

Versatile Ion-polarized Techniques On-line (VITO) at ISOLDE, CERN

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KU Leuven, Belgium
On behalf of the VITO Collaboration

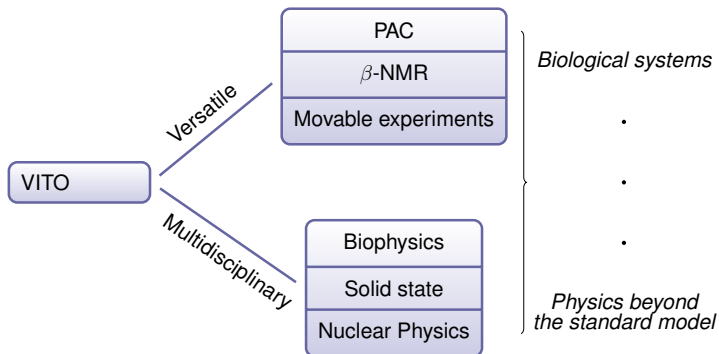
CGS15, Dresden
August 2014

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Motivation

Dedicated beamline for laser-induced nuclear orientation $\Leftrightarrow$ Combine different expertise at ISOLDE.

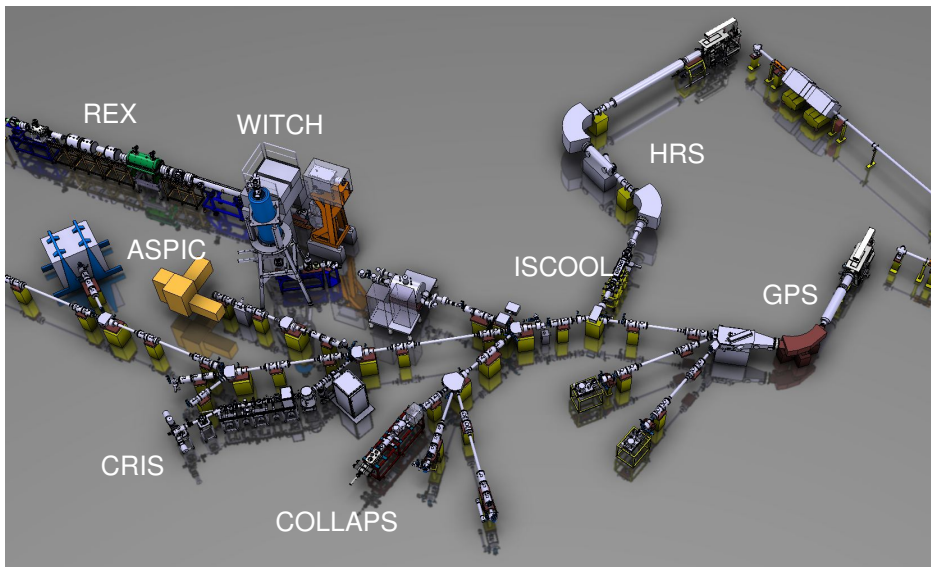


Laser-induced nuclear orientation + β -NMR

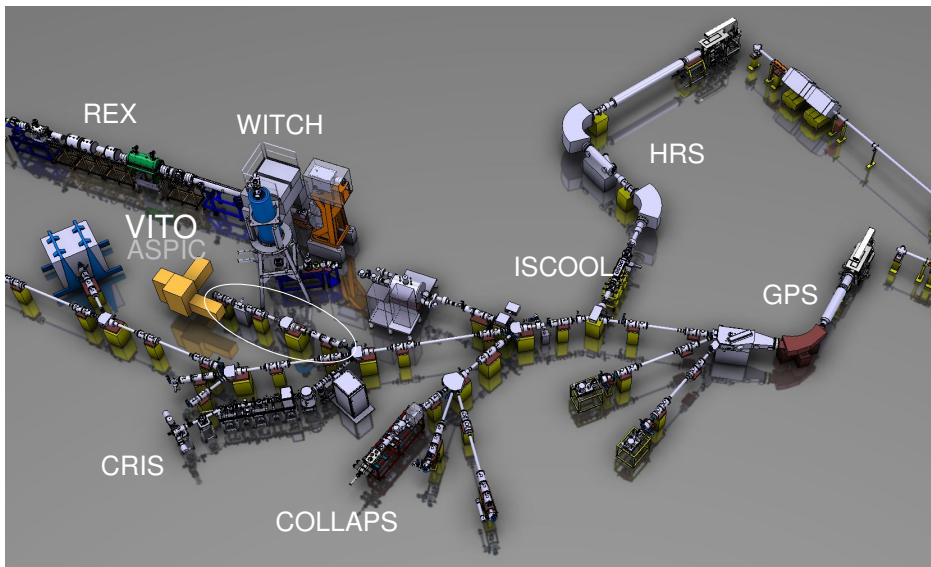
→ introduced at ISOLDE [E. Arnold et al. Phys. Lett. B 197, 311 (1987)]

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

VITO at ISOLDE



VITO at ISOLDE



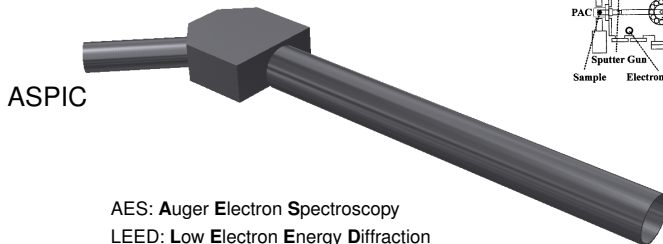
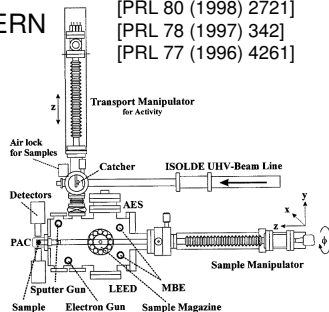
ASPIC

