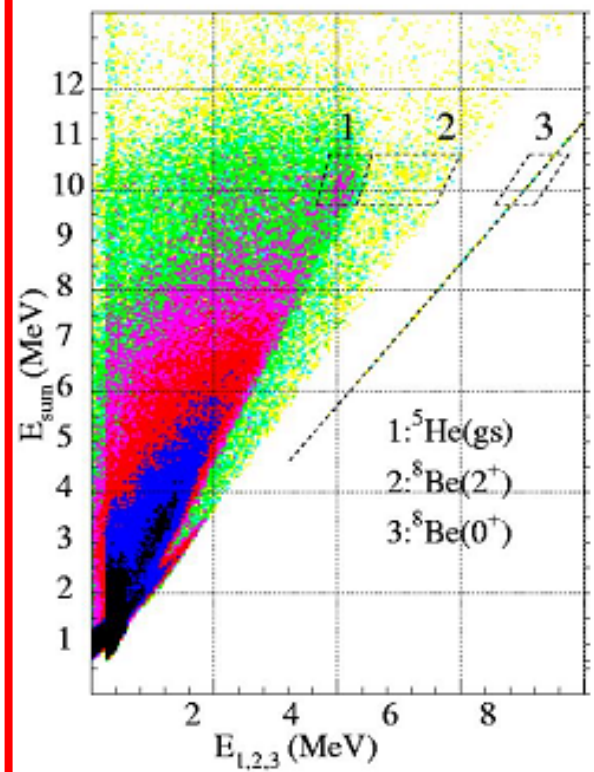
$$\vec{P}_{\alpha 1} + \vec{P}_{\alpha 2} + \vec{P}_{n} = 0 \Rightarrow \vec{P}_{n} = -(\vec{P}_{\alpha 1} + \vec{P}_{\alpha 2})$$

E*(^{9}Be) = E_{sum} + 1.57 MeV (nαα breakup)



October 2002

Ultra-thin entrance window Detectors



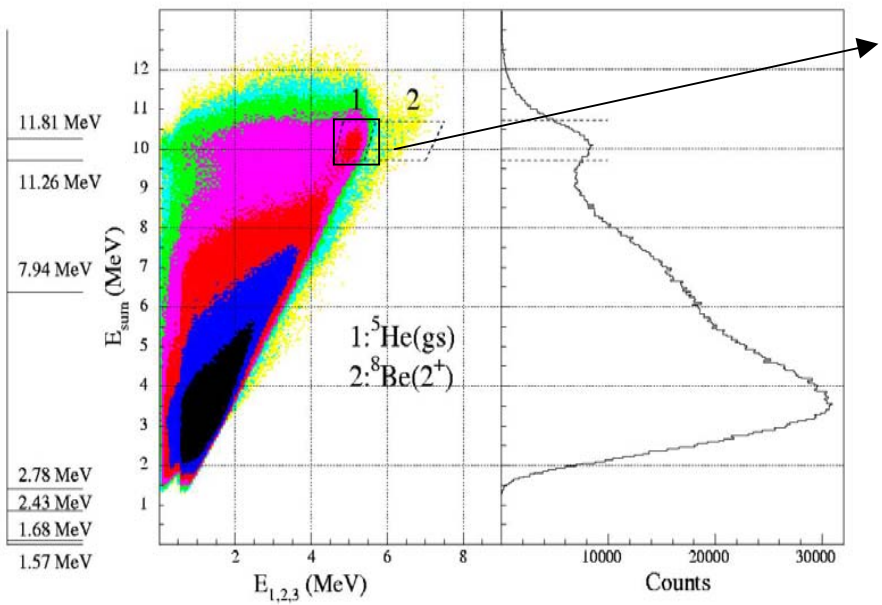
Beta feeding to the 11-12 MeV region in ^{9}Be

