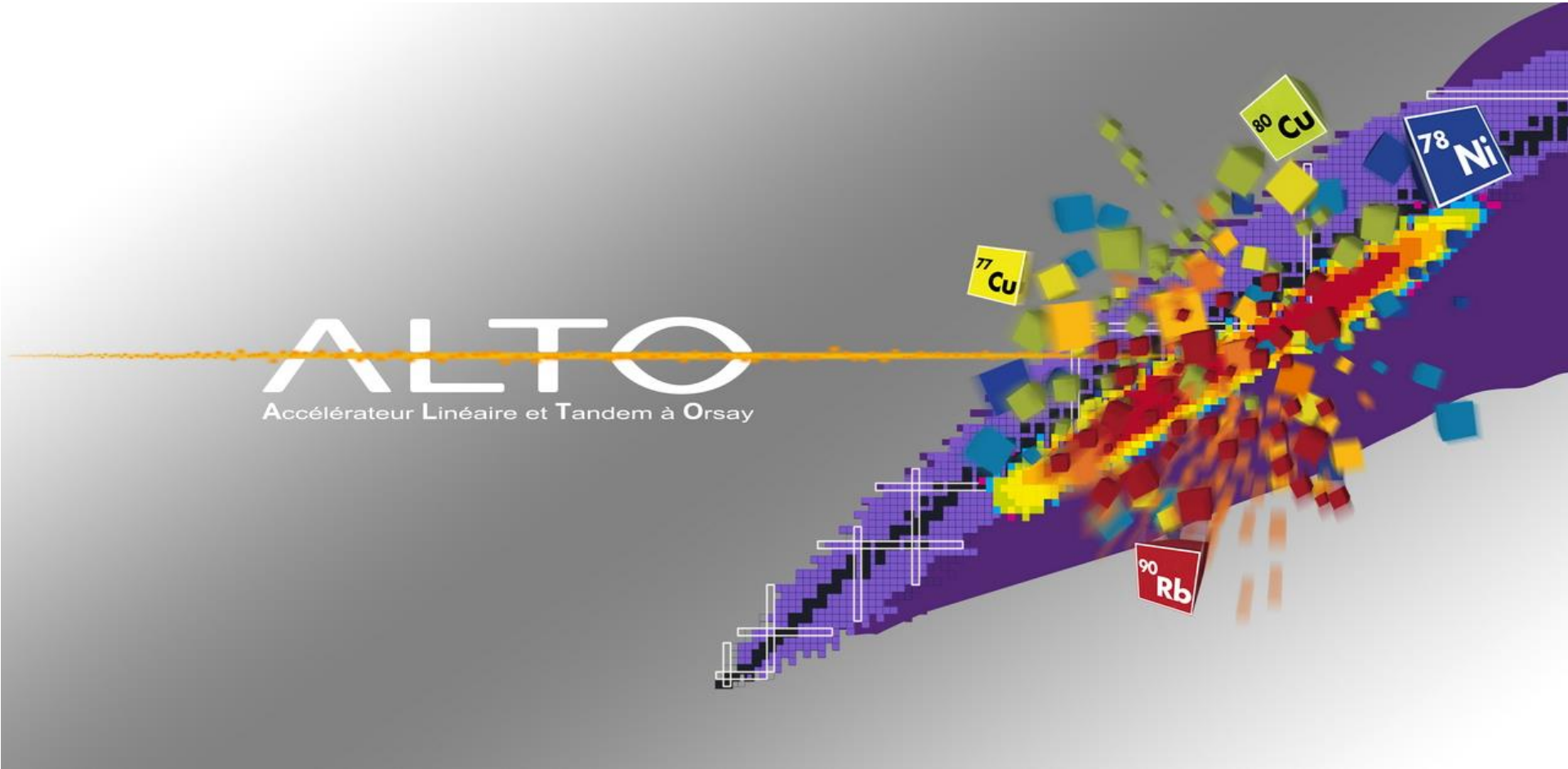
# Nuclear spectroscopy with stable and radioactive beams at Orsay

G. Georgiev



# Experimental areas

**γ-spectroscopy**

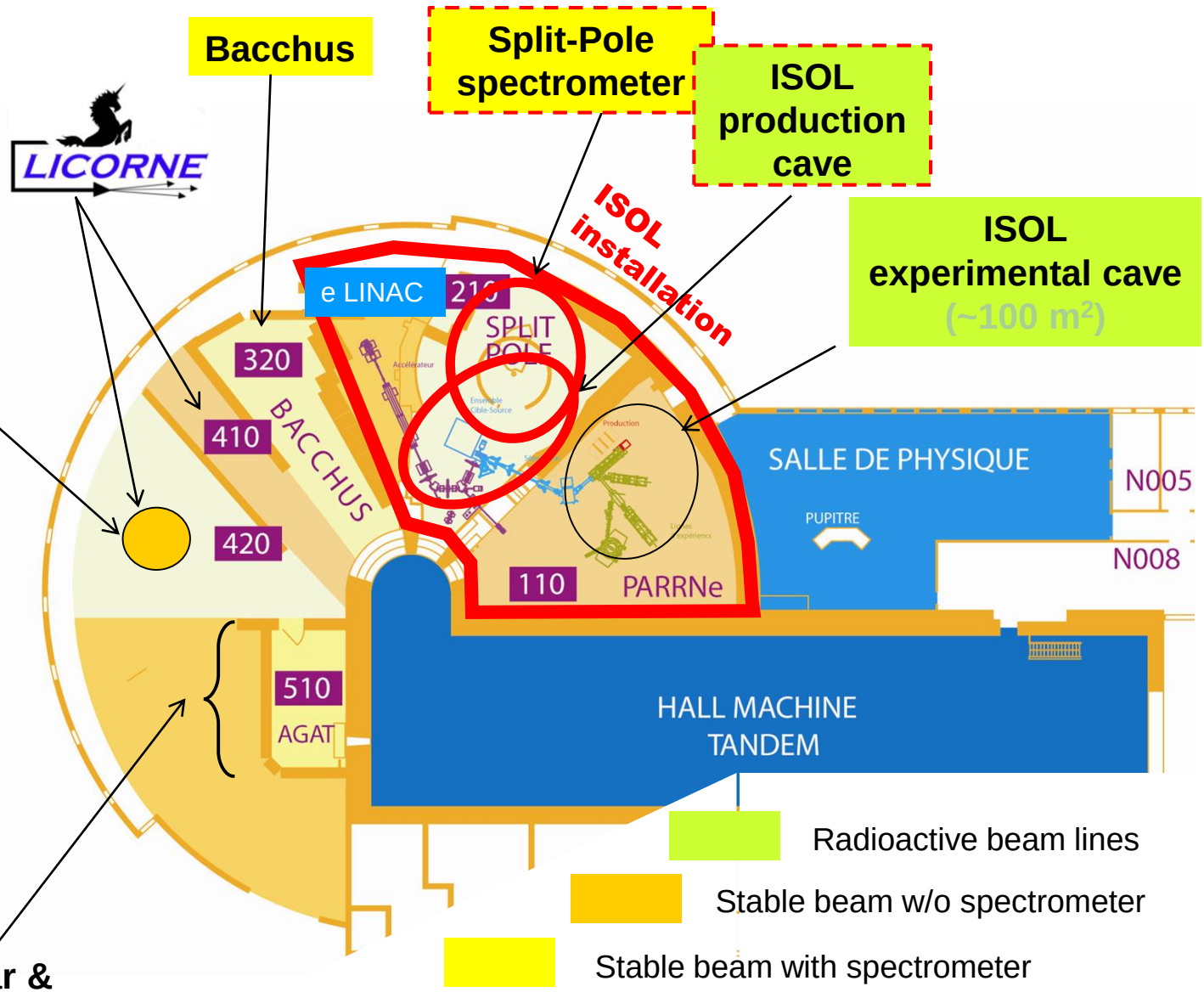
ORGAM

MINORCA

PARIS

nu – ball

**cluster, molecular & droplets beams**



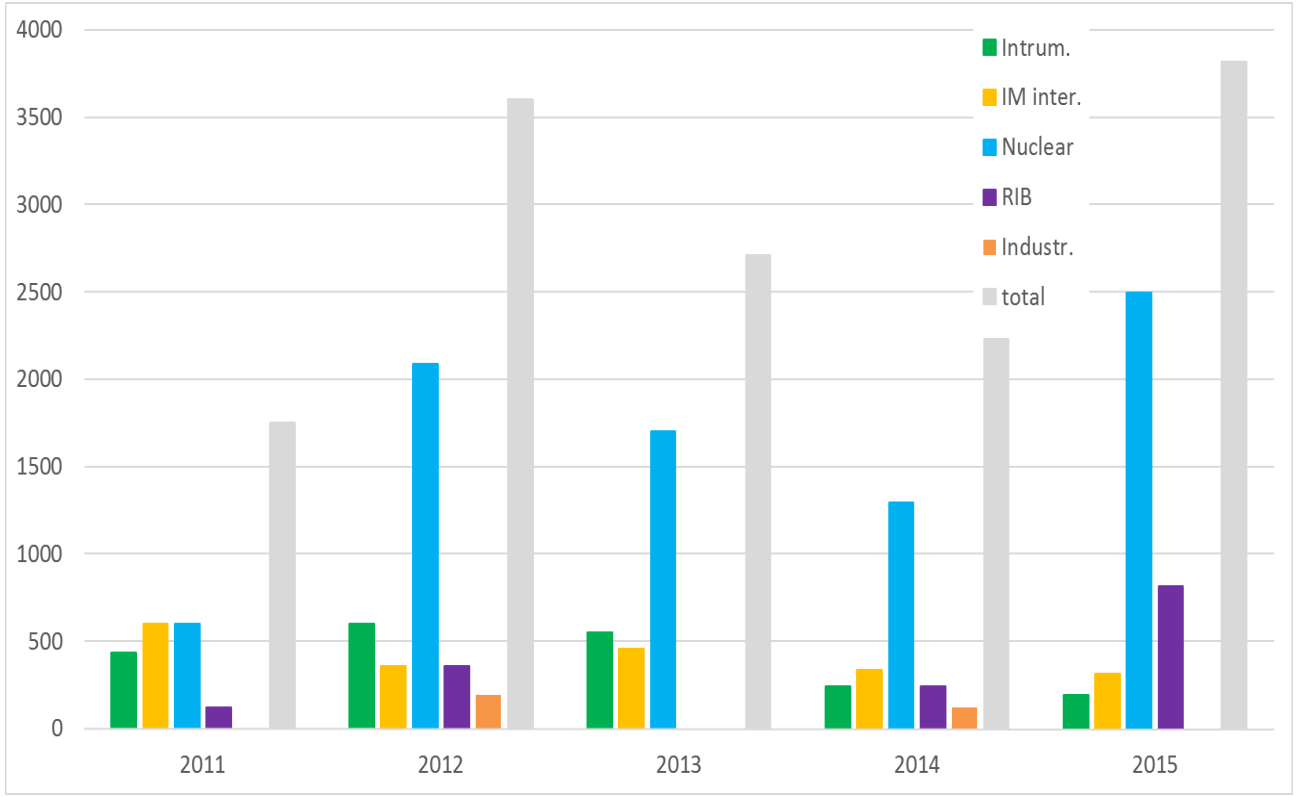
# The ALTO PAC

| | |
|---|---|
| **Richard Casten** | Yale, USA, **Chair** |
| Dimiter Balabanski | ELI-NP, **Romania** |
| Emmanuel Balanzat | CIMAP/GANIL, **France** |
| Marcella Grasso | IPN Orsay, **France** |
| Stéphane Grévy | Bordeaux-Gradignan, **France** |
| Adam Maj | IFJ PAN Kraków, **Poland** |
| Paddy Regan | Univ. Surrey, **UK** |
| Peter Reiter | Univ. Koeln, **Germany** |
| Berta Rubio | CSIC-Univ. Valencia, **Spain** |
| Jean-Charles Thomas | GANIL, **France** |
| Christina Trautmann | GSI, Darmstadt, **Germany** |
| Aurora Tumino | Kore Univ. Enna & LNS-INFN Catania, **Italy** |

Call for proposals once a year

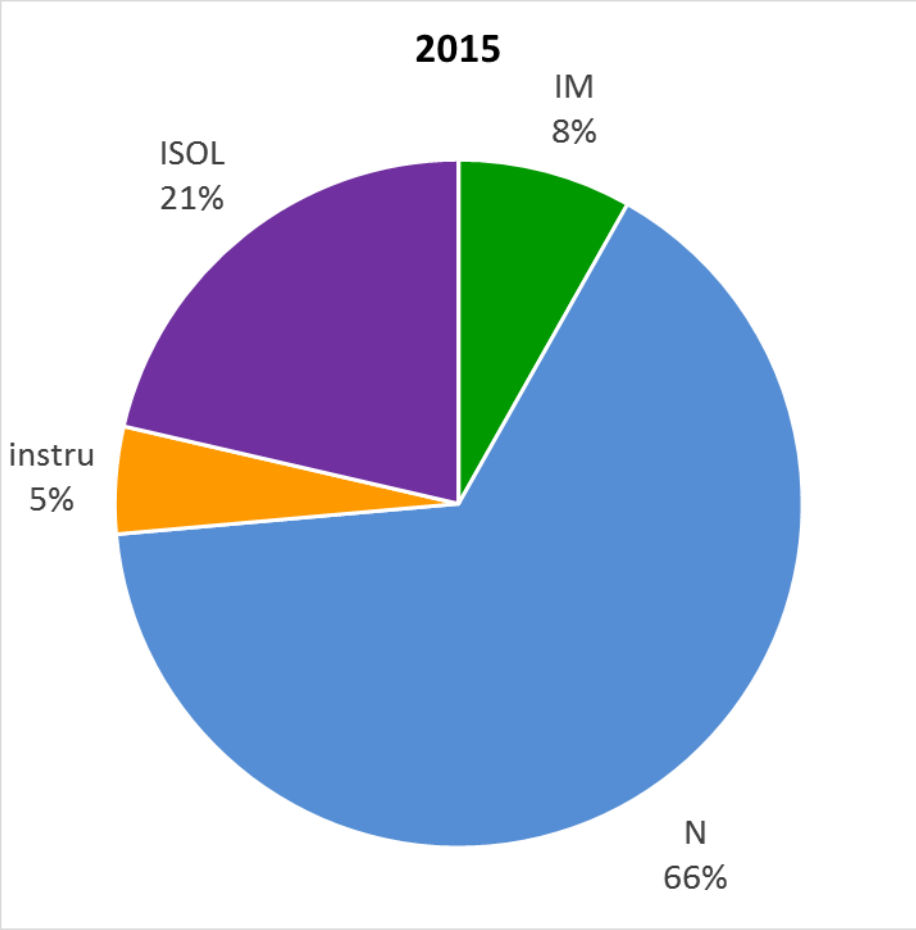
# Beam-time and users (2011 – 2015)

| | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| Users | ~120 | ~240 | 200 | 135 | 246 |
| Beam-time | 1752 h | 3600 h | 2712 h | 2232 h | 3816 h |
| | 219 UT | 450 UT | 339 UT | 279 UT | 477 UT |




