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A Compton Polarised Positron Source : Parameters Optimisation

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Abstract

In the Snowmass meeting a proposal for a polarised positron source based on Compton scattering was submitted. The proposal was a first attempt to elaborate a full scheme that allows reaching the ILC nominal intensity per bunch. Nevertheless it was clear that a lot of optimisation work on all the aspect of the scheme was required. We present here the result of some consideration on the Compton collision point and on the optimisation of the collision parameters. These considerations are very important looking towards a relaxation of the technology constraints imposed by the high expected performances of the Compton source.

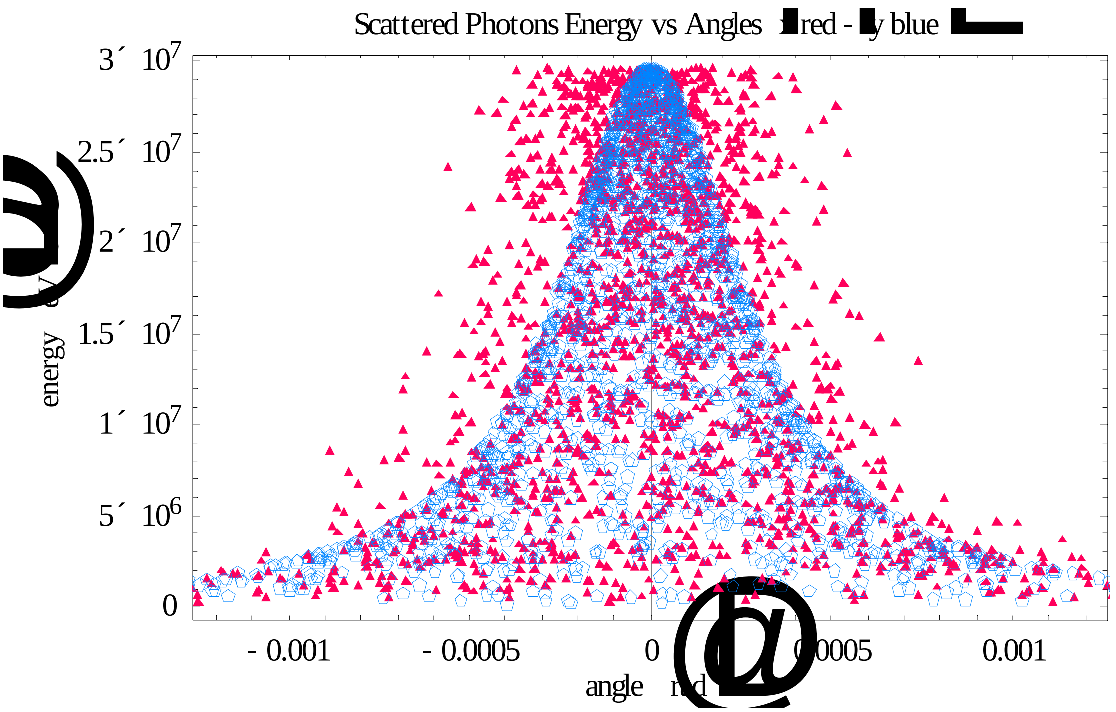
The results of different consideration on the Compton interaction region are presented in this paper.

