MC generators

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ISTAPP 2011

Introduction

- We would like to know
  - the cross section of a process we care about;
  - the impact of the accelerator on which we work;
  - the result of the parton distribution function selection;
  - all the Feynman diagrams for a given final state;
  - branching fractions of a decaying particle

find a theoretician

in ANY MODEL.

- We would like to have
  - Nice drawings of Feynman diagrams;
  - Nice plots of differential cross sections, parameter dependencies etc..
  - MC Events on which further analysis can be performed.

find a painter

find a gambler

A subjectively selective list

- Generic MC generators
  - Herwig : http://hepwww.rl.ac.uk/theory/seymour/herwig/
  - Pythia : http://home.thep.lu.se/~torbjorn/Pythia.html
    - v6 : fortran, v8: c++, swiss army knife of the HE Physicist
  - CompHEP / CalcHEP : http://comphep.sinp.msu.ru/
  - MadGraph / MadEvent : http://madgraph.hep.uiuc.edu/
  - ....

Can interface with other MC tools

This lecture

- Dedicated MC generators
  - Alpgen : bosons + Njets, JHEP 0307:001,2003, hep-ph/0206293.
  - protos : top (or heavier) quarks : http://www-ftae.ugr.es/protos/
  - pandora : e+ / e- / γ @ LC: http://www-sldnt.slac.stanford.edu/nld/new/Docs/Generators/PANDORA.htm
  - ...

CompHEP (CalcHEP)

- Computational tool to
  - calculate interaction cross sections in tree level *(more on this later)*
  - calculate branching fractions
  - make plots, Feynman diagrams and generate events
- Freely available from the web
  - http://comphep.sinp.msu.ru/
  - http://theory.sinp.msu.ru/~pukhov/calchep.html
- Initially proposed by a colleague from Baku (now in Ankara)
  - **The GaP project of computer aided theoretical calculations for future gamma p, gamma e, gamma gamma colliders physical programs.**
    E. Boos, M. Dubinin, V. Edneral, V. Ilyin, A. Pukhov, V. Savrin (Moscow State U.) , G. Jikia, S. Shichanin (Serpukhov, IHEP) , S. Sultanov (Baku, Inst. Phys.) . Mar 1991. 10pp.
    Prepared for 9th International Conference on Computing in High-energy Physics (CHEP 91), Tsukuba, Japan,11-15 Mar 1991. Published in Tsukuba 1991, Computing in high energy physics 391-400

CompHEP 4.5.1

- Works on Unix (Linux, OSX, etc.)
- Do the following to install it in your computer

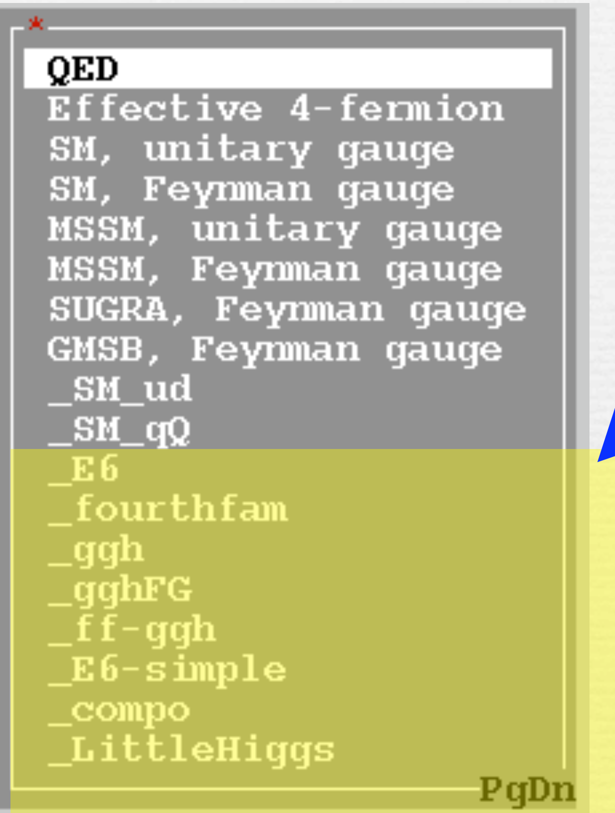
Do it once

  - Register to download & download a TGZ file. (comphep-4.5.1.tgz)
  - tar xzf comphep-4.5.1.tgz ; cd comphep-4.5.1
  - ./configure *(dont mind the warning about the CERNLIB)*
  - make
  - make setup WDIR=${HOME}/istapp2011/comphep_workdir
    (make a new dir for each project)
  - cd ${HOME}/istapp2011/comphep_workdir ; ./comphep
    (do this when you work on your project)

Already done for the ISTAPP computers

- Now we are ready to run

Model selection



- by default comphep has QED,SM,susy..
- You may add your own model in 4 items
  1. Variables (masses, mixings)
  2. Constraints (CKM unitarity)
  3. Particle definitions (add fermions or bosons)
  4. Lagrangian (the new interactions)
- Define composites to have: Jets, W+/W-,..
- Effective lagrangians to imitate well known loops possible. e.g. ggh *effective* vertex

Beam & process selection

- Select the machine: (LEP, LHC..)
  - Proton, electron, μ, γ beams are available
    - with lots of options (PDF, ISR, Beamstrahlung, Compton backscattering photon) allows simulation of processes in the existing (or new) colliders.
  - Missing: beam polarization not available (CalcHEP2.5j onwards has it.)
    - 2 in, max 7 out !

```
p1 (u,d,U,D,G)                   PDF: cteq6l1(pr
P1 (u,d,U,D,G)                   PDF: cteq6l1(an
p (u,d,U,D,s,c,S,C,G)            PDF: cteq6l1(pr
P (u,d,U,D,s,c,S,C,G)            PDF: cteq6l1(an
pb (u,d,U,D,s,c,S,C,b,B,G)       PDF: cteq6l1(pr
Pb (u,d,U,D,s,c,S,C,b,B,G)       PDF: cteq6l1(an
ebeam (e)                        PDF: ISR(100 Be
Ebeam (E)                        PDF: ISR(100 Be
gamL (A)                         PDF: Laser phot
gamE (A)                         PDF: WWA (m=0.
p1-noPDF (u,d,U,D,G)             PDF: OFF
p-noPDF (u,d,U,D,s,c,S,C,G)      PDF: OFF
```

```
Enter Decay Process
Enter Scattering Process
Edit Beams Table
Edit Str. Functions Table
Edit Model
Delete Model
```

- Select the process: (collision or decay)
  - initial and final particles to be declared

```
G(G)      gluon          A(A)
W+(W-)    W boson        ne(Ne)
nm(Nm)    mu-neutrino    m(M)
l(L)      tau-lepton     u(U)
c(C)      c-quark        s(S)
b(B)      b-quark        H(H)

Enter Final State: e,E -> m,M
Exclude diagrams with H
Keep diagrams with Z
```

intermediate state particles can be excluded or they can be forced.

Order of things

1) Choose a model

- lets work within the SM for the moment.

2) Choose a process

- we also chose the collider on which this process is happening.

3)Take the square of the Feynman Diagrams and have the result written in “C” language

- Look at the proposed diagrams, do not run blindly.
- make a separate directory for each process you need to study.

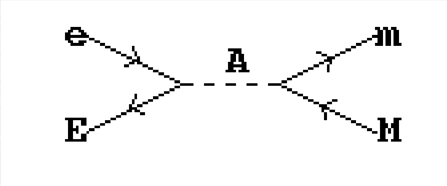
4) compile the “C” code to make a numerical study.

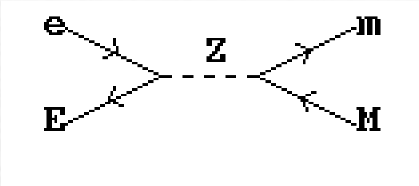
- You obtain the calculation results at this step.

☑ Lets see the details...

test drive...

- Start with SM (Unitary gauge)
- Enter the process you study:
  - e+ e- → γ/Z → μ+ μ-   is the “hello world” of CompHEP.

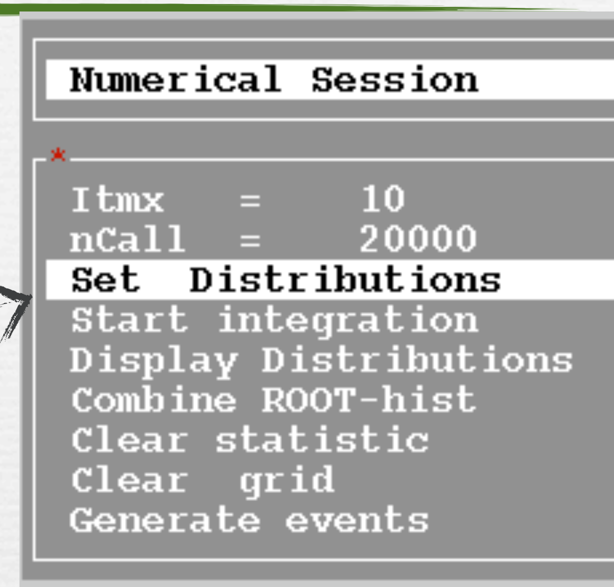




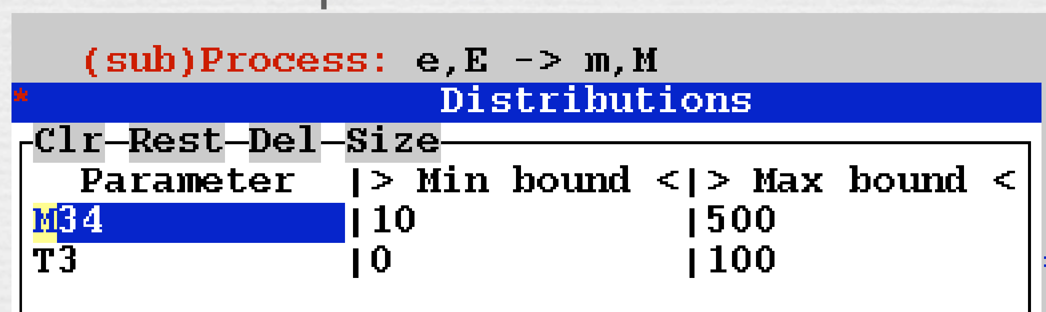
- Do the below steps in the given order:
  - Square diagrams, Symbolic Calculations, Write results (C), C-compiler
- Now a new file, n_comphep, is created in the “results” directory.
  - This binary file will be needed later on.
- Beam Energy, ISR & BS (depending on your accelerator) should be set.
  - Histograms of the interesting quantities should be booked.

