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SUMMARY OF POLARIZED BEAMS AND TARGETS

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ABSTRACT

This summary is an overview on Polarized Beams and Targets based on presentations at the 5th International Symposium on High-Energy Spin Physics and the two Workshops on Targets and on Accelerators. The highlights of the Symposium were, in my opinion, the results on irradiated NH_3 polarized target material, and the successful acceleration at Saturne II of polarized protons using the slow adiabatic resonance crossing. The first will immediately make possible new inclusive experiments, and the second gives a new means of fighting resonances in proton machines. Good news was heard about the plans and progress of the Tevatron polarized beam and of the acceleration of polarized protons in the AGS. These will provide the basic tools for high-energy spin physics for many years. Great hopes are placed in the use of stable atomic hydrogen in new polarized proton sources, which are expected to reach intensities comparable with the unpolarized ones; and, for polarized electrons, in new cathode materials with a non-degenerate top of the valence band, in which theoretically a twice higher electron polarization can be reached compared with that of the present GaAs photocathodes. Keeping all this in mind we might predict that spin will play an increasingly important role both in fixed target and collider physics; remembering the interest expressed by many physicists in the polarized lepton-proton experiments, polarization could become a standard tool at the future ep colliders.

INTRODUCTION

First of all I would like to thank the Organizers for the smooth running of the Symposium and for the pleasant atmosphere in which we have been working. Alan Krisch warned me that I should include all names in this Summary if I do not want lose my friends. I have tried my best, but if there are omissions they are simply due to the impossibility of attending all parallel sessions; I apologize for the omissions and take the responsibility for possible errors.

In his opening talk, Nick Samios pointed out that one count gives the total cross section, two the angular distribution, but three are required for polarization. The last number becomes 300 if we put in the effective nucleon polarization of 10% in a target today. This shows the difficulty of the new spin physics with the present tools. Our ultimate aim is to improve the tools so that the three counts will suffice.

In the beginning I thought that there might be much in common

in the different scientific and technical disciplines needed to produce high-energy collisions of spin-aligned particles. It turns out that the Thomas precession is the only thing they have in common. To this we have to add radiative effects in electron synchrotrons, statistical quantum mechanics in polarized targets, solid-state physics in electron sources, atomic physics in ion sources, and so on. The vocabulary in the few common things may be confusing: the 'slow adiabatic resonance crossing' is called 'fast adiabatic passage' in NMR of solids, because, at the time of its discovery, the speed of the adiabatic passage had a lower limit due to the spin lattice relaxation. The hardware has even more diversity: we go from large circular machines with their sophisticated controls and huge beam lines, passing by molecular beam and laser optic systems in polarized sources, to ultra-low temperature and millimetre wave set-ups in polarized targets. Nearly all high technology fields are represented here.

Because not much common structure is found in the above, the following text is divided into sections dealing with Polarized Targets, Sources, Atomic Hydrogen, and Beams. There is no reference list at the end; the reader should consult the Table of Contents according to the author names given in the text (often in parentheses).

In the text I have adopted the following shorthand notation: $\uparrow$ = proton spin polarized, $\downarrow$ = electron spin polarized. When the relative orientation matters, the arrow points up for spins aligned parallel to the field, and down for spins aligned antiparallel. In particular, $H\downarrow$ means stable atomic hydrogen (not necessarily proton spin polarized), $H^-\uparrow$ means polarized negative hydrogen ion, and $H\downarrow\uparrow$ means b-state H atom. Unpaired electron spins in free radicals are denoted by "." after the chemical symbol; $H\cdot$ then means free atomic hydrogen without specification of state or polarization. Note that the electron and nucleon spin symbols are often reversed in discussions on stable atomic hydrogen.

