26th Advanced ICFA Beam Dynamics Workshop, Nanometre-Size Colliding Beams,
Lausanne, Sep. 2002   H.Burkhardt CERN-SL

Muon background simulation and Geant4

The process of gamma conversion into a pair of muons has recently been added as standard process to the Geant4 program.
The main features of the process and the potential of Geant4 for combined machine/detector background simulations will be described

- **Introduction**
  μ-background potentially very high, particularly at very high (CLIC) energies.
  Should be part of both in BDS and Detector design
  Motivates flexible / standard approach ->

- **Geant4**

- the process $\gamma \rightarrow \mu^+\mu^-$

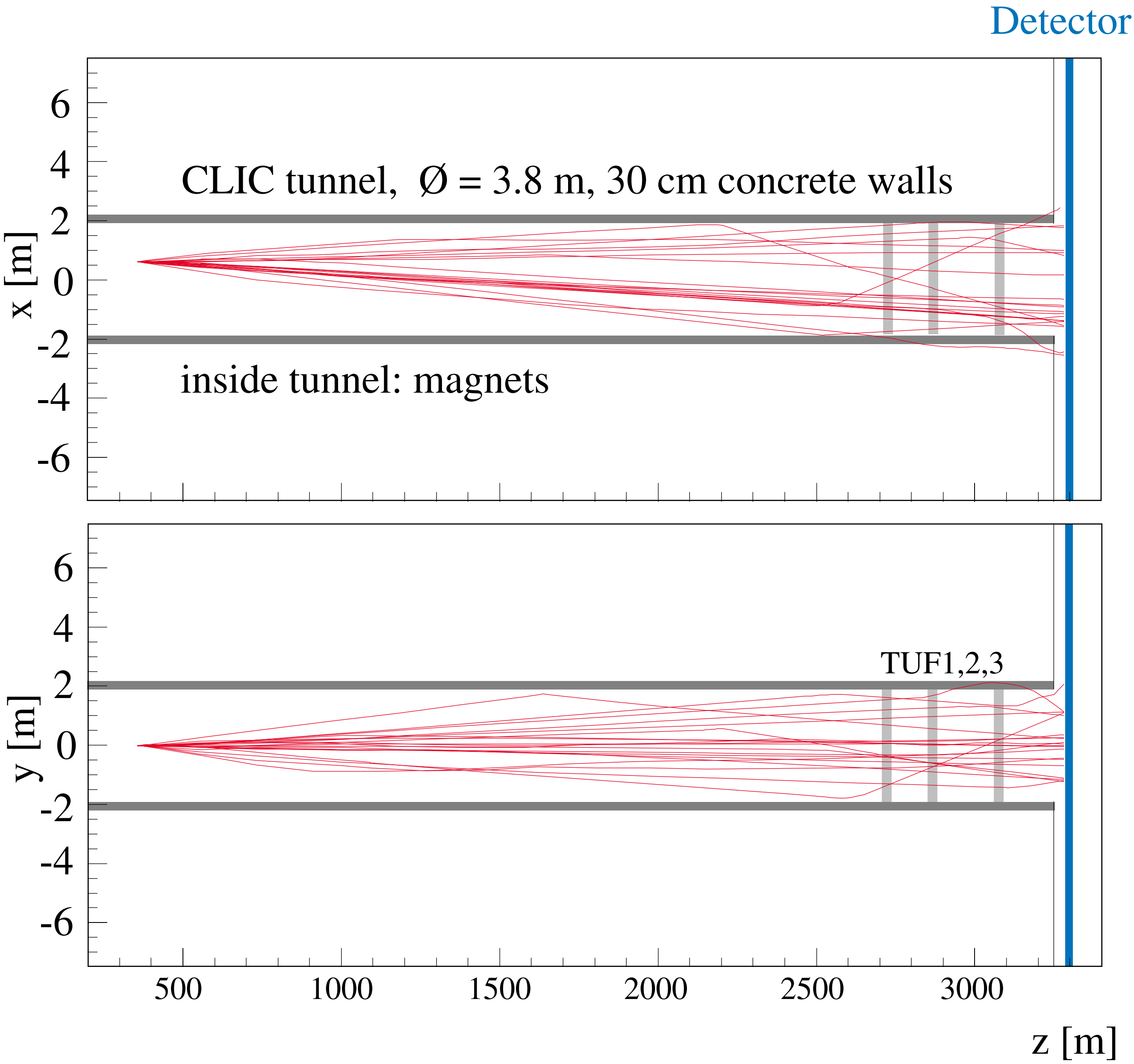
- BDSIM and application to CLIC, prospects ...

