An efficient multi-parameter new-physics event generator

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Importance of new-physics MC

- New-physics Monte Carlo simulation is essential in particle physics experiment and phenomenology
- It gives us an indication of where new physics may be hiding by connecting theoretical ideas to experimental observables
- It helps us optimize our experimental kinematic selection requirements
- It is used for setting cross-section and mass limits
- In case of discovery, it is used for determining the theory's parameters

Why is new-physics MC generation exceptional?

- ***We do not know the values of the new-physics theoretical parameters !***
- Ordinary MC generators are not ideal for new physics studies, as they assume fixed known parameters (for SM or non-SM physics)
- As a result, the user has to
  - set the parameters to some fixed/arbitrary values
  - run the simulation,
  - change the parameters
  - and repeat **MANY** times

Problem with current event-generators

- Repeating the simulation for several parameters in order to properly cover the parameter-space of a theory is usually prohibiting

- If we have N parameters and we would like K points per parameter, we need to generate N^K samples
  - For mSUGRA with N~4 and K=10, this would mean 20,000 samples!

- Even if we had infinite CPU and disk-space, it would be not efficient to blindly generate MC samples on a N-dimensional evenly spaced grid
  - knowledge of how the parameters affect our cross-section times (BR to particles of interest) times acceptance would help but it is not trivial

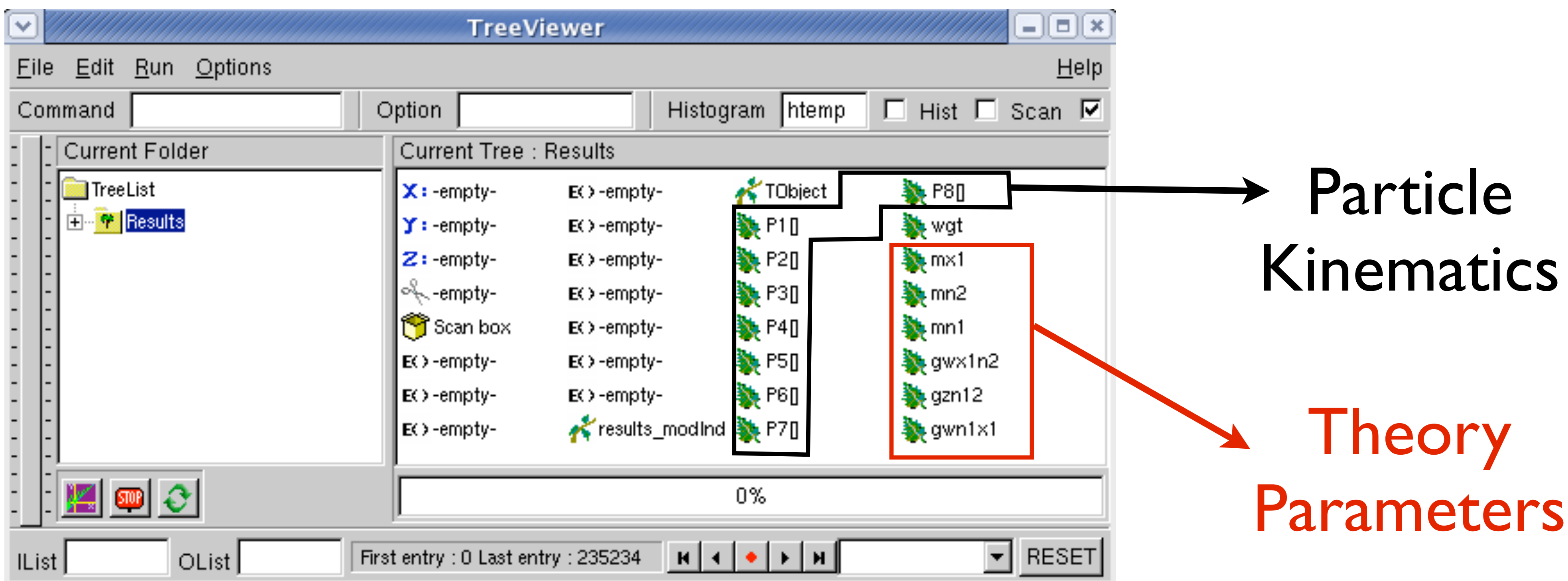
So what do we usually do?

- We very conveniently fix most theory parameters to some arbitrary values and we leave only 1 or 2 parameters free
  - we fix at "benchmark" values that we are very sensitive at (good to set good limits but probably miss a discovery)
  - or we fix at "benchmark" values that other experiments used in the past (to compare -- i.e., to show that <u>our</u> experiment is better)
- We then proceed to use the existing generators to produce samples on a grid in a blind manner
  - i.e., we are inefficient, waste resources and we will most probably miss a discovery or a strong limit somewhere else in the parameter space.

Proposal

- **We propose the use of an adaptive MC generation scheme that allows simultaneous sampling of not only the 4-vectors of the particles, but also the parameters of the theory**

- One MC sample will contain **both** the kinematic variables and the parameters of the theory



The usual adaptive MC scheme for event generation at a hadron collider

$$\sigma = N \int \sum_{q_i, q_j} f_i(x_i, \mu) f_i(x_j, \mu) |\mathcal{M}(\boldsymbol{P_i}, \boldsymbol{P_j}, \boldsymbol{P_{\mathrm{out,k}}})|^2 \delta^4(\boldsymbol{P_i} + \boldsymbol{P_j} - \sum_k \boldsymbol{P_{\mathrm{out,k}}}) \prod_k \frac{\boldsymbol{dP_{\mathrm{out,k}}}}{E_k} \frac{dx_i dx_j}{E_i E_j}$$

- Integrate the matrix element using an adaptive integrator
- The importance sampling enables the generation of 4-vectors at phase-space regions where the cross-section is higher
- This is what nature does as well → You get an event generator

The new-physics adaptive MC scheme for event generation

$$\sigma = N \int \sum_{q_i, q_j} f_i(x_i, \mu) f_i(x_j, \mu) |\mathcal{M}(\boldsymbol{P_i}, \boldsymbol{P_j}, \boldsymbol{P}_{\mathbf{out,k}}, Q_n)|^2 \delta^4(\boldsymbol{P_i} + \boldsymbol{P_j} - \sum_k \boldsymbol{P}_{\mathbf{out,k}}) \prod_k \frac{\boldsymbol{dP}_{\mathbf{out,k}}}{E_k} \frac{dx_i dx_j}{E_i E_j} \prod_n dQ_n$$

- Include the parameters of the theory in the integral
  - This way you sample the parameter space as well, based on its effect on the total cross section
- Integral over parameter space of theory (i.e., integral over universes)
  - landscape theorist would love it
- It has a physical meaning in our universe if we constrain it within a "flat" parameter-space region and divide by the parameter-space hyper-cube volume (get average cross section within a region)

Advantages

- The MC generator will concentrate in regions of the parameter space were the cross-section is higher and our limit-setting or discovery potential much better (assuming known backgrounds)
  - efficient and physics-based generation
- We can have all significant regions of parameter-space in one file
  - efficient use of resources
- We can study all possible correlations between observables and kinematic variables
  - understand our theory and phenomenology
- Possibility of model-independent studies

Advantages (continued)

- We will be more efficient in optimizing our analyses and understanding our sensitivity to new physics
  - same file can be used by different analyses and different parameter-space regions
- We can set multi-dimensional limits
  - limits on different combinations of parameters as well
- And, if we make a discovery, we can easier determine the region of the parameter space that is allowed, given the observation
  - we will have the full range of parameters to investigate
- All the above with only 1 (one!) MC sample per theory and parameter range

But, can it be done?