POLARIZED TARGETS

Irradiated target materials are becoming a standard. At SLAC an impressive list of hydrogen-rich materials has been studied (Seely); the outcome seems to be that ammonia (NH_3 or ND_3) still performs best. Detailed studies of NH_3 and ND_3 have been made at Bonn (Meyer, Riechert). The results on ND_3 , where a small fraction of D is substituted by H, show convincingly that the main mechanism of dynamic nuclear polarization (DNP) is based on two-spin transitions such as the differential solid effect, rather than on the cooling of the nuclear spins (by the electron spin-spin interactions). Meyer and Riechert also showed that the EPR line broadening of the $NH_2\cdot$ and $ND_2\cdot$ radicals comes mainly from their hyperfine structure, and little (if at all) from g-factor anisotropy. This gives good hope for

higher deuteron polarizations, and for a possible selective destruction of the polarization of ^{14}N spins. In a polycrystalline material, such as ammonia, large g-anisotropy would give rise to poor DNP; this might actually be the cause of the rather low polarizations in most of the other materials tried out by the SLAC group (Seely). I would like to take this opportunity to emphasize the importance of also publishing the results which may look unsuccessful from the point of view of the applications; the failure to be able to polarize may have a physics reason that is interesting in its own right. If correctly interpreted, these results might also help to understand and improve the better materials and, at least, to avoid needless duplication of the work.

The radiation resistance was also discussed intensively. Puzzling differences were pointed out in the SLAC and Bonn results: the NH_3 material, irradiated near 1 K, has 30 times better radiation resistance in comparison with butanol-water, whereas the NH_3 prepared beforehand by irradiating at 80 K gives an improvement by a more modest factor of 3 only. A careful comparison was made during the Workshop on all available information, and it was concluded that a different paramagnetic radical might be responsible for the DNP in the two cases. It occurred to me only when writing this, that all the pieces of the puzzle join nicely together: irradiation at 80 K is known to produce only $\text{NH}_2\cdot$ because $\text{H}\cdot$ is much more unstable, whereas at 1 K and high field (which may also be necessary) the $\text{H}\cdot$ is stable against chemical reactions and becomes trapped in lattice faults. Because of the narrow EPR lines of the $\text{H}\cdot$, its resonance is much stronger than that of the nearly equally abundant $\text{NH}_2\cdot$, and one may therefore polarize the target, with the $\text{H}\cdot$ radical, at an irradiation energy deposit 100 times below the usual Bonn doses. The so far unexplained sudden losses of polarization, without cryogenic failure, might be due to the instability of the $\text{H}\cdot$ under beam heating when a critical density is reached. The improvement due to controlled annealing at 13 K might be explained by the diffusion of $\text{H}\cdot$, which would settle to an equilibrium trap site at or near to a distortion of the NH_3 lattice, thereby narrowing the $\text{H}\cdot$ linewidth due to the distribution of its g-factors in different kinds of traps. Annealing at higher temperature would probably cause destruction of $\text{H}\cdot$, and DNP can then be done with the $\text{NH}_2\cdot$ radical only, whose concentration might be too small.

The same discussion applies to ND_3 , explaining the radical instability at 20-40 K temperatures at SLAC, contrasting the complete conservation of the Bonn samples stored at 77 K for over a year. Summarizing, at SLAC the DNP is produced by what causes the radiation damage at Bonn and vice versa.

An in situ irradiation study of NH_3 was also performed at BNL (Crabb). The target was initially irradiated with 2.4×10^{15} high-energy protons before annealing at 50 K and polarizing. The

polarization results during the subsequent data-taking with 3×10^{10} protons per pulse on the target look very promising. Quite probably the $\text{NH}_2\cdot$ radical was used here for DNP, because annealing at 40 K improved the polarization. The radiation damage up to 8.3×10^{15} protons was small.

We might conclude that the best procedure would be the irradiation of the ammonia at high temperature (80 K) beforehand, which allows the recovery from damage by a fast annealing at a relatively low temperature. A practical facility for such irradiations has been created at Bonn; it uses the 20 MeV electron LINAC of the Bonn Synchrotron and liquid-argon cooling (Meyer). At SLAC a similar facility has been approved (Seely). Target material irradiations will also be performed at the Saclay ALS (Deregel). In these facilities it would be also interesting to do EPR, DNP, and radiation resistance studies; such an installation would attract radiochemists, too. For understanding the chemical reaction dynamics of H $\cdot$ at low temperatures, one might study its substitute muonium in the existing μSR (muon spin rotation) equipment, available at SIN, TRIUMF, LAMPF, and CERN.

The main advantage of the irradiated materials is that they can be returned to the state where the most stable radical dominates, by a simple annealing operation, nearly an infinite number of times. The ultimate chemical destruction of the material requires such high doses that other experimental equipment will start suffering by that time also.

