Exploring densities and neutron excitation of near drip-line nuclei via direct reactions on proton target

DREB2007 - RIKEN - 30 May-2nd June2007

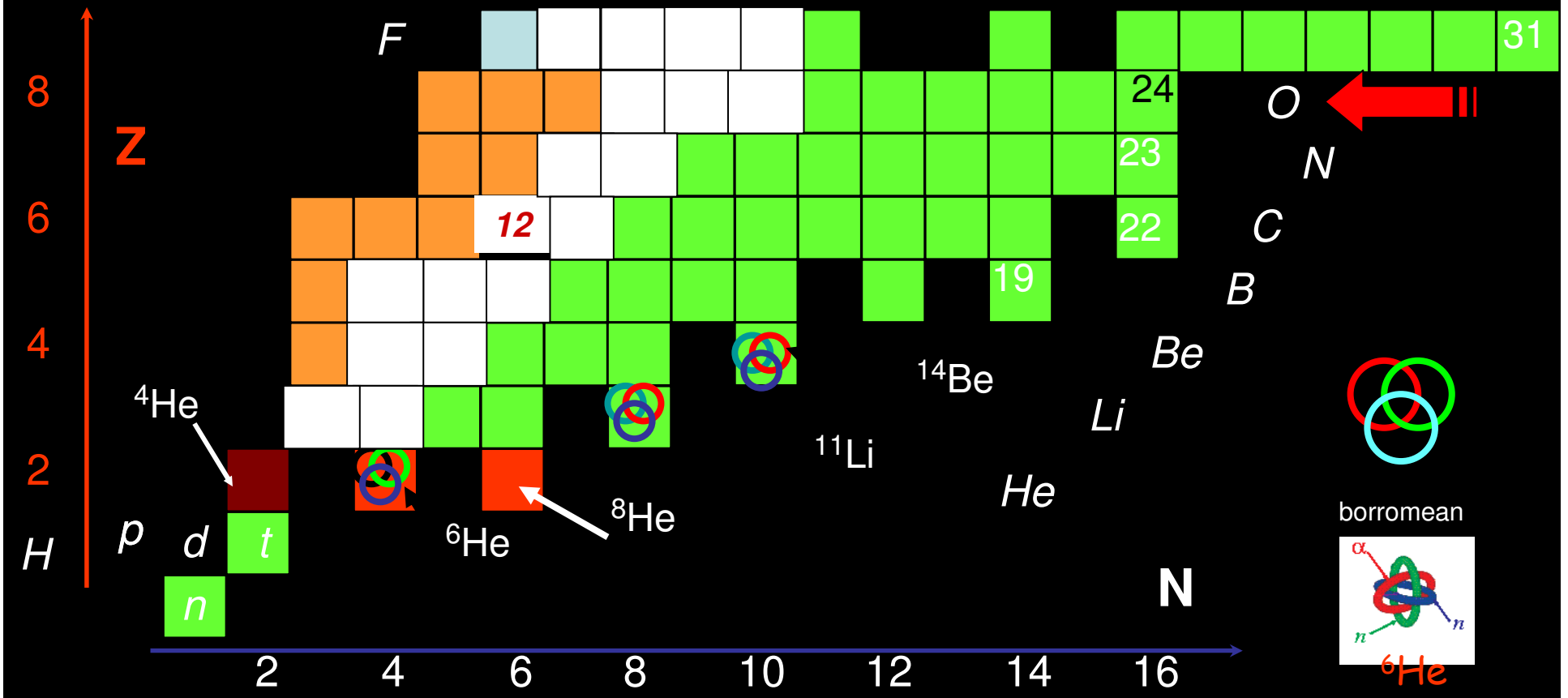
- Probe the structure & spectroscopy at large isospin
  (p,p') probe : Tools & detection devices — ρ_n , ρ_p
- Insight on the variation of the neutron excitation : ex $^{20,22}O$
- Measure unbound states $^{8}He(p,p')$
- INTERPRETATION
- PROSPECTIVES

What do we know ?
What do we need ?

vlapoux@cea.fr

2007 Nuclear landscape towards the drip-lines

Structure and correlations at large isospin ? ...$V_{NN}(T_z)$



Testing ground: weakly-bound nuclei

Weakly bound states ?
Continuum **coupling** ?
Isospin dependence ?

Evolution of shell structure far from the valley of stability

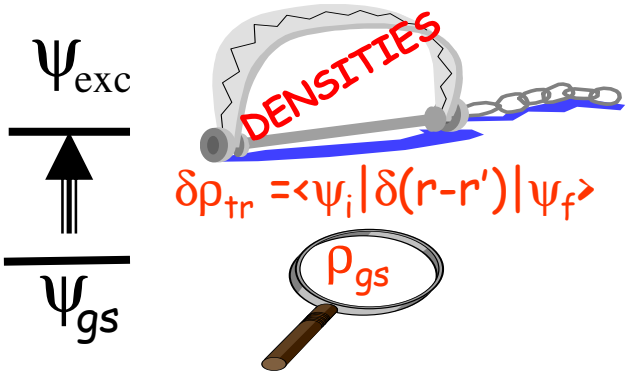
^{22}O

Neutron-skin structure

Drip-line : ^{8}He neutron-skin

Nuclear structure explored via elastic and inelastic scattering (p,p')

