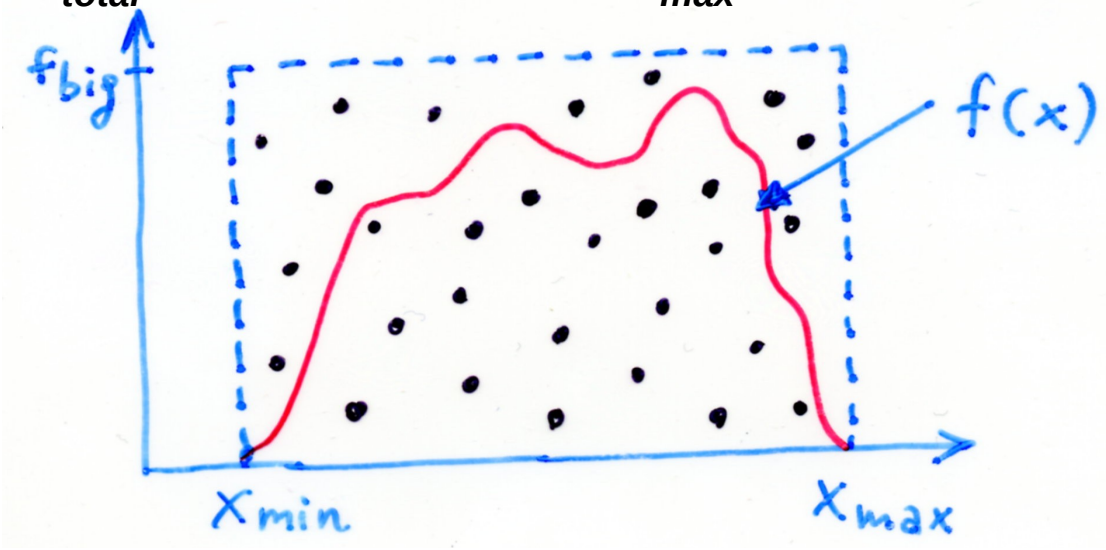
MC inegration and event generation is based on John von Neumann selection-rejection procedure

- ***sample*** u_1=rnd1, u_2=rnd2
- $x = x_{min} + (x_{min} - x_{max})\, u_1$
  $f^* = fmax * u_2$
- ***check whether or not f(x) > f****
  - ***If this holds, accept x as a realization of f(x)***
  - ***if not, reject the value of x and repeat the sampling step***
- ***as a results, the x will be generated according to a f(x),***
  $N_{accepted}/N_{total} * (x\_min - xmax) * f_{max}$ = square



Events generation with CalcHEP

- ***format of the event_nn.txt files***

```
#CalcHEP version 2.5.1
#Type 2 -> 3
#Initial_state
  P1_3=7.000000E+03  P2_3=-7.000000E+03
  StrFun1="PDT:cteq6m(proton)" 2212
  StrFun2="PDT:cteq6m(proton)" 2212
#PROCESS   2(u) -5(B) -> 24(W+) 5(b) -5(B)
#MASSES  0.0000000000E+00 3.2588068426E+00 7.9945520808E+01 3.2588068426E+00 3.2
#Cross_section(Width) 2.276199E-04
#Number_of_events          0
#Events        P1_3 [Gev]         P2_3 [Gev]         P3_1 [Gev]         P3_2 [Gev]
       1   1.7923832011E+03 -6.8581781926E+00  1.3284736587E+01  2.9090505045E+0
       1   1.3346128427E+03 -6.4780880073E+01  1.6367502247E+01  2.8018282294E+0
```

- ***the idea is to generate events for production and decay process and connect them together into LHE file***

Events generation with CalcHEP

```
~/proj/intro_to_hep_tools/calc_work_2.5.4/pp_wbb_ckm1>
../bin/subproc_cycle 1000 1000
#Subprocess 1 ( u, D -> W+, b, B ) Cross section = 9.7505E+00 , 1000 events
#Subprocess 2 ( U, d -> W-, b, B ) Cross section = 5.5019E+00 , 1000 events
#Subprocess 3 ( d, U -> W-, b, B ) Cross section = 5.5315E+00 , 1000 events
#Subprocess 4 ( D, u -> W+, b, B ) Cross section = 9.7105E+00 , 1000 events
#Subprocess 5 ( s, C -> W-, b, B ) Cross section = 1.5902E+00 , 1000 events
#Subprocess 6 ( S, c -> W+, b, B ) Cross section = 1.3525E+00 , 1000 events
#Subprocess 7 ( c, S -> W+, b, B ) Cross section = 1.3425E+00 , 1000 events
#Subprocess 8 ( C, s -> W-, b, B ) Cross section = 1.5716E+00 , 1000 events
Sum of distributions is stored in file distr_34_41
Total Cross Section 36.3512 [pb]

~/proj/intro_to_hep_tools/calc_work_2.5.4/w_decay>
../bin/subproc_cycle 1000
width(W+)=0.67001
#Subprocess 1 ( W+ -> E, ne ) width=2.2339E-01 Br=0.3334129341 Nevents= 334
#Subprocess 2 ( W+ -> M, nm ) width=2.2339E-01 Br=0.3334129341 Nevents= 334
#Subprocess 3 ( W+ -> L, nl ) width=2.2323E-01 Br=0.3331741317 Nevents= 334
width(W-)=0.67001
#Subprocess 4 ( W- -> e, Ne ) width=2.2339E-01 Br=0.3334129341 Nevents= 334
#Subprocess 5 ( W- -> m, Nm ) width=2.2339E-01 Br=0.3334129341 Nevents= 334
#Subprocess 6 ( W- -> l, Nl ) width=2.2323E-01 Br=0.3331741317 Nevents= 334
```

