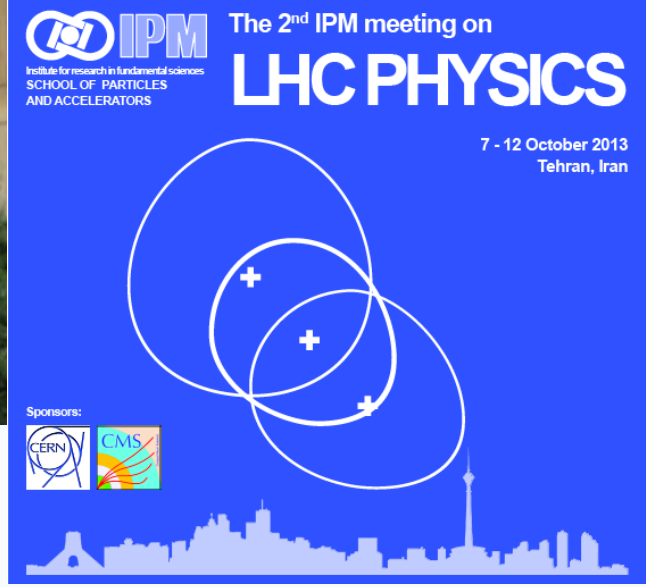
پژوهشگاه دانش‌های بنیادی (مرکز تحقیقات فیزیک نظری و ریاضیات)
IPM
INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES

School of
Particles and
Accelerators



Search of new resonances at the LHC

Barbara Clerbaux
Université Libre de Bruxelles, ULB
For the CMS and ATLAS experiments

CMS
Compact Muon Solenoid

ATLAS
EXPERIMENT

iihe
BRUXELLES BRUSSEL

ULB
UNIVERSITÉ
LIBRE
DE BRUXELLES

Apologize for arriving late

Overview

1. Introduction
2. Experiment setup
3. Dilepton : ee, μμ, ττ
4. Di-boson resonances
5. Di-jet resonances
   - Inclusive di-jets
   - Di-bquark jet
   - Top-antitop resonances
6. Excited leptons and quarks
7. Conclusions and Prospect

Many studies/results
→ a focus on recent results

Searches covered in previous talk:
- Leptoquarks
- W' → lν, tb and W'→ WZ
- Vector-Like quarks: t', b'

ALL Public physics results :
CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic
ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic

1. Introduction

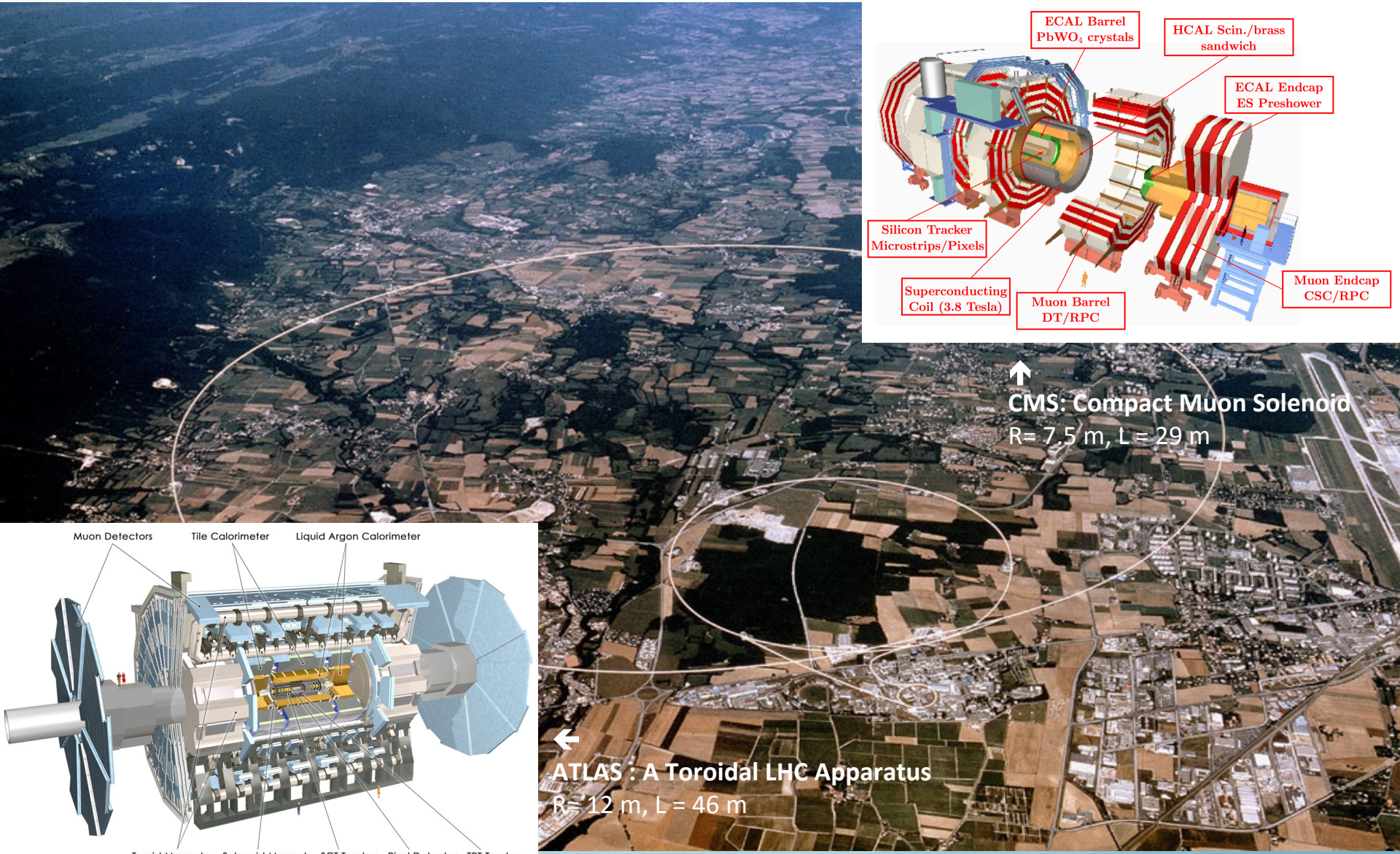
Search for heavy resonances
→ BUMP HUNTING

Results are interpreted:
- in terms of benchmark models
- but most limits are presented in a general way and can therefore be interpreted in many models

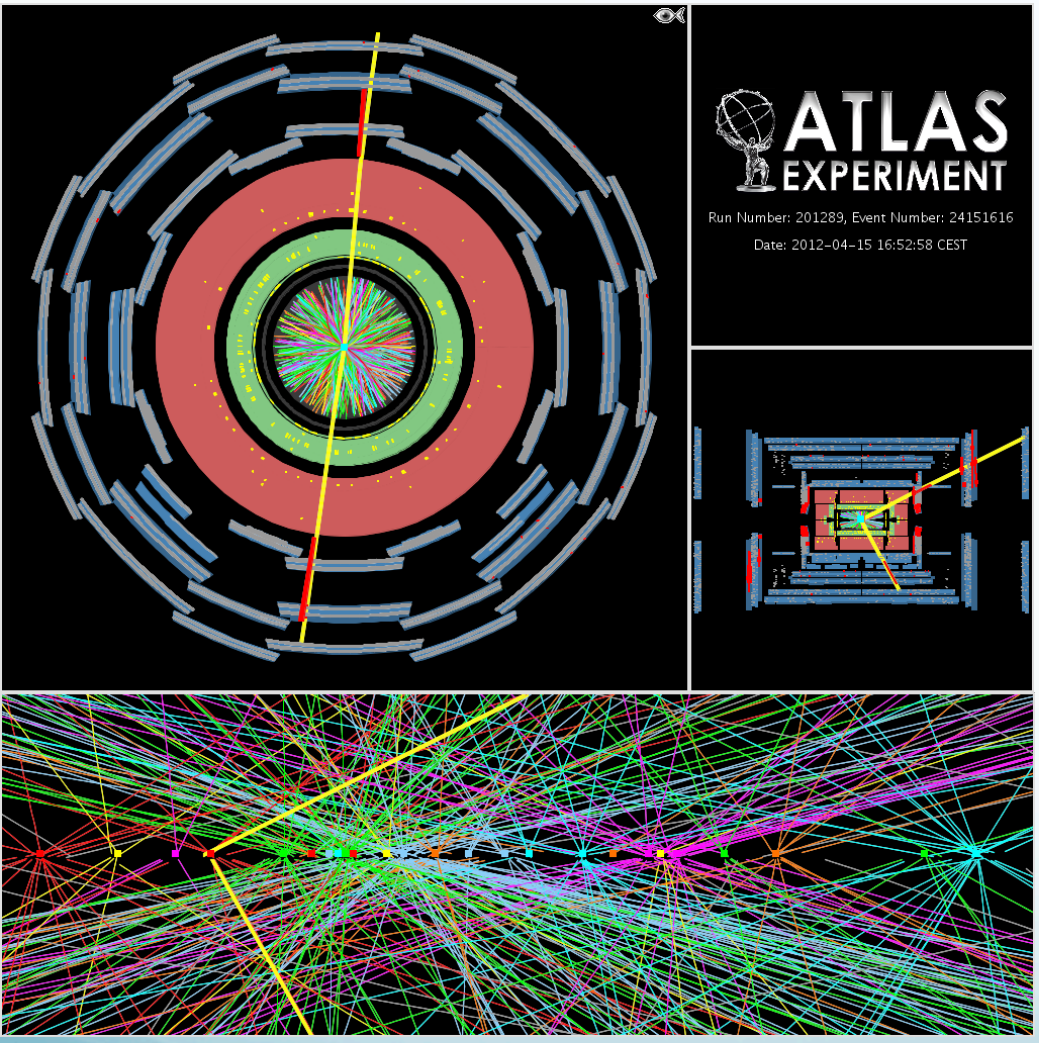
Many BSM extensions predict heavy resonances:
- Grand uniffy Theory (GUT) :
  Heavy spin 1 boson Z' from broken E6, SO(10), also W'
- Extra Dimensions :
  Spin 2 Randall-Sundrum graviton G*, also KK tower of Z, W, gluon
- Technicolor - narrow technihadrons
- Compositness models : excited leptons, excited quarks
- …

Experimental challenges :
- Understand Detector effects (trigger, resolution, efficiency..)
- Very high pT reconstructed objects close to TeV scale!
  almost no control regions
- Clean signal expected, often on SM distribution tail

2. Experimental Setup



LHC Performance

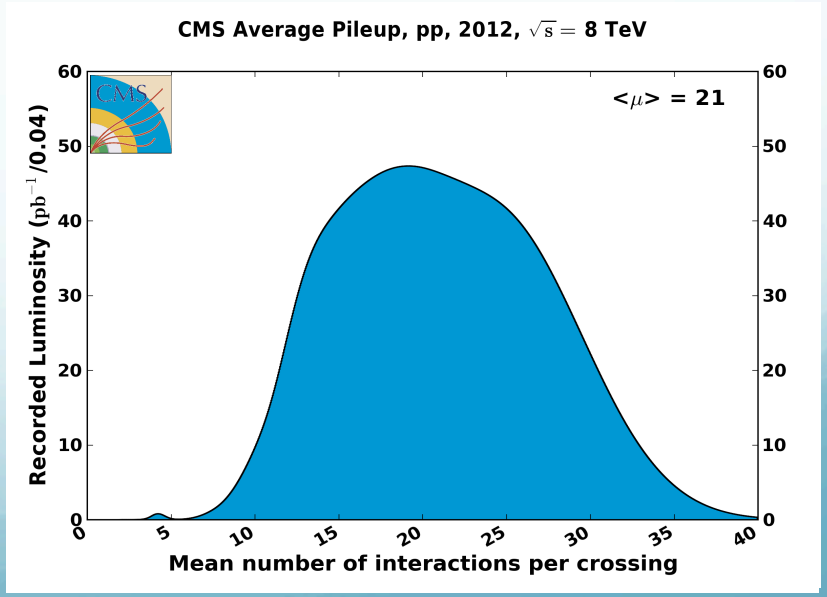


Z → μμ event with 25 reconstructed
(recorded by ATLAS in April 2012)

LHC – Excellent performance
Available dataset for analysis :
2011 : √s = 7 TeV, about 5 fb^{-1}
2012 : √s = 8 TeV, about 20 fb^{-1}

In 2012 :
Peak lum = 7.7x$10^{33}cm^{-2}s^{-1}$
Mean pile-up (PU) = 21 events
Per bunch crossing

Challenges: Pile-up (PU)



3. Z'/G→Dilepton

Event selection:

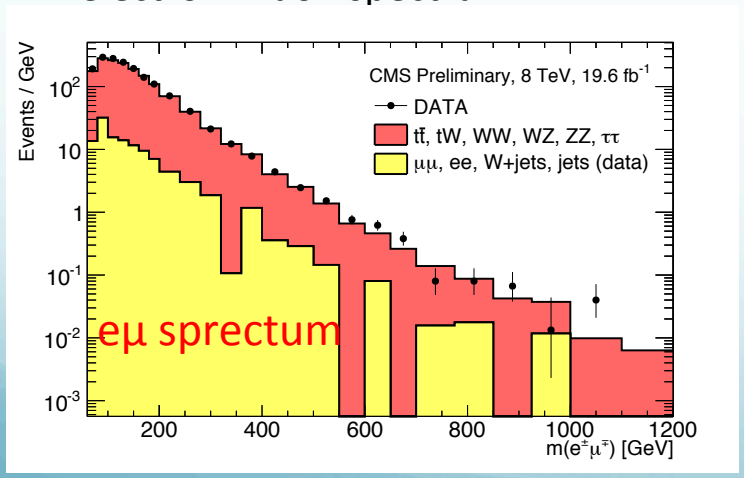
- Single (double) muon (electrons) trigger
- 2 Same Flavor (Opposite sign for muons) leptons
- Isolation

Main background:

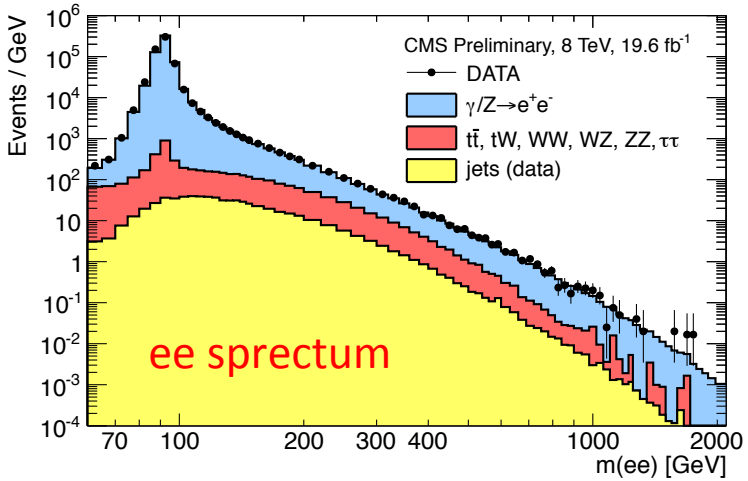
- Drell-Yan, top-antitop, Diboson estimated from MC (using NNLO K-factors)
- QCD multijets and W+jets (in electron channel) estimated from data

