Versatile **I**on-polarized **T**echniques **O**n-line (VITO) at ISOLDE, CERN

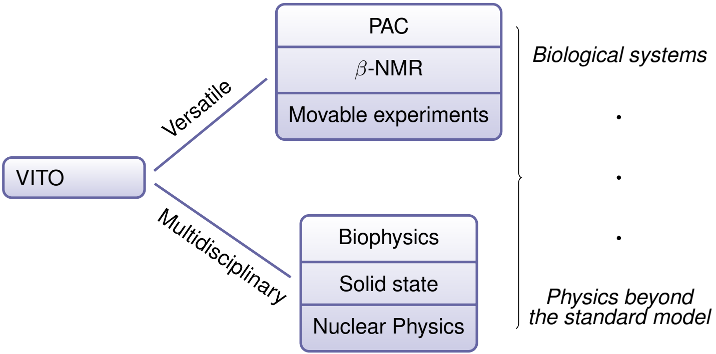
R. F. Garcia Ruiz
KU Leuven, Belgium
On behalf of the VITO Collaboration

CGS15, Dresden
August 2014

Table of contents

Motivation

Dedicated beamline for laser-induced nuclear orientation ⇔ Combine different expertise at ISOLDE.

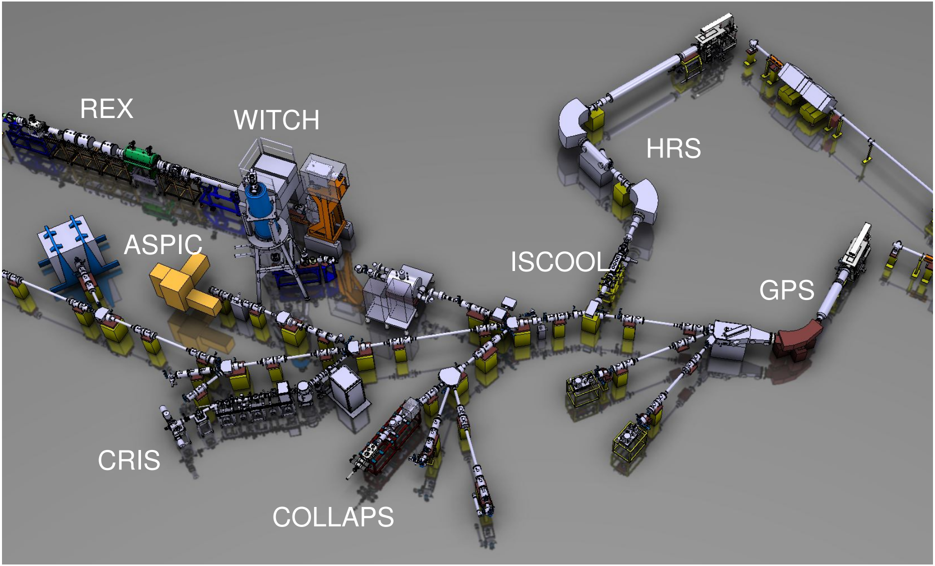


Laser-induced nuclear orientation + β-NMR

→introduced at ISOLDE [E. Arnold et al. Phys. Lett. B 197, 311 (1987)]

Worldwide there is only one dedicated beamline for laser-induced nuclear orientation (TRIUMF)

VITO at ISOLDE



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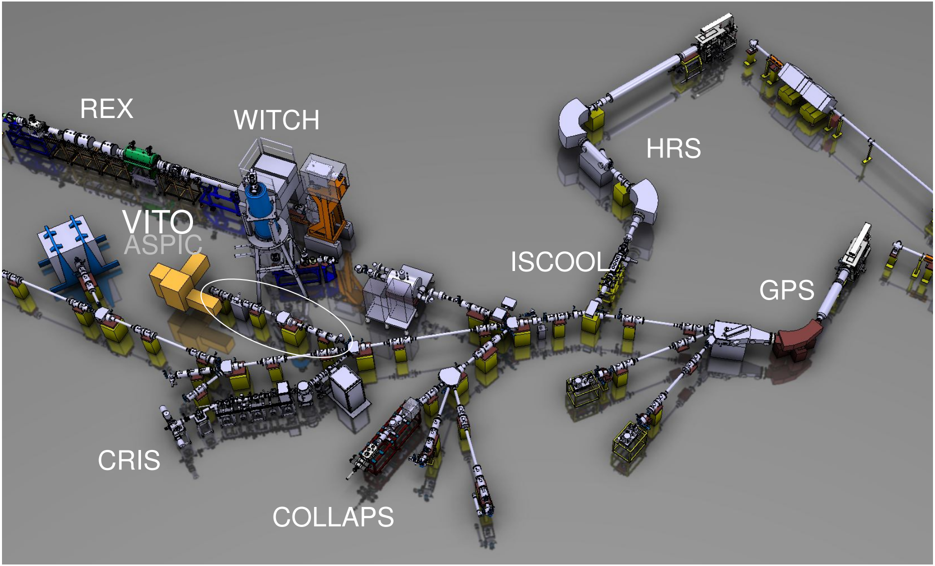
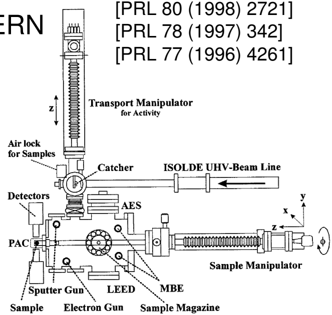


