SUSY SEARCHES STATUS WITH THE CMS DETECTOR

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on behalf of the CMS collaboration

Spring Institute 2014 - Frascati

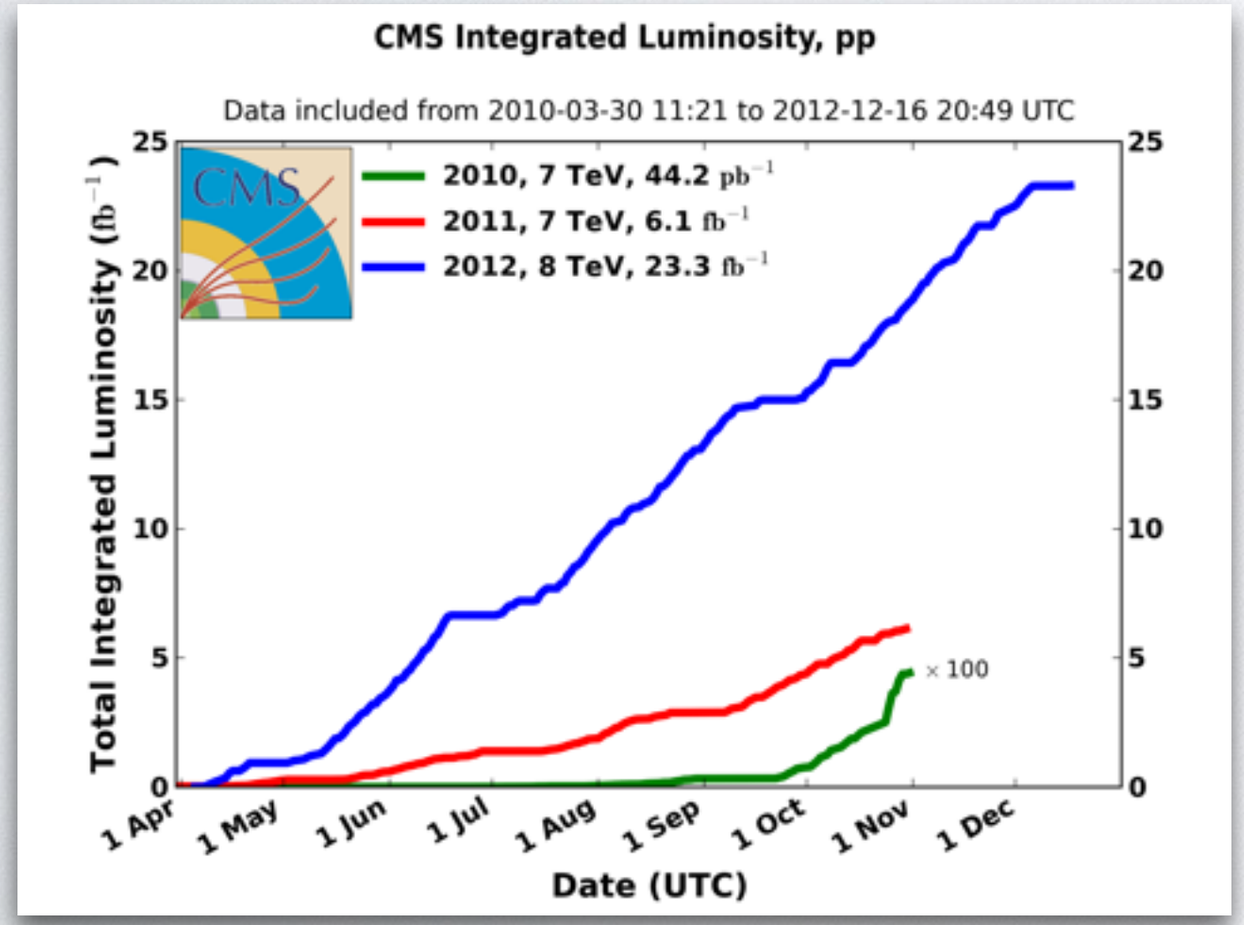
OUTLINE

- LHC and CMS experiment
- Search strategies and techniques
- Direct searches
  - Squarks
  - Gluinos
  - Sleptons
- More "exotic" models
- Conclusions

LHC

Two main run periods

Results presented here are from the second at 8 TeV with 20 fb^{-1}

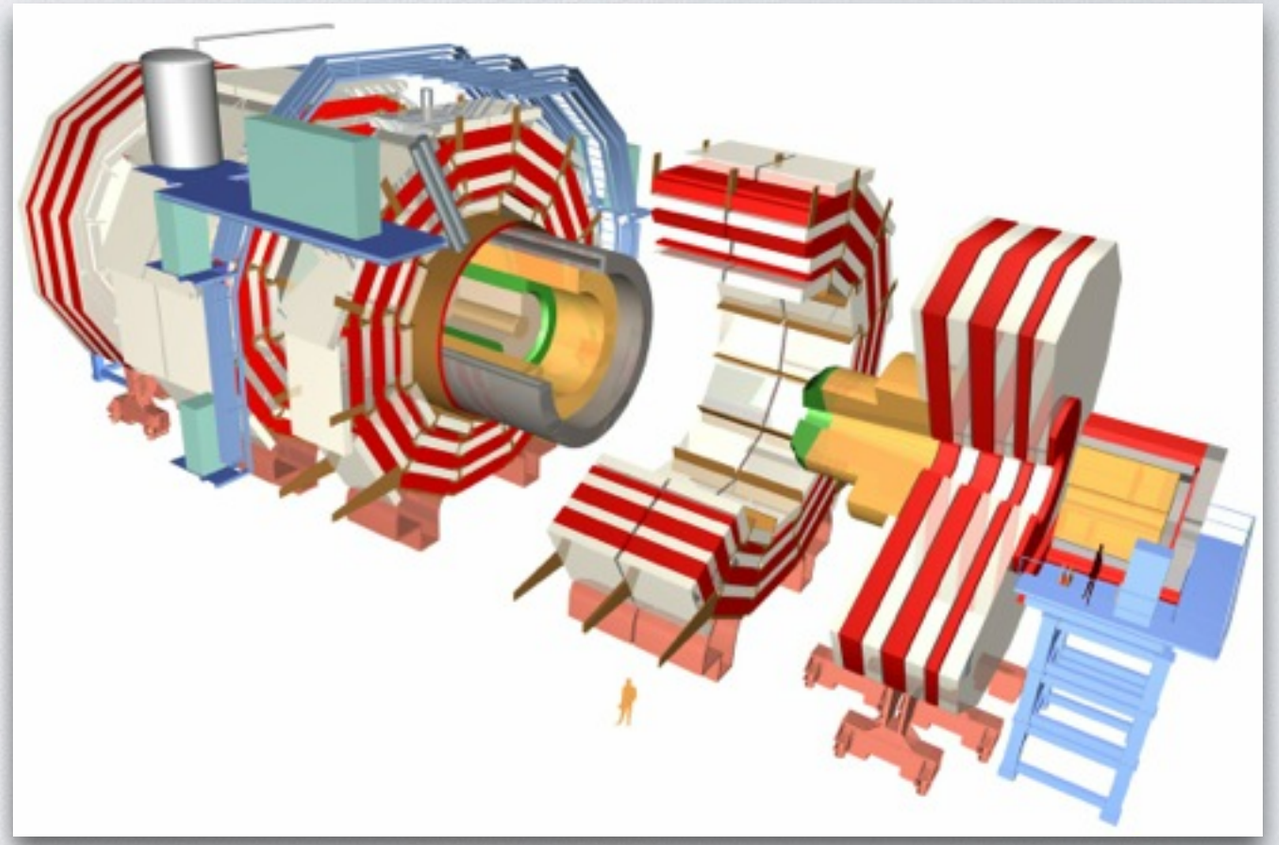


27 km proton proton collider

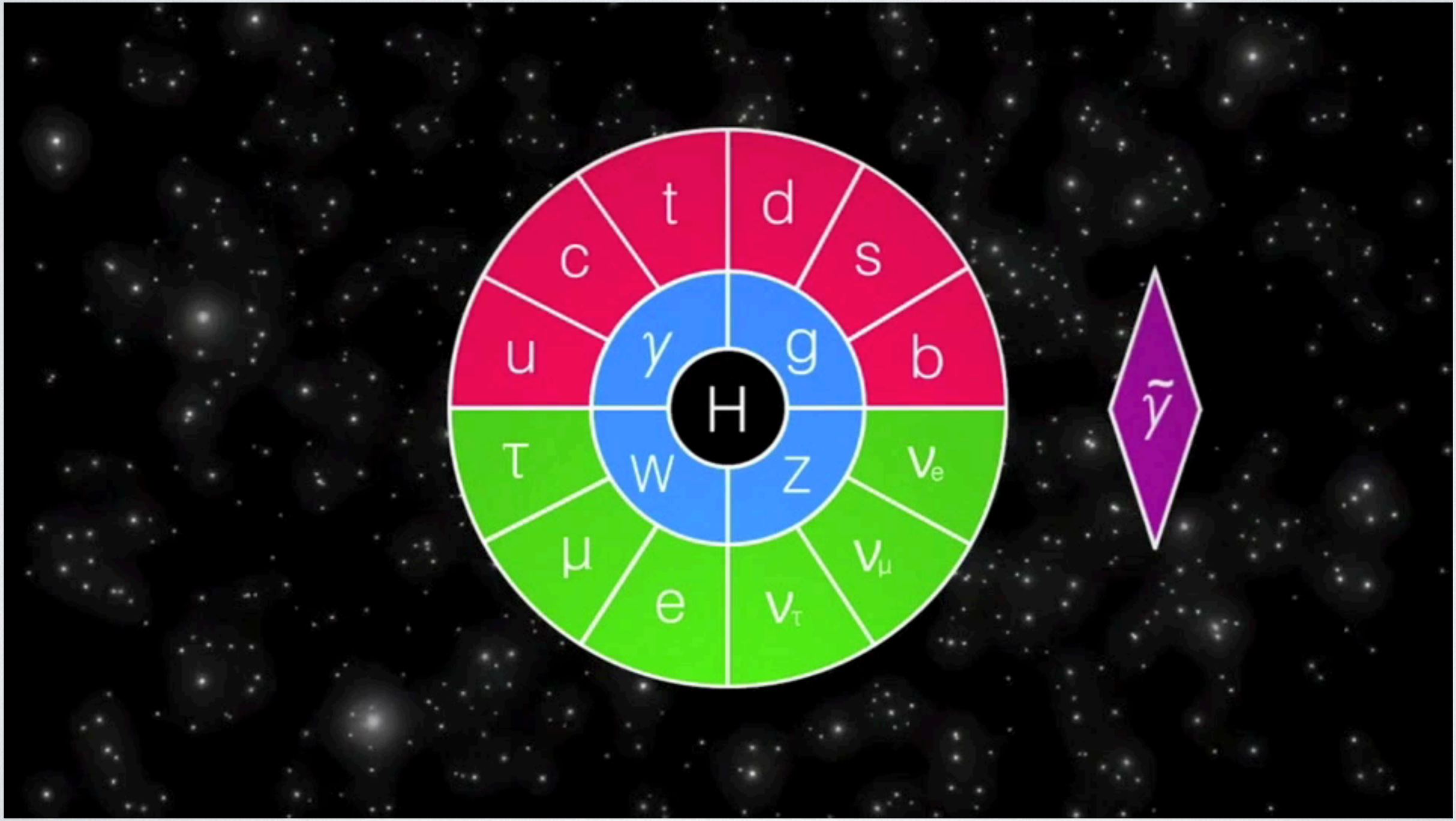
with 4 main experiments

COMPACT MUON SOLENOID

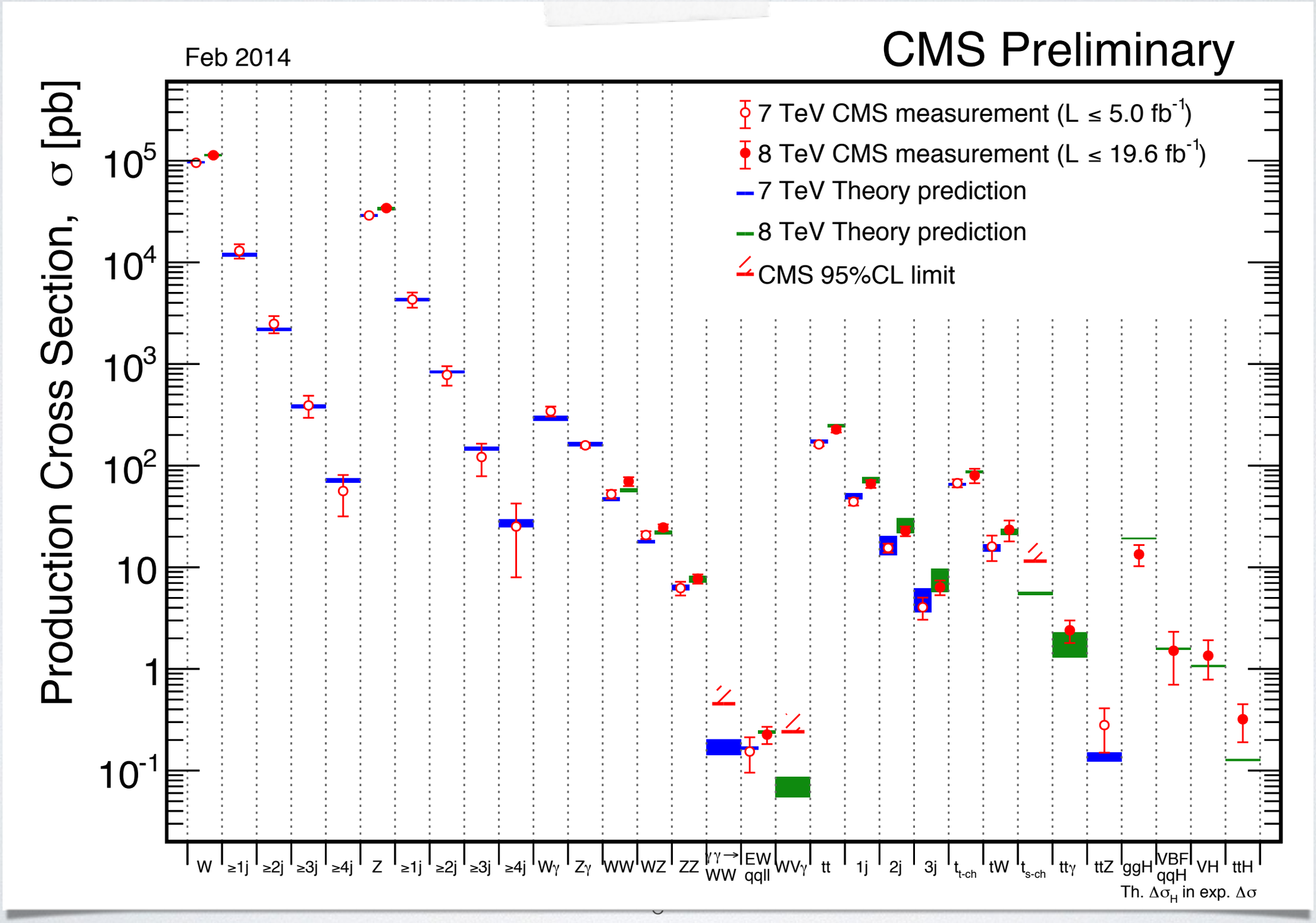
- One of the two general purpose experiments at LHC
- Solenoidal magnetic field 3.8 T and return yoke
- Large Silicon Tracker with great momentum and particle resolution
- Scintillating crystal for ECal
- Sampling HCal (brass and scintillator)
- Redundant muon spectrometer in the iron return yoke



