DIRECT REACTION PERSPECTIVES AT ISOLDE

A. Obertelli
CEA Saclay

ISOLDE "50th anniversary" workshop
December 15th – 17th , 2014

Outline

- **shell evolution: brief overview**

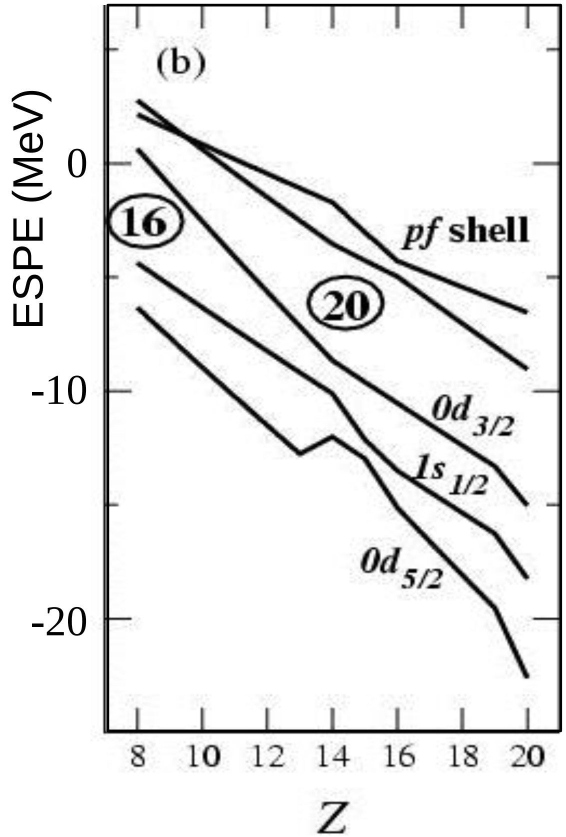
- **structure from transfer reactions**
  - Exclusive neutron and proton transfer around ^{132}Sn
  - Two neutron transfer to probe shape coexistence

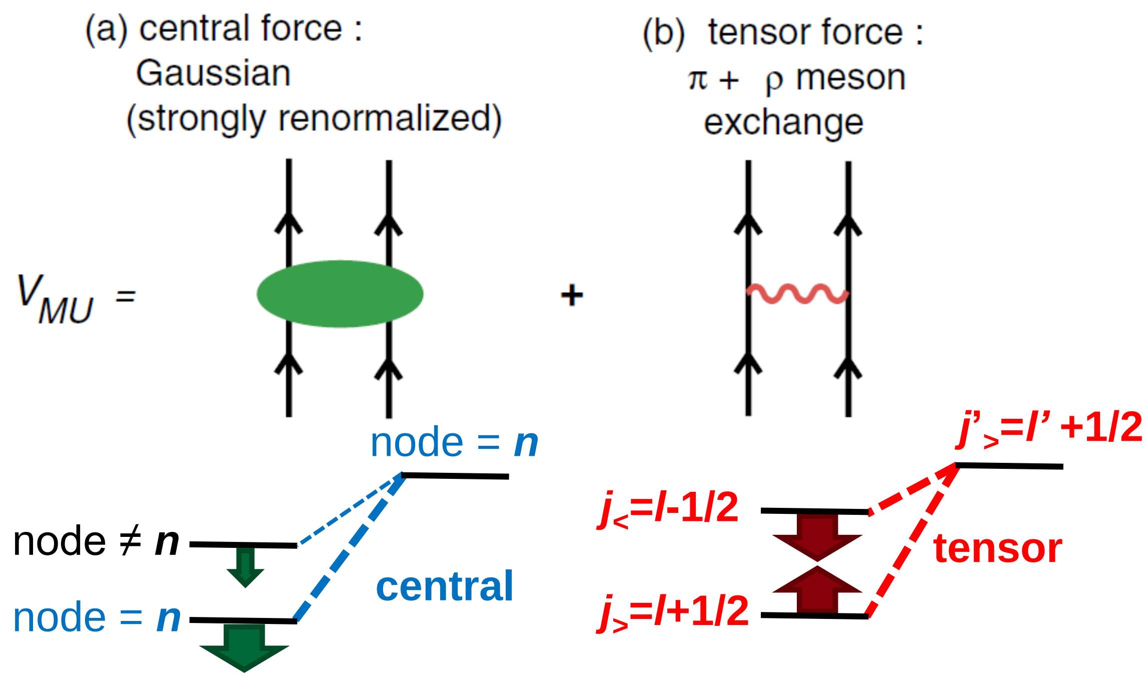
- **cold antiprotons as a new probe**

Shell evolution and direct reactions

Central and tensor forces

T. Otsuka, Phys. Scr. T152, 014007 (2013).



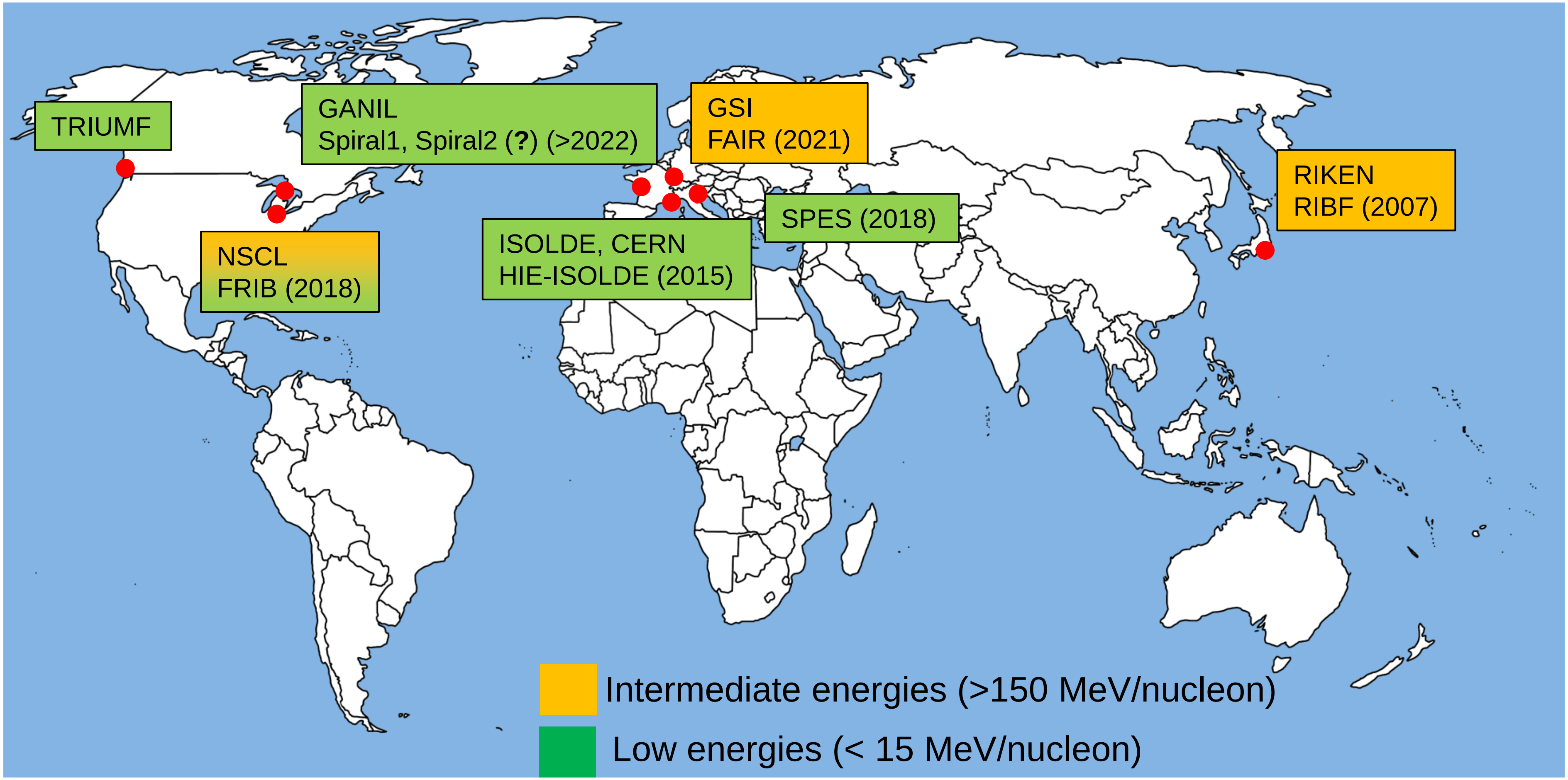


Experimental picture necessary!

Spectroscopy not sufficient: need information on **correlations / single-particle** nature

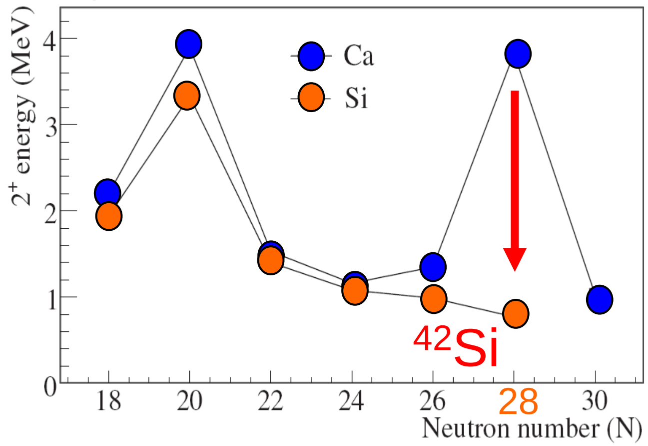
=> **Direct reaction** cross sections / spectroscopic factors

Accelerated rare isotopes in the world



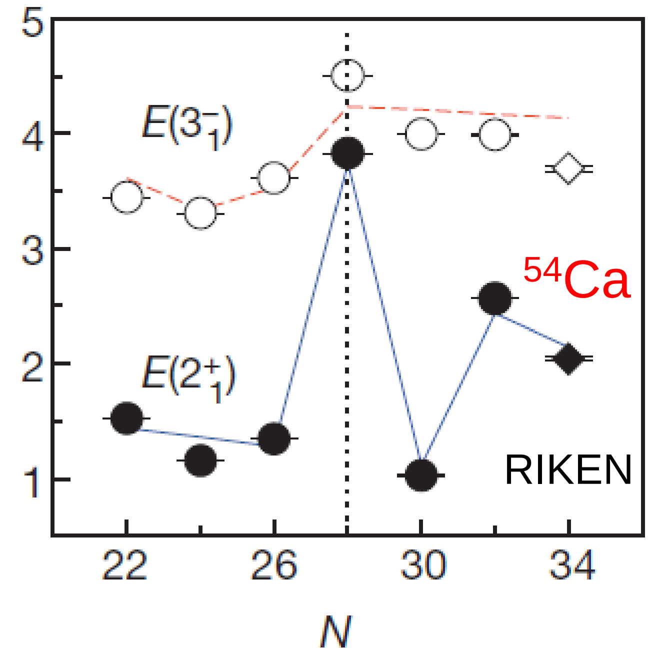
Luminosity: the advantage of in-flight facilities

