Experimental study at CERN of a positron source using channeling

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Abstract

Axially oriented crystals, penetrated by high energy electrons, are powerful photon sources and, henceforth, intense positron sources. Such kinds of positron sources have been studied experimentally at CERN, during the summers 2000 and 2001, with the tertiary electron beam of the SPS having an energy of 6 and 10 GeV. Four and eight mm thick tungsten crystals and a compound target made of a 4 mm crystal followed by a 4 mm amorphous disk, were used with an orientation along the $< 111 >$ axis. A 20 mm tungsten amorphous target was also used. The positrons were detected by a Drift Chamber, partially immersed in a magnetic field, of 0.1 or 0.4 Tesla, working as a magnetic spectrometer in the positron energy range up to 150 MeV. The magnetic field was parallel to the wires. The positron trajectories were reconstructed in the Drift Chamber and allowed the determination of the energy spectrum and of the angular distribution for all the targets. Significant enhancements were observed for the crystal source when compared to the amorphous one. The gain was larger than 4 for the 4 mm target and larger than 2 for the 8 mm and the compound target when the crystal was aligned with the beam direction, compared to the non-aligned case corresponding to an amorphous target. These results are described after short presentations of the experimental set-up and of the method of track reconstruction.

INTRODUCTION

The objective of the experiment is to measure the enhancement in positron production when the incident electron beam is in channeling conditions - at glancing angles to the rows- in a crystal. The main physical parameters, which can be measured, are the emission angle and the momentum of the positrons. These quantities are needed to determine the phase space of such positron source for a comparison with the conventional one in the framework of a possible use in the future e^+e^- linear colliders.

The interest

- a large number of soft photons giving correspondingly a large number of soft positrons easily captured by the known optical matching devices
- a thinner thickness for the targets leading to less energy deposition

Moreover, the difficulties encountered by the conventional devices where excessive heating and mechanical stresses are met brings some additional interest.

We present here:

- some preliminary results of our experiment

The experimental conditions

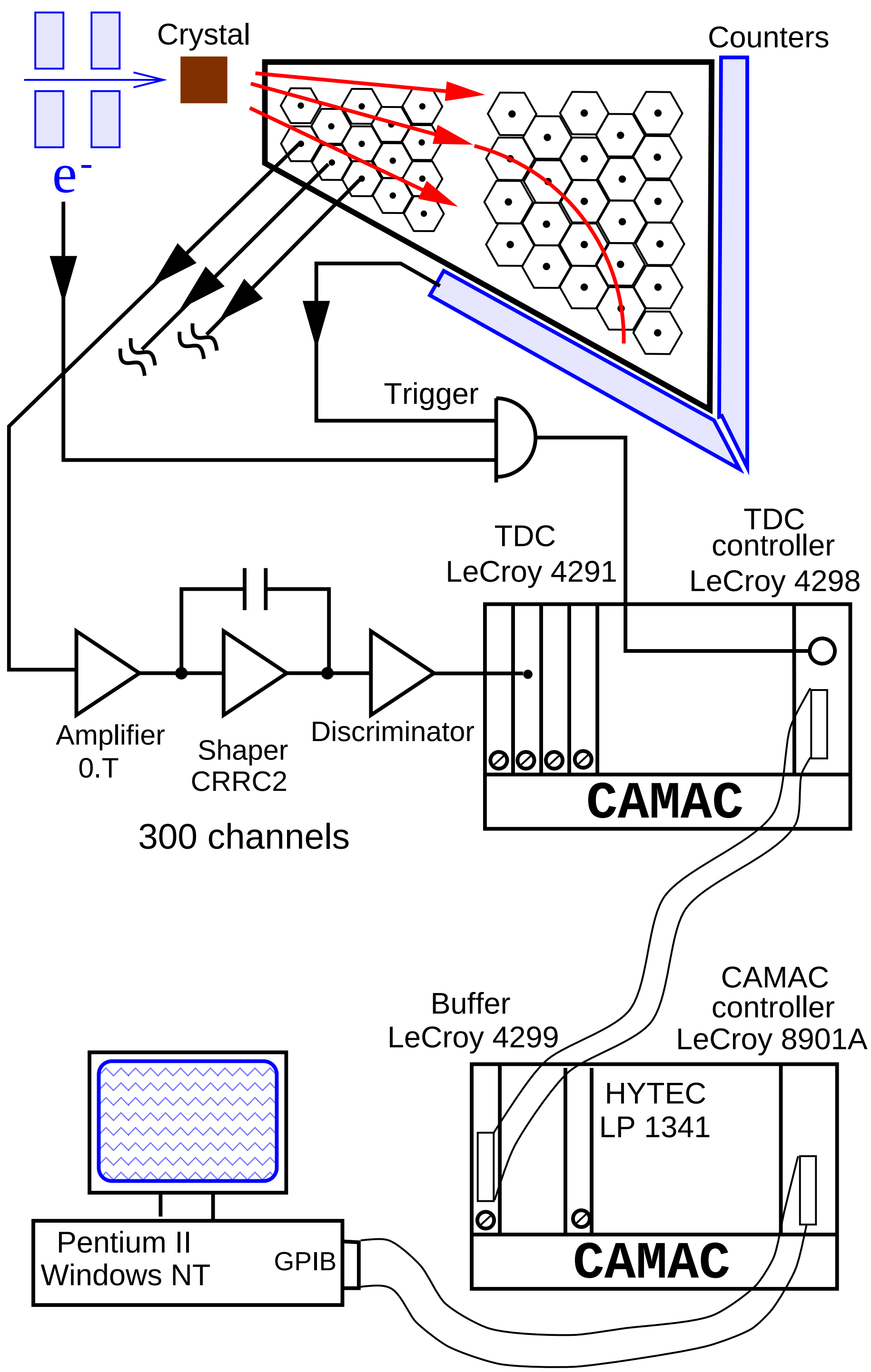
An experiment has been carried out during two weeks in July—August 2000, after a calibration run at the end of May 2000. The experiment was resumed in July 2001. The experiment installed on the X5A transfer line of the SPS provided data on the positrons and photons created in the tungsten targets:

- **a 4 mm thick crystal,**
- **a 8 mm thick crystal,**
- **a compound target made of a 4 mm crystal followed by a 4 mm thick amorphous disk,**
- **an amorphous tungsten target 20 mm thick**

The electron incident energy was taken in the range 5 to 40 GeV mainly at 6 and 10 GeV. The positrons were measured in a magnetic spectrometer made of a Drift Chamber partially immersed in a magnetic field; two values of the magnetic field were used: 1 and 4 kGauss. These field values allowed to investigate the energy domain up to 80—100 MeV. Data has been taken on:

- **the Drift Chamber (DC),**
- **the positron counters installed on two lateral walls of the DC, with a specific domain of acceptance for each of them, with respect to the positron energy level,**
- **the preshower and the calorimeter for the photons.**

The experimental set-up

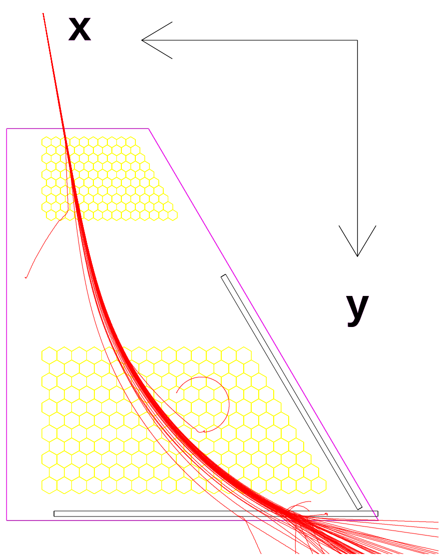


The results obtained with reconstructed positron tracks

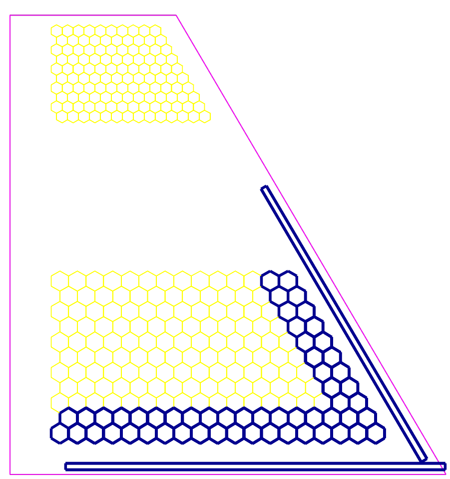
A reconstruction process, taking into account the actual magnetic field distribution in the Drift Chamber, has been operated.

