BSM SEARCHES @ CMS

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Overview - Run 1 legacy

* Higgs discovery!

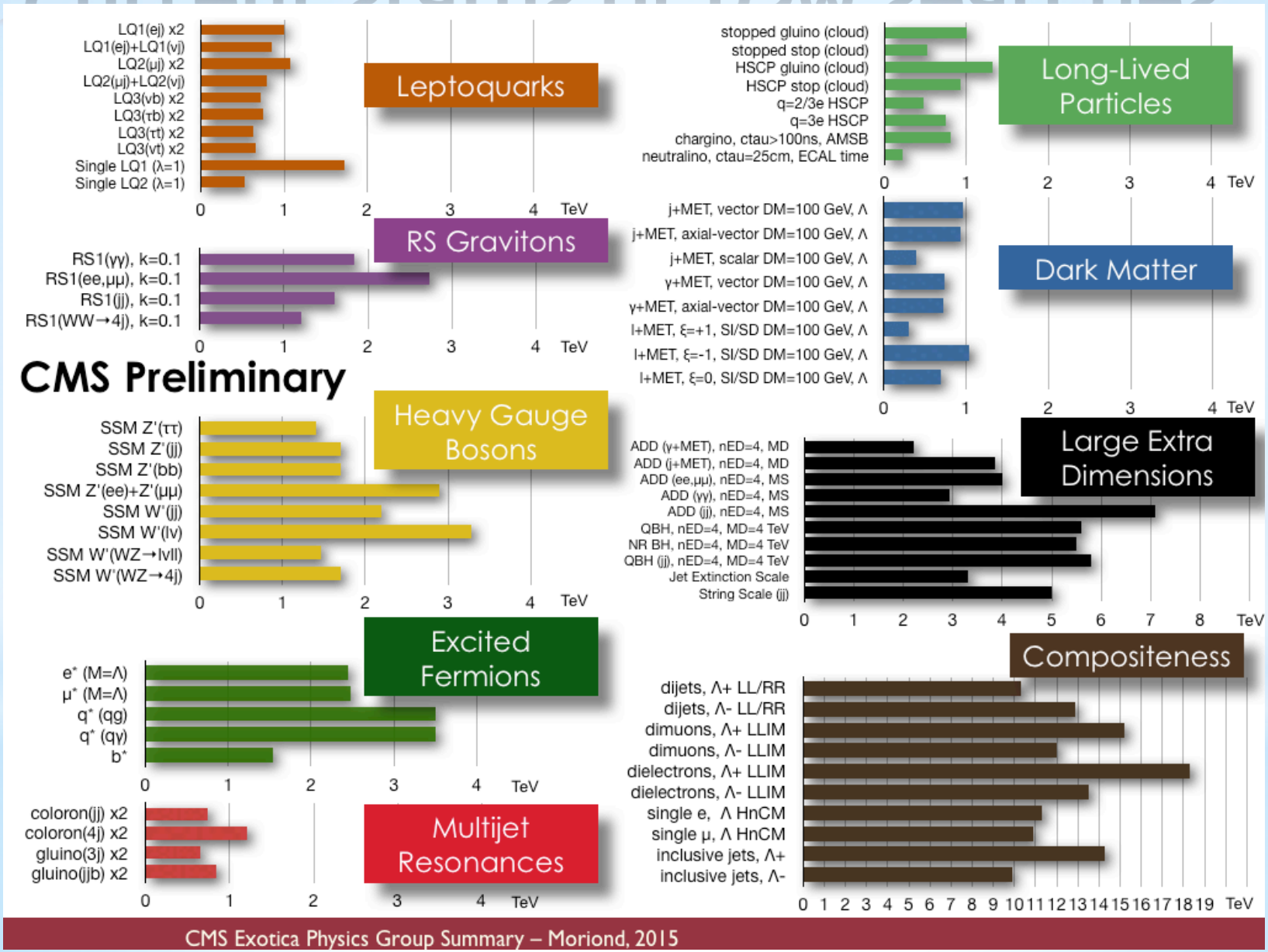
* Many, many BSM searches, all with null result
  * di-jet, di-boson resonances, excited vector bosons, leptoquarks, supersymmetry, etc. etc.

* We're still stuck with our "usual" SM insufficiencies
  * hierarchy problem
  * unification of forces
  * dark matter

* A few (interesting?) small deviations in Run1

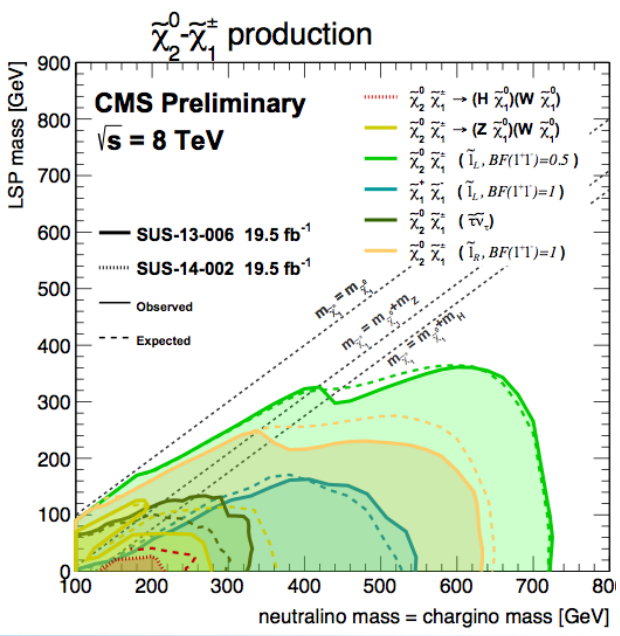
* Motivation enough to keep searching!
  * prospects for resonances, SUSY & Dark Matter

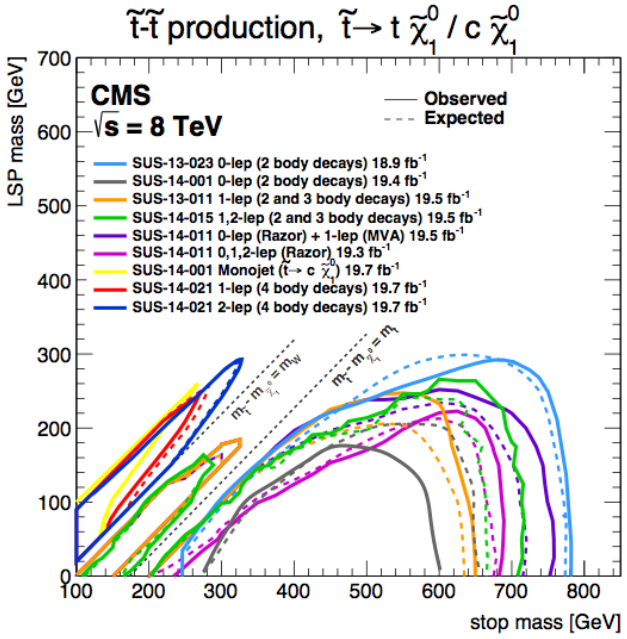
*Current status of BSM searches

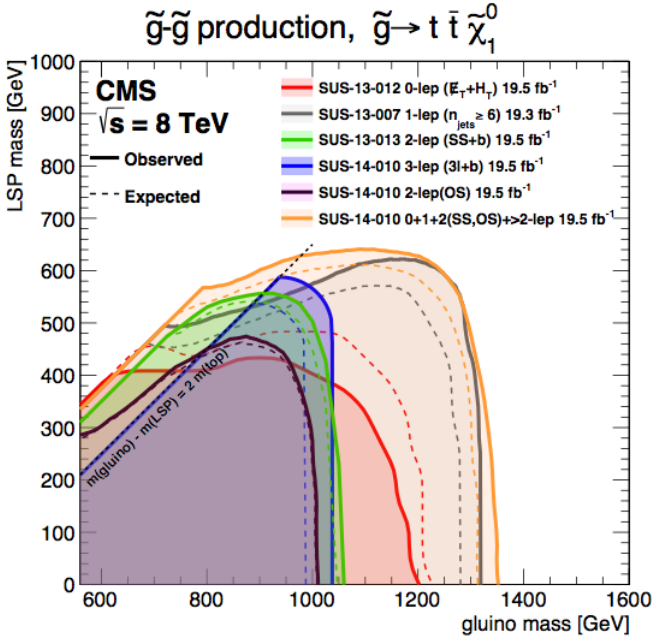


*Status of SUSY searches with 8 TeV

* CMS carried out a comprehensive search for Supersymmetry
  * from model independent inclusive searches to specific decay modes, covering a large number of signatures and final states
  * EWKino production, 3rd generation squarks, gluinos and heavy squarks







$m_{\chi+} = m_{\chi0}$ > 250 - 700 GeV

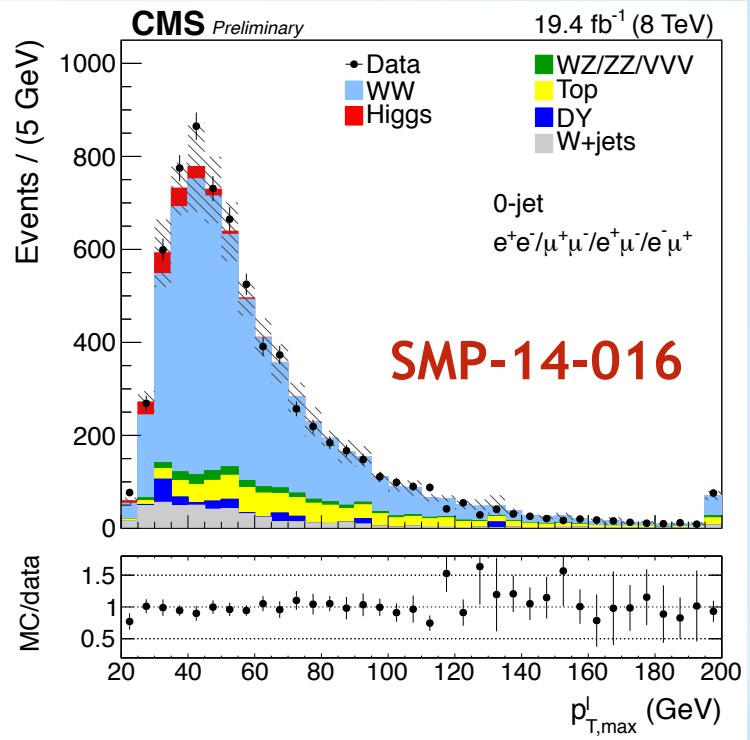
m_{stop} > 750 GeV for very light neutralinos

m_{gluino} > 1.35 TeV

*Some hints in Run 1?

Diboson production: WW->2l2ν

* ATLAS/CMS 7 TeV & ATLAS 8 TeV
  * => excess over NLO prediction
* CMS 8 TeV, 5.3 fb^{-1}
  * $\sigma_{WW} = 69.9 \pm 2.8_{stat} \pm 5.6_{syst} \pm 3.1_{lum}$ pb
* Changes/Improvements:
  * larger dataset
  * included events with one jet
  * most recent improved theoretical description of the signal production, including modeling of the lower region of the p_T spectrum of the W^+W^- system using a resummation technique
  * Higgs boson effects removed from final result to be consistent with this recent theoretical calculation (8% effect).
* CMS 8 TeV full dataset 19.4 fb^{-1}
  * good agreement with theory



total σ [pb] 8TeV	theory
CMS: 60.1 ± 0.9 (stat) ± 3.2 (exp) ± 3.1(th) ± 1.6 (lumi)	$59.8^{+1.3}_{-1.1}$ (NNLO)
Atlas: $71.4^{+1.2}_{-1.2}$ (stat) $^{+5.0}_{-4.4}$ (syst) $^{+2.2}_{-2.1}$ (lumi)	$58.7^{+3.0}_{-2.7}$ (qq NLO, gg LO) H->WW included

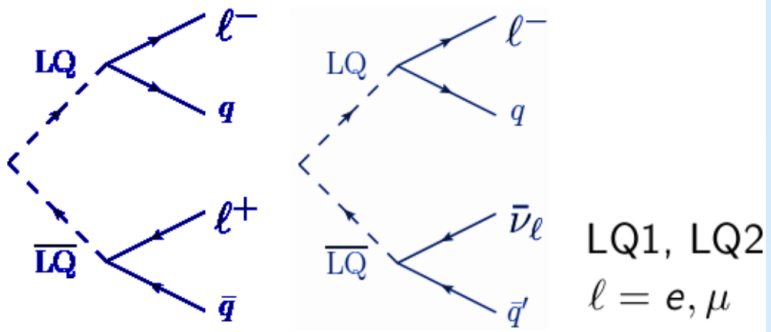
Speculative interpretation: light stops in near-degenerate mass scenario?

