Neutralino to Gravitino + Gamma:

Gauge Mediated Supersymmetry Breaking at the LHC

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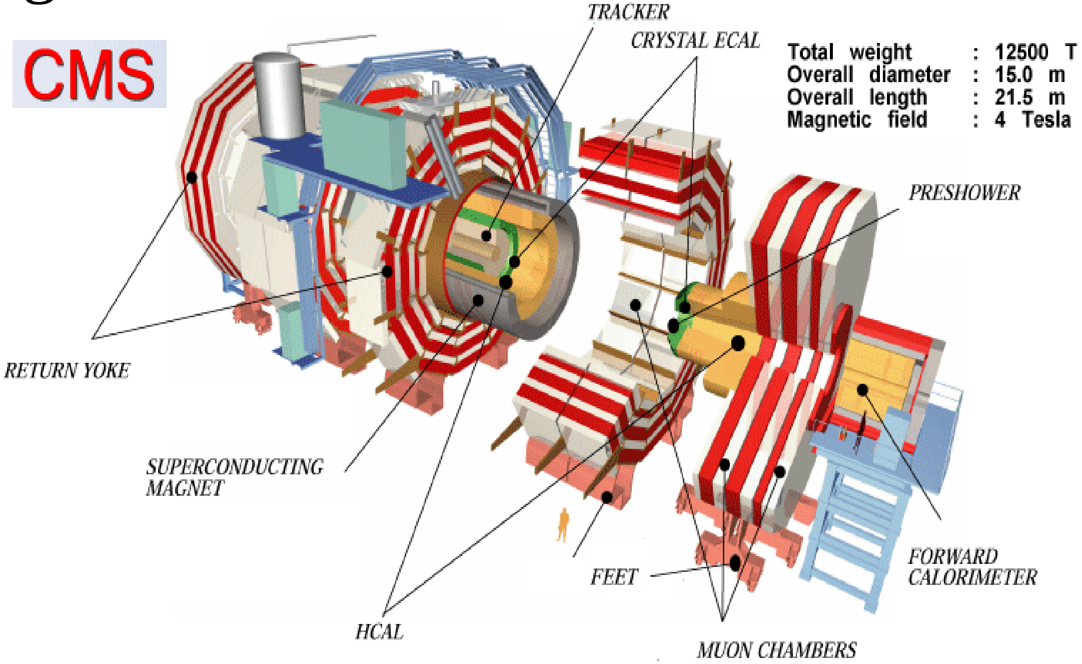
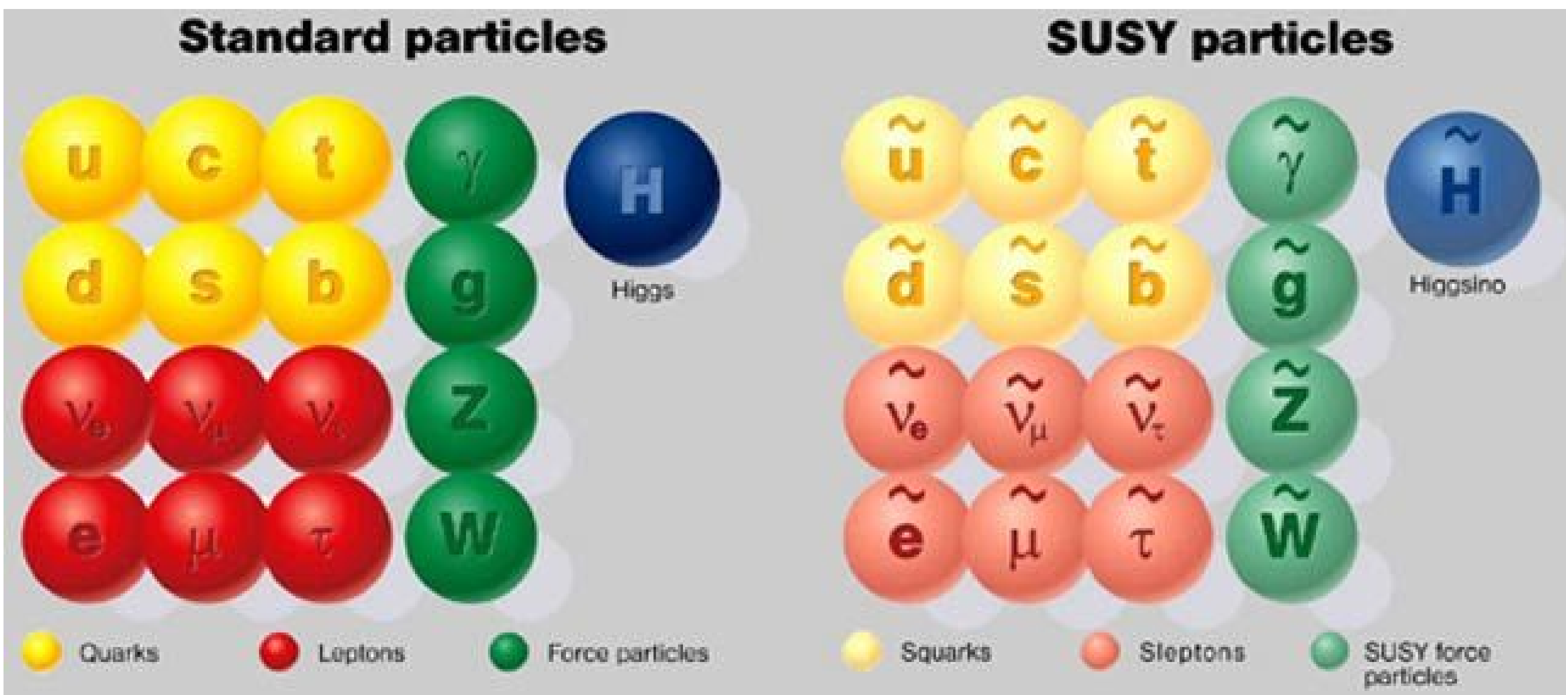
Compact Muon Solenoid Experiment

