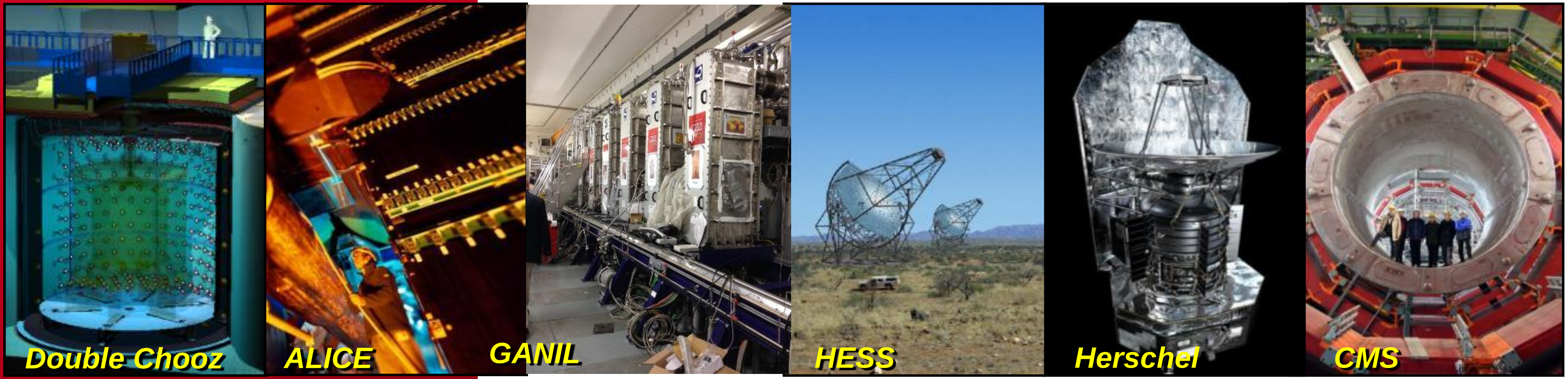
DE LA RECHERCHE À L'INDUSTRIE

4th Workshop on New Aspects and Perspectives in Nuclear Physics (HINPW4) 5-6 May 2017



Interpreting radiations from the Universe.

Nicolas Alamanos Deputy Director of the Institute of research into the fundamental lows of the universe

DIRECT REACTIONS AND SUB-BARRIER FUSION

WHERE DO WE STAND - WHAT'S NEXT ?

OR

COLLABORATING WITH ATHENA (WE MET ~1997)

Nicolas Alamanos
(nicolas.alamanos@cea.fr)

The situation at GANIL (France)

1985: Publication of the article by Isao Tanihata.

1994: Construction of SISSI for production of exotic nuclei

2001: First beams from the SPIRAL facility

~1997 the scientific committee of the SPIRAL facility

In 2015 we celebrated 30 years of radioactive ion beam physics

Nuclear Physics with RIB's: How it all started

Isao Tanihata

DOI: 10.1140/epjp/i2016-16090-x

What's next in nuclear physics with RIB's

Björn Jonson

DOI: 10.1140/epjp/i2016-16020-0

Focus Point on Rewriting Nuclear Physics textbooks:

30 years with radioactive ion beam physics

EPJ Plus - Published online: 23 January 2017 - DOI: 10.1140/epjp/i2017-11296-0

N. Alamanos, C. Bertulani, A. Bracco, A. Bonaccorso, D. Brink and G. Casini

The situation at GANIL (France)

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Direct reaction analysis – elastic and inelastic scattering

We were looking with **Athena** for a microscopic model able to describe without free parameters elastic and inelastic exotic nucleus+p scattering.

i) Elastic scattering : proton and neutron density distributions

i) Inelastic scattering : proton and neutron transition density distributions

Transition densities depend on the multipolarity. This is not the case in a macroscopic model description.

$$\boxed{r^{l-1}\, d\rho(r)/dr}$$

$$\boxed{\beta R\, dV(r)/dr}$$

Direct reaction analysis –elastic and inelastic scattering

In collaboration with F.S. Dietrich from Livermore we have imported at Saclay an ensemble of codes based on the JLM approach.

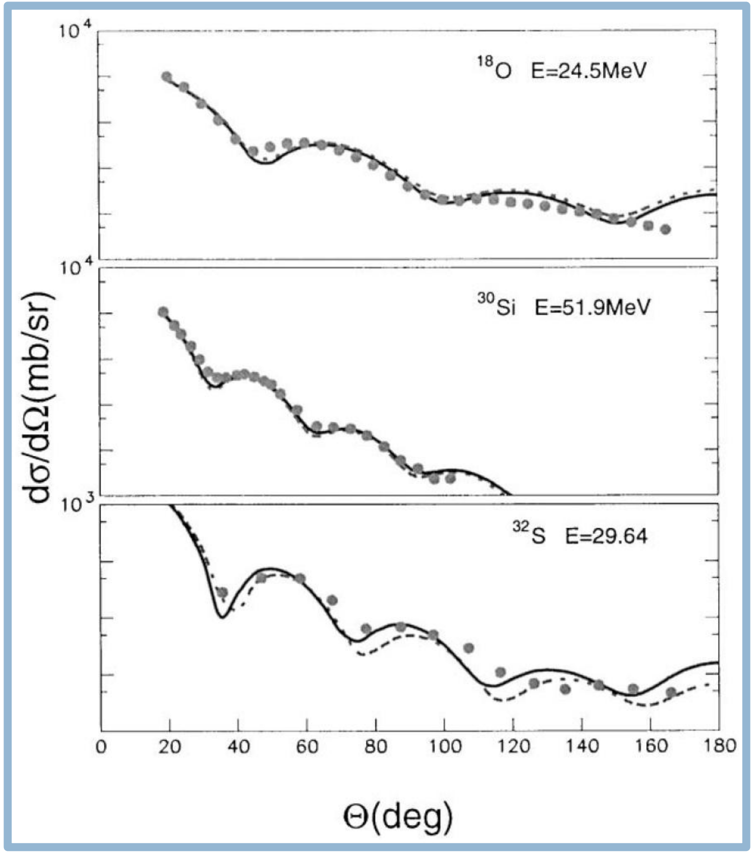
In one of our first papers we have decided to analyze elastic and inelastic scattering for few nuclei for which we had :

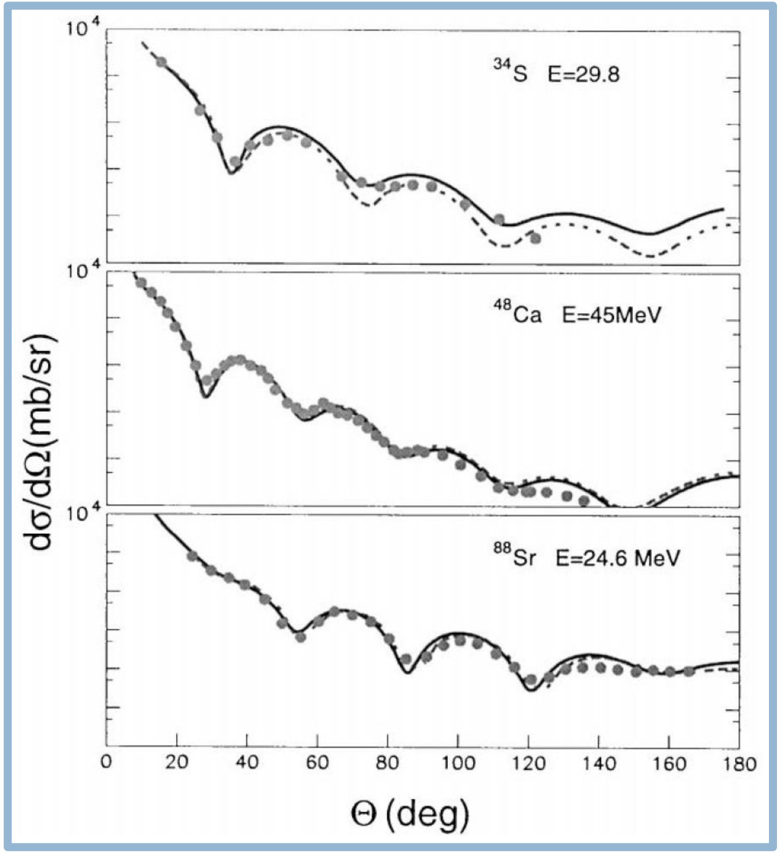
=> experimental measurements of elastic and inelastic scattering

=> the proton and neutron density distribution and proton and neutron transition density distributions were known from electron or proton high energy elastic and inelastic scattering. (**see also Vasileios Soukeras**)

Among these nuclei : ^{18}O, ^{30}Si, ^{32,34}S, ^{48}Ca, ^{88}Sr….

