Polarisation of longer-lived isotopes and Zero to Ultra low Field Radiation Detected NMR

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On behalf of RD-ZULF NMR team

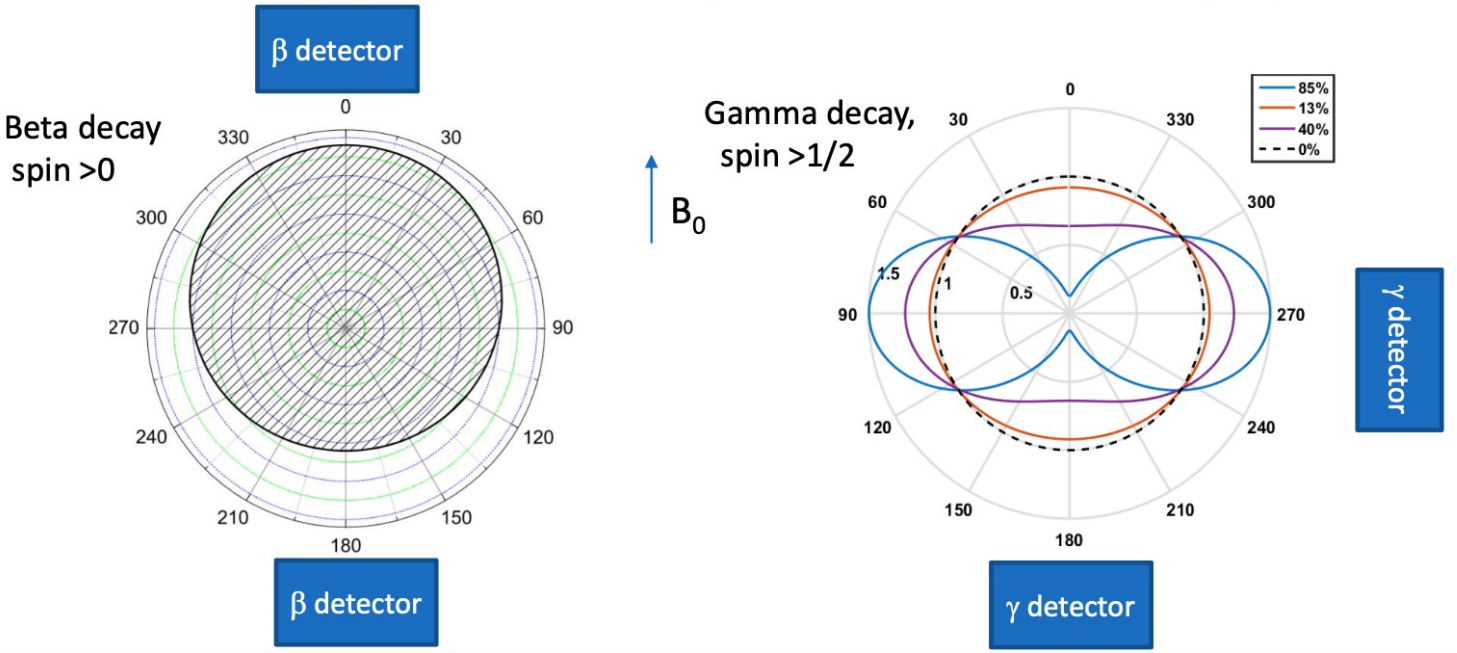
Outline

- Motivation
- Radiation detected (RD) NMR
- Zero to ultra low field (ZULF) NMR
- Polarisation methods
- RD-ZULF NMR setup
- Current status and plans

Motivation

- Development of new NMR technique
- Compact, relatively cheap setup
- Use of β-NMR without dedicated beam-line
- Study of chemistry and biology samples

