# SUSY Searches at CMS

- Introduction
- CMS Experiment
- SUSY Modeling and Interpretation of results
- SUSY search strategies in CMS
- Experimental Results
- New search strategies ($3^{rd}$ generation searches)
- Summary – Outlook

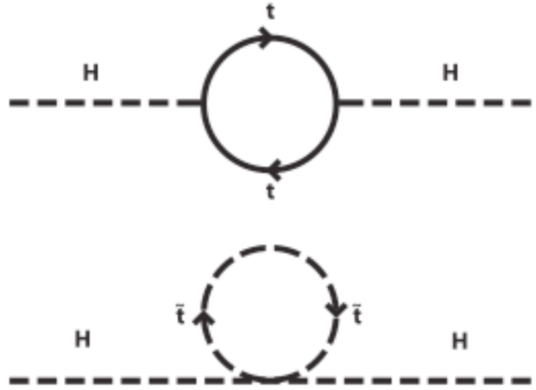
On behalf of the CMS Collaboration: N. Saoulidou, Univ. of Athens, Greece

**ICFP2012: First International Conference on New Frontiers in Physics, 10-16 Jun 2012, Kolymbari (Greece)**

# Introduction : SM incomplete

## Theoretical point of view

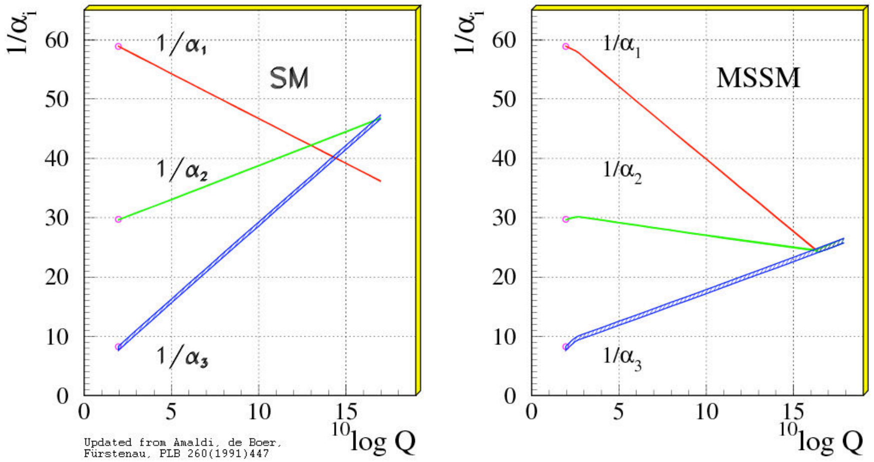
- **Quantum Gravity : ** *SM describes three of the four fundamental interactions at the quantum level (microscopically) BUT gravity is only treated classically.*




- **Origin of Mass :** *Higgs mechanism in place, Higgs particle absent.*

- **Hierarchy Problem :** *Why is $M_{Pl}/M_{EW}$~$10^{15}$ What is the mechanism of cancelation of quadratic divergencies?*

- **Unification of Gauge couplings** *: Why couplings are so different?*

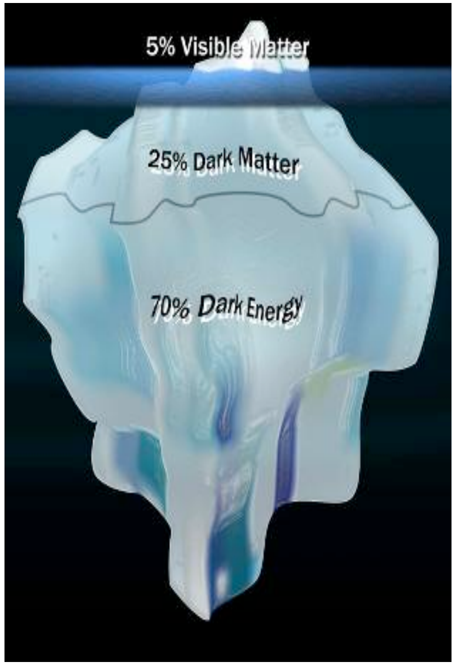



- **Origin of generations :** Why three?

# Introduction : SM incomplete

## Experimental point of view

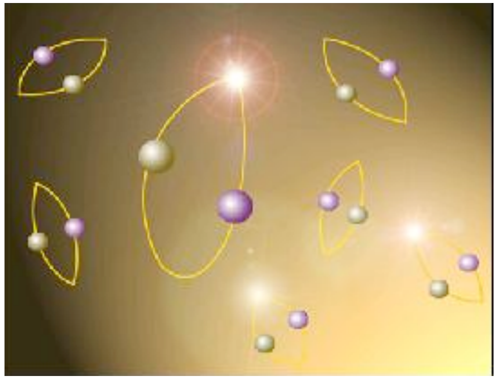
- **Dark matter – Dark Energy :** *What is 95% of the Universe made off?*




- **Cosmological constant** *: Why is vacuum energy SO small?*

  $\rho_{VAC} = M_{Pl}^4 = 10^{120}\rho_{VAC}^{obs}$ (!!!)

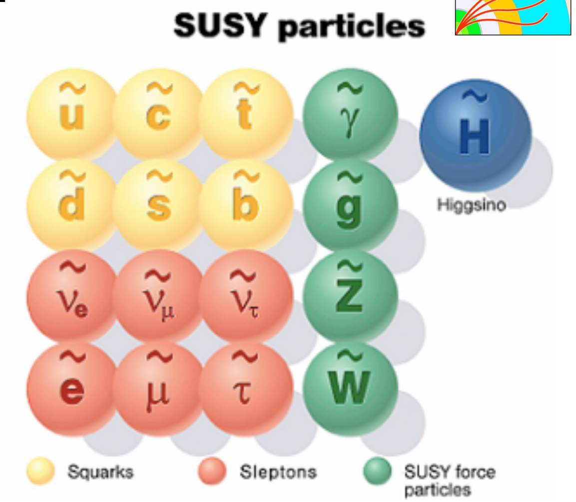
- **CP Violation***: Why are we here? OR What is the source of the dramatic matter-antimatter asymmetry in the Universe?*



- **Neutrino masses and mixings** *: What is the Origin of neutrino masses, what is the nature of neutrino, why are ν mixings so different than quark ones?*

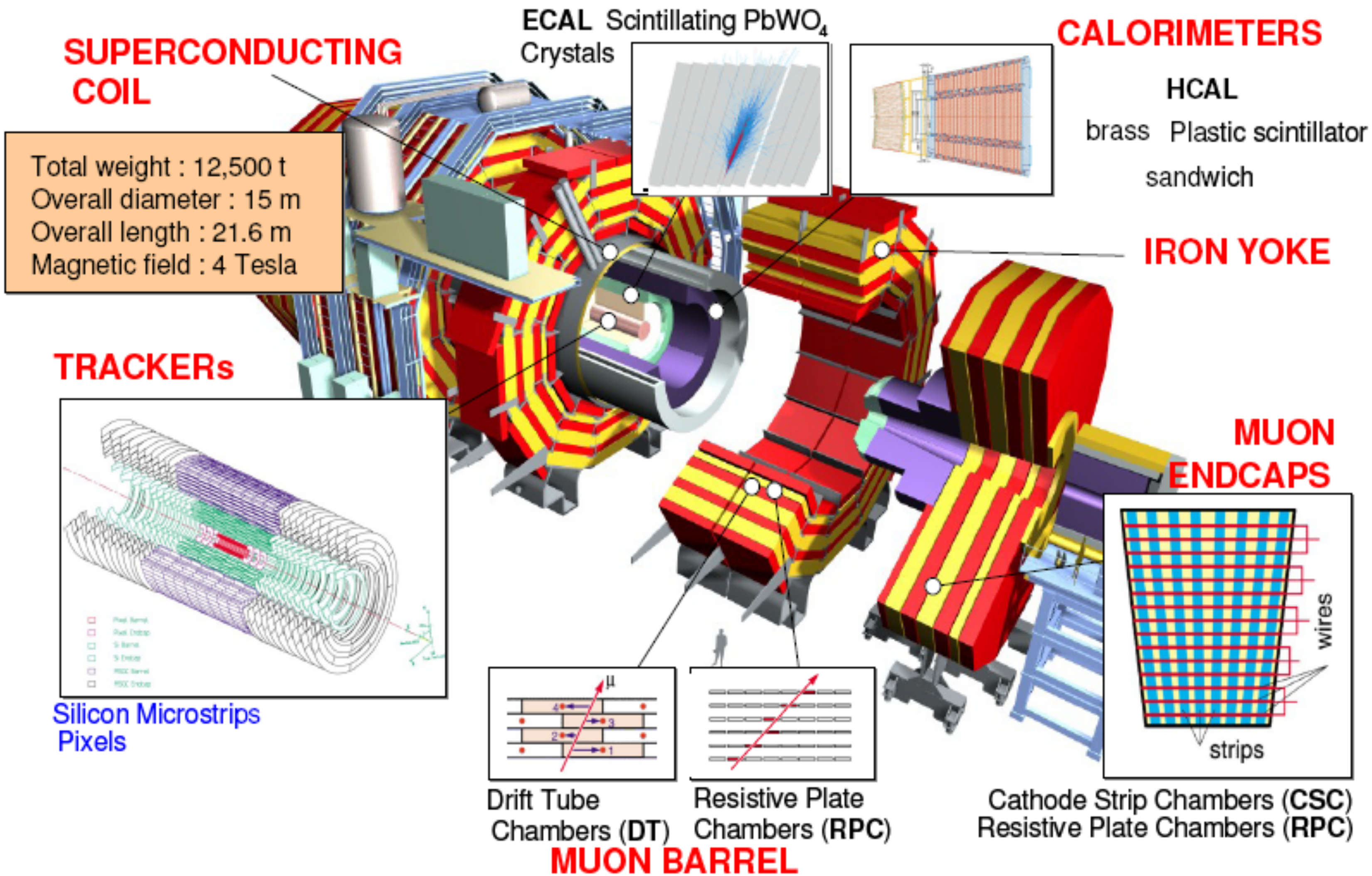
# Introduction : SUSY

Super-symmetry is a symmetry under the exchange of bosons and fermions.



