Some considerations about the gamma-tagging experiment

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This short note is an attempt to describe the conditions that will prevail at PS in the gamma-tagging mode. It is aimed at serving as a basis for defining the best strategy to meet our needs, i.e. cover the largest gamma-ray energy range in the most effective way.

The different constraints are:

- time: the total allocated time is 28 days, with 15 to 18 days being a reasonable share devoted to this mode;

- electron energy: because of beam line constraints, the minimum usable energy is 1 GeV. The maximum energy is governed by the transverse distance of the electron behind the magnet at the dump entrance plane, which must be such the induced shower does not leak significantly sideways and contribute particles susceptible to hit the CU. It is estimated to be around 2.5 GeV-3 GeV. This point is being investigated at the time of this writing. We will assume 3 GeV in the following. This energy limitation arises indirectly from the limited size of the cave.

- silicon detector coverage: the detectors have a finite size (92 mm in both directions). Two detectors arranged in X-Y positions constitute a chamber, enclosed in an Al container with thin windows. At the moment, two chambers (to be installed back to back) are available, one or two more can possibly become available in a near future. For the sake of the discussion, it will be assumed that we have only a set of two chambers. It is assumed that the distance of the first chamber to the magnet exit is 100 cm, so that no significant fringe field is present (which would otherwise bend the electron trajectory between the two chambers). The second is placed 15 cm behind the first one and thus constraints the solid angle spanned by the set. The active size of the first one working in coincidence is thus 92*100/115= 80 mm. The 15 cm distance is considered sufficient given the 40 μm resolution in position of the Si chambers. The circuit board holding the silicon wafer and the Al container housing the detectors must be taken into account if one considers placing the inner edge of the Si chambers only a few cm off the position of the unradiated particles.

- energy resolution: the energy resolution is dominated by multiple-scattering in the second silicon chamber before the magnet. Michela Prest quotes a value of 2.5%, the current simulation predicts 1.4% at 1 GeV. However, multiple scattering in the windows of the Si chamber container is not taken into account yet.

- dead time: the CU DAQ dead time is neglected here (26.5 μs, with a limitation arising from the buffer saturation estimated at 6 KHz), the only significant contributor being the ancillary-detector DAQ with a dead time in zero-suppress mode of 500 μs (2.5 ms in non zero-suppress mode). It is assumed that the dead-time needed for the later DAQ to process an event without silicon readout would be significantly shorter (100 μs, to be determined).

- magnet bending power: the maximum field is 0.96 T for an active distance of 50 cm.

It may be useful to recall a few general features concerning this mode:

- The silicon chambers before the magnet amount to 1.7% X_0. The probability for producing a photon with energy greater than 20 MeV within these detectors is 6.7%. The total matter thickness (cerenkov counters, windows, air, detectors) before the magnet should be about 4% X_0, leading to an actual probability of 0.16 (this probability must be kept small to limit the fraction of events with multiple gamma-rays). So about 80\% of the incident electron will not be associated with a gamma-ray with energy in the useful range.

- The size of the secondary electron beam is large (a few cm sigma). For our purpose, the actual beam size will be constrained by a set of detectors to about 2 cm in both horizontal and vertical directions (this may possibly be reduced to 1 cm at the expense of the rate).

- The bremsstrahlung gamma energy distribution scales as 1/E, i.e. there is about the same number of photons per bin in logarithmic energy. As the electron residual energy is measured with a resolution essentially constant, the energy of the low-energy photons is best measured using a low beam energy. Obviously, the high-energy photons can be only produced with a high-energy beam.

- The magnetic field has be to calibrated whenever the magnet current is changed. This is done by measuring the position of the unradiated particles in the Si chambers behind the magnet. The beam energy can be changed to obtain several calibration points. It is desirable to keep the field as high as possible to limit the sideward leakage from the beam dump as much as possible as mentioned above.

To explore quantitatively the different effects at play, some MC simulations were performed with the beamtest06 package using the following parameters: B=0.96 T, magnet active distance=0.5 m, beam size: 2 x 2 cm^2, beam divergence (sigma): H: 0.12 deg, V: 0.14 deg, energy dispersion 1%, air in the cave. In th simulation a W foil corresponding to 3.7% X_0 was placed on the beam axis to model the effect of the ancillary detectors (this thickness is probably slightly too large). For each energy, a total of 50000 events were run.

