A beam line for tagged polarized γ-rays

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Status of γ-rays astrophysics

High energy γ-ray astrophysics above 50 MeV has been revolutionized in the last decade by FERMI and AGILE (both still active).

That was realized largely through detectors developed by the high energy physics community: solid state detectors, calorimeters, scintillators readout by PMTs.

FERMI/AGILE discovered thousands of galactic and extragalactic γ-ray sources plus the diffused background: Pulsars, Blazar, AGN, Magnetstars and many others.

Additional advances are difficult.

Future direction for γ-ray astrophyscis

Several directions for future missions are possible:

- **Larger telescopes**: must be huge and very expensive
- **Smaller PSF** : challenging and requires low A_{Eff} .
- **Very high energy:** calorimetric CR experiments.
- **Low energy:** range down to 1-100 MeV **AMEGA/ASTROGAM**
- **Polarization:** how to do in pair-creation regime?

Polarization in γ-ray astrophysics

The physics cases behind the search for polarization in middle to high energy γ-rays are the identification of different emission mechanisms from sources:

- **GRBS**
- **Pulsars**
- **AGNS**
- **Blazars**

In addition fundamental physics items can be investigated

Birefringence of space due to Lorentz invarinace violation

Axions-photons coupling

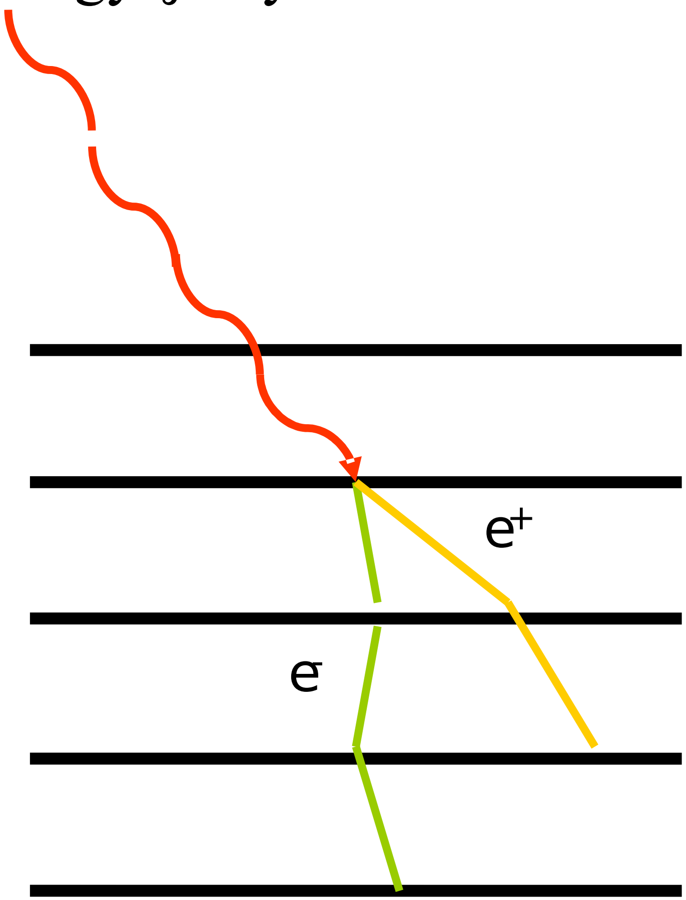
D. Bernard, Nucl. Instr. Meth. A 729 (2013) 765

