Direct Search of New Physics at LHC

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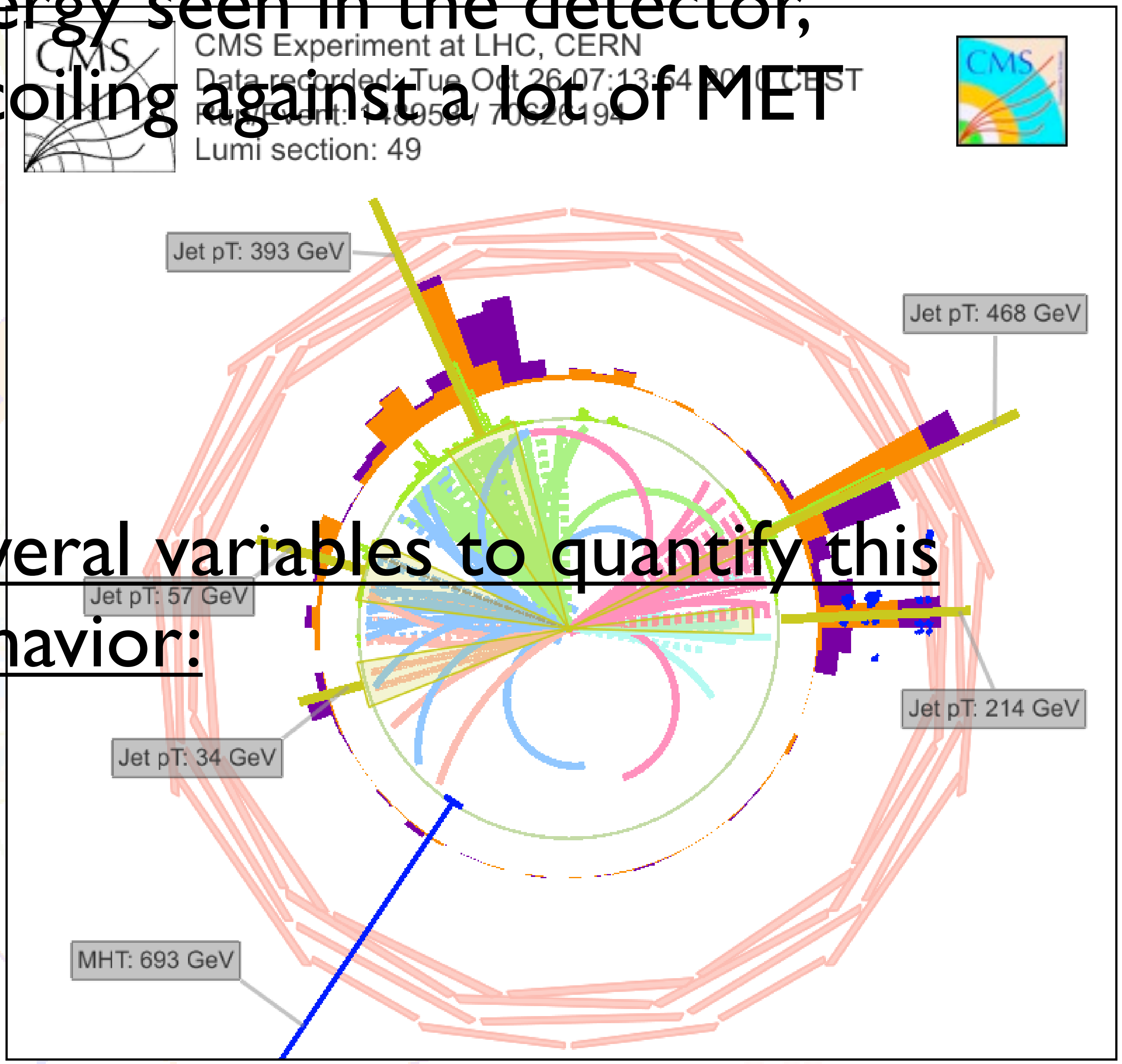
Disclaimer

- 30 min are not enough to cover a physics program that covers SUSY searches, as well as new resonances (RS gravitons, techniParticles, Z', etc)
- For more information look at
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- I will concentrate on SUSY searches, with emphasis on the hadronic searches and to new techniques
- Here SUSY is just a paradigm of any new physics in which stable neutral particles (e.g. Dark Matter candidates) are produced in the cascade of pair-produced heavy particles

A "classic" SUSY search

<u>The typical signature:</u> a lot of energy seen in the detector, recoiling against a lot of MET



<u>Several variables to quantify this behavior:</u>

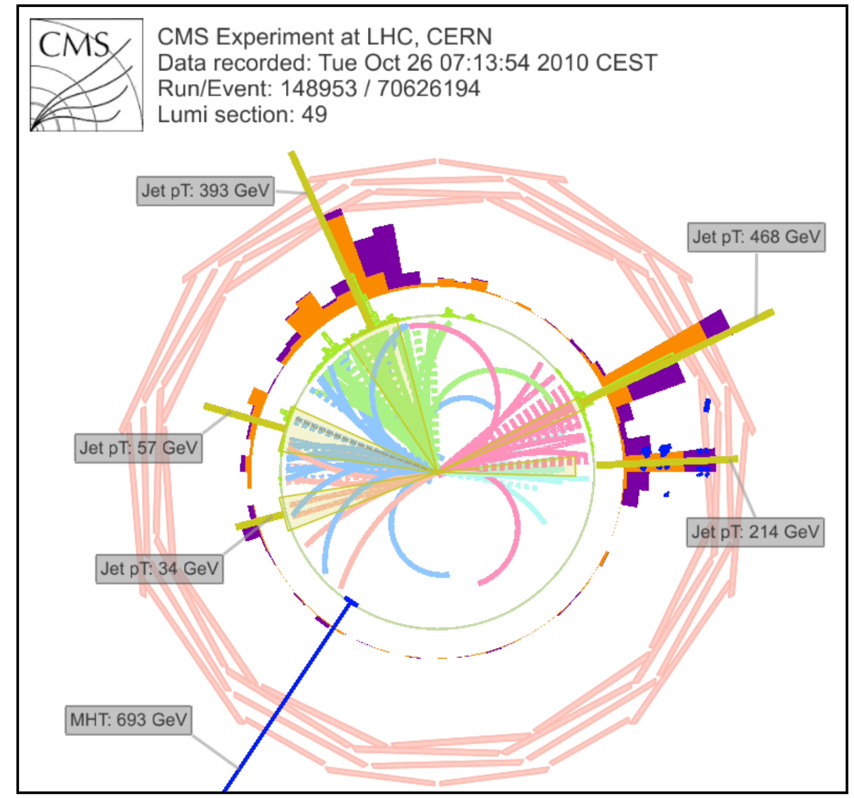
$$HT = \Sigma_{jet} |p_T^{jet}|$$

$$|MHT| = |\Sigma_{jet} p_T^{jet}|$$

$$|MET| = |\Sigma_{cell} \mathrm{E}_T^{cell}|$$

$$m_{eff} = HT + |MET|$$

A "classic" SUSY search



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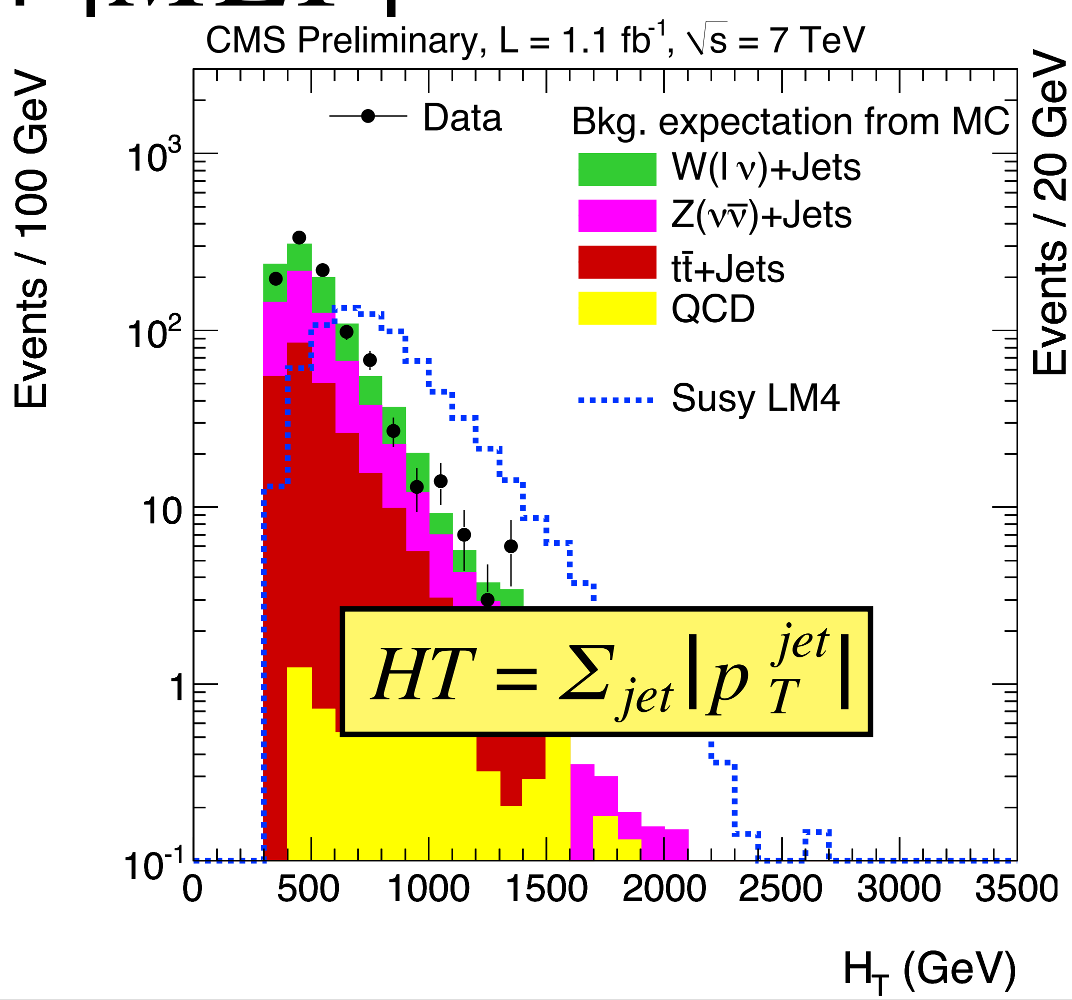
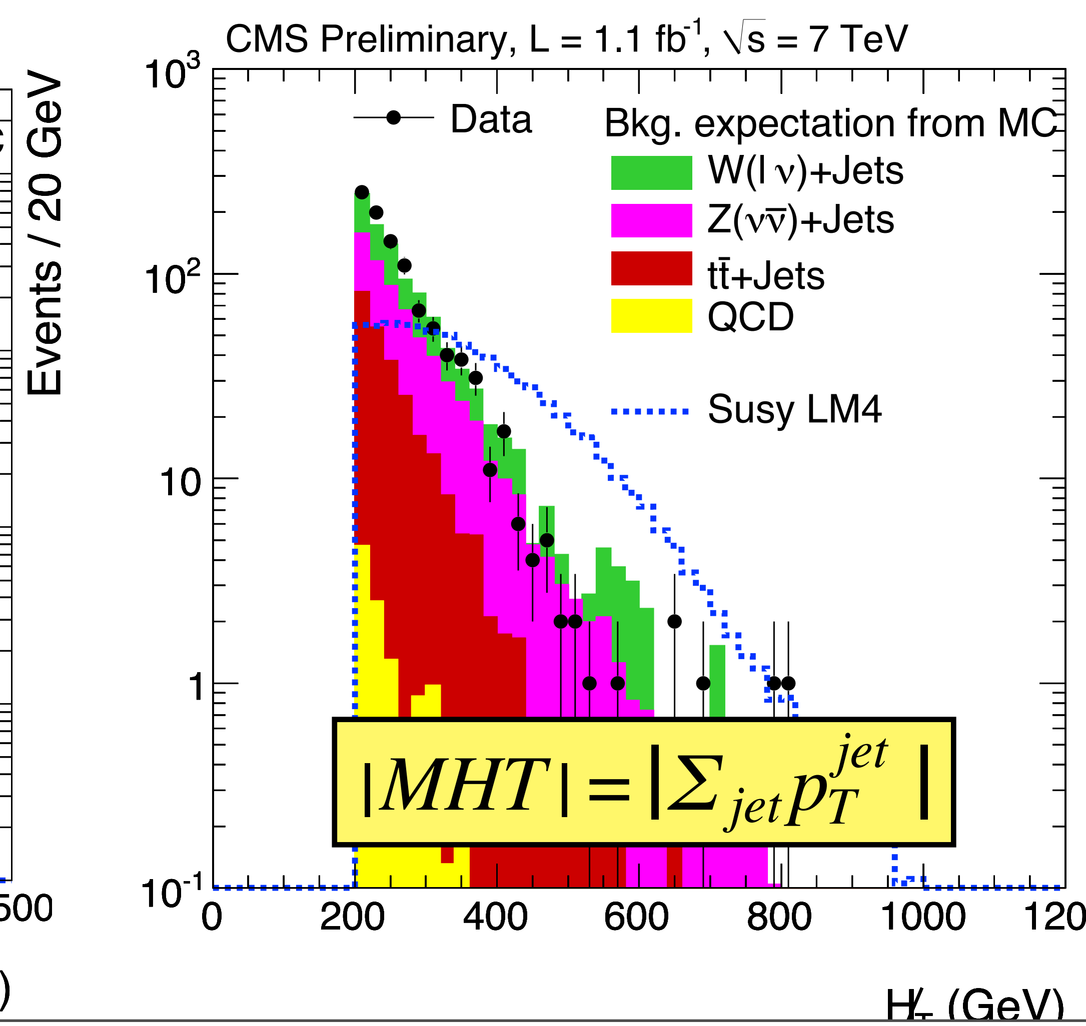
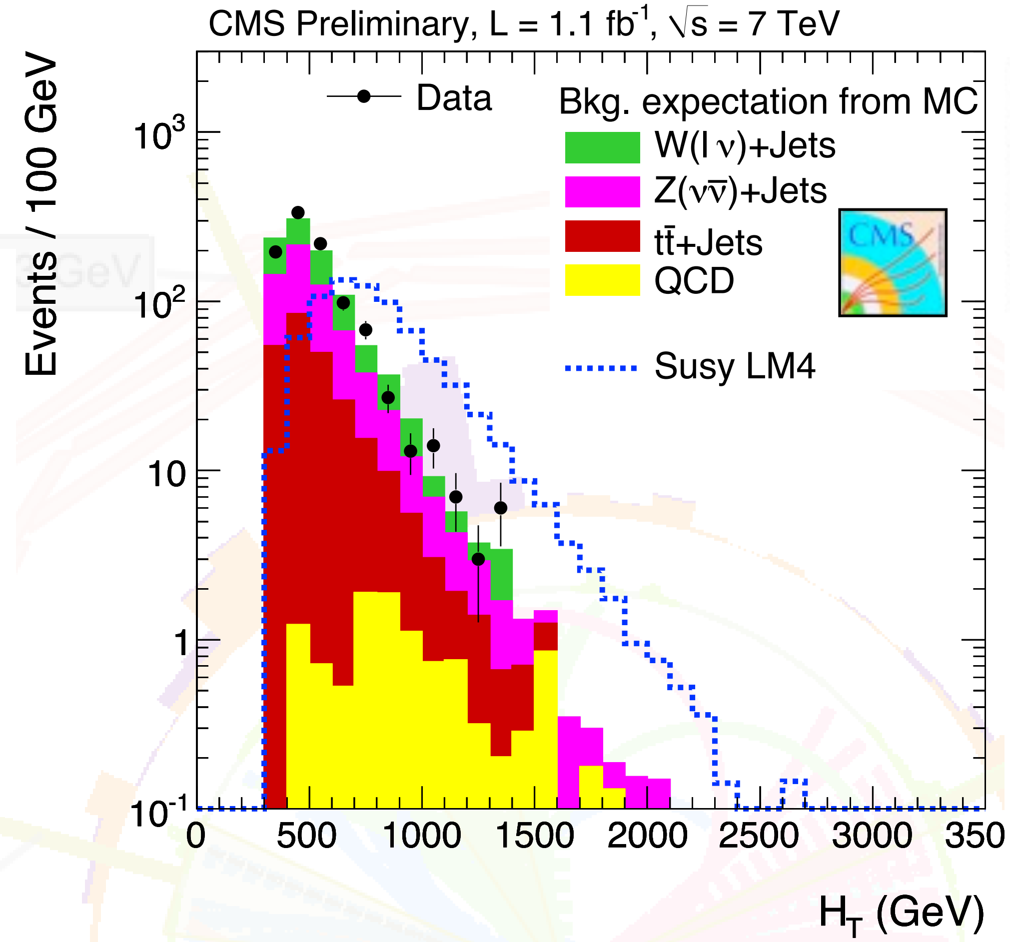
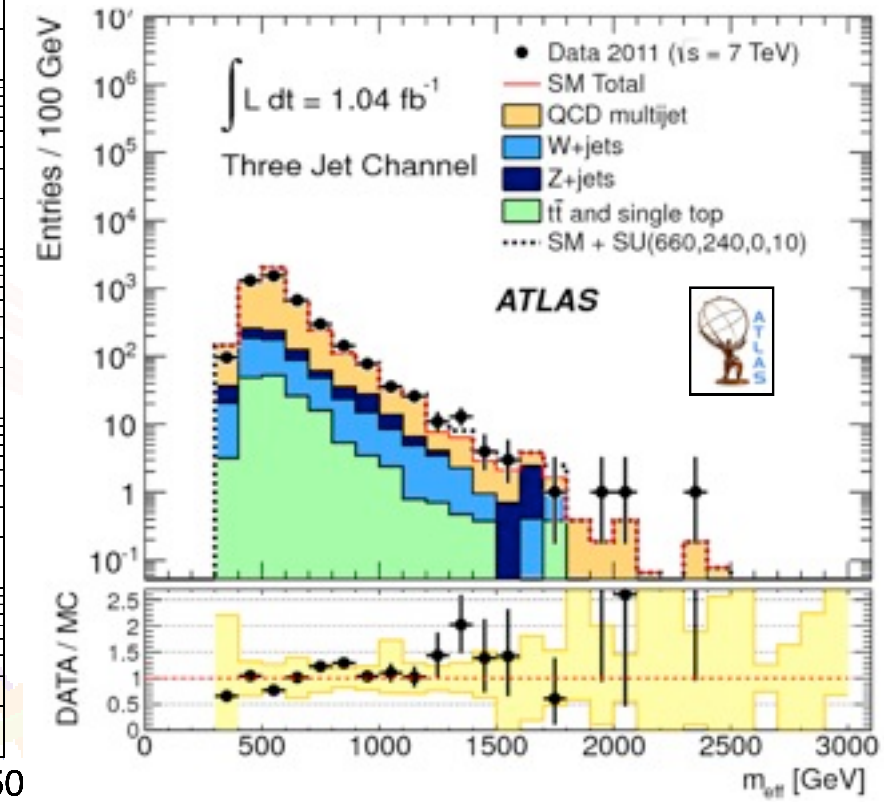


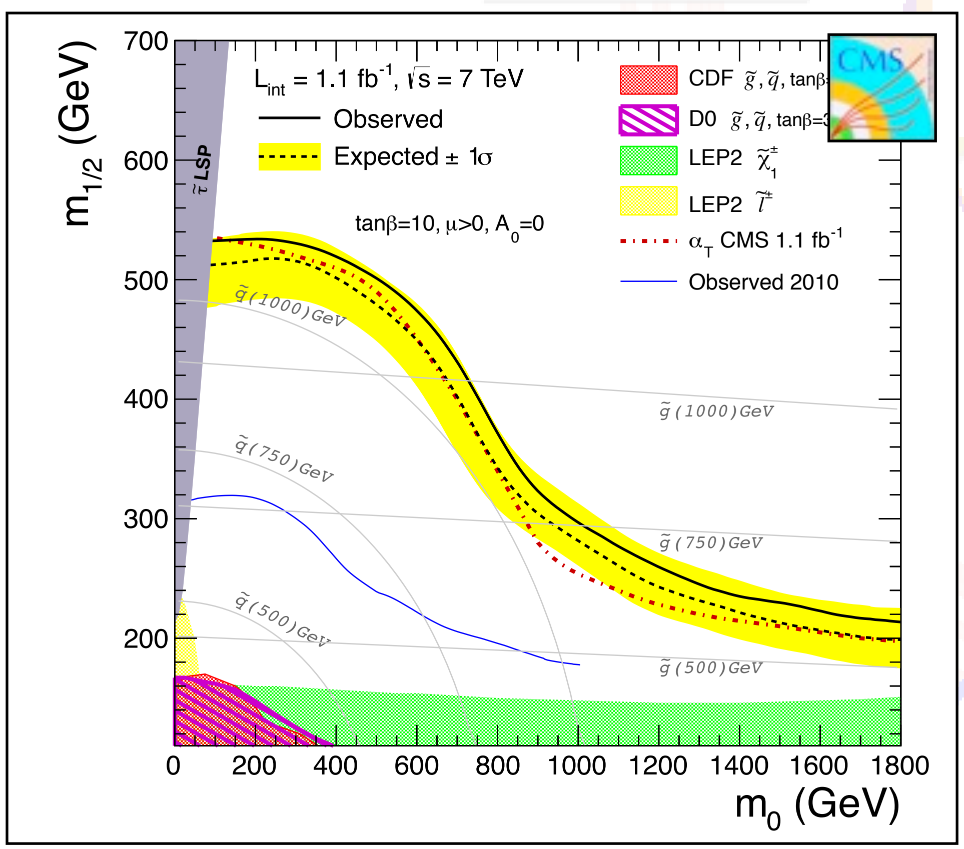


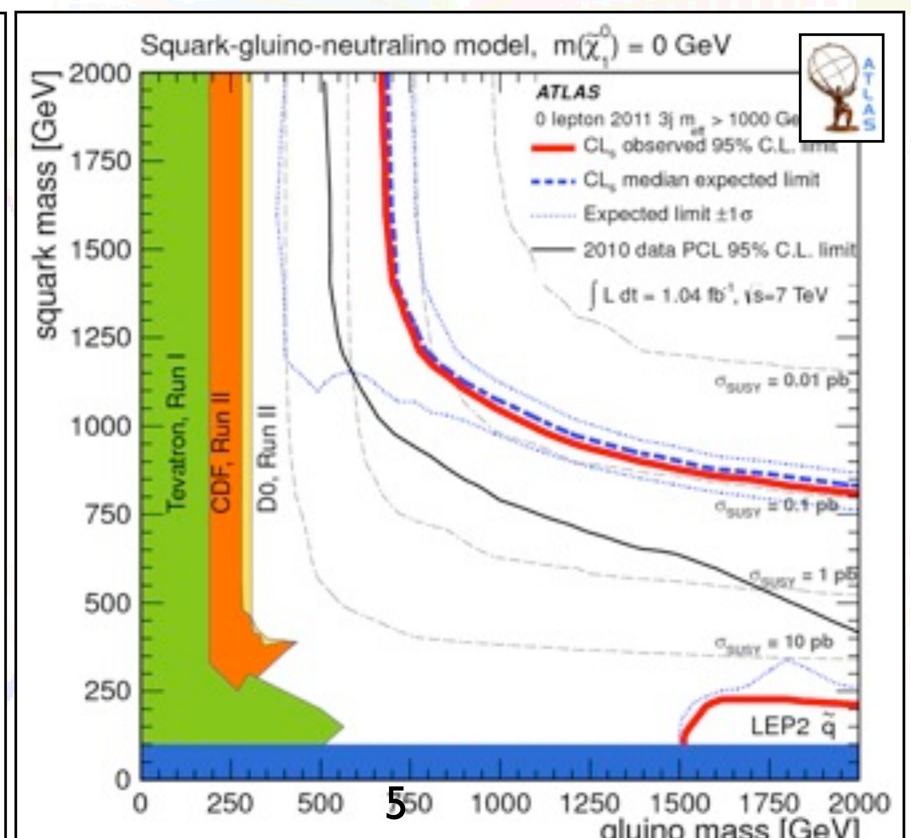
A “classic” SUSY search

A counting experiment is performed on the tail of the distribution





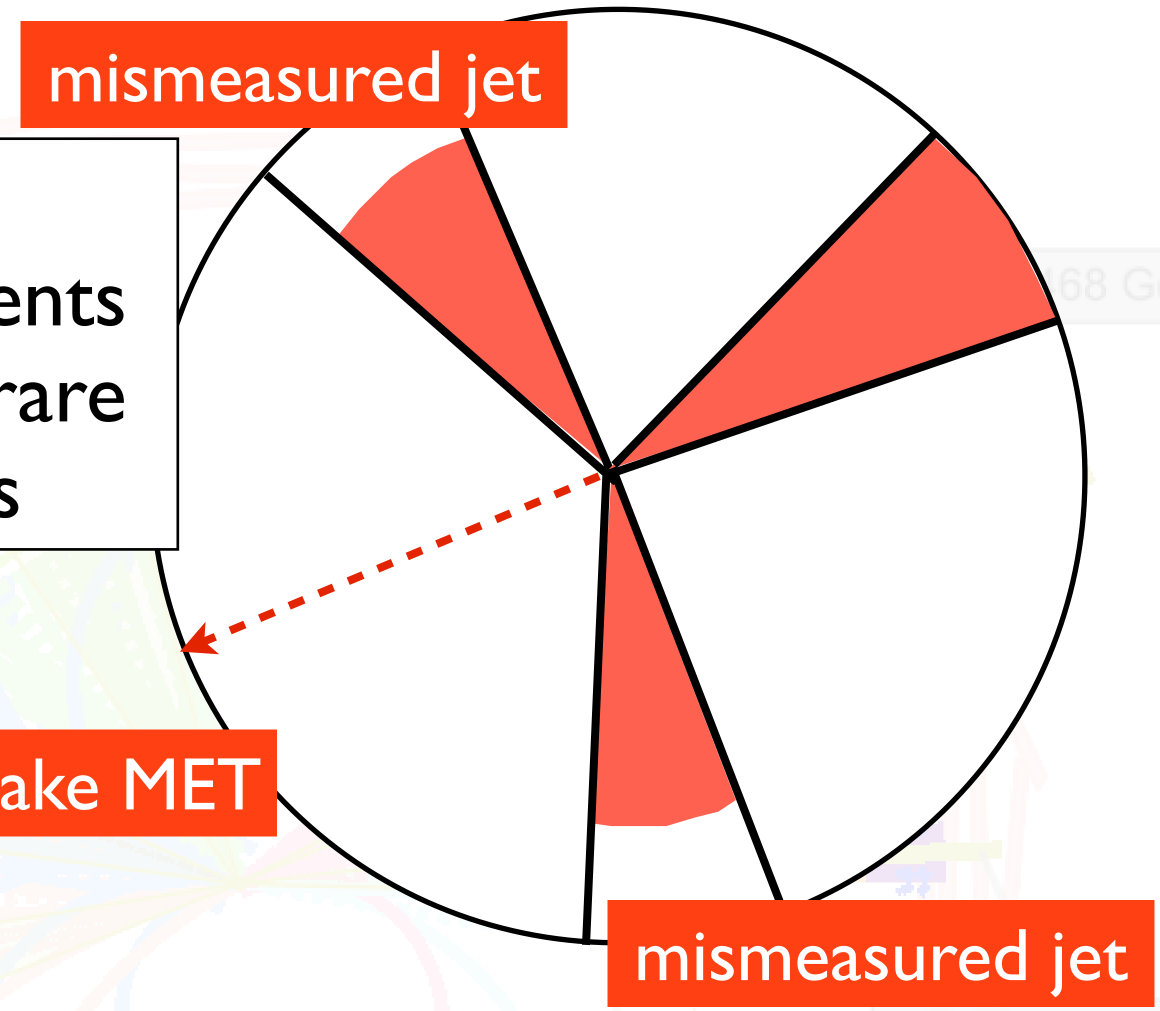


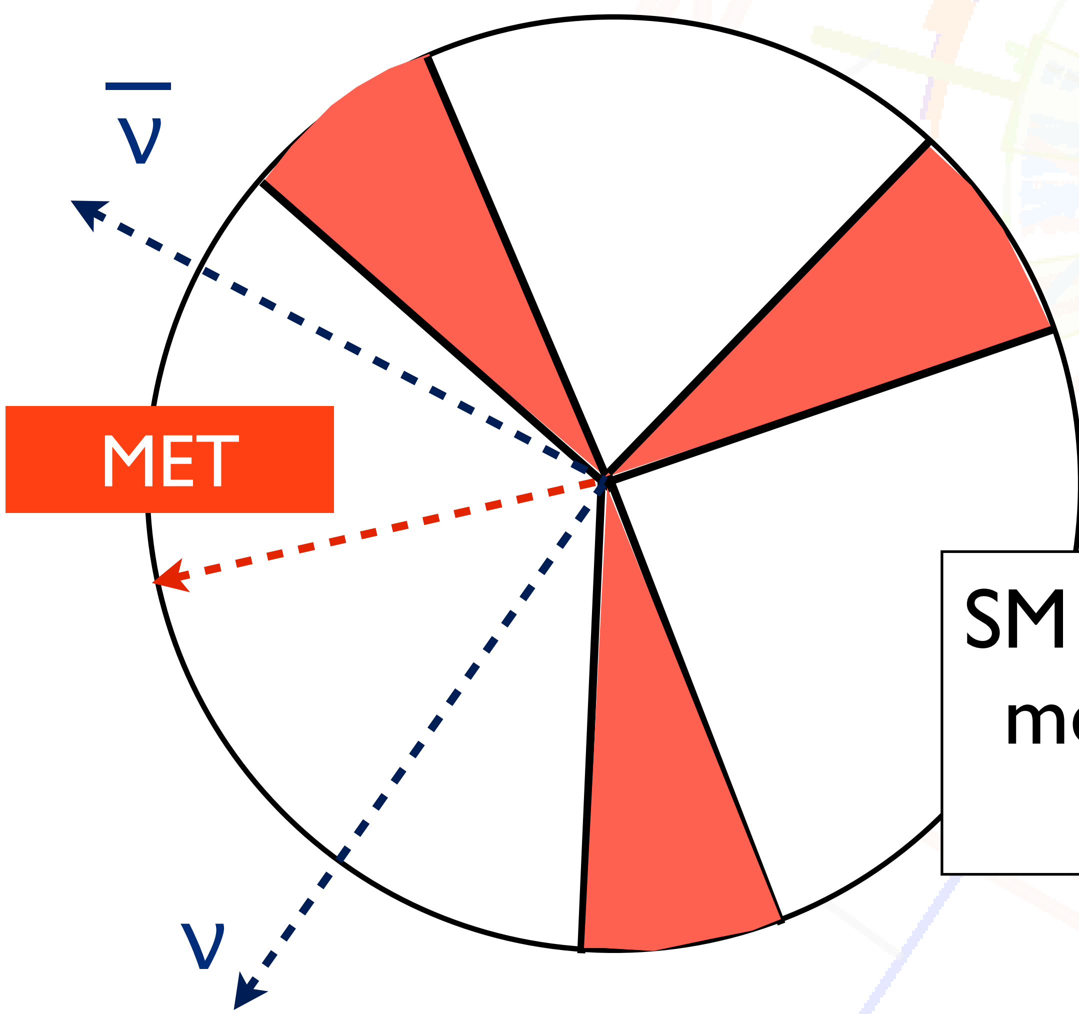


An exclusion limit is set on some NP parameter space

Bkg To Fight

<u>QCD with fake MET</u>
related to pathological events require understanding of rare detector-related effects