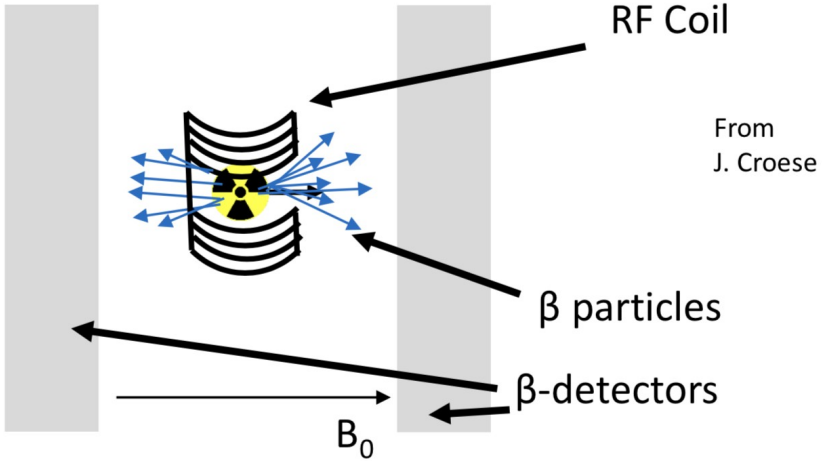
RD NMR



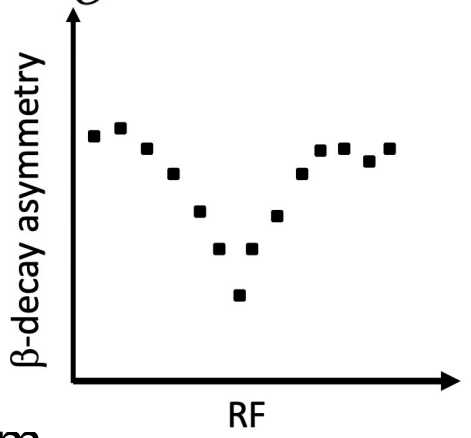
- Related talks and posters:
- Decay spectroscopy with polarised nuclei – M. Piersa-Silkowska, talk 30 , I. Michelon, poster 23
- Gamma MRI - M. Chojnacki, poster 67
- Hyperfine anomaly – M. Bissell, talk 59
- Magnetic moments – M. Jankowski, poster 62
- Solid state batteries measurements – A. Sparks, poster 44
- Hardware developments – RF line D. Havranek, poster 89, new β-detector D. Paulitsch, poster 40, upgrade of beam-line for decay spectroscopy N. Azaryan, poster 56

RD NMR

- Use of anisotropic β-decay or γ-decay
- Spin >1/2 for β-decay or spin >1 for γ-decay
- RF-excitation to “destroy” the asymmetry
- Example: Measure β-decay asymmetry



$$W(\theta) = 1 + a\frac{v}{c} P_I \cos\theta$$



- Needs initial polarisation above thermal equilibrium
- Enhanced sensitivity wrt conventional NMR >10^6

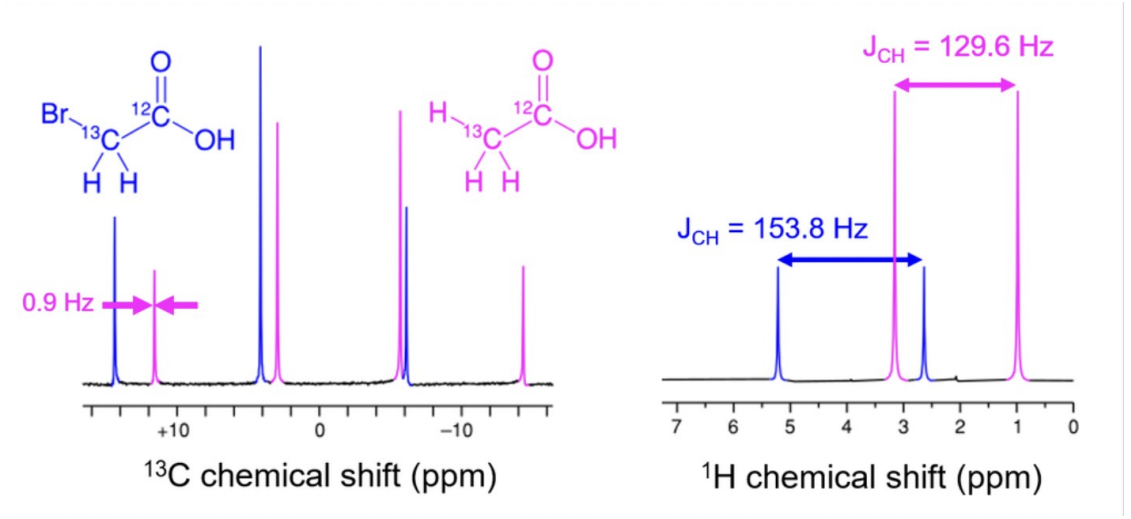
ZULF NMR

1.5 T

- Conventional NMR:

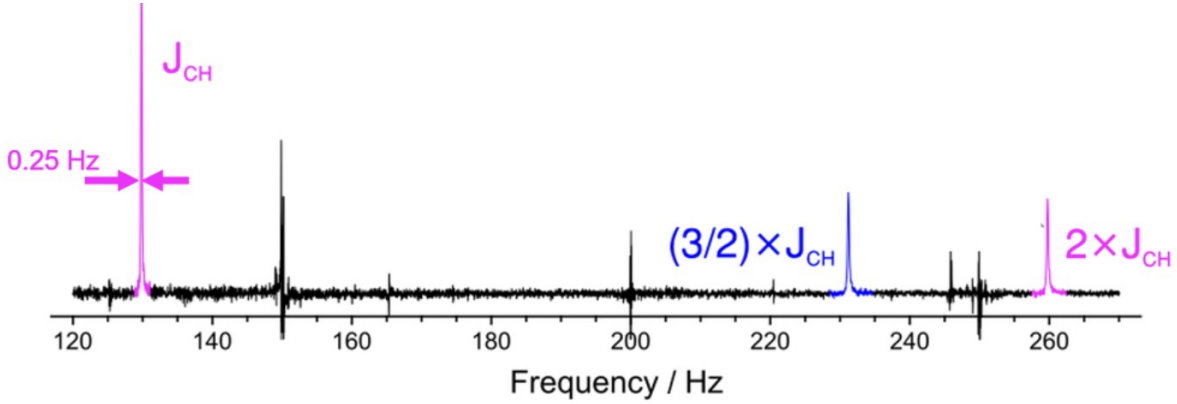
  polarisation of nuclei by external field

  $H_{Zeeman} >> H_{spin-spin}$



- ZULF: $H_{Zeeman} << H_{spin-spin}$
- Need to provide polarised sample
- No more chemical shift, but scalar-couplings dominate
- Advantages:
- No need for large magnet → small setup
- Low resonance frequency
- Can measure on metal samples

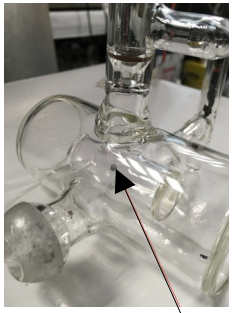
From M. Tayler, wiki



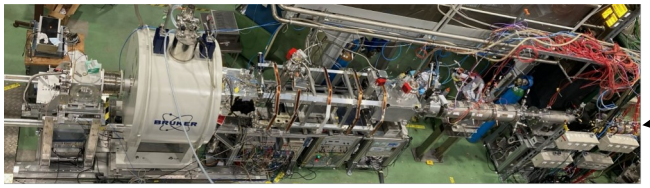
1 nT

Polarisation methods

Spin exchange optical pumping (SEOP)

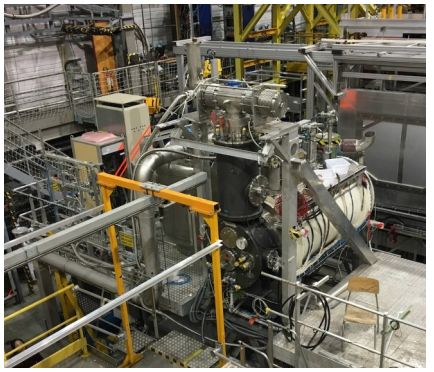


Optical pumping (OP)

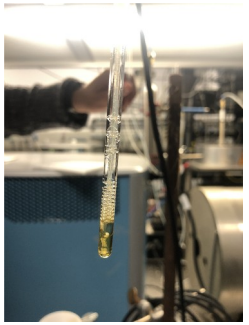


Nuclear Polarisation

Dynamic nuclear polarisation (DNP)