**ALTO - TNA within ENSAR and ENSAR2**

# 2015 run



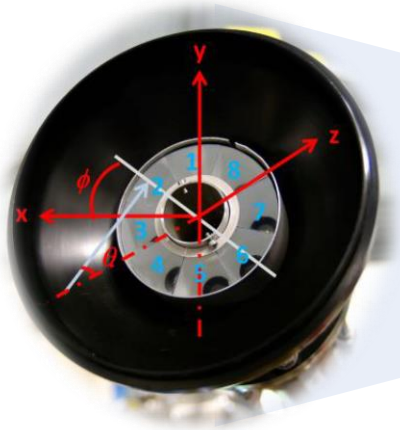

- **2015 – record beam time**, limited by the number of operators available
- High percentage of stable and radioactive nuclear physics experiments
- **Split Pole** – 2 campaigns
- **RIB** – 2 campaigns

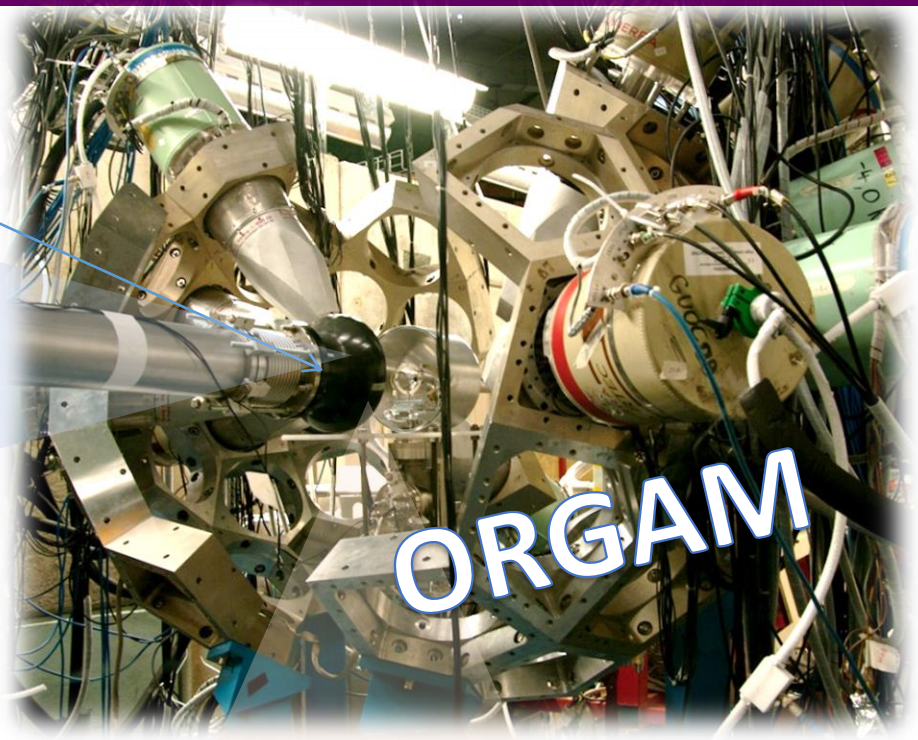
- **True parallel operation of stable and radioactive beams over several weeks**
- **34 days of RIB in two campaigns**

# Stable-beam Studies at ALTO

# Gamma-ray spectroscopy with ORGAM

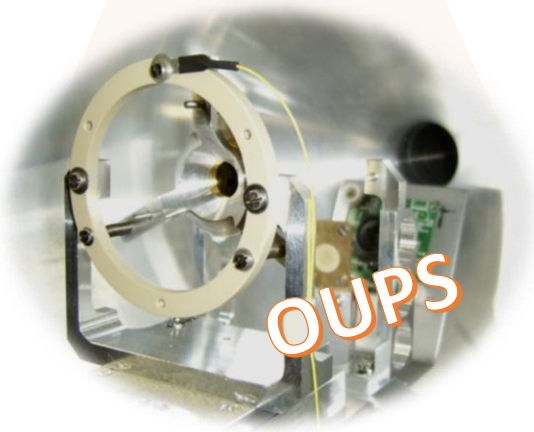
*Plastic scintillator*



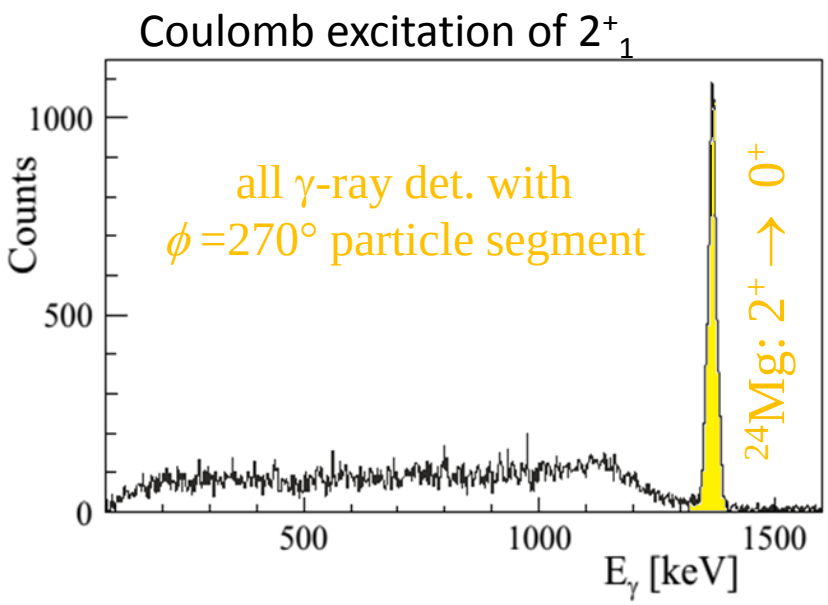

**beam:** $^{24}$**Mg @120 MeV (5 MeV/u)**
**target:** **2.4 mg/cm$^2$** $^{93}$**Nb**
**reset Foil:** **1.7 mg/cm$^2$** $^{197}$**Au**

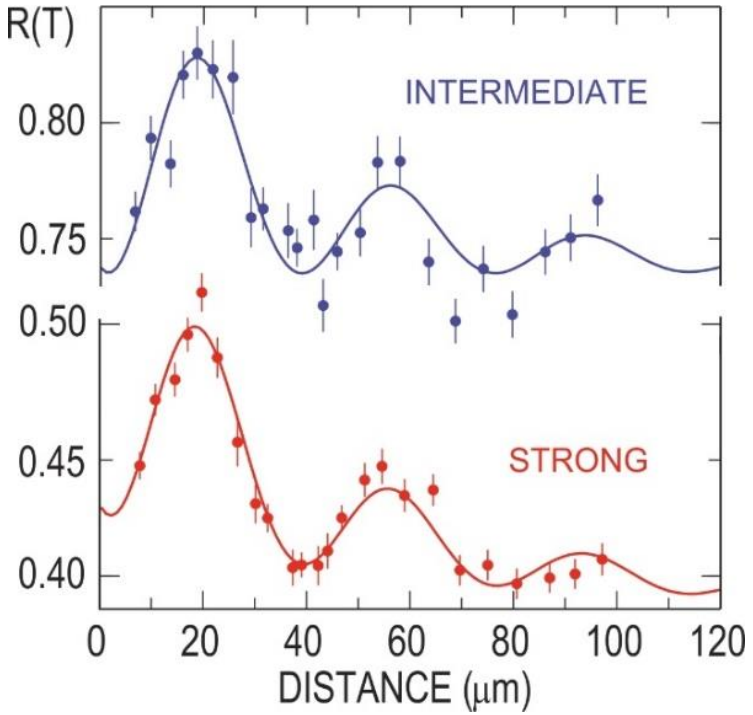
- ✓ 13 HPGe @ θ= 46.5°, 72.1°, 85.8°, 94.2°, 108.0°, 133.6°, 157.6°
- ✓ 8-fold segmented annular detector
- ✓ Orsay Universal Plunger System (OUPS)




Orsay Universal Plunger System

# TDRIV results on H-like ions




Previous measurement:

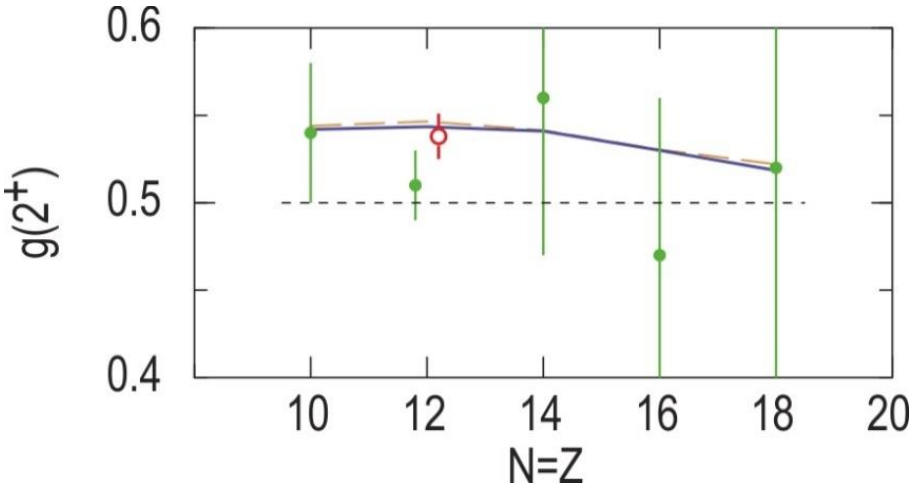
$|g(2^+)| = 0.51\ (2)$

R.F. Horstman et al., NPA 248, 291 (1975)

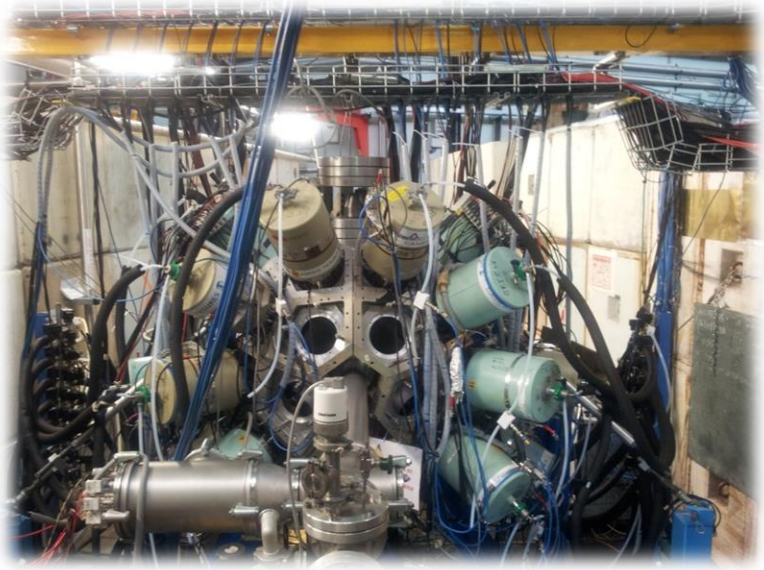
Our result:

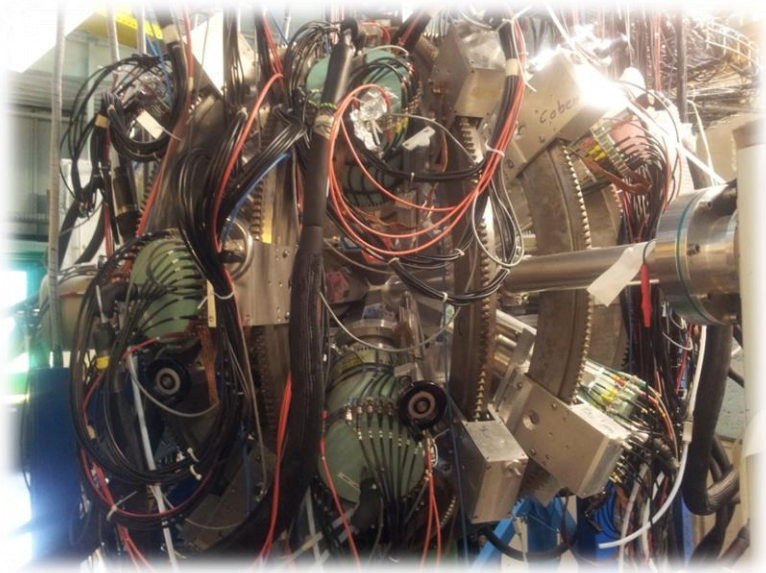
$|g(2^+)| = 0.538\ (13)$

***A. Kusoglu et al. PRL 114, 062501 (2015)***



# MINORCA at ALTO (June 2014 – March 2015)





**12 ORGAM *CS* HPGe x 0.1%**

**8 Miniball TC at ~14 cm from target**

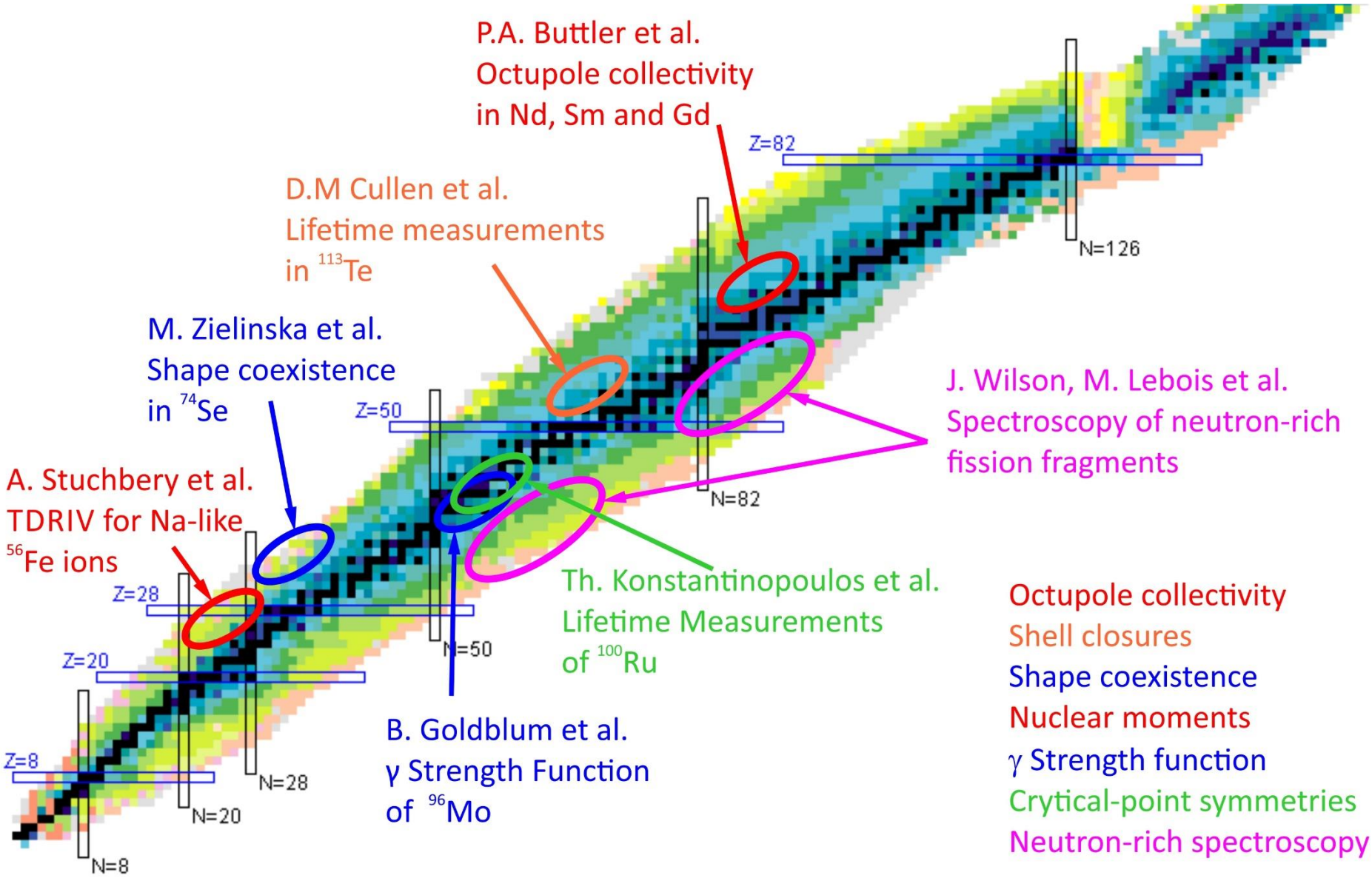
**7.3% efficiency @ 1.33 MeV**

**ancillary detectors:**

- **Orsay plunger (OUPS)**
- **particle detector**
- **DSSD**

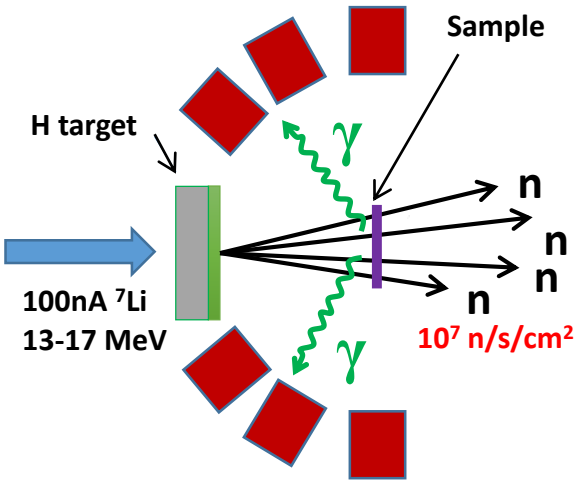
*Campaign managers: I. Matea and G.G.*

# MINORCA physics cases




*Campaign managers: I. Matea and G.G.*

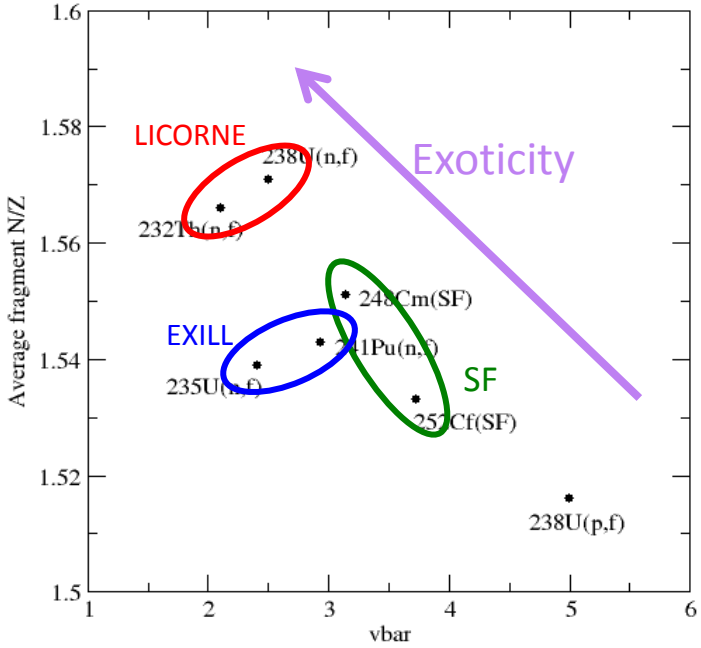
# Lithium Inverse Cinematics ORsay NEutron source



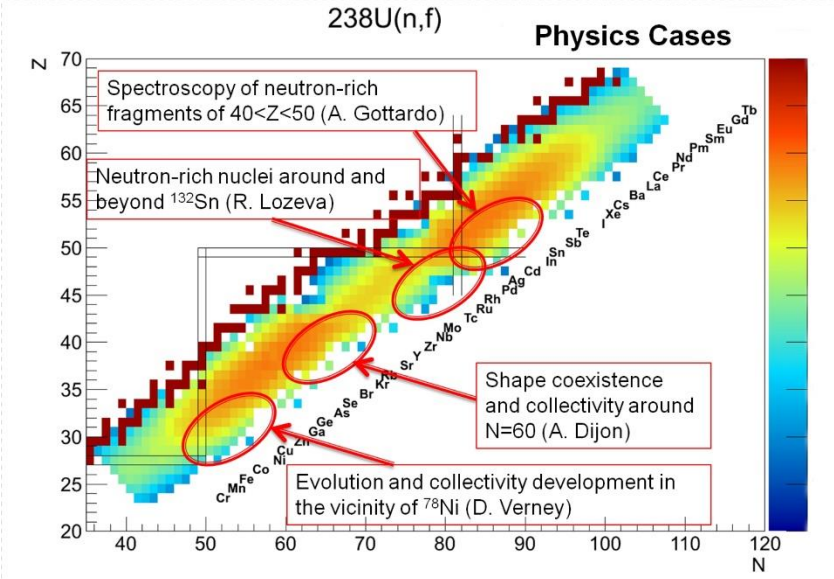

*n-induced fission of $^{238}$U*

*TIPS – tagging of isomer partners*

LICORNE +MINORCA

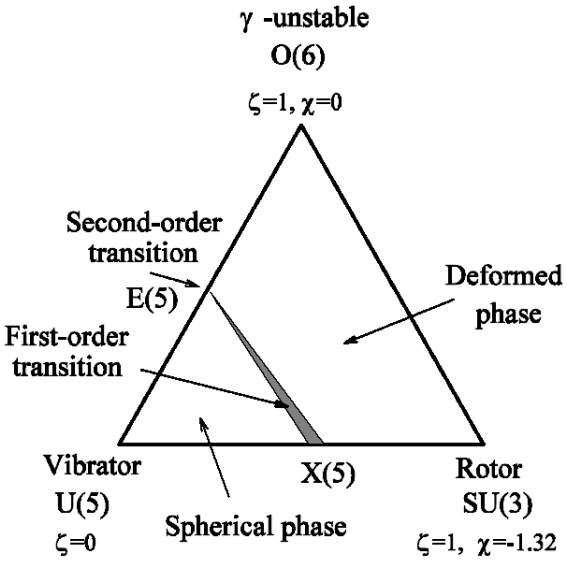



J. Wilson, M. Lebois *et al.*

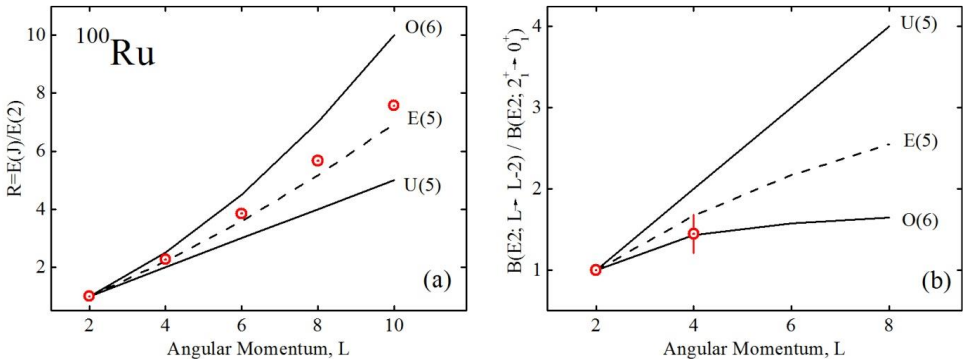



***Testing ground for NFS@SPIRAL2***

# Is $^{100}$Ru an E(5) nucleus?

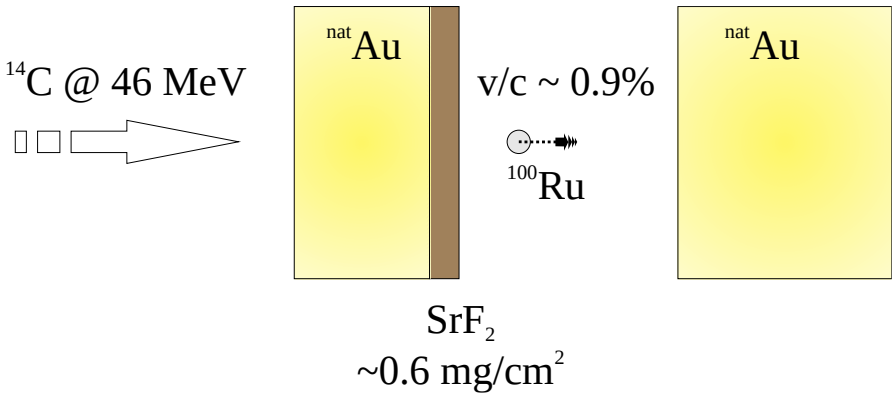



**T. Konstantinopoulos *et al.***



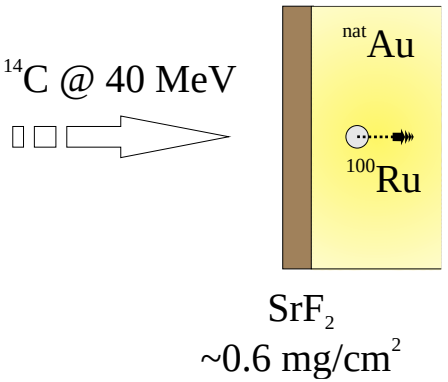

- $^{88}$Sr($^{14}$C, 2n)$^{100}$Ru : 200 mbarn @ 42 MeV
- $^{14}$C beam @ <1.5 pnA
- Orsay Universal Plunger System (OUPS)

## RDDS ($2^+$, $4^+$, $6^+$) :




* 12 plunger dist. from 1 um to 1 mm

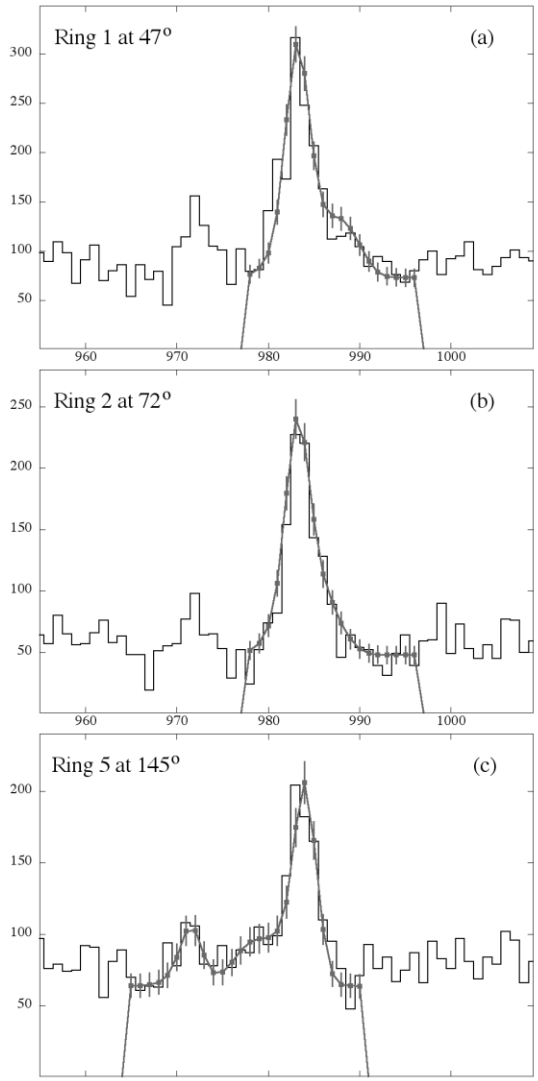
## DSAM ($8^+$) :




6.5*10$^8$ γ–γ coincidences collected

# DSAM for the $8^+$

Fit with DSAM code for
3 different detector angles




**T. Konstantinopoulos *et al.***

| $I_i^\pi$ | $E_x$ (keV) | $\tau$ (ps) | $I_i^\pi \rightarrow I_f^\pi$ | $E_\gamma$ (keV) | B(E2) (W.u.) |
|---|---|---|---|---|---|
| $2_1^+$ | 539.510 | 18.1 (2) | $2_1^+ \rightarrow 0_1^+$ | 539 | 35.6 (5) |
| $4_1^+$ | 1226.465 | **3.4 (10)** | $4_1^+ \rightarrow 2_1^+$ | 686.972 | **57 (17)** |
| $6_1^+$ | 2075.674 | **9.4 (15)** | $6_1^+ \rightarrow 4_1^+$ | 849.20 | **7.1 (11)** |
| $8_1^+$ | 3060.068 | **0.72 (15)** | $8_1^+ \rightarrow 6_1^+$ | 984.45 | **45 (9)** |

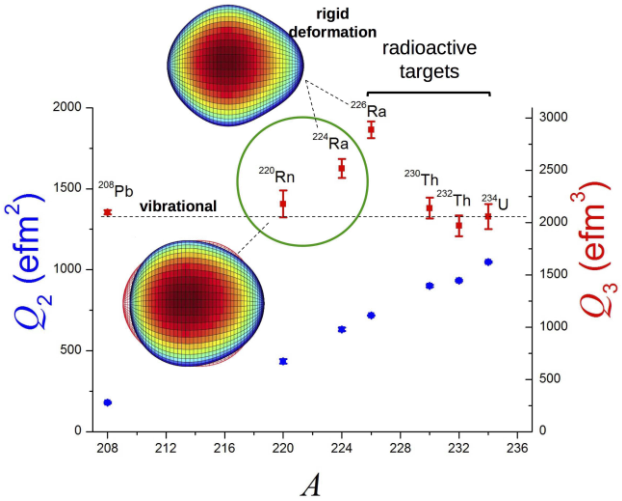
Preliminary!