Measuring γ-rays polarization

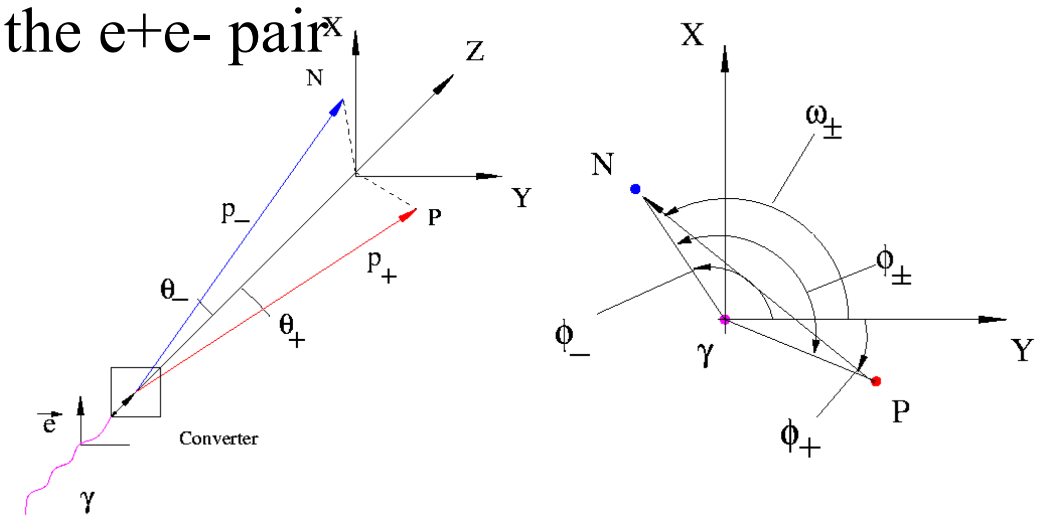
The physics processes governing the interactions of middle-high energy γ-rays are:

1) $\gamma + A \rightarrow A + e^{+} + e^{-}$

2) $\gamma + e^{-} \rightarrow e^{-} + e^{+} + e^{-}$



The parameter sensitive to the polarization is the azimuthal angle of the e+e- pair



Polarized γ-ray beam

There are several possible approaches to generating (partially) polarized γ-rays:

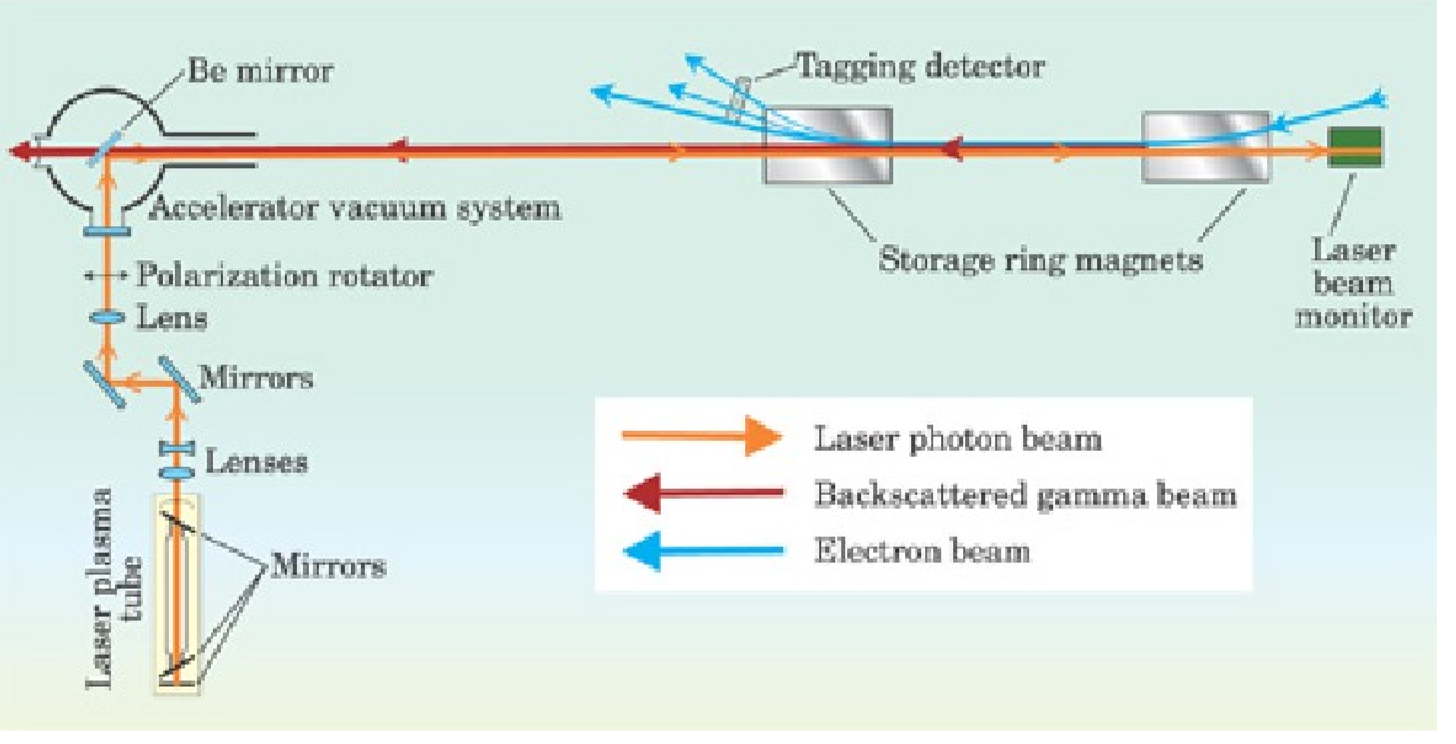
- Compton scattering of polarized laser light with high energy e+-

