Polarized target for J-PARC

Shigeru Ishimoto
KEK

International symposium on polarized target and its applications
29(Fri) Feb. -1(Sat) March 2008
Tukioka Hotel at Kaminoyama, Yamagata

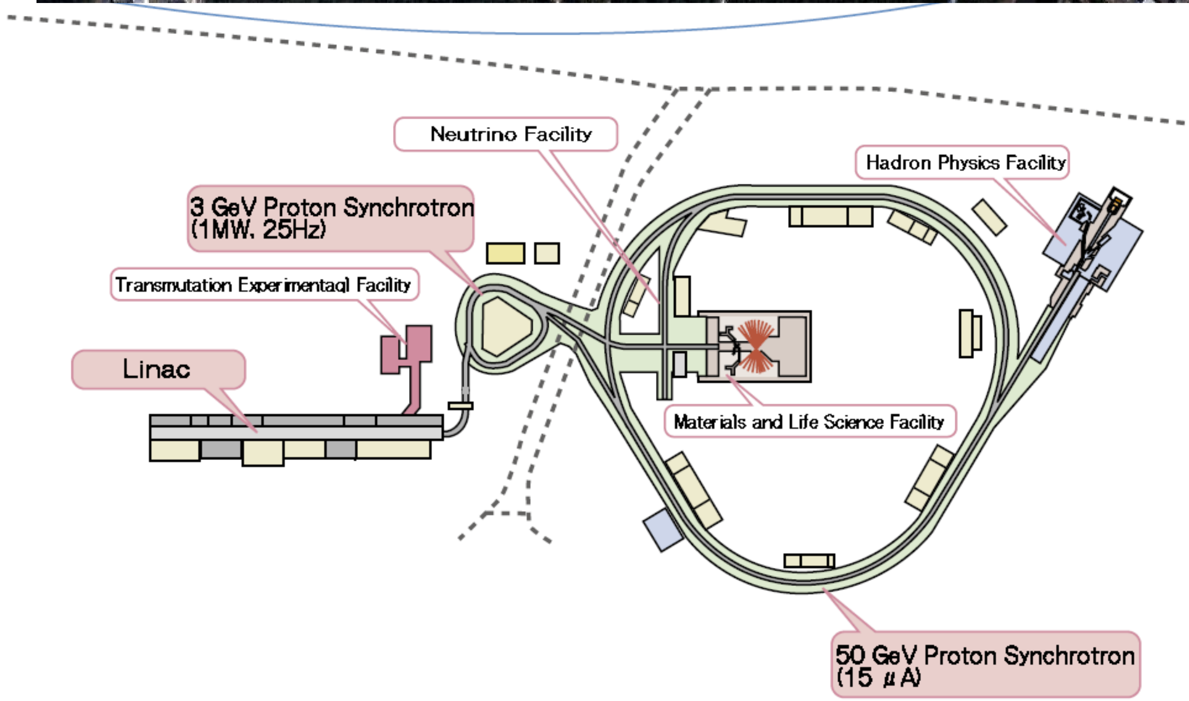
KEK/J-PARC Status

KEK; spin frozen p/d targets
(KEK/LosAlamos)
pol. proton filter for neutron beam
(KENS)

↓

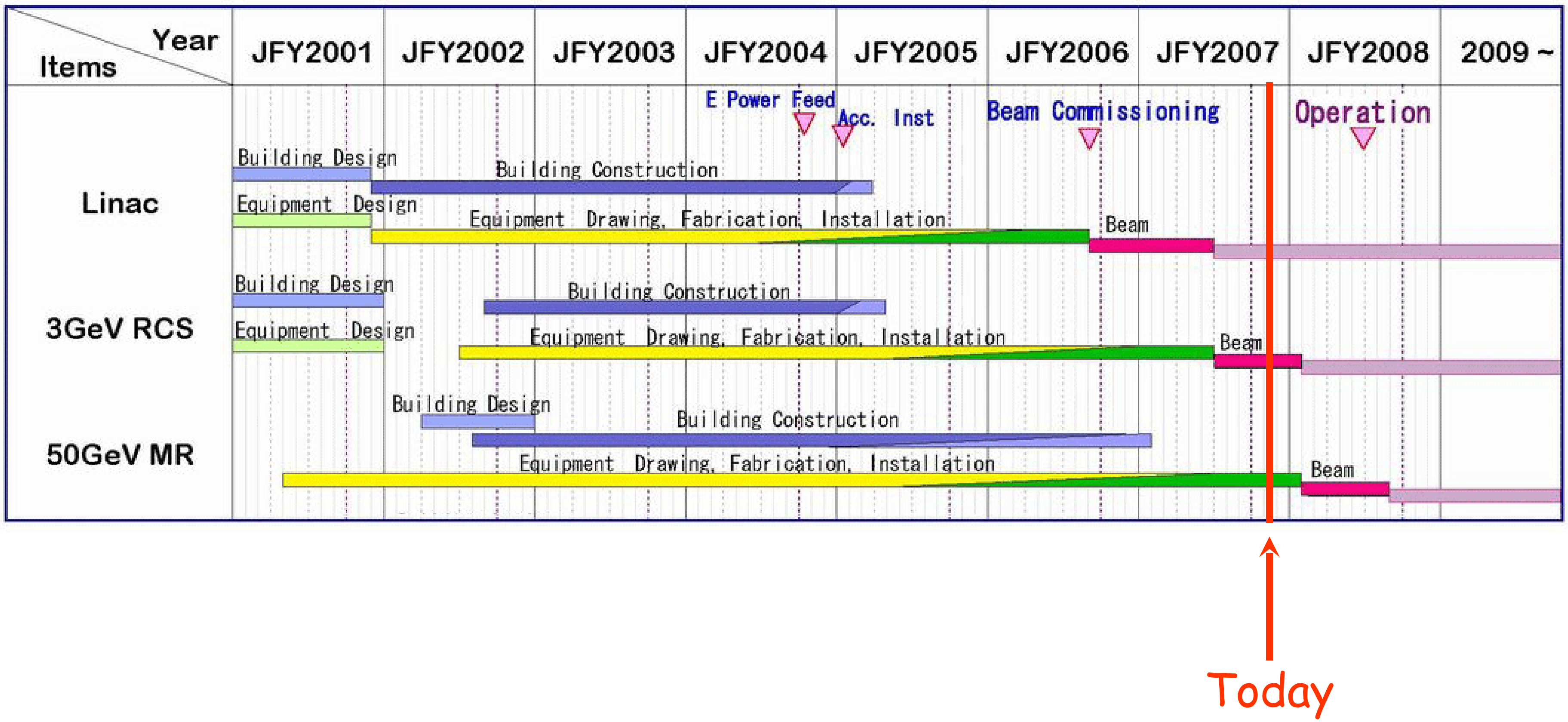
J-PARC; what new subjects?

J-PARC

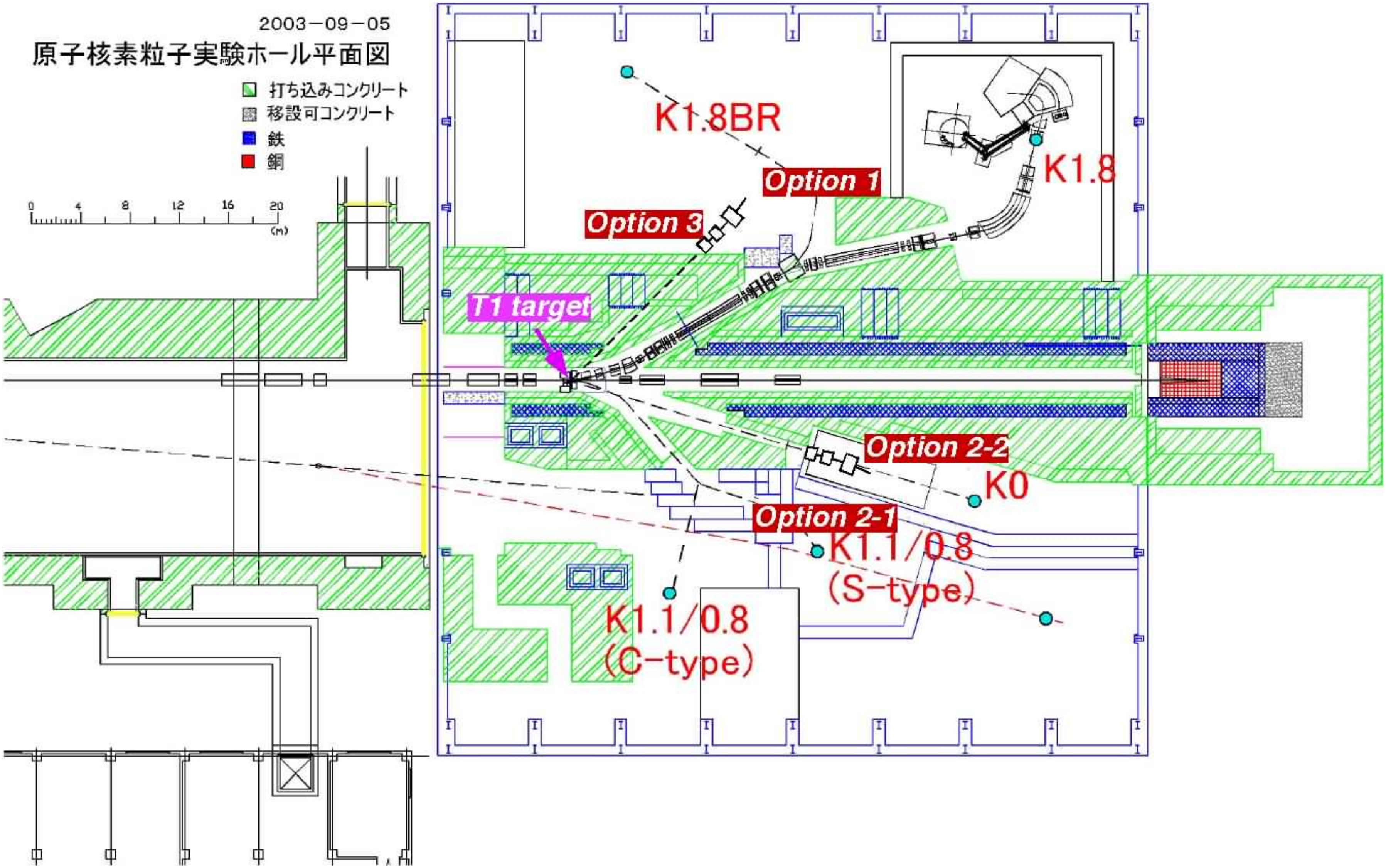


Neutrino Facility
Hadron Physics Facility
3 GeV Proton Synchrotron
(1MW, 25Hz)
Transmutation Experimentaql Facility
Linac
Materials and Life Science Facility
50 GeV Proton Synchrotron
(15 μA)

J-PARC Construction Schedule



J-PARC Hadron Hall

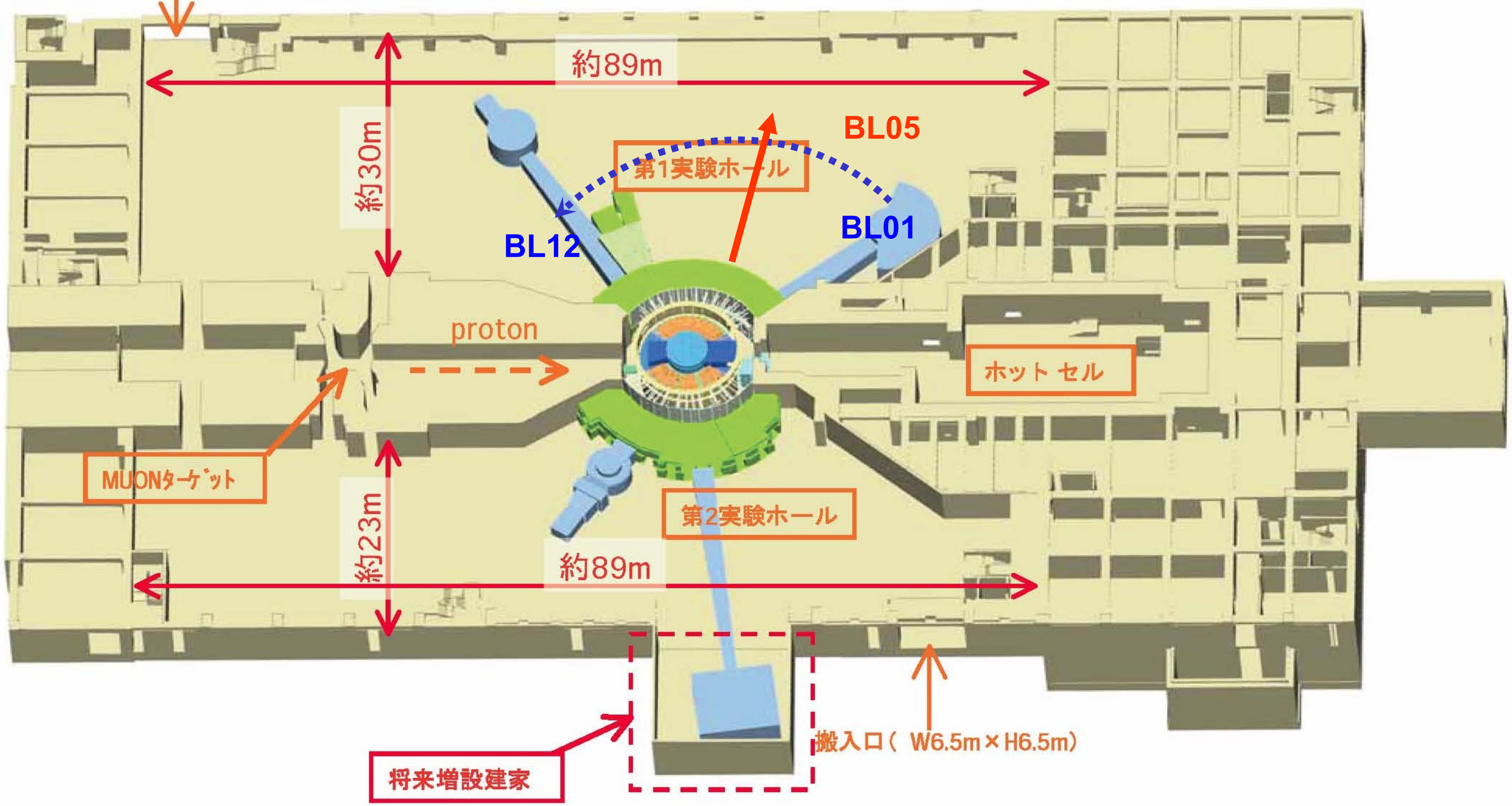


J-PARC Hadron Hall

J-PARC Hadron Hall

J-PARC, Jul-27, 2007

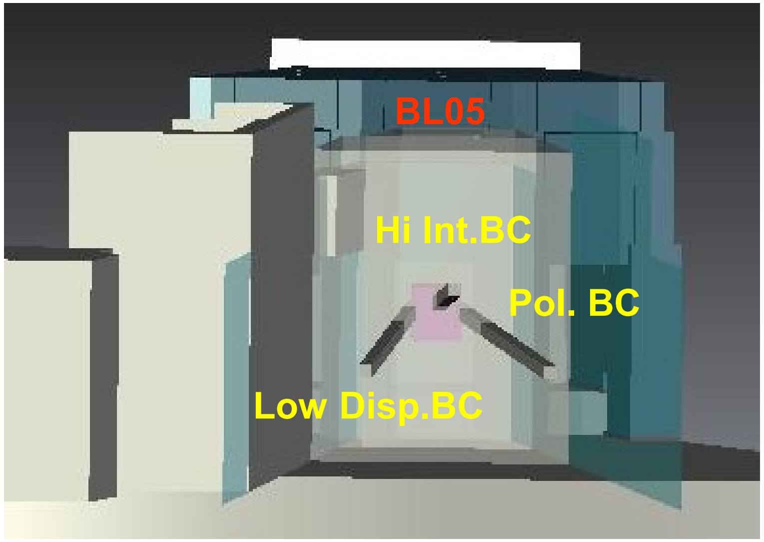
Materials and Life Science Facility (MLF)

