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POLARIZED PROTONS AT RHIC

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ABSTRACT

The approval for construction of the Relativistic Heavy Ion Collider (RHIC) provides a potential opportunity to collide polarized proton beams at energies up to 500 GeV in the center of mass and high luminosities approaching 2 x $10^{32}/cm^2/sec$. This capability is enhanced by the fact that the AGS has already accelerated polarized protons and relies on the newly completed Accumulator/Booster for providing the required polarized proton intensity and a system of spin rotators (Siberian snakes) to retain the polarization.

The RHIC Spin Collaboration was formed and submitted a Letter of Intent to construct this polarized collider capability and utilize its physics opportunities. In this presentation, I will discuss the plans to upgrade the AGS, the proposed layout of the RHIC siberian snakes, and timetables.

The physics focus is the measurement of the spin dependent parton distributions with such accessible probes including high p(t) jets, direct photons, and Drell Yan. The attainable sensitivities and the progress that has been reached in defining the detector requirements will be outlined.

Introduction

The studies of spin effects in high energy physics have so far been constrained to relatively low center of mass energies and are primarily in the domain of fixed target experiments. As such these experiments have probed lower transverse momenta and could not effectively reach the hard scattering domain to provide a more complete picture and potentially additional tests of perturbative QCD.

The precursor for pursuing collider spin physics at RHIC was a successful workshop(1) on polarized colliders that was held at Penn State University in November 1990 which focussed on the physics issues that could be studied in next generation of colliders such as RHIC, LHC and the SSC. The physics payoff, specially in the area of understanding the spin structure of the proton, was seen as substantial and the relative ease of attaining polarized pp collisions at RHIC was enough of an impetus for a number of theorists, experimentalists, and machine physicists to form the RHIC SPIN COLLABORATION (2) with the intent of proposing a comprehensive spin program at RHIC.

Since then, a Letter of Intent(3) describing the collider spin program in addition to a proposal to construct and install a partially excited snake in the AGS (4) were submitted to Brookhaven National Laboratory. The snake proposal (E880) received approval and the Letter of Intent was given a warm reception by the program advisory committee.

The Accelerator

The Brookhaven Relativistic Heavy Ion Collider received the U.S. DOE approval for construction. The funding profile assumes that the machine will be ready for physics by mid 1997. The search for quark gluon plasma and studies of quark matter at extreme temperatures and high nuclear densities represent the primary research goal for this facility. This accelerator is designed (5) to collide a wide range of ion species from protons to gold. The beam energies are variable with a maximal reach of 250 and 100 GeV/nucleon for proton and gold beams respectively. The capability of colliding different ion species is also available, Fig. 1.

The injector to RHIC comprises several different accelerators depending on which ion species are required. Heavy ions require a sequence consisting of the Tandem, Accumulator/Booster, and the AGS. However,the 200 MeV Linac replaces the Tandem as the low energy accelerator when protons are required. This latter injection sequence is the subject of this presentation. I shall now describe with some detail the steps that are required to inject and maintain polarized proton beams in RHIC. A schematic is shown in Fig. 2.

Polarized protons have been accelerated in the AGS to record energies of 22 GeV and intensities up to $2x10^{10}$ particles per pulse. The extracted polarization depended on the number and strength of the depolarizing resonances crossed (6).

The source provides polarized H- beams with 80-85% polarization measured at 200 MeV which is then injected into the accumulator/booster. This new accelerator has 1/4th the diameter of the AGS and is designed to accumulate 20 linac pulses before injecting them into one AGS bucket providing a comparable increase in polarized beam intensities which is well over the RHIC limit of $2x10^{11}$ particles per bunch set by intra beam scattering. We anticipate the same luminosities at RHIC whether we run with polarized or unpolarized protons.

