

22 August 1994

**PROPOSAL UPDATE TO U.S. DEPARTMENT OF ENERGY**  
**High Energy Spin Physics Group**  
**University of Michigan**

## Introduction

The High Energy Spin Physics group at the University of Michigan has mostly studied large- $P_{\perp}^2$  proton-proton scattering since the 1960's. The group obtained several significant results including: early evidence for structure in the proton; the first inclusive data; and the first evidence for Feynman-Yang inclusive scaling. Starting around 1970, the group began to study the spin dependence of proton-proton collisions by building state-of-the-art polarized proton targets and helping to develop the world's first accelerated polarized proton beams, first at the ZGS in 1973 and then at the AGS in 1984. The group then used these polarized beams and targets to discover large and unexpected spin effects in violent proton-proton elastic collisions.

During the 1990's the group has concentrated on three main efforts:

1. The study of spin effects in higher energy  $p$ - $p$  collisions:
  - a. AGS E-794: One-spin asymmetry in 24 GeV  $p$ - $p$  elastic scattering at high  $P_{\perp}^2$ .
  - b. NEPTUN-A: One-spin asymmetry in  $p$ - $p$  elastic scattering at 400 GeV at UNK in Protvino, Russia
  - c. PROZA: Left-right asymmetry in  $\pi^0$  production at 70 GeV at U-70 in Protvino, Russia
2. The development of state-of-the-art spin-polarized targets and jets:
  - a. Solid  $\text{NH}_3$  target used at the AGS in 1990 with 96% polarization with  $10^{11} \text{ sec}^{-1}$  beam intensity
  - b. Prototype ultra-cold spin-polarized atomic hydrogen Jet for R&D
  - c. Mark II ultra-cold spin-polarized atomic hydrogen Jet for NEPTUN-A (Under construction)
3. Research and development on TeV polarized proton beams using Siberian snakes:
  - a. Siberian snake studies at the IUCF Cooler Ring
  - b. Design of polarized beam capability for the SSC
  - c. Design of polarized beam capability for the Main Injector and Tevatron (Funded by Fermilab)

During 1993 and 1994, the High Energy Spin Physics group carried out the activities described on the following pages. Despite the UNK construction delay due to Russia's financial problems, the group's highest priority project continues to be the NEPTUN-A experiment on the 400 GeV UNK-1 accelerator at IHEP-Protvino. While awaiting UNK-1, we have increased our involvement in the annual PROZA runs at the existing 70 GeV accelerator at IHEP-Protvino.

Our Siberian snake program at IUCF and Fermilab has been unexpectedly successful. It continues to become a larger part of our total program; perhaps our funding distribution should again be readjusted to reflect this change.

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## NEPTUN-A at UNK in Protvino, Russia

The NEPTUN-A experiment<sup>11,12,13,17,18,19,46</sup> will study spin effects in violent proton-proton collisions as the first experiment at the new 21 km circumference 400 GeV UNK-1 accelerator at IHEP-Protvino in Russia. UNK-1 should be the world's largest proton accelerator when it begins operation around 1997 or 1998; this date depends on the funding level from the financially troubled Russian government.

The changing situation in Russia has strongly affected NEPTUN-A. Russia's financial problems have delayed the UNK-1 accelerator until at least 1997 and postponed the superconducting 3-TeV UNK-2 ring into the next century. This postponement of UNK-2 has sharply increased NEPTUN-A's priority. Apparently IHEP is now making special efforts to prepare for NEPTUN-A. Our large underground experimental hall, which is shown in Fig. 1, was dedicated on 1 October 1993. W.N. Hess and J.R. O'Fallon participated in the dedication which included the transfer of \$100,000 for UNK-1 dipoles from DOE to IHEP via Michigan. Moreover, IHEP recently fabricated the four quadrupoles for the NEPTUN-A spectrometer and is now fabricating the five spectrometer dipoles.

Thus, despite the complex Russian financial situation, IHEP continues to make painful but significant progress on UNK-1 and NEPTUN-A. Unless we receive clear directions otherwise, we plan to continue to give our highest priority to NEPTUN-A, which is an important part of the USA-Russian JCC Agreement.

The NEPTUN-A group now has about 20 Americans and about 20 Russians; Michigan is the lead institution. Primarily due to NEPTUN-A, the University recently provided \$475,000 for the new High Energy Spin Physics laboratory in the Kipke Building.

