R20 Response to PAC—Praveen Chaudhari

The PAC asked us to address two aspects of the proposal to build and demonstrate the feasibility of a small detector to search for magnetic monopoles, possibly produced by proton-proton (pp) and Gold-Gold (AuAu) collisions at RHIC. The first was in regard to the motivation (goal) of the experiment and, the second, to encourage us to begin to test feasibility of the detector in the forthcoming RHIC run.

MOTIVATION

Since the first accelerator based search for monopoles in 1959 [1], there have been more than two dozen searches, so far without success. It is therefore reasonable to ask: why another one? Does the new search, for example, result in a lower cross section or higher monopole mass limit?

The answer in our case [2], as we show below, is that if a full detector is built following the successful demonstration of the feasibility detector proposal presented to the PAC, we expect to establish the lowest cross section limit for monopole production using colliding beam experiments such as pp. More importantly from our perspective, we expect to demonstrate the functioning of a new detector that makes no assumption about the properties of a monopole other than its intrinsic character.

We plan to illustrate the importance of the second point by using the two most recent experimental results from FNAL [3, 4] and two other experiments [5, 6], on fixed targets, which have set the lowest limits on cross sections in monopole searches at accelerators.

In order to respond to the motivation concern of the PAC, we plan to cover the following:

1. Monopole production cross sections as a function of monopole mass by the Drell-Yan mechanism.
2. Theoretical estimates of monopole masses.
3. The cross section and mass limits achievable at RHIC and LHC.
4. Comparison of these cross sections with existing experimental data.
5. Discussions of three FNAL and one IHEP papers.

1. Monopole production: There is no field theoretical model for the production of monopoles. The most widely used model is the Drell-Yan mechanism, where the dilepton is replaced by a pair of oppositely charged monopoles. We have used the calculations of Gavin et al [7] for dilepton production, and multiplied their results by (ng/e)*2, where we have set n=1, g and e are the monopole and electric charges respectively, to obtain the cross sections for monopole productions. In order to extend the mass range to energies available at RHIC and LHC, we have used the formula developed by the MOEDAL [8] group on monopole searches. We have some confidence in the use of this formula for we have computed the cross section suitable for the FNAL experiment and found it to compare quite

well with the calculations of that group. We show the results in Fig.1 for pp, AuAu, and Lead-Lead (PbPb) collisions appropriate for RHIC and LHC energies.

2. Monopole masses: From an experimental perspective it is highly desirable to have a theoretical estimate of the mass of a monopole. Using the Drell-Yan mechanism of monopole production, we could then design an optimal experiment. Unfortunately, there is great latitude in the choice of a mass of a monopole. We list in Table 1, the mass or mass limits proposed in the literature. If we assume, for example that the mass limits proposed by the three virtual processes listed in the table are reliable, then once the feasibility of the detector is tested at RHIC the full detector should be built for the LHC, which can exceed these limits. In the absence of firm theoretical guidance we plan to keep the use of RHIC as an option.

3. Cross sections versus masses: The calculations for cross section limits for pp collisions for both RHIC and LHC are straightforward for we know the values of the projected integrated luminosities. Assuming a detector efficiency of 50 pct we obtain the cross sections shown in Fig. 2. (We emphasize that the feasibility detector we have proposed to the PAC has an acceptance efficiency of 0.5 pct.) Experiments with heavy ion collisions can result in much lower cross sections obtained from nucleon collisions because of the Z^4 term. We show the results of the calculations by Dr. A. Baltz [9] and, for masses below approximately 10GeV this is indeed what he finds for AuAu collisions at RHIC. We show this in Fig. 2. We have multiplied the integrated gold luminosity by 231, as per Dr. D. Kharzeev [10], to take into account the number of nucleons involved in a AuAu collision. In Fig.3 we have plotted LHC projected Drell-Yan cross section estimates and expected cross section limits at 95% confidence level for the pp and PbPb interactions.

4. Comparison with published experimental searches: We plot in Fig. 4 and Fig.5 the published cross section limits as a function of monopole mass [11]. These include the results from the four papers we plan to use in our discussions below. We have superimposed the projected cross sections achievable at RHIC and LHC, shown in Figs. 2 and 3 above. We note that at RHIC we could set the lowest cross section limits for monopole masses of up to 250 GeV obtained in direct search experiments by using proton beams.

