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Physics with Tagged Forward Protons with the STAR Detector at RHIC

Proposal to the STAR Collaboration

H. Spinka
Argonne National Laboratory, USA

R.E. Chrien, R. Gill, W. Guryn*, B. Hackenburg, J. Landgraf, T.A. Ljubičič, D. Lynn,
C. Pearson, P. Pile, S. Tepikian, K. Yip
Brookhaven National Laboratory, USA

A. A. Bogdanov, S.B. Nurushev, M.F Runtzo
Moscow Engineering Physics Institute (MEPHI), Moscow, Russia

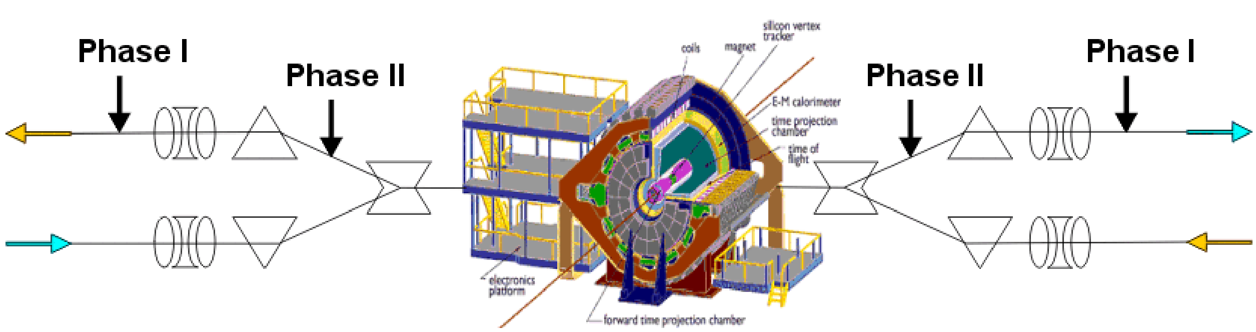
I. G. Alekseev, V. P. Kanavets, L. I. Koroleva, B. V. Morozov, D. N. Svirida
ITEP, Moscow, Russia

B. Surrow
MIT, Boston USA

S. Khodinov, M. Rijssenbeek
SUNY Stony Brook, USA

A.Sandacz
Soltan Institue for Nuclear Studies, Warsaw, Poland

*Contact person
E-mail guryn@bnl.gov
Phone (631) 344 3878



Executive Summary

We propose to extend the physics reach of the STAR detector at RHIC to include the measurement of very forward protons. Tagging on very forward protons, detected by the pp2pp Roman Pots, selects processes, in which the proton stays intact and the exchange has the quantum numbers of the vacuum, thus enhancing the probability of measuring reactions where colorless gluonic matter dominates the exchange. The processes include both elastic and inelastic diffraction.

In order to characterize the diffractive processes well, the measurement of the momentum of the forward proton is crucial. Because of the layout of STAR and its solenoidal magnetic field, RHIC accelerator magnets must be used for momentum analysis resulting in forward proton taggers installed either between the DX-D0 magnets or in the warm straight section between Q3 and Q4 magnets, see Fig. 1. Also, to extend the t and ξ ranges to the lowest values, a moveable detector system, approaching the beam as closely as possible, is needed. Hence the use of pp2pp Roman Pots (RPs) is advantageous not only because it is a working system but because it will also allow maximizing the t and ξ ranges.

We propose a scenario of executing the physics program in two phases, which optimizes the use of available resources and maximizes physics output. Phase I can be realized in a short time frame and requires only minimal resources because of the use of the existing and already debugged equipment of pp2pp experiment. To maximize the physics reach one must tag forward protons between the DX-D0 magnets. This would be achieved in Phase II, for which design work is needed.

Both elastic and inelastic diffraction can be studied with the Phase I setup, with the STAR detector and pp2pp RPs installed in the straight section between Q3 and Q4.

We would also like to note that the method described in this proposal has direct application to eRHIC where triggering on the forward protons is used to identify Deeply Virtual Compton Scattering (DVCS) process, which is an important part of the eRHIC physics program.

