Addendum to Experiment IS *415* at CERN

Magnetic moments of Coulomb excited 2_1^+ states for radioactive beams of ^{132,134,136}Te and ^{138}Xe isotopes at REX-ISOLDE

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Abstract

This is an addendum to the CERN experiment IS 415 (CERN INTC-P-166) with the goal to measure the $g(2_1^+)$ factors in the unstable isotopes $^{132,134,136}Te$ and ^{138}Xe following Coulomb excitation and utilizing the Transient Field method. We will report on the analysis of the data and the results obtained from the experimental campaign on ^{138}Xe in October 2006. It will be shown that problems related to the beam have prevented us from taking precession data for more than 14 hours. However, using the obtained data we will demonstrate that transient field g-factor measurements are indeed feasible under the experimental conditions at REX-ISOLDE and consequently we will ask for a total of 12 shifts (6 of which are still available as recovery from the 2006 run) to improve on the uncertainty of the g-factor value of g=+0.15(31) obtained so far for the 2_1^+ state in ^{138}Xe.

1 Physics case

^{138}Xe belongs to the group of neutron rich unstable Te and Xe isotopes which was proposed for g factor measurements on the first excited states at REX-ISOLDE. In comparison to the stable even-A Te isotopes $^{120-130}Te$ which are collective of vibrational nature the properties of the unstable neutron-rich isotopes ^{132}Te, ^{134}Te and ^{136}Te and the corresponding Xe isotones ^{134}Xe, ^{136}Xe and ^{138}Xe are influenced by their proximity to the doubly-magic ^{132}Sn, i.e. the $Z = 50$ and $N = 82$ shell closures. This becomes evident already from their 2_1^+ excitation energies and the known $B(E2; 2_1^+ \rightarrow 0_1^+)$ values. The microscopic structure of the Te isotopes in this mass region has been studied extensively in many calculations and different approaches, e.g. QRPA [1], shell model studies using either the CD-Bonn renormalized G-matrix [2] or the V_{low-k} approach [3]. Beyond ^{136}Te results from Monte-Carlo shell model calculations exhibit an intriguing and unusual slow evolution of collectivity and deformation with increasing neutron number [4,5]. In addition, the experimental $B(E2)$'s in $^{132,134,136}Te$ show an anomalous behaviour contradicting the systematic relations between excitation energies and transition probabilities. Recent measurements of the $g(2_1^+)$ factor in ^{132}Te utilizing the Recoil-In-Vacuum (RIV) technique [6,7] or the Transient-Field method [3] have yielded similar results of $|0.38(4)|$ and $+0.28(15)$, respectively, in fair agreement with the predicted value of $+0.491$ from [1]. While for the $N = 80$ and $N = 82$ Te isotopes ^{132}Te and ^{134}Te the various calculations for the $g(2_1^+)$ factors agree very well, a large discrepancy between the different approaches and applied residual interactions is observed in the results for ^{136}Te and heavier Te isotopes and require with urgency experimental verification (see fig. 1). The experimental $g(2_1^+)$ factors of $^{134,136}Xe$ are dominated by $\pi g_{(7/2)}$ components with the corresponding Schmidt value of $+0.491$ while in ^{138}Xe shell model calculations suggest a configuration with main components from 2 $f_{7/2}$ neutrons and 2 proton holes in the $g_{7/2}$ orbital [1]. The larger experimental value in ^{136}Xe supports the idea of small additional proton compo-

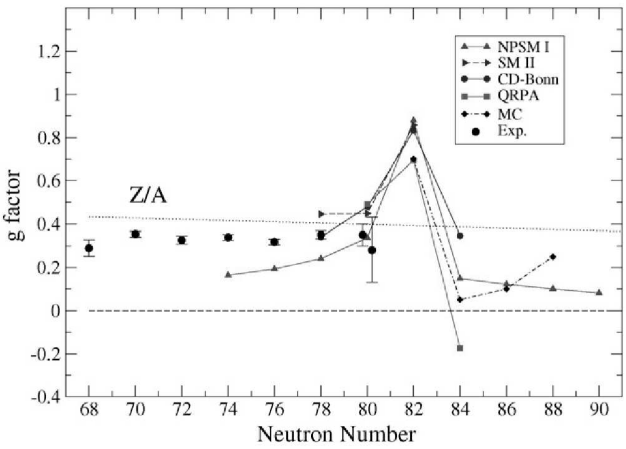

Fig. 1. Experimental and calculated g factors for $^{120-142}Te$ isotopes (taken from [3]). Black circles refer to experimental data.

