Study of High Energy Positron Annihilation in GEANT4

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Outline

- Introductioin
- Modification of High Energy Process in GEANT4
- Validation of GEANT4 cross-section versus theory
- Simulation in a simple setup

Introduction

Introduction

- High energy positron annihilation

  — In high energy physics, incident e^+ would annihilate with atomic e^- by the following processes[1].

  — these processes may provide a background to the interaction region of linear collider(for example, CLIC[2]) or to search for new physics at LHC(this work).

Processes

e^+e^-

$\rightarrow \gamma\gamma$

$\rightarrow \mu^+\mu^-$

$\rightarrow \pi^+\pi^-$

$\rightarrow \pi^+\pi^-\pi^0$

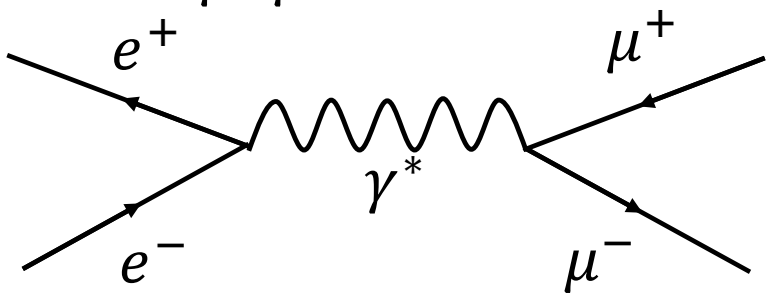
$\rightarrow K^+K^-$

$\rightarrow K_L K_S$

$\rightarrow \eta\gamma$

$\rightarrow \pi^0\gamma$

ex) $e^+e^- \rightarrow \mu^+\mu^-$



Modification of High Energy Process in GEANT4

Problem in EmCalculator

- Extract cross sections of positron annihilation to 2γ, $\mu^+\mu^-$, or hadrons($\pi^+\pi^-$, $\pi^+\pi^-\pi^0$,K^+K^-,etc…) in GEANT4

G4EmCalculator* emCal;

emCal.**ComputeCrossSectionPerAtom**(energy,particle,processName, Z,A,cut)

- processName = “annihil” ⇒ work
- processName = “AnnihiToMuPair” ⇒ NOT work
- processName = “ee2hadr” ⇒ NOT work

Class

G4EmCalculator

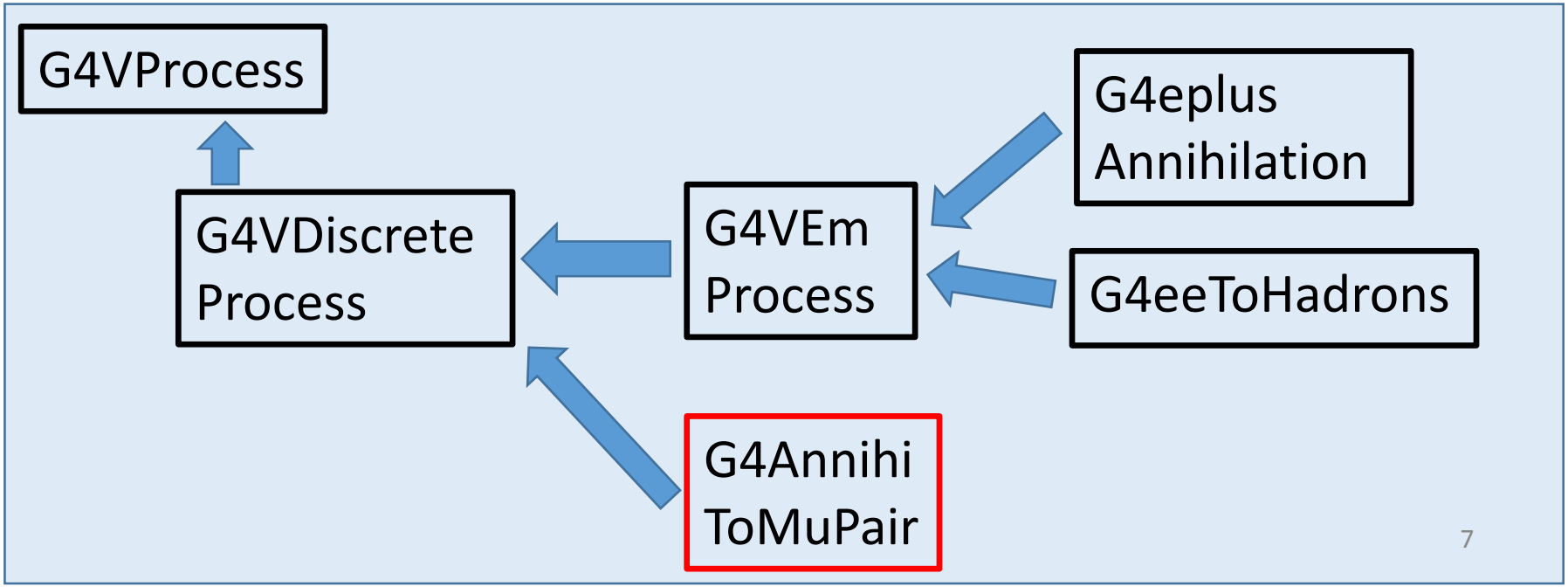
Classes for each process

G4eplusAnnihilation
G4AnnihiToMuPair
G4eeToHadrons

Modification of EmCalculator

- The reason why “AnnihiToMuPair” did not work:
  - Could NOT find the process by the name “AnnihiToMuPair”
  - “AnnihiToMuPair” is NOT included in G4VEmProcess

