Intense and pure samples of $^{129m,131m,133m}Xe$ for a novel medical imaging technique, gamma-MRI

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ISOLDE WORKSHOP AND USERS MEETING 2022

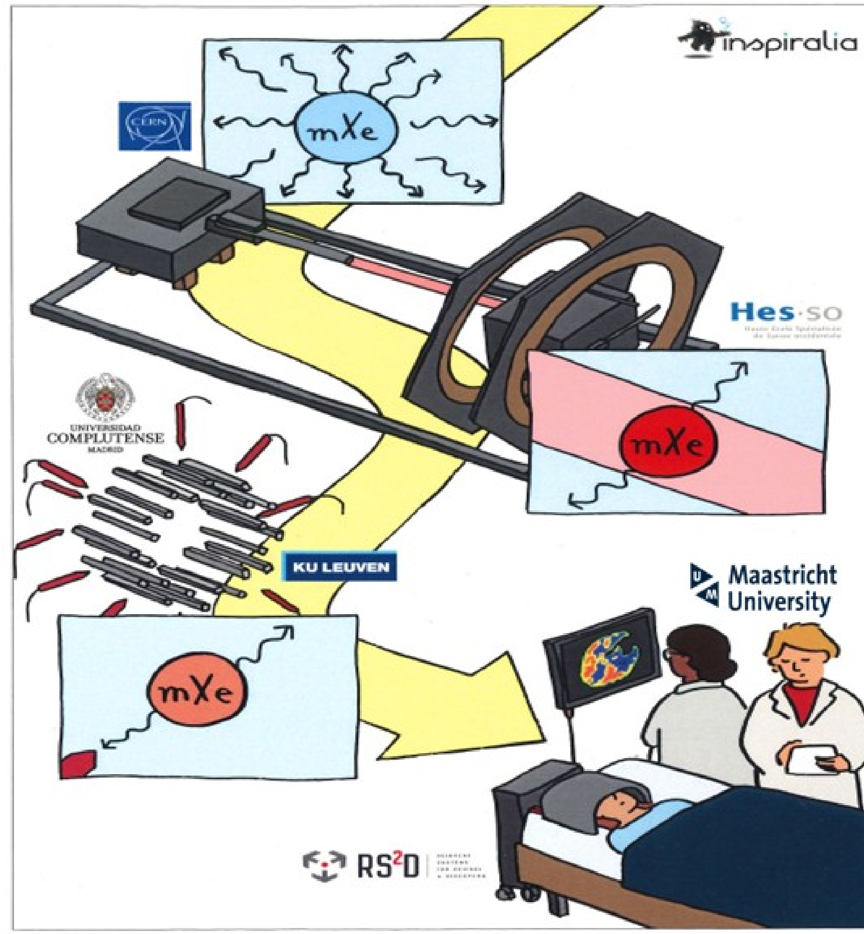
Gamma-MRI project

MRI

+

SPECT

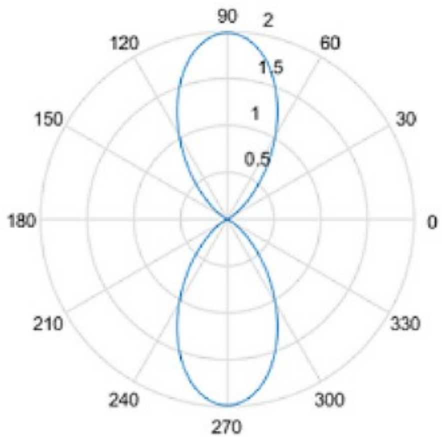
Asymetric gamma emission from aligned radionuclei



