Searches for New Physics at CMS

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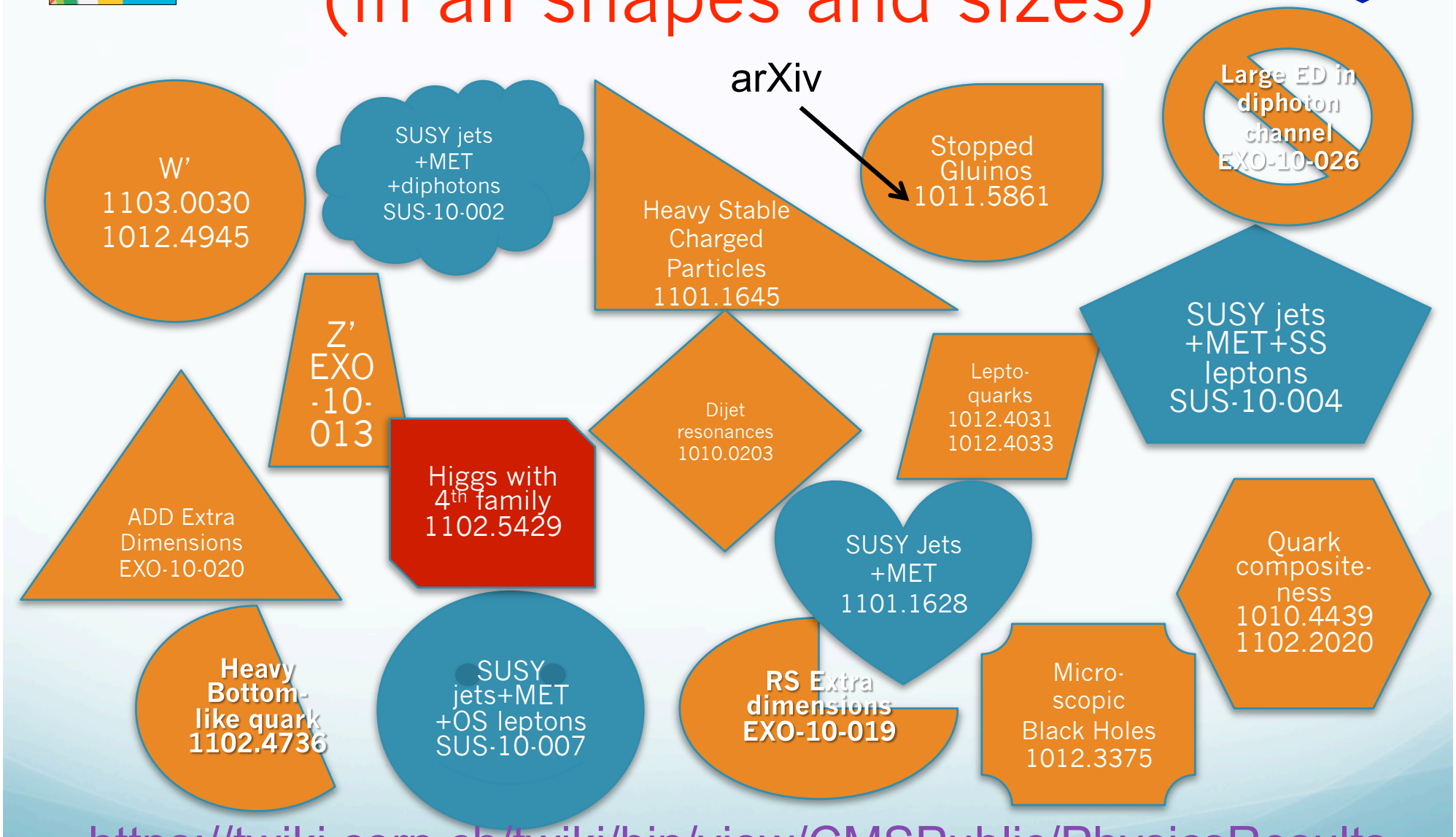
on behalf of the CMS Collaboration

XXV Rencontres de Physique de La Vallee d'Aoste

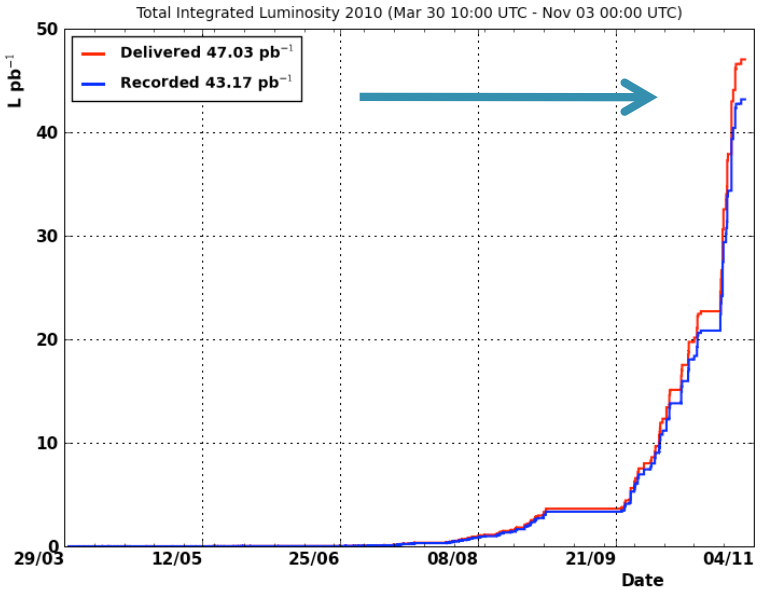
Search for New Physics (in all shapes and sizes)



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

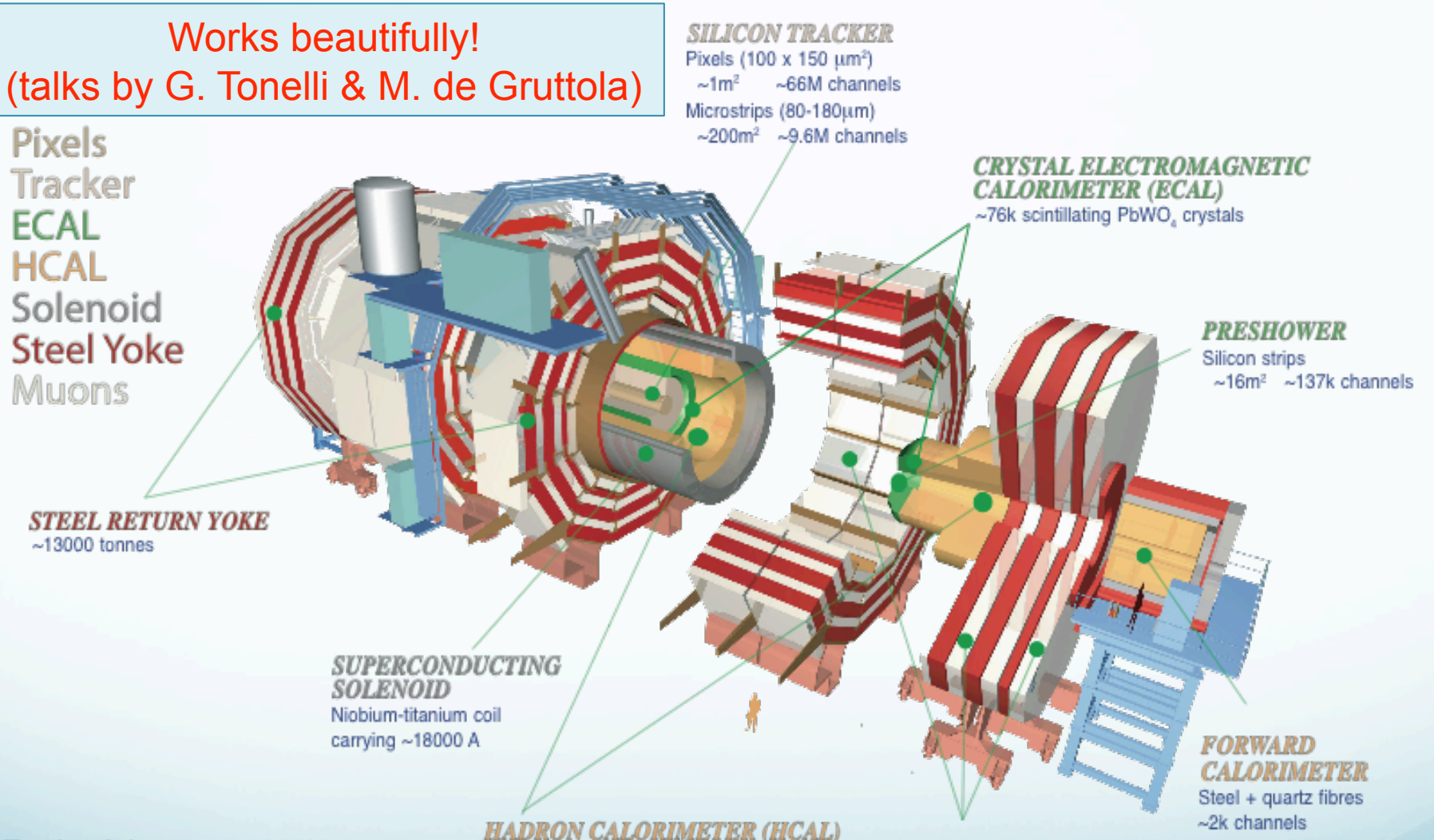
Overview

- CMS is looking for signs of New Physics in all possible directions
- All results based on full 2010 dataset: ~35 pb^{-1}
- In this talk:
  - "Exotica"
    - W' and Z' searches
    - Leptoquarks
    - Extra Dimensions
      - Microscopic Black Holes
  - SUSY missing energy searches
    - Jets + missing energy
    - Jets + missing energy + 2 OS leptons
    - Jets + missing energy + 2 photons
  - Higgs
    - WW production & $H \rightarrow W^+W^-$