Numerical Session

- For simple processes set
  - Itmx=10 & nCall=20000
  - or increase nCalls until $\chi^2 \sim 1$ in the result.



- Book histograms to understand the process.
  - These distributions will show you why some calculations might not be converging or which cuts will help best to find the signal events.
  - F1 for "help" (explanations).

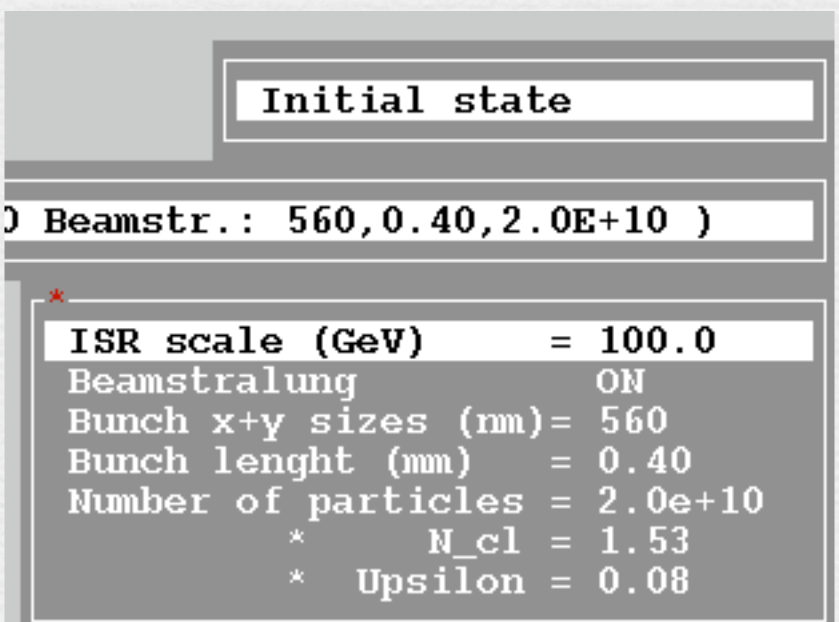


M34: invariant mass of particle 3 & 4
T3 : Transverse momentum of particle 3

- "Start Integration" is used to get the solutions and to fill the previously booked histograms.

cross sections

- Cross section results depends on the experimental conditions
- Lets check the x-section variations on a 500+500 GeV e+e- collider via μ+μ- production.
  - This is our test process



all e- same energy

measurement conditions	cross section (fb)
needle beams	113
needle beams w/ measurability of outgoing particles	110
realistic beams (ISR,BS)	338
realistic beams w/ measurability of outgoing particles	162

one obtains..

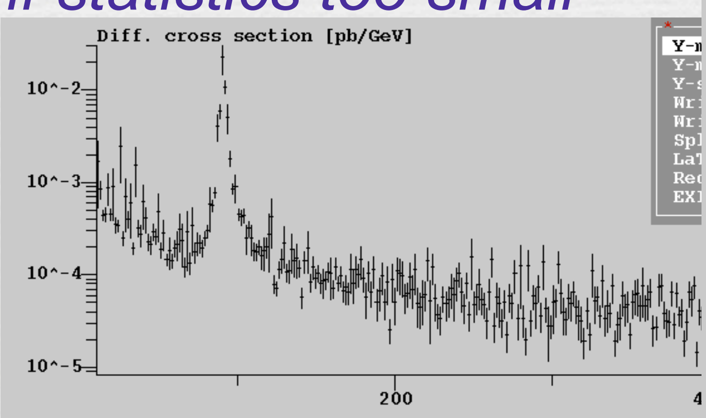
- cross section (in pb)
- di-muon invariant mass distribution
  - latex & text output possible.
  - log & linear Y axis possible.
  - Spline fit to the spectrum

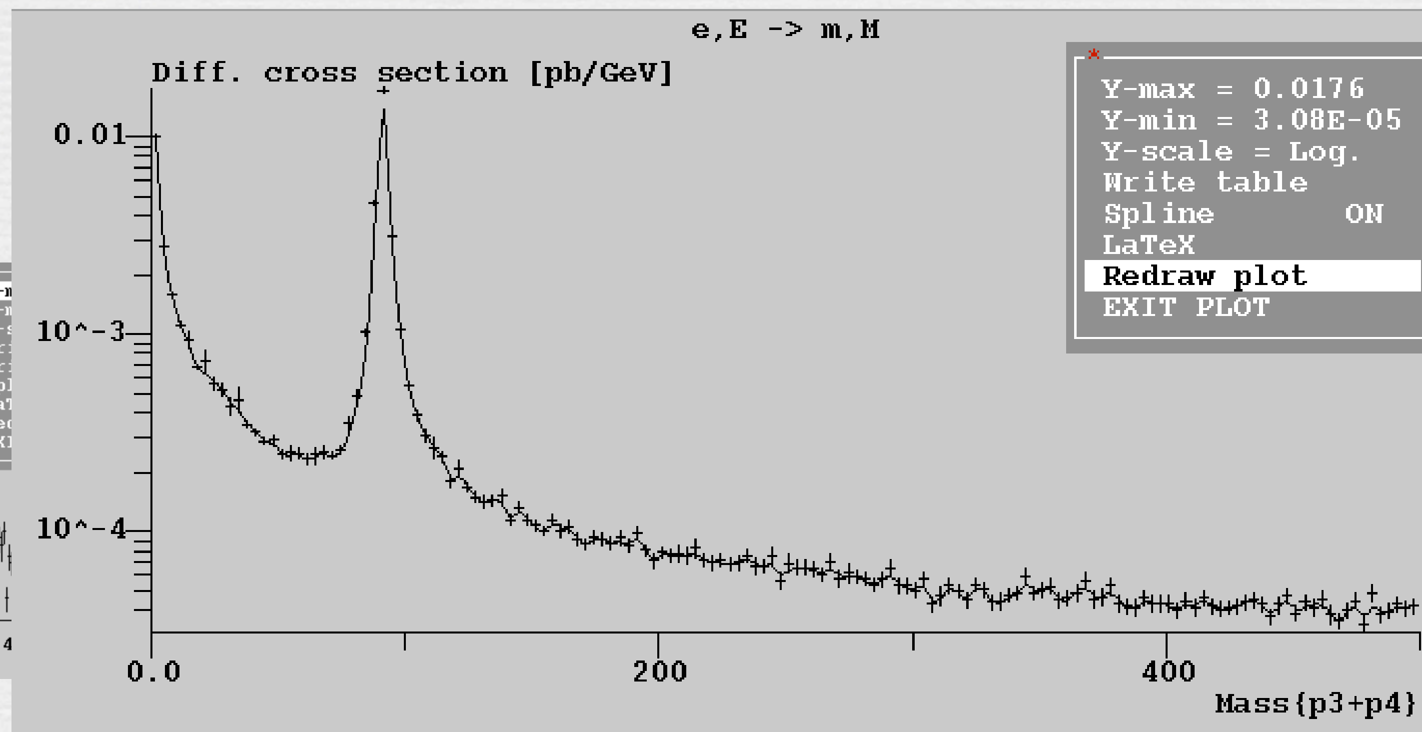
(sub)Process: e,E -> m,M
Monte Carlo session: 1(continue)

#IT	Cross section [pb]	Error %	nCall	chi**2
15	3.0972E-01	1.70E-01	19404	
16	3.0938E-01	1.77E-01	19404	
17	3.0964E-01	1.81E-01	19404	
18	3.0919E-01	1.84E-01	19404	
19	3.0989E-01	1.88E-01	19404	
20	3.0916E-01	1.95E-01	19404	
< >	3.0945E-01	4.35E-02	388080	0.5