JLM elastic scattering. The Solid lines correspond to a potential with real and imaginary parts normalized to 1. Dashed lines to renormalization factors shown in table.





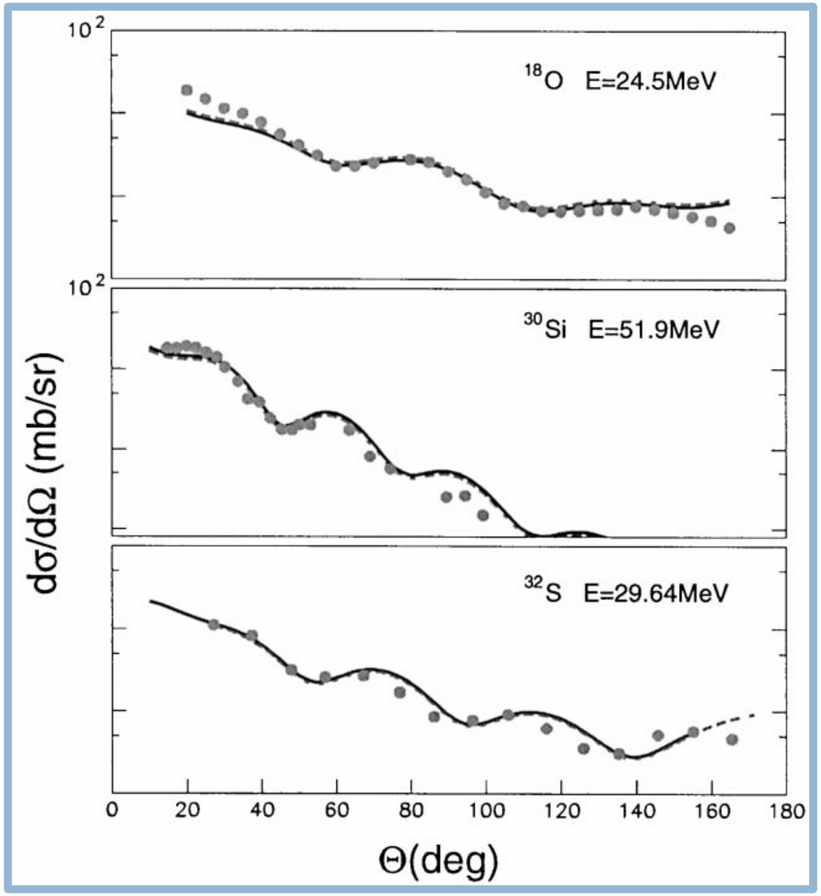
Renormalization factors of the JLM potential

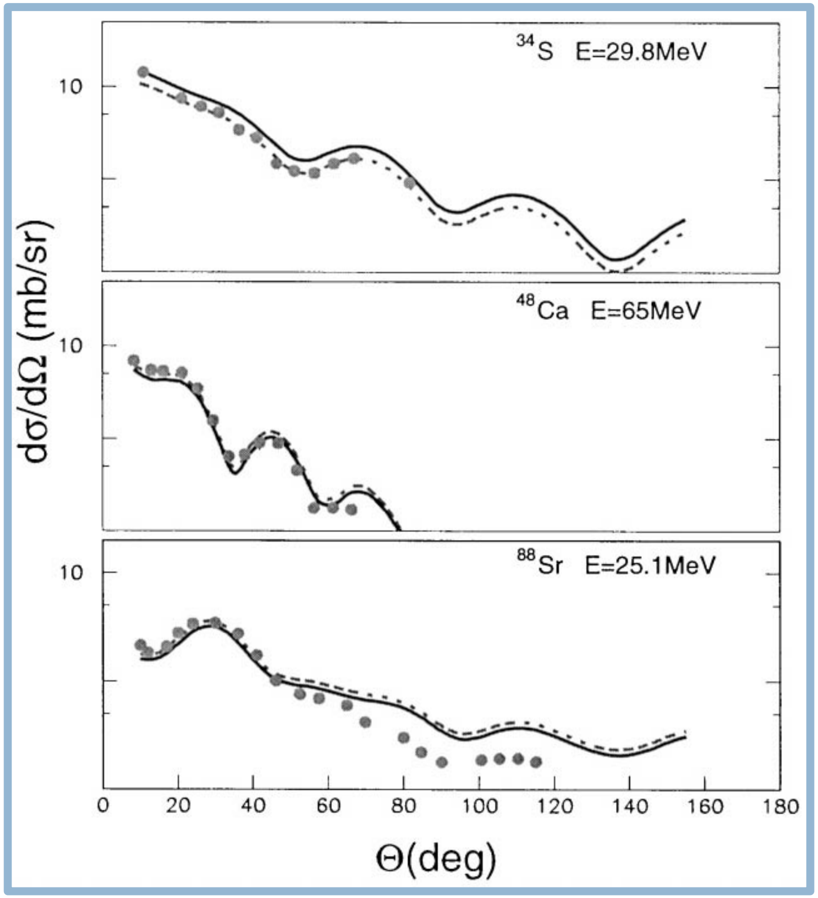
	^{18}O	^{30}Si	^{32}S	^{34}S	^{48}Ca	^{88}Sr
λ_V	1.0	1.0	0.9	0.9	1.04	0.95
λ_W	0.9	1.1	1.0	0.9	1.0	1.0

JLM inelastic scattering. The solid lines were calculated using experimental proton and neutron transition densities, the Mn/Mp ratio is equal to the experimental values. Dashed lines are the best fit assuming a certain Mn/Mp ratio.