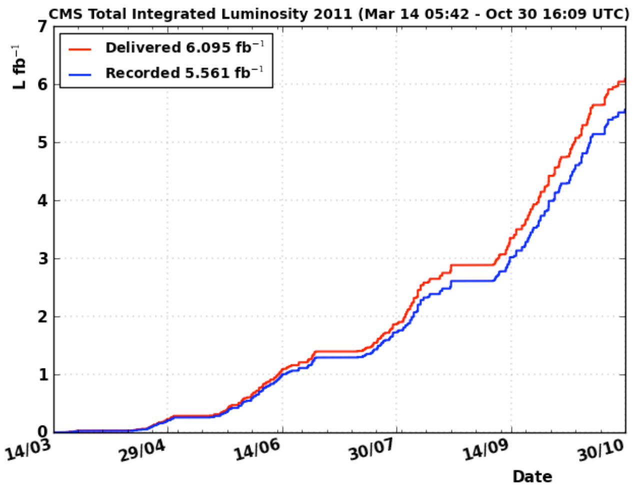

- Every fermion has a bosonic super-partner and vice versa.
  - *Provides a Dark Matter candidate (if R-parity conserved) .*
  - *Provides a solution to the hierarchy problem.*
  - *Allows unification of gauge couplings at the Planck scale (connection to GUT theories).*
  - *Provides a connection to gravity and strings.*
  - *Makes the cosmological constant problem less dramatic (instead of 120 “just” 60 orders of magnitude difference).*
  - *Provides new sources of CP violation.*
  - *Provides many new experimental signatures for us to study and measure.*

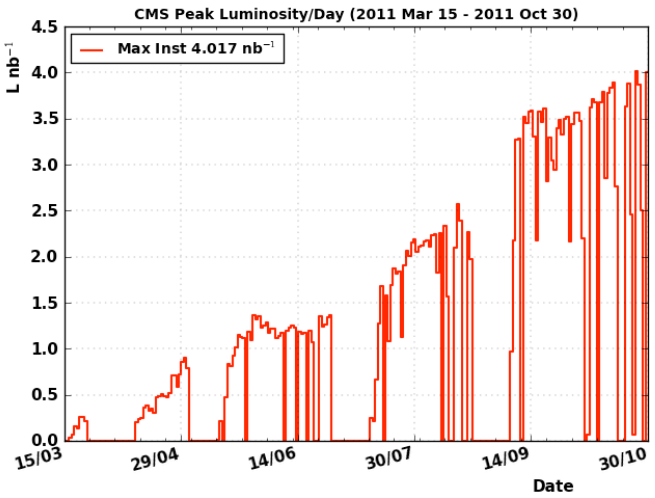
# CMS Experiment



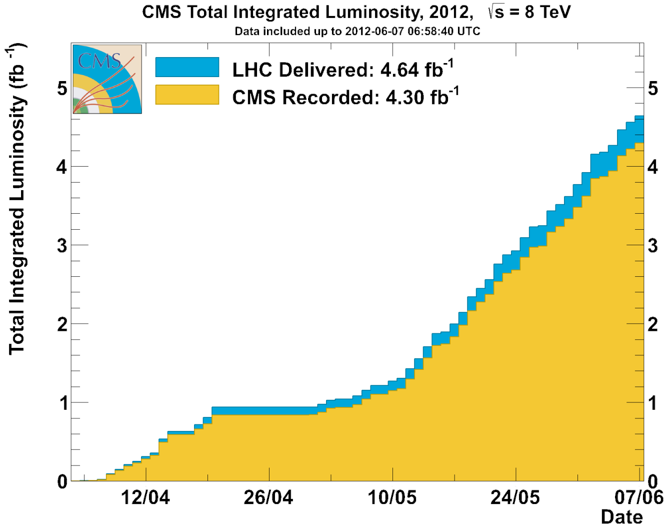
# CMS Data Taking

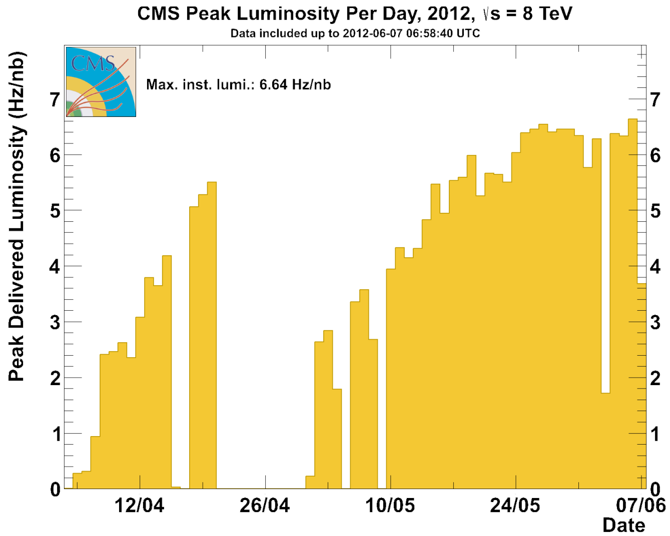
## 7 TeV running
## (results shown in this talk)



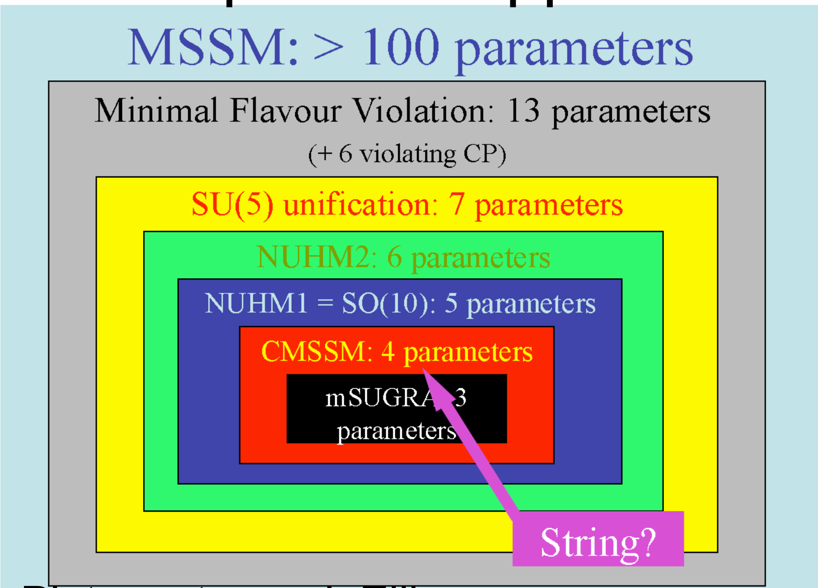

## 8 TeV running
## Many thanks to the accelerator!!



# SUSY modeling and Interpretations of SUSY Searches

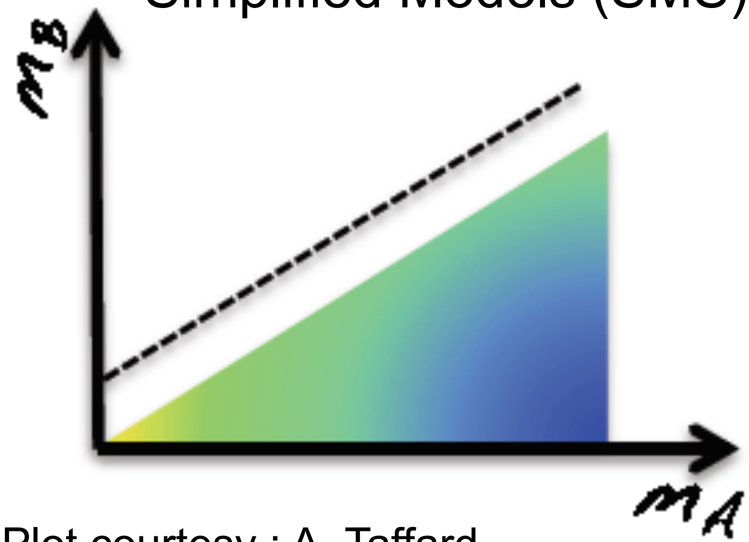
Top-Down approach




Plot courtesy : J. Ellis

Bottom-Up approach

Simplified Models (SMS)

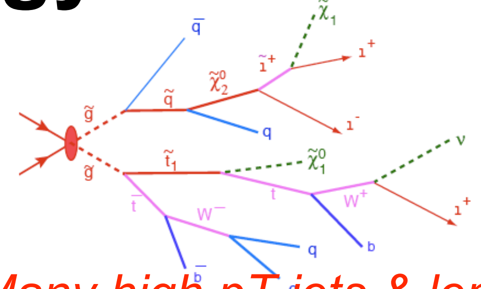



Plot courtesy : A. Taffard

**SMS vs CMSSM**

- **Provide a wider spectrum of mass splittings than allowed by the CMSSM**
- **Mass parameters of the simplified models cover a large volume of the kinematic phase space of all the final states considered.**
- **Assume that a particular decay signature can be realized without specifying the exact mechanism, offering the possibility to overcome small branching ratios.**
- **One common requirement of all topologies studied is the presence of a "physical" source of missing transverse energy.**

# SUSY Search Strategy in CMS



- **R-parity conserved (RPC) :**

  SUSY particles created in pairs
  If squarks, gluinos heavy long decay chains -> *Many high pT jets & leptons.*
  Lightest SUSY Particle (LSP) stable -> *Missing $E_T$ (MET)*


- **R-parity violated (RPV) :**

  SUSY particles can be created singly
  LSP decays, study invariant mass and decay properties -> *No Missing $E_T$*

- **In general rich phenomenology :**
  - High (RPC) or Low MET (RPV or compressed spectra) and $\Sigma$ $E_T$ jets (HT)
  - Long or short decay chains
  - With or without leptons

- **Searches categorized on final state signatures defined by Standard Model (SM) backgrounds** : 0-lepton, 1-lepton, 2-lepton, multi-leptons, b-jets searches, photons searches

# Background Estimation Strategy

- **Physics Backgrounds** : Try to rely on simulation as little as possible, deploying so called **"Data-Driven" methods**. In reality **no background method estimation is entirely data-driven.**

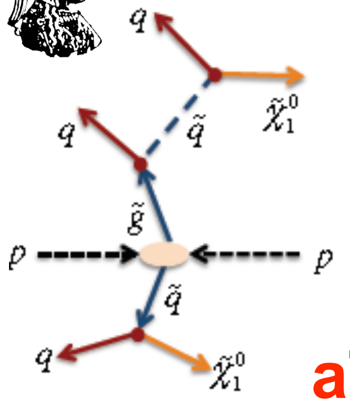
  - *Define "Control Regions" where little signal is expected.*

  - *Test performance of analysis in control region, and/or extract background template in control region.*

  - *Extrapolate (using assumptions based on simulation) background template from control to signal region.*

- **Detector Effects – Noise Backgrounds**: Try to examine performance of key analysis quantities in many control regions.

