Direct Reactions with Exotic Beams: A Historical Overview

Yorick Blumenfeld

IJCLab Orsay

CNRS Researcher Emeritus

The Initial Physics Motivation

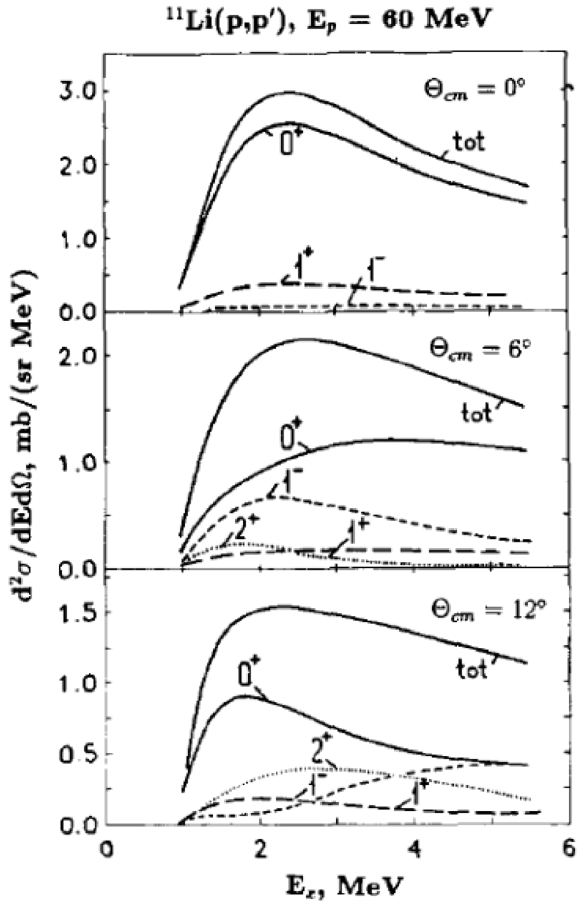
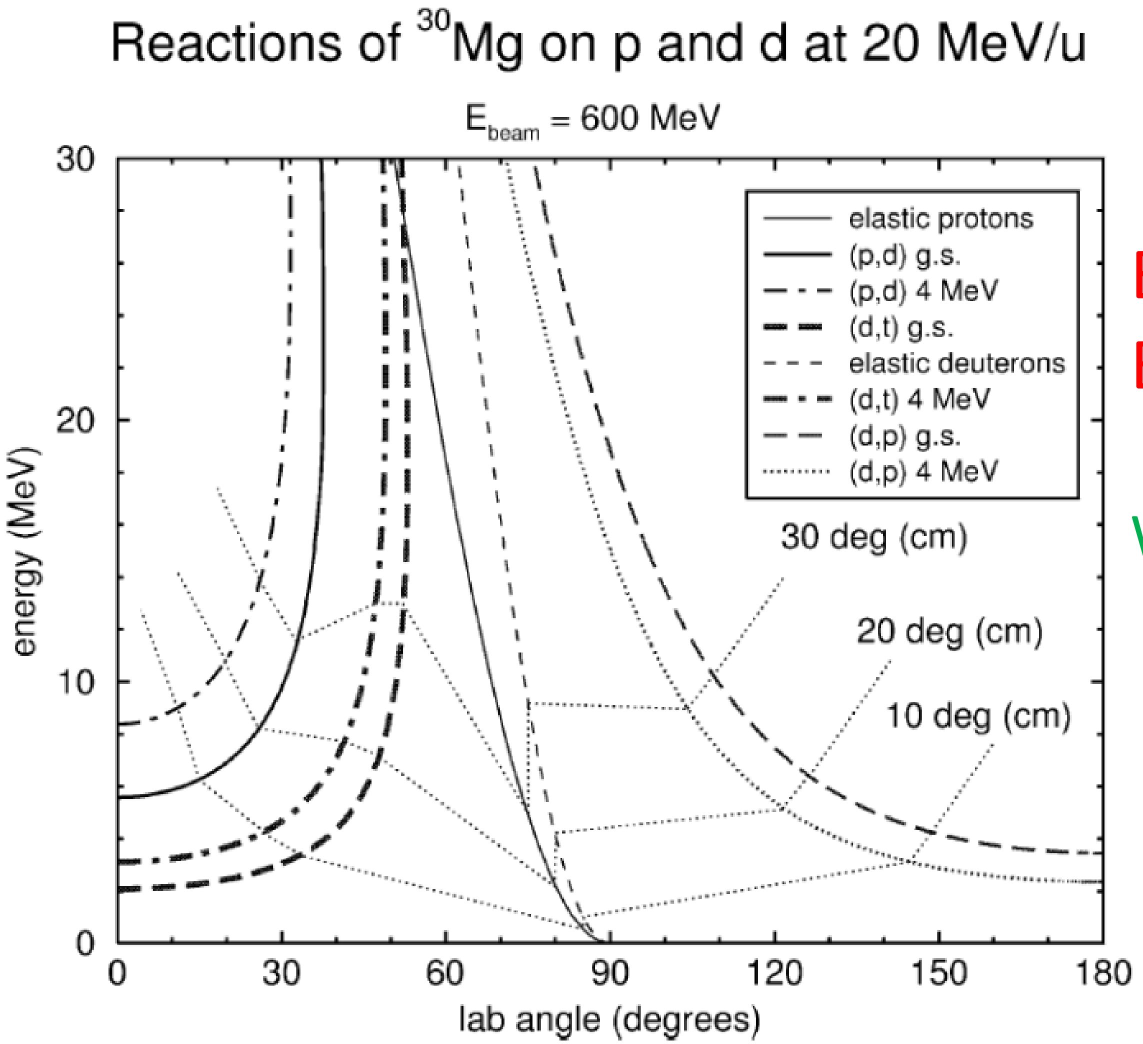


Fig. 1. Inclusive proton energy spectra from the ^{11}Li(p, p′) reaction at $E_p = 60$ MeV versus the excitation energy E_x for the three values of scattering angle θ_{cm}. The contributions from excitations with various J^π transfers are shown separately.

Soft modes in halo nuclei excited by (p,p') scattering

S.A. Fayans, S.N.Ershov and E.F. Svinareva
Physics Letters B292 (1992) 239.

Inverse Kinematics



E/A (inverse kinematics) =

E_p (normal kinematics)

W.N. Catford; Nucl. Phys. A 701 (2002) 1c

First Inverse Kinematics Experiment

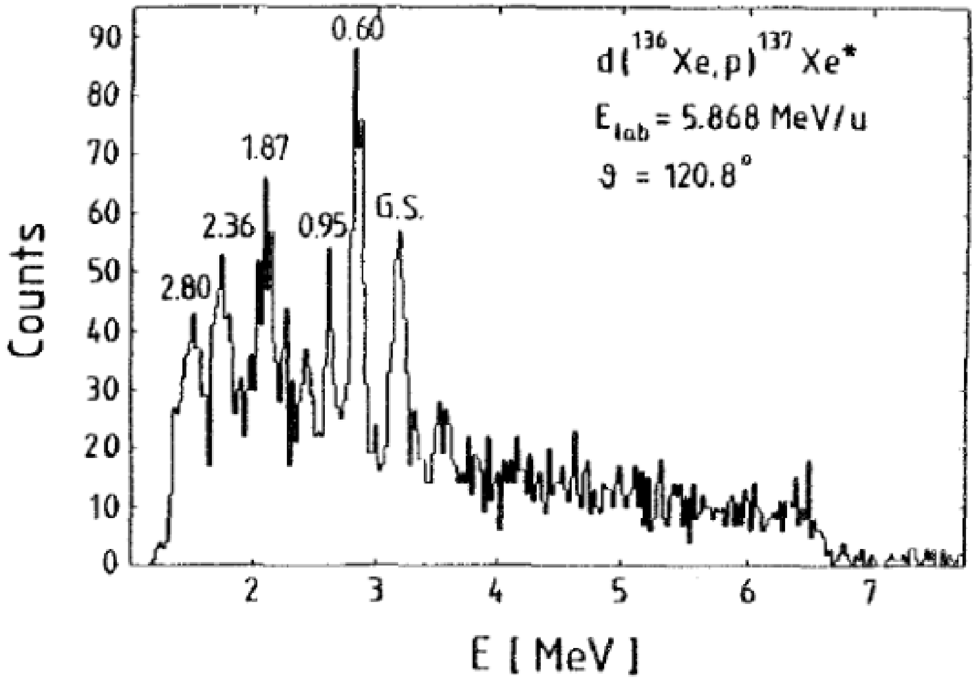
Z. Phys. A – Hadrons and Nuclei 340, 339–340 (1991)

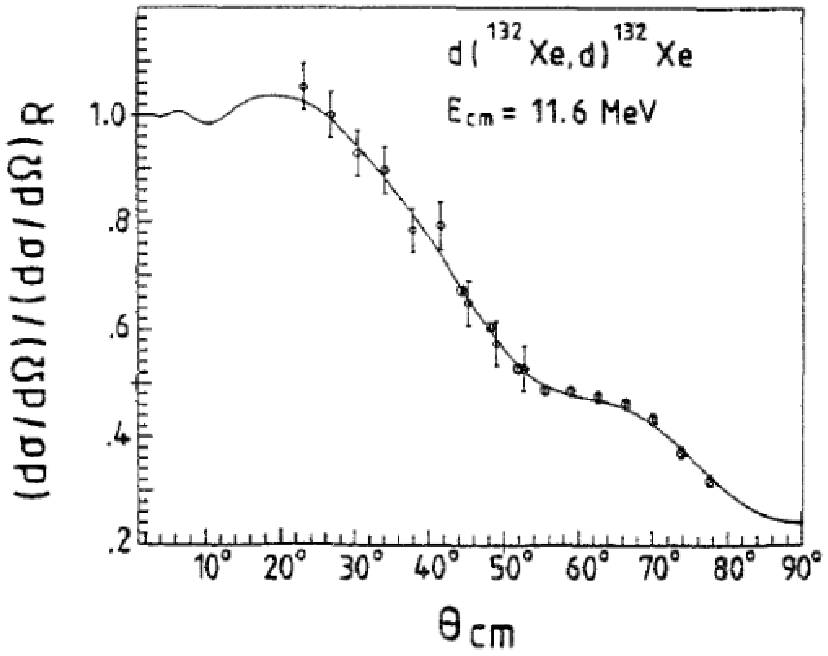
Zeitschrift für Physik A Hadrons and Nuclei

Short note

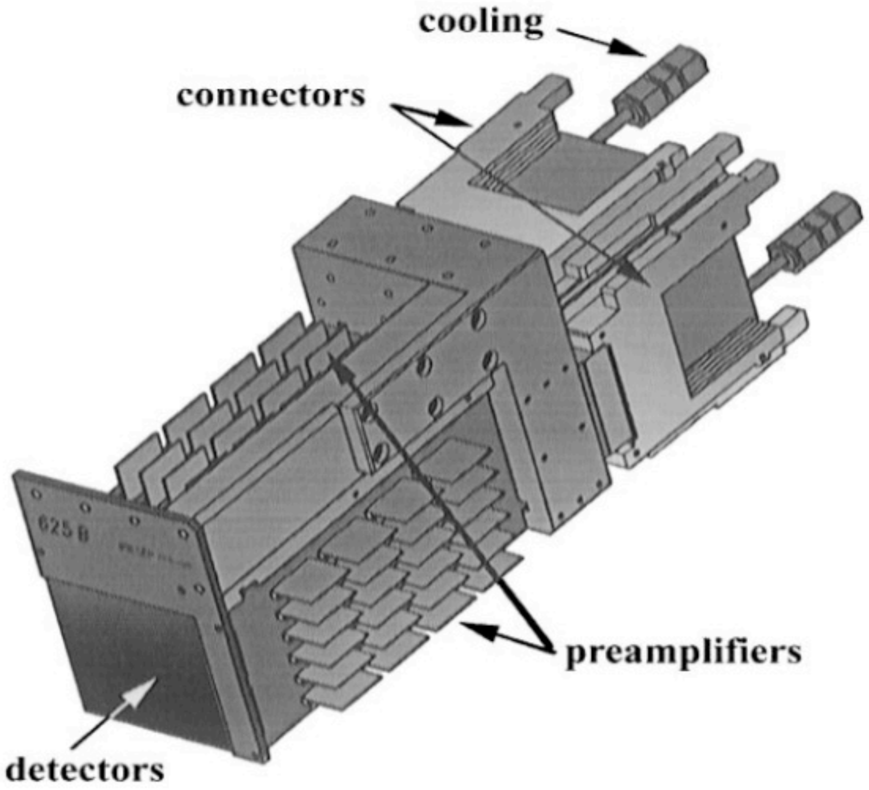
Investigation of the (*d*, *p*)-reaction on ^{136,132}Xe in inverse kinematics*

