BSM Searches and Material Provided for Reinterpretation

On behalf of CMS Collaboration

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Oct 16, 2017

LPC, Fermilab, Batavia, IL, USA

Many thanks to Sezen Sekmen, Andrew Whitbeck, Roberto Leonardi, Benjamin Fuks, Claudio Campagnari, Stephen Mrenna for providing the material and useful discussions

Outline

- Goal and general principals
- Target users and their wishlist
- What CMS do and do not provide
- Few example analyses where CMS BSM results have been re-casted into new model interpretations
- Conclusion and food for thought!

Goal and General Principals

- We like to facilitate phenomenologist to recast and interpret our BSM search results

- We do our best to fulfill the wishlist of our users, however we like to limit the burden on CMS analysts

- Re-interpreters are ultimately responsible for the results and not the CMS experiment

- Forum like BSM interpretation, MC4BSM, Les Houches workshops etc are healthy places to discuss and brain storm practical ideas to make effective contribution to the Physics Community!

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/InterpretingLHCresults

Target Users

- Phenomenologists with BSM MC model processed through hadronization

  - Obviously are expected to be an expert of event generator tools

- Able to cluster jets with FastJetpackage

- Knowledgeable about fast simulation package (PGS, Delphes..) or smears things by hand. Its up to them!

- Minimally knows how to use Root to read the digitized data, or tools like HEPDATA

Wishlist of Users (1)

- Analysis description
  - An auxiliary cut flow table depicting the sequence, with reasonable statistics
  - Efficiencies for physics objects such as electrons, muons, taus, di-leptons, b-tagging, mis-tagging rates, etc as a function of p_T and η
  - Efficiencies for triggers, event cleaning
  - Code modules for special kinematical variables (e.g; M_{T2})
- Validation material
  - Benchmark points: mother-daughter masses, properties of off-shell particles both in production and decay, and mixings of final states, e.g; SLHA files
  - Configuration of Monte Carlo tools: run cards and input scripts for MadGraph, Pythia, Herwig in HEPDATA

https://indico.cern.ch/event/379384/contributions/1804395/attachments/756912/1038302/recast-wishlist-sep14.pdf

Wishlist of Users (2)

- Digitized plots
  - final limit and discriminant variable
  - kinematic distributions of signal MC
  - general variables kinematics after preselection
- Statistical interpretation
  - In order to combine the limits a full description of correlation between uncertainties is required
  - Breakdown backgrounds into all components in all signal region with stat.+syst. uncertainties or provide an error correlation matrix
  - Final likelihood model for each analysis: a small standalone code modules that reads the number of expected signal and return the likelihood
    - Card files for Higgs Combined tools etc.

https://indico.cern.ch/event/379384/contributions/1804395/attachments/756912/1038302/recast-wishlist-sep14.pdf

Material Provided

- Well defined event kinematics and selections
- Trigger efficiencies
- Lepton/photon reconstruction efficiencies, b-tagging, heavy jet (top, W/Z, H) tagging efficiencies vs. p_T (and possibly η)
- If not, then they are clearly referenced to our public Detector Performance notes (e.g; https://twiki.cern.ch/twiki/bin/view/CMSPublic/PublicPlotsEPS2015).

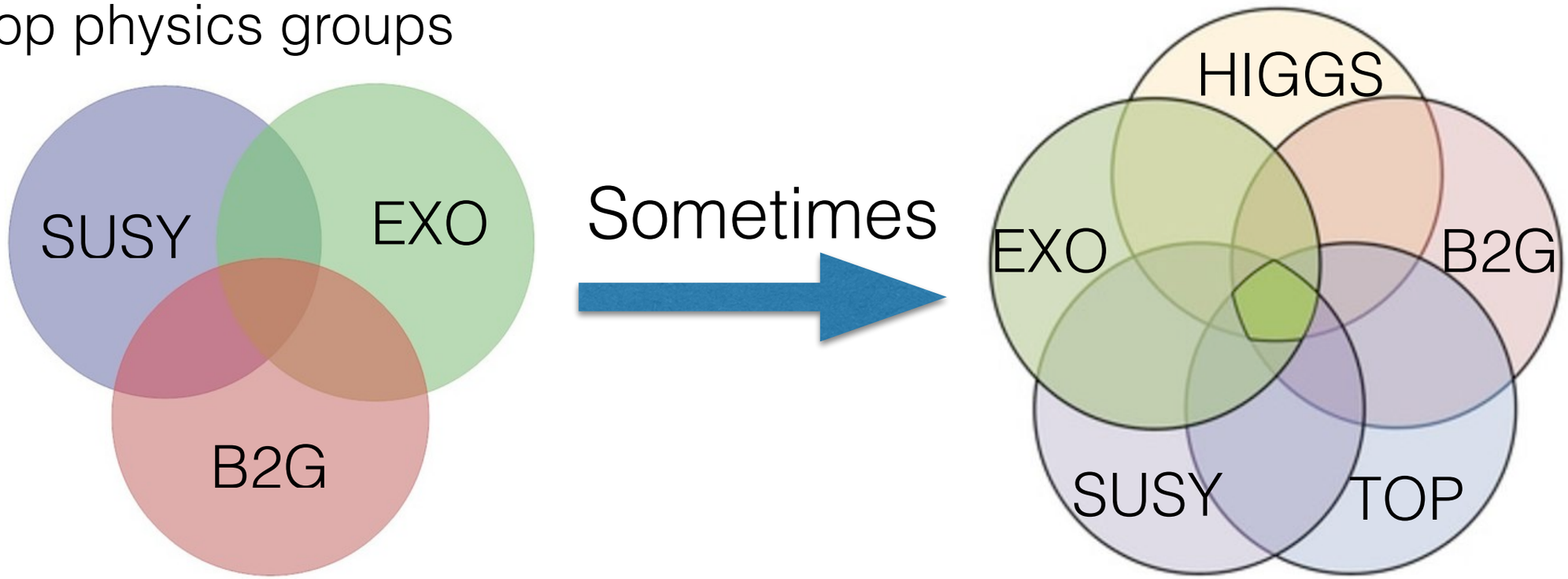
- Cut flow tables for a few well-defined benchmarks
- If a complex kinematical variable is used, then a standalone code
- Signal efficiencies or acceptance maps (when they make sense)
- Full breakdown of backgrounds and details on systematic uncertainties
- Guidelines to construct simplified likelihoods for the re-interpretation (https://cds.cern.ch/record/2242860?ln=en)
- HEPDATA only after analysis is accepted by journal

Material NOT Provided

- Jet, lepton, photons, MET resolutions
  - These are usually not so important, and if they are, re-interpretations by outsiders are likely problematic (use judgment)
- Efficiencies or over-efficiencies for lepton vetoes, light quark b-tagging probability, fake lepton probabilities
  - These are 2nd order effects provided right search is picked for a given BSM model.
  - They can be very important for BG estimates, but we do not expect re-casters to redo the background estimation
- Tools or data card files for statistical combination of analyses
  - We prefer experimentalist to do the job (https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HiggsCombination), since often combinations make sense when full details and uncertainty correlation are known

CMS BSM Physics Program

- Reminder: CMS BSM searches groups are divided into 3 Physics groups (SUSY, EXO, B2G), which at times are also at the boundaries of Higgs and Top physics groups



- The extra material for phenomenologist is provided by many analyses but not always in a consistent way
- Since Moriond 2017, all BSM analyses are required to provide all the information in HEP DATA, by the time analysis is published
  - Each physics group has dedicated contact person(s) to ensure centralize and standardize way to record the information

Additional Material by SUSY

CMS-SUS-16-033 ; CERN-EP-2017-072

Search for supersymmetry in multijet events with missing transverse momentum in proton-proton collisions at 13 TeV

CMS Collaboration

25 April 2017

Phys. Rev. D 96 (2017) 032003

Abstract: A search for supersymmetry is presented based on multijet events with large missing transverse momentum produced in proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 13$ TeV. The data, corresponding to an integrated luminosity of 35.9 fb^{-1}, were collected with the CMS detector at the CERN LHC in 2016. The analysis utilizes four-dimensional exclusive search regions defined in terms of the number of jets, the number of tagged bottom quark jets, the scalar sum of jet transverse momenta, and the magnitude of the vector sum of jet transverse momenta. No evidence for a significant excess of events is observed relative to the expectation from the standard model. Limits on the cross sections for the pair production of gluinos and squarks are derived in the context of simplified models. Assuming the lightest supersymmetric particle to be a weakly interacting neutralino, 95% confidence level lower limits on the gluino mass as large as 1800 to 1960 GeV are derived, and on the squark mass as large as 960 to 1390 GeV, depending on the production and decay scenario.

