HERWIG Event Generator

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- Recent Additions (Version 6.2)
  - SUSY and Higgs processes
  - Extra dimension physics
- Forthcoming Attractions (Version 6.3)
  - New gauge and Higgs boson processes
  - Negative weights option
- Future Plans & Conclusions

http://hepwww.rl.ac.uk/theory/seymour/herwig/

G Corcella, IG Knowles, G Marchesini, S Moretti, K Odagiri,
P Richardson, MH Seymour, BRW, JHEP 0101 (2001) 010

Recent Additions (Version 6.2)

- SUSY 2→ 2 processes
  - Interface to ISAJET for input SUSY spectra & decays
  - R-parity violation allowed
  - No parton showering on spartons

- SM Higgs processes

IPROC	Process
1600+ID	$gg/q\bar{q} \to H^0_{\rm SM}$
1900+ID	$q\bar{q} \to q'\bar{q}'W^+W^-/Z^0Z^0 \to q'\bar{q}'H^0_{\rm SM}$
2500+ID	$gg/q\bar{q} \to t\bar{t}H^0_{\rm SM}$
2600+ID	$q\bar{q}' \to W^\pm H^0_{\rm SM}$
2700+ID	$q\bar{q} \to Z^0 H^0_{\rm SM}$

  - ID controls Higgs decay

ID	Decay
1–6	$H^0_{\rm SM} \to q\bar{q}$
7–9	$H^0_{\rm SM} \to \ell\bar{\ell}$
10,11	$H^0_{\rm SM} \to W^+W^-, Z^0Z^0$
12	$H^0_{\rm SM} \to \gamma\gamma$
99	$H^0_{\rm SM} \to$ anything

- MSSM Higgs processes

IPROC	Process
3310,3315	$q\bar{q}' \to W^{\pm}h^0, H^{\pm}h^0$
3320,3325	$q\bar{q}' \to W^{\pm}H^0, H^{\pm}H^0$
3335	$q\bar{q}' \to H^{\pm}A^0$
3350	$q\bar{q} \to W^{\pm}H^{\mp}$
3355	$q\bar{q} \to H^{\pm}H^{\mp}$
3360,3365	$q\bar{q} \to Z^0h^0, A^0h^0$
3370,3375	$q\bar{q} \to Z^0H^0, A^0H^0$
3410	$bg \to b\ h^0$ + ch. conj.
3420	$bg \to b\ H^0$ + ch. conj.
3430	$bg \to b\ A^0$ + ch. conj.
3450	$bg \to t\ H^-$ + ch. conj.
3610	$q\bar{q}/gg \to h^0$
3620	$q\bar{q}/gg \to H^0$
3630	$q\bar{q}/gg \to A^0$

