

30 aug 07

# **Polarizing Anti-protons using DNP in Flight**

**A.D. KRISCH**  
**University of Michigan**

**“Crazy idea” of “moving” Dynamic Nuclear Polarization proposed at Bodega Bay**

**Evaluated by C. Jeffries and D. Kleppner**

Together at Bodega Bay (California) to discuss polarized antiprotons – Simon van der Meer of CERN (left) and Dave Jackson of Berkeley. At another meeting at Berkeley earlier in the year, tributes flowed on the occasion of Jackson's 60th birthday (see page 287).



and photons deriving from kaon decays. The contribution from background neutrinos should be reduced by an order of magnitude. With  $10^{14}$  protons per pulse, the number of tagged neutrino interactions in 100 t of detector should reach  $10^4$  particles per day for muon neutrinos and 200 particles per day for electron neutrinos.

A straight section 60 m below the surface will house experiments using internal targets. This main hall will be 60 m long with 9 m diameter, with an adjacent hall 30 m long.

For colliding beams, four matched sections are to be used for experiments. Two halls at a comparatively small depth will be excavated. The halls will be approximately  $24 \times 24$  m, with preassembling halls of approximately the same size. Maximum luminosity in these intersection points should achieve  $10^{32} \text{cm}^{-2} \text{s}^{-1}$ .

## WORKSHOP Polarized antiprotons?

In April, 22 physicists gathered for a long weekend of 'brainstorming' in the isolated village of Bodega Bay overlooking the rugged coastline of north California. They were trying to find some way to polarize (align the spins of) antiprotons. To attack this very difficult problem the physicists were drawn about equally from the fields of high energy physics, atomic physics, nuclear physics and accelerator physics.

The workshop opened with lectures by two experts who defined our present knowledge of the two fields which the workshop hoped to unite: Willy Haeberli (Wisconsin) reviewed polarized proton ion sources and Simon van der Meer (CERN) reviewed storage of anti-

protons. The workshop was not publicized in advance partly because the organizers, Owen Chamberlain (Berkeley) and Alan Krisch (Michigan), were concerned that it might be totally impractical to obtain enough polarized antiprotons to do useful high energy physics experiments. They were also eager to maintain a very informal atmosphere where people were willing to propose 'crazy' ideas.

Indeed, most of the twelve ideas which emerged were not very practical. For example the idea of using 'stochastic techniques' to enhance the polarization of a stored antiproton beam was dispatched in a short talk by Simon van der Meer. He pointed out, perhaps with a small smile, that it was a fine idea except that the signal to background ratio was  $10^{-42}$ . However there were two ideas which emerged from the workshop which did seem quite promising and a third idea which might result in some interesting atomic physics.

The atomic physics idea started as a plan to pass beams of positrons and antiprotons together with the same velocity into a drift region, where they could form atoms of antihydrogen. One could then polarize the antihydrogen atoms using the same atomic beam techniques used in polarized proton ion sources. The formation rates were estimated by distinguished atomic physicists Carson Jeffries (Berkeley) and Daniel Kleppner (MIT) to be about  $10^3$  per second. This is clearly too low to be useful for high energy accelerator experiments. However no one has ever produced one single atom of antihydrogen, polarized or unpolarized. With even a very weak single beam of antihydrogen

it would be possible to do some very interesting experiments such as comparing the Lamb shift for antihydrogen with that for hydrogen. A number of the participants, especially K. Imai (Kyoto) and Arthur Rich (Michigan) left the workshop with plans to begin antihydrogen experiments. Antihydrogen has also been discussed by the LEAR Low Energy Antiproton Ring community at CERN (see June issue, page 188).

One promising idea for producing high energy antiproton beams was presented by A. Yokosawa (Argonne). Fermilab is now constructing a polarized proton beam which will use protons captured from hyperon decay. These protons are known to have a polarization of about 50 per cent. The antiprotons from antihyperon decay should have exactly the same polarization. The intensity and kinematics may make it difficult to store and accelerate these polarized antiprotons but it should certainly be possible to scatter them from a polarized (or unpolarized) proton target.