500+500 GeV, e+e- beam

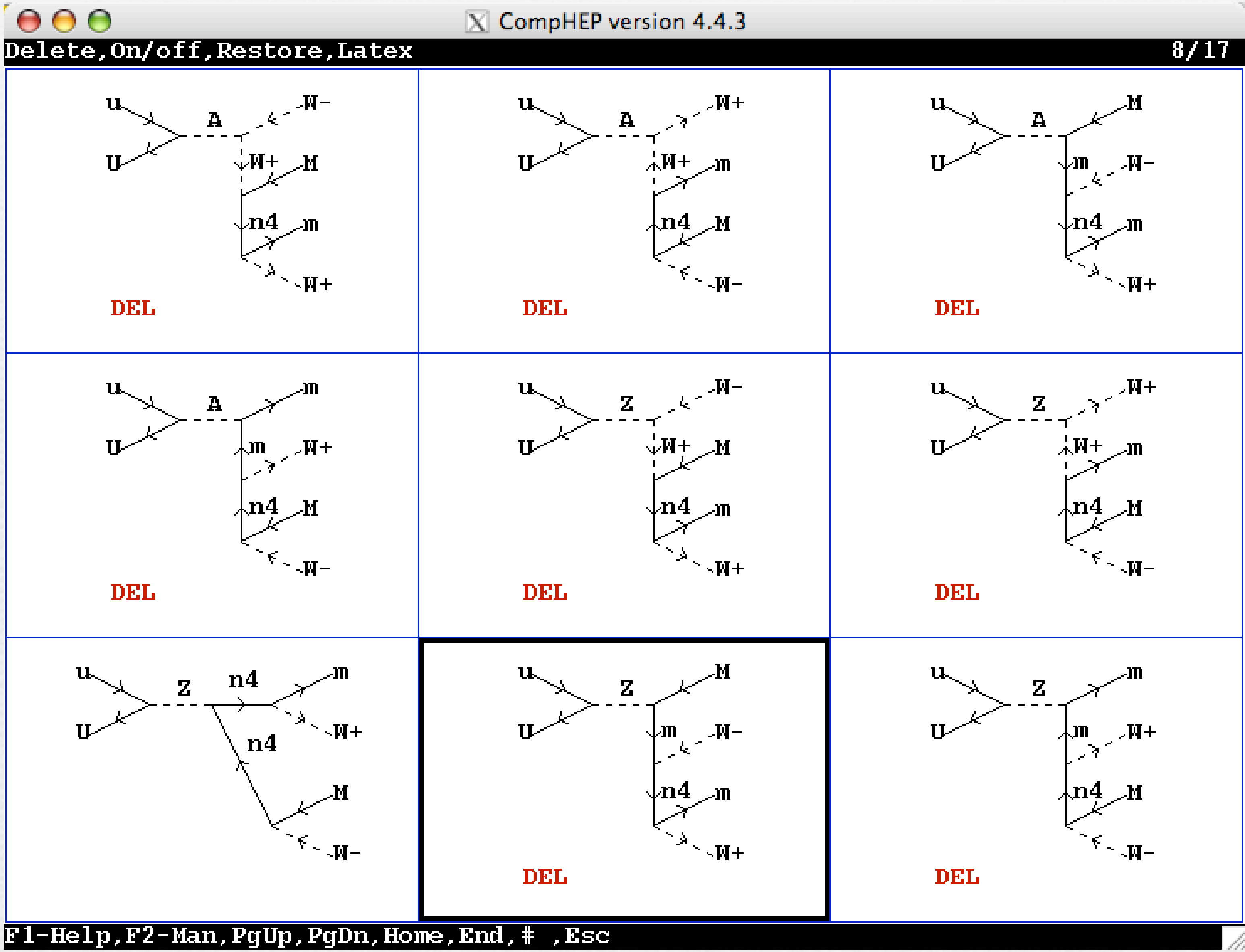
if statistics too small





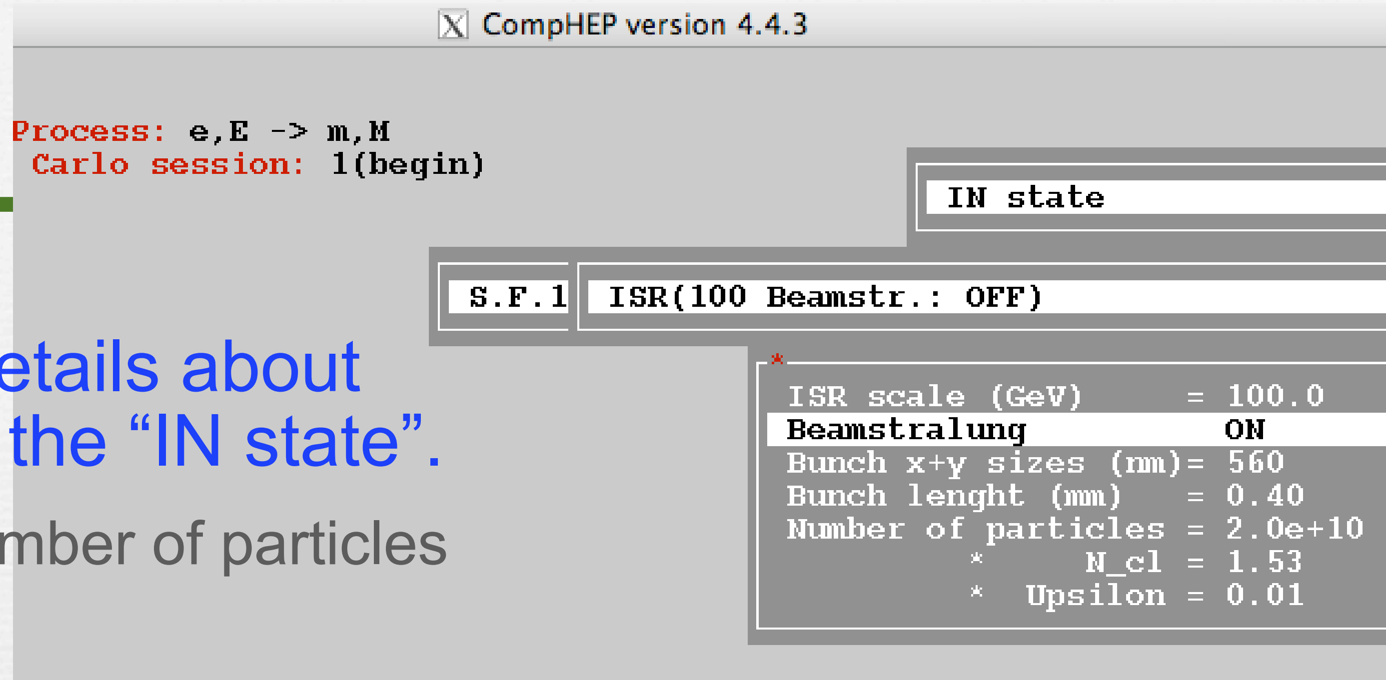
A more complicated example

- p-p or p-antip collider
- n4 : heavy neutrino, non-SM
- A number of diagrams deleted.
- $W^+W^-\mu^+\mu^-$ final state being examined.

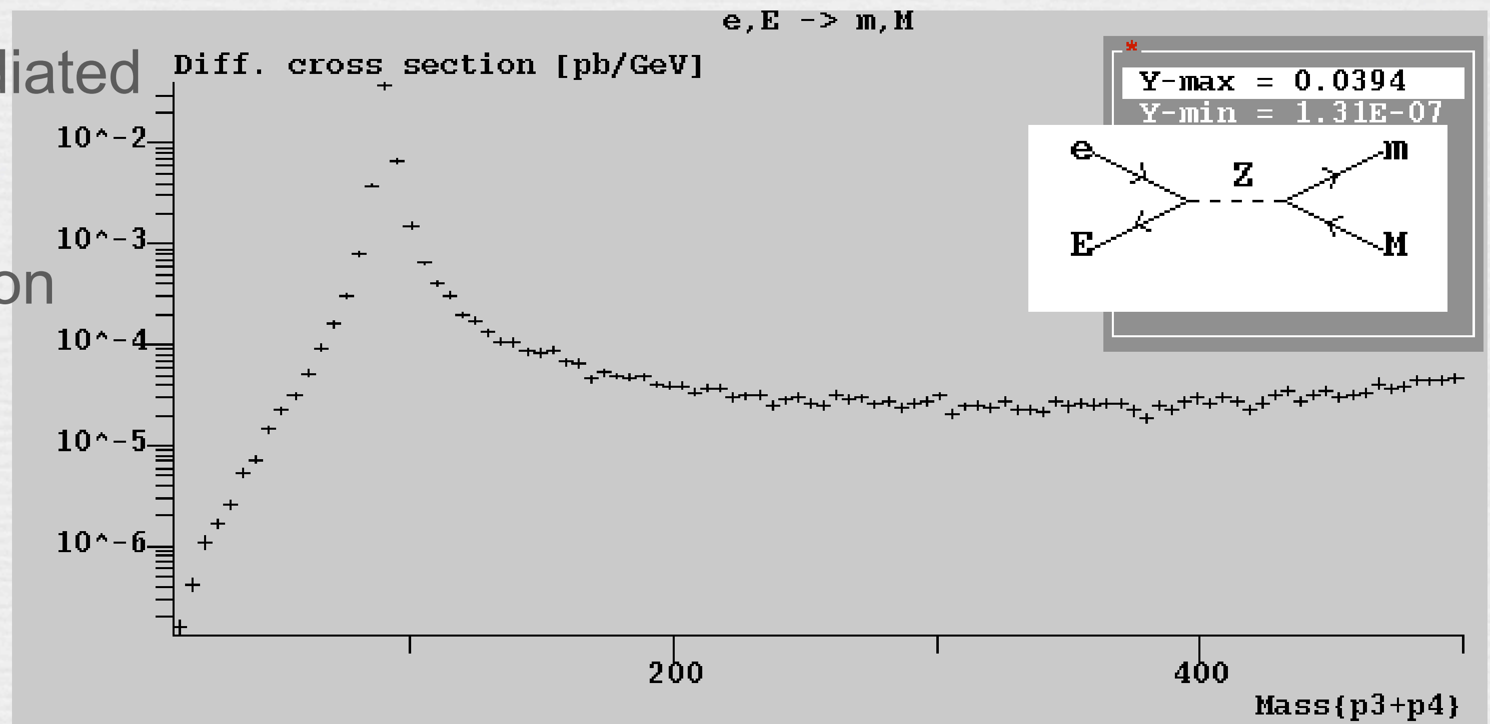


Details..

- One can give more details about the accelerator using the “IN state”.
  - Bunch size, length, number of particles per bunch..

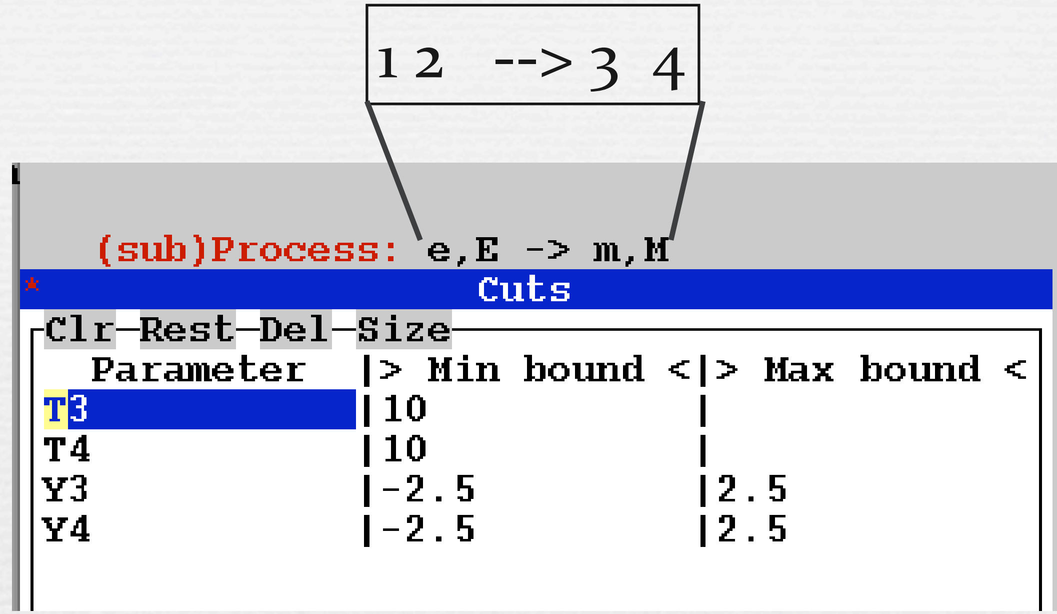


- One can turn off some sub-processes.
  - Turn off the γ mediated process to see the effect of the Z-boson



Event selection-cuts

- To impose some selection at the generator level:
  - to select certain event types or later to separate signal & bg.
- To obtain a more realistic cross section:
  - Certain particles (low E or high η) can not be recored.
- To be able to obtain the cross section:
  - Some QCD processes have IR divergences, to make the calculations converge we need to impose some restrictions.



