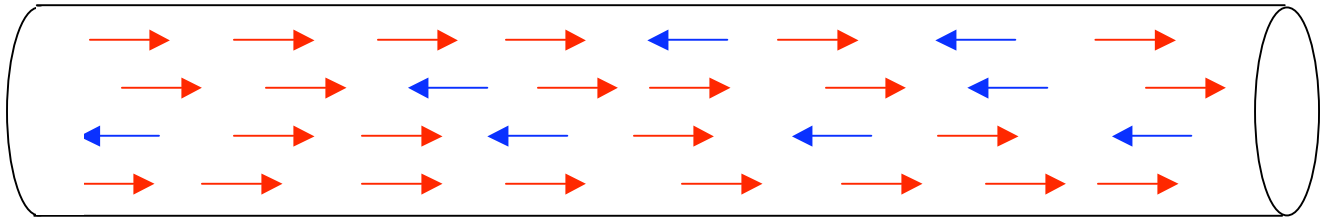
Gaseous ^{3}He Neutron Spin Filters
The early days with Francis

Tim Chupp
University of Michigan

Setting the Stage

Polarisation: **contro**l of the spin-state *populations* in an ensemble of particles

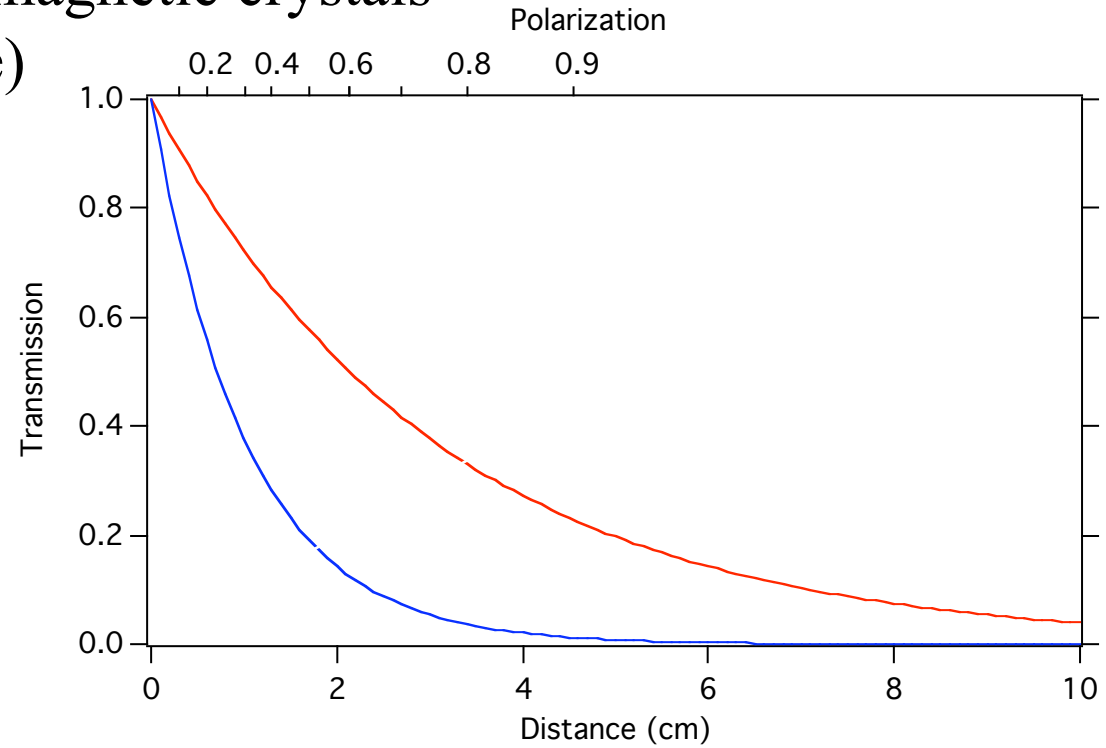
50%



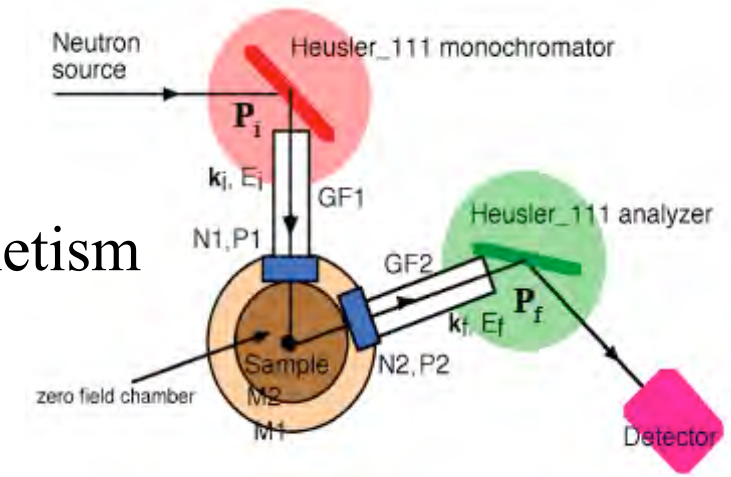
Stern-Gerlach

Scattering from magnetic crystals

Spin filters: (^{3}He)



Polarisation has been a crucial variable:



in neutron scattering: materials and magnetism

in neutron atomic physics: EDM, magnetic moment

in neutron decay: correlations and the structure of weak int.

in neutron nuclear physics: nuclear forces, nucleon structure

Workshop on Polarized ^{3}He Beams and Targets at PRINCETON (1984) (AIP Conf. Proc. 131)