- Magnetic field = 1 or 4 kGs as maximum value with fringe field at the entrance of the Drift Chamber
- Method of templates (trajectories of determined energy and angle)
  - influence of interaction processes in the medium is studied
  - geometrical track ∼ average track for tracks affected by multiple scattering
  - angular domain: -5^{o} *to* 35^{o} (steps of 0.5^{o})
  - energy domain: 5 *to* 150 MeV (steps of 1 MeV)
- Parametrisation with 9-degree polynomial [$y(x)$]

  Coefficients are stored in the database



Set of positron tracks with energy 20 MeV and angle 10^{o} simulated by GEANT. Magnetic field is 1 kGs.



Sketch of the DC with the positron counters and the cells near to the lateral walls.

The reconstruction programme makes 2 maps of the functions:

$$L_0(E_i^{\pm}, \theta_k^{\pm}) = \frac{1}{N_1 + N_2} \sum_{n}^{N_1+N_2} \exp\left(-\frac{\mid d_n - r_n \mid}{\lambda}\right), \tag{1}$$

$$L_2(E_i^{\pm}, \theta_k^{\pm}) = \frac{1}{N_2} \sum_{n}^{N_2} \exp\left(-\frac{\mid d_n - r_n \mid}{\lambda}\right) \quad with\ \lambda = 1cm, \tag{2}$$

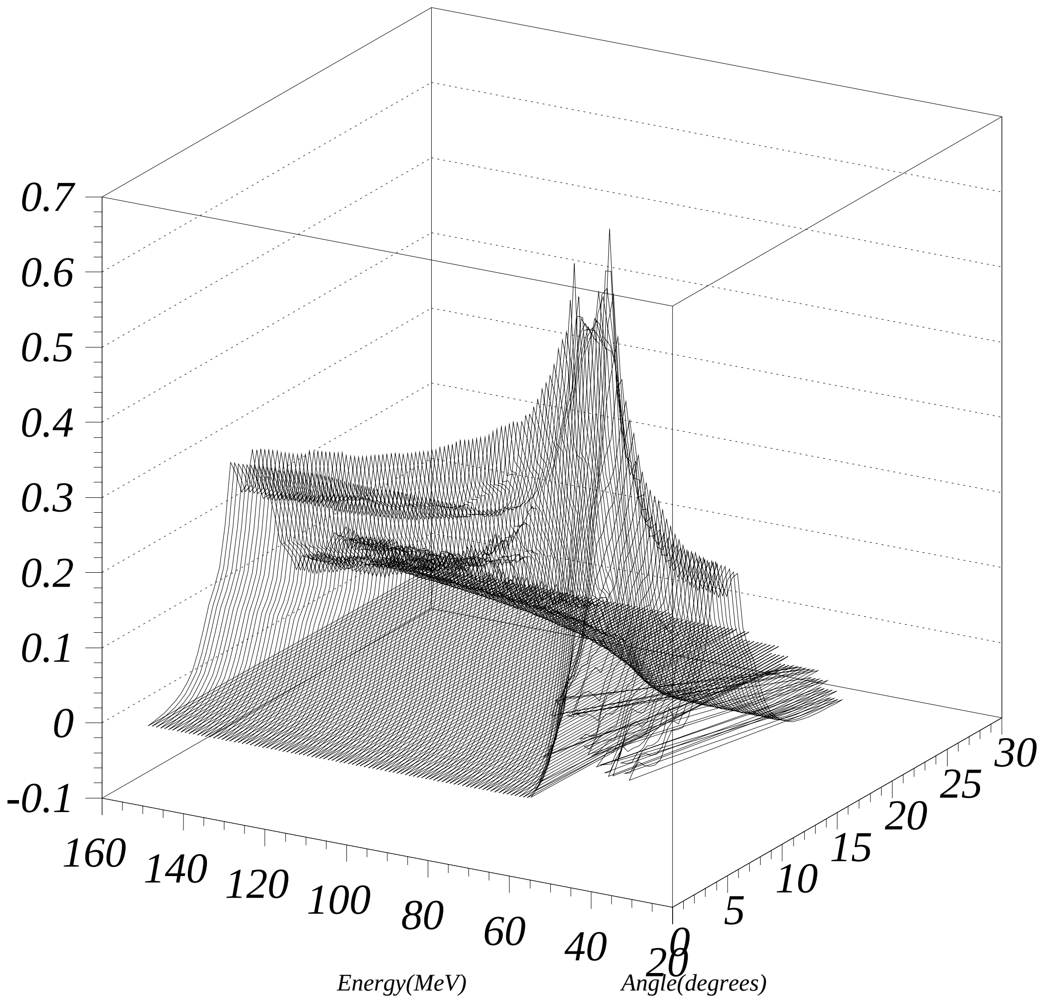
representing the distance between the simulated tracks of known initial angle and energy and the hitted wires of the DC.

Indexes 1 and 2 mean DC1 (part of the DC outside of the magnetic pole) or DC2 (part of the DC inside of the magnetic pole), N — number of hitted wires, $\lambda = 1$ cm — coefficient characterising the dimension of the DC cells, d_n[cm] — distance between the track $(E_i^{\pm}, \theta_k^{\pm})$ and the n-th wire, r_n[cm] — the radius calculated from TDC value of the n-th wire.

