# Search for an exotic three-body decay of ortho-Positronium (o-Ps)

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For more detail see hep-ex/0206054

# Motivation of the experiment

Long standing 5□ discrepancy between measured and predicted decay rate of ortho-positronium ($e^+e^-$ bound system in triplet spin state (o-Ps)).

Recently confirmed by Adkins et al. calculations up to $□^2$.

Might be explained by an exotic decay of o-Ps if the BR □ $10^{-3}$ .

Exotic decay of o-Ps in □X ,□□X, **invisible (but not in vacuum), 2□, 4□ has been extensively searched and definitely they are not the source of this discrepancy.**

# Search for the exotic decay of ortho-Positronium (o-Ps)

$$e^+e^-(o\text{-}Ps) \rightarrow \gamma + X_1 + X_2$$

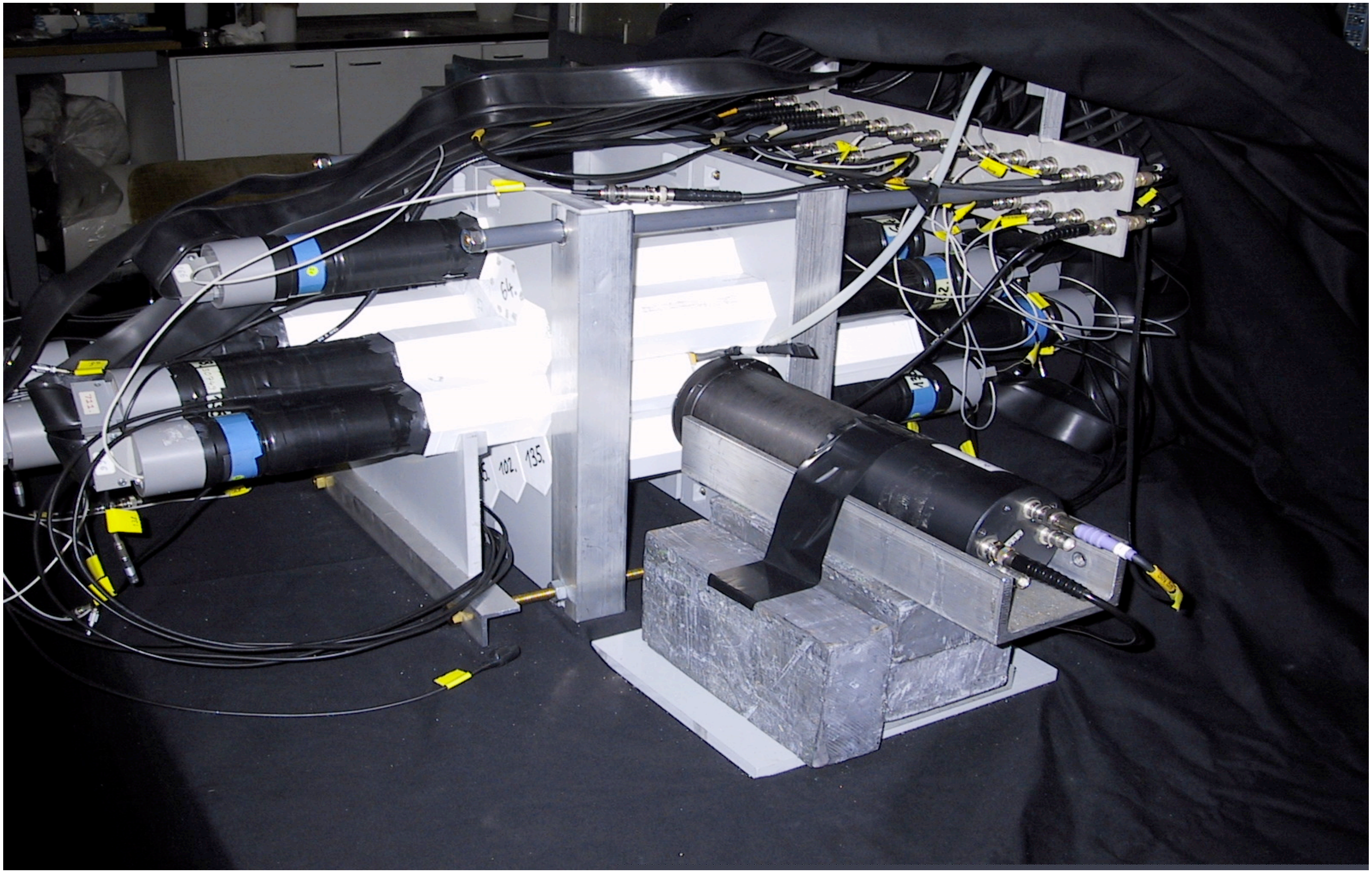
Two weak interacting massive particles

This three-body decay mode could be the origin of the discrepancy.

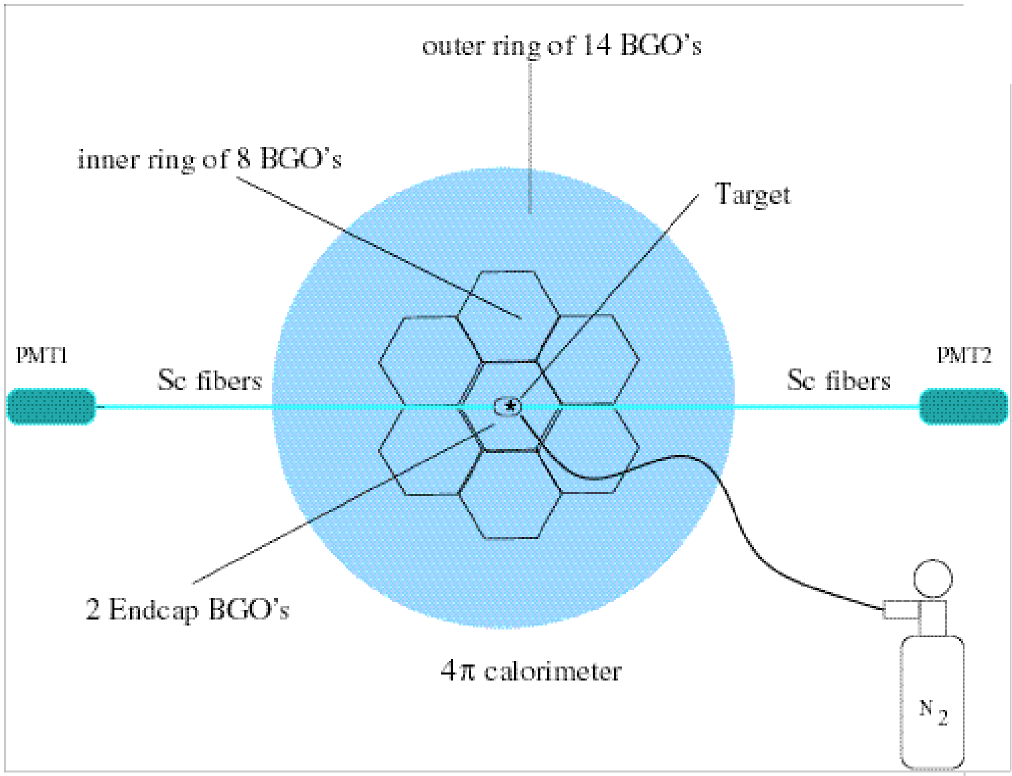
Astrophysics gives a strong constraint, but we wanted to excluded it directly.