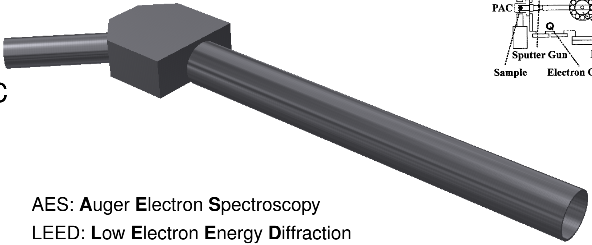
ASPIC

Apparatus for **S**urface **P**hysics and **I**nterfaces at **C**ERN



[PRL 80 (1998) 2721]
[PRL 78 (1997) 342]
[PRL 77 (1996) 4261]

ASPIC



AES: **A**uger **E**lectron **S**pectroscopy

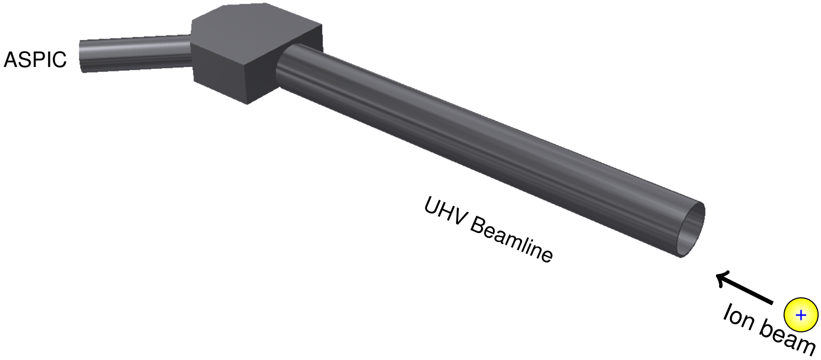
LEED: **L**ow **E**lectron **E**nergy **D**iffraction

MBE: **M**olecular **B**eam **E**pitaxy

PAC: **P**ertubed **A**ngular **C**orrelation

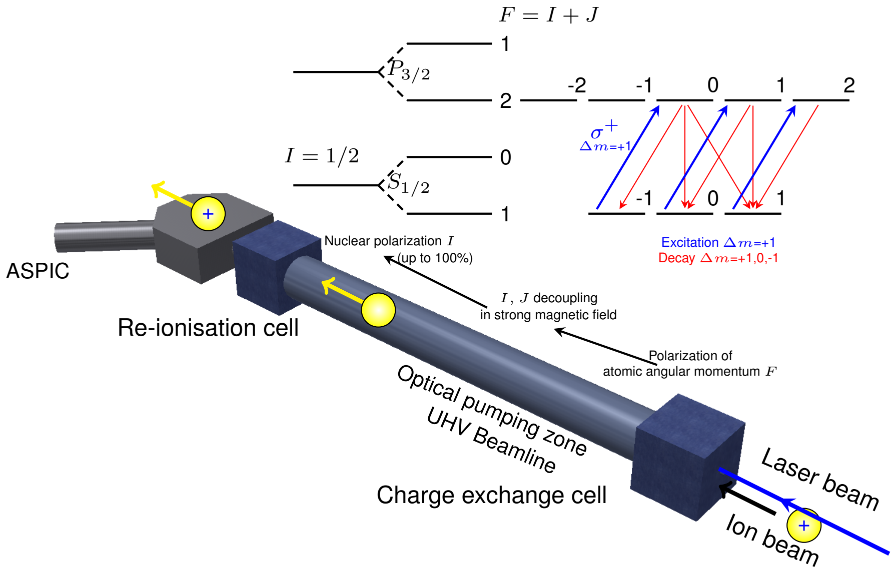
VITO Beamline

VITO $=$ ASPIC $+$ Laser-induced nuclear orientation $+$ β-NMR $+$...



VITO Beamline

VITO = ASPIC + Laser-induced nuclear orientation + β-NMR +...