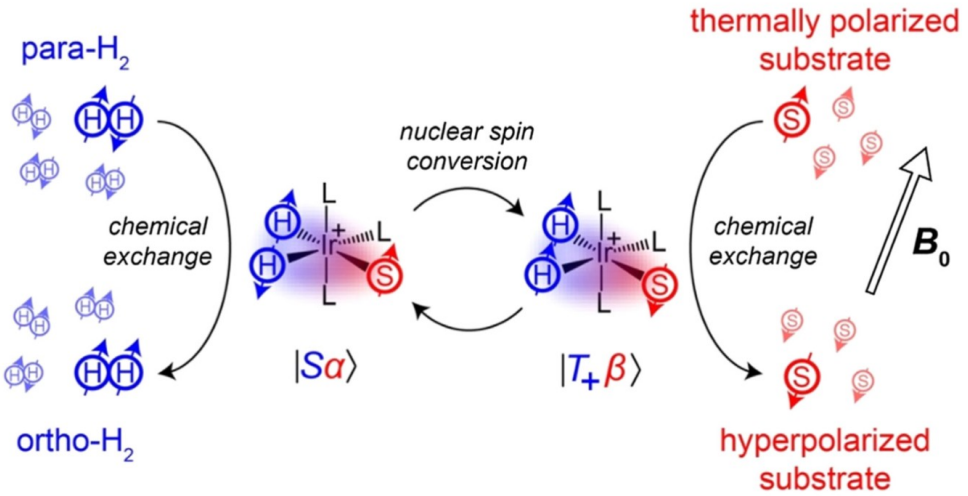


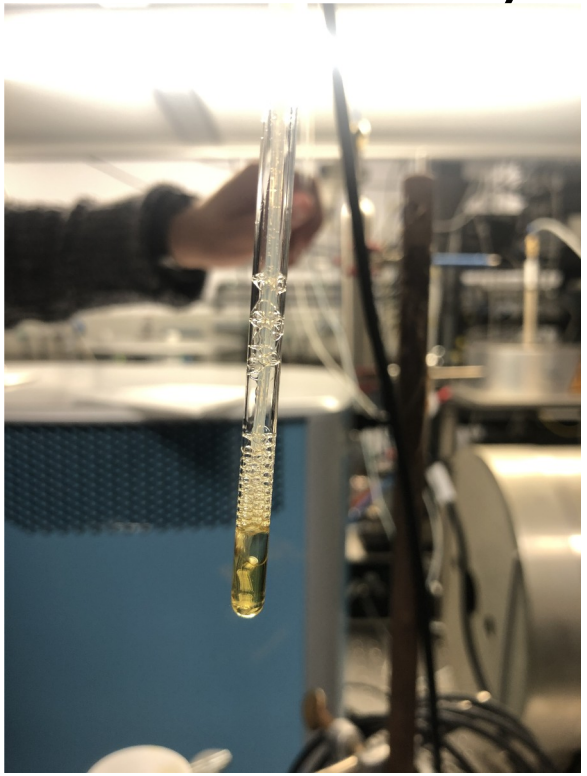
Signal amplification by reversible exchange (SABRE)



SABRE method

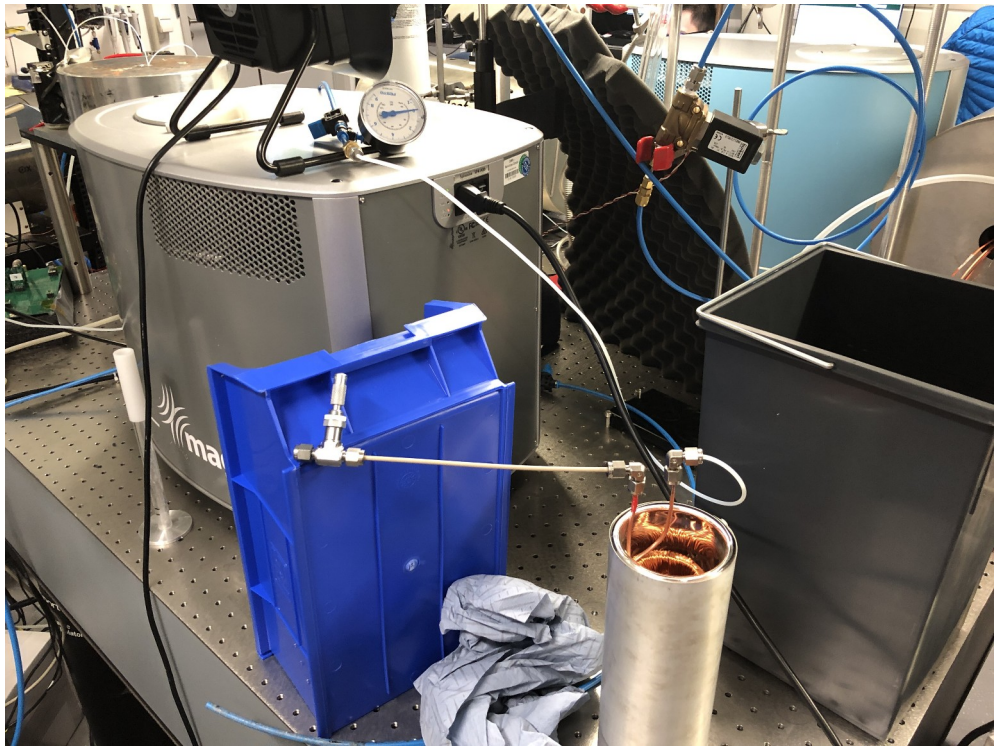
- Based on para-hydrogen induced polarisation
- Para vs ortho hydrogen
- Basic concept: bubbling para-H_2 through liquid sample
- Ir complex+substrate (i.e. chemical of interest)