- Extra dimension physics: graviton resonance production

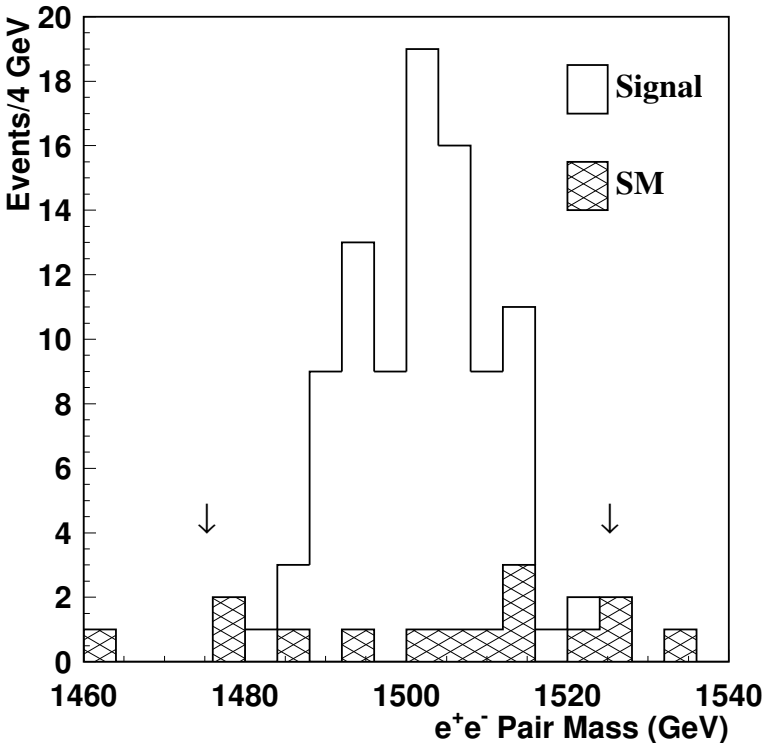
IPROC	Process
4210	$gg/q\bar{q} \to G \to gg/q\bar{q}$ (all partons)
4210+IQ	$gg/q\bar{q} \to G \to q\bar{q}$ (IQ for q flavour)
4220	$gg/q\bar{q} \to G \to gg$
4250	$gg/q\bar{q} \to G \to \ell\bar{\ell}$ (all leptons)
4250+IL	$gg/q\bar{q} \to G \to \ell\bar{\ell}$ (IL for ℓ flavour)
4260	$gg/q\bar{q} \to G \to \gamma\gamma$
4270	$gg/q\bar{q} \to G \to W^+W^-/Z^0Z^0/H^0_{\rm SM}H^0_{\rm SM}$
4271	$gg/q\bar{q} \to G \to W^+W^-$
4272	$gg/q\bar{q} \to G \to Z^0Z^0$
4273	$gg/q\bar{q} \to G \to H^0_{\rm SM}H^0_{\rm SM}$

Searching for Graviton Resonances at LHC

BC Allanach, K Odagiri, MA Parker & BRW, JHEP 0009(2000)019

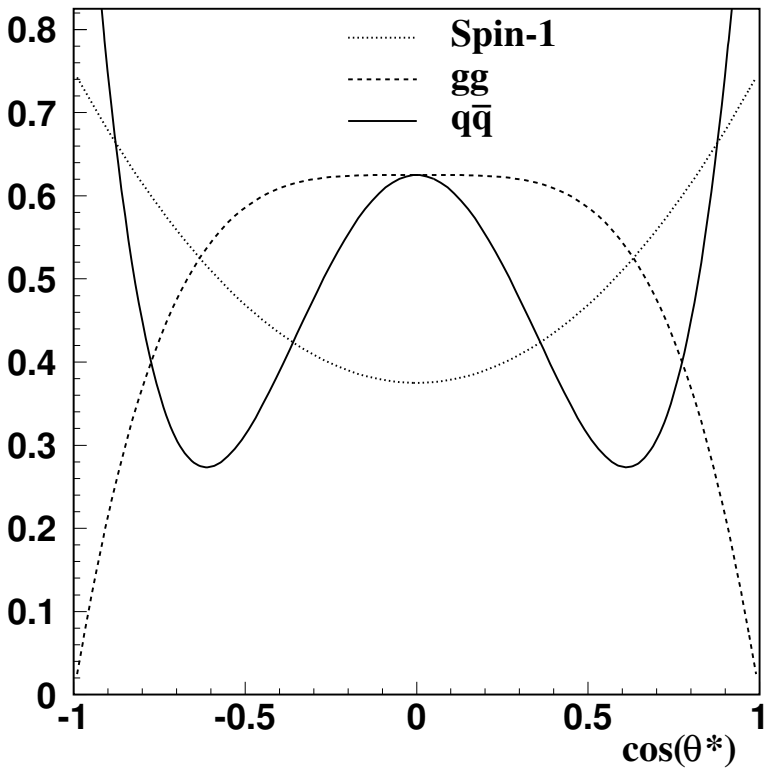
- In non-factorisable geometry (Randall-Sundrum) models there may be narrow graviton excitations G with TeV-scale masses.