GANIL

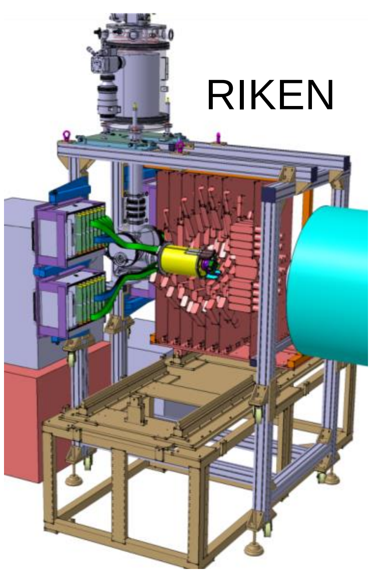


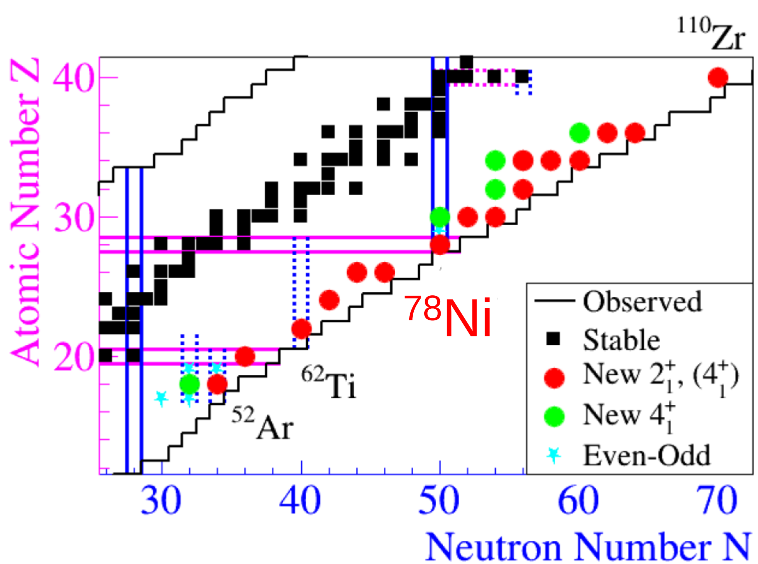
B. Bastin *et al.*, PRL **99**, 022503 (2007)

D. Steppenbeck et al., Nature **502**, 207 (2013).



RIKEN





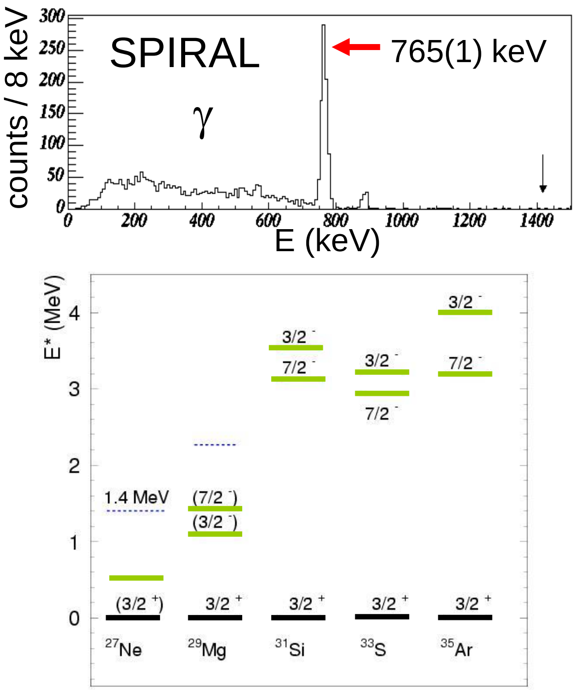
SEASTAR program at RIKEN: Spectroscopy of neutron-rich nuclei (since 2014)

Unique assets for transfer at low energies

Quantitative picture of the nuclear shell structure:

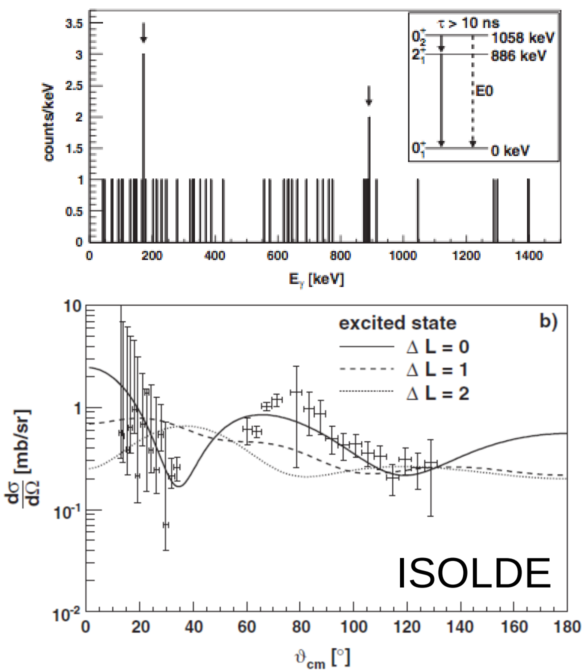
- Momentum matching and **state selectivity**
- **Particle states** from pickup reactions (missing mass spectroscopy)
- High statistics and differential cross sections: **reliable analysis**

^{26}Ne(d,p)^{27}Ne, 10 MeV/u

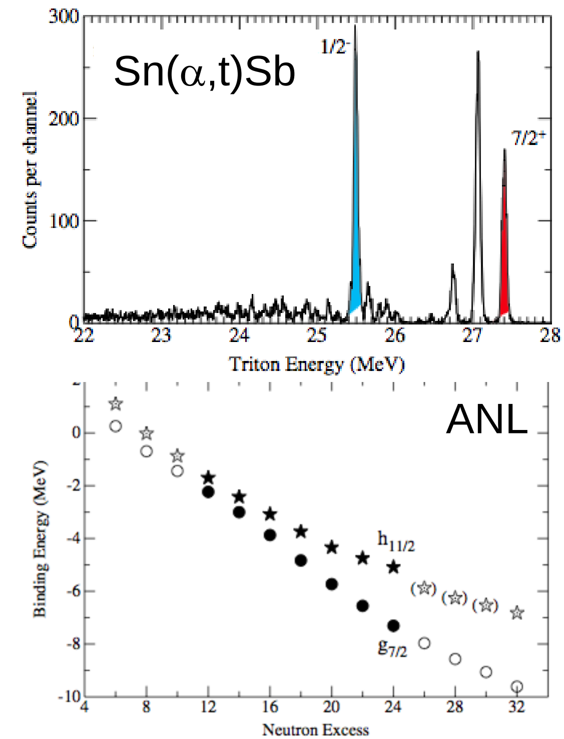


Intruder states in N=17 nuclei
AO et al., PLB (2007)

^{30}Mg(t,p)^{32}Mg, 1.8 MeV/u



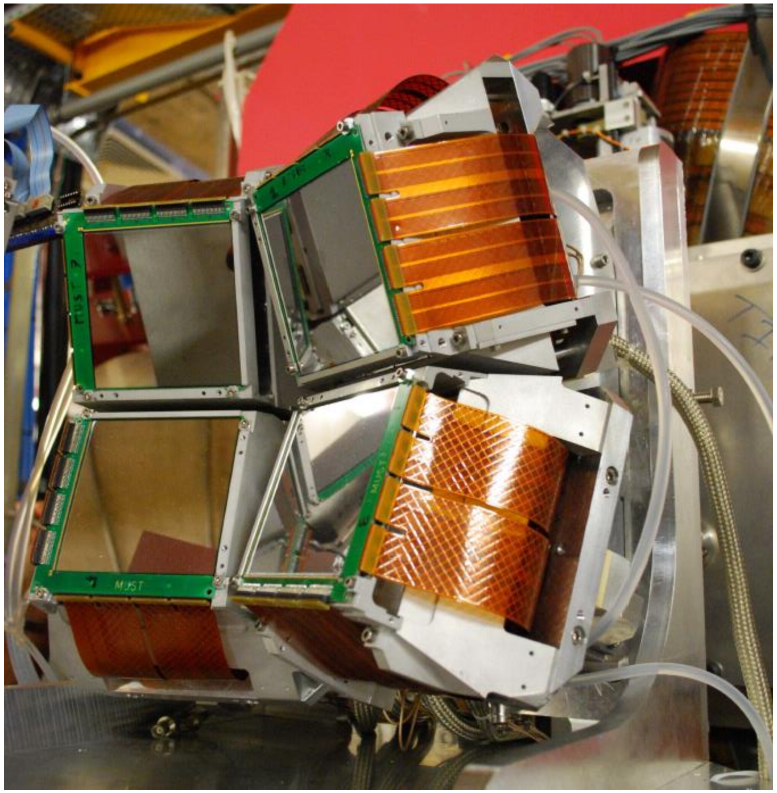
Intruder 0$^+$ state in ^{32}Mg
K. Wimmer et al., PRL **105** (2010)



Shell evolution along Sb chain
J. P. Schiffer et al., PRL **92** (2004)

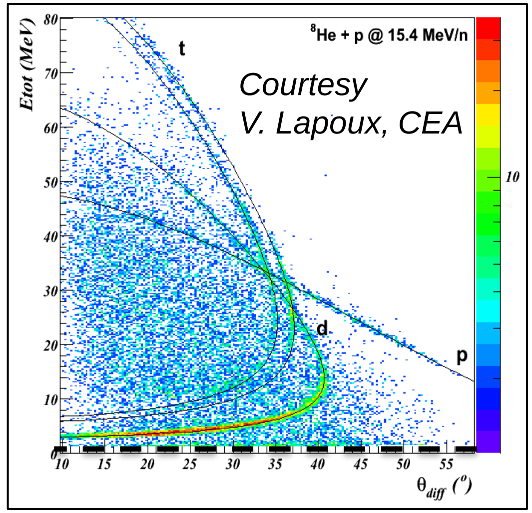
The MUST2 telescope array

MUST2 (2004- today):
CEA/IRFU, IPN, GANIL collaboration



8 telescopes – 10×10 cm^2 each.
E.C. Pollacco *et al.*, EPJ A **25** (2005)

