BNL-52659
FORMAL REPORT

Proceedings of RIKEN BNL Research Center Workshop Volume 39

RHIC Spin Collaboration Meeting VII

February 22, 2002

Organizer

B. Fox

RIKEN BNL Research Center

Building 510A, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

Available electronically at-

http://www.doe.gov/bridge

Available to U.S. Department of Energy and its contractors in paper from-

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(423) 576-8401

Available to the public from-

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22131
(703) 487-4650

Printed on recycled paper

Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of a new generation of young physicists.

During the first year, the Center had only a Theory Group. In the second year, an Experimental Group was also established at the Center. At present, there are seven Fellows and eight Research Associates in these two groups. During the third year, we started a new Tenure Track Strong Interaction Theory RHIC Physics Fellow Program, with six positions in the first academic year, 1999-2000. This program has increased to include ten theorists and one experimentalist in the current academic year, 2001-2002. Beginning this year there is a new RIKEN Spin Program at RBRC with four Researchers and three Research Associates.

In addition, the Center has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. Each workshop speaker is encouraged to select a few of the most important transparencies from his or her presentation, accompanied by a page of explanation. This material is collected at the end of the workshop by the organizer to form proceedings, which can therefore be available within a short time. To date there are thirty-eight proceeding volumes available.

The construction of a 0.6 teraflops parallel processor, dedicated to lattice QCD, begun at the Center on February 19, 1998, was completed on August 28, 1998.

T. D. Lee
August 2, 2001

*Work performed under the auspices of U.S.D.O.E. Contract No. DE-AC02-98CH10886.

CONTENTS

INTRODUCTION

B. Fox, March 18, 2002

for
RHIC Spin Collaboration Meeting VII
February 22, 2002
RIKEN BNL Research Center

Since its inception, the RHIC Spin Collaboration (RSC) has held several, semi-regular meetings each year to discuss the physics possibilities and the operational details of the program. At the beginning of this year, we completed our first data-taking period with polarized protons in both rings. In many ways, this run was highly successful; notably,

(1) the machine reached a luminosity that was within a factor of four of the goal for this run,
(2) the RHIC CNI polarimeters installed in both rings operated as expected for the course of the eight week run,
(3) both major experiments were able to collect data for transverse single spin asymmetries, and
(4) the PP2PP experiment demonstrated that it is technically feasibility.

Given the effort required to realize these achievement, it is surprising that there was just one disappointment, namely, the polarization of the protons coming out of the AGS was limited to 30% during this run. To a large extent, this shortcoming was not unexpected because the AGS had to be operated with the backup power supply which, because of its slower ramp rate, resulted in larger polarization losses at spin resonances than had been forecasted in the original plans for the run.

For this milestone in the program, it is appropriate to reflect upon the progress made this year and focus on what is necessary for the next proton-proton run. For this purpose, we are planning a series of RSC meetings from which we aim to form an accurate assessment of this run and a realistic goals for the next run.

In the first meeting of this series (which took place at BNL on February 22, 2002), we focused on the upgrades which are expected to be completed prior to the end of this year and thus available for the next run. The two main items are the Spin Rotators in RHIC and the CNI polarimeter for the AGS. In addition, because of the progress on technical issues related to the design of partial snake in the AGS, we also had a presentation on this topic. And, finally, in keeping with a tradition of having some theoretical presentations to accompany the experimental and machine presentations, we had presentations on single spin transverse asymmetries in proton-proton reactions and Coulomb-Nuclear Interference analyzing powers in proton-carbon elastic scattering.

B. Fox
18 March 2002

SUMMARY OF ACHIEVEMENTS FOR THE PROTON-PROTON RUN IN LATE 2001 (RUN02)

The run included the new high intensity polarized source, additional forward arms for the AGS polarimeter for low energy measurements, AGS tools for polarization (partial Siberian Snake, rf dipole, AGS pp polarimeter), 4 Siberian Snakes in RHIC, first pp collisions in RHIC, 2 p-carbon CNI polarimeters in RHIC (each ring), spin-flipper (rf dipole in RHIC), work on greatly reduced orbit variations in RHIC and device to control betatron tune on ramp.

For the experiments, the run included -

STAR: commissioning new forward pi^0 calorimeter, beam-collision counters, and emcalorimeter modules and high tower energy trigger;

PHENIX: commissioning additional beam counters and new triggers, including high-p_T pi^0, charged particle, and muon triggers, DAQ with 1 kHz rate for these triggers; luminosity scalers sorted by crossing and by spin type;

pp2pp Experiment: 2 Roman Pot stations (4 pots) with silicon tracking for pp elastics, and beam-beam inelastic counters;

Photon Polarimeter (IP12): test setup near 0 degrees to measure transverse asymmetries of photons and neutrons produced at very forward angles.

Polarized source: regularly had above 70% polarization, and intensity of several x 10^11 polarized protons per pulse.

AGS Polarization: after tuning Booster, got full polarization into AGS at injection; ramp used backup motor generator, with half the normal ramp rate, increasing spin resonance strengths in AGS by factor 2; achieved typical polarization of 25% to 30% at extraction to RHIC in last 2 weeks.

RHIC Polarization: measured full polarization in RHIC at injection; measure polarimeter asymmetries between 80% to 100% of injection asymmetry at 100 GeV; in most cases, asymmetry after ramp to 100 GeV is maintained over multi-hour stores (8 hours frequently). A 14 hour store for the pp2pp Experiment which ended this morning had the same measured polarization at the end as at the beginning (25%).

RHIC Luminosity: typically at goal with beta*=3m focus, 1.5 x 10^30 cm^-2 s^-1, in last 2 weeks of run. Decided not to squeeze to beta*=1m due to lack of time left in run. This luminosity uses 4 x 10^12 polarized protons in 55 bunches in each ring, with alternating polarization in each bunch.

RHIC Polarimetry: p-carbon Coulomb Nuclear Interference polarimeter typically measured 2-3 x 10^-3 asymmetries with statistical error of 10% of itself, in 1 minute. A_{raw}=.003 corresponds to about 25% polarization.

Absolute polarization: known only at 24 GeV. Plan to accelerate to 100 GeV, and then to decelerate back to 24 GeV to carry known analyzing power from 24 GeV to 100 GeV was not completed. Beam lost at about 50 GeV on downramp -- this effort requires measurements of transfer functions of magnets for this cycle.

Spin flipping in RHIC: successful, flipped spin twice in test.

Betatron tune control: succeeded with several ramps locking the tune. (Important, since the tunes must be controlled closely to maintain polarization. This was done successfully by hand for most of this run. Measured loss of polarization typically traced to changes in tunes.)

Vertical polarization: used for entire run. No longitudinal spin was tried due to lower polarization (2-spin asymmetries such as A_LL have figure of merit P^4 x L.).

Experiments: data were taken for A_N for the following (this list is partial; successful measurements require successful control of systematic errors, yet to be studied by the experiments):

For root(s)=200 GeV pp:

-very forward (p_T up to 0.5 GeV/c, x_F above 0.2) photon, neutron, pi^0 A_N

-forward (p_T 1 to 2 GeV/c or so, x_F above 0.2) photon, pi^0 A_N

-forward muons A_N

-mid-rapidity pi^0, jets, photons, electrons, charged hadrons, p_T to 8 GeV/c or so A_N

-proton-proton CNI A_N and slope

For fixed target using polarimeter with carbon fiber target:

-proton-carbon CNI A_N and slope vs. t for -t=.005-.04

First looks at these reactions show good signals for the processes, and possible physics asymmetries.

To summarize, we believe (or hope!) there will be a number of excellent A_N measurements at root(s)=200 GeV, using the first ever collisions of polarized protons. The AGS polarization was low, at least partly due to using a back up motor generator with a slow ramp. We did not do longitudinal polarization, due to the lower polarizations. The commissioning was very successful, including sustained use of the high intensity polarized H^- source, use of alternating polarization sign bunches in RHIC for polarimetry and physics, many studies of AGS polarization issues, high transfer of polarization to RHIC and up to 100 GeV (although uncalibrated polarization at 100 GeV), tune control on ramp, maintaining polarization over long stores in RHIC (often 8 hours or more), spin-flipping in RHIC, luminosity at goal (for beta*=3m).

Gerry Bunce and Thomas Roser

The Strong Snake for the AGS

Haixin Huang

- Why strong snake?
- How strong it needs to be?
- Design Status

Why Strong snake?

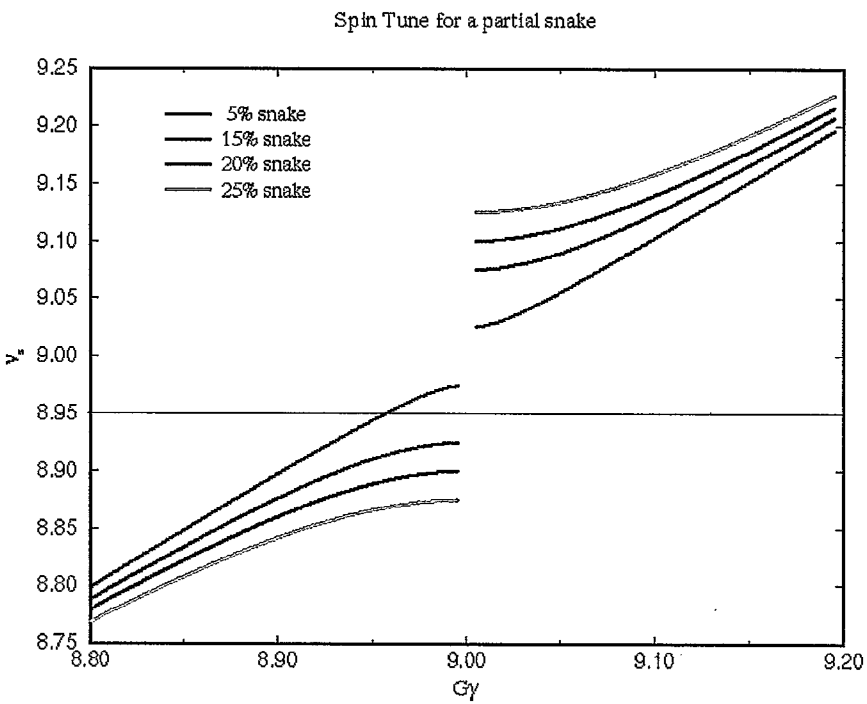
- AC dipole operation need precise control of betatron tunes to the level of 0.0005 and need to be constantly monitored for polarized proton operation.
- Due to the linear coupling from the solenoidal field of 5% partial snake, there are polarization loss at the so-called coupling resonances, which is due to the the vertical betatron motion with horizontal betatron tune. So we would like to have a new snake with less coupling.
- The polarization loss at those weak intrinsic resonances can not be overcome by AC dipole.

A strong snake can eliminate the use of AC dipole can correct all intrinsic resonances when betatron tunes are set properly.

8

How a strong snake works

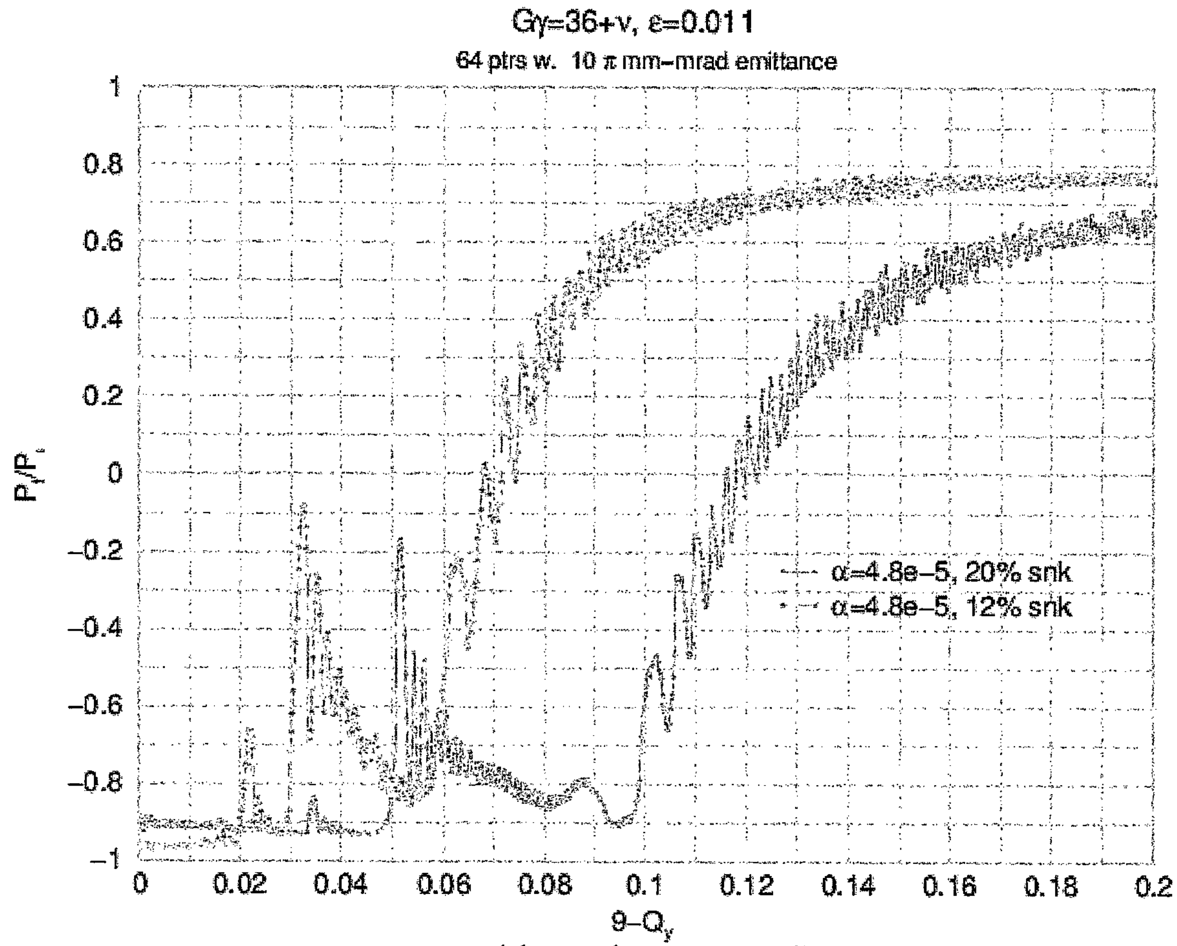
- The stronger the snake, the larger the spin tune gap when Gγ=N. When the snake is strong enough so we can put betatron tune in the gap, then the resonance condition will never be met.
- In a different view, The snake acts as a resonance at Gγ=N. If the intrinsic resonance is overpowered by the snake, then full spin flip can be achieved.
- Note: With a strong snake, the stable spin detection will be deviate from vertical significantly(18 degree for 20% snake).



Simulation results

•A simple model simulation shows that 20% snake is needed to overcome the strongest resonance 36+ν. More simulation is going on especially for 9-ν_y between 0.05 and 0.1.

•Snake resonances occur when factional betatron tune equals 1/2, 1/3 of spin tune.



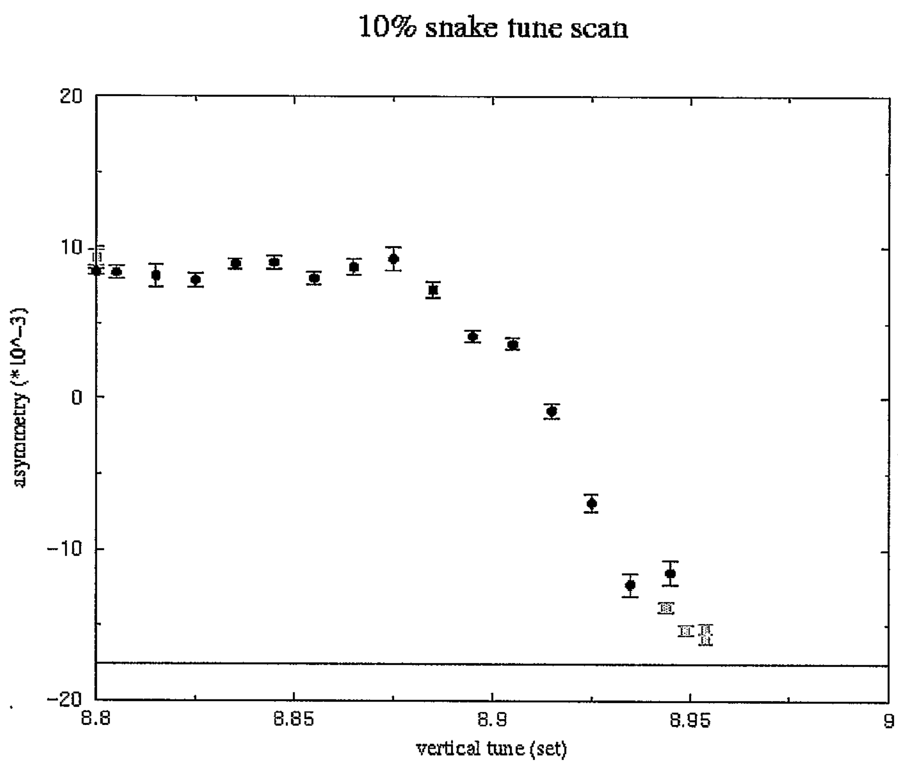
(done by M. Bai)

2/22/02

10

Test results with 10% snake at 0+ν

- Experiment done in January. It follows the simulation trend nicely.
- The blue line is the injected beam polarization. The difference between the red dots and blue line is due to the coupling resonance and tilted stable spin direction.



Spin matching at injection and extraction

- Stable Spin Direction (SSD)in AGS is tilted away from vertical due to a strong snake. We have to match the injected and extracted beam stable spin direction to avoid polarization loss.

Injection:

1. one possibility is to raise the injection energy to get $G\gamma$ from 4.7 to 5 (2.27GeV/c to 2.44GeV/c) and run the Booster vertical tune at 5.1 (in the past it was set at 4.9). Then the SSD is in horizontal plane in both Booster and AGS. A proper choice of 5th harmonic corrector setting of the Booster can match the SSD in the Booster to the SSD in AGS.
2. Use the current solenoid snake in the BtA lline as a spin rotator. But it needs a lot space.

Extraction:

There are many ways to manipulate SSD in RHIC (snakes, spin rotators). It is less a problem.

Operation Scenario

- 20% partial snake at top energy (24.3GeV/c), which means ~30% at injection (2.27GeV/c). More simulation is still going on (M. Bai).
- Radiation environment needs to be evaluated:

  From high intensity protons: power off but cold;
  From polarized protons: power on and maybe the limiting aperture.
  2"×2" collimator in the upstream will be needed for polarized proton operation as a protection device.
- Suppose 15π beam at injection(Pol. Proton), σ=3.6mm. Orbit excursion ±4cm in horizontal, 4cm in vertical. So the available room is >9 σ.
- High intensity proton beam: 100 π at injection, σ=1.1cm. There is no aperture problem for high intensity operation.
- Betatron tune settings: ν_y~8.95, ν_x~8.55.

Design of the snake

- The snake is going to be a super-conducting full helical dipole magnet.
- The available space in the AGS is 2.6 meter long. Two bending dipole magnets on both sides of the helical snake.
- 2-layer design with 400A to reach 4T.
- Beam pipe is 6" by 6" (15cm by 15cm).
- 1.36 meter long and operation field is 3.28T(30% at injection).
- Cryogenic design: try to reach 1w heat load. But as long as the heat load is below 5w, then the cryo dewar can be filled once/day (without ring access).
- Coupling at injection is still significant due to sextupole field feed down. The design goal is to have no sextupole field along the beam trajectory by adding compensation coils.

