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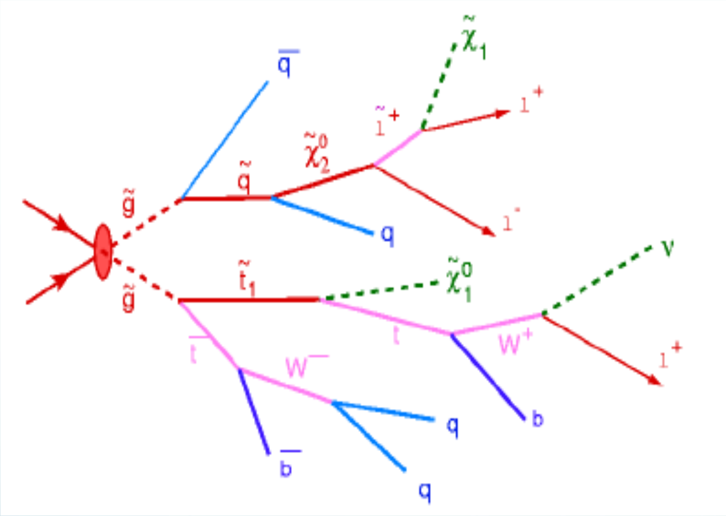
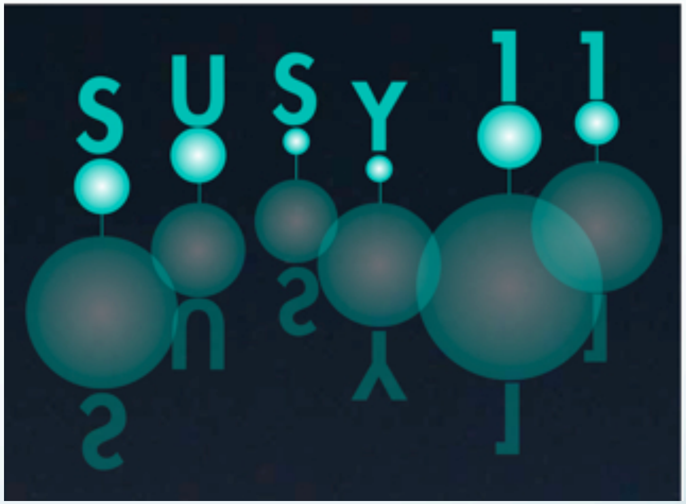
Using Top-Quark as a probe for NewPhysics with the use of MatrixElements Generators





Alexis Kalogeropoulos

SUSY11 - Fermilab, 29/8/2011

Outline

- SM reminder & the need for SUSY
- Setting exclusion limits on the phase space
- Why top-topologies on the hunt for NP?
- Method
  - Find the tools you need for the hunt for NewPhysics
  - Selecting sensitive variables for NP
  - RESULTS!

The Standard Model

A theory that describes very well the already known elementary particles , predicts the remaining pieces and combines the 3 of the 4 fundamental forces…

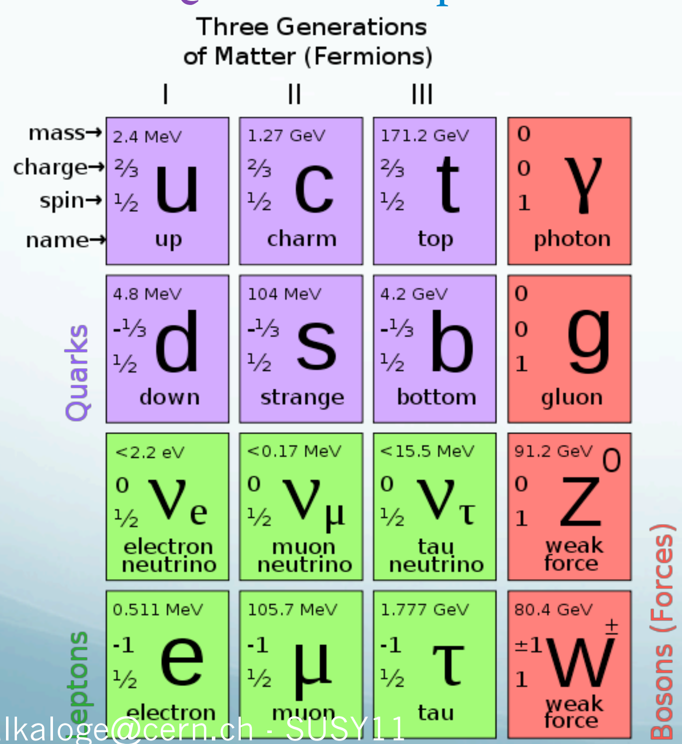
Fundamental Forces

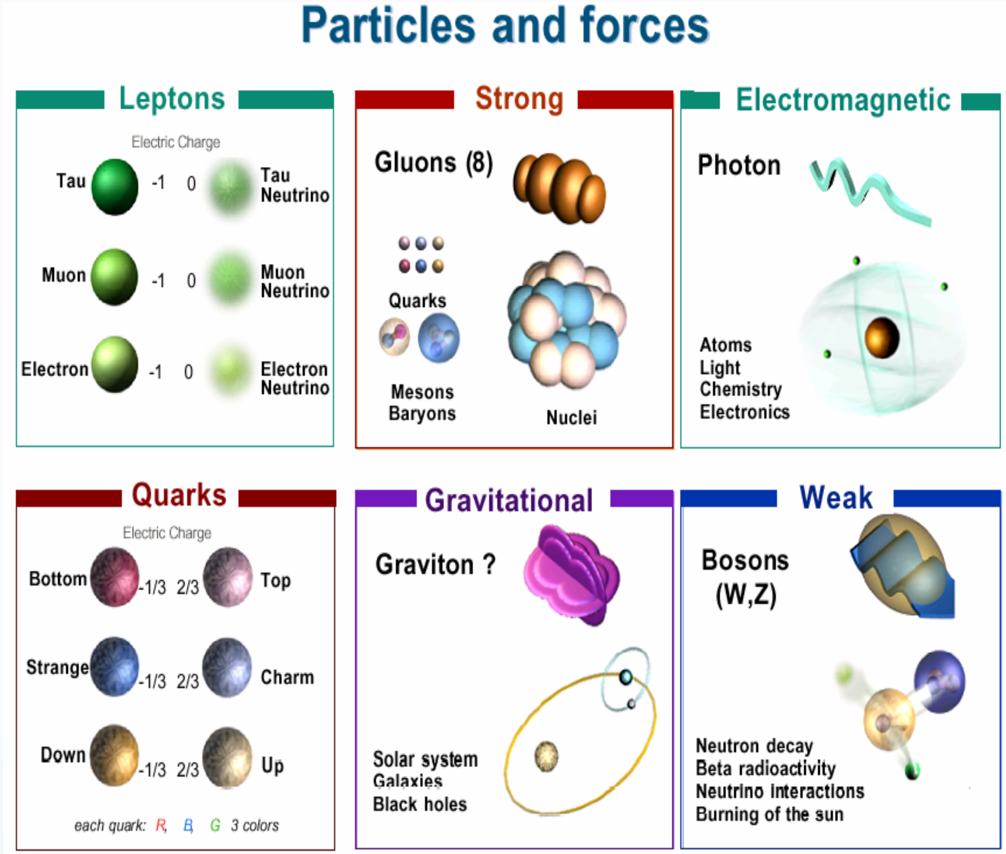
3 coupling constants, g_1,g_2,g_2

Mediators : $W^{\pm}$, Z^{o} , γ, 8gluons, gravitons?

3 generations of matter

6 Quarks – 6 leptons





$$m_e = 0.5\ 10^{-3}\ \text{GeV},\ \frac{m_\mu}{m_e} \simeq 200,\ \frac{m_\tau}{m_\mu} \simeq 20$$

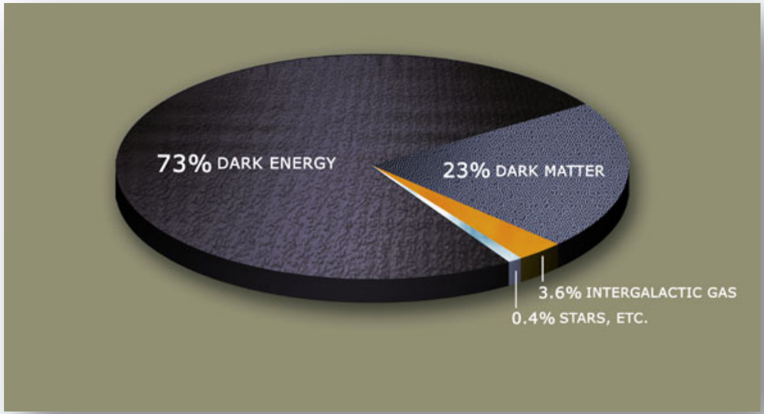
$$m_t \simeq 175\ \text{GeV} \qquad m_t/m_e \propto 10^5$$

!!!Very different masses !

Neutrino masses less than 10^{-9}GeV!

Problems of the Standard Model

- Why (and even if…) happens the Spontaneous Symmetry Breaking?
- We have not seen Higgs ..at least not until this morning!!!



- Why 3 generations of matter and 3 forces?
- SM does not include gravity
- Why neutrinos have so little mass (?)
- Why there is the CP violation?
- Why matter is more that antimatter? Is there cold dark matter?
- Are there only 3 dimension in space?
- Hierarchy problem –(Higgs mass is lighter that "should " be)
- Cannot give an unification of electroweak and strong force

We can find some answers with SUSY…

- Symmetry between fermions/bozons
- Every particle at SM has a super-partner (spin differs by ½)

- SM outline & need for SUSY
- Setting exclusion limits on the phase space
- Why top-topologies on the hunt for NP?
- Method
  - Find the tools you need for the hunt for NewPhysics
  - Setting our “hunting area”
  - Selecting sensitive variables for NP
  - RESULTS!

Setting our limits

- What is left after we exclude region(s) from theory+pheno+exp?
  - **Gauge coupling constant unification**. This is one of the most restrictive constraints. It sets the scale of SUSY breaking ~1 TeV.
  - **M_Z from electroweak symmetry breaking**

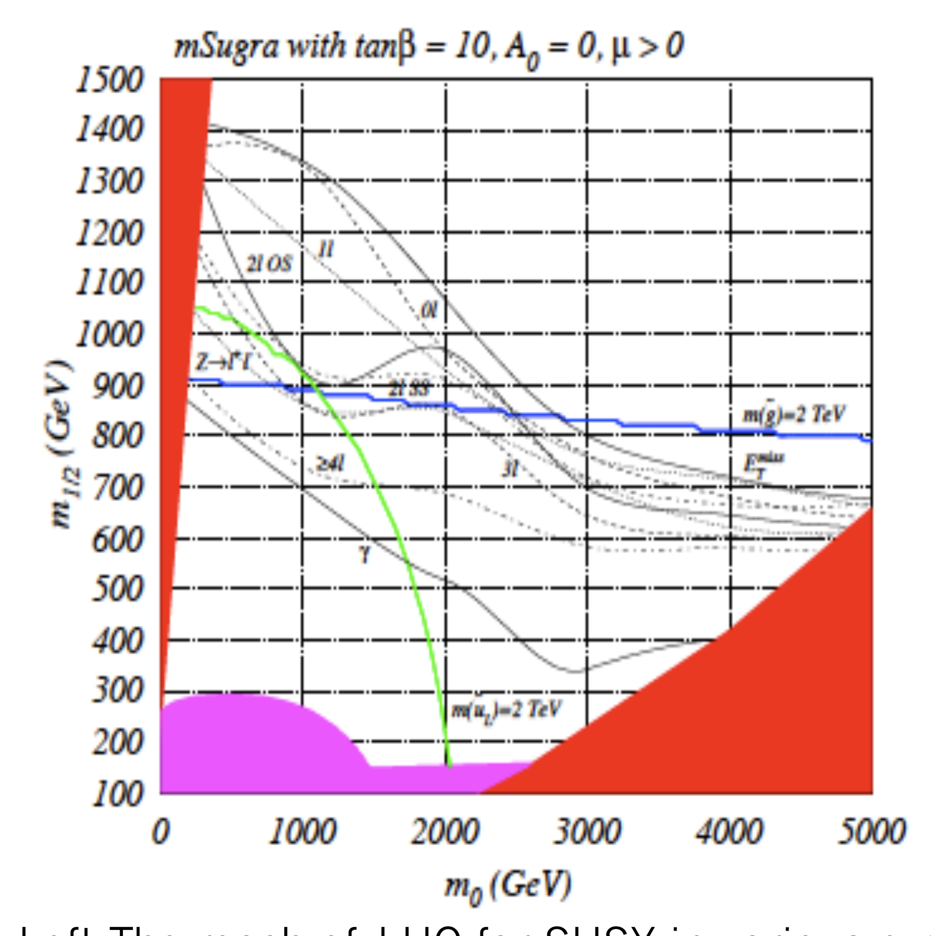
$$\frac{M_Z^2}{2} = \frac{m_1^2 - m_2^2 \tan^2\beta}{\tan^2\beta - 1} = -\mu^2 + \frac{m_{H1}^2 - m_{H2}^2 \tan^2\beta}{\tan^2\beta - 1}.$$