# 0-lepton Searches

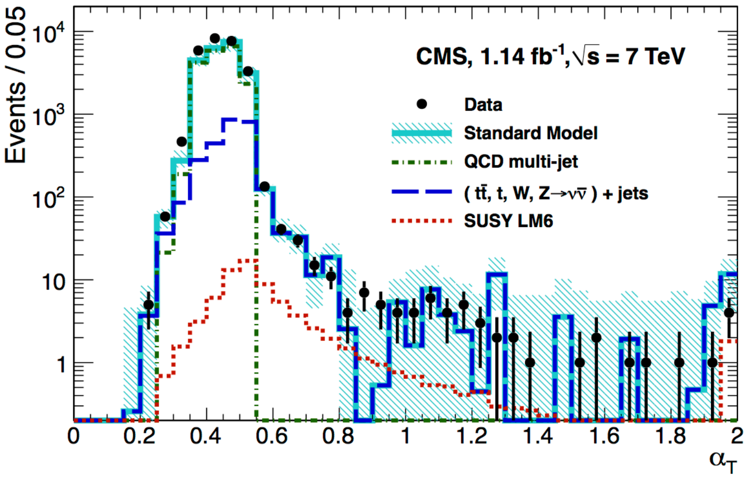



**Signal : Jets, no isolated leptons in the final state, w/o MET, and HT**

**Backgrounds: QCD, Z->vv, W+jets**

**Search Strategies : aT, MHT, Razor, $M_{T2}$ ,all complementary to each other, with similar reach.**

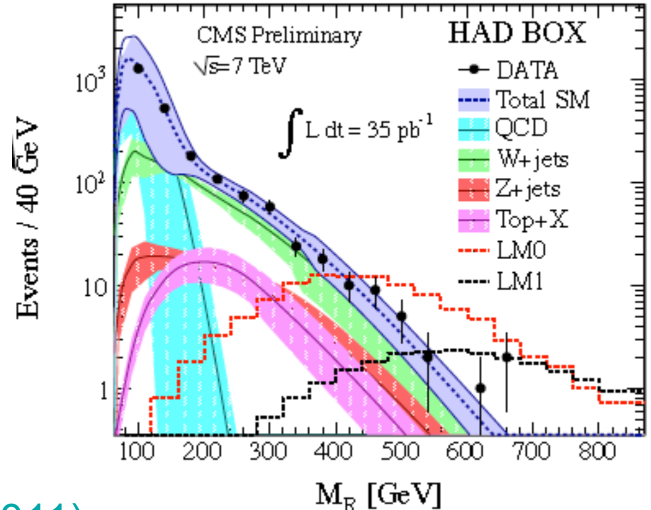
## aT




arxiv:1109.2352, PRL 107, 221804 (2011)

$$\alpha_T = \frac{\sqrt{E_T^{j2} / E_T^{j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

## Razor



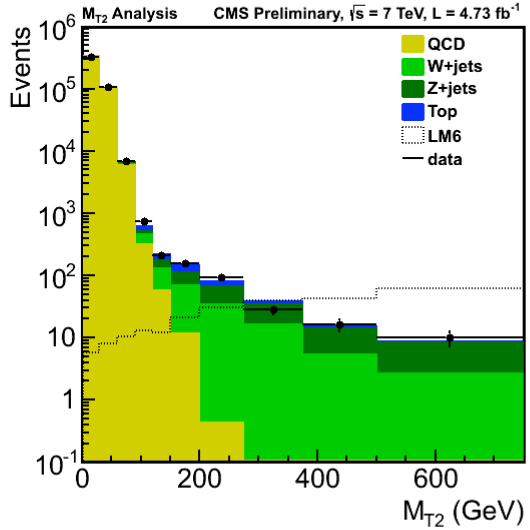

PAS-SUS-12-005

$$M_R \equiv \sqrt{(E_{j_1}+E_{j_2})^2-(p_z^{j_1}+p_z^{j_2})^2}$$

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1}+p_T^{j2})-\vec{E}_T^{miss}\cdot(\vec{p}_T^{j1}+\vec{p}_T^{j2})}{2}}.$$

$$R \equiv \frac{M_T^R}{M_R}$$

## $M_{T2}$

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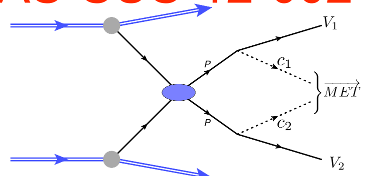
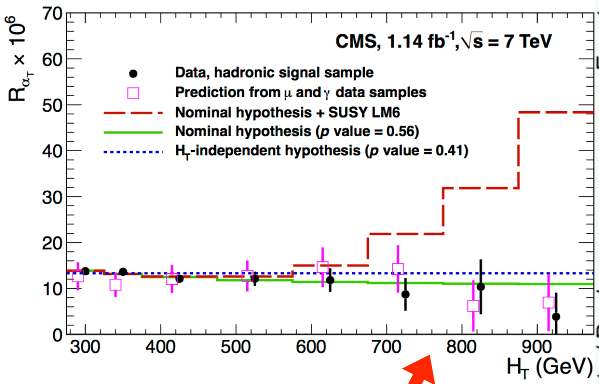
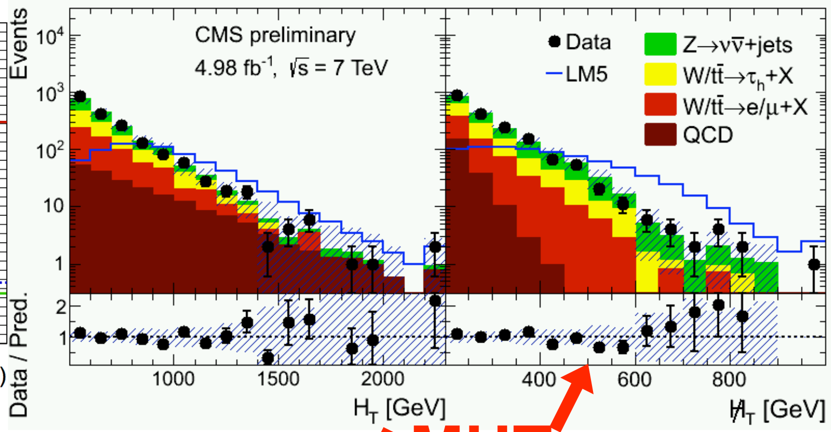


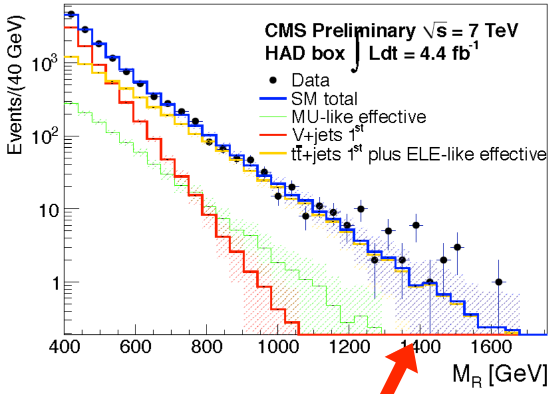

$$M_{T2} = \min_{p_T^{\chi(1)}+p_T^{\chi(2)}=p_T^{miss}}\left[\max\left(m_T^{(1)}, m_T^{(2)}\right)\right]$$

$$m_T^{(i)} = \left(m^{vis(i)}\right)^2 + m_\chi^2 + 2\left(E_T^{vis(i)}E_T^{\chi(i)} - \vec{p}_T^{vis(i)}\cdot\vec{p}_T^{\chi(i)}\right)$$

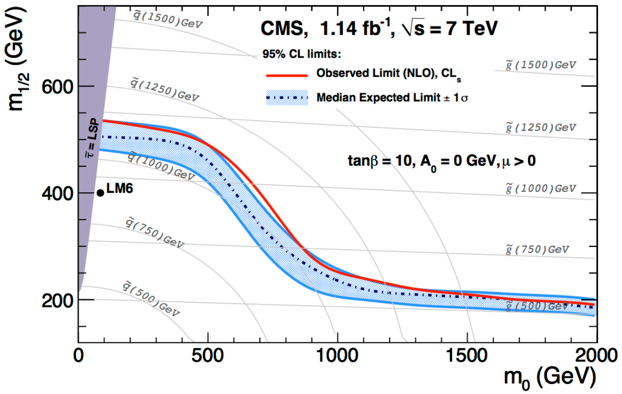
# 0-lepton Searches

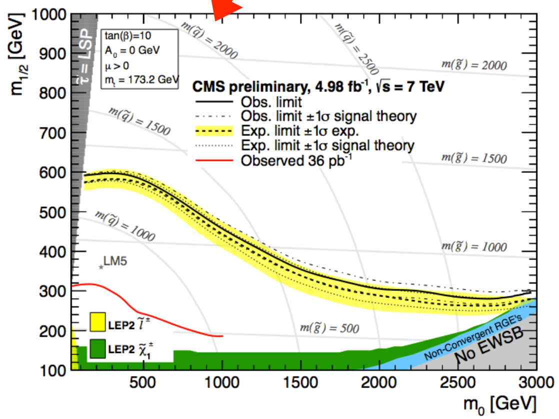


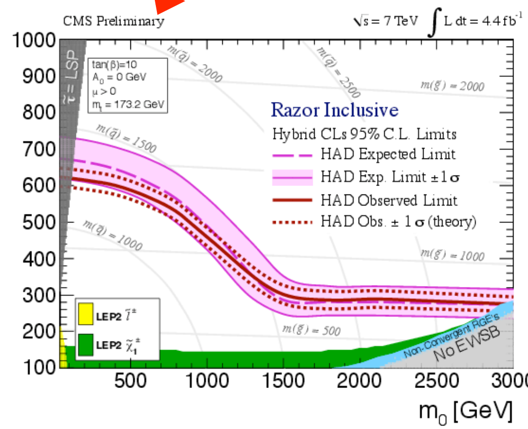




**aT** **MHT** **Razor**

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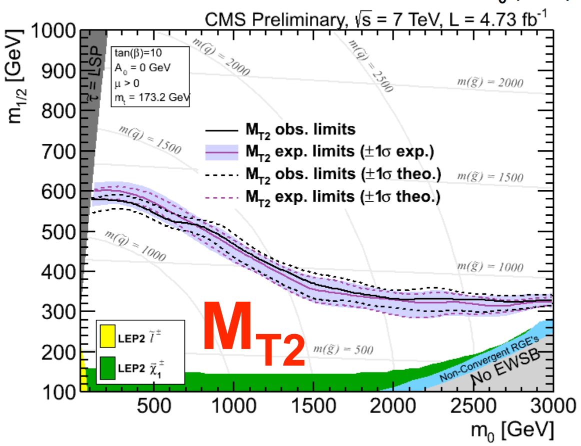