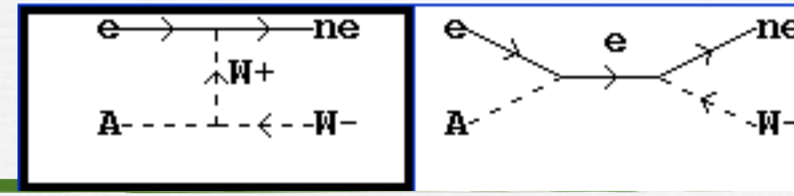
T : Transverse momentum

1st line records μ- which have transverse momentum > 10 GeV

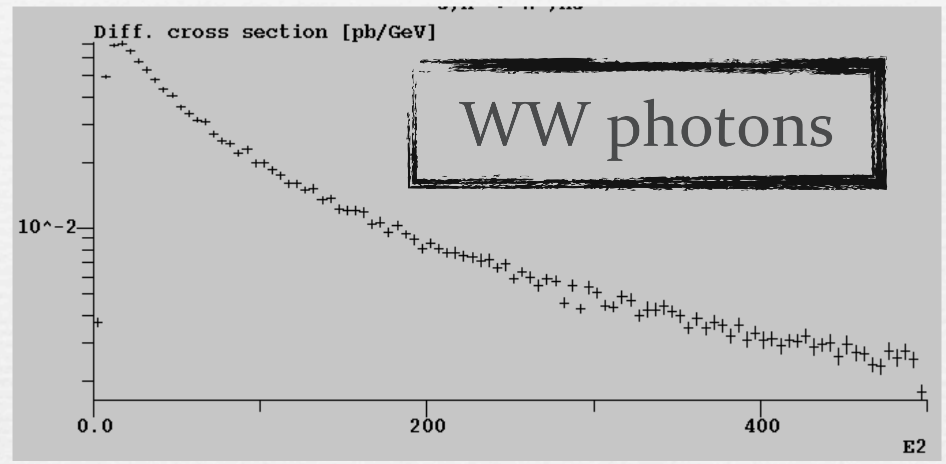
Y : rapidity

Assume I have an inner detector which sits between ± 2.5 in eta, lines 3 & 4 represent this constraint.

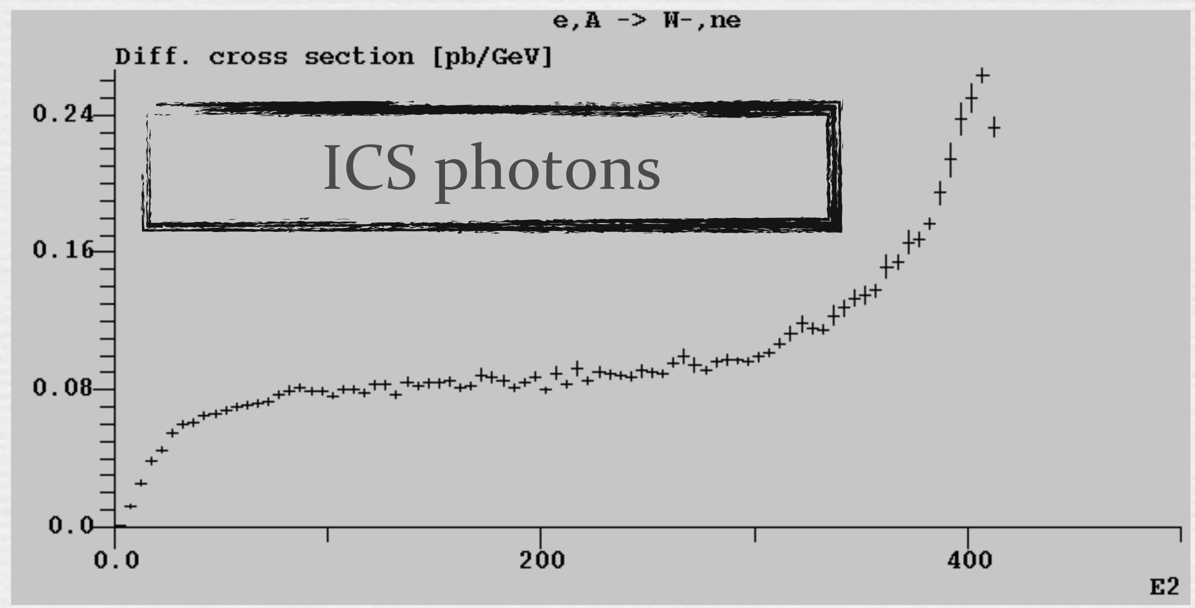
Photon beam



- 2 separate photon beams are defined.
  - gamE: WW photons (ISR,BS)
  - gamL: Inverse Compton Scattering (ICS) photons



- Always the electron beam energy is written.



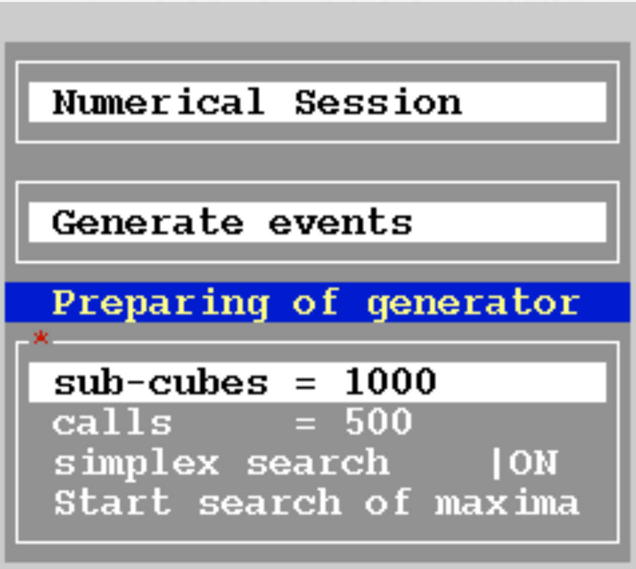
what to do with this tool ?

- We could study a particular mode. (e.g. its measurability)
  - Enter the Lagrangian of the model you want to study into CompHEP.
- We could obtain the cross sections and branching fractions
- Generate MC events
  - Mix events from separate sub-processes
  - At this point the process could be studied at the generator level.
- Hadronization via another tool, (Herwig/Pythia)
- Detector simulation via another tool, (PGS/Delphes)
- We could study the MC events as if they were real data.

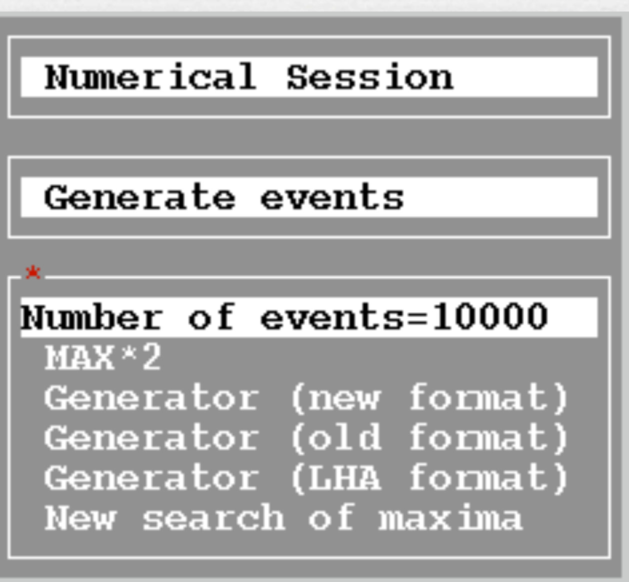
Advanced topics

- Event Generation
  - might be needed to feed to other programs.
- ‘Kinematics’ settings
  - might needed for the 2 in 4 out processes.
- ‘Regularization’ options
  - might be needed when there are a multitude of same outgoing particles (e.g. two Z bosons).
- Run in ‘Batch mode’ - scripting
  - might be needed to scan the x-section as a function of a parameter (e.g. mass of Higgs boson)

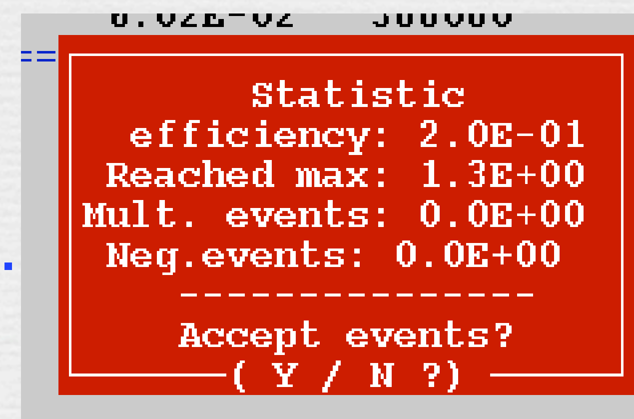
Event Generation



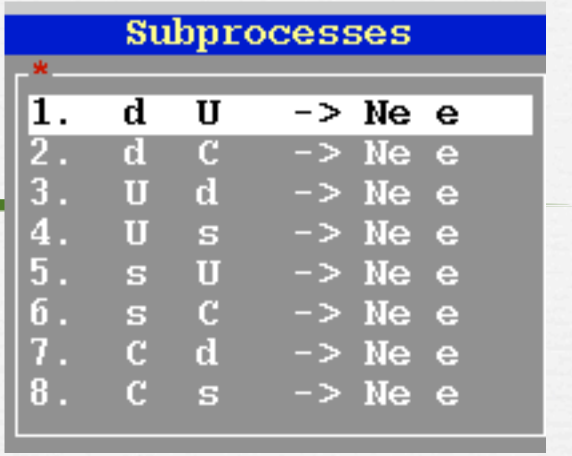
- From the “Generate Events” heading choose the “start search of maxima” option
  - if the maxima is not found, turn off the “simplex” option.
- Do not produce same number of events for all sub-processes, make it proportional to the x-section
  - Make more events for higher x-sections



- When the generation is over, a red window appears, waiting for confirmation. Check:
  - Any negative events ?
  - Any multiple ?
- The file is written on disk.



Mixing the events



- Produce events from different sub-processes
- Now we have to merge these and make a single file:
  - A single file containing all generated events
  - merging / mixing coefficients should be proportional to the cross sections of the (sub) processes
- There is a scipt to mix & merge the sub-processes
  - cd **results**
  - ../mix events_1.txt events_2.txt
- Mixed events are written into the mixed.lhe file.
- This text file contains:
  - Generic Info about the processes (e.g.: initial / final state particles, x-section)
  - Specific info about each event (e.g.: energy & momenta of each particle.)