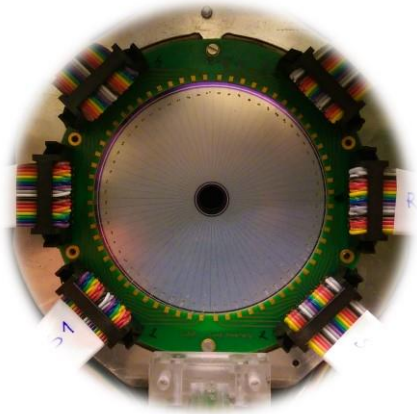
"$^{100}$Ru not confirmed as E(5) nucleus"

# Pear-shaped nuclei in the N~88 region

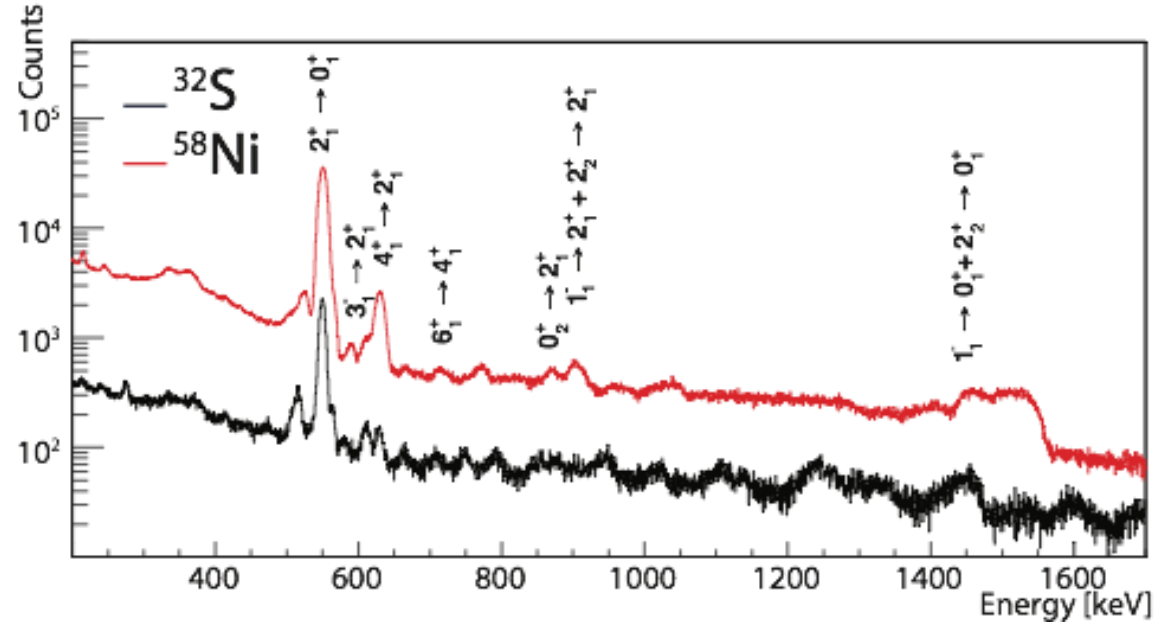
## Octupole collectivity in $^{146}$Nd and $^{148}$Sm

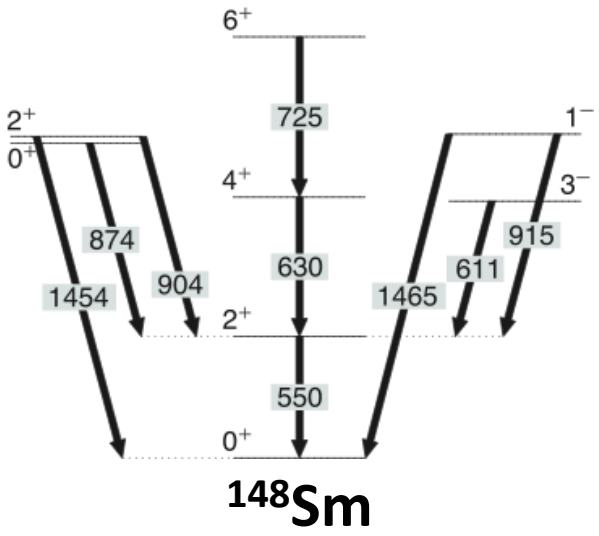
*P. Butler,* M. Zielinska *et al.*



Coulex

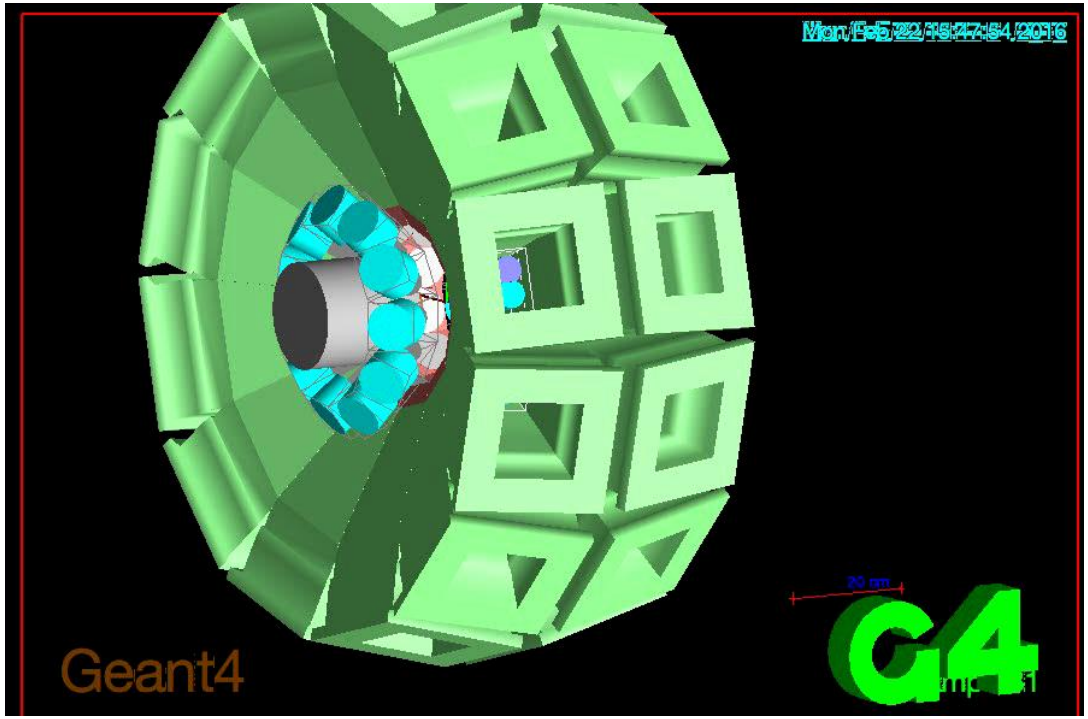





*Courtesy M. Komorowska*

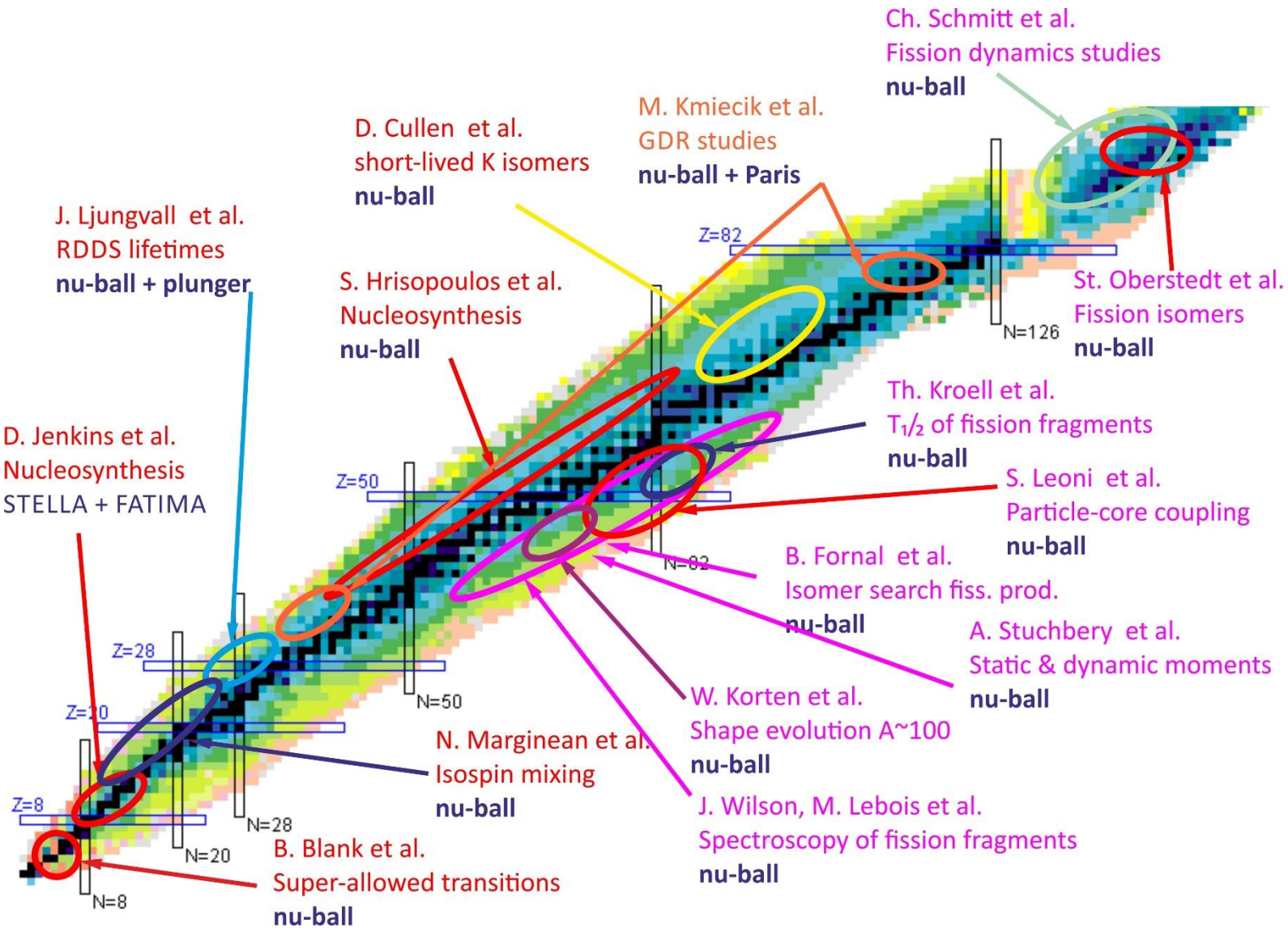
# ν-ball: a hybrid $LaBr_3$-Ge array for γ-ray spectroscopy studies




- Hybrid Ge + $LaBr_3$ array + ancillaries @ ALTO
- 24 gamma-pool **Clover detectors** + 36 $LaBr_3$ from **FATIMA** or 10 – 15 "phase 1" Ge's
- **Ge efficiency ~ 7 % total; LaBr3 efficiency ~5 %**
- Combination with "ancillary" devices (OUPS, particle detection, neutron source …)
- Campaign – from 2017 for up to 2 years
- Call for proposals – December 2016