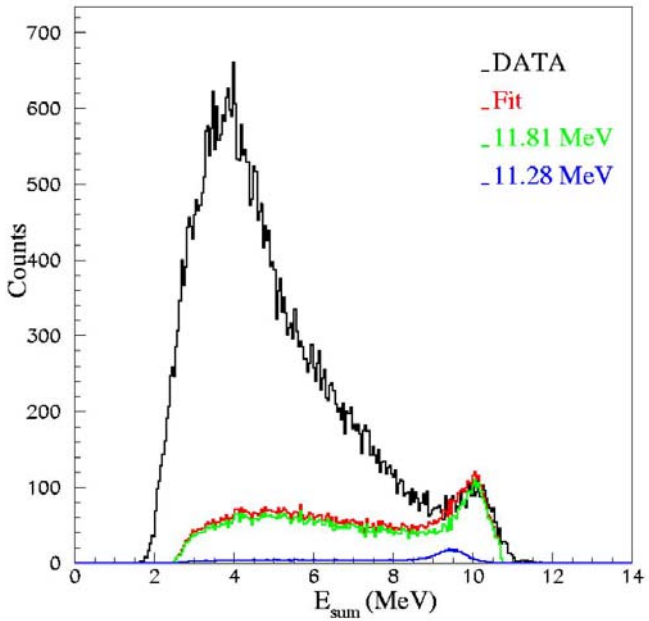
Fit of the high energy peak gating on the ^{5}He(3/2^{-}) channel

11.81 MeV state → 91±10%

11.28 MeV state → 9 %

(e,p)-scattering on ^{9}Be assumed J = 7/2

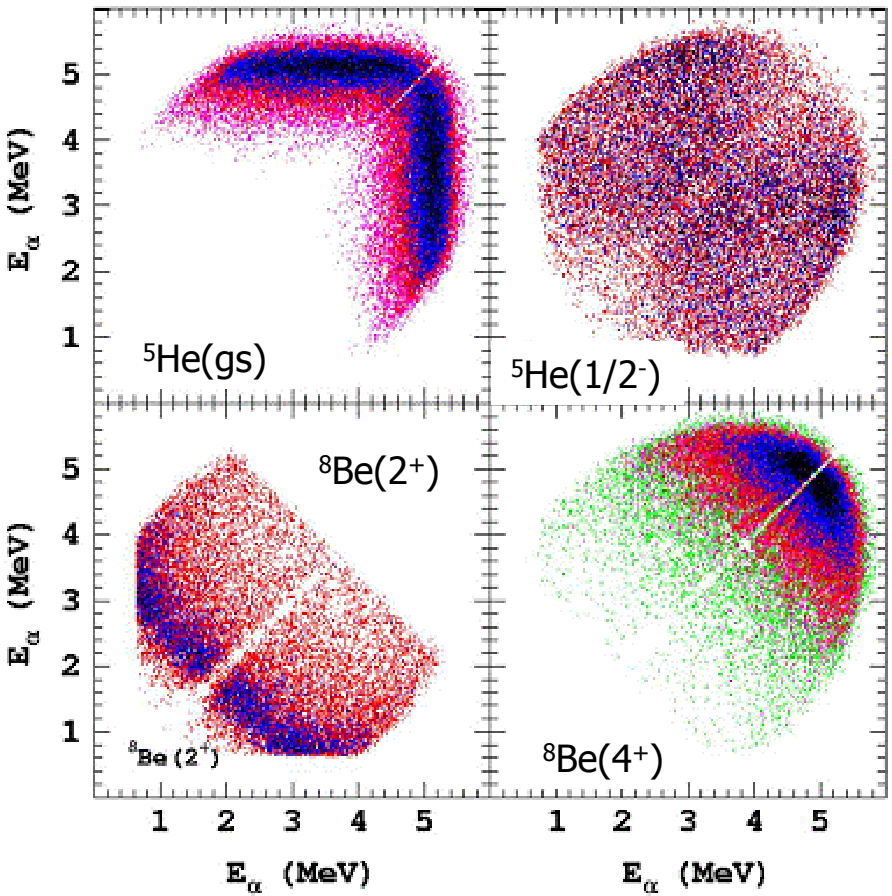




Only the participation of the 11.81 MeV state in ^{9}Be for the beta feeding is considered

