TRIUMF

β-NMR applications in biology and chemistry

M. Stachura, L. Hemmingsen, W.A. MacFarlane

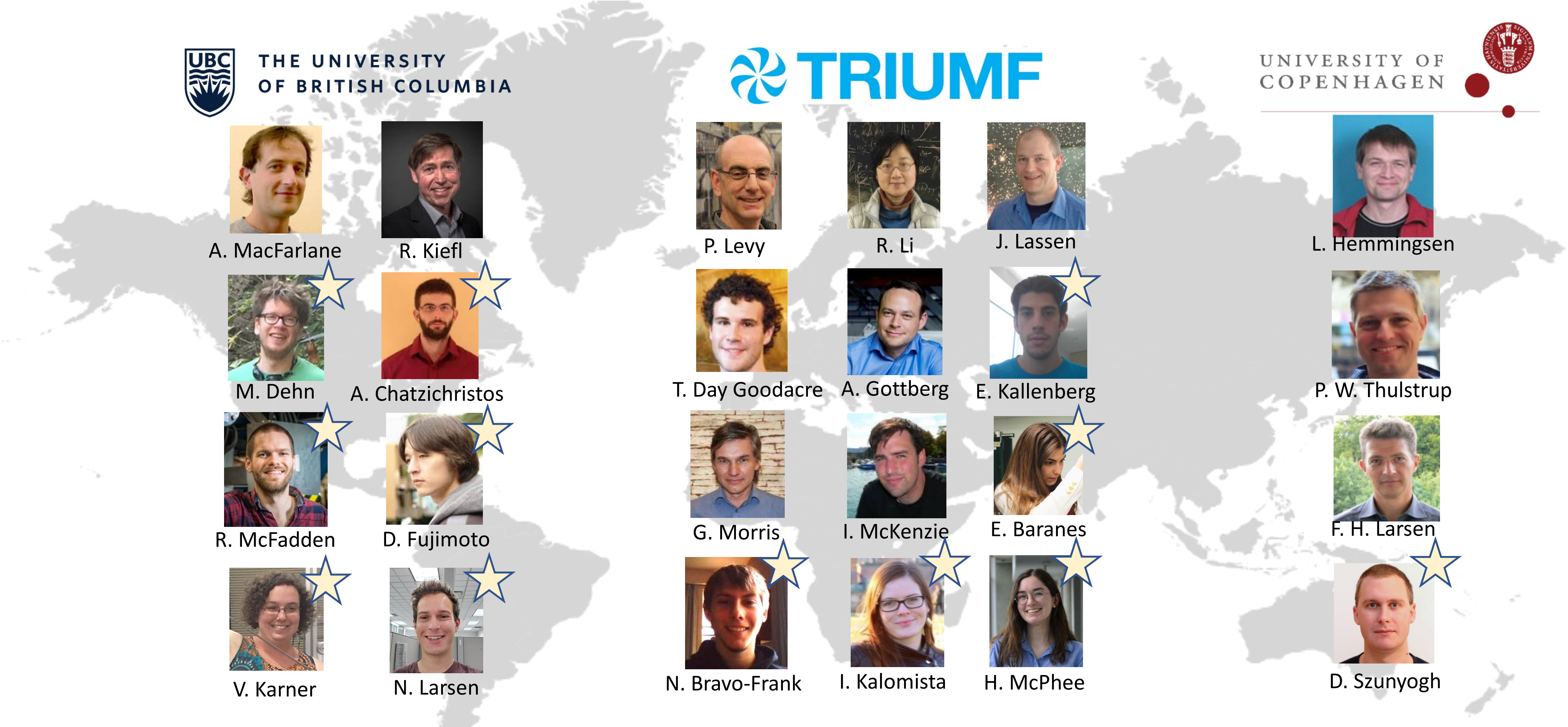
THE UNIVERSITY OF BRITISH COLUMBIA

UNIVERSITY OF COPENHAGEN

2021-06-04

Discovery, accelerated

Collaboration and Acknowledgements



Danish Agency for Science Technology and Innovation
Ministry of Science Technology and Innovation

DET FRIE FORSKNINGSRÅD
DANISH COUNCIL FOR INDEPENDENT RESEARCH

Canada
NRC·CNRC

NSERC CRSNG

NSERC CRSNG IsoSiM

Why β-NMR Spectroscopy?

NMR is powerful BUT has limitations:

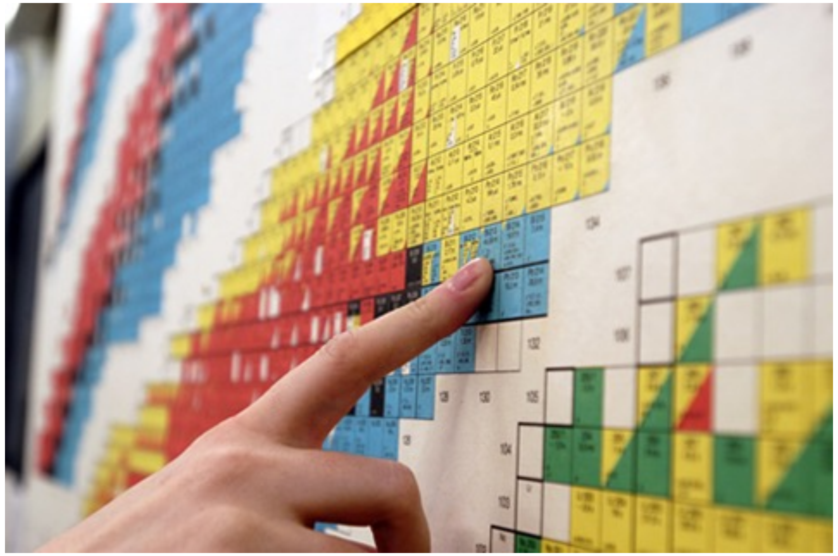
- ✓ Not all elements are accessible (e.g. Mg, Zn - poor or no response)
- ✓ Small degree of magnetization (<< 1%)
- ✓ Requires strong magnets (high B_0 needed, Boltzmann distribution)
- ✓ Intrinsically weak signals (nuclear magnetic moments are small)
- ✓ Solubility is a limiting factor (M concentrations required for biomolecules)

http://www.lakeforest.edu/academics/programs/chemistry/spectroscopy_tables.php

Why β-NMR Spectroscopy?

