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# Upper limit to the cosmic-ray positron flux generated at the pulsar polar cap

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We have determined the upper limit to a possible positron flux excess with respect to the secondary component above a few GeV. This upper limit shows the same trend of the calculated flux of positrons generated at the pulsar polar cap above 20 GeV. Nevertheless, if $e^+$ production at the pulsar polar cap works fully in the whole sample of isolated pulsars in the Galaxy, a much larger excess of positrons is expected. At the present time, there is no evidence that outer gap electromagnetic energy losses explain observations, while it is estimated that gravitational wave emission can be disregarded. Within the next year the PAMELA experiment will allow us to confirm or disprove these speculations.

## 1. Introduction

Studies of the electron and positron energy spectra in cosmic rays shed light on many different aspects of cosmic-ray and fundamental physics (see for example [1] and references therein). Electrons outnumber positrons by about one order of magnitude ($e^-/p = 10^{-2}$; $e^+/p = 10^{-3}$). Consequently, they are considered of primary origin, generated at the cosmic-ray sources while positrons are estimated to be essentially of secondary origin, final products of the primary cosmic-ray interactions in the interstellar medium (ISM). Electrons and positrons are the smallest mass charged particles in cosmic rays. They undergo energy losses via inverse Compton scattering and synchrotron radiation during their propagation in the ISM. Only the most recent experiments carrying magnetic spectrometers have presented rejection factors against background contamination high enough to guarantee reliable observations of positrons. In fact, measurements carried out before middle 90s seemed to show a major excess of positrons [2] above a few GeV with respect to the estimate of the secondary component [3] . Many possibilities were suggested such as primary black hole annihilation, supersymmetric particle annihilation, pair production from photon-photon interactions, pair production in the pulsar magnetosphere, etc... (see for example [4] and references therein). Grimani ([1]) has shown that recent positron-to-electron ratio measurements are consistent with a mild excess of positrons when the uncertainty on the secondary calculations ([5]; [6]) is taken into account. This excess is compatible with a polar cap positron production [7] from young pulsars when a pulsar birthrate (PB) of one pulsar born every 200$\pm$100 years is considered. However, Lorimer has recently presented the results by Parkes radio telescope showing that 1/PB ranges in the interval 43-67 years [8] . Moreover in [9] it has been stressed that middle aged pulsars are supposed to be favoured over young ones in contributing to polar cap $e^+$ interstellar flux. These last clues might indicate additional electromagnetic energy losses at the pulsar outer gap ([10]; [11]) while gravitational wave emission are not supposed to be relevant except in the very first part of a pulsar life ([12] and references therein).

In this paper we present a different approach to the study of the most recent and accurate measurements of the $e^+/(e^+ + e^-)$ ratio above 7 GeV. We have carried out a $\chi^2$ test to the data. The upper limit to an extra $e^+$ component with respect to the secondary one has been obtained subtracting to the data best fit the lowest estimated values for the secondary $e^+/(e^+ + e^-)$ ratio [6]. The resulting flux seems to show the same trend of the $e^+$ flux produced at the pulsar polar cap ([7]) above 20 GeV.

**Table 1.** $\chi^2$ test to the $e^+/(e^+ + e^-)$ ratio data above 7 GeV

| Fit function | Fit result | dof | $\chi^2$/dof |
|---|---|---|---|
| Constant Value (k) | 0.0620±0.0032 | 18 | 0.74 |
| Power-law (A $E^{-\gamma}$) | 0.0796 $E^{-0.112}$ | 17 | 0.76 |
| Stephens calculations | - | 19 | 0.70 |
| Moskalenko & Strong | - | 19 | 6.59 |

## 2. Comparison of positron measurements to positron production models

In fig. 1 we have reported the $e^+/(e^+ + e^-)$ ratio data published during this last decade. Thin dashed and dot-dashed curves correspond to the positron fraction expected near Earth on the basis of the secondary $e^+$ calculations according to [5] and [6], respectively. References to the data and details are reported in [13]. The calculation by Protheroe ([3]) lies in the band between the Moskalenko & Strong and Stephens models above a few GeV. We reasonably assume that this band represents the uncertainty on the secondary positron production. When the measurements reported in fig. 1 are compared to this range of uncertainty, it can be noticed that a mild excess (if any) of positrons is found. In order to evaluate quantitatively this excess we have calculated here the $\chi^2$/dof when the data are best fitted with a constant function, with a power-law function or a comparison is made with the Moskalenko & Strong and Stephens calculations. This study has been carried out above 7 GeV where the solar modulation is supposed to play a minor role on particles of different charge. The results are reported in Table 1. It can be noticed that the best fits correspond to a constant value (thin continuous line in fig. 1) and to the Stephens model (the power-law function is found very flat and close to a constant). In case the Stephens model will be found correct, when low error measurements will be available between a few hundreds of MeV and hundreds of GeV, no excess of positrons will be claimed at all. In [1] it was shown that by taking into account the whole band of uncertainty for the secondary $e^+$ component above a few GeV, data are compatible with positron production at the pulsar polar cap with a PB of one pulsar born every 200±100 years when the model discussed in [7] is assumed. However, the Parkes result show that 1/PB ranges between 43 and 67 years [8]. This last evidence might indicate an $e^+$ component generated at the outer gap of pulsar magnetosphere. A comparison of $e^+/(e^+ + e^-)$ ratio measurements with outer gap models is reported in Fig. 1. Chi, Cheng and Young ([10]) consider an outer gap and a polar cap $e^+$ production in middle aged pulsars with 1/PB=100 years. A relevant excess of positrons (thick dot-dashed line in fig. 1) is expected when a secondary $e^+$ component is considered on the basis of the calculations by Protheroe. Zhang and Cheng ([11]) consider an outer gap model in middle aged pulsars and secondary calculations by Moskalenko and Strong. The predictions of their model with 1/PB of 30, 50 or 100 years are reported as thick solid, dashed and dotted lines, respectively, in fig. 1. Middle aged pulsars are considered to be favoured in producing $e^+$ and $e^-$ reaching the interstellar medium since an increasing fraction of them, versus age, lies outside host remnants even if the efficiency for $e^+$ production decreases. This case has been discussed in [9] on the basis of the model reported in [7], but it has been found that a much larger excess of positrons should be observed if $e^+$ polar cap production is fully working in all isolated pulsars. In [12] it has been stressed how even in a young pulsar, such as Crab, gravitational wave energy losses can be disregarded. As large uncertainties are in model normalization and data, we try to focus on the trend of a possible positron flux in excess with respect to the secondary component.

