Dynamical limits of nucleon knockout at intermediate energy.

F. Flavigny[1,2]

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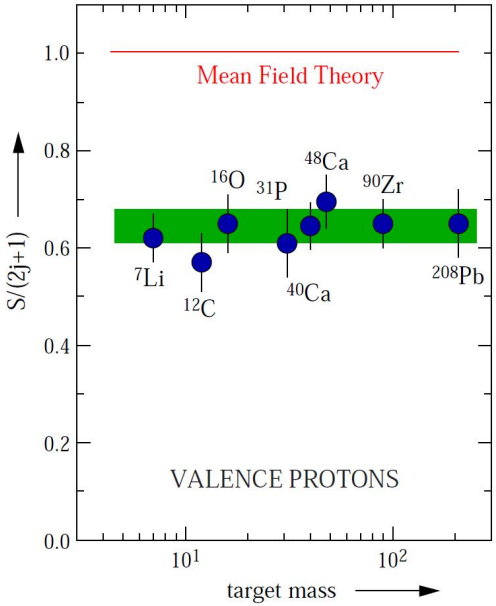
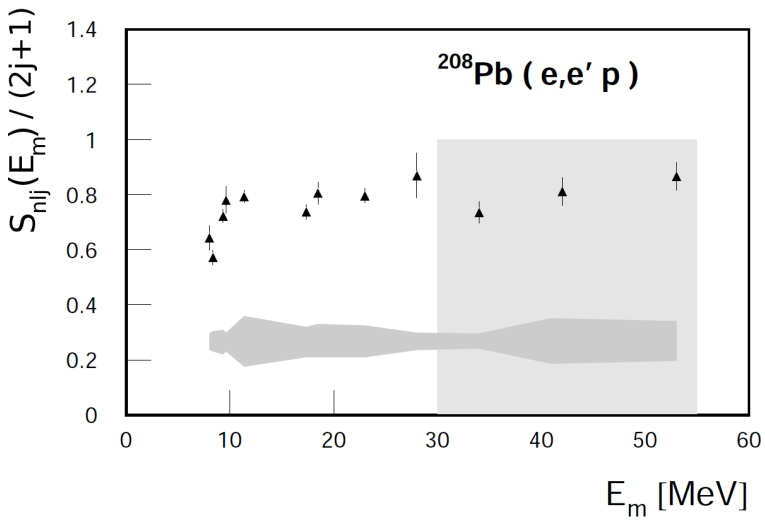
[2]Instituut voor Kernen Stralingsfysica, K. U. Leuven, Belgium.

DREB conference, 25-29th March 2012, Pisa

Shell occupancies in stable nuclei





(e,e'p) reactions

- electromagnetic probe
- 30-40% reduction
- Beyond mean-field correlations

W. Dickhoff, Prog. Nucl. Phys. **52**, 377 (2004).

L. Lapikas, Nucl. Phys. A. **553**, 297-308 (1993).

No binding energy dependance

- Deeply bound orbitals, $0.78 \pm 0.02 \pm 0.08$.

M. F. Van Batenburg, PhD thesis, University of Utrecht (2001).

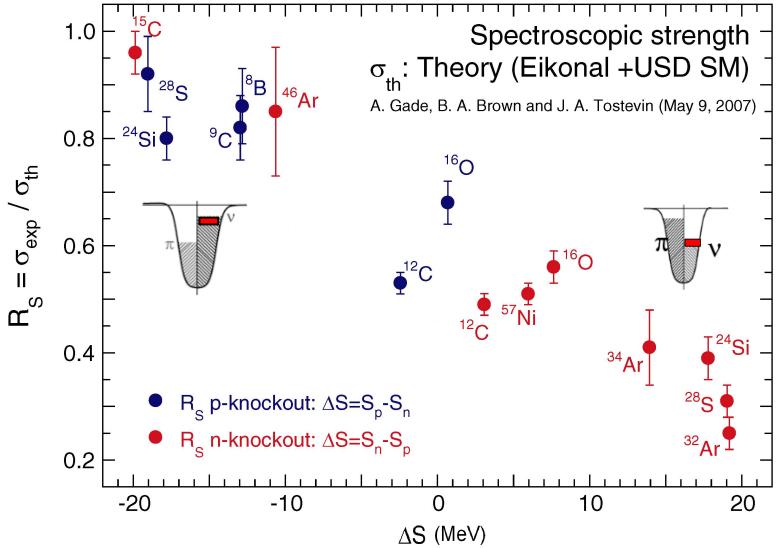
Agreement between (d,^{3}He) and (e,e'p)

G. J. Kramer *et al.*, NPA **679** (2001) 267.

Reminder : Shell occupancies are not observables / SF are model dependent (R. J. Furnstahl, H. W. Hammer, PLB **531** 203 (2002)).

Deeply-bound nucleon knockout from exotic nuclei

A. Gade *et al*, PRL. **93** 042501 (2004) ; PRC **77**, 044306 (2008).



Intermediate energy knockout

Disagreement between theory and experiment :

Possible sources :

- ⇒ The calculated shell occupancies C^2S.
- ⇒ The single particle cross section σ_{sp}.

$$\sigma_{th} \propto C^2 S_{th} \cdot \sigma_{th}^{sp}$$

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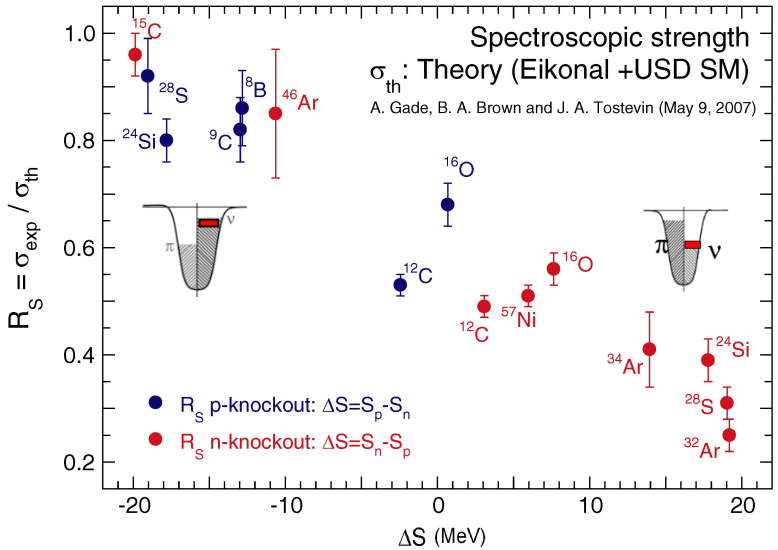