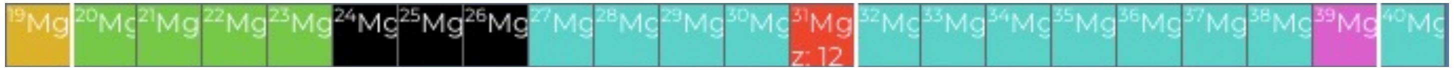
β-NMR is powerful AND sensitive

- ✓ In principle, more than 70 chemical elements accessible
- ✓ High degree of polarization (up to 80%)
- ✓ Doesn't require strong magnets (hyperpolarization with lasers)
- ✓ Very effective detection (radiotracer)

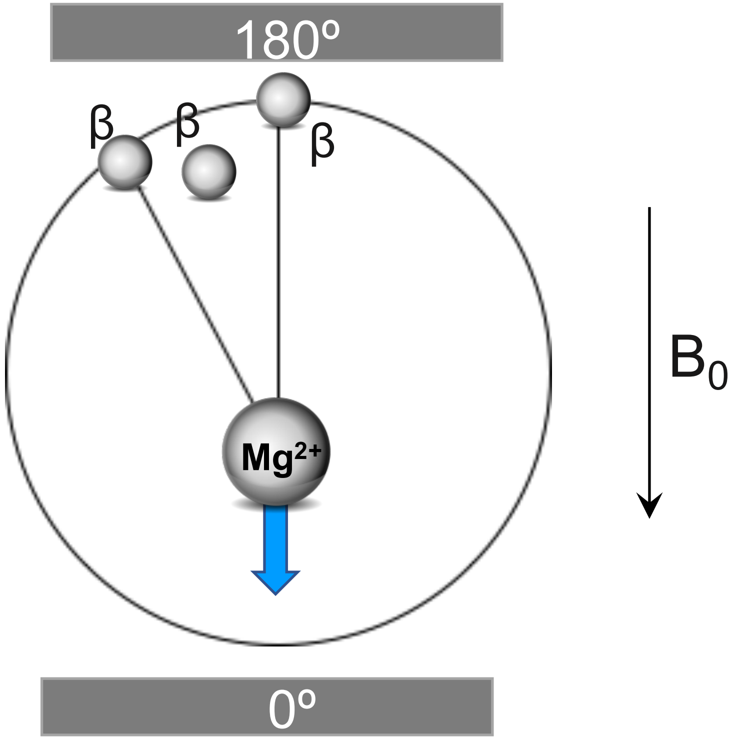


- ✓ Ultrahigh sensitivity (10^7 probes, physiological relevant concentrations achievable)
- ✓ Possible to select oxidation state (e.g. Mg^+ or Mg^{2+})
- ✓ Elements with no stable isotope accessible (e.g. Ac^{3+})
- ✓ Zero-field measurements possible
- ✓ Small sample volumes (2-4 μL)

β-NMR Spectroscopy in a Nutshell



$$^{31}Mg \rightarrow 31Al + e^{-} + \nu_e \ \left(I = \tfrac{1}{2}\right)$$

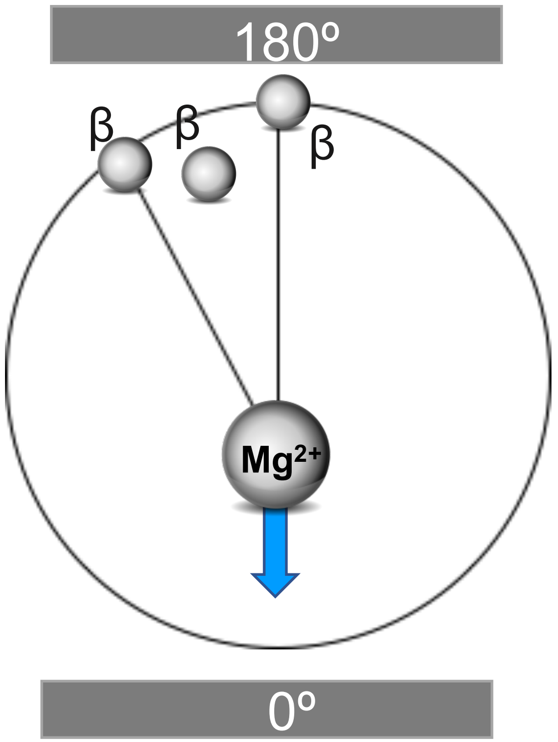


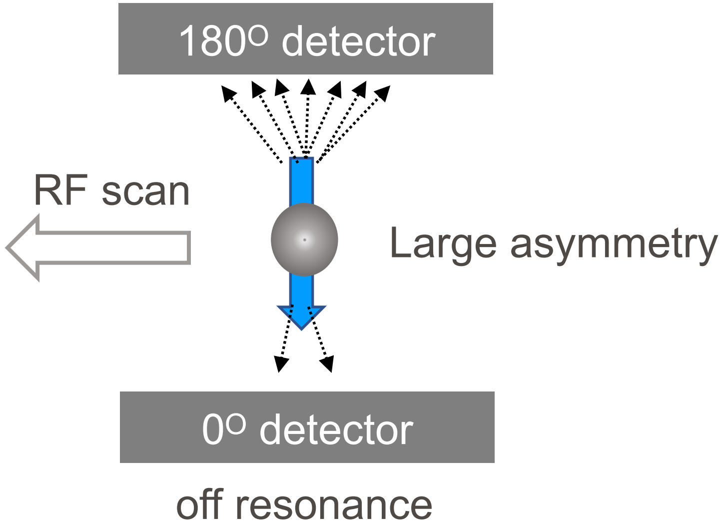
- β (e^{-}) emission correlated with the spin direction of the decaying nucleus
  - Asymmetric nuclear β decay
  - Angular distribution of β radiation

