Exotica searches at ATLAS and CMS

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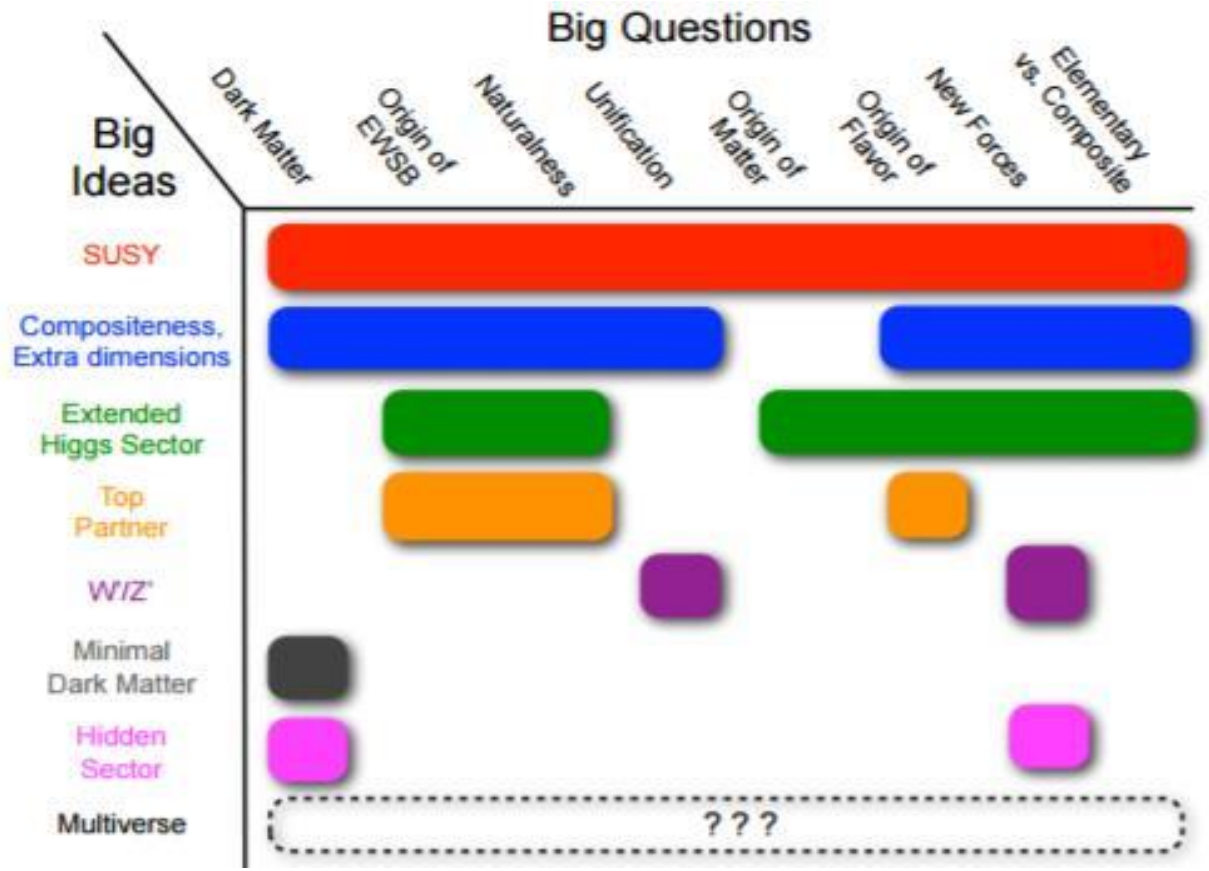
Exotics: Beyond the Standard Model Physics

- Many Big Questions beyond the SM to be answered at TeV scale
- Big Ideas highly constrained from theory and observed phenomena

Xuai Zhuang's talk

Ye Chen's talk

Scope of this talk

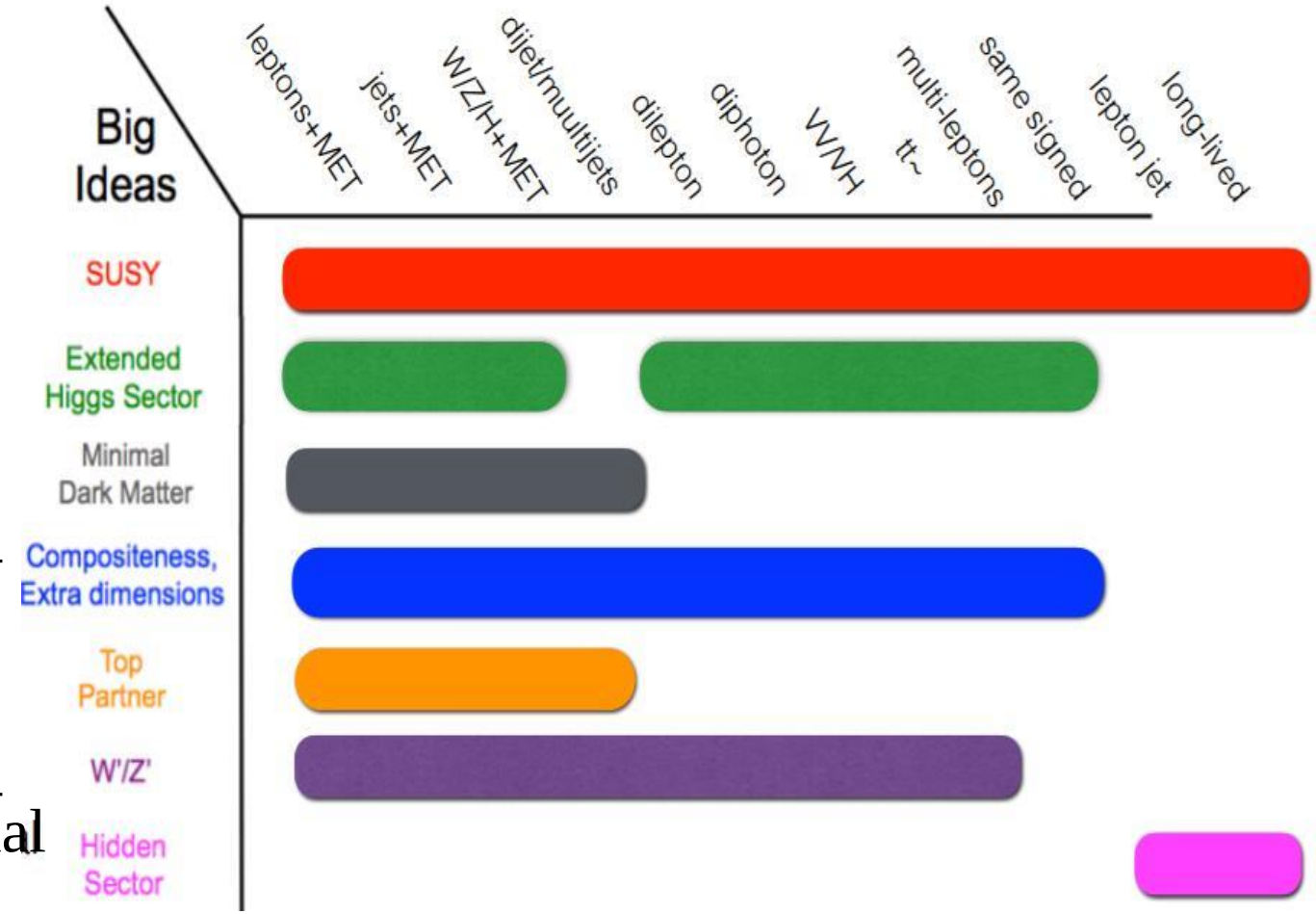


Search signatures for Big Ideas

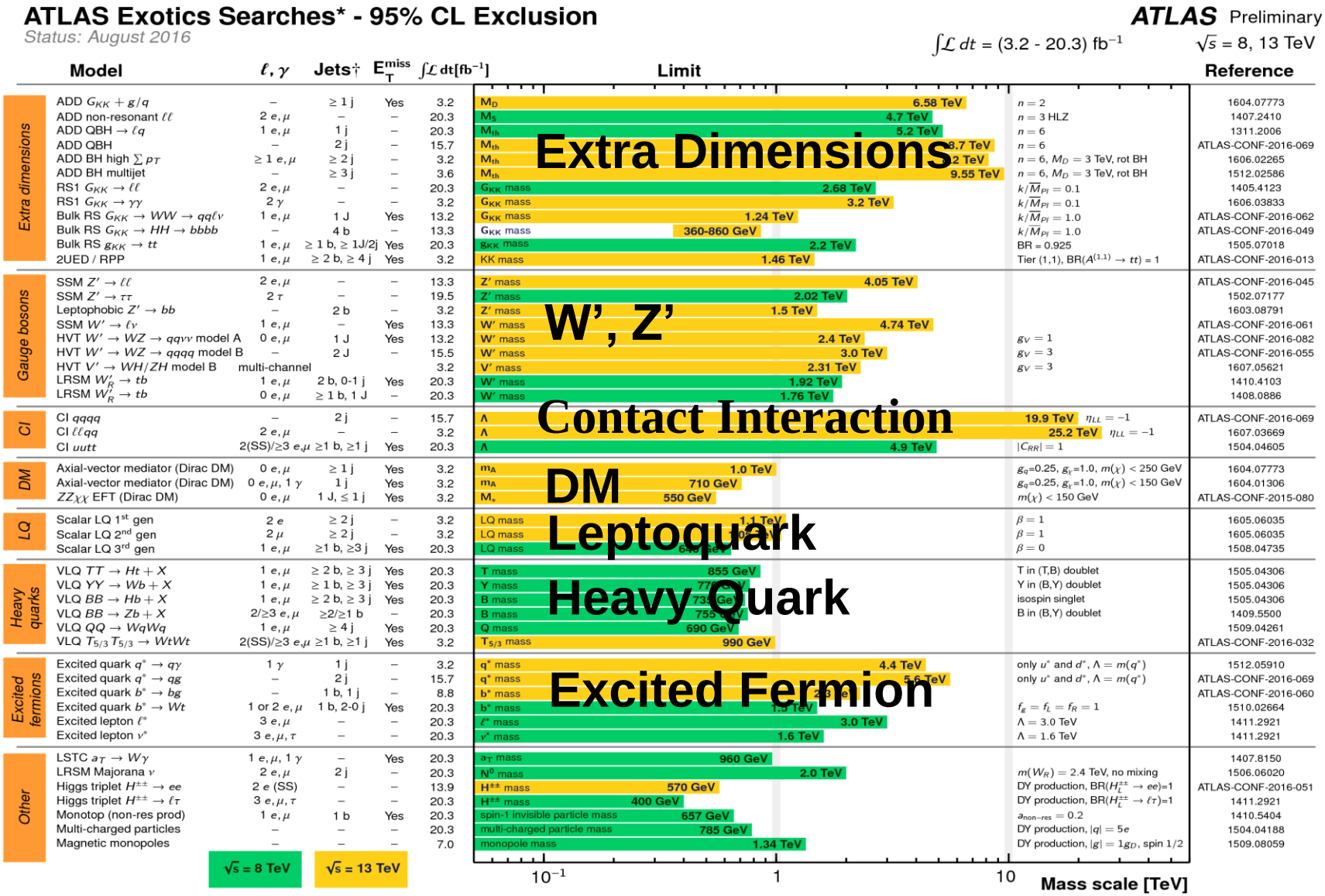
- Quite often the same Big Idea probed by different signatures
- It's crucial to search all complementary signatures