- Dirs are accessible at

http://www.hep.phys.soton.ac.uk/~belyaev/proj/intro_to_hep_tools/

Events generation with CalcHEP

- **bin/event_mixer** ***nevents event_dirs***

mixes subprocesses and connects scattering and decay events

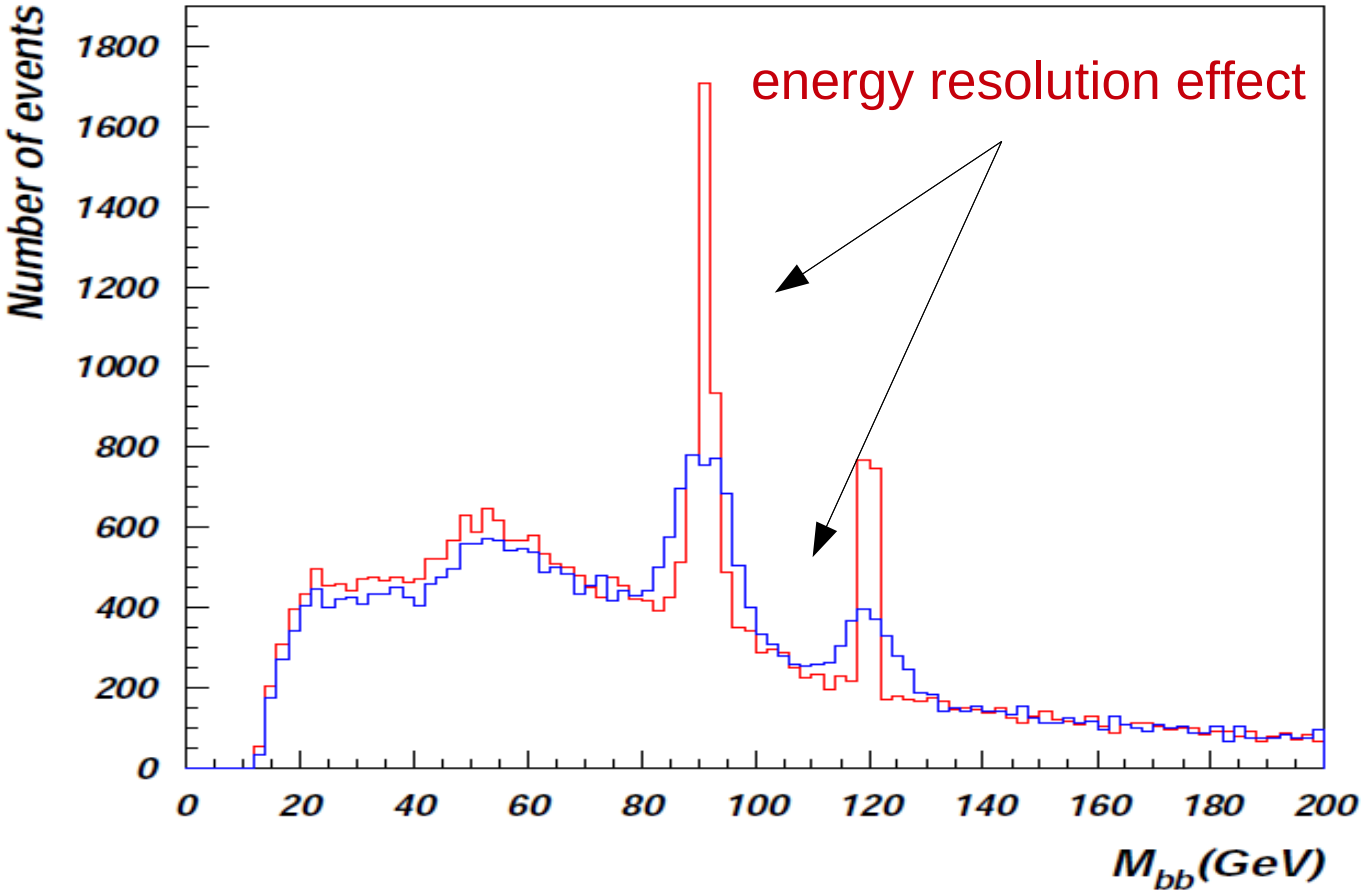
```
bin/event_mixer 1000 pp_wbb_ckm1 w_decay
total cross section 1.166E+01
Max number of events 3728
```

- ***the output is*** **event_mixer.lhe** ***file***

```
<LesHouchesEvents version="1.0">
<!--
File generated with CalcHEP-PYTHIA interface
-->
<header>
<slha>
</slha>
</header>
<init>
  2212  2212  7.00000006860E+03  7.00000006860E+03    -1    -1    -1    -1     3     1
  1.16593335502E+01  0.00000000000E+00  1.00000000000E+00   1
</init>
<event>
 7    1   1.0000000E+00   2.8420000E+02  -1.0000000E+00  -1.0000000E+00
       -3   -1    0    0    0  501  0.00000000000E+00  0.00000000000E+00  1.54424456520E+02
        4   -1    0    0  500    0  0.00000000000E+00  0.00000000000E+00 -1.30792414700E+02
       24    2    1    2    0    0 -9.99292465447E+01 -1.63668803915E+01 -6.48692987742E+01
        5    1    1    2  500    0  7.34149473360E+01  2.15593961832E+01  4.23390519202E+01
       -5    1    1    2    0  501  2.65142992097E+01 -5.19251579179E+00  4.61622886720E+01
      -11    1    3    3    0    0 -7.19345413730E+01  7.47572186340E-01 -8.03452022142E+01
       12    1    3    3    0    0 -2.79947051718E+01 -1.71144525779E+01  1.54759034400E+01
</event>
```

What do we do with LHE file?