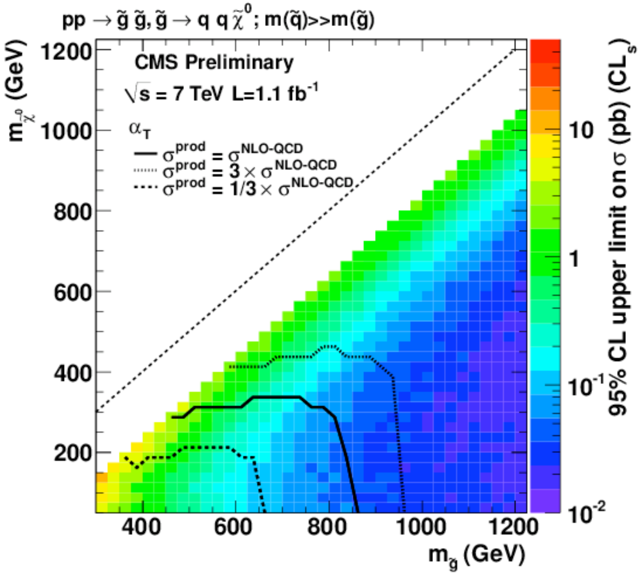

**$M_{T2}$**

## Results and CMSSM Interpretation

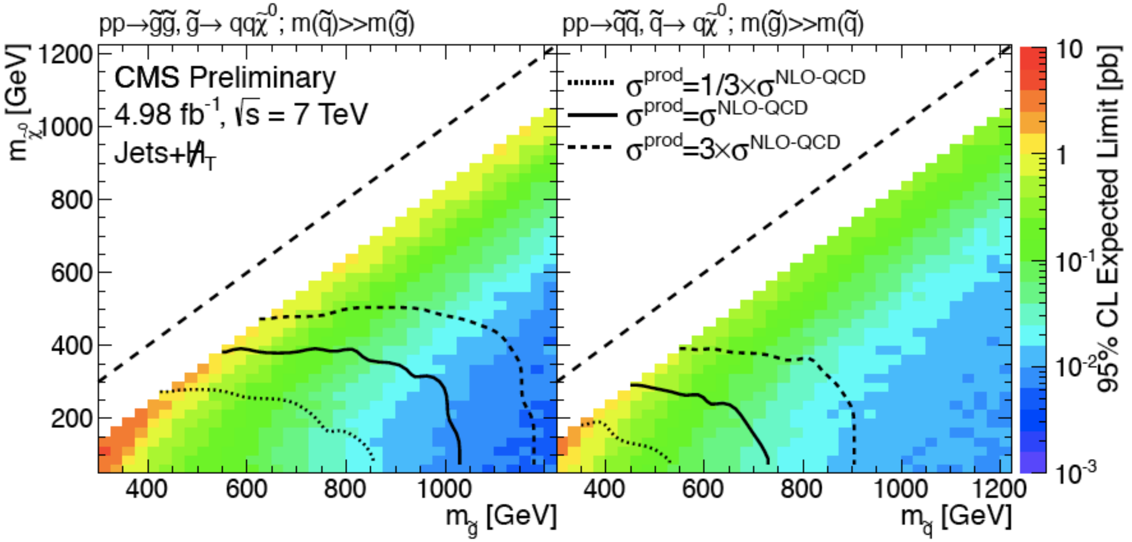
N. Saoulidou (Univ. Of Athens, Greece)

# 0-lepton Searches

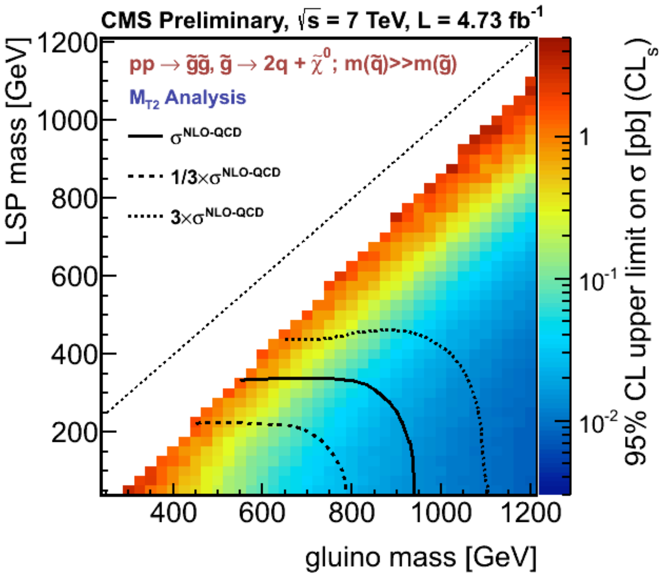
## aT




## MHT

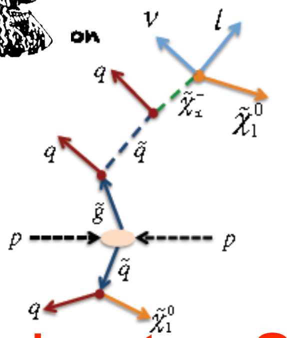



## $M_{T2}$




Results and SMS Interpretation

# Single Lepton Searches

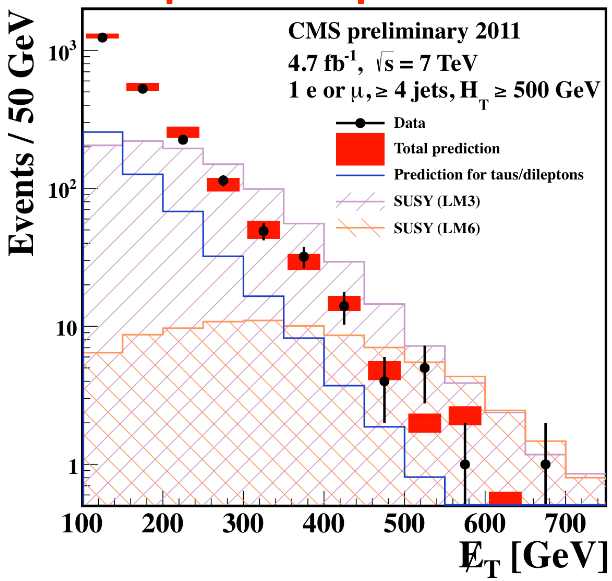


**Signal : One isolated lepton, jets, MET**

**Main Backgrounds : W+jets, ttbar, Single top, QCD**

**Search Strategies : Lepton spectrum, Lepton projection, Artificial Neural Nets, all <u>complementary</u> to each other, with similar reach.**

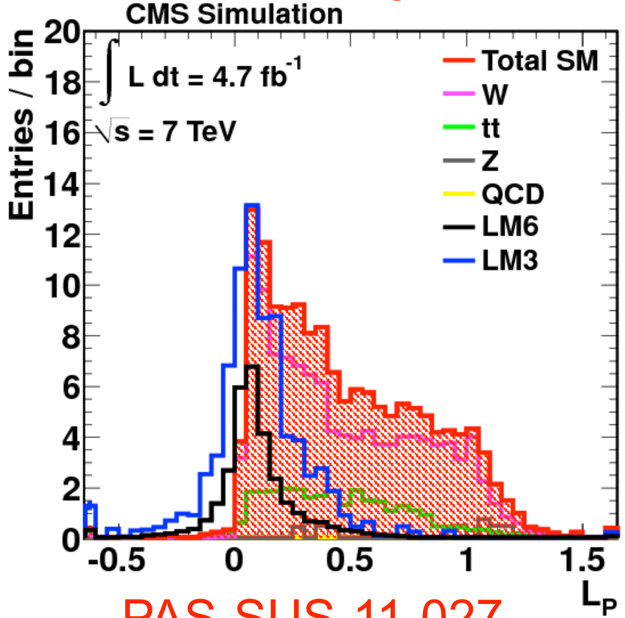
## Lepton Spectrum




PAS-SUS-11-027

Lepton pT spectrum used to predict MET

## Lepton Projection

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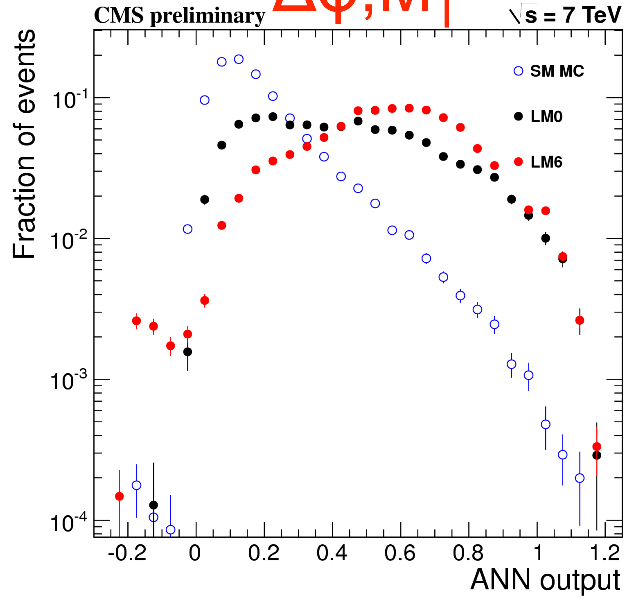
$$L_P = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2} \quad R_{CS} = \frac{N_{MC}(L_P < 0.15)}{N_{MC}(L_P > 0.3)}.$$