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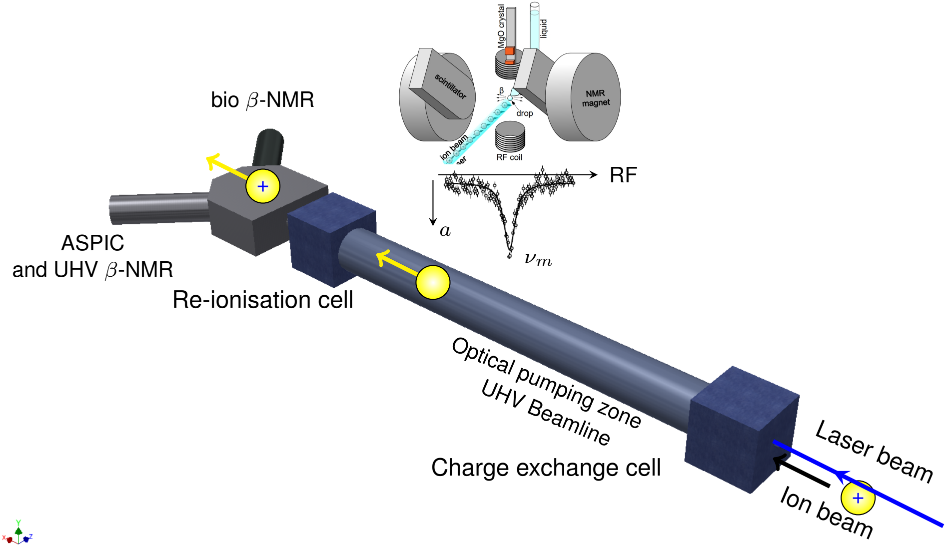

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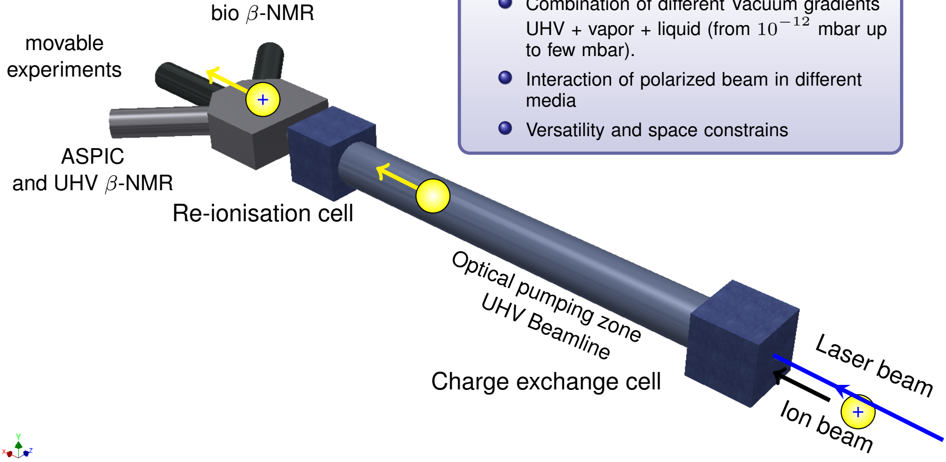
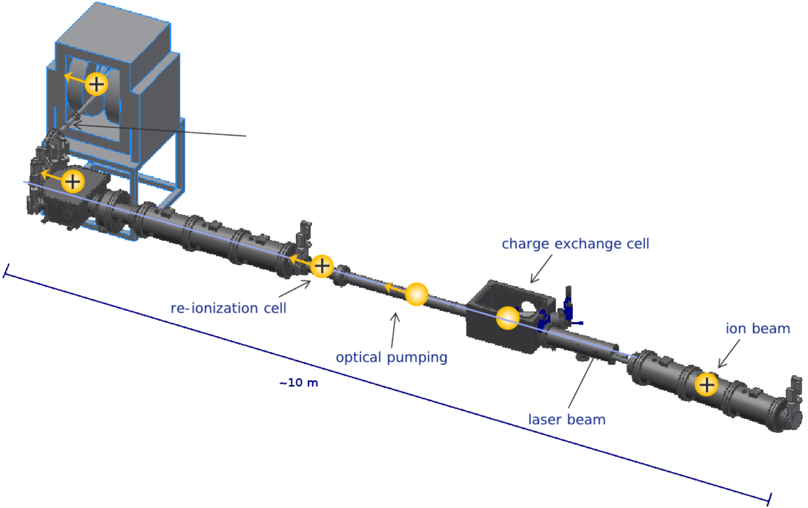


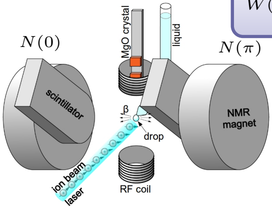
Challenges:

- Combination of different Vacuum gradients UHV + vapor + liquid (from 10^{-12} mbar up to few mbar).
- Interaction of polarized beam in different media
- Versatility and space constrains

VITO Beamline: Final Design



Polarized nuclei and β-NMR



Angular distribution of β-particles:
$W(\theta) = 1 + \frac{v}{c} A_\beta . P \cos\theta$

$P = \frac{I_z}{I} \rightarrow$ Nuclear polarization
$A_\beta \rightarrow \beta$-asymmetry

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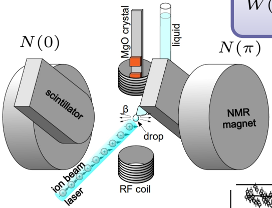

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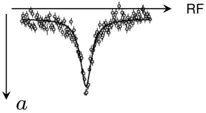

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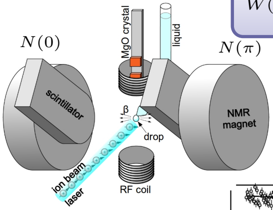

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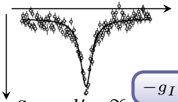

$\nu_m \propto$ $-g_I \mu_N B$, eQV_{zz}/h

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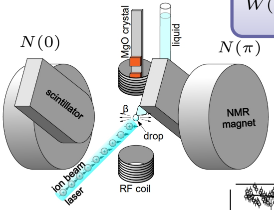

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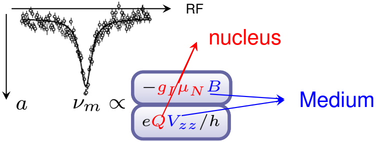

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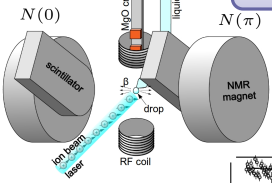

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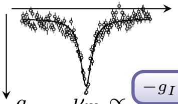


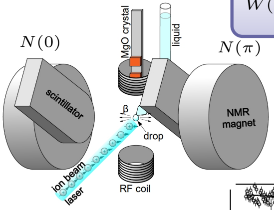
$\nu_m \propto$ $-g_I \mu_N B$ / eQV_{zz}/h

If V_{zz} and B are known:

Nuclear structure (Q, μ_N)

- Nuclear quadrupole moment Q
- Magnetic dipole moment μ_N
- Nuclear spin, I, and changes in rms charge radii $\langle r^2 \rangle$

Polarized nuclei and β-NMR



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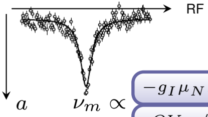

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If Q and μ_N are known:

Solid State, Biophysics (B, V_{zz})
- Magnetic probe: Surface magnetism, superconductivity,...
- Chemical shifts, line broadening, Chemical bonding,...

Polarized nuclei and β-NMR

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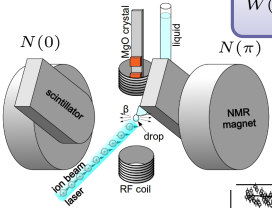

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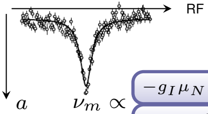
$\rho \rightarrow$ Gamow-Teller to Fermi mixing ratio

$$A_\beta = \begin{cases} \pm 1 & \text{for } I_f = I_i - 1 \\ \frac{\pm\rho^2/(I_i+1) - 2\rho\sqrt{I_i/(I_i+1)}}{1+\rho^2} & \text{for } I_f = I_i \\ \mp \frac{I_i}{I_i+1} & \text{for } I_f = I_i + 1 \end{cases}$$



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Measuring A_β:

Spin assignment (I)
By measuring the β-delay particles

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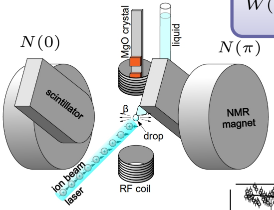

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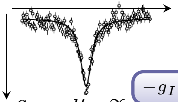

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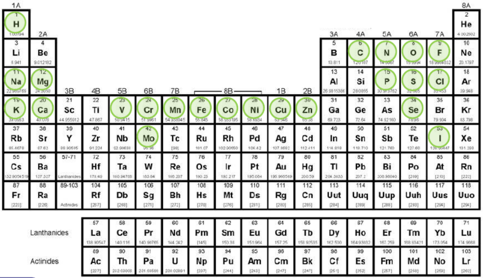
Fundamental physics (ρ)
V_{ud} of the Kobayashi-Maskawa (CKM) quark mixing matrix
$V_{ud}^2 \propto \left(1 + \frac{f_A}{f_V}\rho^2\right)^{-1}$

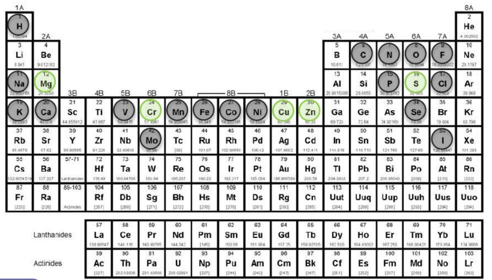


Human body:

- 99% 4 major elements: O (43 kg), C (16 kg), H (7 kg), N (1.8 kg)
- 1% 21 other elements: Ca, Mg, Fe, Zn, Cu ...