SM processes with real MET, e.g. $Z(\nu\nu)$+jets measurable from control samples defined on data

QCD prediction

Background prediction:

QCD Re-balance and smear

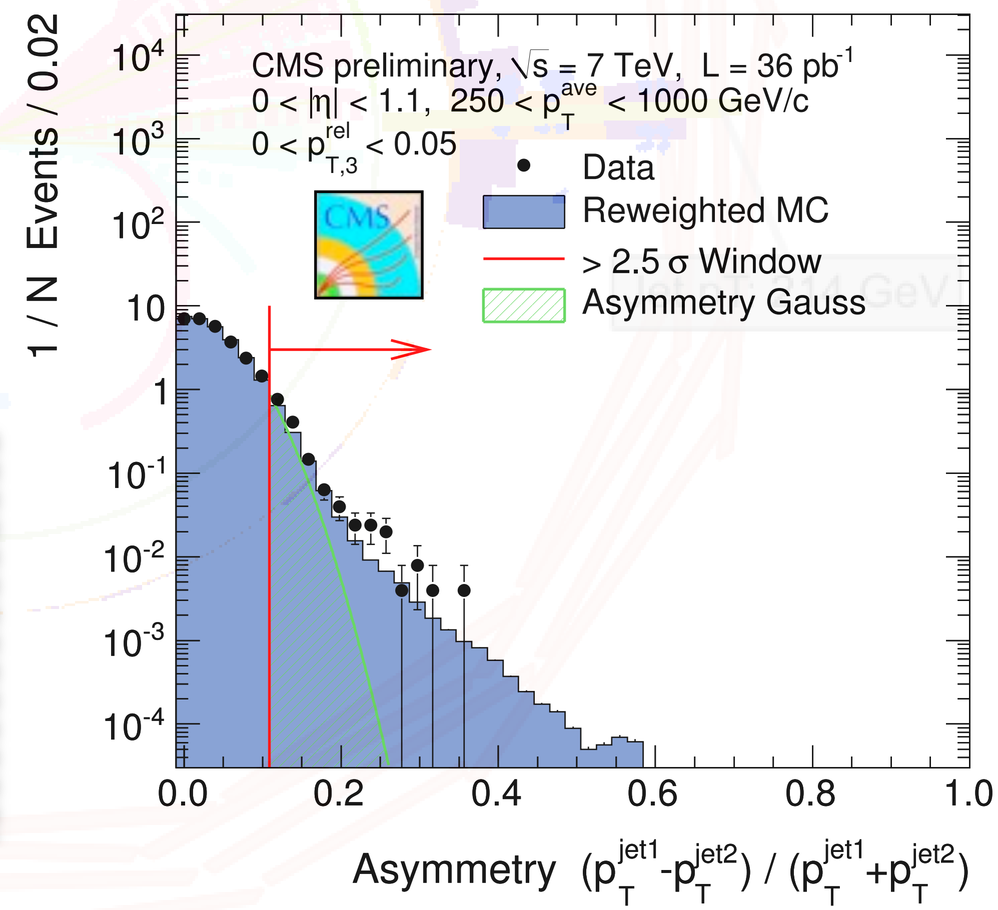
$W(\ell\nu) + \text{jets},\ t\bar{t}$ Use μ control sample

$Z(\nu\nu) + \text{jets}$ Use γ+jets and Z($\mu\mu$)+jets control samples

Search for high p_T jets, high HT and high MHT

QCD multi-jet events do not intrinsically populate the phase-space defined by our requirements on scale and angle -- BUT, mis-measurements of jets can result in large measured MHT

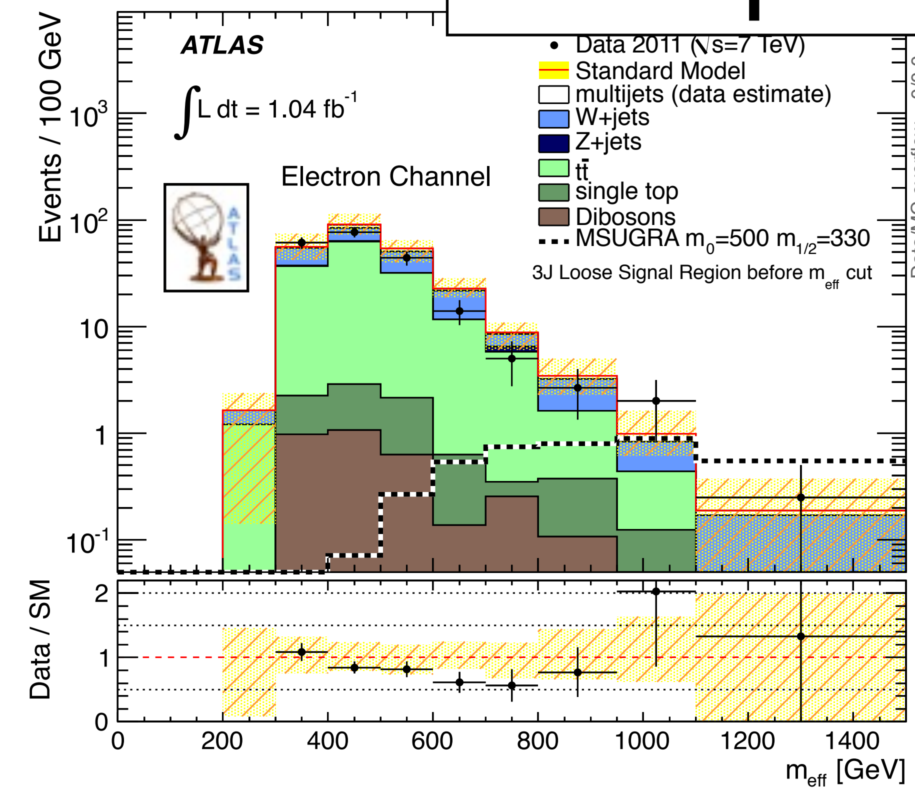
QCD multi-jet background predicted by 'smearing' balanced (no MHT) events with measured resolution functions



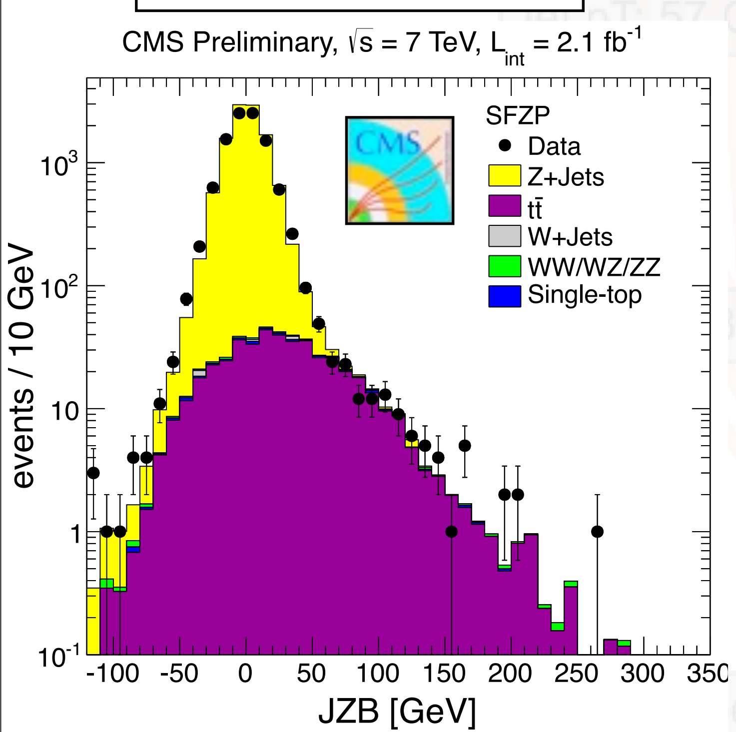
Adding Leptons

- Whenever a lepton is added to the final state, the QCD background is reduced to manageable/negligible level
- In these conditions, one can go looser with the kinematic requirements

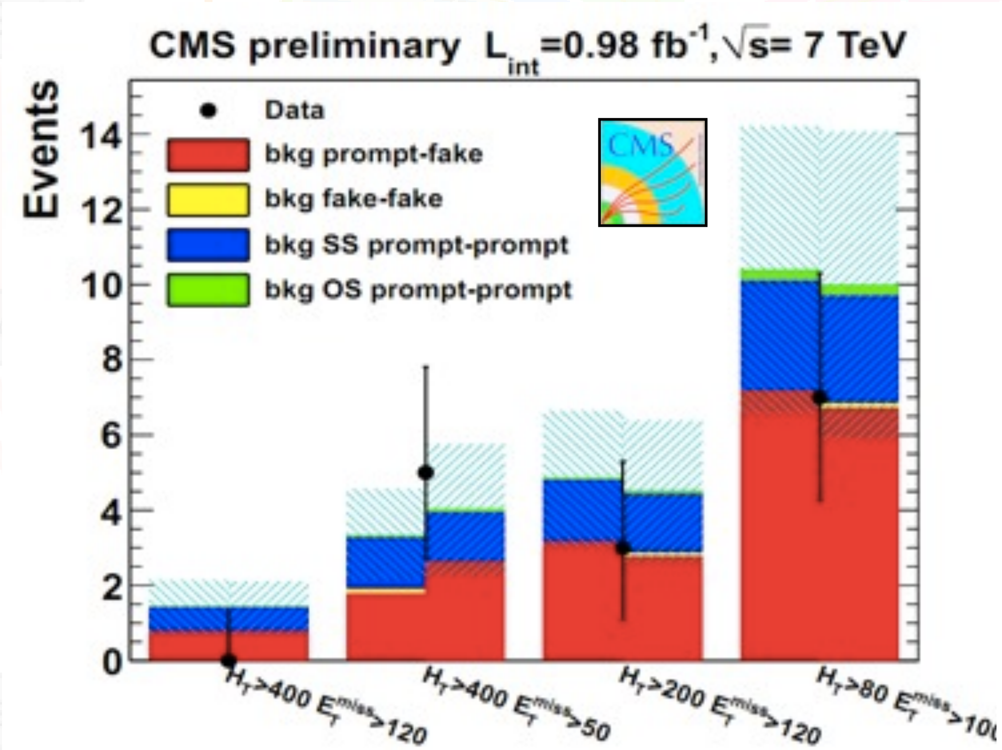
one lepton



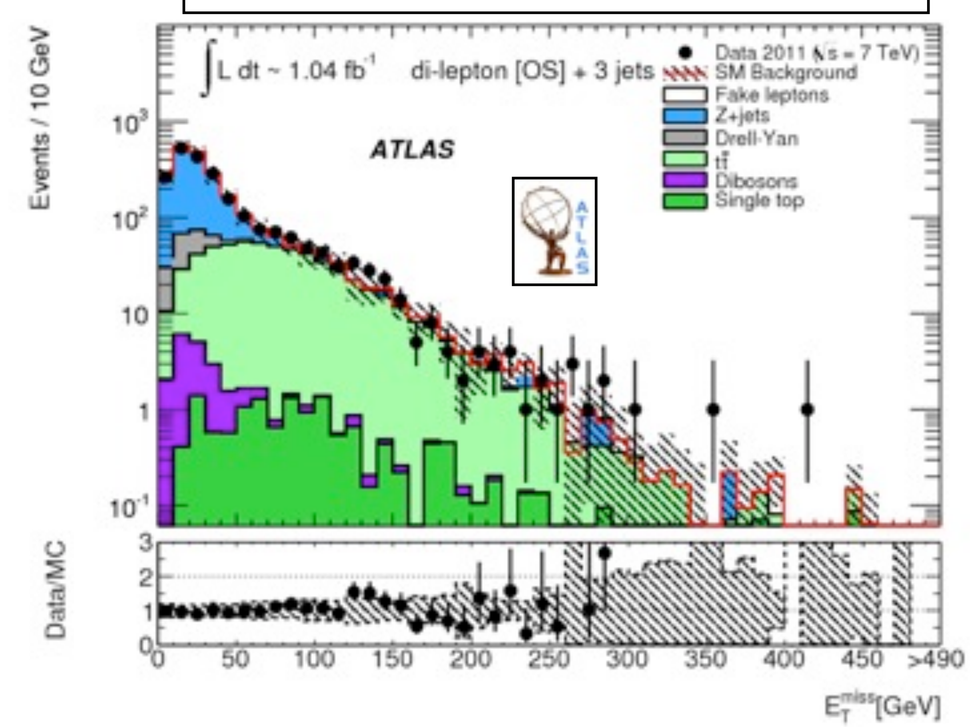
Z(ll)+jets



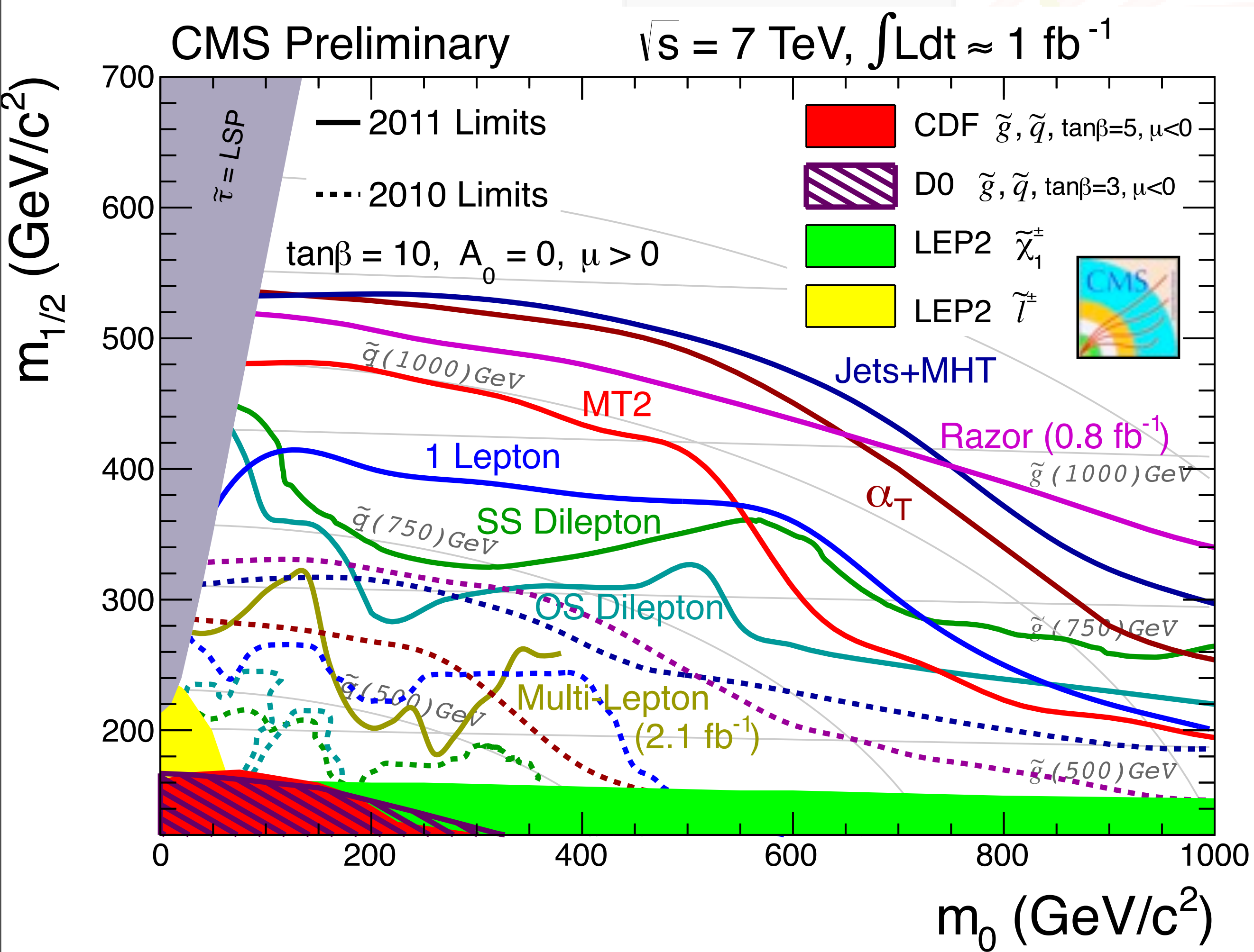
SS two leptons

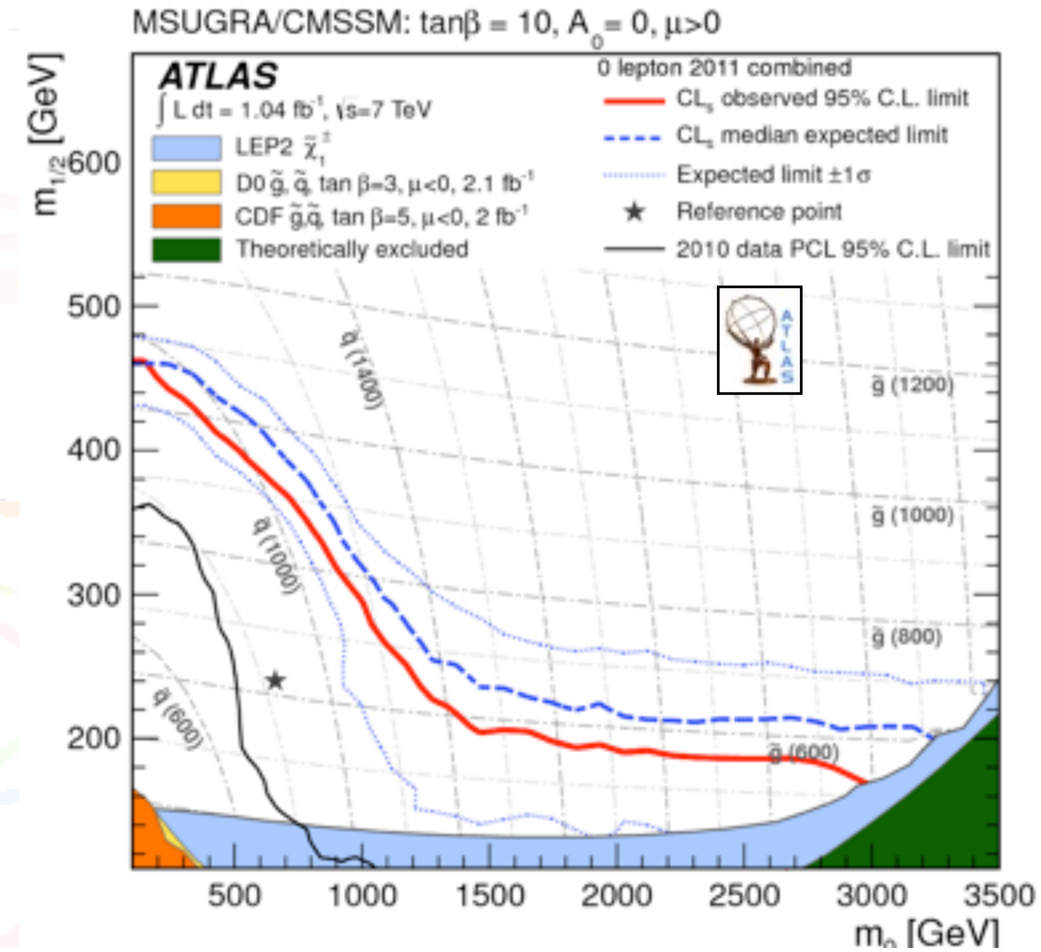


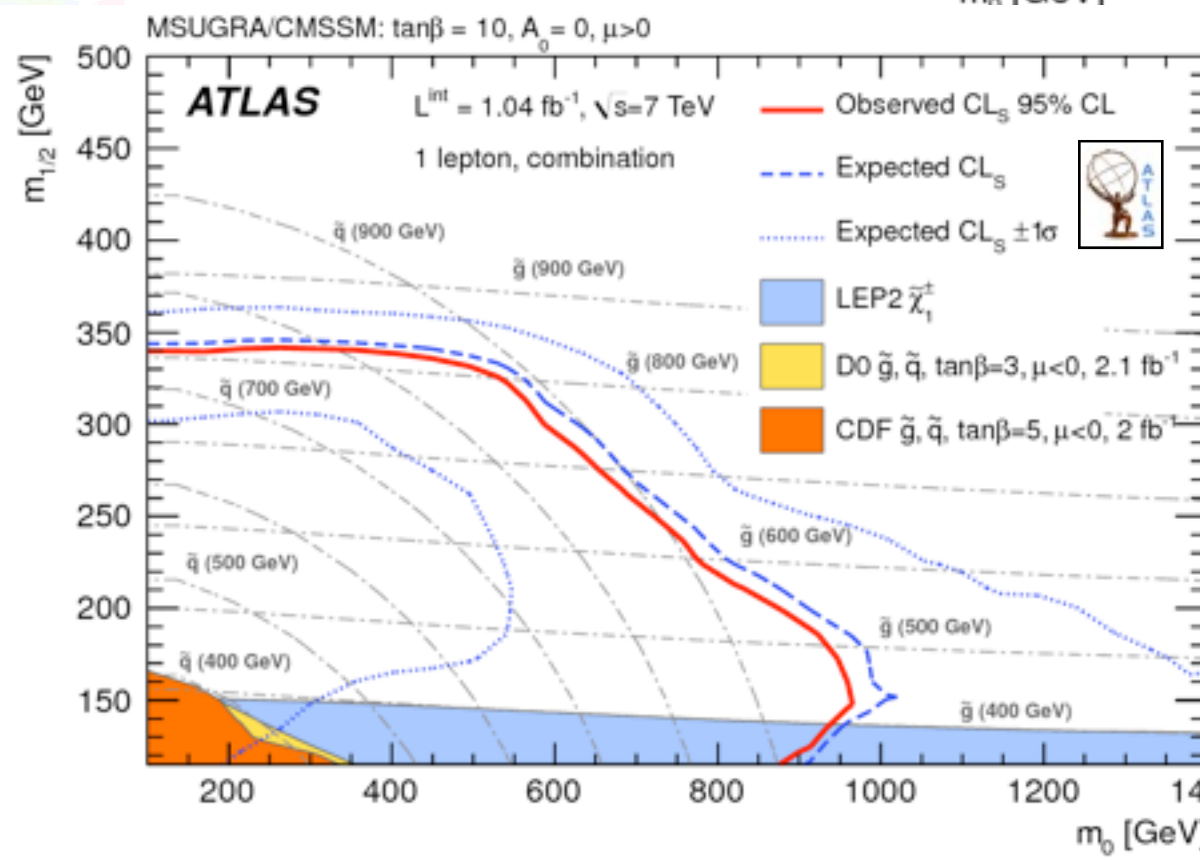
OS two leptons



Results on CMSSM







QCD Killing

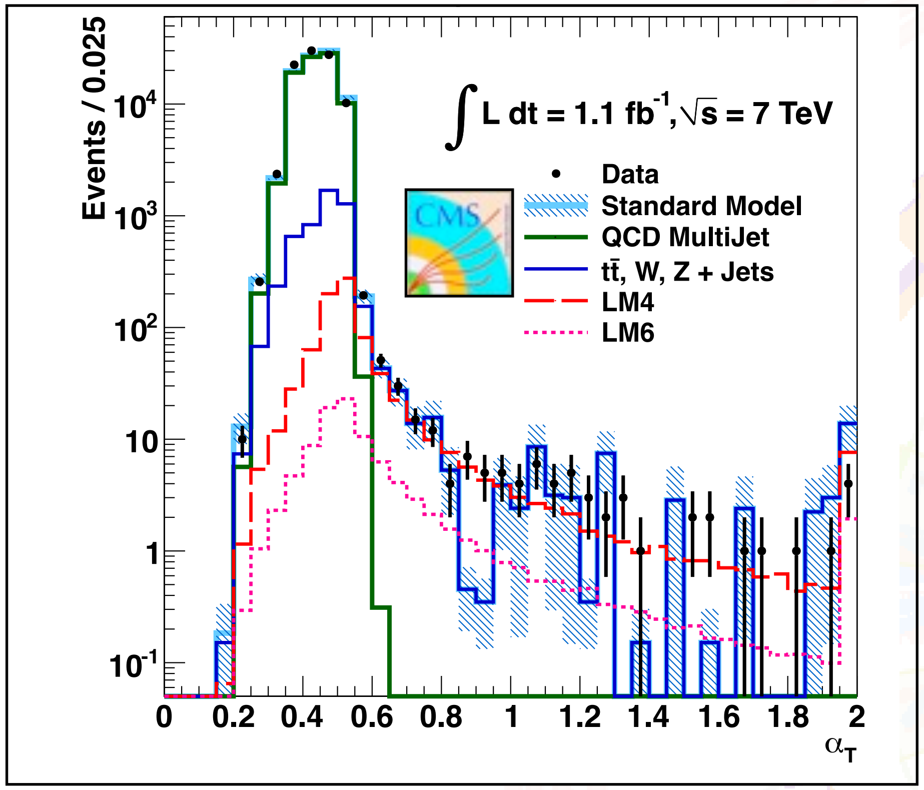
- Predicting the QCD bkg is the more problematic task of a "classic" analysis
- New approaches proposed to reduce the QCD to negligible level and deal with the residual SM background through data-driven control samples
- Different layers of extra assumptions give different signal vs. background separation
  - αT: unbalanced events
  - MT2: MET coming from two particles
  - RAZOR variables: pair production of heavy objects producing two missing particles