$\theta_k^{\pm} > \theta_{lim} = 5^{\circ} \rightarrow L_0$

$\theta_k^{\pm} <= \theta_{lim} = 5^{\circ} \rightarrow L_2$

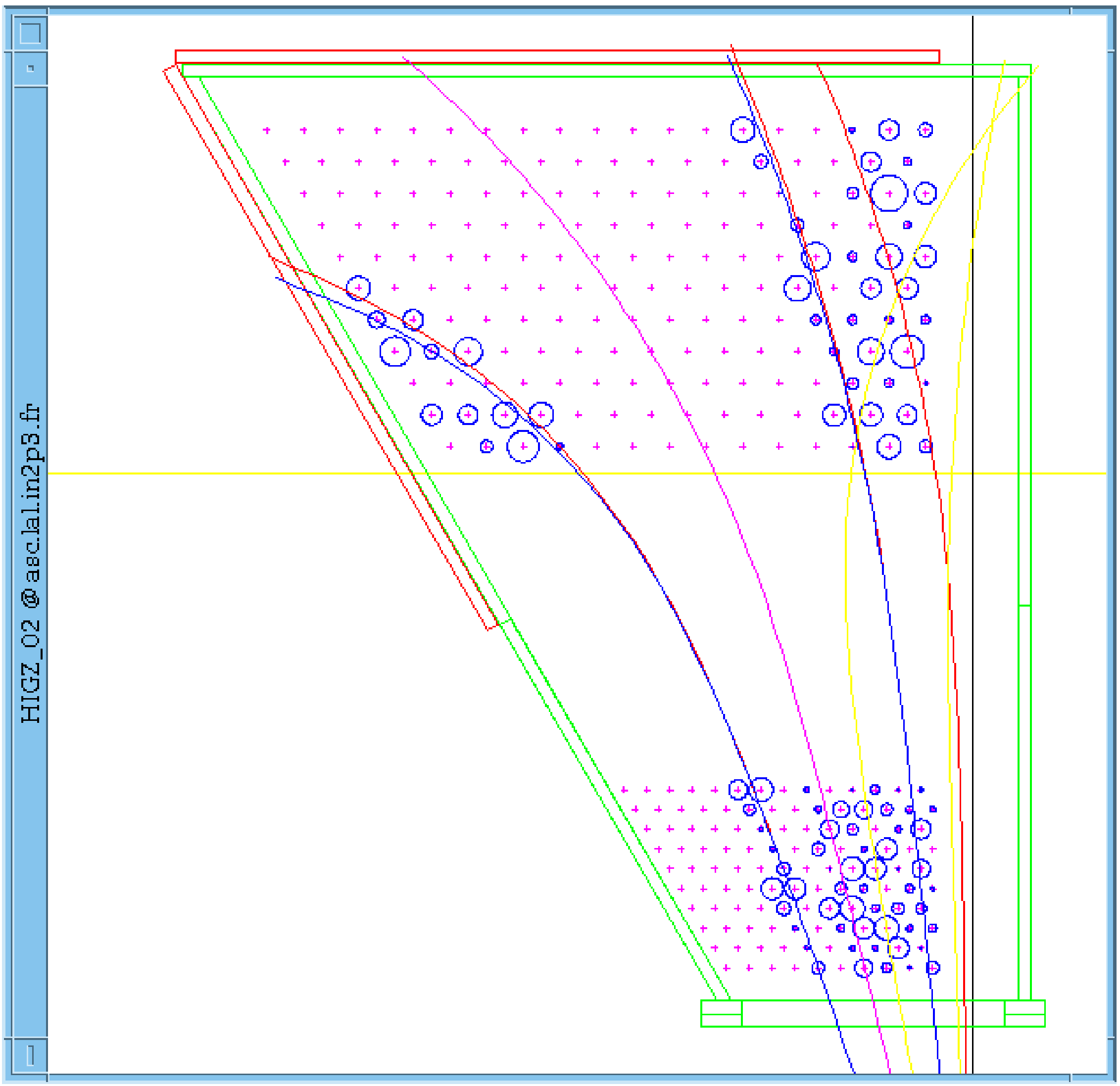
Peaks on the map $L_{0/2}(E_i^{\pm}, \theta_k^{\pm}) \rightarrow$ real tracks.



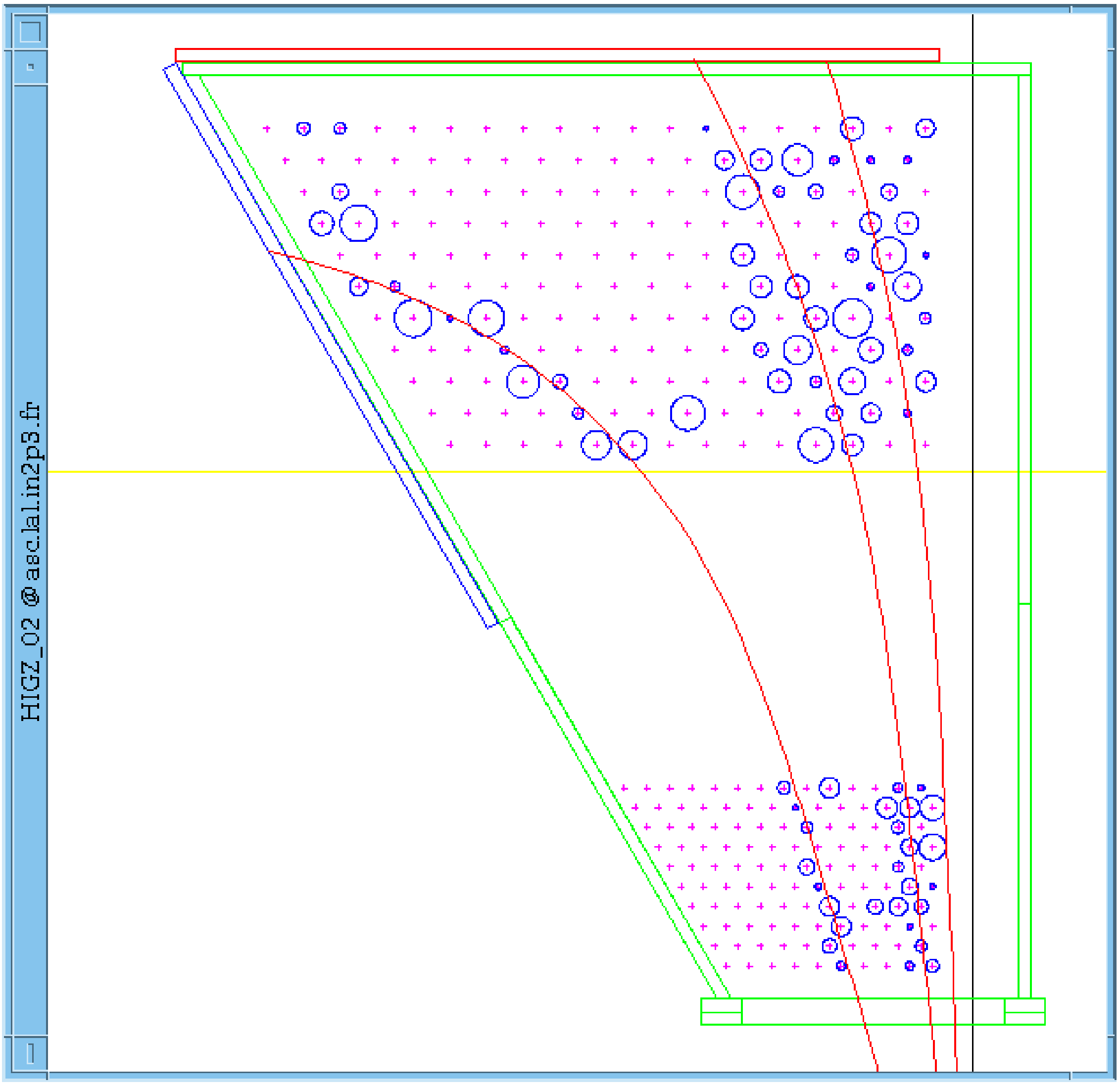
Distribution $L_{0/2}(E_i^{\pm}, \theta_k^{\pm})$ for two simulated positron tracks:

(57 MeV, 8°), (71 MeV, 10°).