The CMS detector

Works beautifully!
(talks by G. Tonelli & M. de Gruttola)

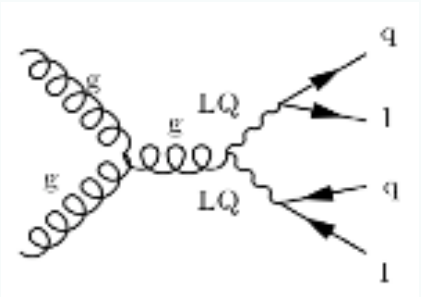


Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Exotica Searches: Overview

- Excited Vector Bosons
  - W' – search for enhancement/peak in transverse mass spectrum
  - Z' – search for resonance in dilepton invariant mass spectrum

- Leptoquarks
  - 1st and 2nd generation searches via pair-production from gluon fusion
  - decay to quark and lepton



- Extra Dimensions
  - Microscopic Black Hole search
    - Decay via Hawking radiation with equal probability to all SM particles
  - (additionally, searches for large ED in dimuon events and Randall-Sundrum gravitons in diphoton channel)

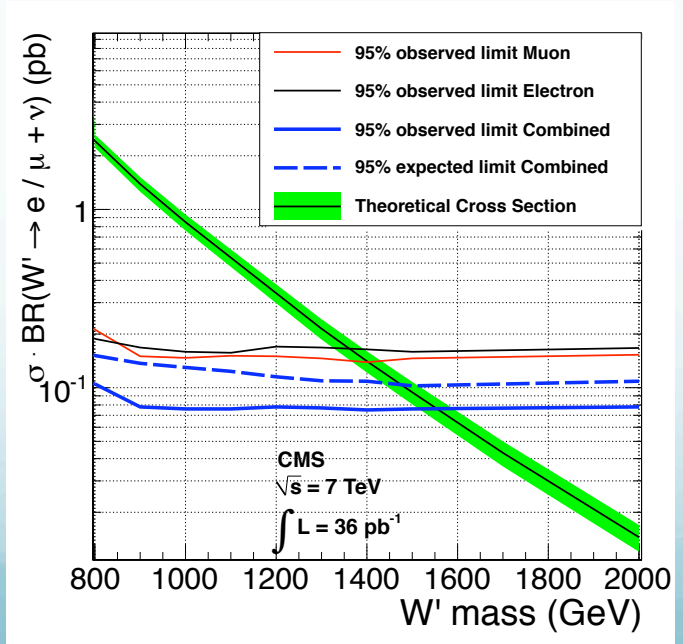
W' searches

- W' a heavy analogue of SM W with same couplings
- identify high p_T lepton (e or μ), p_T > 30 GeV
- Search for peak/enhancement in transverse mass spectrum (e/μ + missing transverse energy)

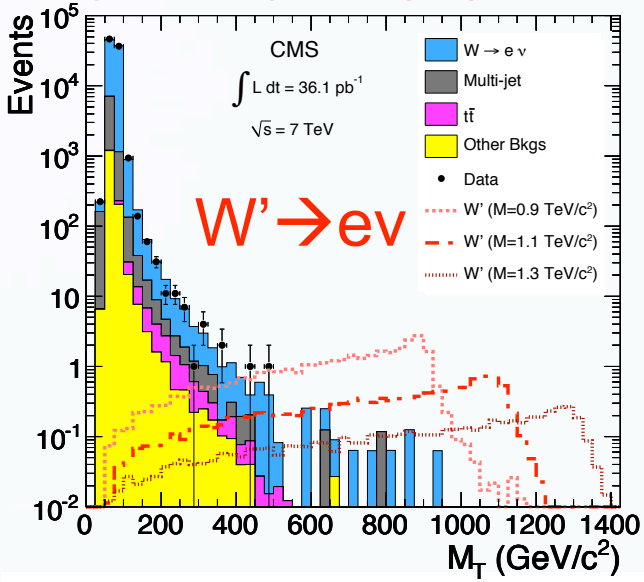
$$M_T = \sqrt{2 \cdot p_T \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{\mu,\nu})}$$

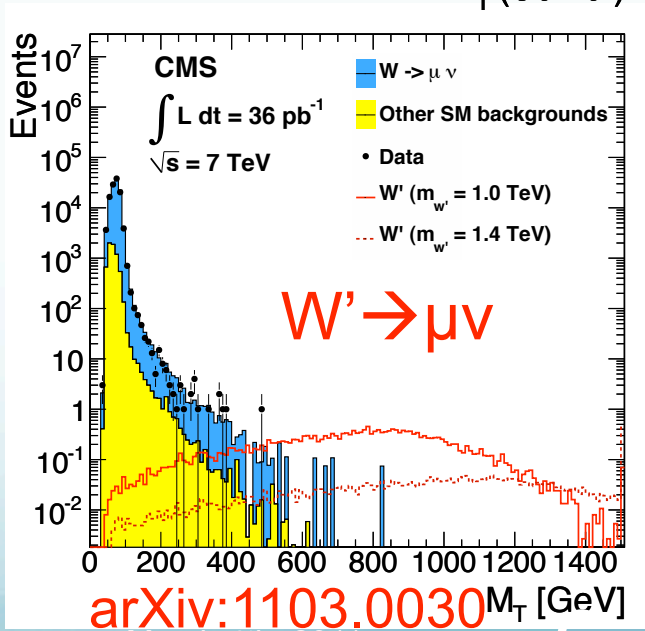
- Data agree with SM expectation
  - from W'→eν channel exclude W' masses below 1.36 TeV
  - from W'→μ ν channel exclude W' masses below 1.40 TeV
- Combination of e and μ channel results in 95% CL exclusion of W' masses below 1.58 TeV

more stringent limit compared D0 & CDF (1.1 TeV)



arXiv:1012.4945



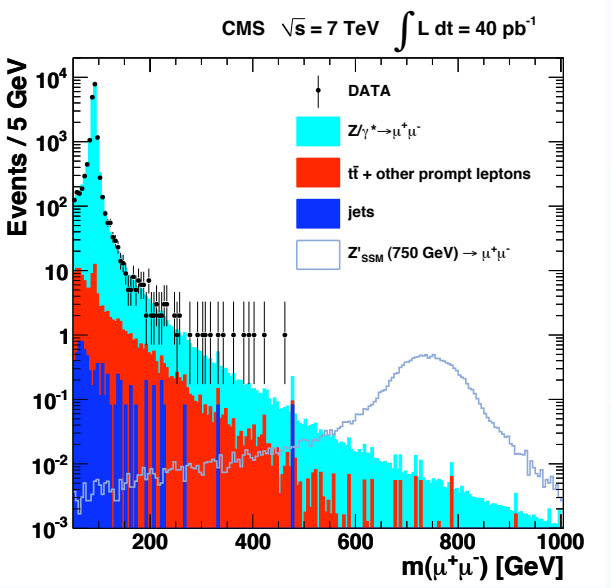


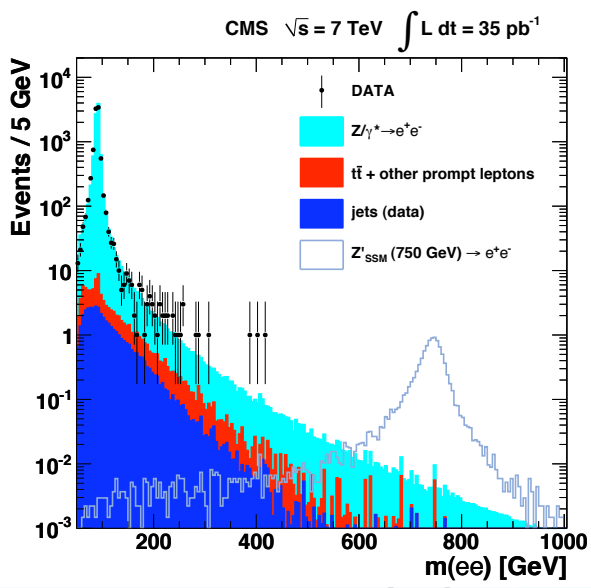
arXiv:1103.0030

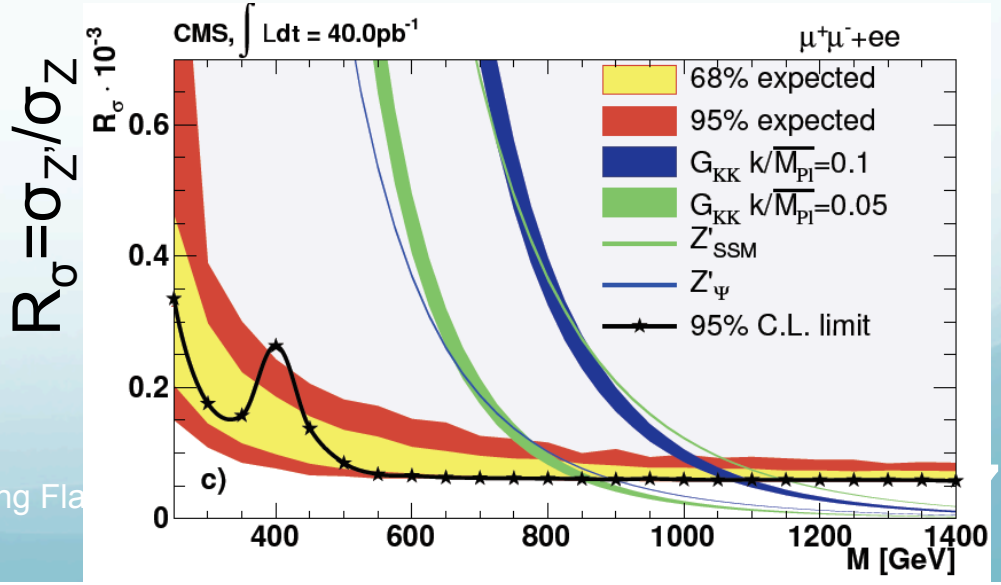
Z' searches

- Search for resonance in di-lepton mass distribution

- Identify 2 muons with p_T>20 GeV or 2 electrons with p_T > 25 GeV
- Dilepton invariant mass spectra consistent with SM expectations
- No sign of new resonance
- Z'_{SSM} with Standard-Model-like couplings can be excluded below 1140 GeV
- Superstring-inspired Z'_{ψ} excluded below 887 GeV
- RS Kaluza-Klein gravitons below 855–1079 GeV for couplings of 0.05–0.1
- (all at 95% C.L.)