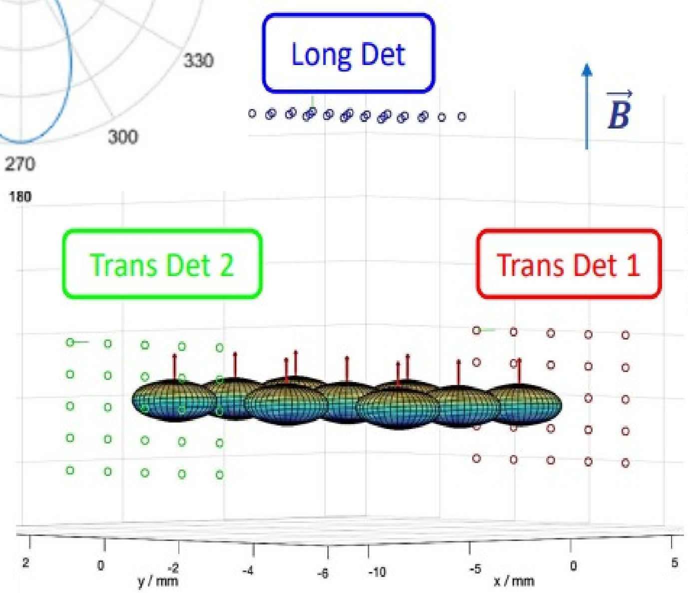
EU FET-OPEN project

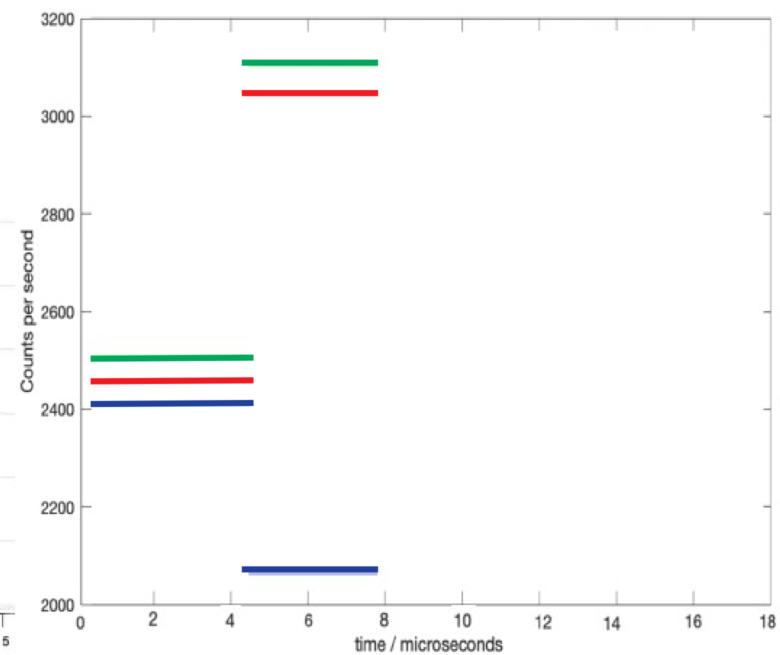
Gamma-MRI: principles

- **Asymetric gamma emission from aligned radionuclei:**



An ensemble of aligned radionuclei represented by 9 voxels





Simulation software for anisotropic gamma decay by R. Engel and E.L. Wistrom

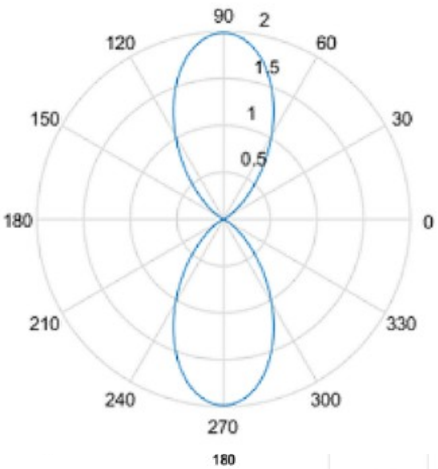
proof of principle
Y. Zheng, et al., Nature (537), 652 (2016)