Plan of this talk

1. Dark Matter
2. Resonance
3. Unconventional Signatures



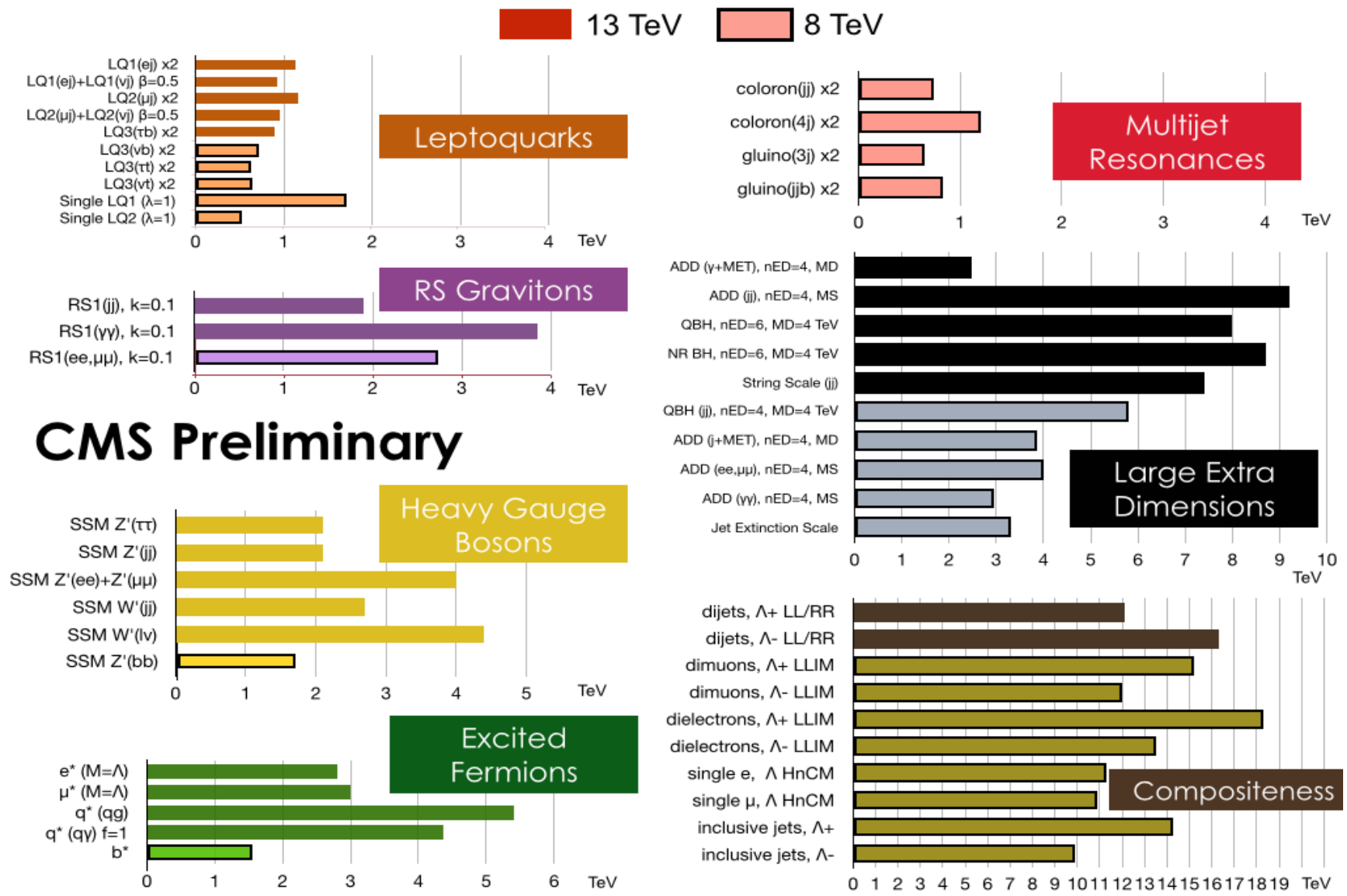
ATLAS Exotica



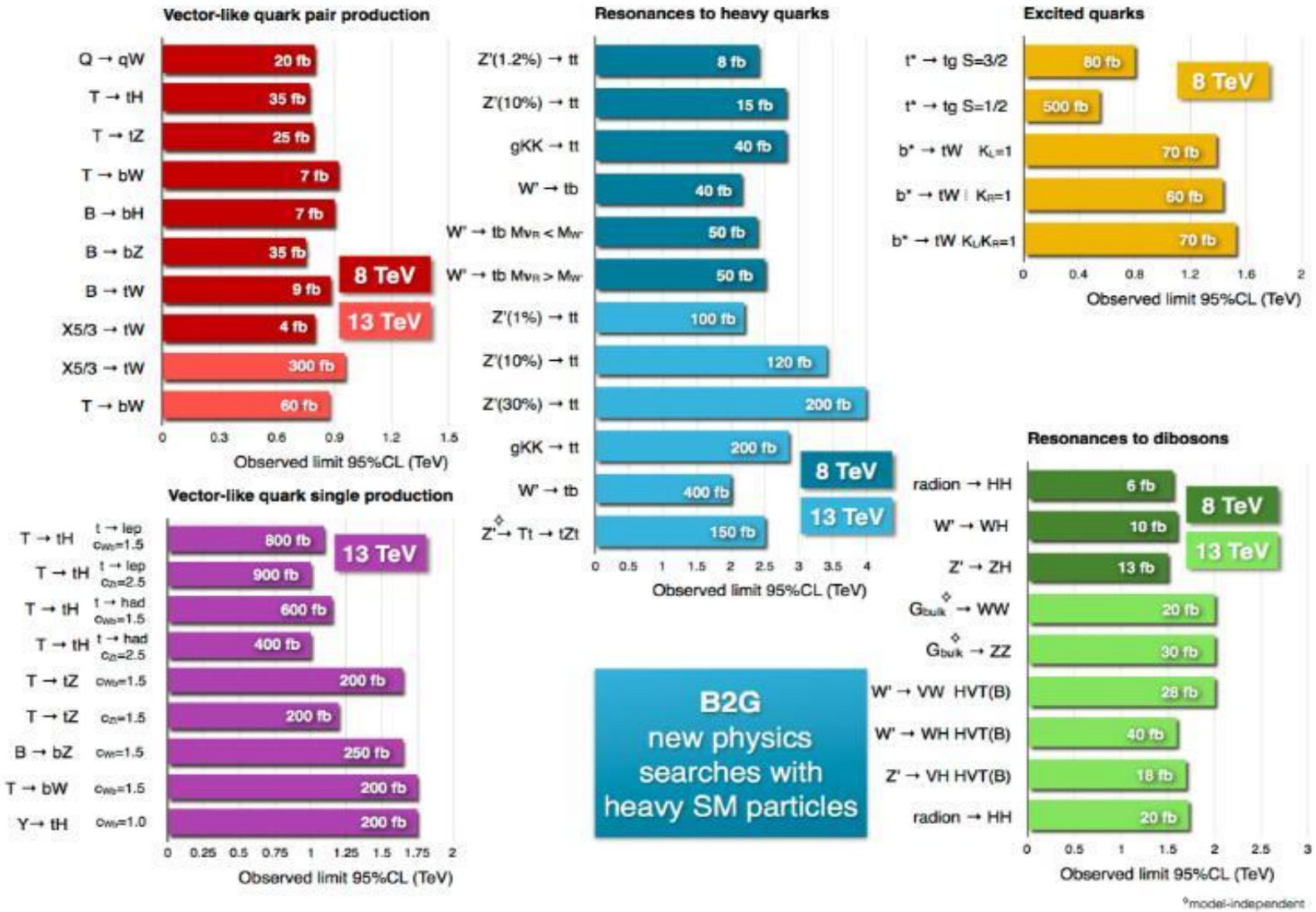
*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

†Small-radius (large-radius) jets are denoted by the letter j (J).

CMS Exotica


13 TeV
8 TeV
Leptoquarks
LQ1(ej) x2
LQ1(ej)+LQ1(νj) β=0.5
LQ2(μj) x2
LQ2(μj)+LQ2(νj) β=0.5
LQ3(τb) x2
LQ3(νb) x2
LQ3(ττ) x2
LQ3(νt) x2
Single LQ1 (λ=1)
Single LQ2 (λ=1)
0 1 2 3 4 TeV
Multijet Resonances
coloron(jj) x2
coloron(4j) x2
gluino(3j) x2
gluino(jjb) x2
0 1 2 3 4 TeV
RS Gravitons
RS1(jj), k=0.1
RS1(γγ), k=0.1
RS1(ee,μμ), k=0.1
0 1 2 3 4 TeV
Large Extra Dimensions
ADD (γ+MET), nED=4, MD
ADD (jj), nED=4, MS
QBH, nED=6, MD=4 TeV
NR BH, nED=6, MD=4 TeV
String Scale (jj)
QBH (jj), nED=4, MD=4 TeV
ADD (j+MET), nED=4, MD
ADD (ee,μμ), nED=4, MS
ADD (γγ), nED=4, MS
Jet Extinction Scale
0 1 2 3 4 5 6 7 8 9 10 TeV
CMS Preliminary
Heavy Gauge Bosons
SSM Z'(ττ)
SSM Z'(jj)
SSM Z'(ee)+Z'(μμ)
SSM W'(jj)
SSM W'(lν)
SSM Z'(bb)
0 1 2 3 4 5 TeV
Excited Fermions
e* (M=Λ)
μ* (M=Λ)
q* (qg)
q* (qγ) f=1
b*
0 1 2 3 4 5 6 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 – ICHEP, 2016

CMS B2G


Vector-like quark pair production
Q → qW 20 fb
T → tH 35 fb
T → tZ 25 fb
T → bW 7 fb
B → bH 7 fb
B → bZ 35 fb
B → tW 9 fb
X5/3 → tW 4 fb
X5/3 → tW 300 fb
T → bW 60 fb
8 TeV
13 TeV
0 0.3 0.6 0.9 1.2 1.5
Observed limit 95%CL (TeV)
Vector-like quark single production
T → tH t → lep cWb=1.5 800 fb
T → tH t → lep cZt=2.5 900 fb
T → tH t → had cWb=1.5 600 fb
T → tH t → had cZt=2.5 400 fb
T → tZ cWb=1.5 200 fb
T → tZ cZt=1.5 200 fb
B → bZ cWt=1.5 250 fb
T → bW cWb=1.5 200 fb
Y→ tH cWb=1.0 200 fb
13 TeV
0 0.25 0.5 0.75 1 1.25 1.5 1.75 2
Observed limit 95%CL (TeV)
Resonances to heavy quarks
Z'(1.2%) → tt 8 fb
Z'(10%) → tt 15 fb
gKK → tt 40 fb
W' → tb 40 fb
W' → tb MνR < MW 50 fb
W' → tb MνR > MW 50 fb
Z'(1%) → tt 100 fb
Z'(10%) → tt 120 fb
Z'(30%) → tt 200 fb
gKK → tt 200 fb
W' → tb 400 fb
Z'◇→ Tt → tZt 150 fb
8 TeV
13 TeV
0 0.5 1 1.5 2 2.5 3 3.5 4
Observed limit 95%CL (TeV)
Excited quarks
t* → tg S=3/2 80 fb
t* → tg S=1/2 500 fb
b* → tW KL=1 70 fb
b* → tW KR=1 60 fb
b* → tW KLKR=1 70 fb
8 TeV
0 0.4 0.8 1.2 1.6 2
Observed limit 95%CL (TeV)
Resonances to dibosons
radion → HH 6 fb
W' → WH 10 fb
Z' → ZH 13 fb
Gbulk◇ → WW 20 fb
Gbulk◇ → ZZ 30 fb
W' → VW HVT(B) 28 fb
W' → WH HVT(B) 40 fb
Z' → VH HVT(B) 18 fb
radion → HH 20 fb
8 TeV
13 TeV
0 0.5 1 1.5 2 2.5 3
Observed limit 95%CL (TeV)
◇model-independent
B2G
new physics
searches with
heavy SM particles

Impossible to cover all

Select some recent Exotica Searches， More will be covered by my colleagues

Beyond SM Higgs	Ye Chen	IHEP
Search for lighter Higgs-boson like resonances in the diphoton final state	Junquan Tao	IHEP
Search for Higgs boson rare and exotic decays	Bo Liu	SDU
Searching for Dark matter with 2 associated jets at ATLAS	Ning Zhou	SJTU
Search for new resonances decaying to WW/WZ to lvqq in the CMS experiment	Zijun Xu	PKU
Search for heavy resonances decaying into diboson pairs in the boosted hadronic final state	Yanyan Gao	UOL
Search for a high mass Higgs decaying into vector vector final state	Weimin Song	IHEP
Search for BSM di-Higgs with final state of gammagamma and the semileptonic decays of W	Yaquan Fang	IHEP
High mass search in the ZGamma final state	Han Shuo	IHEP
Search for heavy neutral resonances in vector boson fusion qq -> lvlvqq with the ATLAS	Guangyi Zhang	USTC
Search for a heavy scalar boson decaying into a pair of Z bosons in the 2l2nu final state	Yuan Li	BHU

✓ **More results from ATLAS and CMS can be found at:**

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublications

http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html

http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G/index.html

✓ **Contributions from Chinese colleagues are labeled as**

Experiment-Team (such as CMS-IHEP)

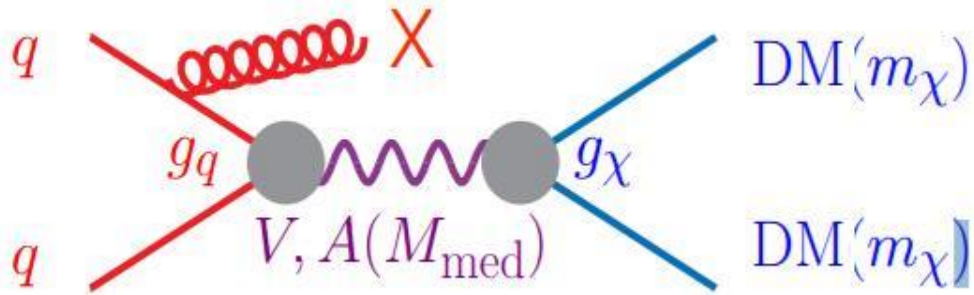
1. Dark Matter

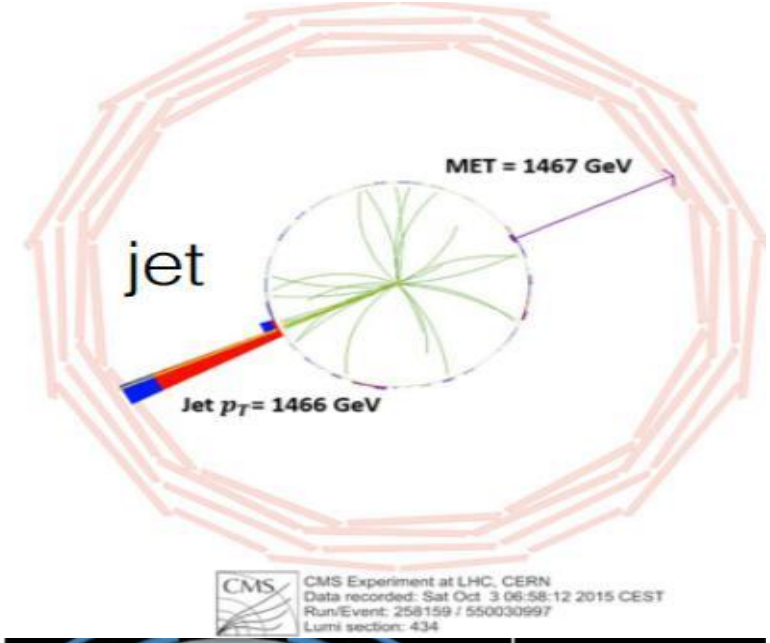
Collider Dark Matter Signature - Mono-X

Zhou Ning's talk

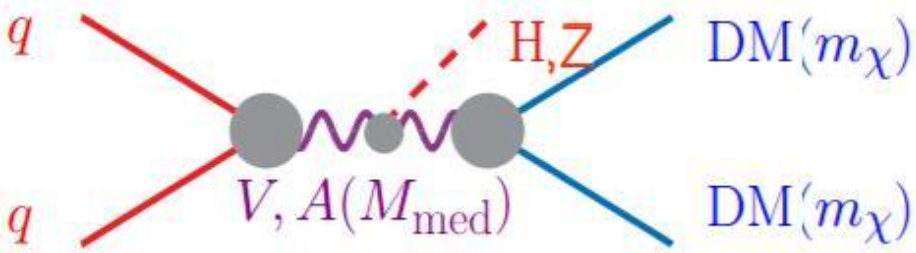
MET + X : Mono-X

- X from ISR jet, b, t, W, Z, ϒ





- X from mixing with mediator



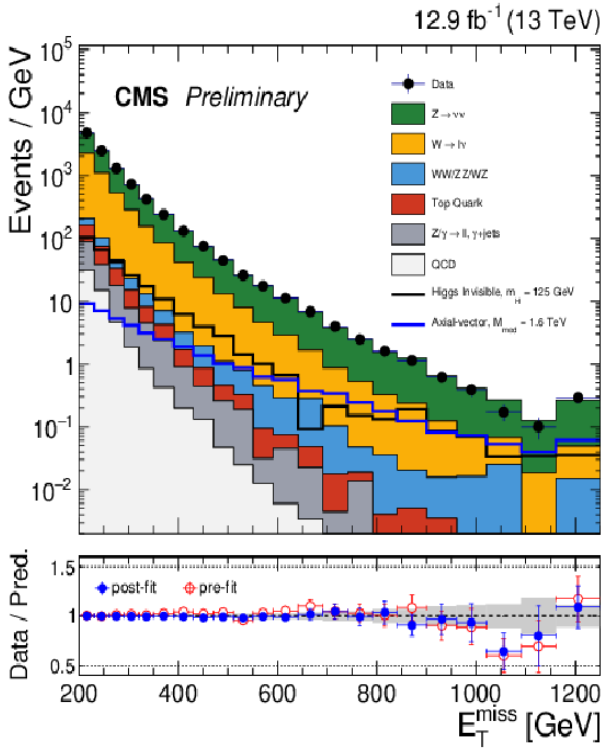
- X from paired ttbar, bbbar

Mono-jet/b-jets/top

- ✓ Key observables - imbalanced transverse momentum MET
- ✓ Irreducible background : Z(vv) + jets