The most promising idea for accelerating polarized antiprotons was named the 'Spin Filter' technique. This uses a polarized proton gas jet which is placed inside an antiproton ring. One then accelerates or decelerates the antiprotons to some energy where the proton-antiproton reaction rate is different when the spins are parallel and antiparallel. The antiprotons in one spin state are then scattered more often and disappear more quickly from the storage ring. After perhaps 10 or 20 hours the remaining antiprotons should have a significant spin polarization. Fortunately several groups are already developing po-

larized atomic hydrogen jets for various reasons. Tapio Niinikoski (CERN) described some of these efforts including his own at CERN and the Michigan-MIT effort at Brookhaven (see April 1984 issue, page 100).

This Spin Filter technique appeared practical and quite promising provided some energy is found at which the antiproton-proton scattering depends markedly on whether the colliding particles have parallel or antiparallel spins. There are no data on total reaction rates (cross-sections) for polarized antiprotons colliding with polarized protons. Hopefully a significant spin-dependence will be found in the energy region below 1 GeV, where the proton-proton spin dependence is so large that some physicists feel that it indicates the existence of dibaryon resonances or bound states. A low energy beam of antiprotons can be polarized by elastically scattering them at certain angles. By scattering these upon a polarized proton target one can measure the spin dependence of the antiproton-proton total cross-section. This measurement should be made both with the spins parallel to the beam direction and then transverse to the beam direction. A number of participants, especially Willy Haeberli, Erhard Steffens (Heidelberg) and Dave Cline (Wisconsin), began planning such measurements probably at LEAR (CERN) or at Fermilab. The larger the spin effect the easier it will be to polarize a coasting beam of antiprotons.

*From Owen Chamberlain and Alan Krisch*

WORKSHOP ON POLARIZED ANTIPROTON SOURCES  
FINAL PROGRAM

April 18-21, 1985 BODEGA BAY, CALIFORNIA  
Meeting Rooms in Bodega Bay Lodge

Working Groups

HYP. --Polarization of Antiprotons by Antihyperon Decay	Coordinator: A. Yokosawa
POL.N--Polarization of Antiprotons by Collisions with Polarized Nucleii or Polarized Protons	Coordinator: D. Cline
STOC.--Polarization of Antiprotons Using Stochastic Techniques	Coordinator: O. Chamberlain
DNP. --Polarization of Antiprotons Using Dynamic Nuclear Polarization with Polarized Electrons	Coordinator: A. Krisch
RAD.---Polarization of Antiprotons Using Radiation	Coordinator: L. Teng

WEDNESDAY - APRIL 17, 1985 ---- 6:00-10:00 pm. Registration, Wine, and Cheese

THURSDAY APRIL 18, 1985

9:00 Welcome-----O. Chamberlain  
9:10 Introduction-----A. Krisch  
9:20 Status of Antiproton Accumulator--S. van der Meer  
10:00 Status of Polarized Sources-----W. Haeberli

10:40 Coffee  
11:10 Intro to HYP Working Group-----A. Yokosawa  
11:40 Intro to POL.N Working Group-----D. Cline  
12:10 Intro to STOC. Working Group-----O. Chamberlain  
12:40 Lunch  
2:00 Intro to DNP Working Group-----A. Krisch

2:30	HYP	DNP
4:15		

Coffee

4:45	POL.N	STOC.
6:00		

SATURDAY APRIL 20, 1985

9:00 Status of HYP W.G.-----A. Yokosawa  
9:10 Status of POL.N W.G.-----D. Cline  
9:20 Status of DNP W.G.-----A. Krisch  
9:30 Trapped p-----G. Gabrielse

9:50		POL.N
10:50		

Coffee

11:20	POL.N.	RAD
12:30		

Lunch

2:00		POL.N
3:30		

Coffee

4:00		DNP ANTI H
5:30		

5:30 Roundtable-----O. Chamberlain  
6:00 End  
7:00 Banquet

FRIDAY APRIL 19, 1985

9:00 Status of HYP. W.G.-----A. Yokosawa  
9:15 Status of POL.N W.G.-----D. Cline  
9:30 Status of STOC W.G.-----O. Chamberlain  
9:45 Status of DNP W.G.-----A. Krisch  
10:00 Roundtable-----D. Kleppner  
10:30 Coffee  
11:00 Polarization of Directly Produced Antiprotons---B. Bonner  
11:30 Polarization of Antiprotons using Synchrotron----L. Teng  
and other Radiation  
12:30 Lunch  
2:00 Polarization of Antiprotons using the-----T. Niinikoski  
Stern-Gerlach Effect

