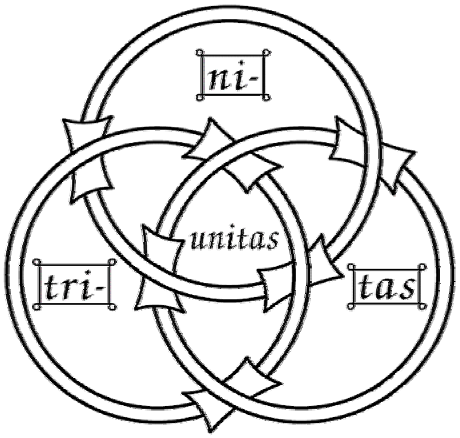
Correlation studies in breakup experiments

Haik Simon • Gesellschaft für Schwerionenforschung / Darmstadt



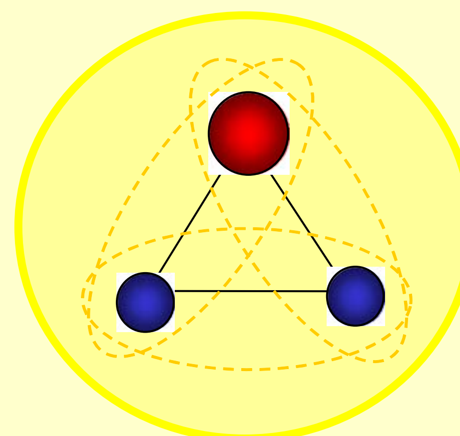
Borromean Nuclei

→ 3body correlations

$^{6}He = {}^{4}He + n + n$

$^{11}Li = {}^{9}Li + n + n$

$^{14}Be = {}^{12}Be + n + n$

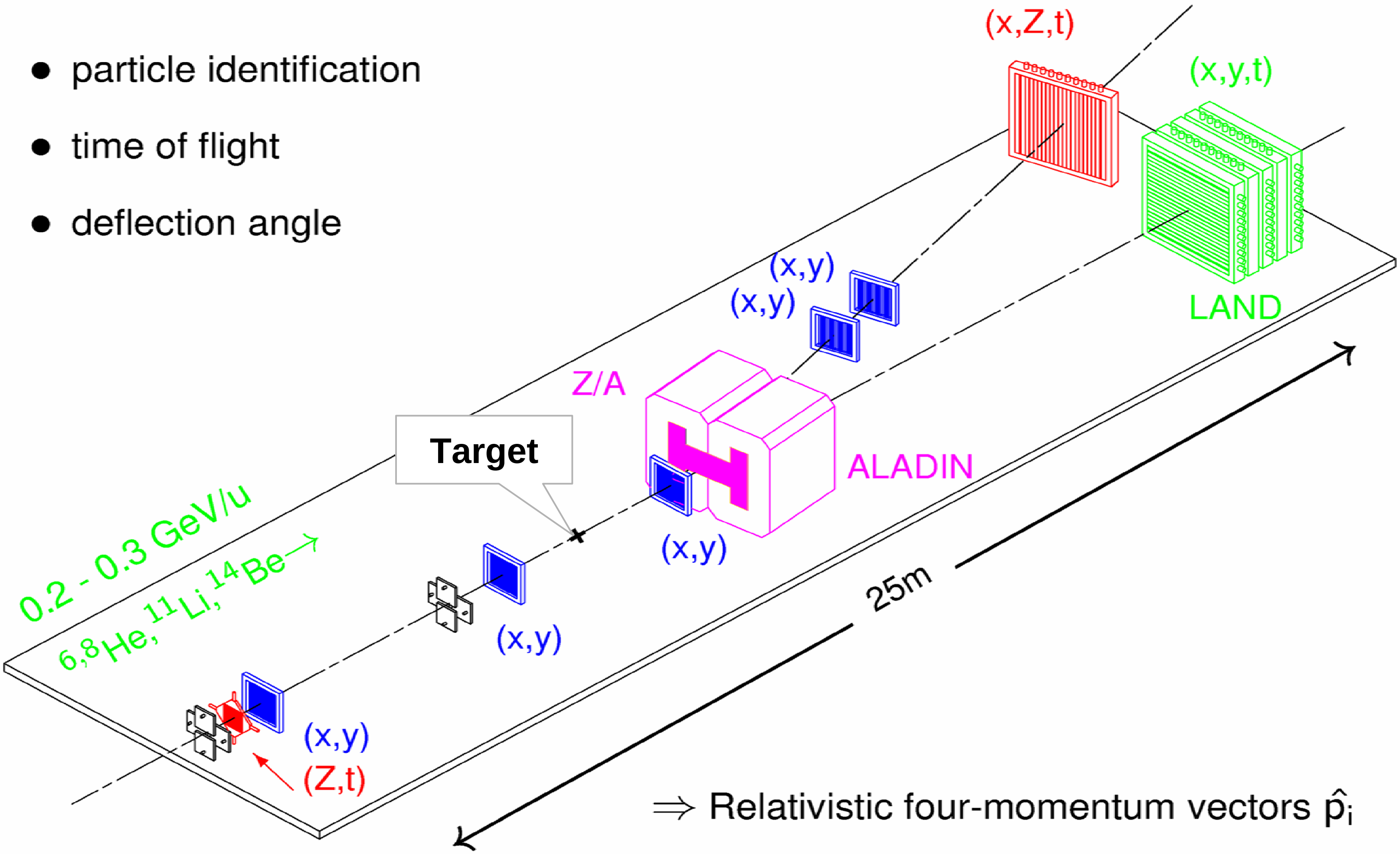


Outline

- 2 body final state
- 3 body final state
  - (i) detection system
  - (ii) experimental results

Experimental Setup (kinematically complete)

- particle identification
- time of flight
- deflection angle

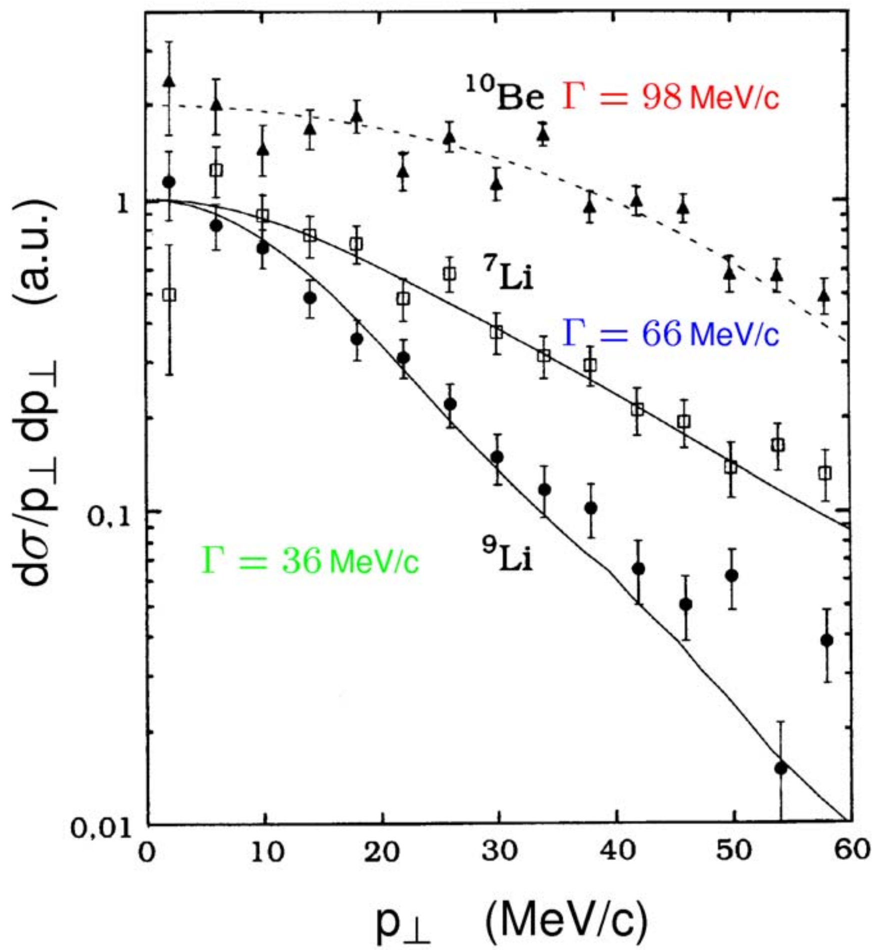


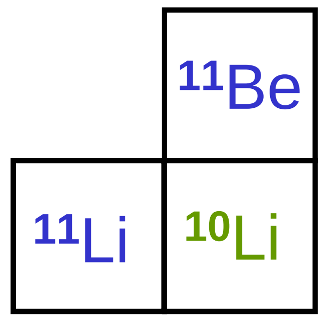
⇒ Relativistic four-momentum vectors $\hat{p}_i$

Starting point:

How to treat two (many) neutron halo nuclei ?