# nu-ball – a few physics cases

***nu-ball hybrid spectrometer workshop – 19 – 20 May, 2016, Orsay***

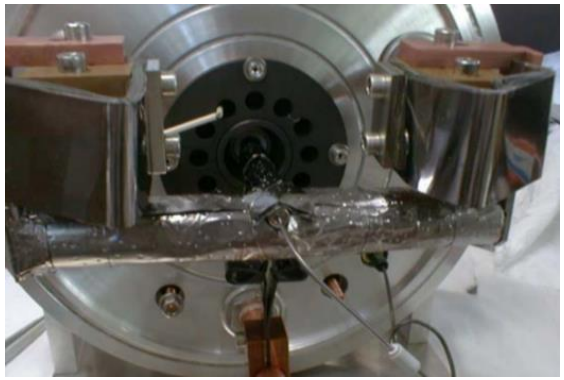


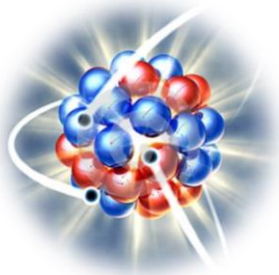
# Radioactive Ion Beams at ALTO

# ALTO – RIB production

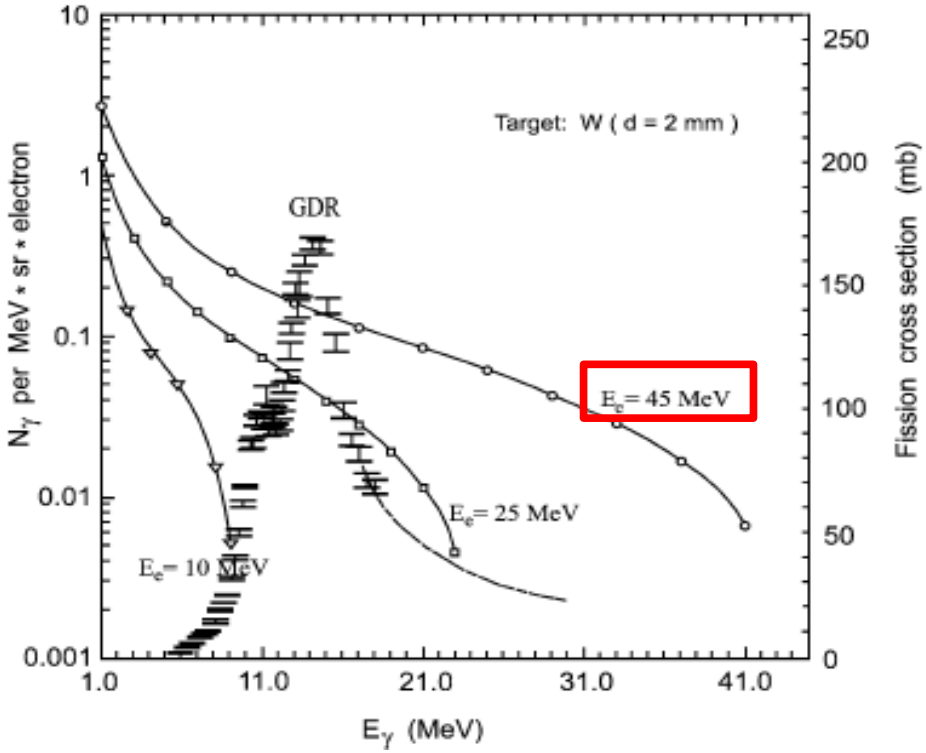
## First ***operational*** RIB facility based on photo-fission

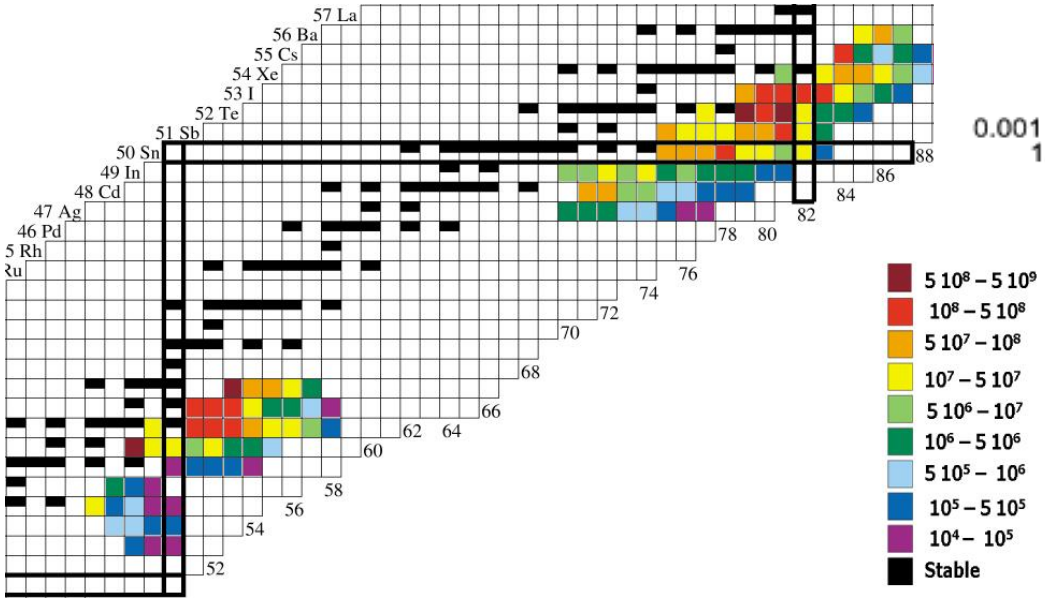
standard ISOLDE target
Ø = 14 mm; L = 200 mm
ρ = 3.2 g/cm$^3$; T ≤ 2100$^o$ C





Y. Oganessian *et al.*, NPA 701 (2002) 87c



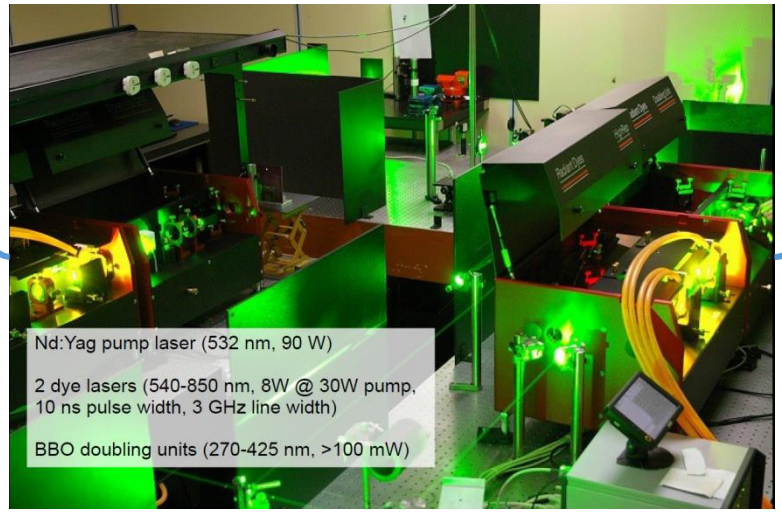

→ Yields for 10 µA,
50 MeV e$^-$ beam
(10$^{11}$ fissions/s)

# Rialto: Resonant laser ionisation for beam selectivity

S. Franchoo et al.

The variety of the physics program at ALTO strongly depends on RIB availability, intensity and purity

LASER ION SOURCE

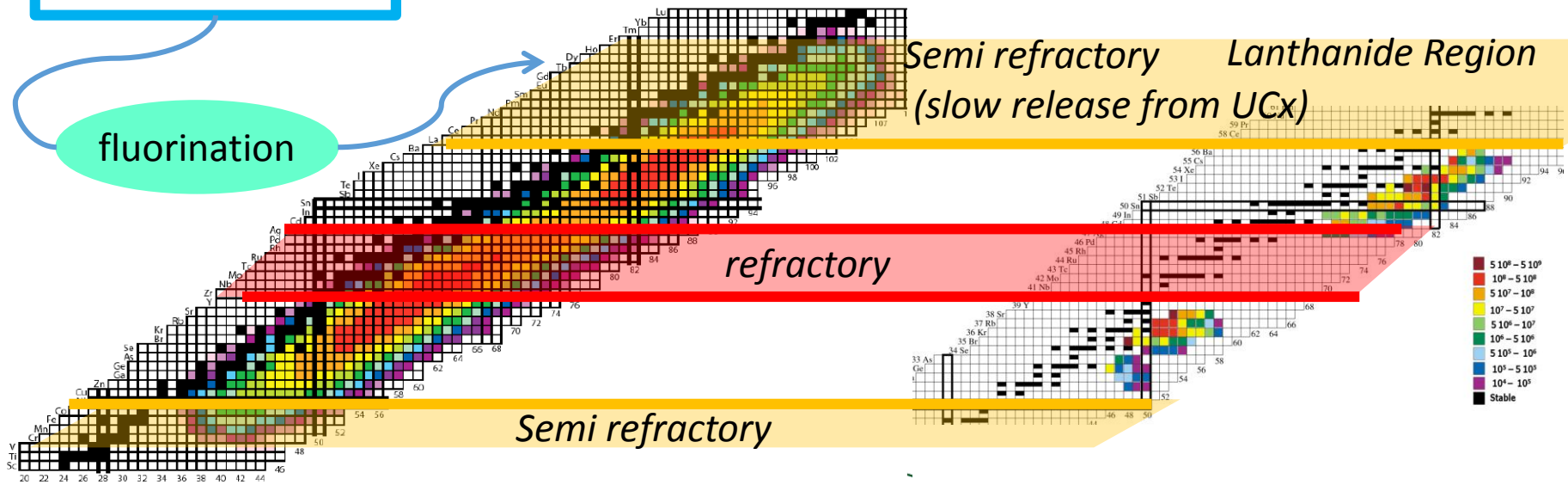



efficiency, Z-selectivity

first successfully laser ionized beam Phys. Rev. C 88, 047301 (2013)

IN-TIS CHEMISTRY

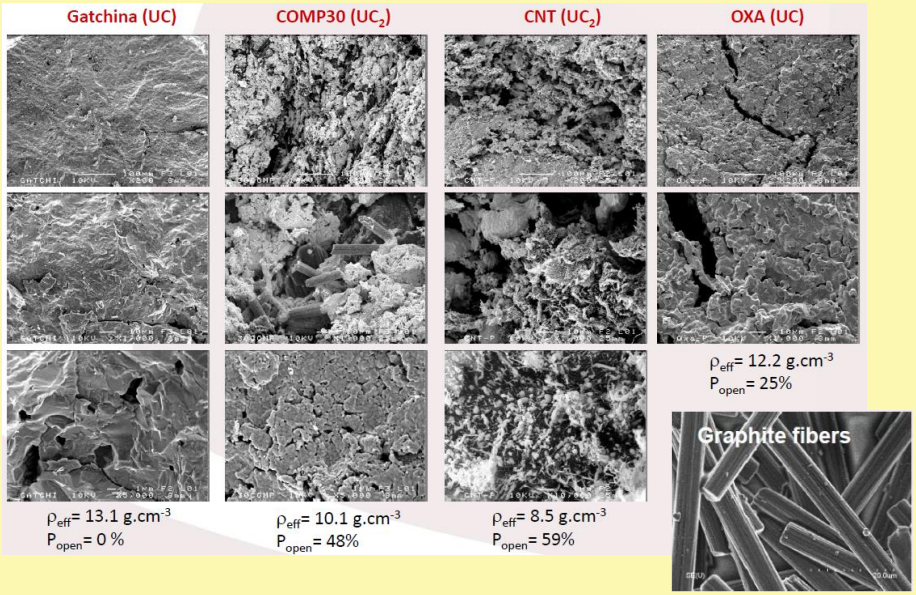
fluorination



# Target and ion source developments

M. Cheikh *et al.*

## Control porosity
## Reduce pellet thickness

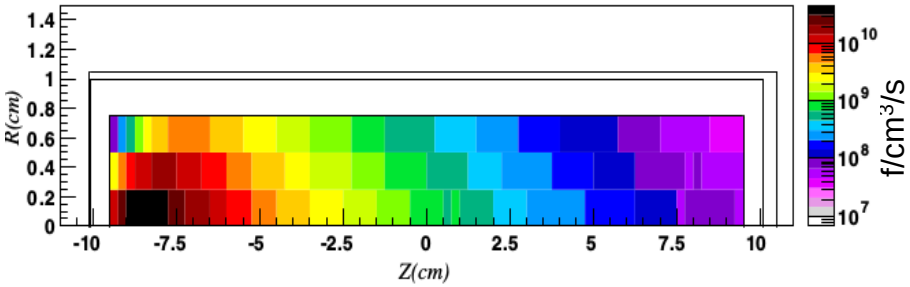



B Hy *et al.*, NIM B 288,34 (2012)

ENSAR Actilab:
IPN, CERN, GANIL, INFN, Univ. Rennes, PSI

## target size optimization →

$e^-$ energy deposit in the first 2.65 cm

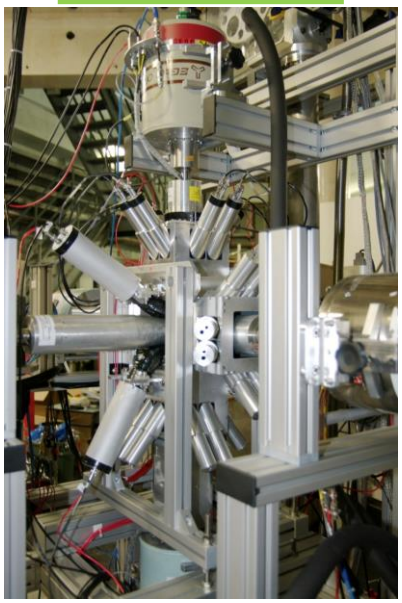



Fluka fission rate in 3.2 g/cm$^3$ $UC_x$ target
M. Cheikh Mhamed *et al.*, NIM B 266, 4092 (2008)

# Progress in the RIB instrumentation (so far)


3 modes, 3 commissioning's, 3 physics results

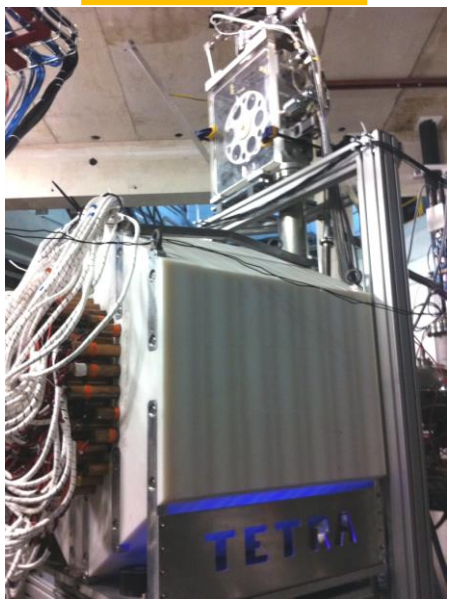

**BEDO setup in gamma mode**
**4 small EXOGAM clovers**



IPN, coll. CSNSM, IPHC

PhD: A. Etilé (CSNSM)
**PRC 91, 064317 (2015)**

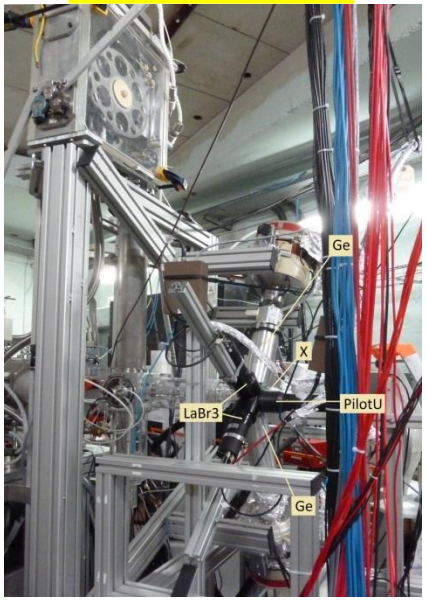
**BEDO setup in neutron mode**
**Dubna neutron detector TETRA**