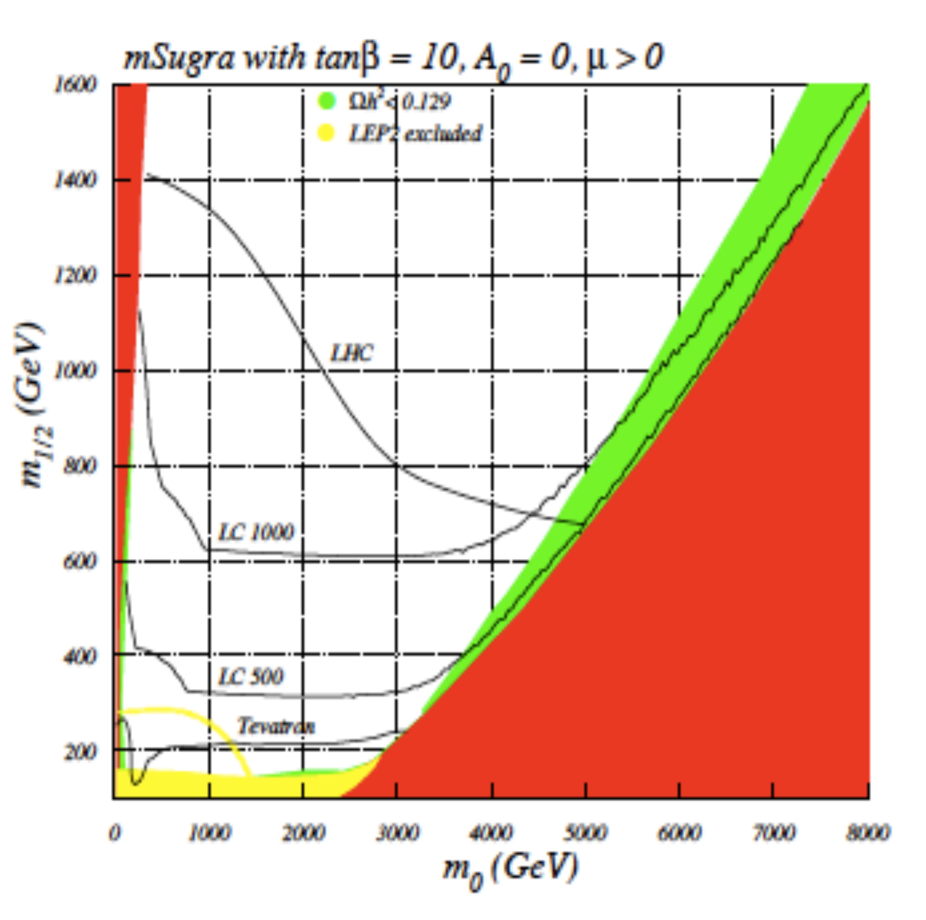
    - Determines the value of μ^2 for given values of m_0 and $m_{1/2}$. The sign of μ remains undefined though.
  - Yukawa coupling constant unification .The masses of *t, b,* τ can be be obtained from the low energy values of the running Yukawa couplings

$$m_t = y_t\ v \sin\beta, \quad m_b = y_b\ v \cos\beta, \quad m_\tau = y_\tau\ v \cos\beta.$$

    - They can be translated to the pole masses taking into account the radiative corrections, which restricts possible solutions in the GUT.
  - Precision measurement of decay rates. The *BR(b->sγ)* for which the SM contribution is slightly lower than what the one that has been measured opens a window for SUSY .This requirement imposes severe restrictions on the parameter space, especially for the case of large tan β
  - Anomalous magnetic moment of muon. Measured deviations from SM of the order of 2σ, which could be filled by SUSY ~ μ , *tan* β. This requires positive sign of μ and kills a half of the parameter space of the MSSM
  - Experimental lower limits on SUSY masses . Excluded regions from LEP + Tevatron + LHC
  - Dark Matter constraint . Should be ~23% and combined with h_0 confines the available phase-space

The hunt for new physics…





Left:The reach of LHC for SUSY in various event topologies assuming $100fb^{-1}$ in the mSUGRA model.
Right: The reach of SUSY for various colliders assuming $100fb^{-1}$ at LHC and $10fb^{-1}$ at Tevatron [arXiv:0909.1515v1]

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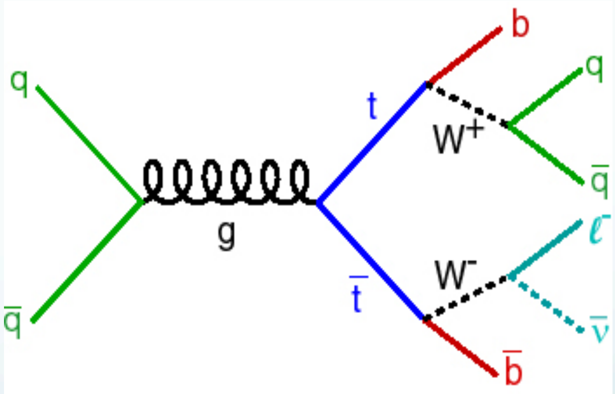
Why bothering searching for NP in top topologies ?

- Top is the heavier quark.
  - Large coupling to the longitudinal component of the *W* boson and thus it decays prior to hadronization. Hence, the spin of the decaying top quark leaves its imprint on the kinematical distributions of the decay products: the *W* boson and the *b* quark.

- Possible new physics of EWSB may alter *t* quark coupling with the *W* boson
  - This leads to changed decay width and distributions. Further, new physics may also appear in its production process, potentially affecting kinematical distributions and possibly polarization.

- NP is there ?
  - The simultaneous presence of new physics both in production and decay processes of top quark may complicate the analysis and it may become difficult to probe new physics couplings of top quark.
  - If one can construct observables that are sensitive to production and decay mechanism independent of each other, we might have a shot…



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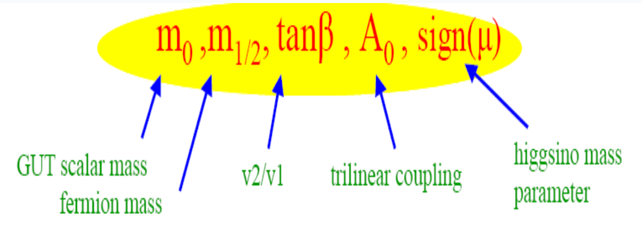
- Strategy : (mSUGRA scenario)
  - LMx – HMx : standard benchmark points.
    - “scattered” and not covering all the phase space
    - No common $\tan\beta$, A_0, $\mathrm{sgn}(\mu)$
  - We need samples to cover the p.s., (step=20GeV, in m_0 (0,2000)/ m_{12} (0,1400) ~ 7000 samples !!!)
  - Different regions = different physics



- STau is LSP(excluded)
- $m_{gluinos} > m_{squarks}$

$$\tilde{g} \rightarrow \tilde{q}\bar{q} \;,\; \tilde{q} \rightarrow q\chi$$

- Some squarks are heavier that gluinos, some aren’t

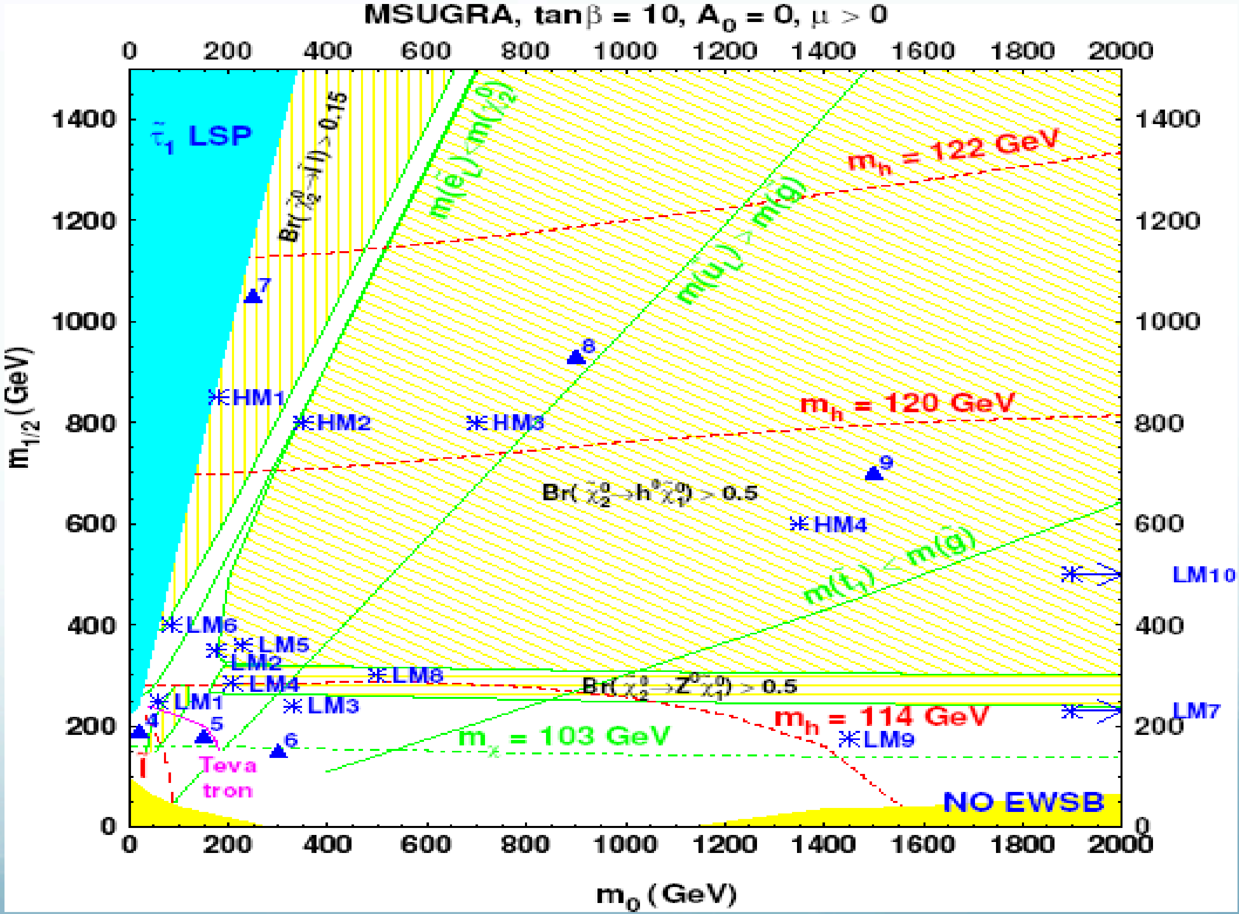
$$\tilde{q}_L \rightarrow \tilde{g}q \;,\; \tilde{g} \rightarrow \tilde{b}\bar{b} \;,\; \tilde{b} \rightarrow b\chi$$

- $m_{gluinos} < m_{squarks}$

$$\tilde{q} \rightarrow \tilde{g}q \;,\; \tilde{g} \rightarrow q\bar{q}\chi$$

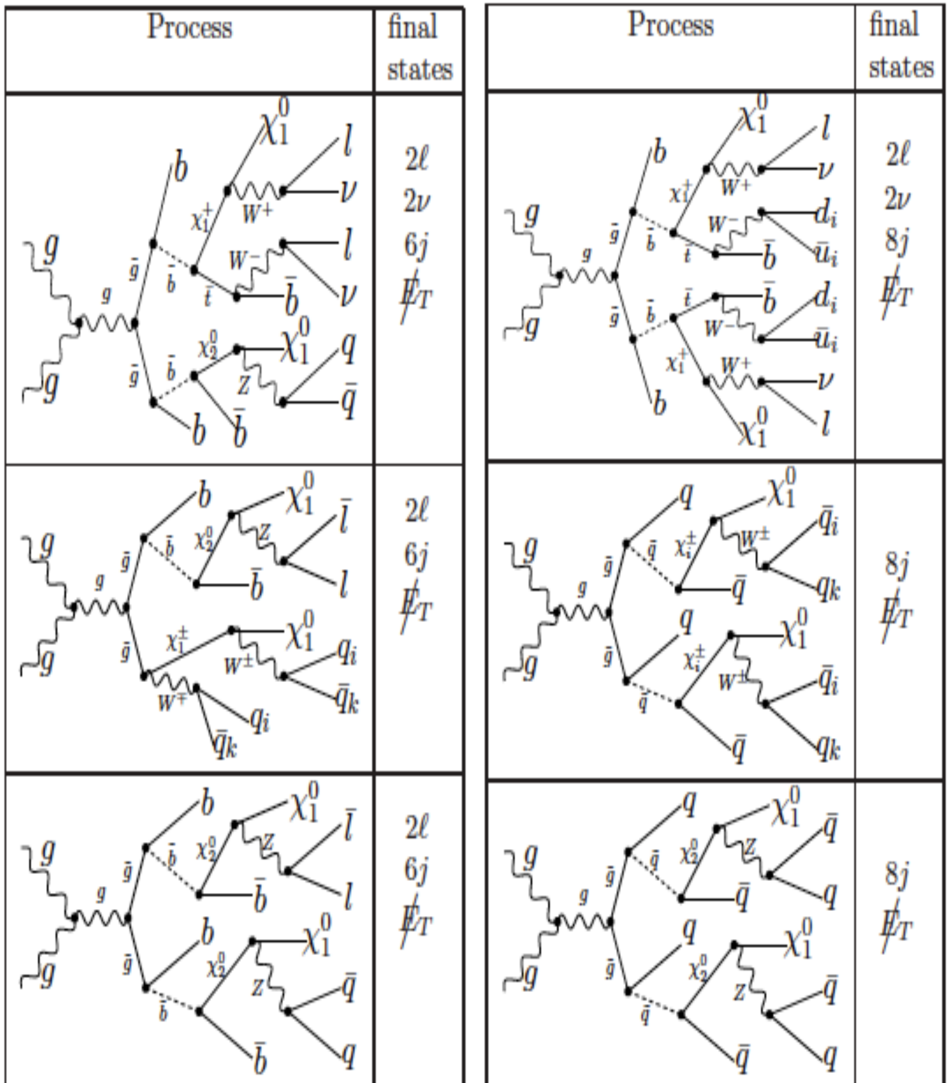
- All these, change out topology’s x-section and efficiency of selection..