Results directory

```
1 ngu  ngu        47 Dec 28 22:34 LOCK
1 ngu  ngu      3376 Dec 28 21:14 Makefile
1 ngu  ngu     10240 Dec 28 22:34 diags.tar
1 ngu  ngu   1601570 Dec 28 22:51 events_1.txt
1 ngu  ngu         0 Dec 28 22:34 extern.h
1 ngu  ngu      5696 Dec 28 22:34 f_0.a
1 ngu  ngu       999 Dec 28 21:14 n_comphep*
1 ngu  ngu    257280 Dec 28 22:34 n_comphep.exe*
1 ngu  ngu      2071 Dec 28 22:51 prt_1
1 ngu  ngu      2029 Dec 29 23:51 prt_10
```

comphep is now working

Generated events

script to re-study the current process

details of the session 10

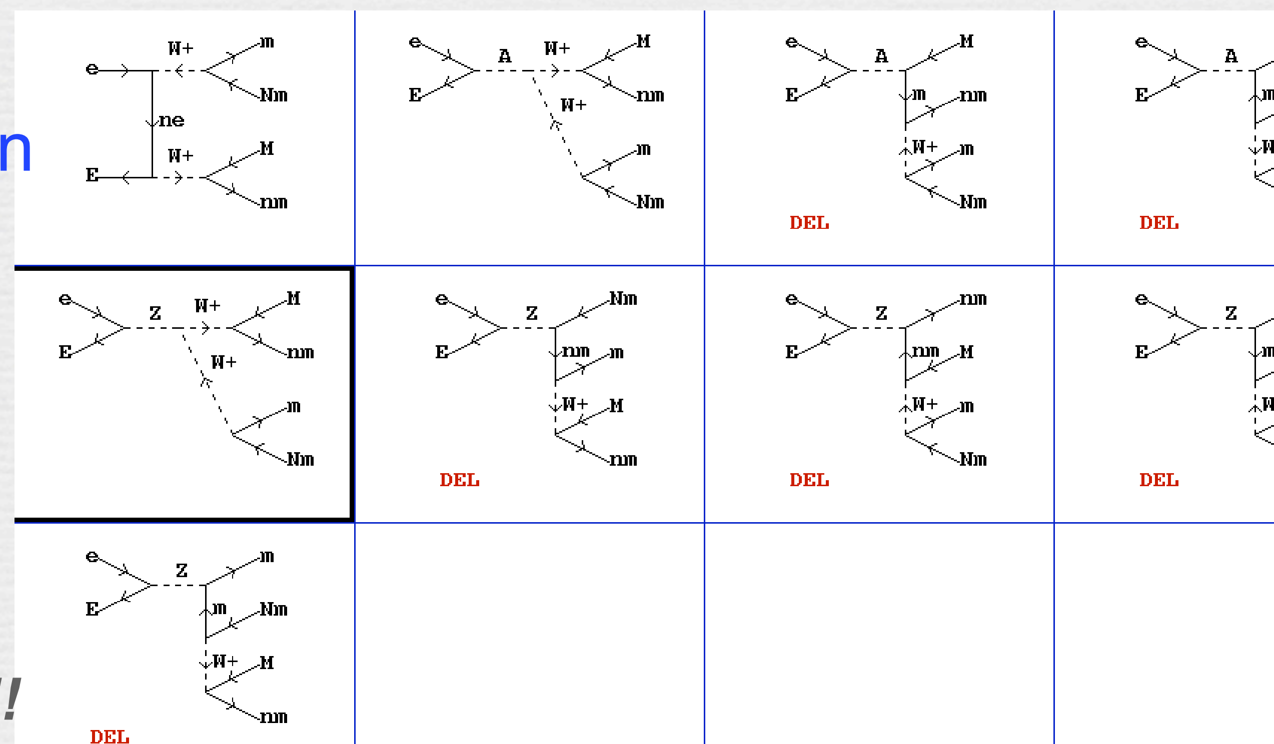
Kinematics 1

(sub)Process: e,E -> W+,W-
Monte Carlo session: 1(begin)

#IT	Cross section [pb]	Error %	nCall	chi**2
1	2.6899E+00	6.23E-01	20000	
2	2.6781E+00	4.31E-02	20000	
3	2.6772E+00	2.01E-03	20000	
4	2.6773E+00	3.99E-04	20000	
5	2.6773E+00	3.58E-04	20000	
6	2.6773E+00	3.61E-04	20000	
7	2.6773E+00	3.58E-04	20000	
8	2.6773E+00	3.67E-04	20000	
9	2.6773E+00	3.75E-04	20000	
10	2.6772E+00	3.82E-04	20000	
< >	2.6773E+00	1.40E-04	200000	0.7

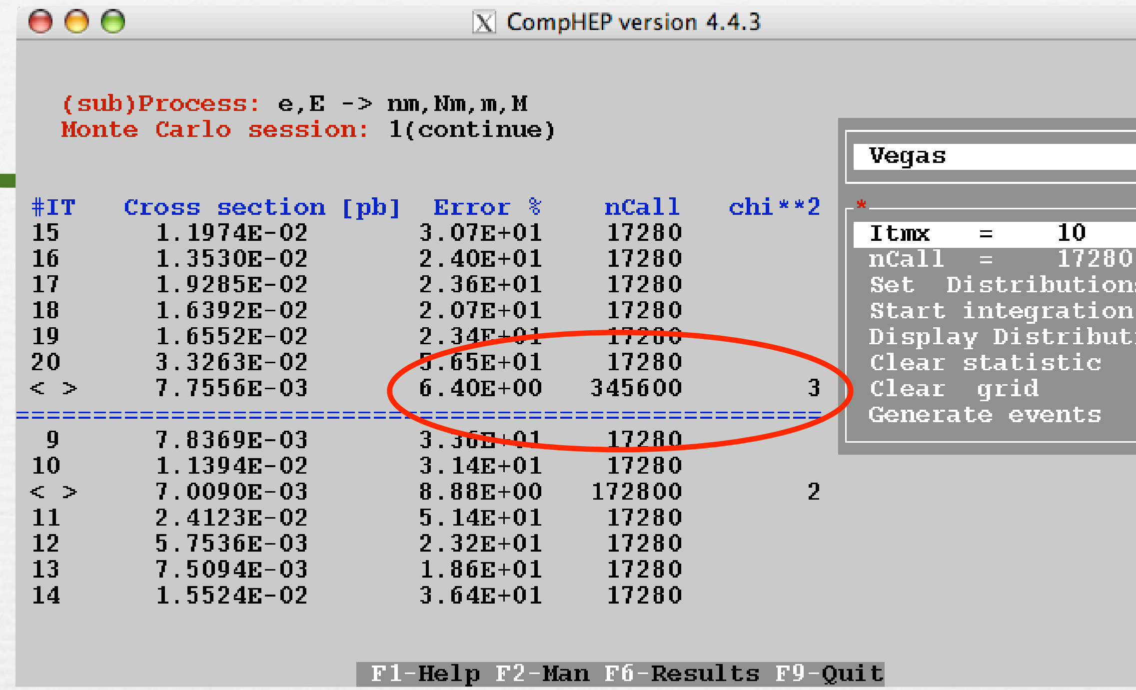
- 500+500 GeV ideal beams and calculate the $W^+ W^-$ production.
  - cross section = 2677 fb,
  - W BF for μ decay: BR(W→ μν)=0.11
    - final x-section (ee→WW→μν μν)= 2677*0.11*0.11=
    - **32fb** .
- get the μνμν final states in CompHEP
  - Delete all diagrams except the 3 previous diagrams
  - calculate the x-section
  - *and*

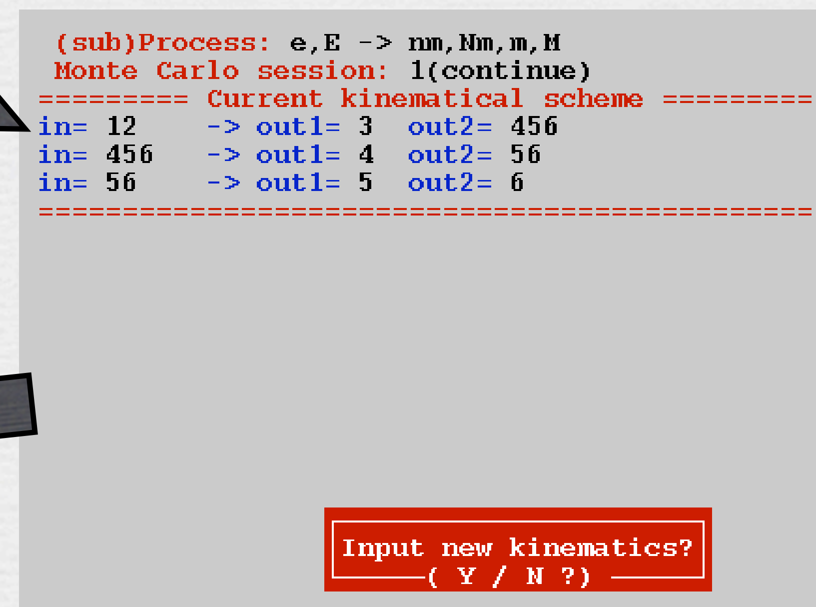
    find the wrong answer!!!!!



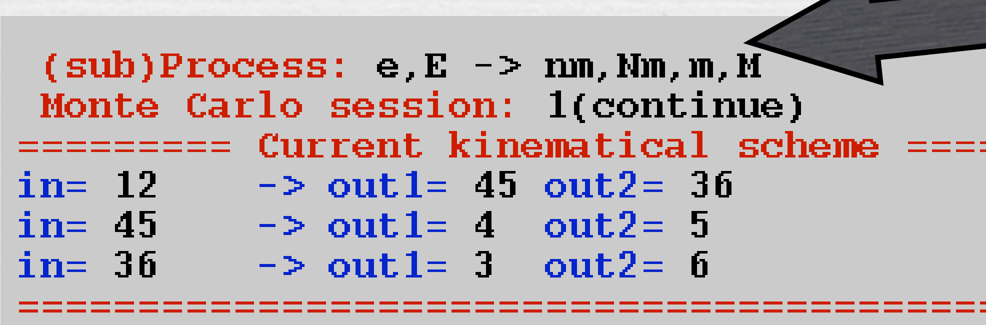
Kinematics 2

- error & χ^2 too large!
  - Why? Check the Kinematics option. The process you want to study is **not** this one !
    - particles 4,5,6 are not coming from the decay of particle 3..
  - Computer doesn't know physics,you do.