references to talks an literature: http://hbu.home.cern.ch/hbu/Clic.html

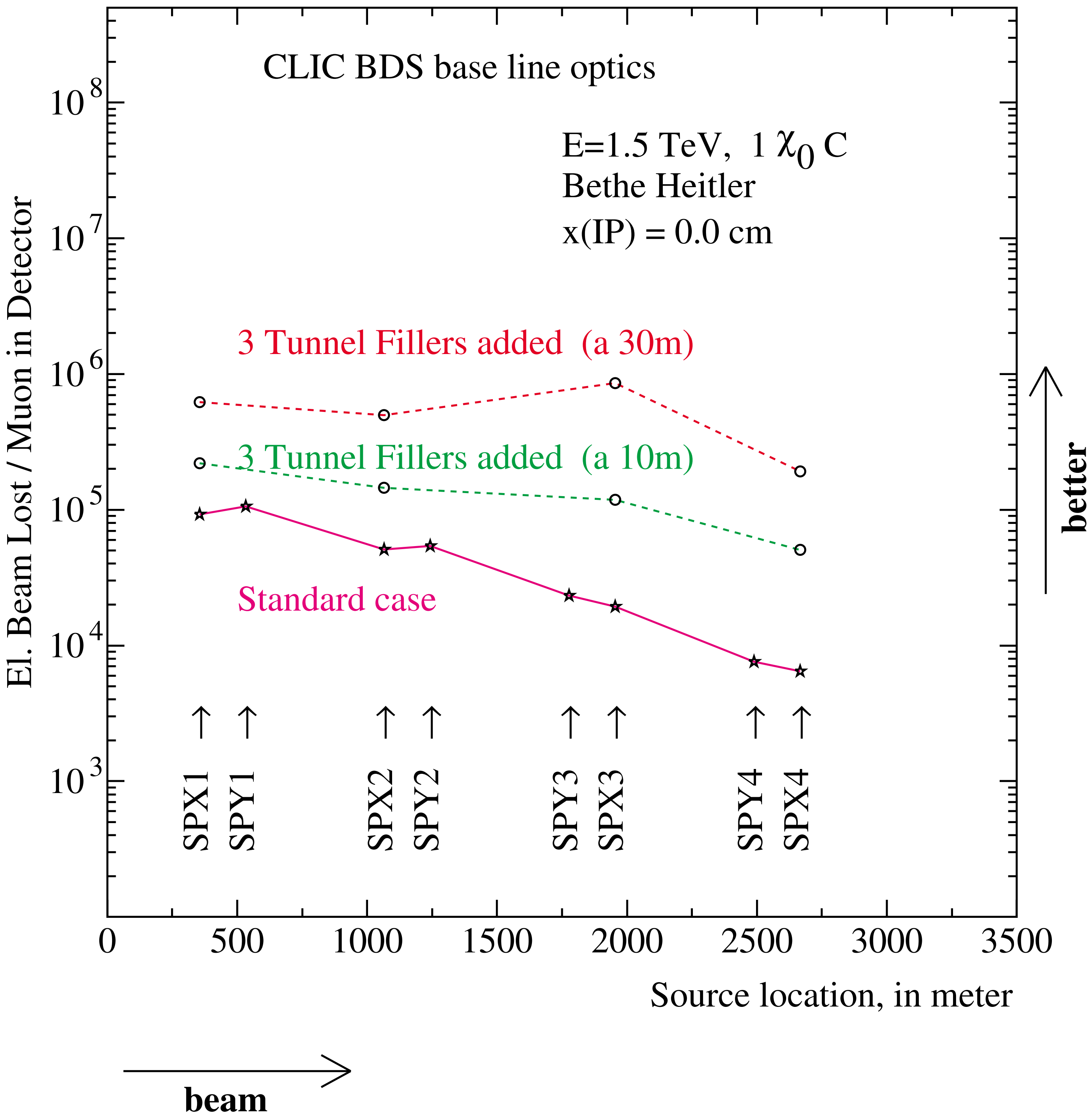
μ Background simulation for CLIC

Started in collaboration with H.J. Schreiber (DESY-Zeuthen)
based on mu-pair generation from G. Feldman, L. Keller
physics based on Tsai (Rev. Mod. Phys. 46 (1974) 815)

μ's from first spoiler, SPX1 ($1X_0$ carbon)



Estimated rates, with/without muon protection systems



ClicPhys4/SimulRes.eps

CLIC μ BKG potentially very high, Estimate

Based on current Geant3 (Bethe Heitler only, baseline optics), simulation

muon background increases strongly with energy
(about 10• from 0.25 TeV to 1.5 TeV, more produced, harder to sweep away, very hard to stop)
expected rate roughly
$e^{\pm}$/halo = 9.2×10^4 / (2•2) = 2.3×10^4 / bunch = 1.5×10^2 / train

both beams
154 bunches/train
other mechanisms

with 4×10^9 e / bunch, and assuming a fraction of 10^{-3} tail particles to be collimated, that would result in a flux of
4×10^6 / 2.3×10^4 = 170 μ/bunch or **27 000 μ / train**