This vertically polarized beam is injected and accelerated in the AGS. Two kinds of depolarizing effects come into play as the beam experiences horizontal magnetic fields along its path that precess the spin axis away from the vertical. A resonance condition is satisfied when the spin precession tune is equal to an integer ($G\gamma = n$, where G is the anomalous magnetic moment of the proton and γ is the Lorentz factor E/m). Such resonances occur at the rate of about two per GeV and their strength is proportional to the degree of magnet misalignment which results in horizontal fields where purely vertical guide fields were expected. Thus the label imperfection resonances.

The second form of resonances occurs when horizontal fields are experienced by the particles when moving at points away from the quadrupole centers. This frequency is modulated by that arising from the betatron motion and the resonance condition arises when $G\gamma = P +/- \nu_y$ (where ν_y is the betatron frequency for the AGS ν_y is 8.75 and P is the accelerator periodicity for the AGS P=12).

Imperfection resonance are avoided by a series of harmonic corrections using a large number of dipoles that are excited at the appropriate γ to compensate for any distortion. The intrinsic resonances are avoided a fast shift in the vertical tune using 12 ferrite quadrupoles that can reach maximum excitation in less than 2 micoseconds.

The process of resonance jumping is quite tedious and requires careful tuning and extreme control. The AGS beam passes through 39 such imperfection resonances and 6 intrinsic resonances before it reaches 22 GeV. Although small losses of polarization are expected at each resonance crossing, in practice the extracted beam polarization was closer to 40% in comparison to above 80% at injection.

An elegant solution to this is to insert a local spin rotator in the AGS. This will force an additional term in the spin tune equation

$$\mathrm{COS}(\pi\nu_s) = \mathrm{COS}(\pi G\gamma)\mathrm{COS}(\delta/2)$$

By choosing $\delta = 180$ degrees, ν_s can only take values of (n+1/2) the result of which is that the resonance conditions are never satisfied regardless of beam energy. This solution can be achieved either by a series of dipoles or a solenoid. For the AGS, both have their drawbacks; The dipoles require long straight sections and the beam excursions specially at low energies make the magnet sizes unmanageable. While there are no beam excursions with a solenoid, a 180 degree rotation requires high fields and exceedingly long solenoids.

Tom Roser (7) realized that a partially excited solenoid could provide yet another condition that increases the strength of imperfection resonance to a point that the spin flips by nearly 180 degrees every time a resonance is encountered.

Calculations show that using a 9 degree snake in the AGS, the beam will retain 99% of its polarization. This concept forms the basis of the "Partial Siberian Snake" proposal at the AGS (E 880) in which a 4.7 T-M solenoidal spin rotator will be built and installed in one 10 ft. straight section. If successful, the lengthy AGS tuning process will be significantly simplified.

The transfer line from the AGS into RHIC has a vertical drop in addition to the horizontal bend that is required for injection. This will precess the injected beam polarization away from vertical. Calculations (8) found that at an energy of 24.8 GeV the transfer line is spin transparent. This happens to be above the RHIC transition energy and as such it is consistent with design injection requirements.

Once the beam is in RHIC similar gymnastics are required to preserve the beam polarization as γ is increased to full energy. Special care was taken in the design of the RHIC lattice that it did not compromise the polarized proton capability. In particular the resonance strengths (9) were kept well below 1, assuring that only two siberian snakes in each ring will be required to preserve the beam polarization. While this represents a minimal configuration, some specific conditions have to be met; the snakes should be positioned 180 degrees apart and their action is to precess the spin around two orthogonal axes. Furthermore, the two snakes were designed in a split fashion each half of which is inserted in a straight section surrounding the respective interaction region thus eliminating the need for additional spin rotators at these crossings, Fig. 3. With such an arrangement, one experiment can run with longitudinal polarization while the rest will, by necessity, run with transverse spin. This concept is undergoing further design revisions and refinement.

The program for the spin collider at RHIC calls for a luminosity of 2×10^{32} cm^{-2} sec^{-1}. This is at least an order of magnitude above that in the RHIC design report. This luminousity requires that the β^* at the intersection regions be squeezed from 2m to 0.5m, and the number of particles per bunch be about 10^{11}. Both conditions are within reach. It should be noted that the RHIC design calls for 57 bunches spaced 220 nsec apart. Future improvements allow for doubling the number of bunches thus putting some stringent constraints on detector design. The expected diamond length has a sigma of 22 cm for zero-degree crossing. However, the crossing angle could be as high as 7 mr.