1. T. B. Clegg - An electron-cyclotron-resonance ionizer for ^{3}He
2. Barry R. Holstein - Possible weak interaction experiments with polarized ^{3}He
3. R. W. Dunford and S. Oh - Comparison of polarized ^{3}He ion sources
4. R. G. Milner - Spin structure of neutron
5. J. D. Brown - Review of polarized ^{3}He induced reaction studies at Birmingham
6. C. Rioux, R. Roy, and R. J. Slobodrian - Nuclear physics program with polarized ^{3}He beam
7. D. P. May and S. D. Baker - The polarized ^{3}He beam on the Texas A&M cyclotron
8. S. Roman - Some aspects of polarized ^{3}He interactions
9. R. W. Dunford and T. E. Chupp - Discussion of polarized targets
10. J. G. Alessi and K. Prelec - A high efficiency ionizer using a hollow cathode discharge plasma
11. Aron M. Bernstein - Experiments with polarized electrons and ^{3}He nuclei
12. Keith DeConde, Stephen A. Langer, and D. L. Stein - To polarize liquid ^{3}He by spin transfer
13. J. Dupont-Roc, M. Leduc, and P. J. Nacher - Low temperature techniques
14. J. M. Daniels - Polarzied ^{3}He targets
15. R. T. Kouzes - The Princeton Cyclotron QDDD spectrograph system
16. R. J. Slobodrian, C. Rioux, J. Giroux, and R. Roy - Polarized He ion source based
17. D. E. Murnick and Ping Mei - Proposed optical pumping of a metastable beam of 3He
18. F. Laloë, P. J. Nacher, M. Leduc, and L. D. Schearer - Polarization in ^{3}He by laser optical pumping
19. A. D. Krisch - Polarized proton acceleration at the AGS
20. Saewoong Oh -Axial injection of polarized ^{3}He ions

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DISCUSSION OF POLARIZED TARGETS

R.W. Dunford and T. E. Chupp
Joseph Henry Laboratories
Princeton University
Princeton, N.J. 08544

Discussion periods on the subject of polarized targets took place on Tuesday afternoon, October 23, 2004, and Wednesday morning October 24, 2004. The discussions focused on the problem of developing polarized ^{3}He targets for electron scattering experiments[1,2]. The reaulrements are for highly polarized targets wlth densities of 10^{19} cm^{-3} to be used for external beamlines and also internal targets with densities of 10^{16} cm^{-3} for use in storage rings. These targets would be required to have thin entrance and exit windows. In the case of the Internal targets the windows need to be less than 20 μg/cm 2. The external targets would be subjected to beam currents in the range of 20-50 μA while the internal targets would be subjected to currents of up to 50 mA. The beam energies would be from 1 to 20 Gev.

One possibility for these targets is the technique described at the workshop by J. Dupont-Roc. This involved the use of a double cell. One cell was at a pressure of 0.3 to 0.5 torr which is optimum for polarization of the gas by optical pumping. The other cell was coupled to the first by a long tube and cooled to low temperature so that the gas density was about 10^{18} cm^{-3}. In this way, a dense gas with a polarization of greater than 60% was achieved. It was thought that an increase in density to 10^{19} cm^{-3} could be achieved with an improved apparatus.

Another possibility for obtaining the required targets would be an improved version of the technique described by Jim Daniels whereby compression of polarized ^{3}He gas to a pressure of 1 atmosphere was achieved using a mercury Toeppler pump.

An important question was raised concerning the problem of the interaction of the electron beam and the target. The lonizatlon of the gas by the beam might lead to substantial depolarization particularly through the formation of He_2^+ molecular ions[2]. **Will Happer** suggested another polarization scheme which would take advantage of the fact that a large number of ions were present. The idea is to put a small amount of an alkali such as rubidium into the target and polarize the alkali by optical pumping. Polarization would quickly be transferred to the helium ions by spin exchange collisions and to the SHe nucleii by the hyperfine interaction. It was suggested that it would be easy to test this scheme using standard optical pumping cells by adding an alpha source or tritium gas to the cell to produce ions.

REFERENCES

I. A. M. Bernstein, contribution to these proceedings.
2. R. G. Milner, contribution to these proceedings.

Notes:

1. Daniels and Dupont-Roc present
   MEOP + compression

2. No SEOP discussion
   Happer: polarization times too slow
   (following work of Bouchiat, Carver, Varnum)

Art MacDonald

Nuclear Physics A396(1983)221c-230c. © North-Holland Publishing Co., Amsterdam

PARITY MIXING IN ^{21}Ne; EVIDENCE FOR WEAK NEUTRAL CURRENTS IN NUCLEI

E.D. Earle†, A.B. McDonald†, E.G. Adelberger*, K.A. Snover*, H.E. Swanson*, R. von Lintig*, H.B. Mak and C.A. Barnes††**

†AECL, Chalk River Nuclear Labs., Chalk River, Ont. K0J 1J0, Canada
*Phys. Dept., Univ. of Washington, Seattle, Washington 98195, U.S.A.
**Queen's Univ., Kingston, Ontario, Canada K7L 3N6
††California Inst. of Technology, Pasadena, California 91125, U.S.A.

Abstract: The parity nonconserving circular polarization of γ-rays from the 2.789 ± 0.0 MeV transition in ^{21}Ne is found to be $(0.8 \pm 1.4) \times 10^{-3}$, which corresponds to a parity mixing matrix element $|\langle H_W \rangle| = 0.009 \pm 0.016$ eV between the two members of the 2.8 MeV doublet. This matrix element can be combined with parity mixing matrix elements measured in ^{18}F and ^{19}F to predict isoscalar and isovector weak nucleon-nucleon coupling constants in excellent agreement with theoretical "best" values obtained in a Weinberg-Salam model calculation.

New Princeton Professor - suggested ^{21}Ne polarization

Will Happer

REVIEWS OF MODERN PHYSICS VOLUME 44, NUMBER 2 APRIL 1972

Optical Pumping*

WILLIAM HAPPER
Columbia Radiation Laboratory, Department of Physics, Columbia University, New York, New York 10027

Optical pumping of ground-state and metastable atoms and ions is reviewed. We present a critical survey of the literature on pumping mechanisms, light propagation, relaxation mechanisms, spin exchange, and experimental details on the various atomic species which have been successfully pumped.

