

An efficient multi-parameter new-physics event generator

John Strologas
University of New Mexico

PHENO 2008
Madison, WI

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

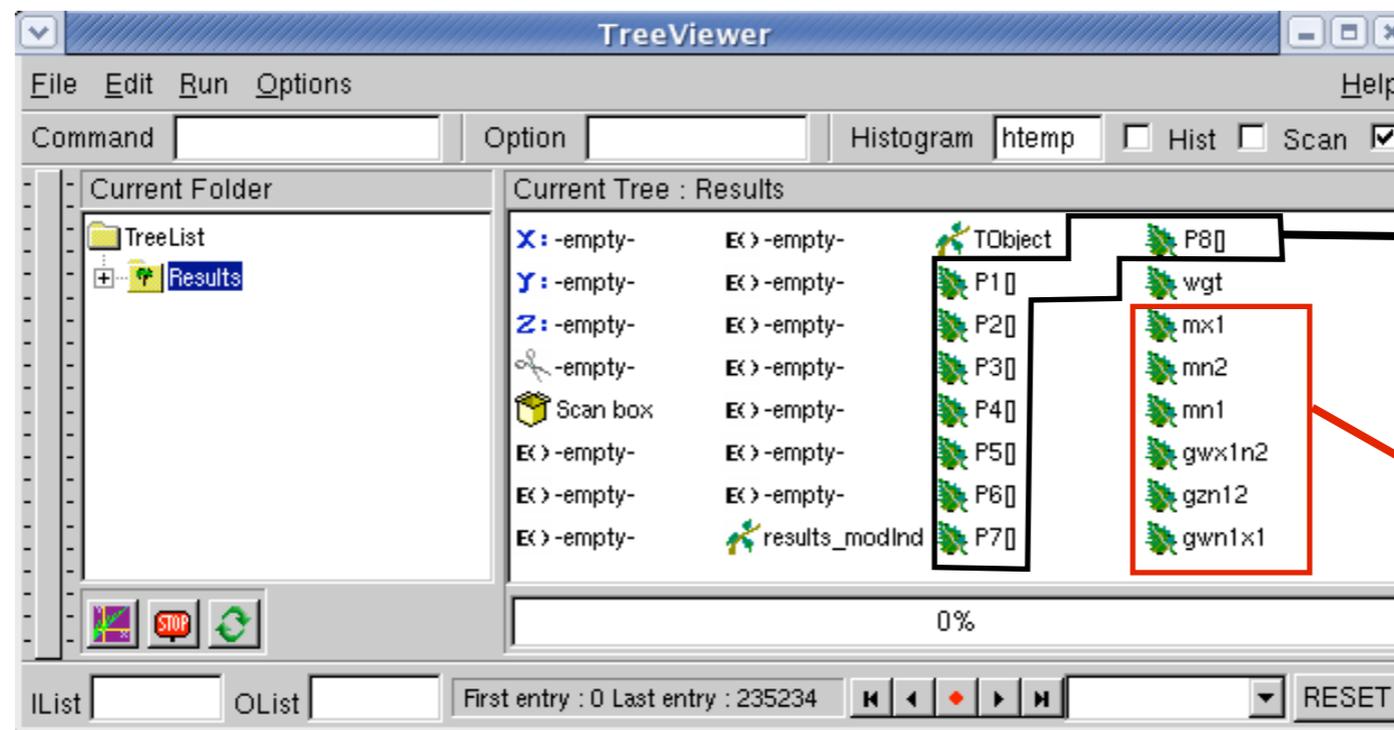
- Repeating the simulation for several parameters in order to properly cover the parameter-space of a theory is usually prohibiting
- If we have N parameters and we would like K points per parameter, we need to generate N^K samples
 - For mSUGRA with $N \sim 4$ and $K = 10$, this would mean 20,000 samples!
- 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 our 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



Particle Kinematics

Theory Parameters

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

$$\sigma = N \int \sum_{q_i, q_j} f_i(x_i, \mu) f_j(x_j, \mu) |\mathcal{M}(\mathbf{P}_i, \mathbf{P}_j, \mathbf{P}_{\text{out},k})|^2 \delta^4(\mathbf{P}_i + \mathbf{P}_j - \sum_k \mathbf{P}_{\text{out},k}) \prod_k \frac{d\mathbf{P}_{\text{out},k}}{E_k} \frac{dx_i dx_j}{E_i E_j}$$

- 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

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

- 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 where 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?

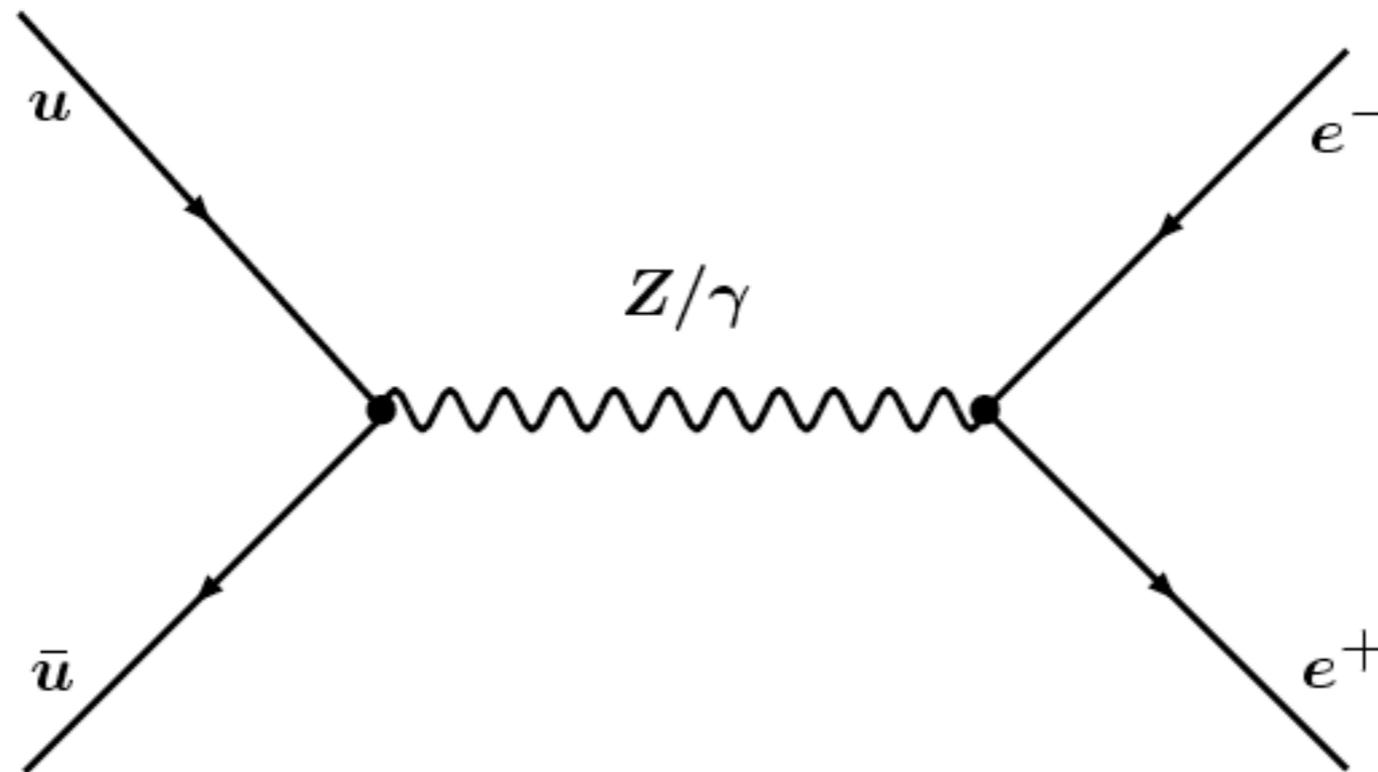
- Usually, the issue with adaptive multi-dimensional integrators is convergence (even for just kinematic integration)
- Can we have convergence if we include the parameters of the theory in the integral?
- **In other words: can we have convergence when no two events are generated with the same theoretical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