- $G \to e^+e^-$ is a good mode to study:

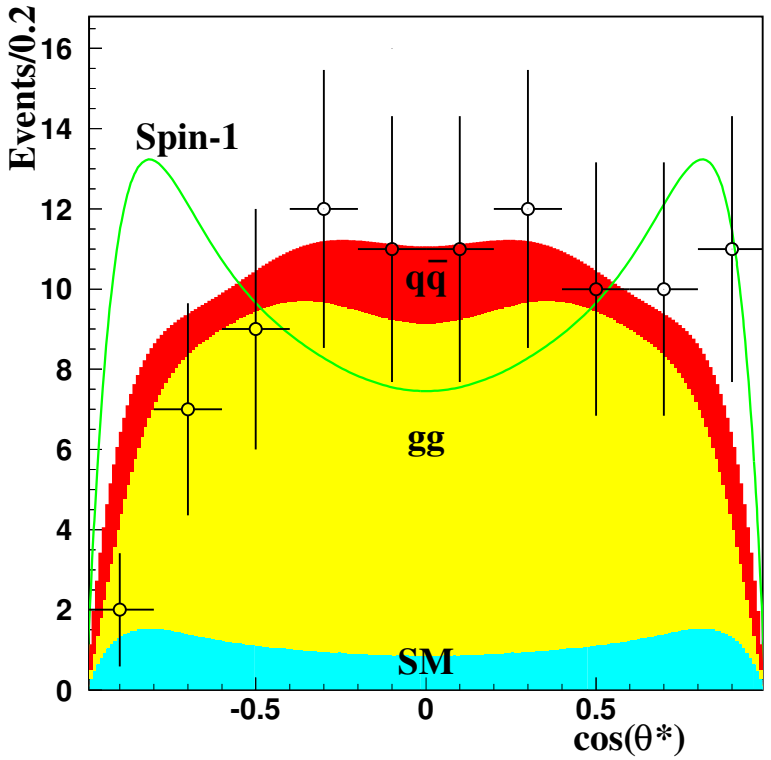


- Observed width $\gg \Gamma_G \sim 200$ MeV, due to detector effects.

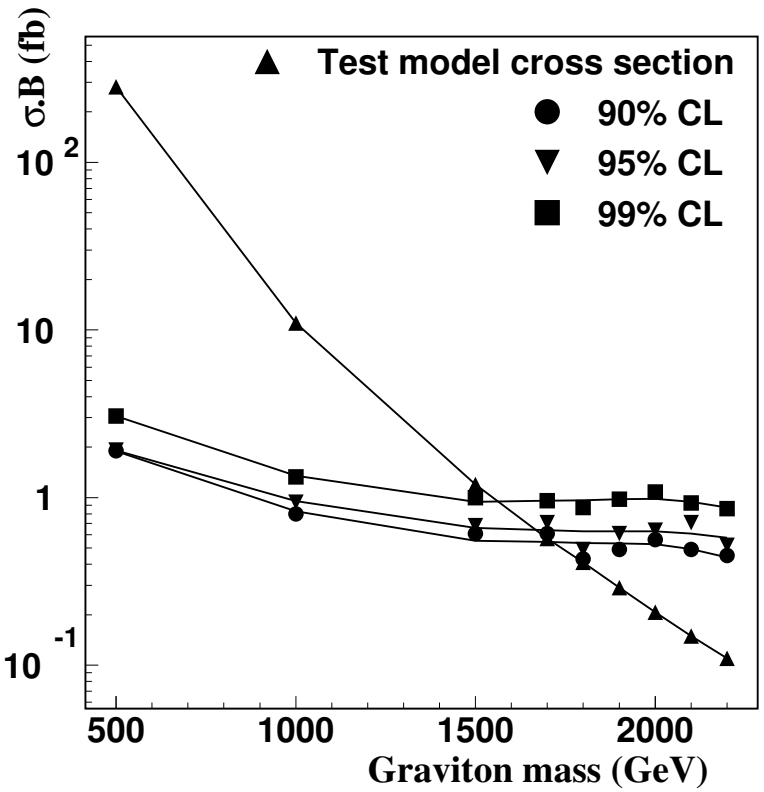
- $q\bar{q} \to G$ and $gg \to G$ give characteristic angular distributions:



- After full simulation (including ATLAS detector):