$$M_{n(p)} = \int \rho_{\mathrm{tr}}^{n(p)} r^{\lambda+2}\, dr$$

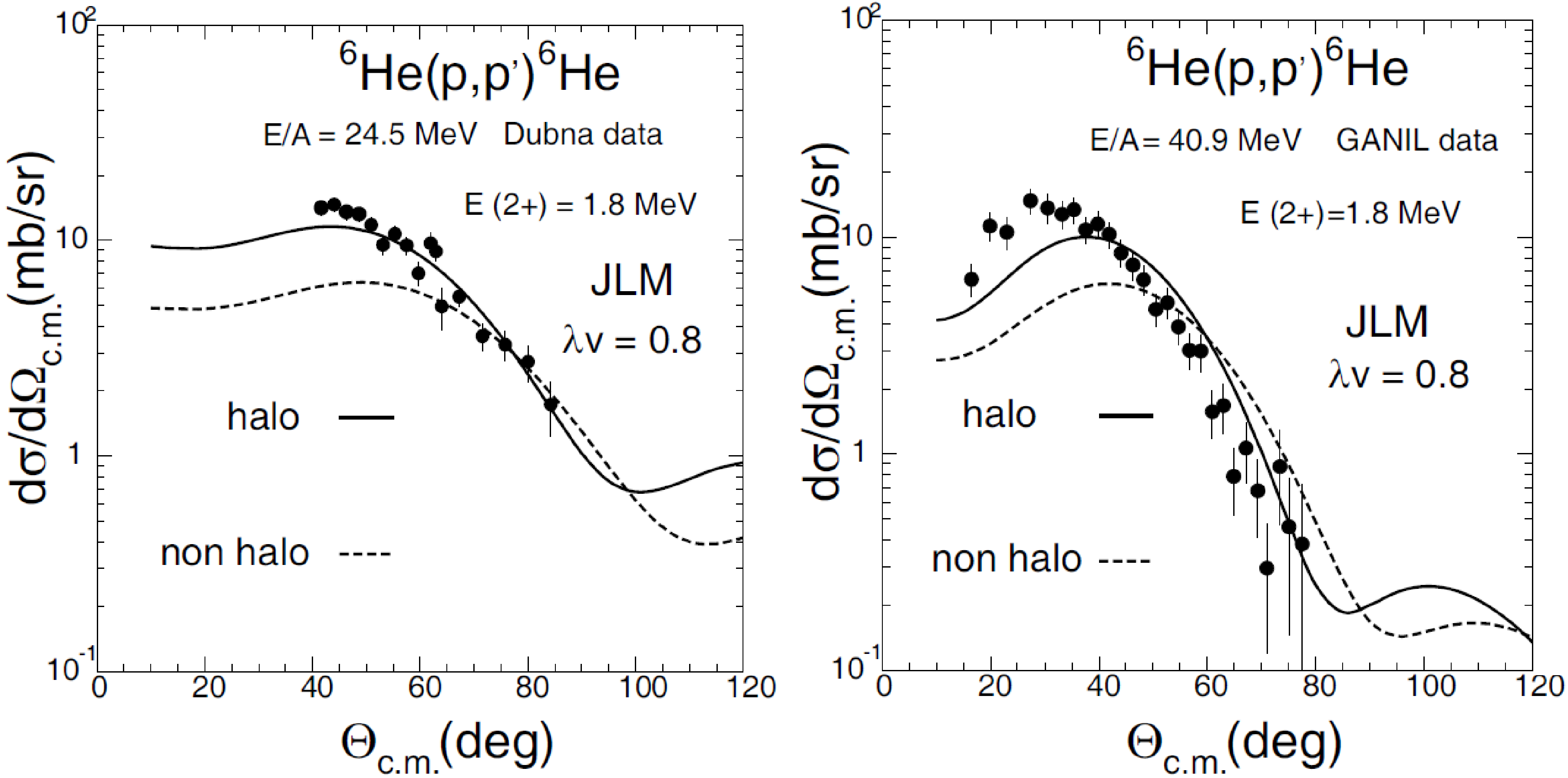
$$M_n / M_p$$





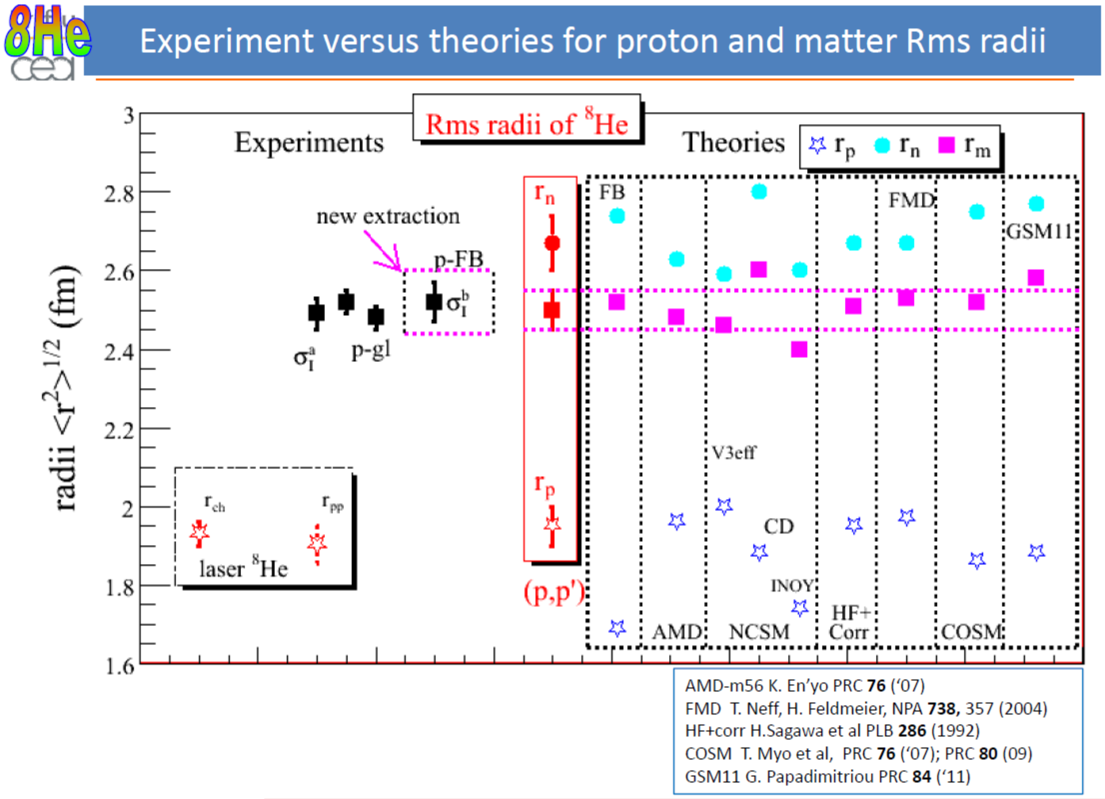
JLM inelastic scattering

A. Lagoyannis, ….., A. Pakou et al., Phys. Lett. B 518, 27 (2001)



V. Lapoux and N. Alamanos, *EPJA* ***51**, 91 (2015)*

Experimental matter radii for $^{6,8}He$ were obtained (inferred) through a complete evaluation of the available elastic proton scattering data of oxygen isotopes.



Experiment versus theories for proton and matter Rms radii

AMD-m56 K. En'yo PRC **76** ('07)
FMD T. Neff, H. Feldmeier, NPA **738,** 357 (2004)
HF+corr H.Sagawa et al PLB **286** (1992)
COSM T. Myo et al, PRC **76** ('07); PRC **80** (09)
GSM11 G. Papadimitriou PRC **84** ('11)

V. Lapoux and N. Alamanos, *EPJA* ***51****, 91 (2015)*,

The energy- and density dependent Jeukenne – Lejeune - Mahaux (JLM) potential, derived from a G-matrix formalism, was employed. This complex potential depends only on the incident energy E and on neutron and proton densities.

The rm radii were extracted with uncertainties of the order of 0.1 fm.

Where do we stand - What's next

N. Keeley, N. Alamanos, K.W. Kemper, K. Rusek Progress in Particle and Nuclear Physics 63 (2009) 396-447

Radii and binding energies in oxygen isotopes : A challenge for Nuclear Forces

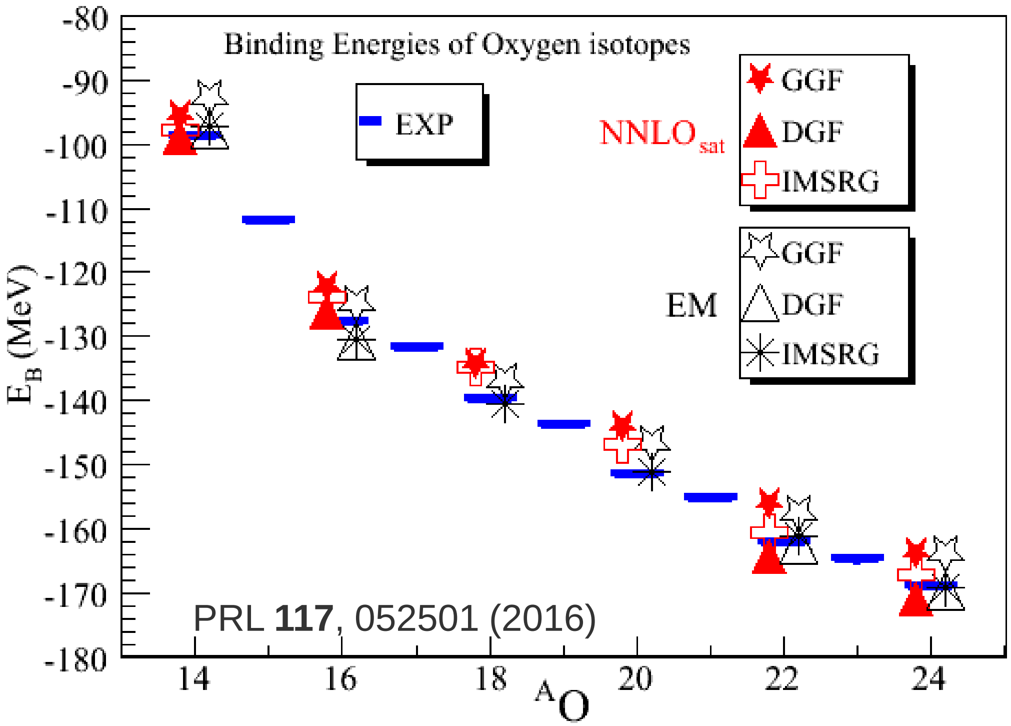
V. Lapoux, V. Somà, C. Barbieri, H. Hergert, J. D. Holt, and S. R. Stroberg