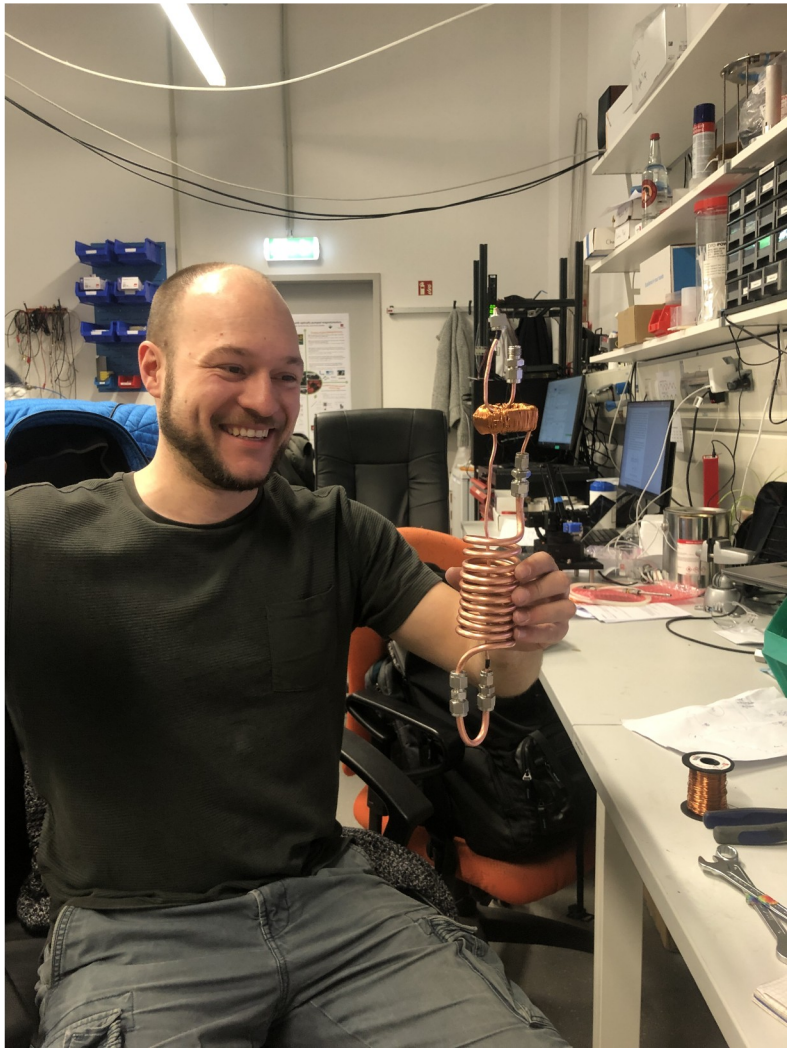


para-H_2 production

- Room Temperature: 75% ortho : 25% para
- LN_2 temperature 50 : 50 %
- Para-H2 generator:



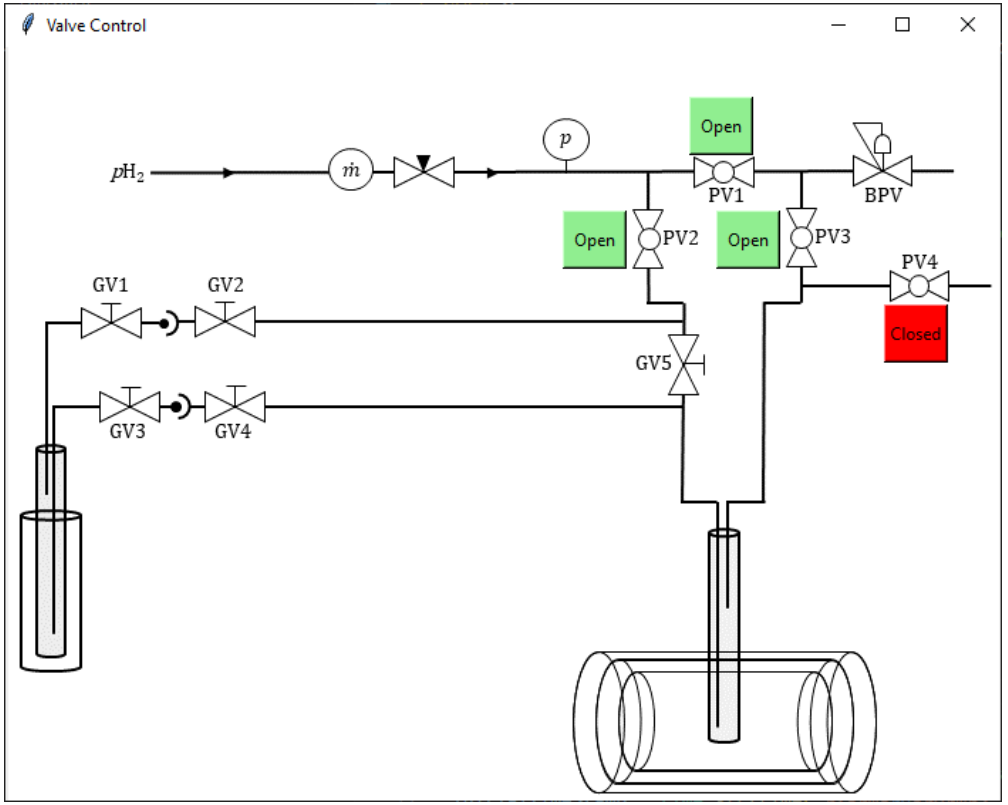
Generator pressure test

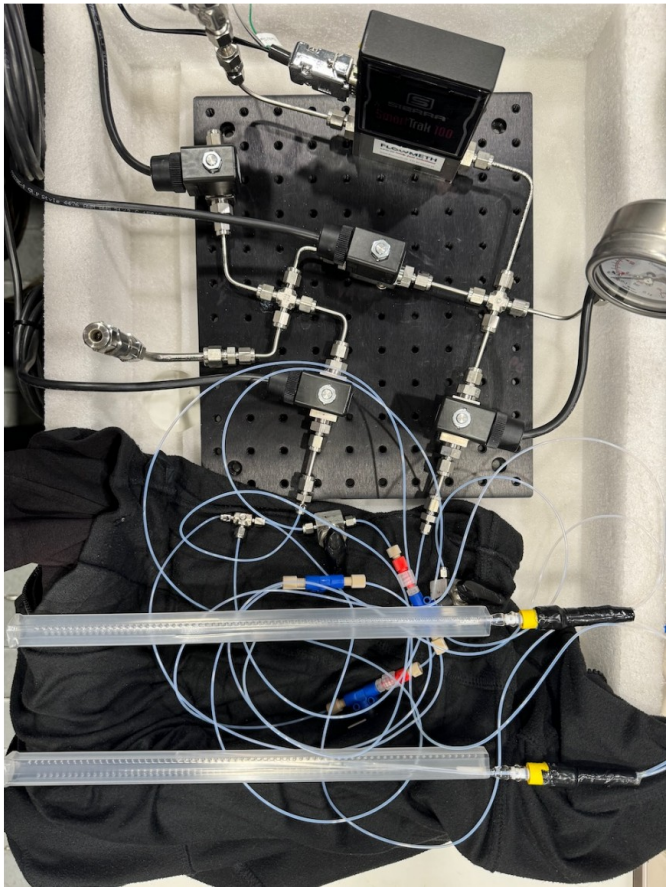


First prototype

Gas system for SABRE

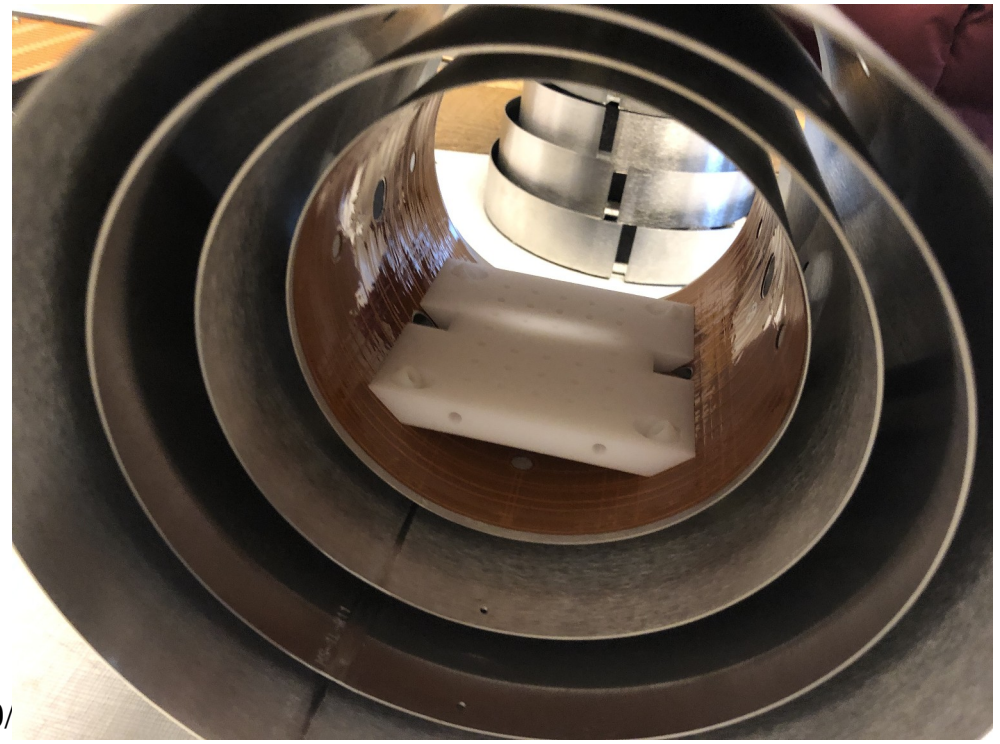
- Need system to handle para-H_2
- Allow for bubbling of para-H_2 at 6 bar through sample