The first section briefly describes the physics motivation. The next section describes the experimental setup, and the third section summarizes the specific efforts needed to integrate the pp2pp RPs within the STAR trigger and readout. Some scheduling issues are also discussed. A table of the (direct) cost associated with the relocation of the pp2pp RPs is appended.

We are requesting a speedy review of this proposal in order to be able to be prepared for a possible physics run in fiscal year 2006.

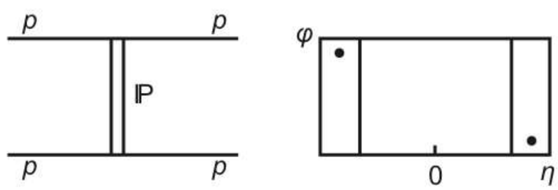
What we are proposing will naturally integrate with and extend the physics reach of activities of the UPC group and the hadron resonance group of STAR.

1 Physics motivation

In this chapter we shall briefly describe physics topics, which can be addressed very well using the Roman Pots of the pp2pp experiment [1,2,3] and the STAR detector. A more detailed description of the physics can be found in [4,5]. At RHIC the processes of interest in polarized proton-proton and proton nucleus collisions are [6]:

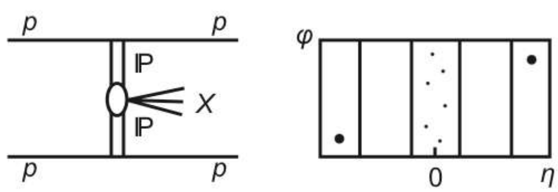
1. Elastic scattering $p^{\uparrow}p^{\uparrow} \rightarrow pp$;

Elastic Scattering



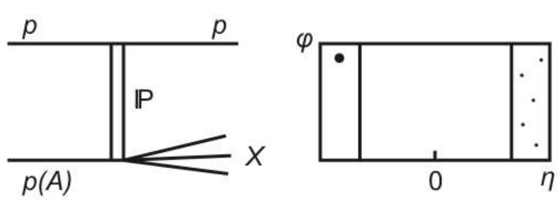
2. Central production through double Pomeron exchange (DPE) process $p^{\uparrow}p^{\uparrow} \rightarrow pM_Xp$;

Central Production



3. Single Diffraction Dissociation (SDD) $p^{\uparrow}p^{\uparrow} \rightarrow pX$ or $p^{\uparrow}A \rightarrow pX$.

Single Diffraction



The common feature of these reactions is that the proton undergoes quasi-elastic or elastic scattering and that they occur via the exchange of colorless objects with the quantum numbers of the vacuum, historically called Pomeron exchange. In terms of QCD, Pomeron exchange consists of the exchange of a color singlet combination of gluons. Hence, triggering on forward protons at high (RHIC) energies dominantly selects exchanges mediated by gluonic matter. In addition, the use of polarized proton beams, unique at RHIC, will allow exploring unknown spin dependence of diffraction.

The above processes are commonly characterized by using variables t, ξ and M_X, where t is four-momentum transfer between the incoming and outgoing protons, $\xi = \Delta p/p$ is the momentum fraction carried off by the Pomeron and M_X is invariant mass of the system produced. In case of double Pomeron exchange, separate t and ξ variables exist for each proton-Pomeron vertex.

Tagging and measuring forward protons also removes the ambiguity of a (complementary) rapidity gap tag, which has a background due to the low multiplicity of diffractive events, and allows the full characterization of the event in terms of t, ξ and M_X.

1.1 Single Diffraction Dissociation

The PHENIX collaboration observed that the production of forward neutrons, with near-beam momentum, is sensitive to the beam polarization. Single transverse spin asymmetries of the order of few percent were measured. It is interesting to see if the same can be observed with the forward protons, given the tag they provide on the Pomeron exchange at the proton vertex with the technique we are proposing. This measurement is an important addition to the "standard" SDD physics we will also measure.