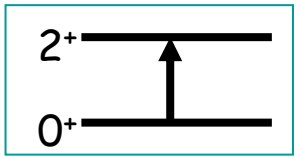
(p,p') probe : sensitive to densities, excitation of neutrons & protons



+ Angular cross sections (p,p') :
test of the validity of the densities
+ Missing mass method
Eexc of ^{A}Z
access to unbound states

Principles & basic ingredients

Analysis :
Fix parameter of proton excitation

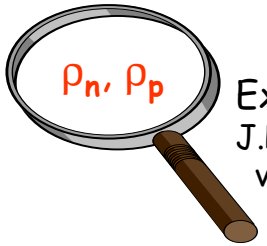


proton densities & excitation
from **EM probe**
Stable nuclei : (e,e') probe
RIB : no direct access to protons
but integrated value **B(E2)** from Coulex

Microscopic potential
nucleus- nucleon U(rho,E)

$M_n, M_p = \int \rho_{fi}^{p(n)}(r) r^{L+2} dr$

$B(E2;,i \quad f) = |M_p|^2/(2J_i+1)$

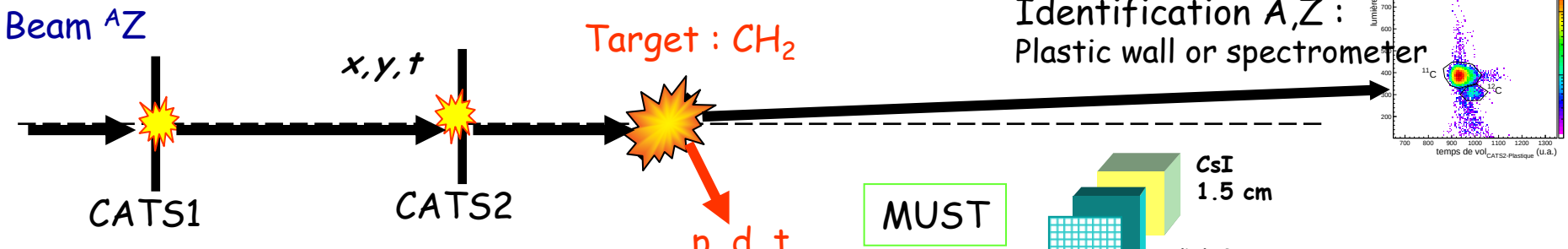


Ex : local **microscopic complex potential JLM,**
J.P. Jeukenne, A. Lejeune & C. Mahaux, PRC 16 ('77) 80
valid for Ep, En up to 160 MeV

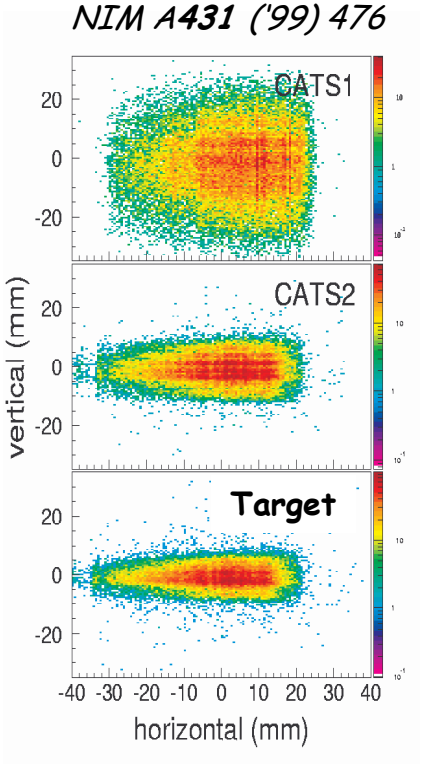
$$U(\rho,E) = \lambda_V V(\rho,E) + i \lambda_W W(\rho,E)$$

+ Good relationships with theorists providing you with radial densities

Experimental set-up for direct reactions on proton : ^{A}Z (p,p') (p,d) (p,t)



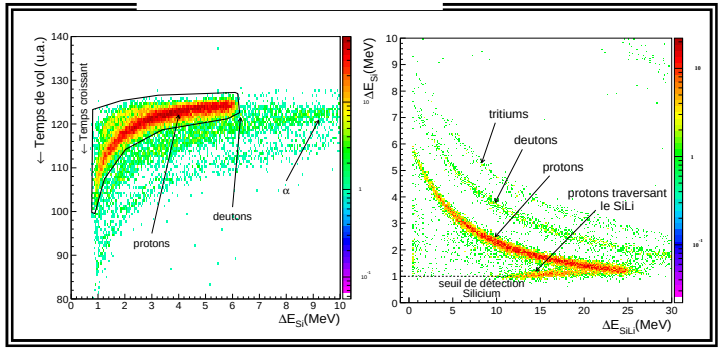
Beam tracking
DAPNIA/SEDI
NIM A431 ('99) 476



