TAS MEASUREMENTS TO PROBE LOW LYING COLLECTIVE MODES @ THE ALTO FACILITY, AND THE TOSCA DETECTOR PROJECT

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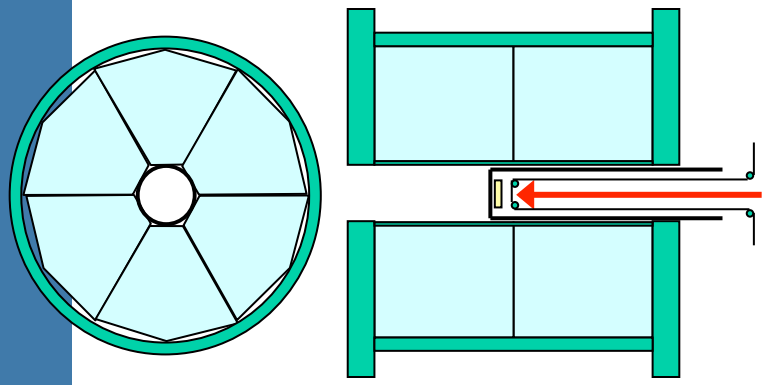
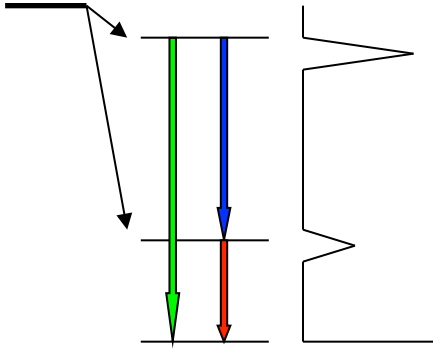
Experiment accepted by the ALTO PAC in Jan. 2014

Outline

- Total Absorption Spectroscopy (TAS) technique
- Physics Motivations to study the ^{132}Sn region
- Physics Motivations: Low-lying collective modes
- Proposal to test: the potential relationship btw GT strength and neutron skin
- Proposal to test: the access of low-lying collective modes through the large Q_β window in exotic n-rich nuclei
- Conclusions & Outlooks
- TOSCA detector project

Total Absorption Spectroscopy (TAS)
Big cristal, 4π => A TAS is a calorimeter !





Observable:

β-intensity => β-strength:

An ideal TAS would give directly the β-intensity I_β which is linked with the β-strength S_β:

$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}} \qquad \left[s^{-1}\right]$$

Allows to avoid the Pandemonium effect:**

$$I_i = \frac{f_i}{\sum_k f_k}$$

** J.C.Hardy et al., Phys. Lett. B, 71, 307 (1977)

- **Spectrum must be clean**
- **Response must be accurately known**
- **Solution of inverse problem must be stable**

NIM A430 (1999) 333 NIM A571 (2007) 719
NIM A430 (1999) 488 NIM A571 (2007) 728

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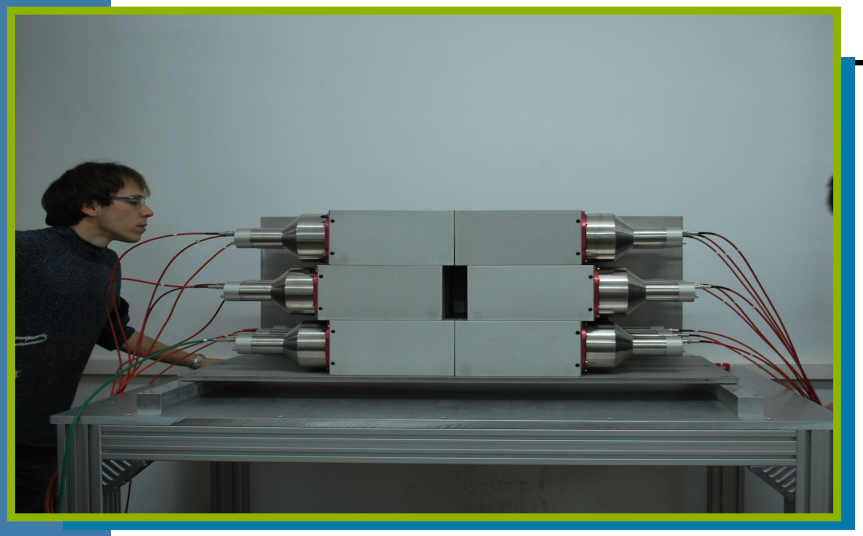

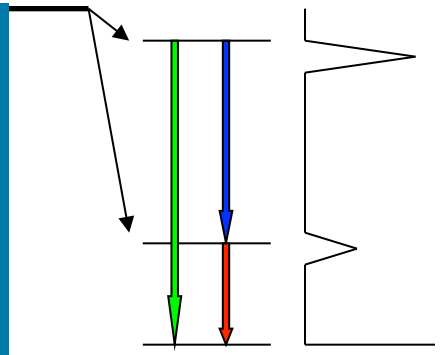

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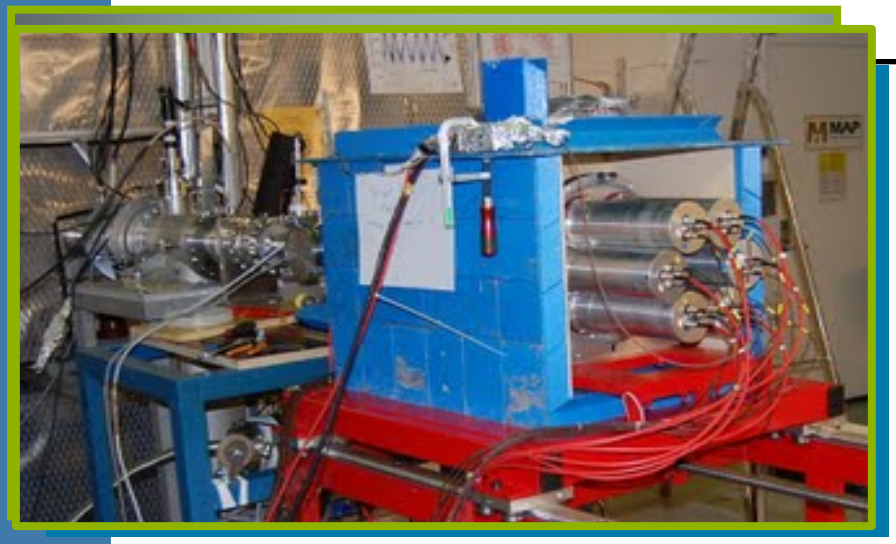

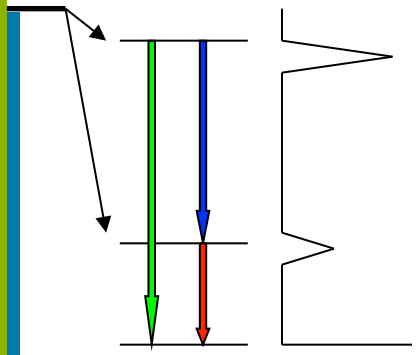

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- **2 TAS detectors could be possibly installed at ALTO:**
  - ✓ Decay Total Absorption Spectrometer (DTAS) for FAIR: 17 NaI modules to be used in Jyvaskyla in Feb. 2014
  - ✓ Or 12 BaF_2 TAS (Surrey-Valencia): used for the 2009 measurement at IGISOL-JYFLTRAP

- **Spectrum must be clean**
- **Response must be accurately known**
- **Solution of inverse problem must be stable**

TAS detectors developed by the Valencia team (Spain, B. Rubio, J.L. Tain, A. Algora et al.). See Proceedings of the Int. Conf. For nuclear Data for Science and technology (ND2013)

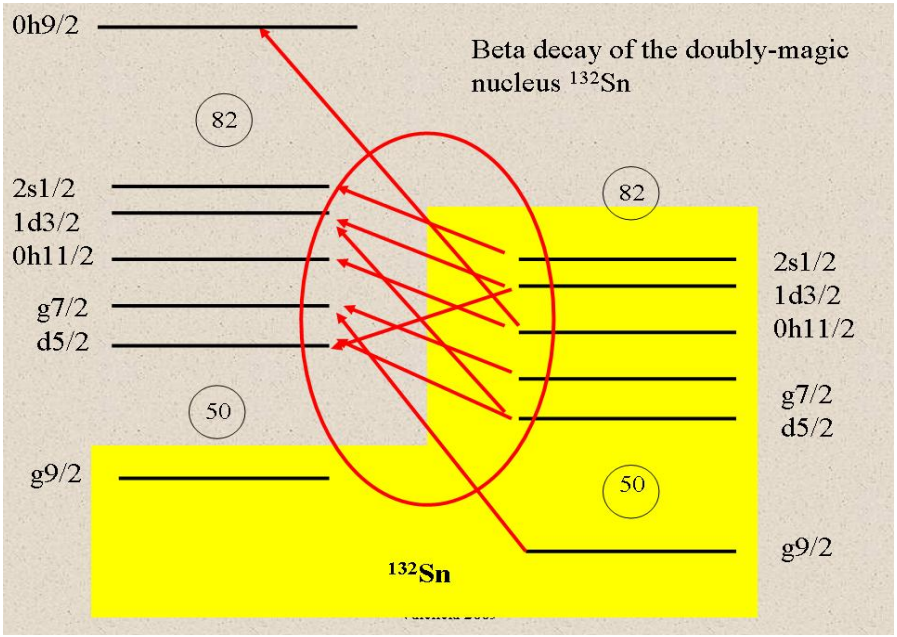
NIM A430 (1999) 333 NIM A571 (2007) 719
NIM A430 (1999) 488 NIM A571 (2007) 728

