UST Global Internship Program

Title: <u>Simulations for Dark Matter</u>

```
┌─────────────────────────┐
│  High Energy Physics    │
│   (Standard Model)      │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│      Dark Matter        │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│       Mad Graph         │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│       Geant 4           │
└─────────────────────────┘
```

High Energy Physics

What is High Energy Physics?

It is the branch of physics that studies the nature of the particles that constitute *matter* and *radiation,* usually investigates the irreducibly smallest detectable particles and the fundamental forces necessary to explain their behaviour.

Main Models: Standard Model, Supersymmetry etc..

The currently dominant theory explaining these fundamental particles and fields, along with their dynamics, is called the Standard Model.

Standard Model

Dark Matter

What is it?

It is a hypothetical type of [matter](#) distinct from Standard Model (ordinary matter such as [protons](#) and [neutrons](#)), [neutrinos](#) and [dark energy](#). The existence of dark matter would explain a number of otherwise puzzling astronomical observations.The name refers to the fact that it does not emit or interact with [electromagnetic radiation](#), such as light, and is thus invisible to the entire [electromagnetic spectrum](#).

Observational Evidence:

Galaxy rotation curves

Gravitational lensing

Cosmic Microwave Background Radiation etc ..

Timeline of my internship

First 2 weeks

- Studied related Physics and basic examples on Geant 4

Next 4 weeks

- Studied advanced examples on Geant 4, completed profiling. Did basic Madgraph examples

Last 2 weeks

- Performed advanced Madgraph examples and did data collection and analysis of the simulations

Two main things that I did:
- Madgraph
- Geant 4 profiling

Madgraph

What's Madgraph ?

Madgraph is a fortran-based software package that is used for high-energy physics analysis, most often for particle colliders.

It's basically an implementation of Feynman diagrams of particle interactions

What did I do?

- Studied two following interactions to learn the system:

  e+ e- > mu + mu –

  e+ e- > e+ e-

- And three **Dark Matter** background interactions:

  e+ e- > vm vm~

  e+ e- > ve ve~

  e+ e- > mu+ mu- mu+ mu-

e+ e- > mu+ mu-

Energy (MeV)	G1	G2	Sum
10.1	24.11	0.008618	24.119
10.1	24.11	0.008618	24.119
20	47.02	0.3569	47.372
30	23.54	1.81	25.345
47	10.06	332.9	342.9
50	42.39	8.924	51.318
100	2.288	0.4986	2.7867
150	1.017	0.1688	1.1862
200	0.5723	0.08692	0.65924
250	0.366	0.0535	0.41946
300	0.2543	0.03631	0.29065
350	0.1869	0.02634	0.21321
400	0.143	0.02	0.163
450	0.133	0.01571	0.12871
500	0.09155	0.01268	0.10423

e+ e- > mu+ mu-

Cross Section

(Pb)

GeV ((s^0.5)/2)

e+ e- > e+ e-

Energy (MeV)	G1	G2	G3	G4	Sum
10.1	19.61	0.007005	199.5	0.01455	219.13
11	52.45	0.02679	625.3	0.05199	677.8
20	41.35	0.325	1808	0.349	1823.024
30	21.73	1.692	2262	0.7551	2286.6
45.5	10.97	1992	2653	1.572	4658
50	4.412	20.65	2350	0.9915	2376.6
100	1.223	0.2647	960.6	2.162	964.3
150	0.522	0.08646	426.2	2.631	429.41
200	0.2892	0.04368	239.4	2.822	242.58
250	0.183	0.02659	153	2.834	156.06
300	0.1263	0.01797	106	2.769	108.88
310	0.1181	0.01676	99.4	2.743	102.17157
320	0.1107	0.01567	93.28	2.72	96.131
330	0.1041	0.01469	87.65	2.693	90.459
340	0.09799	0.0138	82.58	2.667	85.234
350	0.09227	0.01298	77.81	2.65	80.565
360	0.08728	0.01224	73.52	2.609	76.233
370	0.08265	0.01156	69.81	2.578	72.48221
380	0.07822	0.01094	66.07	2.547	68.705
390	0.07418	0.01036	62.72	2.515	65.32
400	0.0706	0.009832	59.66	2.484	62.224
410	0.06716	0.009342	55.13	2.43	57.642
420	0.06399	0.008889	54	2.418	56.488
430	0.06102	0.008467	51.55	2.384	54.001
440	0.05827	0.008076	48.69	2.34	51.095
450	0.05563	0.007715	46.41	2.304	48.773
500	0.04505	0.006215	38.12	2.142	40.718715

diagram 1   QCD=0, QED=2

diagram 2   QCD=0, QED=2

diagram 3   QCD=0, QED=2

diagram 4   QCD=0, QED=2

e+ e- > e+ e-

Cross Section

(Pb)