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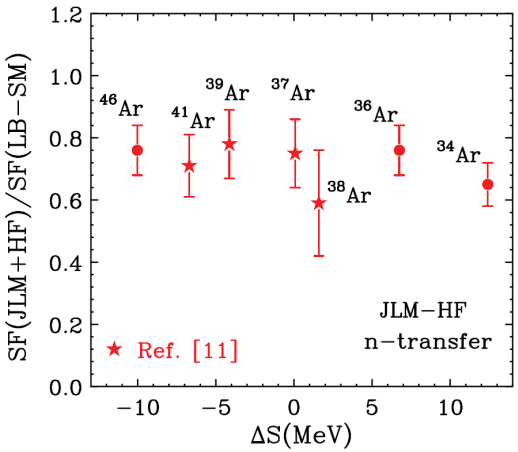
J. Lee *et al*, PRC **83**, 014606 (2011).



Low energy transfer (d,p)

- ⇒ Constant reduction $\simeq$ 30%
- ⇒ Limited ΔS range up to $\simeq$ 12 MeV

Outline

Question

What are the limits of standard eikonal+sudden approaches ?

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Experimental investigation

- One-nucleon knockout from ^{16}C and ^{14}O, NSCL

  F. Flavigny, A. Obertelli et al., in preparation (2012)

- One-nucleon transfer from ^{14}O at SPIRAL, GANIL

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Interpretation

- Beyond the "sudden approximation" dynamics.
- Core-target excitations in deeply-bound nucleon removal

  C. Louchart, A. Obertelli, A. Boudard, and F. Flavigny, PRC **83** 011601 (2011)

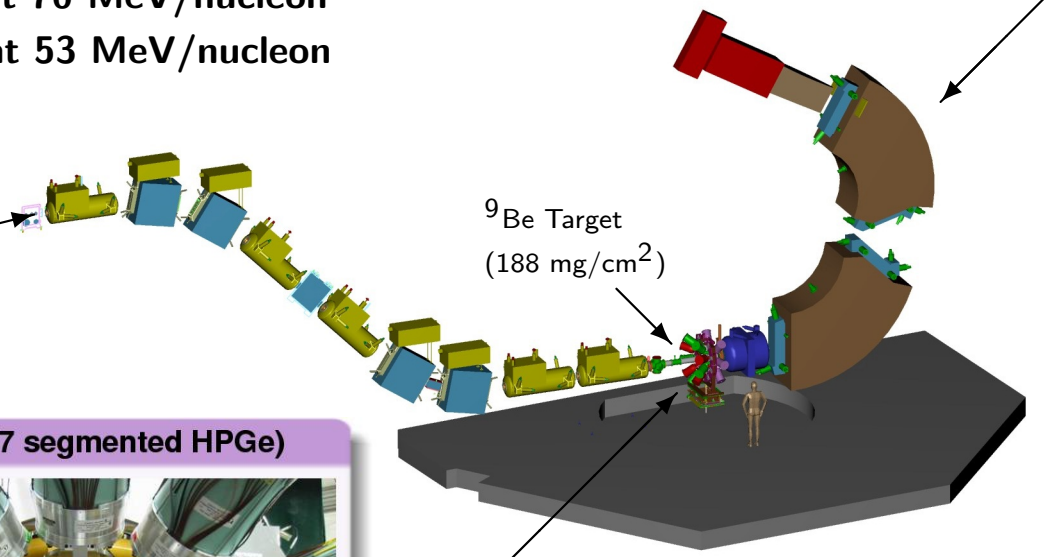
Experimental setup

Primary beam : ^{18}O (120 MeV/nucleon)

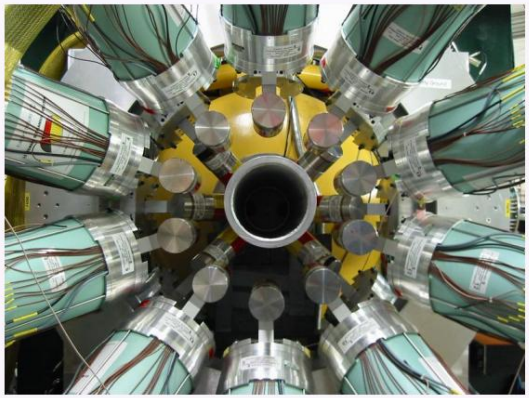
Secondary beams :

^{16}C beam at 70 MeV/nucleon
^{14}O beam at 53 MeV/nucleon

Cocktail beam from A1900
$\langle I \rangle \simeq 5.10^5$ pps



SeGA (17 segmented HPGe)

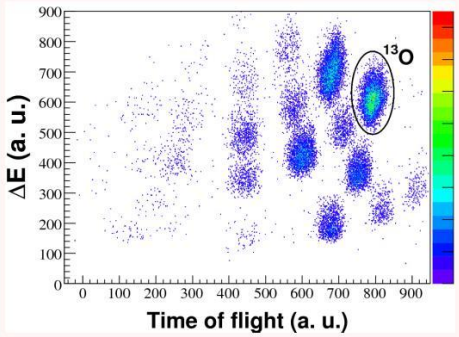


W. F. Mueller et al, NIM A 466, 492 (2001)

S800 magnetic spectrometer

Focal Plane Detectors :