- The CMS experiment is one of the two general purpose detectors designed to search for new physics at the LHC.
- Together with ATLAS, CMS will study proton–proton collisions at the highest energies ever realized in the laboratory and sift through billions of events to find a handful of unusual ones.
- These events may set the course of our understanding of space and matter for decades to come.



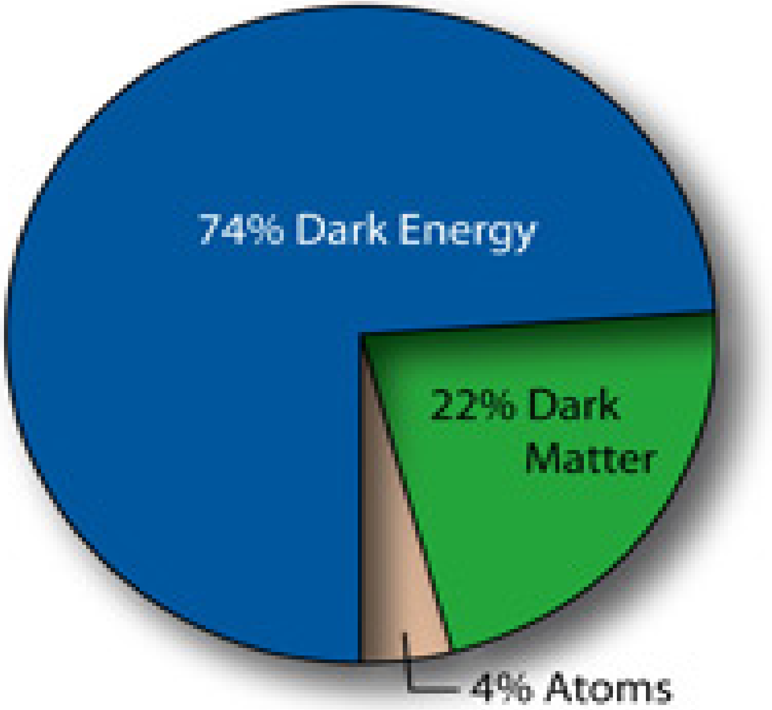
Supersymmetry

- Supersymmetry is a symmetry that relates elementary particles of one spin to another particle that differs by half a unit of spin and are known as superpartners.



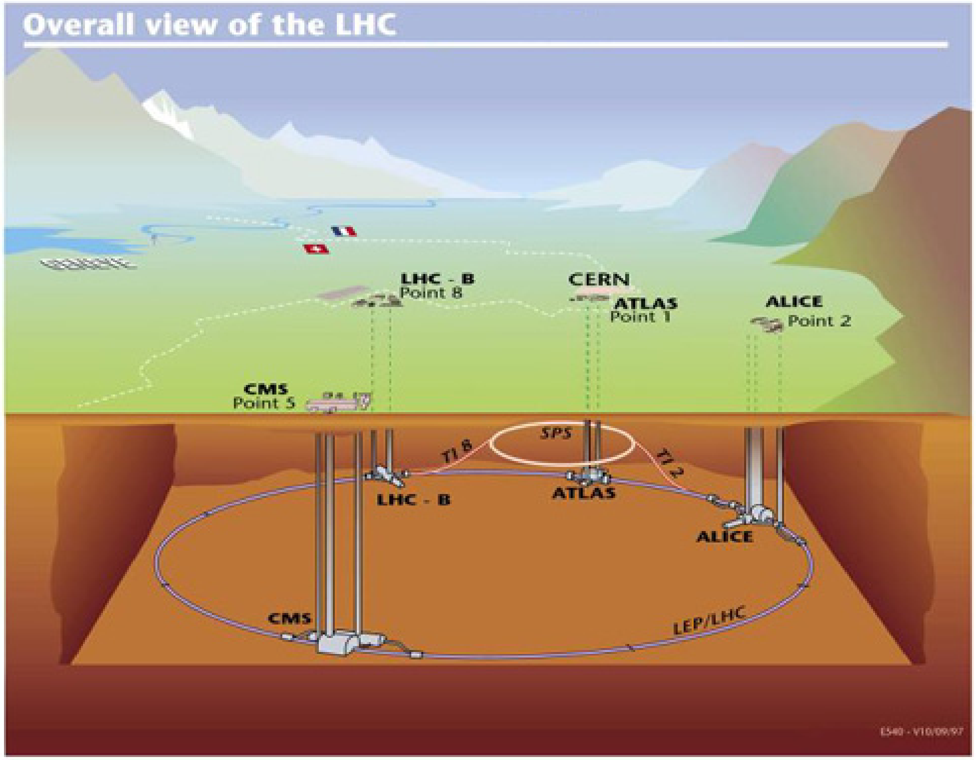
Why the Gravitino?