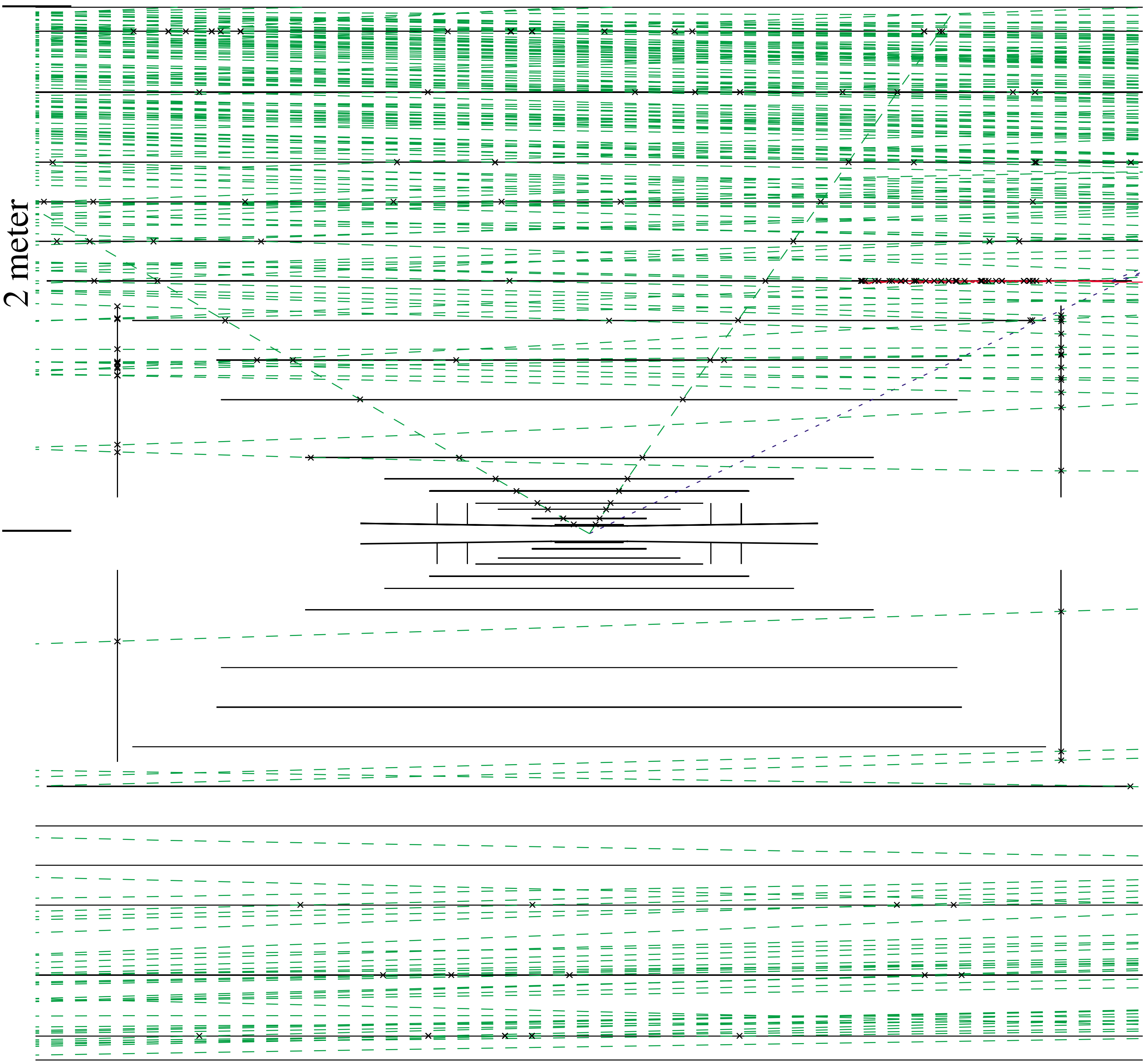
with full magnetized 90 m muon protection system
$e^{\pm}$/halo improves from 9.2×10^4 to 6.2×10^5 by factor 7
resulting in 26 μ/bunch or **4000 μ / train**

Muon background increases very strongly with energy, major concern for CLIC.
Increase of secondary muon-production with energy not yet taken into account.

Full simulation needed → Geant4

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 μ) of this run such, that μ-background still to be multiplied with factor 3-15 to simulate full batch

NanoBeam9-2002/evt_mu_smu.eps

Geant4

OOP (C++) version of Geant, many developers and users, LHC, TESLA..
should be the choice for any major further development

so far: muon production + follow particles by Geant3, geometry
from Mad, coded by hand in to Geant3

- more natural, particularly for secondaries to integrate μ production in to Geant
- at the same time, take advantage of G. Blairs BDSIM to get the geometry automatically via Mad.

new standard em.process G4GammaConversionToMuons
written by me in close collaboration with Kelner, Kokoulin
and with help of M. Maire; handles $\gamma \rightarrow \mu^+\mu^-$
(in addition to many existing processs like G4GammaConversion
$\gamma \rightarrow e^+e^-$ and the already existing μ energy loss codes)

Status:

- Now part of standard Geant4 distribution
starting from version 4.1 on, which was released this summer.
test-example $G4INSTALL/examples/extended/electromagnetic/TestEm6
and full documentation (draft CLIC Note -> Geant4 Phys. Manual,
section Section 3.4
http://wwwinfo.cern.ch/asd/geant4/G4UsersDocuments/UsersGuides/PhysicsReferenceManual/html/PhysicsReferenceManual.html
part of the distribution, available on the web

http://wwwinfo.cern.ch/asd/geant4/geant4.html (Geant4 home)