α_T: Killing QCD

$$\alpha \equiv \frac{p_{T2}}{m_{jj}}.$$

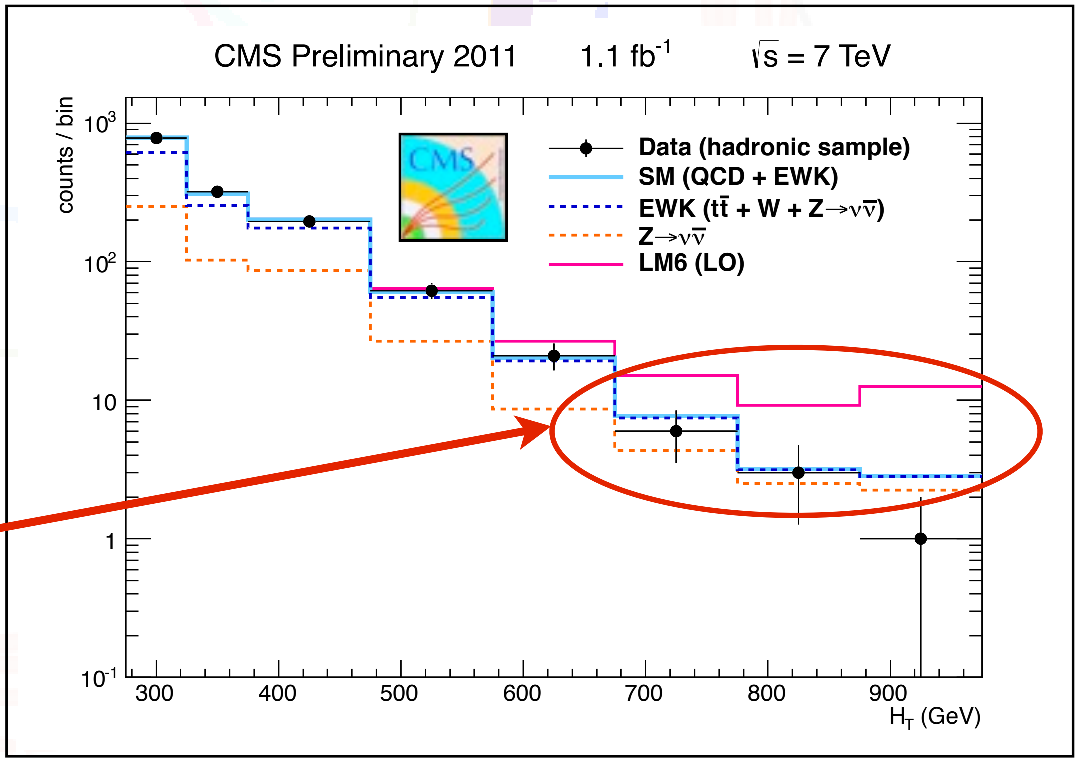
$$\alpha_T = \frac{E_T^{\text{jet}_2}}{M_T} = \frac{E_T^{\text{jet}_2}}{\sqrt{\left(\sum_{i=1}^{2} E_T^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{\text{jet}_i}\right)^2}}$$

Randall & Tucker-Smith



- αT = 0.5 for perfectly balanced dijet events
- αT<0.5 for dijet + mismeasurements
- EW main bkg after αT cut
- QCD events could leak to αT>0.5 because of detector effects (rare)
- large fraction of signal events removed (efficiency vs purity)

- After αT cut the signal looks similar to bkg in αT
- another variable needs to be used to characterize the signal
- Back to the "classic" paradigm": HT used by CMS



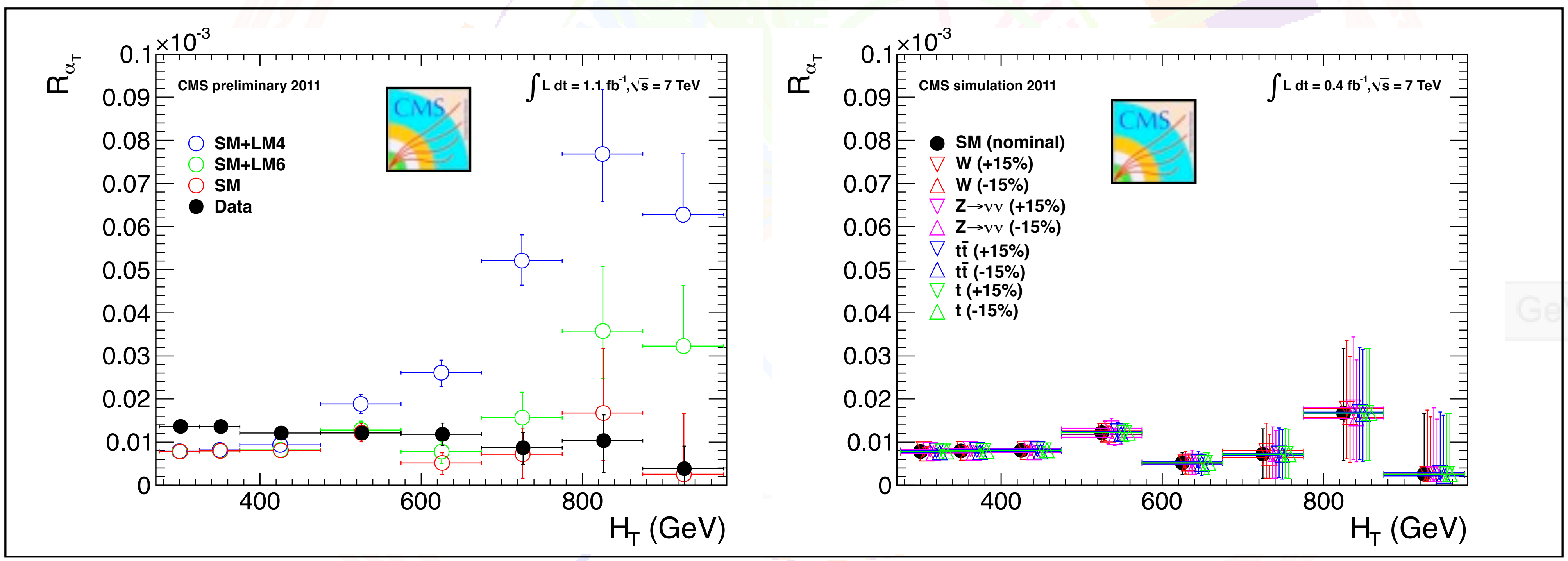
α_T: BKG Estimate

- EW bkg is estimated using the RαT (*) ratio

$$\boxed{R_{\alpha_T} = N^{\alpha_T > \theta} / N^{\alpha_T < \theta}}$$

- This is computed scaling the pT of the jets with the HT threshold, to event topology

- The ratio is found to be compatible with the flat hypothesis within the available data and SM MC statistics

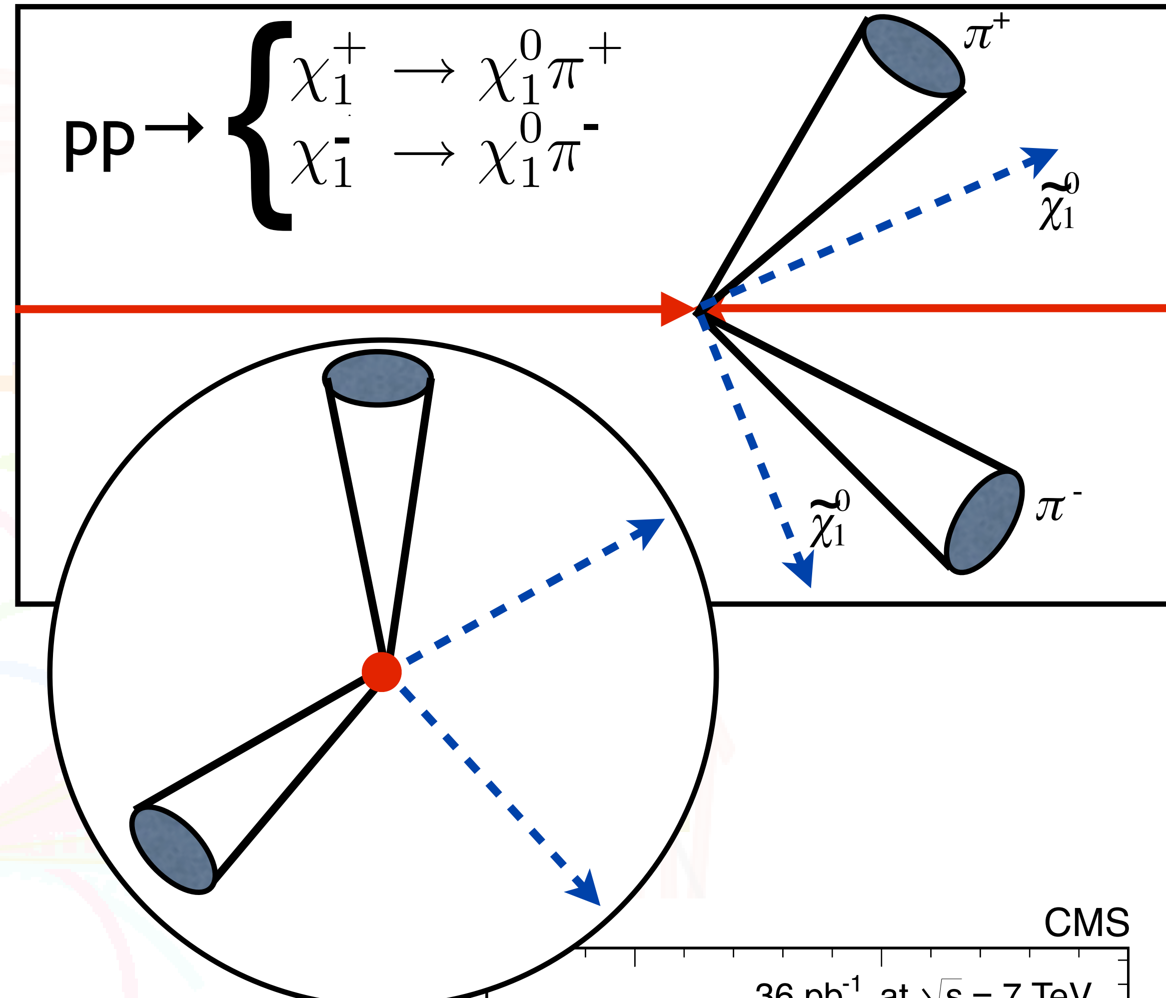


- This is used to predict the bkg expected in each bin of HT. Then a fit to the HT shape is used (more on this later) <--- TODO

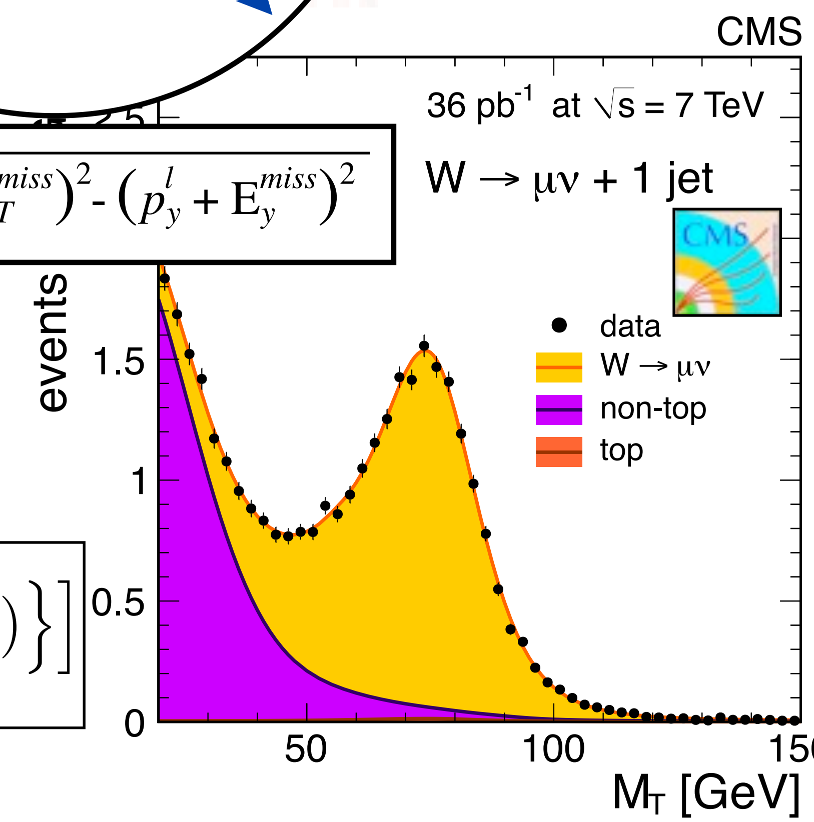
(*) Number of EW events with αT>θ / number of QCD events with αT<θ

M_{T2}: two missing particles

- We are looking for events with two undetected neutral particles leaving the detector
- We measure the sum of their pT as MET
- This is similar to the detection of the W, for which the edge of the mT distribution is used
- The presence of two missing particles make the picture more complicated. With some reasoning (see backup) one gets



$$M_T = \sqrt{E_T^l E_T^{miss} - (p_x^l + E_T^{miss})^2 - (p_y^l + E_y^{miss})^2}$$



$$m_{T2}^2(\chi) \equiv \min_{\not{q}_T^{(1)} + \not{q}_T^{(2)} = \not{p}_T} \left[\max \left\{ m_T^2(\mathbf{p}_T^{\pi^{(1)}}, \not{q}_T^{(1)}; \chi),\ m_T^2(\mathbf{p}_T^{\pi^{(2)}}, \not{q}_T^{(2)}; \chi) \right\} \right]$$

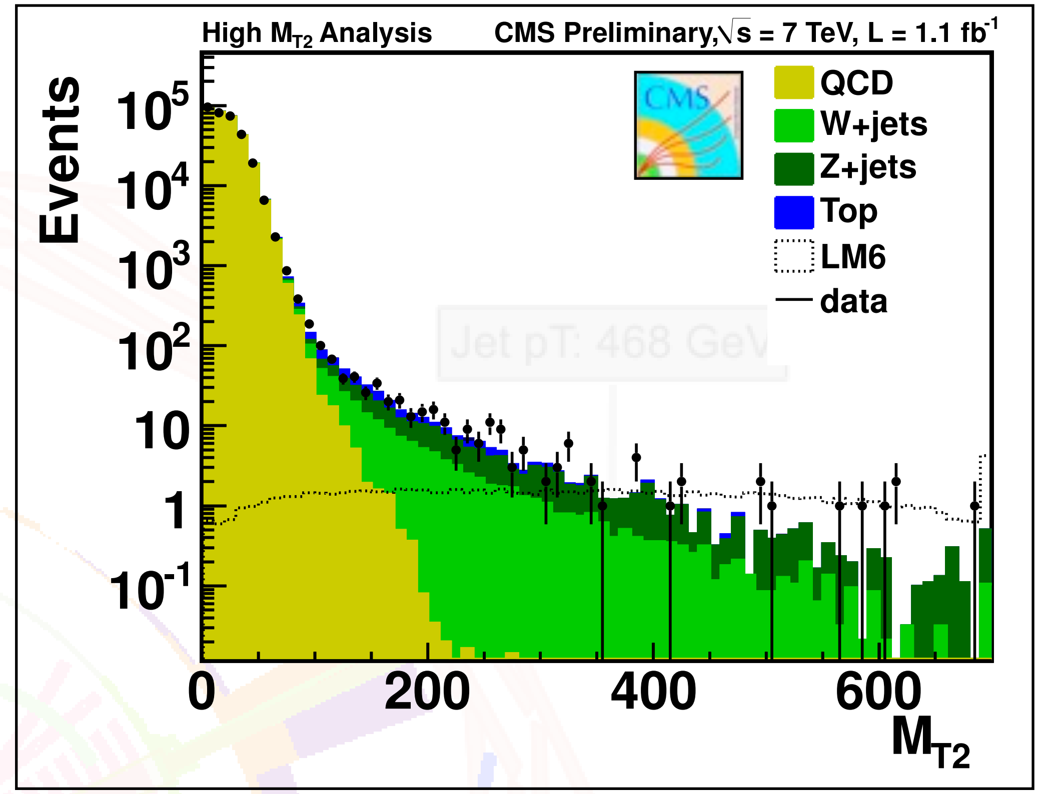
M_{T2}: two missing particles

- M_{T2} is found to be useful for searches, since it allows to reduce QCD to negligible level

  - Assume a mass value (eg mLSP=0)
  - Assume that the visible system in has 0 mass
  - An analytical expression for M_{T2} is found

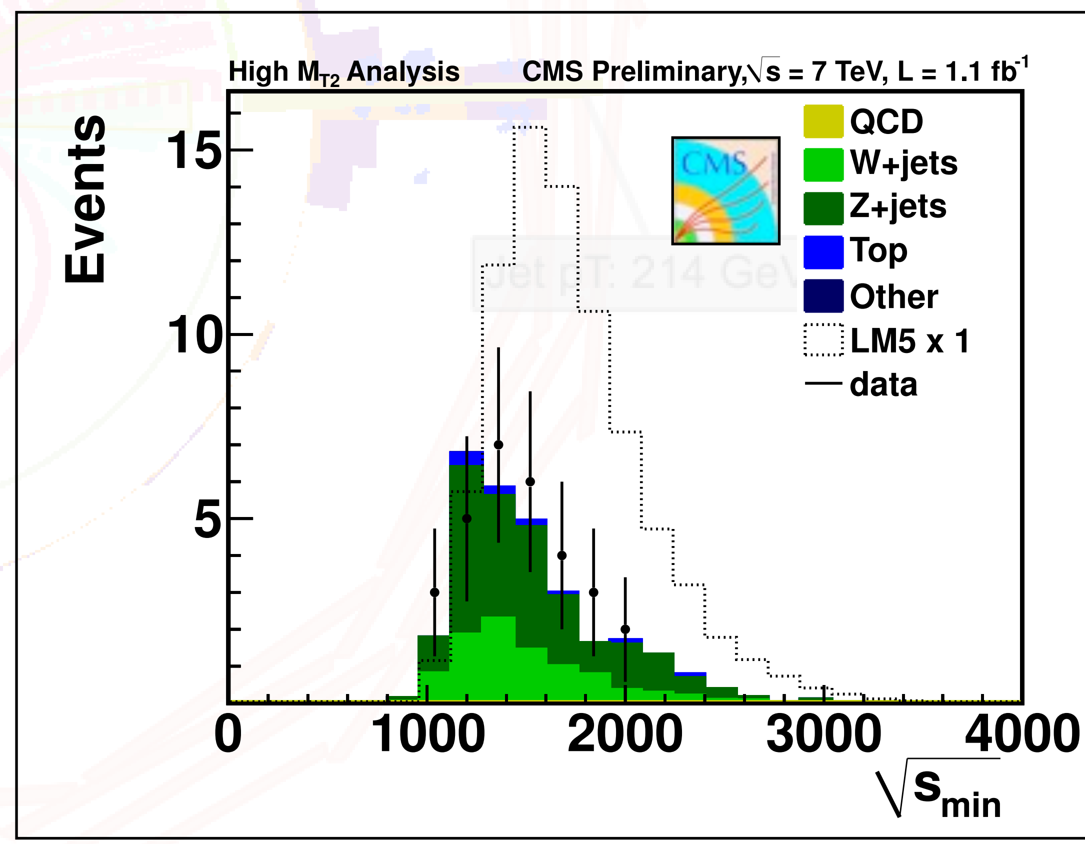
$$(M_{T2})^2 = 2A_T = 2p_T^{vis(1)} p_T^{vis(2)} (1 + cos\phi_{12})$$

  - The edge is lost but we have an α_T-like variable to kill the QCD



- Other variables could be used to characterize the signal, in case of a discovery. CMS would use $\sqrt{s}_{min}$ for that

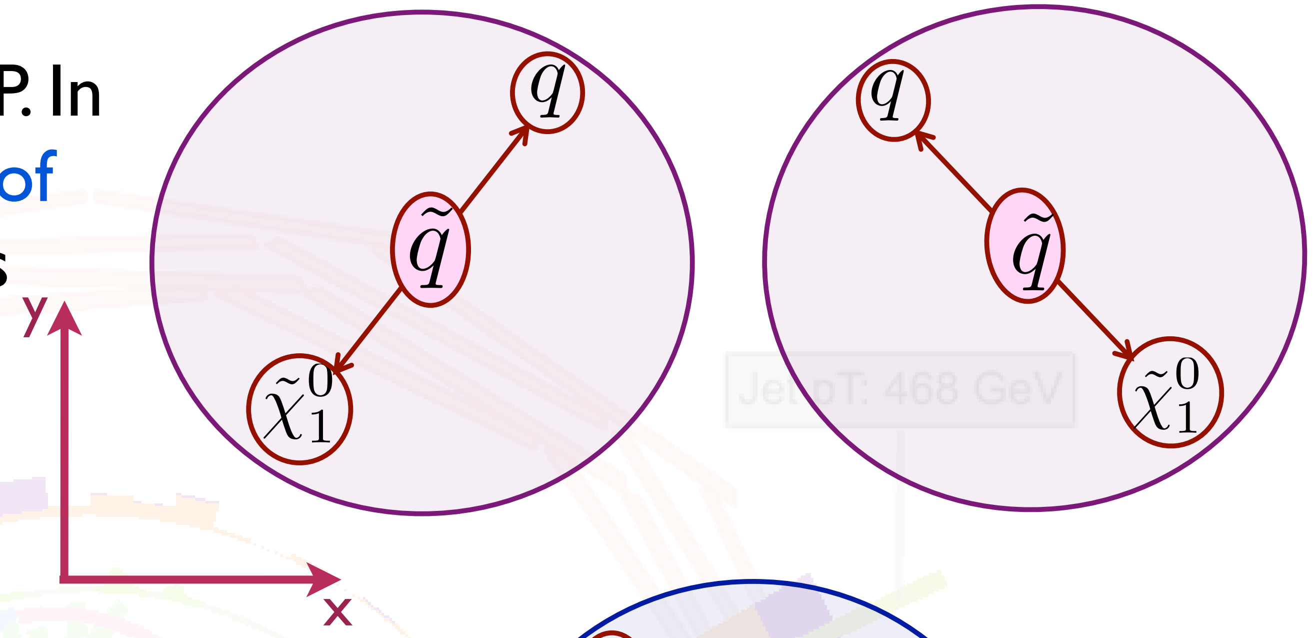
$$\sqrt{s}_{min}(M_{miss,min}) = \sqrt{M_{vis}^2 + P_{T,vis}^2} + \sqrt{M_{miss,min}^2 + \not{E}_T{}^2}$$



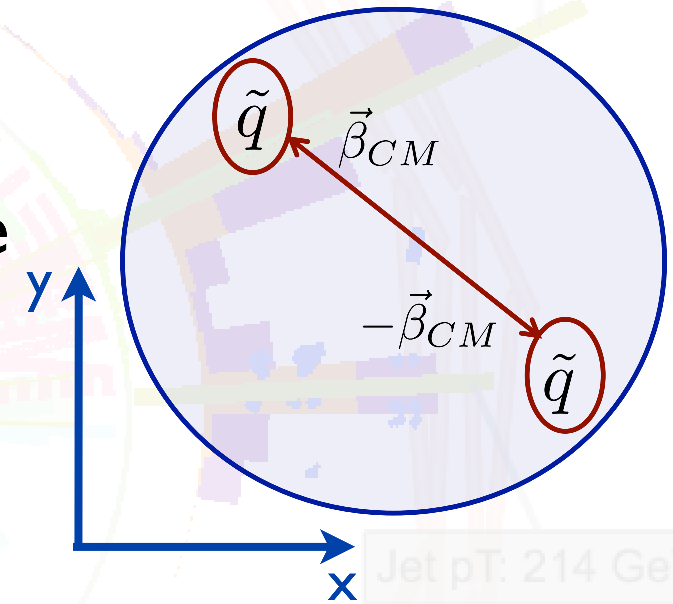
The Razor Frame

- Two squarks decaying to quark and LSP. In their rest frames, they are two copies of the same monochromatic decay. In this frame p(q) measures M_Δ

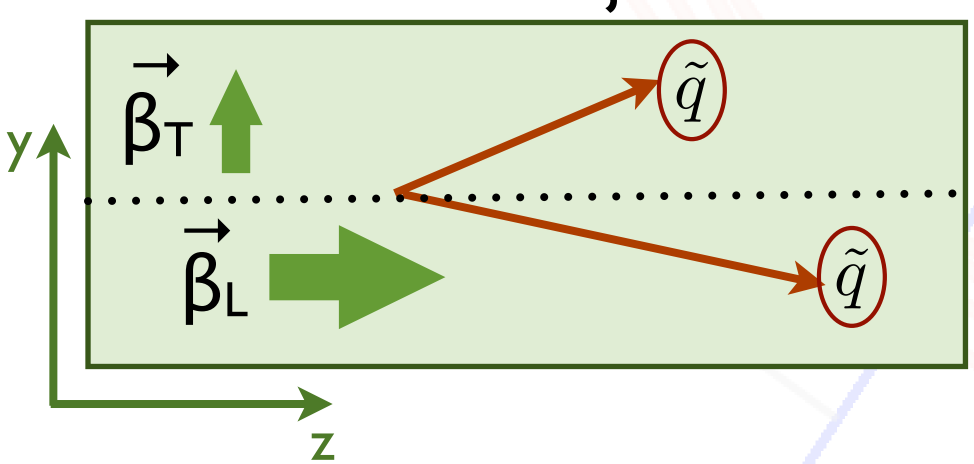
$$M_\Delta \equiv \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}} = 2M_{\tilde{\chi}}\gamma_\Delta\beta_\Delta$$



- In the rest frame of the two incoming partons, the two squarks recoil one against each other.