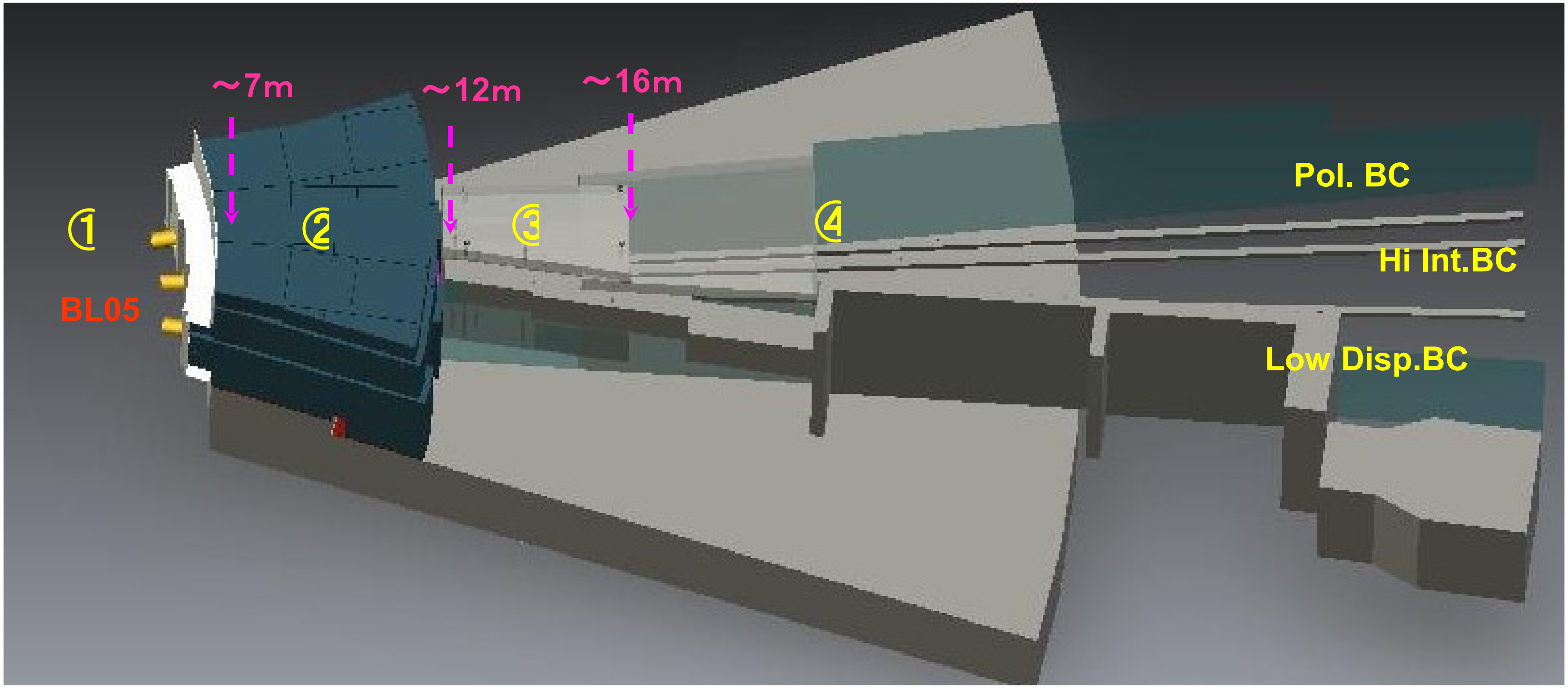


Materials and Life Science Facility (MLF)

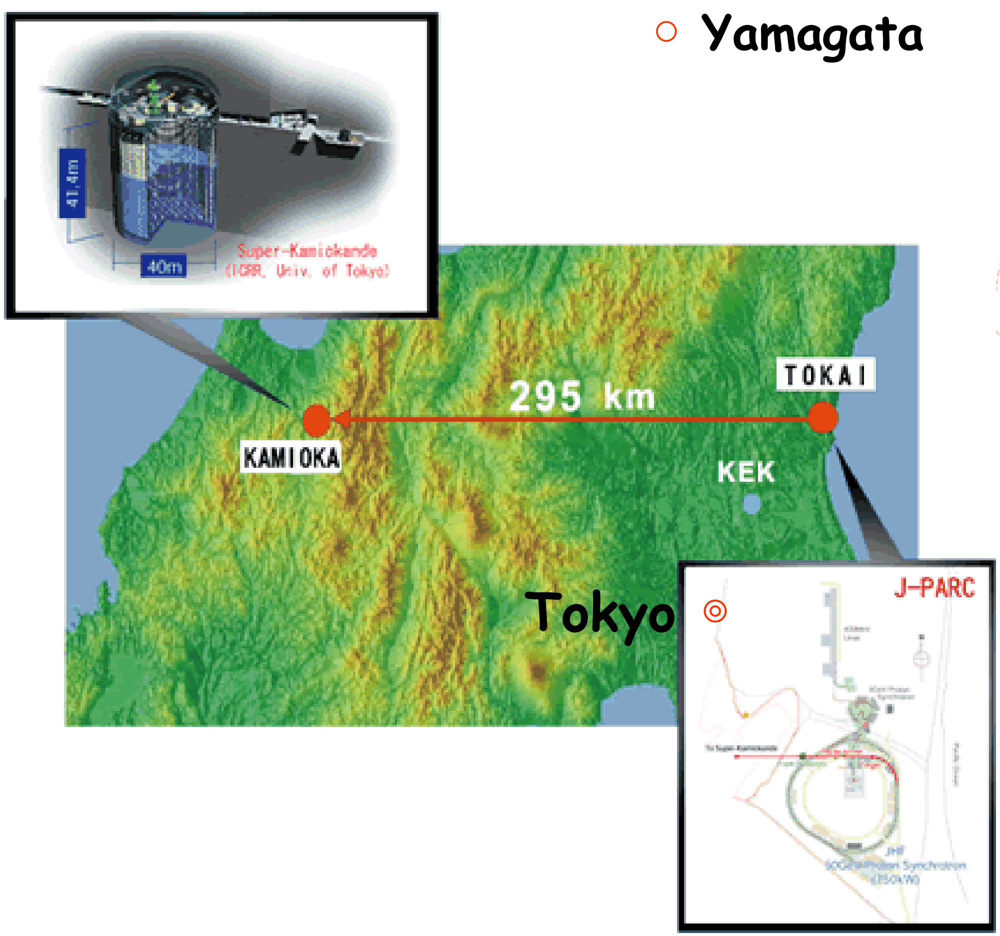
BL05(NOP) BEAM LINE

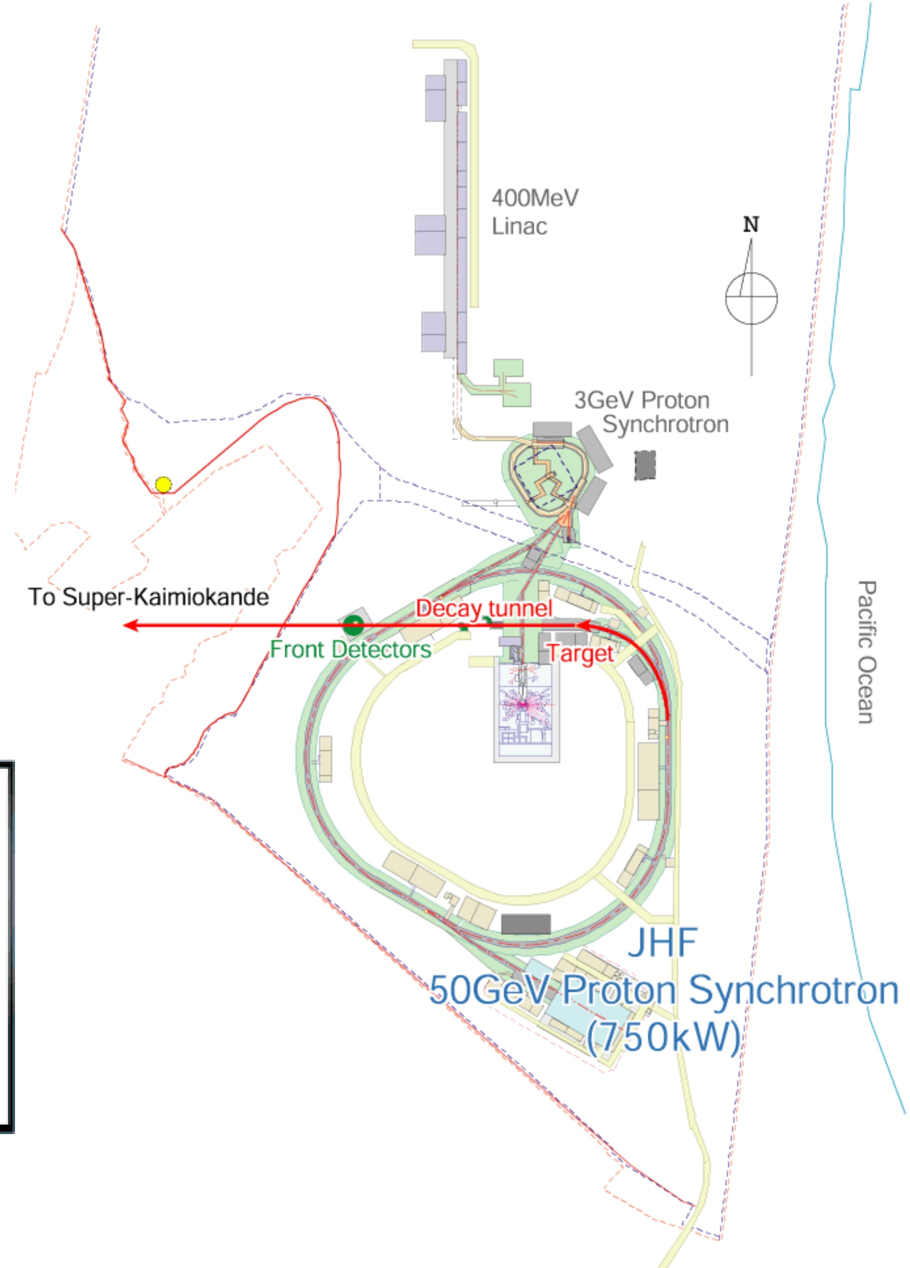
CROSSSECTION →





Neutrino (T2K) Tokai to Kamioka





Neutrino (T2K)

Michigan PPT System

J-PARC; (1) Neutron program
(2) Hadron program
(3) Target material R&D

Transfer the Michigan PPT System to J-PARC

R.S.Raymond (UM;left)

H.M.Shimizu (KEK;right)

A.D. Krisch (UM)