1.2 Hard and Soft Diffraction

In the double Pomeron exchange process each proton "emits" a Pomeron and the two Pomerons interact producing a massive system M_X. The massive system could form resonances or consist of jet pairs. Because of the constraints provided by the double Pomeron interaction, glueballs, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes.

The production of high p_T jet pairs in hard central diffraction has been observed at other colliders: The CERN Sp $\bar{p}$S Collider, the Tevatron, and at HERA. At RHIC at $\sqrt{s}$=200GeV one may investigate the onset of hard diffraction both in single diffraction and in the double Pomeron exchange processes.

In the kinematical region, which we are proposing to cover, those processes allow exploration of the non-perturbative regime of QCD. The strength of the STAR detector: excellent charged particle identification in the central rapidity region and p_T resolution, coupled with ability to tag diffractive events with the forward protons with Roman pots, will allow measurements of single particle spectra as function of t and ξ of the outgoing proton. STAR has established that using the leading particle, with highest p_T, one can characterize jet like phenomena in hadron-hadron collisions.

1.3 Central Production of glueballs

The idea that the production of glueballs is enhanced in the central region in the process $pp \rightarrow pM_Xp$ was first proposed by [7] and was demonstrated experimentally [8]. The crucial argument here is that the pattern of resonances produced in central region, where both forward protons are tagged, depends on the vector difference of the transverse momentum of the final state protons

$\overline{k}_{T1}$, $\overline{k}_{T2}$, with $dP_T \equiv | \overline{k}_{T1} - \overline{k}_{T2} |$. The so-called dP_T filter argument is that when dP_T is large ($\geq \Lambda_{QCD}$) $\overline{q}q$ states are prominent and when dP_T is small the surviving resonances include glueball candidates [7,8].

In what we are proposing large data samples of diffractive states can be obtained and analyzed as function of diffractive mass and t ($d^2\sigma/dM_X{}^2dt$) for both single diffraction dissociation and for central production.

1.4 Collisions involving nuclei

Of interest is inclusive diffraction in p(d)A$\rightarrow$ pX and its dependence on A and beam polarization. This process includes spectator effects in deuteron Nucleus collisions dA$\rightarrow$pX. Due to spectator effects the p_T spectrum of the outgoing proton shows a clear diffractive pattern because of the absorption of the center of incoming wave, and has been calculated in [9].

One can also study the size of the rapidity gap in the same reaction, where the size of the "rapidity gap" reflects the different contributions of various Fock configurations of the proton that scatters through the color field of the nucleus [10].

2 Implementation Plan

We are proposing the execution of the above physics program in two phases. In both phases pp2pp Roman pots and STAR detector shall be used, Fig. 1.

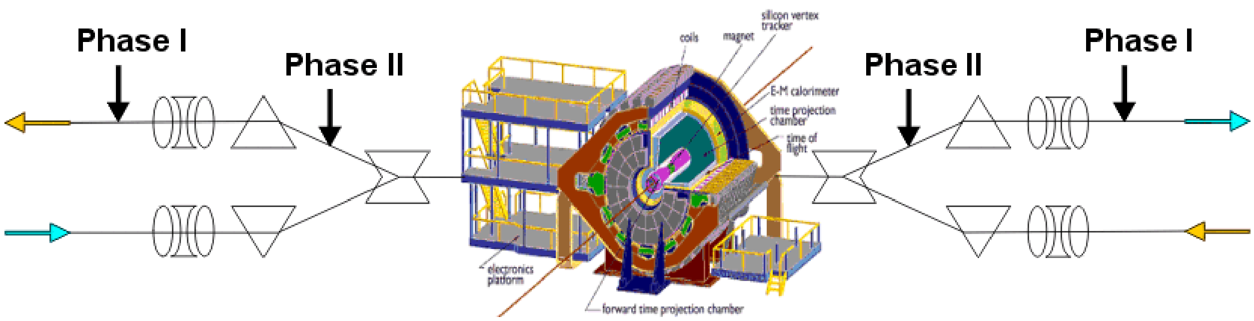


Fig. 1. The Roman pots of the pp2pp experiment in the STAR interaction region, with the arrows indicating proposed locations for Phase I and Phase II.