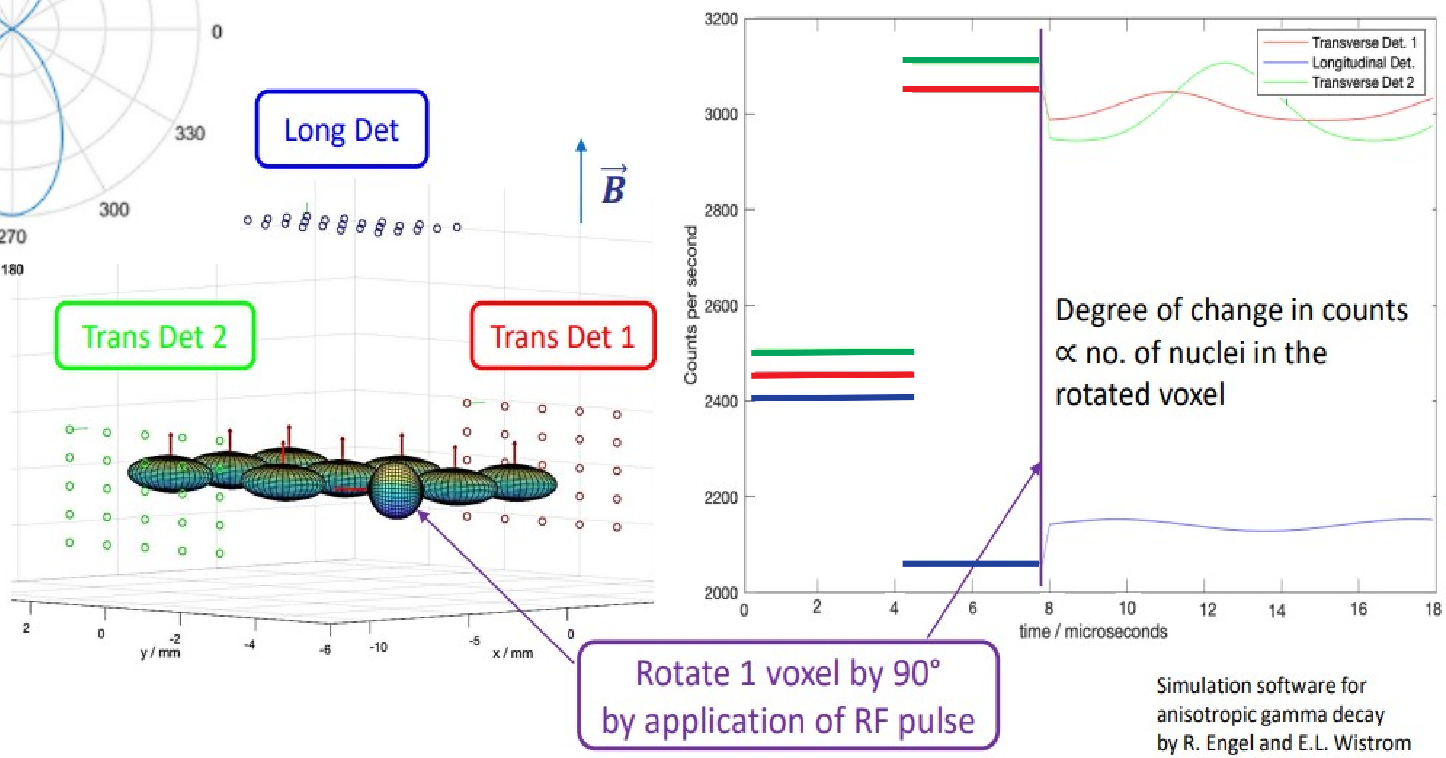
Gamma-MRI: principles

- **Changing gamma asymetry upon RF-excitation in a gradient field:**

`

π/2 RF pulse in resonance with 1 voxel





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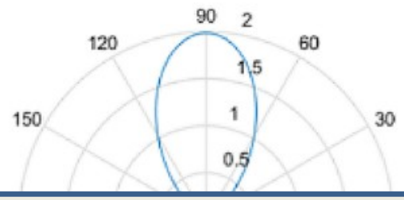
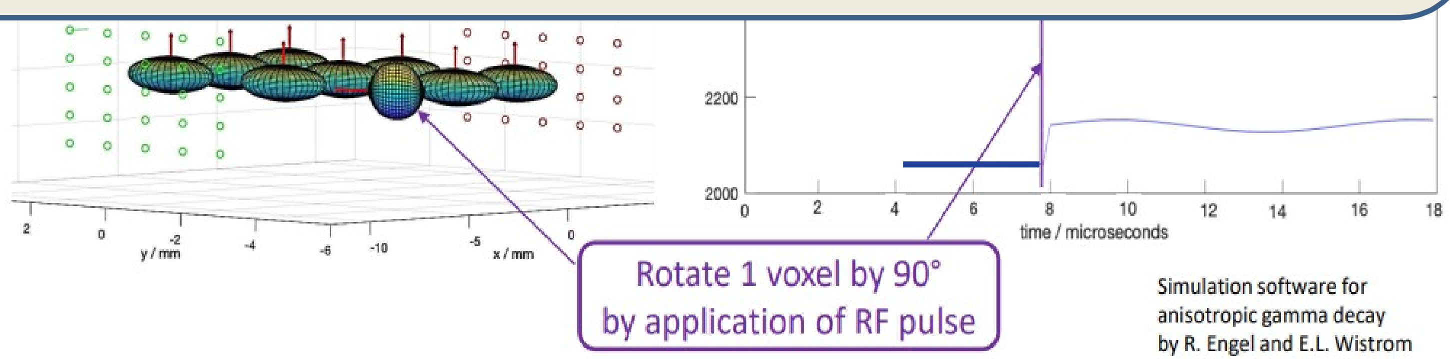


π/2 RF pulse in resonance with 1 voxel

MANIPULATION LIKE IN MRI
→HIGH SPATIAL RESOLUTION
DETECTION LIKE IN SPECT
→HIGH SENSITIVITY



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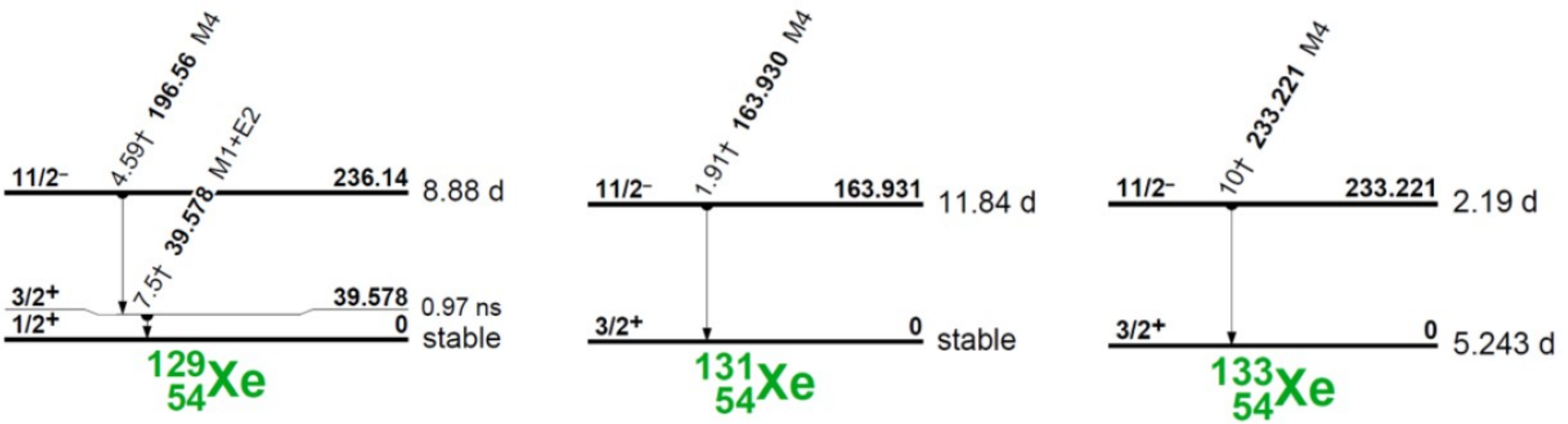
ISOLDE

Xe isomers



Why Xe isomers:

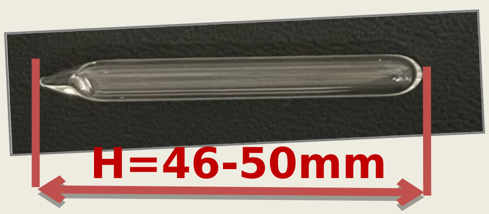
- polarization of ^{129}Xe well established
- ^{129}Xe is already used in MRI studies of the lungs and brain
- isomers with spin 11/2 show a very high degree of gamma emission asymmetry
- Xe (as a noble gas) is neutral to the human body