- Bremstrahlung of polarized e+- on thin target

- Coherent Bremstrahlung in crystals

Polarized γ-ray beam: laser

γ-rays are produced scattering polarized laser light off electrons circulating in a ring.



Pioneering work in Frascati in previous decades.

Polarized γ-ray beam: laser

The γ-rays maximum energy is $E_\gamma \sim 4\gamma_e\omega$

Where γ_e is the Lorentz factor of the electrons and ω is the laser photon energy.

For $E_e \sim 500$ MeV ($\gamma_e \sim 10^3$) a blue/UV laser (~200 nm ~6 eV)

$E_\gamma \sim 24$ MeV somehow marginal.

Possible solution: using wiggler to produce UV/VUV photons to feed into the ring on the electrons.

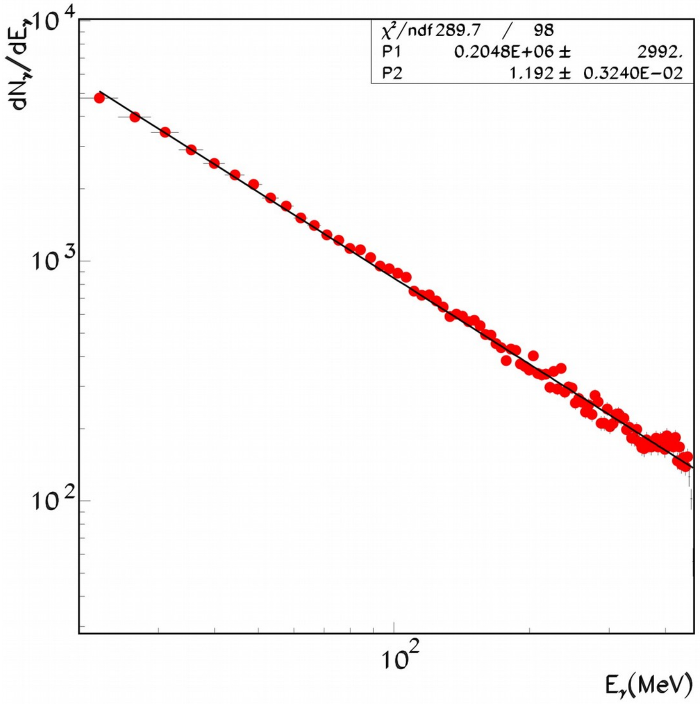
Polarized γ-ray beam: Bremstrahlung

γ-rays are produced by Bremstrahl
a thin target (thin to avoid showeri
The spectrum is ~ $1/E_\gamma$.

If the e^{+-}s are polarized, the spin is transferred to the photon.
The polarization depends on the gamma energy $P(E_\gamma)$.