2 Drift Chambers
(Angle, Position)
↓
Ionization Chamber
(Energy Loss)
↓
Scintillators
(TOF, Energy)

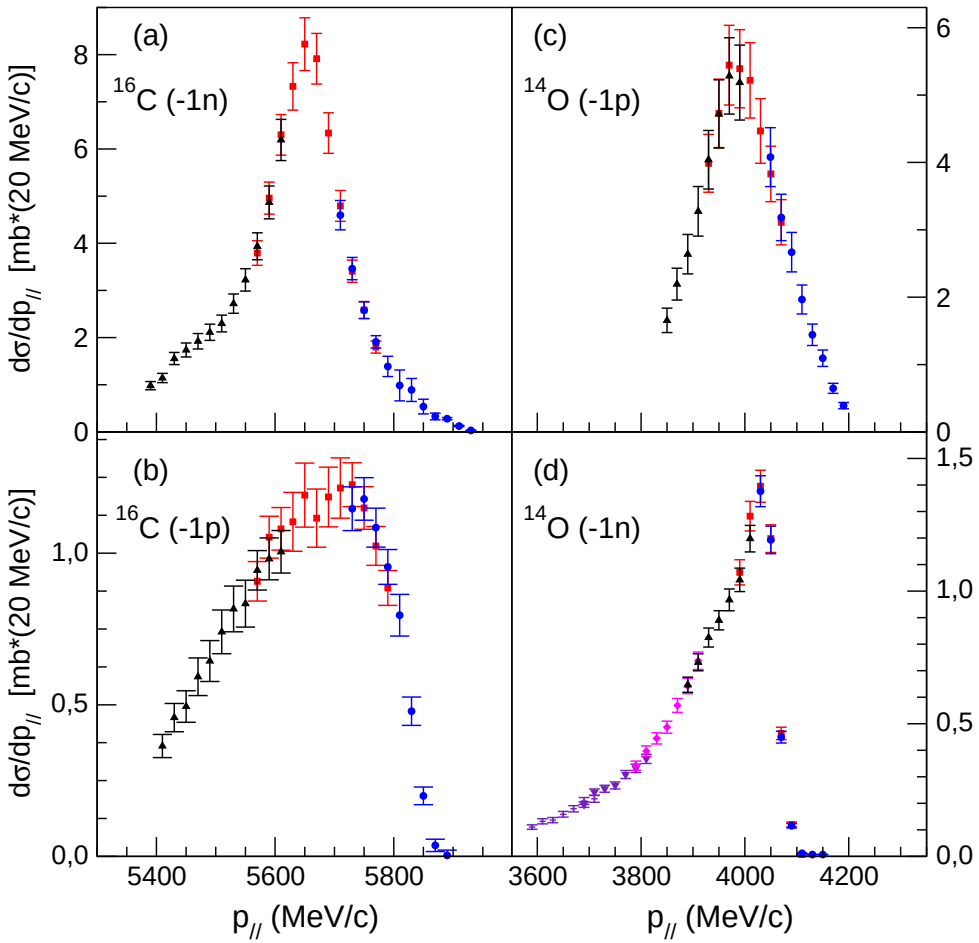


J. Yurkon *et al.*, NIM A **422**, 291 (1999)
D. Bazin *et al.*, NIM B **204**, 629 (2003)

$$\begin{pmatrix} x_f \\ \theta_f \\ y_f \\ \phi_f \end{pmatrix} = \mathrm{T} \begin{pmatrix} \theta_{ta} \\ y_{ta} \\ \phi_{ta} \\ d_{ta} \end{pmatrix}$$

Inclusive parallel momentum distributions and cross sections

Loosely-bound nucleon



Deeply-bound nucleon

E = 75 MeV/u E = 53 MeV/u

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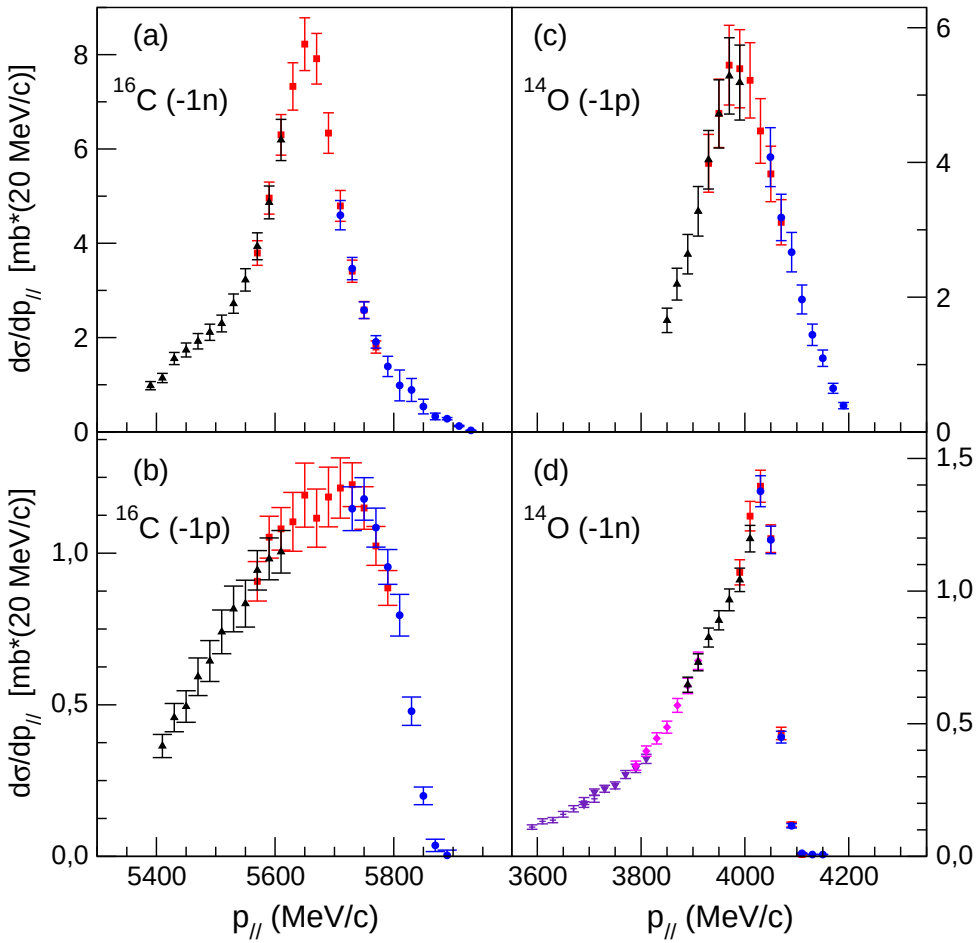
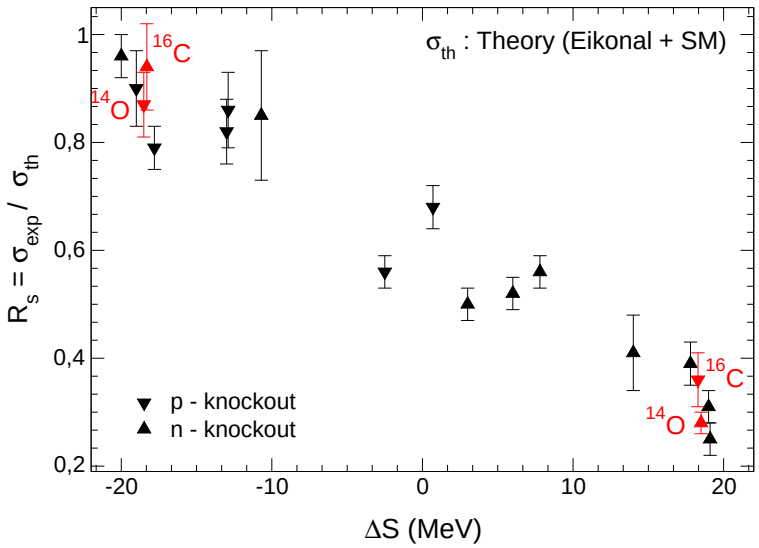