- Believed to be the Lightest Supersymmetric Particle (LSP) in the Gauge Mediated Susy Breaking Model.
- It is a neutral, colorless and a super weakly interacting massive particle (S-WIMP)
- The combination of these properties makes it a very good candidate for dark matter.



Why GMSB?

- Gravitino dark matter is only possibility in supersymmetric models in which the scale of supersymmetry breaking is low, about 100 TeV, which is true of GMSB.



- This scale is also that which can be probed at the LHC at CERN.

GMSB Parameters

- Λ - SUSY breaking scale
- M_m - Messenger mass scale
- $\tan\beta$ - Ratio of Higgs Vacuum Expectation Value
- N_m - Number of SU(5) messenger multiplets
- Sign(μ) - μ from Higgs sector
- C_{grav} - Sets NSLP lifetime

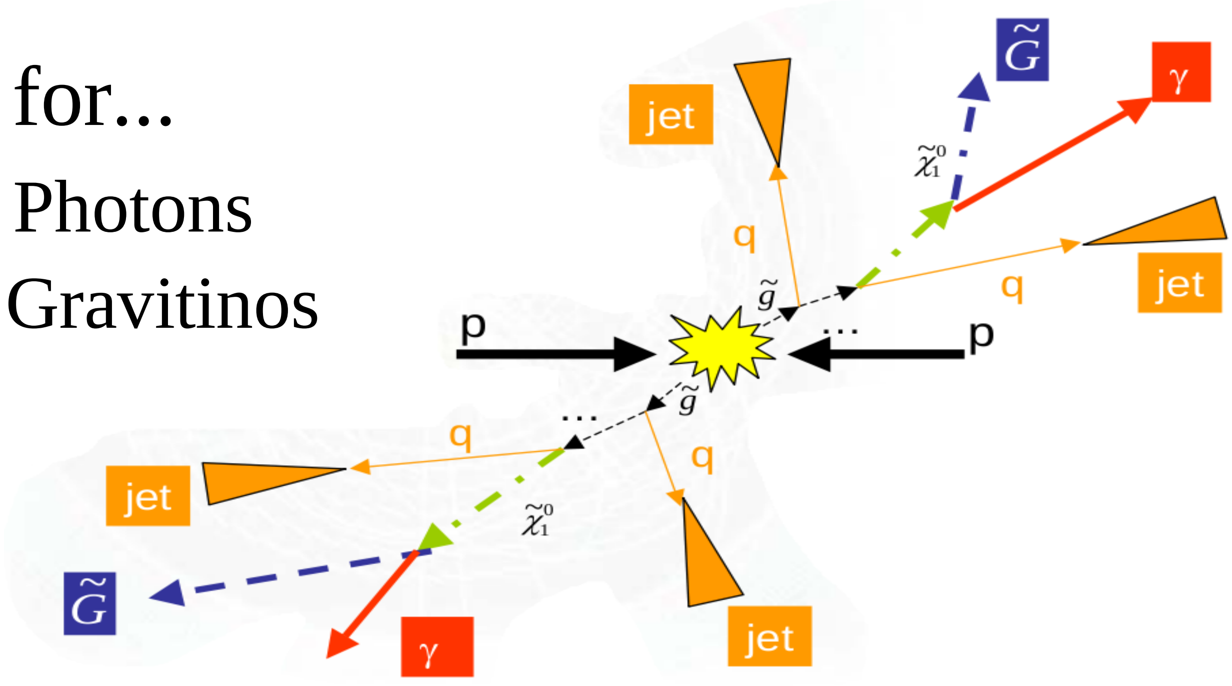
Why Neutralino Decays?

- In GMSB models the gravitino is very light, of order of an eV and interacts very weakly with our detector.
- Also, direct thermal production after the big bang is too inefficient to account for the observed dark matter abundance.
- Rather, gravitinos would have to be produced through the decay of the next-to-lightest supersymmetric particle (NLSP).
- The NLSP is predicted by GMSB to be neutralino.

$\tilde{\chi}^0 \rightarrow \tilde{G}\gamma$ Signature

- Neutrailnos are pair produced and predominantly decay to a Gravitino plus a high energy Photon.