^{11}Be + C $\longrightarrow$ n + ^{Z}A + X





knockout mechanism !

→final state interaction

➔ reconstruction of the unbound intermediate system necessary !

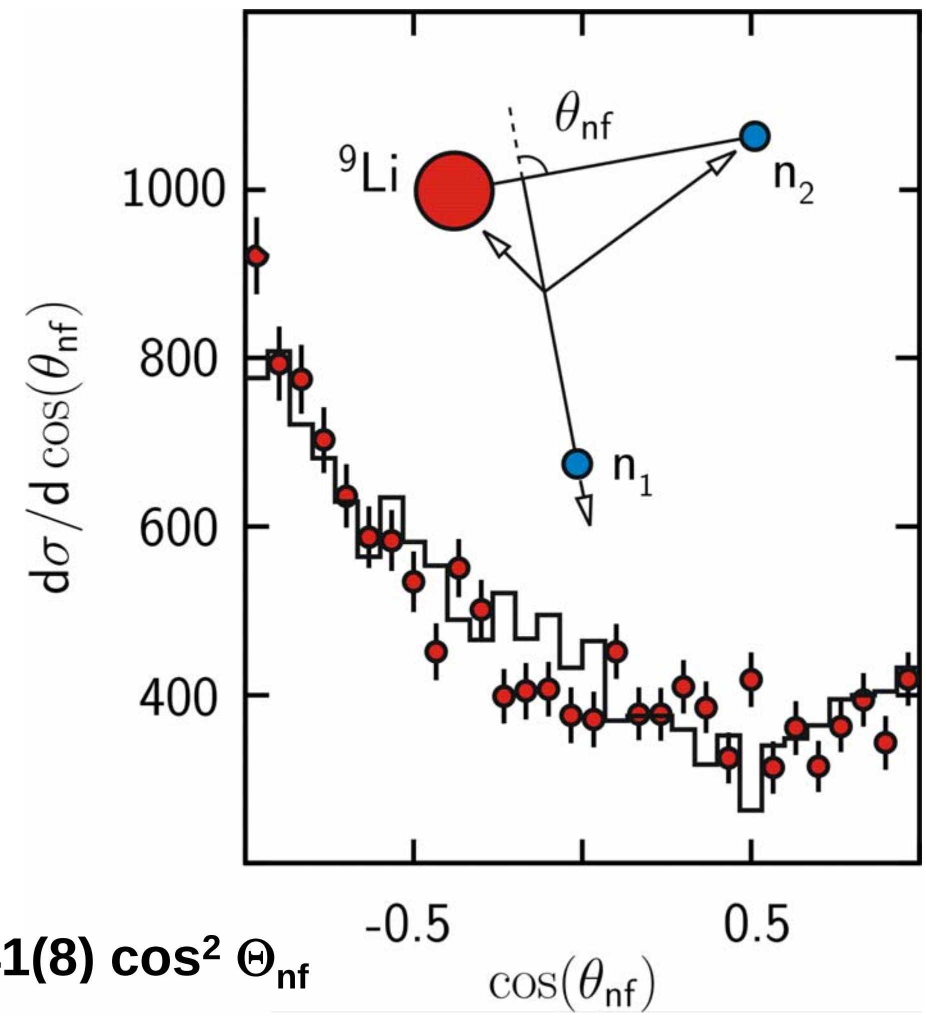
M.P.J. Zinser et al. PRL75 (1995) 1719

Angular correlation $^{11}Li \rightarrow {}^{10}Li^{*} + x$

s-shell : isotropic

p-shell S=1 : $\propto \sin^2 \Theta_{nf}$

p-shell S=0 : $\propto \cos^2 \Theta_{nf}$



Interference (s- and p- shell)

S=0 : $\propto \cos \Theta_{nf}$

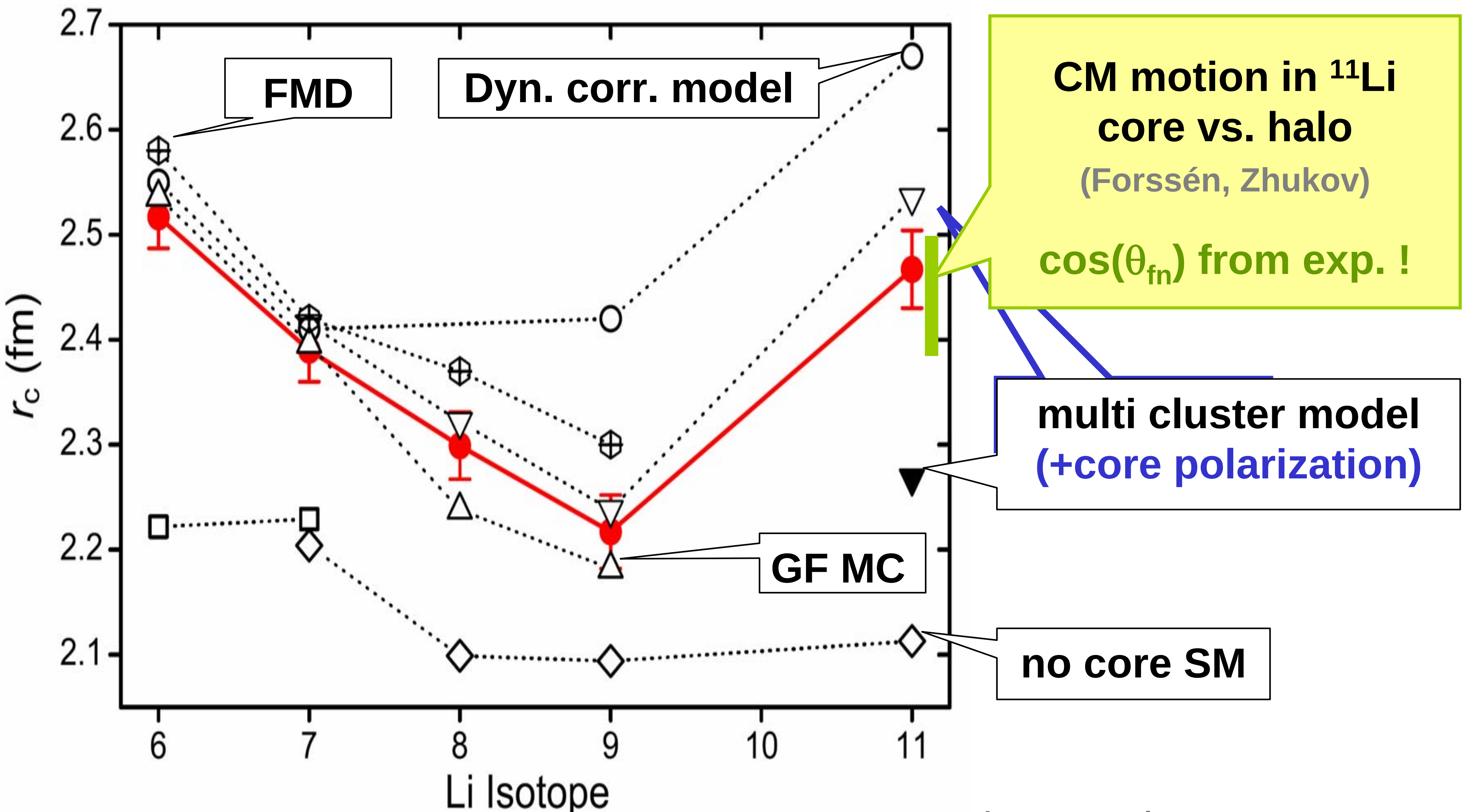
$$W(\Theta_{nf}) = 1 - 1.03(4) \cos \Theta_{nf} + 1.41(8) \cos^2 \Theta_{nf}$$

$$\Rightarrow \quad {}^{11}Li \quad \Big| \quad (1s_{1/2})^2 = 45 \pm 10\,\%$$

H.S. et al. PRL83 (1999) 496

How inert are the cores ?