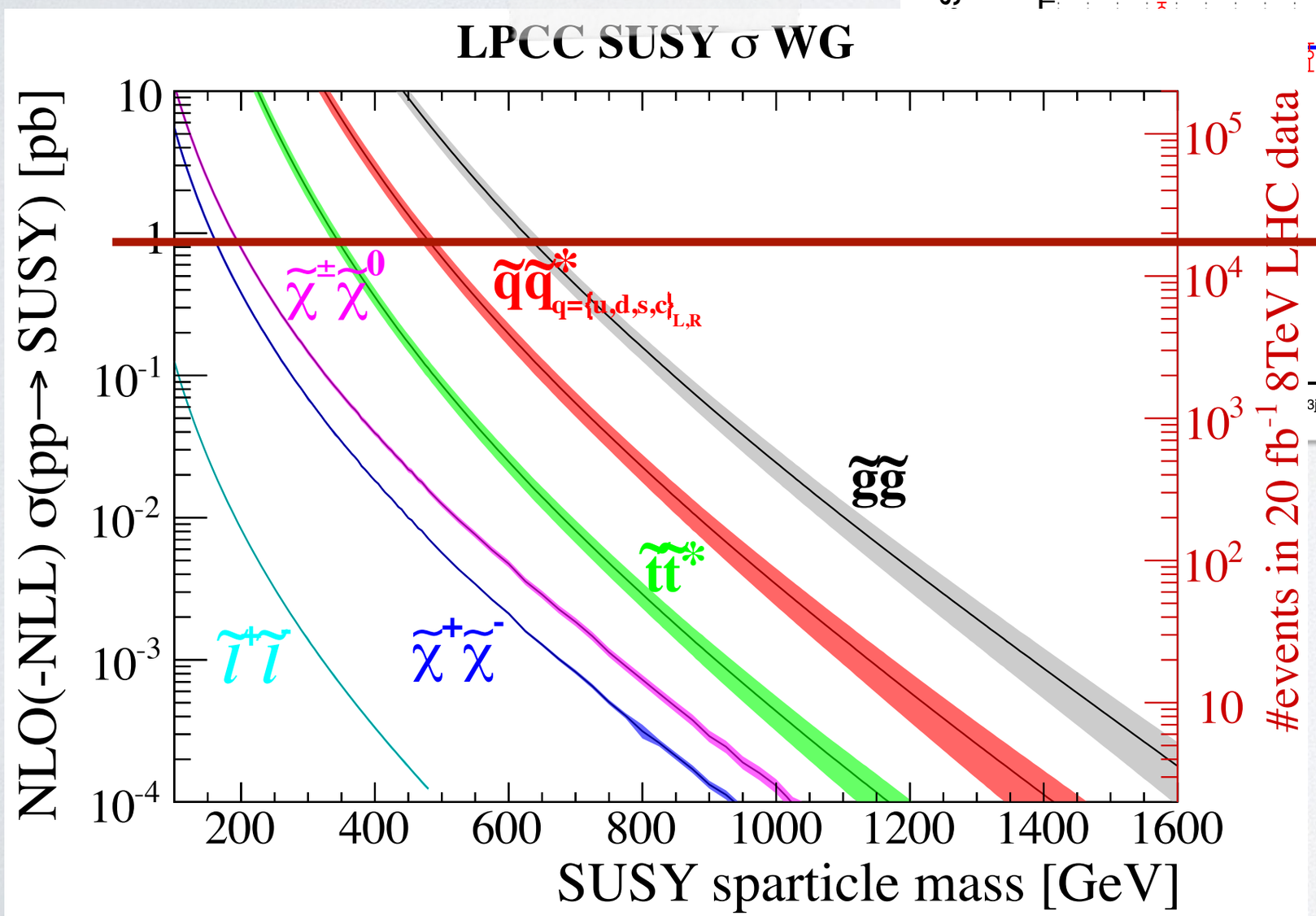
STANDARD MODEL

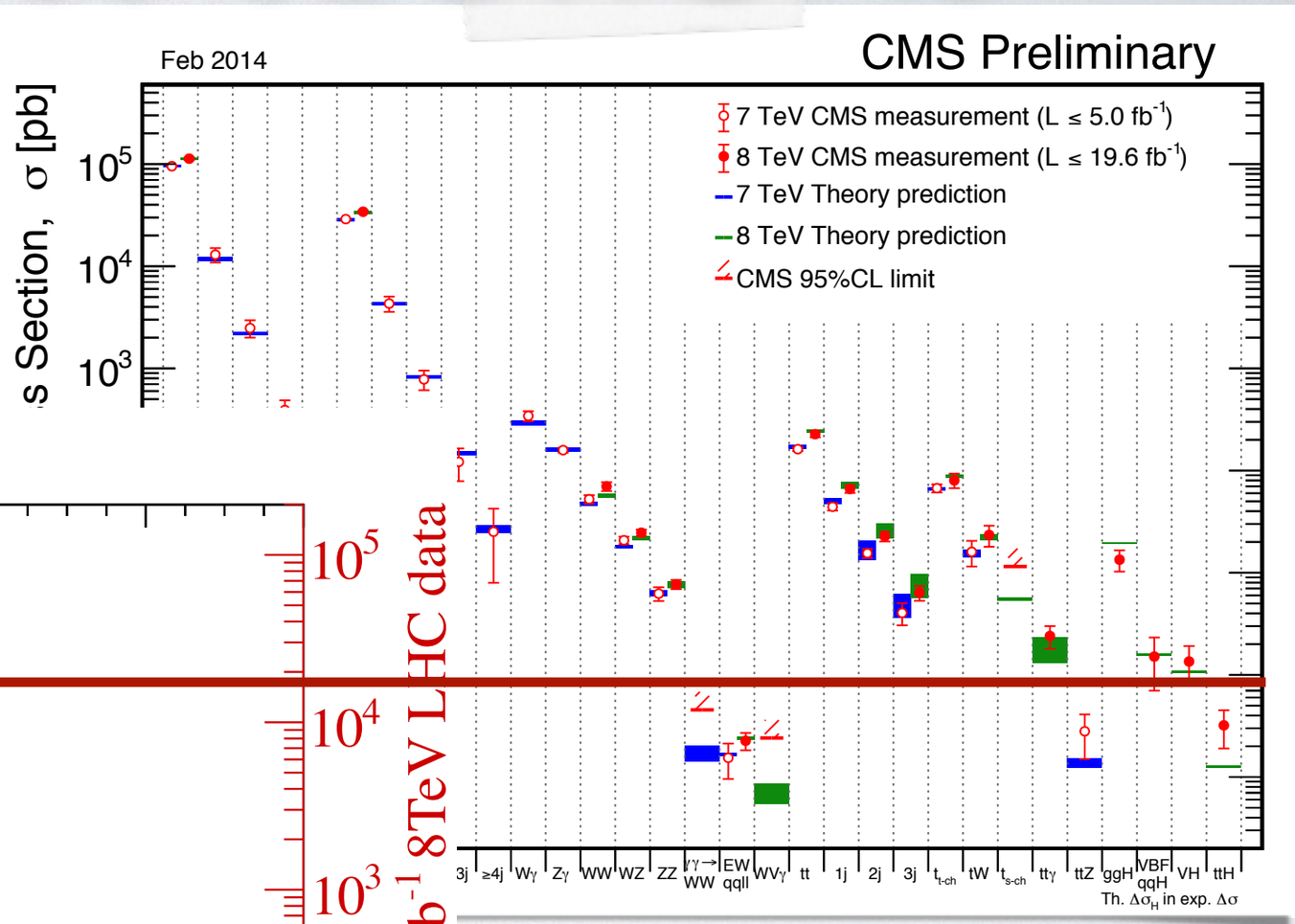


UNDERSTAND SM FIRST



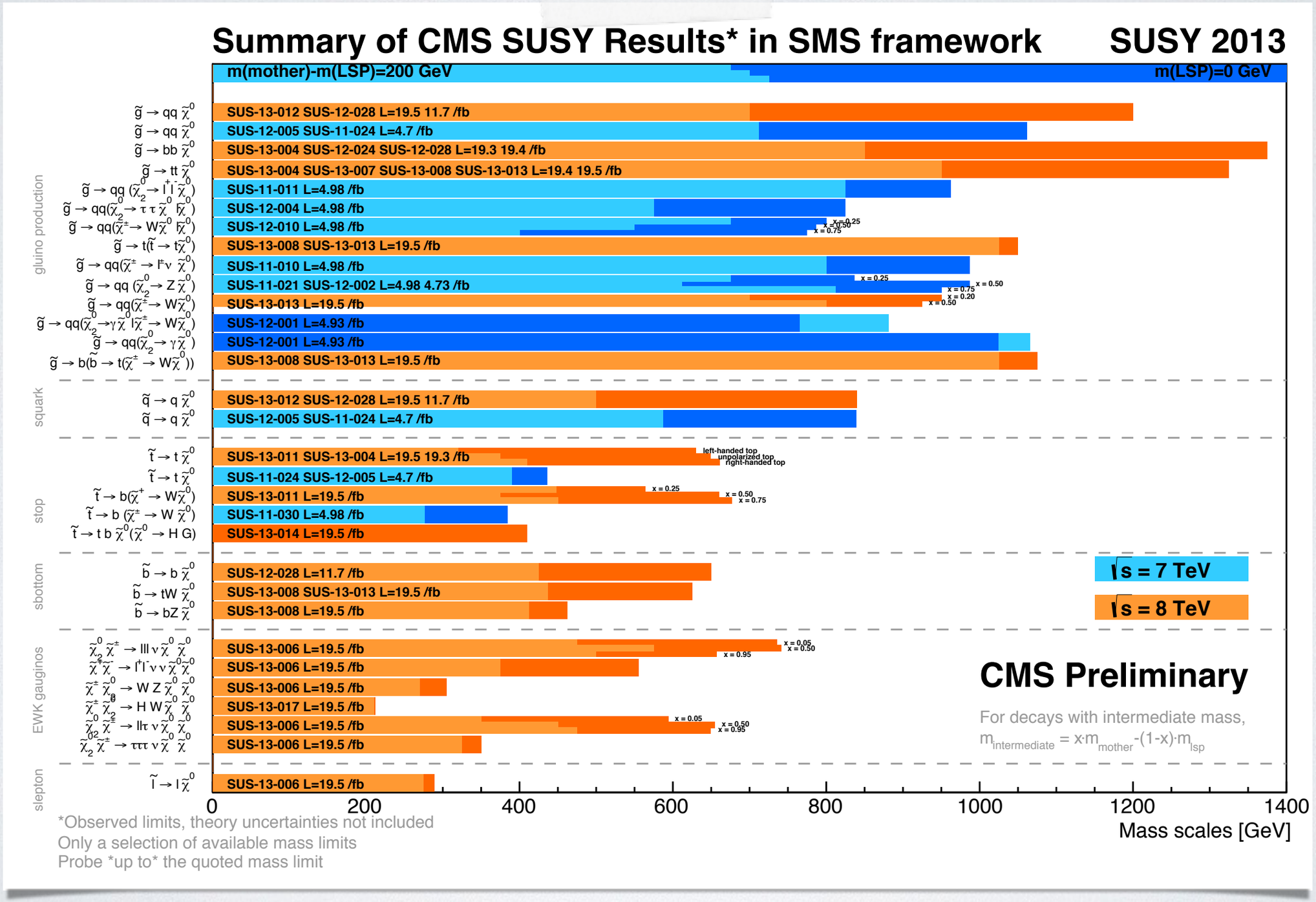
SUSY CROSS-SECTIONS





https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1206.2892

CMS SUSY OVERVIEW



*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

WHAT TO LOOK FOR?

Electrons

- reconstructed with tracking and calorimetry
- high pt and isolated
- ID and charge

Photons

- only calorimetry information
- disentangle photon not coming from primary vertex such as decay and conversion

Muons

- reconstructed with tracking and muon spectrometer
- high pt - resolution
- isolation - muons in jets

Jets

- cluster calorimetry energy with different algorithms
- combine tracker and calorimetry information
- calibrate the energy

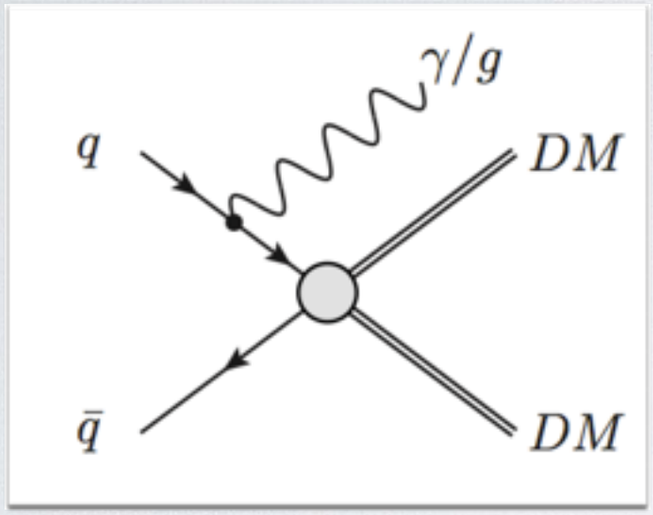
MET

- combine all the information from different sub-detectors
- understand the response in different conditions and the effect of underlying events

SEARCH STRATEGY

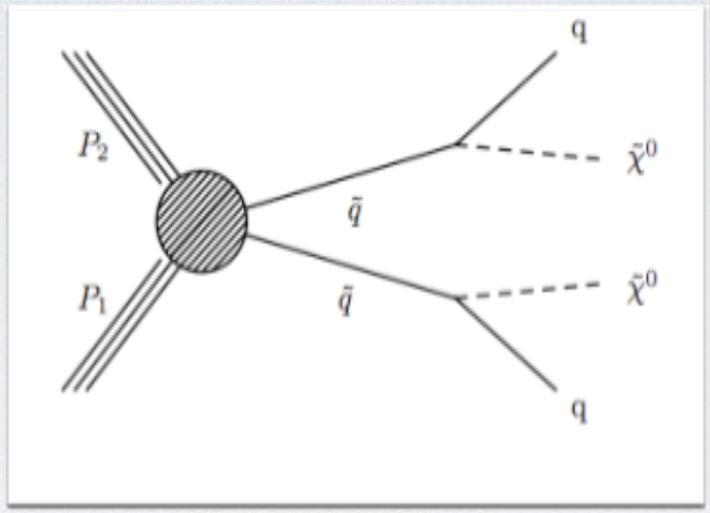
- Inclusive generic searches
- Naturalness-inspired searches
  - Missing Energy
  - b-jets
  - high multiplicity events
- Search for EWKinos & sleptons
- Multi-lepton & R-parity violating signatures

JET(S) + MET



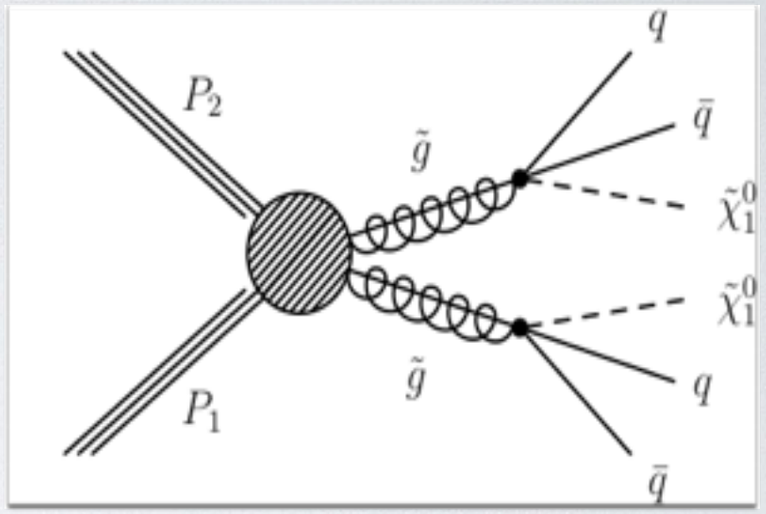
1 jet + MET

SM: Z(**νν**) + jet



2 jets + MET

SM: QCD and fake MET, W + jets, …



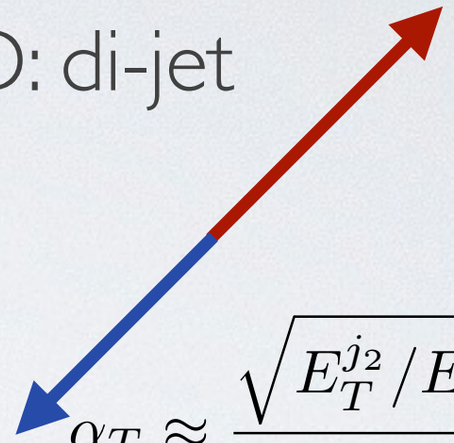
multi-jets + MET

SM: fake MET in QCD or real MET from top pair

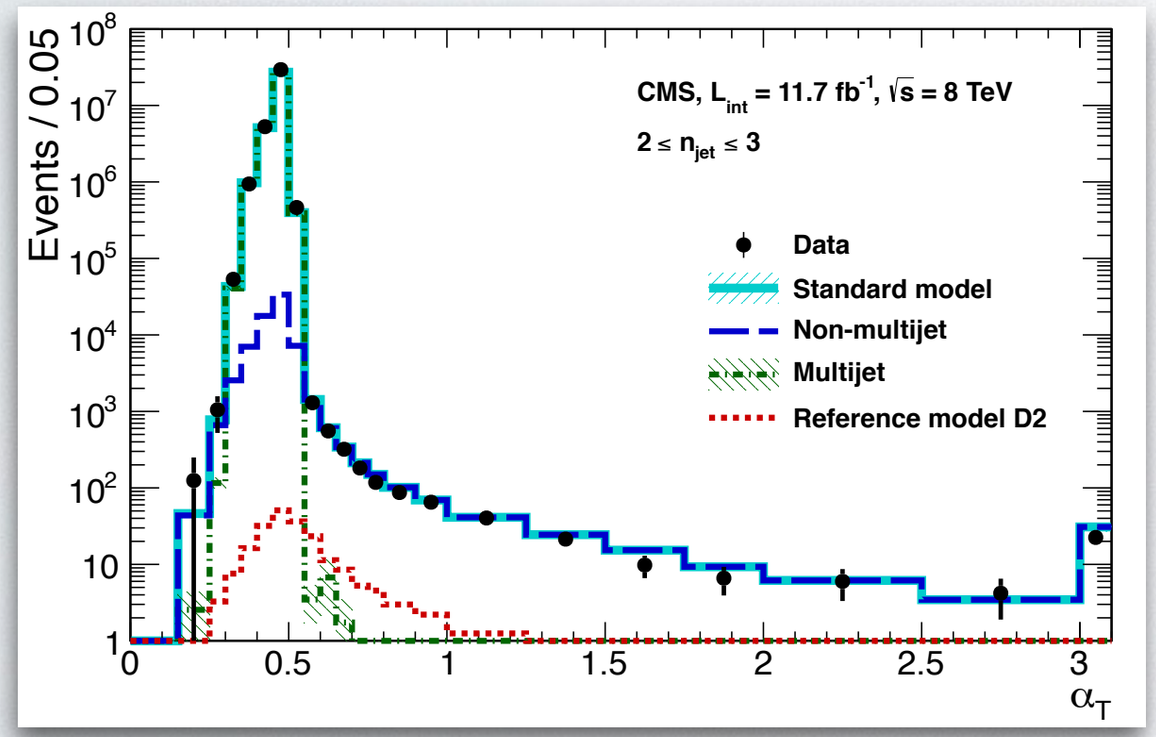
α_T ALL HADRONIC

$$\alpha_T = \frac{E_T^{j_2}}{M_T(j_1, j_2)}$$

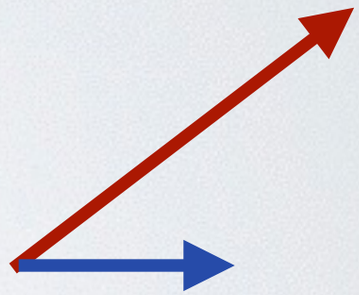
QCD: di-jet



$$\alpha_T \approx \frac{\sqrt{E_T^{j_2}/E_T^{j_1}}}{2} \leq \frac{1}{2}$$



$$\alpha_T \approx \frac{\sqrt{E_T^{j_2}/E_T^{j_1}}}{\Delta\phi_{j_1,j_2}}$$

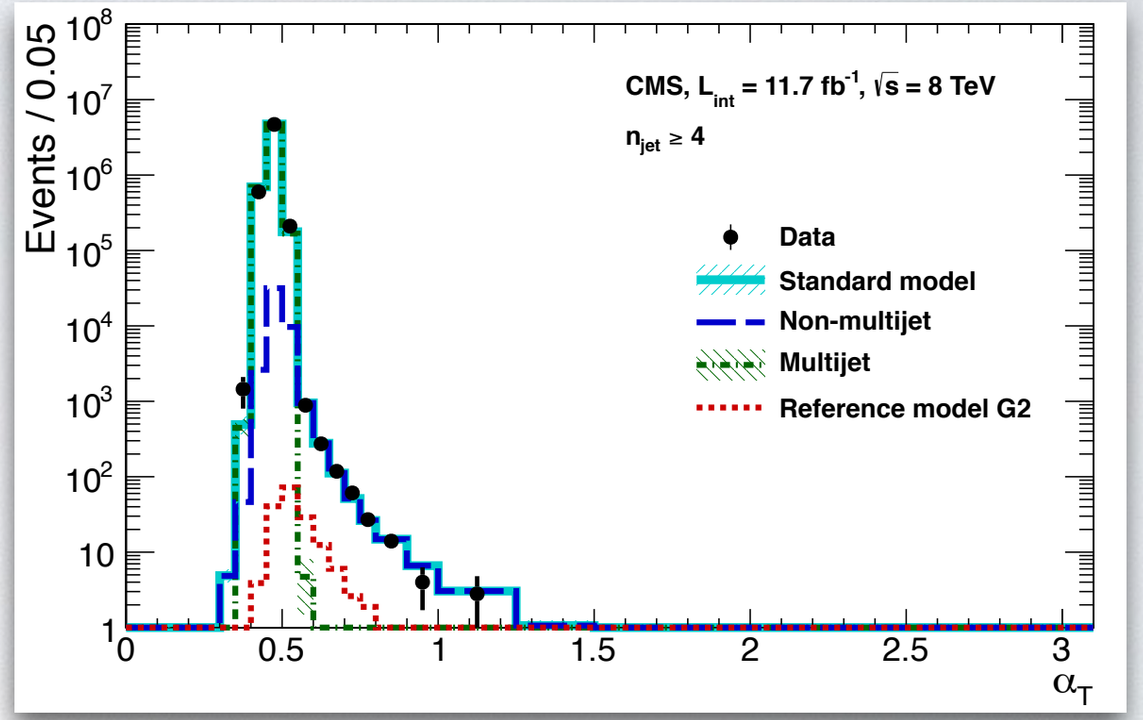


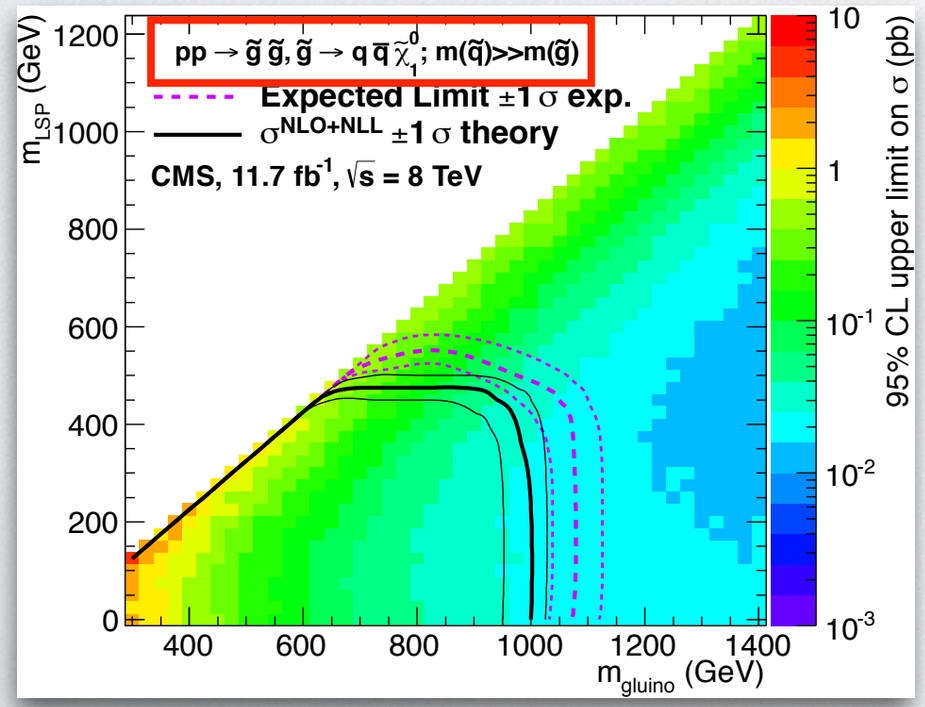
SUSY:
di-jet+MET

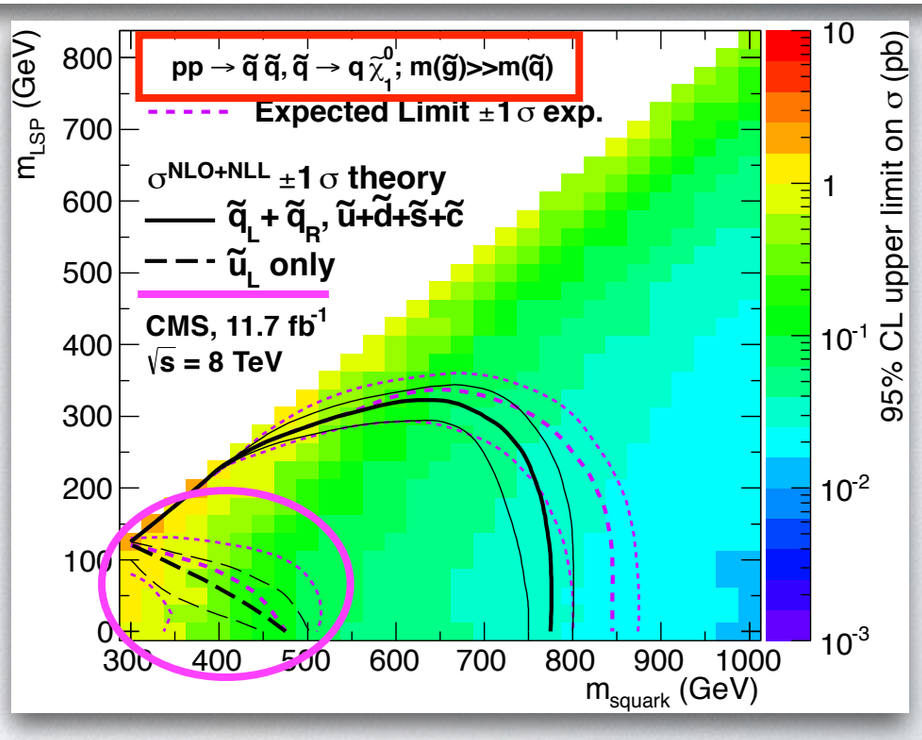
CMS-SUS-12-028

α_T GENERALIZATION

$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - \not{H}_T^2}}$$







MULTI-JETS AND MHT

- Selection, events with 3 or more jets plus missing HT (no lepton):
  - 3 central jets (η<2.5) above 50 GeV (used also for H_T)
  - Missing H_T larger than 200 GeV (jets with p_T threshold at 30 GeV and η<5.0)
  - Veto events if MH_T is aligned with one of the three leading jets
- Bin data in:
  - H_T
  - missing H_T
  - jet multiplicity (3-5, 6-7, ≥8)

