CMS: Performance, Prospects, Results

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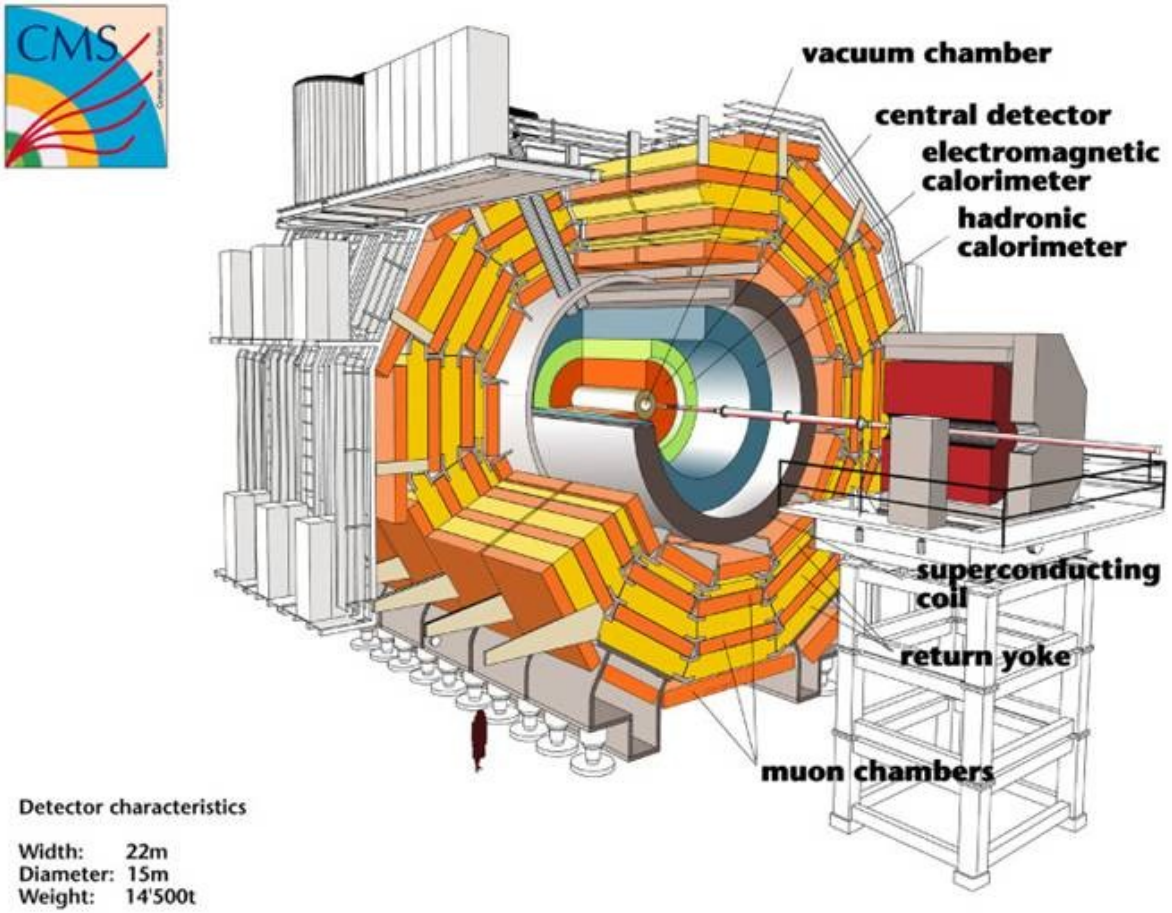
Plan of the talk

- CMS detector, performance
- Some SM measuremens
- CMS Searches
  - New results in Higgs search
  - New result in Searches for Supersymmetry
  - Other BSM searches: updates and new
- Conclusion

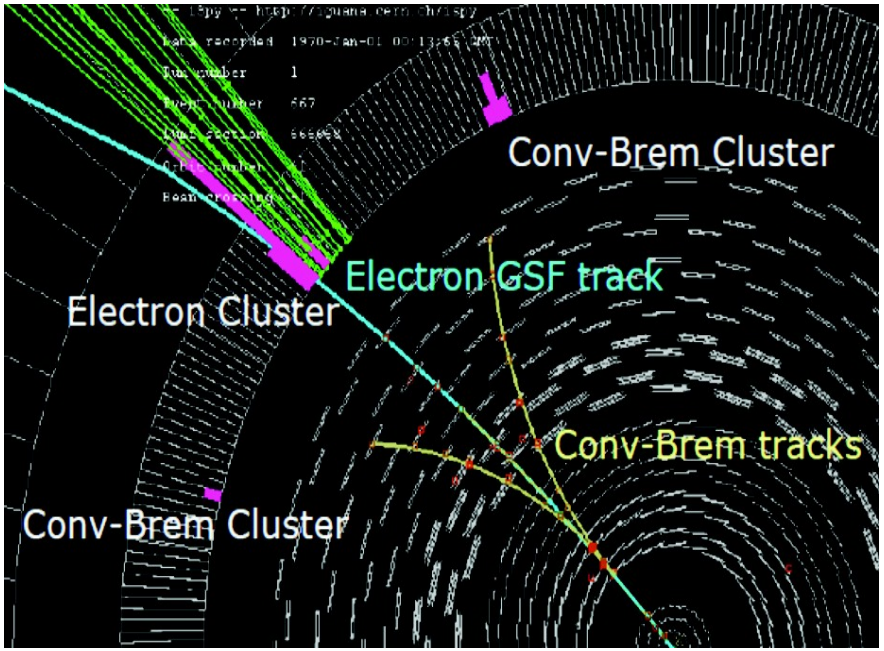
(Note: focus on results from Moriond 2016.)

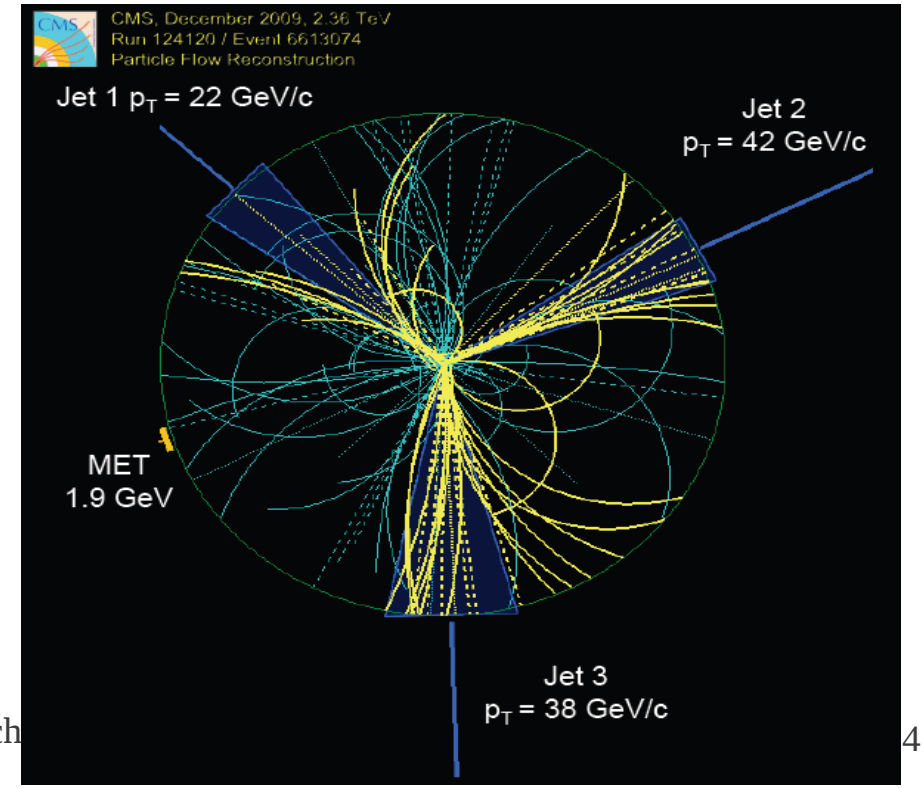
The CMS Detector



Particle Flow

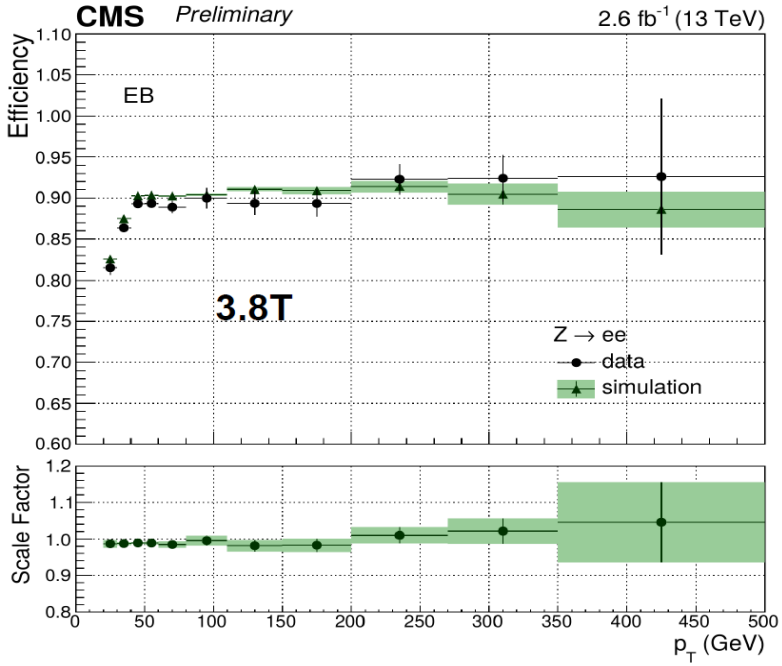
- Reconstruct all stable particles in CMS detector by linking responses of subdetectors
  - Photon, electron, muon, charged and neutral hadrons
  - Resulting list of particles can be used as if they came from a MC generator
  - Composite objects like jets, taus, MET can be reconstructed from the “PF candidates”

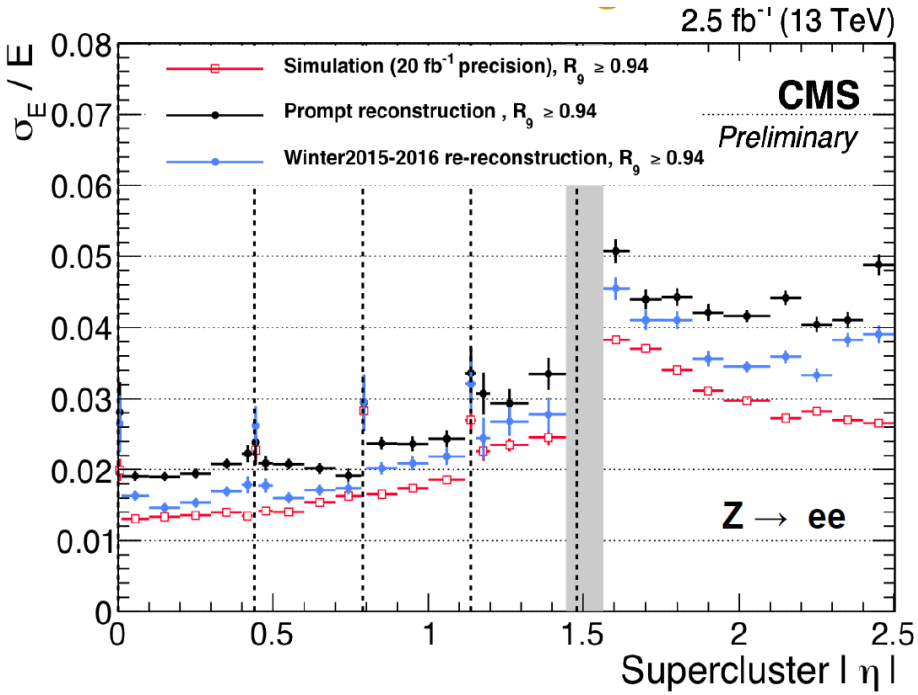


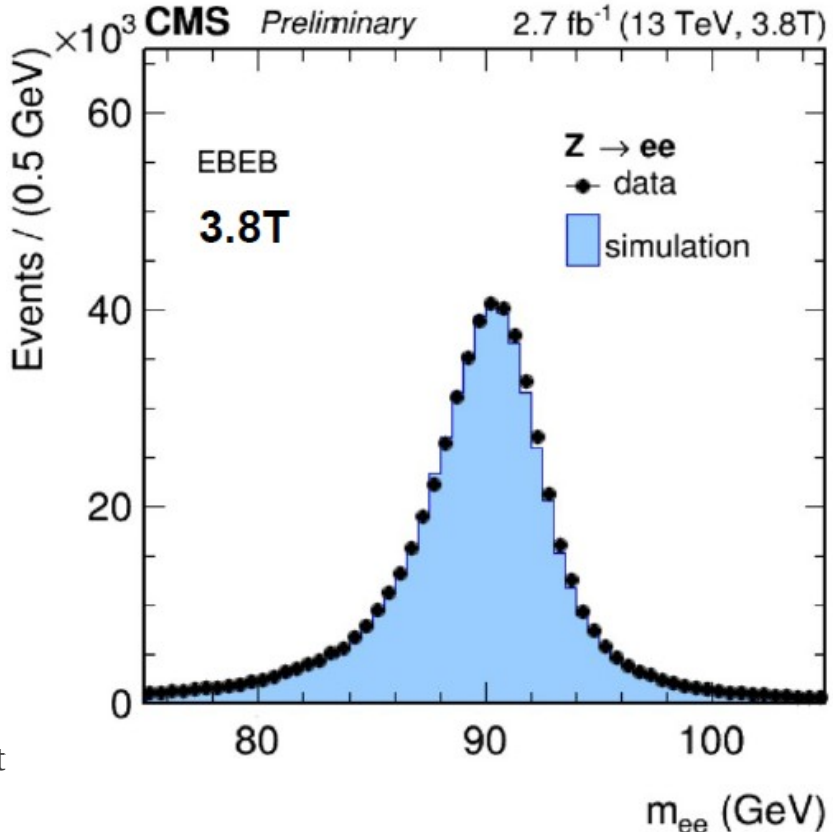


Electrons and photons

- Photon identification efficiency ~ 90%
- Photon energy resolution ~ 1% from Z to ee data

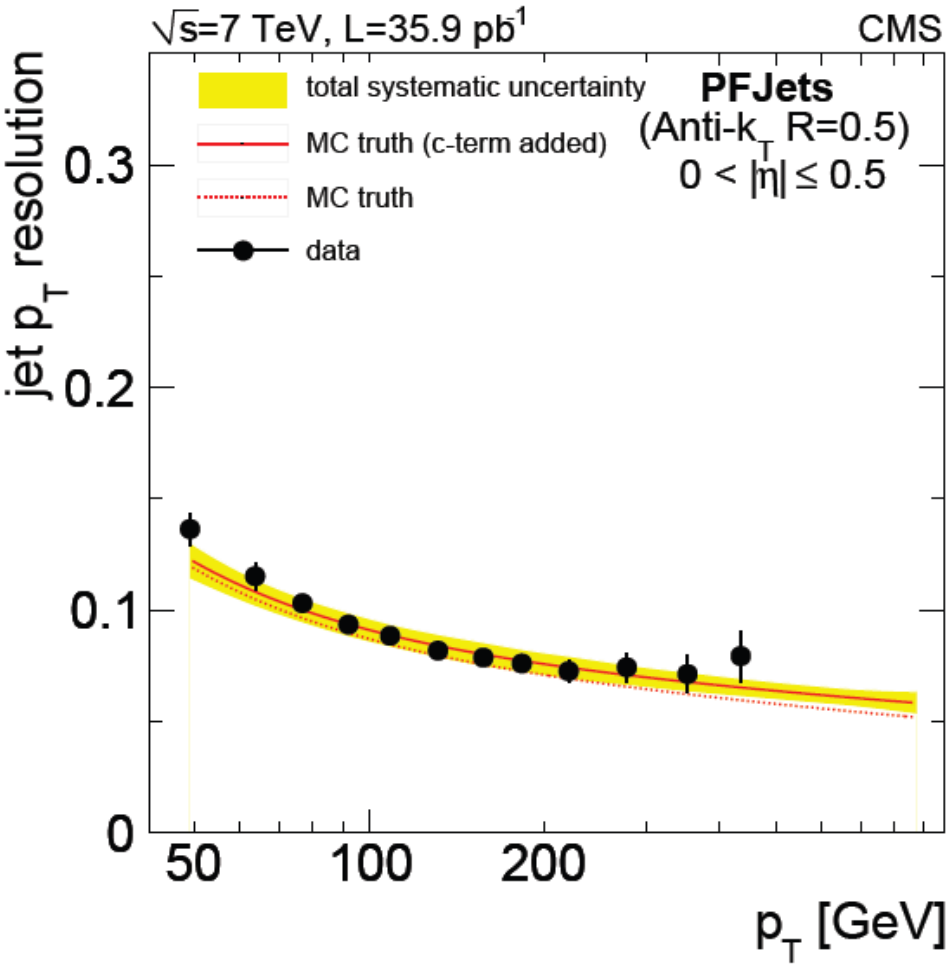






Jets

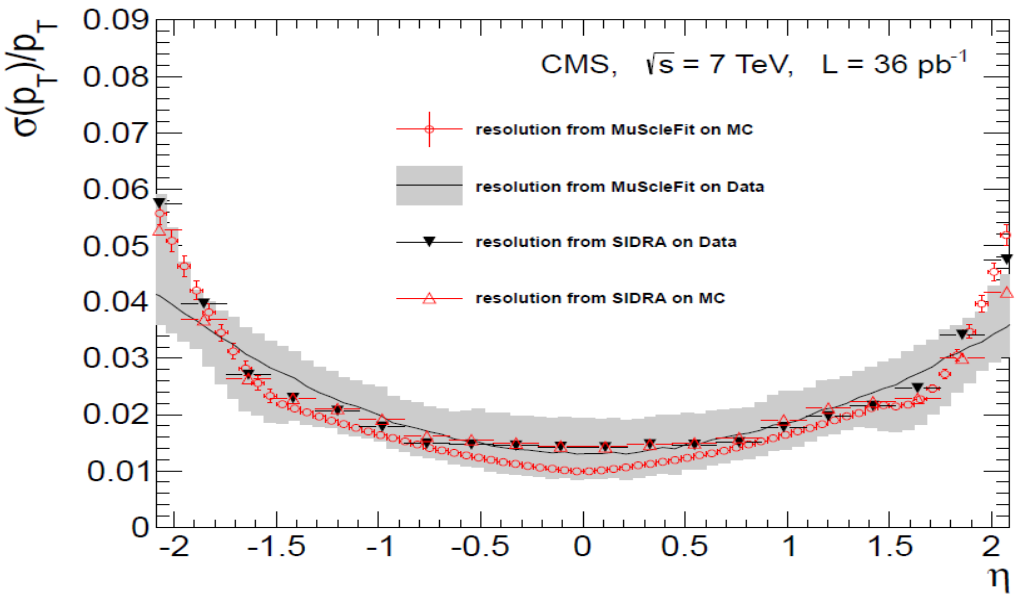
- Anti-KT with distance parameter 0.5
- CALO, JPT, PF
- PF jets clustered from PF candidate particles
- Resolution measured from MC and various energy balancing methods



2011 JINST 6 P11002

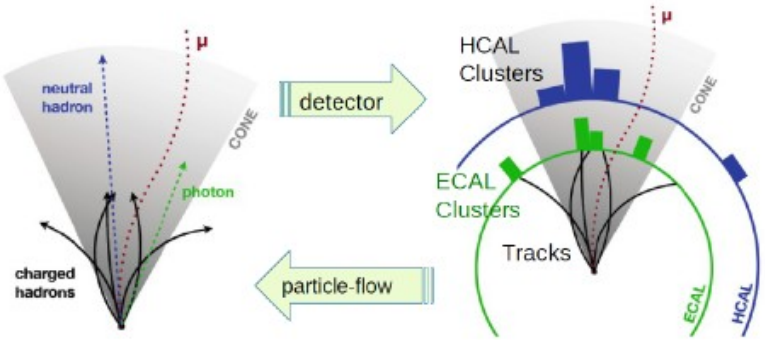
Muons

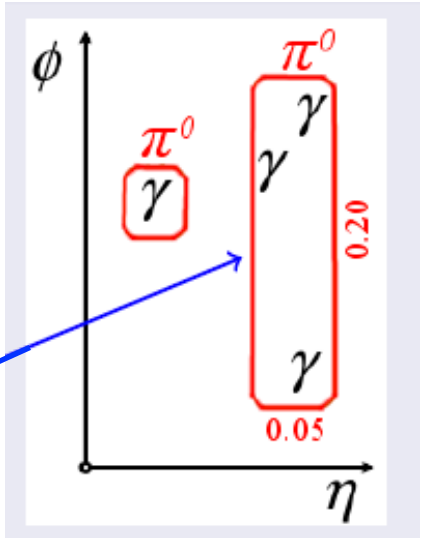
- 1-6% relative momentum resolution for pT<100GeV
- > 10% at a TeV
- > 1% hadron to muon fake probability
- Single muon trigger rates (much) better than 90% above a few GeV



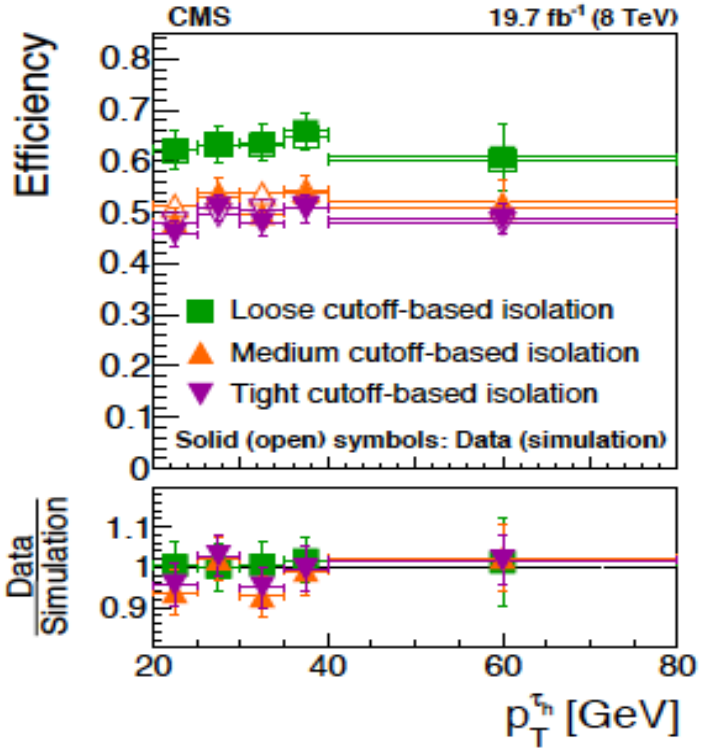
Taus: the HPS algorithm

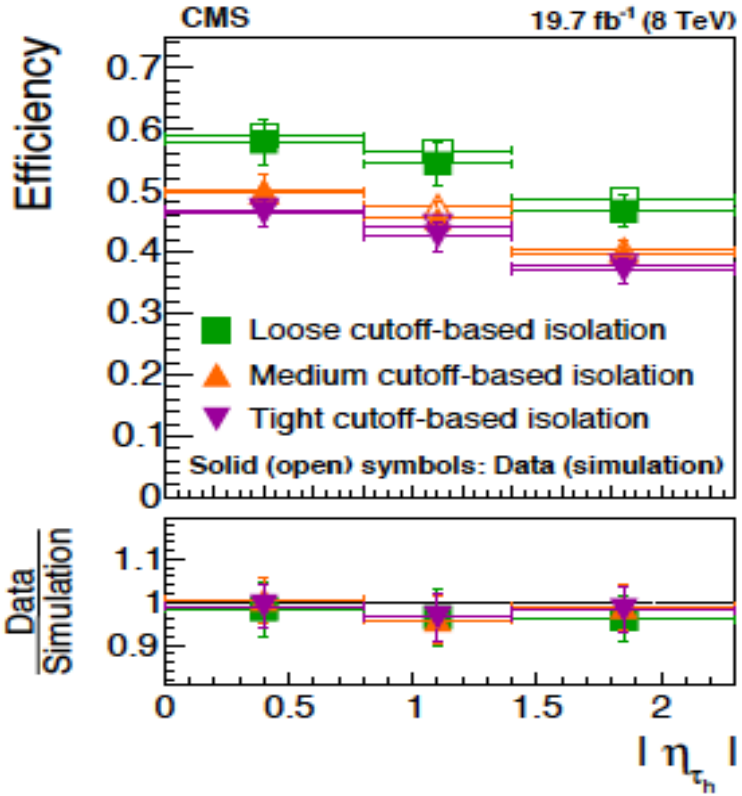
- charged hadrons reconstructed using PF algorithm
  - π0's are reconstructed in ECAL as strips
- Strips:
  - π0 -> γγ
  - Photon conversion in the tracker material
  - electron tracks bending in the magnetic field: broadening of the signal in the azimuthal direction
  - A strip of 0.05 in η and 0.2 in φ is built
  - Mass is required to be consistent with π0





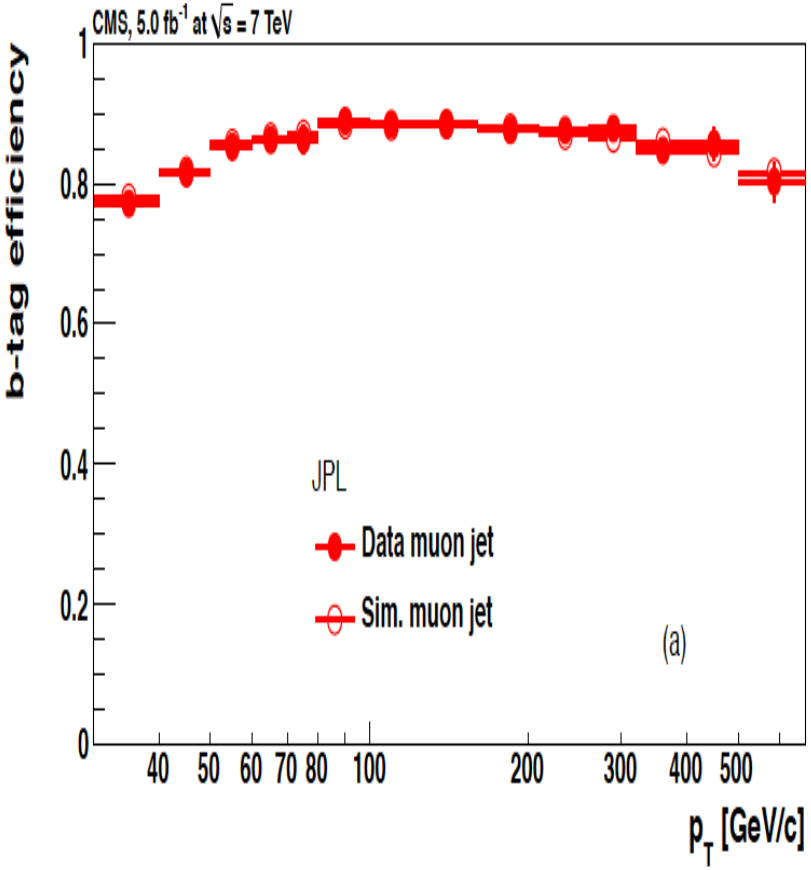
Tau efficiency





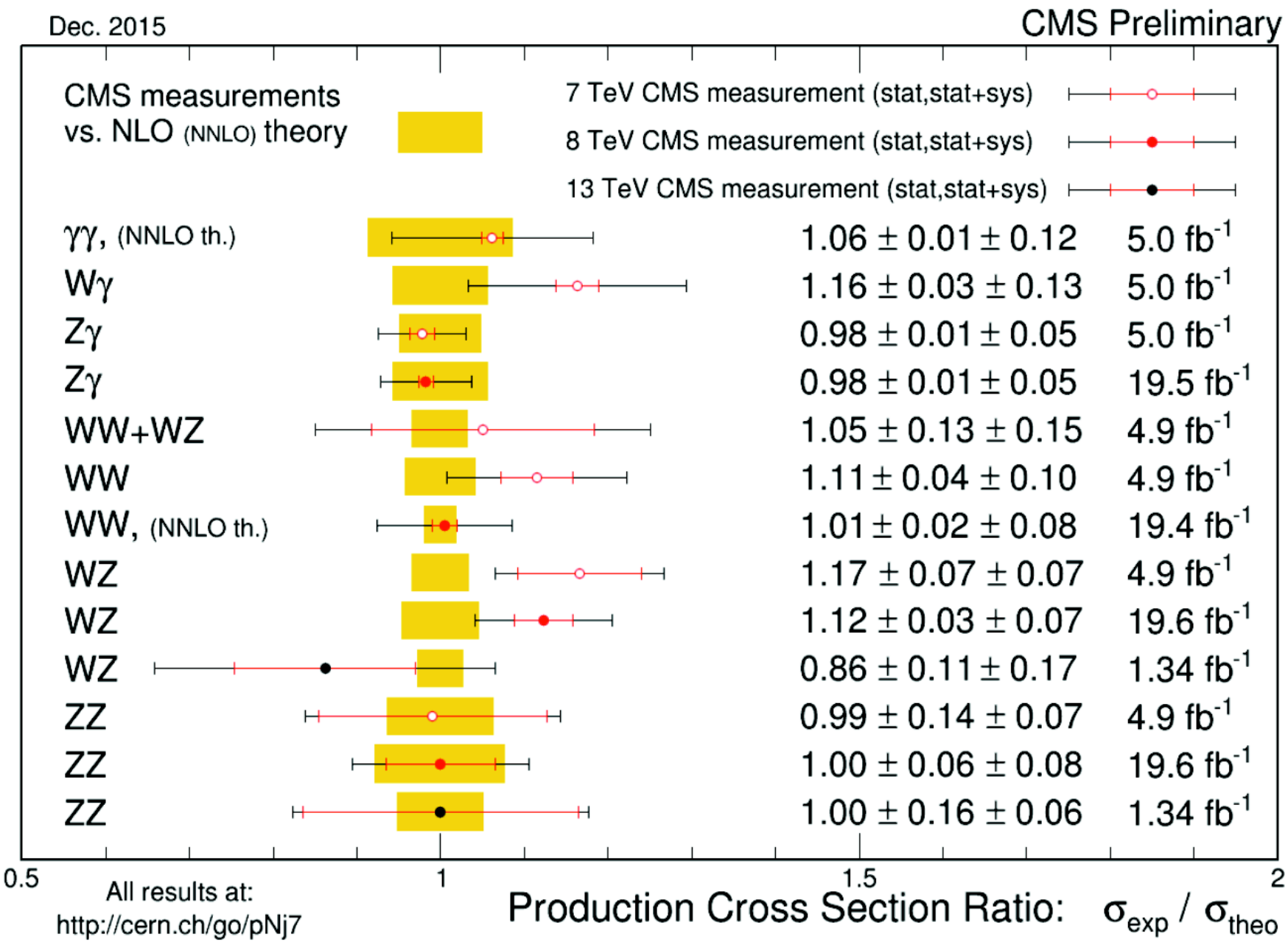
b-tagging efficiency

- The impact parameter (IP) of the track wrt the primary vertex is used to distinguish the decay product of the b hadron from the prompt tracks
- Algorithms:
  - Track counting: sorts tracks in a jet by decreasing value of IP significance
  - Jet probability (JP): uses estimate of the likelihood that all the tracks associated to the jet come from primary vertex
  - Jet B probability (JBP): same as JP, in addition, it gives more weight to the tracks with high IP significance



Standard model measurements

Di boson cross sections

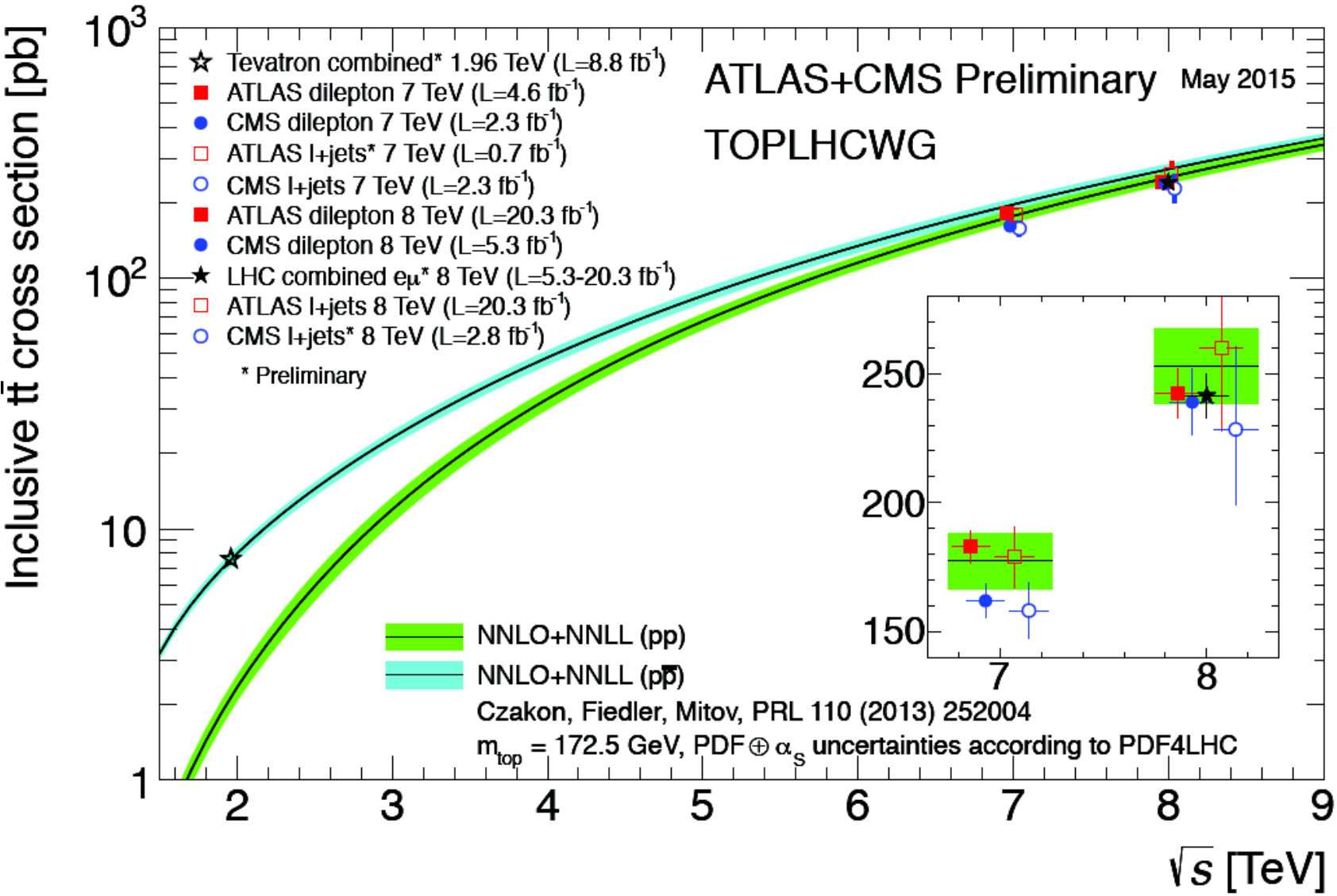


13 TeV

13 TeV

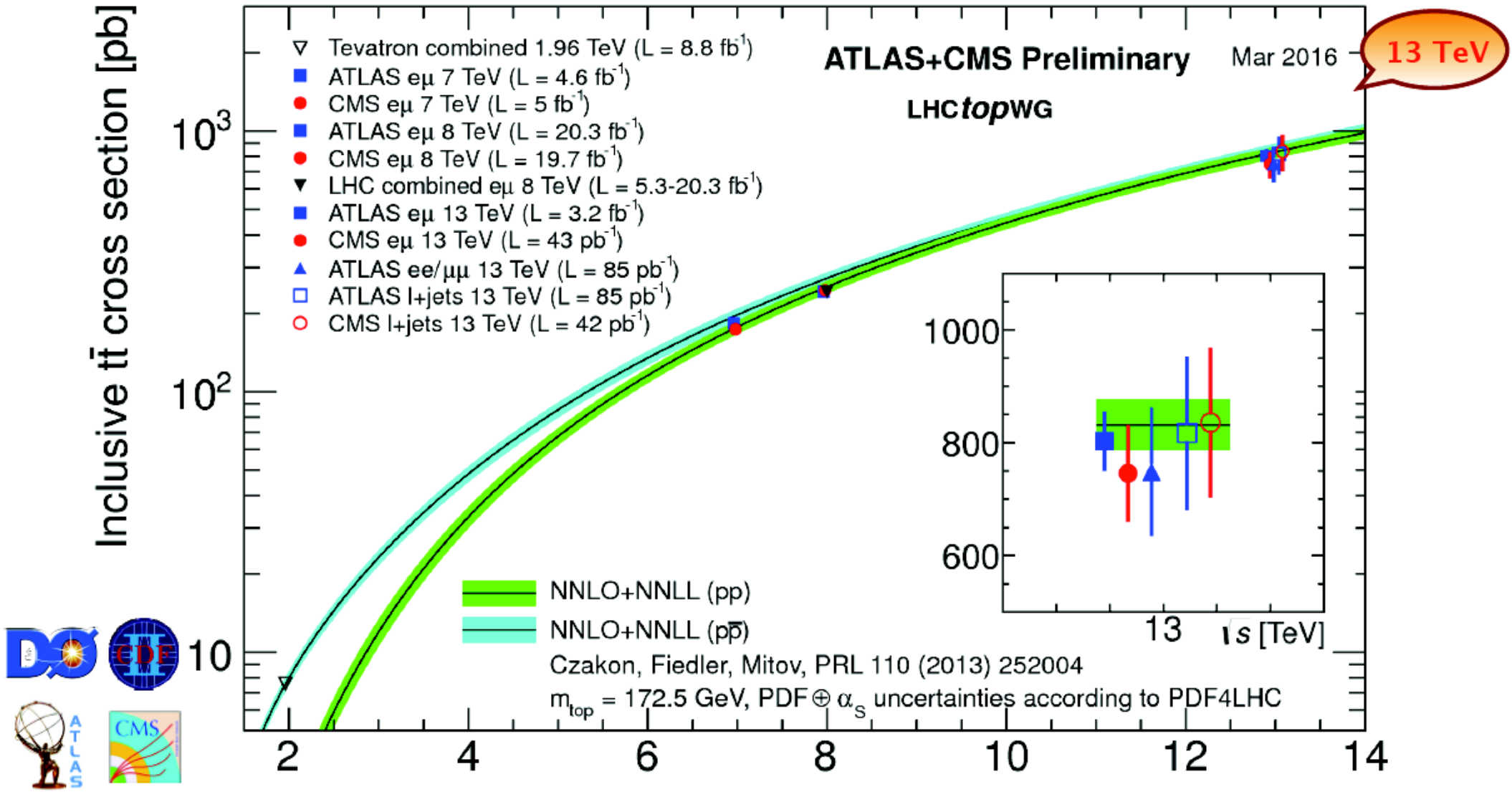
No evidence for anomalous couplings!

top pair cross sections



±5.7% (theo)

±3.9% (eμ)