$$N^{pred}_{SM}(L_P < 0.15) = R_{CS} N_{data}(L_P > 0.3).$$

## ANN : # of jets, HT, Δφ,$M_T$




PAS-SUS-11-026

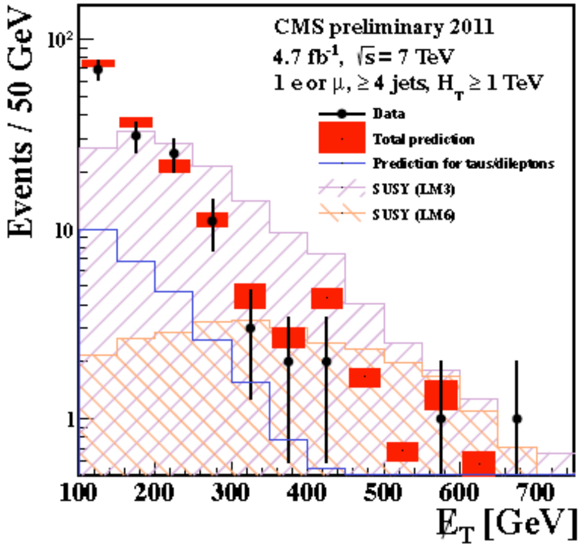
ANN > 0.4 MET> 500 GeV

ANN > 0.4 and

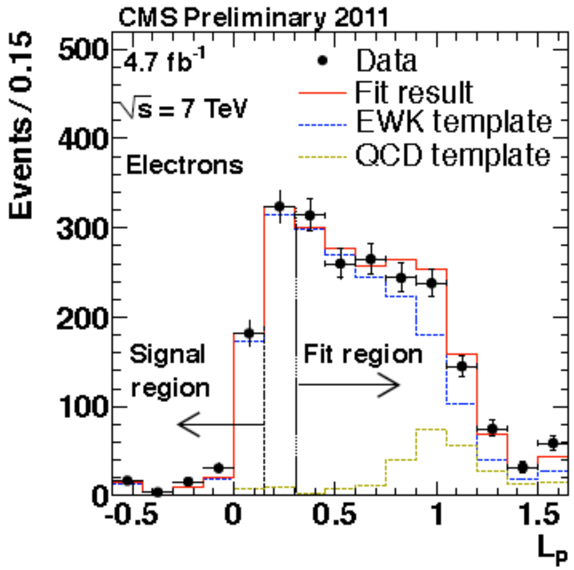
350 <MET< 500 GeV

# Single Lepton Searches

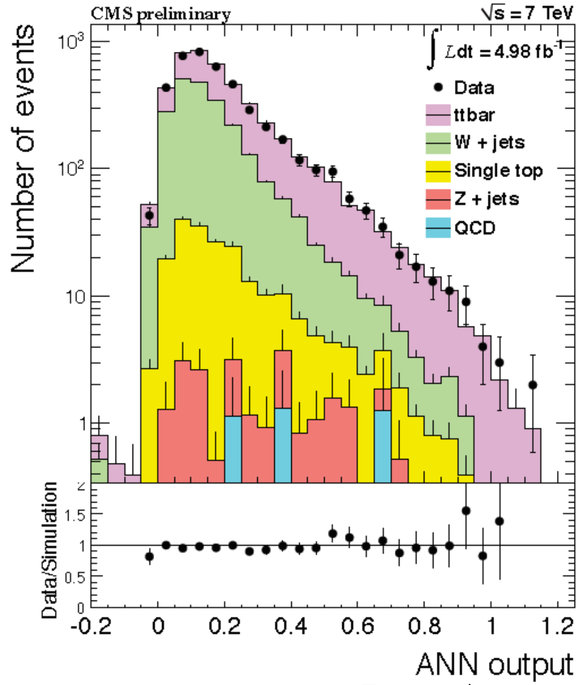
## Lepton Spectrum

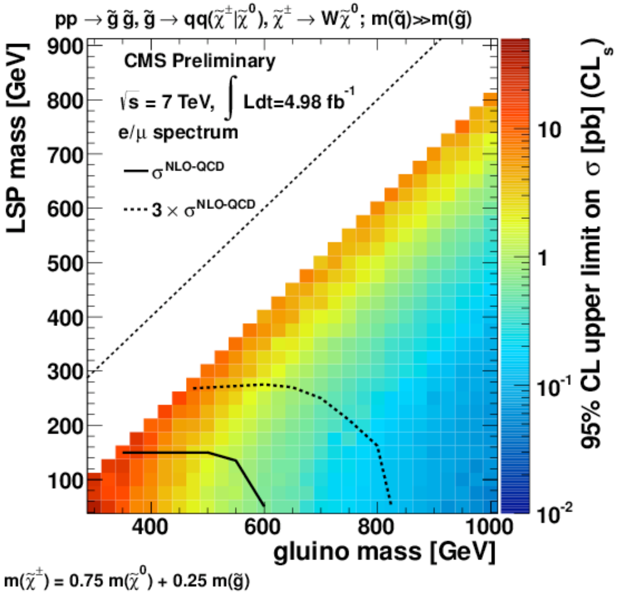


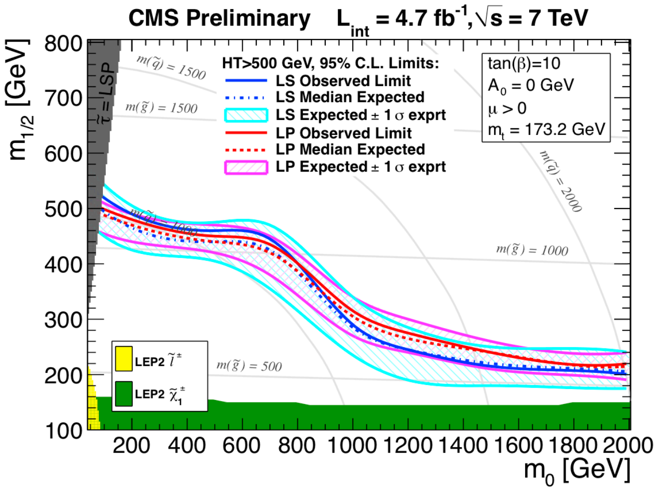

## Lepton Projection

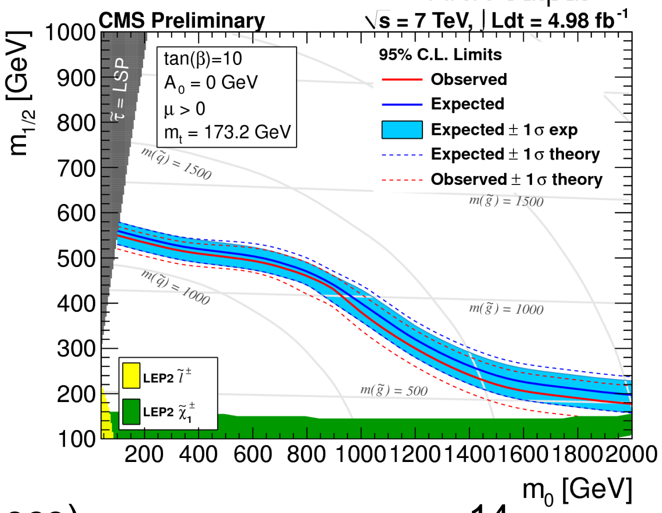



## ANN : Njets, HT, $\Delta\varphi$,$M_T$

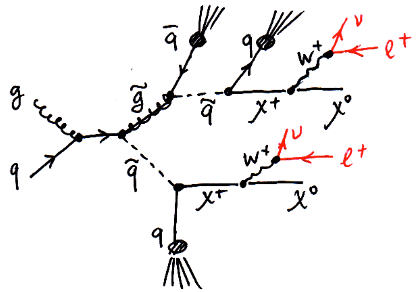


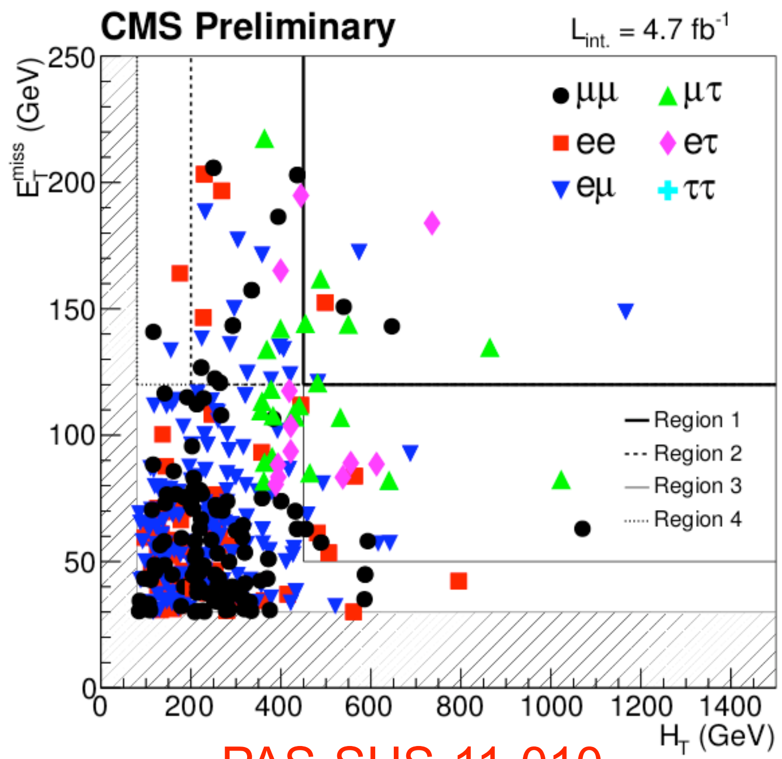
# SS Dilepton Lepton Searches

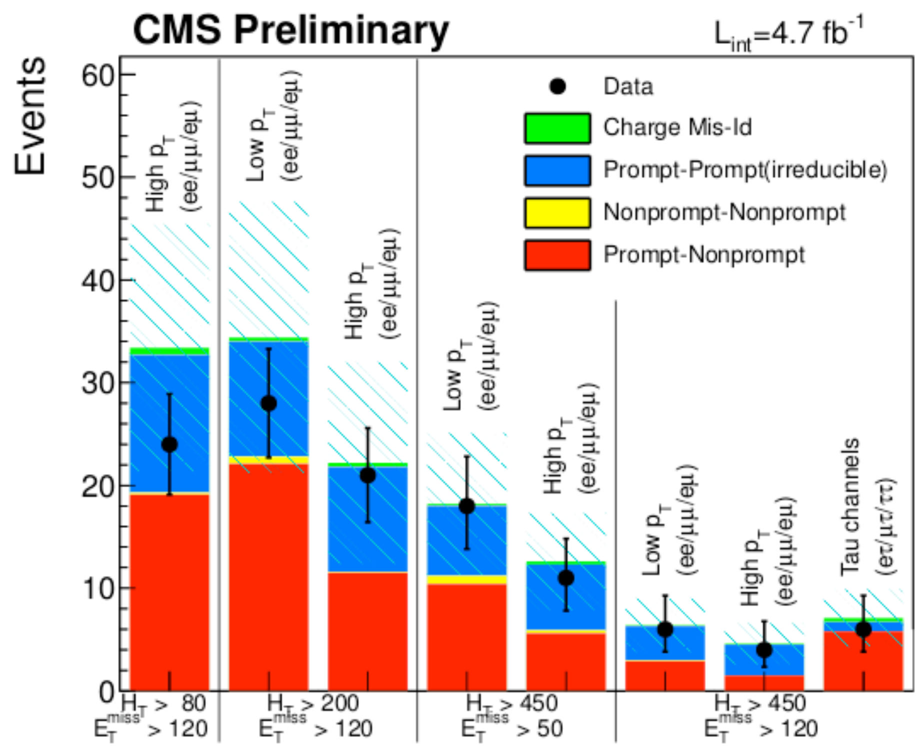


Signal : Two isolated SS lepton, jets, MET

Main Backgrounds : Very small in general , W+jets, Z+jets WW,WZ,WW,ttW,ttZ,ttγ

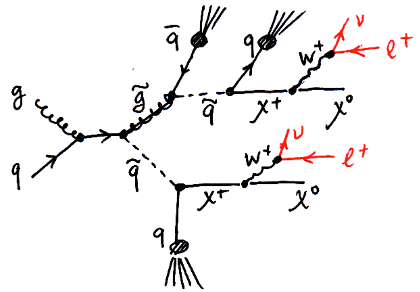
Search Strategies : MET and HT

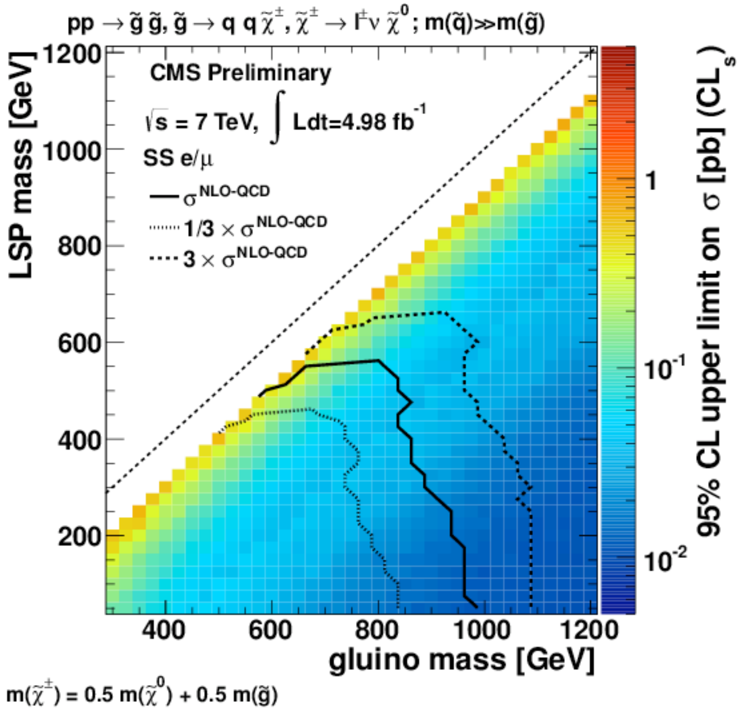