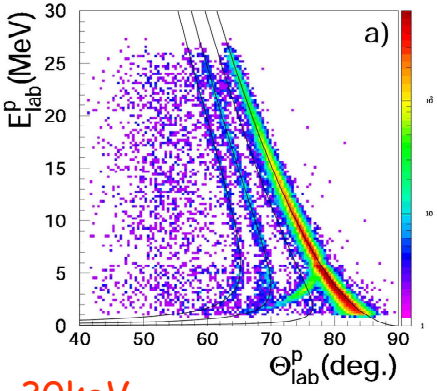
+

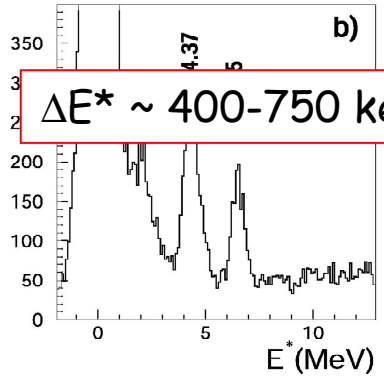
detection of light ions
Z & A PID ($^{1,2,3}H$ $^{3,4}He$)
NIM A421 ('99) 471

+ large E range
+ low threshold (~ 500 keV)
+ Resolution for position
Dx, Dy ~ 1 mm



$(Ep, \theta p)_{LAB} \rightarrow (E^*, \theta)_{CM}$



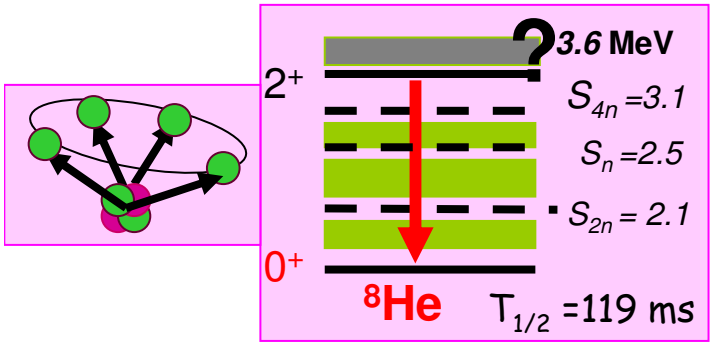


ΔE* ~ 400-750 keV

precision E* ~ 30keV

$^{10,11}C$(p,p') : PRC **72**, 014308 ('05)

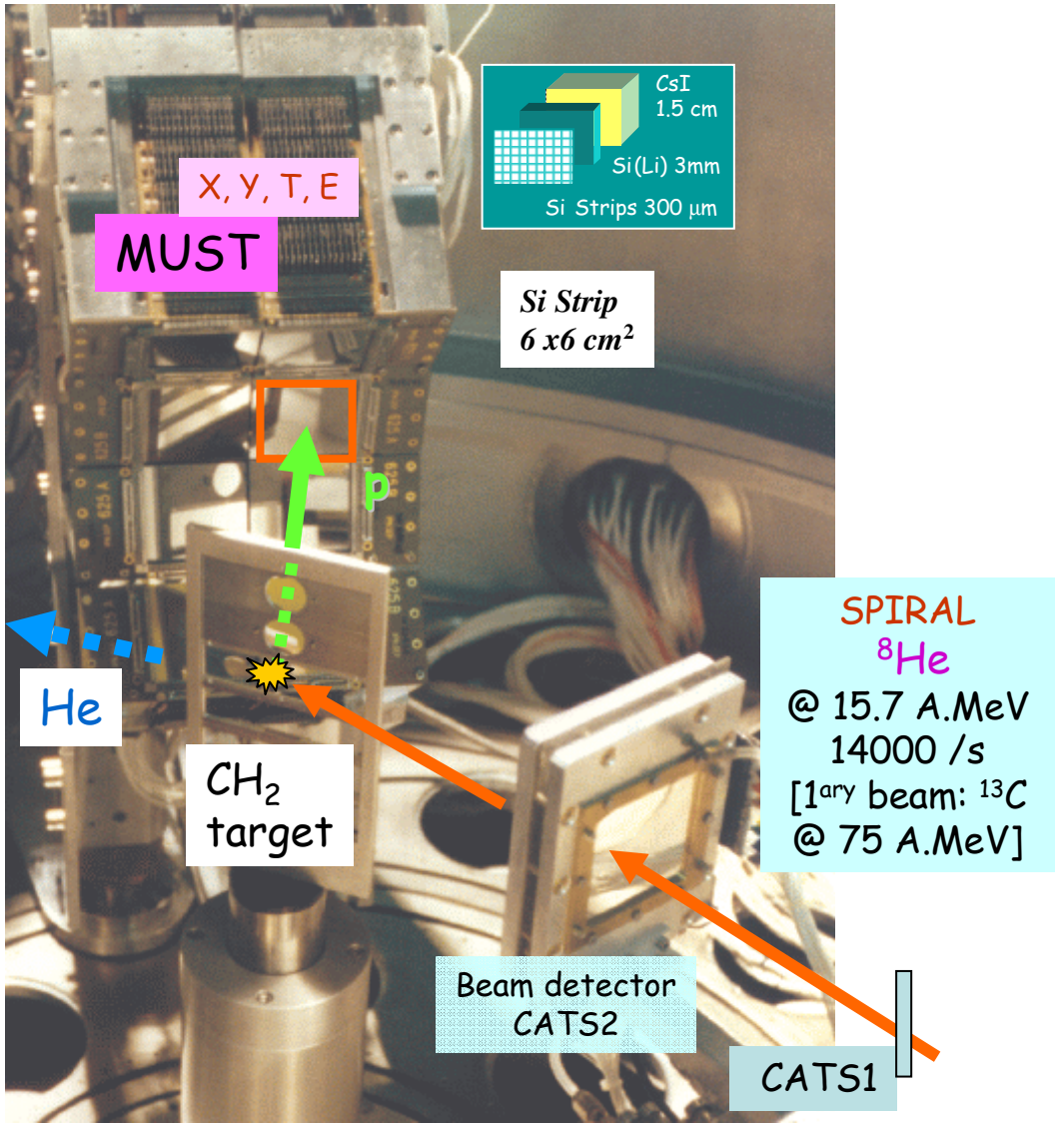
Direct reactions of ^{8}He+p : set-up at GANIL