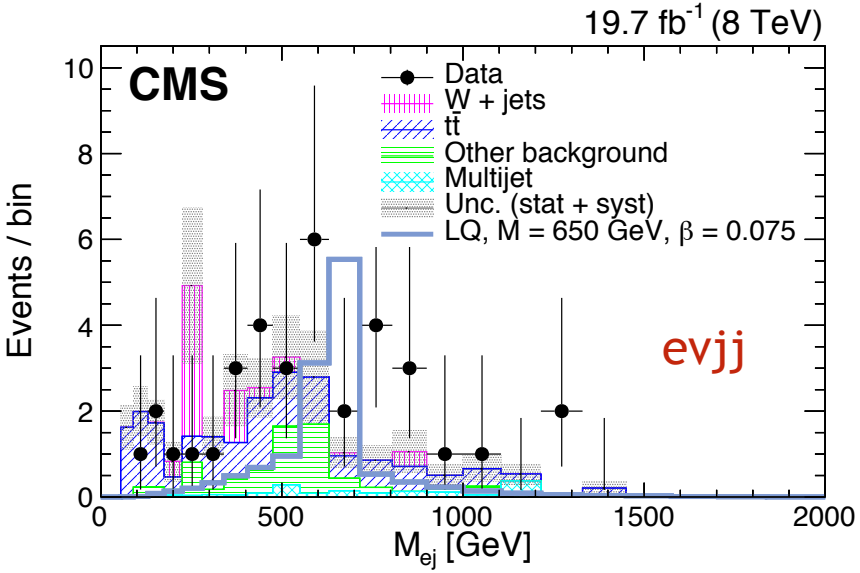
Electron excesses (I)

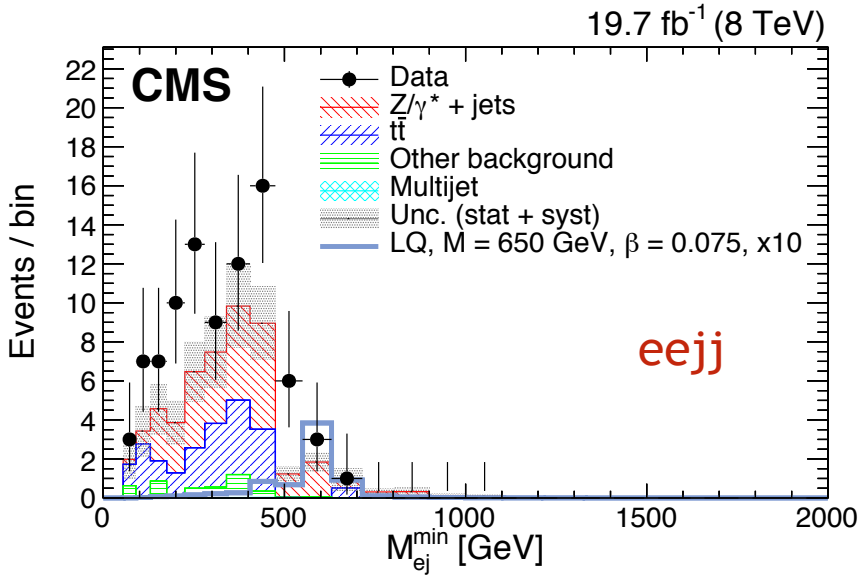
EXO-12-041

* First generation leptoquarks in eejj and evjj final states
  * optimized cuts for individual LQ mass hypothesis on M(lv), M(ll), S_T and MET to suppress backgrounds
  * broad excess in both channels for 650 GeV LQ mass hypothesis
  * 2.4 (2.6) sigma in eejj (evjj) channel
    * not peaking in ej mass

β = branching fraction to the lq final state





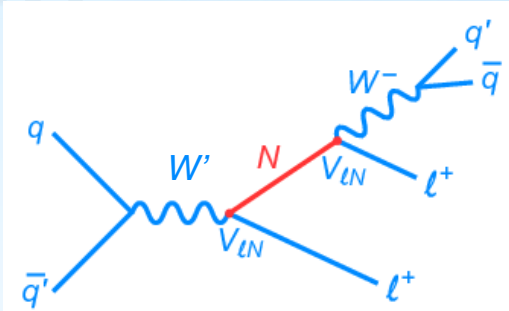


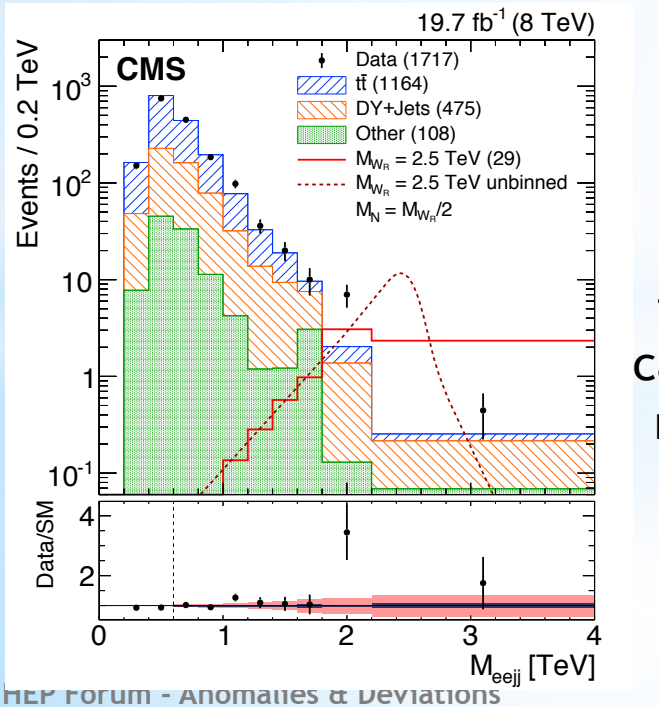
*Electron excesses (II)

EXO-13-008

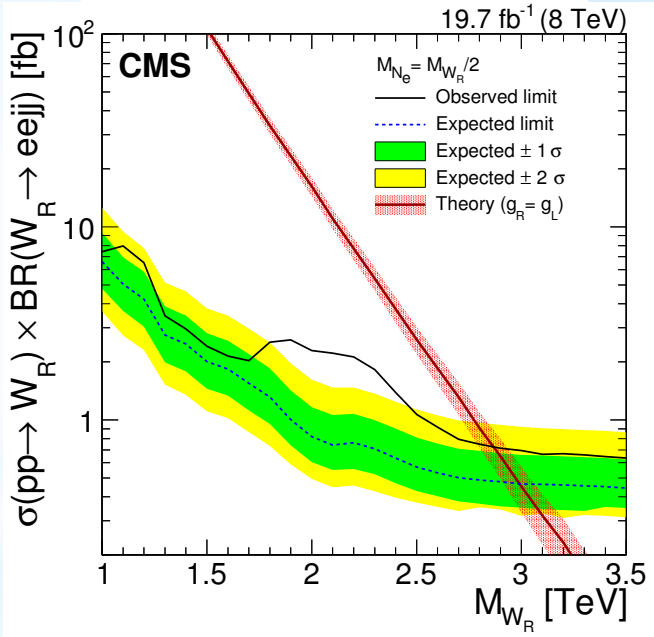
*W' and heavy neutrino

- * Interestingly a search motivated by W' decays through heavy neutrinos also exhibited an excess in same eejj final state
- * search looks for a bump in the eejj invariant mass
  - * ttbar BG estimated using eμ *j j* control sample
  - * DY BG from Z/γ* -> ll control sample
- * there is little overlap in events between this and the LQ analysis





2.8 sigma significance for W_R boson candidate with mass 2.1 TeV



Cross-section exclusion, assuming only electron flavor heavy neutrino accessible at LHC energies, as a function of the mass of the W_R for M(N) = 1/2 M(W_R)

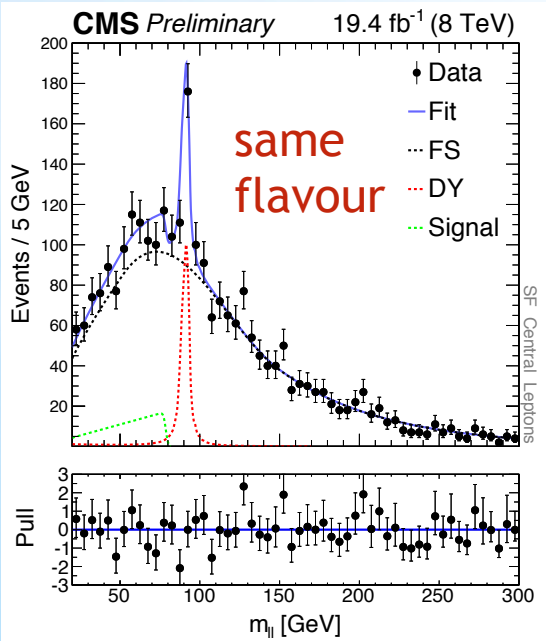
Kinematic edge in opposite sign, same flavour dilepton events

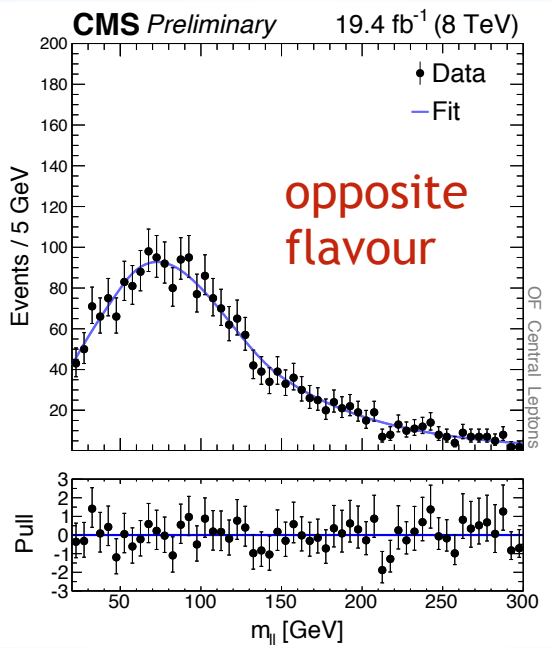
* Generic search for kinematic endpoint in dilepton mass spectrum, e.g.,
  * $\tilde{\chi}_2^0 \to l\tilde{l} \to \chi_1^0 l^+ l^-$ (produces triangular shape with endpoint)
  * three body decays of $\tilde{\chi}_2^0 \to \chi_1^0 l^+ l^-$ (produces an "edge")

SUS-12-019

* Background estimation with opposite sign, opposite flavour leptons
  * Two search regions: central $|\eta| < 1.4$, forward $1.6 < |\eta| < 2.4$

* Signal and background contributions determined from shape fit





	Central	Forward
Drell–Yan	158 ± 23	71 ± 15
Flav. Sym. [OF]	2270 ± 44	745 ± 25
$R_{SF/OF}$	1.03	1.02
Signal events	126 ± 41	22 ± 20
$m_{\ell\ell}^{edge}$ [GeV]	78.7 ± 1.4	

