**DIRAC-NOTE-2012-03**

# Investigation of the magnetic field of the permanent magnet applied in the DIRAC experiment

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**Abstract**

An analysis of the experimental data obtained during the run of 2011 has revealed the effect of degradation of the permanent magnet used. This effect is investigated, and average magnetic field is estimated for each day of the run.

## Introduction

The main purpose of the 2011 run is a search of pion atoms in a metastable state. To achieve this goal, it is very important to analyse the transverse momenta $Q_y$ of $\pi^+\pi^-$ pairs.

Fig. 1 shows that the peak in the distribution of experimental events over $Q_y$ is shifted with respect to the same peak for simulated events. This shift may be explained by degradation of the permanent magnet situated downstream of the Be target. The following situation occurred several times during the run: elements of the experimental setup, including, also, the magnet, were hit by the incident beam. With time, the energy of atomic nuclei released in transitions from excited to lower states could lead to an increase in the temperature of certain magnet domains up to values exceeding the Curie temperature, which on the whole would result in a decrease of the magnetic field of the permanent magnet. And even at normal beam condition magnet is hit by secondary high energy particles which also could provide demagnetization of the permanent magnet.

This paper presents a quantitative description of the magnet degradation. An attempt to determine the average magnetic field corresponding to each day of the run has been made.

To resolve the problem, analysis of the transverse momentum $Q_y$ of $e^+e^-$ pairs from conversion of the $\gamma$-quanta was carried out. The choice of $e^+e^-$ pairs for the analysis is explained by the fact that in this case quantitative description of the magnet degradation can be performed with higher accuracy (due to the narrower peak we are interested in, as one can see from Fig. 2, comparing it with Fig. 1).

As it can be seen from Figs. 3 and 4, the leftward shift of the peak of interest is also evident in the case of $e^+e^-$ pairs from $\gamma$ conversion.

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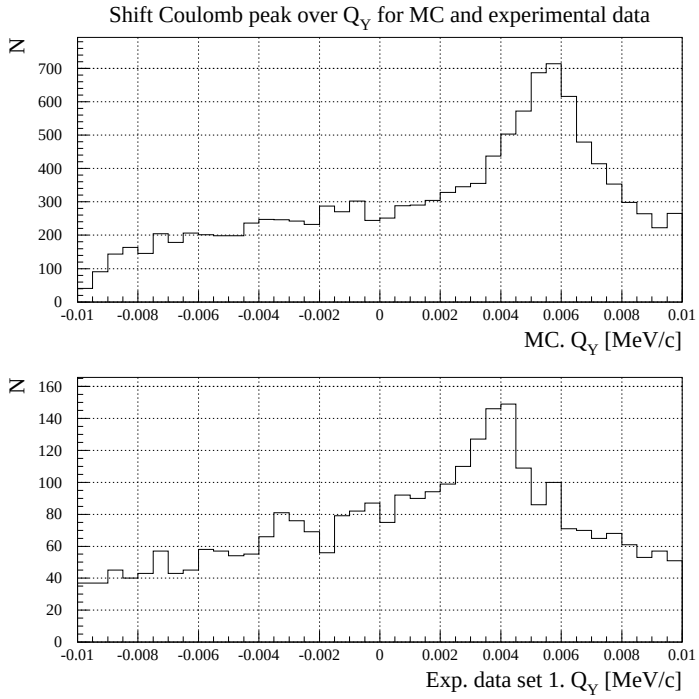


Figure 1: Simulated (upper) and experimental (lower) distributions of $\pi^+\pi^-$ pairs over $Q_y$. Statistics have been collected during the period from June 25 up to July 1.

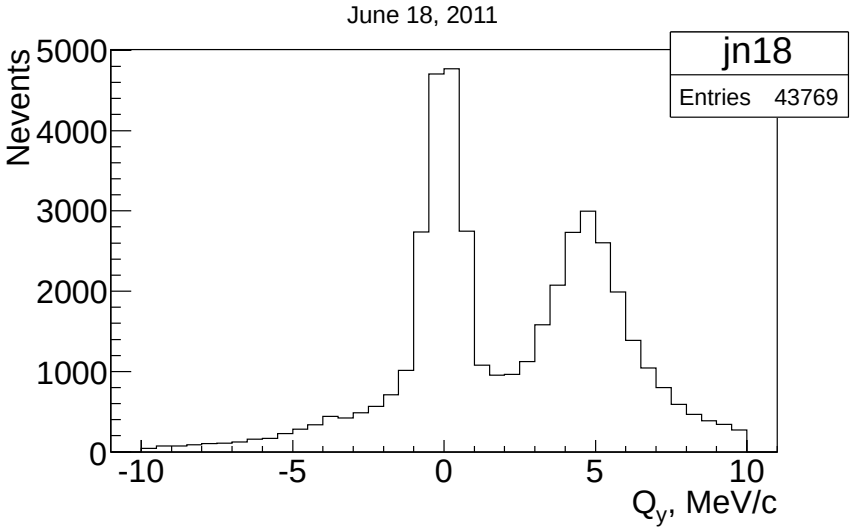


Figure 2: Example of experimental distribution over $Q_y$ for $e^+e^-$ pairs from $\gamma$ conversion.