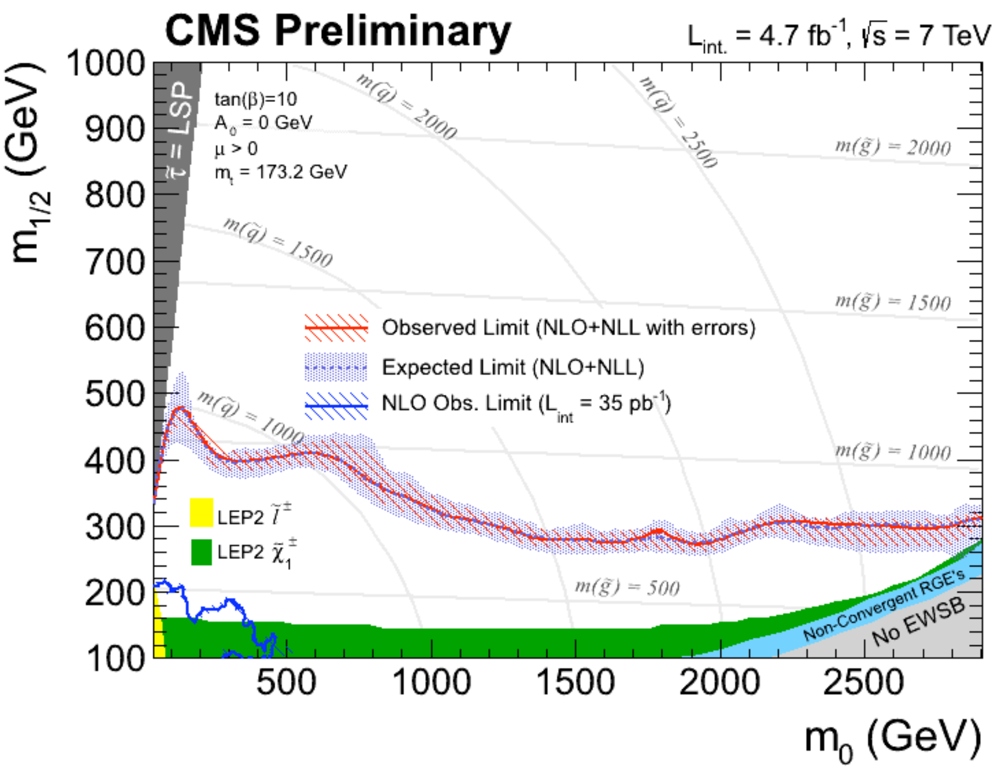




PAS-SUS-11-010
Submitted to PRL

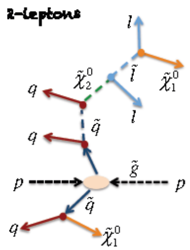
# SS Dilepton Lepton Searches





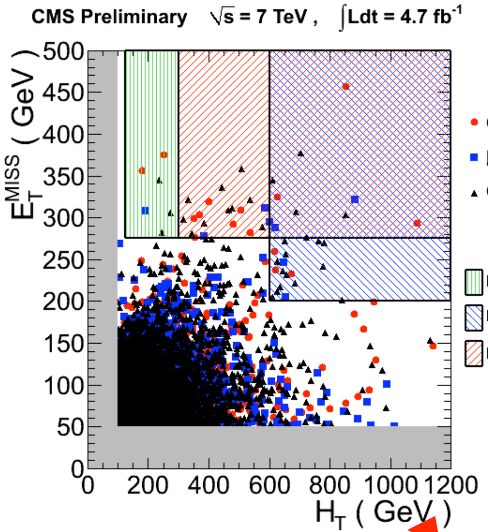
# OS Dilepton Lepton Searches

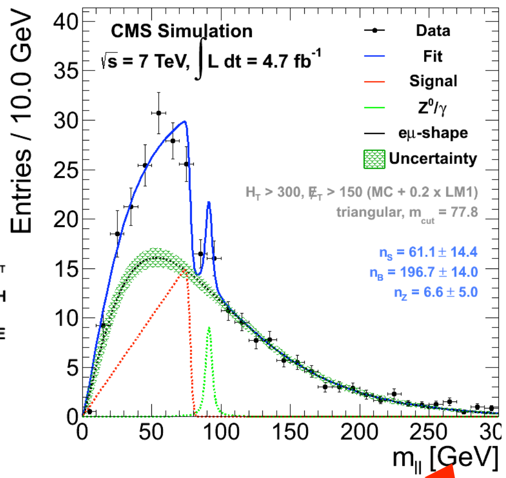



**Signal : Two isolated OS lepton, jets, MET**

**Main Backgrounds : ttbar, DY, W+jets**

**Search Strategies : MET and HT, Artificial Neural Networks, Dilepton shape fit, "Jet Z Balance".**

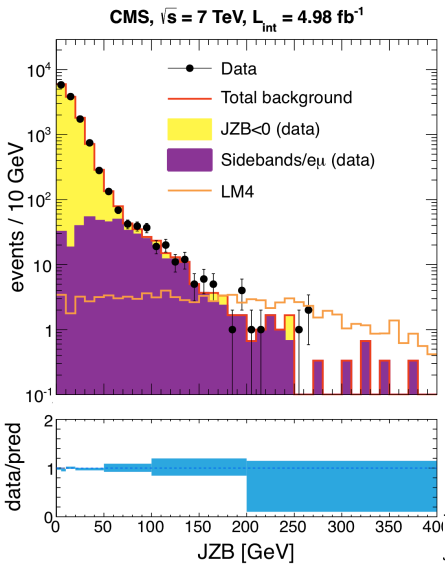


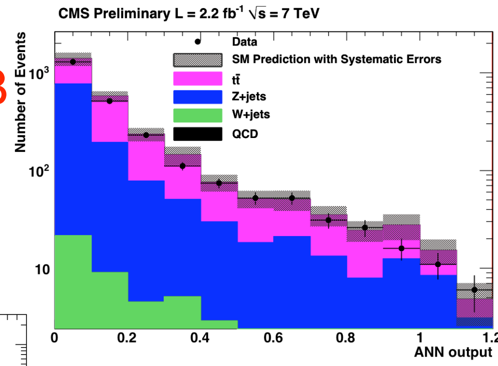




Submitted to PLB

arXiv:1204.3774

**JZB**



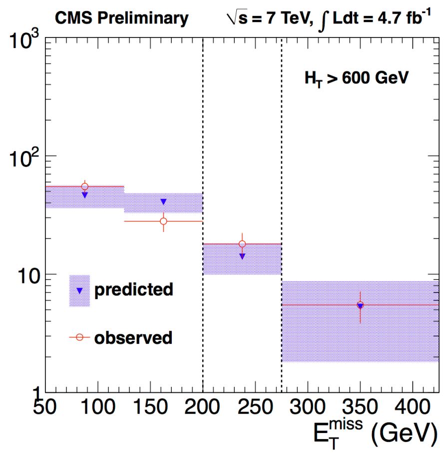

PAS-SUS-11-018

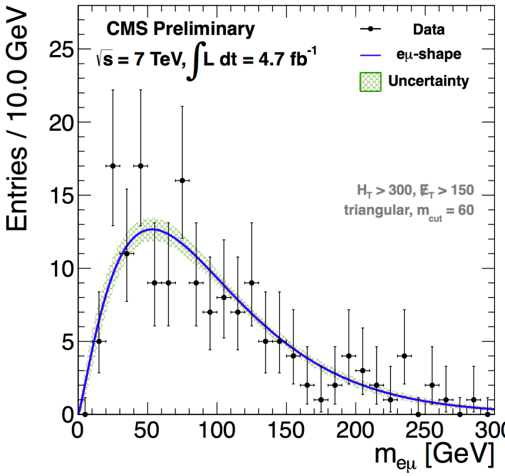
**ANN (low MET)**

**MET - HT**

**SUS-11-011 submitted to PRL**

**M$_{ll}$ Shape**

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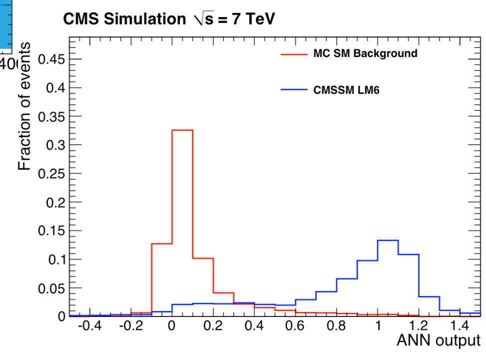
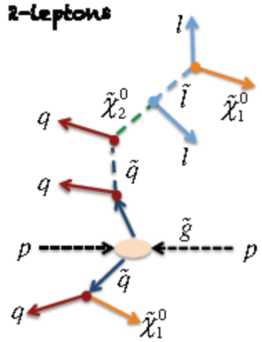
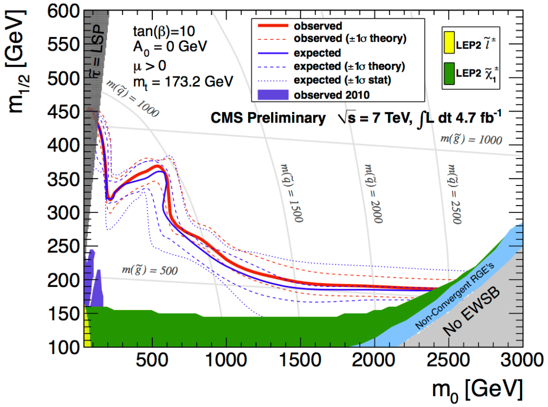