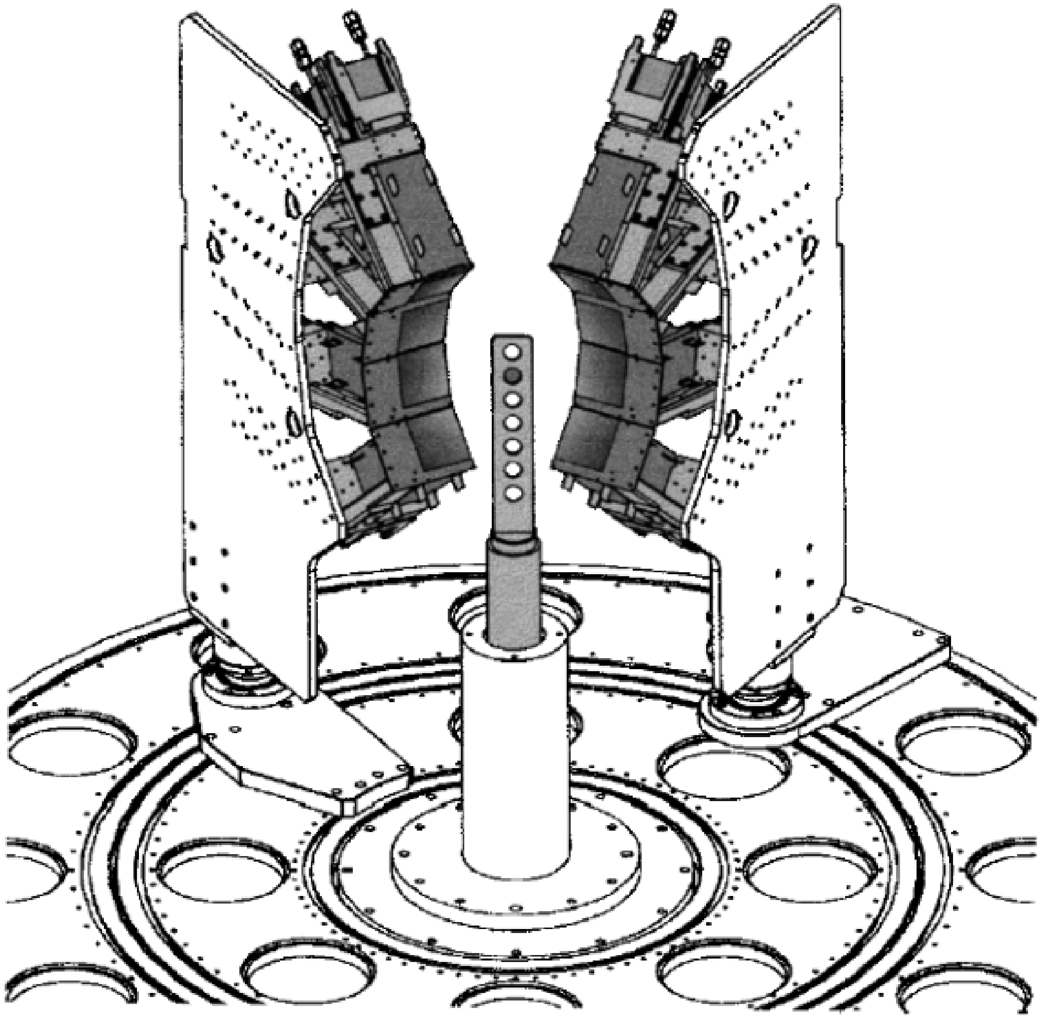
G. Kraus[1], P. Egelhof[1], H. Emling[1], E. Grosse[1], W. Henning[1], R. Holzmann[1], H.J. Körner[2], J.V. Kratz[3], R. Kulessa[4], Ch. Schießl[2], J.P. Schiffer[5], W. Wagner[2], W. Walus[4], and H.J. Wollersheim[1]





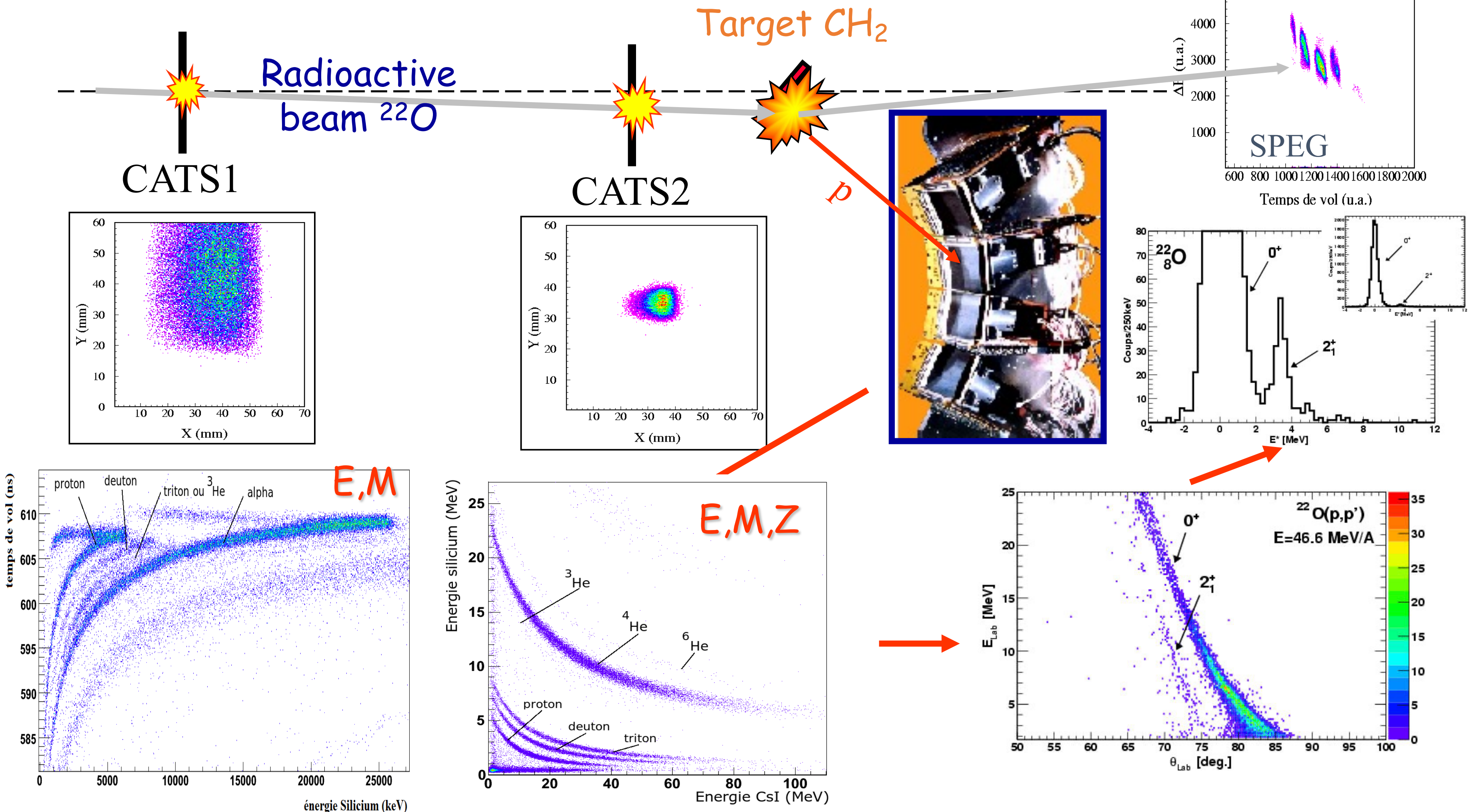
The MUST Array





A Typical Direct Reaction Experiment $^{22}O(p,p')$

MUST: Y. Blumenfeld et al., *NIM* **A366** (1999) 298
CATS: S. Ottini-Hustache et al., *NIM* **A431** (1999) 476



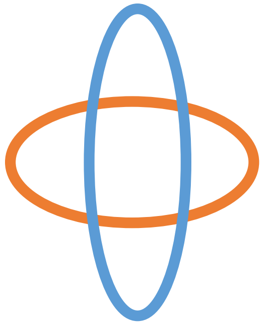
Simple interpretation of M_n/M_p

Low lying collective state

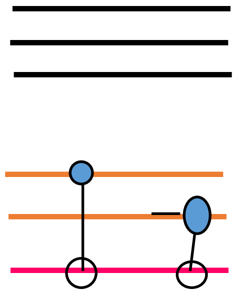
$$M_{n,p} = \int \rho^{tr}_{n,p}(r) r^{l+2} dr$$

$$\frac{M_n}{M_p} = \frac{b_p}{b_n}\left[\frac{\delta^F}{\delta_p}\left(1+\frac{N}{Z}\frac{b_n}{b_p}\right)-1\right]$$

Bernstein Formula
Proof by Elias Khan PRC 105 014306 (2022)



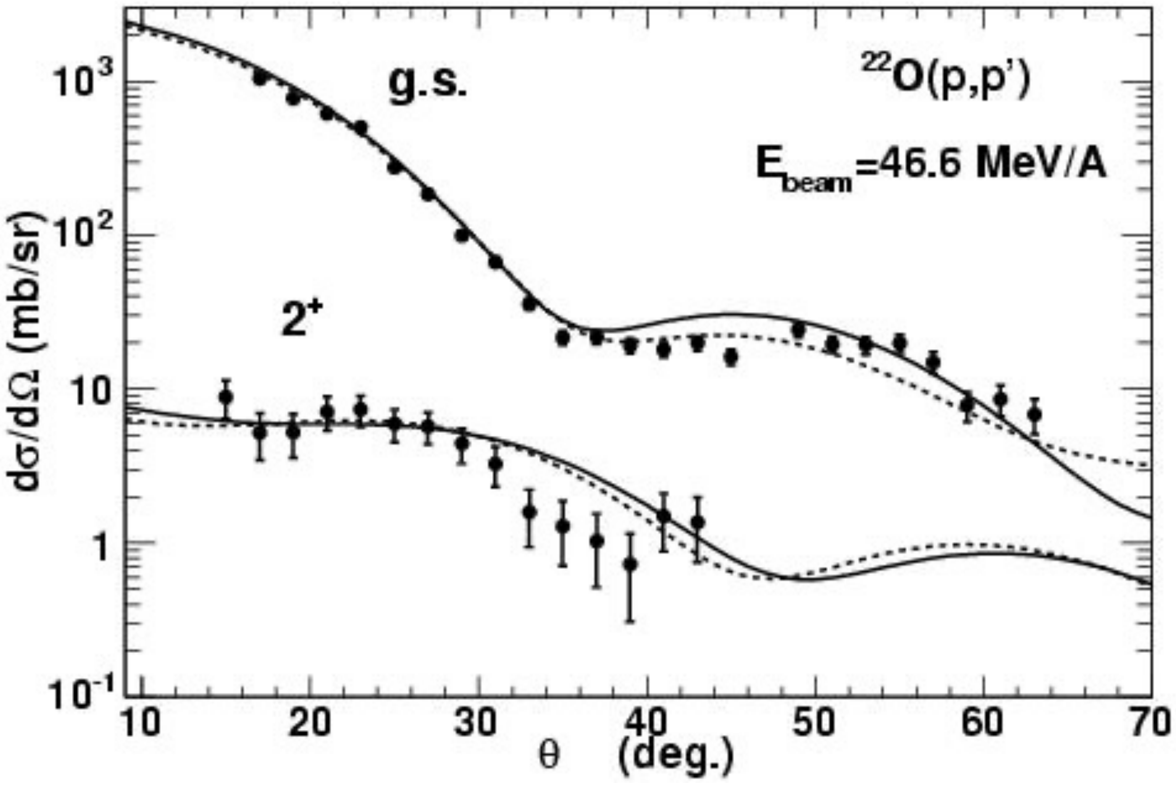
Hydrodynamic model : Vibration of a homogeneous fluid $M_n/M_p = N/Z$



Shell model (single closed shell nucleus)
mainly coherent 0 ħω excitations
closed proton shell $M_n/M_p \rightarrow \infty$
closed neutron shell $M_n/M_p \rightarrow 0$

but 1 and 2hω components tend to «almost» restore the value of N/Z
this is called «core polarization»

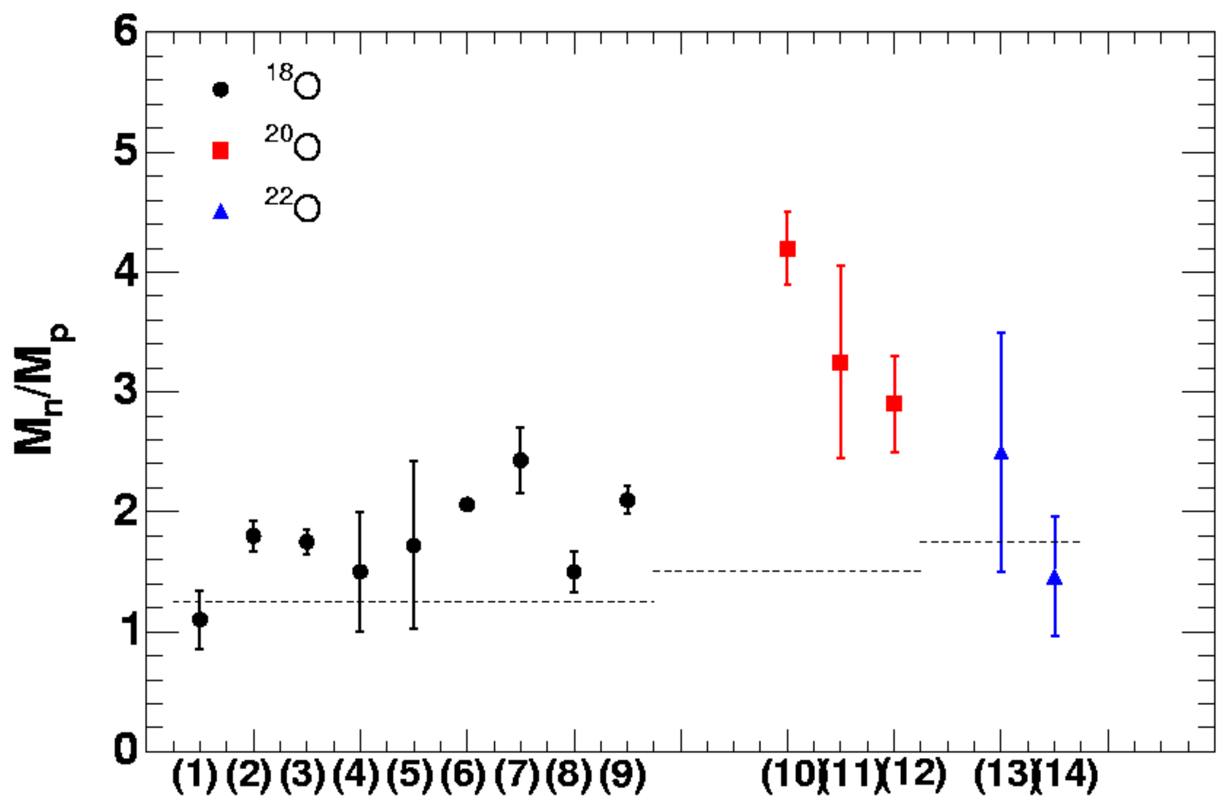
Microscopic analysis



- Solid Line: König Delaroche global optical potential
- Dashed line: Folding model : CDM3Y6 interaction
  Imaginary part : Koning&Delaroche