- We are looking for...
  - 2 High Energy Photons
  - MET from the Gravitinos



Goal

- To find a set of cuts that would optimally identify signal events at a high level of data analysis.
- Thus allowing the quick formation of candidate events to which further analysis can be applied.
- The more sophisticated cuts can then be better optimized to cutting background that is more likely to be faking signal.

Data

- Monte Carlo: Pythia + GEANT + CMSSW (with Detector Effect Estimates)
- Signal Monte Carlo Set:
  - GMSB 1e
    - σ=450 fb^{-1}, Λ=140 TeV, $c\tau$=0, M=2Λ, tanβ=15, n=1, sign(μ)=+1
  - 7,198 Events (post-preselection, see next slide)
  - 413 Integrated Events at one fb^{-1} post trigger (one year at the LHC)
- Background Monte Carlo (Pythia + GEANT) Sets:
  - W+Jets, Z+Jets and ttbar +Jets
  - QCD: Regular and Lepton Enriched
  - Photon + Jets
  - Various Exotic (New Physics) Processes
  - 416,002 Events (post-preselection, see next slide)
  - 752,090 Integrated Events at one fb^{-1} post trigger (one year at the LHC)

Preselection

- It was found by in previous studies that after all photon isolation cuts, the requirement of two photons with one greater than 90 GeV and a second greater than 30 GeV was ideal for signal isolation.

- Thus I have required all my events to meet this criteria before they are included in the optimization of my cuts.

- Note: This preselection needs to be reexamined in light of newer cut parameters.

Optimization Parameter

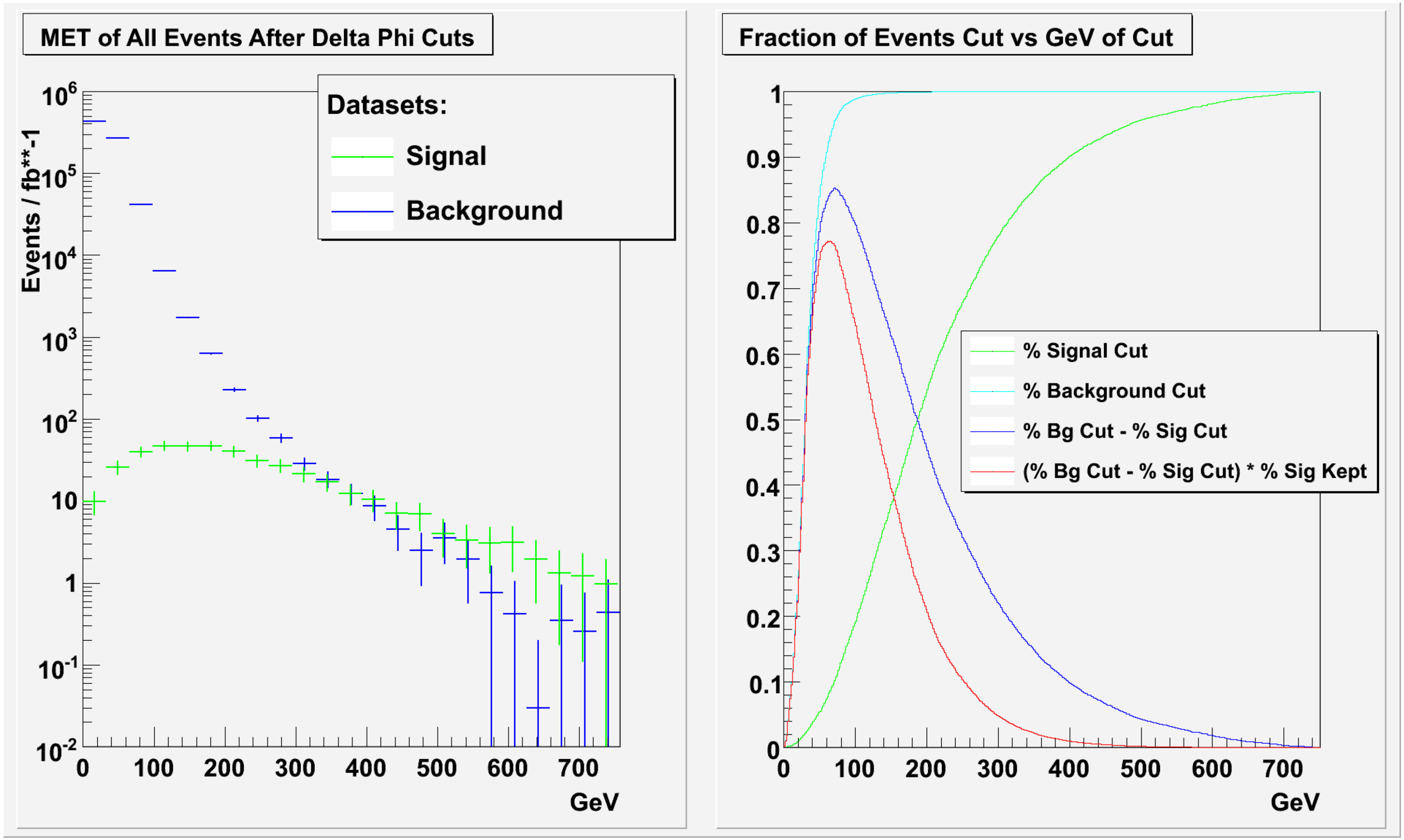
- Due to the extremely small number of signal events we expect at one fb^{-1} it is not ideal to use signal/sqrt(background) at this point in the optimization.