Apparatus for **S**urface **P**hysics and **I**nterfaces at **CERN**

[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

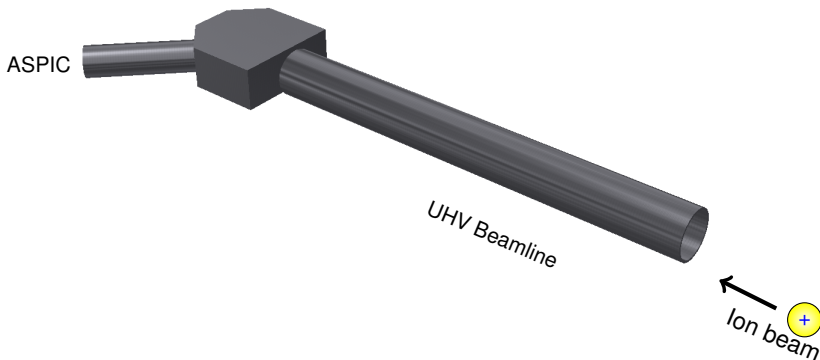
MBE: **M**olecular **B**eam **E**pitaxy

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



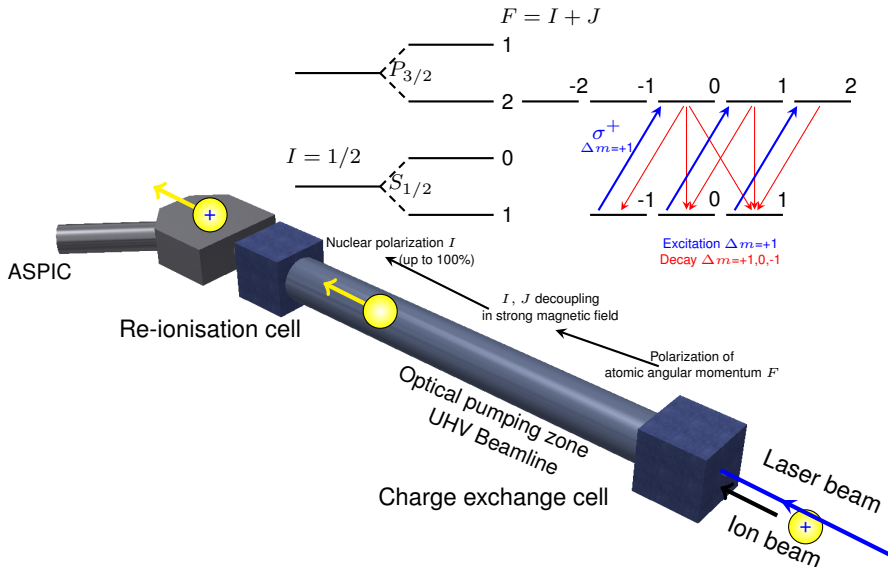
VITO Beamline

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



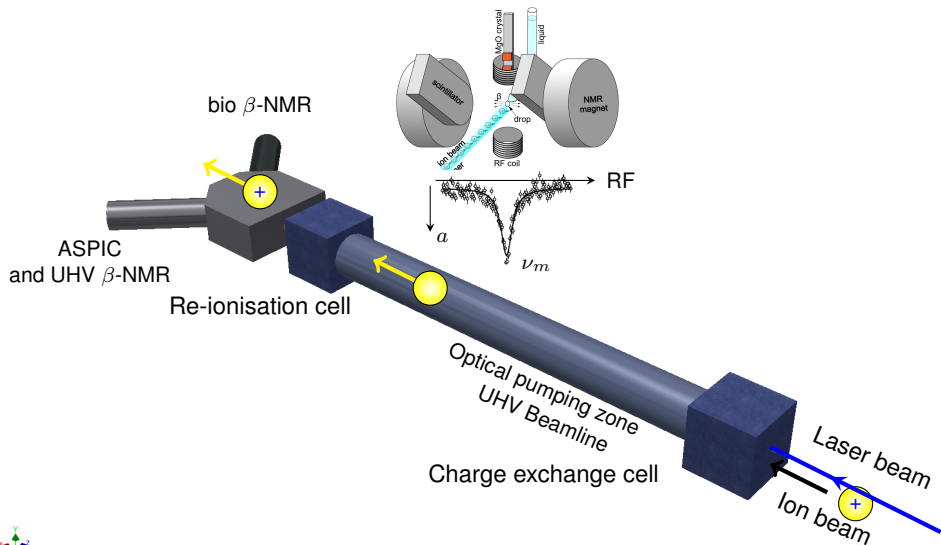
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VITO = ASPIC + Laser-induced nuclear orientation + β -NMR + ...