E. Becheva et al., Phys. Rev. Lett. 96 (2006) 012501

M_n/M_p ratio



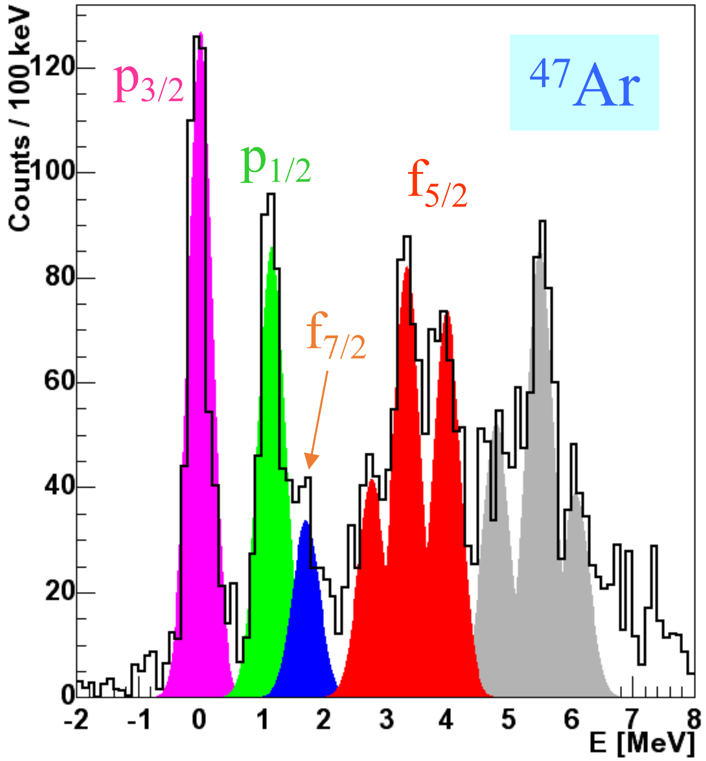
M i c r o

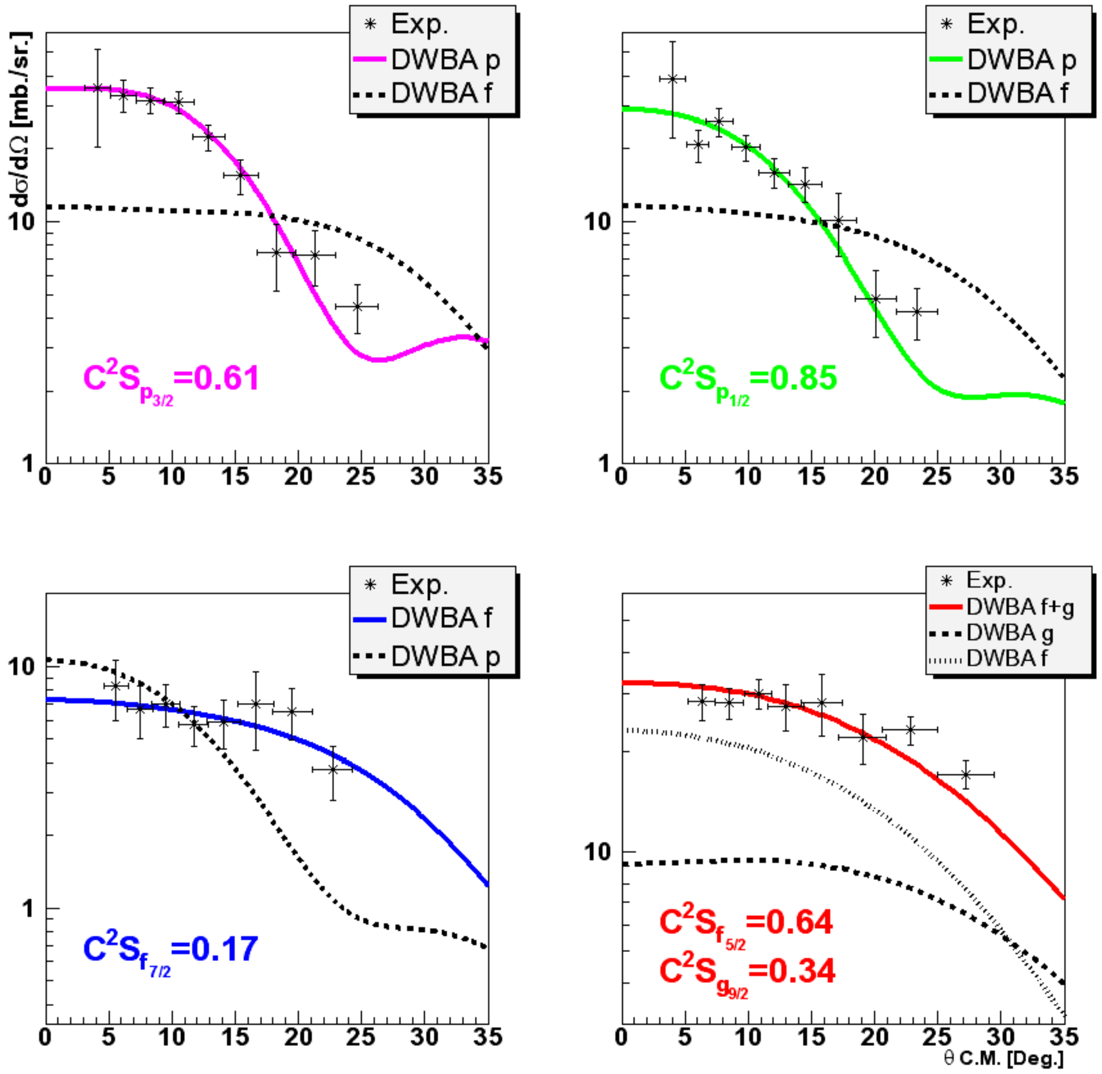
P h e n o

Z=8 closed shell

Transfer Reactions

N=28 gap : 4.47(8)MeV





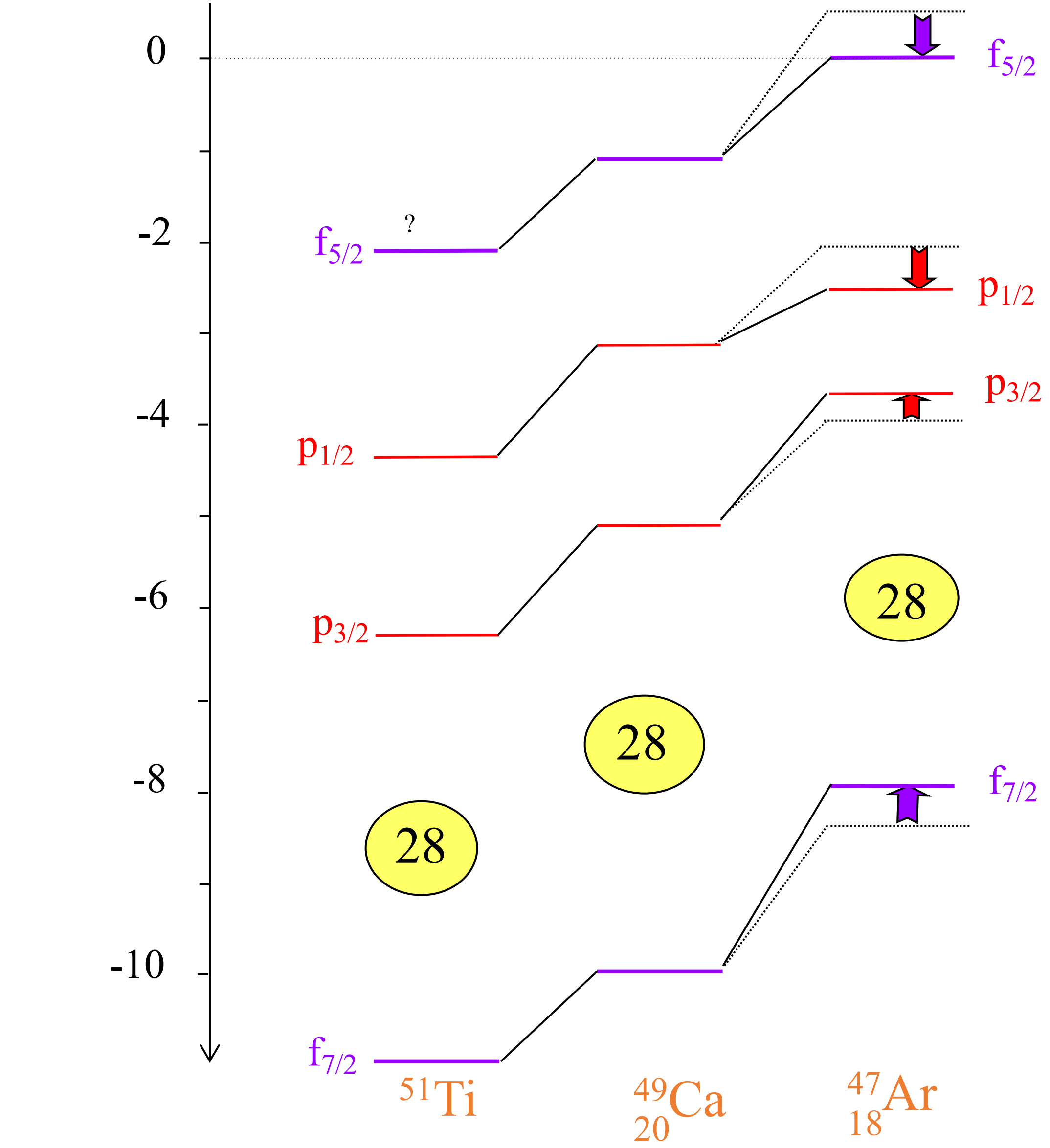
Expérimental

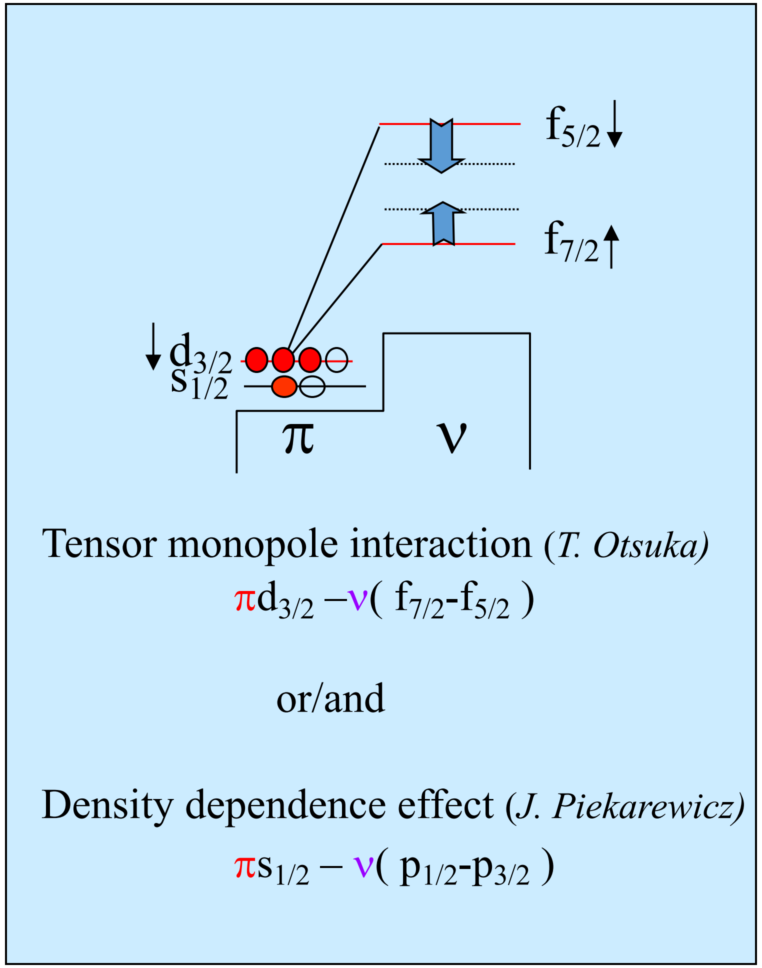
SM calcul.