- In the lab frame, the two squarks are boosted longitudinally. The LSPs escape detection and the quarks are detected as two jets

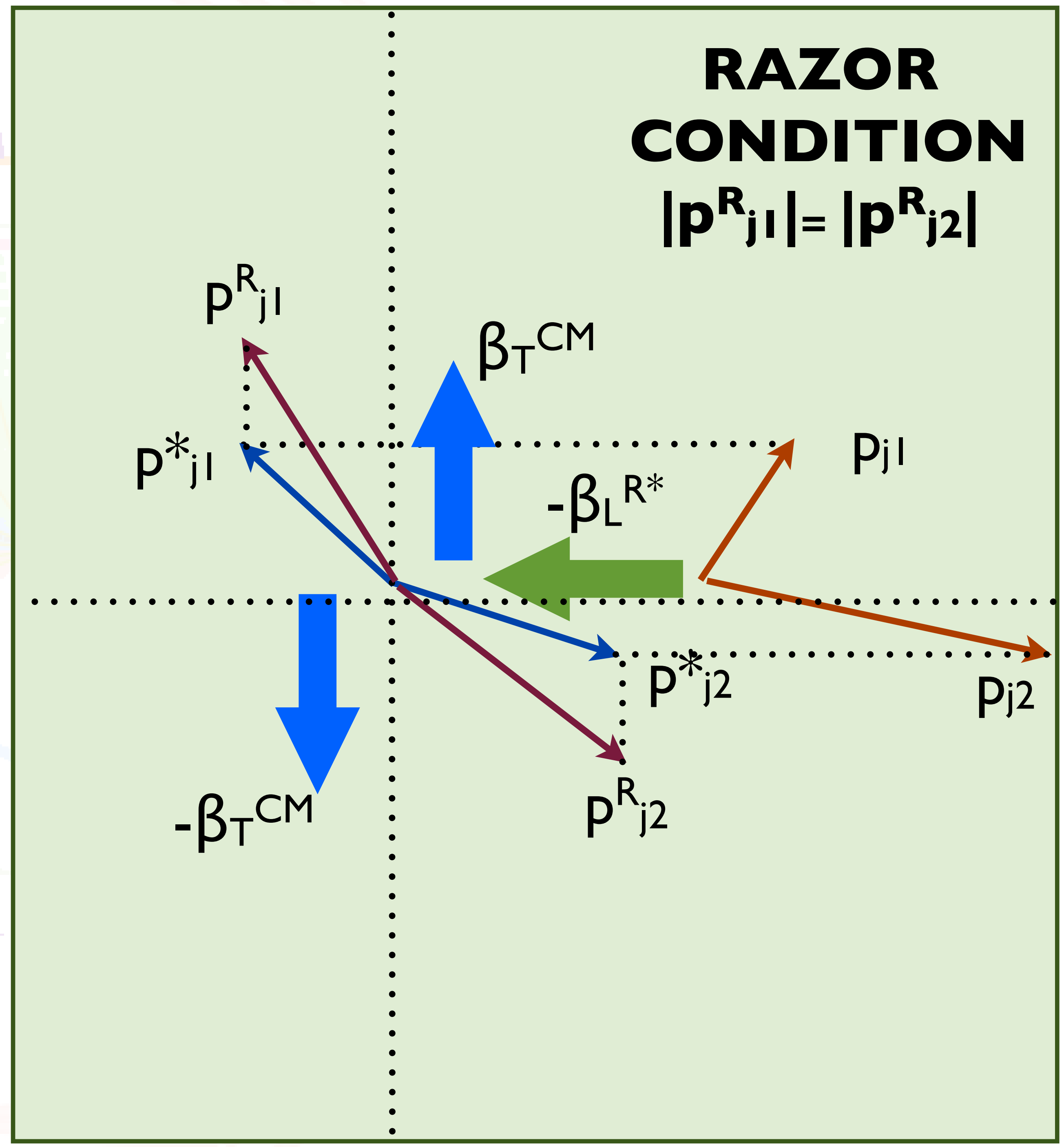


If we could see the LSPs, we could boost back by β_L, β_T, and β_{CM}
In this frame, we would then get
$|p_{j1}| = |p_{j2}|$
Too many missing degrees of freedom to do just this

The Razor Frame

- In reality, the best we can do is to compensate the missing degrees of freedom with assumptions on the boost direction

- The parton boost is forced to be longitudinal
- The squark boost in the CM frame is assumed to be transverse



- We can then determine the two by requiring that the two jets have the same momentum after the transformation

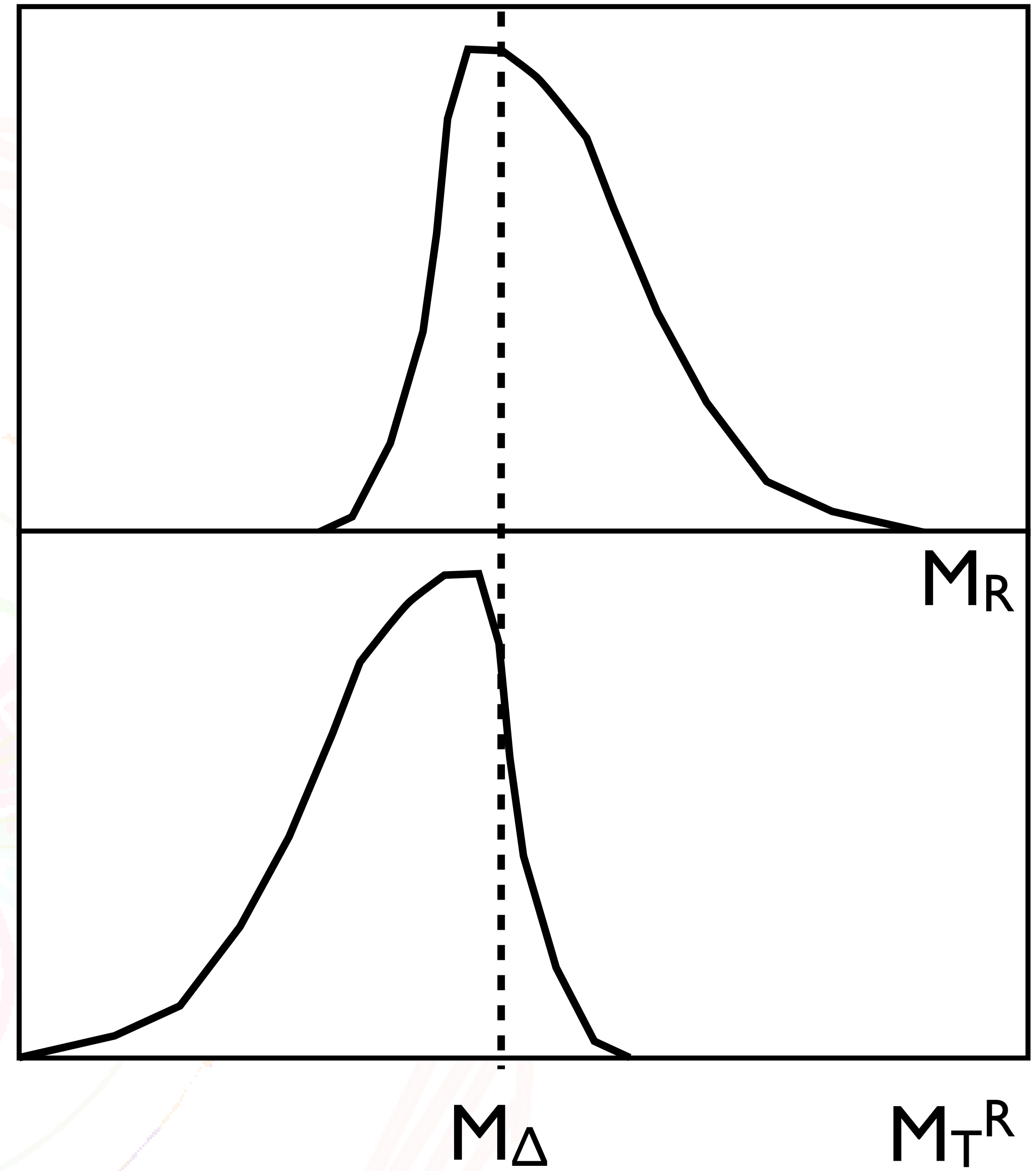
- The transformed momentum defines the M_R variable

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

The Razor Variable

- M_R is boost invariant, even if defined from 3D momenta
- No information on the MET is used
- The peak of the M_R distribution provides an estimate of M_Δ
- M_Δ could be also estimated as the "edge" of M_T^R

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

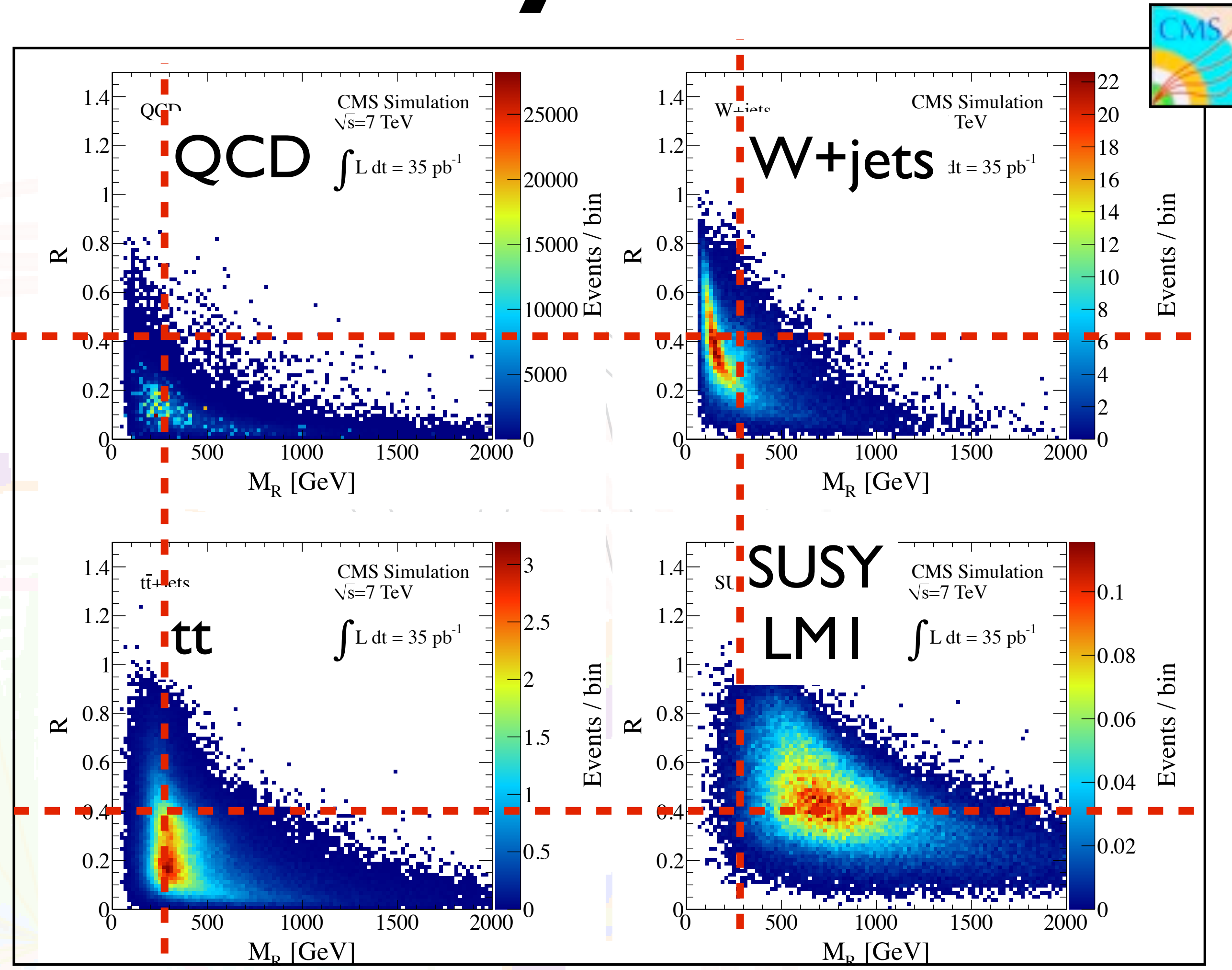


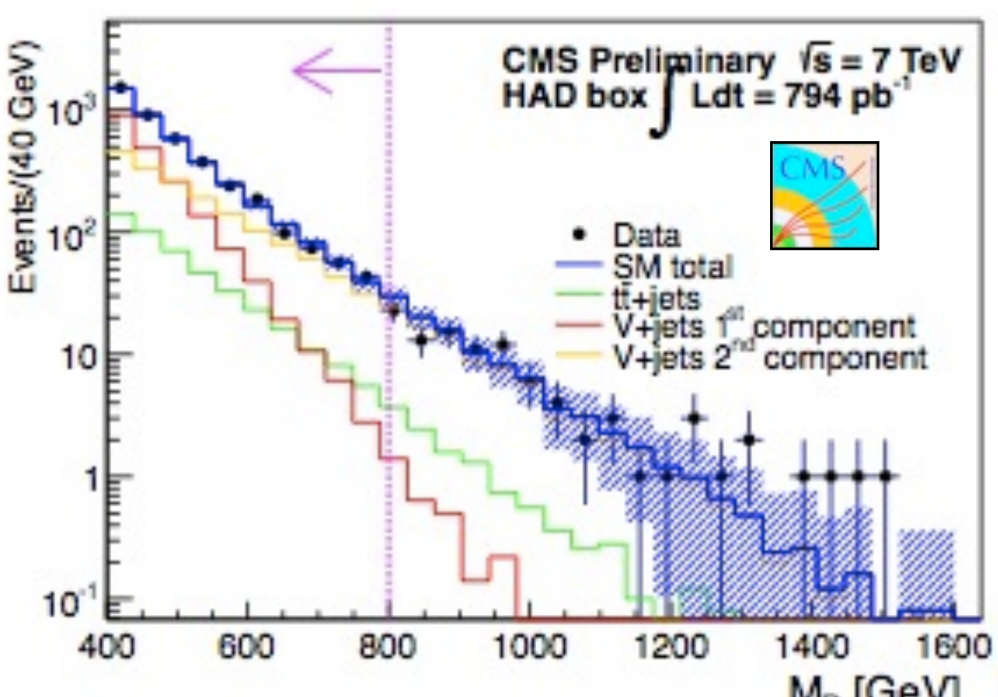
- M_T^R is defined using transverse quantities and it is MET-related
- The Razor (aka R) is defined as the ratio of the two variables

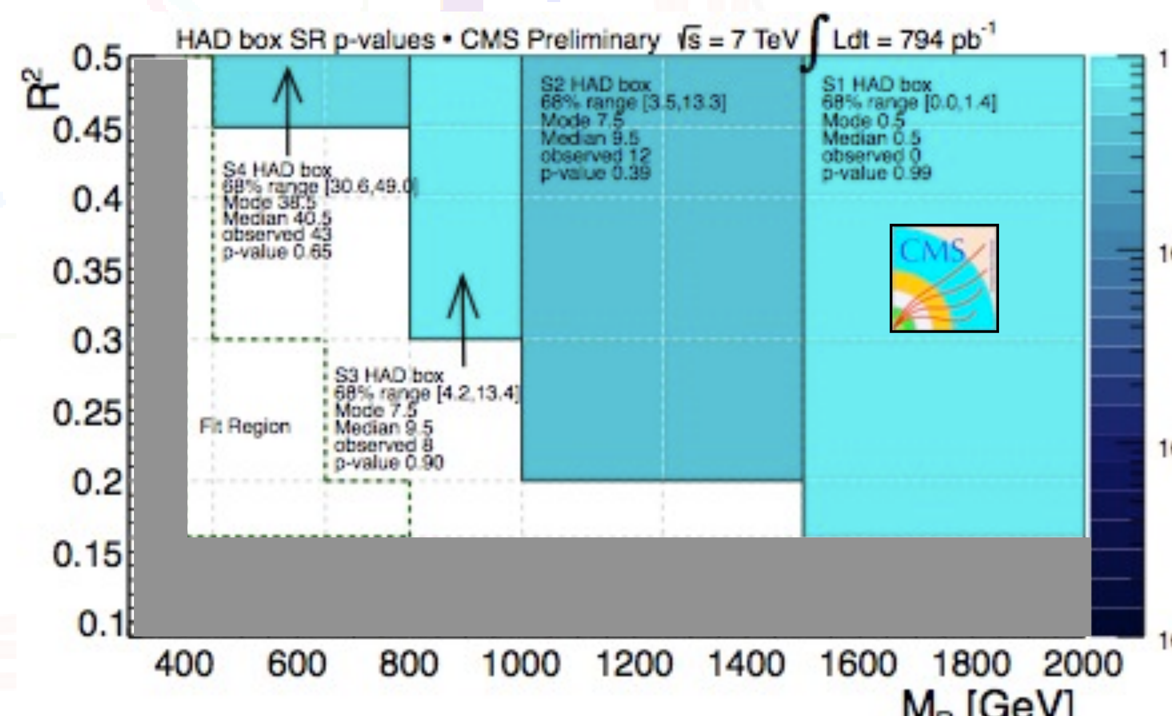
$$R \equiv \frac{M_T^R}{M_R}$$

The Razor Analysis

- The backgrounds are characterized by a turn-on (they have their own M_Δ), after which they decay ~ exponentially
- The two variables exhibit a clear correlation, regardless of the process under consideration
- This is used to fit the signal in a sideband and extrapolate to the signal region

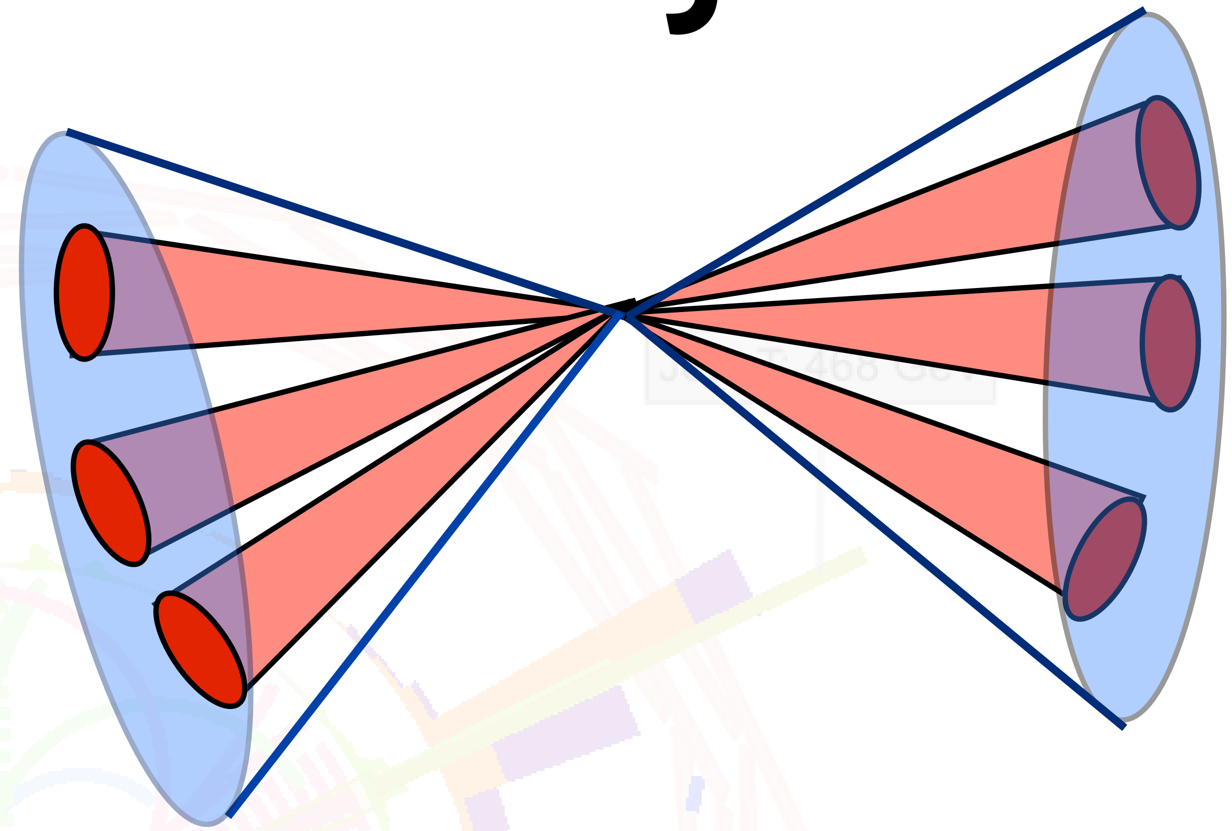






From DiJet To MultiJets

- The "new" variables rely on the dijet +MET final state as a paradigm
- All the analyses have been extended to the case of multijet final states clustering jets in two hemispheres (aka mega-jets)



<u>Several approaches used</u>

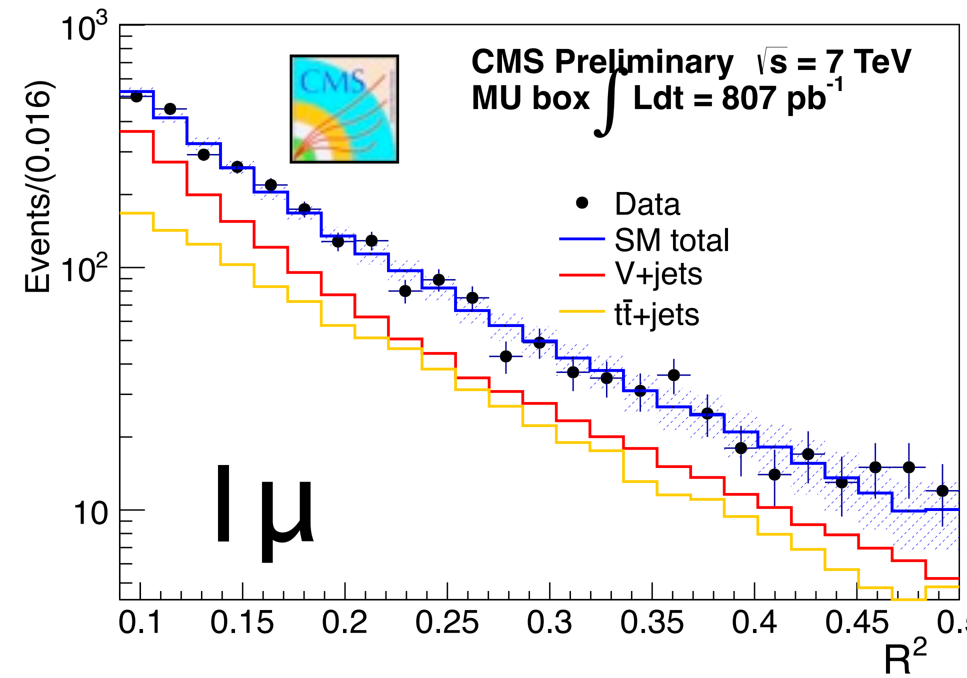
- minimizing the HT difference between the mega-jets (aT CMS)
- minimizing the invariant masses of the two jets (Razor CMS)
- minimizing the Lund distance (MT2 CMS)
- ...

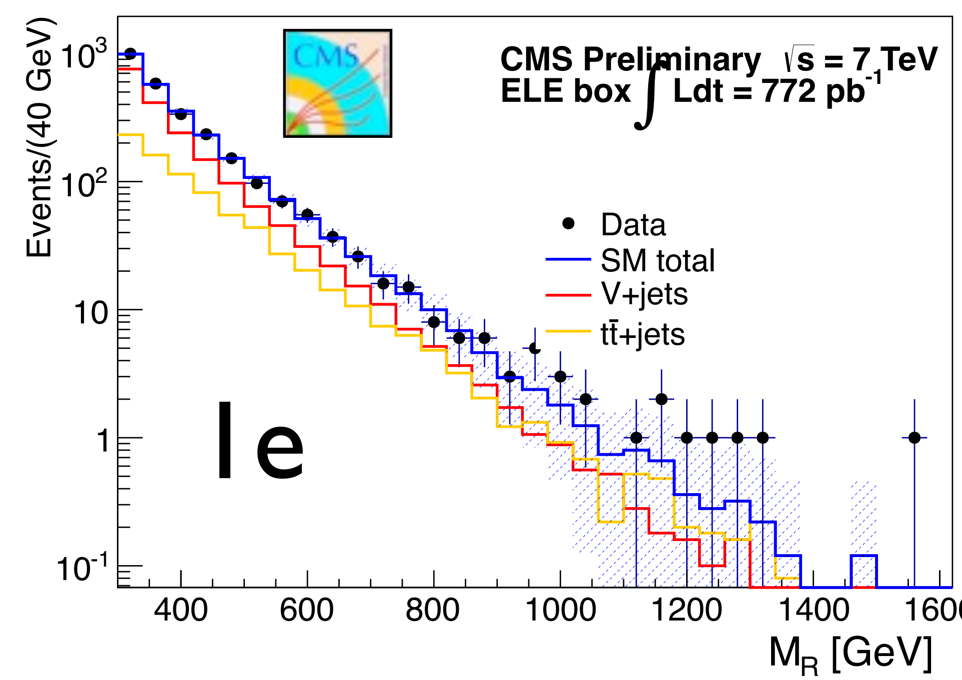
$$(E_i - p_i cos\theta_{ik})\frac{E_i}{(E_i + E_k)^2} \leq (E_j - p_j cos\theta_{jk})\frac{E_j}{(E_j + E_k)^2}$$

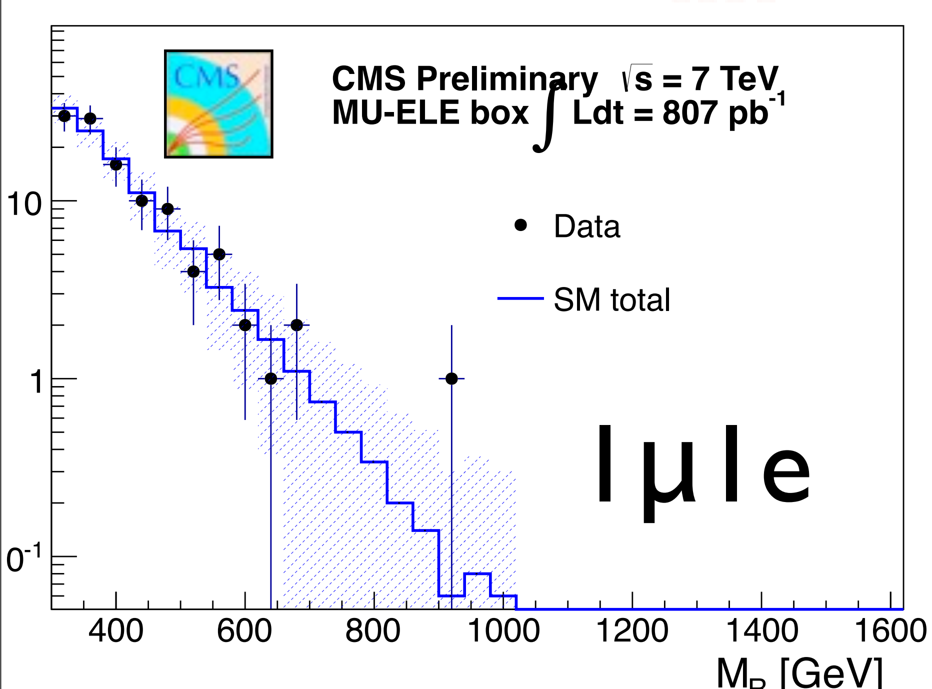
- Is the ultimate hemisphere definition out there (I am not aware of studies on this)?
- Could this improve the signal sensitivity in a significant way?