2:30	HYP	DNP
4:00		

Coffee

4:30	POL.N	
6:00		

SUNDAY APRIL 21, 1985

9:00 Possible Check-out from Hotel  
9:15 Summary of HYP-----A. Yokosawa  
9:25 Compton Scattering-----H. Steiner  
9:35 Summary POL. N-----D. Cline  
10:10 Coffee  
10:30 Summary Anti Hydrogen-----K. Imai  
11:00 Roundtable-----A. Krisch  
11:30 End

Teng/Jackson

WORKSHOP ON POLARIZED ANTIPROTON SOURCES  
April 18-21, 1985  
Bodega Bay, California

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A. Kirsch: Intro to DNP Working Group  
18 April 85

# Polarizing $\bar{P}$ 's using DNP with Polarized $e^-$ 's

1. DNP and Polarized Targets
2. DNP and Polarized Antiprotons
3. Kinematics and Parameters

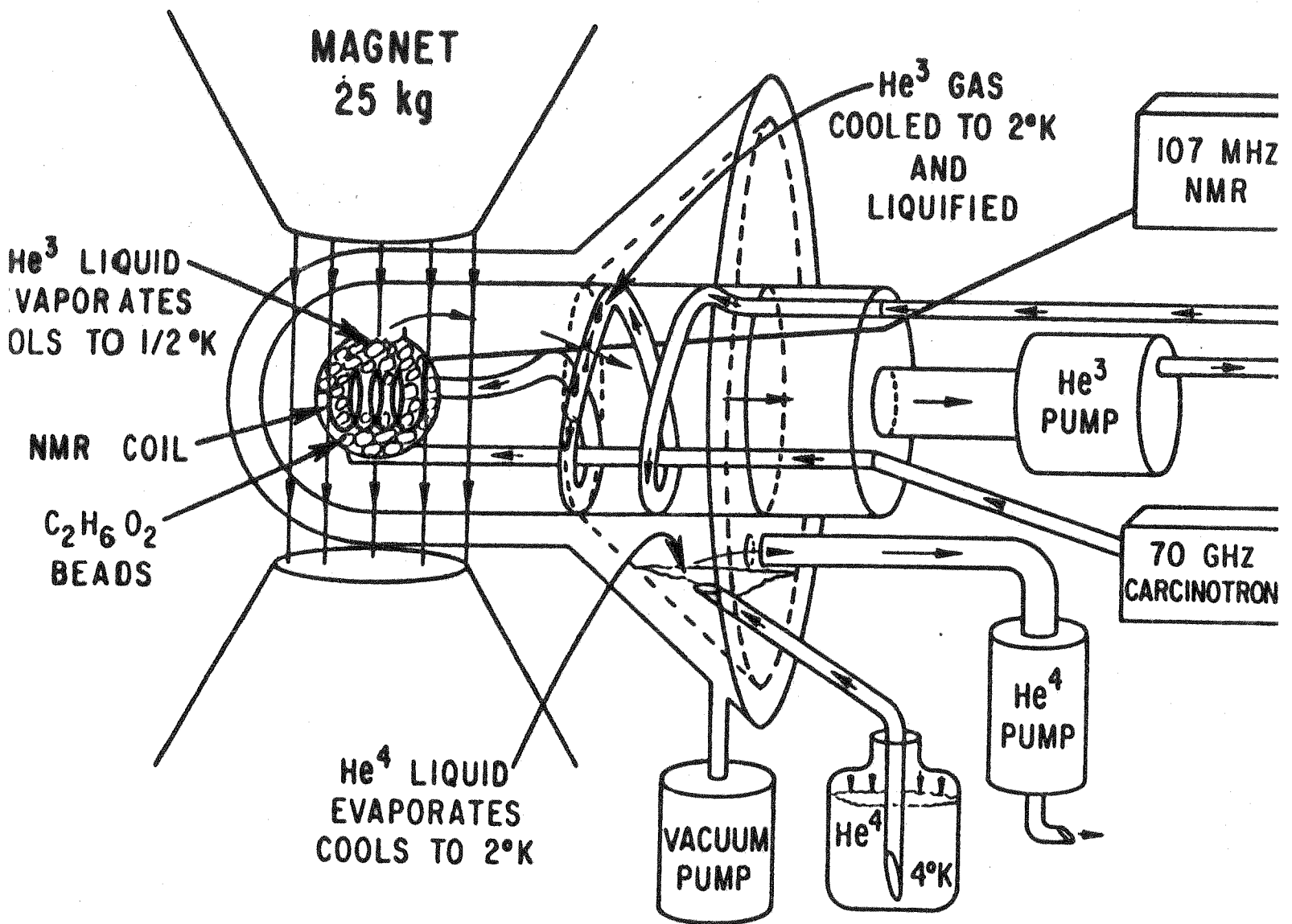
# POLARIZED TARGET

$$P_T = \frac{e^{+\frac{\mu \cdot B}{kT}} - e^{-\frac{\mu \cdot B}{kT}}}{e^{+\frac{\mu \cdot B}{kT}} + e^{-\frac{\mu \cdot B}{kT}}}$$

$$B = 25000 \text{ G}$$

$$T = \frac{1}{2}^\circ \text{K}$$

$$\mu_e = 660 \mu_p$$



**MAGNET  
25 kg**

**$He^3$  GAS  
COOLED TO  $2^\circ K$   
AND  
LIQUIFIED**

**107 MHz  
NMR**

**$He^3$  LIQUID  
VAPORATES  