Example of the simulated event for 8 mm crystal, energy 10 Gev, DC magnetic field 1 kGs



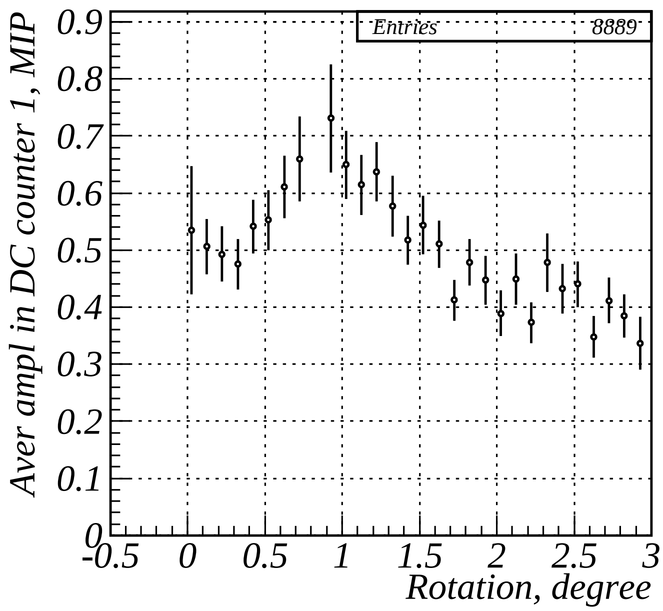
Example of the experimental event for 8 mm crystal, energy 10 Gev, DC magnetic field 1 kGs



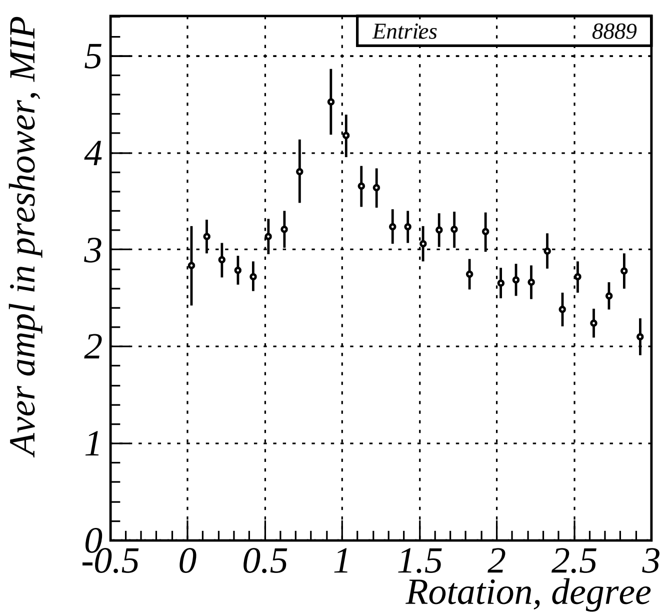
Rotation scan

The 8mm crystal target, 10 GeV, 4kGs. Amplitude of the signal normalised per energy deposition from minimal ionised particle.

Average amplitude on DC counters 1.

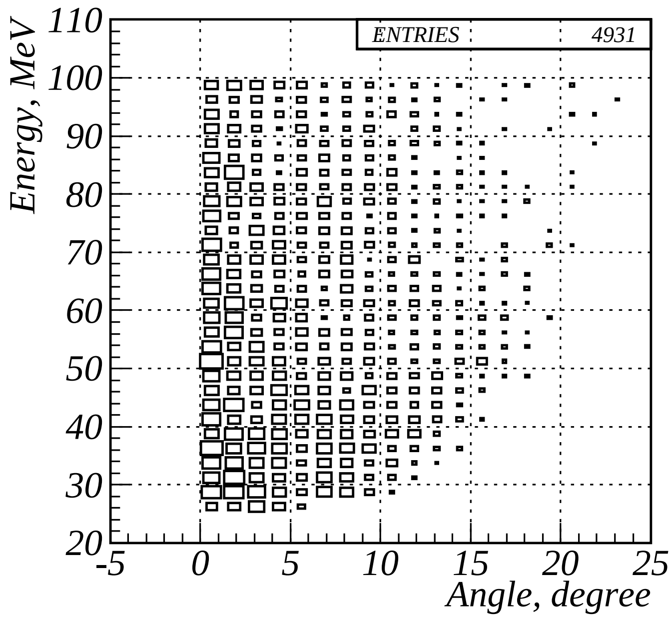


Average amplitude on preshower.

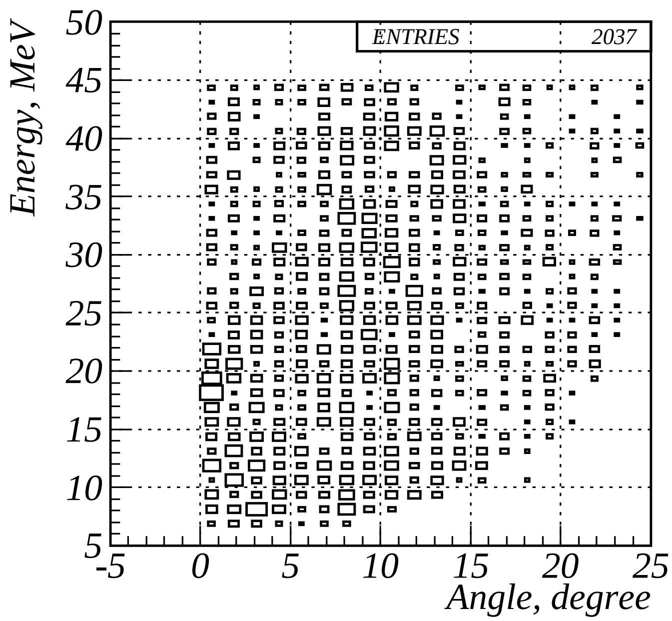


Density of the reconstructed tracks (e^+) with chamber

the 8mm crystal target, 10 GeV, 4kGs



the 8mm crystal target, 10 GeV, 1kGs



Results on 8 mm crystal, 10 Gev

For the "good" events selection the following cuts were supplied:

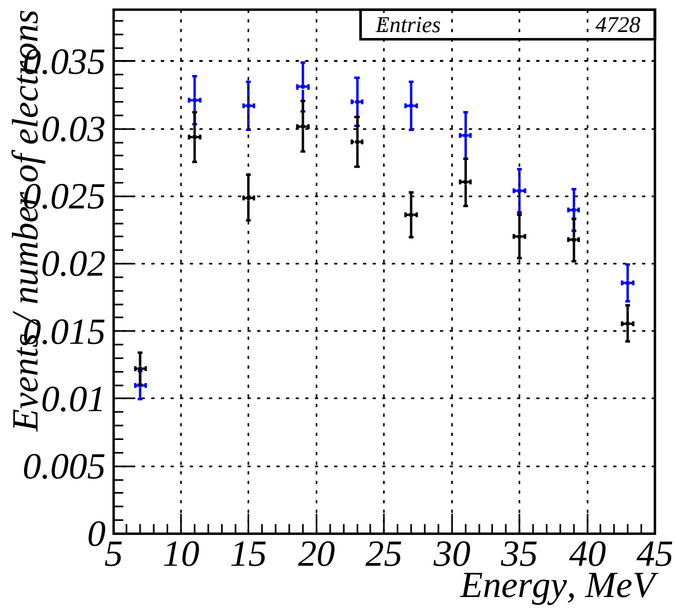
1. reconstructed energy $< 45 MeV$;
   reconstructed angle > 0 degree;
2. the "side" positron counters should have a signal if the particle horizontal angle < 7 degree; one of the positron counters should have a signal if this angle > 7 degree.

All results presented for DC magnetic field 1 kGs.

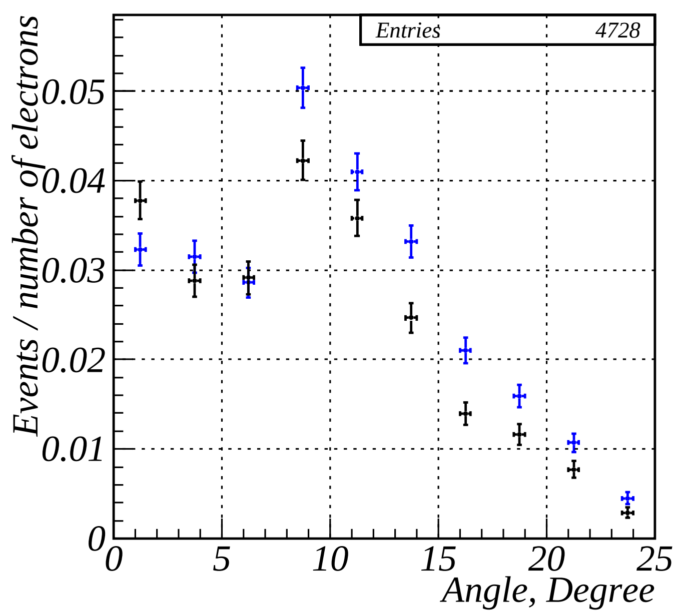
Simulation and experiment

Blue points — simulation. Black one — experiment. 8 mm crystal, 10 GeV.

