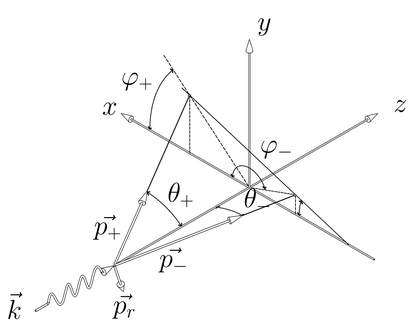
The first VEGAS-free, exact, 5D, polarized $\gamma \to e^+e^-$ pair conversion event generator

D. Bernard, LLR, Ecole Polytechnique, CNRS/IN2P3

$\gamma \to e^+e^-$: 5D phase space



- $+, -, r =$ positron, electron, recoil.
- ϕ azimutal, θ polar angles.
- $\Omega \equiv \phi_+,\ \phi_-,\ \theta_+,\ \theta_-,\ x_+ = E_+/E_\gamma$

Available event generators (Geant4, EGS5)

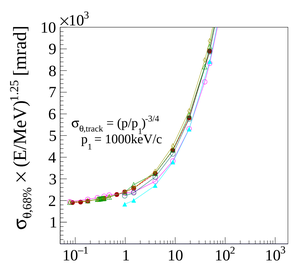
- Designed for EM shower generation
- Product of 1D probability density functions (pdf)
- No generation of target recoil momentum

  $\Rightarrow e^+$ and e^- generated back-to-back
- e^+, e^- polar angles generated independantly

$\Rightarrow$ No energy-momentum conservation

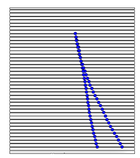
Angular resolution: Fermi-LAT (5°@ 100 MeV)

Single-photon angular resolution for various Geant4 and EGS5 physics models, normalized to $E^{-1.25}$



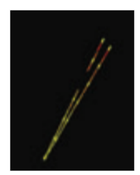
The contribution of the Fermi-LAT single-track angular resolution is so large that the generator differences are washed out. P. Gros & D. Bernard, Astroparticle Physics 88 (2017) 60.

High angular resolution γ-ray projects



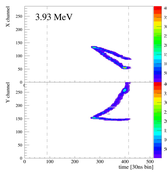
- W-less, Si-stack detectors (AMEGO, e-ASTROGAM) 1.3°@ 100 MeV),

  A. De Angelis *et al.*, Exper. Astron. **44** (2017) 25



- Emulsions (GRAINE, 1°@ 100 MeV)

  S. Takahashi *et al.*, PTEP **2015** (2015) 043H01



- Gas time projection chamber (TPC) (HARPO, 0.4°@ 100 MeV)

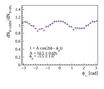
  D. Bernard, Nucl. Instrum. Meth. A 701 (2013) 225

Polarimetry with $\gamma \to e^+e^-$!

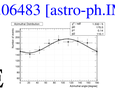
- For emulsions and gas TPC, the single-track angular resolution is good enough, early enough, that polarimetry can be performed

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

- And has actually been demonstrated experimentally on beam !

MeV: HARPO 

P. Gros *et al.*, arXiv:1706.06483 [astro-ph.IM], Astroparticle Physics

GeV: GRAINE 

K. Ozaki *et al.*, Nucl. Instrum. Meth. A **833** (2016)165

VEGAS-based event generator

- Sampling of the full 5D pdf
- Ion ("nuclear") or electron ("triplet") target
- No (high-energy, small angle ...) approximation
- Strict energy-momentum conservation
- Field screening by (other) electrons: form factor (nuclear: coherent, triplet: incoherent).
- Comparison of the Bethe-Heitler approximation to the full Feynman diagrams.
- Extensive validations:

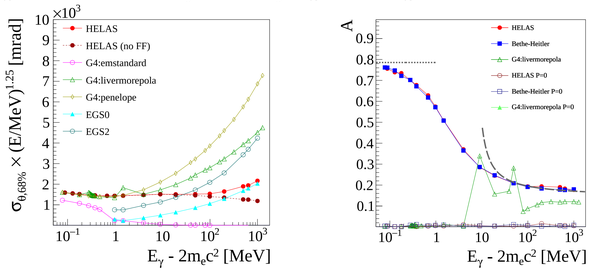
  D. Bernard, Nucl. Instrum. Meth. A 729 (2013) 765

  P. Gros & D. Bernard, Astroparticle Physics 88 (2017) 60
- VEGAS optimizes a 5D grid prior event generation: several seconds CPU overhead each (E, Z)

  G. P. Lepage, J. Comput. Phys. **27** (1978) 192.

Results, compared to Geant4 and EGS5 models

- Left: Single-photon angular resolution for various Geant4 and EGS5 physics models, normalized to $E^{-1.25}$
- Right: polarization asymmetry for fully polarized ($P = 1$) and for non-polarized γ-rays ($P = 0$), compared to the analytical asymptotic expressions



"HELAS": Feynman diagram calculation
"FF": screening formfactor

P. Gros & D. Bernard, Astroparticle Physics 88 (2017) 60

VEGAS-free event generator

- Dumped HELAS (Feynman diagrams)
- Dumped VEGAS
  - Optimized change of variable
  - Parametrize variable limits and 5D-pdf-maximum as a function of (E, Z)
- Extended validation down to 1.05 MeV and up to 40 PeV.

Perspectives

- FORTRAN $\to$ C++

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http://llr.in2p3.fr/∼dbernard/polar/harpo-t-p.html