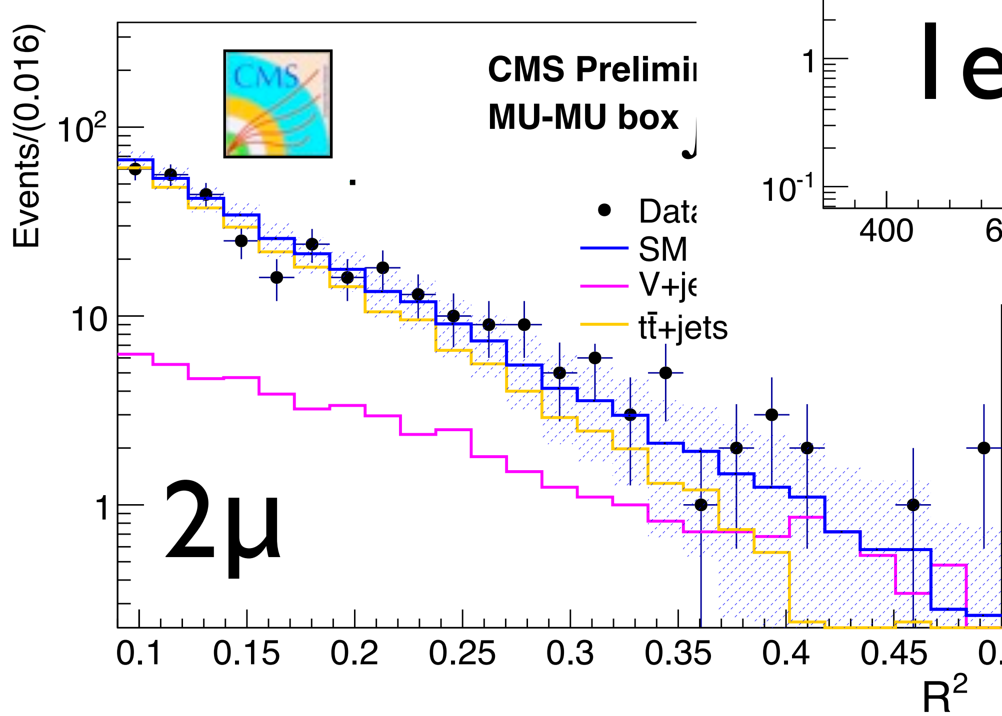
From Hadronic To Inclusive

- Hadronic analyses use to veto leptons and use the vetoed sample as a bkg control sample (including signal contamination)
- Leptonic analyses look for a signal in a subset of this samples
- Thinks can be sync'ed in a common analysis framework, as in the CMS Razor analysis

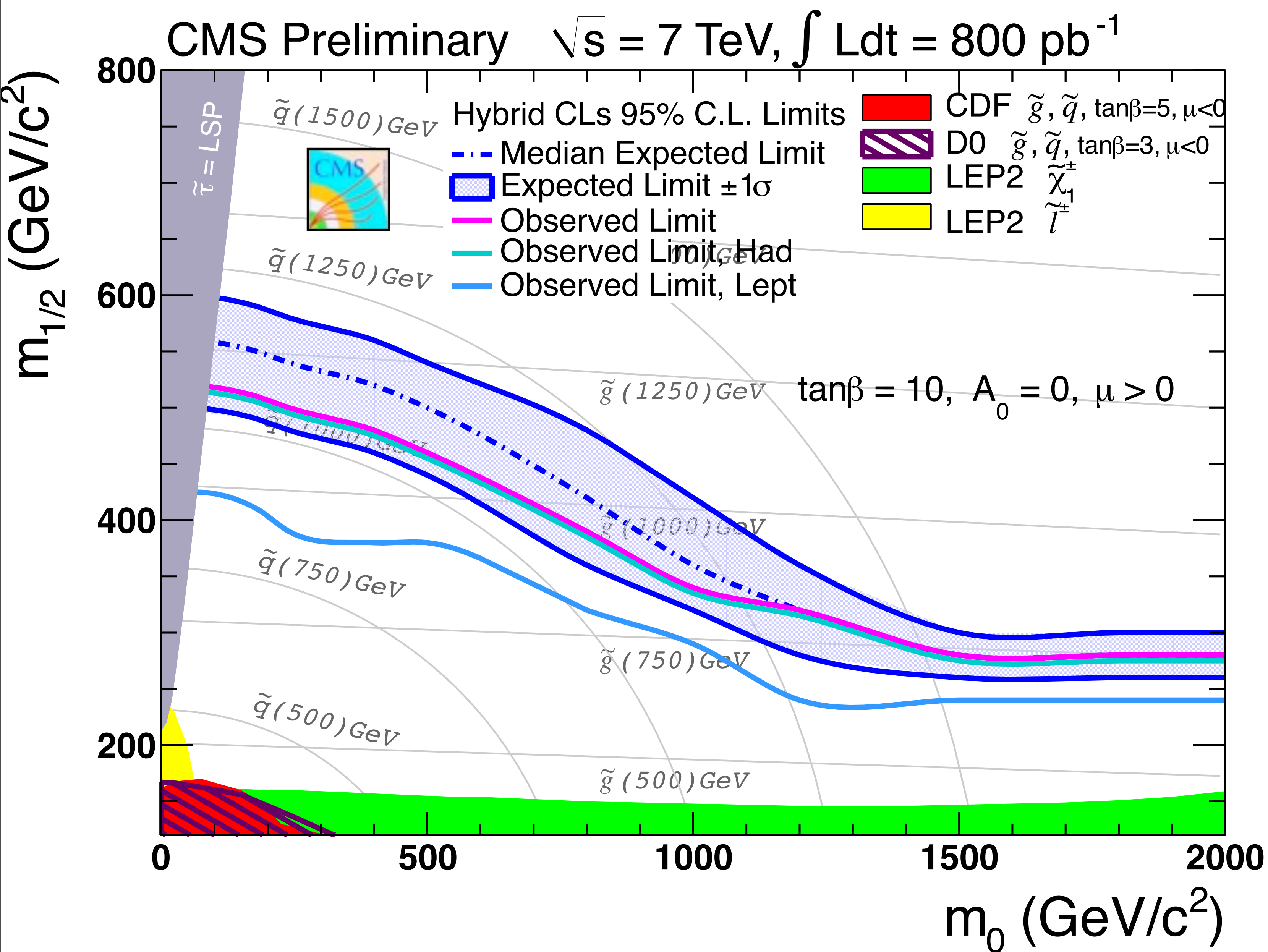


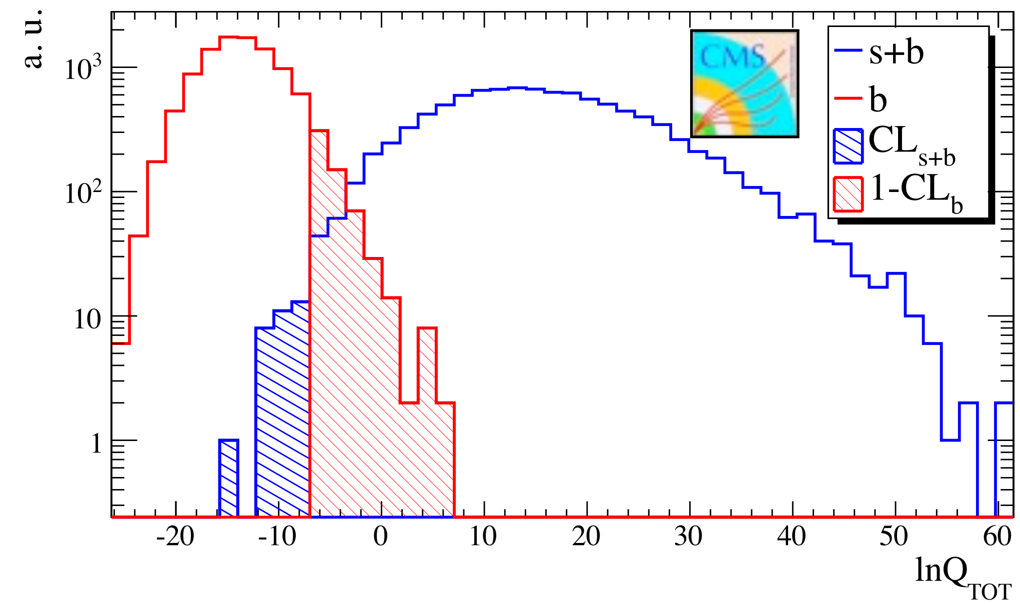






From Hadronic To Inclusive



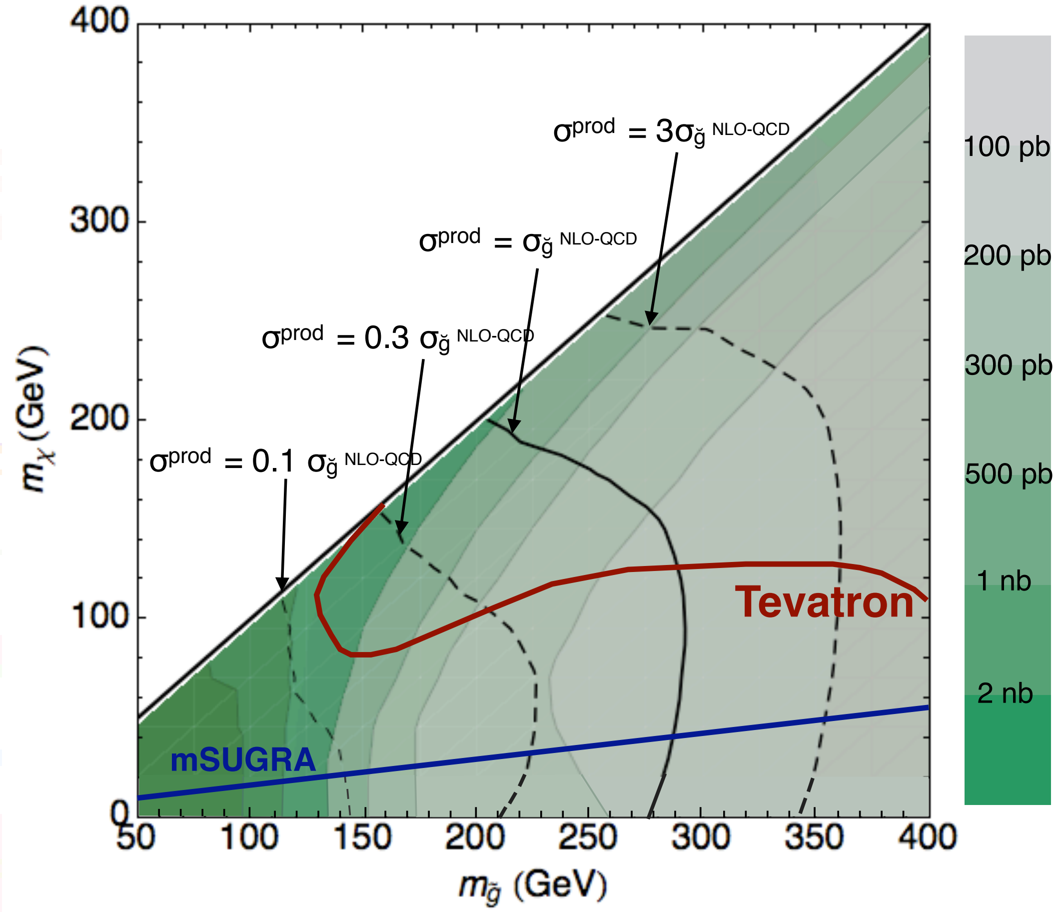


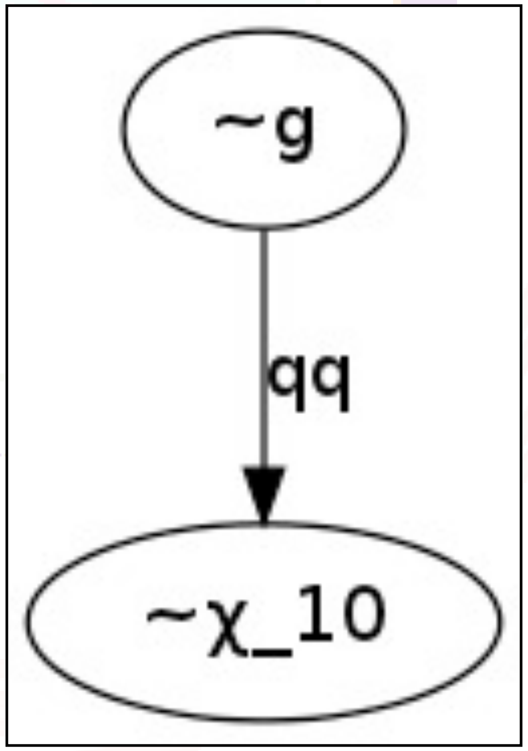
- Limit using CLs
- Most stringent (expected) limit so far
- Result driven by Had analysis
- Remarkable constraint at large m0

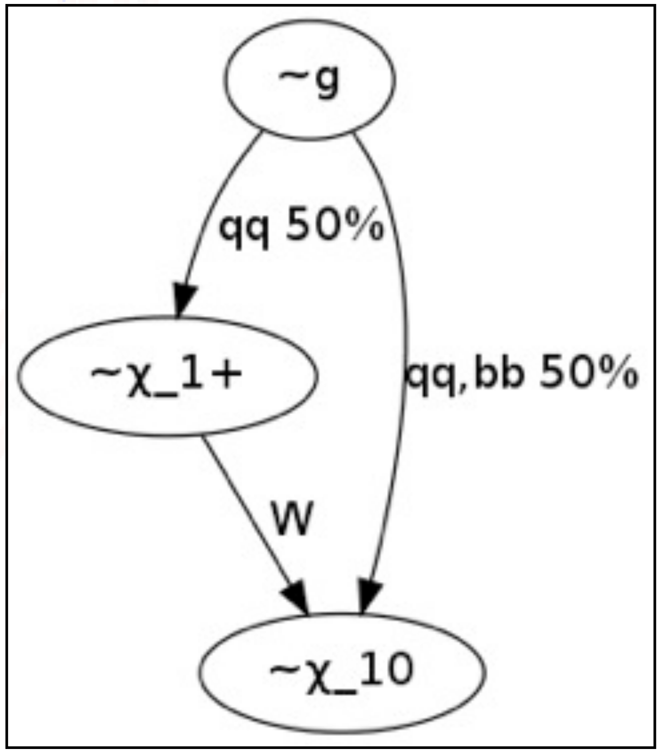
The Simplified Models

- The CMSSM is an established paradigm to present searches
- On the other hand, it is characterized by very peculiar features (eg mass ratios) which makes the result difficult to generalize

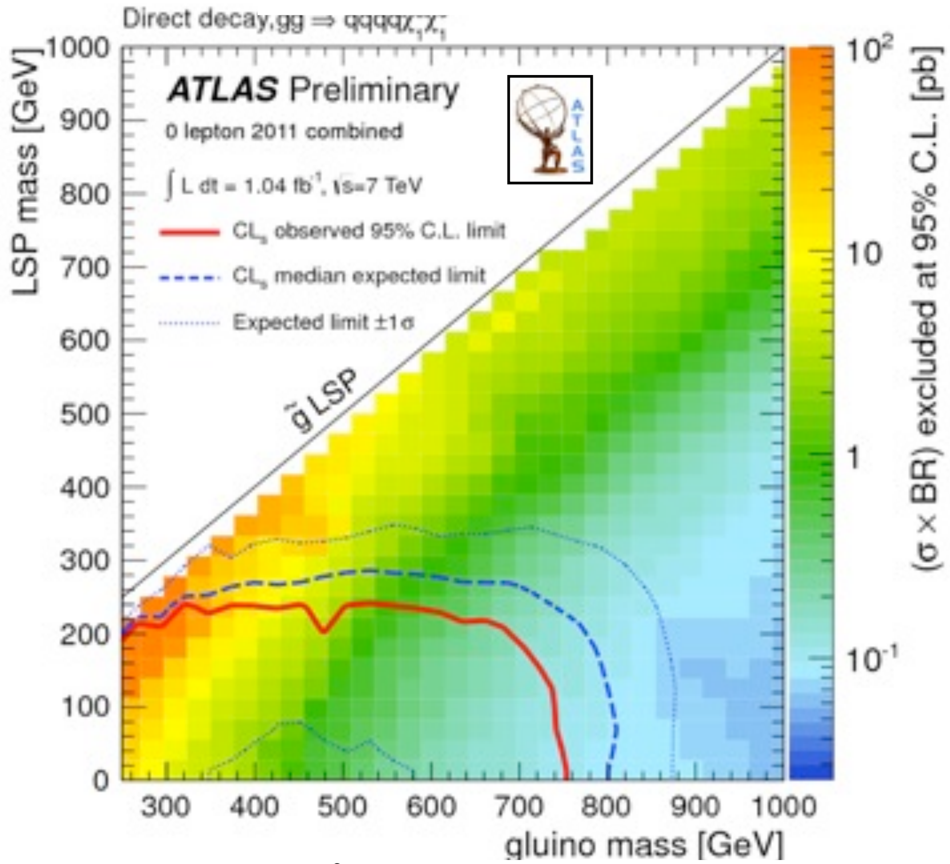
- The experiments decided to focus on a limited set of *simplified* models, in which two sparticle are produced, decaying to visible particles + 2 LSPs
- At most an intermediate step is allowed, such that a few decay chains specify the full model
- Result is presented as the max excluded cross section vs masses of produced particle and LSP