- Shuttling of radioactive liquid sample

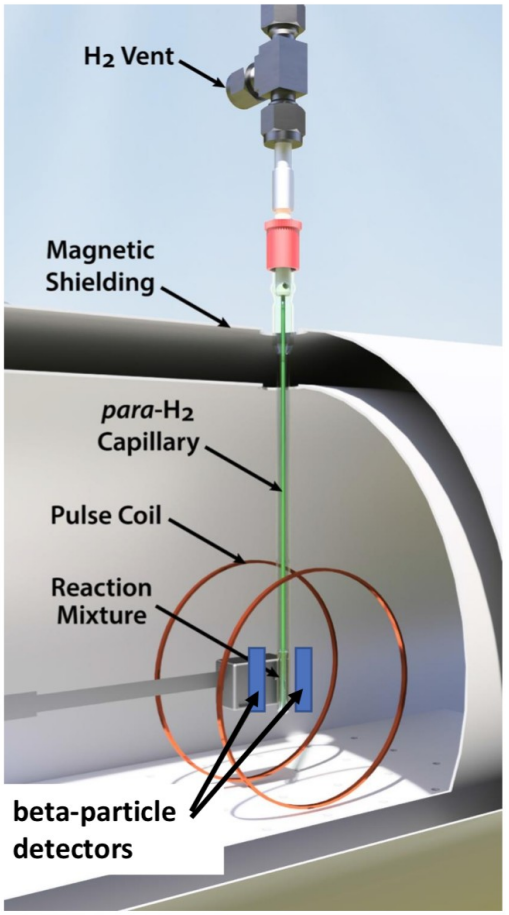




RD-ZULF NMR

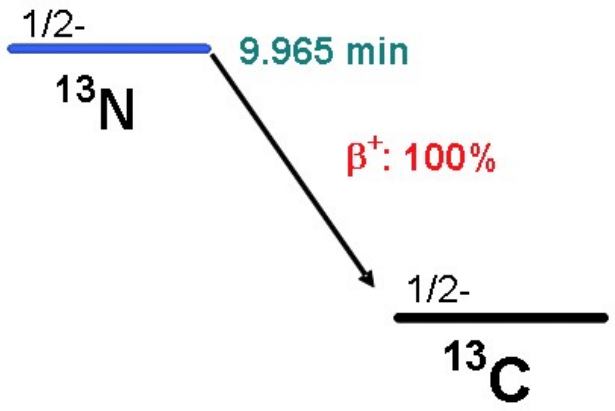
- Magnetic shielding – 4 layers of mu-metal
- Radioactive sample & 2 scintillator detectors inside
- 2 mm thick EJ200 with SiPMs
- Helmholtz coils for “RF” excitation