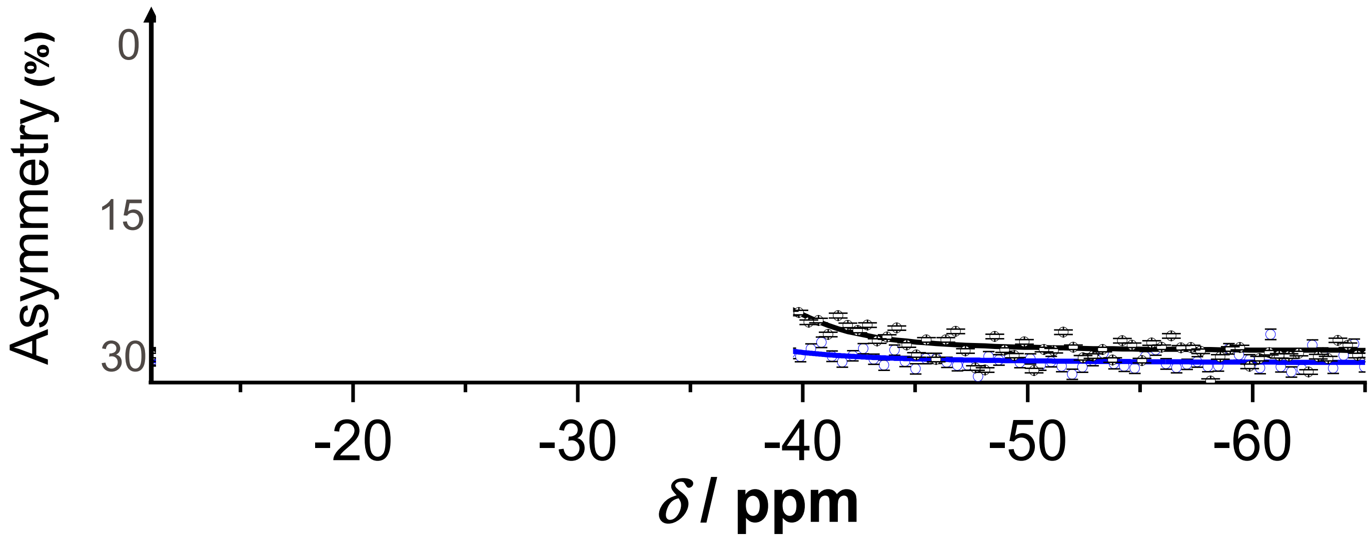
- Asymmetry in β count rate between 180º and 0º detectors:

$$a = \frac{N(0^o) - N(180^o)}{N(0^0) + N(180^o)} \longrightarrow \text{Experimentally measured quantity}$$