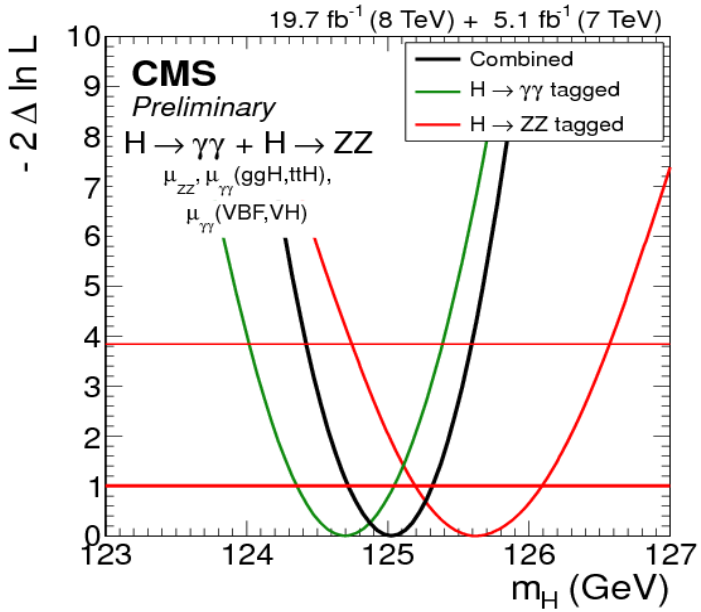
→ agreement with SM prediction

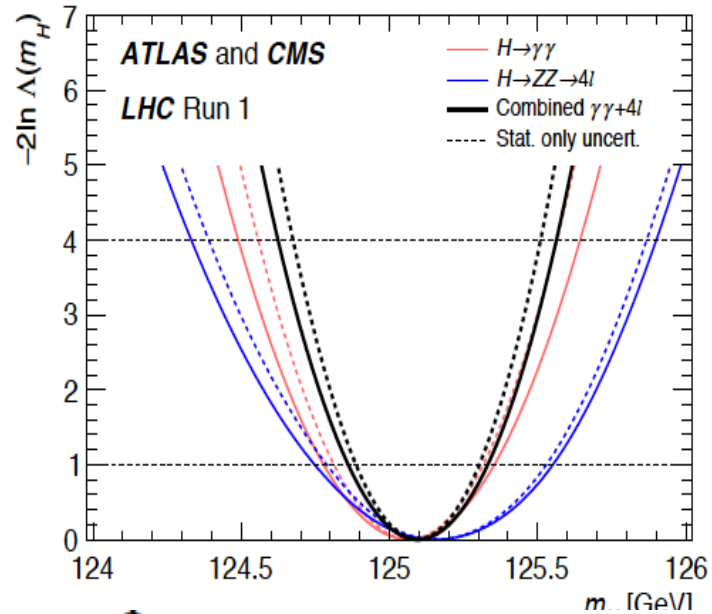
See talk by Christian Schwanenberger in LHC Ski 2016 for more details

Higgs sector

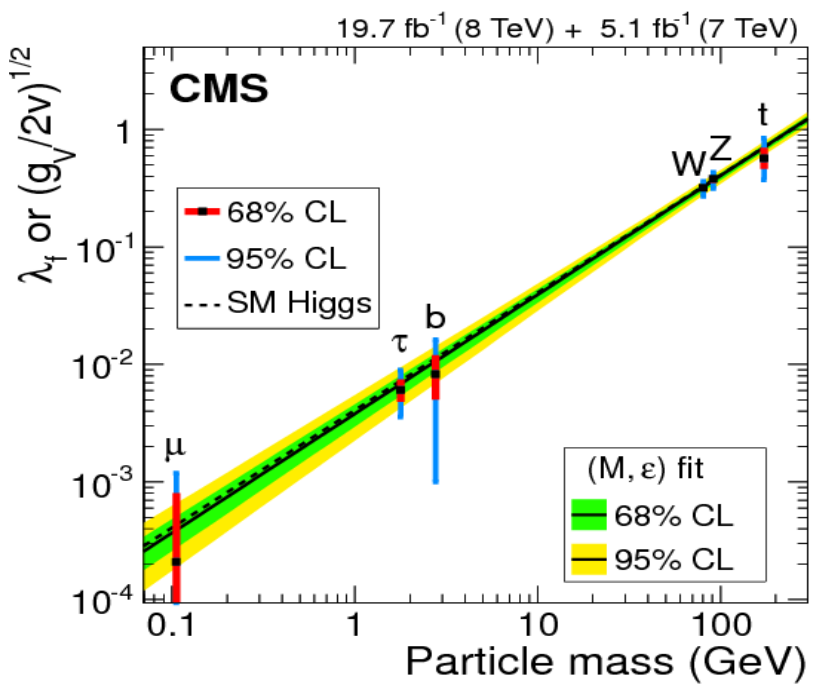
- **(Re)Discovering H(125):**
  - H→4ℓ (13 TeV) HIG-15-004
  - H→γγ (13 TeV) HIG-15-005
  - ttH→multileptons (13 TeV) HIG-15-008
  - ttH→bb (13 TeV) HIG-16-004
- **Search for BSM Higgs production:**
  - BSM Summary (8 TeV) HIG-16-007 NEW!
  - H→ZZ→4ℓ (13 TeV) HIG-15-004
  - H→ZZ→2ℓ2ν (13 TeV) HIG-16-001
  - H→Z(ℓℓ)A(bb) (13 TeV) HIG-16-010 NEW!
  - X→HH→bbττ (13 TeV) HIG-16-013
  - X→HH→bbbb (13 TeV) HIG-16-002 NEW!
  - **Double-Higgs Production**
    - HH→bbττ (8 TeV) HIG-15-013
    - HH→bbττ (13 TeV) HIG-16-012
    - HH→bbγγ (8 TeV) HIG-13-032 (submitted to PRD)
  - **Exotic Decays of H(125)**
    - H→μμbb (8 TeV) HIG-14-041
    - H→μμττ (8 TeV) HIG-15-011
    - Z(ℓℓ)H(invisible) (13 TeV) HIG-16-008

Higgs mass: CMS and ATLAS





$$m_H = 125.03\,^{+0.26}_{-0.27}\,(\text{stat.})\,^{+0.13}_{-0.15}\,(\text{syst.})\ \text{GeV}$$

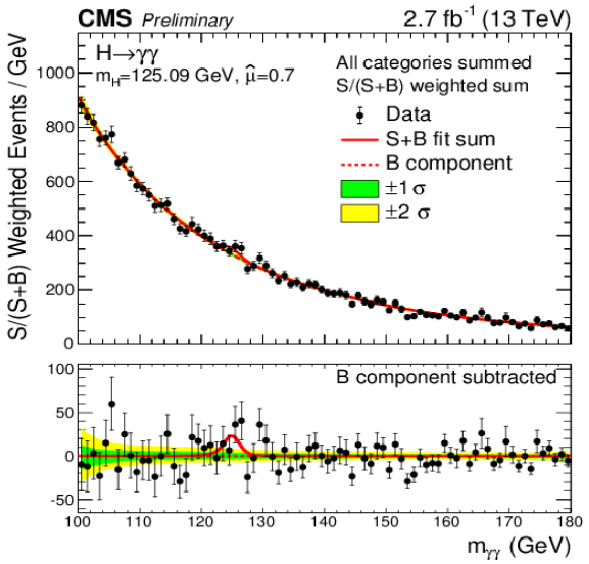


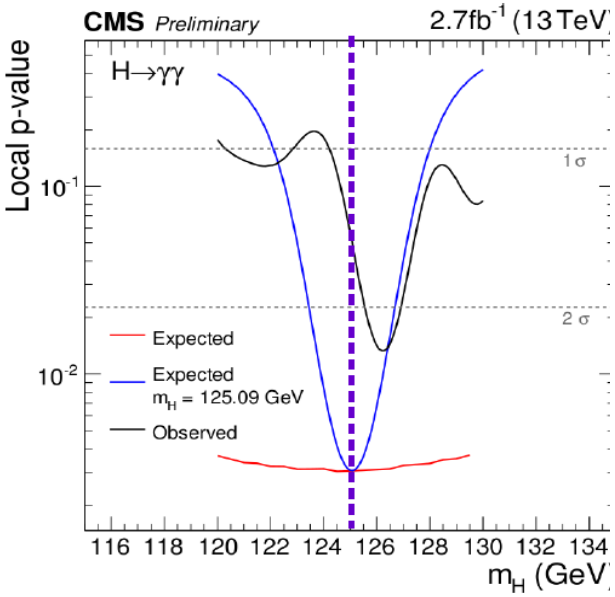
Higgs to diphoton rediscovery

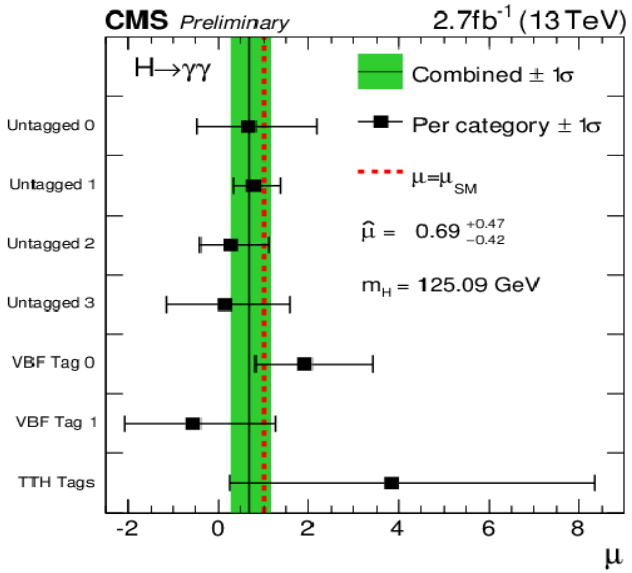
HIG-15-005

David Sperka, Moriond QCD,2016

- MVA based analysis (vertex, photon id, kinematics)
- Background from sideband fit
- Categories:
- ttH leptonic/hadronic
- VBF
- 4 untagged
- Expected (MH=125.09 GeV) $2.7\ \sigma$
- Observed $1.7\ \sigma$
  - Best Fit







$$\mu = 0.69^{+0.47}_{-0.42}$$

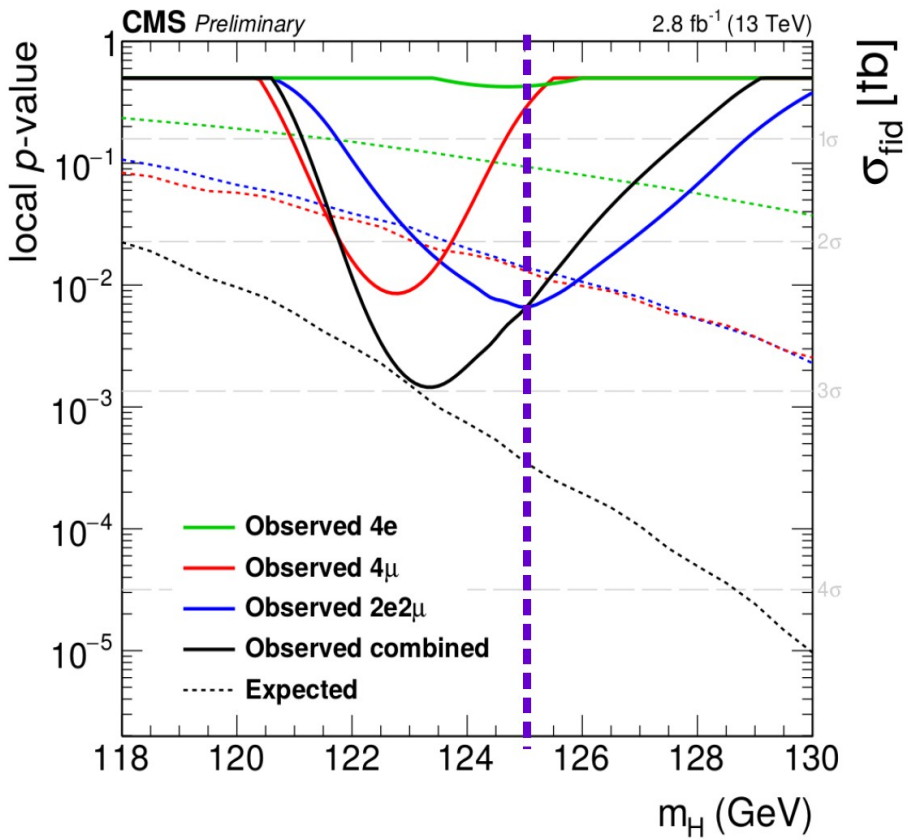
$$\mu_{\mathrm{ggH,\,t\bar{t}H}} = 0.43^{+0.80}_{-0.84}$$

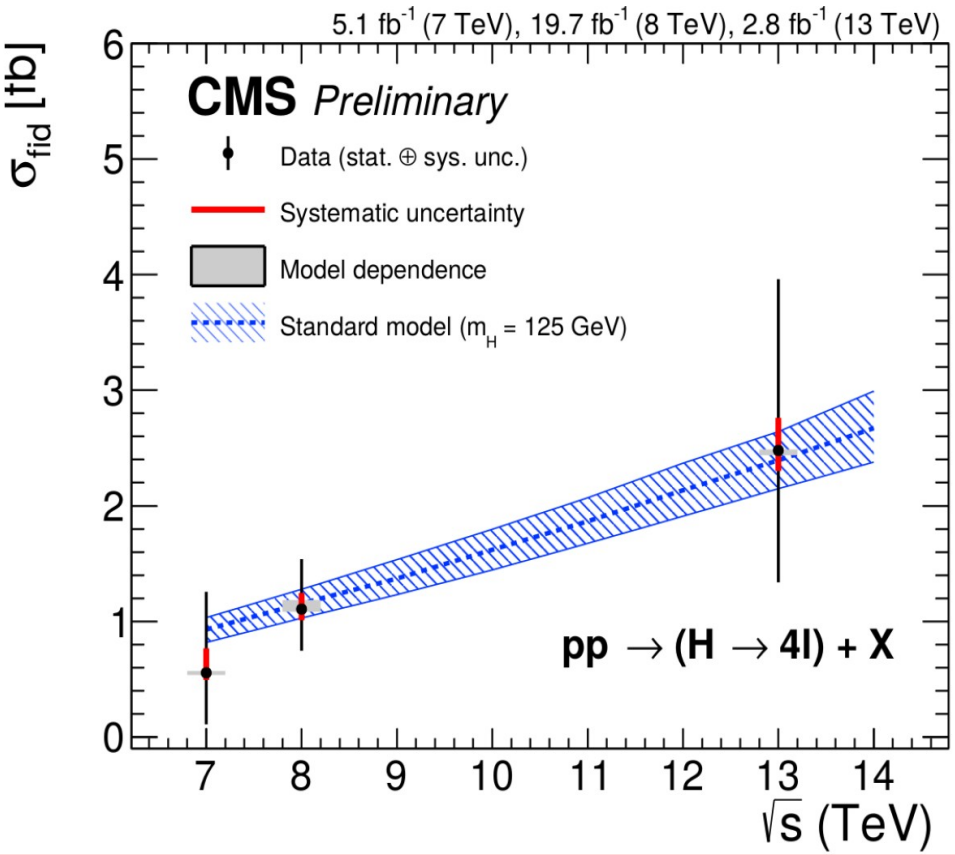
$$\mu_{\mathrm{VBF,VH}} = 1.99^{+2.62}_{-2.45}$$

Higgs rediscovery

$H \to ZZ \to 4\ell$ (13 TeV)

HIG-15-004





Significance: 2.5σ (3.4σ) obs. (exp.) at $m_{\mathrm{H}} = 125.09$ GeV

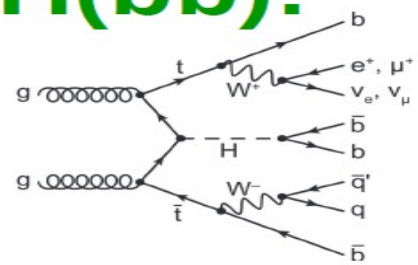
$\mu = 0.82^{+0.57}_{-0.43}$ $\quad \mu_{\mathrm{ggH,\,t\bar{t}H}} = 0.95^{+0.64}_{-0.49}$ $\quad \mu_{\mathrm{VBF,VH}} = 0.0^{+2.5}_{-0.0}$ $\quad m_{\mathrm{H}} = 123.4^{+0.8}_{-0.7}$ GeV

$\sigma_{\mathrm{fid.}} = 2.48^{+1.46}_{-1.13}(\mathrm{stat.})^{+0.28}_{-0.18}(\mathrm{sys.})^{+0.01}_{-0.04}(\mathrm{model\ dep.})$ fb $\quad \sigma^{\mathrm{SM}}_{\mathrm{fid.}} = 2.39 \pm 0.25$ fb

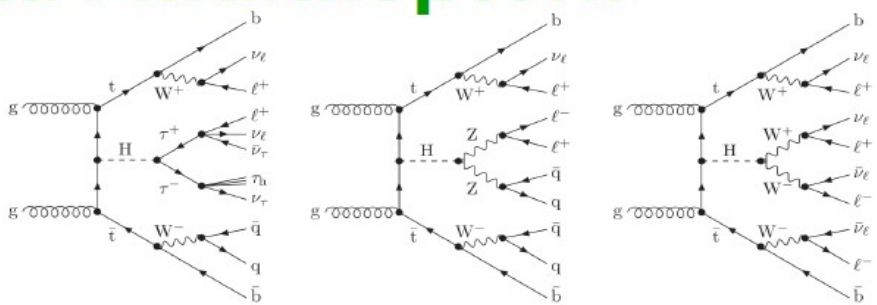
ttH @ 13 TeV

HIG-15-005
HIG-15-008
HIG-16-004

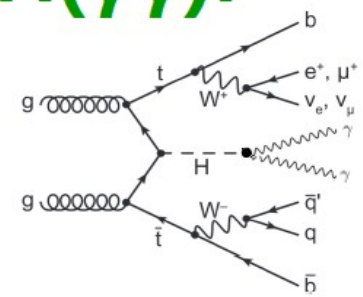
ttH(bb):

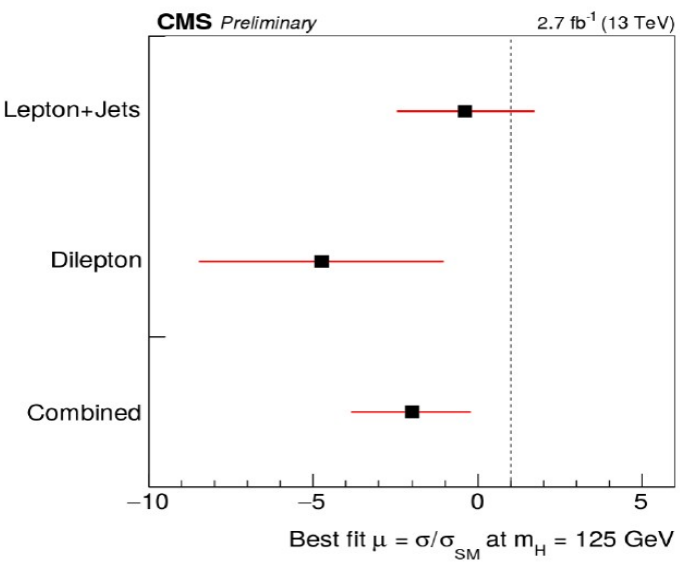


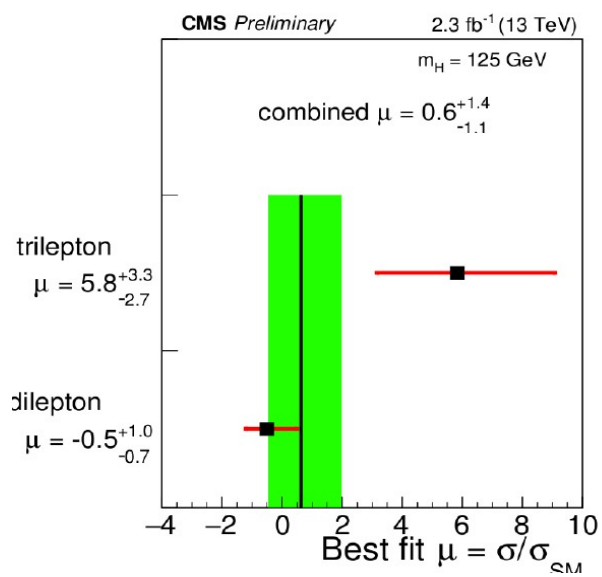
ttH multilepton:

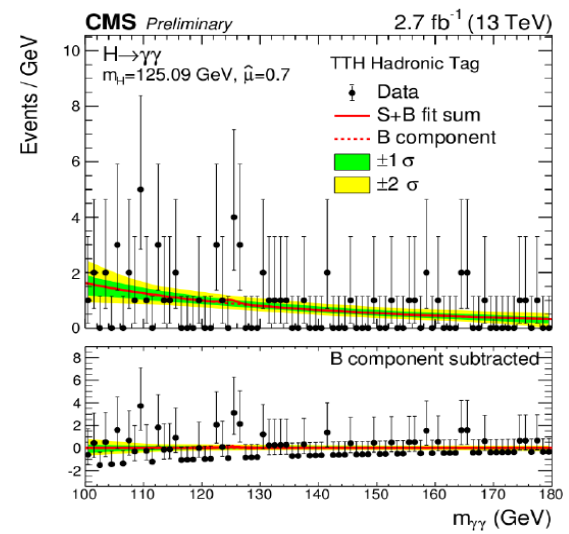


ttH(γγ):









$$\sigma/\sigma_{\rm SM} = -2.0^{+1.8}_{-1.8}$$
$$\sigma/\sigma_{\rm SM} < 2.6 \quad (3.6 \text{ exp.})$$

$$\sigma/\sigma_{\rm SM} = 0.6^{+1.4}_{-1.1}$$
$$\sigma/\sigma_{\rm SM} < 3.3 \quad (2.6 \text{ exp.})$$

$$\sigma/\sigma_{\rm SM} = 3.8^{+4.5}_{-3.6}$$

Heavy Higgs @ 13 TeV

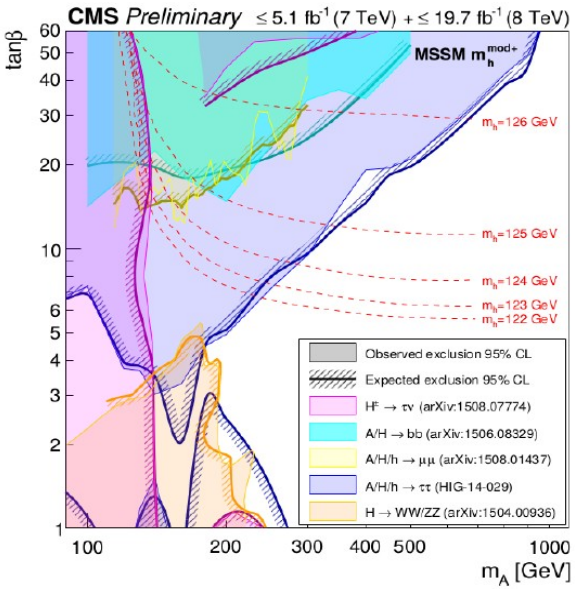
HIG-15-004

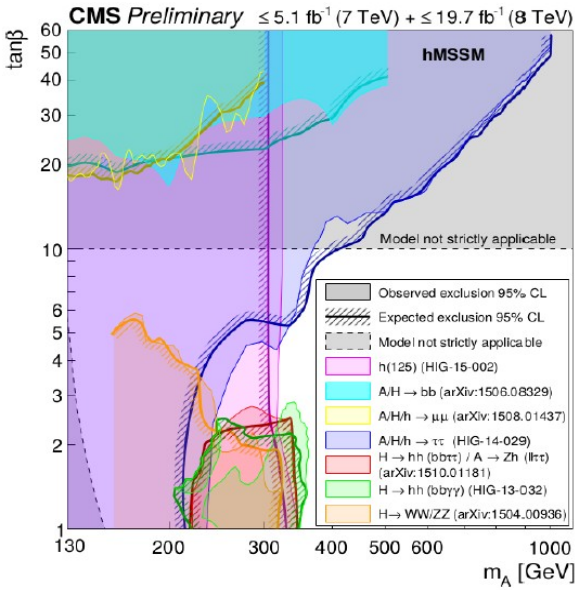
HIG-16-001

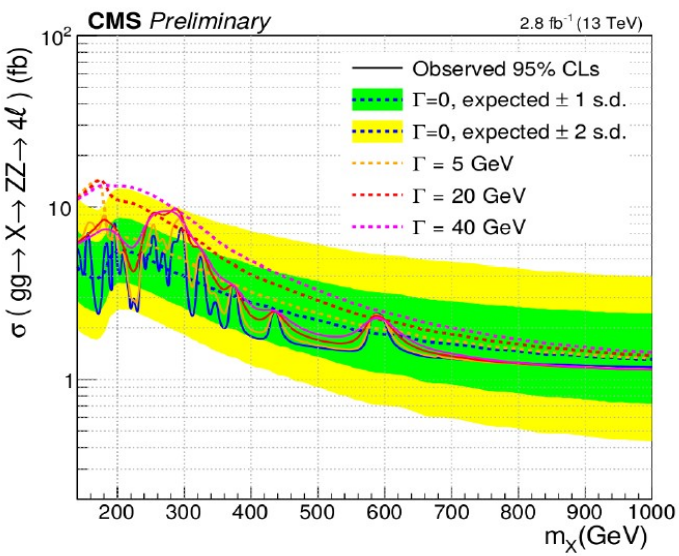
- 8 TeV direct searches put constraints in m_A–tanβ

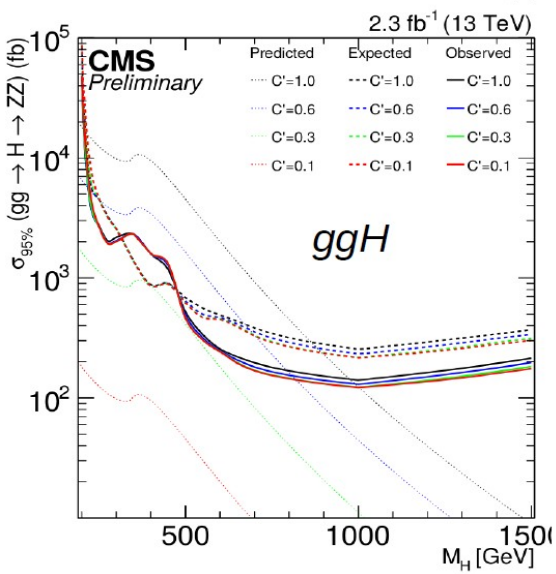
m_h^{mod+} ($m_A \lesssim 200$ GeV excl.)

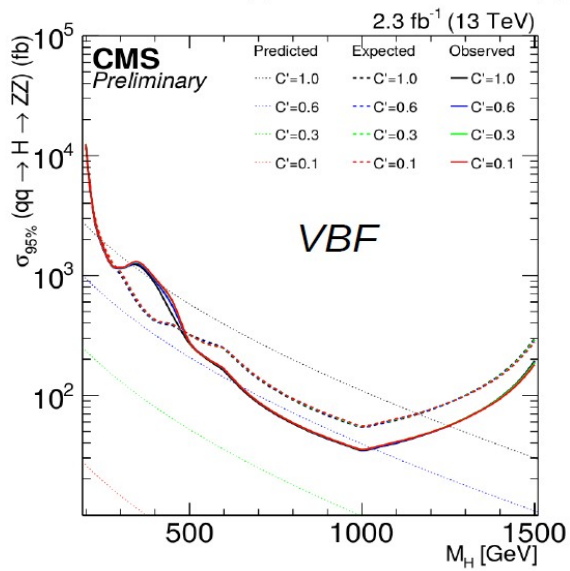
hMSSM ($m_A \lesssim 300$ GeV excl.)







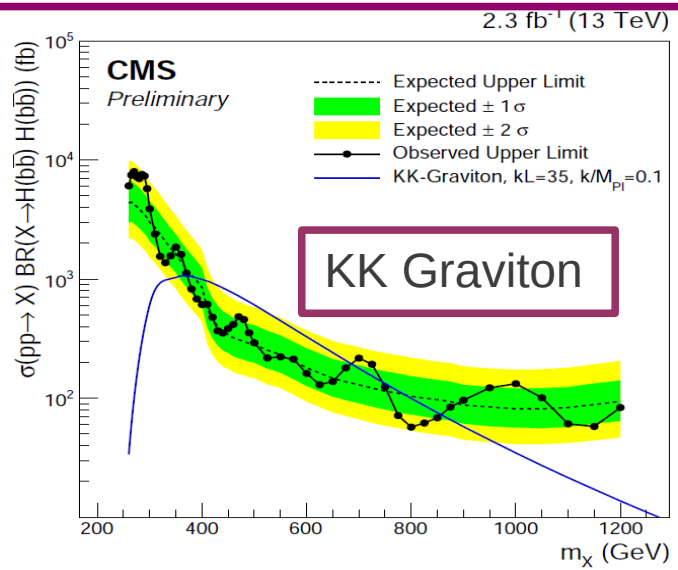




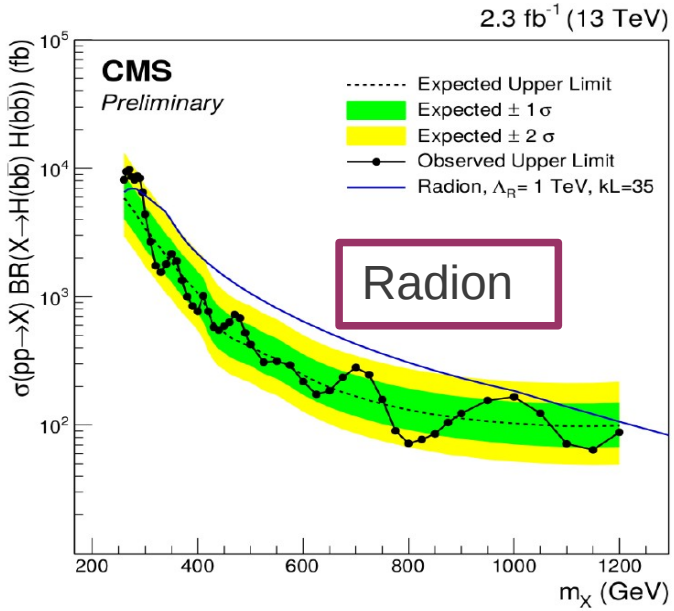
$X \to HH \to bbbb$ NEW!

HIG-16-002

HIG-16-013



KK Graviton



Radion

- First KK excitation of RS1 graviton
- MVA Tag secondary vertex
- 4(2) jets in low (high) mass region

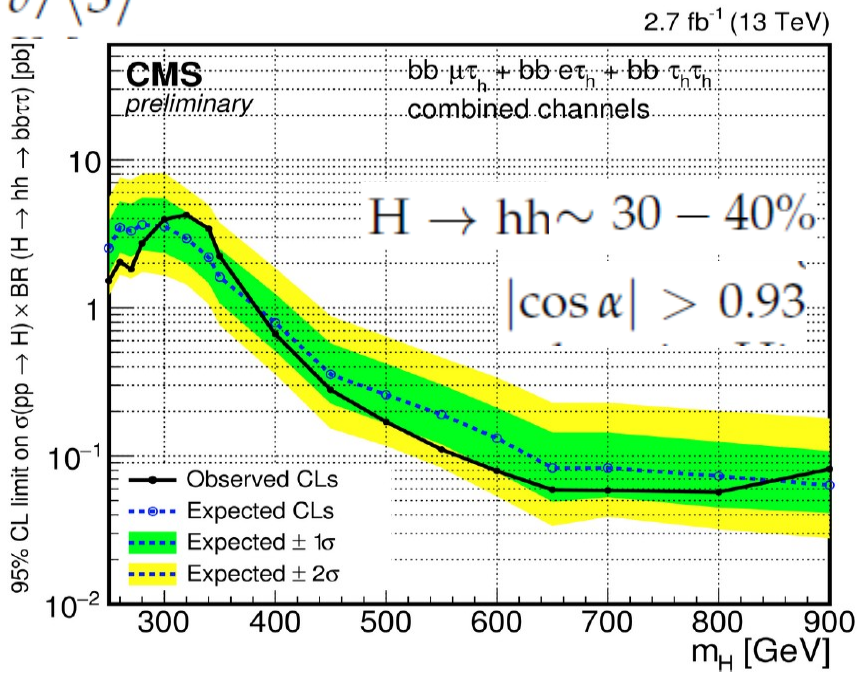
$pp \to H \to hh \to b\bar{b}\tau^+\tau^-$

$$h = \cos\alpha\,\phi_0 + \sin\alpha\,S$$

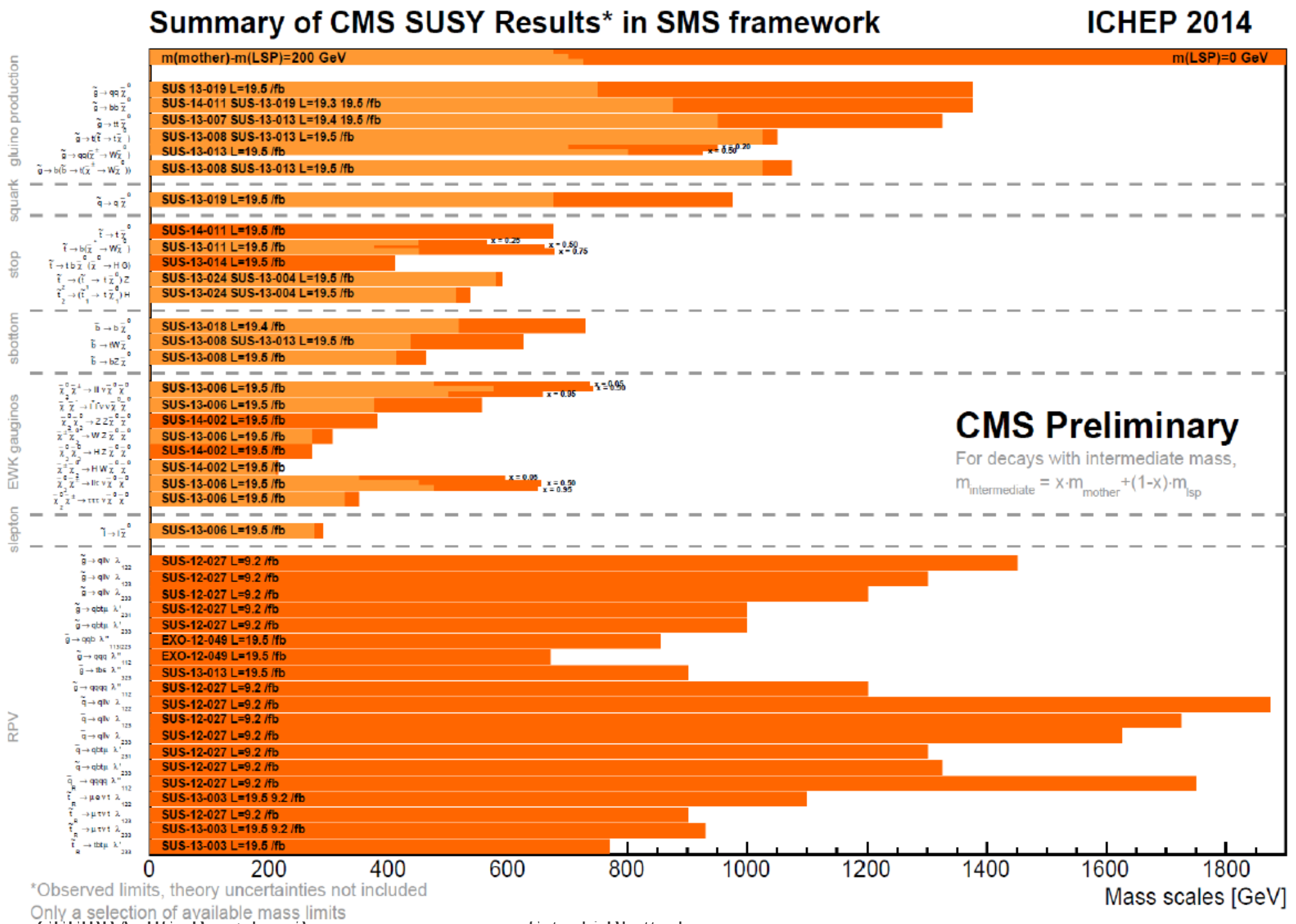
$$H = -\sin\alpha\,\phi_0 + \cos\alpha\,S$$

$$m_h,\ m_H,\ \cos\alpha,\ v = (\sqrt{2}G_F)^{-1/2} \approx 246\ \text{GeV},$$

$$\tan\beta = v/\langle S\rangle$$



Search for Supersymmetry


Summary of CMS SUSY Results* in SMS framework
ICHEP 2014
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-007 SUS-13-013 L=19.4 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
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EXO-12-049 L=19.5 /fb
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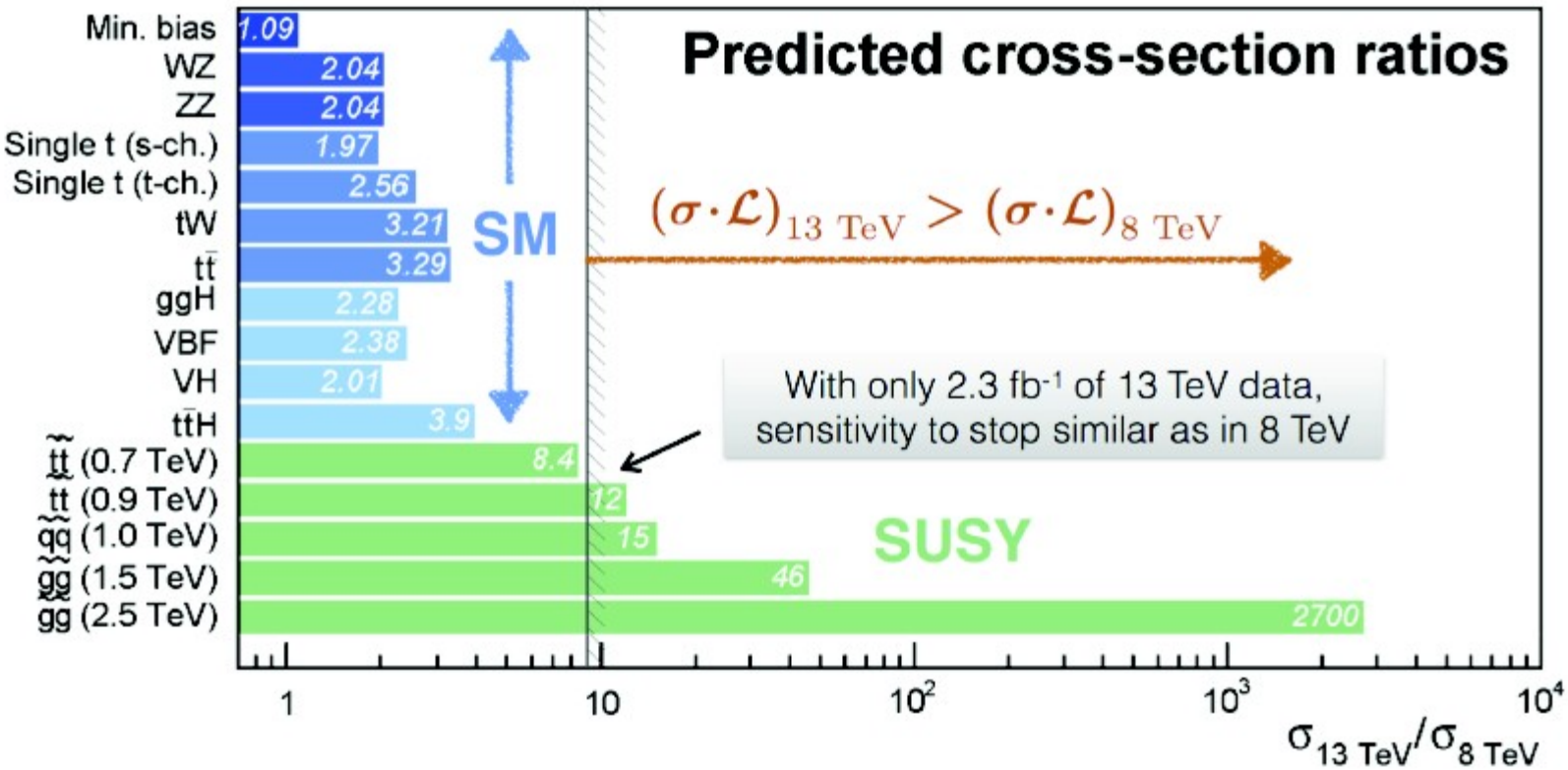
SUS-13-003 L=19.5 /fb
CMS Preliminary
For decays with intermediate mass,
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits

SUSY searches @13 TeV



- Search in all accessible channels
- Focus on stop, sbottom, gluino

Strategy @ 13 TeV

Focused on strongly produced SUSY

Largest gain from 13TeV parton luminosity

Started from *inclusive* searches: M_{T2}, α_T, HT^{miss}, Razor **Updated**

compare data to SM estimates across a large phase space, look for excesses

- No excess is observed, extract limits on cross-section x branching-ratios
- Preliminary results presented in December 2015

New **New for Moriond QCD**

then moved to *targeted* searches: stop and sbottom

similar background estimation techniques, but fine-tuned selection

- First results of 3rd generation searches showed at Moriond

All results available from: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

HT^{miss}	SUS-15-002, arXiv:1602.06581
α_T	SUS-15-005
M_{T2}	SUS-15-003, arXiv:1603.04053
Razor	SUS-15-004

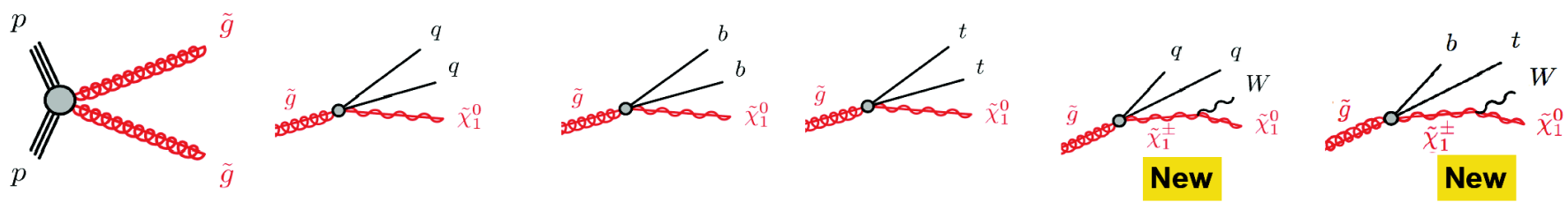
stop	SUS-16-007
sbottom	SUS-16-001
Further Interpretations (Dec. 2015 Analyses)	SUS-16-004
$\gamma\gamma$+MET	SUS-15-012

SUSY Hadronic search channels

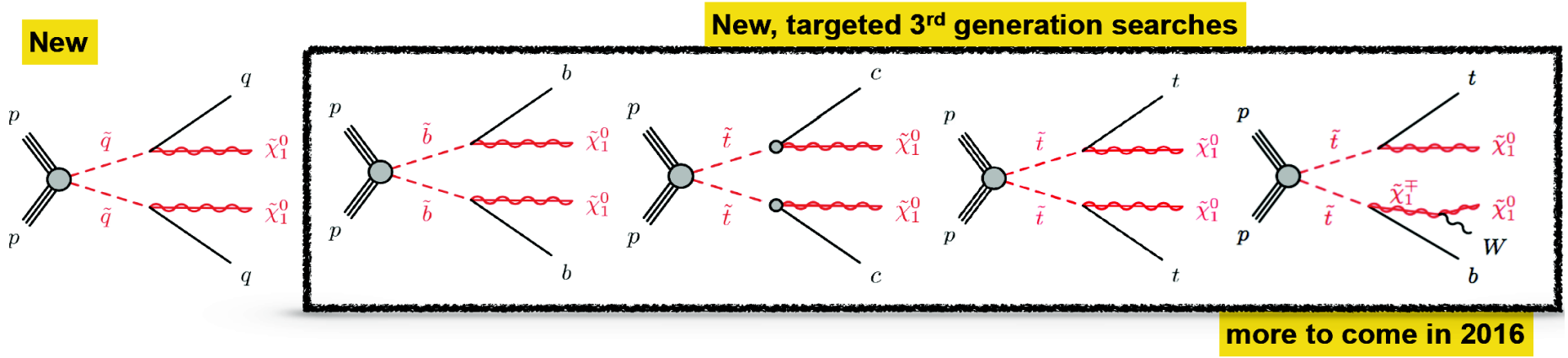
- Look for pair production with simple decay chain
- Exclusion in M_produced-M_LSP plane

Gluino pair-production:

Several decay modes, all relevant depending on squark mass spectra and branchings



Squark pair-production and decays:



SUSY Hadronic search

- Lepton veto to remove W's
- MET related quantities to reject multijets

$$H_{\mathrm{T}}^{\mathrm{miss}} = \left| -\sum_{jets} \vec{p}_{\mathrm{T}} \right| \approx E_{\mathrm{T}}^{\mathrm{miss}}$$

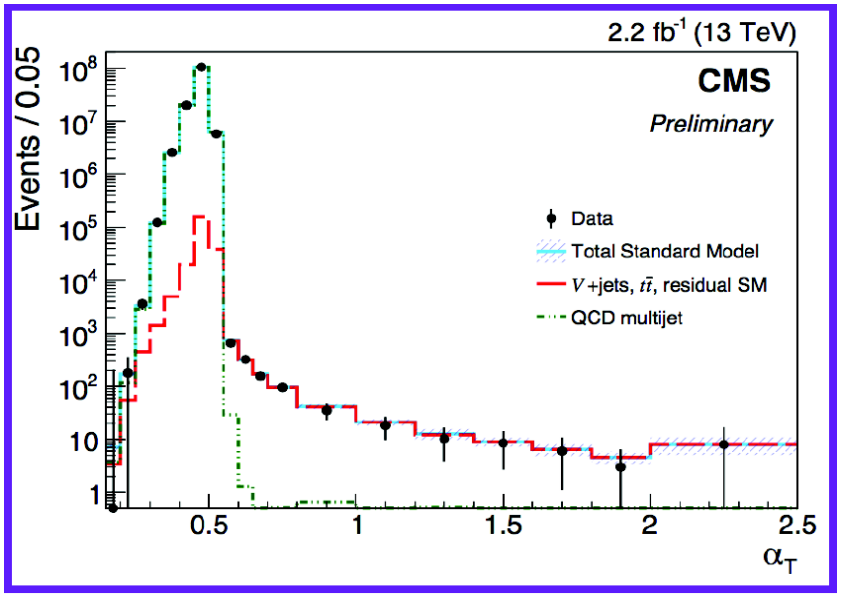
$$M_{\mathrm{T2}} \approx \sqrt{2 p_{\mathrm{T}}^{\mathrm{J1}} p_{\mathrm{T}}^{\mathrm{J2}} (1 + \cos \Delta\phi_{1,2})}$$

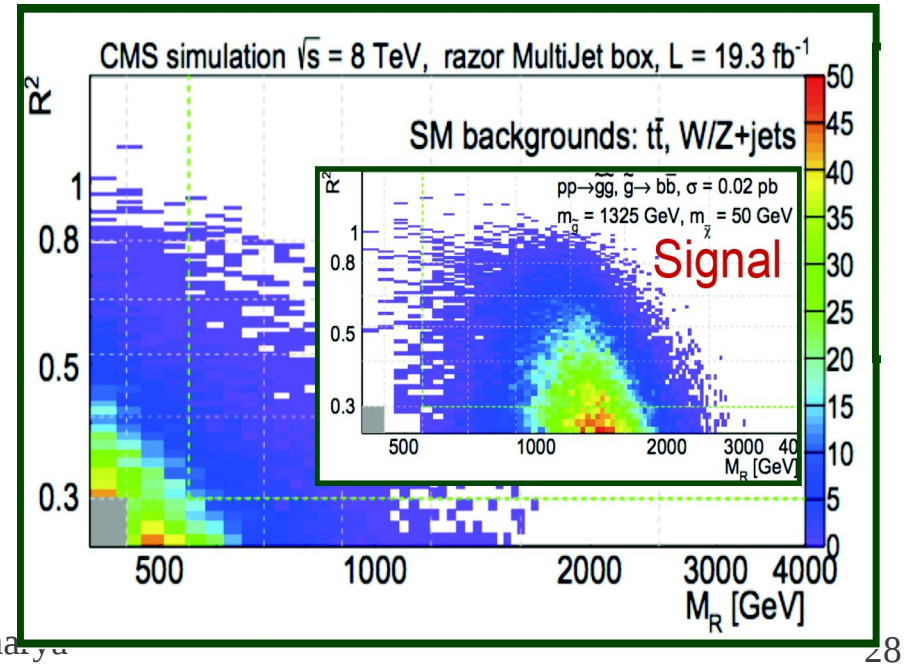
$$\alpha_{\mathrm{T}} \approx \sqrt{\frac{p_{\mathrm{T}}^{\mathrm{J2}}}{2 p_{\mathrm{T}}^{\mathrm{J1}}} \frac{1}{(1 - \cos \Delta\phi_{1,2})}}$$

Razor:

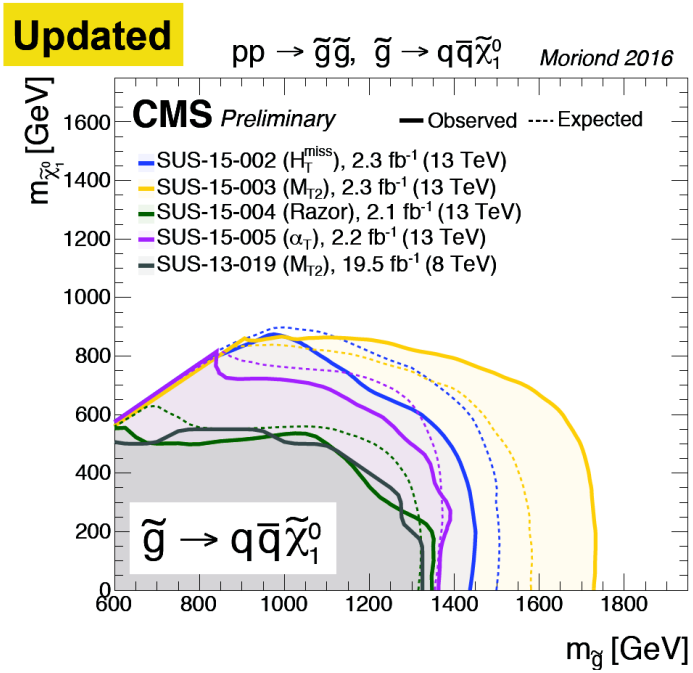
$$\mathrm{R}^2 \approx \frac{E_{\mathrm{T}}^{\mathrm{miss}} (p_{\mathrm{T}}^{\mathrm{J1}} + p_{\mathrm{T}}^{\mathrm{J2}} + E_{\mathrm{T}}^{\mathrm{miss}})}{2 M_{\mathrm{R}}^2}$$

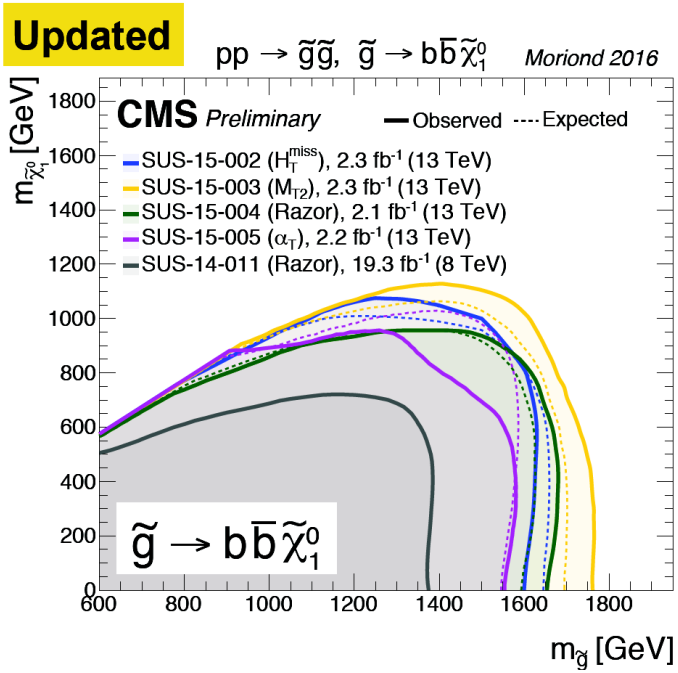
$$M_{\mathrm{R}}^2 = m_{\mathrm{J1,J2}} + (E_{\mathrm{T}}^{\mathrm{miss}})^2$$

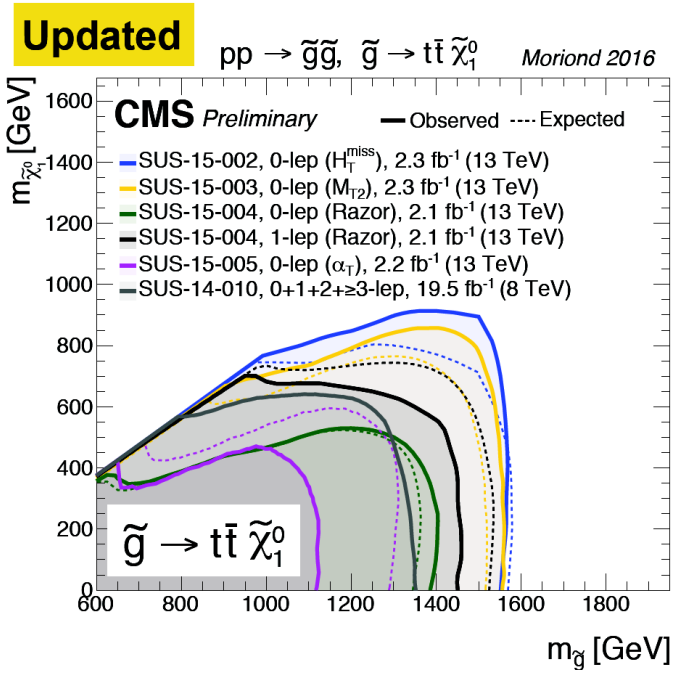




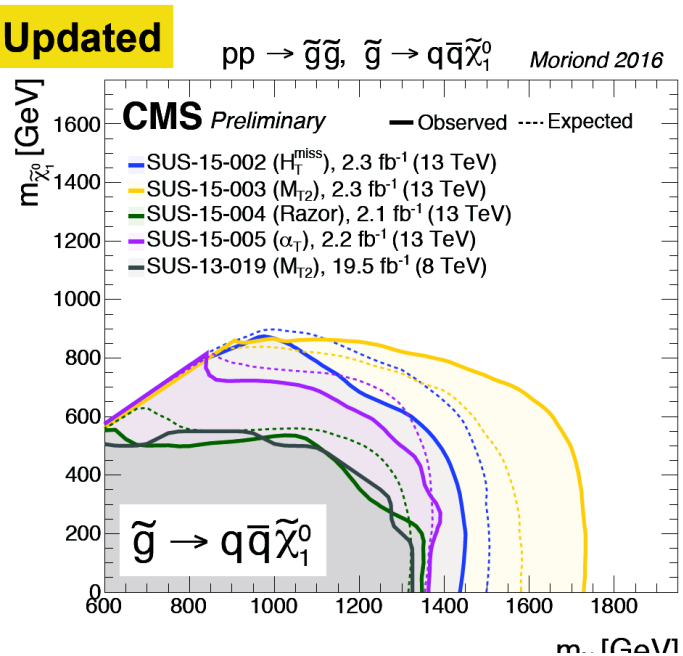
Gluino searches

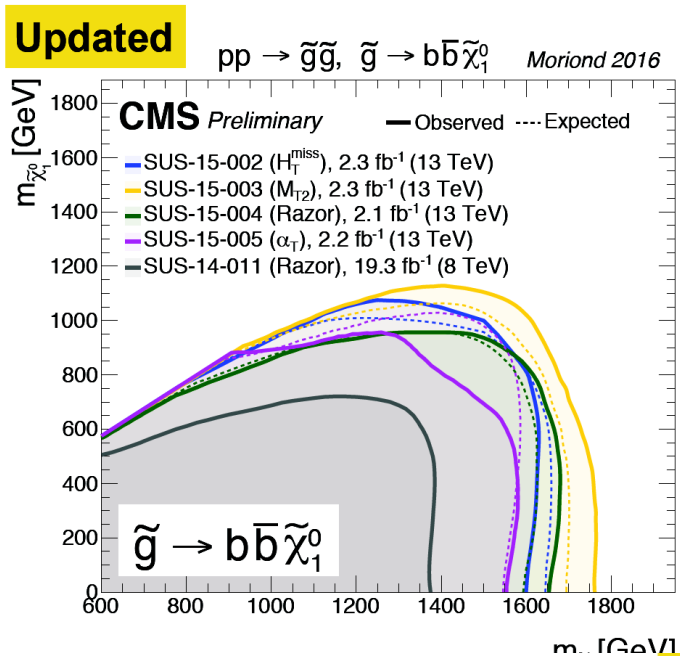


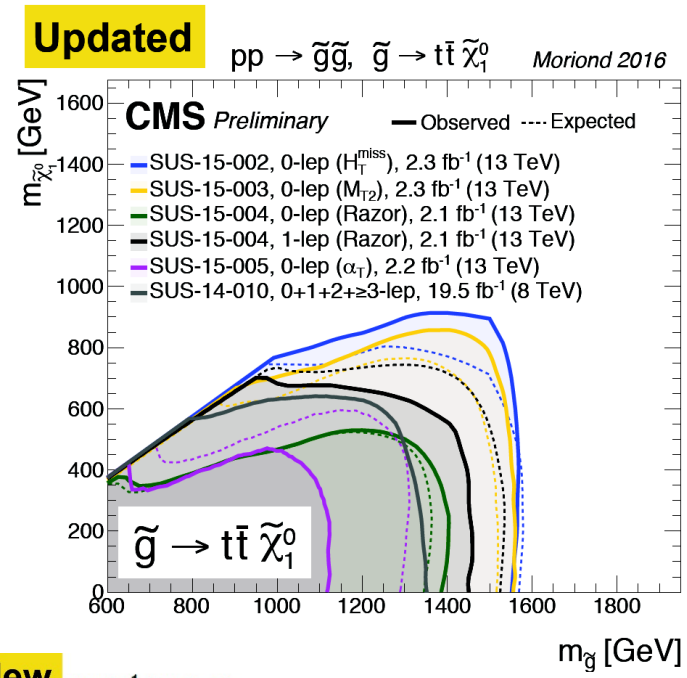




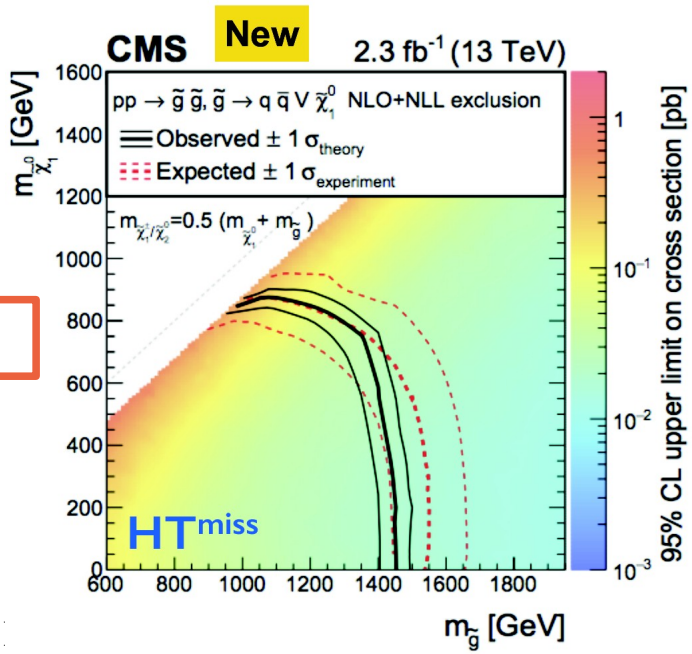
Gluino searches

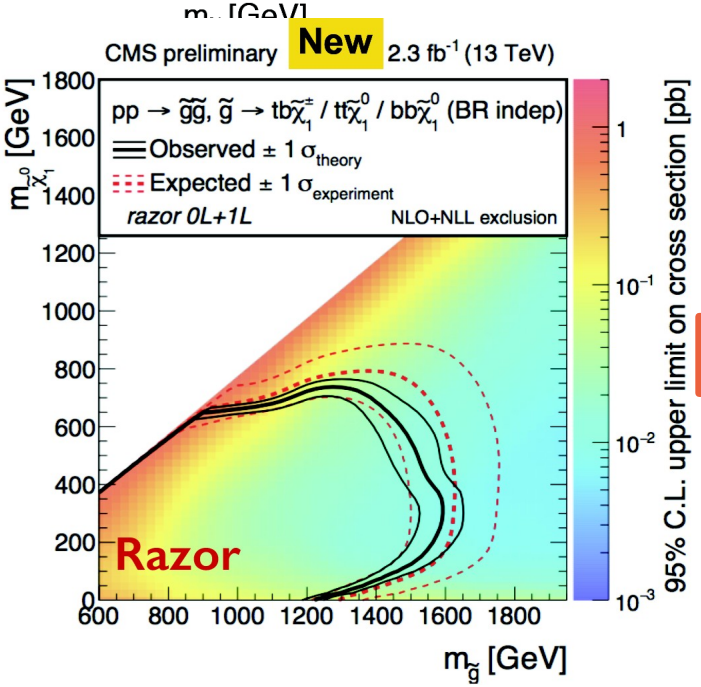






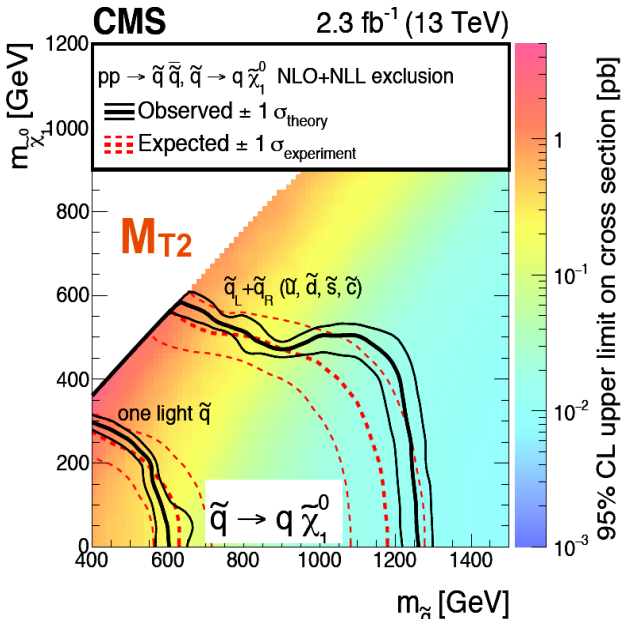
SUS-16-003

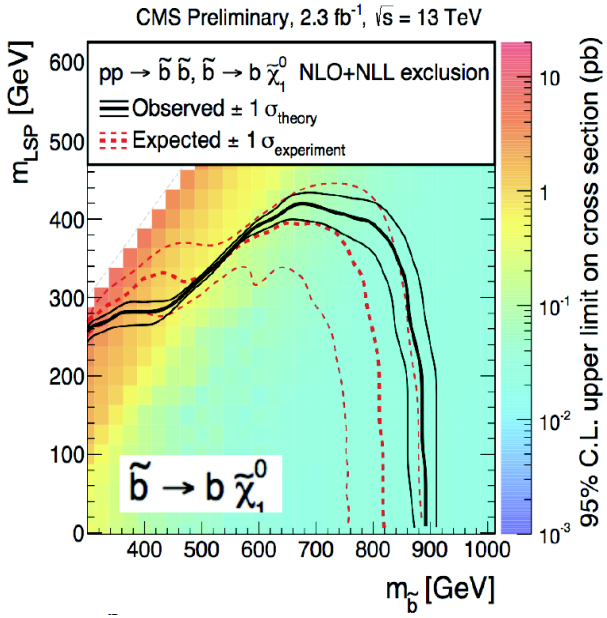


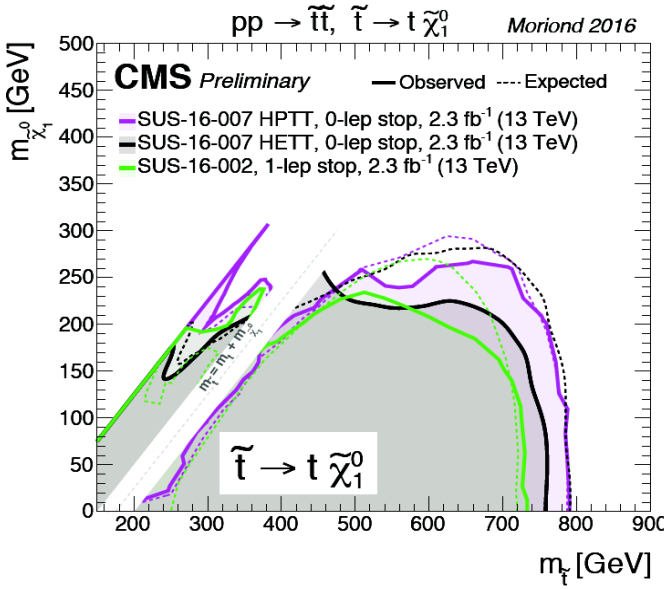


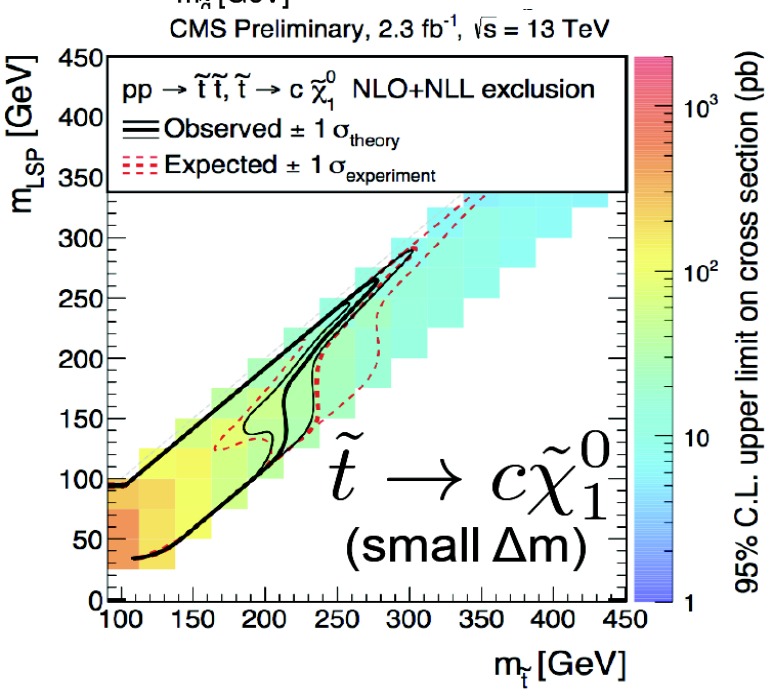
SUS-16-004

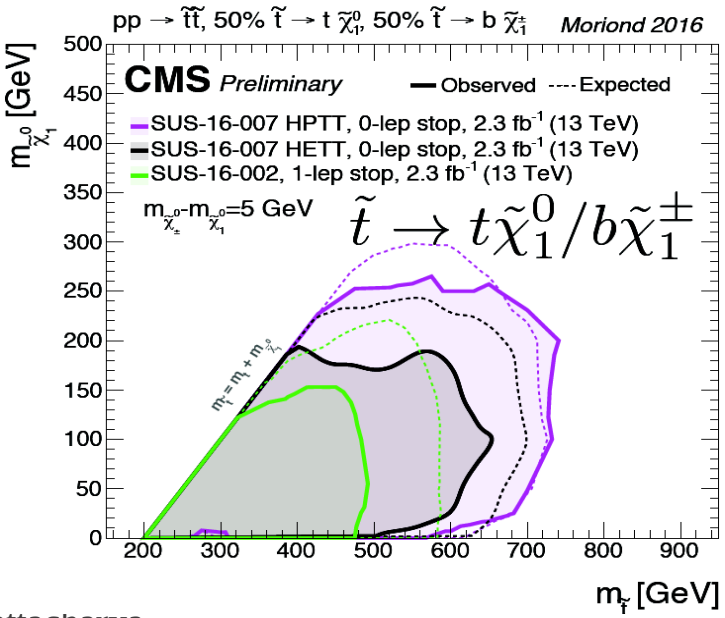
Stop Searches



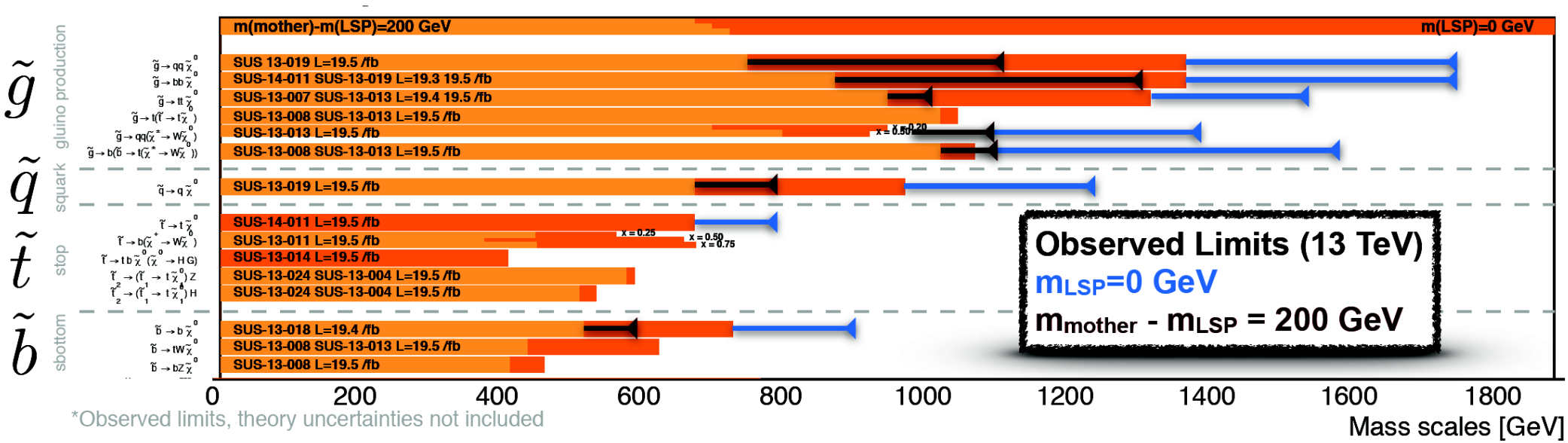








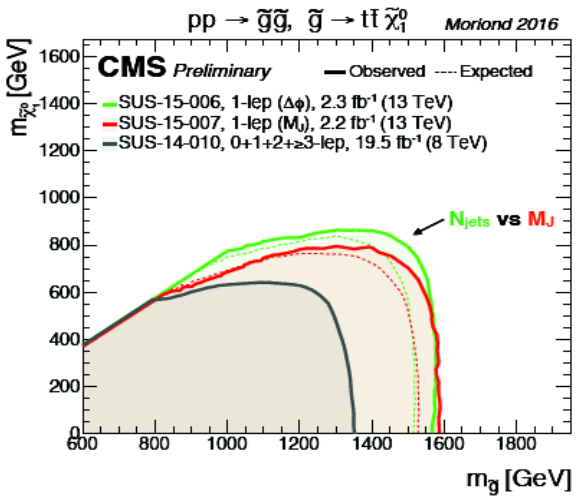
SUSY hadronic summary

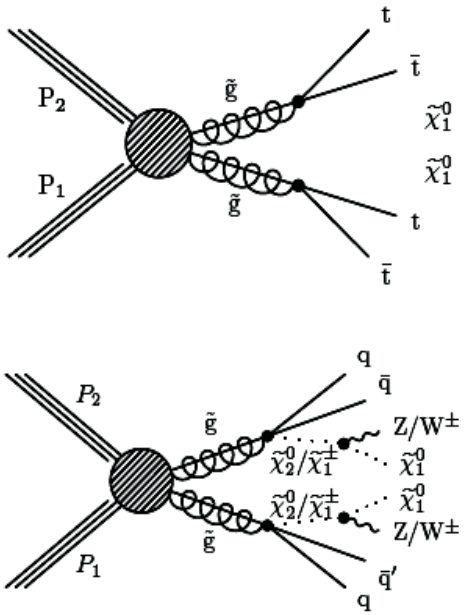


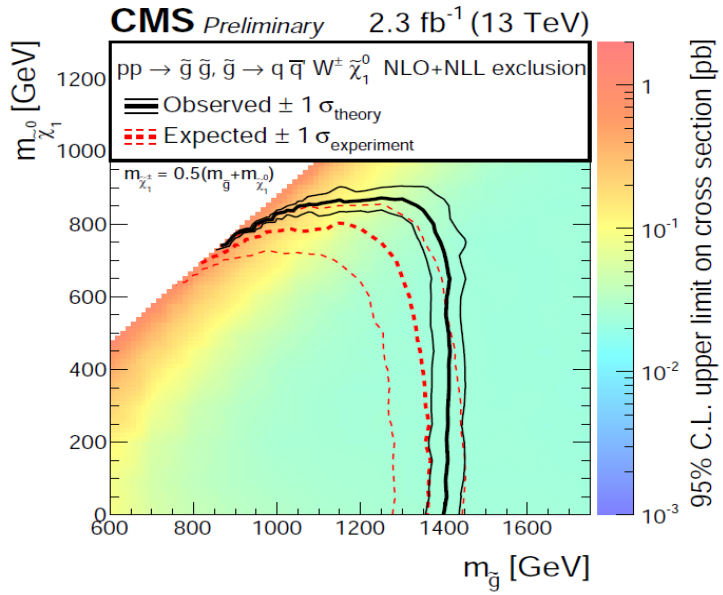
- 2016 will offer 10X opportunity

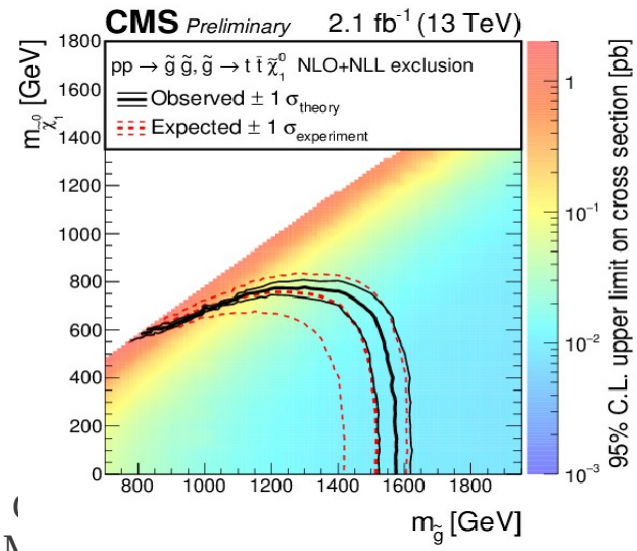
Single lepton gluino limits @ 13 TeV

PAS-SUS-15-007,
PAS-SUS-15-006







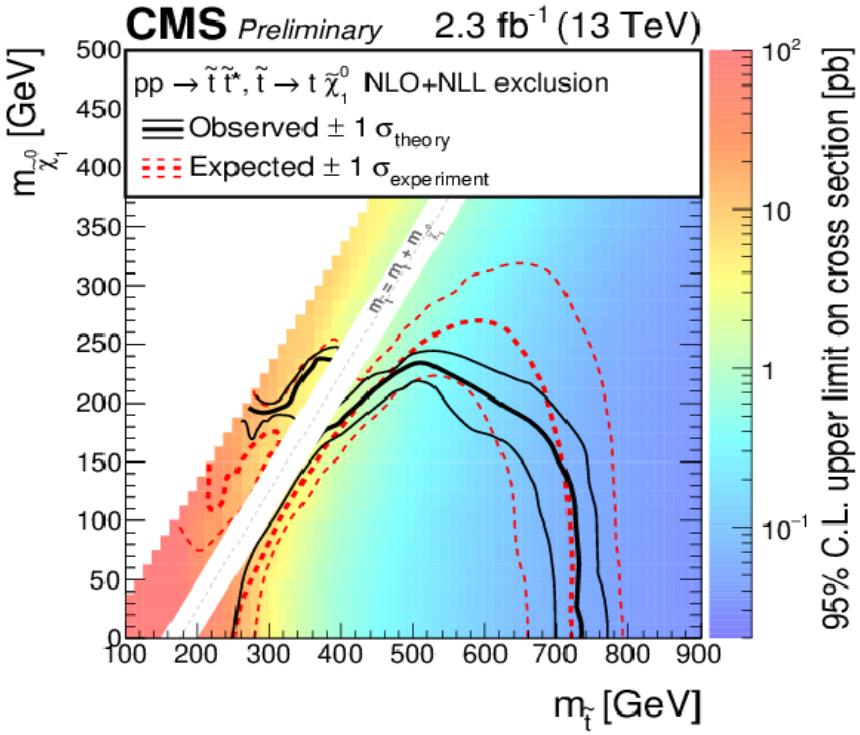


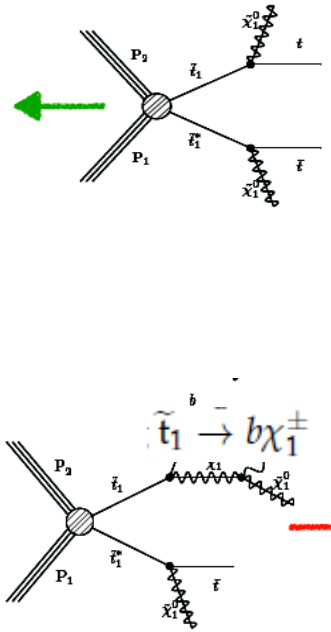
- T5q4WW model
- 0 b analysis

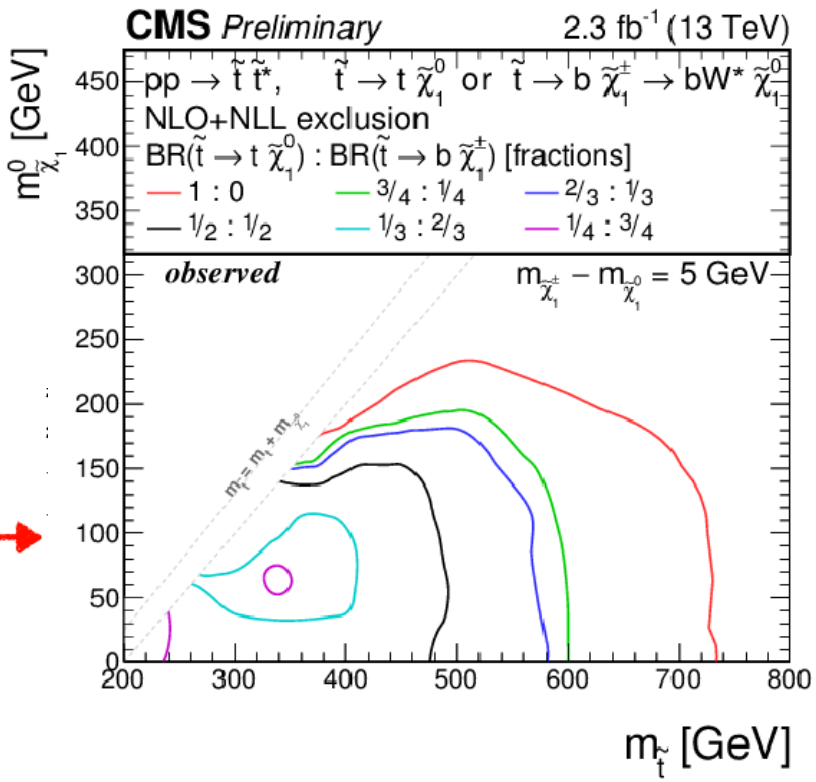
$$m_{\tilde{\chi}_1^\pm} = 0.5(m_{\tilde{g}} + m_{\tilde{\chi}_1^0})$$

Single lepton stop search

PAS-SUS-16-002







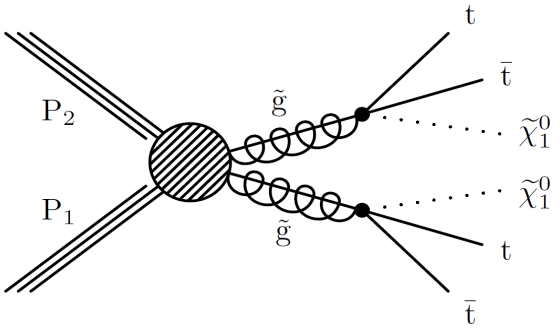
Limits on direct stop production with 100% B.R.