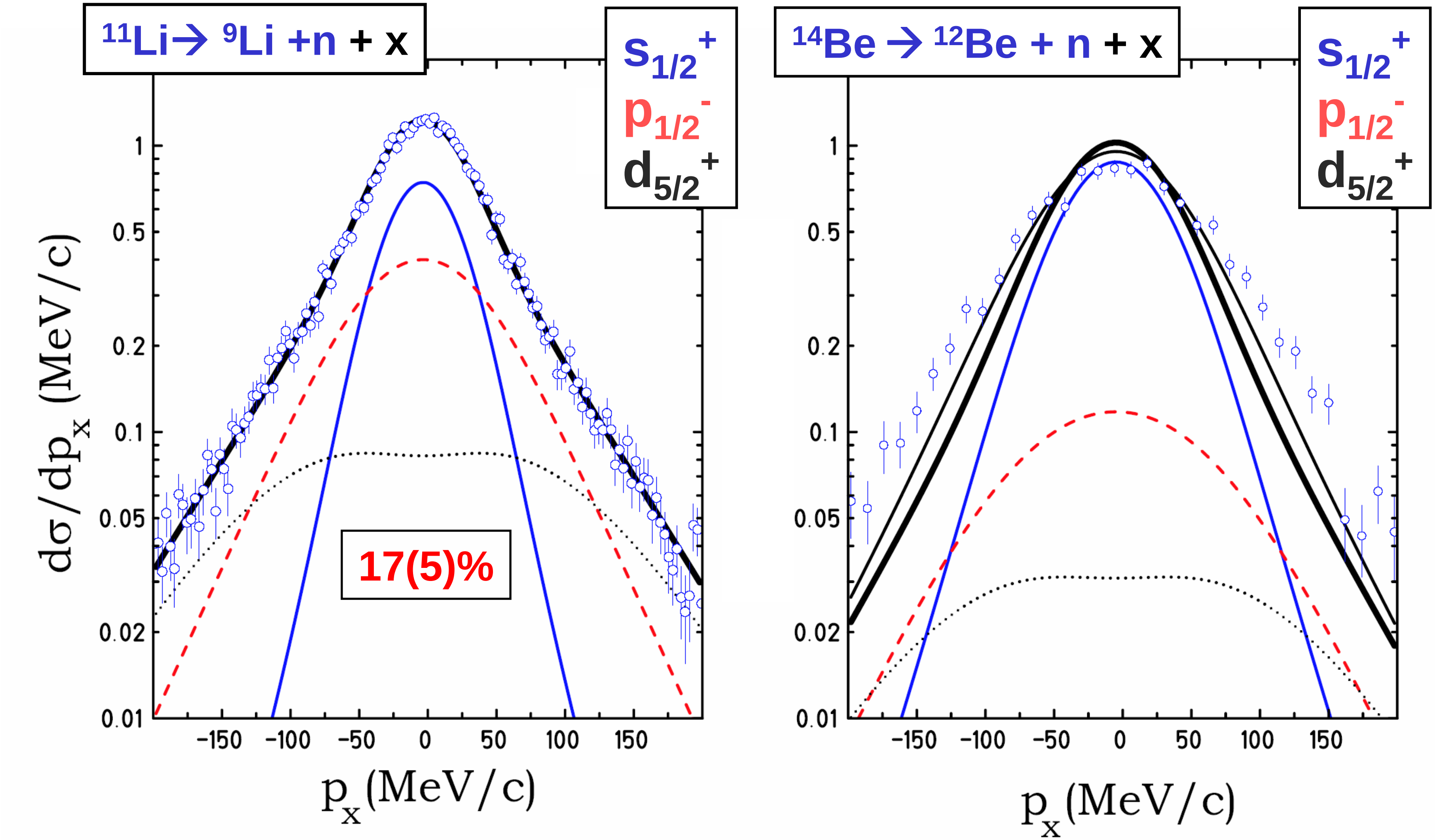
LASER spectroscopy: charge radii for Li isotopes



R. Sanchez, et al.
Phys. Rev. Lett. 96, (2006) 033002

Where is the d-wave ?

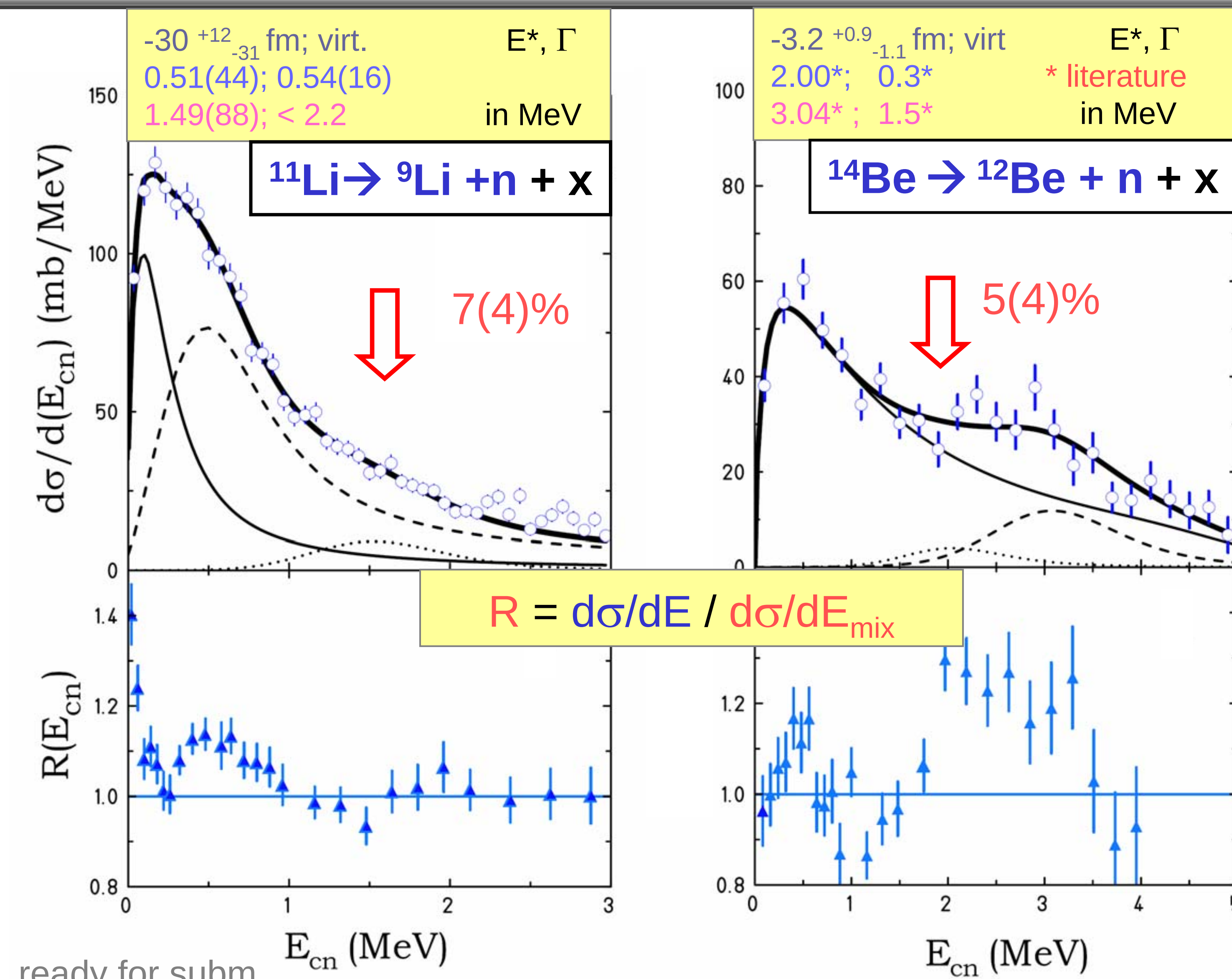
Missing momentum distributions ^{11}Li, ^{14}Be



H.S. et al. ready for subm.

Where is the d-wave ?

Invariant mass spectra ^{11}Li, ^{14}Be



H.S. et al. ready for subm.

Spectroscopic factors ^{11}Li
eikonal calculation, transp. limit, no recoil

PHYSICAL REVIEW C VOLUME 57, NUMBER 3 MARCH 1998

Nuclear breakup of Borromean nuclei

G. F. Bertsch and K. Hencken*
Institute for Nuclear Theory, University of Washington, Seattle, Washington 98195

H. Esbensen
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439
(Received 1 August 1997)

^{9}Li profile function, H.O. Ozawa et al. NPA693(2001)32
exp. RMS, react. x-sec @790 MeV/u reproduced.