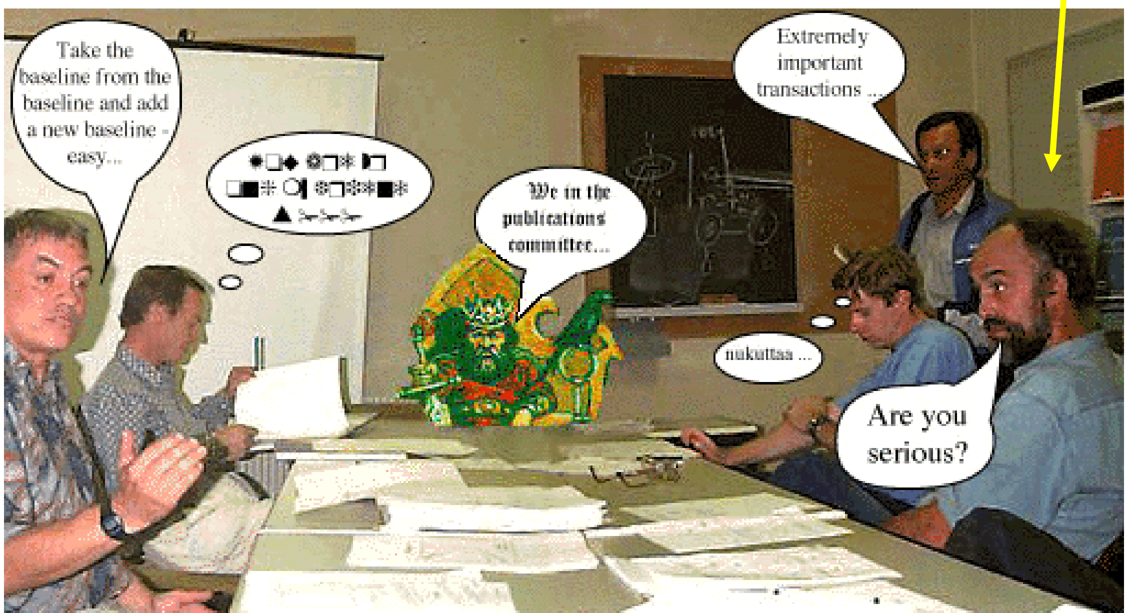
↓

K. Imai (Kyoto)

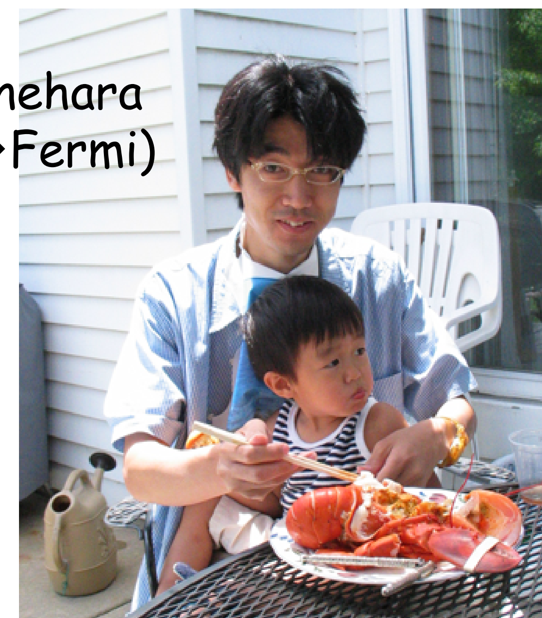
↓

KEK

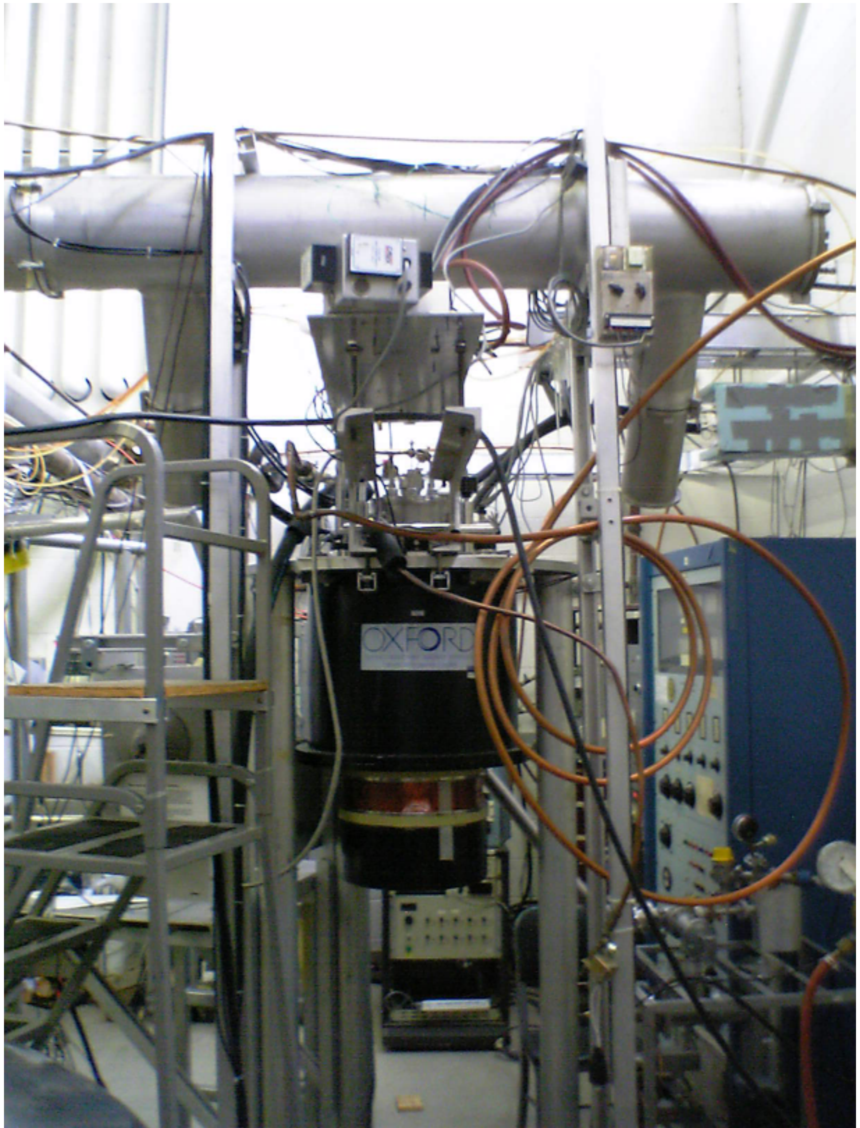
D.G. Crabb (Virginia)



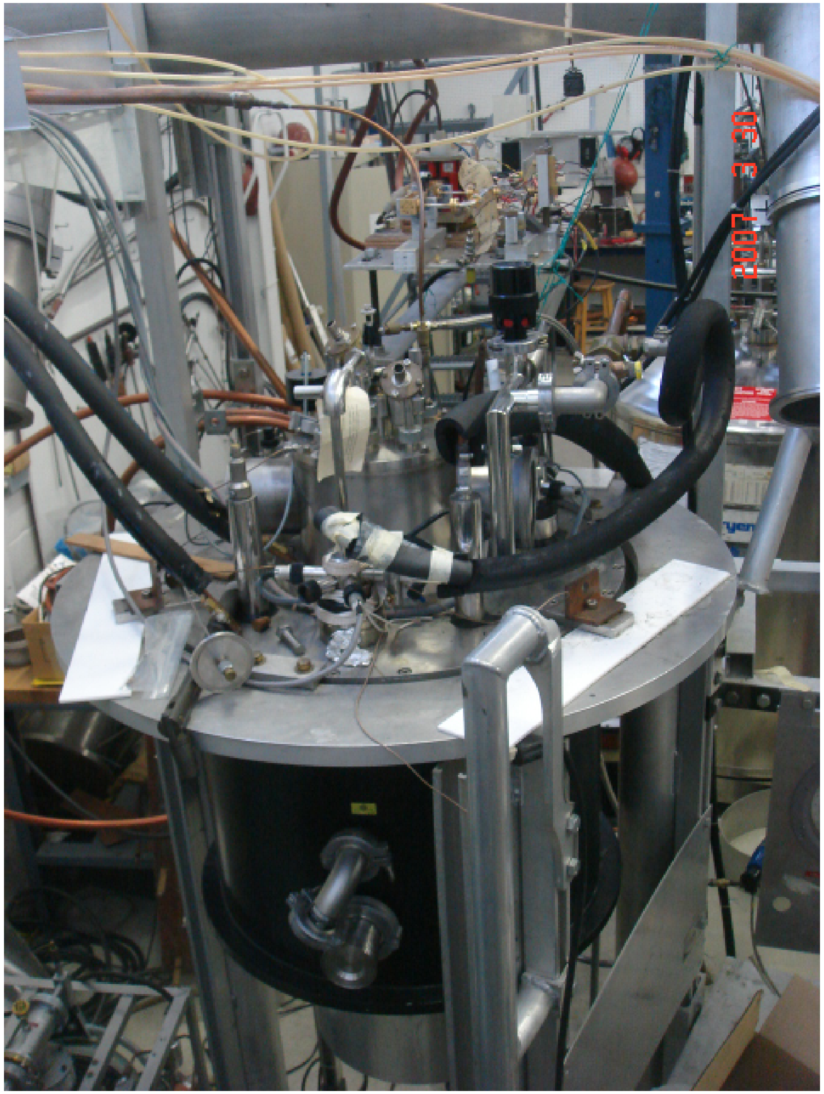
K. Yonehara (UM→Fermi)



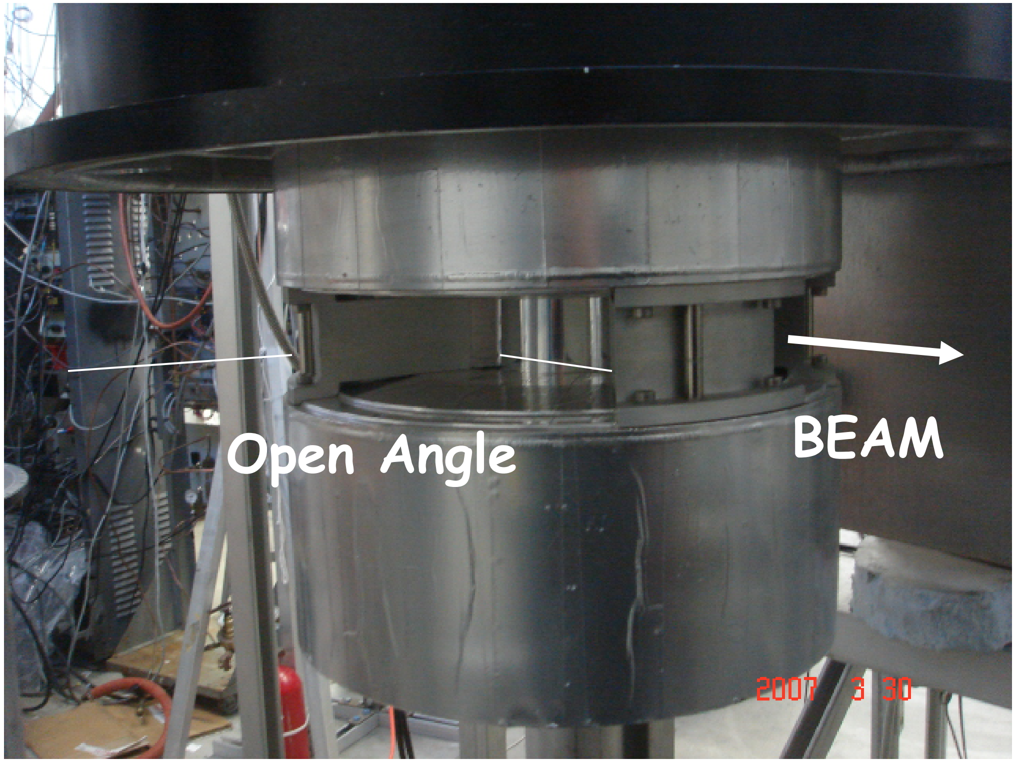
Michigan PPT System

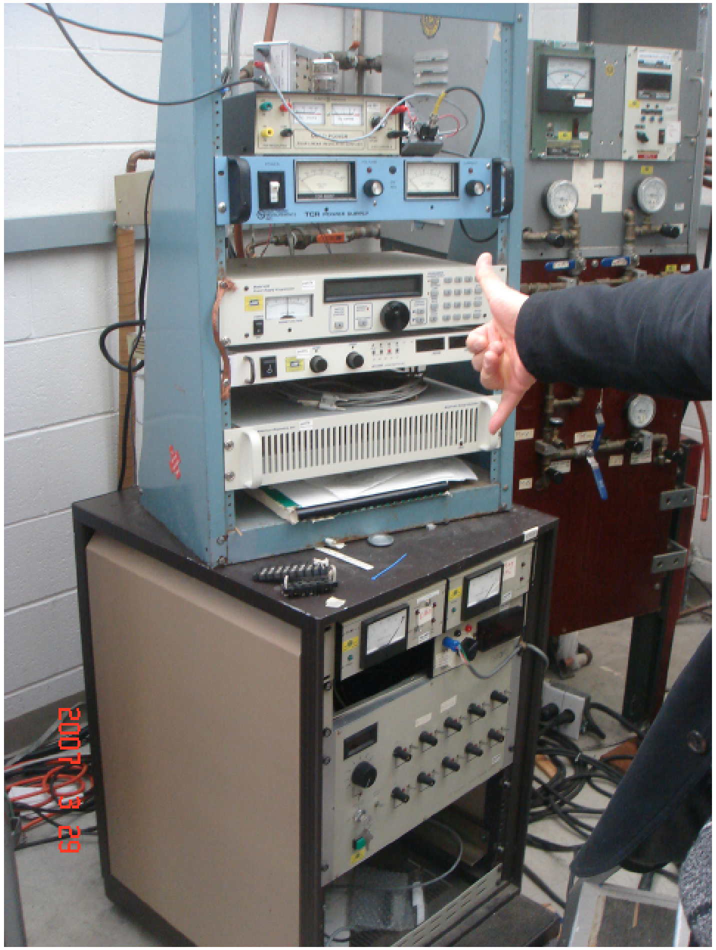


Michigan PPT System



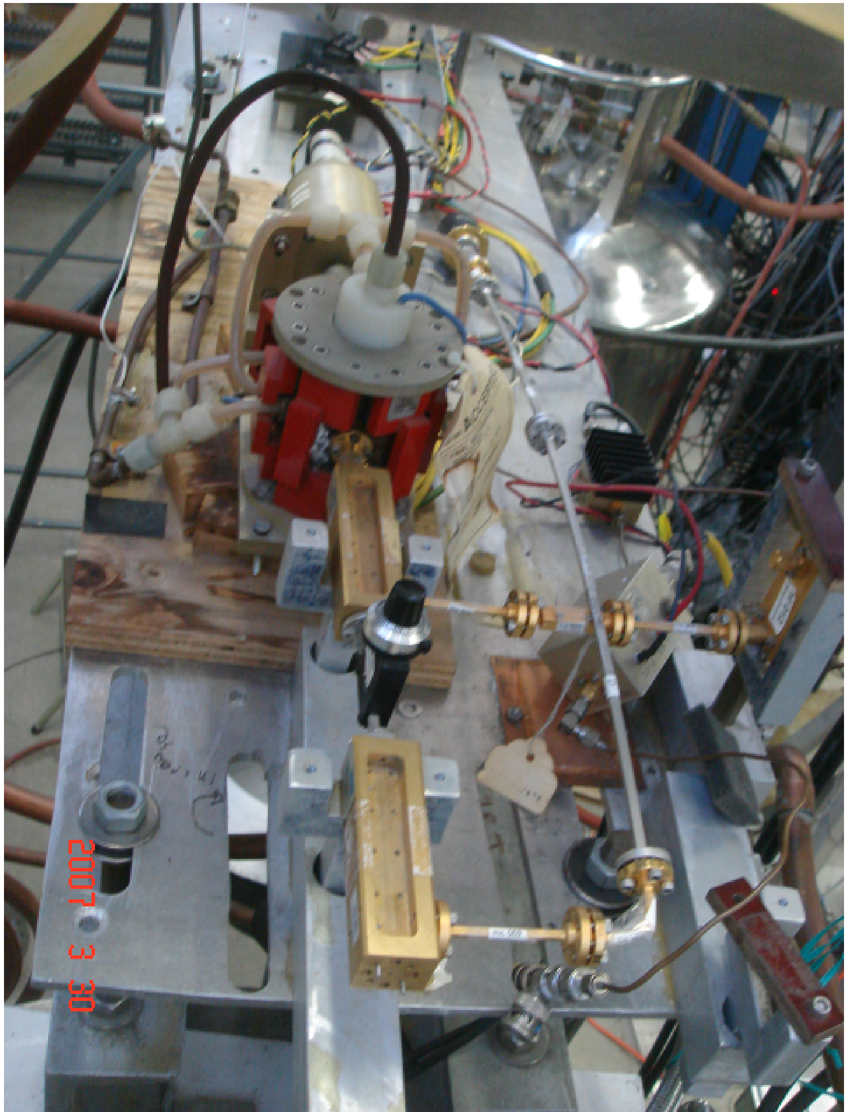
Michigan PPT System (5T SC Mag.)