GeV ((s^0.5)/2)

e+ e- > vm vm~

Energy (MeV)	G1
5	0.03617
10	0.156
20	0.8701
30	3.951
40	42.32
50	85.12
100	0.97938
150	0.33157
200	0.17094
250	0.10521
300	0.07155
350	0.05191
400	0.039427
450	0.030981
500	0.024996

diagram 1   QCD=0, QED=2

e+ e- > vm vm~

Cross Section

(Pb)

G1

GeV ((s^0.5)/2)

e+ e- > ve ve~

Energy (MeV)	G1	G2	Sum
5	0.02108	0.1367	0.15774
10	0.08881	0.5124	0.60121
20	0.438	1.525	1.9634
30	1.573	1.627	3.2005
45.5	3948	14.34	3962.7
50	128.6	29.78	158.4
100	1.279	39.4	40.674
150	0.4101	44.29	44.699
200	0.2077	47.27	47.475
250	0.1268	49.1	49.232
300	0.08585	50.31	50.397
350	0.06212	51.15	51.216
400	0.0471	51.76	51.805
450	0.03697	52.22	52.256
500	0.0298	52.56	52.586

e+ e- > ve ve~

Cross Section

(Pb)

GeV ((s^0.5)/2)

e+ e- > mu+ mu- mu+ mu-

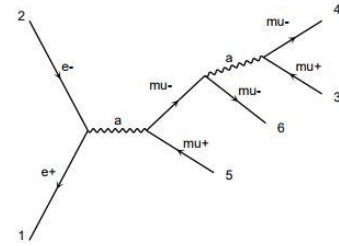| Energy(Me	G1`	G3	G5	G7	G33	G35	G36	G39	Sum
20.9	0	0	0	0	0	0		1.44E-18	1.44E-18
30	4.01E-07	1.05E-10	2.97E-08	8.45E-12	1.99E-05	7.24E-09	7.40E-09	2.54E-12	2.03E-05
40	3.62E-06	1.63E-09	5.37E-06	2.45E-09	9.04E-05	2.63E-07	2.60E-07	1.42E-10	9.99E-05
50	6.25E-06	5.46E-09	2.50E-05	2.66E-08	1.09E-04	1.64E-06	2.07E-06	1.65E-09	1.45E-04
70	9.24E-06	4.51E-07	3.71E-06	1.93E-07	2.02E-04	3.98E-04	4.02E-04	1.75E-06	1.02E-03
80	9.55E-06	1.21E-06	2.83E-06	3.58E-07	1.95E-04	4.24E-04	4.21E-04	8.36E-06	1.06E-03
100	1.05E-05	3.54E-06	2.31E-06	7.75E-07	2.04E-04	3.94E-04	4.07E-04	1.07E-03	2.09E-03
120	1.02E-05	5.05E-06	1.95E-06	9.43E-07	1.45E-04	3.27E-04	3.28E-04	1.08E-03	1.90E-03
140	9.65E-06	6.27E-06	1.67E-06	1.05E-06	1.16E-04	2.64E-04	2.62E-04	9.03E-04	1.56E-03
150	9.76E-06	6.45E-06	1.40E-06	1.10E-06	1.07E-04	2.35E-04	2.35E-04	8.25E-04	1.42E-03
170	8.81E-06	6.99E-06	1.44E-06	1.12E-06	8.67E-05	1.99E-04	1.99E-04	6.81E-04	1.18E-03
190	7.55E-06	7.38E-06	1.12E-06	1.24E-06	7.45E-05	1.71E-04	1.71E-04	5.76E-04	1.01E-03
200	7.72E-06	7.25E-06	1.09E-06	1.18E-06	6.97E-05	1.57E-04	1.58E-04	5.28E-04	9.29E-04
220	6.15E-06	7.21E-06	9.18E-07	1.16E-06	6.07E-05	1.36E-04	1.37E-04	4.49E-04	7.98E-04
240	5.78E-06	7.65E-06	8.86E-07	1.18E-06	5.44E-05	1.17E-04	1.21E-04	3.81E-04	6.90E-04
250	5.89E-06	7.42E-06	8.70E-07	1.18E-06	5.05E-05	1.11E-04	1.16E-04	3.53E-04	6.45E-04
270	5.76E-06	7.37E-06	7.40E-07	1.18E-06	3.45E-05	9.79E-05	9.93E-05	3.07E-04	5.64E-04
290	5.33E-06	7.24E-06	6.70E-07	1.09E-06	4.04E-05	8.76E-05	8.85E-05	2.66E-04	4.96E-04
300	5.32E-06	7.13E-06	6.15E-07	1.08E-06	3.81E-05	8.47E-05	8.43E-05	2.47E-04	4.68E-04
320	4.76E-06	7.12E-06	6.20E-07	1.06E-06	3.37E-05	7.47E-05	7.57E-05	2.16E-04	4.14E-04
340	4.21E-06	6.97E-06	5.54E-07	1.04E-06	3.21E-05	6.69E-05	6.92E-05	1.94E-04	3.75E-04
350	4.04E-06	6.38E-06	5.59E-07	1.01E-06	3.04E-05	6.34E-05	6.66E-05	1.83E-04	3.56E-04
370	3.98E-06	6.49E-06	4.75E-07	1.02E-06	2.66E-05	5.97E-05	5.96E-05	1.58E-04	3.16E-04
390	3.73E-06	6.19E-06	4.84E-07	9.50E-07	2.45E-05	5.46E-05	5.44E-05	1.39E-04	2.84E-04
400	3.76E-06	6.41E-06	4.61E-07	9.12E-07	2.39E-05	5.25E-05	5.35E-05	1.32E-04	2.73E-04
420	3.29E-06	5.85E-06	4.51E-07	8.37E-07	2.16E-05	4.64E-05	4.73E-05	1.15E-04	2.41E-04
440	3.17E-06	5.87E-06	4.35E-07	8.75E-07	2.00E-05	4.45E-05	4.45E-05	1.07E-04	2.26E-04
450	2.78E-06	5.69E-06	4.22E-07	8.74E-07	1.89E-05	4.17E-05	4.26E-05	9.58E-05	2.09E-04
470	2.96E-06	5.74E-06	3.99E-07	8.26E-07	1.81E-05	3.96E-05	3.99E-05	9.05E-05	1.98E-04
490	2.52E-06	5.30E-06	3.77E-07	7.87E-07	1.69E-05	3.68E-05	3.68E-05	7.98E-05	1.79E-04
500	2.68E-06	5.43E-06	3.87E-07	7.67E-07	1.61E-05	3.55E-05	3.57E-05	7.58E-05	1.72E-04