- Can be identified as spin-2 up to > 1500 GeV:



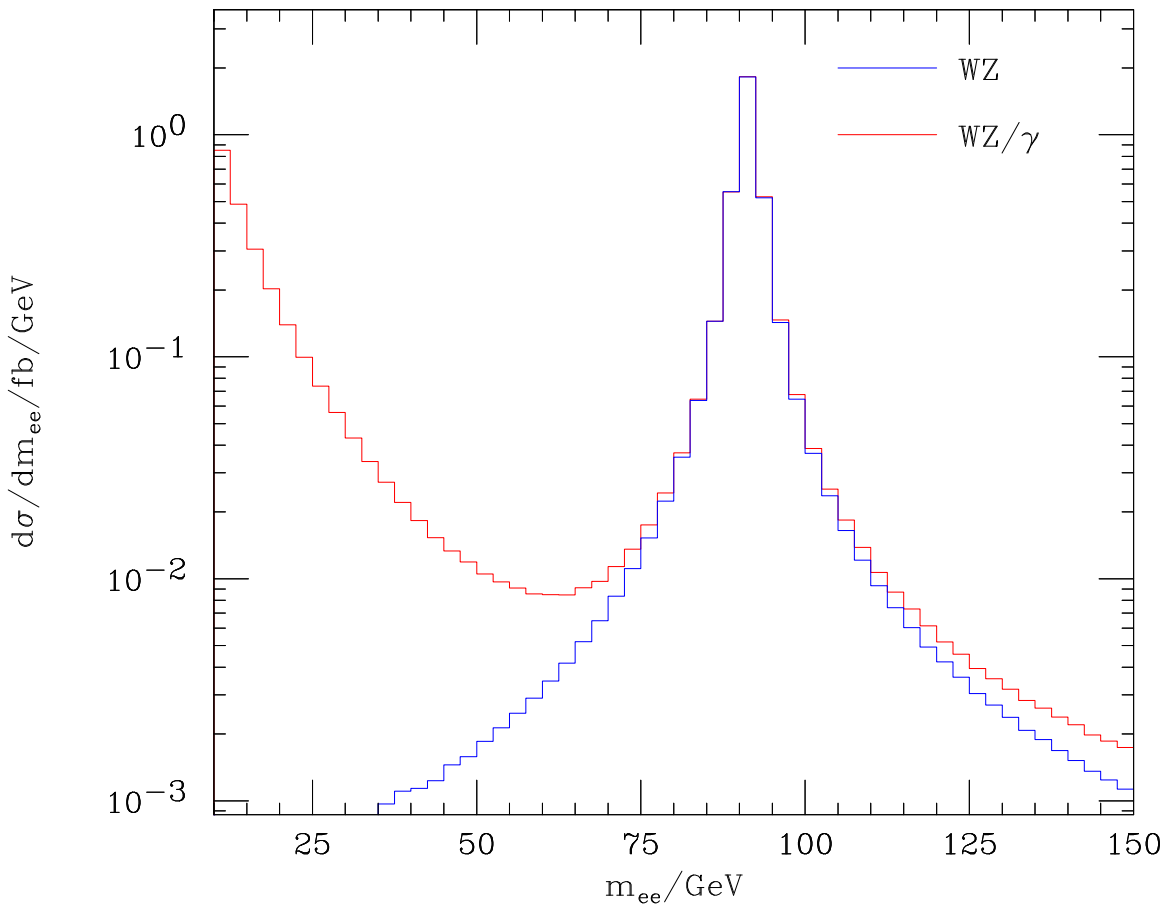
- Other modes can be checked for universality: $\mu^+\mu^-$, $\gamma\gamma$, W^+W^-, . . .

- Tevatron limit?