- *one of the options is to convert LHE file into ntuple and use* **PAW/Root** *packages to perform event analysis at the parton level*
- bin/nt_maker event_mixer.lhe → produces event_mixer_1.nt
- cd paw ; pawX11 ; exe dubna.kumac




```
      SUBROUTINE SMEAR(P,I, DELTA)
      REAL P(4,*) , mass
      PI=ACOS(-1.)

      EI=P(4,I)

      RGEN1=SQRT(-2.*ALOG(RNDM()))
      RGEN2=2.*PI*RNDM()
      R1=RGEN1*COS(RGEN2)

c DELTA=0.15 for EM
c DELTA=0.5  for HAD

      EIP=(1.+ DELTA/sqrt(EI)*R1)
      DO J=1,4
         P(J,I)=P(J,I)*EIP
      ENDDO

      RETURN
      END
```

CalcHEP batch interface: results from CalcHEP in one shot

- calchep_batch batch_file

```
calchep_batch batch_file
Progress information can be found in the html directory.
Simply open the following link in your browser:
file:///home/belyaev/proj/intro_to_hep_tools/calc_work_2.5.4/html/index.html
```

Main Features

- Batch file
- Process library
- Runs
- Combines decays
- Parallelization
- HTML progress

batch_file

```
Model:          Standard Model(CKM=1)
Model changed: False
Gauge:          Feynman
```

```
Process:    p,p->W,b,B
Decay:      W->ll,nn

Composite: p=u,U,d,D,s,S,c,C,b,B,G
Composite: W=W+,W-
Composite: ll=e,E,m,M,l,L
Composite: nn=ne,Ne,nm,Nm,nl,Nl
```

CalcHEP batch interface: results from CalcHEP in one shot

file:///home/belyaev/proj/intro_to_hep_tools/calc_work_2.5.4/html/index.html

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

Thank you for using CalcHEP!
Please cite arXiv:0000.0000

CalcHEP Batch Details

Standard Model(CKM=1)

Done!

	Finished	Time(hr)
Symbolic	14/14	0.00
σ	1/1	0.03
Events	1/1	0.05

CalcHEP batch interface: results from CalcHEP in one shot

file:///home/belyaev/proj/intro_to_hep_tools/calc_work_2.5.4/html/index.html

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Symbolic Sessions

Standard Model(CKM=1)

Processes	Lib	PID	Time(hr)
u,D->W+,b,B	✓		
U,d->W-,b,B	✓		
d,U->W-,b,B	✓		
D,u->W+,b,B	✓		
s,C->W-,b,B	✓		
S,c->W+,b,B	✓		
c,S->W+,b,B	✓		
C,s->W-,b,B	✓		
W+->E,ne	✓		
W+->M,nm	✓		
W+->L,nl	✓		
W-->e,Ne	✓		
W-->m,Nm	✓		
W-->l,Nl	✓		
Widths	✓		

CalcHEP batch interface: results from CalcHEP in one shot

file:///home/belyaev/proj/intro_to_hep_tools/calc_work_2.5.4/html/index.html

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Thank you for using CalcHEP!
Please cite arXiv:0000.0000

Numerical Sessions

Standard Model(CKM=1)

Done!

Runs	σ (fb)	Running	Finished	Time (hr)	N events
Single	12350	0/15	15/15	0.14	50000
				0.14	

CalcHEP batch interface: results from CalcHEP in one shot

file:///home/belyaev/proj/intro_to_hep_tools/calc_work_2.5.4/html/index.html

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Help

Thank you for using CalcHEP!
Please cite arXiv:0000.0000

Standard Model(CKM=1)

Done!

Processes	σ (fb)	PID	Time (hr)	N events	Details
u,D->W+,b,B	10047	27115	0.02	14910/14910	prt_1 session.dat
U,d->W-,b,B	5636.4	27125	0.01	8364/8364	prt_1 session.dat
d,U->W-,b,B	5567.9	27129	0.01	8263/8263	prt_1 session.dat
D,u->W+,b,B	9850.2	27145	0.02	14618/14618	prt_1 session.dat
s,C->W-,b,B	1609.9	27366	0.01	2389/2389	prt_1 session.dat
S,c->W+,b,B	1359.9	27370	0.01	2018/2018	prt_1 session.dat
c,S->W+,b,B	1374.5	27563	0.01	2039/2039	prt_1 session.dat
C,s->W-,b,B	1614.8	27581	0.01	2396/2396	prt_1 session.dat
Total	37061			54997/54997	

Decays	Γ (GeV)	PID	Time (hr)	N events	Details
W+->E,ne	0.22339	27583	0.01	255000/254999	prt_1 session.dat
W+->M,nm	0.22339	27586	0.01	255000/254999	prt_1 session.dat
W+->L,nl	0.22323	27891	0.01	255000/254999	prt_1 session.dat
W-->e,Ne	0.22339	27893	0.01	255000/254999	prt_1 session.dat
W-->m,Nm	0.22339	27896	0.01	255000/254999	prt_1 session.dat
W-->l,Nl	0.22323	27905	0.01	255000/254999	prt_1 session.dat