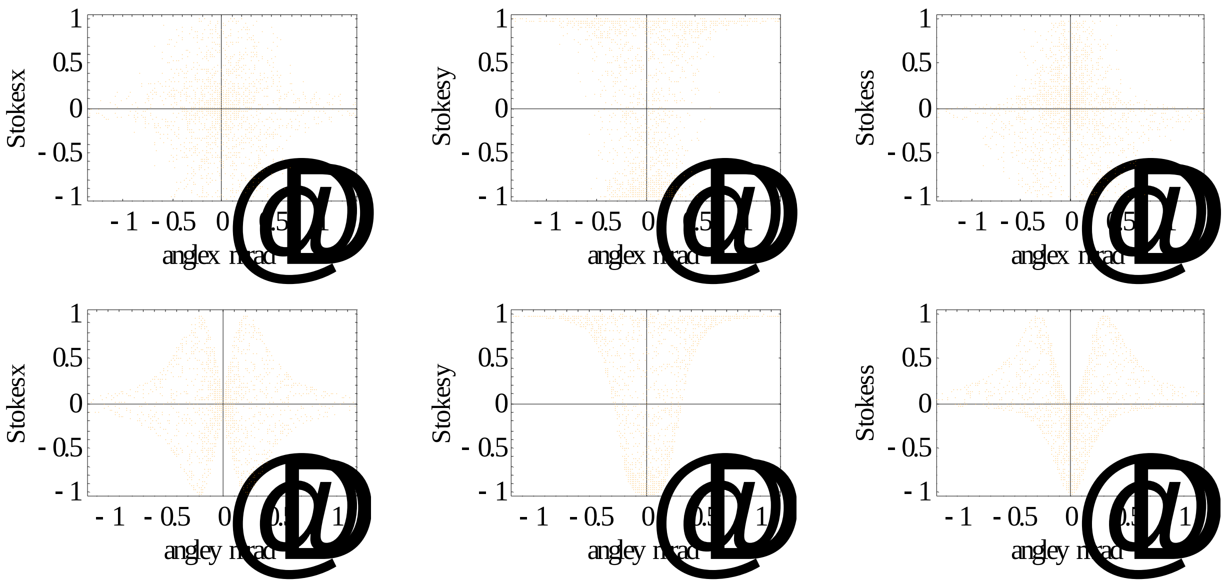
We started making different considerations on the Snowmass proposal [1]. In our opinion, in fact, this scheme was a good starting point but there are still parameters that can be optimised like the crossing angle, the repetition frequency, the interaction point parameters (like the beam sizes and so on), the collection system, the multiple re-injection, the charge per bunch ..etc etc. In this context we made a lot of simulation on the Compton production with the Montecarlo code CAIN and some analytical consideration on the scheme optimisation. This study was focalised essentially on the interaction point and in the influence of different parameters on the final scheme.
As first we take a "reference case" simulation in order to have some reference for comparison. So we take as "realistic" parameters for the Compton collisions:

Electron bunch:
1.3 GeV, 10nC, σ_x = 30mm, σ_y= 5mm, σ_z= 6mm, ε_x = 4.5nm, ε_y = 25pm, β_y = 1m, β_x = 20cm, Collision Angle = 0, Crab angle = 0,

Photon pulse (LASER):
λ = 1.06mm, waist size w_0 = 20mm, Rayleigh length z_R ~ 1.18 mm, Energy/Pulse = 0.1J (5 104 gain with 2 mJ or 5 cavities*104 gain @ Several MHz –or ATF laser)

We also developed an analysis code based on MATHEMATICA that allow exploiting all the result provided by CAIN. Some examples are hereafter illustrated:

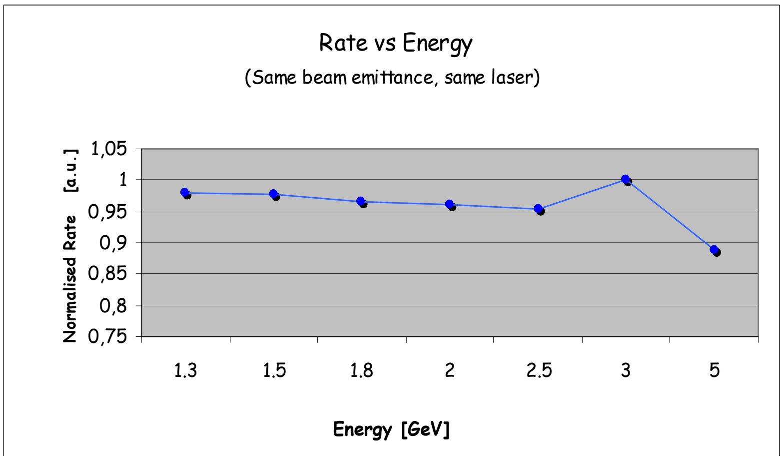


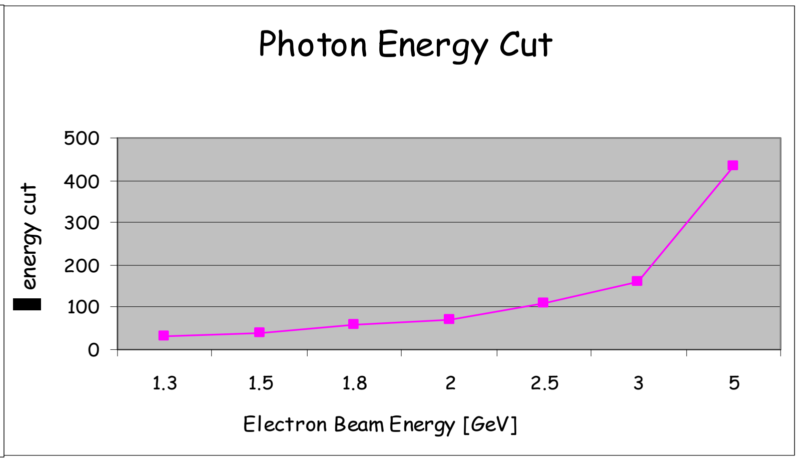


RESULTS OF THE SIMULATIONS:

Gamma vs electron beam energy

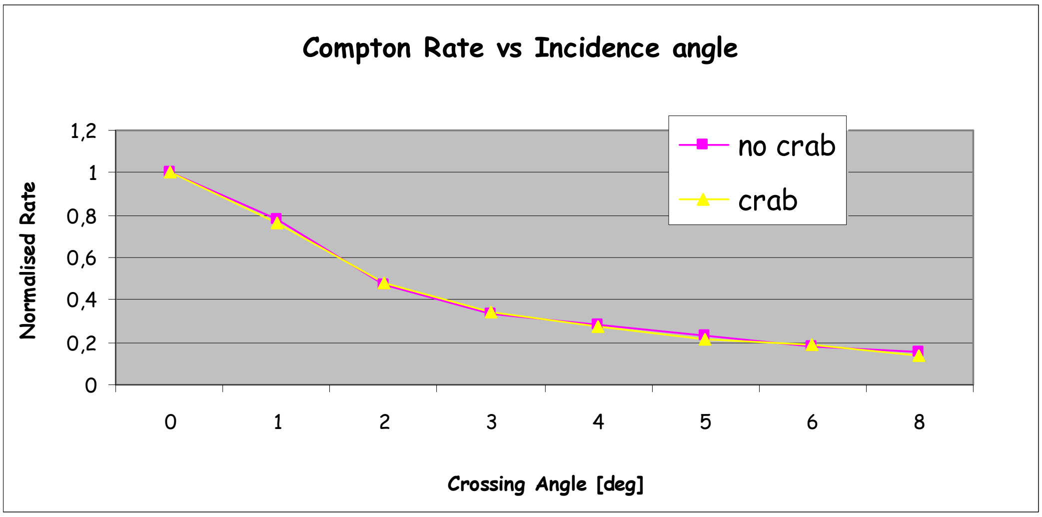
We start to take into account the dependence of the emitted gammas from the impinging electrons beam energy. In the following figures two different plots show respectively the dependence of the emitted gamma rate and the gamma energy cut off. We make a fine analysis from 1.3 to 3 GeV . This is the energy range that we estimate as reasonable for a dedicated Compton ring. We added the case at 5GeV in the case that, if polarisation and so energy selection is possible without diaphragming and so making a pre-selection directly on the gammas, it would be possible to propose the electron damping ring as the Compton Ring. We can notice that at 5 GeV the produced gammas have a cut off of ~ 400 MeV that is a real challenge for the production and collection system. On the other side the fact of having a large energy spectrum will allow a better chance to select energy (and so polarisation) in the produced positrons population. At 5 GeV there is a slight loss (few percent) in emitted rate in respect the 1.3-3 GeV range.