5. Discussion of experiments: One could argue that the cross section limit will be the lowest for direct search experiments, which is a reason enough to do the experiment. We believe there is another, equally, if not more important, reason and that is the detector itself. We make a case for the second reason by discussing four experiments: three from FNAL [3, 4, 6] and one from IHEP [5]. Two of the FNAL experiments have been published within the last two years and the other along with the IHEP more than 30 years ago and hold the records for the lowest cross sections for fixed targets.

The two most recent experiments from the FNAL are designed with very different assumptions about the properties of monopoles and their interaction with matter. The first by Kalbfleisch et al [3] asserts that all monopoles produced in collisions at the intersection point are trapped in the metal tube, such as Al, surrounding it

and the experiment by CDF group [4] that the monopoles pass through the tubes and other intervening materials with sufficient velocities to excite a scintillator. Both sets of experiments have magnetic fields parallel to the beams and both assume values of the monopole charge to assure that they are not swept away from their detector area. The two older experiments assume that monopoles produced on Al, stainless steel, and iron targets, are trapped inside the targets. In the case of iron by its magnetic moment and in the case of Al it is assumed that the monopole diffuses through the Al solid and collects on the surface. It is assumed that with the application of a magnetic field the monopole is pulled away from the trapped site and accelerates before striking the scintillator. We note the assumptions made by these older experiments are very different from those of Kalbfleish et al [3] where the monopole is trapped by the nuclei and so strongly bound that it cannot be pulled away by the type of fields used in the older experiments.

It seems to us that a detector system [2] that shares a common vacuum with the collision point and therefore has no material in the path of a monopole obviates the need to assume the binding property of the monopole with matter. By having no magnetic field at the collision point we can also avoid assuming the magnitude of the charge of the monopole. Finally, by having a velocity independent detector we can detect magnetic monopole relying only on its most important characteristic, the magnetic charge. If we combine all of these requirements, the only practical detector we know of today is the one we are proposing: that of using a superconducting quantum interference device (SQUID) coupled to a sensing element such as superconducting gradiometer. While simple in concept, it is difficult to implement given the harsh accelerator environment. Hence the proposal to build a detector that demonstrates feasibility before embarking on a full detector.

EXPERIMENT

In concurrence with the PAC advice, we have been working the last six months on designing and placing a dewar with detectors adjacent to the intersection region at the former BRAHMS site. We have designed and built two third order gradiometers in coincidence geometry and a magnetometer coil. These have been tested successfully at 4.2K along with the SQUIDs. We have also incorporated a pseudopole to mimic a monopole signal. We have shielded the dewar with μ-metal shields to minimize stray magnetic and the earths field. We have also added a superconducting shield to avoid magnetic and RF noise. We are in particular concerned about the latter for we expect that when the detector and the collider share a common vacuum there will be a large RF signal emanating from the circulating and colliding beams. Although we are confident that the two Cu grids and the superconducting Nb grid we have included in the design will provide adequate shielding of the gradiometer, we plan to simulate the EM wave propagation and if necessary change the grid configuration before we consider embarking on a physical embodiment. The EM simulations have already started.

We hope we have addressed the concerns of the PAC. We are happy to provide any additional details. We hope to get conditional approval in case the RHIC delays prevent us from reaching conclusions from our tests in time for the PAC meeting. We would of course not proceed unless and until these tests are successful.

References

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Table 1. Magnetic monopole mass predictions in different theoretical models.