Widths		PID	Time (hr)		Details
Widths		28254	0.01		session.dat
Total	12350		0.14		

CalcHEP batch interface: results from CalcHEP in one shot

file:///home/belyaev/proj/intro_to_hep_tools/calc_work_2.5.4/html/index.html

Home
Symbolic Results
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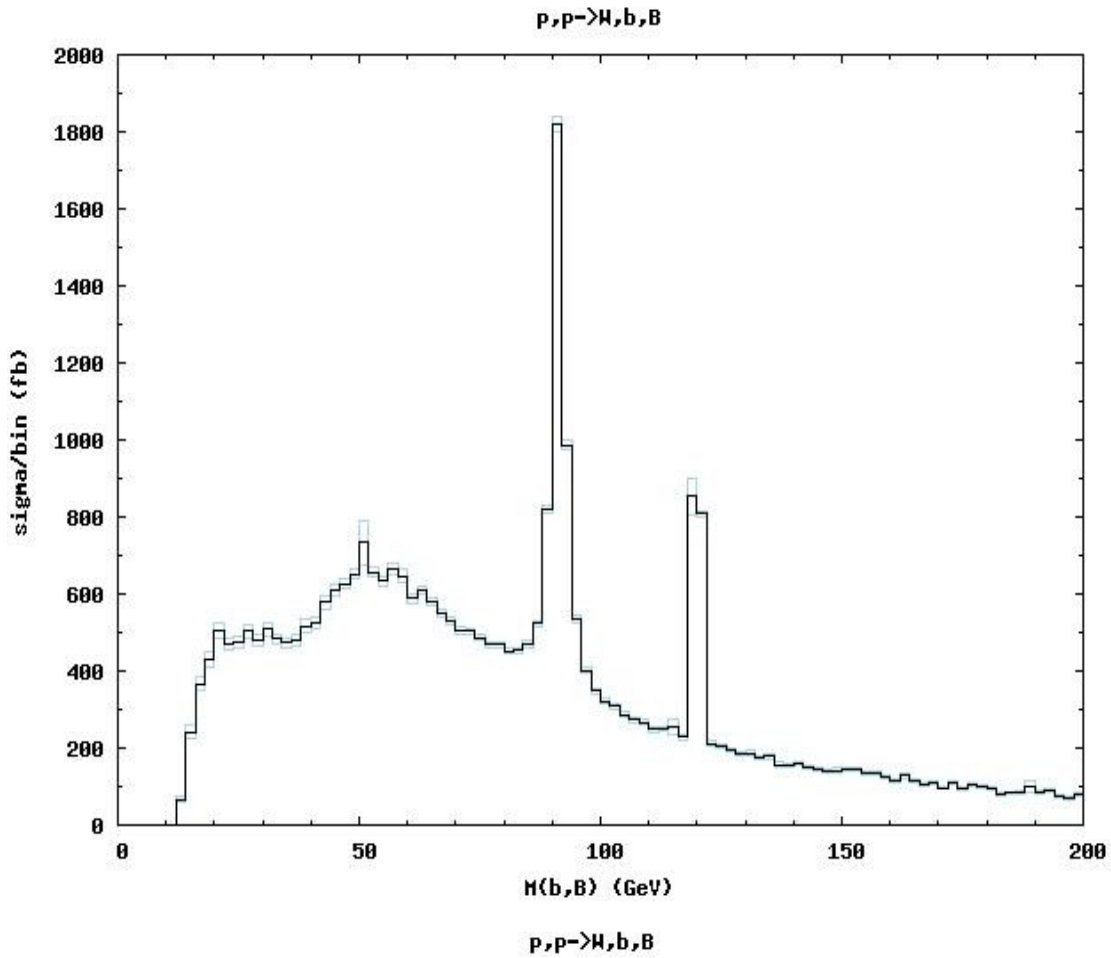
Thank you for using CalcHEP!
Please cite arXiv:0000.0000