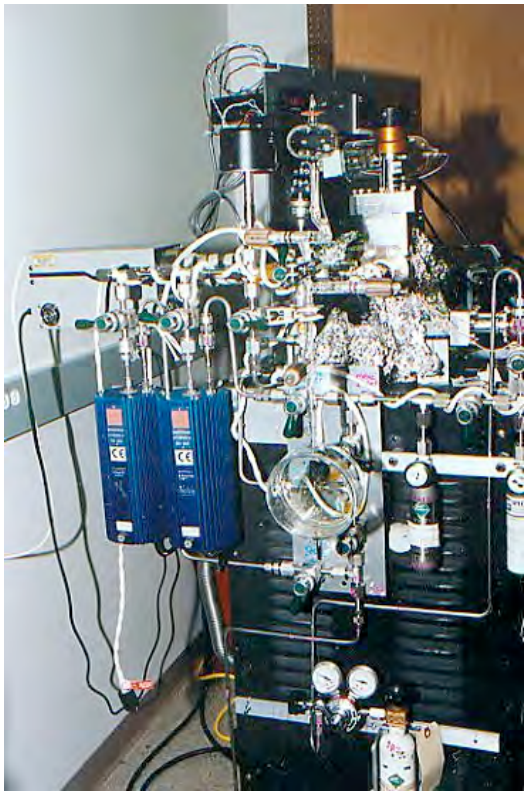
wrote the "Book" on Optical Pumping

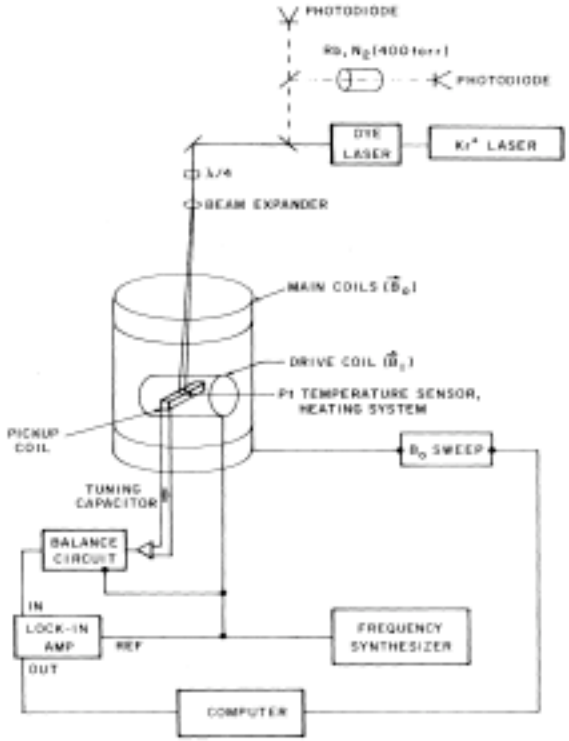
^{21}Ne polarization by Spin Exchange Optical Pumping:

Fill cells with Rb, gases (Happer is an expert glass blower)
N_2 supresses radiation trapping

Dye laser (LD700 pumped by Krypton-ion laser)

NMR to measure ^{21}Ne polarization





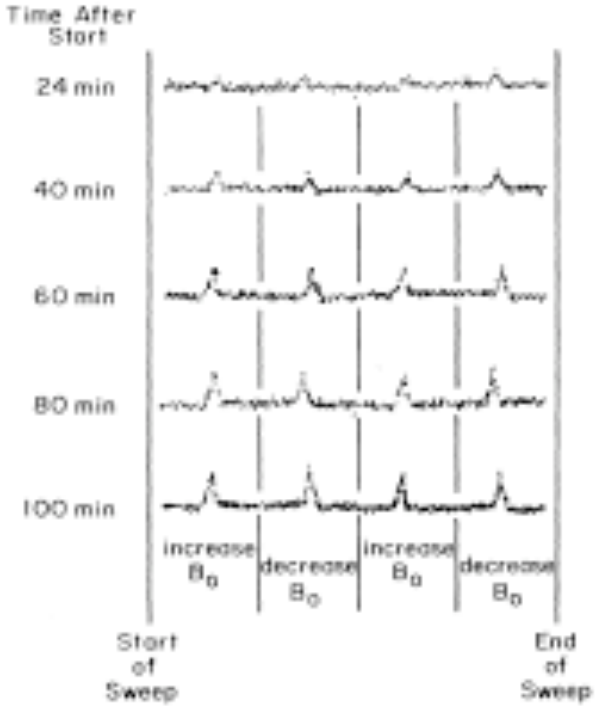
VOLUME 55, NUMBER 10 PHYSICAL REVIEW LETTERS 2 SEPTEMBER 1985

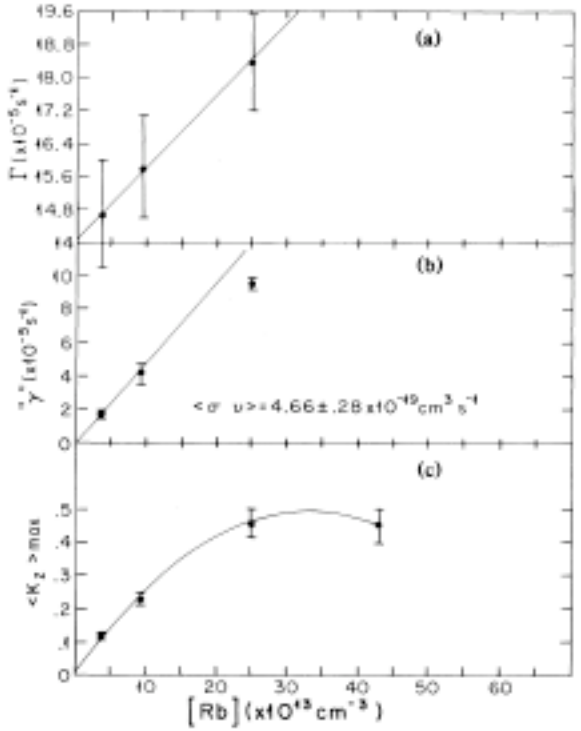
Polarization of ^{21}Ne by Spin Exchange with Optically Pumped Rb Vapor

T. E. Chupp and K. P. Coulter
Joseph Henry Laboratory of Physics, Princeton University, Princeton, New Jersey 08544
(Received 17 June 1985)

We report investigations of spin exchange between ^{21}Ne nuclei and optically pumped Rb vapor. Polarization of 30% ($\langle K_z \rangle = 0.46$) of 2×10^{19} atoms-cm^{-3} has been achieved with a vapor pressure of 3×10^{14} atoms-cm^{-3} of Rb. This high density of alkali metal can be efficiently optically pumped only when light trapping is suppressed by inclusion of at least 100 Torr of N_2. In addition, we have made the first accurate measurement of the binary-collision spin-exchange rate: $\langle \sigma_{ex} v \rangle = (4.66 \pm 0.28)\times10^{-19}$ cm^3-s^{-1}. Extension of these techniques to ^{3}He has yielded 5% polarization of 2×10^{19} atoms-cm^{-3} in a preliminary experiment.

PACS numbers: 32.80.Bx, 29.25.Kf





N_2 “solves radiation trapping problem” - high [Rb] possible - ^{3}He?