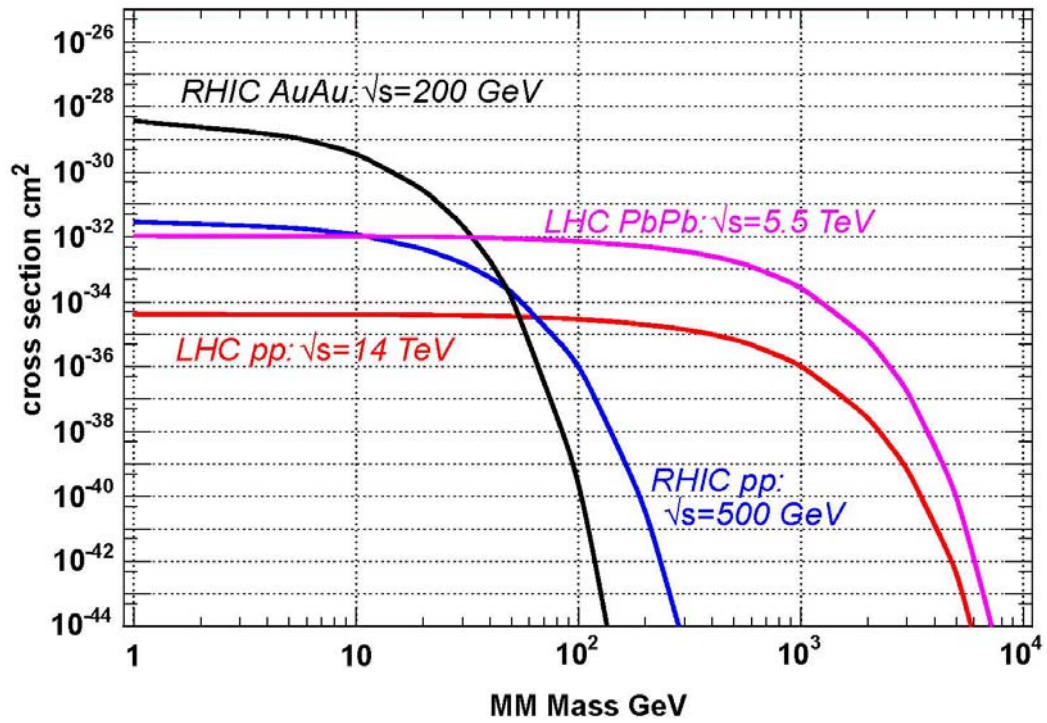| Process	Mass Limit, GeV
Electron radius	= 2.4 GeV
g-2	> 240
High Pt γ 's	> 610, s = 0
High Pt γ 's	> 870, s = ½
High Pt γ 's	> 1580, s=1
Z -> $\gamma\gamma\gamma$	> 400
Electroweak MM	~ 50 – 10^4
Superstring	~ 10^3
GUT	~ 10^{16} - 10^{17}