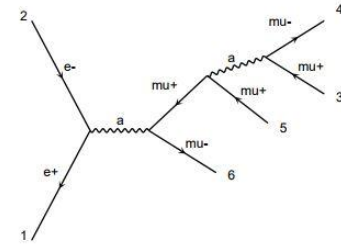diagram 1   QCD=0, QED=4

diagram 2   QCD=0, QED=4
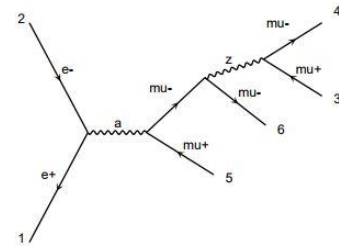
diagram 3   QCD=0, QED=4
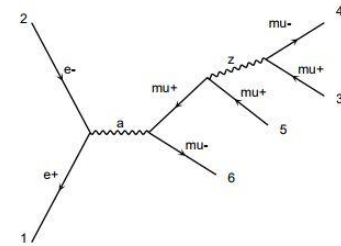
diagram 4   QCD=0, QED=4
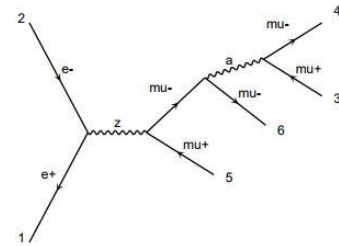
diagram 5   QCD=0, QED=4
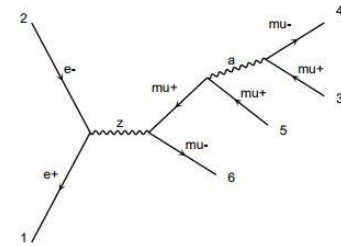
diagram 6   QCD=0, QED=4
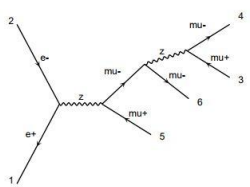
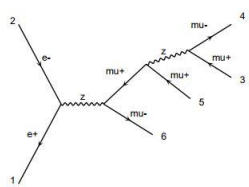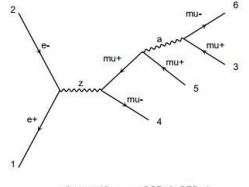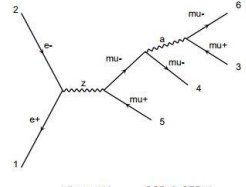diagram 7   QCD=0, QED=4   diagram 8   QCD=0, QED=4   diagram 13   QCD=0, QED=4   diagram 14   QCD=0, QED=4   diagram 19   QCD=0, QED=4   diagram 20   QCD=0, QED=4
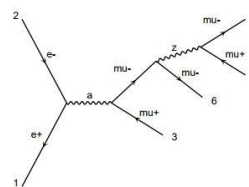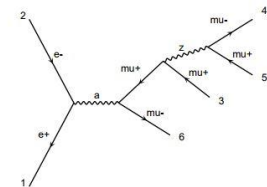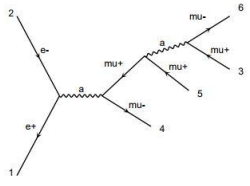
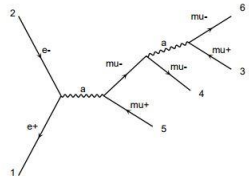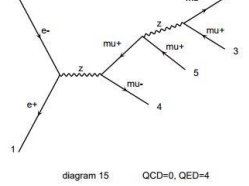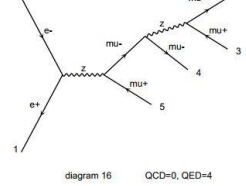diagram 9   QCD=0, QED=4   diagram 10   QCD=0, QED=4   diagram 15   QCD=0, QED=4   diagram 16   QCD=0, QED=4   diagram 21   QCD=0, QED=4   diagram 22   QCD=0, QED=4
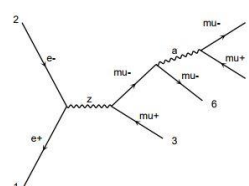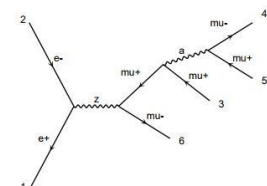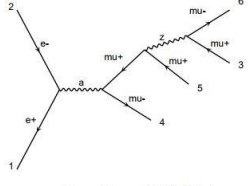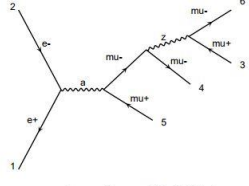
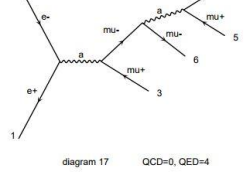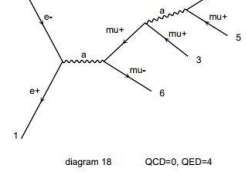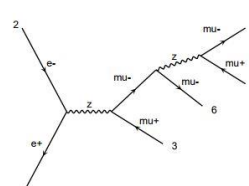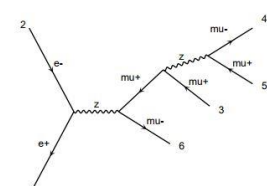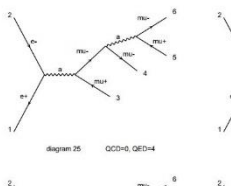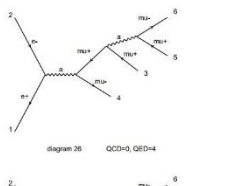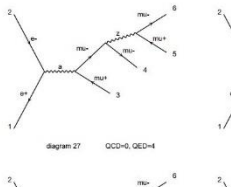diagram 11   QCD=0, QED=4   diagram 12   QCD=0, QED=4   diagram 17   QCD=0, QED=4   diagram 18   QCD=0, QED=4   diagram 23   QCD=0, QED=4   diagram 24   QCD=0, QED=4