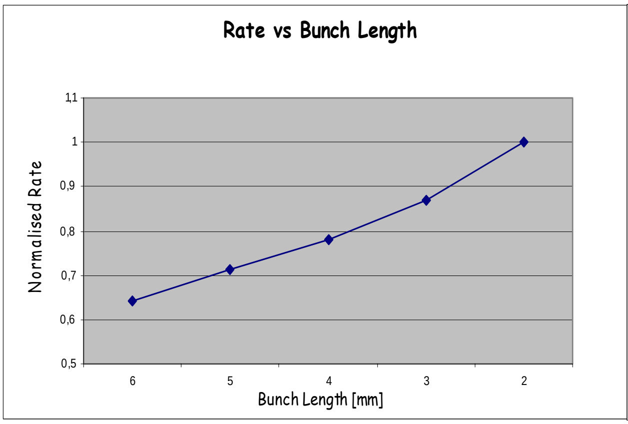


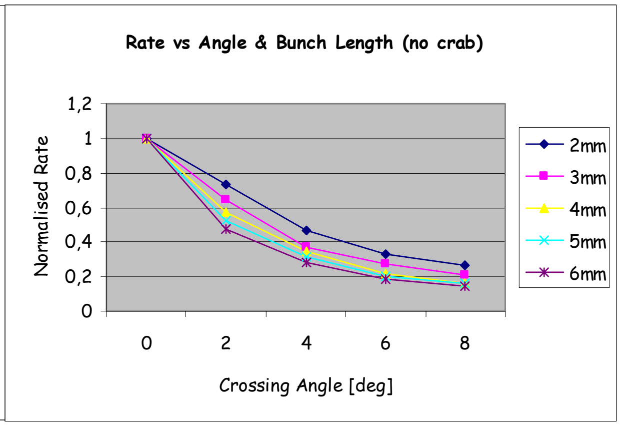
Rate vs crossing angle and bunch length

At the moment we have to take into account a crossing angle in the collision region since we cannot assure that the gamma flux will not drastically damage the optical cavity mirrors coatings. So in the estimation of the gammas total emitted rate two important parameters are the crossing angle and the bunch length of the two beams (laser and electrons). In our case we have in fact to take into account our particular situation where the electron bunch is much longer that the laser pulse. So the real loss in emitted flux is given not by the loss in cross section due to the absence of frontal collision but from the reduced time overlap between the laser and the electrons due to the collision with an angle. So we plot the normalised rate dependence from the incidence angle. We can see that for the nominal beam configuration we have a loss factor ~ 5 for an incidence angle of 8 degrees. In the same plot we show the result of the attempt to compensate the crossing angle effect by crabbing the electron beam by an angle equal to the crossing angle. We can see that there is not visible effect.



To catch up this flux loss we try to estimate the effect of a much shorter bunch, also if in the Compton ring to have a shorter electron bunch will mean a system to compress it and a post de-compressor.



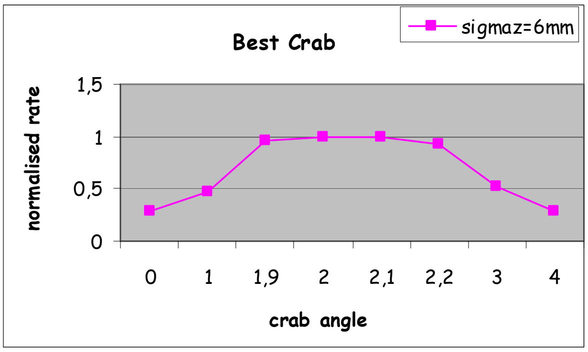


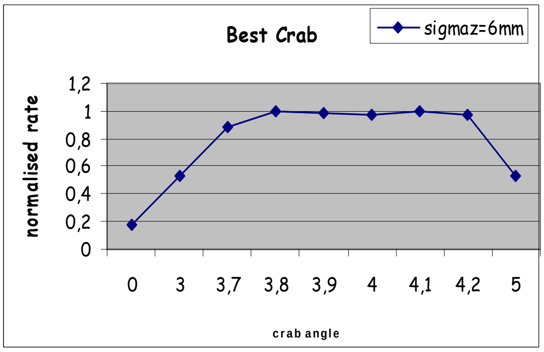
We can see that going from 6 to 2 mm we increase the flux of a factor less than 2. The second figure shows the dependence of the bunch shortening from the incidence angle. We can see that the shorter is the bunch the weaker is the flux loss due to the crossing angle effect.

Summary : following this results we have to try to reduce the crossing angle and the bunch length at maximum.