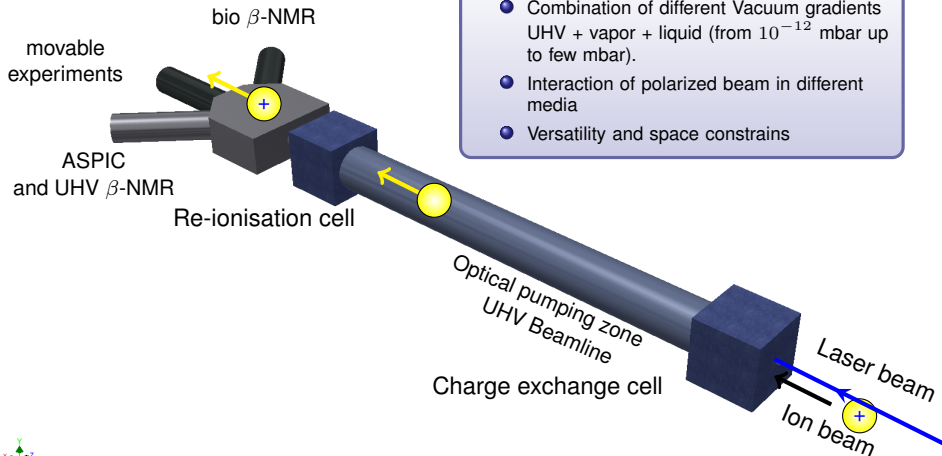
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VITO Beamline

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

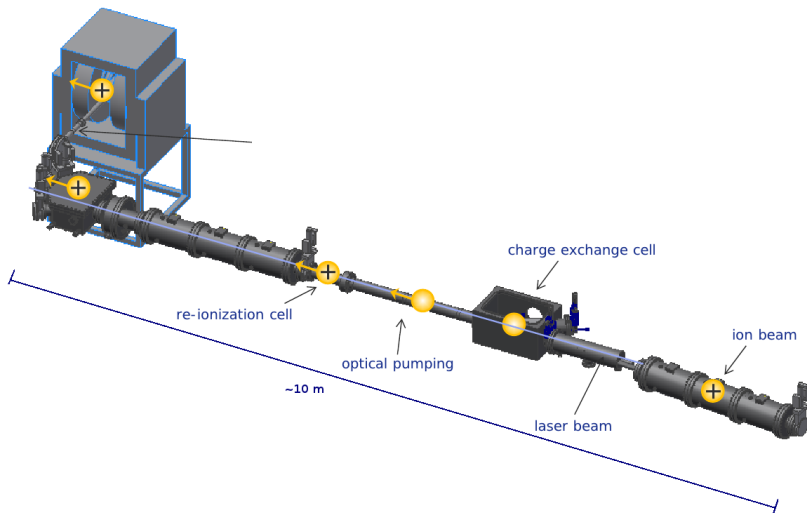


Challenges:

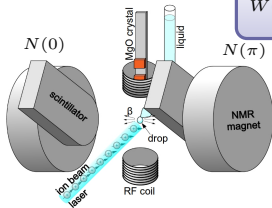
- Combination of different Vacuum gradients UHV + vapor + liquid (from 10^{-12} mbar up to few mbar).
- Interaction of polarized beam in different media
- Versatility and space constraints



VITO Beamline: Final Design



Polarized nuclei and β -NMR

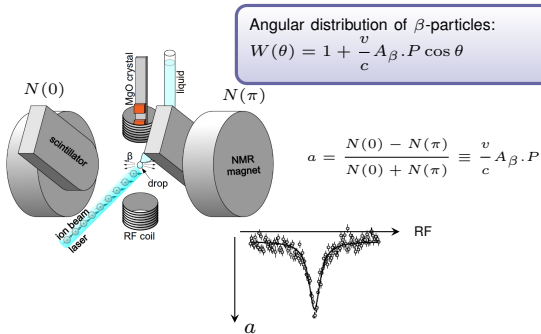


Angular distribution of β -particles:

$$W(\theta) = 1 + \frac{v}{c} A_{\beta} \cdot P \cos \theta$$

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

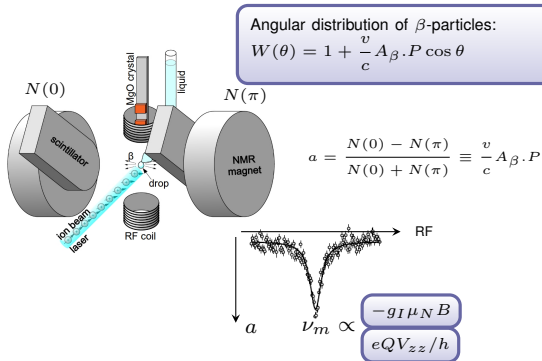
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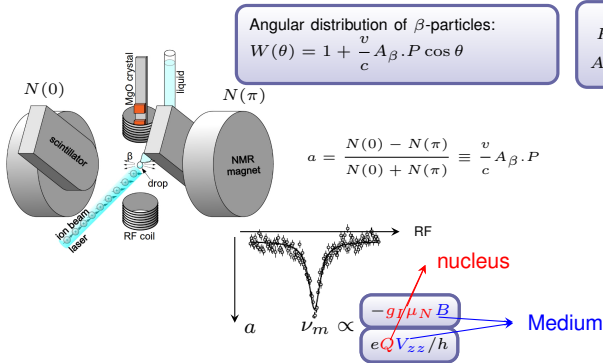
Polarized nuclei and β -NMR



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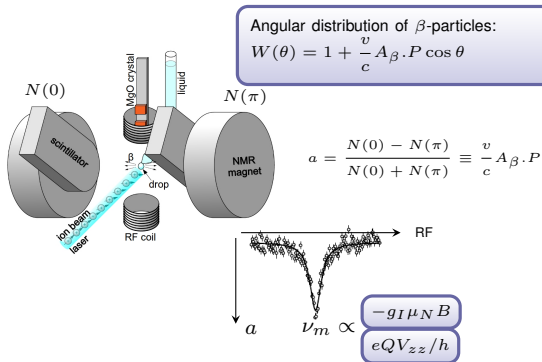
Polarized nuclei and β -NMR