Diagrams made by MadGraph5_aMC@NLO

diagram 25   QCD=0, QED=4   diagram 26   QCD=0, QED=4

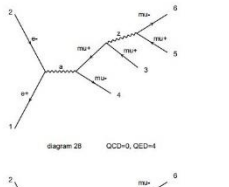diagram 27   QCD=0, QED=4   diagram 28   QCD=0, QED=4
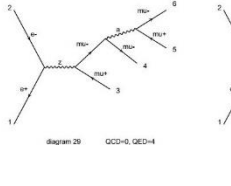
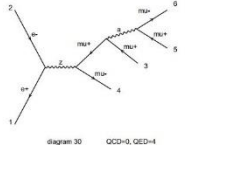diagram 29   QCD=0, QED=4   diagram 30   QCD=0, QED=4
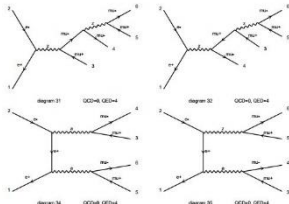
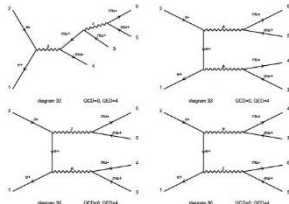diagram 31   QCD=0, QED=4   diagram 32   QCD=0, QED=4   diagram 33   QCD=0, QED=4
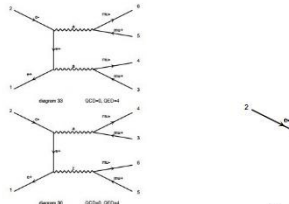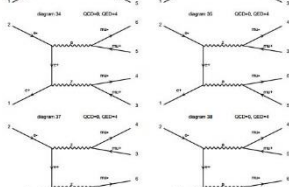
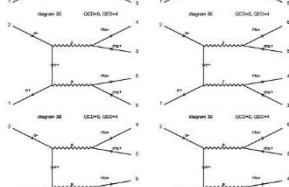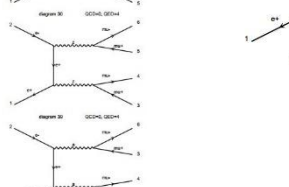diagram 34   QCD=0, QED=4   diagram 35   QCD=0, QED=4   diagram 36   QCD=0, QED=4
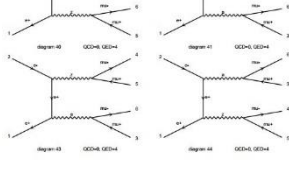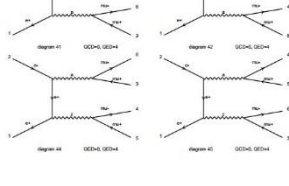
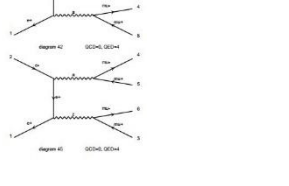diagram 37   QCD=0, QED=4   diagram 38   QCD=0, QED=4   diagram 39   QCD=0, QED=4

diagram 40   QCD=0, QED=4   diagram 41   QCD=0, QED=4   diagram 42   QCD=0, QED=4

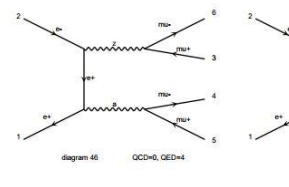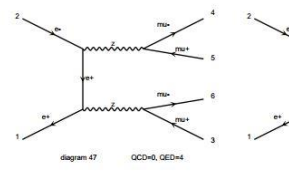diagram 43   QCD=0, QED=4   diagram 44   QCD=0, QED=4   diagram 45   QCD=0, QED=4