Infrastructure

- 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

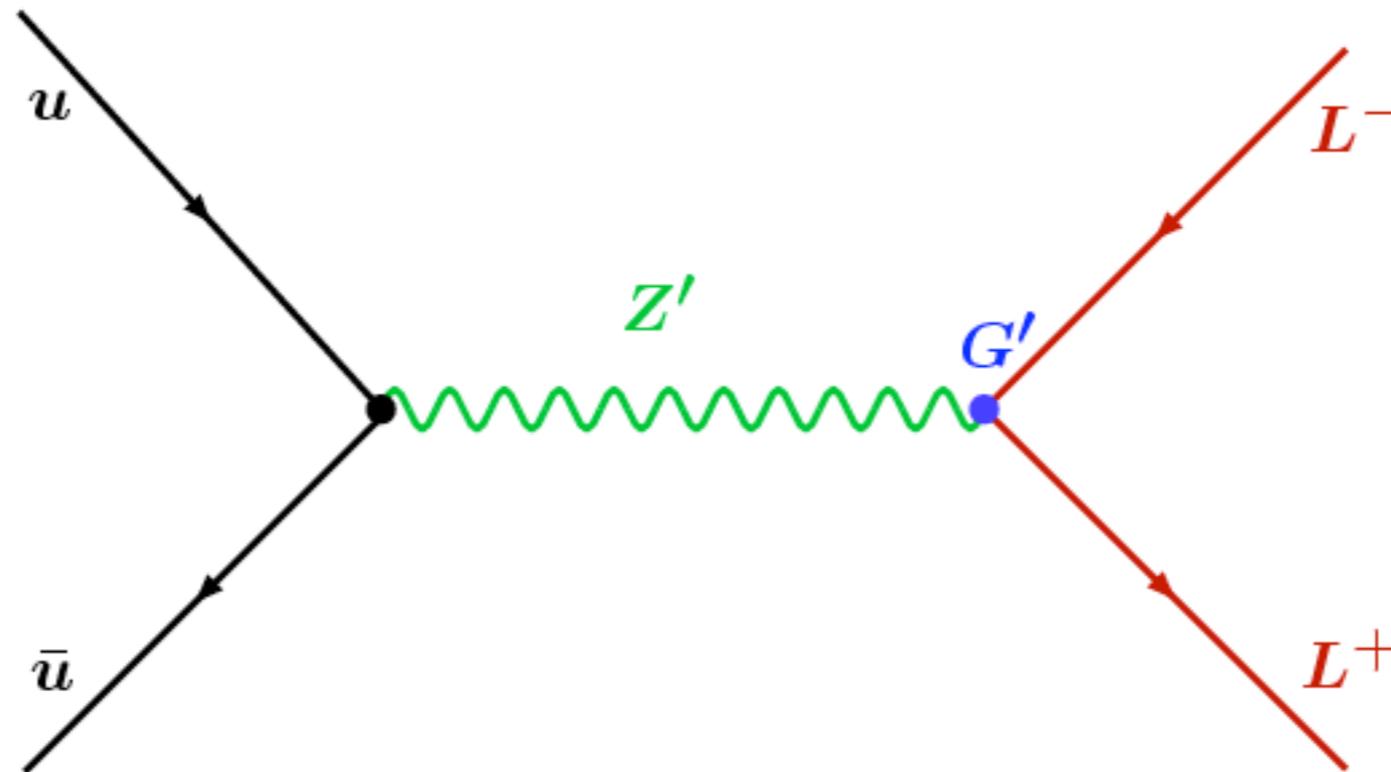
Drell-Yan production

- Take a some-what boring $2 \rightarrow 2$ process:



New-physics Drell-Yan production

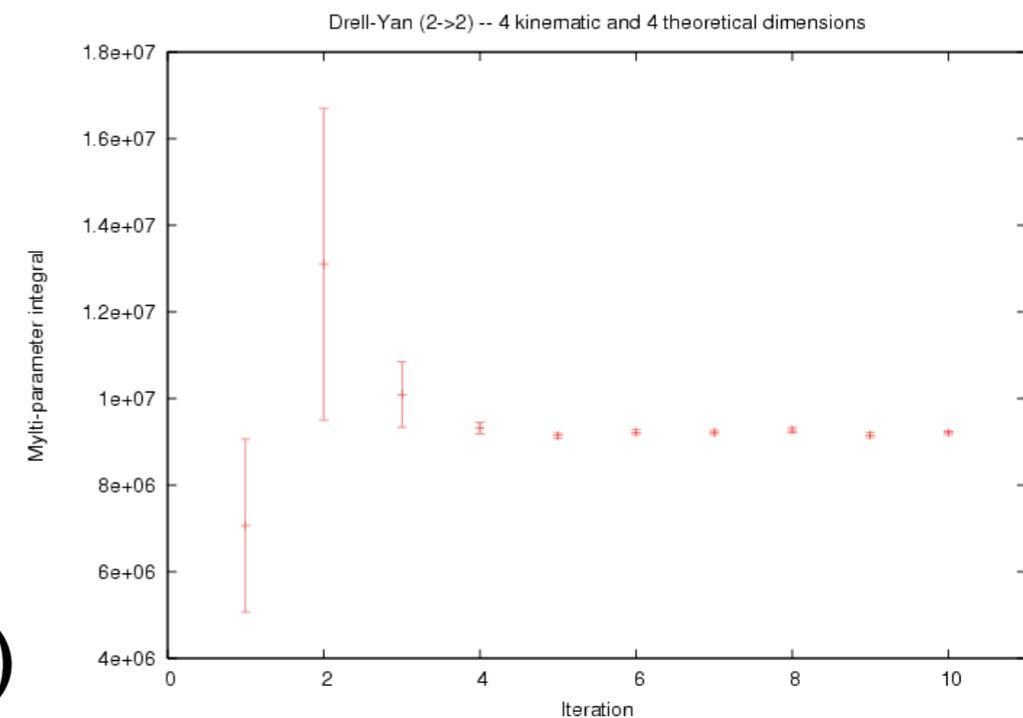
- And start simultaneously varying some SM parameters at the event-generation level (Z and lepton masses, right and left-handed couplings):