β-NMR Spectroscopy in a Nutshell







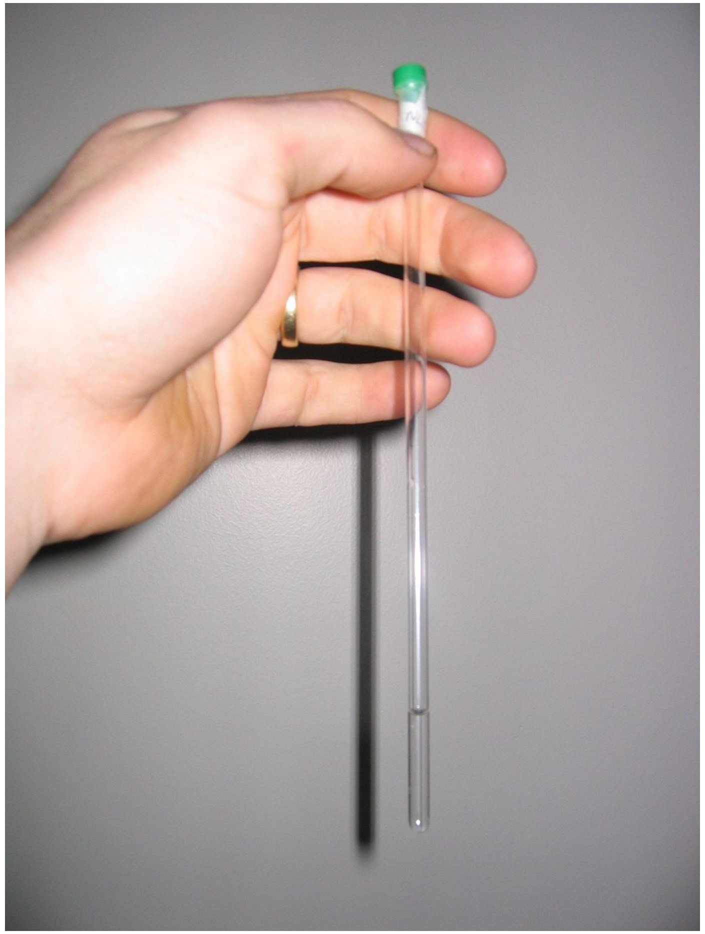
NMR vs β-NMR Spectrometer

Conventional NMR spectrometer

β-NMR spectrometer at TRIUMF

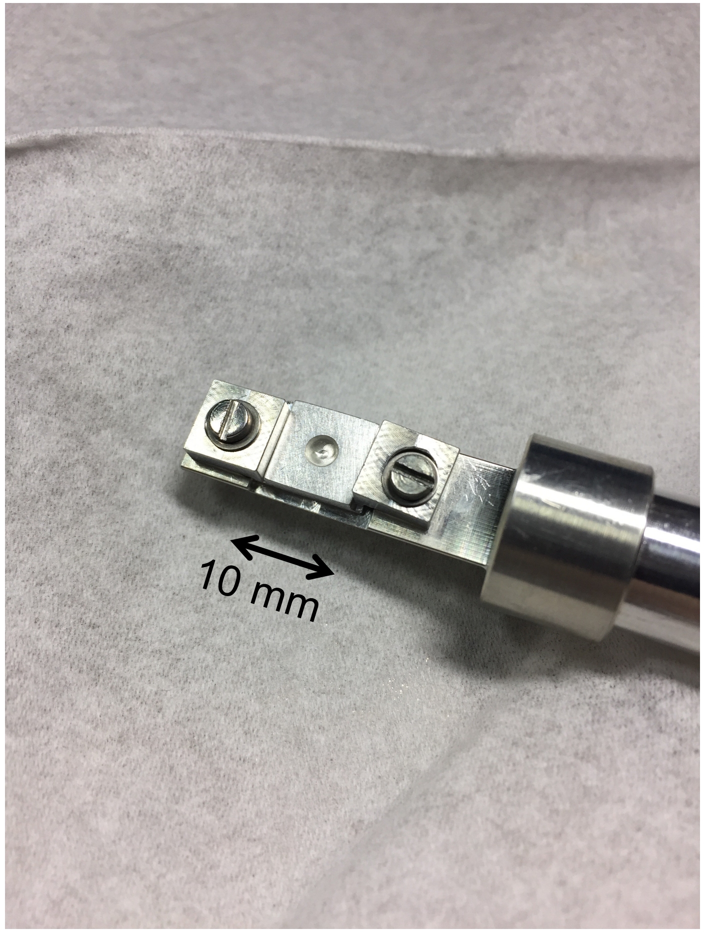
Sample for solution NMR and β-NMR

Conventional NMR spectrometer



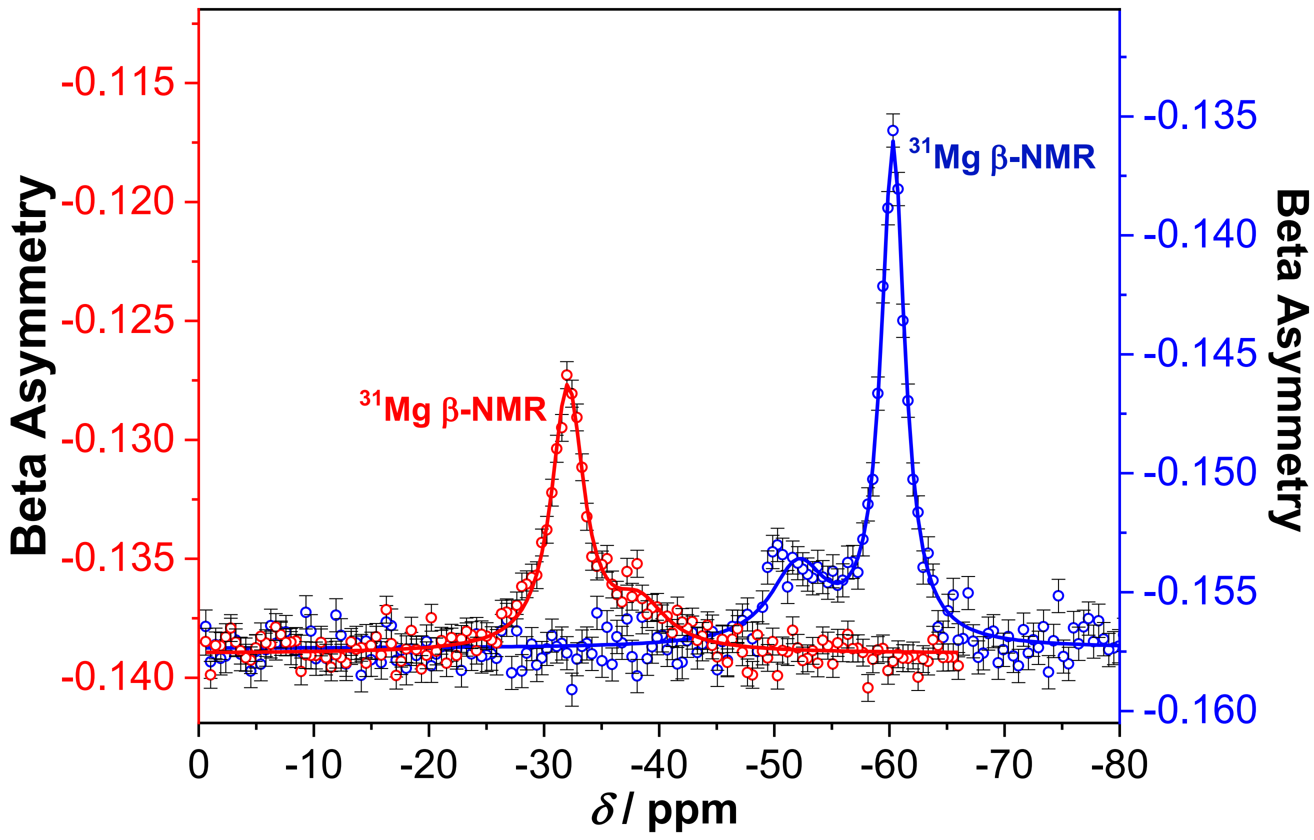
- ✓ Glass tube, plastic cap
- ✓ Typically, M concentrations