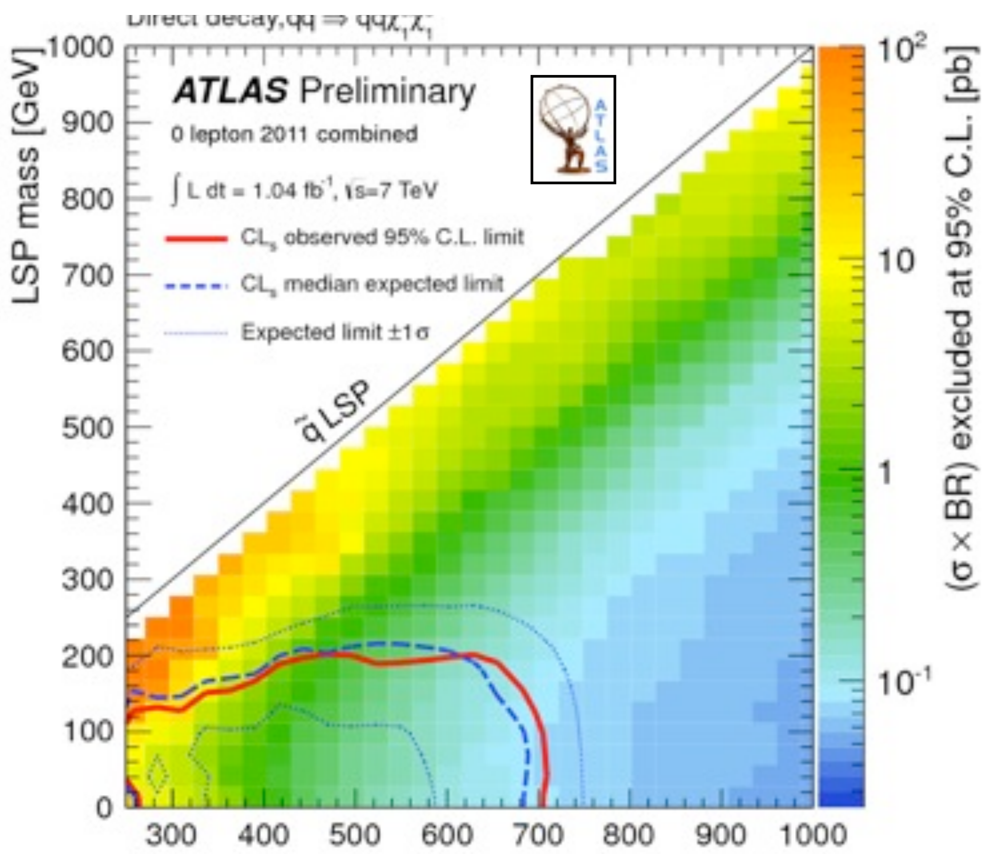


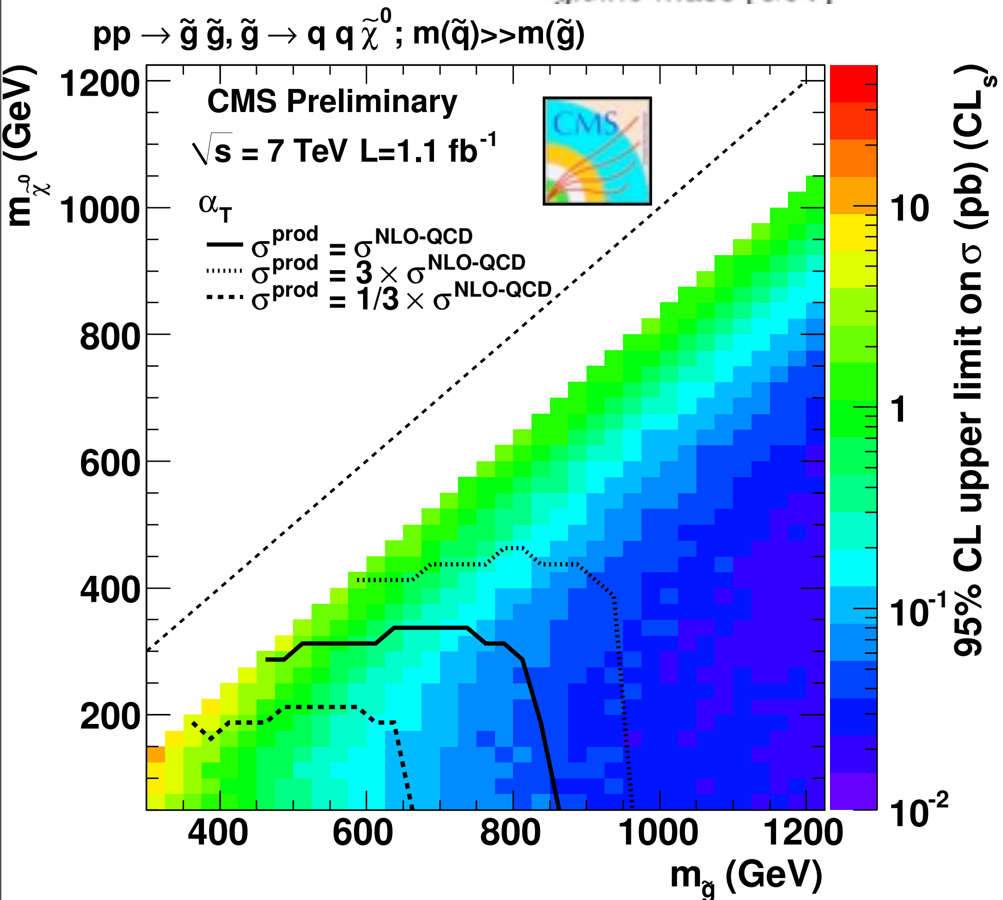


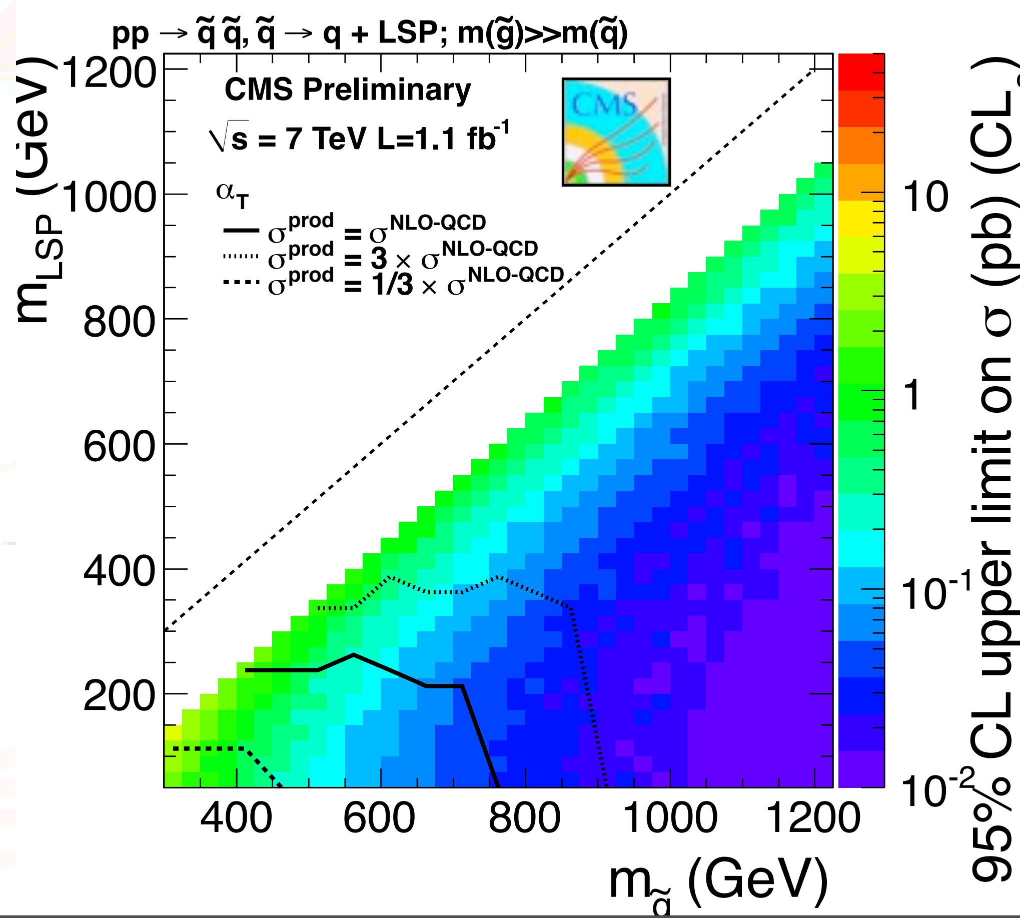


$\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{q}$ SMS

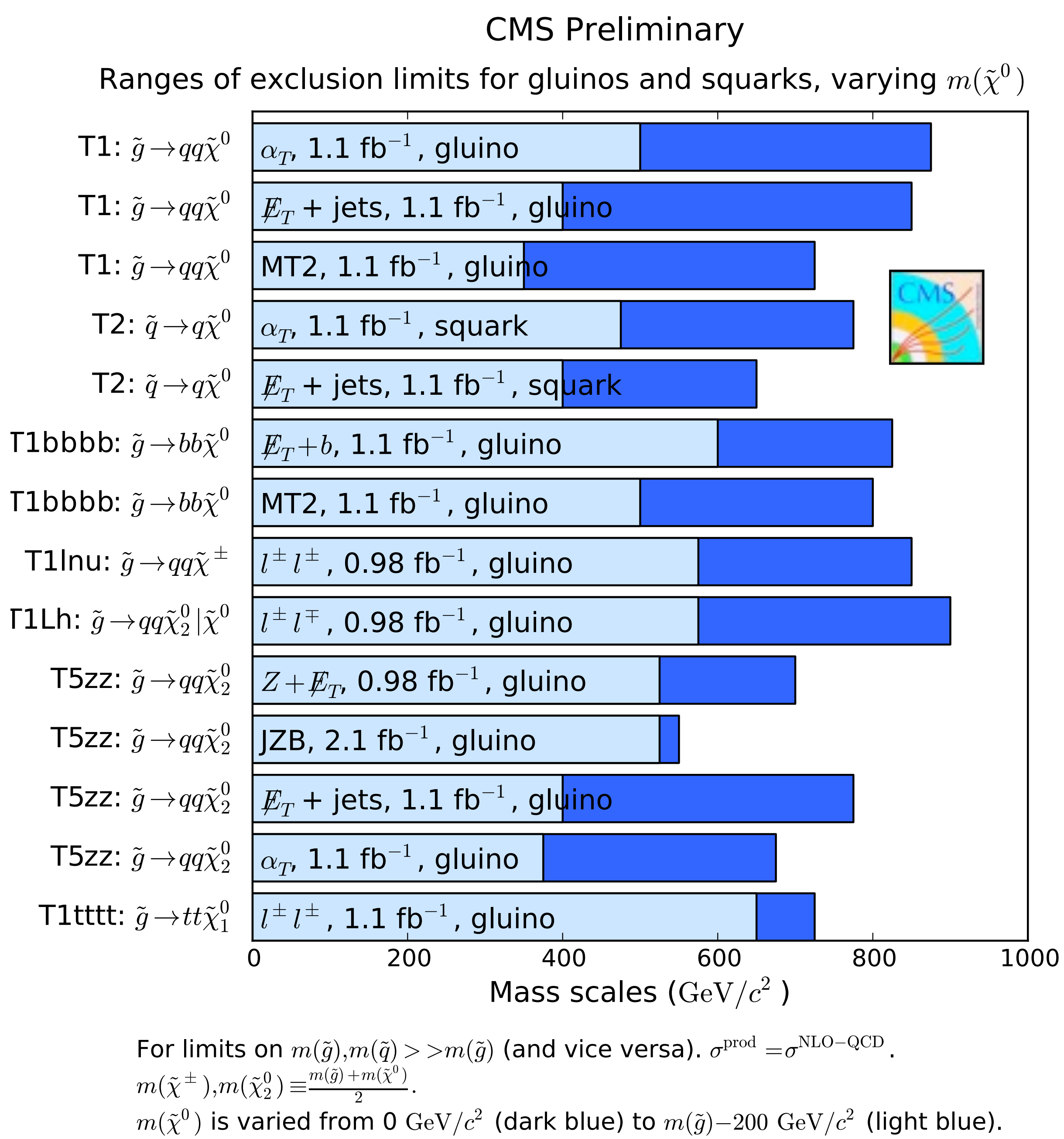


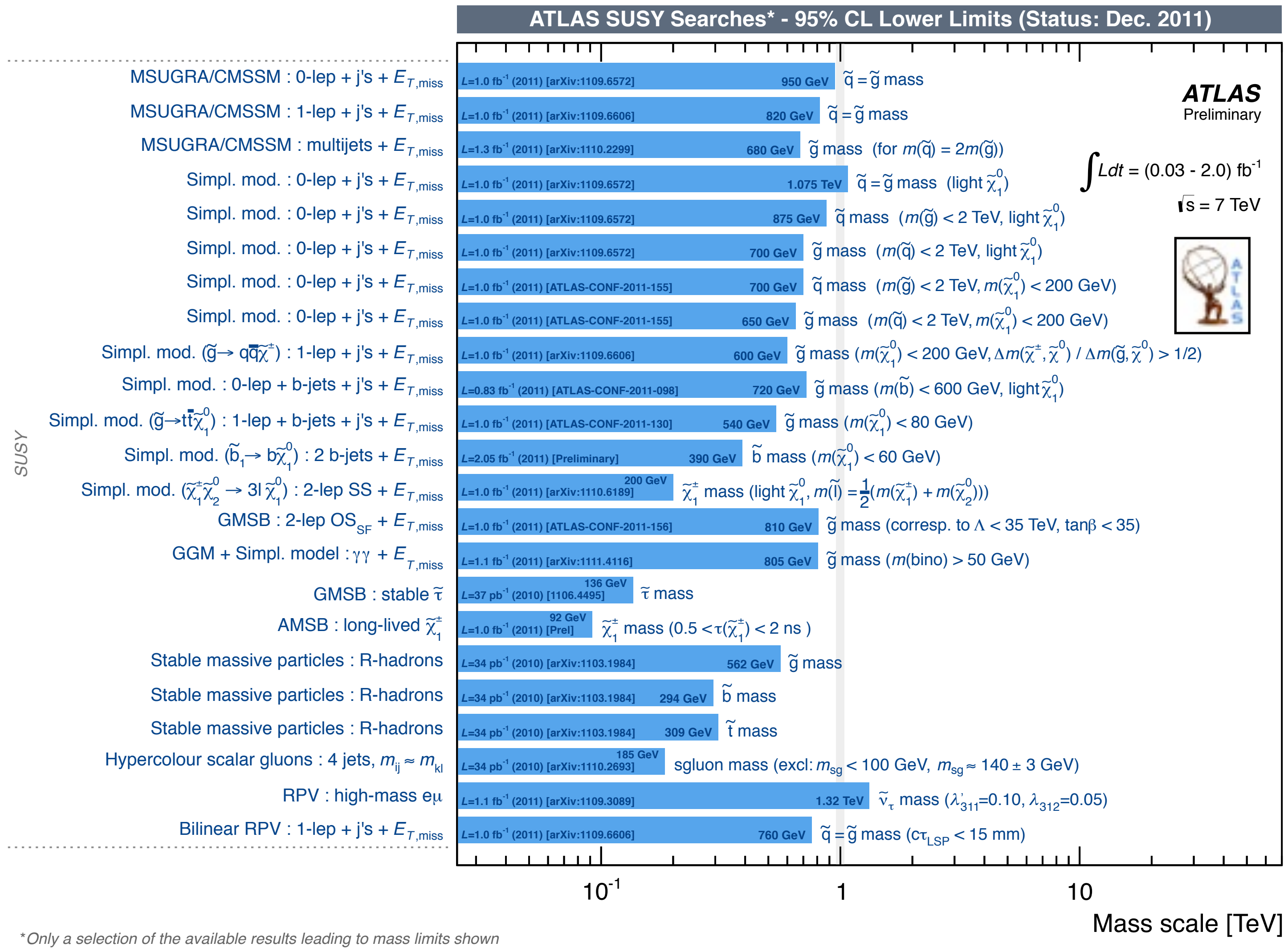






The Simplified Models



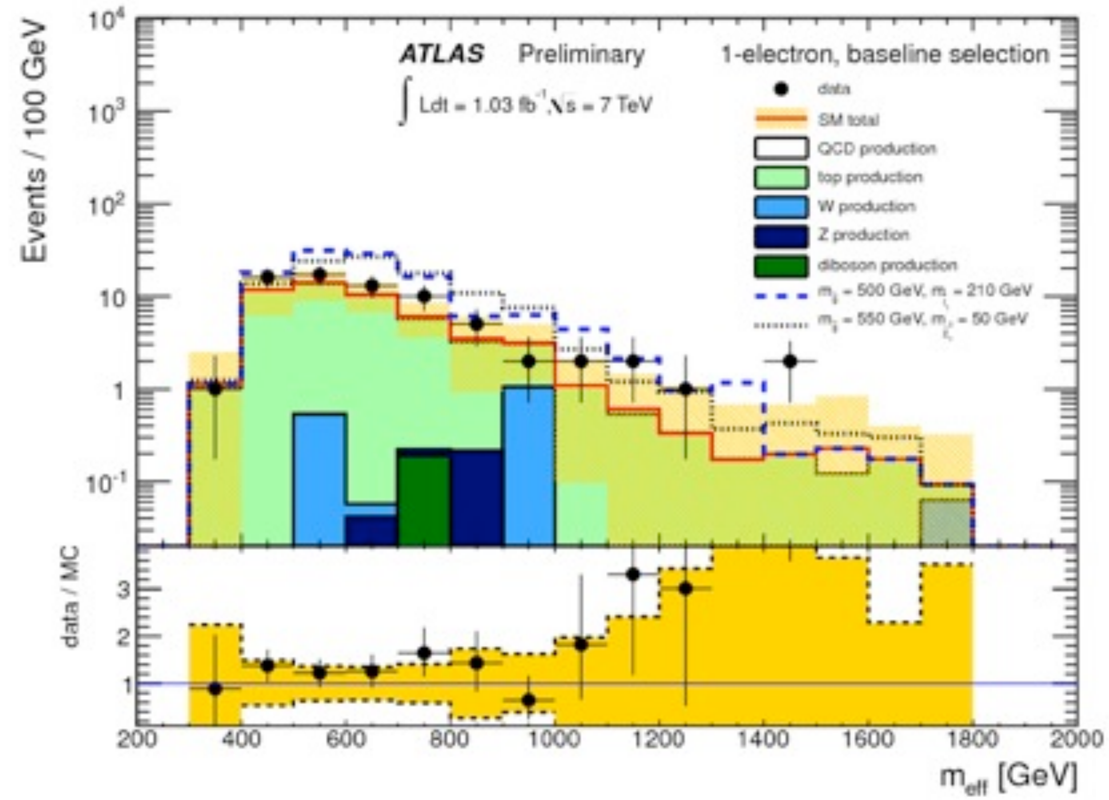


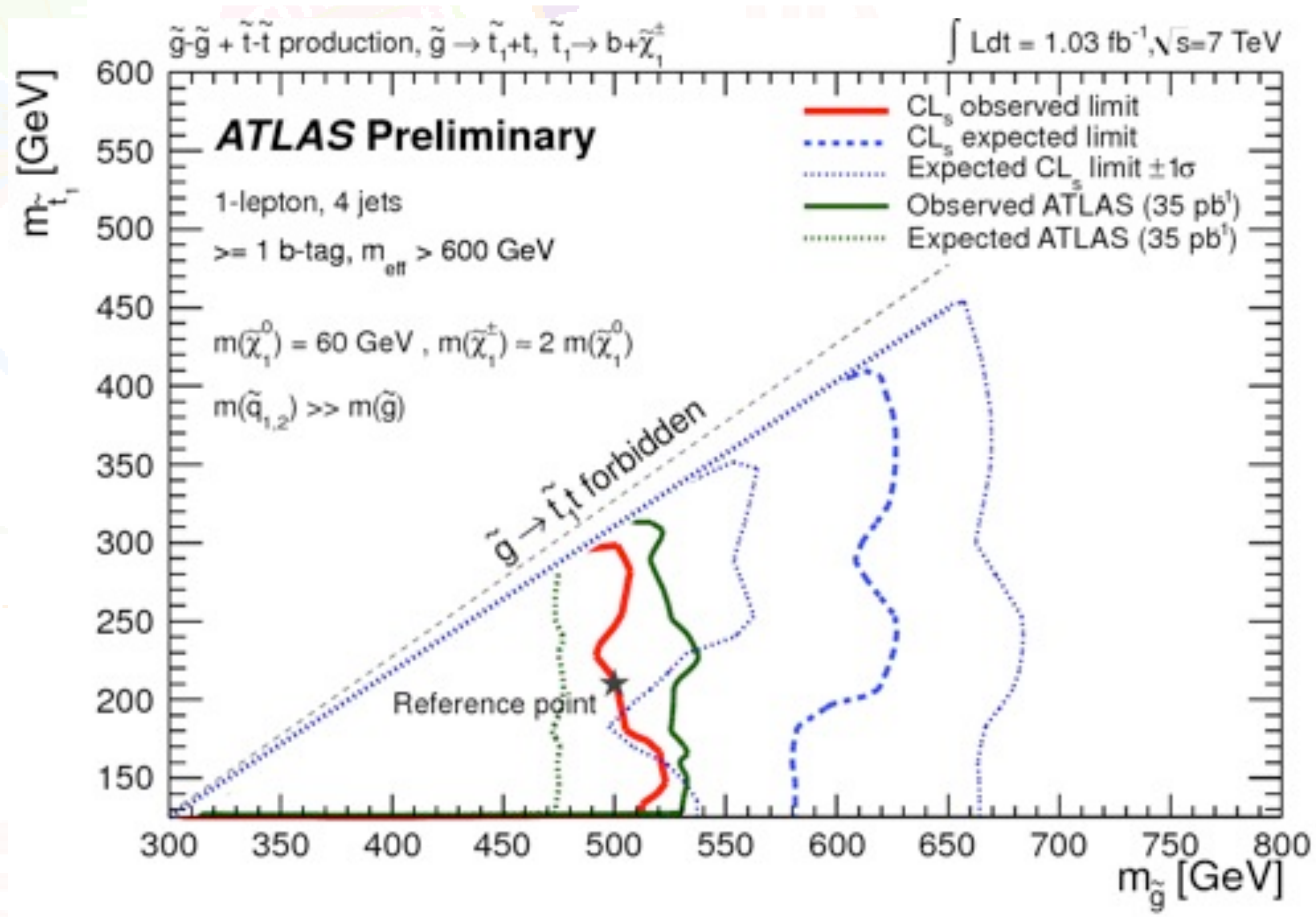
A hot-topic SMS: stop production

A lot of interest in a light-stop scenario, with other colored particles heavy

- Strong penguin not tested in B physics
- b→sɣ effect diluted by cancellations between charginos and charged Higgs

- Search challenging: signal ~ ttbar bkg for light (~top) stop
-First results by ATLAS. Hot topic for this Winter





Conclusion

- Lesson from Tevatron taken: CMS and ATLAS fully committed to "classic" Jet+MET searches
- In parallel, new directions have been explored, exploiting specific features of the signal under considerations
- First results showed the power of the new methods. More results are coming
- Increasing luminosity and no excess seen moves to interest to specific scenarios (eg light stop).
- Results presented with 1 fb-1. About 5 fb-1 on tape to be analyzed for the Winter conferences

Basic/Incomplete Bibliography

- ATLAS SUSY results

  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

- CMS SUSY results

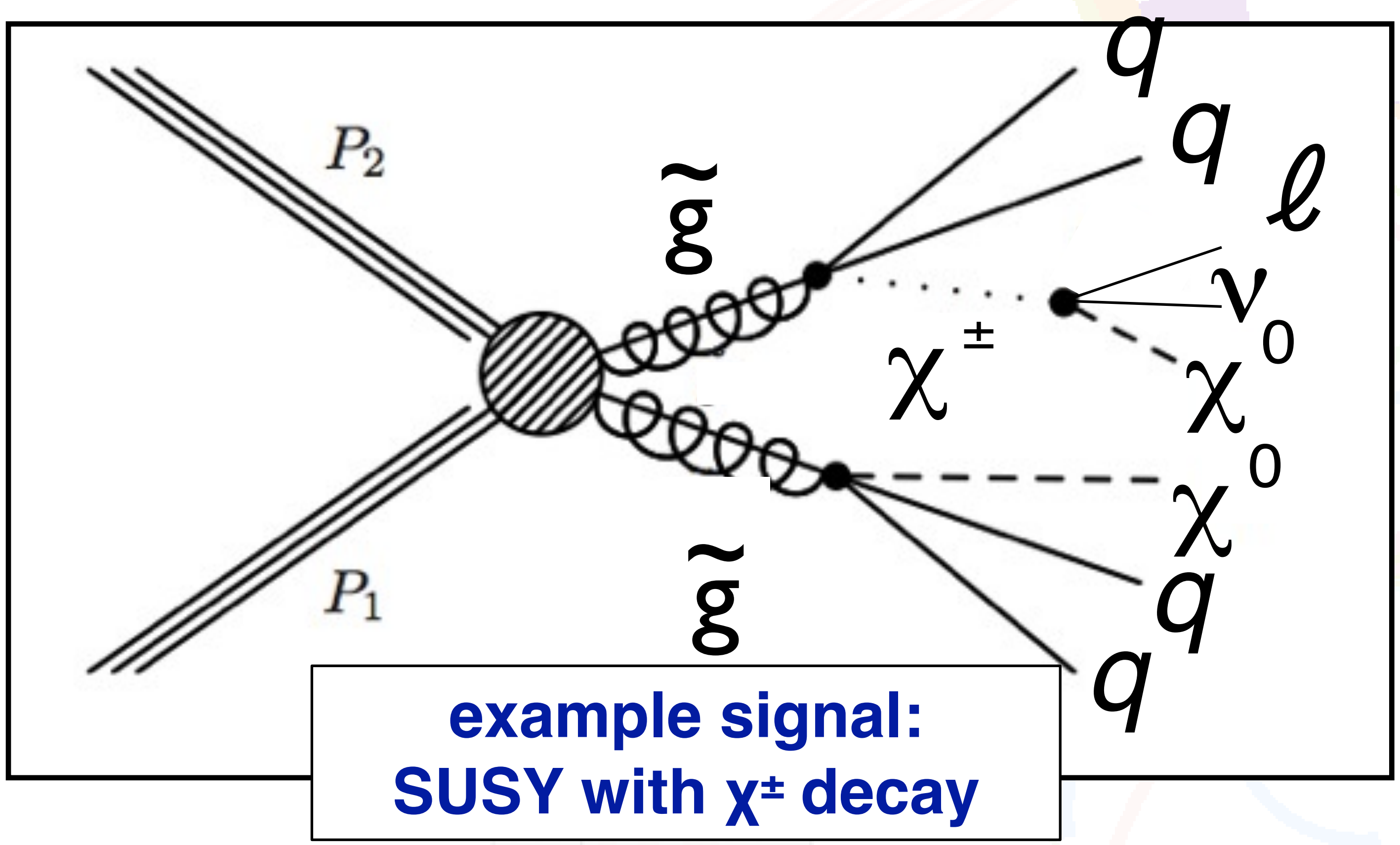
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

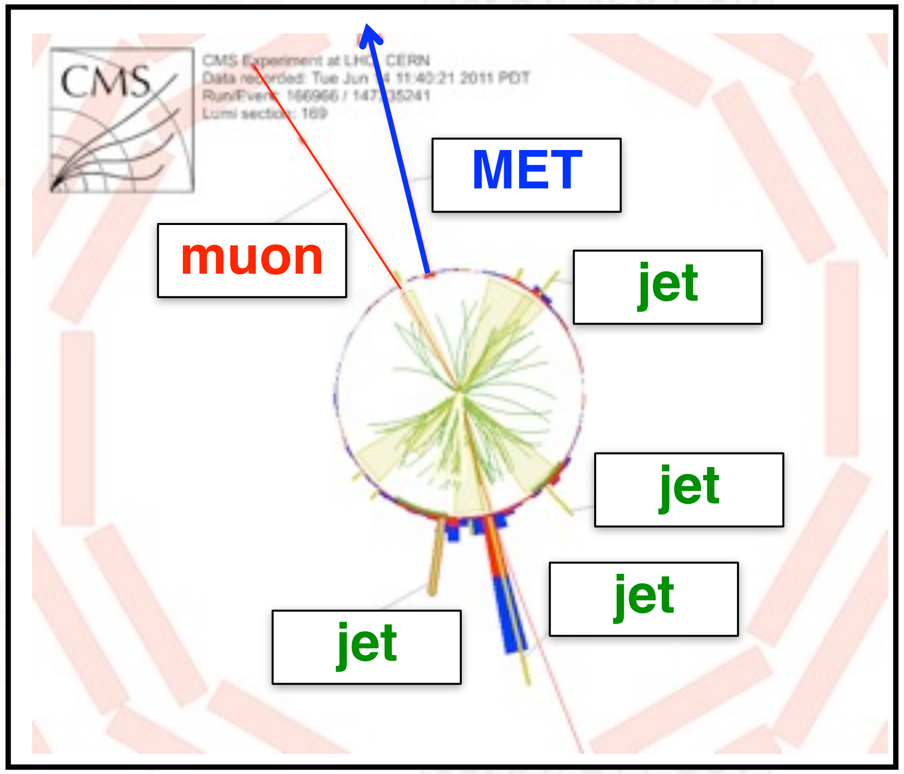
- Other papers
  - Original paper on α http://arxiv.org/pdf/0806.1049
  - Modified α_T paper by CMS http://cdsweb.cern.ch/record/1149915/files/SUS-08-005-pas.pdf
  - MT2 http://arXiv.org/pdf/hep-ph/0304226 http://arxiv.org/pdf/0810.5576v2
  - $\sqrt{s}_{min}$ http://www.arxiv.org/pdf/1006.0653
  - Razor http://arxiv.org/pdf/1006.2727

Backup

Single Lepton Search

- Require isolated lepton → suppress QCD
- **Signature: single lepton (e/μ) + jets + MET**
- Challenge: estimating "tails" of ttbar/W+jets MET, H_T distributions

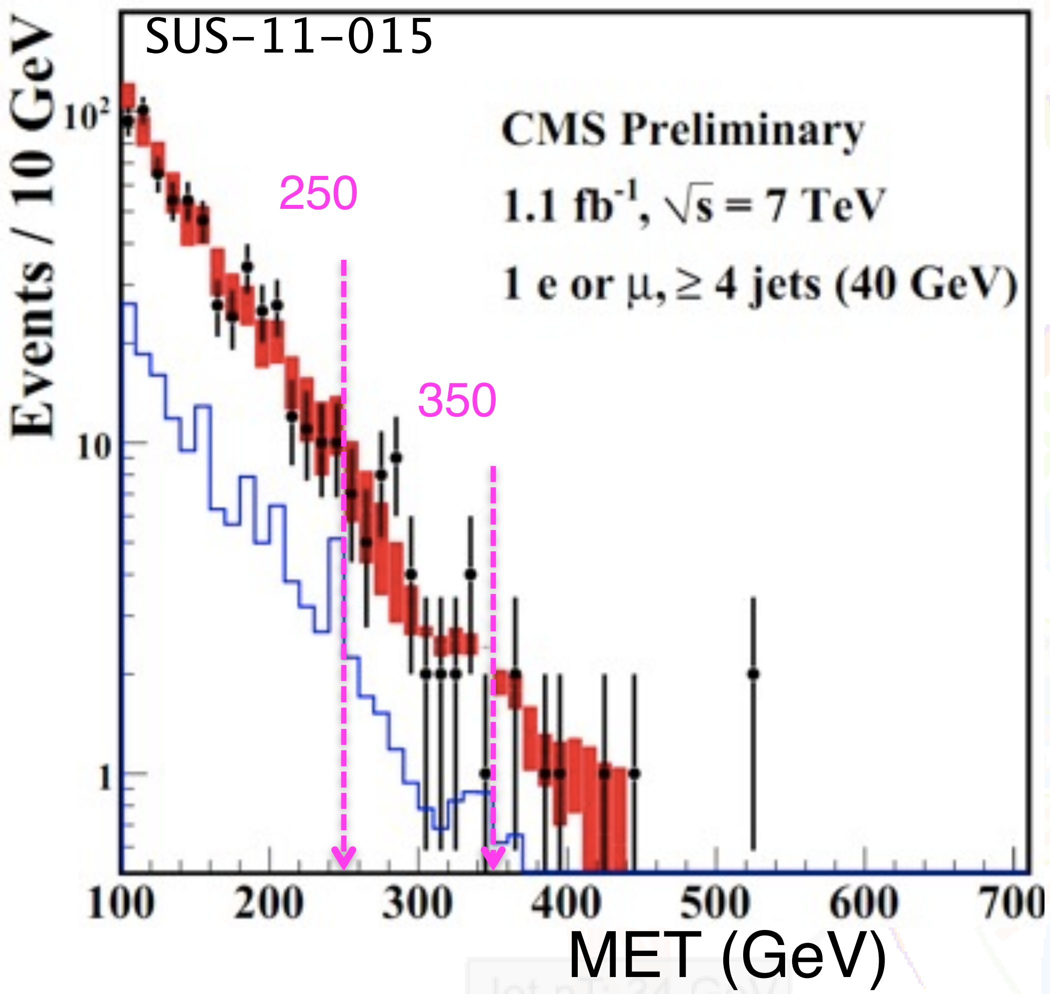




- Main Bkg from semileptonic ttbar and W+jets (75%)
- Leptonic ttbar with lost lepton (15%) from ttbar dilepton
- Other bkgs (QCD 1% and mu from taus 10%) estimated from data

Single-Lepton Bkg

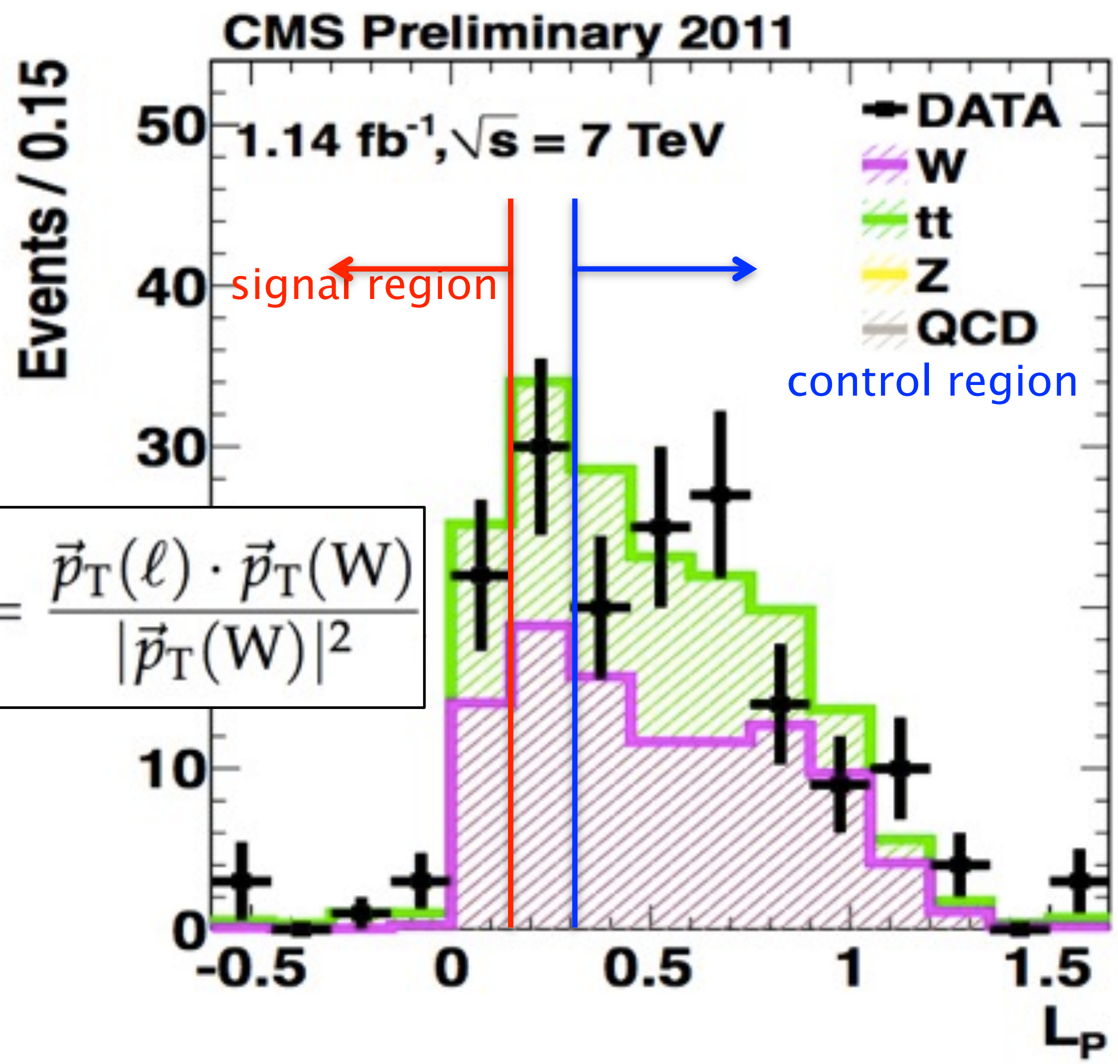
nu spectrum = lepton spectrum
Get the MET from the muon pT