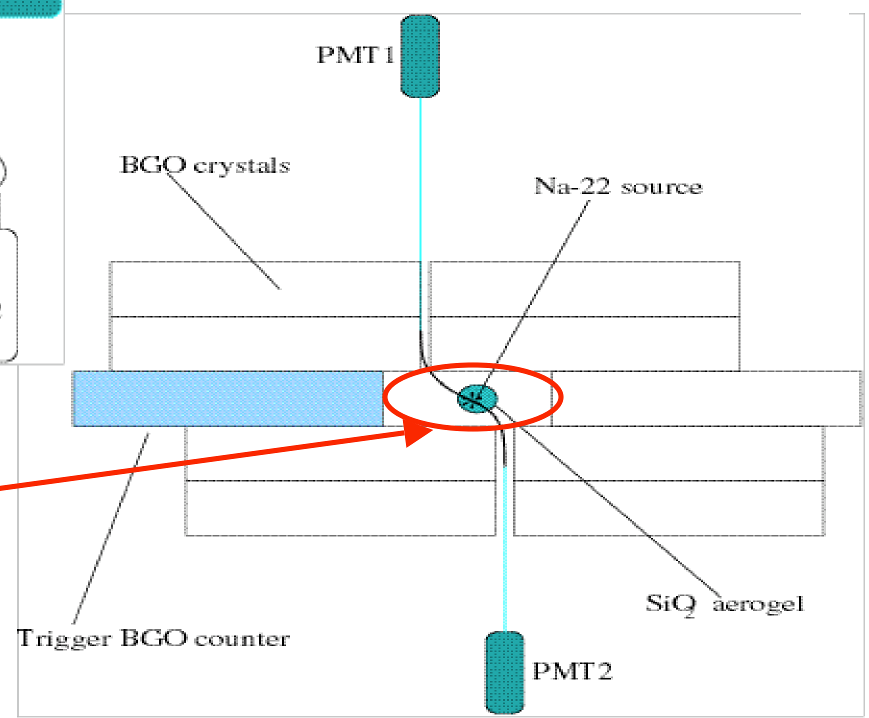
The signature of such an event will be a single photon detected in a hermetic calorimeter accompanied by no other energy deposition.