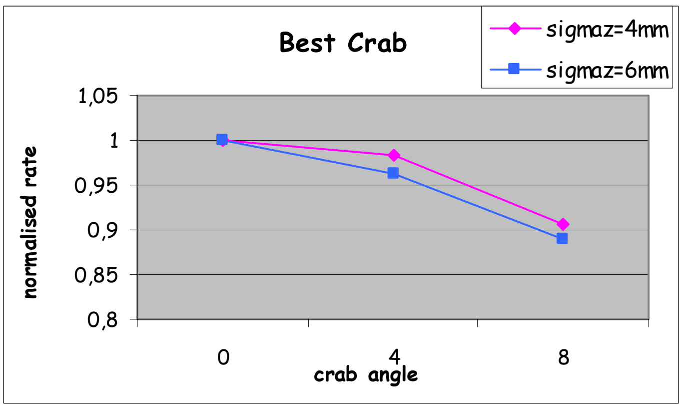
Crab Angle optimisation

After the crossing angle analysis we proceeded to the optimisation of a basic parameter: the crab angle. We have already seen that to compensate for exactly the crossing angle was not effective. So we start to calculate if there was a condition that optimizes the time overlap in our case having a crab electron beam. This optimized path for overlap (OPO) can vary from different situation. In our case we demonstrate trigonometrically that when we have a beam that is much longer that the laser pulse the OPO angle is the half of the crossing angle. We subsequently passed to the numerical simulations that confirm our hypothesis (see following pictures where in pink we illustrate the case of 4 degrees of crossing and the blue the 8 degrees case).





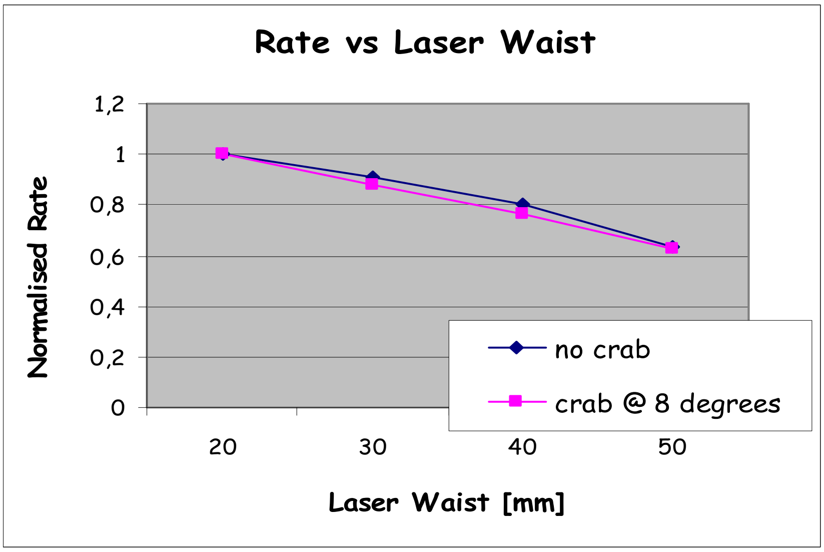
Here the relative analysis is presented. We notice that the range of stability for the optimised solution ~ 10% on the value of the crab angle. Hereafter we present the analysis in respect to the nominal case. We see that for the 8 degree case we reduce the losses from 80% to 10%. This is an important gain that allow reducing drastically the number of optical cavities and/or relaxing the beam/pulse parameter at the interaction point



Summary: crabbing at the OPO angle can increase the flux of a factor 4 / 5. Also crabbing it is better to reduce the crossing angle for a full optimisation.

Laser waist

Another critical point of the Compton scheme is the size of the laser waist. To increase the rate we have in fact to provide cavities with very little waists and this take us in the unstable mechanical regime if we will use a 2 mirror cavity [siegmam]. Since in our case (long e-beam and short laser pulse) the effect of hourglass is important we estimated the effect of the relaxation of the laser waist on the relative gamma rate. The result is presented hereafter.



We can appreciate the fact that passing from a waist of 20 microns to 40 (that is a very important step towards the mechanical stability of the cavity) the reduction of the flux is of the order of 20%. It is noticeable but not dramatic.

ANALYTICAL STUDIES

Link between the cavity mechanical stability and the repetition frequency.