	MET > 250 GeV	MET > 350 GeV
predicted	49.8 ± 8.8 ± 10.8	12.1 ± 4.3 ± 3.6
observed	52	8

CAVEAT: If SUSY has the same property the signal would be washed out

- Analysis is performed by looking at L_P in bins of $S_T^{lep} = P_T(\ell) + MET$
- A signal would show up ay low L_P and high S_T^{lep}

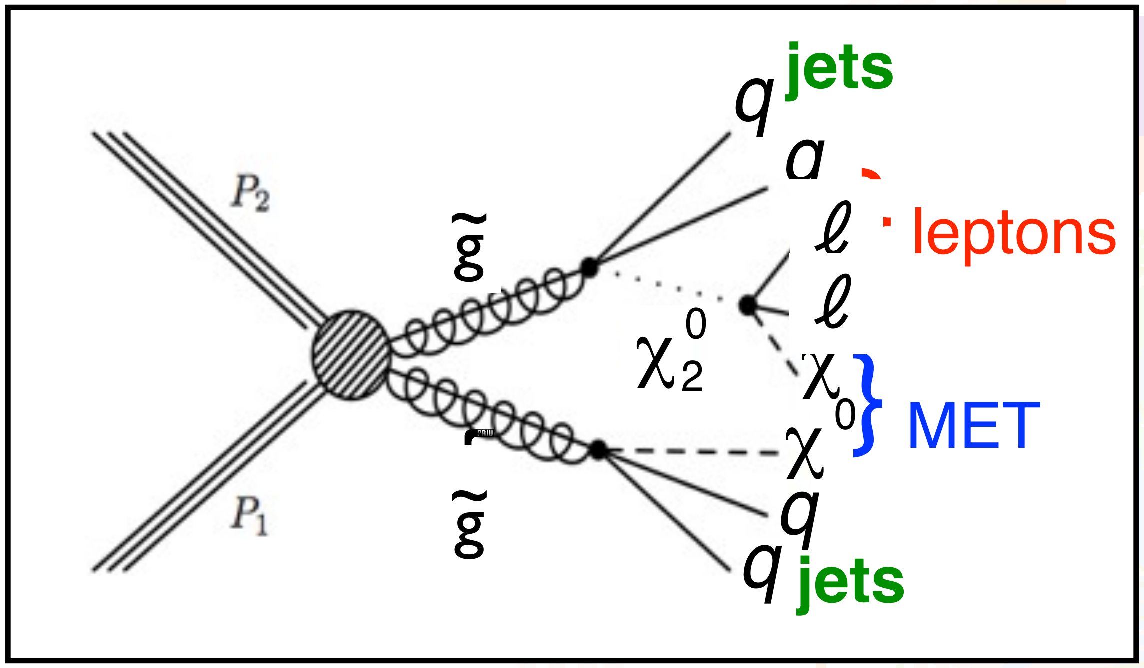


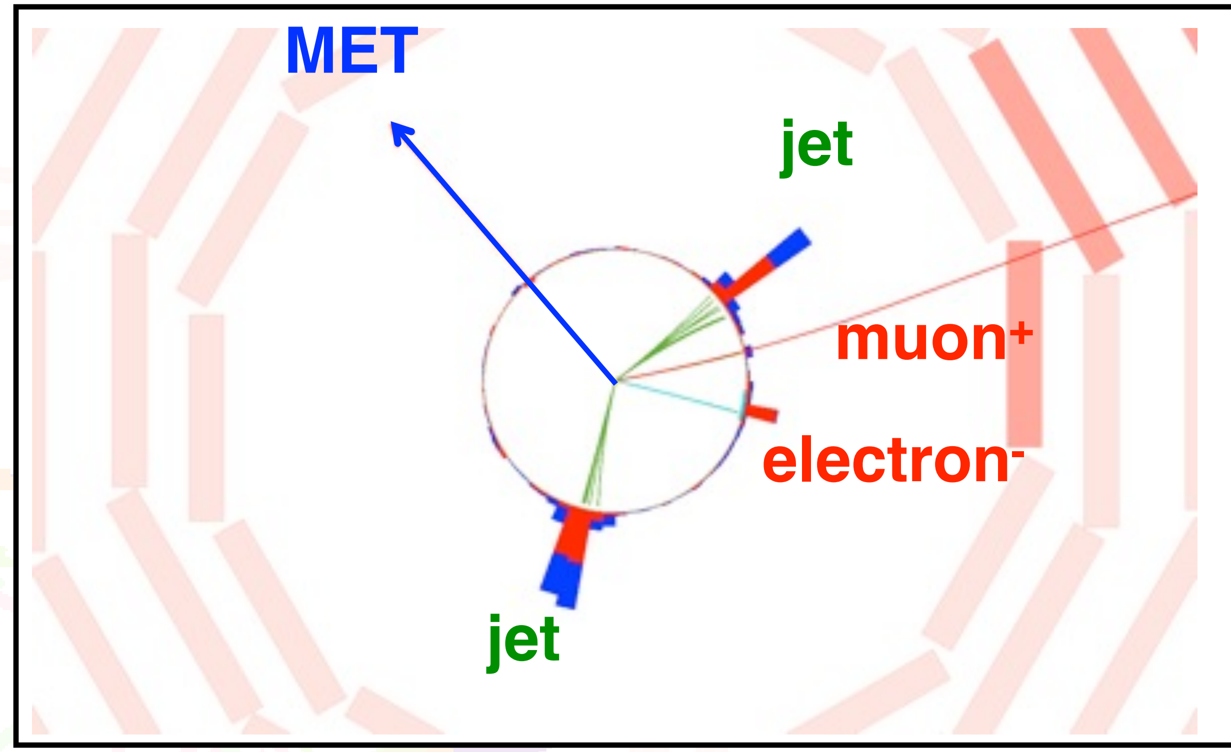
$$L_P = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

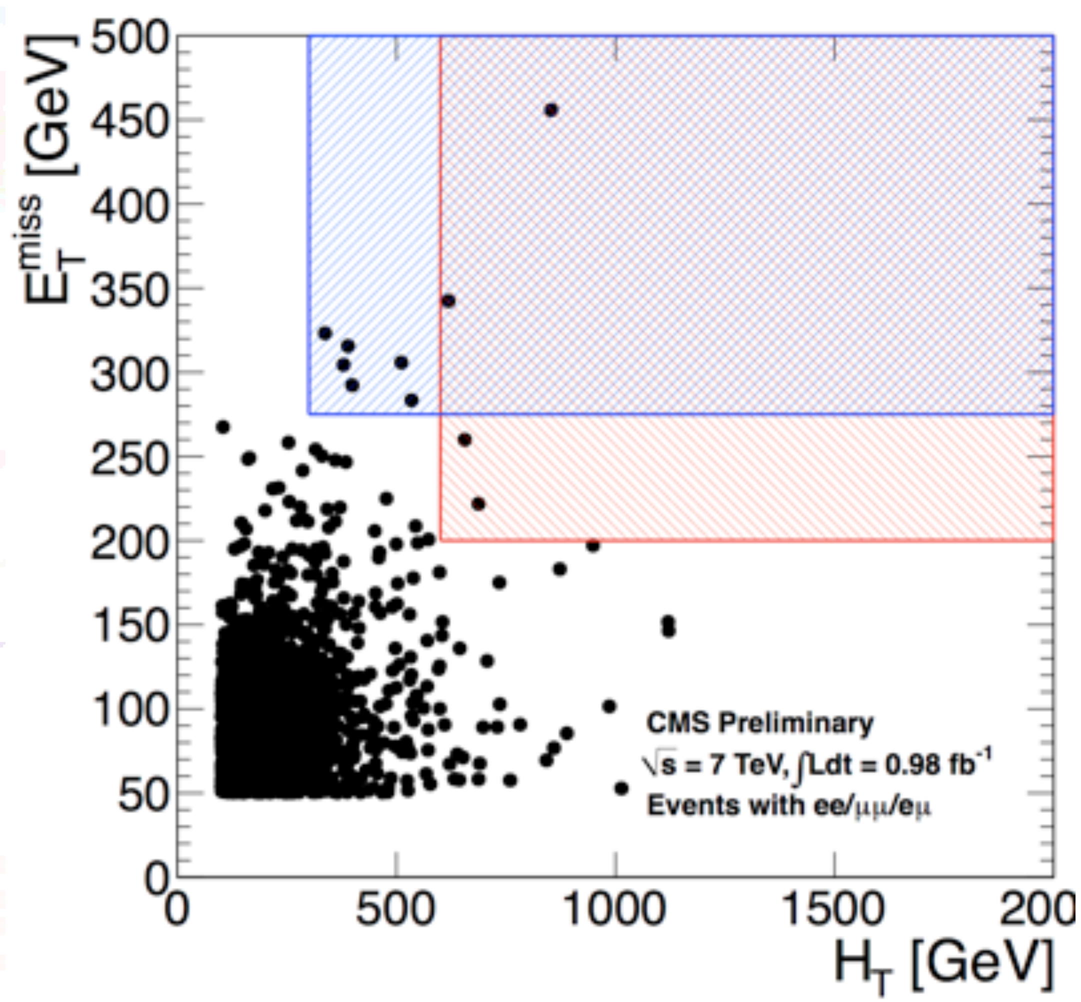
	Control Region (L_P >0.3)		Signal Region (L_P <0.15)		
S_T^{lep} Range (GeV)	Total MC	Data	Total MC	SM estimate	Data
[150-250]	385±7	368	73.9±3.0	70.6±11	84
[250-350]	116±2	112	28.1±1.1	27.2±4.6	29
[350-450]	43.4±2.	41	11.5±0.7	10.9± 2.3	9
> 450	18.4±0.8	15	6.5±0.4	5.3± 1.8	6

OS Dilepton Search

example signal:
SUSY with $\chi_2^0 \rightarrow \ell^+ \ell^- \chi^0$ decay





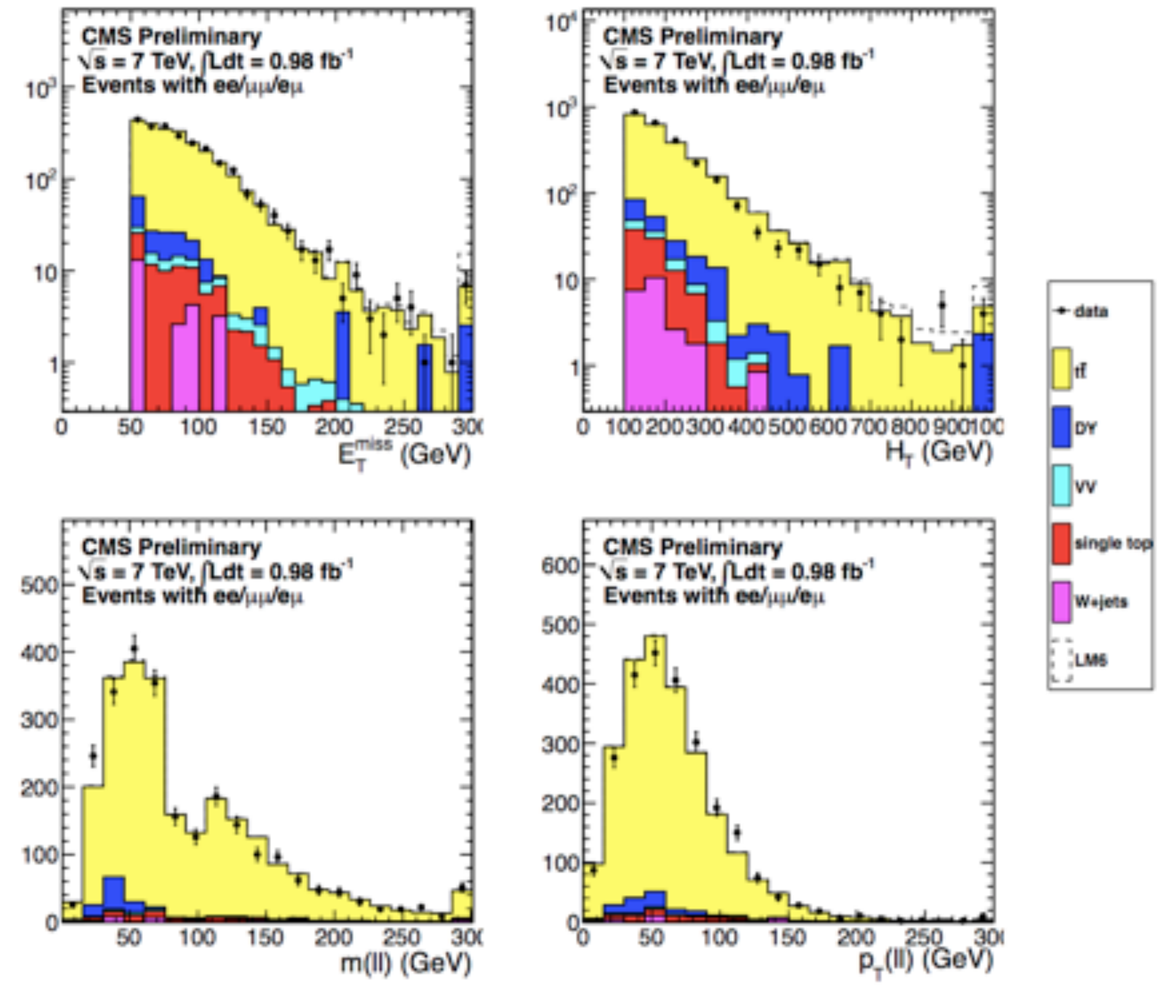


- Define two signal regions in tails of HT and MET
- Tail = were expect "a few" SM events
- Counting experiment
- Compare OF vs SF yield

OS Dilepton Search

<u>BKG Estimate 1</u>: use pT(mu)=pT(n) method as for 1lep analysis

BKG Estimate 2: use the uncorrelation of HT vs MET/sqrt(HT) (empirical fact seen in ttbar data) in a ABCD method



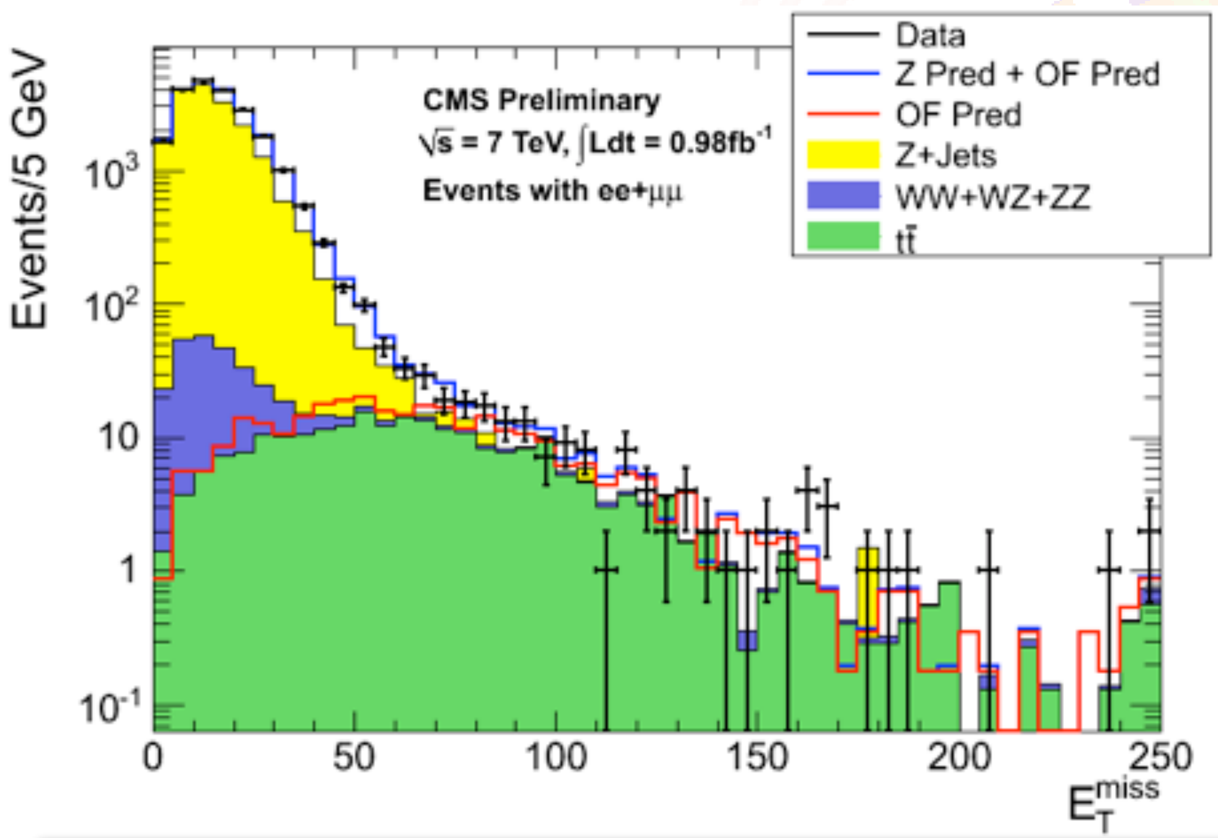
	high E_T^{miss} signal region	high H_T signal region
observed yield	8	4
MC prediction	7.3 ± 2.2	7.1 ± 2.2
ABCD′ prediction	4.0 ± 1.0 (stat) ± 0.8 (syst)	4.5 ± 1.6 (stat) ± 0.9 (syst)
$p_T(\ell\ell)$ prediction	14.3 ± 6.3 (stat) ± 5.3 (syst)	10.1 ± 4.2 (stat) ± 3.5 (syst)
N_{bkg}	4.2 ± 1.3	5.1 ± 1.7
non-SM yield UL	10	5.3
LM1	49 ± 11	38 ± 12
LM3	18 ± 5.0	19 ± 6.2
LM6	8.1 ± 1.0	7.4 ± 1.2

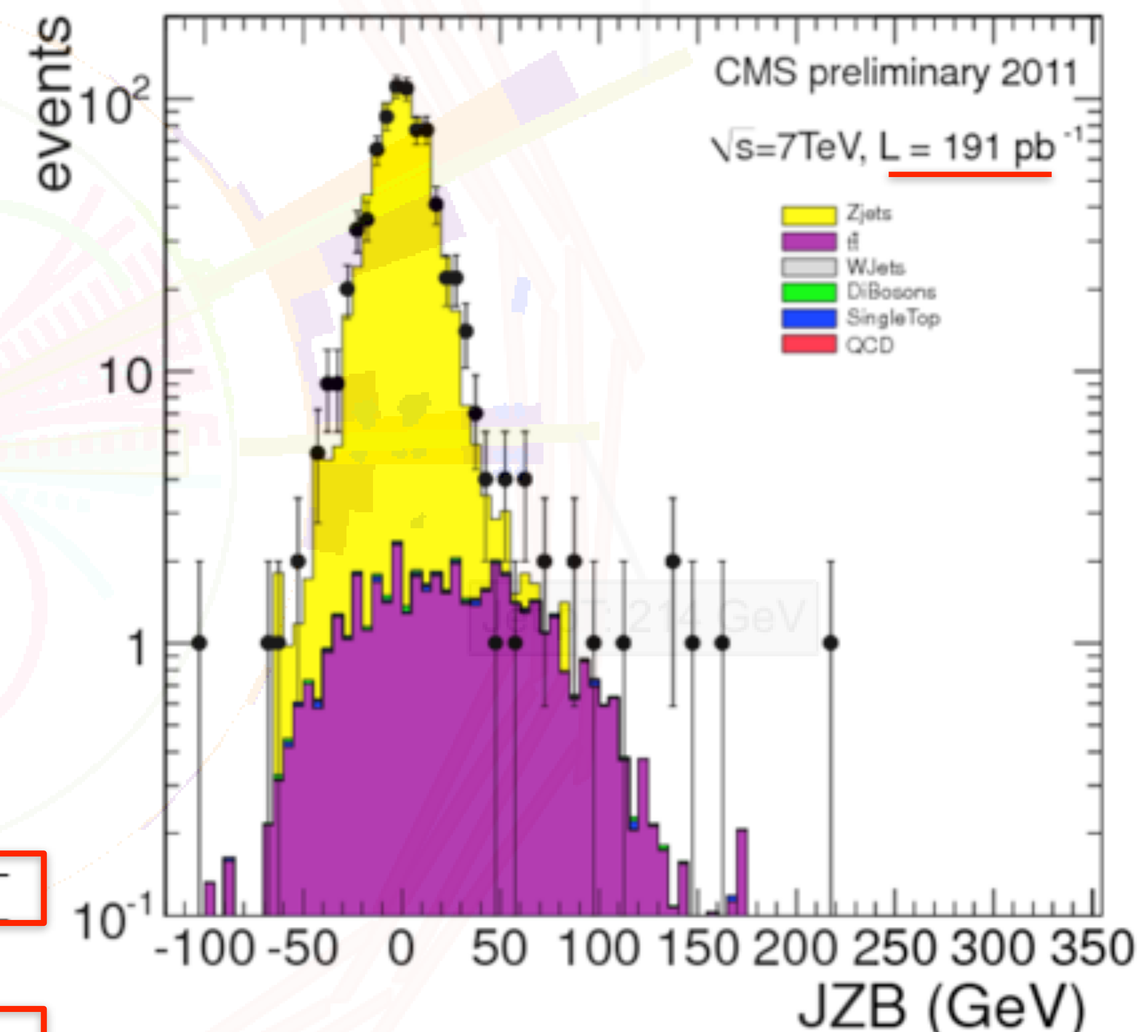
$Z \to \ell\ \ell$ Search

- Similar to previous analysis, but requires the leptons to make a Z
- Use two methods to control BKGs

Region	Observed events	Background prediction	MC expectation
$JZB > 50\,\mathrm{GeV}$	20	$24 \pm 6(\mathrm{stat}) \pm 1.4(\mathrm{peak})^{+1.2}_{-2.4}(\mathrm{sys})$	16.0 ± 1.2 (MC stat)
$JZB > 100\,\mathrm{GeV}$	6	$8 \pm 4(\mathrm{stat}) \pm 0.1(\mathrm{peak})^{+0.4}_{-0.8}(\mathrm{sys})$	3.6 ± 0.4 (MC stat)

Use MET template from γ +jets and multijet events



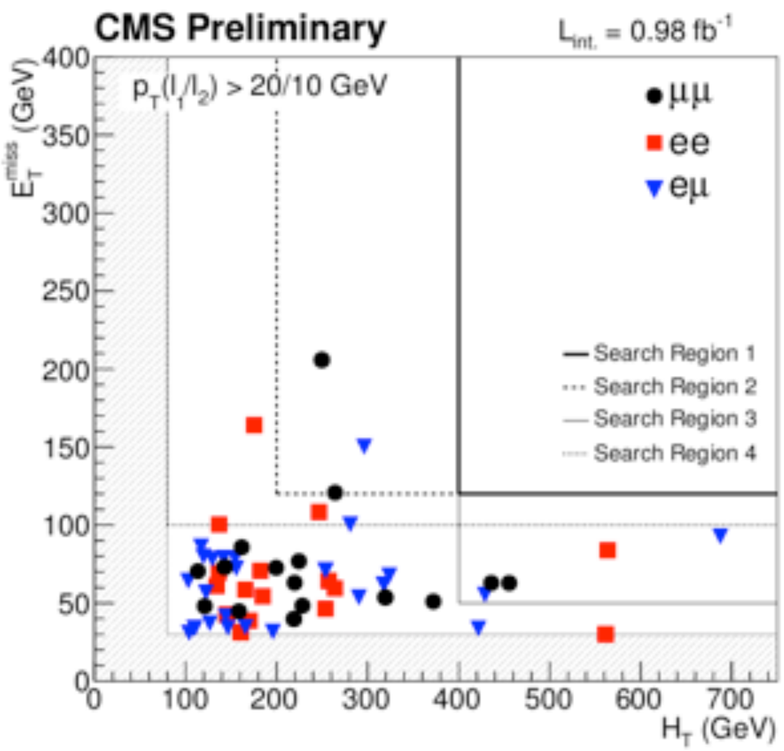


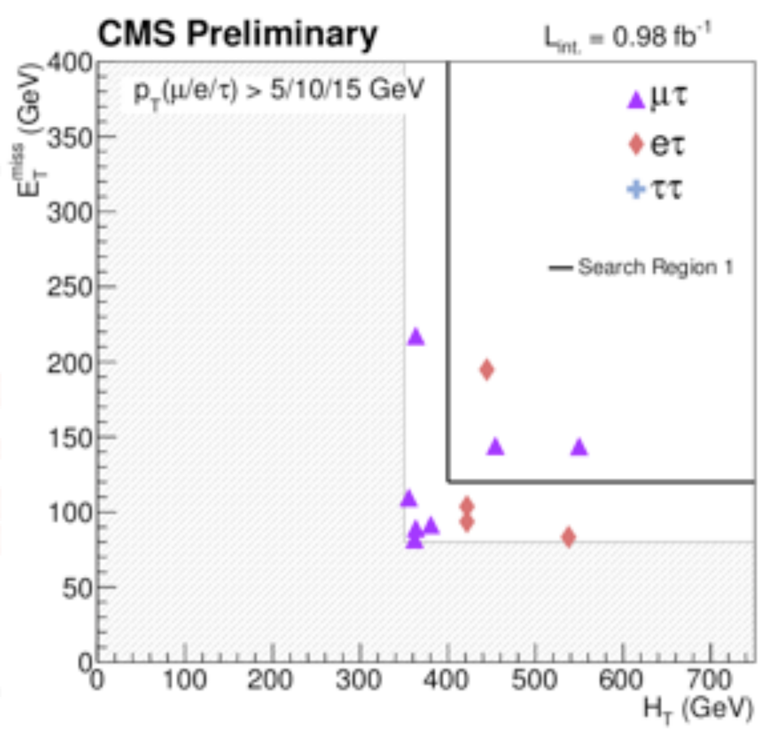
	$E_T^{miss} > 30\,\mathrm{GeV}$	$E_T^{miss} > 60\,\mathrm{GeV}$	$E_T^{miss} > 100\,\mathrm{GeV}$	$E_T^{miss} > 200\,\mathrm{GeV}$
Z Pred	$2060.3 \pm 29.1 \pm 309.1$	$60.8 \pm 4.1 \pm 9.1$	$5.1 \pm 1.0 \pm 0.8$	$0.09 \pm 0.04 \pm 0.01$
$t\bar{t}$ Pred	$246.6 \pm 6.3 \pm 22.2$	$152.5 \pm 4.9 \pm 13.7$	$50.6 \pm 2.8 \pm 4.6$	$3.2 \pm 0.7 \pm 0.3$
Prediction	$2306.9 \pm 29.7 \pm 309.9$	$213.0 \pm 6.4 \pm 16.5$	$55.7 \pm 3.0 \pm 4.6$	$3.3 \pm 0.7 \pm 0.3$
Data	**2287 (1145,1142)**	**206 (114,92)**	**57 (25,32)**	**4 (1,3)**
UL	498	37	20	5.9
LM4	25.4 ± 1.9	22.9 ± 1.8	20.1 ± 1.7	12.3 ± 1.7
LM8	11.8 ± 0.9	10.7 ± 0.8	8.7 ± 0.8	5.0 ± 0.7