Physics Motivations:

Measurement of: $^{124,126,128,130,\ 131\text{-}134}$In, ^{132,133,134,136}Sn

- The Total Absorption technique has never been used near ^{132}Sn due to production difficulties

- A huge strength is expected and has so far not been observed



Many allowed transitions contribute, for instance in ^{132}Sn decay 3 (N-Z)=96 Units are expected from the extreme single particle point of view but only 0.26 have been measured (small Q_b window)

⇒ **TAS technique sensitive to high lying strength** in the daughter nuclei => study neighbouring nuclei with large Q_β window

E.Nácher et al. PRL 92 (2004) 232501
A.B. Pérez-Cerdán et al. PRC 88 (2013) 014324
A.Algora et al., PRL 105 (2010) 202501
D. Jordan et al. PRC87 (2013) 044318

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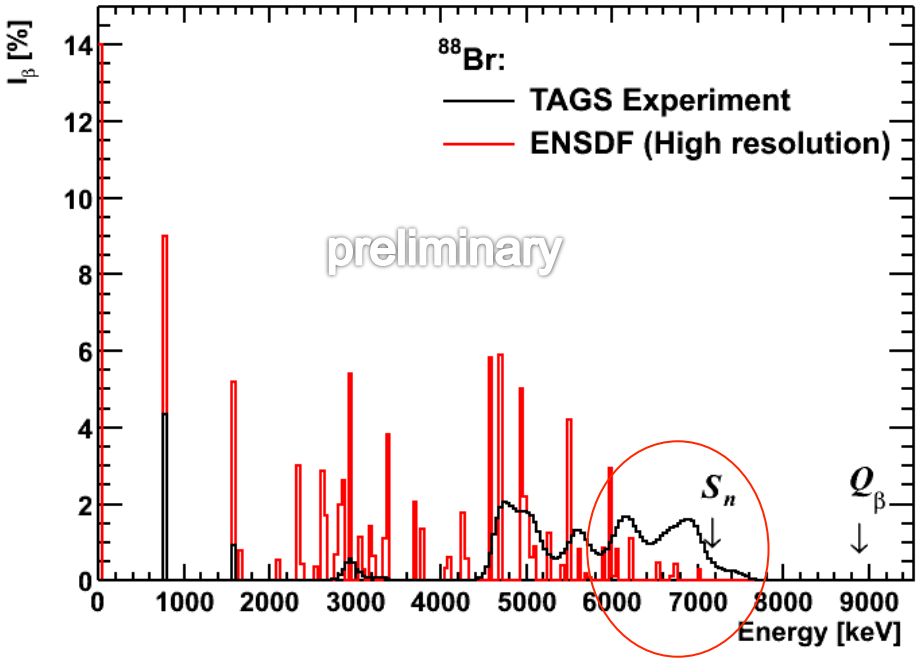

PhD work of E. Valencia-Marin, IFIC (Valencia)

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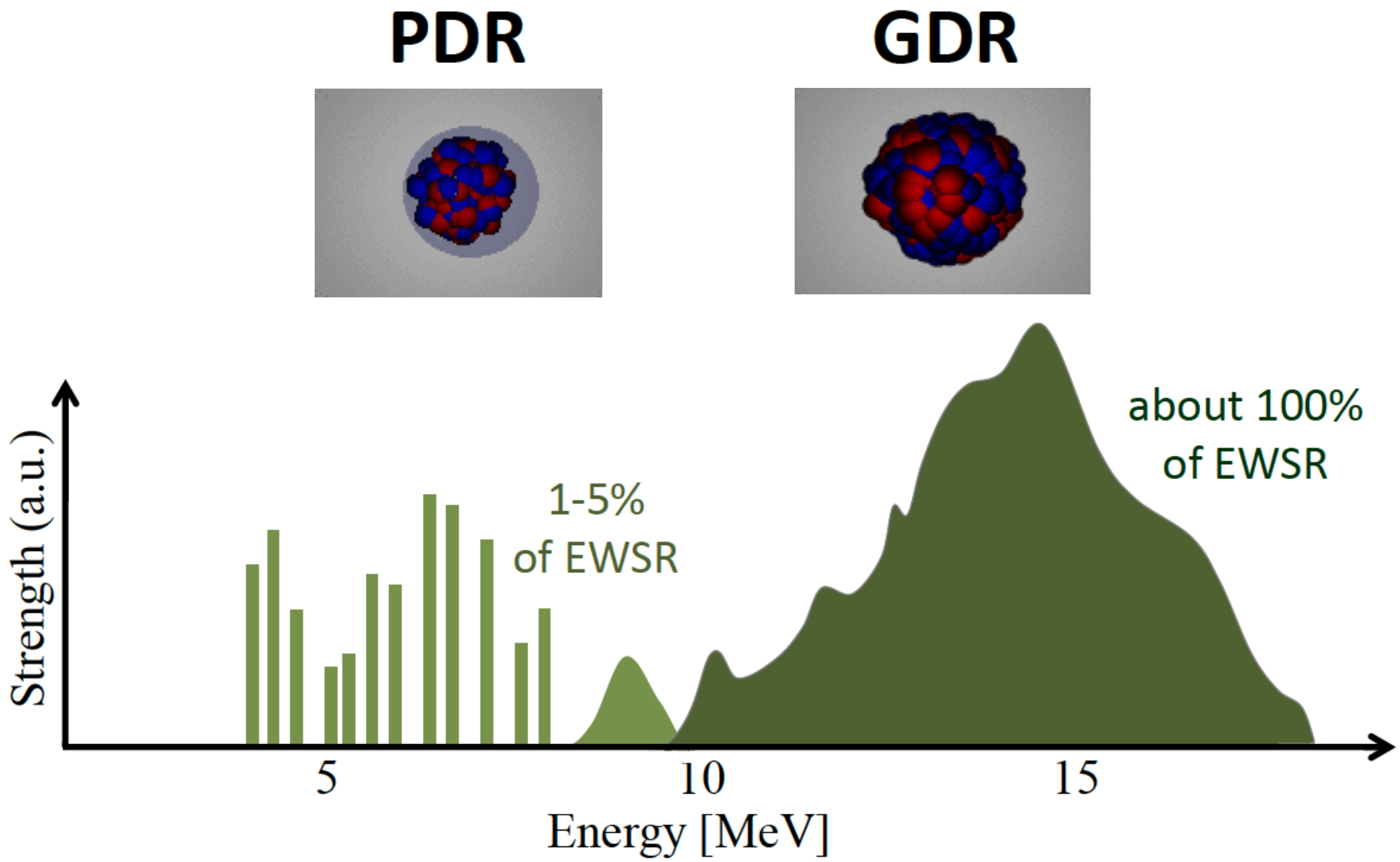
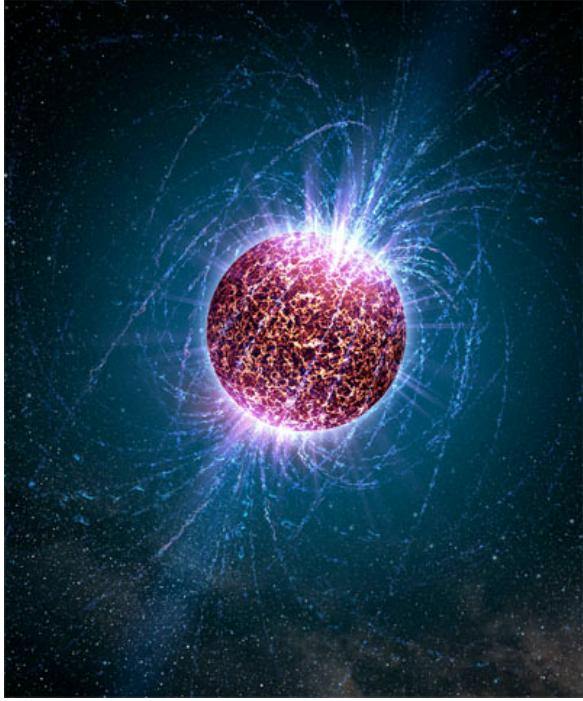
⇒ **The first time that the TAS technique will be used near the doubly magic nucleus around A=132 where a large amount of strength is expected at high energy !**