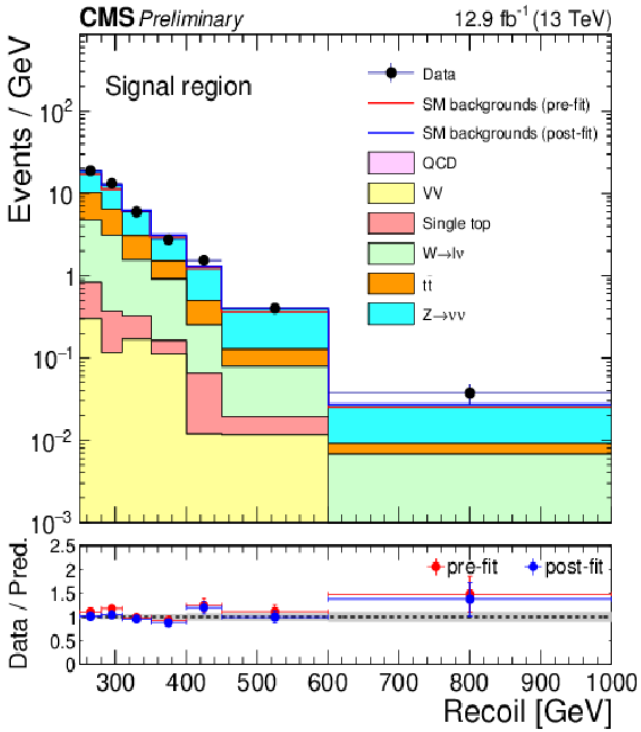
MET+jet

CMS-PAS-EXO-16-037



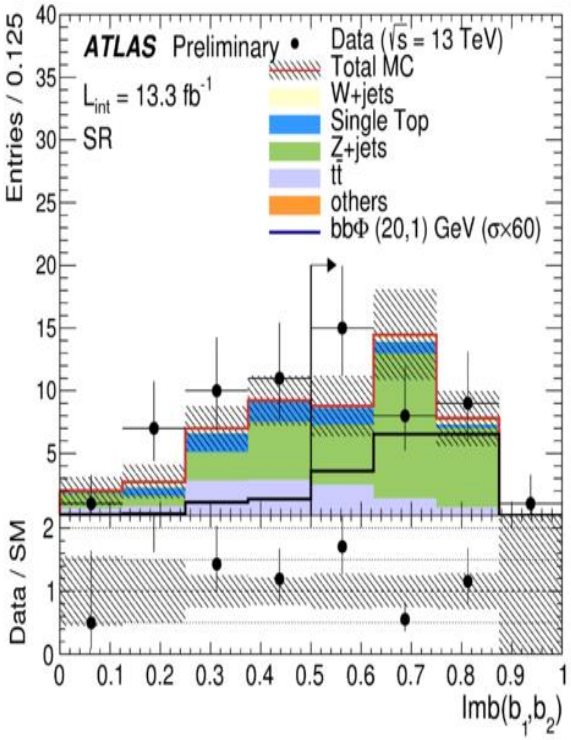
Met+top

CMS-PAS-EXO-16-040



MET+bbbar

ATLAS-CONF-2016-086

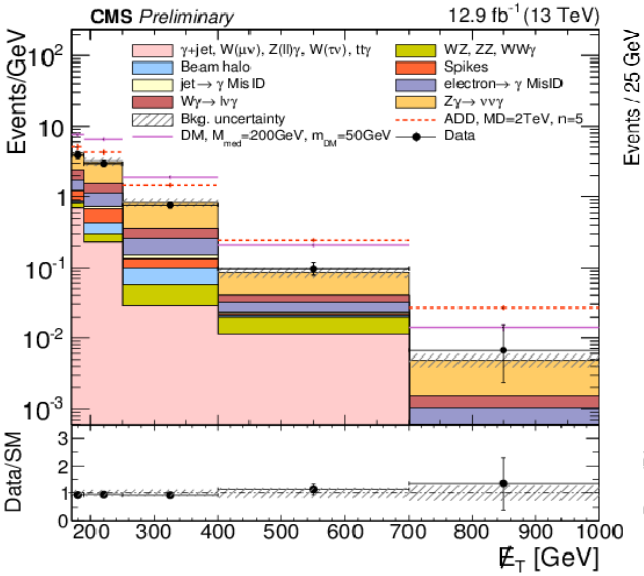


Phys. Lett. B 765 (2017) 11

Mono-ϒ/W/Z/H

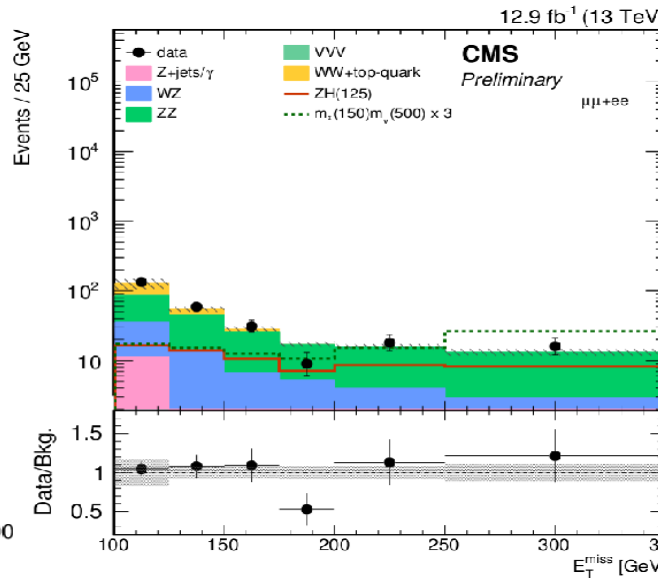
ATLAS-SJTU

MET+ϒ



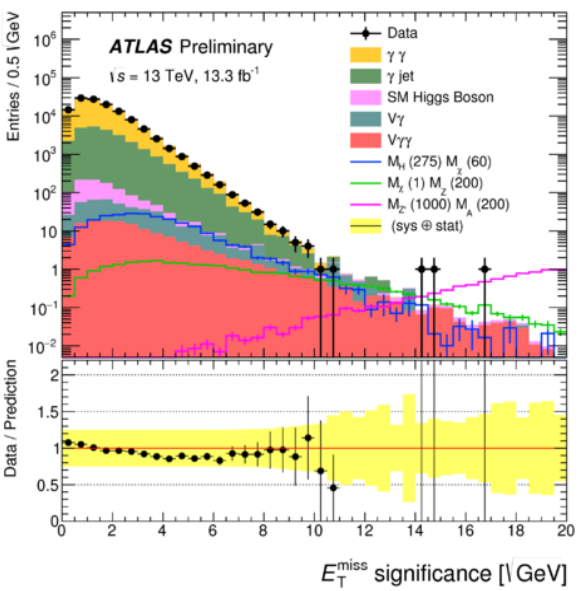
ATLAS-CONF-2015-080
CMS-PAS-EXO-16-039

Met+W/Z



ATLAS-CONF-2016-056
CMS-PAS-EXO-16-037
CMS-PAS-EXO-16-038

MET+H

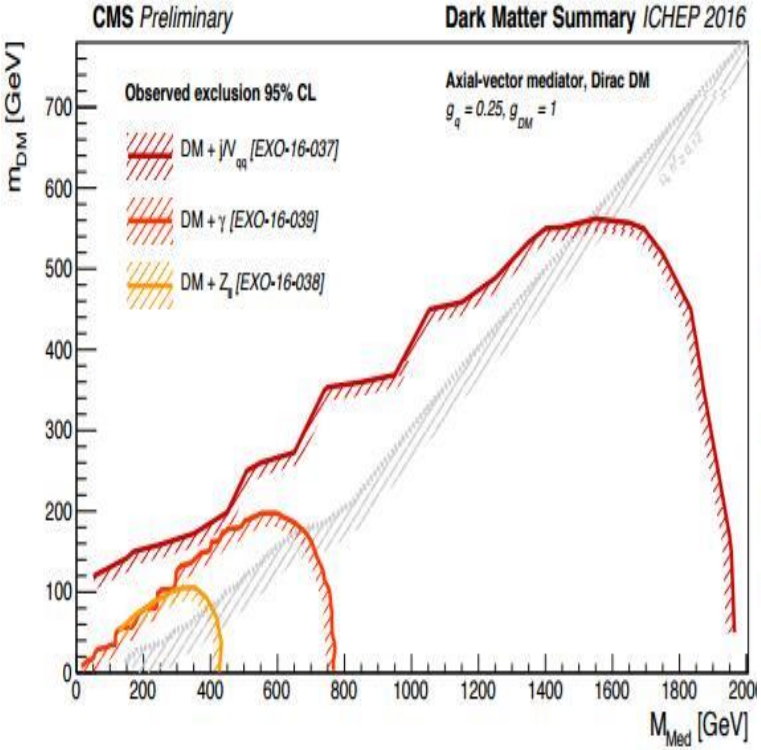


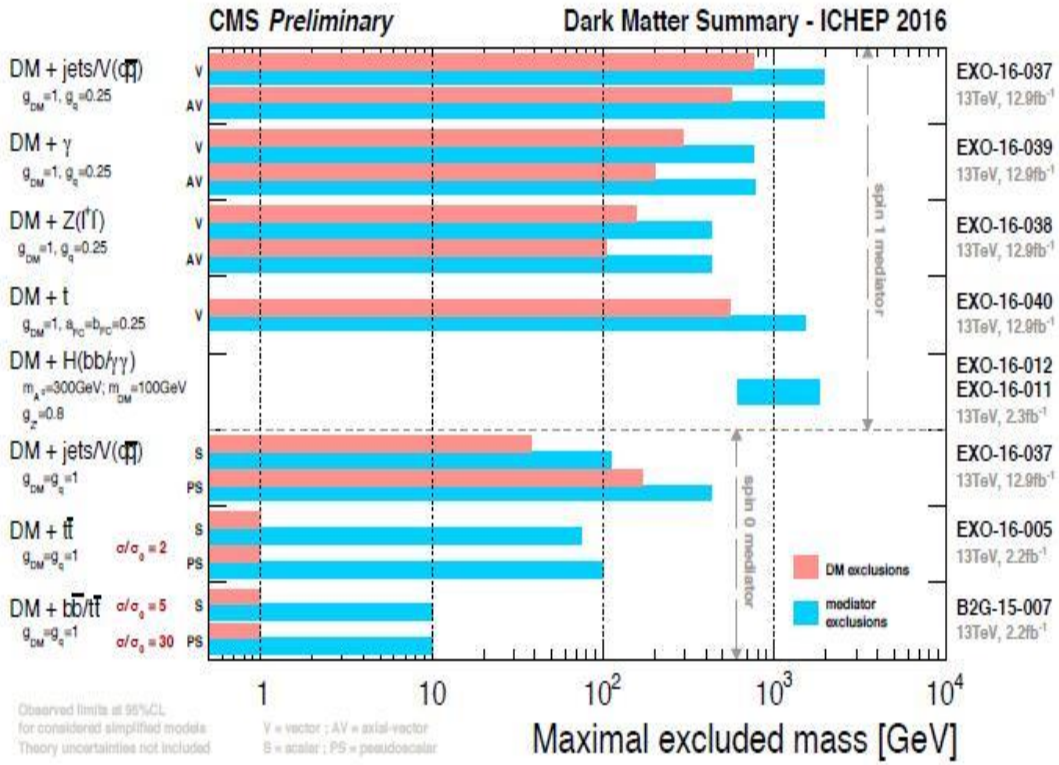
PLB 765 (2017) 11 (ATLAS)
ATLAS-CONF-2016-087
CMS-PAS-EXO-16-011
CMS-PAS-EXO-16-012

- Different W/Z/H decay channels
- Boosted jet substructure technique is used in hadronic W/Z/H

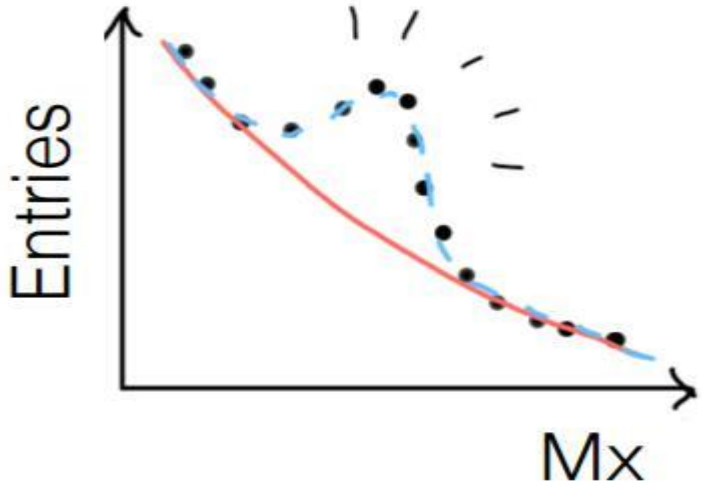
Dark Matter exclusion limit

- So far, no significant excess observed
- DM mass exclusion up to 550 GeV
- Vector Mediator mass exclusion up to 1.95 TeV





2. Resonance



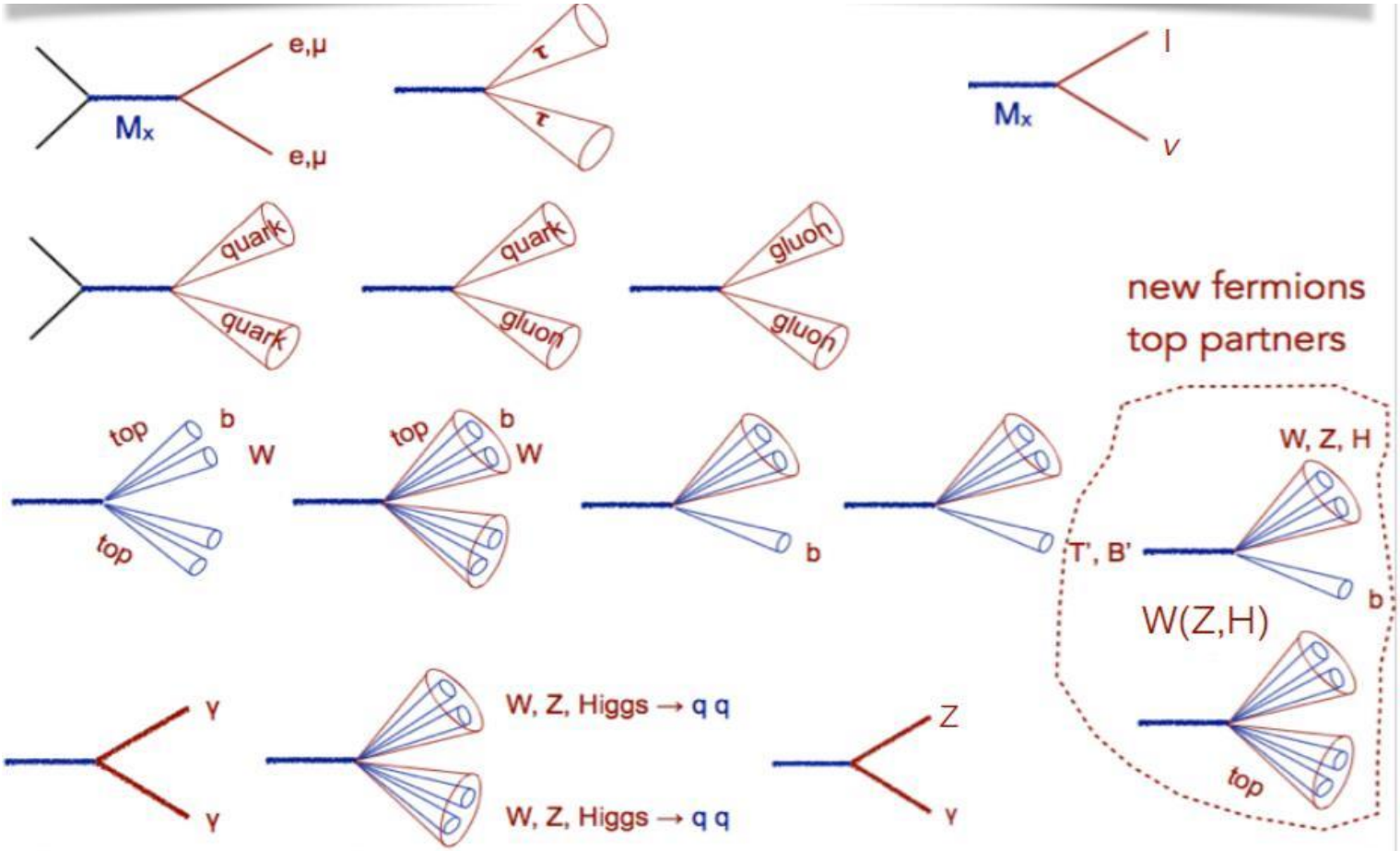
Heavy Resonances

Zijun Xu, Han Shuo, Guangyi Zhang,Yuan LiYanyan Gao's talk

dilepton

dijet

top



diphoton diboson Zgamma

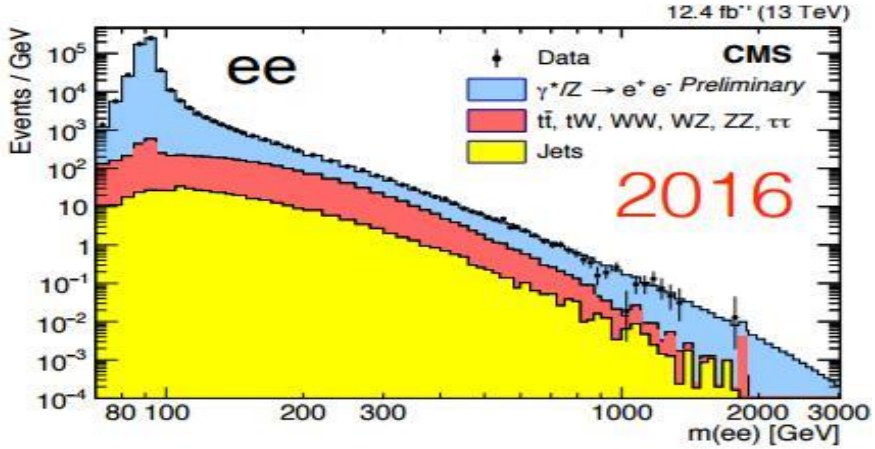
Focus on ATLAS & CMS recent progress, impossible cover all

Dilepton

ATLAS-SJTU, ATLAS-USTC..