Table 1
Calculated and experimental $g(2_1^+)$ factors for $^{132,134}Te$ and the corresponding isotones $^{134,136}Xe$. Experimental data taken from [3,8,6,7]. Calculational results from [1].

N = 80	$g(2_1^+)$ exp.	$g(2_1^+)$ calc.	N = 82	$g(2_1^+)$ exp.	$g(2_1^+)$ calc.
^{132}Te:	| 0.38(4)| +0.28(15)	+ 0.491	^{134}Te:	–	0.695
^{134}Xe:	+0.354(7)		^{136}Xe:	+0.77(5)	

nents from proton orbitals above the $g_{7/2}$ shell whereas $\nu h_{11/2}$ components reduce the $g(2_1^+)$ in ^{134}Xe. For the isotones ^{132}Te and ^{134}Xe as well as ^{134}Te and ^{136}Xe the calculation predicts similar $g(2_1^+)$ factors although the number of $g_{7/2}$ protons is reduced by two (see Table 1). Compared to the predicted $g(2_1^+)$ value of -0.174 in ^{136}Te [1] due to an additional neutron hole configuration in the $\nu h_{11/2}$ orbital the calculated value for the $g(2_1^+)$ in ^{138}Xe is expected to be about +0.29. As mentioned above, large discrepancies exist for results from different calculations, e.g. +0.348 for the $g(2_1^+)$ in ^{136}Te in [2] which could only be clarified by experimental data.

2 Status of the CERN experiment IS 415

In May 2005, a first g factor measurement (according to our proposal) was carried out using a ^{138}Xe beam at 2.8 MeV/u and applying the technique of projectile Coulomb excitation in inverse kinematics combined with transient magnetic fields (TF) in ferromagnetic gadolinium. The ^{138}Xe beam has been favoured as its production and preparation for REX-ISOLDE was considered to be relatively easy and free of isobaric contaminants which are normally present when dealing with other beams. This campaign was carefully prepared by two precedent stable beam experiments at the Cologne tandem accelerator where the MINIBALL detector array was temporarily stationed. In these experiments it was demonstrated that using four MINIBALL detectors in fixed geometry both particle-γ angular correlations as well as spin precessions can be measured simultaneously. Results from these previous experiments can be found in [9].
In the first ^{138}Xe campaign in 2005 severe problems have arised mainly due to the beam energy of 2.8 MeV/u which was significantly lower than the originally envisaged 3.1 MeV/u. The thick multilayer precession target, which had been designed and optimized for the higher energy value, introduced too much straggling of the transmitted beam so that too many scattered beam particles hit the particle detectors and lead to pile-up. Even when using additional absorber foils in front of the detectors no "prompt" peak could be identified in the time spectra due to the overwhelming random coincidences arising from scattered beam ions. Under these conditions and in addition considering the time structure of the pulsed beam during that experiment (3 Hz and a width of only 50 μs) it was not possible to accumulate sufficient statistics in the $(2_1^+ \rightarrow 0_1^+)$ γ line of ^{138}Xe in order to deduce a statistically significant precession angle.

For the second campaign in October 2006, a new target optimized for the lower available beam energies was designed and additional improvements were made to overcome difficulties related to γ radiaton from β decay in the scattering chamber as well as from X-rays from the resonators. In 2005 we had to interrupt the measurement every hour for 20 minutes to reduce the load on the γ detectors. This problem could be solved by a reconstruction of the target chamber where PPAC and collimator were successfully shielded by heavy massive steel cones and lead shields in front of the 9-gap resonator. Instead of using the annular PIPS detector from the experiment in 2005 for particle identification the acceptance for scattered particles could be increased at least by a factor of 4 utilizing one out of two fourfold segmented Si arrays with slit geometry coupled to fast preamplifiers. For this replacement we had 2 reasons. One was to overcome dead-time related problems with the data acquisition. The second was less obvious but nethertheless important. To benefit from the maximum Coulex cross section the opening angle of the Si detector has to be enlarged from 35 degrees to 40 or 45 degrees. But usually, the gain in statistics has to be payed with the loss of nuclear spin alignment if an annular Si counter is used. This is avoidable by particle detection perpendicular to the gamma detection plane. The beam was finally steered through the center hole of the detector array which was shielded with a tantalum foil to stop straggled beam ions which eventually were scattered onto the sensitive area and stopped in a beam dump far away from the target. This prevented from the accumulation of radioactivity and consequently reduced the number of random coinci-