^{129m,131m}Xe production at reactors

- **Thermal neutron irradiation of stable xenon in the nuclear reactor**

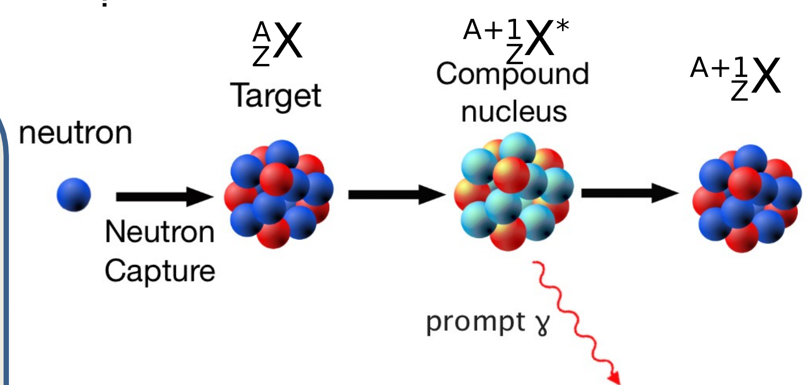
Irradiation of stable ^{128}Xe/^{130}Xe enclosed in quartz tube

QUARTZ TUBE WITH STABLE Xe



P_{Xe}=300 mbar
m=0.7-0.9 mg

Enrichment:
^{128}Xe (99.931%), ^{130}Xe (99.947%)
+other stable xenon isotopes (<0.01%)



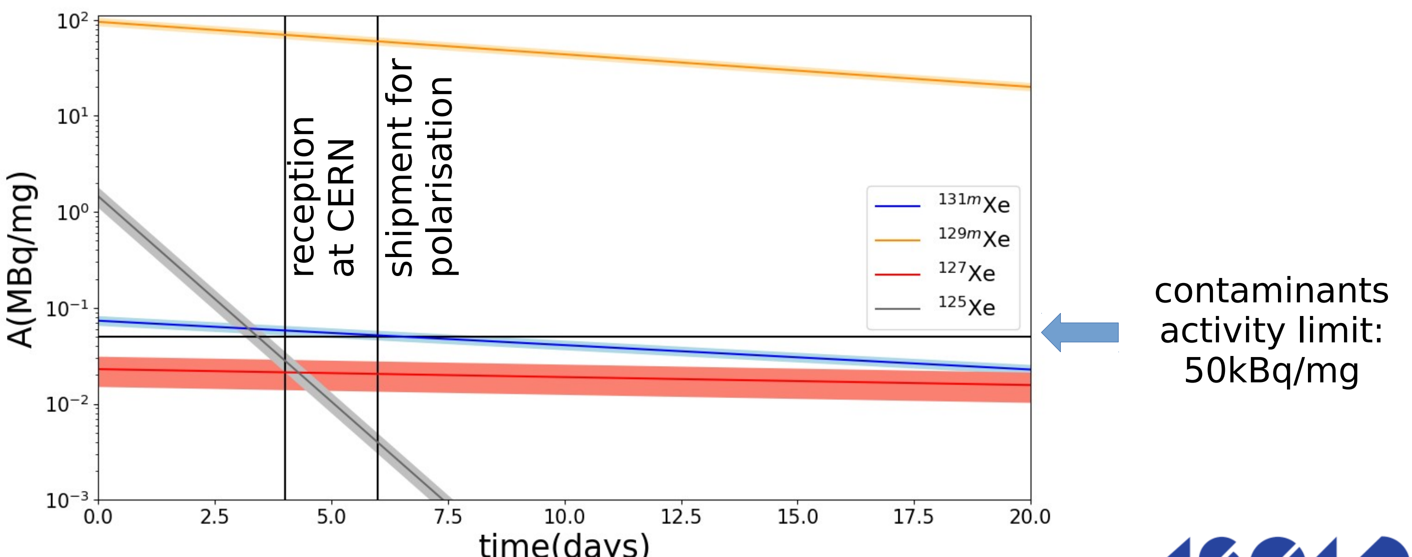
^{128}Xe(n,γ) ^{129m}Xe

^{130}Xe(n,γ) ^{131m}Xe

$^{129m,131m}Xe$ production at reactors

- **Samples activities at the end of irradiation**

	RHF reactor 3 batches in 2019,2021, 13 samples (MBq/mg)	MARIA reactor 4 batches in 2022, 19 samples (MBq/mg)
^{128}Xe	^{131m}Xe: 0.015-0.017 **^{129m}Xe: 478-583** ^{127}Xe: 0.021-0.030 ^{125}Xe: 1.0-1.1	^{131m}Xe: 0.065-0.082 **^{129m}Xe: 86-105** ^{127}Xe: 0.015-0.031 ^{125}Xe: 1.1-1.8
^{130}Xe	**^{131m}Xe: 567-693** ^{129m}Xe: 0.17-0.18 ^{127}Xe: 0.031-0.035 ^{125}Xe: 0.36-0.47	**^{131m}Xe: 95-130** ^{129m}Xe: 0.15-0.35 ^{127}Xe: 0.010-0.017 ^{125}Xe: 0.60-0.74