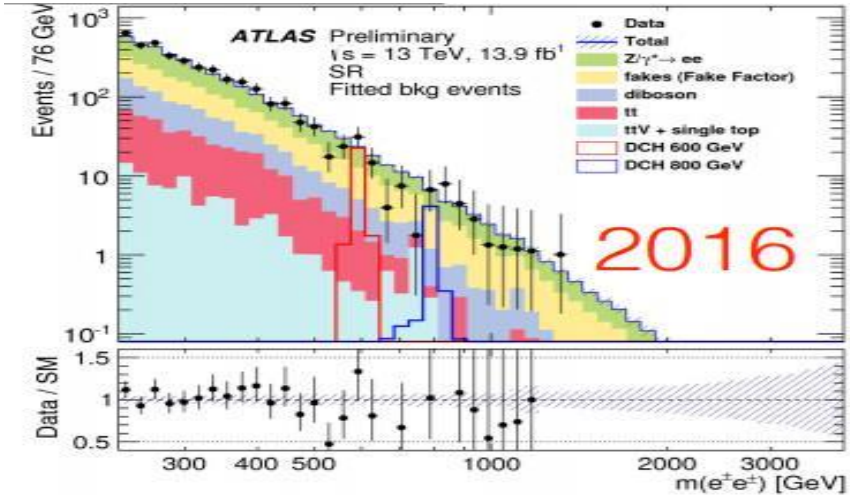
Same Flavor Opposite Sign (ee, μμ, ττ)

ATLAS-CONF-2016-045 CMS-PAS-EXO-16-031



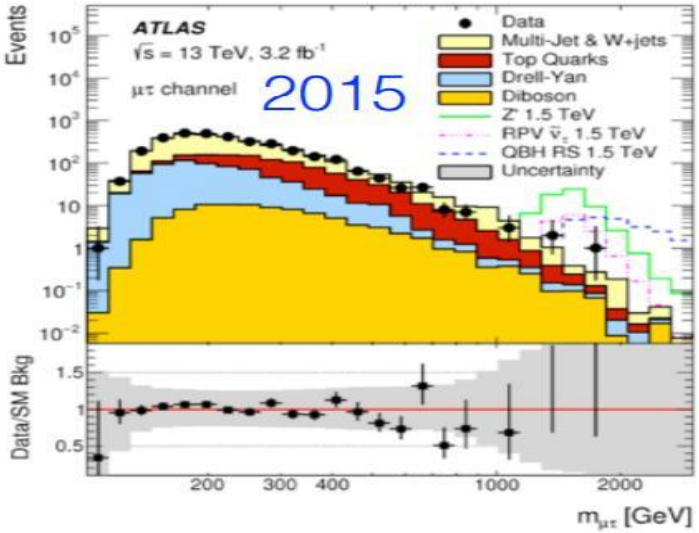
Same Sign (ee, μμ)

ATLAS-CONF-2016-051



Lepton Flavor violation (eμ, eτ, μτ)

ATLAS-CONF-2016-045 CMS-PAS-EXO-16-001

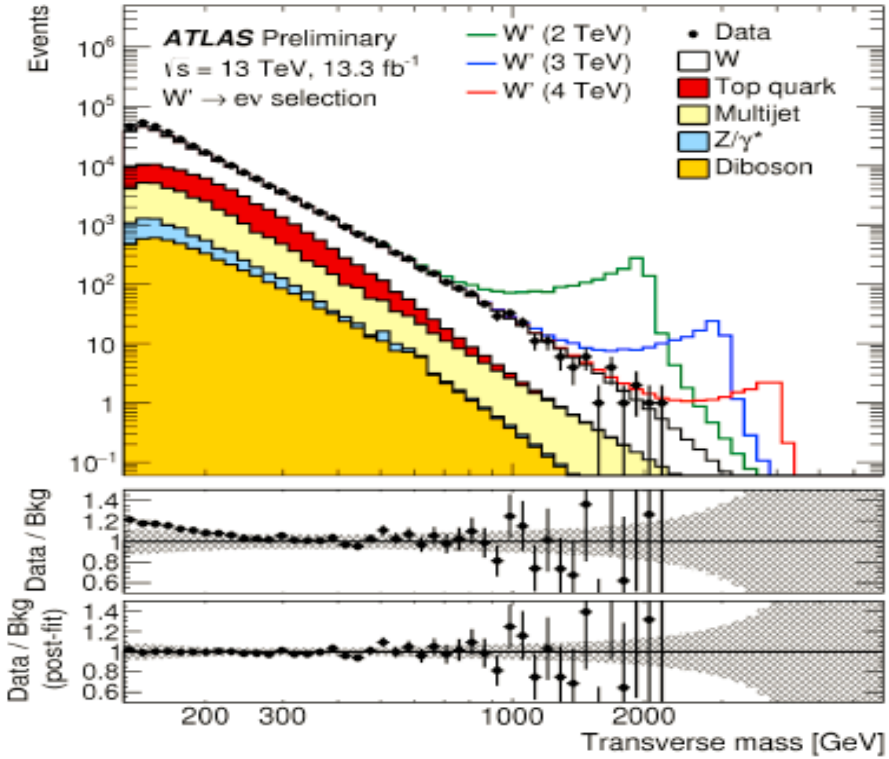


Z'_{SSM}(3% width) >4 TeV

Z'_{ψ} (0.5% width) >3.36 TeV

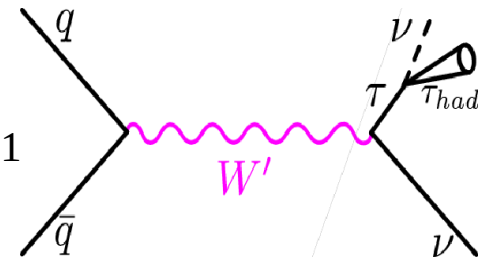
Lepton+MET

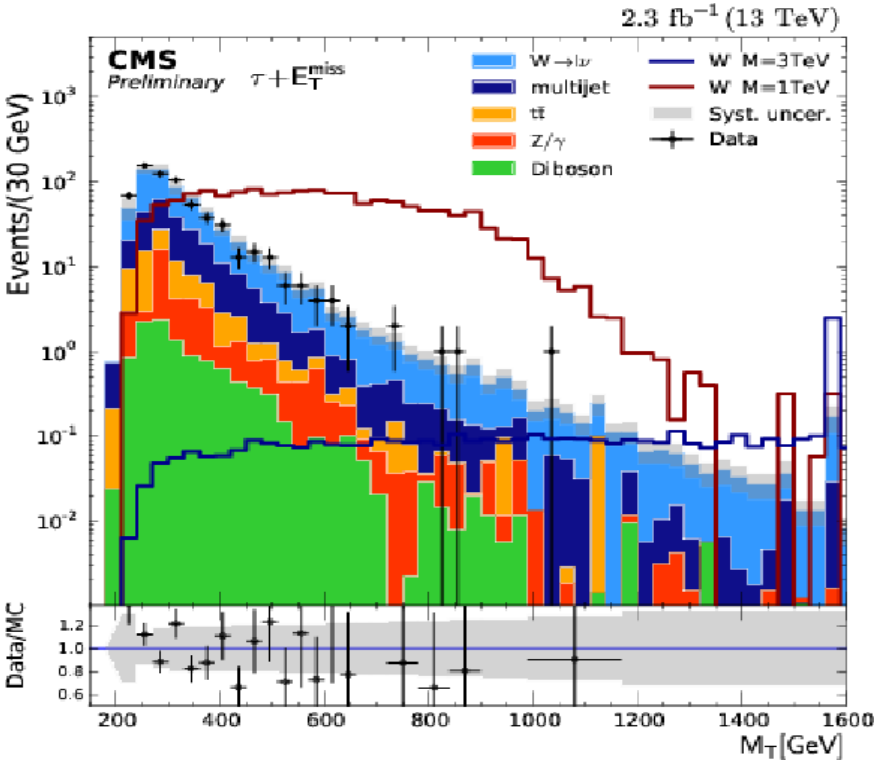
ATLAS-CONF-2016-061 CMS-PAS-EXO-16-031



Decay	$m_{W'}$ lower limit [TeV] Expected	Observed
$W' \to e\nu$	4.44	4.42
$W' \to \mu\nu$	4.13	4.06
$W' \to \ell\nu$	4.62	4.59