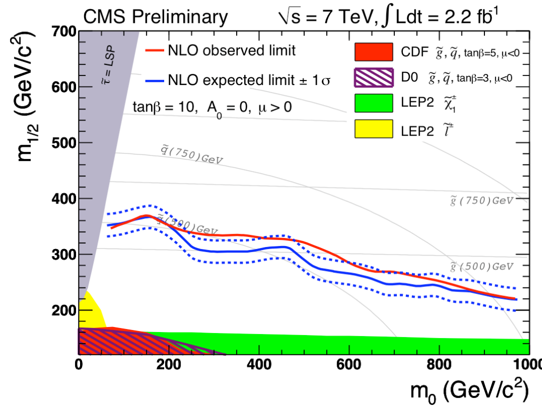
# OS Dilepton Lepton Searches

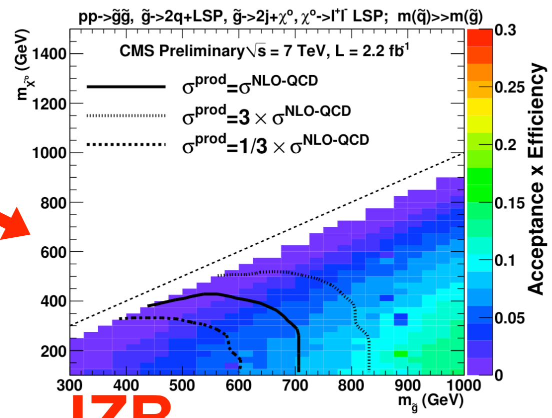



**MET-HT**

**ANN (low MET)**

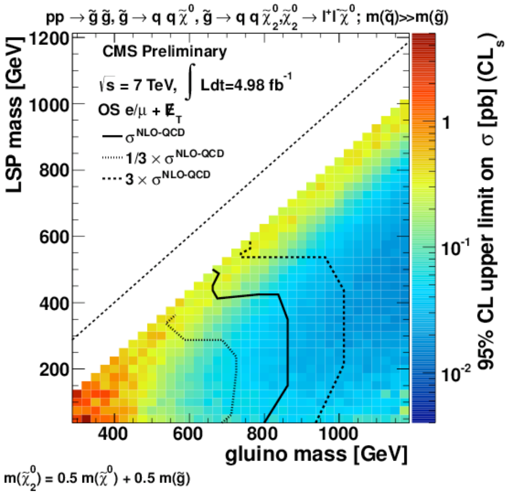


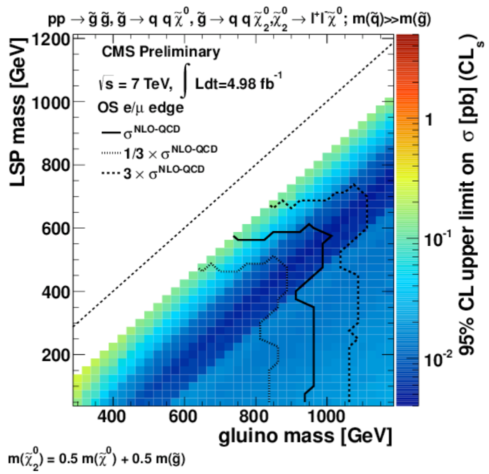



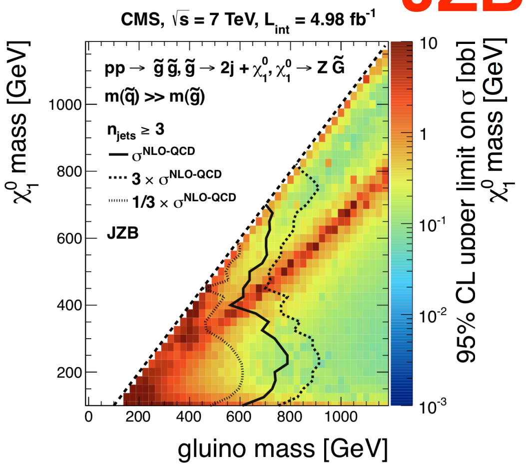

**MET-HT**

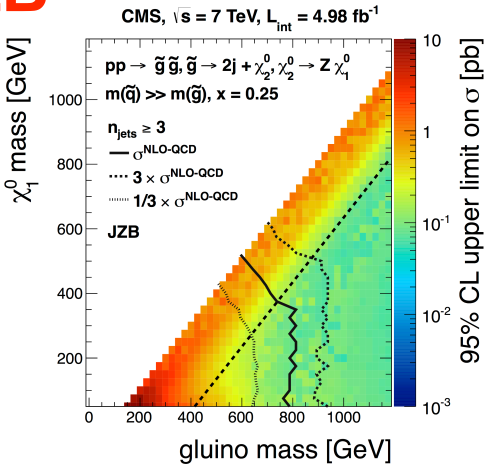
**$M_{ll}$ Shape**

**JZB**

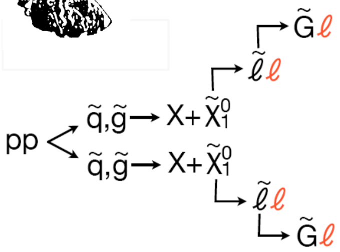


# Multi Lepton Searches




**Signal : At least 3 leptons, jets, MET**

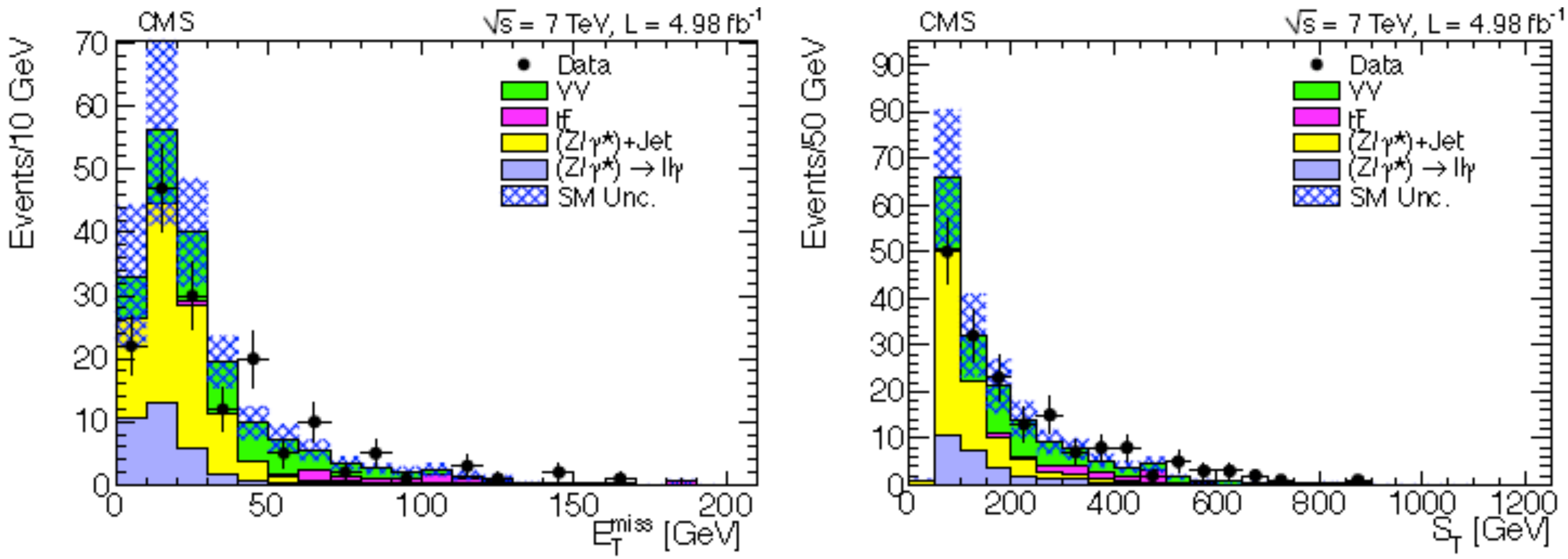
**Main Backgrounds DY pairs+jet, ttbar, ZZ,WZ,WW,WWW**