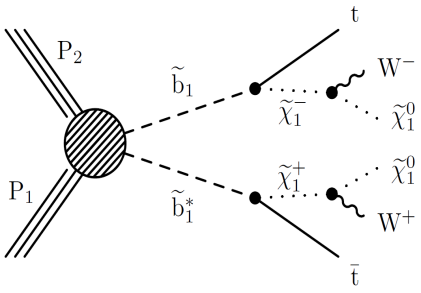
- Run I limit 650 GeV (790 GeV from most sensitive channel)

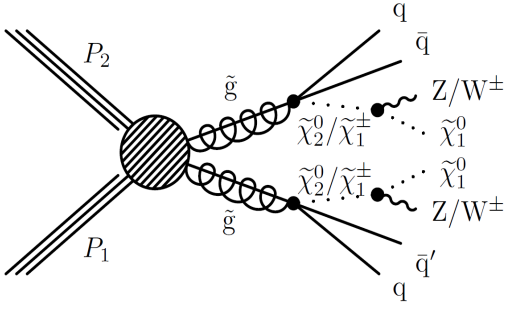
- Assume chargino nearly degnerate with LSP
- Limit worsens with increasing B.R. $\tilde{t}_1 \to b\chi_1^{\pm}$

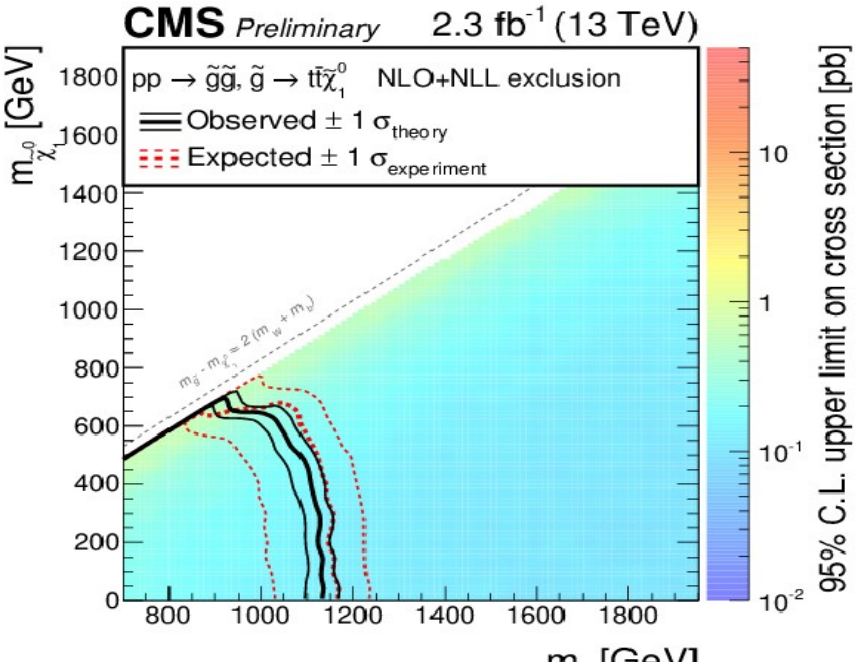
SUSY with Multileptons @ 13 TeV

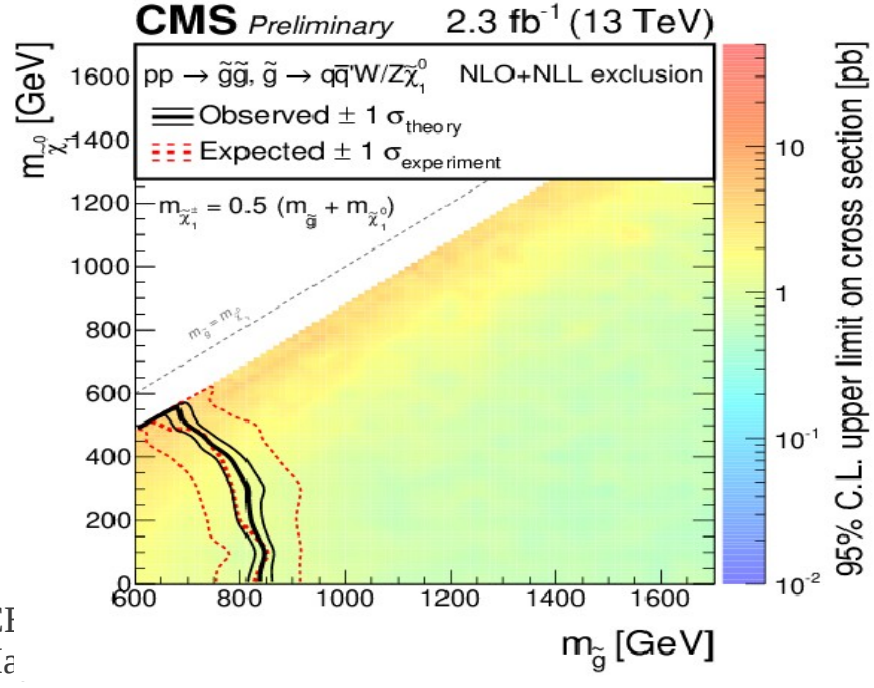
PAS-SUS-16-003

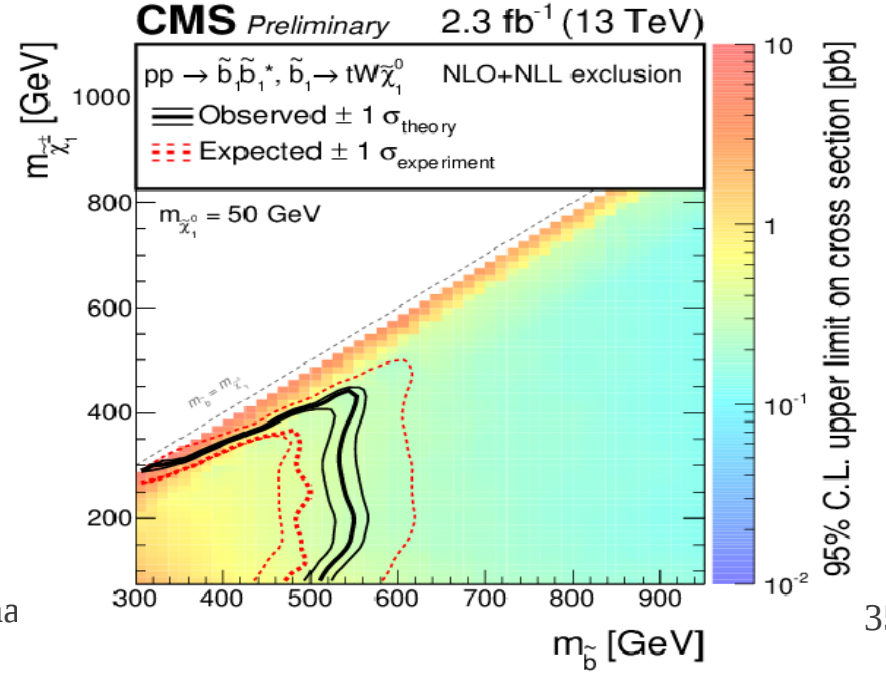








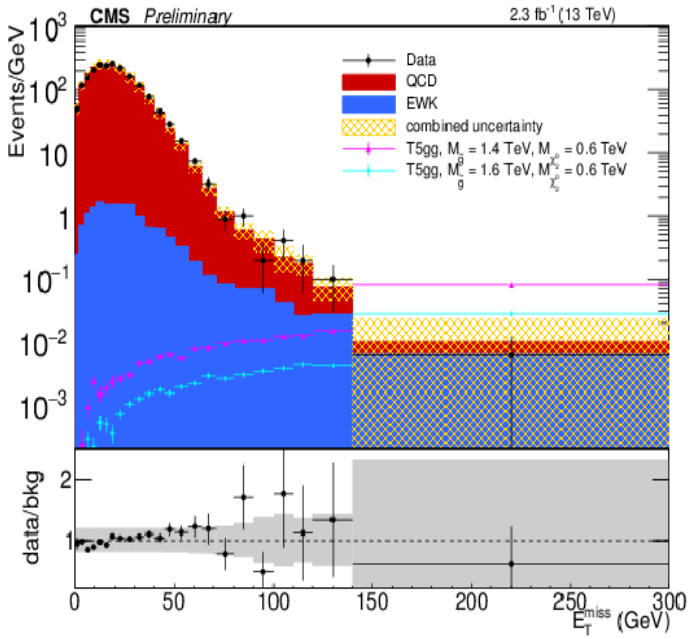


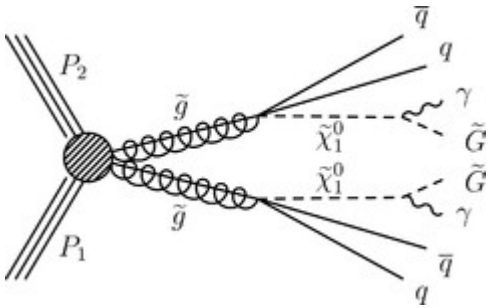


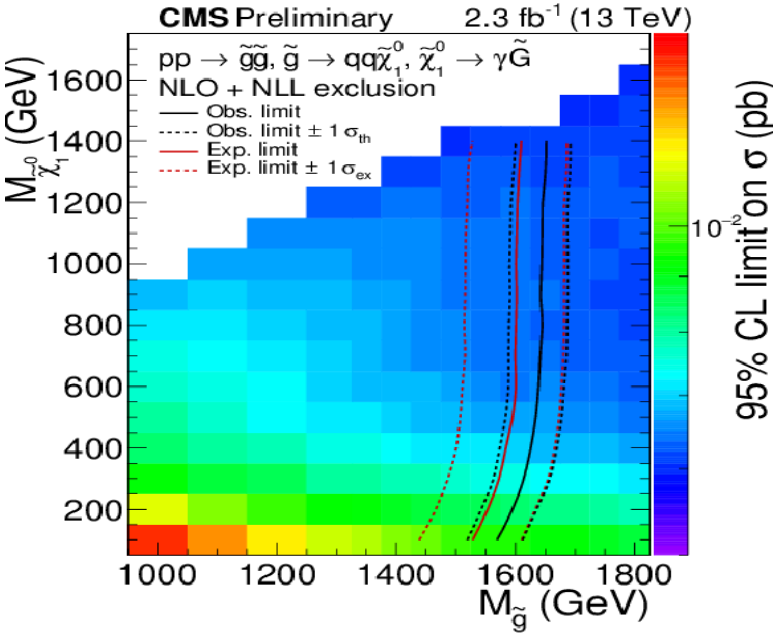
SUSY with photons @ 13 TeV

SUS-15-012

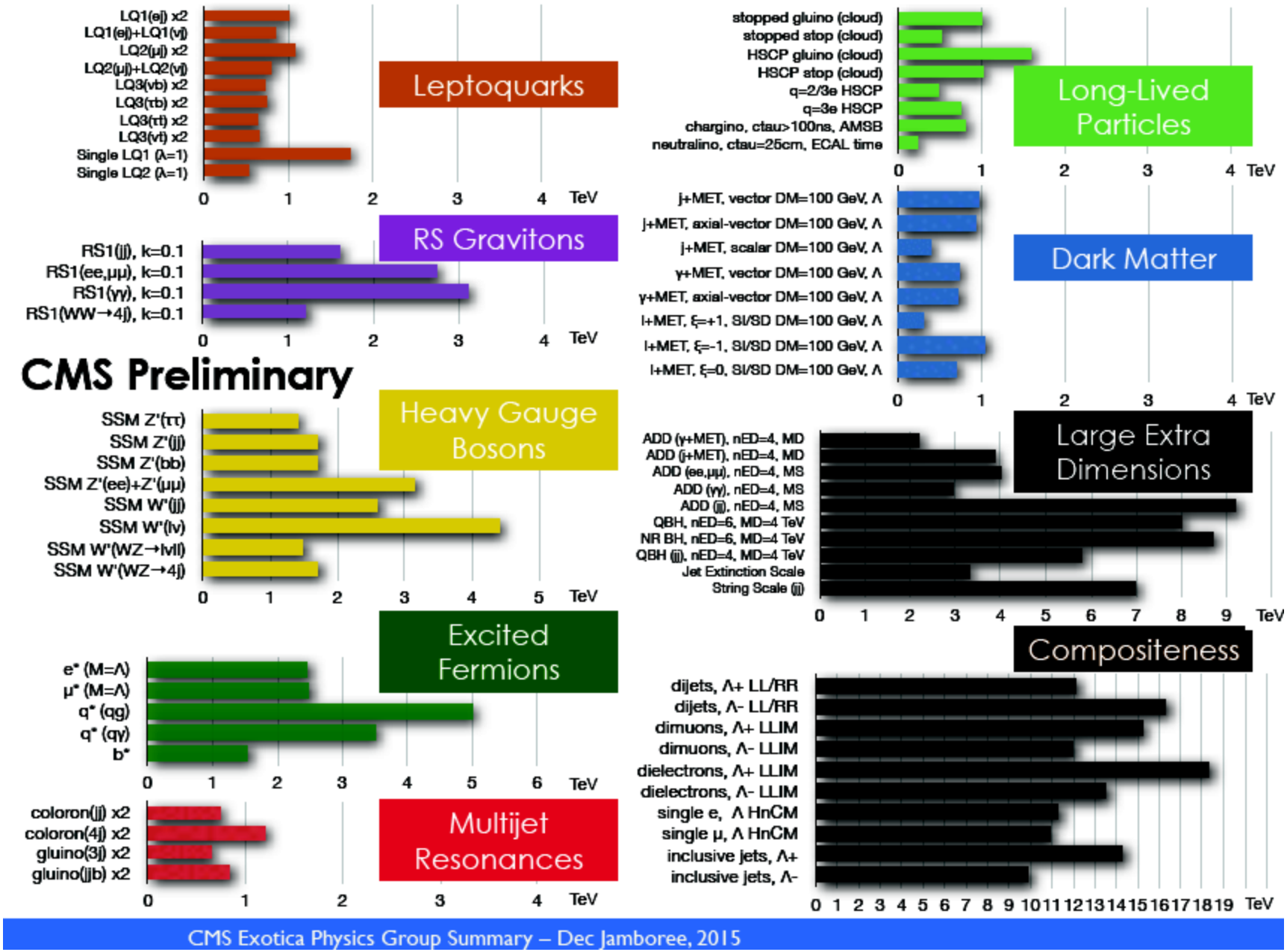
- At least two photons > 40 GeV
- MET > 100 GeV
- No constraints on number of jets
- General Gauge Mediated breaking with Gravitino LSP



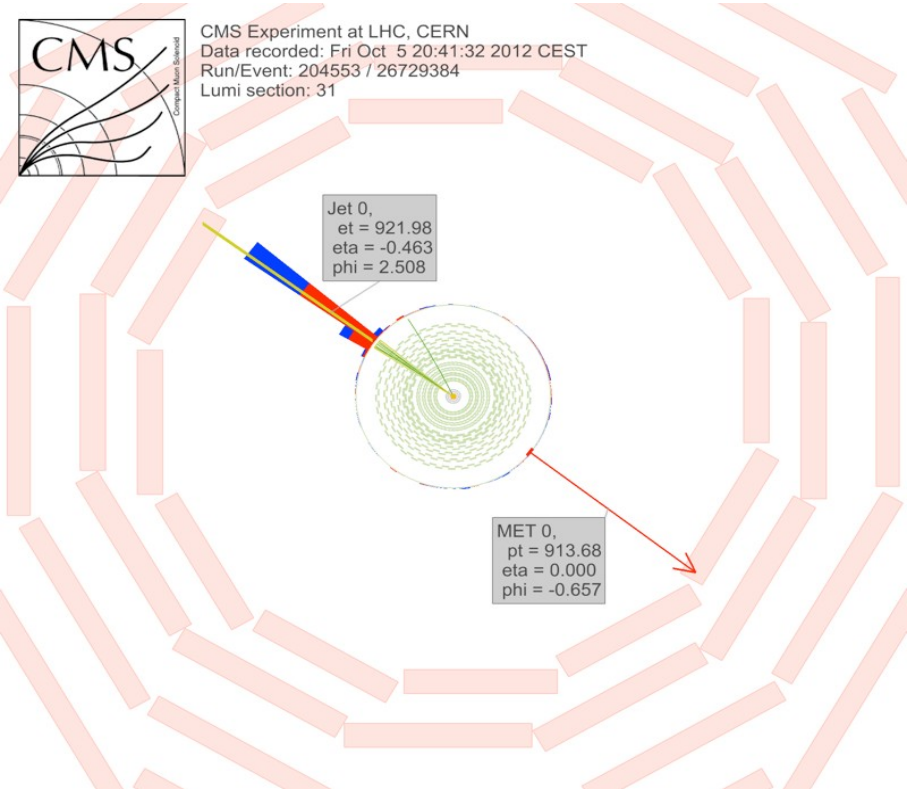


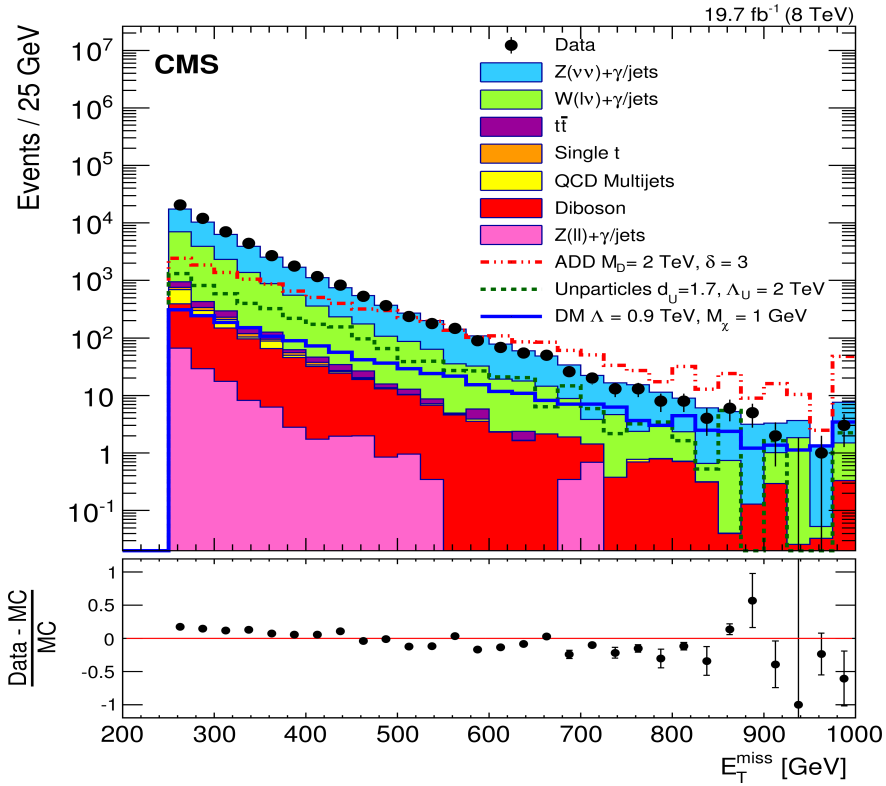


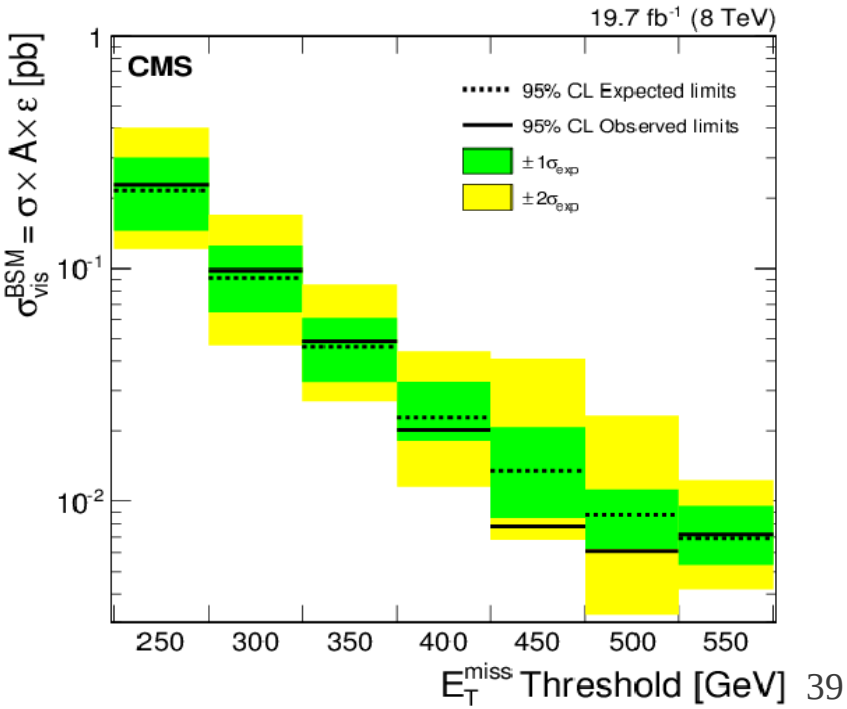
Other BSM Searches (Exotica)


Leptoquarks
LQ1(ej) x2
LQ1(ej)+LQ1(vj)
LQ2(μj) x2
LQ2(μj)+LQ2(vj)
LQ3(vb) x2
LQ3(τb) x2
LQ3(τt) x2
LQ3(vt) x2
Single LQ1 (λ=1)
Single LQ2 (λ=1)
0 1 2 3 4 TeV
RS Gravitons
RS1(jj), k=0.1
RS1(ee,μμ), k=0.1
RS1(γγ), k=0.1
RS1(WW→4j), k=0.1
0 1 2 3 4 TeV
CMS Preliminary
Heavy Gauge Bosons
SSM Z'(ττ)
SSM Z'(jj)
SSM Z'(bb)
SSM Z'(ee)+Z'(μμ)
SSM W'(jj)
SSM W'(lv)
SSM W'(WZ→lvll)
SSM W'(WZ→4j)
0 1 2 3 4 5 TeV
Excited Fermions
e* (M=Λ)
μ* (M=Λ)
q* (qg)
q* (qγ)
b*
0 1 2 3 4 5 6 TeV
Multijet Resonances
coloron(jj) x2
coloron(4j) x2
gluino(3j) x2
gluino(jjb) x2
0 1 2 3 4 TeV
Long-Lived Particles
stopped gluino (cloud)
stopped stop (cloud)
HSCP gluino (cloud)
HSCP stop (cloud)
q=2/3e HSCP
q=3e HSCP
chargino, ctau>100ns, AMSB
neutralino, ctau=25cm, ECAL time
0 1 2 3 4 TeV
Dark Matter
j+MET, vector DM=100 GeV, Λ
j+MET, axial-vector DM=100 GeV, Λ
j+MET, scalar DM=100 GeV, Λ
γ+MET, vector DM=100 GeV, Λ
γ+MET, axial-vector DM=100 GeV, Λ
l+MET, ξ=+1, SI/SD DM=100 GeV, Λ
l+MET, ξ=-1, SI/SD DM=100 GeV, Λ
l+MET, ξ=0, SI/SD DM=100 GeV, Λ
0 1 2 3 4 TeV
Large Extra Dimensions
ADD (γ+MET), nED=4, MD
ADD (j+MET), nED=4, MD
ADD (ee,μμ), nED=4, MS
ADD (γγ), nED=4, MS
ADD (jj), nED=4, MS
QBH, nED=6, MD=4 TeV
NR BH, nED=6, MD=4 TeV
QBH (jj), nED=4, MD=4 TeV
Jet Extinction Scale
String Scale (jj)
0 1 2 3 4 5 6 7 8 9 TeV
Compositeness
dijets, Λ+ LL/RR
dijets, Λ- LL/RR
dimuons, Λ+ LLIM
dimuons, Λ- LLIM
dielectrons, Λ+ LLIM
dielectrons, Λ- LLIM
single e, Λ HnCM
single μ, Λ HnCM
inclusive jets, Λ+
inclusive jets, Λ-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 TeV
CMS Exotica Physics Group Summary – Dec Jamboree, 2015

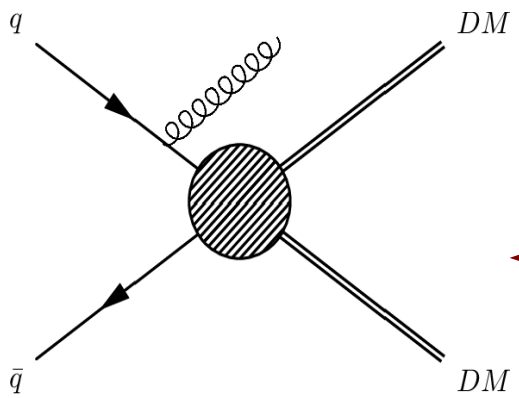
Monojet + MET @ 8 TeV







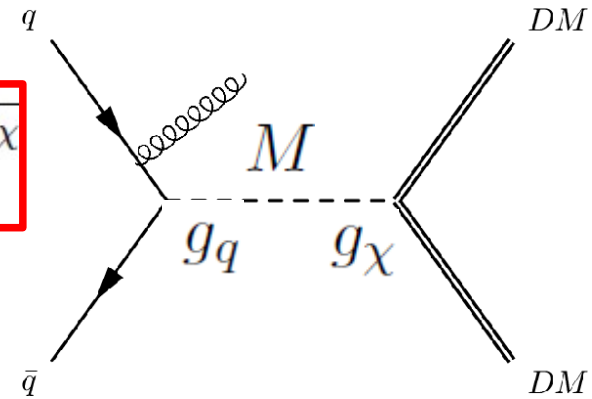
Monojet + MET



$\Lambda = M/\sqrt{g_q g_\chi}$

$Q_{\rm tr} < M$

DM EFT



DM MED

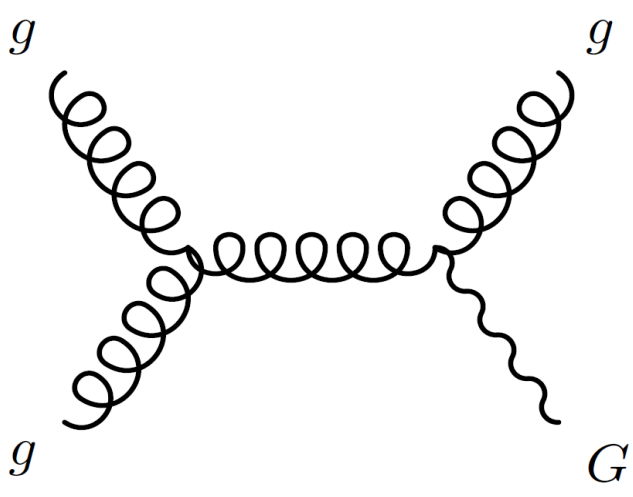
perturbative

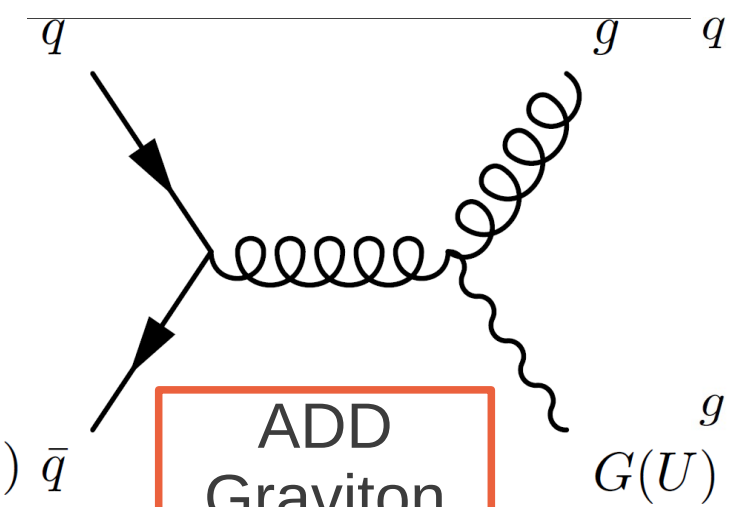
$g_{q,\chi} < 4\pi$

$$\Lambda > \frac{Q_{\rm tr}}{\sqrt{g_q g_\chi}} > \frac{Q_{\rm tr}}{4\pi}$$

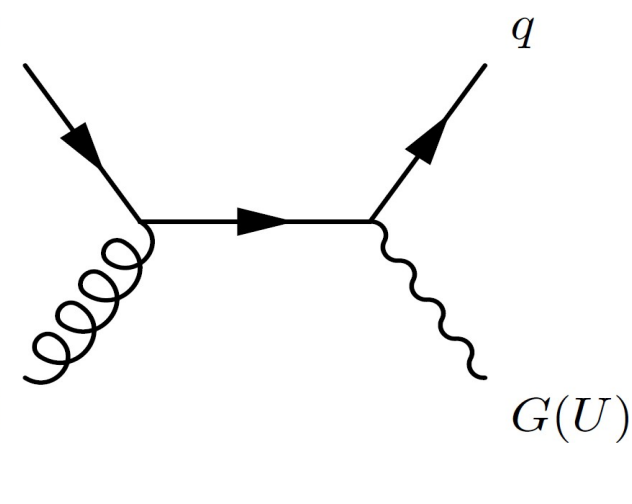
s-channel

$$\Lambda > \frac{m_{\rm DM}}{2\pi}$$

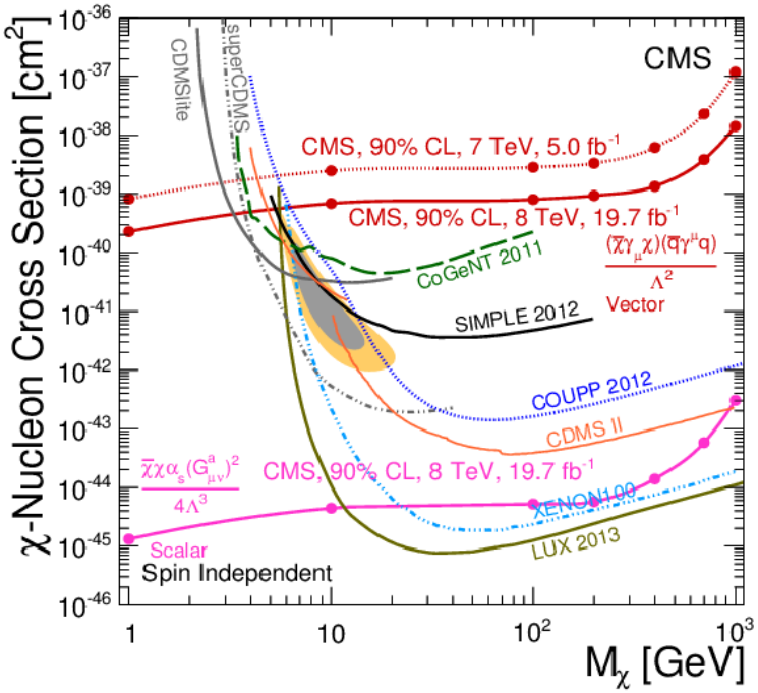


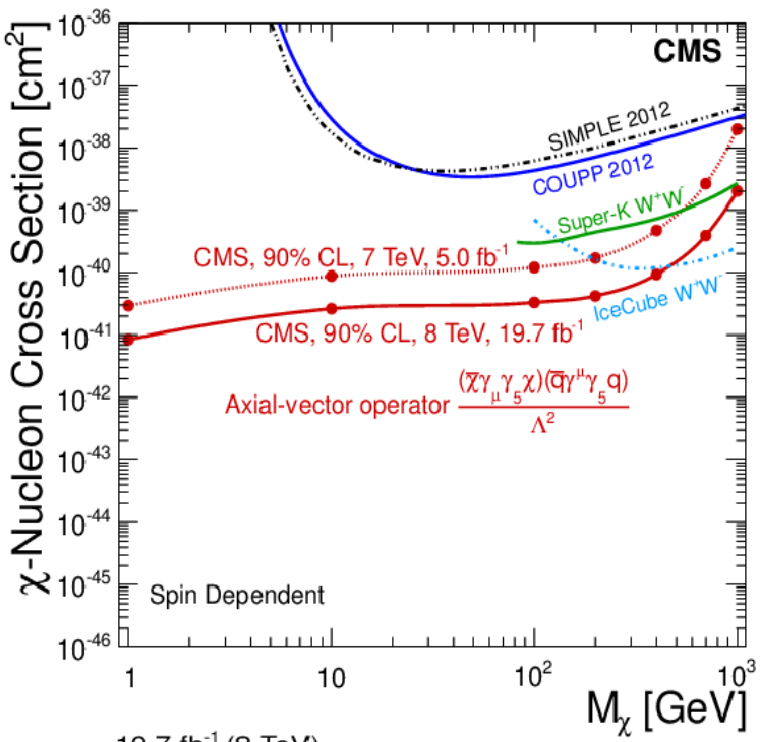


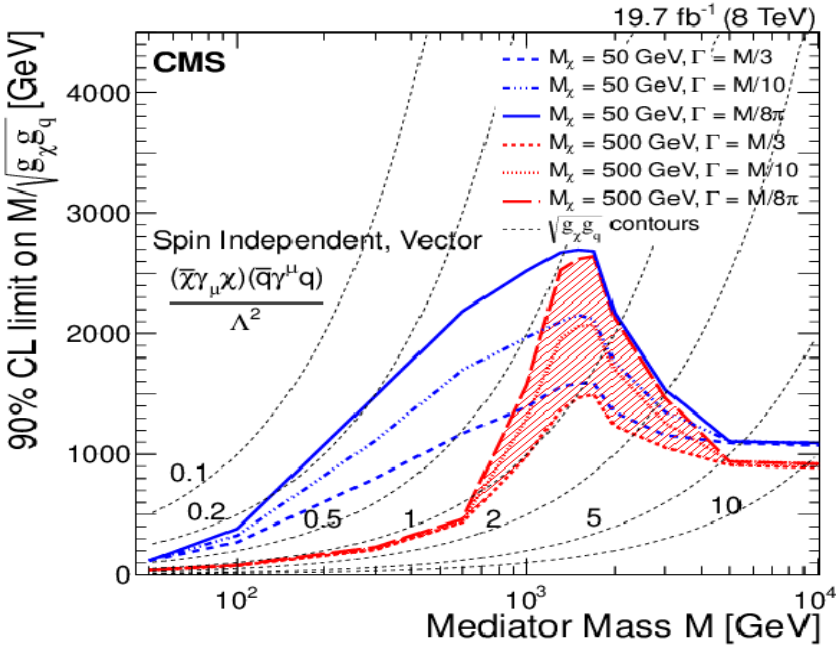
ADD Graviton



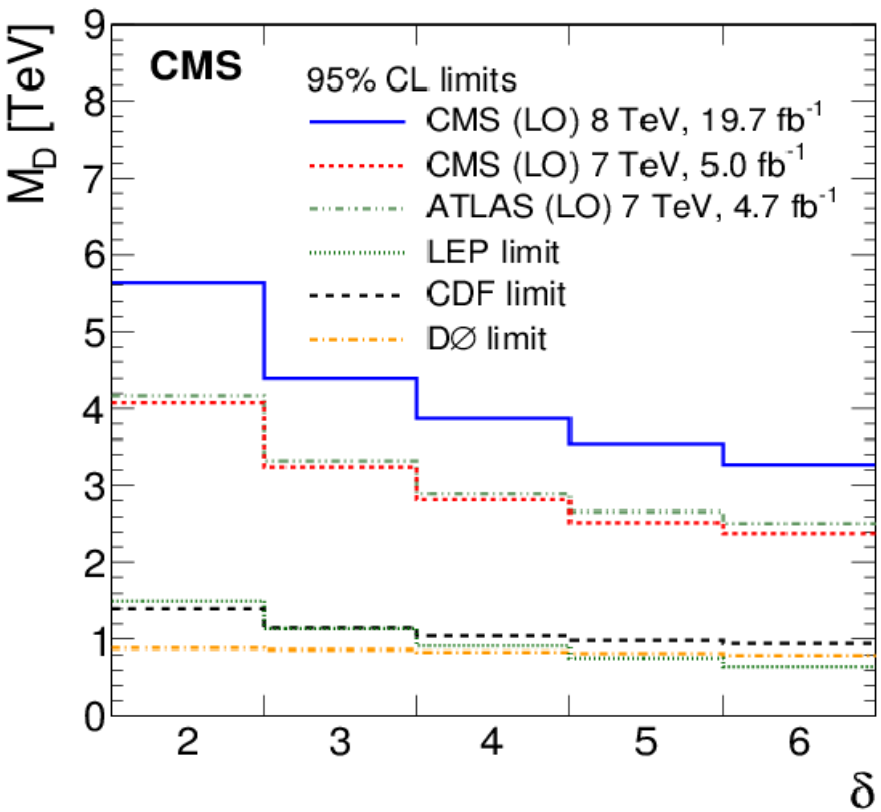
Monojet

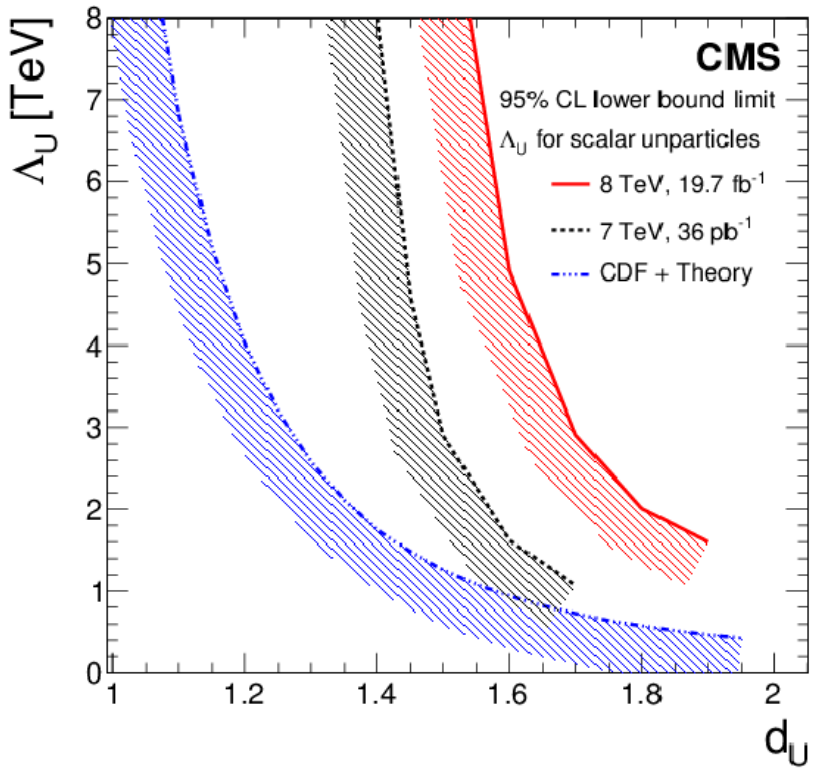

CMS
CDMSlite
superCDMS
CMS, 90% CL, 7 TeV, 5.0 fb^{-1}
CMS, 90% CL, 8 TeV, 19.7 fb^{-1}
CoGeNT 2011
$\frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$
Vector
SIMPLE 2012
COUPP 2012
CDMS II
$\frac{\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2}{4\Lambda^3}$
CMS, 90% CL, 8 TeV, 19.7 fb^{-1}
XENON100
LUX 2013
Scalar
Spin Independent
χ-Nucleon Cross Section [cm^2]
M_χ [GeV]