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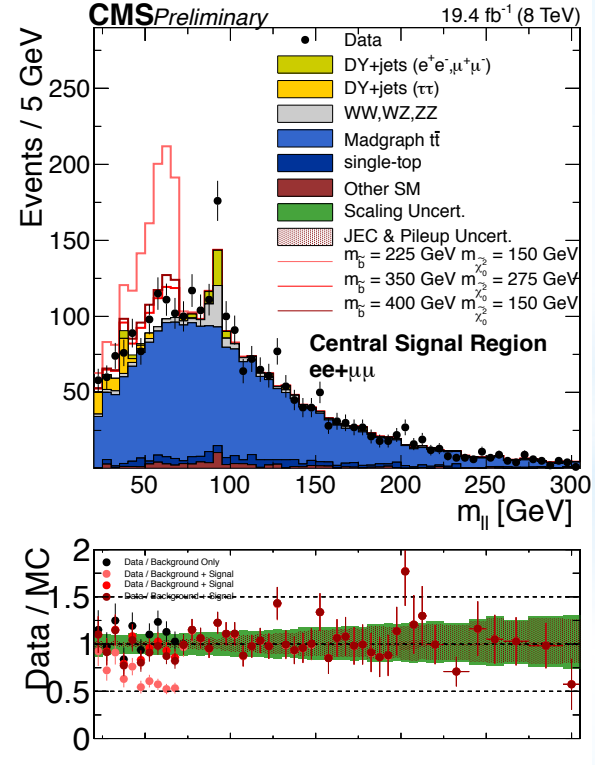

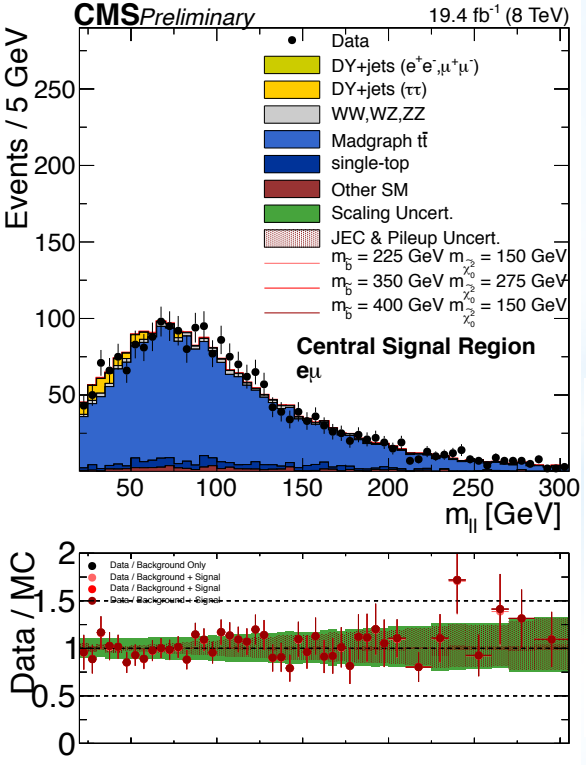

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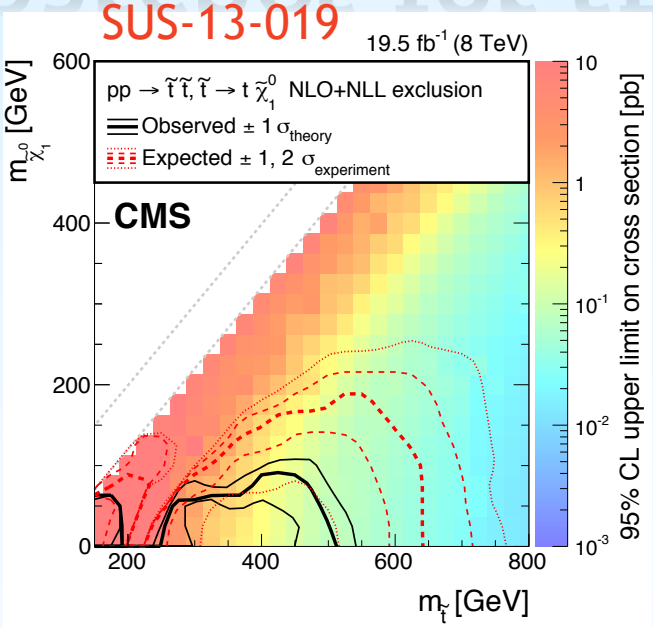
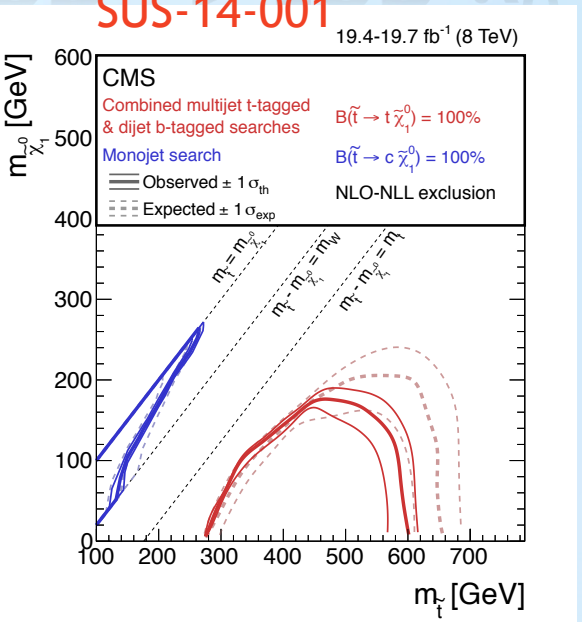
Hadronic searches for stop -> top χ^0

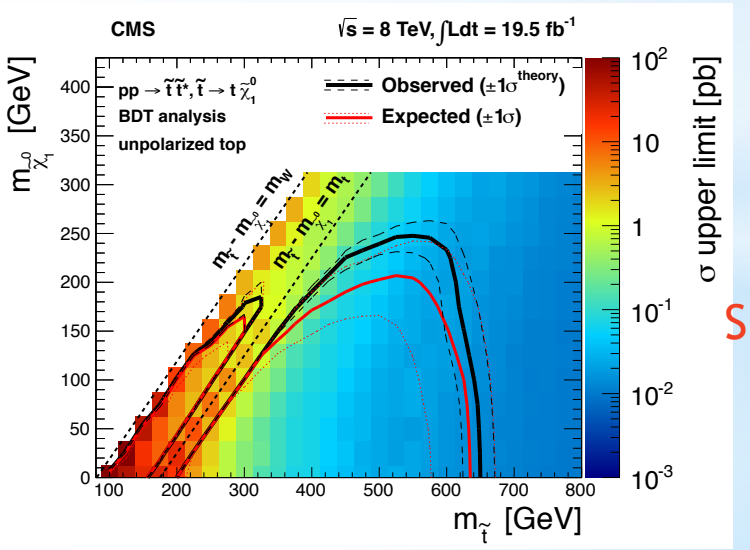
- In hadronic final states observed limits are weaker than expected across different analyses
  - e.g. SUS-12-028, SUS-13-019, SUS-14-001
- not observed in final states with leptons – SUS-13-011

