Neutron Bound-β-Decay, BOB

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On behalf of the BOB Group

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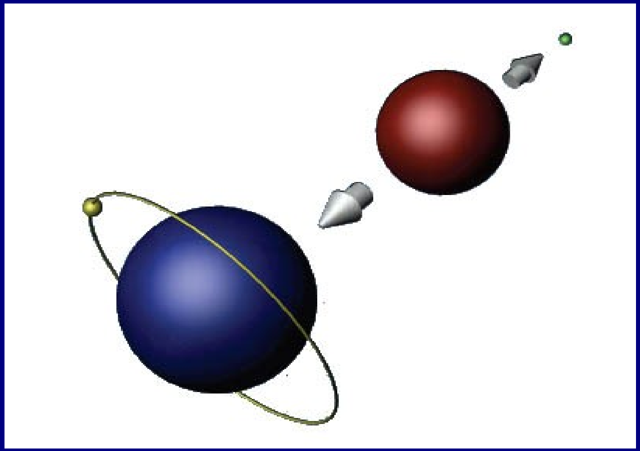
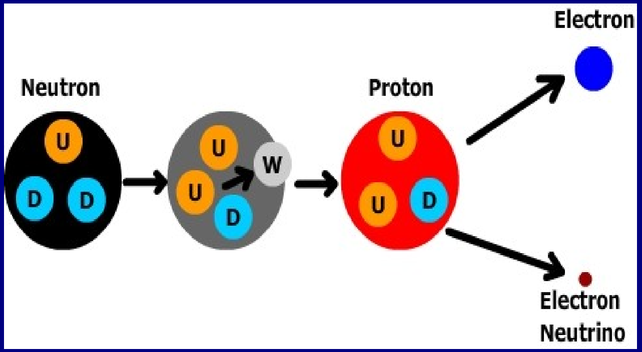
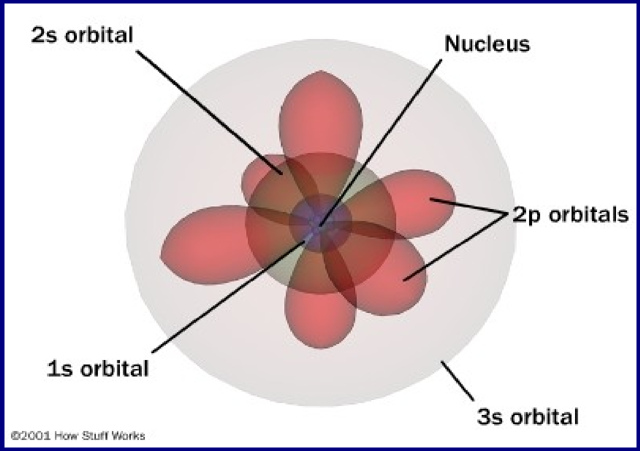
Introduction

- Background
- Proposed Experiment
- Test Set Up
- Simulations
- Current status of the BOB project
- Outlook for BOB







What is Bound-β-Decay (BOB)?

- Rare neutron decay mode predicted by Nemenov (Sov. J. Nucl. Phys. **31** (1980) 115):

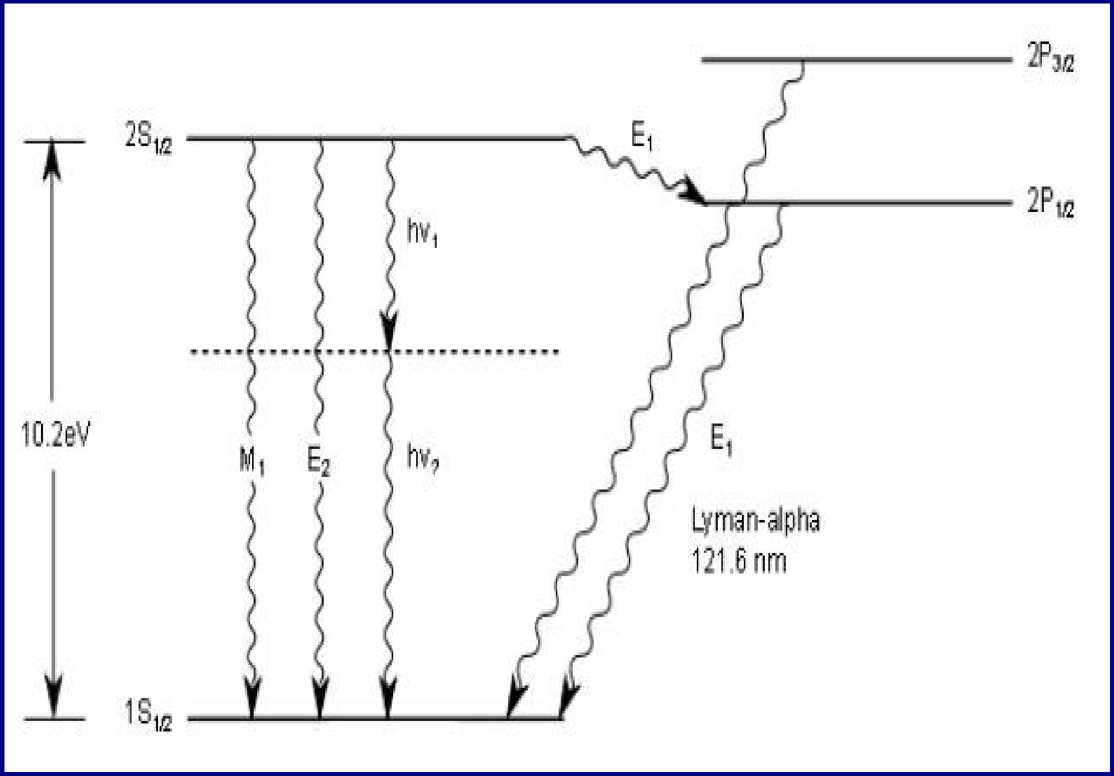
$$\mathbf{n \longrightarrow H + \bar{\nu}_e}$$

- Small predicted branching ratio of 4×10^{-6} of neutron β decay.

- Not yet observed for the free neutron!

Properties of the BOB Hydrogen Atom

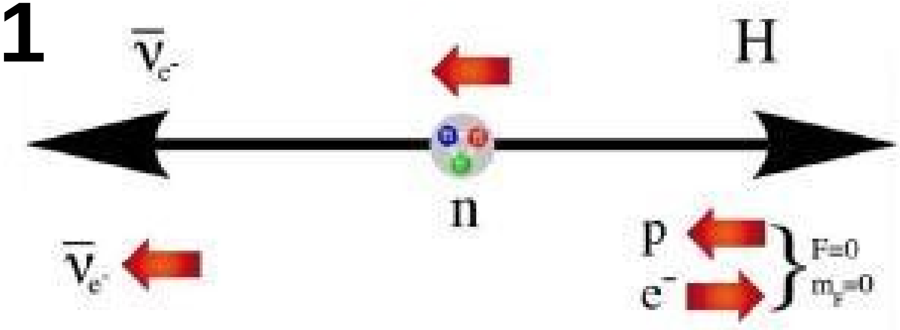
- Two-body decay: $KE_H = 326.5$ keV
- 83.2% of H atoms in 1s state
- 10.4% H atoms in 2s state



Detect the atoms in the H(2s) state.