Geant4 — a simulation toolkit

Geant4 Collaboration

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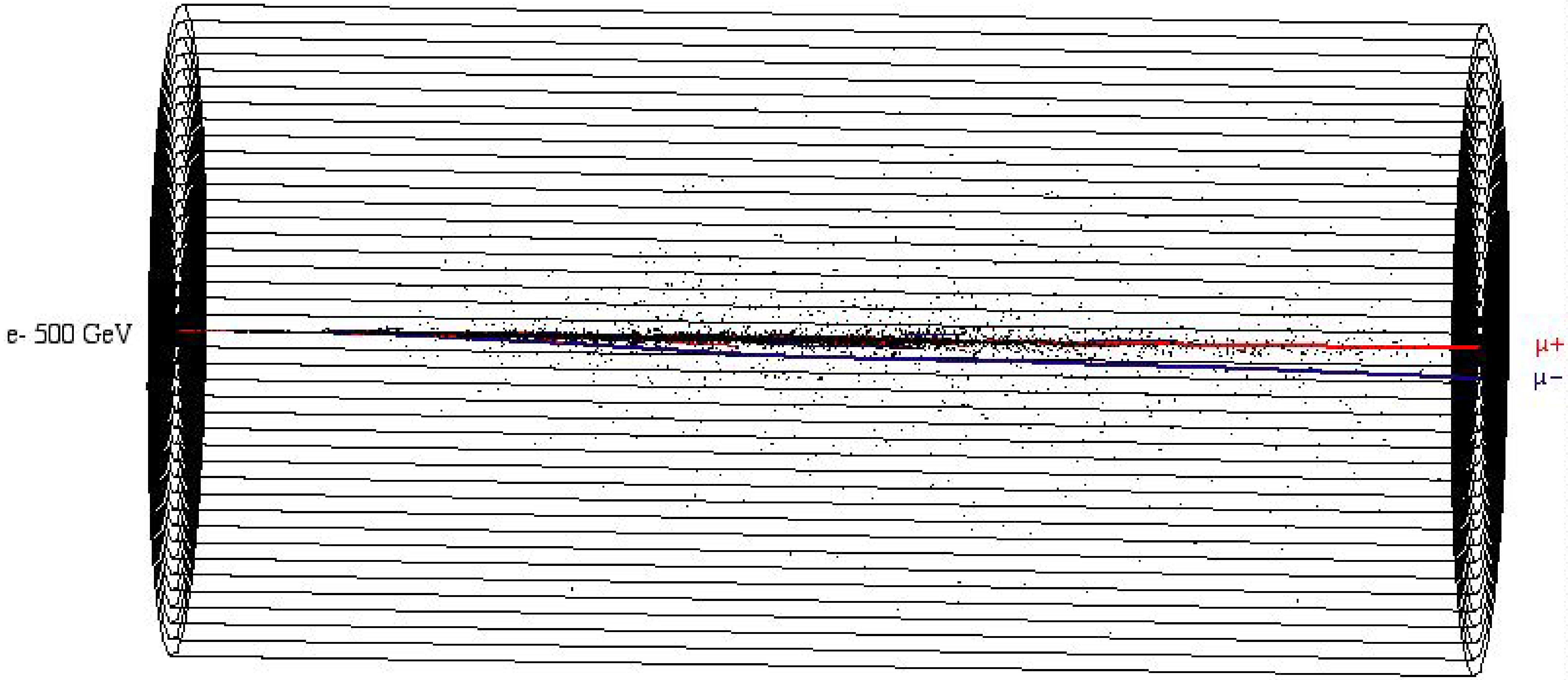
geant4/examples/extended/electromagnetic/TestEm2
here single e-, entering cylindric PbW el.magn calorimeter
with a $\gamma \rightarrow \mu+\mu-$ producing conversion. $E_\gamma = 19.46$ GeV, $E\mu+/E_\gamma = 0.039$



Geometry: 20 X_0 or 18 cm long, 20 rings of 0.25 X_0 radius = 5 X0 or 4.5 cm

g4_00.eps

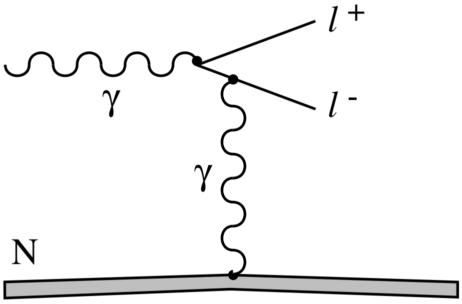
Production mechanisms of Muons

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_μ instead of m_e

$$\sigma \sim \left[\frac{m_\mu}{m_e}\right]^2 = 207^2 = 4.3\text{x}10^4$$

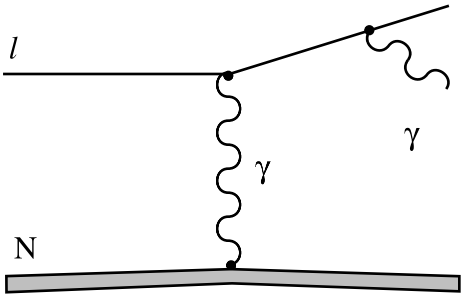
(differences in recoil, screening)



closely

related to

Bremsstrahlung



Physics based on work (μ energy loss, Bremsstrahlung) of
A. Petrukhin et al, Moscow Engin. Physi. Institute., Proc. 10th Intern. Cosmic Ray Conf., Calgary, 1967
(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 μ-production processes

- direct annihilation of beam e+ with e- in matter $e^+e^- \rightarrow \mu^+\mu^-$
- hadronic, eN -> π± +...