- Define the correct kinematics:



Kinematics 3 & Regularization

- Fixing the kinematics should get the correct answer.
  - In this case : 33.6 fb.
- Always check the error & χ^2 .
- Apply regularization if error & χ^2 are too large
  - Specify which intermediate particle decays to which final state particle.
  - Mass and Width values to be specified, power = 2 always.

```
 (sub)Process: e,E -> nm,Nm,m,M
 Monte Carlo session: 1(continue)

14        3.5138E-02        8.59E-01      17280
15        3.4797E-02        9.76E-01      17280
16        3.4986E-02        1.01E+00      17280
17        3.4614E-02        9.02E-01      17280
18        3.4403E-02        1.02E+00      17280
19        3.5140E-02        9.95E-01      17280
20        3.4906E-02        9.19E-01      17280
21        3.5151E-02        1.02E+00      17280
< >       3.3646E-02        2.58E-01     362880
=================================================
 9        3.4319E-02        1.02E+00      17280
10        3.5114E-02        1.19E+00      17280
11        3.5418E-02        1.10E+00      17280
12        3.4922E-02        1.11E+00      17280
13        3.5472E-02        1.03E+00      17280
```

```
 (sub)Process: e,E -> nm,Nm,m,M
*                   Regularization  1
Clr-Rest-Del-Size
 Momentum        |> Mass    <|> Width <|  Power
36               |MW         |wW        |2
45               |MW         |wW        |2
```

Batch processing -1

```
Subprocess 2 (d,C -> Ne,e)

End of CompHEP numerical session.
Subprocess 3 (U,d -> Ne,e)

End of CompHEP numerical session.
Subprocess 4 (U,s -> Ne,e)

End of CompHEP numerical session.
Subprocess 5 (s,U -> Ne,e)

End of CompHEP numerical session.
Subprocess 6 (s,C -> Ne,e)

End of CompHEP numerical session.
Subprocess 7 (C,d -> Ne,e)

End of CompHEP numerical session.
Subprocess 8 (C,s -> Ne,e)

End of CompHEP numerical session.
File results/batch.dat is created.
```

- Go to the comphep_workdir
  - Need to run `./num_batch.pl` once (no arguments)
- to get the total x-section from all sub processes:
  - `./num_batch.pl -run vegas` ==> prints all steps on screen
  - `./num_batch.pl -run vegas| awk 'BEGIN{s=0} {s+=$3} END{ print s}'` ==> prints the total x-section on screen
- One can select the process to work on
  - `./num_batch.pl -run vegas -proc 1,3-5,17,2`
- It is possible to generate events on all subprocesses:
  - `./num_batch.pl -nevnt 5000` (5K events from each sub-process)
  - `./num_batch.pl -run` (for each sub-process, calculate & generate events)

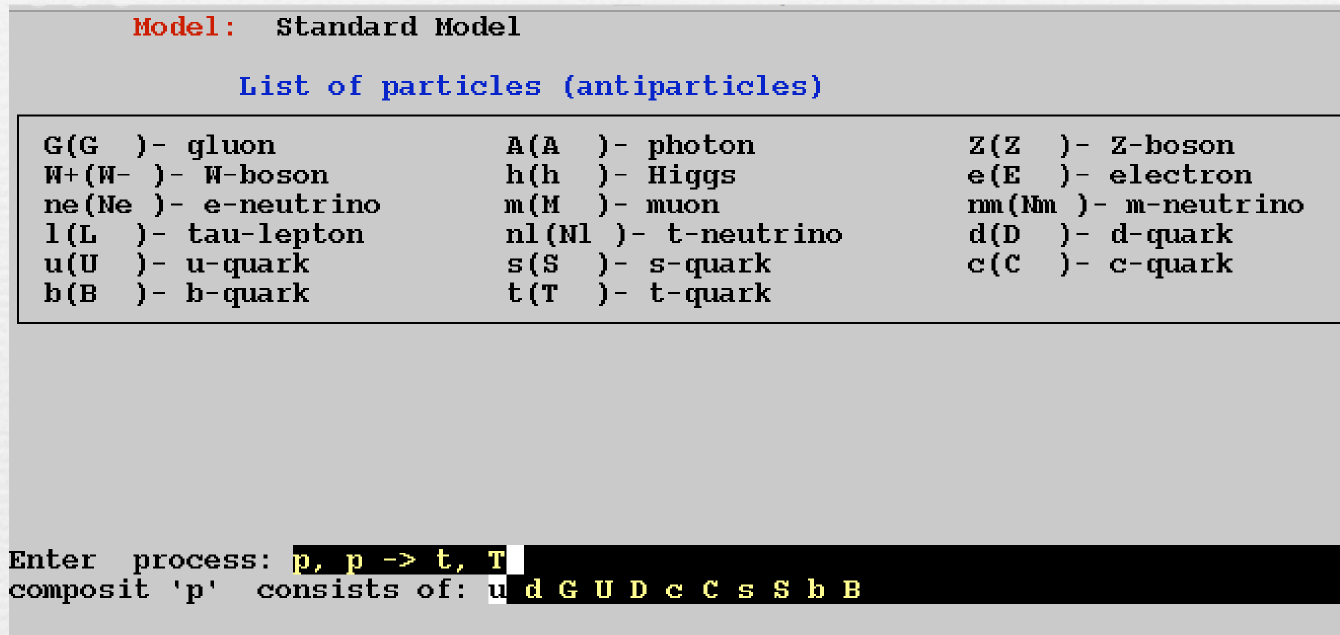
Batch processing -2

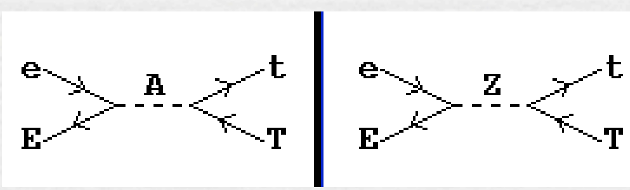
```
#!/bin/bash
rd=/HEP/chep/scripts
outn=$1

${rd}/set_momenta 7000 7000
${rd}/set_vegas 10 20000
#${rd}/set_cuts Y3 -3.2 3.2

#if the same name is given, we purge the old data
rm -f ${outn}.sub*

for Mde in 100 150 200 250 300 350 400 500 600 700 800 ; do {
 ${rd}/set_param Mde  ${Mde}
 ${rd}/set_qcd  ${Mde}
 St=0.045
 echo ${Mde}  ${St} >>${outn}
 ${rd}/set_param St  ${St}

# run and save results
 for ((sp=1;  sp<35; sp++)); do
  ${rd}/select_sub ${sp}
  #${rd}/run_vegas
  echo $sp
  sesno=`grep "Session_number" session.dat| cut -f2 -d' ' `
  tail -1 prt_${sesno} >>${outn}.sub${sp}
 done
}
```

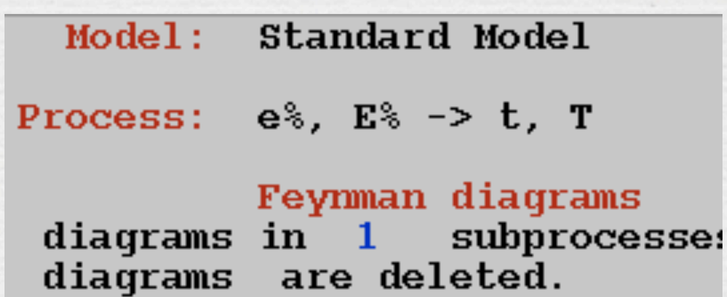
- alternative way:
  - download the comphep/calchep commands from Gokhan's web page
  - put them in a location on your computer (e.g. /HEP/chep/scripts)
- merge these into a shell script for finer control over the calculations

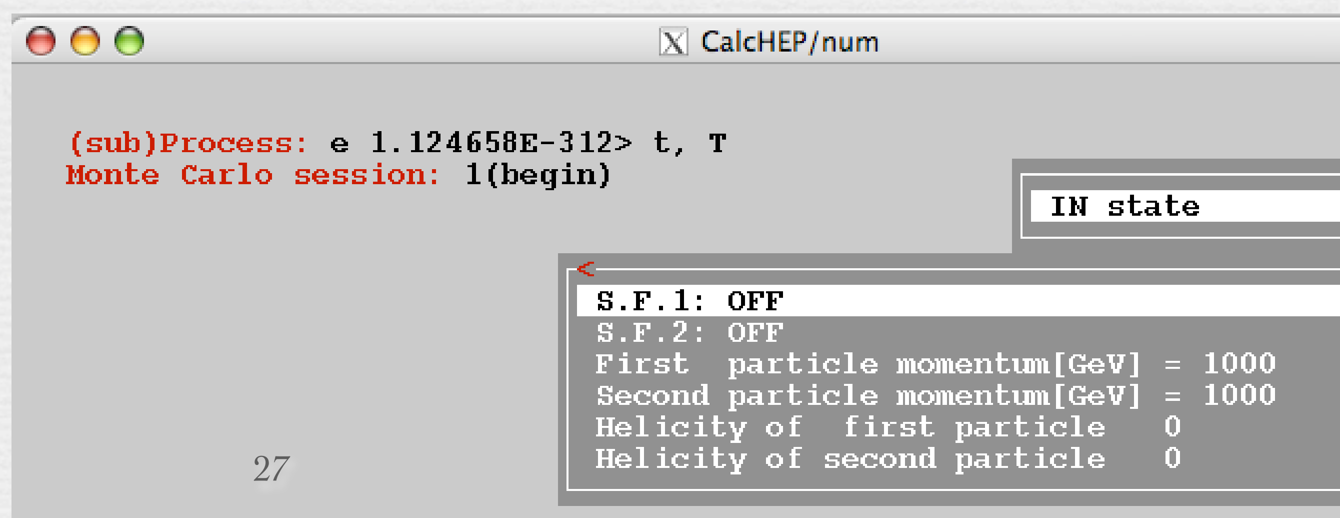
CalcHEP

- Different software from same common origin as CompHEP.
- Small differences:
  - Higgs is **h** <u>not</u> H
  - “proton” not defined!
  - But polarization defined.
    - Example: e% or E% .

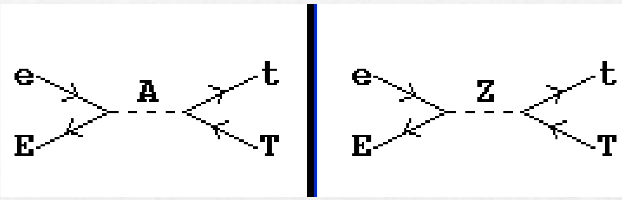








Polarization dependence of σ



e⁻ pol

e⁺ pol

unpolarized beams: 0, 0

```
  (sub)Process: e 1.124658E-312> t, T
P(c.m.s.)     :   1000.000000 [GeV]
Cos(p1,p3): min=-0.999000            max
Cross Section:  0.0331698 [pb]
```

reverse polarized beams: -1, 1

```
  (sub)Process: e 1.124658E-312> t,
P(c.m.s.)     :   1000.000000 [GeV]
Cos(p1,p3): min=-0.999000            m
Cross Section:  0.16234 [pb]
```

- SLAC e- & e+ beams were polarized...

