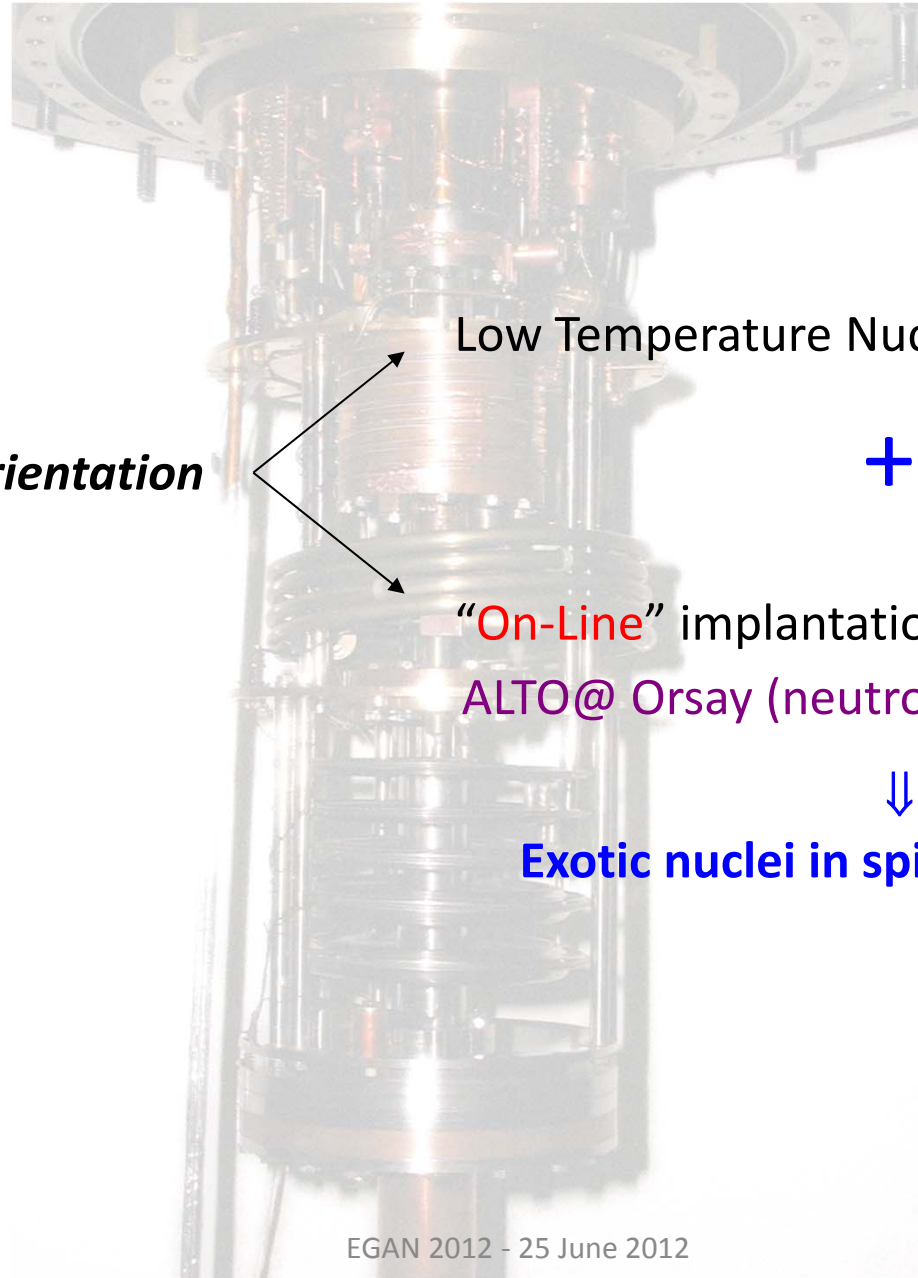


POLAREX :

POLARization of EXotic nuclei with On-Line Nuclear Orientation at ALTO

C. Gaulard

PolarEx : OLNO Technique



On-Line Nuclear Orientation
(**OLNO**)

Low Temperature Nuclear Orientation (**LTNO**)

+

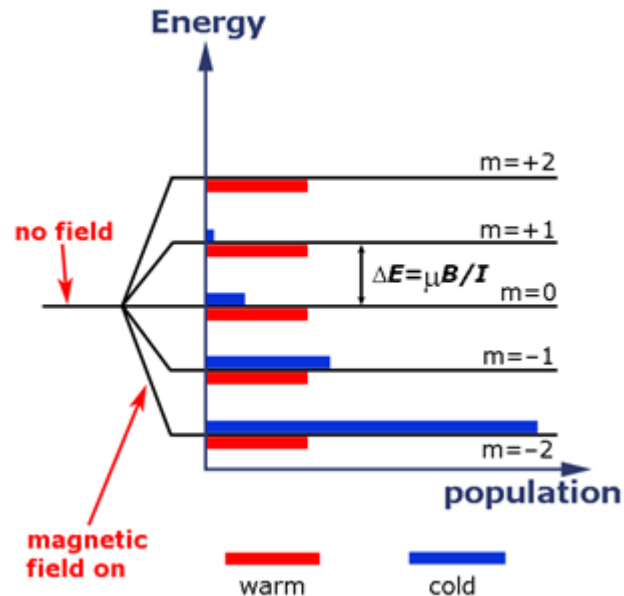
“**On-Line**” implantation of radioactive beam
ALTO@ Orsay (neutron-rich nuclei)

⇓

Exotic nuclei in spin-oriented state

PolarEx: LTNO Principle

How one can polarize a nucleus?