At 1 GeV:

Fig.1 displays the (total) energy of the gamma-rays hitting the CU as a function of the tranverse position of the associated electron at a 100 cm distance from the magnet center. The first conclusion that can be drawn from this figure is that it will be impossible to detect the electrons associated with low energy photons (E = 20-70 MeV) without detecting the unradiated particles as well. **The price to pay for triggering on these low-energy photon events is that about 80% of the recorded events will not be associated with gamma-rays having E> 20 MeV, with a high dead-time toll.** The only way to alleviate this problem would be to set up an electronic coincidence between the CU and the silicon chambers, which is not feasible in practice. The gamma-ray energy distribution selected by placing the chamber with its inner edge at l_{edge}=130 mm is given in Fig. 2. Fig. 3 displays the corresponding distribution resulting from placing the chamber at l_{edge}=190 mm, where it misses most of the unradiated electrons. This distribution extends almost up to 500 MeV. Note that there are still events without gamma-rays in this position range. Some of these events correspond to electrons slowed down by producing high-energy delta ray electrons (some of which may hit the CU and might be confused for gamma-rays), some others to events where the initial bremsstrahlung gamma-rays have pair-converted on air before reaching the CU, finally some are due to unradiated particles have experienced stronger than average multiple-scattering.

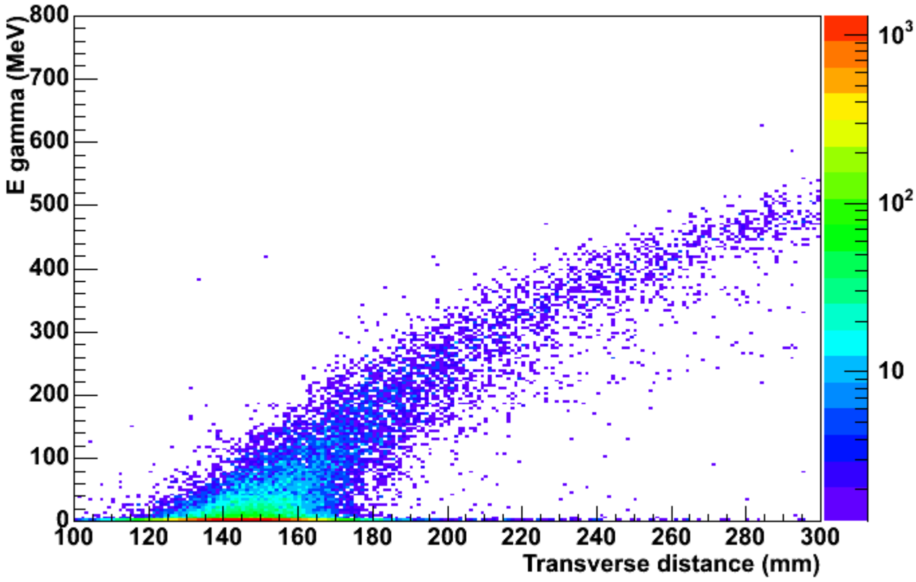

Fig.1: Gamma-ray energy as a function of the transverse distance w.r.t. the beam axis where the associated electron is detected. The incident energy is 1 GeV.

The resolutions in gamma-ray energy or direction established from the spectrometer data still need to be determined. Given the size of the cave, there is little freedom with respect to the chamber positions.