The Physics

This accelerator with its high luminousity potential and high center of mass energy provides the first chance to carry out a detailed spin physics program at high transverse momenta. The primary goal is to probe the spin structure functions of the proton using longitudinal and transverse spin configurations. The physics motivation has been dealt with in some detail elsewhere (10). This is a short description of representative probes, the underlying physics assumptions and the attainable sensitivities for an idealized detector.

The asymmetries that are measured in such experiments involve comparison of scattering cross sections when the proton spins are aligned in the same direction versus those resulting when the spins are opposite. Single spin asymmetries can be deduced from the above measurement simply by averaging over the spin alignment of one of the colliding beams.

Large spin effects have been observed at both high energies and moderate transverse momenta in both inclusive single particle production(11) and pp elastic scattering (12). There are no satisfactory theoretical explanations specially that such effects are not predicted by perturbative QCD. The data from the Yale/SLAC and more recently the SMC experiments (13) measured what appears to be an exceedingly low contribution from the valence quarks to the total spin of the proton. The experiments measured the asymmetries in inclusive scattering of polarized leptons from a polarized proton target. While these results seem to defy our intuitive understanding of the naive parton model, they generated considerable theoretical calculations that point to the need for further experimental data. specifically that which address the gluconic and antiquark contributions to the proton helicity.

In hadronic collisions , the observable represents a sum over all the cross sections of the partonic processes that contribute to the particular reaction. These summations include both the structure functions as well as the subprocess cross sections. When spins are included, then the expressions become summations over parton helicity structure functions, subprocess double helicity asymmetries, and the subprocess scattering cross sections. The subprocess helicity asymmetries have been calculated (14)as a function of x , they are surprisingly large and approaching unity in several cases. These are shown in Fig. 4.

Two probes could be used to access the gluon structure function of the proton; direct photon production and inclusive jet production. Direct photons can be produced either by the quark-gluon Compton scattering process or quark antiquark annihilation, however, with the choice of the proper kinematic region (pt <20 GeV/c) where the Compton process dominates, the reaction provides a clean measure of the gluon contributions. Figure 5, shows a calculation of the double spin asymmetry in direct photon production with two assumptions as to the potential gluon contribution to the proton helicity, one with a small standard contribution and the other being quite large as to make up for the apparent discrepancy from the SMC experiment. Also shown is the sensitivity that could be attained with one month of running at RHIC luminousity with an ideal detector covering rapidity of +/- 1 and 2 pi in azimuth.

The asymmetry in inclusive jet production is shown in Fig. 6. It should be noted that the cross sections are much higher due to the contributions of a larger number of QCD subprocesses. Again, different kinematic regions define the dominance of various subprocesses. Since gluon scattering dominates below 50 GeV/c, this reaction becomes another good probe for the gluon asymmetries. Similarly we show the expected sensitivity for one month of running with a similar detector coverage as indicated above.

The Drell Yan process could provide a clean probe of the antiquark contribution to the proton helicity. This requires a detector with good dilepton coverage. The cross sections are quite small and the production is inversely proportional to the cube of the dilepton mass. Thus for any appreciable event rates one is forced towards lower masses around 4 GeV. Strange particle production could also be utilized as an alternative probe to the sea quark or antiquark contributions. However, inclusive particle experiments are difficult in a collider environment.

Another interesting topic to cover is the transverse spin asymmetries. The parton contributions to the transverse spin structure functions may well be quite different from the helicity contributions. While most lower energy experiments have studied transverse spin asymmetries, their interpretation is still lacking.