IPN, coll. JINR (Russia), IPHC

PhD: D. Testov (IPN)
**NIM A815, 96 (2016)**

**BEDO setup fast timing mode**
**LaBr3**

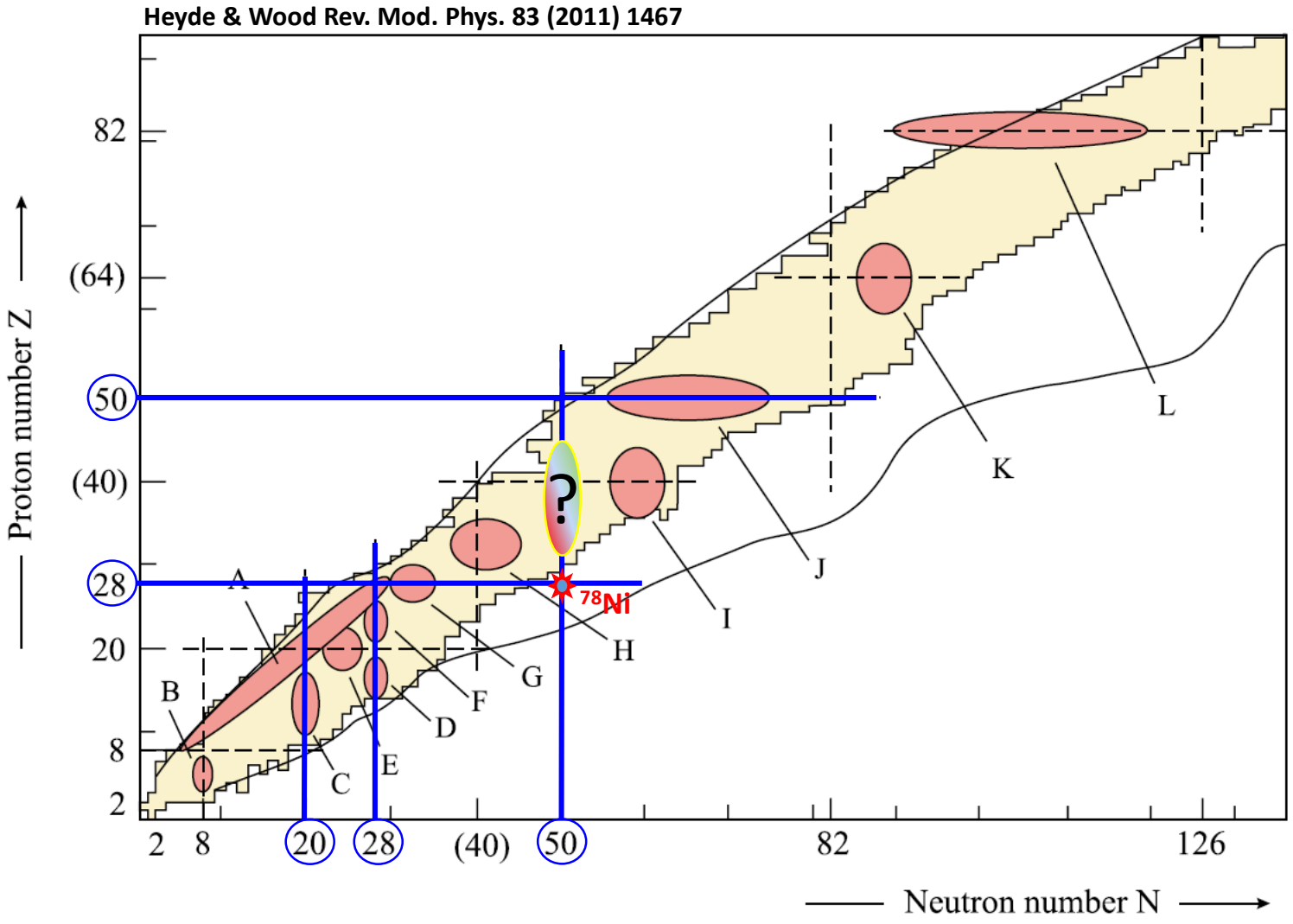



IPN, coll. CSNSM, TANDAR (Argentina), INRNE (Bulgaria)

M.A.Cardona, D.Hojman, B.Roussière, I.Deloncle et al.
**to be submitted**

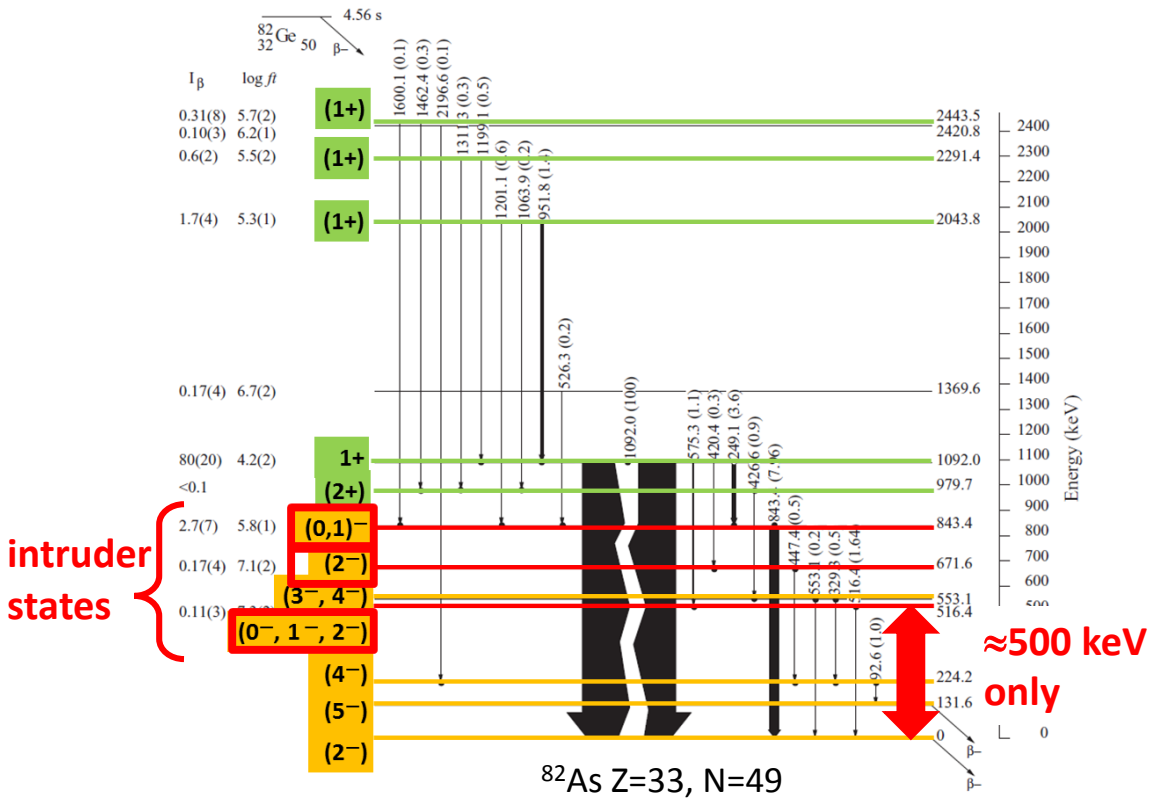
# Shape coexistence in the $^{78}$Ni region by β-delayed conversion-electron spectroscopy of Ge's

## *Shape coexistence throughout the nuclear chart*



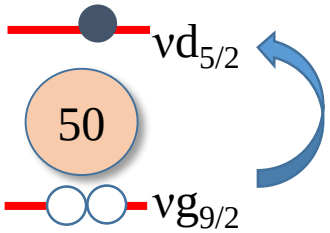
# Are there intruder configurations at Z>28, N=49

$^{82}Ge \rightarrow {}^{82}_{33}As_{49}$




$^{82}As$ Z=33, N=49

**A. Etilé et al. PRC 91 064317 (2015)**



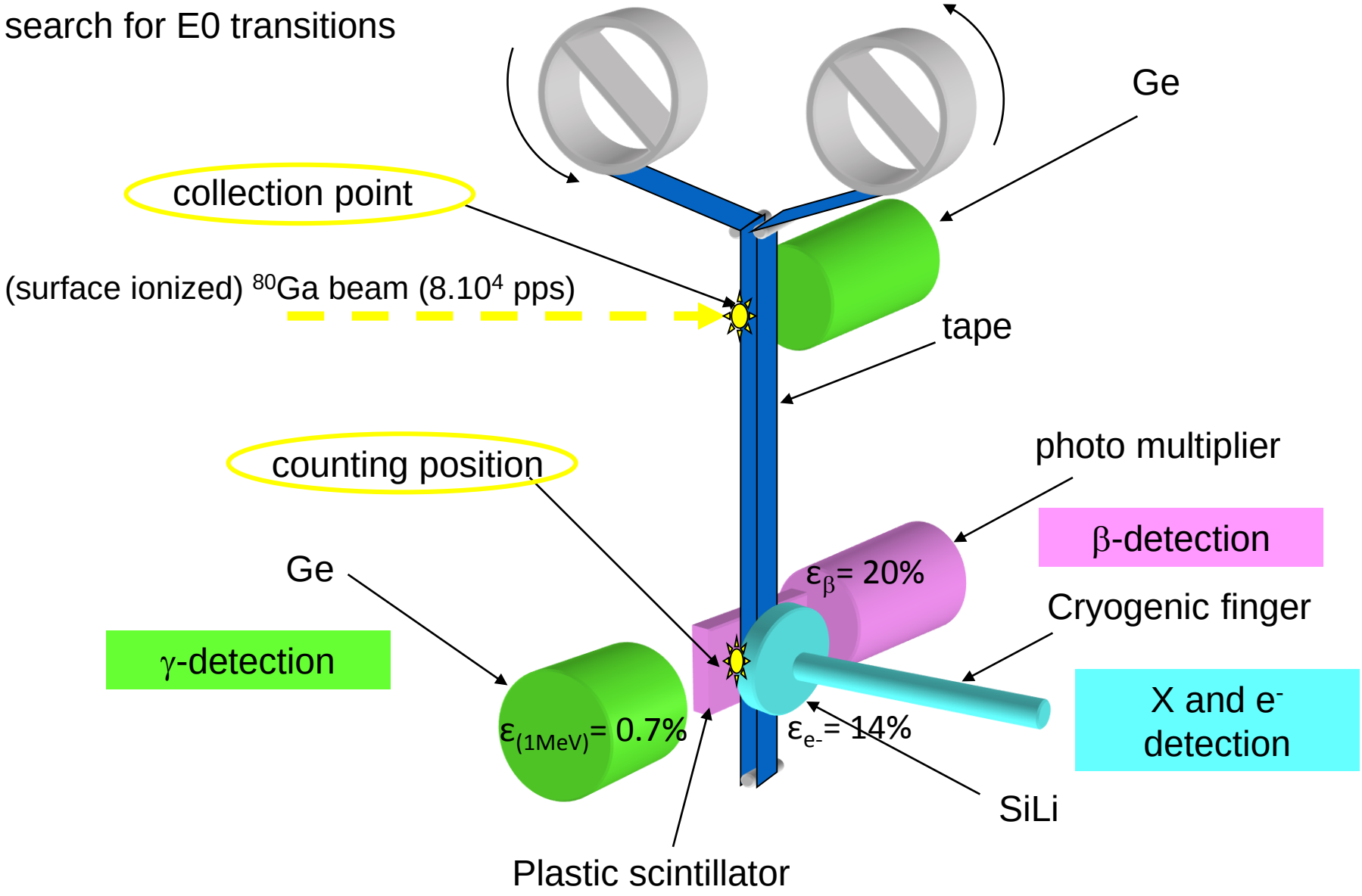

**(1)** large number of $1^+$ states in the N=50 region

(responsible for the half-life of the mother nucleus, possible consequences on the r-process)

*(influence of couplings to 2p-2h and tensor interaction)*

**(2)** lowering of 1p – 2h (intruder) states – an ***indication for shape coexistence*** in the close vicinity of $^{78}Ni$?