PHYSICAL REVIEW C VOLUME 36, NUMBER 6 DECEMBER 1987

Polarized, high-density, gaseous ^{3}He targets

T. E. Chupp and M. E. Wagshul
The Physics Laboratories, Harvard University, Cambridge, Massachusetts 02138

K. P. Coulter, A. B. McDonald, and W. Happer
Joseph Henry Laboratories of Physics, Princeton University, Princeton, New Jersey 08544
(Received 3 June 1987)

The technique of spin exchange between laser optically pumped alkali-metal vapor and ^{3}He can provide several atm cm^{-3} ($\approx 10^{23}$ atoms in a volume of 6 cm^3) of nearly 100% polarized ^{3}He. We have recently produced 40% polarization of 10^{20} atoms of ^{3}He (3 atm in 1.3 cm^3). It should therefore be possible to produce useful polarized ^{3}He targets by this technique. The realization of a practical target is limited by the contribution to depolarization by ionization during bombardment. This has been studied with a 360-nA, 18-MeV α-particle beam with encouraging results. A ^{3}He target with 50–90 % polarization and a thickness of 10^{20} atoms cm^{-2} is feasible. This paper presents the principles of the technique, the recent progress on spin exchange with optically pumped alkali-metal vapor, and studies of ionization-induced depolarization.

Polarized ^{3}He of density ($\approx 10^{21}$ atoms cm^{-3}) and polarization (50–90 %) sufficient for a nuclear target can be produced by spin exchange with optically pumped Rb or K. Such a target has several exciting new applications including investigations of the quasielastic and Δ regions in polarized electron scattering and measurement of the electric form factor of the neutron,[1,2] study of nuclear parity violation[3,4] in ^{4}He and ^{19}Ne, and polarization and polarimetry of neutrons with energies[5] up to 10 eV for sensitive tests of parity and time reversal invariance in resonant neutron capture.[6,7] Since spin exchange is mediated by the hyperfine interaction of the alkali-metal electron with the ^{3}He nucleus during the 10^{-12}-s binary collision time, it is a very weak process. Carefully chosen target-cell wall materials and a high density of alkali-metal atoms are needed in order that the ^{3}He polarization rate be much greater than the wall relaxation rates. Contribution to relaxation of polarization due to ionization produced during bombardment must also be minimized.

Paul Sokol at Harvard told me about neutron polarization - neutron scatterers expected high density (solid/liquid) samples

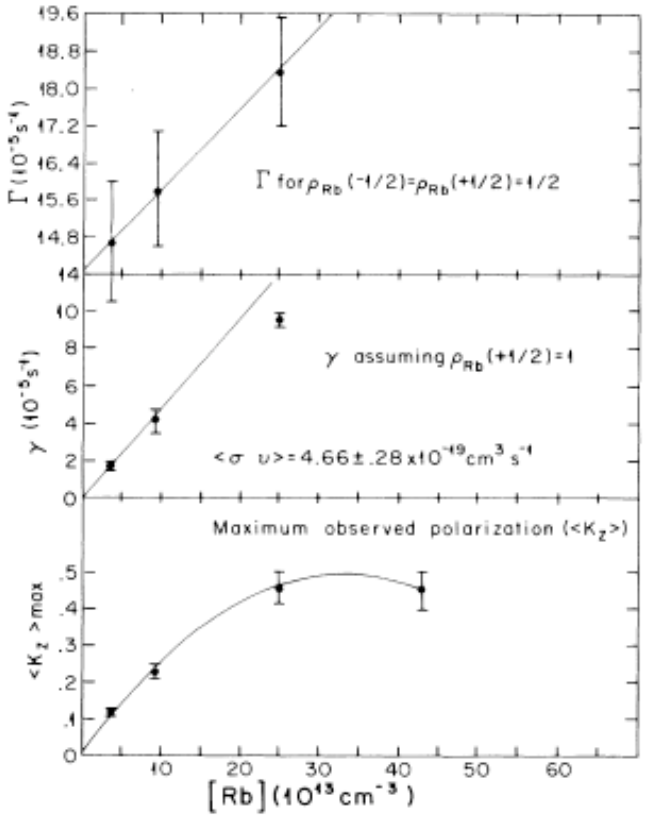
Why not a gas?

It wasn't Easy

$$P_3 = P_{Rb}\,\frac{k_{SE}[Rb]}{k_{SE}[Rb]+\Gamma_3}$$

$k_{SE}[Rb]$ ⟵ rate (1/many hours)

Γ_3 ⟵ relaxation (contaminants)



Cells with >1 bar ^{3}He were filled and sealed under liquid nitrogen.
Possible cryopuming of residual gas - O_2.

Kevin Coulter's PhD at Los Alamos

90 Nuclear Instruments and Methods in Physics Research A270 (1988) 90–94
North-Holland, Amsterdam

NEUTRON POLARIZATION WITH POLARIZED ^{3}He

K.P. COULTER, A.B. McDONALD and W. HAPPER
Physics Department, Princeton University, Princeton, New Jersey 08544, USA

T.E. CHUPP and M.E. WAGSHUL
Physics Department, Harvard University, Cambridge, Massachusetts 02138, USA

Received 4 January 1988

An effective polarizer for thermal and epithermal neutrons is possible with polarized, high density, gaseous ^{3}He. We describe the technique of ^{3}He polarization by spin exchange with laser optically pumped Rb vapor which can provide 6 cm^3 of > 70% polarized ^{3}He at a density of 3×10^{20} atoms cm^{-3} (10 atm at STP). The ^{3}He polarization can be rapidly reversed, a requirement for sensitive symmetry tests.

Nuclear Instruments and Methods in Physics Research A288 (1990) 463–466
North-Holland

NEUTRON POLARIZATION WITH A POLARIZED ^{3}He SPIN FILTER

K.P. COULTER [1] *, T.E. CHUPP [2], A.B. McDONALD [1] **, C.D. BOWMAN [3], J.D. BOWMAN [3], J.J. SZYMANSKI [3], V. YUAN [3], G.D. CATES [1], D.R. BENTON [1] and E.D. EARLE [4]

[1] *Princeton University, Princeton, NJ 08540, USA*
[2] *Harvard University, Cambridge, MA 02138, USA*
[3] *Los Alamos National Laboratories, Los Alamos, NM 87545, USA*
[4] *Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada K0J1J0*