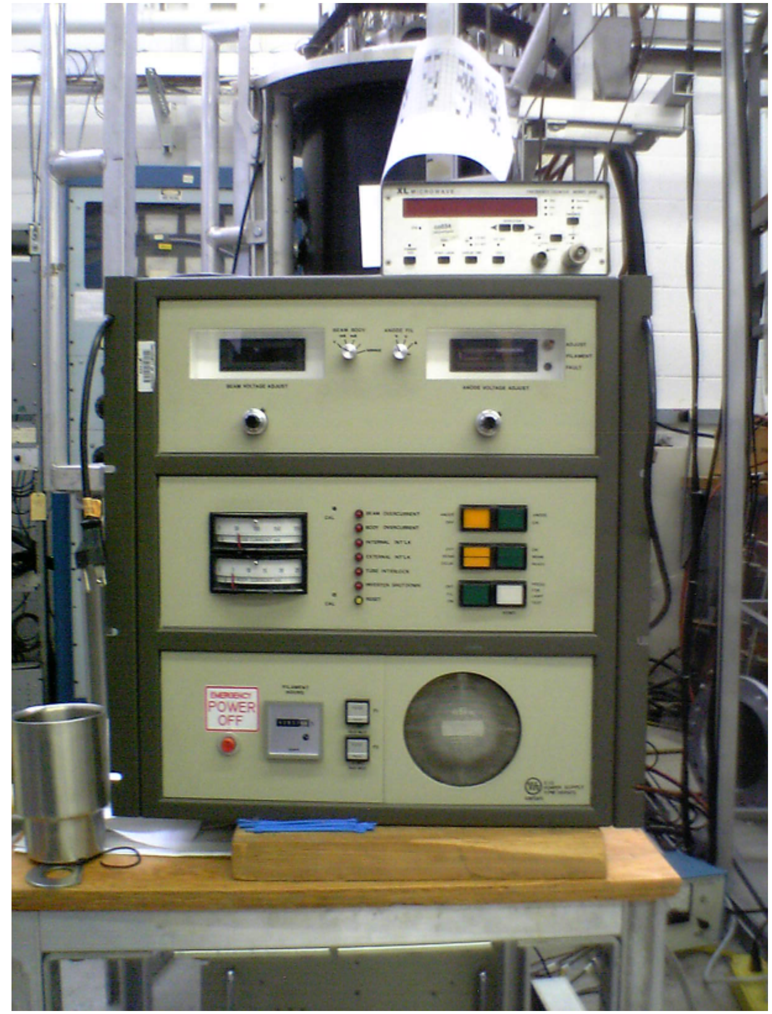




SC Mag. PS

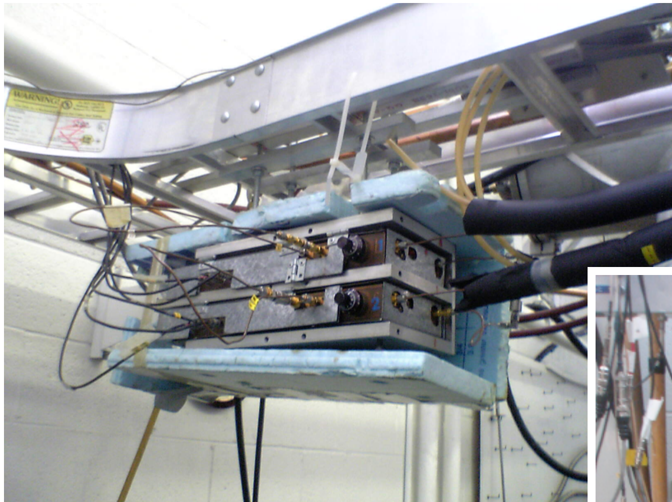
Michigan PPT System (EIO)





EIO(140GHz) and μW-P.S.

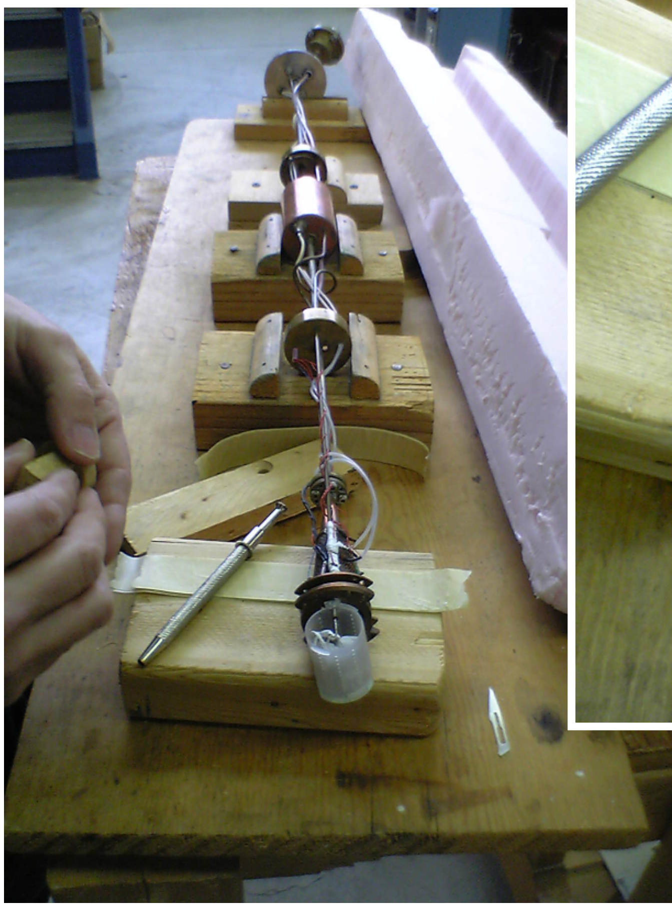
Michigan PPT System (NMR & NH_3)

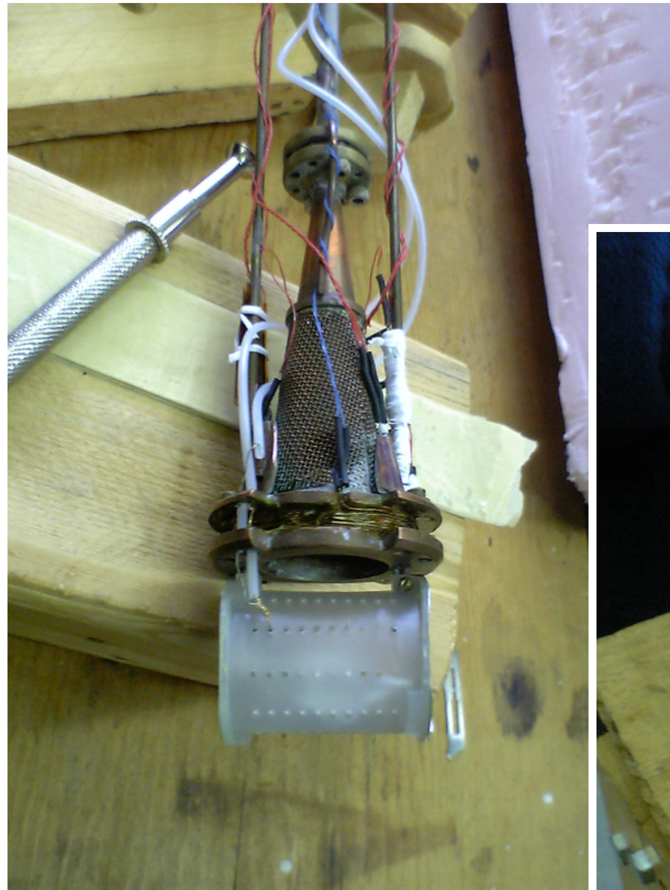


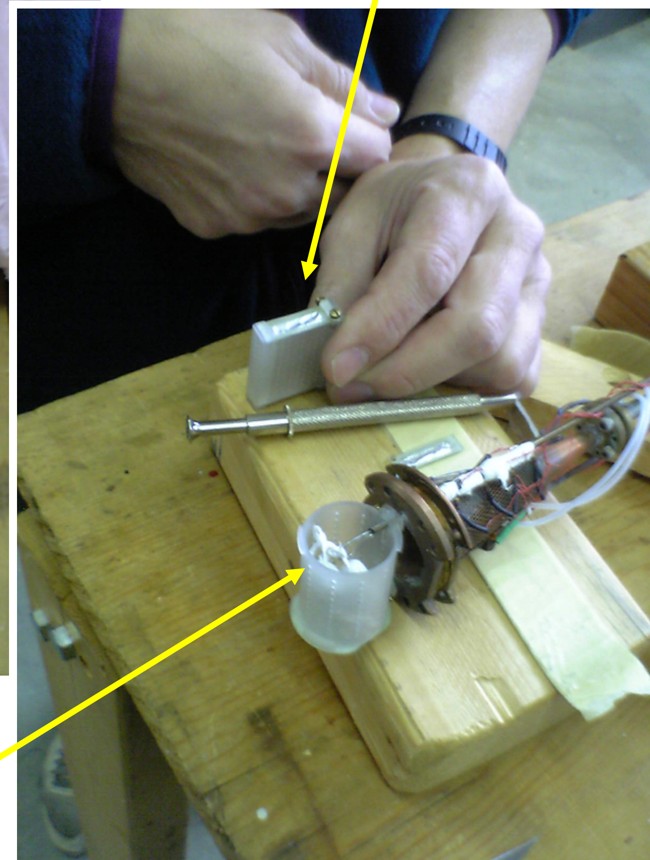
NMR (213MHz)

NH_3 Irradiation cryostat (L-Ar)

Michigan PPT System (Target Holder)