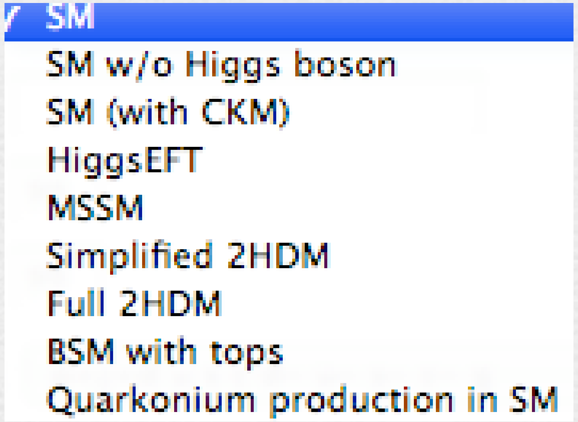
About MadGraph

Gökhan Ünel / *UC Irvine*

ISTAPP 2011

General Information

- Similar to C**HEP, tree level cross section calculation and event generation, V4.4.x *(V5 is in beta version)*
  - to register & download: http://madgraph.hep.uiuc.edu/
- Would work on nay unix, supports single(multi) core and pbs.
  - requires fortran, results in html format.
  - implementing a new model is not very easy
  - Only proton/Anti-proton collider defined
    - different PDFs are available.
  - polarization ve matching is possible



- Notation slightly different
  - pp > t t~ (antiparticle is shown with “~” ; “,” & p~ doesn’t exist.)
  - " x x > z > y y y " ==> force z particle to be in the s-channel.
  - " x x > y y y /z" ==> do not have z at all.

Setting up & installing

- compile MG2 : *(we did this step for you)*
  - `cd istapp2011/mg_me`
  - `cd MadGraphII; make ; cd ..`
- Template directory is to be backed up: *(please do this now)*
  - `tar czf Template.tgz Template-0/`
- Prepare the test process: *(please do this now)*
  - `mv Template-0 Deneme; cd Deneme`
- To work on a new process
  - By cleaning the old one :
    - `bin/clean` and enter a new process - we'll see how.
  - By making a new directory:
    - `tar xzf Template.tgz ; mv Template-0 NewProject`

Example process

- Enter the new process in "proc data card".
  - nedit Cards/proc_card.dat

```
e+e->mu+mu-   @0  # First Process
QCD=4             # Max QCD couplings
QED=4             # Max QED couplings
end_coup          # End the couplings
```

- Process & accelerator properties are in "run data card"
  - nedit Cards/run_card.dat

```
20  = ptj     ! minimum pt for the jets
10  = ptb     ! minimum pt for the b
10  = pta     ! minimum pt for the photons
10  = ptl     ! minimum pt for the charged leptons
```

```
# Collider type and energy
#***************************
      0      = lpp1   ! be
      0      = lpp2   ! be
    500      = ebeam1  !
    500      = ebeam2  !
```

- To start:
  - ./bin/newprocess

```
ngu-mbook:Deneme ngu$ bin/newprocess
Using Stand Alone version of MadGraphII
Started Wed Dec 31 13:10:42 CET 2008
Running....
..Finished Wed Dec 31 13:10:42 CET 2008
Compiling libraries in Source
cd DHELAS; make
f77 -O -I. -c httsxx.F
```

```
Running....
.......tar cf madevent.tar Cards HTML SubProcesses bin lib So
plateVersion.txt MGMEVersion.txt
rm -f madevent.tar.gz
gzip madevent.tar
```

Steps...

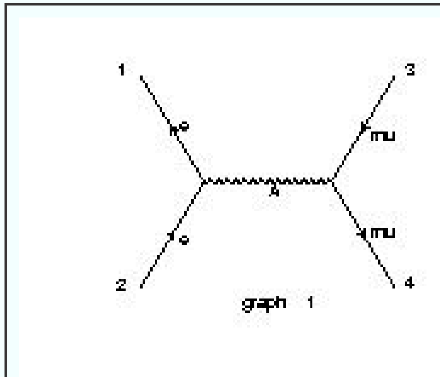
run name, like MC id number

- Results in **index.html** file
- To get the cross section
  - `./bin/survey 0 a`
- To improve the results
  - `./bin/refine 0 0.01 b`
- To produce 100 events
  - `./bin/refine 0 100 a`
- Results in :
  - `SubProcesses/results.html`
- **Events in**
  - `Events/unweighted_events.lhe.gz`

MadEvent Card for e+e->mu+mu-

Created: Mon Dec 29 11:10:35 CET 2008

Process: e+e->mu+mu-
QCD=4
QED=4
Model: sm



Links	Status
Process Information	Generation Complete
Code Download	Available
On-line Event Generation	Only available from the we
Results and Event Database	No runs available

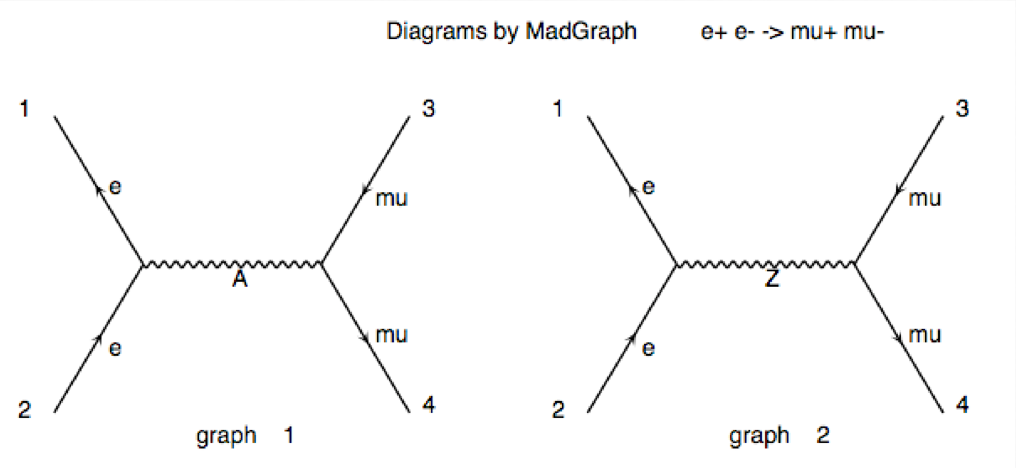
Notes:

0 : single core
1 : PBS farm
2 :multicore

Process results
s= 105.550± 1.376(fb)

Graph	Cross Sect(fb)	Error(fb)	Events (K)	Eff	Unwgt	Luminosity
Sum	105.550	1.376	2	0.7		
P0_e+e-_mu+mu-	105.550	1.376	2	0.7		20.60

Details



Process results

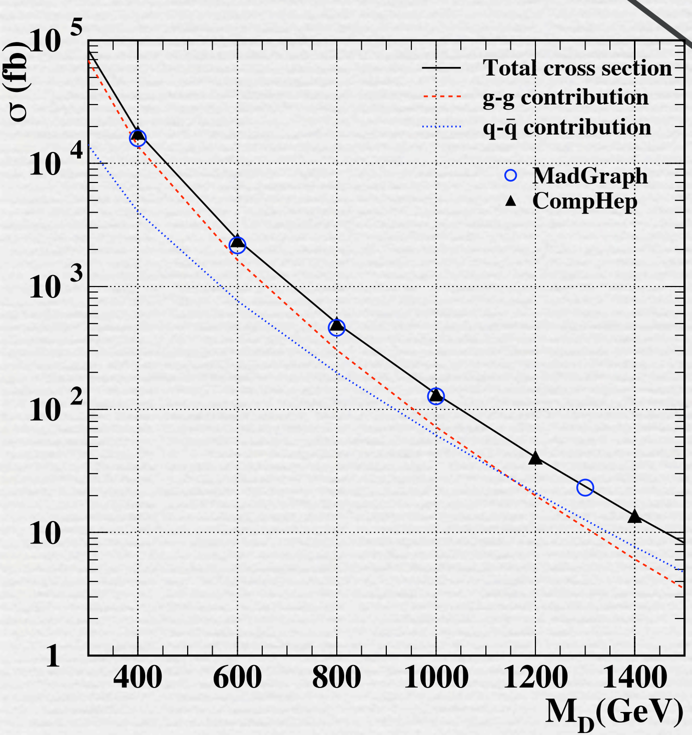
s= 105.550± 1.376(fb)

Graph	Cross Sect(fb)	Error(fb)	Events (K)	Eff	Unwgt	Lum
Sum	105.550	1.376	2	0.7		
P0_e+e-_mu+mu-	105.550	1.376	2	0.7		20.60

e+e-_mu+mu-

s= 105.549± 1.376(fb)

Graph	Cross Sect(fb)	Error(fb)	Events (K)	Eff	Unwgt	Luminosity
Sum	105.549	1.376	30	2.3		
G1	92.664	1.216	15	1.6	1909	20.60
G2	12.885	0.160	15	1.5	795	61.70



- One can find the processes and diagrams contributing most to the total cross section
- CompHEP & MG results are compatible.

A longer example

```
pp>Z>Jbb~      @0
QCD=9
QED=9
end_coup
```

pp collider Z production and decay to bb̄ Jets.