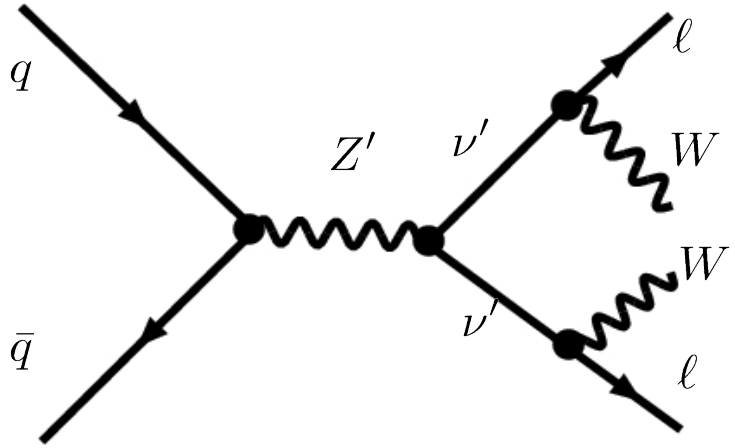
Distributions

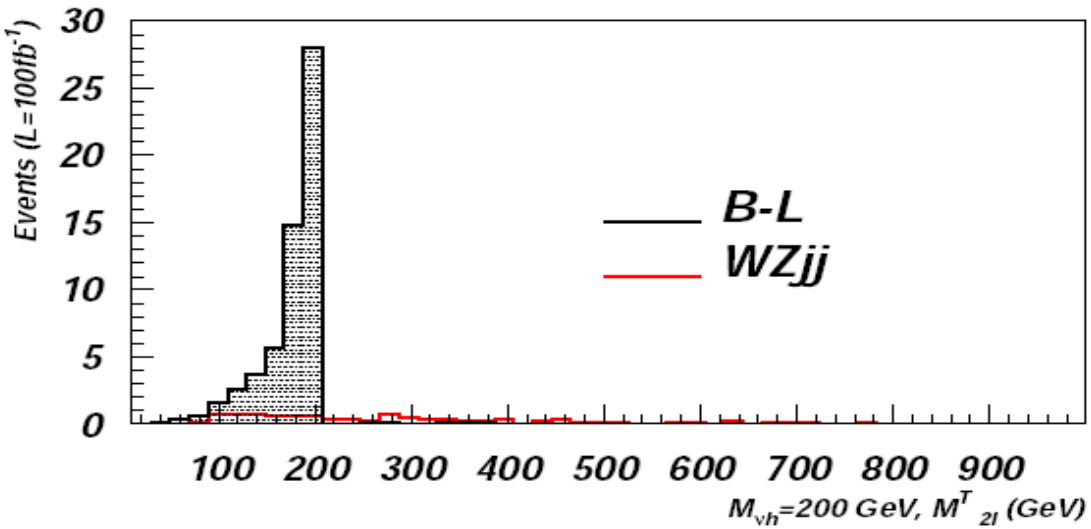


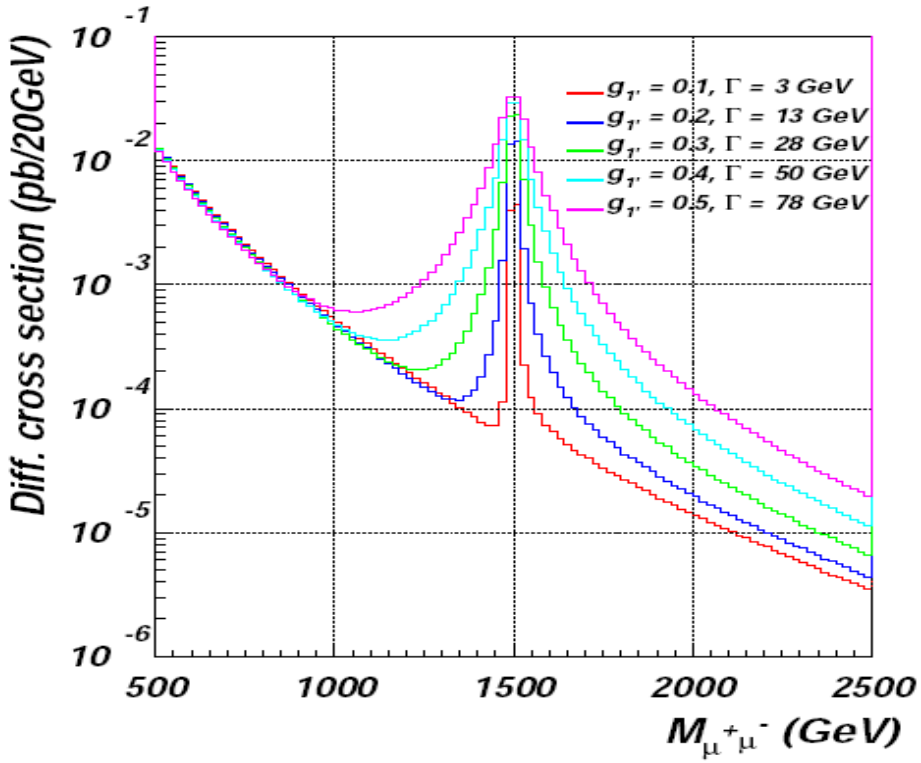
Applications: B-L extension of SM

Extra U(1)' : Z', heavy long leaving neutrino

(in collaboration with S. Moretti, L. Basso, C. Shepherd)





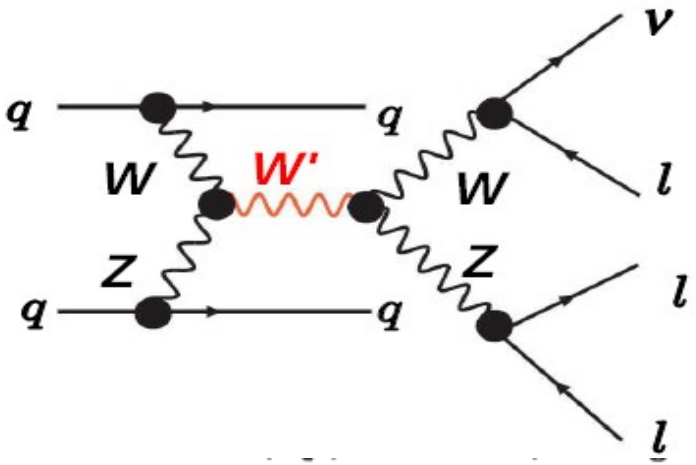


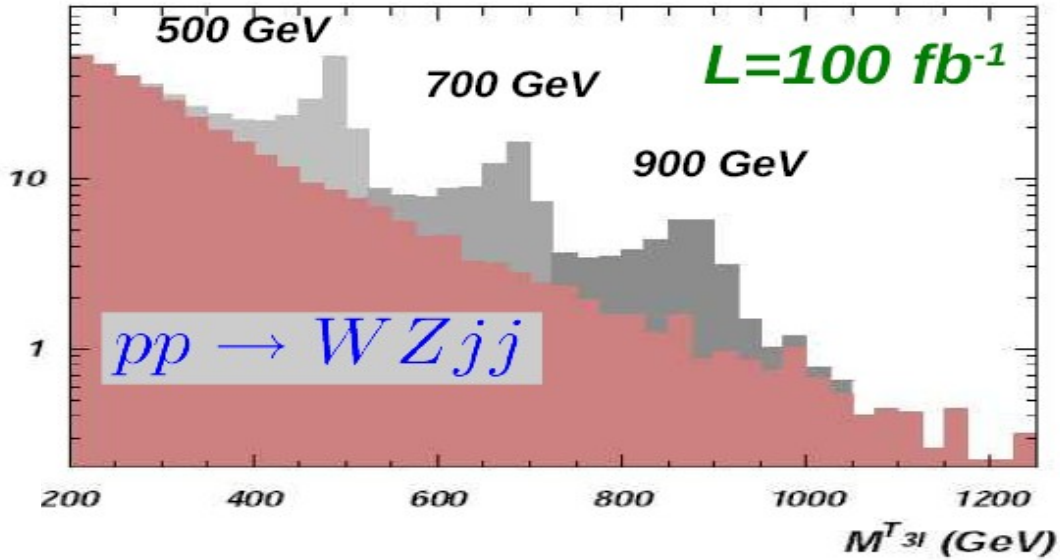
Applications: W' 3-lepton signatures from 3-site Higgsless model

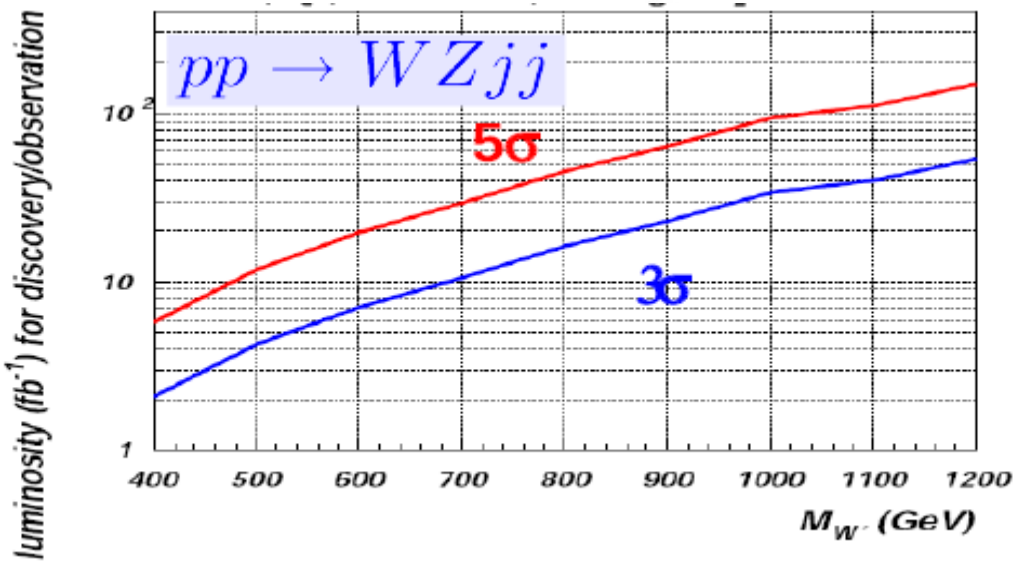
- **CMS: W' 3-lepton signatures from 3-site Higgsless model**