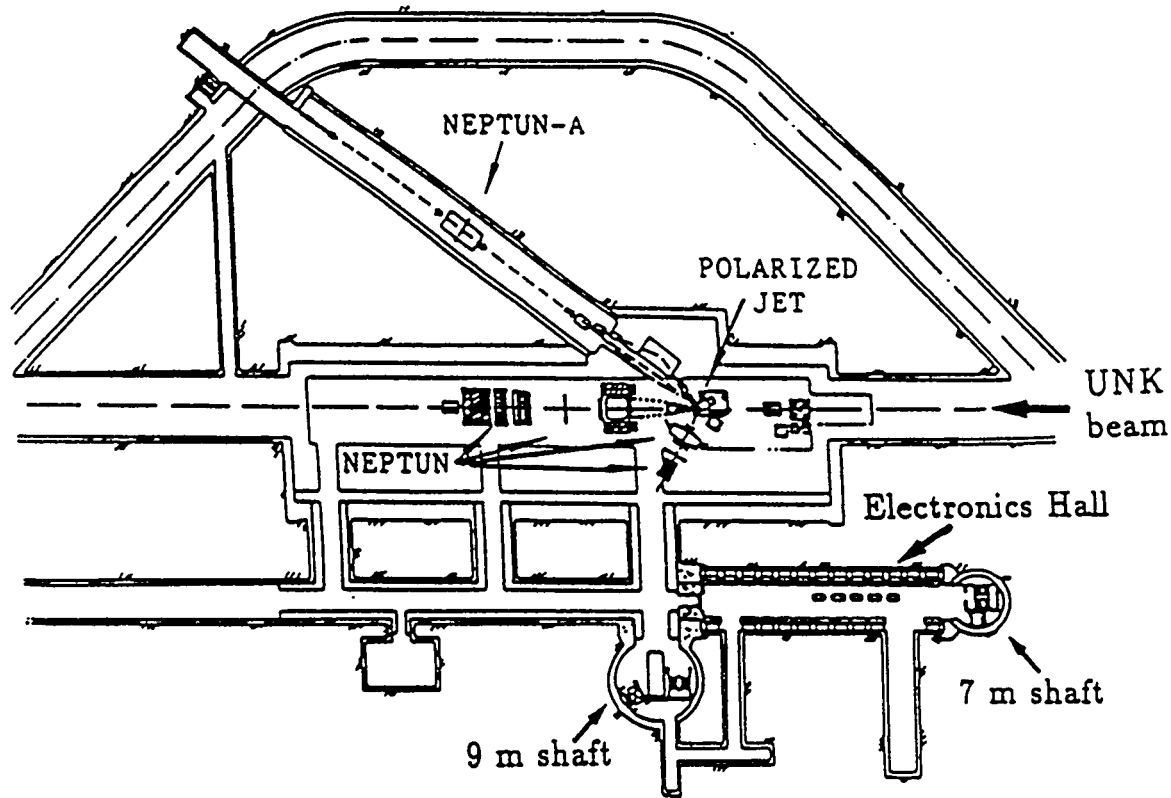


Fig. 1 SS-3 underground experimental hall with NEPTUN-A, NEPTUN and the Ultra-cold spin-polarized atomic hydrogen jet.

## Siberian Snake Tests at IUCF Cooler Ring

Our IUCF Siberian snake studies have been unexpectedly successful. The NSF FY1993 Budget Submission to Congress listed them as *the highlight of the NSF High Energy and Nuclear Physics Program*. Moreover, the five experimental runs of CE-40 during 1993 and early 1994 produced a great deal of interesting new data<sup>1,5,6,7,26,28,29,30,35,37,38,42,43,45,47</sup>. Another run is scheduled for 15-21 November 1994. These runs used two new devices which were built by Michigan:

1. A 15 kV at 1.5 MHz rf solenoid magnet
2. A warm ramped solenoid Siberian snake.

Some highlights of the recent runs are:

1. We found no measurable depolarization of a 370 MeV stored polarized proton beam when we adiabatically turned a partial Siberian snake on and off a total of 10 times<sup>5</sup>, as shown in Fig. 2. This 370 MeV energy corresponds to a spin tune of  $G\gamma = 2.5$ . This data confirmed the prediction that Siberian snakes can be turned on adiabatically at half-integer spin tune energies. This result has some significance for polarized beam acceleration at the Brookhaven AGS and the Fermilab Booster.
2. Last fall, we made the first test of a partial Siberian snake during polarized beam acceleration. We ramped a 10% partial snake while accelerating from 95 to 140 MeV through the  $G\gamma = 2$  imperfection depolarizing resonance at 108 MeV; as shown in Fig. 3, the 10% snake suppressed all observable depolarizing effects<sup>6</sup>. The AGS installed a partial snake and found similar results this spring.
3. We recently flipped the spin direction of a 140 MeV stored polarized proton beam 50 times with no observable polarization loss within our 2% errors; the polarization loss was  $0.0000 \pm 0.0005$  per spin-flip<sup>7</sup>. This new spin-flip capability will allow experiments using stored polarized proton beams to strongly discriminate against most systematic errors.