CMS-PAS-EXO-16-001



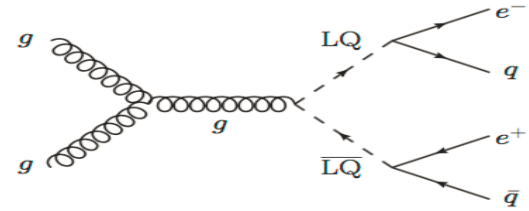


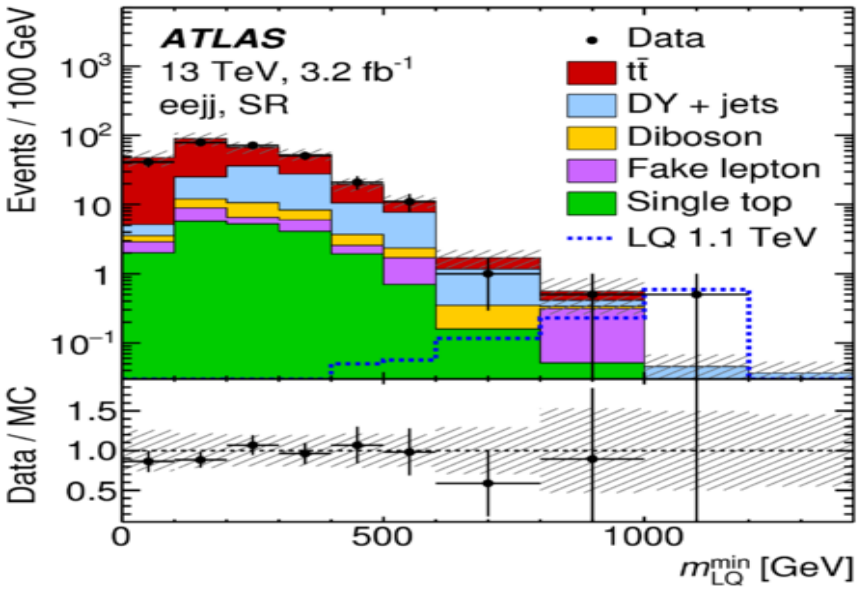
W' >3.3 TeV

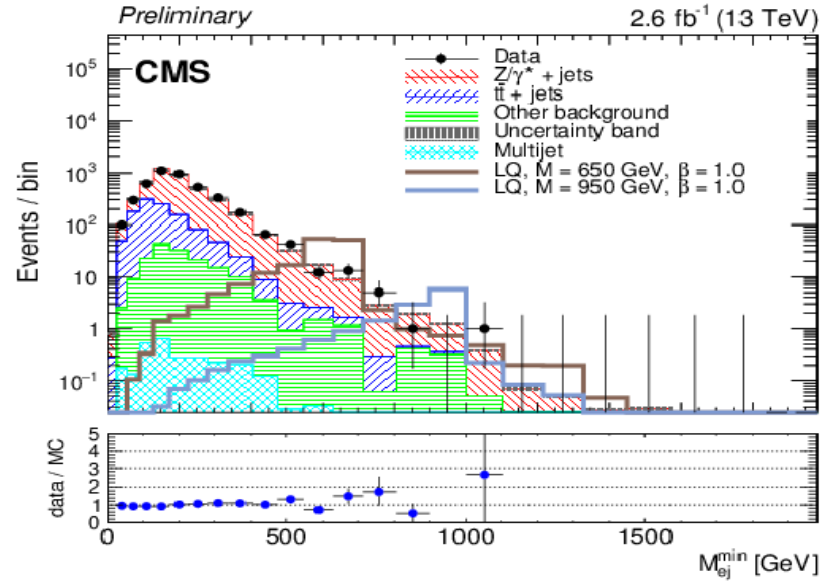
Leptoquark

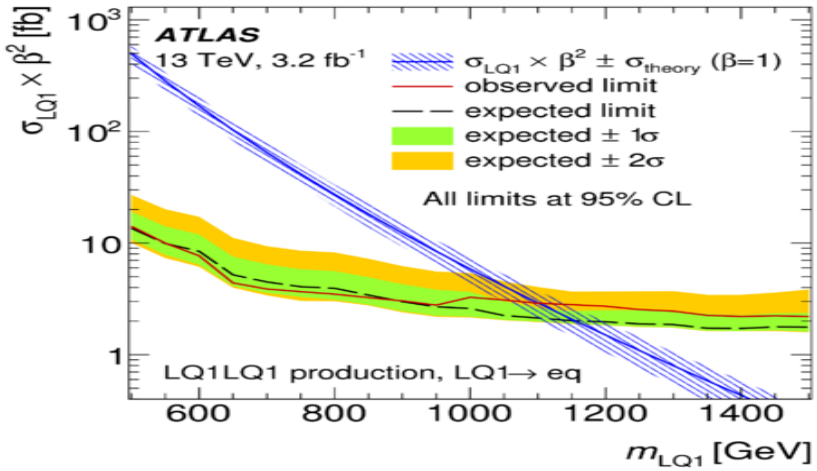
NJP 18 (2016) 093016

CMS-PAS-EXO-16-043



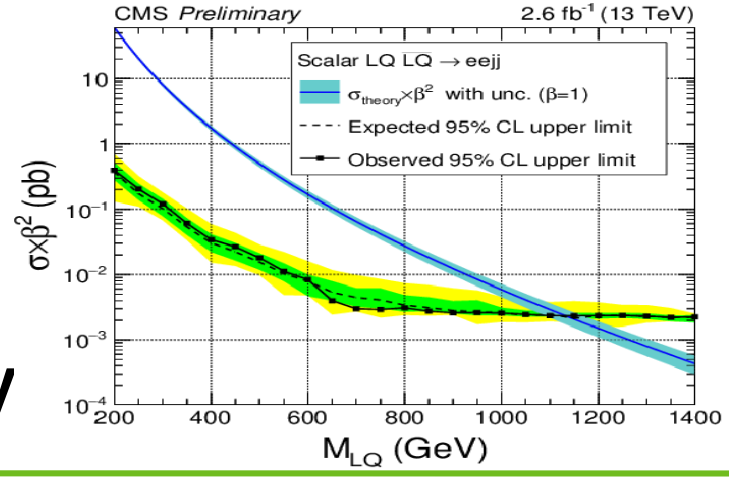






No Excess

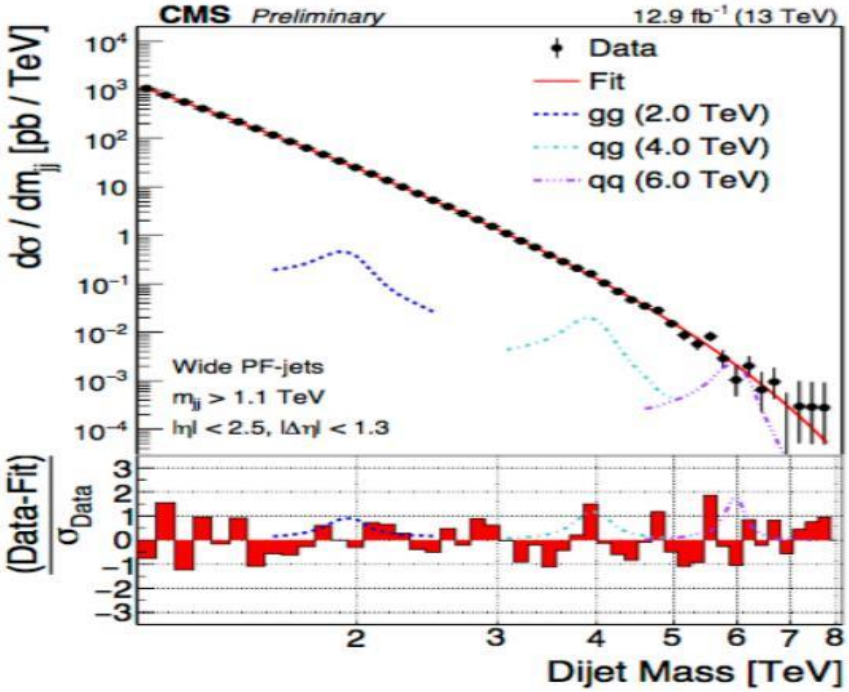
~1100GeV



Dijet

- Background modelled by parametrized function for search
- Narrow width signal checked

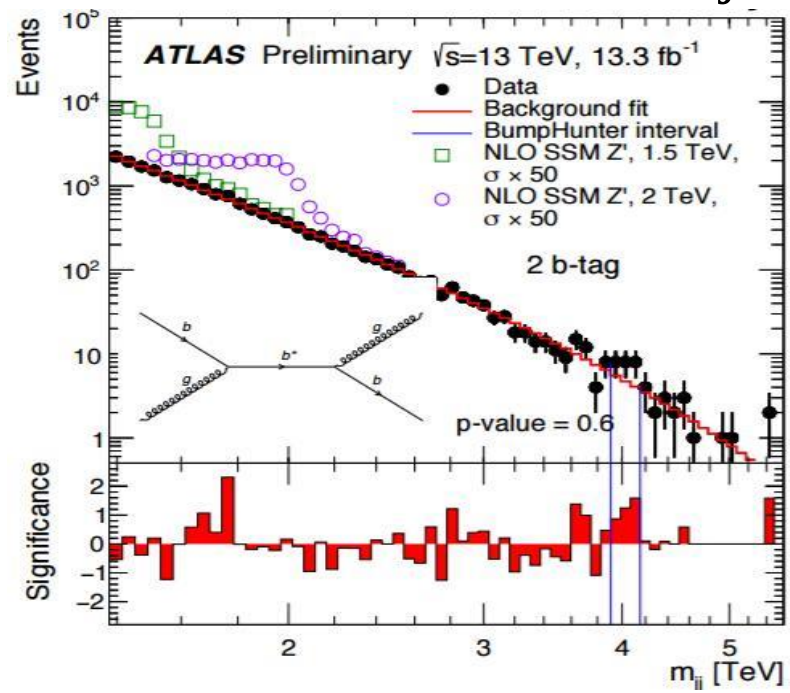
ATLAS-CONF-2016-069 CMS-PAS-EXO-16-032 >=0 b-jet



Model	95% CL Exclusion limit Observed	Expected
Quantum black holes, ADD (BlackMax generator)	8.7 TeV	8.7 TeV
Excited quark	5.6 TeV	5.5 TeV
W'	2.9 TeV	3.3 TeV
W^*	3.3 TeV	3.3 TeV
Contact interactions (η_{LL} =+1)	12.6 TeV	13.7 TeV
Contact interactions (η_{LL} =-1)	19.9 TeV	23.7 TeV

ATLAS-SDU

ATLAS-CONF-2016-060 >=1 b-jet

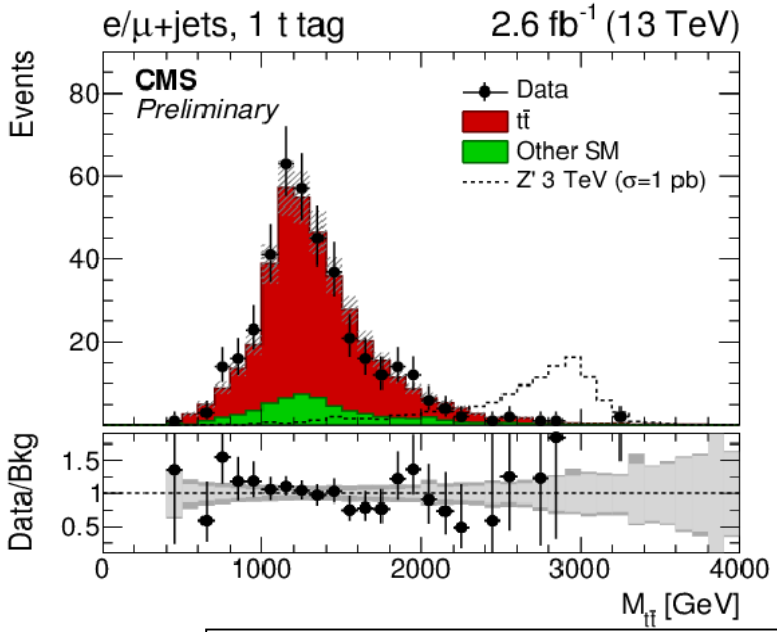


b* (BR(b*→ bg)=0.85) >2.3 TeV

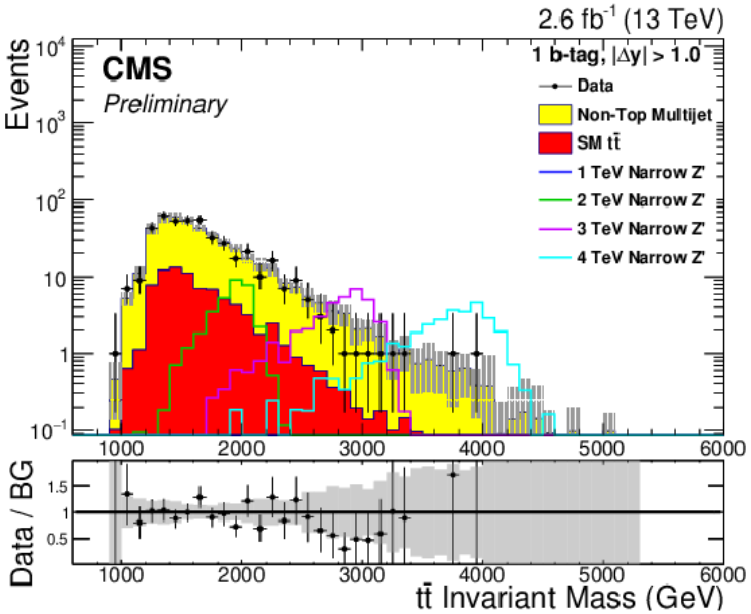
Z' >1.5TeV

Top pair Production

CMS-PAS-B2G-15-002



CMS-PAS-B2G-15-003



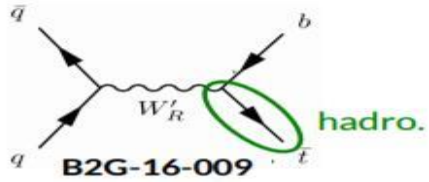
No evidence for resonant ttbar production is found

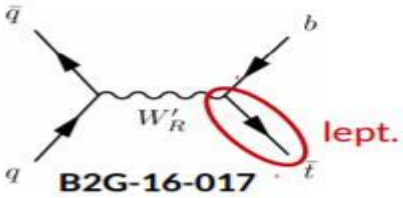
signal	excluded mass regions [TeV]		
	μ + jets observed (expected)	e + jets observed (expected)	combination observed (expected)
Z′ (1% width)	0.5 – 1.8 (0.6 – 1.9)	1.0 – 1.1, 1.3 – 2.2 (0.9 – 1.7)	0.6 – 2.3 (0.6 – 2.1)
Z′ (10% width)	0.5 – 3.2 (0.5 – 3.3)	0.5 – 3.2 (0.5 – 3.2)	0.5 – 3.4 (0.5 – 3.5)
Z′ (30% width)	0.5 – 3.9 (0.5 – 4.0)	0.5 – 3.8 (0.5 – 3.8)	0.5 – 4.0 (0.5 – 4.0)
KK gluon	0.5 – 2.7 (0.5 – 2.8)	0.6 – 2.7 (0.6 – 2.5)	0.5 – 2.9 (0.5 – 2.9)

Mass Exclusion Limits

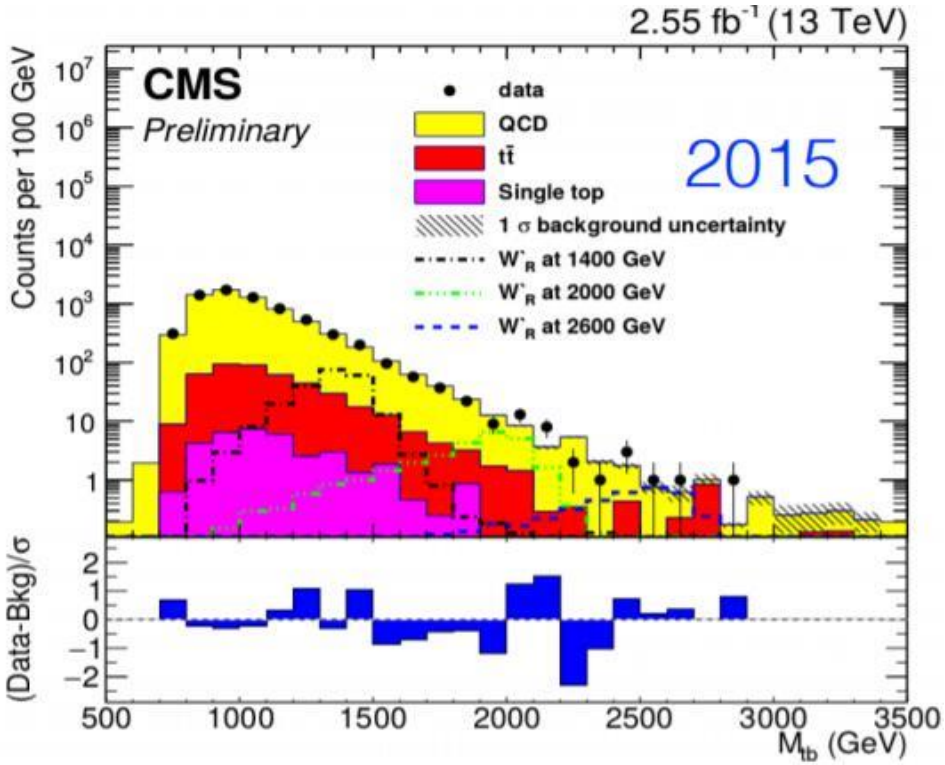
Signal Model	Exclusion Ranges (TeV)	
	Expected	Observed
Z′ (1% Width)	1.2 – 1.6	1.4 – 1.6
Z′ (10% Width)	1.0 – 3.1	1.0 – 3.3
Z′ (30% Width)	1.0 – 3.7	1.0 – 3.8
RS Gluon	1.0 – 2.5	1 – 2.4

Tb Resonance

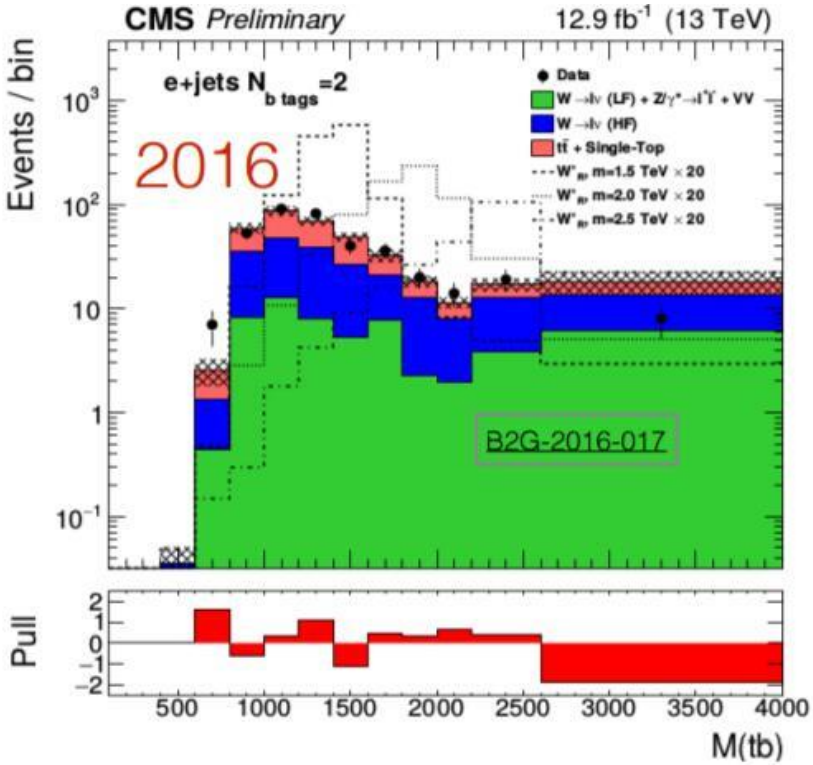




M_{tb} distribution (postfit)



M_{tb} (e channel, 2 b-tags)