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Polarized nuclei and β -NMR

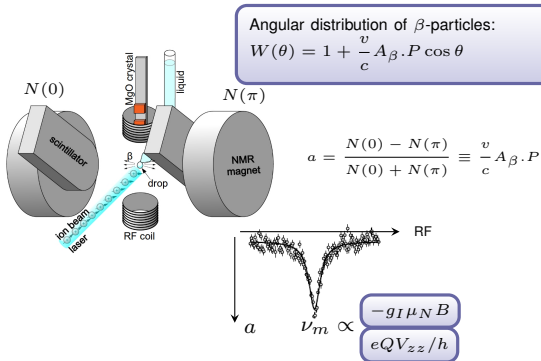


If V_{zz} and B are known:

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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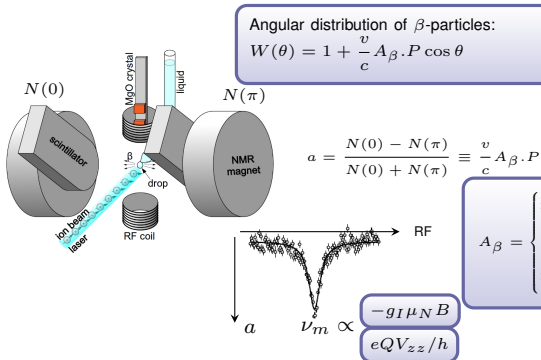
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If Q and μ_N are known:

Solid State, Biophysics (B , V_{zz})

- Magnetic probe: Surface magnetism, superconductivity,...
- Chemical shifts, line broadening, Chemical bonding,...

Polarized nuclei and β -NMR



$$P = \frac{I_z}{I} \rightarrow \text{Nuclear polarization}$$

$$A_\beta \rightarrow \beta\text{-asymmetry}$$

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

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

Measuring A_β :

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

If V_{zz} and B are known:

Nuclear structure (Q, μ_N)

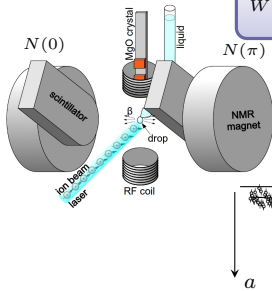
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Polarized nuclei and β -NMR



Angular distribution of β -particles:

$$W(\theta) = 1 + \frac{v}{c} A_{\beta} \cdot P \cos \theta$$

$$P = \frac{I_z}{I} \rightarrow \text{Nuclear polarization}$$

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

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

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

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

Measuring A_{β} :

Spin assignment (I)

By measuring the β -delay particles

Fundamental physics (ρ)

V_{ud} of the Kobayashi-Maskawa (CKM) quark mixing matrix

$$V_{ud}^2 \propto \left(1 + \frac{f_A}{f_V} \rho^2\right)^{-1}$$

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 $\langle r^2 \rangle$

If Q and μ_N are known:

Solid State, Biophysics (B, V_{zz})

- Magnetic probe: Surface magnetism, superconductivity,...
- Chemical shifts, line broadening, Chemical bonding,...

Bio β -NMR: Motivation



1A																	2A									
1 H 1.00794																	2 He 4.002602									
3 Li 6.941	4 Be 9.012182											5 B 10.811	6 C 12.0107	7 N 14.00643	8 O 15.999	9 F 18.998403	10 Ne 20.1797									
11 Na 22.989769	12 Mg 24.304											13 Al 26.981538	14 Si 28.08558	15 P 30.973762	16 S 32.06	17 Cl 35.453	18 Ar 39.948									
19 K 39.0983	20 Ca 40.078	21 Sc 44.955912	22 Ti 47.88	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938045	26 Fe 55.845	27 Co 58.933195	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.630	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.798									
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90584	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc 98	44 Ru 101.07	45 Rh 101.07	46 Pd 106.90558	47 Ag 107.8682	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.757	52 Te 127.6	53 I 126.90547	54 Xe 131.29									
55 Cs 132.9054519	56 Ba 137.327	Lanthanides										57 La 138.90547	58 Ce 140.12	59 Pr 140.90766	60 Nd 144.242	61 Pm [145]	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92513	66 Dy 162.50052	67 Ho 164.93033	68 Er 167.259	69 Tm 168.93421	70 Yb 173.054	71 Lu 174.967
		Actinides										89 Ac [227]	90 Th [232]	91 Pa [231]	92 U [238]	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]	103 Lr [262]

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



1A																	2											8A
1																	2											He
3																	10											18
Li	Be															B	C	N	O	F	Ne							
3A	4A	5A	6A	7A													8A											
Na	Mg															Al	Si	P	S	Cl	Ar							
19	20															31	32	33	34	35	36							
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr											
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54											
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe											
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72											
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn											
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118											
Fr	Ra																	115	116	117	118							
119	120																	129	130	131	132							
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																		173	174	175	176							
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																		217	218	219	220							
																		237	238	239	240							
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																		281	282	283	284							
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																		865	866	867	868							
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																		997	998	999	1000							
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																		4603	4604	4605	4606							
																		4625	4626	4627	4628							
																		4647	4648	4649	4650							
																		4669	4670	4671	4672							
																		4691	4692	4693	4694							
																		4713	4714	4715	4716							
																		4735	4736	4737	4738							
																		4757	4758	4759	4760							
																		4789	4790	4791	4792							
																		4811	4812	4813	4814							
																		4833	4834	4835	4836							
																		4855	4856	4857	4858							
																		4877	4878	4879	4880							
																		4899	4900	4901	4902							
																		4921	4922	4923	4924							
																		4943	4944	4945	4946							
																		4965	4966	4967	4968							
																		4987	4988	4989	4990							
																		5009	5010	5011	5012							
																		5031	5032	5033	5034							
																		5053	5054	5055	5056							
																		5075	5076	5077	5078							
																		5097	5098	5099	5100							
																		5119	5120	5121	5122							
																		5141	5142	5143	5144							
																		5163	5164	5165	5166							
																		5185	5186	5187	5188							
																		5207	5208	5209	5210							
																		5229	5230	5231	5232							
																		5251	5252	5253	5254							
																		5273	5274	5275	5276							
																		5295	5296	5297	5298							
																		5317	5318	5319	5320							
																		5339	5340	5341	5342							