There seems to be a revival in interest in this domain with significant progress in describing transverse spin effects in inclusive hard processes (15). The RHIC snakes are designed to allow spin rotation of both beams in order to provide access to this physics. Several probes could be used such as Drell-Yan and jet production. However, the expected subprocess asymmetries are expected to be lower than their helicity counterparts by about a factor 10 making the experiments more challenging. Another difference is the fact that only quarks contribute to transverse structure functions since gluons do not participate in such processes at the leading twist level.

The Detectors

The reactions described above can best be measured using a detector that has electromagnetic calorimetry with good spacial and energy resolutions to measure direct photon production up to 20 GeV/c in pt while at the same time rejecting possible pion and eta contamination. A hadronic calorimeter is also desired in order to make sure that the direct photons were not part of a jet as well as to measure the jet that is produced opposite the photon in the Compton scattering process.

Of course, the same calorimeter would form the mainstay for inclusive jet production. As the jets are expected to spread out spacially, some minimum coverage in rapidity and azimuth is required.

Single particle production as well as possible experiments with W+/W- which I did not mention would require tracking in a magnetic field. Thus detectors similar to UA2 at the SPPS and R807 at the ISR could be ideal for pursuing this physics.

However, as reality and fiscal constraints dictate, it is anticipated that the RSC would first utilize the potential detectors that are currently proposed for the heavy ions physics program. Towards this end, the RSC is running different Monte Carlo programs with the specific detector geometries in order to assess their usefulness from the spin program point of view and also to determine what possible upgrades could be added to enhance their capabilities.

I shall describe briefly the proposed baseline detectors and list some of their properties for doing spin physics at day one:

STAR, is a tracking detector that employs a large TPC in a 0.5 Tesla solenoidal magnetic field, this in addition to a silicon vertex detector and a crude scintillator barrel for triggering represents the base detector. The acceptance is +/-1 in pseudorapidity and 2pi in azimuth. An upgrade would include a lead scintillator electromagnetic calorimeter with fiber optics readout. Its tower geometry construction would use 8 x 8 cm^2 pixels at a distance of 2.5 meters from the interaction diamond with an energy resolution of $\frac{20\%}{\sqrt{E}}$. A shower max detector with 1x24 cm2 strips would be added in one dimension to provide the needed spacial resolution. A time of flight system with 100 psec resolution would be added and external TPC's would complete the 4pi tracking coverage. No hadron calorimeter is contemplated and jets would be measured using both tracking and the electromagnetic calorimeter. Figure 7 shows the detector in its final configuration.

PHENIX, is a detector that focuses on leptons and photon measurements. It comprises high resolution (better than $\frac{10\%}{\sqrt{E}}$) and high segmentation (5x% cm^2 pixels at 5 meters) electromagnetic calorimetry in addition to several tracking detectors imbedded in an open axial field geometry as well as a silicon vertex detector. One endcap will be instrumented with a magnetic dimuon spectrometer. The detector emphasizes electron pion rejection to levels approaching 10^{-4}. The baseline detector has limited acceptance in both eta (+/-.35) and is configured as two pi/2 sections nearly back to back in azimuth. The detector is shown schematically in Fig. 8. The potential upgrades include increasing the pseudorapidity coverage to the +/-.5 which is limited by the magnet yoke, complete the azimuthal coverage to 2 pi, add muon capability around the barrel and a second muon end cap. This detector in its baseline configuration could do inclusive direct photon production but would have a limited capability for detecting the opposite jet. Drell Yan in dielectron and dilepton modes are possible but the statistics would be relatively low.

A forward and Mid rapidity spectrometer has been proposed which could be well suited to carry out single particle asymmetry measurements. It could also possibly serve as a polarimeter.

Finally, a pp elastic and total cross section experiment is being pursued. This could be used as a polarimeter measuring the beam polarization by the coulomb -nuclear interference effect.

Conclusion

The RSC group feels that the spin physics program at RHIC provides a great opportunity for a better understanding of the parton content of the proton. The technical difficulties are not insurmountable, and the details of which are being studied in hopes of submitting a proposal by the latter part of fiscal year 1992. The partial snake experiment at the AGS will take data in FY 1993 and the hope is that RHIC will be ready for polarized proton physics soon after commissioning.