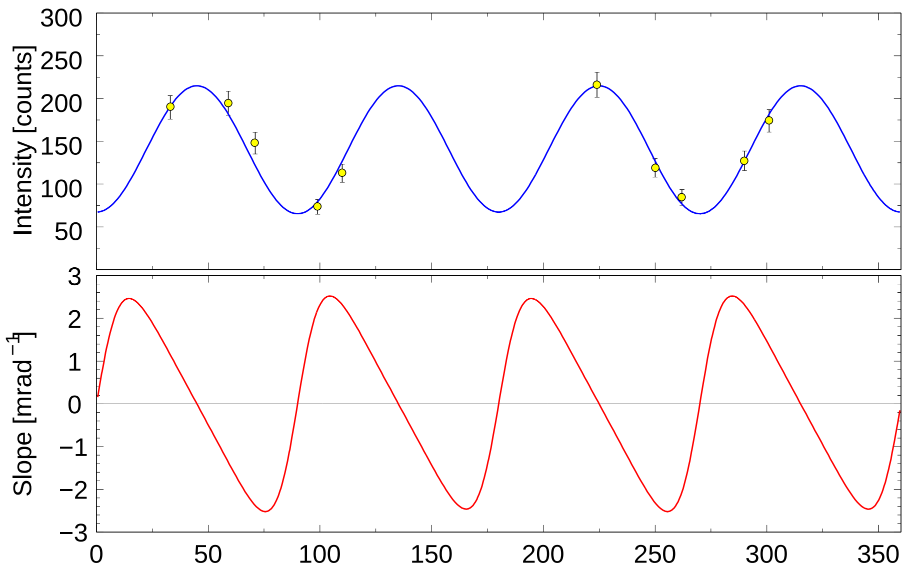

Fig. 4. Upper part : γ-particle angular correlation obtained via least-square fits to experimental data points; lower part: slope derived from the correlation

dences. Two different targets were used with excitation layers of pure ^{50}Ti or ^{nat}Al on ferromagnetic Gd with Cu backings. The latter served as a stopper for the excited Xe nuclei. The Targets were cooled to LN temperature and magnetized to saturation in an external field of 0.06 Tesla. The de-excitation gamma rays were measured in 4 Miniball-Cluster detectors placed at fixed angles in a horizontal plane perpendicluar to the external magnetizing field. One of the major problems in radioactive beam experiments is the flooding of the gamma spectra with transitions from radioactive decays as well as random coincidences. It has been demonstrated already that this is easy to handle by using γ-particle coincidences. A typical γ-single spectrum after some hours of runtime is shown in fig 2 exhibiting mainly γ de-excitation lines following β decay of ^{138}Xe and its daugther ^{138}Cs as well as a small component from the 589 keV $(2_1^+ \to 0_1^+)$ γ transition after Coulomb excitation of the 2_1^+ in ^{138}Xe. By choosing the proper particle energy condition and the prompt or true coulex events in the corresponding time spectra remarkable clean γ spectra with superior peak-to-background ratios could be obtained (fig. 3). The clusters were placed in a way that the single crystals covered six different theta angles for each hemisphere. The photopeak intensities in the efficiency corrected gamma-coincidence spectra of 11 out of 12 crystals were used to apply a least-square fit in order to obtain the particle-γ angular correlation (see fig. 4). The anisotropy of the obtained angular correlation is as large as expected considering the vertical particle detector geometry used in this experiment to maximize the spin-alignment. The same γ coincidence spectra, but now splitted according to the 2 magnetic field directions, were used for the analysis of the nuclear spin precession which is directly correlated with the g factor. The precession angles were calcutated