L. Gaudefroy et al. PRL 97 092501 (2006)

Evolution of single particle energies at N=29

ε [MeV]





Courtesy of Olivier Sorlin

The N=28 gap has decreased by 330(80) keV between Ca and Ar

Decrease of the *f* and *p* spin-orbit splittings not predicted by mean field calculations

During that time…
Exclusive nucleon removal reactions @NSCL

J.Tostevin, J. Phys. G25 (1999) 735

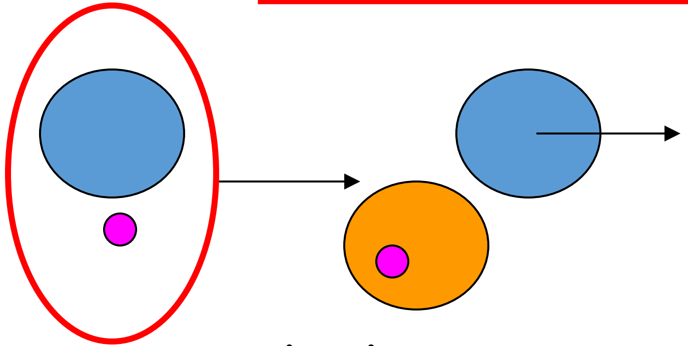
$$\sigma(n) = C^2S(j,n)\ \sigma_{sp}(j,B_n)$$

Spectroscopic factor → $C^2S(j,n)$

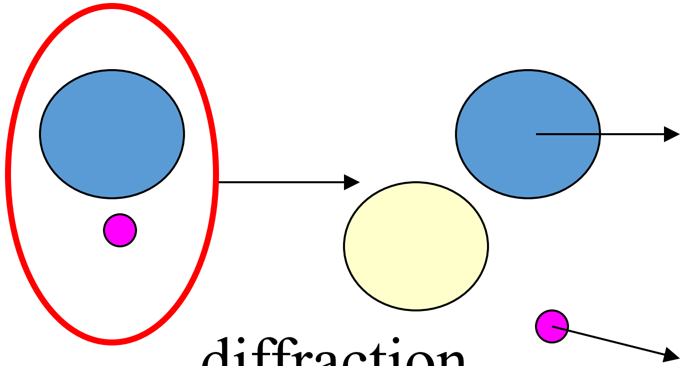
Single particle removal cross section → $\sigma_{sp}(j,B_n)$

$$\sigma_{sp} = \sigma_{stripping} + \sigma_{diffraction}$$

Calculated in the eikonal model (integration over straight line trajectory, ingredients are n-T and C-T interaction potentials) E>50 MeV/A

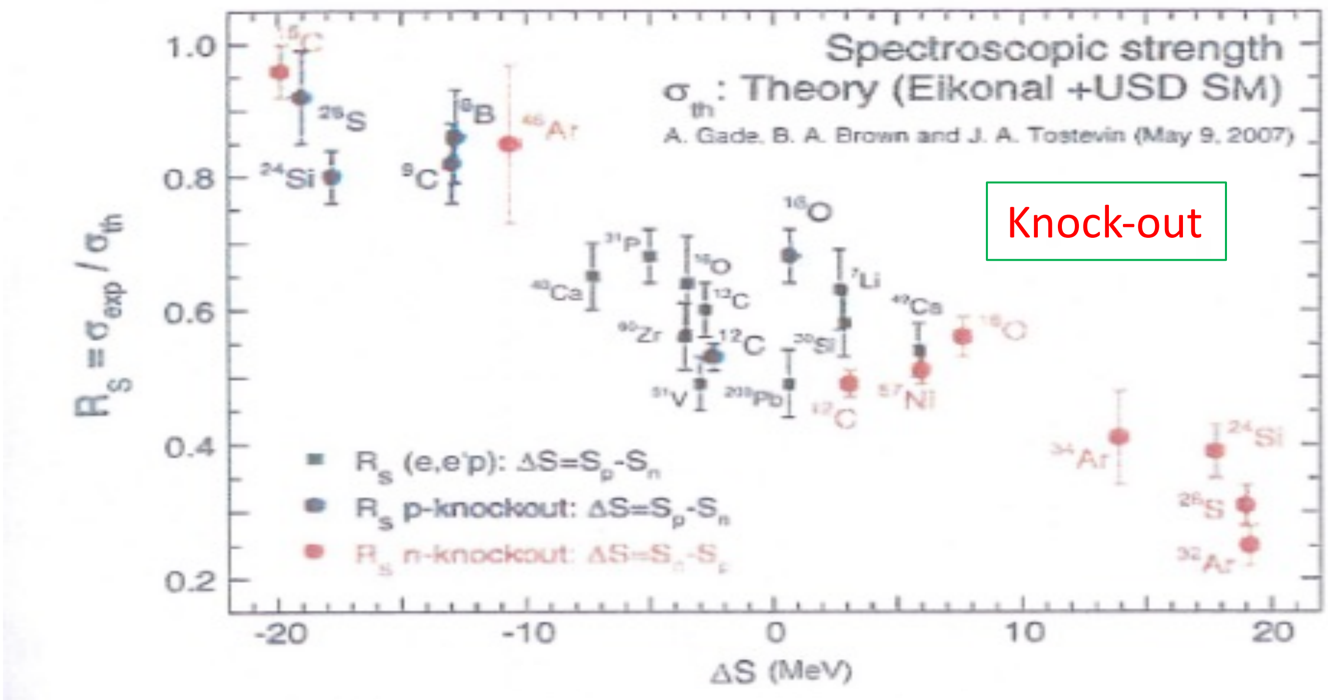


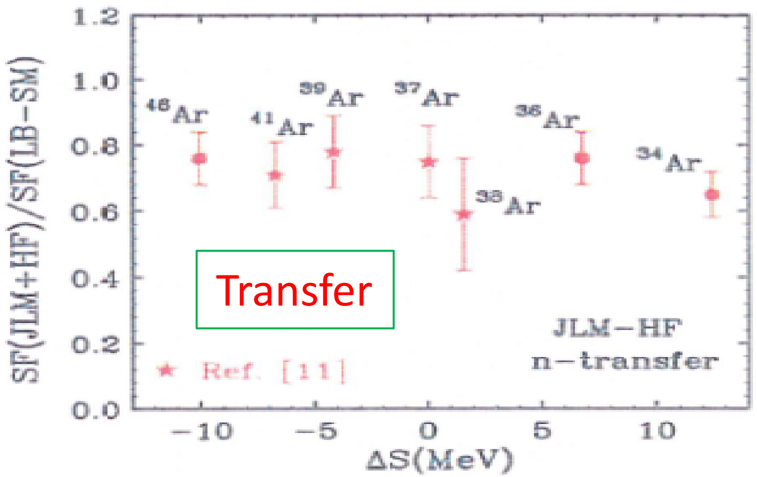
stripping



diffraction

Correlations: Knock-out vs. Transfer





J. Lee et al
PRL 104 (2010) 112701

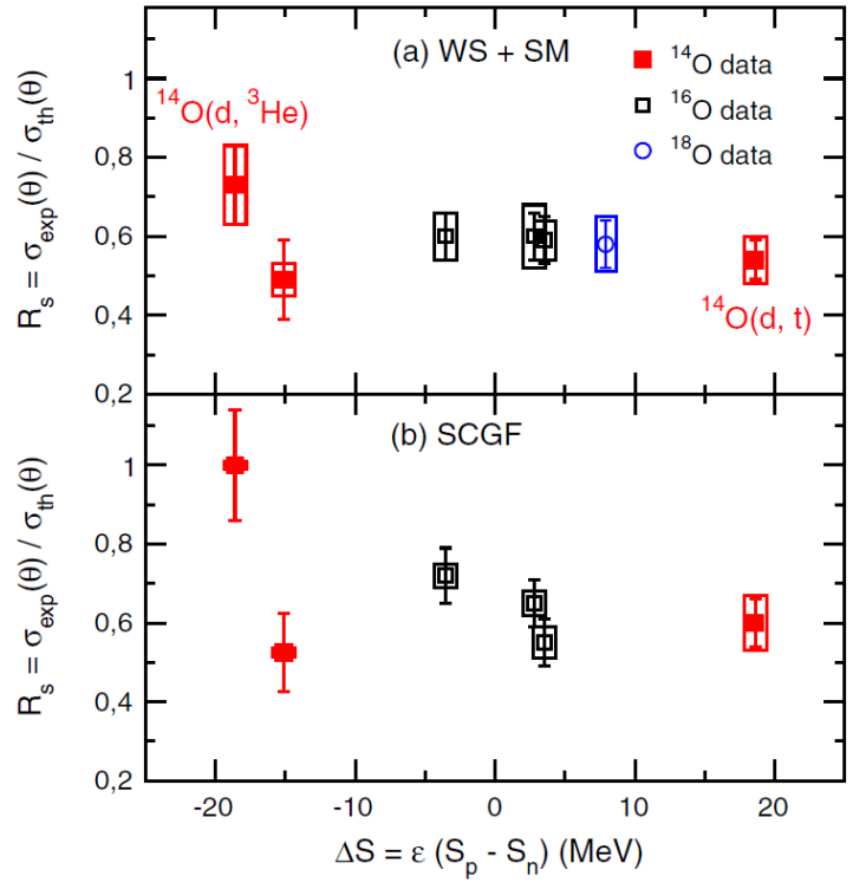


FIG. 4 (color online). Reduction factors R_s obtained with (a) a WS OF and the SLy4 interaction [31], averaged over four entrance and two exit potentials, and compared to shell-model calculations performed with the WBT interaction [37] in the $0p + 2\hbar\omega$ valence space; (b) a microscopic (SCGF) form factor [30]. The detail of error bars is given in text.

Time to improve and diversify experimental approaches

The MUST2 Array

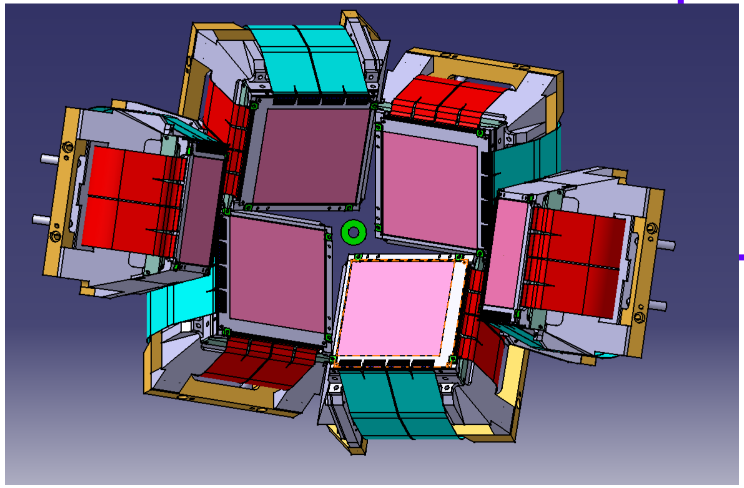
Collaboration: IPNO,SPhN/Saclay,GANIL

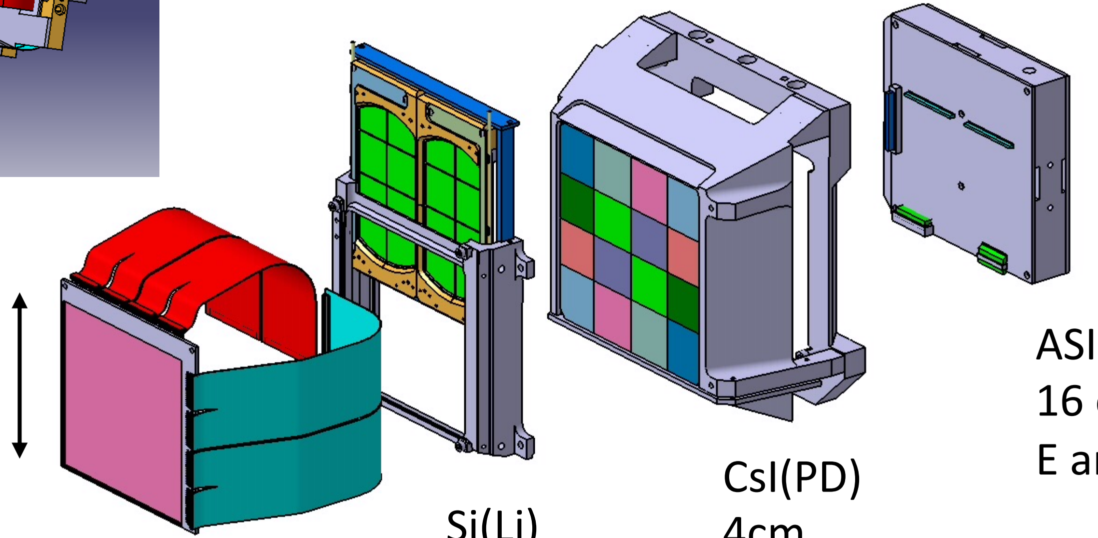
MUST2 : a major upgrade of MUST

- ***Increased angular coverage***
  - ***Better efficiency***
  - ***Measure several reactions in one shot***