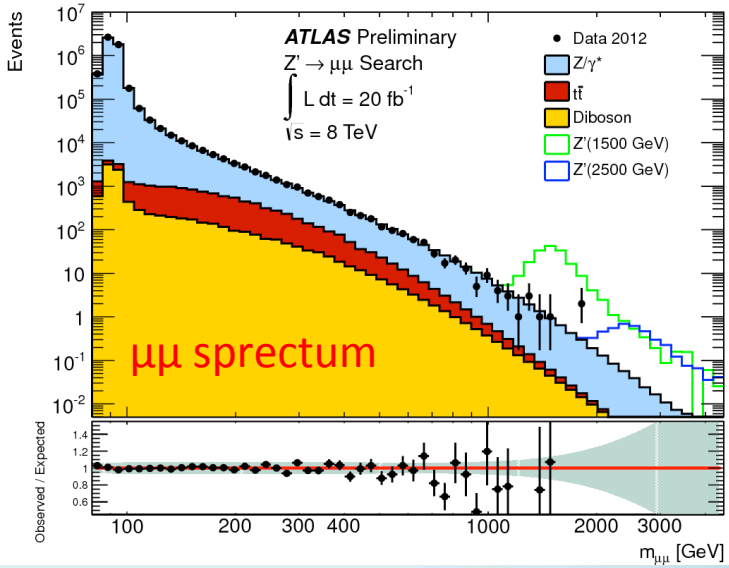
Top-antitop MC cross check

electron-muon spectrum :



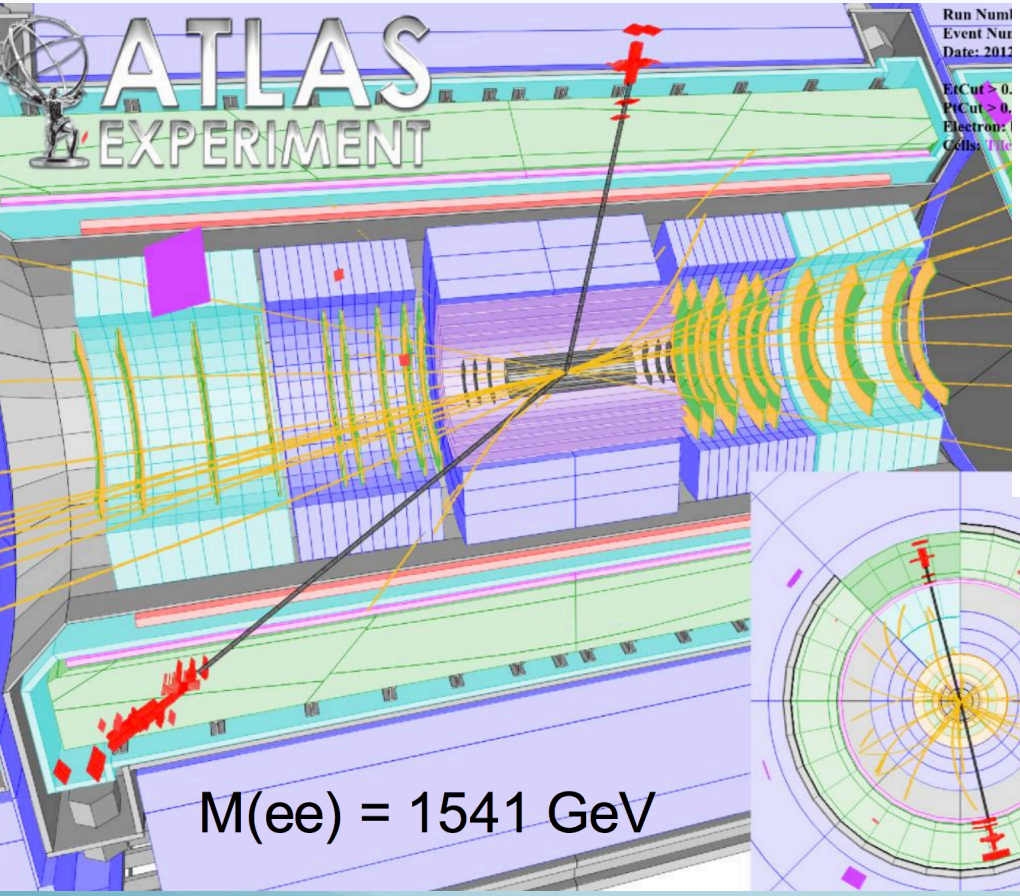
[CMS EXO-12-061]

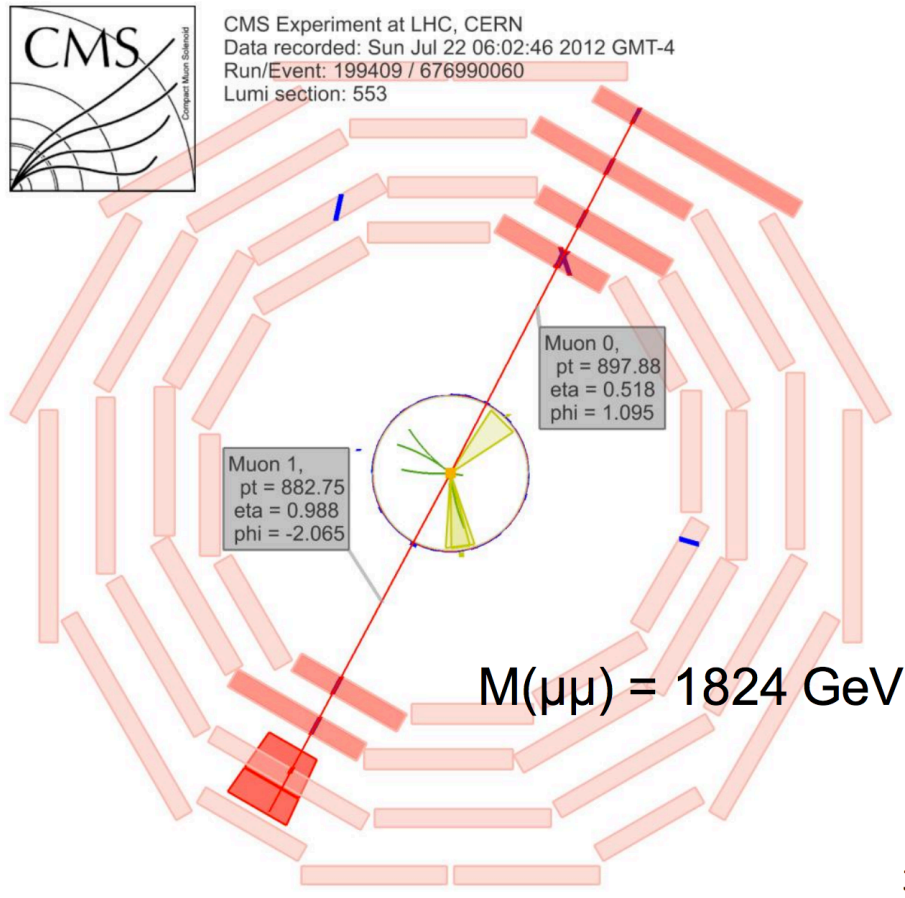




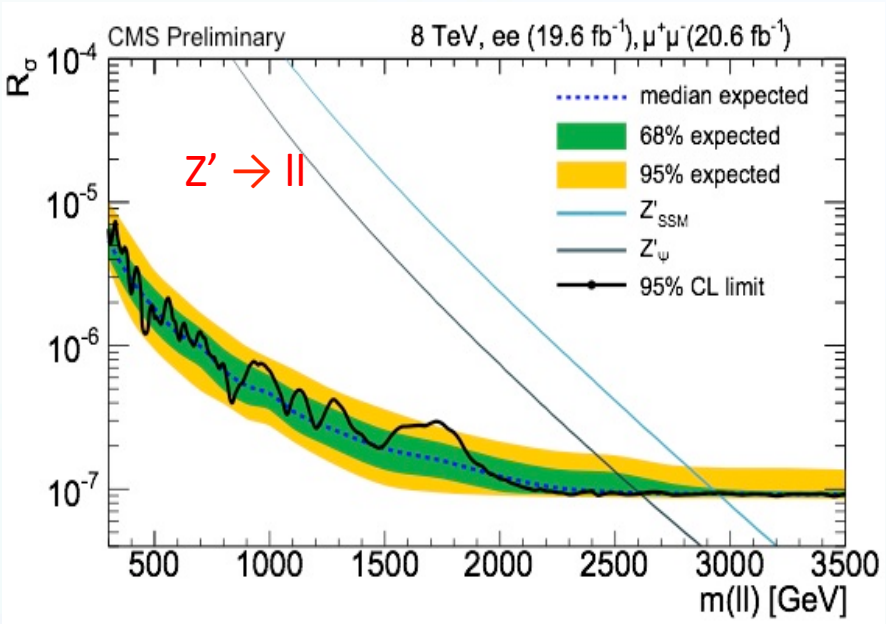
[ATLAS 13-017]

Data/MC agreement over many orders of magnitude: no deviations from bg estimate

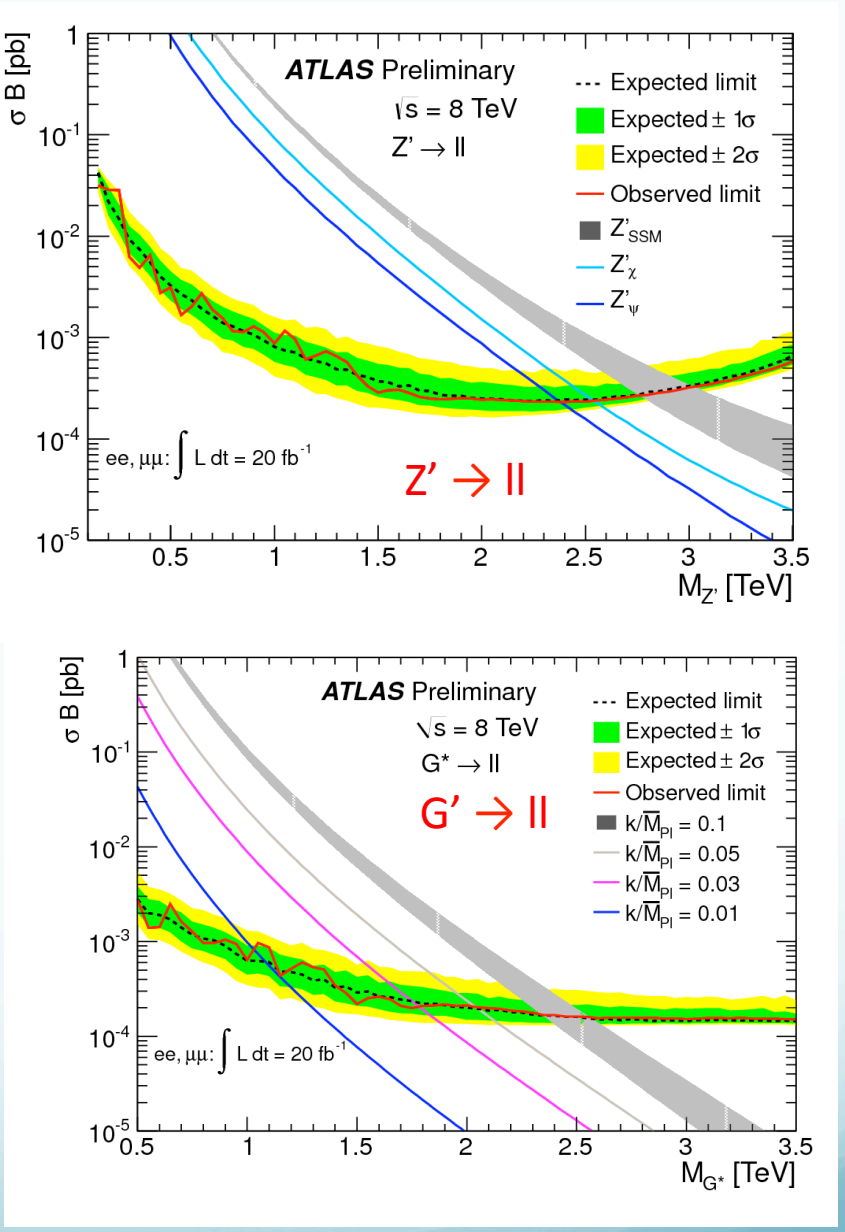

ATLAS
EXPERIMENT
M(ee) = 1541 GeV


CMS
CMS Experiment at LHC, CERN
Data recorded: Sun Jul 22 06:02:46 2012 GMT-4
Run/Event: 199409 / 676990060
Lumi section: 553
Muon 0,
pt = 897.88
eta = 0.518
phi = 1.095
Muon 1,
pt = 882.75
eta = 0.988
phi = -2.065
M(μμ) = 1824 GeV

Limits : ee&μμ combined



R = ratio to Z peak cross section



Mass limits: Typically:
SM-like couplings: M(Z' SSM) > 2.9 TeV
Superstring-inspired: M(Z' psi) > 2.5 TeV
Graviton : M>2.5 TeV (c=0.1)

Z'/G → Di-tau

19.5 fb^{-1}@8TeV

[ATLAS 13-066]

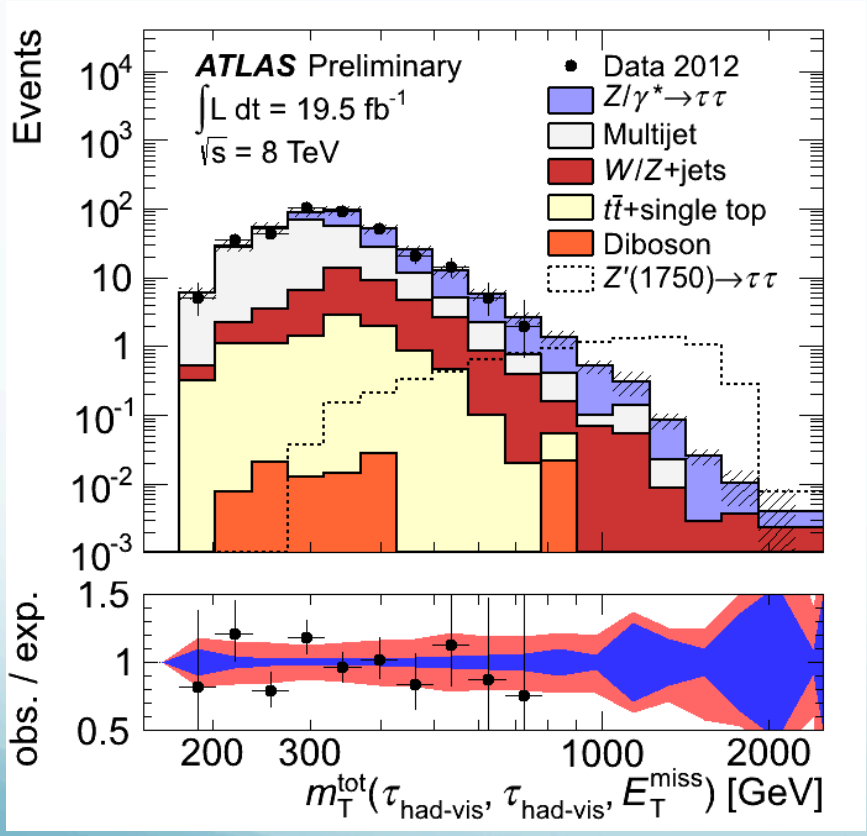
Tau : decaying into fully hadronic final state

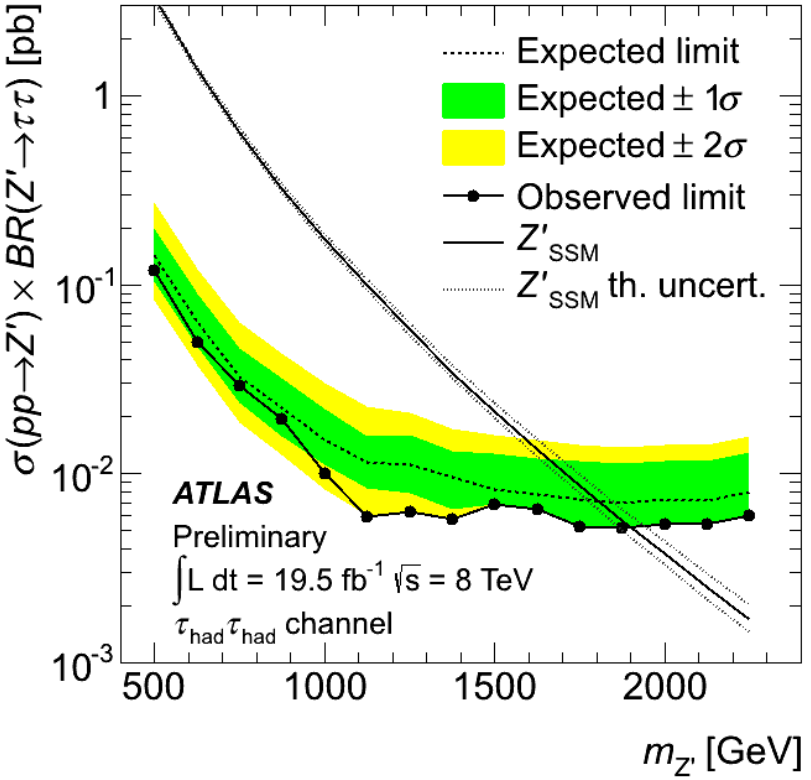
Lepton universality is not necessarily a requirement