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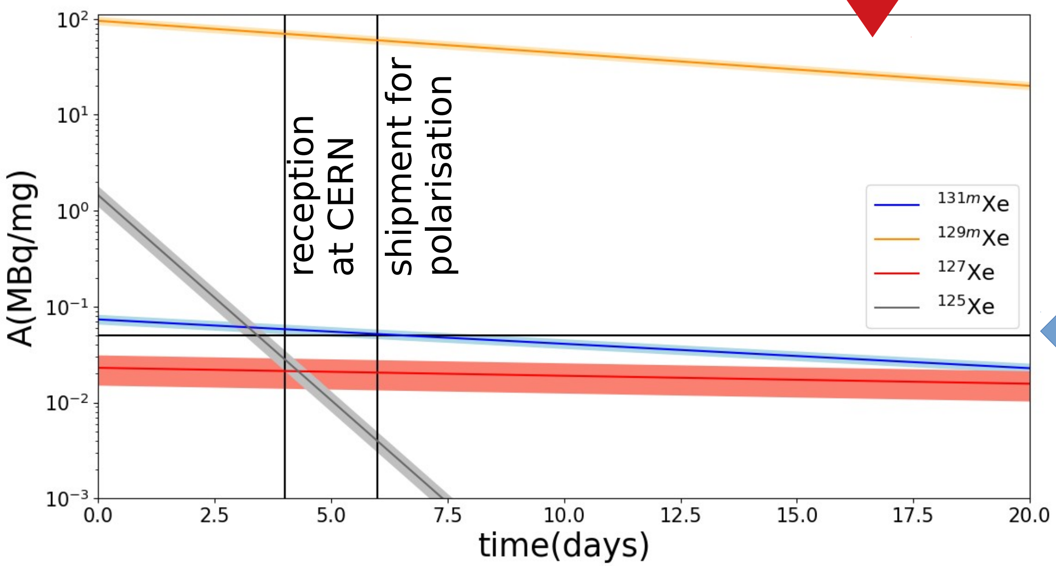
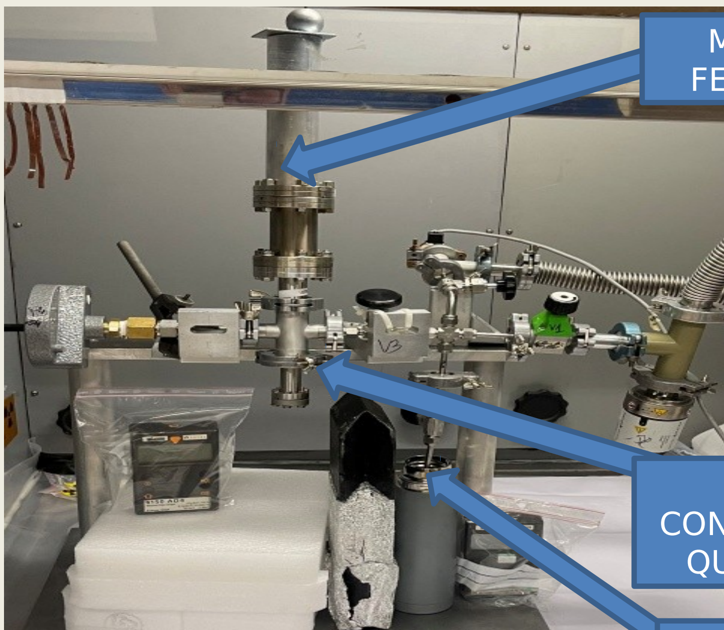


contaminants activity limit: 50kBq/mg

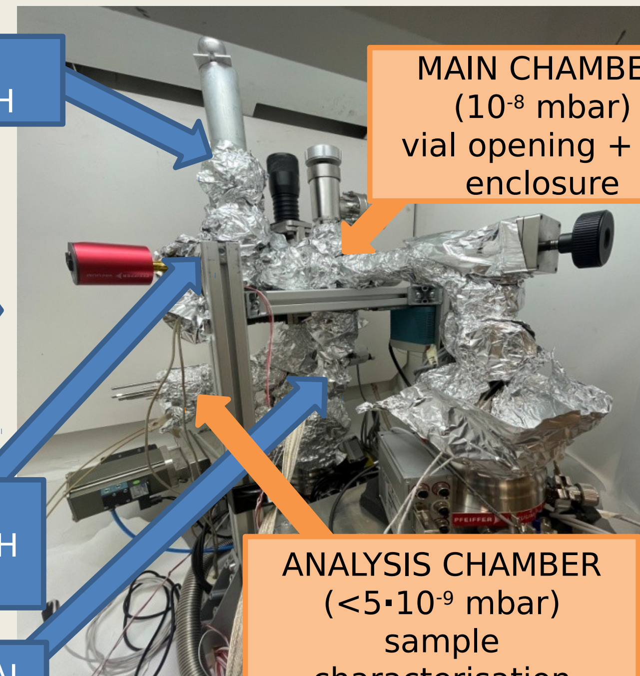
Transfer of reactor samples

2021-2022
HV SETUP (10^{-3}-10^{-6} mbar)
single chamber – opening vials + Xe enclosure in transport vials



TRANSFER EFFICIENCY: **76(2)%**

11/2022
UHV SETUP (<10^{-7} mbar)
two connected chambers via leak valve



TRANSFER EFFICIENCY: **92(2)%**

$^{129m,131m,133m}Xe$ production at ISOLDE

- **TARGET:** UC_x (2000°C)
- **ION SOURCE:** plasma ionization source with cooled transfer line
- **BEAM ENERGY:** 30keV
- **LOCATION:** GLM and GHM chambers
- **MAIN COLLECTIONS:** $^{129m,131m,133m}Xe$
- **TEST COLLECTIONS:** $^{129m,131m,133m}Xe$ + $^{125,127,130,135}Xe$
- **IMPLANTATION MATRIX:** Au (main collections), Al (test collections)
- **BEAMTIMES:** 09/2021(TEST), 11/2021 (OFFLINE), 04/2022, 10/2022