Links: e-print arXiv:1704.07781 [hep-ex] (PDF) ; CDS record ; CADI line (restricted) ;

Figures & Tables | Summary | Additional Figures & Tables | References | CMS Publications

Additional information on efficiencies needed for reinterpretation of these results are available here.
Additional technical material for CMS speakers can be found here

Figures

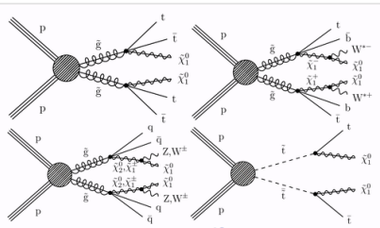


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Figure 1:
Example Feynman d
(lower right) T2tt scer
the lightest chargino.

CMS-PAS-SUS-16-052

Search for supersymmetry in events with at least one soft lepton, low jet multiplicity, and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV

CMS Collaboration

July 2017

Abstract: A search for supersymmetry with a compressed mass spectrum using events with a high-momentum jet attributed to initial state radiation, high missing transverse momentum, and a low-momentum lepton is presented. In particular, scenarios of top squark pair production are investigated, where the mass difference to the lightest supersymmetric particle (LSP) is smaller than the mass of the W boson. The search is performed in a sample of proton-proton collisions recorded with the CMS detector at a centre-of-mass energy of 13 TeV corresponding to an integrated luminosity of 35.9 fb^{-1}. The results are consistent with the expectation from standard model processes and limits are set on the production cross section in the plane of the top squark vs. LSP masses. The signal models used for the interpretation of the results assume either four-body decays of the top squark, $\tilde{t} \to \text{b}ff'\text{LSP}$, or decays via an intermediate chargino, $\tilde{t} \to \text{b}\tilde{\chi}_1^+ \to \text{b}ff'\text{LSP}$. Assuming a 100% branching ratio of the corresponding decay, top squark masses below 500 (540) GeV for four-body (chargino-mediated) decay are excluded at 95% confidence level for a mass difference to the LSP of about 30 GeV. These limits are currently the most stringent in the single lepton final state and are similar to those of analyses targeting other final states in this region of supersymmetry parameter space with 2016 data.

Links: CDS record (PDF) ; CADI line (restricted) ;

Figures & Tables | Summary | Additional Figures & Tables | References | CMS Publications

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Figures

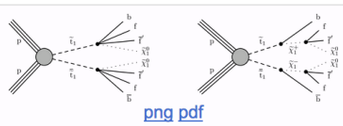

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Figure 1:
Signal models for top squark pair production with subsequent four-body (left) or chargino-mediated (right) decays.

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

Additional Material by SUSY

CMS SUSY Results: Objects Efficiency

- Moriond 2017
  - Light Leptons Selection Efficiency
  - Hadronic Tau identification efficiency
  - B-tagging Efficiency
  - Photon Selection Efficiency

Moriond 2017

In the following the representative object selection efficiencies for the SUSY 2016 analyses presented at Moriond2017 are reported.

Light Leptons Selection Efficiency

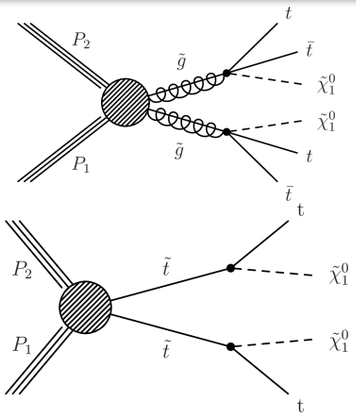
Representative Muon and Electron efficiencies for the WPs of the identification techniques used in SUS-16 analyses:

- only the analyses with at least one light lepton in the final state are considered and only the efficiency for the signal-lepton selections is reported (no veto selections);
- the efficiency refers to the reconstruction + identification + isolation + vertexing requirements for generator-level leptons from W decay in a simulated sample of ttbar events;
- the efficiency is corrected with the corresponding data/simulation scale factors extracted from 2016 data

CADI	Analysis	Muon pT and eta	Muon Selection Eff. vs (pT, eta)	.root file	El pT and eta	Electron Selection Eff. vs (pT, eta)	.root file
SUS-16-042	1L + Jets with ΔΦ	25, 2.4	eff	root	25, 2.5	eff	root
SUS-16-037	1L + Jets with MJ	20, 2.4	eff	root	20, 2.5	eff	root
SUS-16-040	1L RPV	20, 2.4	eff	root	20, 2.5	eff	root
SUS-16-035	2SS Leptons	10, 2.4	eff	root	15, 2.5	eff	root
SUS-16-034	2OS Leptons	20, 2.4	eff	root	20, 2.4	eff	root
SUS-16-041	Multileptons + jets	10, 2.4	eff	root	10, 2.5	eff	root
SUS-16-039	Multilepton EWK	10, 2.4	eff	root	15, 2.5	eff	root
SUS-16-039	2SS Leptons EWK	10, 2.4	eff	root	15, 2.5	eff	root
SUS-16-048	2OS Soft Leptons	3.5, 2.4	eff	root	5, 2.4	eff	root
SUS-16-043	EWK WH(bb)	25, 2.1	eff	root	30,1.442	eff	root

https://twiki.cern.ch/twiki/bin/view/CMSPublic/SUSMoriond2017ObjectsEfficiency

SUSY Recasting Example



arXiv:1610.08059v3 [hep-ph] 2 Sep 2017

Cornering Natural SUSY at LHC Run II and Beyond

Matthew R. Buckley, David Feld, Sebastian Macaluso,
Angelo Monteux and David Shih

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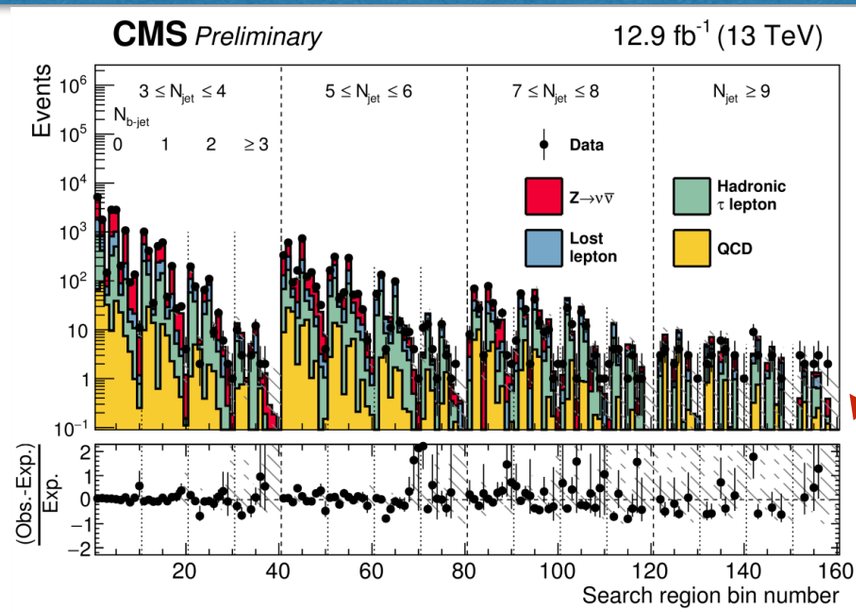
Rutgers, The State University of NJ
Piscataway, NJ 08854 USA

Abstract

We derive the latest constraints on various simplified models of natural SUSY with light higgsinos, stops and gluinos, using a detailed and comprehensive reinterpretation of the most recent 13 TeV ATLAS and CMS searches with ~ 15 fb^{-1} of data. We discuss the implications of these constraints for fine-tuning of the electroweak scale. While the most "vanilla" version of SUSY (the MSSM with R-parity and flavor-degenerate sfermions) with 10% fine-tuning is ruled out by the current constraints, models with decoupled valence squarks or reduced missing energy can still be fully natural. However, in all of these models, the mediation scale must be extremely low (< 100 TeV). We conclude by considering the prospects for the high-luminosity LHC era, where we expect the current limits on particle masses to improve by up to ~ 1 TeV, and discuss further model-building directions for natural SUSY that are motivated by this work.



Search	Data (fb^{-1})	Reference
ATLAS 2-6 jets + MET	13.3	ATLAS-CONF-2016-078 [29]
ATLAS 8-10 jets + MET	18.2	ATLAS-CONF-2016-095 [30]
ATLAS b-jets+MET	14.8	ATLAS-CONF-2016-052 [31]
CMS jets + MET (H_T^{miss})	12.9	CMS-PAS-SUS-16-014 [52]
ATLAS SSL/3L	13.2	ATLAS-CONF-2016-037 [32]
ATLAS 1L+jets +MET	14.8	ATLAS-CONF-2016-054 [53]
ATLAS multi-jets (RPV)	14.8	ATLAS-CONF-2016-057 [33]
ATLAS lepton+many jets	14.8	ATLAS-CONF-2016-094 [34]

Table 1: Searches most important to our study. All use the 13 TeV LHC data.

SUSY Recasting Example

CMS searches have so many signal regions (100+) that they are difficult to reinterpret. A proper approach would require sophisticated statistical methods combining multiple exclusive bins, using information (the correlation matrix of errors) that is not publicly available. In contrast, the ATLAS searches explicitly provide 95% CL limits on number of events due to new physics for each signal region, and generally have far fewer, coarser bins, allowing us to simply use the most sensitive SR to set a conservative (but reasonably accurate) limit.