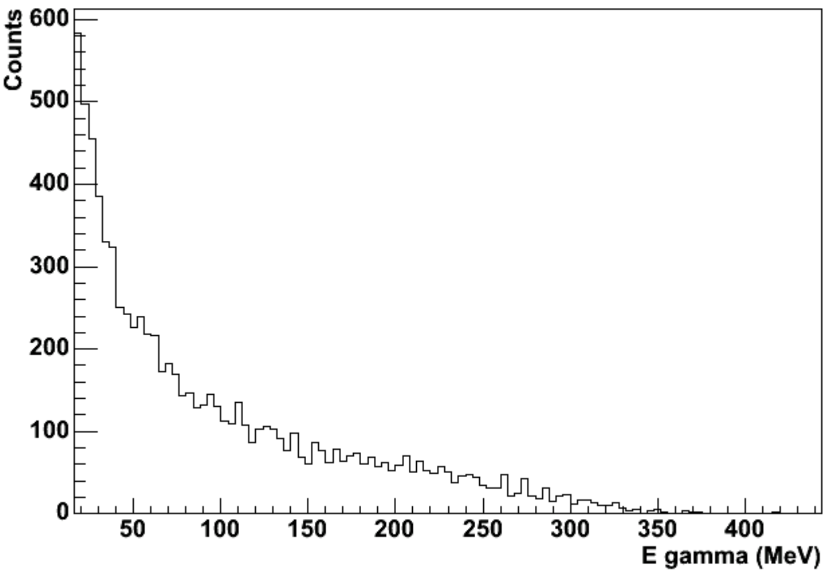

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Fig.2: Gamma-ray energy distribution for events with the electron being detected in the 130-210 mm transverse distance range (E_{inc}=1 GeV). The part of the distribution below 20 MeV representing 80% of the total yield has not been shown for clarity

One may consider using a large plastic detector to intercept the low-energy electrons (associated with high-energy gamma-rays) missing the Si chambers to improve the statistics for studies where the energy information provided by the spectrometer is not needed, the gamma-ray energy being measured by the CAL only. At 1 GeV, this plastic would have to be fairly long (several tens of cm) to cover an appreciable energy range as the gamma-ray energy - transverse distance correlation gradually weakens at large distance.

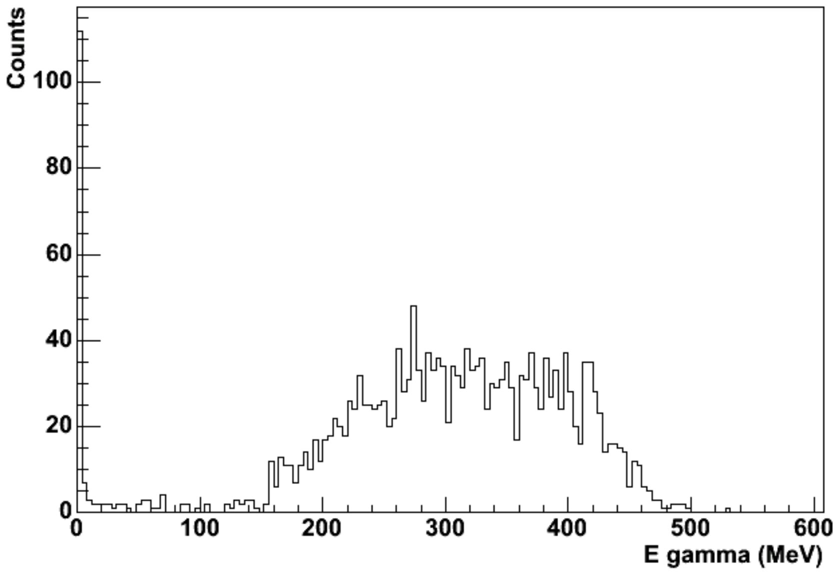

Fig.3: Gamma-ray energy distribution for events for which the electron is detected in the 190-270 mm transverse distance range (E_{inc}=1 GeV).

At 3 GeV:

With the maximum field, the unradiated beam is deflected to a transverse distance of only about 50 mm at 100 cm from the magnet (Fig.4). The gamma-energy distribution covered by placing the chamber with l_{edge}=70 mm is shown in Fig. 5. This distribution extends up to about 2.1 GeV. Attention should be paid so that no structure material (holding board, chamber container) is sitting in the way of the gamma-rays travelling towards the CU. It is desirable to have as little extra matter on this side of the silicon chamber which the unradiated particles would interact with, producing significant background in this “branch” of the spectrometer or in the CU. This may imply the need to modify the board and the container accordingly.

From Fig. 4, with l_{edge}=70 mm, there is not much point in trying to catch the electrons **at lesser transverse distance** with a plastic detector for instance because of the strong pollution of unradiated electrons. One may consider doing so for the electrons at higher tranverse distance, though, with the same caveat as mentioned above for the 1 GeV case. For these events, one could envision not to read out the chambers located behind the magnet in order to lower the dead-time toll, but this would bring little practical benefit as the rate of these events will be low.