  └> μνν

Cross section and energy sharing

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

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

With

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

Total cross section as result of numerical integration, parametrized

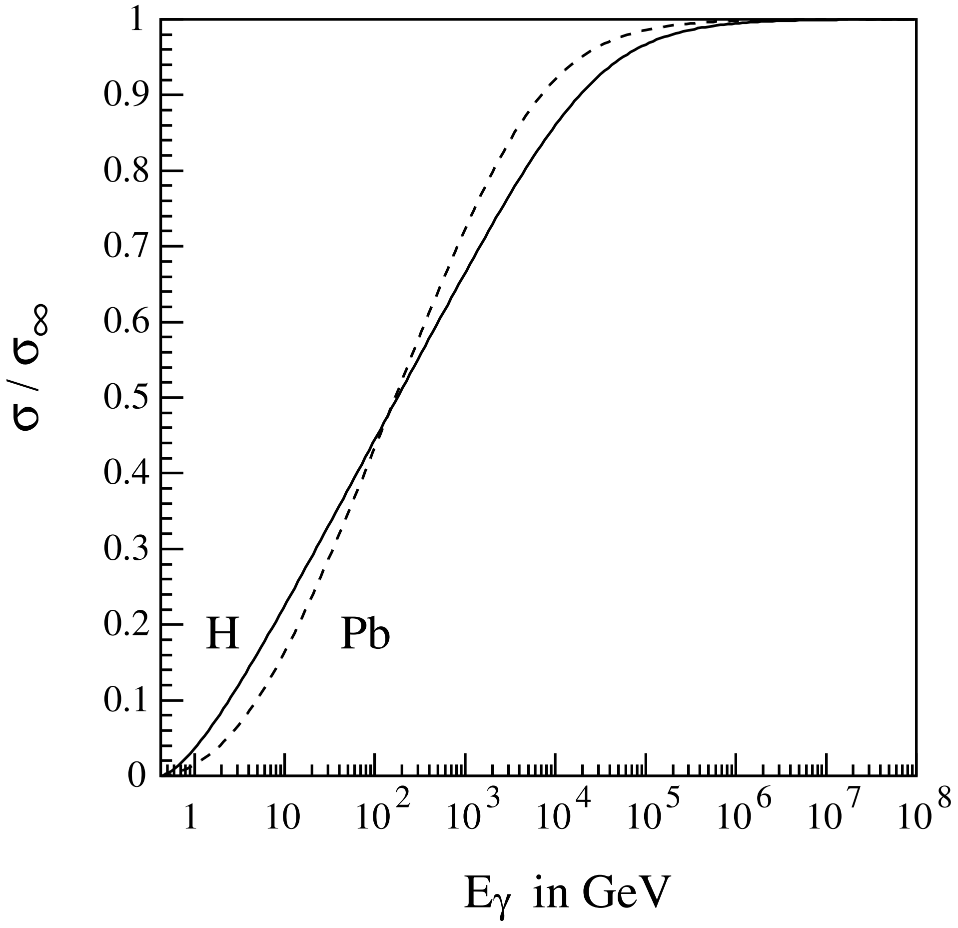


Table 2: Numerical values for the total cross section

E_γ GeV	$\sigma_{\rm tot}$, H μbarn	$\sigma_{\rm tot}$, Be μbarn	$\sigma_{\rm tot}$, Cu μbarn	$\sigma_{\rm tot}$, Pb μbarn
1	0.01559	0.1515	5.047	30.22
10	0.09720	1.209	49.56	334.6
100	0.1921	2.660	121.7	886.4
1000	0.2873	4.155	197.6	1476
10000	0.3715	5.392	253.7	1880
∞	0.4319	6.108	279.0	2042

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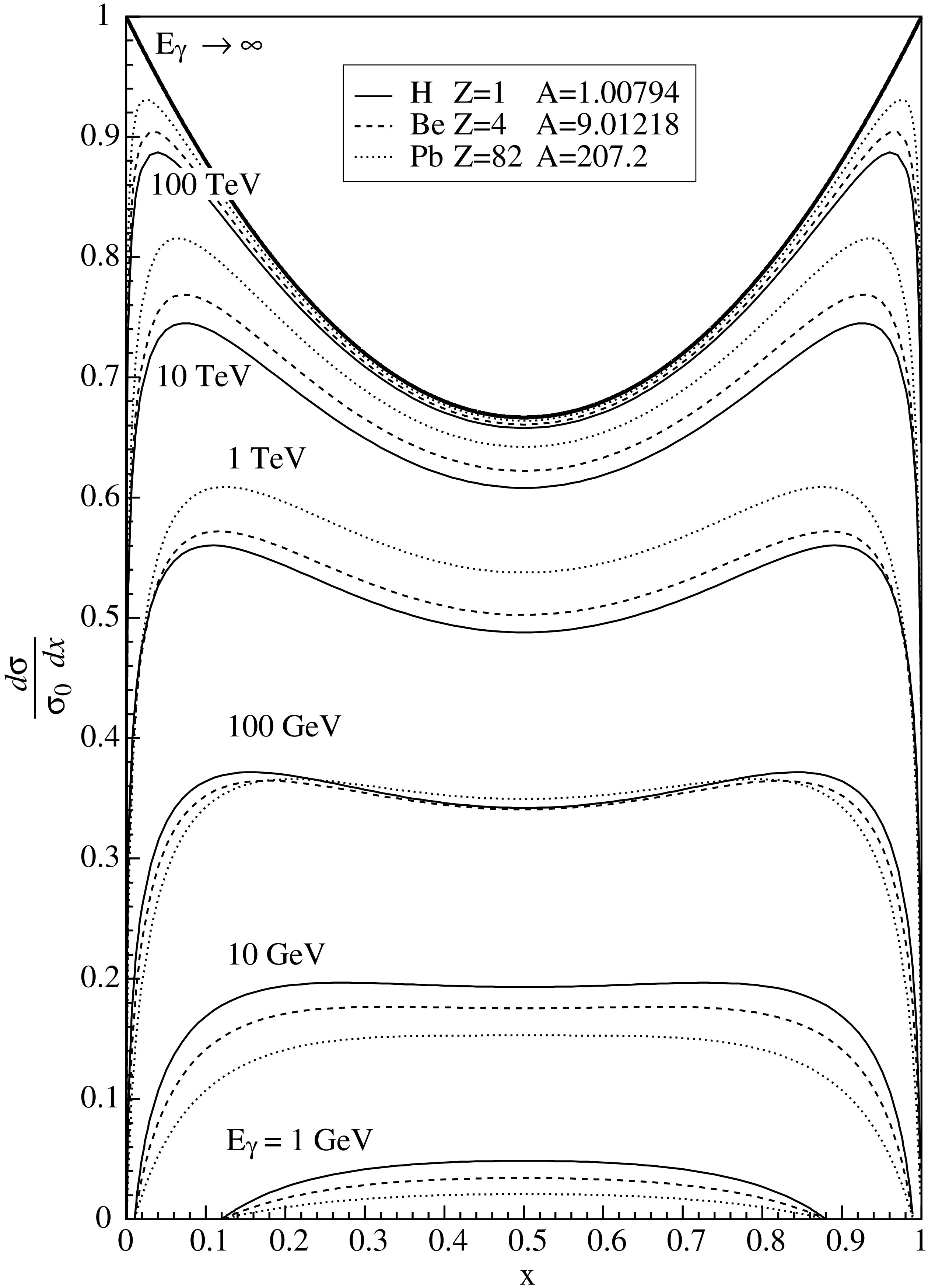