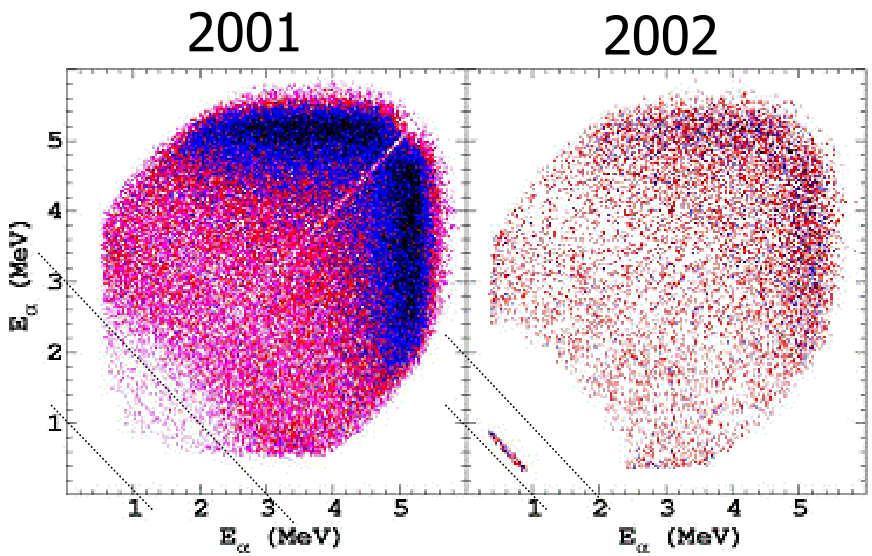
Breakup channels of the 11.81 MeV state in ^{9}Be

Simulated $\alpha\alpha$ distributions for the different decay channels



Experimental $\alpha\alpha$ distributions

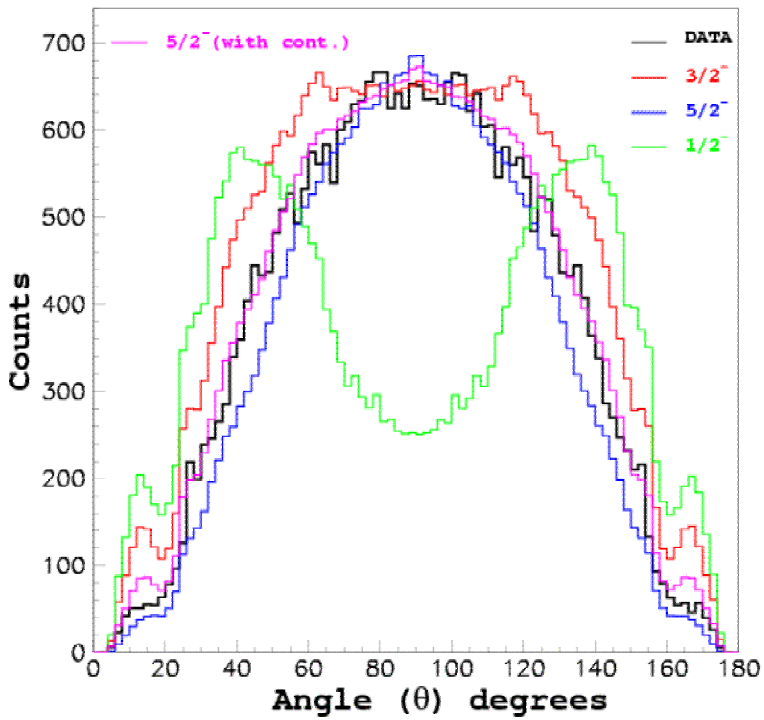
$9.7 < E_{sum} < 10.7$ MeV



The ^{5}He(3/2^{-}) channel dominates

Some contamination from the ^{5}He(1/2^{-}) and ^{8}Be(4^{+}) channels

Spin of the 11.81 MeV state in ^{9}Be



Possible spins:

5/2 → A_2=-0.714
3/2 → A_2=0
1/2 → A_2=1

Fit of the angular distribution of the events coming from the breakup through the ^{5}He(3/2^{-}) channel to the distribution:

$$W(\theta) = 1 + \frac{1}{2} A_2 (3\cos^2(\theta) - 1)$$

$$\downarrow$$

$$A_2 = -0.45 \pm 0.02 \pm 0.05$$

It points at a spin 5/2^{-} (A_2=-0.714)

Good fit (▬) if the contamination from the ^{5}He(1/2^{-}) and ^{8}Be(4^{+}) channels is taken into account

Comparison of mirror transitions in A = 9 system

$^{9}C \rightarrow {}^{9}B$ (12.19 MeV, 5/2) **B(GT) = 1.20 (15) / 1.58(16)** *[PRC61(2000) 064310]*