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
- Ion accessible in established techniques

Bio β -NMR: Motivation



1A	2A											3A	4A	5A	6A	7A	8A																							
1 H (1.0079)	2 He (4.0026)											13 B (10.811)	14 C (12.011)	15 N (14.007)	16 O (15.999)	17 F (18.998)	18 Ne (20.180)																							
3 Li (6.941)	4 Be (9.0122)											19 K (39.098)	20 Ca (40.078)				31 Ga (72.64)	32 Ge (72.64)	33 As (74.922)	34 Se (78.96)	35 Br (79.904)	36 Kr (83.80)																		
Mg ²⁺	5 Na (22.990)											Cu ⁺ Zn ²⁺	21 Sc (44.956)	22 Ti (47.88)	23 V (50.942)	24 Cr (51.996)	25 Mn (54.938)	26 Fe (55.845)	27 Co (58.933)	28 Ni (58.693)	29 Cu (63.546)	30 Zn (65.38)	37 Rb (85.468)	38 Sr (87.62)	39 Y (88.906)	40 Zr (91.224)	41 Nb (92.906)	42 Mo (95.94)	43 Tc (98)	44 Ru (101.07)	45 Rh (101.07)	46 Pd (106.32)	47 Ag (107.87)	48 Cd (112.41)	49 In (114.82)	50 Sn (118.710)	51 Sb (121.76)	52 Te (127.6)	53 I (126.905)	54 Xe (131.29)
	6 Mg (24.305)	11 Na (22.990)	12 Mg (24.305)	17 Cl (35.45)	18 Ar (39.948)	23 V (50.942)	24 Cr (51.996)	25 Mn (54.938)	26 Fe (55.845)	27 Co (58.933)	28 Ni (58.693)		29 Cu (63.546)	30 Zn (65.38)	37 Rb (85.468)	38 Sr (87.62)	39 Y (88.906)	40 Zr (91.224)	41 Nb (92.906)	42 Mo (95.94)	43 Tc (98)	44 Ru (101.07)	45 Rh (101.07)	46 Pd (106.32)	47 Ag (107.87)	48 Cd (112.41)	49 In (114.82)	50 Sn (118.710)	51 Sb (121.76)	52 Te (127.6)	53 I (126.905)	54 Xe (131.29)								
7 Cs (132.91)	8 Ba (137.33)	9-10 La-Lu		19 K (39.098)	20 Ca (40.078)	21 Sc (44.956)	22 Ti (47.88)	23 V (50.942)	24 Cr (51.996)	25 Mn (54.938)	26 Fe (55.845)		27 Co (58.933)	28 Ni (58.693)	29 Cu (63.546)	30 Zn (65.38)	37 Rb (85.468)	38 Sr (87.62)	39 Y (88.906)	40 Zr (91.224)	41 Nb (92.906)	42 Mo (95.94)	43 Tc (98)	44 Ru (101.07)	45 Rh (101.07)	46 Pd (106.32)	47 Ag (107.87)	48 Cd (112.41)	49 In (114.82)	50 Sn (118.710)	51 Sb (121.76)	52 Te (127.6)	53 I (126.905)	54 Xe (131.29)						
11 Na (22.990)	12 Mg (24.305)	9-10 La-Lu		19 K (39.098)	20 Ca (40.078)	21 Sc (44.956)	22 Ti (47.88)	23 V (50.942)	24 Cr (51.996)	25 Mn (54.938)	26 Fe (55.845)	27 Co (58.933)	28 Ni (58.693)	29 Cu (63.546)	30 Zn (65.38)	37 Rb (85.468)	38 Sr (87.62)	39 Y (88.906)	40 Zr (91.224)	41 Nb (92.906)	42 Mo (95.94)	43 Tc (98)	44 Ru (101.07)	45 Rh (101.07)	46 Pd (106.32)	47 Ag (107.87)	48 Cd (112.41)	49 In (114.82)	50 Sn (118.710)	51 Sb (121.76)	52 Te (127.6)	53 I (126.905)	54 Xe (131.29)							
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27 Rb (85.468)	28 Sr (87.62)	9-10 La-Lu		37 Rb (85.468)	38 Sr (87.62)	39 Y (88.906)	40 Zr (91.224)	41 Nb (92.906)	42 Mo (95.94)	43 Tc (98)	44 Ru (101.07)	45 Rh (101.07)	46 Pd (106.32)	47 Ag (107.87)	48 Cd (112.41)	49 In (114.82)	50 Sn (118.710)	51 Sb (121.76)	52 Te (127.6)	53 I (126.905)	54 Xe (131.29)																			
37 Cs (132.91)	38 Ba (137.33)	9-10 La-Lu		47 Fr (223)	48 Ra (226)	9-10 La-Lu		55 Mn (54.938)	56 Fe (55.845)	57 Co (58.933)	58 Ni (58.693)	59 Cu (63.546)	60 Zn (65.38)	61 Ga (72.64)	62 Ge (72.64)	63 As (74.922)	64 Se (78.96)	65 Br (79.904)	66 Kr (83.80)																					
55 Cs (132.91)	56 Ba (137.33)	9-10 La-Lu		65 Mn (54.938)	66 Fe (55.845)	67 Co (58.933)	68 Ni (58.693)	69 Cu (63.546)	70 Zn (65.38)	71 Ga (72.64)	72 Ge (72.64)	73 As (74.922)	74 Se (78.96)	75 Br (79.904)	76 Kr (83.80)																									
87 Fr (223)	88 Ra (226)	9-10 La-Lu		95 Am (243)	96 Cm (247)	9-10 La-Lu		103 Nh (288)	104 Ds (271)	105 Rg (272)	106 Cn (285)	107 Uut (288)	108 Uuq (291)	109 Uup (293)	110 Uuh (294)	111 Uus (295)	112 Uuo (296)																							
Lanthanides																		57 La (138.905)	58 Ce (140.12)	59 Pr (140.908)	60 Nd (144.24)	61 Pm (145)	62 Sm (150.36)	63 Eu (151.964)	64 Gd (157.25)	65 Tb (158.925)	66 Dy (162.50)	67 Ho (164.930)	68 Er (167.259)	69 Tm (168.933)	70 Yb (173.054)	71 Lu (174.967)								
Actinides																		89 Ac (227)	90 Th (232.038)	91 Pa (231.036)	92 U (238.029)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)								

