Gamma Conversion into Mu+Mu-

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• Introduction, Motivation
  Standard process $\gamma \rightarrow \text{lepton pair}$
  previously only implemented for e+e-
  ok for energy deposit in calorimeters
  $\gamma \rightarrow \mu^+\mu^-$ essential for leakage, collimation of high energy e, $\gamma$
  Gave rather high backgrounds at SLC (Mark III); visible at LEP.
  Of concern for high energy linear collider studies,
  potentially several thousand high energy muons per bunch crossing.

• The process $\gamma \rightarrow \mu^+\mu^-$ and its and implementation
  G4GammaConversionToMuons code + Phys.Ref.
  from Geant versions 4.1 (summer ’02)
  included standard distribution

• Example of Application (Beam Delivery Design)
  and Outlook

references to talks and literature: http://hbu.home.cern.ch/hbu/Clic.html
**Motivation:** Example of Background simulations for CLIC

**Orders of magnitude**

$10^{10}$ e / bunch of which $\sim 10^{-3}$ which is $10^7$ to collimate;
Conversion probability $\sim 10^{-4}$; left with $1000 \mu'$s

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Previously simulated for linear collider studies by independent generator (SLAC, G. Feldman, L. Keller)

physics based on Tsai (Rev. Mod. Phys. 46 (1974) 815)

interfaced with Geant3 (H.J. Schreiber (DESY-Zeuthen, TESLA)

Future simulation strategies discussed in linear collider community (NLC, JLC, TESLA, CLIC)

Strong interest in more modern, combined (machine, collimation, detector) flexible approach as potentially possible with Geant4, with some concern on complexity of Geant4 and computing time.
Simulation of $e^+e^- \rightarrow \tilde{\mu} \tilde{\mu} \rightarrow \chi_0 \mu \chi_0 \mu$ event with muon background traversing the detector (M. Battaglia)

Statistics (1650 $\mu$) of this run such, that $\mu$-background still to be multiplied with factor 3-15 to simulate full batch
Implementation

**G4GammaConversionToMuons**.cc, hh, icc
in processes/electromagnetic/standard/

The process name is "**GammaToMuPair**"

(not to confuse with **G4MuPairProduction**, process name "**MuPairProd**" which is energy loss of muons by e+e- pair production)

Physics Description:
"**Monte Carlo Generator for Muon Pair Production**"
H.Burkhardt, S.R. Kelner, R.P. Kokoulin
CERN-SL-2002-016 (AP) and
Geant4 Physics Reference Manual (currently Section 3.4)

Select by:
AddDiscreteProcess **G4GammaConversionToMuons**

Dedicated example:
$G4INSTALL/examples/extended/electromagnetic/**TestEm6**

Optionally multiply the cross section with a factor (here 100) using the command
/run/process/setGammaToMuPairFac 100
here single e-, entering cylindric PbW el.magn calorimeter with a $\gamma \rightarrow \mu^+\mu^-$ producing conversion. $E_\gamma = 19.46$ GeV, $E_{\mu^+}/E_\gamma = 0.039$

Geometry: 20 $X_0$ or 18 cm long, 20 rings of 0.25 $X_0$ radius = 5 $X_0$ or 4.5 cm
Production mechanisms of Muons

The main process, the Bethe Heitler production $\gamma \rightarrow \mu^+\mu^-$ is a standard el. magn. shower process like $\gamma \rightarrow e^+e^-$ mainly just $m_\mu$ instead of $m_e$

$\sigma \sim \left( \frac{m_\mu}{m_e} \right)^2 = 207^2 = 4.3 \times 10^4$

(differences in recoil, screening)


(rather than Tsai, Review of Modern Physics 46 (1974) 815)

adapted to MuonPair production and Monte Carlo by Kelner, Kokoulin

Planned to complete with other $\mu$-production processes

- direct annihilation of beam $e^+$ with $e^-$ in matter $e^+e^- \rightarrow \mu^+\mu^-
- hadronic, $eN \rightarrow \pi^\pm +...$

$\Rightarrow \mu\nu\nu$
Cross section and energy sharing

The photon energy is fully shared by the two muons according to

$$E_\gamma = E_\mu^+ + E_\mu^-$$

With

$$\sigma_0 = 4 \alpha Z^2 r_c^2 \log(W_\infty) \quad \sigma_\infty = \frac{7}{9} \sigma_0$$

Total cross section as result of numerical integration, parametrized

![Graph showing cross section as function of photon energy](Meet17-5-2002/SigTot.eps)

<table>
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<th>$E_\gamma$ (GeV)</th>
<th>$\sigma_{\text{tot}, \ H}$ ($\mu$barn)</th>
<th>$\sigma_{\text{tot}, \ Be}$ ($\mu$barn)</th>
<th>$\sigma_{\text{tot}, \ Cu}$ ($\mu$barn)</th>
<th>$\sigma_{\text{tot}, \ Pb}$ ($\mu$barn)</th>
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</table>
Figure 2: Normalized differential cross section for pair production as function of $x$, the energy fraction of the photon energy carried by one of the leptons in the pair. The function is shown for 3 different elements, Hydrogen, Beryllium and Lead and for a wide range of photon energies.
Distributions, generated with G4GammaConversionToMuons

\[ E_\gamma \]

- 10 GeV
- 100 GeV
- 1000 GeV

\[ x^+ \]

\[ \theta^+ \]

\[ 1 \text{ GeV} \]
\[ 10 \text{ GeV} \]
\[ 100 \text{ GeV} \]
\[ 1000 \text{ GeV} \]
\[ 1 \text{ TeV} \]
Scattering angles and angular correlation $\mu^+, \mu^-$ are rather precisely simulated (solid line exact, histo - generated)
Example here for $E\gamma = 10$ GeV, Fe, $x_+ = 0.3$
Application: **Beam Delivery Simulation with Geant4**

![Graph showing muon flux from first spoiler along the line for 10,000 1.5 TeV Electrons.](G4WorkshopOct2002/BDSIM.eps)

Several cases: **a** magnet elements (20 cm Ø) unmagnetised, case **d** magnetised  
**c** as **a** with 50 cm. Ø, **b** muons only from first photon in cascade

see also "Background simulation for the CLIC Beam Delivery System with Geant"  
by G.A. Blair, H. Burkhardt, H.J. Schreiber,  
CERN-SL-2002-029 (June 2002) contribution to EPAC 2002  
and BDSIM, G. Blair, CLIC Note 509, September 2002

**Outlook, plans:**  
Comparison with independent generators + Geant3  
Implement further µ-production processes in Geant4, $e^+e^- \rightarrow \mu^+\mu^-$