# Photograph of the calorimeter



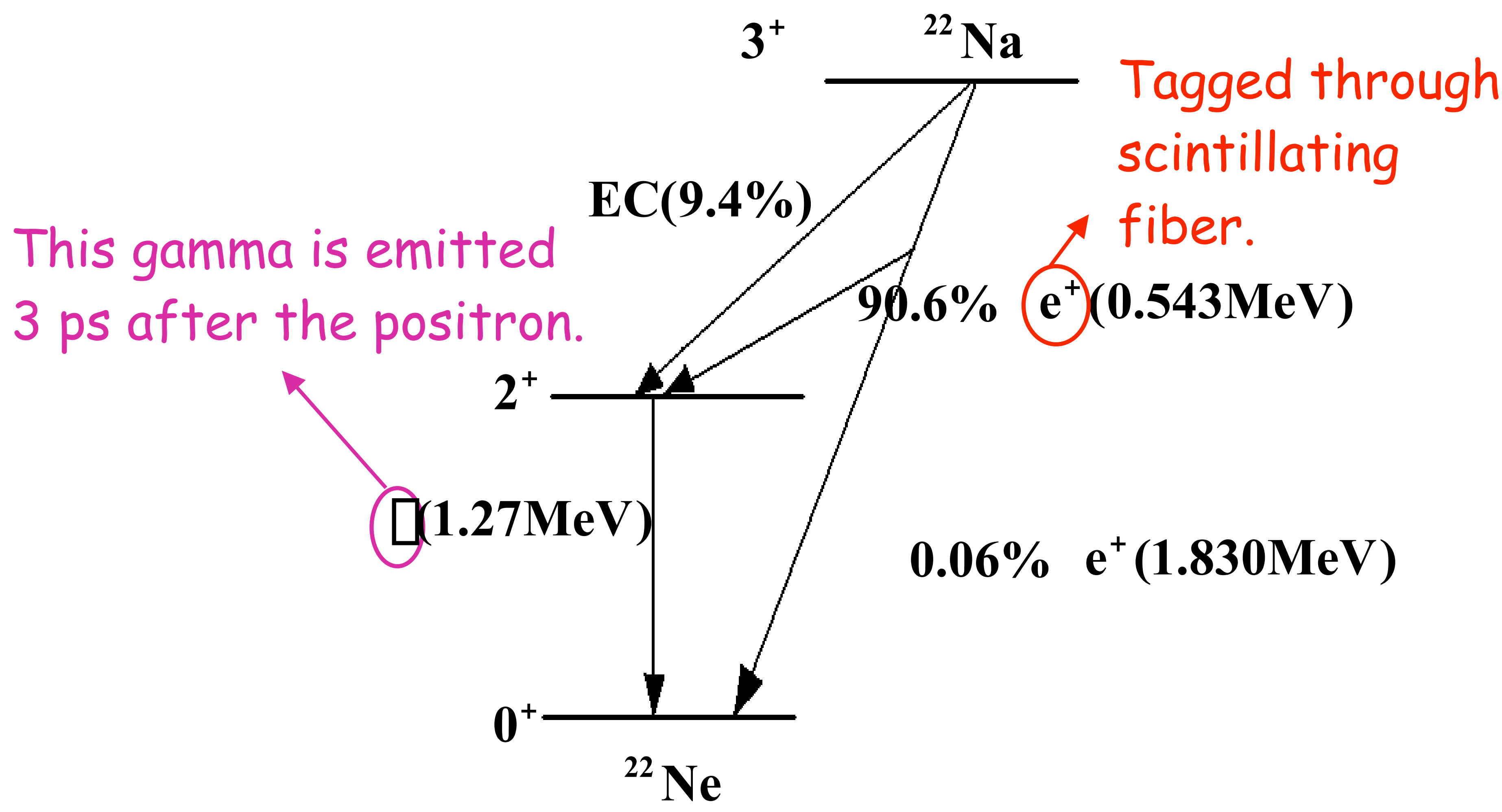
# Front and top view of the calorimeter



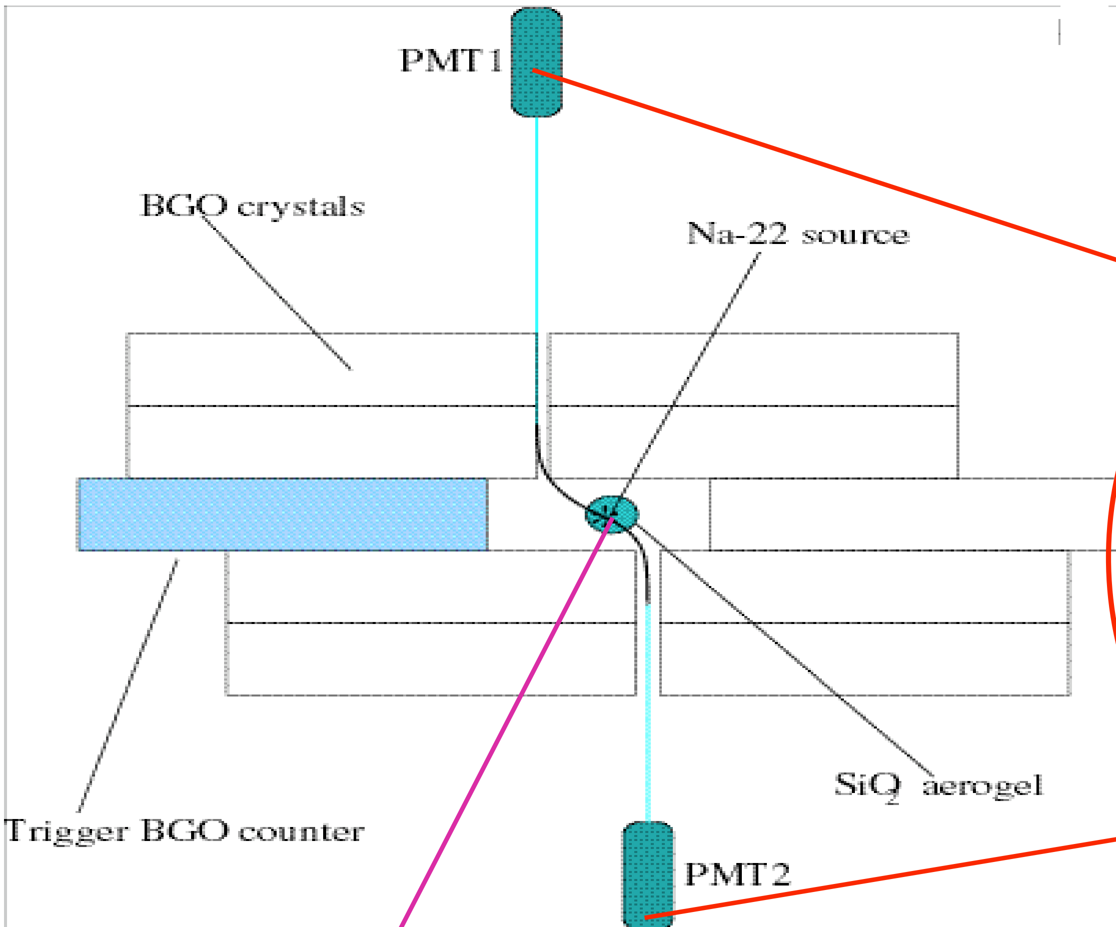




Region of positronium formation

# Description of the source



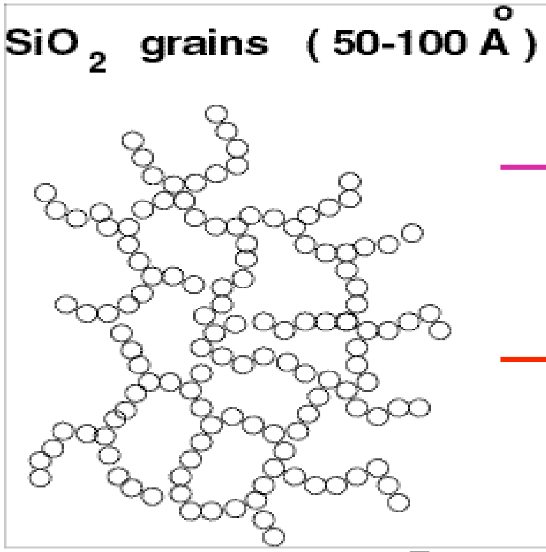
# Positrons tagging




$^{22}$Na source
3.6kBq

The positrons are tagged when the signals from the 2PMT's are in coincidence, then the gate opens.

# Target




After the fiber the positrons enter the Aerogel

→ Positronium can form inside the grain

→ It can migrates in the inter granular space where it decay almost freely

$e^+e^-$(singlet) $\rightarrow \gamma\gamma$ $\tau \approx 125$ps (in vacuum)