^{8}He+p, 15 MeV/nucleon

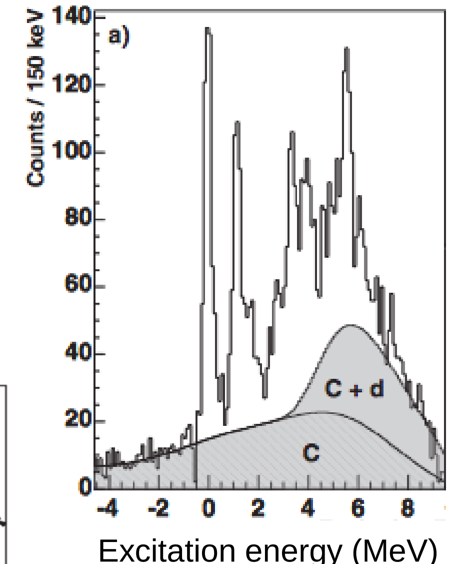


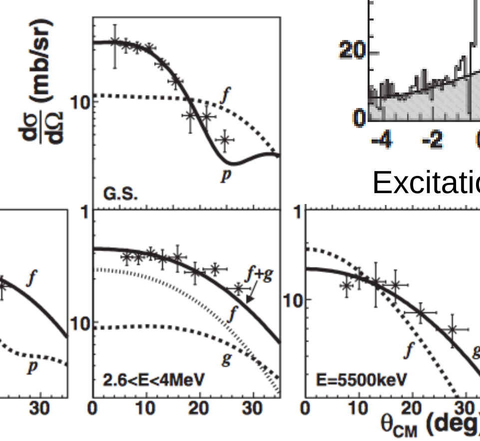
Thresholds: > 300 keV

X. Mougeot *et al.*, PLB **718** (2012)

^{46}Ar(d,p)^{47}Ar, 10 MeV/nucleon

Energy resolution:
σ = 175 keV
CD_2 target of 390 μg.cm^{-2}





L. Gaudefroy *et al.*, PRL **97** (2006)

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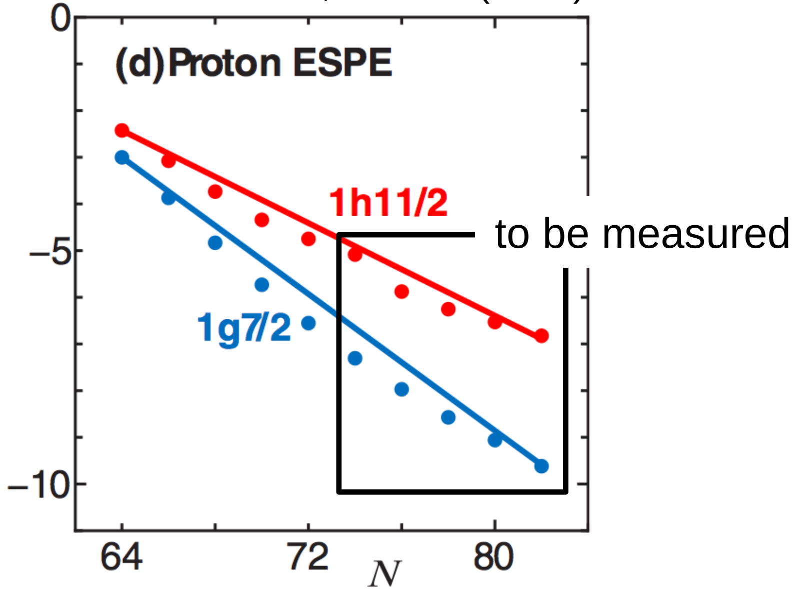
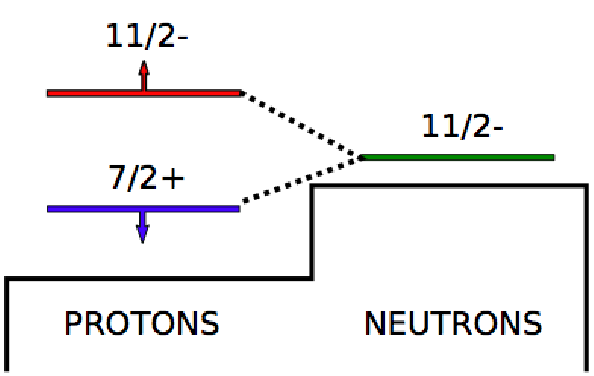
- cold antiprotons as a new probe