Figure 2: Normalized differential cross section for pair production as function of x, the energy fraction of the photon energy carried by one of the leptons in the pair. The function is shown for 3 different elements, Hydrogen, Beryllium and Lead and for a wide range of photon energies.

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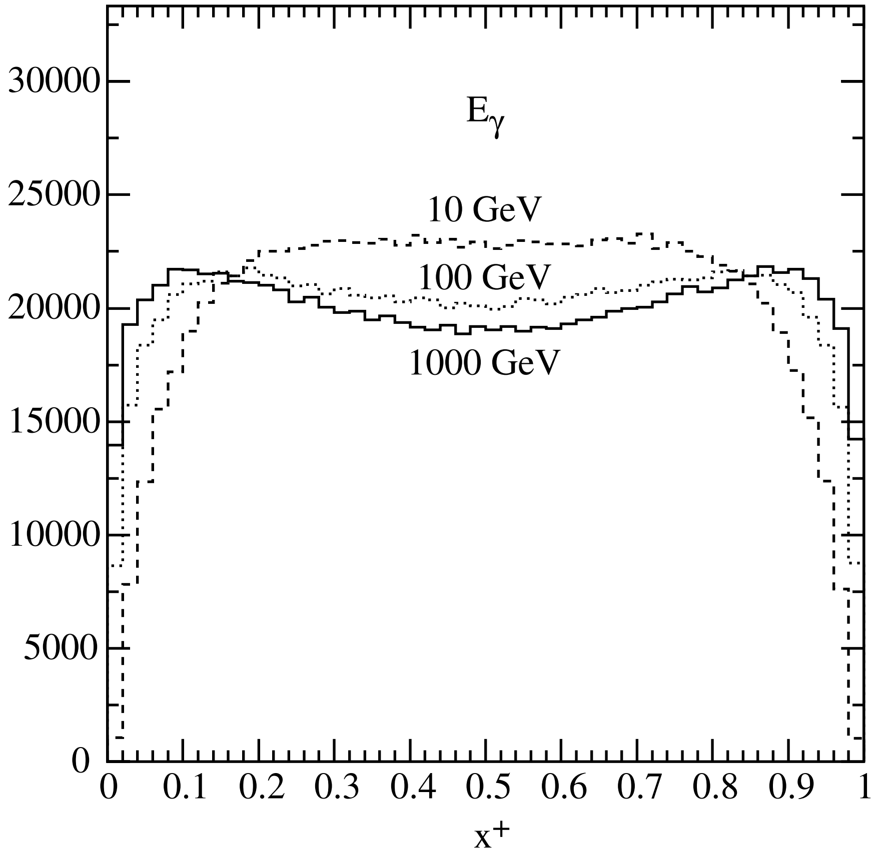