EXO-10-013

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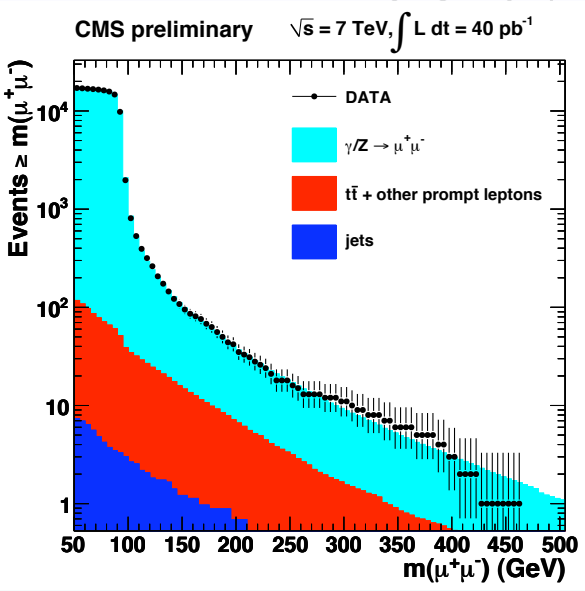
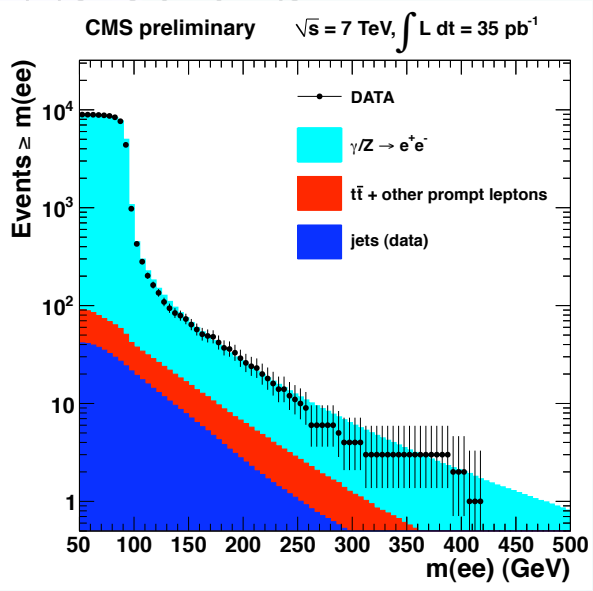
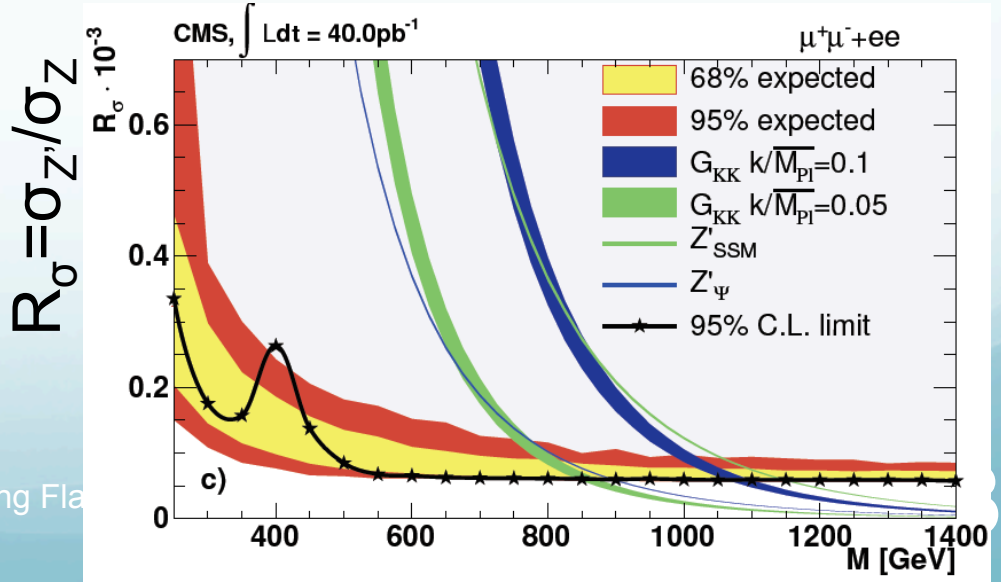






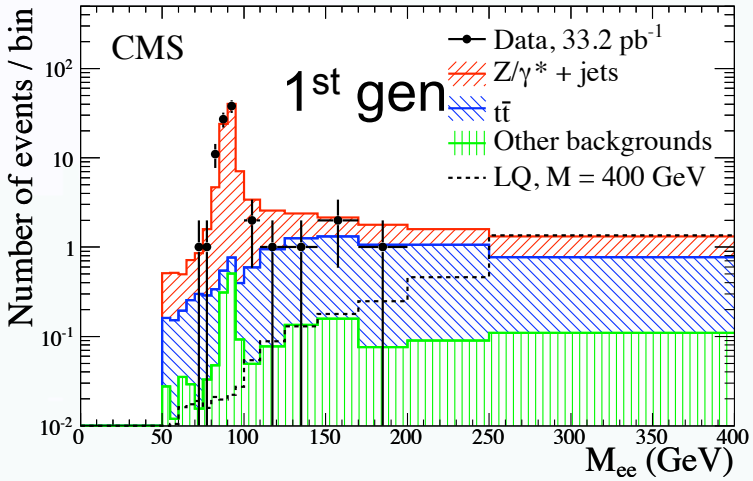
EXO-10-013

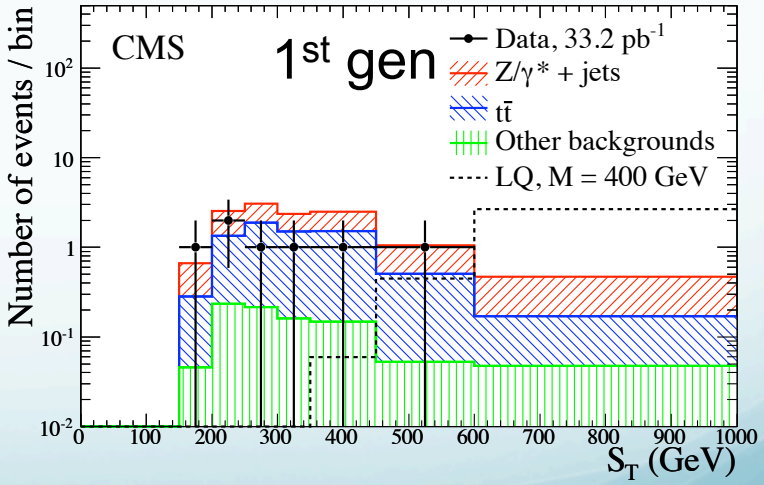
Leptoquarks

arXiv:1012.4031

- Pair production of leptoquarks
  - search for events with two leptons (e and μ) and two jets
  - lepton $p_T > 30$ GeV and $|\eta| < 2.5$ (2.4 for μ's)
  - jets with $p_T > 30$ GeV and $|\eta| < 3.0$
- Discriminating variables:
  - dilepton invariant mass
    - require large mass to reject Z's
    - M_{ee} ($M_{\mu\mu}$) > 125 (115) GeV
  - scalar sum of transverse energies of leading and subleading leptons and jets
    - $S_T = E_T(l_1)+E_T(l_2)+E_T(j_1)+E_T(j_2)$
    - mass dependent S_T cut (>250 GeV)
- Main backgrounds from Drell-Yann + jets and top pair production
  - Normalise DY background in Z control region