Natural elements

Bio β-NMR: Motivation



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- Ion accessible in established techniques

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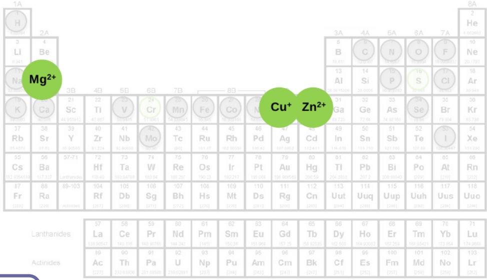

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(+) Closed shell ions $\rightarrow$ silent in most spectroscopic techniques

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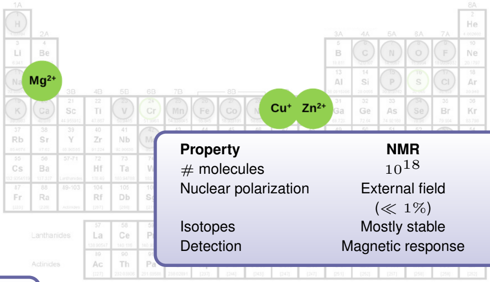

Property	NMR	β-NMR
# molecules	10^{18}	10^{5}
Nuclear polarization	External field ($\ll 1\%$)	Optical pumping, tilted foils, etc up to 100%
Isotopes	Mostly stable	Radioactive
Detection	Magnetic response	β asymmetry

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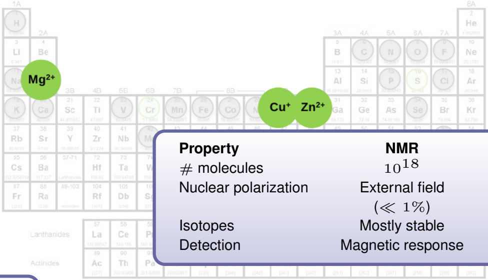

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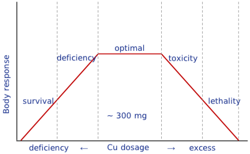

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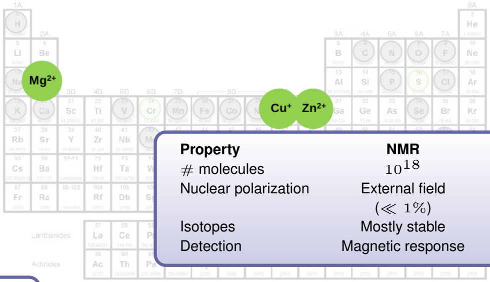

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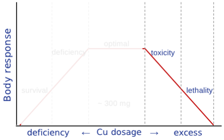
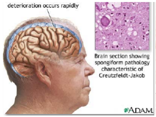


Alzheimer

Parkinson



Prion

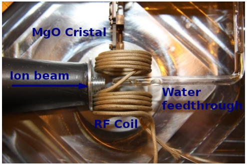
Wilson

[Chem. Rev. (2006) 106] [Neu. Aging (2014) 858] [Progr. Neu. (2014) 33]

Bio β-NMR: First results

A. Gottberg, M. Stachura, and *et al.*, In preparation

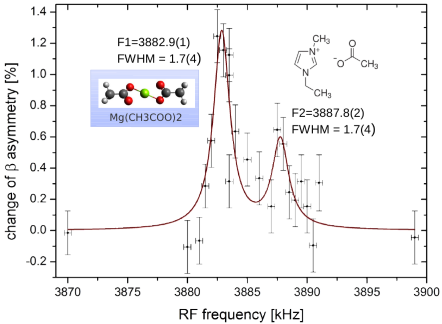
Bio β-NMR: First results

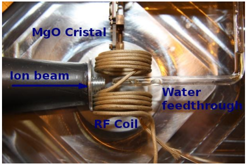


A. Gottberg, M. Stachura, and *et al.*, In preparation

Bio β-NMR: First results

β-NMR spectrum of ^{31}Mg in an Ionic Liquid



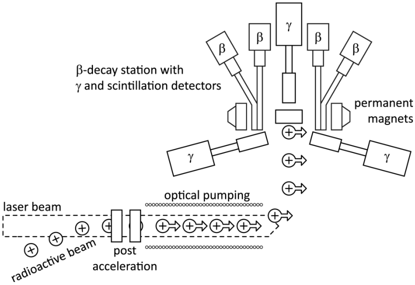


For the first time (August, 2012):