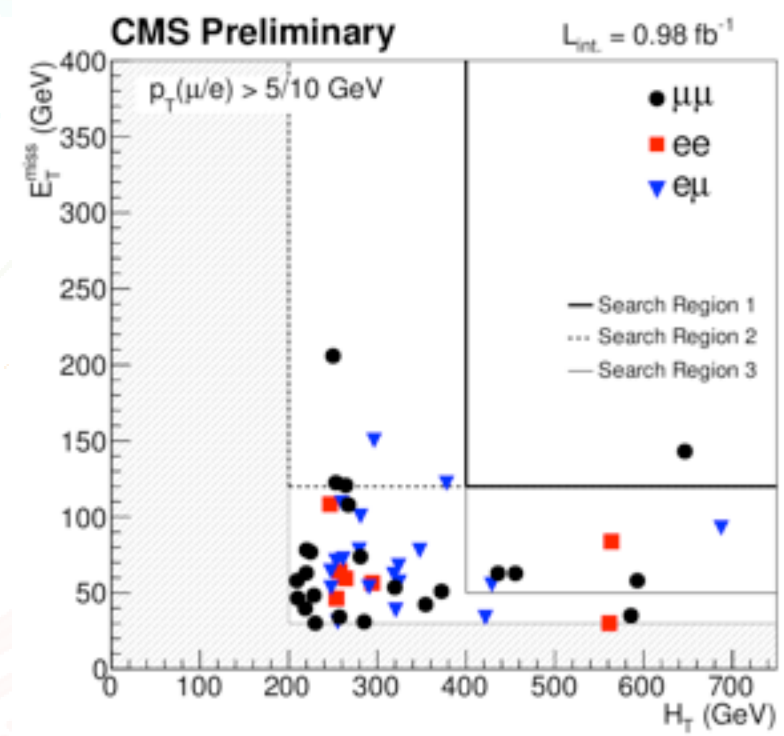
$$JZB = \Sigma(p_T^j(jet)) - p_T(Z)$$

SS Dilepton Search

- Three complementary samples
  - ee, eμ, $\mu\mu$ high P_T (P_T>20,10 GeV)
  - ee, eμ, $\mu\mu$ low P_T (P_T>10 for e, P_T> 5 for μ)
    - More sensitive to compressed SUSY spectra, but higher BG
  - eτ, mτ, $\tau\tau$ (P_T>15 for τ, P_T>10 for e, P_T> 5 for μ)
    - In case New Physics likes taus
- Several signal regions at high MET and HT
  - Where we expect only a few SM events
  - Chosen with an eye towards possible SUSY features

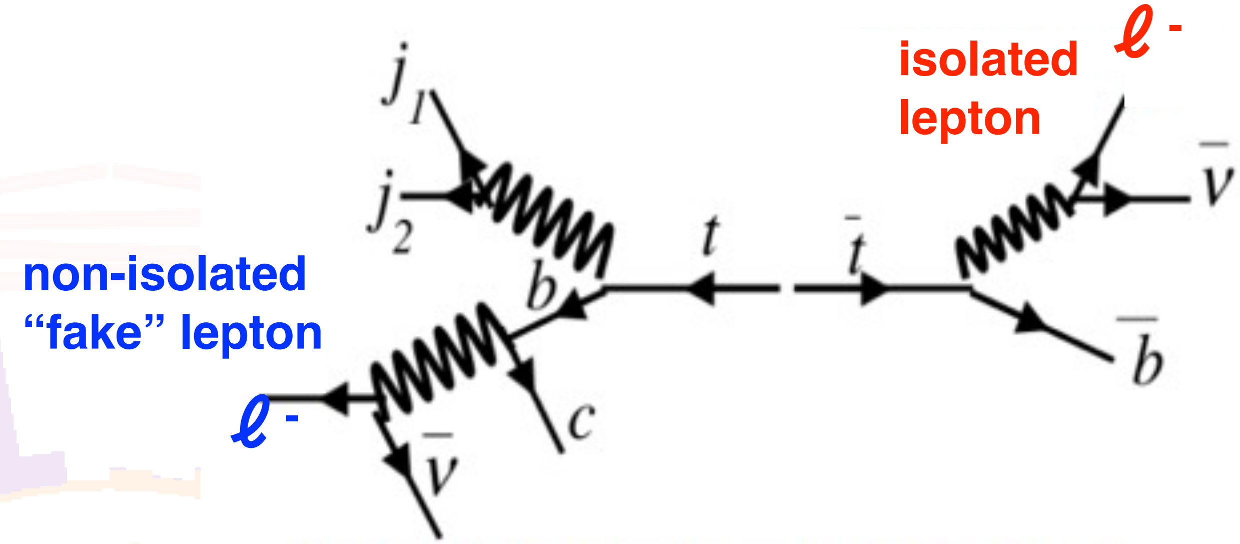






SS Dilepton Search

dominant background:
ttbar with “fake” lepton
from b→$\ell^{\pm}$

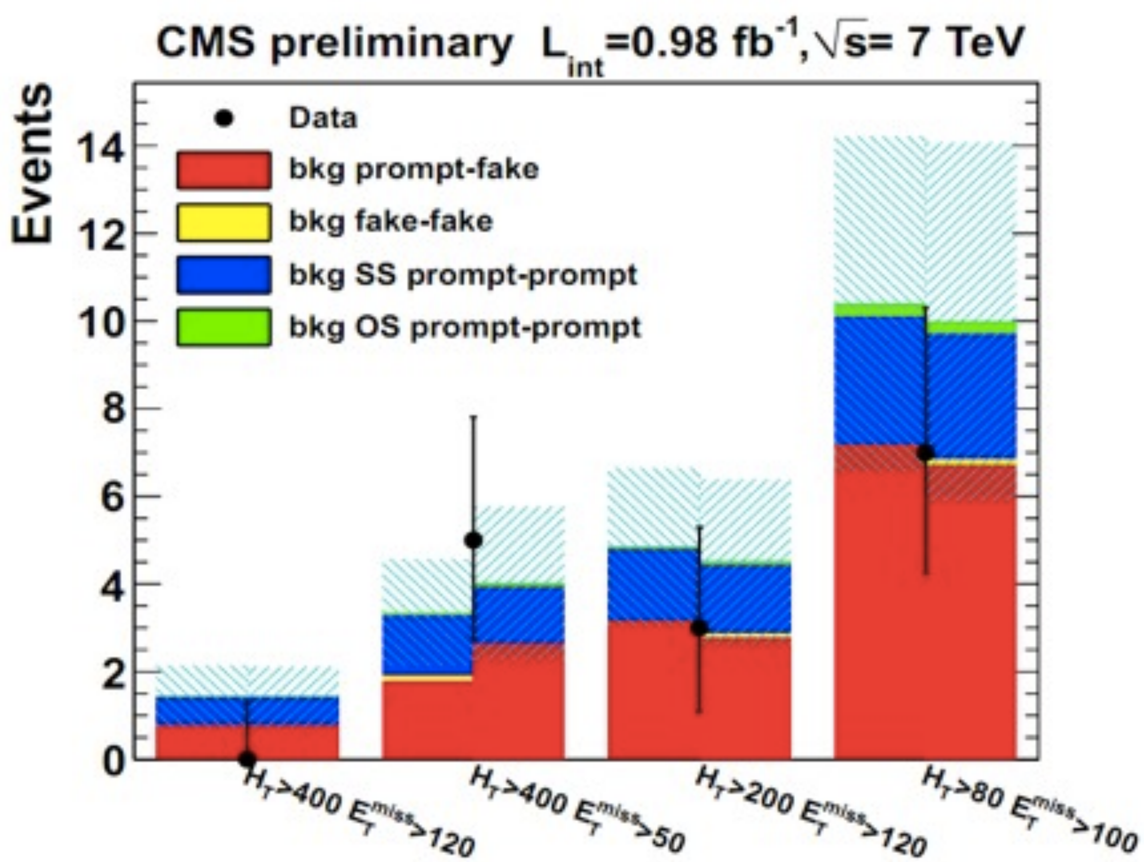


- Events with “fake” (non-W/Z) leptons (dominant)
  - **Must be a data driven BG estimate**
    - Fake rate method (same as H→WW)
    - B tag-and-probe → extract b→$\ell^{\pm}$ isolation distributions from b-enriched sample
  - Validated in lower MET, lower HT control region
- Rare SM processes with SS leptons
  - Estimate from MC
  - ttW, qq→q’q’$W^{\pm}W^{\pm}$: never measured in pp collisions → **measurement critical for future SS analysis**
- Opposite-sign leptons with charge mis-ID (~10%)
  - Charge mis-ID rate validated using same-sign Z sample in data

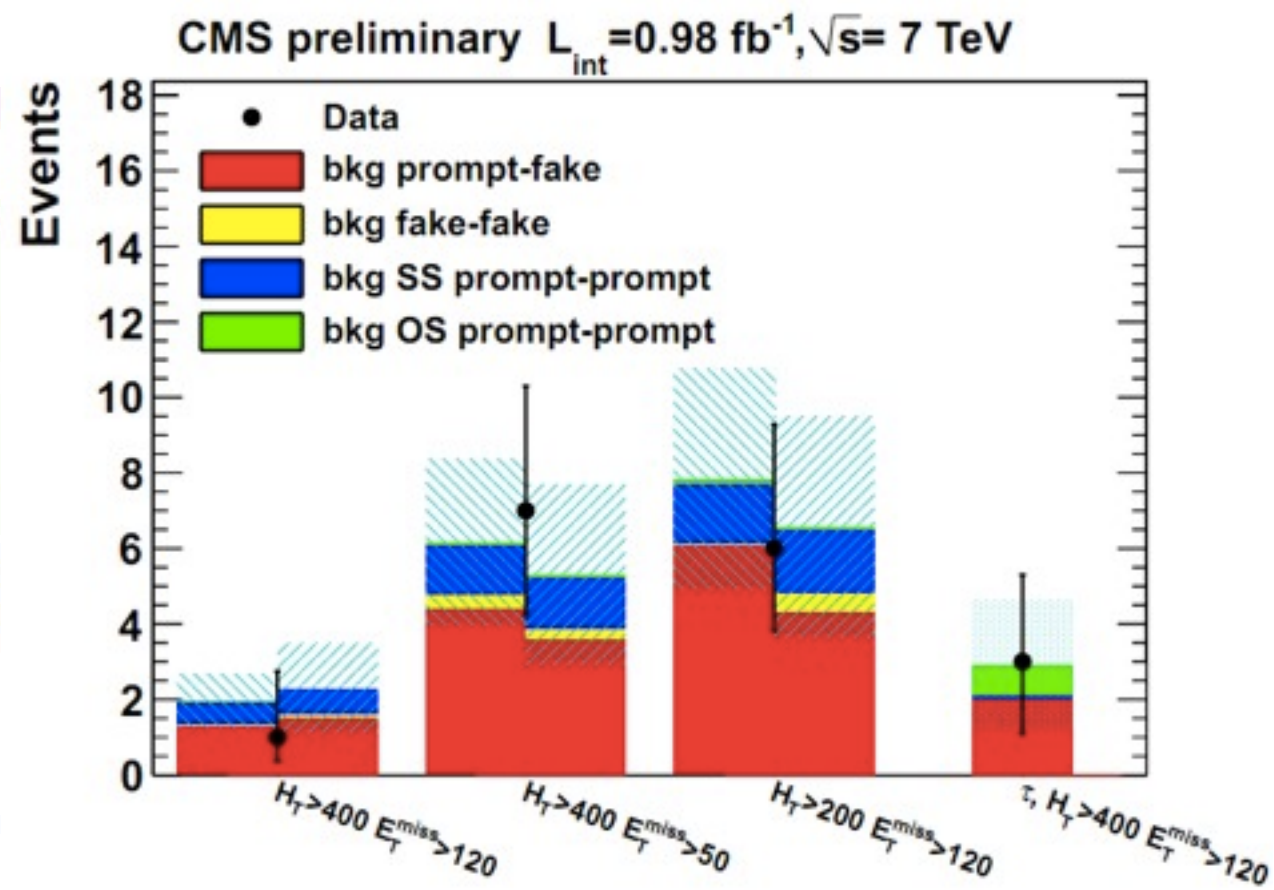
SS Dilepton Search

single fake
double fake
SM SS processes
charge mis-ID

high P_T lepton sample



Low P_T lepton + τ → hadrons sample



- Good agreement observed yields vs. both bkg predictions in all samples and signal regions → **no signs of new physics**
  - Note sizable contribution from **SM SS processes**

Multileptons...

WIRED SCIENCE

NEWS FOR YOUR NEURONS

Hints of New Physics Crop Up at LHC

By Adam Mann | October 21, 2011 | 12:11 pm | Categories: Physics

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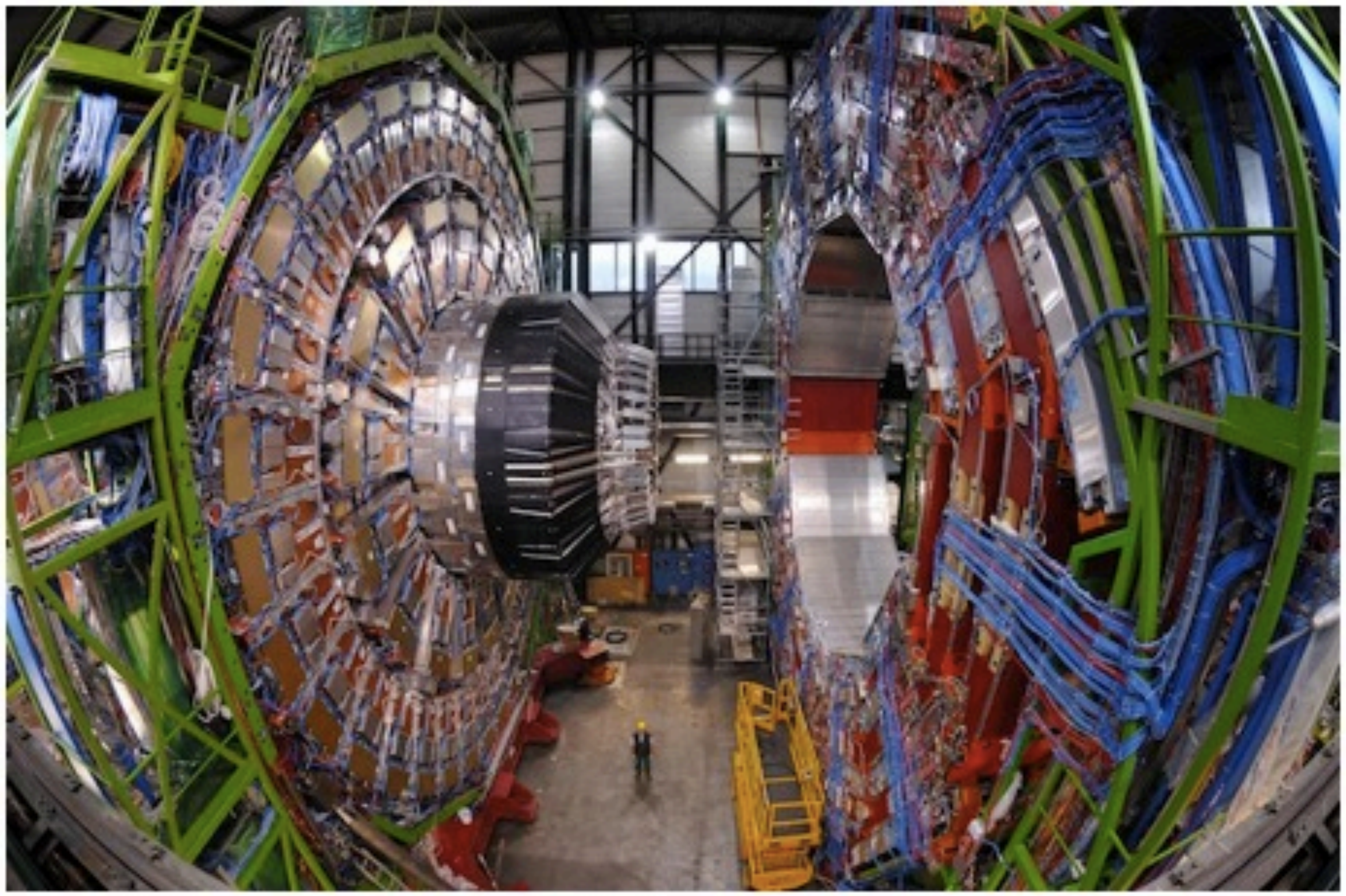


Preliminary findings from CERN's Large Hadron Collider may have uncovered experimental evidence for physics beyond the Standard Model. Data from the CMS experiment is showing significant excesses of particles known as leptons being created in triplets, a result that could be interpreted as evidence for a theory called supersymmetry.

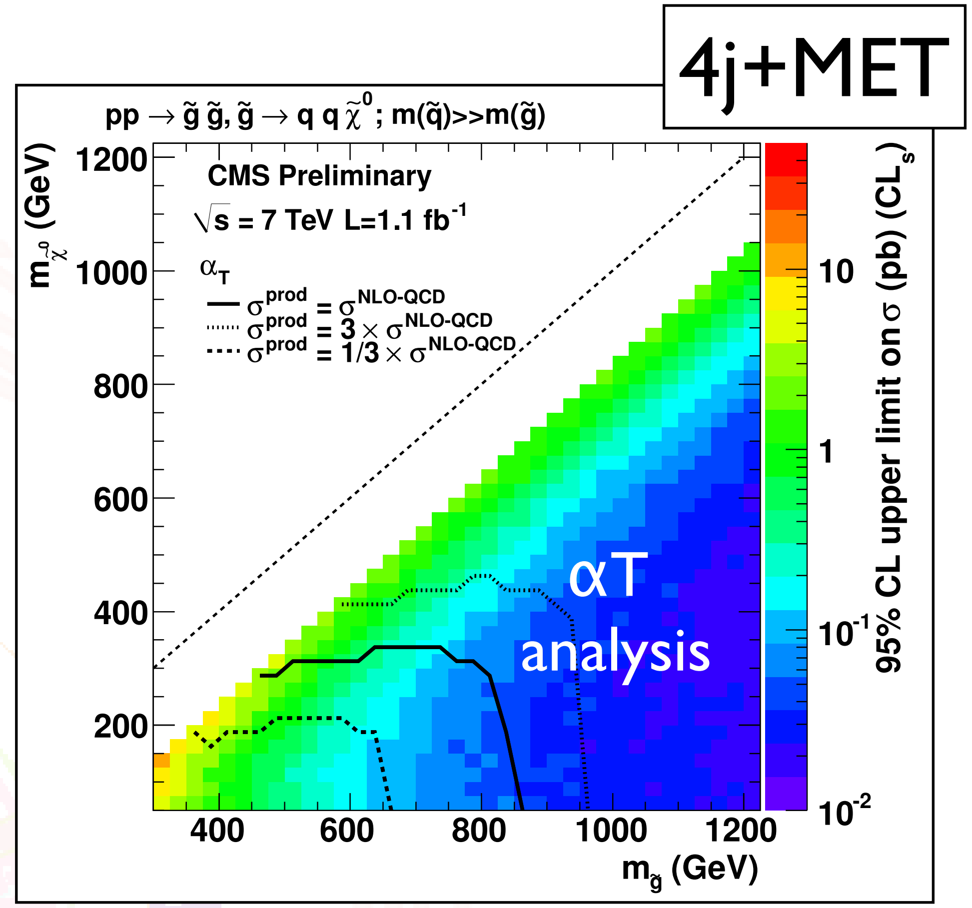
The findings, presented during a talk Oct. 19 at a conference dedicated to LHC searches for new physics, have piqued the interest of some members of the field.

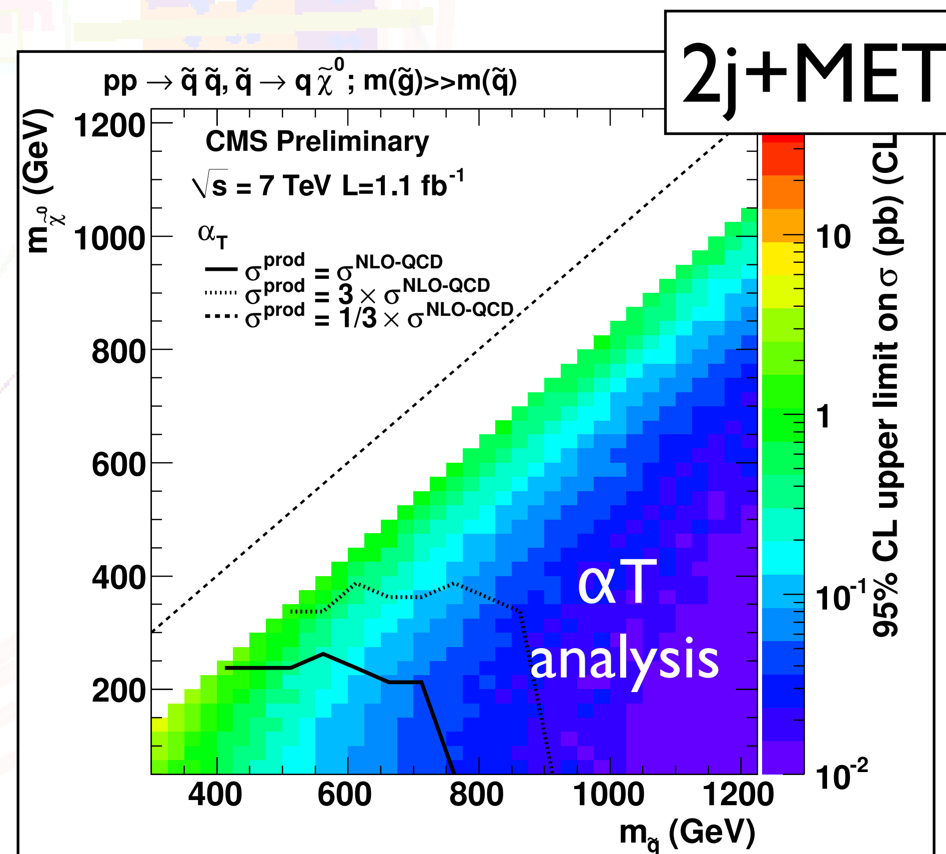
"This is clearly something to watch closely over the coming months," physicist Matt Strassler wrote on his blog. That's because these particular triple lepton signatures are sometimes called the "golden channel" to revealing supersymmetry, a theoretical model that posits the existence of a heavier partner to all known subatomic particles in order to solve certain problems with the Standard Model.

"We do our best, applying different independent approaches and make sure they all give consistent results, but we need to make more cross checks before claiming any inconsistency with the Standard Model," wrote physicist Fedor Ratnikov of the Karlsruhe Institute of Technology in Germany, who presented the CMS results at the conference, in an email.

The Simplified Models

- CMSSM is a very special case, with built-in features
- A generic SUSY can produce more challenging situation, eg compressed spectra (meaning softer seen jets, problems with trigger, etc)
- To study the performances of the searches in these scenarios we look at simplified models: SUSY-like models with only a few (two, at most three) particles





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- CMS SUSY results

  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

- Other papers
  - Original paper on α http://arxiv.org/pdf/0806.1049
  - Modified α_T paper by CMS http://cdsweb.cern.ch/record/1149915/files/SUS-08-005-pas.pdf
  - MT2 http://arXiv.org/pdf/hep-ph/0304226 http://arxiv.org/pdf/0810.5576v2
  - $\sqrt{s}_{min}$ http://www.arxiv.org/pdf/1006.0653
  - Razor http://arxiv.org/pdf/1006.2727

M_{T2}: two missing particles

- If we could see all the particles, we could compute

$$\boxed{m^2_{\chi_1^+} = m^2_\pi + m^2_{\chi_1^0} + 2\left[E_T^\pi E_T^{\chi_1^0}\cosh(\Delta\eta) - \mathbf{p}_T^\pi \cdot \mathbf{p}_T^{\chi_1^0}\right]}$$

- If we could measure $p_T(X^0)$, but not $p_z(X^0)$, the best we could do would be

$$\boxed{m_T^2(\mathbf{p}_T^\pi, \mathbf{p}_T^{\chi_1^0}; m_{\chi_1^0}) \equiv m^2_{\pi^+} + m^2_{\chi_1^0} + 2(E_T^\pi E_T^{\chi_1^0} - \mathbf{p}_T^\pi \cdot \mathbf{p}_T^{\chi_1^0})}$$

- Since cosh>1, $m_T \leq m$, the equality holding for both $pz(X^0)=0$. This means that max(m_T) has an "edge" at m

- For each event we have two values of m_T (two copies of the same decay). Both are such that $m_T<m$. This means that max($m_T(1)$, $m_T(2)$)<m

- We only know $p_T(X^0{}_1)+ p_T(X^0{}_2)=E_T^{miss}$. A wrong assignment of the missing momenta brakes the $m_T<m$ condition. But the condition would hold for the correct assignment. This means that min(m_T)<m_T(true)<m.

- This defined m_{T2} as

$$\boxed{m^2_{T2}(\chi) \equiv \min_{\not{q}_T^{(1)}+\not{q}_T^{(2)}=\not{p}_T}\left[\max\left\{m_T^2(\mathbf{p}_T^{\pi^{(1)}}, \not{q}_T^{(1)};\chi),\ m_T^2(\mathbf{p}_T^{\pi^{(2)}}, \not{q}_T^{(2)};\chi)\right\}\right]}$$

M_{T2}: two missing particles

- The variable we have is a function of the mass of the LSP

- <u>SUSY characterization:</u>

  - Scan the LSP mass and look for the edge developing in your sample of SUSY events (if you have one...)

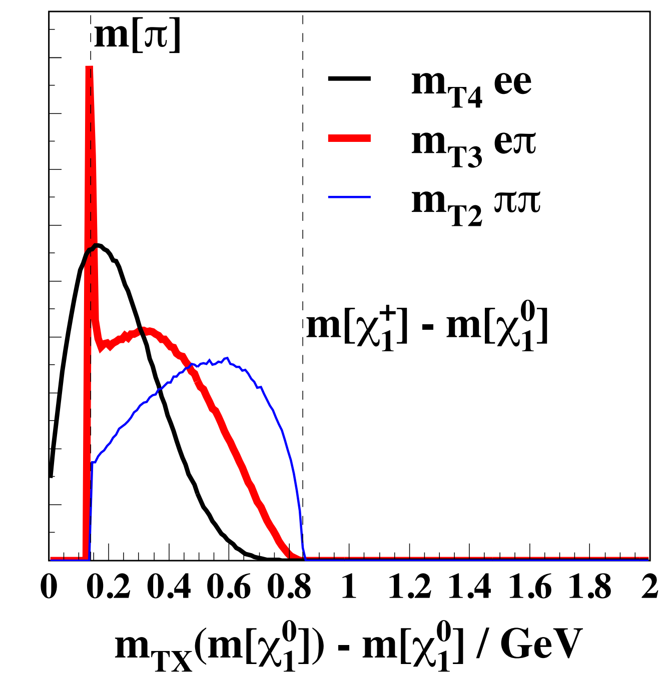

Figure 3: *Simulations of $m_{TX}(m_{\chi_1^0}) - m_{\chi_1^0}$ for $X = 2, 3, 4$ using a simple phase-space Monte-Carlo generator program for a pair of decays $\tilde{q} \to \chi_1^+ q$ followed by $\chi_1^+ \to \chi_1^0\ \pi$ or $\chi_1^+ \to \chi_1^0\ e\ \nu_e$. As the number of invisible particles increases, the proportion of events near the upper limit decreases. Within the figure, subscripts are indicated by square brackets.*

- <u>SUSY search:</u>

  - Assume a mass value (eg mLSP=0)
  - Assume that the visible system in has 0 mass
  - An analytical expression for M_{T2} is found

$$\boxed{(M_{T2})^2 = 2A_T = 2p_T^{vis(1)}\, p_T^{vis(2)}(1 + cos\phi_{12})}$$

  - The edge is lost but we have an α_T-like variable to kill the QCD