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Mg^{2+} , Cu^{+} and Zn^{2+}

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Bio β -NMR: Motivation



1A (H)	2A																	3A B	4A C	5A N	6A O	7A F	8A Ne
3 Li	4 Be																	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
11 Na	Mg²⁺																	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
19 K	20 Ca	39 Sc	40 Ti	41 V	42 Cr	43 Mn	44 Fe	45 Co	46 Ni	47 Cu	48 Zn	49 Ga	50 Ge	51 As	52 Se	53 Br	54 Kr						
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe						
55 Cs	56 Ba	57-71 Lanthanides	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn						
87 Fr	88 Ra	89-103 Actinides	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og						
Lanthanides			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu						
Actinides			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr						

Property	NMR
# molecules	10^{18}
Nuclear polarization	External field ($\ll 1\%$)
Isotopes	Mostly stable
Detection	Magnetic response

Property

molecules

Nuclear polarization

Isotopes

Detection

NMR

10^{18}

External field
($\ll 1\%$)

Mostly stable
Magnetic response

β -NMR

10^5

Optical pumping, tilted foils, etc
up to 100%
Radioactive
 β asymmetry

Human body:

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Mg²⁺, Cu⁺ and Zn²⁺

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Bio β -NMR: Motivation



1A H 1.008	2A He 4.003	3A B 10.81	4A C 12.01	5A N 14.01	6A O 16.00	7A F 18.99	8A Ne 20.18
Li 6.94	Be 9.01	B 10.81	C 12.01	N 14.01	O 16.00	F 18.99	Ne 20.18
Na 22.99	Mg 24.31	Al 26.98	Si 28.09	P 30.97	S 32.07	Cl 35.45	Ar 39.95
K 39.10	Ca 40.08	Sc 44.96	Ti 47.88	V 50.94	Cr 52.00	Mn 54.94	Fe 55.85
Rb 85.47	Sr 87.62	Y 88.91	Zr 91.22	Nb 92.91	Mo 95.94	Tc 98.91	Ru 101.07
Cs 132.91	Ba 137.33	La 138.91	Hf 178.49	Ta 180.95	W 183.84	Re 186.21	Os 190.23
Fr 223.02	Ra 226.03	Ac 227.03	Rf 261.10	Db 262.10	Sg 266.10	Bh 264.10	Hs 277.10

Mg²⁺
Cu⁺ Zn²⁺

Property

molecules

Nuclear polarization

Isotopes

Detection

NMR

10^{18}

External field
($\ll 1\%$)

Mostly stable

Magnetic response

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10^5

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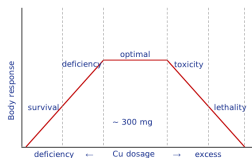
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3A Li 6.941	4A Be 9.012	5A B 10.811	6A C 12.011	7A N 14.007	8A O 15.999	9A F 18.998	10A Ne 20.180																								
11A Na 22.990	12A Mg 24.305	13A Al 26.982	14A Si 28.086	15A P 30.974	16A S 32.06	17A Cl 35.45	18A Ar 39.948																								
19A K 39.098	20A Ca 40.078	21A Sc 44.956	22A Ti 47.88	23A V 50.942	24A Cr 51.996	25A Mn 54.938	26A Fe 55.845	27A Co 58.933	28A Ni 58.693	29A Cu 63.546	30A Zn 65.38	31A Ga 69.723	32A Ge 72.63	33A As 74.922	34A Se 78.96	35A Br 79.904	36A Kr 83.80														
37A Rb 85.468	38A Sr 87.62	39A Y 88.906	40A Zr 91.224	41A Nb 92.906	42A Mo 95.94	43A Tc 98.906	44A Ru 101.07	45A Rh 102.91	46A Pd 106.42	47A Ag 107.87	48A Cd 112.41	49A In 114.82	50A Sn 118.71	51A Sb 121.76	52A Te 127.6	53A I 126.91	54A Xe 131.29														
55A Cs 132.91	56A Ba 137.33	57A La 138.91	58A Ce 140.12	59A Pr 140.91	60A Nd 144.24	61A Pm 144.91	62A Sm 150.36	63A Eu 151.96	64A Gd 157.25	65A Tb 158.93	66A Dy 162.50	67A Ho 164.93	68A Er 167.26	69A Tm 168.93	70A Yb 173.05	71A Lu 174.97	72A Hf 178.49	73A Ta 180.95	74A W 183.84	75A Re 186.21	76A Os 190.23	77A Ir 192.22	78A Pt 195.08	79A Au 196.97	80A Hg 200.59	81A Tl 204.38	82A Pb 207.2	83A Bi 208.98	84A Po 209	85A At 210	86A Rn 222
87A Fr 223	88A Ra 226	89A Ac 227	90A Th 232.04	91A Pa 231.04	92A U 238.03	93A Np 237.05	94A Pu 244.06	95A Am 243.06	96A Cm 247.07	97A Bk 247.07	98A Cf 251.08	99A Es 252.08	100A Fm 257.10	101A Md 258.10	102A No 259.10	103A Lr 262.10															