- Instead, it is better to the cut when we maximize Background Rejection times Signal Efficiency.
    - (% Bg Cut - % Sig Cut) * (1 - % Sig Cut)

- For example, as shown on the next slide it is ideal to cut on MET when it is greater than 58 GeV.
    - Cutting ~94% of the background.
    - Keeping ~93% of the signal.

    Plots on the following pages.

MET Post Preselection



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Post MET Cut

- After applying the MET Cut I found that the majority (~60%) of the background remaining was from the QCD events.
- A large source of MET in QCD events comes from sqrt(E) energy fluctuations of two back to back jets.
- Thus I decided to explore cuts that would remove events where the MET was likely from these types of fluctuations.
- In such events, we would expect the angle phi between the leading jets and the MET (Delta Phi henceforth) to be roughly Pi around which we would see a rise in the MET.
- Our signal on the other hand, by the fact that it is a two-step decay in which the second step is a gravitino decaying back to back with a photon, should be roughly decorrelated.
- *Note: Since we care about angles it is just as practical to use the leading photons (around which jets are formed) rather then the jets themselves.*

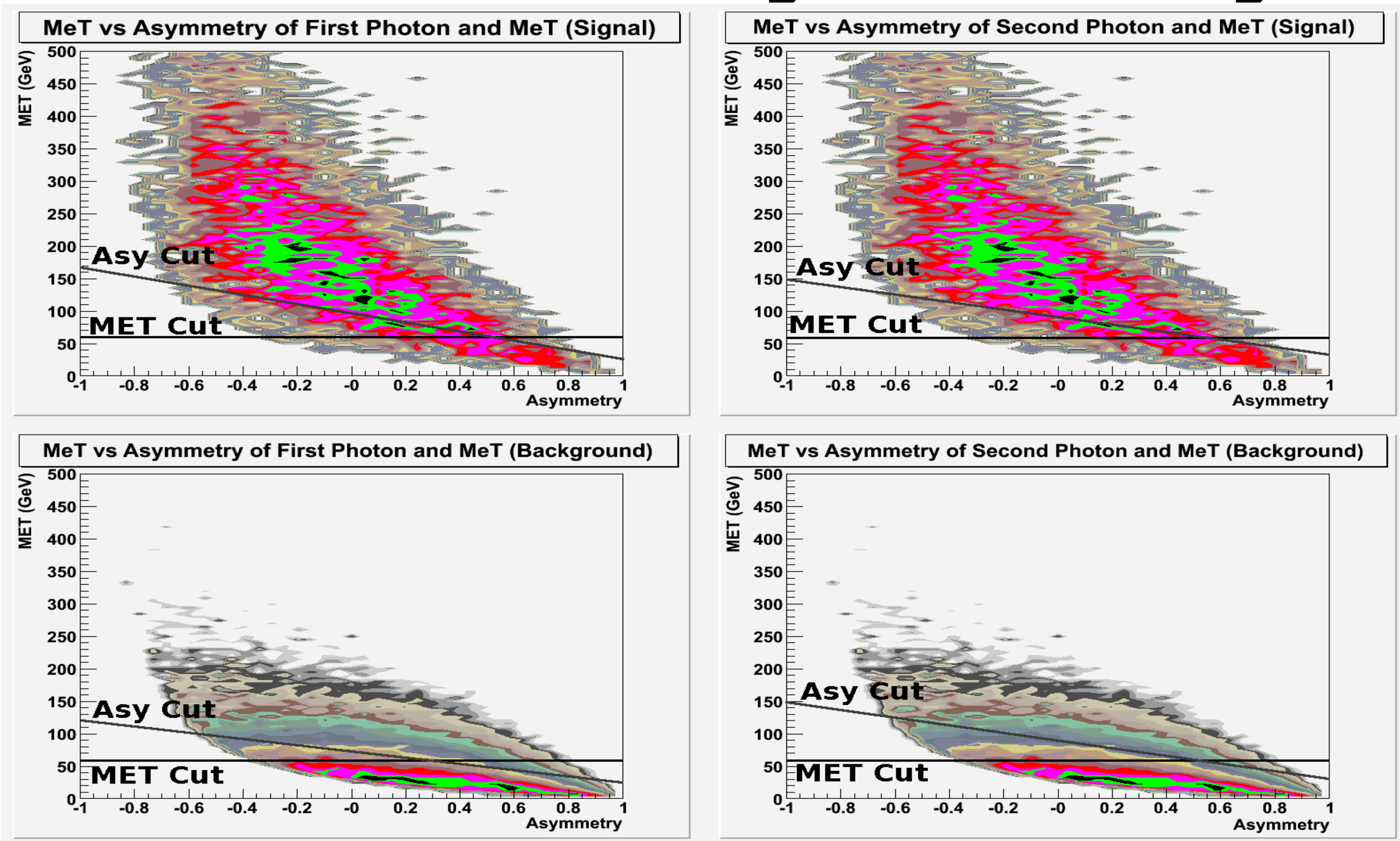
Delta Phi Cut

- As mentioned on the previous slide we would to see a correlation in the background between the angle phi (the transverse angle in our detector) of the leading photons and the MET.
- Specifically...
  - Δ(Gamma One Phi – MET Phi)
  - Δ(Gamma Two Phi – MET Phi)

Asymmetry Cut

- There is also a correlation between asymmetry of the leading photons transverse energy and the MET.
- This allows us to make a more highly tuned MET cut.
- The asymmetry is defined as the sum over the difference of the traverse momentum.
- Specifically...
  - (Gamma One Et – MET) / (Gamma One Et + MET)
  - (Gamma Two Et – MET) / (Gamma Two Et + MET)

MeT vs Asymmetry



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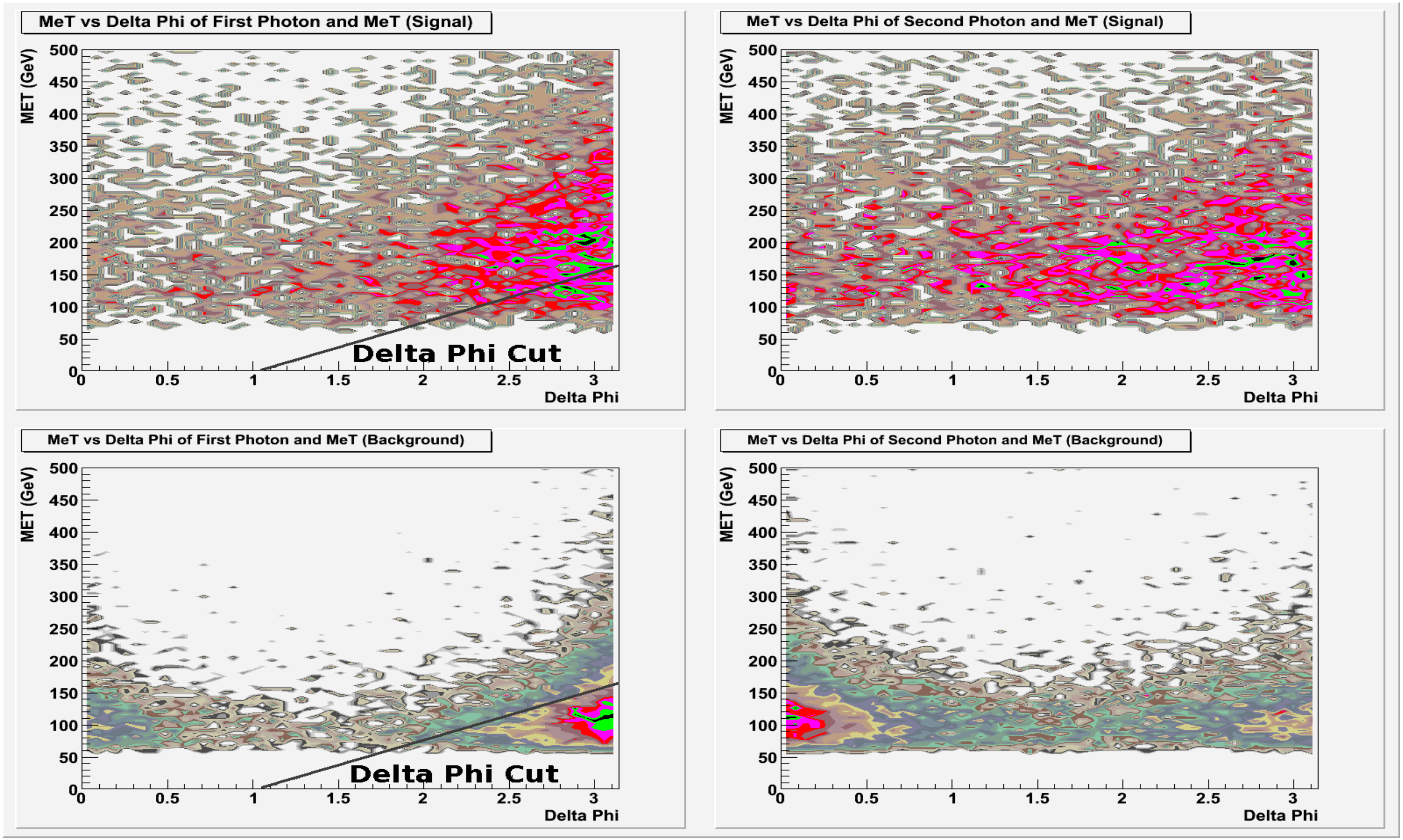
MeT vs Delta Phi