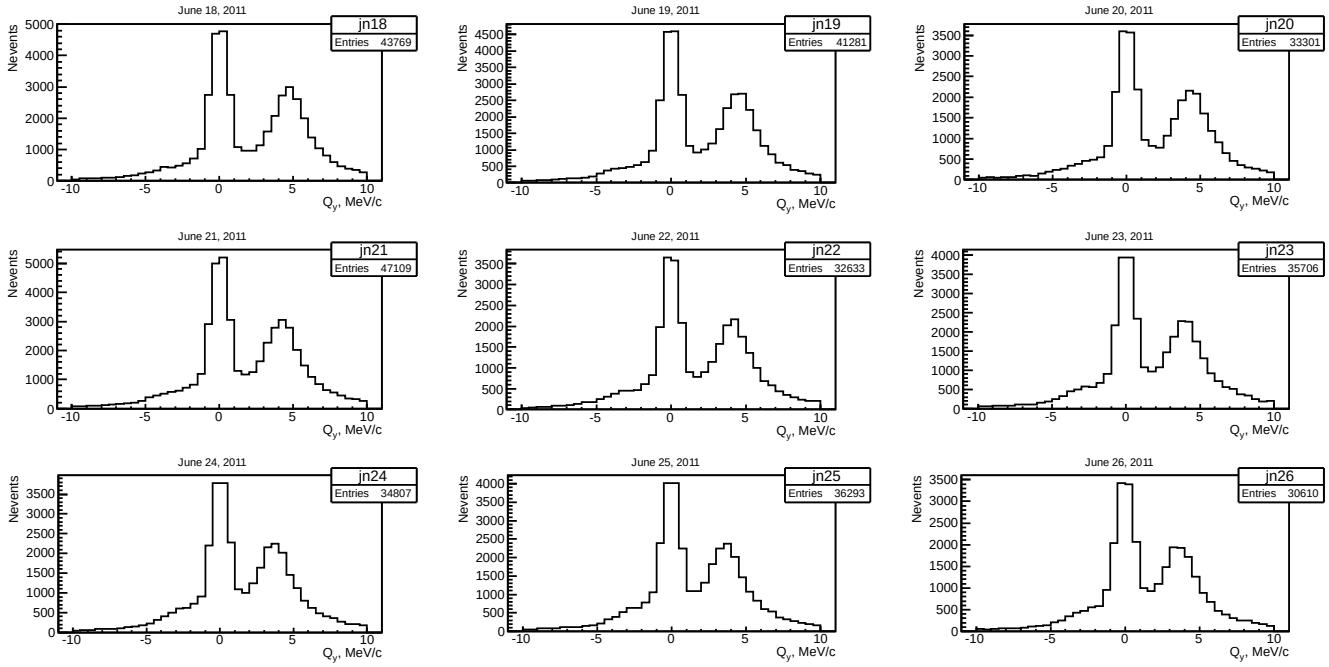


Figure 3: Experimental distribution of $e^+e^-$ pairs from $\gamma$ conversion over $Q_y$ for several days of the 2011 run.

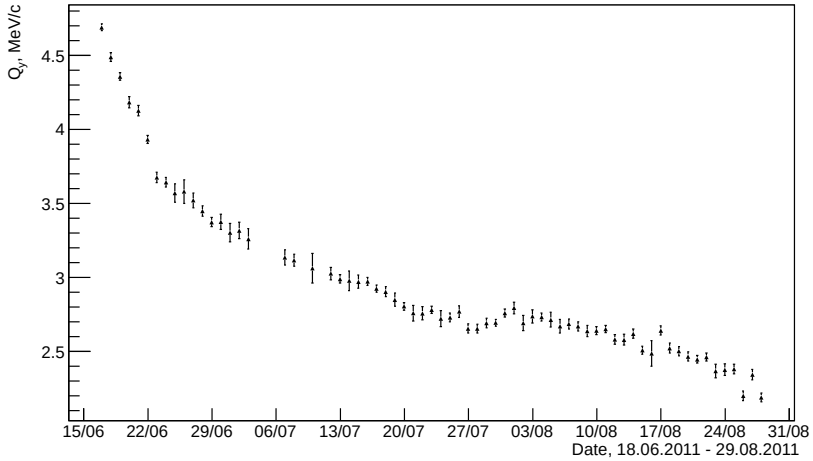


Figure 4: Position of shifted peak in the distribution over $Q_y$ as function of day of the run (data are presented for the first half of the run).