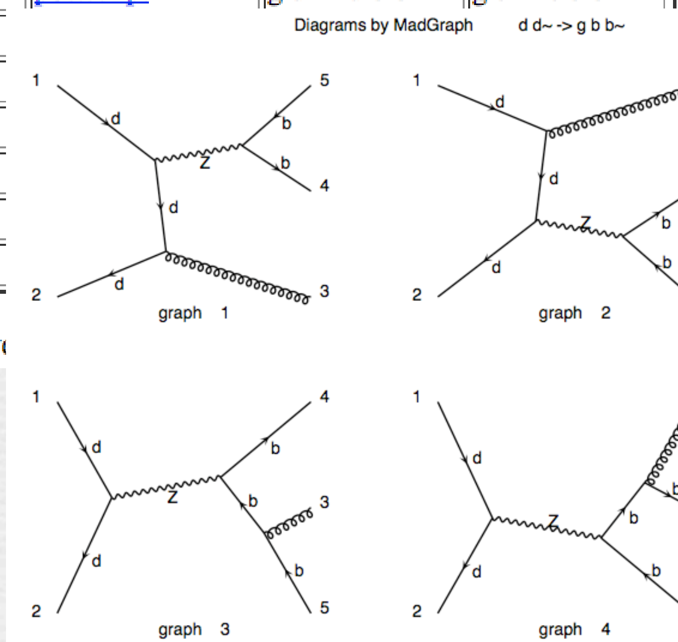
Process results

s= 9163.110± 760.220(fb)

Graph	Cross Sect(fb)	Error(fb)
Sum	**9163.110**	**760.220**
P0_ddx_gbbx	1376.700	156.400
P0_dxd_gbbx	1240.500	94.674
P0_uxu_gbbx	1083.900	93.761
P0_uux_gbbx	1060.000	88.280
P0_bbx_gbbx	625.840	62.016
P0_bxb_gbbx	605.040	52.445
P0_gd_dbbx	324.600	20.416
P0_dg_dbbx	298.770	18.352
P0_gdx_dxbbx	292.830	15.608
P0_dxg_dxbbx	289.450	18.960
P0_gbx_bxbbx	273.830	22.697
P0_bxg_bxbbx	255.510	19.513
P0_bg_bbbx	254.520	21.792
P0_uxg_uxbbx	239.830	17.579
P0_gux_uxbbx	239.150	12.222
P0_gb_bbbx	236.610	19.634
P0_ug_ubbx	234.210	12.679
P0_gu_ubbx	231.820	13.192

Directory	# Diagrams	# Subprocesses	FEYNMAN DIAGRAMS		SUBPROCESS	
P0_uxu_gbbx	4	2	html	postscript	u~ u -> g b b~	c~ c -> g b b~
P0_uxg_uxbbx	2	2	html	postscript	u~ g -> u~ b b~	c~ g -> c~ b b~
P0_uux_gbbx	4	2	html	postscript	u u~ -> g b b~	c c~ -> g b b~
P0_ug_ubbx	2	2	html	postscript	u g -> u b b~	c g -> c b b~
P0_dxd_gbbx	4	2	html	postscript	d~ d -> g b b~	s~ s -> g b b~
P0_dxg_dxbbx	2	2	html	postscript	d~ g -> d~ b b~	s~ g -> s~ b b~
P0_ddx_gbbx	4	2	html	postscript	d d~ -> g b b~	s s~ -> g b b~
P0_dg_dbbx	2	2	html	postscript	d g -> d b b~	s g -> s b b~
P0_gux_uxbbx	2	2	html	postscript	g u~ -> u~ b b~	g c~ -> c~ b b~
P0_gu_ubbx	2	2	html	postscript	g u -> u b b~	g c -> c b b~
P0_gdx_dxbbx	2	2	html	postscript	g d~ -> d~ b b~	g s~ -> s~ b b~
P0_gd_dbbx	2	2	html	postscript	g d -> d b b~	g s -> s b b~
P0_gbx_bxbbx	4	1	html			
P0_gb_bbbx	4	1	html			
P0_bxg_bxbbx	4	1	html			
P0_bxb_gbbx	4	1	html			
P0_bg_bbbx	4	1	html			
P0_bbx_gbbx	4	1	html			

56 diagrams hav



ddx_gbbx

s= 1376.711± 156.402(fb)

Graph	Cross Sect(fb)	Error(fb)	Events (K)	Eff	Unwgt	Luminosity
Sum	**1376.711**	**156.402**	**60**	**27.8**		
G2	689.420	107.400	15	19.1	13	0.02
G1	576.740	43.629	15	9.3	14	0.02
G4	57.004	2.761	15	5.9	76	1.33
G3	53.547	2.612	15	6.0	80	1.49

Short cut

Links	Status
Process Information	Generation Complete
Code Download	Available
On-line Event Generation	Only available from the web
Results and Event Database	No runs available

- There is a command to do all these in 1 step:
  - It should be used after defining the process by editing the proc and run cards
    - `./bin/generate_events`
    - **`index.html`** is automatically updated after completion:

```
ngu-mbook:Template ngu$  bin/generate_events
Enter 1 for parallel 0 for serial run
0
Enter run name
ee2mm
Mon Dec 29 12:03:05 CET 2008
Generating 100 events
Cleaning  SubProcesses.
Cleaning Source:
Cleaning lib:
Cleaning bin:
Compiling libraries
Working on subprocess:
    P0_e+e-_mu+mu-    ld: warning for symbol
```

Links	Status
Process Information	Generation Complete
Code Download	Available
On-line Event Generation	Only available from the web
Results and Event Database	1 runs available

Available Results

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level LHE	fermi	ee2mm	e e 500 x 500 GeV	.10492E+00	100

```
ls -l Events/

 1968 Dec  6  2007 banner_header.txt
20901 Jan  2 21:26 ee2mm_banner.txt
20459 Jan  2 21:26 ee2mm_events.lhe.gz
 8948 Jan  2 21:26 ee2mm_unweighted_events.lhe.gz
```

Details

Accelerator

0	-1	1	2
ideal	$\bar{p}$	p	γ (WW)

polarisation

PDF

QCD scale

matching

```
#*********************************************************************
# Collider type and energy
#*********************************************************************
        0      = lpp1   ! beam 1 type (0=NO PDF)
        0      = lpp2   ! beam 2 type (0=NO PDF)
      500      = ebeam1   ! beam 1 energy in GeV
      500      = ebeam2   ! beam 2 energy in GeV
#*********************************************************************
# Beam polarization from -100 (left-handed) to 100 (right-hande
#*********************************************************************
        0      = polbeam1 ! beam polarization for beam 1
        0      = polbeam2 ! beam polarization for beam 2
#*********************************************************************
# PDF CHOICE: this automatically fixes also alpha_s and its evol
#*********************************************************************
 'cteq6l1'     = pdlabel      ! PDF set
#*********************************************************************
# Renormalization and factorization scales
#*********************************************************************
 T         = fixed_ren_scale  ! if .true. use fixed ren scale
 T         = fixed_fac_scale  ! if .true. use fixed fac scale
 91.1880   = scale            ! fixed ren scale
 91.1880   = dsqrt_q2fact1    ! fixed fact scale for pdf1
 91.1880   = dsqrt_q2fact2    ! fixed fact scale for pdf2
 1         = scalefact        ! scale factor for event-by-event s
#*********************************************************************
# Matching - Warning! ickkw > 0 is still beta
#*********************************************************************
 0         = ickkw            ! 0 no matching, 1 MLM, 2 CKKW matc
```

Cards/proc_card.dat

About parton matching

- What is this, why to match?
  - I would like to calculate 2 and 3 gluon final states @ LHC
    - 1st process originates from Matrix Element calculation: p p→g g
    - 2nd process originates from Matrix Element calculation: p p→g g g
  - During showering, "pythia" does ISR/ FSR as well.
    - by "chance" it doesn't change (2) but makes a gluon radiate in (1)
    - p p→g g BECOMES p p→g g g thanks to shower MC
  - Should I count (1) as 2 gluon final state or 3 gluon final state ?
- Reconstruct jets and match with initial parton properties to avoid double counting. *(MLM vs CKKW matching)*
- For details see
  - http://mlm.web.cern.ch/mlm/talks/lund-alpgen.pdf
  - http://www.isv.uu.se/thep/courses/QCD/QCD_presentation_David.pdf

Pythia - Delphes interface

- MG, can be hooked to Pythia, Delphes and PGS.
- To do the hook *(we did this step for you)*:
  - **cd mg_me/**
  - **tar xzvf ../../pythia-pgs_V2.0.26.tar.gz**
  - **cd pythia-pgs;make ; cd ..**
  - **tar xzvf ../../ExRootAnalysis_V1.0.6.tar.gz**
  - **cd ExRootAnalysis;make**

Ref. simulation lecture

- Run it as before:
  - **cd ../Template**
  - **bin/newprocess**
  - *results updated when done*

```
ngu-mbook:Template ngu$ bin/generate_events
Enter 1 for parallel 0 for serial run
0
Enter run name
ee2mm_hepsi
Fri Jan  2 21:41:33 CET 2009
Generating 100 events
Cleaning  SubProcesses.
Cleaning Source:
```

Code Download	Available
On-line Event Generation	Only available from the web
Results and Event Database	2 runs available

Final Results

- Now MG reports results at 3 levels
  - Parton level
    - quarks, leptons ..
  - Hadron level
    - hadrons, mezons ..
  - Detector level
    - 'physics objects'

Available Results

Links	Events		Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level	LHE	fermi	ee2mm	e e 500 x 500 GeV	.10492E+00	100
results banner	Parton-level	LHE	fermi	ee2mm_hepsi	e e 500 x 500 GeV	.10144E+00	100
	Hadron-level (Pythia)	STDHEP LHE					
	Reco. Objects. (PGS)	LHCO					

Delphes vs PGS

Available Results

Links	Events		Tag	Run
results banner	Parton-level	LHE rootfile	fermi	a
	Hadron-level (Pythia)	STDHEP LHE rootfile (LHE)		
	Reco. Objects. (Delphes)	LHCO rootfile		

New files are now in Events directory

```
Dec  6  2007 banner_header.txt
Jan  2 21:26 ee2mm_banner.txt
Jan  2 21:26 ee2mm_events.lhe.gz
Jan  2 21:44 ee2mm_hepsi_banner.txt
Jan  2 21:44 ee2mm_hepsi_beforeveto.tree.gz
Jan  2 21:42 ee2mm_hepsi_events.lhe.gz
Jan  2 21:44 ee2mm_hepsi_events.tree.gz
Jan  2 21:44 ee2mm_hepsi_pgs.log
Jan  2 21:44 ee2mm_hepsi_pgs_events.lhco.gz
Jan  2 21:44 ee2mm_hepsi_pythia.log
Jan  2 21:44 ee2mm_hepsi_pythia_events.hep.gz
Jan  2 21:44 ee2mm_hepsi_pythia_events.lhe.gz
Jan  2 21:44 ee2mm_hepsi_unweighted_events.lhe.gz
Jan  2 21:44 ee2mm_hepsi_xsecs.tree
Jan  2 21:26 ee2mm_unweighted_events.lhe.gz
```

Concluding remarks

- We learned 3 programs that work at tree level.
  - CompHEP, CalcHEP, MadGraph
  - *For the curious ones: what is MCNLO?*
- By implementing a particle physics model on the computer we can do lots of calculations within that model.
  - If the Lagrangian is known, a new model can also be added.
- We can produce events from a specific model, at a given collider. These events can be used to:
  - estimate the measurability of that model, design an experiment
  - optimize the collider or to design a new one.

A midwinter night's dream

AKA: homework

- Using Comhep (in SM) calculate
  1. $\mu^+\mu^-$ production cross section at LEP-1 & LEP-2
  2. W^+W^- production cross section at LHC.
- Using MadGraph (in SMCKM) calculate
  1. W^+W^- production cross section at LHC.
  2. On a e-γ collider with 500GeV on 500GeV beam energies, produce 100 events for 2jet+MET final states
     1. What is the cross section of this process ?
     2. Run the events on Delphes to obtain a root file.