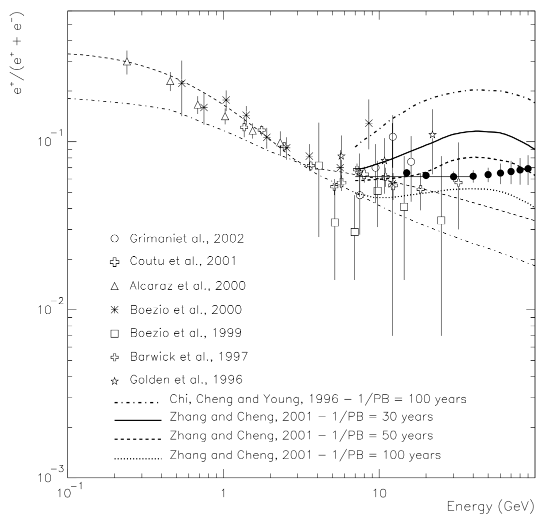


**Figure 1.** Positron fraction measurements in cosmic rays carried out during the last decade [13]. Thin dashed and dot-dashed lines represent the calculated secondary $e^+/(e^+ + e^-)$ reported in [5] and [6], respectively. See text for additional details.

## 3. Upper limit to the positron flux excess with respect to the secondary component

In order to set an upper limit to a possible extra positron component with respect to the secondary one, we have subtracted to the data best fit (constant value=0.0620) the Moskalenko and Strong calculations at the lower edge of the secondary band of uncertainty. In fig. 2 we have reported the obtained results (continuous line). The dot-dashed line indicates the Moskalenko and Strong secondary $e^+$ flux calculation. It is very interesting to notice that above 20 GeV the continuous line shows the same trend of the positron flux observed at ISM calculated in [7] when a normalization factor of 0.9 is applied (dotted line). In [7] the PB was chosen equal to one pulsar born every 30 years. With the 0.9 factor we have found PB=1/(30/0.9)=1/33 years, very close to the Parkes observations. We have chosen to draw the continuous thick line above 20 GeV because above this energy the pulsar polar cap $e^+$ flux is supposed to overcome the secondary one [7]. In fig. 1 solid dots represent the upper limit to the $e^+/(e^+ + e^-)$ ratio measurements expected for the PAMELA experiment next year in case this possibility will be confirmed. The finger print of this process is that the $e^+/(e^+ + e^-)$ ratio is supposed to slowly increase (up to 0.5) because of the steep trend of the secondary $e^+$ flux with respect to the $e^+$ flux generated at the polar cap as a function of the energy. In case the model by Zhang and Cheng will be found correct we expect for the PAMELA measurements the trend indicated by the dotted, dashed and continuous thick lines above 7 GeV in fig. 1.

## 4. Conclusions

An upper limit to the cosmic-ray positron flux in excess with respect to the secondary component has been determined. This upper limit shows the same trend of the $e^+$ flux generated at the polar cap of young pulsars with 1/PB of approximately 35 years above 20 GeV. The PAMELA experiment and experiments devoted to

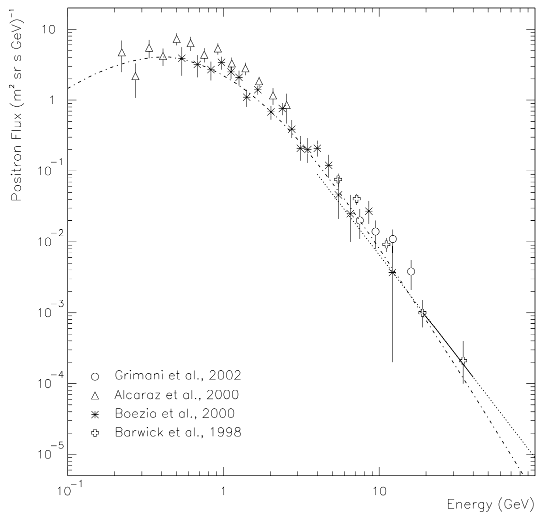


**Figure 2.** Positron energy differential flux measurements (see [13] for references to symbols). Data are compared to the secondary calculations by Moskalenko and Strong (dot-dashed line), to the positron flux from pulsar polar cap calculated in [7] (dotted line) with a normalization factor of 0.9, and to the extra positron component (continuous line) obtained when the secondary component calculated my Moskalenko and Strong has been subtracted from the data best fit.

pulsed gamma-ray measurements (such as GLAST) will allow us to verify this possibility by clarifying the role of the processes for $e^+$ and $e^-$ production in the magnetosphere of pulsars of different age.

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