Polarex in numbers

$$B_{\text{ext}} = 1.5 \text{ T}$$

$$B_{\text{tot}} = 10\text{-}100 \text{ T}$$

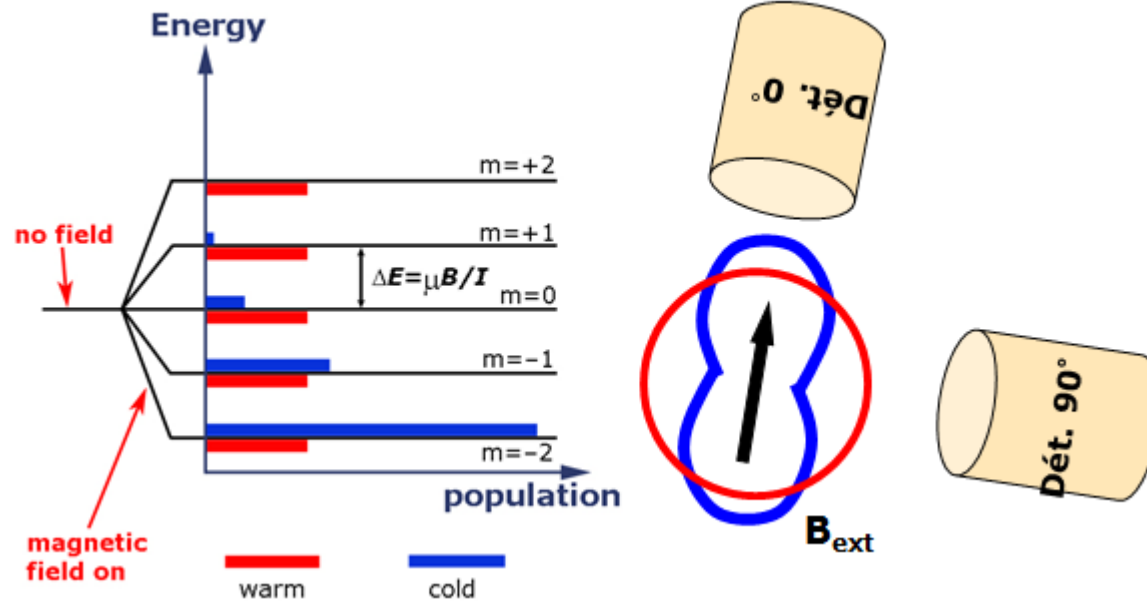
$$T = 6\text{-}20 \text{ mK}$$

Main limitation of LTNO :

- Boltzmann distribution at Low Temperature
 - Time to reach thermal equilibrium depends on spin-lattice relaxation time
 - **Radioactive nuclei should have long enough lifetimes**

PolarEx: LTNO Principle

How one can polarize a nucleus?



Polarex in numbers

$$B_{ext} = 1.5 \text{ T}$$

$$B_{tot} = 10\text{-}100 \text{ T}$$

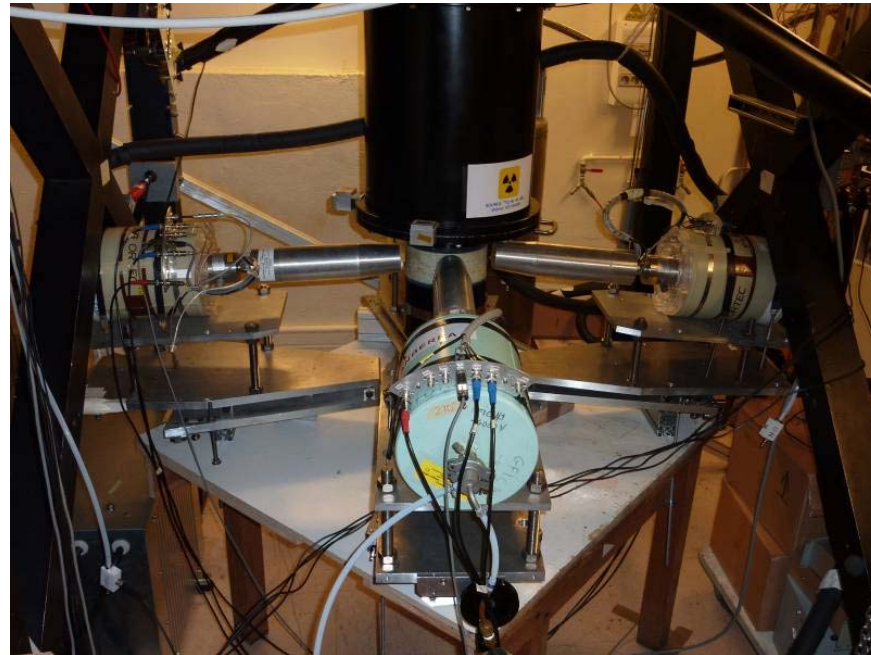
$$T = 6\text{-}20 \text{ mK}$$

- The spins show a preferential direction with respect to \vec{B}
- Anisotropic angular distribution of the radiation emitted

PolarEx: LTNO requirements

- ✓ Very low temperature (≤ 15 mK) \rightarrow ^3He - ^4He dilution refrigerator
- ✓ Superconducting magnet in cryostat (~ 1.5 T)
- ✓ Ferromagnetic foil to host exotic nuclei \rightarrow Hyperfine magnetic field (10 – 100 T)
- ✓ Nuclear thermometer : ^{60}Co
- ✓ Detectors