Deeply-bound nucleon

E = 75 MeV/u E = 53 MeV/u

$\sigma(^{16}\text{C -1n}) = 80(7)^*$ mb

$\sigma(^{14}\text{O -1p}) = 64(6)$ mb



$\sigma(^{16}\text{C -1p}) = 15(1)$ mb

$\sigma(^{14}\text{O -1n}) = 14(1)$ mb

$^*\sigma(^{16}\text{C -1n}) = 77(9)$ mb at 62 MeV/u

V. Maddalena *et al.*, PRC 63 (2001) 024613

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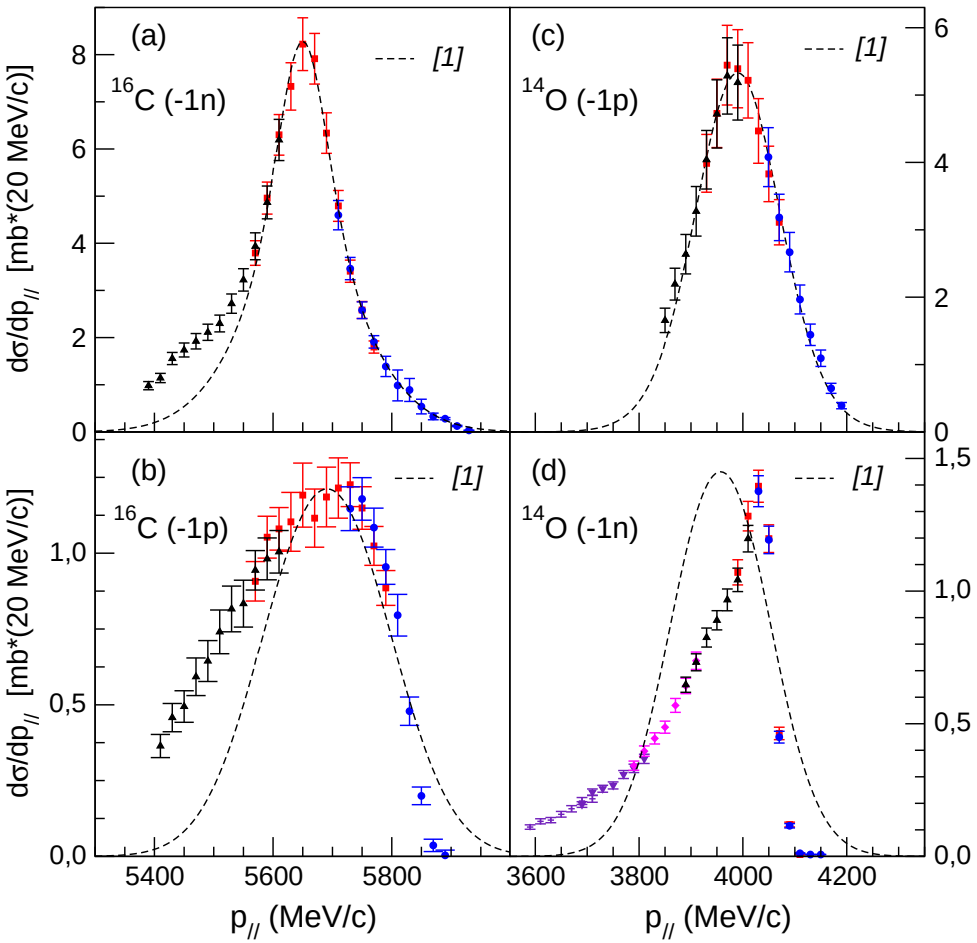

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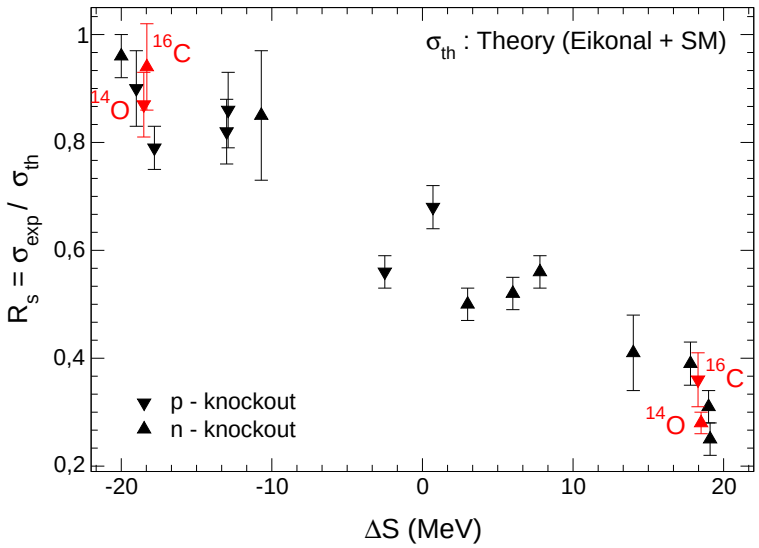

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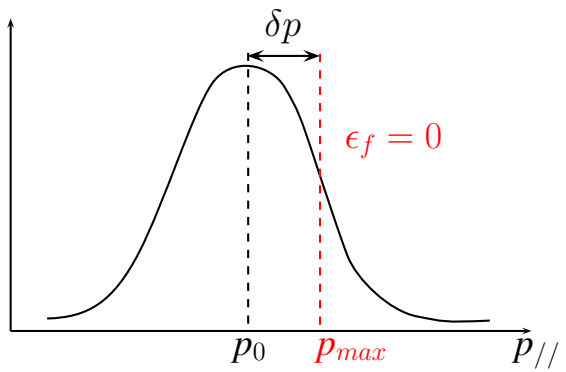
High-momentum cutoff