- β-NMR measured in a liquid medium
- Signal recorded from metal ions (Mg II) in a body-like liquid environment

A. Gottberg, M. Stachura, and *et al.*, In preparation

Nuclear Structure



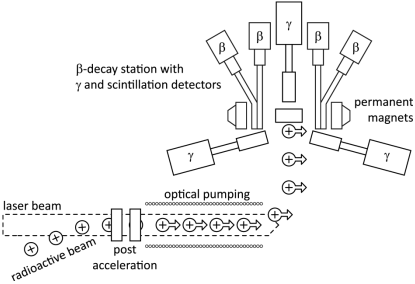
Laser spectroscopy + β-NMR

$$\nu_m \propto \begin{matrix} -g_I \mu_N B \\ eQV_{zz}/h \end{matrix}$$

Extensively used at ISOLDE (COLLAPS) to measure nuclear ground states properties

- Nuclear moments Q, μ_N
- Nuclear spin, I

PRL 108 (2012) 042504
PRL 101 (2008) 132502
PRC 77 (2008) 034307
PRL 97 (2007) 212501
PRL 94 (2005) 022501
PLB 197 (1987) 311



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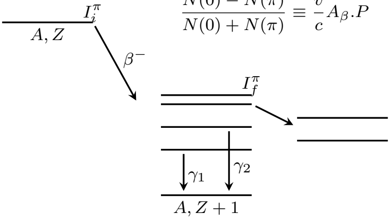
β-delayed spectroscopy of laser-polarized beams
D. T. Yordanov *et al*

Employed at RIKEN using tilted foil technique [PRC 67 (2003) 014306]

$$\frac{N(0)-N(\pi)}{N(0)+N(\pi)} \equiv \frac{v}{c} A_\beta . P$$



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A_β takes well separate discrete values
$\rightarrow$ Unambiguous spin assigments

Fundamental weak interaction physics

V_{ud} from the β-asymmetry of mirror transitions
N. Severijns, G. Neyens, M. Bissell and et *al*

Determining the V_{ud} element of the Cabibbo-Kobayashi-Maskawa (CKM) quart mixing matrix

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1 \qquad ? \longrightarrow$$

(+) Search for new physics

(+) Sensitive test to the standard model

Weighted average of the most precise results (Fermi transitions)

$$V_{ud} = 0.97425 \pm 0.00022$$

Fundamental weak interaction physics

V_{ud} from the β-asymmetry of mirror transitions
N. Severijns, G. Neyens, M. Bissell and et *al*

Determining the V_{ud} element of the Cabibbo-Kobayashi-Maskawa (CKM) quart mixing matrix

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(+) Sensitive test to the standard model

Weighted average of the most precise results (Fermi transitions)

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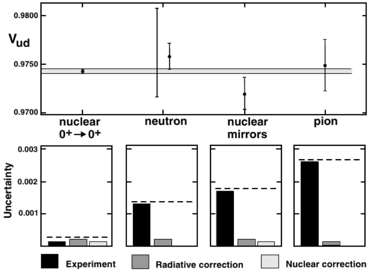

[Figure from: Towner and Hardy. Rep. Prog. Phys. 73 (2010) 046301]

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$$V_{ud}^2 = \frac{K}{FtG_F^2(1+\Delta_R^V)}\left(1+\frac{f_A}{f_V}\rho^2\right)^{-1}$$

O. Naviliat-Cuncic and N. Severijns [PRL 102 (2009) 142302]

V_{ud} very sensitive to ρ

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V_{ud} very sensitive to ρ

Example: ^{35}Ar $\rightarrow$ By measuring A_β with a precision of 0.5 % $\rightarrow$ 0.0004 absolute precision on V_{ud}

VITO Collaboration

Biophysics:

- L. Hemmingsen – University of Copenhagen, DK
- A. Jancso – University of Szeged, Hungary
- P. W. Thulstrup, Kobehnhavn Universitet, Denmark

Solid State Physics:

- M. Deicher - University of Saarlandes, Germany
- Z. Salman - PSI, Switzerland
- V. Amaral - Universitty of Aveiro, Portugal
- J. Röder - Aachen University, Germany
- K. Potzger - Dresden – Rossendorf, Germany
- A. MacFarlane - The University of British Columbia, Canada
- R. Kiefl - University of British Columbia, Canada.
- L. Pereira - IKS KU Leuven, Belgium