In some cases : enhance coupling to third generation

→ search also for the tau decay mode

Leading tau P(t) > 150 GeV



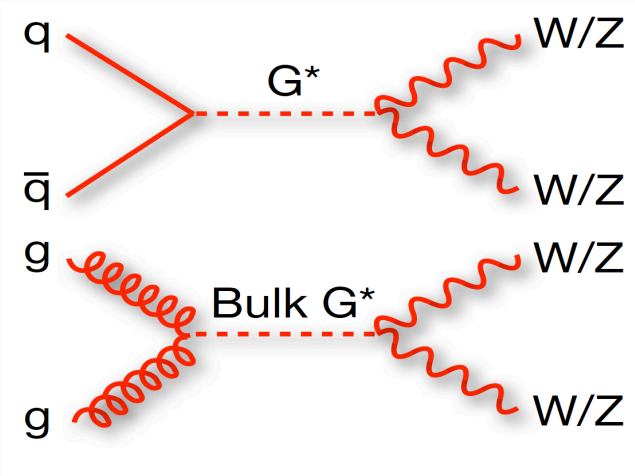


Mass limits for benchmark model :

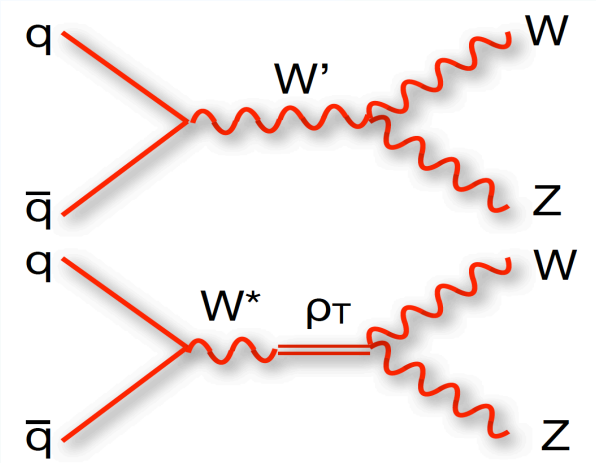
SM-like couplings: M(Z' SSM) > 1.9 TeV

4. Di-boson resonances

Neutral (ZZ, WW)



Charged (WZ)

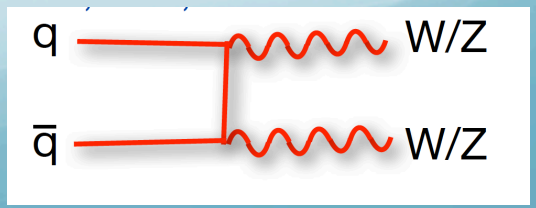


- **Randall-Sundrum graviton (RS G*, spin2)**
  Traditional benchmark model with ED
- **Bulk RS graviton (bulk G*, spin2)**
  G couples more to heavy particles (W,Z,t)
  smaller σ but larger BR to WW, ZZ

- **Sequential Standard Model(W', spin1)**

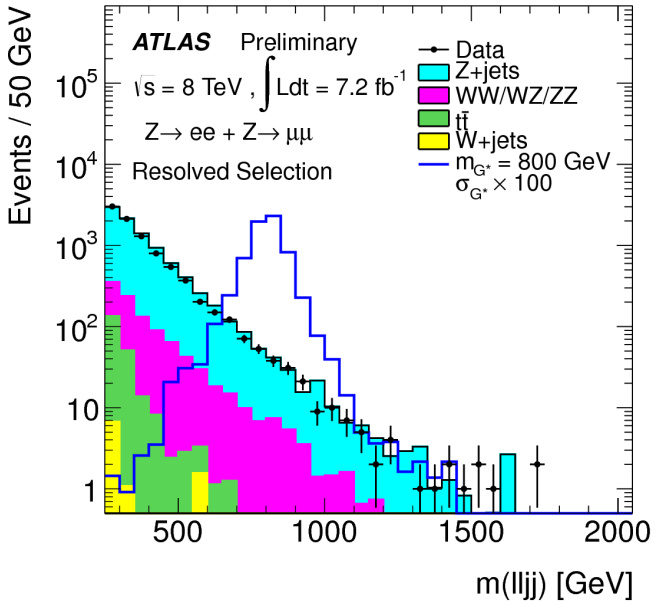
- **Low-scale Technicolor (ρ_T, spin1)**
  ρ_T (with $M\rho < 2*M\pi$) can decay to $W\pi_T$ or WZ
  $M_\rho = M_\pi + M_W$ choice maximizes $\rho_T \rightarrow WZ$

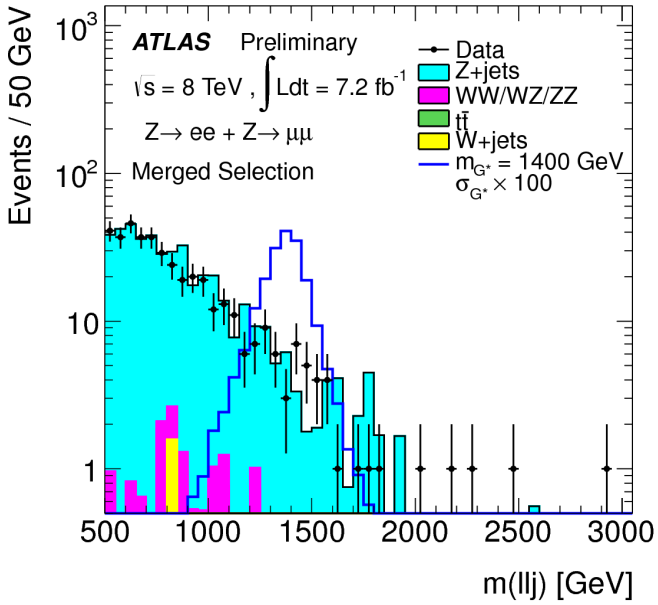
Backgrounds: - Fake leptons : W+jets, Z+jets, tt
- Real leptons , different kinematics : tt (ll), Z (ll)
- Non-resonant WW, WZ, ZZ → Irreducible :



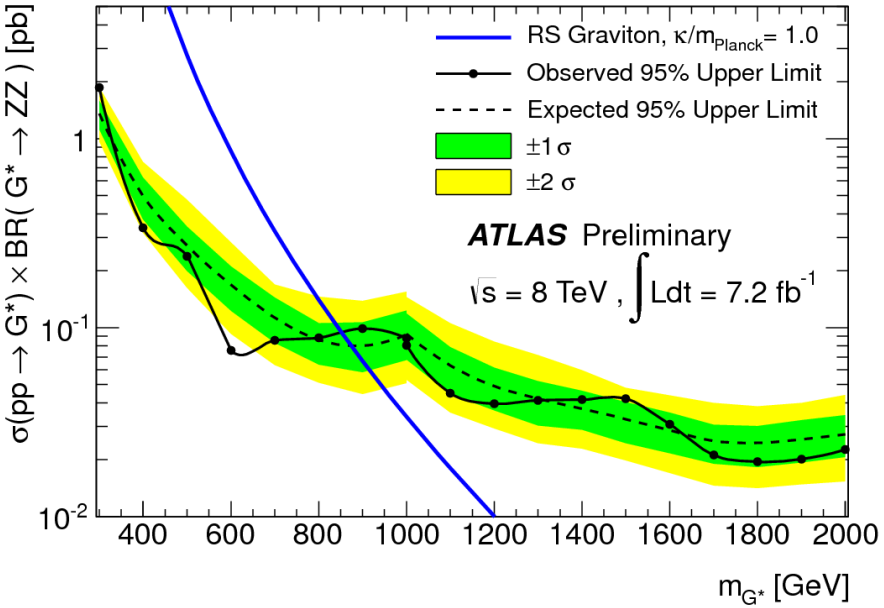
Resonant ZZ→llqq

7.2 fb^{-1}@8TeV [ATLAS 12-150]





- Diboson mass reconstructed from the leptons and jets as the discriminating variable
- Resolved and merged selection (to be sensitive to large range of mass signal 300-2000 GeV)

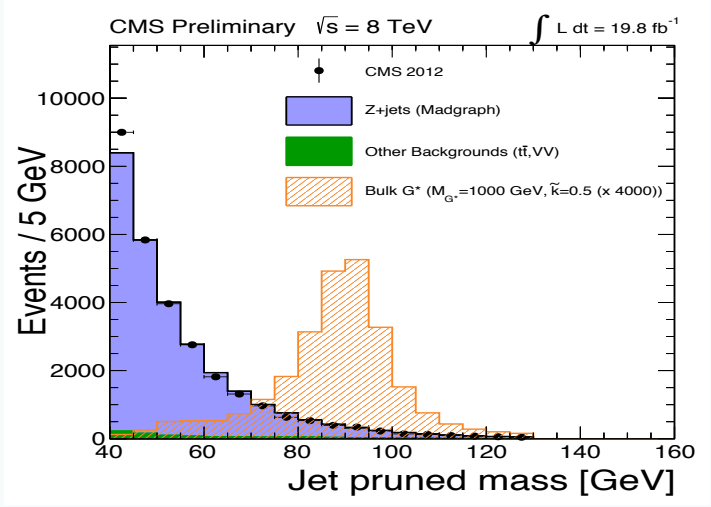


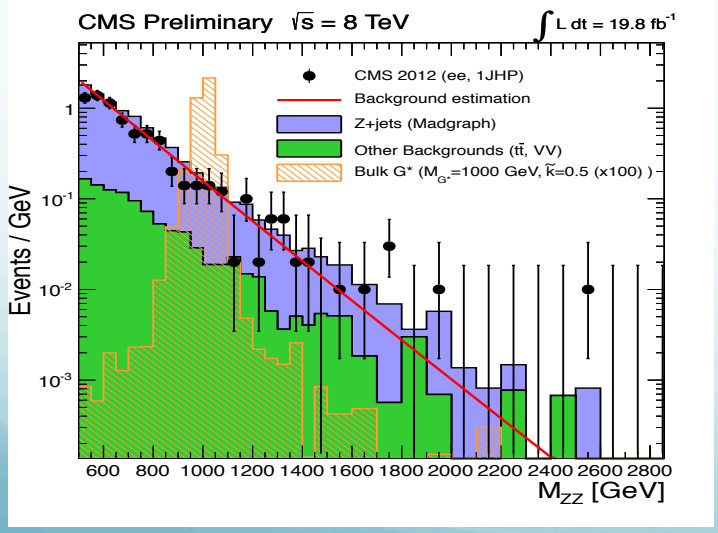
- Limit are set for spin-2 bulk RS G* model on σ(pp → G*)xBR(G* → ZZ)
- Observed (expected) limit : M (G) > 850 (870) GeV.

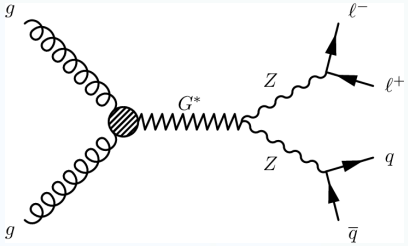
Resonant ZZ→llqq

19.8 fb^{-1}@8TeV [CMS EXO 12-022]