⇒Create new function to find this process in EmCalculator



G4eeToHadrons processes

- Mistake in scale between CM and Lab
  - — Made a inline function “LabToCM”
  - — Changed incident e^+ energy into CM scale, and then extract cross section
- Add a proper initialization of G4eeToHadronsModel
  - — Here define cross section
- Clean up the codes
  - — Remove unnecessary variables
  - — Fix the low energy limit as the process threshold

Classes for hadrons processes

G4eeToHadrons
G4eeToHadronsModel
G4eeToHadronsMultiModel
G4Vee2hadrons

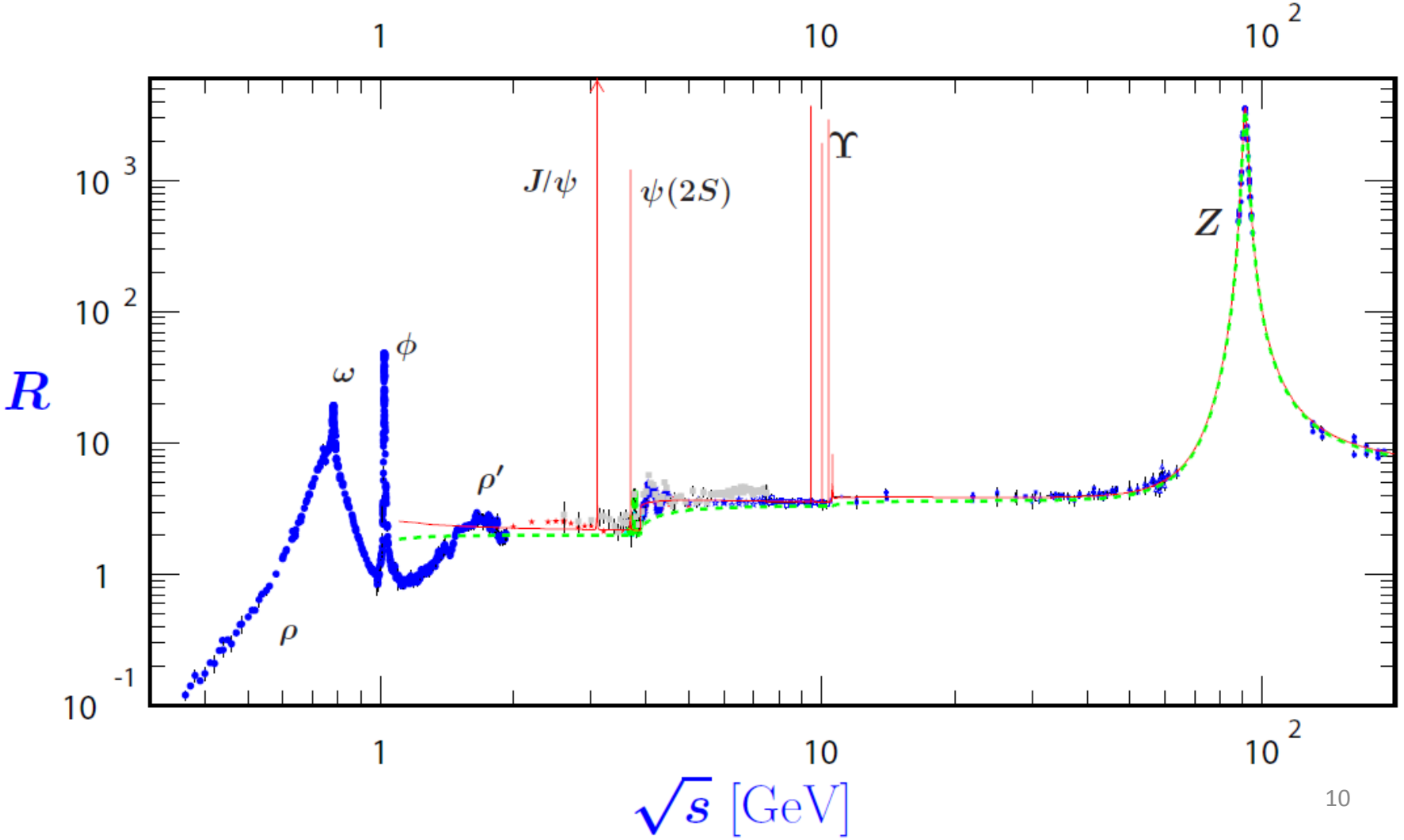
Classes for each process

G4eeToTwoPiModel
G4eeTo3PiModel
G4ee2KChargedModel
G4ee2KNeutralModel
G4eeToPGammaModel