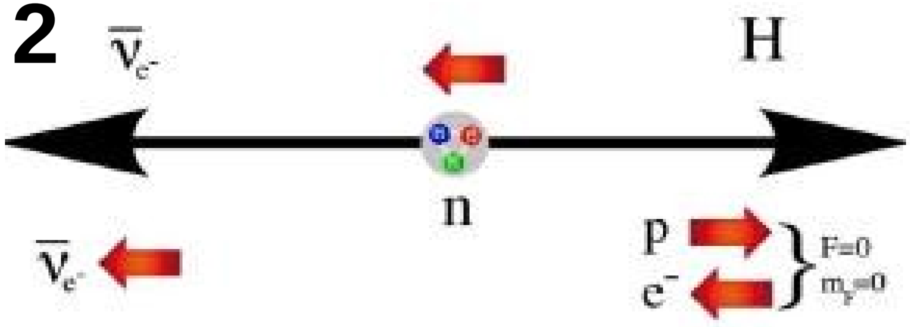
The Hydrogen Hyperfine Spin States

1



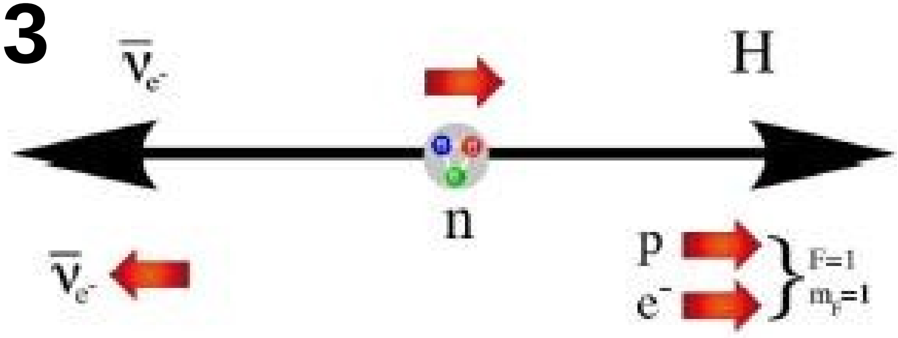
$W_i \approx$ 44.14 +/- 0.05

2



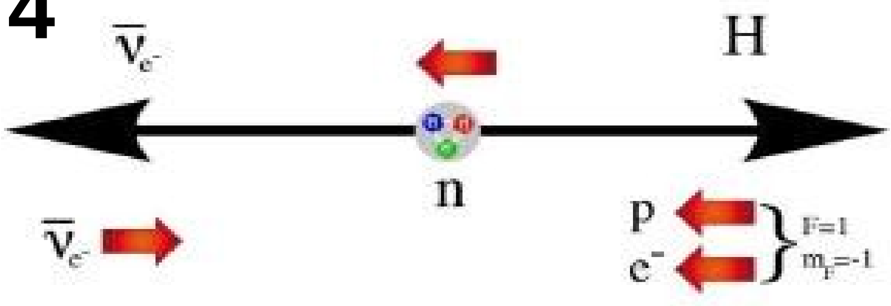
$W_i \approx$ 55.24 +/- 0.04

3



$W_i \approx$ 0.622 +/- 0.011

4



$W_i \approx$ 0

What can we learn from these spin states?

- Measure the population probability of spin configurations 1 to 3 to obtain new limits on g_s and g_t.

$$W_1 = \frac{(\chi - 1)^2}{2(\chi^2 + 3)}$$

$$W_2 = \frac{2}{\chi^2 + 3}$$

$$W_3 = \frac{(\chi + 1)^2}{2(\chi^2 + 3)}$$

config. i	g_S=0, g_T=0	g_S=0.1, g_T=0	g_S=0, g_T=0.02
1	44.114	46.44	43.40
2	55.24	53.32	55.82
3	0.622	0.238	0.78
4	0.	0.	0.

$$\chi = \frac{1 + g_s}{\lambda - 2g_T} \quad , \quad \lambda = \frac{g_A}{g_V} \approx -1,25$$

- Aim: Reduce g_s and g_t upper limits by factor of ten.

What can we learn about neutrino helicity?

- Assuming a left-right symmetric V+A model:

$$W_4 = \frac{(x+\lambda y)^2}{2(1+3\lambda^3+x^2+3\lambda^2 y^2)}$$

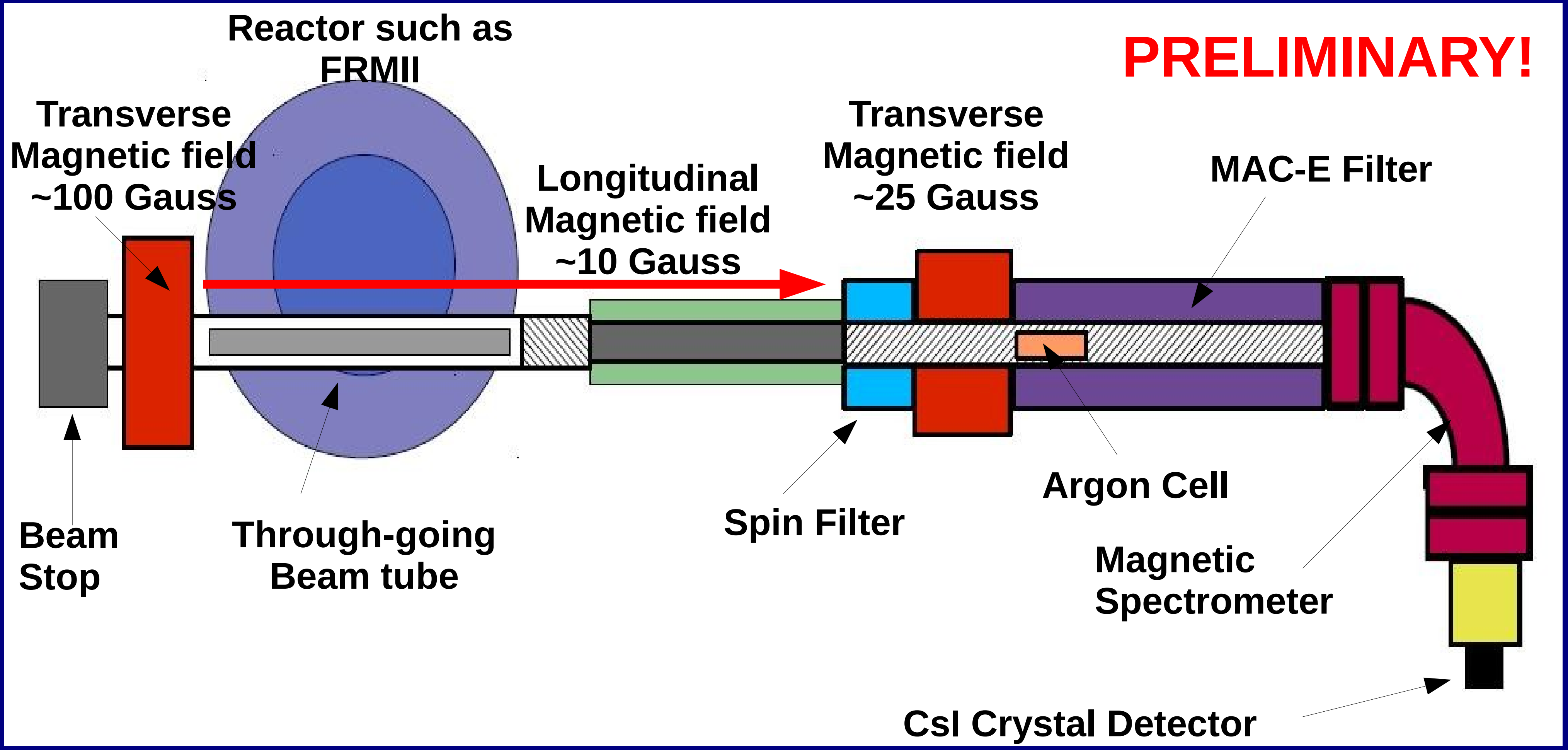
$$H_{\bar{\nu}} = \frac{1+3\lambda^2-x^2-3\lambda^2 y^2}{1+3\lambda^2+x^2+3\lambda^2 y^2}$$

$$x=\eta-\zeta, y=\eta+\zeta, \eta=\left(\frac{M_1}{M_2}\right)^2$$

- In the Standard Model η=0 and ς = 0

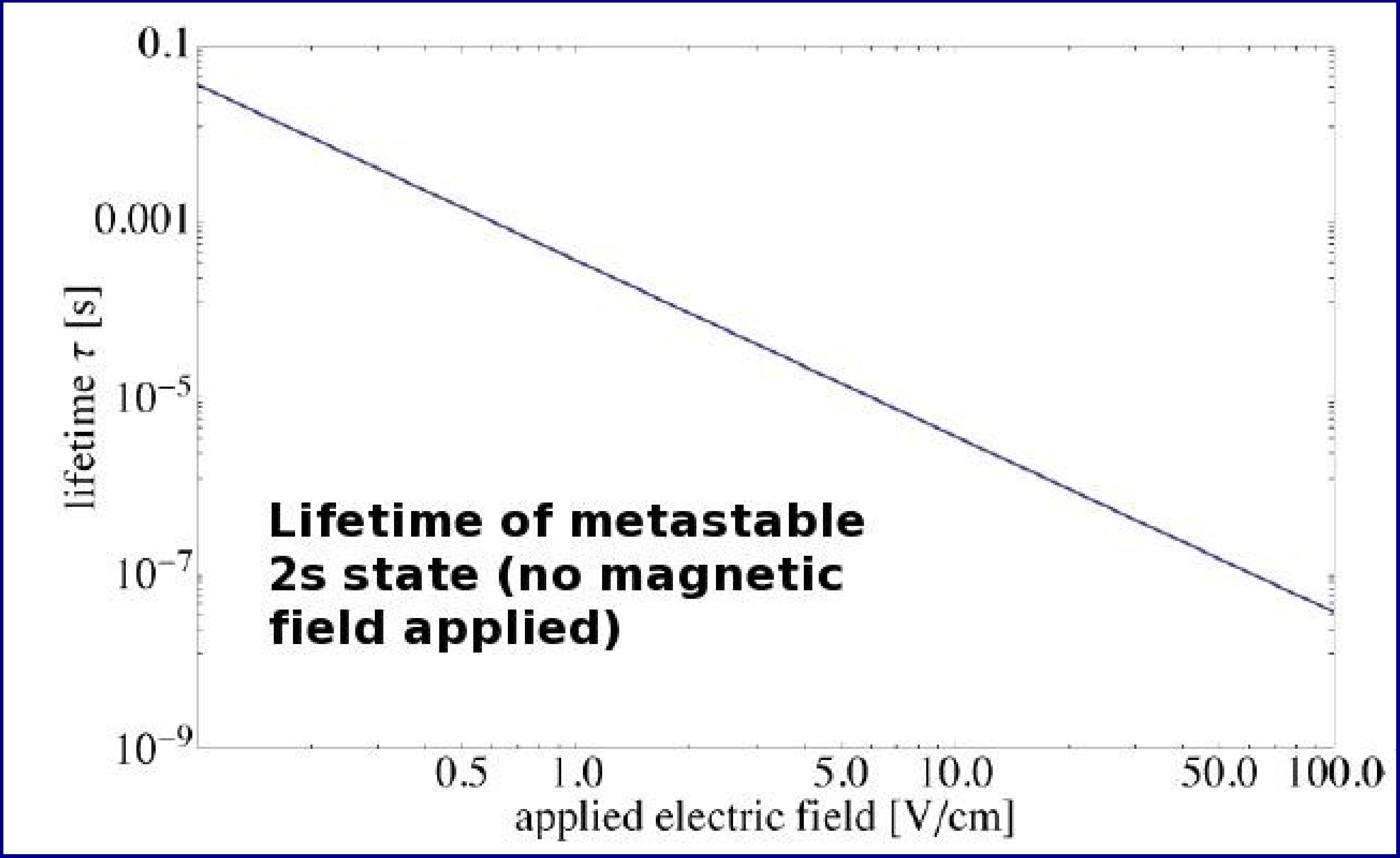
- Observing a non-zero value of spin configuration 4 would imply small contribution of negative helicity to $\bar{\nu}_e$.

Proposed BOB Set Up



Spin Filter

- Spin filter: select hyperfine state of interest by quenching the three other states using electric and magnetic fields and RF radiation.