COOLS TO  $1/2^\circ K$**

**NMR COIL**

**$C_2H_6O_2$   
BEADS**

**$He^3$   
PUMP**

**70 GHZ  
CARCINOTRON**

**$He^4$  LIQUID  
EVAPORATES  
COOLS TO  $2^\circ K$**

**VACUUM  
PUMP**

**$He^4$   
 $4^\circ K$**

**$He^4$   
PUMP**

# Kinematics and Parameters

AA 3.5 GeV/c

160 m circumference  $\rightarrow$  530 ns =  $2 \cdot 10^6$  Hz

$\sim 10^{11}$   $\bar{p}$ 's/day

$\sim 3 \cdot 10^{11}$   $\bar{p}$ 's stored

$\sim 2 \rightarrow 3$  mm<sup>2</sup> cross sectional area

$$2 \cdot 10^6 \text{ Hz} \times 3 \cdot 10^{11} \bar{p} = 6 \cdot 10^{17} \bar{p}'\text{s}/\text{sec}$$

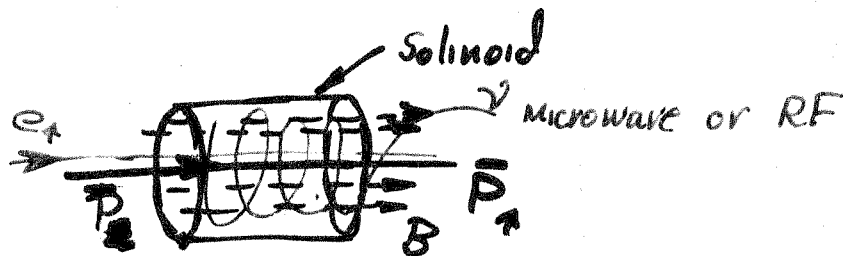
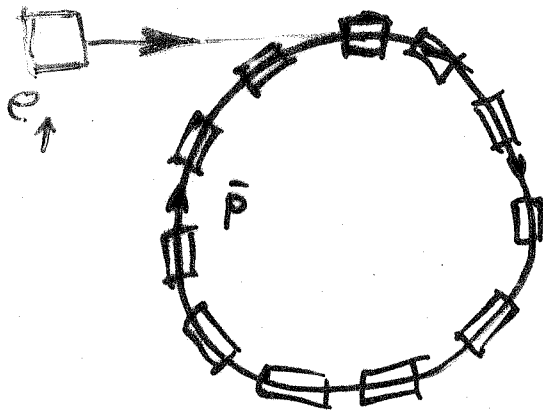
Electrons (6a Ag Source)

$\sim 1$  ma =  $6 \cdot 10^{15}$   $e^-$ /sec  
without recirculation

Polarization  $\sim 50\%$  CK Sinclair

## Kinematics

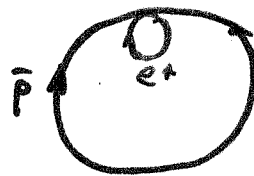
$\gamma$	$\beta$	$P_{\bar{p}}$ [GeV/c]	$P_{e^+}$ [MeV/c]
3.86	.966	3.5 GeV/c	1.90
1.25	.60	.700 GeV/c	.38
1.10	.41	.430 GeV/c	.23
1.05	.30	.300 GeV/c	.16
1.02	.20	.188 GeV/c	.10



$$h\nu = m_e B \pm \mu_{\bar{p}} \cdot B$$

To increase "Luminosity":