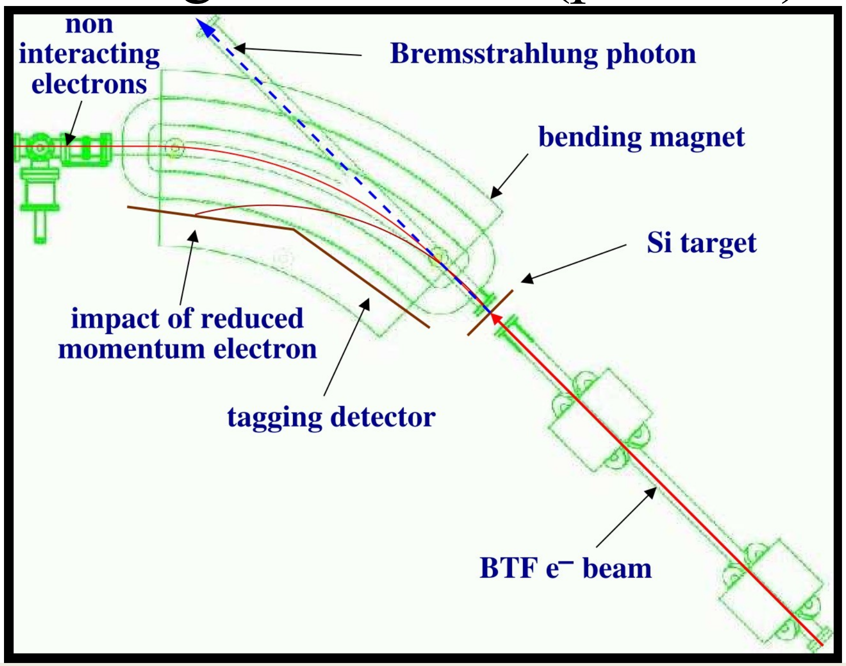
Even less than 100% is adequate if well known.

Beam must be BTF like, tunable down to 1 photon per spill.



Photon tag

Photon tag is the process of identifying the time and direction of arrival of a photon with an estimation of its energy measuring the original electron (positron).



For unpolarized photon beam implemented at BTF for AGILE.

P.W. Cattaneo et al., Nucl. Instr. Meth. B 674 (2012) 55
P.W. Cattaneo et al., Astroph. J., 86 (2018) 125

Photon tag

For polarized photons up to 400 MeV in Mainz (883 MeV microtron) a good photon tagger based on 353 scintillation detectors was designed with ~2 MeV energy resolution.

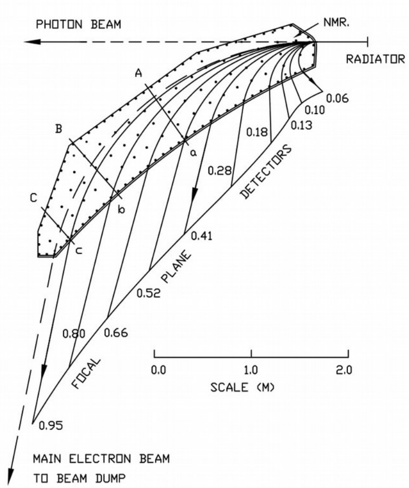


Fig. 2. Plan drawing of the lower pole shim (the upper pole shim is similar) showing the locations of the M8 screws which fix it to the pole (dots). The photon beam, main electron beam, several tagging electron trajectories (labelled by their energy as a fraction of the main beam energy) and the location of the main focal plane detectors are also indicated.

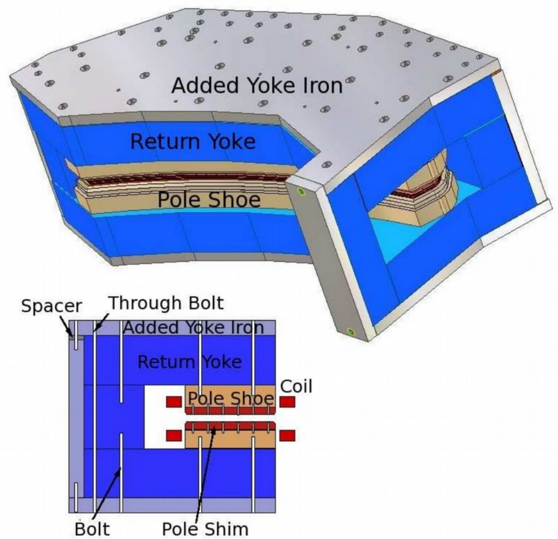


Fig. 1. The upgraded photon tagging spectrometer - 3D view (upper) and cross section (lower).