Phys. Rev. Lett. **117**, 052501 (2016) – Published 27 July 2016

For the O isotopic chain : 3 stable isotopes, r_{ch} known, existing (p,p) data for $^{16-18}O$ and $^{20,22}O$

Consistent results for E_B between various many-body ab-initio calculations up to ^{24}O

Agreement between experiment and theory up to ^{24}O



PRL **117**, 052501 (2016)

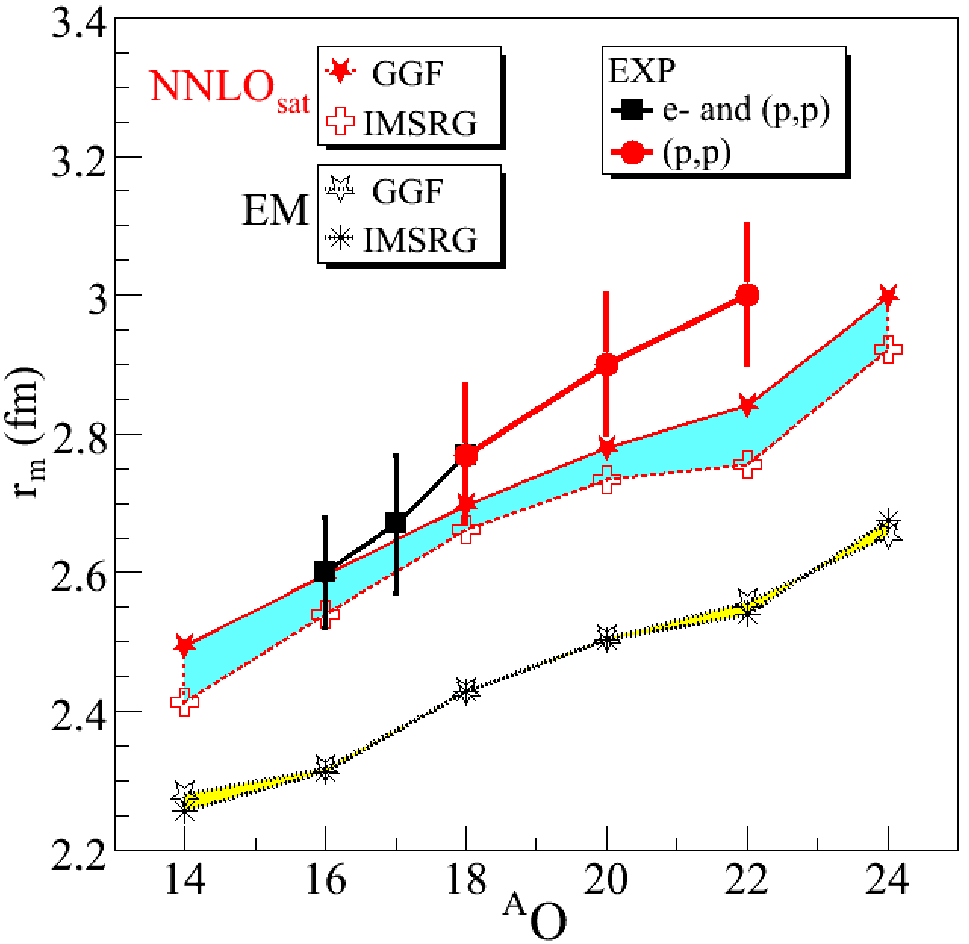
i) **(EM)** : based on a next-to-next-to next-to-leading order 2N and NNLO 3N chiral interaction (EM : Entem, Machleidt)

ii) **(NNLOsat)** : which includes contributions up to NNLO in the chiral effective field theory expansion (both in the 2N and 3N sectors)

Ab initio calculations are able to accurately reproduce binding energies but fail to describe the charge and matter radii of the most neutron-rich systems…..

EM : underestimate evaluated data by about 0.3–0.4 fm for all isotopes. Results significantly improve with

NNLOsat: although the description deteriorates towards the neutron drip line, with a discrepancy of about 0.2 fm in ^{22}O.



Where do we stand - **What's next**

Precise elastic and inelastic

(V. Lapoux and NA EPJA 51,91,(2015))

scattering measurements and….

Electron and **antiproton** scattering measurements

Electron scattering and reactions from exotic nuclei

S. Karataglidis, Eur. Phys. J. A (2017) 53: 70

=> **The SCRIT** experiment (at Japan) will be taking data for medium-mass exotic nuclei.

=> **ELISe** (the electron-ion collider) will be able to measure form factors for a wide range of exotic nuclei, as available from the radioactive ion beams produced by the FAIR experiment.

Attempt to measure directly electron scattering form factors from nuclei far from stability. This will give direct information for the (one-body) charge densities of those systems, about which there is little information available.

The PUMA PROJECT – ERC Grant (2017-2022).

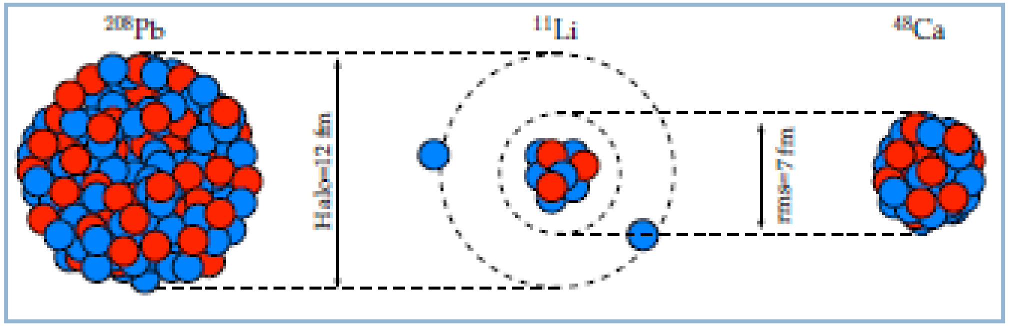
The goal of the PUMA project is to realize annihilation reactions at the surface of short lived radioactive nuclei. Information on the tail of their density distribution could be obtained

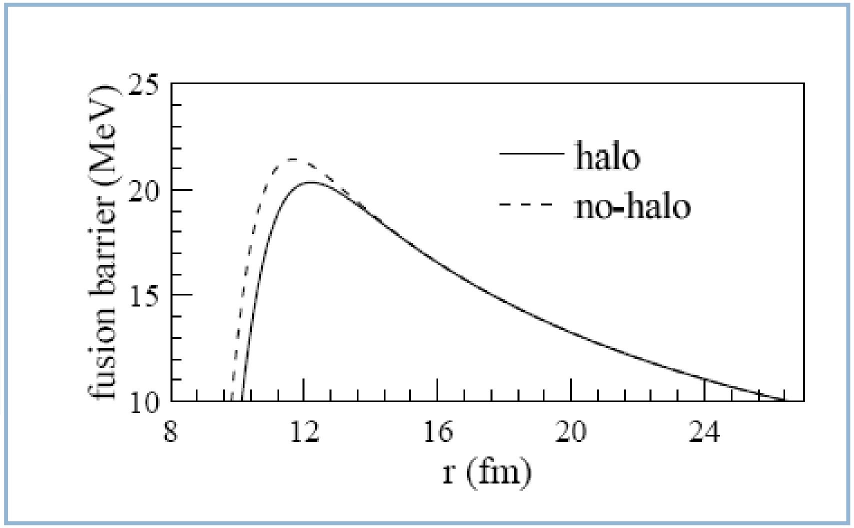
What it will be measured in these experiments are charged pions as products of the decay of anti-protonic atoms. From the experimental side, for a given isotope the ratio of proton-to-neutron annihilations with uncertainties coming from statistics, efficiency corrections and final state interactions will be provided.

Sub- and near Barrier- fusion

Sub-barrier and near-barrier fusion study of halo nuclei

Fusion cross section of halo nuclei will present an increase due to the decrease of the potential barrier and the coupling to soft vibrational modes.





Some background

In the absence of a practical *ab initio* quantal many-body theory for sub-barrier fusion all approaches involve the calculation of an ion-ion potential barrier, usually as a function of the nuclear separation coordinate *R*, and the solution of the corresponding one-body Schrödinger equation for the transmission probability and the fusion cross sections.