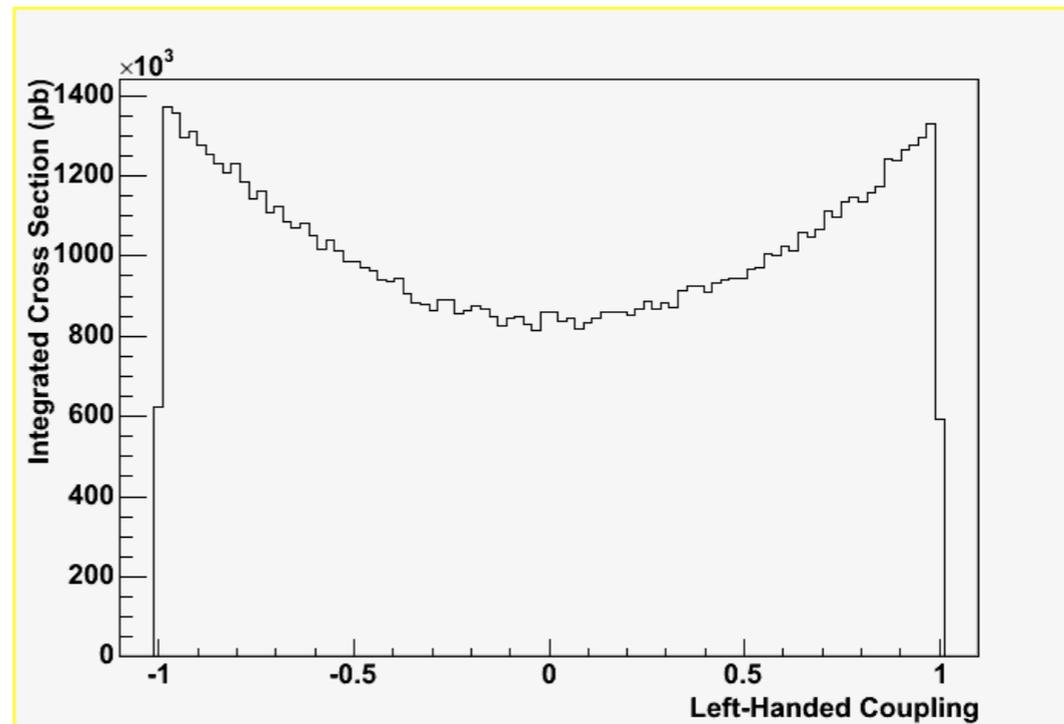
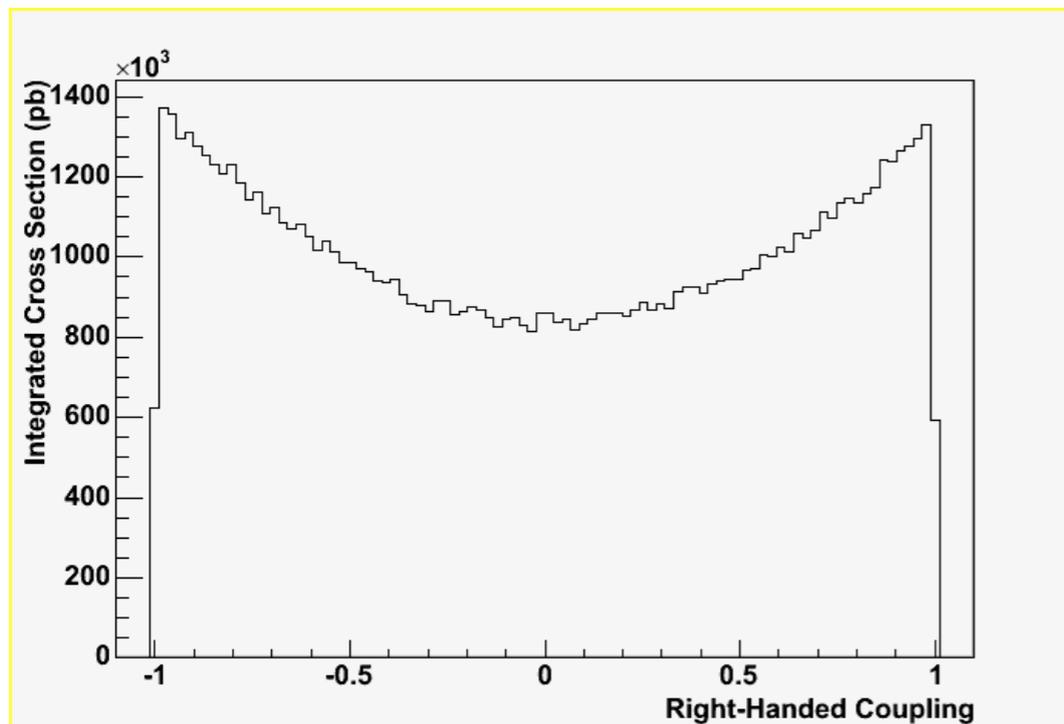
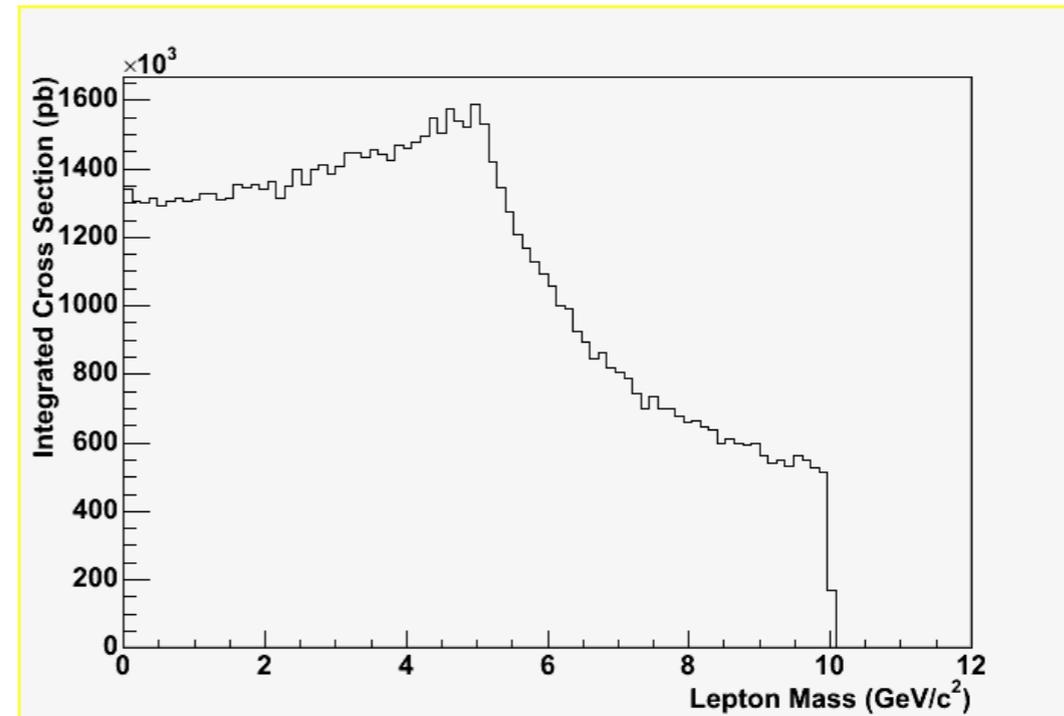
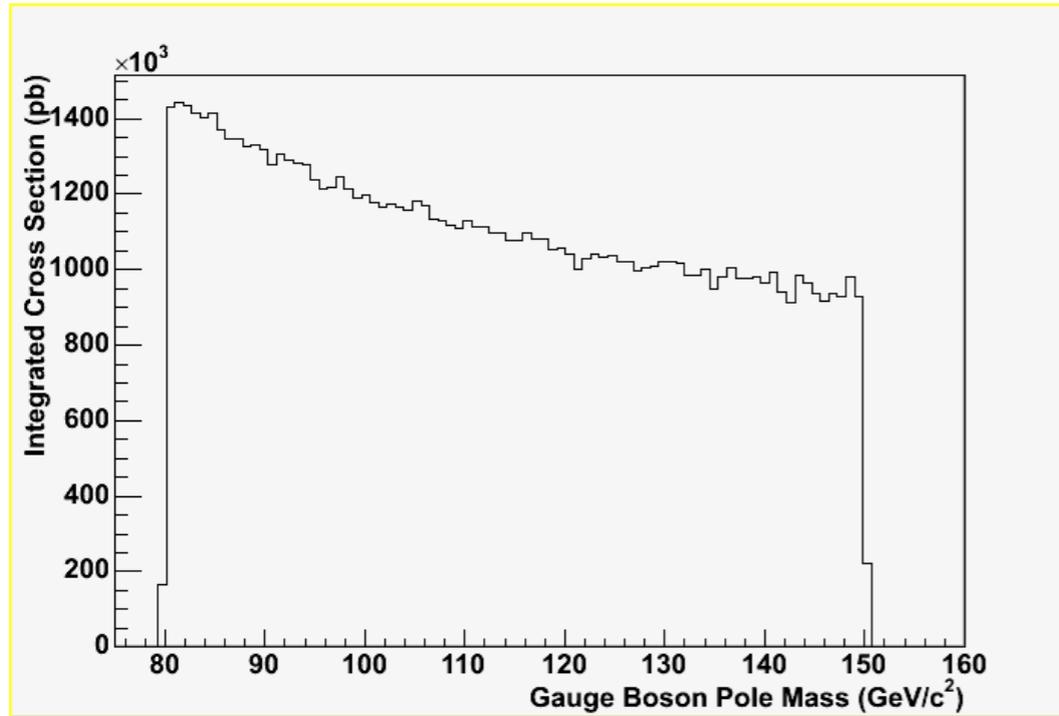
- You can then study Z' , anomalous couplings and 4th generation leptons **within the same sample**