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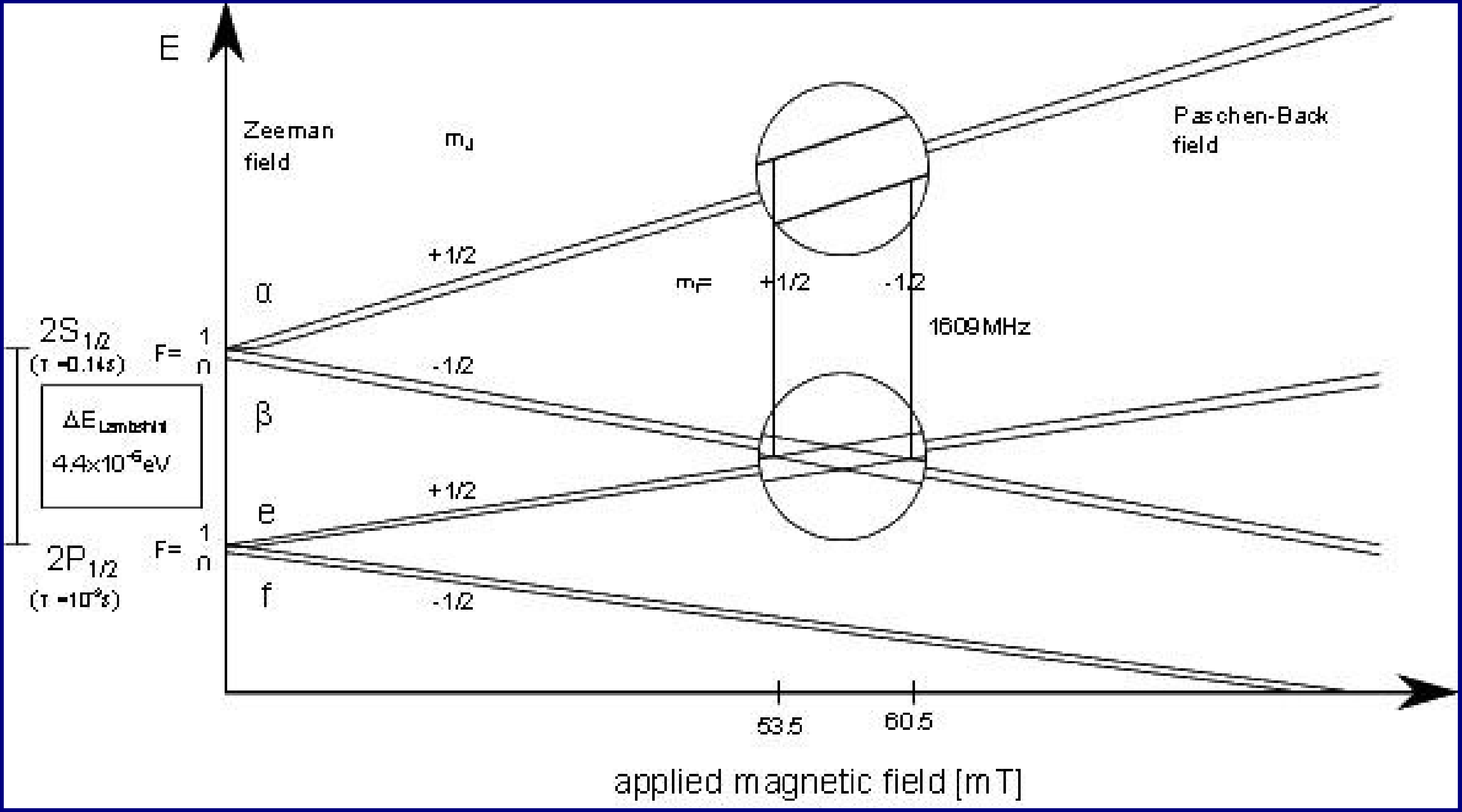

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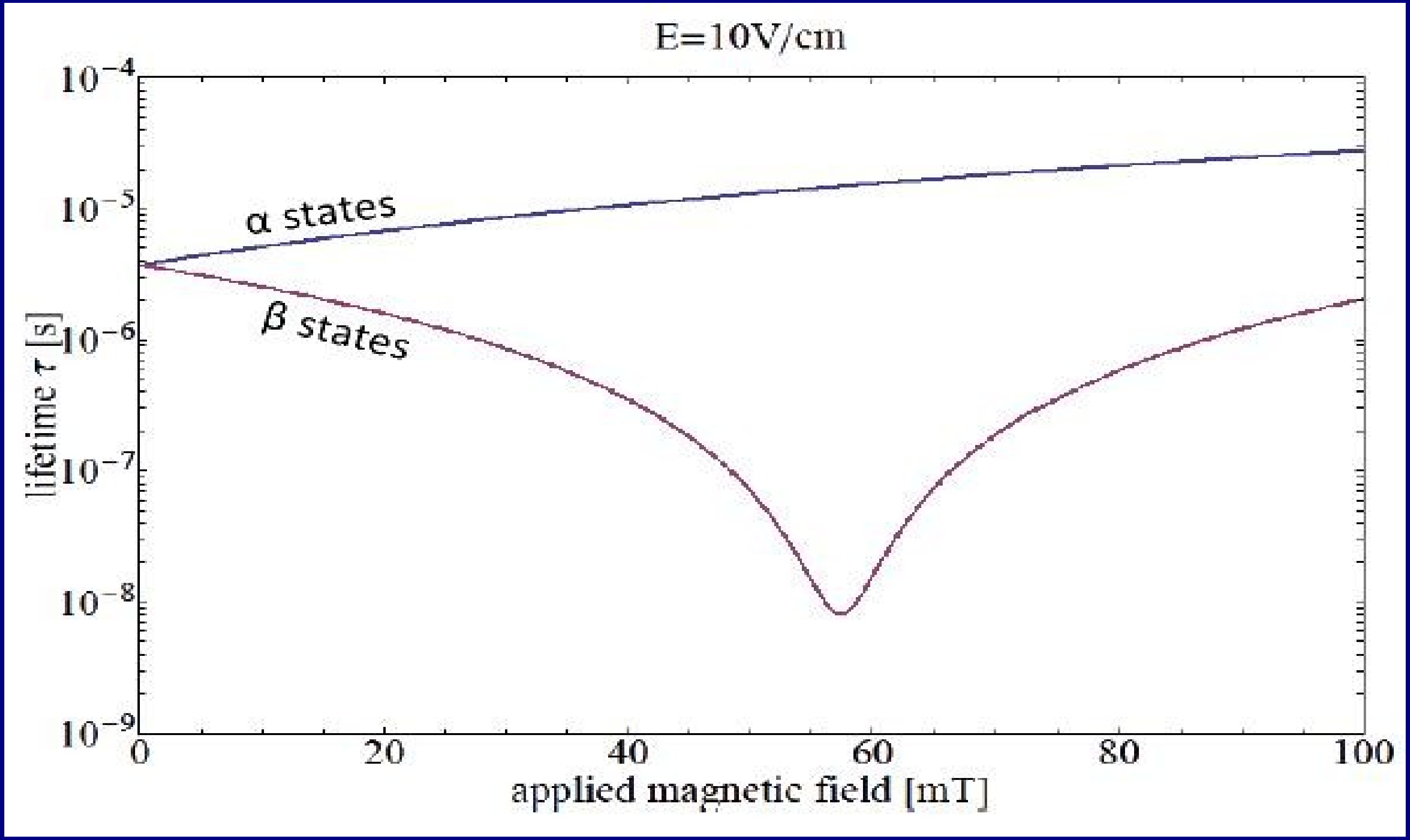
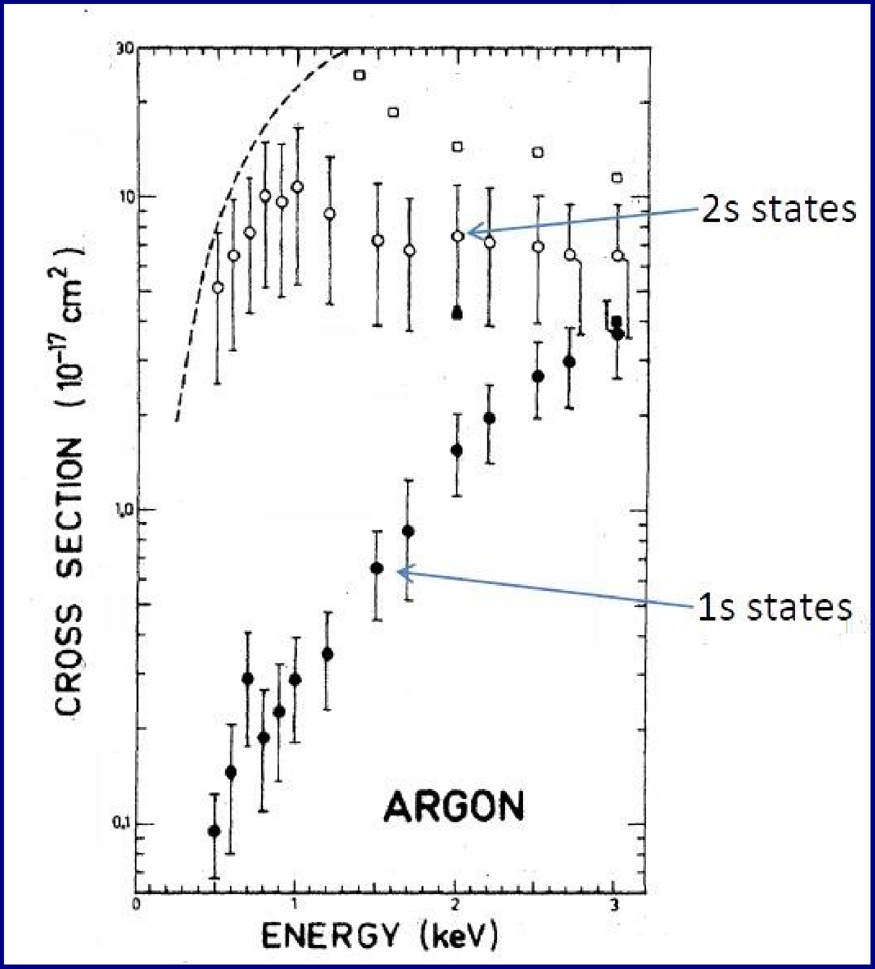