$^{8}Be(0^{+}) + p$	$^{8}Be(2^{+}) + p$	$^{8}Be(4^{+}) + p$	$^{5}He(3/2^{-})+\alpha$	$^{5}He(1/2^{-}) + \alpha$	Ref
0.090 (10)	**0.25 (7)**	-	**0.60 (7)**	**0.06 (4)**	*This work, NPA 692(2001)427*
0.085 (14)	0.18 (3)		0.74 (8)	-	*PRC61(2000)*

$^{9}Li \rightarrow {}^{9}Be$ (11.8 MeV, 5/2) **B(GT) = 5.3 (9)**

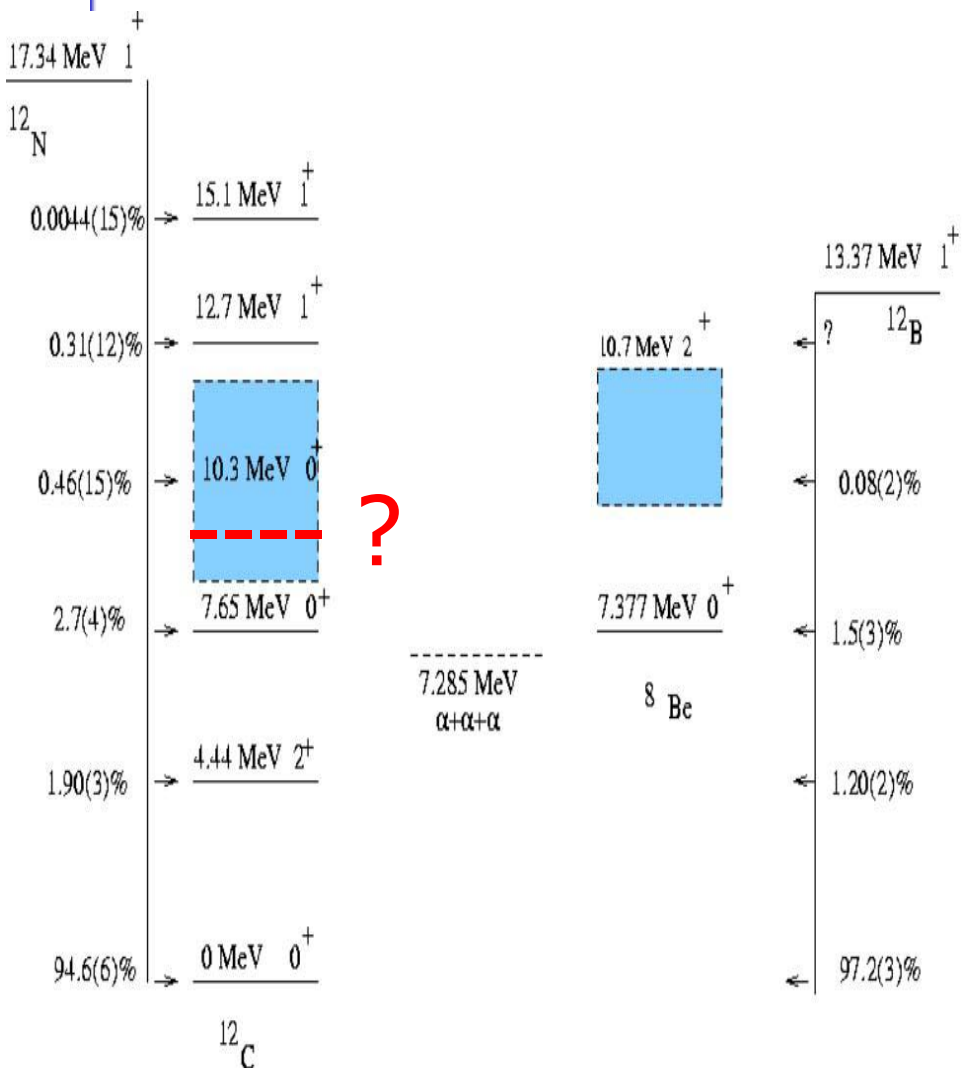
$^{8}Be(0^{+}) + n$	$^{8}Be(2^{+}) + n$	$^{8}Be(4^{+}) + n$	$^{5}He(3/2^{-})+\alpha$	$^{5}He(1/2^{-}) +\alpha$	
0.02(0.01)	**0.11(0.06)**	**0.12(0.08)**	**0.28(0.06)**	**0.47(0.07)**	*This work*
					Y. Prezado, Phys. Lett B. submitted

$\delta = (B(GT)^{-} / B(GT)^{+} - 1) = 3.4(10)$

ii Largest asymmetry reported in strong β-transitions !!

