Analytical study of pol. e+ production by Compton sources

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Why analytical study?

Condemnation of dimensions

- Main output parameters
  - yield (current) of positrons,
  - polarization
- determined with
  1. spectrum of gammas (max energy)
  2. preselection (collimation)
  3. thickness (and geometry) of conversion target
  4. material of conversion target
  5. postselection – selection of subspectra of polarized positrons.

Simulations produce very precise parameters of feasibility for a given set of input parameters (see, e.g. Wei Gai-san simulations or Sabine-san's group ones, or other colleagues), but unable to indicate an optimal set for required yield and/or polarization.

A priori reduction of number of parameters

- Two parameters from the list considered as given
  1. max energy of gammas limited by the beam dynamics in Compton storage rings (the higher the better);
  4. material of the target (the heavier the better, Omori-san).
- Remaining 3 parameters (3D space)
  2. preselection (collimation)
  3. thickness (and geometry) of conversion target
  5. postselection – selection of subspectra of polarized positrons

Analytical Model

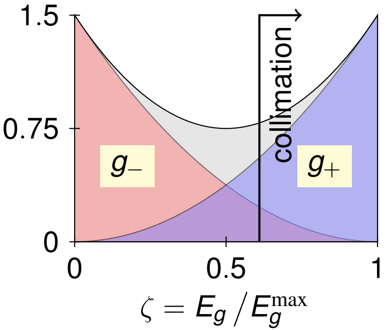
Make things as simple as possible, but not simpler (Albert Einstein)

Positron at output is born from laser photon as a result of subsequent transformations/selections. Each step may change polarization and/or intensity.
The steps are described with simplest possible model aimed at obtaining the result in a closed form (at least in quadratures) to allow search for optimum.

1. Monochromatic laser photons
2. Ideal Compton spectrum of gammas (scattering off monochromatic electrons with parallel trajectories)
3. Preselection discards gammas with energies lower than E_{pre}
4. Pair production cross section independent on the energy of gammas, uniform distribution of positrons over energy
5. Linear energy losses of positrons traversing the target (ionization losses)
6. Postselection discards e+ with energies lower than E_{post}

‘Acceleration’ of Laser Photons

Preselection (Collimation of gammas)

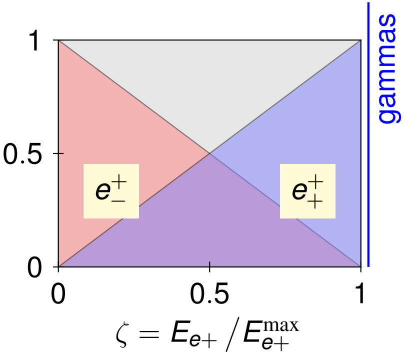


Initially Dirac’s delta distribution of the laser photons split and transformed into two subdistributions.

- Scattered off gammas nonpolarized in average.
- Preselection makes them polarized and reduces power load into the target.

Production of Positrons by Gamma

Model (c.f. Wei Gay-san, Vitaly-san) Theory (Jost, Luttinger, Stolnich)



сравнительно медленно.

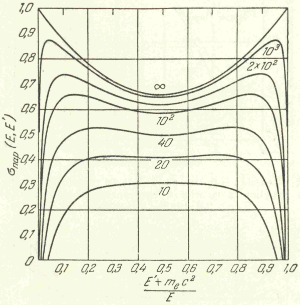


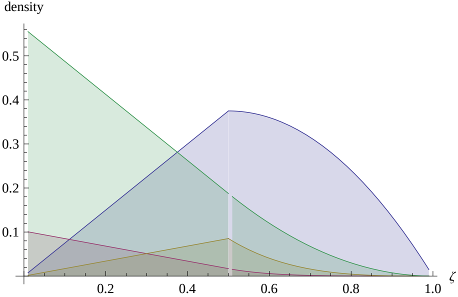
Рис. 1.23. Дифференциальное сечение образования пар в свинце в зависимости от энергии частиц пары для различных энергий налетающих γ-квантов в естественных единицах.

Each gamma produces two subensembles of positrons.