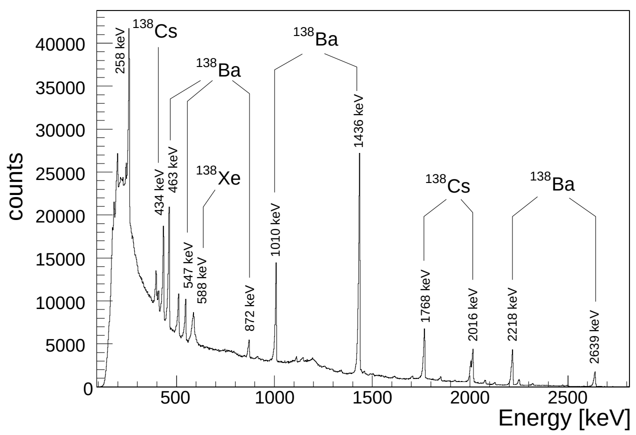

Fig. 2. γ-single spectrum after some hours of runtime, sum of all used MINIBALL cluster detectors

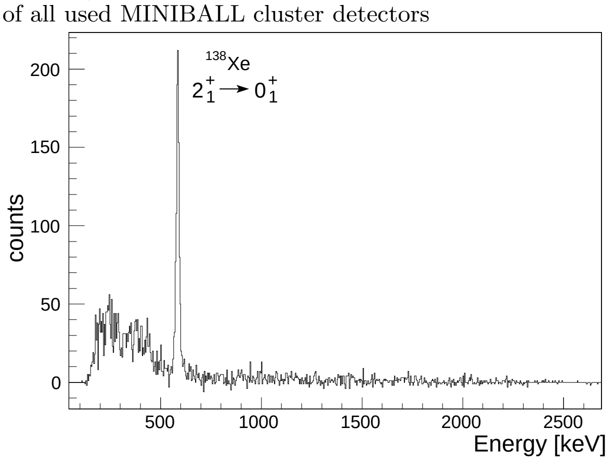

Fig. 3. Random substracted γ-coincidence spectrum of the Coulomb excited ^{138}Xe

via count ratios of symmetric crystal pairs using their individual slope of the angular correlation. One of the 6 different pairs had to be omitted due to a broken detector. It has to be taken into account that only the perpendicular component of the magnetic field causes the spin precession. For crystals out of this horizontal plane the precession is weakend and needs to be corrected by $\cos(\phi)$. In total 575 counts could be used to calculate the precession angle of

$$\Phi^{exp} = 11(25)mrad$$

which corresponds to $g(2_1^+) = 0.15(31)$ for ^{138}Xe (table 2).

The obtained total count rate is certainly at the lower limit for the successfull application of the Transient Field technique. However, the precession data shown in table 2 were obtained in only 14 hours of beamtime with a cooled target (for the angular correlation also data obtained with a warm target have been used doubling the statistics). The reason for the late decision to start cooling down the target is that already during the beam time we noticed that the ^{138}Xe Coulex peak vanished in the γ coincidence spectra in many runs although the particle rate and particle energy spectra barely changed. This behaviour occured randomly and could not be tracked during the beamtime although particle detectors, targets and parts of the electronic were replaced. From the time spectra generated in the offline analysis using the time stamps from the DGF's and ADC's we finally realized that we have also lost the prompt peak of the Coulex events in the same runs. The situation is demonstrated in Fig. 6 showing gamma single sum spectra of all clusters, particle single spectra and the time spectra generated from time stamps of the consecutive runs 65 and 67. Both runs took place under similar conditions with the same target and only a small time gap of 4 hours between the two runs. The gamma single spectra of run 67 clearly exhibits the 589 keV line of the $(2_1^+ \rightarrow 0_1^+)$ transition in ^{138}Xe after Coulomb excitation of the Xe projectiles and a strong prompt peak in the corresponding time spectra. Although the particle single spectra look similar with comparable rates the γ transition and the prompt peak have been almost vanished in run 65.

In a further analysis the photopeak intensity of γ transitions in ^{138}Cs following β decay of ^{138}Xe were plotted against run time. Since the half life of ^{138}Xe is only 14.08 minutes the intensity of the β decay lines should continuously increase with a constant ^{138}Xe beam but decrease within minutes in case the beam is missing at target position. As shown in Fig 5 both situations could be found in the runs 65 and 67. While in run 67 the decay rate is increasing, clearly indicating that ^{138}Xe was deposited in the target area in run 65 the intensity starts to drop between minute 80 to 90 with approximately the half life of ^{138}Xe although particles were still registered. Together with the missing 589 keV transition from ^{138}Xe and the vanishing prompt peak in the time spectra this behaviour leads to the conclusion that the ^{138}Xe beam