Polarized Protons in RHIC with SPIN Rotators

Waldo MacKay

- Goal for last Run
- More details
- Layout of Complex
- Things for next time in AGS
- Things for next time in RHIC
- Deceleration Ramp
- Operation of Rotators
- Status of Rotators
- Calibrations
- Comments on Luminosity

Goals for FY02 Polarized Proton Run

- 2 pC-CNI polarimeters (1 per ring)✓
- 4 snakes (2 per ring) installed.✓
- 8 power supplies (2 per snake).✓
- Source: > 70% polarization, several $\times 10^{11}$/pulse.✓

- Provide 100 GeV × 100 GeV collisions with long. pol. at all IR's. ✓✗
  - Instantaneous Luminosity $\gtrsim 1 \times 10^{30} \mathrm{cm}^{-2}\mathrm{s}^{-1}$✓
  - Hope to achieve at least 50% polarization per beam.✗(AGS)
  - 2 ⇒ 1 snake ramps for longitudinal polarization.✗

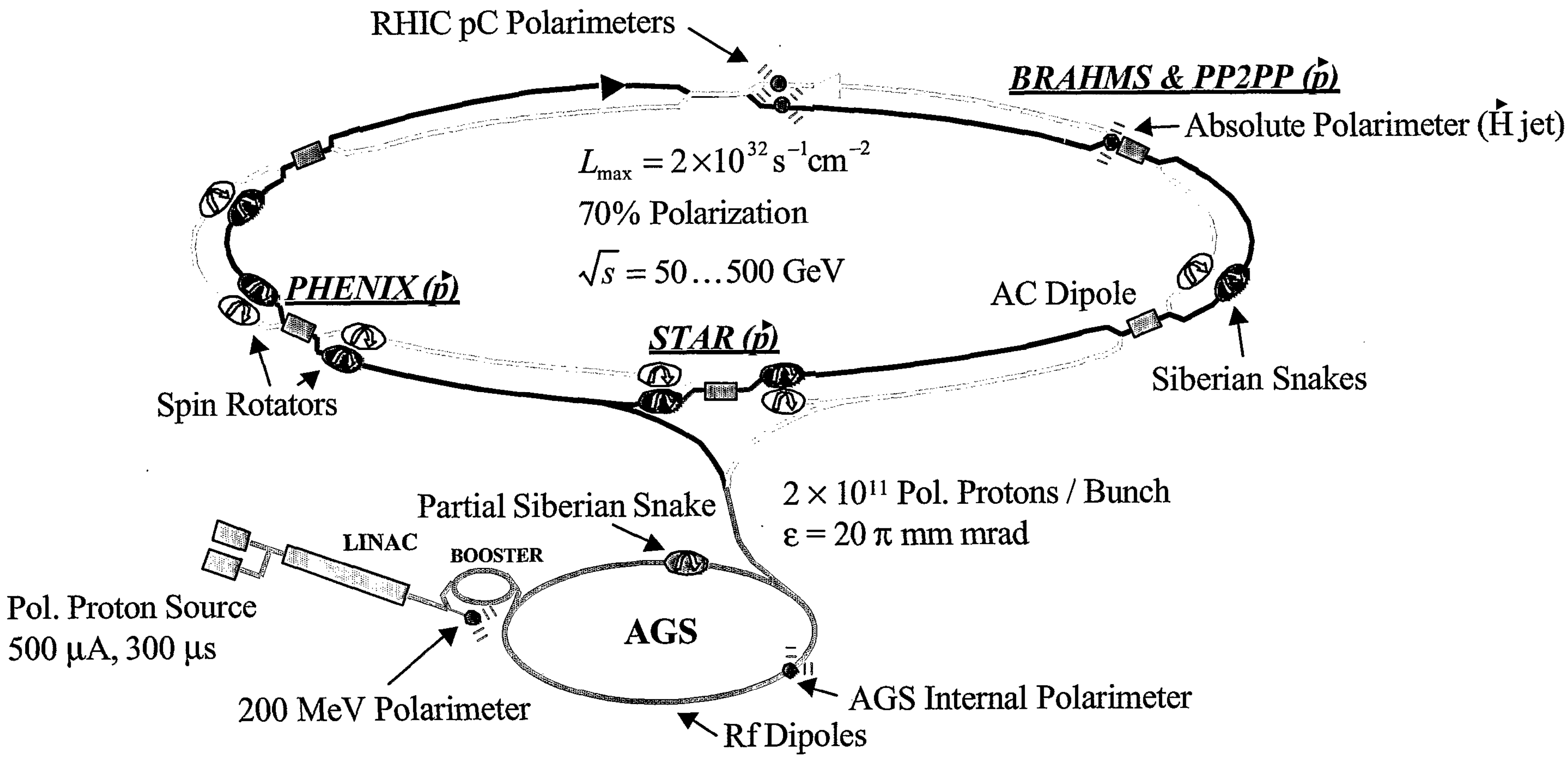
- Decelerate beam to calibrate CNI polarimeters.✗
- Commission PLL: partially successful.
- Accelerate polarized protons to 250 GeV.✗
- Commission Spin Flipper.✓

Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

More details

- Flattened orbit vertically to surveyed coordinates.✓
- Rebucketing.✗
- PLL not routine for up ramps.✗
- $\beta^* = 10$ m at IP2.✓
- AGS problems:
  - AGS polarization too low ($P \lesssim 30\%$).✗
  - AGS emittances large (trans, long).
  - No Siemens: slower ramp rate.
  - J10 bump power supply problem.
  - Polarization dependence vs intensity?
- RHIC polarization transmission varied:
  - Vertical tune control.
    - Snake resonances.
  - Vertical orbit control: sometimes walked away.

Polarized Protons in RHIC



18

Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

Things in AGS for Next Time

- Siemens.
- J10 bump supplies not oscillating.
- Updated apps:
  - Snake control.
  - AC dipole control.
  - Coherence monitor.
  - Betatron tunes.
- Upgraded hardware:
  - AC dipole control.
  - Coherence monitor.
  - Betatron tunes.
- New p+C CNI polarimeter for AGS. (Measure during ramp.)
- Improved logging of AGS data and readbacks.
  - including polarizations of bunches injected into RHIC.
- Multiple bunches in AGS?
  - with different polarizations? What is required?

Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

Things in RHIC for Next Time

- Energy ramp: (symmetric lattice?) fixed $\beta^* = 5?, 10?$ m.
  - to what energy: 100, 250 GeV? (other?)
  - Make PLL operational for up ramp.
- Develop ramps at flattop:
  - Ramps for STAR, PHENIX, and PHOBOS magnets.
  - β-squeeze to 2-3 m at IP2&10, to 1 m at IP6&8
  - to turn on rotators.
- Calibrate snakes with spin flipper.
- Scan tunes for new working point.
- Commission rotators.
- Improve emittances: long. and trans.
- More intensity/bunch: at least 1×10^{11}.
  - 110 bunches?
- Deceleration ramp again. (from what energy?)
- Rebucketing? or other reduction of long. emitt.?
  - Lock rf in both rings up ramp?
- Improve efficiency (of the whole enchilada).

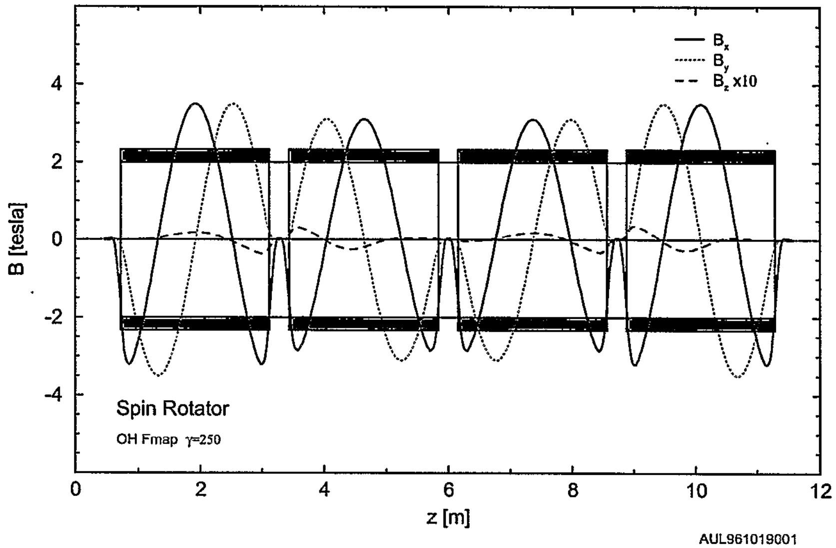
Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

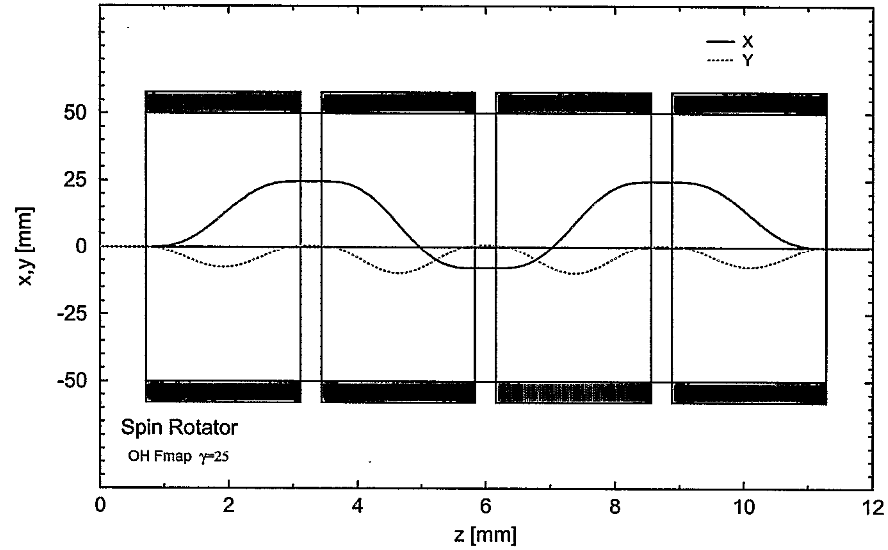
Considerations for Deceleration Ramp

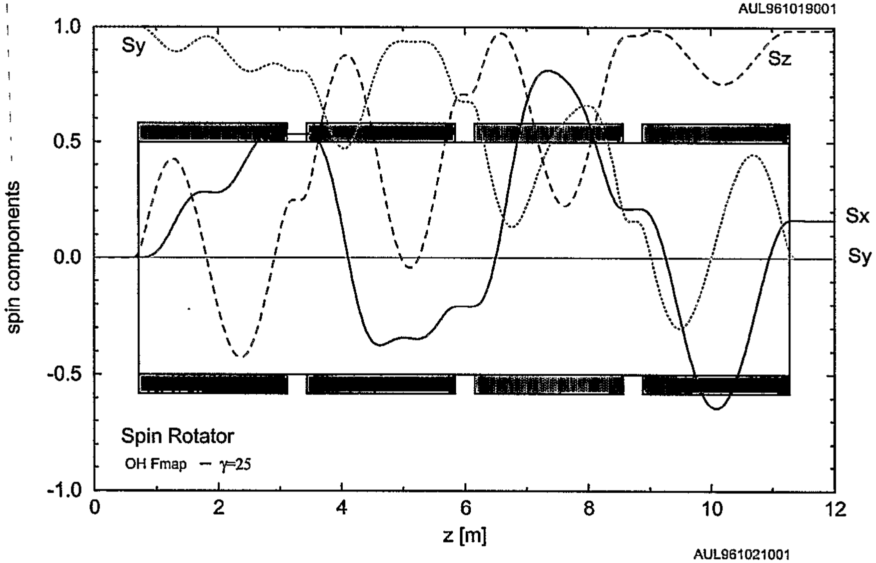
- Measure transfer functions (TF) for typical magnets before next fall:
  - Short dipole (D9) down ramp from 100 GeV, other energies?
  - Sextupole TF's: hysteresis, persistent current decay effects.
- Tune up down ramp to get beam to bottom without PLL.
- Then use PLL to hold tunes constant.
- Develop magnet ramp for counteracting persistent current decay back at injection energy, if necessary.
- Dedicated time (several days) should be set aside for the down ramp.

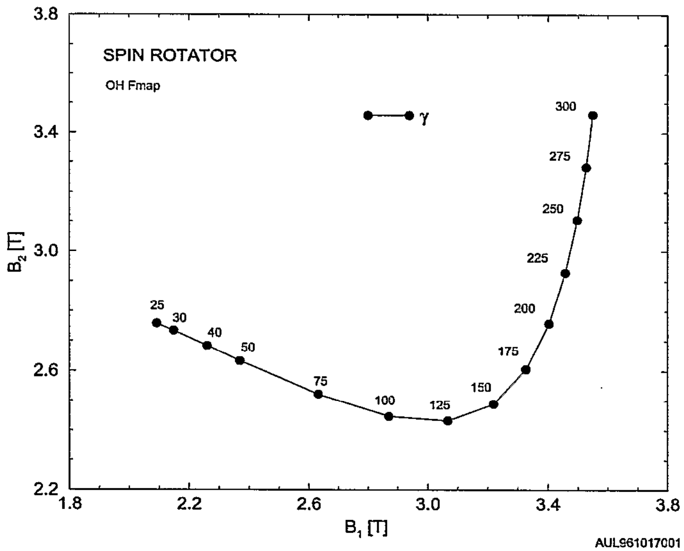
Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

Operation of Rotator





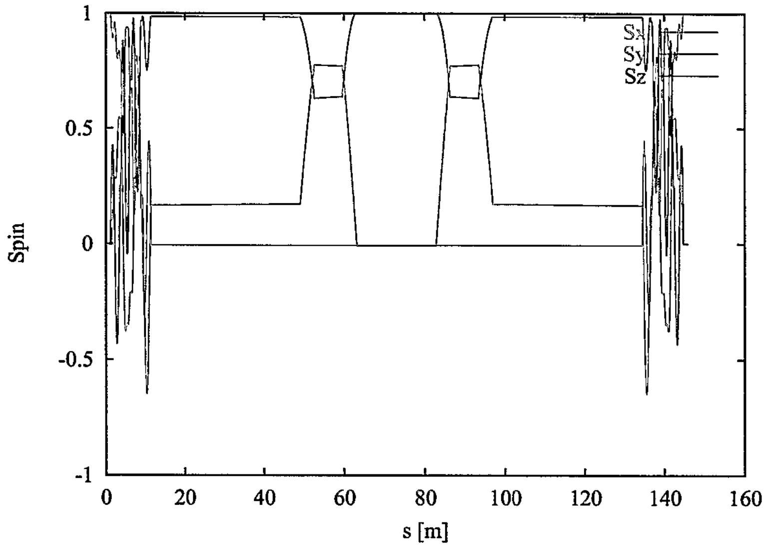


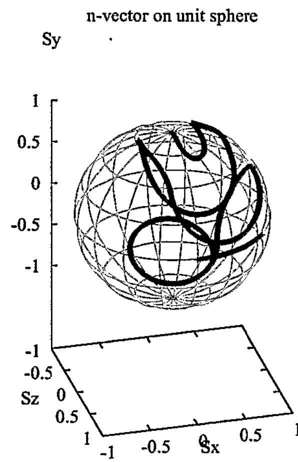


22

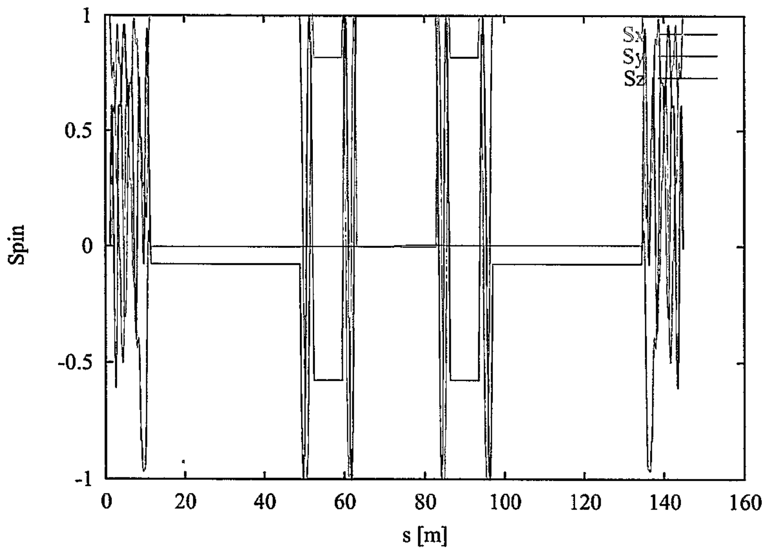
Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

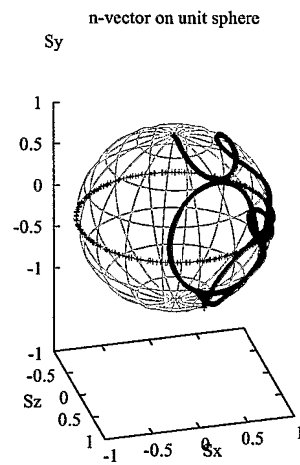
STAR at injection





STAR at 250 GeV





Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

Status of Rotators

- Rotators 1-4 waiting for installation.
- Rotator 5 completed but waiting for final survey.
- Rotator 6 in final wiring of turrets, awaiting survey.
- Rotator 7 cold mass almost completed.
- Rotator 8 helices completed, awaiting fixture.
- Warm-to-cold transitions are being opened.

- Racks in alcoves being prepared for power supplies.
- 24 10 of 16 Quench Protection Assemblies (QPA) have been modified.

Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

Two snakes:

- Set two snakes in one ring for best guess at $\mu_{1,2} = 180°$ and $\phi_{1,2} = \pm 45°$.
- Detune currents by predicted amounts for $\nu_{\mathrm{sp}} = 0.5 - \epsilon$.
- Verify shift of spin tune with ac dipole.
- Remeasure with a few different settings to calculate sensitivity matrix.
- Calculate and apply correct currents.

Energy calibration with $2 \Rightarrow 1$ snake ramp (injection and/or store):

- Ramp down one snake and measure horizontal polarization.
- Do energy scan through at least one full unit of $\Delta(G\gamma)$.
  This should give a calibration of energy vs current.

Rotator calibration:

- This needs work to develop a workable scheme.
  Perhaps measure shift of spin tune with a single rotator on. We could also measure radial and vertical components for different settings.

Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

Comments on Luminosity

Last time:

$$L_{\text{peak}} = f_{\text{rev}} \frac{N_1 N_2 N_b}{4\pi \sigma_x \sigma_y} = f_{\text{rev}} \frac{N_1 N_2 N_b}{4\pi \frac{\epsilon^N_{95\%}}{6\beta\gamma} \beta^*}$$

$$\simeq 78 \text{ kHz} \times \frac{\left(7 \times 10^{10}\right)^2 \times 55}{2 \times \frac{2\times 10^{-5}\text{ m}}{107} \times 3\text{ m}}$$

$$\simeq 1.8 \times 10^{30}\text{ cm}^{-2}\text{s}^{-1}$$

- For the energy ramps we, want equal and constant β^* at all IR's.
  - Ramp with $\beta^* = 5 \rightarrow 10$ m?
  - Squeeze at storage: $\beta_{\text{IP6,8}} = 1$ m? $\beta_{\text{IP2}} \sim 2$ m? $\beta_{\text{IP10}} \sim 3$ m?
- Can we accelerate 55×10^{11} protons per ring?
- 110 bunches.
- Energy: 100 or 250 GeV?