Cut Summary

Cut Name	Cut Parameters	Signal	Background	S/Sqrt(Bg)
Preselection	Leading Photon Pt > 90 GeV and Second Leading Photon > 30 GeV	413	752,090	0.48
MeT	MET > 58	385	80,516	1.36
Asymmetry	The point (Asym(First Photon, Met),Met) is above the line formed between (-1,172) and (1,26)	373	41,155	1.84
Asymmetry	The point (Asym(Second Photon, Met),Met) is above the line formed between (-1,148) and (1,39)	355	10,848	3.41
Delta Phi	The point (Delta Phi(First Photon, Met),Met) is above the line formed between (1.06,0) and (Pi,165)	325	3,425	5.55
HadOverEcal	For E > 90, H/E < 0.65 with dr < .125 and for E < 90, H/E < 0.156 with dr < .150	312	2,879	5.81
Track Isolation	For E > 90, Track Pt Sum < 5.5 GeV with dr < .05 and for E > 90, Track Pt Sum < 15 GeV with dr < .075	223	467	10.32
Selection	Leading Photon Pt > 90 GeV and Second Leading Photon > 30 GeV	205	377	10.56

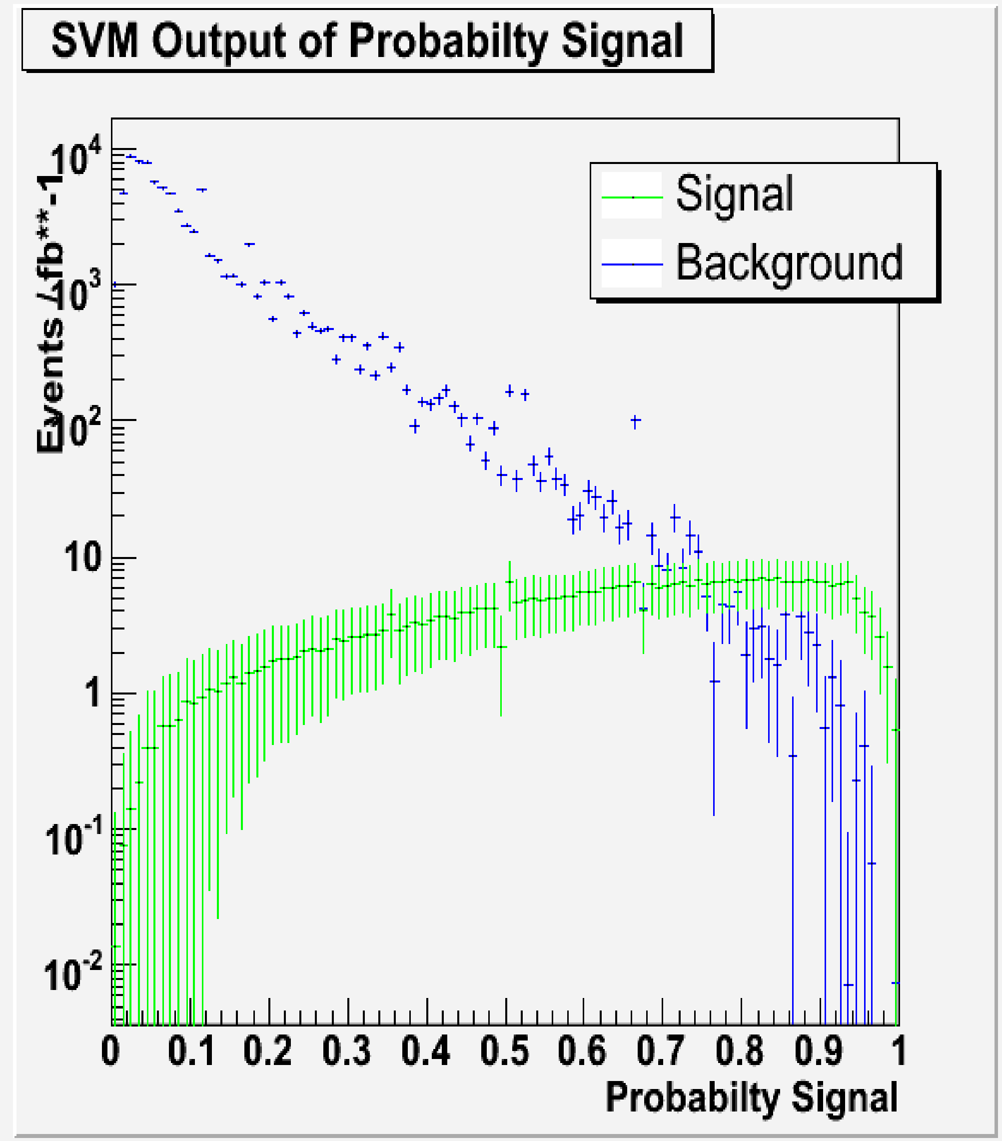
Note: ~91.5% of the signal events have the correct photons identified.