It should be taken into account, that the $e^+e^-$ pairs could be the following:

1. pairs, produced as a result of the conversion of $\gamma$-quanta in the Be target;
2. pairs, resulting from internal conversion in the Be target $\pi^0 \to \gamma e^+e^-$ (i.e. Dalitz pairs);
3. pairs, produced in the conversion of $\gamma$-quanta in platinum foil, mylar, air, the fiber and other detectors.

$e^+e^-$ pairs from conversion (including internal conversion) in the target form the shifted peak, all other pairs contribute to the peak near zero. This is due to the target being situated before the permanent magnet, the magnetic field of which deflects electrons and positrons from $e^+e^-$ pairs produced in the Be target.

# Algorithm and procedure for estimation of the magnetic field

First, the interval of magnetic field values (0.0 ... 1.0)[1] was divided into 40 intervals with bins of 0.025.

The **first step** consisted in applying the GEANT-DIRAC program [1] for simulation of events of $\gamma$ conversion into $e^+e^-$ pairs (Dalitz pairs were also taken into account) within and after the Be target for each value of the magnetic field. It is also very important, that the simulated events contain information on the z-coordinate of the conversion point permitting determination of whether the conversion took place before or after the permanent magnet.

The simulated data were further transferred to the reconstruction program ARIANE, the output of which was recorded in Ntuple's of the form standard for the DIRAC experiment. The Ntuple's were subsequently transformed into ROOT-trees.

At the **second step**, the experimental events for each day (18.06.2011 - 15.11.2011) were fitted by the sum of two simulated distributions (for conversion within and after the Be target, respectively) for each value of the magnetic field (0.0, 0.025, 0.050 ... 0.950, 0.975, 1.0), upon which distributions were constructed demonstrating the dependence of the $\chi^2$ values upon the magnetic field; such dependences are shown in Fig. 5 for several days of the run. From fits obtained for each day, only the one, providing the minimum $\chi^2_{min}$ value, was finally chosen, so as to extract the value $H_{min}$ corresponding to this fit.

Further, distributions for each day, similar to the distributions in Fig. 5, were fitted by second order polynomials (red line in Fig. 5) within the interval $(H_{min} - \delta,\ H_{min} + \delta)$, where $\delta = 0.075$. The value $H^{fit}_{min}$ determined by the minimum of a parabolic fit was considered the averaged value of the magnetic field for each day of the run.

At the **third step** errors were estimated for the reconstructed value $H^{fit}_{min}$ of the magnetic field. This was done in the following way. We took the $\chi^2$ value, differing from the minimum value $\chi^2_{min}$ by unity (i.e. $\chi^2 = \chi^2_{min} + 1$), and, using the parameters of the parabolic fit that yielded $H^{fit}_{min}$, we otained two values $H^{fit}_{left}$ and $H^{fit}_{right}$ ($H^{fit}_{left} < H^{fit}_{min} < H^{fit}_{right}$) by resolving the corresponding quadratic equation.

[1]The value 1.0 corresponds to the initial magnetic field of the magnet, and 0.0 corresponds to the case when no magnetic field is present.