Waldo MacKay
RHIC Spin Collaboration
22 February, 2002

Predicted peak luminosity at PHENIX for next run with 250 GeV protons:

$$L_{\text{peak}} \simeq 78\ \text{kHz} \times \frac{\left(1 \times 10^{11}\right)^2 \times 55}{2 \times \frac{2\times 10^{-5}\ \text{m}}{266} \times 1\ \text{m}} \sim 2.7 \times 10^{31}\text{cm}^{-2}\text{s}^{-1}.$$

- Perhaps higher if we can get more current in the rings.
  - We should try some 110 bunch running at least to shake the bugs out of the systems.

22 February 2002
G. Bunce

AGS CNI Polarimeter

Goal: use proton-carbon CNI elastic scattering, as for the RHIC polarimeters, measure asymmetry from AGS injection energy to RHIC injection energy. If possible, measure on AGS ramp.

---CNI polarimetry, when the recoil carbon is measured using time of flight and energy, clearly identifies the elastic reaction

---the microribbon target survives the high beam intensity we use

---with a wide target width, the measurement can be made in a short time (seconds to minutes)

---it might be possible to measure the asymmetry on the ramp, so that it won't be necessary to set up a flattop at the desired energy

The present polarimeter: uses proton-proton elastic scattering at medium t ($t=0.15\ GeV^2/c^2$)

---with the high polarized source intensity, a hydrocarbon target cannot survive. Therefore a carbon target is used, and quasi-elastic scattering is measured instead of pp elastic. The analyzing power is about half, and the recoil proton is not clearly identified.

---at 24 GeV, the measurement takes about 20 minutes, with a flattop and debunching required

The idea is to provide a better tool to investigate depolarization and corrections in the AGS.

Experience: E950, where we first tested and calibrated the RHIC CNI polarimetry.

Issues:

1. **beam size at injection into AGS ==> longer target than RHIC (Bill Lozowski of Indiana is working on this, along with a wider target.)**

2. **long bunches in AGS, time of flight resolution ==> place detectors at 25 cm radius vs. 15 cm for RHIC (time is then roughly 120 ns for 200 keV carbon)**

3. **noise environment in AGS ==> E950 worked, but this is a major issue requiring work**

4. **analyzing power vs. energy ==> cross calibrate with AGS pp polarimeter, can also consider calibrating at injection energy at COSY. Calibrated at 22 GeV by E950. Absolute calibration not as important—issue is to spot depolarizing resonances in ramp**

5. **sufficient rate ==> factor 100 wider target than for RHIC, use 6 bunches with 2 x 10^{11}/bunch, 2 RHIC type silicon detectors, get 1M events in 300 ms at injection energy****

6. **ramp measurement requires 50 measurements over 600 ms ramp ==> 10 ms time window, or 30 ramps to collect 1M events at lowest energy**

7. **coding wave form digitizer for 50 measurements ==> new WFD has capability (decision to use new version WFDs, which were used for half the channels for the RHIC polarimeter this year, for AGS. RHIC will also use all new version WFDs next year)**

8. **too much rate ==> present calculation gives about 20% double hits in strip. We need to decide what is acceptable, and select the target width**

Plans and schedule: we are designing the chamber, ordering valves and parts for the target mechanism, etc. Plan is to have the AGS CNI polarimeter in place for the 2003 run.

Do we need help? You bet. We have a small group from CAD, UCLA and RBRC working on this now, and certainly can use help!

20 February 2002
G. Bunce

Accelerator Spin Issues and Questions

The RHIC spin run this year was extremely successful, with the new high intensity polarized source, new RHIC polarimetry and readout, new Siberian Snakes (first use at high energy), tune lock on ramp, maintaining polarization at injection, ramp to 100 GeV, storage for up to 14 hours without apparent polarization loss, studies showing the new spin flipper works, and reaching luminosity goals. The AGS polarization was low, and the accelerator and experiments required most of the alloted time for commissioning, but physics data was taken for the first time ever for a polarized proton collider at root(s)=200 GeV. Experiments saw some striking online physics asymmetries.

In preparation for the March RHIC retreat, and also to prepare a spin plan for the future, this list is intended to collect questions which should be addressed on the acceleration and storage of polarized protons.

Source

Is there an understanding of the source polarization being about 70%, and is there a plan or studies planned to improve to over 80%? What is the time scale for this?

Do we understand the absolute polarization of the source (or at the end of the linac)?

What intensity did we reach, what is available, and what maintenance schedule should be used during a run? Polarization vs. intensity for source?

Booster

A significant intensity loss seemed to occur in transfers to and from the Booster. What is the expectation for transfer efficiency, what did we have, do we understand the differences, and what improvement is expected? When?

AGS

Can (and will) we understand the polarization losses in the AGS

with the 2001/2 run? How quantitative is this understanding--
can we use spin tracking confidently to predict AGS polarization?

What polarization should be achieved in the AGS using present techniques, and the Siemens ramp rate?

Issues of polarization vs. luminosity tradeoffs (intensity and emittance)?

What are the systematic errors for the AGS polarimeter? What is the absolute calibration that we should use? Is there any intensity dependence?

Will a new AGS CNI polarimeter be ready for the next run? What are the issues to do this? Team? Schedule? What are its goals?

Will the strong AGS partial snake overcome all polarization issues? What are the predictions of spin tracking? What should we expect for final AGS polarization?

What are the issues with designing and building the strong AGS partial snake? What is a reasonable (if aggressive) time scale for building it? How long to install? What would be the commissioning sequence with it, and rough commissioning time scale? (Without polarized beam as much as possible.)

What is our experience in repeatability of extraction from the AGS? Are there plans to improve reliability? When?

RHIC

Issues of RHIC polarimetry: systematic errors from identified or unidentified sources? Estimates of false asymmetries? Intensity dependence? Other dependence (bunch length, poor transfer from AGS)? Schedule for completing studies on data? Radiation damage--what needs to be replaced, funds required, schedule. Changes for next run in FPGA code, etc.

What do we know about polarization loss in transfer from the AGS to RHIC? Did we see any variation? If so, do we understand why?

What quantitatative information and understanding do we have of polarization loss on the ramp from the 2001/2 run? When will this evaluation be complete?

What are the issues with having reliable tune locking on the ramp?

What work is needed, schedule, plan?

Is the present machine flat enough? What was achieved vs. what is required for polarization?

Quantitative information and understanding of polarization loss at flattop? Plan for using tune lock on flattop?

Intensity vs. lifetime? What are limits? Luminosity vs. lifetime? What should we expect for lifetime with beta*=1m?

Downramp--understanding of difficulties and plan.

Spin flipper--plan to have it operational for next run.

Spin studies in RHIC--what is essential to study, what was missed in this run? Realistic estimate of study time required.

Local polarimeter plan for PHENIX and STAR to calibrate spin rotators--results of tests, plan?

Spin rotators--installation plan, commissioning plan, time estimate for commissioning (separate estimates for using gold, polarized beam).

Evaluation of 2001/2 run in terms of commissioning efforts, time required for steps. What should we expect for next spin run? Issue of time required to reach luminosity goal and polarization studies.

250 GeV/c issues? Additional requirements on flatness, tune control, snake alignment?

For the Executive summary

What should be expected for a 2003 spin run at root(s)=200 GeV? Luminosity, lifetime, integrated luminosity, polarization, commissioning time, studies time? (Without/with AGS strong partial snake.)

What length AGS study should be expected to achieve and demonstrate polarization goal for a 2003 run?

RHIC commissioning time to have physics at root(s)=500 GeV in 2003? Luminosity?

Is the RHIC spin goal of reaching luminosity 2 x 10^32 at root(s)=500 GeV (and 8 x 10^31 at 200 GeV) and 70% polarization achievable in 2004, or what should be assumed based on present understanding?

What issues/studies are seen as crucial/important to know in 2003, to achieve full luminosity and polarization in 2004? Pros and cons from the accelerator perspective of a short run in 2003, longer run in 2004, vs. long run in 2004.

For RHIC Retreat

RHIC Spin Collaboration Meeting

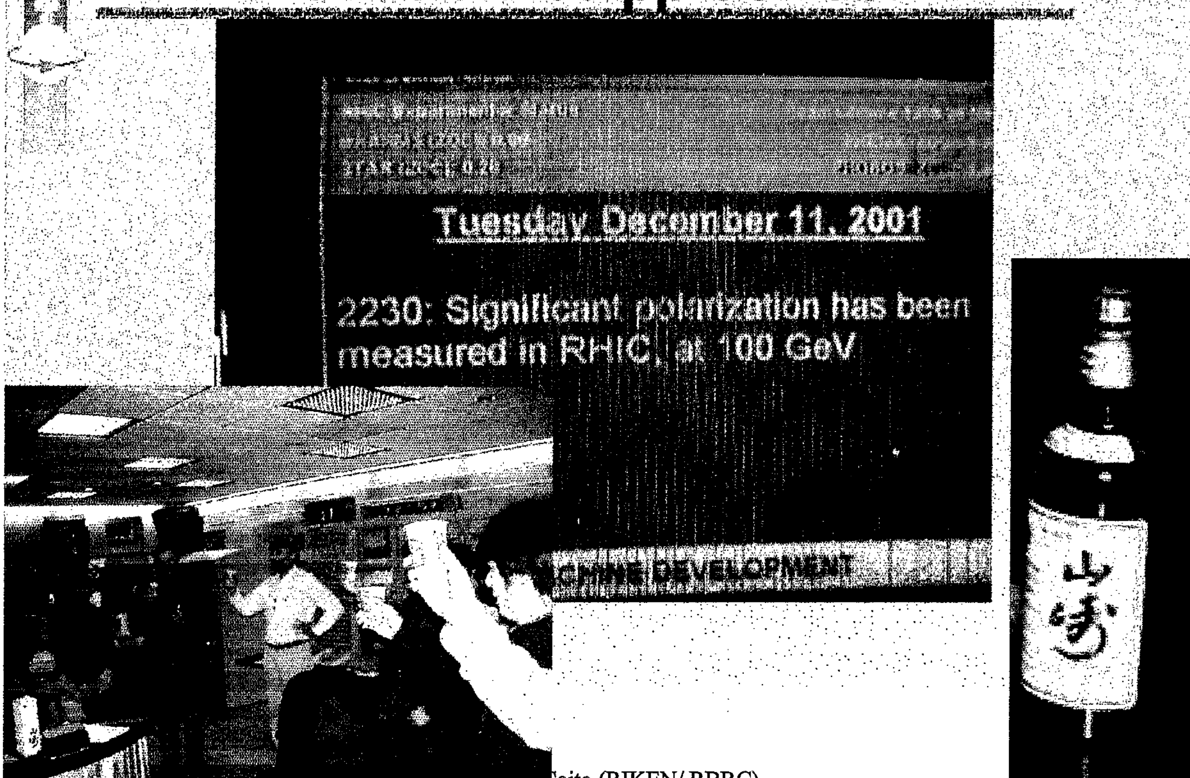
February 22, 2002

Naohito Saito

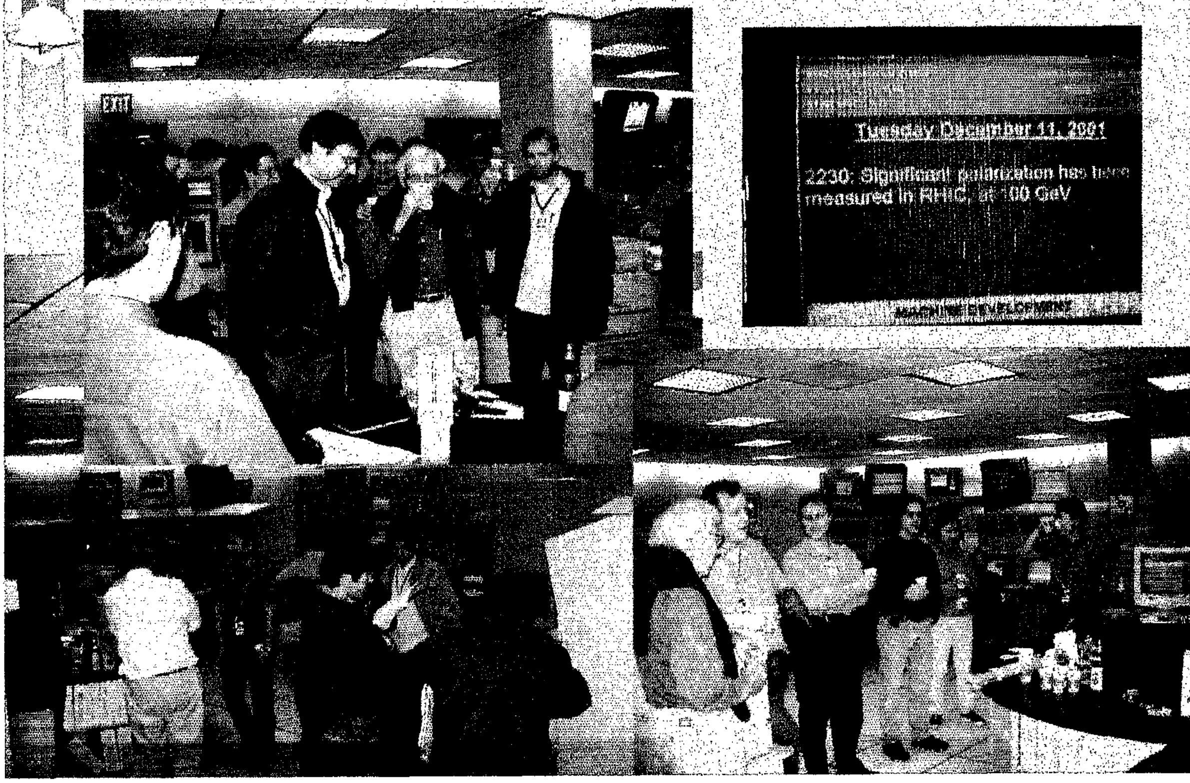
RIKEN / RIKEN BNL Research Center

RIKEN

The First Polarized pp Collider



RHIC Spin Excitement 12/11/01



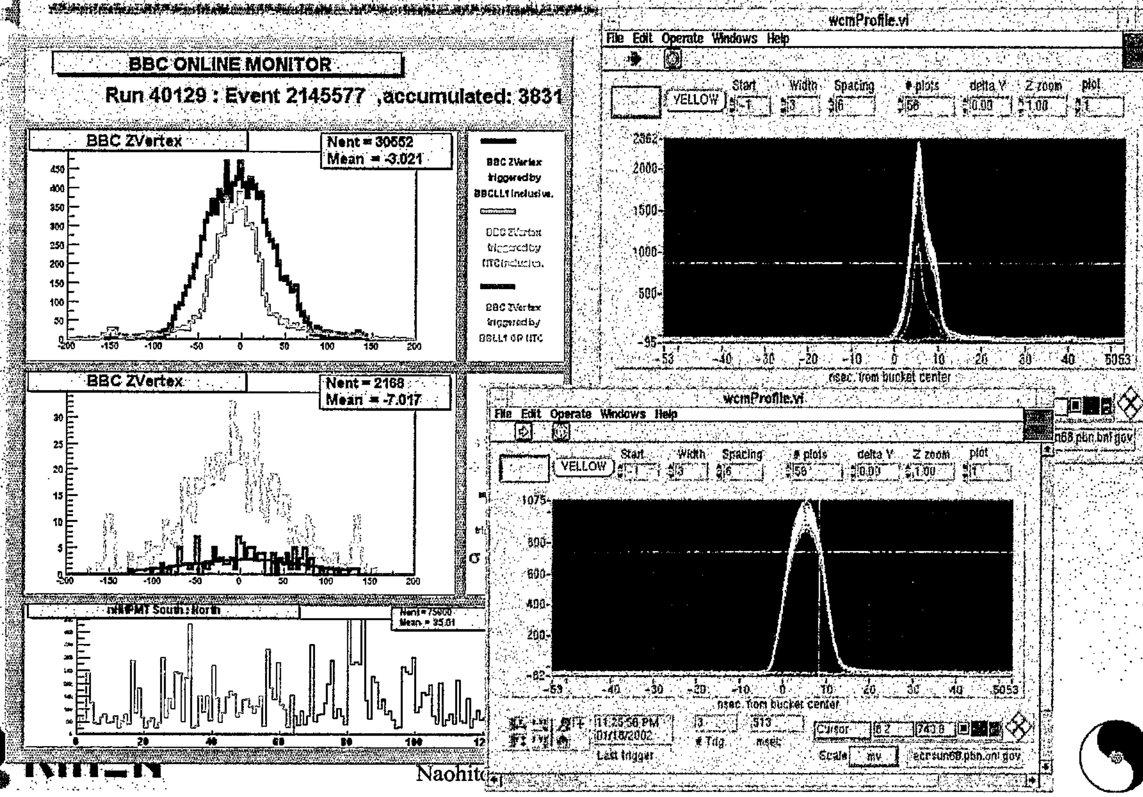
RHIC Spin Retreat

- Questions on Run-2 Performance and Run-3 Plan → Gerry

In Addition, I would add:

- Usefulness of "Gerry's Meeting"
  - Timely discussion for re-focusing efforts towards most optimal working plan
  - Coherent view among all experiments and all machinists
- Better communication with MCR
  - Polarization Measurement
  - Steering
  - Cog / Re-cog / Spin Flip
  - Scraping
  - Dump
  - Spin Pattern Change
  - Experimental Magnet Control
  - Shift-to-Shift Information transfer among MCR shift crews

Vertex Distribution and Bunch Profile



RHIC Spin Retreat (continued)

Better Performance and Reproducibility

- Diagnosis at each step:
  - Source -> 200 MeV -> Booster -> AGS injection -> AGS extraction -> RHIC injection -> RHIC flat top
- Understand systematics of monitoring system
  - Redundant measurements
    - Multiple measurements at RHIC (cf. Emittance growth ?)
    - E880 vs new AGS Polarimeter
    - RHIC CNI Polarimeter and possible Local Polarimeters

Commissioning of New Devices and re-commissioning of "OLD" Devices

- Spin Rotators
  - highly coupled with Local Polarimeters
- Snakes / Spin Flipper / Polarimeter
- Source → Linac → Booster → AGS → AtR

RIKEN

Naohito Saito (RIKEN/ RBRC)

RHIC Spin Retreat (continued)

Roadmap towards Full-Fledged RHIC Spin Operation

- Absolute Polarization Calibration
  - Pol-J target
  - Better calibration at injection energy
  - Down ramp
- Develop Robust Operation Phase space
  - Source → Linac → Booster → AGS → RHIC
  - Any additional device to achieve this goal?
    - "Strong" AGS Partial Snake

How can we arrange these developments with minimal interference with Spin and HI PHYSICS program ?

RIKEN

Naohito Saito (RIKEN/ RBRC)

Agenda (hope still visible...)