Recent studies at ANL on improved hydrogen-rich glasses have revealed a promising material, NH_4BH_4 with 50% NH_3 , in which the new Cr(V) complexes can be dissolved. This glassy material outperforms ammonia in hydrogen content (Hill, Krumpolc); future polarization and radiation damage tests are eagerly awaited. Although NH_4BH_4 is unstable at room temperature, its preparation is possible without sophisticated means.

The recent instrumental developments were reviewed by G. Court. Dilution refrigerators have been employed at CERN, KEK (Masaike), Saclay (Deregel), SIN, Bonn (Meyer), LAMPF (Jarmer), and Michigan (Cameron), and new ones are being constructed at Liverpool and TRIUMF. These refrigerators allow higher polarizations to be achieved (particularly for deuterons), larger targets to be constructed, and the spin-freezing technique to be applied. The so far largest target is one metre long, has a 2.4 litre volume, and is cooled with this technique. The dilution refrigerators, however, might probably not replace the ^4He refrigerators in experiments with very high intensity beams if a 5 T field can be used (Court).

A versatile superconducting solenoid system has been constructed at Saclay for use with a frozen-spin target, which has also recorded an interestingly low polarization loss at 0.4 T holding field and with 10^8 protons per second beam intensity (Deregel).

POLARIZED SOURCES

The status and recent projects of polarized ion sources was presented by V. Hughes in his summary on the 1981 Ann Arbor Workshop. In the following, I shall concentrate only on the new results and plans presented in this Symposium. The emphasis will be on negative ion sources, which allow multiturn injection into synchrotrons.

The ETHZ negative ion source uses a room-temperature polarized atom beam stage, followed by positive ionization by electrons before the 5 kV Na vapour channel double-electron adder. The 5% and 3% efficiencies in the ionization stages result in a 3-6 μA negative ion current; obviously pulsing and cooling would improve these figures, but it was also suggested that the Na channel diameter could be increased. The future recycling of the Na will improve the availability of the source, and it was suggested that Sr vapour should give a 50% yield in the negative ionizer, resulting in a 50-100 μA H^{-} current (Gruebler).

The AGS H^{-} source uses an Anac polarized atom beam stage, followed by negative ionization with $T = 40$ keV Cs^0 beam. The nozzle of the discharge tube is cooled to 30 K with a closed cycle ("Displexer") helium refrigerator. A polarized atom intensity of $2 \times 10^{16} \text{ cm}^{-2} \text{ s}^{-1}$ and density of 10^{11} cm^{-3} has been measured in the ionizer. In pulsed operation the polarized H atoms reach the ionization region well ahead of H_2 , which reduces the ionized beam contamination with unpolarized atoms (Kponou).

The tests of the AGS source were done with a pulsed zeolite Cs^+ ionizer in the Cs^0 gun. An improved Cs^0 gun has been developed and tested in Wisconsin; it uses a spherical porous tungsten Cs^+ ionizer at 1100 °C temperature. Contrary to earlier belief, this W button stands pulsed operation, giving a 10 mA Cs^0 beam pulse after the Cs vapour neutralizer of 90% efficiency (Wise). The new Cs^0 gun produces a 3-10 μA d.c. H^{-} current using an RT discharge; cooling of the atoms to 30 K and going to pulsed operation should improve this figure to 60 μA . It was also speculated that further cooling of the atoms to 4 K should result in a 150 μA H^{-} peak current (Wise and Haeberli). The replacement of the Cs^0 by an H^{-} or D^{-} beam in the negative ionizer might lead to a further large improvement factor, in addition to easier operation and maintenance (Hughes).

A helium cooled RF discharge atom source has undergone preliminary studies at CERN. Unexpected material, geometric, and gas-dynamic problems have been observed, although the results have encouraged the implementation of an improved design (Penttilä). At Dubna some experience has been gained with a cold atom source: the nozzle of the POLARIS source discharge tube was cooled to 4 K with no detectable improvement in the ion beam intensity. The problem is believed to be in the matching of the

multipole magnet, which is optimized for faster atoms (Pilipenko). There is a general consensus that a helium-cooled atomic beam source should be designed to a very compact geometry, making efficient use of the cryopumping ability of the cold walls and, possibly, of superconducting magnets (Hughes, Penttilä, Pilipenko).

Many new ideas based on the use of stable atomic hydrogen in ion sources were presented. These will be discussed separately in the next section.