SUS-13-019



SUS-14-001

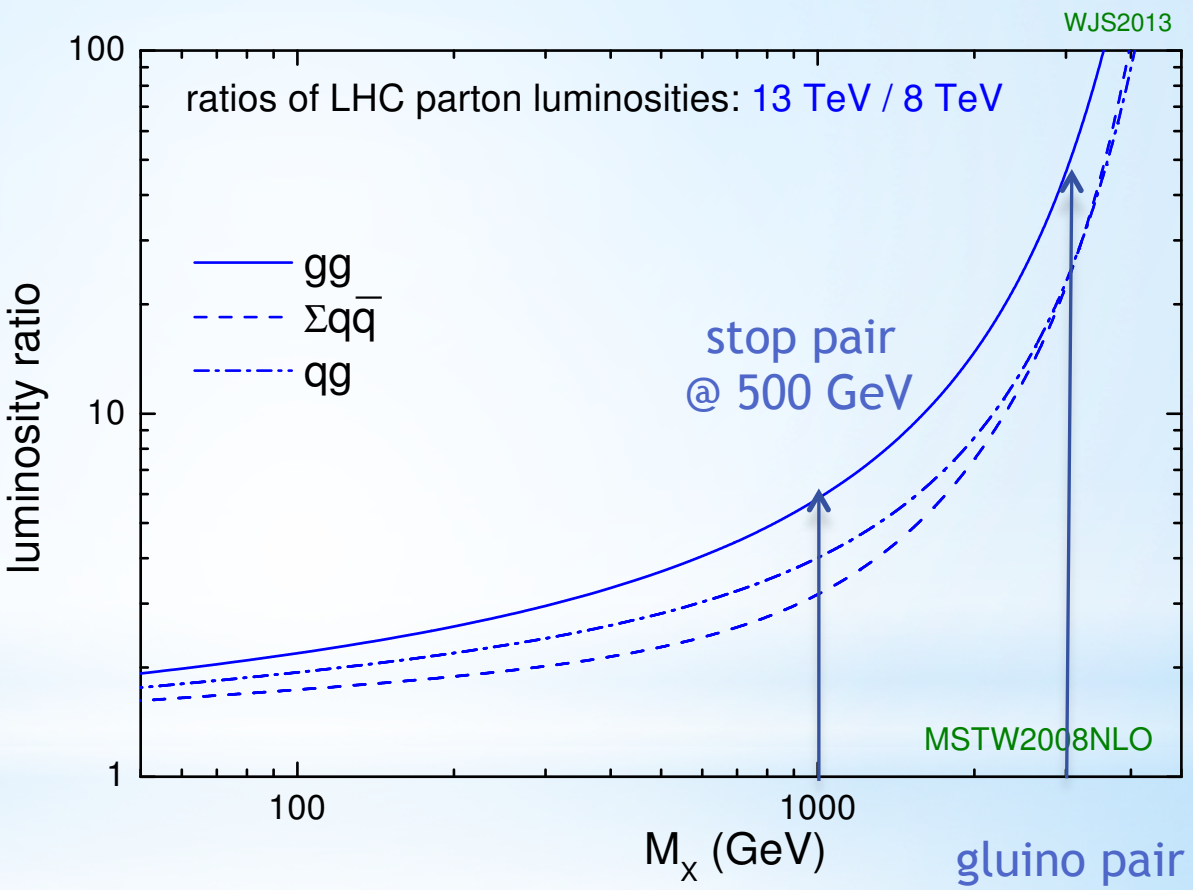




SUS-13-011

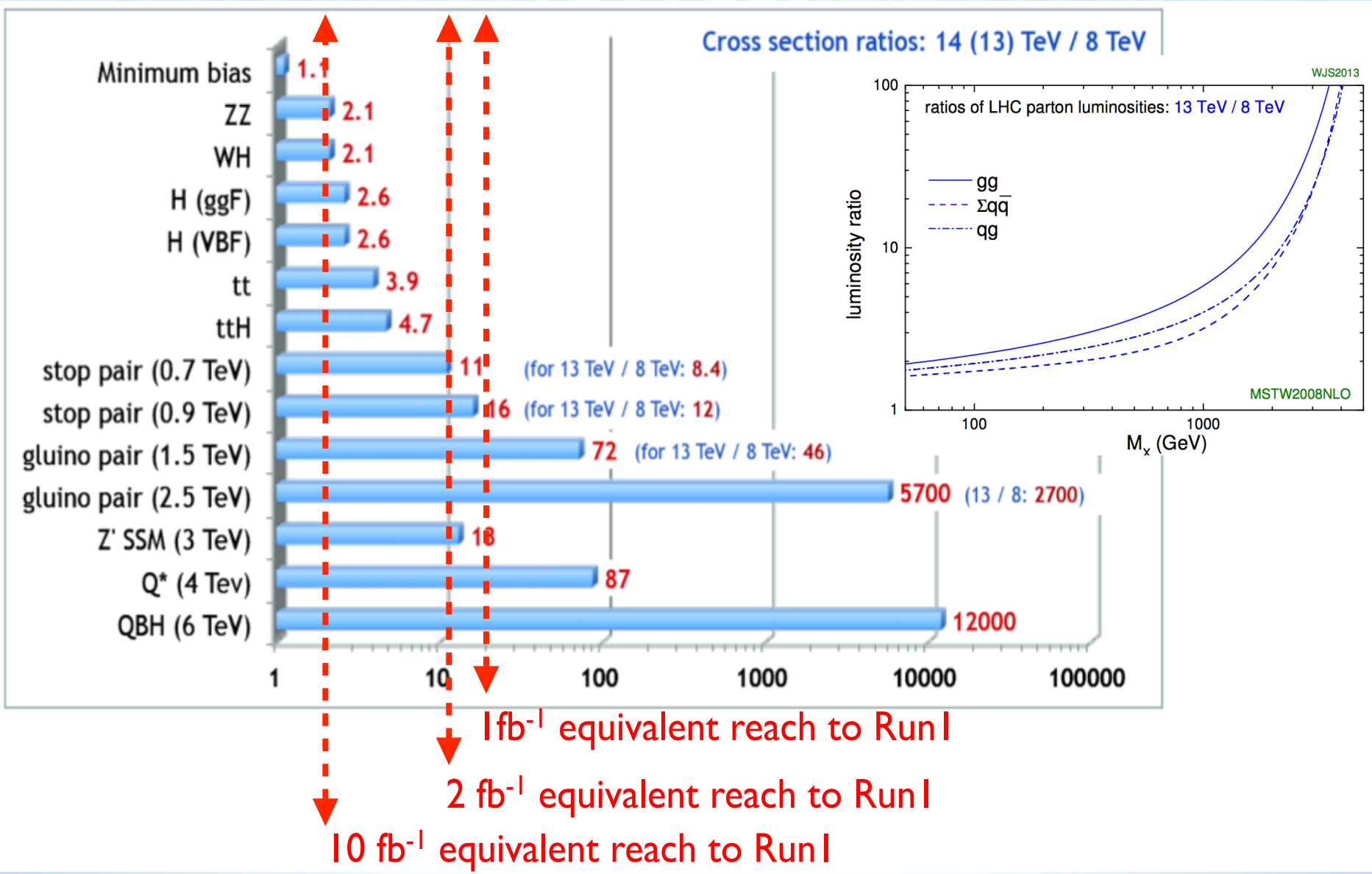
*Prospects for 2015 & 13 TeV

* Good prospects for SUSY from energy increase from 8->13 TeV
* much larger than just ratio of CM energies
* up to factor ~50 for pair production of 1.5 TeV gluinos
* factor 6 for stop pairs of 500 GeV
* Not only good for SUSY but also other heavy objects such as Z' etc.

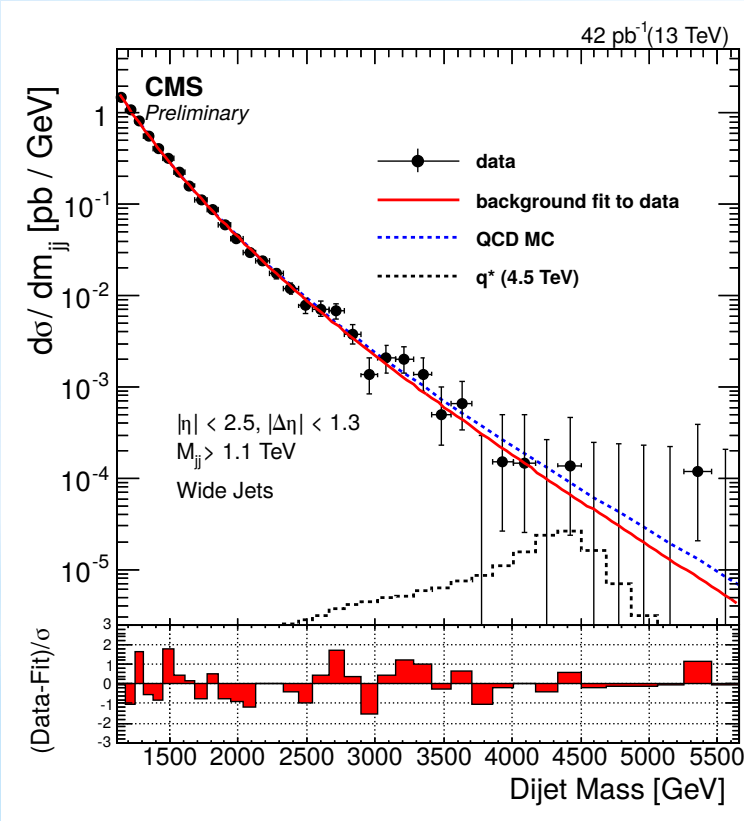


gluino pair @ 1.5 TeV, Z' @ 3 TeV

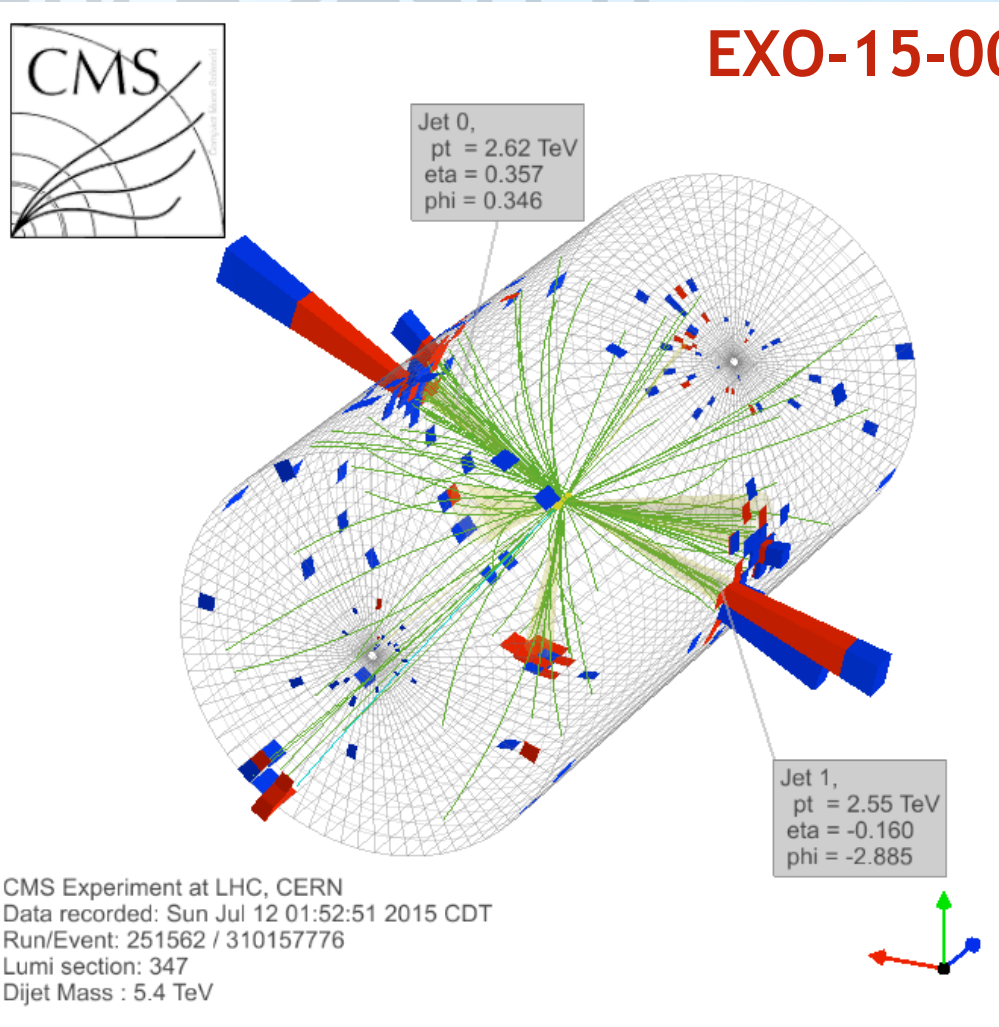
*Consequences for SUSY production



*Example of extended reach - di-jet resonance search



EXO-15-001



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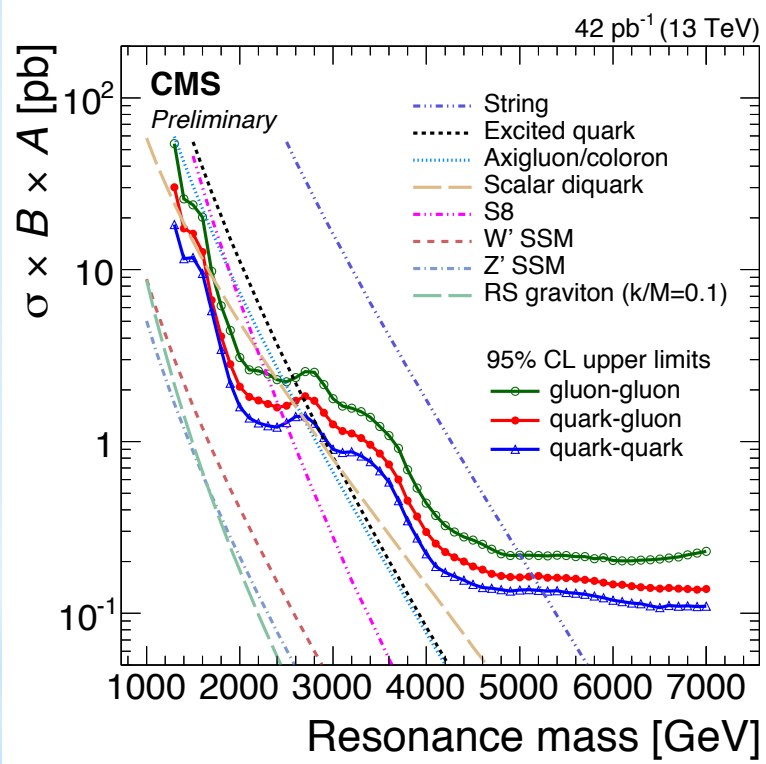
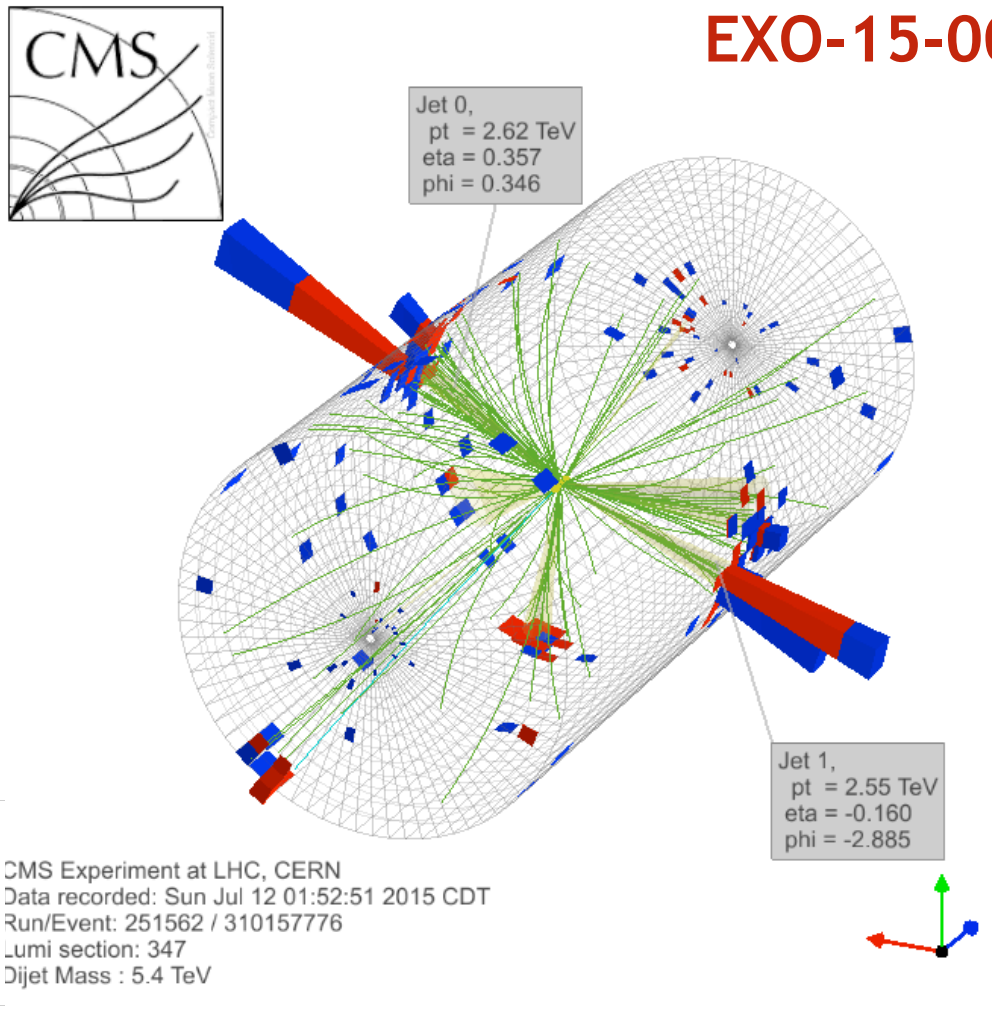