Many of the phenomenological and semi microscopic potentials for fusion utilize the double-folding method which is based on the physical assumption of *frozen densities* or the *sudden* approximation.

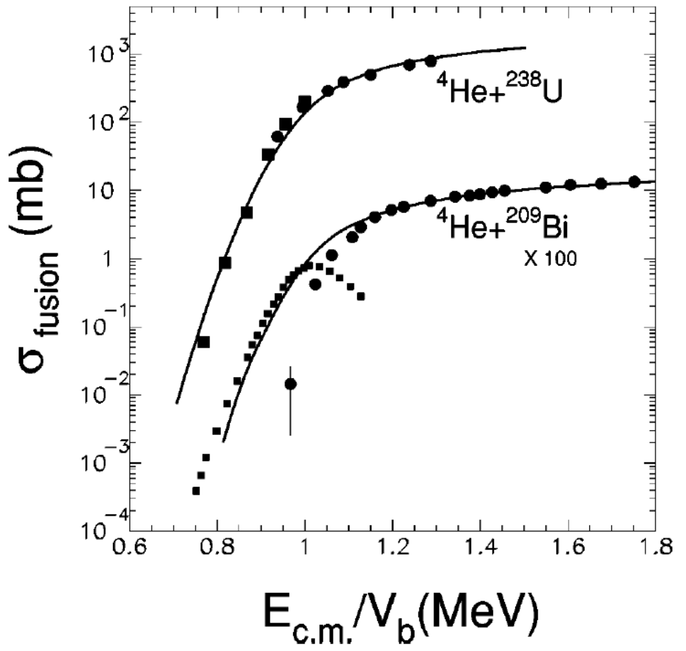
Some background : G.R. R. Satchler and W.G. Love on "folding model" Phys. Rep. 55, 183 (1979)

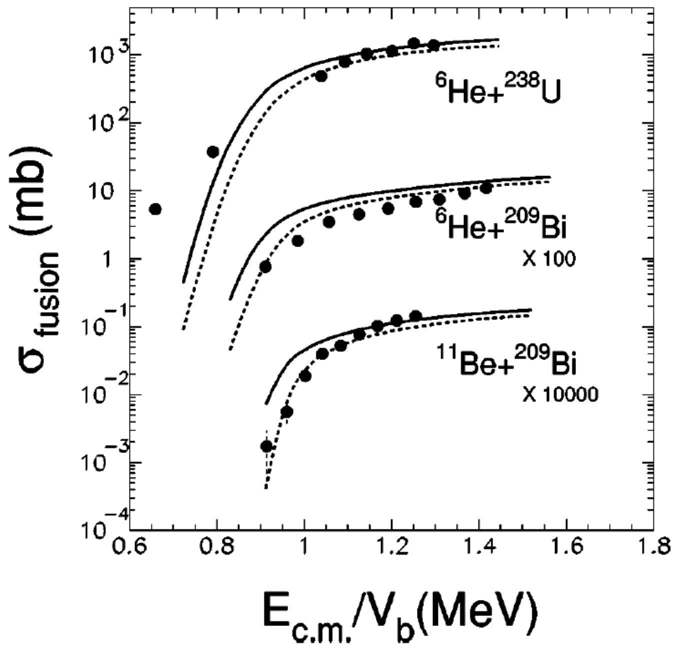
The real potentials for an ensemble of heavy ion inelastic scattering reactions are given correctly if the calculated folded potentials are normalized by a factor N where: N ~1.11±0.13

"…. The only exception established so far occurs for the scattering of ^{6}Li and ^{9}Be which require a reduction in the strength of the calculation by a factor of about two. The reason for this is not known presently…. (**see also Onoufrios Sgouros**)

=> And we had an expertise with double folding model calculations, CC calculations with the code ECIS, tests of IWBC,….. (D. de Castro Rizzo and N. Alamanos (N.P. A443 (1985) 525))

Sub-barrier and near-barrier fusion study of halo nuclei





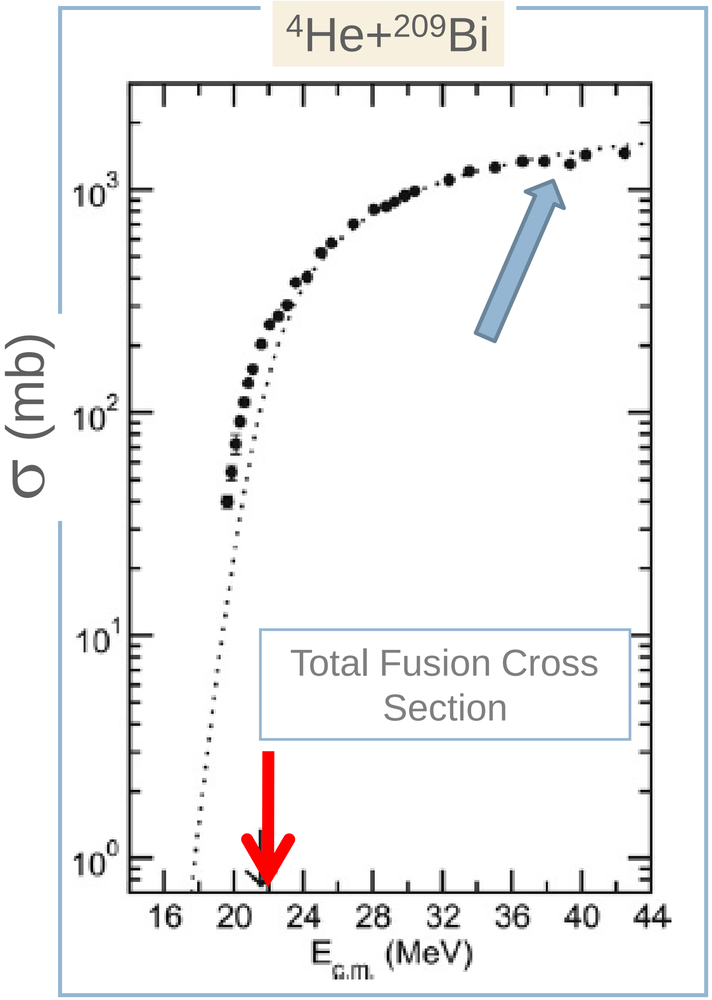
We could draw the conclusion that CC calculations, taking into account transfer or breakup effects in a simple way, via a reduced potential, reproduce the gross properties of near-barrier and sub-barrier fusion of weakly bound nuclei with heavy ions.

N. Alamanos, A. Pakou et al., (Phys. Rev. C65 (2002) 054606)

Discretized CC calculations - Results and discussion

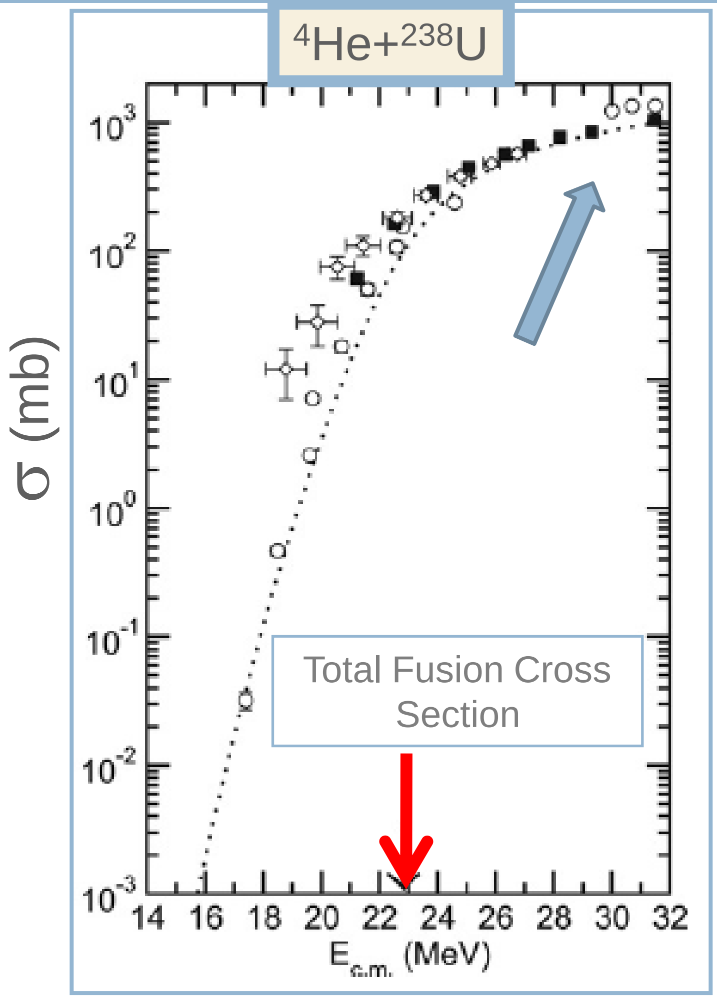
N. Keeley, R. Raabe, N. Alamanos and J.L. Sida, Prog. Part. Nucl. Phys. 59, 579 (2007)