Woods-Saxon neutron wf. (prog.: J.Tostevin) param: a=0.7fm r_0=1.25fm
S_n taken from ^{10}Li data: 0.35, 0.8, 1.8 MeV (s,p,d)

$C^2S\,(1s_{1/2})_2$ =	0.59 ± 0.09	$[\pm 0.12]_{syst.}$	(50% vis. x-sec)
$C^2S\,(0p_{1/2})_2$ =	1.38 ± 0.21	$[\pm 0.54]_{syst.}$	(24% vis. x-sec)
$C^2S\,(0d_{5/2})_2$ =	0.49 ± 0.14	$[\pm 0.34]_{syst.}$	(18% vis. x-sec)
Σ =	2.46 ± 0.44	$[\pm \sim 0.5]_{syst.}$	

Three body final state

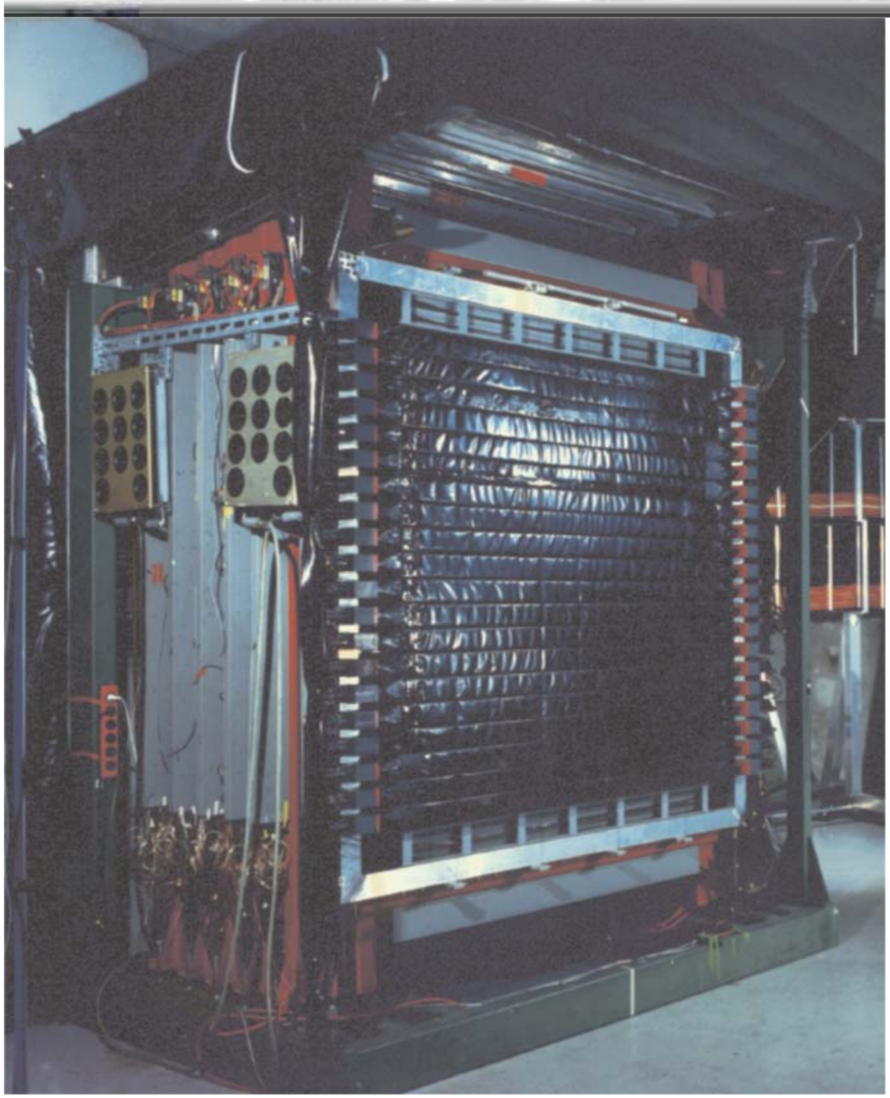
(1) coincident two neutron + charged fragment detection

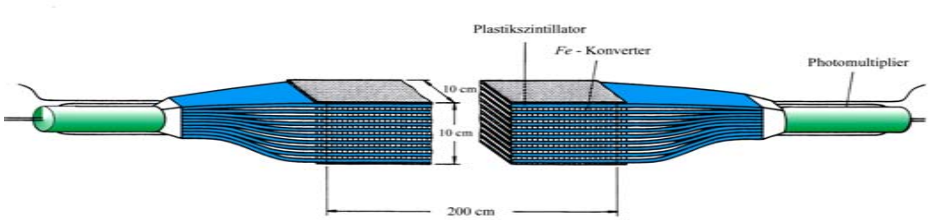
- two neutron detection efficiency
- two neutron reconstruction efficieny
- detector response

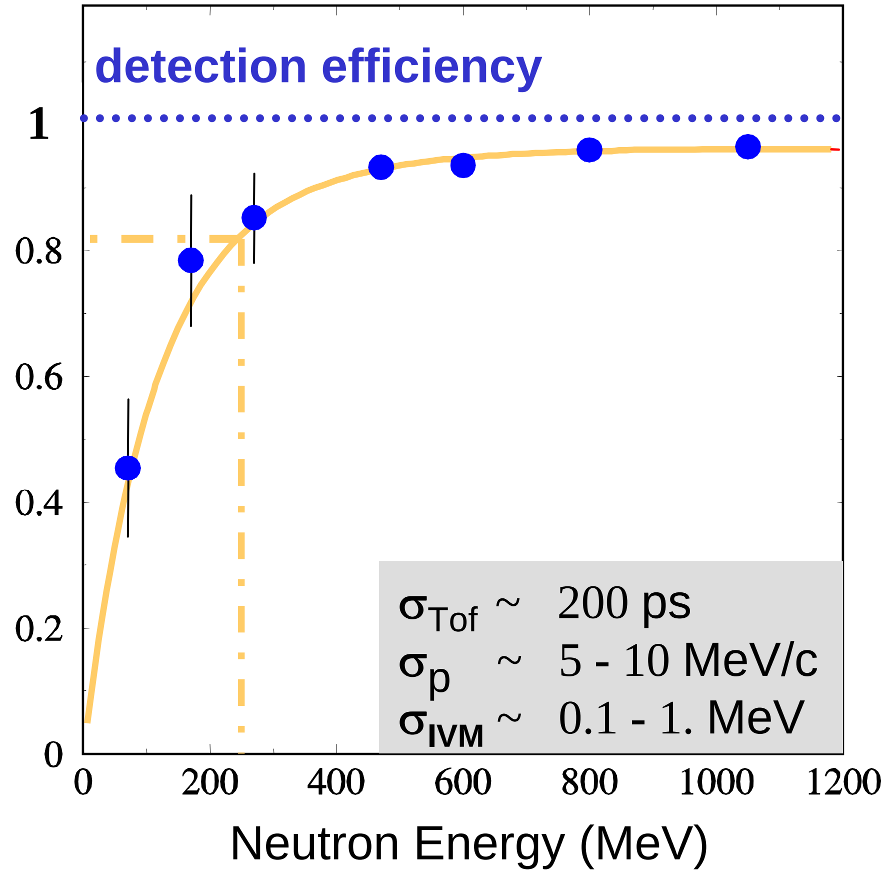
@ low relative energy !