SO IN WHICH FINAL-STATE ONE SHOULD LOOK INTO???

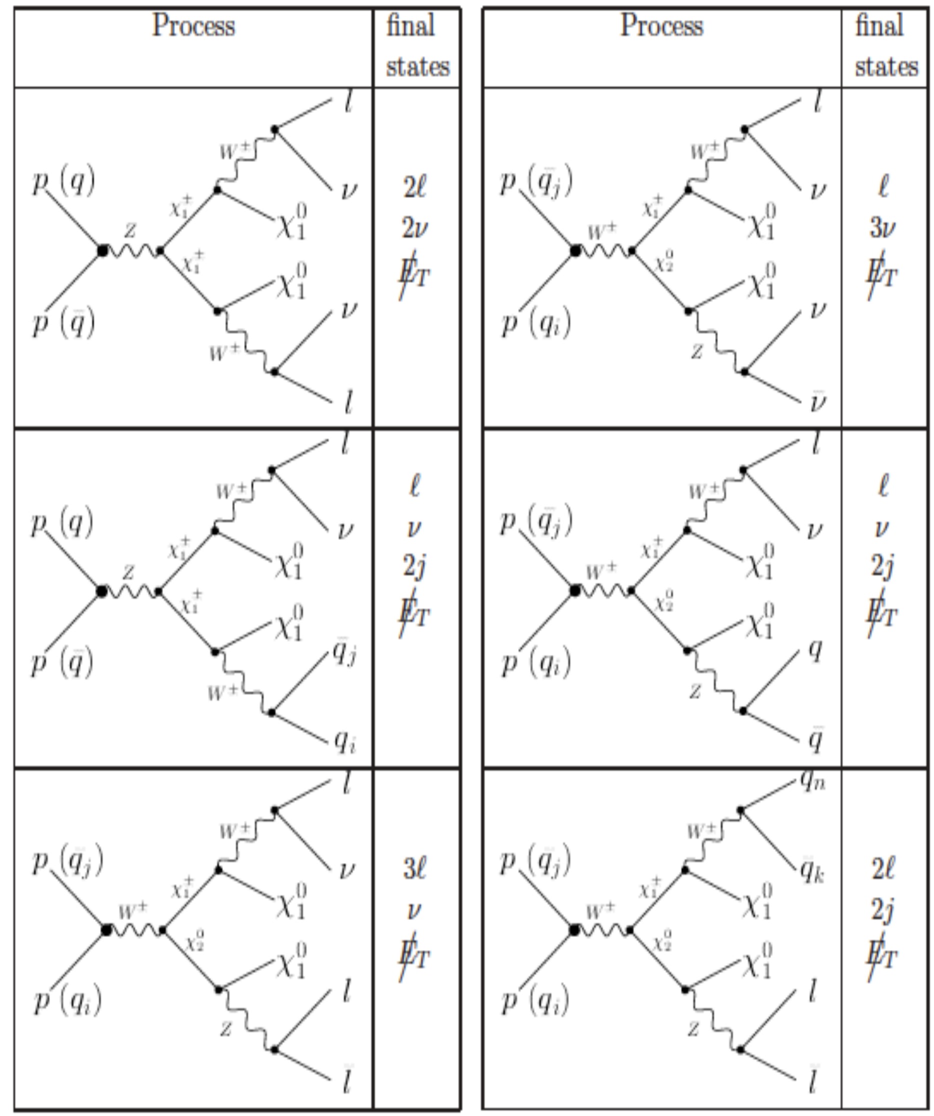


All an experimentalist cares about is final state objects...

Creation of the pair of gluino with further cascade



Creation of the lightest chargino and the second neutralino with further cascade



- SM outline & need for SUSY
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Setting a method using Variables sensitive to New Physics

- Idea remains simple – Scan the p.s. using MC tools and use discriminators/variables to see if they indicate NewPhysics – Compare with Data

  - **Variables** : must be physics-motivated but we can always use trivial ones for cross-checks and sanity tests- Currently, more than 40 variables (kinematic, Reconstructed quantities etc) have been implemented

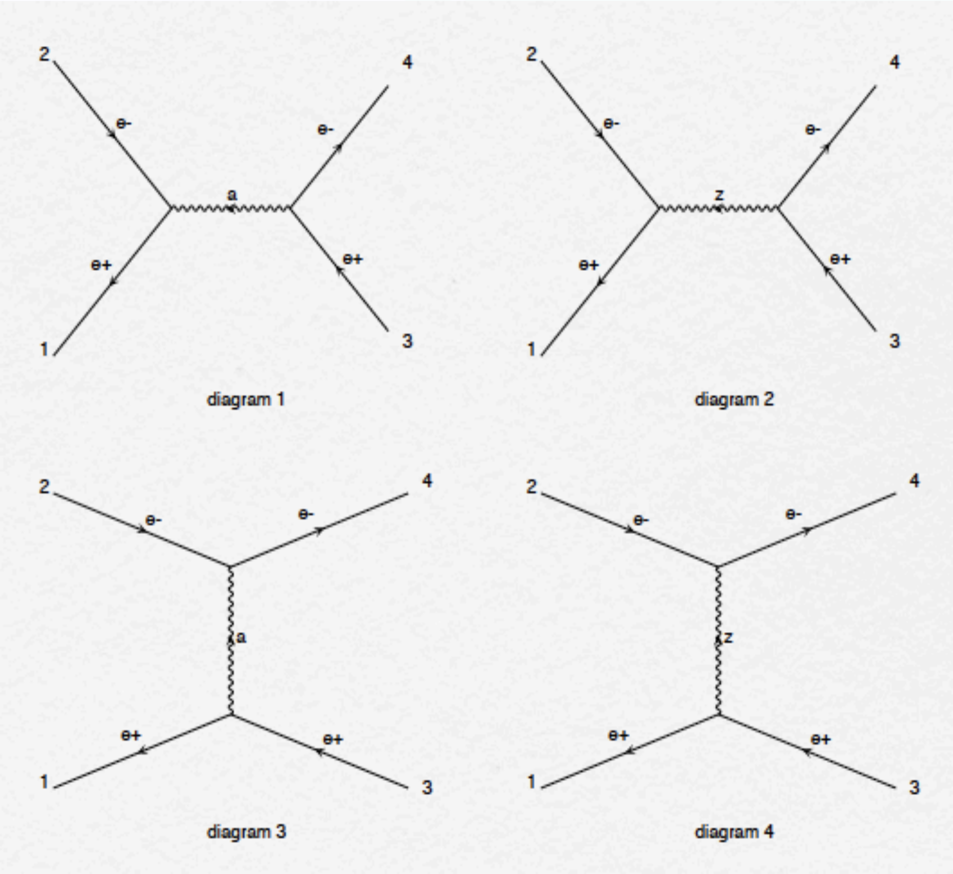
We made use of MadGraph as our event generator for both signal + bkg and Delphes for Simulation

  - Top-Semimuonic channel (but in principle extendable)+ Chi^2 sort for the HadTop
  - Select a proper binning – The choice could be crucial, as this is on which we will compare Data (remember that "excess" depends on what you call MonteCarlo)
  - Make an H_0 (SM/SM+NP) after defining variables. Then sort, reject and & select the most "sensitive" ones...
    - Keypoint *"How one can tell if a variable indicates NewPhysics?"*
      - We need to set criteria how to tag a variable as such... ie where and when stop selecting variables , ($O_i < \varepsilon\ O_1$ or N_{best}) / how to reject high-correlated ones (ρ <0.85)
      - Construct a test statistics and test your hypothesis
  - Finally, draw exclusion limits or claim "discovery"

What is MadGraph?

- MadGraph/MadEvent models particle collisions that take place in particle accelerators. It is a professional research software tool that generates collision data based on the Standard Model (and even more…). Among other things, it calculates cross sections and produces all relevant tree-level diagrams

- Example : e+e-→e+e-
- All possible Feynman diagrams are produced, as well as a number of distributions including invariant mass, momentum, and angular distributions. (Feynman diagrams are show as ps files).
- X-sec calculations : depending on the QED and QCD diagram order you want!
- Direct results:Example --Angular distributions show that when e+ and e- collide, most muons emerge at a low angle relative to the beam line.



Steps for producing CustomScanSamples (CSS) with MatrixElements – Example for MadGraph

Initialization → **Make the gridpack for each point** → **Produce Events in blocks of 20-100k** → **Use Detector Sim like Delphes**

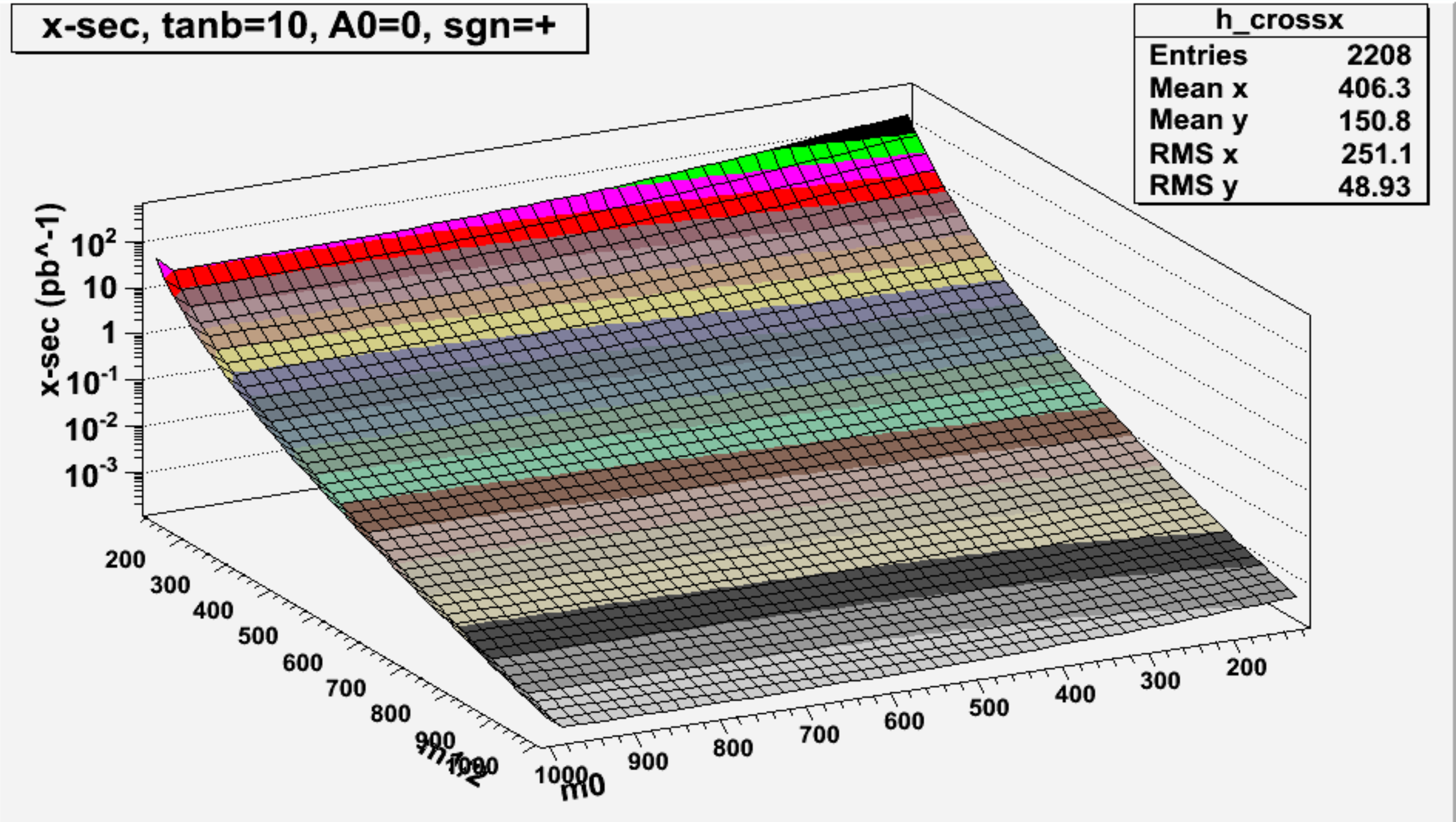
Initialization
- Produce process_card and param_card for each point
  (Not trivial!!!)
- Decay products with SUSYHit – A slha card ready for MG and submission to the grid for the gridpack