EXO-15-001

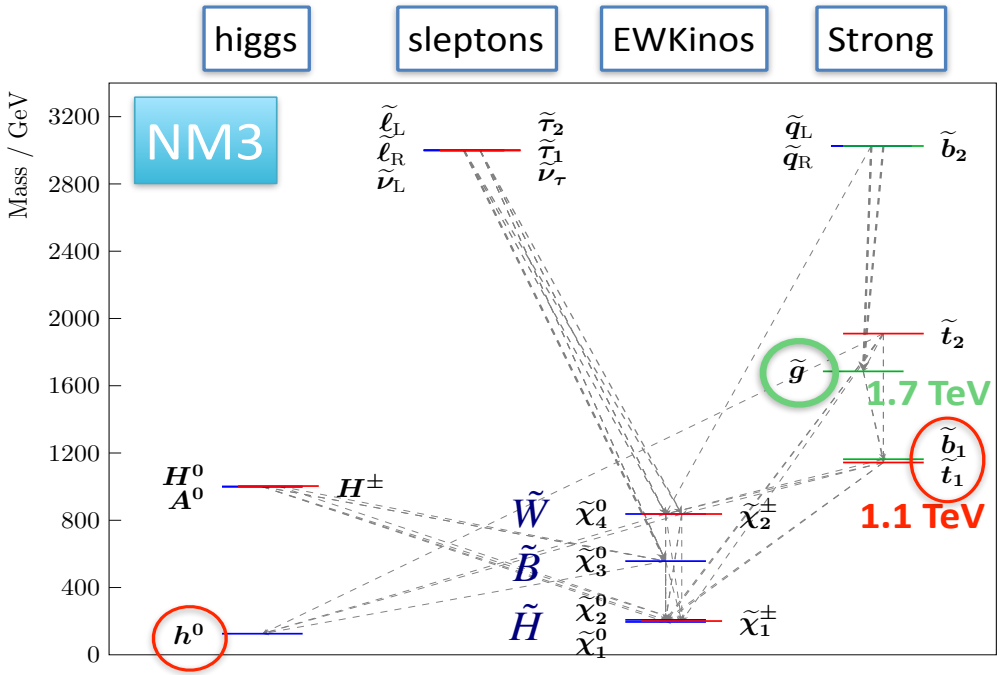


Model	Final State	Obs. Mass Limit [TeV]	Exp. Mass Limit [TeV]
String Resonance (S)	qg	5.1	5.2
Excited Quark (q*)	qg	2.7	2.9
Scalar Diquark (D)	qq	2.7	3.3
Axigluon (A)/Coloron (C)	qq̄	2.7	2.9
Color Octet Scalar (s8)	gg	2.3	2.0

*Outlook on 13 TeV sensitivity - Natural SUSY searches

Discovery scenarios with full-spectrum models

CMS PAS SUS-14-012



The nature of the EWKino sector has a large influence on the decays of the top squark.

	NM1	NM2	NM3
$B(\tilde{t} \to t\tilde{\chi}_1^0)$	0.6%	1.5%	39%

- **Studied 5 full-spectrum SUSY models.**
- **9 analyses performed in parallel.**
- m_H = 125 GeV
- **NM 1,2,3** ="Natural" Model 1, 2, 3

  $m(\tilde{g})$=1.7 TeV, $m(\tilde{t})$=1.1 TeV
- **STC** -Stau co-annihilation. $m(\tilde{\tau}_1) \approx m(\tilde{\chi}_1^0) \approx 190$ GeV
- **STOC**-Stop co-annihilation $m(\tilde{t}_1) \approx m(\tilde{\chi}_1^0) \approx 400$ GeV

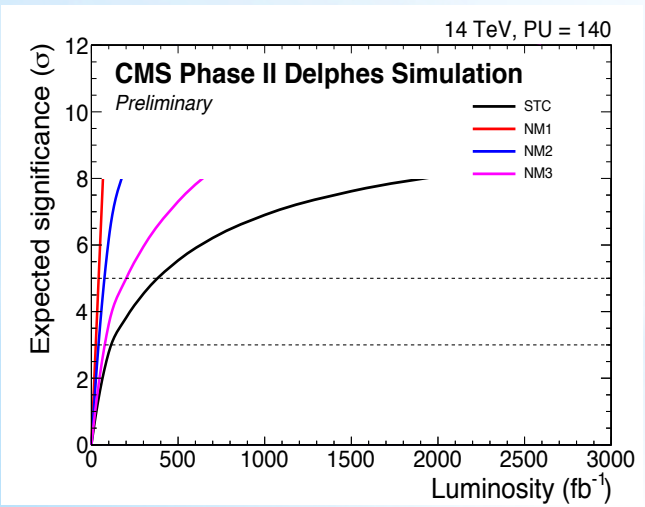
J. Richman

*Outlook on 13 TeV sensitivity

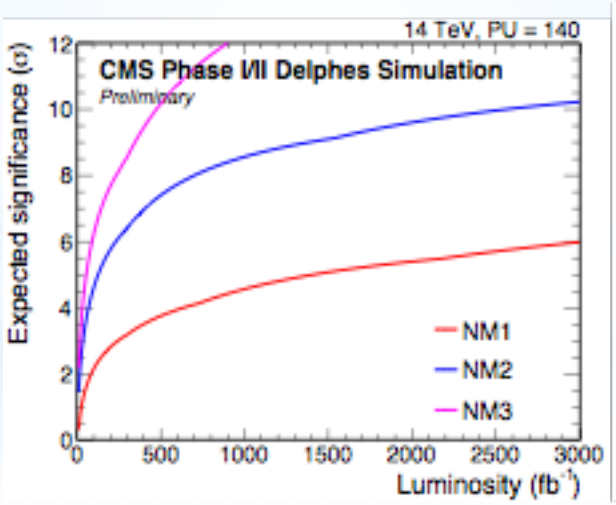
* Discovery sensitivity for SUSY benchmark models **CMS-TDR-15-02**

* 3 natural pMSSM models all with discoverable 1.7 TeV gluino, differing mainly in masses of sleptons and masses/compositions of neutralinos and charginos (details in backup)

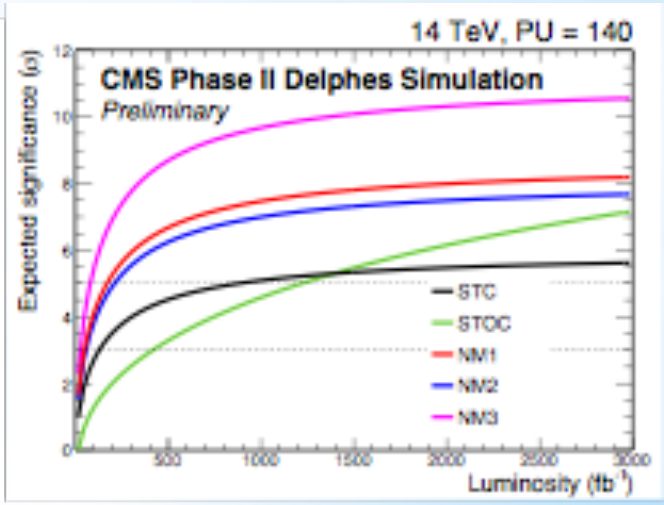
3 lepton + bjet search



Inclusive search in all hadronic final state



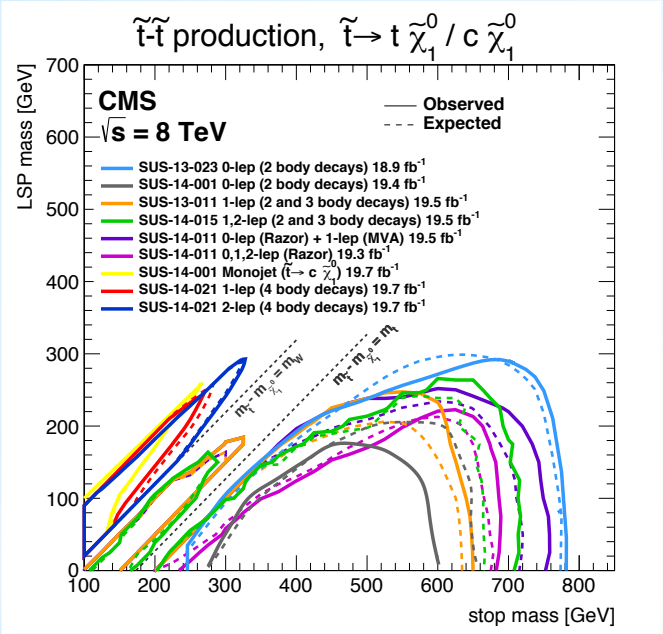
Stop pair production in single lepton final state



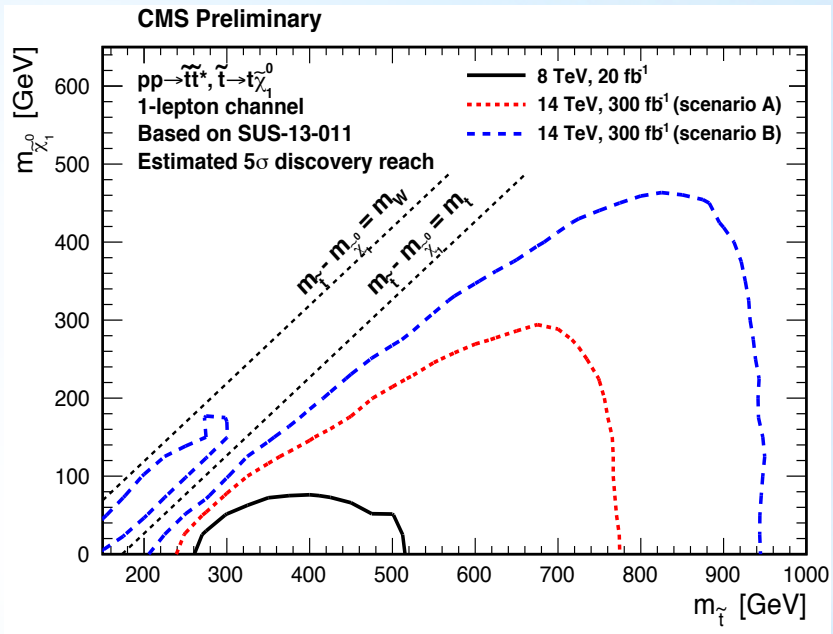
All curves rising steeply - signs would come early, within first 200/fb

Projections for 300/fb @ 14 TeV

Exclusion with 20/fb @ 8 TeV



Discovery with 300/fb @ 14 TeV



arXiv:1307.7135

* Searches will cover the interesting region of stop masses up to 1 TeV with 300/fb @ 13 TeV
* Neutralino masses up to 500 GeV
* In gluino mediated models, reach up to m_{gl} of 2 TeV