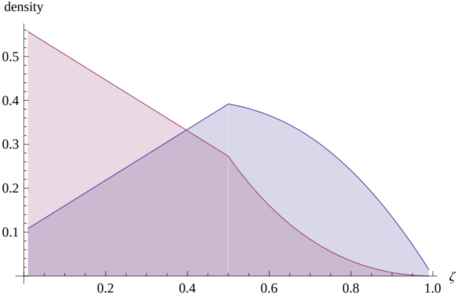
Production of Positrons by All Gammas

Thin target

Convolution of two spectra of positrons with two spectra of gammas results in four subensembles of positrons. (Normalization: per gamma = scattered off laser photon.)



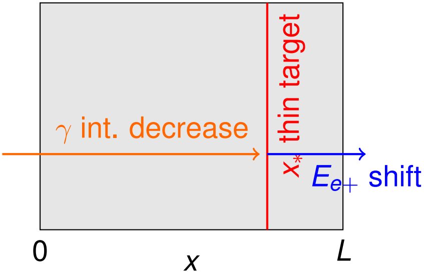
Four spectra for preselection 0.5



Positive and negative cumulated spectra for preselection 0.5

Zero total polarization of positrons for any preselection

Thick–Target Transformations



- Intensity of gammas decreases exponentially from front-end of target:

$$N_{\mathrm{g}}(x) = N_{\mathrm{g}}(0)\exp(-\kappa x)$$

- Energy of positrons decreases linearly on pass to output surface:

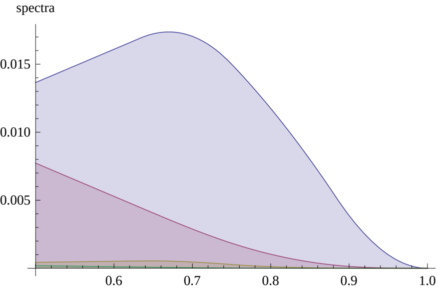
$$D_{\mathrm{out}}(E) = D_x(E + \lambda(L - x))$$

with L the target thickness.

Before Postselection

Four analytical spectra (+ +),(+ -),(- -),(- +) ready for analysis and optimization

May be deduced (and optimized for): yield; polarization; power dissipation in collimator's iris, target, gamma-ray dump; etc.



'Thick' spectra, preselection 0.75

Analytical form for ++, no preselection

$$D^{(++)}(\zeta;\lambda,\kappa,L) = \frac{1}{2\kappa^2}\left\{3\left[-2\lambda^2-\kappa^2(-1+\zeta+L\lambda)(\zeta+L\lambda)+\kappa\lambda(-1+2\zeta+2L\lambda)+e^{-L\kappa}\left((-1+\zeta)\zeta\kappa^2+2\lambda^2+\kappa(\lambda-2\zeta\lambda)\right)\right]\right\}$$

Postselection and Optimization

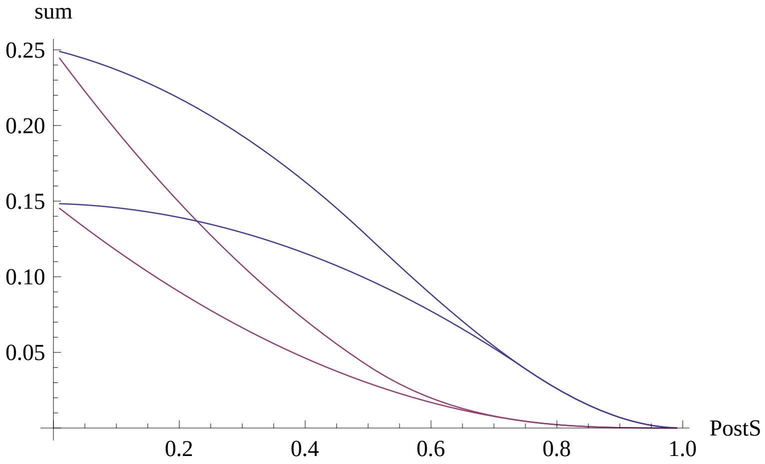
Discarding of positrons with $\zeta < \zeta_{\rm post}$

Important

- Postselection controls yield and polarization: higher $\zeta_{\rm post} \to 1$ lower the yield at higher polarization.
- Postselection $\zeta_{\rm post} < 0.5$ unreasonable.
- Preselection does not change yield and polarization if $\zeta_{\rm pre} \leq \zeta_{\rm post}$.
- Power load in the target decreases with increase of the energy of preselection.
- Optimal target thickness L_* maximizing the yield exists for a given postselection.