Parallel momentum of the residue ^{A-1}X



$$P_{//} = \sqrt{(T_p - S_n - \varepsilon_f)^2 + 2M_r(T_p - S_n - \varepsilon_f)}$$

T_p : initial kinetic energy of the projectile (beam)
S_n : separation energy of the removed nucleon
ϵ_f : final energy of the nucleon with respect to the target

→ Momentum threshold p_{max} for $\epsilon_f = 0$

A. Bonnacorso, PRC **60**, 054604 (1999)

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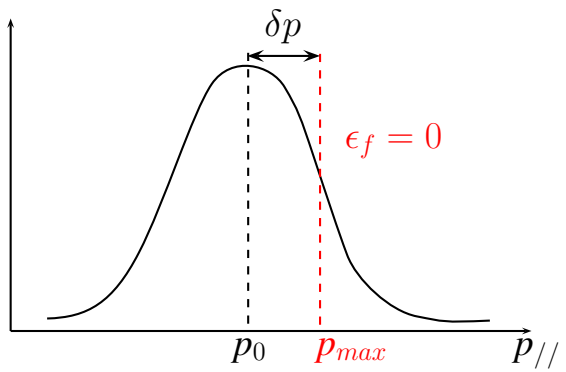

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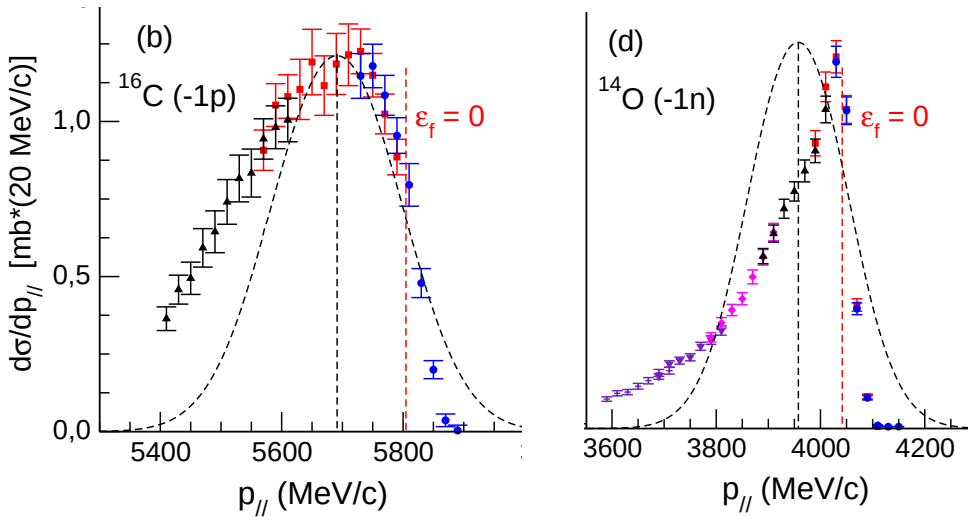
Comparison to experimental data

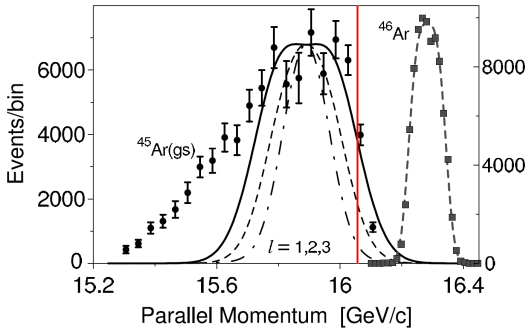
T_p = 75 MeV/u
S_n = 22.6 MeV
p_{max} = 5804 MeV/c