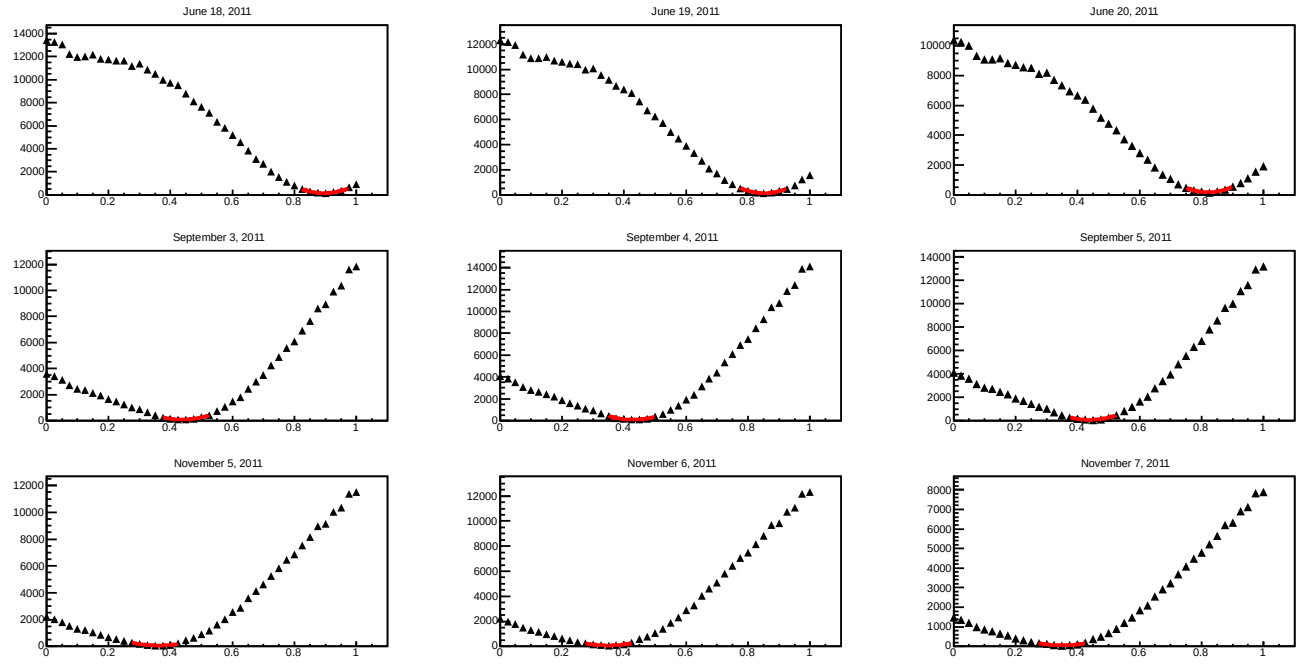


Figure 5: Dependence of values $\chi^2$ values upon the magnetic field for separate days of the run.

As an estimate for the uncertainty in the daily magnetic field we adopted the value

$$\Delta H_{min}^{fit} = \frac{H_{right}^{fit} - H_{left}^{fit}}{2}$$

The results obtained are presented in Fig. 6 and Tab. 1.

# Conclusion

The sharp decrease in the magnetic field corresponding to June 22 - June 23 and November 8 - November 9 (see Fig. 6), could be explained by a strong irradiation of the construction elements of the experimental setup, including the magnet (see above). The slight bump near August 1 (see also Fig. 4) is related to a change in the position of the magnet realized in order to focus the secondary beam in the center of the magnetic field. The drop at the end of the run may be explained by certain problems that occurred at the time with the accelerator.

Table 1: Number of events, value of magnetic field and error in magnetic field for each day of the run of 2011.

| **Date** | $\mathbf{N_{events}}$ | $\mathbf{H_{min}^{fit} \pm \Delta H_{min}^{fit}}$ | **Date** | $\mathbf{N_{events}}$ | $\mathbf{H_{min}^{fit} \pm \Delta H_{min}^{fit}}$ |
|---|---|---|---|---|---|
| June 18 | 43769 | $0.895 \pm 0.004$ | September 3 | 40680 | $0.437 \pm 0.005$ |
| June 19 | 41281 | $0.853 \pm 0.004$ | September 4 | 54222 | $0.429 \pm 0.004$ |
| June 20 | 33301 | $0.821 \pm 0.004$ | September 5 | 48757 | $0.439 \pm 0.004$ |
| June 21 | 47109 | $0.793 \pm 0.004$ | September 6 | 56682 | $0.428 \pm 0.004$ |

Table 1: Number of events, value of magnetic field and error in magnetic field for each day of the run of 2011.