Make the gridpack for each point
- ~3-4 hours for each point *7K = 21k h ~ 875days of running time
- one gridpack for every CM energy

Produce Events in blocks of 20-100k
- Run Pythia for Hadronization –ME and Pythia cards in storage area (~1-4hours)
- Every block of 20-100k events, has a rnd # for the seed seq to avoid duplicated events

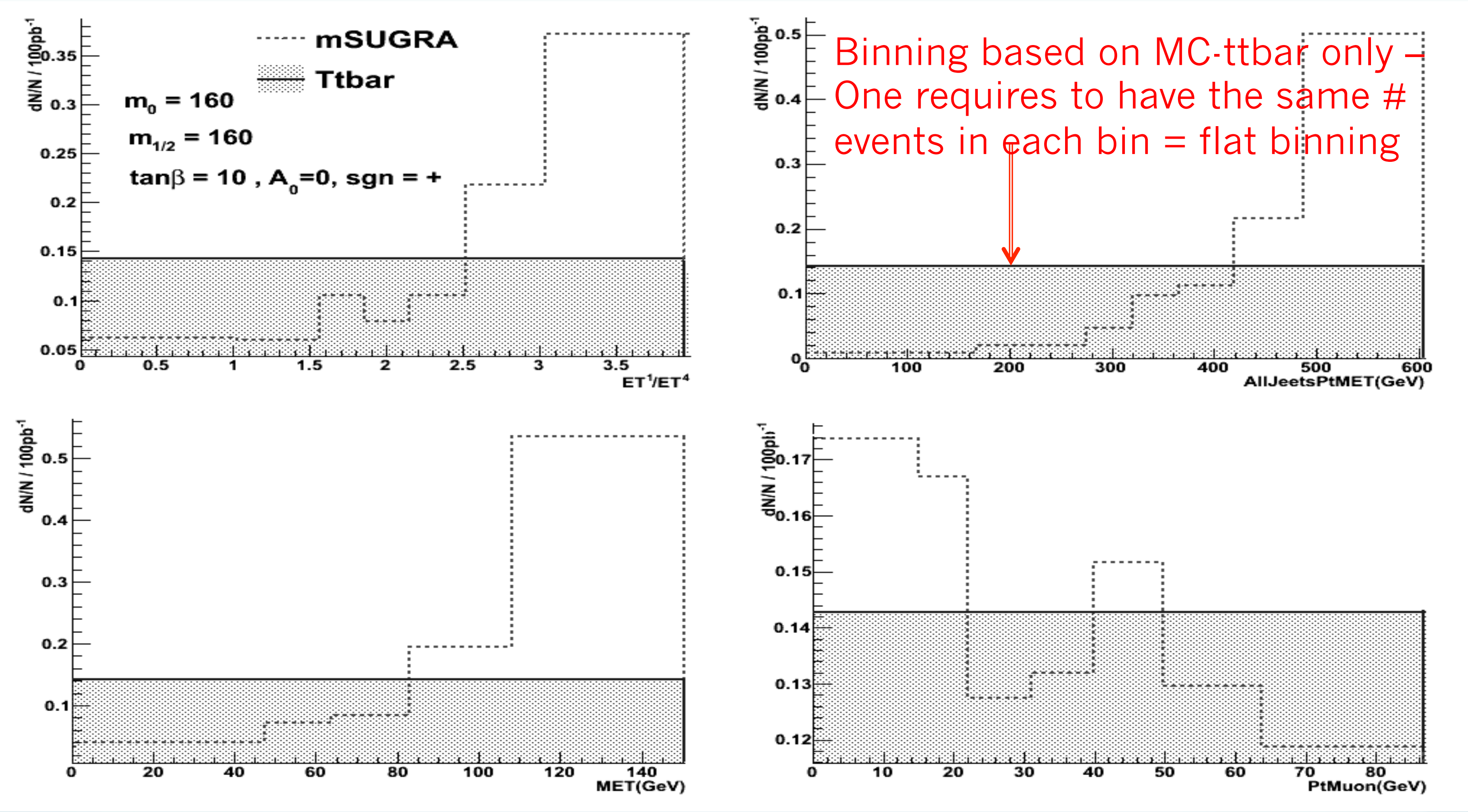
Use Detector Sim like Delphes
- Implement a b-tag param function – IMPORTANT!!!
- Finally, produce an analysis .root file
  (MGTreeProducer on CVS
  UserCode/TopBrussels/MadGraphTreeProducer/

Cross Section for m_0 / $m_{1/2}$ plane



Each point on the grid, represents a produced sample (MG+SUSYhit)-
More than 100M evnts– Close match with the x-sec produced with Pythia (sanity check)

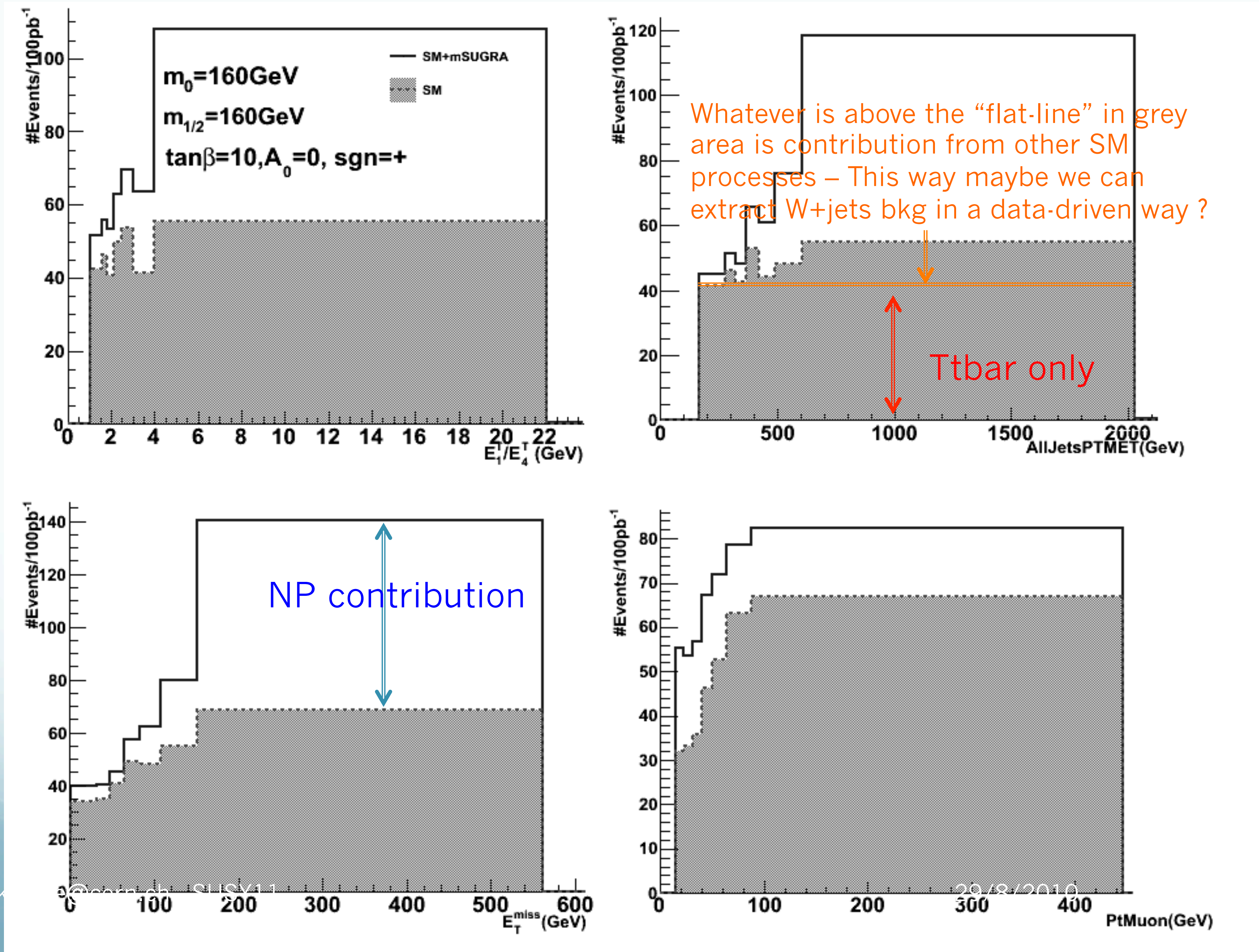
Selecting the correct binning…



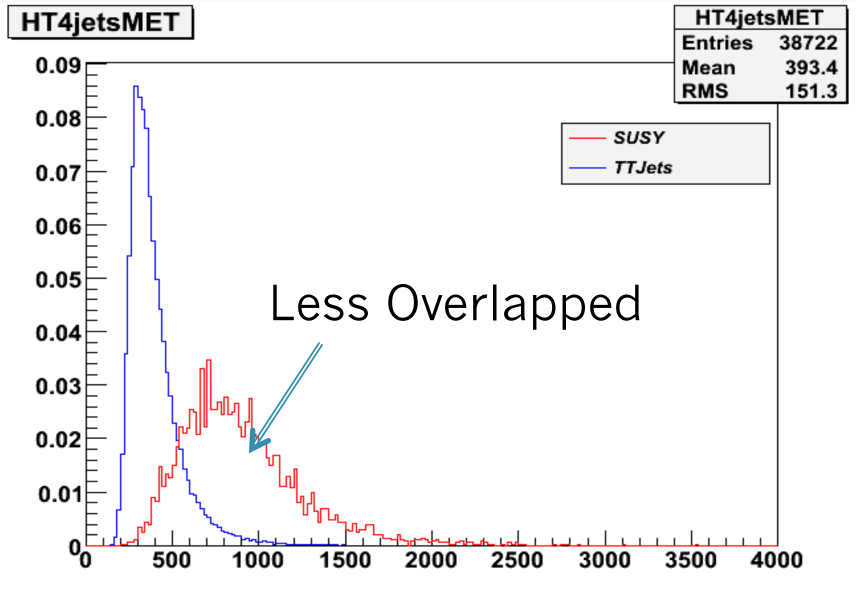
Of course, binning can be chosen in two ways

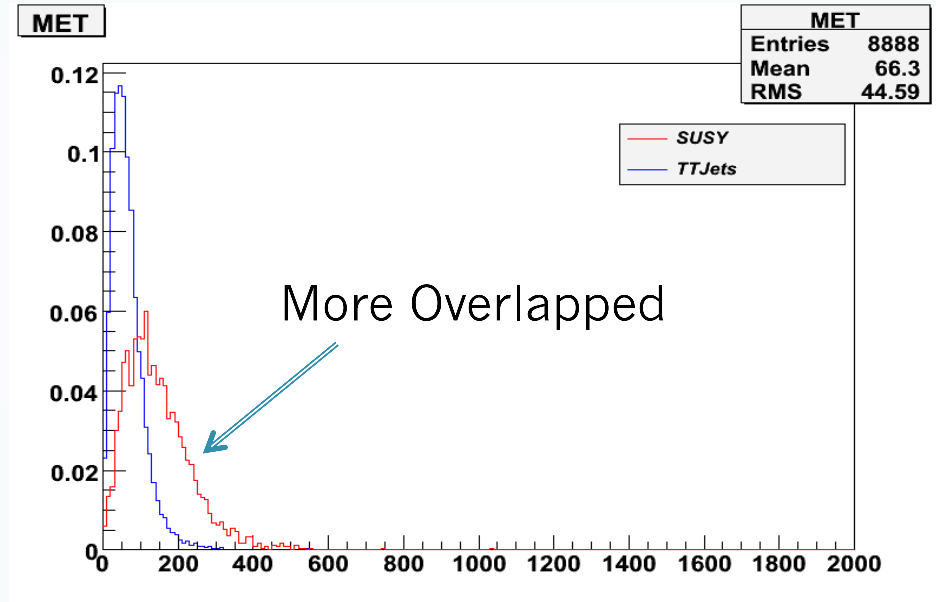
- #events/bin
- Constant # bins

Selecting the correct binning...