The neutral beam diagnostics, in particular polarization measurement, are important for the setting up and debugging of a source. In the AGS source, access is reserved for neutral beam diagnostics (Kponou). Accurate neutral beam polarization measurement was proposed, based on the use of a diabatic transition spin flipper, which has a 98% reversal efficiency for Li atoms (Baum and Schroeder). The H^{-1} beam polarization might also be measured with a beam foil polarimeter by analysing the circular polarization of the Lyman α radiation; this would apply for a high-energy H^{-1} beam at LAMPF as well (Hughes).

The GaAs polarized electron ($e^{-\downarrow}$) sources provide pulsed beam intensities as high as accelerators can accept, contrary to the ion sources. The recent $e^{-\downarrow}$ source improvement work has been concentrated on the photocathode lifetime and quantum efficiency (which determines the laser power requirement), reproducibility of preparation and, above all, improvement in the polarization which is theoretically limited to 50% due to the degeneracy at the top of the valence band in GaAs. Today, 45% polarization can be achieved with RT operation; this avoids the need for annealing due to the cryopumping of contaminants. Much of this improvement comes from the use of molecular beam epitaxy (MBE) which allows excellent growth control leading to clean, faultless crystal surface. A new material, $CdSiAs_2$, will have theoretical maximum electron polarization of 100% because of split energy levels on the top of the valence band; although the practical goal of 60-80% has not yet been reached, the results so far are promising enough to continue along that line (Campagna).

Parity violation experiments with $e^{-\downarrow}$ often require very high stability of the source operation. A control grid has been installed in between a GaAsP photocathode and the extraction electrode; in this way, stable flat top pulses can be provided from the source (Reichert).

STABLE ATOMIC HYDROGEN

The stable atomic hydrogen ($H^{\downarrow}$) will almost certainly become an important tool for spin physics, but it is too early to predict how and when. This is why I have separated the subject in its own section, where possible applications as target (stationary, gas jet, or atomic beam) or in an ion source are discussed, starting from the

special requirements of the stabilization. These requirements are: low temperature (0.3 K or below), high field (5-10 T), and all surfaces coated with superfluid ^4He film, possibly with some ^3He added on top of the film. The current capabilities are: atom density $3 \times 10^{17} \text{ cm}^{-3}$, loading flux 10^{16} s^{-1} , nuclear polarization (one polarity only) 99%, and relaxation time 1 hour (at 10^{17} cm^{-3}) (Kleppner). The above density looks impressive in comparison with the best polarized atom beam densities (10^{11} - 10^{12} cm^{-3}) in the ionizer of a source. On the other hand, the free polarized hydrogen density in solid targets is $5 \times 10^{22} \text{ cm}^{-3}$; their replacement in all applications would require about three orders of magnitude improvement in the atomic hydrogen density.

The proposed applications of $\text{H}\downarrow$ can be divided into two broad categories: those in which the proton-spin-selected atoms are used in situ -- transformed by ionizing or scattering -- in the stabilization cell, and those in which they are extracted by microwave-induced spin flips followed by magnetic field expulsion.

In the first category two very promising techniques emerge. The first is a polarized target confined by a magnetic field in a thin-walled tube (Kleppner). Vacuum problems related to the superfluid film in the open geometry can be avoided by burning the film in a suitable area and then refluxing the vapour onto cold baffles (Kleppner). Experimental evidence suggests that this can be done in dilution refrigerators with sufficient cooling power (Niinikoski). The end result is a physicist's dream target: no walls in the way of the beam if it shares a common vacuum with the target. Secondly, the particle beam through the target (which can be continuously loaded with spin-selected atoms) could be replaced by an ionizing beam (neutral alkali atoms or H^- or D^-) and extraction electrodes could be placed near the stabilization region; this would allow the extraction of very high negative-ion currents (Kleppner). Because no more than about half the atoms coming from the dissociator are wasted in the spin selection and because accumulation can be done in between extraction pulses, the average ion currents might be nearly 1 A (Wise and Haeberli). These currents are of interest even to plasma researchers, who propose to burn polarized deuterons in a magnetically confined plasma, heated by polarized neutral beams (Kulsrud).