Energy spectrum.



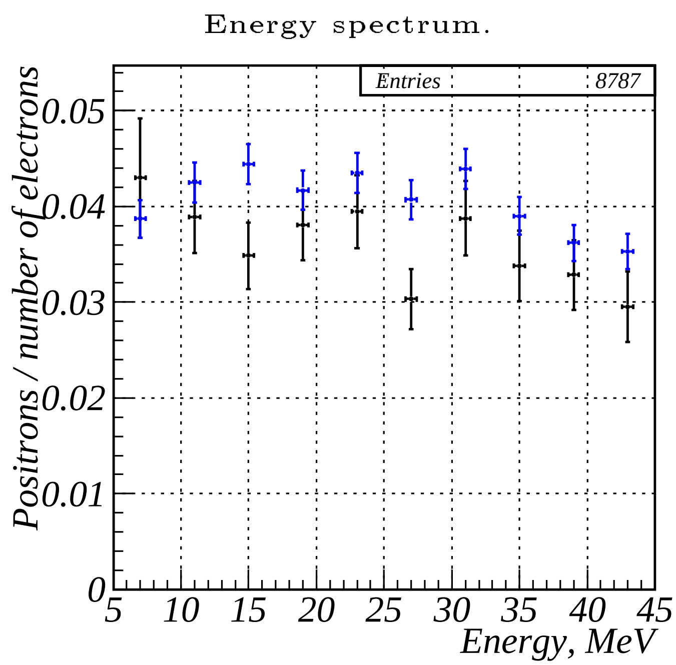
Angular spectrum.

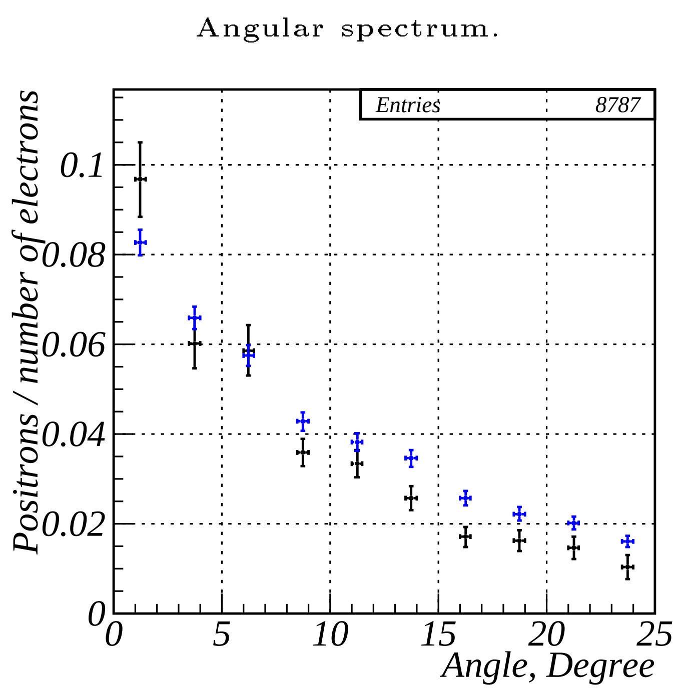


Simulation and experiment

Corrected by efficiency.

Blue points — simulation. Black one — experiment. 8 mm crystal, 10 GeV.

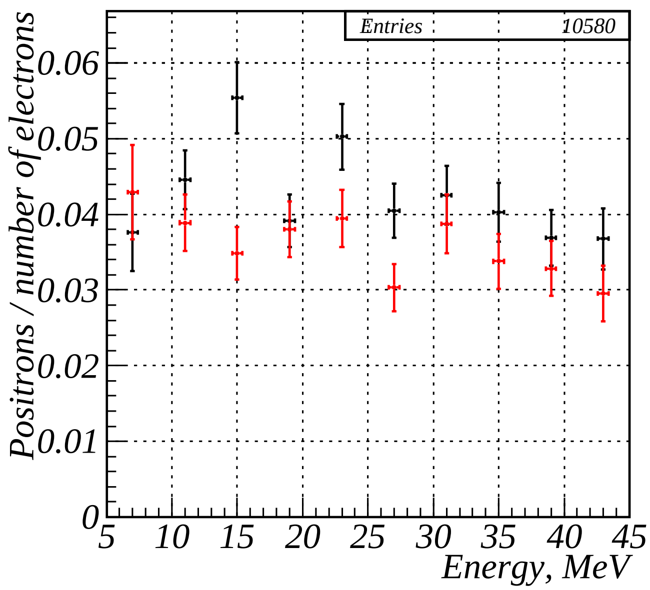




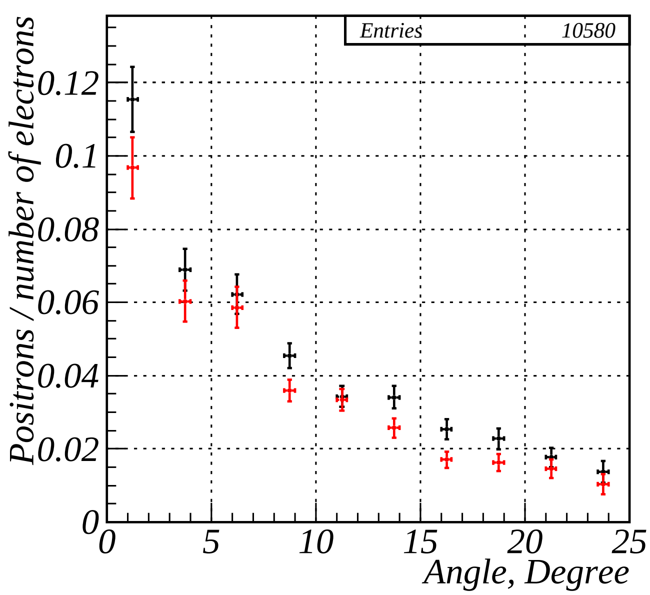
Comparison data from 2000, 2001

Corrected by efficiency. Red points — year 2001. Black one — 2000. 8 mm crystal, 10 GeV.

Energy spectrum.



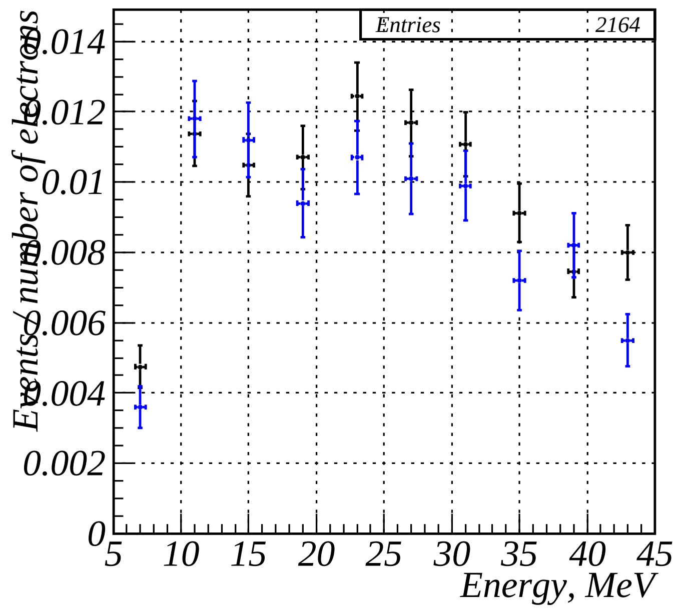
Angular spectrum.