Validation of GEANT4 cross-section

PDG data

$$R(s) = \sigma(e^+e^- \to hadrons)/\sigma(e^+e^- \to \mu^+\mu^-)$$



CrossSections in GEANT4

- Extract cross sections by using a example, TestEm6
- Calculate by theory[3]
  - $e^+e^- \rightarrow \gamma\gamma$:

$$\sigma(Z,E) = \frac{Z\pi r_e^2}{\gamma+1}\left[\frac{\gamma^2+4\gamma+1}{\gamma^2-1}\ln\left(\gamma+\sqrt{\gamma^2-1}\right) - \frac{\gamma+3}{\sqrt{\gamma^2-1}}\right]$$

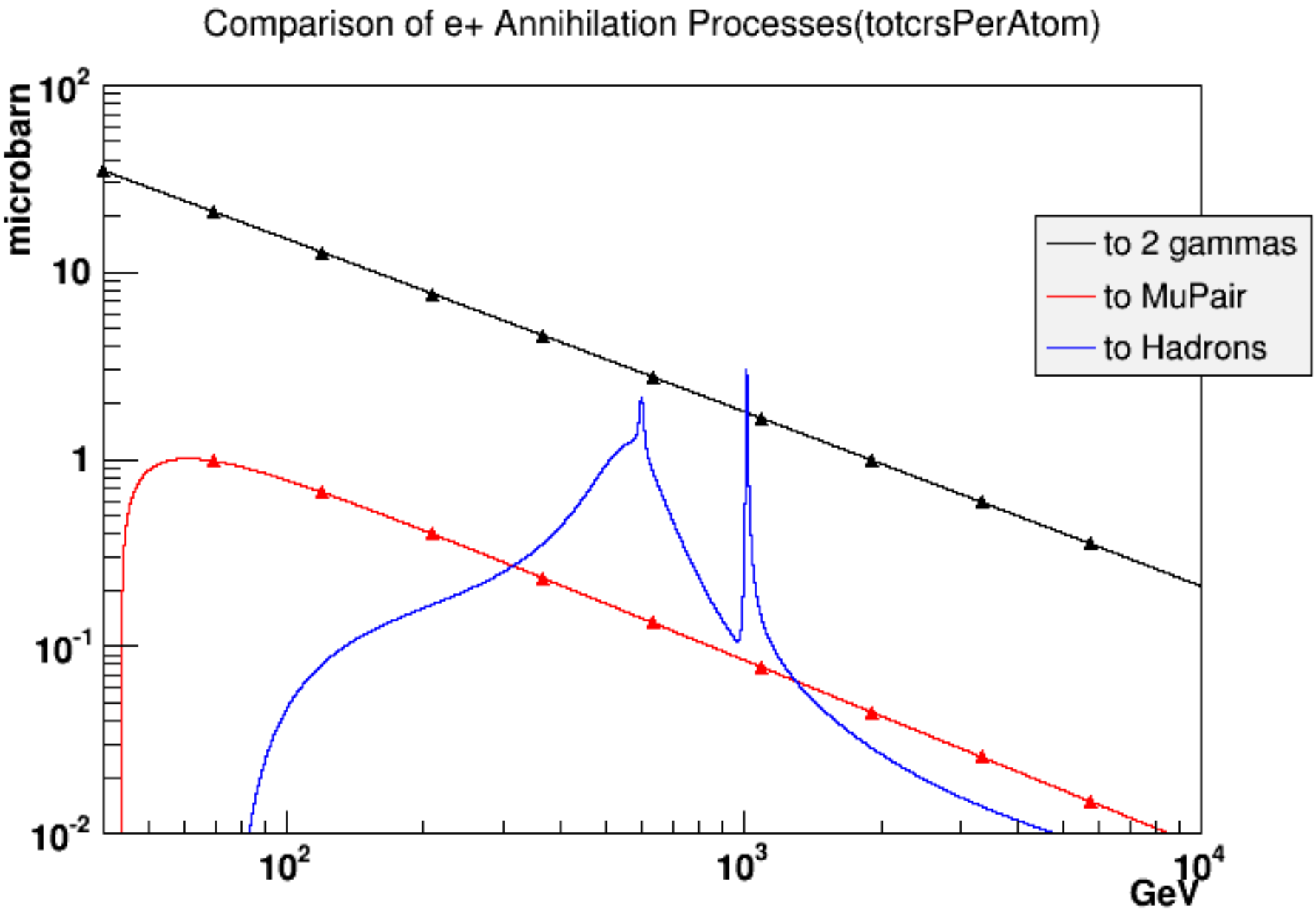
E:total energy of the incident positron in laboratory frame,
$\gamma = \mathrm{E}/m_e$, r_e:classical electron radius