In the second category of applications, it is proposed to extract the stable atoms before using them (ionizing or scattering). The microwave flip extraction has several advantages, but it also has drawbacks compared with the above. Clear advantages are: the possibility of pulse-to-pulse reversal of the polarization by the appropriate choice of one of the allowed transitions $a \rightarrow d$ or $b \rightarrow c$, which are separated by 507 G; no spin selection before stabilization (and therefore smaller losses in atomic flux); and no worry of dumping a large ionizing beam. A drawback might be the possible losses in the subsequent handling of the extracted atom pulses,

both in the flux and in the density. It was suggested that a reasonable density could be maintained by hexapole magnet focusing; the atoms could also be bunched, accelerated, or decelerated by oscillating fields and drift tubes, and they could perhaps be stored in a ring consisting of quadrupole bending magnets and multipole focusing elements (Niinikoski). This might allow further density increases in comparison with single-pass jet target operation.

A solid orthohydrogen frozen-spin target was proposed, based on the following: the b-state gas recombines owing to the surface relaxation $b \rightarrow a$, which results in the formation of solid, nuclear spin-polarized orthohydrogen (Kleppner). The solid could fall into a pool of liquid ^4He ; because of its lower density the solid H_2 would float. By controlling the liquid level, one could position the freshly formed solid in the beam. This technique would work equally well with deuterium. The obvious advantage would be the high density of the solid hydrogen; walls in the way of the beam, however, cannot be avoided.

POLARIZED BEAMS

The slow adiabatic resonance crossing has been successfully applied at the Saclay Saturne II synchrotron to accelerate protons to 2.4 GeV. The positive ion source polarization was about 80%; no more than 5% is lost in nine major resonances. The machine can be corrected by twelve dipole windings in the quadrupole magnets, so that the strength of some of the imperfection (and combined) resonances can be reduced below the level at which less than 1% depolarization occurs when accelerating through them. The strong resonances which could not be corrected were passed by allowing the spin to follow the effective field adiabatically, which results in polarization reversal with no significant loss in its value. To be able to do this, the adiabatic conditions were fulfilled by making some resonances artificially stronger. The resonance crossing and correction strategies were studied systematically; it was reported that running at a new energy now requires no more than six hours of setting up. These studies have also given results which are not yet fully understood: the polarization after resonance crossing, plotted as a function of correction current, exhibits unexpected side-lobes. It is planned to increase the present intensity of 10^9 pppp (polarized protons per pulse) by adding a booster before the synchrotron; the improved intensity would obviously make the machine control easier and polarization measurement faster with the external polarimeter (Grorud).

The side-lobes gave rise to plenty of discussion during the Accelerator Workshop, with views on the future acceleration of protons in the Brookhaven AGS. The Workshop participants signed a letter to the management of the Saturne II Laboratory, stating the interest and importance of performing machine experiments which

would shed light on the spin dynamics in real machines and help to fully understand the large effects that were seen.

It was proposed that the side-lobes could perhaps be understood by evoking two nearby resonances; it was pointed out that no resonances, even well resolved, can in theory be considered isolated, and interference effects should be taken into consideration (Ruth). An analogy can be found in the NMR of a stationary spin system, excited by two rotating fields of slightly different frequencies. Depending on the strength of these fields, the requirements for the adiabaticity in the rotating frame of the stronger field may vary considerably. Interesting experiments for studying these effects in polarized targets could also be suggested.

The AGS goal is to accelerate 10^{11} pppp to 26 GeV with over 60% polarization. Fast ferrite-core quadrupoles (rise-time $< 2 \mu s$) will be used for crossing the intrinsic resonances. The fast rise-time allows the vertical betatron tune shift to be made in less than one machine turn, which is required in order to avoid betatron oscillations. These magnets have been assembled at Michigan and tested successfully. The 96 existing correction dipoles will be used for suppressing the imperfection resonances. The new results from Saturne II encourage the machine team to try also the adiabatic (spin flip) resonance crossing (Ratner). The AGS negative ion-source improvement program is expected to result in an intensity that is sufficient for the initial physics programme. Higher intensities could be envisaged with a booster, which would improve the duty cycle of the source (Lee).