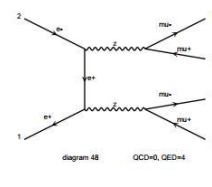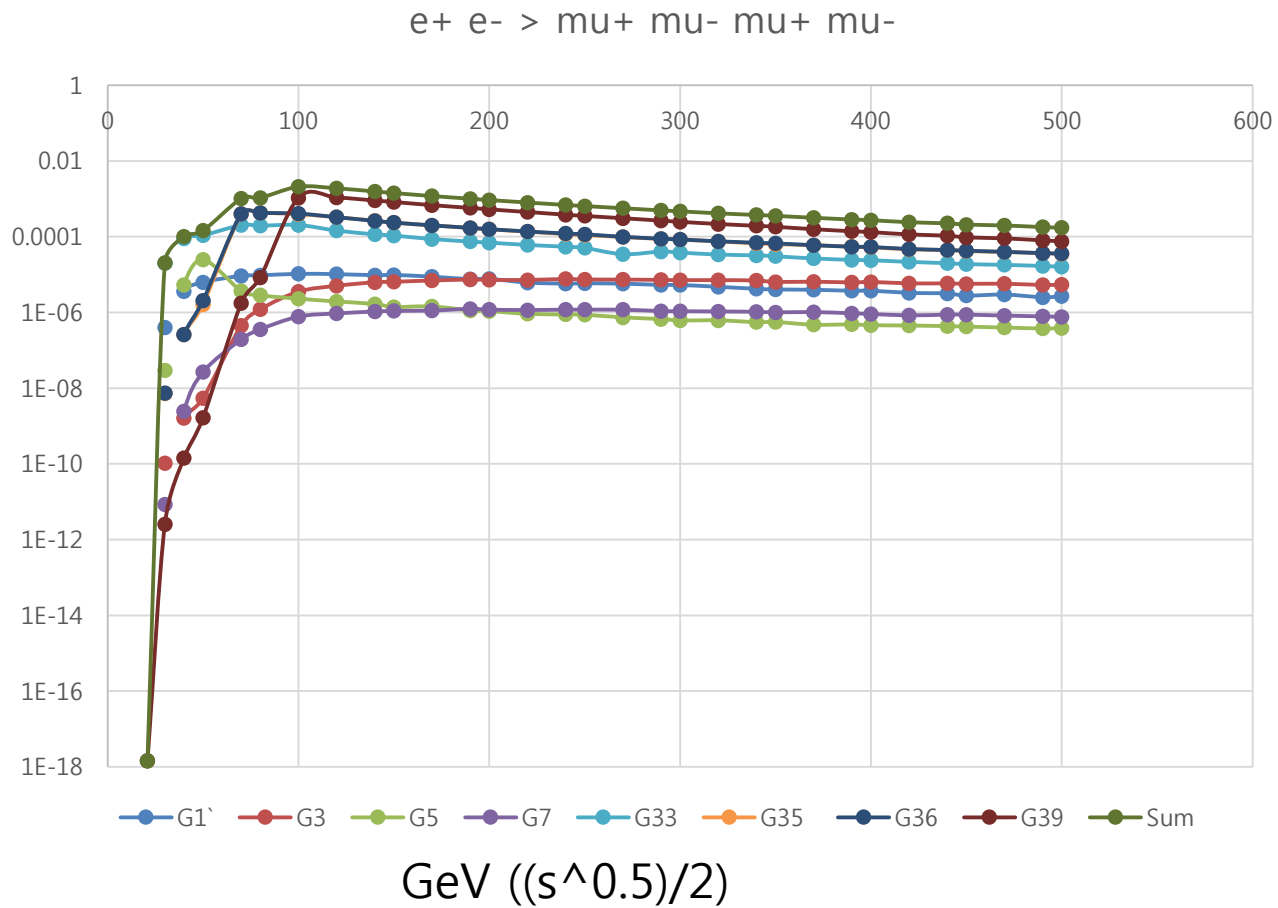diagram 46   QCD=0, QED=4   diagram 47   QCD=0, QED=4   diagram 48   QCD=0, QED=4

e+ e- > mu+ mu- mu+ mu-

e+ e- > mu+ mu- mu+ mu-

Cross Section

(Pb)

GeV ((s^0.5)/2)

G1`   G3   G5   G7   G33   G35   G36   G39   Sum

Findings from this interaction

Found 8 dominant Feynman diagrams from the possible 48

TOTAL AND VISIBLE CROSS SECTIONS FOR MULTILEPTON EVENTS IN e^+e^- COLLISIONS

F.A. BERENDS, P.H. DAVERVELDT and R. KLEISS
Instituut-Lorentz, Leiden, The Netherlands

We calculate cross sections for e^+e^- scattering into four-lepton final states such as $e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, $\mu^+\mu^-\mu^+\mu^-$, $\mu^+\mu^-\tau^+\tau^-$. We