Particle proton states along the Sn chain

Systematics of *(^{3}He,d) and/or (α,t)* measurement to be performed for N=74-82

T. Otsuka *et al.*, PRL **95** (2005)

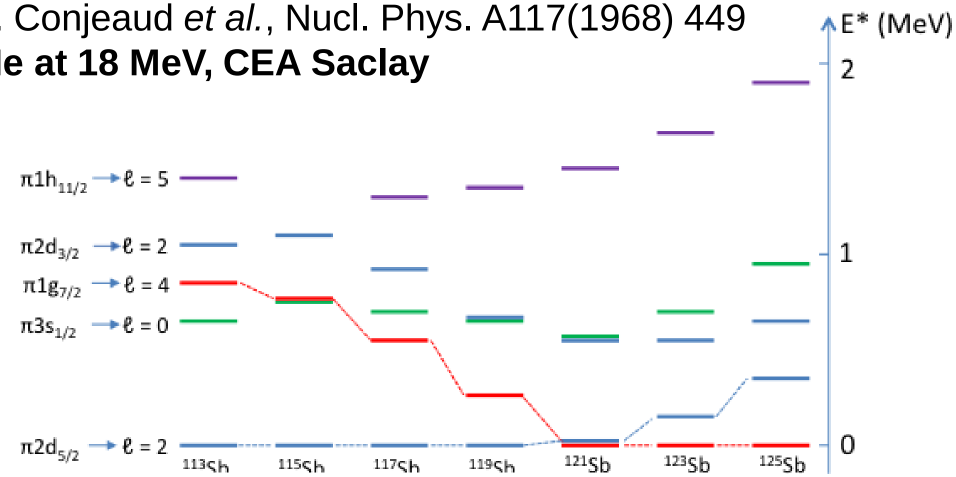


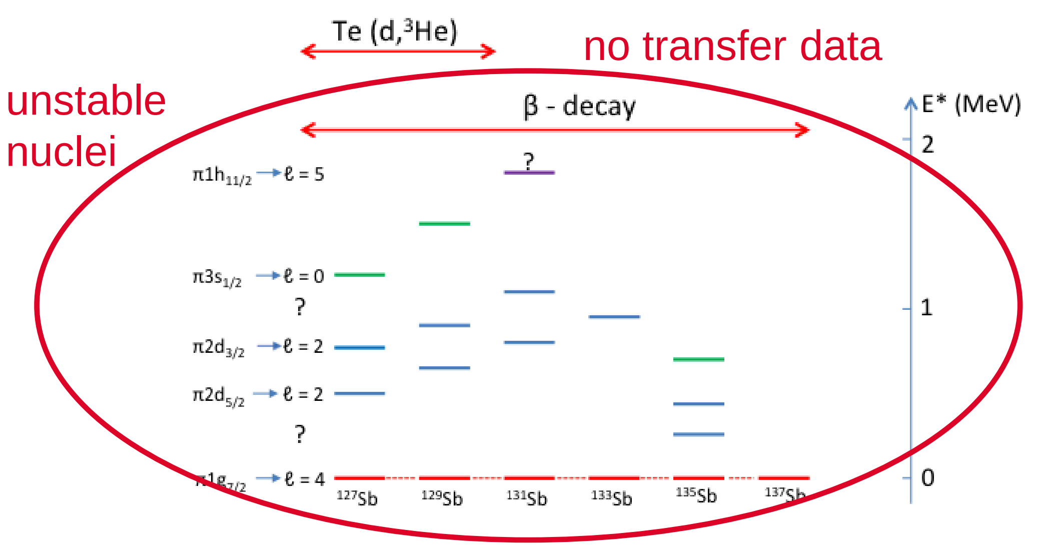


J. P. Schiffer *et al.*, PRL **92** (2004)

M. Conjeaud *et al.*, Nucl. Phys. A117(1968) 449

^{3}He at 18 MeV, CEA Saclay



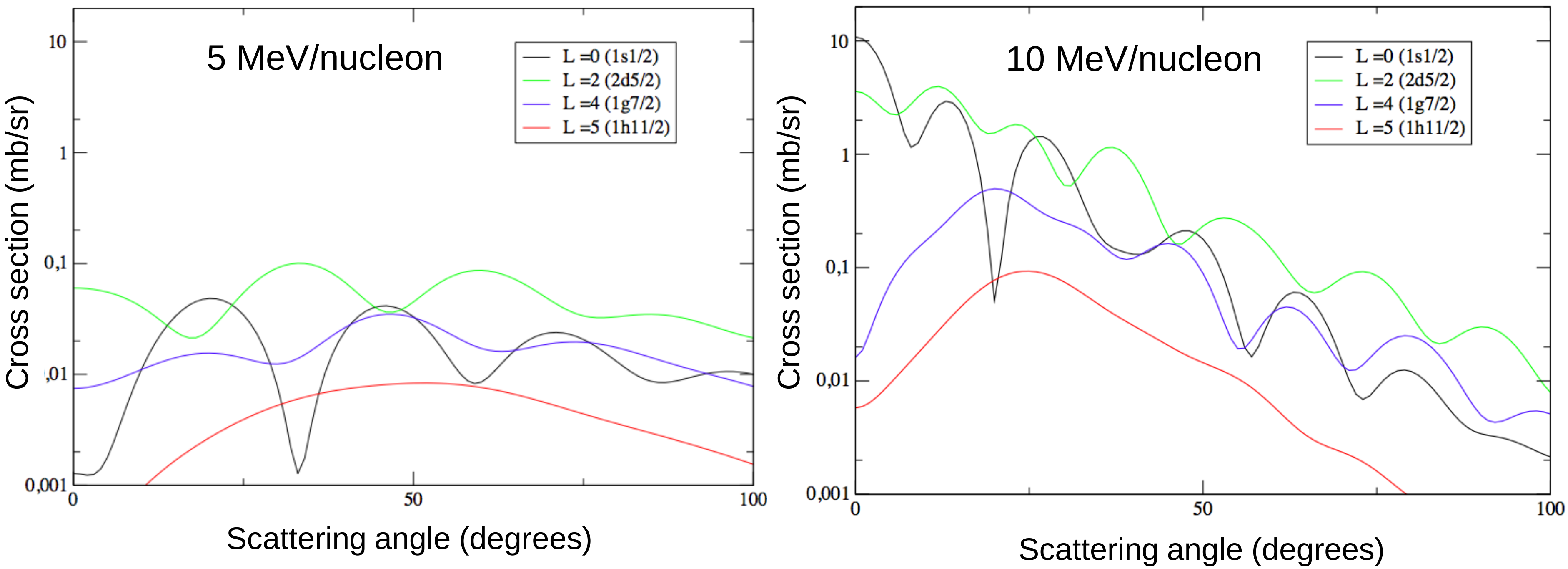


Courtesy A. Gillibert, CEA

Particle proton states along the Sn chain

Systematics of *(^{3}He,d) and/or (α,t)* measurement to be performed for N=74-82

^{132}Sn(^{3}He,d)^{133}Sb

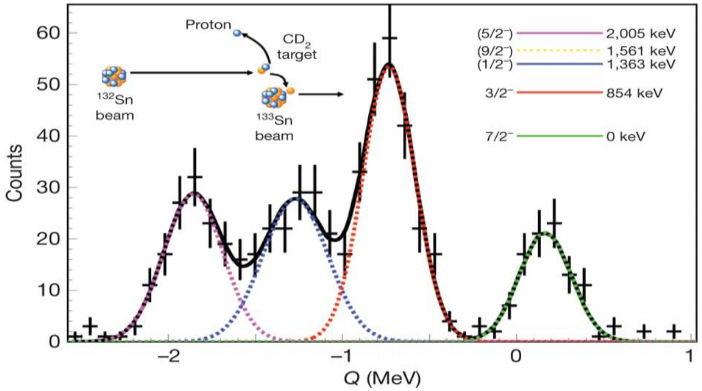


DWBA calculations
Courtesy F. Flavigny, IPN Orsay

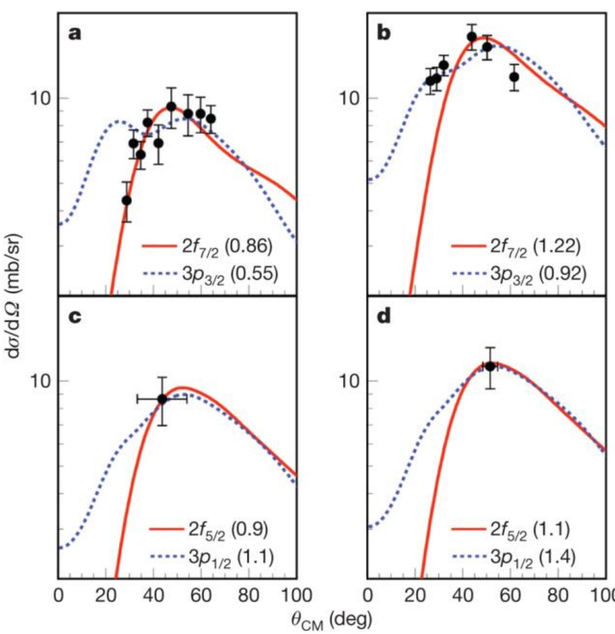
Energies of > 8 MeV/nucleon better suited:
- Higher cross sections
- More selectivity

He gas jet target to be used / developed

Neutron structure of ^{132}Sn and beyond



KL Jones *et al.* *Nature* **465**, 454-457 (2010)



^{132}**Sn(d,p)**^{133}**Sn** at 5 MeV/nucleon at ORNL

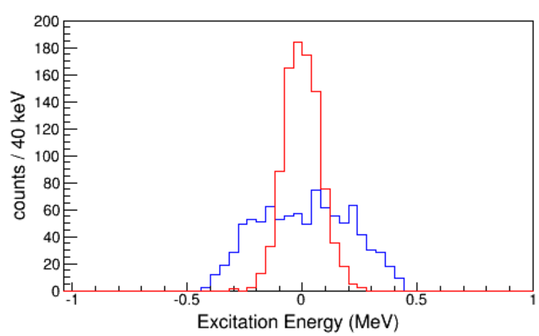
To be *re-measured !*

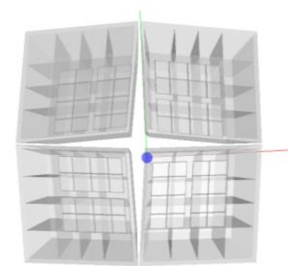
- (d,p) AND (p,d)
- (d,d), (p,p) elastic scattering for optical potentials
- sufficient statistics for differential cross sections
- at energy larger than 6 MeV/nucleon

CD_2 200 μg.cm^{-2} σ= 200 keV FWHM

CD_2 800 μg.cm^{-2} σ= 560 keV FWHM

MUST2
forward angles





Simulations: courtesy A. Corsi, CEA

Extension to ^{134}**Sn(d,p)**^{135}**Sn,** ^{134,136}**Te(d,p)**^{135,137}**Te**