LHC reach for WZ->W' process

[AB, Chivukula, Christensen, He, Kuang, Pukhov, Qi, Simmons, Zhang '07]







Applications: Dark matter relic density – IsaRed and MicorMegas

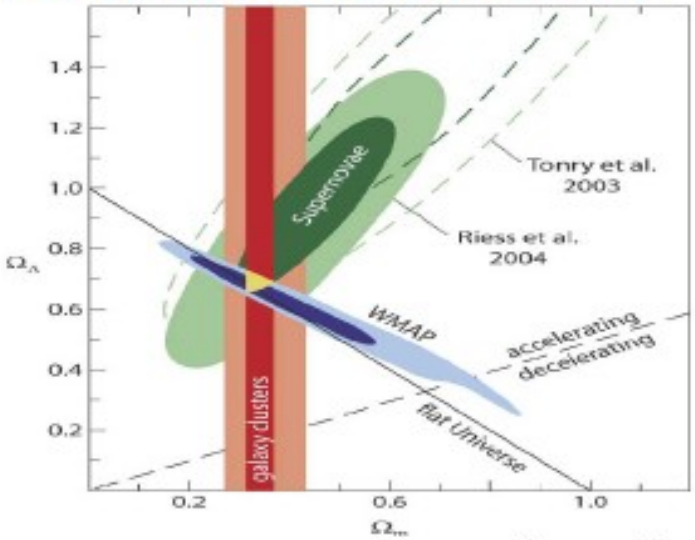
Crucial constraint from Cosmology: DM candidate should be heavy, neutral, stable, non-baryonic Dark Matter candidate

$$\Omega = \Omega_m + \Omega_\Lambda = \rho_{tot}/\rho_{crit} \simeq 1$$

Baryons: 4%± 0.4%

Dark Matter: 23%±4%

Dark Energy: 73%± 4%



Evolution of neutralino relic density

- *Challenge is to evaluate thousands annihilation/co-annihilation diagrams*

relic density depends crucially on $\langle \sigma_A v \rangle$

thermal equilibrium stage: $T > m_\chi, \quad \chi\chi \leftrightarrow f\bar{f}$

universe cools: $T \lesssim m_\chi, \quad \chi\chi \not\to f\bar{f}$, $n = n_{eq} \sim e^{-m/T}$

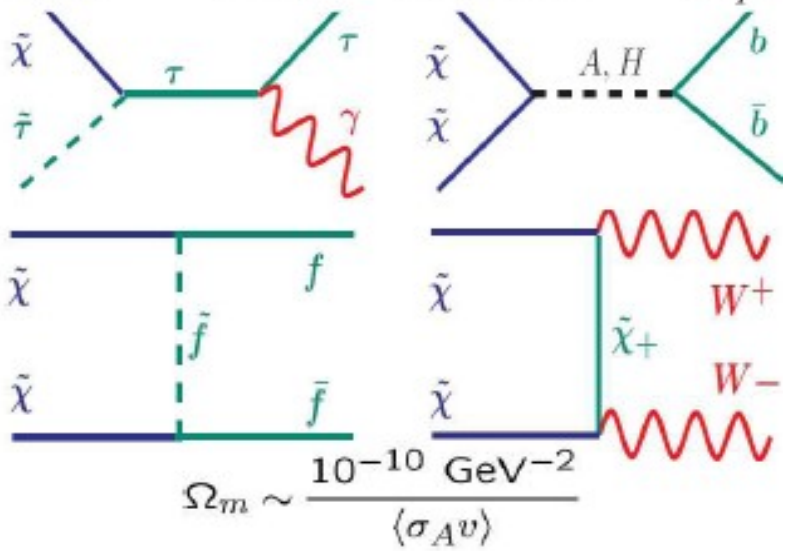
neutralinos "freeze-out" at $T_F \sim m/25$

- *ISARED code: complete set of processes*

Baer, A.B., Balazs '02

exact tree-level calculations using CompHEP

$$dn/dt = -3Hn - \langle \sigma_A v \rangle (n^2 - n_{eq}^2)$$



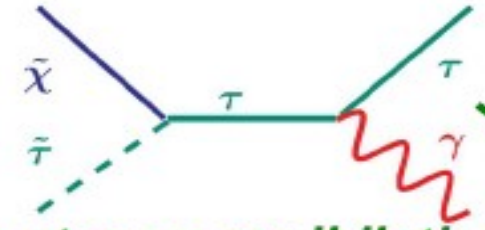
$$\Omega_m \sim \frac{10^{-10}\ \mathrm{GeV}^{-2}}{\langle \sigma_A v \rangle}$$