See details in the Poster of Y. Prezado

Open questions in $^{12}C^*$



Unknown J^{π} of the 10 MeV broad level: 0^+, 2^+

Clusters models predict a 2^+ rotational state over the 7.65 MeV at around 9 MeV

Interferences? / ghost anomaly?

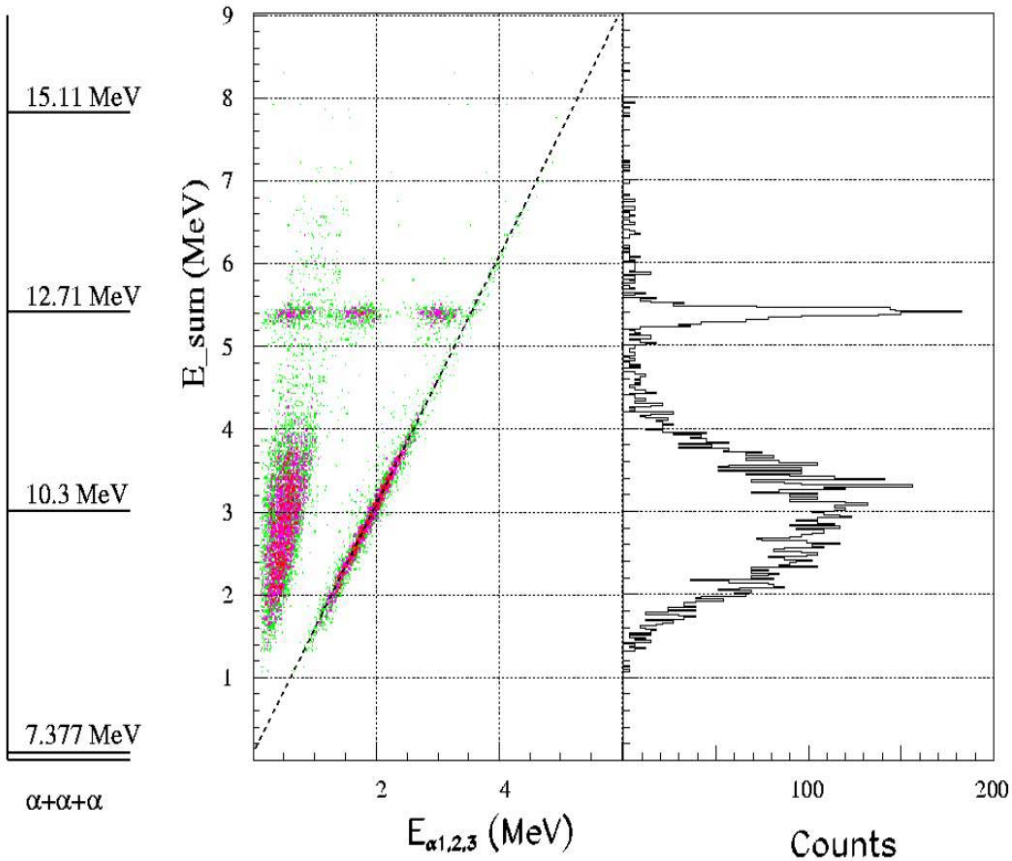
The breakup mechanism of the 12.71 MeV state controverted

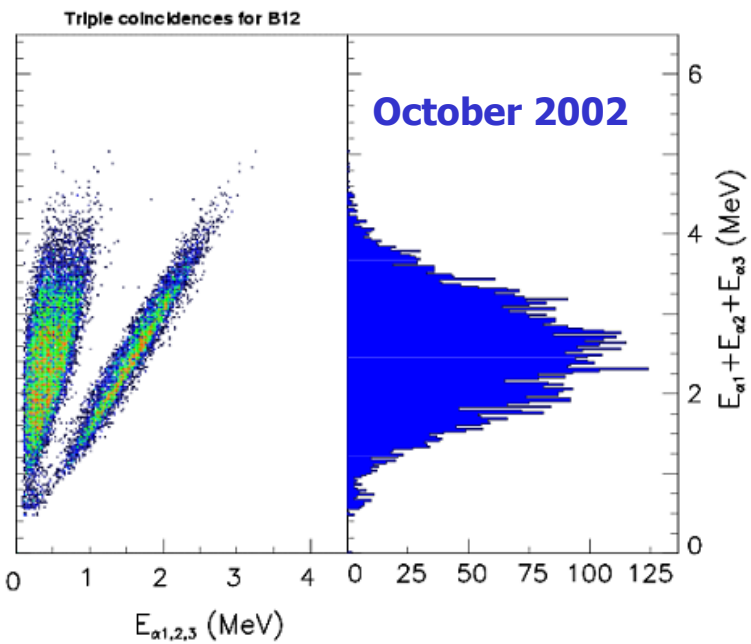
All fed in β procces!!