Received 28 August 1989

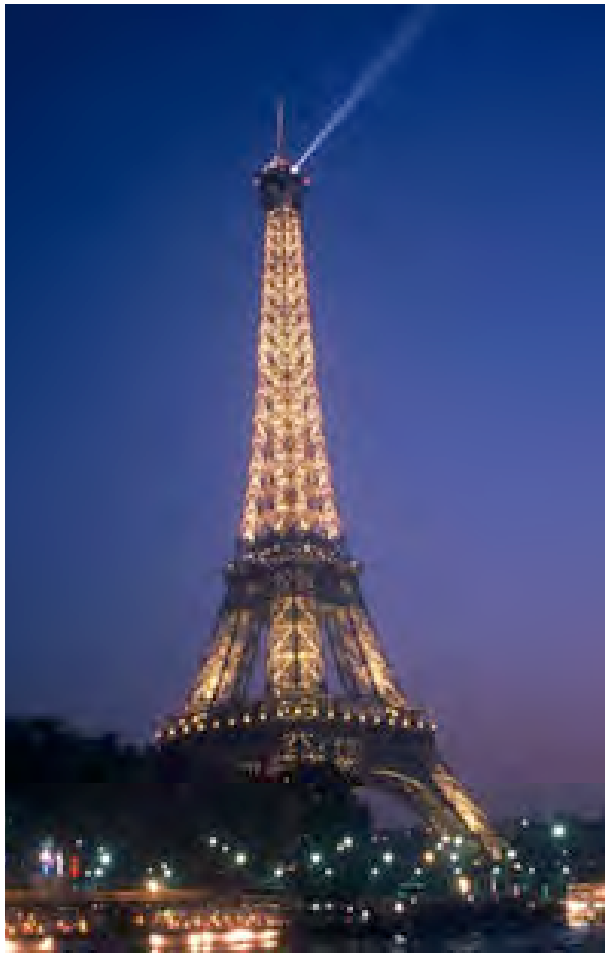
We report the first use of a polarized ^{3}He spin filter to polarize epithermal neutrons. The ^{3}He was polarized to 70% by spin exchange with optically pumped Rb vapor and had a cross sectional area of 0.65 cm^2 and a thickness of 3×10^{20} atoms cm^{-2} of ^{3}He. Neutron polarization up to 20% at 0.734 eV was produced in an epithermal neutron beam at the Los Alamos Neutron Scattering Center and measured by observing the change in neutron transmission produced by the ^{3}He polarization and also the helicity dependent transmission for a parity-nonconserving resonance in ^{139}La.

198? - Francis contacts Ecole-normal group (Leduc, Tastevin, Nacher)

Michèle Leduc

Michèle invited Francis and me to Paris to meet in her office.

Francis LOVED Paris

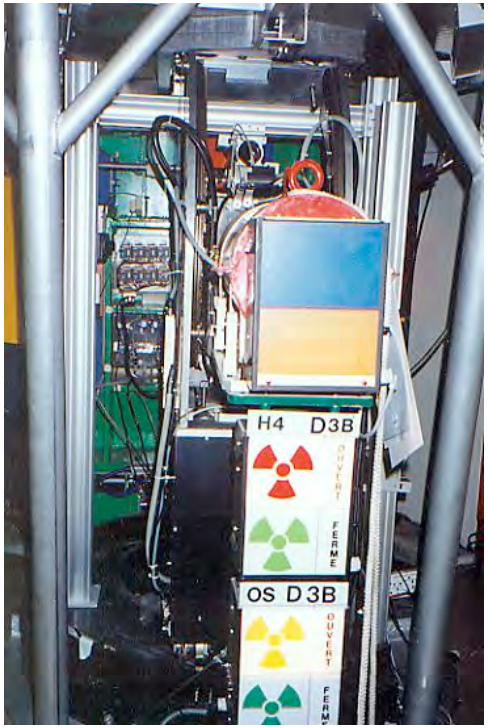


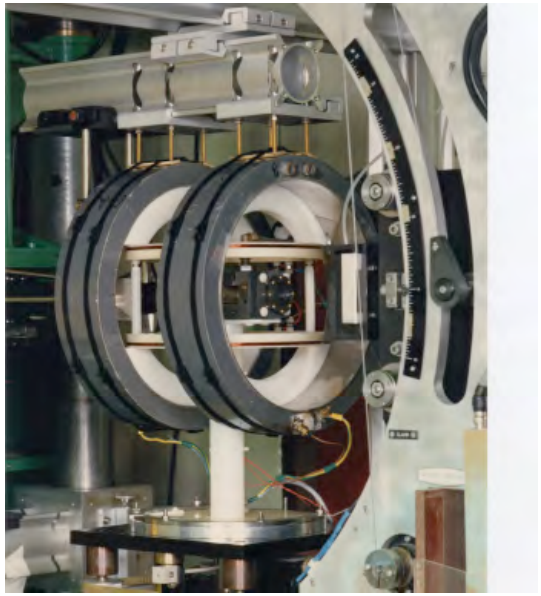
Restaurants, museums, CONCERTS

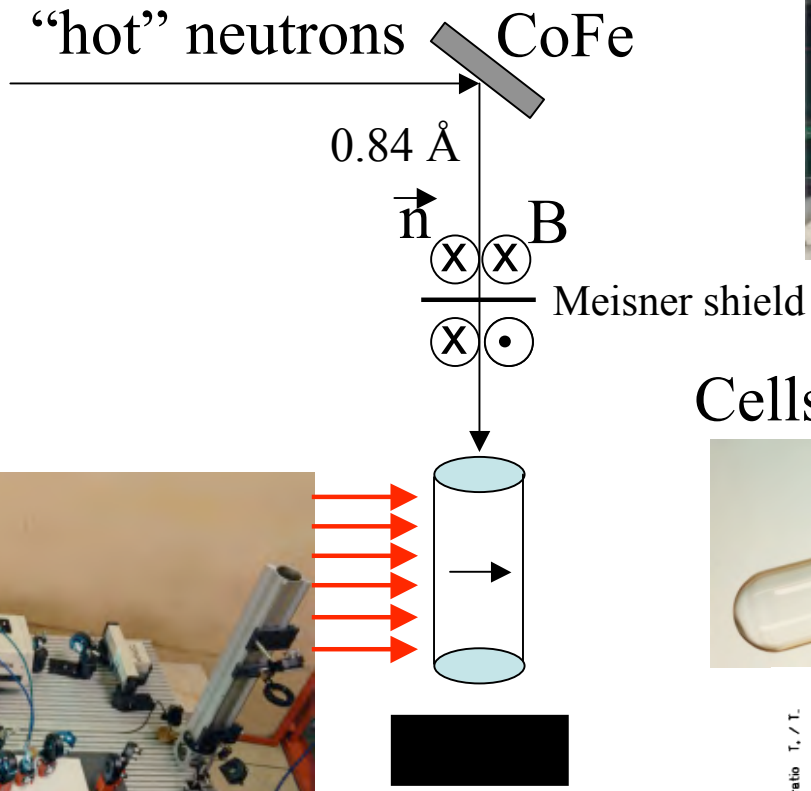
And then on to Grenoble

By the time I departed - we were friends for life
AND
We agreed to do a “test” on D3