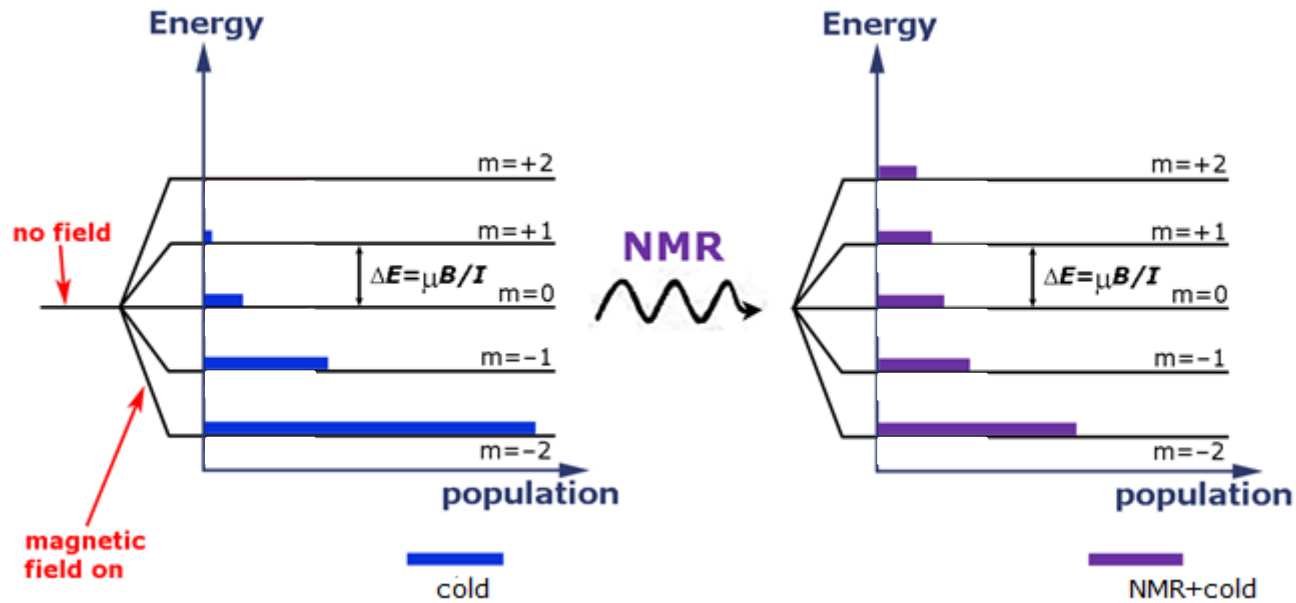
Anisotropic gamma emission
 \rightarrow 4 germanium detectors
(1@0°, 2@90°, 1@180°)



- ✓ NMR

PolarEx: LTNO Principle

How one can play with the nucleus spin?



Magnetic field + low temperature + resonant frequency
 \Rightarrow Nuclear magnetic moment

PolarEx : Objectives

A wide range of objectives have formed the basis of OLNO work:

- level spin
- nuclear structure from gamma multi-polarity
- parity non-conservation in nuclear gamma decay
- nuclear magnetic dipole moment
- g -factor
- weak interaction beyond the Standard Model
- hyperfine field

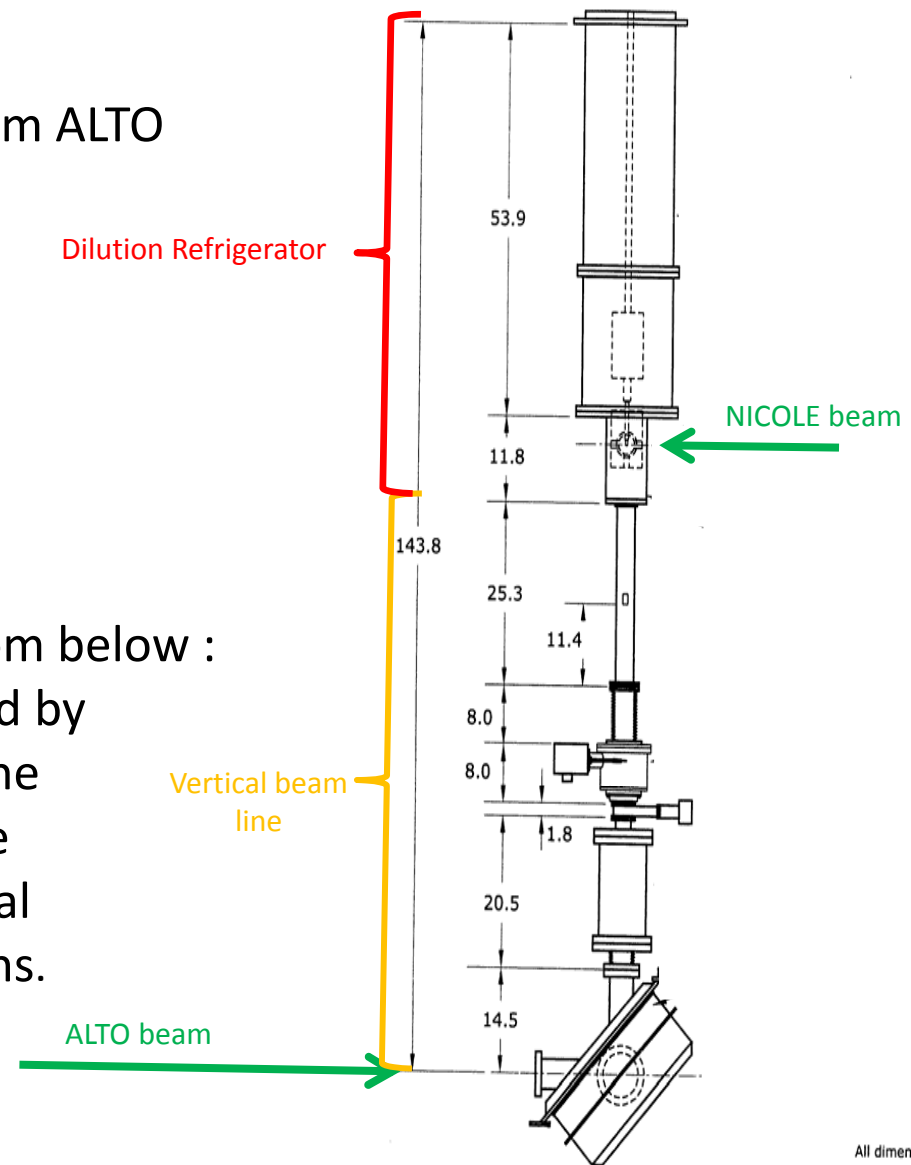
PolarEx : National and International situation