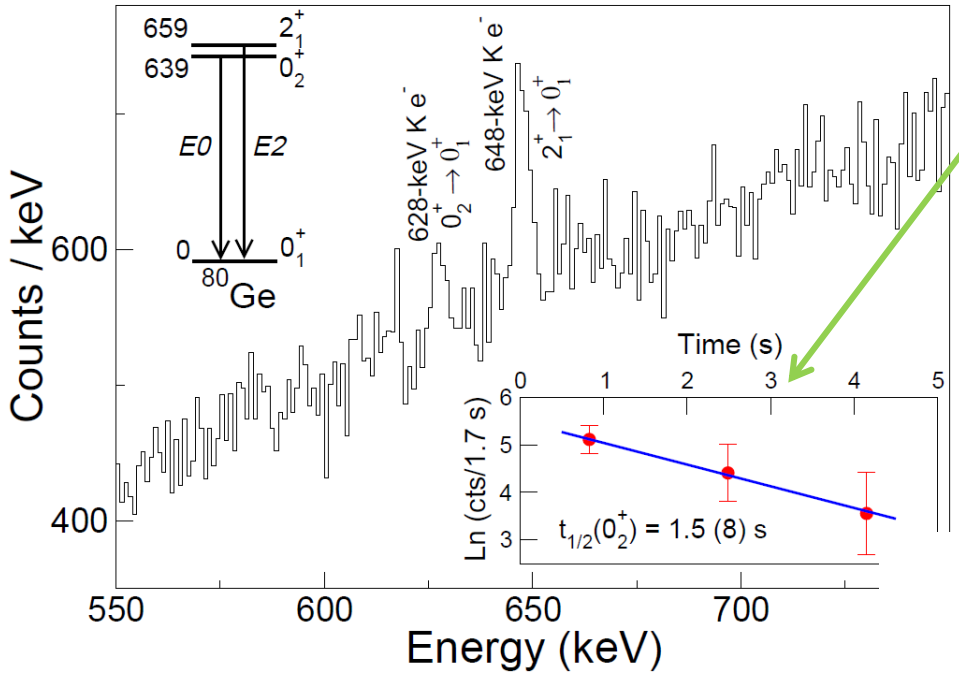
# Experiment at the "PARRNe identification station"



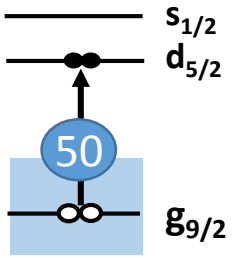


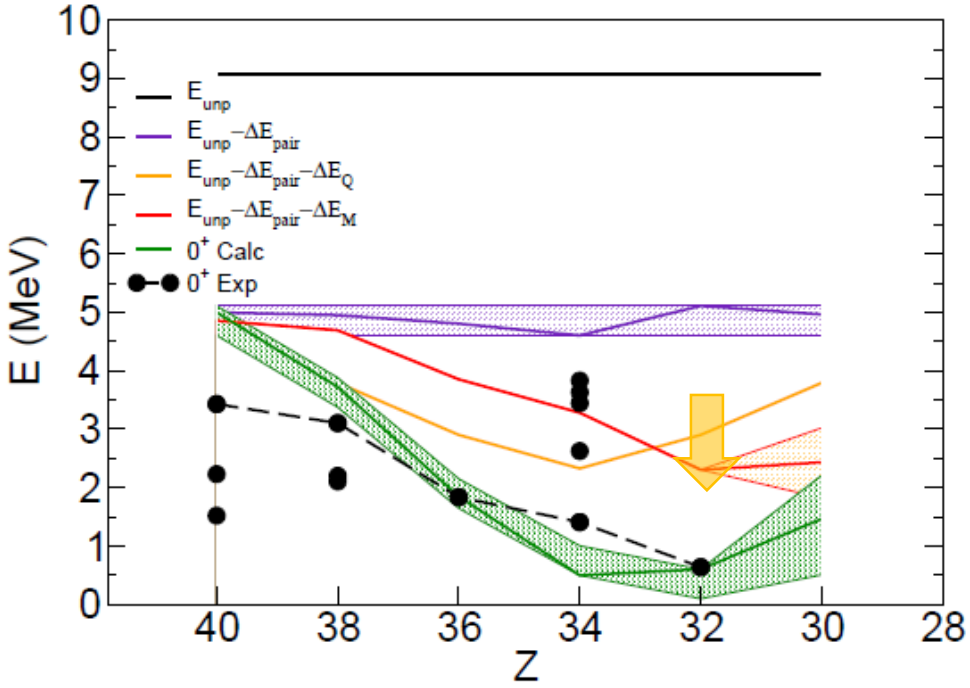

*Courtesy D. Verney*

# The observation

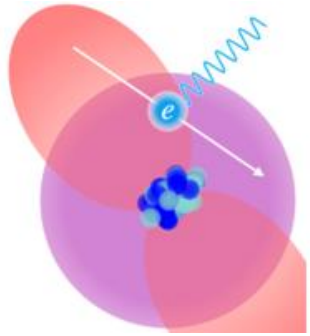



Compatible with the $T_{1/2}$ for the **3** $^-$ isomer in **$^{80}$Ga**
[$T_{1/2}(3^-)$=1.3±0,2 s; Verney et al. PRC 87 (2013)]
A situation very similar : $0^+_2 \rightarrow 0^+_1$ populated in the **3**$^-$ **$^{72}$Ga** decay [Rester et al NPA 162 (1971)]



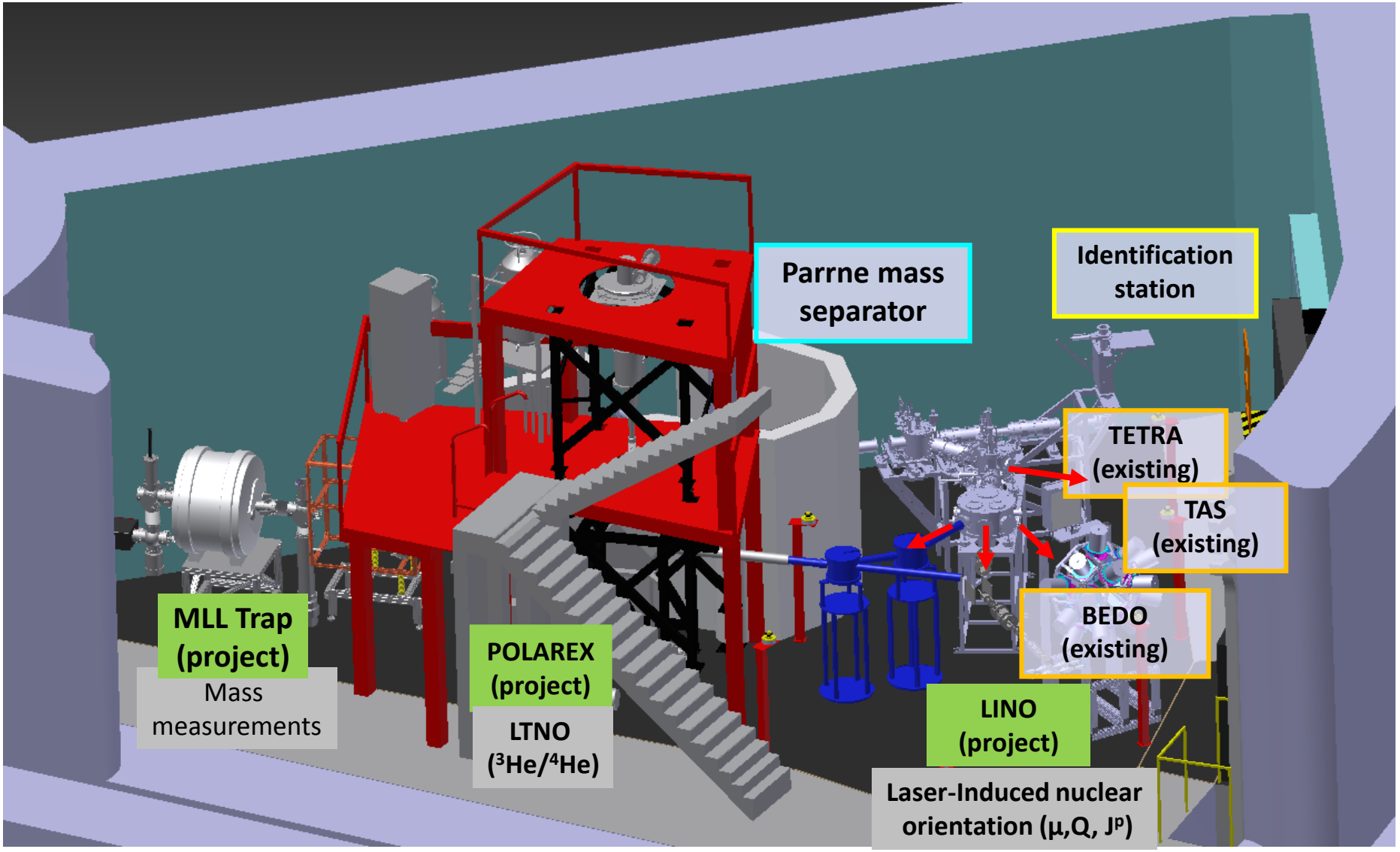

First evidence of shape coexistence in the $^{78}$Ni region




Gottardo, Verney *et al.*
PRL **116,** 182501 (2016)

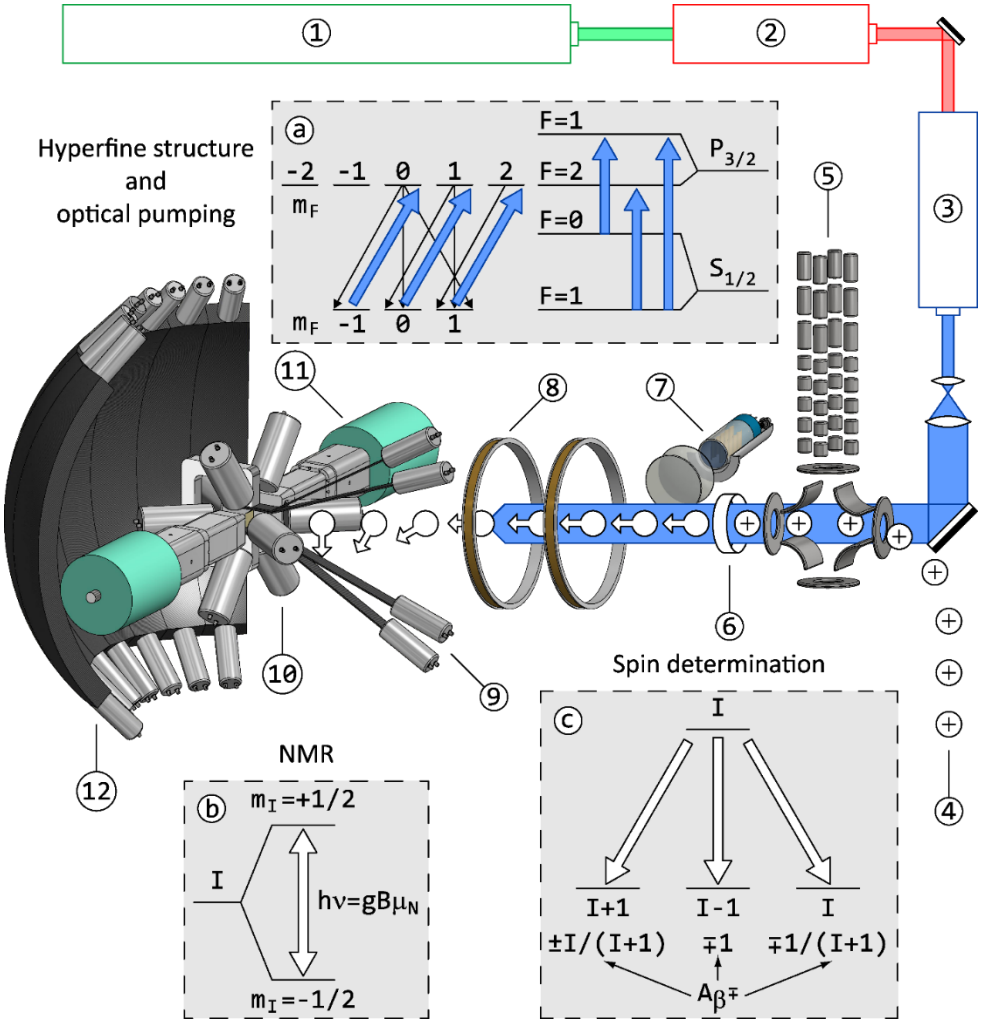
*Courtesy D. Verney*

# Present RIB setups and near-future projects



# LINO: Laser-induced nuclear orientation

- polarization by optical pumping



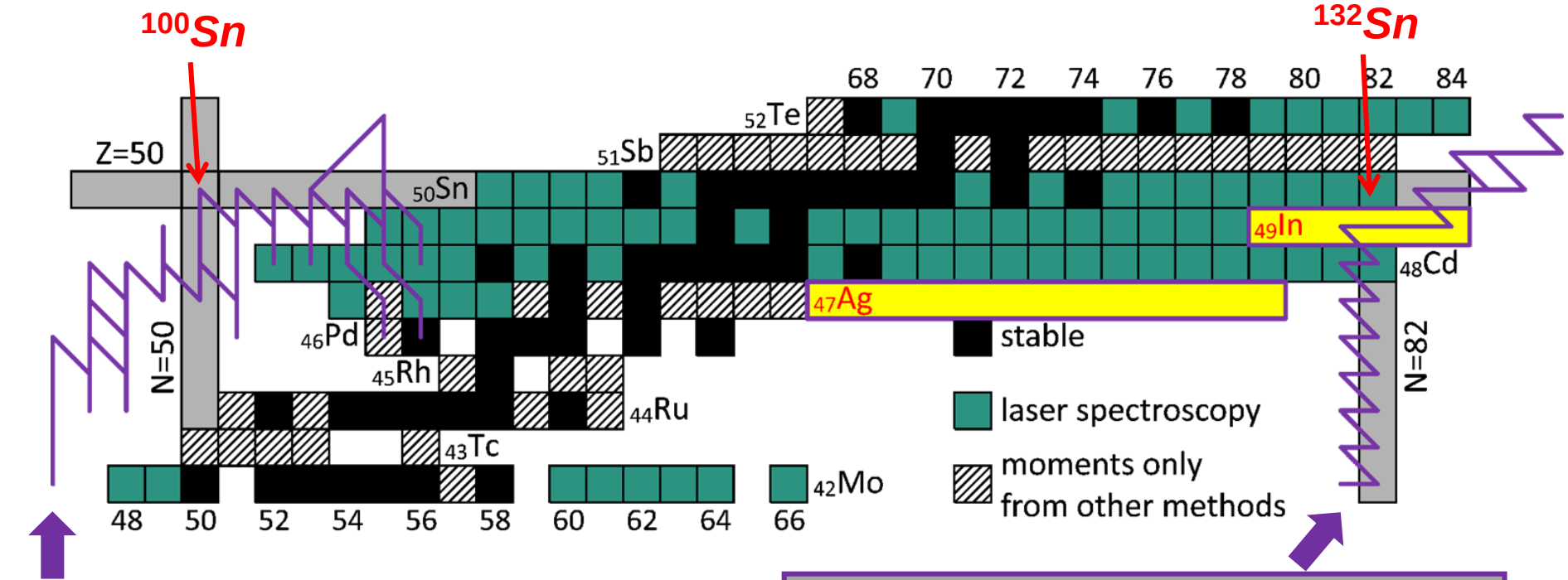

**D. Yordanov et al.**

**Research capabilities:**

- Electromagnetic moments;
- β NMR;
- Atomic hfs;
- Nuclear rms charge radii;
- β delayed γ spectroscopy of laser polarized beams (excited-states spin determination)