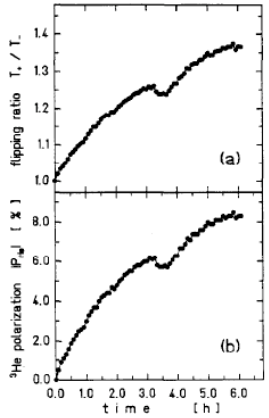
The Idea

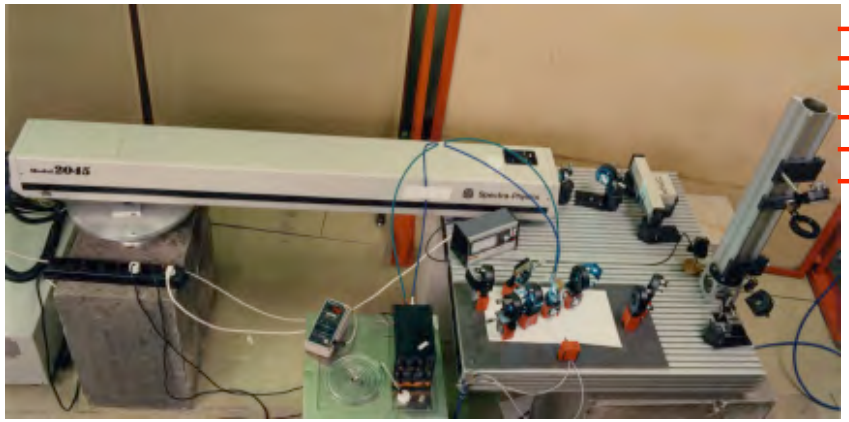






Cells from Harvard

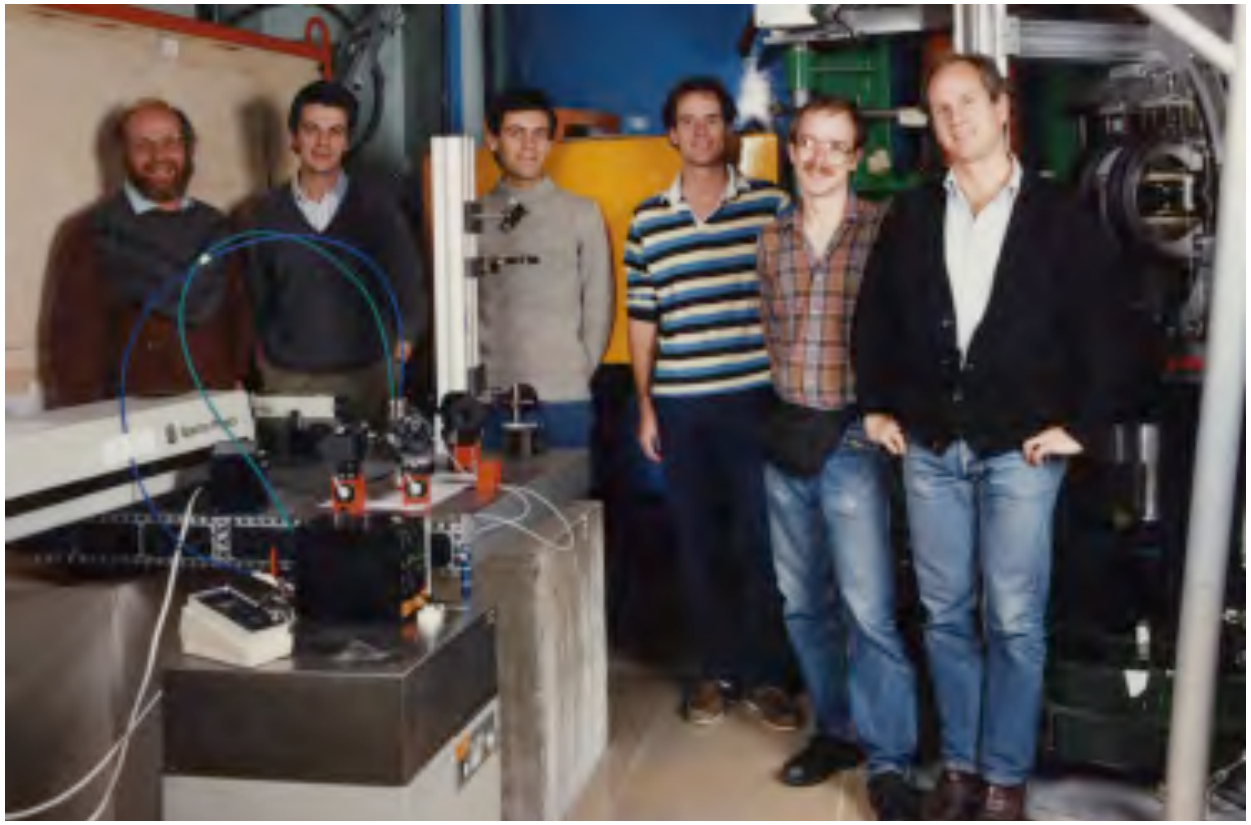




Ti-Sapphire Laser (Jean Paul Pique)