Target holders

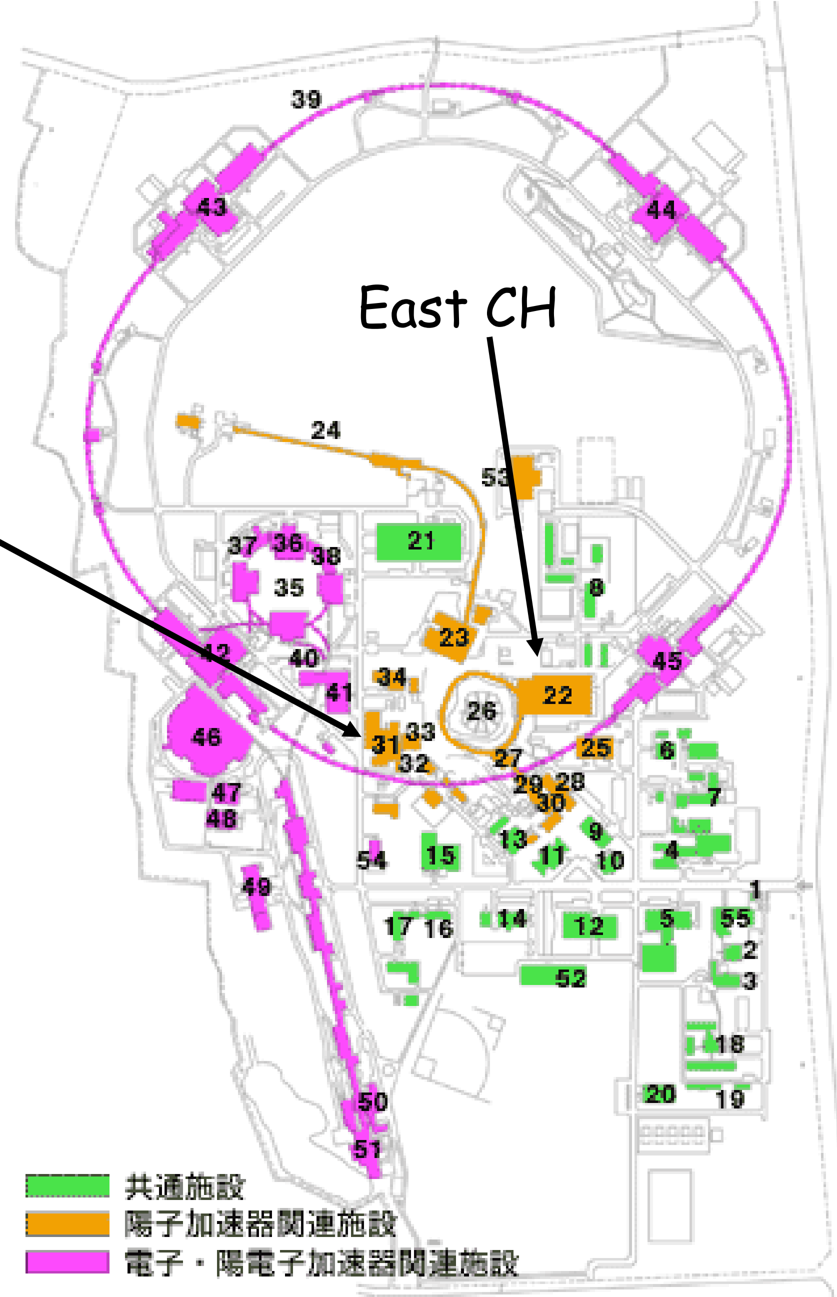
Teflon sample for NMR test

Michigan PPT System

arrived at East Counter Hall/KEK, Nov-2007

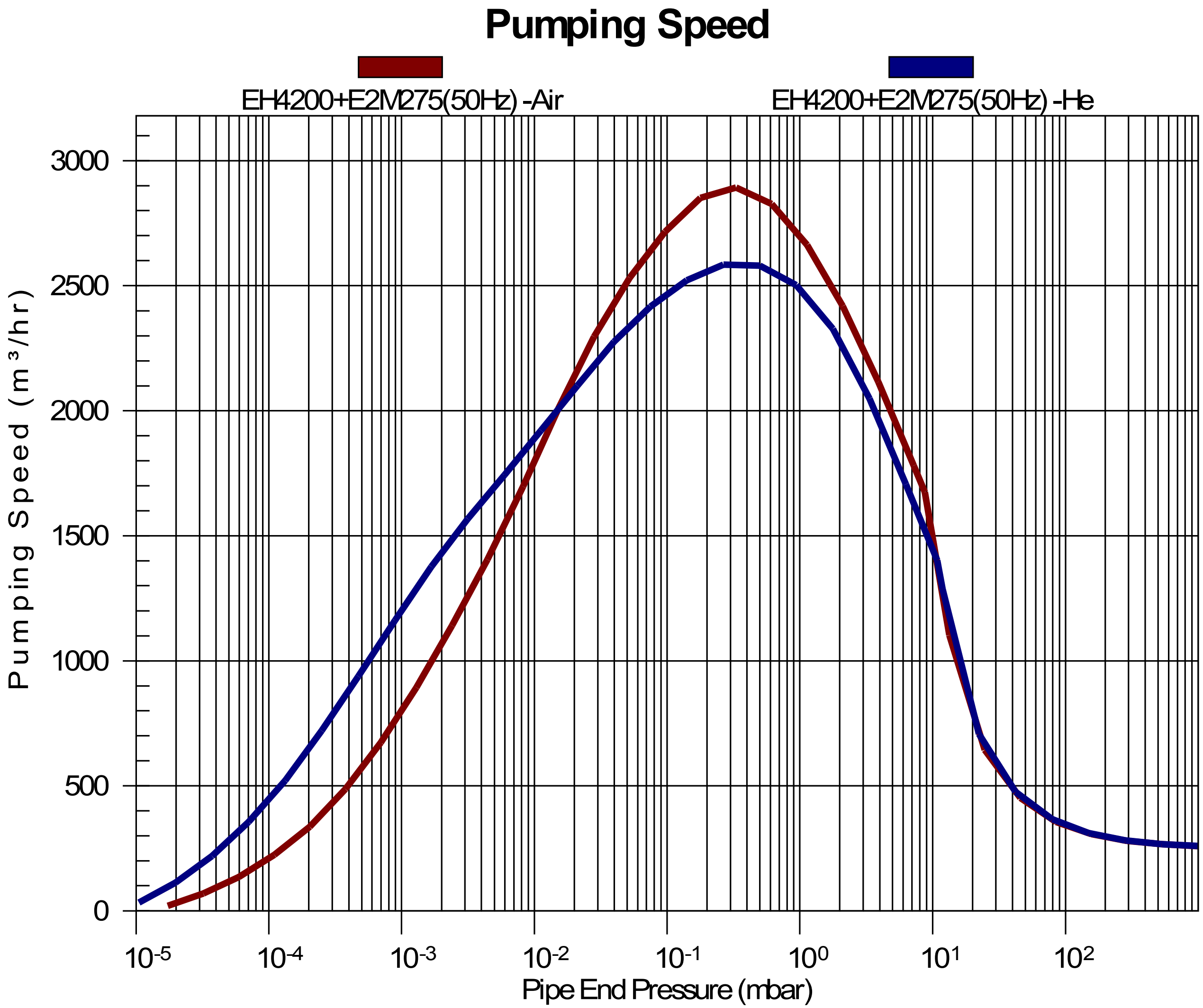
PT Test Area at Tsukuba

Cold neutron exp. Hall, Jan-2008



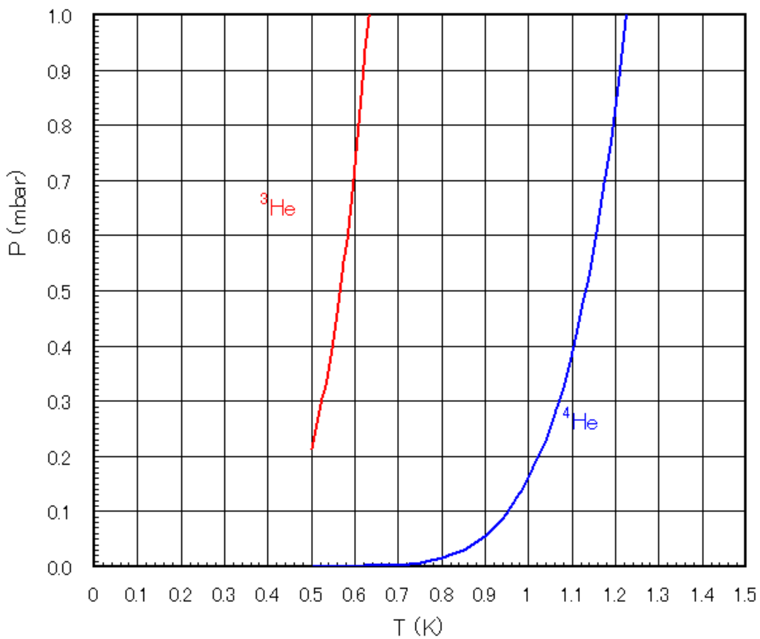
PT Test Area at Tsukuba

Pumping Speed of ^4He &Air

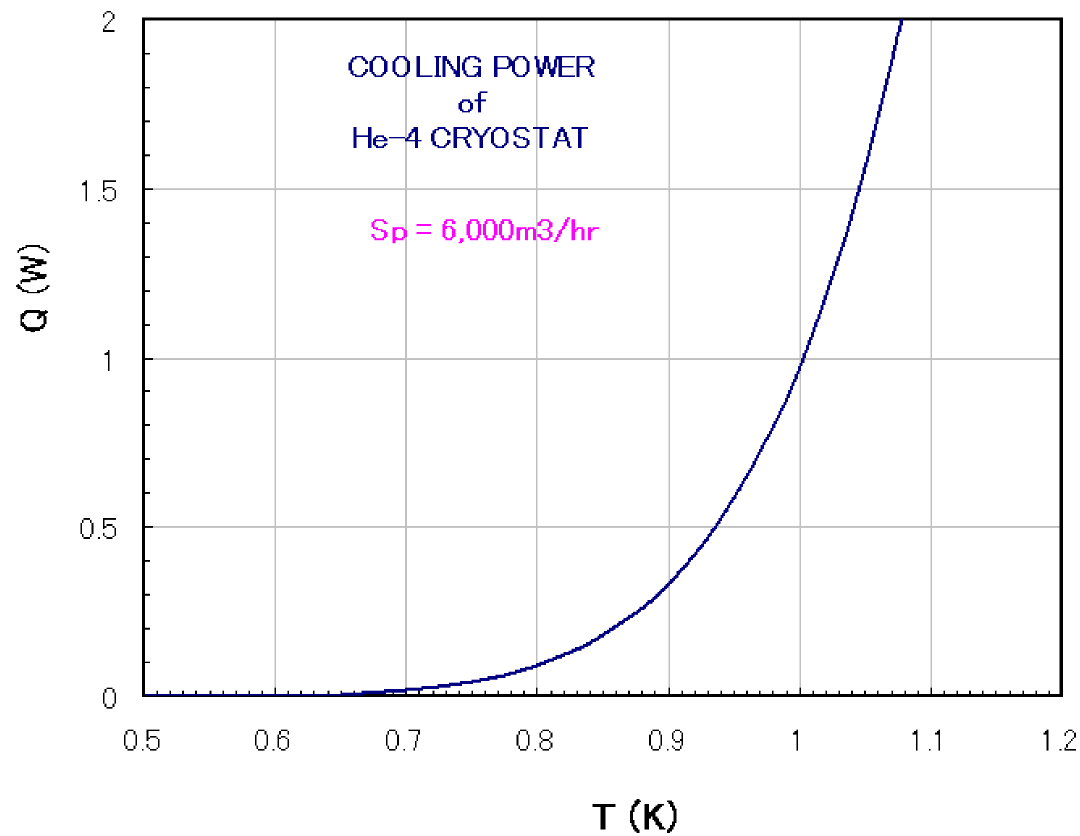


By BOC Edwards

Cooling Power of ^{4}He Cryostat



^{3}He, ^{4}He vapor pressure



^{4}He cryostat cooling power
0.9W @1K, 6,000m^3/hr
LHe~1.3 L/hr

Plan of ^{4}He Pump

7,000 m^3/hr

→ 4,000 m^3/hr pump system from Horikawa-san

Michigan PPT System

PPT parameters

Table 1 lists some specifications of the Michigan solid PPT.

1. Cryostat Temperature	1 K
2. Cooling Fluid	He^4
3. Cooling Power	0.927 watt
4. Operating Magnetic Field	5.0 T
5. Field Uniformity Region	10^{-4} in 4 cm diam. by 3 cm high cylinder
6. $\int B \cdot dl$	0.885 T·m
7. Power Supply Voltage	3 V
8. Superconducting Coil Current	66 A
9. Microwave Frequency	~140 GHz
10. NMR Frequency	213.0 ± 0.3 MHz
11. Vertical Angular Acceptance	± 6
12. Horizontal Angular Acceptance	± 34
13. Target Size	3.2 cm long by 2.0 cm diam. cylinder
14. Target Material	Irradiated NH_3 beads
15. Ave. Beam Intensity at 24 GeV/c	2 10^{11} p per 1 s pulse per 2.4 s cycle
16. Max. PPT Polarization	96 %
17. Average Polarization in AGS Run	85 %

Table 1. Michigan Solid PPT Specifications.

Michigan PPT System

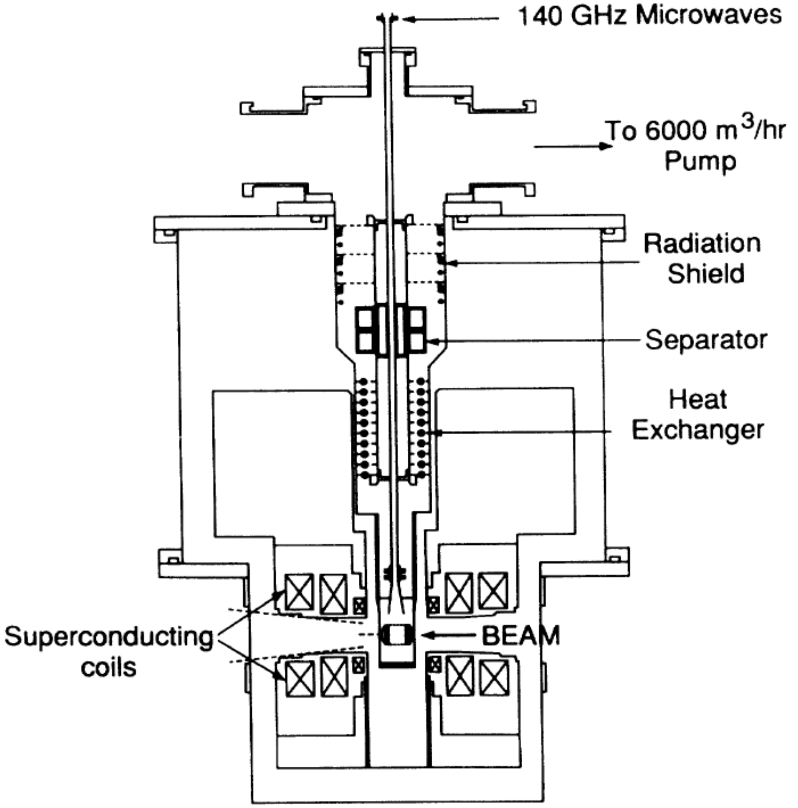


FIG. 1. Diagram of the new polarized-proton-target apparatus. The superconducting magnet produces a highly uniform 5-T field. The ^{4}He cryostat produces about 0.9 W of cooling power at 1 K. The target material is contained in the small cavity at the bottom of the cryostat. The 140-GHz microwaves are fed into the target cavity via the horn. The proton beam will pass through the target cavity.

Pol.(5T/1K) > Pol(2.5T/0.5K)

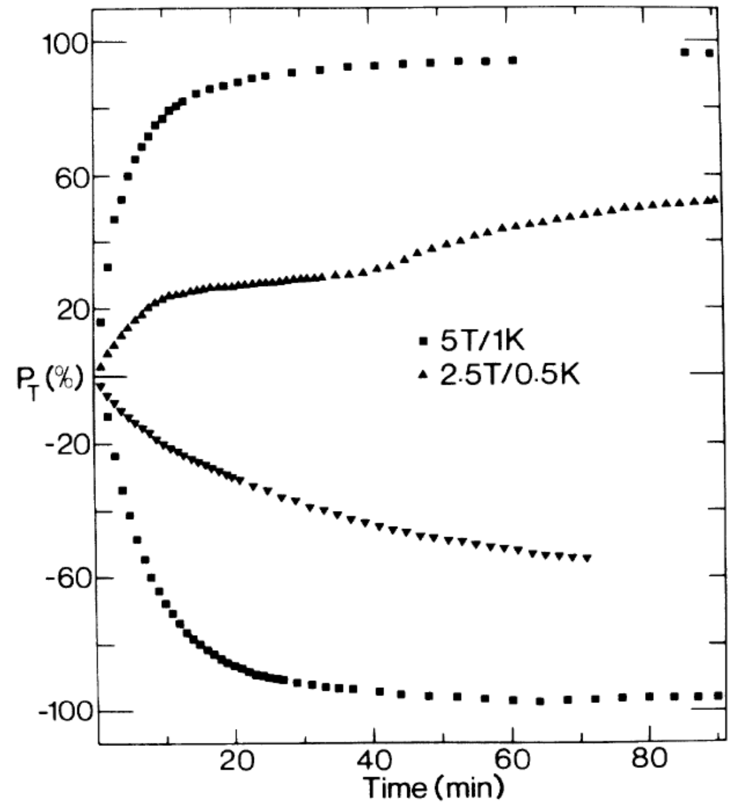


FIG. 2. The spin polarization of the free protons in NH_3 is plotted against the time of microwave irradiation. The new data at 5 T and 1 K are shown as squares; the earlier data at 2.5 T and 0.5 K are shown as triangles.

D.G. Crabb et al., Phys. Rev. Lett. 64, 2627 (1990)

Michigan PPT System

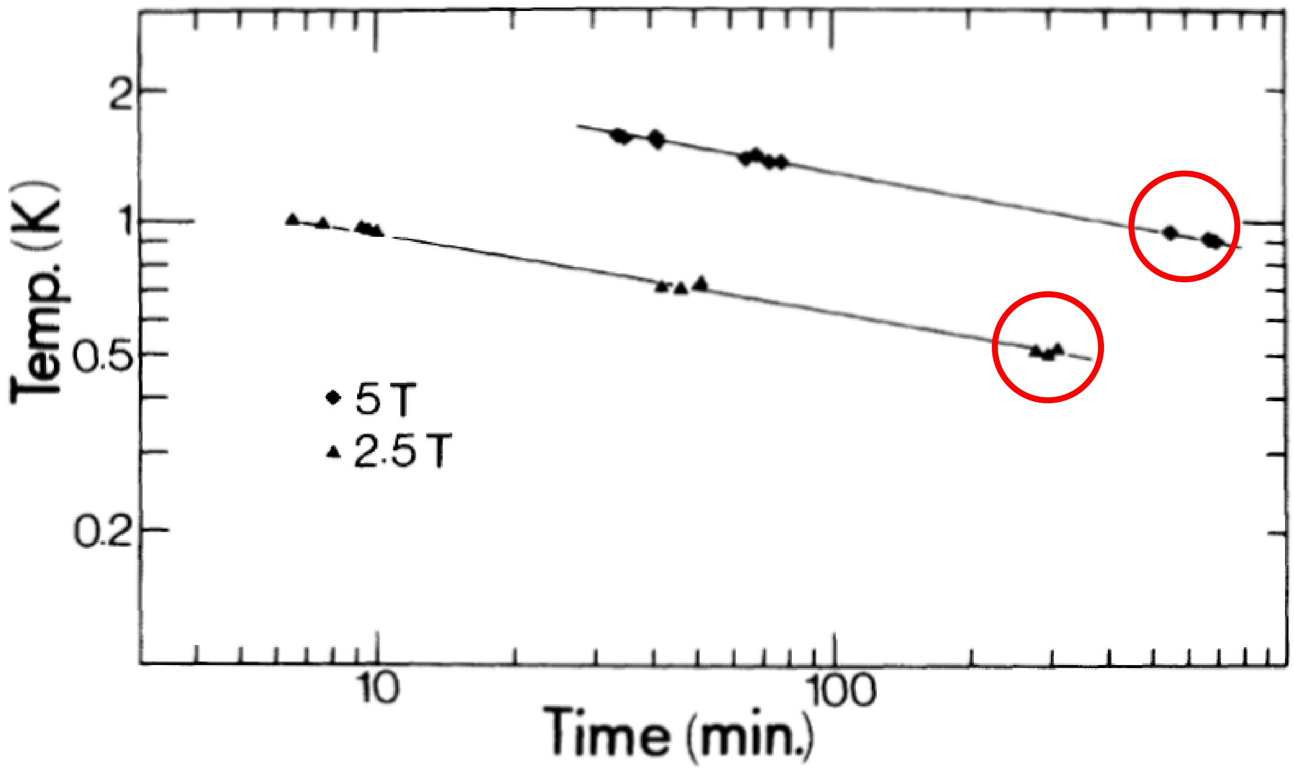
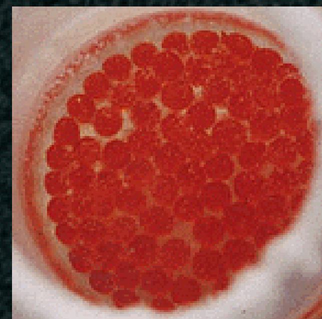
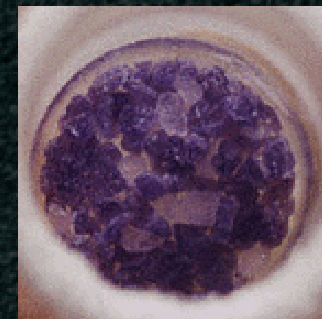


FIG. 3. The spin-relaxation time for the protons in NH_3 is plotted against temperature. The new data at 5 T are shown as diamonds; the earlier data at 2.5 T are shown as triangles.