RD-ZULF NMR

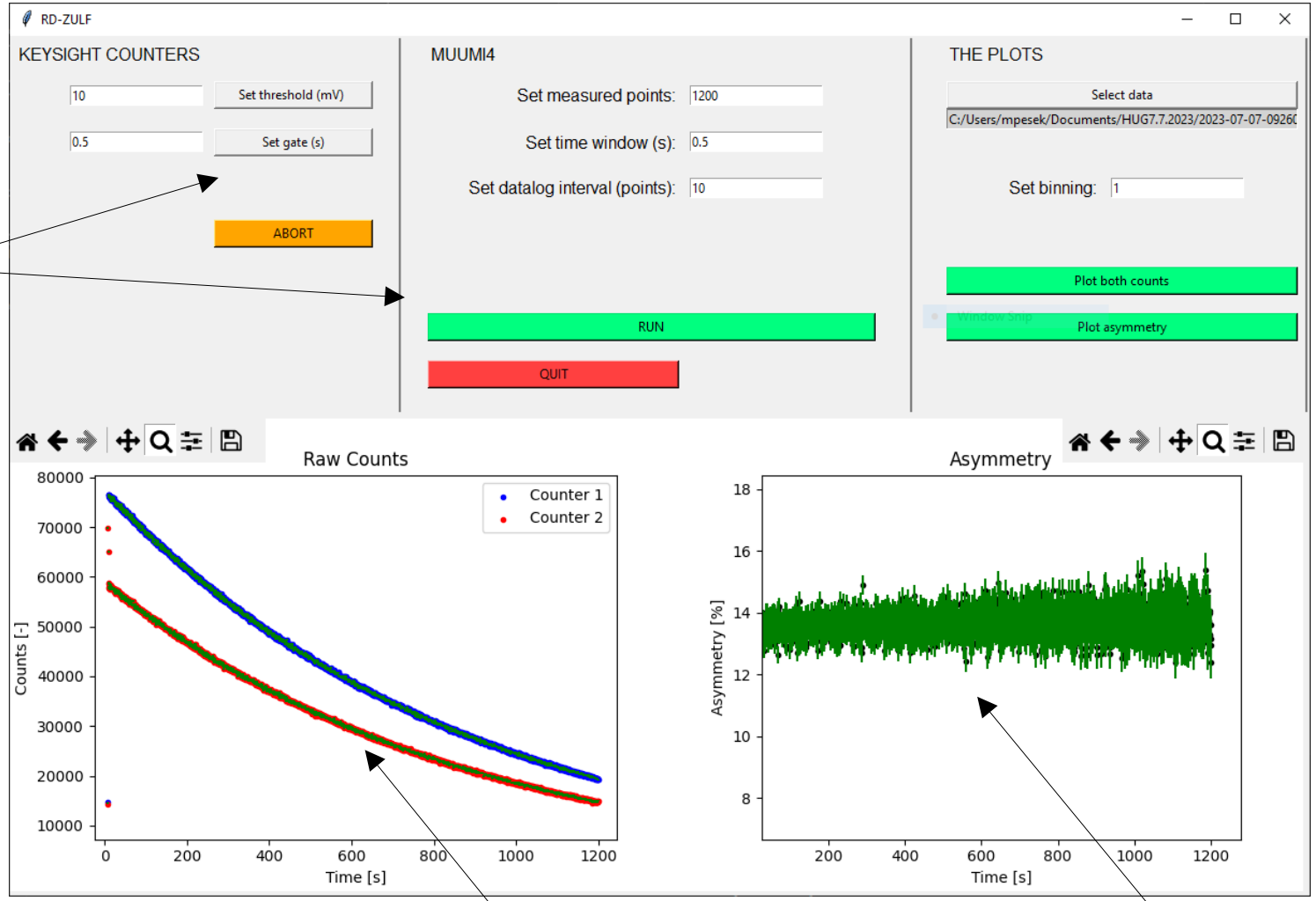
- First isotope ^{13}N in ammonia water solution
- Half-life 10 minutes, a=33 %
- Sample provided by HUG cyclotron
- Expect 70 MBq activity
- Chemistry tested in Mainz on ^{15}N



Setup at HUG

RD-ZULF NMR

- Detectors and DAQ already tested with ^{13}N at HUG



Various settings

Online counts from 2 detectors

Online asymmetry calculation

Summary and Future plans

- RD ZULF will provide a compact and sensitive NMR setup
- Beta detectors tested and working
- Gas and liquid handling system ready

- Future steps:
- Install pH_2 system in HUG
- Commissioning of full setup at HUG
- First polarisation with SABRE on ^{13}N ~next February

Thank you!

- Our team :
- CERN:MP, M. Kowalska, A. Sparks, W. Lindberg + VITO team
- JGU Mainz: D. Barskiy, R. Kircher, D. Budker
- HUG: A. Grotzky, V. Bonvin, V. Garibotto

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