2.1 Phase I

The existing pp2pp experimental setup installed at IP6, at the location analogous to the current location at IP 2, will measure spin dependence of **both** elastic scattering in an unexplored t and √s range, with respect to what has been done already, and diffractive processes described above, for which our studies found that there is good acceptance.

2.1.1 Elastic scattering

By measuring spin related asymmetries one will be able to determine elastic scattering at the amplitude level [11,12]. The availability of longitudinal polarization at STAR in this first phase would allow measuring A_{LL} in addition to A_{NN}, A_{SS}, and A_N resulting in a significant improvement of our physics capabilities. Full azimuthal coverage for elastic events would be implemented in this phase.

One of the physics motivations to measure the A_N is possibility of the rise with energy of the spin-flip to spin-nonflip amplitudes ratio. In other words it may occur that small contribution from hadronic spin-flip to the spin single-spin asymmetry, measured with a polarized jet target at 100 GeV/c, could increase at $\sqrt{s}$=200 GeV. This will help to reveal long standing problem of the energy dependence of the spin flip amplitude, which is best answered experimentally.

Using the capacity of existing power supplies one can run with optics of $\beta^* = 20$ m at $\sqrt{s} = 200$ GeV. This optics would allow extending the t coverage to $0.003 < |t| < 0.03$ $(GeV/c)^2$. Fig. 3 shows the trajectory of a scattered proton of $\theta_x = \theta_y = 400$ μrad scattering angle and the 6σ beam profile. One can see a good separation between the scattered protons and the beam at the position of the detectors.

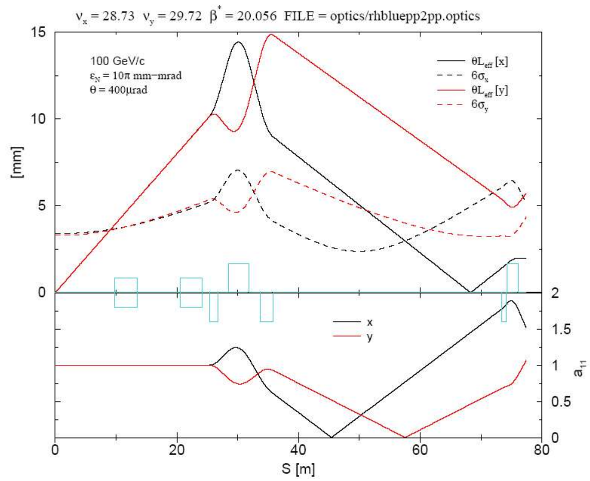


Fig. 3 Trajectory of a proton scattered at $\theta_x = \theta_y = 400\mu$rad.

Reaching such a small |t|-value allows measuring the single spin analyzing power A_N close to its maximum at |t| =0.0024 $(GeV/c)^2$, where A_{max} = 0.04, at $\sqrt{s}$ = 200 GeV. The A_N and its t-dependence in the covered range are sensitive to a possible contribution of the single spin-flip amplitude, ϕ_5, from the interference between the hadronic spin-flip amplitude with the electromagnetic non-flip amplitude.

An additional contribution of the hypothetical Odderon to the pp scattering amplitude can be probed by measuring the double spin-flip asymmetry, A_{NN} [13]. Their calculation shows that A_{NN} is sensitive to contributions of the real and imaginary parts to the double spin-flip amplitude, ϕ_2, in the range $0.003 < |t| < 0.010$ $(GeV/c)^2$. At a higher value of |t| the difference between pure Pomeron contribution and an equal mixture of Pomeron and Odderon at the five percent level are hard to distinguish, while a pure Odderon contribution would lead to a very small double spin-flip asymmetry.

Almost the entire energy range of this proposal has been inaccessible to proton-proton scattering in the past. A measurement of the total cross section, σ_{tot} at the highest possible energy will probe the prevalent assumption that the cross sections for pp and p $\bar{p}$ scattering are asymptotically identical.