(2) three body correlations

Large Area Neutron Detector



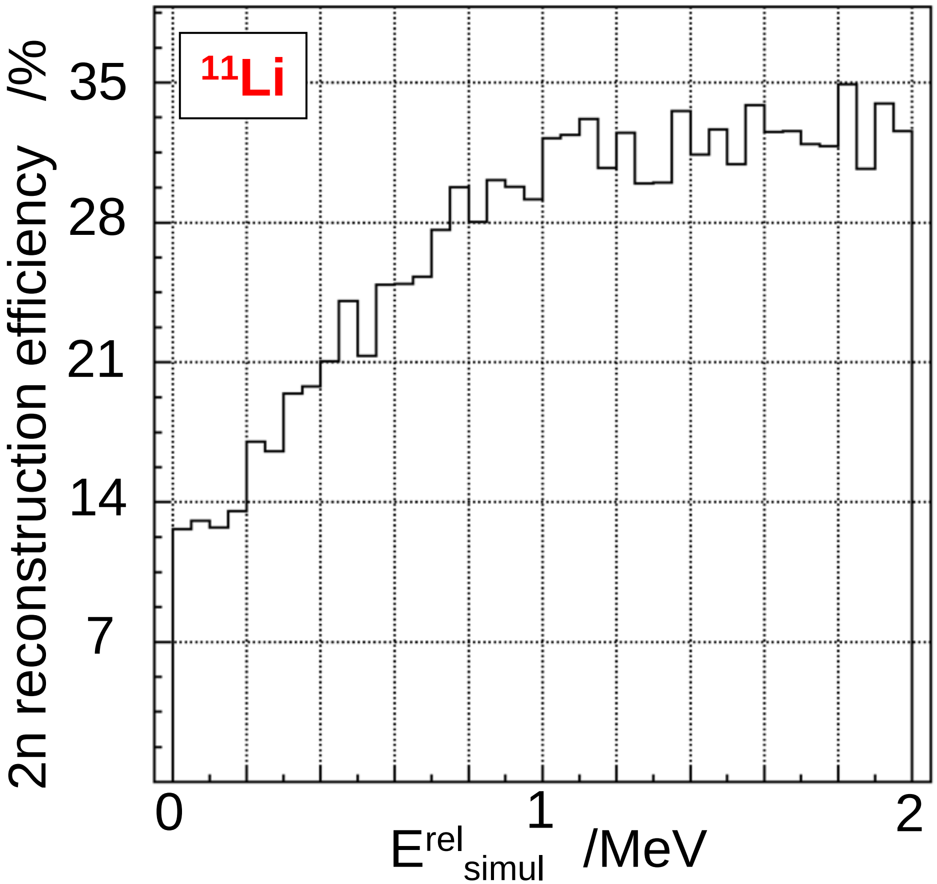




Nucl. Instr. Meth. A314 (1992) 136

LAND reconstruction efficiency (2n) at low energies

- detection efficiency 72%
- tracking algorithm
  → 2n reconstruction efficiency
- reconstruction efficieny (~ 10 %) even at zero relative energy
- experimental data
  → reconstruction & tracking efficiency superimpose tagged 1n events in LAND

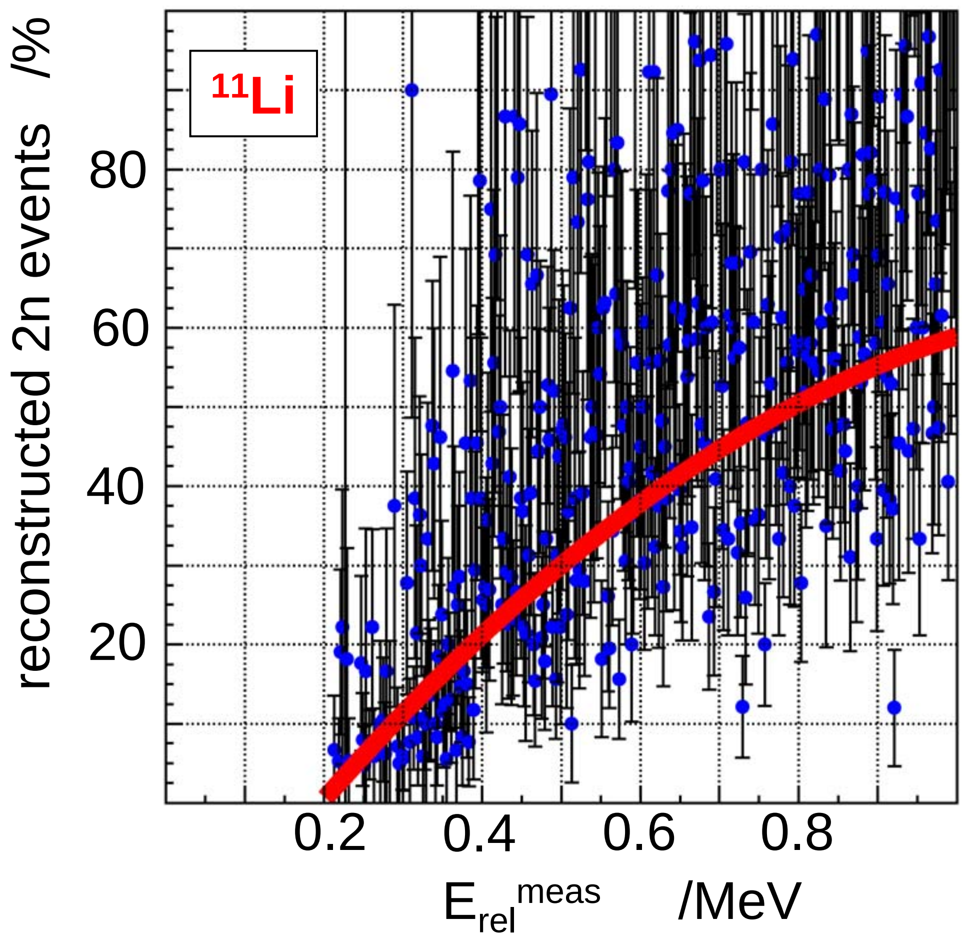


LAND tracking efficieny at low energies

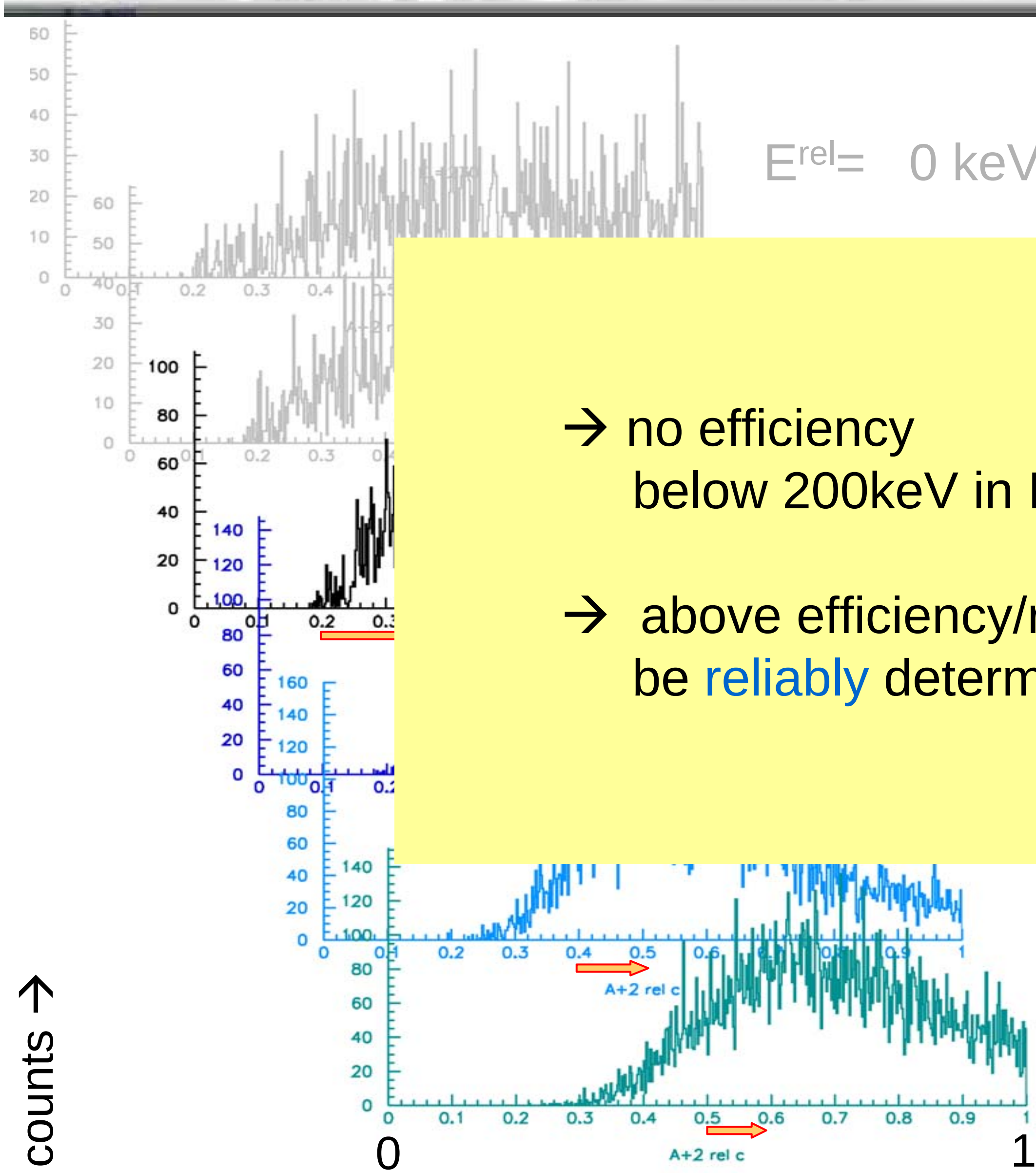
- no tracking efficieny below 200keV in ^{11}Li (seems to contradict reconstruction efficiency)

- so: how does response look like ?