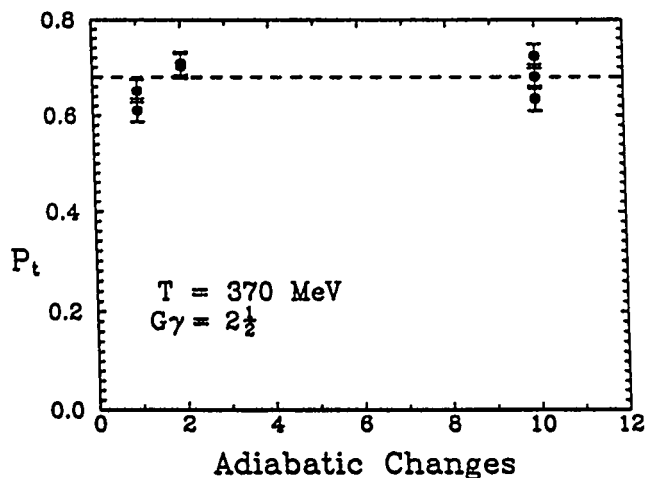


Fig. 2. The transverse polarization,  $P_t = \sqrt{P_y^2 + P_z^2}$ , at 370 MeV is plotted against the number of times the 25% partial Siberian snake was turned on or off. The dashed line is the best fit to the data; the data shows no depolarization within our 2% precision.

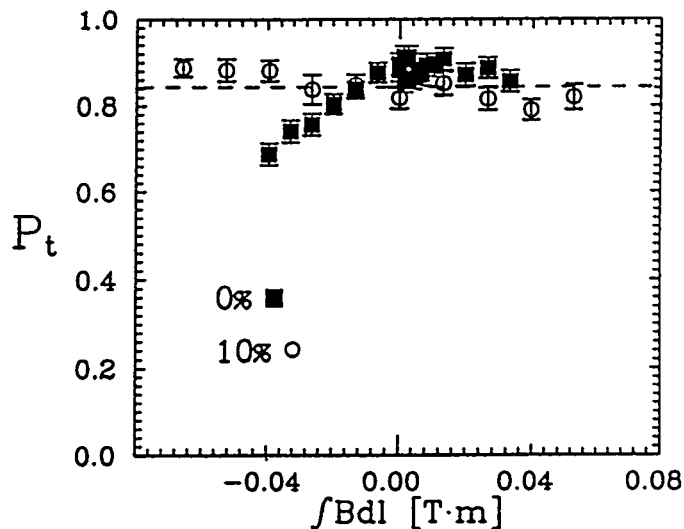


Fig. 3. The measured transverse polarization,  $P_t = \sqrt{P_y^2 + P_z^2}$ , at 140 MeV is plotted against the imperfection  $\int B \cdot dl$  with no snake and with a 10% partial Siberian snake. The dashed line is the best constant polarization fit to the snake-on data. The beam was accelerated from 95 to 140 MeV.

### Polarized Gas Jets

After completing our studies with the Prototype polarized gas jet, we are now fabricating in our new laboratory the 6-meter-high Mark II jet for NEPTUN-A, which is shown in Fig. 4. A quasi-parabolic mirror coated with "reflecting" superfluid helium focussed the Prototype jet's outgoing polarized hydrogen atoms and thus increased the jet's intensity by a factor of 7.5; this result<sup>16,27,33,36</sup> was published in Physical Review Letters<sup>2</sup> and discussed in the CERN Courier. We are now designing a similar mirror for the Mark II jet.

Due to the delay in UNK-I, we decided to launch an R & D program to improve the intensity of the Mark II jet<sup>3,4,15,32,39,40,41,51</sup>. The Pert Chart for the Mark II project is shown in Fig. 5. We have also done some preliminary design work on a similar Mark III polarized jet, which might be used as an internal jet target in the Tevatron at C0 if the Polarized Tevatron project is funded.