Selecting Variables sensitive to New Physics





✓Use the CorFactor. ρ -> remove the high correlated ones and keep the "more sensitive" ones (0.5< ρ <0.9)

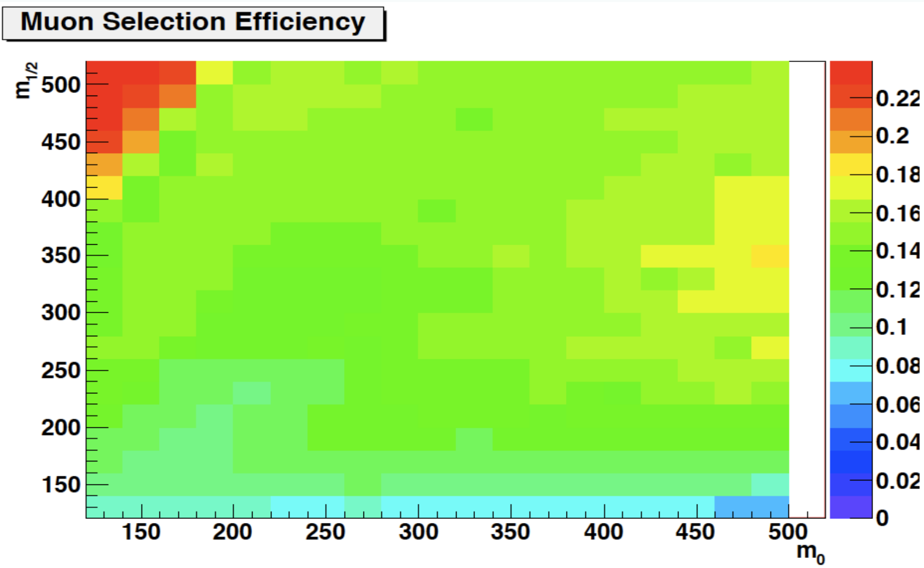
✓Then, sort Variables from most NP-like to more SM-like

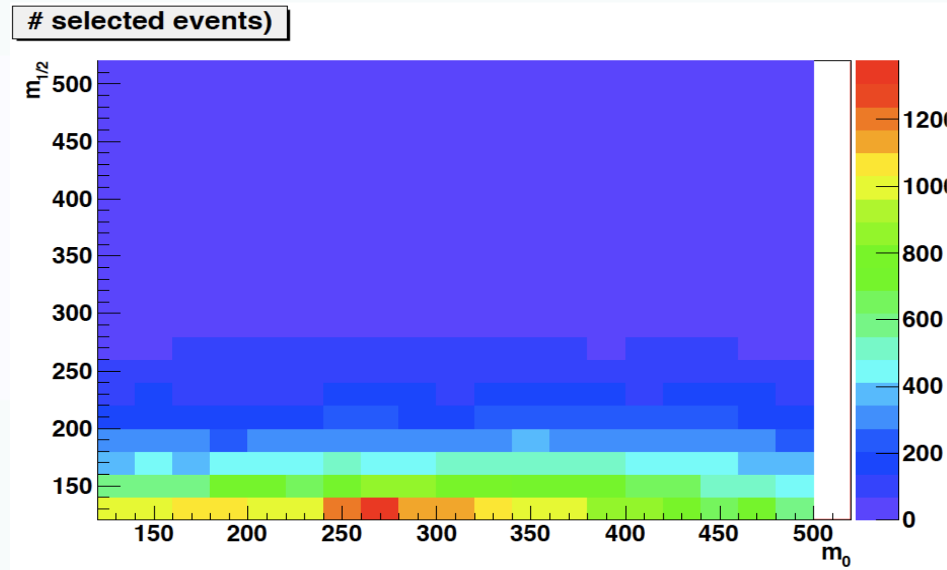
✓less Overlapped shapes, *could* indicate NP

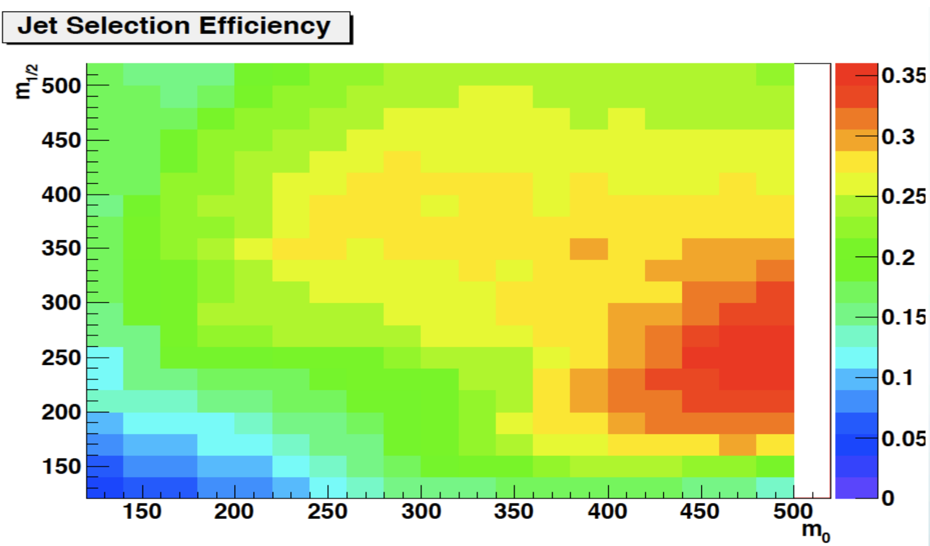
✓You can stop selecting variables with a combination of ρ and ε, ie ε =1.1 means that you stop when the $O_i < 1.1 * O_1$ where

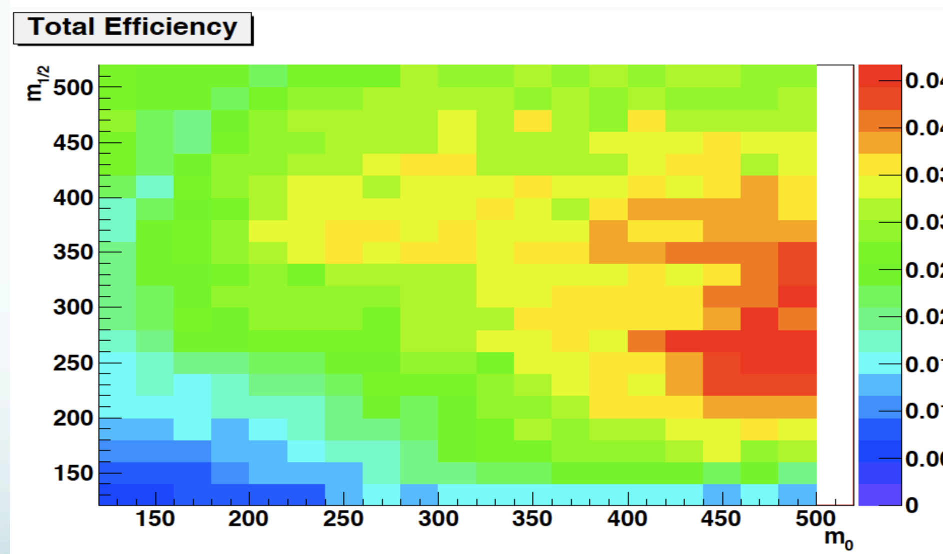
- O_i= overlap of i-th best-variable
- O_1 = overlap of the best-variable (least Overlapped from all variables survived the ρ criterion)
- You can still select just a x% of events falling in the "suspected" NP-region

tt~ + jets (0,1,2,3) (lumi =1fb^{-1}) vs mSUGRA plane









Plots like these, will tell us where is useful to look into..For example, if the selected events are too few, there is no meaning searching there

Selection : 4jets, JetPt>35, Jets|η|<2.4 MuonPt>15, exactly 1mu & 0e^{-}

Some Pattern?

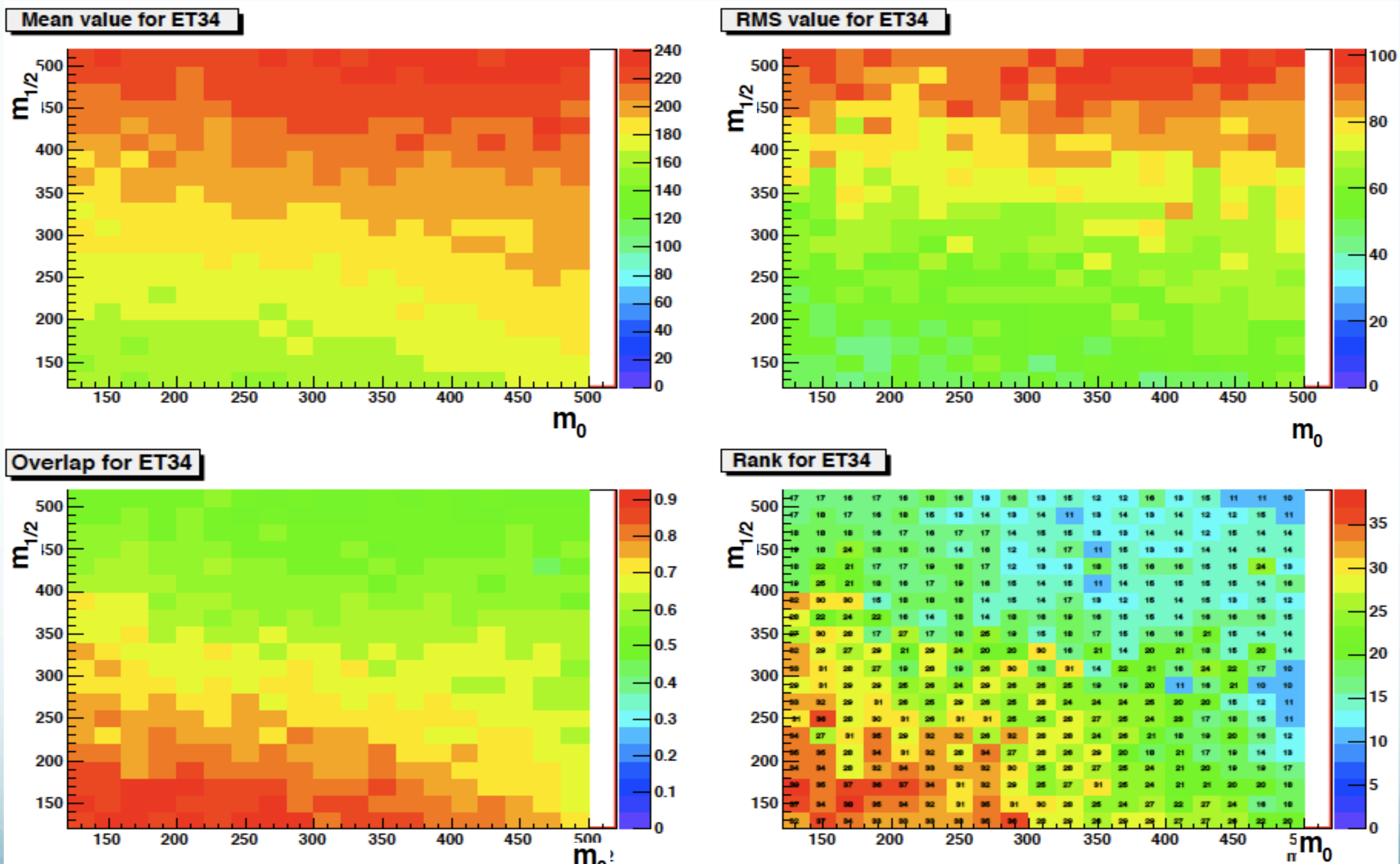
Below 0.20

Above 0.20

Table 1: Overlaping Sorting

Variables LM0	AllJetsPt∉	∉	TrvMasLepT	MyExtendedHT	TrvMasTtbar	ET34	M3	∉DivHadTPt	ET1oET4	ET1oET3
Overlap	0.456702	0.520743	0.597275	0.620544	0.70302	0.7034	0.711882	0.736256	0.743221	0.778221
Variables LM1	HT4jets ∉	∉	MyExtendedHT	TrvMasLepT	TrvMasTtbar	M3	ET1oET4	∉ DivHadTPt	ET34	ET1oET3
Overlap	0.24666	0.259064	0.314822	0.317374	0.401342	0.501336	0.518242	0.581227	0.61327	0.621803
Variables LM2	HT4jets∉	∉	MyExtendedHT	TrvMasLepT	TrvMasTtbar	M3	ET34	ET1oET4	∉DivHadTPt	TrvMasHadT
Overlap	0.167281	0.200437	0.243103	0.257212	0.336212	0.419301	0.488479	0.504423	0.533946	0.584762
Variables LM3	AllJetsPt∉	∉	MyExtendedHT	TrvMasLepT	ET34	TrvMasTtbar	M3	∉DivHadTPt	ET1oET4	ET1oET3
Overlap	0.243554	0.344232	0.417815	0.419969	0.522226	0.52318	0.562532	0.635416	0.638024	0.68653
Variables LM4	AllJetsPt∉	∉	MyExtendedHT	TrvMasLepT	TrvMasTtbar	M3	ET34	ET1oET4	∉DivHadTPt	TrvMasHadT
Overlap	0.211686	0.288301	0.322286	0.331597	0.425591	0.472581	0.49878	0.563475	0.612266	0.640406
Variables LM5	AllJetsPt∉	∉	MyExtendedHT	TrvMasLepT	TrvMasTtbar	M3	ET34	ET1oET4	∉DivHadTPt	TrvMasHadT
Overlap	0.154419	0.230973	0.249012	0.266684	0.405772	0.413222	0.530382	0.573108	0.574999	0.621049
Variables LM6	HT4jets∉	∉	MyExtendedHT	TrvMasLepT	TrvMasTtbar	M3	ET34	ET1oET4	TrvMasHadT	∉DivHadTPt
Overlap	0.123212	0.16856	0.182783	0.197397	0.261304	0.352112	0.447003	0.463029	0.49368	0.551146
Variables LM7	AllJetsPt∉	ET34	MyExtendedHT	∉	TrvMasLepT	M3	TrvMasTtbar	TrvMasHadT	∉DivHadTPt	MassHadT
Overlap	0.248075	0.3967	0.439743	0.44756	0.458956	0.52350	0.529514	0.661647	0.77194	0.778654
Variables LM8	AllJetsPt∉	∉	MyExtendedHT	ET34	TrvMasLepT	TrvMasTtbar	M3	∉DivHadTPt	ET1oET4	TrvMasHadT
Overlap	0.159953	0.291551	0.347404	0.368853	0.371487	0.46683	0.4957	0.601992	0.692489	0.713198
Variables LM9	AllJetsPt∉	ET34	∉	MyExtendedHT	TrvMasLepT	M3	TrvMasTtbar	TrvMasHadT	∉DivHadTPt	ET1oET4
Overlap	0.32799	0.494484	0.522056	0.534156	0.546007	0.61395	0.623175	0.742692	0.79227	0.796575
Variables LM10	∉	TrvMasLepT	MyExtendedHT	HT4jets ∉	TrvMasTtbar	∉DivHadTPt	ET34	M3	TrvMasHadT	Centrality
Overlap	0.44754	0.51061	0.537415	0.544251	0.610436	0.634061	0.677907	0.689586	0.739271	0.76698

How to use the plots...

