This carefully prepared expert advice was ignored and the farce continued.

# Report for PAC32 on Proposal 170 by the SPIN@COSY Collaboration

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## Contents



## 1 Preamble

A full written dissection of this proposal would be of little interest to most members of the PAC. I will therefore limit myself to a few key or illustrative points. In order to get quickly to the point, I begin with a summary and recommendations. I then provide some information on the Froissart–Stora formalism which I use to justify my recommendations. I finish with a few opinions on material that I find in the proposal.

## 2 Summary and Recommendations

Among other things, this proposal requests beam time to follow up findings from earlier work at COSY. This work has led to the claim by the SPIN@COSY collaboration that measurements on proton and deuteron rf spin flip using an rf dipole are difficult to explain. In my opinion it is highly likely that this position of some members of the SPIN@COSY collaboration is due to their lack of interest in standard numerical techniques for understanding and analysing spin phenomena in storage rings. The proposal also implies a request for beam time to test the effect of an rf solenoid.

## 2.1 Recommendations

- A programme of spin–orbit tracking simulations of the effect of an rf dipole on spin–orbit motion should be undertaken as a matter of urgency with the aim of explaining all the measurements on protons and deuterons that SPIN@COSY has made at COSY so far. There is no excuse for not doing this.

- All measurements with rf dipoles should be suspended until the results of the simulations are available. Expenditure of resources at COSY should be justified by physics.

- Preparations for tests with the rf solenoid should continue and when the rf solenoid is ready, one week of beam time should be scheduled for initial tests.

- The preparations for the rf solenoid should include spin–orbit tracking simulations so that a rough idea of the results to be expected is available beforehand.

- Preliminary results from simulations should be made available at the next meeting of the PAC so that it can get a better understanding of the outcome of the previous investments of COSY resources.

- The spokesman for SPIN@COSY should circulate this document to all members of SPIN@COSY.

A demonstration, via simulations, that the spin flip measurements could be understood would be a service to the community and of much more value than repeated declarations that it's all very very mysterious followed by requests for more resources to make arbitrary further measurements.

In other words, the obvious organisational skills and enthusiasm of the SPIN@COSY collaboration, should be redirected along more fruitful directions.

# 3 Some matters of theory

The Froissart–Stora (FS) formula for the prediction of the level of polarisation to be expected after the crossing of a single spin–orbit resonance (SOR) is based on the so–called single resonance model (SRM) in which the spin motion is assumed to be dominated by a single nearby resonance. This simple approach was introduced in the 1960s in the days before powerful computers were available and it has the advantage that the predictions are encapsulated in a simple formula which contains two parameters. These are the so–called resonance strength and a parameter encoding the rate of SOR crossing. The FS picture was welcome in an age when full spin–orbit tracking simulations with computers were impractical.

Of course, since the FS picture is an approximation nobody expects it to give an perfect fit with real measurements. Nevertheless, the FS picture has been an important aid in the understanding of polarisation during acceleration at several rings. For example it has been useful for understanding how to maintain proton polarisation at the AGS when accelerating up to extraction energy before transfer to RHIC. It has also been useful in connection with the use of so-called partial snakes at the AGS. The FS picture is a standard part of the culture and it is a very useful pedagogical aid.

However, the limitations of naive use should be recognised. Thus the SRM and FS pictures are only appropriate when SOR are sufficiently separated ( e.g., the width of a resonance should be much smaller than the separation). Furthermore, special care is needed when the FS picture is used to describe the effect of an externally applied rf field. In mathematical terms, this amounts to introducing an inhomogeneous term into the equations of spin and orbital motion. In the presence of an rf field there are two contributions to the spin motion. Specifically, there is the primary (P) effect of the rf fields on the spins as they pass through the field, and there is the secondary (S) effect arising from the fact that the rf field excites extra betatron motion. The spins are then disturbed by the extra fields on the extra parts of the trajectories. The influence of rf fields on betatron motion is well known and, in fact, the best way to show that an rf dipole is correctly connected is to run it at the betatron frequency and confirm that the beam is destroyed. A radial rf field excites vertical betatron motion and that causes the radial fields in the quadrupoles to have an extra effect on the spins. A longitudinal field usually has just a small effect on the betatron motion (some coupling). So, for the rf dipoles the S effect can be significant and for an rf solenoid, the S effect is usually weak. In both cases both the P and S parts contribute to the resonance strength and of course, the P and S effects must be correctly combined. Each results in a 3–D spin rotation. But within the philosophy of the SRM, a linearisation is allowed (this is at the basis of the definition of the resonance strength!). Then the P and S parts can be combined by addition of some vectors in an appropriate coordinate system and it can happen that the P and S terms reinforce each other or that they cancel each other or that something in between results. In any case, it should come as no surprise that with rf. dipoles, measured resonance strengths deviate markedly from the values derived naively from the rf field strength. These things have been part of the culture at the BINP (Novosibirsk) for the last thirty years and a colleague from the BINP has told me that he has reminded SPIN@COSY of the S effect on several occasions. A recent carefully written paper (ref. 8 in the proposal) explains about the S effect very clearly and provides credible estimates to show that the S effect should not be neglected in the estimate of the real resonance strength. This paper also points out that the situation can be complicated and implies that great care is needed.