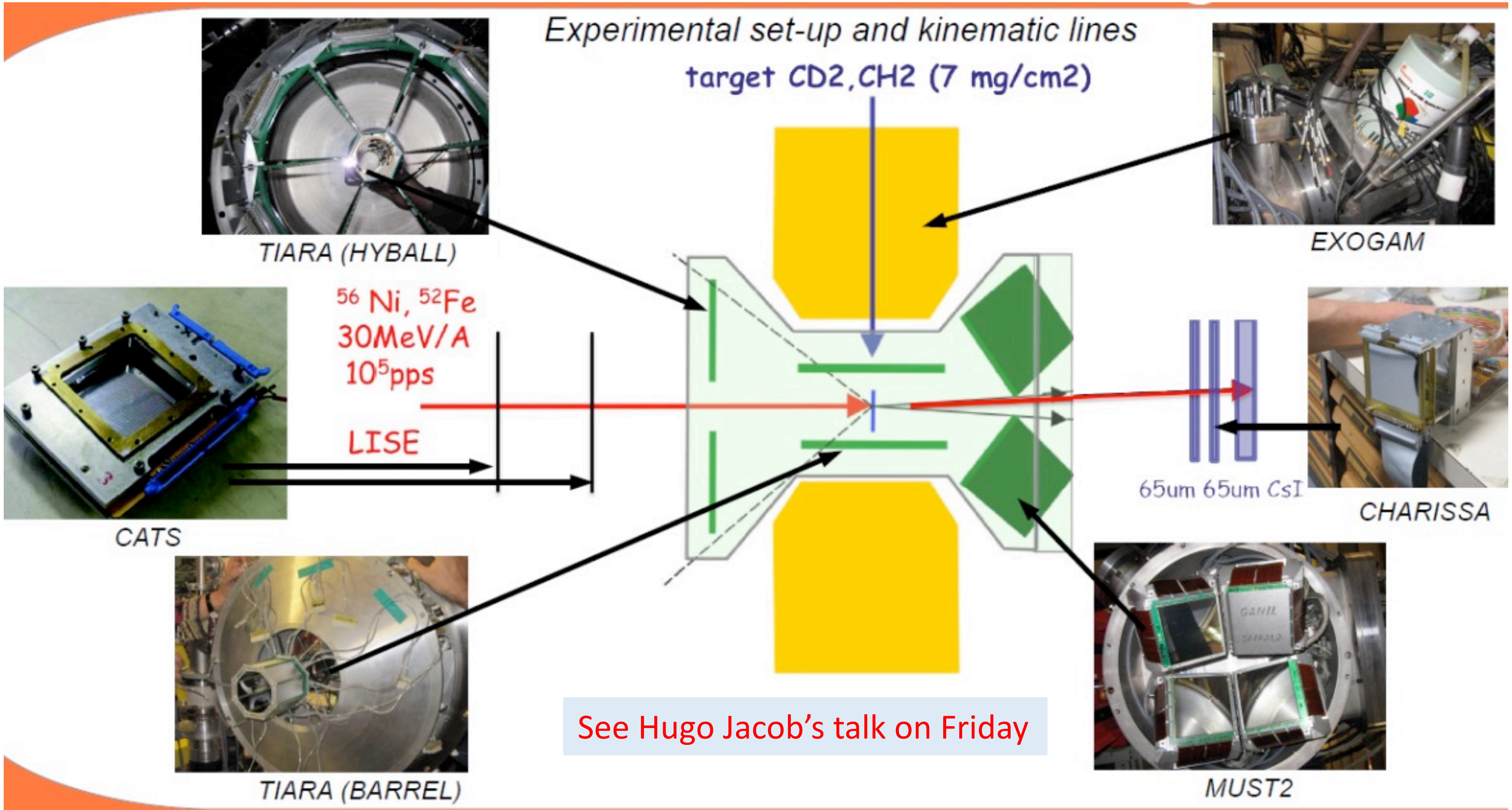
Increased granularity (multiparticle events)

New ASIC based electronics : more compact



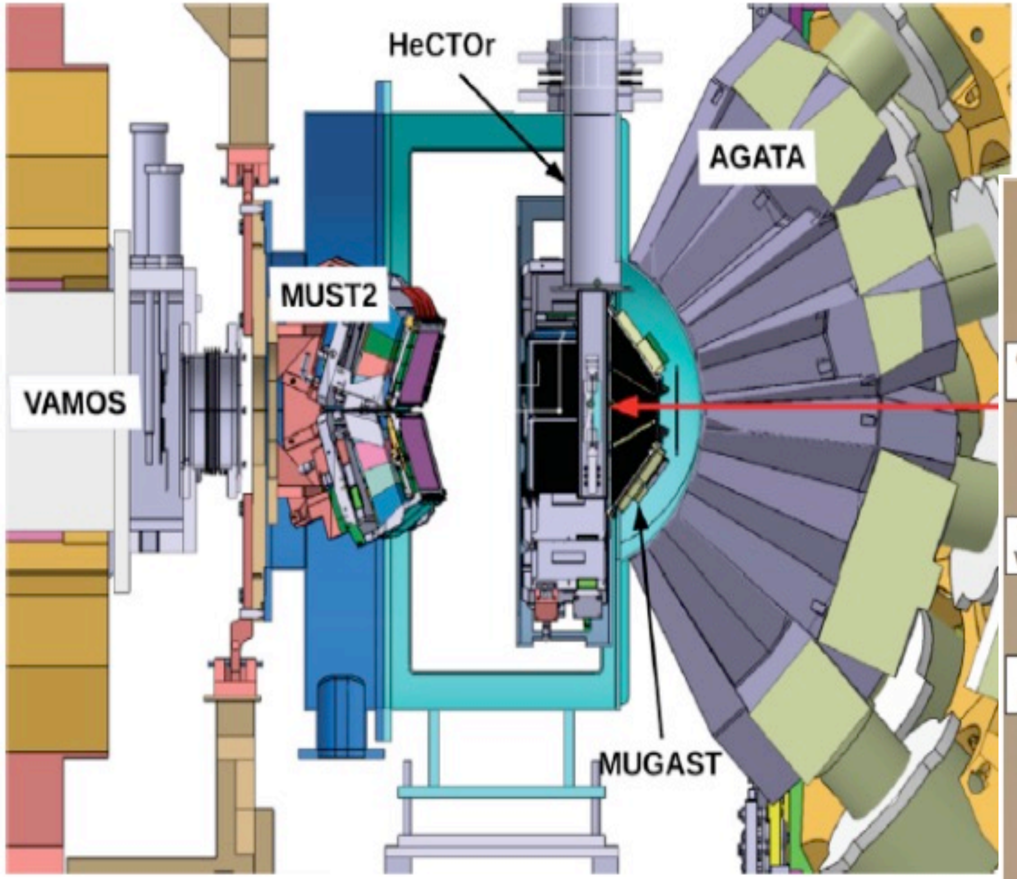


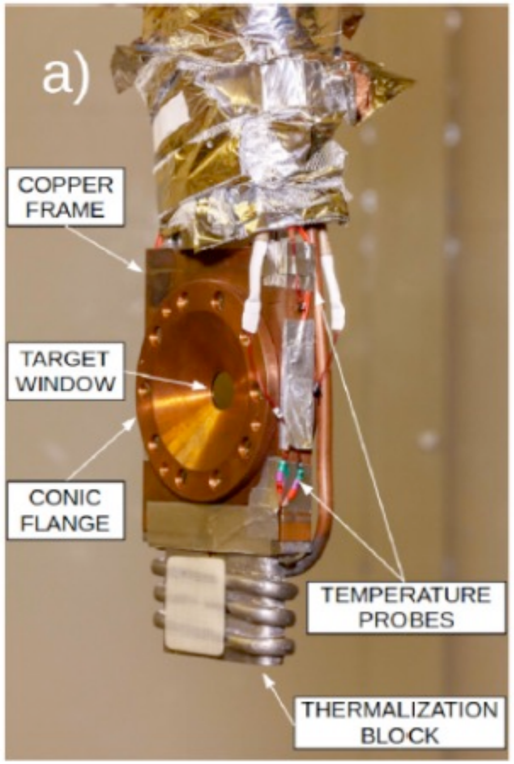
γ-ray Coincidences with MUST2, TIARA and EXOGAM

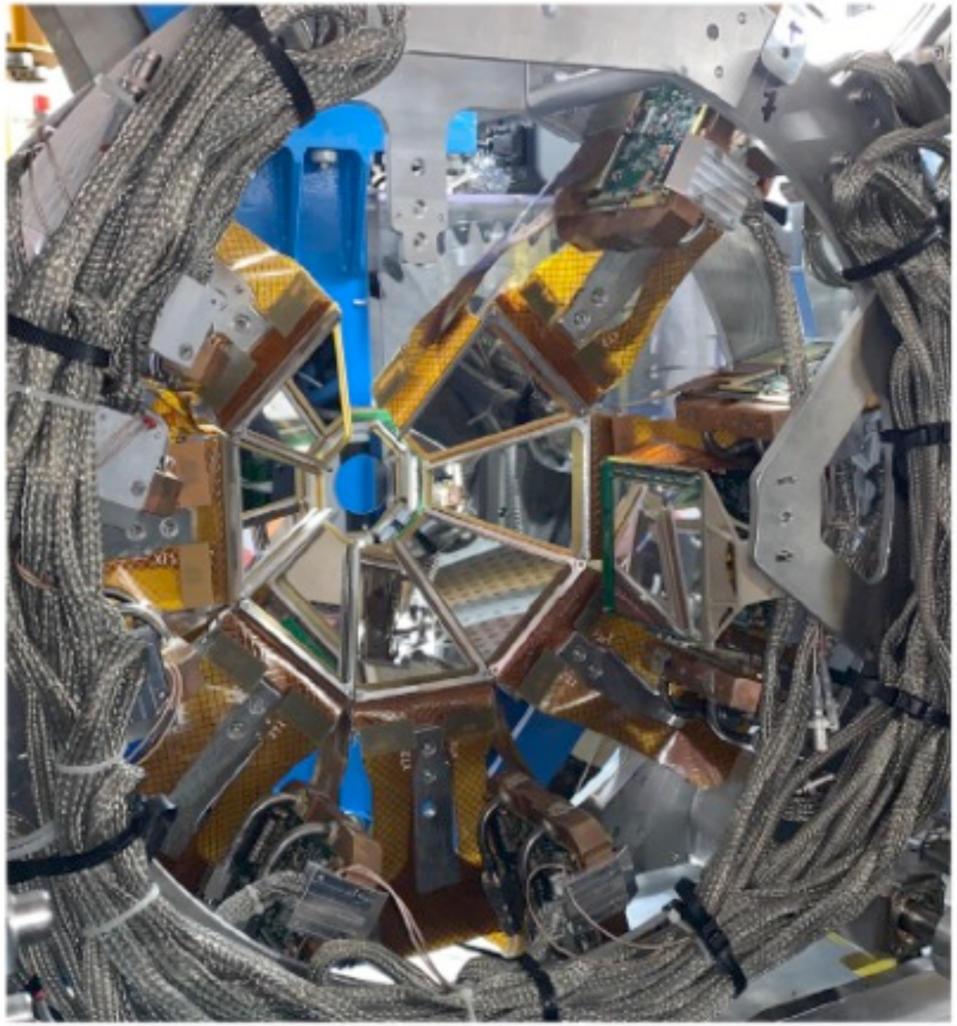


See Hugo Jacob's talk on Friday

MUGAST + AGATA + Vamos (+ Cryo Target)