β-NMR spectrometer at TRIUMF



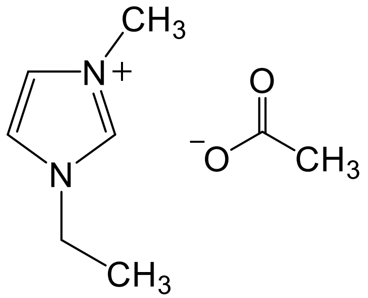
- ✓ Al sample holder
- ✓ Typically, mM concentrations

^{31}Mg β-NMR of $MgCl_2$ in EMIM-Ac and EMIM-DCA



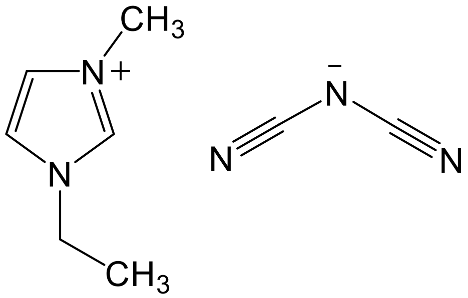
EMIM-Ac

1-ethyl-3-methyl-imidazolium-acetate



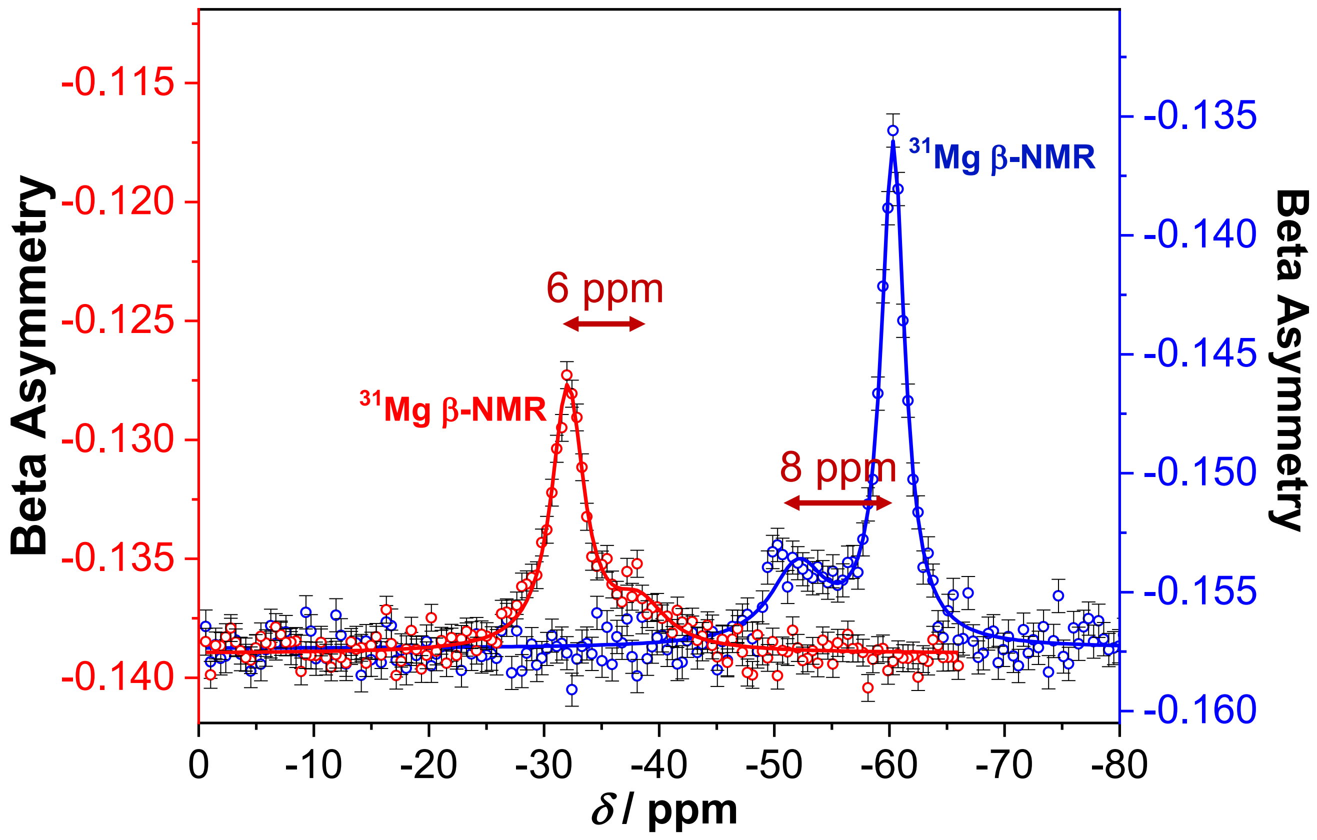
EMIM-DCA

1-ethyl-3-methyl-imidazolium-dicyanamide



D. Szunyogh, *et.al*. Dalton Trans. 2018, **47**, 14431-14435.

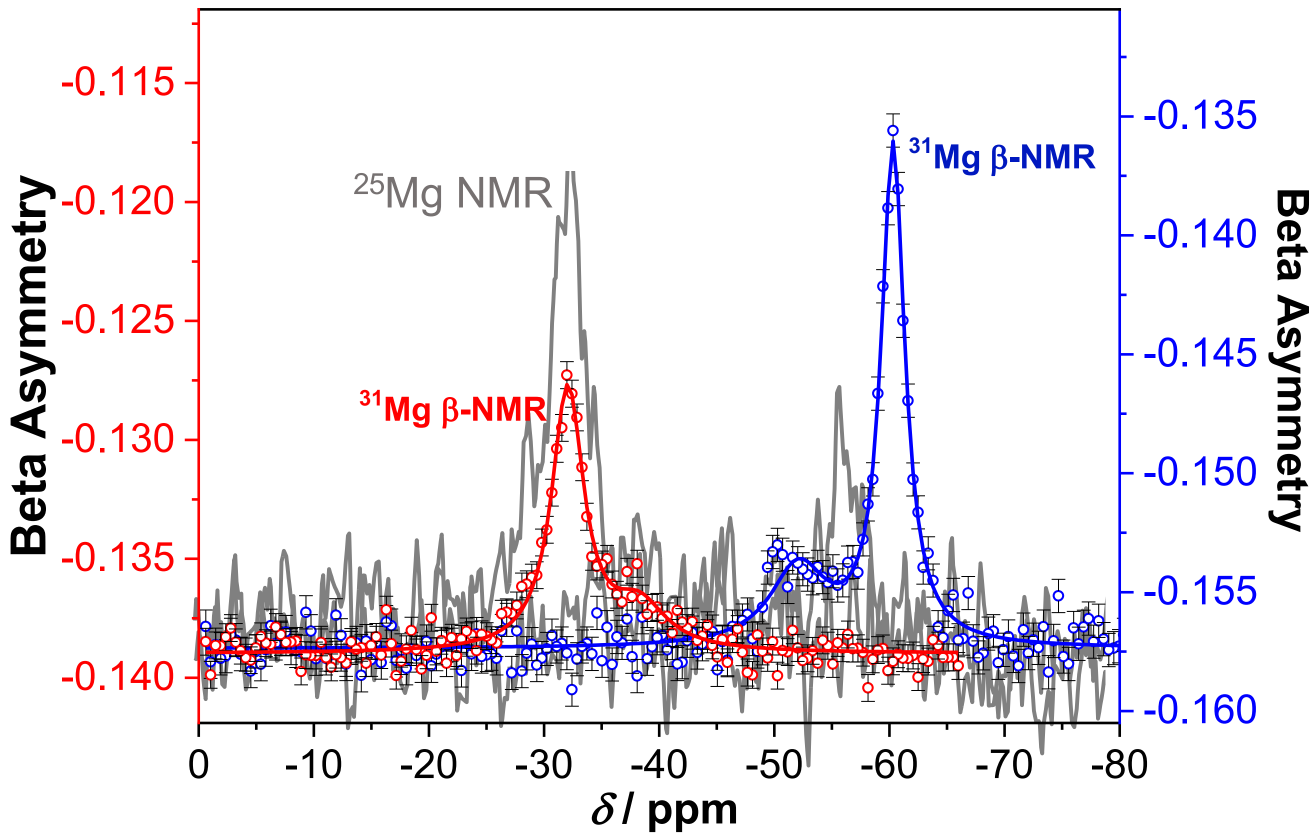
^{31}Mg β-NMR of $MgCl_2$ in EMIM-Ac and EMIM-DCA



Structure	Chemical shift (ppm)
$[Mg(DCA)_6]^{4-}$	-60
$[Mg(DCA)_5(H_2O)]^{3-}$	-52