- experimental data used to reconstruct response by invariant mass analysis of simulated events



LAND response at low energies



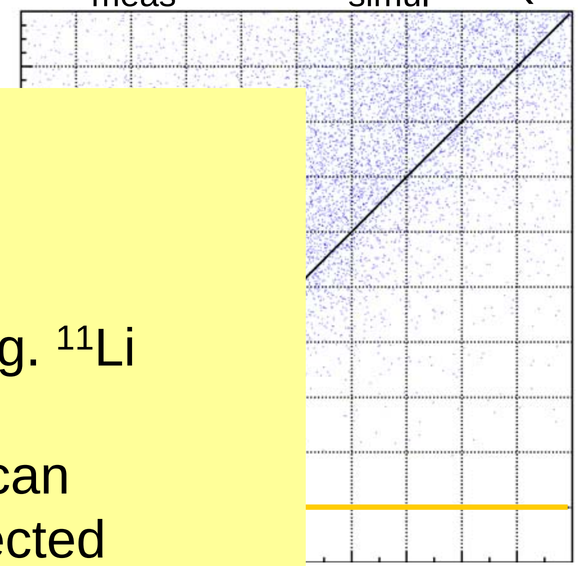
E^{rel}= 0 keV

E^{rel}= 500 keV

counts →

0 1 /MeV

E^{rel}_{meas} vs. E^{rel}_{simul} (2,2)



→ no efficiency below 200keV in Erel for e.g. ^{11}Li

→ above efficiency/response can be reliably determined/corrected

^{11}Li

Full description of the three body continuum

- Reduction of coordinates

9 variables $\rightarrow$ 6 variables $\rightarrow$ 5 variables $\rightarrow$ 2 variables (ε, θ)

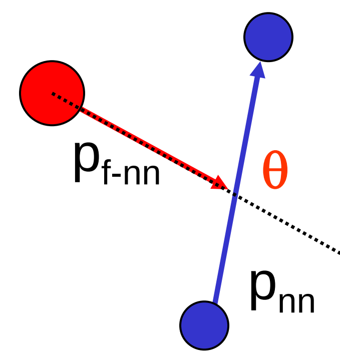
c.m. E* rot. inv.

ε is the fraction of total energy in a subsystem (e.g. $\varepsilon = E_{nn}/E_{nnf}$)

θ is the angle between the relative momenta (e.g. p_{nn}, $p_{f\text{-}nn}$)

- Three body correlation function (expansion in hyperspherical harm.):

$$\mathrm{W}(\varepsilon,\theta) \propto \frac{d^2\sigma}{d\varepsilon d\theta} \propto \sum_{\alpha,\alpha'} C^{\dagger}_{\alpha'} C_{\alpha}\, \mathcal{Y}^{\dagger}_{\alpha'}(\varepsilon,\theta)\mathcal{Y}_{\alpha}(\varepsilon,\theta)$$



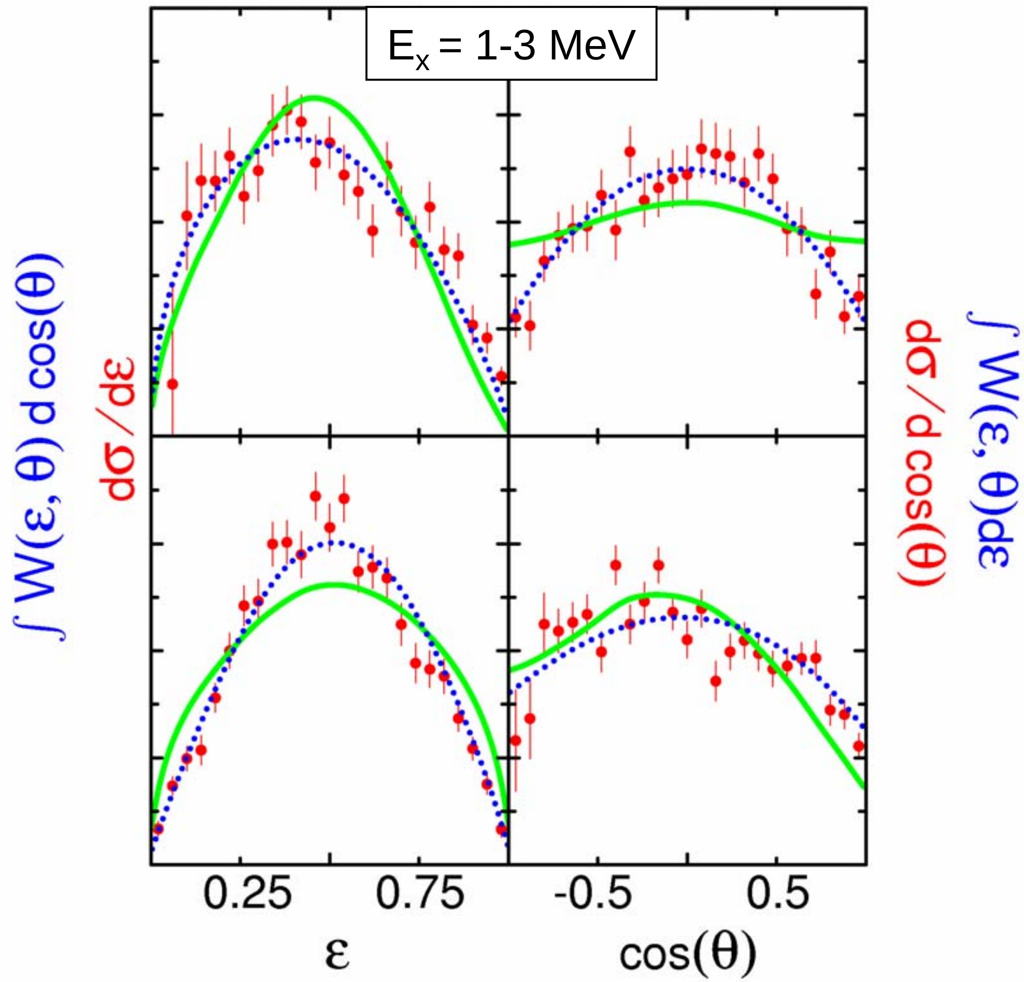
- Complex coefficients C depend on quantum numbers $\alpha=\{K,L,S,l_x,l_y\}$

➔applied to ^{6}He, ^{5}H

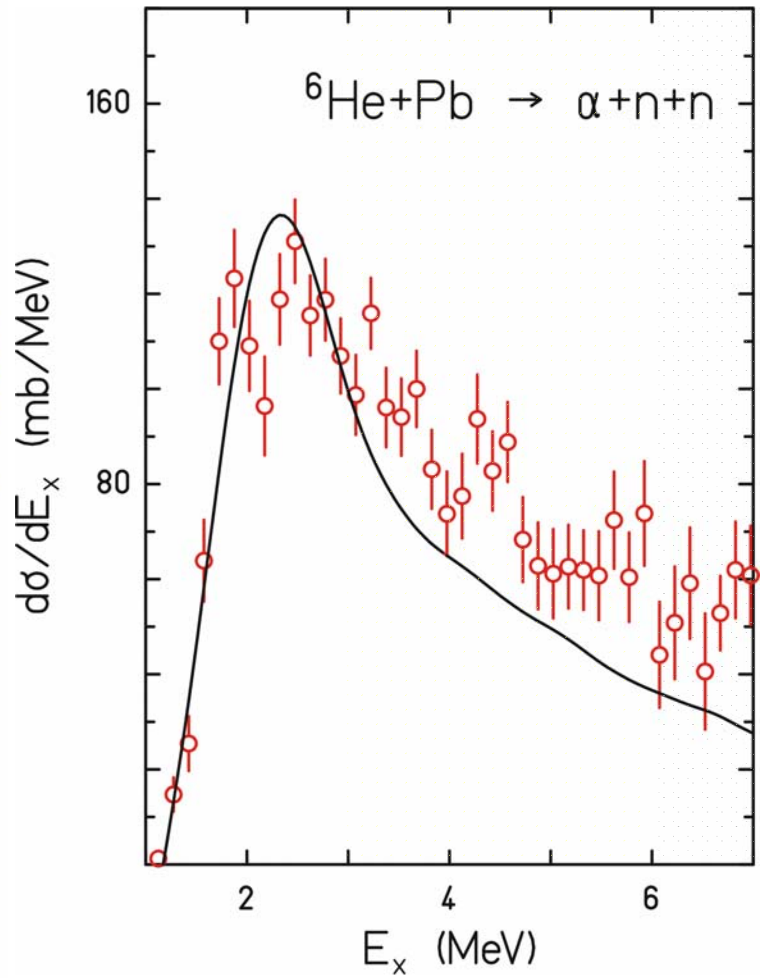
L.V. Chulkov, H.S., I.Thompson, et al., NPA759 (2005) 23
M.Meister, L.V. Chulkov, H.S., et al., PRL91 (2003) 16504