$$H_T = \sum_{jets} \vec{p}_T$$

$$\not{H}_T = \left| -\sum_{jets} \vec{p}_T \right|$$

CMS-SUS-12-012

BACKGROUND PREDICTION

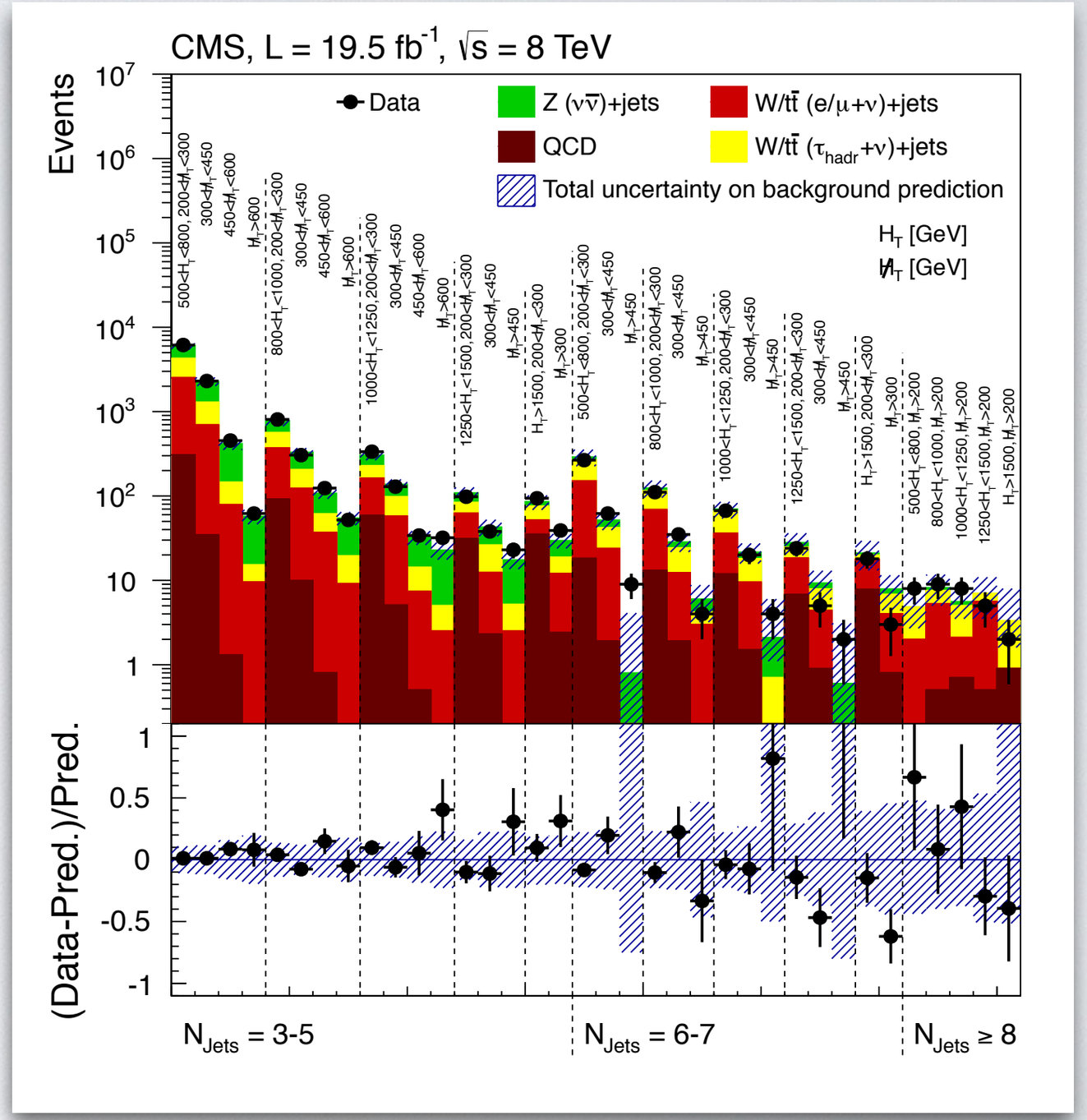
- Based on data-driven methods with MonteCarlo closure test
- Z to invisible
  - **γ** + jets and Z(**μμ**) + jets
- missing lepton and hadronic **τ**
  - semi-leptonic top and W
- QCD multijet
  - re-balance and smearing procedures

RESULTS

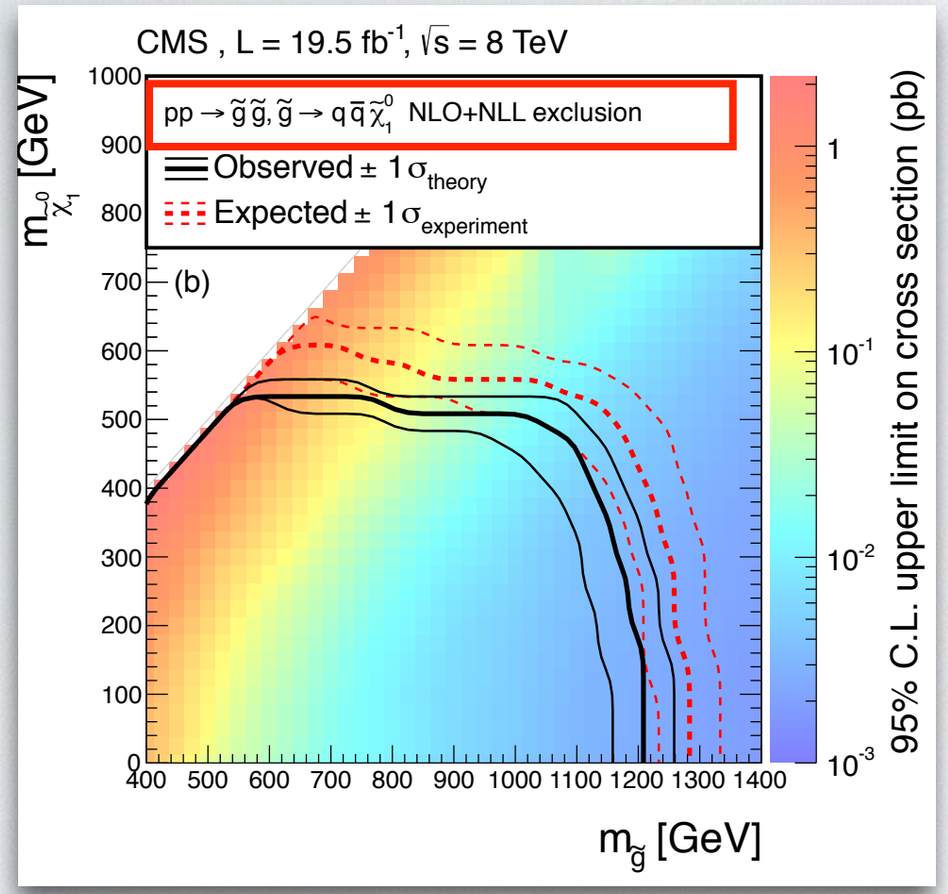
Do not be fooled by the Njets = 6-7, H_T 500-800 GeV and MH_T>450 GeV bin.

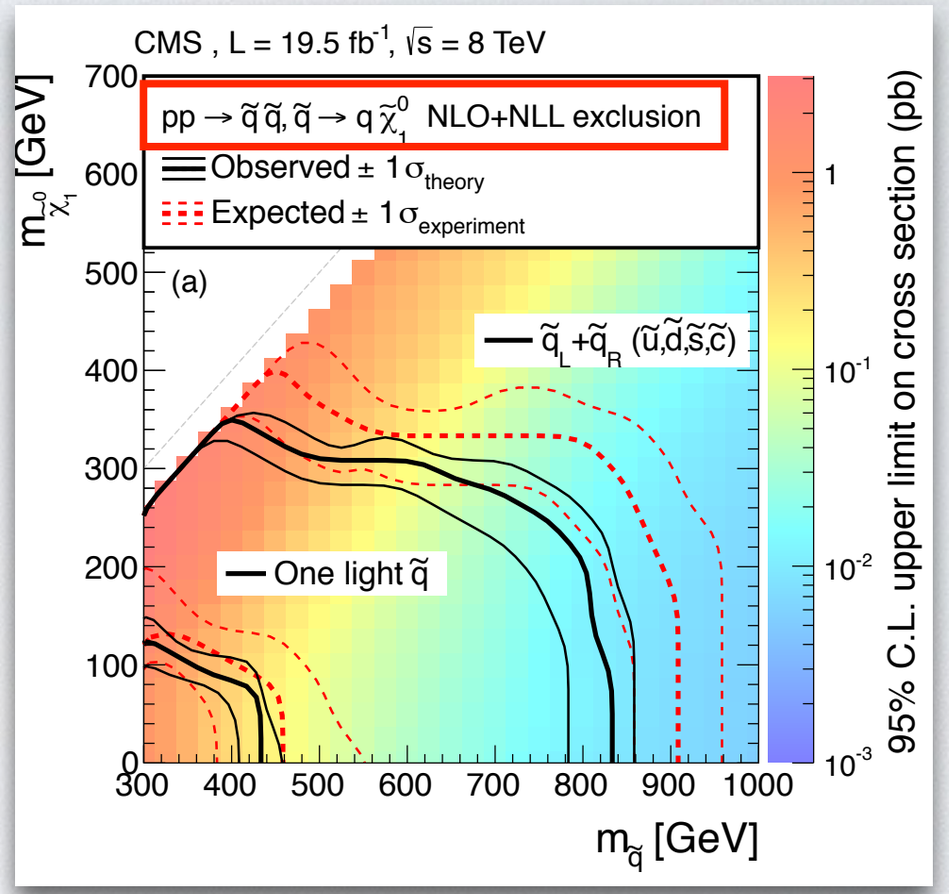
The central value is 0.8 but the uncertainty 1.7, therefore 9 events observed are not enough to claim any discovery.

$$\text{Prob}(\, n \geq 9 \mid \mu = 0.8 \pm 1.7) \approx 0.15$$



EXCLUSION PLOTS





- Exclusion for simplified model assuming 100% BR
- Higher signal efficiency away from the diagonal

HADRONIC MT_2

- Similar to the previous search with α_T but using a generalization of the M_T variable.

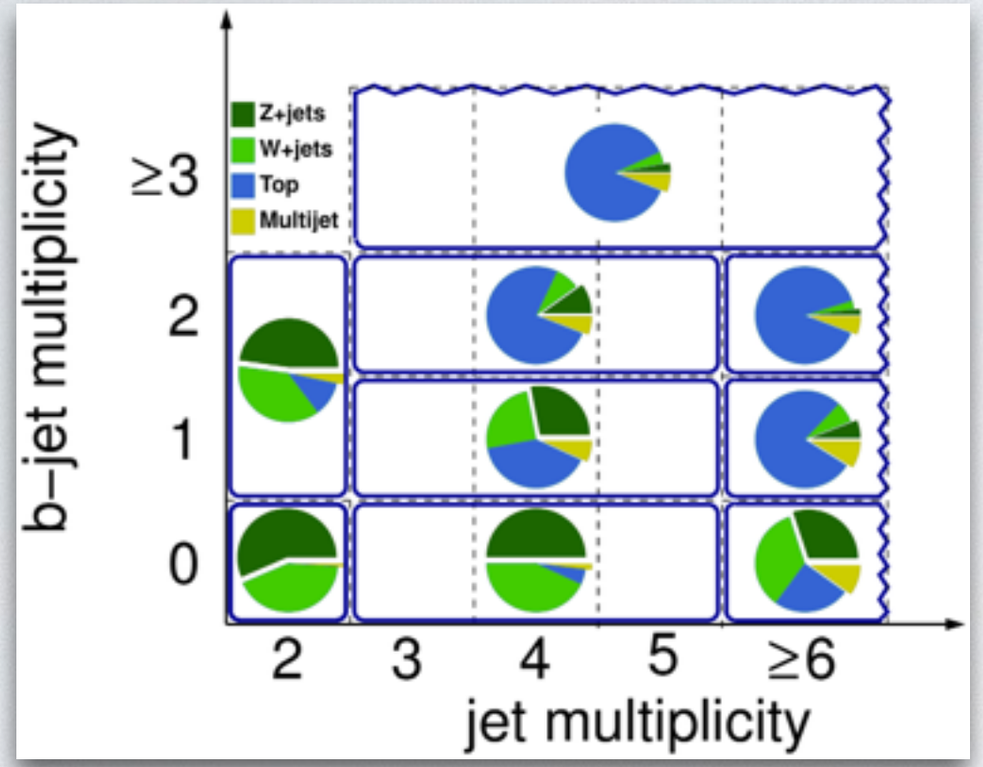
- M_T is well defined for decaying with only one invisible particle (such as $W \rightarrow l\nu$).

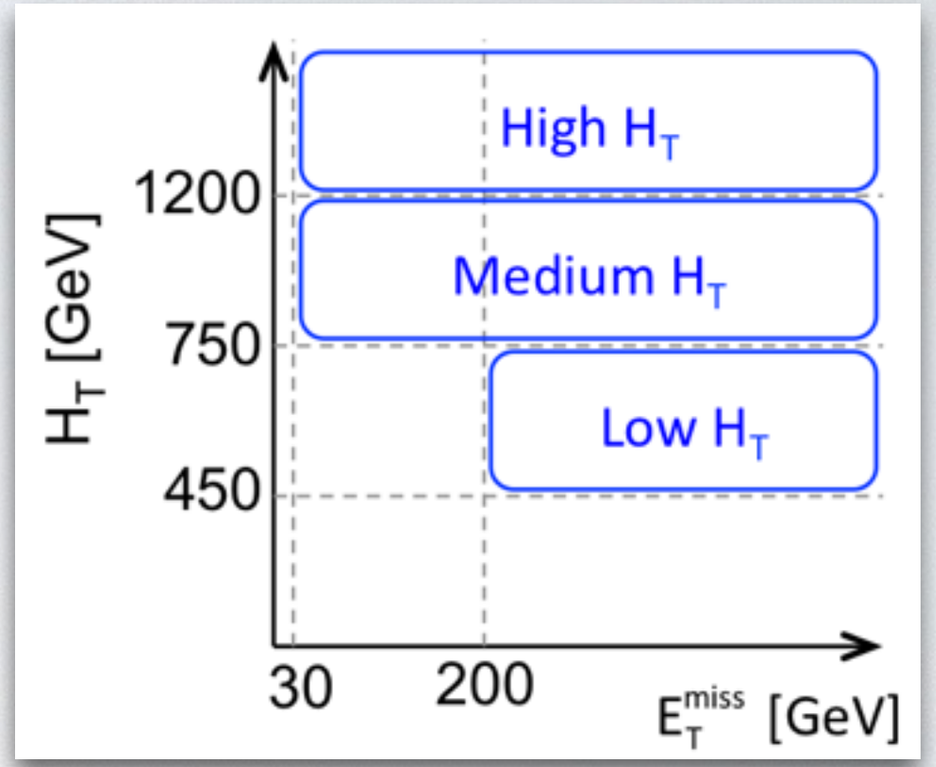
- When to symmetric decay legs, each with an invisible particle, are present M_{T2} better describes these processes.

$$M_{T2} = \min_{\vec{p}_T^{(1)} + \vec{p}_T^{(2)} = \vec{p}_T^{miss}} \left[\max \left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

CMS-SUS-13-019

HADRONIC MT_2





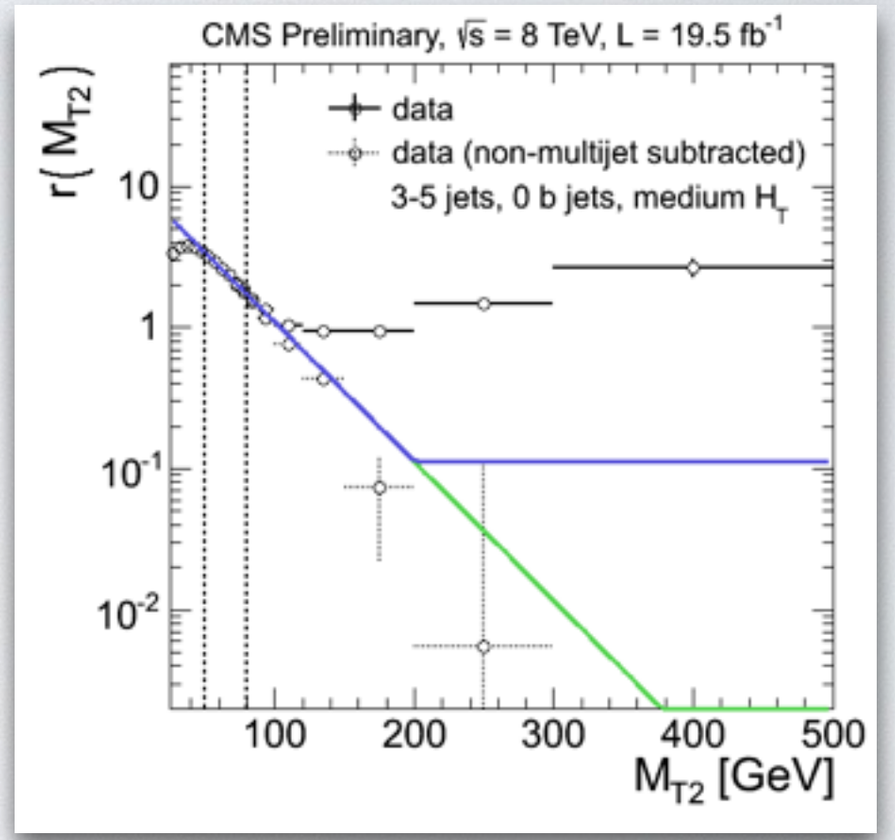
- Different searches regions with different backgrounds
- Similar background composition and estimation techniques as α_T
  - Z to invisible and missing lepton

CMS-SUS-13-019

MULTI-JET BACKGROUND

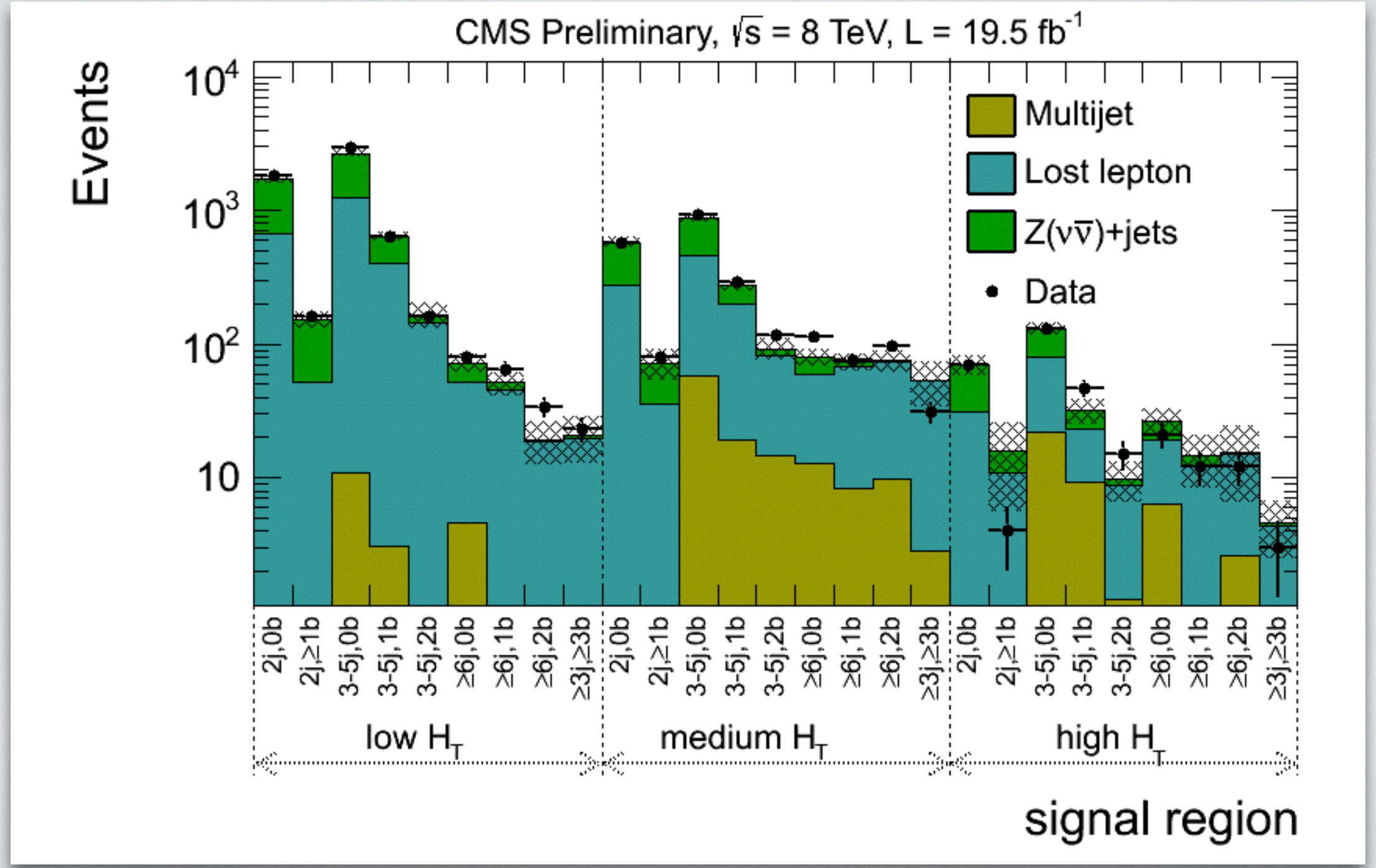
- QCD control region defined by **ΔΦ**<0.2 (angle of the 4 leading jets w.r.t. MET)

- Estrapolation to **ΔΦ**>0.3 via:

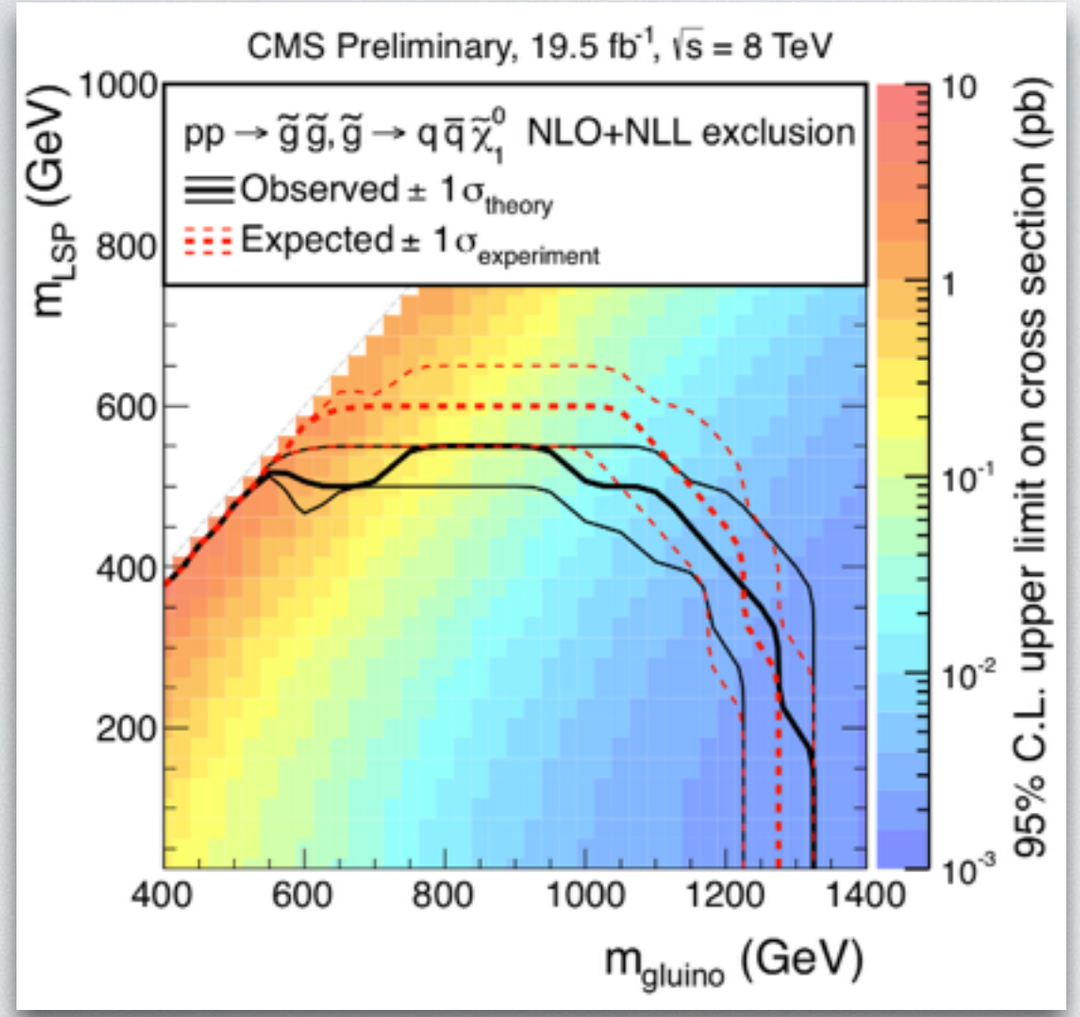


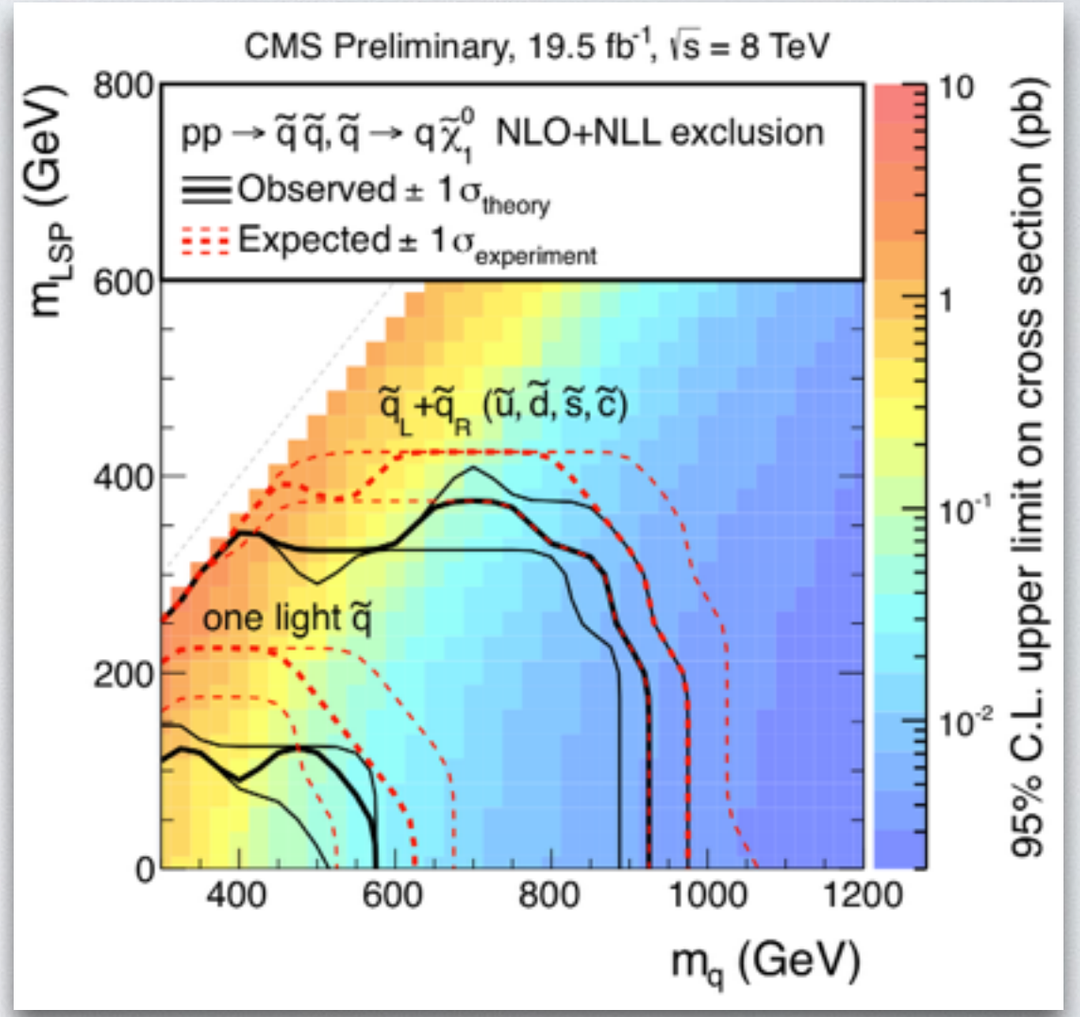
$$r(M_{T2}) = \frac{N(\Delta\phi_{min} \geq 0.3}{N(\Delta\phi_{min} \leq 0.2} = \exp\left(a - b \cdot M_{T1}\right) + c$$

RESULTS


CMS Preliminary, √s = 8 TeV, L = 19.5 fb-1
Events
10^4
10^3
10^2
10
Multijet
Lost lepton
Z(νν̄)+jets
Data
2j,0b
2j,≥1b
3-5j,0b
3-5j,1b
3-5j,2b
≥6j,0b
≥6j,1b
≥6j,2b
≥3j,≥3b
low H_T
medium H_T
high H_T
signal region

EXCLUSION PLOTS





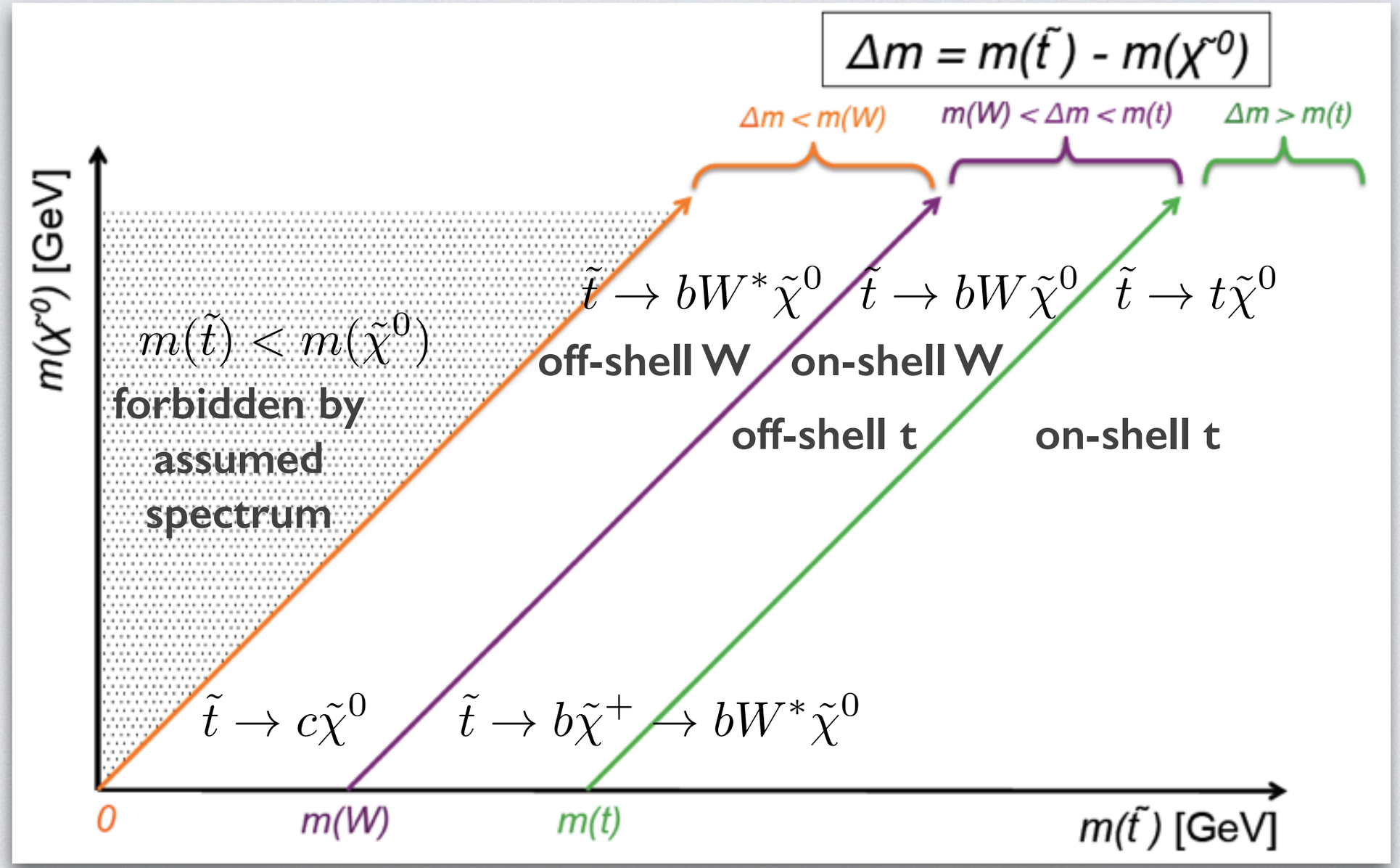
NATURAL SUSY?

- Naturalness is the most important reason to search for SUSY at the LHC

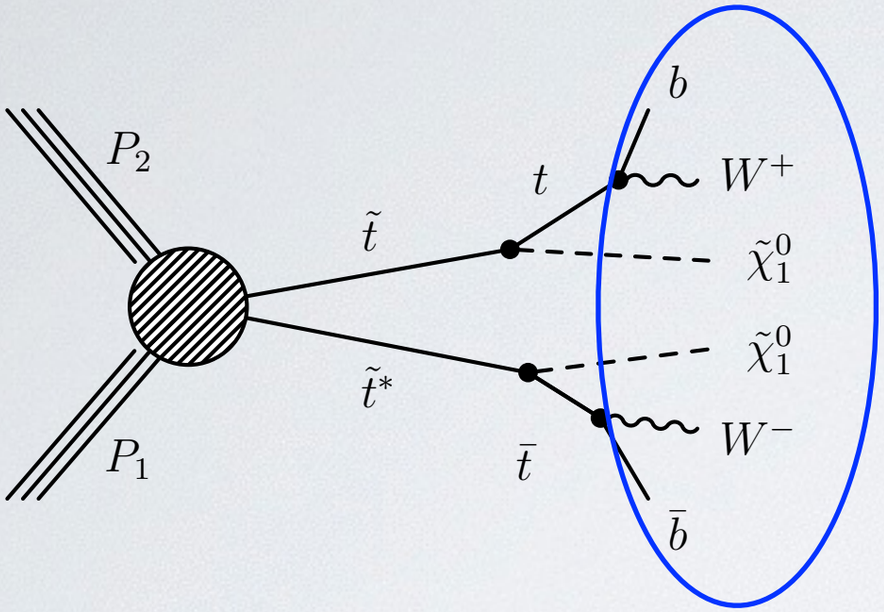
- The discovery of a "light" higgs boson supports the idea of natural SUSY within of LHC reach

- This justify the search for direct production of SUSY particles at LHC8 and even more in the next higher energy run

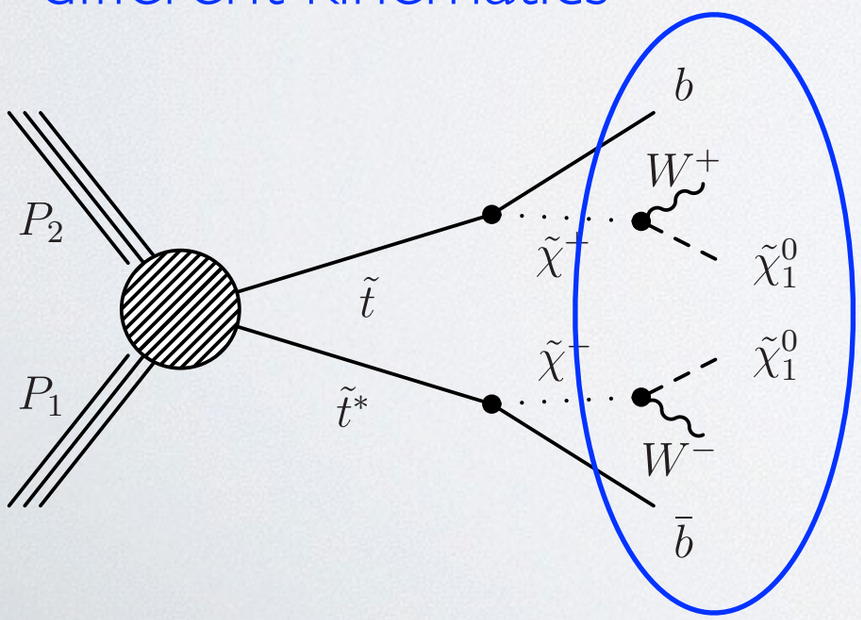
DIRECT STOP PRODUCTION

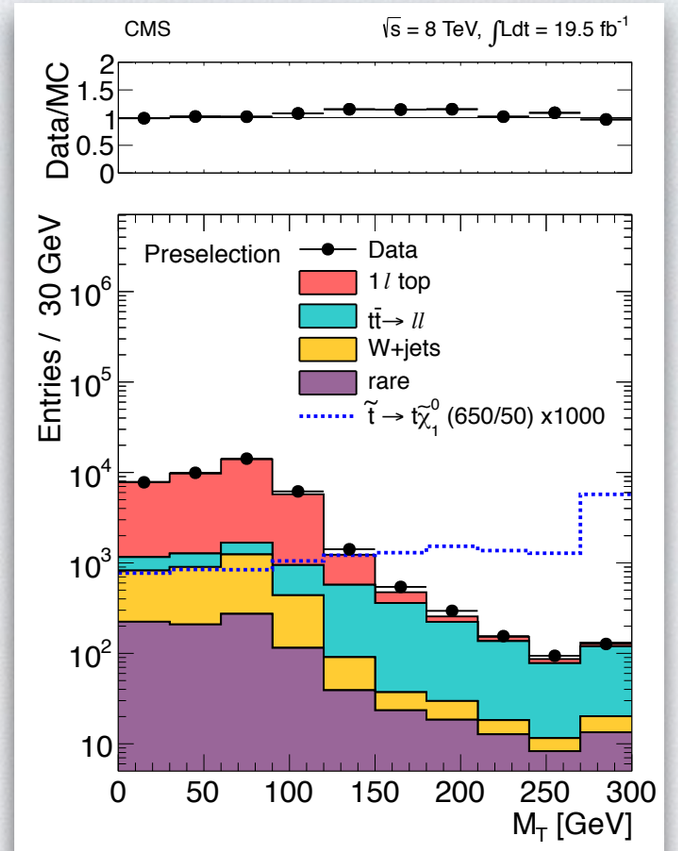


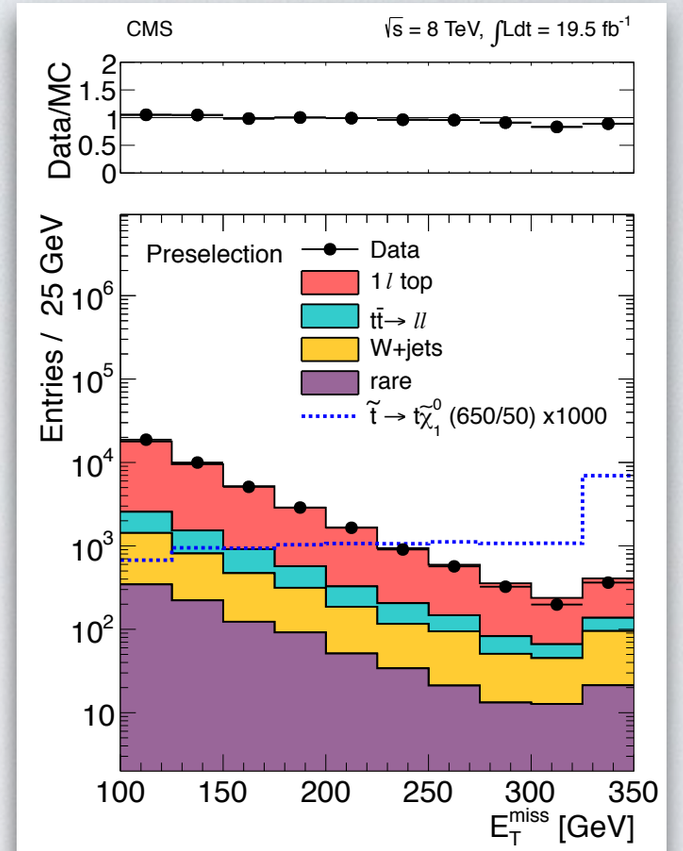
DIRECT STOP PRODUCTION



Similar but different:
same final state particles but different kinematics





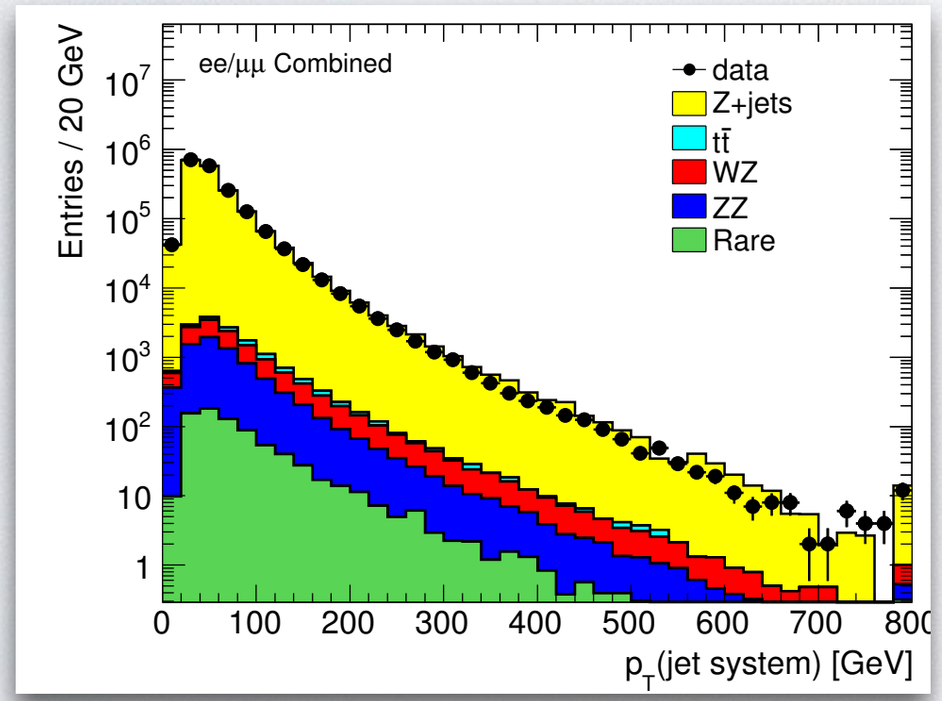


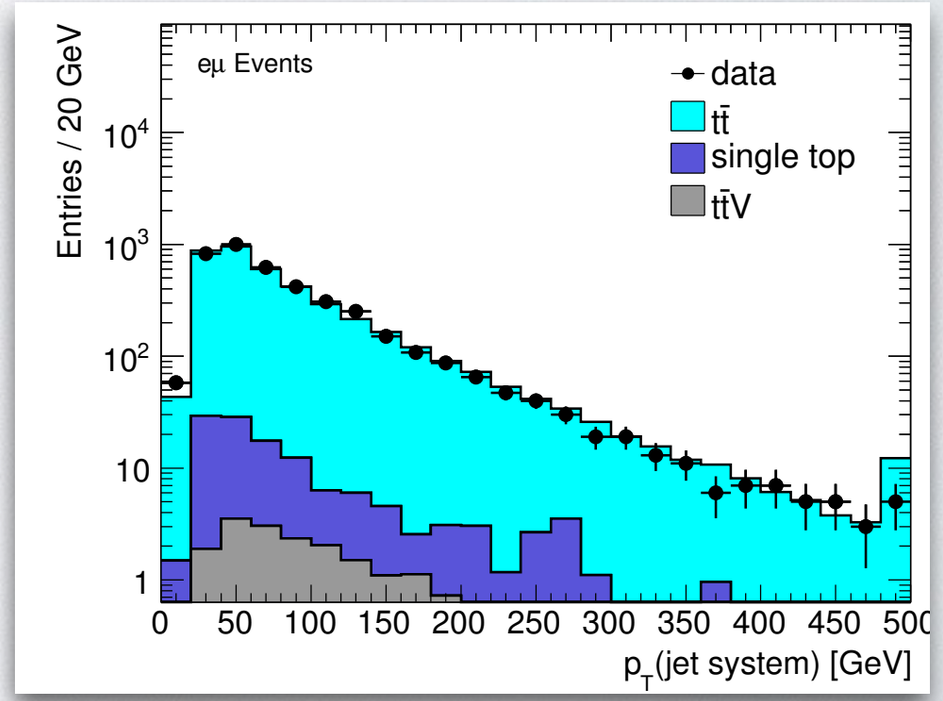
- BDT's are used to discriminate different modes and select signal
- Important to understand well all the variables