⇒ **Comparisons with theoretical calculations: to get an insight into the structure of these nuclei in a region of utmost importance with the study of the GT strength**

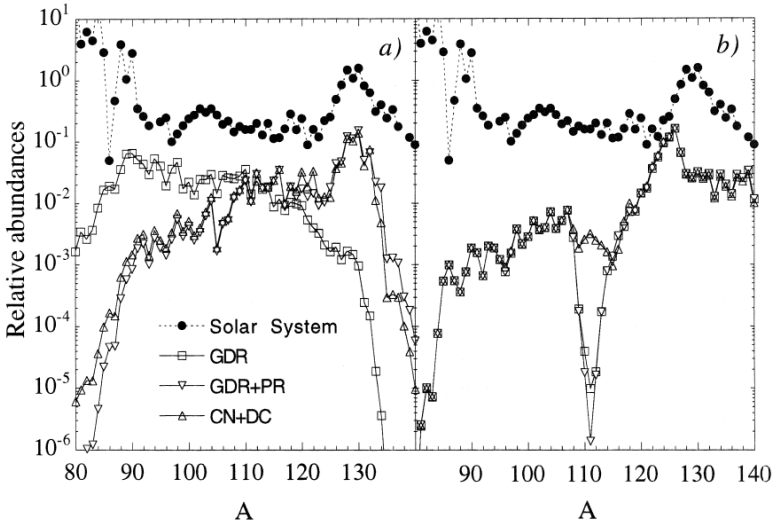
Low-lying Collective Modes



Low-lying Collective Modes



- **Pygmy Dipole Resonance as a universal „collective“ excitation mode**
- **Connection to neutron skin, PDR might deliver information on neutron-star properties. C.J. Horowitz et al, PRL 86 (2001) 5647**
- **Important information on equation of state (EOS) of neutron-rich matter via strength-neutron-skin thickness correlation. J. Piekarewicz, PRC 73 (2006) 044325**
- **Influence on nucleosynthesis processes especially (n,γ), (γ,n) reactions. S. Goriely, PLB 436, (1998) 10-18**
- **PDR‘s study puts constraints on theoretical models**
- **Other Pygmy Modes ? PQR ? Low-energy Magnetic Dipole Mode ?**

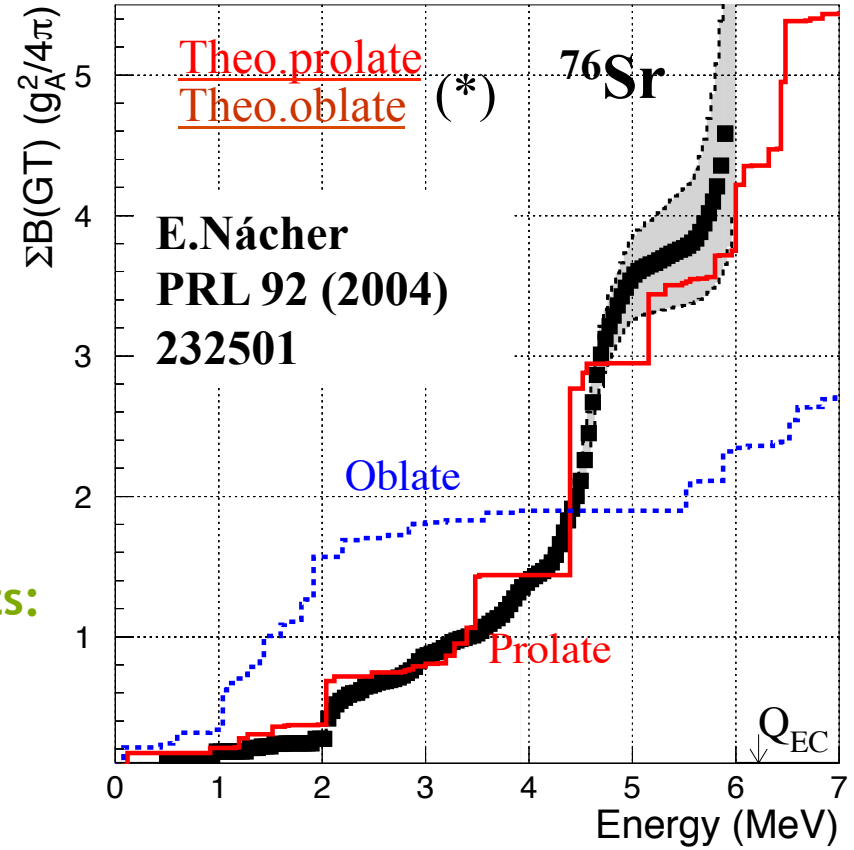


Physics Motivations: Neutron skin and beta strength

⇒ GT strength distribution sensitive to deformation

Oblate-prolate competition

N~Z nuclei with A~70-80



(*) P.Sarriguren et al.NPA 658 (1999)13

⇒ more recent examples from TAS experiments:

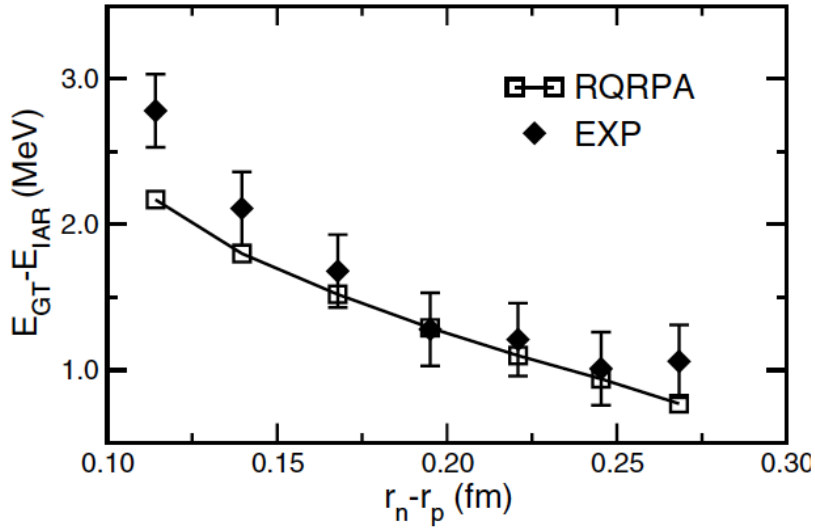
A. Pérez-Cerdá, Phys. Rev. C 88 (2013)014324.

J. Briz Ph.D 2013 Univ. Complutense Madrid.

⇒ Could GT strength also be sensitive to the neutron skin thickness ?

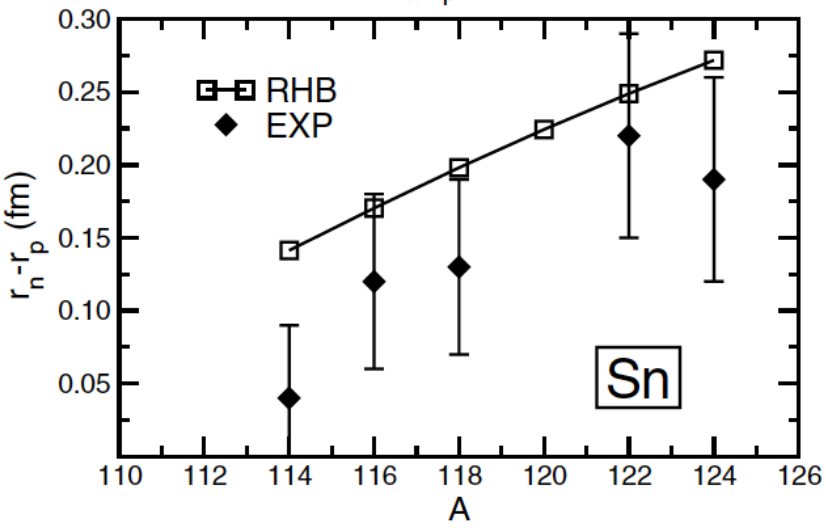
Physics Motivations: Neutron skin and beta strength

⇒ **TAS measurements allow accessing the low energy part of the GT strength**, and thus **may also be sensitive to the neutron skin thickness**



- An indication that could support this idea:

Vretanar et al. found a **direct relationship** btw the relative positions in energy of the GTR and the IAS and **the neutron-skin thickness along the Sn isotopic chain**.
(model: RHB + p-nQRPA)