Opening Session - March 5 (morning)

8:30-10:10		
Welcome:	F.Pilat	5
Opening address:	D.Lowenstein	15
Physics goals for the the next run:	S.Aronson	40
Machine goals for the next run:	T.Roser	40
10:10-10:40	coffee break	
10:40-12:00		
The Injectors:	L.Ahrens	20
The gold run:	D.Trbojevic	20
The proton run:	W.MacKay	20
Retreat organization:	F.Pilat	20

Machine Reliability - March 6 (morning)

8:30-10:10		
Overview and some definitions:	M. Brennan	20
Reliability of Tune/Chromaticity/Orbit:	T.Satogata	20
Reliability of Schedule:	A. Drees	20
Correlations in FY01 statistics:	P. Ingrassia	40
10:10-10:40	coffee break	
10:40-12:00		
Summaries of systems hardware plans:		
·RF	M. Brennan	10
·Power supplies	D. Bruno	10
·Cryo	A. Nicoletti	10
·Quench detection	G. Ganetis	10
·Controls	B. Oerter	10
·Vacuum	H-C. Hseuh	10
Reliability of Machine Physics:	S. Peggs	20

Machine Experiments and Diagnostics - March 7 AM

8:30-10:00		
Tune and Chromaticity:	P. Cameron	20
LHC Chromaticity Control:	H. Schmickler	15
E-detectors, IPMs, and Trans. Emittance:	R. Connolly	15
Longitudinal Dampers:	M. Brennan	10
Transverse Coherence Monitor:	M. Brennan	5
E-detectors, IPMs, and Trans. Emittance:	R. Connolly	20
Transverse Dampers:	A. Drees	10
10:00-10:30	coffee break	
10:30-12:00		
Benefits of Beam Experiments:	F. Pilat	5
Transition Crossing Studies:	C. Montag	10
Local Non-linear IR Correction:	V. Ptitsyn	15
Transv. and Longit. Instabilities:	M. Blaskiewicz	10
Beam-beam Effects:	W. Fischer	15
Polarized Beam Manipulations:	M. Bai	15
Pressure rise:	S-Y Zhang	20

Machine Performance - March 5 (afternoon)

14:00 - 15:30		
Linear lattice, optics matching:	T Satogata	15
Coupling, working point:	F.Pilat	15
Chromaticity, snapback, transverse emittance:	S.Tepikian	15
Beta squeeze, triplet correction/performance:	V.Ptitsyn	15
110 bunches, beam-beam/ramping, e-cloud:	W.Fischer	15
Au transition crossing, triplet vibration:	C.Montag	15
15:30-16:00	coffee break	
16:00-17:30		
Impedances and instabilities, single-bunch Imax:	M.Blaskiewicz	20
Backgrounds, collimation, gap cleaning:	A.Drees	15
Abort performance and issues:	L.Ahrens	15
AGS polarization efficiency/plans:	H.Huang	15
RHIC polarization transmission, issues:	V.Ptitsyn	10
d/Au performance issues:	J.Van Zeijts	15

Machine Integration - March 6 (afternoon)

14:00-15:30		
RHIC experiments integration:	A. Drees	10
Brahms:	F. Videbaek	10
Phenix:	A. Frawley	10
Phobos:	R.Pak	10
PP2PP:	W.Guryn	10
Star:	W. Christie	10
Spin Physics:	N.Saito	10
Polarimeter:	TBD	10
Discussion:		10
15:30-16:00	coffe break	
16:00-17:30		
RHIC and injectors integration:	J.Morris	15
Logger System:	R. Lee	15
Ramps at flattop:	J. van Zeijts	10
Cryogenics integration:	A. Nicoletti	10
Quench tuning:	G.Ganetis	10
RF ramp integration:	M. Brennan	15
MCR operation:	G. Marr	15

Closing Session - March 7 (afternoon)

14:00-16:00		
The RHIC e-cooling projects:	I.Ben-Zvi	30
The EIC project:	S.Peggs	30
RHIC: the CERN perspective:	H.Schmickler	20
RHIC: the FNAL perspective:	M.Syphers	20
Preliminary summary:	F.Pilat	20

Naohito Saito (RIKEN/ RBRC)

SINGLE TRANSVERSE-SPIN ASYMMETRIES

A_N AT RHIC

Jianwei Qiu *

Iowa State University

February 22, 2002

Table of Contents:

---

*Some related references: J.Q. and G. Sterman, Phys. Rev. Lett. 67, 2264 (1991); Nucl. Phys. B378, 52 (1992); Phys. Rev. D59, 014004 (1999); D. Boer and J.Q., Phys. Rev. D65, 034008 (2002); C. Kouvaris, J.Q., and W. Vogelsang, in preparation.

1. INTRODUCTION

- Single Spin Process at RHIC:

$$A(p,\vec{s}) + B(p') \Longrightarrow C(\ell) + X$$

  - only one initial-state hadron is polarized
  - observed particle $C(\ell)$ is unpolarized, and can be any high transverse momentum particle π, p, γ, or lepton
  - cross section: $\sigma(\ell,\vec{s})$

- Single Spin Asymmetry – definition:
  - Spin-avg X-section: $\sigma(\ell) = \frac{1}{2}[\sigma(\ell,\vec{s}) + \sigma(\ell,-\vec{s})]$
  - Spin-dep X-section:

$$\Delta\sigma(\ell,\vec{s}) = \frac{1}{2}[\sigma(\ell,\vec{s}) - \sigma(\ell,-\vec{s})]$$

  - Single-spin asymmetry:

$$A(\ell,\vec{s}) \equiv \frac{\Delta\sigma(\ell,\vec{s})}{\sigma(\ell)} = \frac{\sigma(\ell,\vec{s}) - \sigma(\ell,-\vec{s})}{\sigma(\ell,\vec{s}) + \sigma(\ell,-\vec{s})}$$

  - Single longitudinal-spin asymmetry: A_L
    particle spin $\vec{s}$ is parallel to its momentum $\vec{p}$
  - Single transverse-spin asymmetry: A_N
    particle spin $\vec{s}$ is perpendicular to its momentum $\vec{p}$

Even though X-section $\sigma(\ell, \vec{s})$ is finite, single spin asymmetry can vanish due to fundamental symmetries of interactions

- Parity and time-reversal invariance

  $\Rightarrow A_N = 0$ for inclusive DIS

  - Inclusive DIS X-section:

$$\sigma(\vec{s}_T) \propto L^{\mu\nu} W_{\mu\nu}(\vec{s}_T)$$

  - Hadronic tensor:

$$W_{\mu\nu}(\vec{s}_T) \propto \langle P, \vec{s}_T | j^\dagger_\mu(0) j_\nu(y) | P, \vec{s}_T \rangle$$

  - Parity and time-reversal invariance:

$$\langle P, \vec{s}_T | j^\dagger_\mu(0) j_\nu(y) | P, \vec{s}_T \rangle = \langle P, -\vec{s}_T | j^\dagger_\nu(0) j_\mu(y) | P, -\vec{s}_T \rangle$$

$$\Rightarrow W_{\mu\nu}(\vec{s}_T) = W_{\nu\mu}(-\vec{s}_T)$$

  - Spin-dependent X-section:

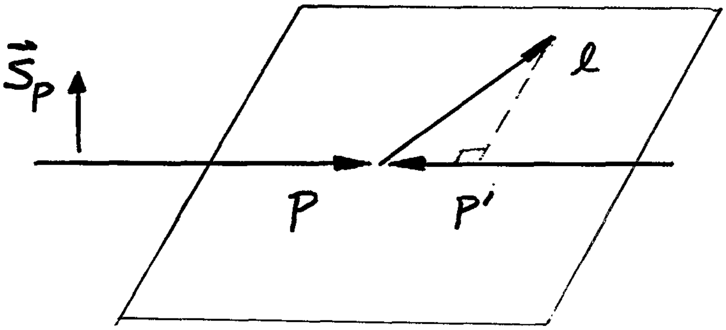
$$\Delta\sigma(\vec{s}_T) \propto L^{\mu\nu} \left[W_{\mu\nu}(\vec{s}_T) - W_{\mu\nu}(-\vec{s}_T)\right] = L^{\mu\nu} \left[W_{\mu\nu}(\vec{s}_T) - W_{\nu\mu}(\vec{s}_T)\right] = 0$$

    because $L^{\mu\nu}$ is symmetric for a unpolarized lepton

  - Above result is valid for any two-current correlators

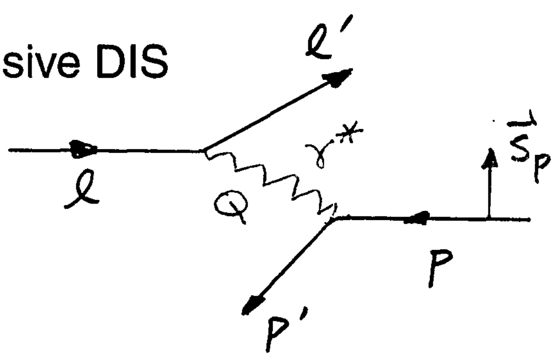
- Parity conserved interactions $\Rightarrow A_L = 0$

- Single spin asymmetries correspond to T-odd triple product: $A_N \propto i\, \vec{s}_p \cdot (\vec{p} \times \vec{\ell})$
  - $\vec{p}$ is beam particle's three momentum
  - $\vec{\ell}$ is momentum of observed particle
  - the phase "i" is required by time-reversal invariance
  - covariant form: $A_N \propto i\epsilon^{\mu\nu\alpha\beta}\, p_\mu s_\nu \ell_\alpha p'_\beta$



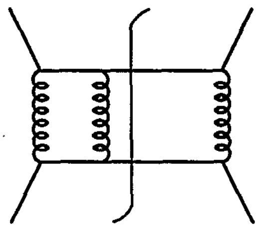
- Nonvanishing A_N requires a phase, a spin flip, and enough vectors to fix a scattering plan
  - Inclusive DIS does not have enough vectors
    Note: q and p can only fix a line

- Following examples can generate nonvanishing A_N:
  - Single hadron (or photon) at high ℓ_T
  - Drell-Yan lepton angular distribution
  - Semi-inclusive DIS
  - . . .

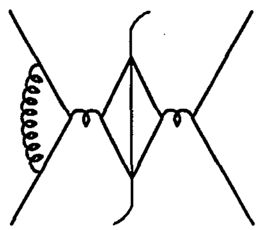


2. A_N FOR SINGLE HADRON PRODUCTION

- pQCD was first used to study single transverse-spin asymmetry by Kane, Pumplin, and Repko in 1978



+ c.c.

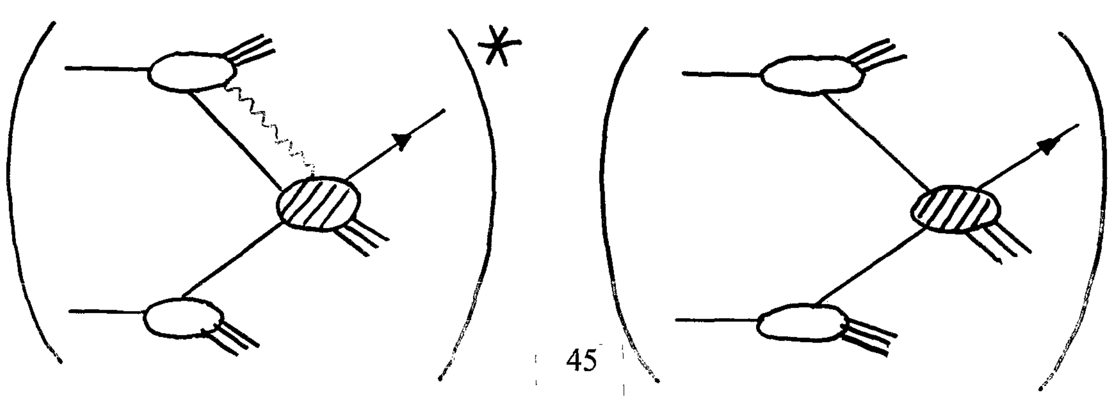


+ c.c.

  - imaginary part of the loop provides the phase
  - quark mass provides the needed spin flip
  - $A_N \propto \frac{m_q}{\ell_T} \langle p, \vec{s}_T | \bar{\psi} \Gamma \psi | p, \vec{s}_T \rangle$ where $\Gamma = \gamma^+ \gamma_5 \gamma_T$, ...

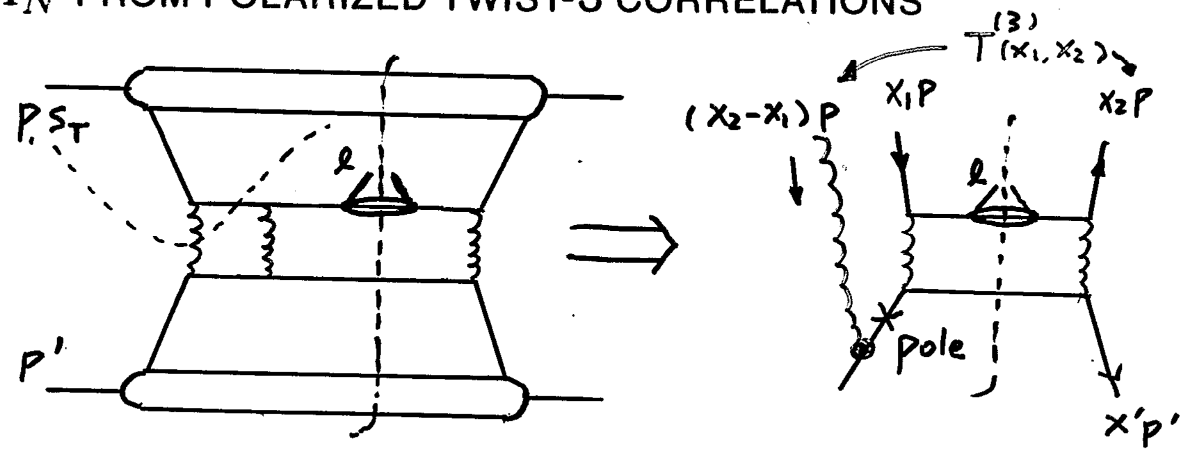
- The fact that $A_N \propto m_q$ indicates that A_N is a twist-3 effect in QCD perturbation theory

- QCD dynamics is much richer than the parton model
  - twist-3 arises from "intrinsic" k_T
    $\Rightarrow A_N \propto T_{k_T} \sim \langle p, \vec{s}_T | \bar{\psi} \Gamma \partial_T \psi | p, \vec{s}_T \rangle$
  - twist-3 from interference between a quark state and a quark-gluon state
    $\Rightarrow A_N \propto T_{A_T} \sim \langle p, \vec{s}_T | \bar{\psi} \Gamma A_T \psi | p, \vec{s}_T \rangle$



+ C.C.

A_N FROM POLARIZED TWIST-3 CORRELATIONS



- Unpinched pole $\Rightarrow\ i\delta(x_1 - x_2)$
- Color gauge invariance combines T_{k_T} and T_{A_T} to

$$T_{D_T}(x_1, x_2) \quad \propto \quad \langle p, \vec{s}_T | \bar{\psi}\Gamma D_T \psi | p, \vec{s}_T \rangle$$
$$T_F(x_1, x_2) \quad \propto \quad \langle p, \vec{s}_T | \bar{\psi}\Gamma F_T^+ \psi | p, \vec{s}_T \rangle$$

- $A_N \neq 0$ requires
  - $T(x_1, x_2, \vec{s}_T) \neq 0$ when $x_1 = x_2$
  - $T(x_1, x_2, \vec{s}_T) \neq T(x_1, x_2, -\vec{s}_T)$
  - Combination of $T(x_1, x_2, \vec{s}_T)$ and partonic part is real

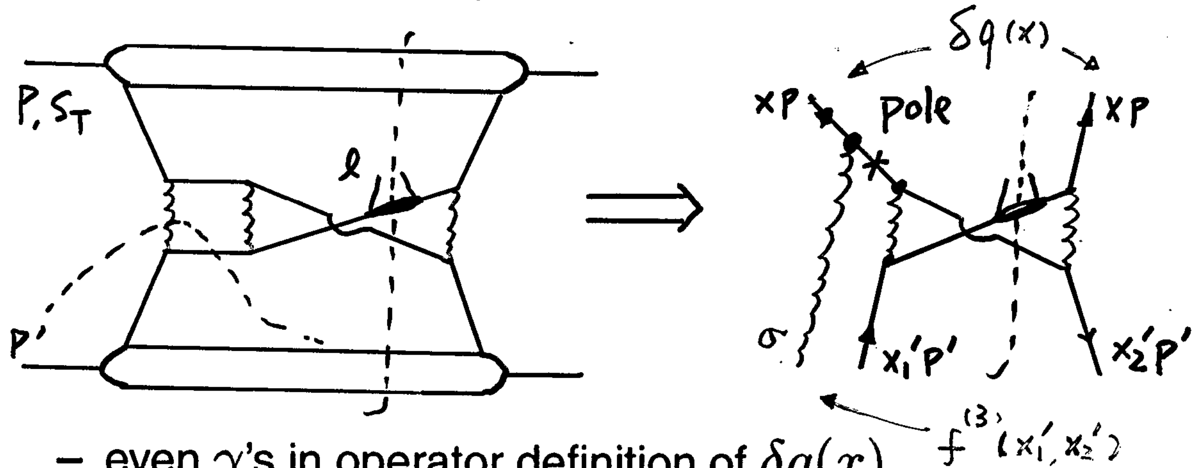
  $\Rightarrow\ A_N \propto T_F(x_1 . x_2)$ with $x_1 = x_2$, and

$$T_F(x_1, x_2) = \int \frac{dy_1^- dy_2^-}{4\pi} \mathrm{e}^{ix_1 P^+ y_1^- + i(x_2 - x_1)P^+ y_2^-}$$
$$\times \langle P, \vec{s}_T | \bar{\psi}_a(0)\gamma^+ \left[\epsilon^{s_T \sigma n \bar{n}}\, F_\sigma^{\ +}(y_2^-)\right] \psi_a(y_1^-) | P, \vec{s}_T \rangle$$

- Three field operator does not have the probability interpretation of normal parton distributions

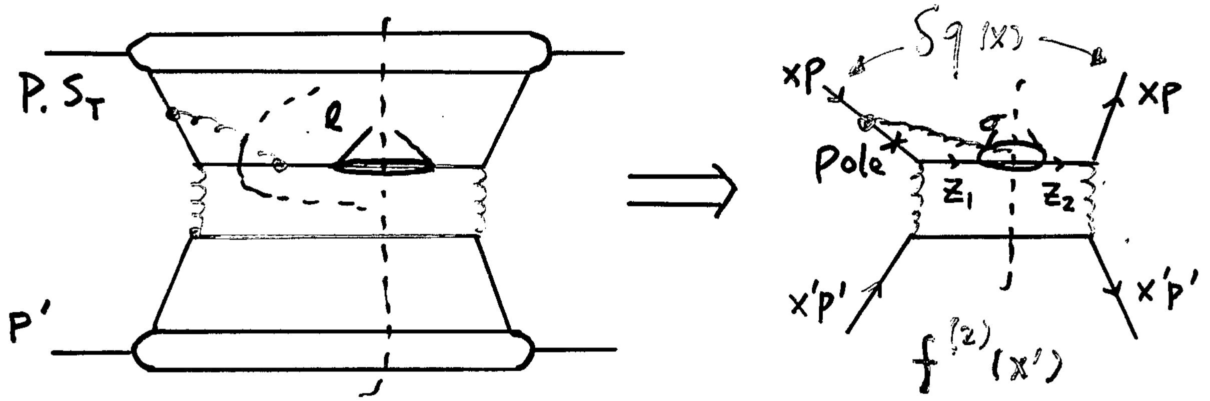
A_N FROM TWIST-2 TRANSVERSITY DISTRIBUTION