- The **first** of its kind in France
- The association with the nuclides from ALTO

⇒ **Unique worldwide**

- **NICOLE@ISOLDE \neq POLAREX@ALTO**

- ✓ Different nuclei productions
- ✓ Beam line connected to POLAREX from below :
The implantation region is surrounded by a ring of detectors in a horizontal plane
⇒ more detectors around the sample
⇒ more accurate picture of the spatial anisotropy of the emitted radiations.



All dimensions in Inches

PolarEx

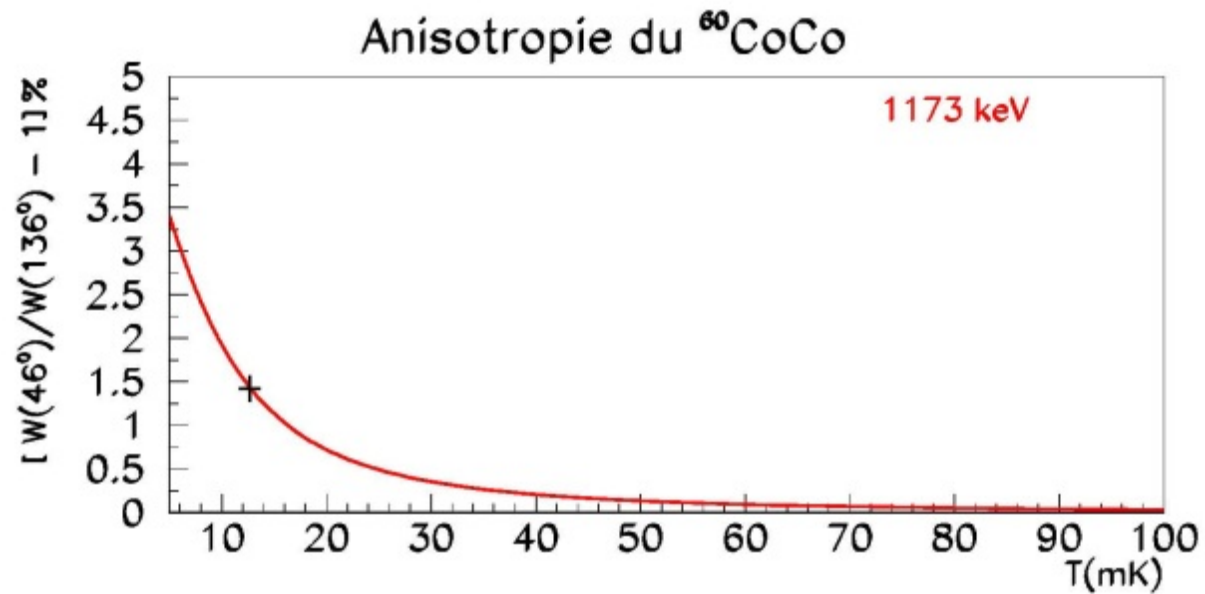
- ☑ Renovation of the dilution refrigerator
- ☑ Thermometry
- ☑ Electronics
- ☑ NMR
- ☑ Acquisition control
- ☑ All subsystems together