Applications: Dark matter relic density – IsaRed and MicorMegas

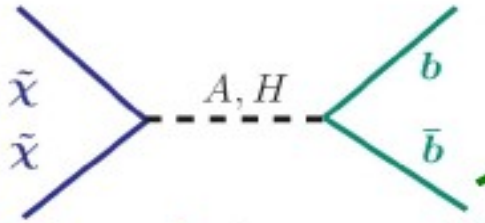
Neutralino relic density in mSUGRA

most of the parameter space is ruled out! $\Omega h^2 \gg 1$

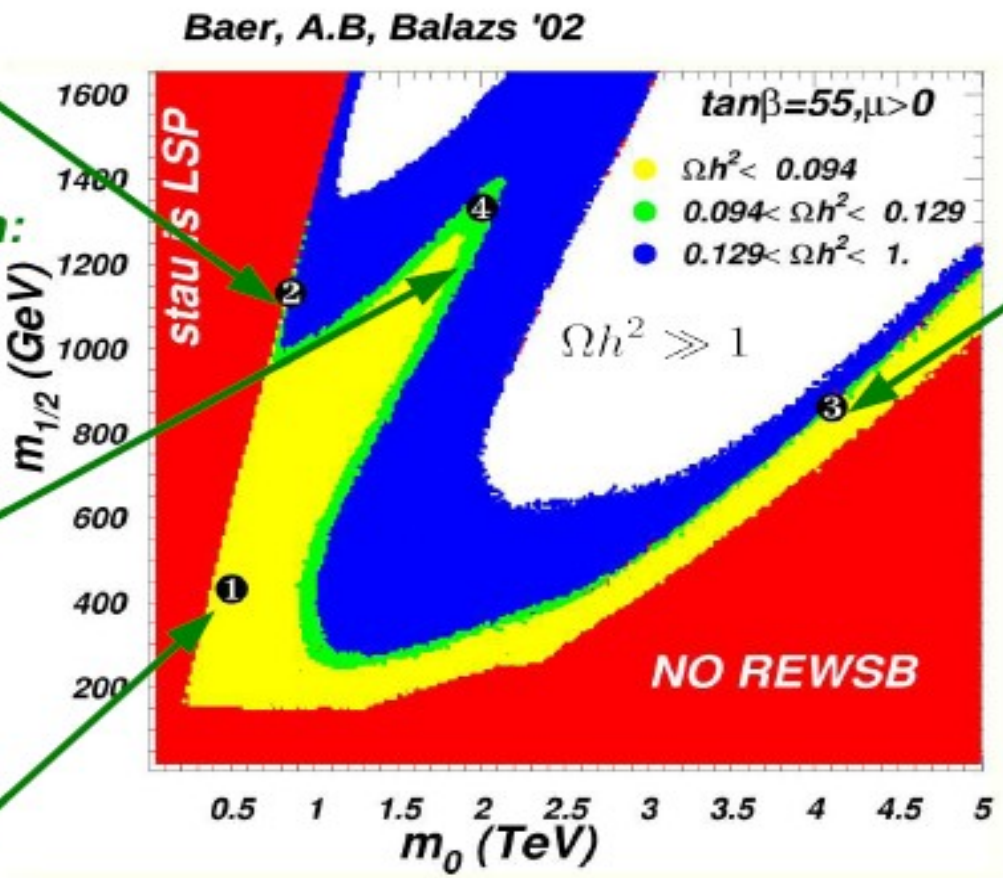
special regions with high σ_A ***are required to get*** $0.094 < \Omega h^2 < 0.129$



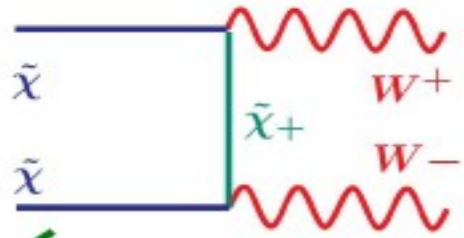
2. stau coannihilation:
degenerate χ and stau



4. funnel: (large tanβ)
annihilation via A, H



1. bulk region: light sfermions

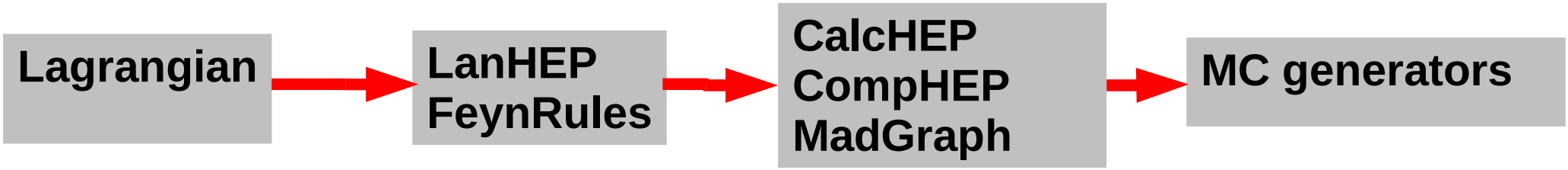


3. focus point:
mixed neutralino,
low μ, importance of
higgsino-wino
component

$\mu^2 + M_Z^2/2 \approx -\varepsilon m_0^2 + 2m_{1/2}^2$

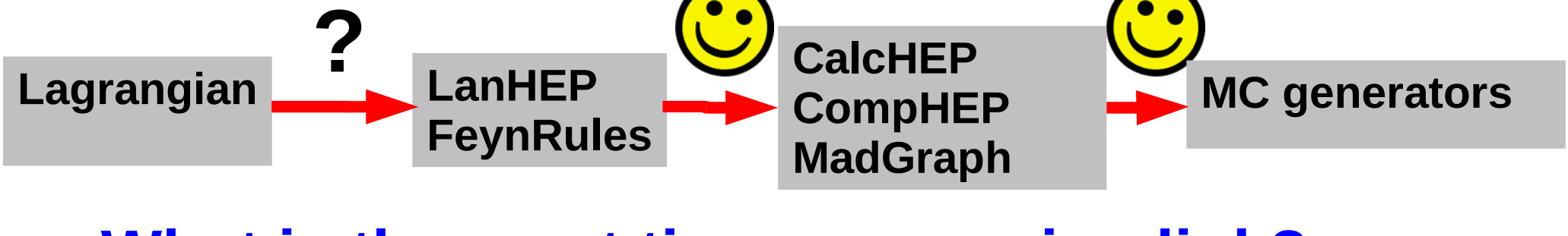
additional regions:
Z/h annihilation
stop coannihilation

We have powerful tools in one chain!