One important case where CMS did include aggregate signal region information is the jets+MET search with H_T^{miss} [52], which we find to be very powerful. The CMS jets+MET search has b-tagged categories, low-MET and high-MET categories, few jet and many jet categories. As a result, it is equivalent to the union of several different ATLAS jets+MET searches.[5]

Our simulation methodology is as follows. We generate hard events using MadGraph 5.2.3.3 [56], generating pairs of gluinos, squarks, and antisquarks in all possible combinations. Decay and showering is performed via Pythia 8.219 [57] (with which we implement the RPV and stealth decays of the higgsino), and we use Delphes 3.3.2 [58] with an ATLAS-approximating detector geometry for detector simulation. In order to speed up the event generation, we worked with unmatched samples in most cases.[6] The NLO cross sections for the superparticle production are obtained via Prospino [59–61]. The cutflows for the ATLAS and CMS analyses are recasted using Root 5.34 [62], and validated against the published experimental limits on supersymmetric simplified models.

Complaints 😕

Envious Statement 😕

Compliments 😀

Event Generator 🤔

SUSY Recasting Example

- Simplified Models
  - Mostly based on MSSM , except in one case with HV /Stealth scenario
  - LSP is the higgsino, and for that naturalness ≤ 300 GeV (Δ ≤10)

For each choice of μ, we consider the following models:

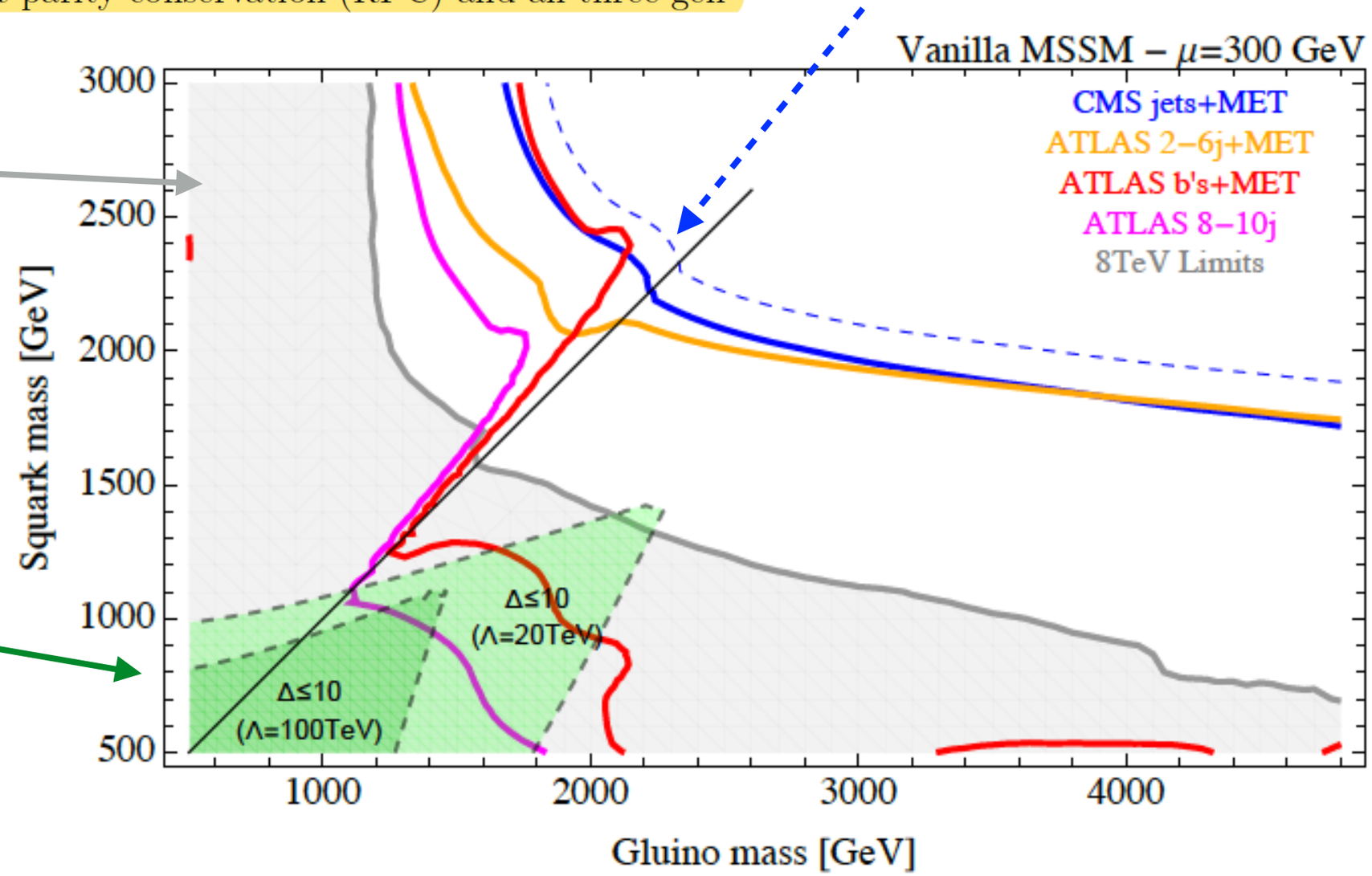
1. *"Vanilla SUSY"*: the MSSM with R-parity conservation (RPC) and all three generations of squarks degenerate.[7]

The nominal limits without recasting uncertainty (factor of 1.5 efficiency reduction)

excluded by 8 TeV searches

Δ ≤ 10 naturalness bound on the gluino and stop masses for Λ = 20 and 100 TeV

$$\delta m_H^2 \propto \mu^2; \quad \Delta \equiv \frac{2\delta m_H^2}{m_h^2}$$



SUSY Recasting Example

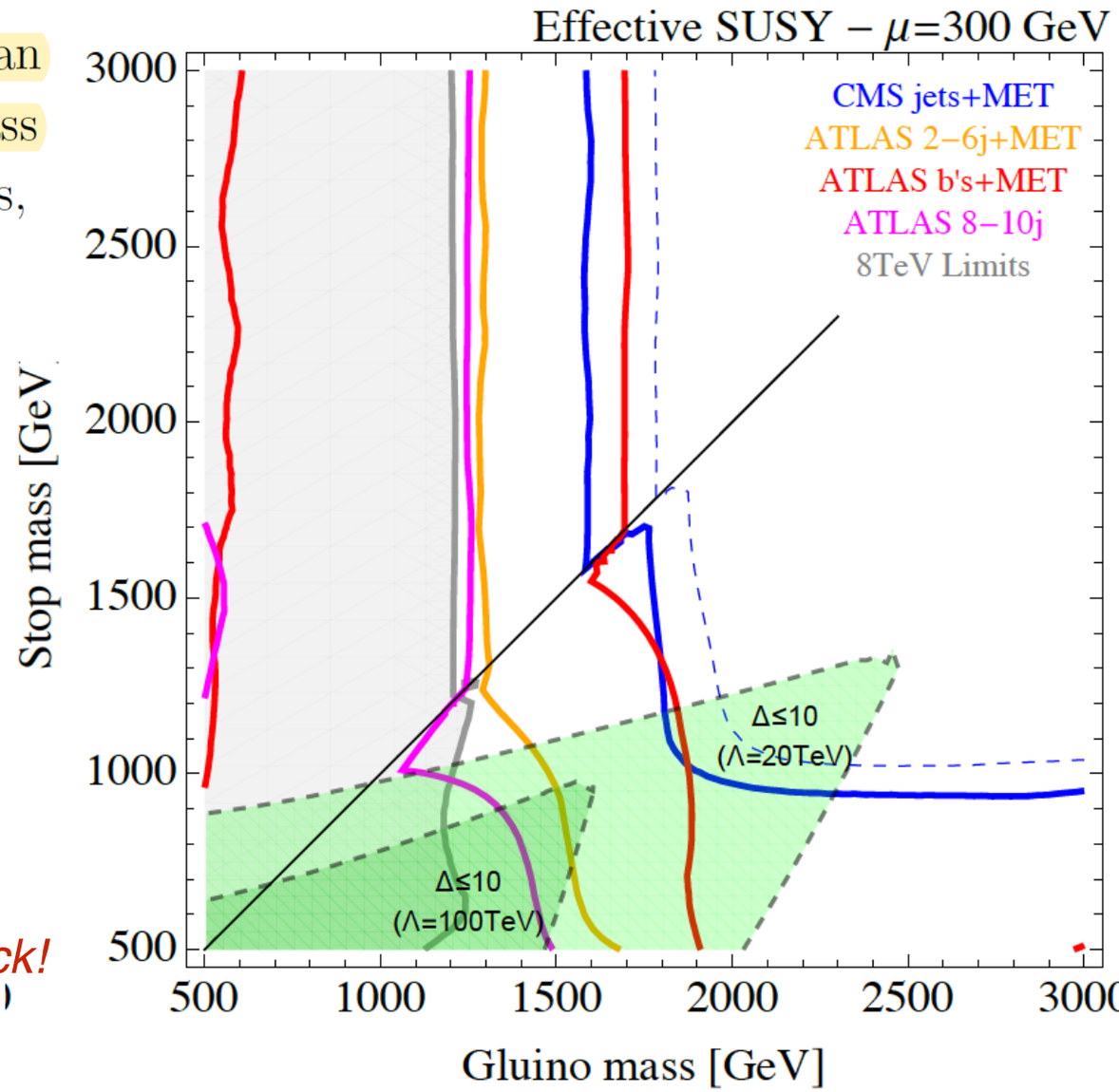
- Simplified Models
  - Mostly based on MSSM
  - LSP is the higgsino, and for that naturalness ≤ 300 GeV (Δ ≤10)

2. *"Effective SUSY"*: The RPC MSSM with all squarks other than the stops and the left-handed sbottom decoupled from the mass spectrum (see Refs. [7, 8]). For the light third-generation fields, their (pole) masses are taken to be the same, but our results will still hold if they are of the same order.