PROBE : ^{8}He(p,p')^{8}He*

test of the validity of the densities
eg ^{6}He(p,p') @ 40.9 MeV/n GANIL-MUST
A. Lagoyannis et al., PLB **518**, 27 ('01)
Halo features ^{6}He NP***A722***, 49c('03)

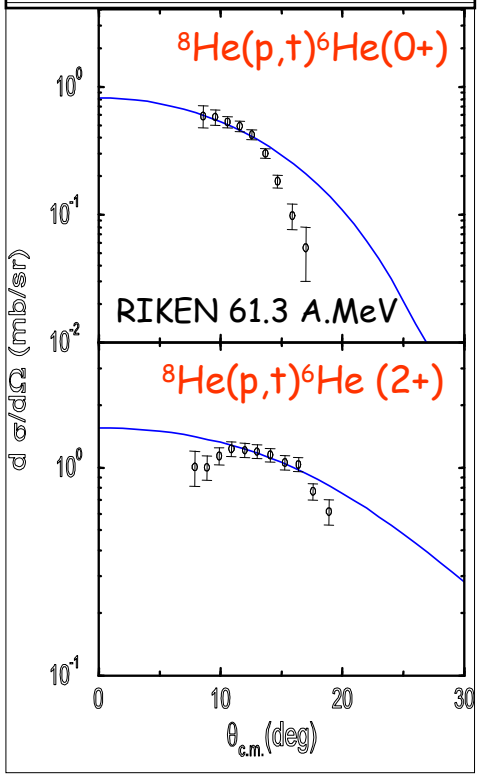
Collaboration : SPhN, GANIL, IPN-Orsay, FLNR-Dubna, Univ. Ioannina (Greece)



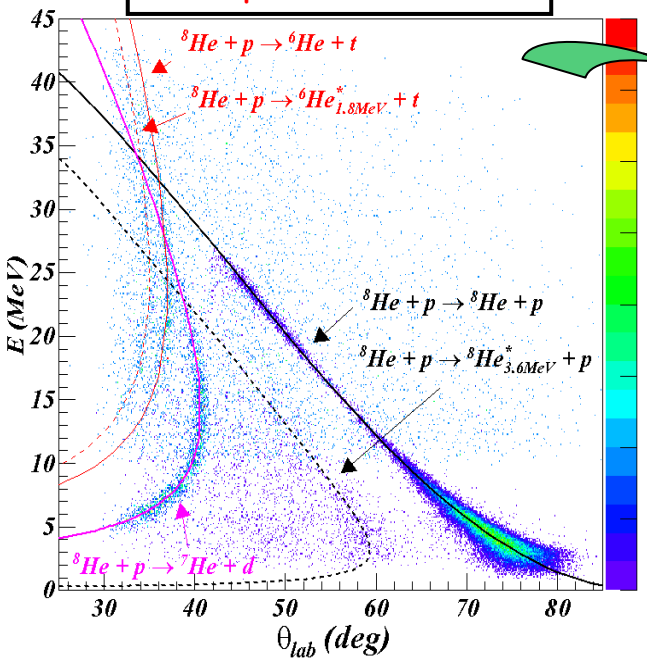
SPIRAL
^{8}He
@ 15.7 A.MeV
14000 /s
[1^{ary} beam: ^{13}C
@ 75 A.MeV]

Structure of ^{8}He extracted from direct reactions on proton target

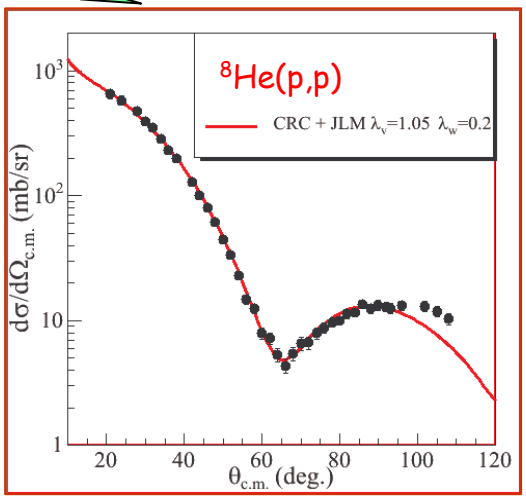
Data: A. A.Korsheninnikov et al, PRL **90**, 082501 ('03)