Ar^{++} laser rented from SpectraPhysics

The Team

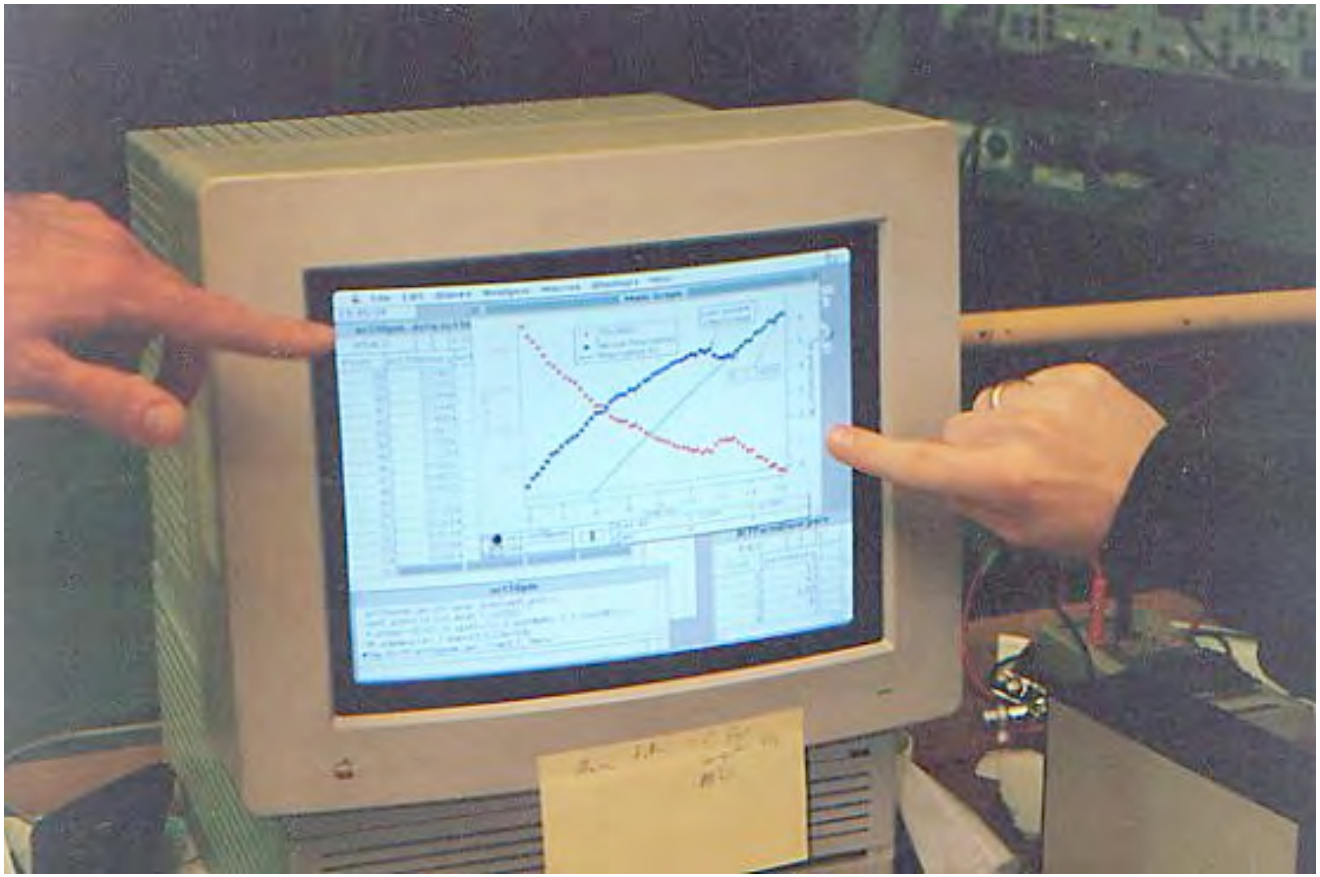


Francis, J.P. Pique, M. Ziade, E. Wasserman, A. Thompson, TC

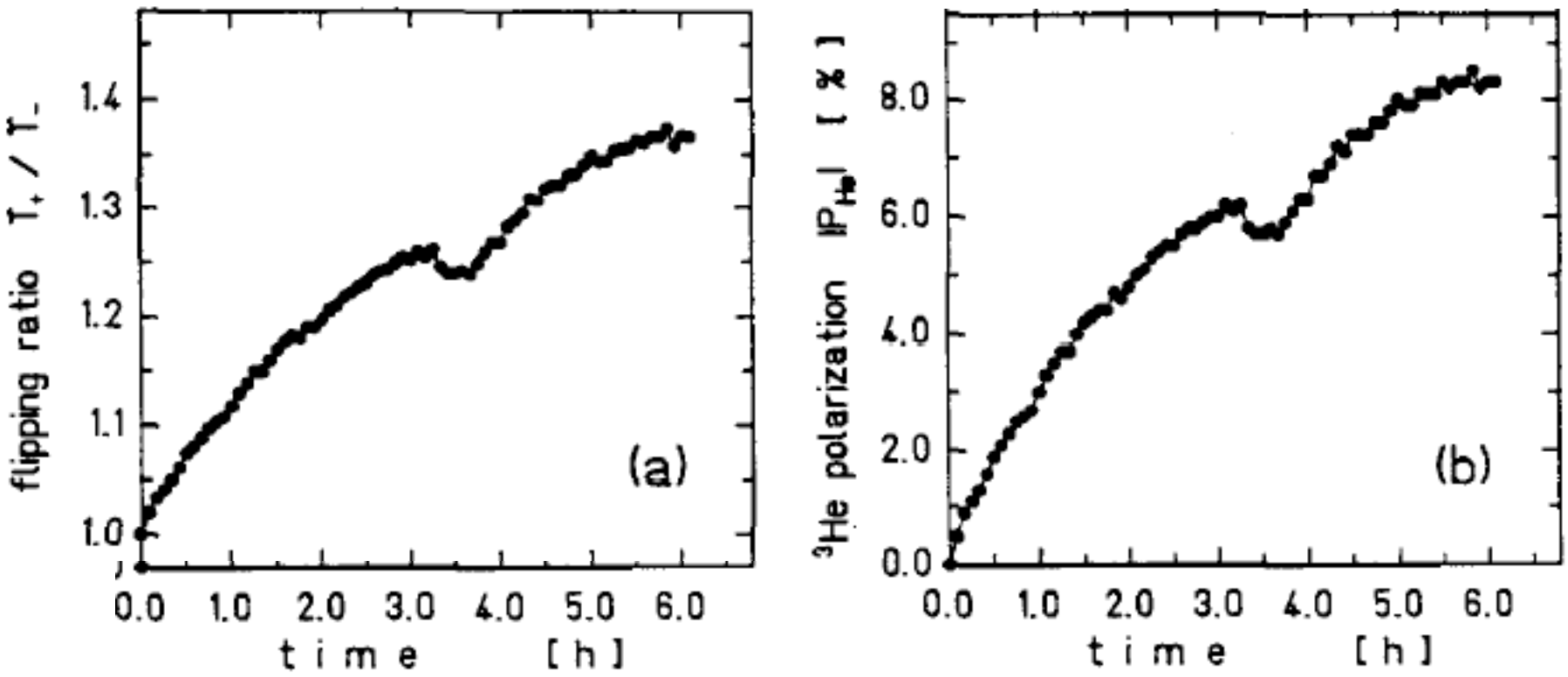
The Team at Work

Mustafha, Alan, Francis, Axel Steinhof

The Team at Work

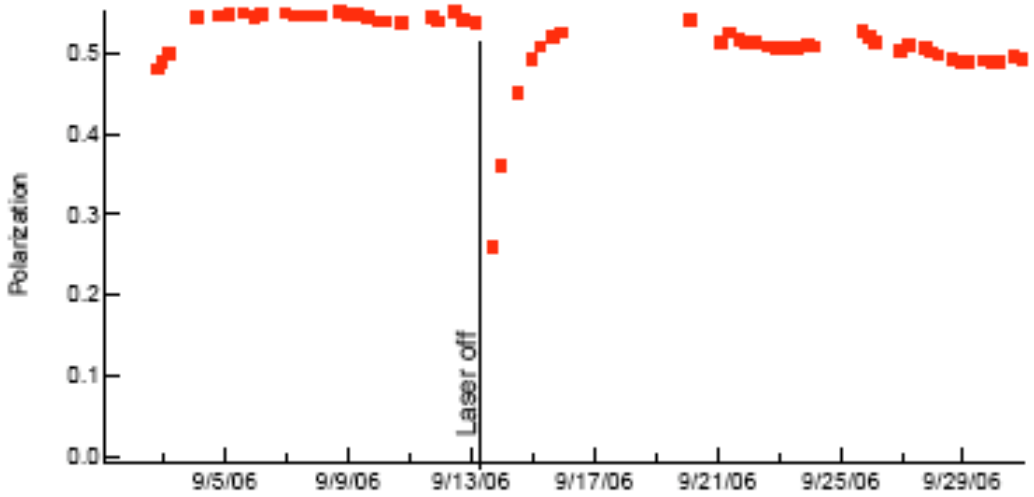


Is it working?



10 % maximum ^{3}He polarization (due to 2.3 hr cell lifetime)