Target materials

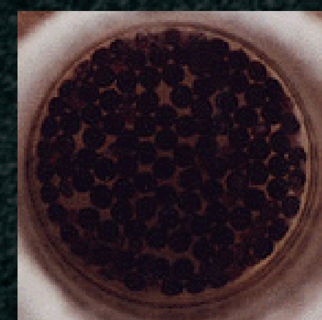


Butanol with Porphyrexide



Ammonia

LiD or LiH



Butanol with CrV complexes

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18-JUL-95

SMC and COMPASS

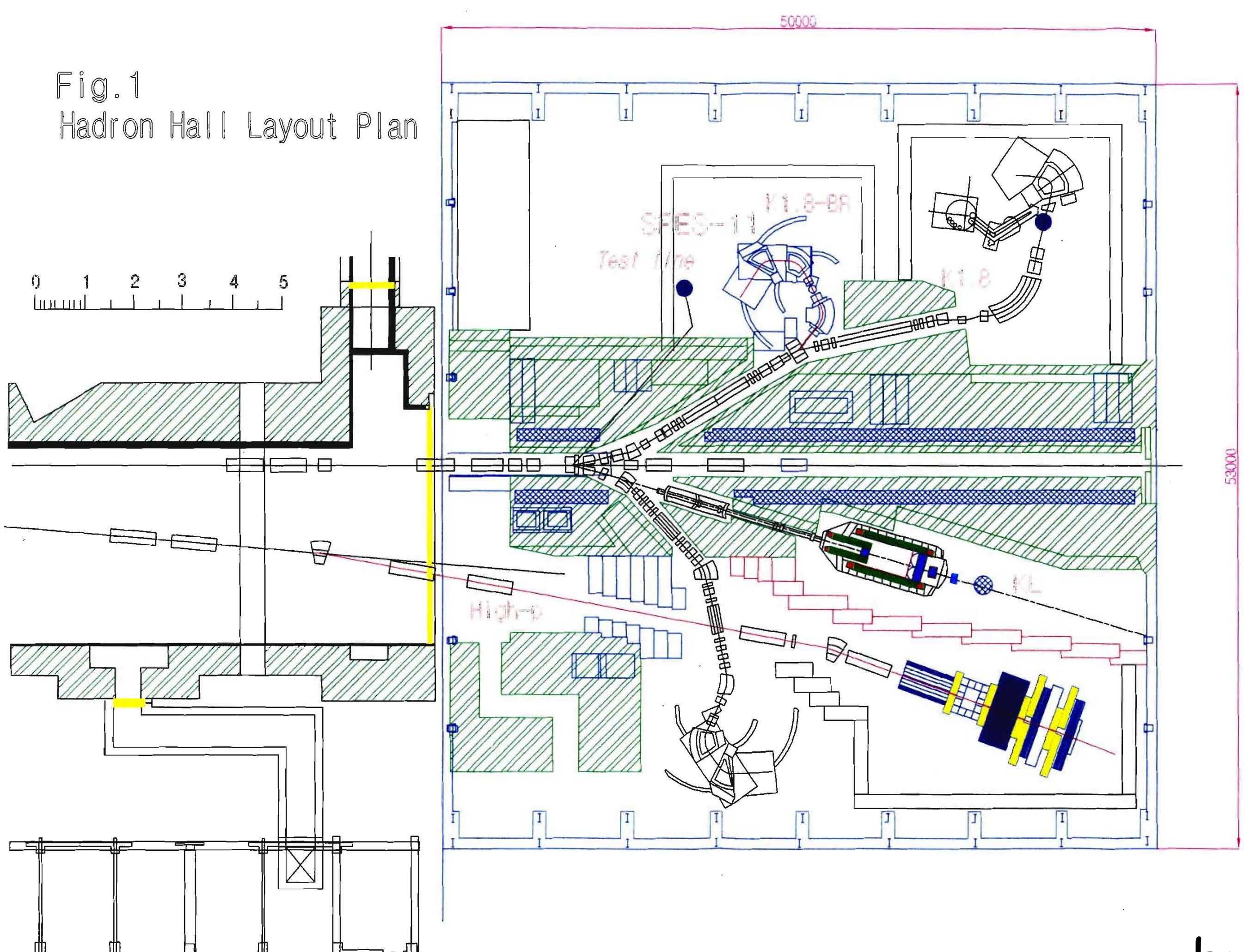
Proposals for Nuclear and Particle Physics Experiments at J-PARC

- P24: Polarized Proton Acceleration at J-PARC
  Y. Goto (RIKEN), H. Sato (KEK)

- P23: Analyzing power A_n and A_{nn} in 30-50 GeV very-high-$P_{\perp}^2$ proton-proton elastic scattering
  A.D. Krisch (U. of Michigan, USA)

P24 Dimuon experiment at J-PARC

- Possible layout of the hadron hall



by Y. Goto

P23
A.D. Krisch
(U. of Michigan)

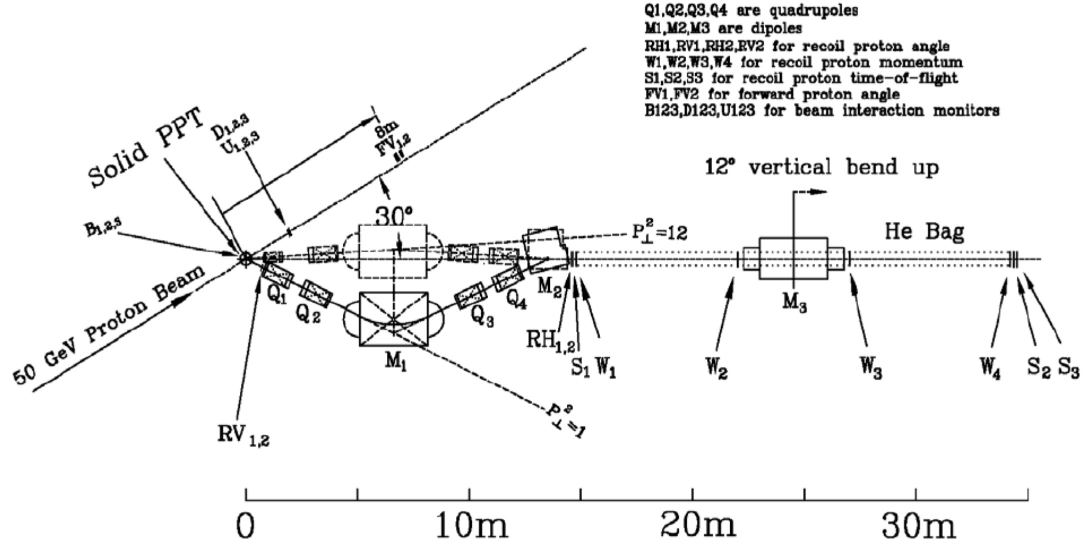
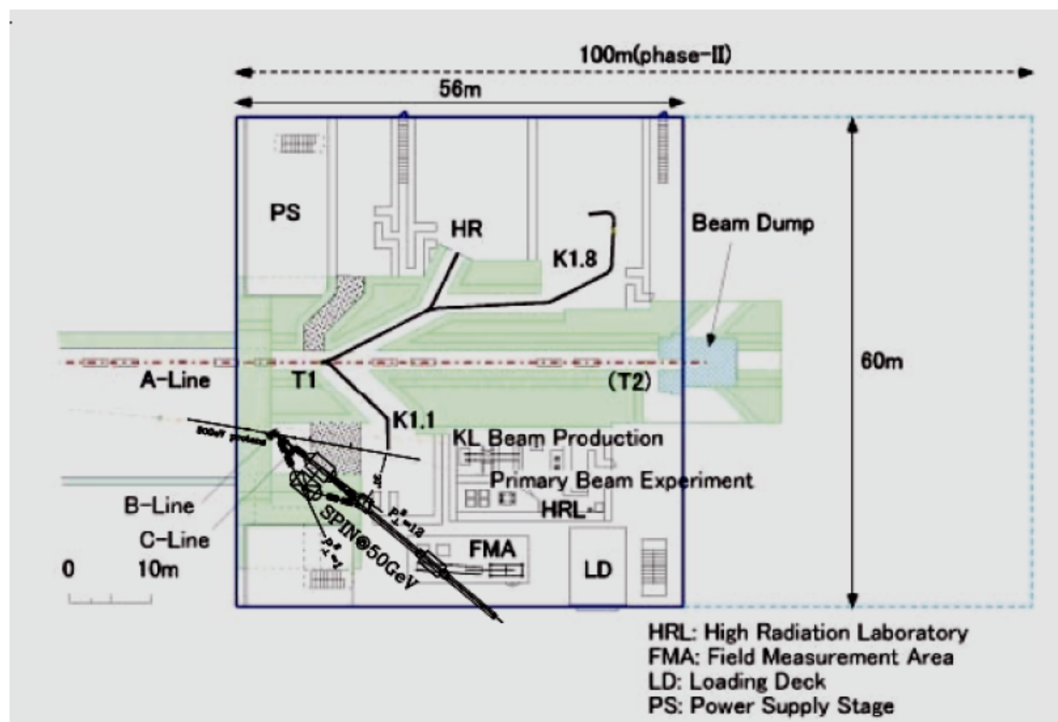


Fig. 6. The proposed 35-meter-long recoil spectrometer in the J-PARC extracted beam line.



Summary and Plan

1) Michigan PPT was moved to Neutron Exp. Hall

Set-up start; March 2008

Piping (^{4}He-pump, Vac, Mag..)

2) Parts;
- T.M.P. set
- PC + interface + software (Labview)
- ^{4}He pump from Spring-8

3) First test of cryostat + magnet; FY2008

(with Dr. Raymond, Michigan Univ.)

4) First test of NMR + EIO; FY2008

Sample (TEMPO + Polyethylene)

5) Pt will be used with neutron beam;

TRI, biomaterial, filter …

6) Pt will be used for hadron physics; Ann, Drell-Yan…

7) Pt will be used for Pt sample test bench.

Polarized Neutron Filter

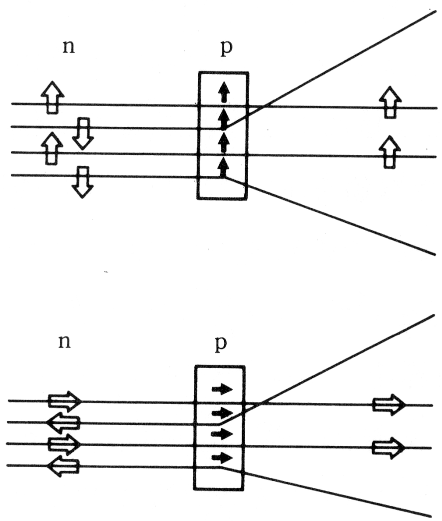


図 6.5　偏極陽子標的を用いた中性子ビーム偏極フィルターの原理図。偏極していない中性子が偏極した陽子標的を通過すると，陽子と同じ向きのスピンをもつ中性子はほとんど散乱されずに透過するが，陽子と反対向きのスピンをもつ中性子はほとんどすべて散乱されることを示している。

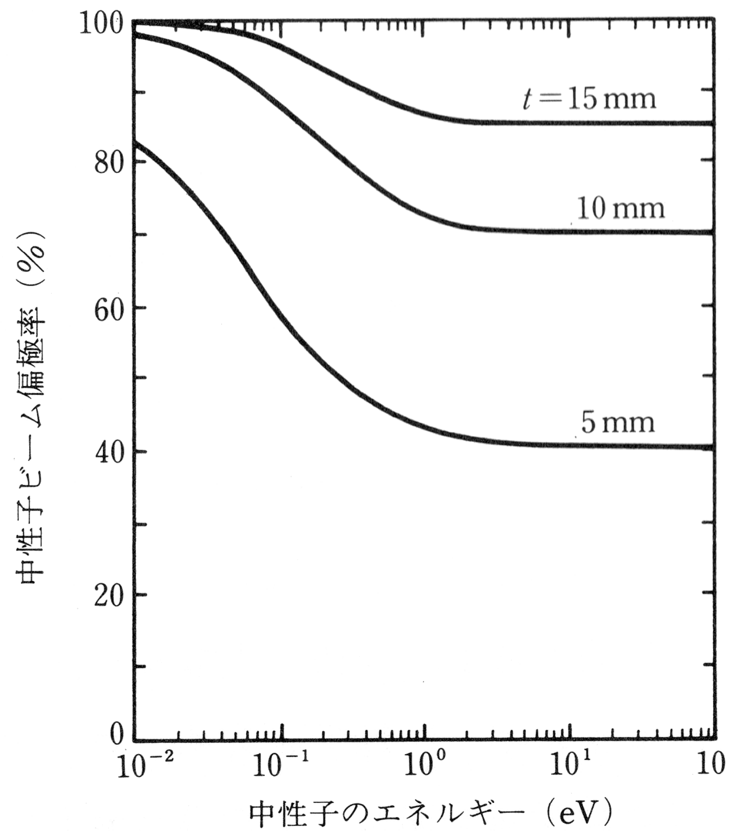
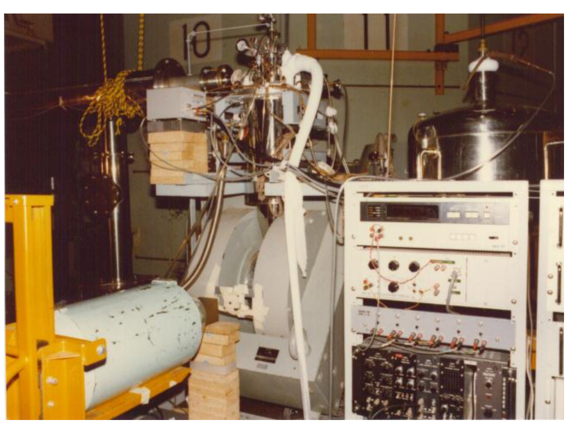