	^{129m}Xe	^{131m}Xe	^{133m}Xe
Activity [MBq/h]	**0.70(5)**	**1.2(1)**	**3.1(2)**

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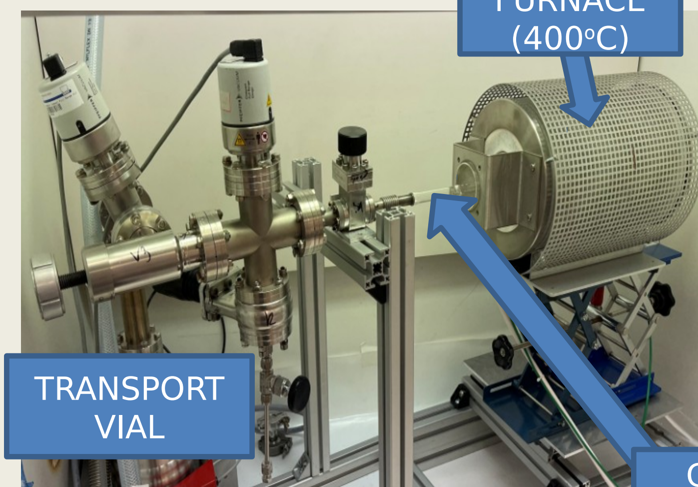
MORE DETAILED DESCRIPTION OF ISOLDE PRODUCTION IN 04/2022 WAS PRESENTED ON POSTER #40 BY ILARIA MICHELON:
„CHALLENGING PRODUCTION OF LONG-LIVED XENON ISOTOPES AT ISOLDE: EXPERIMENT VS THEORY"

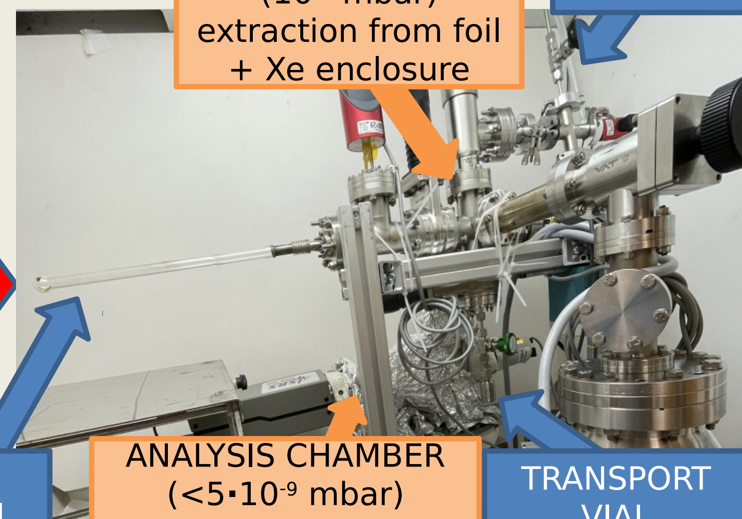
Transfer of ISOLDE samples

2021-2022
HV SETUP (10^{-6} mbar)
single chamber – Xe extraction + enclosure in transport vials



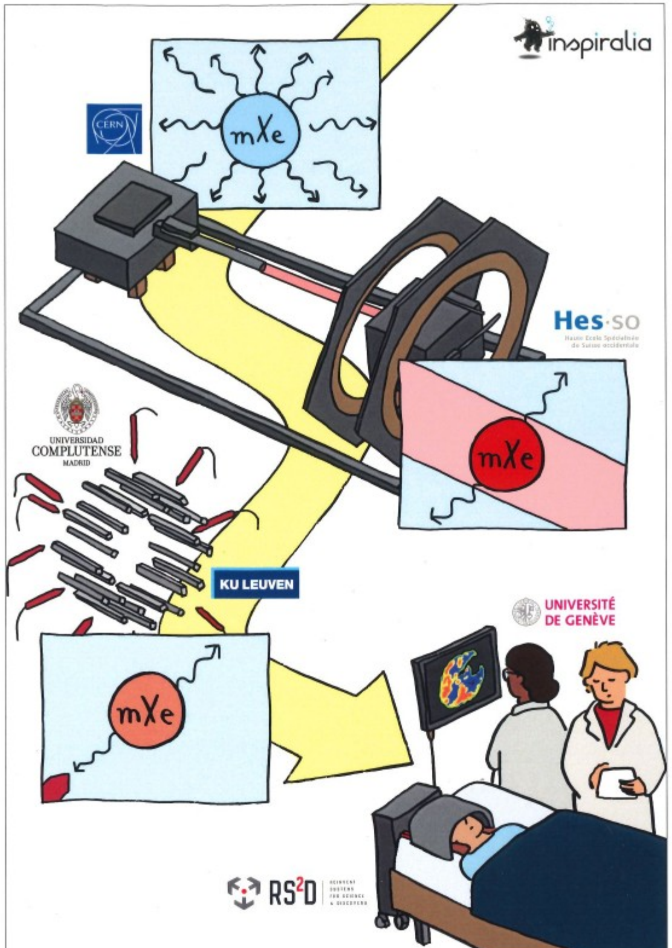
EXTRACTION EFFICIENCY: **84(2)%**
TRANSFER EFFICIENCY:
81(3)% (in vacuum condition)

10/2022
UHV SETUP (<10^{-7} mbar)
two connected chambers via leak valve



EXTRACTION EFFICIENCY: **84(1)%**
TRANSFER EFFICIENCY:
78(3)% (in He atmosphere)
87(2)% (in vacuum condition)

Summary & Outlook



- Gamma-MRI: EU funded collaborative project developing a novel medical imagining modality
- ISOLDE team works on providing intense and pure samples of $^{129m,131m,133m}Xe$
- Regular production at MARIA and HFR reactors with about 100-500MBq activity
- Upgraded experimental chambers allow UHV conditions and characterisation of samples
- Next step: more detailed analysis of samples purity
- Aim: provide good samples to be used in the next step of the gamma-MRI project