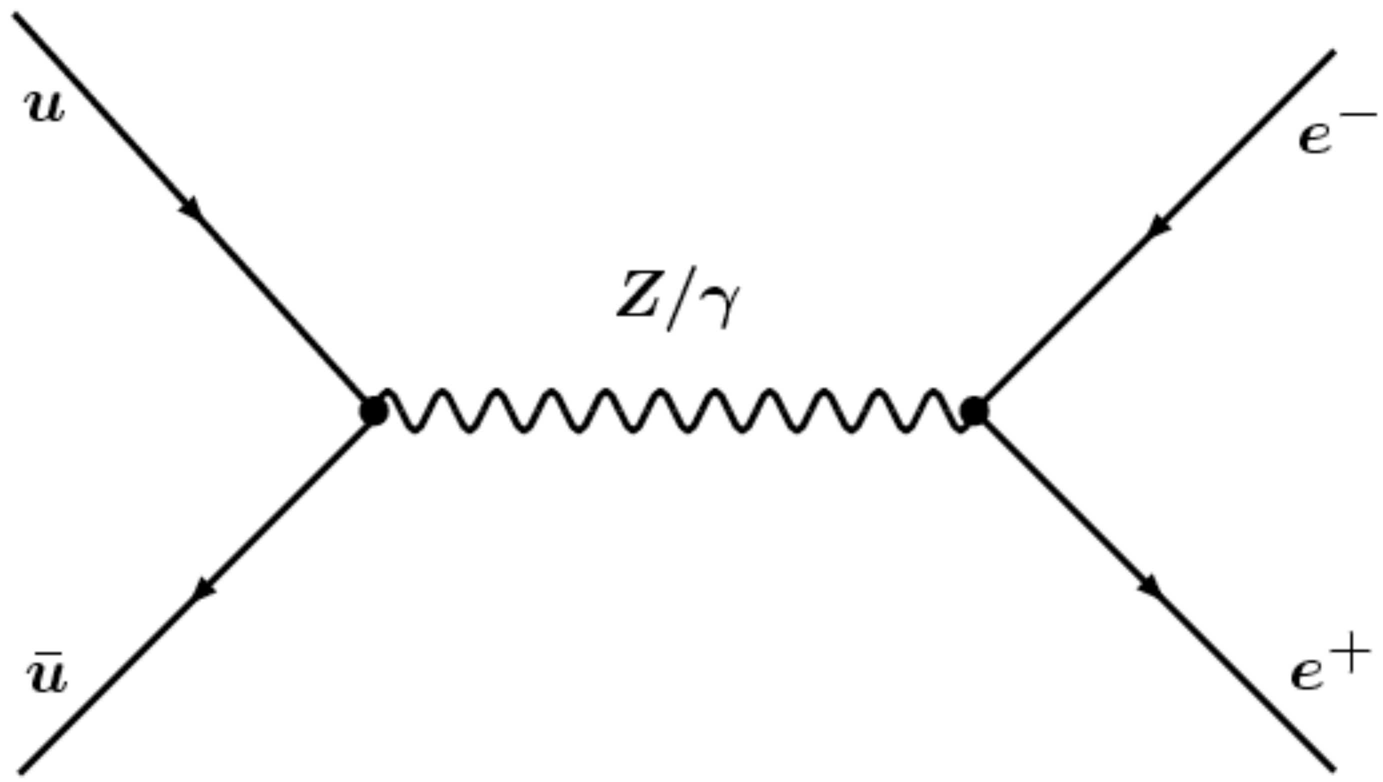
- Usually, the issue with adaptive multi-dimensional integrators is convergence (even for just kinematic integration)
- Can we have convergence if we include the parameters of the theory in the integral?
  - **In other words: can we have convergence when no two events are generated with the same theoretical parameters?**
- In the rest of the talk I will show that it is doable
  - 2→2 processes with 4 free theoretical parameters
  - 2→6 processes with 6 free theoretical parameters

Infrustructure

- Madgraph LO matrix element (using DHELAS for the amplitudes construction and helicity combinations)
- Vegas adaptive MC integration algorithm (optimized for clever random number sampling)
- CERN libraries for PDF (CTEQ5L)
- Tevatron accelerator parameters

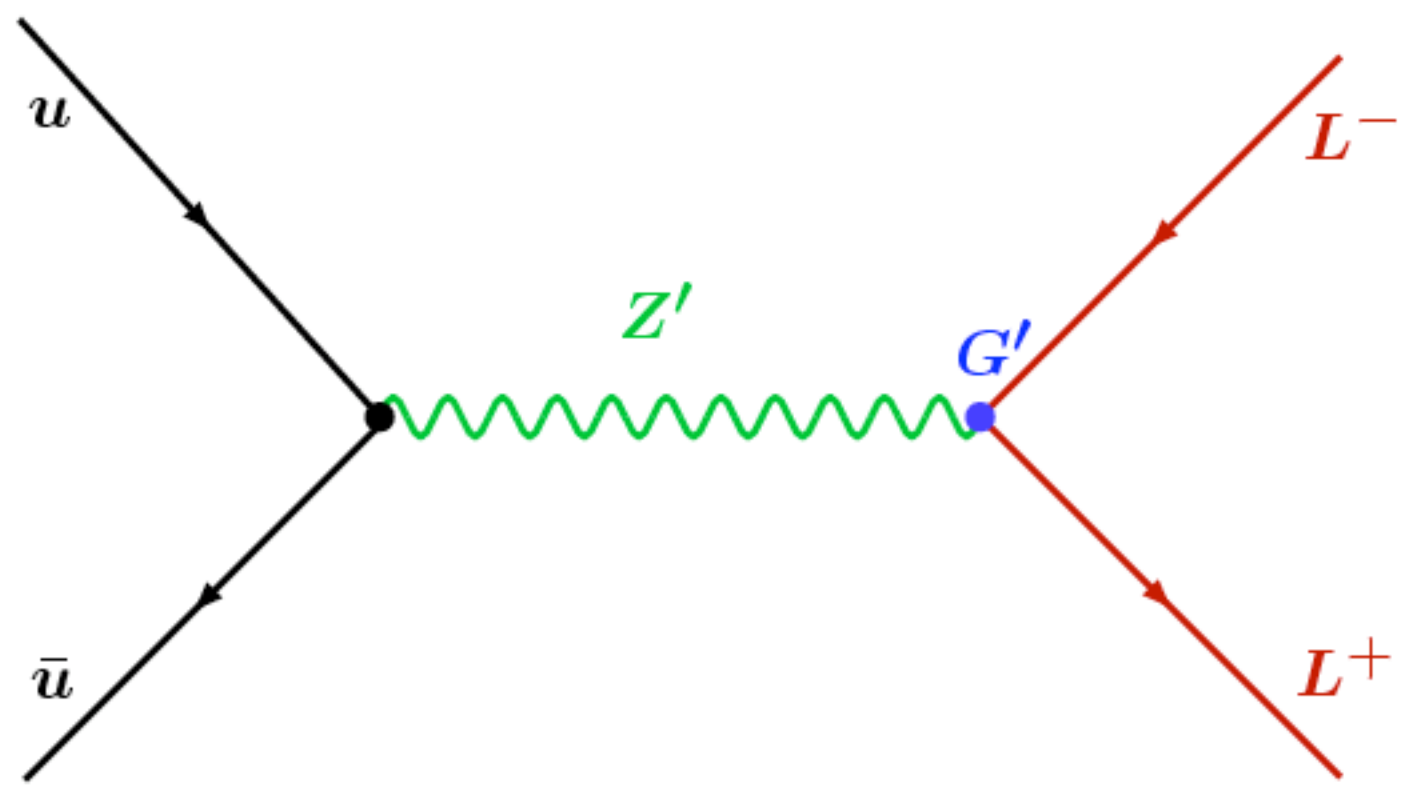
Drell-Yan production

- Take a some-what boring 2→2 process:



New-physics Drell-Yan production

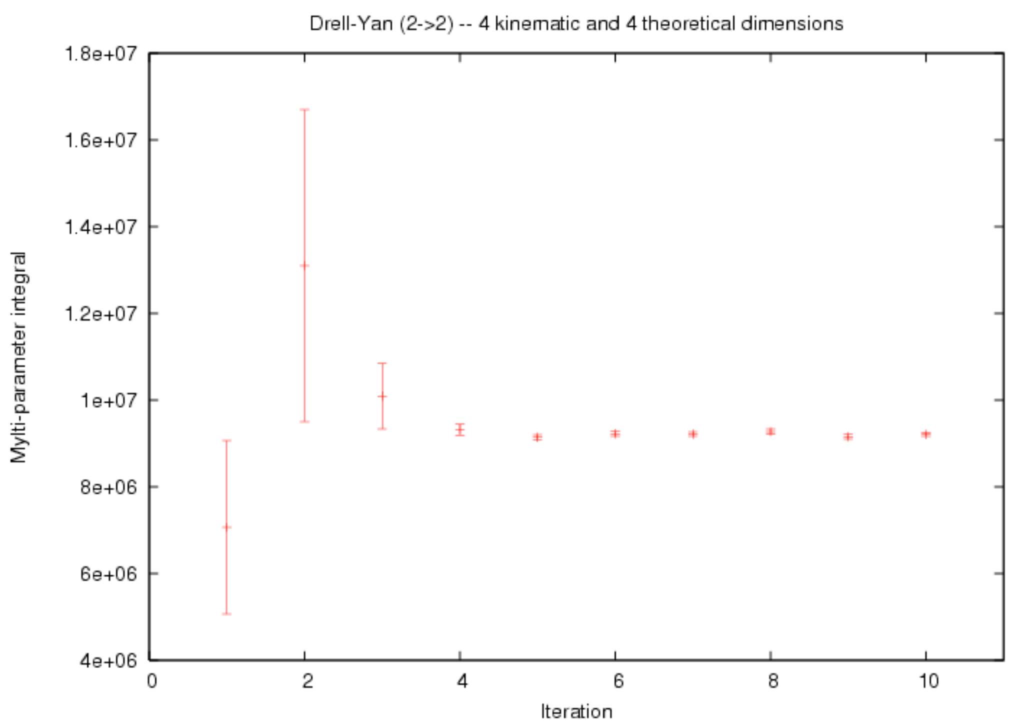
- And start simultaneously varying some SM parameters at the event-generation level (Z and lepton masses, right and left-handed couplings):



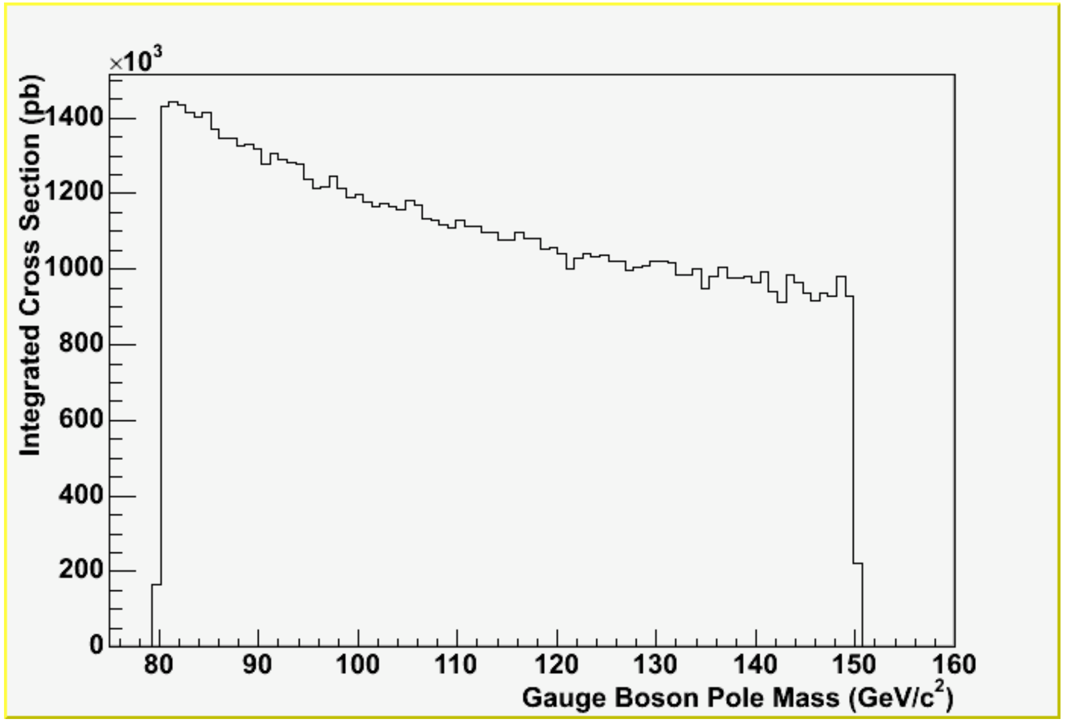
- You can then study Z', anomalous couplings and 4th generation leptons **within the same sample**