CMS
SIMPLE 2012
COUPP 2012
Super-K W^+W^-
CMS, 90% CL, 7 TeV, 5.0 fb^{-1}
IceCube W^+W^-
CMS, 90% CL, 8 TeV, 19.7 fb^{-1}
Axial-vector operator $\frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$
Spin Dependent
χ-Nucleon Cross Section [cm^2]
M_χ [GeV]


19.7 fb^{-1} (8 TeV)
CMS
M_χ = 50 GeV, Γ = M/3
M_χ = 50 GeV, Γ = M/10
M_χ = 50 GeV, Γ = M/8π
M_χ = 500 GeV, Γ = M/3
M_χ = 500 GeV, Γ = M/10
M_χ = 500 GeV, Γ = M/8π
$\sqrt{g_\chi g_q}$ contours
Spin Independent, Vector
$\frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$
0.1
0.2
0.5
1
2
5
10
90% CL limit on $M/\sqrt{g_\chi g_q}$ [GeV]
Mediator Mass M [GeV]

Monojet extra dim, unparticle

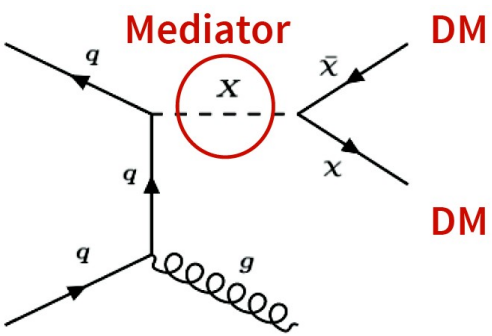


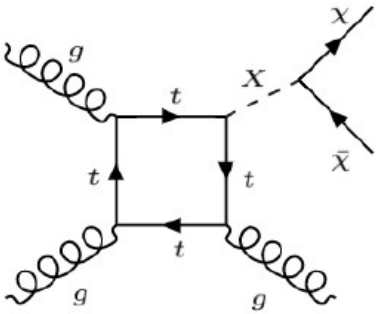


Monojet @13 TeV

EXO-15-003

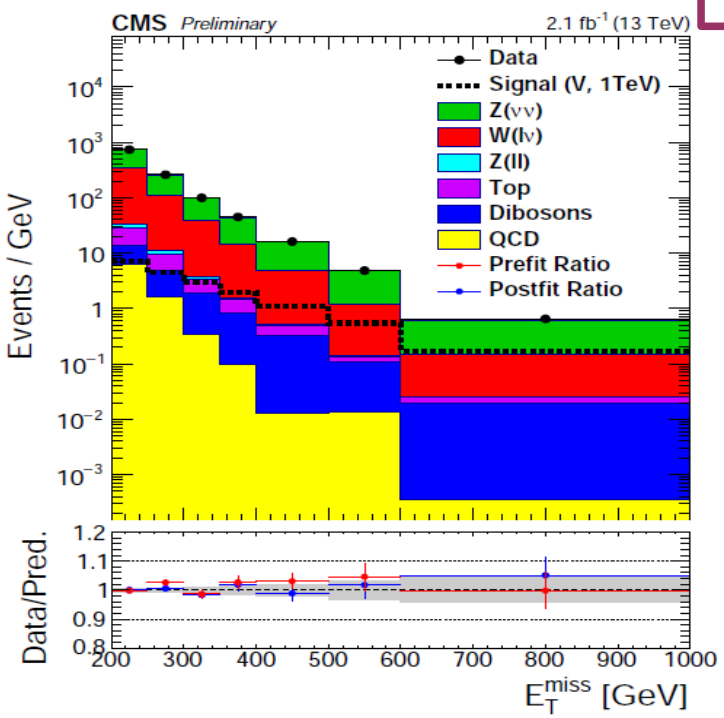
- Central high pT jet + large MET
- Lepton, b-jet veto
- Large azimuthal opening between jet-MET

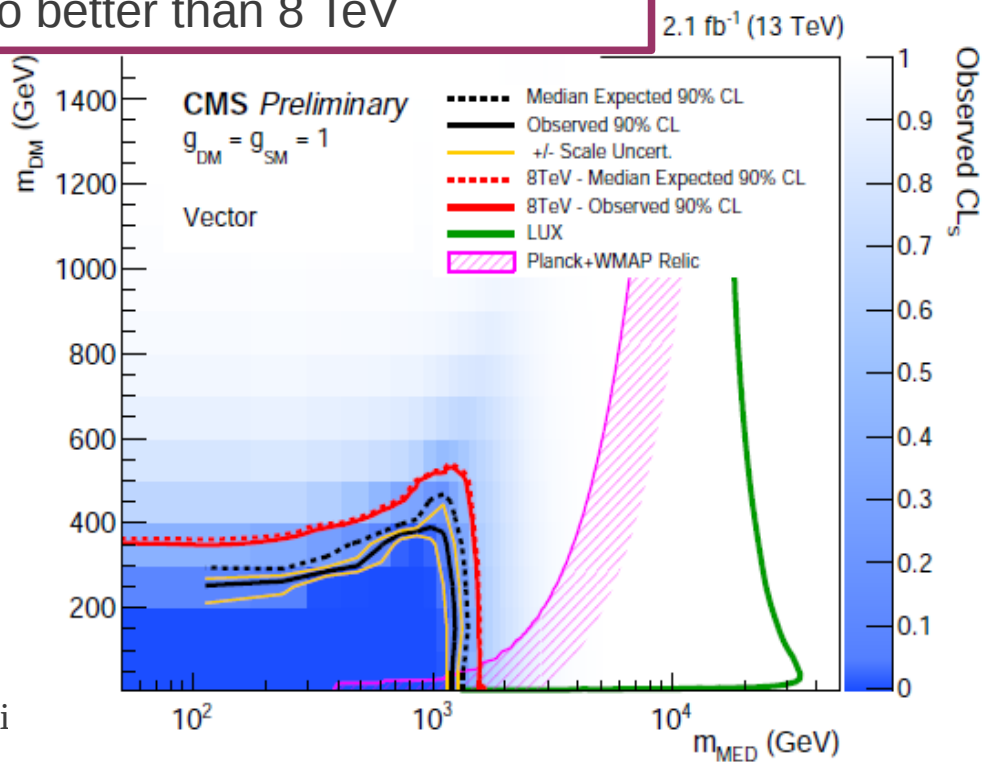




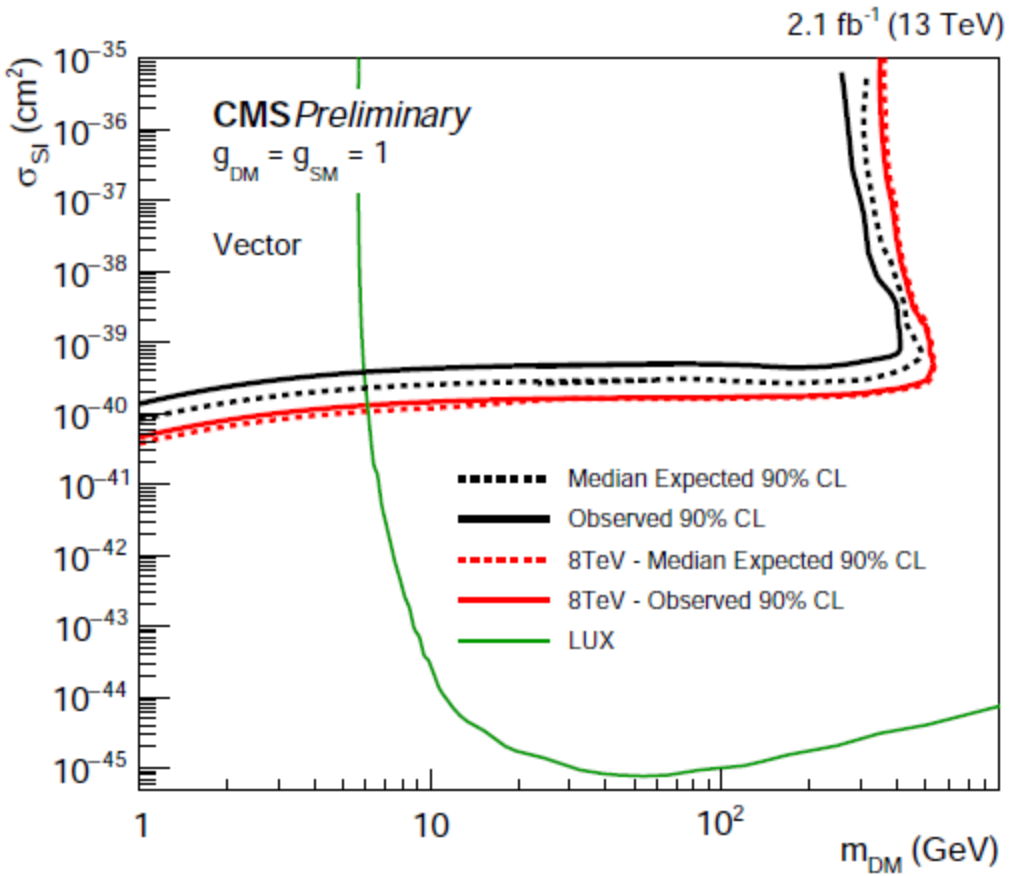
90% upper limit on signal strength

Yet to do better than 8 TeV





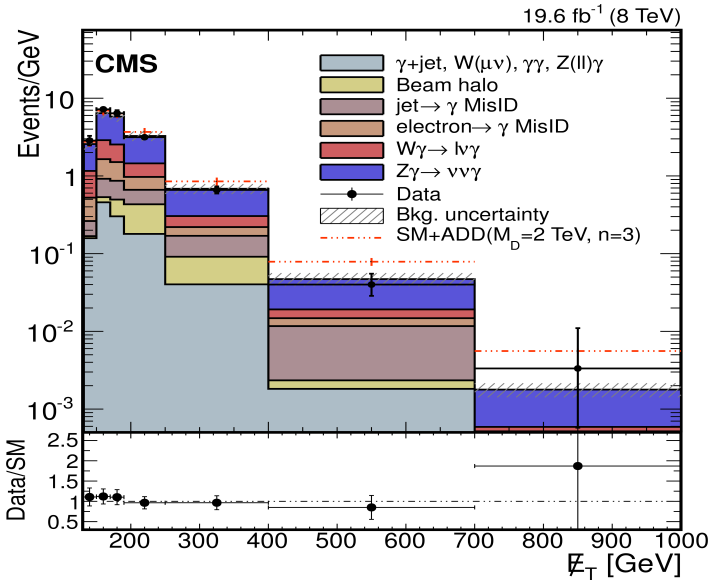
Monojet @13 TeV

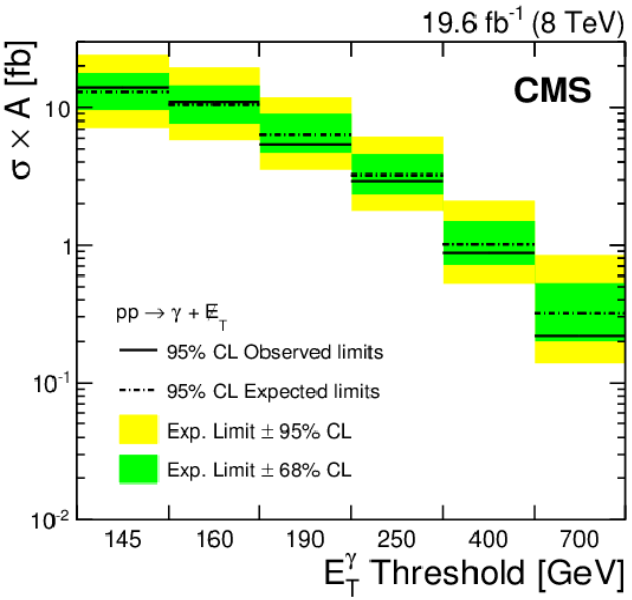


Couplings taken to be unity

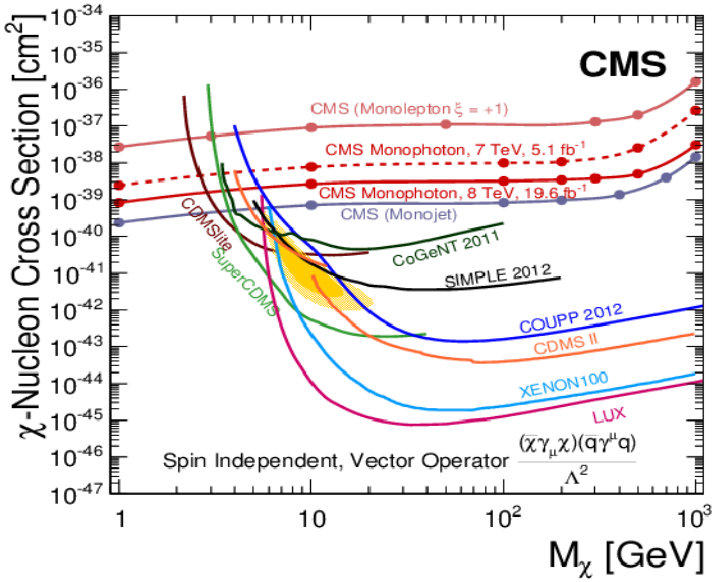
Monophoton

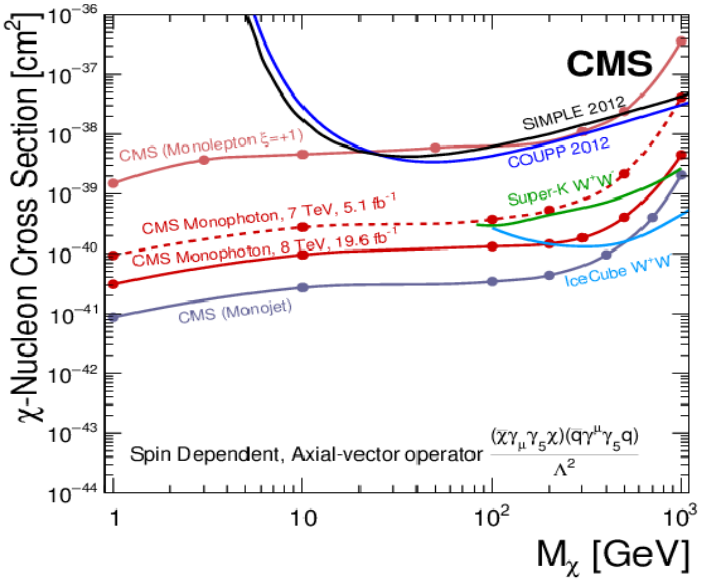
- Photon pT > 150 GeV
- Met > 135 GeV
- No jet
- No lepton
- Discriminator for beam halo, cosmics, anomalous ECAL signals

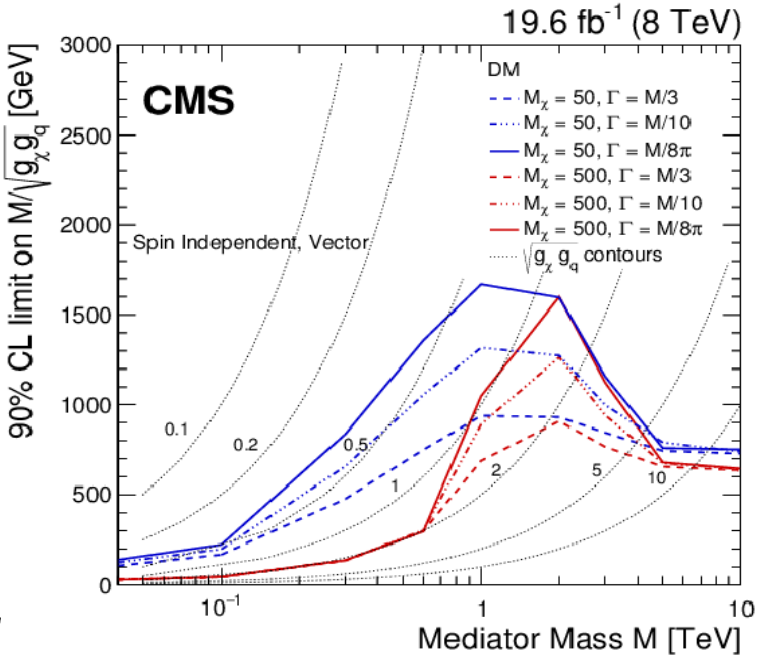




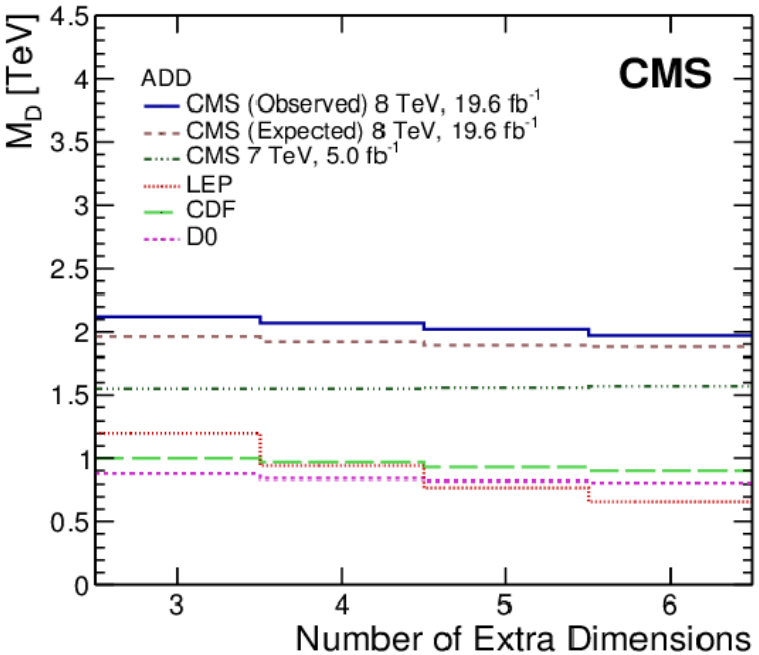
Monophoton

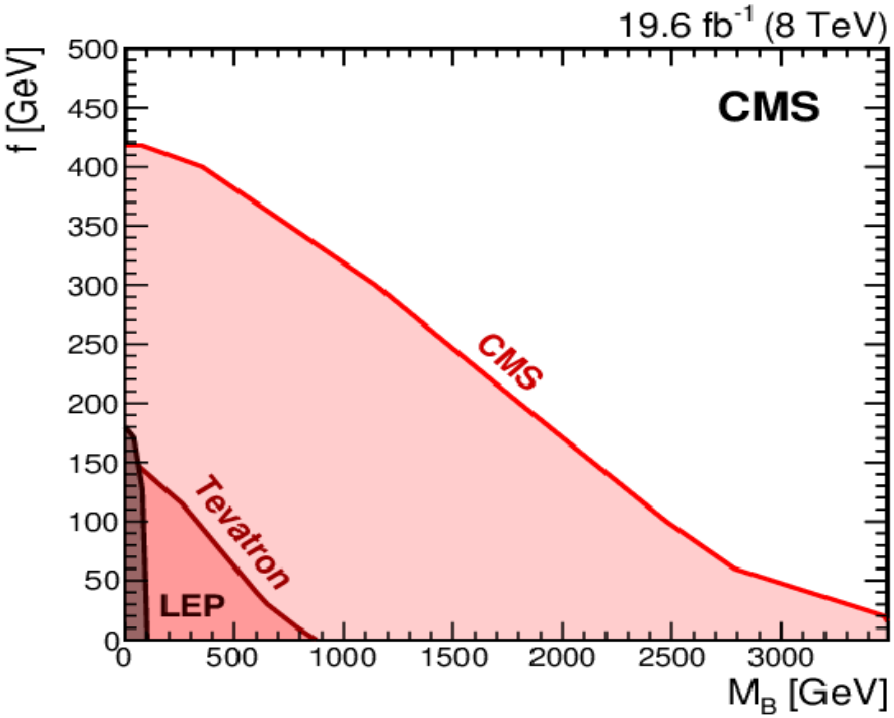

CMS
CMS (Monolepton ξ = +1)
CMS Monophoton, 7 TeV, 5.1 fb⁻¹
CMS Monophoton, 8 TeV, 19.6 fb⁻¹
CMS (Monojet)
CoGeNT 2011
SIMPLE 2012
COUPP 2012
CDMS II
XENON100
LUX
CDMSlite
SuperCDMS
Spin Independent, Vector Operator
χ-Nucleon Cross Section [cm²]
M_χ [GeV]


CMS
SIMPLE 2012
COUPP 2012
CMS (Monolepton ξ=+1)
Super-K W⁺W⁻
CMS Monophoton, 7 TeV, 5.1 fb⁻¹
CMS Monophoton, 8 TeV, 19.6 fb⁻¹
IceCube W⁺W⁻
CMS (Monojet)
Spin Dependent, Axial-vector operator
χ-Nucleon Cross Section [cm²]
M_χ [GeV]


19.6 fb⁻¹ (8 TeV)
CMS
DM
M_χ = 50, Γ = M/3
M_χ = 50, Γ = M/10
M_χ = 50, Γ = M/8π
M_χ = 500, Γ = M/3
M_χ = 500, Γ = M/10
M_χ = 500, Γ = M/8π
√(g_χ g_q) contours
Spin Independent, Vector
90% CL limit on M/√(g_χ g_q) [GeV]
Mediator Mass M [TeV]

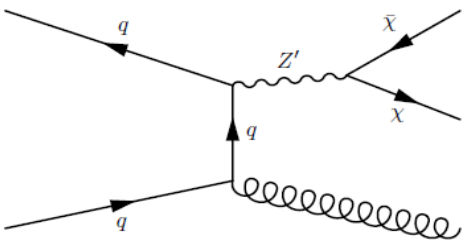
Monophoton: graviton and branon

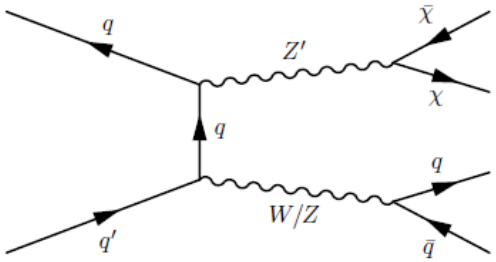


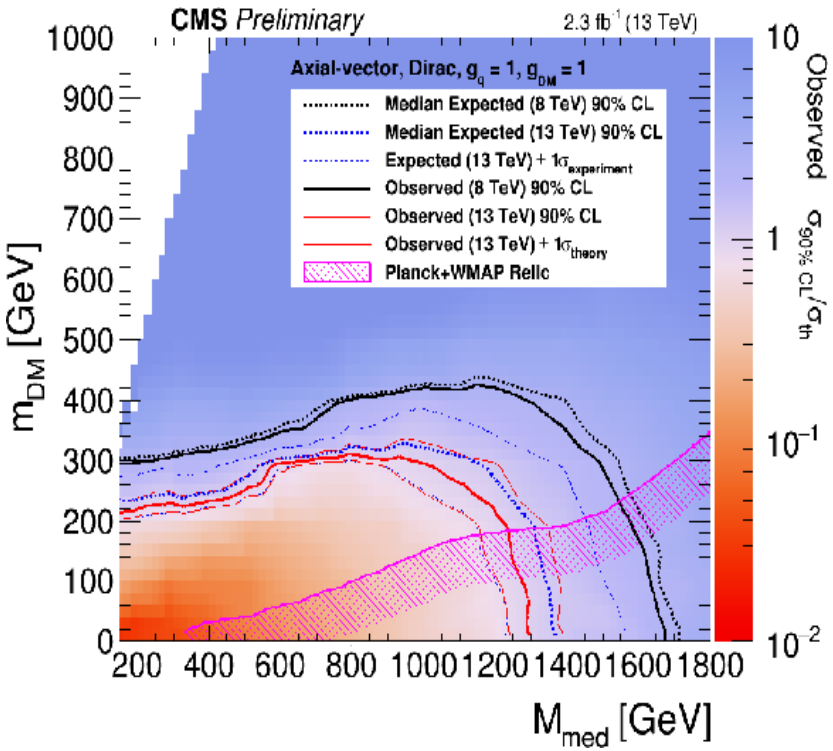


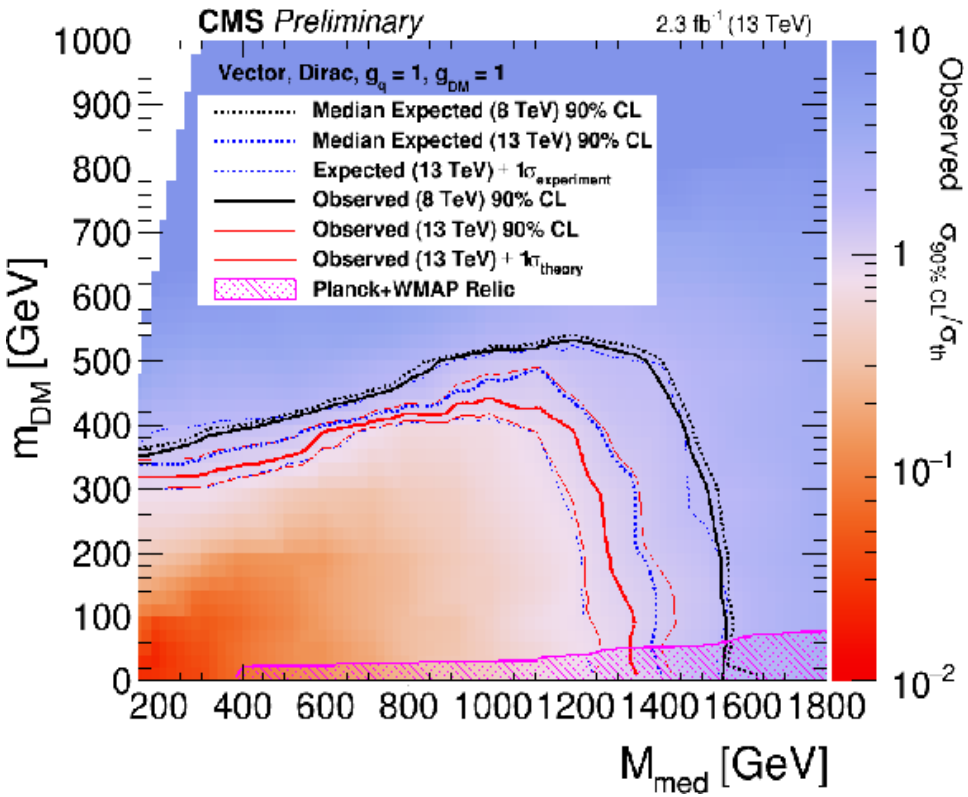
Mono jet and mono V(hadronic) @ 13 TeV

NEW!! EXO-16-018



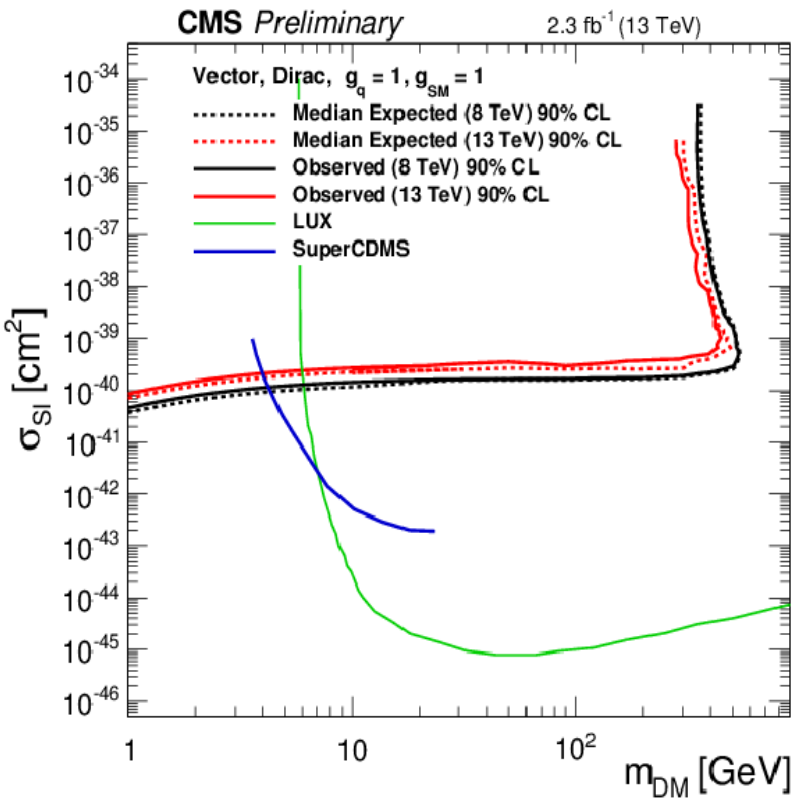


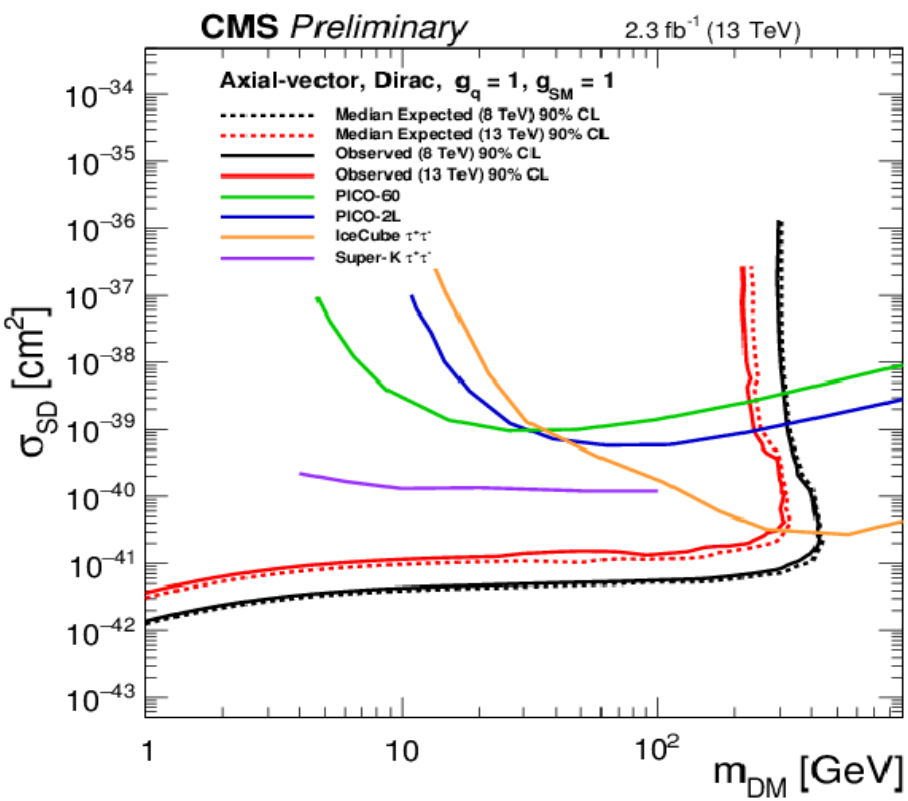




- Jet + MET(>90 GeV)
- For mono-V jet substructure (pruned mass, N-jettiness) used
- Couplings taken as unity

Mono jet and mono V(hadronic) @ 13 TeV



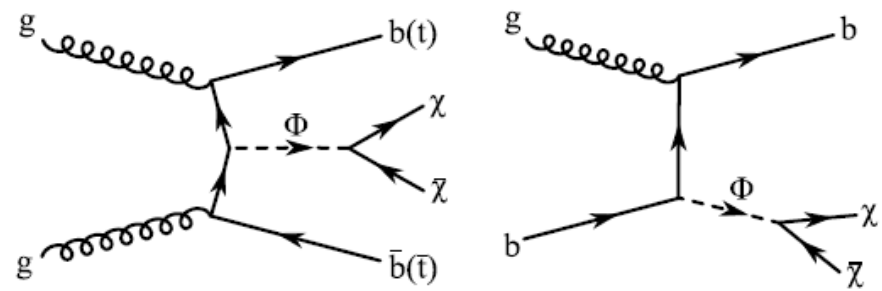


DM + Heavy Flavor

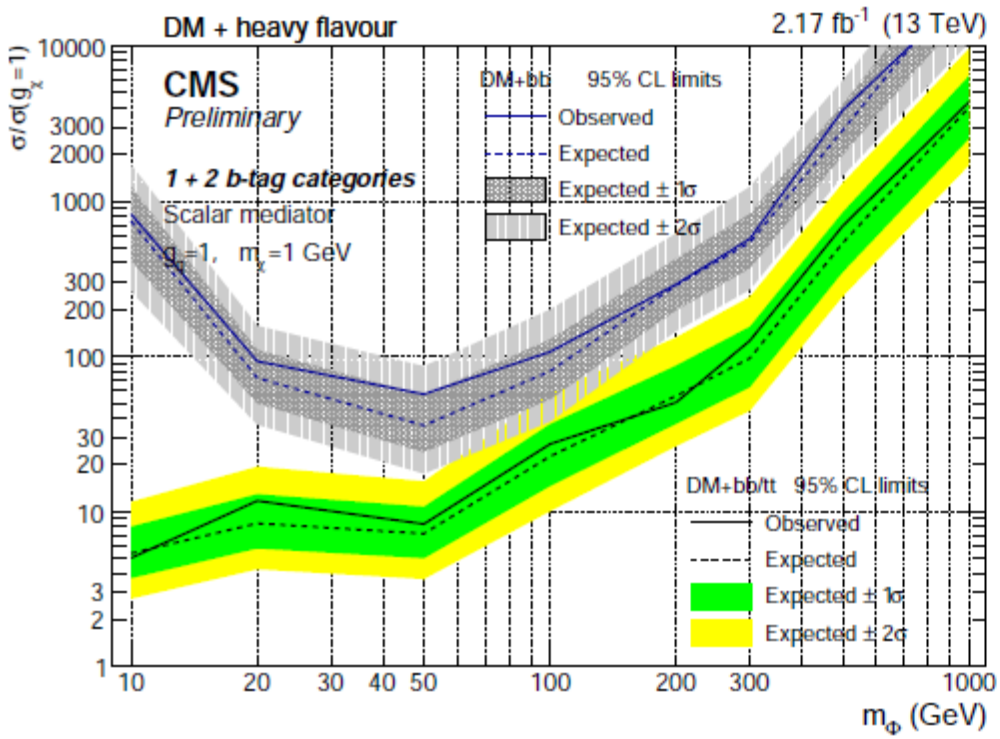
NEW!!