W'_R : [1~2] TeV

W'_R : [1~2.67] TeV

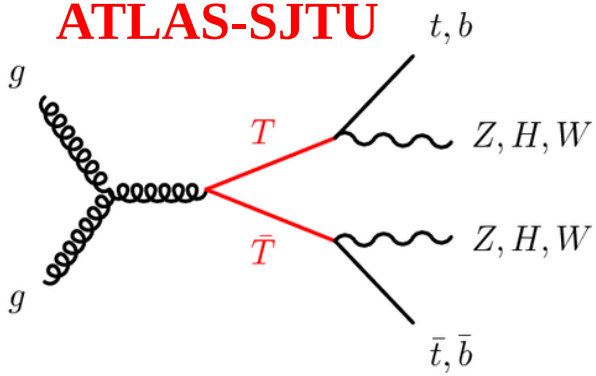
Vector-like quark

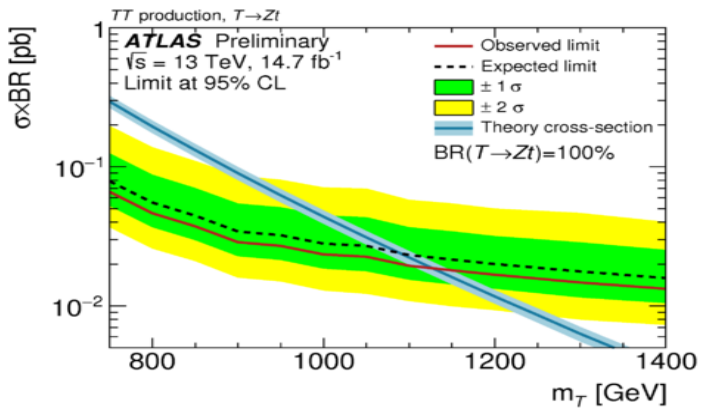
- ✓ **pair production** through QCD - dominant in low mass
- ✓ **single production** through EWK coupling - dominant in high mass

pair production

ATLAS-CONF-2016-101

ATLAS-SJTU

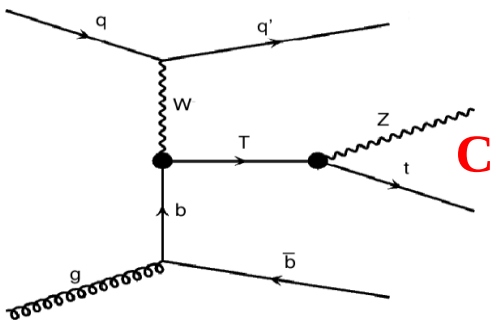




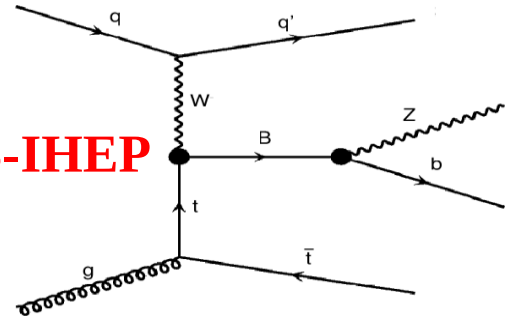
Exclude T < 1100 GeV

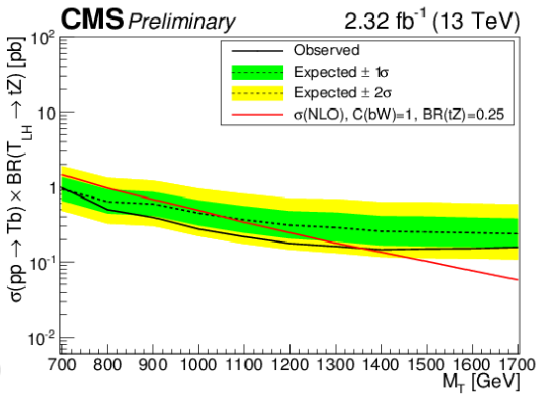
single production

CMS-PAS-B2G-16-001

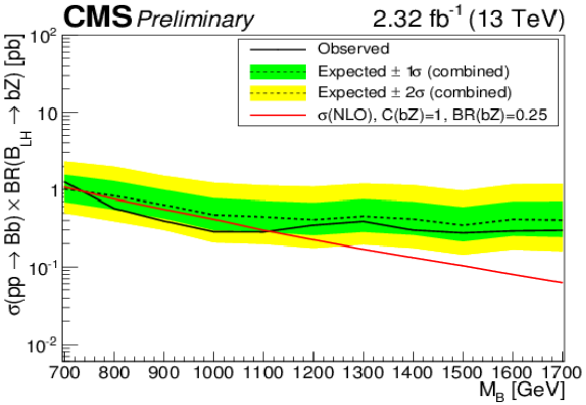


CMS-IHEP





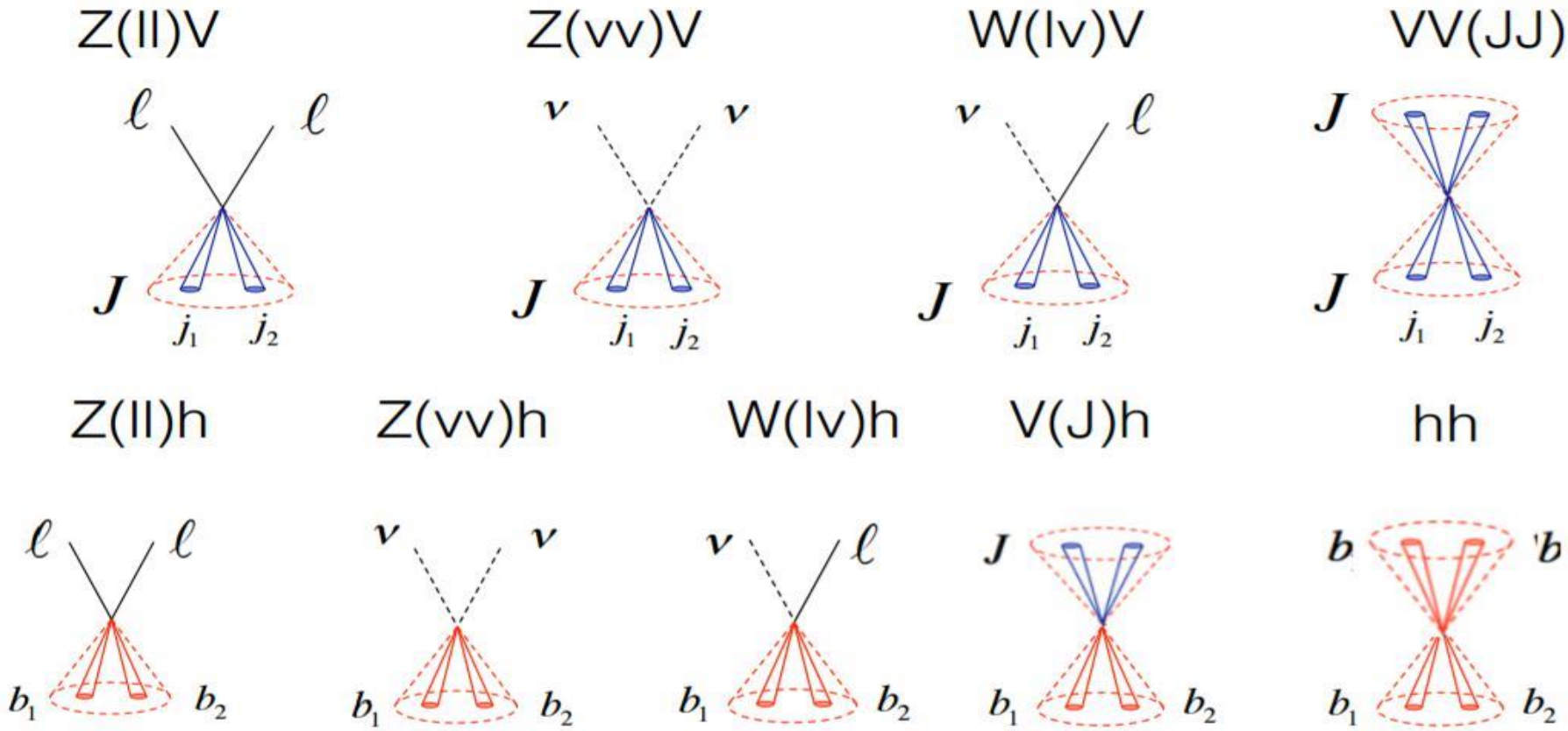
Exclude T < 1350 GeV



Exclude B < 1120 GeV

VV/VH/HH resonance

- **Search for VV/Vh/hh resonance in leptonic/haronic decay channels using boosted substructure techniques**



ATLAS-USTC
ATLAS-IHEP

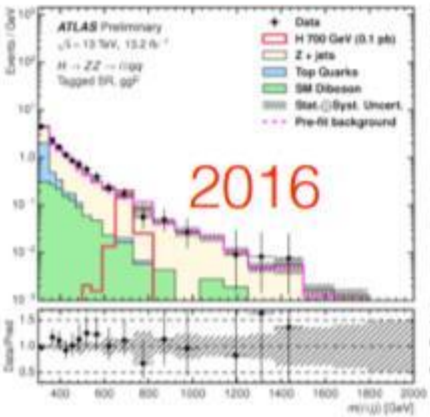
VV/Vh/hh Search Results

CMS-PKU
CMS-BHU

Z(ll)V

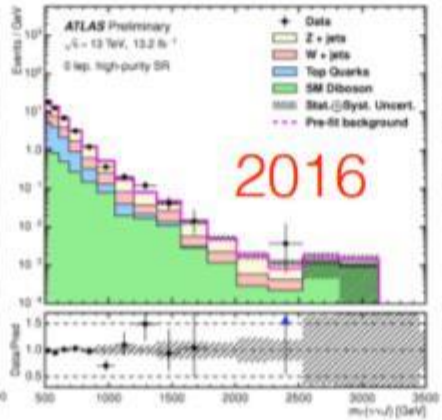
ATL-CONF-2016-082

B2G-16-010



Z(vv)V

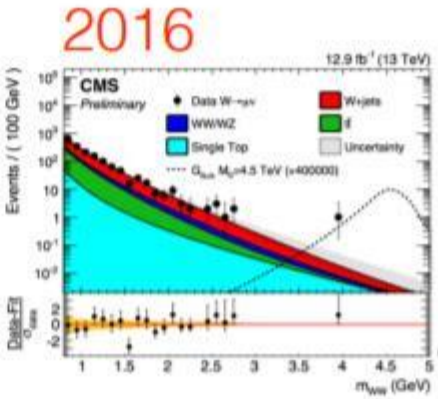
ATL-CONF-2016-082



W(lv)V

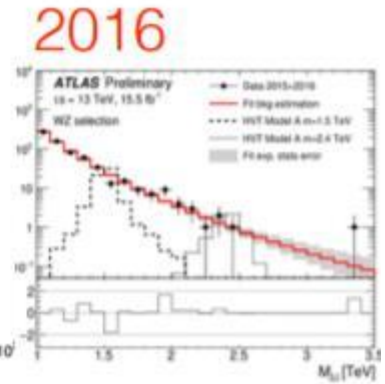
ATL-CONF-2016-062

B2G-16-020



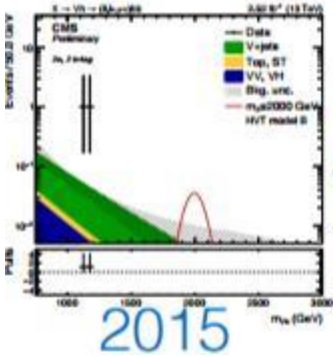
VV(JJ)