**Search Strategies : Count events in MET, $S_T$ bins**

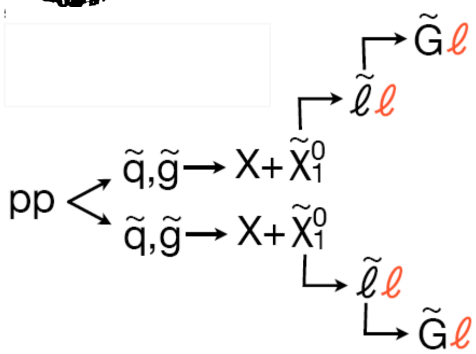
sum of the parent particle masses

$$S_T = MET + HT + p_T lep$$

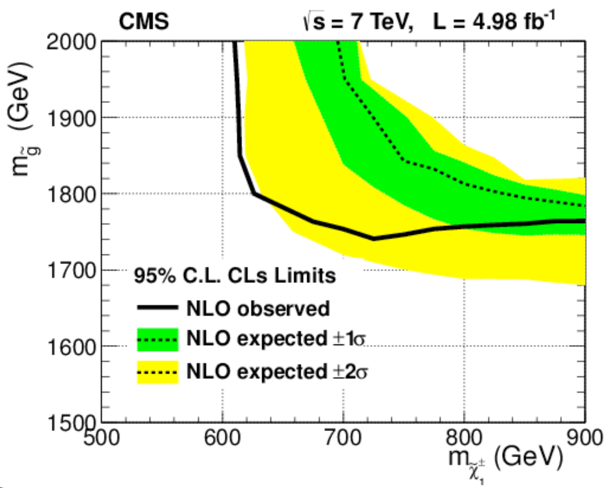
**Submitted to JHEP arXiv:1204.5341**



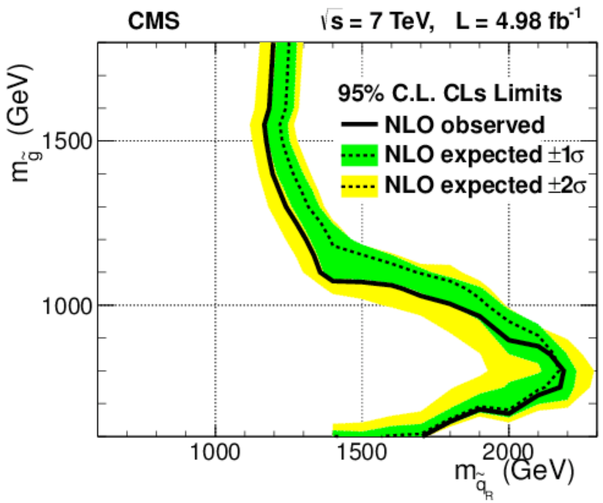
# Multi Lepton Searches



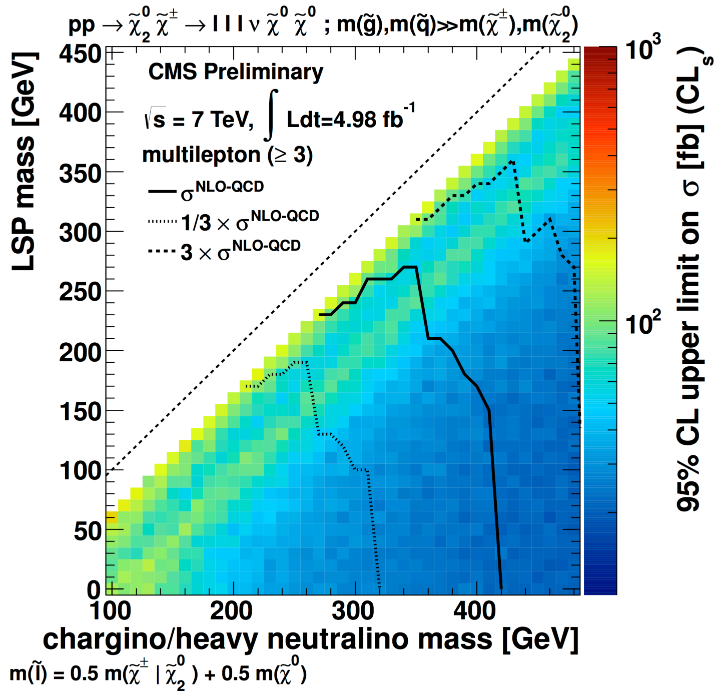
## co NLSP Scenario



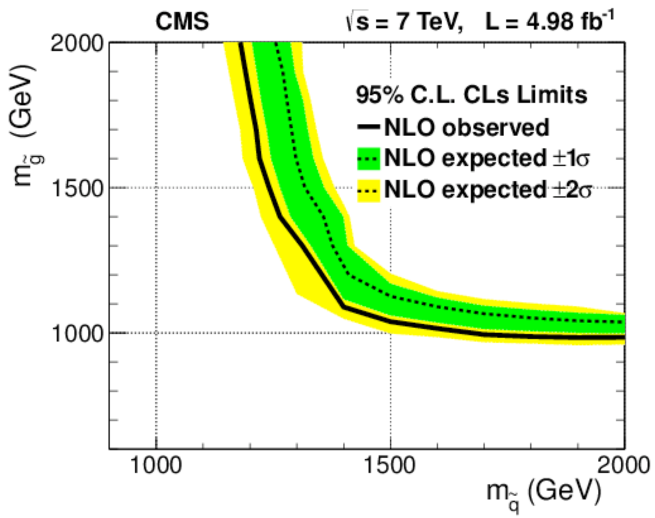

## Hadronic RPV




## SMS SUSY RPC



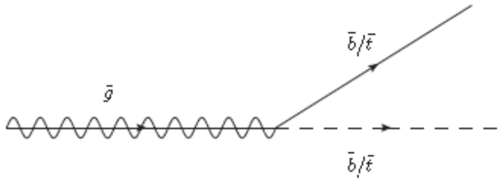

## Leptonic RPV



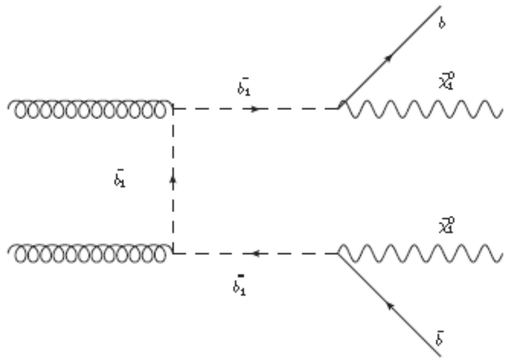
# Developing New Strategies

- **"Third generation" searches looking for stops and sbottoms are developed and ongoing. So far null results there as well.**
- **Hierarchy problem solved naturally if the 3rd generation is light.**
- $\tilde{t}_1, \tilde{b}_1$ search strategy (***b-tagging is the key***) :

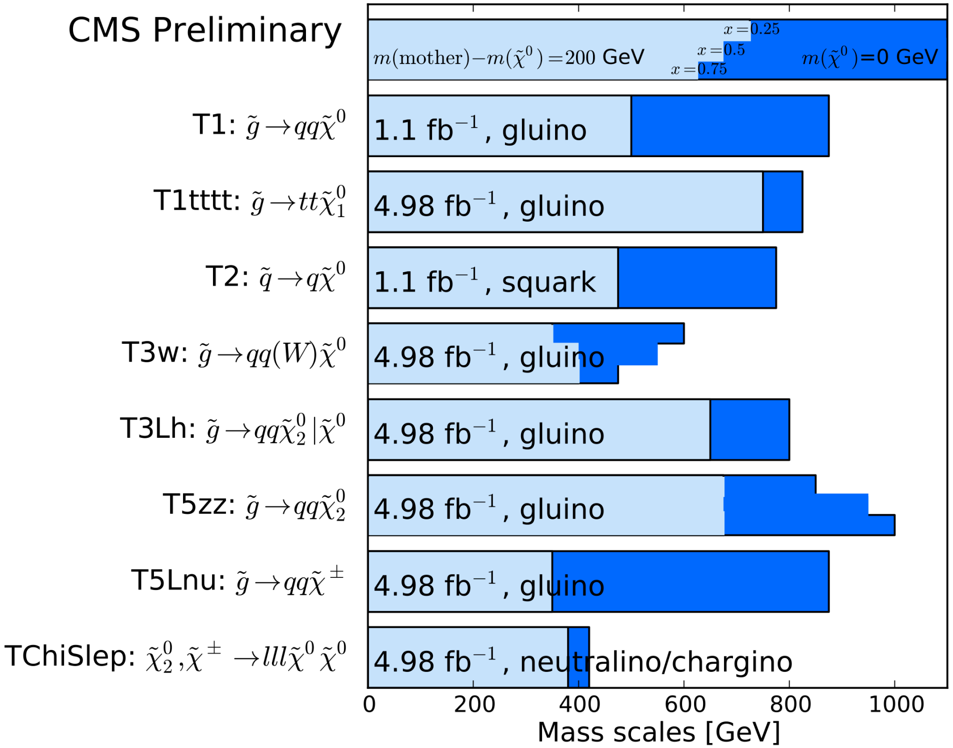
**-If gluino mass accessible at 7 (8) TeV then one can search for gluino mediated sbottom/stop pair production.**

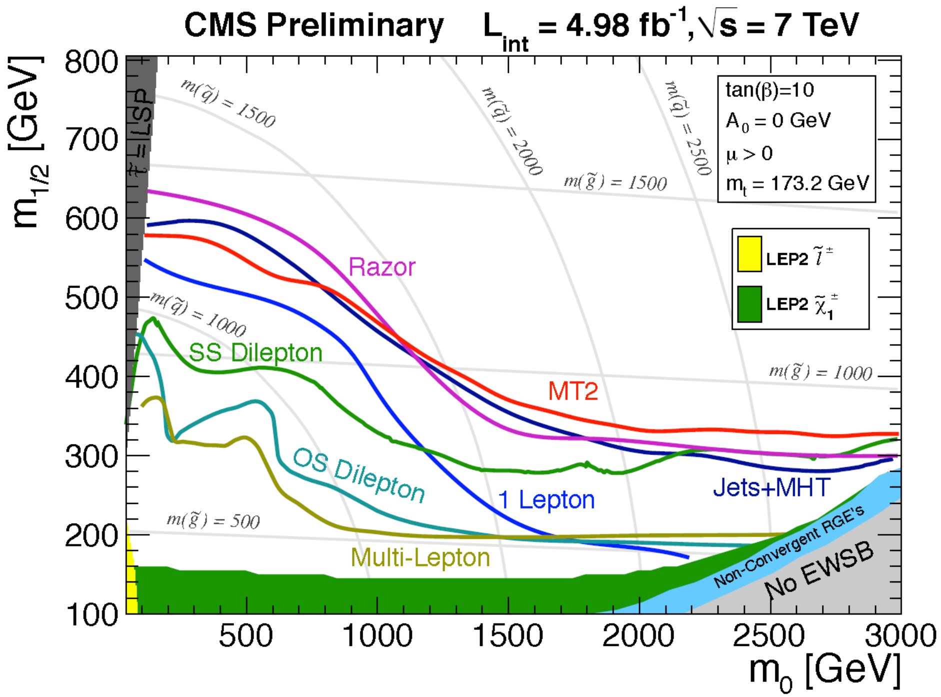


**-If gluino mass not accessible at 7 (8) TeV then one can search for direct sbottom/stop pair production.**



# Summary




CMS has been searching for evidence of SUSY :

- In many different final states : 0-lepton, 1-lepton, 2-lepton, multi-lepton.

-With complementary and independent searches (in all cases more than one analysis is deployed).

-Using data-driven approaches for the estimation of SM backgrounds.

-Using cut-based and multivariate techniques to select the possible SUSY signals.

# Outlook

- It is clear that SUSY is not "just around the corner". No evidence of any excess is seen with the analyzed 5 $fb^{-1}$ of the 2011 7 TeV data-set.
- With the excellent detector performance and understanding and the very successful MC modeling, new multivariate techniques start to be deployed looking in "difficult" regions of phase space (low MET/HT)
- 3$^{rd}$ generation searches are advancing and developing as well.
- New combined search strategies (looking for moderate disperse signal along many different final states) are now being developed.
- **SUSY is not just around the corner but it might be two blocks down the way…so stay tuned.**

# Backup