A. Recirculate polarized electrons



B. Focus very hard at interaction region  
as at SLC

# DNP

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1.  $e_{\uparrow}$  Density  
 $10^8$  (OK),  $10^{10}$  (Difficult),  $10^{18}$  (SLC)  
 $3 \times 10^{-4}$  cm  $10^{-1}$  cm long
2. May need  $\sim 10^{15}$  for DNP to work
3. Niinikoski: Rotating B-Field  
Rather than Microwaves
4. Jeffries: Pol Transfer Rate  $\sim 1/r^6$   
 $\Rightarrow$  Occasional very close interactions  
may be main effect
5. Need at least 2000 Oscill of MW or Rot B  
to transfer pol from  $e$  to  $\bar{p}$  ??  
 $\Rightarrow$  Length of Int Region  $\geq 2000 \lambda$

DNP

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Kleppner / Jeffries

With  $e^+$  Density of  $10^{10}/\text{cm}^3$   
Pol Transfer Rate  $\approx 10^{-5}/\text{sec}$   
Fairly Independent of  
Relative Vel. of  $e^+$  and  $\bar{p}$

Some problems with high  $v$   $e$  charge  
will produce noise which  
may drop

" Difficult but not hopeless "

Anti hydrogen

Imai: Get Anti Hydrogen by passing  
 $e^+$  and  $\bar{p}$  beams together with some  
Polarize  $\bar{H}$  using Optical Pumping  $\beta^+ \gamma$

Rich: Technique for producing  $10^6 e^+/\text{sec}$   
with 60-70% polarization  
with bigger (more expensive) source  
may get to  $10^7 \sim \$300K$

Alan: here is a summary of my conclusions on DNP of anti-p.

April 19, 1985, Friday 5 pm  
Carson Jeffries

1.) Assume we have a hot non-thermal equilibrium distribution of (many) polarized electrons and (fewer) unpolarized protons in a box or in a torus. This is not really much like the case of conventional DNP in solid targets because:

- 1) there is no spin lattice relaxation;
- 2) the distance  $r$  is variable and large,

where  $r$  is the average distance between electron and anti-proton (or proton).

Nevertheless let's try to analyze the problem using DNP ideas. The Hamiltonian

$$H = H_e \text{ Zeeman} + H_p \text{ Zeeman} + H_{\text{dipole-dipole}}$$

gives these states  $(M, m)$  in zero<sup>th</sup> order, where  $M = \langle P_{ez} \rangle$   $m = \langle P_{pz} \rangle$ . The  $H_{d-d}$  term admixes these states so that a microwave field  $B_1$  [in a DC field  $B$ ] induces forbidden transitions such as  $(e_-, p_-)$  to  $(e_+, p_+)$  that flip simultaneously both the electron and proton spins with transition probabilities:

$$W_f(\text{forbidden}) \text{ for } [(-) \rightarrow (+)] \quad \text{and} \quad W_a(\text{allowed}) \text{ for } [(-) \rightarrow (+)].$$

$$W_a \begin{array}{c} (+) \\ | \\ (-) \end{array} \begin{array}{c} (-) \\ / \\ (+) \end{array} \begin{array}{c} (-) \\ / \\ (+) \end{array}$$

From [??] one has  $\frac{w_f}{w_a} = \left( \frac{\mu_e}{r^3 B} \right)^2$ . Then by using  $\frac{1}{r^3} = \left( \frac{\text{electron}}{\text{density}} \right) = n_e$  we get  $\frac{w_f}{w_a} = \left( \frac{\mu_e}{B} \right)^2 n_e^2$ .

One also has [??]  $w_a = \frac{\mu_e \cdot B_1^2}{\hbar \cdot \Delta B}$  where  $\Delta B/B = B$ -field spread [or  $\Delta f/f$ ] that broadens the resonance line.