CMS-SUS-13-011

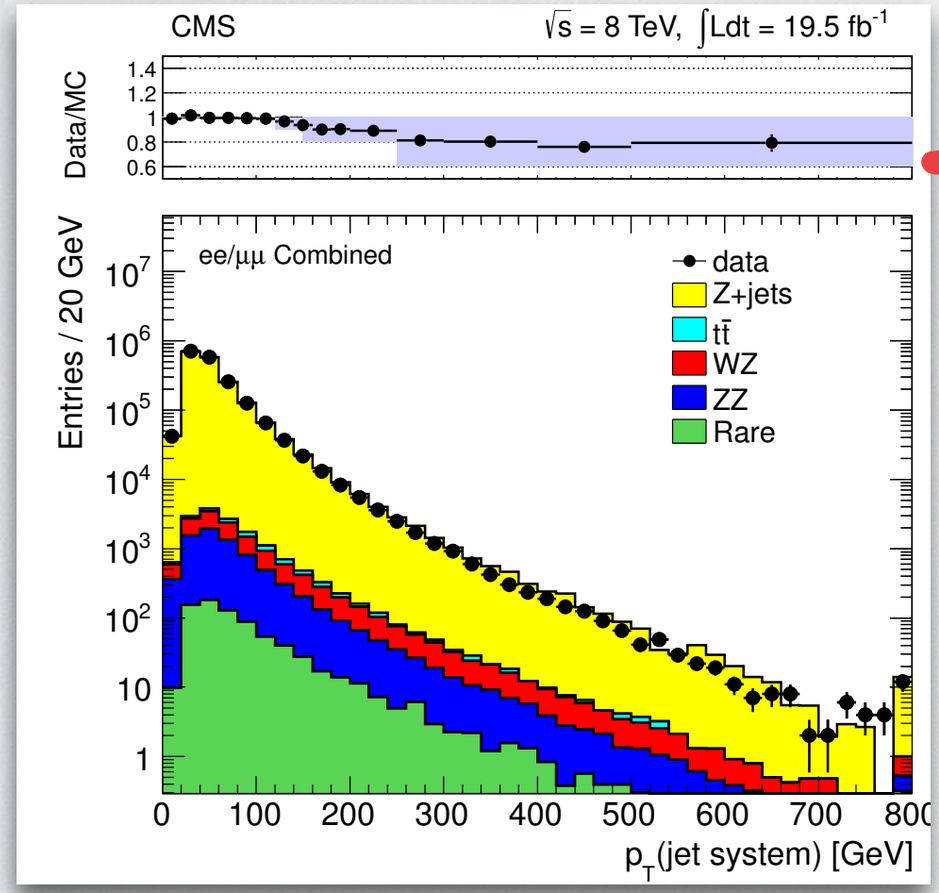
INITIAL STATE RADIATION

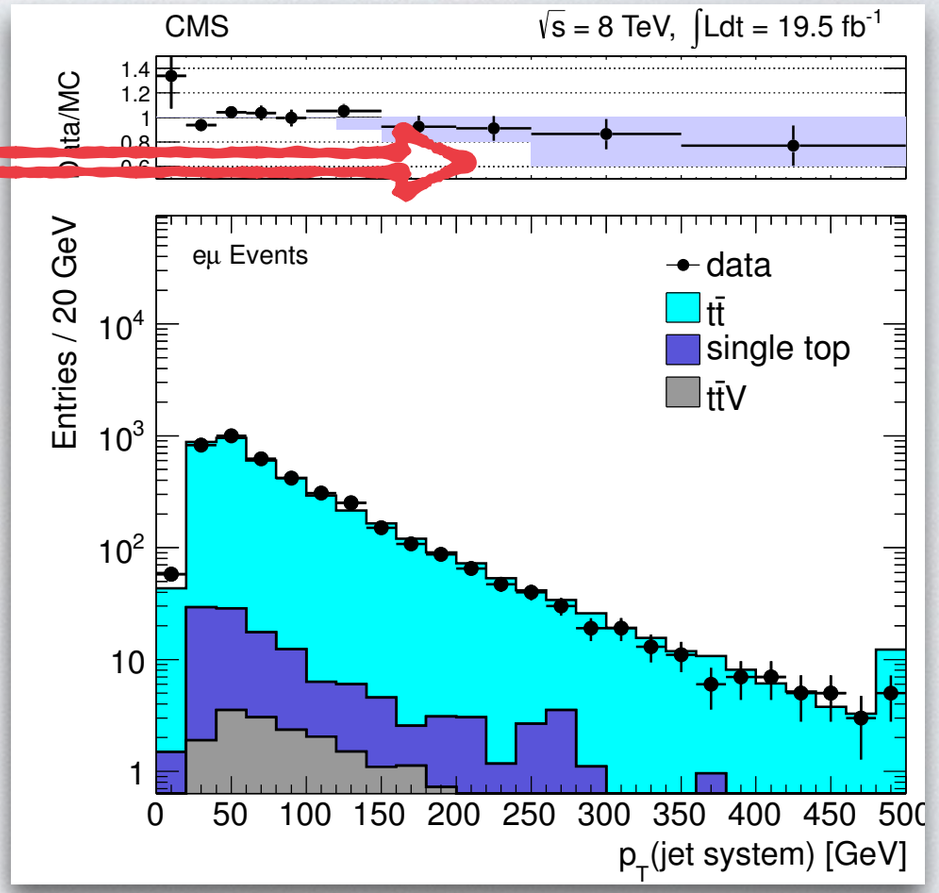
- ISR is important and often a crucial discriminating variable
- Test if MadGraph MC predicts it well in ttbar and Z+jets events





INITIAL STATE RADIATION





At high p_T the MC is found to over predict by 20%

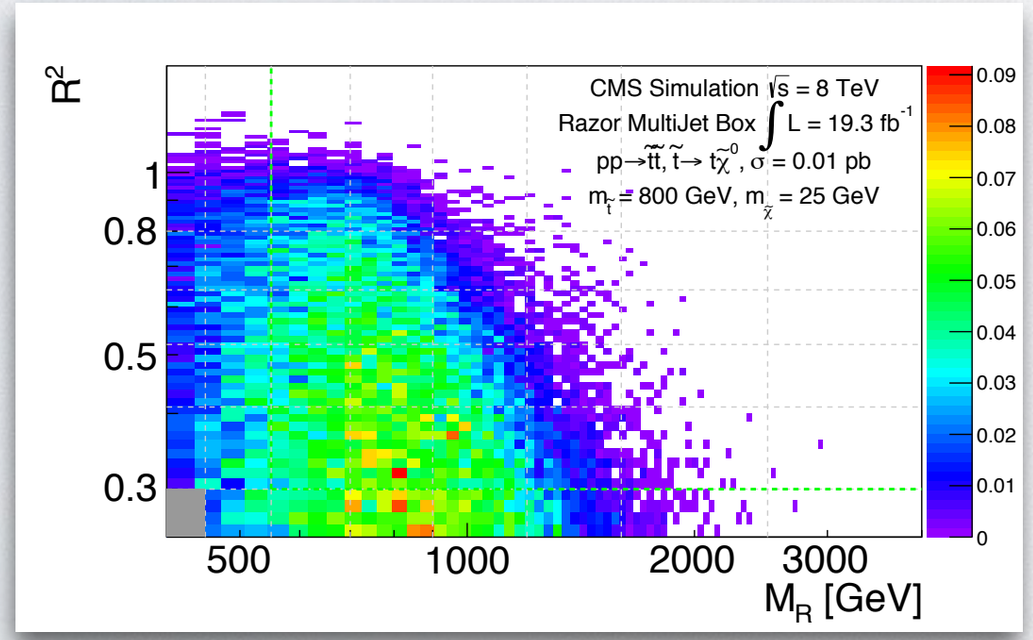
RAZOR SEARCHES

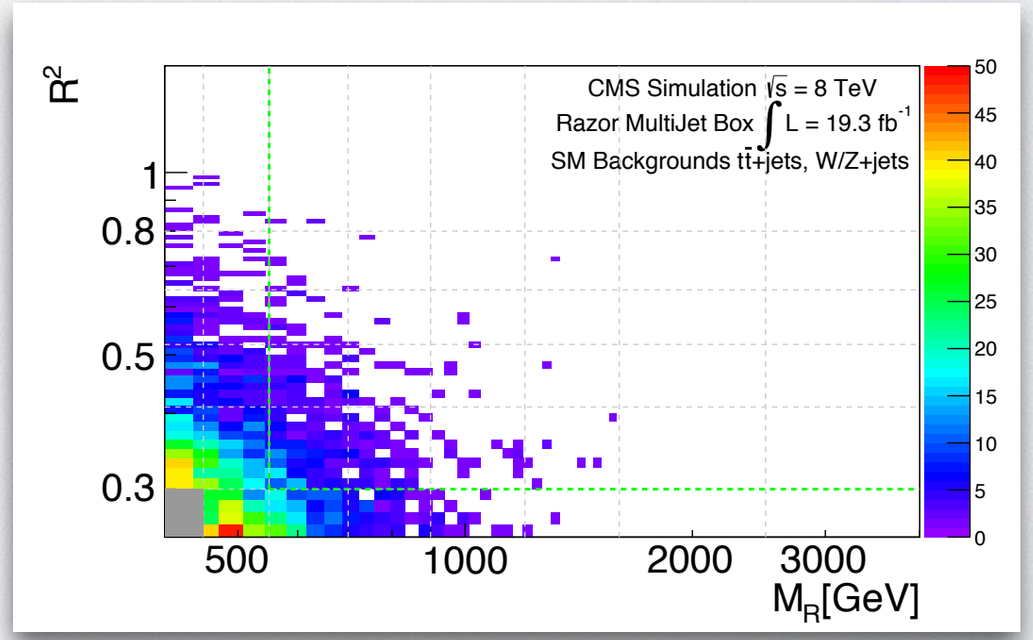
- Cluster all the particles into two "megajets"
- Starting form at lest two jets above 80 GeV (all jets above 40 GeV used to compute the razor variables)
- 1 b-tagged jet at least

$$M_R \equiv \sqrt{(p_{j1} + p_{j2})^2 - (p_z^{j1} + p_z^{j2})^2}$$

$$M_T^R \equiv \sqrt{\not{E}_T(p_T^{j1} + p_T^{j2}) - \vec{\not{E}}_T \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}$$

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

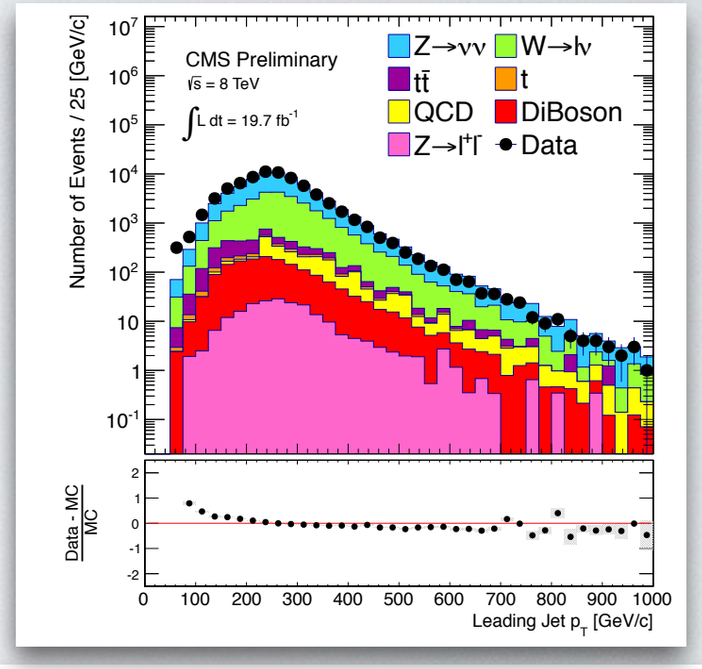


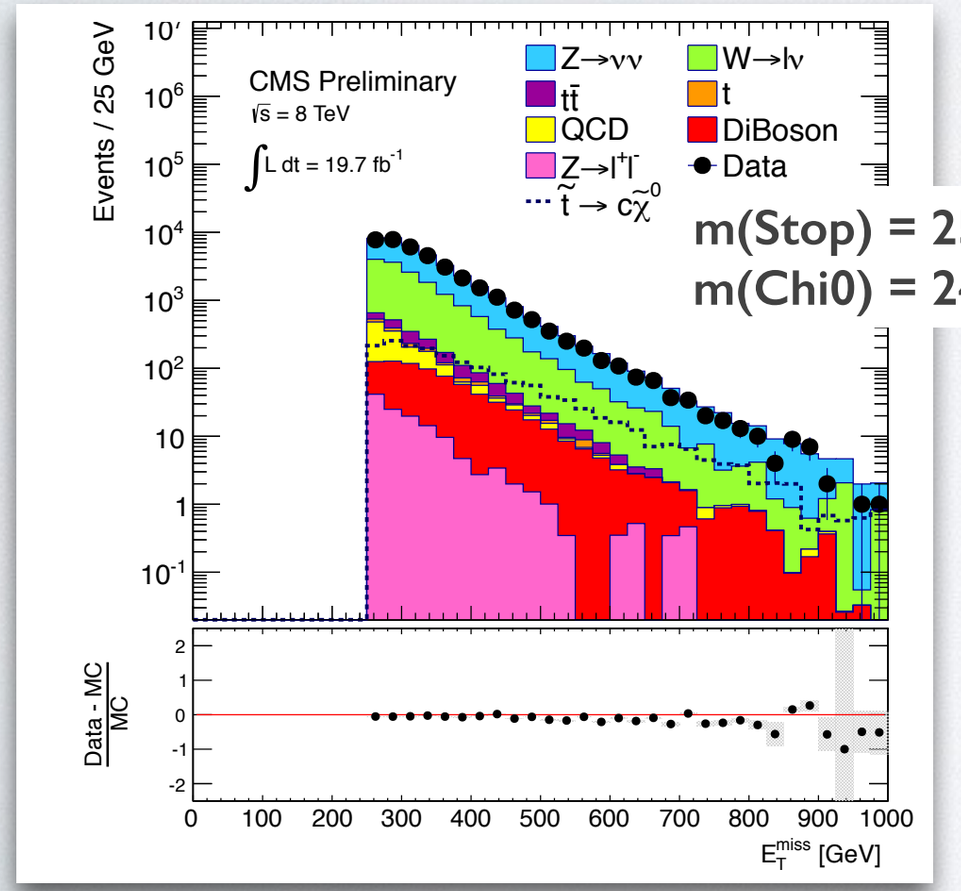


CMS-SUS-13-004

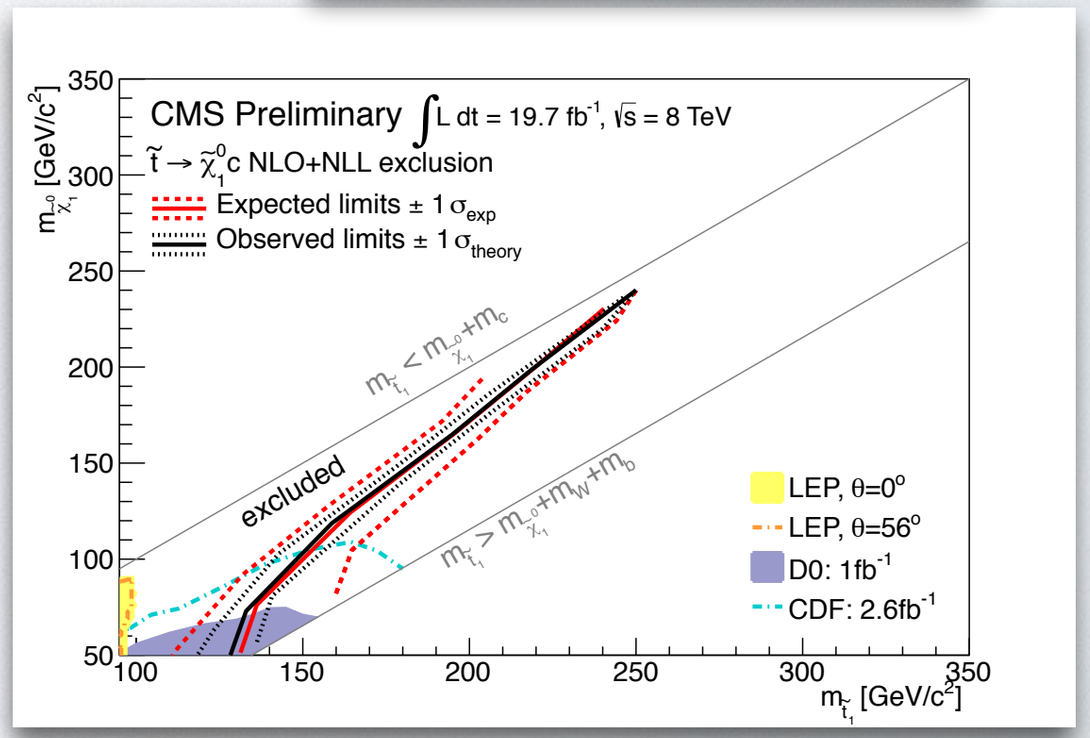
"LIGHT" STOP

- Large MET (>250 GeV) and separated from jet
- 1 energetic jet above 110 GeV (search performed in 7 inclusive bins: 250, 300, 350, 400, 450, 500, and 550 GeV + 1 jet above 60 GeV)
- Lepton veto