Coulomb break-up ^{6}He

B.V. Danilin et al., NUPA632 (1998) 383



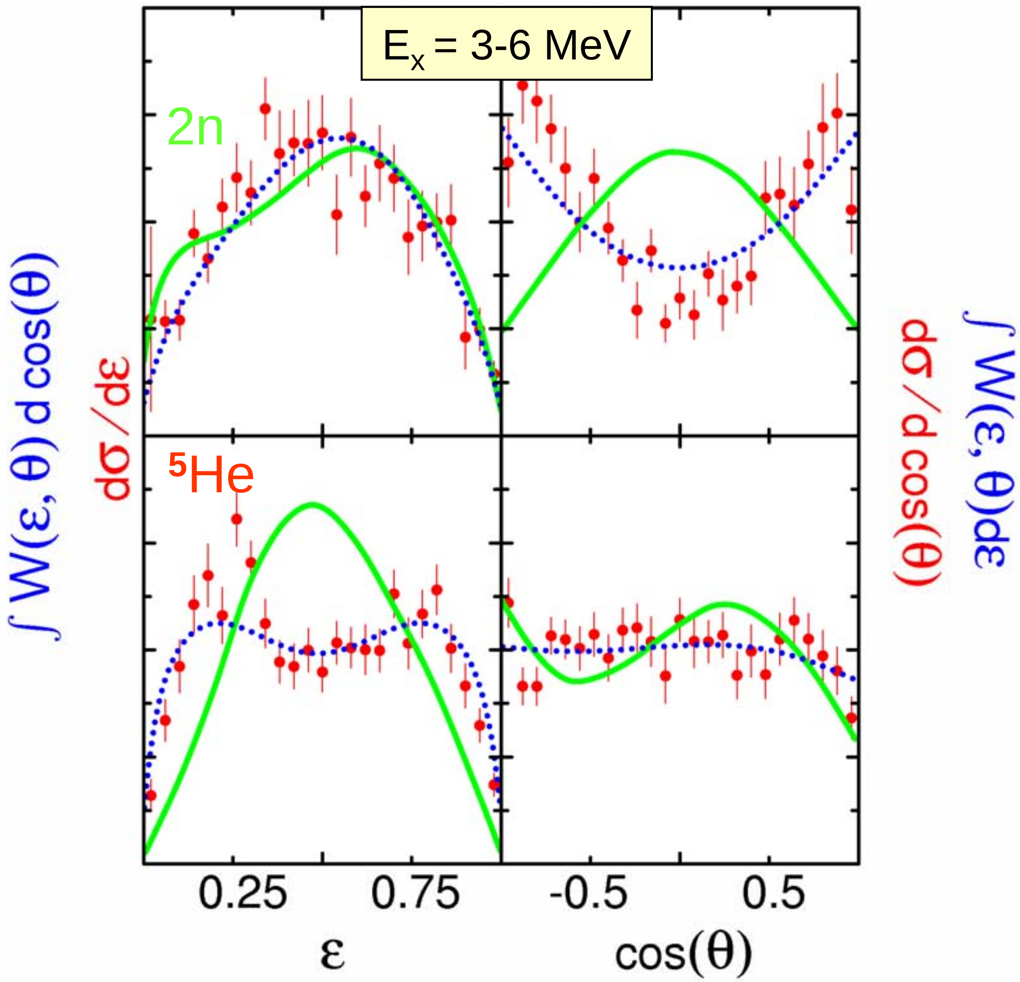
T. Aumann et al., PRC59(1999)1252



L.V. Chulkov, H.S., I.Thompson, et al., NPA759 (2005) 23

Coulomb break-up ^6He

B.V. Danilin et al., NUPA632 (1998) 383



Deviations for part (E^* = 3-6 MeV) of the spectrum:

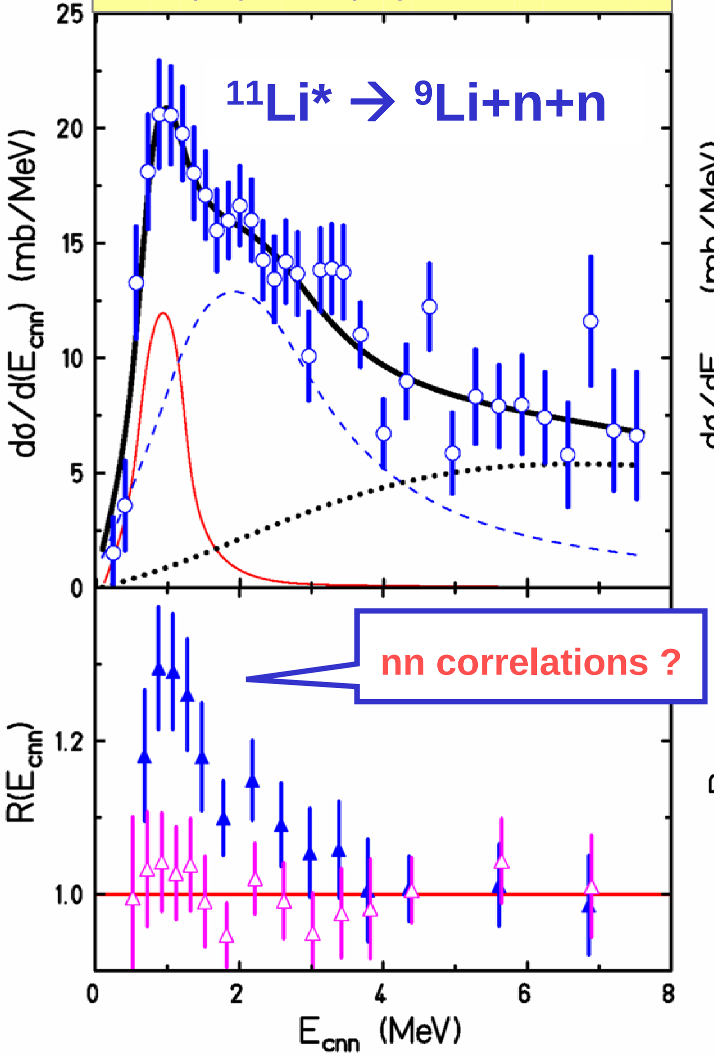
- ✔ qualitative agreement in predicted/observed states resp. quantum-numbers
- ✖ α-n (^{5}He) interaction too weak
- ✖ n-n (dineutron) interaction overestimated

L.V. Chulkov, H.S., I.Thompson, et al., NPA759 (2005) 23

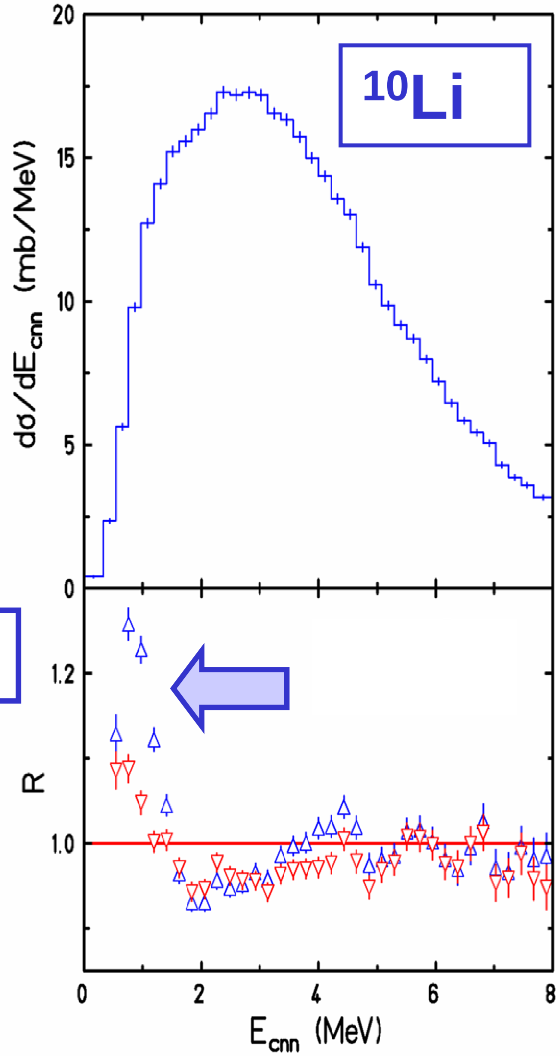
Sequential Decay : Inelastic scattering of $^{11}Li^*$