W. Haeberli, Annu. Rev. Nucl. Sci., (1967) **17** 373-426

Detection of the metastable H(2s) state (1)

- First ionise the H atoms using the charge exchange reaction:



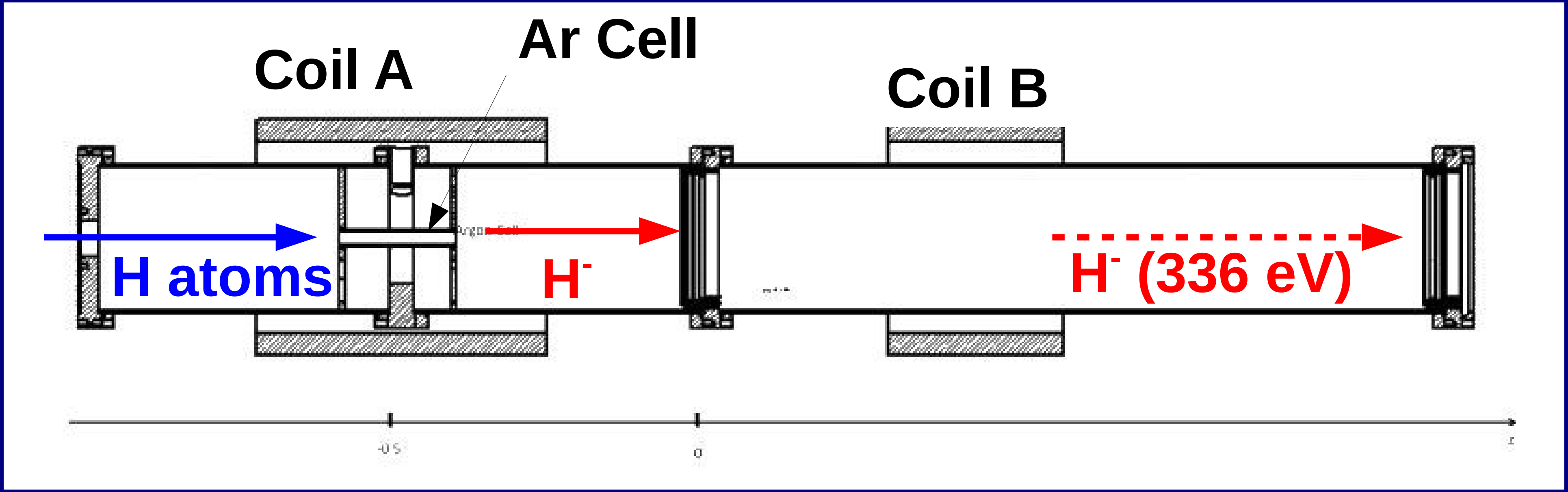
$$H + Ar \longrightarrow H^{-} + Ar^{+}$$

- H(2s) leaves as H^{-} with energy 336 eV
- H(1s) leaves as H^{-} with energy 326 eV