- Twist-3 initial-state unpolarized correlation[a]



  - even γ's in operator definition of $\delta q(x)$
    $\Rightarrow$ much smaller number of diagrams
  - double suppression from $\delta q(x)$ and chiral-odd twist-3 correlation function
  - contribution to A_N is a factor of 5-10 smaller than that from polarized initial-state T_F

- Twist-3 unpolarized fragmentation function



  - Expect to be of similar size, and much smaller than that from polarized initial-state T_F

---

[a] Y. Kanazawa and Y. Koike, Phys. Lett. B490 (2000) 99

FACTORIZABLE SINGLE TRANSVERSE-SPIN ASYMMETRIES

- Generalized factorization formula for hadronic single transverse-spin asymmetries

$$\Delta\sigma_{AB\to h}(\vec{s}_T) = \sum_{abc} T^{(3)}_{a/A}(x_1, x_2, \vec{s}_T) \otimes f_{b/B}(x') \otimes \hat{\sigma}_{ab\to c}(\vec{s}_T) \otimes D_{c\to h}(z)$$
$$+ \sum_{abc} \delta q^{(2)}_{a/A}(x, \vec{s}_T) \otimes \Big\{ f_{b/B}(x') \otimes \hat{\sigma}'_{ab\to c}(\vec{s}_T) \otimes D^{(3)}_{c\to h}(z_1, z_2) + f^{(3)}_{b/B}(x'_1, x'_2) \otimes \hat{\sigma}''_{ab\to c}(\vec{s}_T) \otimes D_{c\to h}(z) \Big\}$$

- $\hat{\sigma}$, $\hat{\sigma}'$, and $\hat{\sigma}''$ are perturbatively calculable
- T,P–invariance $\longrightarrow$ at least one function has TWO x's
- Chiral-odd $\delta q(x)$ requires chiral-odd $f^{(3)}_{b/B}$ and $D^{(3)}_{c\to h}$
  $\Rightarrow$ first term is larger than the other two
- Can generalize $\otimes$ to convolution in k_T for both initial-state and final-state interactions
  - Initial-state $k_T \Rightarrow$ Sivers effect

    D. Sivers, Phys. Rev. D43 (91) 261;

    M. Anselmino et al., Phys. Lett. B362 (95) 164; ...
  - Final-state $k_T \Rightarrow$ Collins effect

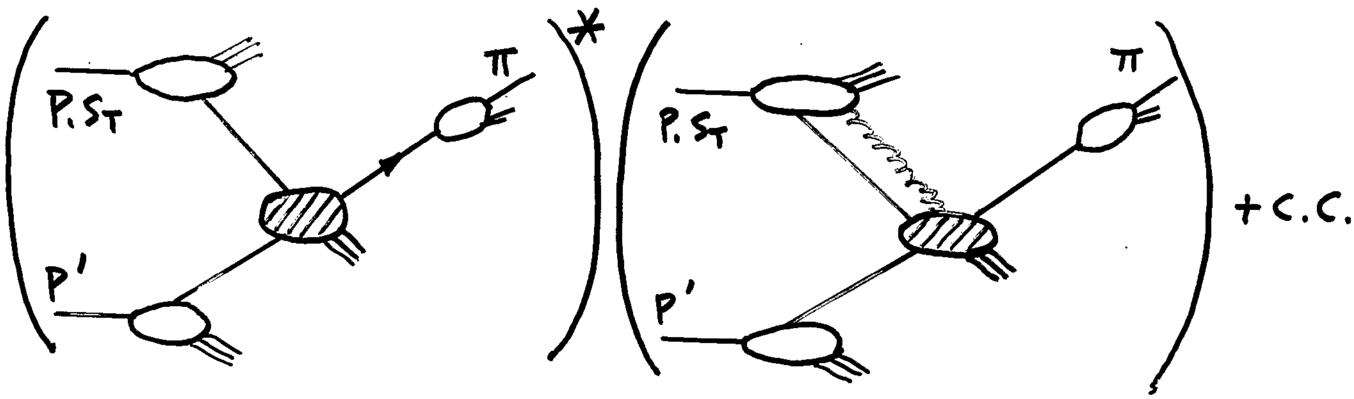
    J. Collins, Nucl. Phys. B396 (93) 161;

    R.L. Jaffe, et al., Phys. Rev. Lett. 80 (1998) 1166; ...

LEADING CONTRIBUTION TO THE ASYMMETRY OF PION PRODUCTION

- Minimal approach (collinear factorization):

$$\Delta\sigma_{AB\to h}(\vec{s}_T) \approx \sum_{abc} T^{(3)}_{a/A}(x_1, x_2, \vec{s}_T) \otimes f_{b/B}(x') \otimes \hat{\sigma}_{ab\to c}(\vec{s}_T) \otimes D_{c\to h}(z)$$



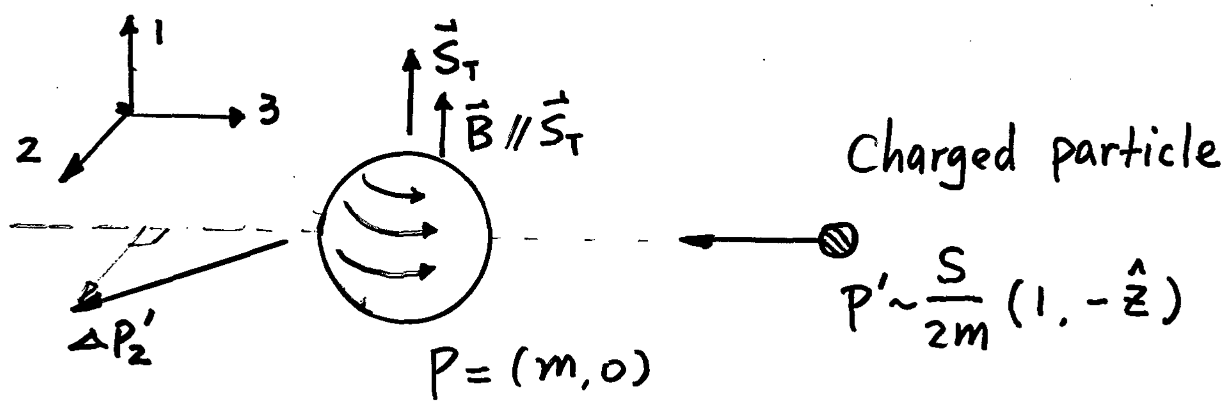
- Keep only quark fragmentation
  - observed momentum: $\ell_T^2 \propto x x' z^2 S$
  - parton distributions are steeply falling as $x \to 1$
    e.g., $f_q(x) \propto (1-x)^\alpha$ with $\alpha > 3-4$
  - quark fragmentation function falls slower as $z \to 1$
    e.g., $D_{q\to\pi}(z) \propto (1-z)^{n_q}$ with $n_q \sim 2$
    $\Rightarrow$
    X-section is dominated by small $x \sim x'$ and large z
- Need gluon fragmentation contribution at low ℓ_T and large S

WHAT $T_F(x,x)$ TELLS US?

$$T_F(x,x) \propto \langle P, \vec{s}_T | \bar{\psi}_a(0)\gamma^+ \left[\int dy_2^- \, \epsilon^{s_T \sigma n \bar{n}} \, F_\sigma^{\ +}(y_2^-) \right] \psi_a(y_1^-) | P, \vec{s}_T \rangle$$

- a classical (Abelian) analog:

  rest frame of $(p, \vec{s}_T)$



  – change of transverse momentum

$$\frac{d}{dt}p_2' = e(\vec{v}' \times \vec{B})_2 = -ev_3 B_1 = ev_3 F_{23}$$

  – in the c.m. frame

$$(m, \vec{0}) \to \bar{n} = (1, 0, 0_T), \quad (1, -\hat{z}) \to n = (0, 1, 0_T)$$

$$\Longrightarrow \quad \frac{d}{dt}p_2' = e \, \epsilon^{s_T \sigma n \bar{n}} \, F_\sigma^{\ +}$$

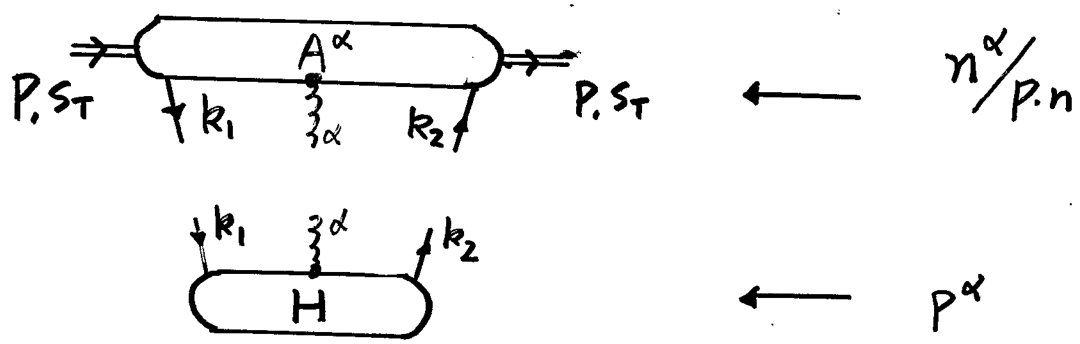
  – total change: $\Delta p_2' = e \int dy^- \epsilon^{s_T \sigma n \bar{n}} \, F_\sigma^{\ +}(y^-)$

- Color field strength $F^{+\sigma}$ alone is not gauge invariant

- T_F represents a fundamental quantum correlation between quark and gluon inside a hadron

TECHNICAL STEPS TO CALCULATE THE ASYMMETRIES

— in a color covariant gauge



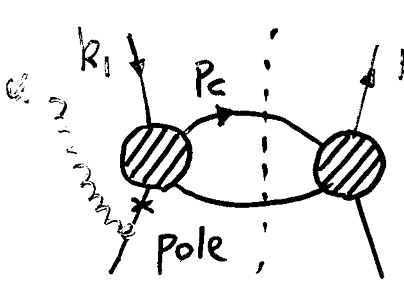
- gluon field: $A^\alpha \to n \cdot A = A^+$
- expand $H(k_1, k_2)$ to linear in k_T

$$H(k_1, k_2) \to H(x_1 p, x_2 p) + \frac{\partial H}{\partial k_{2_\sigma}} (k_{2_T} - k_{1_T})^\sigma + \ldots$$

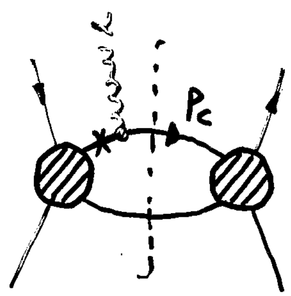
- convert $(k_{2_T} - k_{1_T})^\sigma A^+ \to \partial^\sigma A^+ \to F^{\sigma +}$
- factorized formula:

$$\Delta\sigma(\vec{s}_T) = \int dx_1 dx_2\, T_F(x_1, x_2) \left[i\epsilon^{\sigma s_T n \bar{n}} \frac{\partial H}{\partial k_{2_\sigma}} \right]_{k_{2_T}=0}$$

- either x_1 or x_2 is fixed by the pole in partonic part.

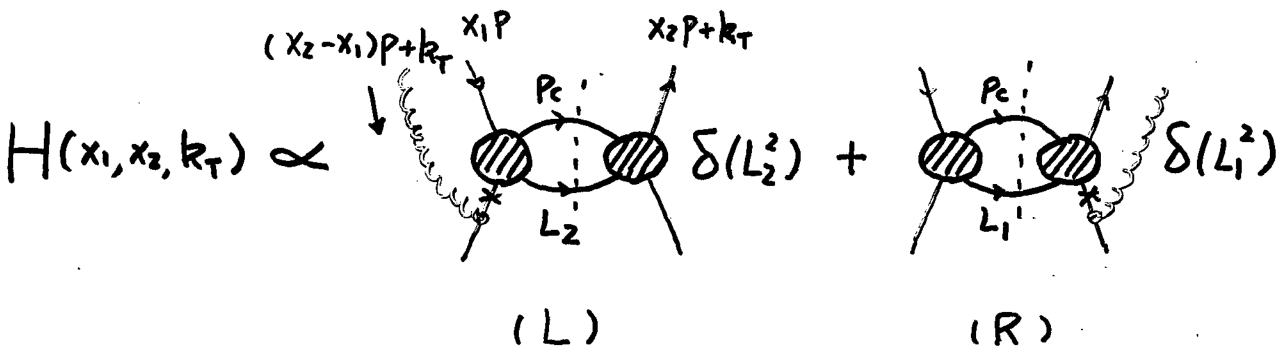


Initial-state



Final-state

CONTRIBUTION FROM INITIAL-STATE INTERACTION



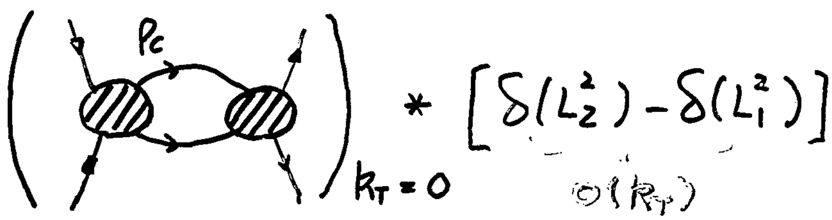
- Soft-gluon pole gives the needed phase:

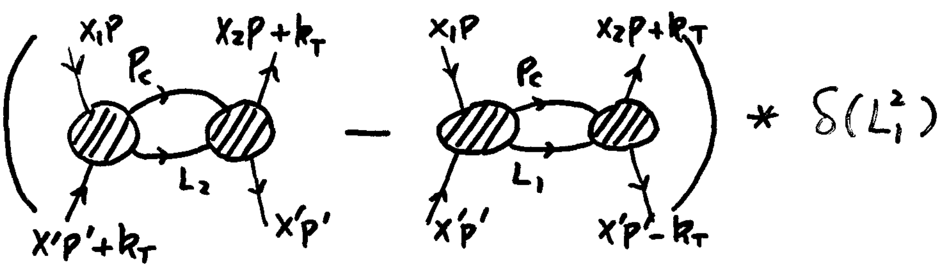
$$\frac{1}{x_2 - x_1 + i\epsilon} \to -i\pi\delta(x_2 - x_1)$$

- Two type contributions to partonic $\frac{\partial H}{\partial k_T}$:

$L_2 = x_2 P + x' p' - p_c + k_T$

$L_1 = x_1 P + x' p' - p_c$





  - phase space δ-functions $\Rightarrow$ derivative term

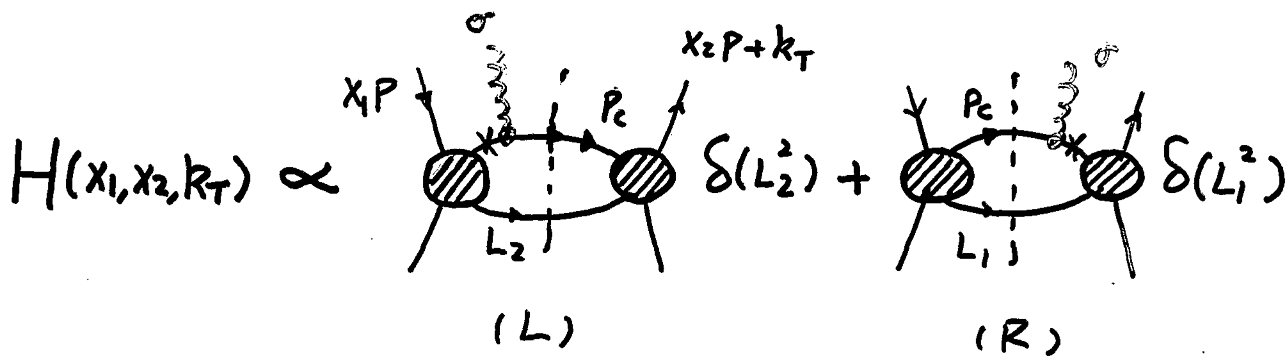
    $\delta(L_2^2) - \delta(L_1^2) \approx \delta'(L_1^2)(-2p_c \cdot k_T) \Rightarrow x\frac{d}{dx}T_F(x,x)$

  - non-derivative term

    $(L) - (R) \propto \frac{2p_c \cdot k_T}{\hat{u}} \Rightarrow T_F(x,x)$

- in forward region, $x\frac{d}{dx}T_F(x,x) \gg T_F(x,x)$
  because $T_F(x,x) \propto (1-x)^\alpha$ as $x \to 1$.

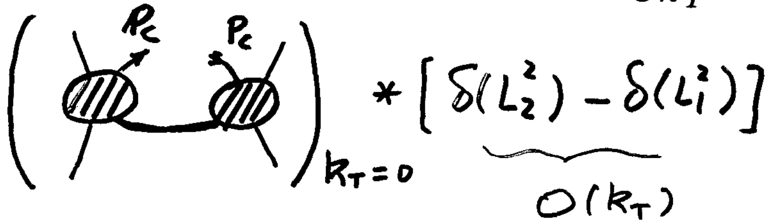
CONTRIBUTION FROM FINAL-STATE INTERACTION

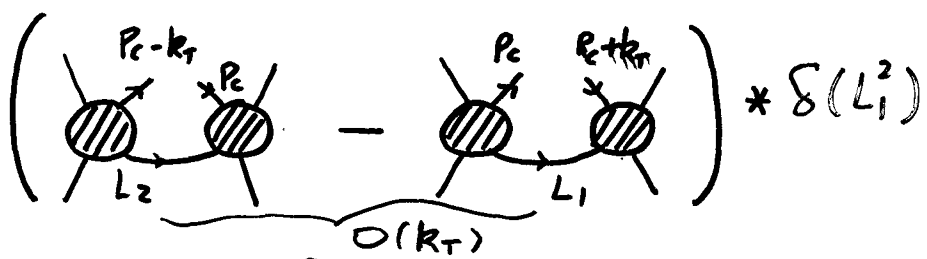


- Soft-gluon pole gives the needed phase:

$$\frac{-1}{x_2 - x_1 + \frac{p_c \cdot k_T}{p_c \cdot p} - i\epsilon} \to -i\pi\delta(x_2 - x_1 + \frac{p_c \cdot k_T}{p_c \cdot p})$$

- Two type contributions to partonic $\frac{\partial H}{\partial k_T}$:





  - phase space δ-functions $\Rightarrow$ derivative term

    $\delta(L_2^2) - \delta(L_1^2) \approx \delta'(L_1^2)(-2p_c \cdot k_T) \Rightarrow x\frac{d}{dx}T_F(x,x)$

  - non-derivative term

    $(L) - (R) \propto \left[\frac{2p_c \cdot k_T}{\hat{u}} + \frac{2p_c \cdot k_T}{\hat{t}}\right] \Rightarrow T_F(x,x)$

- most contribution to $A_N \propto \ell_T/u$

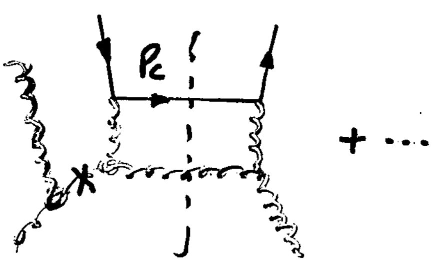
- part of final-state effect $\propto \ell_T/t \sim 1/\ell_T$

  $\Rightarrow A_N$ does not fall as fast as $1/\ell_T$ as ℓ_T increases.