図 6.6　陽子の偏極度が 80% のエチレン・グリコールをフィルターとした場合の中性子偏極度のエネルギー依存度。t はエチレン・グリコールの厚みである



JRR-3 (1977)

Spin Frozen Target

KEK-12GeVPS → Los Alamos
(1974-1983) (1984-86)

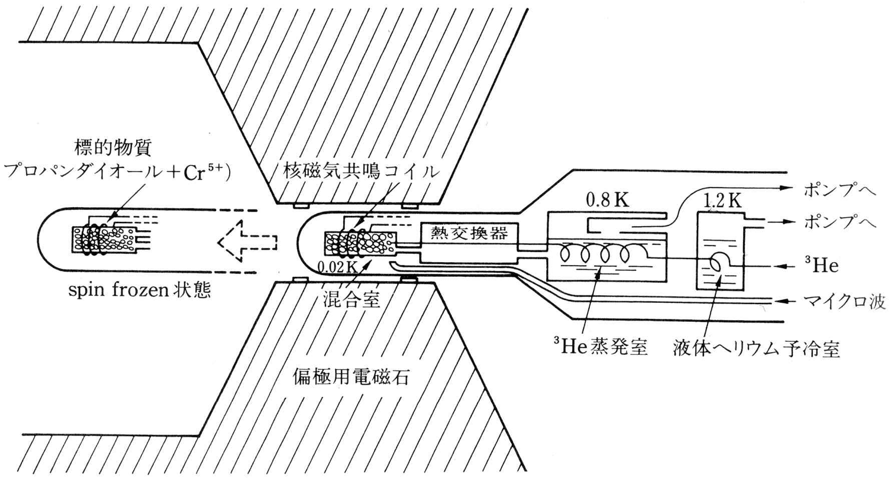
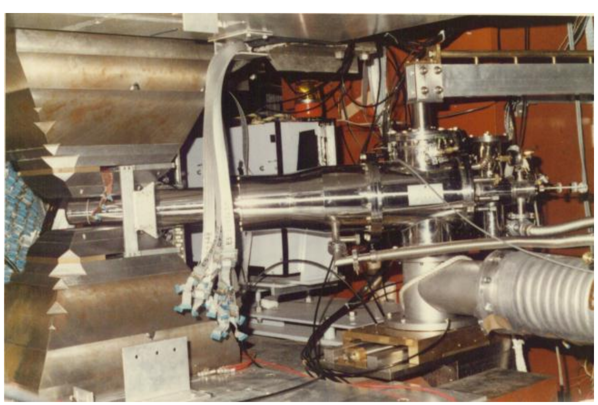


図 6.3 希釈冷凍法を用いたスピン冷凍型偏極標的（高エネルギー物理学研究所）。希釈冷凍装置の混合室内に入れられた偏極物質を偏極用電磁石の中心部で偏極させたのち，低い磁界の広いスペースに移動させて散乱実験に用いる。



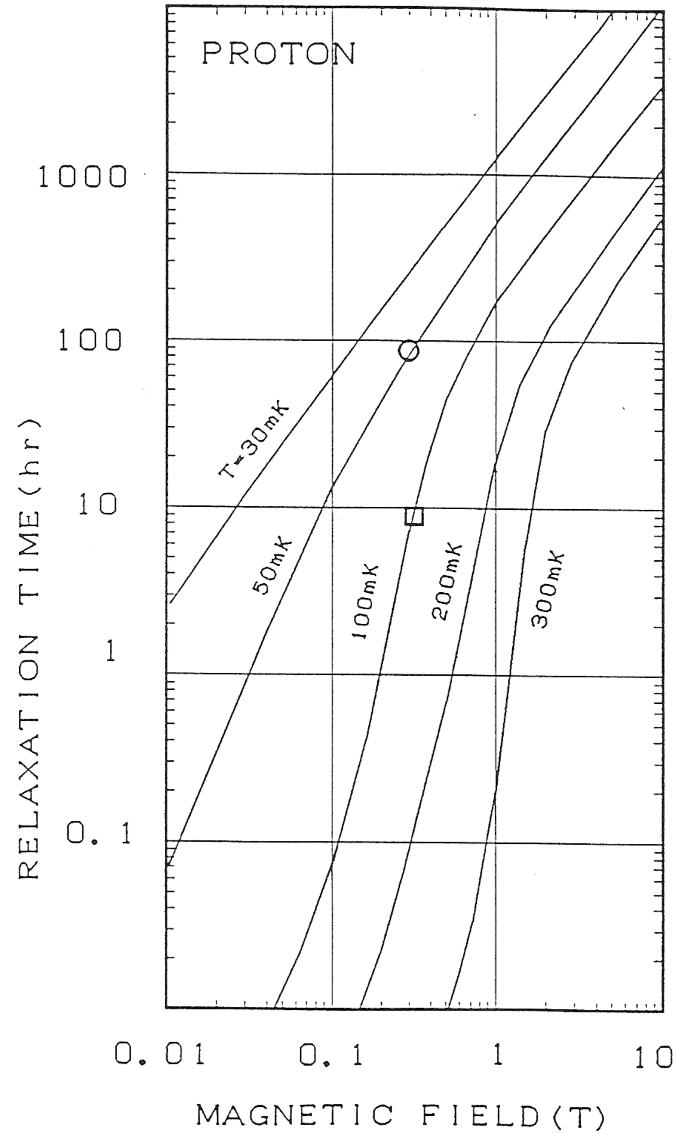


Fig.-5-18 陽子核スピン－格子緩和時間 T_{1p} と磁場の関係

Michigan PPT System
(East Counter Hall at KEK)


10 TON
KAMIUCHI

OUTLINE

- KEK/J-PARC Status
- Michigan 1 K, 5 T System
- PT for Neutron Physics at J-PARC
- PT for Hadron Physics at J-PARC

動的偏極の中性子物理への応用

- **中性子ビーム偏極フィルター／アナライザー**

JRR-3 (1977) → KENS – prePEN

→ KENS –PEN

^{3}He Cryostat 0.5 K, 2.5 T

ESR 70 GHz, NMR 106 MHz

エチレングリコール(Cr)

→ n↑ + La P非保存実験

→ Spin Rotation 実験(Los Alamos)

- **スピンコントラスト法による偏極物質の研究**

KENS – PEN; ^{3}He Cryostat 0.5 K, 2.5 T

- **時間反転実験用 La 偏極**

^{3}He Cryostat, Dilution Refrigerator

J-PARC

J-PARC

Michigan PPT ^{4}He Cryostat 1 K, 5 T(鉛直方向磁場)

ESR 140 GHz, NMR 213 MHz、NH_3 P_p ～90%

長期（5年間）借り受け、5年後 Michigan 大学から返還要望がなければ、KEKに譲渡される。 (Prof. A. Krisch)

＊低温装置が簡単である。ただしマグネット・マイクロ波部品が高価
＊古い装置なので、ビーム実験には部品の予備やメンテナンスが必要

● **中性子物理　　Soft Matter 等の研究**

＊^{3}He を用いないので偏極フィルターその他の中性子実験に有利

＊磁場 5T は問題ないが、零磁場を避ける必要がある。

• **SPIN物理（ハドロン実験室）　核子(p,n)の spin 構造**

＊1K冷凍機は大強度陽子ビームに対して冷却力が大きい(～1W@1K)
ので有利。また NH_3 は放射線ダメージに強い偏極物質である。

＊磁場方向や開口角度を変更するには磁石を作り直す必要がある。

● **偏極物質の研究　Material, Radical**

＊装置が簡単であるため、偏極物質の開発に適している

＊一般的な 0.5 K, 2.5 T のデータと比較できる。1 K, 5 T のほうが有利？

J-PARC Hadron Hall

J-PARC, Jul-27, 2007

核偏極

	冷凍機	磁　場	マイクロ波
静的偏極 HD	希釈冷凍機　< 0.1K	> 5 T	不要
動的偏極 ※sample	^{4}He 冷凍機　1 K ^{3}He 冷凍機　0.5K 希釈冷凍機　< 0.3K	2.5 T (高均一度) 5 T (高均一度)	70 GHz 140 GHz

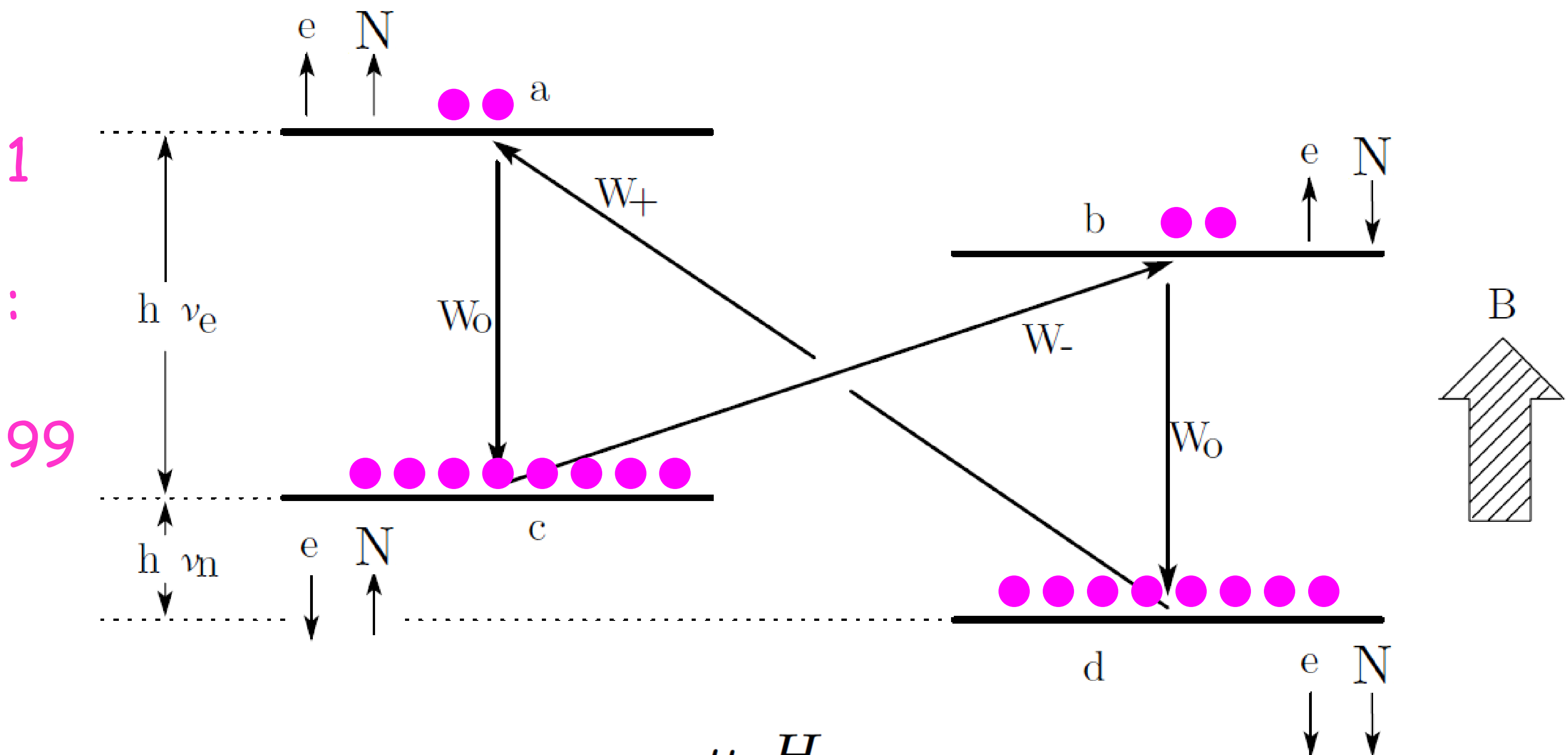
※ sample + Electron Spin　～ 10^{19} el./cm^3

> free Radical;　Cr(5+), DPPH, EHBA, TMPO ...

> Radiation Damage;　NH_3, LiD ...