^{4}He+^{209}Bi



Total Fusion Cross Section

^{4}He+^{238}U



Total Fusion Cross Section

The filled squares and open diamonds denote fission data

Discretized CC calculations - Results and discussion

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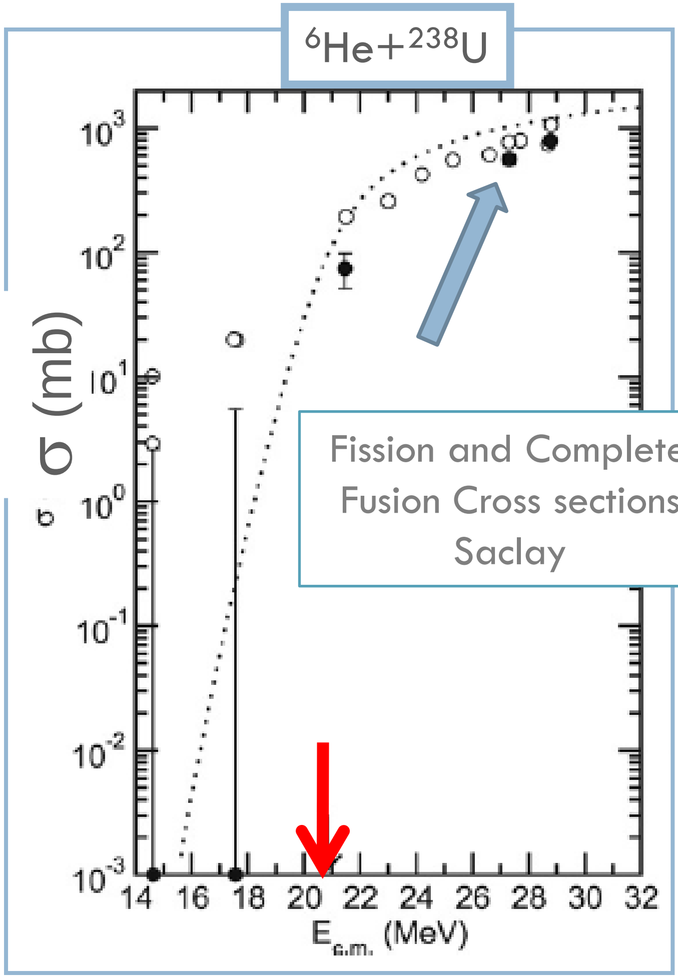
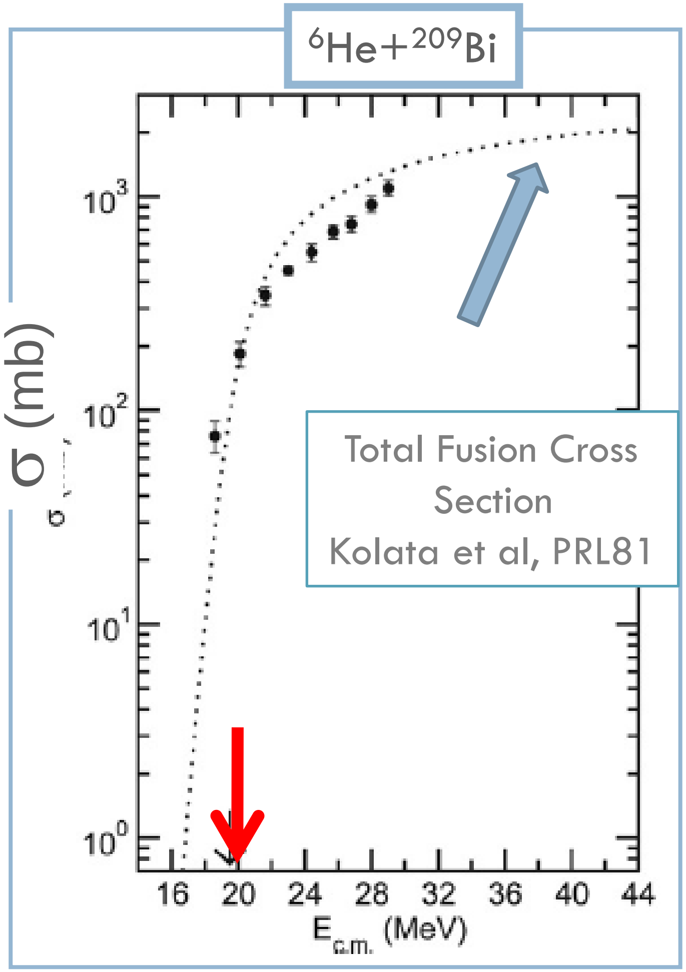


Fission and Complete Fusion Cross sections Saclay



Total Fusion Cross Section
Kolata et al, PRL81

Where do we stand or what was (is) our present understanding

⇨ The data are consistent with an-above-barrier suppression and possibly a sub-barrier enhancement of the total fusion cross section although the latter remains to be confirmed.

⇨ Calculations suggest that the above-barrier suppression may be attributed in large part to the effect of coupling to neutron transfer reactions, although break-up will also contribute.

⇨ In this approach (CCC) the densities of the colliding nuclei are frozen, don't depend on the readjustment of the surface of the combined nuclear system. Start to fail at deep sub-barrier energies. This has been addressed with the addition of a repulsive core potential at small nuclear separations. (PRC 85, 055801 (2012))

Recent evolutions

- ❖ An ensemble of new experiments with better quality data.

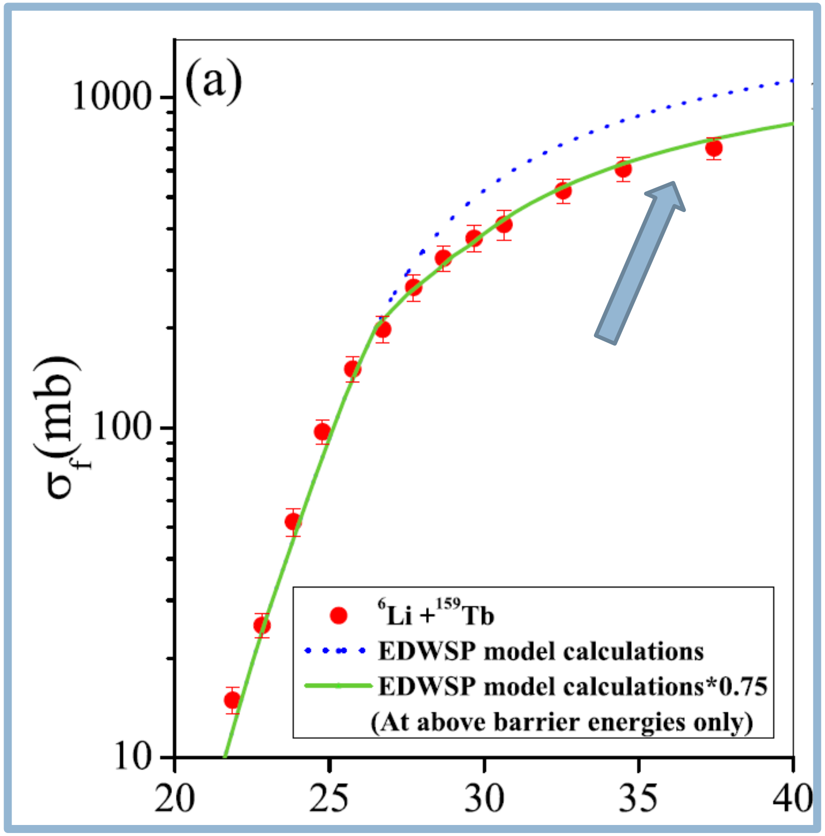
- ❖ The development of different models for describing sub-barrier fusion.