4.2 Effective SUSY

We show the limits on the Effective SUSY model (with 1st/2nd generation squarks decoupled to 5 TeV) in Fig. 3: gluinos below 1.8 TeV are excluded while limits on direct stop production are at 900 GeV, significantly raising the previous 8 TeV limits.

Food for thought: I leave the discussion to Andrew Whitbeck!



SUSY Recasting Example

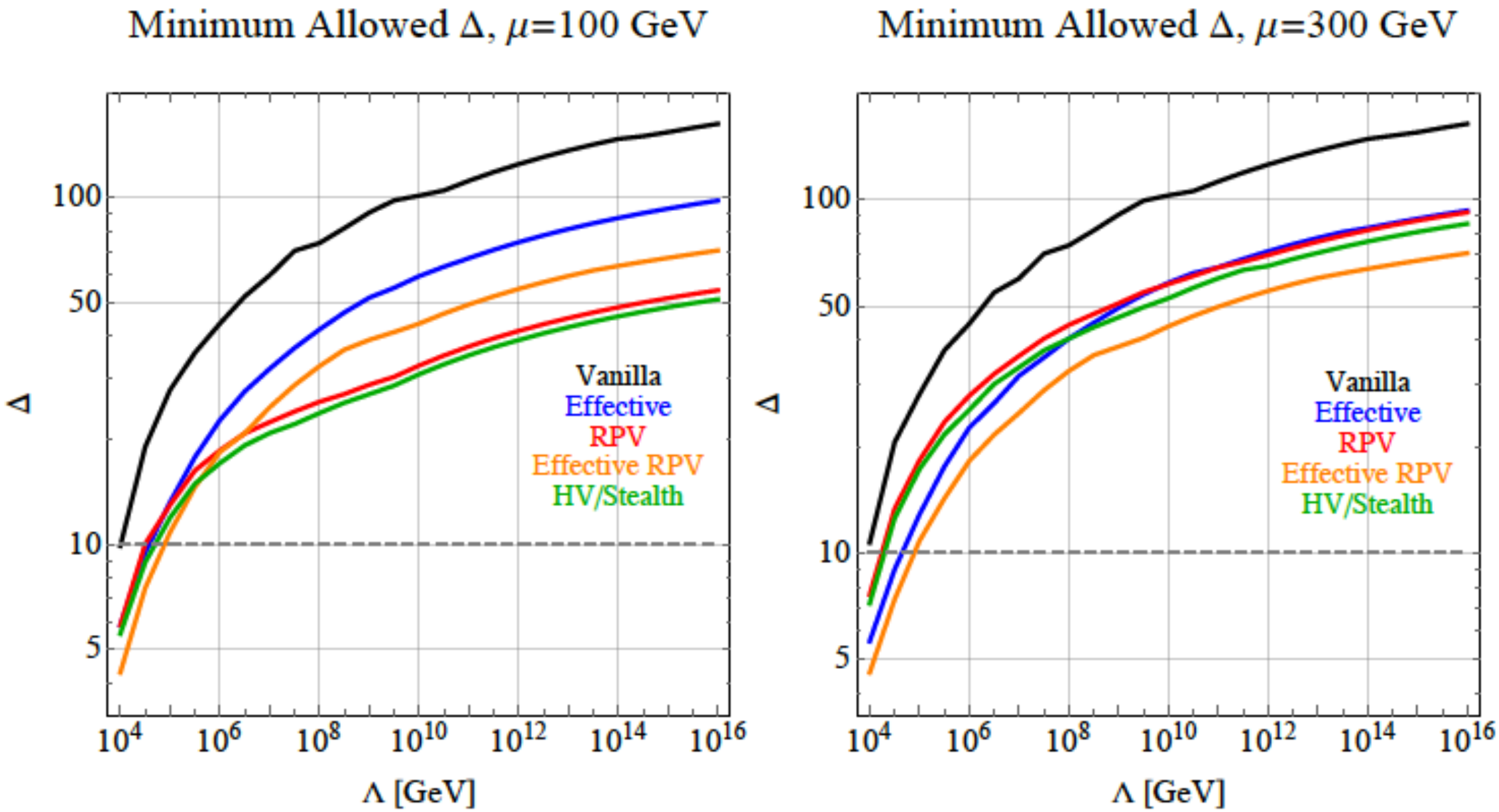


Figure 6: Minimum amount of tuning Δ which is experimentally allowed as a function of SUSY breaking scale Λ.

Food for thought: I leave the discussion to Andrew Whitbeck !

Additional Material by EXO

- Many EXO analyses practiced it since early days of LHC

Search for Isosinglet Heavy Majorana Neutrinos in $e^{\pm}e^{\pm}$ and $\mu^{\pm}\mu^{\pm}$ Events in pp Collisions at $\sqrt{s}$ = 7 GeV

Abstract

We present a search for heavy Majorana neutrinos (N) that transform as isosinglets under the $SU(2)_L$ group of gauge transformations. The event signature is defined by two charged leptons of the same kind and two jets in data collected with the CMS detector at the Large Hadron Collider. The data correspond to an integrated luminosity of 4.98 /fb of pp collisions at a center-of-mass energy of 7 TeV. No excess of events is observed beyond the expected standard-model background and this is used to set upper limits on the square of the mixing element $V_{\ell N}$, for ℓ = μ, e as a function of Majorana neutrino mass.

Approved Tables and Plots: Additional Material -- $\mu^{\pm}\mu^{\pm}$ Channel Analysis (click on plot or table to download file)

Figure	Abbreviated Caption
$\lvert\eta\rvert \setminus p_T$ | 10 – 15 GeV/c | 15 – 20 GeV/c | 20 – 25 GeV/c | 25 – 35 GeV/c 0 – 1.0 | 0.1068 ± 0.0017 | 0.0698 ± 0.0010 | 0.0571 ± 0.0014 | 0.0593 ± 0.0017 1.0 – 1.479 | 0.1278 ± 0.0026 | 0.0874 ± 0.0016 | 0.0714 ± 0.0023 | 0.0690 ± 0.0028 1.479 – 2.0 | 0.1378 ± 0.0029 | 0.0992 ± 0.0019 | 0.0901 ± 0.0028 | 0.0882 ± 0.0035 2.0 – 2.5 | 0.1713 ± 0.0047 | 0.1107 ± 0.0033 | 0.0981 ± 0.0049 | 0.1196 ± 0.0068	Muon misidentification rate ("fake rate") in bins of |η| and p_T, where the misidentification rate is defined as the fraction of loose muons passing the tight muon selection. Loose muons are defined by relaxing the relative isolation requirement.
Sample | p_T Cut (GeV/c) | Predicted | MC Truth | Ratio $t\bar{t}$ | 40 | 171 ± 4 | 107 | 1.59 ± 0.04 $t\bar{t}$ | 60 | 145 ± 4 | 107 | 1.36 ± 0.04 $t\bar{t}$ | 80 | 133 ± 6 | 107 | 1.25 ± 0.05 W + jets | 40 | 5.98 ± 1.35 | 6 | 1.00 ± 0.23 QCD | 40 | 2.23 ± 0.67 | 2 | 1.12 ± 0.34 QCD double-to-single | 40 | 109 ± 4 | 80 | 1.36 ± 0.05	Predicted and observed fake backgrounds in $t\bar{t}$, W + jets, and QCD Monte Carlo samples for events passing the loose selection. For the $t\bar{t}$ samples the effect of varying the cut on the p_T of the leading jet in the sample used to measure the fake rates is shown. All signal selection requirements are applied except for the missing E_T requirement, and for the QCD tests only, the same-sign requirement. Uncertainties are statistical only. The results are normalized to the total effective integrated luminosity of the Monte Carlo samples used.
Sample | p_T Cut (GeV/c) | Predicted | MC Truth | Ratio $t\bar{t}$ | 40 | 182 ± 4 | 116 | 1.57 ± 0.03 $t\bar{t}$ | 60 | 156 ± 4 | 116 | 1.34 ± 0.03 $t\bar{t}$ | 80 | 143 ± 6 | 116 | 1.23 ± 0.05 W + jets | 40 | 13.4 ± 1.1 | 12 | 1.12 ± 0.09 QCD | 40 | 2.96 ± 0.72 | 3 | 0.98 ± 0.24 QCD double-to-single | 40 | 112 ± 4 | 91 | 1.23 ± 0.04	As above, but with the jet p_T requirement used in event selection lowered to 20 GeV instead of the standard 30 GeV.
Source | Events Monte Carlo: WZ | 3.22 ± 0.3 (stat.) ± 0.13 (syst.) ZZ | 1.02 ± 0.10 (stat.) ± 0.04 (syst.) $W\gamma$ | 0.75 ± 0.27 (stat.) ± 0.07 (syst.) $t\bar{t}W$ | 1.06 ± 0.05 (stat.) ± 0.53 (syst.) W^+W^+ | 0.76 ± 0.06 (stat.) ± 0.38 (syst.) W^-W^- | 0.45 ± 0.03 (stat.) ± 0.23 (syst.) dp $W^{\pm}W^{\pm}$ | 0.07 ± 0.02 (stat.) ± 0.04 (syst.) Total Monte Carlo | 7.33 ± 0.42 (stat.) ± 0.71 (syst.) Data-driven background estimate: Fake muon background | 63.09 ± 4.20 (stat.) ± 22.08 (syst.) Total background | 70.42 ± 4.22 (stat.) ± 22.09 (syst.) Observed in data (4.96 fb^{-1}) | 65	Observed event yields and estimated backgrounds for the analysis in the muon channel analysis. The first quoted uncertainty on each background estimate is statistical and the second is systematic.