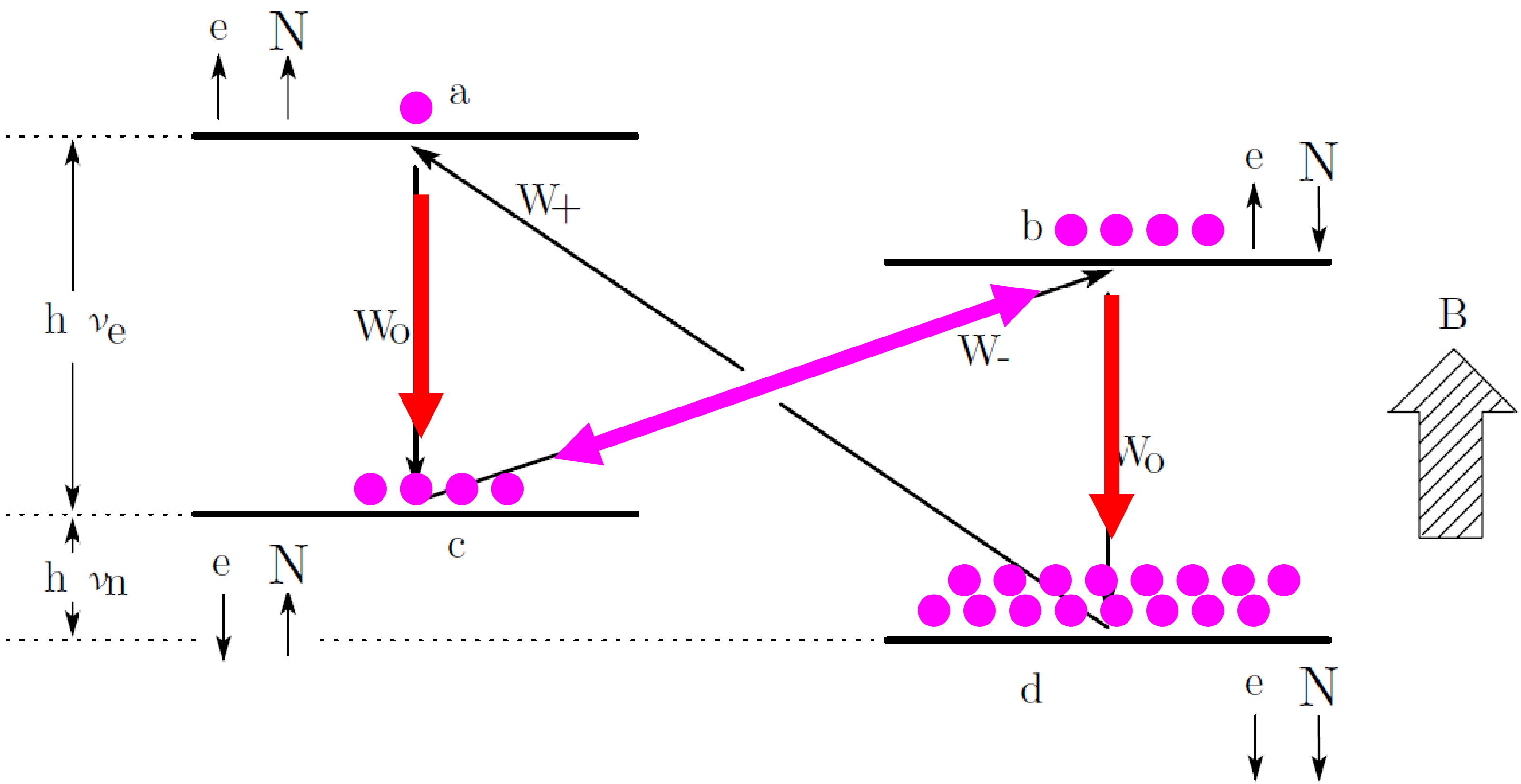
熱平衡状態 $n_m = exp(-\frac{E_m}{k_B T})$

P_0(ele.) ~ 99% at 2.5T, 1K



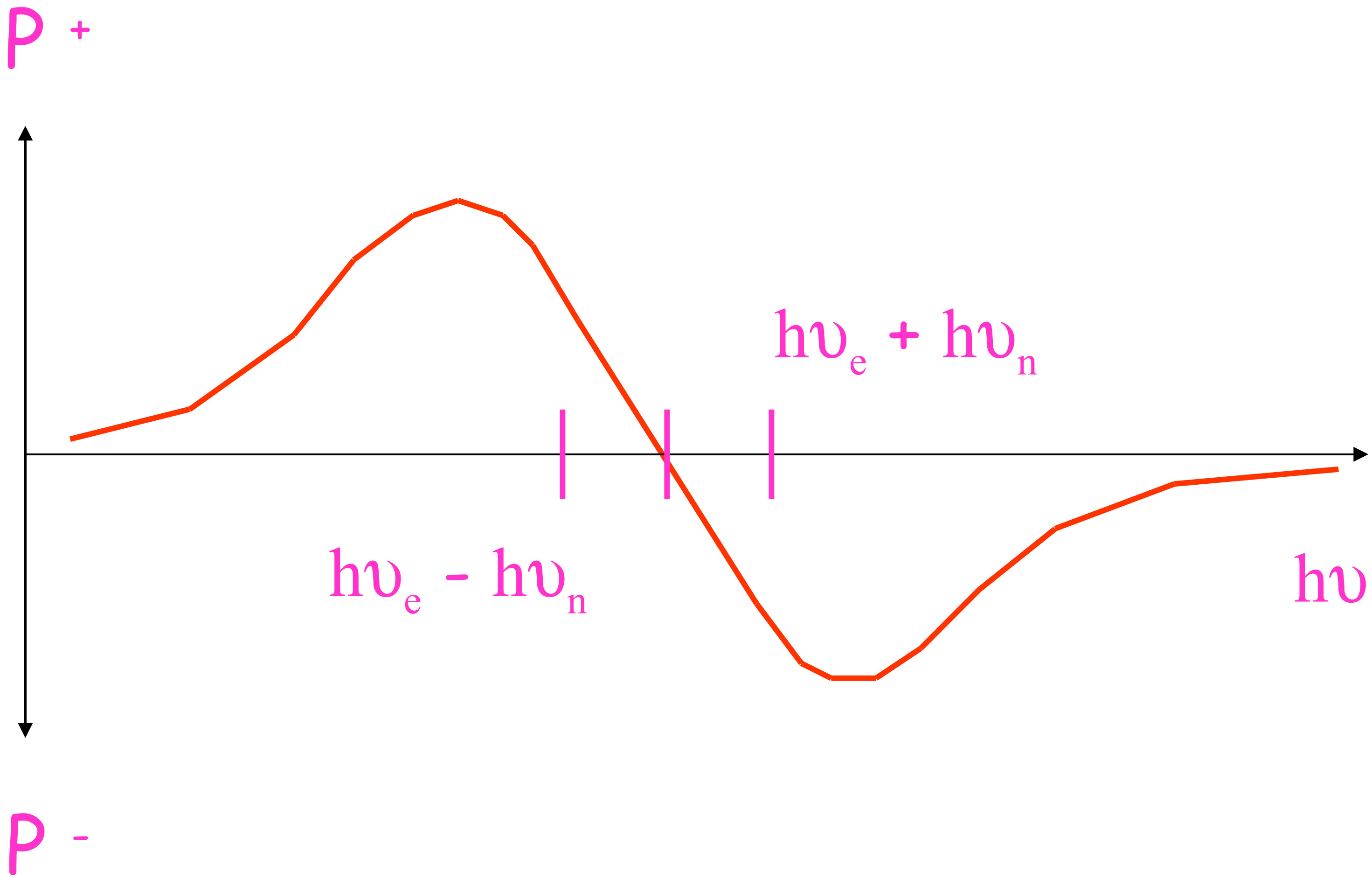
P_0(proton) = $\tanh(\frac{\mu_p H_0}{k_B T})$ ~ 0.5% at 2.5T, 1K

マイクロ波照射（飽和）　$h\upsilon_e - h\upsilon_n$



P^+

動的偏極（マイクロ波周波数依存）



ESR; $h\upsilon_e$ ~ 70 GHz at 2.5 T, 140 GHz at 5 T

Proton NMR; $h\upsilon_n$ ~ 106 MHz at 2.5 T, 213 MHz at 5 T

polyethylene + TMPO   PSI, Nagoya

NIM A356(1995)36-38
原子核研究 Vol. 41 No.6
原子核研究 Vol. 43 No3

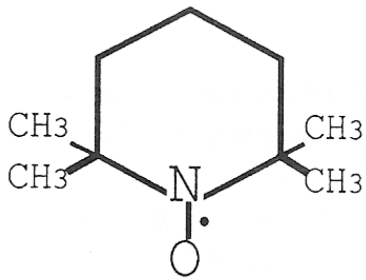


図 1: TEMPO(2,2,6,6-tetramethyl-piperidine-1-oxyl) の構造式

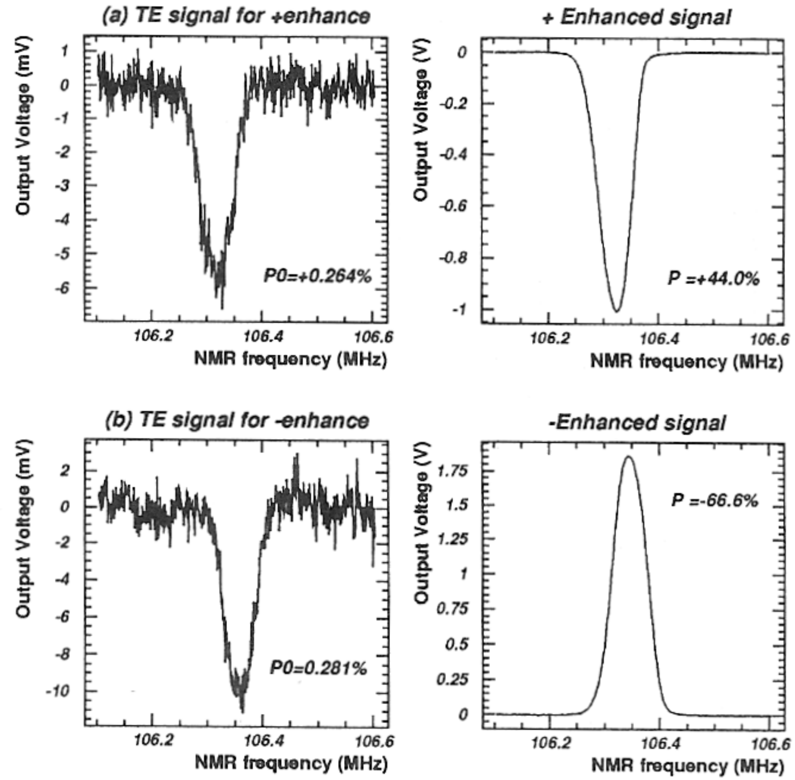


図 5: ポリエチレン試料の NMR 信号

Polyethylene; t~ 0.03 mm
TMPO 80℃ ~10 hr

使用試料	30μm ポリエチレンシート	
混入される不対電子	TEMPO	
濃度 ($\times 10^{19}$spins/cm^3)	2.4 ± 0.2	2.2 ± 0.2
総重量 (mg)	77	97
マイクロ波周波数 (GHz)	70.00	70.27
最高偏極度 (%)	$+44.0 \pm 2.9$	-66.6 ± 2.6

新しい Radical　Finland D36

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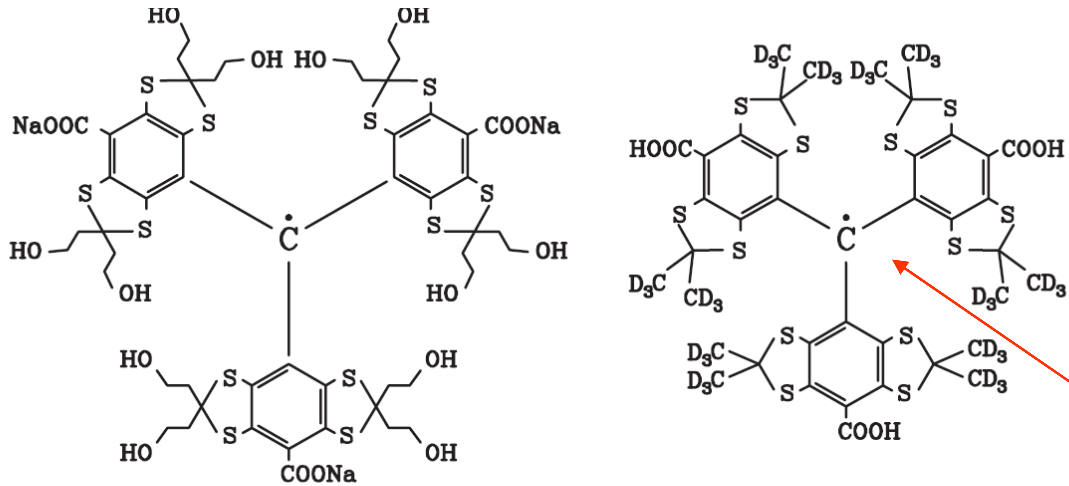

(a)　(b)

Fig. 7. Structures of the trityl radicals OX063 (a) and 'Finland D36' (b). The molecular weights are 1426.78 and 1036.14, respectively.

電子スピンが独立

→ *g* の広がりが小

・高偏極

Radical	$\Delta g/g$ $[10^{-3}]$
TEMPO	3.85 ± 0.2
Porphyrexide	3.0 ± 0.3
EHBA/EDBA	6.0 ± 0.2

OX063

$\Delta g/g \sim 0.3 \times 10^{-3}$

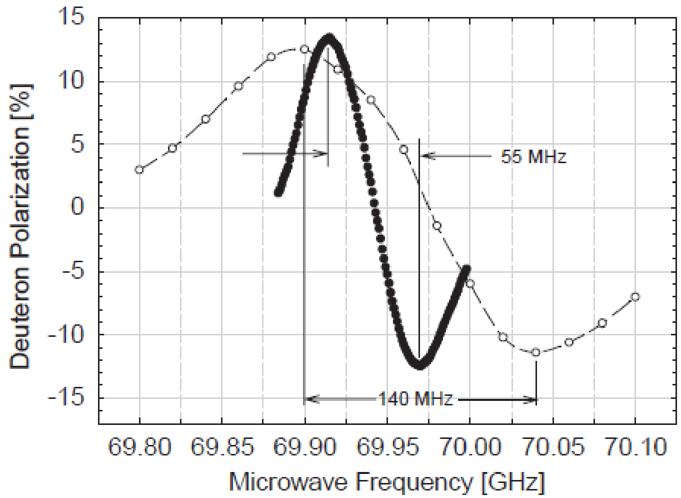

Fig. 9. Deuteron polarization as a function of the applied microwave frequency in irradiated D-butanol (open circles) and in trityl doped D-propanediol (closed circles) at 1 K, 2.5 T.

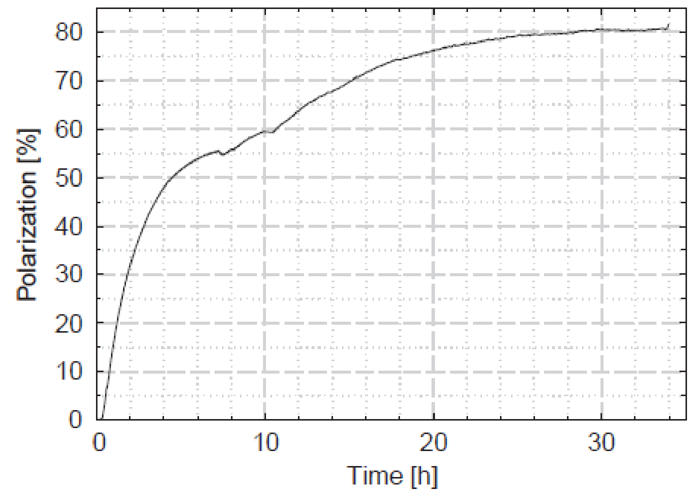

Fig. 10. Build-up curve of D-butanol doped with 'Finland D36' at $T \simeq 150$ mK, $B = 2.5$ T.

D-butanol + Finland D36

OX063 is readily solved in highly polar substances like the diols, it is not solvable in the longer chained alcohols as it is the case for the 'Finland D36' radical. The optimum spin density for both materials was found to be $1.5 \times 10^{19}/g$, which is somewhat lower than the usual nitroxyl concentration of $2 \times 10^{19}/g$. The highest deuteron polarizations under the conditions mentioned above were achieved after about 1.5 days of continuous microwave irradiation. They correspond to -81% for D-propanediol and to and $+80\%$ for D-butanol, while values of $\pm 60\%$ can be obtained within 10 h of polarizing time. As an example Fig. 10 shows the polarization build-up for D-butanol. Two remarks should be made at that point:

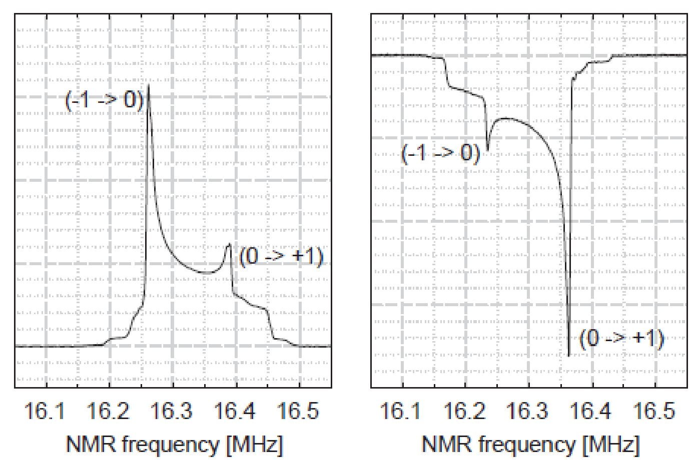

Fig. 11. NMR signals of D-propanediol (left) and D-butanol (right) with polarizations of -81% and $+80\%$, respectively.