1st Generation: LQ→qe





similar for 2nd generation: LQ→qμ

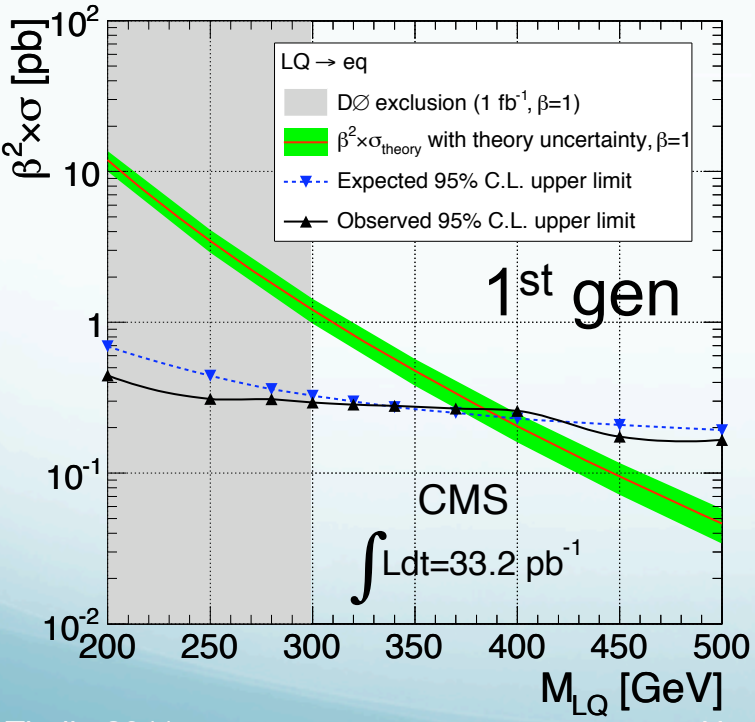
arXiv:1012.4033

Leptoquarks

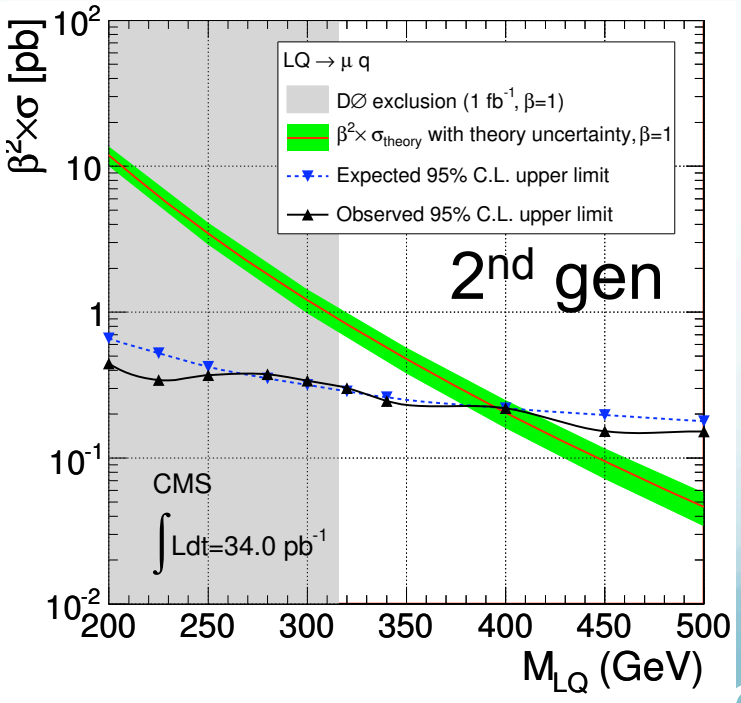
- Set limit on BF * Cross section in absence of excess
  - β is BF for LQ → qe
  - $(1-\beta)$ is BF for LQ → q ν_e
- $M_{LQ} > 384$ GeV for $\beta = 1$ (1^{st} gen)
- $M_{LQ} > 394$ GeV for $\beta = 1$ (2^{nd} gen)

Exceed Tevatron limits

arXiv:1012.4031



arXiv:1012.4033



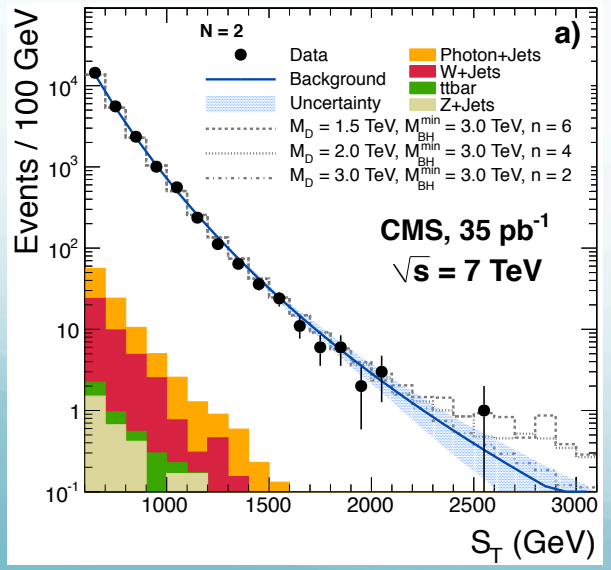
Extra Dimensions: Black Holes

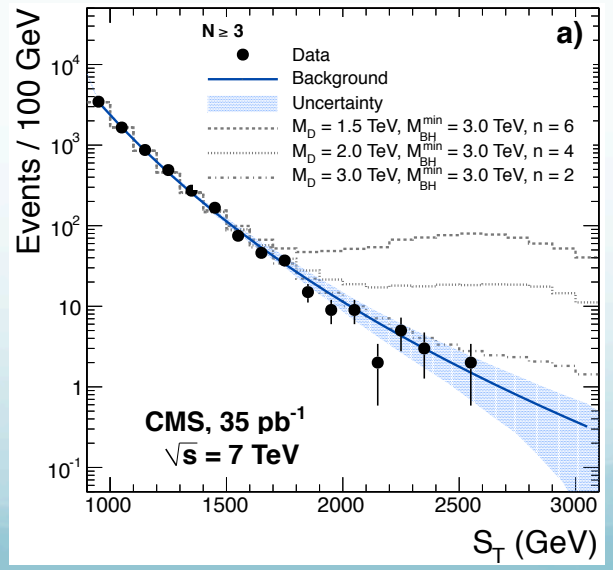
- Creation of microscopic Black Holes possible when the two partons from colliding beams pass each other at a distance smaller than the Schwarzschild radius corresponding to their invariant mass

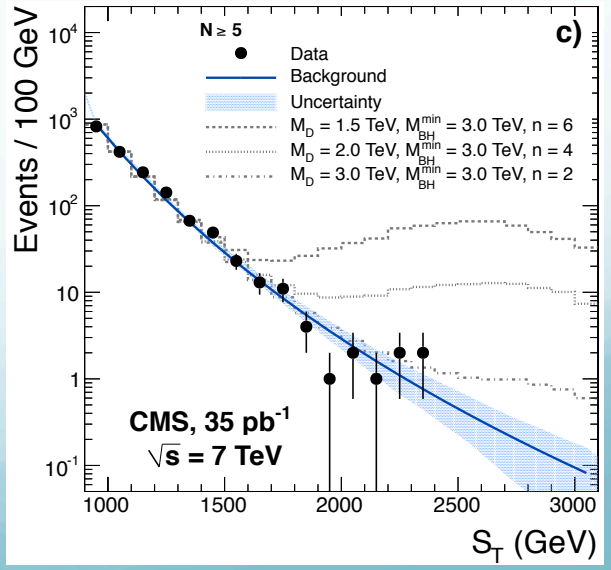
$$r_S = \frac{1}{\sqrt{\pi} M_D}\left[\frac{M_{BH}}{M_D}\frac{8\Gamma\left(\frac{n+3}{2}\right)}{n+2}\right]^{\frac{1}{n+1}} \qquad M_{Pl}^2 = 8\pi M_D^{n+2} r^n$$

- Black holes instantaneously decay via Hawking evaporation with an emission of large number of energetic objects:
  - dominated (75%) by quark and gluons, with the rest going into leptons, photons, W/Z, h, etc.
- Discriminating variable:
  - $S_T = \Sigma E_T$, where the sum is over all the objects with $E_T > 50$ GeV, including ME_T
- Completely data-driven QCD background determination using a novel technique:
  - S_T-invariance of the final state multiplicity