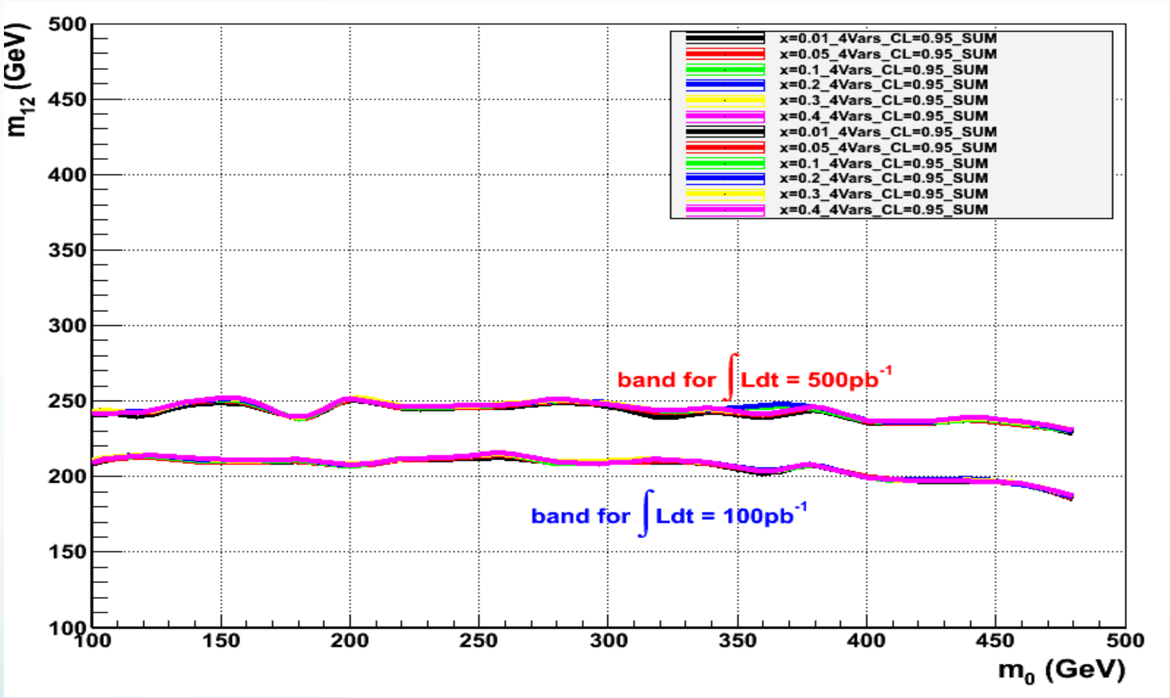


- You get plots like these for all the variables
- Makes really easy to see the evolution of each variable

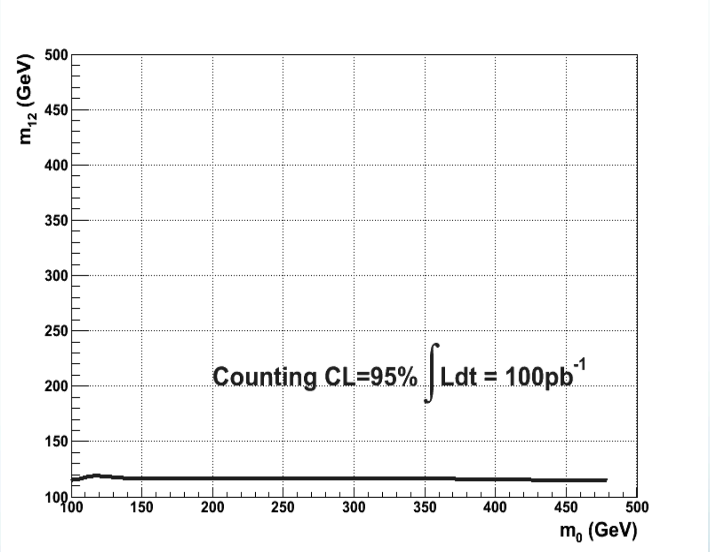
Different "running" modes

Alternatively, one could inject a preselected number of variables, like

- Any given number of "frozen" variables
  - For example, scan all the p.s. with just MET, AllJetsPTMET, PtMuon and ET_1/ET_4

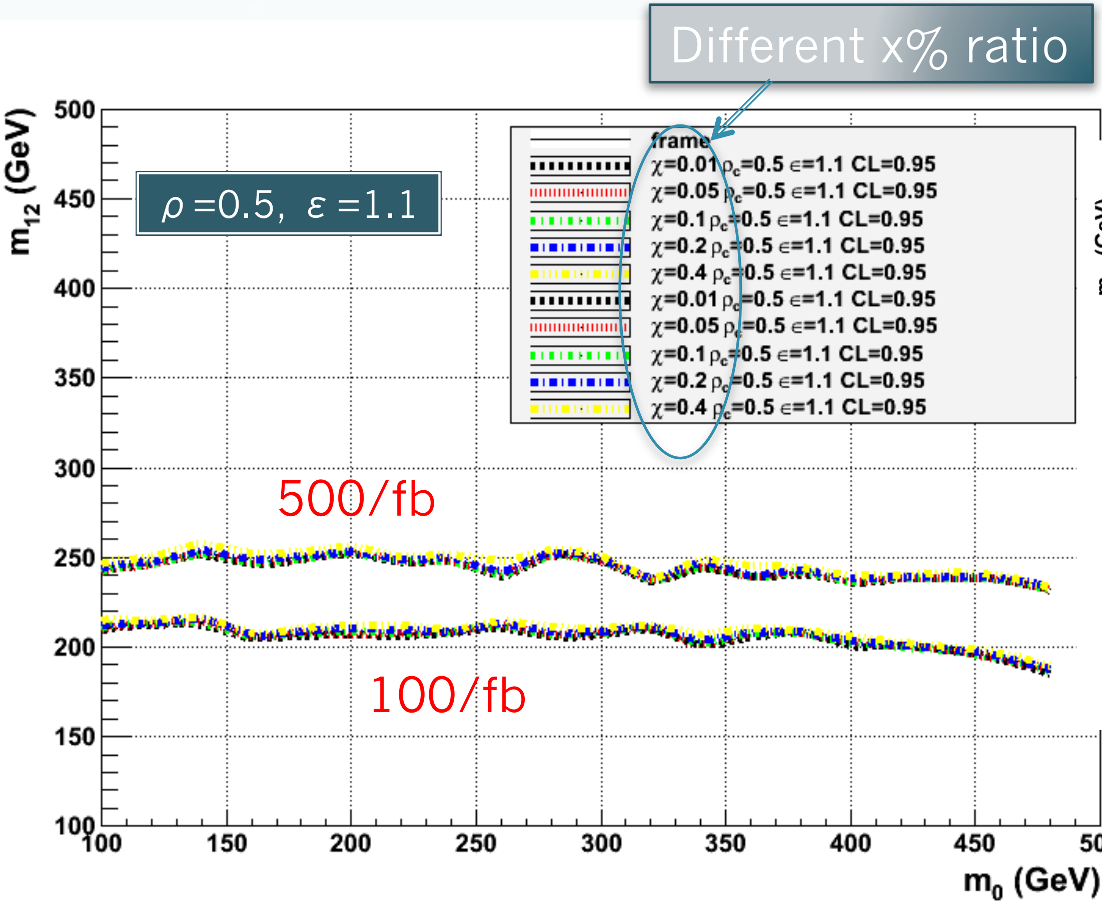


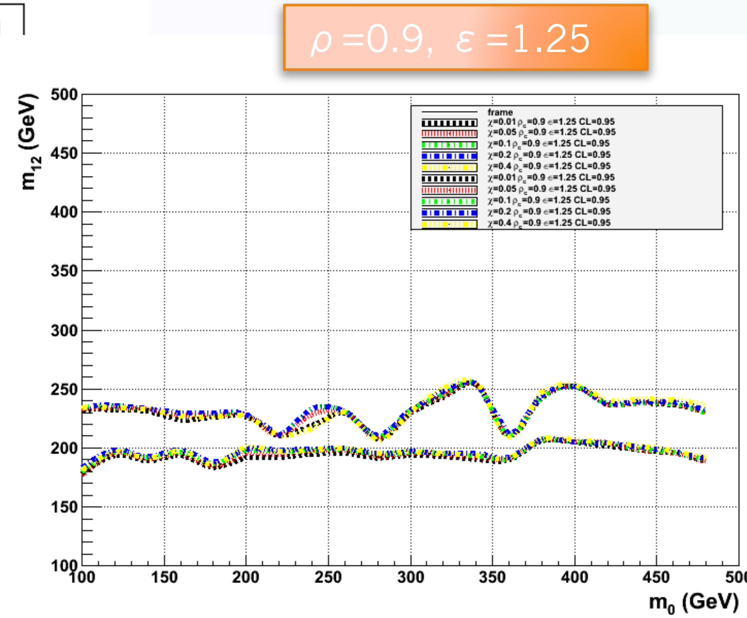
A simple fast-and-dirty comparison wrt to a simple counting experiment

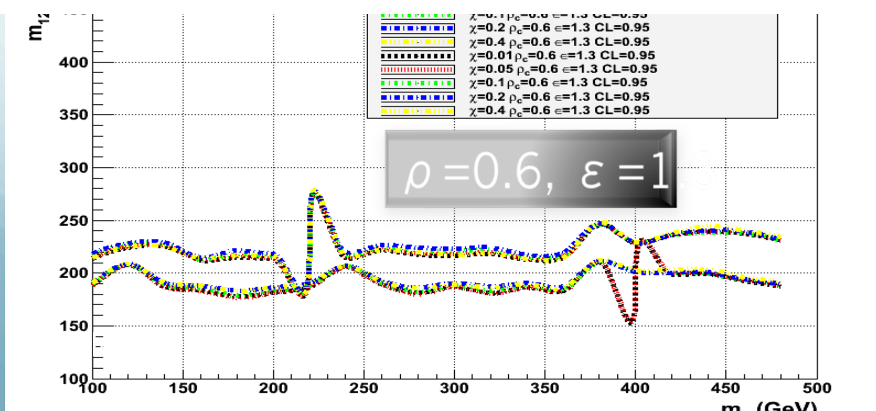


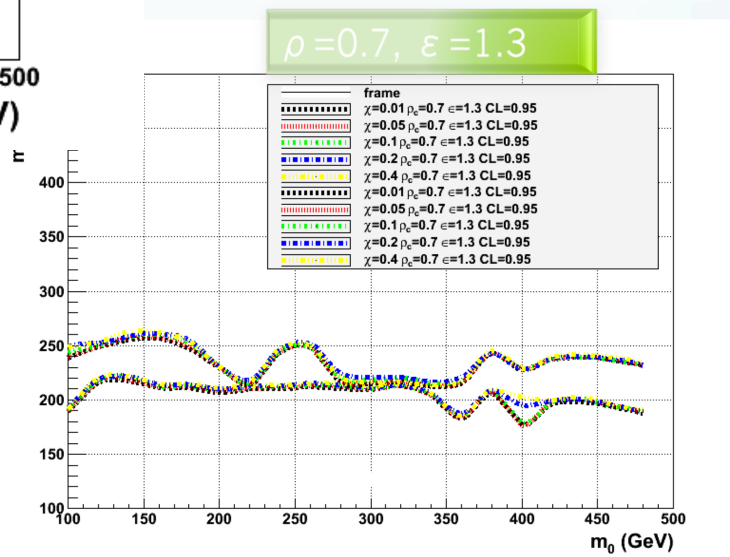
- Or, just request to always run on the *N-best* variables for every $m_0/m_{1/2}$ point
  - For example for $m_0/m_{1/2}$ (200,400) these could be MET, AllJetsPTMET, JetPt1, TTbarMt but for the $m_0/m_{1/2}$ (260,500) could be MET, AllJetsPTMET, ET1/ET4,M3)

And some more plots









Conclusions and plans..