Search for a narow spin-2 resonance

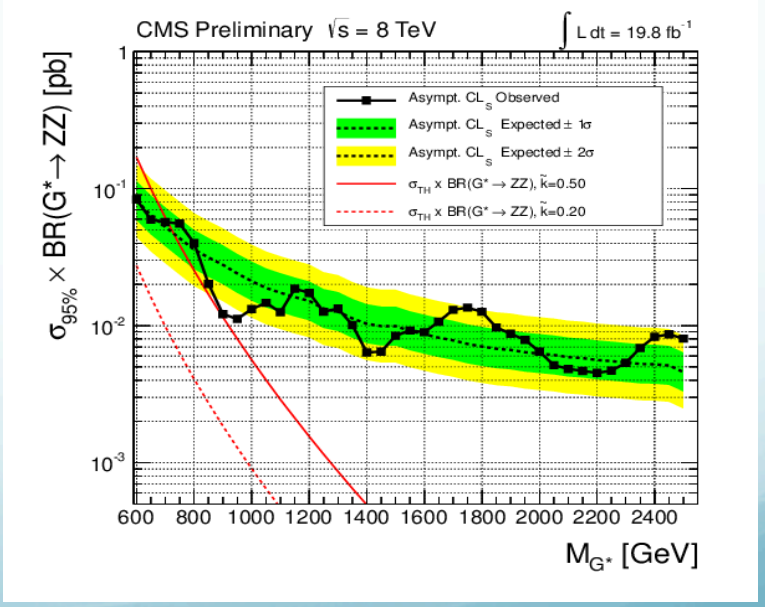




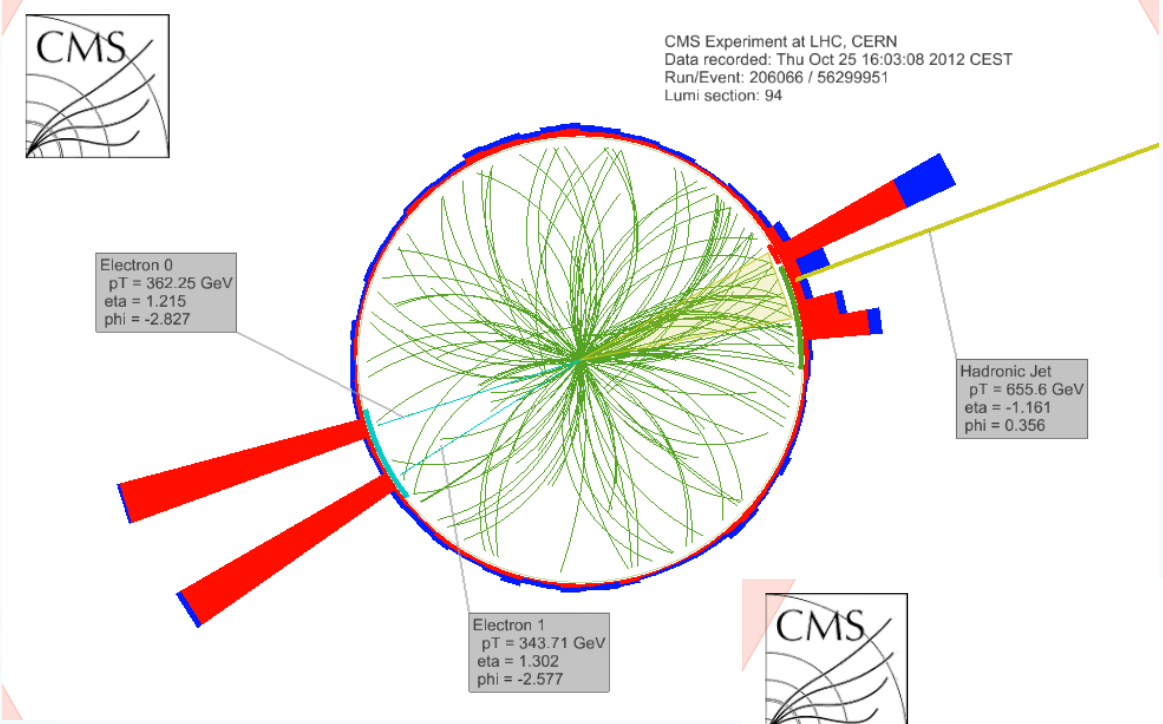


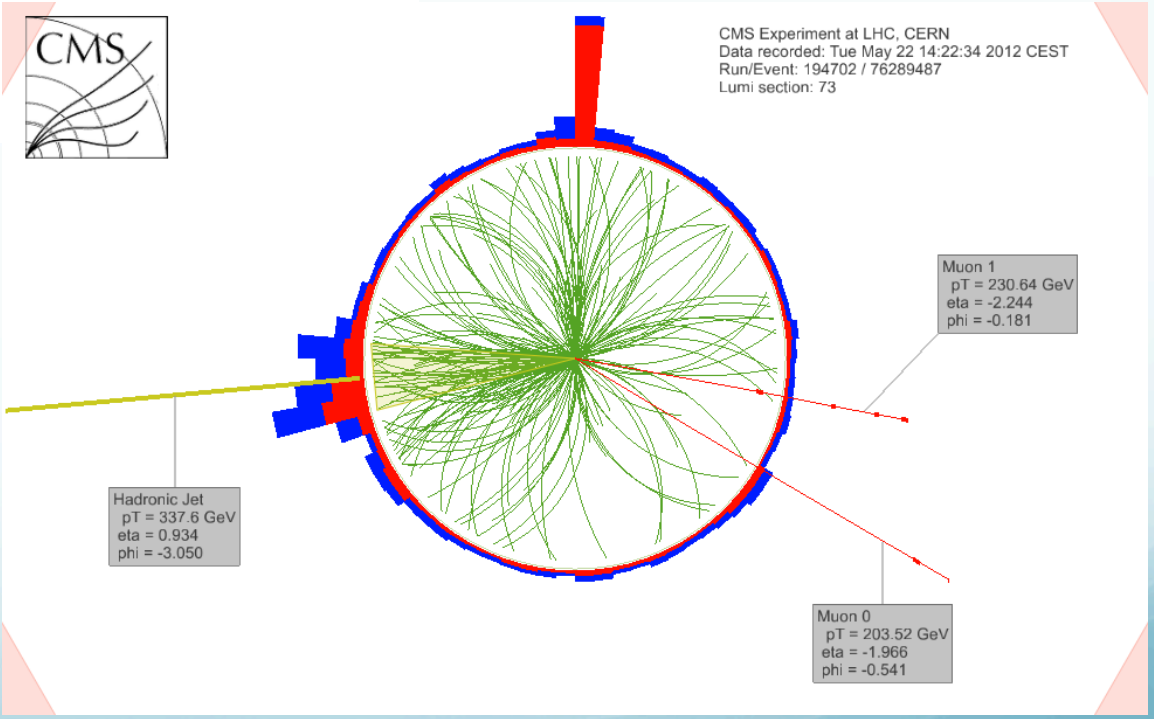
- Jet sub-structure techniques are exploited pt of both Z > 80 GeV

- Limits on a narrow-width bulk RS Graviton: RS G, with coupling k=0.5, and mass lighter than 710 GeV are excluded at the 95% C.L. .



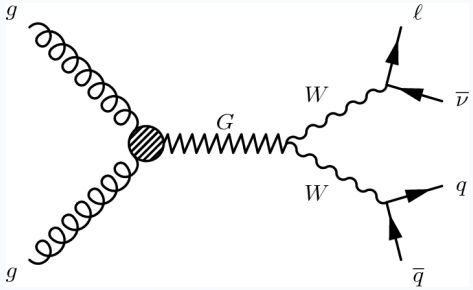
Resonant ZZ


CMS
CMS Experiment at LHC, CERN
Data recorded: Thu Oct 25 16:03:08 2012 CEST
Run/Event: 206066 / 56299951
Lumi section: 94
Electron 0
pT = 362.25 GeV
eta = 1.215
phi = -2.827
Hadronic Jet
pT = 655.6 GeV
eta = -1.161
phi = 0.356
Electron 1
pT = 343.71 GeV
eta = 1.302
phi = -2.577

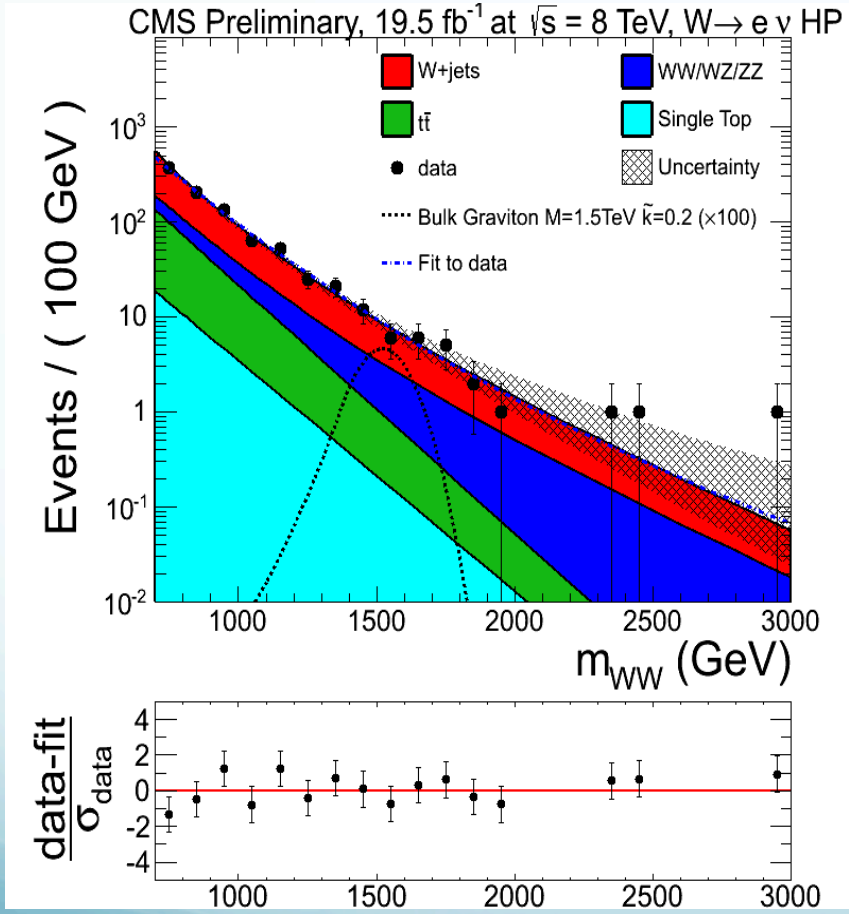

CMS
CMS Experiment at LHC, CERN
Data recorded: Tue May 22 14:22:34 2012 CEST
Run/Event: 194702 / 76289487
Lumi section: 73
Muon 1
pT = 230.64 GeV
eta = -2.244
phi = -0.181
Hadronic Jet
pT = 337.6 GeV
eta = 0.934
phi = -3.050
Muon 0
pT = 203.52 GeV
eta = -1.966
phi = -0.541

Resonant WW→lvqq

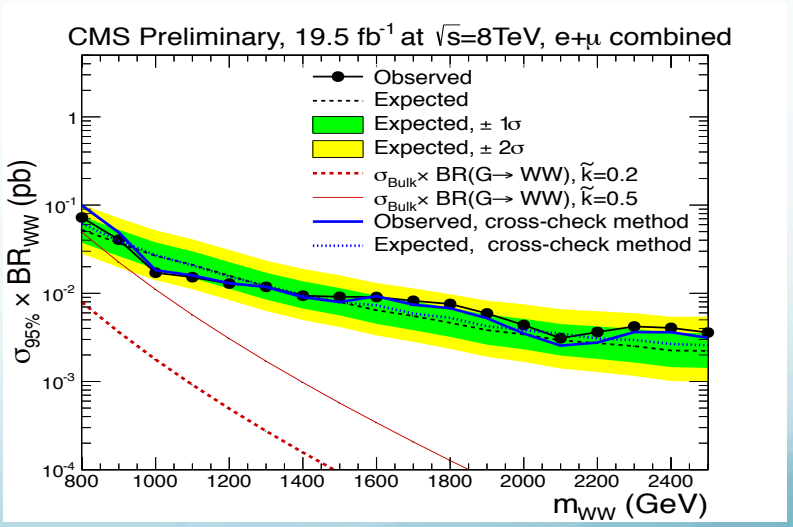
19.5 fb^{-1}@8TeV [CMS EXO 12-021]



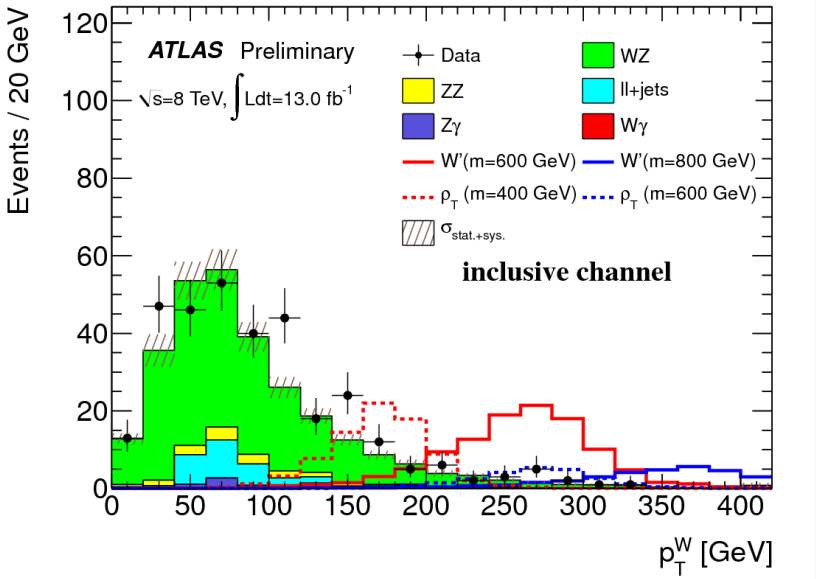
Search for a narow spin-2 resonance

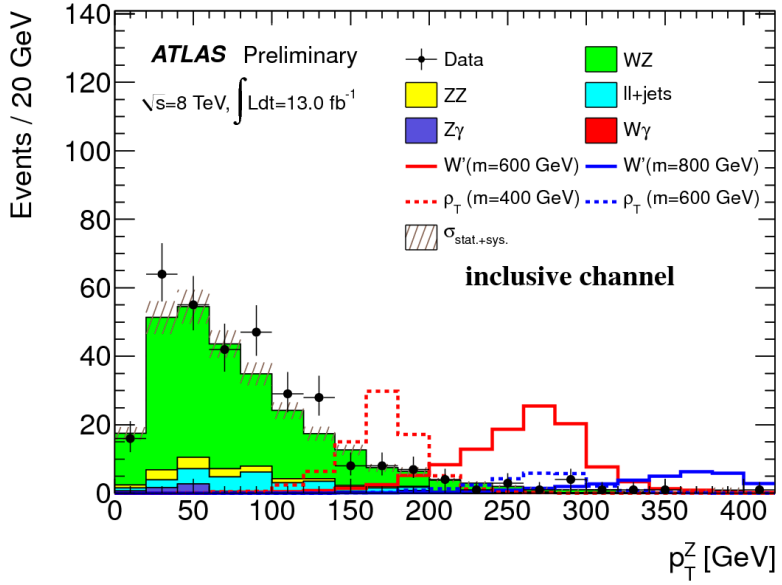


- Jet sub-structure techniques are exploited
- Upper limits on the bulk G production cross section times BR to WW are set in the range from 70 fb to 3 fb for masses between 0.8 and 2.5 TeV

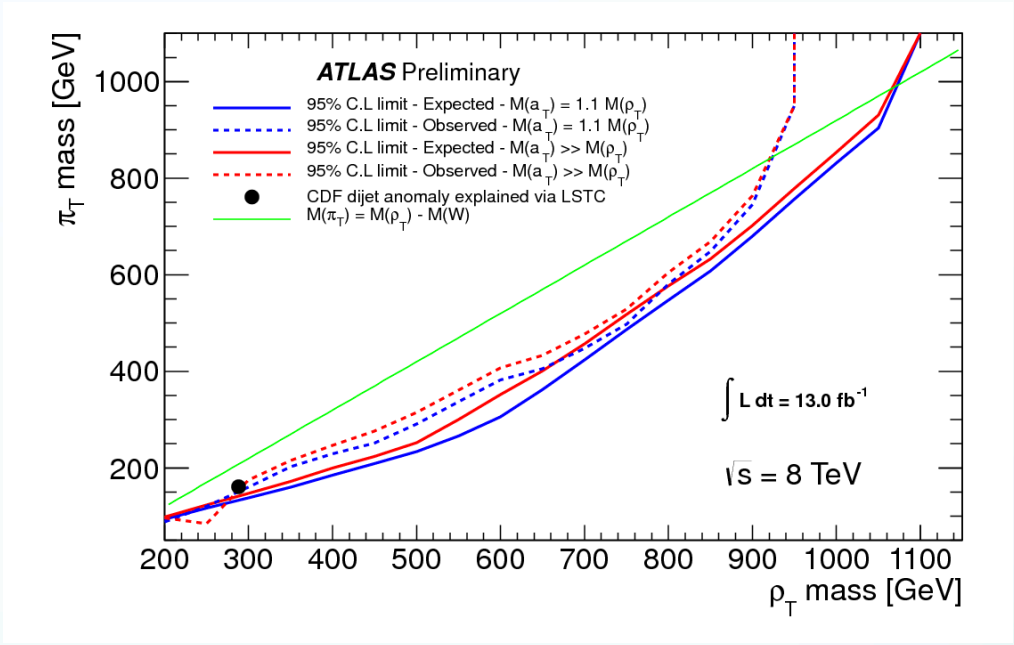


Resonant ZW→ lllν





13 fb^{-1}@8TeV [ATLAS 13-015]

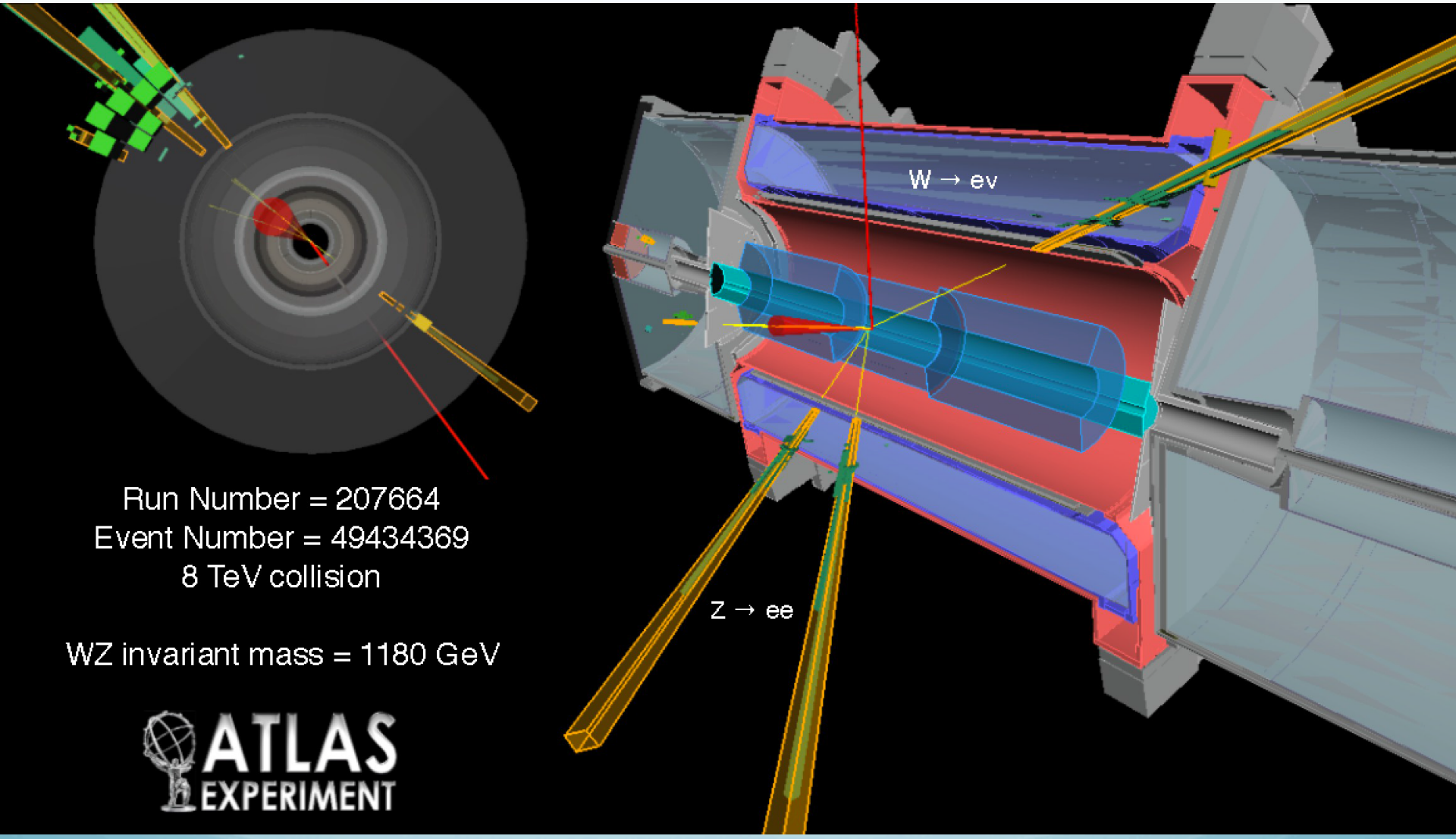


Excluded Limits :

