First nuclear spin-polarized beams at REX-ISOLDE

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Introduction and motivation

- Benefits of ensembles of spin-oriented nuclei
  + May improve sensitivity of some classes of experiments.
  + Permits access to otherwise inaccessible observables.
  - Example: Spin/parity assignments in certain Rb and In isotopes.

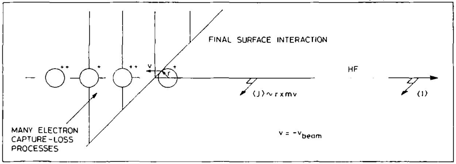
- ISOLDE has polarized a variety of nuclei at low energies

- So why tilted foils after REX?
  + Assumed wide range of polarizable nuclei.
  + In-flight polarization for post acceleration.
  + Deterministic and easily changed polarization direction.
  + Non-destructive setup in existing beam-lines.
  − Not as efficient as special methods...

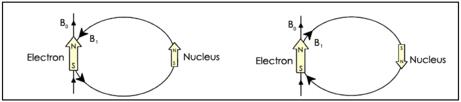
- β-NMR to observe and measure polarization

Tilted foils polarization

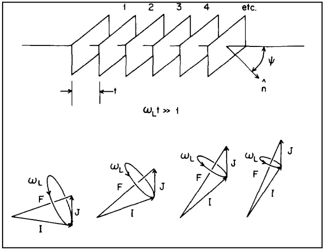
- Electrons at the exit surface of a foil interact and polarize the atomic spin of a traveling ion ($\vec{P} = \alpha \vec{n} \times \vec{v}$, $\alpha > 0$)



- Hyperfine interaction "transfers" part of the atomic spin polarization to the nuclear spin

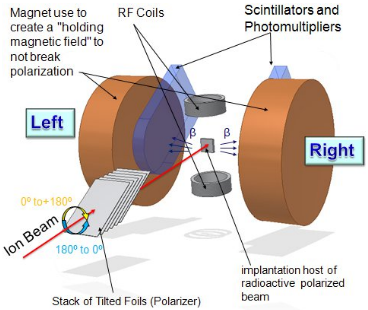


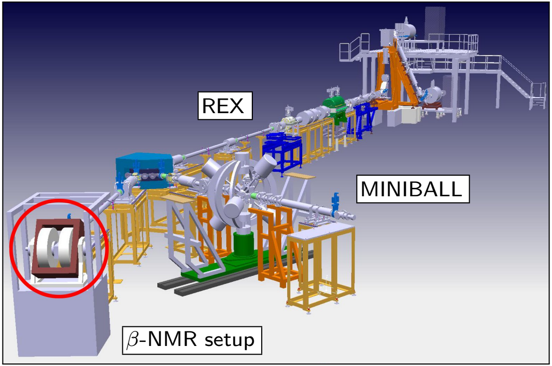
- Multiple foils progressively increase polarization until saturation ($I \geq J$)



Setup: Overview

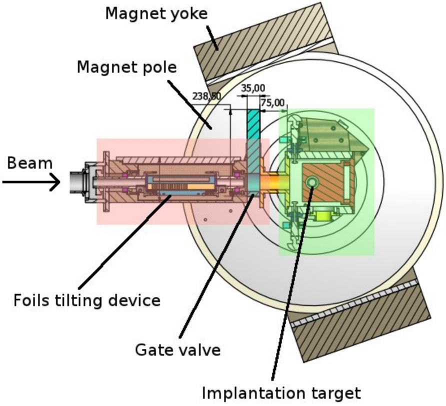
- β-NMR equipment donated by W. D. Zeitz, former HMI Berlin
- Positioned at 2nd beamline behind REX
  - Available space for other experiments to be plugged in.
- 0.3..3 MeV/u beam energy

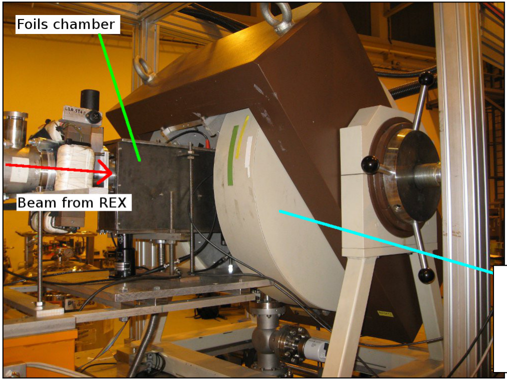




Setup: Main parts

- Schematic overview of setup
  - Foil tilting device.
  - Implantation target.