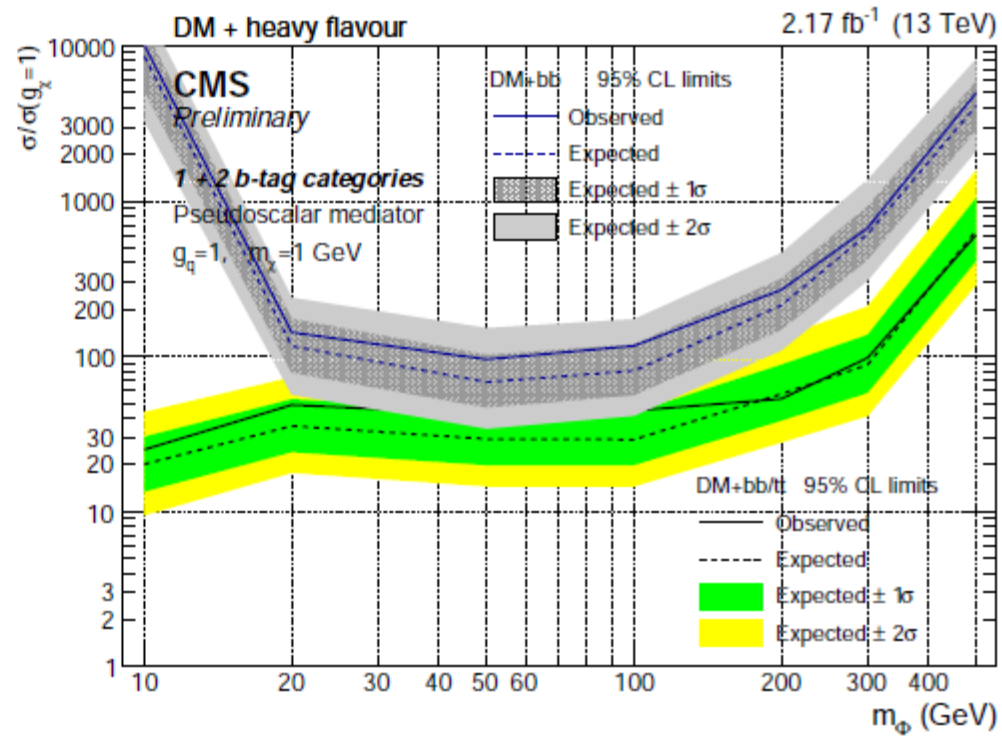
B2G-15-007

- **MET + b + lepton veto**
- Sample divided in categories of b jet multiplicity
- Signal extracted from MET spectrum

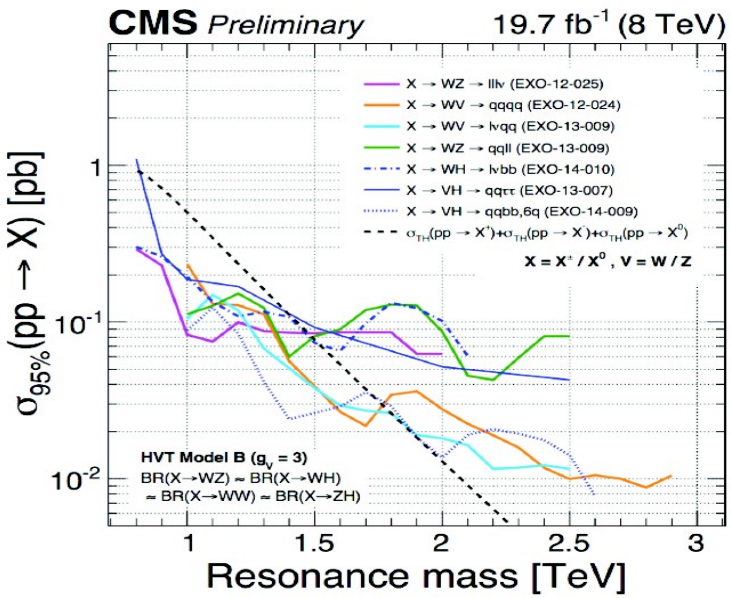


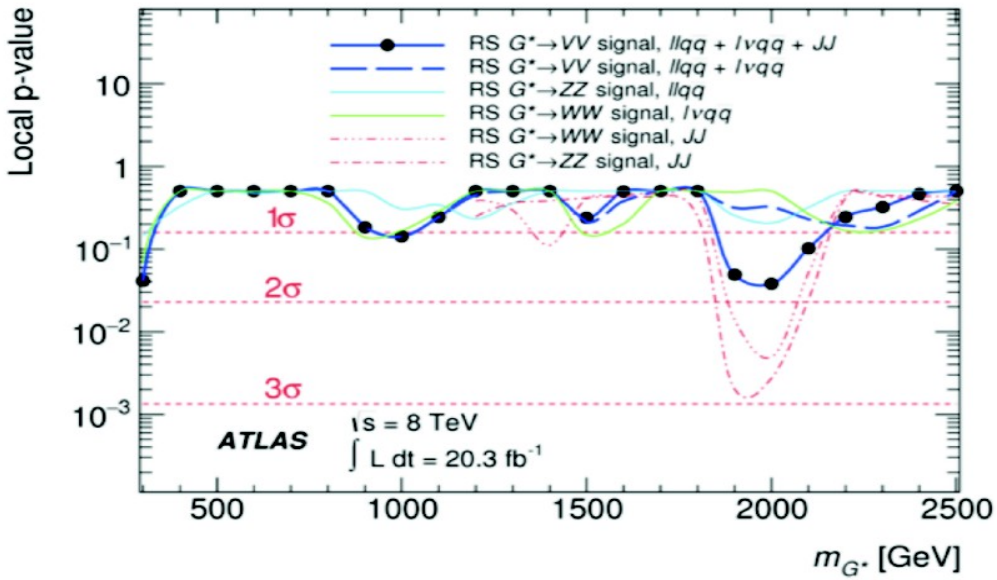
- Scalar/pseudoscalar mediator
- Signal efficiency strongly depends on mediator mass (10^{-6} to 10^{-2} for mass 10 GeV to 1 TeV)



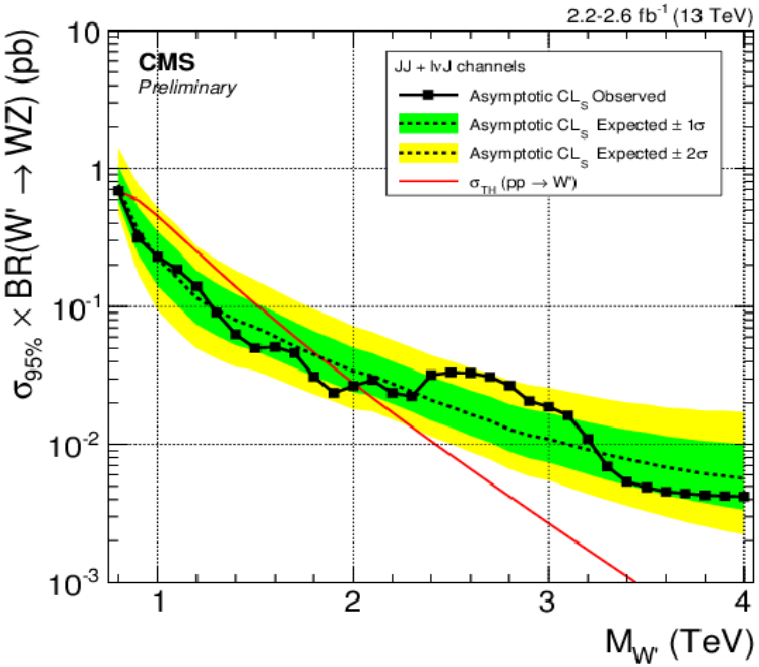


CMS diboson: 8 to 13 TeV





- massive narrow resonances decaying to pairs of W and Z
- Spin-1, spin-2 resonances < 0.8 TeV
- WW, WZ, or ZZ to ℓνqq or qqqq



Dilepton OSSF @ 8 TeV

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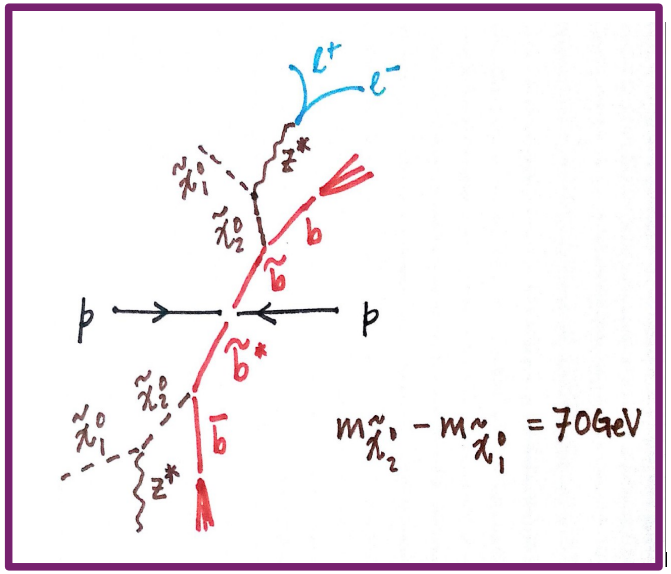
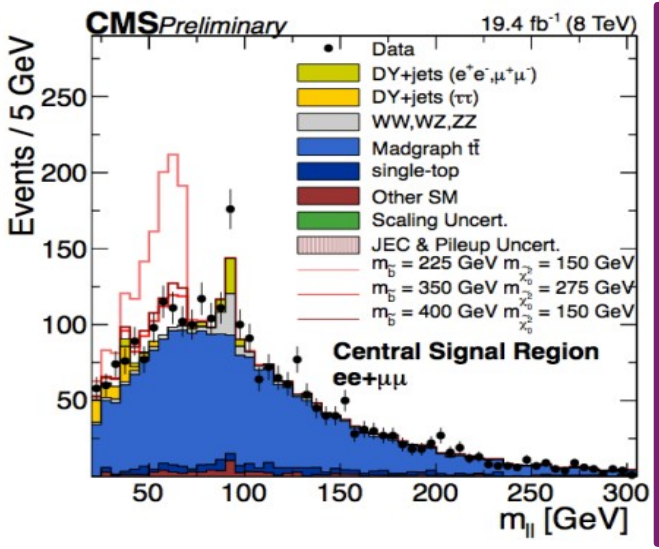
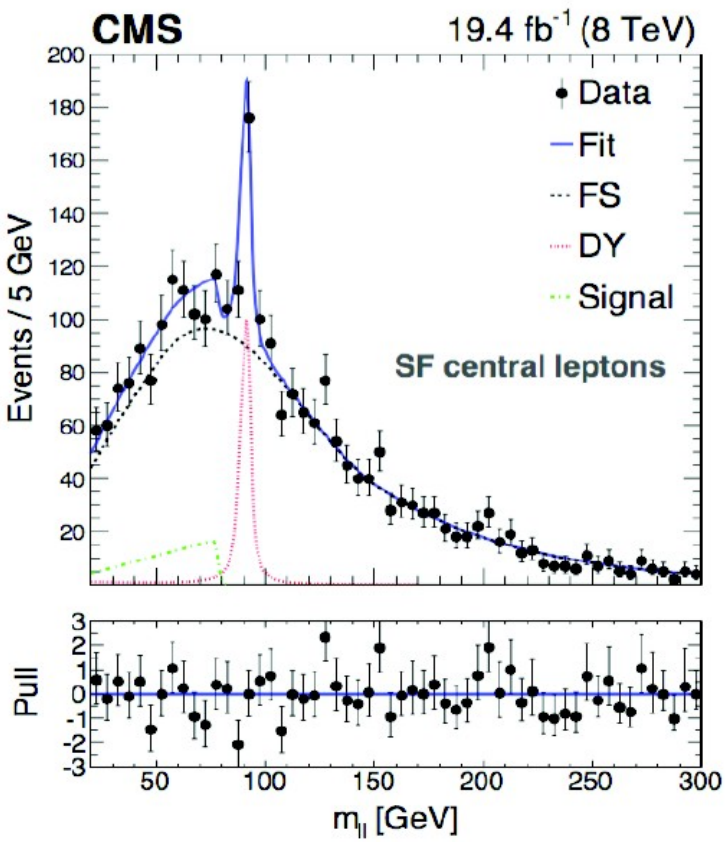
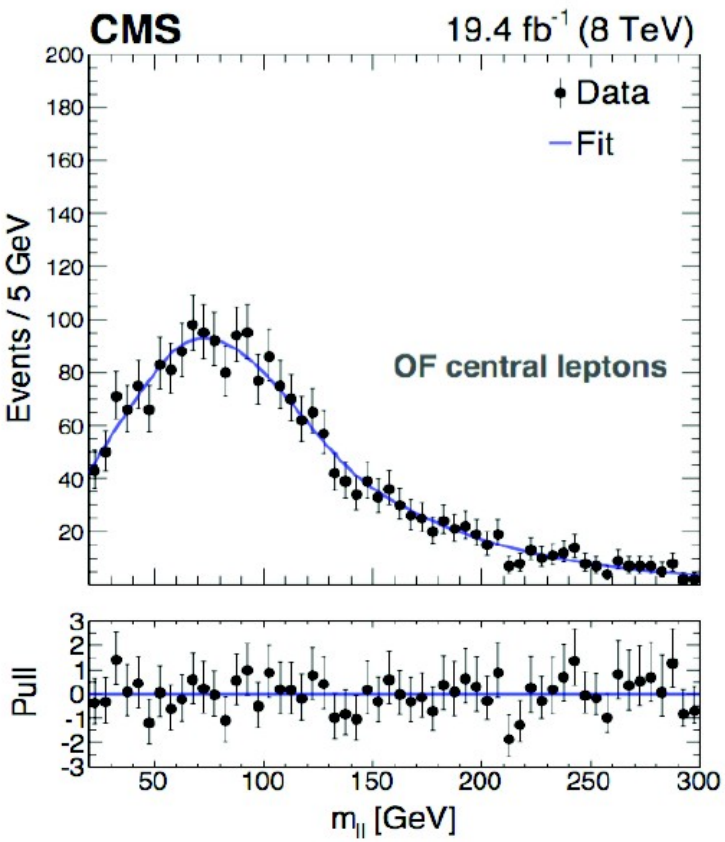




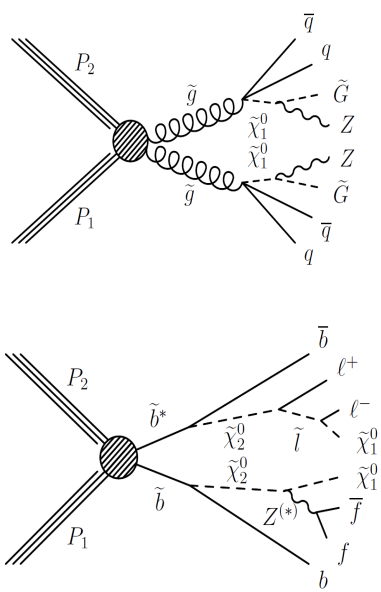
- Best fit edge:78.7 +-1.4 GeV
- Local p-value with -2logQ statistic is 0.009
- Gaussian one sided tail probability → 2.4 sigma
- No look-elsewhere effect

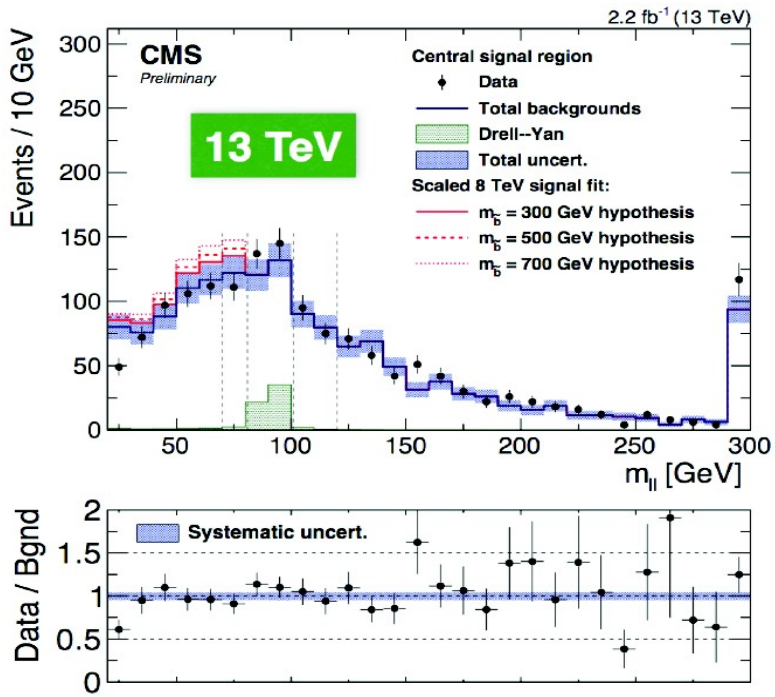


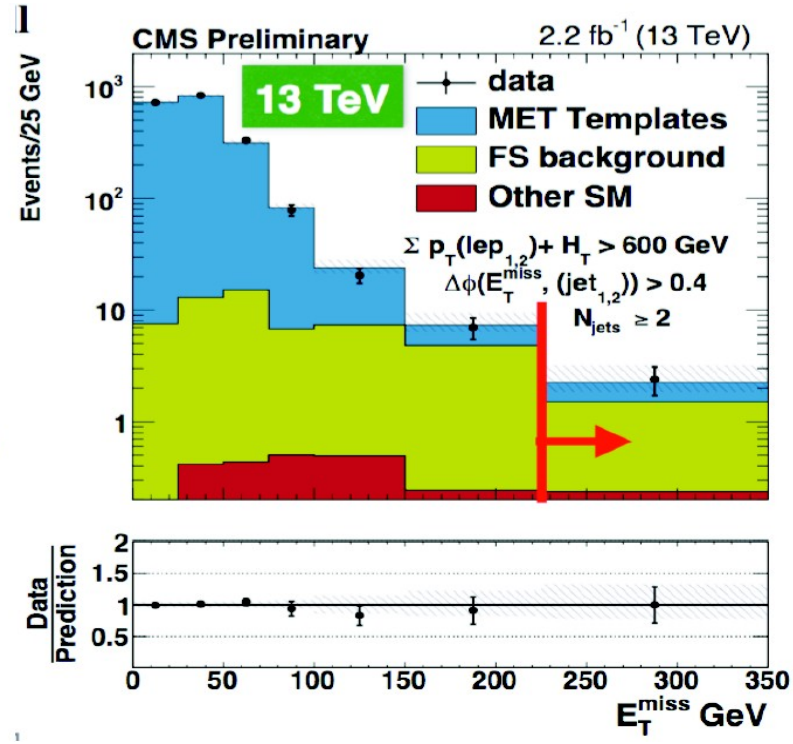


Search for new physics in final states with two opposite-sign same-flavor leptons, jets and EmissT in pp collisions at s√= 13 TeV

SUS-15-011







- Should see 61 events offshell
- 57 is upper limit

- Should see 12 events offshell
- 9 is upper limit

High mass diphoton search

Ref	Title	M_x	interpreted as	
			spin-0	spin-2
PLB 750 (2015) 494	Search for diphoton resonances in the mass range from 150 to 850 GeV in pp collisions at √s = 8 TeV	150-850GeV	✔	✔
EXO-12-045	Search for High-Mass Diphoton Resonances in pp Collisions at √s = 8 TeV with the CMS Detector	0.5-3TeV	✘	✔
EXO-15-004 Dec'15	Search for new physics in high mass diphoton events in proton-proton collisions at √s = 13 TeV	0.5-4.5TeV	✘	✔
EXO-16-018 NEW	Search for new physics in high mass diphoton events in **3.3 fb^{-1}** of proton-proton collisions at √s=13 TeV and combined interpretation of searches at √s=8 TeV and 13 TeV.	0.5-4.5TeV	✔	✔

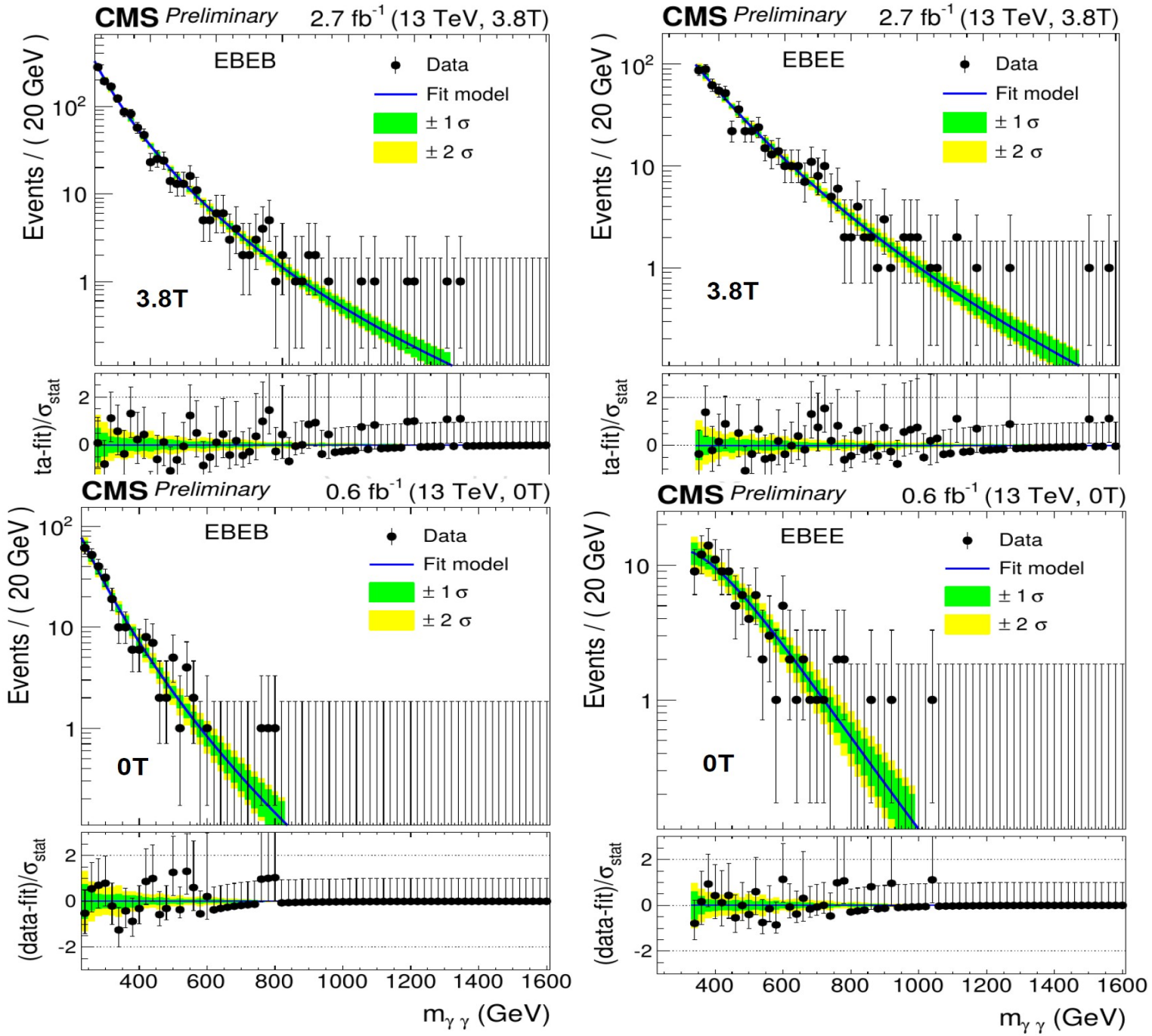
P. Mussella, Moriond EWK,2016

High mass diphoton

EXO-16-018

- Signal model:
  lineshape X
  detector resolution
- Background model:

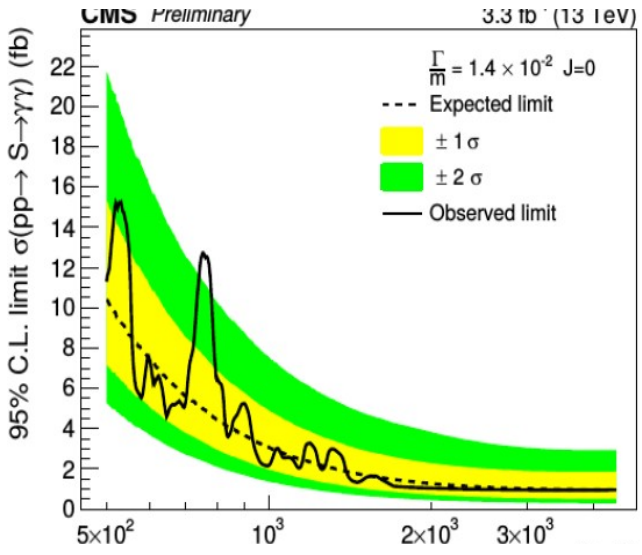
$$f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot\log(m_{\gamma\gamma})}.$$



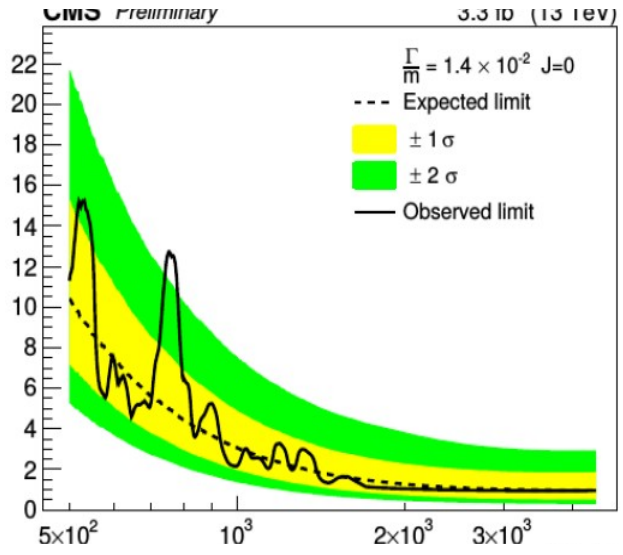
High mass diphoton

Frequentist, unbinned likelihood

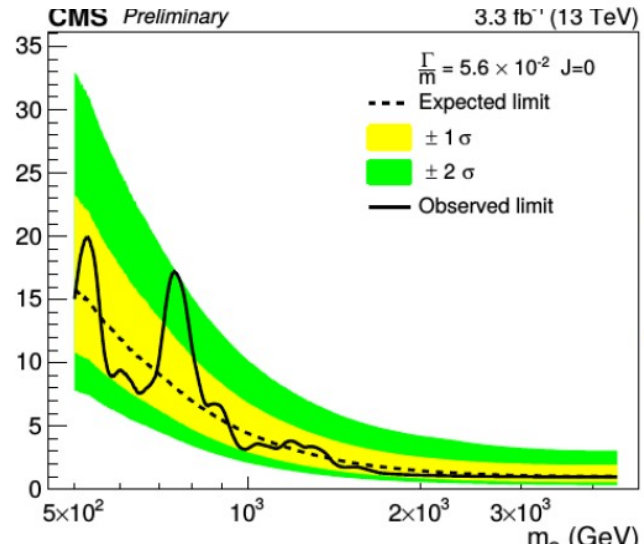
$$L(\mu,\theta)=\prod_{i=1}^{N_{events}}\left[\ \mu S(m_i|\theta_S)\ +\ B(m_i|\theta_B)\ \right]\cdot Poisson(N_{events}|N_B+\mu N_S)$$



$\Gamma/m = 1.4\times10^{-4}$

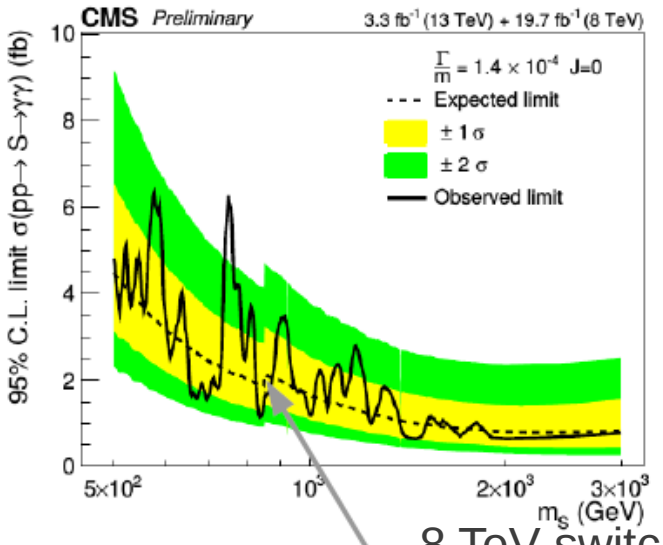


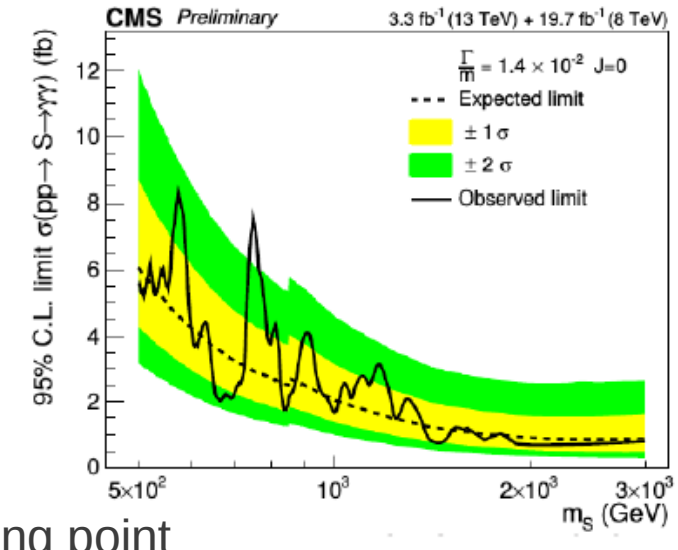
$\Gamma/m = 1.4\times10^{-2}$

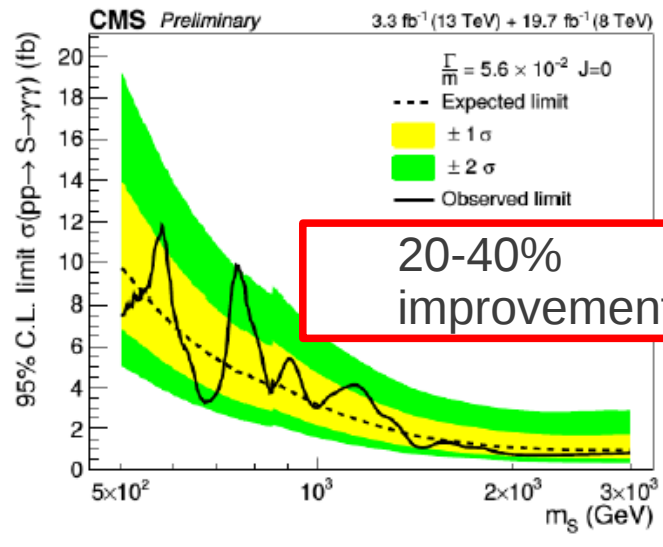


$\Gamma/m = 5.6\times10^{-2}$

Spin 0





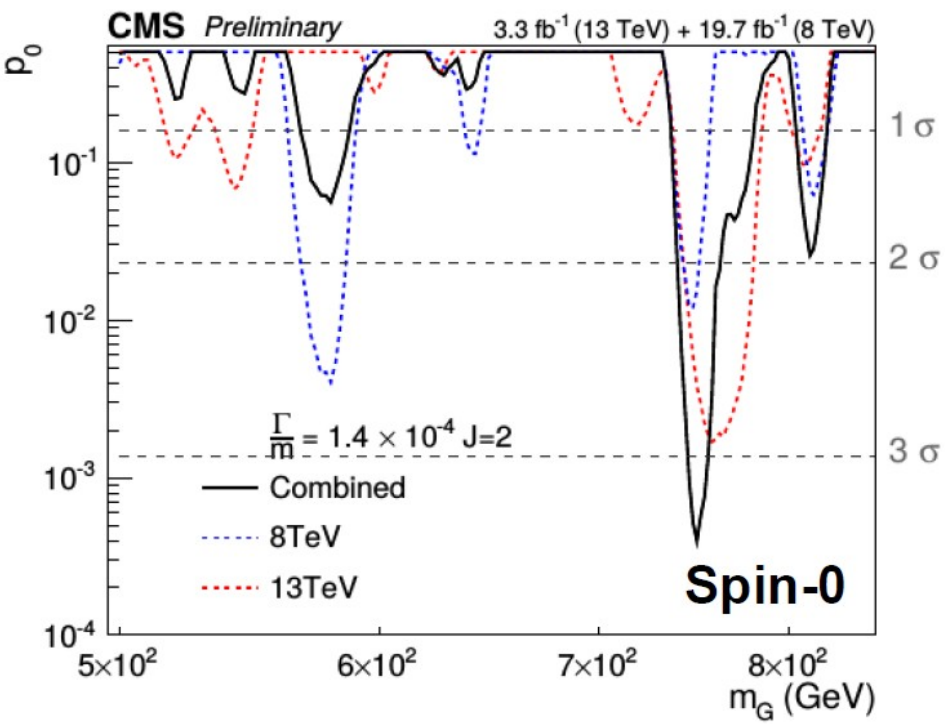


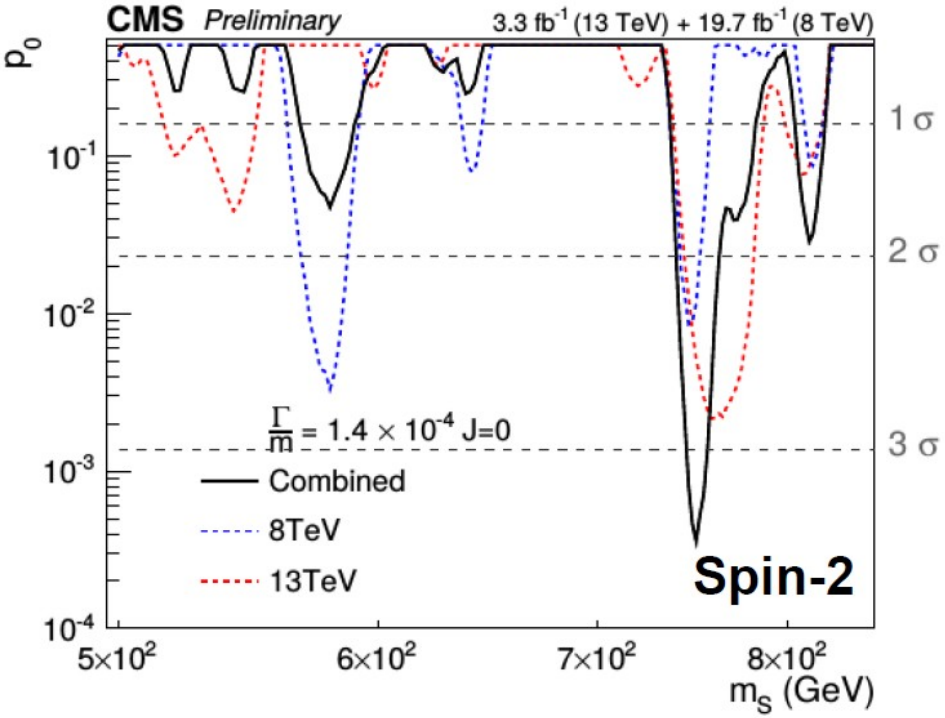
20-40% improvement

8 TeV switching point

High mass diphoton

- Largest excess @ **M_x =750 GeV, narrow** width
- **3.4 sigma** local significance
- **1.6 sigma** global in range 500-3500 GeV

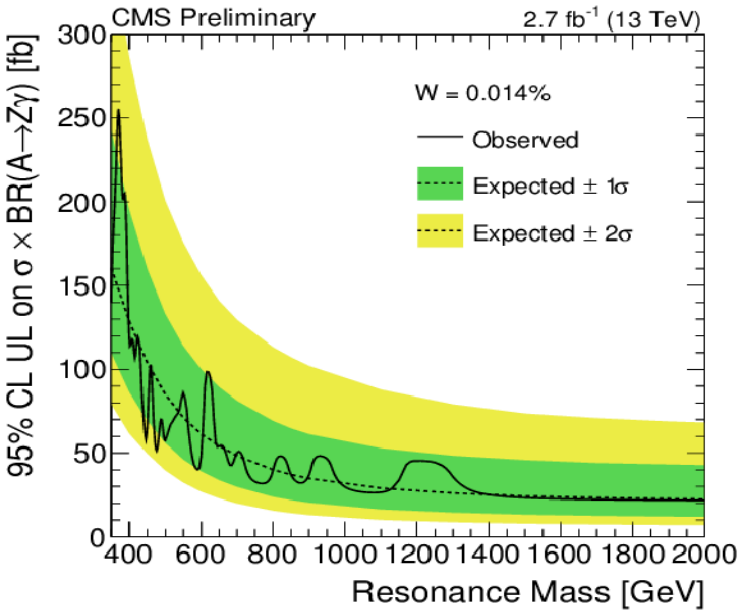


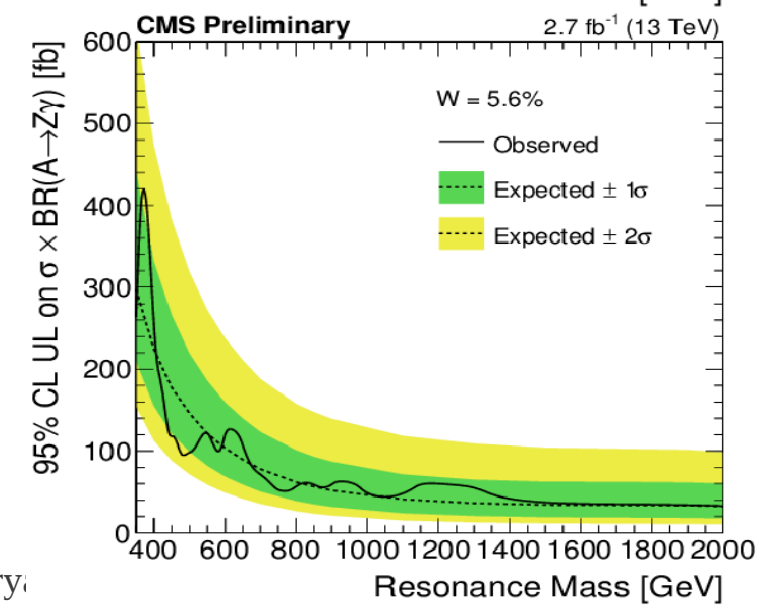


High-mass resonances in Zγ→e+e−γ/μ+μ−γ final states @ 13 TeV

EXO-16-019

- Higgs to diphoton style analysis
- Unbinned likelihood fit of background sideband
- Supported by an independent cut and count analysis
- No excess seen





Conclusion

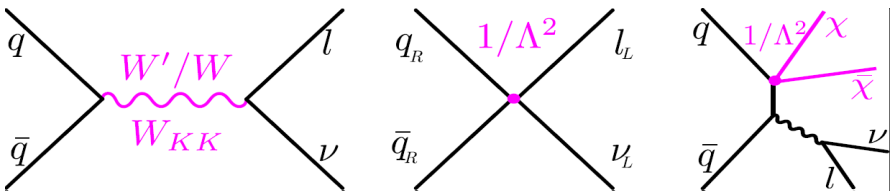
- Many new results @ 13 TeV already
- Almost everything is consistent with the Standard Model
- Except the excess in diphoton channel
- Not supported by any other channel
- A more definitive answer in next months
- A lot more interesting physics ahead

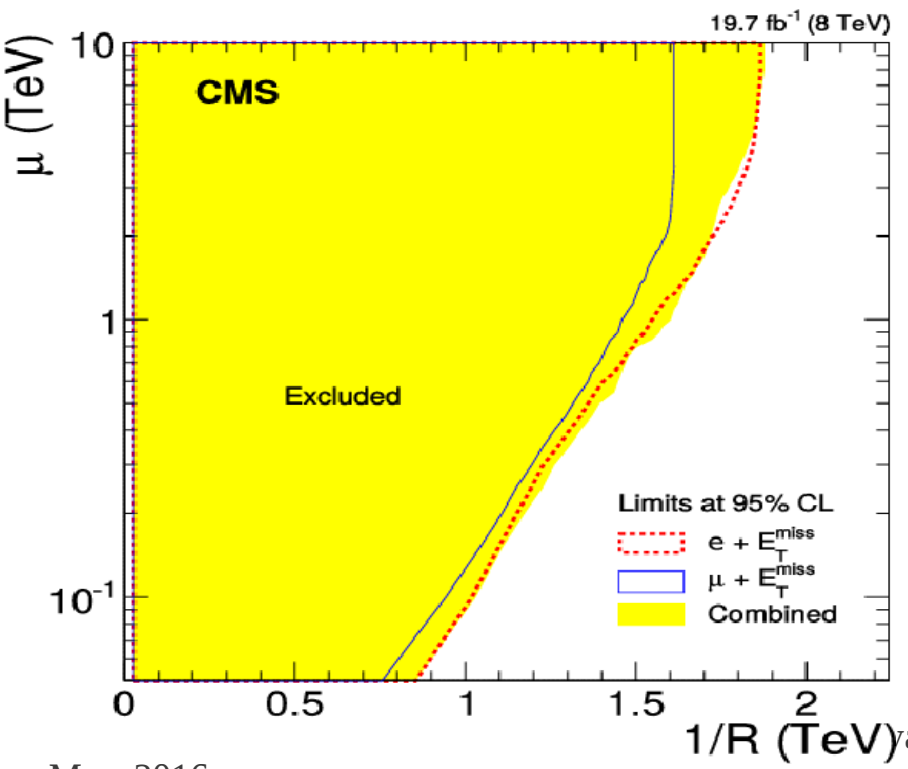
backup

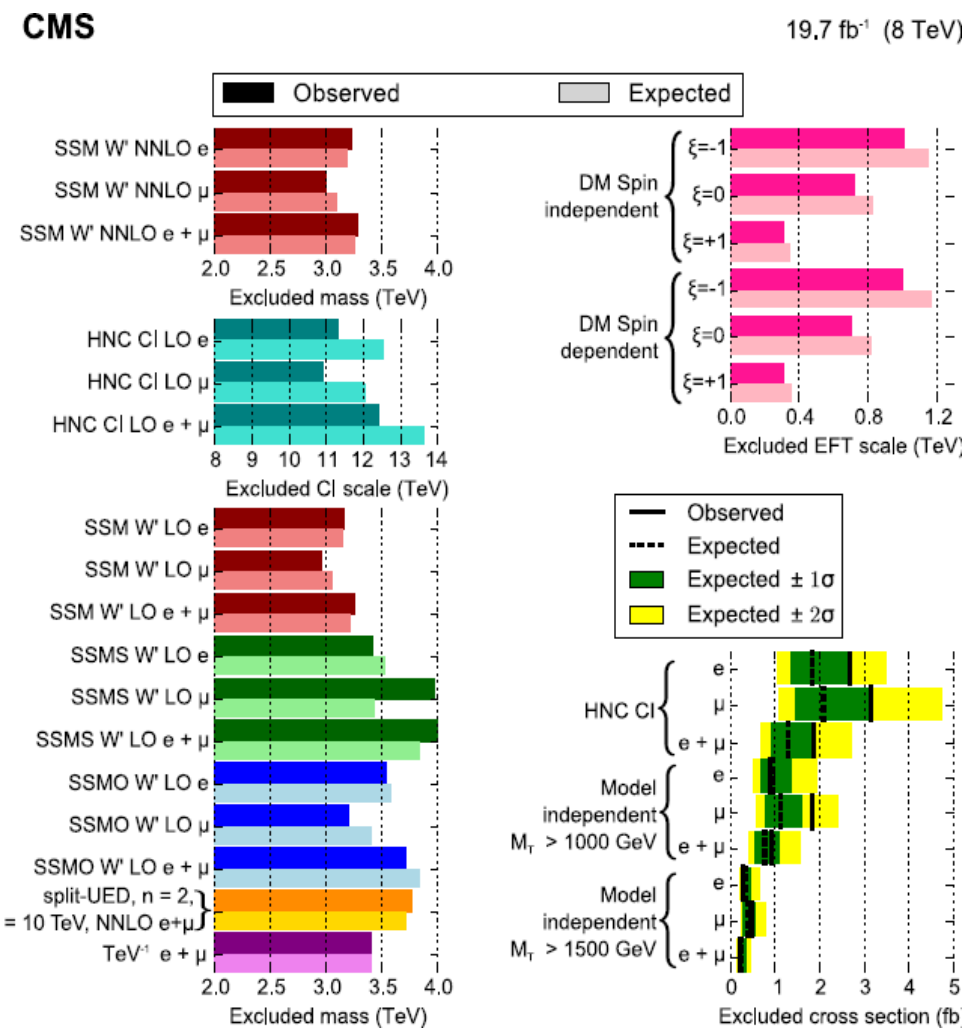
Search for physics beyond the standard model in final states with a lepton and missing transverse energy in proton-proton collisions at s√ = 8 TeV