3α from the ^{12}N decay @ JYFL

$^{12}C(p,n)^{12}N$ @ IGISOL

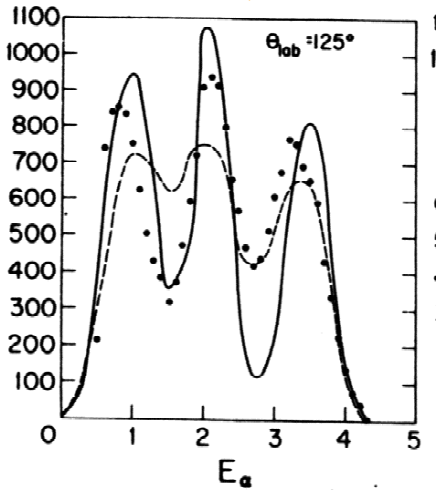
- *Good resolution!!*
- *Three alpha groups from the breakup of the 12.71 MeV state*
-





Breakup of the 12.71 MeV state in ^{12}C

Balamuth, Zurmuhle and Tabor Phys. Rev. C10 (1974) 975



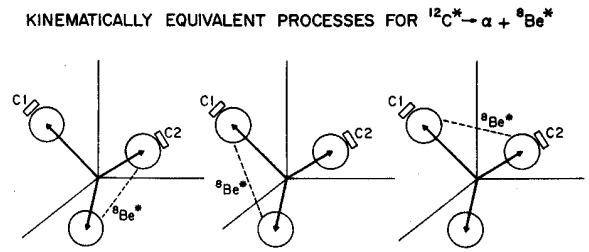
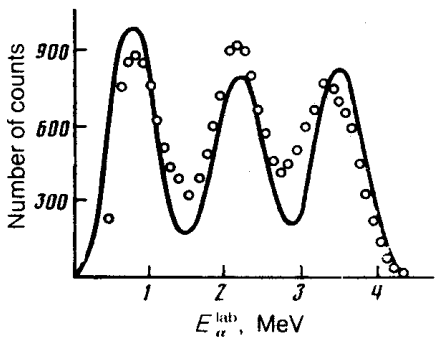
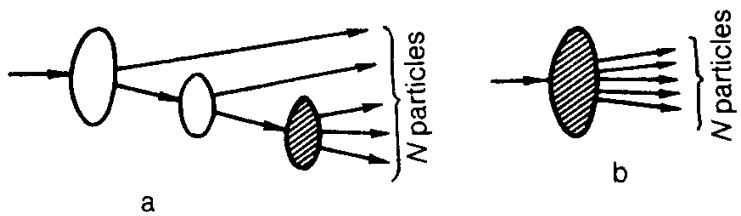


FIG. 2. Diagrams representing the three possible amplitudes which must be coherently added in calculating the breakup spectra.