Figure 1. Drell-Yan cross section curves for RHIC at 500 GeV (pp), 200 GeV/nucleon (AuAu), and LHC 14 TeV (pp), 5.5 TeV/nucleon (PbPb).
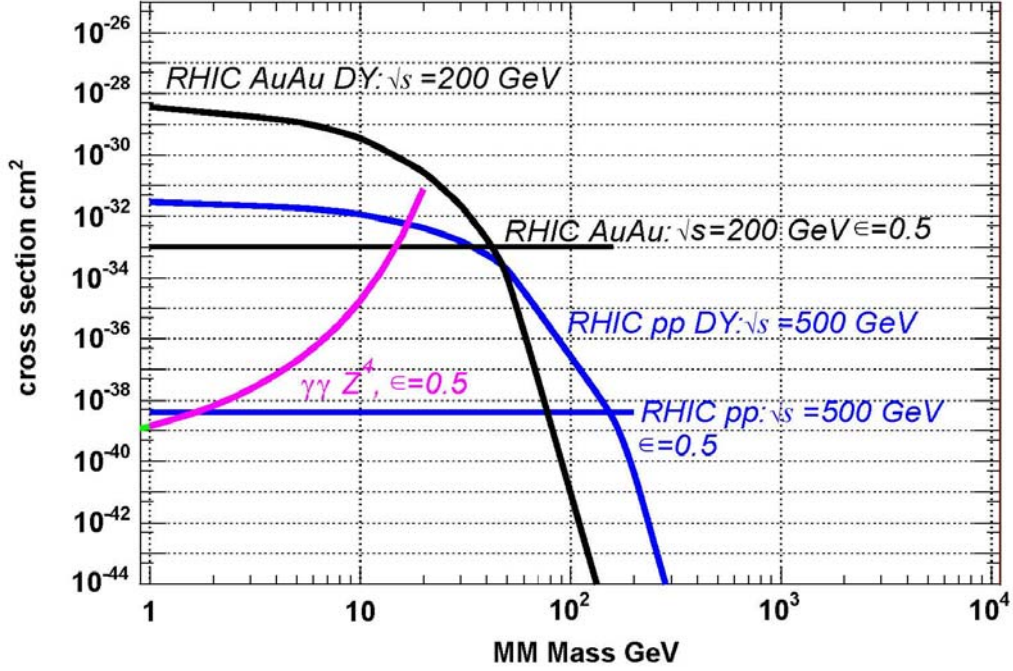
Figure 2. RHIC: DY cross sections (curves) and expected cross section limits at 95% CL level (horizontal lines) for pp, $\sqrt{s} = 500$ GeV (blue) and Gold-Gold, $\sqrt{s} = 200/n$ (black) interactions. The pink curve is for expected cross section limits calculated for $\gamma\gamma$ interactions (Z^4 enhancement) for Gold-Gold collisions.
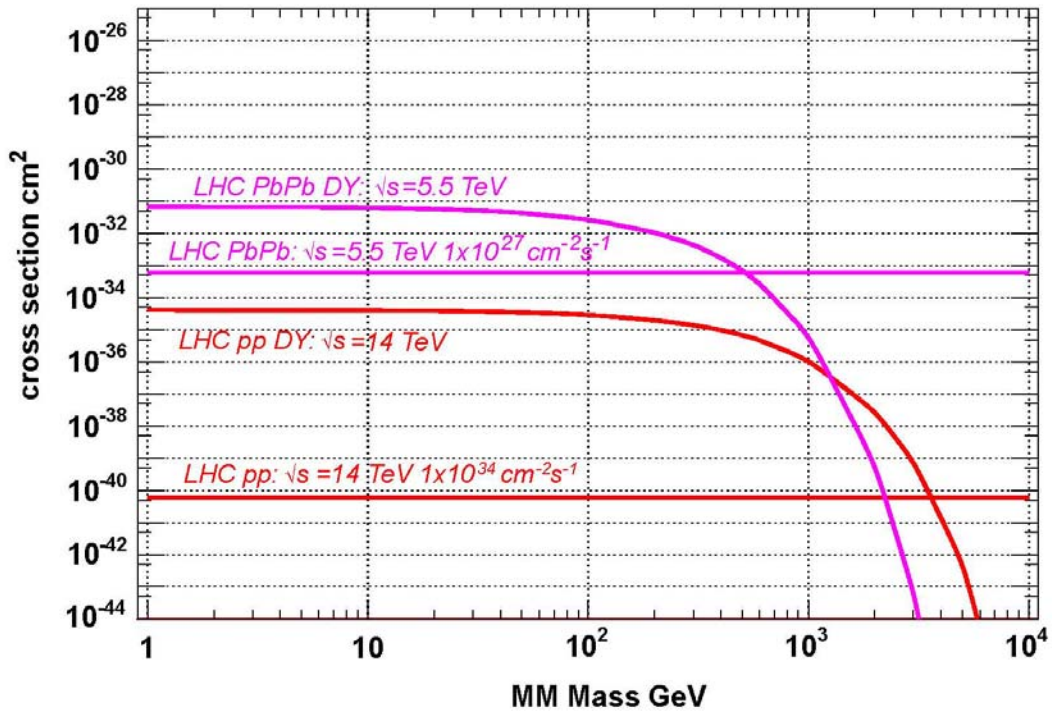
Figure 3. LHC: DY cross sections (curves) and expected cross section limits at
95% confidence level (horizontal lines) for pp, $\sqrt{s}$ = 14 TeV (red) and Lead-Lead,
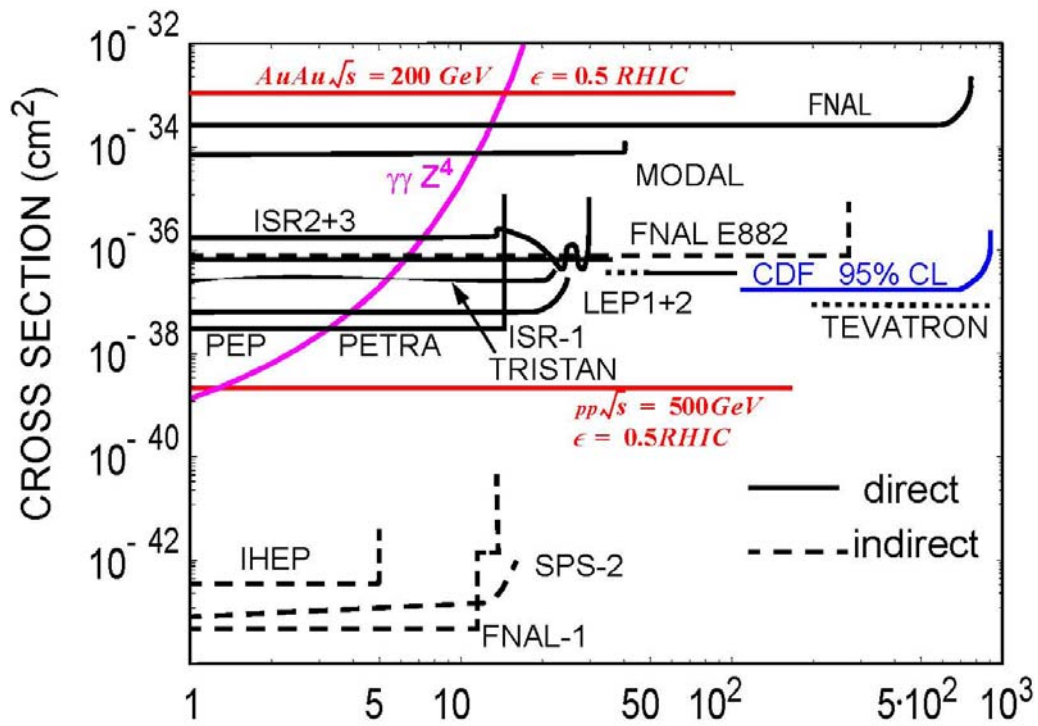$\sqrt{s}$ = 5.5/nucleon (pink) interactions.