ATL-CONF-2016-055



Z(ll)h

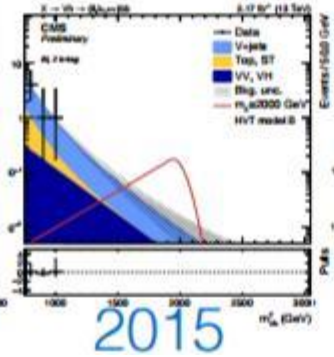
arxiv.1503.08089



Z(vv)h

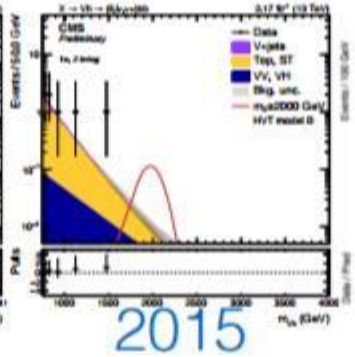
B2G-16-003

arXiv:1607.05621



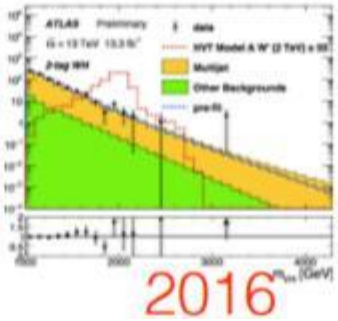
W(lv)h

arxiv.1503.08089



V(J)h

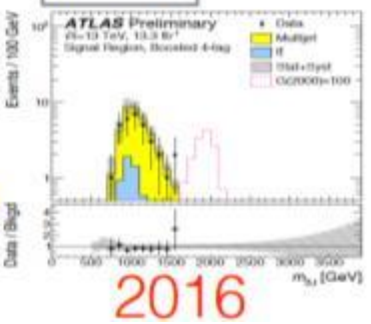
ATL-CONF-2016-083



hh

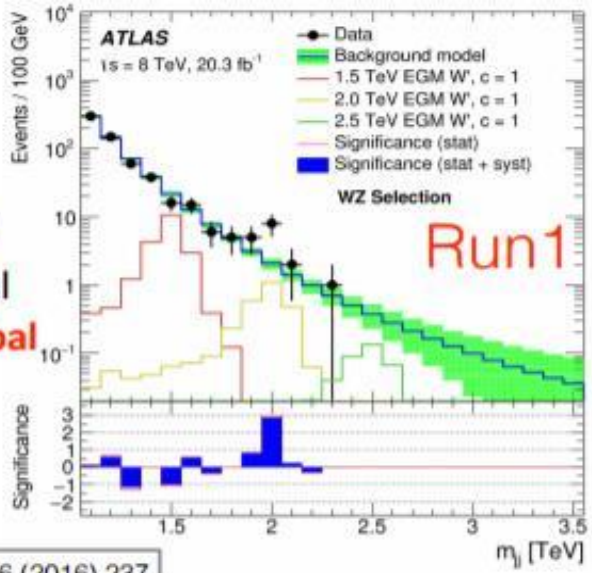
ATL-CONF-2016-049

B2G-16-008



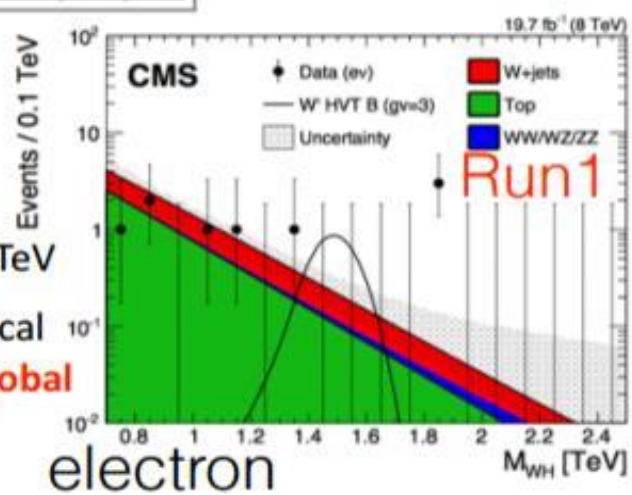
Diboson excesses

JHEP 12 (2015) 055



m= 2TeV
3.4σ local
2.5σ global

EPJC 76 (2016) 237



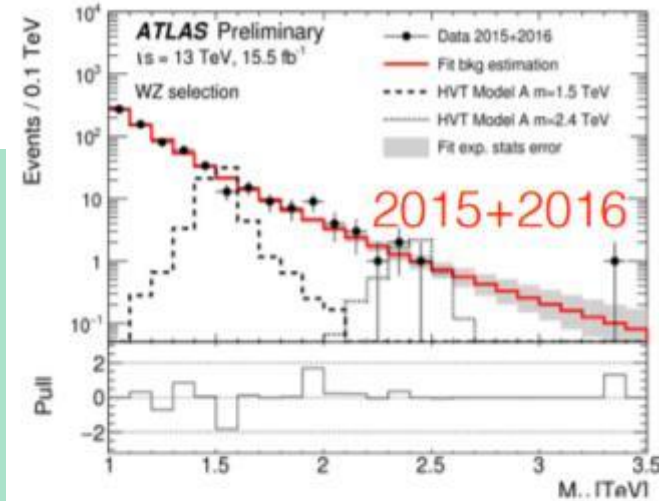
m=1.8 TeV
2.9σ local
1.9σ global

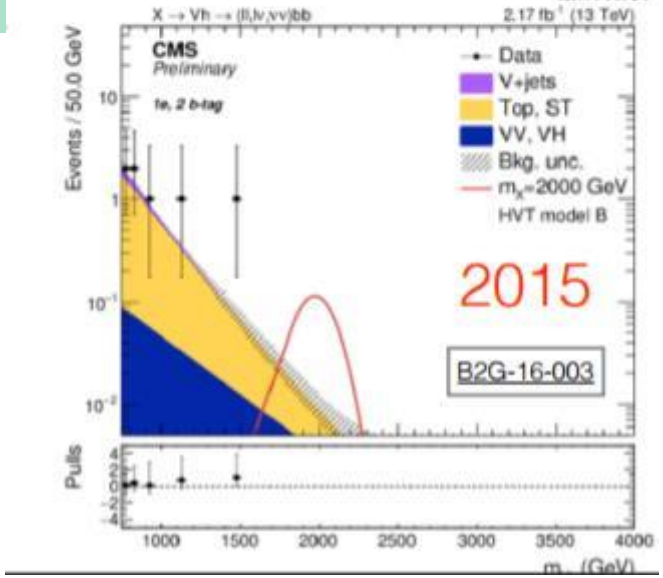
electron

Excesses not confirmed in Run2

CMS-PKU

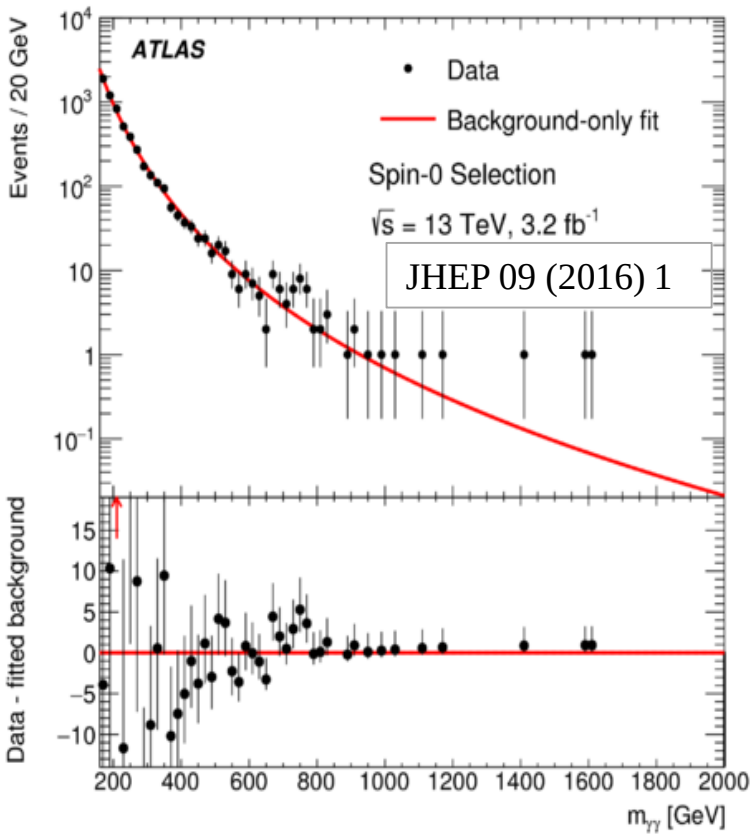
ATLAS-CONF-2016-055

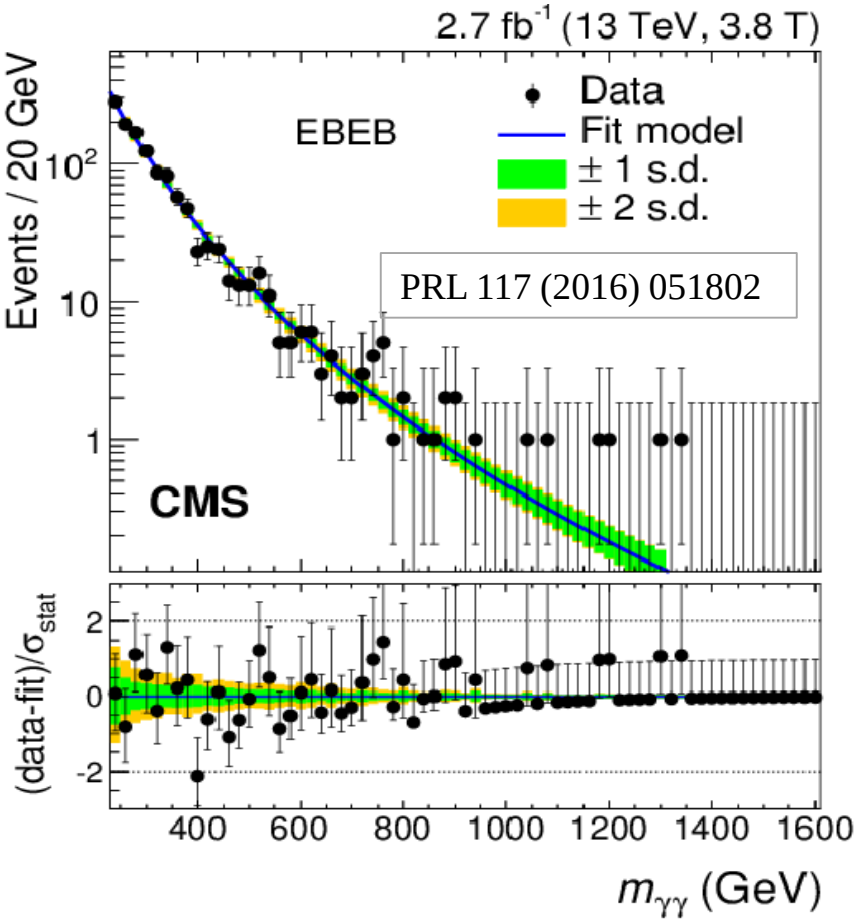




Diphoton

Significant excesses observed in 2015 data



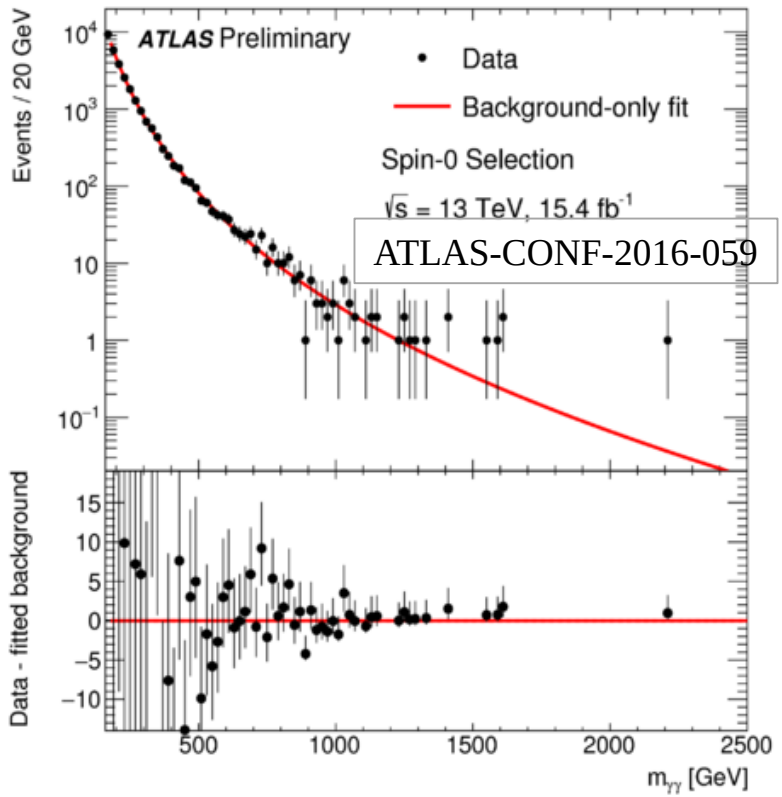


m =750 GeV(Γ/M = 6%)
3.4σ (local)/~2σ (global)

m =760 GeV(Γ/M = 1 X 10^{-4})
3.4σ (local)/1.6σ (global) 2015+8TeV

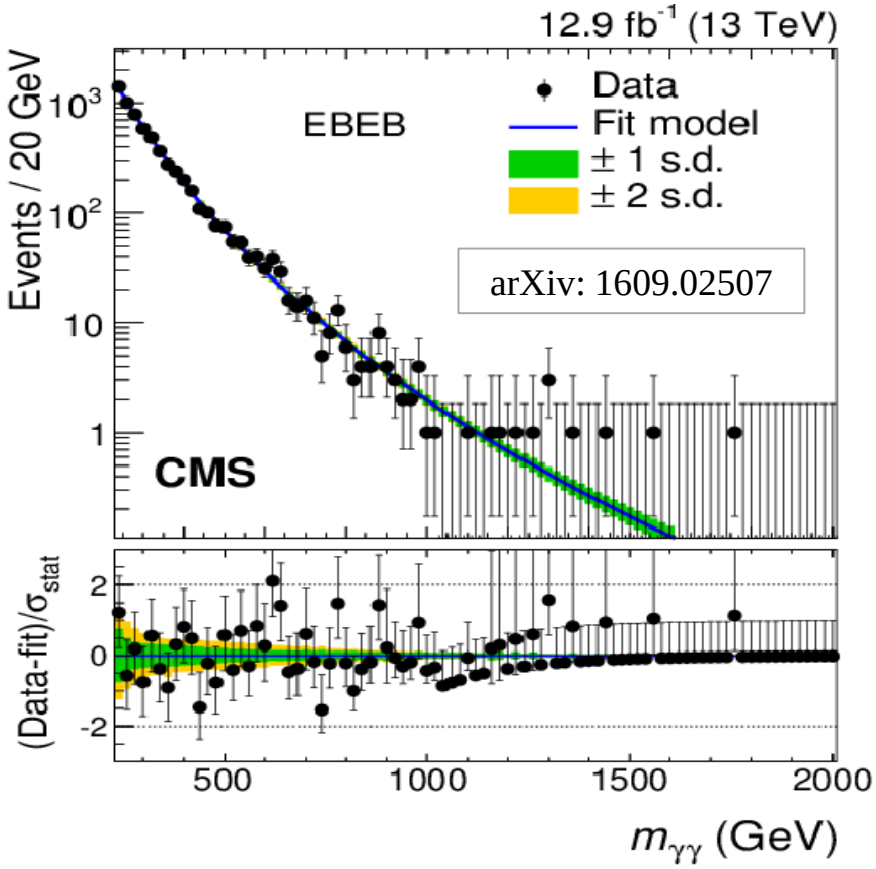
Diphoton

Excesses not confirmed in 2016



2015+2016

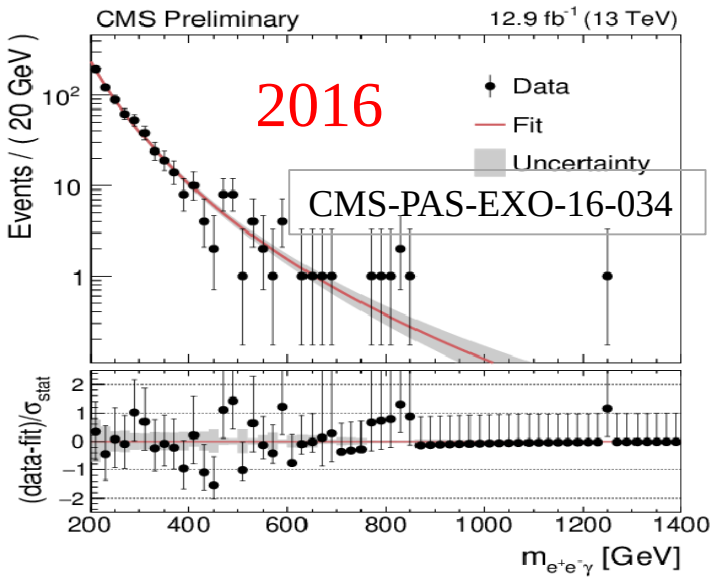
m =710 GeV(Γ/M = 10%)
2.3σ (local)/<1σ (global)



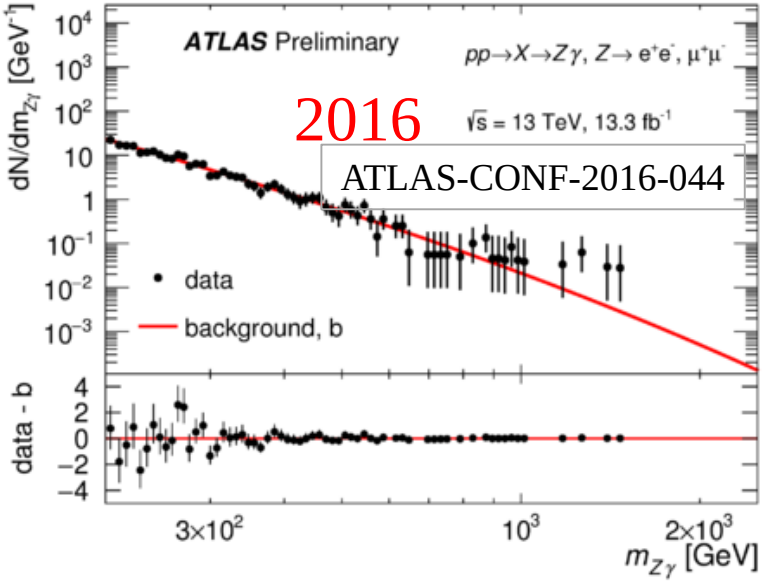
m =760 GeV(Γ/M = 1.4 X 10^{-4})
<1σ (local)