M. Assié et al; NIMA 1014 (2021) 165743
F. Galtarosssa et al; NIMA 1018 (2021) 165830

Lifetime Measurements without Top-Feeding

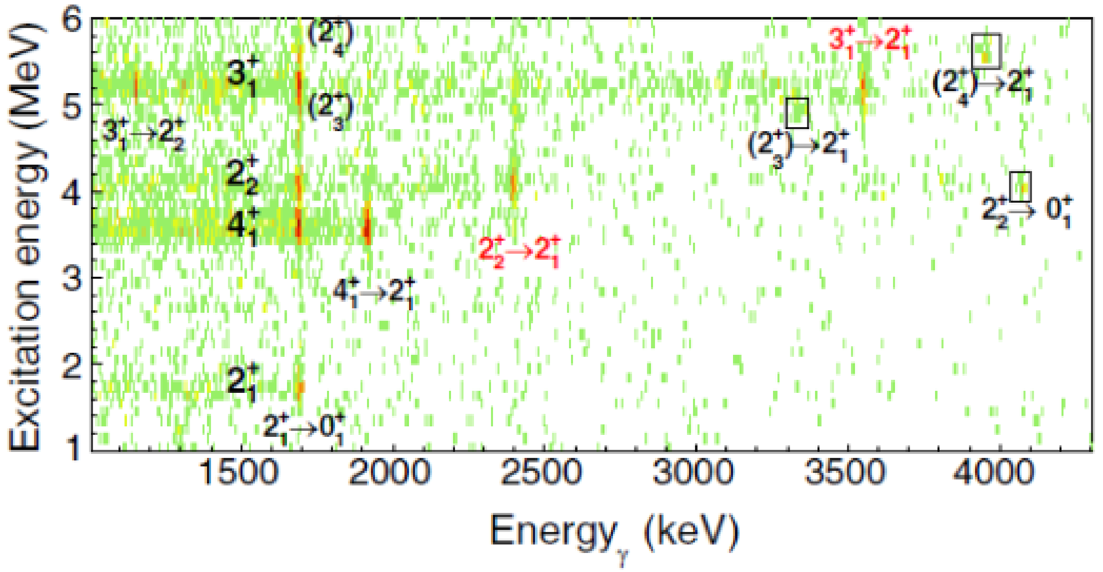
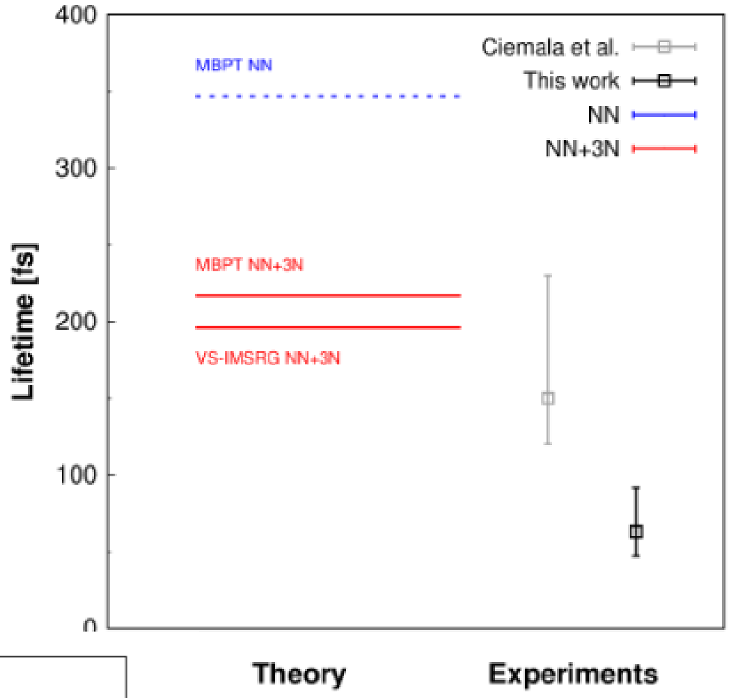


FIG. 1. Two-dimensional correlation between the ^{20}O excitation energy on the y axis and the corresponding γ-ray decays on the x axis. The transitions from which the lifetimes are extracted are highlighted in red. The weakest transitions depopulating the $2^+_{2,3,4}$ states are marked with black boxes.



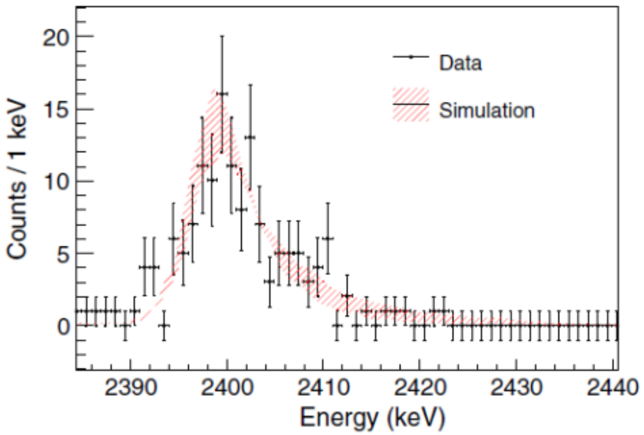
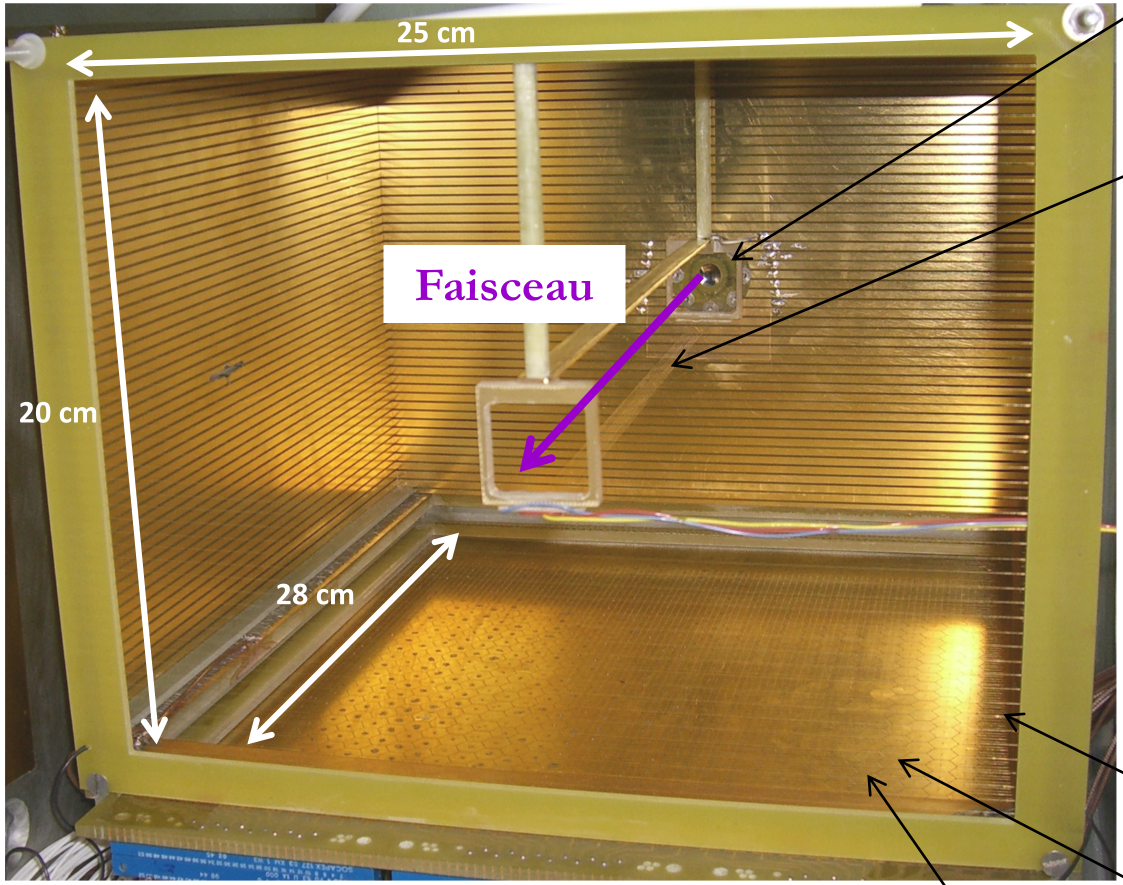
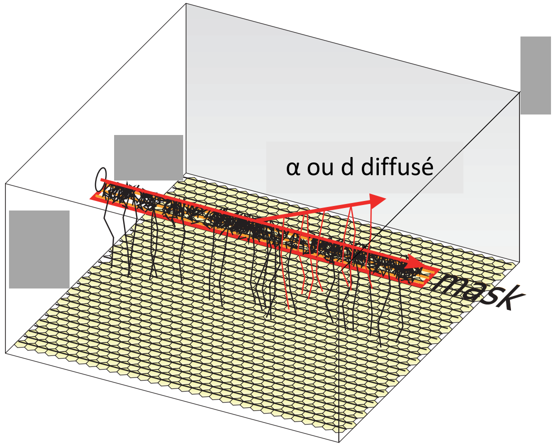


FIG. 3. Comparison between experimental data and simulation for the lifetime of the 2^+_2 state in ^{20}O.

I. Zanon PhD and I. Zanon et al.; PRL 131 262501 (2023)

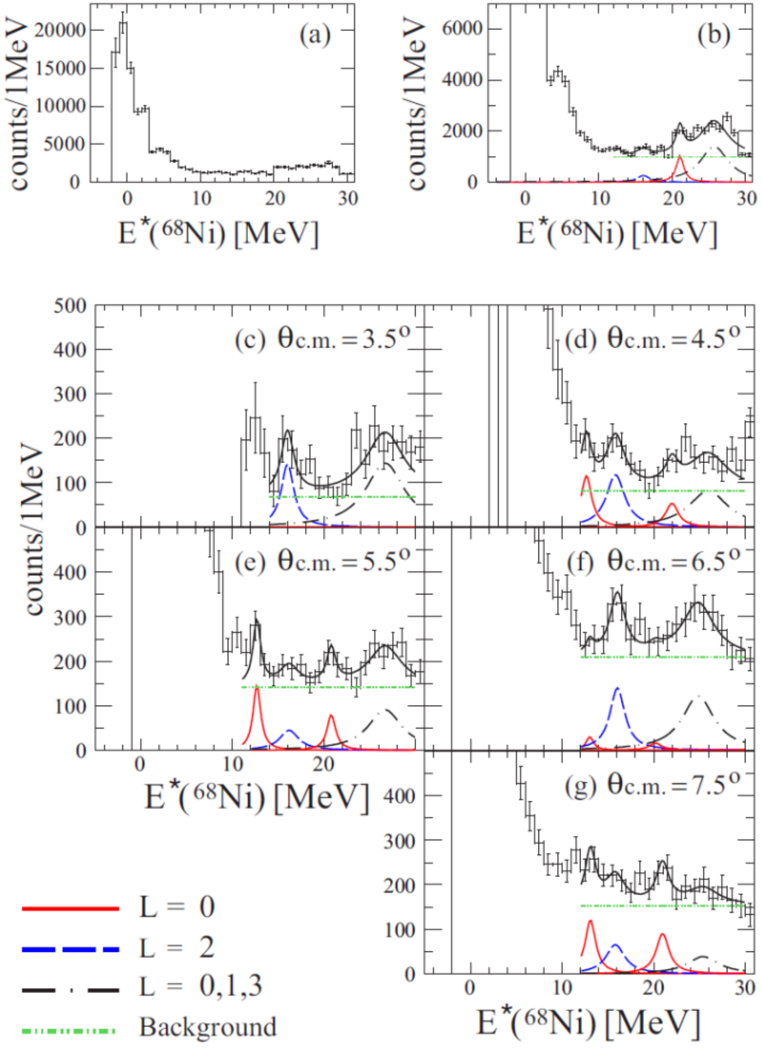
2.2 La cible active MAYA





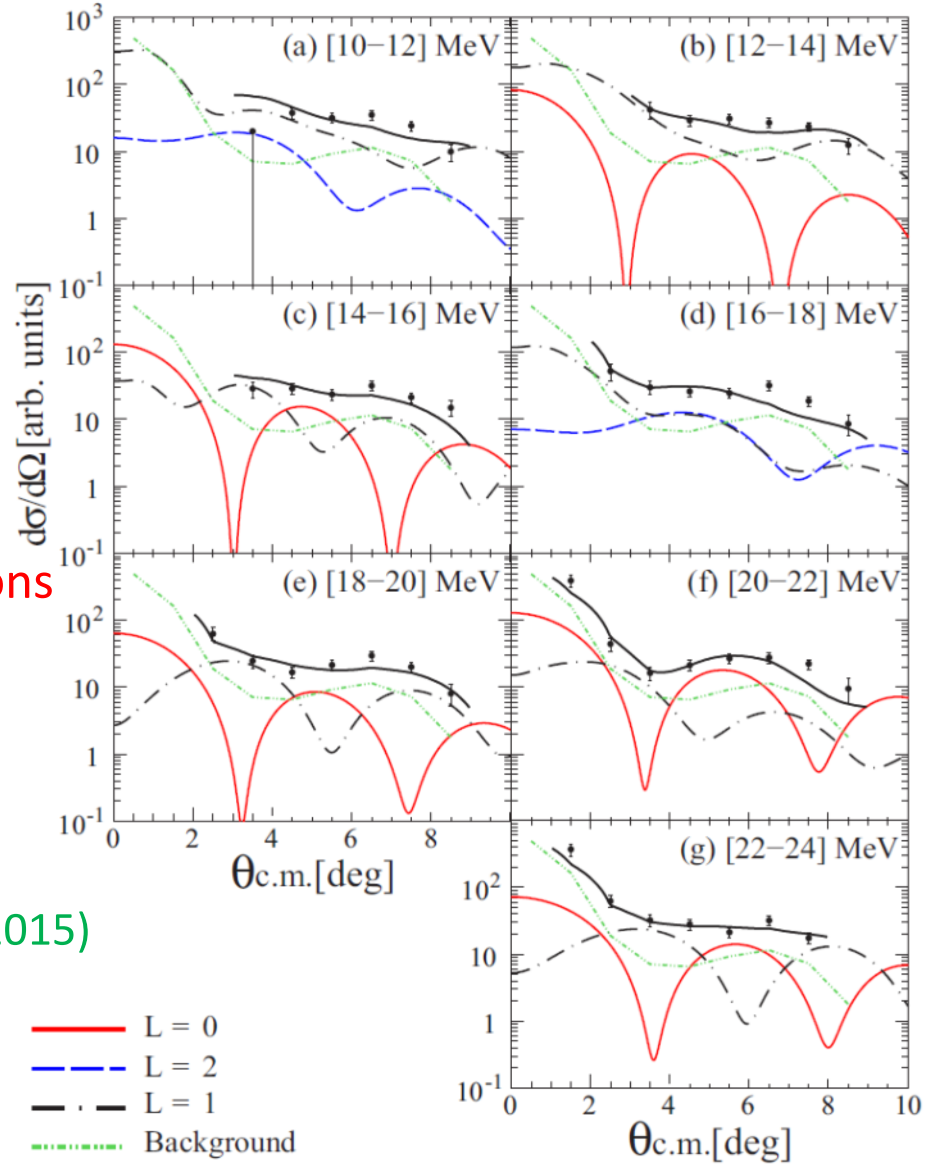
J. Pancin *et al.*, *JINST* **7**, 01006 (2012)