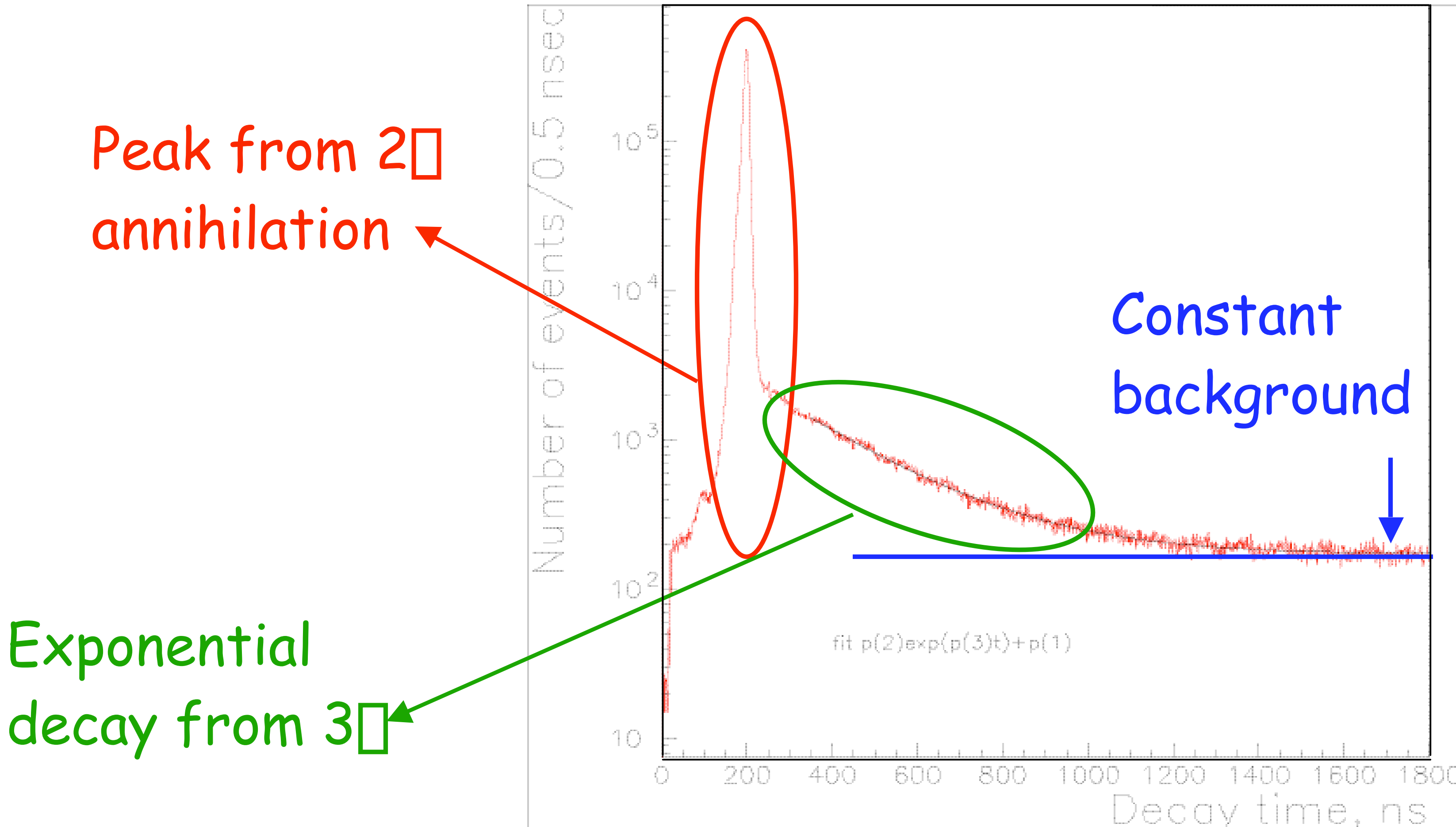
or

$e^+e^-$(triplet) $\rightarrow \gamma\gamma\gamma$ $\tau \approx 142$ns (in vacuum)

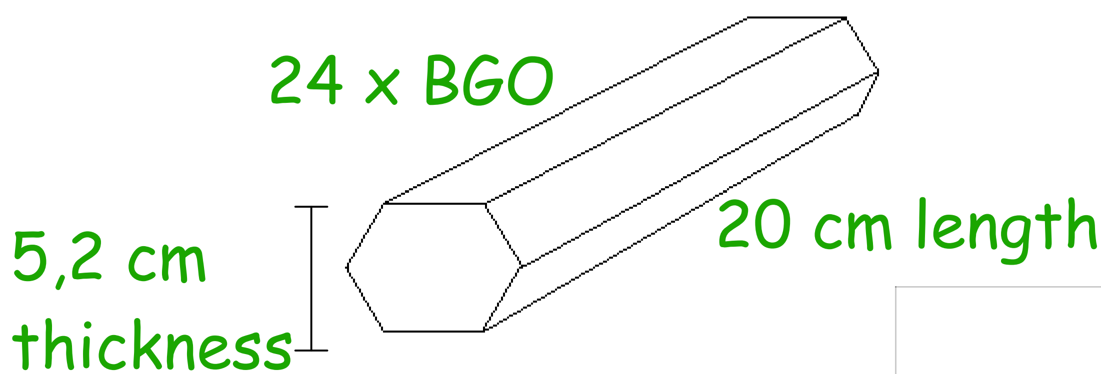
Collisional quenching ↓

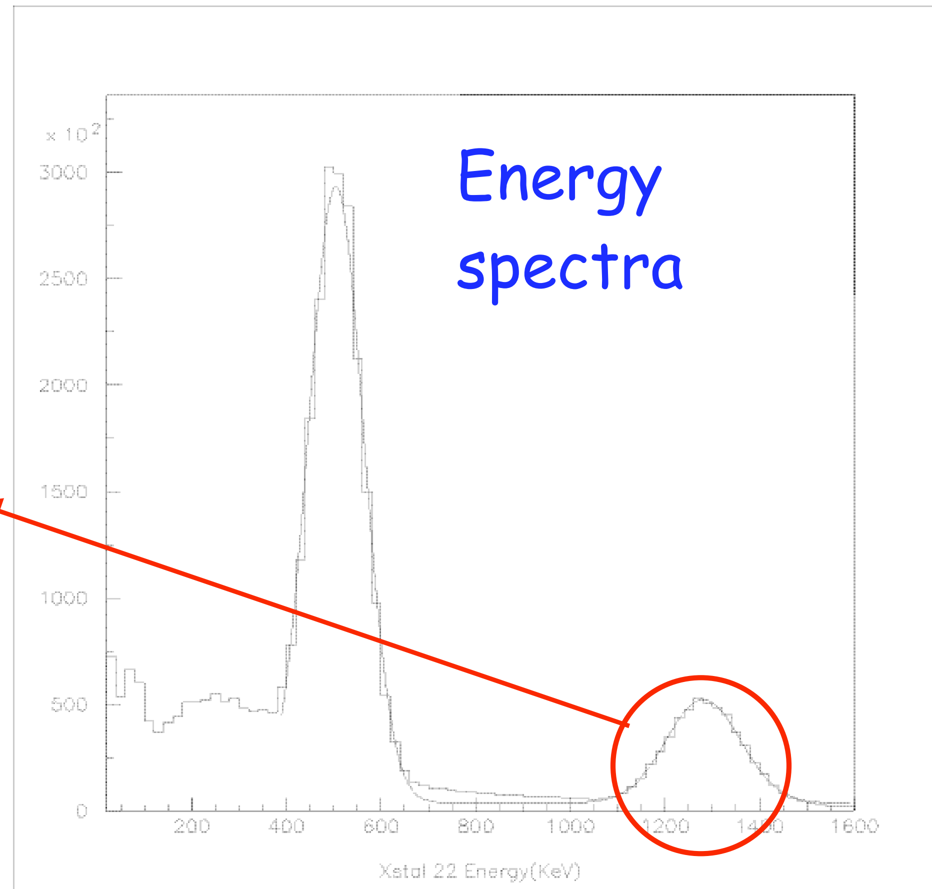
In Aerogel pores filled with nitrogen: $\tau \approx 132$ns