$[Mg(Ac)_4(H_2O)_2]^{2-}$	-32
$[Mg(Ac)_2(H_2O)_4]$	-38

D. Szunyogh, *et.al*. Dalton Trans. 2018, **47**, 14431-14435.

^{31}Mg β-NMR of $MgCl_2$ in EMIM-Ac and EMIM-DCA



β-NMR	Properties	NMR
^{31}Mg	Isotope	^{25}Mg
1/2	Spin	5/2
3.41	Magnetic Field (T)	11.7
22	Temperature (°C)	72
2-4	Sample volume (uL)	550
20 min	Time of meas.	72 hours

D. Szunyogh, *et.al*. Dalton Trans. 2018, **47**, 14431-14435.

Past, Present, Future…

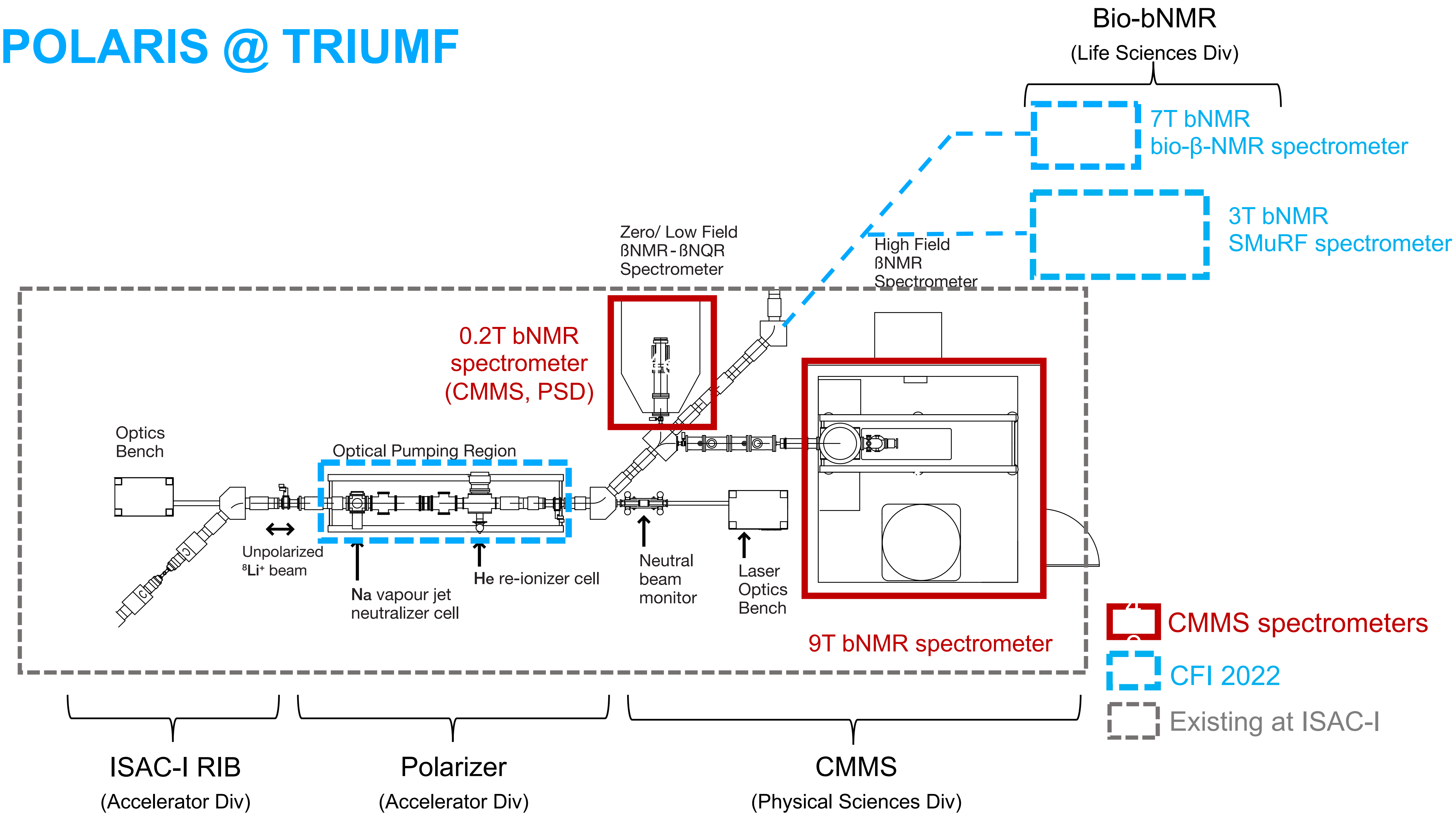
Routine at TRIUMF
- ^{8}Li (I=2, condensed matter)
- ^{31}Mg (I=1/2, chemistry, biology)
- ^{29}Mg (I=3/2, nuclear physics)