| **Date** | $\mathbf{N_{events}}$ | $\mathbf{H^{fit}_{min} \pm \Delta H^{fit}_{min}}$ | **Date** | $\mathbf{N_{events}}$ | $\mathbf{H^{fit}_{min} \pm \Delta H^{fit}_{min}}$ |
|---|---|---|---|---|---|
| June 22 | 32633 | 0.784 ± 0.004 | September 7 | 49614 | 0.428 ± 0.004 |
| June 23 | 35706 | 0.747 ± 0.004 | September 8 | 61810 | 0.425 ± 0.004 |
| June 24 | 34807 | 0.699 ± 0.004 | September 9 | 47201 | 0.419 ± 0.005 |
| June 25 | 36293 | 0.685 ± 0.004 | September 10 | 54305 | 0.421 ± 0.004 |
| June 26 | 30610 | 0.685 ± 0.004 | September 11 | 14166 | 0.42 ± 0.01 |
| June 27 | 15841 | 0.68 ± 0.01 | September 12 | 33061 | 0.420 ± 0.005 |
| June 28 | 27416 | 0.665 ± 0.005 | September 13 | 30619 | 0.413 ± 0.005 |
| June 29 | 32508 | 0.661 ± 0.005 | September 14 | 58493 | 0.419 ± 0.004 |
| June 30 | 34446 | 0.646 ± 0.004 | September 15 | 45344 | 0.410 ± 0.005 |
| July 1 | 19946 | 0.64 ± 0.01 | September 16 | 48383 | 0.406 ± 0.004 |
| July 2 | 21305 | 0.63 ± 0.01 | September 17 | 55107 | 0.416 ± 0.004 |
| July 3 | 19217 | 0.63 ± 0.01 | September 18 | 48473 | 0.402 ± 0.004 |
| July 4 | 13739 | 0.61 ± 0.01 | September 19 | 44334 | 0.404 ± 0.004 |
| July 7 | 7668 | 0.61 ± 0.01 | September 20 | 53151 | 0.403 ± 0.004 |
| July 8 | 15806 | 0.60 ± 0.01 | September 21 | 57893 | 0.401 ± 0.004 |
| July 9 | 18784 | 0.591 ± 0.005 | September 22 | 24150 | 0.405 ± 0.005 |
| July 10 | 7091 | 0.59 ± 0.01 | September 23 | 43982 | 0.399 ± 0.004 |
| July 11 | 2428 | 0.58 ± 0.01 | September 24 | 38801 | 0.400 ± 0.005 |
| July 12 | 15451 | 0.57 ± 0.01 | September 25 | 61149 | 0.390 ± 0.004 |
| July 13 | 24005 | 0.574 ± 0.005 | September 26 | 49011 | 0.396 ± 0.004 |
| July 14 | 31916 | 0.573 ± 0.004 | September 27 | 56301 | 0.391 ± 0.004 |
| July 15 | 18498 | 0.573 ± 0.005 | September 28 | 32316 | 0.391 ± 0.005 |
| July 16 | 27184 | 0.566 ± 0.005 | September 29 | 43304 | 0.392 ± 0.005 |
| July 17 | 43128 | 0.563 ± 0.004 | September 30 | 55305 | 0.393 ± 0.004 |
| July 18 | 46709 | 0.557 ± 0.004 | October 1 | 63972 | 0.388 ± 0.004 |
| July 19 | 43631 | 0.557 ± 0.004 | October 2 | 53564 | 0.389 ± 0.004 |
| July 20 | 38956 | 0.546 ± 0.004 | October 3 | 59152 | 0.385 ± 0.004 |
| July 21 | 44630 | 0.536 ± 0.004 | October 4 | 58661 | 0.384 ± 0.004 |
| July 22 | 37116 | 0.531 ± 0.004 | October 5 | 62475 | 0.385 ± 0.004 |
| July 23 | 47070 | 0.523 ± 0.004 | October 6 | 52749 | 0.384 ± 0.004 |
| July 24 | 46068 | 0.524 ± 0.004 | October 7 | 44098 | 0.385 ± 0.004 |
| July 25 | 38797 | 0.520 ± 0.004 | October 8 | 65514 | 0.377 ± 0.004 |
| July 26 | 39968 | 0.519 ± 0.004 | October 9 | 63661 | 0.384 ± 0.004 |
| July 27 | 19393 | 0.52 ± 0.01 | October 10 | 59388 | 0.382 ± 0.004 |
| July 28 | 49750 | 0.505 ± 0.004 | October 11 | 38270 | 0.373 ± 0.005 |
| July 29 | 42739 | 0.503 ± 0.004 | October 12 | 35008 | 0.377 ± 0.005 |
| July 30 | 35993 | 0.503 ± 0.005 | October 13 | 59095 | 0.376 ± 0.004 |
| July 31 | 45581 | 0.506 ± 0.004 | October 14 | 29622 | 0.379 ± 0.005 |
| August 1 | 51263 | 0.517 ± 0.004 | October 15 | 62042 | 0.369 ± 0.004 |

Table 1: Number of events, value of magnetic field and error in magnetic field for each day of the run of 2011.