arXiv:1012.3375

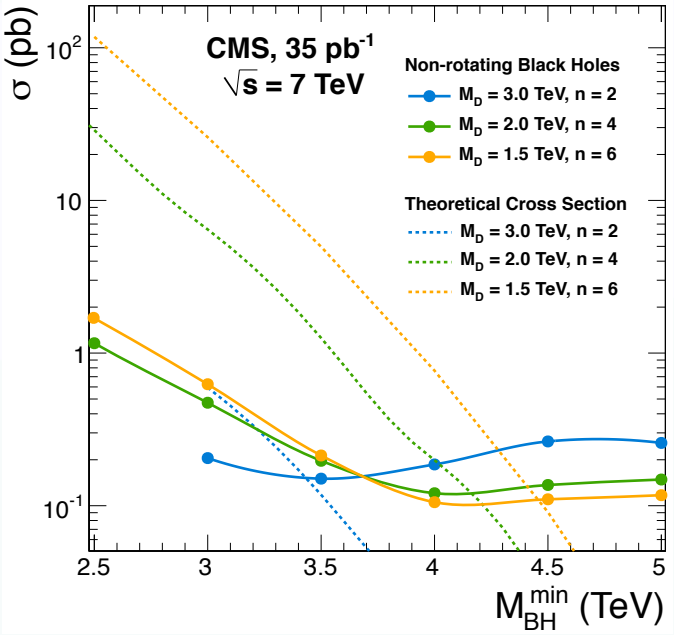


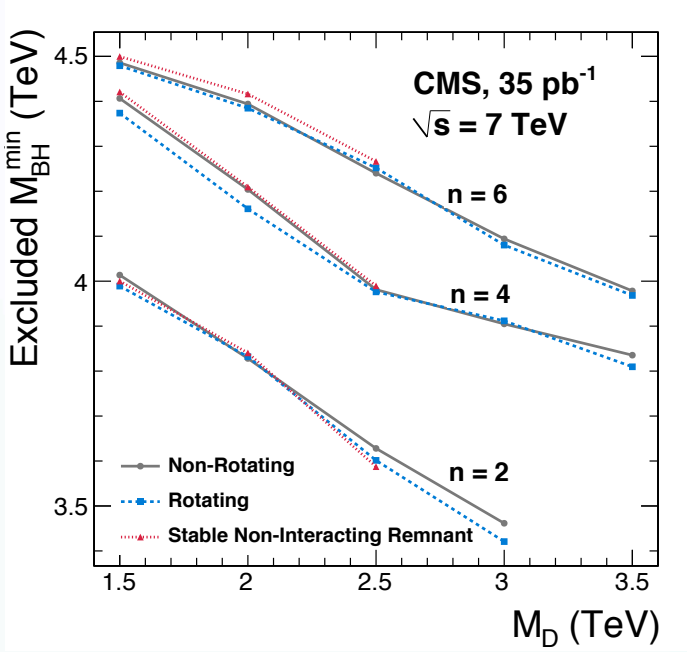




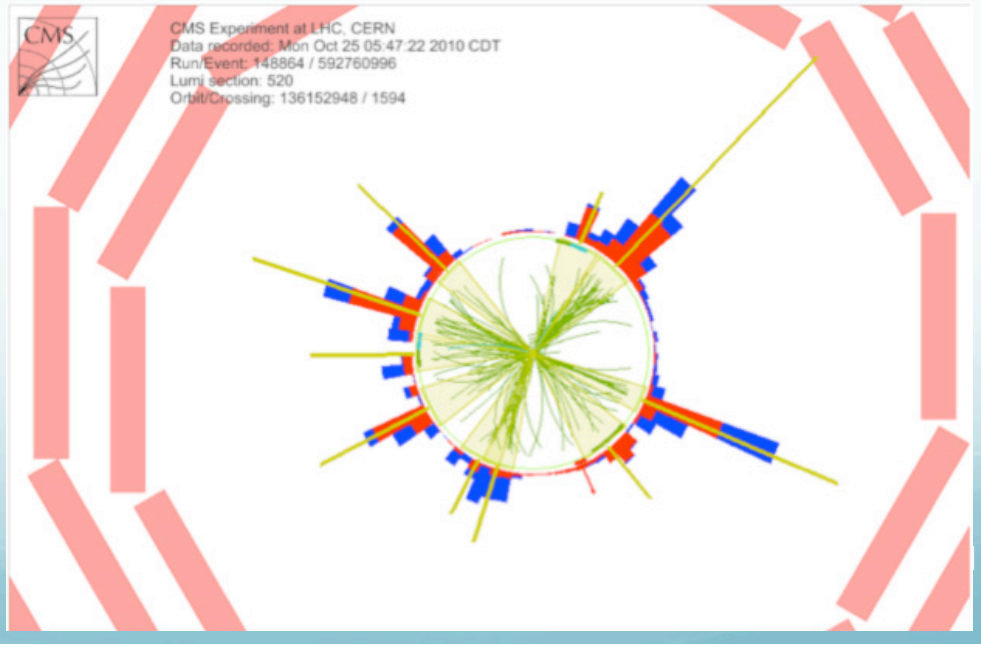
Extra Dimensions: Black Holes

- In absence of an excess, set limits on the minimum BH mass
- 3.5-4.5 TeV in semi-classical approximation





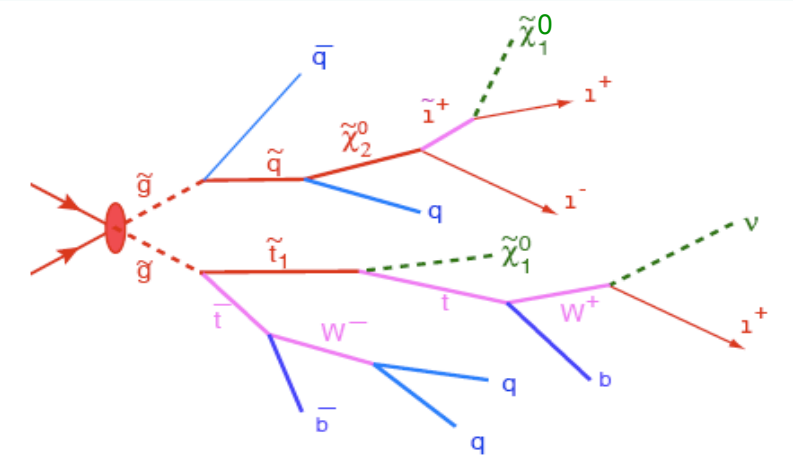
- 10 jet candidate event with S_T = 1.3 TeV



arXiv:1012.3375

SUSY Searches: Overview

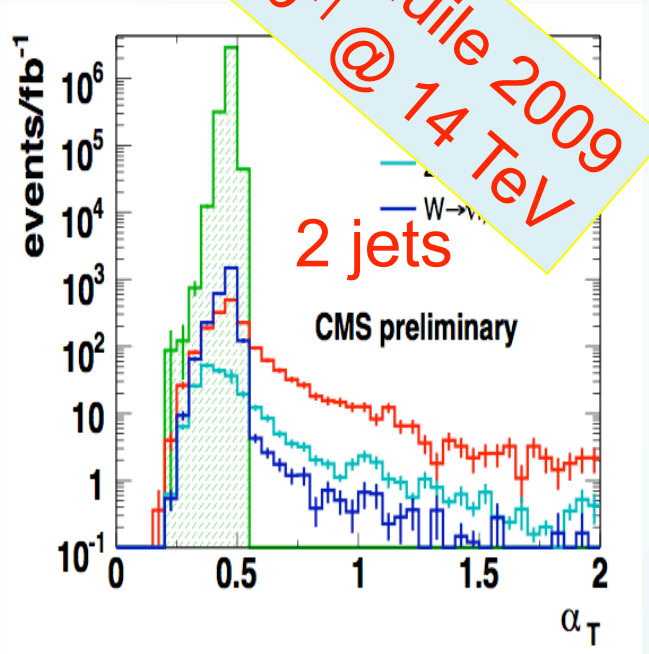
- Supersymmetry an excellent candidate for Dark Matter
- R-parity conserving SUSY gives rise to stable lightest SUSY particle (LSP)
  - missing energy signature
- CMS follows a topology driven approach:
- Search for heavy pair-produced particles that decay to SM particles and LSP
  - direct decay of squarks or gluinos to quarks (jets) + LSP
  - cascade decays via charginos resulting in leptons



- In case of GGM, neutralino decay to photon + gravitino (LSP)
  - diphoton + jets + missing energy signature

SUSY searches: jets + missing energy

- pair production of heavy particles whose decay results in high p_T jets
- Main problem: huge QCD multijet background!
- Basic Idea: deploy a simple and robust analysis based on kinematics – appropriate for early data
  - Simplicity: use of kinematic information (α_T variable)
  - Robustness: protection against mis-measurements of jets in QCD events; signal region is practically QCD free
  - Result: remaining backgrounds dominated by processes with real MET [i.e. EWK+top]
  - Define:
    - $H_T = \Sigma\, p_T(j_i)$
    - $MH_T = |-\Sigma\, \vec{p_T}(j_i)|$
    - $\Delta H_T = E_T(pj_1) \cdot E_T(pj_2)$



inspired by
L. Randall & D. Tucker-Smith,
Phys.Rev. Lett. 101 (2008) 221803

α_T for dijets:

$$a_T = \frac{E_{T\,j2}}{M_{T\,j1j2}} = \frac{\sqrt{E_{T\,j2}/E_{T\,j1}}}{\sqrt{2(1-\cos\Delta\varphi)}} \leq 0.5$$

Expectation for QCD: $\alpha_T = 0.5$
Jet mis-measurements: $\alpha_T < 0.5$

α_T for n jets:

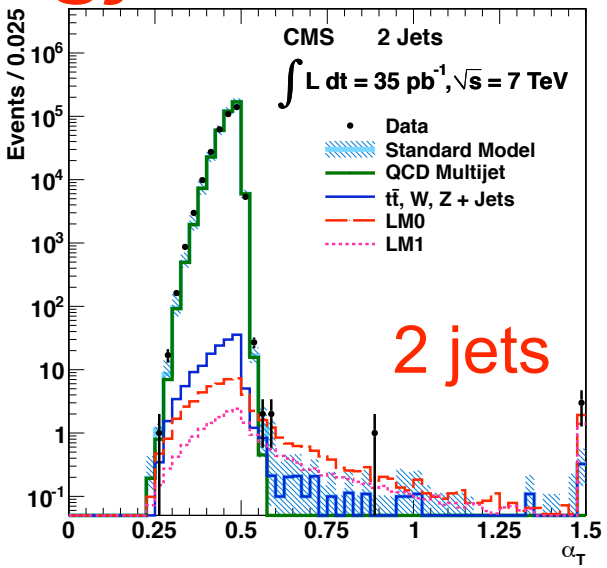
$$\alpha_T = \frac{1}{2}\,\frac{H_T - \Delta H_T}{M_T}$$

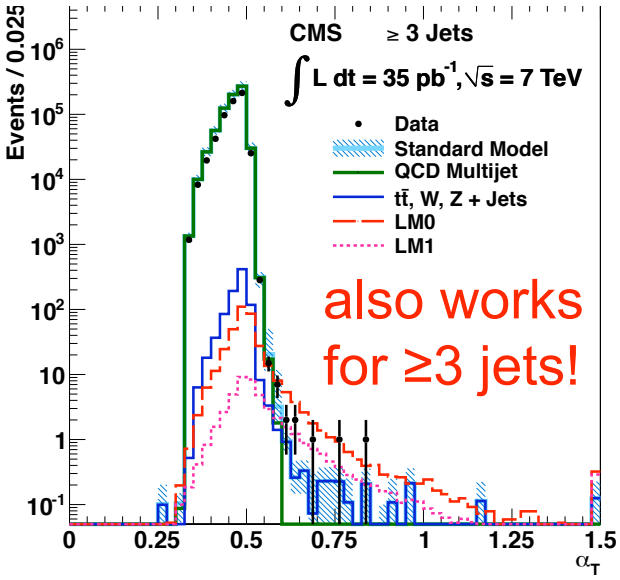
(form two pseudo-jets – defined by balance in "pseudo-jet" $H_T = \Sigma E_T$)