Nuclear Physics:

- G. Neyens – IKS KU Leuven, Belgium
- N. Severijns - IKS KU Leuven, Belgium
- D. Yordanov - IPN Orsay, France

At ISOLDE:

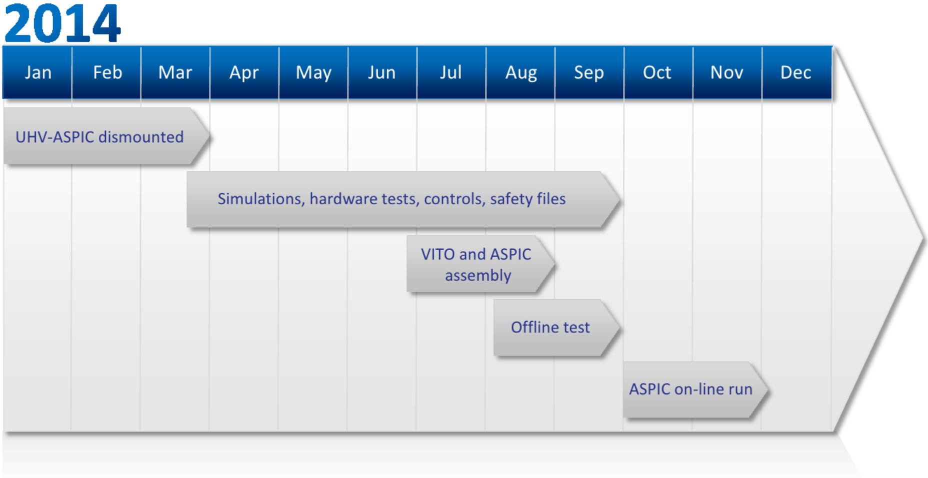
- Alexander Gottberg – EN-STI
- Joao G. Correia - SSP
- Karl Johnston – SSP coordinator
- Magdalena Kowalska – ISOLDE PH
- Mark Bissell (KU Leuven)- COLLAPS
- Monika Stachura, ISOLDE PH
- Ronald Garcia (KU Leuven)– COLLAPS, CRIS

Summary

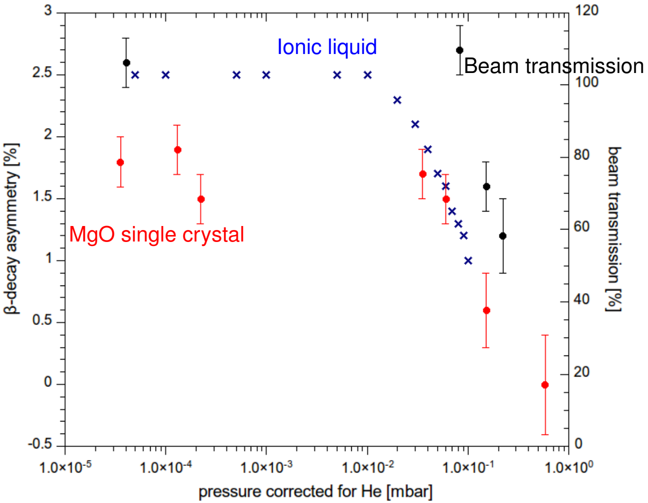
- A unique beam line in Europe $\rightarrow$ Several experiments can benefit from a dedicated beamline for laser-induced nuclear orientation.
- VITO $\rightarrow$ Multidisciplinary research
  - Biophysics
  - Solid state
  - Nuclear physics ...
- For the first time β-NMR in a body-like environment
- 51 shifts approved: β-NMR (33) and ASPIC (18)

Thanks for your attention!

Timeline

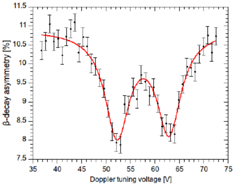

2014
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
UHV-ASPIC dismounted
Simulations, hardware tests, controls, safety files
VITO and ASPIC assembly
Offline test
ASPIC on-line run