| **Date** | $\mathbf{N_{events}}$ | $\mathbf{H^{fit}_{min} \pm \Delta H^{fit}_{min}}$ | **Date** | $\mathbf{N_{events}}$ | $\mathbf{H^{fit}_{min} \pm \Delta H^{fit}_{min}}$ |
|---|---|---|---|---|---|
| August 2 | 59517 | 0.524 ± 0.004 | October 16 | 59815 | 0.368 ± 0.004 |
| August 3 | 52725 | 0.516 ± 0.004 | October 17 | 54442 | 0.372 ± 0.004 |
| August 4 | 19327 | 0.52 ± 0.01 | October 18 | 51499 | 0.371 ± 0.004 |
| August 5 | 45917 | 0.515 ± 0.004 | October 19 | 59203 | 0.367 ± 0.004 |
| August 6 | 48639 | 0.514 ± 0.004 | October 20 | 54824 | 0.368 ± 0.004 |
| August 7 | 31205 | 0.508 ± 0.005 | October 21 | 50171 | 0.367 ± 0.004 |
| August 8 | 42419 | 0.513 ± 0.004 | October 22 | 59366 | 0.364 ± 0.004 |
| August 9 | 35291 | 0.504 ± 0.004 | October 23 | 58346 | 0.363 ± 0.004 |
| August 10 | 32966 | 0.505 ± 0.005 | October 24 | 48948 | 0.36 ± 0.01 |
| August 11 | 52049 | 0.498 ± 0.004 | October 25 | 48082 | 0.37 ± 0.01 |
| August 12 | 53174 | 0.500 ± 0.004 | October 26 | 12604 | 0.35 ± 0.01 |
| August 13 | 56859 | 0.492 ± 0.004 | October 27 | 37250 | 0.36 ± 0.01 |
| August 14 | 37390 | 0.489 ± 0.004 | October 28 | 40099 | 0.35 ± 0.01 |
| August 15 | 50021 | 0.490 ± 0.004 | October 29 | 15547 | 0.35 ± 0.01 |
| August 16 | 35974 | 0.485 ± 0.004 | October 30 | 30437 | 0.36 ± 0.01 |
| August 17 | 31736 | 0.481 ± 0.005 | October 31 | 24872 | 0.36 ± 0.01 |
| August 18 | 29049 | 0.485 ± 0.005 | November 1 | 35027 | 0.35 ± 0.01 |
| August 19 | 42461 | 0.481 ± 0.004 | November 2 | 32495 | 0.35 ± 0.01 |
| August 20 | 63908 | 0.472 ± 0.004 | November 3 | 38996 | 0.36 ± 0.01 |
| August 21 | 64515 | 0.475 ± 0.004 | November 4 | 40277 | 0.35 ± 0.01 |
| August 22 | 65075 | 0.471 ± 0.004 | November 5 | 32953 | 0.36 ± 0.01 |
| August 23 | 65130 | 0.467 ± 0.004 | November 6 | 33683 | 0.35 ± 0.01 |
| August 24 | 51988 | 0.459 ± 0.004 | November 7 | 17492 | 0.35 ± 0.01 |
| August 25 | 53698 | 0.464 ± 0.004 | November 9 | 18353 | 0.34 ± 0.01 |
| August 26 | 52902 | 0.456 ± 0.004 | November 10 | 33248 | 0.30 ± 0.01 |
| August 27 | 66916 | 0.445 ± 0.004 | November 11 | 33248 | 0.30 ± 0.01 |
| August 28 | 62714 | 0.448 ± 0.004 | November 14 | 7337 | 0.13 ± 0.01 |
| August 29 | 61568 | 0.441 ± 0.004 | November 15 | 12759 | 0.11 ± 0.01 |
| $N_{total} = 5896101$ | | | | | |

Fig. 7 presents the number of experimental events for each day of the run; Fig. 8 and Table 2 show the number and fraction of events corresponding to the magnetic field $H_{min}$.

# References


[1] DIRAC-NOTE-2012-01: The generator of photons in the reaction $p + Ni \to \gamma + X$ at 24 GeV/c, O. Gortchakov [JINR].