D. Vretenar et al., PRL 91, 262502 (2003)

Physics Motivations: Neutron skin and beta strength in Sn isotopes

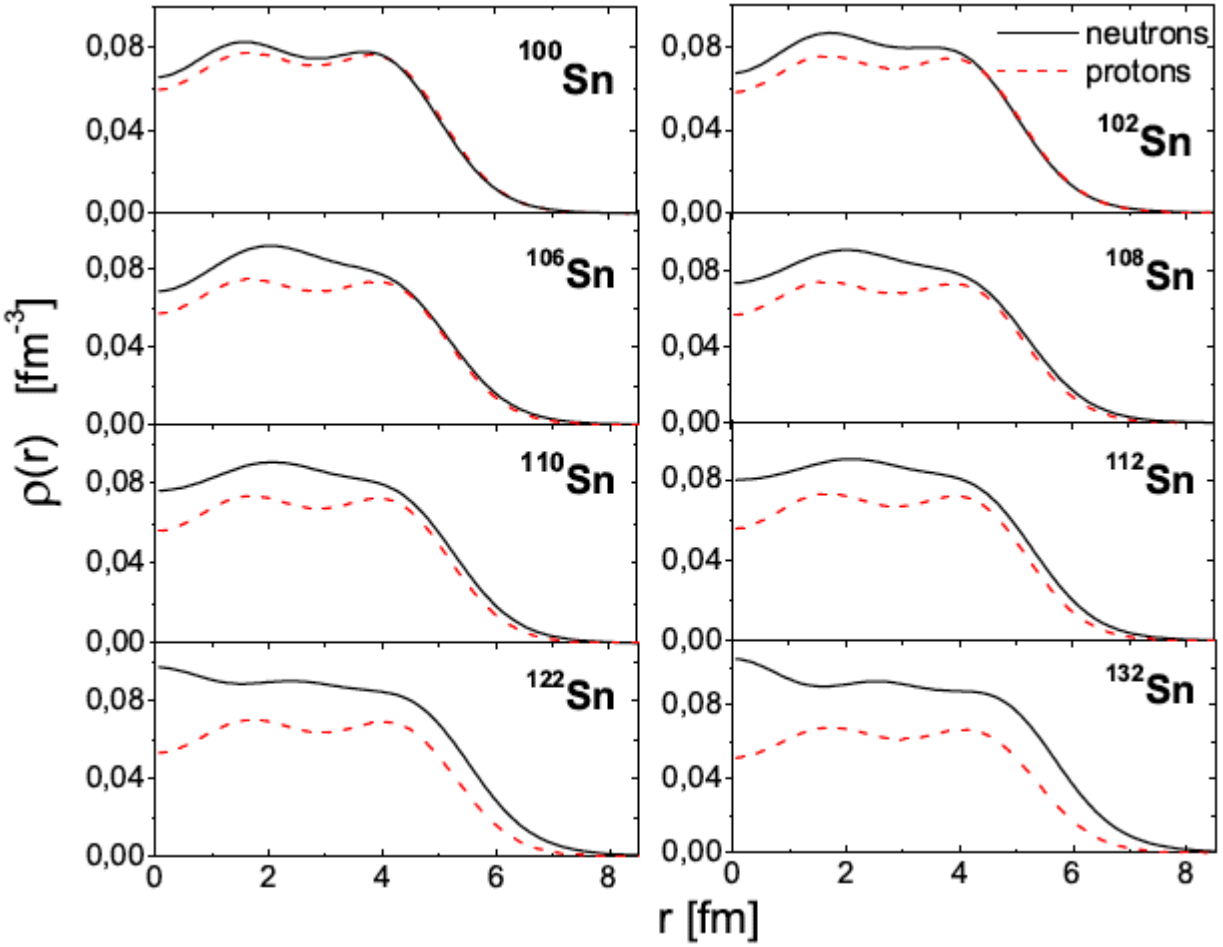


FIG. 1. BCS ground state densities of Sn isotopes obtained by the phenomenological DFT approach and used in the QPM calculations.

N. Tsoneva and H. Lenske, EPJ A 38 03002(2012)

Physics Motivations: Neutron skin and beta strength in Sn isotopes

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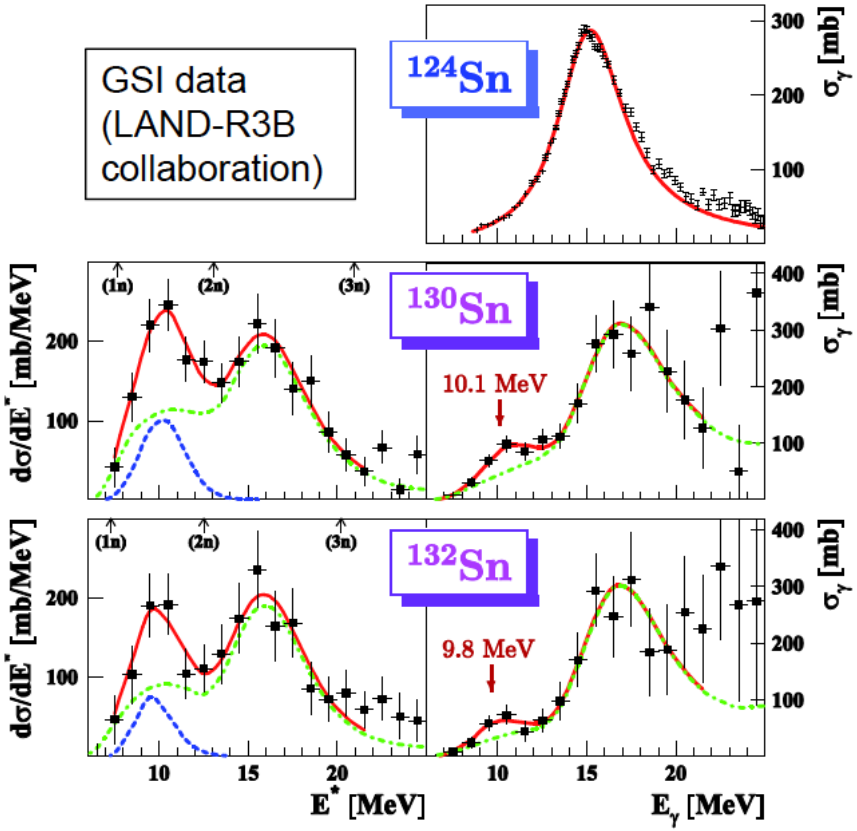

P. Adrich et al. Phys. Rev. Lett. 95, 132501(2005)
A. Klimkiewicz et al., Phys. Rev. C 76 (2007) 051603(R)

Neutron skin thickness:
0.23(4) fm for ^{130}Sn,
0.24(4) fm for ^{132}Sn

⇒ **^{134,136}Sn: 2 and 4 extra neutrons w.r.t ^{132}Sn core** => good candidates for searching for **influence of neutron skin** on nuclear structure (BGT)

⇒ Studies in this region may be used to find out how far a shell model interpretation is adequate for neutron-rich nuclei