PolarEx: Measurements

- **$^{60}\text{CoCo}$ (Done)**

Absolute temperature \Rightarrow **11 mK**



- **$^{125}\text{SbFe} + ^{60}\text{CoCo}$ (on going)**

Ph.D. of A. Etilé

PolarEx: OFF-Line Program

Study of lanthanides implanted either at ALTO or ISOLDE

145 Dy $\beta^+ = 100\%$	146 Dy $\beta^+ = 100\%$	147 Dy $\beta^+ = 100\%$	148 Dy $\beta^+ = 100\%$	149 Dy $\beta^+ = 100\%$	150 Dy $\beta^+ = 64\%$	151 Dy $\beta^+ = ?$	152 Dy E C = 100%	153 Dy $\beta^+ \approx 100\%$	154 Dy $\alpha = 100\%$	155 Dy $\beta^+ = 100\%$	156 Dy Abundance = 0.06%	157 Dy $\beta^+ = 100\%$	158 Dy Abundance = 0.10%	159 Dy E C = 100%	160 Dy Abundance = 2.34%	161 Dy Abundance = 18.91%
144 Tb $\beta^+ = 100\%$	145 Tb $\beta^+ = ?$	146 Tb $\beta^+ = 100\%$	147 Tb $\beta^+ = 100\%$	148 Tb $\beta^+ = 100\%$	149 Tb $\beta^+ = 83.3\%$	150 Tb $\beta^+ = 100\%$	151 Tb $\beta^+ \approx 100\%$	152 Tb $\beta^+ = 100\%$	153 Tb $\beta^+ = 100\%$	154 Tb $\beta^+ \approx 100\%$	155 Tb E C = 100%	156 Tb $\beta^+ = 100\%$	157 Tb E C = 100%	158 Tb $\beta^+ = 83.4\%$	159 Tb Abundance = 100%	160 Tb $\beta^+ = 100\%$
143 Gd $\beta^+ = 100\%$	144 Gd $\beta^+ = 100\%$	145 Gd $\beta^+ = 100\%$	146 Gd E C = 100%	147 Gd $\beta^+ = 100\%$	148 Gd $\alpha = 100\%$	149 Gd $\beta^+ = 100\%$	150 Gd $\alpha = 100\%$	151 Gd E C = 100%	152 Gd Abundance = 0.20%	153 Gd E C = 100%	154 Gd Abundance = 2.18%	155 Gd Abundance = 14.80%	156 Gd Abundance = 20.47%	157 Gd Abundance = 15.83%	158 Gd Abundance = 24.84%	159 Gd $\beta^+ = 100\%$
142 Eu $\beta^+ = 100\%$	143 Eu $\beta^+ = 100\%$	144 Eu $\beta^+ = 100\%$	145 Eu $\beta^+ = 100\%$	146 Eu $\beta^+ = 100\%$	147 Eu $\beta^+ \approx 100\%$	148 Eu $\beta^+ = 100\%$	149 Eu E C = 100%	150 Eu $\beta^+ = 100\%$	151 Eu Abundance = 47.81%	152 Eu $\beta^+ = 72.1\%$	153 Eu Abundance = 52.13%	154 Eu $\beta^- = 100\%$	155 Eu $\beta^- = 100\%$	156 Eu $\beta^- = 100\%$	157 Eu $\beta^- = 100\%$	158 Eu $\beta^- = 100\%$
141 Sm $\beta^+ = 100\%$	142 Sm $\beta^+ = 100\%$	143 Sm $\beta^+ = 100\%$	144 Sm Abundance = 3.07%	145 Sm E C = 100%	146 Sm $\alpha = 100\%$	147 Sm Abundance = 14.99%	148 Sm Abundance = 11.24%	149 Sm Abundance = 13.82%	150 Sm Abundance = 7.38%	151 Sm $\beta^- = 100\%$	152 Sm Abundance = 28.75%	153 Sm $\beta^- = 100\%$	154 Sm Abundance = 22.75%	155 Sm $\beta^- = 100\%$	156 Sm $\beta^- = 100\%$	157 Sm $\beta^- = 100\%$
140 Pm $\beta^+ = 100\%$	141 Pm $\beta^+ = 100\%$	142 Pm $\beta^+ = 100\%$	143 Pm E C = 100%	144 Pm E C = 100%	145 Pm E C = 100%	146 Pm E C = 66.0%	147 Pm $\beta^- = 100\%$	148 Pm $\beta^- = 100\%$	149 Pm $\beta^- = 100\%$	150 Pm $\beta^- = 100\%$	151 Pm $\beta^- = 100\%$	152 Pm $\beta^- = 100\%$	153 Pm $\beta^- = 100\%$	154 Pm $\beta^- = 100\%$	155 Pm $\beta^- = 100\%$	156 Pm $\beta^- = 100\%$
139 Nd $\beta^+ = 100\%$	140 Nd E C = 100%	141 Nd $\beta^+ = 100\%$	142 Nd Abundance = 27.2%	143 Nd Abundance = 12.2%	144 Nd Abundance = 23.8%	145 Nd Abundance = 8.3%	146 Nd Abundance = 17.2%	147 Nd $\beta^- = 100\%$	148 Nd Abundance = 5.7%	149 Nd $\beta^- = 100\%$	150 Nd Abundance = 5.6%	151 Nd $\beta^- = 100\%$	152 Nd $\beta^- = 100\%$	153 Nd $\beta^- = 100\%$	154 Nd $\beta^- = 100\%$	155 Nd $\beta^- = 100\%$
138 Pr $\beta^+ = 100\%$	139 Pr $\beta^+ = 100\%$	140 Pr $\beta^+ = 100\%$	141 Pr Abundance = 100%	142 Pr $\beta^- \approx 100\%$	143 Pr $\beta^- = 100\%$	144 Pr $\beta^- = 100\%$	145 Pr $\beta^- = 100\%$	146 Pr $\beta^- = 100\%$	147 Pr $\beta^- = 100\%$	148 Pr $\beta^- = 100\%$	149 Pr $\beta^- = 100\%$	150 Pr $\beta^- = 100\%$	151 Pr $\beta^- = 100\%$	152 Pr $\beta^- = 100\%$	153 Pr $\beta^- = 100\%$	154 Pr $\beta^- = 100\%$
137 Ce $\beta^+ = 100\%$	138 Ce Abundance = 0.251%	139 Ce E C = 100%	140 Ce Abundance = 80.45%	141 Ce $\beta^- = 100\%$	142 Ce Abundance = 11.14%	143 Ce $\beta^- = 100\%$	144 Ce $\beta^- = 100\%$	145 Ce $\beta^- = 100\%$	146 Ce $\beta^- = 100\%$	147 Ce $\beta^- = 100\%$	148 Ce $\beta^- = 100\%$	149 Ce $\beta^- = 100\%$	150 Ce $\beta^- = 100\%$	151 Ce $\beta^- = 100\%$	152 Ce $\beta^- = 100\%$	153 Ce $\beta^- = ?$

Why?