M(W') < 1180 GeV

M(ρ_T) < 920 GeV with M(ρ_T) = M(π_T)+ M(W)

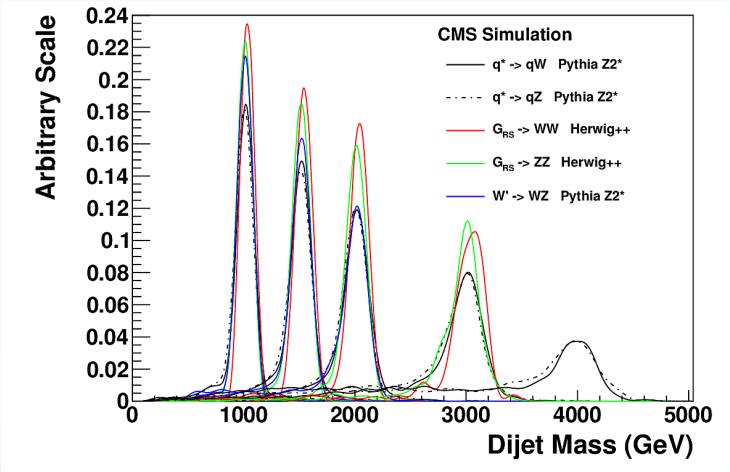
Resonant ZW→ lllν

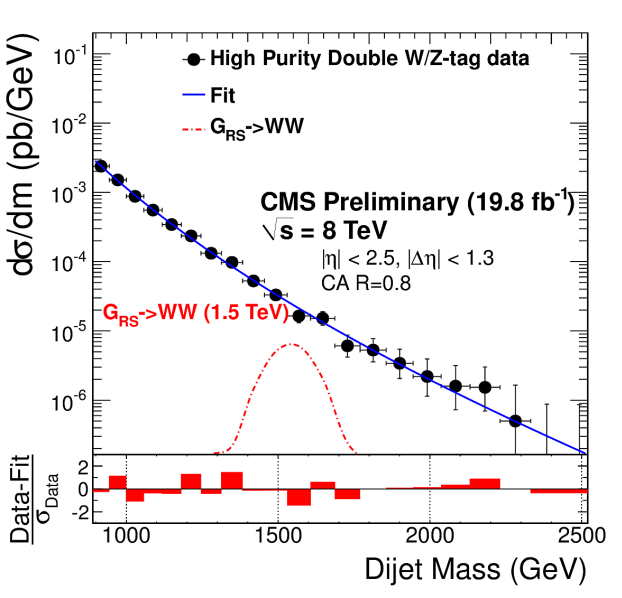


ZW-tagged dijet

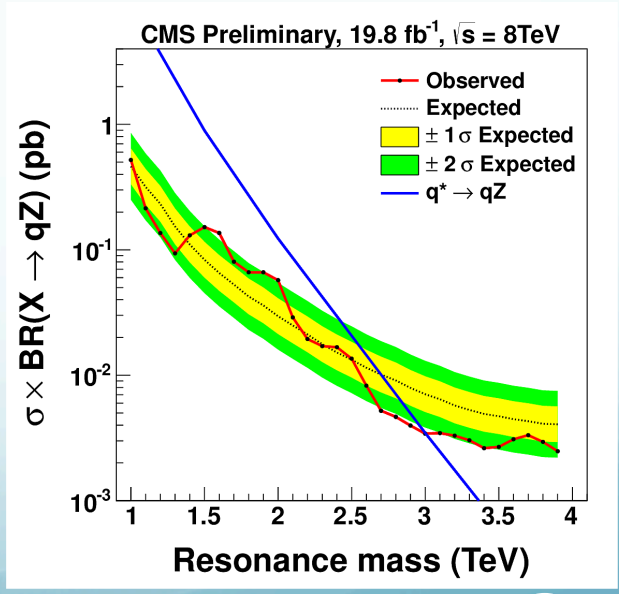
19.8 fb^{-1}@8TeV [CMS EXO 12-024]

- **M decaying : qW or qZ, or WW, WZ, or ZZ where each V decays to hadronic final states**
- At high M : the decay products of each vector boson may merge into a single jet -> event : dijet topology. V : identified with jet substructure tagging techniques.





Process	Observed Mass Exclusion(TeV)		Expected Mass Exclusion(TeV)	
	8 TeV	7 TeV	8 TeV	7 TeV
$q* \to qW$	$[1.00, 3.23]$	$[1.00, 2.38]$	$[1.00, 3.03]$	$[1.00, 2.43]$
$q* \to qZ$	$[1.00, 3.00]$	$[1.00, 2.15]$	$[1.00, 2.70]$	$[1.00, 2.07]$
$G_{RS} \to WW$	$[1.00, 1.59]$	NA	$[1.00, 1.49]$	NA
$G_{RS} \to ZZ$	$[1.00, 1.17]$	NA	$[1.00, 1.13]$	NA
$W' \to WZ$	$[1.00, 1.73]$	NA	$[1.00, 1.68]$	NA



5. Di-jet resonance searches

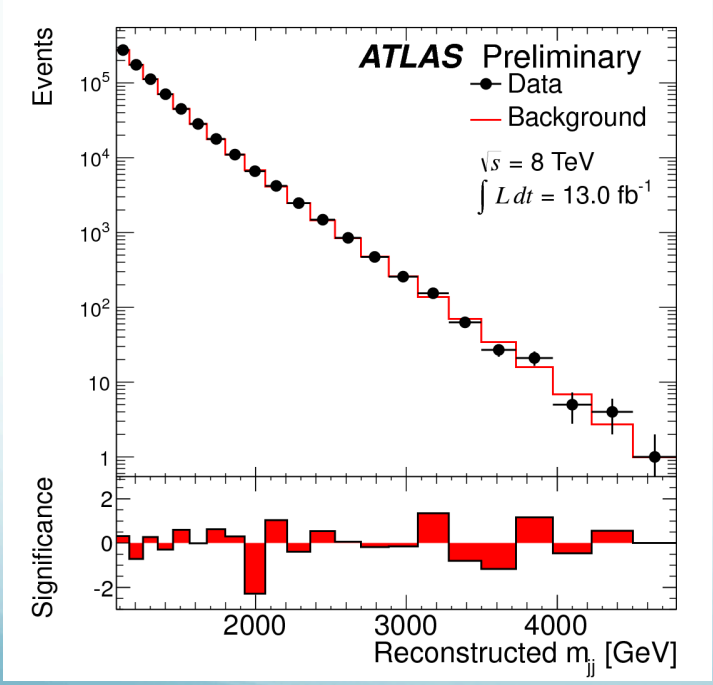
Di-jet inclusive searches

Search for a bump in the di-jet mass spectrum :
Main background : mutijets from QCD production
Cut on delta(eta) of the 2 jets (central jets)
The parametrisation used for the fit function is :

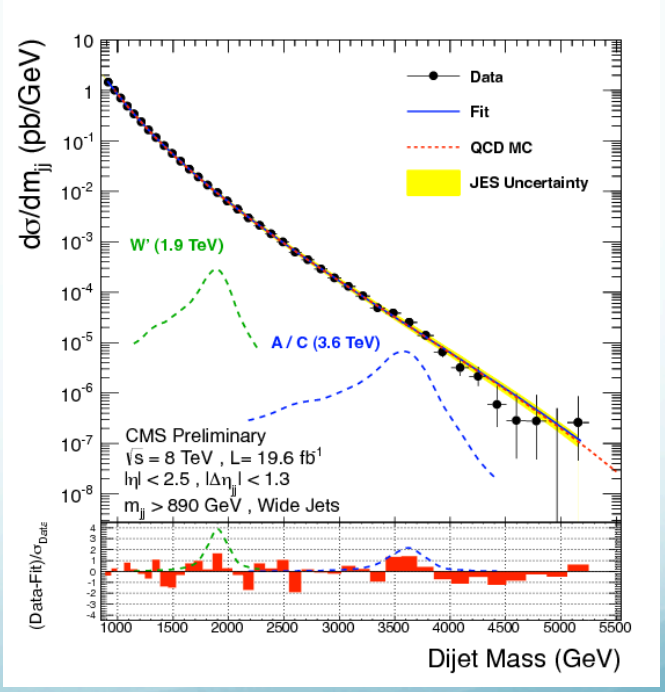
$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}$$

$$x = m_{jj}/\sqrt{s}$$

ATLAS uses Anti-kT, R = 0.6 jets
CMS starts with Anti-kT, R = 0.5 jets and close jets are combined into “wide” jets with R=1.1
Wide jet : to reduce sensibility to gluon radiation : select the 2 highest pt jets (leading jets), and add lorentz vectors of other jets to the closest leading jet.



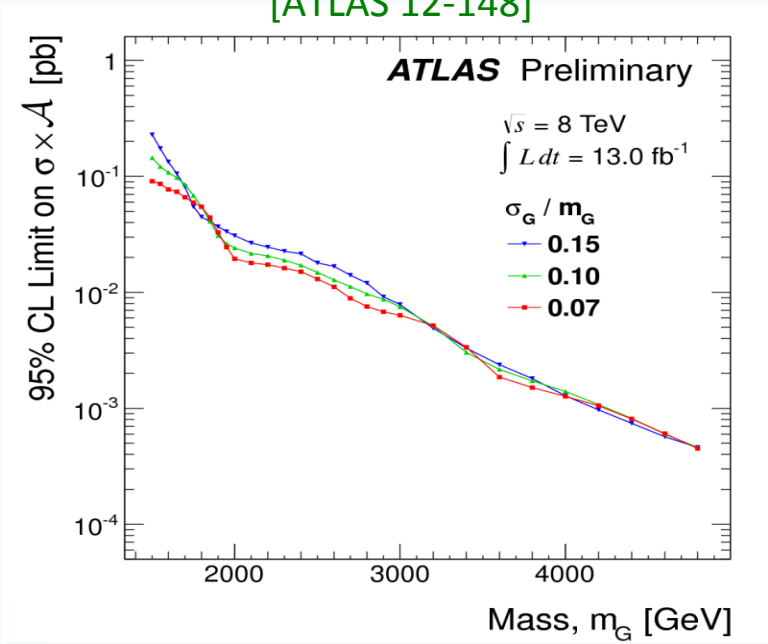
[ATLAS 12-148]



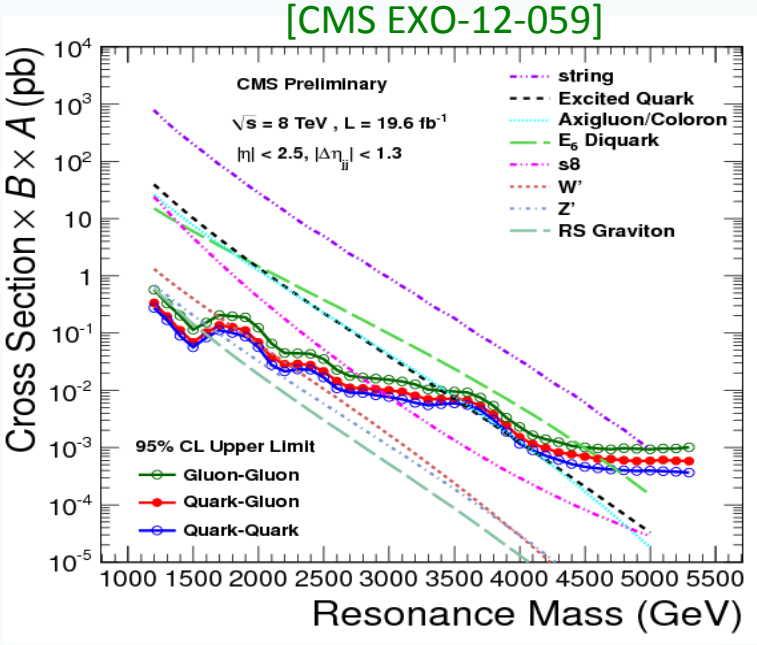
[CMS EXO-12-059]

Di-jet results : limits

[ATLAS 12-148]



[CMS EXO-12-059]



Excluded limits :

ATLAS:

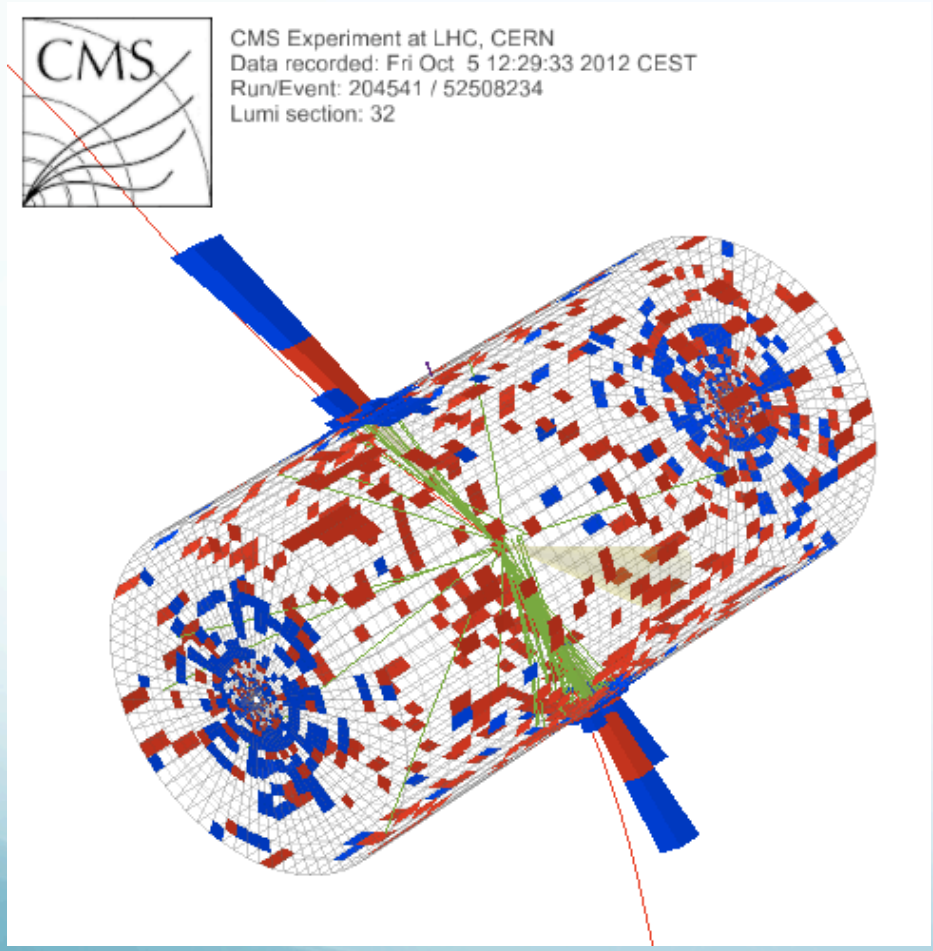
– m(q*) < 3.84 TeV

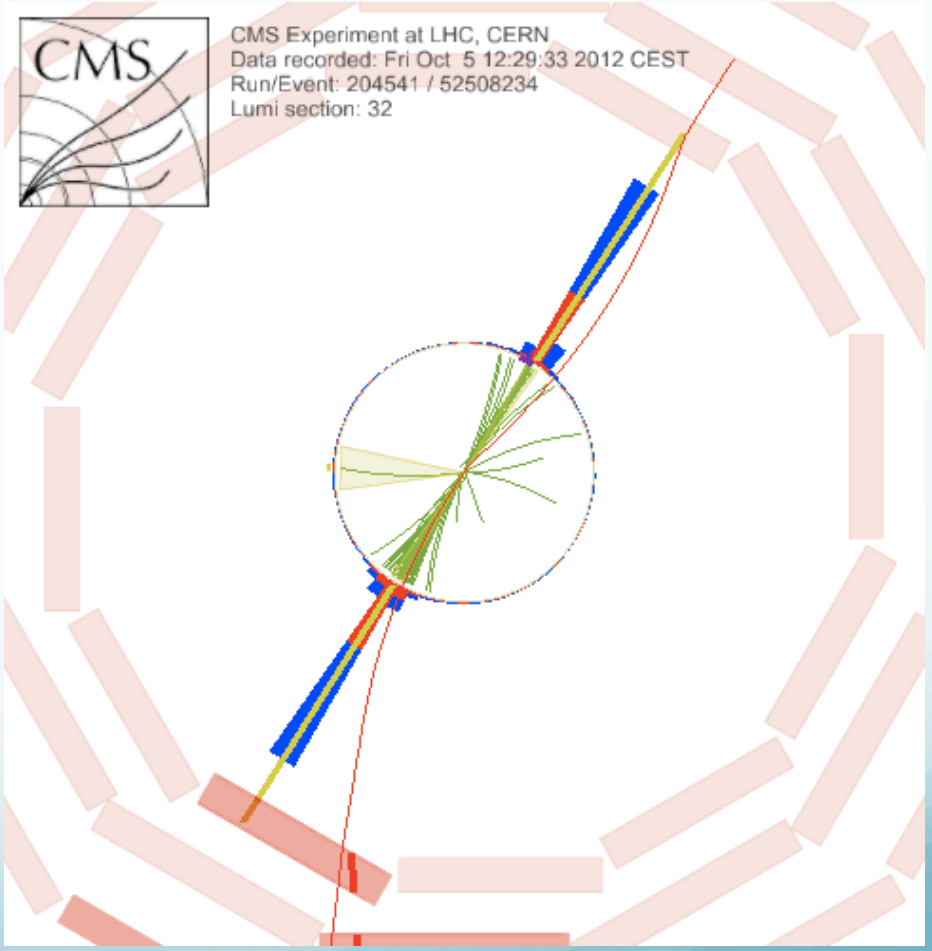
– Cross-section limits on generic Gaussian resonances

CMS:

Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	qq	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[1.20,2.79]	[1.20,2.74]
W′ Boson (W′)	$q\bar{q}$	[1.20,2.29]	[1.20,2.28]
Z′ Boson (Z′)	$q\bar{q}$	[1.20,1.68]	[1.20,1.87]
RS Graviton (G)	$q\bar{q}$+gg	[1.20,1.58]	[1.20,1.43]

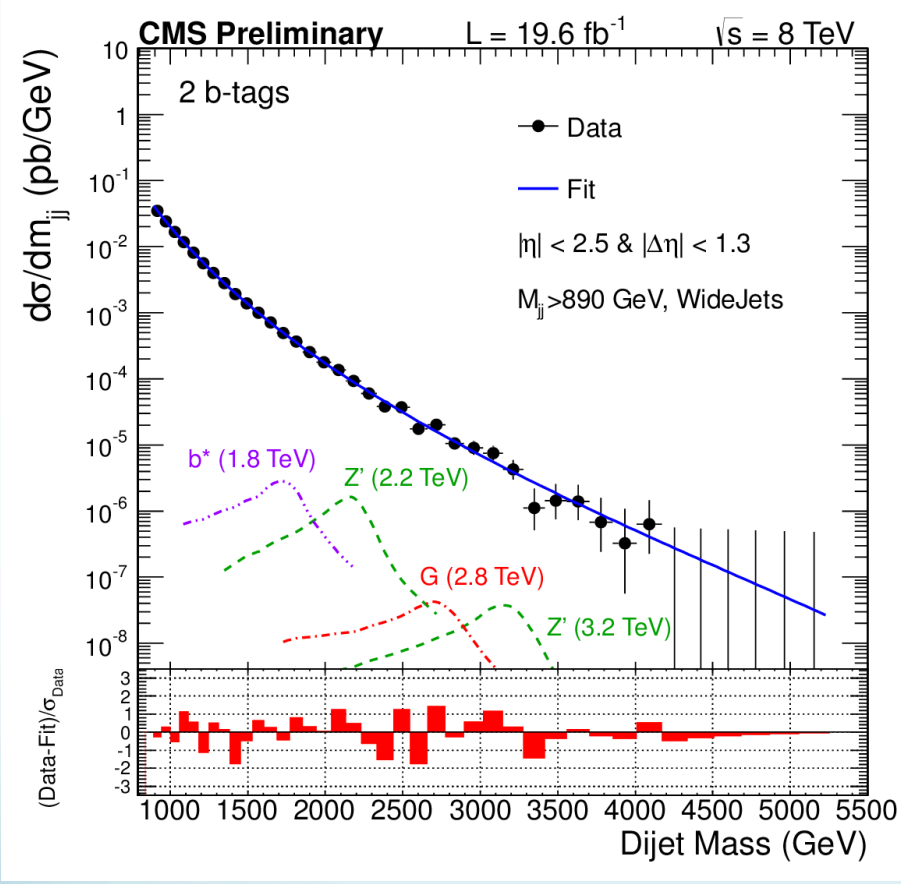
Highest di-wide-jet mass event
M=5.15 TeV

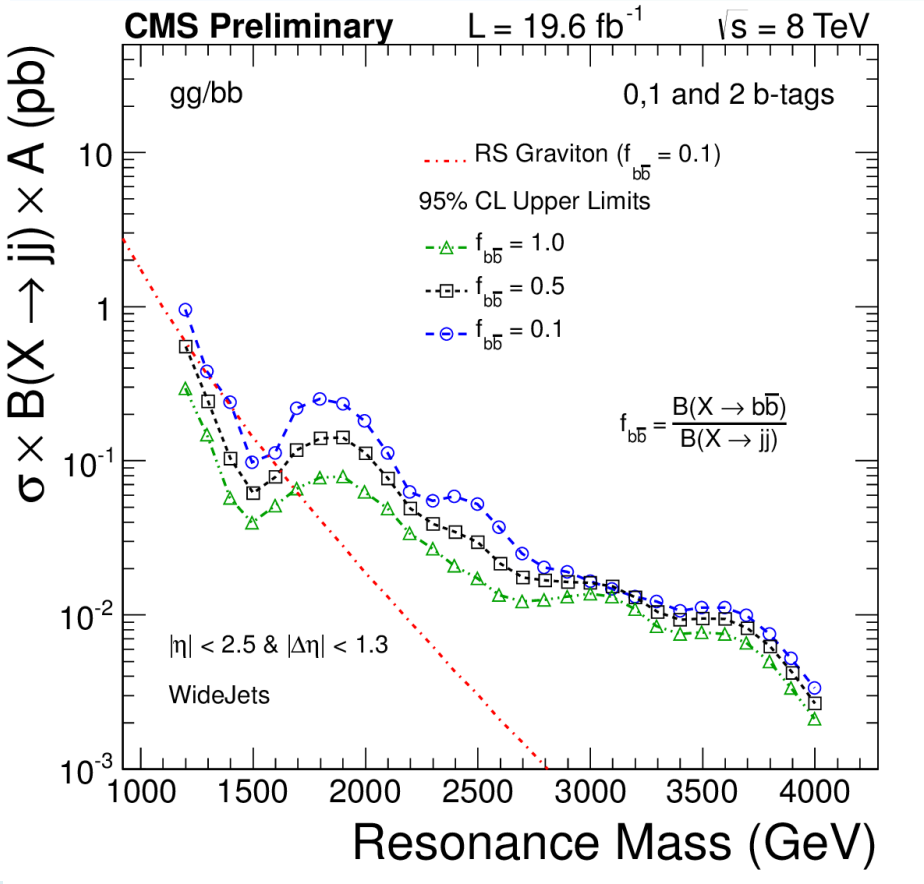




Di b-quark jet resonances

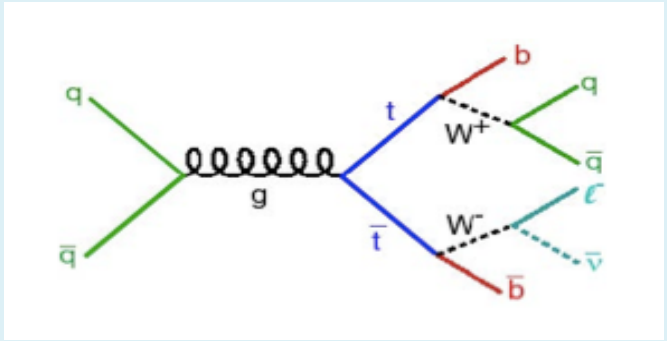
[CMS EXO-12-023] 19.6 fb^{-1}@8TeV





Exclusion regions : SSM Z' in 1.20 < M <1.68 TeV,
RS Graviton in 1.42<M<1.57
Excited b quark in 1.34<M<1.54

Top-antitop resonances

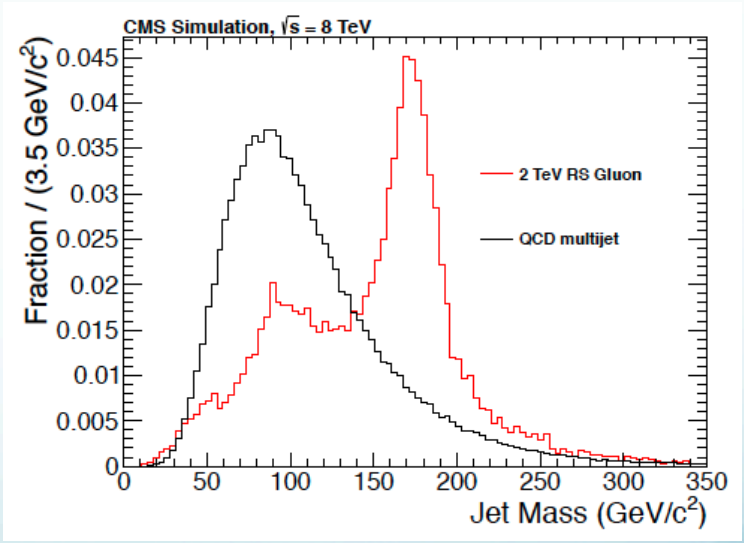


BSM extensions:
leptophobic top-color Z', RS KK gluons

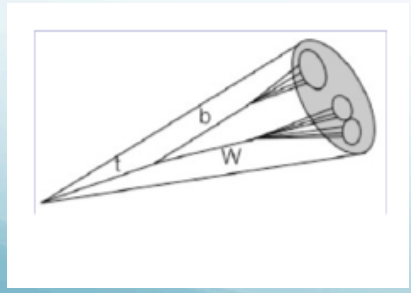
Event selection:
- lepton+jets final state
- All hadronic final state

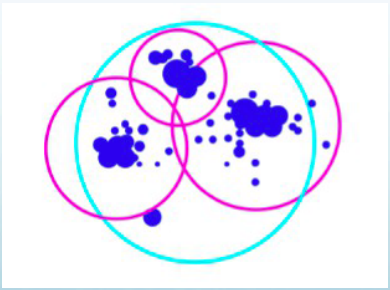
Boosted top :
→ non-isolated lepton

→ non-isolated jets:
Combine resolved (looks for individual hadronic jet from t decay) and boosted (large radius) jet



[CMS B2G-12-005]

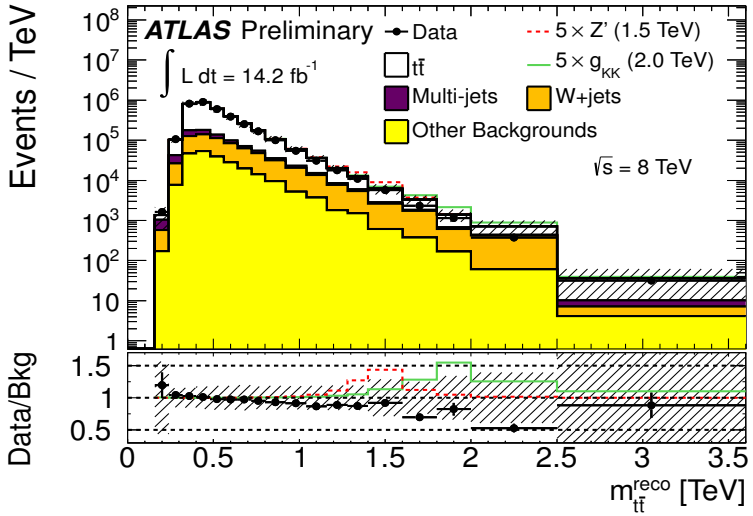




Top-antitop resonances

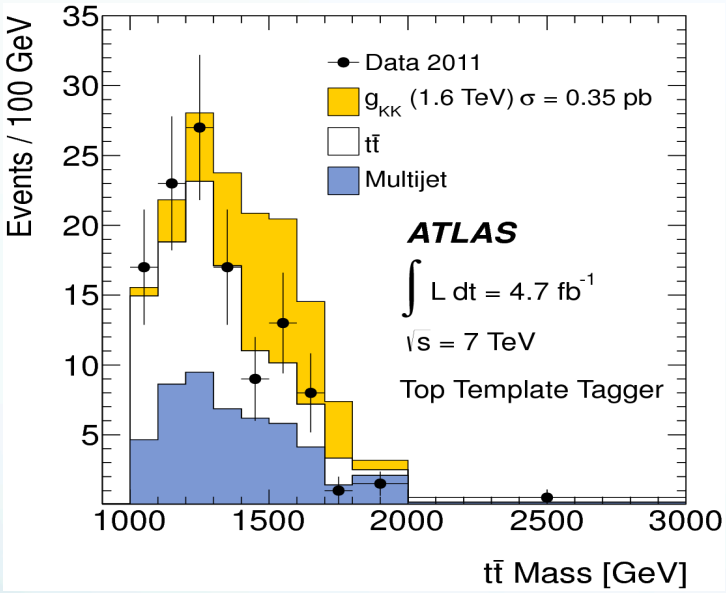
Lepton+jet final state

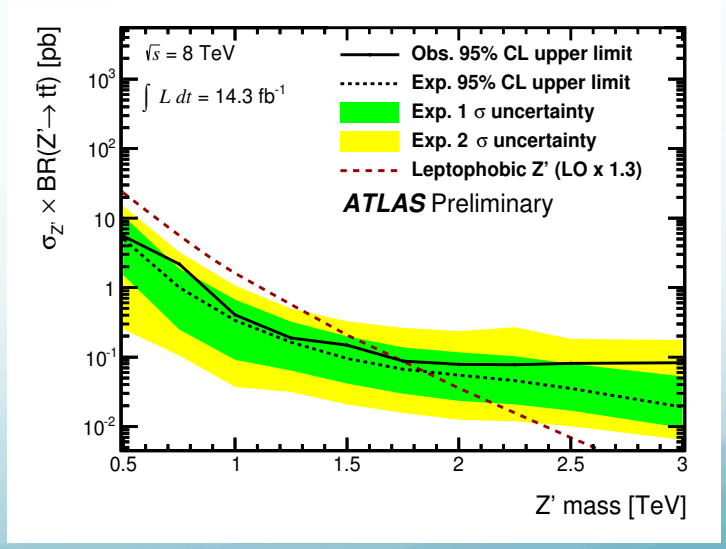
14.2 fb^{-1}@8TeV [ATLAS 13-052]