Physics Motivations: Neutron skin and beta strength: ^{134,136}Sn

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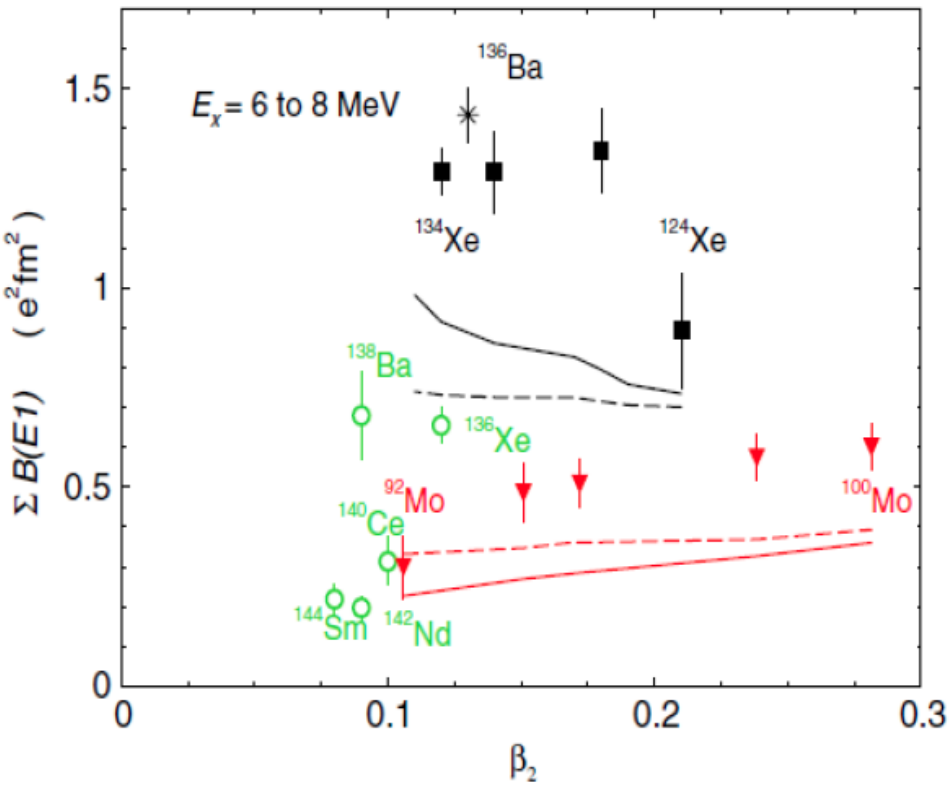
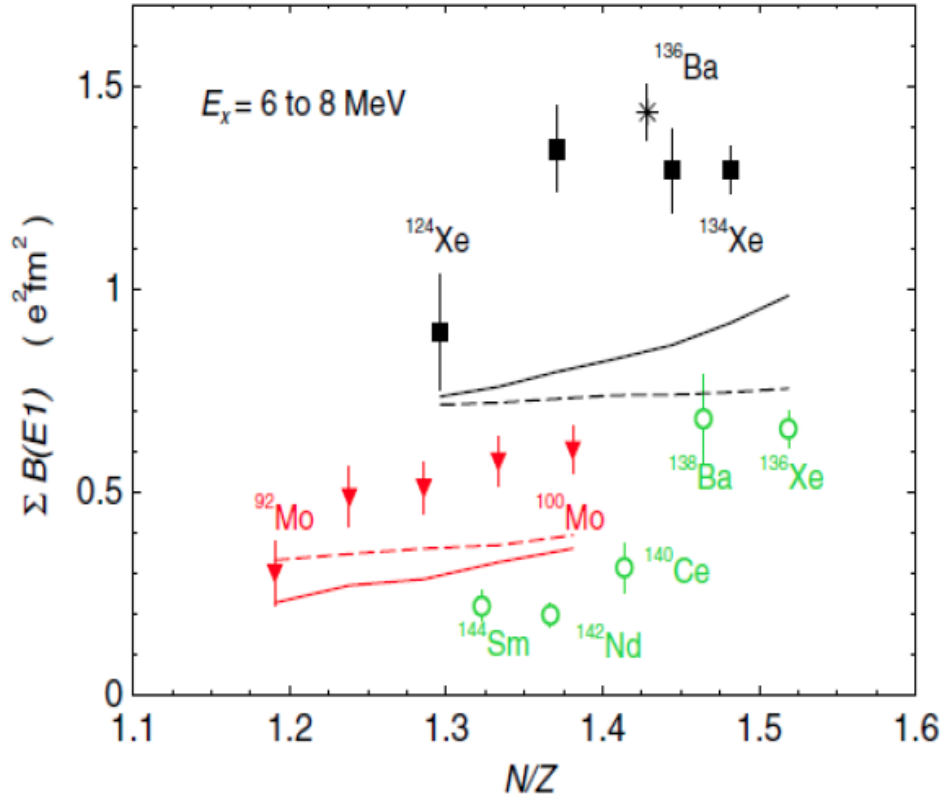




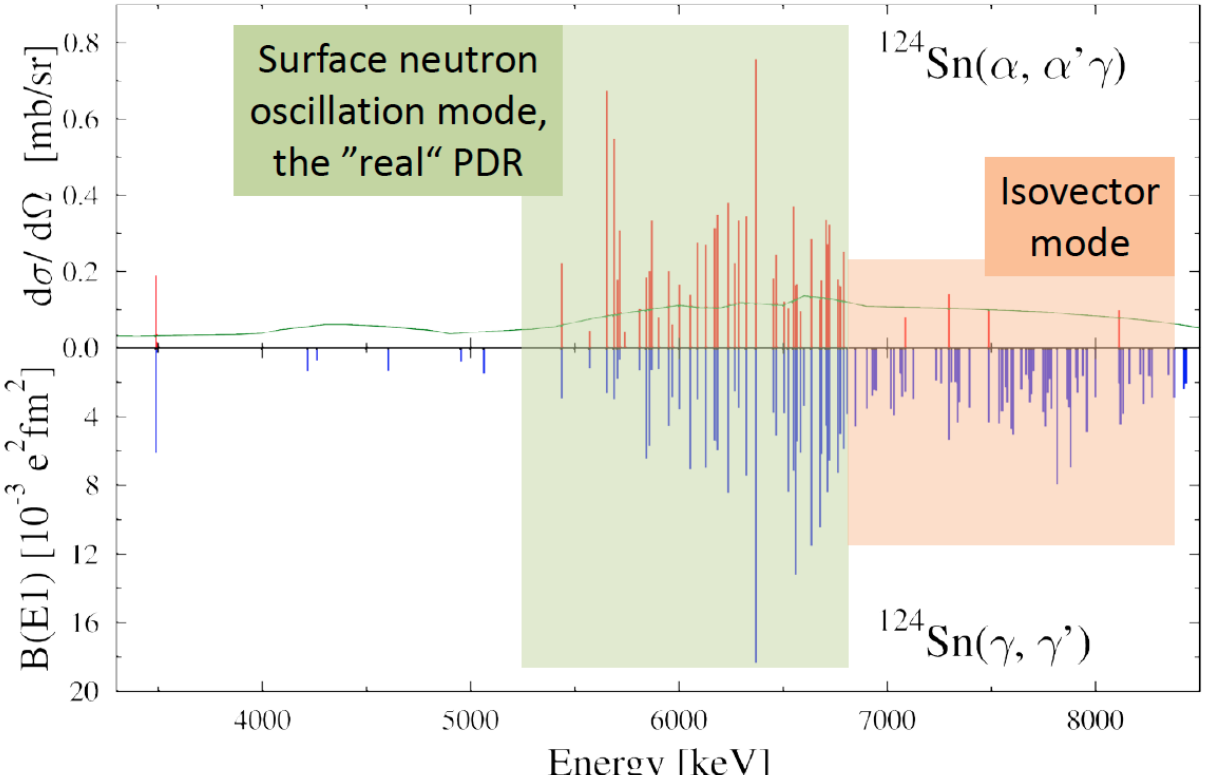
R. Massarczyk , R. Schwengner et al., PRL 112 (2014) 072501

« We conclude that the **deformation has only a minor effect on the summed E1 strength in the PDR region** and that it is sensitive to the local shell structure. This suggests that **the neutron excess is the key element for the global N − Z dependence of the strength below the neutron separation threshold** »

Physics Motivations: Beta strength distribution as a window on low energy collective modes: ^{124,126,128,130,132,134}In

⇒ **Access to low-lying collective modes in the Sn daughter nuclei**, providing **another means to access information on these collective modes** in very exotic nuclei ?

The **isospin structure of the pygmy dipole resonance** characterized **up to ^{124}Sn**:
J. Endres et al., PRL 105 (2010) 112503, J. Endres et al. Phys. Rev. C 85 (2012) 064331.
K. A. Krasznahorkay Phys. Rev. Lett. 82, 3216–3219 (1999).



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Example of the beta decay of **^{124}In** to **^{124}Sn**:

Precursor	Half life	Q_β(keV)	Ground state feeding	Sn(keV)	Pn	Daughter	Half Life
^{124}In (1)+ (8-)	3.12s (3.7s)	7360 (7360)	0%?	8489	0%	^{124}Sn	> 1.2E+21 y