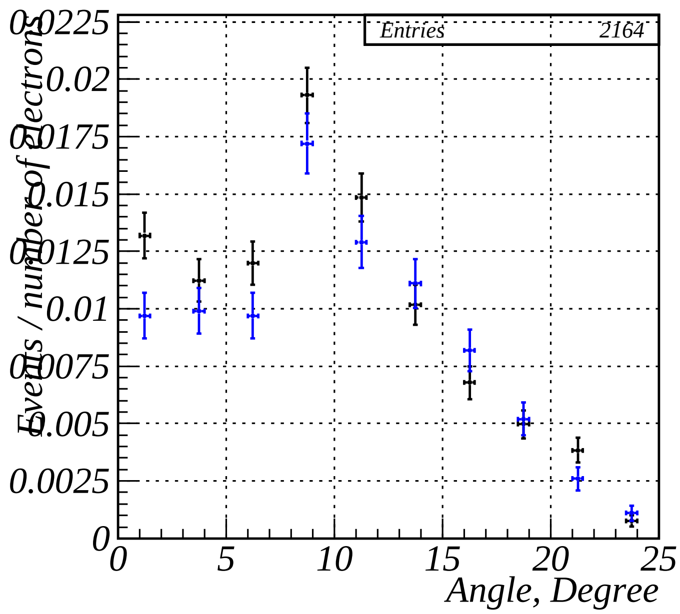
Amorphous 8mm target

Blue points — simulation. Black one — experiment. Energy 10 GeV.

Energy spectrum.



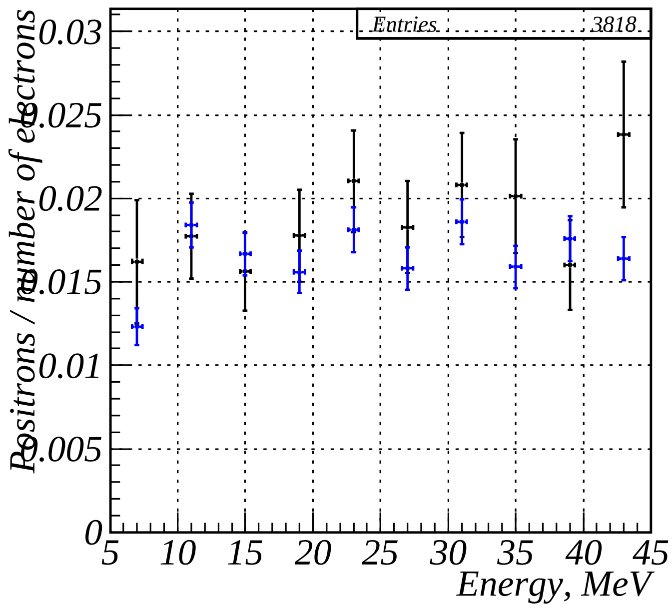
Angular spectrum.



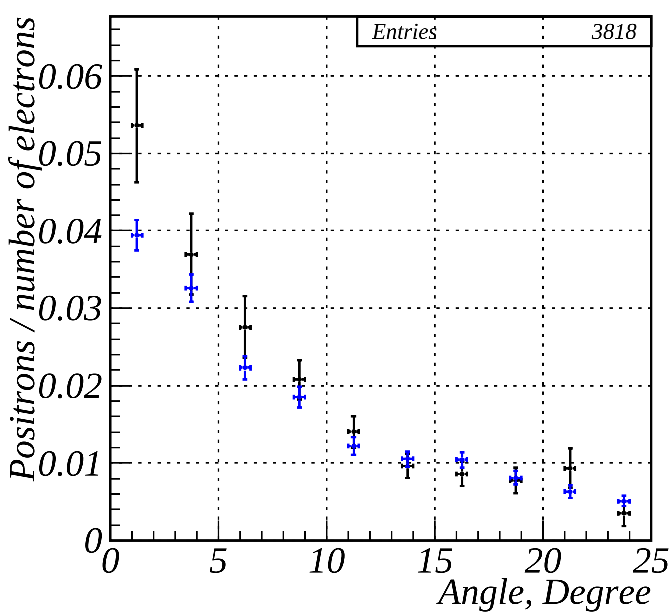
Amorphous 8mm target

Corrected by efficiency. Blue points — simulation. Black one — experiment. $E = 10\ GeV$.

Energy spectrum.

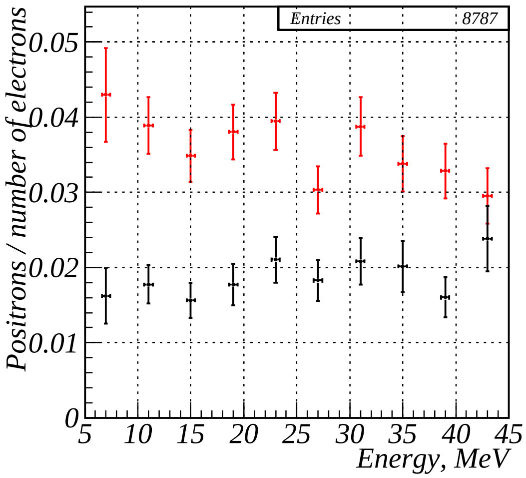


Angular spectrum.

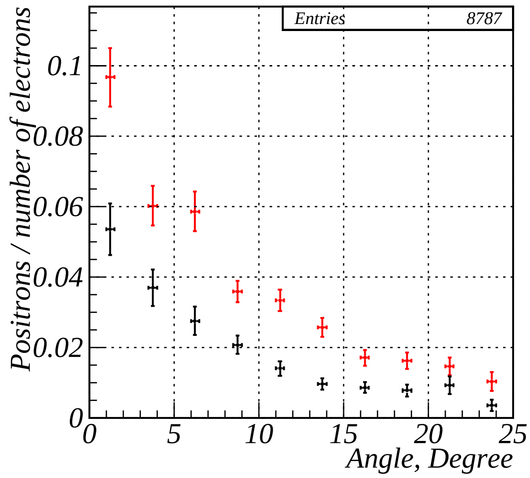


Crystal and amorphous targets

Corrected by efficiency. Red points — crystal. Black one — amorphous. 8 mm, 10 GeV

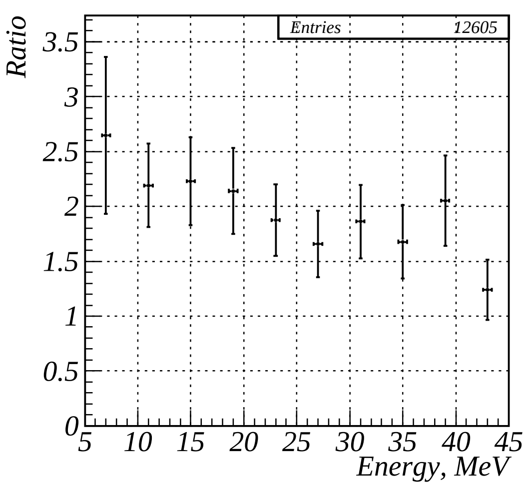


Energy spectrum

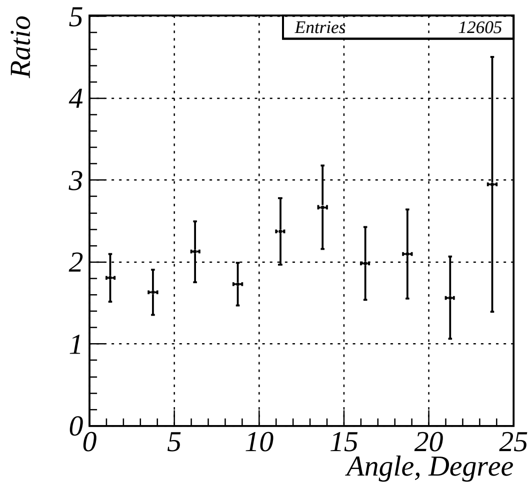


Angular spectrum.