Property

molecules

Nuclear polarization

Isotopes

Detection

NMR

10^{18}

External field

($\ll 1\%$)

Mostly stable

Magnetic response

Property

molecules

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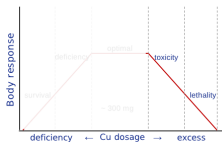
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Alzheimer



Parkinson



Prion



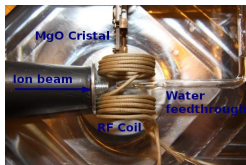
Wilson

[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

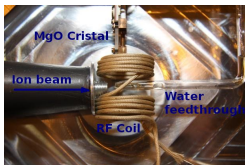
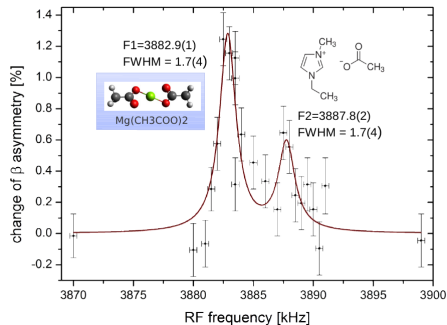
Bio β -NMR: First results



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Bio β -NMR: First results

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

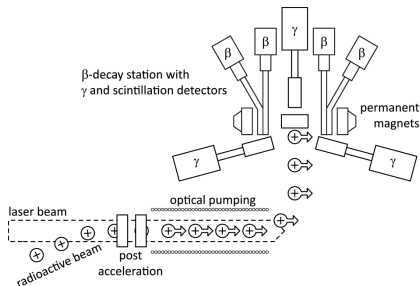


For the first time (August, 2012):

- 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

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

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

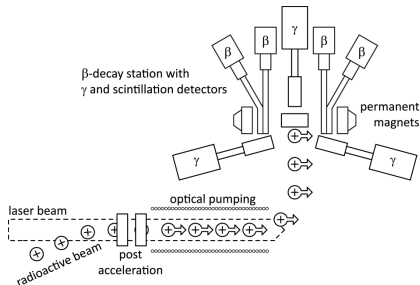
PRC 77 (2008) 034307

PRL 97 (2007) 212501

PRL 94 (2005) 022501

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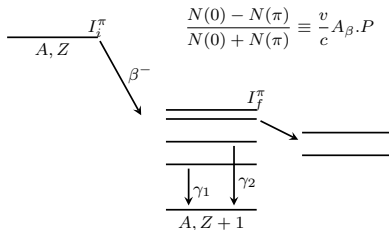
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PLB 197 (1987) 311

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

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



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

A_β takes well separate discrete values
→ Unambiguous spin assignments

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

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1 \quad ? \rightarrow \begin{array}{l} (+) \text{ Search for new physics} \\ (+) \text{ Sensitive test to the standard model} \end{array}$$

Weighted average of the most precise results (Fermi transitions)

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

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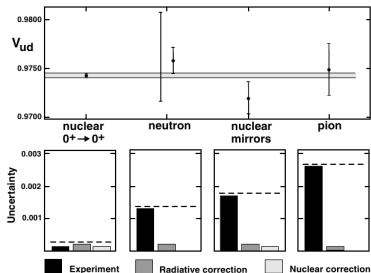
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[Figure from: Towner and Hardy. Rep. Prog. Phys. 73 (2010) 046301]

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For $I_f = I_i \rightarrow$

$$A_\beta = \frac{\pm \rho^2 / (I_i + 1) - 2\rho \sqrt{I_i / (I_i + 1)}}{1 + \rho^2}$$

V_{ud} can be obtained by combining Ft values with Gamow-Teller/Fermi mixing ratios, ρ

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

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

Biophysics:

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

Solid State Physics:

- M. Deicher - University of Saarlandes, Germany
- Z. Salman - PSI, Switzerland
- V. Amaral - University 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

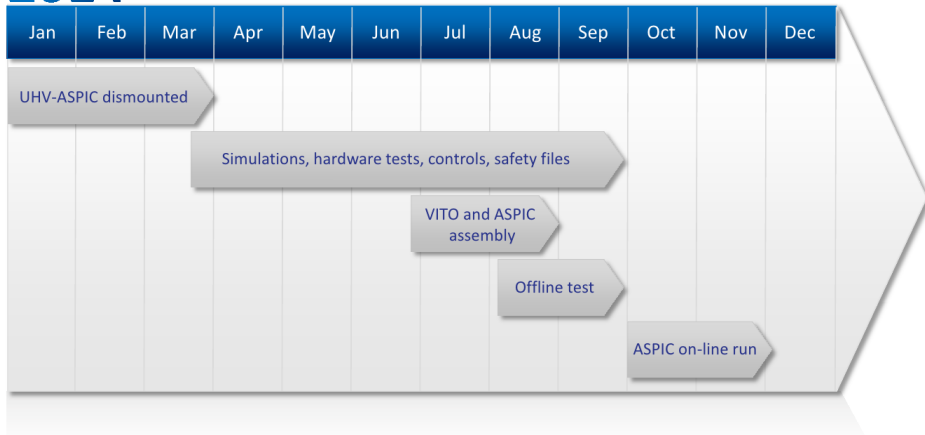
At ISOLDE:

- 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

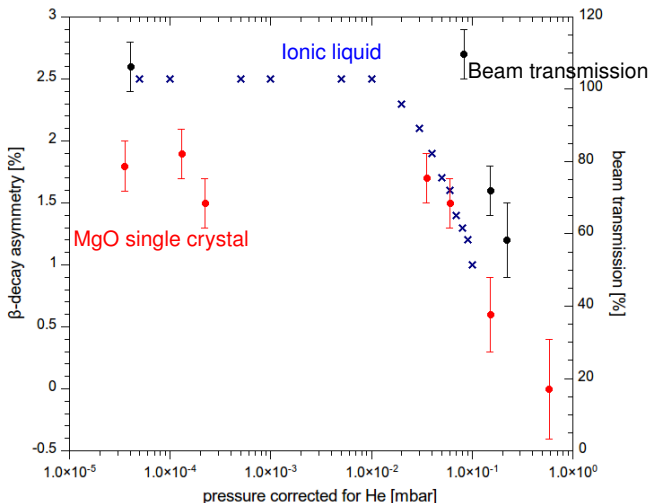
- A unique beam line in Europe → Several experiments can benefit from a dedicated beamline for laser-induced nuclear orientation.
- VITO → Multidisciplinary research
 - Biophysics
 - Solid state
 - Nuclear physics ...
- For the first time β -NMR in a body-like environment
- 51 shifts approved: β -NMR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

Thanks for your attention!

2014

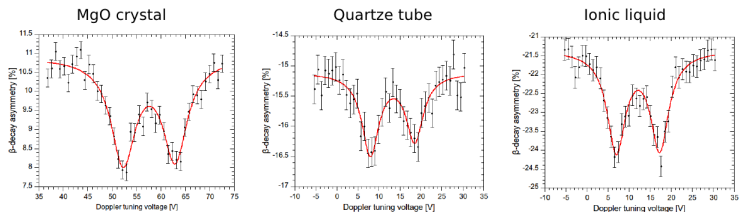


Pressure-dependent β -decay asymmetry

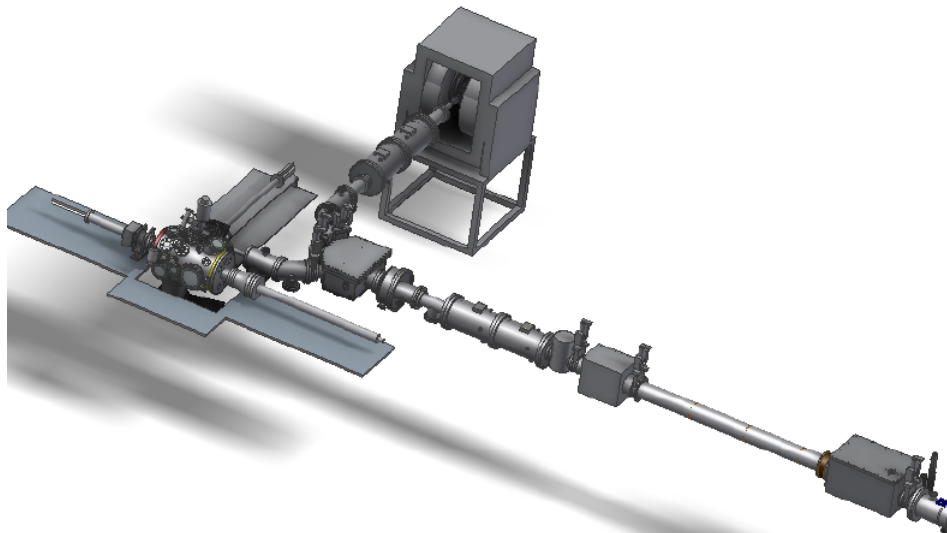


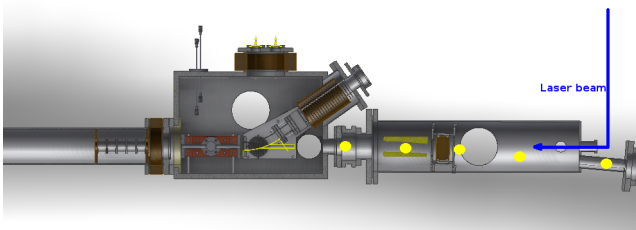
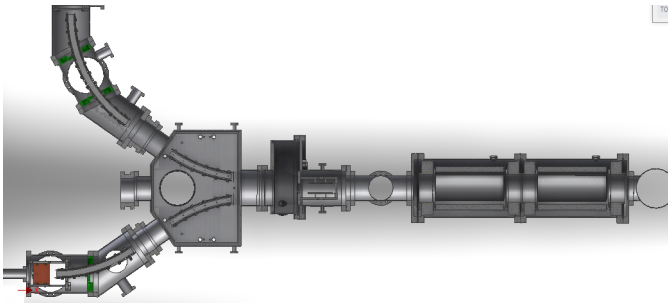
Pressure-dependent β -decay asymmetry

HFS of ^{31}Mg in different materials



	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)





	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]