December 2019
September 2021
- ^{230}Ac (I=1, chemistry, radiopharmaceutical design)
- ^{232}Ac (I=1, chemistry, radiopharmaceutical design)

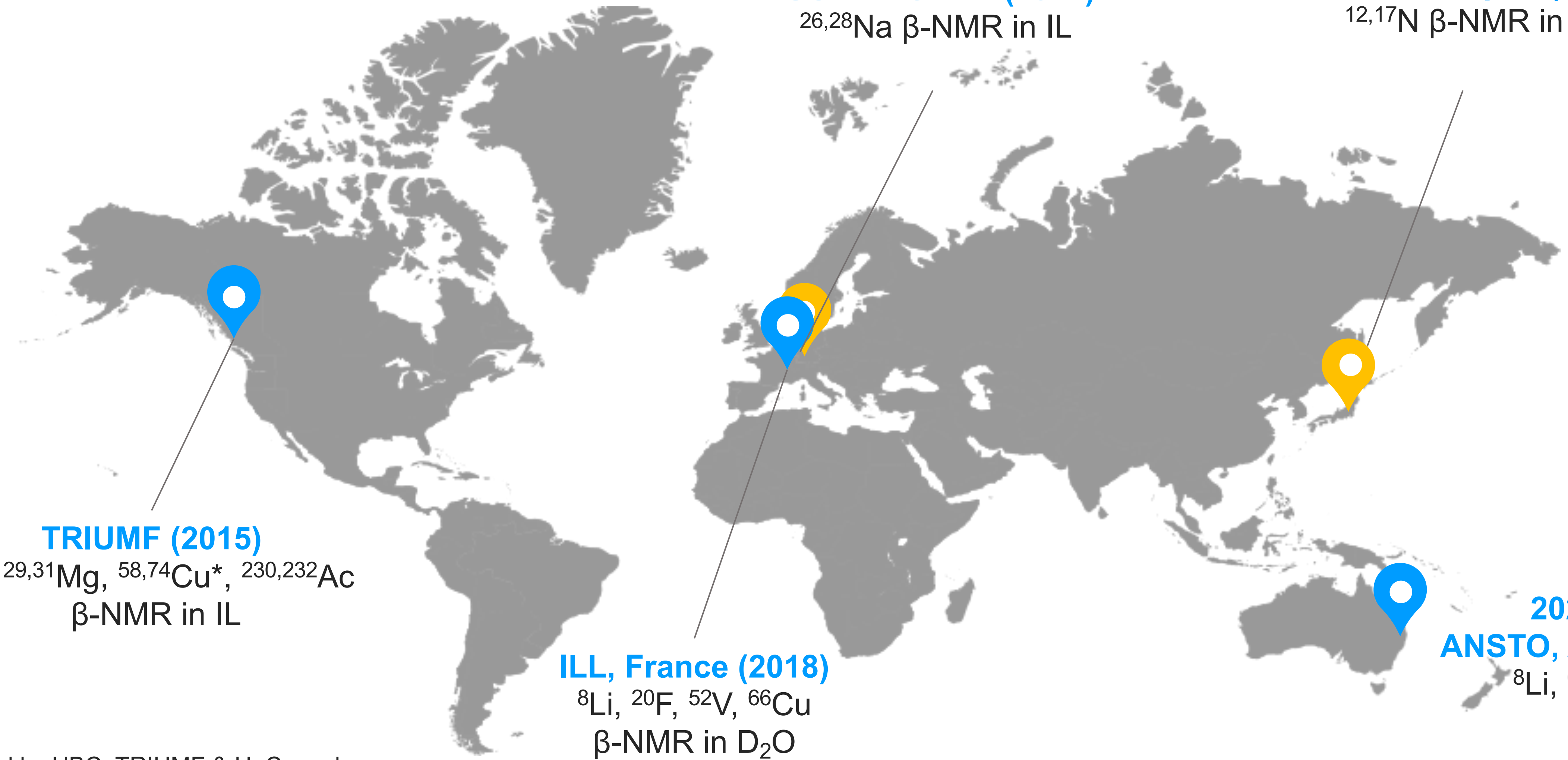
Planned in 2021
- ^{58}Cu (I=1, chemistry, biology, radiopharmaceuticals)
- ^{74}Cu (I=2, chemistry, biology, radiopharmaceuticals)