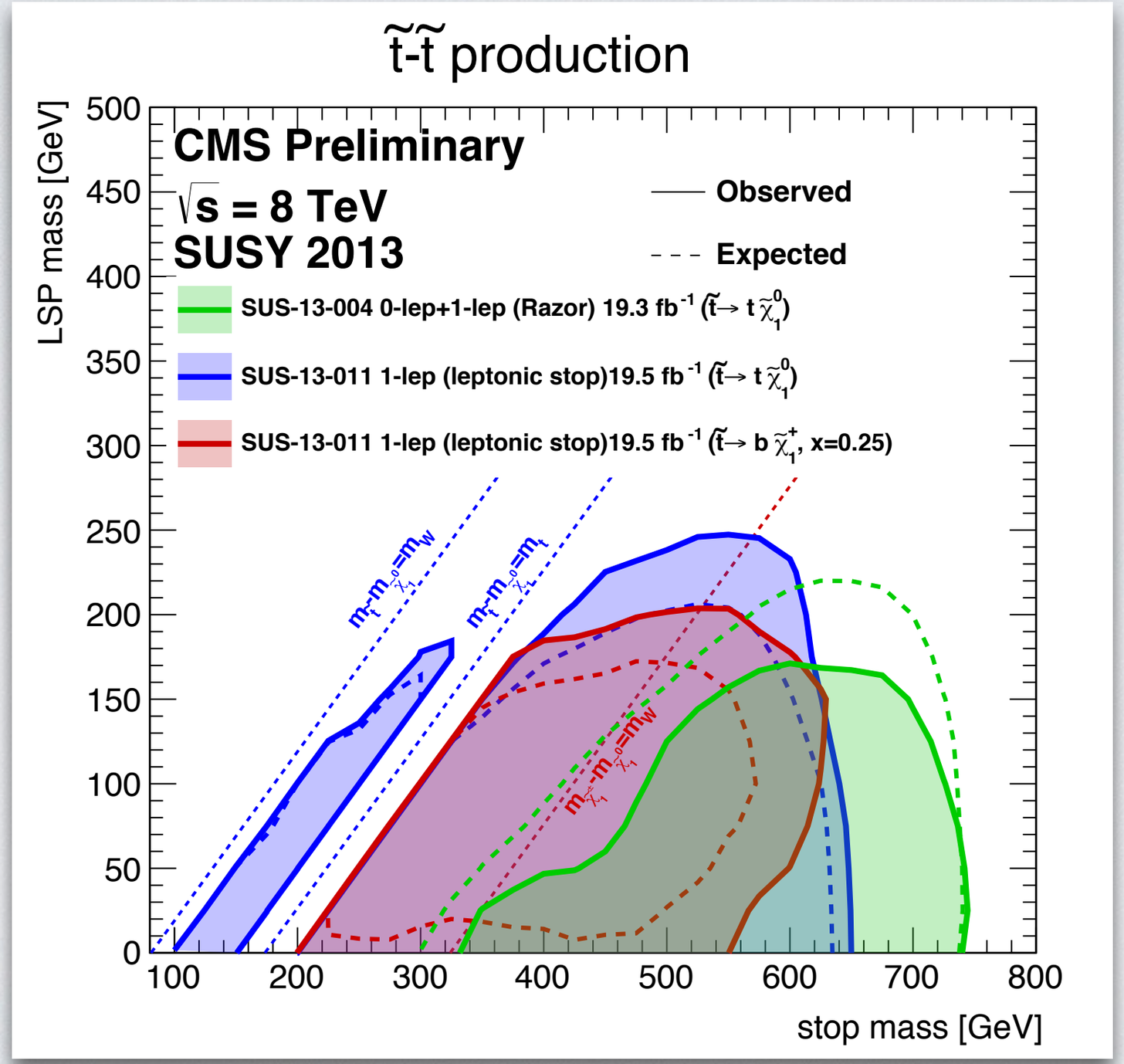




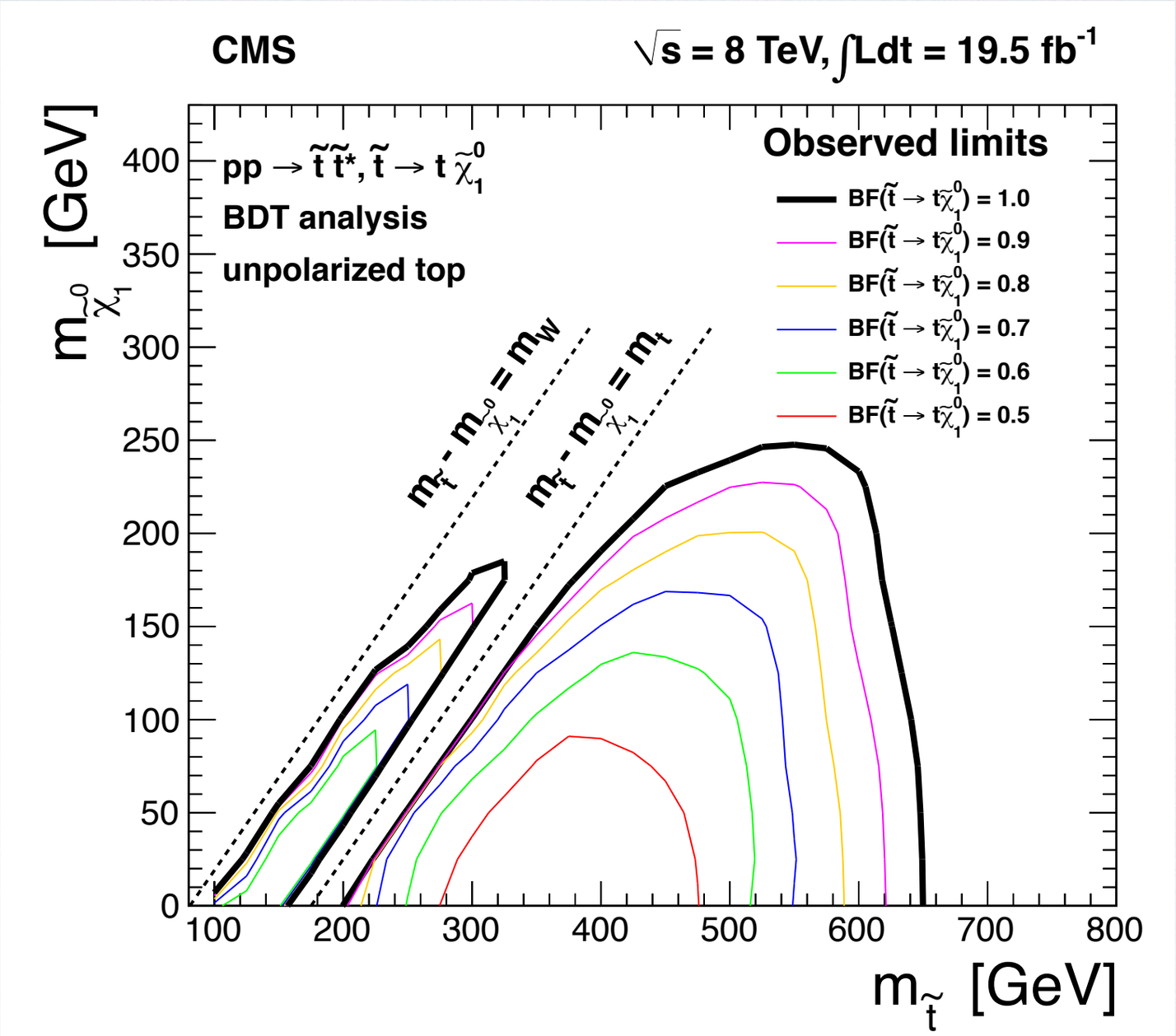
m(Stop) = 250 GeV
m(Chi0) = 240 GeV



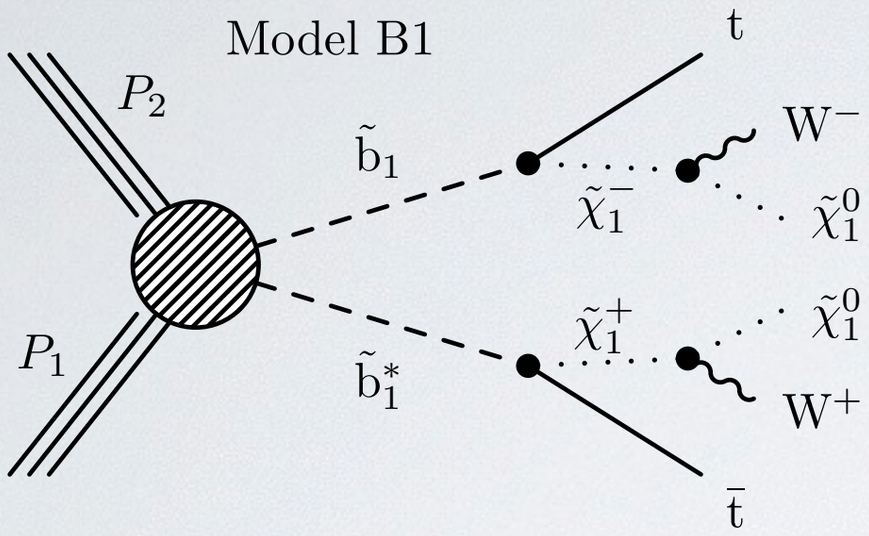
STOP SUMMARY PLOT



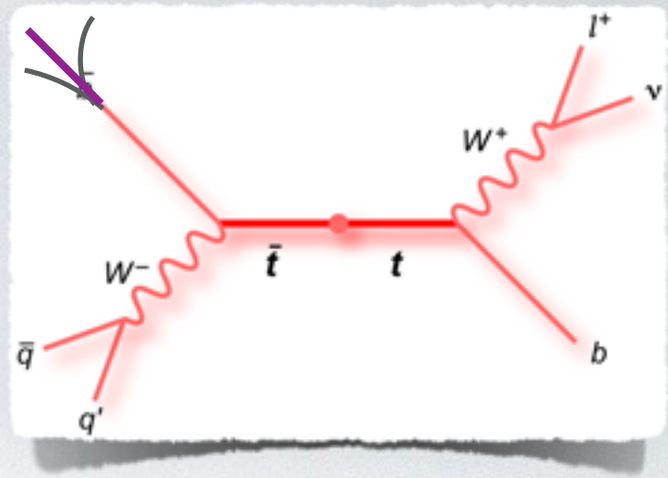
DEPENDANCY ON BF



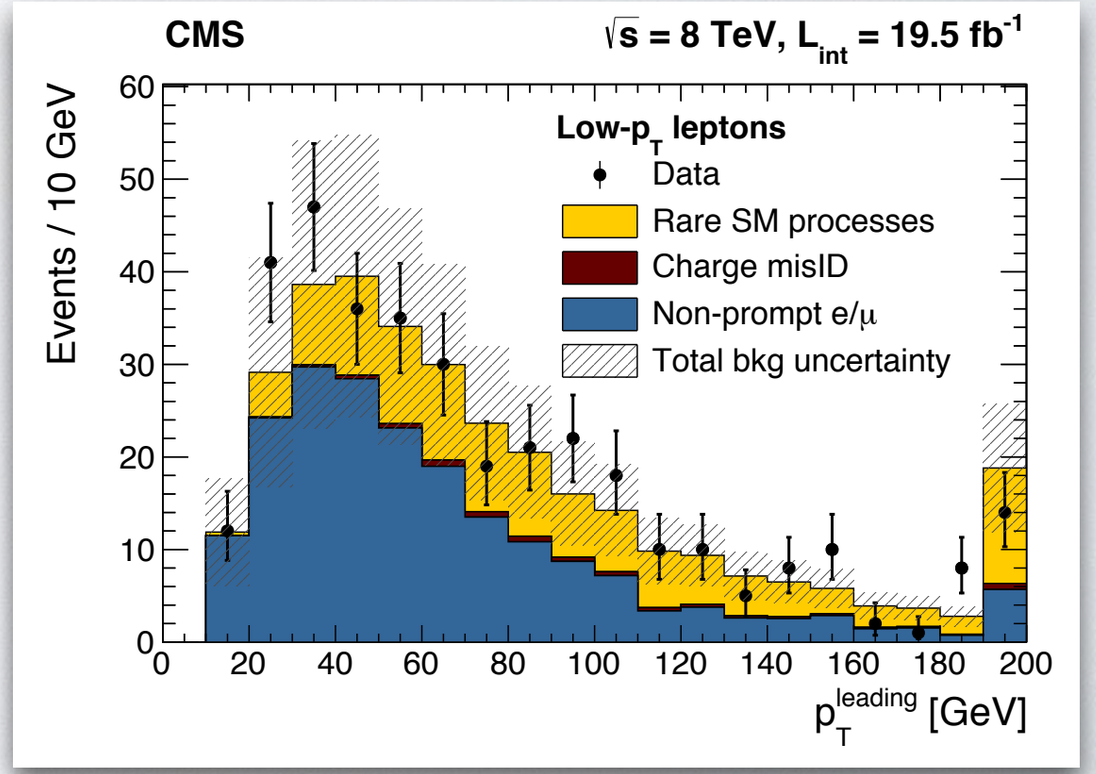
SBOTTOM



fake leptons



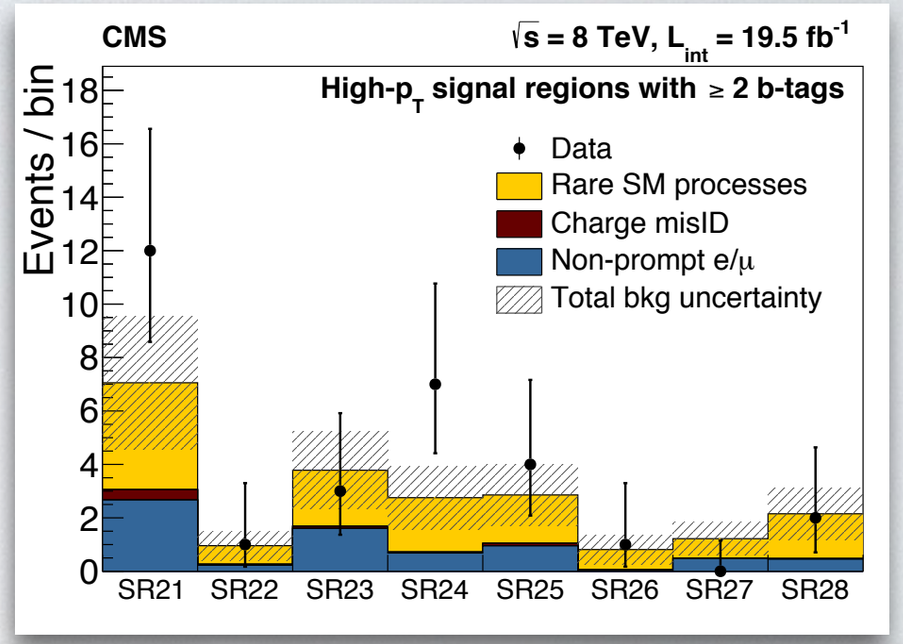
- 56 signal bins!
- b-jets = 0,1,2; n-jets = 2-3, ≥4; MET = 50-120, ≥120; H_T = 200-400, ≥400;
- low-pt leptons starting at 10 GeV (higher HT cut) high-pt leptons at 20 GeV (lower MET cut)

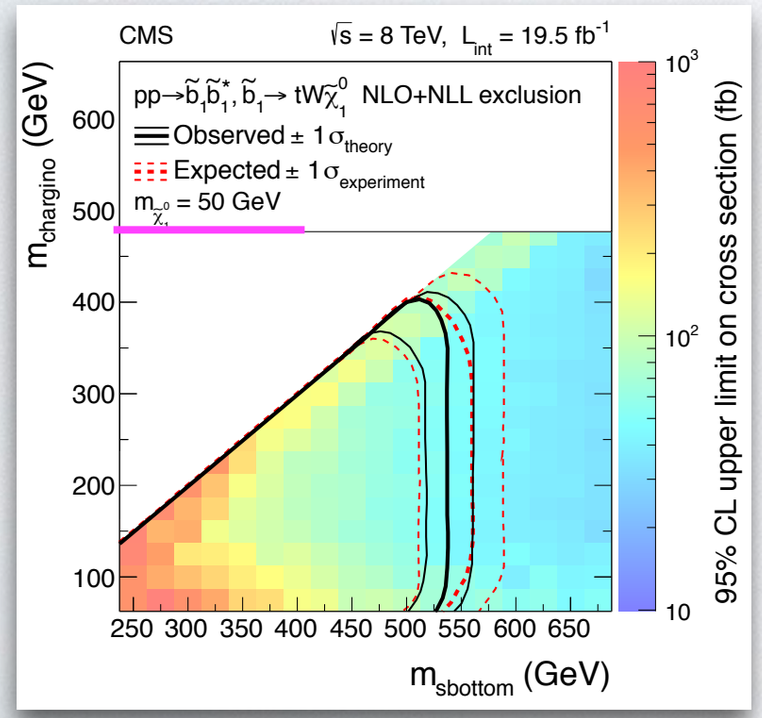


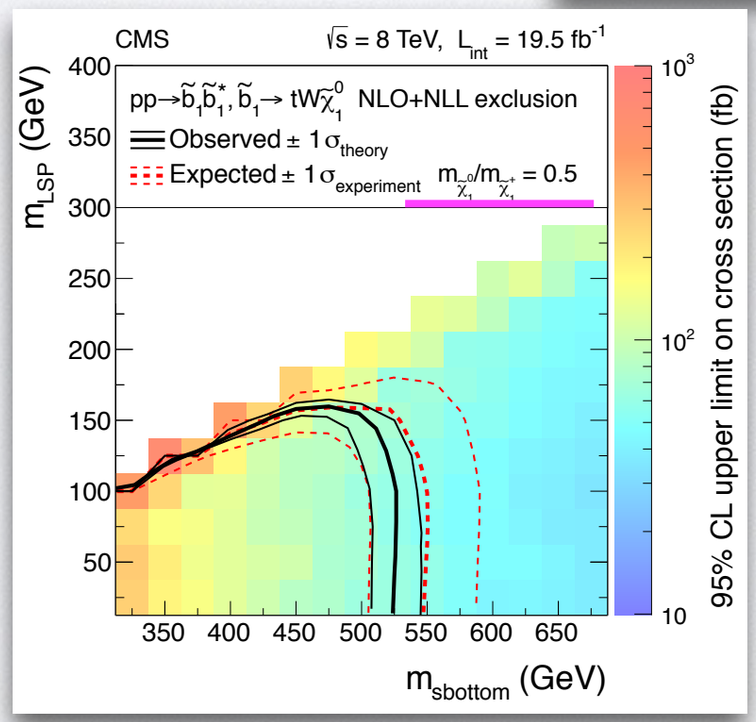
CMS-SUS-13-013

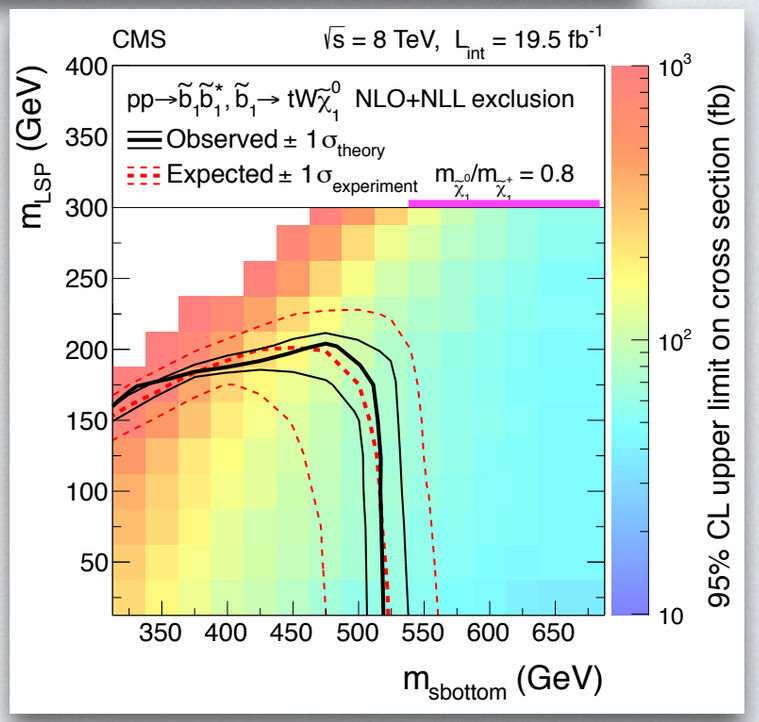
EXCLUSION PLOTS

- Most effective signal region is selected for each benchmark model
- For the sbottom direct production SR28 is used (highest MET, H_T, n-jet and b-tag)