Positrons ratio between crystal and amorphous targets



Energy spectrum

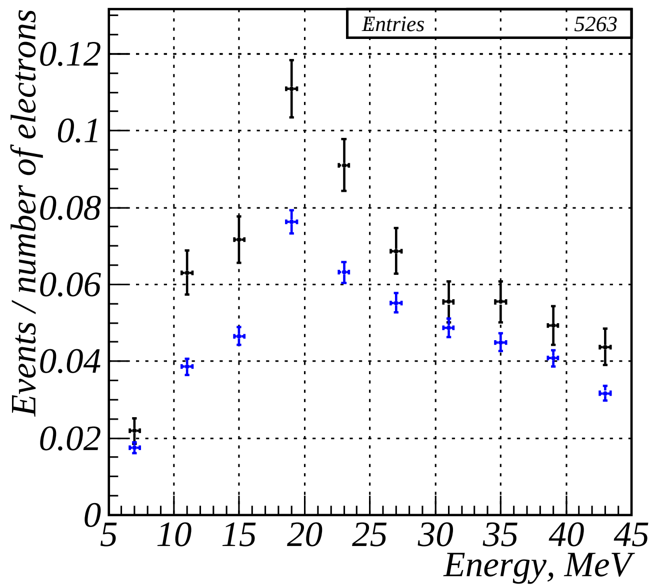


Angular spectrum.

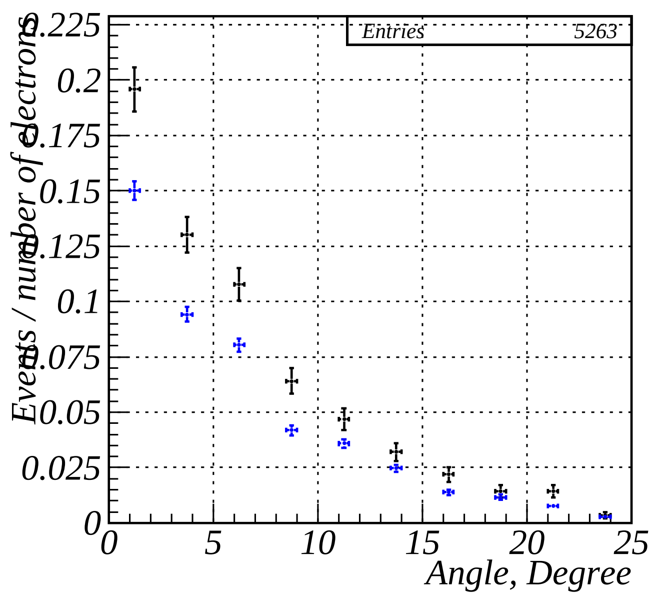
Crystal 8 mm & 20 mm amorphous

Blue points — 8mm crystal. Black — 20 mm amorphous. Energy 10 GeV.

Energy spectrum.



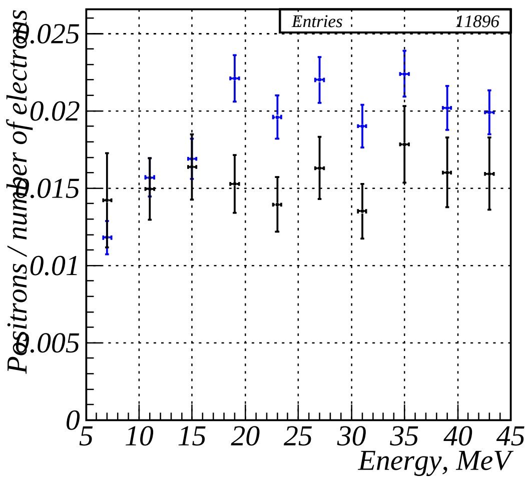
Angular spectrum.



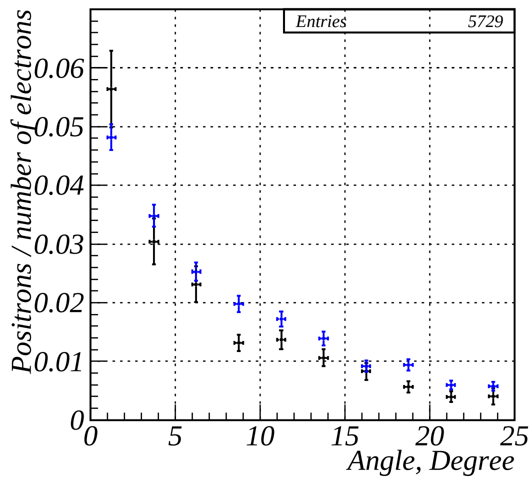
4 mm targets, 10 Gev, 1 kGs

Corrected by efficiency. Blue points — simulation. Black one — experiment.

Crystal target

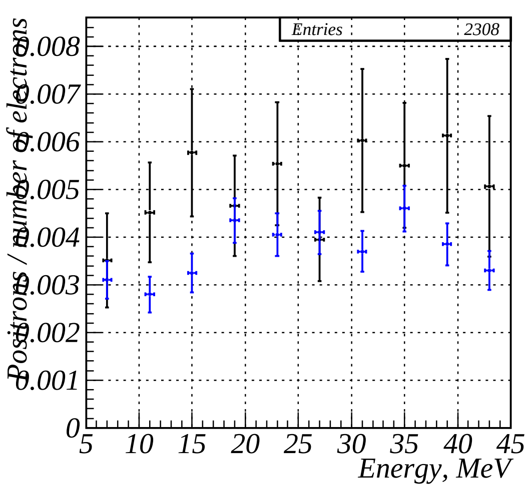


Energy spectrum

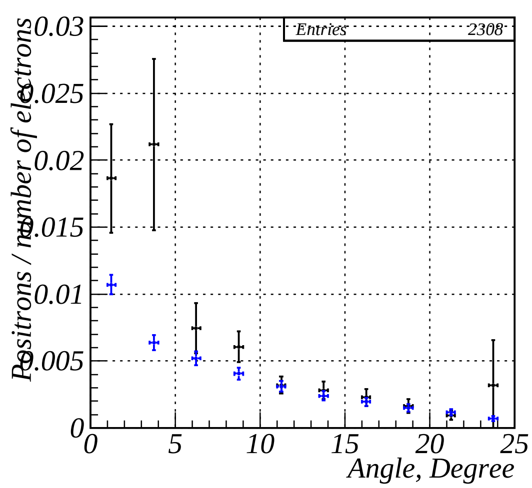


Angular spectrum.