# LINO: Laser-induced nuclear orientation

β-delayed spectroscopy of laser-polarized beams
ground and isomeric state properties of $^{110-126}$Ag and $^{128-133}$In
β-decay of polarized $^{121-126}$Ag and $^{128-133}$In




***rp process***

***r process***

- ***more accurate theoretical lifetimes of the N=82 isotones below $^{129}$Ag***
- ***shell quenching vs deformation***
- ***shell effect in radii***

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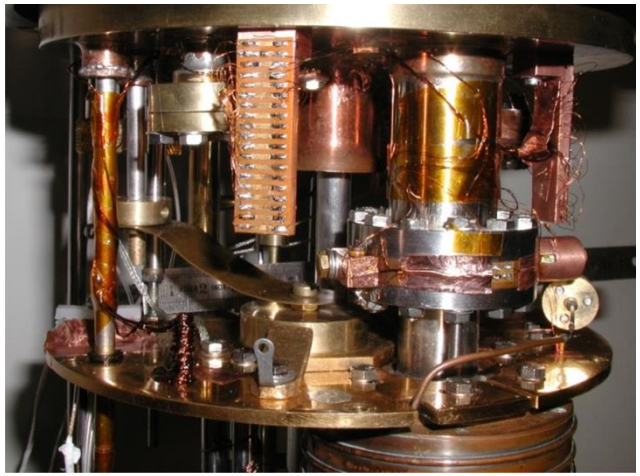
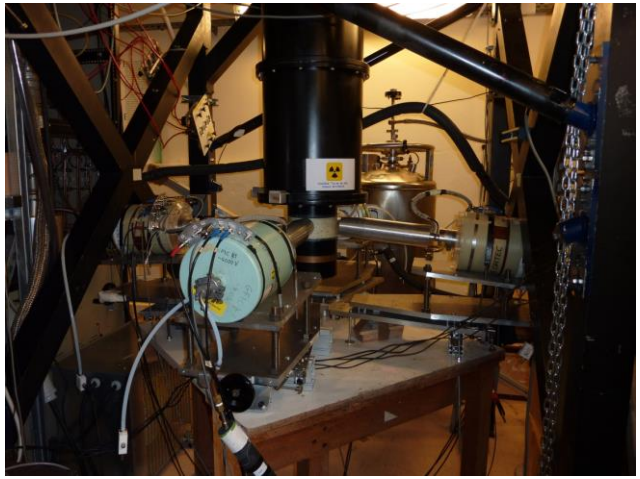
# Polarex: Nuclear Orientation On-Line

**CSNSM off-line validation**

Rejuvenation of dilution cryostat





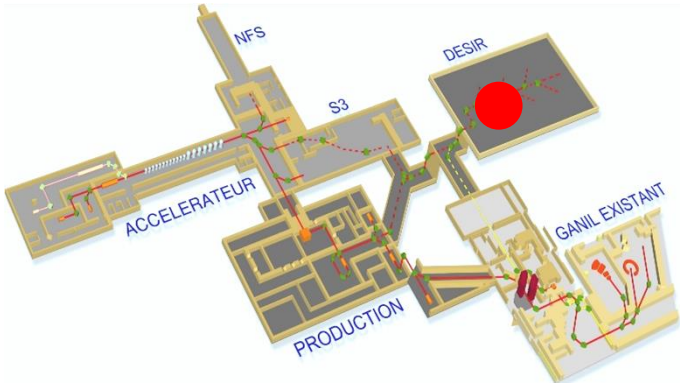
CSNSM Orsay
LPSC Grenoble
IPN Orsay
INM Paris
University of Tennessee
University of Maryland
University of Oxford
University of Novi Sad

**Preparation at Alto**

Structural integration & beam-line design

**C. Gaulard et al.**

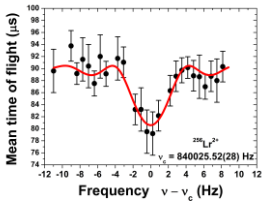
# MLL trap - high-precision mass measurements at ALTO

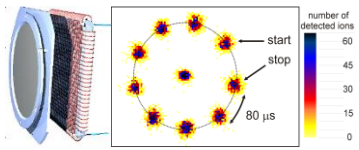

## *High-precision mass measurements ("M")*

| Field | δm/m |
|---|---|
| Chemistry: identification of molecules | $10^{-5}$ - $10^{-6}$ |
| Nuclear physics: shells, sub-shells, pairing | $10^{-6}$ |
| Nuclear fine structure: deformation, halos | $10^{-7}$ - $10^{-8}$ |
| Astrophysics : r-process, rp-process, waiting points | $10^{-7}$ |
| Nuclear models and formulas: IMME | $10^{-7}$ - $10^{-8}$ |
| Weak interaction studies: CVC hypothesis, CKM unitary | $10^{-8}$ |
| Atomic physics: binding energies, QED | $10^{-9}$ - $10^{-11}$ |
| Metrology: fundamental constants, CPT | $\leq 10^{-10}$ |

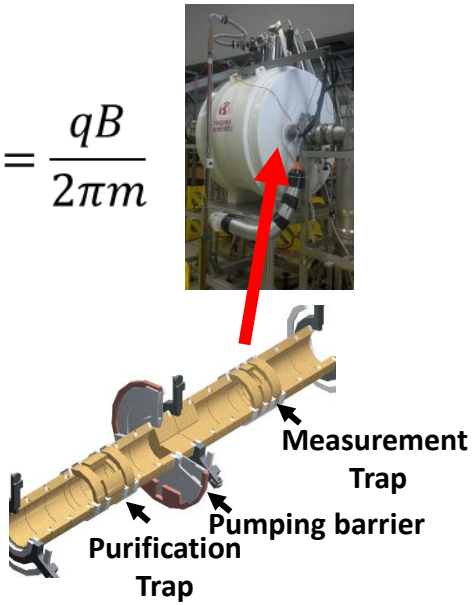
***TOF-ICR***




***PI-ICR***




$$\nu = \frac{qB}{2\pi m}$$

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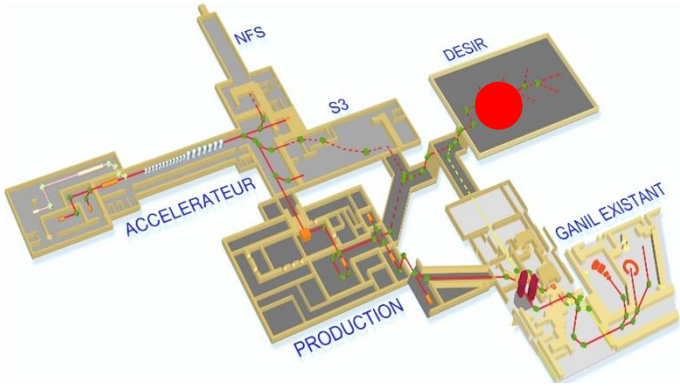
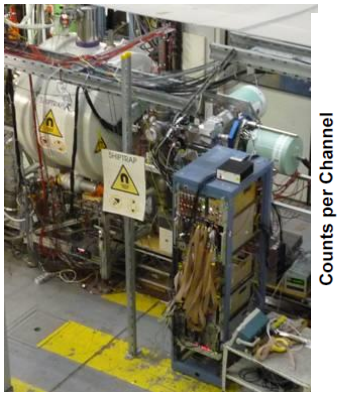
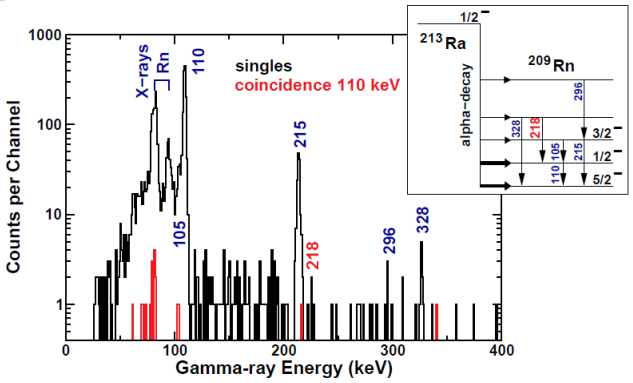
# Spectroscopy with MLL trap at ALTO

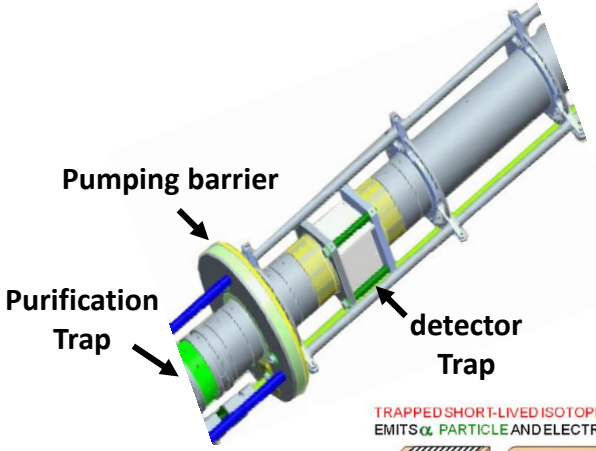




## *Trap-assisted spectroscopy ("S")*

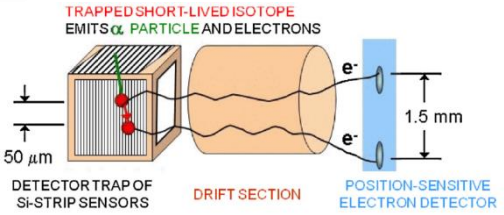





## *In-trap decay spectroscopy ("S")*




LMU



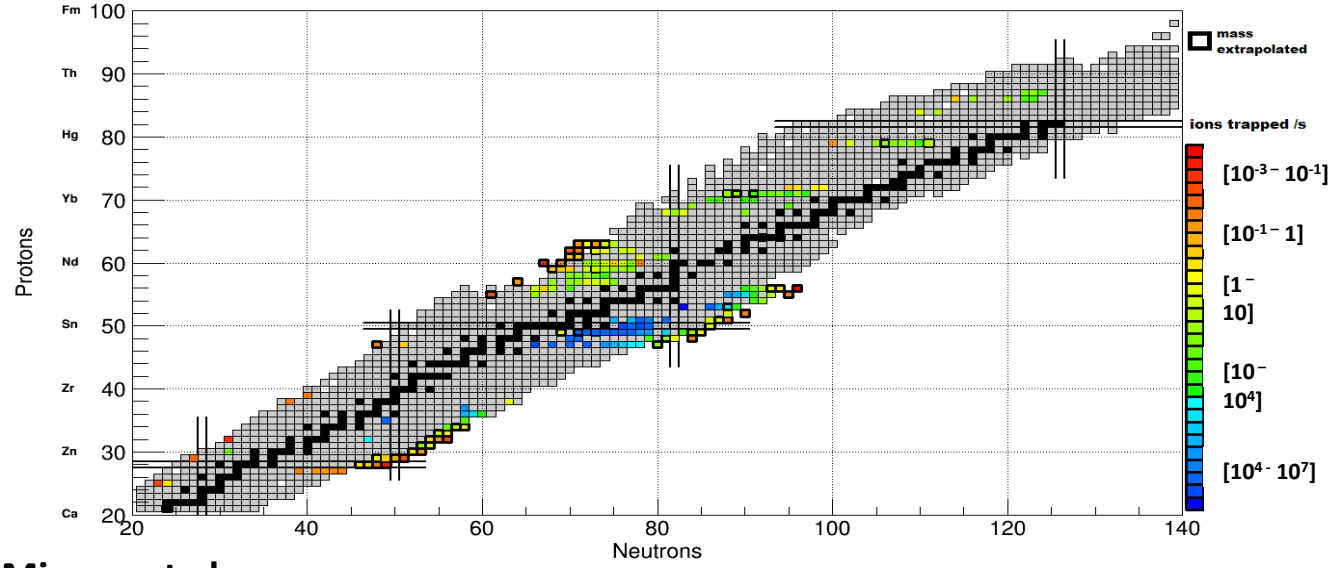

**E. Minaya et al.**

# RFQ cooler/buncher for MLL trap

*Cooled bunched beam*


*Selected ions*

*Detection "M" and/or "S" mode*




- **δm > 10 keV**
- **$T_{1/2}$ > 80 ms**
- **Trapped ions in 10h > 100**

**+ Fusion evaporation source**

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# Timeline

## LINO:

- beamline elements being presently built and purchased;
- setup elements (charge-exchange cell, det. chamber etc. ) under construction – to be ready by the end of 2016
- ***first experiments foreseen for 2017***

## POLAREX:

- fridge tested off-line at CSNSM (8 mK achieved) in 2015
- move to ALTO possibly in 2016
- off-line and near-line experiments in 2017
- ***on-line experiments in 2018***

## MLL-trap:

- superconducting magnet – warmed up and prepared to move to Orsay (May – June 2016)
- construction of beamlines and RFQ – till end of 2017
- off-line tests in 2018
- ***on-line tests and measurements – from 2019 on***

# Before Conclusions

- **NuSpIn** - Subtask 2.4, working group 4: Devices for nuclear moments and transition probabilities.

**Work in progress**

- Nuclear moment studies @ ALTO:
  - **ground-state moments** (with RIB) – Polarex, LINO
  - **excited-states moments**: TDPAD on *isomeric states*; TDRIV – very short-lived states (well-defined charge states)
- Transition-probabilities studies @ ALTO
  - RDDS (plunger) and DSAM lifetime measurements (**OUPS**)
  - longer-lived states – ***nu-ball hybrid array***

# Conclusions

- **ALTO – a small-scale facility for stable and radioactive beams that provides physics results with considerable impact**
- **Gamma-ray spectroscopy has been providing strong contributions to the nuclear structure studies at ALTO**
- **ISOL - RIB studies (beyond standard beta-decay) start already providing results with significant impact**
- **The R&D and the physics program at ALTO a step towards a next-generation ISOL RIB facility – address physics cases, train ISOL physicists, develop instruments and methodologies**

# Thank you!