# Time spectra between tagged positron and photon detected in the calorimeter (with aerogel)



# Calorimeter



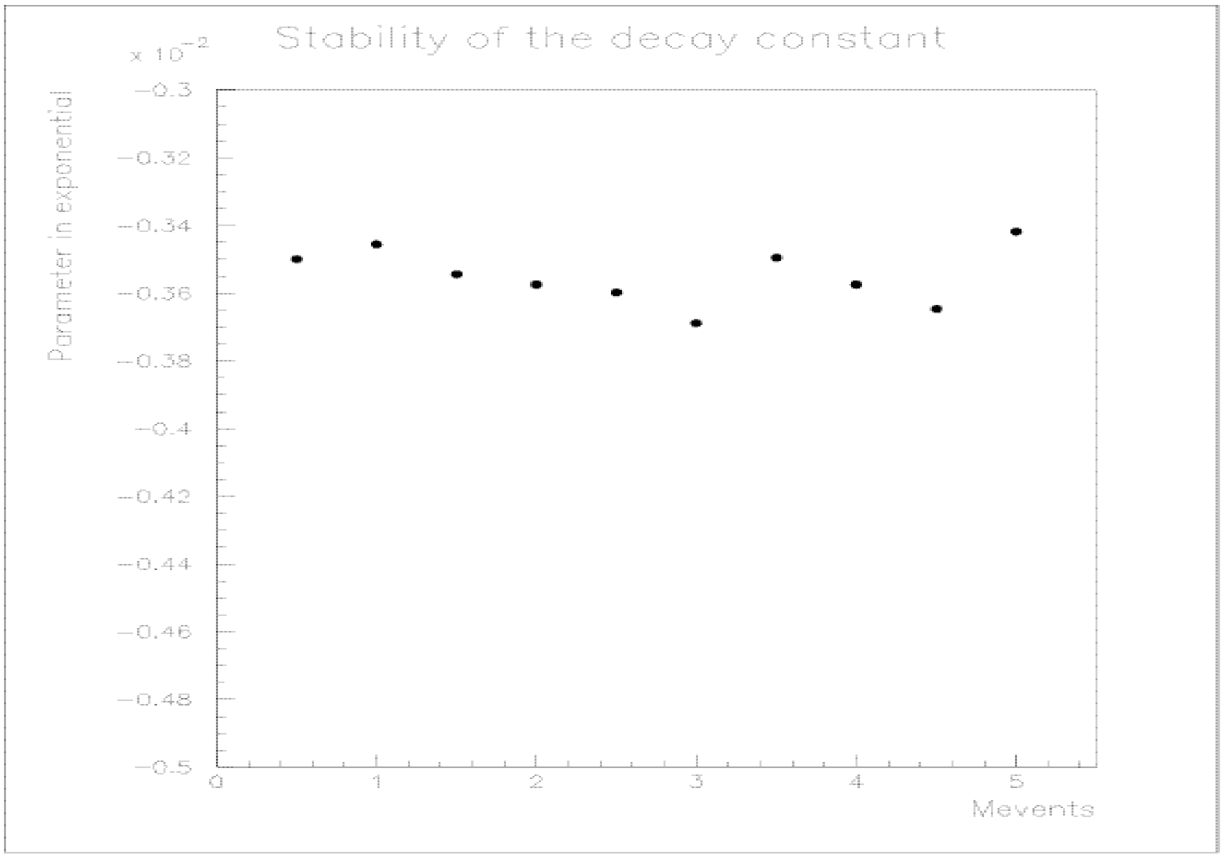

The resolution of the crystals determined with a fit is about 16% at 1.27Mev (FWHM)

# Analysis

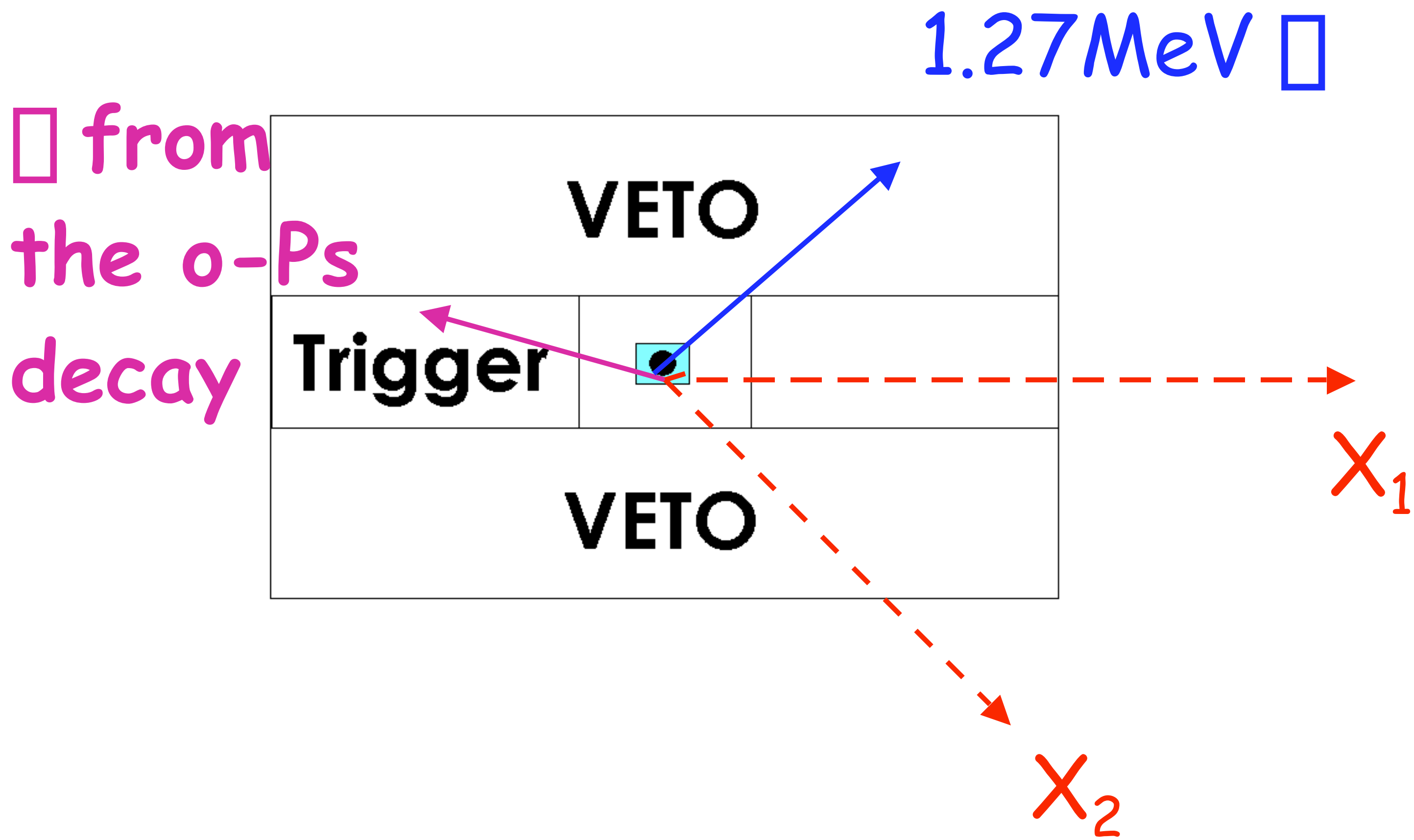
We collected $2x\mathbf{10^7}$ data during one week running, after the filtering and the cuts we **get** $3.5x\mathbf{10^5}$ **good events**.