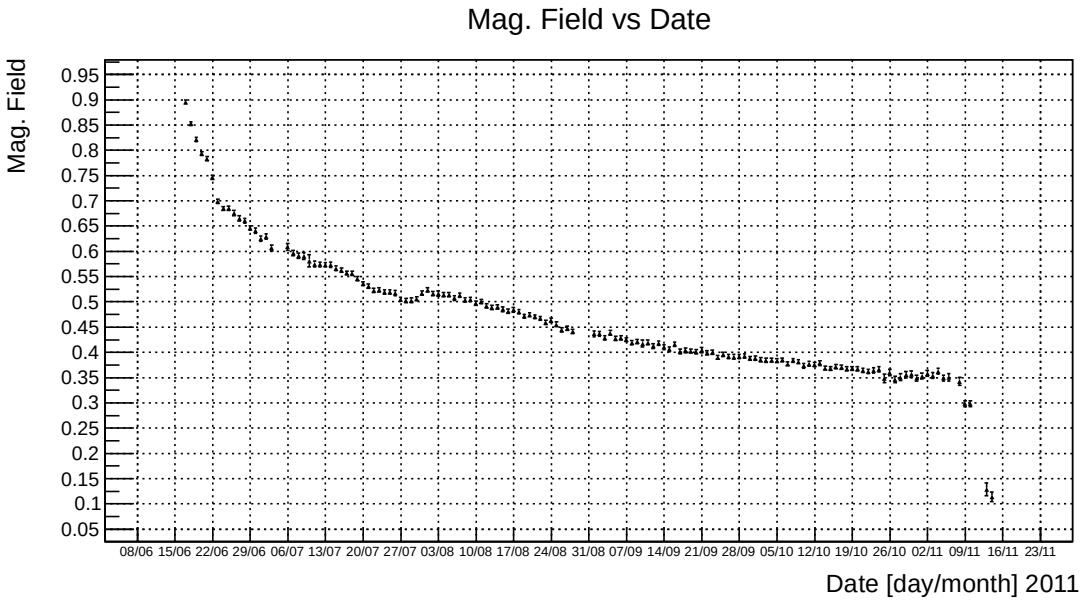


Figure 6: Average value of magnetic field for each day of the run.

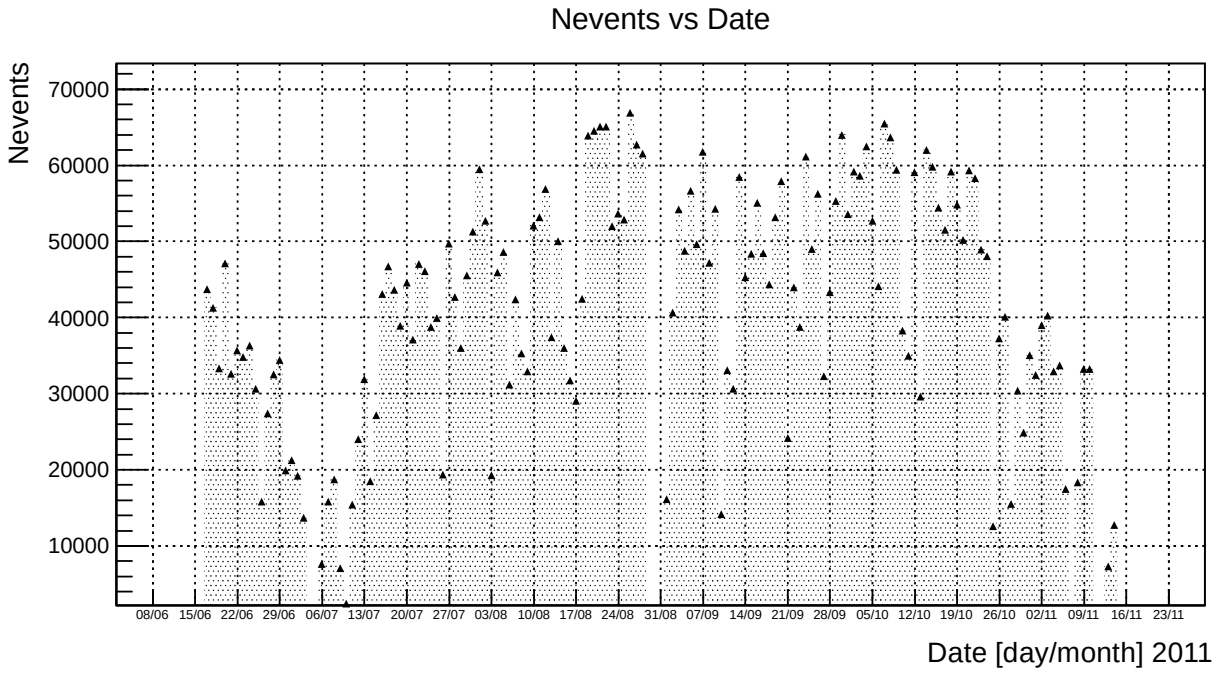


Figure 7: Number of experimental events for each day of the run.