To summarise, until proper account is taken of the S effect in the resonance strength for rf dipoles, it will not be acceptable to claim that there is a real discrepancy between the predictions of the FS picture and the measurements. Moreover, although the FS picture is an approximation which has fitted well into the development of the subject, it is not indispensable now that detailed spin–orbit tracking simulations can be made. Such tracking simulations not only provide a more complete description of the spin motion but they also have the advantage that they allow investigations ("diagnostics") to be made which are impossible in a real ring [1]. For example, the effects of horizontal betatron motion can be switched off or the P and S effects on the spins can be switched on and off separately without modifying the betatron motion. A spin–orbit tracking simulation can be a very powerful

[1]The codes SPINK from BNL and SPRINT from DESY could be considered. SPINK can already handle external rf fields whereas SPRINT contains extensive facilities for calculating invariant spin fields.

model–independent tool leading to important insights. In the 21st century a programme of measurements such as those proposed here should be accompanied by simulations. Of course, it should not be expected that such simulations give an exact account of observations. For a start, one often needs an adequate description of the misalignments of the ring. Nevertheless, as soon as it is seen that the S effect can be large or that tracking simulations make predictions significantly different from the predictions of a naive FS picture which only includes the P effect, the use of tracking simulations as a replacement for blind measurement will have been justified. A more professional approach is needed.

# 4 Miscellaneous

As I indicated at the beginning, I do not intend to go into too much more detail about this proposal. So I will finish by commenting on a few things that caught my eye.

- In an apparent justification for the work at COSY, mention is made on page 3 of polarisation at several other rings. However, most of these rings have been out of business for many years, the LHC will have no proton polarisation and BNL needs no help. In any case, in most of the rings mentioned, rf depolarisation or spin flip was well under control. On the other hand, no mention is made of eRHIC or the planned rings at GSI.

- There is surely only one justification for these investigations, namely to provide reliable and non-intrusive spin flip for protons and deuterons at COSY, at GSI and at J-PARC. Once reliable, non-intrusive spin flip has been attained nothing more is needed. It does not matter if the required magnet strengths do not agree with those from the P effect in the naive FS picture.

  If the required rf fields are uncomfortably high, spin–orbit tracking simulations will explain why, and will provide a means of evaluating the efficacy of adjustments to the optic or to the position of the rf magnets – diagnostics again!

- Ad hoc modifications of the FS formula might be convenient but it is unlikely that they improve understanding of the underlying mechanisms.

- Page 7 contains the astonishing statement that “our experimental collaboration has no useful opinion” about the material in refs. 6–8. I suggest that a group of physicists wishing to use the resources at COSY, *should* have an opinion. We are dealing with electromagnetism, relativistic mechanics and the T–BMT equation. There will nothing mysterious in this story until it is shown that tracking simulations cannot give an approximate account of the measurements. Why the mysticism?

- On page 9 it is suggested that one could use COSY to study some quantum effects associated with deuterons. Before looking for quantum effects, one should do spin–orbit tracking simulations to see what the *classical* effects look like.

- The enhanced FS model in ref. 9 is a valuable contribution, but to me it makes little sense (page 9) to test it when the resonance strength for the most naive FS model is not understood.

- It is implied on page 9 that the results of using the time dependence suggested in ref. 12 are essentially indistinguishable from those obtained with fast crossing. That should not come as a surprise since the suggestion in ref. 12 amounts to little more than fast crossing.

- It is stated on page 3 that the Stable Spin Direction tips over on passing through the resonance. This is incorrect. The Stable Spin Direction referred to on page 3 is the vector $\hat{n}_0$. This is defined on the closed orbit of a ring. Spins on the closed orbit precess around $\hat{n}_0$ and the number of precessions per turn, the closed orbit spin tune, $\nu_s$ is $G\gamma$ for perfect alignment in the absence of solenoids. In real rings it deviates from $G\gamma$ by an amount depending on solenoid strengths and orbit distortion. The Stable Spin Direction $\hat{n}_0$ is *not* rotated rotated by rf fields. However, the vector $\hat{n}$ of the invariant spin field (ISF), is. See. for example, A. Kondratenko's talk at SPIN2006. A. Kondratenko is a member of the SPIN@COSY collaboration. The ISF vector $\hat{n}$ coincides with $\hat{n}_0$ up to a sign well below and well above the resonance. In between, the ISF vector $\hat{n}$ is not stable but, among other things, has Fourier components at the rf frequency. See also modern (and old!) literature on spin dynamics where one sees that the SRM simply describes the ISF vector $\hat{n}$ and that the FS formula gives the variation of the spin action $J_{\mathrm{s}}$.

- A proposal should be proof–read before submission. The first paragraph does not read easily. I assume that "make it" refers to a Siberian Snake. In footnote 6 on page 1: what is rotated?

- For the more distant future: no consideration should be given to tests with snakes. The snake resonance phenomenon is now largely understood as a result of *very* detailed and costly spin–orbit tracking studies. In any case, people at RHIC have learned to live with it and it is unlikely that tests at COSY at a couple of GeV will be relevant at 250 GeV at RHIC, where the spin motion is much more extreme. Moreover, in order to make a useful contribution to this particular mine field, SPIN@COSY would have to equip itself with a very high power spin–orbit tracking code and a familiarity with concepts like the ISF. Finally, one does not use snakes to overcome snake resonances – it's the snakes which *cause* the phenomenon!

- In my opinion it might not help the Institut für Kernphysik when members of SPIN@COSY give talks on these matters (e.g., at SPIN2006) which demonstrate that the treatment by SPIN@COSY is incomplete.

# 5 Questions

There is no need for questions at this stage.