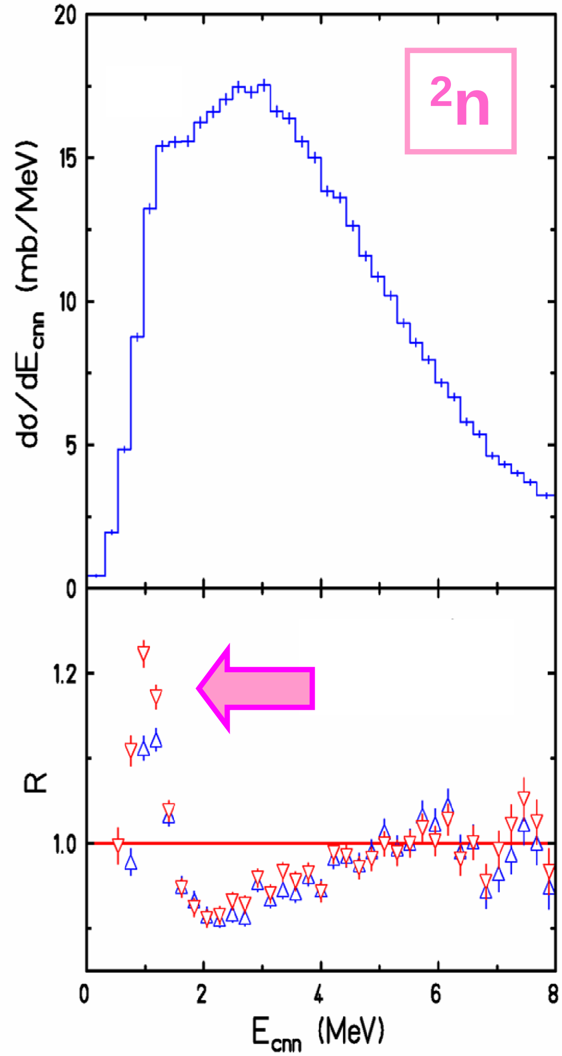
H.S. et al. ready for subm.

1.24(5); 0.26(24)	E*, Γ
2.45(27); 2.91(72)	in MeV



Model: E*=1.3MeV, decay via





summary

- ^{11}Li g.s. properties analysed via the 2 body final state
  - d-wave admixture in the order of 10% in cross section
  - spectroscopic factors extracted

$C^2S\ (1s_{1/2})_2 =\ \ 0.59 \pm 0.09\ \ [\pm 0.12]_{syst.}$

$C^2S\ (0p_{1/2})_2 =\ \ 1.38 \pm 0.21\ \ [\pm 0.54]_{syst.}$

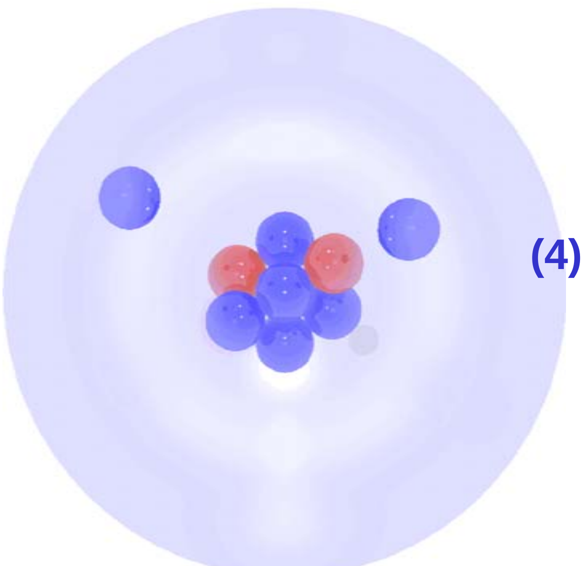
$C^2S\ (0d_{5/2})_2 =\ \ 0.49 \pm 0.14\ \ [\pm 0.34]_{syst.}$

- Low energy response for LAND analysed using experimental data

- Three body contiuum of ^{6}He and ^{11}Li analysed and compared to theoretical calculations

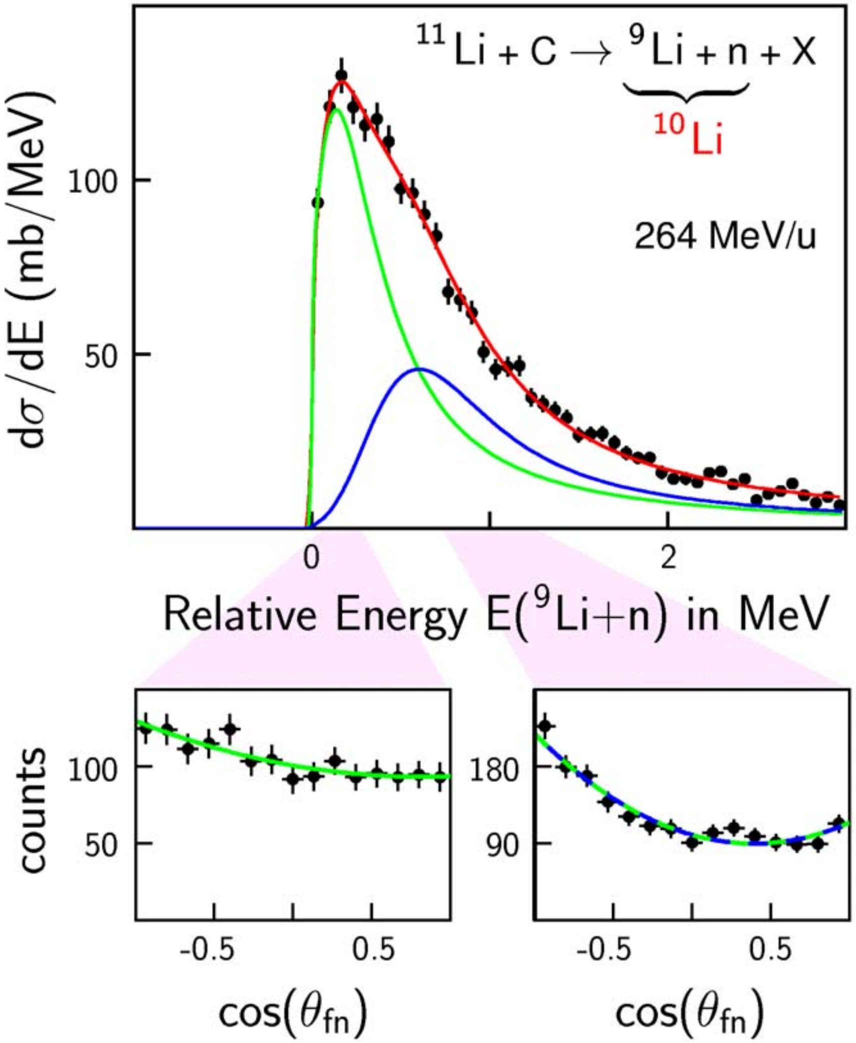
The S135/S245 collaboration

T. Aumann [1], Y. Aksyutina [1], M.J.G. Borge [2], L.V. Chulkov [3], Th. W. Elze [4], H. Emling [1], C. Forssén [5], H. Geissel [1], A. Grünschloß [4], M. Hellström [1], J. Holeczek [1], H. Johansson [1,5], B. Jonson [5], J.V. Kratz [6], R. Kulessa [7], Y. Leifels [1], M. Meister [5,8], K. Markenroth [5], G. Münzenberg [1], F. Nickel [1], T. Nilsson [5,8,9], G. Nyman [5], M. Pantea [8], M. Pfützner [1], V. Pribora [3], A. Richter [8], K. Riisager [10], C. Scheidenberger [1], G. Schrieder [8], H. Simon [1,8], J. Stroth [1,4], O. Tengblad [2], and M.V. Zhukov [5].



(1) GSI, Darmstadt, Germany
(2) Instito Estructura de la Materia, Madrid, Spain
(3) Kurchatov Institute, Moscow, Russia
(4) Johann-Wolfgang-Goethe-Universität, Frankfurt, Germany
(5) Chalmers Tekniska Högskola, Göteborg, Sweden
(6) Johannes-Gutenberg-Universität, Mainz, Germany
(7) Universytet Jagiellonski, Kraków, Poland
(8) Technische Universität, Darmstadt, Germany
(9) CERN, Genève, Switzerland
(10) Aarhus Universitet, Aarhus, Denmark

^{11}Li gs.: energy gated angular correlations



- ^{11}Li properties are reflected in the population of states in ^{10}Li* following the knockout reaction.
- Consistent picture in different observables.
- Continuum spectroscopy of an unbound system ^{10}Li*.

H.S. et al., NPA734 (2004) 323

energy gated angular momentum spectra