New-physics DY generation parameters

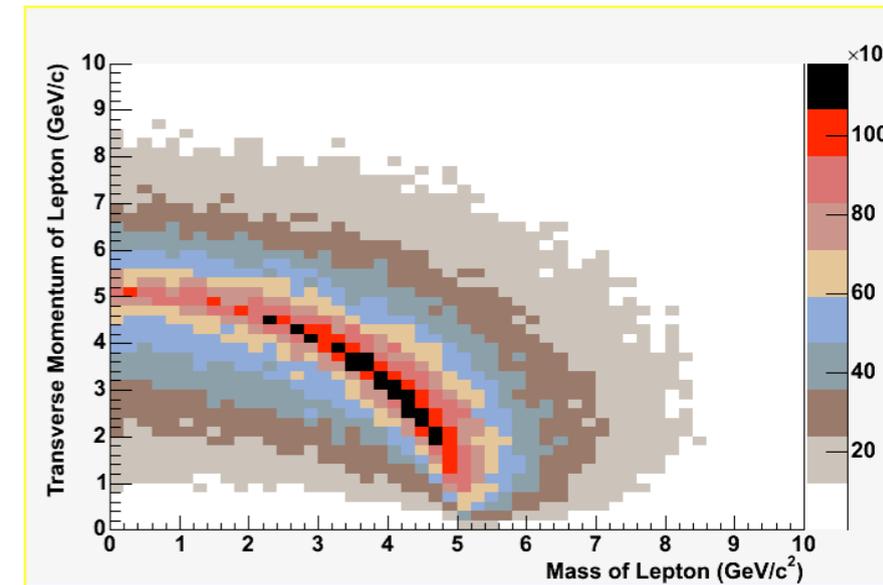
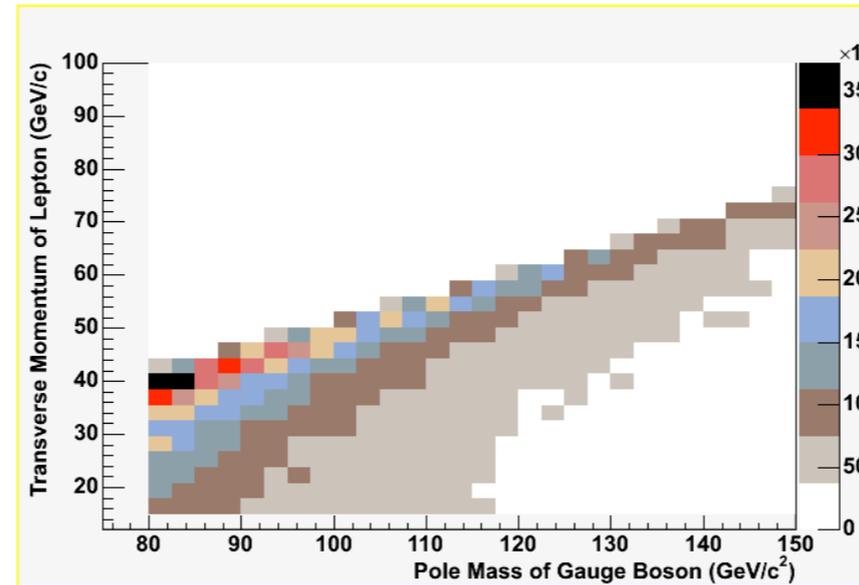
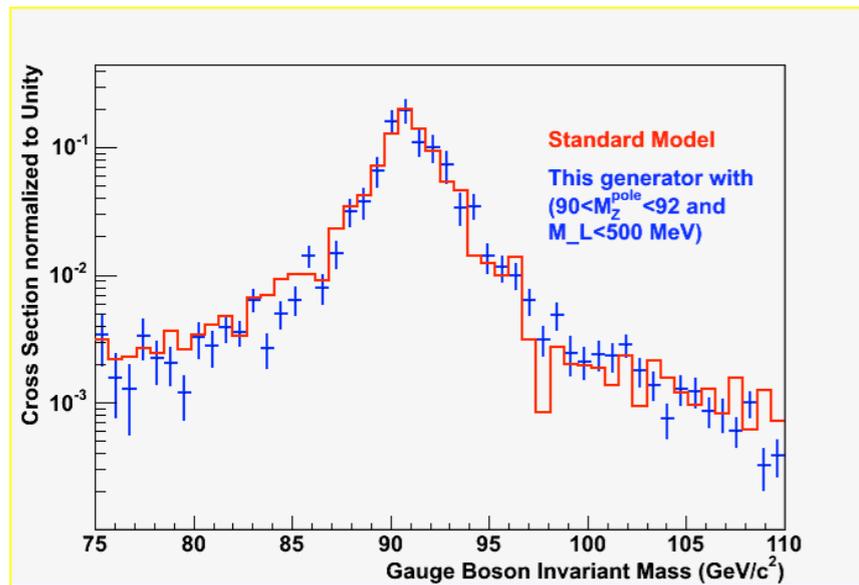
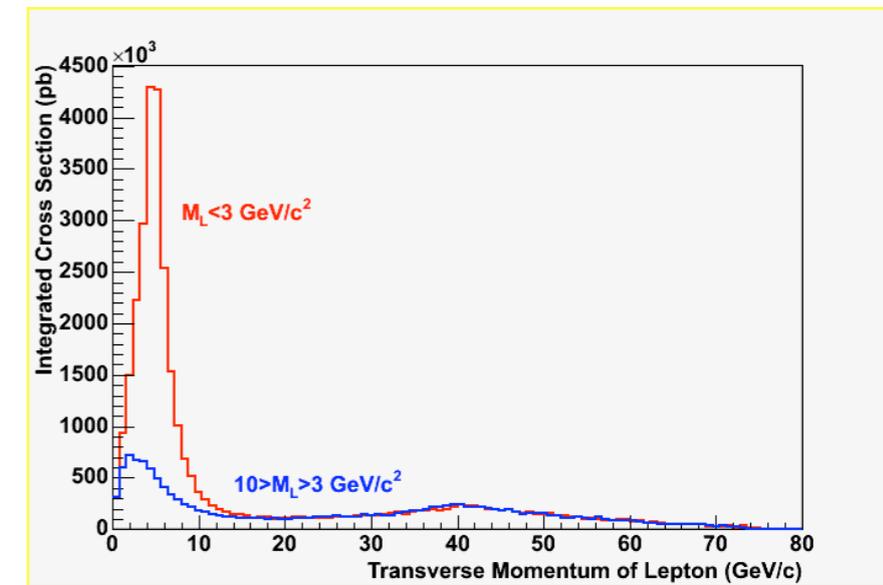
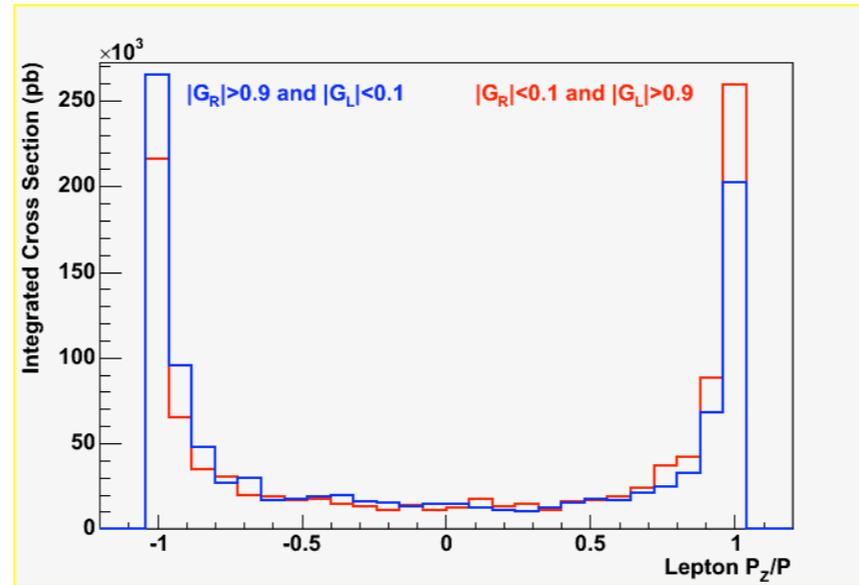
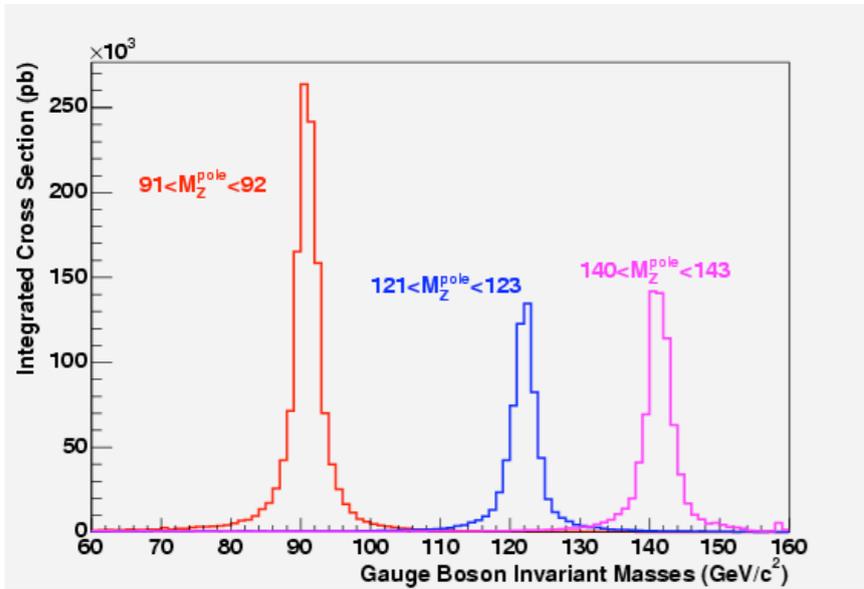
- **8**-dimensional integral (4 kinematic + 4 theoretical variables)
- $M_Z \in [80, 150]$ GeV, $M_L \in [0, 10]$ GeV, $G_L \in [-1, 1]$, $G_R \in [-1, 1]$
- 300,000 calls per iteration
- 50 original grid points per dimension
- 23 sec per iteration
- Convergence in 4 iterations
- Generated about 2M events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