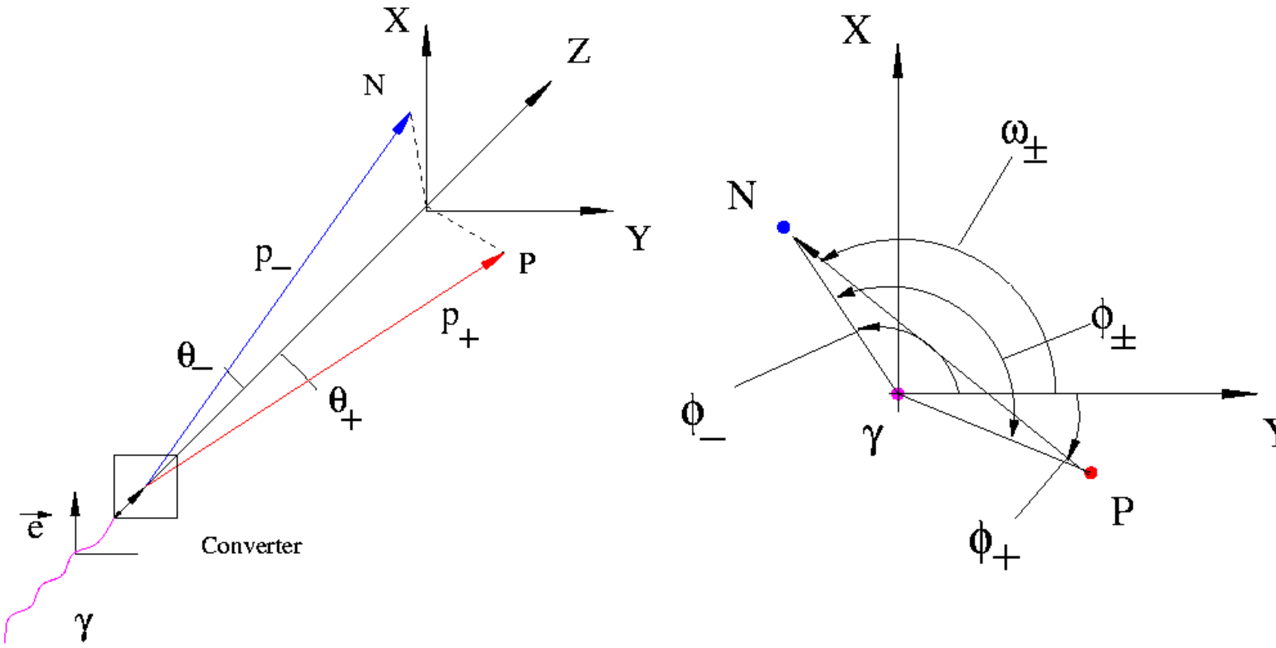
Polarimeter

The polarization versus the energy of the calibration beam γ-rays must be measured accurately independently from the DUT.