Last excited level populated in daughter nucleus: 4.6MeV

⇒ **TAS technique is very well adapted to such studies**

Physics Motivations: ^{124,126,128,130,132,134}In

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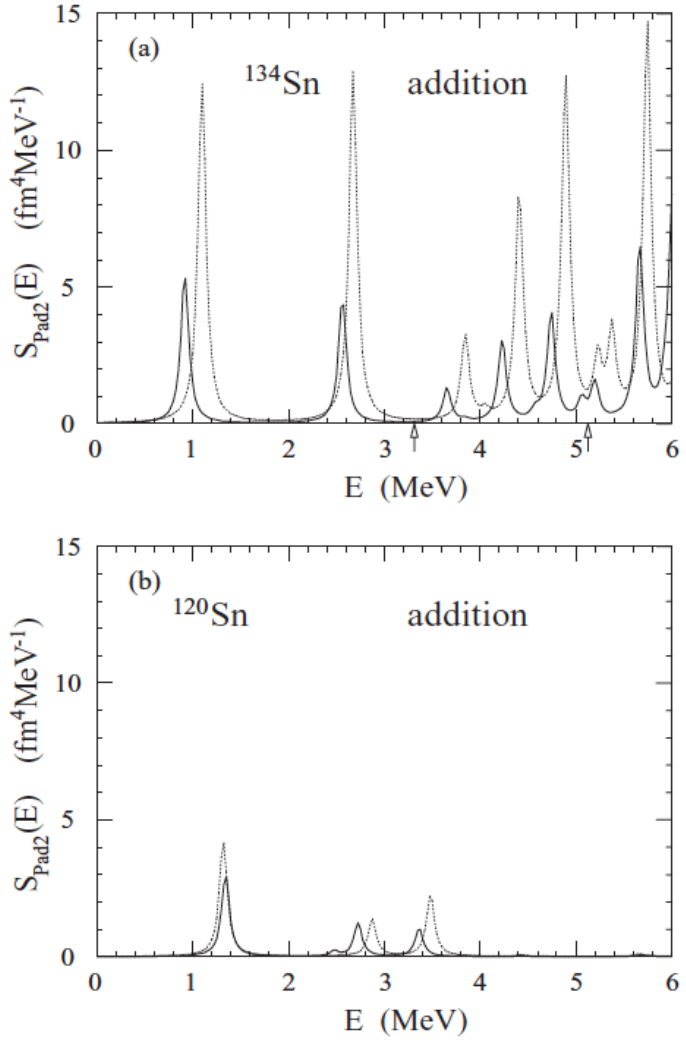
^{126}In 3(+)	1.53 s	8207	0%?	8190	0%	^{126}Sn	2.30E+5 y
(8-)	(1.64)s	(8207)					
^{128}In (3)+ (0,34MeV (8-)	0.84s (0.72s)	8976 (8976)	0%?	7962	<0.05%	^{128}Sn,	59.07m
^{130}In (1)-, (10-), (5+)	0.29s (0.54s, 0.54s)	10249	>8% (for 1-)	7597	0.93% (1.65%)	^{130}Sn, ^{129}Sn	1.7m, 2.3m, 6.9m
^{131}In (9/2+), (1/2-), 21/2+)	0.28s (0.35s, 0.32s)	9177	? (for 9/2+),≈95 (for 1/2-)	5247	<2% (<2%, ≈0.03%)	^{131}Sn, ^{130}Sn	56s, 58.4s 3.72m,1.7m
^{132}In (7-)	0.207s	14140	0%?	7343	6.3%	^{132}Sn, ^{131}Sn	39.7s, 56s, 58.4s
^{133}In (9/2+), (1/2-)	0.165s (0.180s)	12917	?	2370	85%	^{133}Sn, ^{132}Sn	1.46s, 39.7s
^{134}In (4- to 7-)	0.140s	14800	?	3629	65%	^{134}Sn, ^{133}Sn	1.05s, 1.46s

Physics Motivations: Beta strength distribution as a window on low energy collective modes: ^{124,126,128,130,132,134}In

⇒ **Access to low-lying collective modes in the Sn daughter nuclei**, providing **another means to access information on these collective modes** in very exotic nuclei ?

With a Skyrme HFB model, Matsuo and Serizawa predict **an increase of the transition strength of the quadrupole pair-addition mode in Sn isotopes with A ≥ 132** (probes the surface density, neutron pairing correlation):

M. Matsuo and Y. Serizawa Phys. Rev. C 82, 024318 (2010).



M. Matsuo and Y. Serizawa Phys. Rev. C 82, 024318 (2010).

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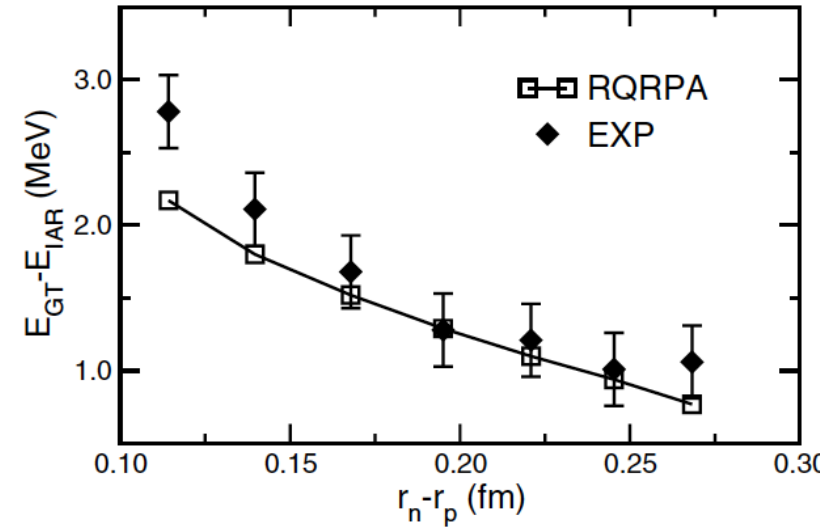
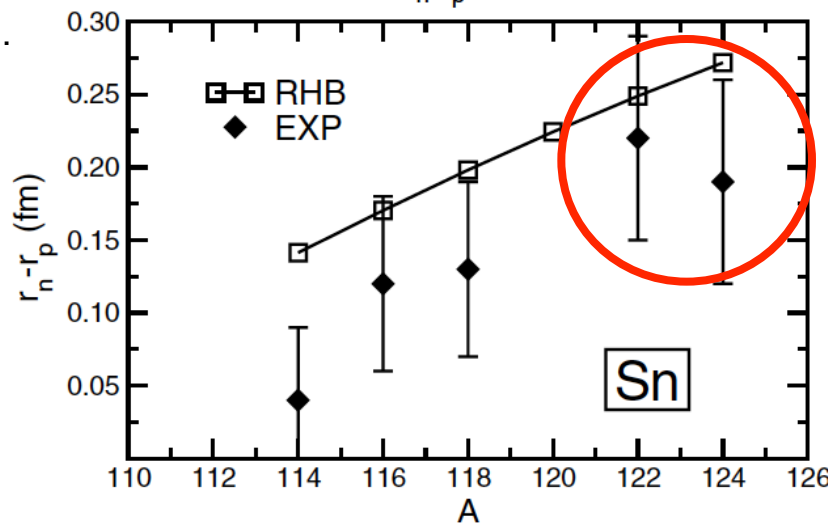
⇒ **Access to low-lying collective modes in the Sn daughter nuclei**, providing **another means to access information on these collective modes** in very exotic nuclei ?

Experimental data **seem to show a change in trend of neutron skin thickness in Sn isotopic chain**, while theory shows monotonic behaviour:

K. A. Krasznahorkay Phys. Rev. Lett. 82, 3216–3219 (1999) and D. Vretenar et al., PRL 91, 262502 (2003)





D. Vretenar et al., PRL 91, 262502 (2003)

Physics Motivations: Neutron skin and beta strength in Sn isotopes: Pygmy Quadrupole Mode

N. Tsoneva and H. Lenske, EPJ A 38 03002(2012)

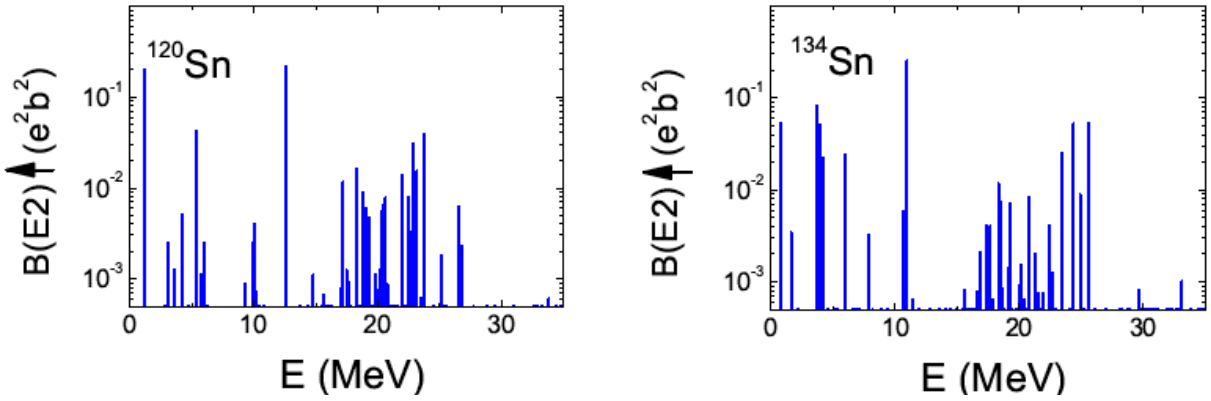
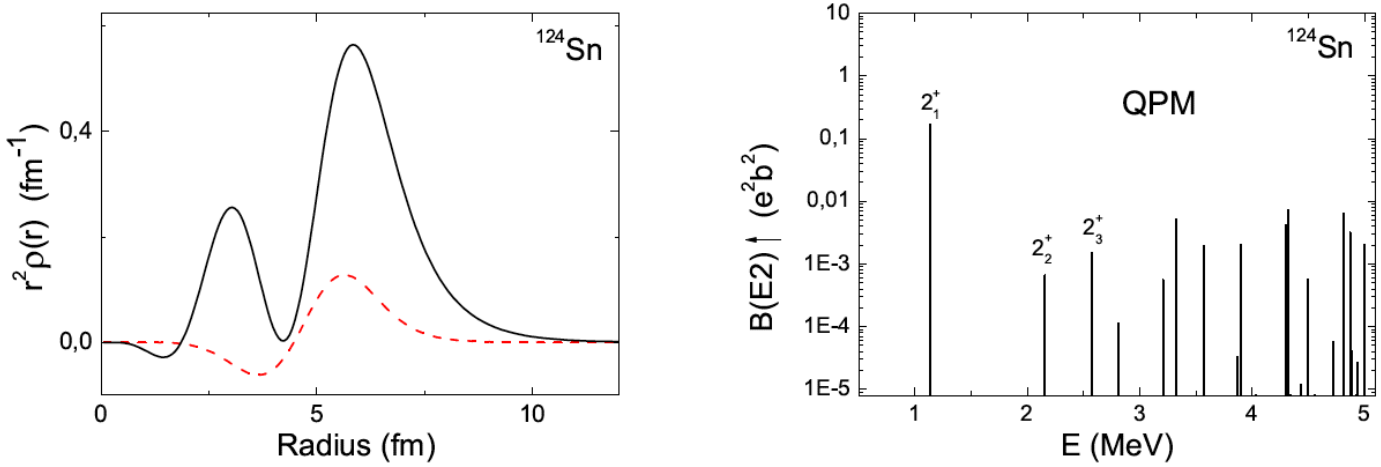


FIG. 7. QRPA calculations of electric quadrupole strength distributions in Sn isotopes.