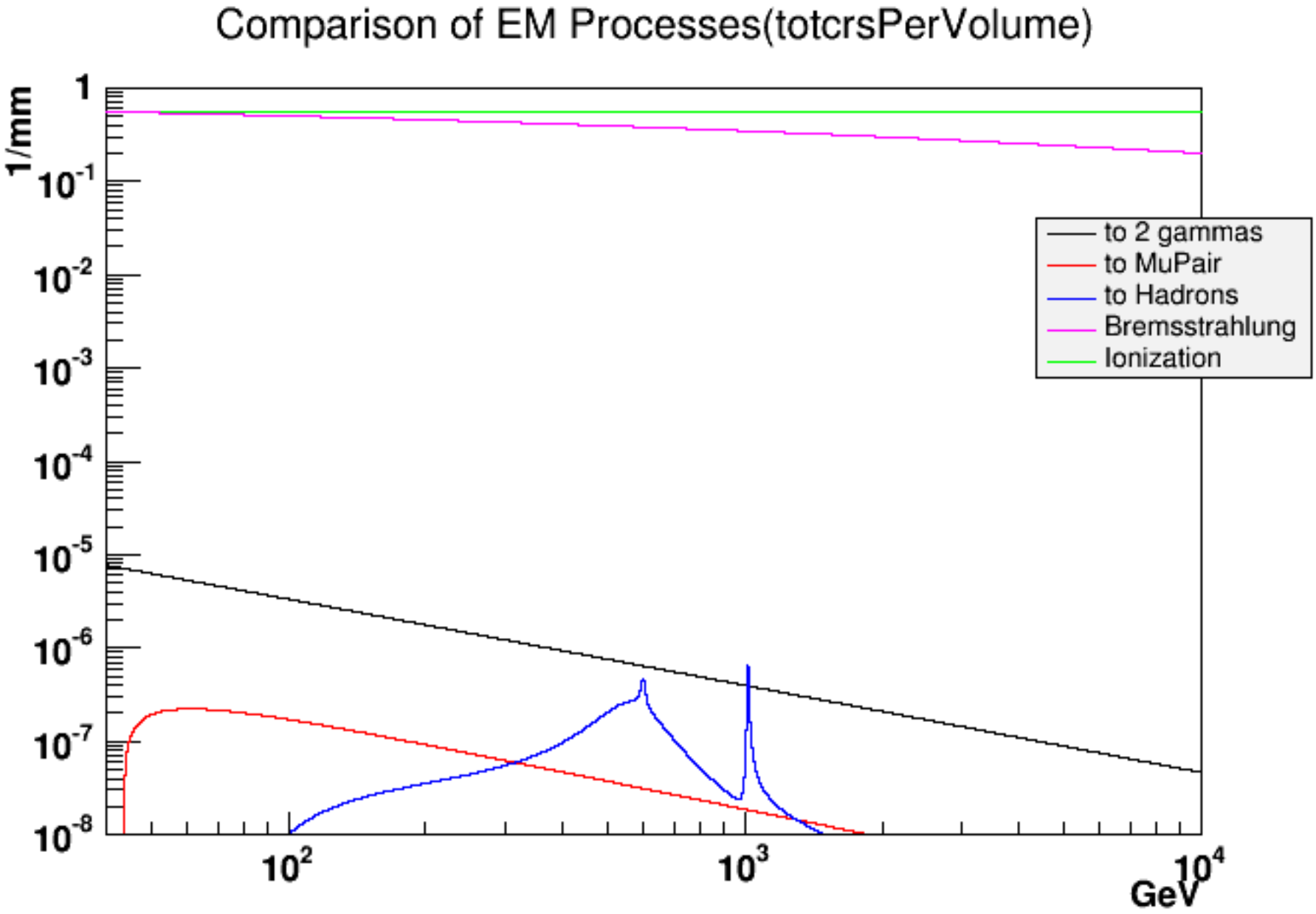
  - $e^+e^- \rightarrow \mu^+\mu^-$:

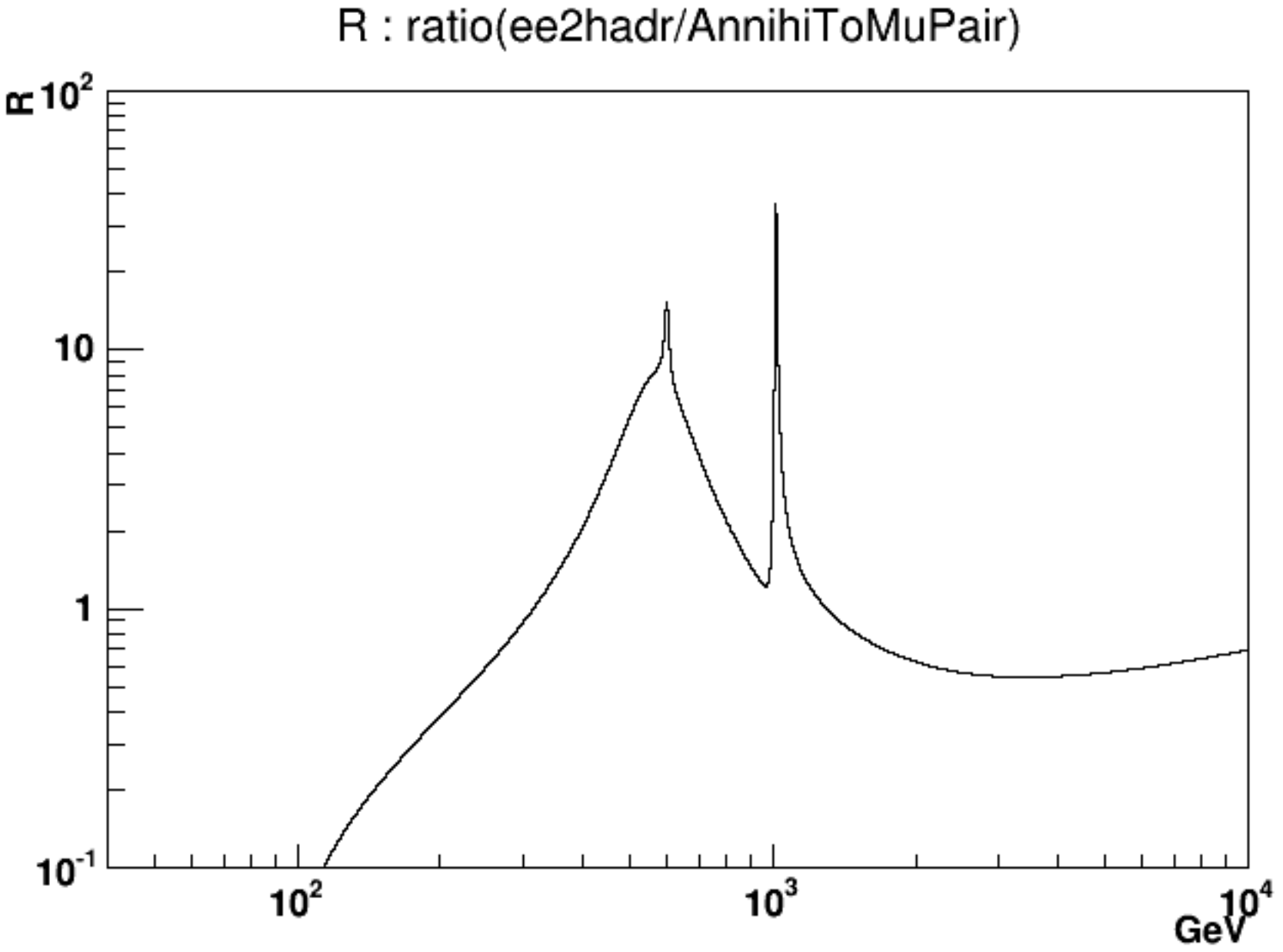
$$\sigma = \frac{\pi r_\mu^2}{3}\xi\left(1+\frac{\xi}{2}\right)\sqrt{1-\xi}$$

$$r_\mu = r_e m_e/m_\mu,\ \xi = E_{th}/E,\ E_{th} = 2m_\mu^2/m_e - m_e$$

- Make histograms for each cross section and theoretical calculations


Comparison of e+ Annihilation Processes(totcrsPerAtom)
microbarn
10^2
10
1
10^{-1}
10^{-2}
10^2
10^3
10^4
GeV
to 2 gammas
to MuPair
to Hadrons


Comparison of EM Processes(totcrsPerVolume)
1/mm
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{2}
10^{3}
10^{4}
GeV
to 2 gammas
to MuPair
to Hadrons
Bremsstrahlung
Ionization


R : ratio(ee2hadr/AnnihiToMuPair)
R
10^2
10
1
10^{-1}
10^2
10^3
10^4
GeV

Simulation in a simple setup

Simple Simulation

- Made a cubic box target (variable material and size)
- Irradiate e^+ (variable energy, 10^7 events)
- Count the number of annihilation processes