- ✓ Hyperfine interactions are strong
- ✓ Region still not well-known

N=82 shell closure on the neutron rich side in the Lanthanide area

➤ Study of ^{149}Pm :

μ is unknown

B_{hf} in Fe is badly known : 400 ± 100 T

(modern ab-initio methods give ~ 395 T, D. Torumba, P. Novák and S. Cottenier)

How to get B_{hf} ?

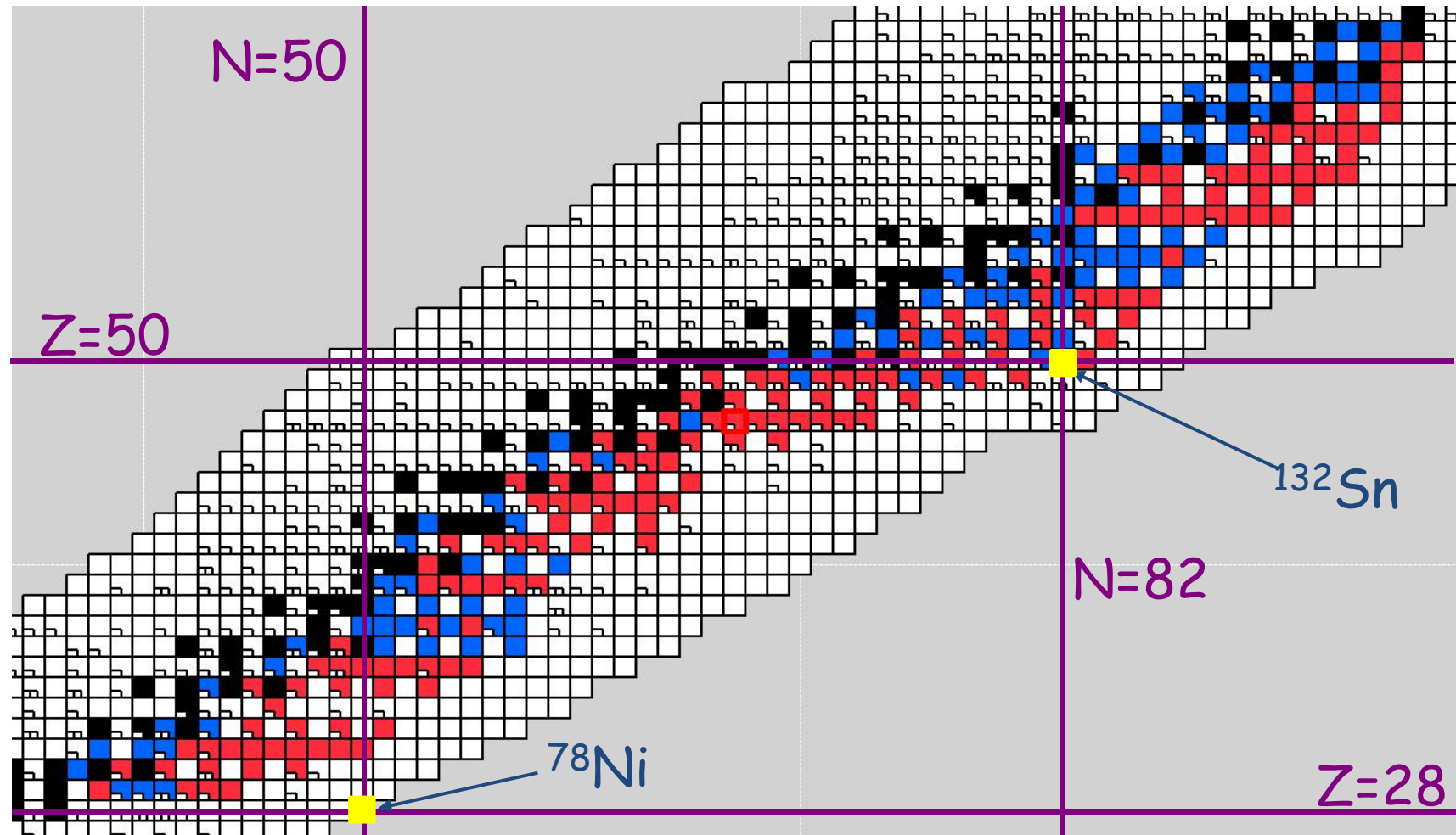
✓ $\mu(^{147}\text{Pm})$ is known by laser spectroscopy