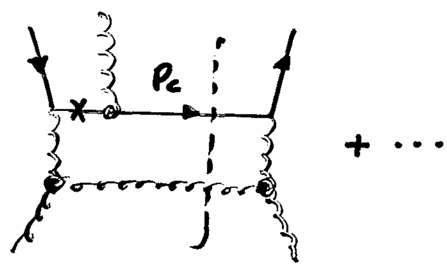
Leading $(\partial/\partial x)T_F(x,x)$ contribution to the asymmetries

$$E\frac{d\Delta\sigma}{d^3\ell} \propto \epsilon^{\ell T s T n \bar{n}} D_{c\to\pi}(z) \otimes \left[-x\frac{\partial}{\partial x}T_F(x,x)\right]$$
$$\otimes \frac{1}{-\hat{u}}\left[G(x')\otimes\Delta\hat{\sigma}_{qg\to c} + \sum_{q'} q'(x')\otimes\Delta\hat{\sigma}_{qq'\to c}\right]$$

- $\Delta\hat{\sigma}_{qg\to c}$ and $\Delta\hat{\sigma}_{qq'\to c}$ are perturbatively calculable
- Example, $qg \to qg$ scattering



I-S



F-S

– initial-state:

$$\frac{1}{2(N_C^2-1)}\left[-\frac{\hat{s}}{\hat{u}}-\frac{\hat{u}}{\hat{s}}\right]\left[1-N_C^2\frac{\hat{u}^2}{\hat{t}^2}\right]$$

– final state:

$$\frac{1}{2N_C^2(N_C^2-1)}\left[-\frac{\hat{s}}{\hat{u}}-\frac{\hat{u}}{\hat{s}}\right]\left[1+2N_C^2\frac{\hat{s}\hat{u}}{\hat{t}^2}\right]$$

– unpolarized:

$$\frac{N_C^2-1}{2N_C^2}\left[-\frac{\hat{s}}{\hat{u}}-\frac{\hat{u}}{\hat{s}}\right]\left[1-\frac{2N_C^2}{N_C^2-1}\frac{\hat{s}\hat{u}}{\hat{t}^2}\right]$$

- extra gluon interaction leads to a different color factor

MODEL FOR QUARK-GLUON CORRELATION $T_F(x,x)$

- Twist-3 correlation $T_F(x,x)$:

$$T_F(x,x) = \int \frac{dy_1^-}{4\pi} e^{ixP^+ y_1^-}$$

$$\times \langle P, \vec{s}_T | \bar{\psi}_a(0) \gamma^+ \left[\int dy_2^- \, \epsilon^{s_T \sigma n \bar{n}} \, F_\sigma^{\ +}(y_2^-) \right] \psi_a(y_1^-) | P, \vec{s}_T \rangle$$

- Twist-2 quark distribution:

$$q(x) = \int \frac{dy_1^-}{4\pi} e^{ixP^+ y_1^-} \langle P, \vec{s}_T | \bar{\psi}_a(0) \gamma^+ \psi_a(y_1^-) | P, \vec{s}_T \rangle$$

- Model for $T_F(x,x)$ of quark flavor a:

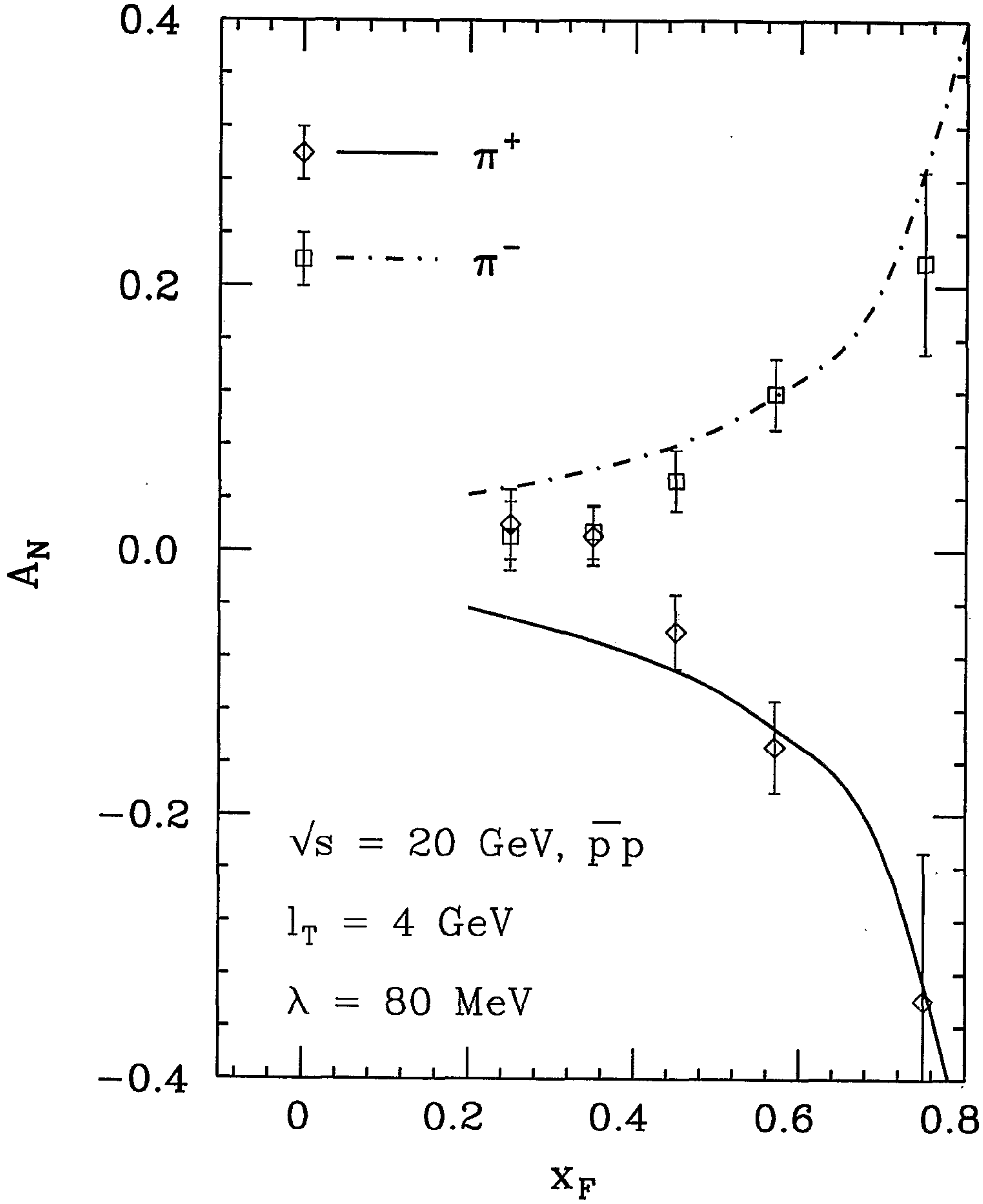
$$T_{F_a}(x,x) \equiv \kappa_a \, \lambda \, q_a(x)$$

with $\kappa_u = +1$ and $k_d = -1$ for proton

- Fitting parameter $\lambda \sim O(\Lambda_{\rm QCD})$

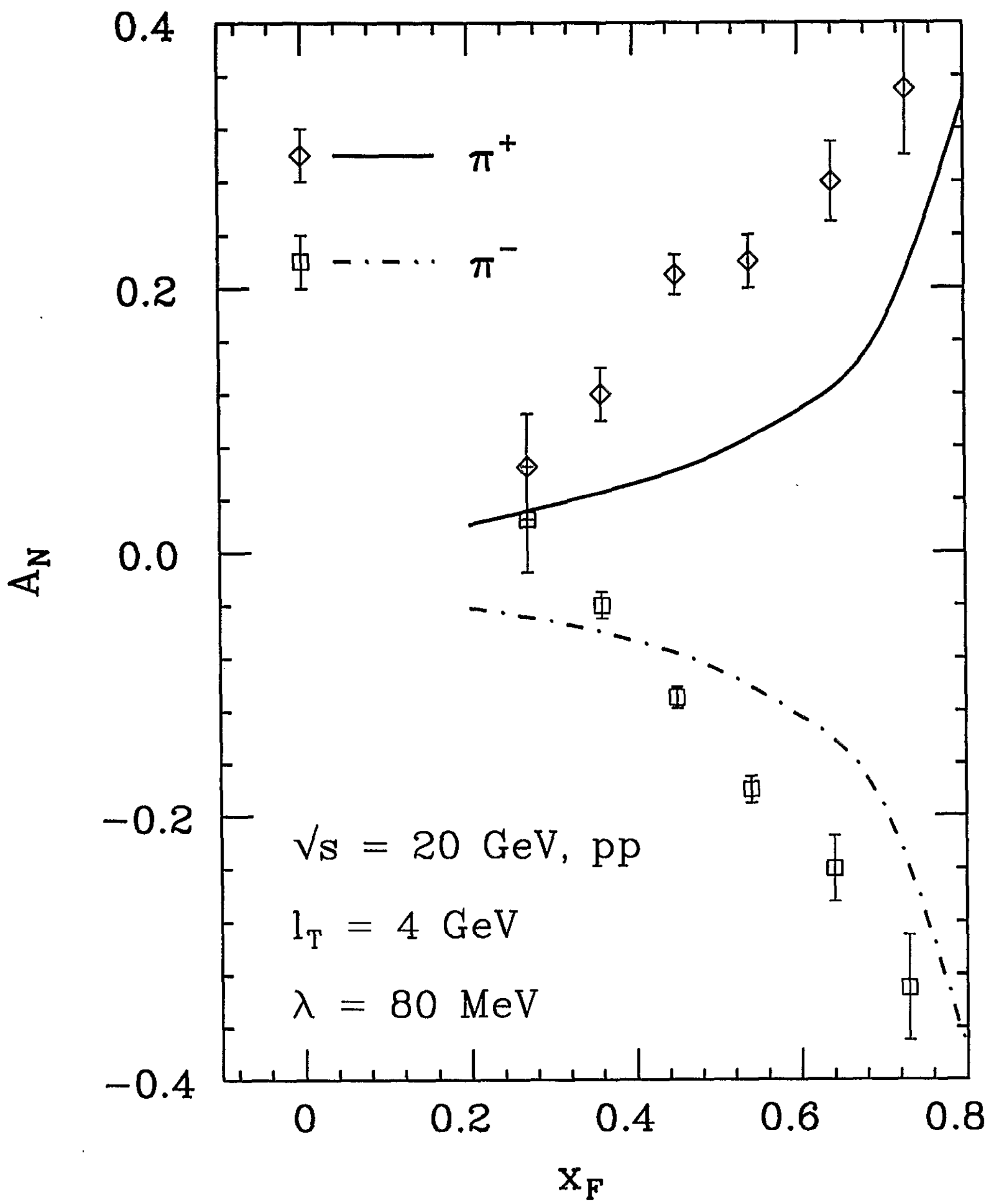
- Predictive power of the factorization approach:
  - extract $T_F(x,x)$ from one observable, say π^+ or π^-
  - use it to predict other observable, say π^0
  - $(\partial/\partial x) T_F(x,x)$ leads to enhancement of the asymmetries in forward region
  - same partonic parts can be used for calculating the asymmetries in production of other types of single hadron, say in k, or p production

COMPARE AN APPLE WITH AN ORANGE (I)



Fermilab data with ℓ_T up to 1.5 GeV

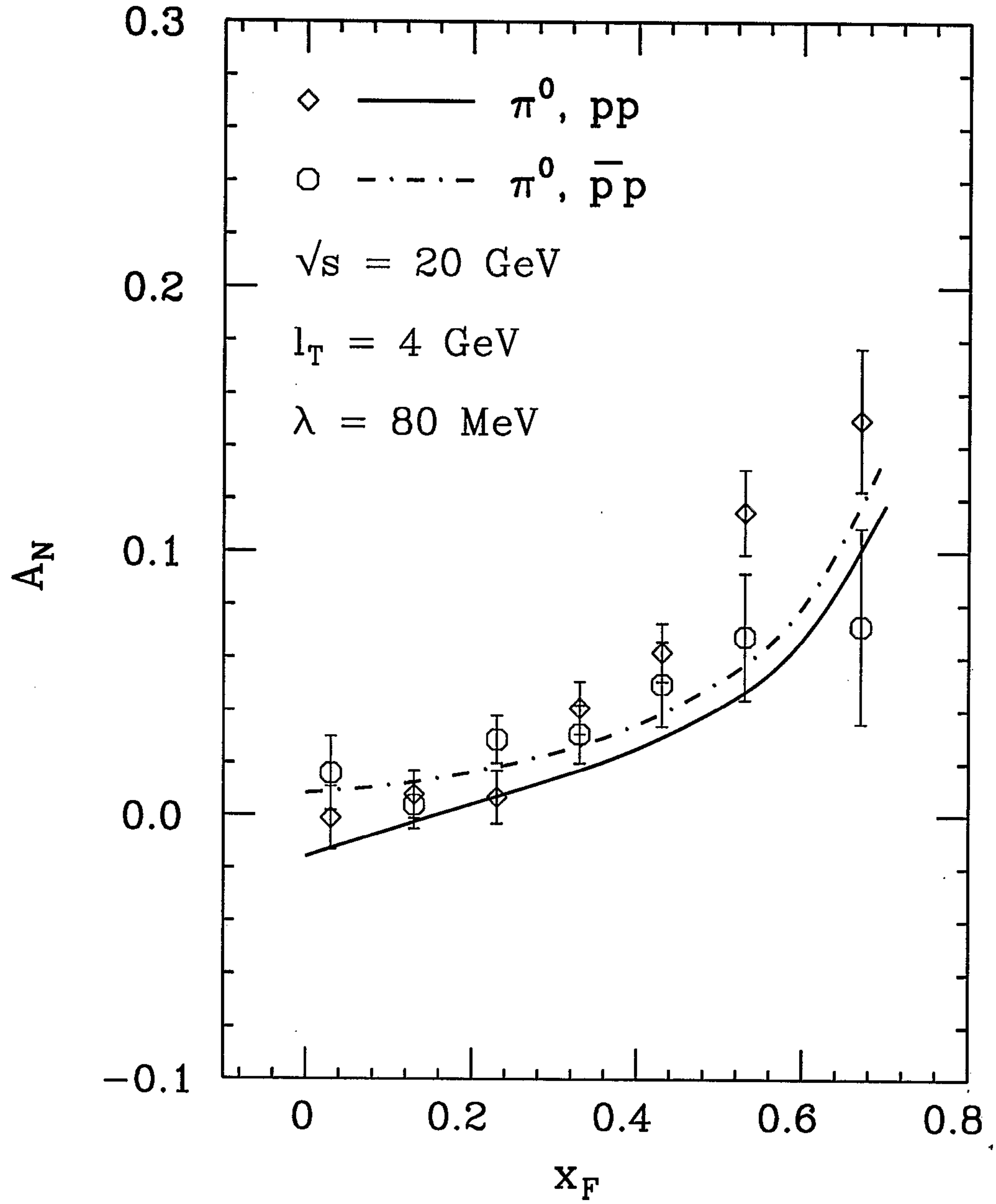
COMPARE AN APPLE WITH AN ORANGE (II)



Fermilab data with ℓ_T up to 1.5 GeV

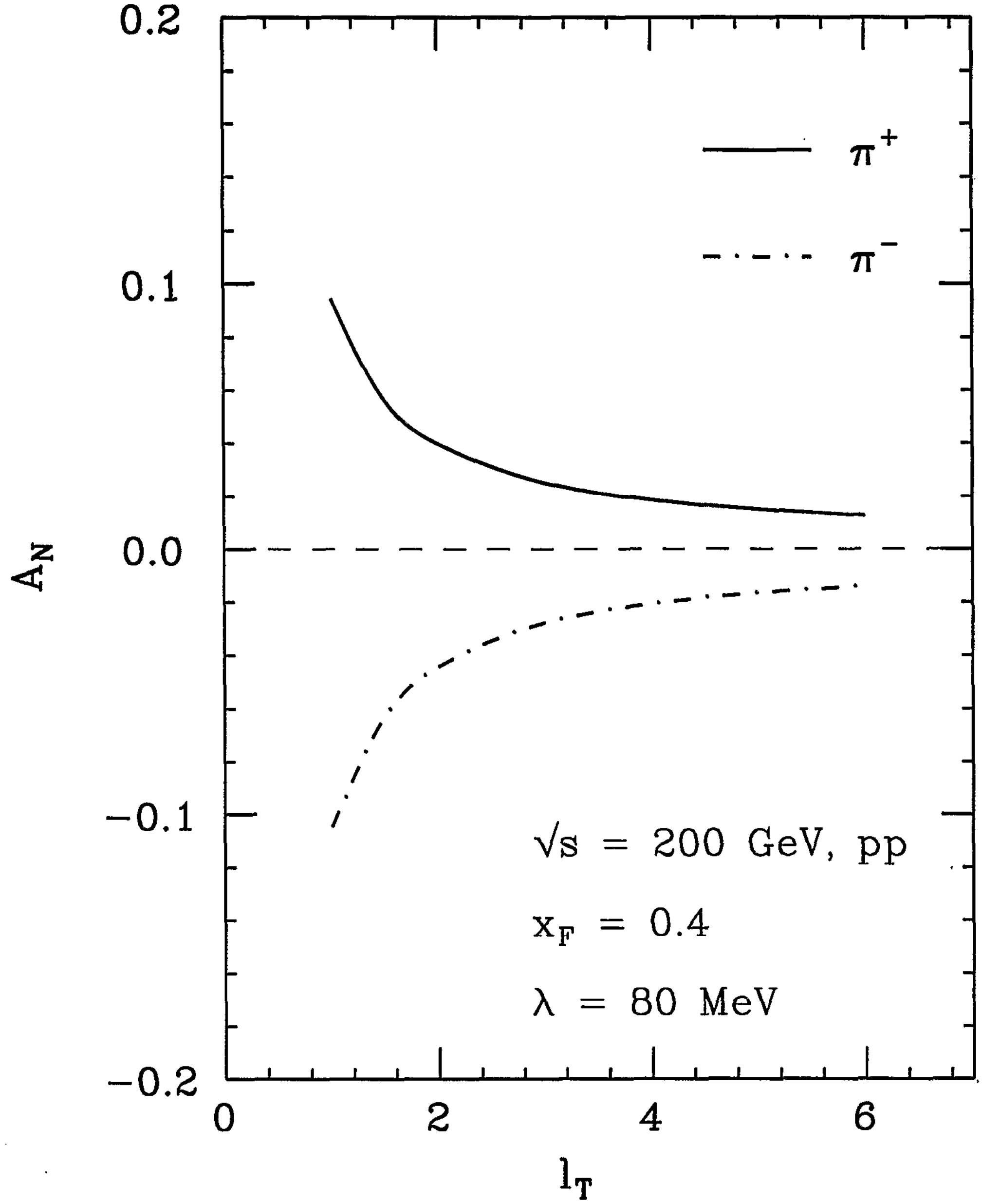
Theory curves fit data better if evaluated at a lower ℓ_T