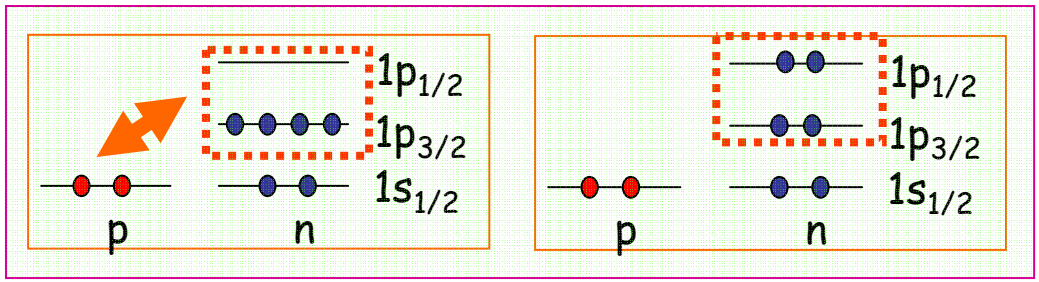


^{8}He +p @ 15.7 A.MeV



F. Skaza, N. Keeley, VL *et al.*, PLB **619**. 82 ('05)
+ PLB **646**, 222('07)

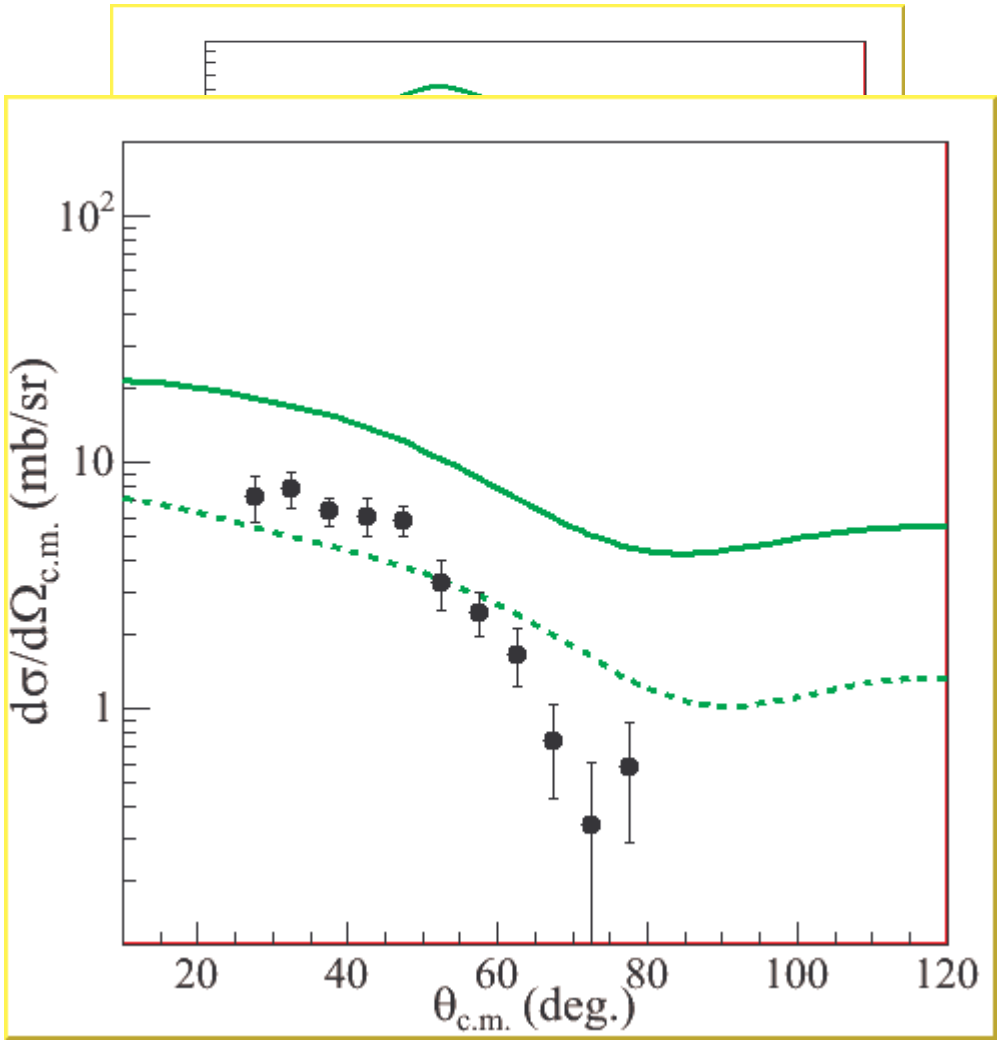


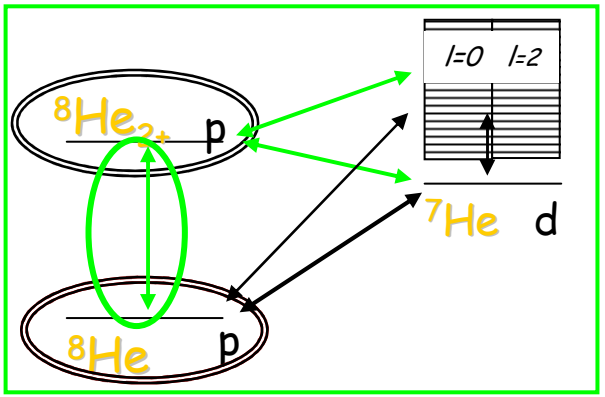


^{8}He(p,d)^{7}He C^2S = 4.4 ± 1.3
Mixing : $(p3/2)^4$ + $(p3/2)^2$ $(p1/2)^2$

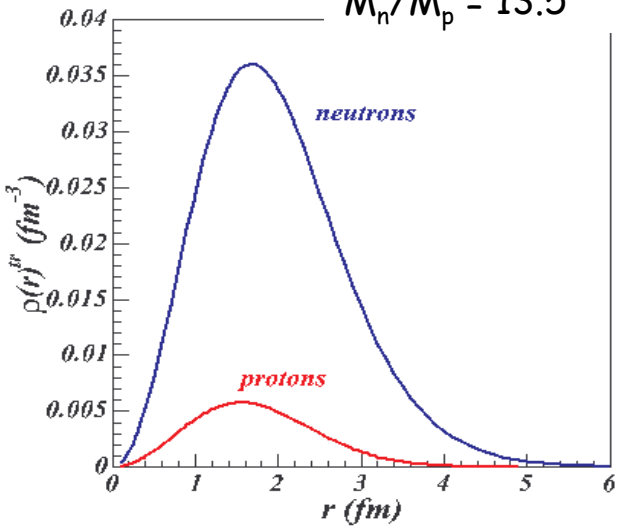
Consistent with results from quasi-free scattering of ^{8}He measured at GSI, LV Chulkov et al, NP***A759***, 43('05)