Additional Material by EXO

TWiki > CMSPublic Web > PhysicsResults > PhysicsResultsEXO > PhysicsResultsEXO11095 (2013-02-20, SteveWorm)

Search for heavy resonances in the W/Z-tagged dijet mass spectrum in pp collisions at 7 TeV

- Plots from the paper EXO-11-095 (*click on plot to get .pdf*)
- Additional material for EXO-11-095 (*click on plot to get .pdf*)

TWiki > CMSPublic Web > PhysicsResults > PhysicsResultsEXO > PhysicsResultsEXO13004 (2013-08-05, JohnPaulChou)

Edit Attach PDF

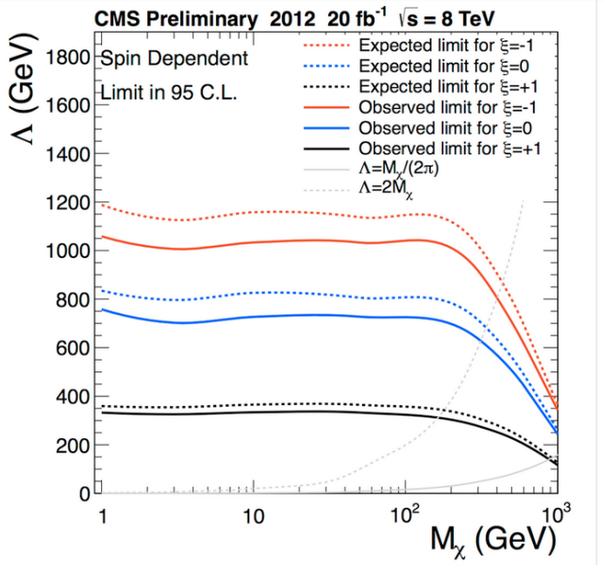
Mono-lepton dark matter interpretation at sqrt{s} = 8 TeV

A search for new physics in final states with an electron or a muon and a neutrino has been performed and is documented in EXO-12-060.The results can be interpreted in terms of the cross section of a W-boson recoiling against a pair of dark matter particles in an effective theory. Such process would be visible in the detector as a lepton + MET final state.

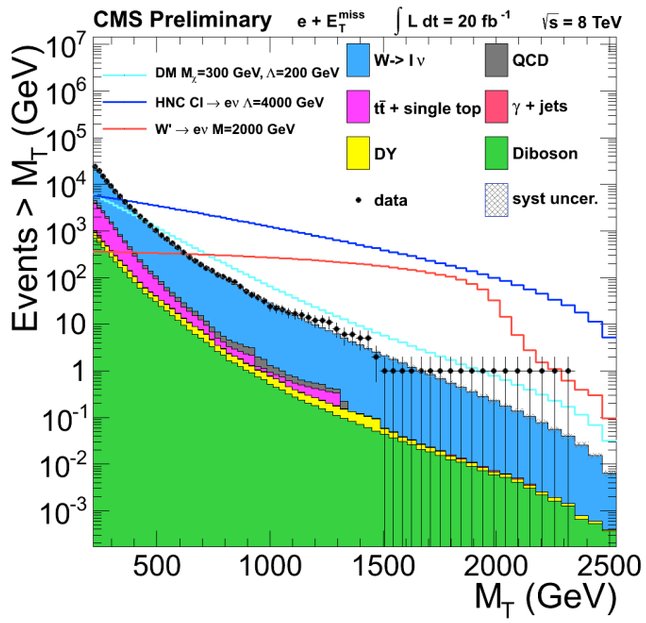
The dark matter model consideres two possible couplings, vector- and axial-vector like. They could couple to up- and down-type quarks with different strengths, parametrized by xi and leading to interference for the cases xi = 1. Possible consequences on the signal cross section and shape could be studied in this channel. The results are presented in terms of pp cross section limits, which are being transformed to limits on the effective parameter Lambda and DM-nucleon cross sections as measured by the direct detection experiments.

Additional Material

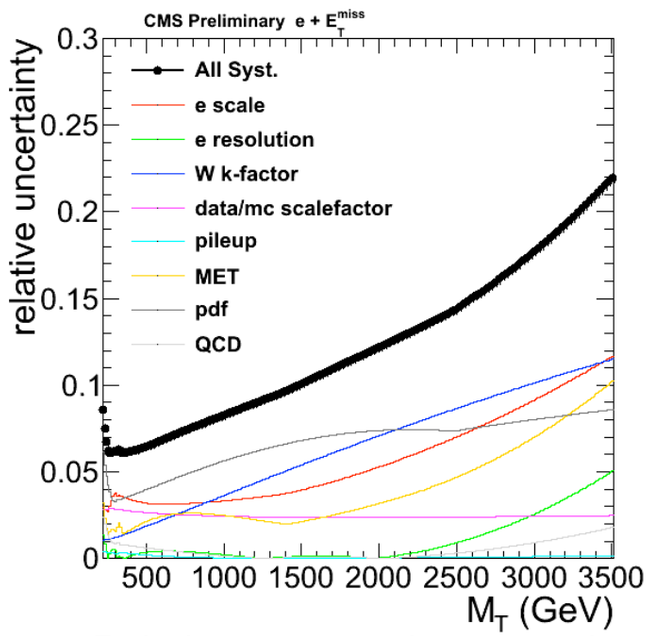
Figure



Exclusion plane in Λ vs. Mχ, for axial-vector-like (spin dependent) and xi=+1,0,-1



Cumulative MT-distribution for the electron channel.



Relative systematic uncertainty in the electron channel

Additional Material by B2G

- Not much, but results are self sufficient for those interested

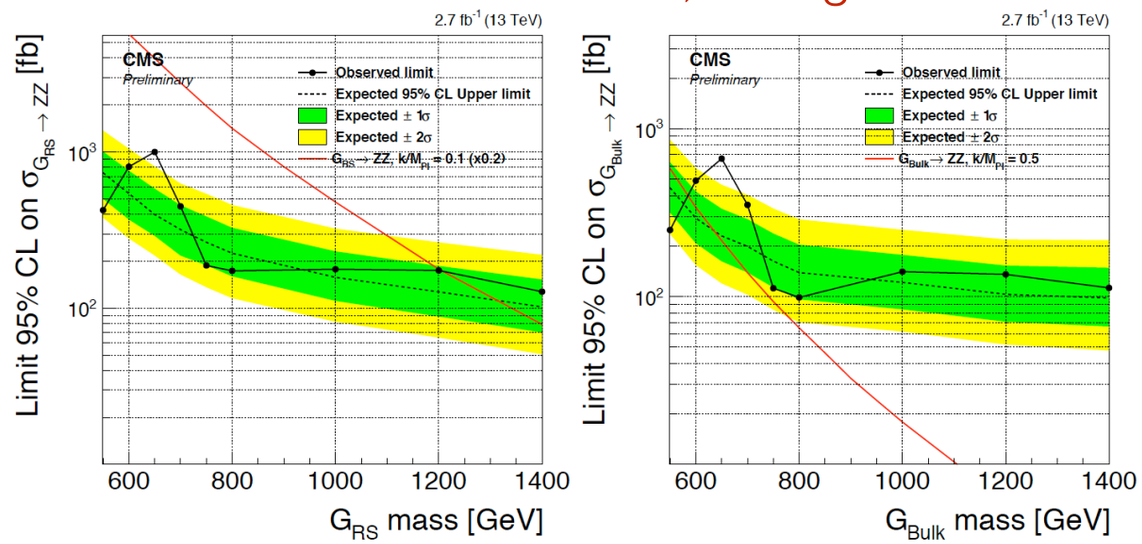
Search for diboson resonances in the semileptonic $X \to ZV \to \ell^+\ell^-\,q\bar{q}$ final state at $\sqrt{s} = 13$ TeV with CMS