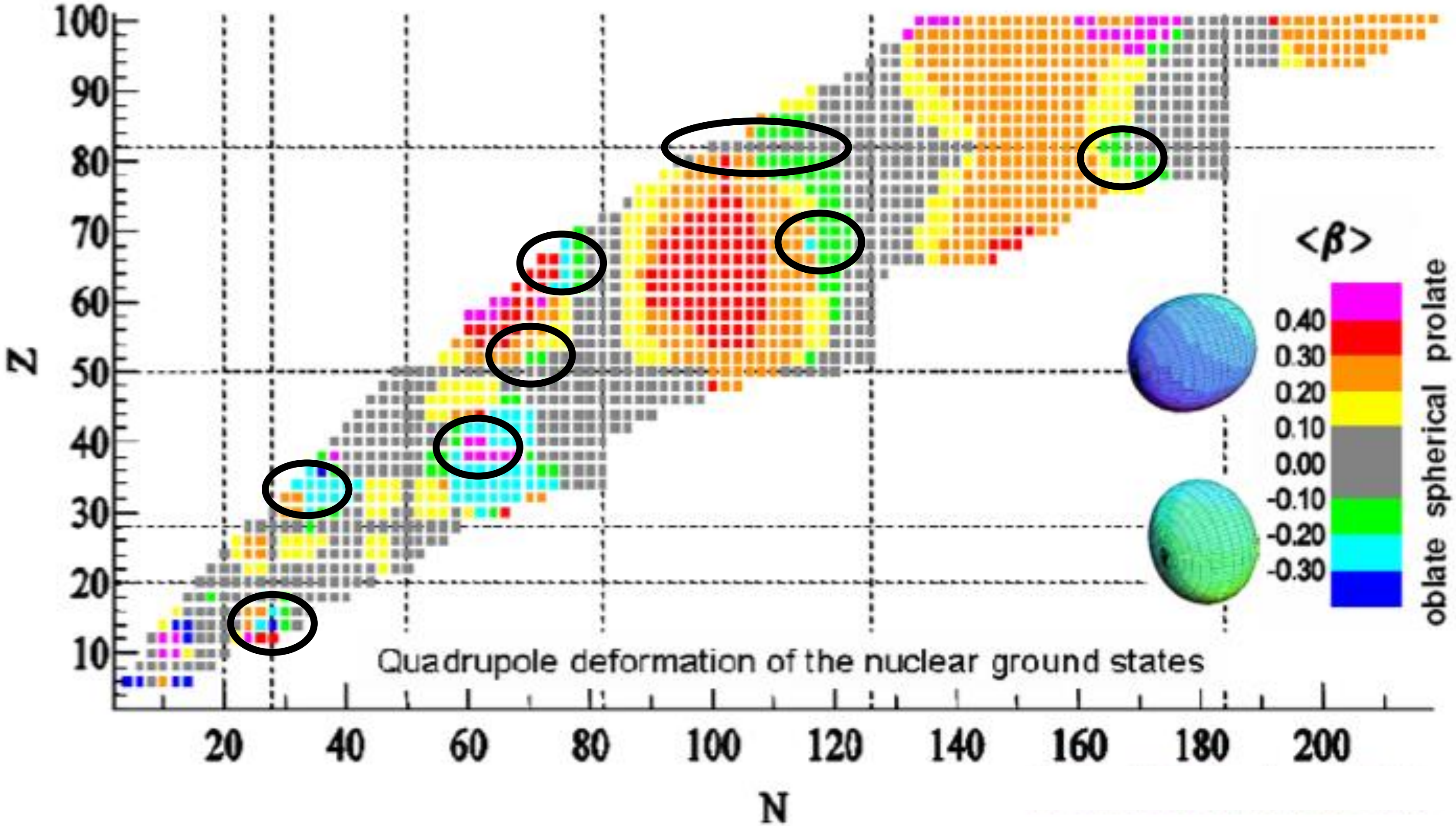
SPIRAL2 Letters of Intent

LOI 2006: LoI 16, V. Lapoux *et al.*,

LOI 2011: LoI_SP2_Ph2 33, V. Lapoux, O. Sorlin *et al.*

Probing shapes: coexistence and transitions

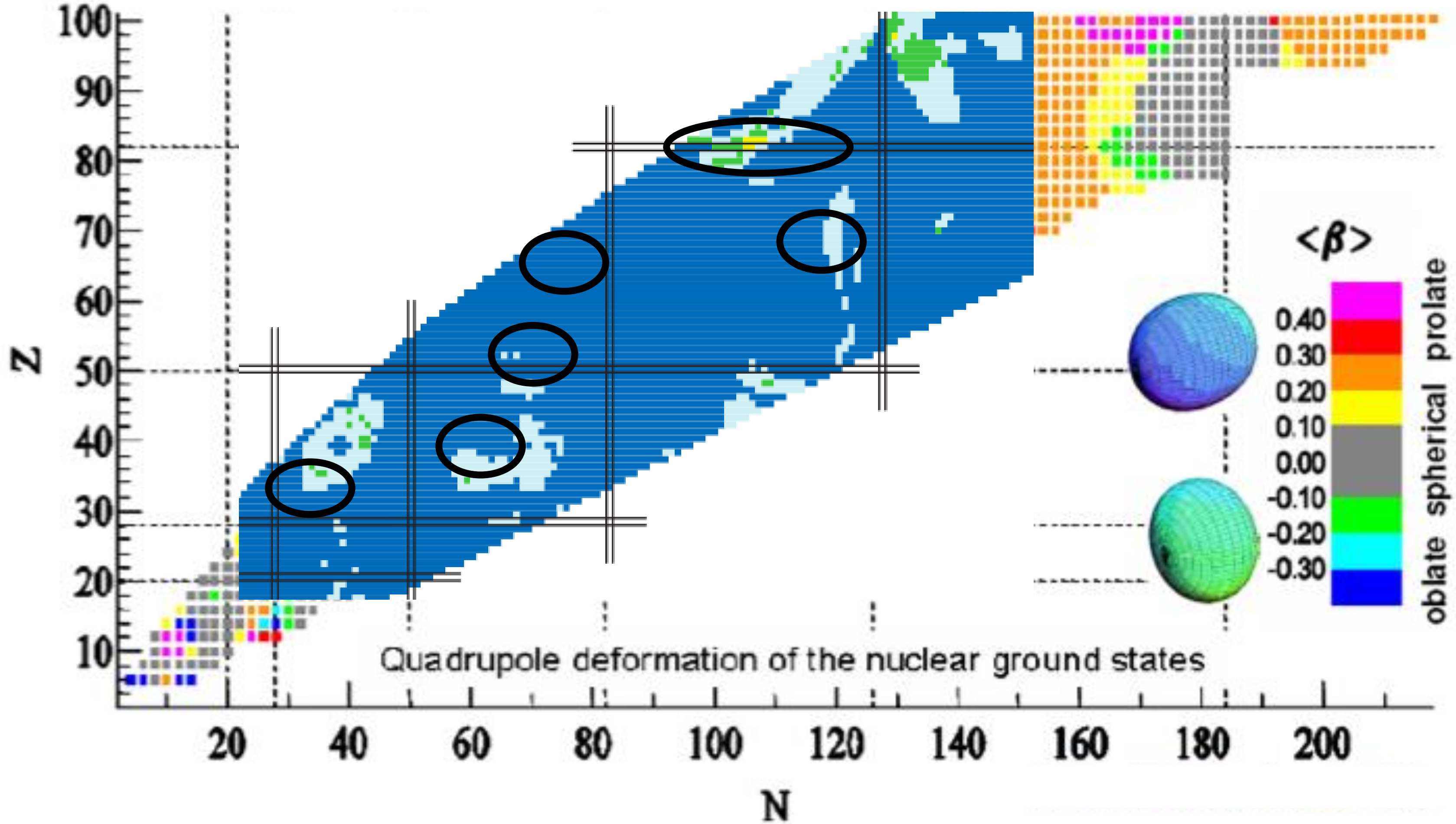
Letter of Intent for SPIRAL2 (nº 32): shape coexistence in n-rich Sr and Kr isotopes around N=60
E. Clément, L. Nalpas *et al.*



Calculations by M. Girod, CEA/DAM, see also J.-P. Delaroche *et al.*, PRC **81** (2010)

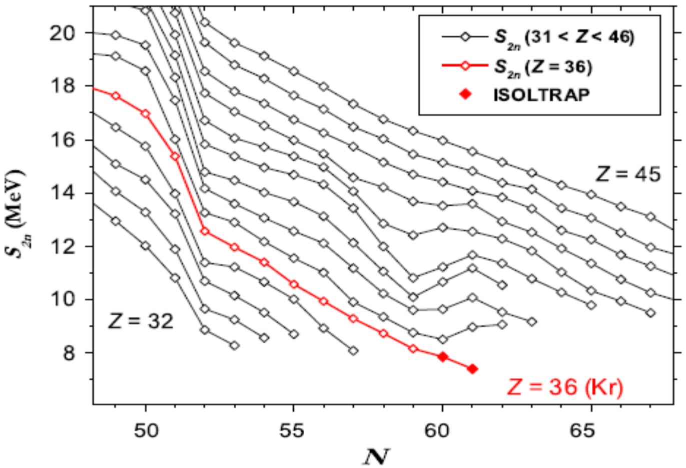
Probing shapes: coexistence and transitions

P. Moller *et al.*, Phys. Rev. Lett. **103** (2009)

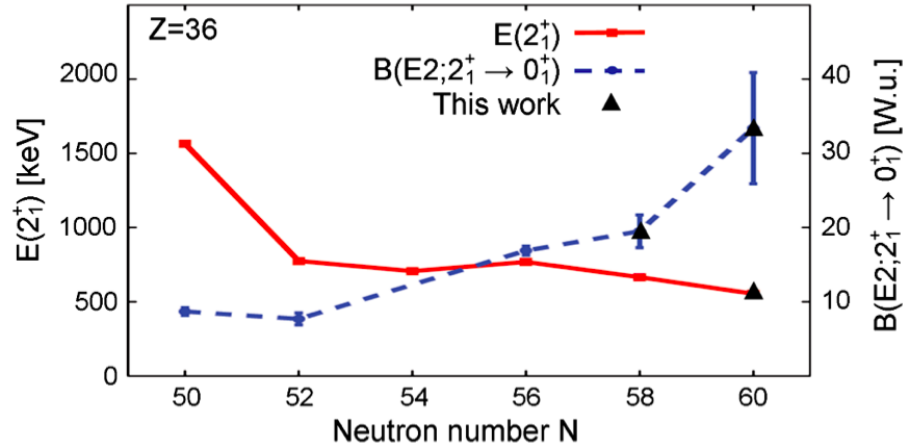


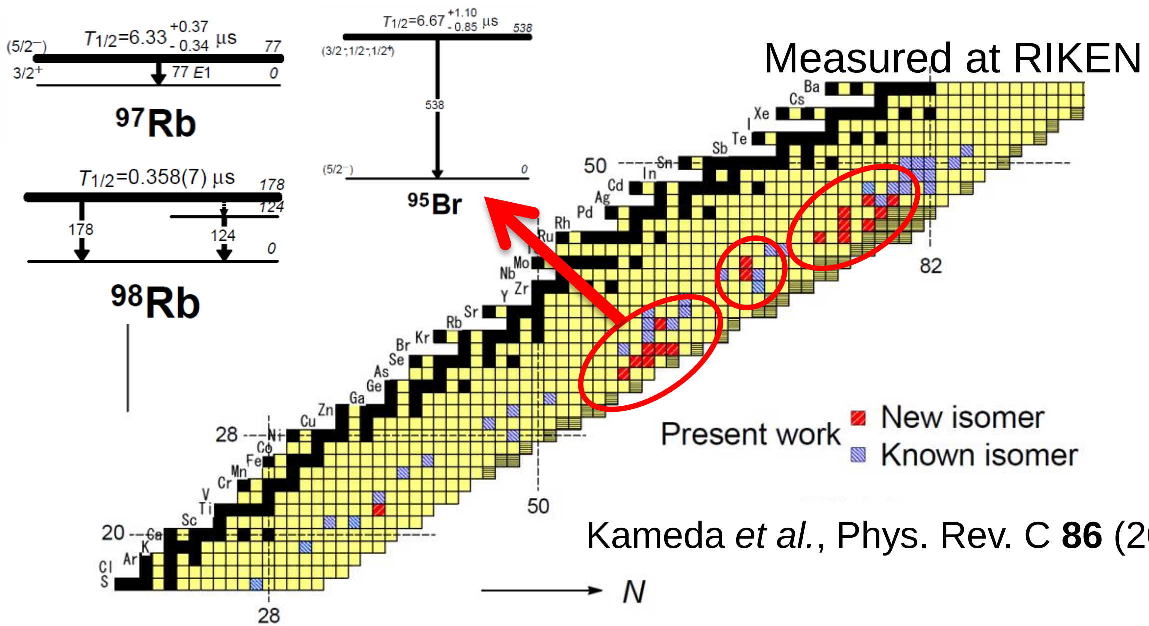
Shape coexistence at N=60

S.Naimi *et al.*, PRL **105** (2010)



M. Albers *et al.*, PRL **108** (2012)

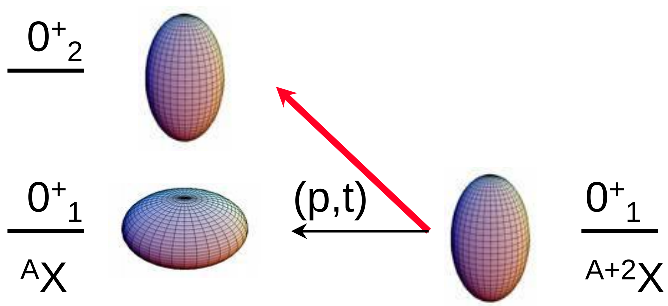


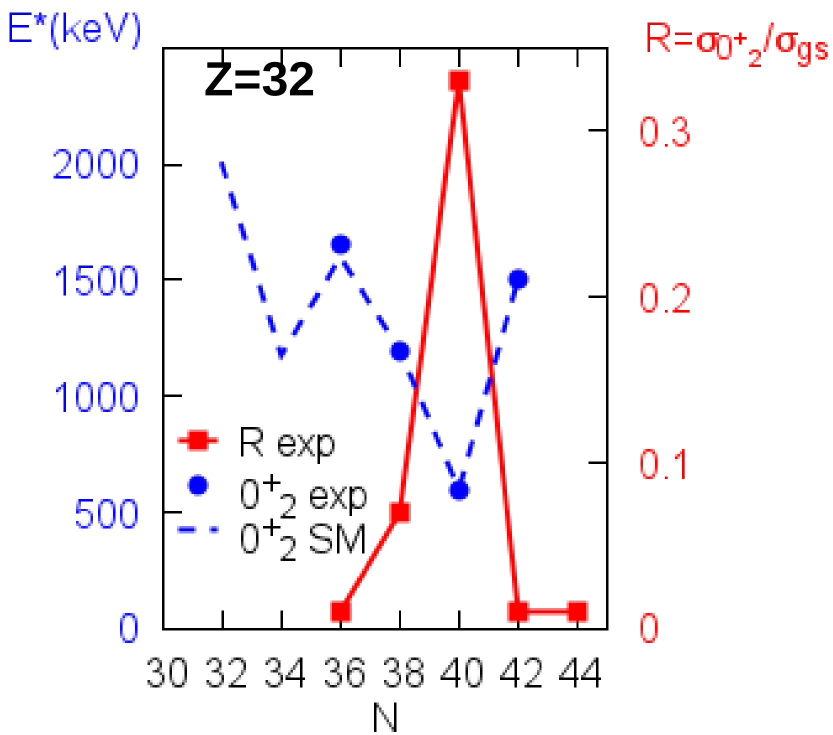


Kameda *et al.*, Phys. Rev. C **86** (2012)