SUSY searches: jets + missing energy

- Event selection:
  - Require >=2 jets with p_T>50 GeV
  - leading 2 jets with p_T > 100 GeV
  - Scalar sum of jet p_T, H_T > 350 GeV
  - Explicit veto on
    - isolated el/mu with p_T>10 GeV
    - photons with p_T > 25 GeV
  - α_T > 0.55
- QCD multijet events eliminated

Selection	Data	SM	QCD multijet	$Z \to \nu\bar{\nu}$	W + jets	$t\bar{t}$
$H_T > 250$ GeV	4.68M	5.81M	5.81M	290	2.0k	2.5k
$\not{E}_T > 100$ GeV	2.89M	3.40M	3.40M	160	610	830
$H_T > 350$ GeV	908k	1.11M	1.11M	80	280	650
$\alpha_T > 0.55$	37	30.5±4.7	19.5±4.6	4.2±0.6	3.9±0.7	2.8±0.1
$\Delta R_{ECAL} > 0.3 \vee \Delta\phi^* > 0.5$	32	24.5±4.2	14.3±4.1	4.2±0.6	3.6±0.6	2.4±0.1
$R_{miss} < 1.25$	13	9.3±0.9	0.03±0.02	4.1±0.6	3.3±0.6	1.8±0.1



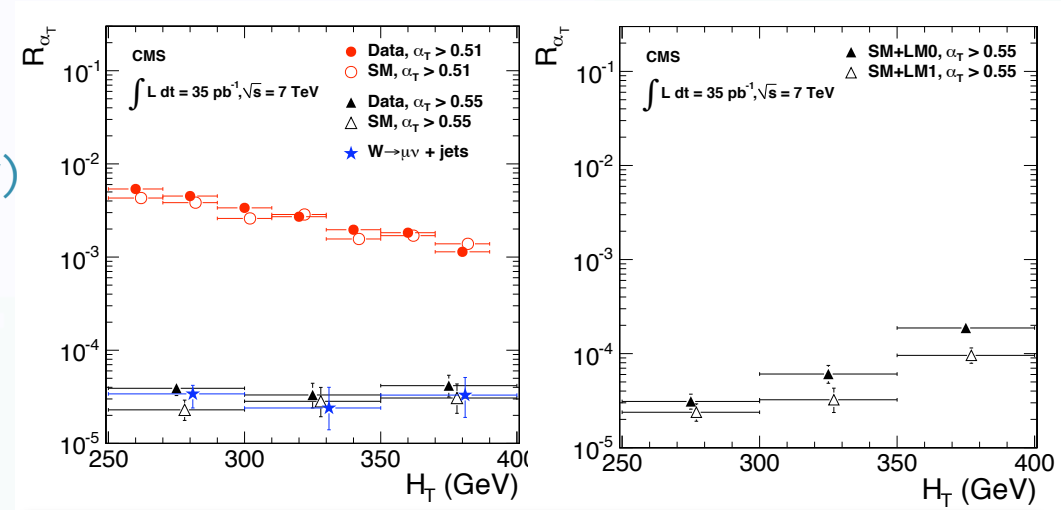


arXiv:1101.1628

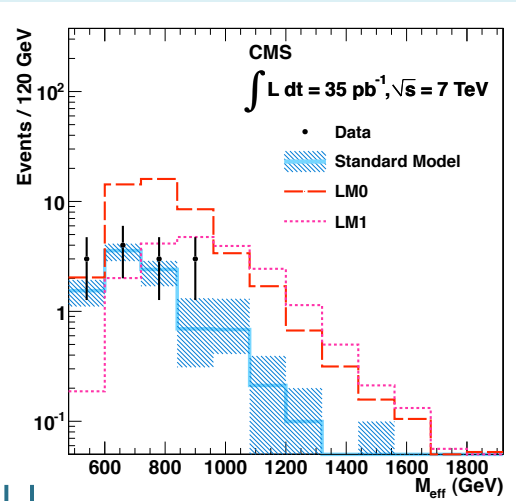
SUSY searches: jets + missing energy

SM backgrounds predicted with 3 data-driven methods

- Total background (QCD, W/tt, Z→νν) extrapolating α_T ratio ($R_{\alpha T}$) from low H_T to high H_T region
  - Two methods based on data only:
    - 1) exponential H_T dependence: $9.4^{+4.8}_{-4.0\ stat} \pm 1.0_{syst}$
    - 2) No HT dependence (const. $R_{\alpha T}$) $12.5 \pm 1.9_{stat} \pm 0.7_{syst}$
- W/tt background from muon control sample
  - invert muon veto
  - $6.1^{+2.8}_{-1.9stat} \pm 1.8_{syst}$
- Z→νν background from photon control sample
  - invert photon veto
  - $4.4^{+2.3}_{-1.6stat} \pm 1.8_{syst}$

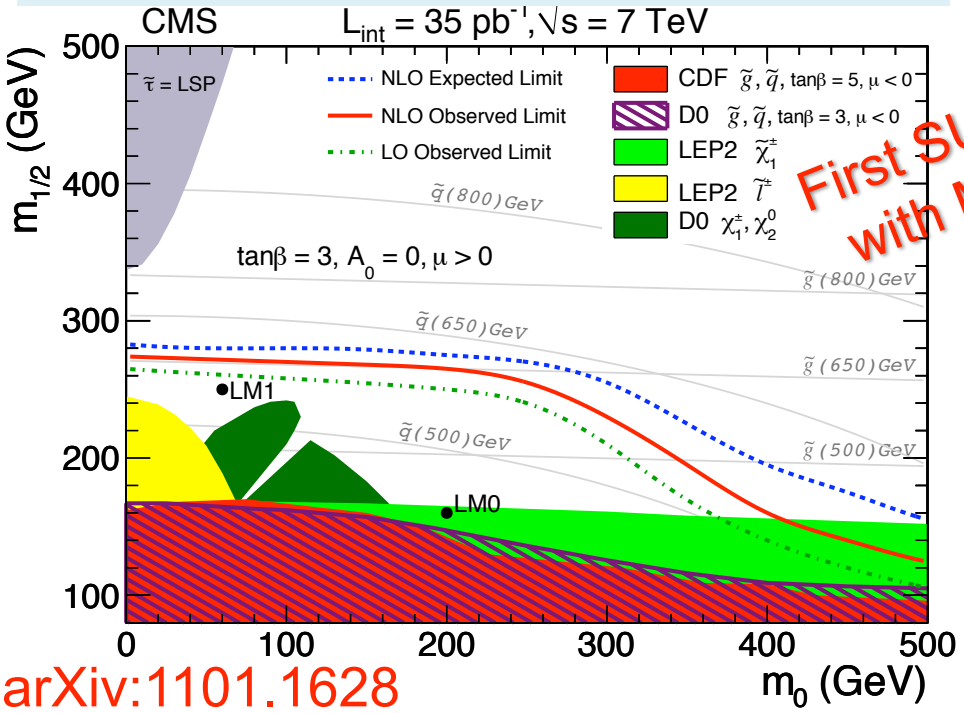


- 13 events in data after full selection
- kinematic properties compatible with SM expectation
- $M_{eff} = H_T + MH_T$



Exclusion in the CMSSM

- CMSSM: 4 parameter model assuming common gaugino and scalar masses at GUT scale ($m_{1/2}$, m_0)
- In absence of signal, calculate 95% CL exclusion limit using Feldman-Cousins
- $\tan\beta$ independent exclusion
- Exclude squark and gluino masses of ~550-650 GeV in CMSSM



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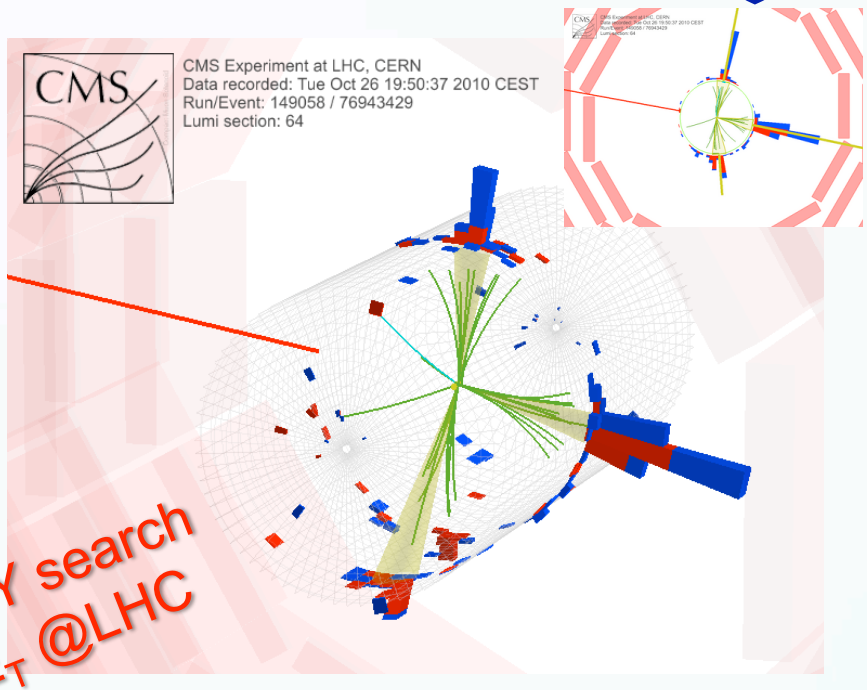