All hadronic final state

[JHEP01(2013)116] 4.7 fb^{-1}@7TeV





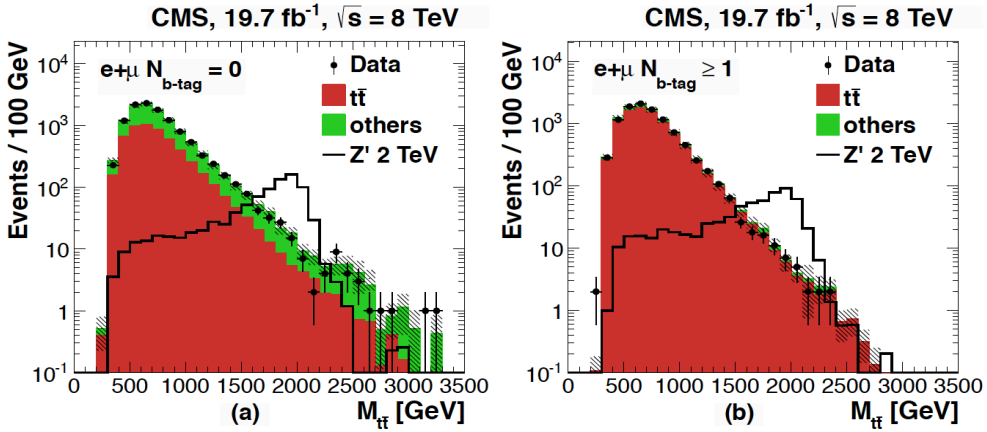
Excluded mass regions @ 95% CL:

ATLAS topcolor Z': width 1.2% : $M_{Z'} < 1.8$ TeV

RS KK gluon : $0.5 < M_G < 2.0$ TeV

Top-antitop resonances

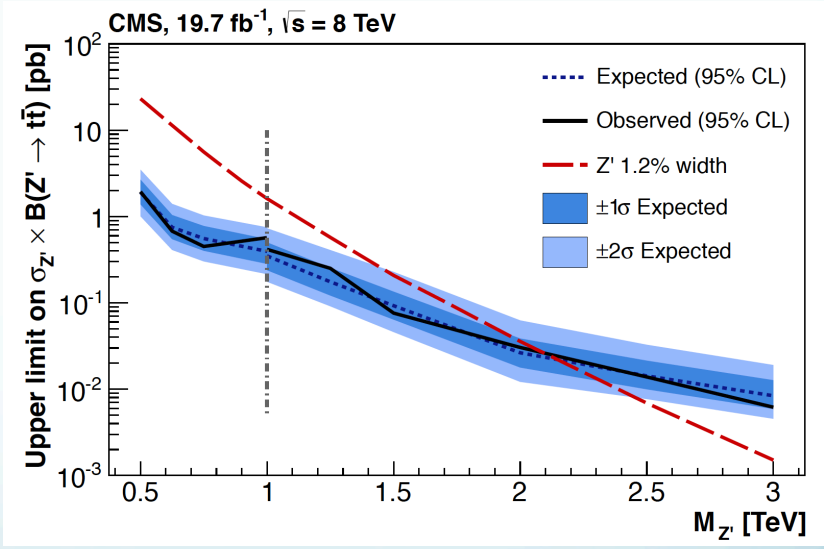
[CMS arXiv:1309.2030, subm. Phys.Rev.Lett]



Three regions :

- Resolved semi leptonic (M<1 TeV)
- Boosted semi-leptonic (M>1 TeV)
- Boosted all hadronic

Semi leptonic and all hadronic results are combined



Excluded mass regions @ 95% CL:

Topcolor Z', width 1.2% : $m_{Z'}$<2.10 TeV
Topcolor Z' width 10% : $m_{Z'}$< 2.7 TeV
RS KK gluon: M_G < 2.5 TeV

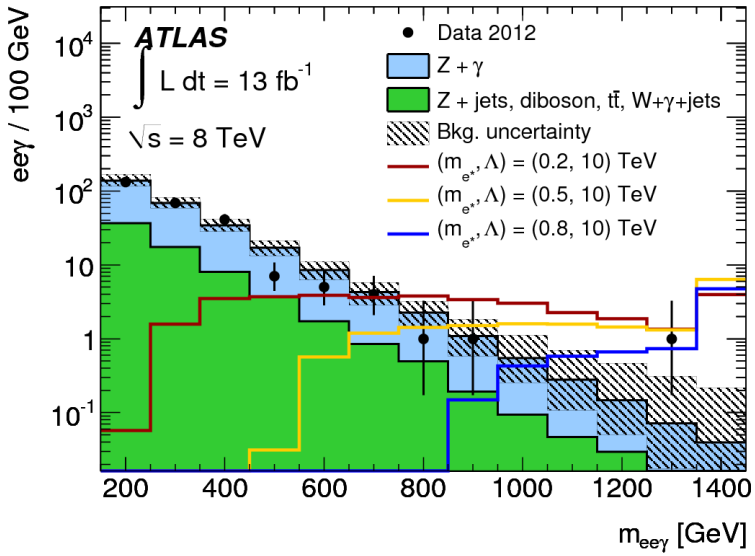
6. Excited lepton and quark searches

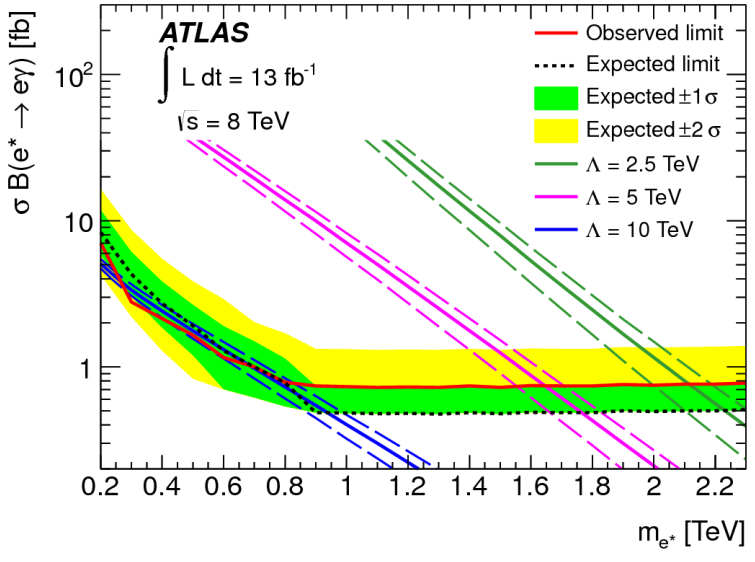
Excited e* and mu*

13.0 fb^{-1}@8TeV

[ATLAS NJP15(2013)093011]

pp → ℓℓ* XY → ℓℓγ XY



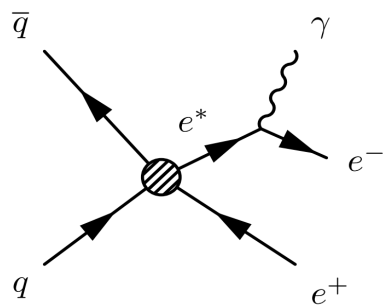


Fermion compositeness models :

- Describe SM fermions as bound states of more-elementary particles
- The existence of excited states would then be a direct consequence of the fermion substructure

Searches are based on a benchmark model :

- Effective Lagrangian ℓ* produced via four-fermion contact interactions

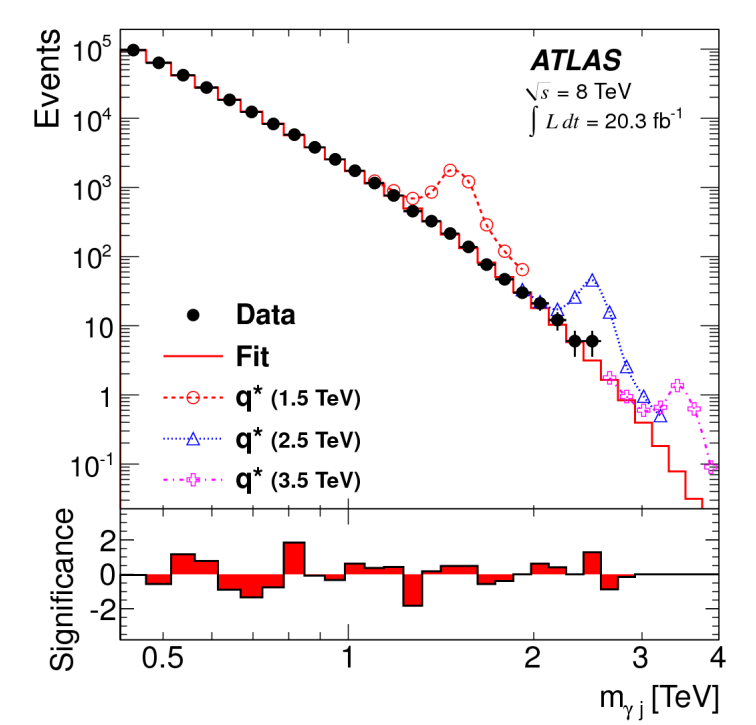


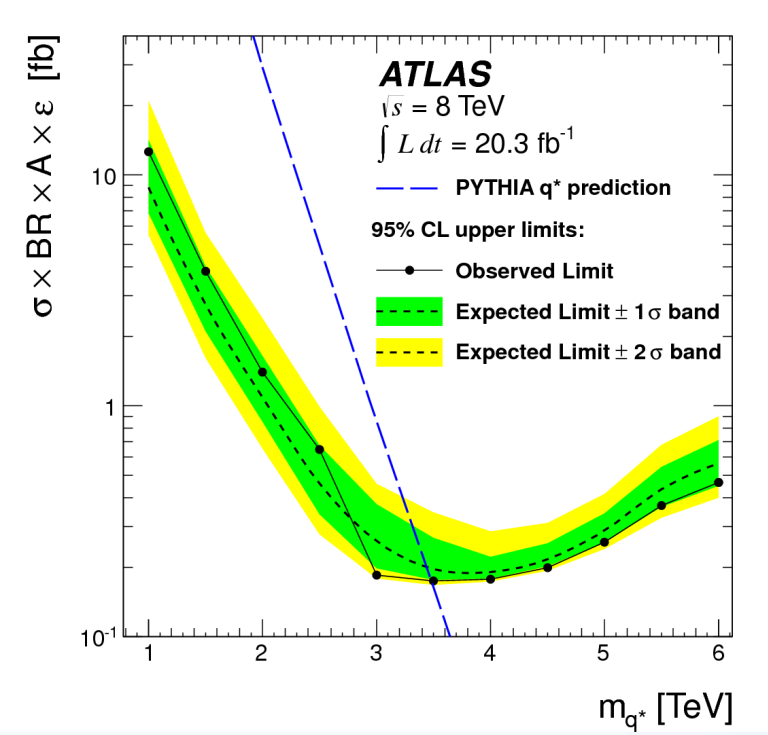
- Upper limit is set at 95% CL on σB(ℓ* → ℓγ)
- For m(l*)≥ 0.8 TeV, σB < 0.75 fb (e*) and σB < 0.90 fb (μ*)
- Converted to bounds on compositeness scale Λ
- In case Λ=m(l*), m(e*) and m(mu*) > 2.2 TeV.

(Photon+jet) resonance

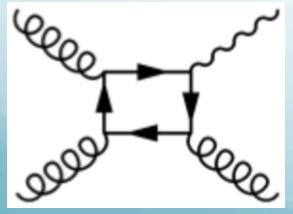
20.3 fb^{-1}@8TeV

[ATLAS arXiv:1309.3230, subm. to PLB]

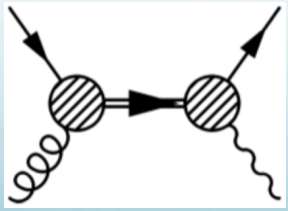




SM process

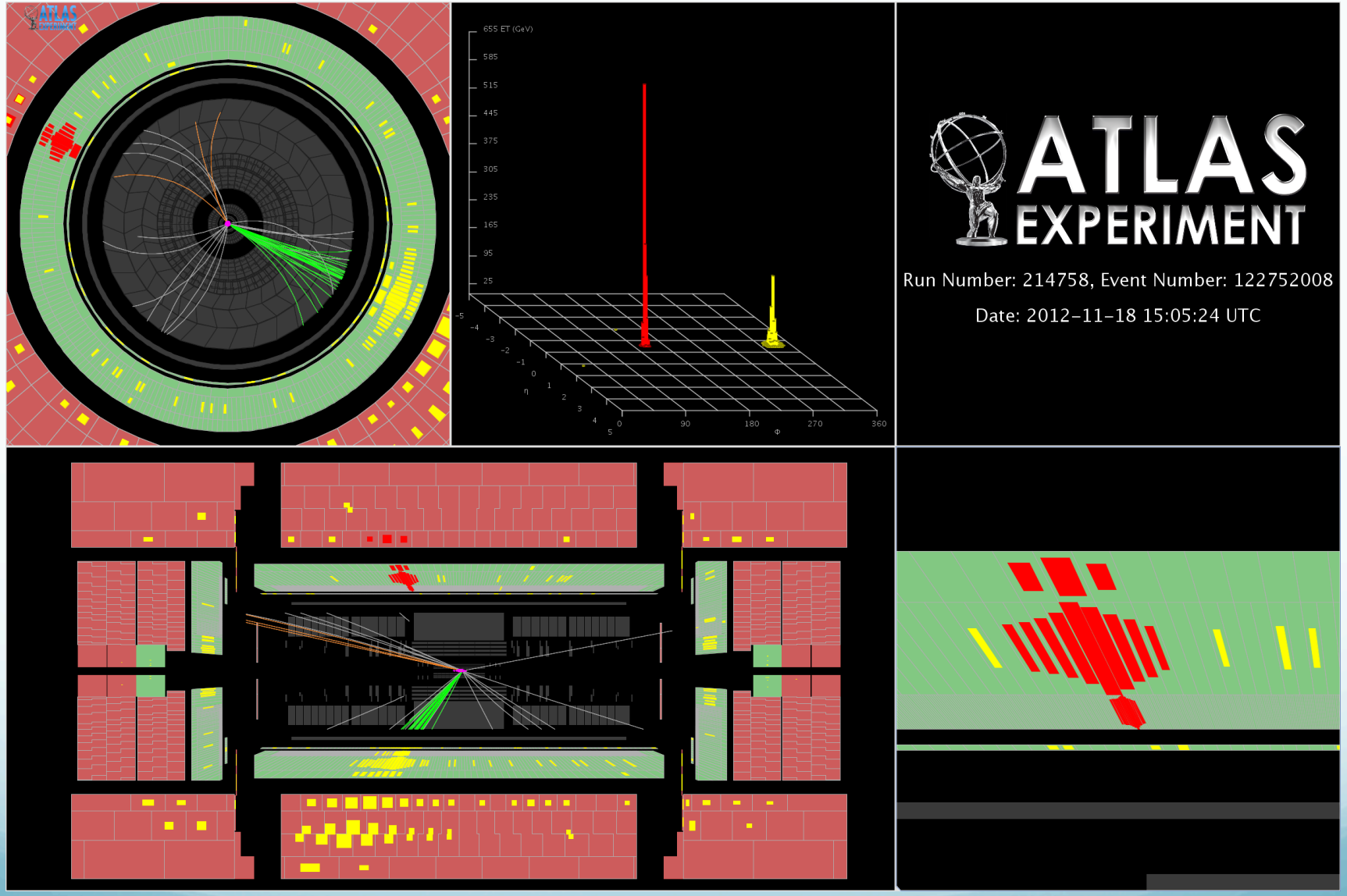


BSM diagram



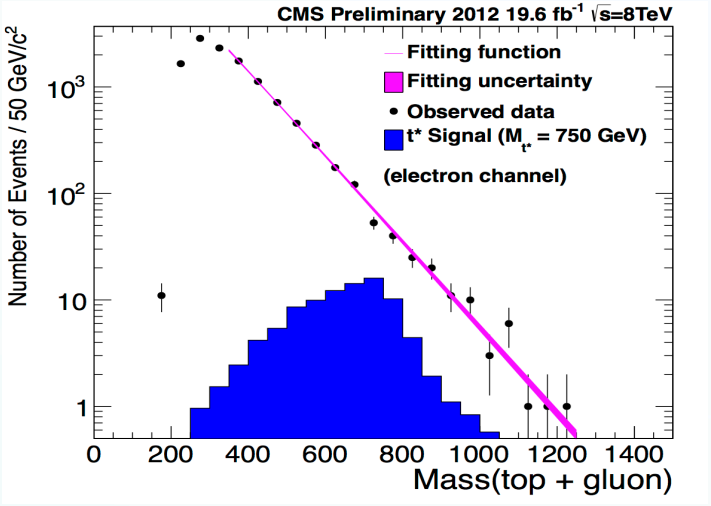
- The limits on Gaussian-shaped resonances exclude 4 TeV resonances with visible cross-sections near 0.1 fb.
- Excited-quark : M>3.5 TeV
- Non-thermal quantum black hole : M>4.6 TeV