⇒ Measurement of its resonant frequency by LTNO

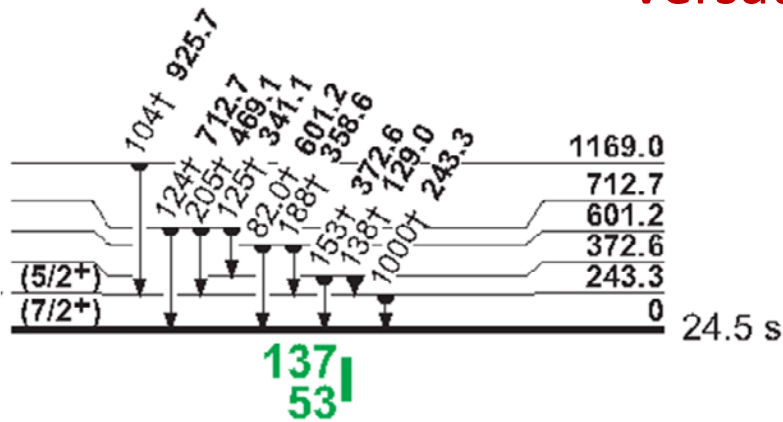
⇒ Precise B_{hf} in Fe at Pm site

➤ Moments of $^{143,144,146,151}\text{Pm}$ with an accuracy of a few percent

Structure around the doubly-magic neutron-rich nuclei : ^{78}Ni and ^{132}Sn

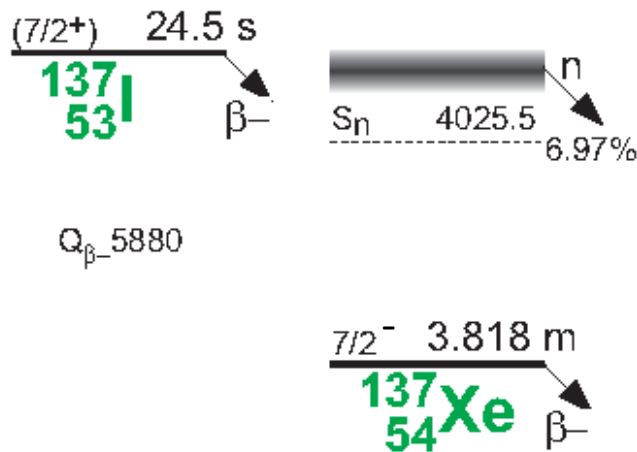


Versatility of POLAREX



- Measurement of magnetic moment of the odd proton $7/2^+$ state

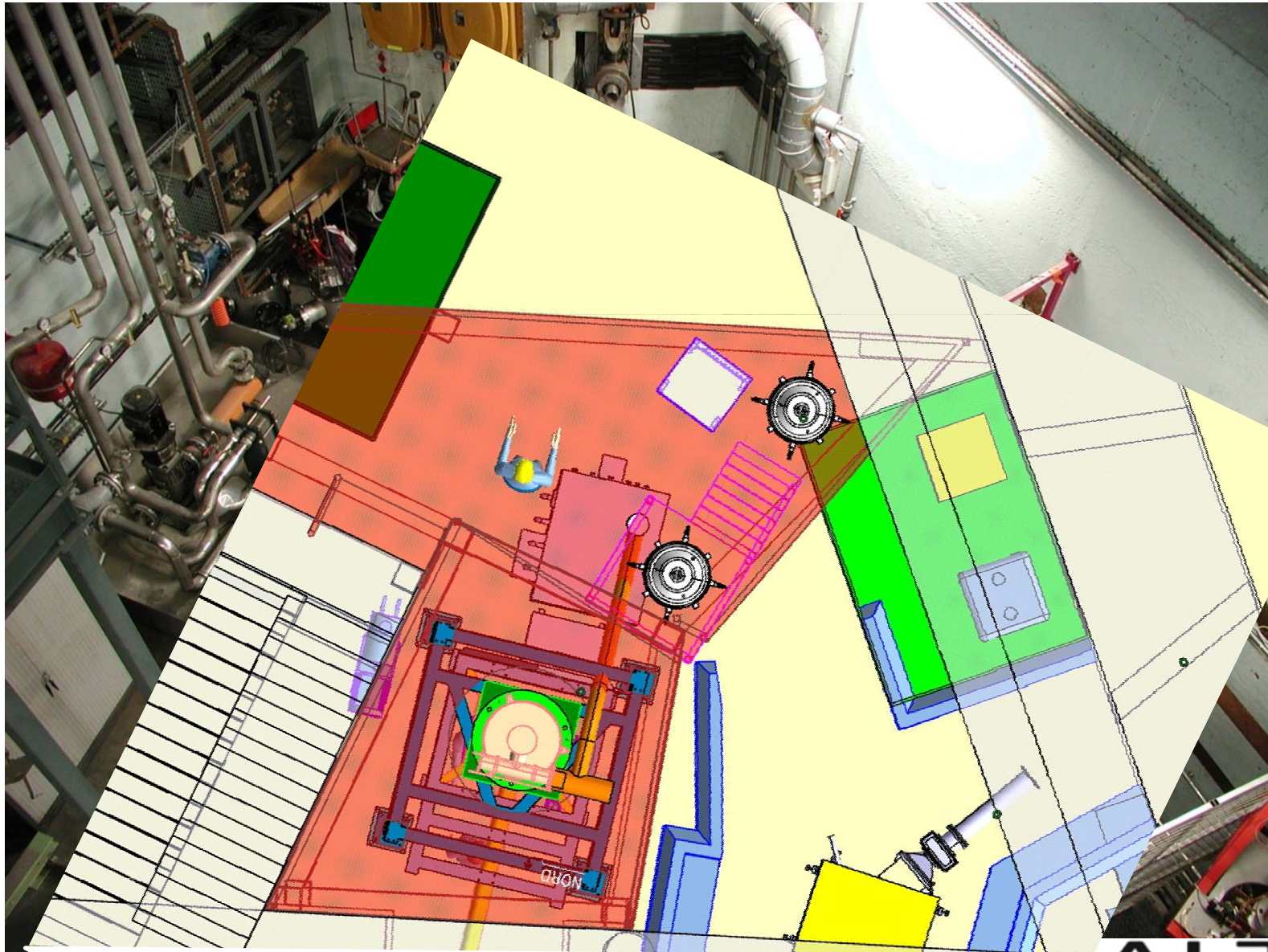
γ -decay of $^{137}\text{Xe}^*$ and β -delayed neutron emission from ^{137}Xe