F. Roussel, Phys. Rev. A16 (1977) 1854

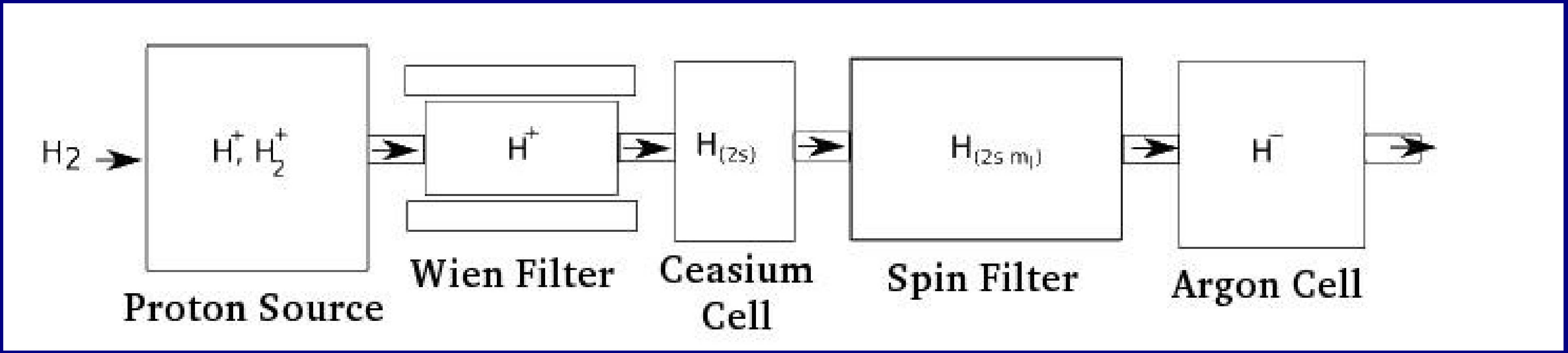
Detection of the metastable H(2s) state (2)

- Then select the H^- originating from H(2s) using an adaptation of the MAC-E filter:



BOB Test Set Up

- Test set up at the TU Munich allows testing of all "downstream" components of BOB.



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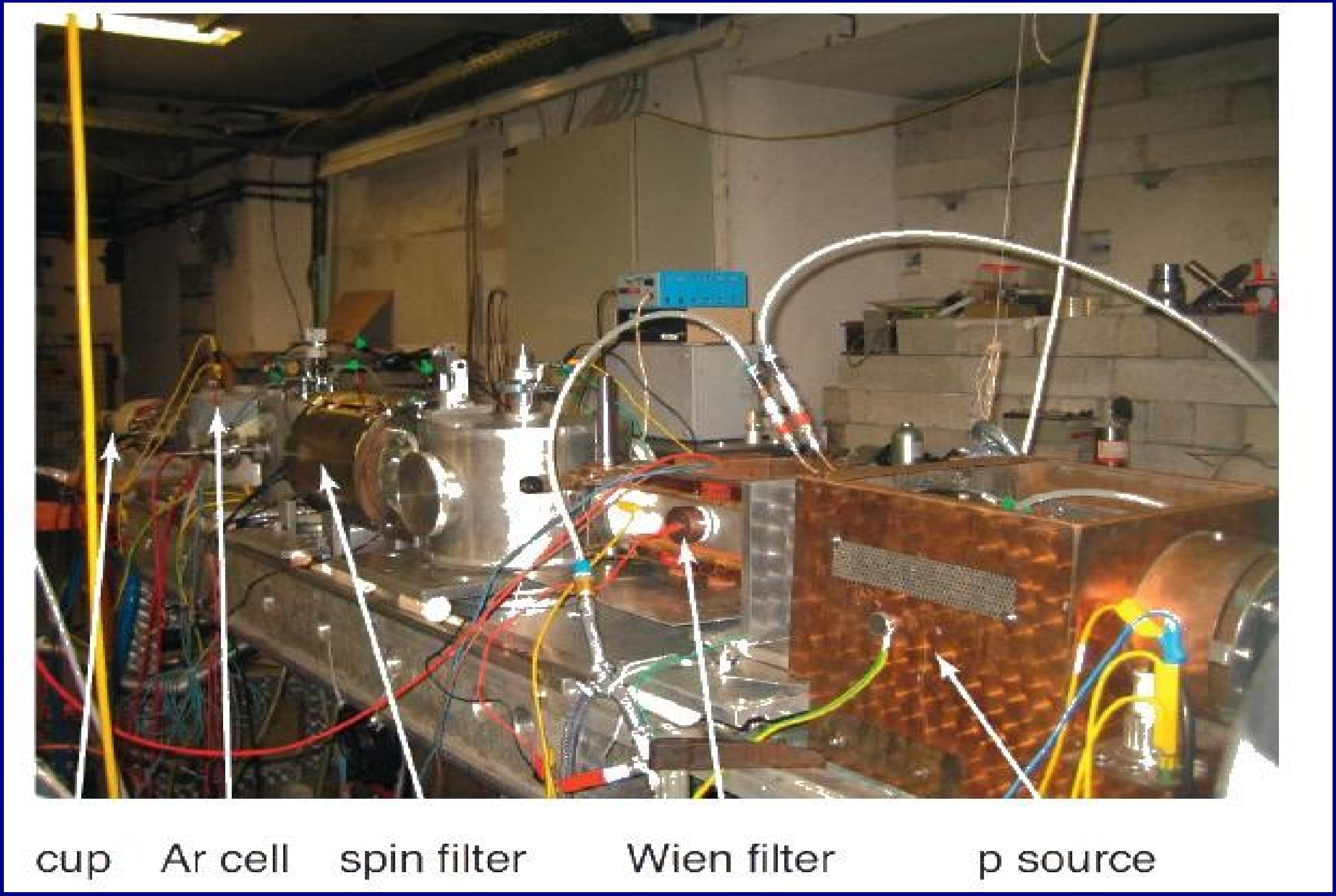