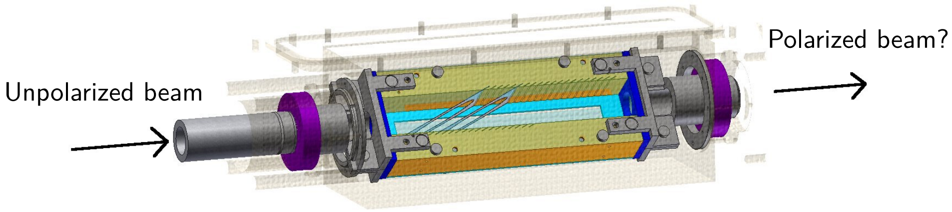




β-NMR magnet with implantation chamber, RF coils and scintillator telescopes.

Setup: Foil tilting device

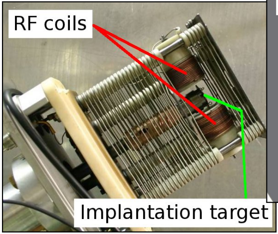
- Up to 20 foils in the setup
  - Diamond like carbon, 4 μg/cm^2, ∼20 nm thin, TU München.
  - Mylar, 0.5 and 0.7μm, for beam energy degradation.
  - Set of fixed tilting angles, ±65°, ±70° and ±75°.
- Stepper motor turns foil holder around beam axis
  - Turning 180° flips foil tilting angle → flips polarization direction.
- Soft iron shield to reduce β-NMR magnetic field close to foils

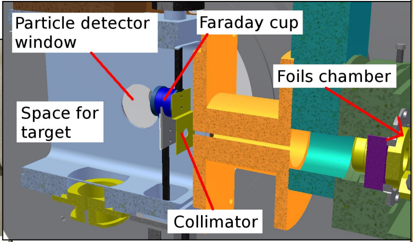


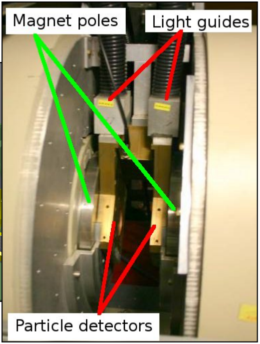
Manufactured at Weizmann Institute, Rehovot, Israel

Setup: Implantation chamber

- Beam diagnostics and collimation inside chamber
  - Collimator size adjustable.
  - Small Faraday cup between entry and target.
- RF coils driven externally by generator and amplifier
- $\beta - \Delta E/E$ detector setup on each side of the implantation target
  - Fast plastic scintillators (2 mm and 10 mm).







Experiment

- ^{8}Li, ∼4e5 ions/s in front of foil chamber
  - $\tau_{1/2} \approx 0.84\,\text{s}$, $Q_e \approx 13\,\text{MeV}$, $A = -1/3$, $A/q = 4$ @ 300 keV/u.
- Implantation in Pt crystal
  - Spin-lattice relaxation ($T = 295\,\text{K}$) ∼4.3 s[1].
- Mylar foil for slowing down the beam in front of the carbon foils
  - From 300 keV/u to 200 keV/u.
- RF to destroy polarization
- Runs with and without iron shield
- Third time's the charm?
  1. **2011-08**: ^{27}Na, good beam transmission, problems in DAQ.
  2. **2011-10**: ^{27}Na, DAQ problems solved, bad beam transport.
  3. **2012-07**: ^{8}Li, good beam, good DAQ ⇒ Success!

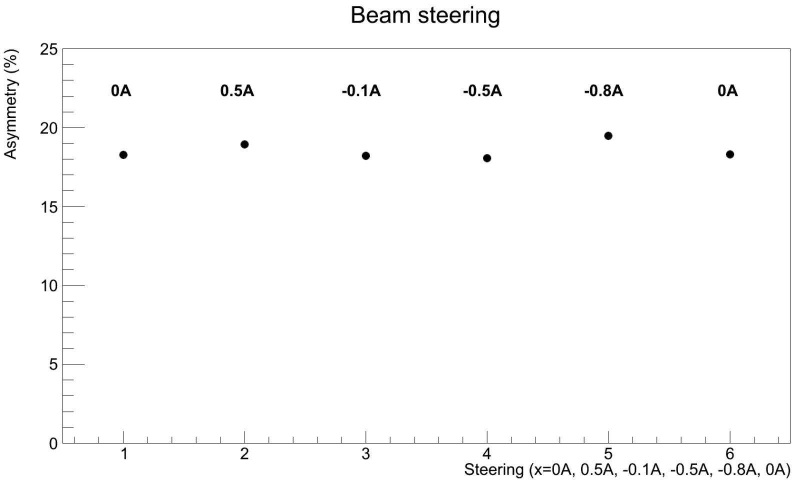
[1] Ofer O et. al., Phys. Rev. B 86, 064419 (2012)