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[7]School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM), Teheran, Iran
[8]University of Applied Sciences and Arts of Western Switzerland, Geneva, Switzerland
[9]Universidad Complutense de Madrid, Madrid, Spain
[10]Maastricht University, Maastricht, Netherlands
[11]National Centre for Nuclear Research, Świerk, Poland
[12]University of Warsaw, Warsaw, Poland;
[13]Institut Laue-Langevin, Grenoble, France
[14]Technische Universitaet Darmstadt, Germany
[15]University of Oldenburg, Germany

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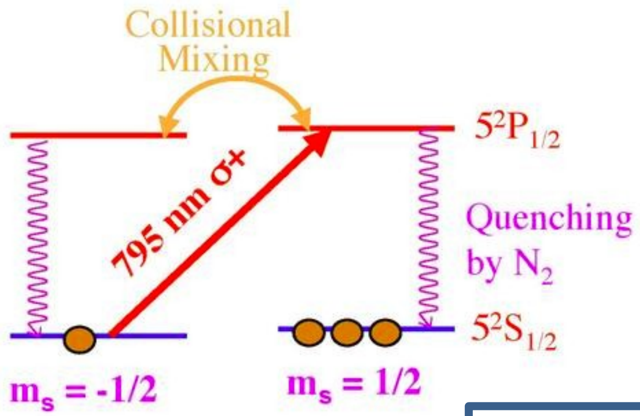
BACK-UP SLIDES

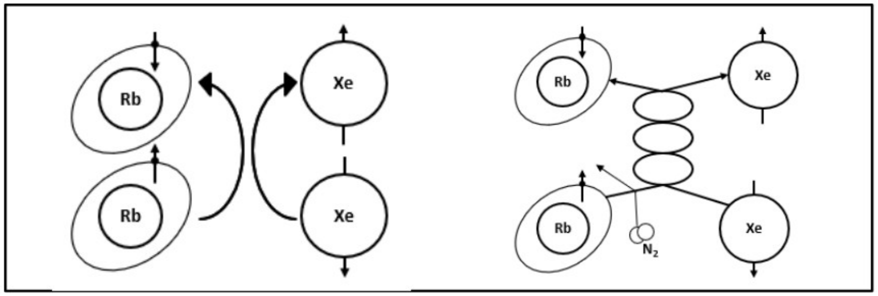
Gamma-MRI – ^{m}Xe polarization

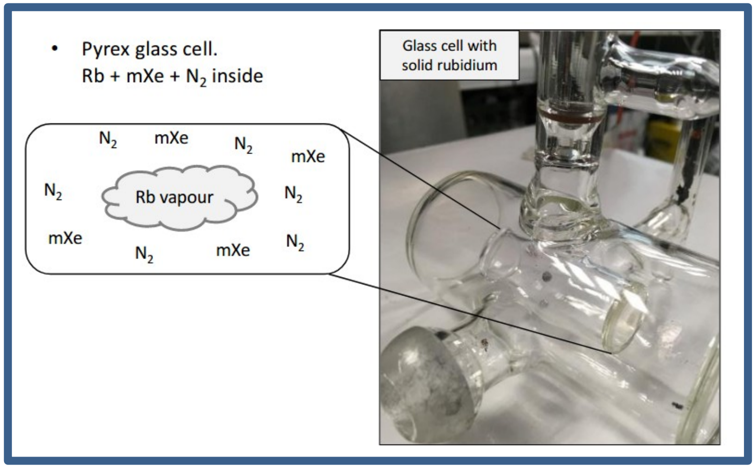
- **POLARIZATION EXPERIMENT:**
  - **METHOD: SPIN-EXCHANGE OPTICAL PUMPING (SEOP)**