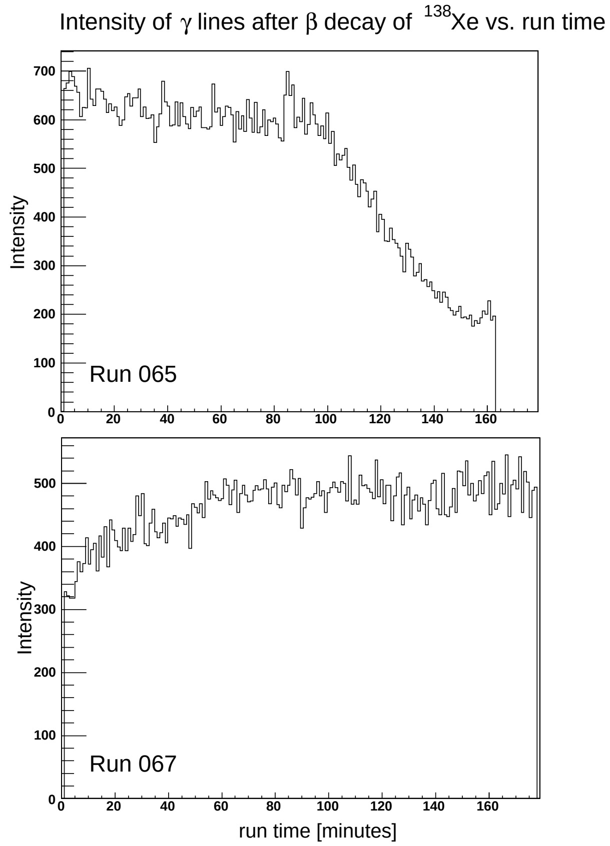

Fig. 5. β decay rate of ^{138}Xe vs. run time

was not steared onto target position but must have been stopped elsewhere while registered particles were produced in secondary reactions or have been arised from unknown other sources. The offline analysis revealed a loss of approximately 50% of the active beam time due to the mentioned problem.

3 Beam time request

The available data impressively demonstrate the applicability of the Transient Field method under the experimental conditions at REX-ISOLDE. In comparison to the excellent data for the angular correlation it would be highly desirable to increase the accuracy for the $g(2_1^+)$ result. The average count number for one crystal is only about 29 per field direction thus increasing the uncertainty in the analysis for the individual detectors. The experimental result obtained so far for the $g(2_1^+)$ in ^{138}Xe of $+0.15(31)$ can neither exclude negative values indicating a strong influence of $\nu h_{11/2}$ components in the nuclear wave function nor more positive values beyond the predicted $+0.29$ from Teresaki et al. [1] which would require proton configurations in orbitals above $\pi g_{7/2}$.

If we take into account an average slope of $|S| = 1.75$ the reduction of the error by a factor of 2 would require