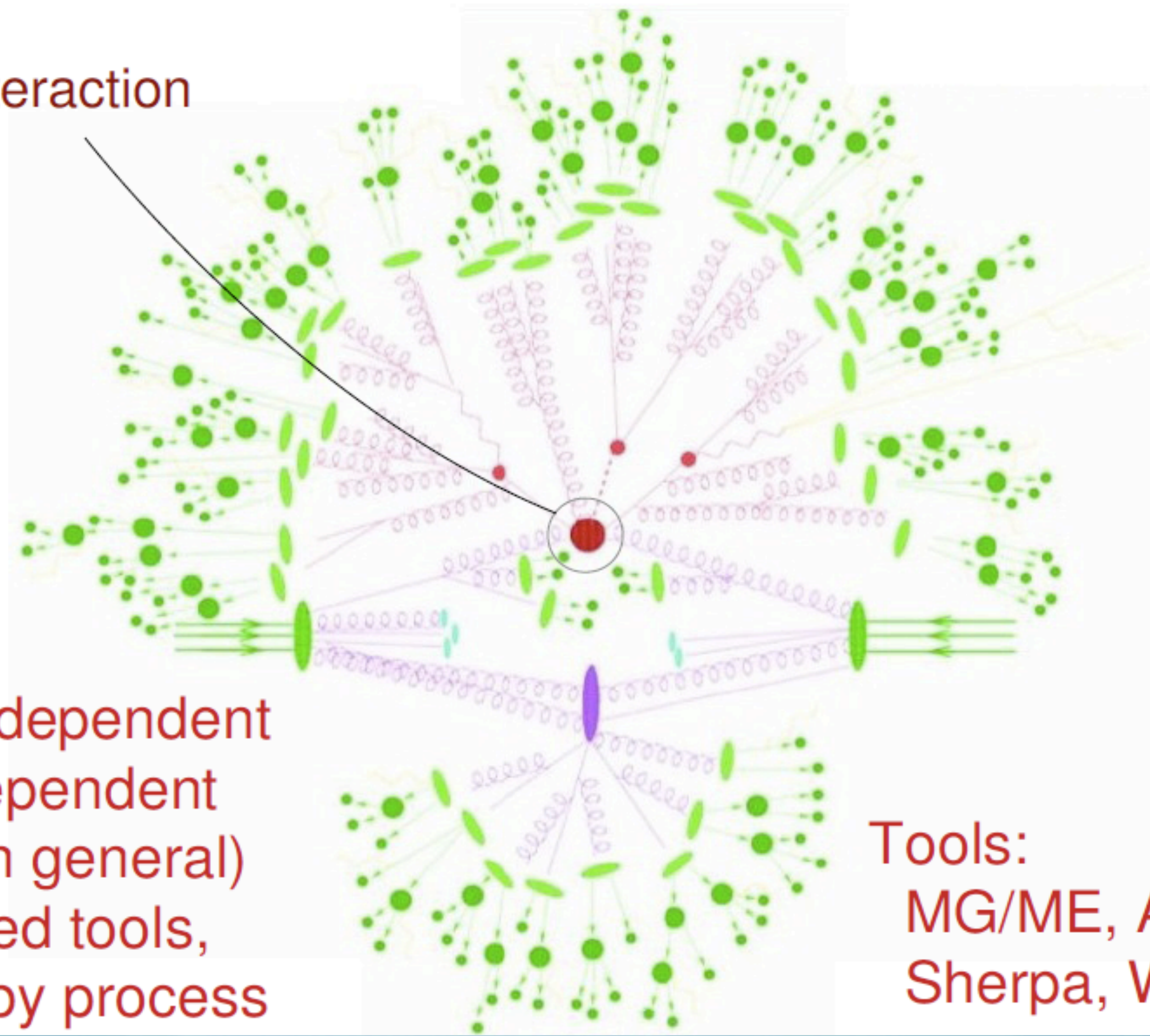
- Most of on-going studies, are performed for in narrowed region of the phase space while available phase space is “huge” – so, this is good sea to dive-in for some “pearls”..

- This analysis is being perfomed at 7TeV(for now) with the use of MG for the MonteCarlo for both signal+ bkg and Delphes for Detector Simulation

- In one line, is all about designing observables, sort-clean-rank them, and make exclusion plots with the use of a test statistics like gof
  - Freedom to choose different configs for the 5 mSUGRA params
  - Freedom to select from “fixed” variables or #best-discrimating ones, or from a combination of ρ + ε
  - Tested on Top-semimuonic topology for now – Aiming to test it on top-inclusive and even more generic topologies in the near future.

BackUps

Elements of a simulation



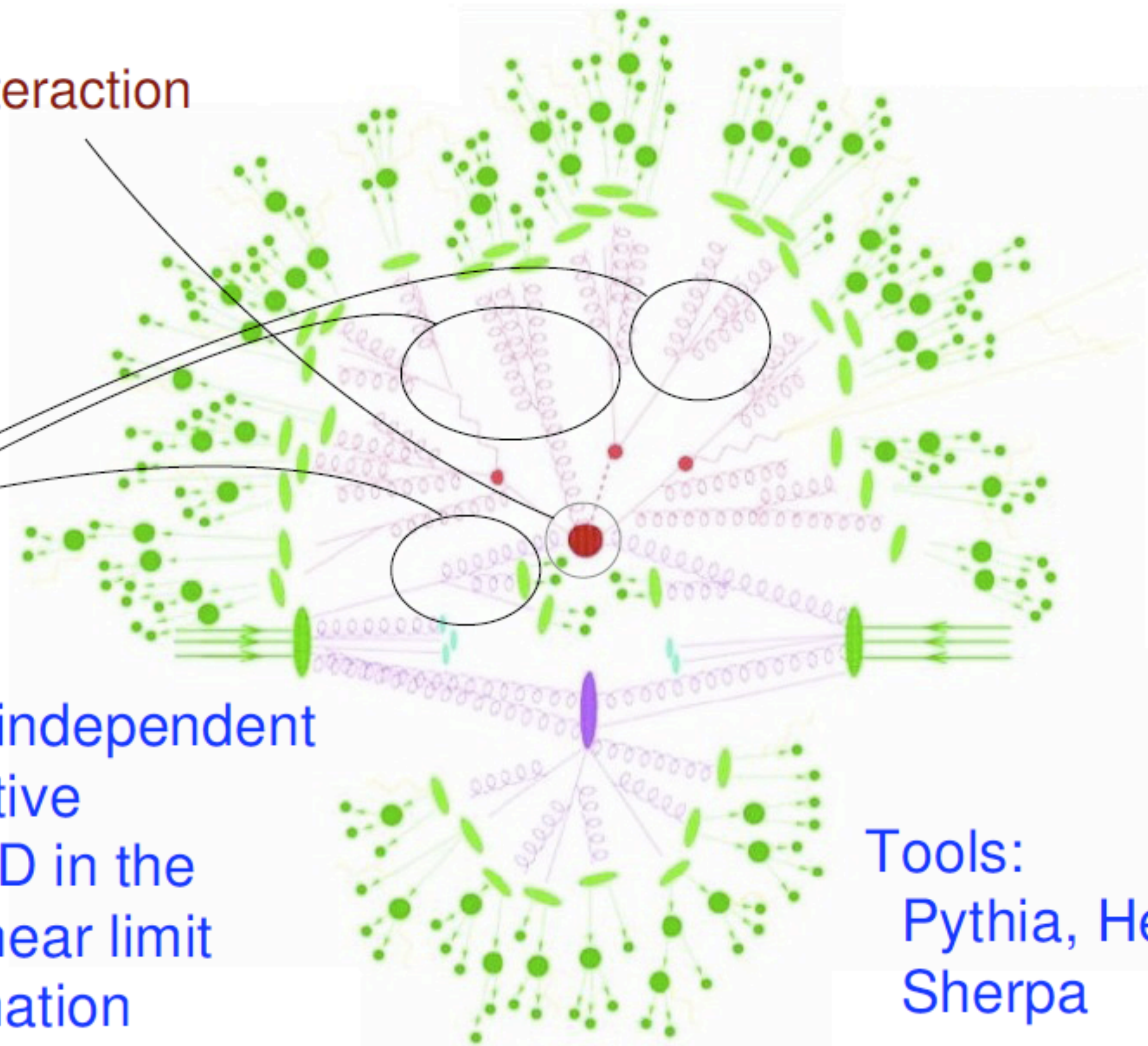
- Process dependent
- Model dependent
- Needs (in general) specialized tools, process by process

Tools:
MG/ME, AlpGen, Sherpa, Whizard, ...

Elements of a simulation

1. Hard interaction

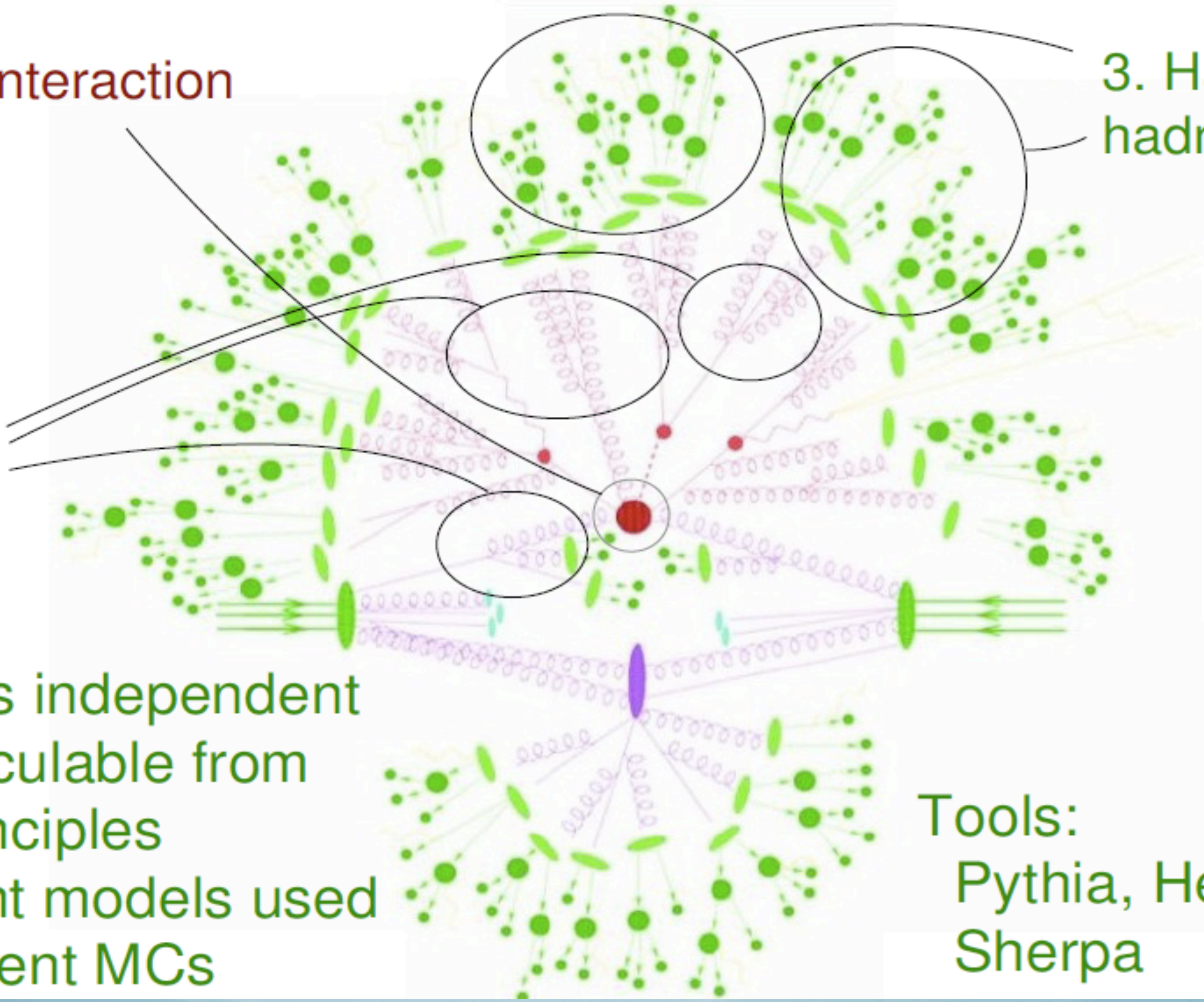
2. Parton showers



- Process independent
- Purturbative QCD/QED in the soft/collinear limit approximation

Tools:
Pythia, Herwig, Sherpa

Elements of a simulation



- Process independent
- Not calculable from first principles
- Different models used in different MCs