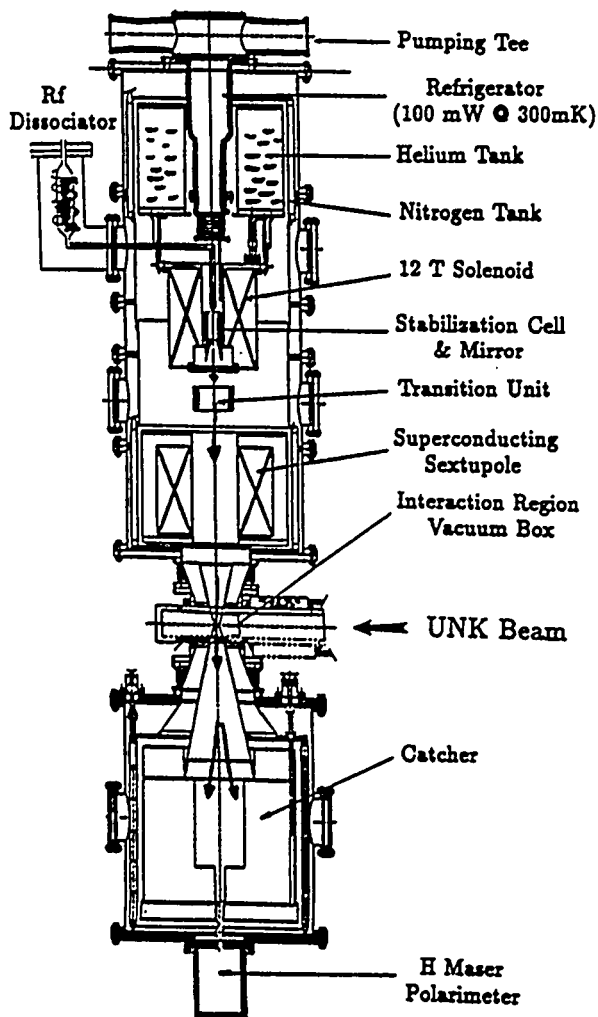


Fig. 4. Mark II ultra-cold spin-polarized atomic-hydrogen jet.

Design  
Manufacture  
Assemble and Test

Mark II Pert Chart

VGL/WAK/ISP/BBB  
07/16/94

1994

	Jan	Feb	Mar	Apr	May	June	July	Aug.	Sept	Oct	Nov	Dec
Dilution Refrigerator	→	→	→									
<sup>3</sup> He Circ. System		→	→	→	→							
<sup>4</sup> He Gas Cart & Circ. System		→	→	→	→							
Mixing Chamber w/Mirror												
Dissociator & Hydrogen Feed System												
HFS Shielding & Pumping System												
Film Burners												
Detection System												
Instrumentation												
Superconducting Sextupole												
Sextupole Crystal & services												
Sextupole LN2 tank												
Mini-catcher												
Outer Vacuum Chamber												
RF Transition Unit												
Maser Polarimeter												
Catcher												
Inter. Region Vac. Box												

Fig. 5. Mark II jet pert chart.

## Polarized Proton Acceleration to 1 TeV at Fermilab

Fermilab first commissioned the SPIN Collaboration to study polarized proton acceleration in the Main Injector by giving Michigan a \$100,000 grant to produce a Design Study Report. The resulting 144 page Report<sup>24</sup> provides a detailed plan for the Acceleration of Polarized Protons to 120 and 150 GeV in the Fermilab Main Injector; it was submitted in March 1992. Fermilab then provided another \$170,000 as the first two installments of a three year Design Study on Accelerating and Storing Polarized Protons in the Tevatron-Collider; some of this money provided R & D subcontracts to IUCF, TRIUMF, IHEP-Protvino, and INR-Moscow. A 113 page Progress Report<sup>25</sup> was submitted to Fermilab on 1 August 1994. We recently requested \$100,000 to finish the study and produce the final Report. The new hardware required for a Tevatron polarized beam<sup>11,12,14,17,18,20,21,22,23,28,31,44,53,54</sup> is shown in Fig. 6. The total Polarized Tevatron Project cost is about \$25- \$30 Million.

This polarization capability would allow studies of the one-spin dependence of  $\bar{p} - p$  collisions at  $\sqrt{s} = 2$  TeV in CDF and D0. It would also allow fixed target two-spin experiments at 1 TeV and 120 GeV by using a Mark III polarized jet at C0 in the Tevatron and the Michigan solid polarized proton target in an extracted beam area such as P-West.

The SPIN collaboration now contains about 47 accelerator experts and 47 experimenters and theorists from Michigan, Indiana, Fermilab, IHEP-Protvino, JINR-Dubna, INR-Troitsk, Moscow State University, KEK, and TRIUMF; Michigan is the lead institution. The present collaboration list is given in Fig. 7.