Forthcoming Attractions (Version 6.3)

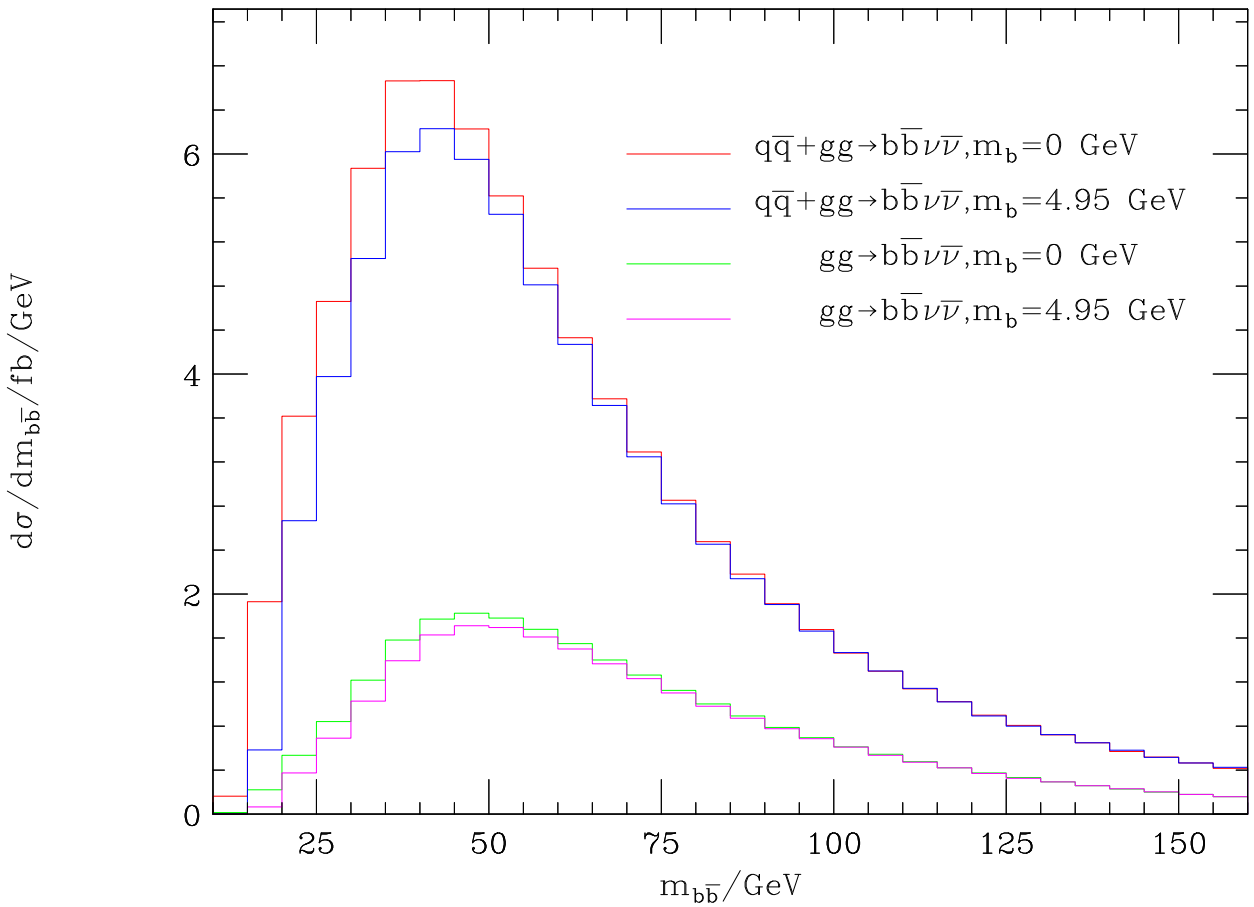
- SM gauge diboson production

IPROC	Process
2800	$q\bar{q} \to WW$
2810	$q\bar{q} \to ZZ$ (including γ^*)
2815	$q\bar{q} \to ZZ$ (Z only)
2820	$q\bar{q} \to WZ$ (including γ^*)
2825	$q\bar{q} \to WZ$ (Z only)



- SM gauge boson + $Q\bar{Q}$ production

IPROC	Process
2900+IQ	$gg/q\bar{q} \to Q\bar{Q}Z$ (IQ for Q flavour, massless)
2910+IQ	$gg/q\bar{q} \to Q\bar{Q}Z$ (", massive)