CMS-EXO-12-060 ; CERN-PH-EP-2014-176

Phys. Rev. D 91 (2015) 092005



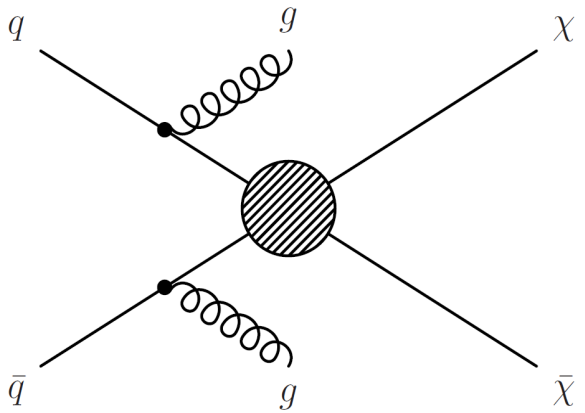


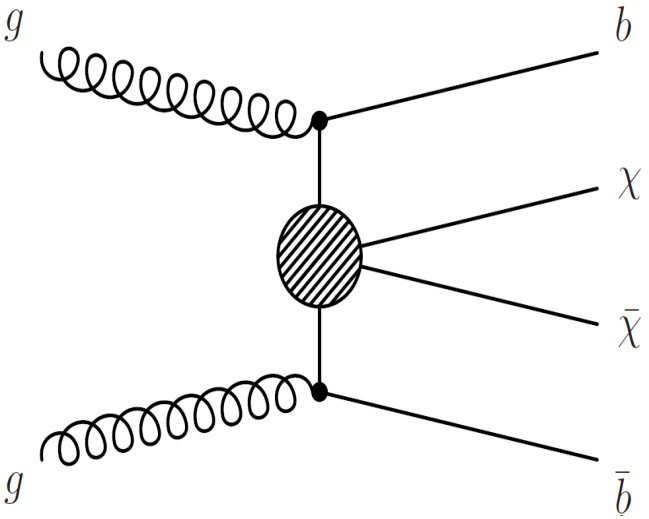


Dark matter razor analysis

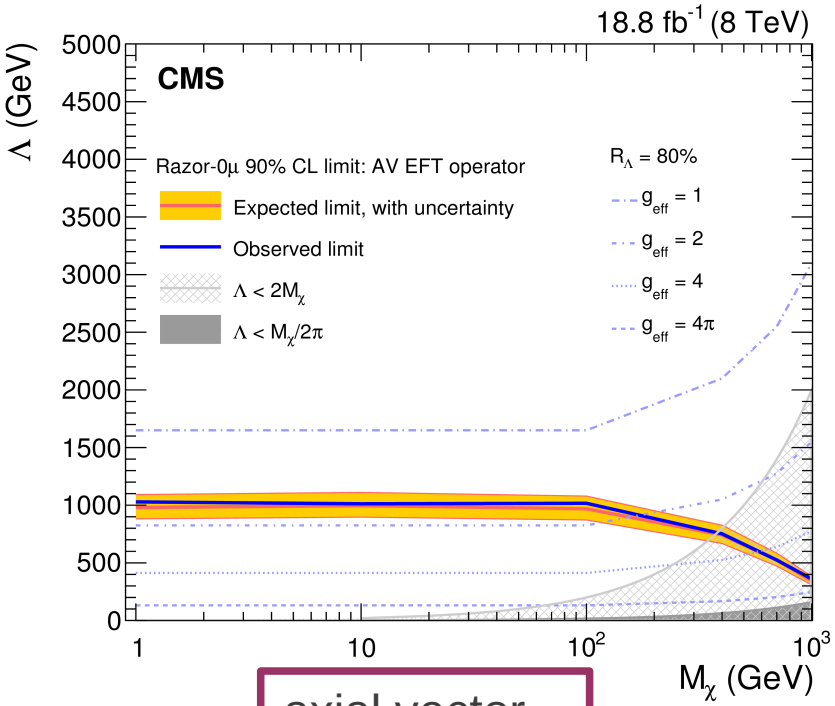
EXO-14-004

- Two Jets
- No leptons
- Razor variables used
- Separate analysis for b-jets

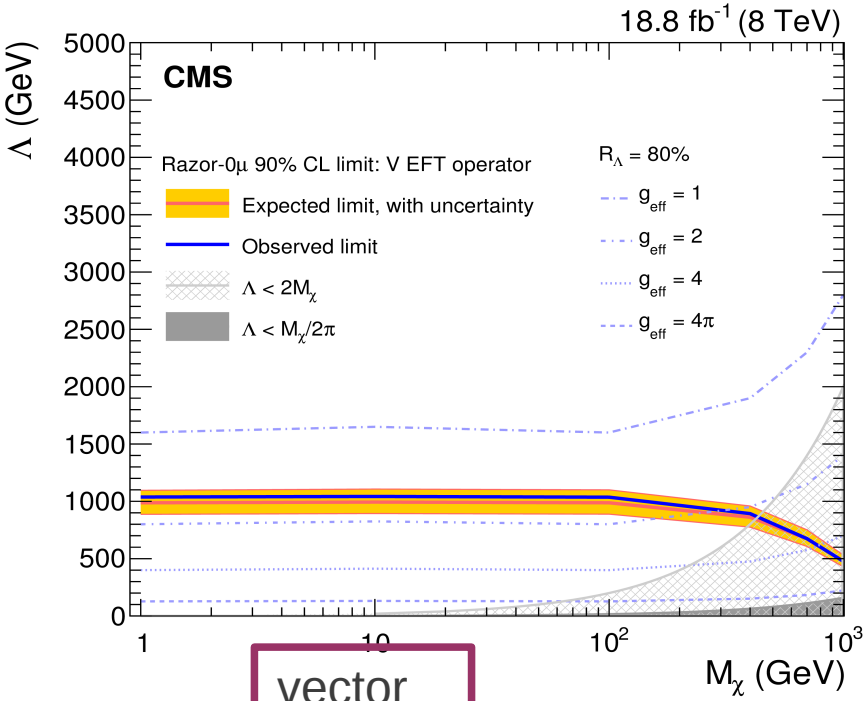




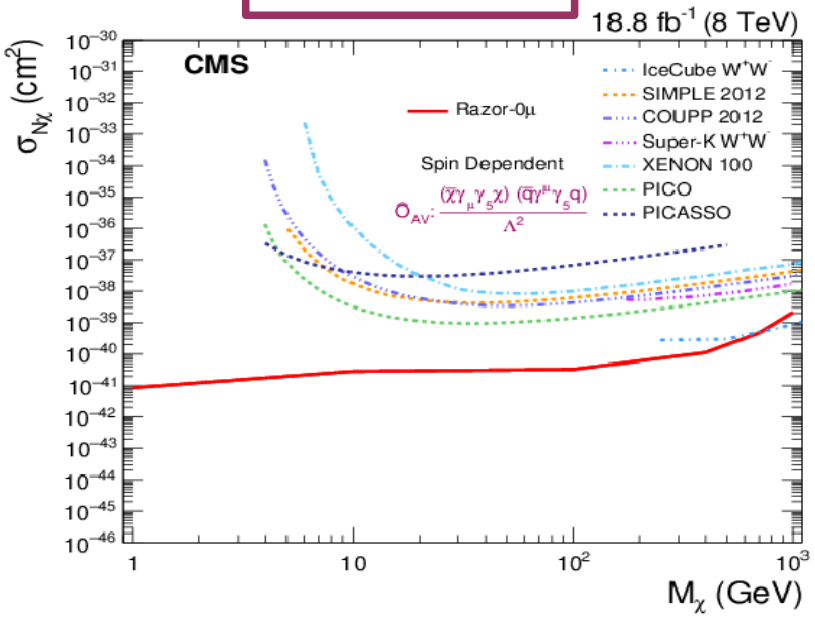
Dark matter razor analysis

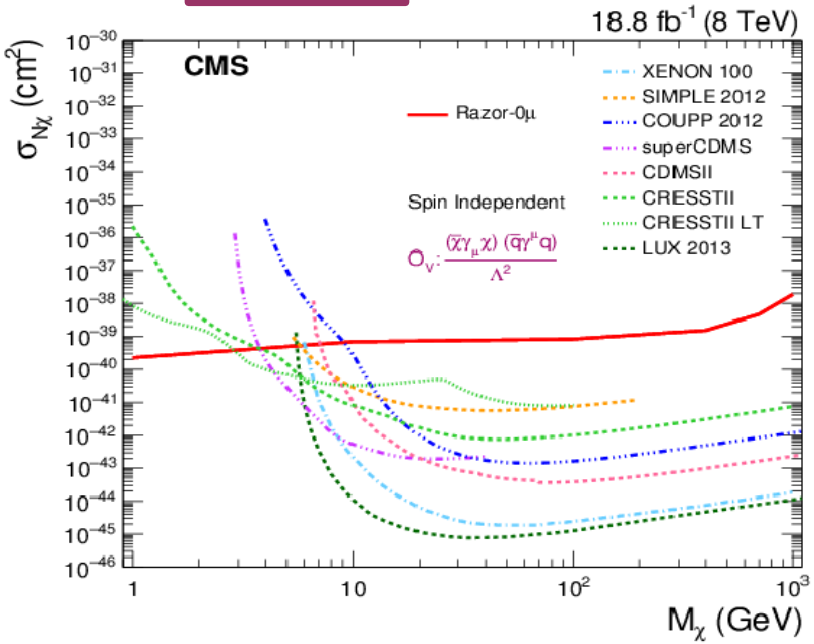


axial vector

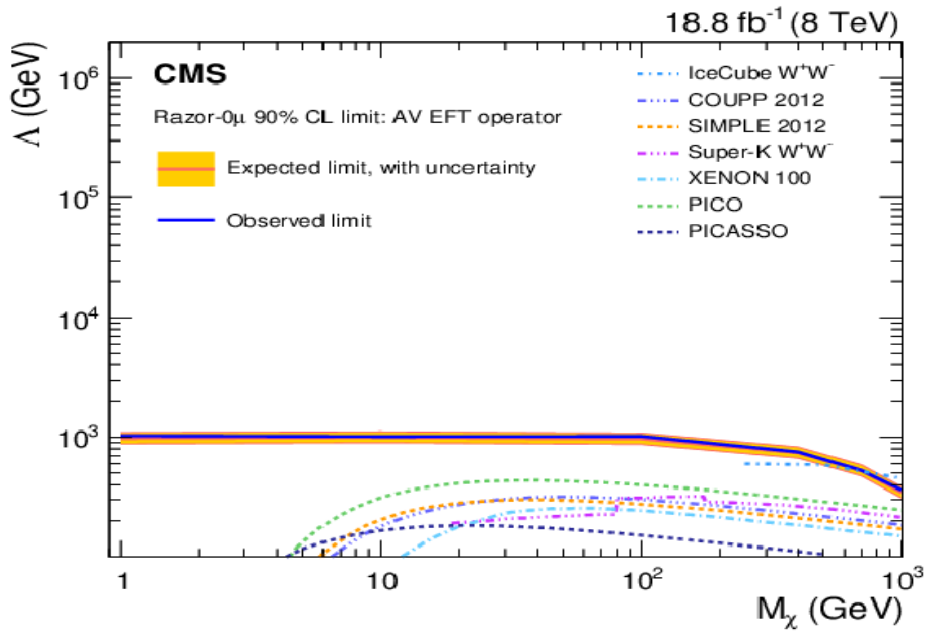


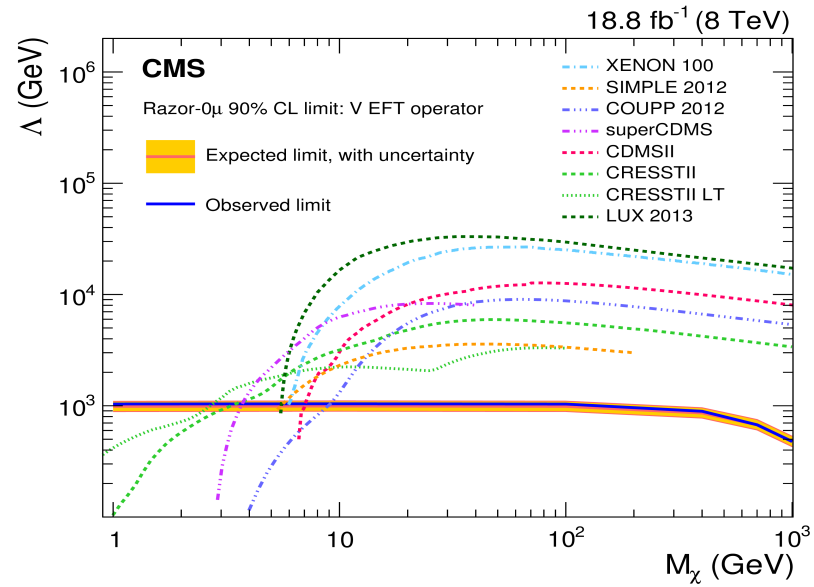
vector

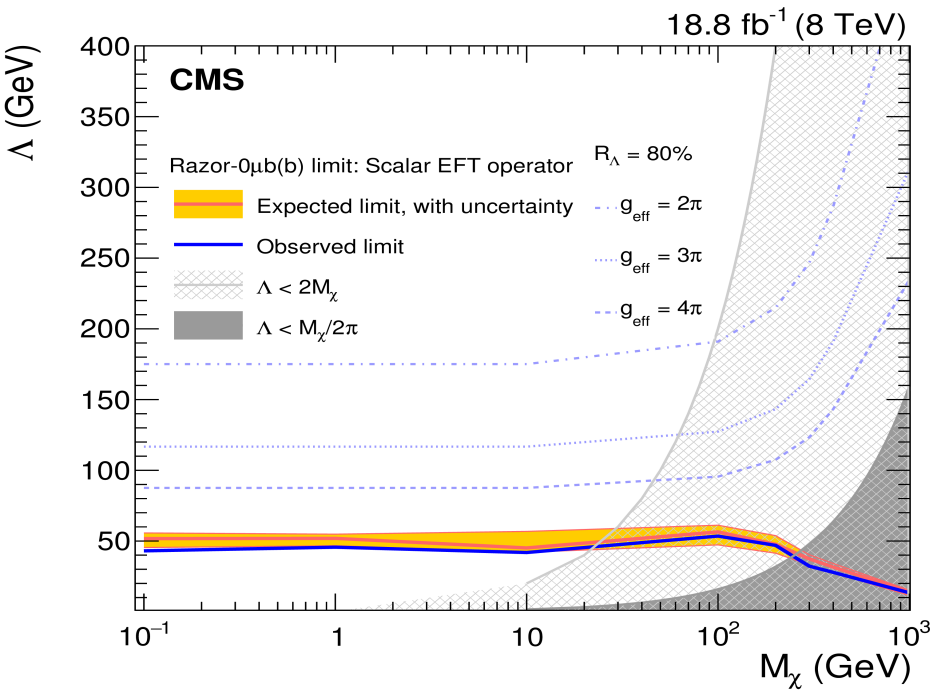


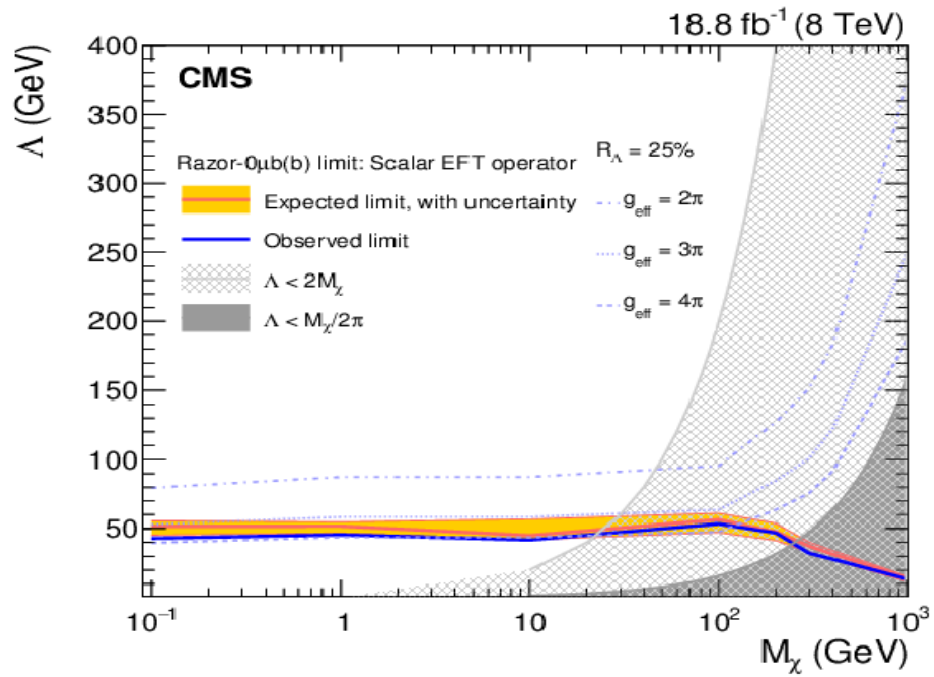


Dark Matter razor analysis



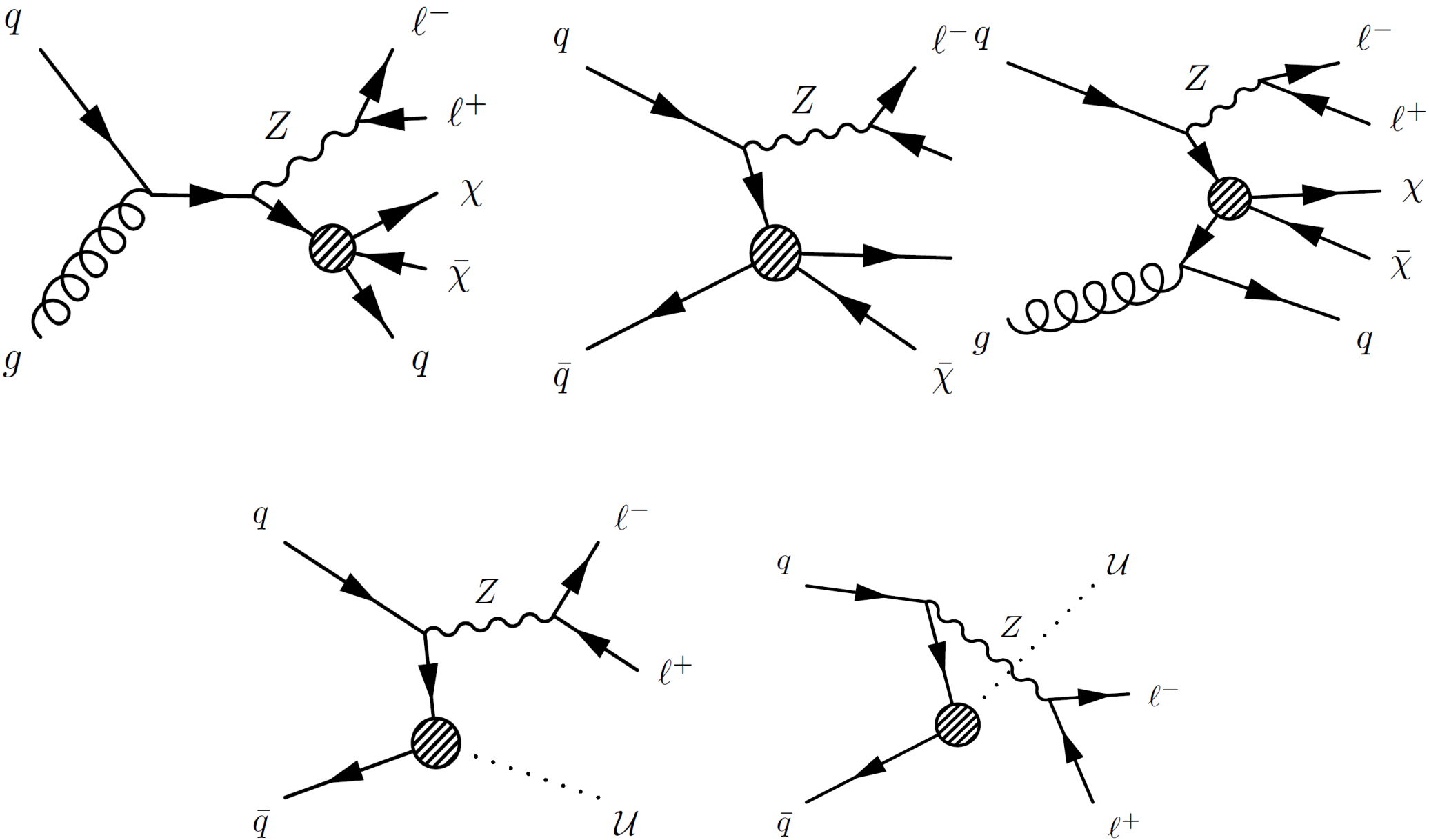




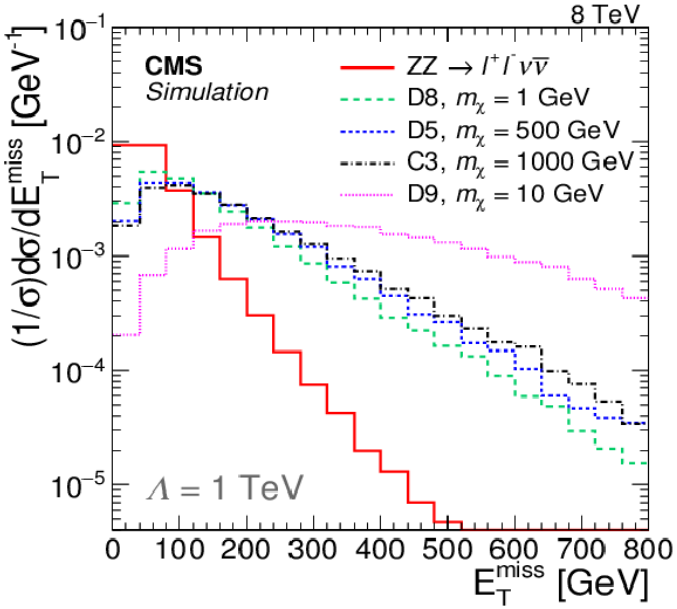


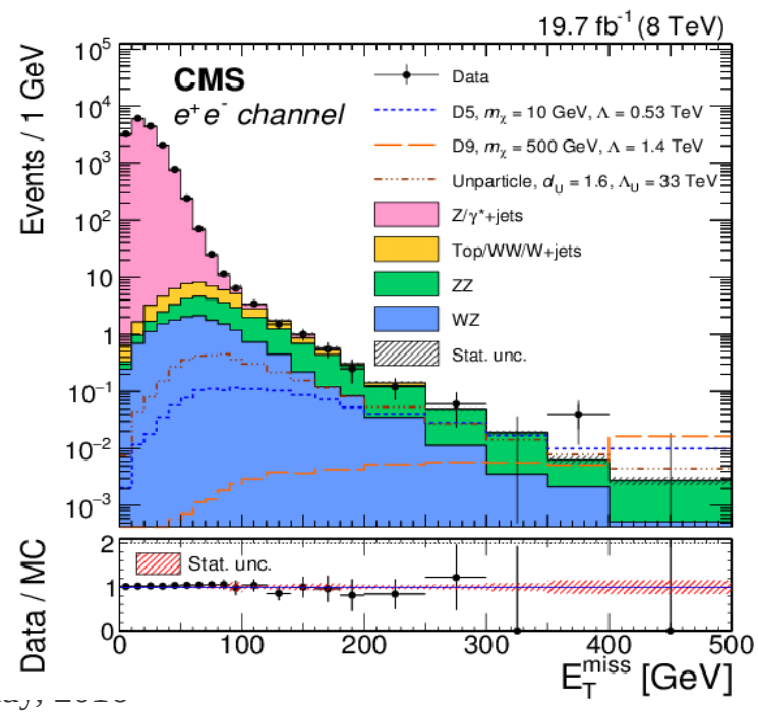
Bhat

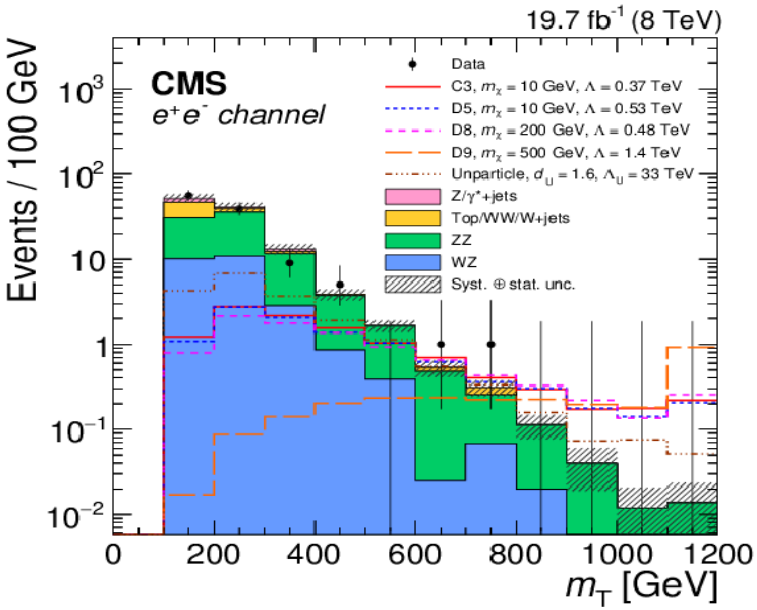
Mono Z @ 8 TeV



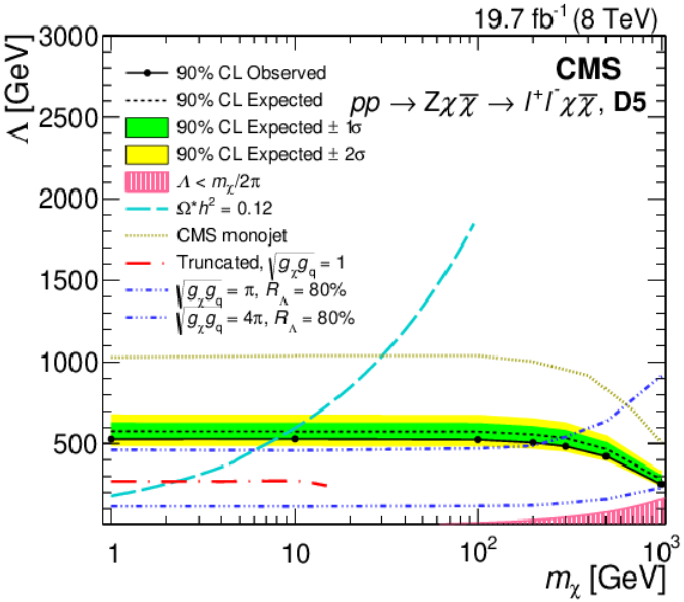
Mono-Z @ 8 TeV

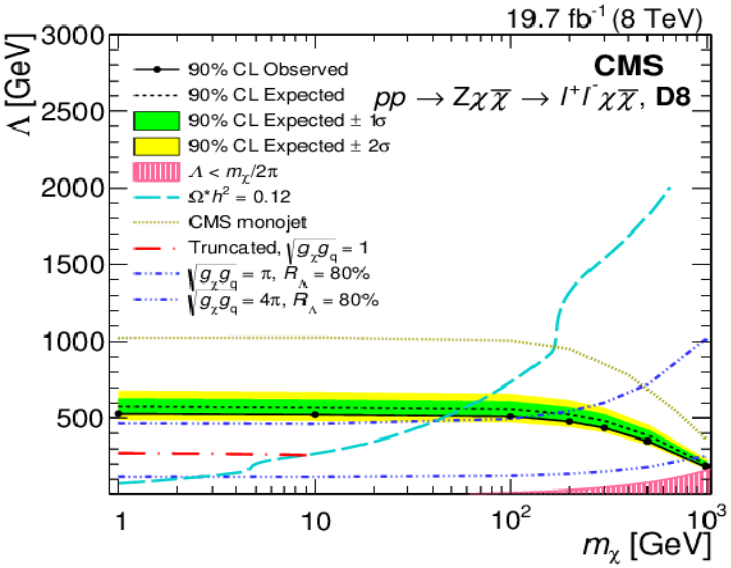

8 TeV
CMS
Simulation
ZZ → l⁺l⁻νν̄
D8, m_χ = 1 GeV
D5, m_χ = 500 GeV
C3, m_χ = 1000 GeV
D9, m_χ = 10 GeV
Λ = 1 TeV
(1/σ)dσ/dE_T^miss [GeV⁻¹]
E_T^miss [GeV]

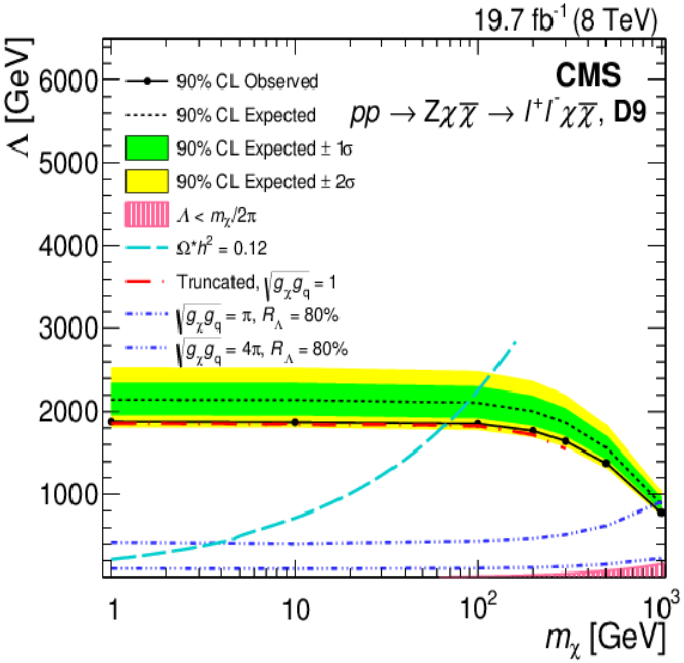

19.7 fb⁻¹ (8 TeV)
CMS
e⁺e⁻ channel
Data
D5, m_χ = 10 GeV, Λ = 0.53 TeV
D9, m_χ = 500 GeV, Λ = 1.4 TeV
Unparticle, d_U = 1.6, Λ_U = 33 TeV
Z/γ*+jets
Top/WW/W+jets
ZZ
WZ
Stat. unc.
Events / 1 GeV
Data / MC
E_T^miss [GeV]

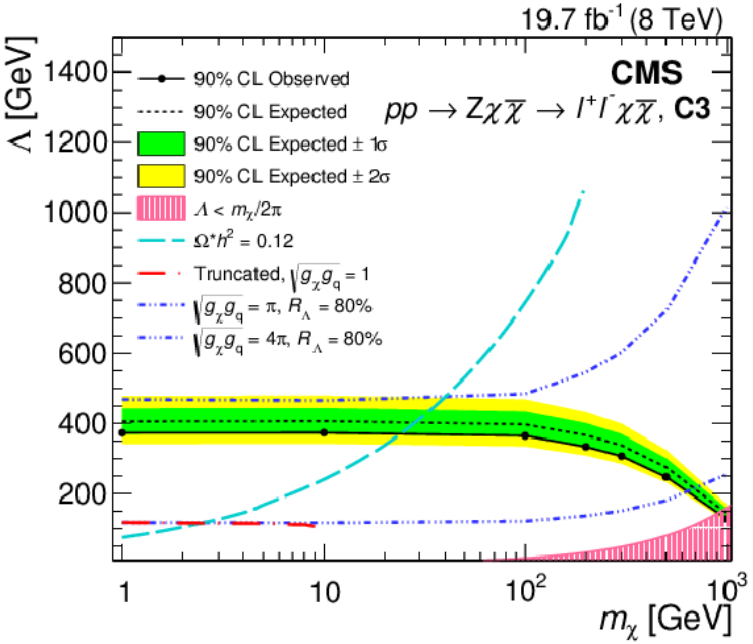

19.7 fb⁻¹ (8 TeV)
CMS
e⁺e⁻ channel
Data
C3, m_χ = 10 GeV, Λ = 0.37 TeV
D5, m_χ = 10 GeV, Λ = 0.53 TeV
D8, m_χ = 200 GeV, Λ = 0.48 TeV
D9, m_χ = 500 GeV, Λ = 1.4 TeV
Unparticle, d_U = 1.6, Λ_U = 33 TeV
Z/γ*+jets
Top/WW/W+jets
ZZ
WZ
Syst. ⊕ stat. unc.
Events / 100 GeV
m_T [GeV]

Mono Z @ 8 TeV

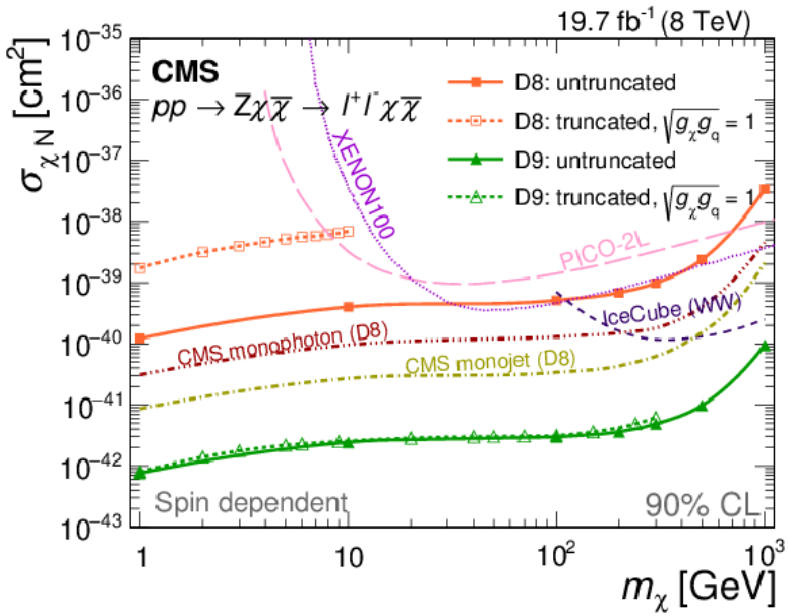

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, D5
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^* h^2 = 0.12$
CMS monojet
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]

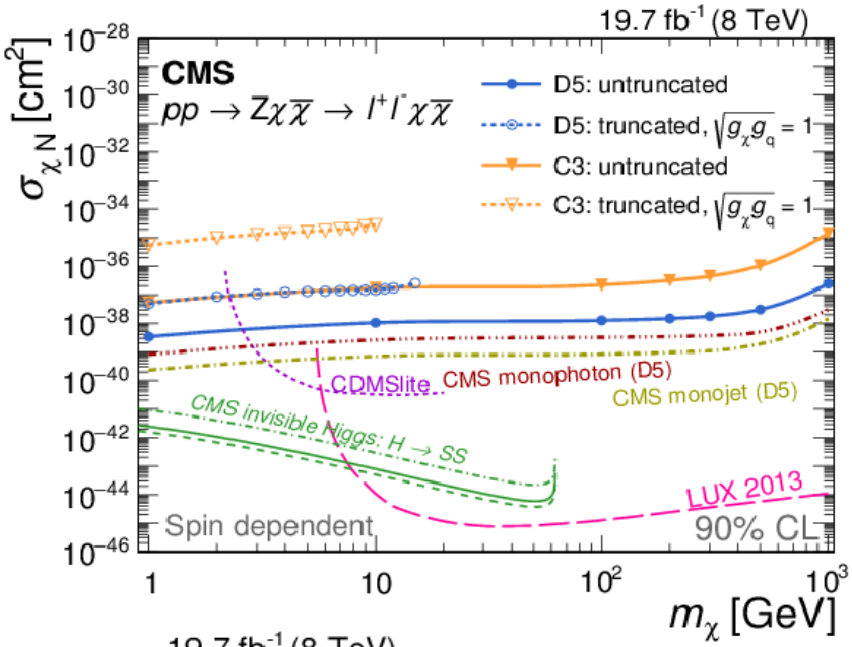

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, D8
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^* h^2 = 0.12$
CMS monojet
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]

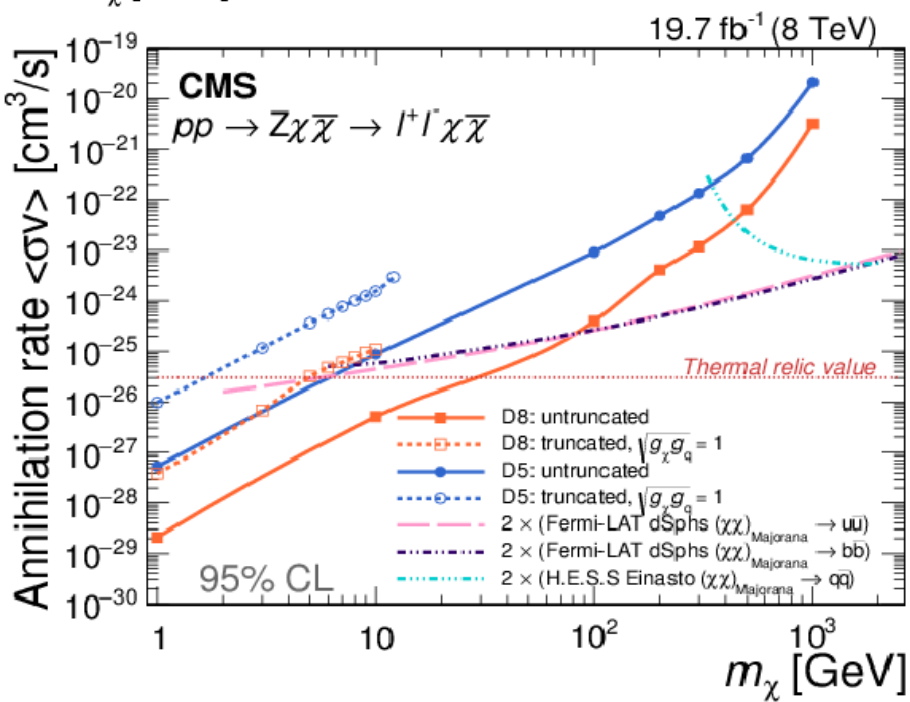

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, D9
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^* h^2 = 0.12$
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]