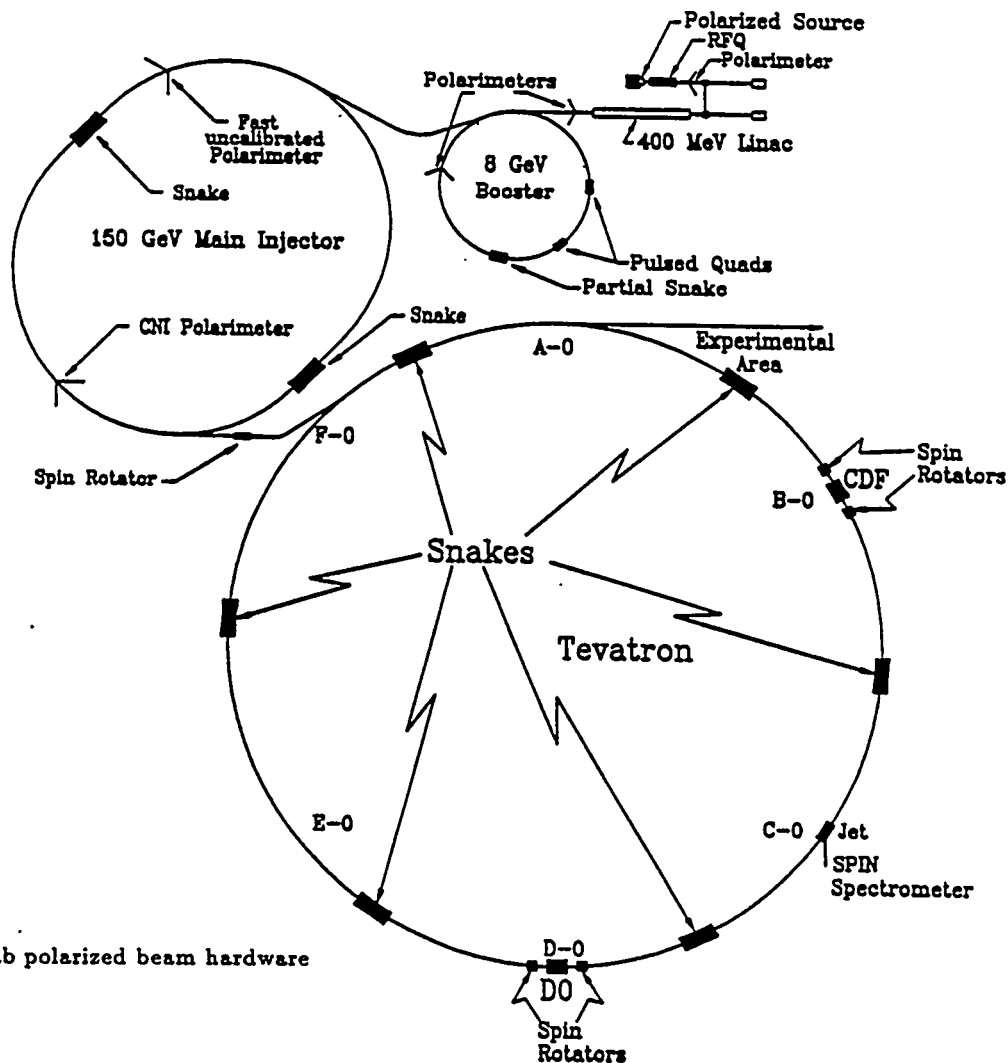


Fig. 6 Fermilab polarized beam hardware

## SPIN collaboration

19 July 1994

L. V. Alexeyeva<sup>a</sup>, V. A. Anferov<sup>a</sup>, B. B. Blinov<sup>a</sup>, J. A. Bywater, D. D. Caussyn,  
C. M. Chu, E. D. Courant, D. G. Crabb<sup>b</sup>, D. A. Crandell, Ya. S. Derbenev<sup>c</sup>,  
S. V. Gladysheva, W. A. Kaufman, F. Z. Khiari<sup>d</sup>, A. D. Krisch, A. M. T. Lin,  
V. G. Luppov, T. S. Nurushev, D. C. Peaslee, R. A. Phelps, J. S. Price, L. G. Ratner,  
R. S. Raymond, J. A. Stewart<sup>e</sup>, S. M. Varsar<sup>a</sup>, V. K. Wong  
THE UNIVERSITY OF MICHIGAN, ANN ARBOR, U.S.A.

J. M. Cameron, T. B. Clegg<sup>f</sup>, V. Derenchuk, T. J. Ellison<sup>g</sup>, D. L. Friesel, S. Y. Lee,  
M. G. Minty<sup>h</sup>, T. Rinckel, P. Schwandt, F. Sperisen, E. J. Stephenson,  
B. von Przewoski  
INDIANA UNIVERSITY CYCLOTRON FACILITY, BLOOMINGTON, U.S.A.

R. Baiod, C. M. Bhat, G. P. Goderre, P. S. Martin, S. M. Pruss, A. D. Russell  
FERMILAB, BATAVIA, U.S.A.

Yu. M. Ado, V. A. Kachanov, V. Yu. Khodyrev, O. L. Kisly, A. V. Koulsha,  
V. V. Mochalov, S. B. Nurushev, D. I. Patalakha, A. F. Prudkoglyad,  
V. V. Rykalin, V. P. Sakharov, D. S. Shoumkin, V. L. Solovianov, V. P. Stepanov,  
V. A. Teplyakov, S. M. Troshin, A. G. Ufimtsev, M. N. Ukhanov, A. V. Zherebsov  
INSTITUTE OF HIGH ENERGY PHYSICS, PROTVINO, RUSSIA

V. V. Fimushkin, M. V. Kulikov, A. V. Levkovich, V. A. Nikitin, P. V. Nomokonov,  
A. V. Pavlyuk, Yu. K. Pilipenko, V. B. Shutov  
JOINT INSTITUTE FOR NUCLEAR RESEARCH, DUBNA, RUSSIA