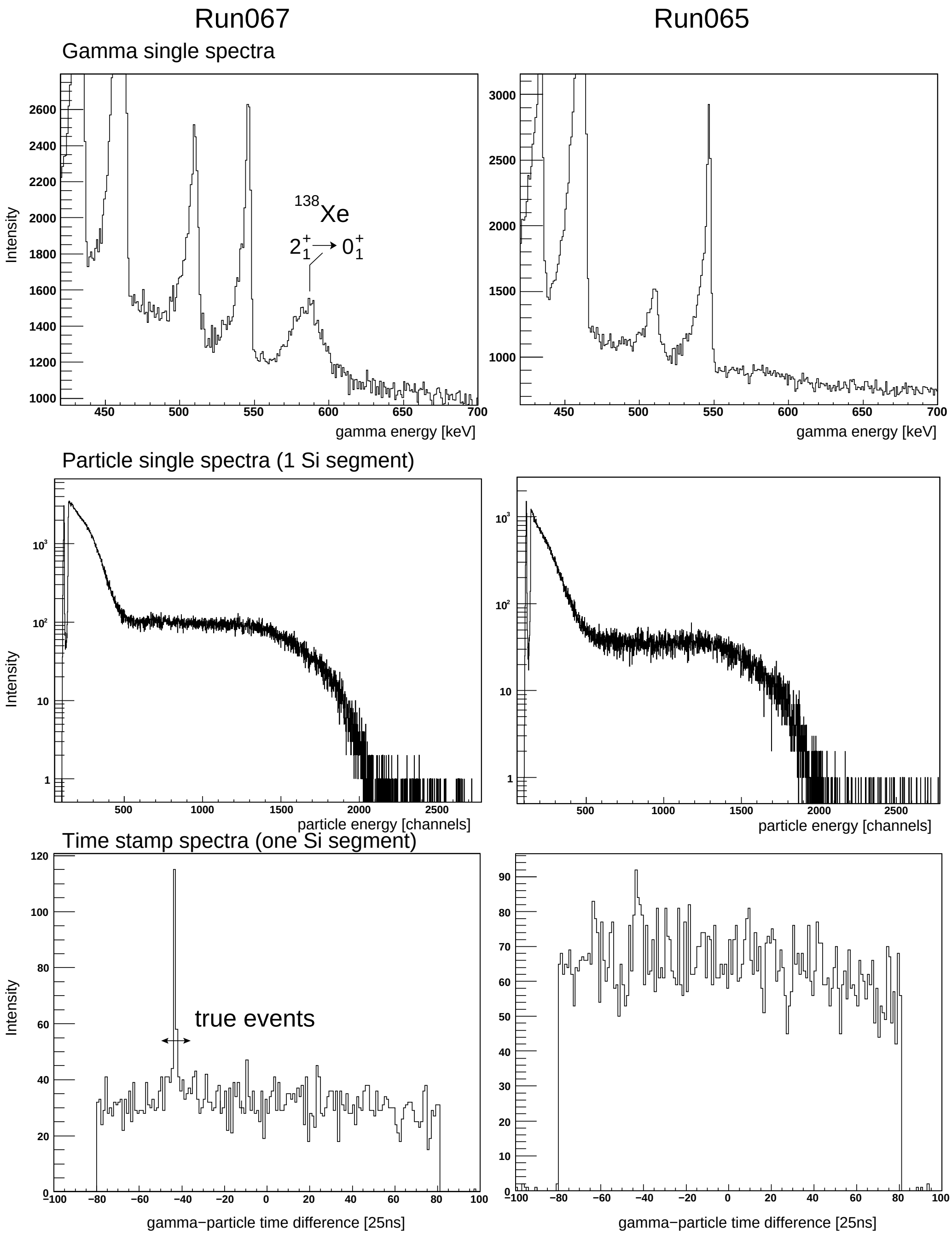

Fig. 6. Comparison of γ single, particle single and time difference spectra of two consecutive runs under the same experimental conditions and comparable rates. The 589 keV line from the $(2_1^+ \rightarrow 0_1^+)$ transition in ^{138}Xe is clearly visible in run no. 67 as well as the prompt peak for the Coulex events in the time spectra. Both were not present during the preceding run no. 65. The broad γ line results from Doppler broadening in the gamma sum spectra for detectors at forward and backward angles.

Table 2
Experimental precession angles Φ^{exp} and Φ^{exp}_{corr} (corrected by $\cos(\phi)$) of symmetric detector pairs with their individual slopes of the angular correlation, average and resulting $g(2_1^+)$. Count rates are given only for precession runs (see text).

ϑ	φ	Counts	Slope $[mrad^{-1}]$	Φ^{exp} $mrad$	Φ^{exp}_{corr} $mrad$	$\langle\Phi^{exp}_{corr}\rangle$ $mrad$	$g(2_1^+)$
33°	6.9°	160	1.20(33)	-40(64)	-40(64)		
59°	21.4°	169	-1.32(17)	99(59)	106(63)		
70.5°	15.2°	95	-2.35(42)	-20(43)	-21(45)	11(25)	+0.15(31)
98.5°	15.2°	63	2.14(61)	71(61)	73(63)		
110°	21.4°	88	2.35(42)	-14(47)	-15(50)		
136°	6.9°	–	omitted (see text)				

approximately 300 counts per crystal and field direction. According to the 14 hours of useful data in the precession runs this would correspond to additional 60 hours of precession measurement or 8 shifts. 6 shifts are still available and result mainly from the lack of protons after power failures in the PS-Booster during the precession runs at the end of the experimental campaign in 2006. It must be stated that more accurate data could have been obtained without the problems related to the beam mentioned above. In conclusion we ask for **12 shifts (4 days) in total**, including 4 shifts to prepare the beam and to set-up the precession chamber.

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