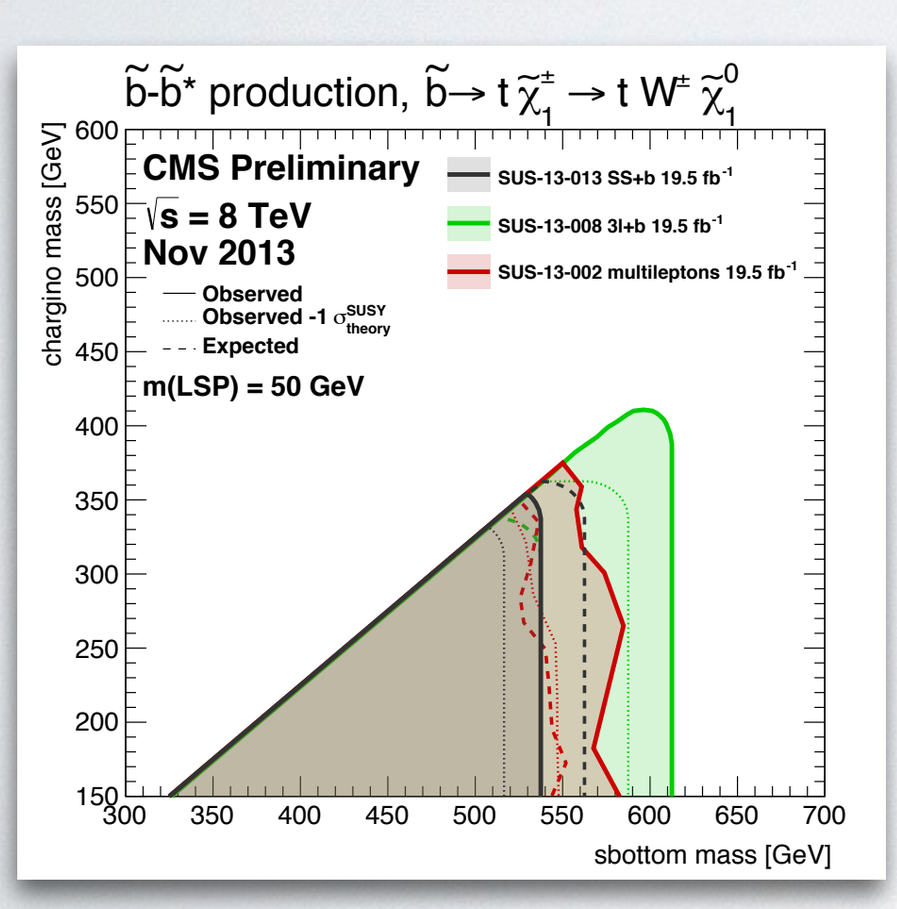


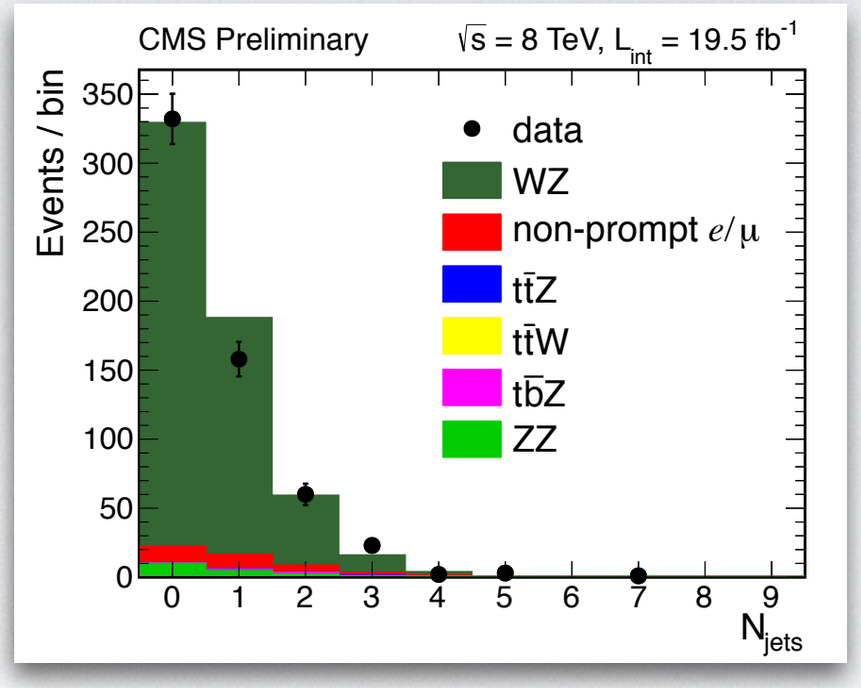




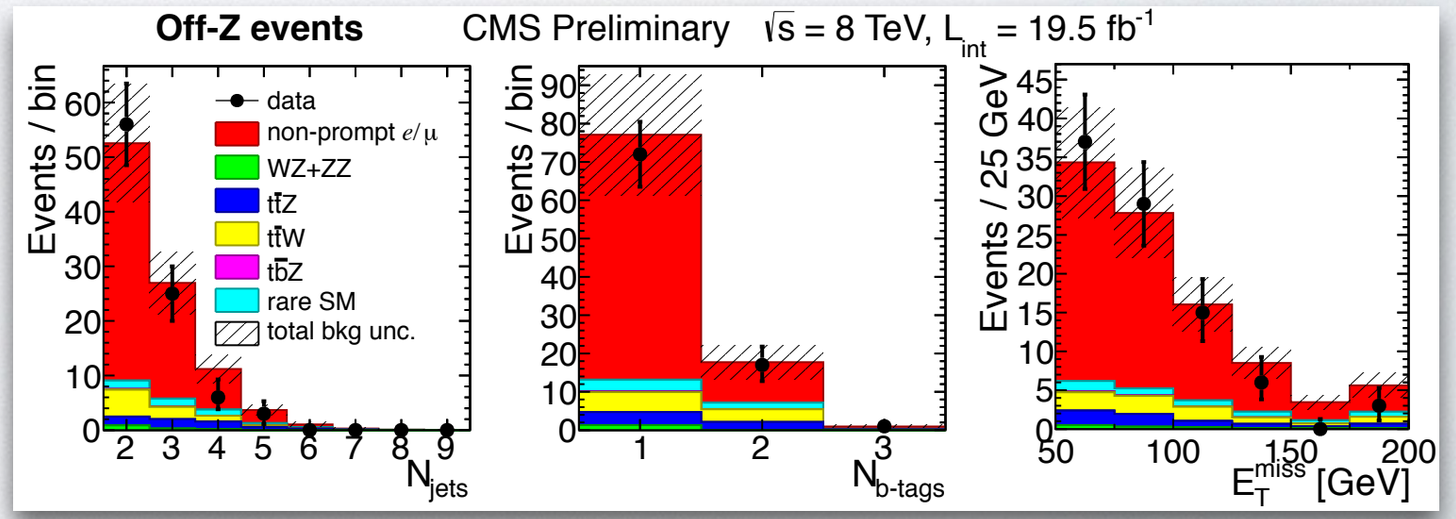
TRI-LEPTON SEARCH

Low background and clean signal fro many SUSY models



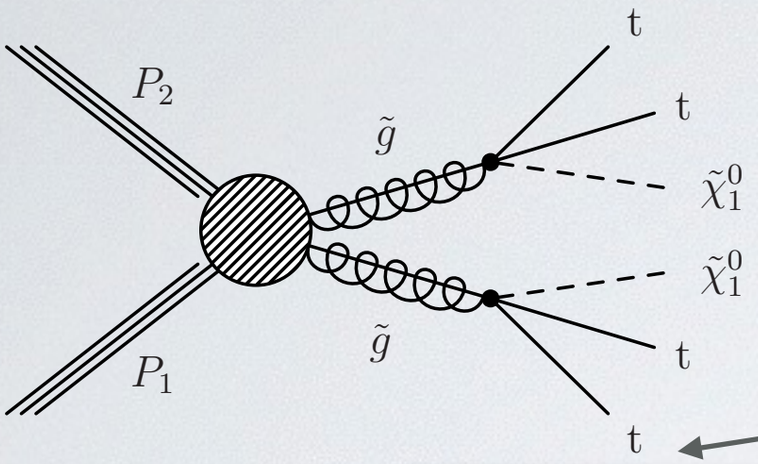


Important to well model rare SM processes



CMS-SUS-13-008

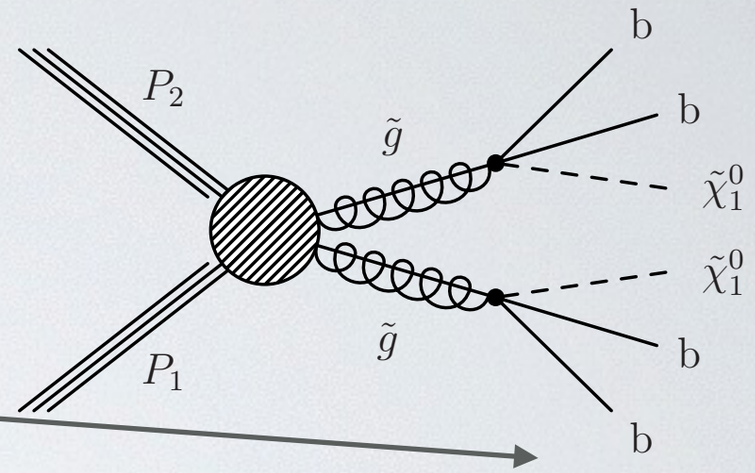
GLUINO



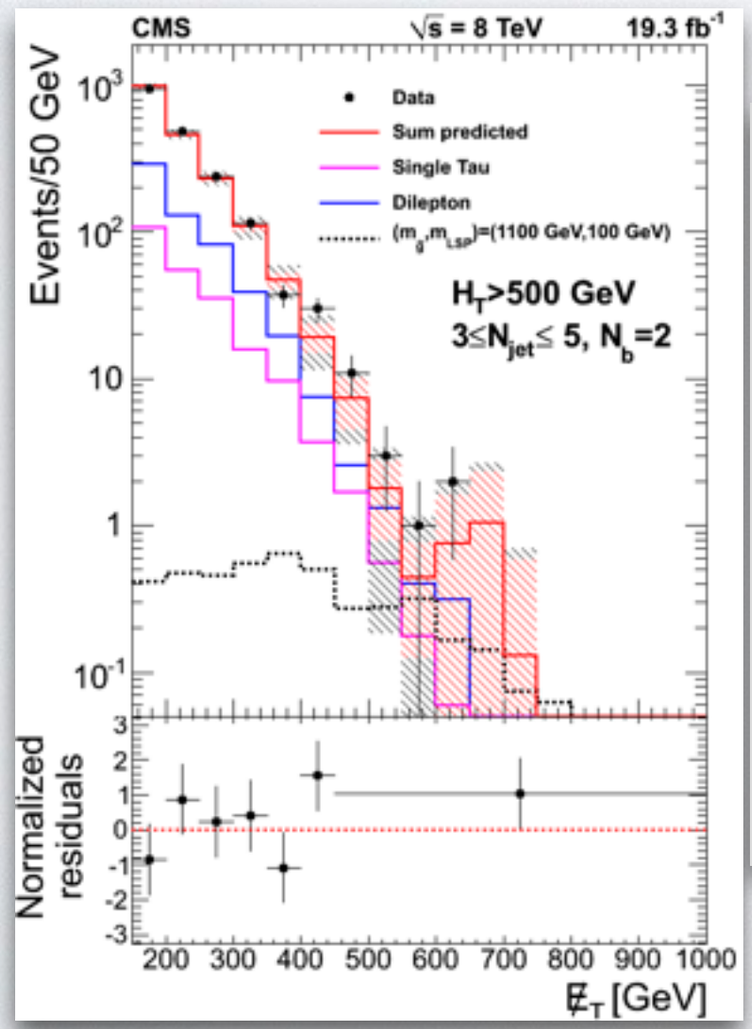
A lot of jets (b-jets)

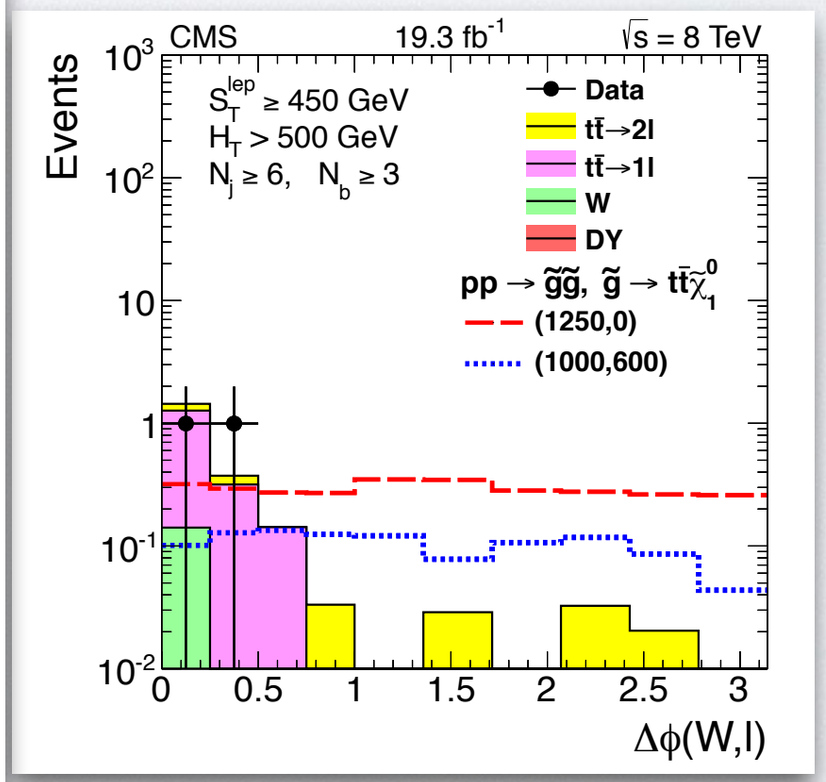
Large MET

Leptons or not



Lepton Spectrum method and MT template.



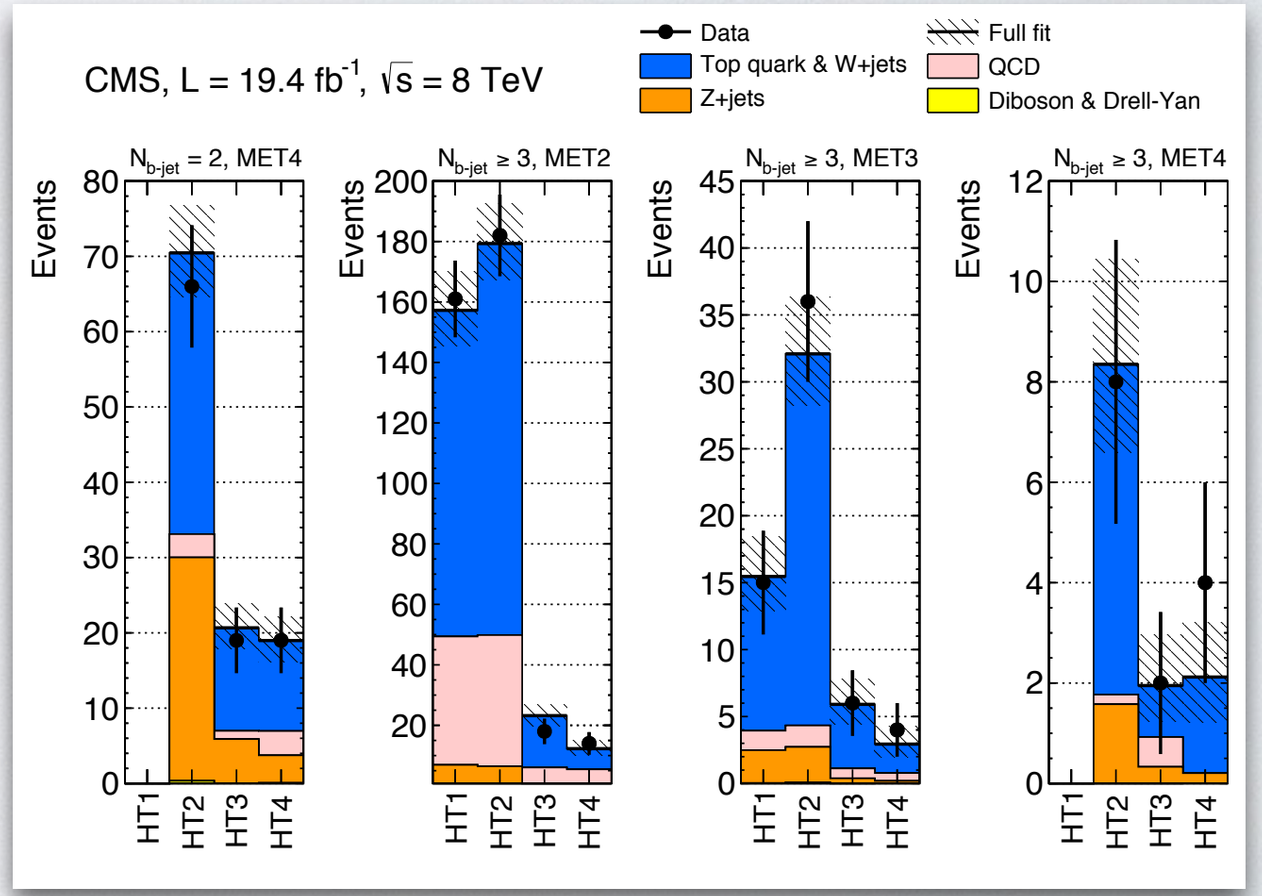


$\Delta\Phi$ small for W leptonic decay.
Not the case if there are extra SUSY particles.

CMS-SUS-13-007

GLUINO IN MULTI-JETS

- looking at high b-jet multiplicity
- 3 central jets above 50 GeV (two most energetic above 70 GeV)
- H_T > 400 GeV
- MET > 125 GeV
- MET and leading jets must be separated
- veto on charged tracks and identified leptons
- at lest 1 b-jet



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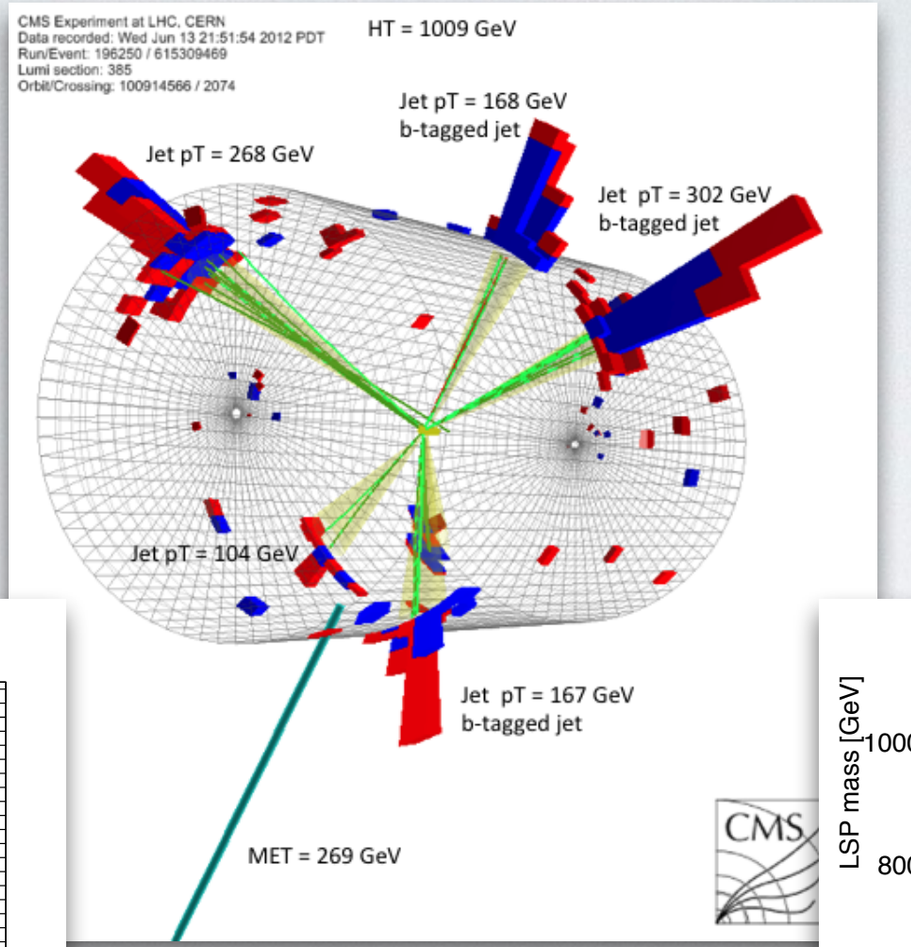
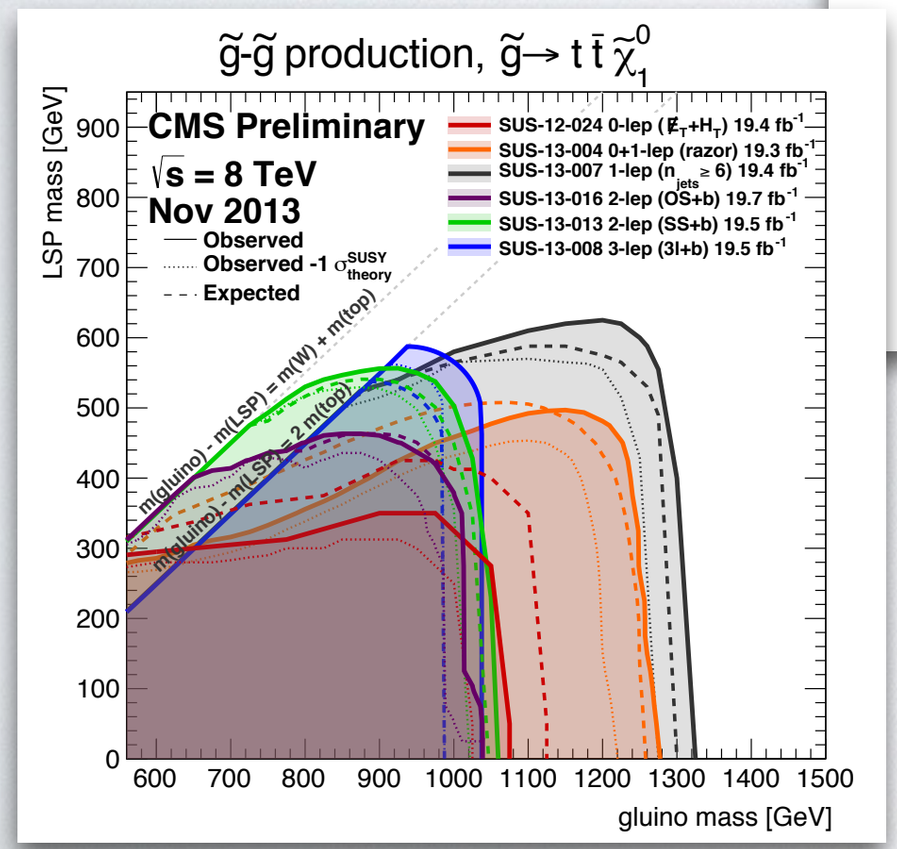
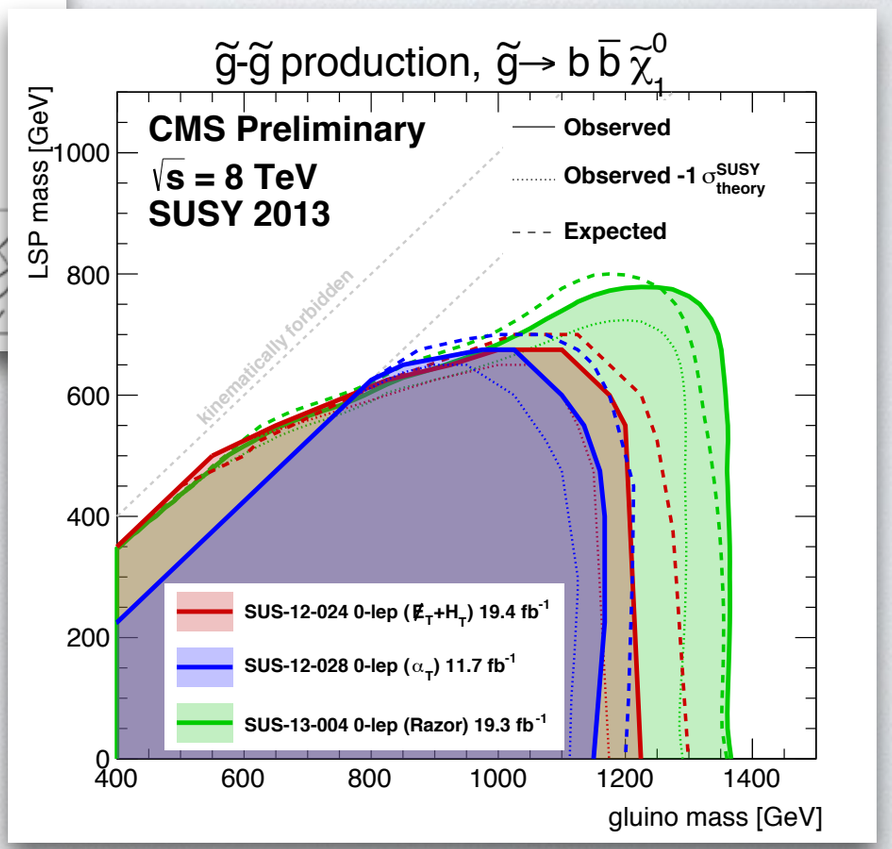
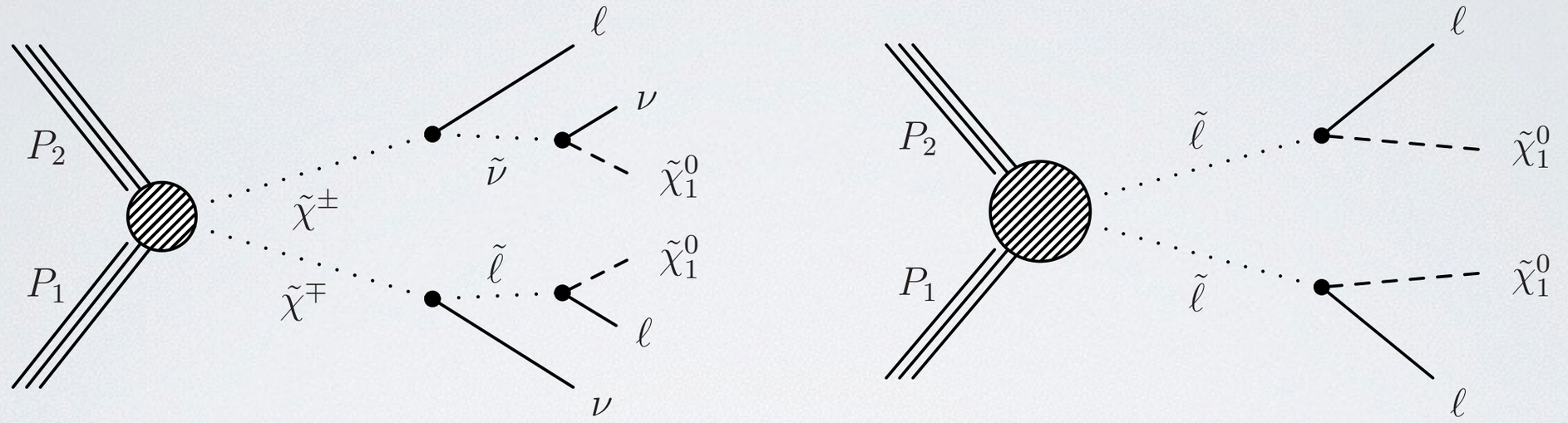
GLUINO EXCLUSIONS