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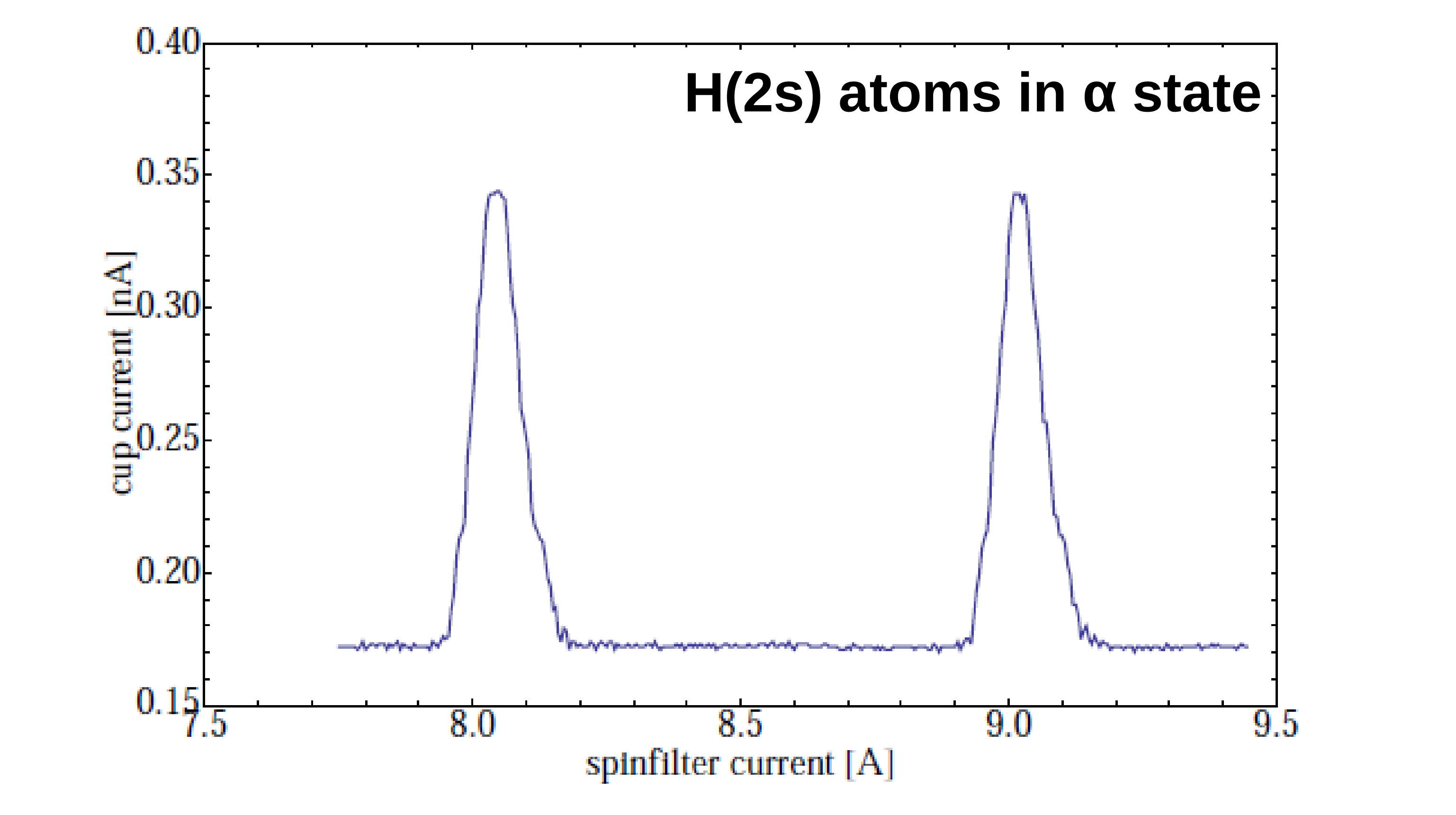
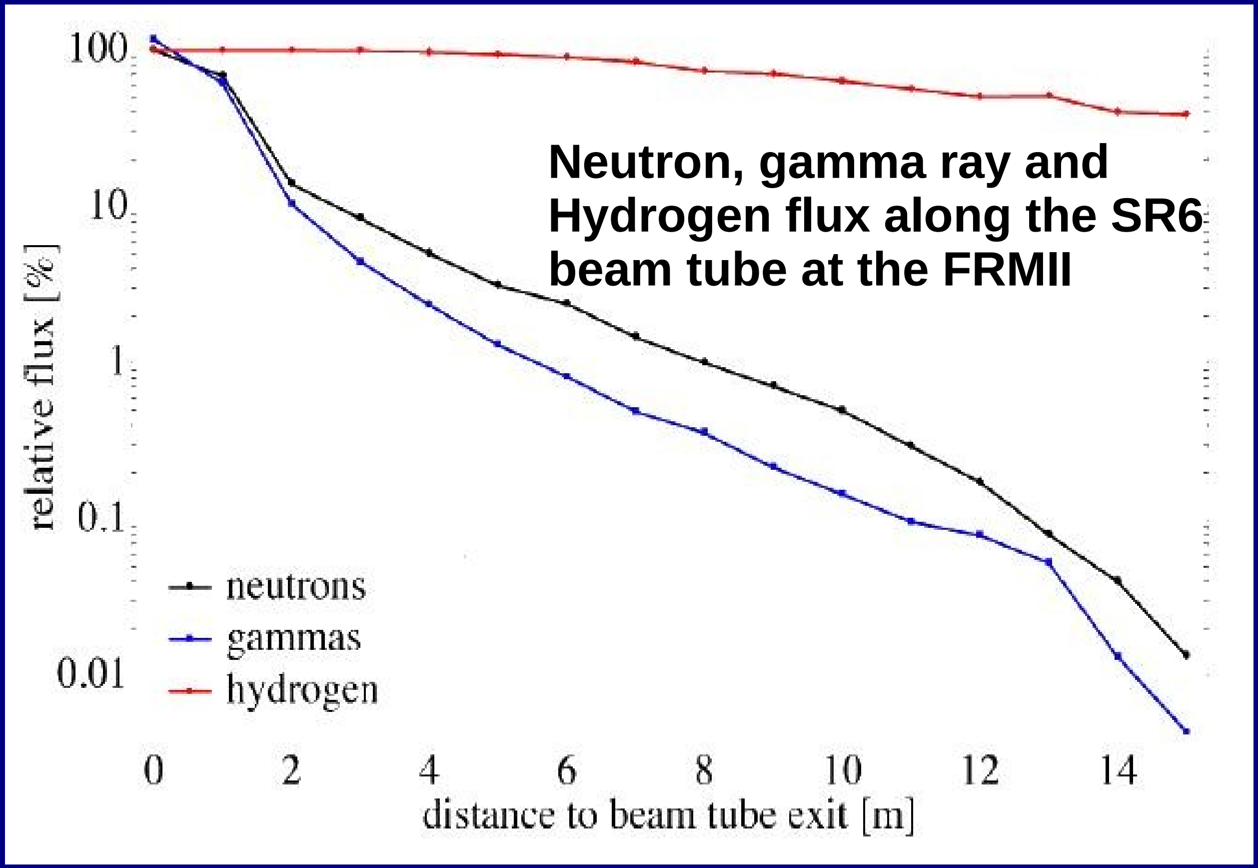


Spin Filter Spectrum with Ar Charge Exchange Reaction

BOB Simulations

- Simulations aid design of the guide tube and shielding.
- Important for calculations of expected background and the expected event rate.



Current Status of the Project

- MAC-E Filter under construction and will be available for tests at the end of September.

- Measure the Ar charge exchange cross section at energies down to ~326 eV.