In the proposed scheme the laser parameters and the parameters of the electron ring are connected by the repetition frequency. In fact this is the parameter that must match between the laser-cavity system and the Compton ring if we want to maximize the efficiency of our scheme. Moreover the Compton cross section mixes the beam size at the interaction point with the laser waist, the bunch and pulse length and the crossing angle:

$$Rate = N_\gamma N_{e^-} g; \qquad g = \frac{f_{rep} Cos\frac{\theta}{2}}{2\pi} \frac{1}{\sqrt{\sigma^2_{ye^-} + \sigma^2_{y\gamma}} \sqrt{\left(\sigma^2_{xe^-} + \sigma^2_{x\gamma}\right) Cos^2\frac{\theta}{2} + \left(\sigma^2_{ze^-} + \sigma^2_{z\gamma}\right) Sin^2\frac{\theta}{2}}}$$

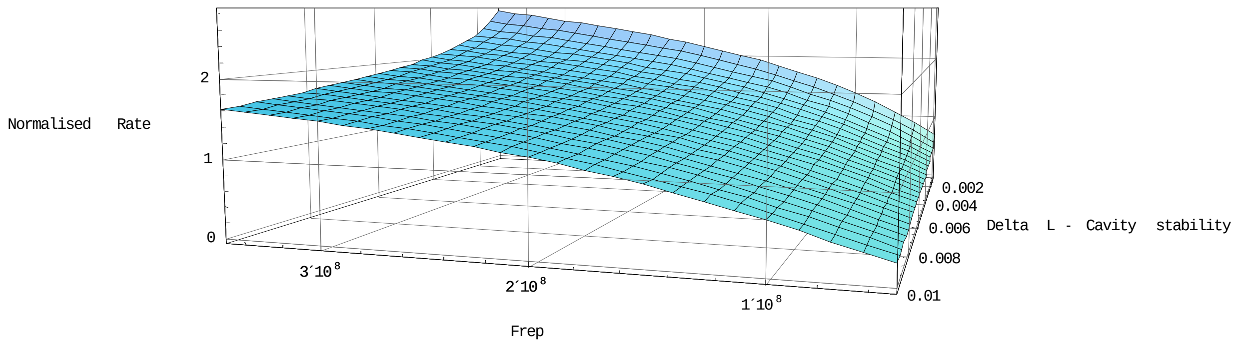
The minimal crossing angle (when we do not take into account the OPO angle) is given by the geometrical sizes of the laser cavity mirrors. So we can define the crossing angle in the previous formula by the tangent of the ratio of the length of the optical cavity (that is proportional to the frep) and of the mirror radius (proportional to the beam waist).

So plugging in all the definition we obtain:

$$where: \theta = Arctg\left(\frac{4f_{rep}}{c}\left(\frac{3}{2}\sqrt{\frac{c\lambda_L}{\pi\ f_{rep}}\sqrt{\frac{c}{2f_{rep}\Delta L}}}+sp+2\sqrt{\varepsilon\left(\beta^{*}+\frac{\left(\frac{c}{4f_{rep}}\right)^{2}}{\beta^{*}}\right)}\right)\right)$$

$$where: \omega_{\text{waist}}^{2} \approx \frac{L\lambda_L}{\pi}\sqrt{\frac{\Delta L}{4L}} \qquad \text{and} \qquad \frac{\omega_{\text{waist}}^{2}}{\omega_{\text{mirror}}^{2}} = \frac{\Delta L}{4L}$$

Where β* is the beta function at the interaction point and ΔL is the distance of the optical centres of the two mirror of the cavity (inversely proportional to mechanical stability).
We can an analysis in a three dimensional space considering the Rate as a function of the mechanical stability and of the repetition frequency:



From the figure we can notice that in our case the increasing of the Rate with the frep is not linear. The derivative is advantageous up to ~150 MHz than it slows down. To have an effective gain a very high frep we have to go towards the zone at high instability (little ΔL).

Summary : Without crabbing at OPO angle it is not convenient to operate at very high frep. A good range seems be identified between 50 and 150 MHz.