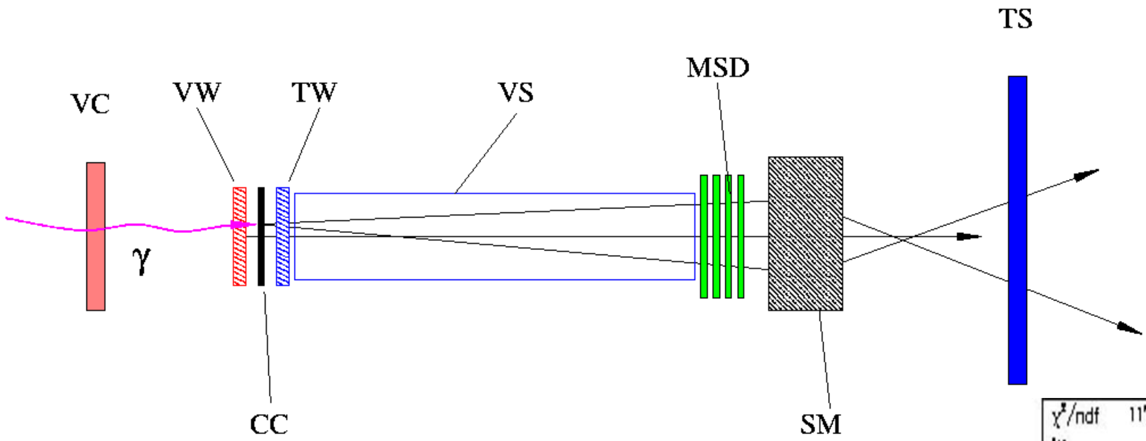
This task must be performed by a ad-hoc detector: a polarimeter.

This detector can be large and with low efficiency.

Direct measure of ω+- provides an estimation of the polarization



Polarimeter



Polarimeter studied at Spring8 in Japan for polarized γ-rays in Jlab. Strip detector + Separator magnet.

This or other designs are easy to implement.

Eur. Phys. J. A **19** (2004) 275

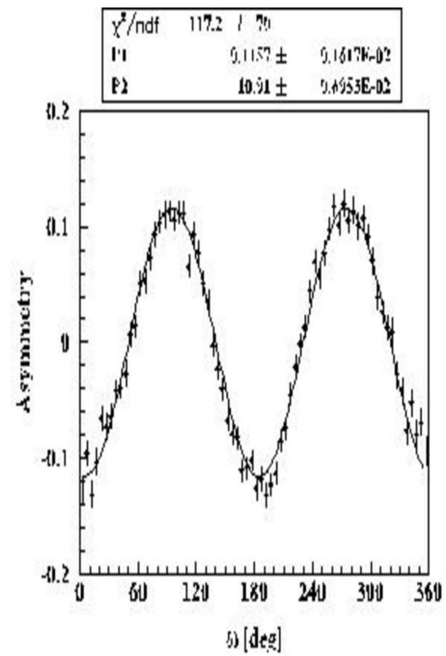
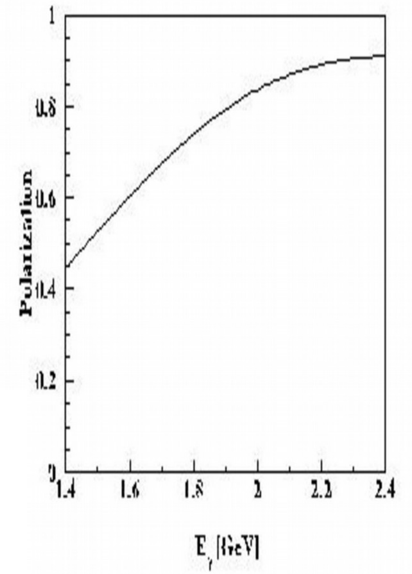


Fig. 6. The beam polarization effect in the azimuthal distribution of e^+e^- pairs. ω is the angle between the e^+e^- plane and the photon polarization plane. Parameters P1 and P2 of the fit reflect the asymmetry A_{exp} and Δ in 1



5. The photon polarization as a function of the photon energy

The road to polarized high-energy γ-ray astrophysics

- Up to now the road to high-energy γ-ray astrophysics was:

- **Define mission** → **Existing detectors** → **Existing test infrastructure**

As an **afterthought**: try to measure polarization

High energy polarization is very difficult to measure.

Revert the order:

Design test infrastructure (including tagged polarized γ-ray beam) → **Design detectors for polarization** → **Define mission**

Summary

- The ingredients are:
- A **polarized γ-ray beam** in the range **30 MeV-500 MeV** with
- single photon per bunch.
- A **spectrometer** (magnet + detection plane) as **photon tagger**

- A precise **polarimeter** (possibly bulky and at low efficiency)
- to calibrate the beam
- A vigorous program of **R&D** for detectors sensitive to **γ-ray**
- **polarization**