also give exclusive cross sections for all cases where one or more lepton tracks are at large angles to the beams. The calculations are performed using a Monte Carlo event generator which takes into account the complete set of relevant lowest order Feynman diagrams.
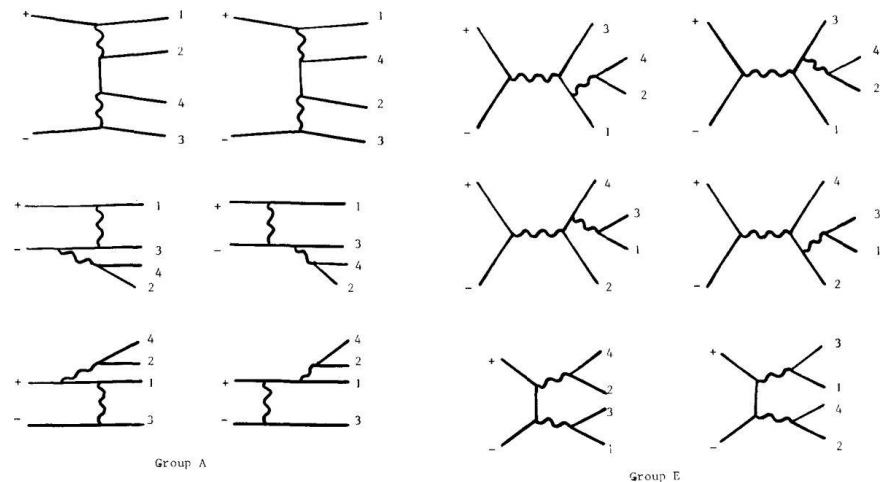
Group A

Group E

Fig. 1. Feynman graphs for four-lepton production. Groups B, C and D are obtained from A by interchanging, respectively: $1 \leftrightarrow 2$; $3 \leftrightarrow 4$; $1 \leftrightarrow 2$ and $3 \leftrightarrow 4$. Group F is obtained from E by interchanging $1 \leftrightarrow 2$. The groups contributing to the various processes are $\mu\mu\tau\tau$: E; $\mu\mu\mu\mu$: E, F; $ee\mu\mu$: A,E; $eeee$: all groups.