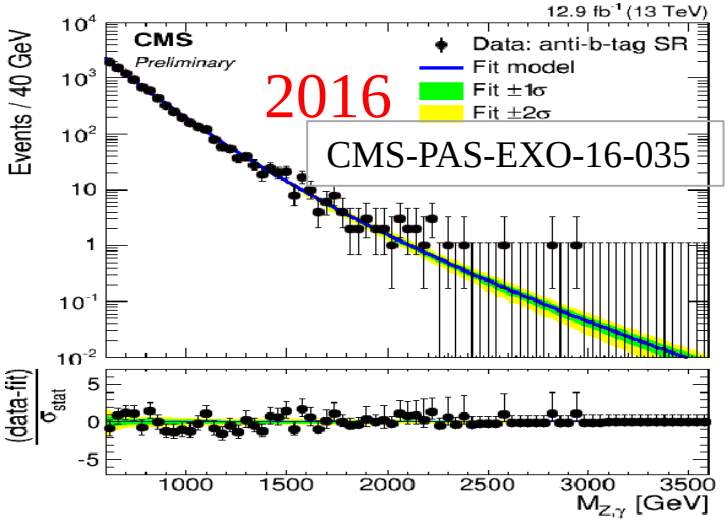
Zgamma

ATLAS-IHEP

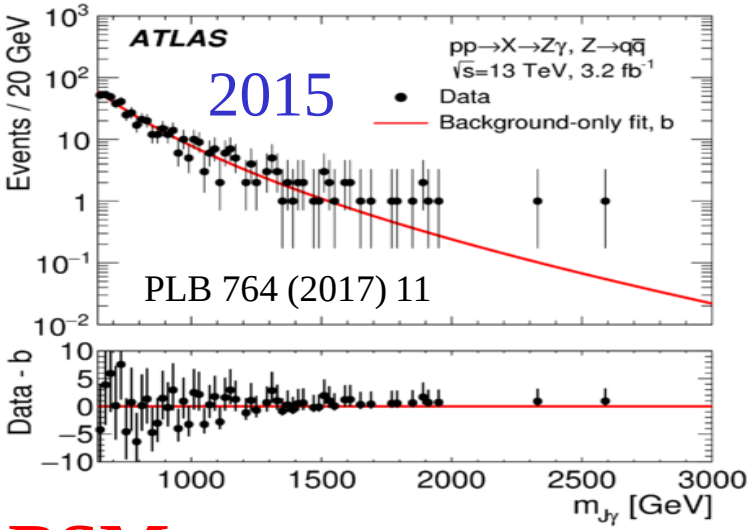


ee/uu





qq



No sign of BSM

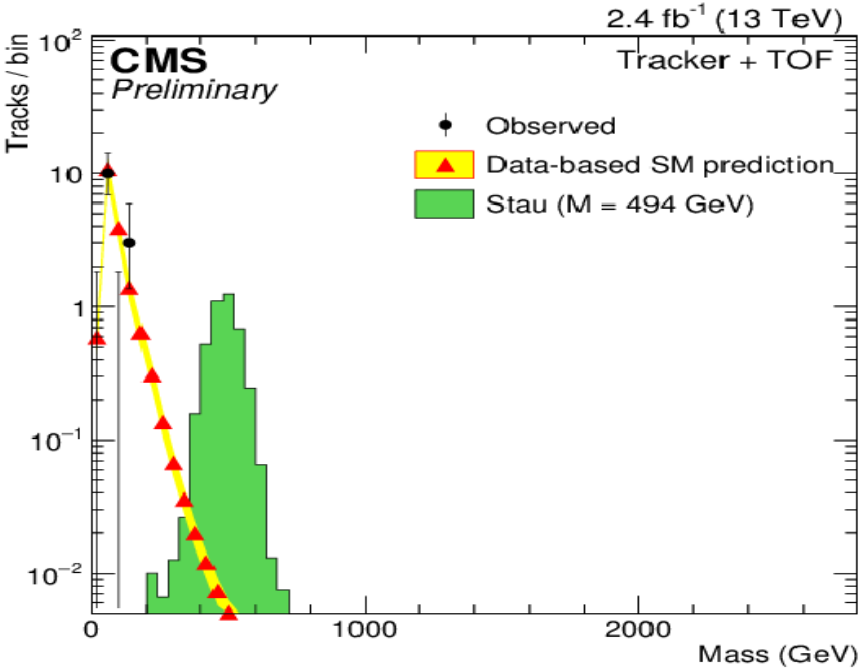
3. Unconventional Signatures

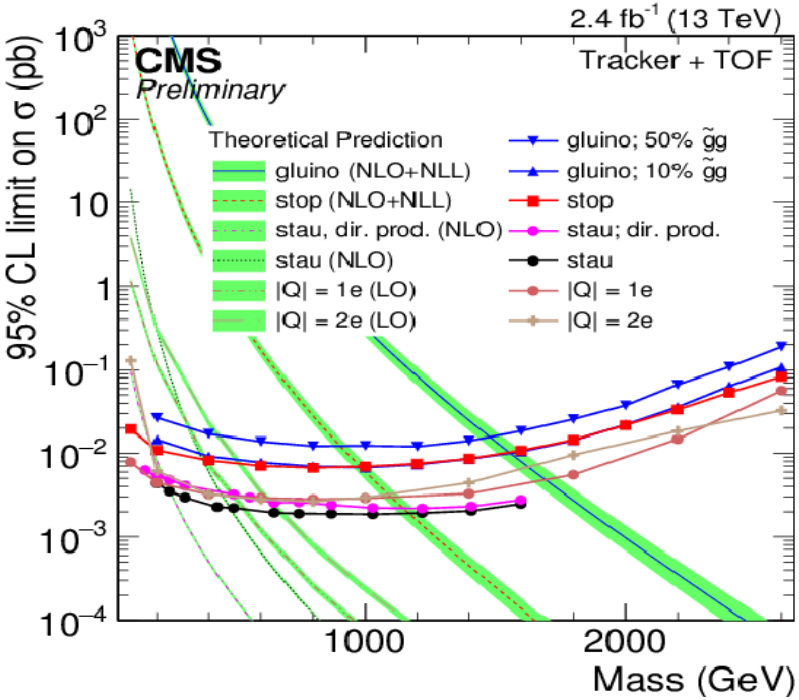
Long-lived Charged Particles

Long lived particles predicted by Hidden sector/Dark sector

- ✓ anomalously high energy deposition in the silicon tracker
- ✓ long time-of-flight to the muon detectors

CMS-PAS-EXO-15-010

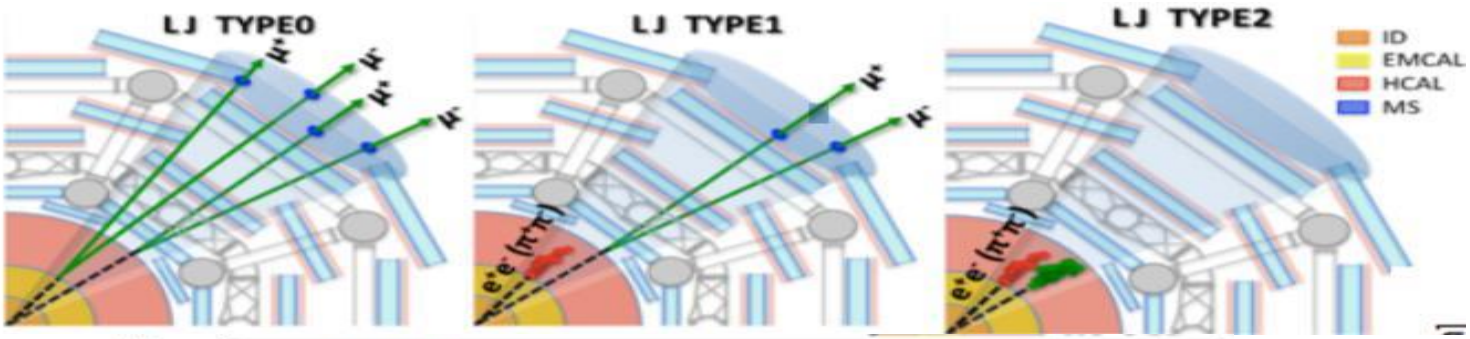


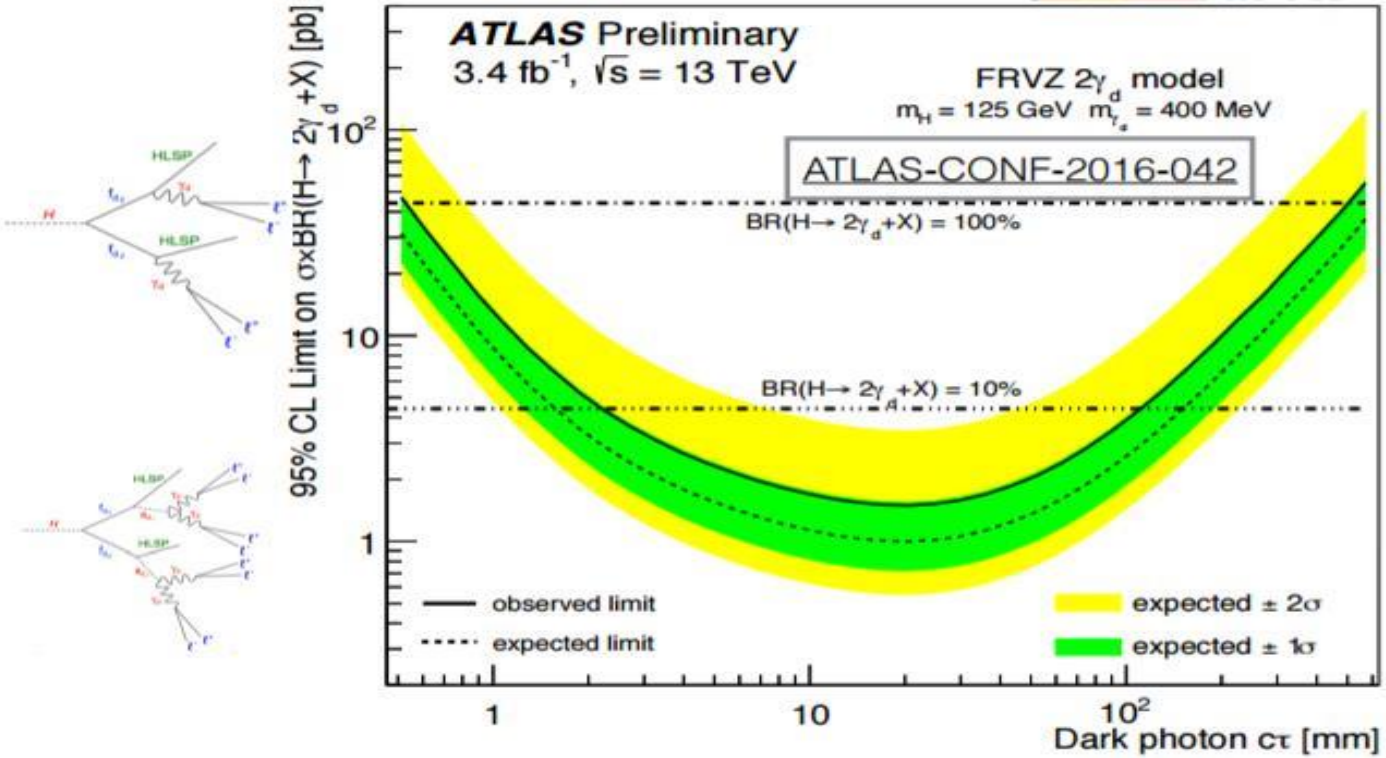


- ➢ The data are consistent with the expected background
- ➢ Limits for production of long-lived gluinos, scalar tops and taus are set

Lepton Jets

Collimated jet-like structures containing e/mu/pions

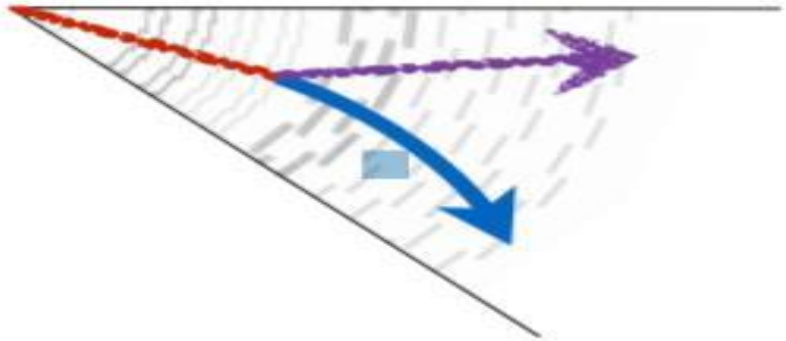


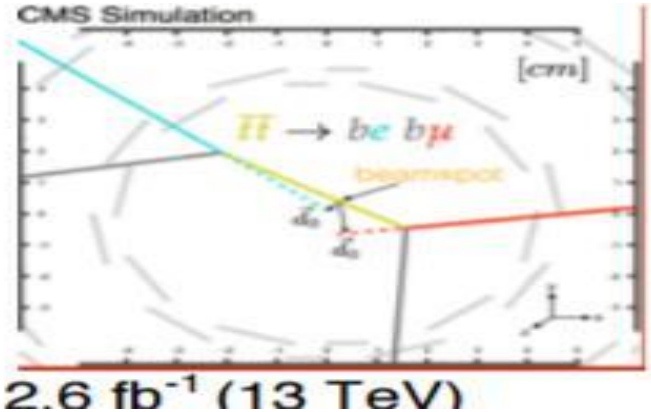


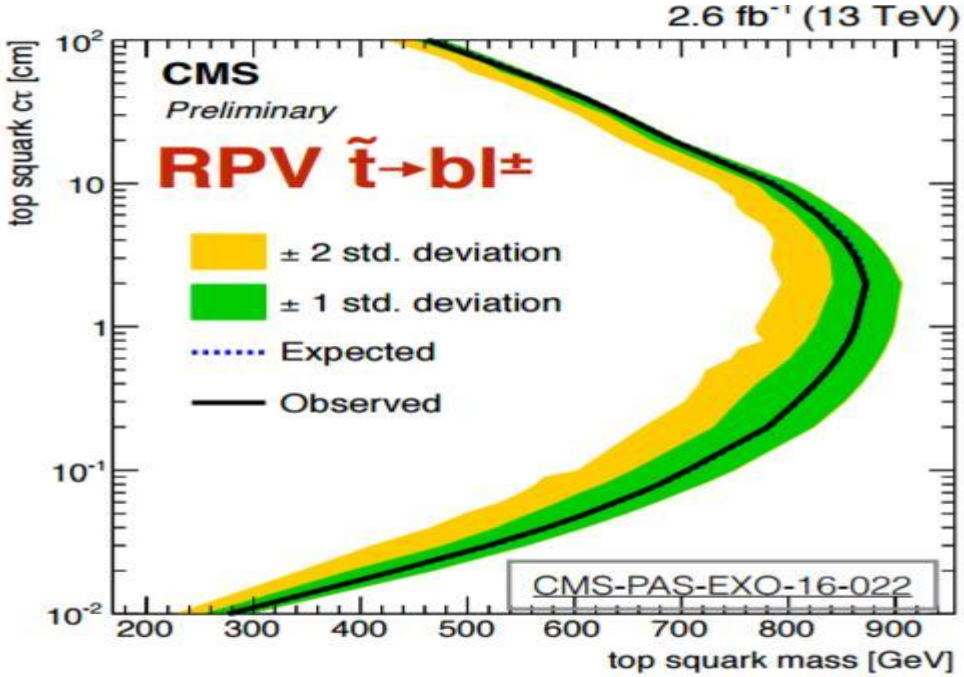
No excess found in the data

Displaced tracks

Diplaced e-u pair: large transverse impact parameter







No excess found in the data

Summary

- **LHC experiments conducting BSM searches in broad and complementary signatures**
  - **γ/e/μ/tau/jets/MET**
  - **Resolved and Boosted W/Z/H/top**
- **Two well-known excesses (Diboson in Run1 and Diphoton in 2015) not confirmed using 2016 data**
- **No new significant excesses observed (so far!)**
- **Sensitivity of new physics searches largely extended with 2016 data @ 13 TeV**
- **More data collected, more and more to come : stay tuned**