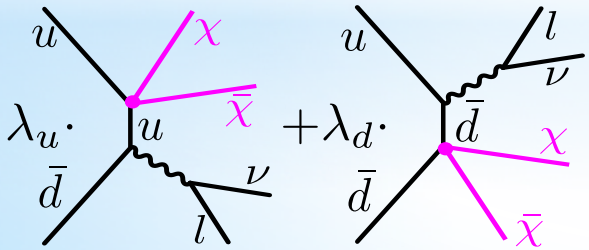
*Prospects for Dark Matter

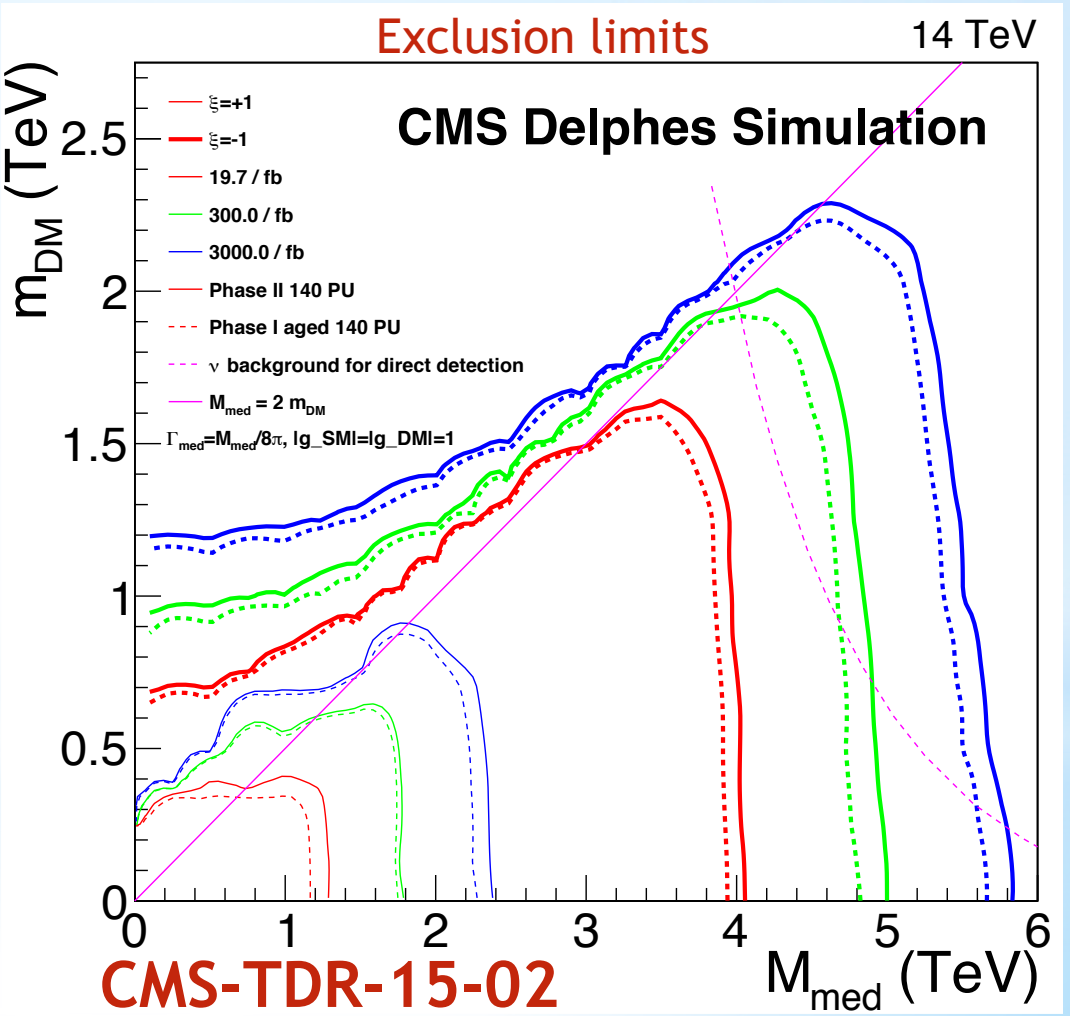
*Monolepton channel

*Dark matter is one of the hot topics for Run2!

*Monolepton channel: W-boson recoiling against dark matter

- *model allows different coupling of DM to up- and down-type quarks, parameterized by $\xi = \lambda_u\lambda_d$
- *reach depends strongly on assumption for ξ (interference)





mediator modeled as Z' like particle

* Monojet projections for AV DM scenario

Based on **arXiV:1409.4075**

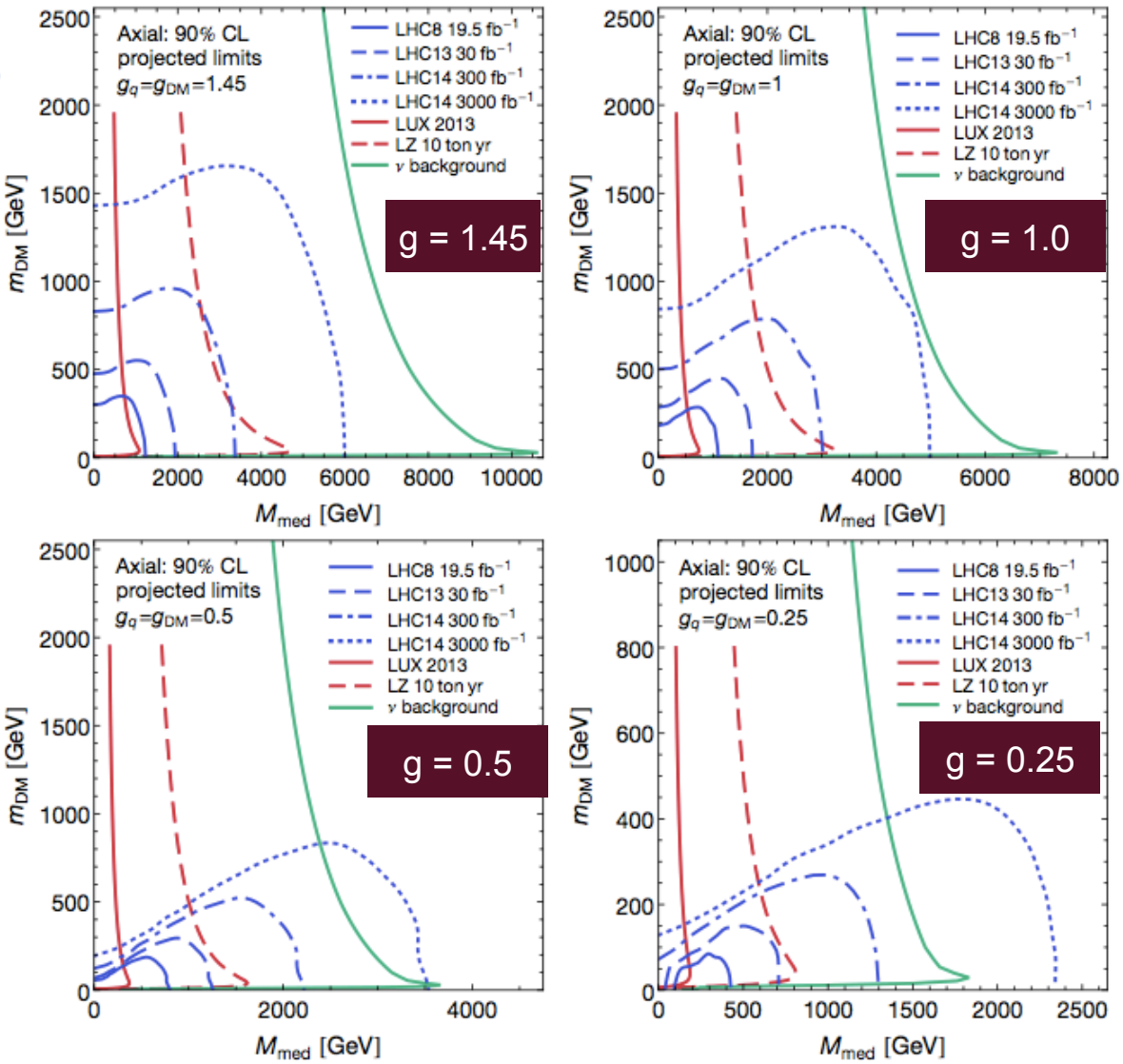
Limits from 8 TeV CMS monojet search (EXO-12-048) and projected limits for 3 LHC scenarios:
- 13 TeV 30 fb^{-1}
- 14 TeV, 300 fb^{-1}
- 14 TeV, 3000 fb^{-1}

LUX 2013 limits and projected limits for LZ assuming 10 tonne-year exposure

Discovery reach accounting for coherent neutrino scattering

Nicely illustrates interplay between collider and direct detection experiments

Axialvector (Example)



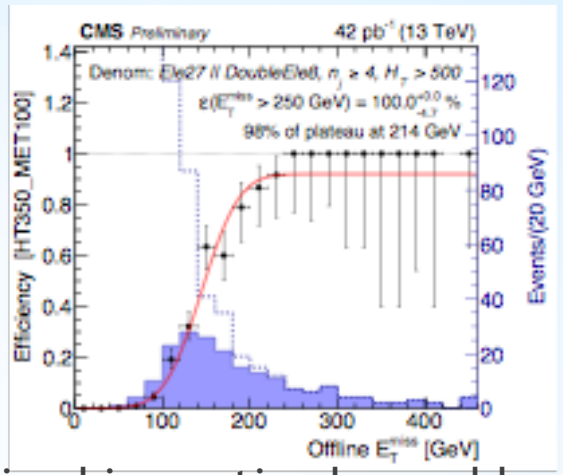
*Any interesting news @ 13 TeV?

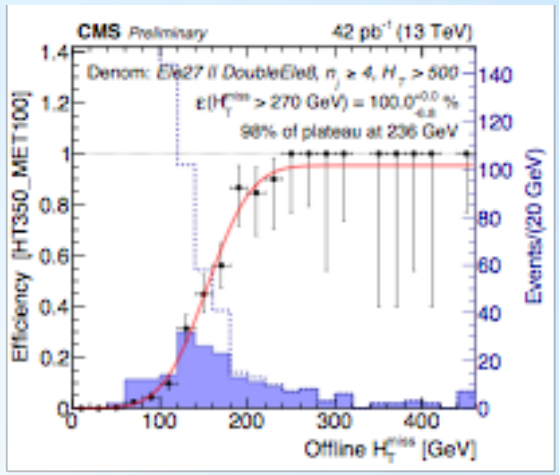
Readiness with 13 TeV data

* SUSY search commissioning of key observables with 13 TeV data

* Examples of trigger turn-ons

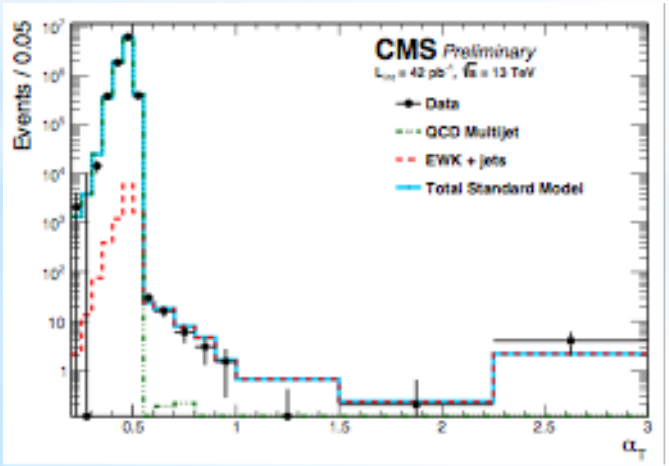
HT300_MET100 trigger



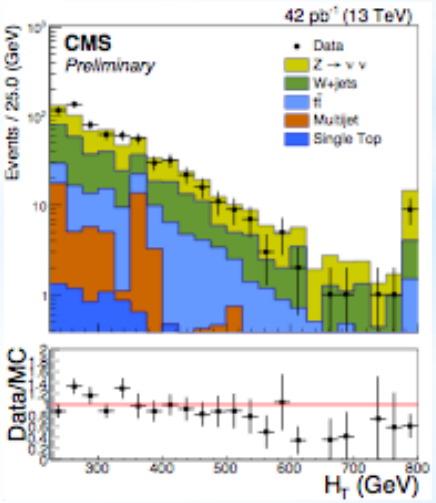


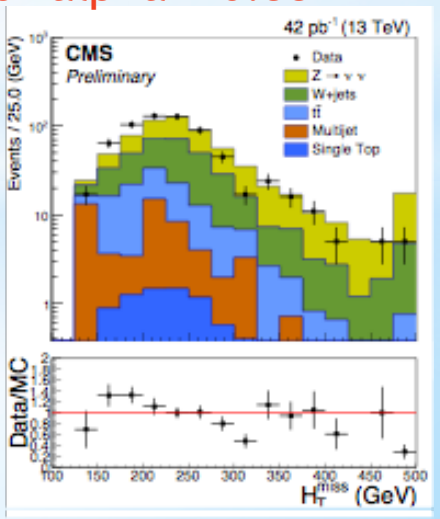
* Examples of key discriminating kinematic observables