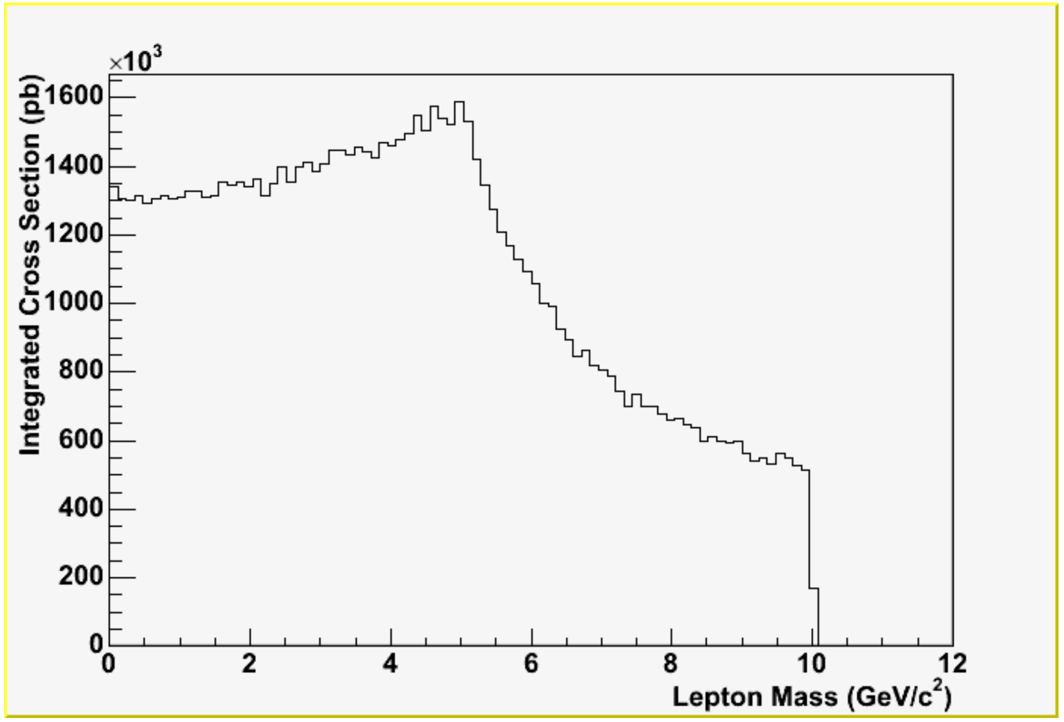
New-physics DY generation parameters

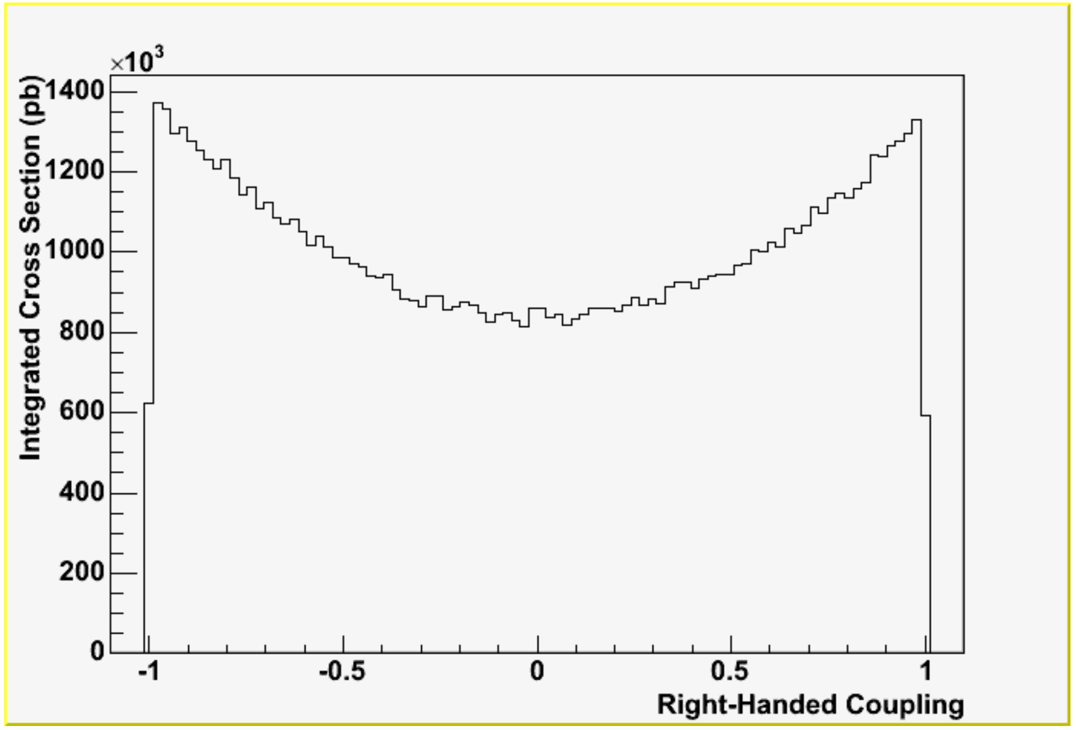
- **8**-dimensional integral (4 kinematic + 4 theoretical variables)
- $M_Z \in [80, 150]$ GeV, $M_L \in [0, 10]$ GeV, $G_L \in [-1, 1]$, $G_R \in [-1, 1]$
- 300,000 calls per iteration
- 50 original grid points per dimension
- 23 sec per iteration
- Convergence in 4 iterations
- Generated about 2M events (~10K/sec)
- Applied dilepton mass cut at 10 GeV