Inelastic scattering ^{8}He(p,p ') within optical model & CRC



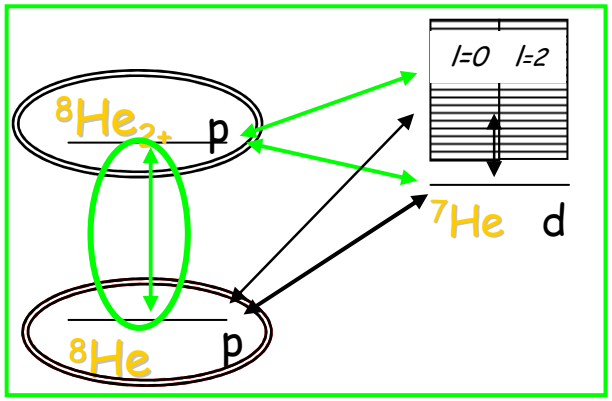


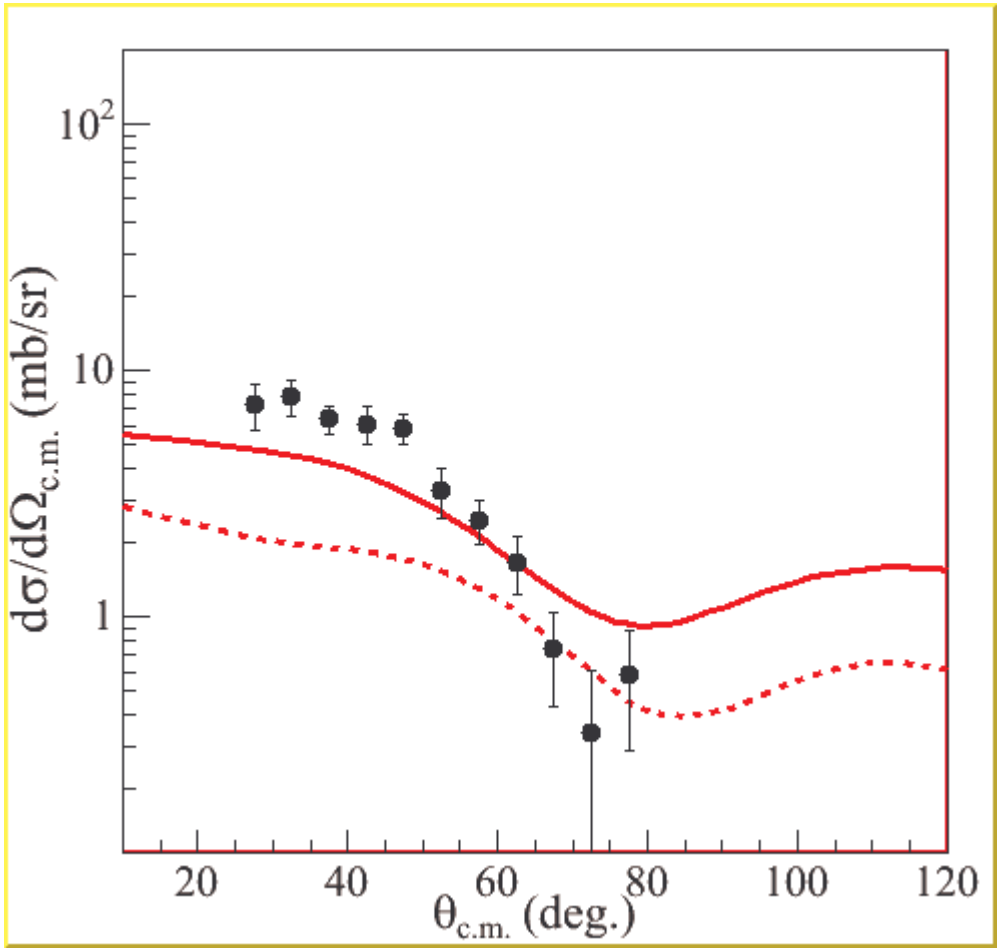
B(E2) = 0.25e^{2}fm^4
M_n/M_p = 13.5

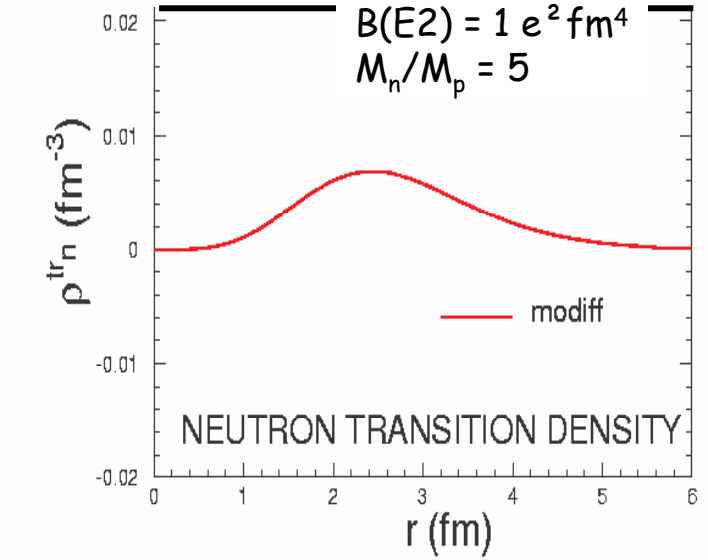


Navratil's densities
V3eff, 4hw, priv. co

Analysis of inelastic ^{8}He(p,p ') within optical model & CRC





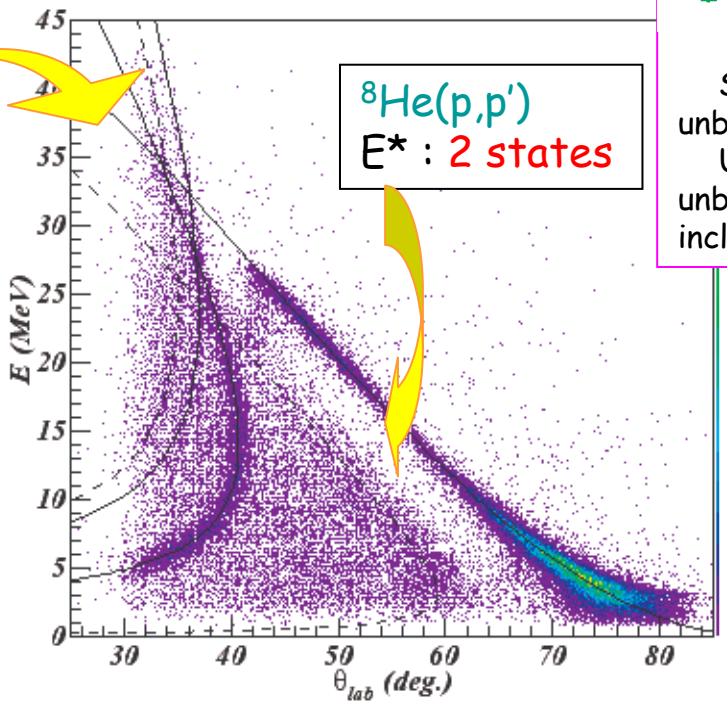


Modified transition densities

V. L *et al., in preparation*

Conclusions: structure and spectroscopy of ^{8}He (p,p') (p,d) (p,t) @ 15.7 A.MeV

SPIRAL



^{8}He(p,p')
E* : 2 states

^{8}He(p,p')
a new resonance

Structure models overestimate Eexc for unbound excited states