Assuming optimum pumping  $\begin{cases} B_1 = 10 \text{ Gauss} \\ \Delta B = 1 \text{ Gauss} \end{cases}$ , one typically has  $w_a = 10^9 \text{ sec}^{-1}$

Now let us use  $n_e = 10^8 \text{ electrons/cm}^3$  as the density in our accumulator (assuming  $n_e = n_{\text{anti-p}}$ ), then

$$\frac{w_f}{w_a} = \left( \frac{10^{-21}}{10^4} \right)^2 \times (10^8)^2 = 10^{-34}$$

$w_f = 10^{-34} \times 10^9 = 10^{-25} \text{ /sec}$ , This is a very small spin-flip rate for anti-protons.

We could get a rate of  $10^{-5}/\text{sec}$  (1 day to polarize anti-protons) by increasing the electron density to  $10^{10} \times 10^8 = 10^{18}/\text{cm}^3$ . This is relatively enormous; and it must be maintained for at least 1000 cycles  $10^3 \times 10^{-11} = 10^{-8} \text{ sec}$ . This corresponds to about several meters along the torus in the accumulator.

2.) Conclusion: even though this model is not valid, the results are so far from realization that it seems nearly hopeless to use DNP, unless some tricky effects can reduce the effective radius  $r$  between e and p.

3.) Dan Kleppner calculated this in detail and finds that when he takes a scattering approach to the e-p dipole-dipole interaction, the results are still not favorable. In this case, one probably wants high relative velocities to make the impact parameter as small as possible. But this also adds a random field pulse at the proton; this will have a broad Fourier spectrum and the component at the p Larmor frequency will act as a noisy saturating field that tends to equalize the up/down p spin states and thus relaxes away the p polarization build up. This will be true even in the microwave method. Detailed calculations could be done but it is not too promising.

[...] added by ADK

# Polarizing Anti-protons using DNP in Flight

A.D. KRISCH

University of Michigan

Return to “crazy idea” of “moving” Dynamic Nuclear Polarization proposed at Bodega Bay.

Evaluated by C. Jeffries and D. Kleppner:

Will be very difficult because polarization transfer rate may be very small due to:

- large  $\Delta v/v$  between the polarized electrons and the unpolarized antiprotons;
- low luminosity.

However, there have been interesting advances in physics since then:

- Spin-flipping by adiabatically sweeping an RF magnet's frequency through a resonance, proposed by R. Phelps, was successfully tested at IUCF and is now widely used.
- Electron cooling technique proposed at Novosibirsk was successfully demonstrated at IUCF by R. Pollack *et al.*

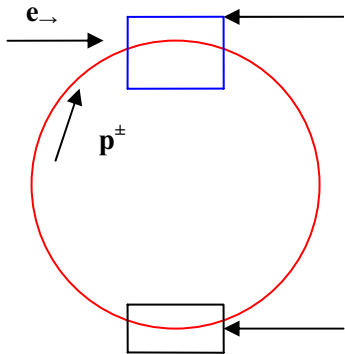
Thus, one might now inject a stochastically-cooled polarized electron beam parallel to a stored unpolarized but electron-cooled anti-proton (or proton) beam. Then one might sweep, by a range  $\Delta f$ , the frequency of microwave radiation injected into a region of longitudinal magnetic field  $B$ ; this could flip the polarization of *only* those anti-protons (or protons) whose spins are anti-parallel to the electrons' spins.

- a) At the  $\Delta f$  sweep's center  $\frac{1}{2} h \cdot f \approx B(\mu_e + \mu_p)$ ;
- b)  $\Delta f$  must be too small for  $\frac{1}{2} h \cdot f$  to ever cross  $B(\mu_e - \mu_p)$ ;
- c)  $\Delta f/f$  must be larger than  $\{(\Delta p_e/p_e)^2 + (\Delta p_p/p_p)^2\}^{1/2}$ .

Thus, both the electron and anti-proton (or proton) beams, must be cooled (electron cooling for p-beam; stochastic cooling for e-beam).

A “solenoid” magnet and a matching microwave source must satisfy  $\frac{1}{2} h \cdot f \approx B \cdot \mu_e$ .

If this suggestion seems practical, then one might test it at COSY.



## **Polarizing Device**

Strong longitudinal uniform B-field;  
Microwaves for  $e^- \rightarrow p^\pm$  pol. transfer  
-with sweepable frequency;  
Strong focusing of pol. electrons

## **Siberian Snake**

# POSSIBLE DEVICE: Don Crabb's PPT\*