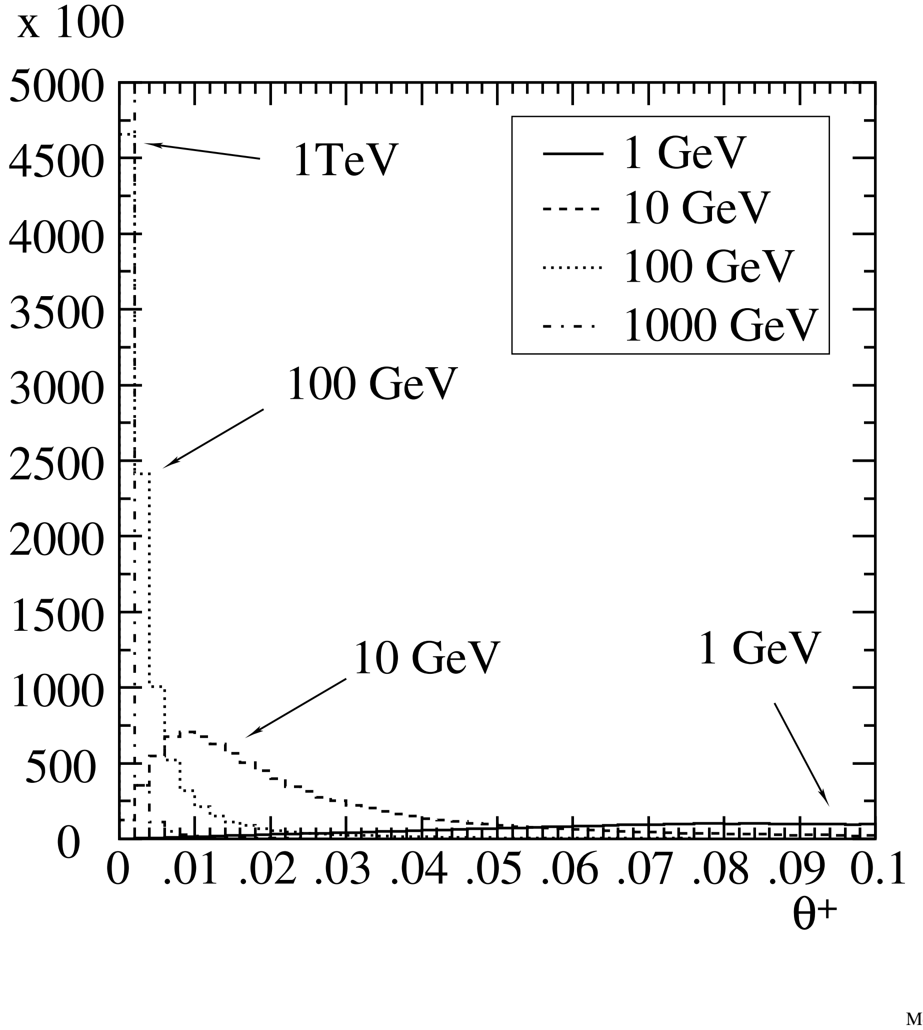
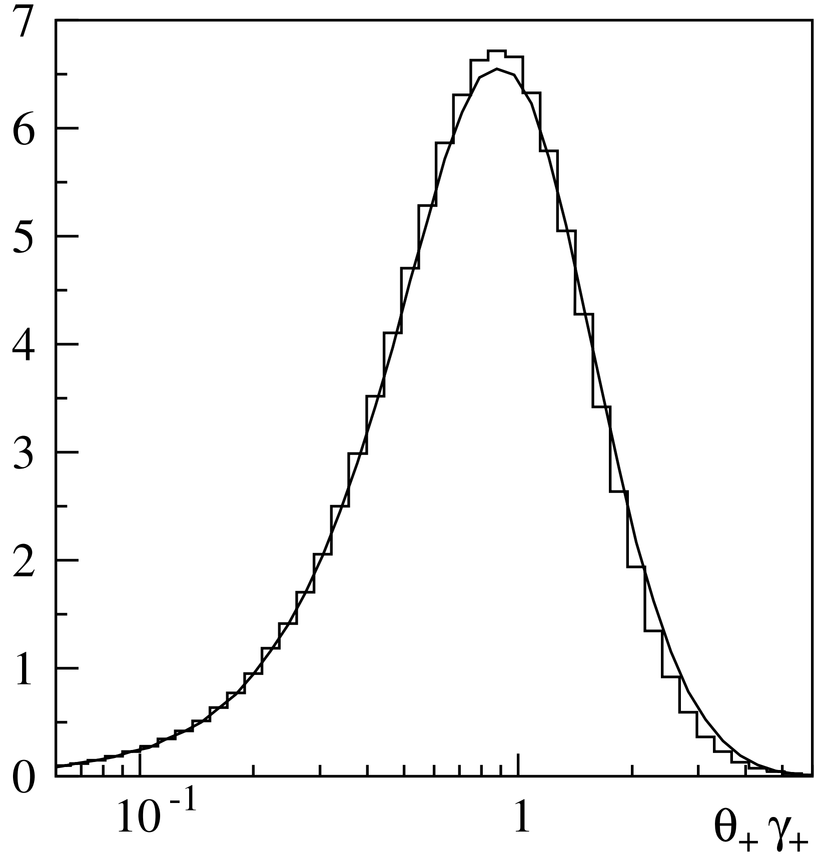
Distributions, generated with

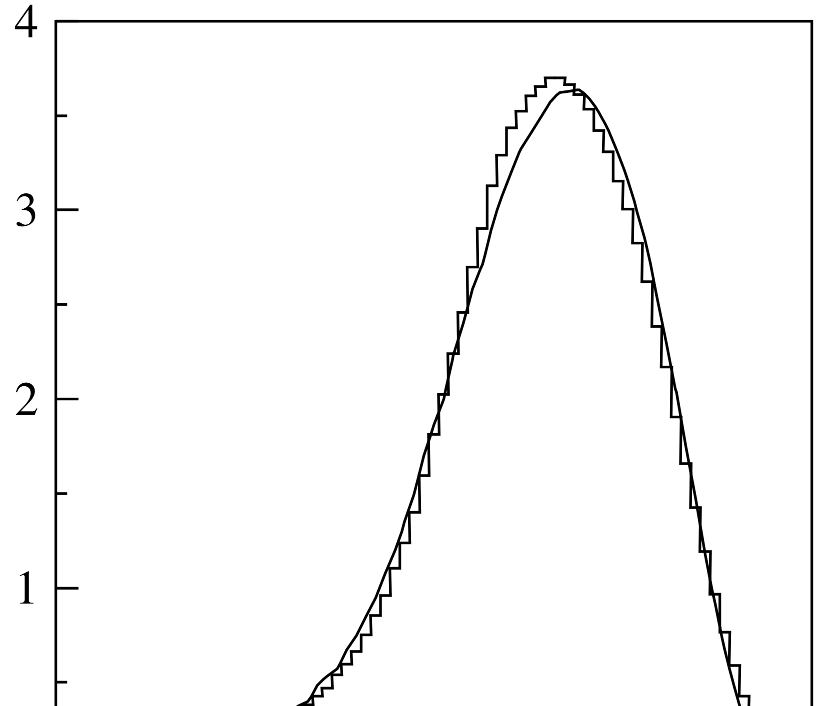
G4GammaConversionToMuons





Scattering angles and angular correlation μ+,μ- are rather precisely simulated (solid line exact, histo - generated)
Example here for Eγ = 10 GeV, Fe, x+ = 0.3