First SUSY search with ME_T @LHC

- Selection efficiency approximately production-process independent

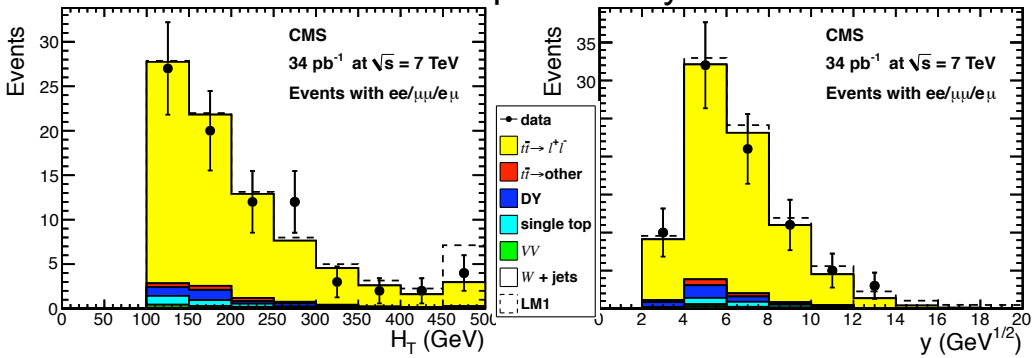
Production mechanism	Yields for 35 pb^{-1}	ϵ_{total}(%)	$\epsilon_{signature}$(%)
$\tilde{q}\,\tilde{q}$	9.7±0.1	16.0±0.1	22.2±0.4
$\tilde{q}\,\tilde{g}$	8.8±0.1	14.4±0.1	23.0±0.5
$\tilde{g}\,\tilde{g}$	0.71±0.02	12.0±0.4	22.5±2.0

- 12% uncertainty on signal efficiency, dominated by 11% luminosity uncertainty

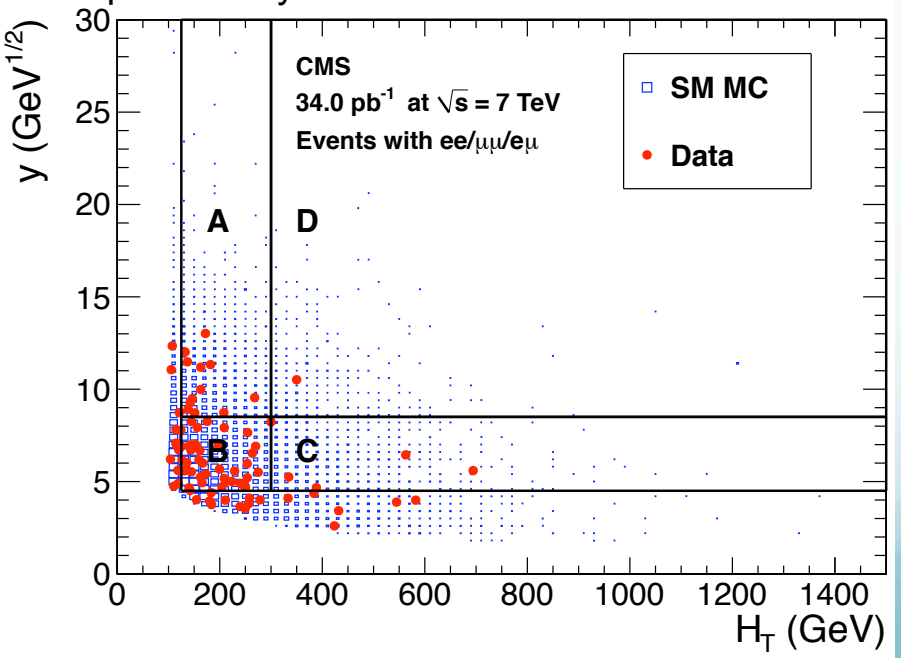
SUSY Searches: jets+ME_T+2leptons (OS)

- Selection:
  - 2 isolated leptons (e or μ) with $p_T > 10$ GeV
    - opposite charge
  - Presence of leptons strongly reduces QCD background
  - >=2 jets with $p_T > 30$ GeV and $|\eta| < 2.5$
  - require $H_T > 300$ GeV and $y = ME_T/\sqrt{H_T} > 8.5$ $\sqrt{\text{GeV}}$ to suppress top background
    - define signal and control regions in both variables (uncorrelated)
  - Relate SM BG in signal region as $N_D = N_A \times N_C / N_B$
  - Additionally use similarity of lepton and neutrino spectra to model missing energy distribution
  - Cross check same flavour tt background with opposite flavour events

CMS preliminary



CMS preliminary SUS-10-007

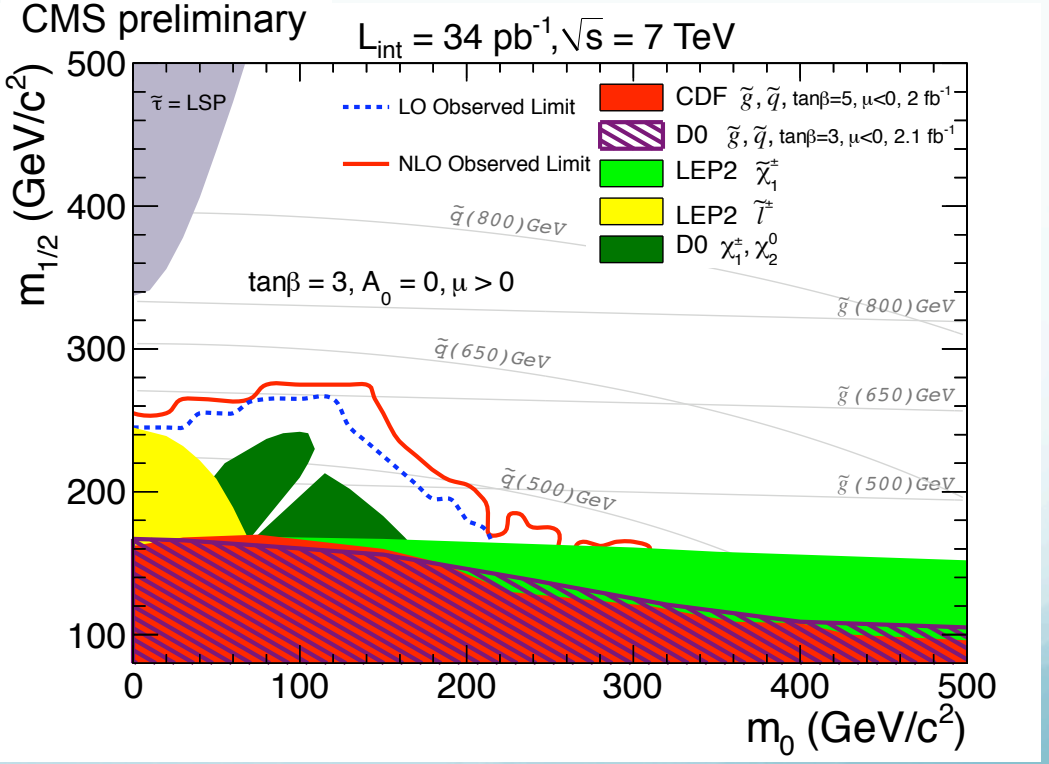


SUSY Searches: jets+ME_T+leptons

- Set limit in absence of signal
- 95% CL upper limit on BSM contribution is 4.7 events
- limit tan β dependent and most sensitive for low tan β values
- extended reach over Tevatron tri-lepton analysis
- Equivalent search in same sign dilepton channel: SUS-10-004

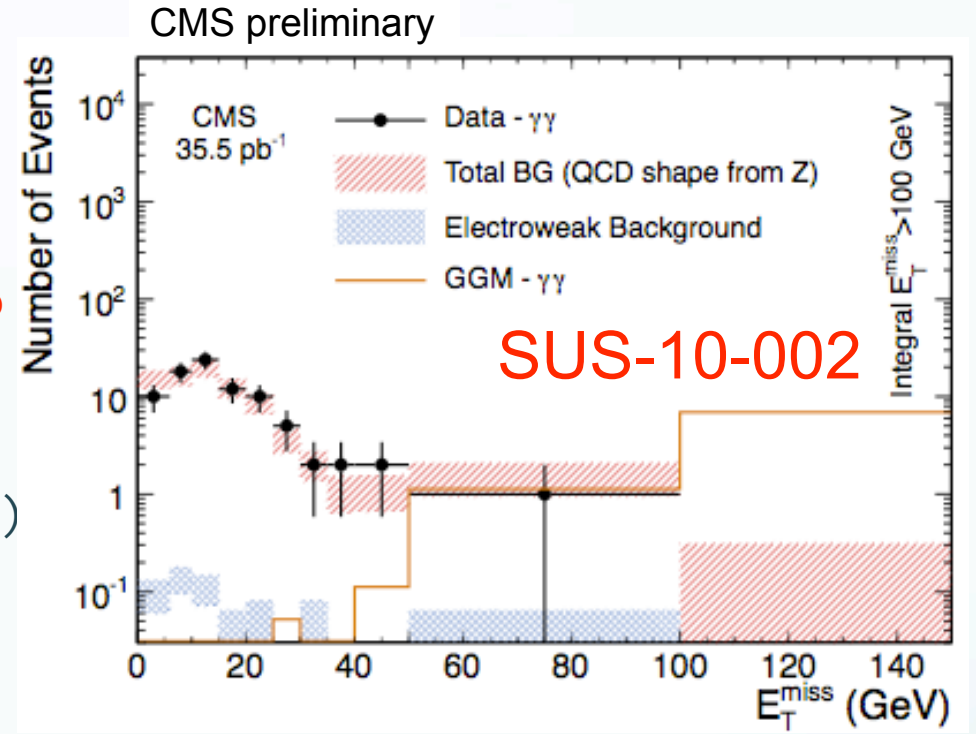
Data	BG Prediction	SM MC
1	1.4 ± 0.8	1.3