- Anisotropy of γ emission
High density of $7/2^+$ and $7/2^-$ states in ^{137}Xe
⇒ strong parity admixture
- Anisotropy of β -delayed neutron emission
⇒ access to quantum barrier penetration studies
⇒ neutron wave function

World first experiment

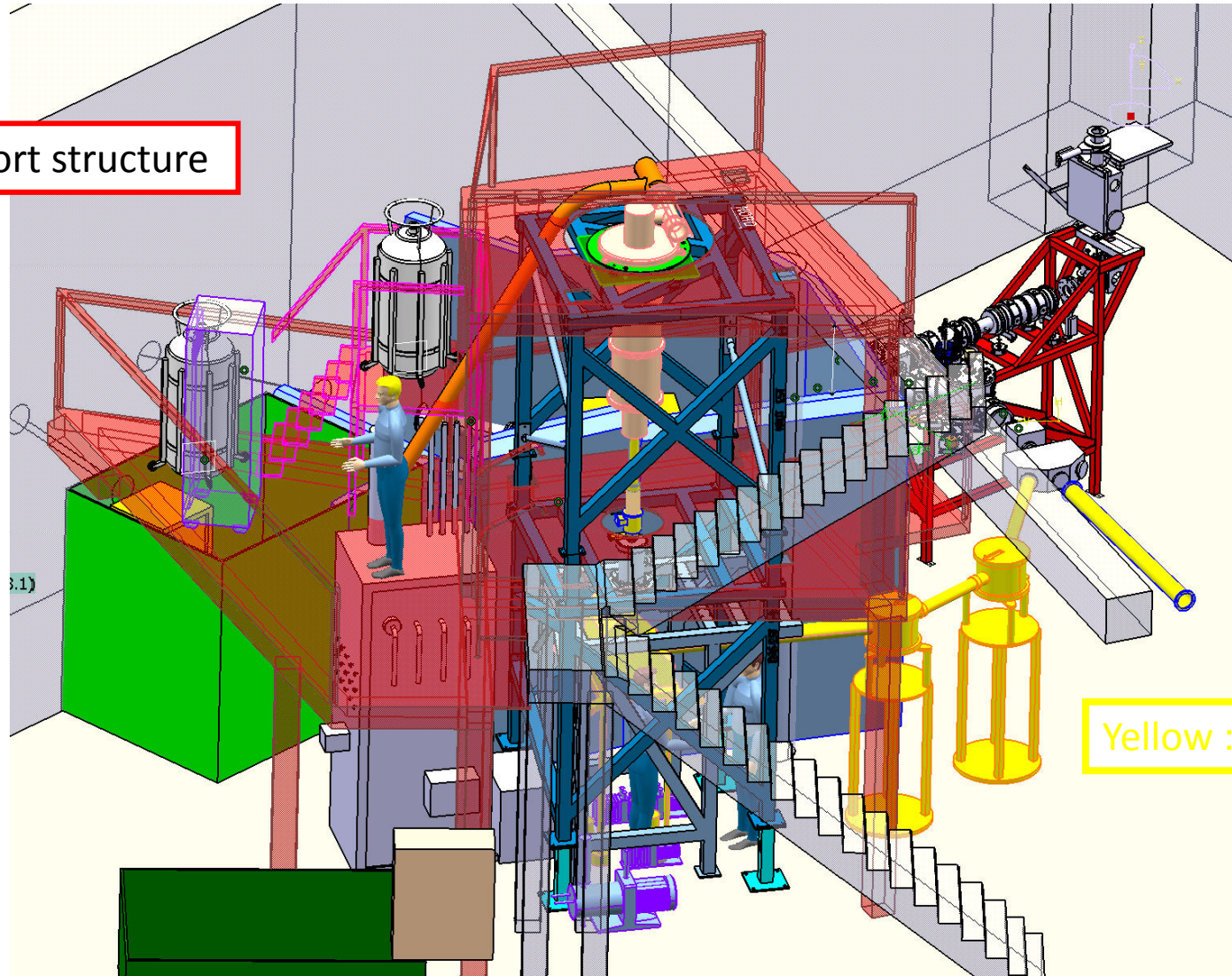
PolarEx: ALTO



EGAN 2012 - 25 June 2012

PolarEx: ALTO

Red : Support structure



Yellow : Beam Line

Unique combination of a **NMR/LTNO** setup together with a **Neutron-rich** beam

EGAN 2012 - 25 June 2012

PolarEx: Collaboration

CSNSM :

A. Astier, G. Audi, S. Cabaret, A. Etilé, C. Gaulard, G. Georgiev, S. Rocca

LPSC :

G. Simpson

IPNO :

F. Ibrahim, D. Verney

INM :

L. Risegari

University of Tennessee

University of Oxford

N.J. Stone

University of Maryland

University of Oxford

J.R. Stone

University of Novi Sad :

M. Veskovic, J. Nikolov