A. I. Demianov, A. A. Ershov, A. M. Gribushin, N. A. Kruglov, A. S. Proskuryakov,  
A. I. Ostrovidov, L. I. Sarycheva, N. B. Sinejv, A. S. Yarov  
MOSCOW STATE UNIVERSITY, MOSCOW, RUSSIA

A. S. Belov, V. E. Kuzik, Yu. V. Plohinskii  
INSTITUTE FOR NUCLEAR RESEARCH OF RUSSIAN ACADEMY OF SCI-  
ENCES, MOSCOW, RUSSIA

Y. Mori, C. Ohmori<sup>i</sup>, H. Sato, T. Toyama, K. Yokoya  
KEK, TSUKUBA, JAPAN

R. Abegg, P.P.J Delheij, G. Dutto, C. D. P. Levy, C.A. Miller, G. Roy<sup>j</sup>,  
P. W. Schmor, W. T. H. van Oers, A. N. Zelenski<sup>k</sup>  
TRIUMF, VANCOUVER, CANADA

The spokesperson for the SPIN Collaboration is:

A. D. Krisch	Telephone: 313-936-1027
Randall Laboratory of Physics	Telefax: 313-936-0794
The University of Michigan	Telex: 4320815 UofM UI
Ann Arbor, Michigan 48109-1120 USA	E-mail: KRISCH@UMIPHYS,MICH::KRISCH

Permanent address:

a Moscow State University	b University of Virginia	c IUCF; Novosibirsk
d King Fahd University	e University of Liverpool	f Univ. of N. Carolina; TUNL
g Energy Conversion Devices	h SLAC	i Tokyo University
j University of Alberta	k INR-Moscow	DISCLAIMER

Fig. 7. Present SPIN Collaboration list

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## PROZA in Protvino, Russia

In February-March 1994, four members of the High Energy Spin Physics Group worked on the 70 GeV polarized target experiment PROZA at IHEP-Protvino. This run and earlier PROZA runs have helped us to prepare for NEPTUN-A; they also obtained some interesting data<sup>34</sup> on the spin asymmetry in 70 GeV  $\pi^0$  production. We are now helping to analyze the PROZA data using our computers at Michigan with advice from D.I. Patalakha, who will visit Michigan for 4 months this fall. We plan to participate in the next PROZA run this winter.

## Students and Symposia

During 1993 and 1994, the High Energy Spin Physics Group had: one Michigan PhD, C. M. Chu; two Michigan PhD thesis students, D. A. Crandell and T. S. Nurushev; one Moscow State University Doctorate thesis student, V. A. Anferov; and four Moscow State University Diploma thesis students, A. V. Koulsha, B. B. Blinov, L. V. Alexeyeva and S. M. Varzar. We also had about 20 other graduate and undergraduate students as research assistants at Michigan.

We also helped organize and sponsor several International Symposia and Workshops including:

Workshop on Polarized Ion Sources and Targets, Madison, Wisconsin, May 1993.

SPIN-93 Workshop, Protvino, Russia, September 1993.

Workshop on Solid Polarized Targets, Bonn, Germany, June 1994.

11<sup>th</sup> International High Energy Spin Physics Symposium, Indiana University, September 1994.

2 August 1994

## HIGH ENERGY SPIN PHYSICS GROUP

### University of Michigan

Faculty:	A. D. Krisch, V. K. Wong
Visiting Faculty:	A. W. Chao, E. D. Courant, Ya. S. Derbenev
Research Scientists:	A. M. T. Lin, V. G. Luppov, D. C. Peaslee, R. A. Phelps L. G. Ratner
Research Staff:	W. A. Kaufman, R. S. Raymond
Postdoctoral Fellow:	D. D. Caussyn, J. S. Price
Consultants:	J. A. Bywater, G. R. Court, D. Kleppner
Graduate Students:	S. Chin, C. M. Chu, D. A. Crandell, S. V. Gladysheva, S. Hu, T. S. Nurushev
Student Assistants:	M. D. Ball, B. T. Bernard, L. S. Dahl, D. P. Lo, J. B. Muldavin, P. J. Noffke, D. V. Ostrovsky, D. B. Raczkowski L. C. Shackman, S. J. Wheeler
Visiting Collaborators:	V. V. Churakov, Yu. M. Melnik, F. Z. Khiari
Visiting Students:	L. V. Alexeyeva, B. B. Blinov, S. M. Varzar
Secretarial Staff:	P. Bousley, L. McCrystal, D. Walls