The measurement of the differential pp cross section dσ/dt over the extended t-range will include the region at the lower |t| that is particularly sensitive to the ρ-parameter. This will allow extracting the ρ-parameter and the nuclear slope parameter b in a combined fit to the differential cross section possible and might also lead to an extraction of σ_{tot}.

An asymptotic difference between the differential and total cross sections for pp and p $\bar{p}$ could be explained by a contribution of the Odderon to the scattering amplitude. The absence of an Odderon contribution would lead to identical cross sections, approaching each other roughly as $s^{1/2}$.

For the amount of data discussed in the section 2.1.3, and assuming σ_{tot} = 51.5 mb, emittance ε= 12 $\pi \times 10^{-6}$ m, an estimated error on the slope parameter is Δb=0.31 $(GeV/c)^{-2}$ and on the ratio of real to imaginary part $\Delta\rho$=0.01, which is comparable to the existing measurements from the pp and p $\bar{p}$ data.

2.1.2 Diffractive processes

We studied the geometrical acceptance of our setup for both SDD and DPE processes. We have generated protons with t and ξ uniformly distributed in the regions 0.003< |t|< 0.04 and 0.005 < ξ < 0.05 respectively. We assumed that the Roman Pots are 10mm from the beam center, which is at least 12σ of the beam size at the detection point. Fig. 3 shows the acceptance for SD process, whose range is up to 45% for some t. The plot on the left in Fig. 4 shows generated M_X distribution at the interaction point (IP), whereas the plot on the right shows the M_X distribution for the proton pairs, which would hit two of the Roman pots (RP's) on each side of the IP.

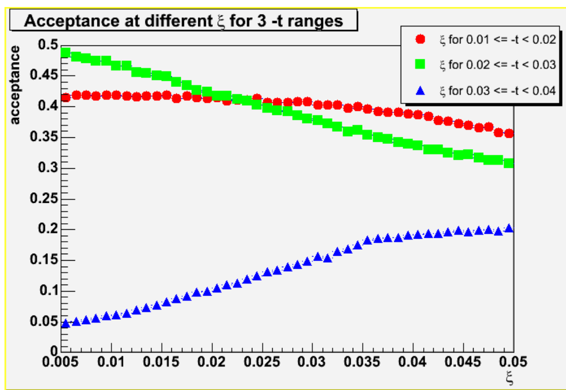


Fig. 3. Geometrical acceptance as function of ξ for different t bins for SDD process in Phase I.

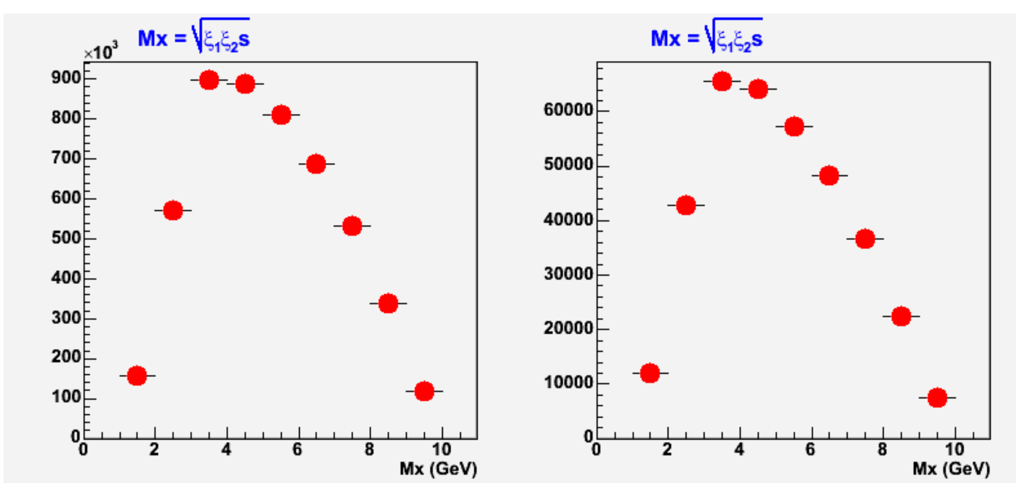


Fig. 4 Mass range DPE processes, left generated at the IP, right reconstructed from the protons arriving at the RPs as in Phase I.