Analysis

- Larmor frequency for ^{8}Li @ $B = 0.05\,\mathrm{T} \Rightarrow f_L = 315\,\mathrm{kHz}$
- β-decay angular distribution
  - $W(\theta) = 1 + A\,\boxed{P}\,\beta_e \cos\theta, \quad P = \langle I_z \rangle / I$
    - ★ A=asym. param.
    - ★ β_e=beta param. of e^-
    - ★ θ=angle between P and e^-.
- Side-ways asymmetry → polarization, solid angle α of β detectors
  - Asymmetry $\varepsilon = \frac{N_R - N_L}{N_R + N_L}$
  - $P = \frac{4\varepsilon(1-\cos\frac{\alpha}{2})}{A\beta_e(1-\cos\alpha)} = [E(\beta_e) \approx 13.0/3\,\mathrm{MeV},\ \alpha \approx 20°] \approx -3.05\,\varepsilon$
- Spin relaxation in target
  - $\tau_{1/2}$ =840 ms & τ_r =4.3 s → $f_r \approx 0.848$
- Total correction: $P_0 \approx -3.6\,\varepsilon$

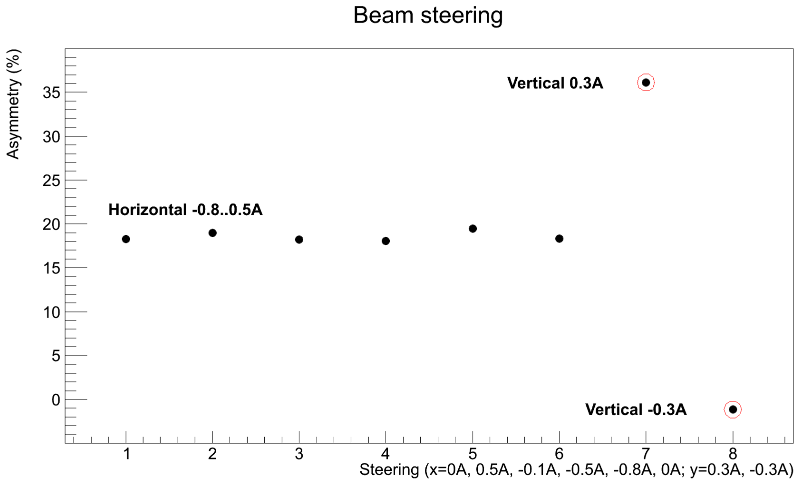
Beam steering

Horizontal, 0 A..0.8 A $\rightarrow \sim 1\%$ changes in asymmetry



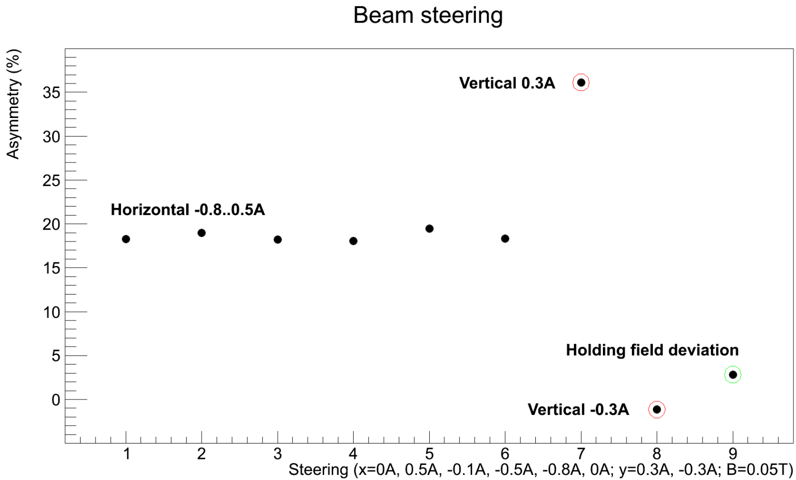
Beam steering

Vertical, 0 A..0.3 A $\rightarrow \sim 20\%$ changes in asymmetry

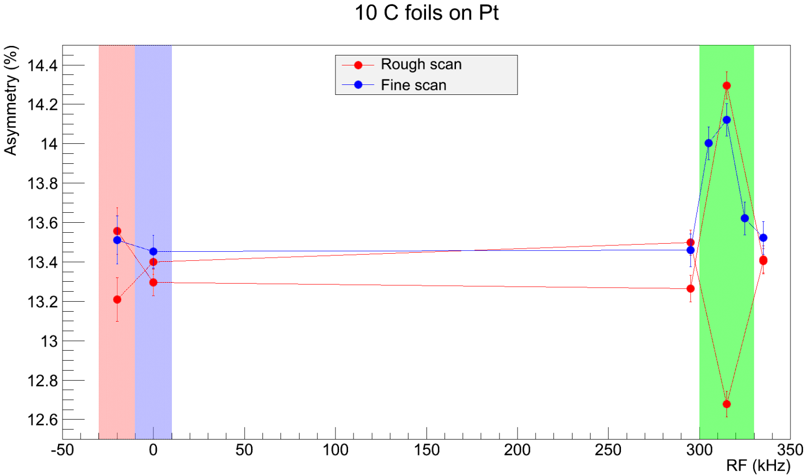


Beam steering

Holding field deviation, 0.05 T $\rightarrow \sim 15\%$ change in asymmetry



β-NMR spectrum



Red = Relaxation from applied RF.

Blue = No RF.

White = Off-resonance RF.

Green = RF in resonance, destruction of polarization.

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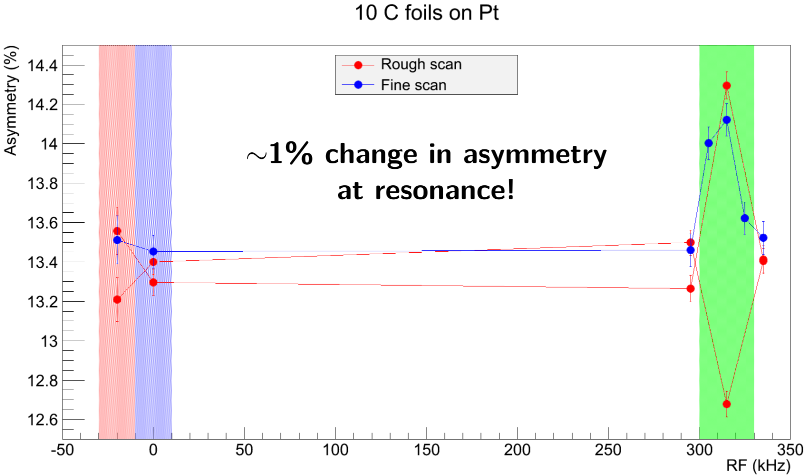

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Discussion

- First of all:
  - ✓ **We have an intermediate energy nuclear spin polarized beam at REX-ISOLDE!**
    - Double ratio calc with fixed foil orientation $\rightarrow$ $\mathbf{3.56 \pm 0.29\%}$ and $\mathbf{-2.77 \pm 0.27\%}$ (-70° and $+70^\circ$ resp.)

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  - Baseline changes with foil tilting angle!
  - Angular straggling in foils, or collision with foil frames.
  - Other geometric asymmetries close to implantation?
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- But clear β-NMR signal proves polarization
- Changes 6h before run ended (2 days earlier than intended) gave results
  - Impact of iron shield, target, foil configuration?

Summary and outlook

- Nuclear spin of ^{8}Li @ 300 keV/u polarized with 10 carbon foils
  - Measured up to 3.6% degree of polarization in Pt target with β-NMR.
- Need to investigate what impact the last changes had
  - Iron shield, target, beam degrading, foils...
- Other nuclei
- Move foils earlier in linac for post-acceleration
  - Need energies >300 keV/u for MINIBALL experiments.
  - Beam straggling and emittance simulations underway.
- HIE-ISOLDE
  - Proposal to study magnetic moments of isotopes of indium accepted by the CERN Research Board[2].

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