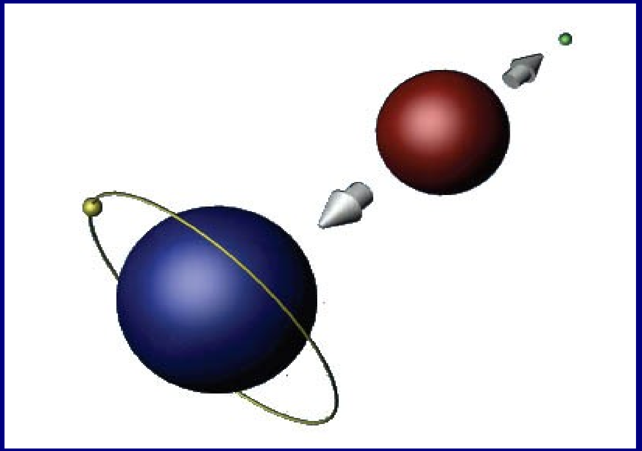
- Using the test set up for material tests to reduce background from proton collisions with beam tube.

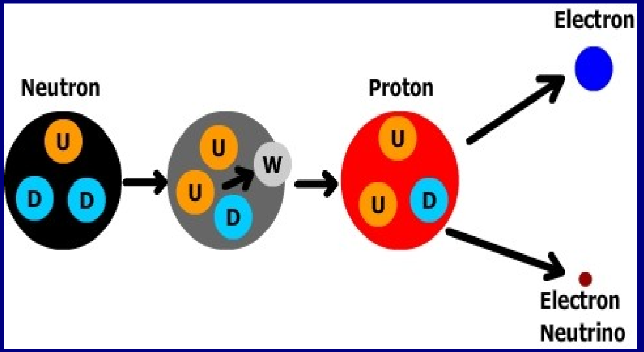
- Neutron, gamma, and proton background simulations are on going.

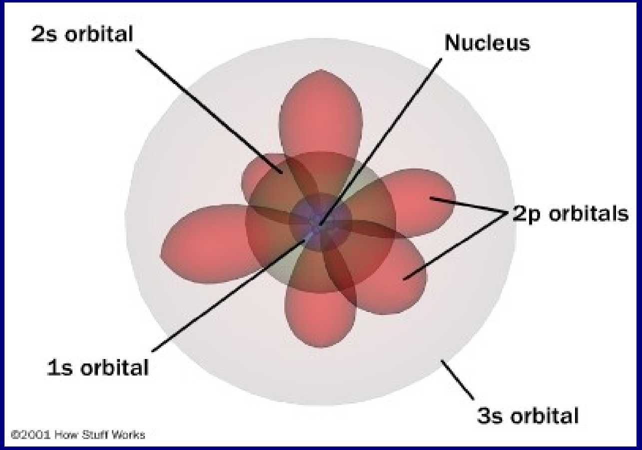
- Investigation of vacuum conditions being carried out at the ILL, Grenoble.

Outlook

- Aim: Finalise designs by the end of 2011/early 2012.
- Install BOB Experiment at the FRMII by the end of 2012
- Observe bound-β-decay and confirm branching ratio at the FRMII at the end of 2012/ early 2013.
- Then begin phase 2: measurement of the H(2s) spin states (FRMII and/or ILL).







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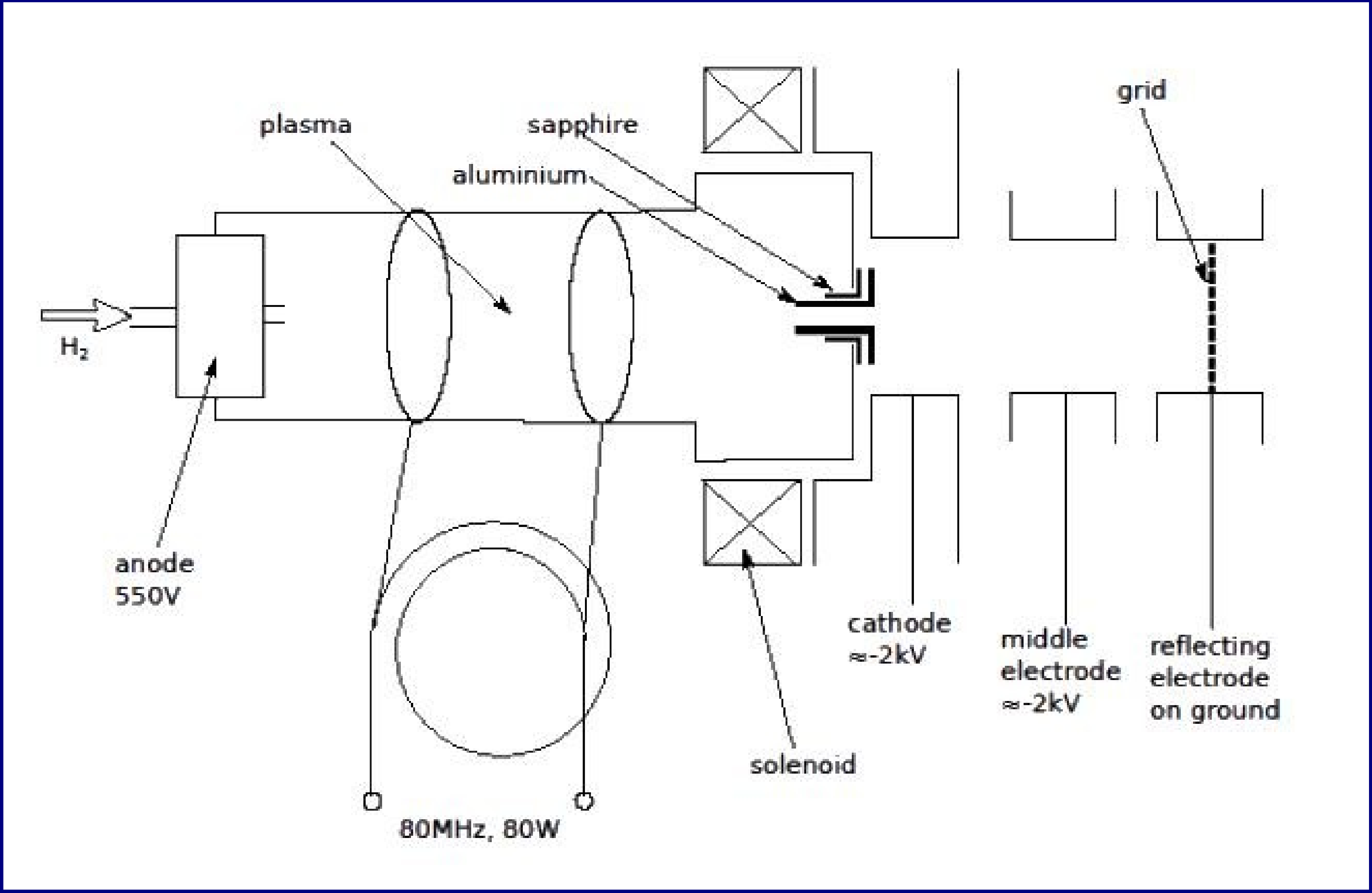
S. Ruschell, J. Schoen, W. Schott, U. Schubert,
A. Trautner, A. Ulrich

Proton Source



Caesium Cell