T_p = 53 MeV/u
S_n = 23.2 MeV
p_{max} = 4042 MeV/c

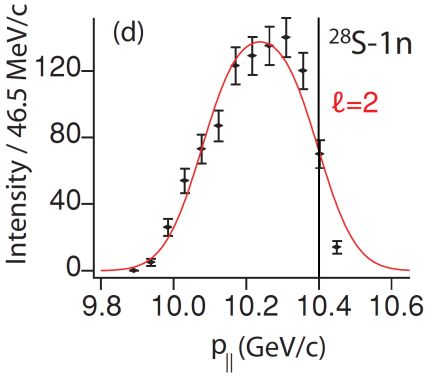
High momentum cutoff : existing data

$E(^{46}Ar) = 70$ MeV/u

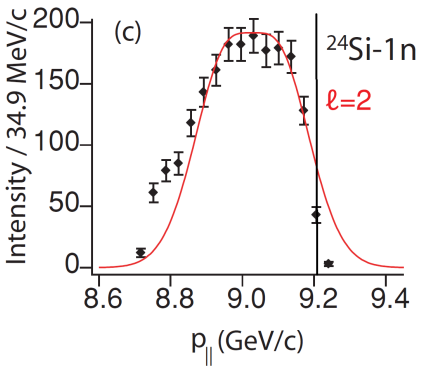


A. Gade *et al.* PRC **71** (2005) 051301.

$E(^{28}S) = 81$ MeV/u

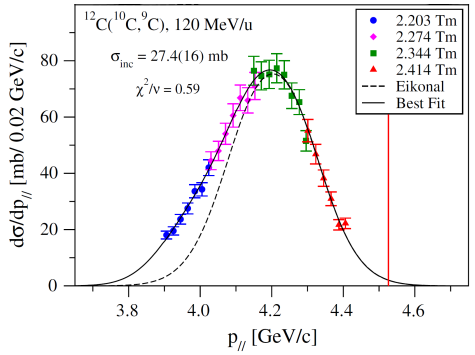


$E(^{24}Si) = 85$ MeV/u



A. Gade *et al.* PRC **77** (2008) 044306.

$E(^{10}C) = 120$ MeV/u

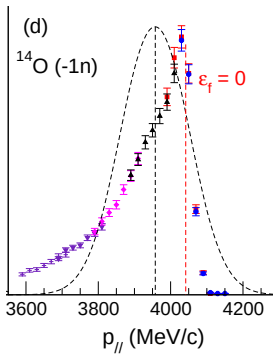


G. Grinyer *et al.* PRL **106** (2011) 162502.

"Barely visible" effect in published data

High momentum cutoff : existing data

$E(^{14}O) = 53$ MeV/u



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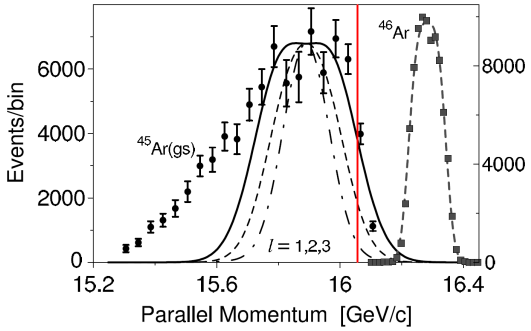
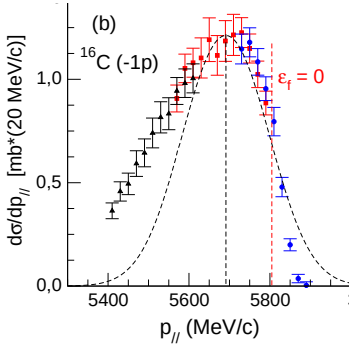


A. Gade *et al.* PRC **71** (2005) 051301.

$E(^{16}C) = 75$ MeV/u



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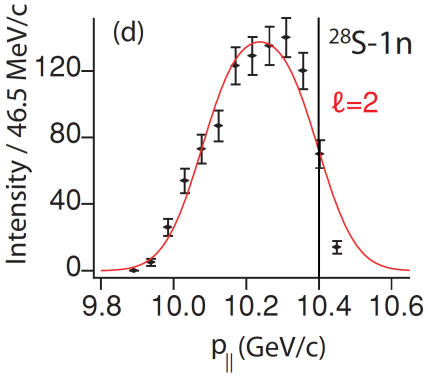

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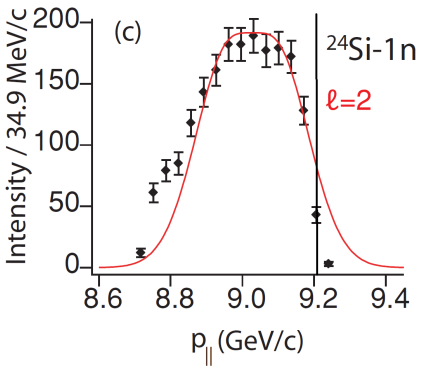

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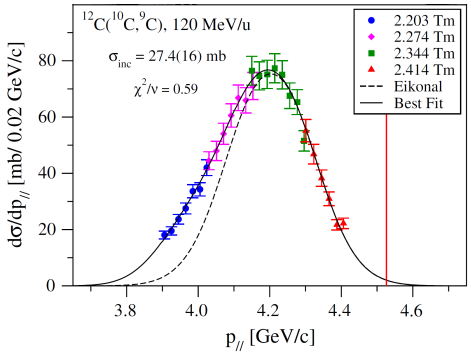

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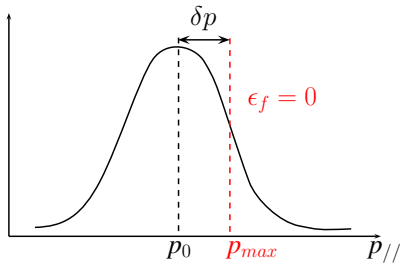
"Barely visible" effect in published data

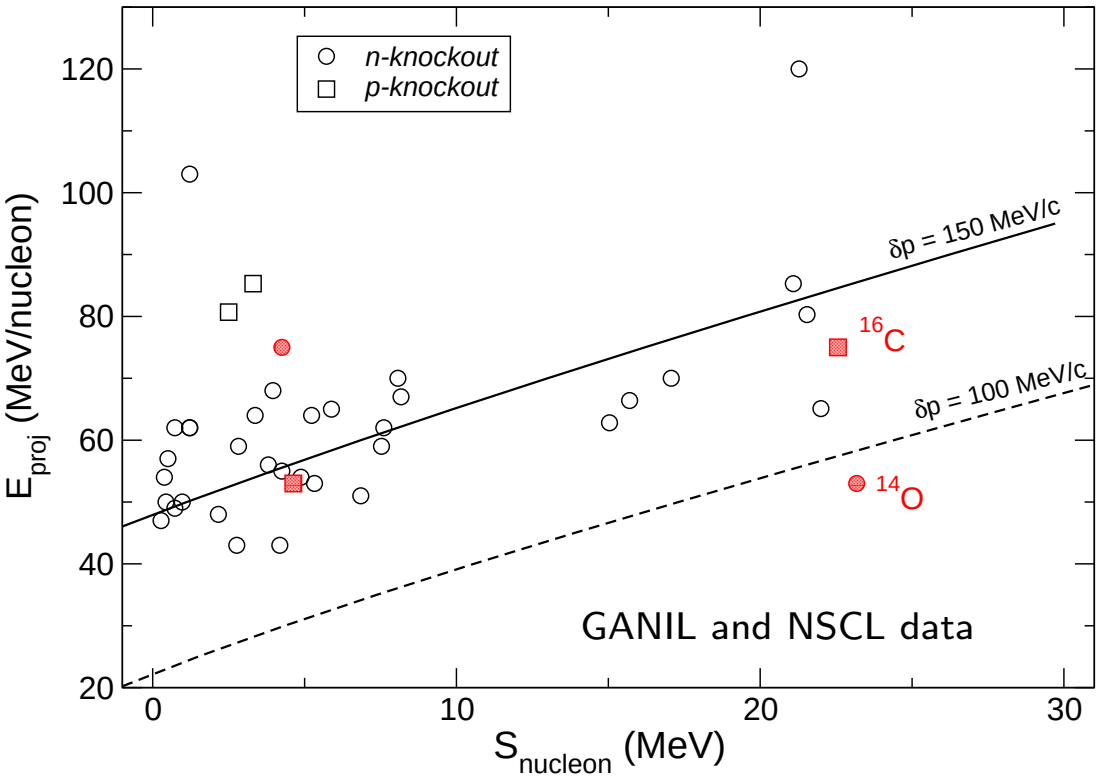
Dynamical limit for nucleon knockout

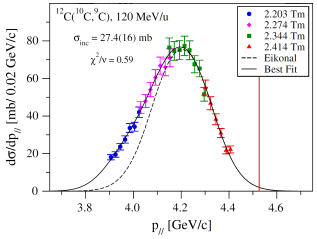


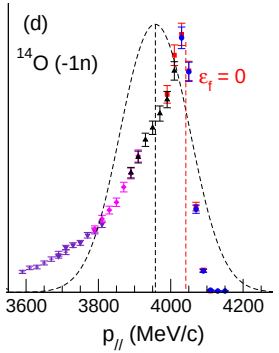
$$P_{//} = \sqrt{(T_p - S_n - \varepsilon_f)^2 + 2M_r(T_p - S_n - \varepsilon_f)}$$

$$p_{max} = P_{//}(\epsilon_f = 0)$$

$$\delta p\,(E_p, S_n) = p_{max} - p_0$$







F. Flavigny *et al.*, in preparation (2012)

Transfer to the continuum model

Intrinsic momentum of the removed neutron + Energy dependent (n+^{9}Be) potential