« The connection of the low-energy 2+ states with a PQR is demonstrated in the analysis of transition densities [10]. Strong neutron oscillations at the nuclear surface play a dominant role in the PQR energy range... »

Outlooks

Existing TAS measurements

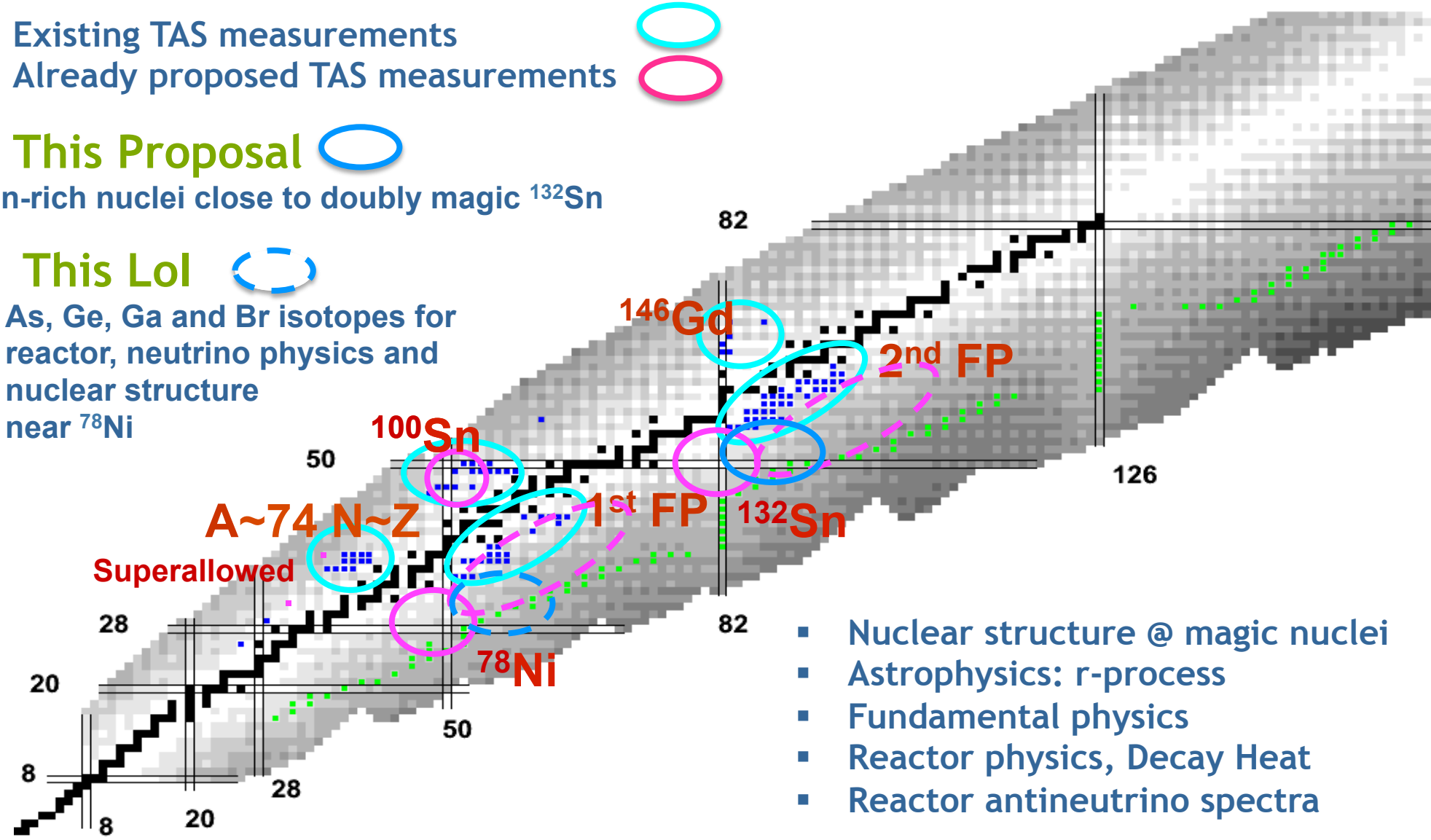
Already proposed TAS measurements

This Proposal

n-rich nuclei close to doubly magic ^{132}Sn

This LoI

As, Ge, Ga and Br isotopes for reactor, neutrino physics and nuclear structure near ^{78}Ni



- Nuclear structure @ magic nuclei
- Astrophysics: r-process
- Fundamental physics
- Reactor physics, Decay Heat
- Reactor antineutrino spectra

LoI: TAS for Nuclear Structure, Neutrino Physics and Reactor Physics

⇒ **Beta strength distribution of isotopes near ^{78}Ni:**

- ✓ **This region has been the object of previous studies at ALTO:**
  M. Lebois et al. Phys. Rev. C 80, 044308 (2009), K. Kolos et al. Phys. Rev. C 88,047301 (2013),
  D. Verney et al. Phys. Rev. C 87, 054307 (2013)

- ✓ **Recently measured at HRIBF Oak Ridge Lab.**
  C. Mazzochi et al. Phys. Rev. C 87, 034315 (2013). A. Korgul et al. Phys. Rev. C 88,044330 (2013)
  K. Rykaczewski, first meeting of the IAEA CRP on beta-delayed neutron emission, Vienna, August 2013.
  https://www-nds.iaea.org/beta-delayed-neutron/

- ✓ **Large Q_β windows and large P_n values, and in some cases beta-delayed emission of 2 neutrons has been measured recently or a predicted P_{2n} branch has not been observed experimentally**
  P. Möller et al. Atomic Data and Nuclear Data Tables 98 (2012) 149–300

- ✓ **TAS measurements complementary to BEDO + combined with a neutron detector = measure the beta strength distribution over the full energy window in order to compare it with theoretical models**

Conclusions & Outlooks

⇒ **TAS technique is a privileged tool to access beta-strength distribution**

⇒ **12 nuclei near doubly magic ^{132}Sn for nuclear structure and nuclear astrophysics, Experiment accepted for beam time in 2015 @ ALTO**

⇒ **Another region to study: nuclei near ^{78}Ni**

⇒ **As seen in the motivations, low-energy dipole modes have been evidenced in numerous nuclei, which could be the object of beta-decay studies:**

- ⇒ **What does Theory predict:**
  - ⇒ **Sensitivity of the GT strength distribution to the neutron skin ?**
  - ⇒ **Can the GT operator excite low energy collective modes ?**

⇒ **As seen in the cases presented above: experimental challenge: β-delayed neutron emission: needs neutron detection to get the strength in the full Q_β window**

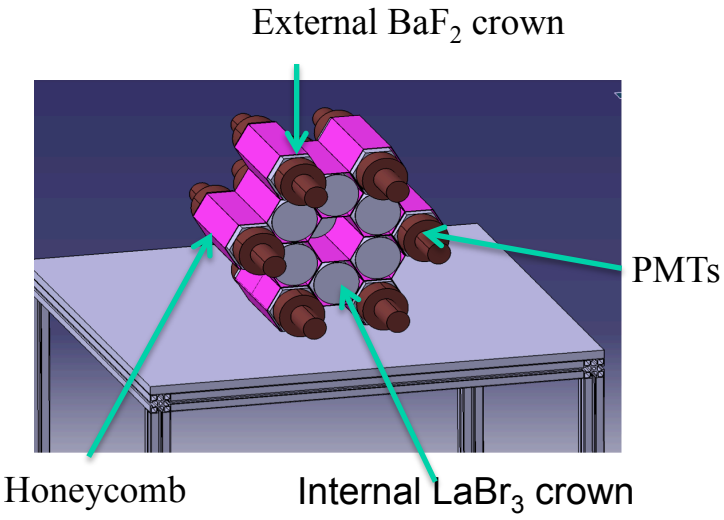
TOSCA project

TOSCA : The Orsay Subatech Calorimeter Array

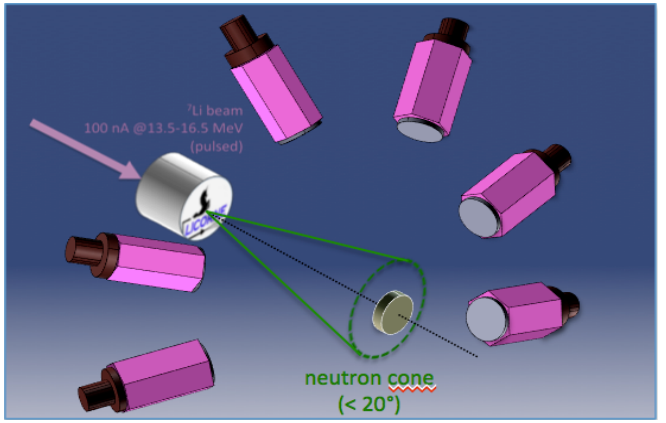
A multipurpose detector, composed of 7 large $LaBr_3$ (9 cm diameter, 25 cm length) and 12 hexagonal BaF_2.