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Figure Captions

Figure 1 The design luminosity for various operating modes of the RHIC collider.

Figure 2 A proposed schematic of the RHIC accelerator complex for polarized protons.

Figure 3 A schematic layout of the split-siberian snake surrounding an intersection region.

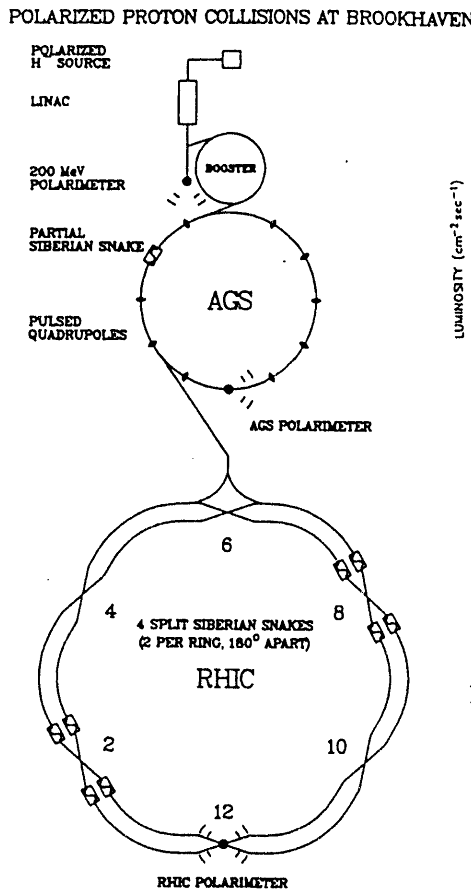
Figure 4 Longitudinal asymmetries in various partonic processes.

Figure 5 The predicted asymmetries in direct photon production versus p_t. The upper curve is for large gluon contribution and $\theta_{cm} = 45°$, the second is for a similar contribution and $\theta_{cm} = 90°$, and the lowest is for the standard gluon contribution. Indicated is the expected sensitivity for a one-month run.

Figure 6 Predicted A_{LL} vs. exclusive jet production as a function of p_t. The upper curve is for a large positive gluon contribution and the dashed curve for standard gluon contribution. Also shown is the attainable sensitivity.

Figure 7 The proposed STAR detector.

Figure 8 The proposed PHENIX detector.