## PUBLICATIONS AND REPORTS (1993-1994)

### Published Manuscripts

1. "A Siberian snake with overlapping depolarizing resonances", R. Baiod *et al.*, Phys. Rev. Lett. **70**, 2557 (1993).
2. "Focusing a Beam of Ultra-Cold Spin-Polarised Hydrogen Atoms with a Helium-Film-Coated Quasi-Parabolic Mirror", V. G. Luppov *et al.*, Phys. Rev. Lett. **71**, 2405 (1993).
3. "Ultra-Cold Atomic Hydrogen Beam", W. A. Kaufman *et al.*, Nucl. Instrum. & Methods **A17**, 335 (1993).
4. "Solenoid and Sextupole Optics of Ultra-cold Atomic Hydrogen Beams", W. A. Kaufman, Nucl. Instrum. & Methods **A330**, 363 (1993).
5. "Adiabatic partial Siberian snake turn on with no beam depolarization", R. A. Phelps *et al.*, Phys. Rev. Lett. **72**, 1479 (1994).
6. "First test of a partial Siberian snake during polarized beam acceleration", B. B. Blinov *et al.*, Phys. Rev. Lett. **73** xxxx (12 September 1994).

### Manuscripts in Preparation

7. "Spin-flipping a stored polarized proton beam", D. D. Caussyn *et al.*, to be submitted to Phys. Rev. Lett. Aug 1994.
8. "Beam Loss in a Synchrotron due to a frequency modulation of Longitudinal Motion", D. D. Caussyn *et al.*, UM HE 92-22, in preparation.
9. "High-Precision Measurement of the Spin Analyzing Power in Large- $P_{\perp}^2$  Proton-Proton Elastic Scattering at 24 GeV/c", J. A. Stewart *et al.*, UM HE 92-24, in preparation.
10. "Siberian snakes for the Fermilab Main Injector", V. A. Anferov *et al.*, UM HE 94-16, to be submitted to Phys. Rev.

### Invited Lectures

11. "Spin Experiments at UNK, Fermilab, and SSC", A. D. Krisch, Proc. 10<sup>th</sup> International Symposium for High Energy Spin Physics, Nagoya, Japan (Universal Acc. Press, Tokyo, 1993), pp 301-310.
12. "Violent Collisions between Spinning Protons", A. D. Krisch, Coral Gables Conference (January 1993).
13. "High- $P_{\perp}^2$  Elastic Spin Experiments at UNK", R. A. Phelps, Hadron-Hadron Workshop, Brookhaven, New York (March 1993).
14. "Polarised Beam at Fermilab", A. D. Krisch, Working Meeting on Spin Physics, Fermilab, Batavia, Illinois (May 1993).
15. "Status of the Ultra Cold Polarized Hydrogen Jet for NEPTUN and NEPTUN-A at UNK", R. S. Raymond, Proc. Workshop on Polarized Ion Sources and Polarized Gas Targets, Madison, May 1993, AIP Conf. Proc. **293**, pp 32-35(1994).
16. "A Helium-Film-Coated Quasi-Parabolic Mirror to Focus a Beam of Ultra-Cold Spin-Polarized Atomic Hydrogen", V. G. Luppov *et al.*, *ibid.*, pp 40-43.

17. "Elastic Spin Experiments at UNK, Fermilab, and SSC" A.D. Krisch, Proc. 5<sup>th</sup> Blois Inter. Conference on Elastic and Diffraction Scattering, Brown, June 1993, World Scientific Press, pp 392-397.
18. "Spin Experiments at UNK and Fermilab", A. D. Krisch, at SPIN-93 Workshop, IHEP-Protvino, Russia (September 1993) [to be published].
19. "Status of NEPTUN-A Experiment", A. D. Krisch, at Workshop on "Physics Research Program at UNK-600", IHEP-Protvino, Russia (23-24 November 1993), UM HE 94-03.
20. "Siberian Snakes and Polarized Beam at Fermilab", A. D. Krisch at TRIUMF Users' Group Annual Meeting, Vancouver, Canada (7-8 December 1993).
21. "Polarized Beams after the ZGS", A. D. Krisch, at ZGS 30<sup>th</sup> Anniversary Symposium, Argonne National Laboratory (6 May 1994) [to be published].
22. "Spin-flipping a high energy stored polarized beam", R. A. Phelps, at Siberian Snake Workshop, Brookhaven National Laboratory (12-13 September 1994).
23. "Highlights and Future Prospects", A. D. Krisch, at 11<sup>th</sup> Int. Symp. on High Energy Spin Physics, Indiana (15-22 September 1994).

## Reports

24. Report on *Acceleration of Polarized Protons to 120 and 150 GeV in the Fermilab Main Injector*, commissioned by Fermilab, University of Michigan Report, March 1992.
25. Progress Report on *Acceleration of Polarized Protons to 1 TeV in the Fermilab Tevatron*, commissioned by Fermilab, University of Michigan Report UM HE 94-15, 1 August 1994.