Next….
- ^{75m}Zn

POLARIS @ TRIUMF



β-NMR in Liquids – Metals for Life



TRIUMF

Thank you
Merci

mstachura@triumf.ca

www.triumf.ca

Follow us **@TRIUMFLab**

TRIUMF

- TRIUMF – Tri University Meson Facility
- Canada’s particle accelerator centre
- Founded in 1968, now 21 member universities

Member Universities:

- University of Alberta
- University of British Columbia
- University of Calgary
- Carlton University
- University of Guelph
- University of Manitoba
- Université de Montréal
- Queen’s University
- University of Regina
- Simon Fraser University
- University of Toronto
- University of Victoria
- York University

Associate Members:

- McGill University
- McMaster University
- University of Northern BC
- Saint Mary’s University
- Université de Sherbrooke
- University of Waterloo
- Western University
- University of Winnipeg

Past…

2016 Dec — TRIUMF
First ^{31}Mg β-NMR in liquids

optimization →

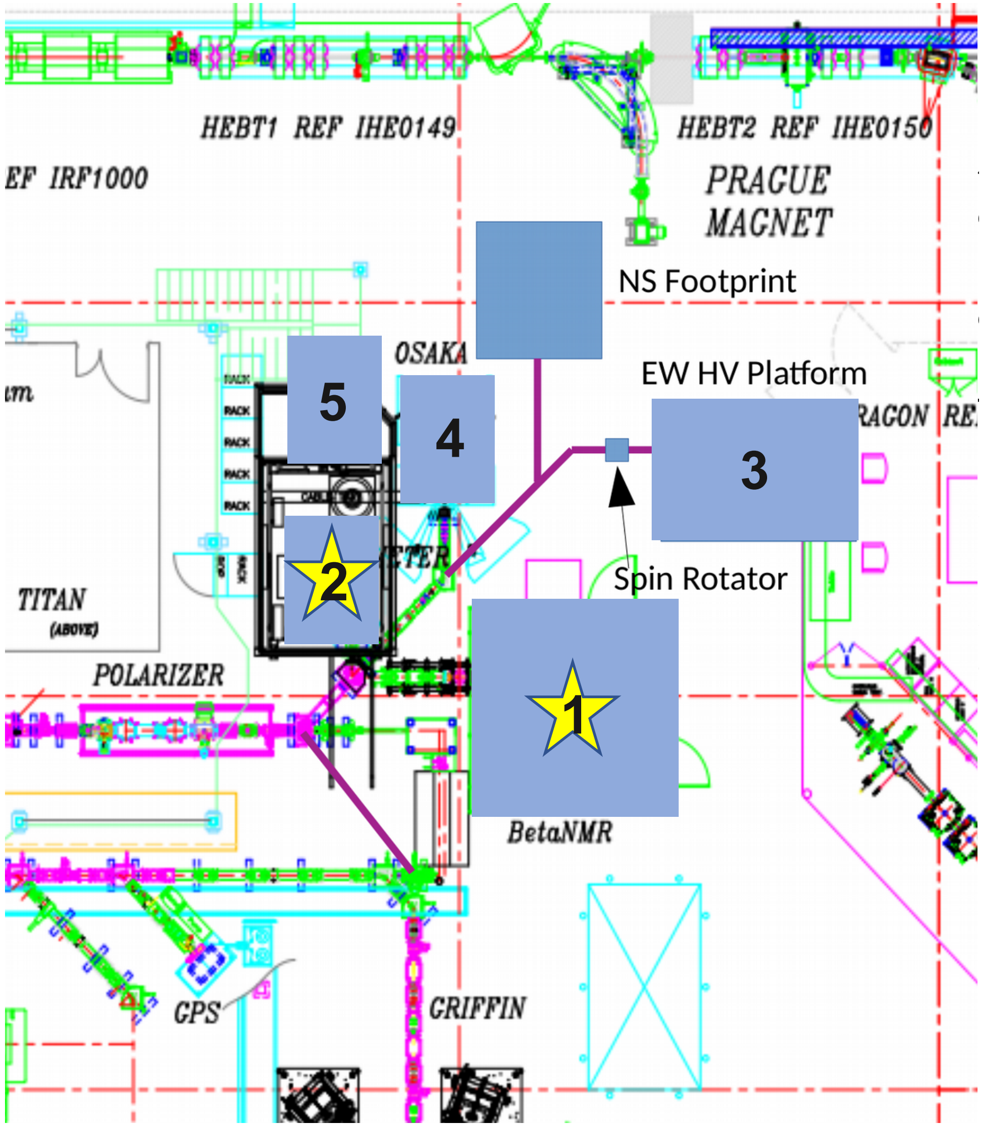
2017 April — TRIUMF
^{31}Mg β-NMR in different ionic liquids

2017 — University of Copenhagen
Conventional ^{25}Mg NMR measurements

2018 April — ILL Neutrons for Science
First ^{8}Li, β-asymmetry measurements in D_2O at atmospheric pressure

2018 July — TRIUMF
β-NMR of ^{31}Mg in Mg-ATP complexes

Future…



1. 9 T, β-NMR spectrometer
   field ⊥ sample surface
2. 300 G, β-NQR spectrometer
   field || sample surface
3. 1 T, β-NMR spectrometer
   field ⊥ sample surface or 0.3 T field || sample surface
4. 10 T, β-NMR spectrometer for biological applications, field ⊥ sample surface
5. 0.3 T, β-NMR spectrometer for Nb research, field || sample surface