For the filtering the stability of the calorimeter is checked:

1) The peak position of each counter
2) The measured decay constant of the positronium

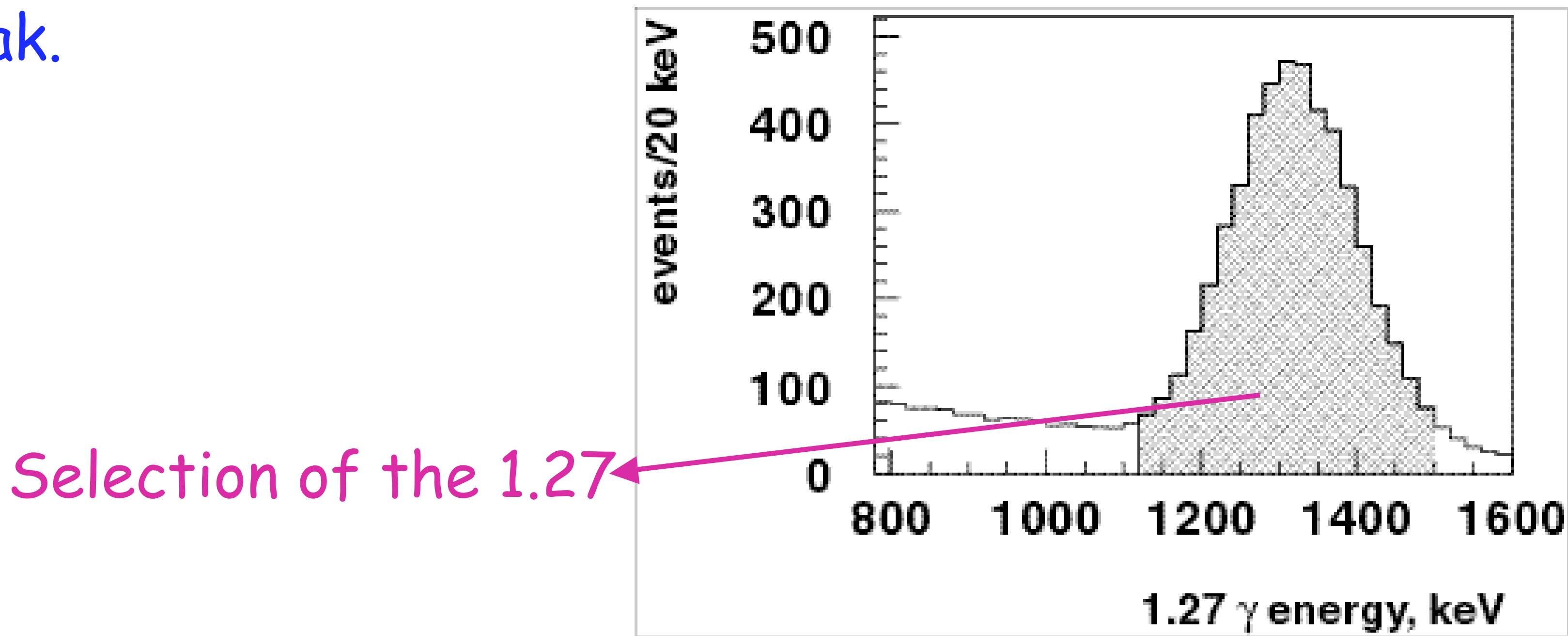


# Example of signal signature



# Events selection

- One of the photons with energy between 40 and 700 keV from the decay is asked to be in the trigger BGO.
- For the same event the 1.27MeV (not more then one) should be present in one of the other crystals. We excluded the end-cap in front of the trigger BGO, in order to avoid that the photons from the decay are "absorbed" in the 1.27 peak.

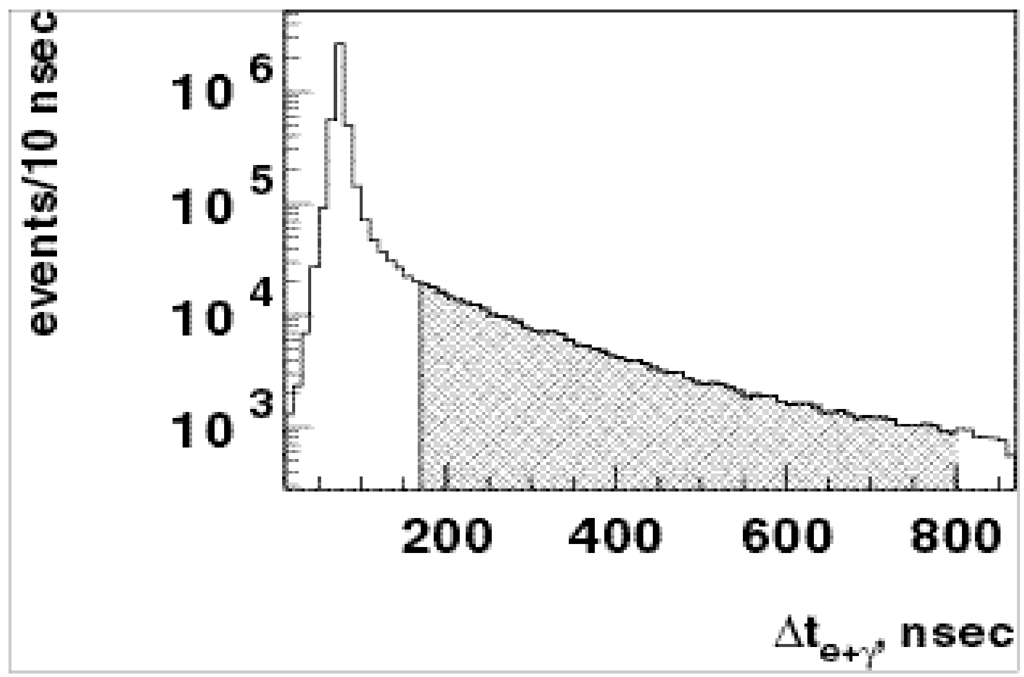


# o-Ps decays selection

In order to decrease the background from the 2 photons, we select the 3 photons from the o-Ps applying a cut on the time.