^{3}He spin filter at Los Alamos



Spin Flipper

Detector (48 CsI Array)

^{3}He Spin Filter

n+p —> d + γ (LANSCE & SNS)

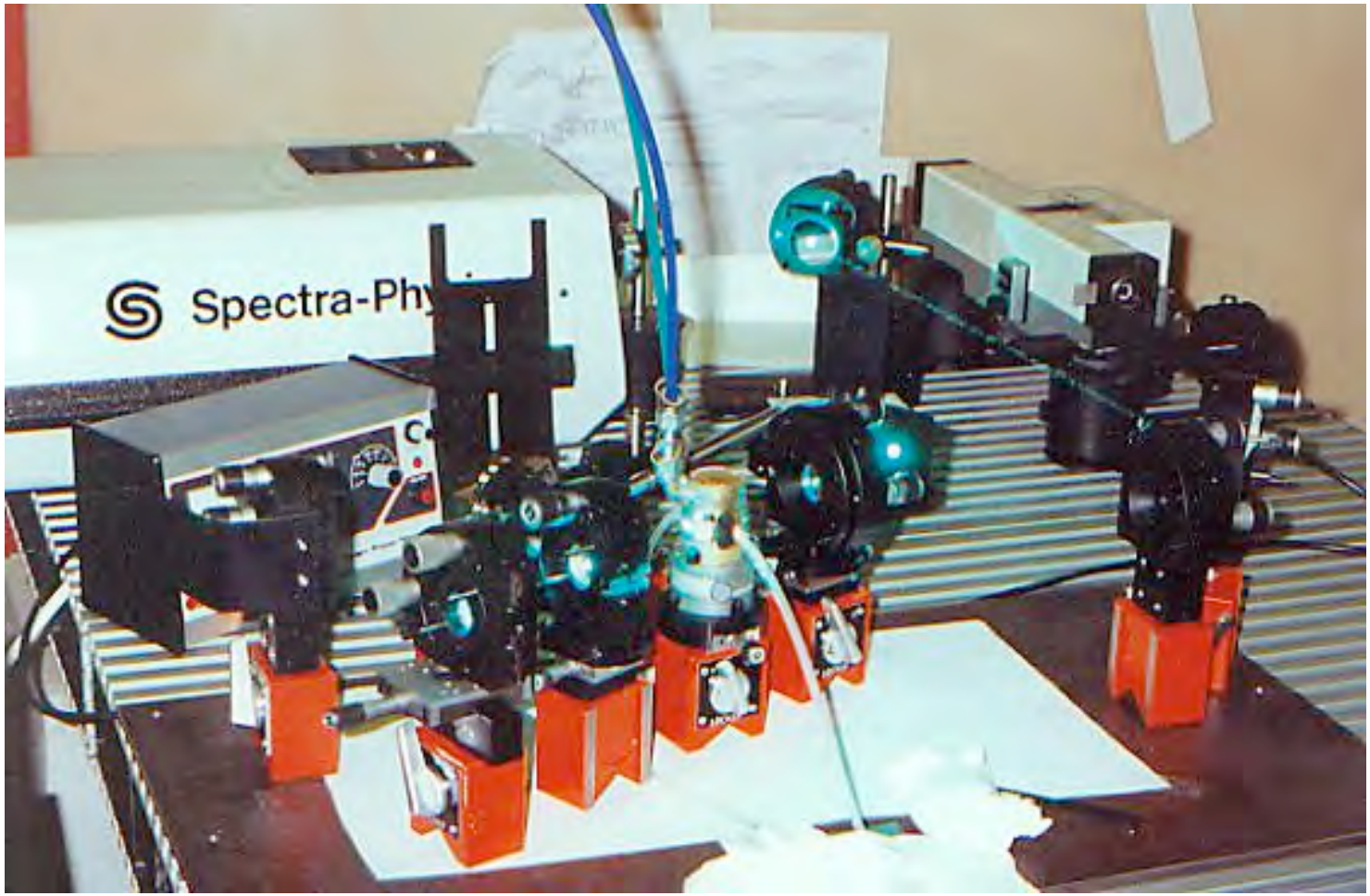
The Team at Work

"A friend of mine is shedding some light on the neutron beam."
F. Tasset

The Team at Work

How it’s really done.

Ti-sapphire laser



The Team after Work at Jasse des Fees


Congratulations Francis!
Martine, Marika, Ethan, Theo and Tim