What is the most time consuming link?

We have powerful tools in one chain!



What is the most time consuming link?

CalcHEP 2.5:recap of important new features

- ***automatic witdh calculation ("on the fly")***

```
Z prime boson|~Z  |~Z  |        0|2      |MZP    |!wZP   |1      |G   |Z'
W prime boson|~W+|~W-|        0|2      |MWP    |!wWP   |1      |G   |W'+
```

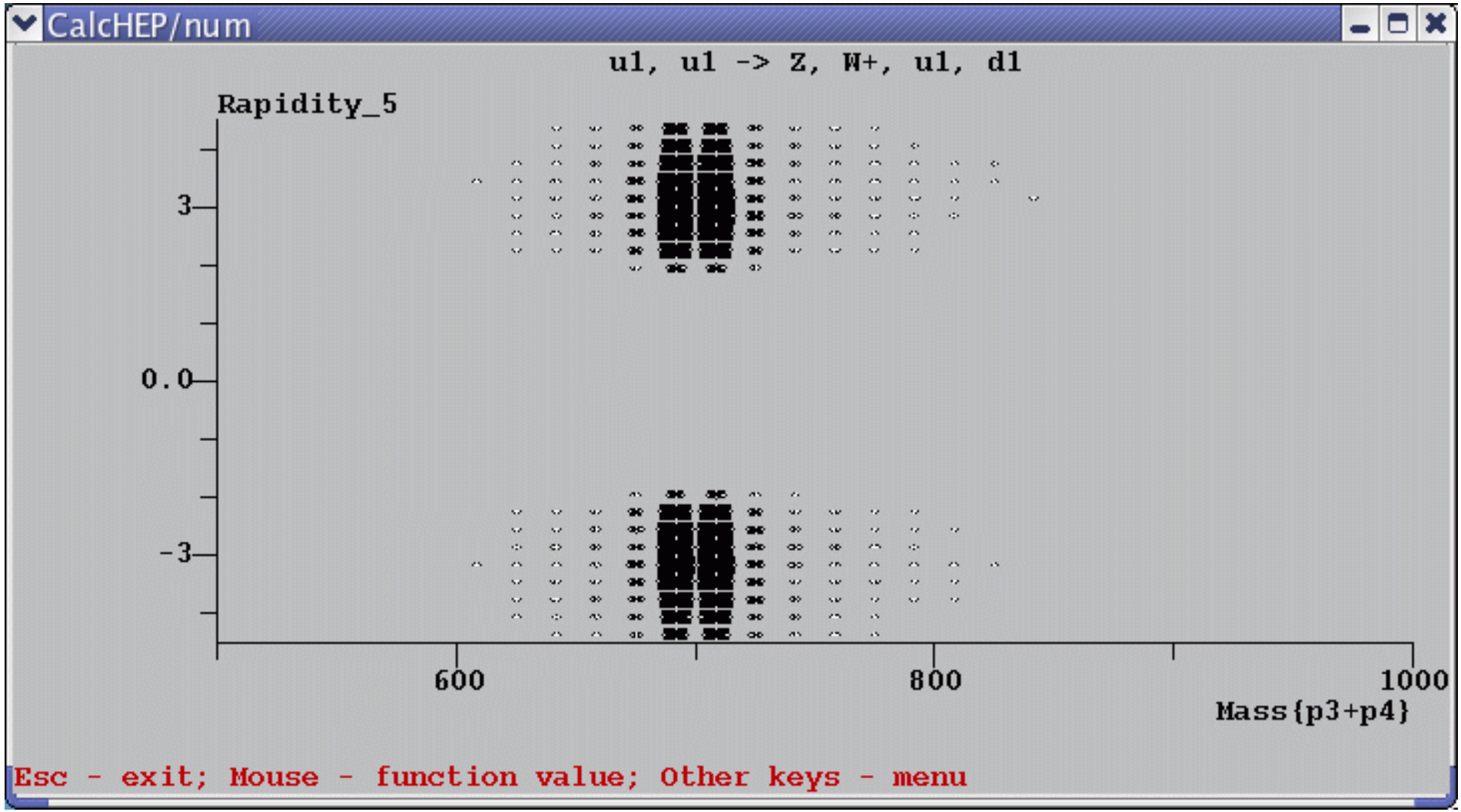
- ***polarized beams:*** $E\%, e\% \rightarrow 2 * x \quad or \quad A\%, A\% \rightarrow 2 * x$
- ***ppin 3/2 and spin 2 massive particles are available in CalcHEP now***
- ***2d distributions***
- ***PAW and Gnuplot for plots***

```
#--- GNUPLOT section ---
#GNUPLOT set title  'E,e ->m,M'
#GNUPLOT set xlabel 'cos(p1,p3)'
#GNUPLOT set ylabel 'Diff. cross section [pb]'
#GNUPLOT plot[-1:1] 'plot_1.txt' using (-1 +$0*0.02):1 w l
```

```
#--- PAW section ---
#PAW  TITLE 'E,e ->m,M'
#PAW  vector/Create X1(101)
#PAW  sigma X1=ARRAY(101,-1#1)
#PAW  vector/Create Y1(101)
#PAW  vector/Read Y1 'plot_1.txt' ' ' 'OC
#PAW  GRAPH 101 X1 Y1
```

- ***dynamical linking!***
- ***batch interface***

CalcHEP 2.5: examples of 2d plots



Future plans

- **Including finite width into production-decay connection**

  (done!)
- **Including polarization effects into production-decay chain**
- **kinematical cuts generalization (done!)**
- ***QCD scale definition (leading diagram)***
- ***polarization for massive particles***
- ***database of the models***

Final remarks

- ***Advantages of CalcHEP –***

  easy model implementation, convenient interface, batch mode.

  Ready to be used by wide range of HEP community:

  from model builders to experimentalists!

- ***Read manuals – they have many more details***

- ***Automation tools are powerful but should not be blindly trusted!***