At the AGS, 60 resonances will be crossed to reach the full energy. This number for ISABELLE is 800, which looks impossible with the normal means of correction. Snakes are proposed to help in tolerating resonances; a snake in a ring machine inverts the spin once each turn. The spin precession error is nullified each two turns, in analogy with the NMR spin echo technique. In accelerator language, the spin tune is changed from $\nu_p = \gamma G$ to $\nu_p = 1/2$. Still better tolerance can be achieved with two snakes, one on each side of the machine: one (named Cobra) turns the spin by π around the beam axis, the other (Sidewinder) around a transverse horizontal axis. These raise the tolerable strength of the resonances by about 3000. Even with a careful machine alignment a few strong resonances must still be corrected, but the task does not seem impossible. The additional advantage of the Sidewinder is that in its centre the spin is along the beam direction. The snake could therefore be positioned at an intersection where longitudinal polarization is required (Courant).

The Dubna Synchrophasotron has accelerated polarized deuterons to 10 GeV. Future development work should increase the present intensity of 5×10^8 dpp to 10^{10} dpp (Pilipenko).

The depolarizing resonances in electron synchrotrons obey the same laws as they do in the proton machines, the only difference

being the much smaller value of the anomalous magnetic moment of the electron. There is, however, an additional quantum depolarization (the Baier and Orlov effect) for electrons due to the emission of synchrotron radiation, via spin diffusion in the energy distribution. The same radiative (Sokolov and Ternov) effect can be used for polarizing a stored beam; because the same phenomenon causes both polarization and depolarization, an elegant -- but not simple -- theory can describe the time evolution of the polarization. Experimental results from PETRA confirm some of these calculations performed with the SLIM code of A. Chao; with one beam 50% polarization has been reached, as measured with the laser Compton polarimeter. The integer depolarizing resonances, spaced at each $m_0 c^2/a = 440$ MeV, have been used for accurate energy calibration with the help of the polarimeter. To avoid polarization (!) in PETRA, a 60.7 kHz oscillating field can be used to excite a depolarizing resonance. A spin rotator is foreseen for future longitudinal polarization in an intersection (Schmidt).

The theory of Sokolov and Ternov has been used to compute predictions for HERA and LEP. At HERA the plans include spin rotators for polarization reversal; the wigglers can also be operated at negative polarization (Steffen). At the moment the LEP plans involve only a laser polarimeter; the rest can be crystallized in Darriulat's phrase "LEP's wait and see" (Montague).

G. Voss presented a report on a recent Workshop on Electron Polarization; the reader is referred to it for more information on this vast subject.

The Tevatron 200 GeV/c $p\bar{p}$ ($\bar{p}p$) beam will transport some 10^7 protons, with 45% average polarization, every 1-2 minutes over 1100 feet to the experimental area. The primary beam of a few 10^{12} ppp strikes the production target of one interaction length, producing Λ 's ($\bar{\Lambda}$'s) the decay of which produces the polarized p ($\bar{p}$). Both signs of polarization are present at the experimental target; a tagging system will tell the sign and expectation value of the polarization for each particle. This system limits the beam intensity to $\approx 3 \times 10^7/\text{spill}$. A future upgrade to 400 GeV/c is possible with superconducting quadrupoles (Read).

It has been stated on several occasions that the success of future highest energy (collider?) spin physics will depend largely on the availability of fast and reliable non-destructive beam polarimeters. They should preferably be absolute and independent of energy. The AGS team will use a nylon thread target sweeping through the beam in the ring, to measure pp elastic asymmetry which will be calibrated with an external polarized target (Ratner).

The most promising reactions for beam polarization measurement were reviewed by Kuroda. A polarimeter based on the elastic pp scattering in the Coulomb-nuclear interference region is being constructed for the Tevatron beam. The analysing power, although small (4.6%), is calculable and approximately independent of beam

momentum. Another polarimeter, based on the Primakoff effect, would measure the beam polarization to $\Delta P = 3\%$ every 25 Tevatron spills; this reaction was proposed for transferring the NMR calibration of target polarization to the beam. It was also suggested that the large asymmetry of the inclusive π^0 production would provide a rapid means of measuring the relative polarization in an accelerator, using an H_2 jet target and eight counters. The analysing power is $60 \pm 30\%$ at 24 GeV/c but the energy dependence is not known (Kuroda). This could be circumvented by a method proposed by Roubeau, where the beam polarization is always measured at a fixed energy. The resonance crossing losses would occur twice because a deceleration would be required. It remains to be studied if the polarization losses at each resonance are unchanged with inverse sequence.

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