Properties

- Transfer from initial neutron bound state to continuum neutron-target state.
- Generalization of a semi-classical method.
- Contain energy and momentum conservation

Inputs

- Neutron bound-state wf (HF constraint)
- Core-target S-matrix (same as model 1)
- n+^{9}Be pot. (fitted on cross section data)

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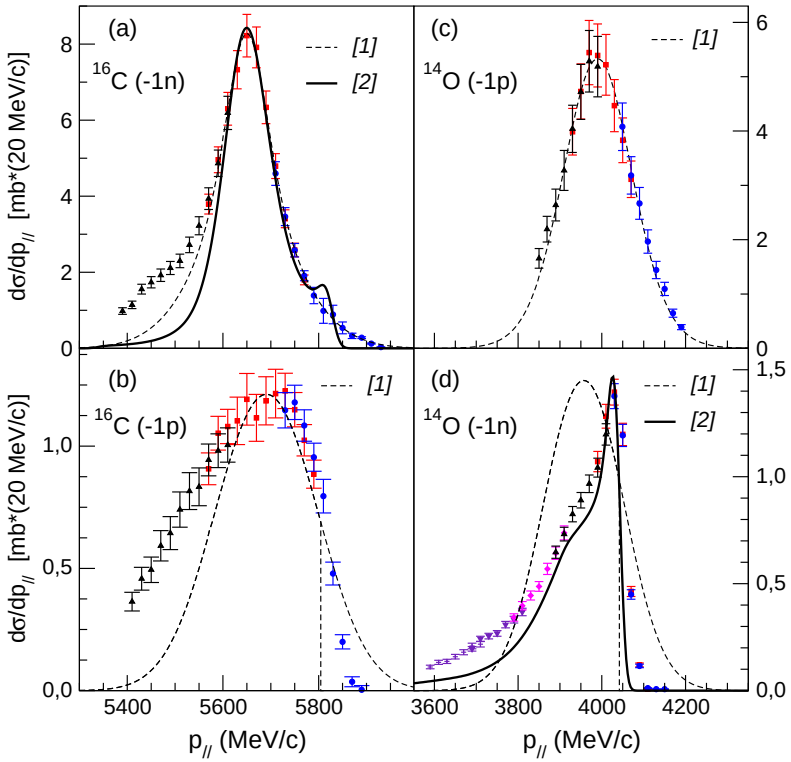
Limits

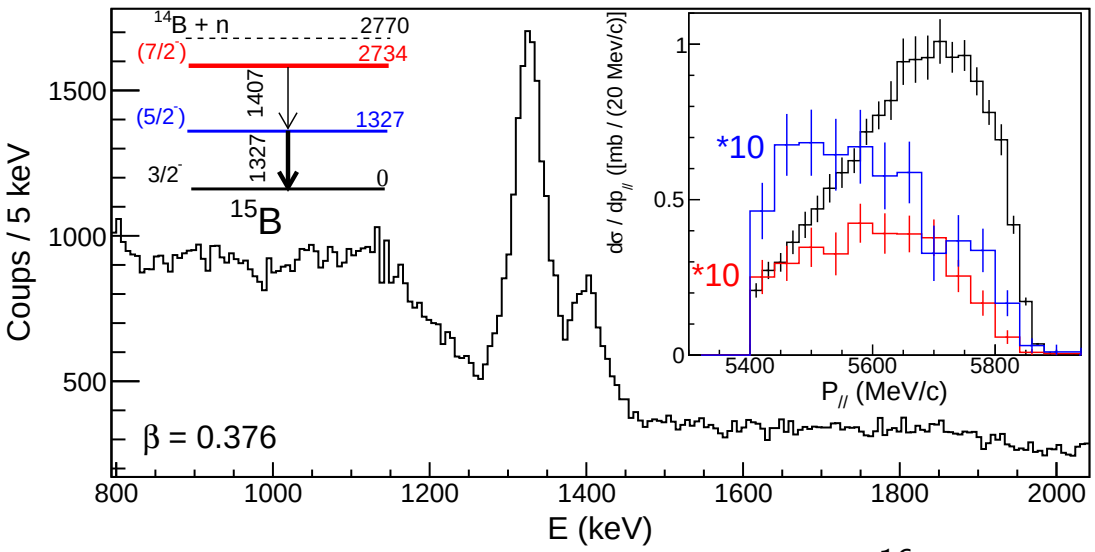
- Restricted to neutron removal
- No breakup of ^{9}Be target
- No final state interactions