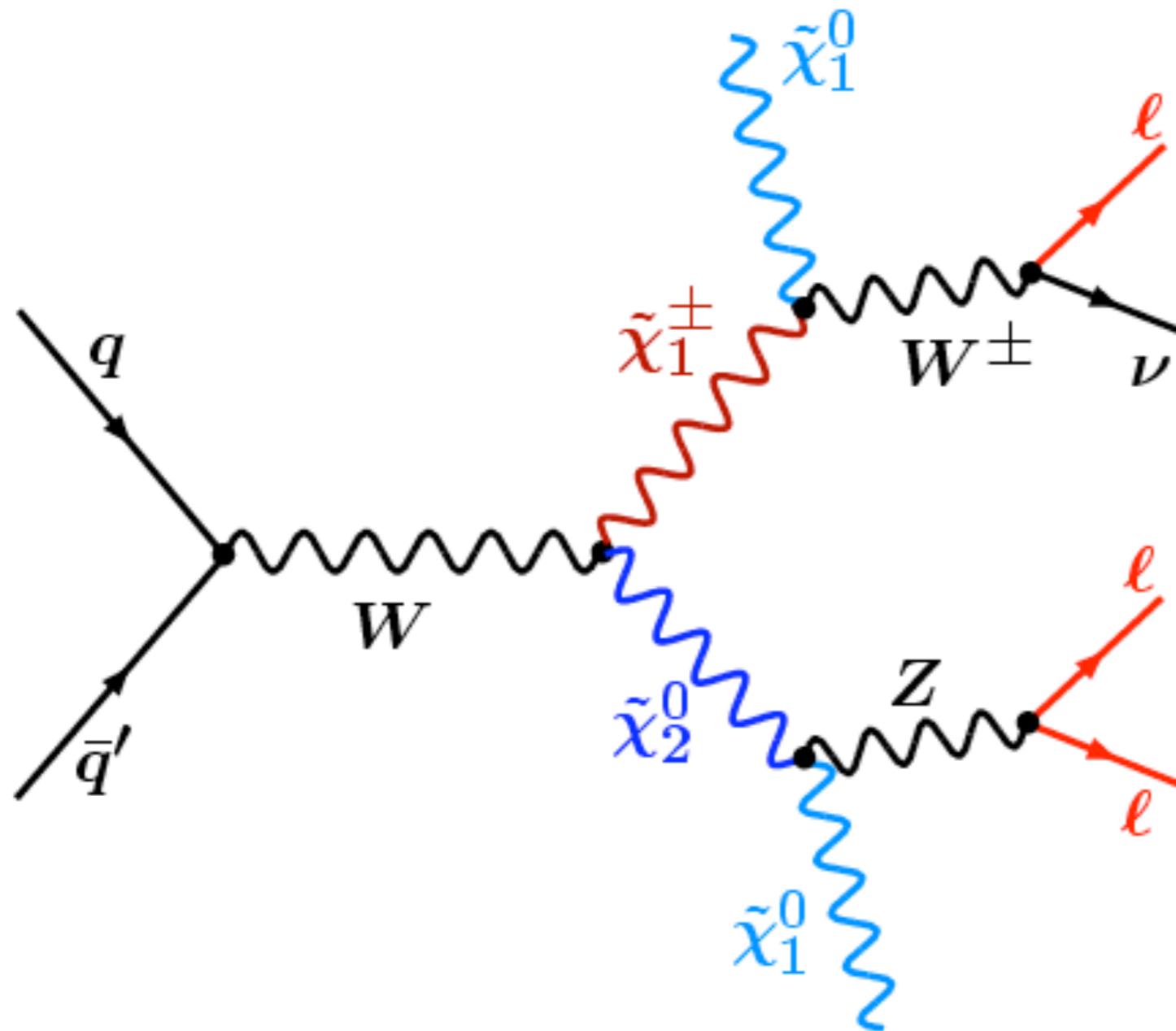
Sampling the theory parameters



Kinematics for different parameters

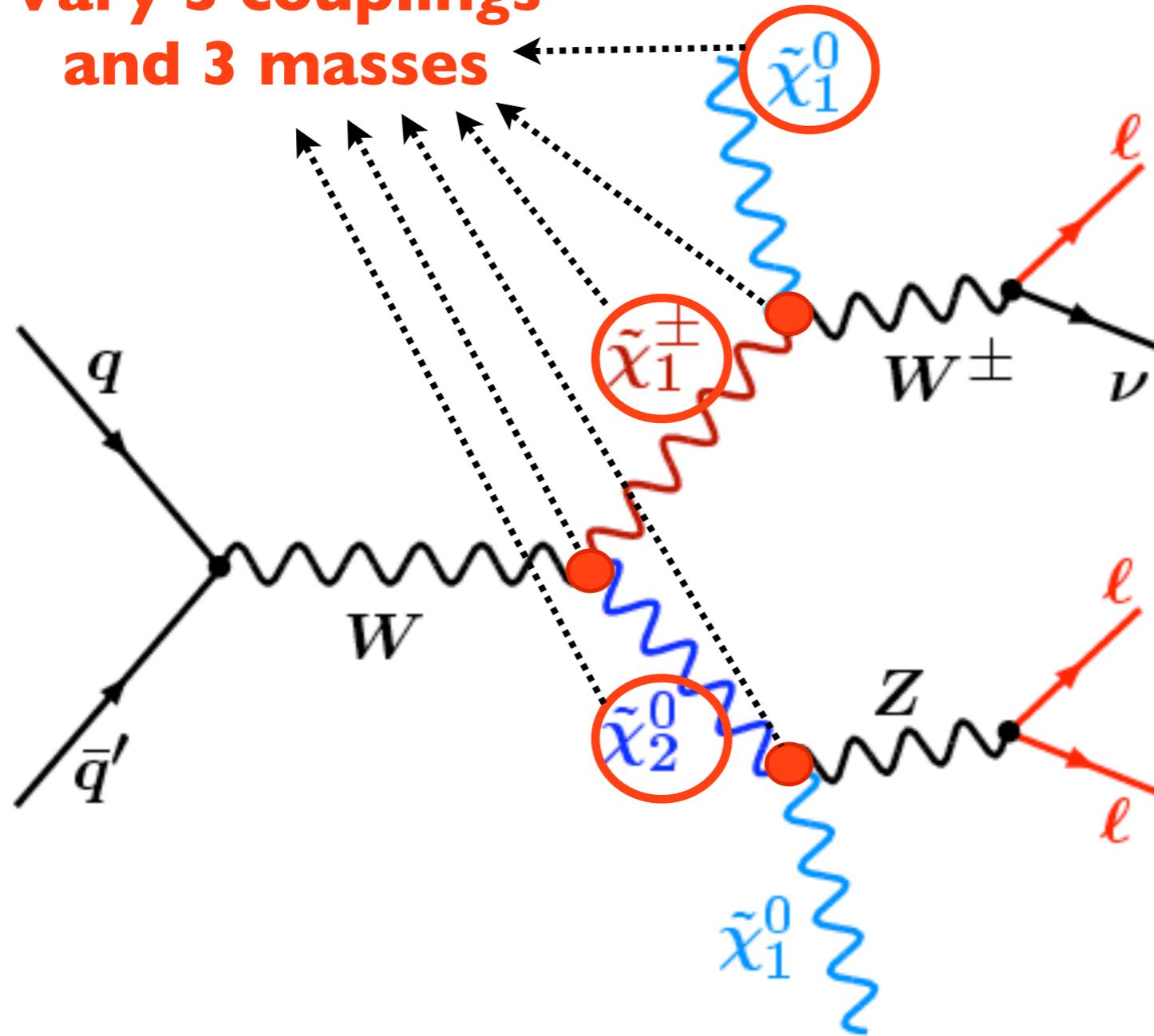


Chargino-Neutralino production example



Chargino-Neutralino production example without assuming any particular point

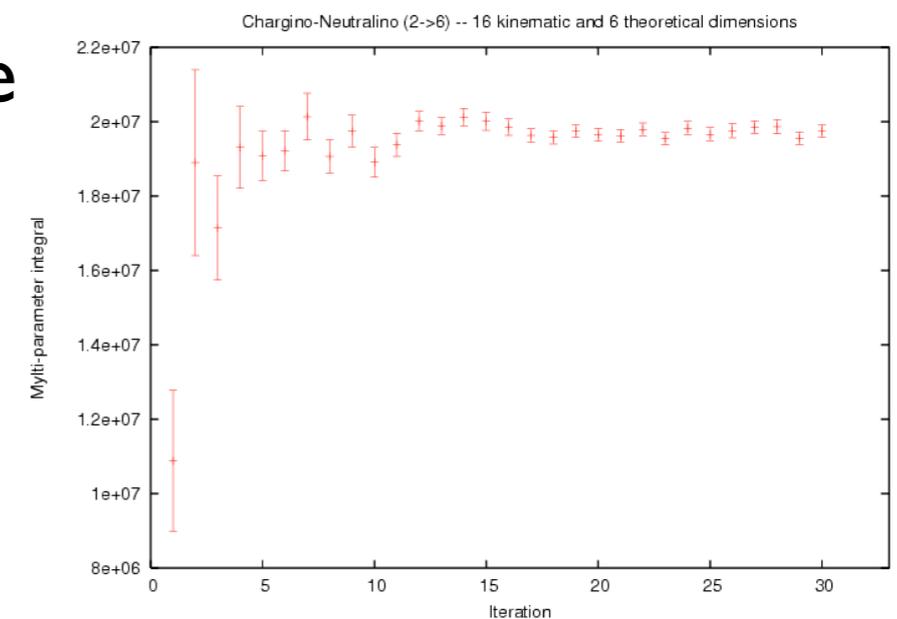