1st step: Rb polarization



2nd step: ^{m}Xe polarization by Rb through hyperfine interaction

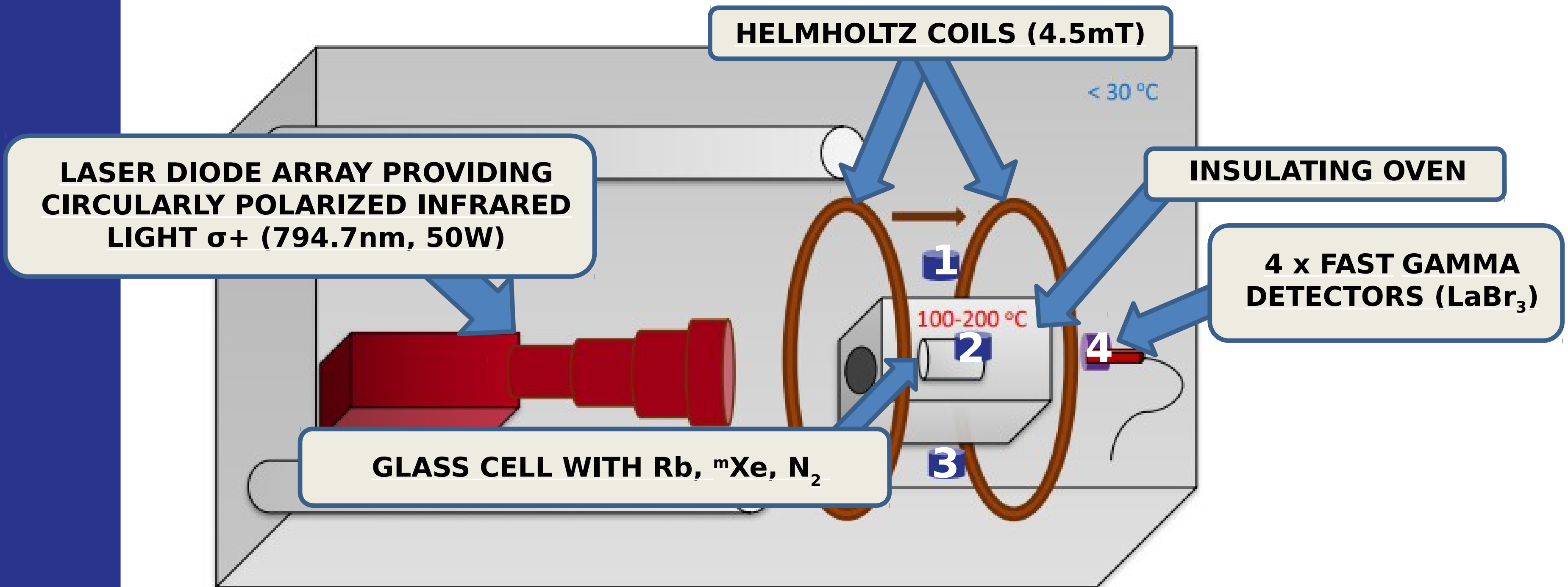




T.G.Walker, W.Harper, Rev.Mod.Phys.69(1997) 629-642

Gamma-MRI – ^{m}Xe polarization

- **POLARIZATION EXPERIMENT - SETUP:**
  - **METHOD: SPIN-EXCHANGE OPTICAL PUMPING (SEOP)**

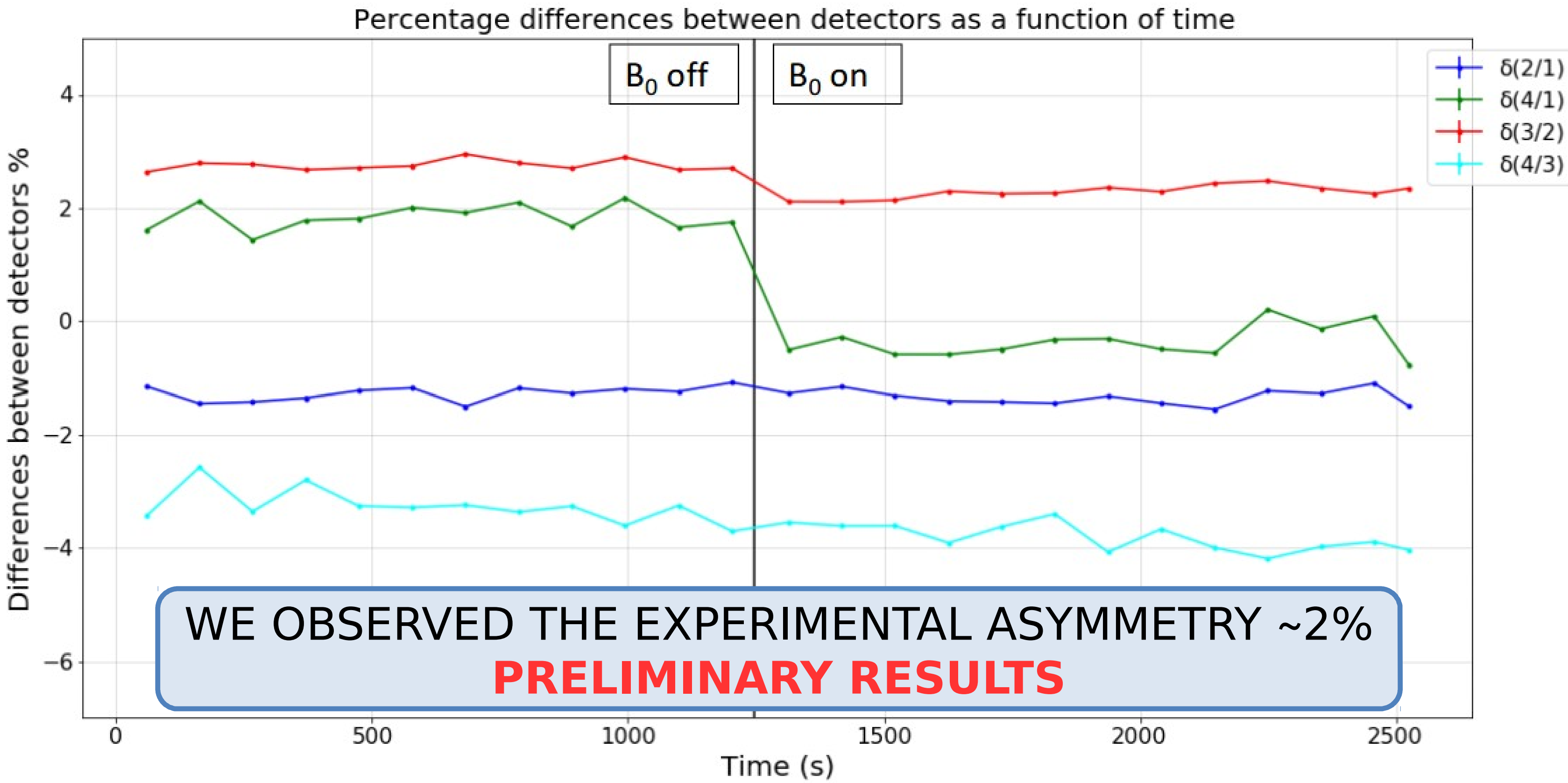


ASYMMETRY:

$$\delta(4/1) = \frac{det4 - det1}{det4}$$

Gamma-MRI – ^{m}Xe polarization

- **POLARIZATION EXPERIMENT – PRELIMINARY RESULTS:**



WE OBSERVED THE EXPERIMENTAL ASYMMETRY ~2%

PRELIMINARY RESULTS