A. Bonnacorso and D Brink, PRC **43** 299 (1991)

A. Bonnacorso and G. M. Bertsch, PRC **63** 04604 (2001)

γ-ray spectroscopy of ^{15}B : dissipative processes

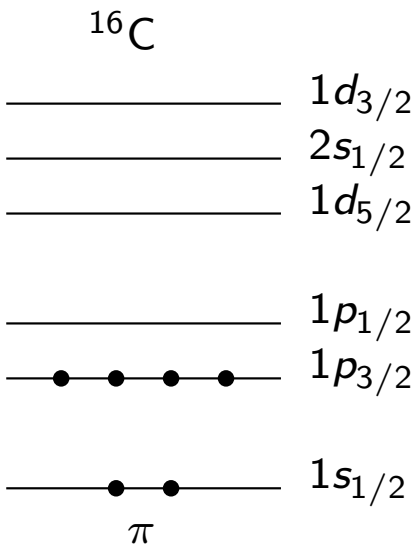


σ_{gs}(-1p)= 18.3 ± 2.2 mb

$\sigma_{5/2-}$(-1p)= 1.3(2) mb

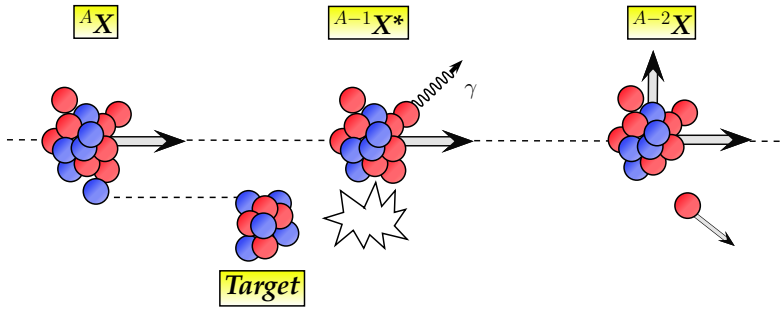
$\sigma_{7/2-}$(-1p)= 0.8(1) mb

σ(-1p)= 20.4 ± 2.2 mb

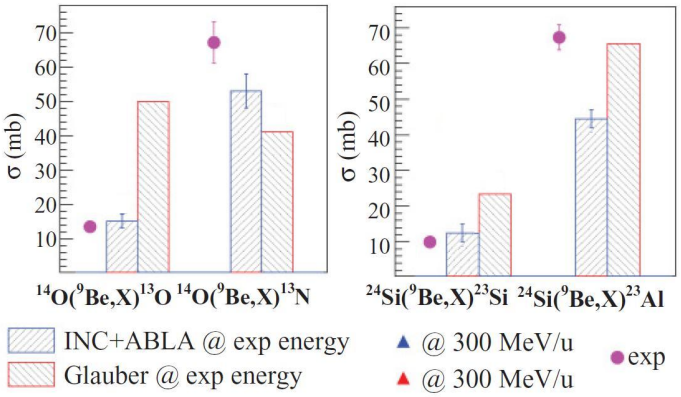


Questioning the "inert core" approximation

Intra Nuclear Cascade model (INC)



$$\sigma_{th} = \sigma_{casc} + \sigma_{evap}$$



Structure inputs :

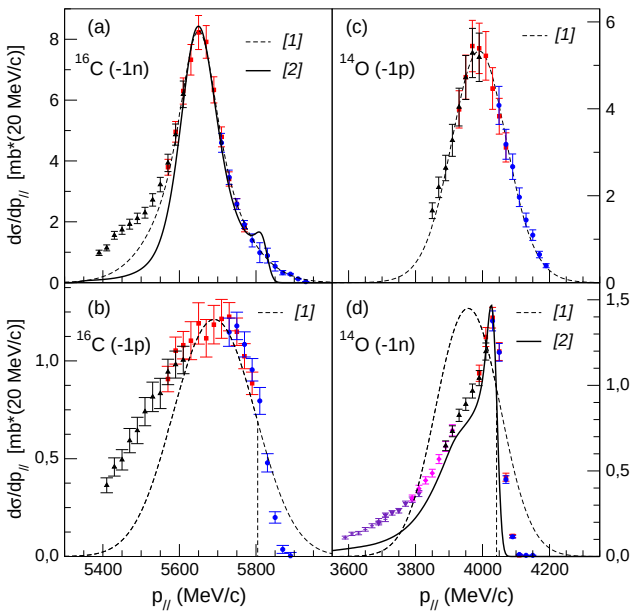
- HF neutron and proton densities.
- Spectroscopic factors.

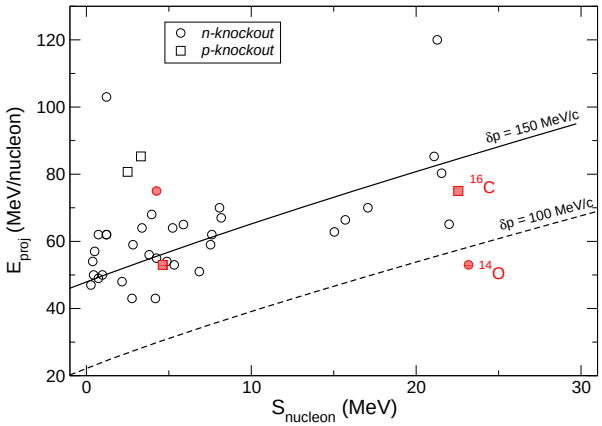
C. Louchart, A. Obertelli, A. Boudard, and F. Flavigny, PRC **83** 011601 (2011)

Deeply-bound nucleon removal :

- **Core excitations** deplete the one-nucleon removal channel
- Call for **exclusive measurements**, along the line of D. Bazin *et al.*, PRL **102** 232501 (2009).

Summary and Conclusion





Loosely-bound nucleon knockout

- **Good agreement between th. and exp.**
  - Rs $\simeq$ 0.8-0.9 .
  - Mom. distributions in agreement with eikonal predictions.

Deeply-bound nucleon knockout

- **Strong deviations from eikonal/sudden picture**
  - Rs $\simeq$ 0.2-0.3 .
  - High-momentum cutoff $\longrightarrow$ Kinematical effect (E,S_n)
  - Important low-energy tail $\longrightarrow$ Hypothesis : Dissipation, core-target int.
  - Indirect population of excited states.

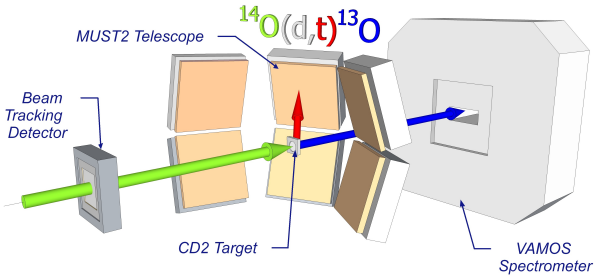
Determination of dynamical limits for nucleon knockout

Role of indirect processes in the mechanism questioned

Outlook

Comparison with transfer results on ^{14}O in GANIL

See A. Gillibert's talk tomorrow !



Exclusive measurement at RCNP (2013)

- $^{12}C(^{14}O,^{13}O+X)$ — Population of unbound states in ^{13}O (proton detection)
- $^{1}H(^{14}O,^{13}O)$ and $^{1}H(^{14}O,^{13}N)$ — Proton induced nucleon breakup

Spokepersons : J. Lee, A. Obertelli, Y. Ye.

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