The lower limit has been set at 160ns, which suppress the 2 □ strongly enough, but it doesn't decrease too much statistic.

The upper limit is set at 800ns, because then the background from accidentals becomes dominant.

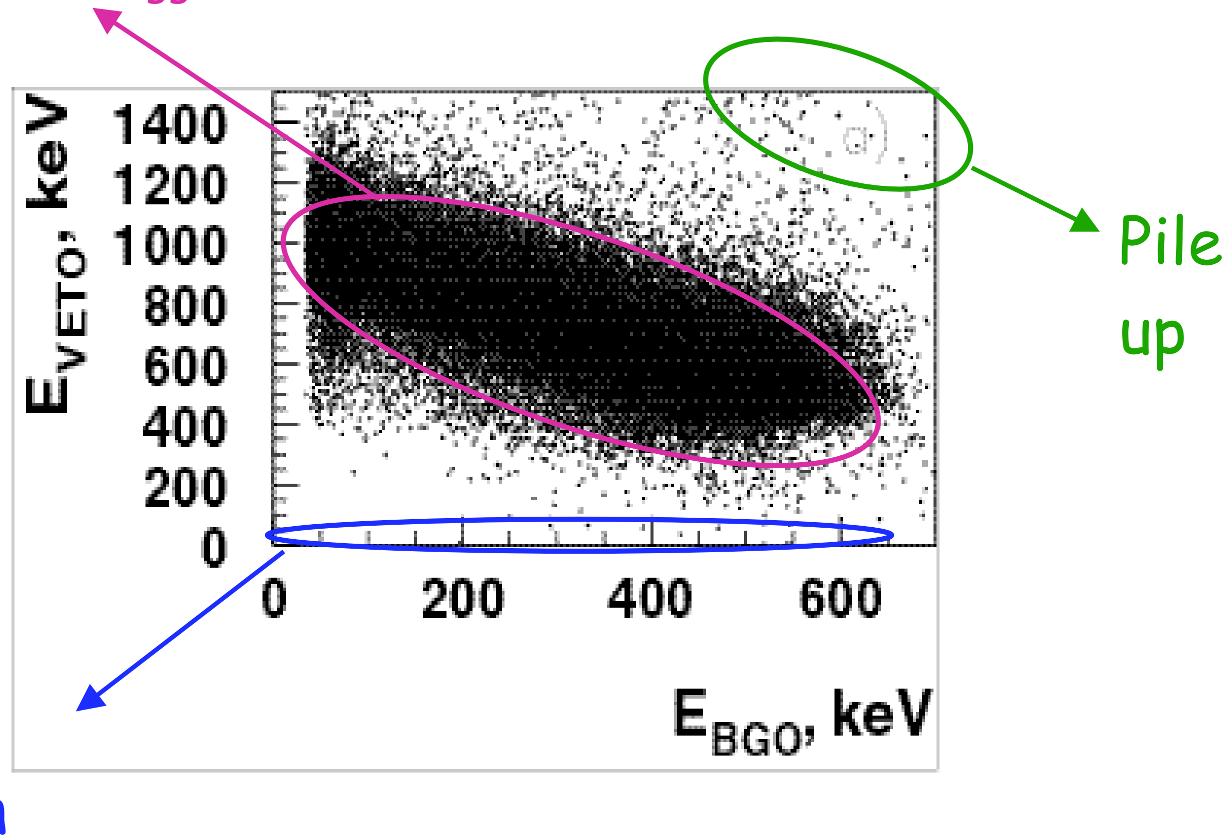


# Results

After selection, the sum is calculated.

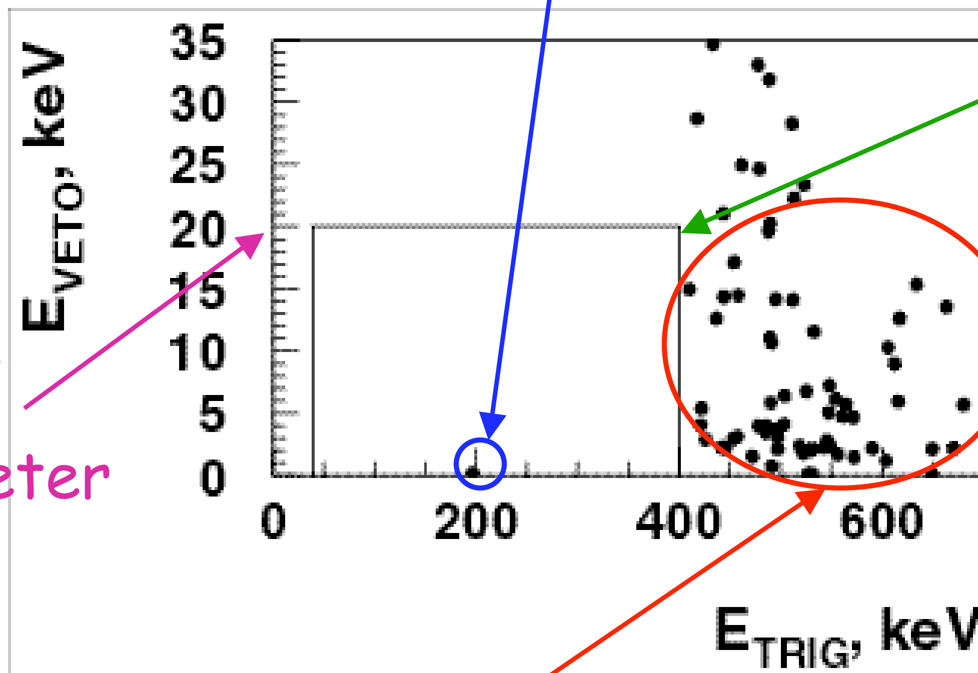
$$E_{VETO} = \sum_{all} E_{1.27} - E_{TriggerBGO}$$

The sum $E_{VETO} + E_{TriggerBGO}$ = 1MeV (Mass of Positronium)