SUS-10-007



SUSY Searches: jets+ME_T+diphotons

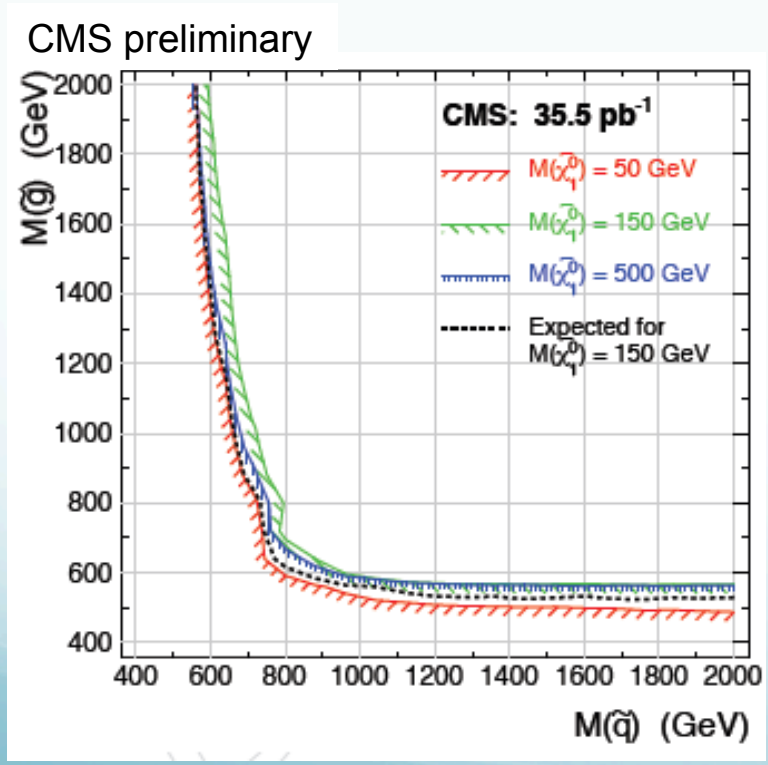
- Search for General Gauge Mediated SUSY Breaking
  - LSP is the gravitino
  - Neutralino is NLSP
    - decaying to photon and gravitino
- Event selection
  - photon candidates with p_T > 30 GeV and $|\eta|$<1.4 (barrel)
  - >=1 jet with p_T > 30 GeV and $|\eta|$ < 2.6
- Main Backgrounds:
  - QCD processes with diphoton or photon + jet production
  - W→eν + jets with electron misidentified as photon
  - estimated from Z→ee data control sample

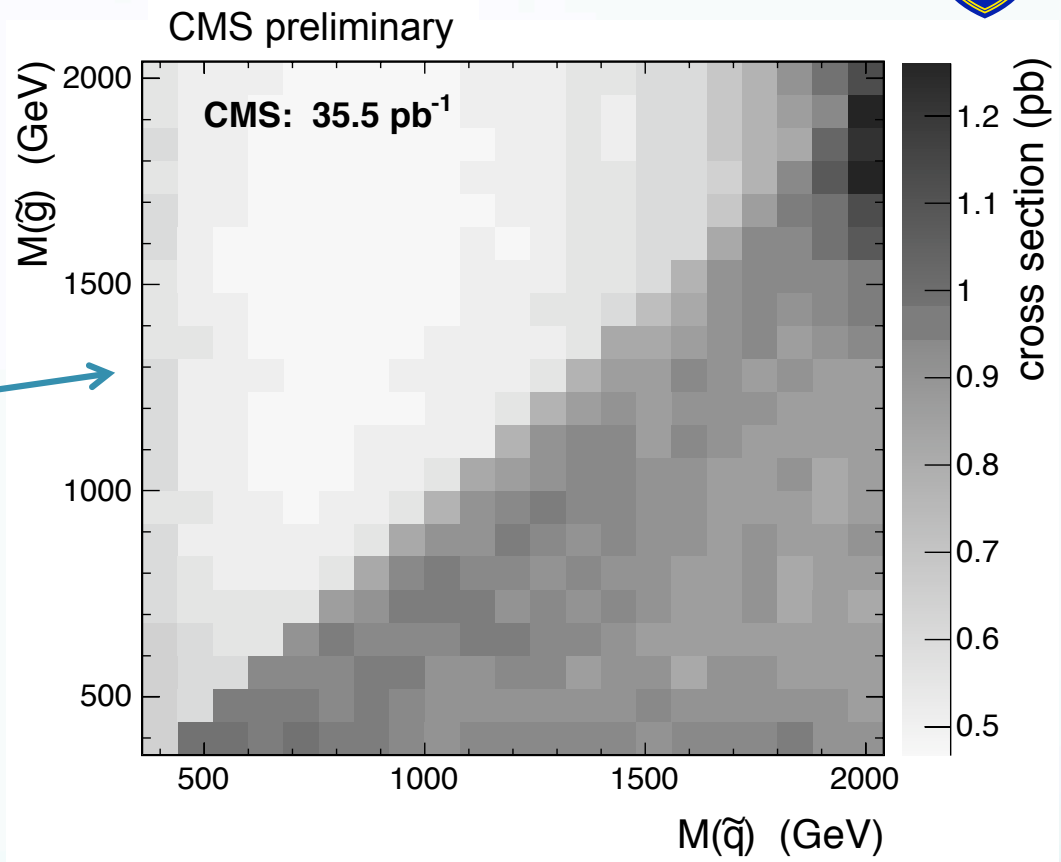


No excess of diphotons events observed

SUSY Searches: jets+ME_T+photons

- Upper limits on production cross-section in squark-gluino mass plane ranging from 0.3 – 1.1 pb for gluino and squark masses between 500 – 2000 GeV
- assumes Neutralino mass of 150 GeV





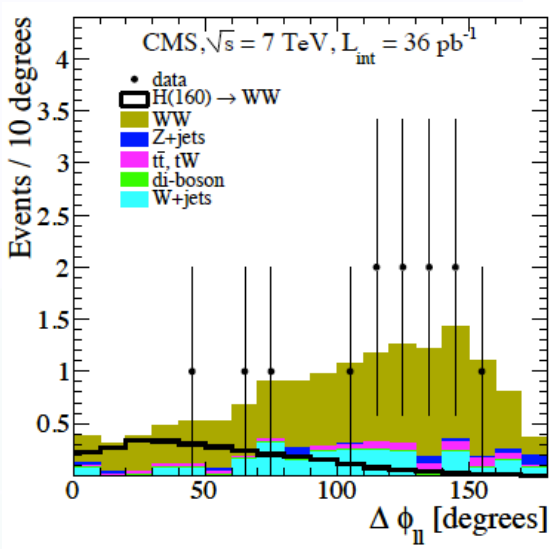
- 95% CL limit excluded squark and gluino masses

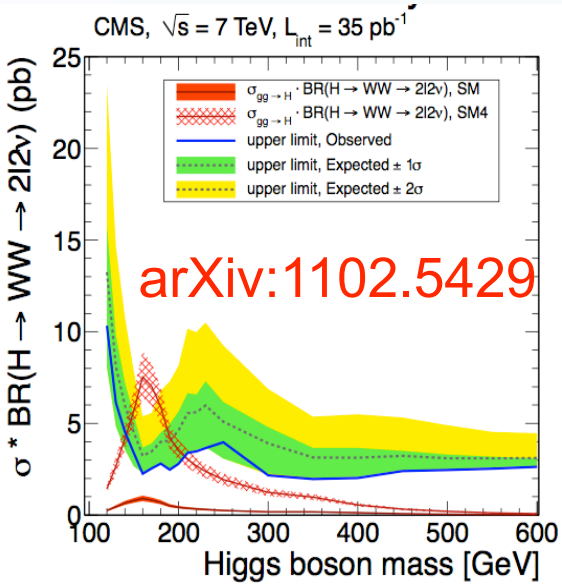
SUS-10-002

WW production and consequences for Higgs search

- Diboson production main background to $H \rightarrow W^+W^-$ channel
- select two high-p_T, oppositely charged isolated leptons
  - $p_T > 20$ GeV
- Missing $E_T > 20$ GeV and projected $ME_T > 35$ GeV
- Z veto: $M_{ll} > M_Z + 15$ GeV
- top veto:
  - jet veto ($p_T > 25$ GeV), soft muon & b-tag veto
- To gain sensitivity to $Higgs \rightarrow W^+W^-$ consider opening angle of leptons $\Delta\Phi_{ll}$ and M_{ll}

arXiv:1102.5429





- W^+W^- cross section:
  - 13 events in data with estimated BG of $3.3 \pm 0.5_{stat} \pm 1.1_{syst}$
  - $\sigma_{W+W-} = 41.1 \pm 15.3_{stat} \pm 5.8_{syst} \pm 4.5_{lumi}$ pb
  - SM: $\sigma_{W+W-} = 43.0 \pm 2.0$ pb @ NLO
- SM $H \rightarrow W^+W^-$ cross section limits:
  - 3 times SM @ $M_H = 160$ GeV @ 95%CL
- Sequential fourth family of fermions with very high masses and Higgs with SM couplings
  - $144 < M_H < 207$ GeV excluded @ 95% CL

Conclusions & Outlook

- New Physics searches well underway
  - with focus on data driven background estimation methods
- Investigating a wide variety of New Physics scenarios:
  - Excited V-Bosons
  - Leptoquarks
  - Extra-Dimensions
  - Supersymmetry
  - Higgs
  - and many more I didn't have time to cover
  - see https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
- Unfortunately no smoking gun seen so far, but
- CMS (and ATLAS) have entered new territory, superseeding Tevatron searches in many areas
- Many more exciting results can be expected for Summer