Giant Resonances in ^{68}Ni through ^{68}Ni (α,α’)



Energy Spectra

Angular Distributions

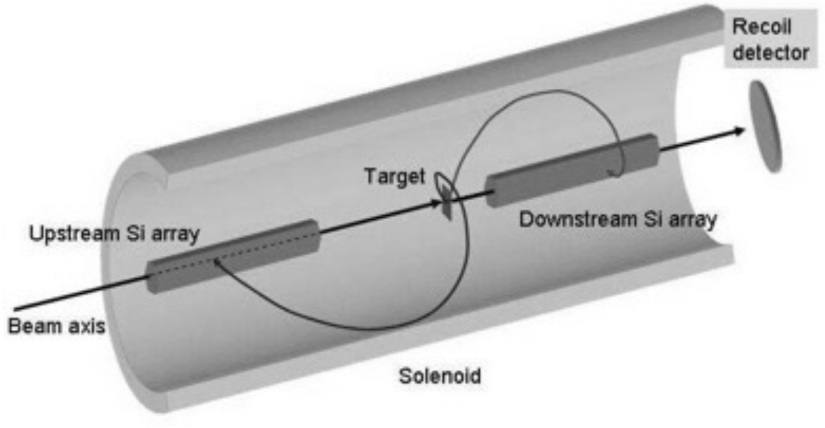


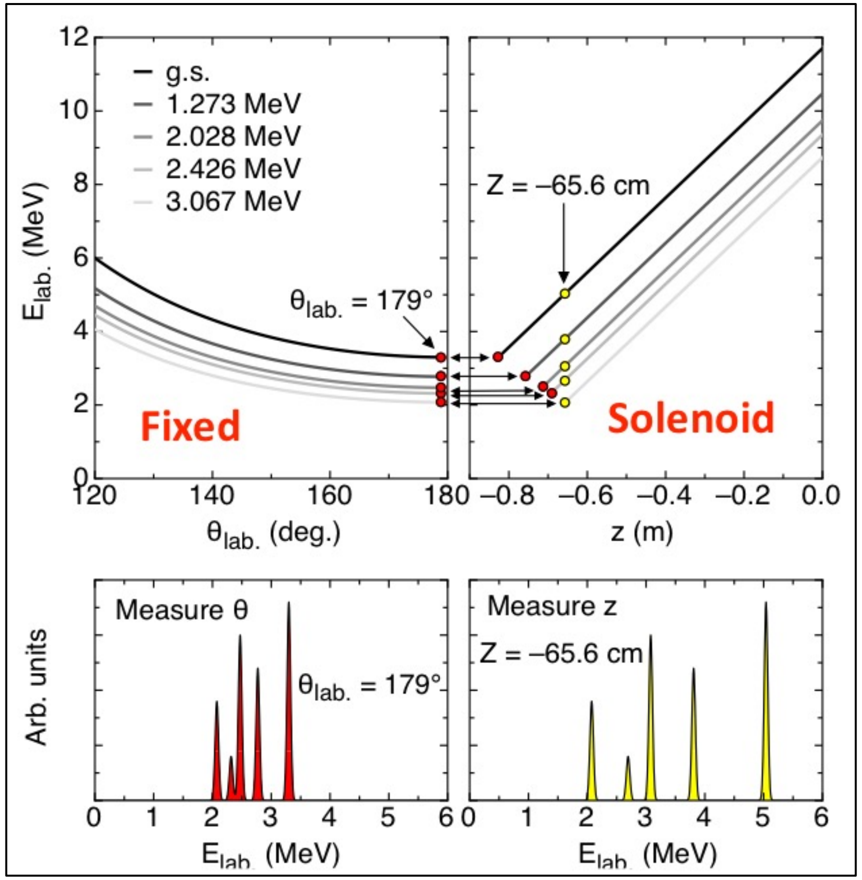
M. Vandebrouck et al.; PRC 92 024316 (2015)

Solenoid technique : HELIOS @ Argonne, ISS@ISOLDE

Proton follows helical orbit in field of solenoid

$$T_{\rm cyc} = \frac{2\pi}{B}\frac{m}{qe}$$





Measure position of interaction

Beam ~10 Mev/u

MEASURED QUANTITIES: position z, cyclotron period T_{cyc} and lab particle energy E_p.

$$E_{\rm cm} = E_{\rm lab} + \frac{mV_{\rm cm}^2}{2} - \frac{mzV_{\rm cm}}{T_{\rm cyc}}$$

Suffers no kinematic compression of the Q-value spectrum.

Linear relationship between E_{cm} and E_{lab}.

What does the future hold?

For Physics Prospectives see Olivier Sorlin's talk on Friday.

The GRIT array and AGATA

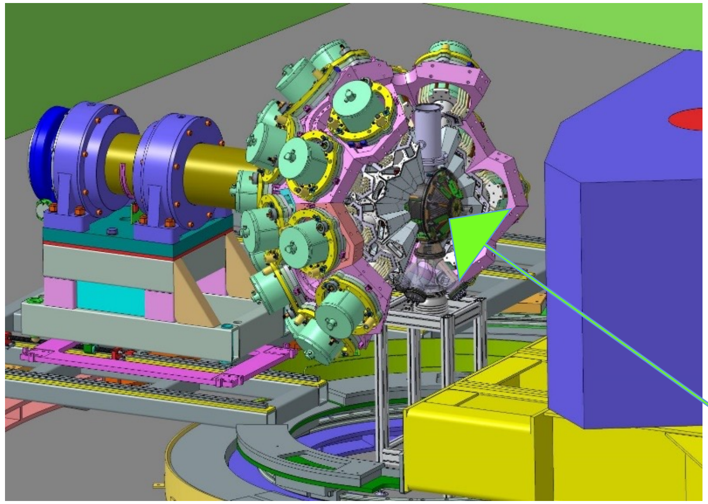
4π Silicon array fully integrable in AGATA

DETECTORS

- High efficiency for particles
- High granularity (strip pitch < 0.8 mm)

Layers of Silicon

- 500 um DSSD pitch < 0.8 mm
- 1.5 mm DSSD pitch ~10mm
- 1.5mm DSSD (fwd angles)



SPES exotic beams for science

GANIL SPIRAL2 laboratoire commun CEA/DRF CNRS/IN2P3

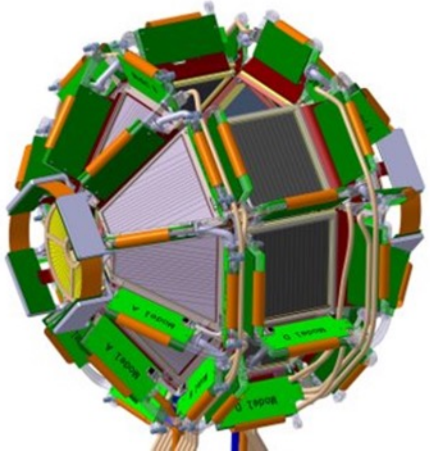
ELECTRONICS

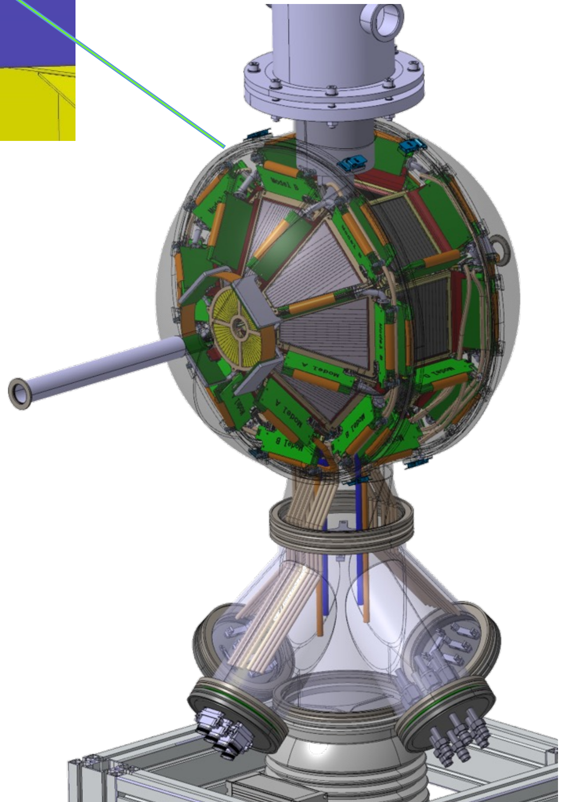
- Large dynamical range
- PID using Pulse Shape Analysis techniques

New Integrated Digital electronics designed by IJCLab, LPC Caen, INFN

MECHANICS

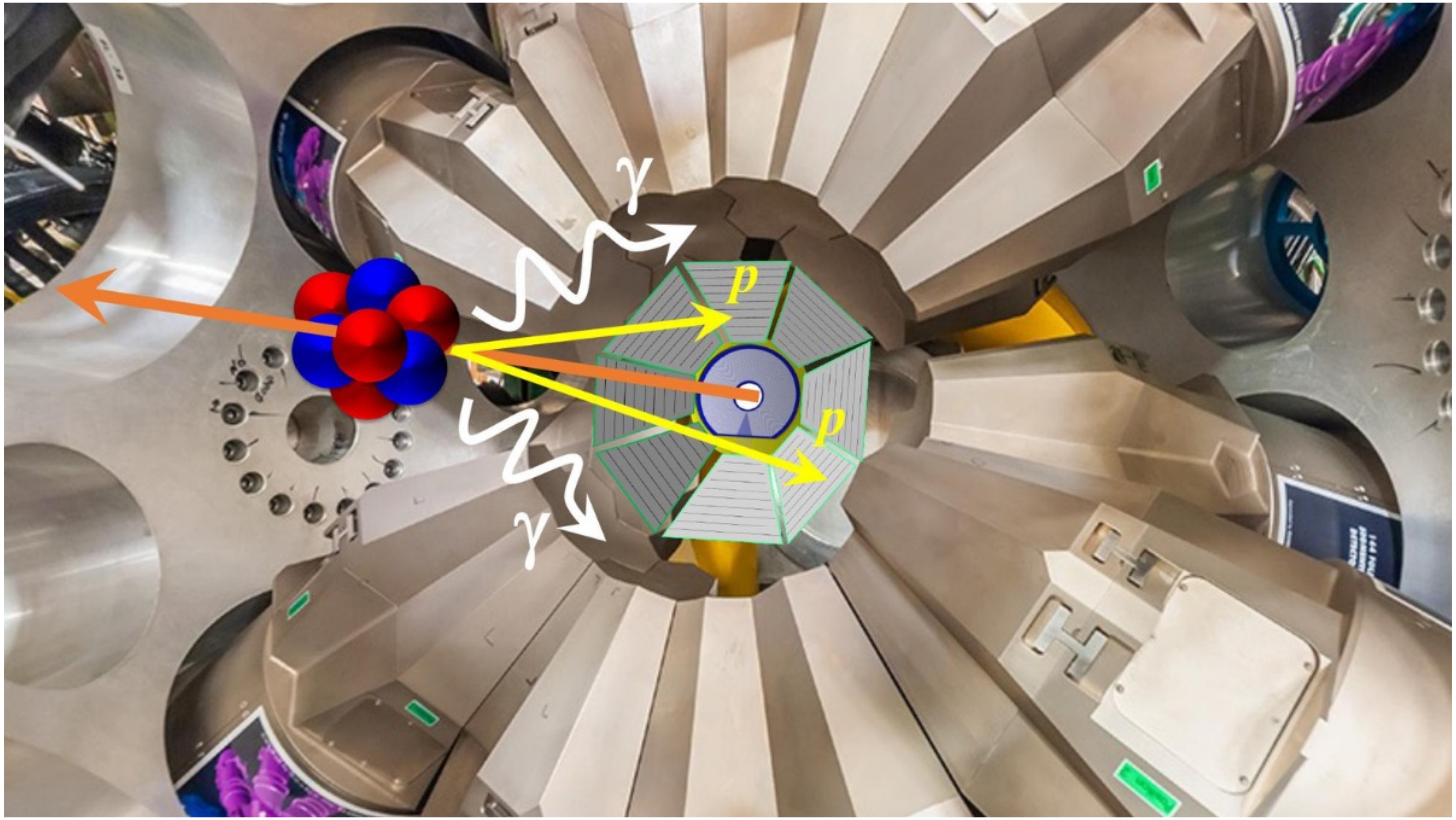
- Integration into **AGATA (radius=23 cm)**
- transparency to gamma-rays
- high compacity
- Special targets : cryogenic, tritium, windowless