Figure 4. Classical Dirac magnetic monopole cross section upper limits versus magnetic monopole mass obtained from direct accelerator searches (solid lines) and indirect searches (dashed lines) with RHIC projected cross sections.
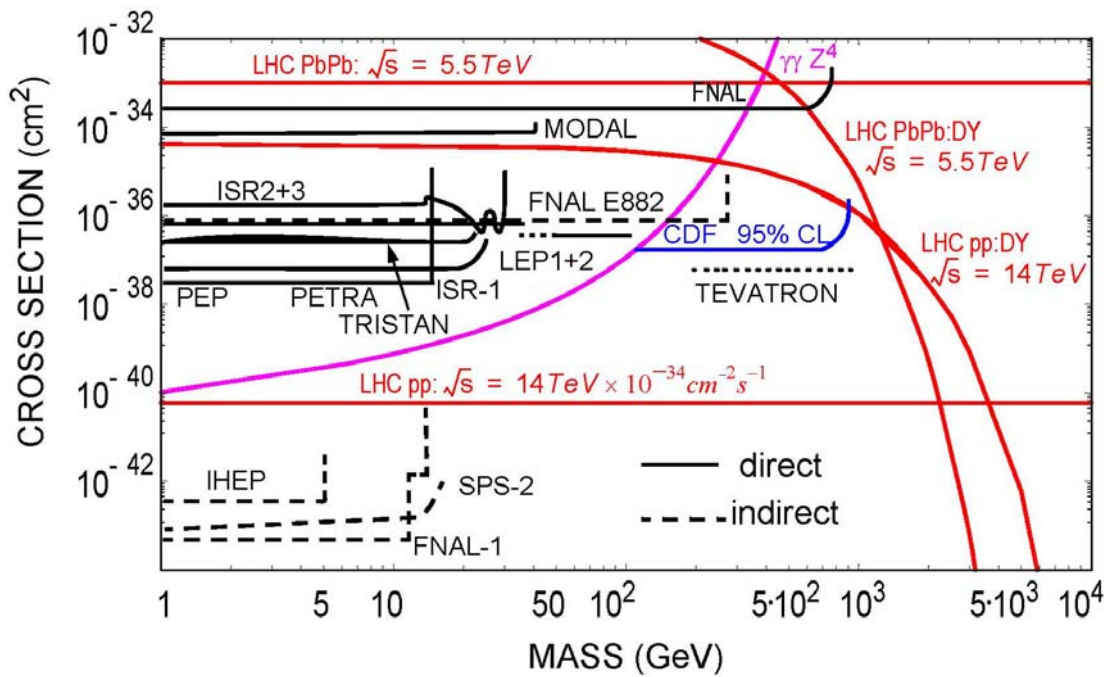
Figure 5. Classical Dirac magnetic monopole cross section upper limits versus magnetic monopole mass obtained from direct accelerator searches (solid lines) and indirect searches (dashed lines) with LHC projected cross sections.