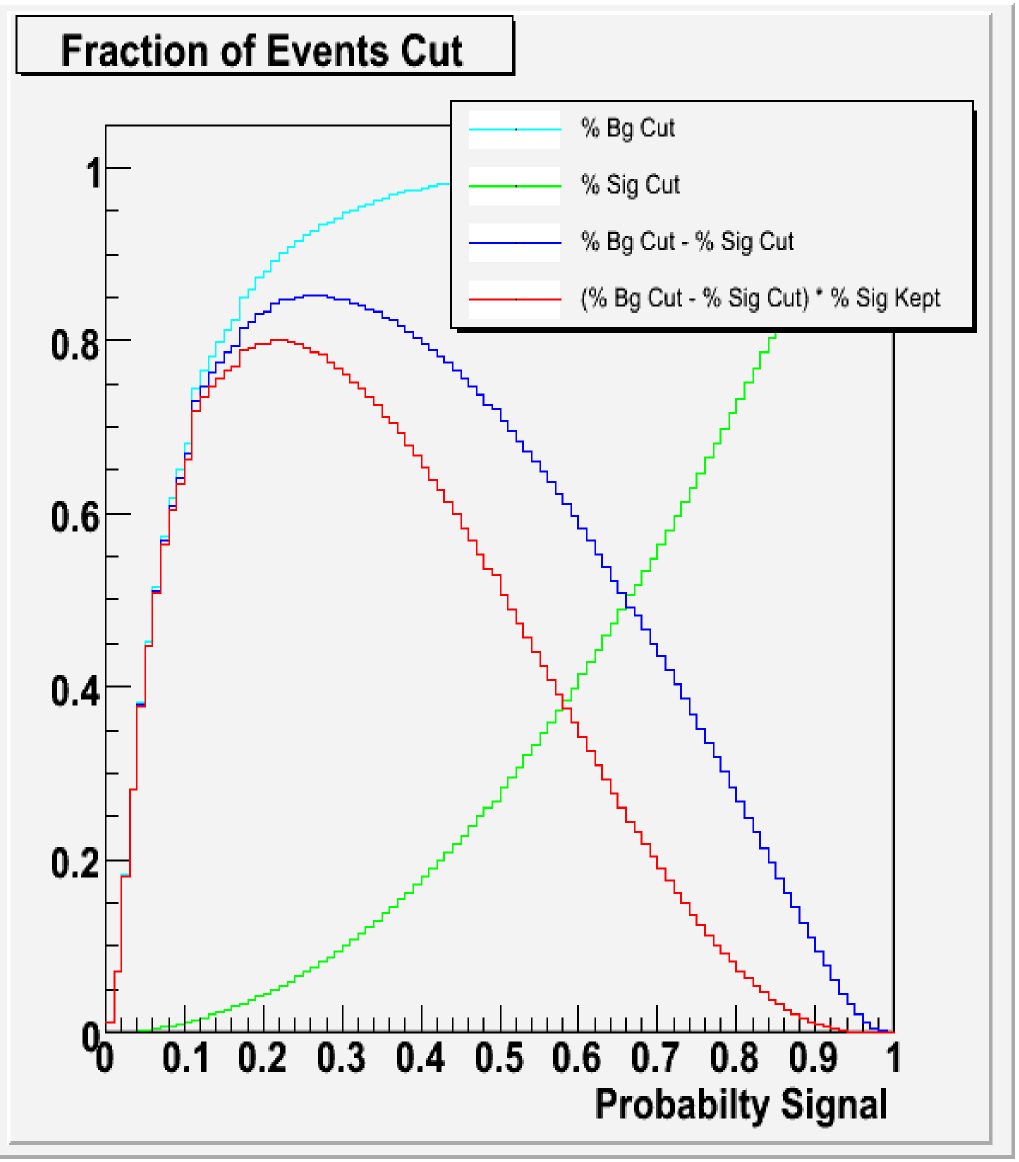
ORCA Study	Original study preformed with only photon level cuts (in blue above.)	121	28,054	0.72
Rome Group Study	Photon cuts plus MET Cut of 120 GeV optimizing only S/Sqrt(Bg) (Note: Bg is missing exotic processes.)	53	7	20.03

Next Steps

- Multi-Variate Analysis Techniques:
  - State Vector Machines
  - Preliminary Results before Photon Level Cuts
    - 325 Signal Events and 2166 Background Events
    - A S/Sqrt(Bg) of 6.98, an improvement of ~25%
    - See plot on next slide.
- Better Photon Identification:
  - Poor photon identification is the real source of the large background in this study.
  - I have been recently tasked with an effort to apply a technique I came up with, similar to digital image recognition methods, to improve photon identification.
- Define a control region to be found with anti-photon cuts.

SVM Identification





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