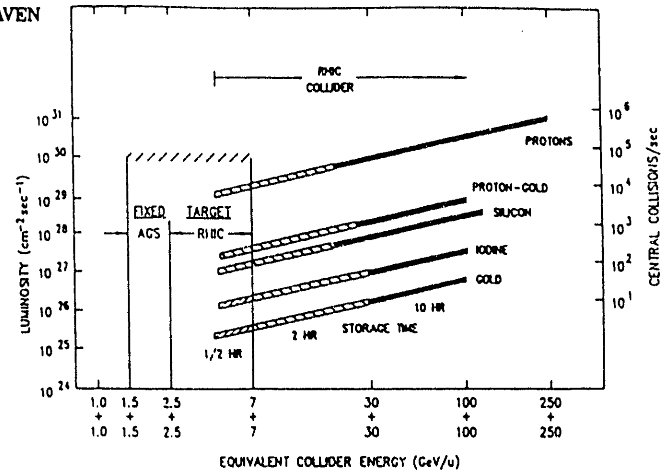


Fig. 1

Fig. 2

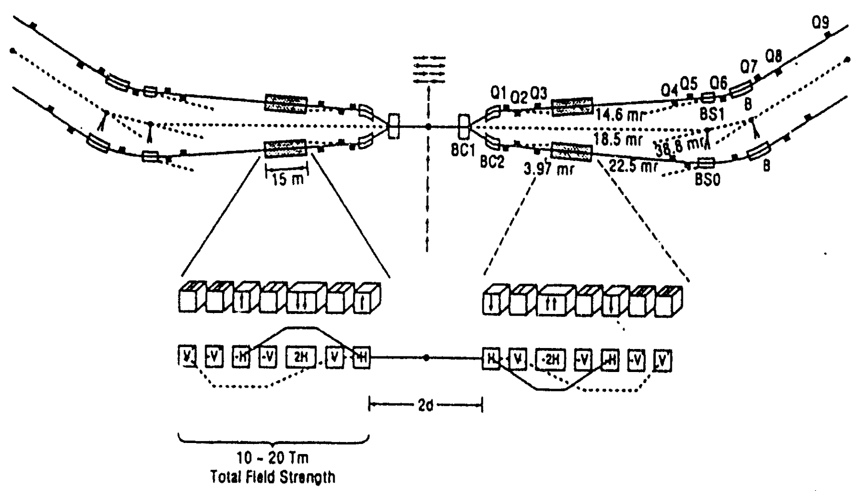


Fig. 3

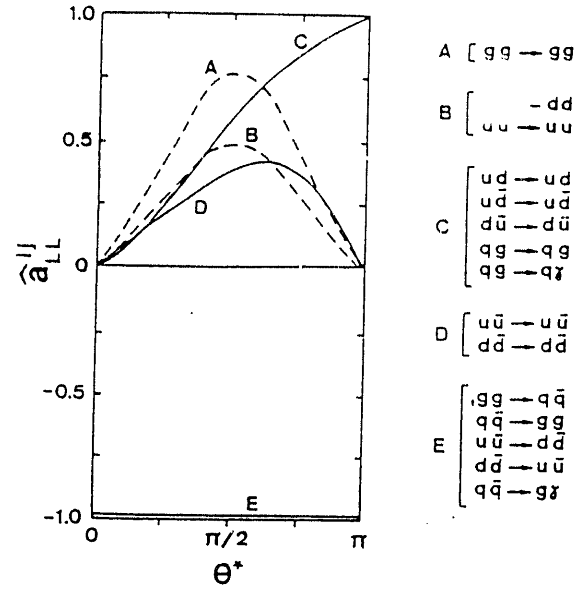


Fig. 4

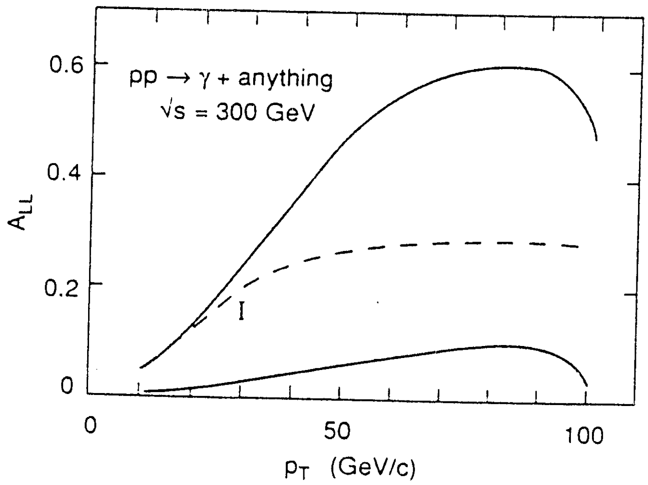


Fig. 5

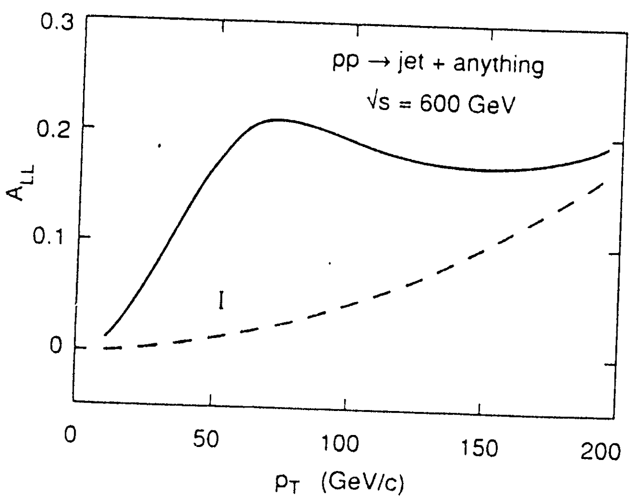
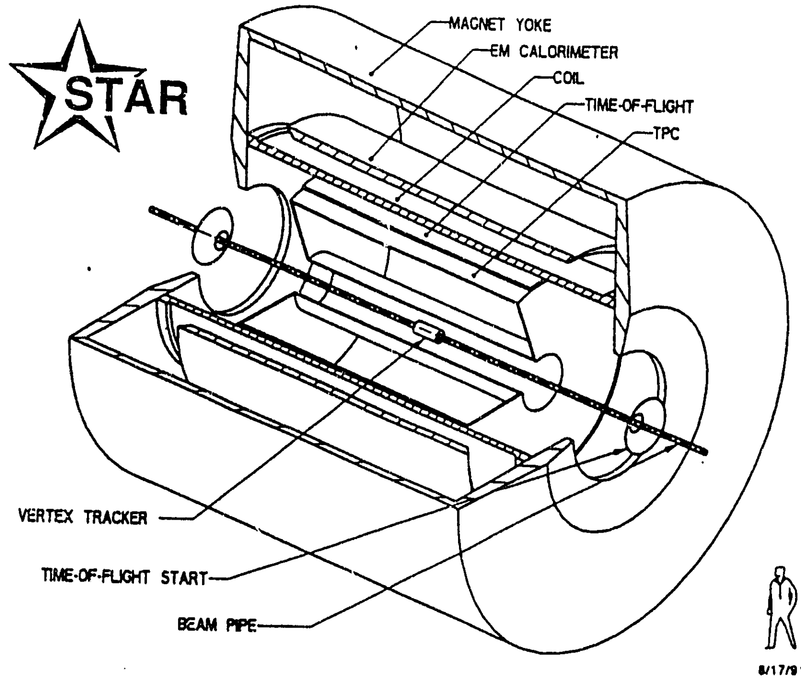


Fig. 6


STAR
MAGNET YOKE