Conclusion (partial):

It is highly desirable to have the Si chamber set mobile. Ideally one would have this set placed on a rotating arm with the (virtual) pivot coinciding at the magnet center. In practice, having the chamber mounted on a cart moving along a graduated rod perpendicular to the beam axis (or slightly tilted so as to maximize the covered solid angle) would be sufficient. The relative change in position can be checked by using the beam at a given energy (1 GeV for instance) and verifying that the change in position of the unradiated peak observed with the chamber data does match that expected from the new position of the cart.

As mentioned above, the chamber windows and material on the inner side of the Si chambers must be as light as possible, with modifications possibly needed on the existing devices.

Running with the conditions corresponding to Fig. 2, 3 and 4, the energy range 20-2000 MeV would be more or less correctly covered. An additional setting at 2 GeV would be useful, but probably not crucial. Further investigation is in progress to optimize the settings and gain more insight into these issues.

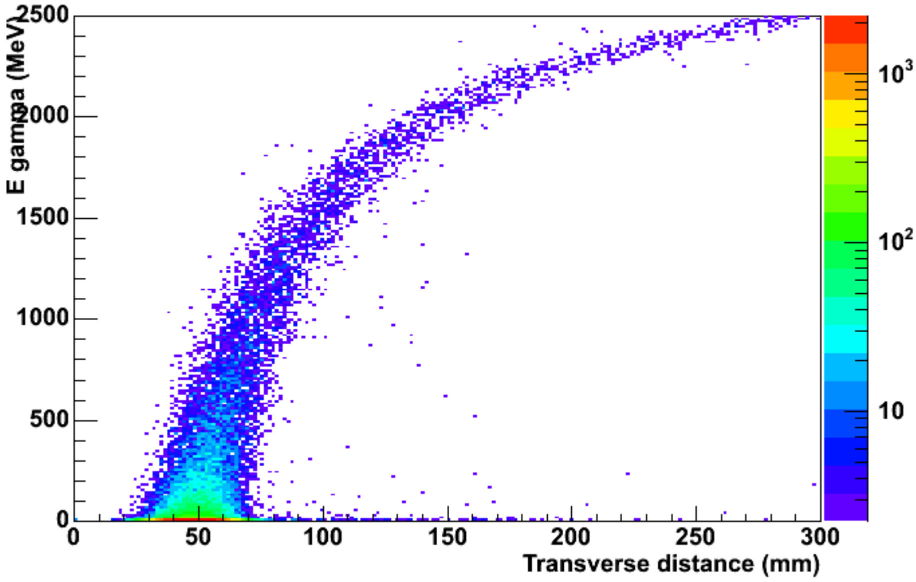

Fig.4: Same as Fig. 1 , but for 3 GeV incident energy.

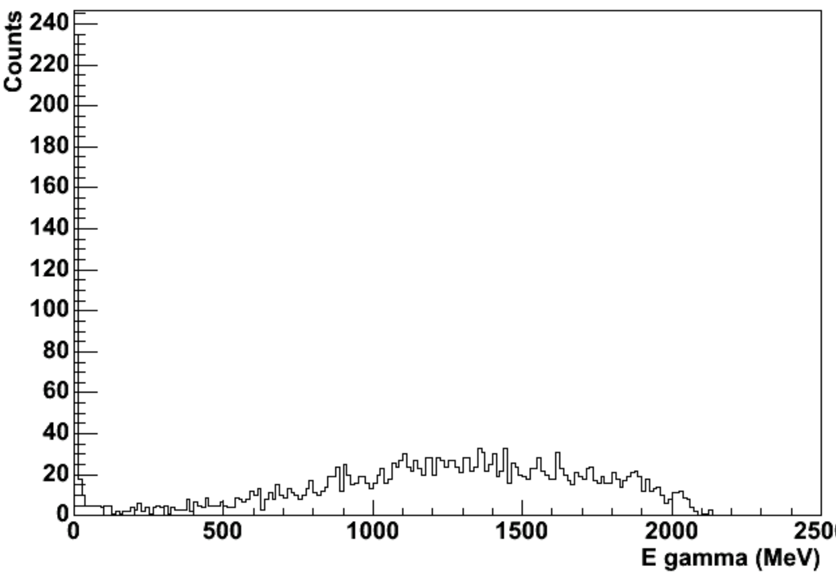

Fig.5: Same as Fig. 3, but the electrons are detected between 70 and 150 mm (E_{inc}=3 GeV).