Geant 4 Profiling

What's Geant 4?

Geant4 (for **GEometry ANd Tracking**) is a [platform](#)for "the [simulation](#) of the passage of [particles](#) through [matter](#)," using [Monte Carlo methods](#). It is the successor of the [GEANT](#) series of software toolkits developed by [CERN](#), and the first to use [object oriented programming](#) (in [C++](#))

www.geant4.cern.ch

What did I do?

- Studied four examples to profile following three different versions of Geant 4 on KISTI supercomputer Tachyon 2:
  g4 10.01.p01 - sequential
  g4 10.03mt - multithread
  g4 10.03 - sequential

- Basic : B1 (Energy deposit calculated in a volume)
       B2 (Simulates a fixed target experiment)
       B3 (Simulates a Positron Emitted Tomography System)

- Advanced: Brachytherapy (Simulates energy deposit by Iridium, Iodine sources in water)

B1 comparison

Hadronic Processes for He3

- Process: hadElastic

- Model: hElasticLHEP: 0 eV /n ---> 100 Te

- Cr_sctns: Glauber-Gribov nucleus nucleus: 0 eV ---> 2.8

- Cr_sctns: GheishaElastic: 0 eV ---> 100 TeV

- > ===
- ======   Pre-compound/De-excitation Physics Parameters
- ===
- Type of pre-compound inverse x-section   3
- Type of de-excitation inverse x-section   3
- Min excitation energy (keV)   0.1
- Level density (1/MeV)   0.1
- Time limit for long lived isomeres (ns)   1e+07
- Correlated gamma emission flag   0
- ===

>

>

g4.10.01.p01 sequential	No
G4.10.03 mt	Yes
G4.10.03 sequential	Yes

>

>

>

>

>

>

```
Start closing geometry.                                                        <
G4GeometryManager::ReportVoxelStats -- Voxel Statistics        <

   Total memory consumed for geometry optimisation:   0 kByt <
   Total CPU time elapsed for geometry optimisation: 0 secon <

   Voxelisation: top CPU users:                                          <
   Percent   Total CPU    System CPU      Memory  Volume     <
   -------   ----------   ----------      --------  --------- <
     0.00        0.00         0.00            0k Envelope  <

   Voxelisation: top memory users:                                  <
   Percent    Memory     Heads   Nodes  Pointers    Tota <
   -------   --------     ------  ------  --------   ----- <
    100.00       0k         1        3         4          <
```

g4.10.01 .p01 seq uential	Yes
G4.10.03 mt <	No
G4.10.03 sequenti al	Yes

OpenGL graphics B1

Version 10.01.p01

Version 10.03mt

B2 comparison

g4.10.01.p01 sequential	No
G4.10.03mt	Yes
G4.10.03 sequential	Yes

g4.10.01.p01 sequential	No
G4.10.03mt	Yes
G4.10.03 sequential	Yes

g4.10.01.p01 sequential	Yes
G4.10.03mt	No
G4.10.03 sequential	Yes

OpenGL graphics B2

V 10.01.p01

V 10.03mt

V 10.01.03

B3 Comparison

g4.10.01.p01 sequential	No
G4.10.03mt	Yes
G4.10.03 sequential	No

OpenGL graphics B3

V 10.01.p01

V 10.03mt

V 10.01.03

Brachytherapy Comparison

```
.... G4ScoringMessenger::MeshBinCommand - G4ScoringBox
/score/quantity/energyDeposit eDep
/score/close
/score/list
G4ScoringManager has 1 scoring meshes.
G4ScoringBox : boxMesh_1 --- Shape: Box mesh
 Size (x, y, z): (15, 15, 15) [cm]
 # of segments: (300, 300, 300)
 displacement: (0, 0, 0) [cm]
 registered primitve scorers :
   0  eDep
/control/execute iridium_source_primary.mac
/gps/particle gamma
/gps/energy 356.0 keV
/gps/pos/type Volume
/gps/pos/shape Cylinder
/gps/pos/radius 0.30 mm
/gps/pos/halfz 1.75 mm
/gps/pos/centre 0. 0. -1.975 mm
/gps/ang/type iso
/run/beamOn 1000
/run/geometryModified
```

```
> /score/mesh/nBin 801 801 1
  .... G4ScoringMessenger::MeshBinCommand - G4ScoringBox
  /score/quantity/energyDeposit eDep
  /score/close
  /score/list
  G4ScoringManager has 1 scoring meshes.
| G4ScoringBox : boxMesh_4 --- Shape: Box mesh
|  Size (x, y, z): (10.0125, 10.0125, 0.0125) [cm]
|  # of segments: (801, 801, 1)
   displacement: (0, 0, 0) [cm]
   registered primitve scorers :
     0  eDep
| /run/beamOn 5000
<
<
<
<
<
<
<
<
<
  /run/geometryModified
```