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COIL
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TIME-OF-FLIGHT START
BEAM PIPE
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Fig. 7

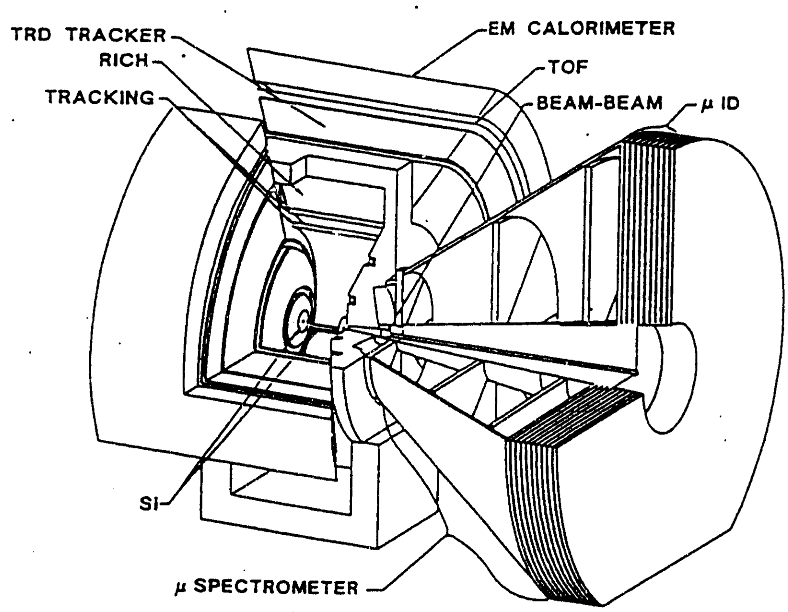
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Fig. 8

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