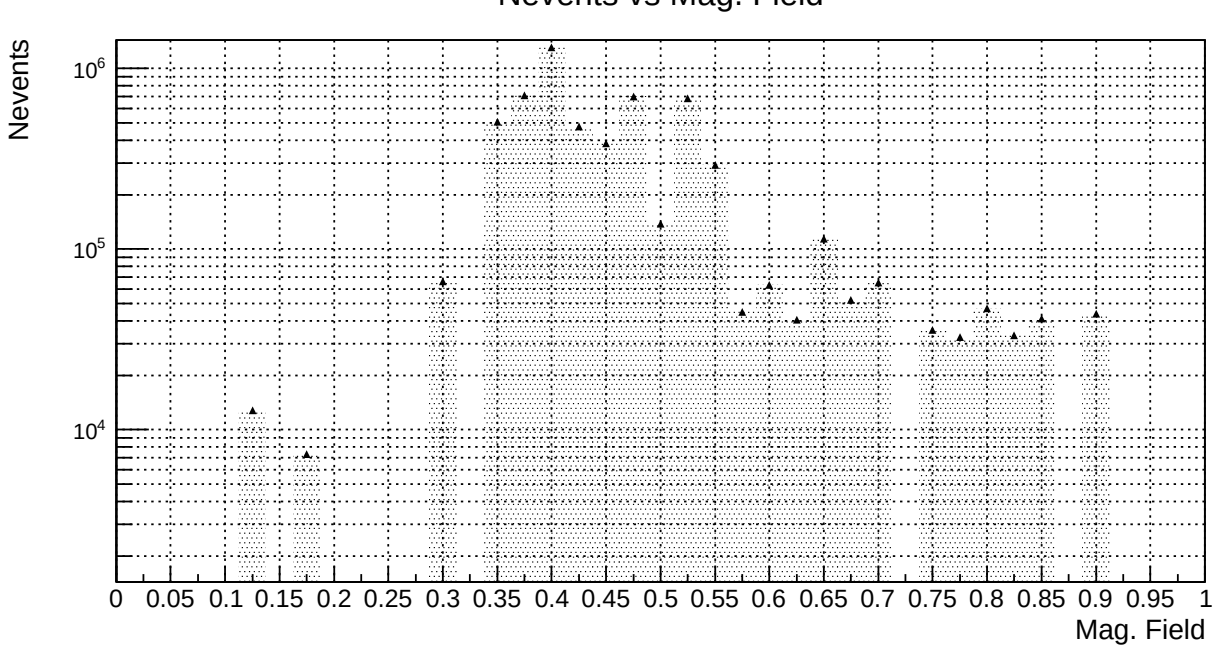


Figure 8: Number of events corresponding to magnetic field $H_{min}$.

Table 2: Number and fraction of experimental events corresponding to discrete value $H_{min}$.

| $H_{min}$ | $\mathbf{N_{events}}$ | $\eta, \%$ | $H_{min}$ | $\mathbf{N_{events}}$ | $\eta, \%$ |
|---|---|---|---|---|---|
| 0.025 | 0 | 0 | 0.525 | 683674 | 11.60 |
| 0.050 | 0 | 0 | 0.550 | 291605 | 4.95 |
| 0.075 | 0 | 0 | 0.575 | 44931 | 0.76 |
| 0.100 | 0 | 0 | 0.600 | 63088 | 1.07 |
| 0.125 | 12759 | 0.22 | 0.625 | 40522 | 0.69 |
| 0.150 | 0 | 0 | 0.650 | 114316 | 1.94 |
| 0.175 | 7337 | 0.12 | 0.675 | 52134 | 0.88 |
| 0.200 | 0 | 0 | 0.700 | 65417 | 1.11 |
| 0.225 | 0 | 0 | 0.725 | 0 | 0 |
| 0.250 | 0 | 0 | 0.750 | 35706 | 0.61 |
| 0.275 | 0 | 0 | 0.775 | 32633 | 0.55 |
| 0.300 | 66496 | 1.13 | 0.800 | 47109 | 0.80 |
| 0.325 | 0 | 0 | 0.825 | 33301 | 0.56 |
| 0.350 | 507115 | 8.60 | 0.850 | 41281 | 0.70 |
| 0.375 | 707595 | 12.00 | 0.875 | 0 | 0 |
| 0.400 | 1304350 | 22.12 | 0.900 | 43769 | 0.74 |
| 0.425 | 476333 | 8.08 | 0.925 | 0 | 0 |
| 0.450 | 385525 | 6.54 | 0.950 | 0 | 0 |
| 0.475 | 701039 | 11.89 | 0.975 | 0 | 0 |
| 0.500 | 138070 | 2.34 | 1.000 | 0 | 0 |