COMPARE AN APPLE WITH AN ORANGE (III)



Fermilab data with ℓ_T up to 1.5 GeV

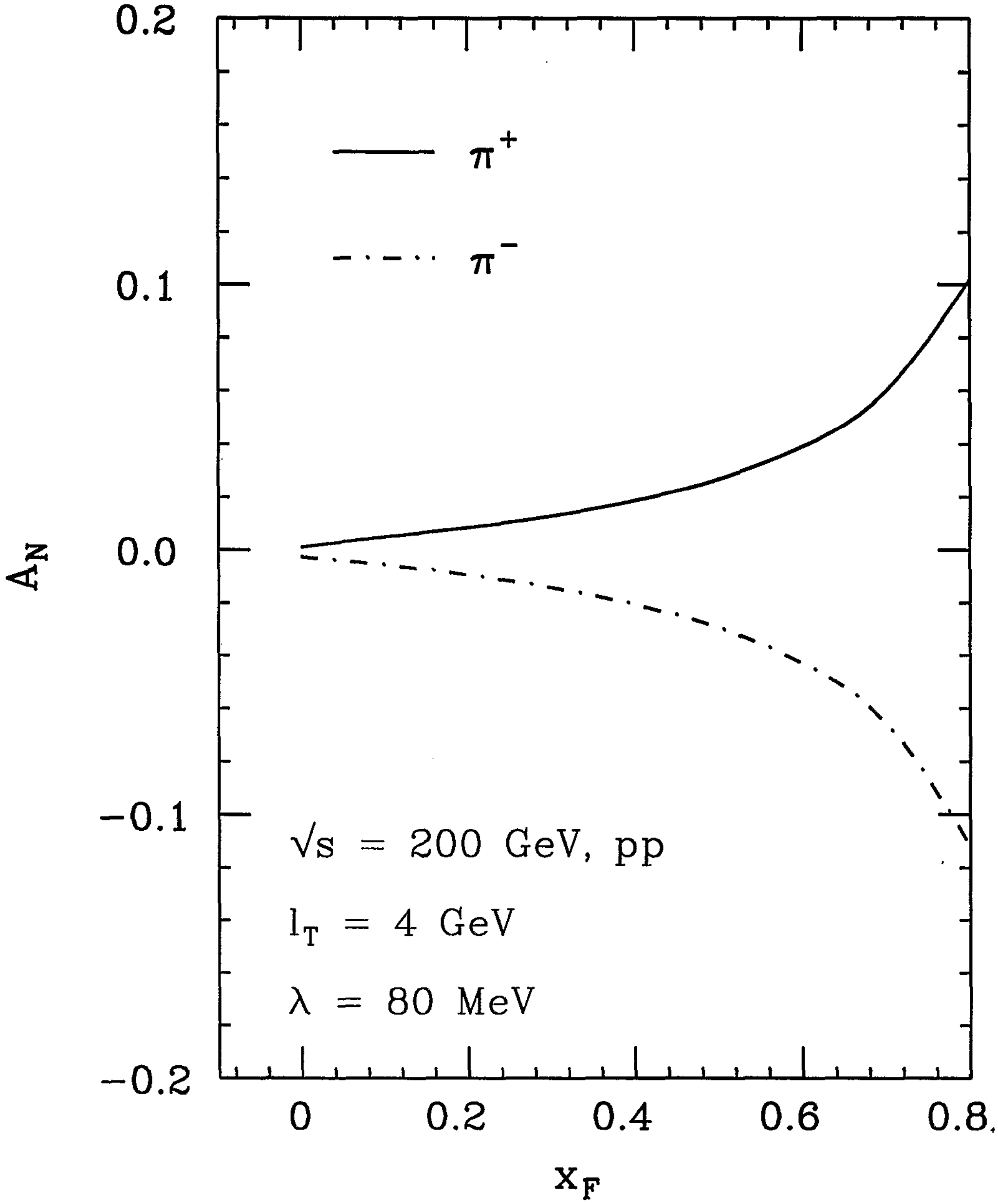
A_N AT RHIC ENERGY (I)



Derivative term only for partonic hard part

Non-drivative term are getting calculated by Kouvaris, Qiu, and Vogelsang

A_N AT RHIC ENERGY (II)



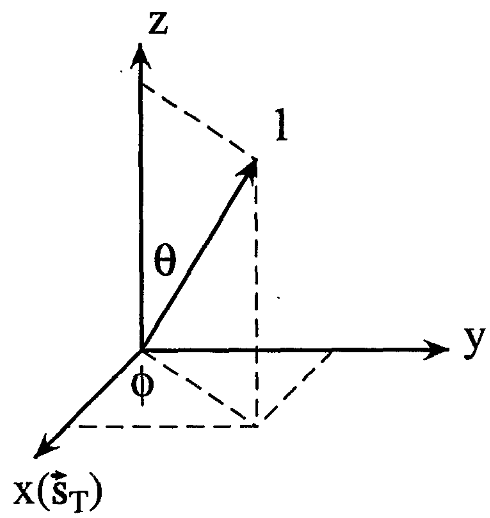
Derivative term only for partonic hard part

4. A_N FOR DRELL-YAN MASSIVE DILEPTON[a]

- Process:

$$A(p, \vec{s}) + B(p') \Rightarrow \gamma^*(Q)[\to \ell\bar{\ell}] + X$$

- Frame:



- Single transverse-spin asymmetry in $\frac{d\sigma}{dQ^2 d\Omega}$

$$A_N = \sqrt{4\pi\alpha_s}\left[\frac{\sin 2\theta \sin\phi}{1+\cos^2\theta}\right]\frac{1}{Q} \times \frac{\sum_q e_q^2 \int dx\, T_q(x,x)\, \bar{q}(Q^2/xS)}{\sum_q e_q^2 \int dx\, q(x)\, \bar{q}(Q^2/xS)}$$

- No derivative term at the tree level!

- In principle, there is no free parameter!

- A_N is very small and is estimated to be 2-4%

---

[a] D. Boer and J.Q., Phys. Rev. D65 (2002) 034008, and references therein.

5. Summary and Outlook

- Single transverse-spin asymmetry is a unique tool to explore nonperturbative physics beyond parton distributions

- QCD factorization approach allows to quantify the size of high order corrections, because of infrared safe partonic hard parts

- QCD factorization approach provides a systematic way to calculate the asymmetries in different processes

- Single transverse spin asymmetry in single hadron production is an excellent observable to test the QCD factorization

- Data on the asymmetries provide nonperturbative information on quark-gluon correlation

- Theoretical calculation with derivative term only are consistent with Fermilab data

- A full leading order calculation will soon be available.

- Drell-Yan single transverse-spin asymmetry is a clean probe. But, the asymmetry is small

Energy Dependence of the Analyzing Power for Proton-Carbon Scattering

A procedure based on Regge pole phenomenology is developed to determine the energy dependence of the analyzing power in pC elastic scattering in the CNI region. The model contains the Pomeron and two lower lying, I=0, Regge poles corresponding to the f_2 and the ω. It is shown that the measurement of the polarization P at one energy plus the measurement of the shape of the CNI peak at two energies is sufficient to predict the analyzing power at all energies. It is further shown that if the spin-flip factors for the f_2 and the ω are equal , the energy dependence can be predicted based on measurements of P and the shape at only one energy. Such information is available from E950. Using the Spin 2000 data from E950 we determine the real and imaginary parts of the spin-flip factor for pL=21.7 GeV/c. From those and making the assumption just mentioned, we calculate the spin-flip factor for the Pomeron and for the lower lying Regge poles. With these the analyzing power at pL=100 and 250 GeV/c is predicted. This simple assumption can be tested using the data recently obtained at pL=100 GeV/c; if it fails that data can be used, without knowledge of P at pL=100 GeV/c, to determine the three Regge spin-flip factors and thereby obtain the prediction of the model for the energy dependence, free from this assumption. The robustness of the assumption is tested by using two different Regge fits to the non-flip data. Comparison with the pp data from FermiLab E704 shows that the I=1 spin-flip factors must be much larger than the I=0 spin-flip factors. Considerable attention is given to the correlated errors at each stage.

Larry Trueman

Energy Dependence of CNI Analyzing Power for proton – carbon scattering

$$P\, A_N(t) = \frac{N_\uparrow(t) - N_\downarrow(t)}{N_\uparrow(t) + N_\downarrow(t)}$$

small $|t| \lesssim 0.05\ \text{GeV}^2$

non-flip $\quad f_0(s,t) = g_0(s,t) + g_0^{em}(s,t)$

"nuclear" $\qquad g_0^{em} \sim \frac{\alpha}{t}$

helicity-flip $\quad f_5(s,t) = g_5(s,t) + g_5^{em}(s,t)$

$$g_5^{em} \simeq \frac{\alpha \kappa}{2m\sqrt{-t}}$$

$\kappa = 1.79$

$$A_N(t) \propto \text{Im}\left(f_0(s,t)\, f_5^*(s,t)\right)$$

"pure" CNI $\quad \text{Im}\left(g_0(s,t)\, g_5^{em}(s,t)\right) \propto \frac{\sigma_{tot}(s)\, e^{Bt/2}\, \kappa\alpha}{2m\sqrt{-t}}$

but

$\text{Im}\left(g_5^*(s,t)\, g_0^{em}(s,t)\right)$ has same shape

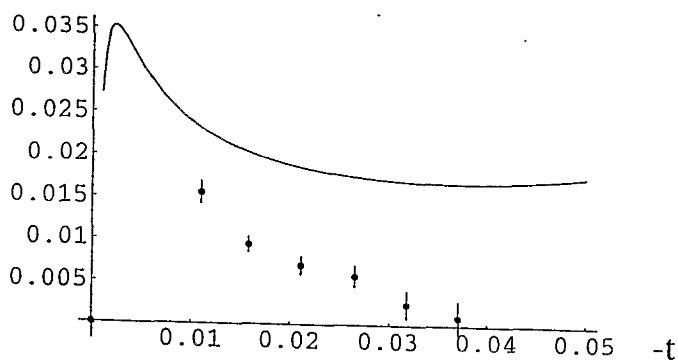
parametrize $\quad g_5(s,t) = \frac{\tau(s)\sqrt{-t}}{M}\, g_0(s,t)$

$$= r_5 \frac{\sqrt{-t}}{M}\, \text{Im}\, g_0(s,t)$$

$\text{Im}\, r_5 = \text{Re}\,\tau + \rho\, \text{Im}\,\tau, \quad \text{Re}\, r_5 = -\text{Im}\,\tau + \rho\, \text{Re}\,\tau$

Pure CNI (no hadronic spin-flip, $\tau = 0$) compared with Spin 2000 data.

A_N



To determine τ, fit ratios of measured asymmetry to pure CNI to

$$R(t) = \frac{A_N(t,\tau)}{A_N(t,0)} = \left(1 - \frac{2}{\kappa}\mathrm{Re}\,\tau(s)\right) + \frac{2}{\kappa}\mathrm{Im}\,\tau(s)\left(\frac{t}{t_c}\right)\frac{F^h(t)}{F^{em}(t)} + \text{small}$$

$$t_c = -\frac{8\alpha\pi}{\sigma_{tot}} = -0.00127\ GeV^2$$
for pC

If P is not known, can still determine shape parameter

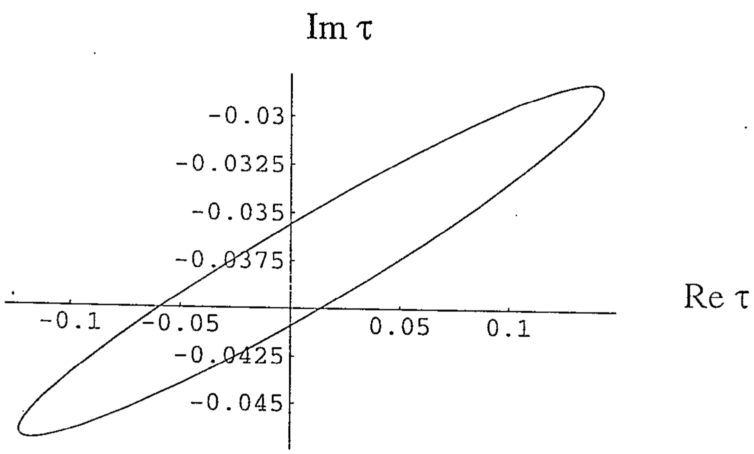
$$S(s) = \frac{\mathrm{Im}\,\tau(s)}{1 - \frac{2}{\kappa}\mathrm{Re}\,\tau(s)}$$

Kopeliovich & Trueman:

$$\tau_{pC} = \frac{1}{2}\left(\tau_{pp} + \tau_{pn}\right)$$

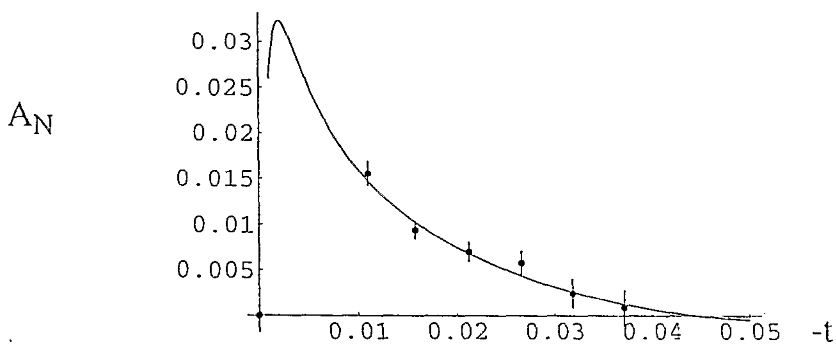
(non-flip nearly pure $I = 0$)

68.3% confidence level ellipse for fit to Spin 2000 data



Best fit to Spin 2000 data for A_N

τ=0,010-0,038 i



First try: Berger, Irving + Sorenson
Regge pole expectations (1978)

7 Regge poles: Pomeron + 6 exchange-deg. Regge poles: 4 at $\alpha = 1/2$
2 at $\alpha = -1/2$

for A_N

spin-dependence determined by "residues"

$$M^i_{\lambda_c \lambda_d; \lambda_a \lambda_b} \propto s^{\alpha_i(t)} \beta^i_{\lambda_a \lambda_c}(t) \beta^i_{\lambda_b \lambda_d}(t)$$

Compares to Argonne data at $p_L = 6, 12$ GeV/c

(Pomeron is assumed to be pole at J=1 so σ_{tot} is flat - not bad through pC fixed target range, but fails above)

(Comparisons are made for mainly above CNI region)

Use energy dependence of model to set

$$\tau_{pp}(21.7) = 0.045 + 0.061\,i$$

$$\tau_{pC}(21.7) = 0.037 + 0.034\,i \qquad \text{n.b. pos. imag. part}$$

far from measured value $0.010 - 0.038i$ at 21.7 GeV/c
(Consistent within large errors with E704
$.03 \pm .02i$)

Second try -

Plan -

Model: PP

$$g_0(s,t) = g_P(s) + g_f(s) + g_\omega(s)$$

$$g_P(s) = X \frac{(1+e^{-i\pi\alpha_P})}{\sin\pi\alpha_P} s^{\alpha_P - 1}$$

$$g_f(s) = Y \frac{(1+e^{-i\pi\alpha_f})}{\sin\pi\alpha_f} s^{\alpha_f - 1}$$

$$g_\omega(s) = Y' \frac{(1-e^{-i\pi\alpha_\omega})}{\sin\pi\alpha_\omega} s^{\alpha_\omega - 1}$$

fit by Cudell et al

$\alpha_P = 1.0933$
$\alpha_f = 0.64$
$\alpha_\omega = 0.44$ etc.

Assume

$$g_s(s,t) = \tau(s) \frac{\sqrt{-t}}{m} g_0(s,t)$$

$$= \frac{\sqrt{-t}}{m} \left\{ \tau_P\, g_P(s) + \tau_f\, g_f(s) + \tau_\omega\, g_\omega(s) \right\}$$

$\tau_P, \tau_f, \tau_\omega$ real constants

$$\tau_P = \frac{\beta^P_{+-}}{\beta^P_{++}} \quad \text{etc.}$$

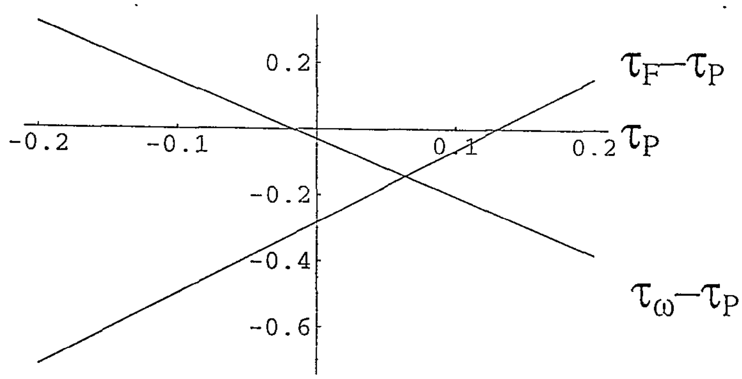
$$\tau(s) = \tau_p + (\tau_f - \tau_p)\frac{S_f(s)}{S_0(s)} + (\tau_\omega - \tau_p)\frac{S_\omega(s)}{S_0(s)}$$

Knowing P at s_0 (E950) determine Re and Im of $\tau(s)$ giving $(\tau_f - \tau_p)$ and $(\tau_\omega - \tau_p)$ as linear function of τ_p.

Then measure $S(s_1)$ without knowing P at s_1 and solve for τ_p.

Then A_N at all energies is known.