- Fuller coverage of MSSM Higgs production

IPROC	Process
3100+ISQ	$gg/q\bar{q} \to \tilde{q}\tilde{q}'^{*}H^{\pm}$
3200+ISQ	$gg/q\bar{q} \to \tilde{q}\tilde{q}'^{*}h, H, A$
3500	$bq \to bq'H^{\pm}$ + ch. conj.
3710	$q\bar{q} \to q'\bar{q}'h$
3720	$q\bar{q} \to q'\bar{q}'H$
3810+IQ	$gg + q\bar{q} \to Q\bar{Q}h$ (IQ for Q flavour)
3820+IQ	$gg + q\bar{q} \to Q\bar{Q}H$ (")
3830+IQ	$gg + q\bar{q} \to Q\bar{Q}A$ (")
3839	$gg + q\bar{q} \to b\bar{t}H^{+}$ + ch. conjg.
3840+IQ	$gg \to Q\bar{Q}h$ (IQ as above)
3850+IQ	$gg \to Q\bar{Q}H$ (")
3860+IQ	$gg \to Q\bar{Q}A$ (")
3869	$gg \to b\bar{t}H^{+}$ + ch. conjg.
3870+IQ	$q\bar{q} \to Q\bar{Q}h$ (IQ as above)
3880+IQ	$q\bar{q} \to Q\bar{Q}H$ (")
3890+IQ	$q\bar{q} \to Q\bar{Q}A$ (")
3899	$q\bar{q} \to b\bar{t}H^{+}$ + ch. conjg.

- NME $= 200$ gives matrix element for free-particle decay $t \to bH^{+}$. But better to use IPROC $= 3839$, which includes Higgsstrahlung and interference.

Negative Weights Option

- Monte Carlo generates weights

$$\sigma = \frac{1}{N_w} \sum_{i=1}^{N_w} w_i \equiv \overline{w}$$

- Error depends on width of weight distribution

$$\frac{\delta\sigma}{\sigma} = \frac{1}{\sqrt{N_w}} \frac{\delta w_{\text{rms}}}{\overline{w}}$$

- If $w_i > 0$, unweighted events can be generated by 'hit and miss': $w_i' = 0$ or 1 with $P(w_i' = 1) = w_i / w_{\text{max}}$. Then

$$\frac{\delta\sigma}{\sigma} = \sqrt{\frac{w_{\text{max}} - \overline{w}}{N_w \overline{w}}} = \sqrt{\frac{w_{\text{max}} - \overline{w}}{N_e w_{\text{max}}}} \sim \frac{1}{\sqrt{N_e}}$$

where $N_e = N_w \overline{w} / w_{\text{max}}$ is number of events generated. Time needed (especially for detector simulation) depends mainly on number of events. Hence inefficiency of 'hit and miss' is not a disaster.

- Negative weights can be generated by subtraction procedure for matrix element corrections. These are not a problem of principle but prevent naive 'hit and miss'.

- To generalize 'hit and miss', consider generating unweighted events ($w_i' = 1$) and antievents ($w_i' = -1$) with

$$\begin{aligned} \text{sign}(w_i') &= \text{sign}(w_i) \\ P(w_i' = \pm 1) &= |w_i|/|w|_{\text{max}} \end{aligned}$$

- Then

$$\frac{\delta\sigma}{\sigma} = \sqrt{\frac{\overline{|w|}|w|_{\text{max}} - \overline{w}^2}{N_w \overline{w}^2}} \sim \frac{1}{\sqrt{N_e}} \frac{\overline{|w|}}{\overline{w}}$$

  where $N_e = N_w \overline{|w|}/|w|_{\text{max}}$ is now the total number of events+antievents generated.

- Again, time $\propto N_e$, so this is tolerable as long as $\overline{|w|} \sim \overline{w}$.