The CMS Collaboration

Abstract

A search for diboson resonances is performed in the semileptonic $X \to ZV \to \ell^+\ell^-\,q\bar{q}$ final state, where one vector boson decays hadronically ($V = W, Z$) and the other, a Z boson, decays into two leptons, in the mass range $550 \leq m_{ZV} \leq 2500$ GeV. In this

3.9σ local excess, 3.5σ global



See talk by Jack Collins (W'/Z' → V (A → bb))

Search for vector-like light-flavor quark partners in proton-proton collisions at $\sqrt{s} = 8$ TeV

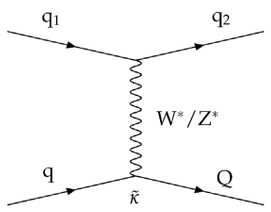
CMS Collaboration

8 August 2017

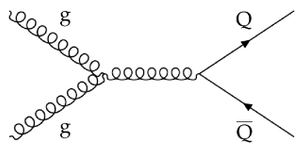
Submitted to Phys. Rev. D

Event Description

Single



Pair



Production	Channel
Single (electroweak)	$Dq \to Wqq$ $Dq \to Zqq$
Pair (strong)	$Q\bar{Q} \to WqWq$ $Q\bar{Q} \to WqZq$ $Q\bar{Q} \to WqHq$ $Q\bar{Q} \to ZqZq$ $Q\bar{Q} \to ZqHq$

Selection

Event category	Tight leptons (μ,e)	Additional selection criteria
W^-qq	1 with $p_T > 30$ GeV negative charge	1 or 2 selected central jets, all anti-tagged leading $p_T > 200$ GeV 1 selected forward jet $p_T(W \to \ell\nu) > 150$ GeV $\Delta R(\ell, \nu) < 1.5$ $p_T^{miss} > 60$ GeV, $M_T > 40$ GeV
Zqq	2 opposite-sign same-flavor leading $p_T > 30$ GeV subleading $p_T > 20$ GeV	1 or 2 selected central jets, all anti-tagged leading $p_T > 200$ GeV 1 selected forward jet $\lvert m_{\ell\ell} - mZ \rvert < 7.5$ GeV $p_T(Z \to \ell\ell) > 150$ GeV

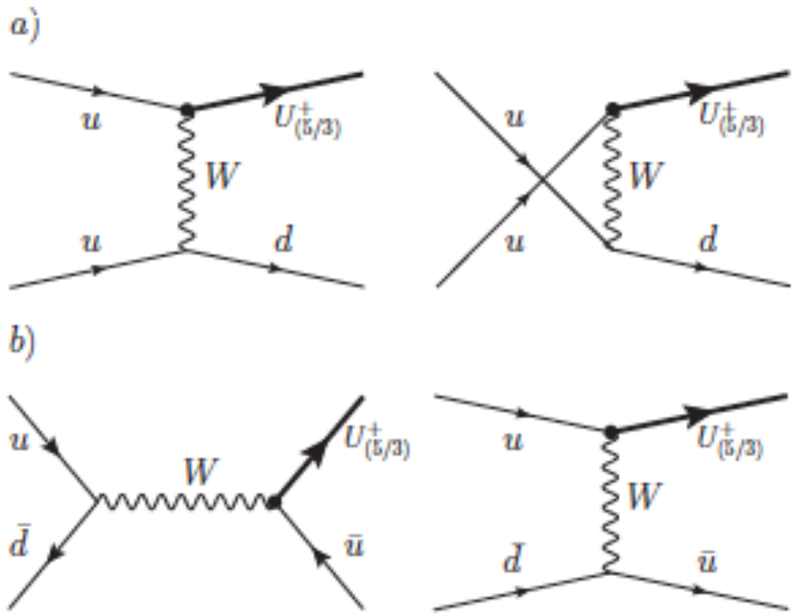
B2G Recasting Example

Production of exotic composite quarks at the LHC

- Extended Weak Isospin Model: The excited states trough the weak isospin symmetry
- SM $q,\ell \in I_W = 0, 1/2$ and $W^{\pm}/Z/\gamma \in I_W = 0, 1$
- $\Rightarrow$ excited fermions $\in I_W \leq 3/2$
- Multiplets with $I_W = 1, 3/2$ contain ordinary and exoticly (5/3, -4/3) charged excited quarks (U , D) and (U^+, D^-)
- U^+, D^- excited quarks interact with the SM fermions only via $W^{\pm}$

I_W	Multiplet	Q	Y
0	L^-	-1	-2
$\frac{1}{2}$	$\mathbf{L} = \begin{pmatrix} L^0 \\ L^- \end{pmatrix}$	$\begin{matrix} 0 \\ -1 \end{matrix}$	-1
1	$\mathbf{L} = \begin{pmatrix} L^0 \\ L^- \\ L^{--} \end{pmatrix}$	$\begin{matrix} 0 \\ -1 \\ -2 \end{matrix}$	-2
$\frac{3}{2}$	$\mathbf{L} = \begin{pmatrix} L^+ \\ L^0 \\ L^- \\ L^{--} \end{pmatrix}$	$\begin{matrix} 1 \\ 0 \\ -1 \\ -2 \end{matrix}$	-1

I_W	Multiplet	Q	Y
0	U	2/3	4/3
0	D	$-1/3$	$-2/3$
$\frac{1}{2}$	$\Psi = \begin{pmatrix} U \\ D \end{pmatrix}$	$\begin{matrix} 2/3 \\ -1/3 \end{matrix}$	1/3
1	$U = \begin{pmatrix} U^+ \\ U \\ D \end{pmatrix}$	$\begin{matrix} 5/3 \\ 2/3 \\ -1/3 \end{matrix}$	4/3
1	$D = \begin{pmatrix} U \\ D \\ D^- \end{pmatrix}$	$\begin{matrix} 2/3 \\ 1/3 \\ -4/3 \end{matrix}$	$-2/3$
$\frac{3}{2}$	$\Psi = \begin{pmatrix} U^+ \\ U \\ D \\ D^- \end{pmatrix}$	$\begin{matrix} 5/3 \\ 2/3 \\ -1/3 \\ -4/3 \end{matrix}$	1/3



- Example: Resonant production of U^+ D^-

$$u\,u \to U^+ d \to W^+ u\,d \qquad d\,d \to D^- u \to W^- d\,u$$
$$u\,\bar{d} \to U^+ \bar{u} \to W^+ u\,\bar{u} \qquad d\,\bar{u} \to D^- \bar{d} \to W^- d\,\bar{d}$$