g4.10.01.p01 sequential	**No**
G4.10.03mt	Yes
G4.10.03 sequential	Yes

```
 ICRU49NucStopping :  Emin=       0 eV    Emax=      1 M
### === Deexcitation model UAtomDeexcitation is activated fo <
       DefaultRegionForTheWorld                            <
                                                           <
msc:   for alpha    SubType= 10
    RangeFactor= 0.2, stepLimitType: 0, latDisplacement: 0  |
    ===== EM models for the G4Region  DefaultRegionForTheWo
       UrbanMsc :  Emin=      0 eV    Emax=      10 T |
```

```
 ICRU49NucStopping :  Emin=       0 eV    Emax=      1 M

msc:   for alpha    SubType= 10
    RangeFactor= 0.2, stepLimitType: 0, latDisplacement: 1
    ===== EM models for the G4Region  DefaultRegionForTheWo
       UrbanMsc :  Emin=      0 eV    Emax=      1 T
```
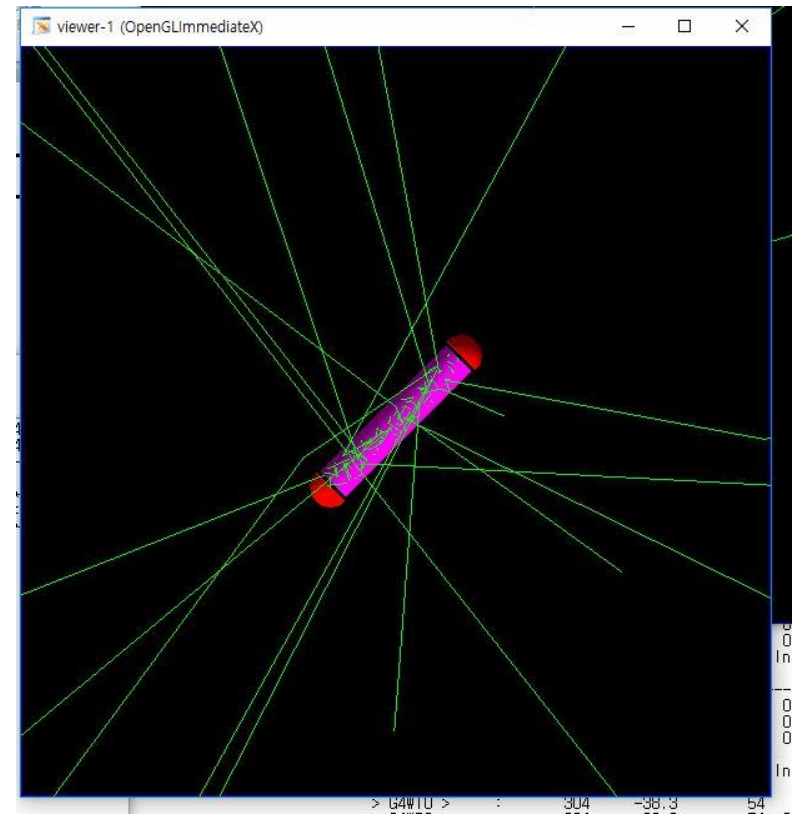
OpenGL Brachytherapy

V 10.03mt

V 10.01.03

Conclusion of Geant 4 profiling

- **Found errors** in OpenGL in 10.03mt version, led to reinstallation of Geant 4 at KISTI's supercomputer Tachyon 2. New version 10.03 sequential installed
- Found **three** main differences in three versions:

    - Both versions 10.03mt and 10.03 have new physics features such as deexcitation parameter data (in short, they give more info than 10.01.p01)

    - 10.03mt has **additional information** in output files as G4MT0 and G4MT1

    - Both sequential versions, 10.01.p01 and 10.03 give some information about the **memory** used

Future Prospects

Got interested in Deep Learning and its application in high energy physics

Using Geant 4, I can work in not only particle physics but also space physics, radiation medicine, microelectronic radiation and nuclear physics

- It was an amazing experience!

Thank you!