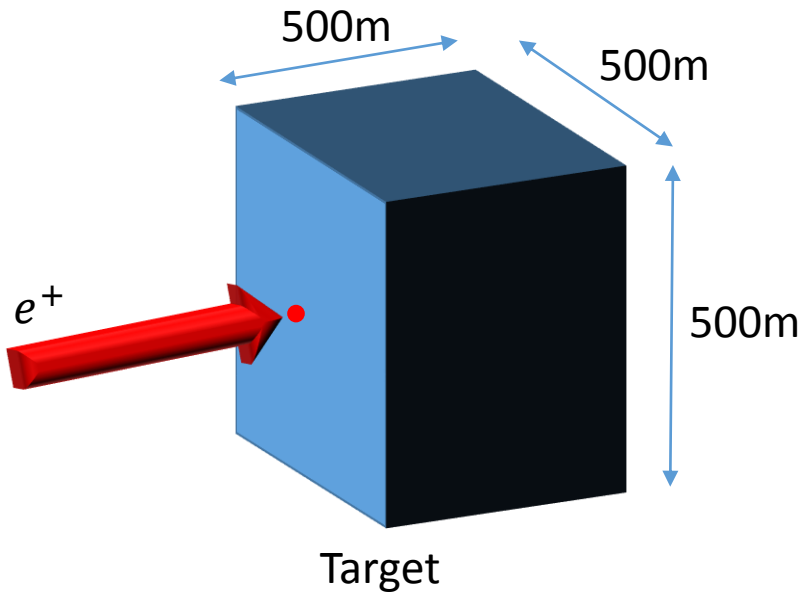
Processes

e^+e^-

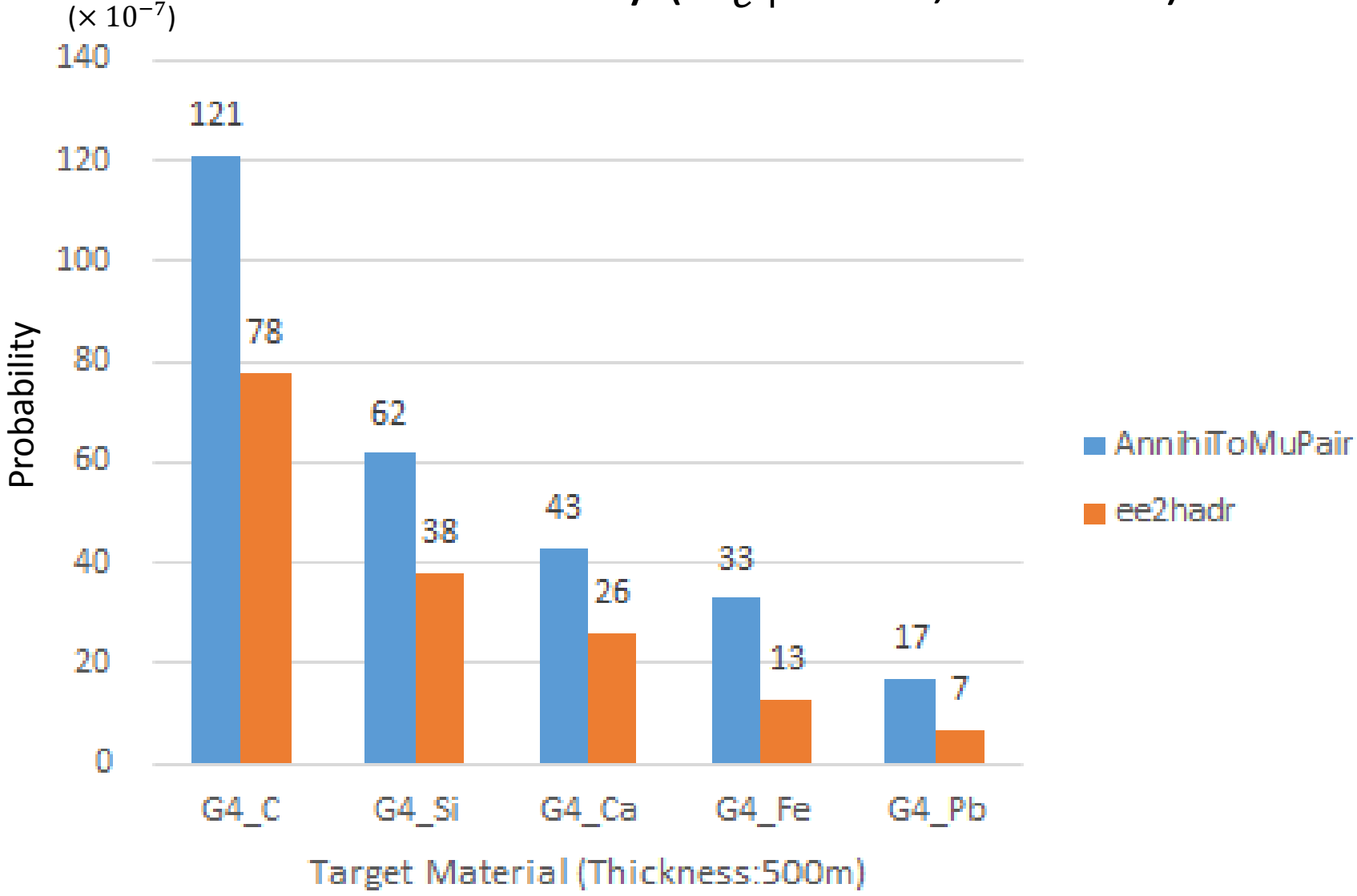
$\rightarrow \gamma\gamma$

$\rightarrow \mu^+\mu^-$

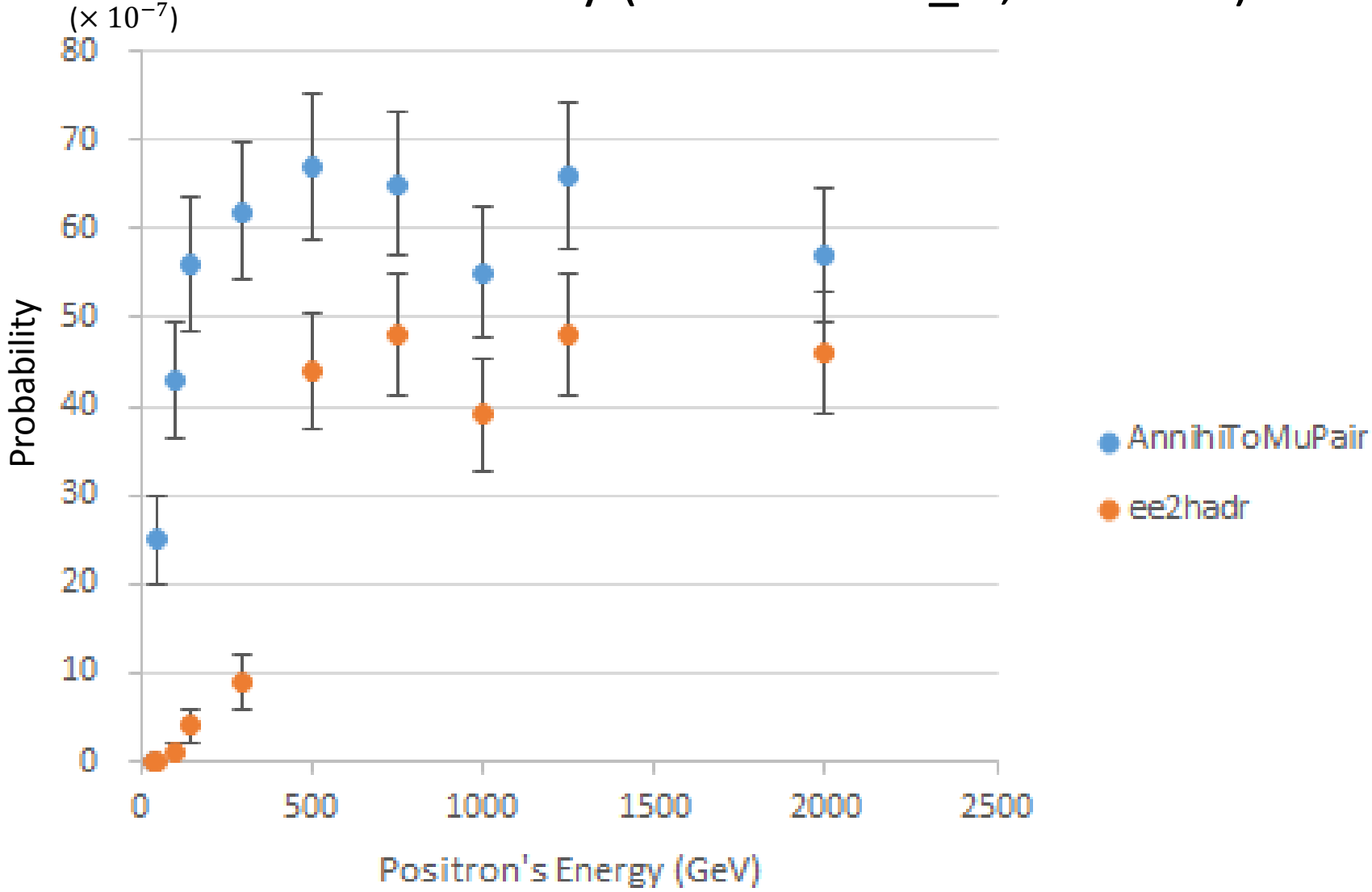
$\rightarrow$hadrons

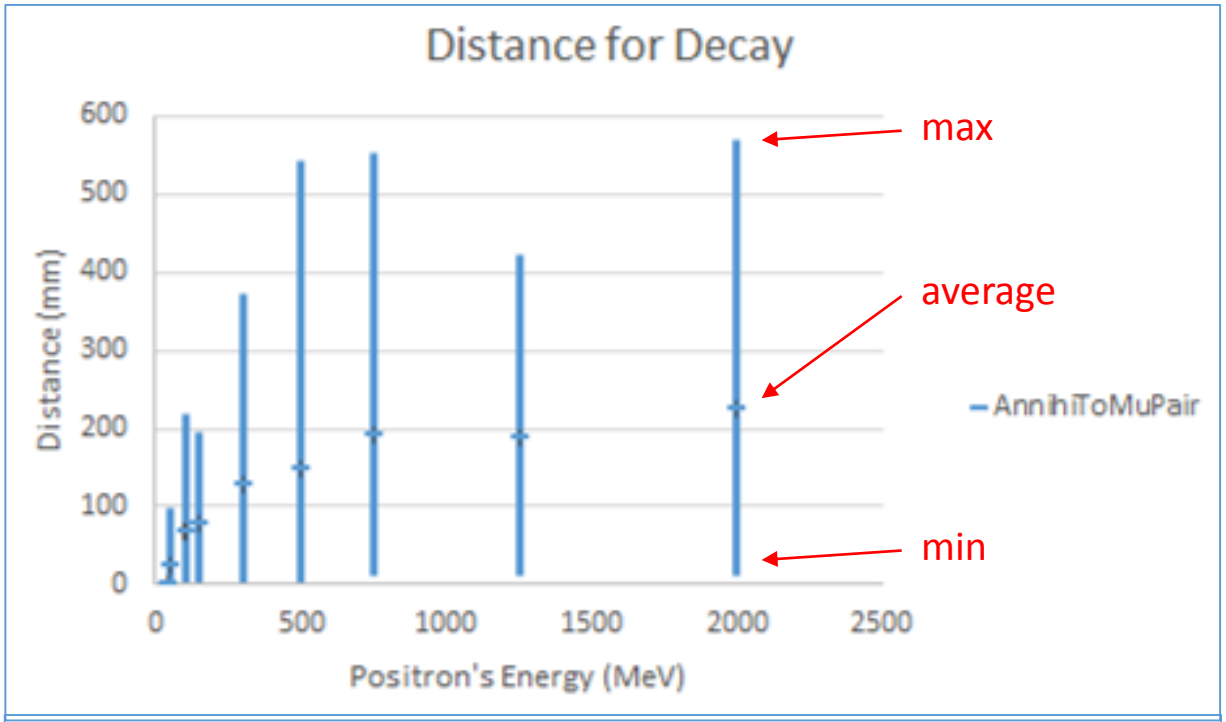


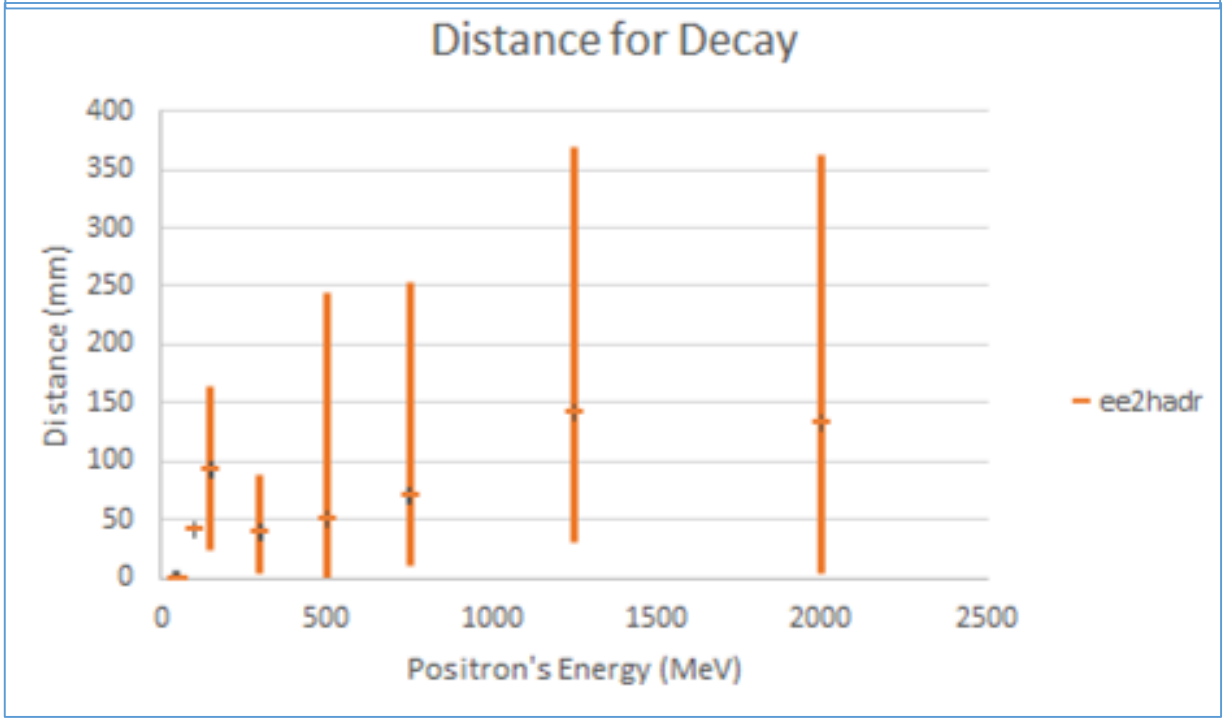
Process Probability (E_{e+}=1TeV,Cut=1cm)



Process Probability (Material:G4_Si,Cut=1cm)




Distance for Decay
600
500
400
300
200
100
0
Distance (mm)
0
500
1000
1500
2000
2500
Positron's Energy (MeV)
max
average
min
AnnihiToMuPair


Distance for Decay
400
350
300
250
200
150
100
50
0