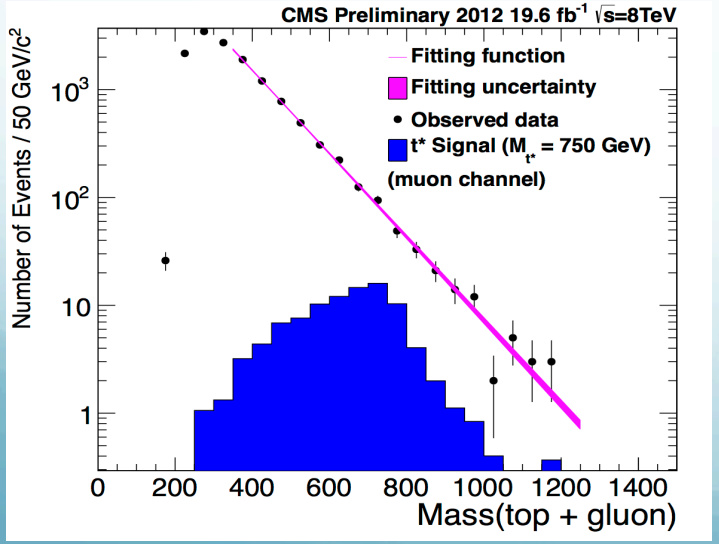
(Photon+jet) resonance



Search for pair-produced excited top : with t* → t gluon

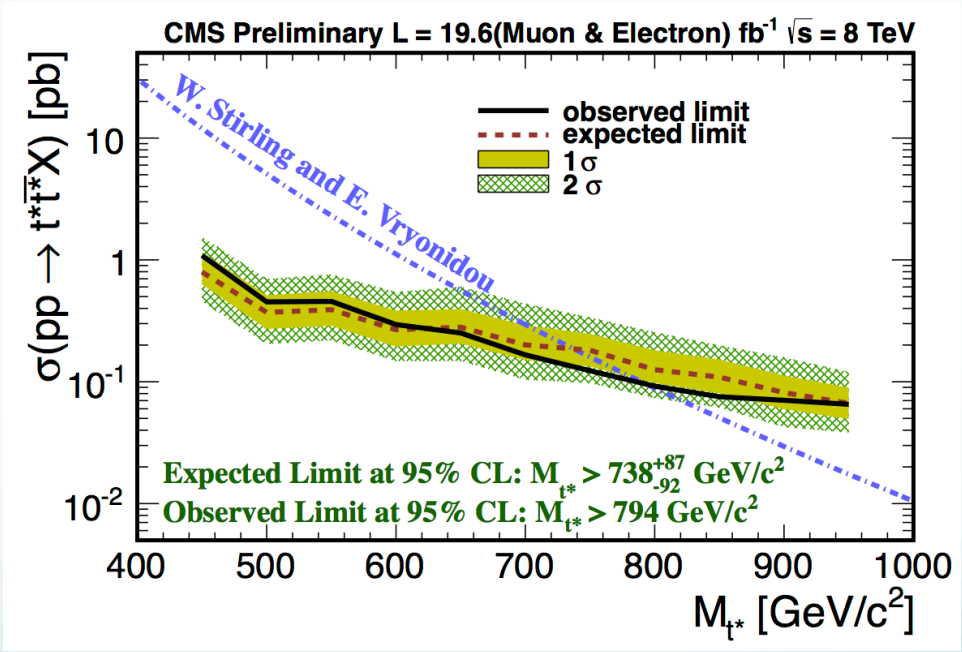
[CMS B2G 12-014]





Final state : semileptonic decay

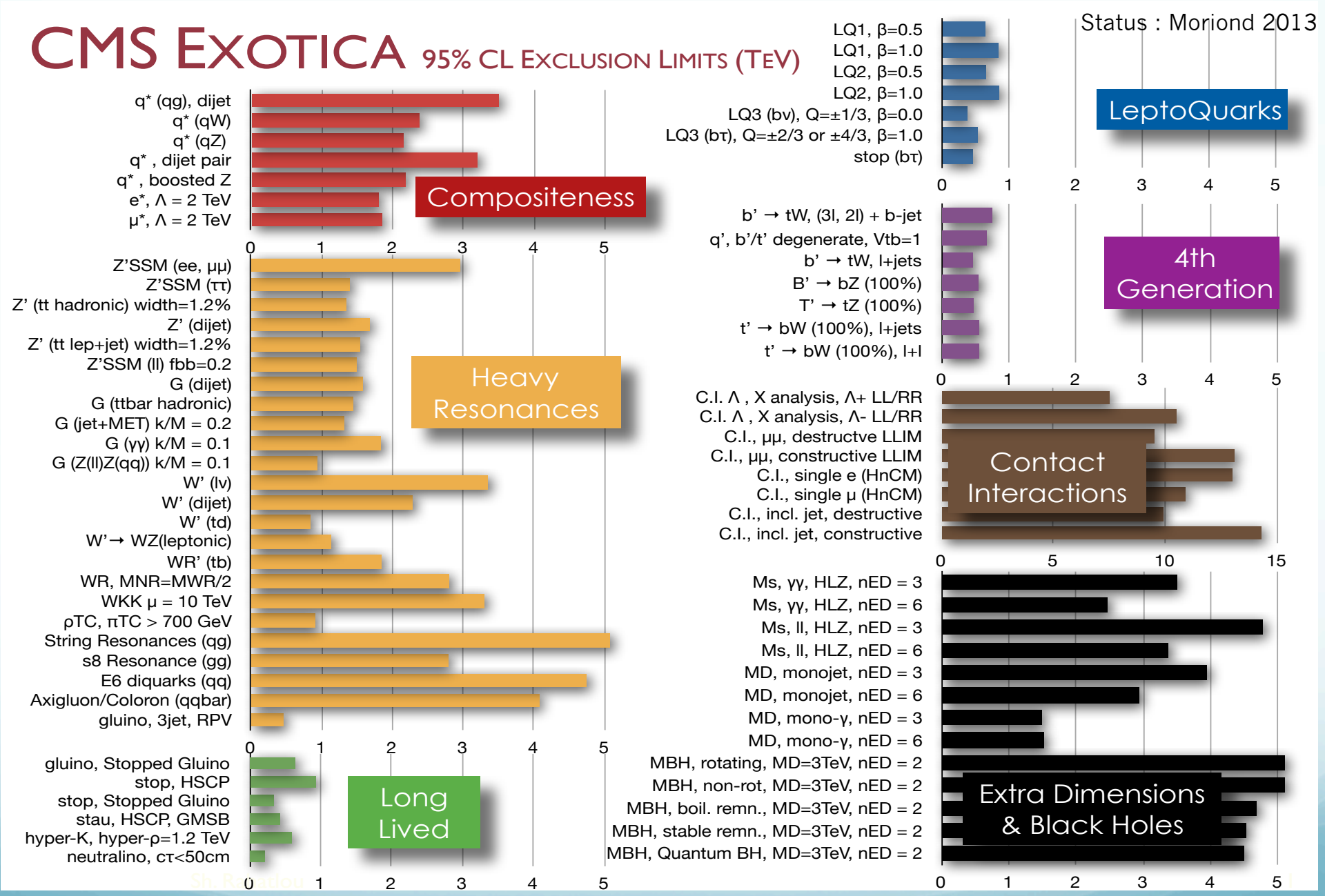
-> one isolated lepton, MET,
at least 6 jets, one of which : b-tag

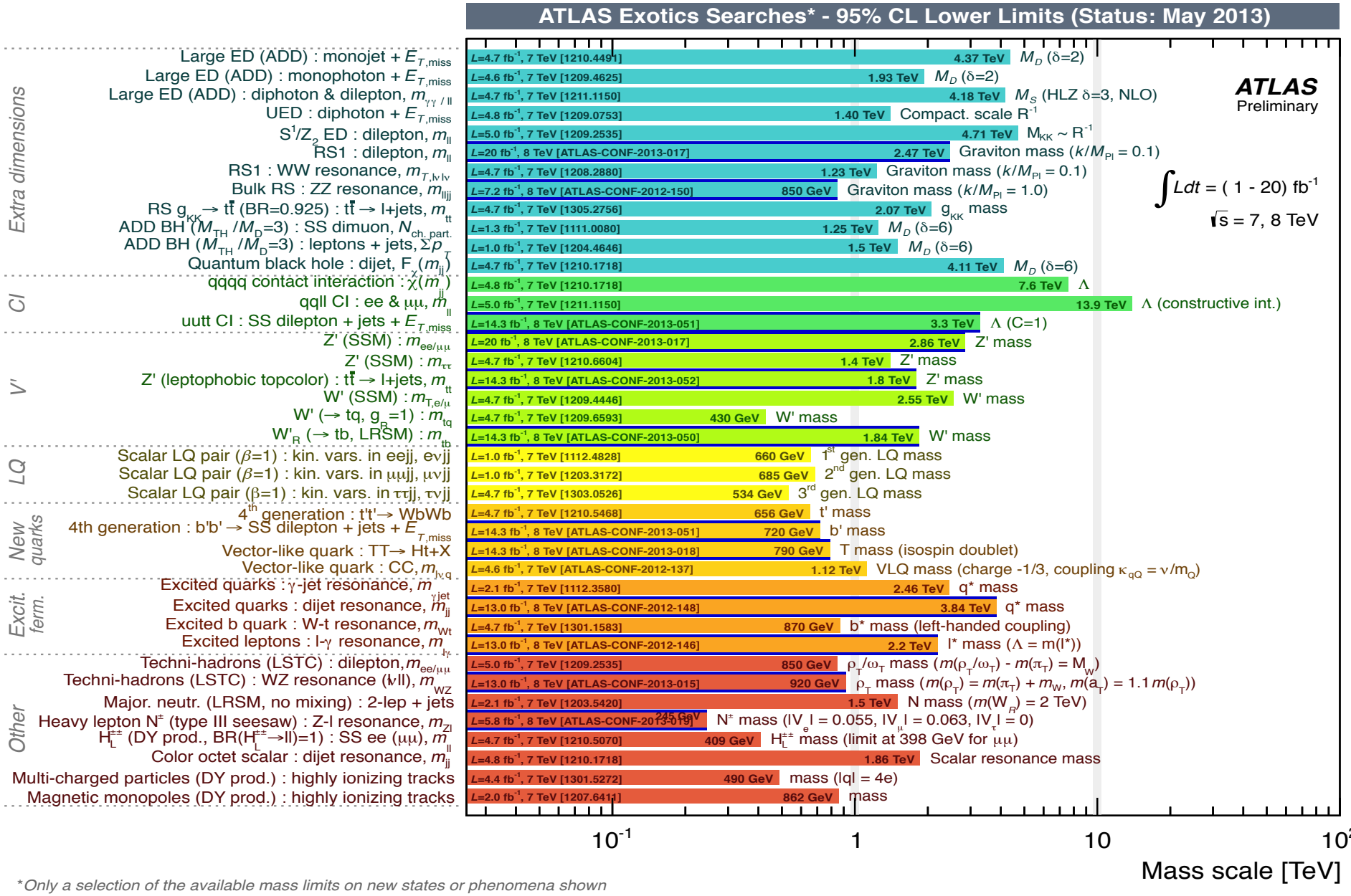


lower limit is on a t* quark mass of :
M > 794 GeV at 95% CL

7. Conclusions and prospects

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)



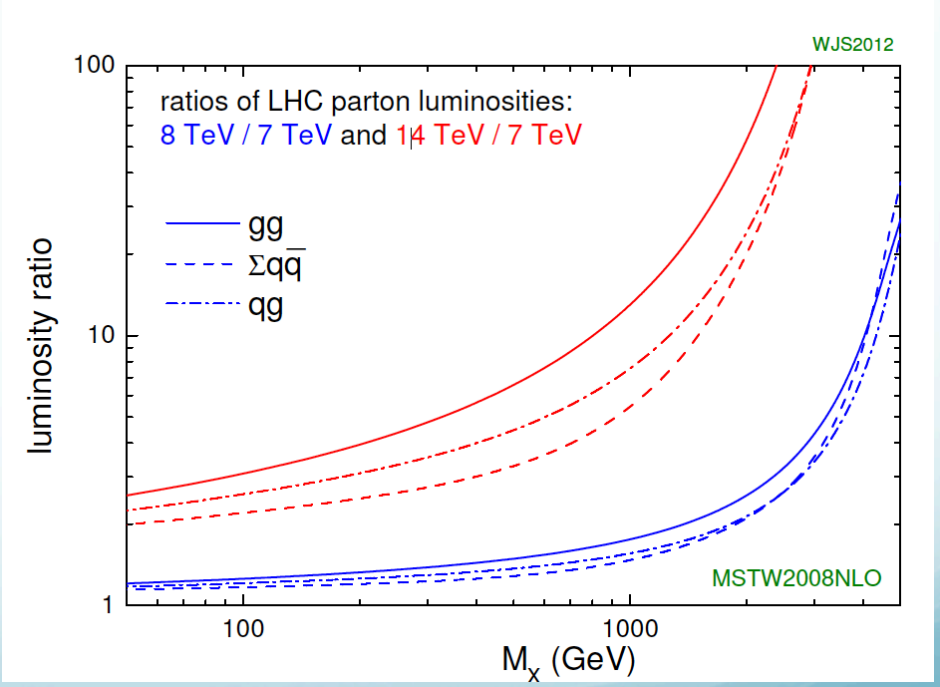


*Only a selection of the available mass limits on new states or phenomena shown

- Impressive results on BSM searches by ATLAS and CMS
- **No evidence for BSM signal !**
  All what we see so far: well compatible with the SM
- For some analysis : update with the full 8 TeV dataset will come soon

More to come; we are not done : RUN2

High energy – high lumi
RUN2 coming in 2015-17 with 13-14 TeV will enlarge the phase space : significant step towards for small couplings and large masses



THANK YOU SO MUCH FOR THE INVITATION!

VERY WARM THANKS TO THE LOCAL ORGANISATION COMMITTEE
For absolute great job!
In talk session organisation, transports, constant food , excursions …