Courtesy Didier Beaumel - Orsay

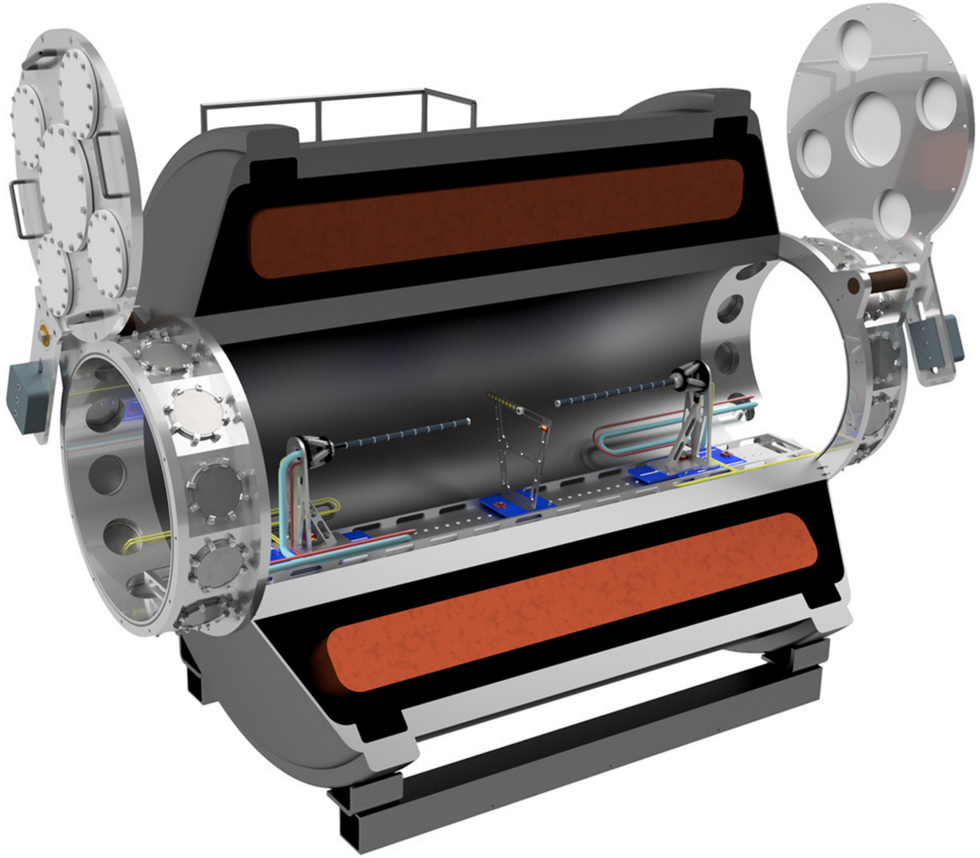
The FAUST array and GRETA



FRIB

Wilton Catford and Gavin Lotay
Surrey

Solaris for FRIB and Argonne: Dual mode Solenoid



Benjamin Kay - Argonne

READOUT ELECTRONICS

GET
1-100MS/s 12bit
3072+256 channels

SCINTILLATION ARRAY

45 $CeBr_3$
48×48×48mm

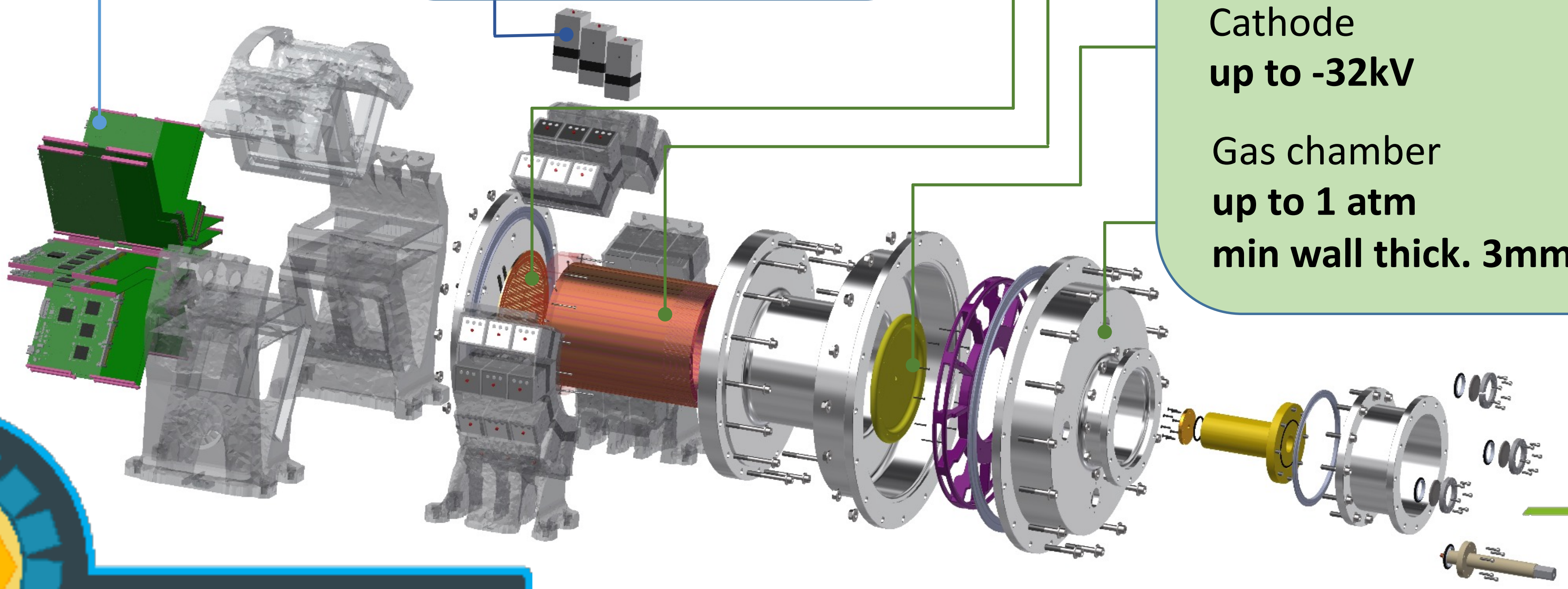
TPC

MICROMEGAS detector
2916 channels

Field cage
homogeneous electric field ~2%

Cathode
up to -32kV

Gas chamber
up to 1 atm
min wall thick. 3mm



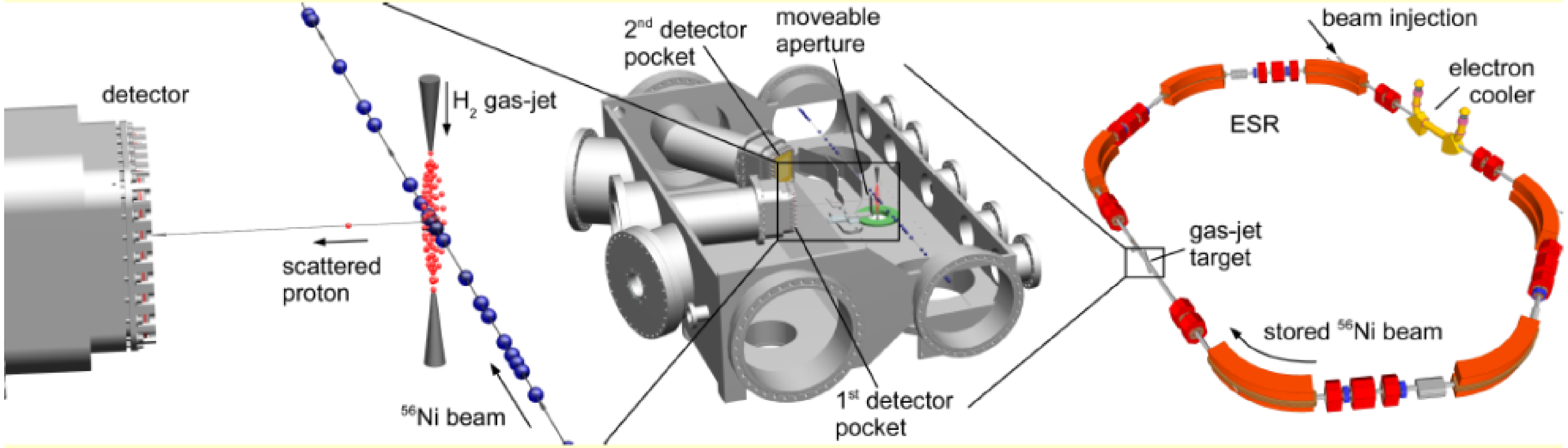
SpecMAT

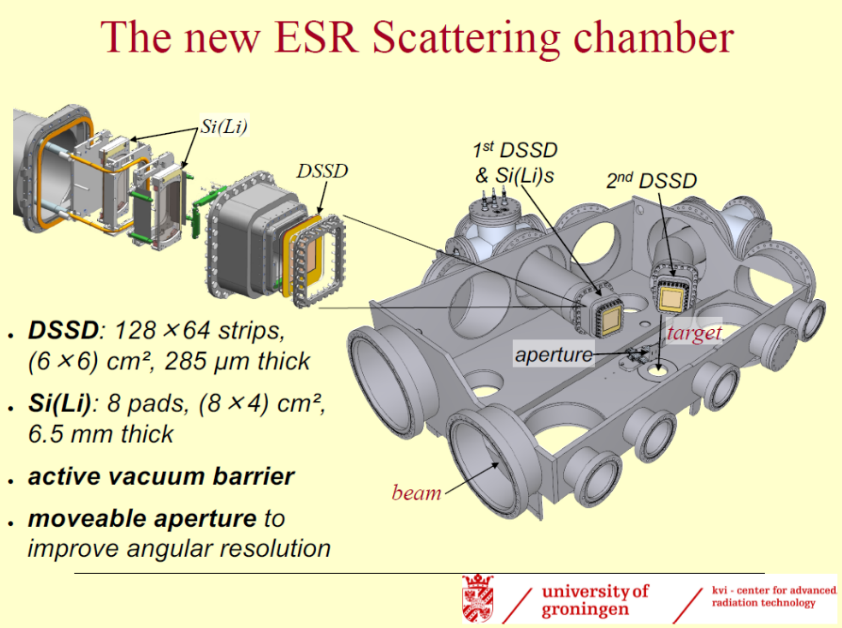
ISOLDE

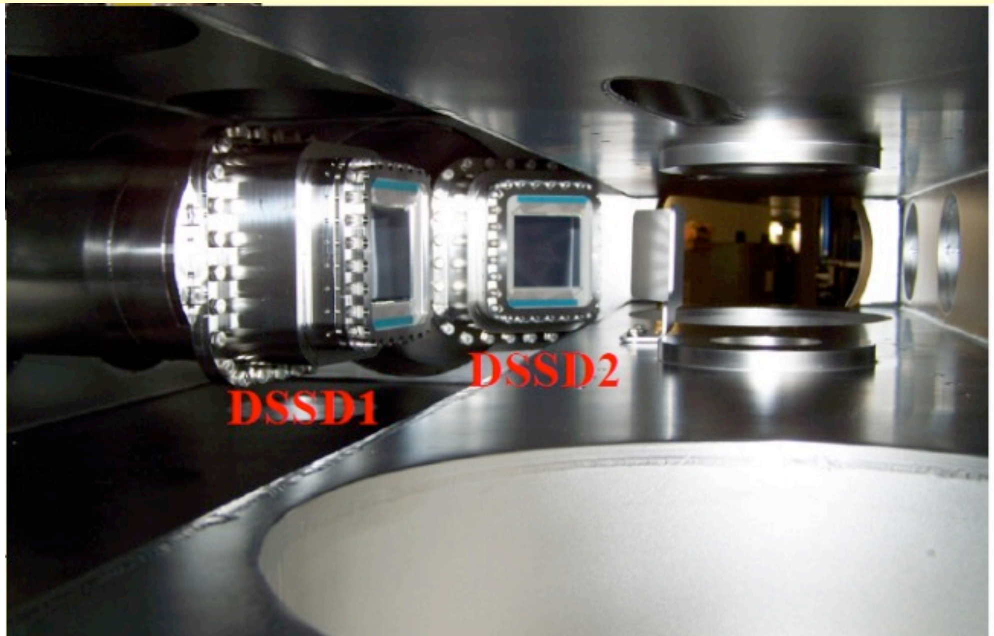
KU LEUVEN
KERN- EN STRALINGSFYSICA

Riccardo Raabe -Leuven

Scattering in a storage ring: EXL @ESR (GSI)





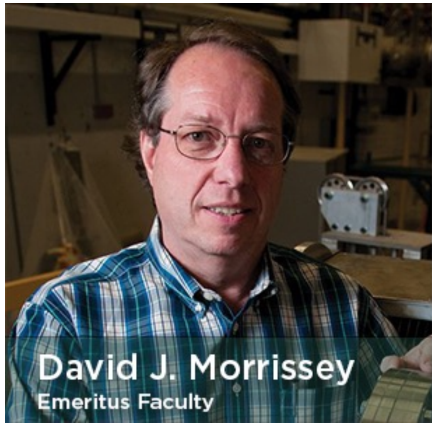


Nasser Kalantaar - KVI

FAIR — Facility for Antiproton and Ion Research in Europe

The first DREB workshop

June 1999 at MSU
2 ½ days
~ 50 participants



P. Gregers Hansen

Kirby Kemper

The DREB workshop/conference series





ORSAY 2001 | SURREY 2003 | EAST LANSING 2005 | WAKO 2007 | TALLAHASSEE 2009





PISA 2012 | DARMSTADT 2014 | HALIFAX 2016 | MATSUI 2018 | SANTIAGO 2022