Postselection Example

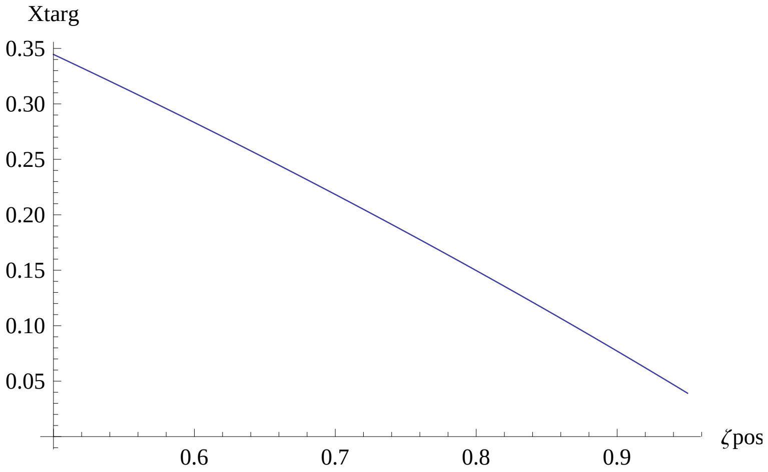
Yield vs. postselection for preselection 0.5/0.75



Thin target

Optimal Target Thickness

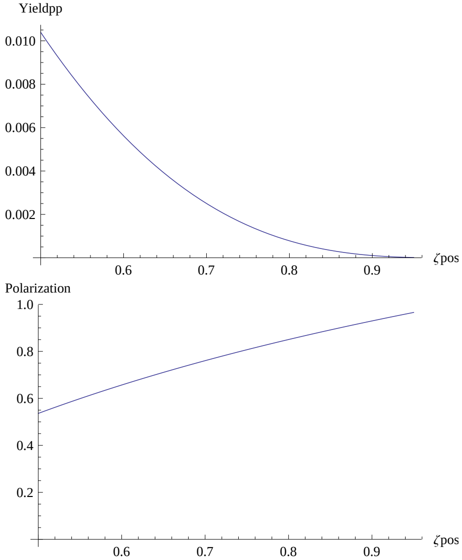
Tungsten, $E_g^{\max} = 20\,\mathrm{MeV}$



Optimal target thickness (rl) vs. energy of postselection

Summary

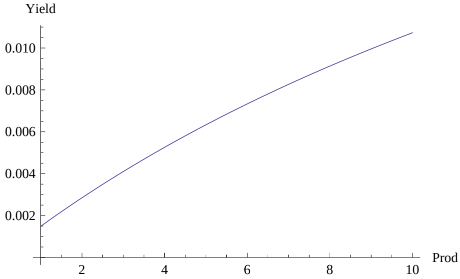
‘Theory produces dependencies not numbers’ (V. Kurilko, my teacher)



Tangsten optimal target

- Simple analytical model able to localize volume of parameters where to search for optimum
- Given polarization degree require optimal target and selections
- Example: tungsten, $E_g^{\max} = 20\,\text{MeV}$
  - $E_{\text{post}} = 15\,\text{MeV} \to$ yield 1.7e-3; polarization 0.82; optimal thickness 0.185 rl
  - $E_{\text{post}} = 10\,\text{MeV} \to$ yield 1.25e-2; polarization 0.62; optimal thickness 0.344 rl

Outlook



Yield vs. rod target parameter for $\zeta_{\text{post}} = 0.75$
(Rod target parameter ≈ rod length / 2 average positron pass length)

- The rod target seems to be effective if high polarization required
- Theoretical curves to validate in a few points with simulations (realistic Compton spectra, positron dynamics in the target, etc.)
  (10 MeV gammas with 2 MeV postselection; 0.4 rl Ti target shows good agreement with *Sabina-san et al* simulations)