* alphaT for QCD rejection



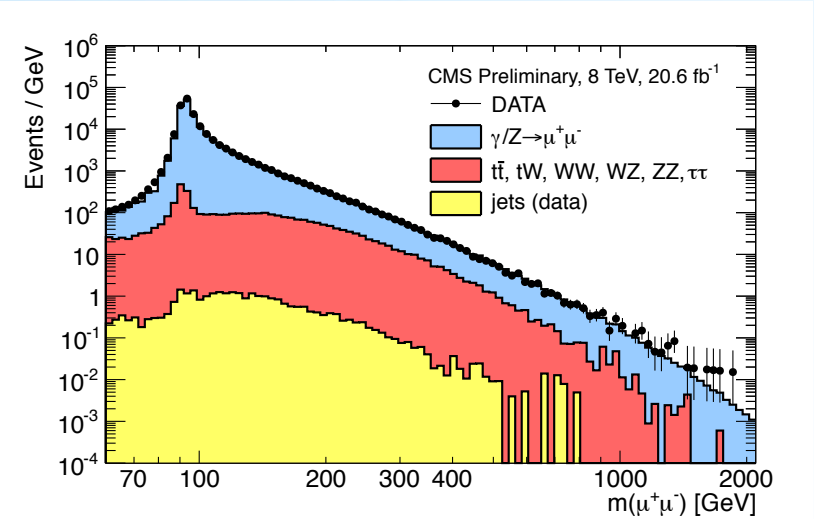
HT and HT^{miss} for alphaT>0.55

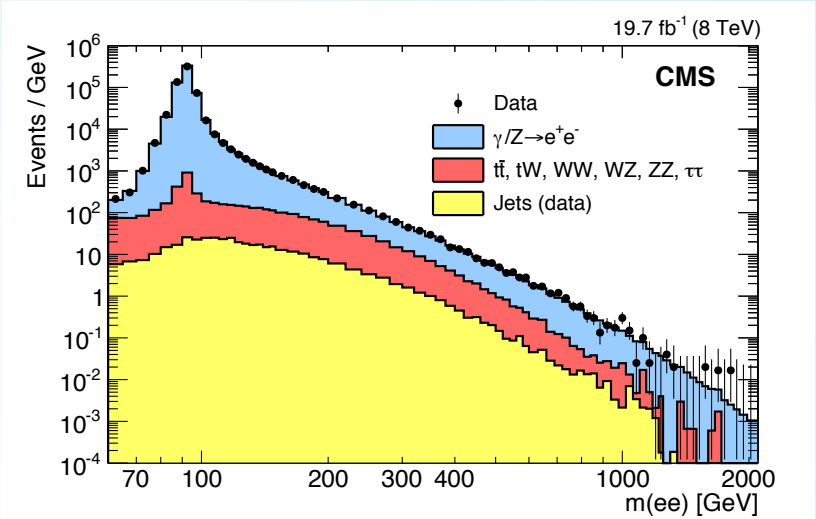




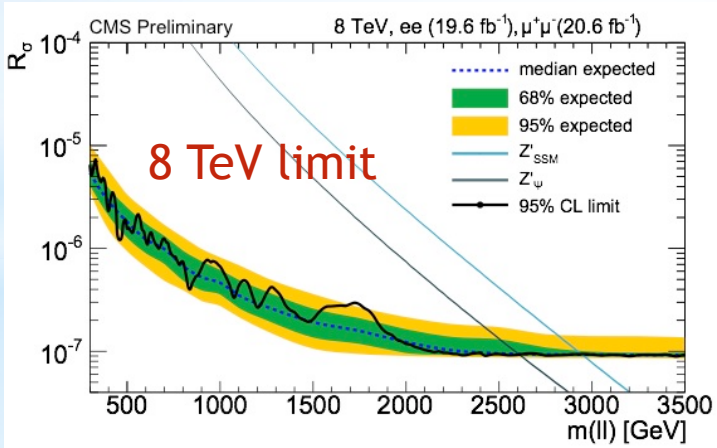
*Search for excited Vector bosons: Z'

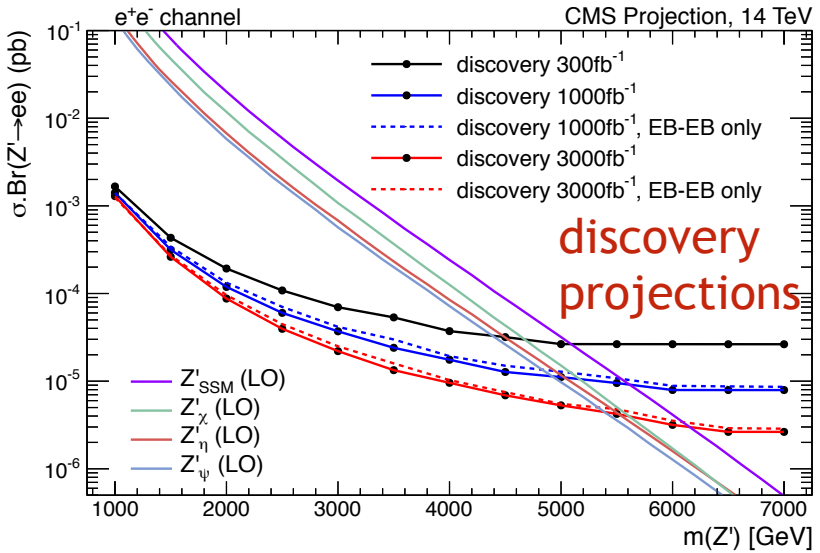
*Search in invariant mass of opposite sign di-muon and di-electon pairs



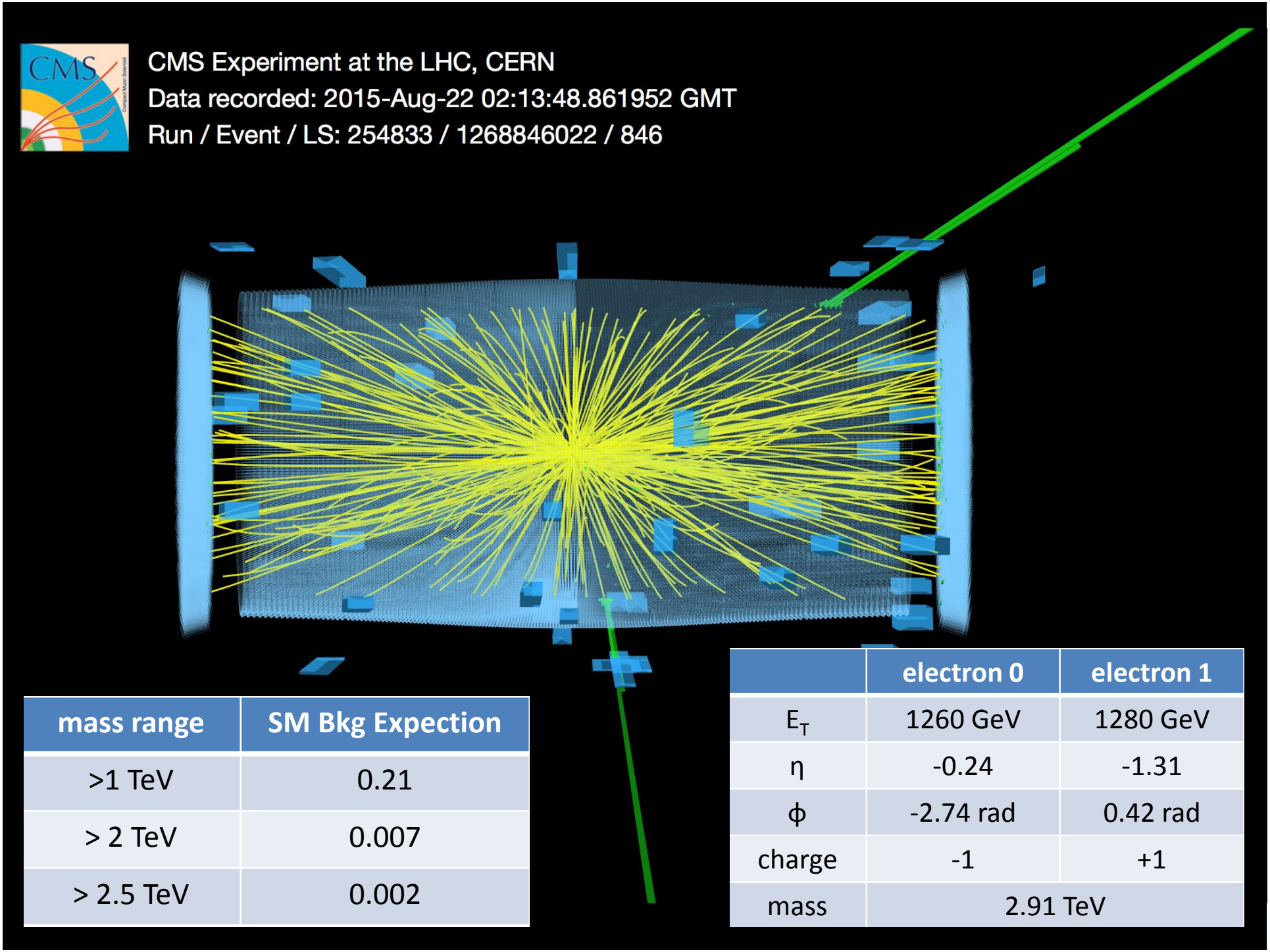


EXO-12-061





* 8 TeV limits:
  * Sequential SM: Z'_{SSM} > 3 TeV
  * Grand Unification model: Z'_{ψ} >2.6 TeV



mass range	SM Bkg Expection
>1 TeV	0.21
> 2 TeV	0.007
> 2.5 TeV	0.002

	electron 0	electron 1
E_T	1260 GeV	1280 GeV
η	-0.24	-1.31
ϕ	-2.74 rad	0.42 rad
charge	-1	+1
mass	2.91 TeV	

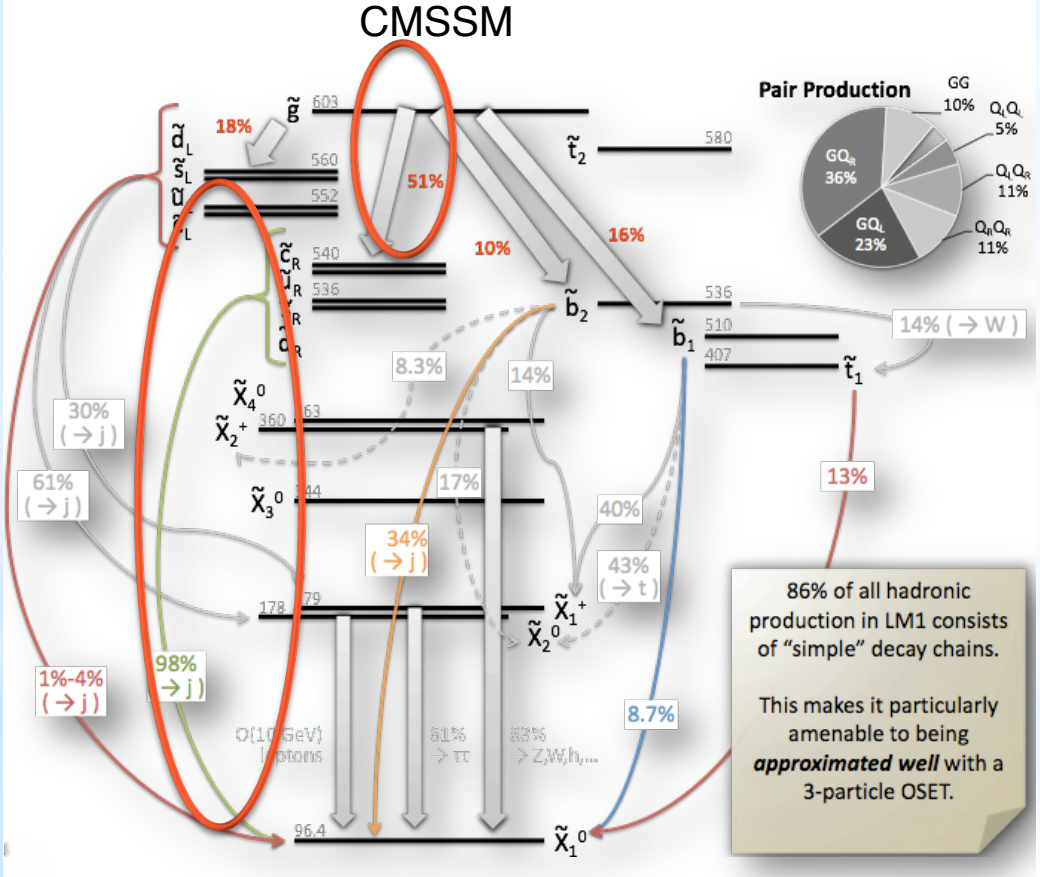
*Summary

- *LHC Run1 was a big success even though no evident sign of New Physics
  - *we discovered the Higgs boson
  - *a few deviations at the 2-3 sigma level
  - *http://cms-results.web.cern.ch/cms-results/public-results/publications/
- *Run2 offers good prospects for discovery
  - *e.g., resonances, SUSY but also Dark Matter
- *CMS analyses are ready and analyzing data
  - *CMS recorded around 3.5fb^{-1} in 2015
  - *some first interesting events