ELECTROWEAK PRODUCTION



- Similar to previous multi-lepton searches
- Optimized for non-resonant signal

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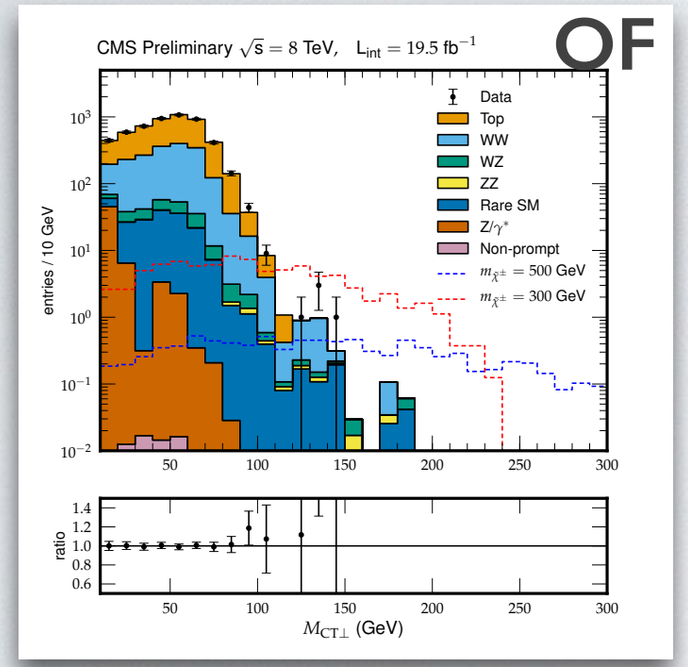
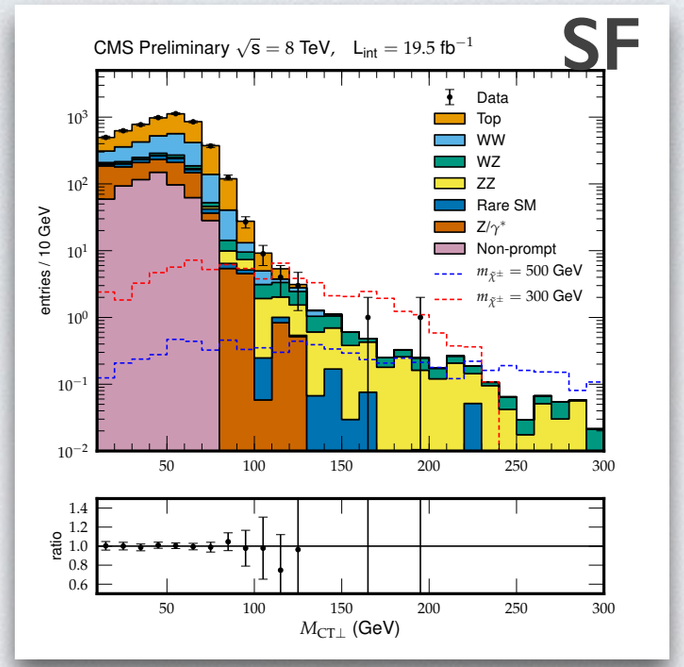
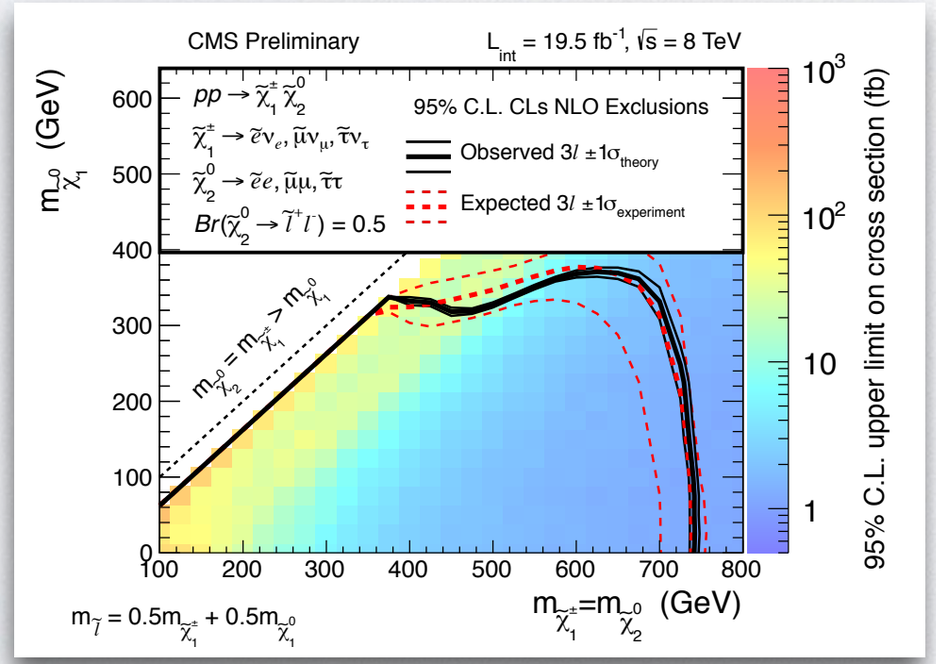
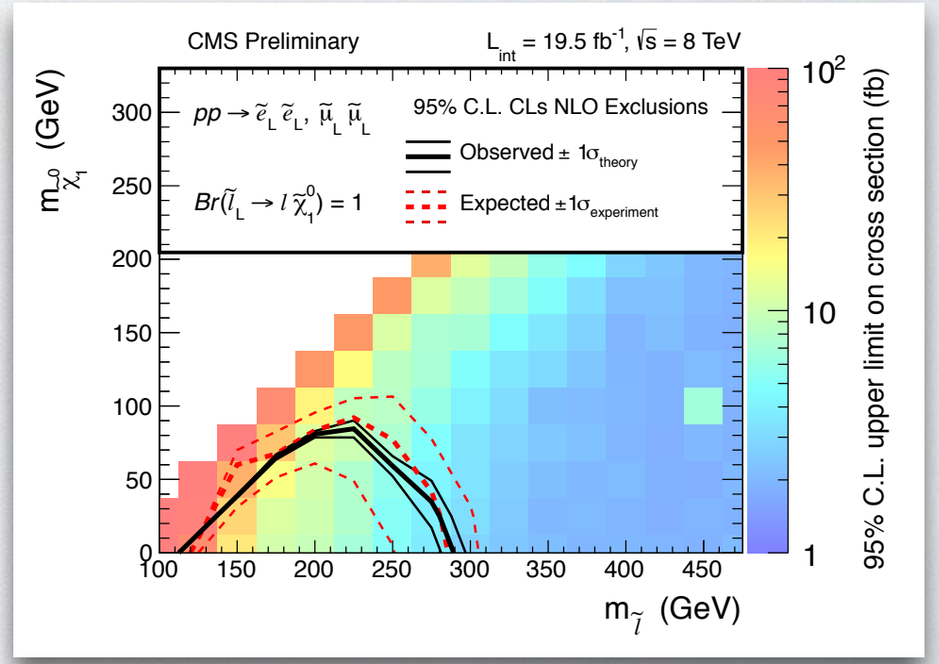
CHARGINO AND SLEPTON





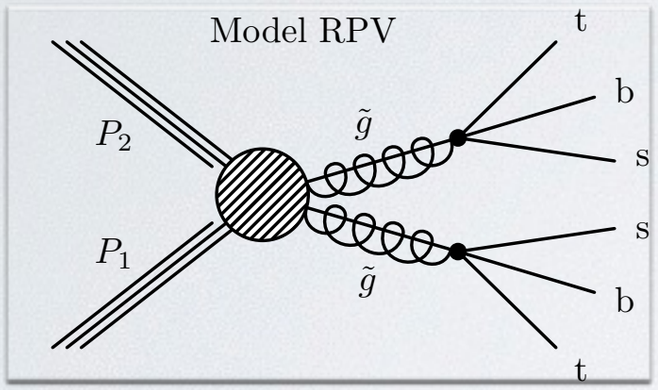
$M_{CT\perp}$ used to disentangle SM backgrounds which show an endpoint at the W mass

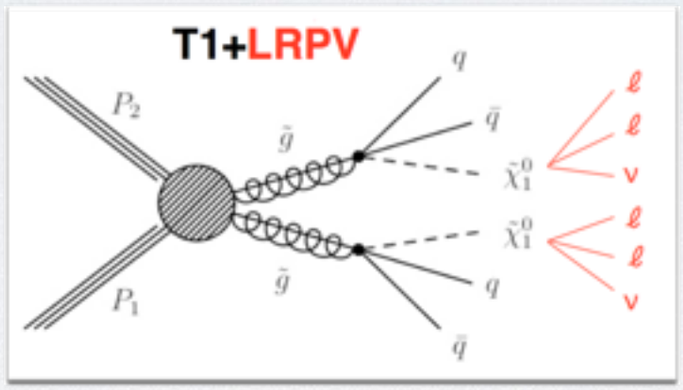


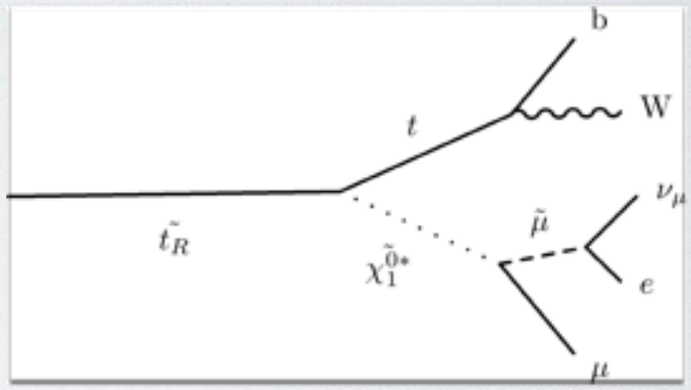


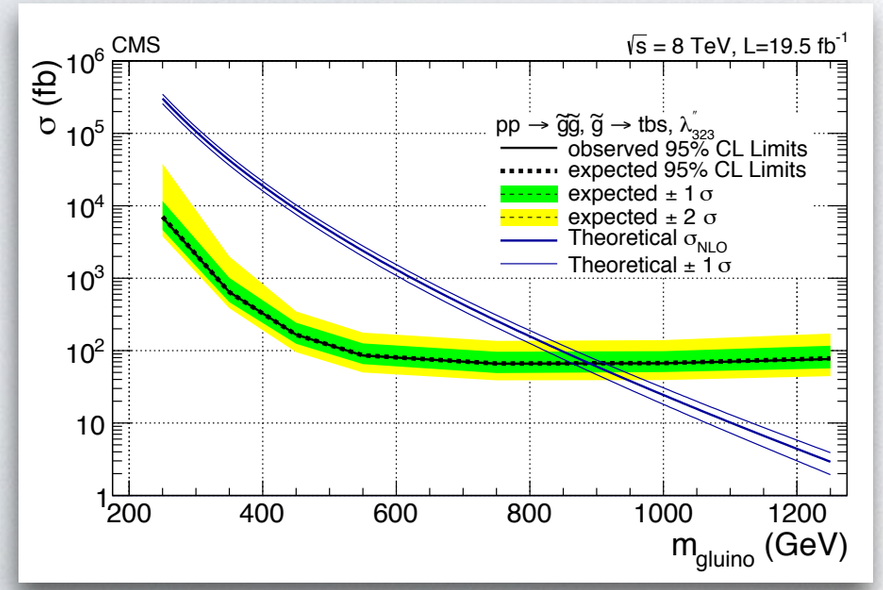
R PARITY VIOLATING

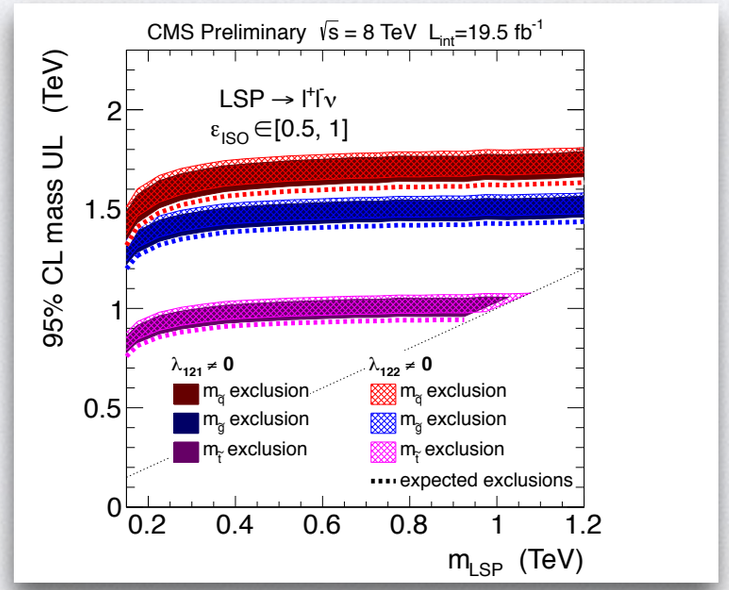
SUSY could also not conserve R-parity producing an interesting phenomenology

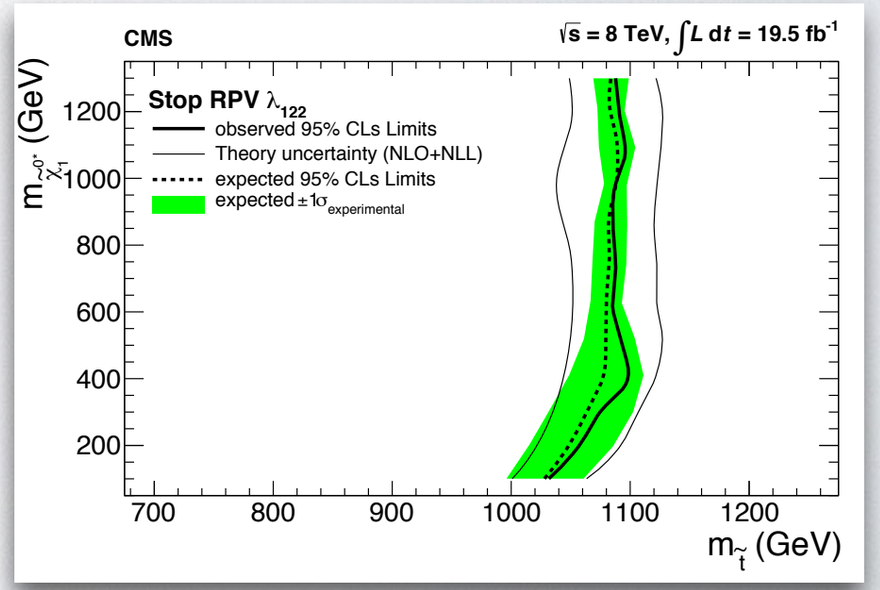




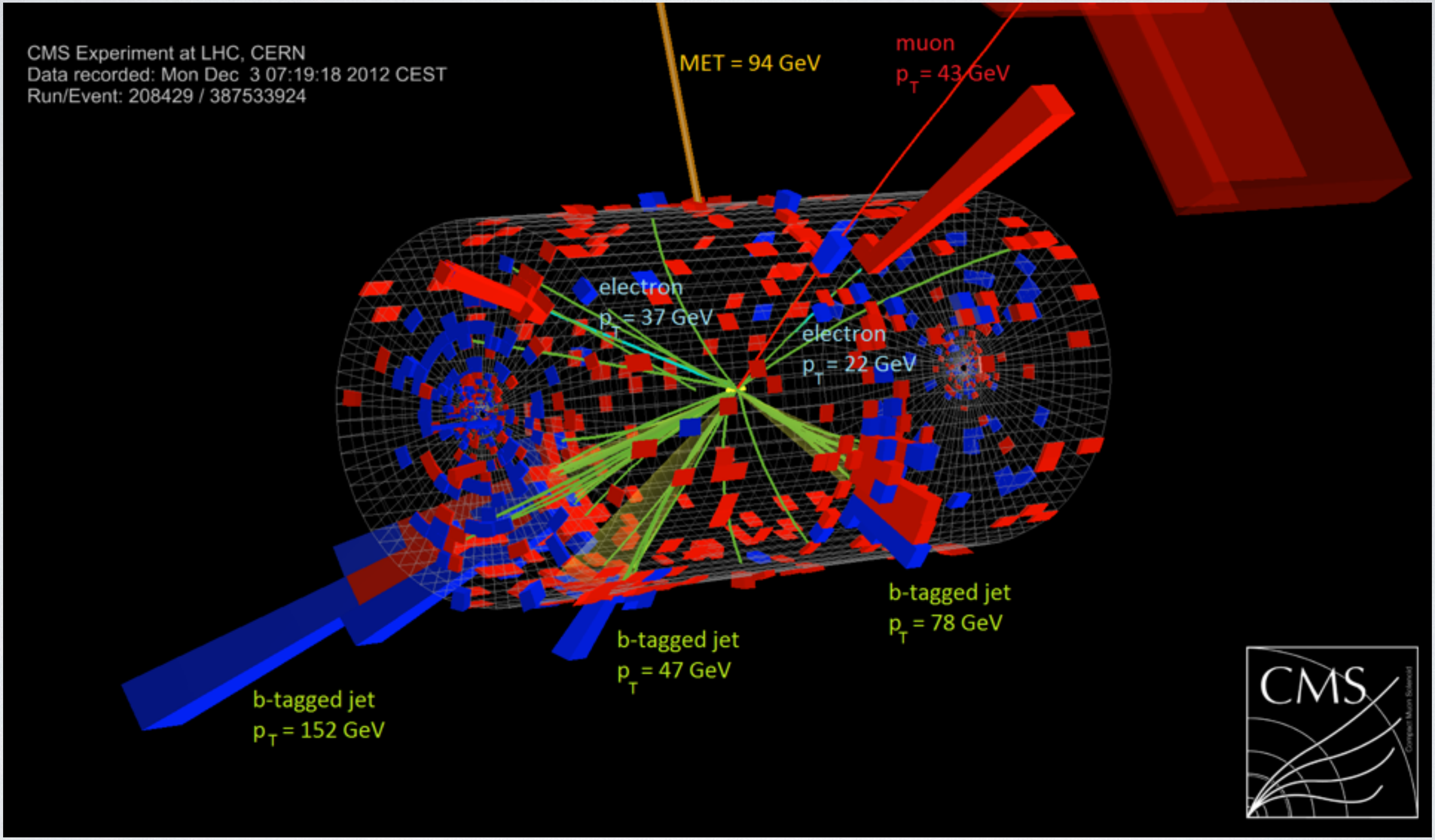








CMS-SUS-13-013 CMS-SUS-13-010 CMS-SUS-13-003


CMS Experiment at LHC, CERN
Data recorded: Mon Dec 3 07:19:18 2012 CEST
Run/Event: 208429 / 387533924
MET = 94 GeV
muon
p_T = 43 GeV
electron
p_T = 37 GeV
electron
p_T = 22 GeV
b-tagged jet
p_T = 78 GeV
b-tagged jet
p_T = 47 GeV
b-tagged jet
p_T = 152 GeV
CMS

CONCLUSION

- Over the first 3 years of LHC running, we have developed a broad SUSY program, with an extensive set of searches.
- Unfortunately no evidence for a signal has been found yet.
- We have reached a reply good understanding of the overall behaviour of SM backgrounds.
- New tools have been engineered to look for specific signature and more are in the pipeline.
- Interpretation is complex: ongoing work.
- Excited and ready for the upcoming run!