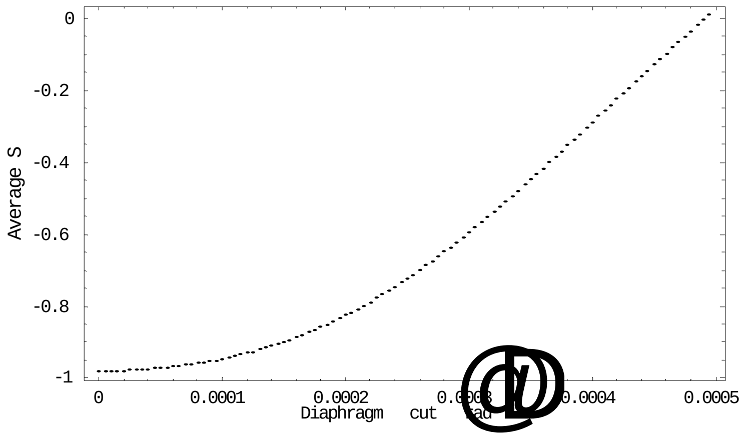
Polarisation constraints

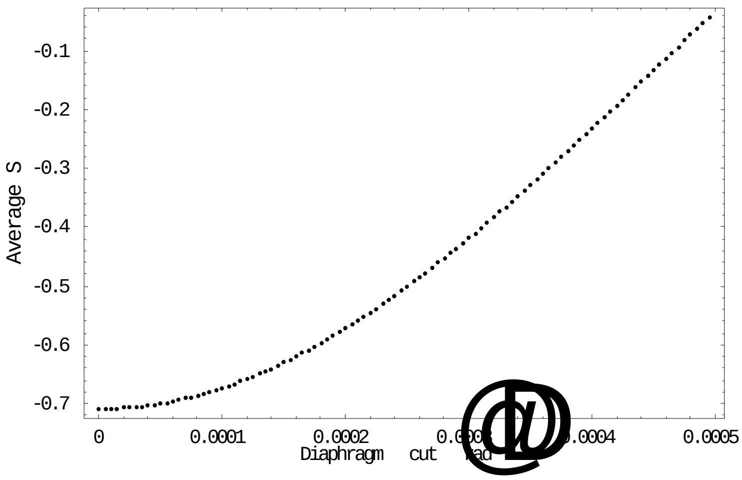
The fact that we have to produce a polarised beam is a strong constraint. In fact the good polarisation is produce for the high energy gammas and than transported to the produced positron. In this analysis we have taken into account ONLY the possibility of select the polarisation putting a diaphragm for the produced gammas. No post selection on the converted positrons has been analysed.

So we know that for a single particle the Compton spectrum is selective in Energy vs angles of emission. At the same time the polarisation follow an ARCCOS law in respect to the energy. So with simple algebra we can obtain the angular dependence of the gamma polarisation.

$$S = Cos\,[\pi \frac{8\gamma^2 \lambda_{cut}}{\lambda_{Laser}\,(2+\gamma^2\theta^2)}]$$

Since we must take into account a beam we have to convolute this formula with its angular distribution and define as beam polarisation the average polarisation.
So making the calculus we can plot the degree of average polarisation as a function of the angular acceptance of the diaphragm:





The first figure show the case in which the angular dispersion of the electron beam is 1/3γ (g = relativistic parameter) and the second for 1/ γ. We can see how, independently to the capability to diaphragm, the angular energy spread influence the average polarisation of the gammas. This is also dependent from the energy of the electron beam. In fact if the emission cone (1/ γ) is smaller in respect to the angular divergence is difficult to diaphragm without cutting all polarisations. Already at 1.8 GeV we cannot have better than 0.5 polarisation also with a beam energy spread of 1/3γ. Since the angular spread in the collision point is fixed also by the beta function we can obtain a condition for a minimum polarisation on the collision parameters:

$$\sqrt{\frac{\varepsilon}{\beta^*}} < \frac{1}{4\gamma}$$

So we cannot have a very low beta!

Summary: The constraint on polarisation is strong if we take into account only the selection on the gammas. This excludes very high energy production and limits the beta in the interaction point.

Conclusions:

At the end we present a first attempt of a scheme to be proposed. In our point of view there are good margins of rate gain applying the crabbing OPO angle, shortening the bunch and optimizing the collection system. Another important point is to study a solution in which we decrease the frep but we increase the Duty Cycle (and so the number of re injection). This surely must be validated by simulations taking into account the longer pulse in the transfer linac and the bigger number of multiple re-injections in the damping ring. This solution will also allow relaxing the extremely demanding electron beam and laser pulse parameters in the interaction point that we have taken into account up to now.

Acknowledgements

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