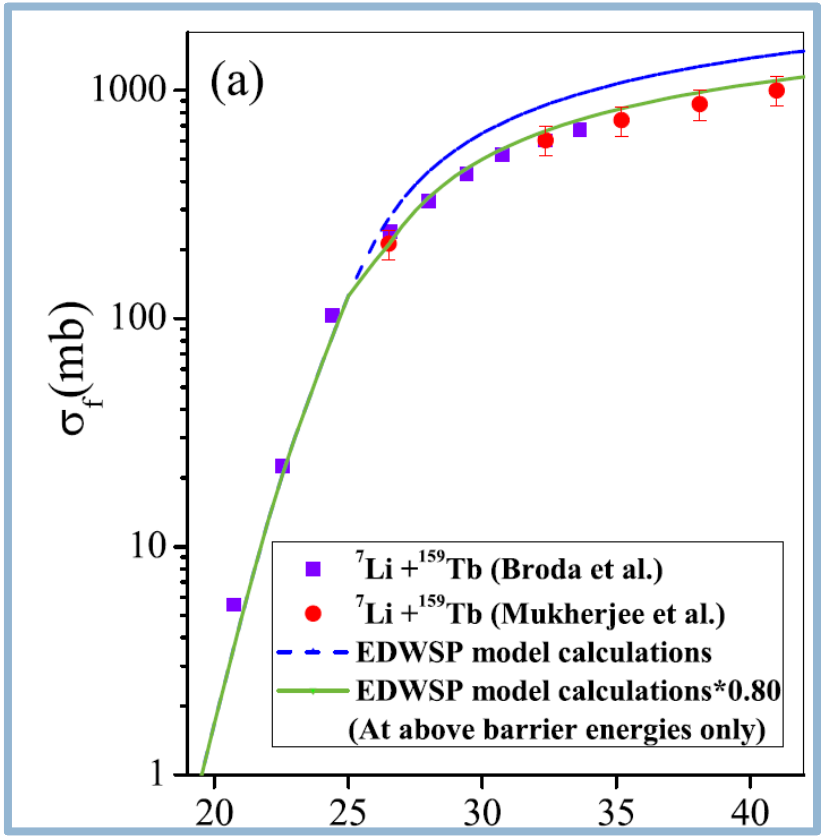
i) Energy-dependent Woods-Saxon potential model (example ^{6,7}Li+^{159}Tb) – Toy model calculations to obtain the near- and sub-barrier fusion cross sections.

ii) DC-TDHF calculations. TDHF evolution of the nuclear system coupled with density-constrained Hartree Fock calculations to obtain the ion-ion interaction potential. The fusion barrier penetrability is obtained by numerical integration of the two-body Schröndiger equation using the incoming wave boundary condition.

Energy-dependent Woods-Saxon potential model (example ^{6,7}Li+^{159}Tb)

(complete fusion (CF) and incomplete fusion (ICF) cross-sections



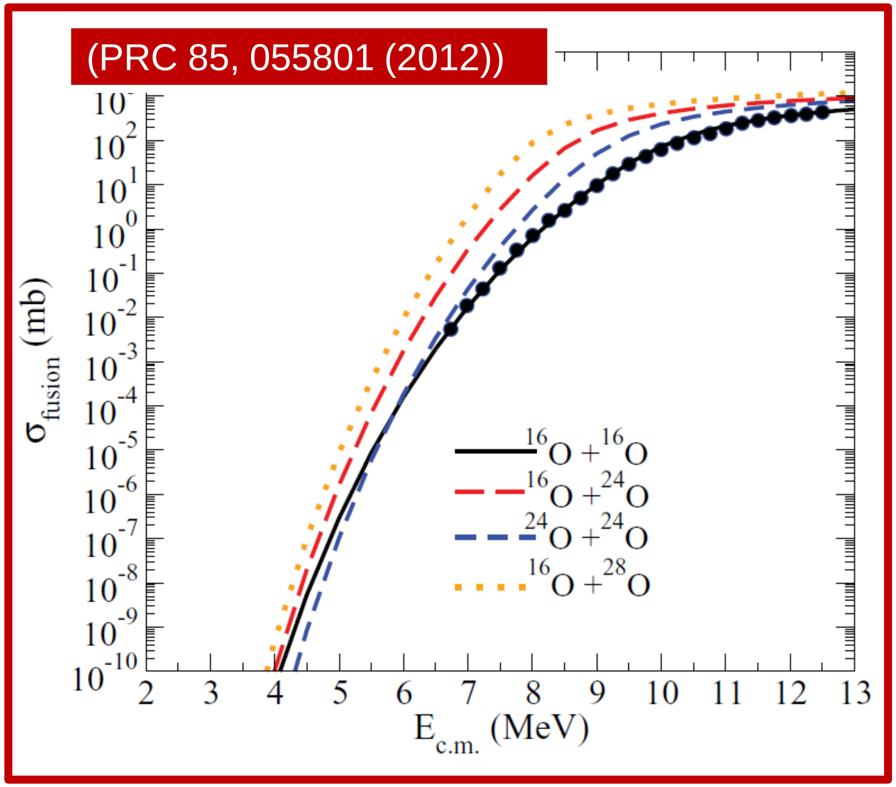


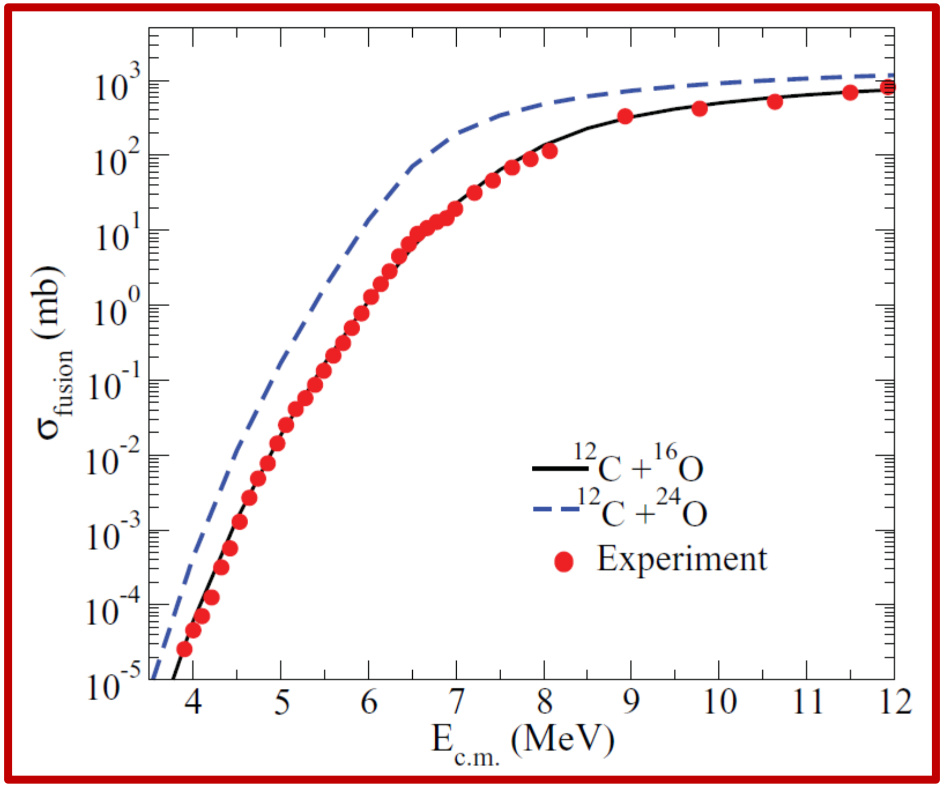
M. JS. Gautan et al., (EPJA (2017) 53: 12)

Where do we stand - **What's next**

Fusion of very neutron-rich nuclei may be important to determine the composition and heating of the crust of accreting neutron stars.