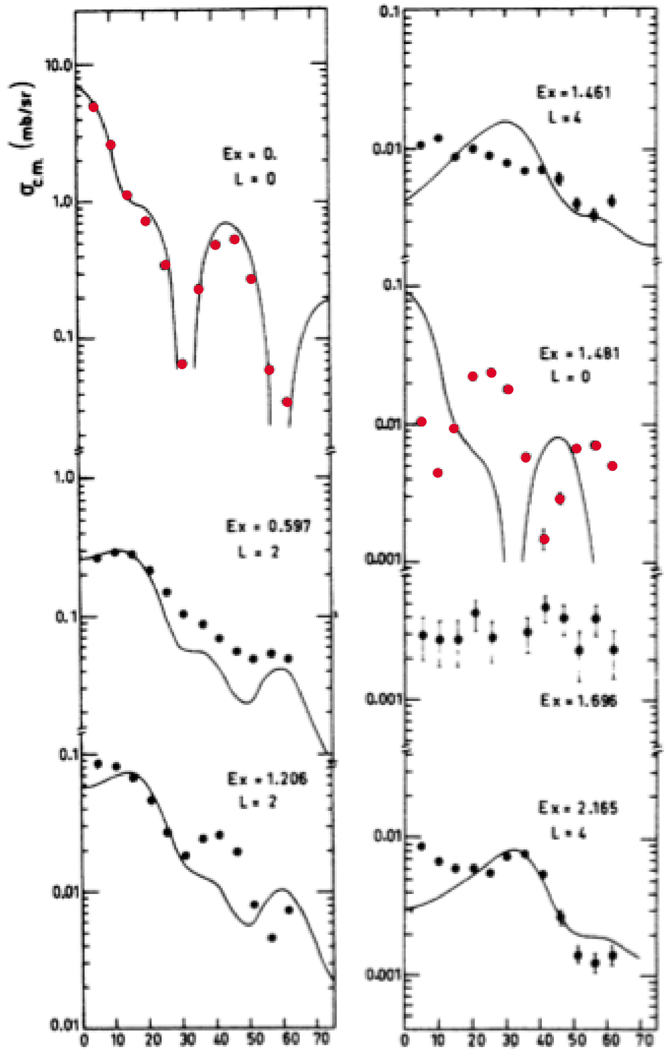
Two nucleon transfer to probe shape transitions

***Ex.* Shape transition** in light Ge isotopes



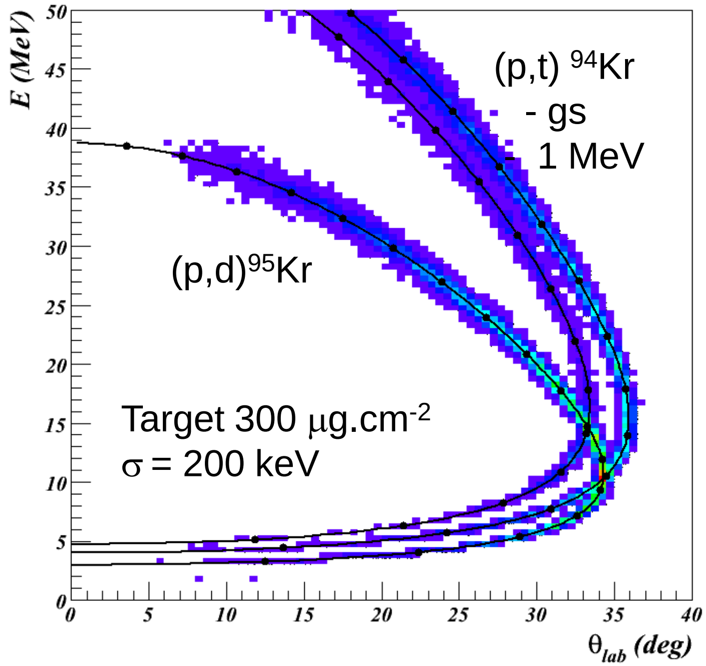


F. Guilbault *et al.*, PRC **16** (1977)



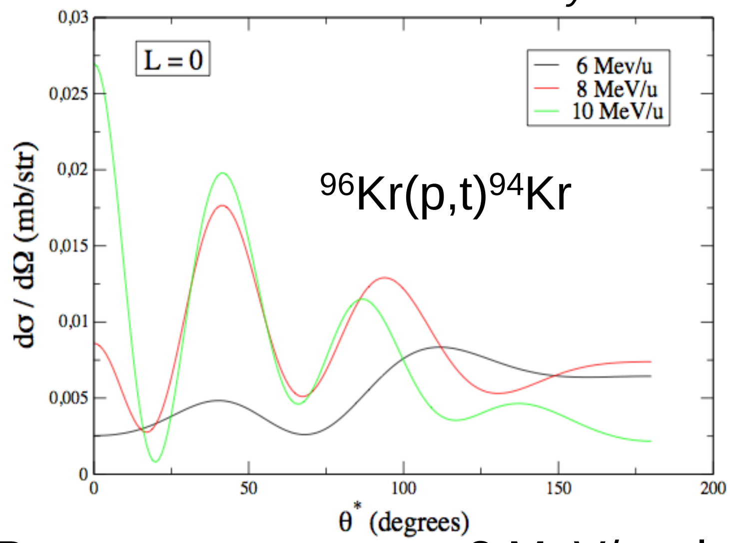
Note: does not (too much) depend on the incident energy

Investigation in heavy Kr isotopes and light Hg

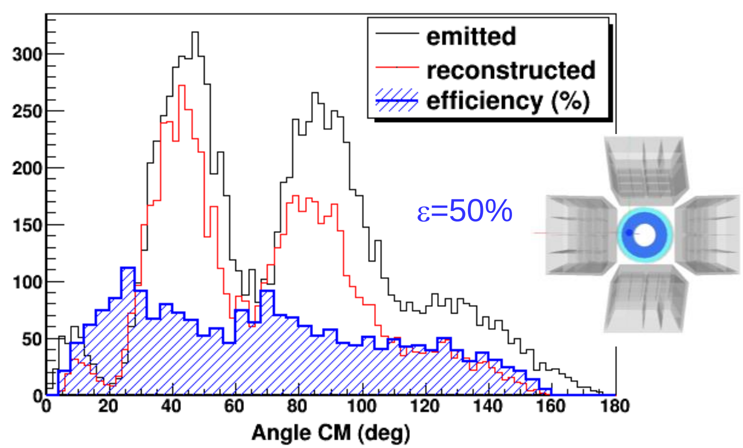


Coupling to gamma detection necessary!

Courtesy N. Keeley, Warsaw



Best energy range : > 8 MeV/nucleon



Case of light Hg isotopes:
Existing HIE-ISOLDE Letter of Intent
Shape coexistence in the neutron-deficient region around Z=82 studied via Coulomb excitation and few-nucleon transfer reactions

P. Van Duppen (Leuven), D. Joss (Liverpool),
D. Jenkins (York), J. Pakarinen (CERN)

CHyMENE: pure and thin solid hydrogen target

Objective

Solid H_2 or D_2 target 50 µm
50 µm H2 = 350 μg.cm^{-2}
Windowless

CHyMENE specifications

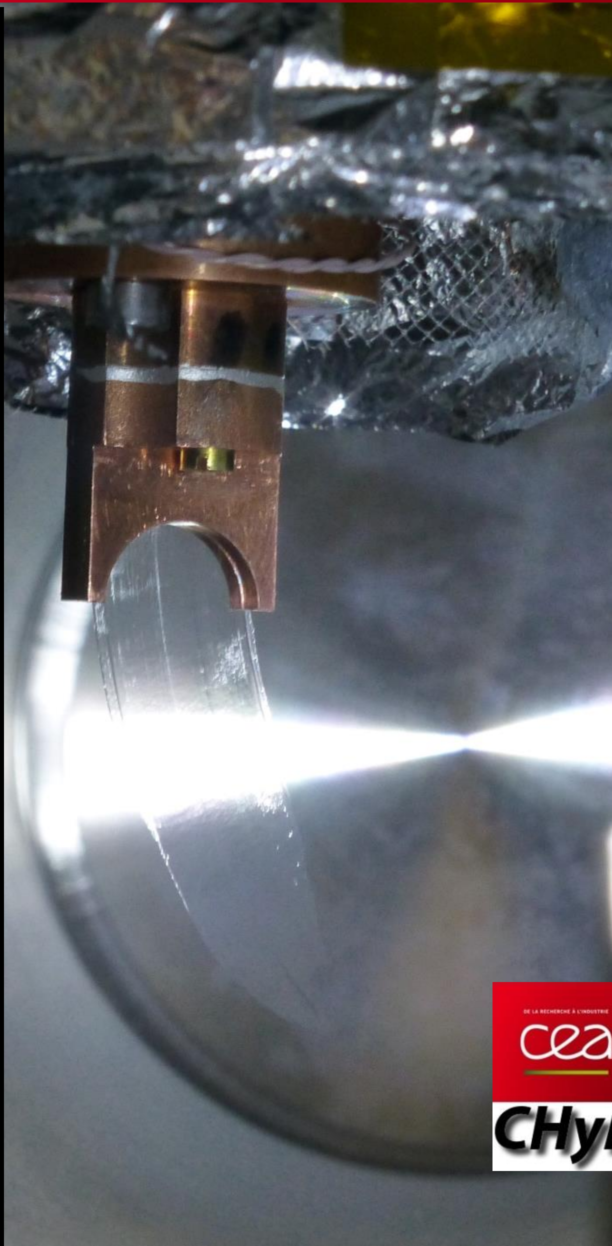
Cryogenic Power: 15 W at 12 K
Extrusion speed: 2 to 10 mm/s
Correct positioning of the ribbon
Vacuum reaction chamber: 5.10^{-5} mbar
Autonomy: At least 2 weeks
Target vertical translation: 100 mm
Target rotation: +/- 45 °