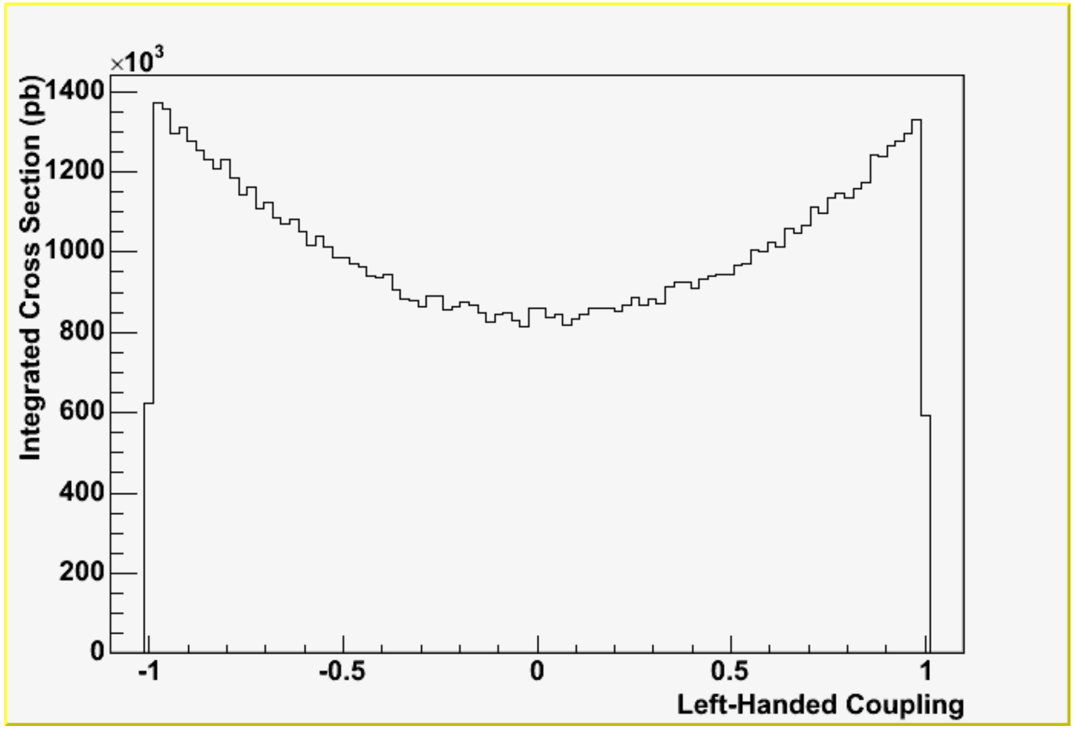


Sampling the theory parameters

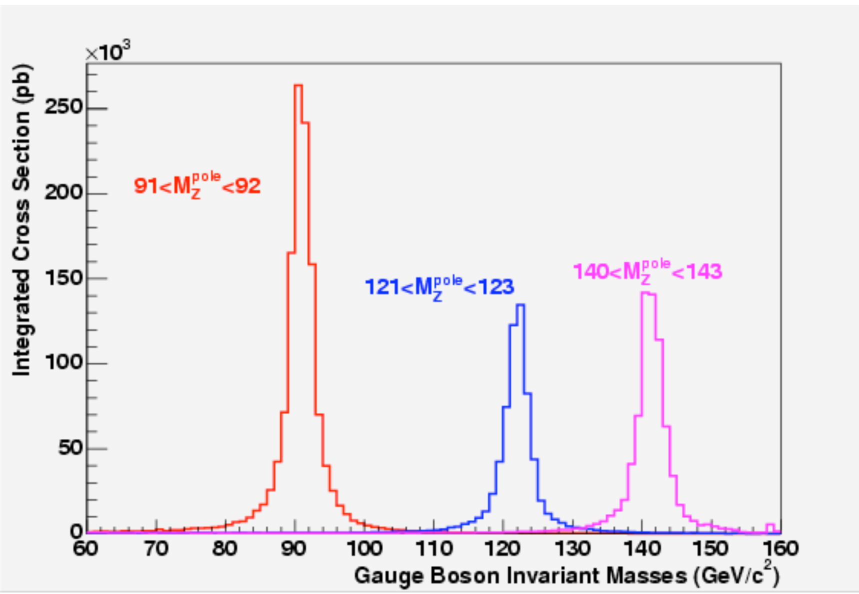


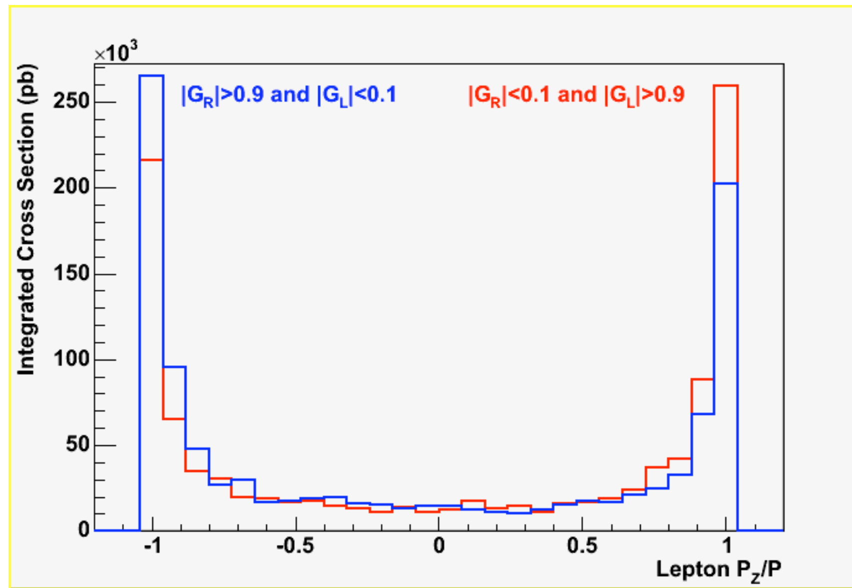


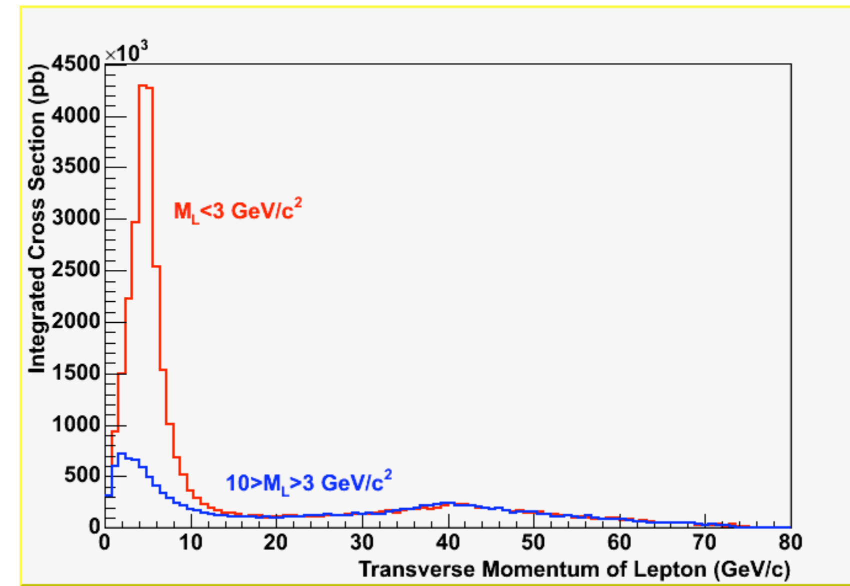


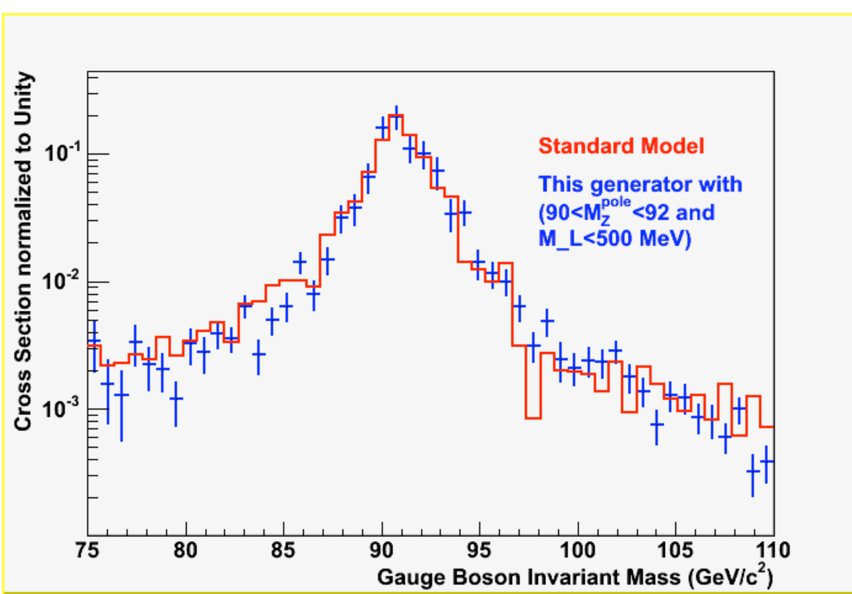


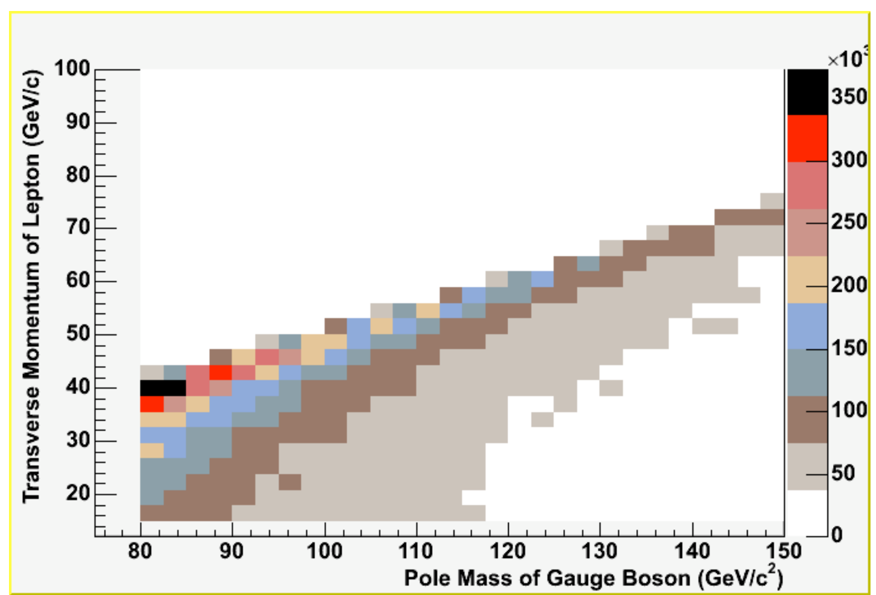
Kinematics for different parameters

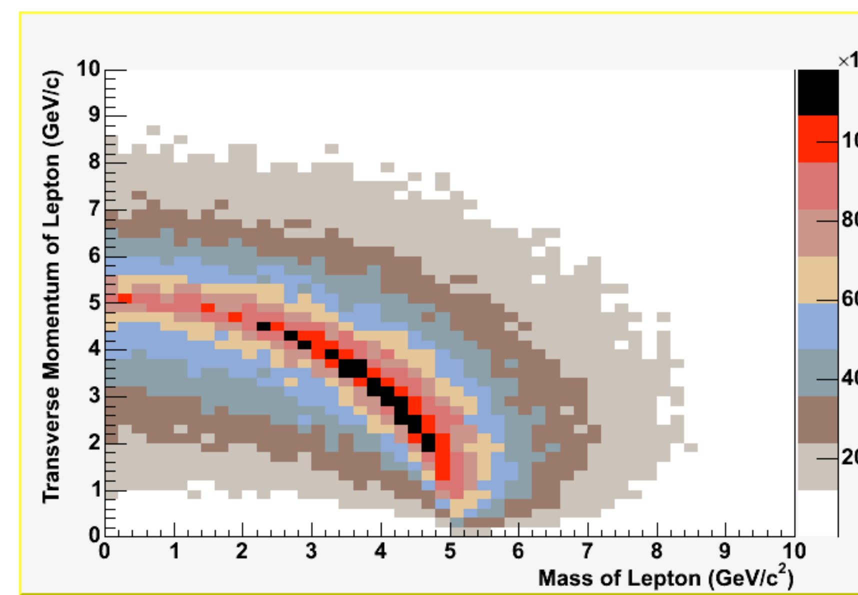




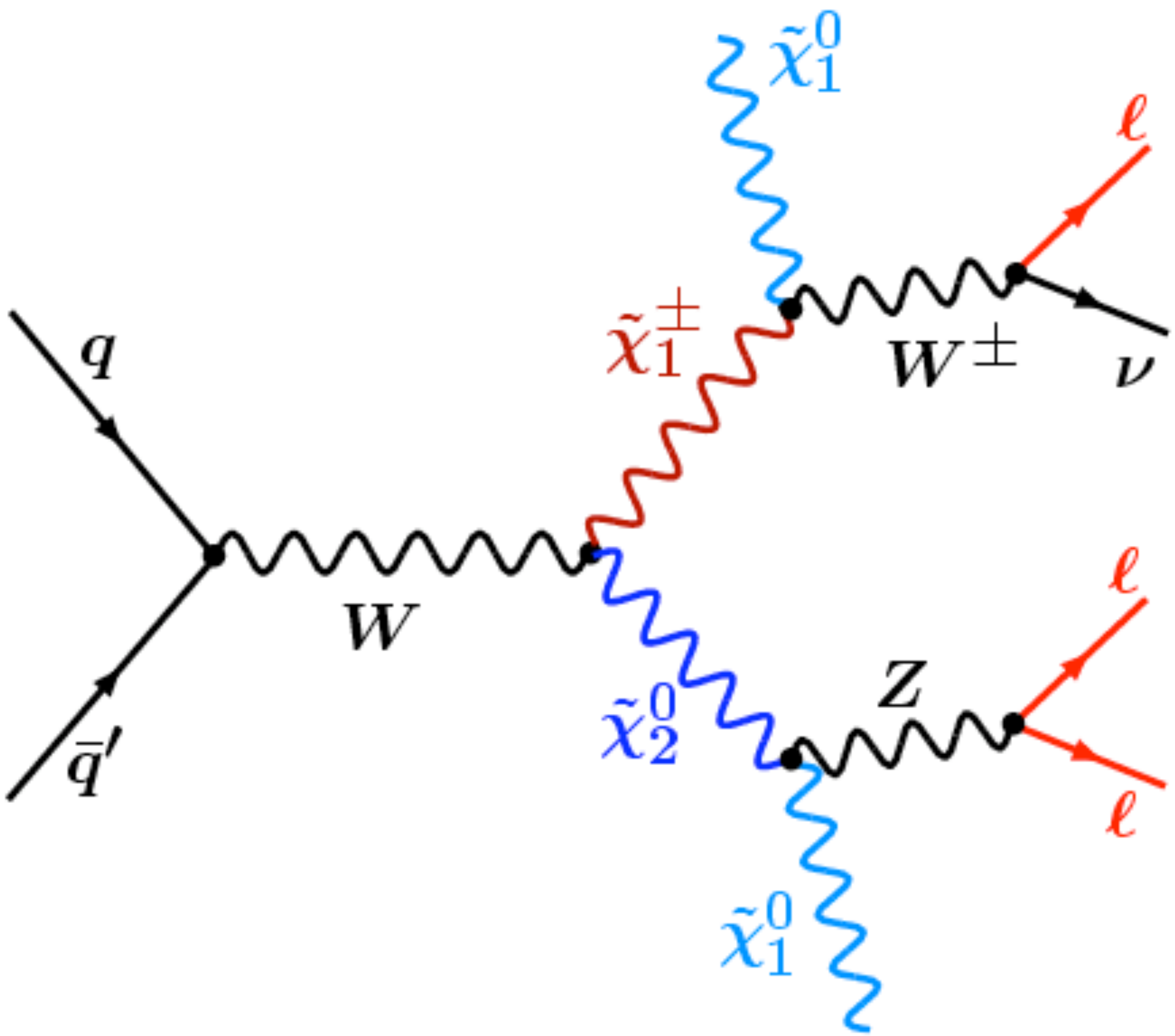






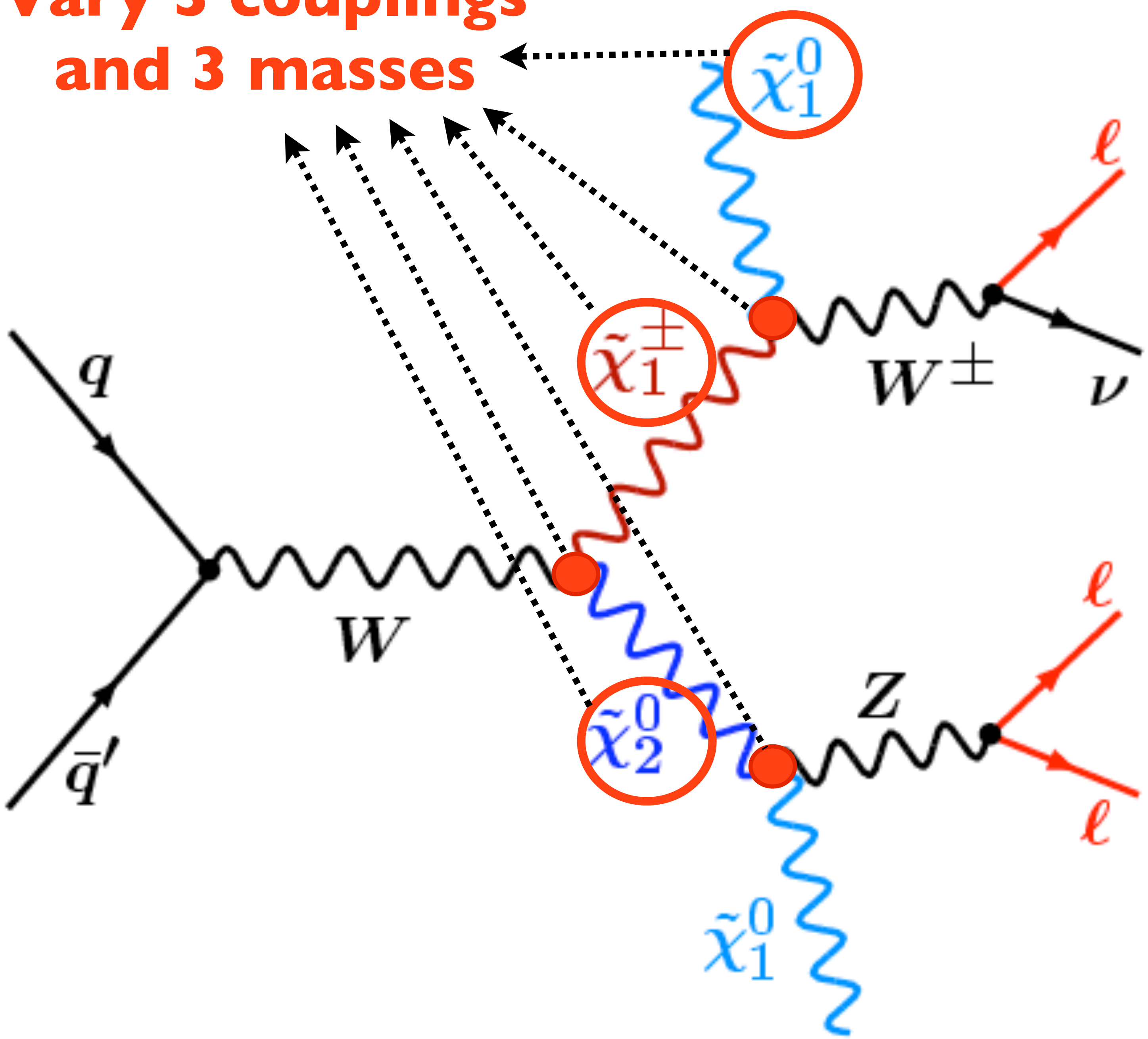


Chargino-Neutralino production example