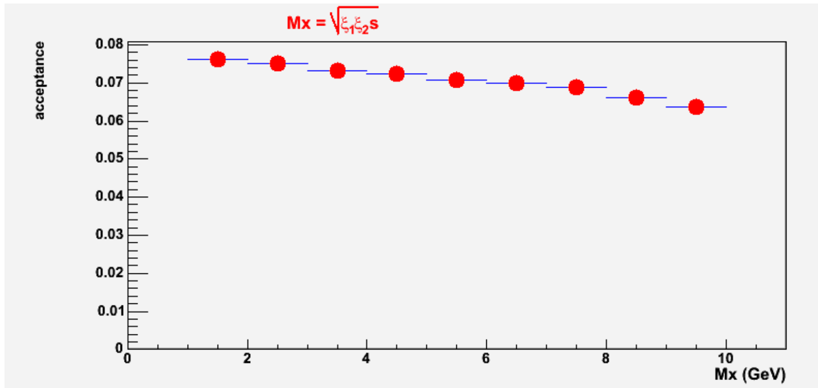


Fig. 5 Mass geometrical (only) acceptance for DPE processes in Phase I.

We conclude that our studies indicate that there is good acceptance to measure inelastic diffraction processes SDD and DPE with β^*=20m optics for Phase I. So while taking elastic data, a fraction of the trigger band-width could be dedicated to include events with two or one proton in the forward direction.

2.1.3 Running scenario

A possible running scenario, which we feel will maximize physics output in Phase I is to have a dedicated three-day run to take data. The main reason is that in order to reach the t and ξ values needed for both diffractive and elastic data, beam scraping and special optics are needed.

Based on our previous experience the commissioning of the trigger can be done using beam halo, with Roman pots outside of the beam pipe, while RHIC is running with standard optics.

The setup time of the β^*=20 m optics is estimated by the C-AD to be 12 hours. With 40 hrs data taking, luminosity $2 \cdot 10^{28}$ cm^{-2}sec^{-1}, useful interval with 100% acceptance for elastic scattering is $0.004 < |t| < 0.024$. Given polarization 50% and 2.3mb cross section within our acceptance we shall get $6.62 \cdot 10^6$ events. For four t subintervals we shall have $1.66 \cdot 10^6$ in each. The corresponding errors are $\delta A_n=0.0017$, $\delta A_{NN}=\delta A_{SS}=0.0053$. The four subintervals are also adequate for double-spin asymmetries. To estimate the A_{NN} error the ϕ intervals $-45° < \phi < 45°$ and $135° < \phi < 225°$ were used, and complementary intervals for A_{ss}.

2.2 Phase II

To maximize the acceptance and the range in t, ξ and M_X in this phase the Roman Pot system needs to be installed between DX-D0 magnets and will be used in conjunction with the STAR TPC to reconstruct and fully constrain events with resonance in central production process. A study needs to be done in the upcoming months to determine that range. The search for exotics is one of the topics of interest here, but not the only one.

The cost estimate for this step would have to be done since it requires modifications to the vacuum chamber in the DX-D0 region. By the time this part is implemented, the controls, the readout and the trigger will already be done and ready, since it comes after executing of the program in Phase I.

2.3 Integration of pp2pp with STAR

We shall move existing apparatus of the pp2pp experiment that includes its Roman Pots, controls and the DAQ from the 2 o'clock IP to the 6 o'clock IP. The cost estimate of the move was estimated by Charlie Pearson from C-AD and is shown in the attached table. There are two parts of the cost, which include 25 % contingency: 1) The C-AD labor, which we expect to be absorbed by the C-AD; 2) The materials cost and shop time is about $60k direct cost. The shop time might be supplied by one of the collaborating institutions. Some of the issues related to integration of the pp2pp apparatus into the STAR infrastructure are discussed below.