**Vary 3 couplings
and 3 masses**



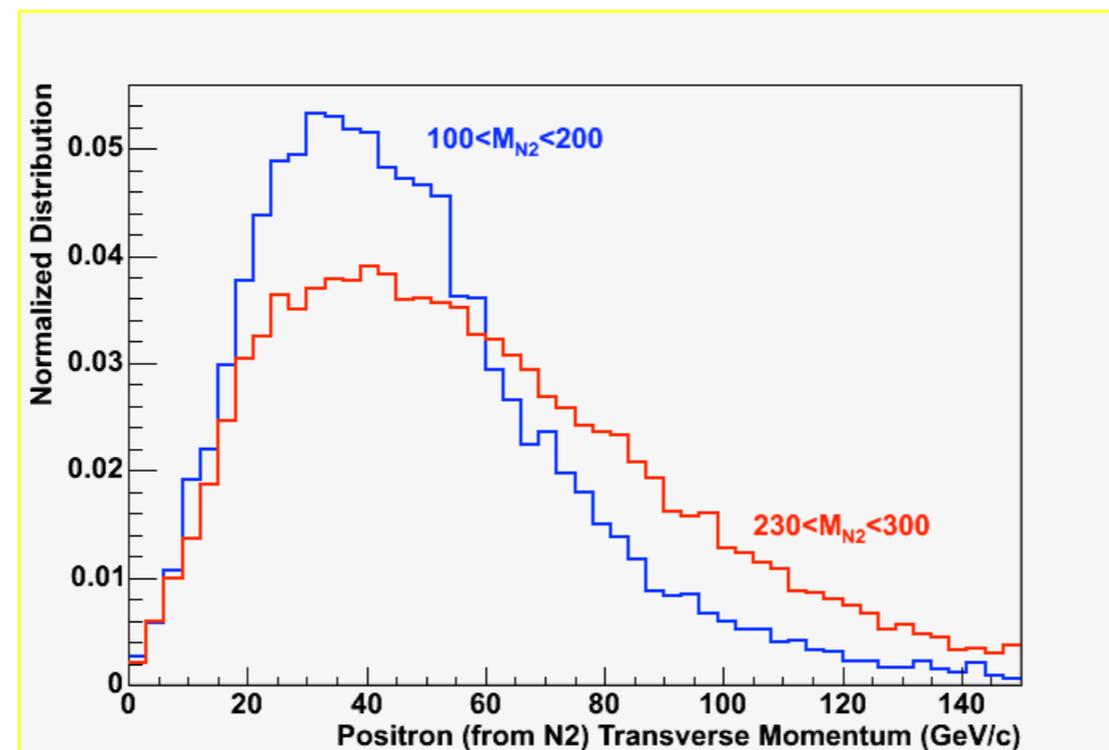
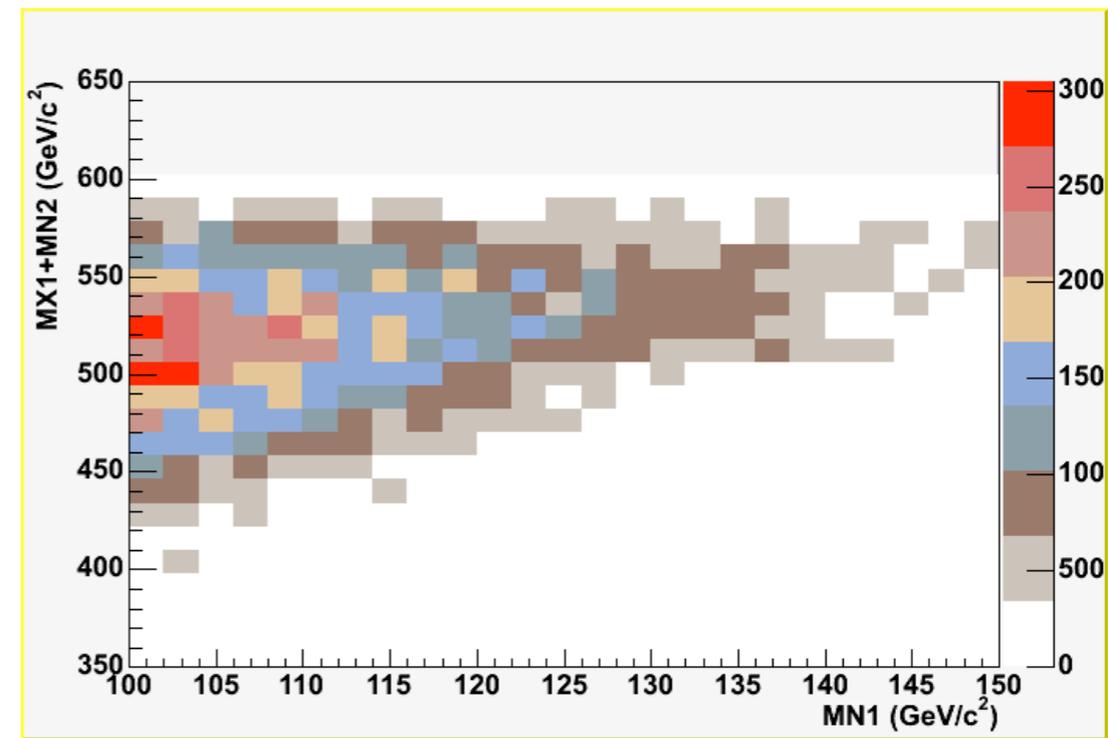
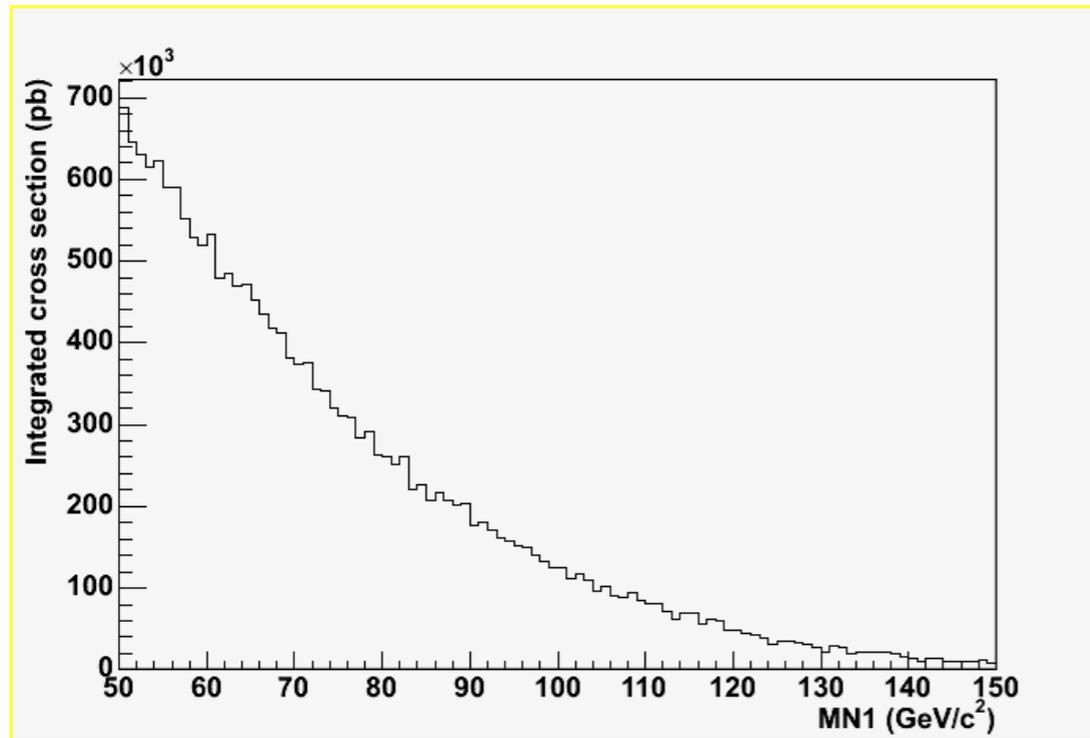
Generic MSSM

Chargino-neutralino parameters

- **22**-dimensional integral (16 kinematic + 6 theory variables)
- $M_{\chi_1} \in [100, 300]$ GeV, $M_{\tilde{\chi}_2^0} \in [100, 300]$ GeV, $M_{\tilde{N}_1} \in [50, 150]$ 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 ($\sim 10\text{K}/\text{sec}$)



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 $2 \rightarrow 6$ case, with all masses and couplings varied)