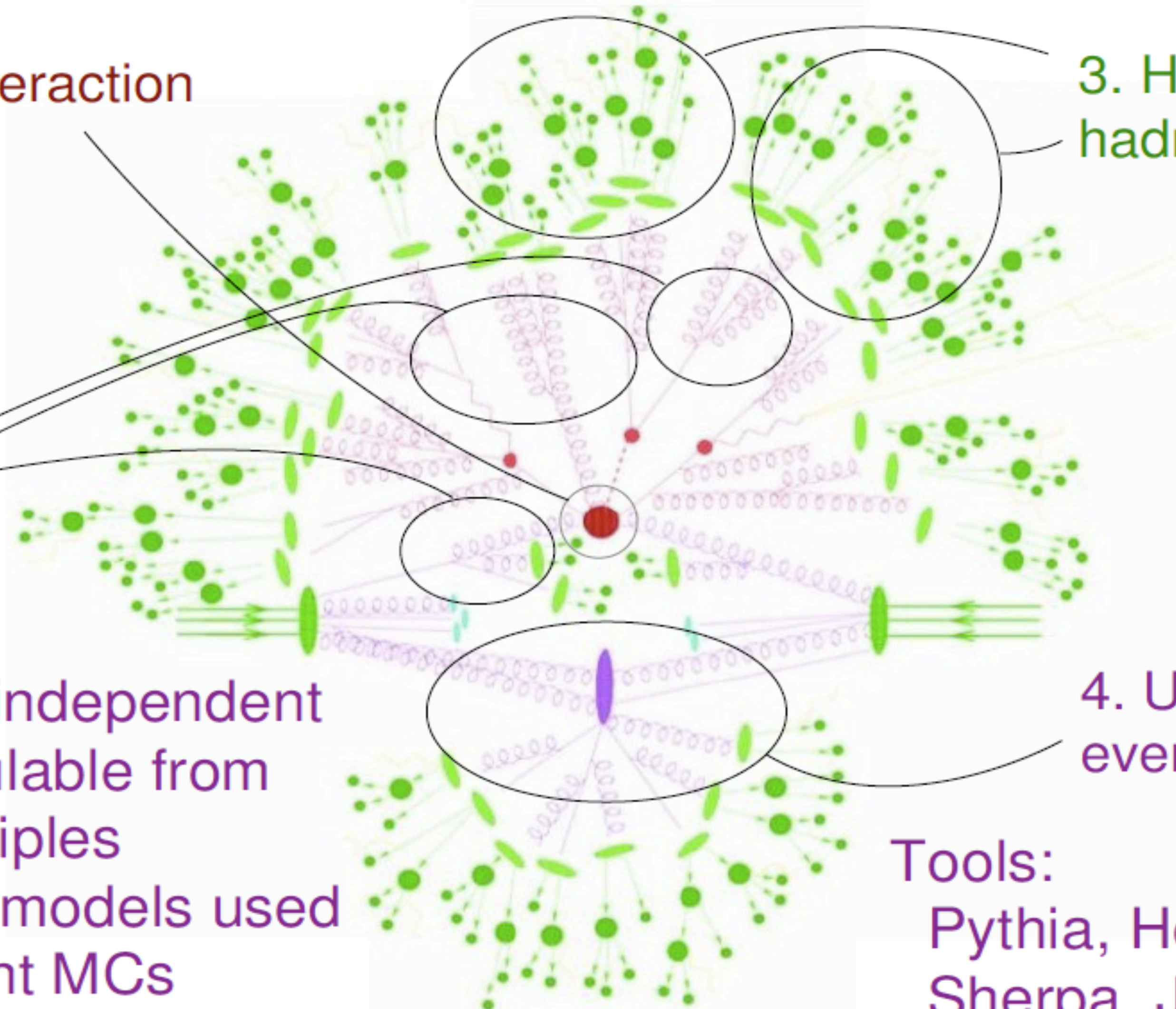
Tools:
Pythia, Herwig, Sherpa

Elements of a simulation

1. Hard interaction

2. Parton showers

3. Hadronization, hadron decay



4. Underlying event

- Process independent
- Not calculable from first principles
- Different models used in different MCs

Tools:
Pythia, Herwig, Sherpa, Jimmy, ...

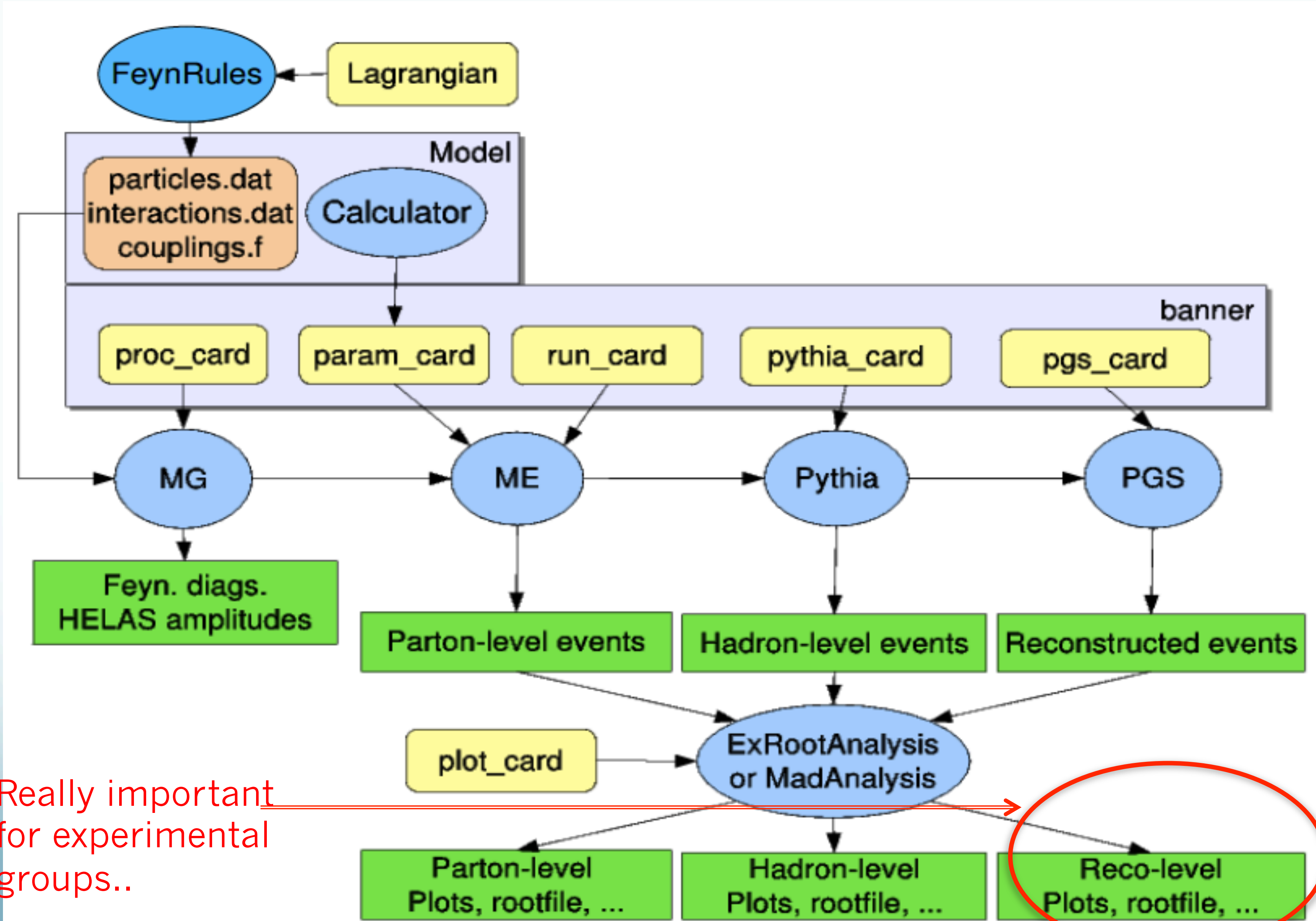
MG

- Diagram Generation
- Amplitude (Helas)
- Link to set of pck (MadDipole, MadFKS, MadWeight)

MadEvent

- Cross Section
- Distribution & Events
- Quarkonium
- Matching

Madgraph workflow..

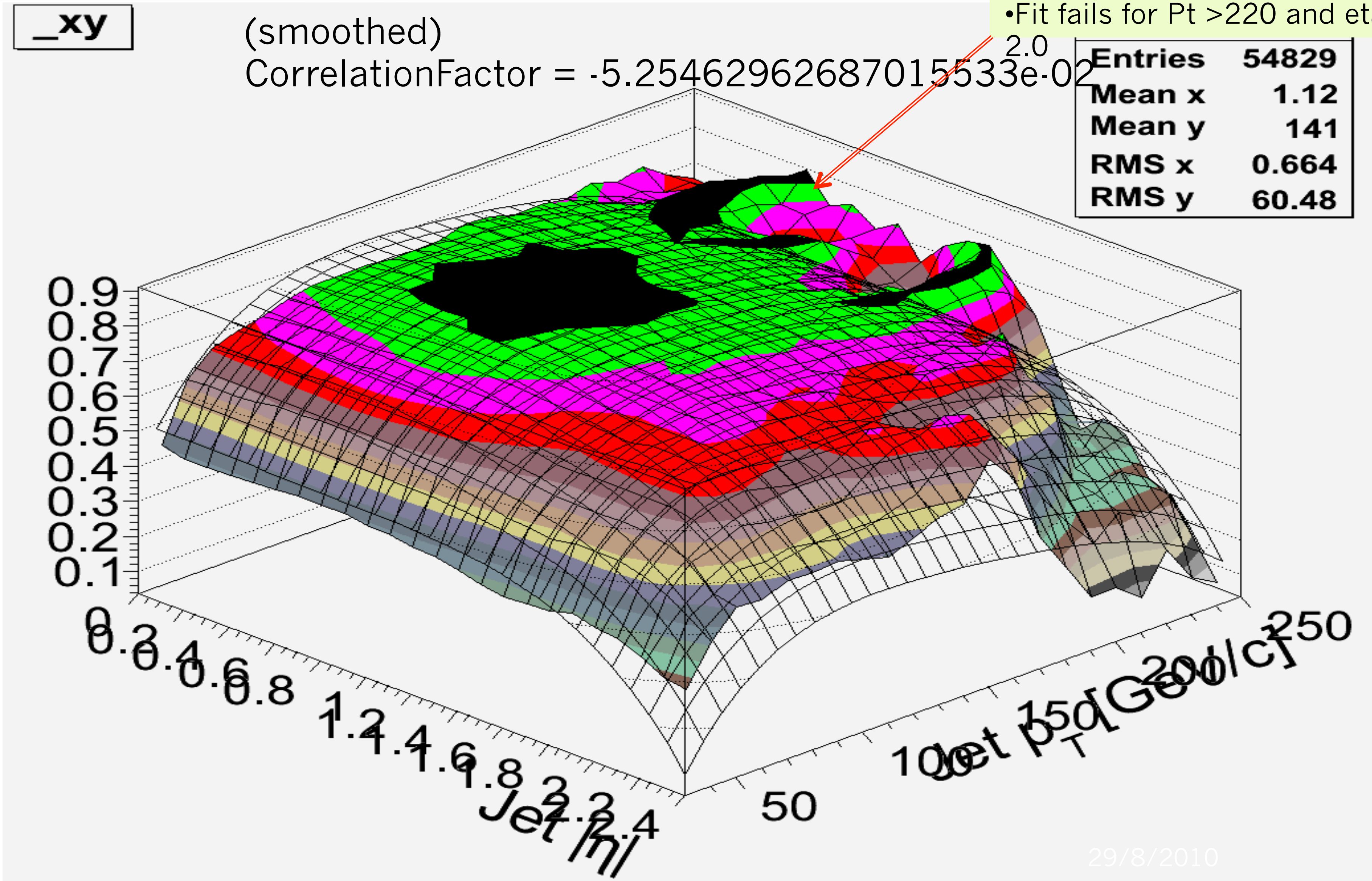


Really important for experimental groups..

Just some variables...

Variable	Description
	Individual object kinematics
$p_T(\text{jet1}_{\text{tagged}})$	Transverse momentum of the leading tagged jet
$p_T(\text{jet1}_{\text{untagged}})$	Transverse momentum of the leading untagged jet
$p_T(\text{jet2}_{\text{untagged}})$	Transverse momentum of the second untagged jet
$p_T(\text{jet1}_{\text{non-best}})$	Transverse momentum of the leading non-best jet
$p_T(\text{jet2}_{\text{non-best}})$	Transverse momentum of the second non-best jet
	Global event kinematics
$\sqrt{\hat{s}}$	Invariant mass of all final state objects
$p_T(\text{jet1},\text{jet2})$	Transverse momentum of the two leading jets
$M_T(\text{jet1},\text{jet2})$	Transverse mass of the two leading jets
$M(\text{alljets})$	Invariant mass of all jets
$H_T(\text{alljets})$	Sum of the transverse energies of all jets
$p_T(\text{alljets} - \text{jet1}_{\text{tagged}})$	Transverse momentum of all jets excluding the leading tagged jet
$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	Invariant mass of all jets excluding the leading tagged jet
$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	Sum of the energies of all jets excluding the leading tagged jet
$H_T(\text{alljets} - \text{jet1}_{\text{tagged}})$	Sum of the transverse energies of all jets excluding the leading tagged jet
$M(W,\text{jet1}_{\text{tagged}})$	Invariant mass of the reconstructed top quark using the leading tagged jet
$M(\text{alljets} - \text{jet}_{\text{best}})$	Invariant mass of all jets excluding the best jet
$H(\text{alljets} - \text{jet}_{\text{best}})$	Sum of the energies of all jets excluding the best jet
$H_T(\text{alljets} - \text{jet}_{\text{best}})$	Sum of the transverse energies of all jets excluding the best jet
$M(W,\text{jet}_{\text{best}})$	Invariant mass of the reconstructed top quark using the best jet
	Angular variables
$\eta(\text{jet1}_{\text{untagged}}) \times Q_\ell$	Pseudorapidity of the leading untagged jet × lepton charge
$\Delta\mathcal{R}(\text{jet1},\text{jet2})$	Angular separation between the leading two jets the top quark with the best jet
$\cos(\text{alljets},\text{jet1}_{\text{tagged}})_{\text{alljets}}$	Cosine of the angle between the leading tagged jet and the alljets system in the alljets rest frame
$\cos(\text{alljets},\text{jet}_{\text{non-best}})_{\text{alljets}}$	Cosine of the angle between the leading non-best jet and the alljets system in the alljets rest frame

B-tag param functions for Delphes



•Fit fails for Pt >220 and eta > 2.0