Chargino-Neutralino production example
without assuming any particular point

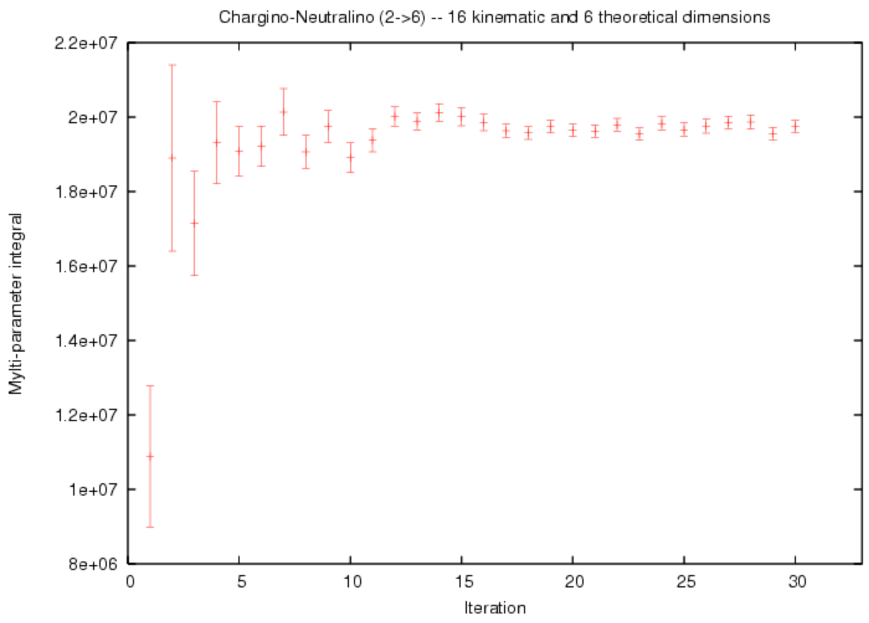
Vary 3 couplings and 3 masses



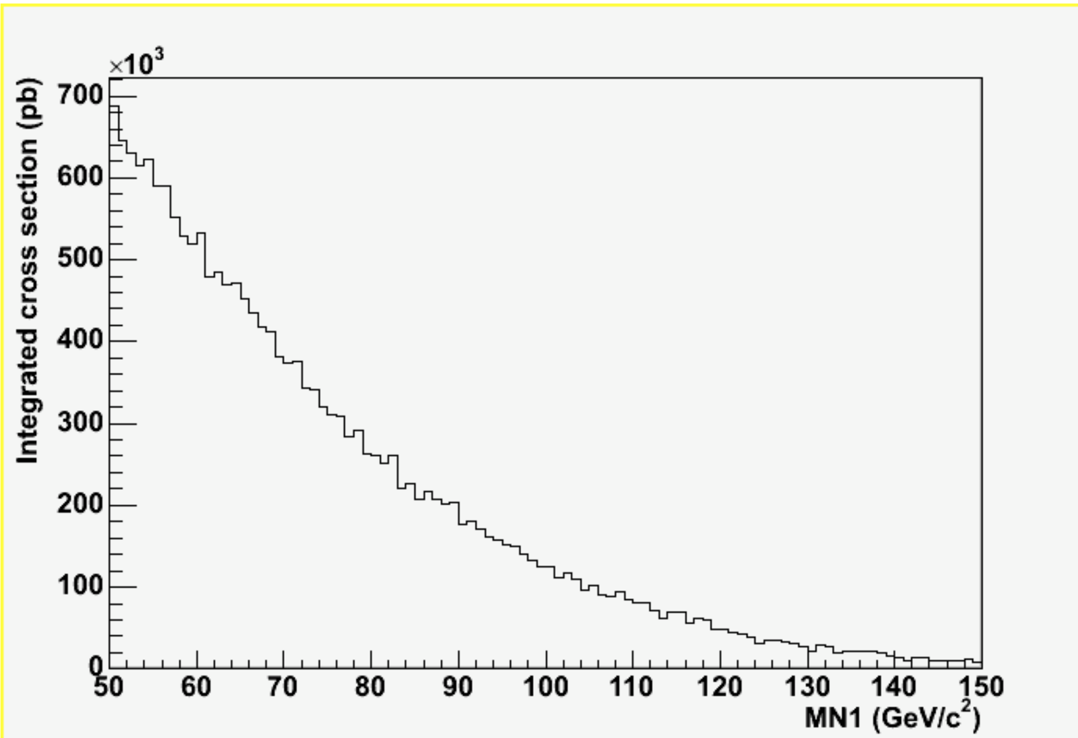
Generic MSSM

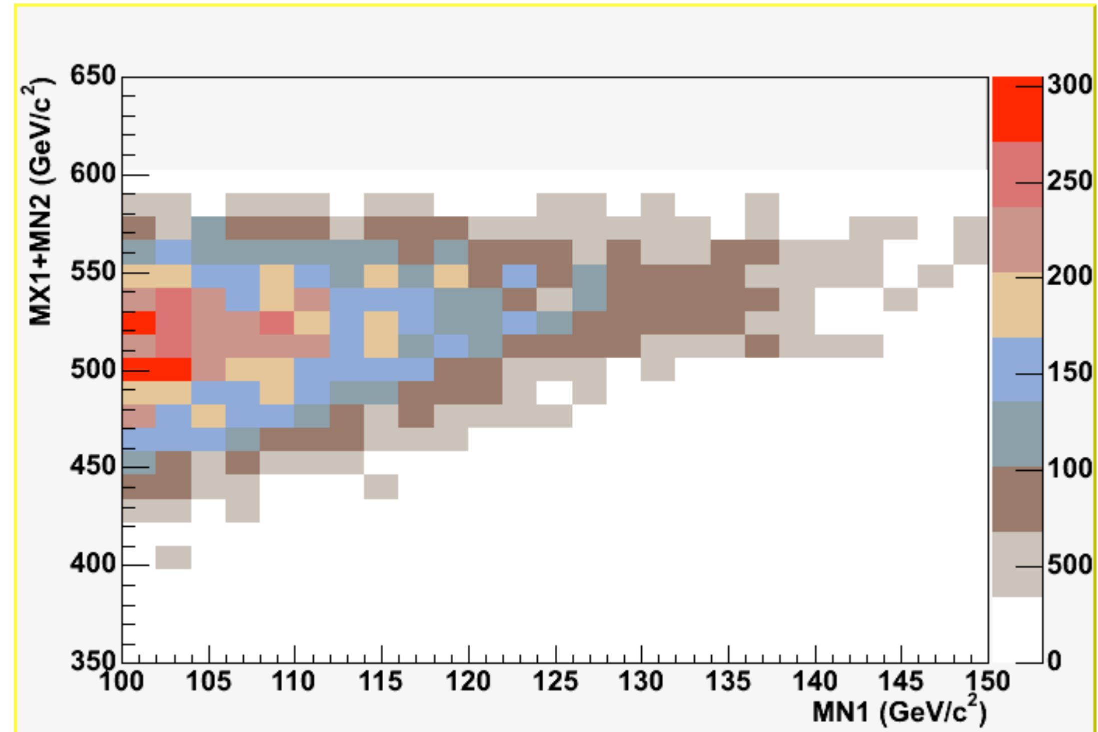
Chargino-neutralino parameters

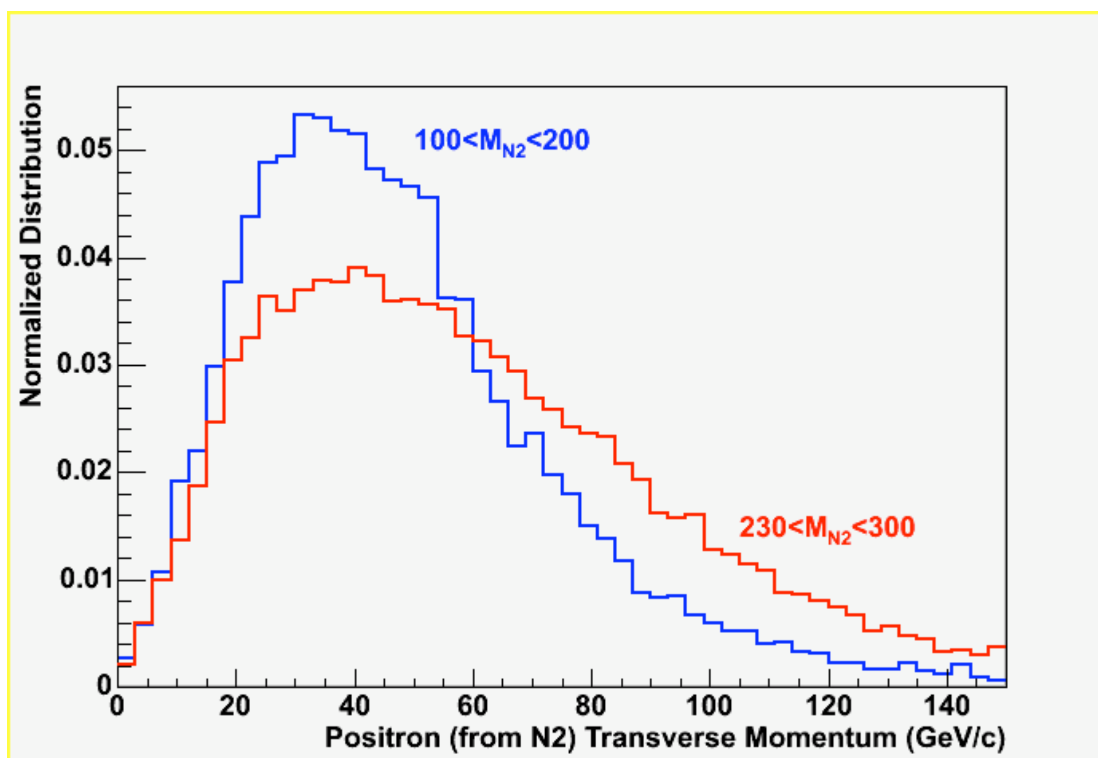
- **22**-dimensional integral (16 kinematic + 6 theory variables)
- $M_{\chi 1} \in [100,300]$ GeV, $M_{n2} \in [100,300]$ GeV, $M_{N1} \in [50,150]$ GeV, 3 couplings $\in [0,1]$
- 10M calls per iteration
- 50 original grid points per integral variable
- 10 min per iteration
- convergence in 12 iterations
- Generated about 23M events (~10K/sec)



Some chargino-neutralino parameters and kinematics







Plans

- Use the program for optimizing our analyses cuts
- Discover new physics or/and set strong limits
- Extension to MSUGRA underway
  - slow due to the calls to SOFTSUSY for the RGE solving

Conclusions

- New-physics event generation is critical in our field
- Still, we artificial limit the parameter space investigated
- If we include the parameters in an adaptive MC integration scheme, we
  - understand our physics in a wide range of parameters
  - dynamically decide where to generate more events
  - optimize our analyses pluralistically
  - set strong multidimensional limits or make discoveries
  - manage our limited resources more efficiently
- **It works!** (even in the demanding 2→6 case, with all masses and couplings varied)