# Signal region: $40keV \le E_{\gamma} \le 400keV$ and $E_{VETO} \le 20keV$

One event has been observed



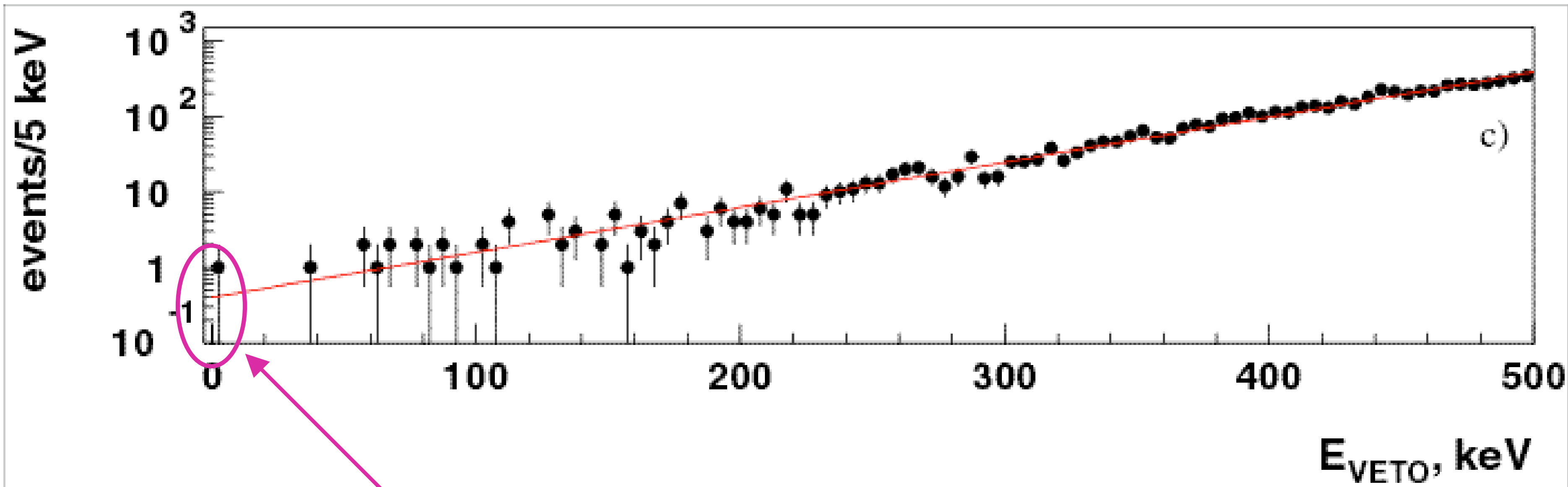

Sensivity of the calorimeter 20keV

The single photon maximal energy depends on the mass of the two exotic particles.

For the 511 keV photons from the 2 photons decay the unhermeticity of the calorimeter is in the order of $10^{-3}$.

# Background estimation

The expected background is extrapolated assuming a linear fit (in log scale) of the projected energy in the VETO.




For $E_{VETO}$ □ 20keV, 1.6 event (± 0.8) is expected, which is consistent with the measurements.

# Calculation of the upper limit

$$BR(o-Ps \rightarrow \gamma + X_1 + X_2) \leq \frac{\varepsilon_{3\gamma}}{\varepsilon_{1\gamma}} \frac{N^{up}_{o-Ps \rightarrow \gamma+X_1+X_2}}{N_{o-Ps \rightarrow 3\gamma}}$$

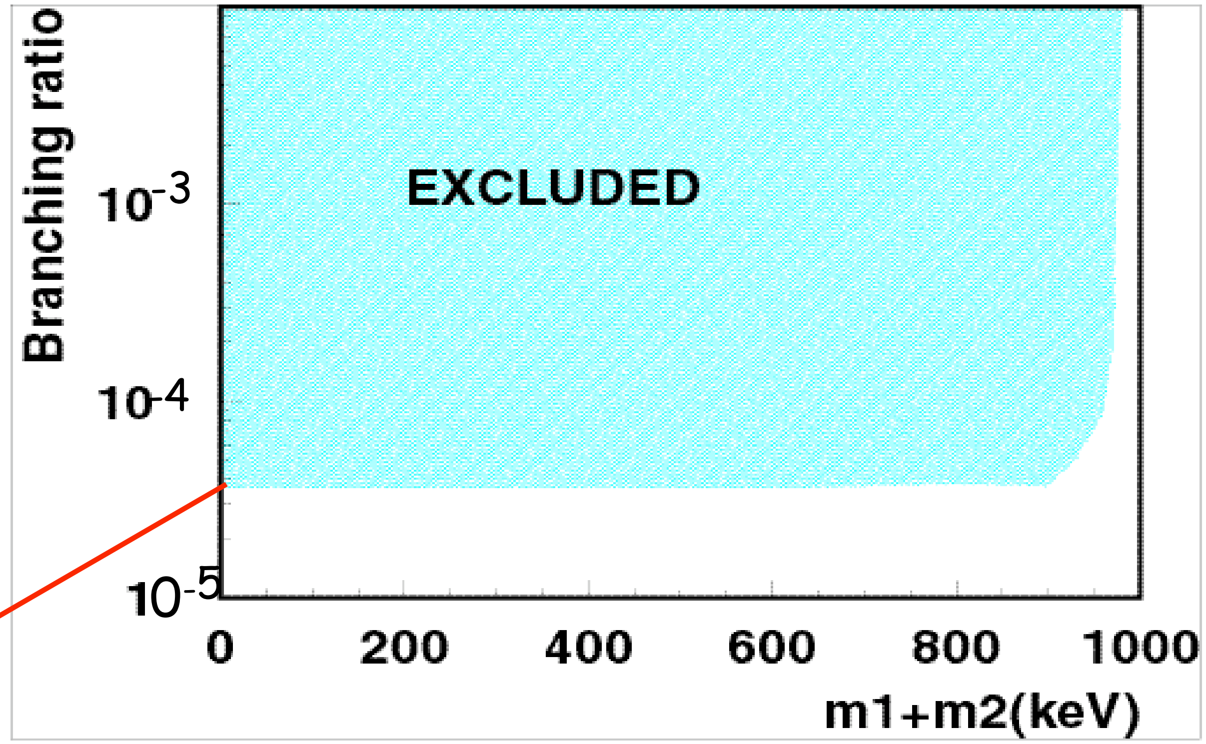
$N^{up}_{o-Ps \rightarrow \gamma+X_1+X_2} = 3.8$ has been calculated with Poisson statistic for 1 event observed and 0-background expected (conservatively).

Using a Monte-Carlo simulation (assuming phase space) we estimate the different detection efficiencies for a photon from the three photon and from the single photon decay:

$3.0 < \varepsilon_3 / \varepsilon_1 < 3.7$ for: $0 \leq M_{x_1} + M_{x_2} \leq 900keV$

The number of o-Ps decays in the target is measured from the decay curve, the measured lifetime is 6.6% less than in vacuum, it follows that $N_{o-Ps \rightarrow 3\gamma} \simeq 3.2x10^5$

# Conclusions




$BR(e^+e^-(o\text{-}Ps) \rightarrow \gamma + X_1 + X_2) < 4.4\times10^{-5}$ at 90% CL

It follows that this decay mode can not explain the discrepancy (the limit is 20 times smaller)!