2.3.1 Data acquisition (DAQ)

The essential parts of the pp2pp DAQ system, both hardware and software, would remain unchanged and can be easily integrated into the STAR-DAQ framework. It is worth emphasizing that the current pp2pp DAQ was written by two STAR collaborators (TL, JL) as a detector extension to STAR. The pp2pp core DAQ system, Run Control, Data Monitoring & Online Q&A histograms are all exactly the same as in STAR-DAQ and as such can be easily integrated into STAR DAQ.

The "new" STAR-pp2pp DAQ would retain the possibility of running pp2pp in a contained standalone fashion, which would allow pp2pp to test and debug its equipment without interference with STAR. It would also allow pp2pp to take data decoupled from STAR in the same manner as it did while it was at IP2, if the need arises.

It should also be noted that the pp2pp data formats are the same as in the STAR online framework and all the necessary tools exist.

2.3.2 Trigger

The current pp2pp trigger is based on coincidences of a small number of (16) signals from scintillators, which can be adapted to the STAR CDB/DSM trigger scheme with only one pair of CDB/DSM STAR Trigger boards. Such a system is conceptually equivalent to many of STAR Trigger detectors (i.e. CTB, ZDC) and should not pose a problem. In case there is no ready trigger hardware available, it would most likely come from a set of five boards that need to be repaired.

Once this has been done an opportunity naturally presents itself to run pp2pp's Roman Pots together with STAR central rapidity (or any other) detectors to enhance the inelastic physics program. At the same time the elastic physics can be run in parallel with only the Roman Pots being read out at a higher rate, in the so called "fast detectors only" mode.

The analysis programs and data structures have been developed within the C/C++/ROOT framework, so the effort of integrating our data structures into STAR should be also minimal.

2.3.3 Schedule

Schedule and execution of both steps will depend on the start of the next RHIC run. The major issue is scheduling of the vacuum work at RHIC if the next run starts in November of 2005. The preliminary discussions with C-AD indicate that Phase I could be implemented if the next RHIC starts in January 2006.

Summary

In summary the physics program with tagged forward protons at STAR will:

1. Study elastic scattering and its spin dependence in unexplored t and $\sqrt{s}$ range;
2. Study the structure of color singlet exchange in the non-perturbative regime of QCD;
3. Search for diffractive production of light and massive systems in double Pomeron exchange process;
4. Search for new physics, including glueballs and Odderon.

Finally we stress that the studies we are proposing will add to our understanding of QCD in the non-perturbative regime where calculations are not easy and one has to be guided by measurements. In this way adding pp2pp Roman Pots will increase the physics reach of both STAR detector and RHIC.

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Table 1 Cost of move of pp2pp Roman Pots to STAR

					Labor Rates				
				$67.95	$58.11	$53.58	$67.05	$99.40	
	Materials		Total		Labor Hours				Total Labor Cost
Description	<$25000	>$25000	Mat'ls	Eng'r	Design	Tech	DTS	Shops	
Instrumentation/Controls									
Cable purchases	$19,310		$19,310						
Various parts	$9,484		$9,484						
Tech labor						600			$32,148
Electricians							48		$3,218
FES Support									
Rigging							96		$6,437
M-Group						120			$6,430
B-group						112			$6,001
Electricians							80		$5,364
Carpenter							24		$1,609
Survey						80			$4,286
2 new Stands	$3,000		$3,000			16		120	$12,785
Vacuum									
Materials	$3,000		$3,000						
Tech labor						1280			$68,582
design / documentation					40				$2,324
Total Direct Costs			**$34,794**						**$149,185**
Assumptions:	Engineering support not costed								
	Reuse sector 1 Roman Pot support stands					**Total Direct Cost w/25% contingency**			**$229,974**
	Motor control racks & cabling remain at BRAHMS, hodoscopes not costed								