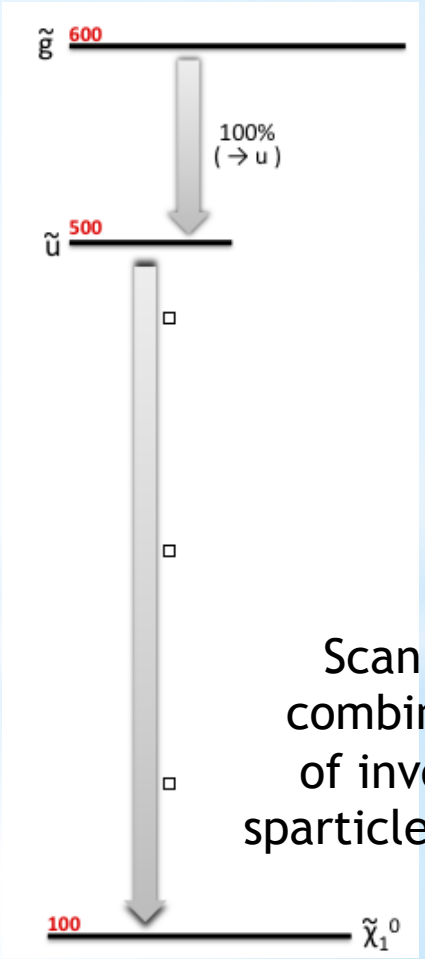
*backup

Interpretation of searches: from full spectra to simplified models

- often a few dominant decay chains
- approximate full spectrum by a few decay chains

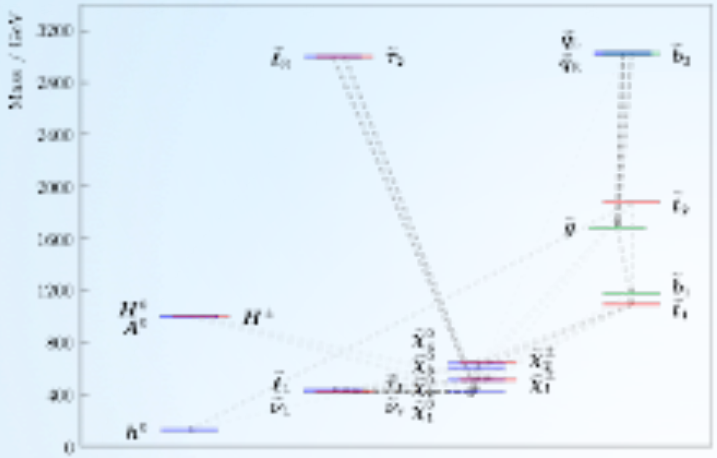


Simplified model spectrum (SMS)
with 3 particles, 2 decay modes

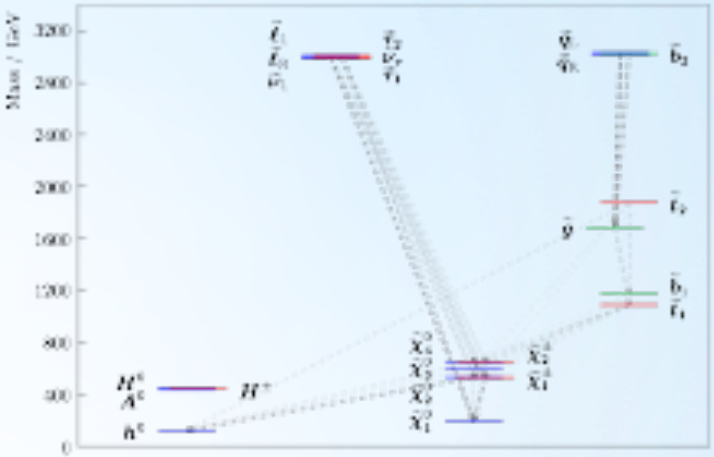


Scan any combination of involved sparticle masses

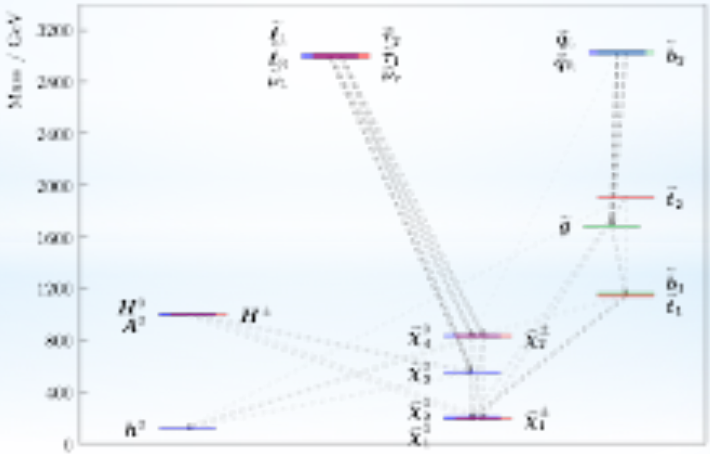
*SUSY benchmark models



(a) NM1



(b) NM2



(c) NM3

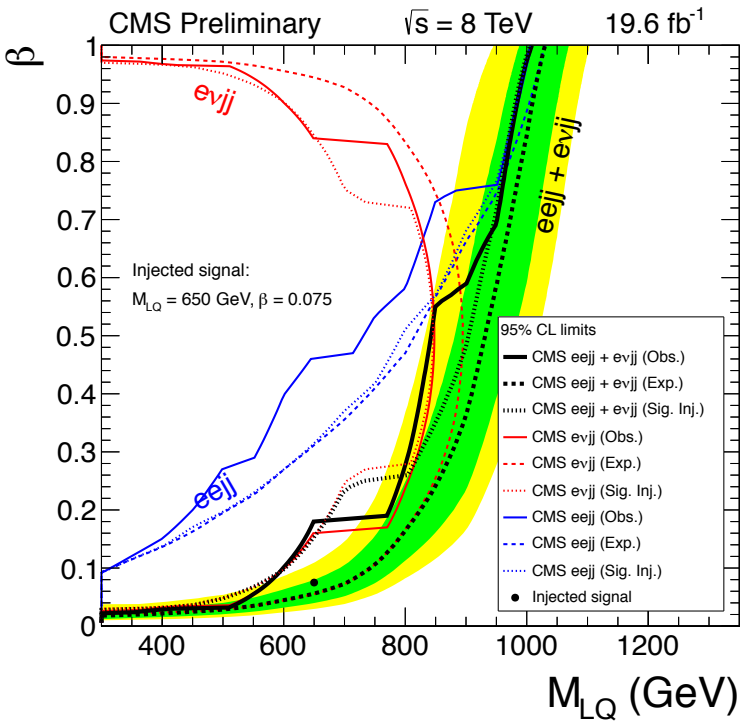
CMS-TDR-15-02

*Electron excesses (II)

1ST GENERATION LEPTOQUARKS

- Very difficult to reconcile with a LQ hypothesis
  - kinematics are too broad (no peak structure)
- Other possibilities?
  - several propsals, e.g.: arXiv: 1410.5947, arXiv:1408.5439, arXiv:1408.1082, arXiv: 1407.4466

[EXO-12-041]

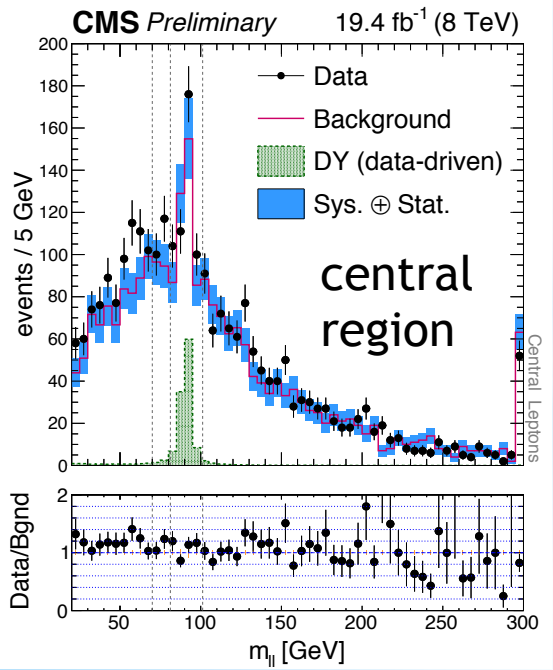


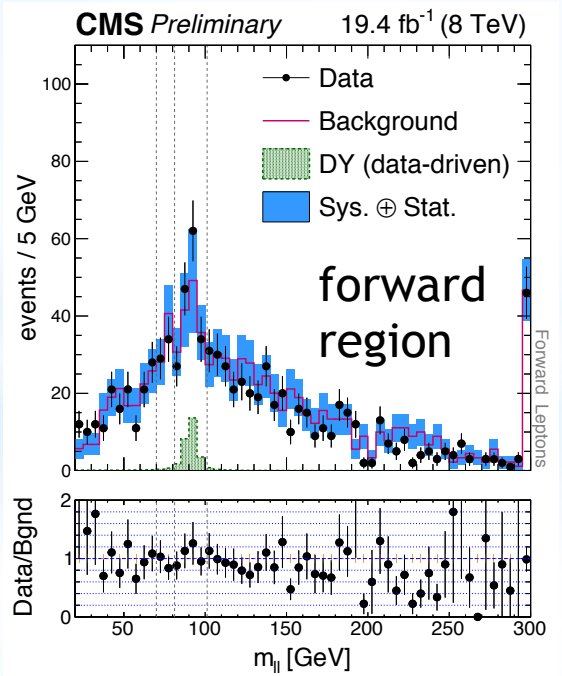
JP Chou

Kinematic edge in opposite sign, same flavour dilepton events SUS-12-019

- Generic search for kinematic endpoint in dilepton mass spectrum, e.g.,
  - $\tilde{\chi}_2^0 \to l\tilde{l} \to \chi_1^0 l^+ l^-$ (produces triangular shape with endpoint)
  - three body decays of $\tilde{\chi}_2^0 \to \chi_1^0 l^+ l^-$ (produces an "edge")

- In addition, cut and count analysis of events with 20 GeV < m_{ll} < 70 GeV (no shape assumption)





	Central	Forward
Observed [SF]	860	163
Flav. Sym. [OF]	$722 \pm 27 \pm 29$	$155 \pm 13 \pm 10$
Drell–Yan	8.2 ± 2.6	1.7 ± 1.4
Total estimates	730 ± 40	157 ± 16
Observed – Estimated	130^{+48}_{-49}	6^{+20}_{-21}
Significance [σ]	2.6	0.3

Experimental Challenges in Run2

- Unfortunately boost in sensitivity from increase in CM energy doesn't come for free
- Large increase in pile-up guaranteed
- Effects on:
  - trigger performance
  - object reconstruction
  - isolation variables

Real data event with 78 reconstructed verteces from high pile-up run (in 2012)