Pressure-dependent β-decay asymmetry

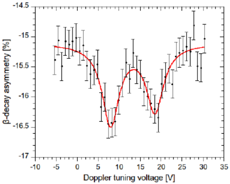


HFS of 31Mg in different materials

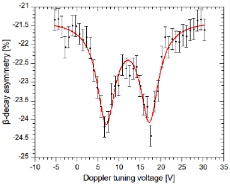
MgO crystal



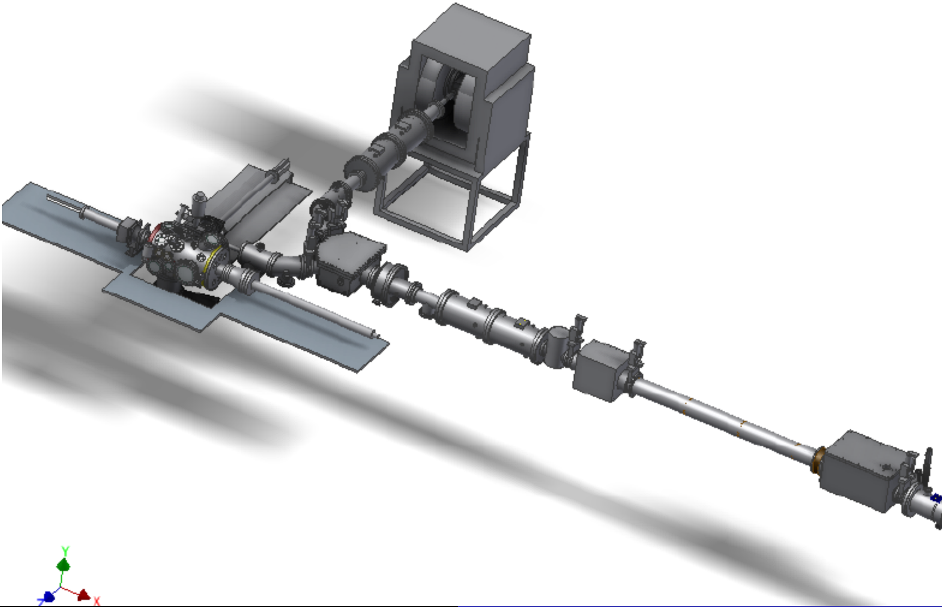
Quartze tube

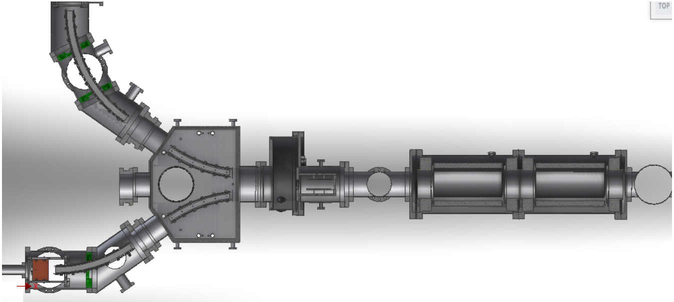


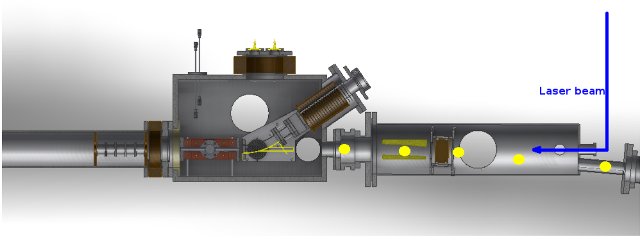
Ionic liquid



	MgO crystal	Quartz tube	EMIM-Ac
No. scans	25	40	23
1st peak [V]	7.7(2)	7.9(3)	6.9(1)
β-decay asymmetry [%]	1.9(2)	1.3(1)	2.6(2)
2nd peak [V]	17.5(3)	18.4(3)	17.1(2)
β-decay asymmetry [%]	1.9(2)	1.1(1)	2.6(2)
FWHM [V]	4.8(6)	4.9(8)	5.2(4)


Y
X


TOP


Laser beam

	^{19}Ne	^{21}Na	^{29}P	^{35}Ar	^{37}K
J	1/2	3/2	1/2	3/2	3/2
$\mathcal{F}t$ [s][a]	1720.3(30)	4085(12)	4809(19)	5688.6(72)	4562(28)
f_A/f_V[b]	1.0143(29)	1.0180(36)	1.0223(45)	0.9894(21)	1.0046(9)
E_0 [MeV][c]	2.728 31(17)	3.036 58(70)	4.431 45(60)	5.455 14(70)	5.636 46(23)
E [MeV][d]	0.511	1.60	2.39	3.14	3.35
M [amu][e]	19.000 141 99(9)	20.995 750 9(4)	28.979 147 65(30)	34.972 055 1(4)	36.970 076 11(12)
b[f]	−148.5605(26)	82.6366(27)	89.920(15)	−8.5704(90)	−44.99(24)
$a_{\beta\nu}$		0.5502(60)[g]			
A_β	−0.0391(14)[h]		0.681(86)[i]	0.430(22)[j]	
B_ν					−0.755(24)[k]
ρ	1.5995(45)	−0.7136(72)	−0.593(104)	−0.279(16)	0.561(27)
$\mathcal{F}t_0$ [s]	6184(30)	6202(48)	6537(606)	6128(49)	6006(146)

O. Naviliat-Cuncic and N. Severijns [PRL 102 (2009) 142302]