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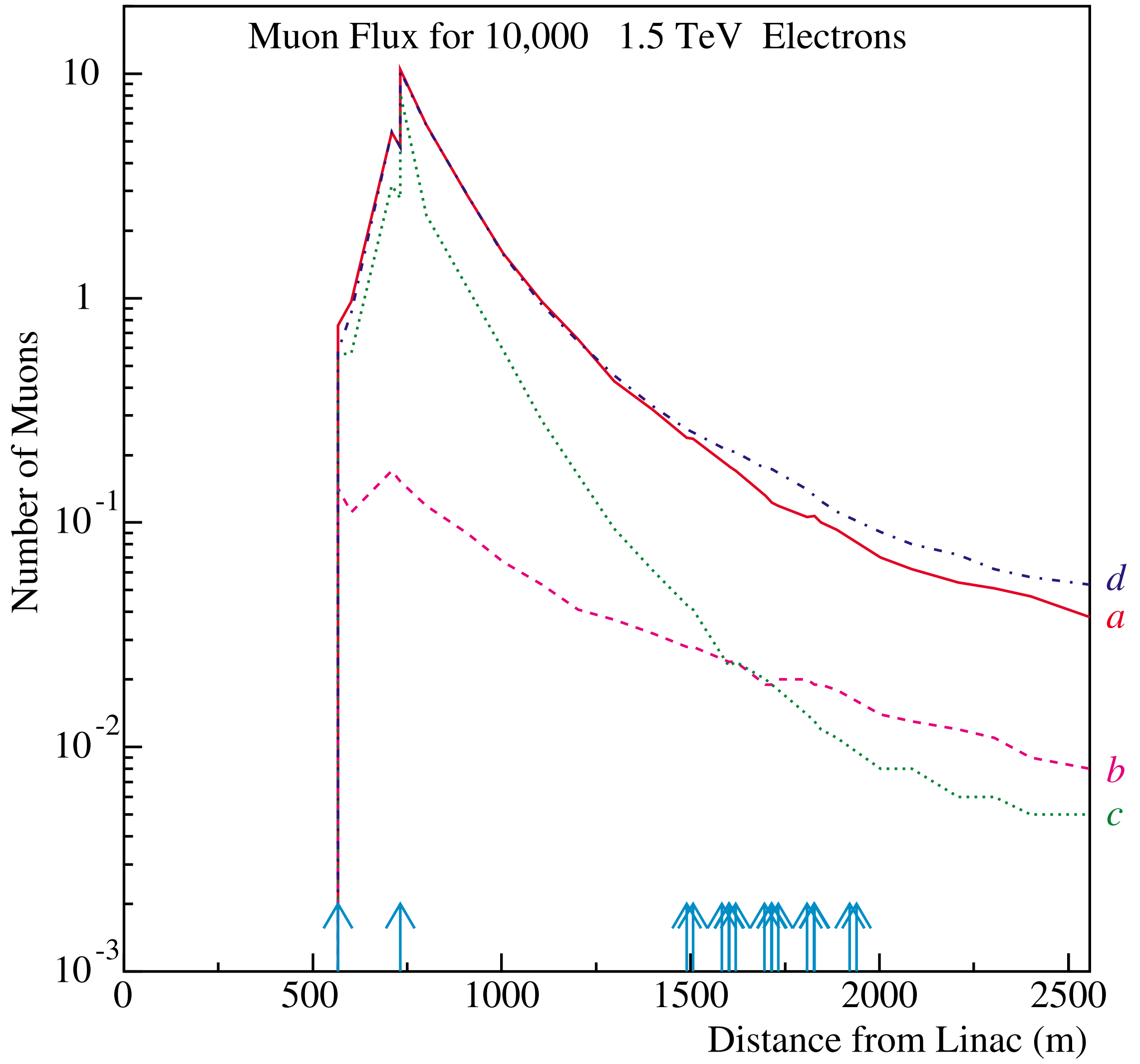
First look at CLIC beam delivery using Geant4, with G. Blair's BDSIM (Mad -> Geant4) and $\gamma \rightarrow \mu^+\mu^-$ as standard process



The figure shows first, preliminary Geant4 results, for the muon production from a 1.5 TeV electron beam, which impinges completely on the energy spoiler, is shown for a variety of cases.

The positions of the spoilers and collimators are shown by arrows.

Case ***a*** corresponds to magnet elements consisting of unmagnetised (and case ***d*** magnetised) cylinders of iron of diameter 20 cm with fully simulated showers, case ***b*** for the case with only the first photon of a shower contributing. Case ***c*** is the same as case ***a*** except that magnet elements have diameter 50 cm.

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

Planned: comparison with Geant3, optimization of geometry for backgr. ....

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