Solutions to equations generated by measurement of $\tau(s)$ at s=42 with known beam polarization



Speculative but reasonable assumption:

$$\tau_\omega = \tau_f \equiv \tau_R$$

allows determination of τ_p and τ_R from existing E950 data, and so AN at any energy can be calculated. Get

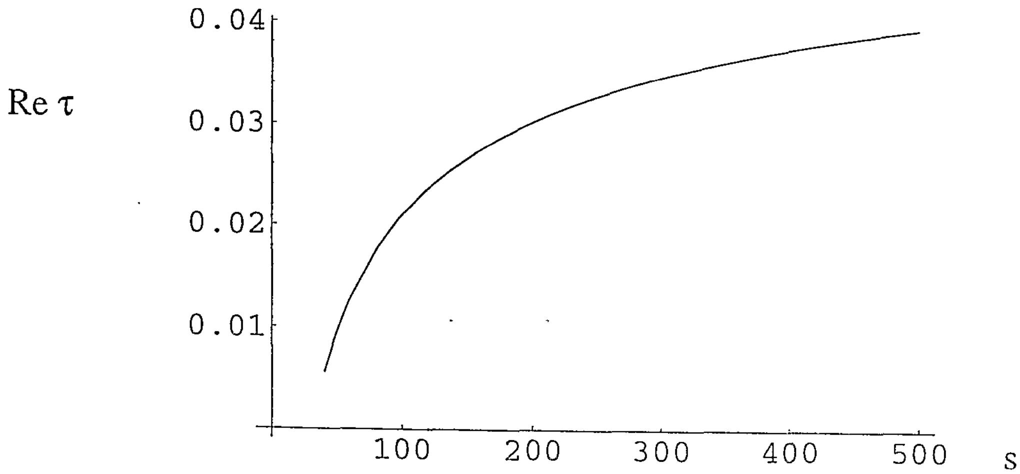
$$\tau_p = 0.064$$

$$\tau_R = -0.078$$

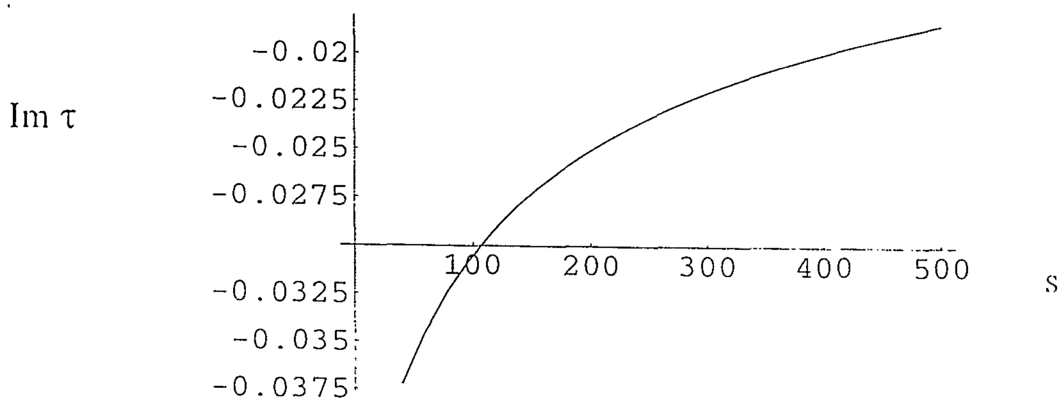
so $\quad Re\,\tau(s) \to 0.064 \quad$ as $\quad s \to \infty$

$\quad Im\,\tau(s) \to 0 \quad$ from below

Energy dependence of τ

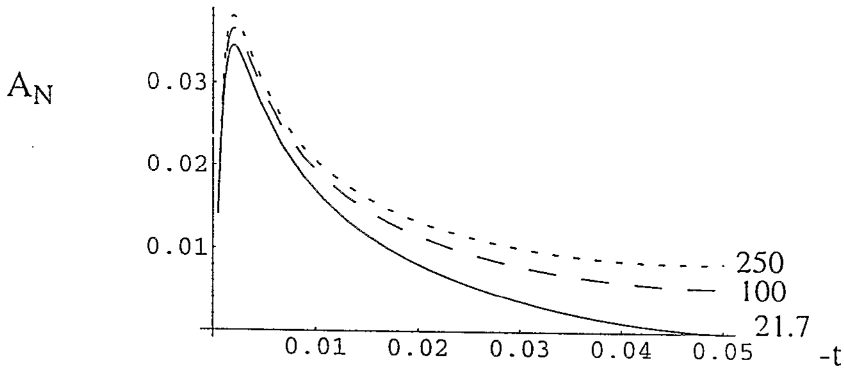


a.



b.

Analyzing power for pL=100, 250 GeV/c based on Regge model and fit at 21.7 GeV/c/



Stability & uniqueness ?

Block et al (1999) use different form for Pomeron.

$$f_0^{pp}(s) = i\left(A + B\left[\log\frac{s}{s_0} - i\frac{\pi}{2}\right]^2\right)$$

$$+ \; i C_+ s^{\mu - 1} e^{i\pi(1-\mu)/2} \qquad (f, A_2)$$

$$+ \; C_- s^{\alpha - 1} e^{i\pi(1-\alpha)/2} \qquad (\rho, \omega)$$

numerically Pomeron much more important relative to Regge than in Cudell et al

Both fits (σ_{tot} , ρ) equally good over our energy range.

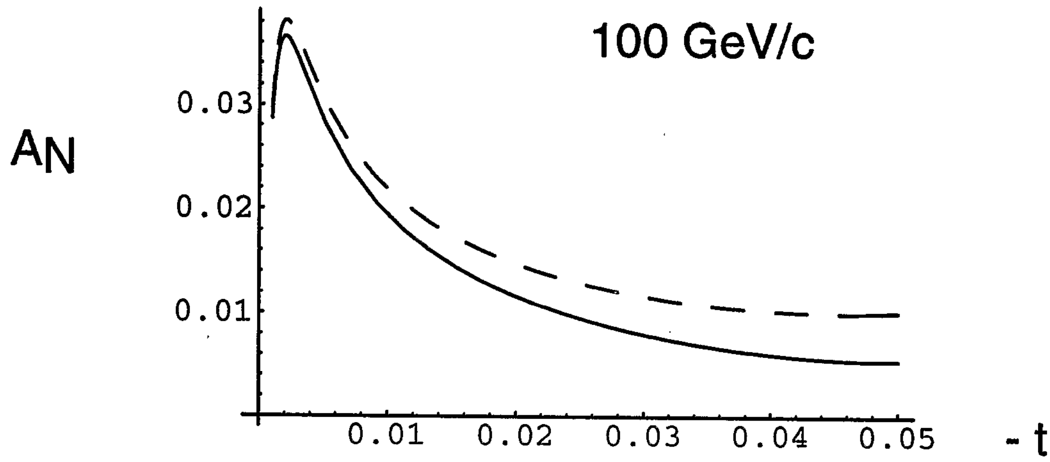
Results of same 2 pole game are somewhat different

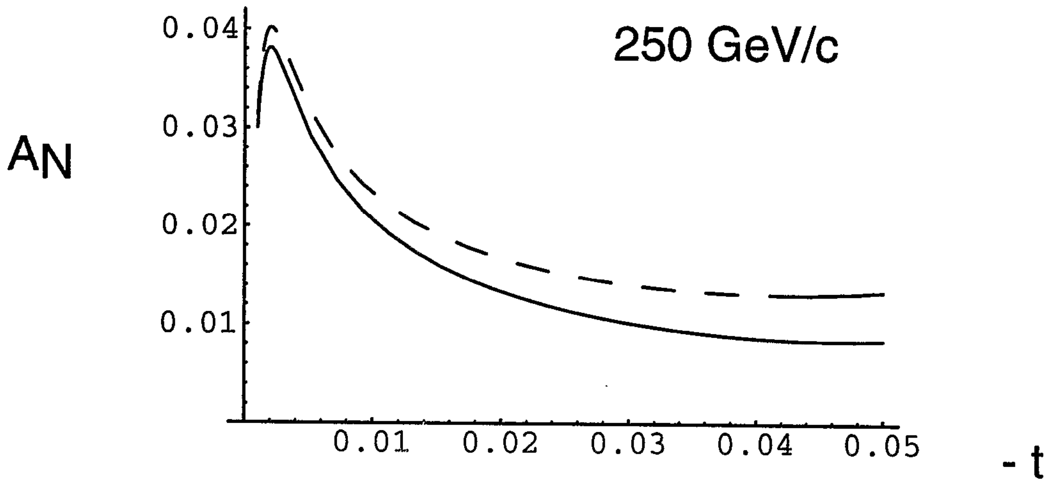
P_L	Block et al	Cudell et al
100	0.028 − 0.017 i	0.053 − 0.026 i
250	0.027 − 0.010 i	0.043 − 0.017 i

95% Confidence Level ellipses don't overlap

Difference about 5% near peak, nearly a factor of 2 for $t = -0.05$

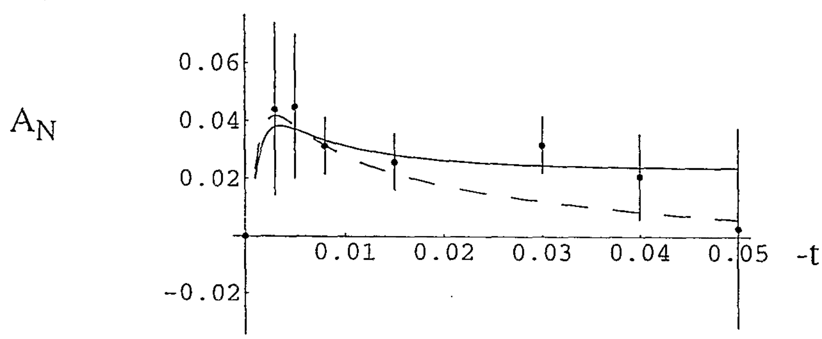
Comparison of projections for A_N to higher energy using non-flip inputs of Cudell et al and of Block et al



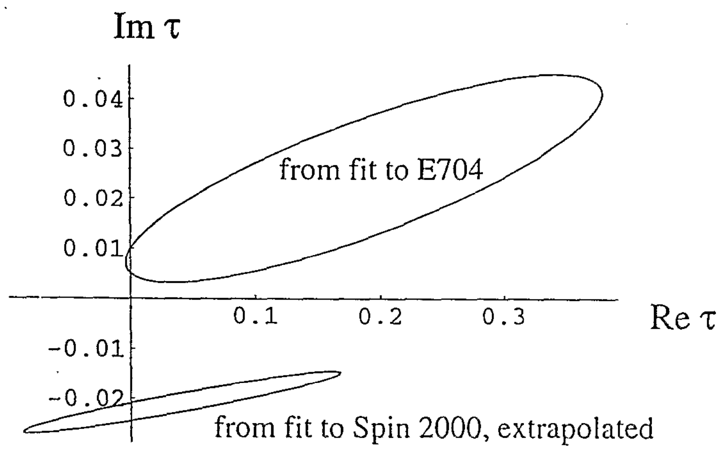


solid line uses Cudell et all as input
dashed line uses Block et al as input

A_N for pp at pL = 200 GeV/c with E704 low-t data. Solid curve is best fit with τ= 0.188 + .024 i; dashed curves uses the values obtained from fit to Spin 2000 pC data extrapolated to s=400, τ= 0.041 -0.02 i.



Comparison of the error ellipse (68.3% confidence level) obtained from fit to E704 data below |t|=0.05 with that obtained by using Regge model applied to Spin 2000 data. Strong indication of large I=1 contribution to proton-proton scattering.



RHIC Spin Collaboration Meeting VII

February 22, 2002

RIKEN BNL Research Center

LIST OF REGISTERED PARTICIPANTS

NAME	AFFILIATION AND ADDRESS	E-MAIL ADDRESS
Christine Aidala	BNL Physics, Bldg. 510C Upton, N.Y. 11973-5000	caidala@bnl.gov
Les Bland	BNL Physics, Bldg. 510A Upton, N.Y. 11973-5000	bland@bnl.gov
Stephen Bueltmann	BNL Physics, Bldg. 510A Upton, N.Y. 11973-5000	bueltmann@bnl.gov
Gerry Bunce	RBRC / BNL Physics, Bldg. 510A Upton, N.Y. 11973-5000	bunce@bnl.gov
Bill Christie	BNL Physics, Bldg. 510A Upton, N.Y. 11973-5000	christie@bnl.gov
Abhay L. Deshpande	RBRC Physics, Bldg. 510A Upton, N.Y. 11973-5000	abhay@bnl.gov
Wlodek Guryn	BNL Physics, Bldg. 510C Upton, N.Y. 11973-5000	guryn@bnl.gov
Takuma Horaguchi	Tokyo Institute of Technology Tokyo, Japan	horaguchi@nucl.phys.titech.ac.jp
Haixin Huang	BNL Bldg. 911B Upton, N.Y. 11973-5000	huanghai@bnl.gov
George Igo	BNL / UCLA Bldg. 902B ~ STAR Upton, N.Y. 11973-5000	igo@physics.ucla.edu
Osamu Jinnouchi	RBRC / RIKEN Physics, Bldg. 510A Upton, N.Y. 11973-5000	josamu@bnl.gov
Joanna Kiryluk	UCLA Physics & Astronomy 405 Hilgard Ave. Los Angeles, CA 90095-1547	joanna@physics.ucla.edu
Hideyuki Kobayashi	RBRC / RIKEN Physics, Bldg. 510A Upton, N.Y. 11973-5000	hyuki@bnl.gov
Waldo Mackay	BNL - CAD Bldg. 1005S Upton, N.Y. 11973-5000	mackay@bnl.gov
Yousef Makdisi	BNL Bldg. 911B Upton, N.Y. 11973-5000	makdisi@bnl.gov
Federica Messer	State University of New York Stony Brook, N.Y. 11794-3800	federica@bnl.gov or federica@skipper.physics.sunysb.edu
Kensuke Okada	RIKEN BNL Research Center Bldg. 510A – Physics Dept. Upton, N.Y. 11973-5000	okada@bnl.gov
Vitaly Okozokov	UEPHI, Moscow / BNL	okozokov@bnl.gov

RHIC Spin Collaboration Meeting VII
February 22, 2002
RIKEN BNL Research Center

LIST OF REGISTERED PARTICIPANTS

NAME	AFFILIATION AND ADDRESS	E-MAIL ADDRESS
Jianwei Qiu	Iowa State University Department of Physics Ames, IA 50011	jwqiu@bnl.gov or jwq@iastate.edu
Greg Rakness	Indiana University Cyclotron Facility 2401 Milo B Sampson Ln. Bloomington, IN 47408	rakness@iucf.indiana.edu
Thomas Roser	BNL Bldg. 911B Upton, N.Y. 11973-5000	roser@bnl.gov
Naohito Saito	RBRC / RIKEN Physics, Bldg. 510A Upton, N.Y. 11973-5000	saito@bnl.gov
Susumu Sato	JSPS	ssato@bnl.gov
Bernd Surrow	BNL Bldg. 510, Physics Dept. Upton, N.Y. 11973-5000	surrow@bnl.gov
Michael J. Tannenbaum	BNL Physics, Bldg. 510C Upton, N.Y. 11973-5000	mjt@bnl.gov
Larry Trueman	BNL Physics. Bldg. 510 Upton, N.Y. 11973-5000	trueman@bnl.gov
Werner Vogelsang	RBRC Physics, Bldg. 510A Upton, N.Y. 11973-5000	wvogelsang@bnl.gov
Jeff Wood	UCLA PO Box 516 Upton, N.Y. 11973-5000	wood@physics.ucla.edu

RIKEN BNL Research Center

RHIC Spin Collaboration Meeting VII

February 22, 2002

Small Seminar Room, Physics Dept., Brookhaven National Laboratory

*******AGENDA*******

Opening Session

09:00 - 09:10 Opening Comments.. N. Saito

09:10 - 09:50 The Strong Snake for the AGS................................ H. Huang

09:50 – 10:30 The Spin Rotators.. W. Mackay

10:30 – 11:00 Coffee Break

11:00 – 11:30 The CNI Polarimeter for the AGS........................... G. Bunce

11:30 – 12:00 Discussion of RHIC Spin Group Commentary for RHIC.. Retreat N. Saito

12:00 – 13:00 Lunch

Afternoon Session

13:00 - 14:00 Theoretical Presentation on A_N at RHIC.................. J. Qui

14:00 - 15:00 Analyzing Powers in the CNI Region........................ L. Trueman

15:00 Coffee Break & Discussion

Additional RIKEN BNL Research Center Proceedings:

Volume 39 – RHIC Spin Collaboration Meeting VII – BNL-
Volume 38 – RBRC Scientific Review Committee Meeting – BNL-52649
Volume 37 – RHIC Spin Collaboration Meeting VI (Part 2) – BNL-
Volume 36 – RHIC Spin Collaboration Meeting VI – BNL-52642
Volume 35 – RIKEN Winter School – Quarks, Hadrons and Nuclei – QCD Hard Processes and the Nucleon Spin – BNL-52643
Volume 34 – High Energy QCD: Beyond the Pomeron – BNL-52641
Volume 33 – Spin Physics at RHIC in Year-1 and Beyond – BNL-52635
Volume 32 – RHIC Spin Physics V – BNL-52628
Volume 31 – RHIC Spin Physics III & IV Polarized Partons at High Q^2 Region – BNL-52617
Volume 30 – RBRC Scientific Review Committee Meeting – BNL-52603
Volume 29 – Future Transversity Measurements – BNL-52612
Volume 28 – Equilibrium & Non-Equilibrium Aspects of Hot, Dense QCD – BNL-52613
Volume 27 – Predictions and Uncertainties for RHIC Spin Physics & Event Generator for RHIC Spin Physics III – Towards Precision Spin Physics at RHIC – BNL-52596
Volume 26 – Circum-Pan-Pacific RIKEN Symposium on High Energy Spin Physics – BNL-52588
Volume 25 – RHIC Spin – BNL-52581
Volume 24 – Physics Society of Japan Biannual Meeting Symposium on QCD Physics at RIKEN BNL Research Center – BNL-52578
Volume 23 – Coulomb and Pion-Asymmetry Polarimetry and Hadronic Spin Dependence at RHIC Energies – BNL-52589
Volume 22 – OSCAR II: Predictions for RHIC – BNL-52591
Volume 21 – RBRC Scientific Review Committee Meeting – BNL-52568
Volume 20 – Gauge-Invariant Variables in Gauge Theories – BNL-52590
Volume 19 – Numerical Algorithms at Non-Zero Chemical Potential – BNL-52573
Volume 18 – Event Generator for RHIC Spin Physics – BNL-52571
Volume 17 – Hard Parton Physics in High-Energy Nuclear Collisions – BNL-52574
Volume 16 – RIKEN Winter School - Structure of Hadrons - Introduction to QCD Hard Processes – BNL-52569
Volume 15 – QCD Phase Transitions – BNL-52561
Volume 14 – Quantum Fields In and Out of Equilibrium – BNL-52560
Volume 13 – Physics of the 1 Teraflop RIKEN-BNL-Columbia QCD Project First Anniversary Celebration – BNL-66299
Volume 12 – Quarkonium Production in Relativistic Nuclear Collisions – BNL-52559
Volume 11 – Event Generator for RHIC Spin Physics – BNL-66116
Volume 10 – Physics of Polarimetry at RHIC – BNL-65926

Additional RIKEN BNL Research Center Proceedings:

Volume 9 – High Density Matter in AGS, SPS and RHIC Collisions – BNL-65762

Volume 8 – Fermion Frontiers in Vector Lattice Gauge Theories – BNL-65634

Volume 7 – RHIC Spin Physics – BNL-65615

Volume 6 – Quarks and Gluons in the Nucleon – BNL-65234

Volume 5 – Color Superconductivity, Instantons and Parity (Non?)-Conservation at High Baryon Density – BNL-65105

Volume 4 – Inauguration Ceremony, September 22 and Non -Equilibrium Many Body Dynamics – BNL-64912

Volume 3 – Hadron Spin-Flip at RHIC Energies – BNL-64724

Volume 2 – Perturbative QCD as a Probe of Hadron Structure – BNL-64723

Volume 1 – Open Standards for Cascade Models for RHIC – BNL-64722

RIKEN BNL RESEARCH CENTER

RHIC Spin Collaboration Meeting VII

February 22, 2002

Li Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T.D. Lee

Speakers:

G. Bunce	H. Huang	W. Mackay	J. Qui
N. Saito	L. Trueman		

Organizer: Brendan Fox

For information please contact:

Ms. Pamela Esposito
RIKEN BNL Research Center
Building 510A
Brookhaven National Laboratory
Upton, NY 11973-5000 USA

Phone: (631) 344-3097
Fax: (631) 344-4067
E-Mail: pesposit@bnl.gov

Ms. Tammy Heinz
RIKEN BNL Research Center
Building 510A
Brookhaven National Laboratory
Upton, NY 11973-5000 USA

(631) 344-5864
(631) 344-2562
theinz@bnl.gov

Homepage: http://quark.phy.bnl.gov/www/riken.html
http://penguin.phy.bnl.gov/www/riken.html