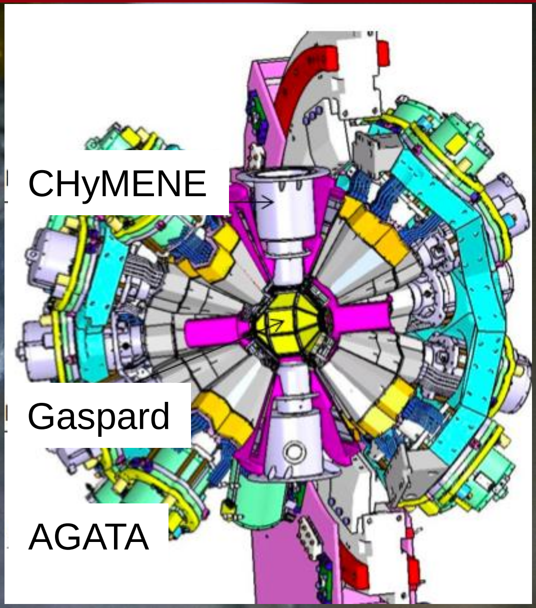
Homogeneity

Estimated in-beam to about 10%
To be improved with current system

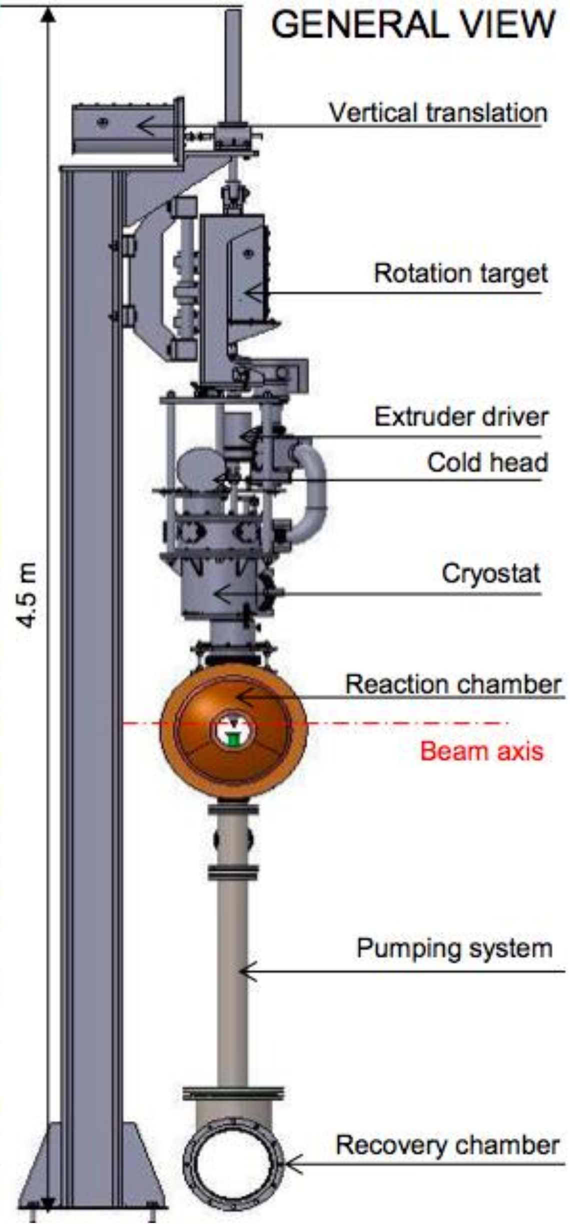
A. Gillibert *et al.*, EPJA **49** (2013).

Operational from 2016

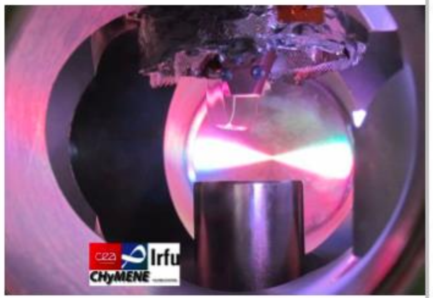




CHyMENE: pure and thin solid hydrogen target

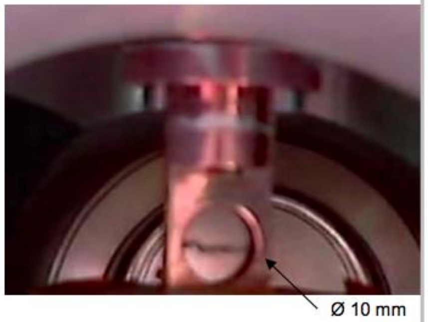


No guide
Nozzle without side guides: no vertical flow but nice ribbon quality

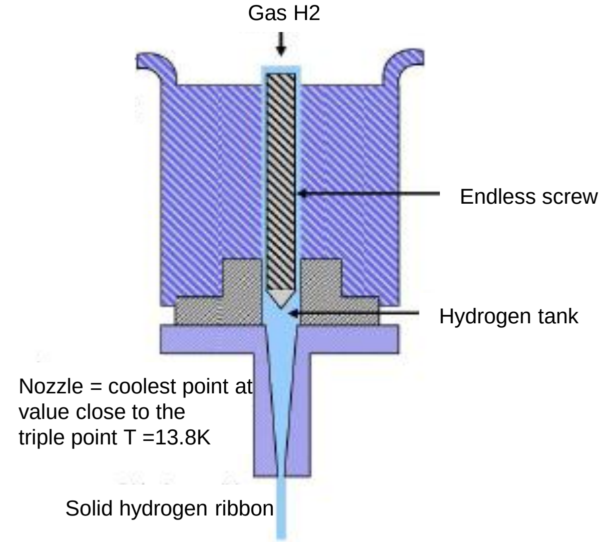


Thickness: 90 µm

Total guide
Nozzle polished, equipped with side guides for a vertical flow with a good ribbon quality



Thickness: 75µm



ASIC electronics for particle detection

Several ongoing Si-detection arrays:
- GASPARD TRACE array (IPNO, Padova project: 5-year term)
- Update of T-REX (discussion organized by D. Mucher in 2014)
- New generation array for ISOLDE?

ASIC-based system required!

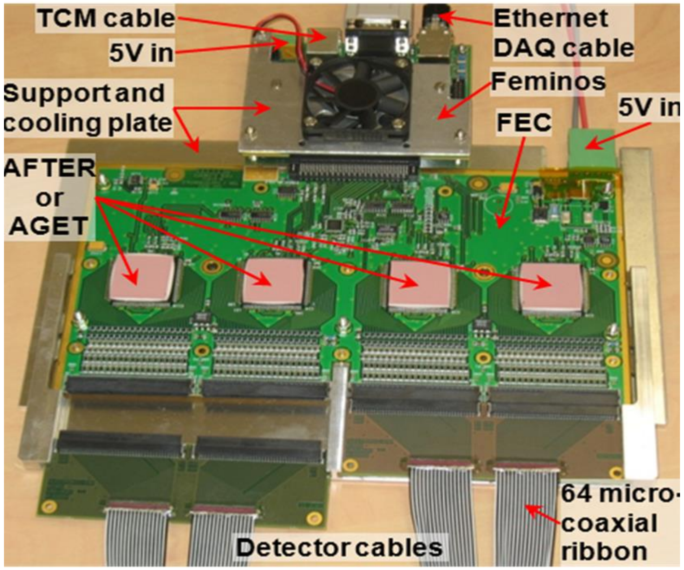
Existing expertise:
***MUST2** developments:*
Si detection and associated electronics (MATE, ATHED)

*Recently, **GET**: General Electronics for TPCs*
IRFU-IPNO-GANIL-NSCL collaboration
(Aget from IRFU, used for MINOS)

CEA IRFU : about 15 engineers + software/DAQ

Possible solution for particle detection at ISOLDE:
Feminos+MATE or ATHED (about 1 year development)

FEMINOS: used at RIKEN in 2014



MINOS developed in 2010-2013:
5000 digital electronics channels

Internal discussions on potential detection developments at ISOLDE with E.C. Pollacco and CEA engineers

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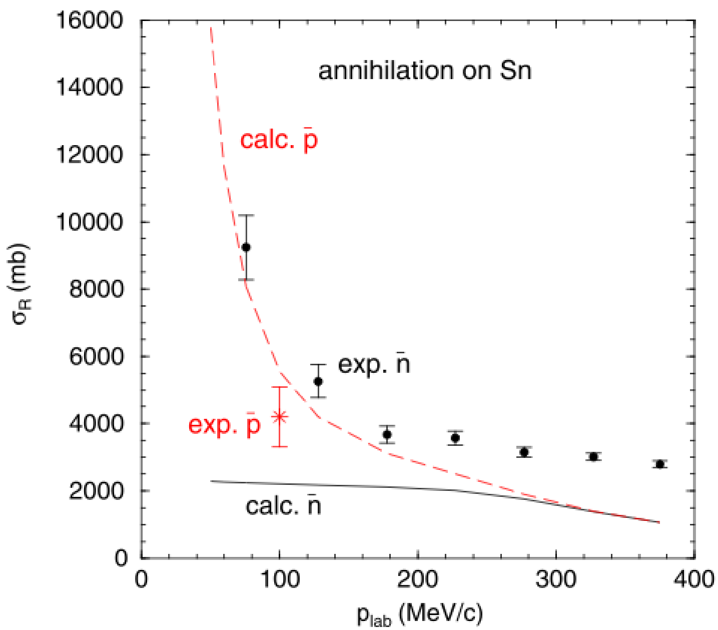
Antiproton – nucleus interaction

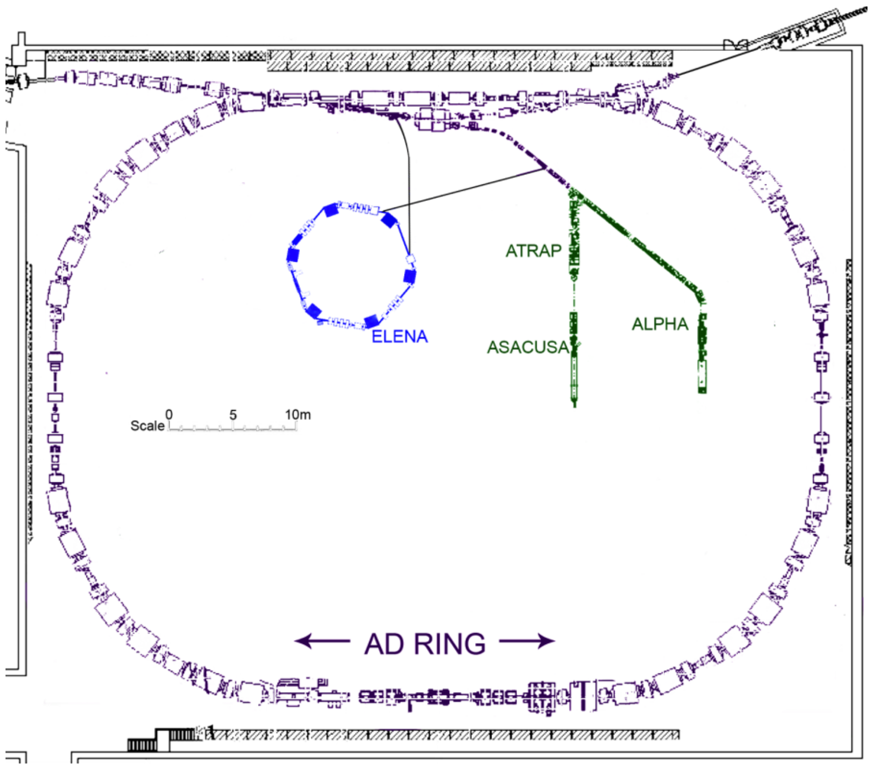
- Nucleon annihilation: most perfect « stripping »
- Surface process

- P + N -> pions (mean multiplicity = 3)
- High survival probability: p + A ➔A-1
  P= 10-60%

- Stable nuclei studies at LEAR/CERN
  in the 70s-90s



E. Friedman, NPA **925** (2014)



Antiprotons at CERN
AD (antiproton decelerator): 5.3 MeV
ELENA: down to 100 keV from 2017