Final state: ℓ + MET +jj

B2G Recasting Example

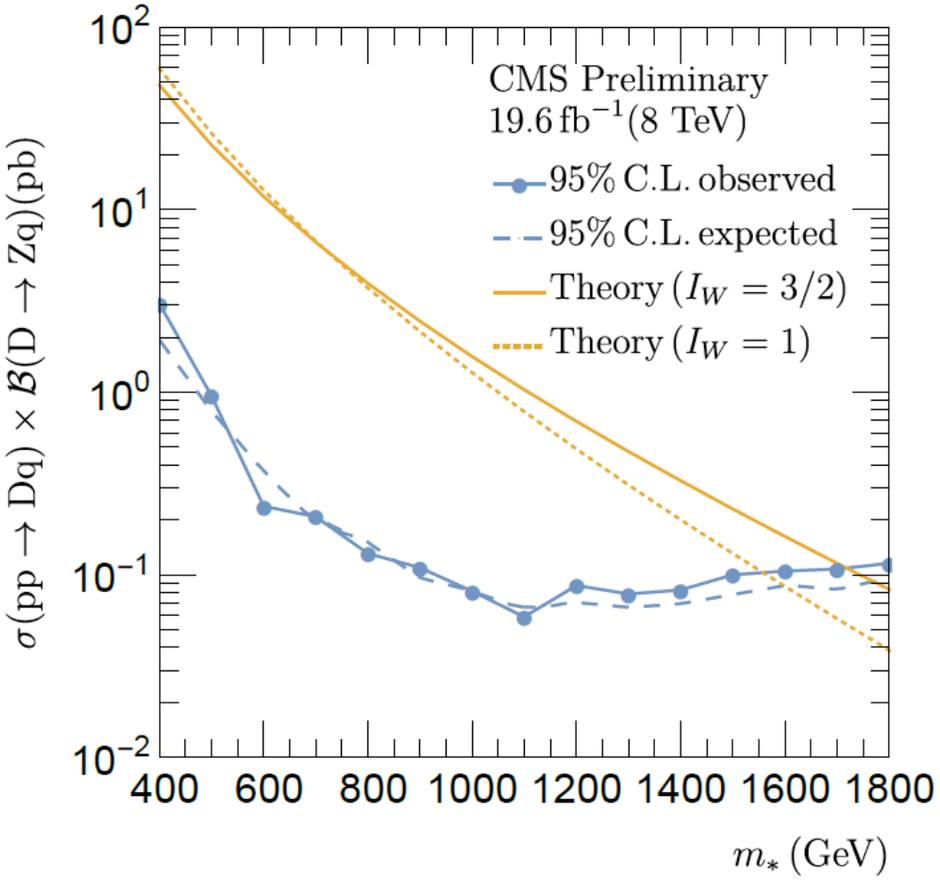


FIG. 11. (Color online) 95% Confidence Level limits observed (solid line with disk markers) and expected (dashed line) as reported by a CMS search [60] for light flavour quark partners in the Zqq channel with the prediction of our model are compared with predictions from our theoretical model. For $I_W = 3/2$, solid line (orange) masses lower than $m_* \approx 1710$ GeV are excluded at 95% C.L. while for $I_W = 1$, dotted line (orange), the lower bound is $m_* \approx 1550$ GeV.

Production of exotic composite quarks at the LHC

	3-σ	5-σ
L (fb^{-1})	m_* (GeV)	m_* (GeV)
30	$2570 + 50 - 30$	$2330 + 40 - 30$
300	$3130 + 50 - 40$	$2890 + 60 - 40$
3000	$3630 + 50 - 40$	$3420 + 60 - 50$

TABLE VI. Discovery reach, in the case $I_W = 1$, for m_* at 3- and 5-σ level within the statistical error at different values of the integrated luminosity $L = (30, 300, 3000)$ fb^{-1}.

Finally we have also estimated a bound on the mass of the excited quarks of our composite scenario with extended weak iso-spin multiplets comparing predictions of our models ($I_W = 1$, and $I_W = 3/2$) against published data from a CMS search [60] of exotic light flavour quark partners in pp collisions at $\sqrt{s} = 8$ TeV at LHC. Our analysis shows that typical lower bounds on the mass of excited quarks from extended weak iso-spin models would be around $m_* \approx 1710$ GeV for $I_W = 3/2$ and $m_* \approx 1550$ GeV for $I_W = 1$ based on the 95 confidence level observed limits in the Zqq channel.

The above are quite interesting results which in our opinion warrant more detailed studies. For instance the two dimensional parameter space (Λ, m_*) could be fully explored. Also the effect of expected contact interactions should be taken into account. This could improve the sensitivity of the signature to larger portions of the parameter space.

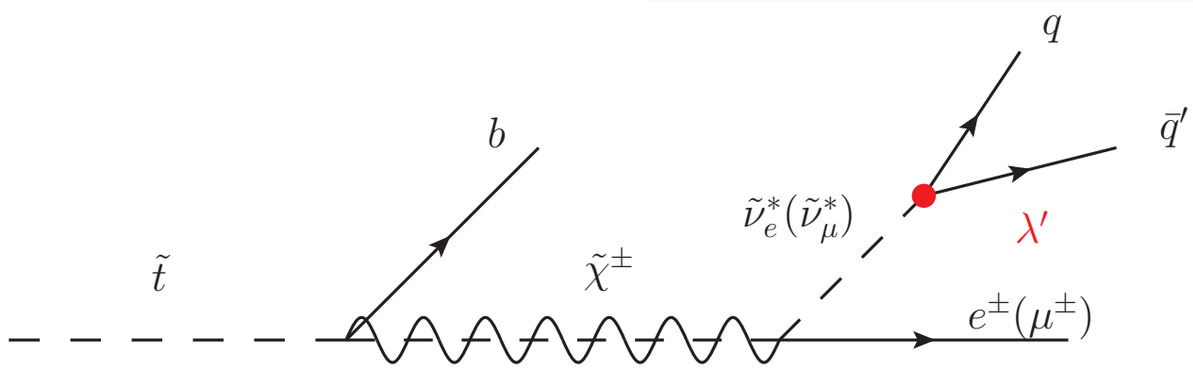
Conclusion and Open Discussion

- CMS recognize the importance of providing information for re-interpretations and work towards improvements compared to past practices
- Many SUSY analyses have a high number of signal regions to keep generality, however few practices that SUSY follows
  - Define aggregated inclusive regions, such as a re-caster can pick "best" region for particular BSM mode
  - If aggregated regions are not possible, then provide the appropriate correlations of the background estimates
- When can a re-interpretation go wrong?
- What are limitations of simplified likelihoods approaches?
  - Simplified likelihood for the re-interpretation of public CMS results
- MadAnalysis 5: Public analysis database for LHC BSM Physics (https://arxiv.org/pdf/1407.3278.pdf)

Open Discussion

Recasting vs Dedicated Analysis

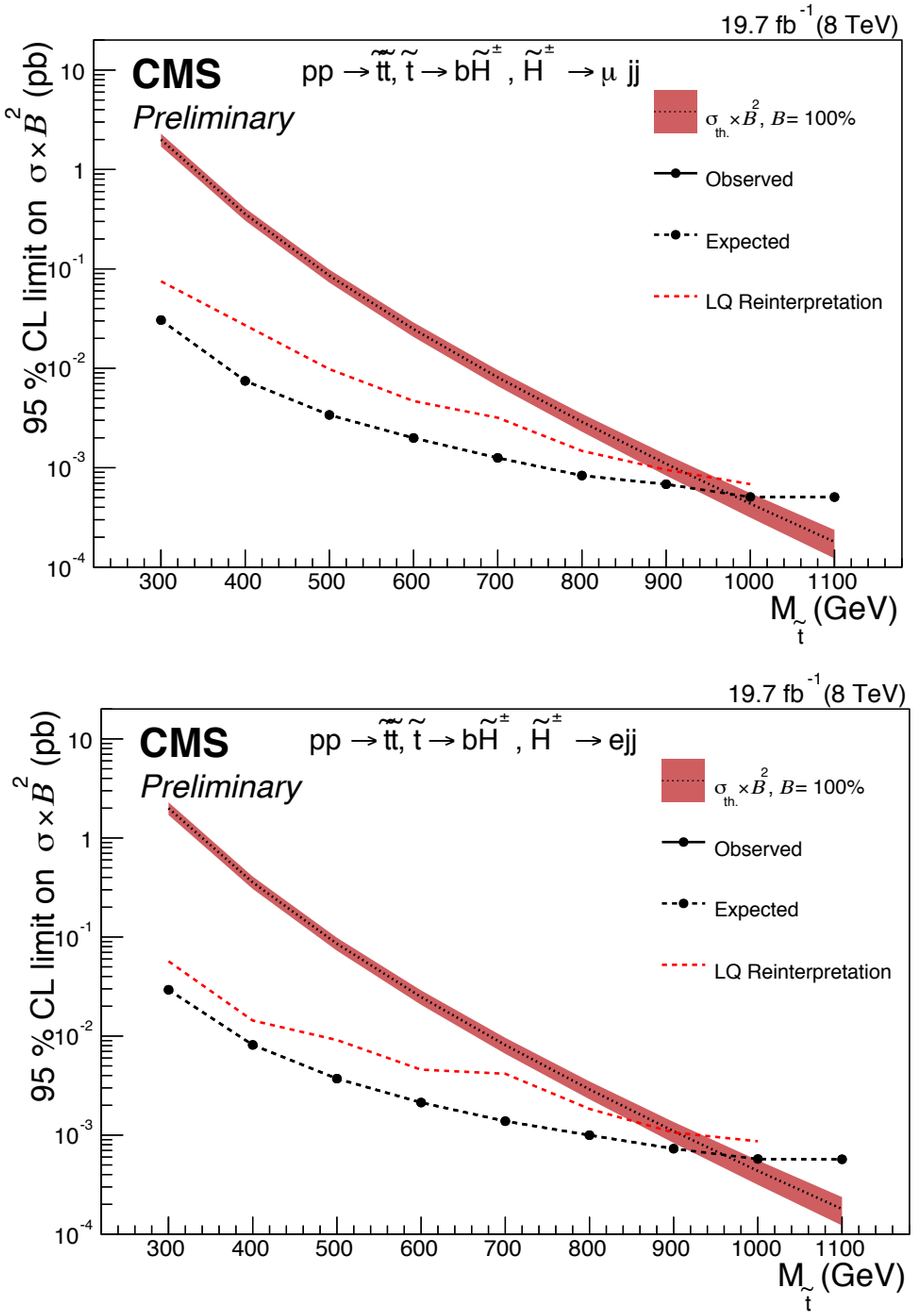
$$M_{\tilde{\chi}^{\pm}} = M_{\tilde{t}} - 100\ GeV$$



$$\tilde{t} \to \tilde{\chi}^{\pm} b \to \tilde{\nu}^* \ell^{\pm} b$$
$$(\tilde{\nu}^* \to jj)\ell^{\pm} b$$

- We initially checked if a reinterpretation of LQ (EXO-12-041, EXO-12-042) will be sufficient?
- After observing a factor of 2-3 improvement on x-sections, we decided to go for a dedicated analysis

EXO-14-013



These plots are for illustration!