Amorphous target



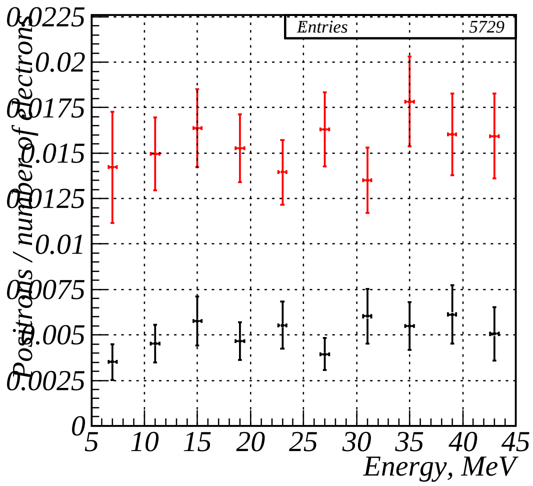
Energy spectrum



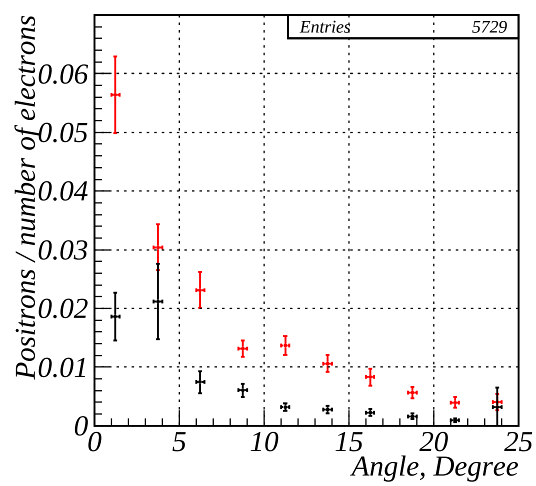
Angular spectrum.

Crystal / amorphous 4mm targets

Corrected by efficiency. Red points — crystal. Black one — amorphous. Energy 10 GeV

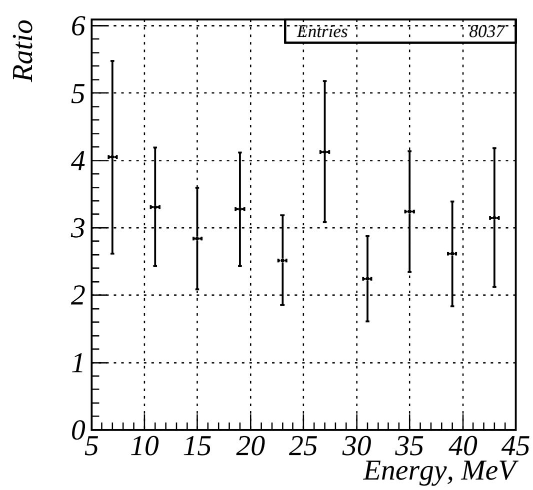


Energy spectrum

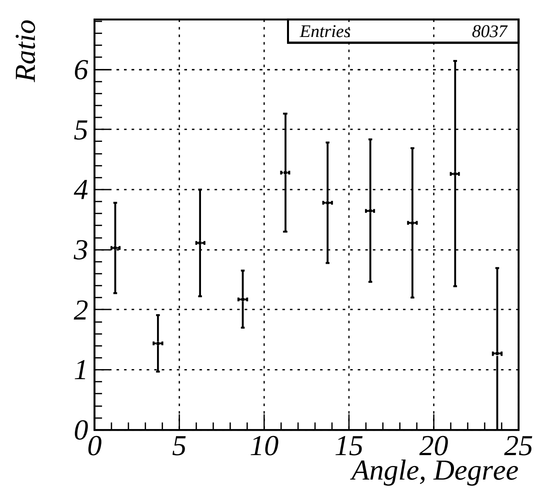


Angular spectrum.

Positrons ratio between crystal and amorphous targets



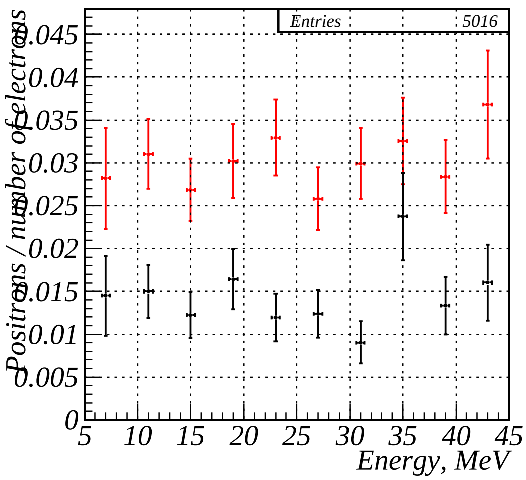
Energy spectrum



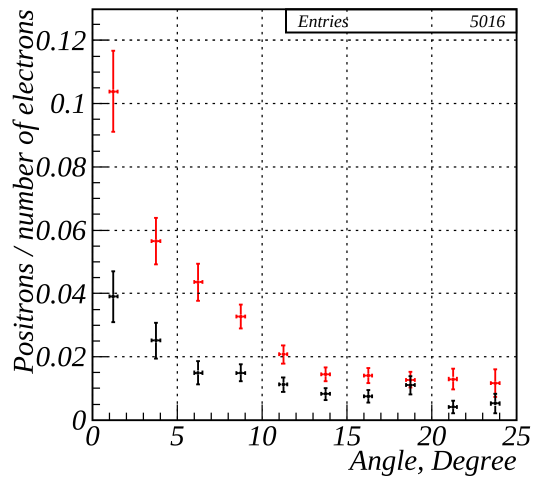
Angular spectrum.

8 mm targets, 6 GeV, 1 kGs

Corrected by efficiency. Corrected by efficiency. Red points — crystal. Black one — amorphous.

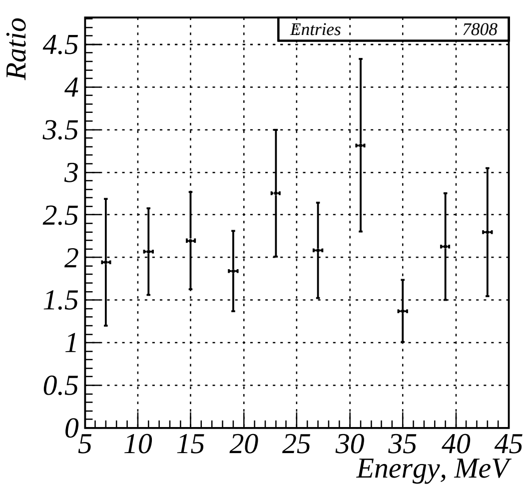


Energy spectrum

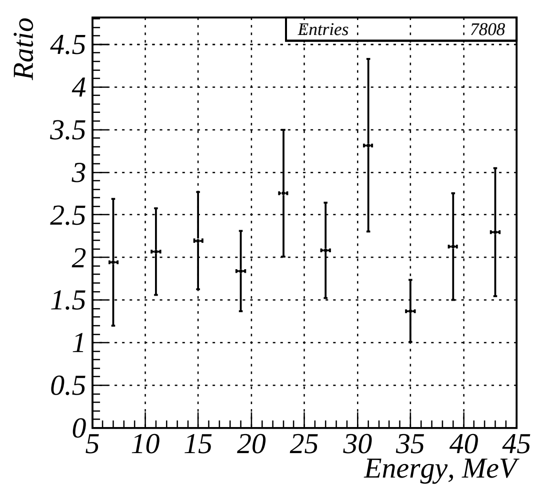


Angular spectrum.

Positrons ratio between crystal and amorphous targets



Energy spectrum



Angular spectrum.

SUMMARY / CONCLUSIONS

- the reconstruction programme works
- the experimental results are in good agreement with the simulations
- enhancements in e^+ production for the 4 mm as for the 8 mm crystal, for 10 and 6 GeV electron beam, are noticeable when comparing crystal and amorphous targets of the same thickness
  - enhancement somewhat larger than 3, for the 4mm target;
  - enhancement somewhat larger than 2, for the 8 mm target;
- in the regions of interest (in energy and angle) the enhancements show good perspectives for low energy and small angle positrons. This is more pronounced for the 4 mm target
- Estimation of systematic error (difference between simulation and experiment, between different experiment) is 20 %. Further analysis is necessary for decreasing the systematic error
- photon detectors used mainly for crystal orientation gave also indications on the enhancement in photon production on the axis
- The preliminary results represent an analysis of part of the gathered data. The full analysis will be completed in nearest future