Bunches of 10^6 low-energy antiprotons

Unstable nuclei – antiproton collisions

ions – antiprotons collider
(AIC project, phase 3 of FAIR, not funded)

OR

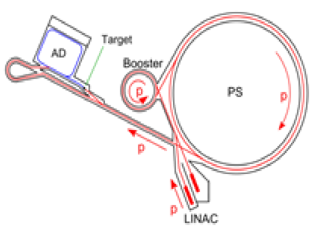
stored antiprotons – slow ions collisions
(PUMA concept)

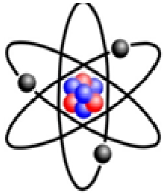
Antiproton factory
- CERN, Fermilab,...
- Future machine

trapping → long storage → transport

Users facility
- RIB factory
- Space agency lab

controlled extraction → Fundamental physics, Application





CERN: AD+ELENA

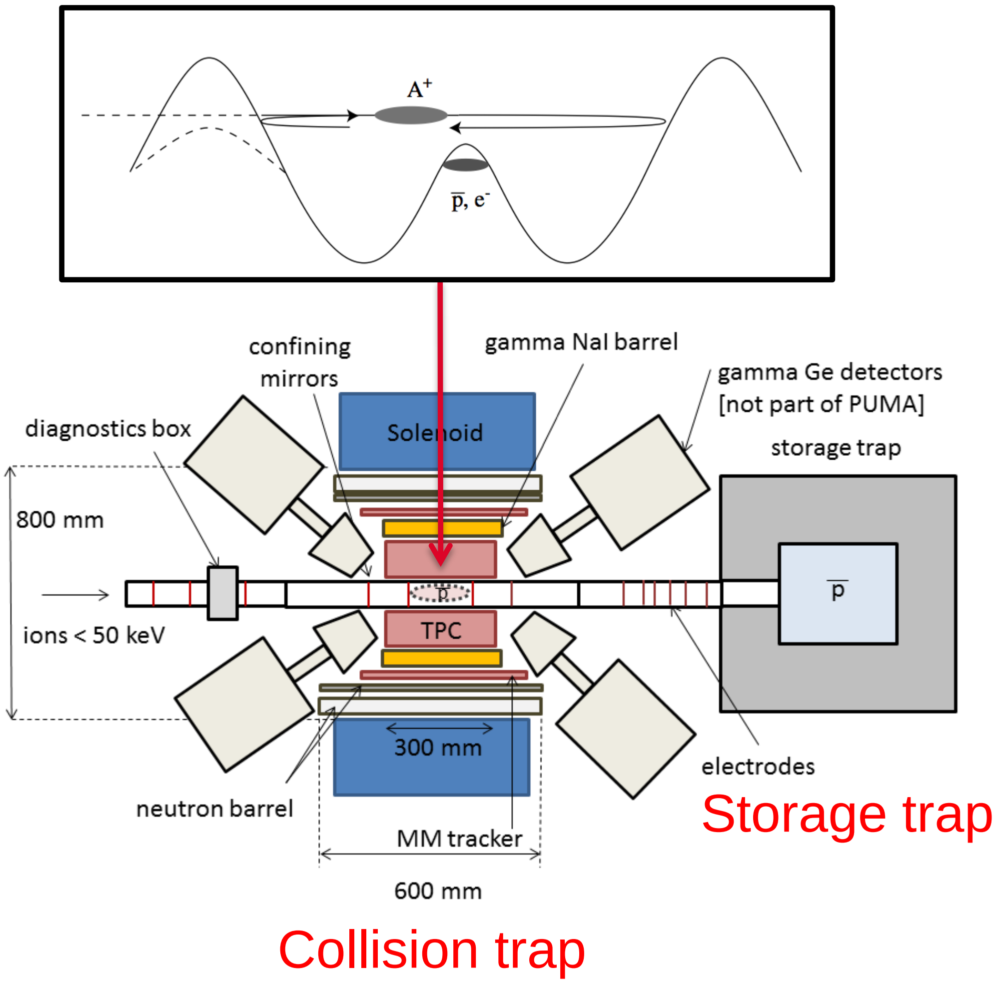
ISOLDE (or SPIRAL2)

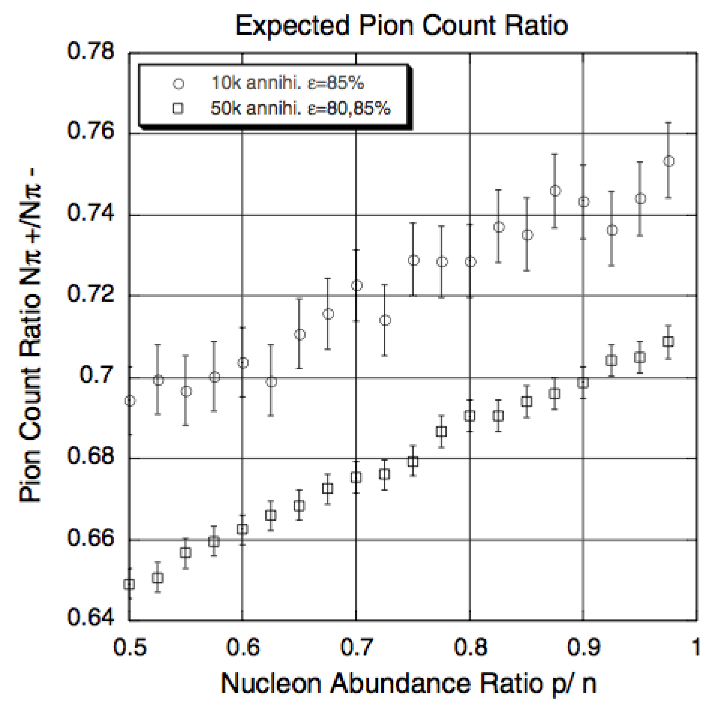
Project for R&D: transportable storage of antiprotons (10^9) with controled extraction
Main difficulty: extreme vacuum (< 10^{-13} mbars)

PUMA: Pbar Unstable Matter Annihilation

PUMA: a first-of-its-kind project at AD-ELENA and CERN-ISOLDE

Objectives: neutron skin, ρ_n/ρ_p, spectroscopy of heavy elements





M. Wada and Y. Yamazaki, NIM B **214** (2004)

Summary

- **Low-energy transfer** is a key tool to investigate nuclear structure

- HIE-ISOLDE offers **new opportunities** for energies above 8 MeV/nucleon
  ex. high quality transfer data from (d,p),(p,d) from ^{132,134}Sn and ^{134}Te
  ex. proton single-particle states Sn(^{3}He,d)Sb
  ex. ^{96}Kr and Hg regions from two nucleon transfer

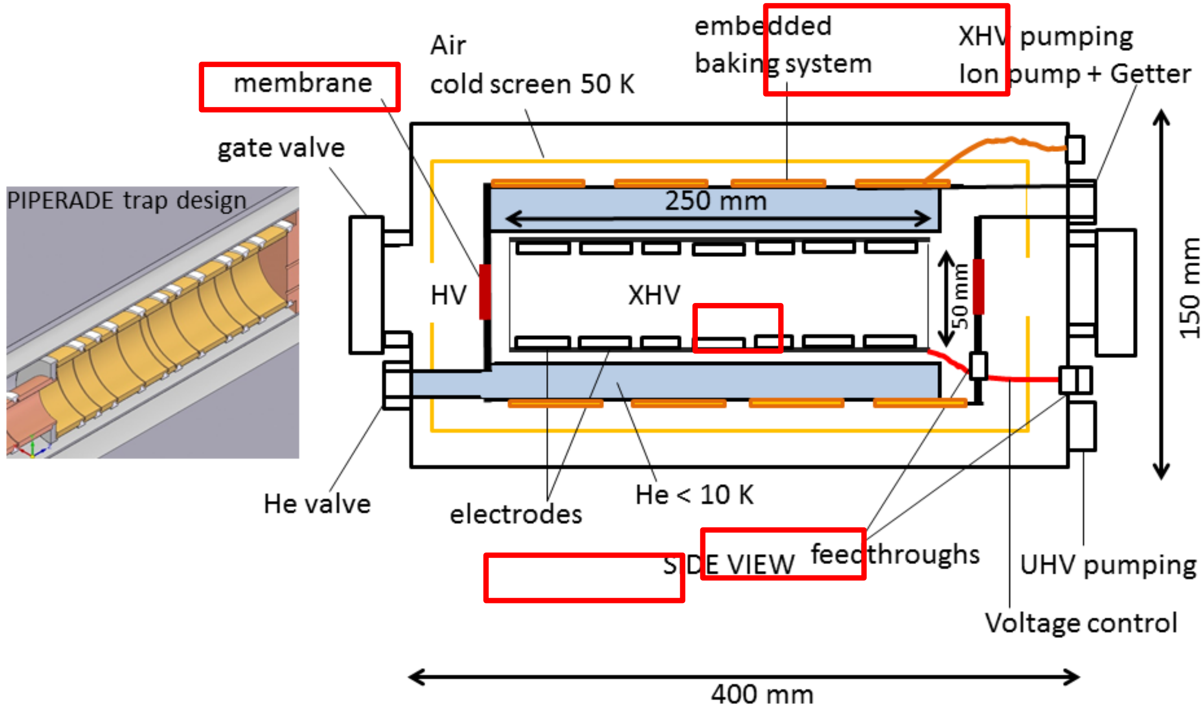
- Members of the **MUST2** collaboration willing to commit and collaborate
  - participate/collaborate to first experiment(s)
  - propose a program at >8 MeV/nucleon on a second stage (>2016)
  - take part / collaborate on technical developments for HIE-ISOLDE

- **New developments, ideas** are ongoing
  ex. CHyMENE a THIN windowless solid pure hydrogen target
  ex. PUMA: cold antiprotons for annihilation from low-energy rare isotopes

Thank you for your attention! … and special thanks to
D. Calvet, A. Gillibert, J.-M. Gheller, V. Lapoux, E.C. Pollacco (CEA Saclay)
Y. Blumenfeld, F. Flavigny (IPN Orsay)
N. Keeley (Warsaw)

DE LA RECHERCHE À L'INDUSTRIE

Necessary R&D for PUMA



Objectives:

Phase 1 (1.5 years)

- transmission through thin membranes
- extreme vacuum (<10^{-13} mbar): *pre-baking* *(150 °C)*, surface treatment, ion pumps, getters, cryo-pumping (<10 K)

Phase 2 (1.5 years) trapping, cooling (electrons) et controled extraction of ions

Phase 3 (1 year) antiproton trapping

Phase 4 (0.6 years) experiment at ISOLDE