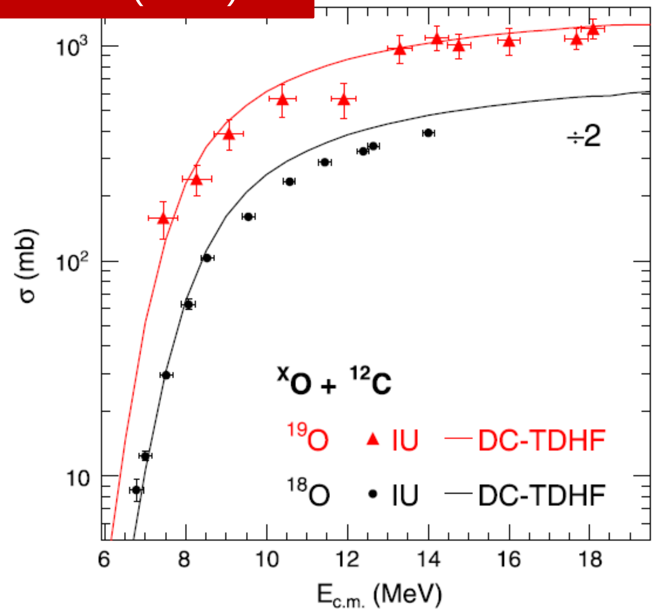
Measurements of sub-barrier fusion for light « exotic » nuclei – $^{16}O+^{16}O$, $^{16}O+^{24}O$, $^{24}O+^{24}O$, $^{12}C+^{16}O$, $^{12}C+^{24}O$…… PRC 85,055801(2012)



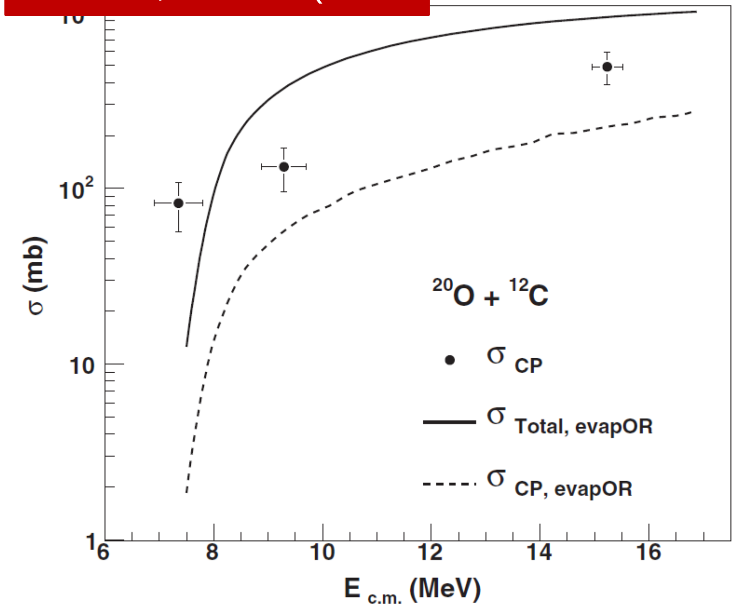


Measuring the fusion excitation function for an isotopic chain of projectile nuclei provides a stringent test of the microscopic description of fusion

PLB 765 (2017) 99



PRC 85, 024605 (2012



The description of the fusion excitation function for ^{18}O is notably poor

New experiments will be realized at GANIL.

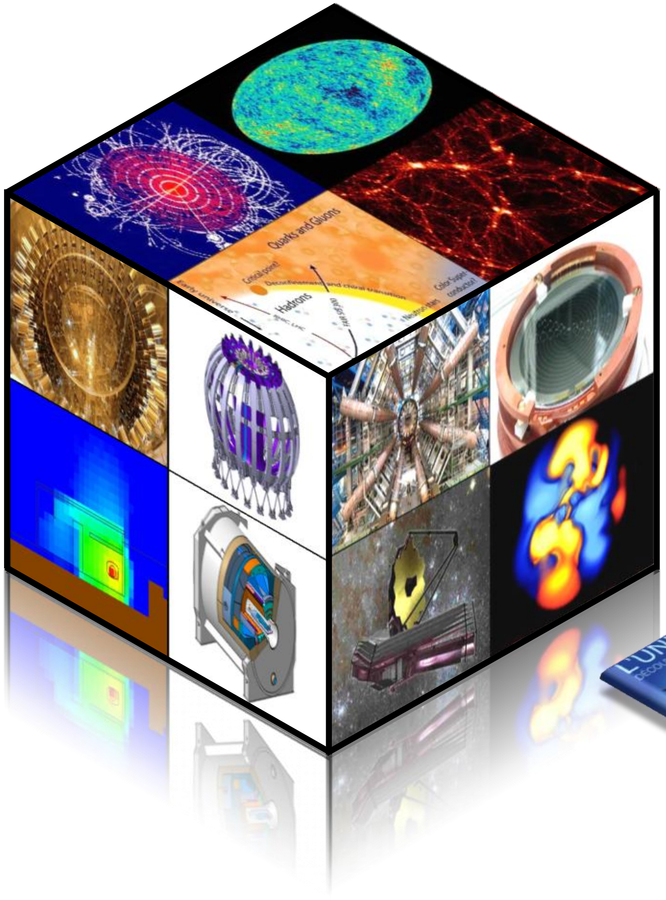
In the near future,……….

Produce text-book experimental results

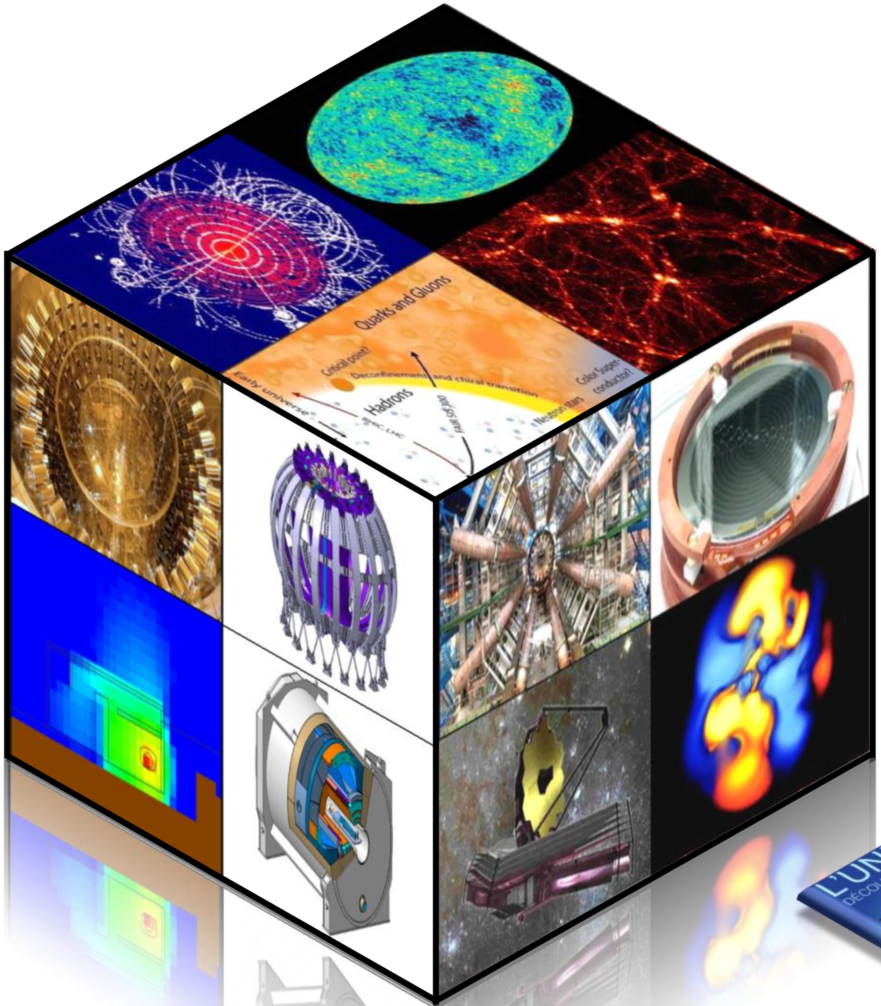
Precise measurements of the ensemble of the reaction channels with traditional and new techniques (Electron and antiproton scattering) : elastic, inelastic, transfer, break-up, fusion… ($^{18,20}O+^{12}C$ or $^{8}B+^{12}C$ or ^{208}Pb)-

New theoretical developments (even for elastic scattering)

Sub barrier fusion reactions for isotopic chains and new theoretical developments.



Thank you for your attention



Irfu

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DÉCOUVREZ SES MYSTÈRES
ANNÉE MONDIALE DE
L'ASTRONOMIE
2009