Understanding of the weakly bound & unbound states requires calculations including the continuum coupling

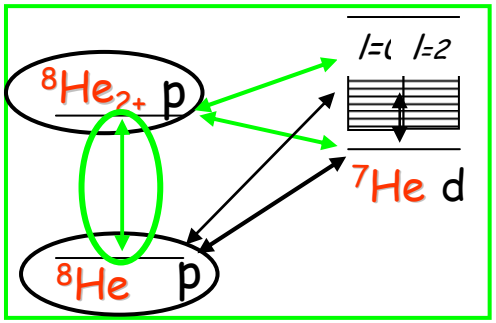
^{8}He(p,d)^{7}He
transfert 1n
Resonant states of ^{7}He
Indication of a possible 1/2^{-} resonance at low energy
PRC**73**, 044301('06)

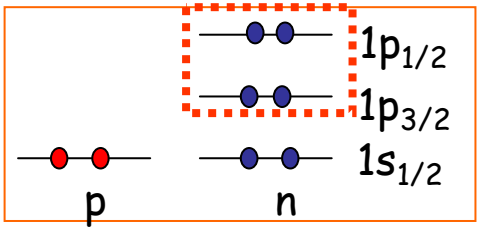
	E(MeV)	Γ (MeV)
2+	3.62 ± 0.14	0.3 (2)
?	5.4 ± 0.5	0.5 (3)

NP ***A788***, 260 (2007)

Coupling to the (p,d) channel to understand the (p,p)
PLB **619**, 82('05)

^{8}He(p,d)^{7}He C^2S = 4.4 ± 1.3
mixing : $(p3/2)^4 + (p3/2)^2 (p1/2)^2$

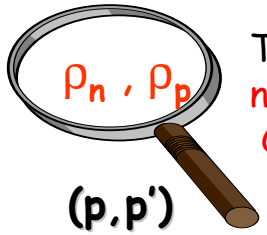




PLB **646**, 222('07)

All direct reactions at the same energy : a need for a complete coupled-channel analysis