Two goals:

- **Total Absorption Spectroscopy of fission products with a compact configuration**
  - ✓ Total efficiency larger than 70 % at 5 MeV
  - ✓ Very good time resolution: Possible neutron discrimination through ToF
  - ✓ Very good Energy resolution of $LaBr_3$
  - ✓ Allowing for stand-alone measurement of b and b-n decay of exotic fission products



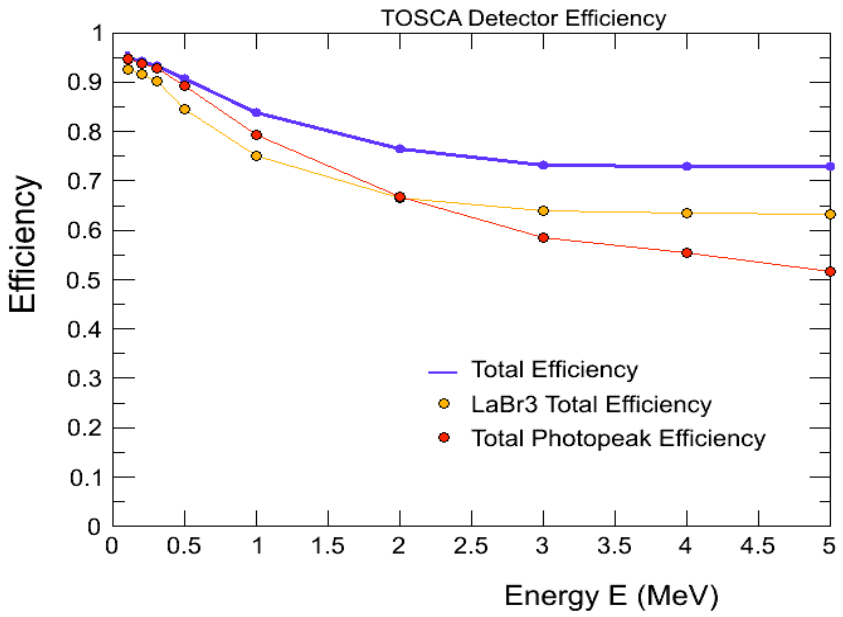
- **Prompt fission gamma ray detection with a ring configuration**
  - ✓ Very good time resolution: Neutron- gamma discrimination through ToF
  - ✓ No data exist for prompt gamma (and neutron) emission for fast neutron induced fission (fission process knowledge and reactor safety)

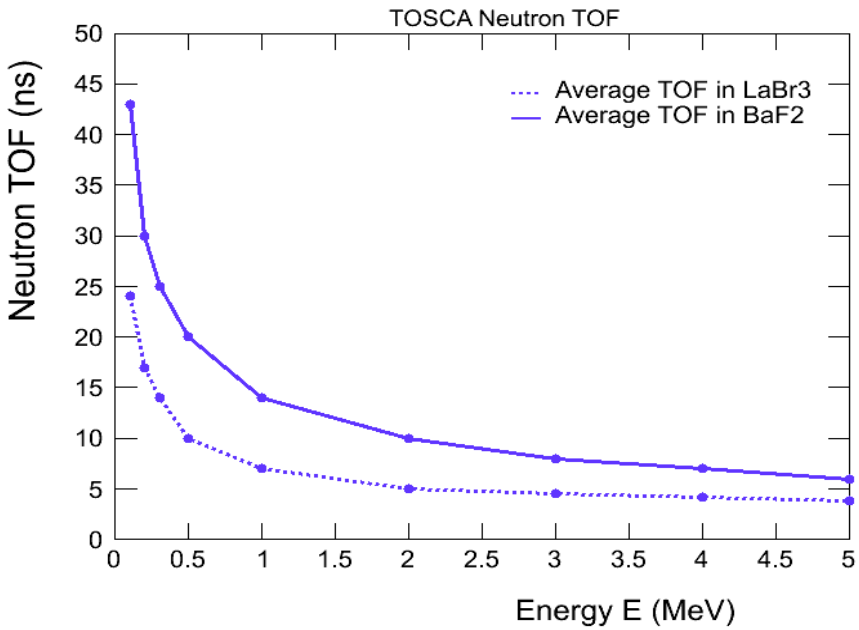


Collaboration: CSNSM-IPNO-SUBATECH: J. A. Briz-Monago, M. Fallot, P. Halipré, M. Lebois, J. Ljungvall, A. Porta, J. Wilson

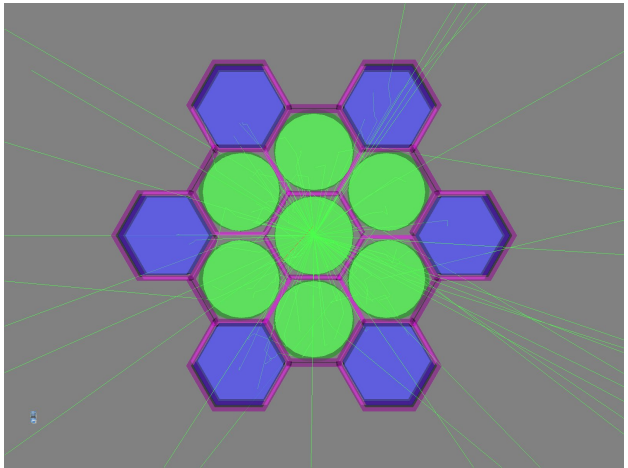
TOSCA : The Orsay Subatech Calorimeter Array

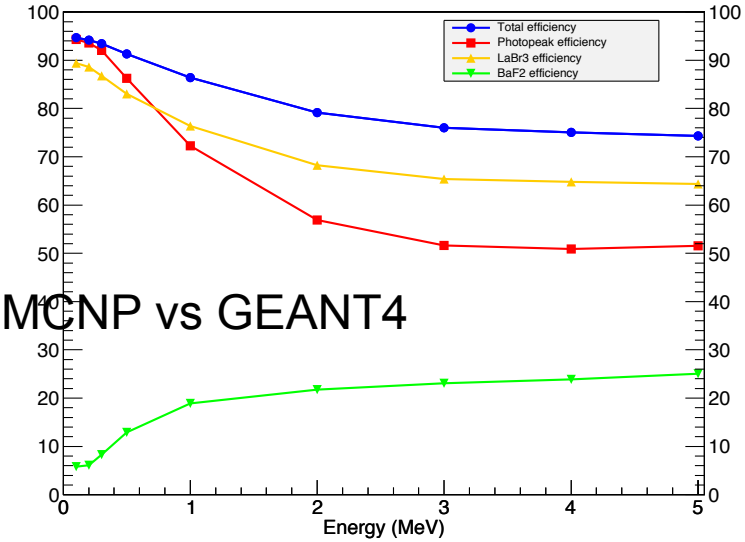
Preliminary results from simple MCNP simulation: detection efficiency and neutron ToF





A detailed GEANT4 simulation is on-going (by Jose A. Briz-Monago, Subatech):





Very good agreement MCNP vs GEANT4

TOSCA : The scientific program

- **Main advantages:**

- Very good time resolution: possibility of measuring gamma-rays and neutrons simultaneously: study of b-delayed n emitters (still more n-rich nuclei)
- Very good energy resolution of LaBr3: reach more exotic nuclei through the TAS technique
- High detection efficiency
- Versatile detector

- **Scientific Program: discussions on-going with GANIL, LPSC Grenoble, IPNL, … TOSCA collaboration is open !**

- Measurement of beta decay properties of exotic nuclei → nuclear structure astrophysics with GT strength studies in n-rich nuclei, study of radiative capture reactions of interest for nuclear astrophysics, …
- Measurement of beta decay properties of fission products for decay heat and reactor antineutrino spectra calculation. Possibility for integral decay heat measurements.
- Measurement of prompt gamma (and neutron) emission for fast neutron induced fission

Thank You