Thank you

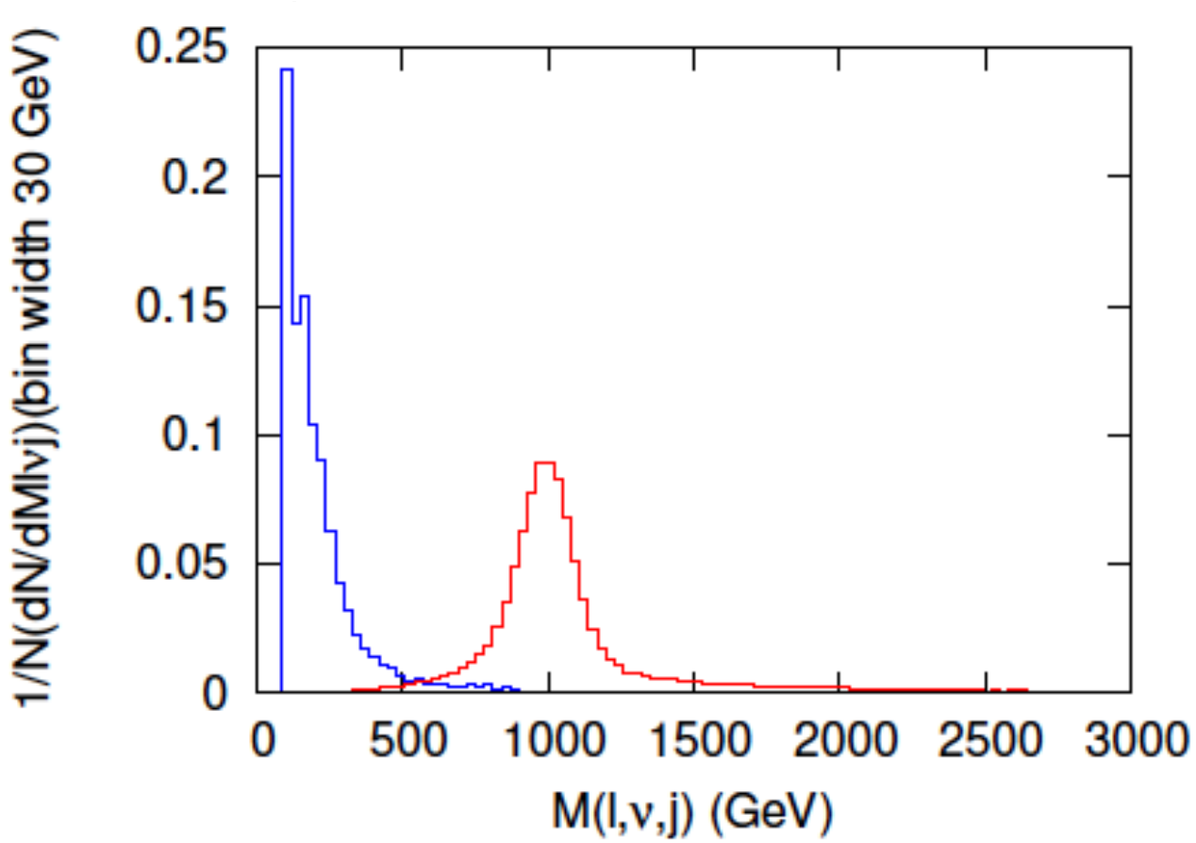
Special thanks to Sezen Sekmen, Andrew Whitbeck, Roberto Leonardi, Benjamin Fuks, Claudio Campagnari, Stephen Mrenna for providing the material and useful discussions

Backup

B2G Recasting Example

Production of exotic composite quarks at the LHC

- MC Generation
  - Partonic processes simulation (CalcHEP)
    - m* ∈ [500; 5000] GeV with steps of 250 GeV
    - 100000 events per sample
  - Simulation of detector effects (DELPHES): efficiency, resolution, geometrical acceptance of CMS experiment etc.
- Selection
  - 2 jets and 1 lepton with
    - p_T (j1) ≥ 180 GeV
    - p_T (j2) ≥ 100 GeV



Additional Material by B2G

- Not much, but results are self sufficient for those interested

CMS-B2G-15-008 ; CERN-EP-2016-279

Search for single production of a heavy vector-like T quark decaying to a Higgs boson and a top quark with a lepton and jets in the final state

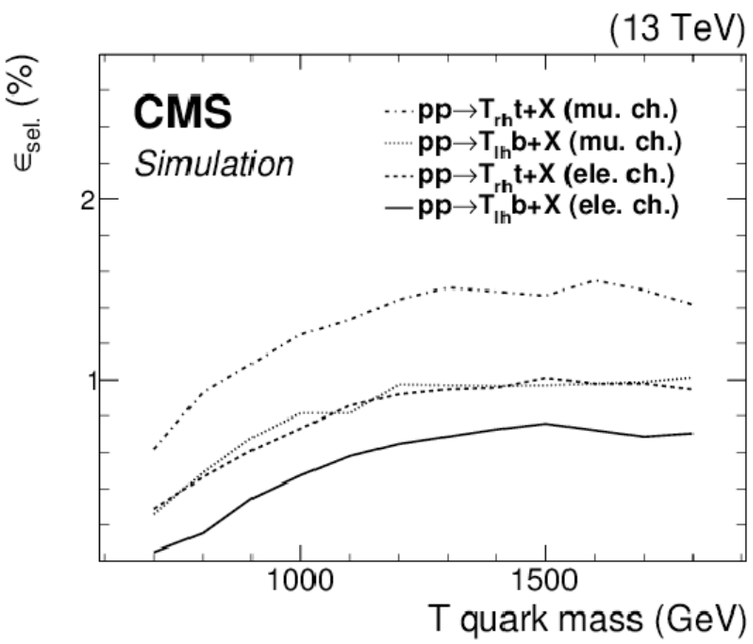
CMS Collaboration

3 December 2016

Phys. Lett. B 771 (2017) 80

Abstract: A search for single production of vector-like top quark partners (T) decaying into a Higgs boson and a top quark is performed using data from pp collisions at a centre-of-mass energy of 13 TeV collected by the CMS experiment at the CERN LHC, corresponding to an integrated luminosity of 2.3 fb^{-1}. The top quark decay includes an electron or a muon while the Higgs boson decays into a pair of b quarks. No significant excess over standard model backgrounds is observed. Exclusion limits on the product of the production cross section and the branching fraction are derived in the T quark mass range 700 to 1800 GeV. For a mass of 1000 GeV, values of the product of the production cross section and the branching fraction greater than 0.8 and 0.7 pb are excluded at 95% confidence level, assuming left- and right-handed coupling of the T quark to standard model particles, respectively. This is the first analysis setting exclusion limits on the cross section of singly produced vector-like T quarks at a centre-of-mass energy of 13 TeV.

Links: e-print arXiv:1612.00999 [hep-ex] (PDF) ; CDS record ; CADI line (restricted) ;



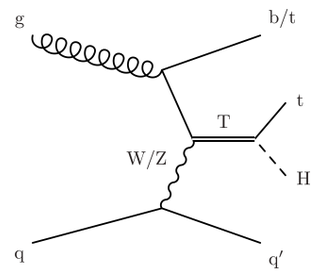


Table 3
Impacts of the largest systematic uncertainties in the signal event yields. The signal samples for $T_{lh}b$ production are shown. The uncertainties in the forward jet, and lepton isolation and trigger are rate uncertainties, all other uncertainties are evaluated bin-by-bin. All values are reported as percentage of the signal event yield.

	Electron channel			Muon channel		
	$T_{lh}(700)$	$T_{lh}(1200)$	$T_{lh}(1700)$	$T_{lh}(700)$	$T_{lh}(1200)$	$T_{lh}(1700)$
b tagging, heavy flavour	7.8	7.6	8.7	6.0	7.5	8.5
b tagging, light flavour	0.7	0.7	0.5	1.2	0.6	0.7
Forward jet	15	15	15	15	15	15
Jet energy resolution	7.0	0.6	0.2	0.2	2.3	0.9
Jet energy scale	9.0	4.2	4.9	3.8	3.8	4.4
Lepton isolation and trigger	5.0	5.0	5.0	5.0	5.0	5.0
Soft-drop mass	3.1	1.1	0.3	0.5	0.3	1.3
PDF	4.8	2.7	4.2	4.8	2.8	4.1
Luminosity	2.7	2.7	2.7	2.7	2.7	2.7
Pileup	1.4	0.6	0.1	1.3	0.7	1.1