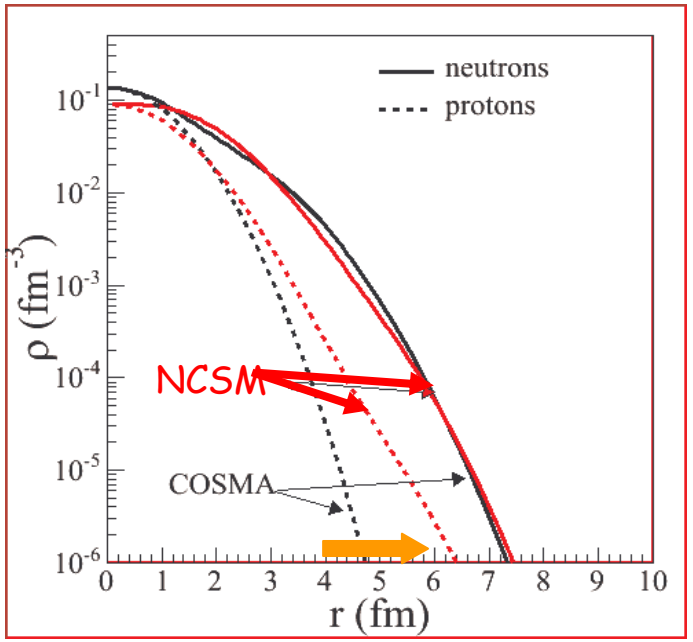
conclusions ... prospectives



Test of the validity of ^{8}He gs densities using (p,p) :
neutron-skin features close to NCSM densities
COSMA not valid

^{8}He	Rms (fm)		
	Proton	Neutron	Matter
COSMA 5-body	1.69	2.74	2.52
HF+corr Sagawa	1.95	2.67	2.51
NCSM, Navrátil	2.00	2.59	2.46

NCSM (No Core Shell Model)
(*V3eff 4hw, 13MeV*)



(p,p') mainly sensitive to the neutron excitation ;
Transition densities 2+ 0+ : NCSM calc. overestimate the p & n excitations

Test of transition densities ; Analysis in progress → **CRC (p,p')** *Coupling with the (p,t)*

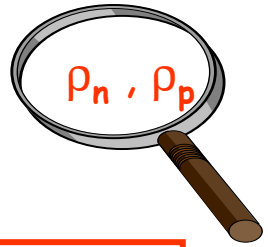
dapnia
cea
saclay

prospectives

GOALS

Drip-lines : limit of nuclear binding, large isospin
Exploration : new structures of exotic nuclei
Tests : nuclear modelling & interactions $V_{NN}(T_z)$

Extension of the systematics of neutron excitation along isotopic chains



local shell change : like N=16 (34, 70..) indicated by Ex(2+), B(E2) S_{2n}, and evolution of neutron excitation

>>> New improved tools
for direct reactions in inverse kinematics
and missing mass method

Projects @ SPIRAL 1, 2
@ RIBF

dapnia

saclay

Theoretical framework for direct nuclear reactions analysis

analysis of ^{8}He(p,p') & (p,d) : reaction framework, PLB **619**, 82('05)

Usual framework : DWBA, not valid

How good (potential, framework) are really good for exotic beams ?
To be checked by measuring carefully the elastic scattering ,
TESTING GROUND FOR THE INTERACTION POTENTIAL AND THE REACTION MODEL

COUPLED-REACTION CHANNEL MEASUREMENT & ANALYSIS

effects enhanced in the case of exotic weakly-bound nuclei :
coupling to the continuum, three-body correlations, shell structure embedded in the continuum

Use predictions of improved nuclear structure models
newly developed theories with appropriate isospin-dependence in the nuclear interaction

The best we can do:

- MICROSCOPIC COMPLEX POTENTIALS
  To test the validity of the nuclear densities
- COUPLED REACTION CHANNEL FRAMEWORK
  To include coupling to excitations and reaction channels

Participants of the experiment ^{8}He(p,p')

SPIRAL EA05S

CEA-SACLAY DSM/DAPNIA/SPhN :
N. Alamanos, F. Auger, A. Drouart, A. Gillibert, V. Lapoux,
L. Nalpas, E. Pollacco, R. Raabe, J-L. Sida, F. SKAZA (PhD).
IPN-Orsay : D. Beaumel, Y. Blumenfeld, F. Delaunay, E. Becheva, J-A. Scarpaci
Ganil : L. Giot, P. Roussel-Chomaz
FLNR - Dubna S. Stepantsov, R. Wolski University of Ioannina A. Pakou

ANALYSIS :

INTERPRETATION

Microscopic densities P. Navrátil + interaction Argonne
H. Sagawa HF +correlations
Futur : cf M . Ploszajczak Ganil
JLM potential: code Dietrich (Livermore) ; form factors (*home made, VL)*
+ CRC calc. N. KEELEY
With the Fresco code (IJ Thompson, Surrey Univ).

CEA DAPNIA, GANIL, IPN-Orsay

COLLABORATION MUST2

- DAPNIA SEDI E. Atkin, P. Baron, F. Druillole, F. Lugiez, B. Paul, M. Rouger ;
- SPhN : A. Drouart, A. Gillibert, V. Lapoux, L. Nalpas, E. Pollacco
- IPN-Orsay SED: P. Edelbruck, L Lavergne, L. Leterrier, A. Richard, M. Vilmay, E. Wanlin,
- Structure Y. Blumenfeld, D. Beaumel, E. Becheva
- GANIL GIP M. Boujrad, L. Olivier, B. Raine, F. Saillant M. Tripon, *Physics* P. Roussel Chomaz