## Contributed Lectures and Papers

26. "Partial Siberian snake Studies at the IUCF Cooler", R. A. Phelps, Proc. 10<sup>th</sup> International Symposium for High Energy Spin Physics, Nagoya, Japan (November 9-14, 1992) (Universal Acc. Press, Tokyo, 1993), pp 423-427.
27. "Formation of a Beam of Ultracold Spin Polarized Atomic Hydrogen with a Helium Film Coated Mirror", W. A. Kaufman, *ibid.*, pp 341-344.
28. "Siberian snakes for the Fermilab Main Injector", V. A. Anferov *et al.*, presented at the 1993 Spring Meeting of the American Physical Society, Washington, D. C. (April 12-15, 1993), Bull. Am. Phys. Soc. **38**, 986 (1993).
29. "Effect of a Partial Siberian snake on an 'Rf-induced' Depolarizing Resonance", C. M. Chu *et al.*, *ibid.*, 986.
30. "Adiabatic Siberian snake turn-on and acceleration through depolarizing resonances", A. V. Koulsha *et al.*, *ibid.*, 986.
31. "Polarized proton beam acceleration at Fermilab", A. M. T. Lin *et al.*, *ibid.*, 987.
32. "Ultra-cold Spin-polarized Jet for the NEPTUN-A Experiment at UNK", T. S. Nurushev *et al.*, *ibid.*, 987.
33. "A Helium-film-coated quasi-parabolic mirror to focus a beam of ultra-cold spin-polarized Atomic Hydrogen", V. G. Luppov *et al.*, *ibid.*, 987.

34. "Measurement of the Spin Asymmetry in  $p + p_1 \rightarrow \pi^0 + X$  at 70 GeV at  $90^\circ_{c.m.}$ ", D. A. Crandell *et al.*, *ibid.*, 1054.
35. "Siberian Snake Overcomes "Overlapping" Depolarizing Resonances", V. A. Anferov *et al.*, pp 101-107, 1993 IUCF Annual Report.
36. "Beam Transport of Low Temperature Atomic Hydrogen", W. A. Kaufman, Proc. Workshop on Polarized Ion Sources and Polarized Gas Targets, Madison, May 1993, AIP Conf. Proc. 293, pp 36-39 (1994).
37. "Adiabatic Partial Siberian Snake Turn-on", C. M. Chu *et al.*, presented at the Spring Meeting of the American Physical Society, Washington, D. C. (April 1994), Bull. APS 39, No. 2, 1093 (1994).
38. "Spin Flip of a Stored Polarized Proton Beam by an RF Solenoid", V. A. Anferov *et al.*, *ibid.*, 1170.
39. "Ultra-Cold Spin-Polarized Jet for the NEPTUN-A Experiment at UNK", T. S. Nurushev *et al.*, *ibid.*, 1170.
40. "Progress in Development of a 4K RF Transition Unit for use with an Ultra-Cold Polarized Hydrogen Beam", J. B. Muldavin and J. S. Price, *ibid.*, 1109.
41. "Transient Operation of a Hydrogen Maser as a Polarimeter for Ultra-Cold Polarized Hydrogen Beam", Shin C. Chin *et al.*, *ibid.*, 1109.
42. "First Partial Siberian Snake Test during Acceleration, Adiabatic partial Siberian Snake Turn-on, and Spin Flipping", V. A. Anferov *et al.*, 1994 IUCF Annual Report (to be published).
43. "Spin flipping a stored polarized proton beam", R. A. Phelps, Conference on Intersections of Particle and Nuclear Physics, St. Petersburg, Florida, June 1994.
44. "Prospects of RHIC spin and Tevatron spin projects", E. D. Courant, 11<sup>th</sup> Int. Symp. on High Energy Spin Physics, Indiana, September 1994.
45. "First partial Siberian snake test during acceleration", D. D. Caussyn, *ibid.*
46. "NEPTUN-A spectrometer for measuring the spin analyzing power in  $p$ - $p$  elastic scattering at large  $p_t$  at 400 GeV (and 3 TeV) at UNK", A. M. T. Lin, *ibid.*
47. "Spin flipping a stored polarized proton beam", R. A. Phelps, *ibid.*
48. "A concept of Stern-Gerlach polarization in storage rings", Ya. S. Derbenev, *ibid.*
49. "RF-intrinsic spin flipper", Ya. S. Derbenev, *ibid.*
50. "RF-resonance beam polarimeter", Ya. S. Derbenev, *ibid.*
51. "Status of the Michigan-MIT ultra cold polarized hydrogen jet target", V. G. Luppov, *ibid.*

### Unpublished Manuscripts

52. "Rotation of the plane of transverse particle motion using skew quadrupoles", V. A. Anferov and Ya. S. Derbenev, UM HE 93-6.
53. "Siberian snakes with small number of magnets for high energy accelerators", V. A. Anferov and Ya. S. Derbenev, UM HE 93-7.
54. "Helical snakes with no orbit correction and their discrete analogs", V. A. Anferov, UM HE 93-9.