R-matrix based sequential break-up with order-of-emission interference

A.A. Korshenninikov Sov. J. Nucl. Phys. 52 (1990) 827

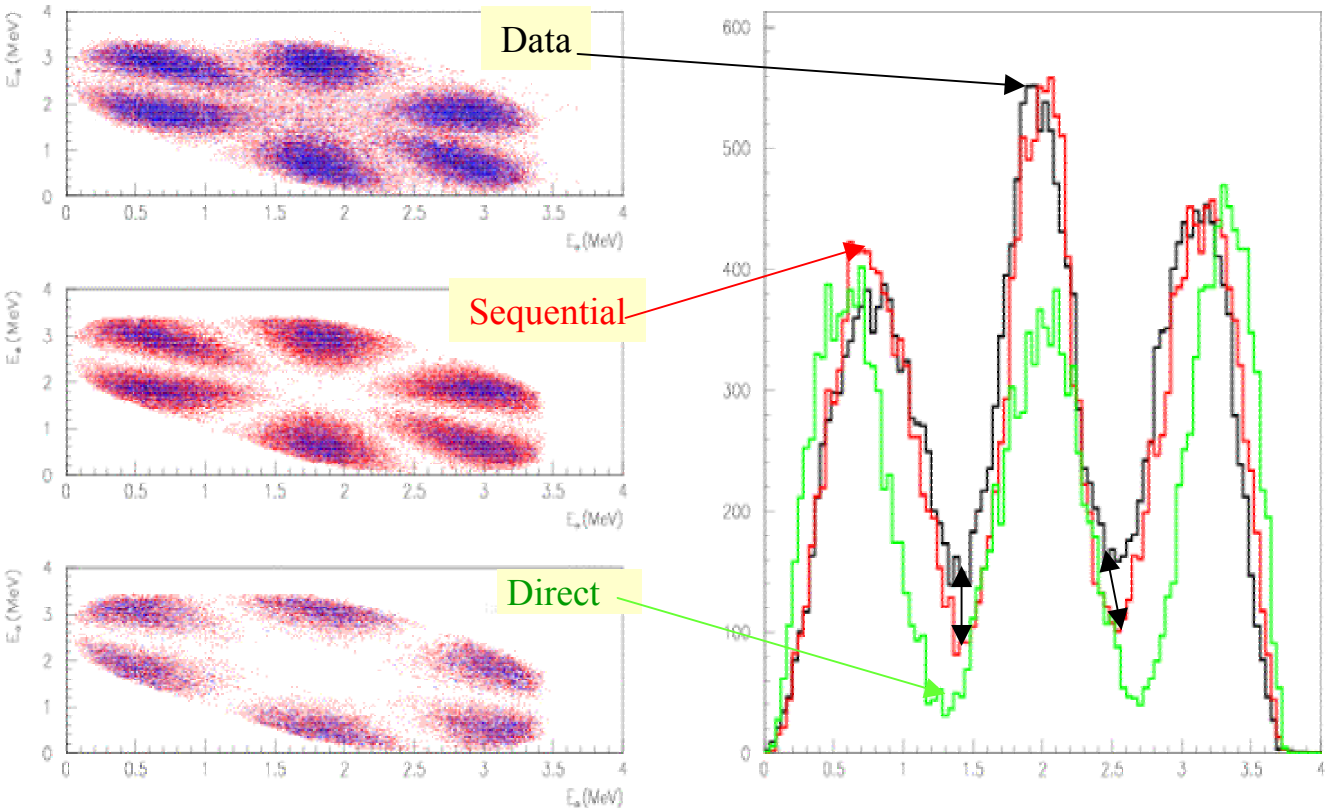




Hyperspherical Harmonics expansion Simultaneous emission

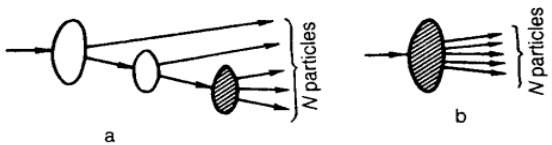
SAME DATA !!

3α break up of the 12.71 MeV state in ^{12}C



Break-up mechanism ?

Sequential or ***Direct***



... mainly sequential

+ Coulomb int. between the 3 α

Fynbo et al, Phys. Rev. Lett. 91(2003) 082502

Summary & Outlook

- **Beta-delayed multi-particle emission is a powerful tool**
  If study in full kinematics
    - Decay mechanism
    - E, Γ, spin...
- **The beta-decay asymmetry in the A= 9 isobar system studied for the high excited (≈ 12 MeV) states in ^{9}Be & ^{9}B**
    - **Sequential breakups for pαα and nαα**
    - **Confirmed large asymmetry δ = 3.4 (1.0)**
    Beta asymmetry to the g.s. negligible → δ must be due to differences in the structure of the two final state resonances
- **The breakup into 3α of the 12.7 MeV state in ^{12}C is mainly sequential**
    For a perfect fit of the α–spectrum ⇒ interaction between the 3α has to be considered

- **FUTURE:**
    - **^{12}C: Spin of the 10.3 MeV state/interferences with Hoyle state**
      Presence of the 9.2 MeV, 2^{+} rotational state
    - **^{11}Li: Disentangle the breakup of the 18.1 MeV state in ^{11}Be**

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