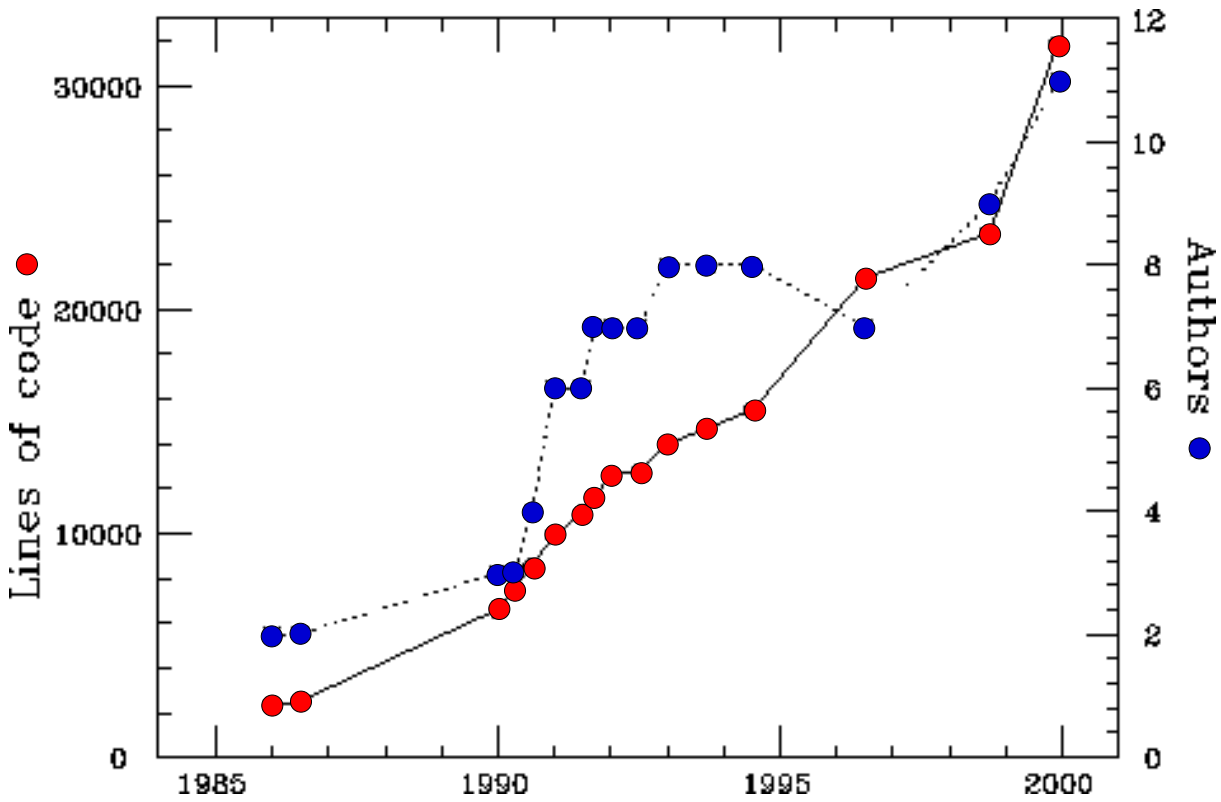
- Cross section after cuts is

$$\sigma_c = \frac{\overline{|w|}}{N_e}(N_+ - N_-)$$

  where N_+ events and N_- antievents pass cuts.

Future Plans

- Program has expanded $\times 10$ over 15 years



- Software maintenance and development becoming impossible (and students don't learn Fortran . . .)

- New Object Oriented Program HERWIG++ under construction

  - Standard class structure and interfaces (CLHEP, PYTHIA7, . . .)
  - New physics (multijets, SUSY showering, . . .)

A Ribon, MH Seymour, AN Other & BRW, 2003?

Conclusions

- HERWIG contains the right perturbative physics to describe wide range of data from LEP and Tevatron (also HERA):
  - Angular ordered parton showers
  - Matrix element corrections
- Non-perturbative physics needs improvements:
  - Heavy flavour hadronization
  - Baryon production
  - Underlying event
- New physics: plenty of scope
  - SUSY, including RPV
  - SM and MSSM Higgs
  - Extra dimensions
- Negative weights option for NLO
- Future: HERWIG++