Distance (mm)
0
500
1000
1500
2000
2500
Positron's Energy (MeV)
ee2hadr

Summary

Modification and validation

- Electromagnetic/high-energy sub-library has been improved.
- TestEm6 has been updated.
- G4EmCalculator has been updated.

  ⇒Everything pass STT validation.
- GEANT4 cross-section is validated up to around 1 TeV.

  — other models are needed for higher energy than 1 TeV.

  (including decay into 4 pions, ρ' meson, …)

  ⇒high-energy sub-library is included into private patch to CMSSW.

Simulation in simple setup

- High energy positron may annihilate into “muon pair” or ”hadrons” by the probability of 10^{-6}～10^{-5}.

  — these may become background in a high rate event.
- These high energy processes happen for ～10cm in Si.

  — these process may happen within tracker.

References

[1] Geant4 simulation of production and interaction of muons. A.G. Bogdanov, H. Burkhardt, V.N. Ivanchenko et al. 2006. 7pp. Published in IEEE Trans. Nucl. Sci. 53 (2): 513-519, 2006.

[2] CLIC Conceptual Design Report. M. Aicheler, et al. CERN, 2012. – 841 p.

[3] Physics Reference Manual, Version: geant4 10.0
(6 December 2013)

Backup

Average Distance for Annihilation