19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$, C3
90% CL Observed
90% CL Expected
90% CL Expected ± 1σ
90% CL Expected ± 2σ
$\Lambda < m_\chi/2\pi$
$\Omega^* h^2 = 0.12$
Truncated, $\sqrt{g_\chi g_q} = 1$
$\sqrt{g_\chi g_q} = \pi$, $R_\Lambda = 80\%$
$\sqrt{g_\chi g_q} = 4\pi$, $R_\Lambda = 80\%$
Λ [GeV]
m_χ [GeV]

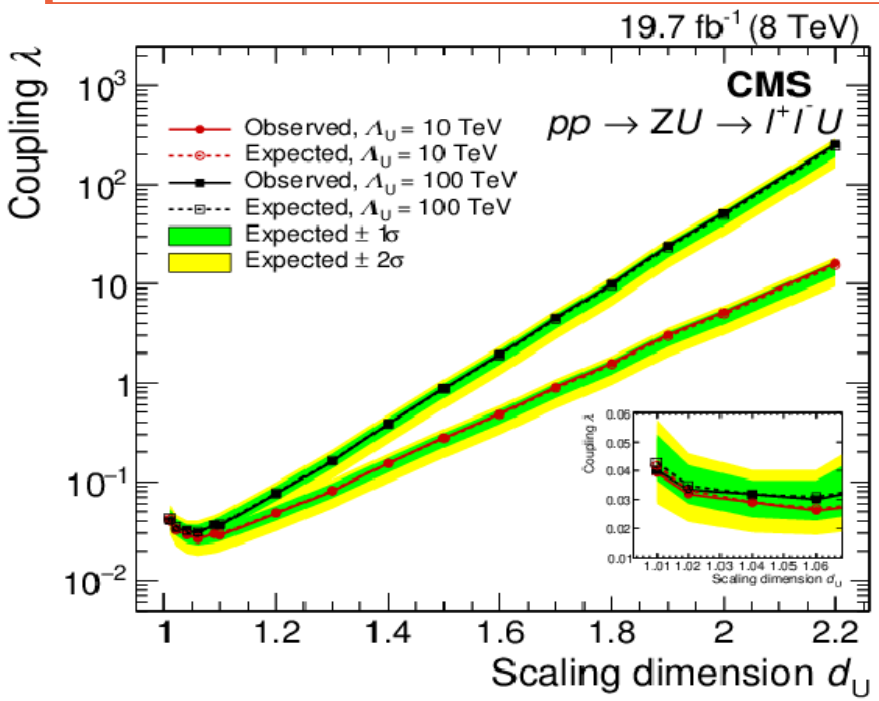
Mono-Z

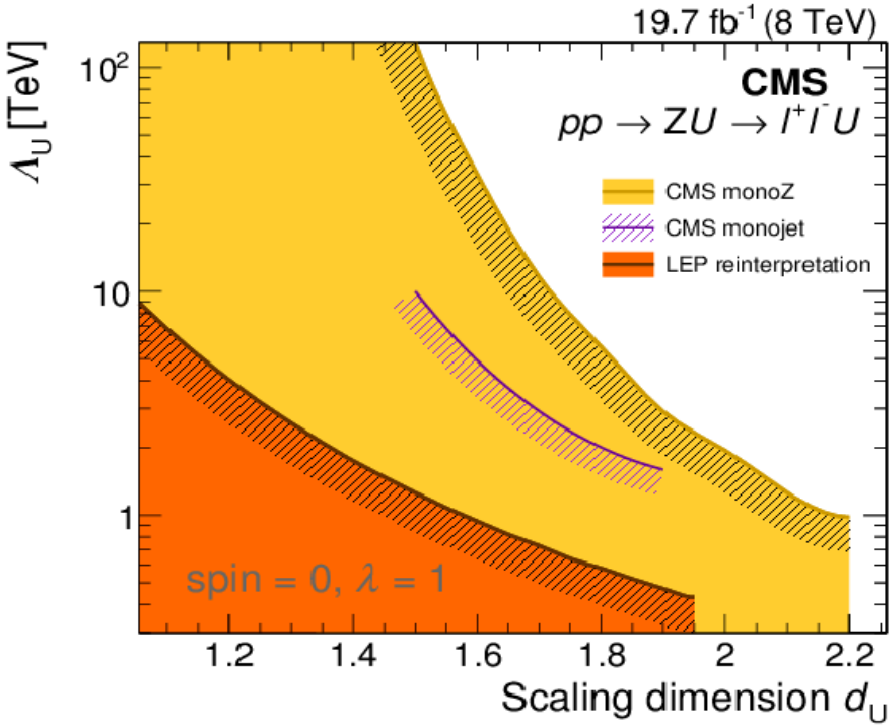

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$
D8: untruncated
D8: truncated, $\sqrt{g_\chi g_q} = 1$
D9: untruncated
D9: truncated, $\sqrt{g_\chi g_q} = 1$
XENON100
PICO-2L
IceCube (WW)
CMS monophoton (D8)
CMS monojet (D8)
Spin dependent
90% CL
$\sigma_{\chi N}$ [cm^2]
m_χ [GeV]

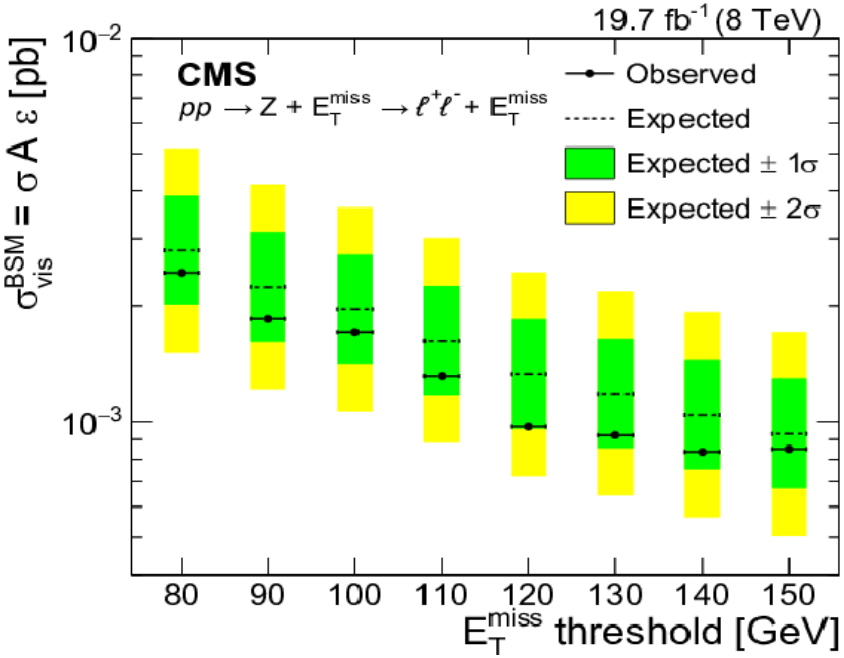

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$
D5: untruncated
D5: truncated, $\sqrt{g_\chi g_q} = 1$
C3: untruncated
C3: truncated, $\sqrt{g_\chi g_q} = 1$
CDMSlite
CMS monophoton (D5)
CMS monojet (D5)
CMS invisible Higgs: $H \to SS$
LUX 2013
Spin dependent
90% CL
$\sigma_{\chi N}$ [cm^2]
m_χ [GeV]


19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z\chi\bar{\chi} \to l^+l^-\chi\bar{\chi}$
Thermal relic value
D8: untruncated
D8: truncated, $\sqrt{g_\chi g_q} = 1$
D5: untruncated
D5: truncated, $\sqrt{g_\chi g_q} = 1$
2 × (Fermi-LAT dSphs $(\chi\chi)_{Majorana} \to u\bar{u}$)
2 × (Fermi-LAT dSphs $(\chi\chi)_{Majorana} \to b\bar{b}$)
2 × (H.E.S.S Einasto $(\chi\chi)_{Majorana} \to q\bar{q}$)
95% CL
Annihilation rate <σv> [cm^3/s]
m_χ [GeV]

Mono-Z


19.7 fb^{-1} (8 TeV)
CMS
$pp \to ZU \to l^+l^-U$
Observed, Λ_U = 10 TeV
Expected, Λ_U = 10 TeV
Observed, Λ_U = 100 TeV
Expected, Λ_U = 100 TeV
Expected ± 1σ
Expected ± 2σ
Coupling λ
Scaling dimension d_U

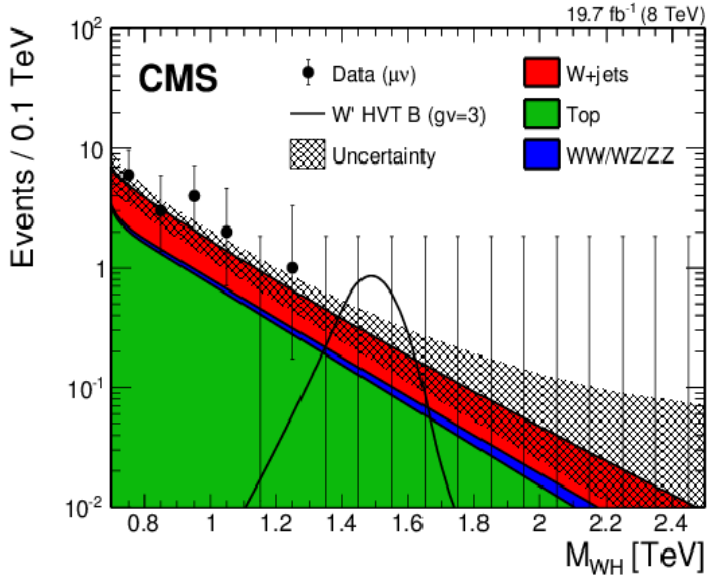

19.7 fb^{-1} (8 TeV)
CMS
$pp \to ZU \to l^+l^-U$
CMS monoZ
CMS monojet
LEP reinterpretation
spin = 0, λ = 1
Λ_U [TeV]
Scaling dimension d_U

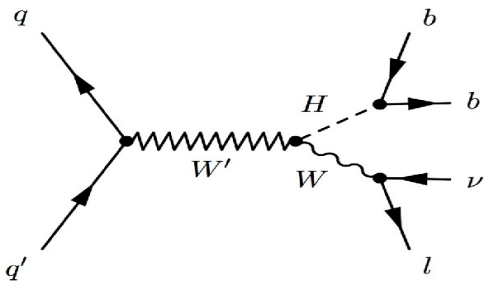

19.7 fb^{-1} (8 TeV)
CMS
$pp \to Z + E_T^{miss} \to \ell^+\ell^- + E_T^{miss}$
Observed
Expected
Expected ± 1σ
Expected ± 2σ
$\sigma_{vis}^{BSM} = \sigma A \varepsilon$ [pb]
E_T^{miss} threshold [GeV]

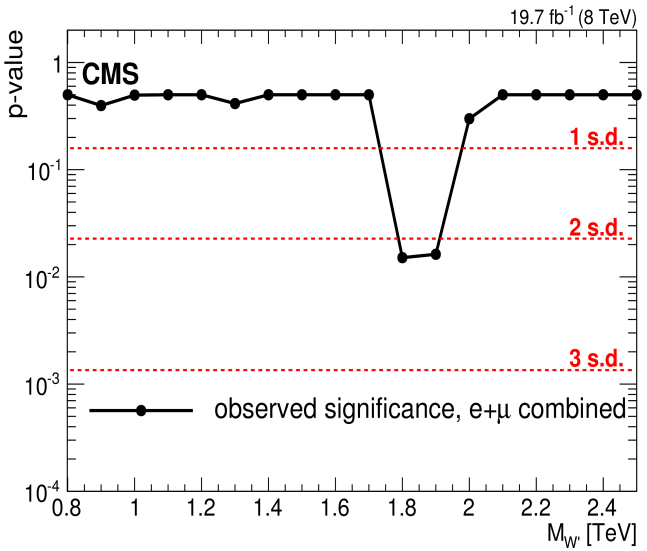
Search for massive WH resonances decaying into the ℓνbb̄ final state at s√= 8 TeV

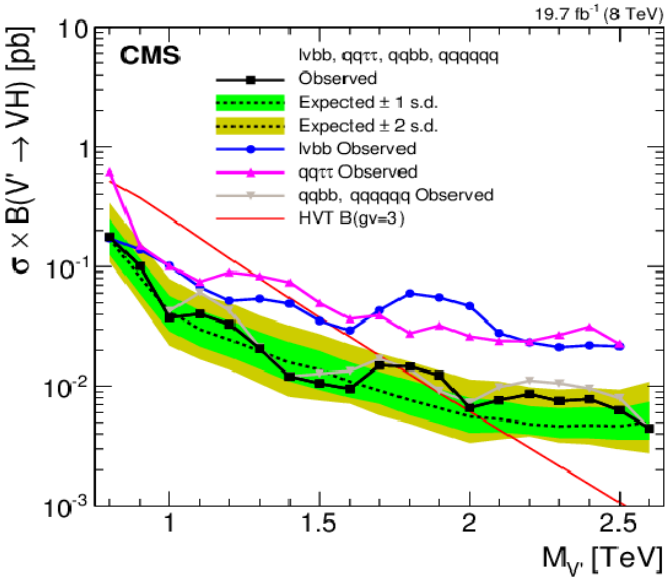
- exo-14-010

- B 's reconstructed as a single jet
- Tagged by substructure
- In HVT model limit of
- 1.5 TeV on W' mass









High mass diphoton

- Compatibility of 8 and 13 TeV

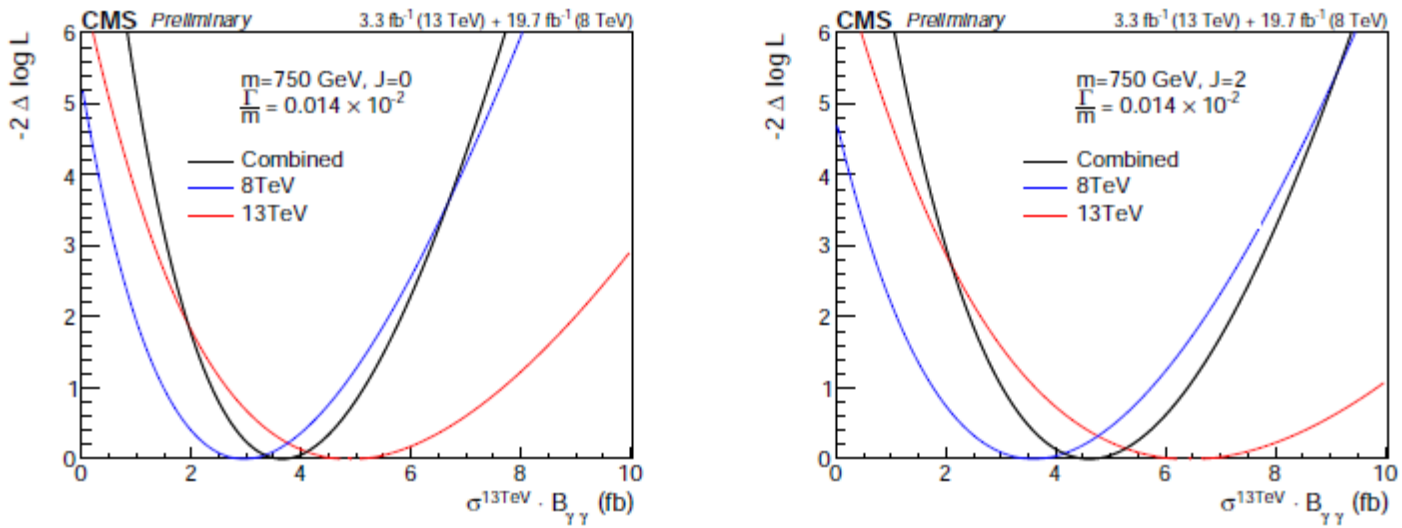
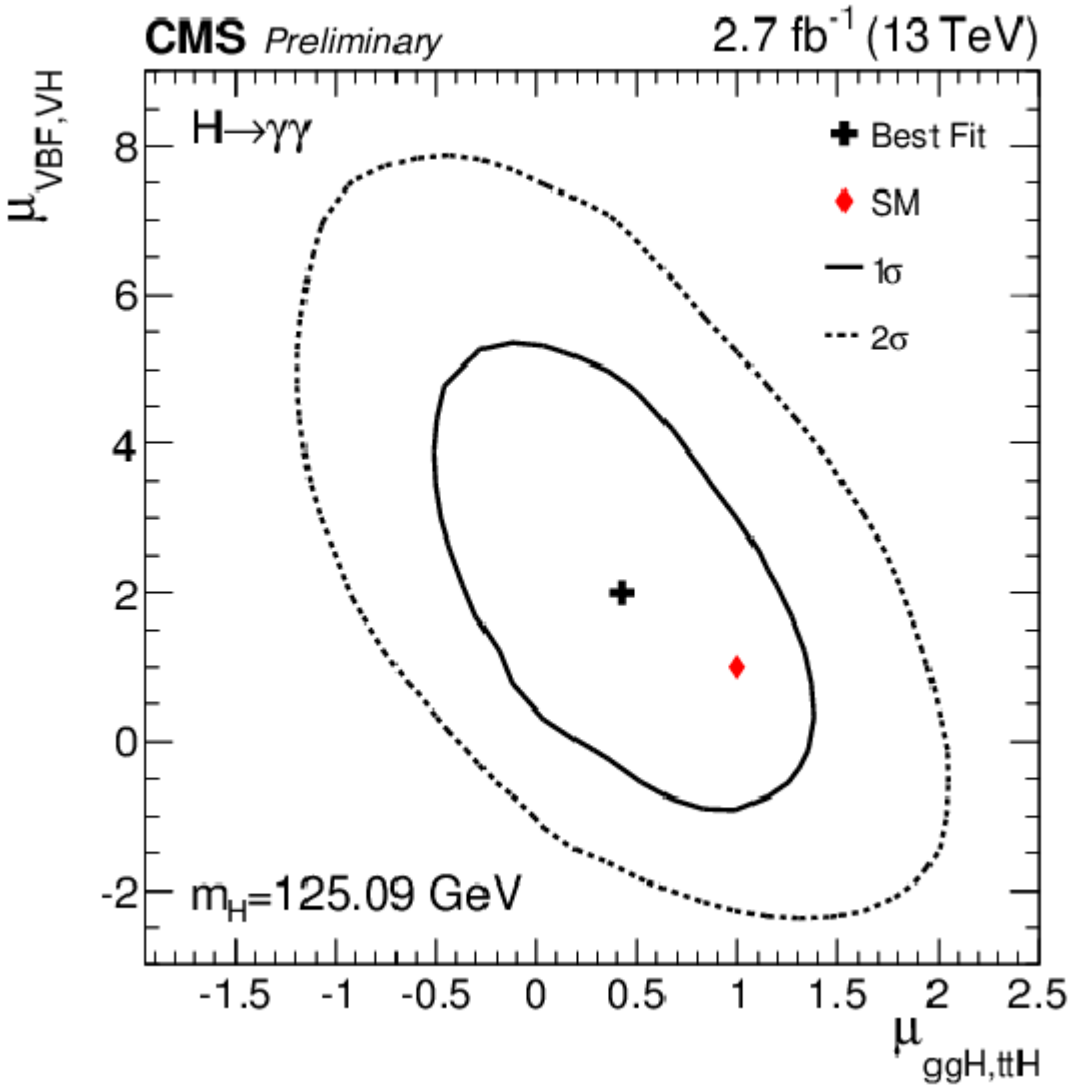


Figure 10: Likelihood scan for the cross section corresponding to the largest excess in the combined analysis of the 8 and 13 TeV datasets. The left (right) column corresponds to the scalar (RS graviton) signals. The 8 TeV results are scaled by the expected ratio of cross sections in each scenarios.

Higgs to diphoton



Rediscovering H(125)

HIG-15-004

H→ZZ→4ℓ (13 TeV): Analysis Overview

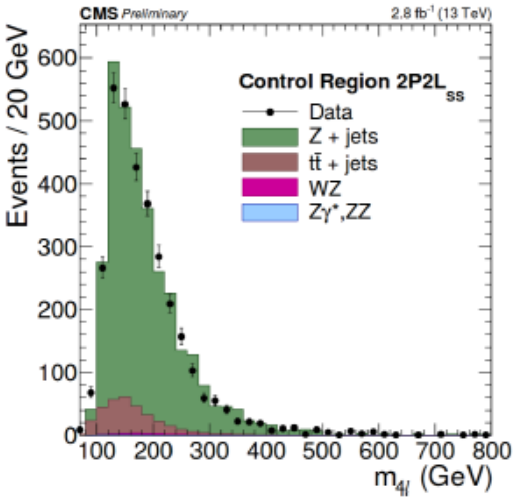
- Excellent mass resolution:
  - Calibrated using $Z \to \ell\ell$
- Very High Signal/Background
  - ZZ bkg. scaled to NNLO pred.
  - Reducible bkg. from data (two methods)
- Event Categorization:
  - 2 jets + $\mathcal{D}_{\rm jet} > 0.5$: VBF tagged
  - Other events: Untagged
- ME Discriminant in likelihood:

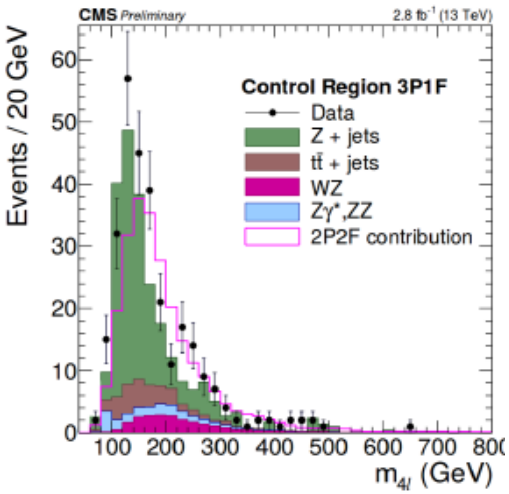
$$\mathcal{L}_{2D}(m_{4\ell}, \mathcal{D}^{\rm kin}_{\rm bkg}) = \mathcal{L}(m_{4\ell})\mathcal{L}(\mathcal{D}^{\rm kin}_{\rm bkg}|m_{4\ell})$$

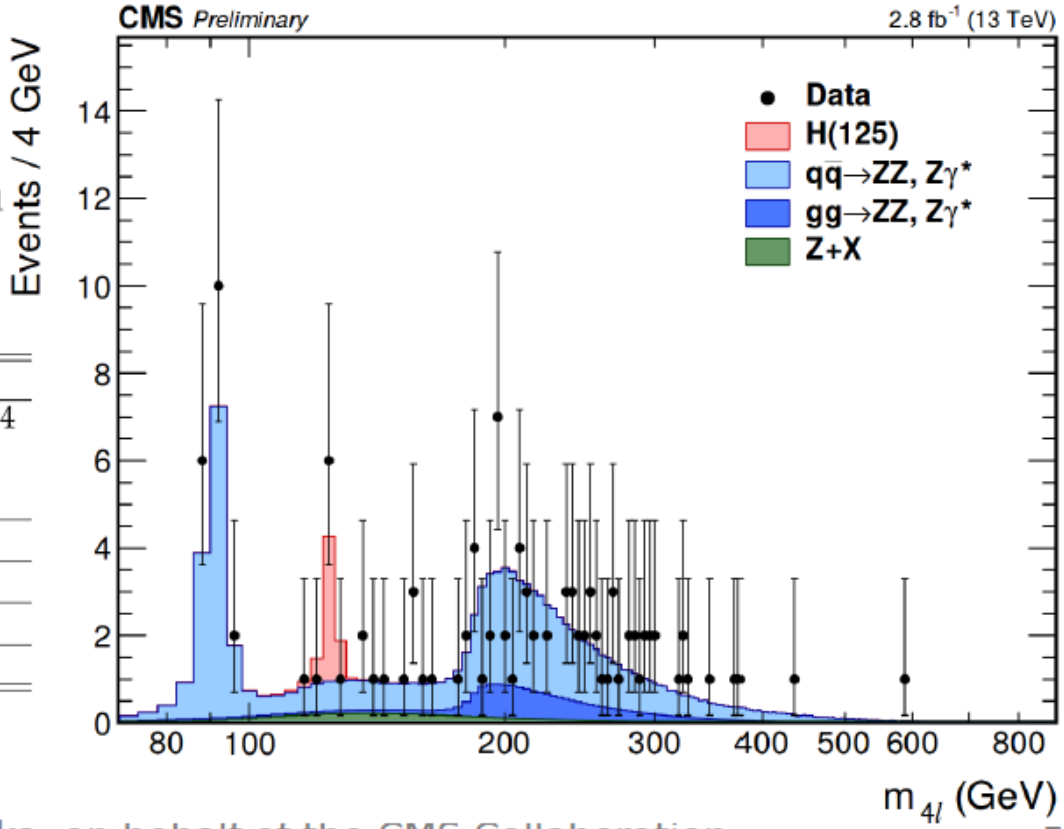
$$\mathcal{D}^{\rm kin}_{\rm bkg} = \left[1 + \frac{\mathcal{P}^{q\bar{q}}_{\rm bkg}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}{\mathcal{P}^{gg}_{\rm sig}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}\right]^{-1} \quad \mathcal{D}_{\rm jet} = \left[1 + \frac{\mathcal{P}_{\rm HJJ}(\vec{\Omega}^{\rm H+JJ}|m_{4\ell})}{\mathcal{P}_{\rm VBF}(\vec{\Omega}^{\rm H+JJ}|m_{4\ell})}\right]^{-1}$$

Channel	4e	4μ	$2e2\mu$	4ℓ
$q\bar{q} \to ZZ$	0.33 ± 0.03	0.75 ± 0.05	0.92 ± 0.07	2.00 ± 0.14
$gg \to ZZ$	0.04 ± 0.01	0.08 ± 0.01	0.07 ± 0.01	$0.18^{+0.03}_{-0.02}$
Z+X	$0.17^{+0.15}_{-0.09}$	0.19 ± 0.08	0.26 ± 0.10	$0.62^{+0.20}_{-0.16}$
Sum of backgrounds	$0.54^{+0.16}_{-0.10}$	1.02 ± 0.09	1.25 ± 0.13	$2.80^{+0.25}_{-0.22}$
Signal ($m_{\rm H} = 125$ GeV)	$0.91^{+0.11}_{-0.10}$	1.70 ± 0.15	2.21 ± 0.22	$4.82^{+0.44}_{-0.45}$
Total expected	$1.45^{+0.21}_{-0.16}$	2.72 ± 0.20	3.45 ± 0.29	$7.62^{+0.58}_{-0.56}$
Observed	1	3	4	8

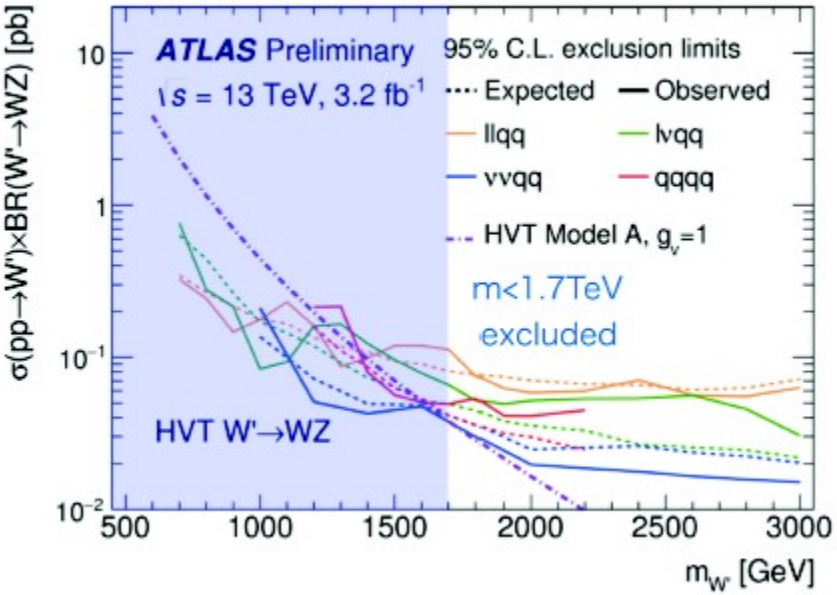
118 GeV < $m_{4\ell}$ < 130 GeV



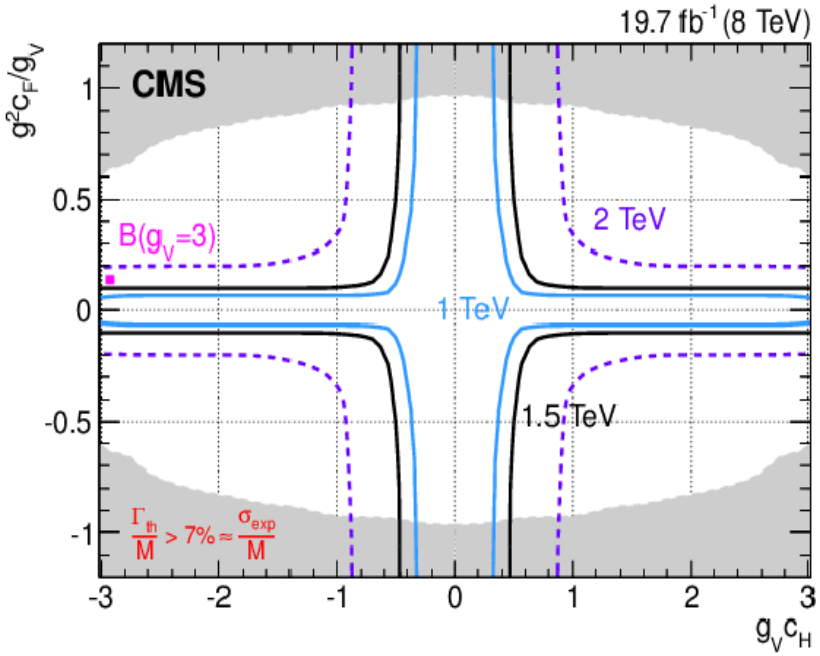




HVT Model

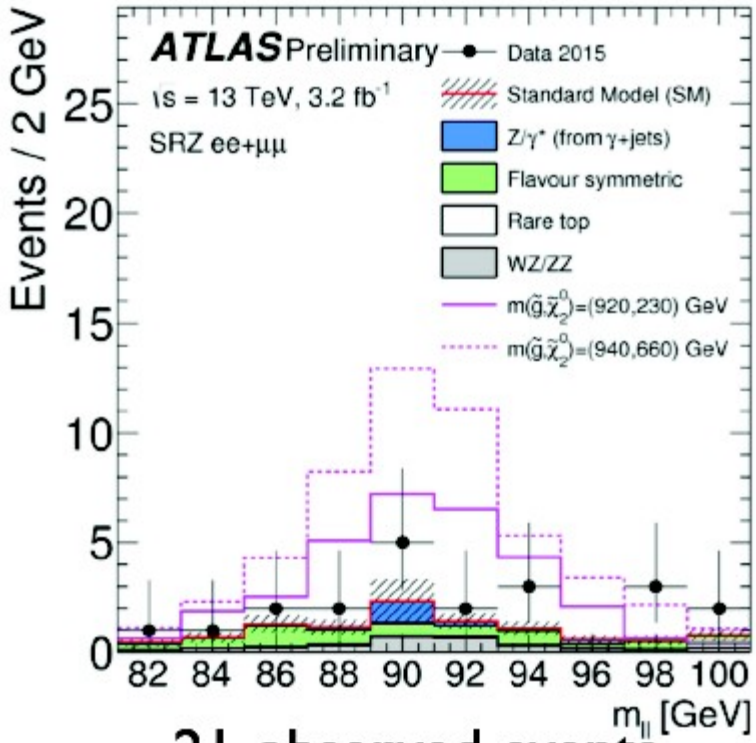


- exo-14-010



ATLAS dilepton excess

excess on-shell

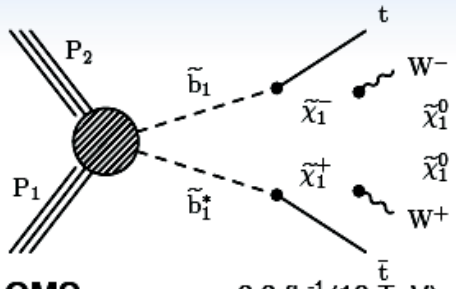


21 observed events with 10 expected (2.2σ)

2ℓ same-sign, ≥3ℓ: limits

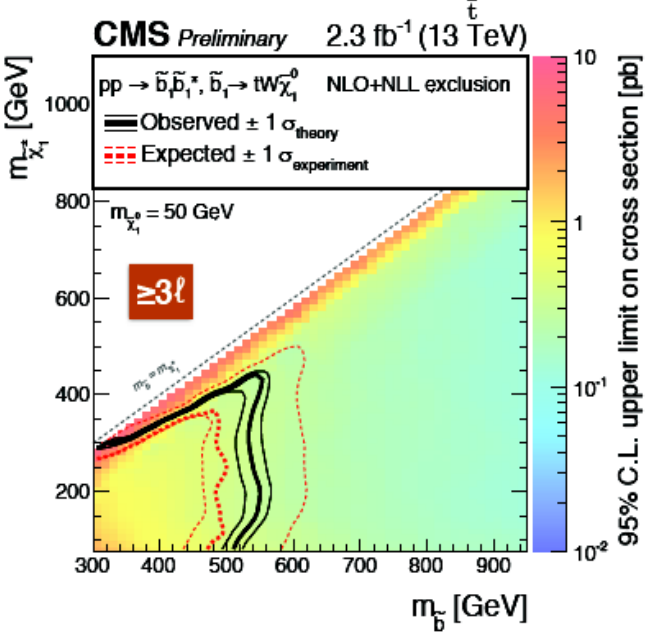
SUS-15-008 ≥2ℓ, SS

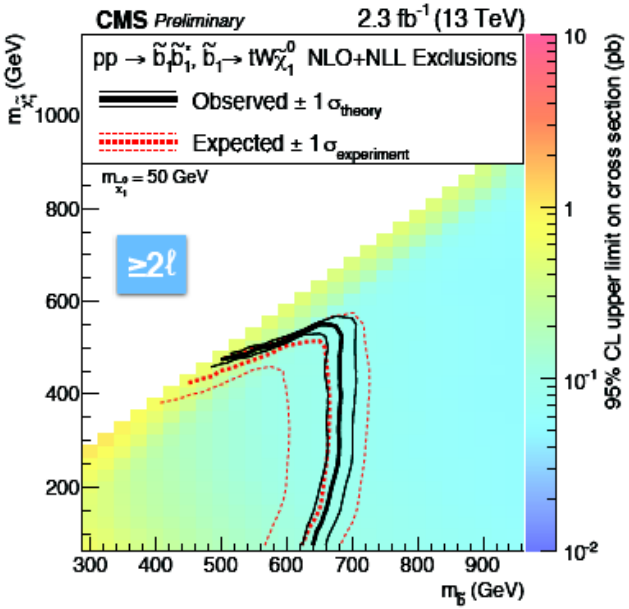
SUS-16-003 ≥3ℓ

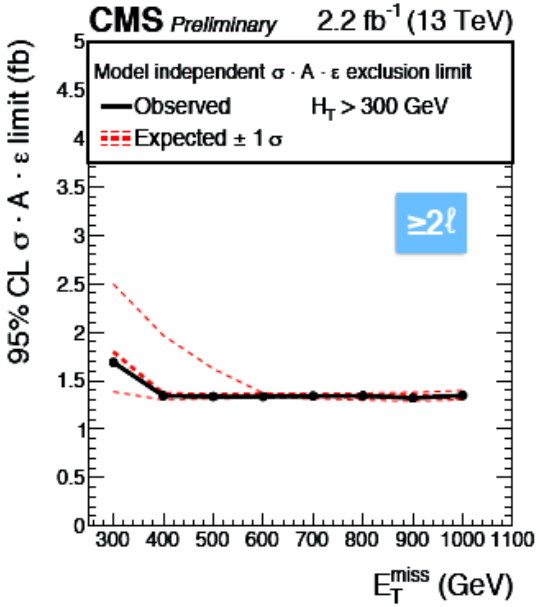


Limits on direct sbottom production

Excluded model-independent NP with σ•A•ε ~ 1.3 fb







Higgs singlet branching

$$
\begin{aligned}
\Gamma(\mathrm{h} \to X_{\mathrm{SM}} X_{\mathrm{SM}}) &= \cos^2\alpha\, \Gamma(\mathrm{h} \to X_{\mathrm{SM}} X_{\mathrm{SM}})_{\mathrm{SM}} \\
\Gamma(\mathrm{H} \to X_{\mathrm{SM}} X_{\mathrm{SM}}) &= \sin^2\alpha\, \Gamma(\mathrm{H} \to X_{\mathrm{SM}} X_{\mathrm{SM}})_{\mathrm{SM}} \\
\Gamma_{\mathrm{H}} &= \sin^2\alpha\, \Gamma_{\mathrm{H,SM}}(m_{\mathrm{H}}) + \Gamma(\mathrm{H} \to \mathrm{hh}) \\
\Gamma_{\mathrm{h}} &= \cos^2\alpha\, \Gamma_{\mathrm{h,SM}}(m_{\mathrm{h}})
\end{aligned}
$$

Figure 1. The photon p_T distribution for the candidate sample, compared with estimated contributions from SM backgrounds and a prediction from ADD for $M_D = 1TeV$ and $n = 3$.

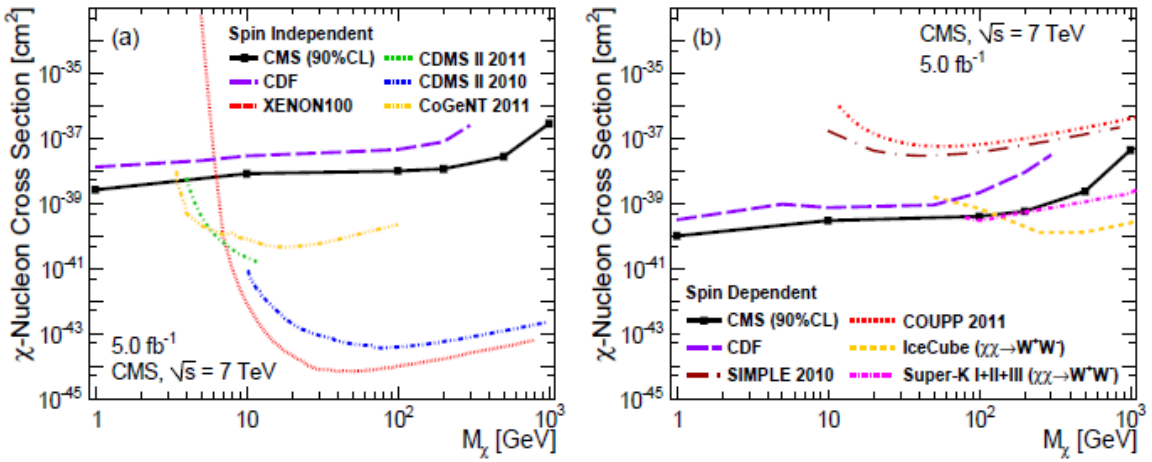


Figure 2. The 90% CL upper limits on the χ-nucleon cross section as a function of M_χ for (a) spin-independent and (b) spin-dependent scattering

11.1 ± 5.6 events.