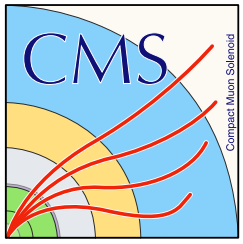


Lake Louise Winter Institute 2016

Search for New Physics in Final States with Jets and Bosons at CMS

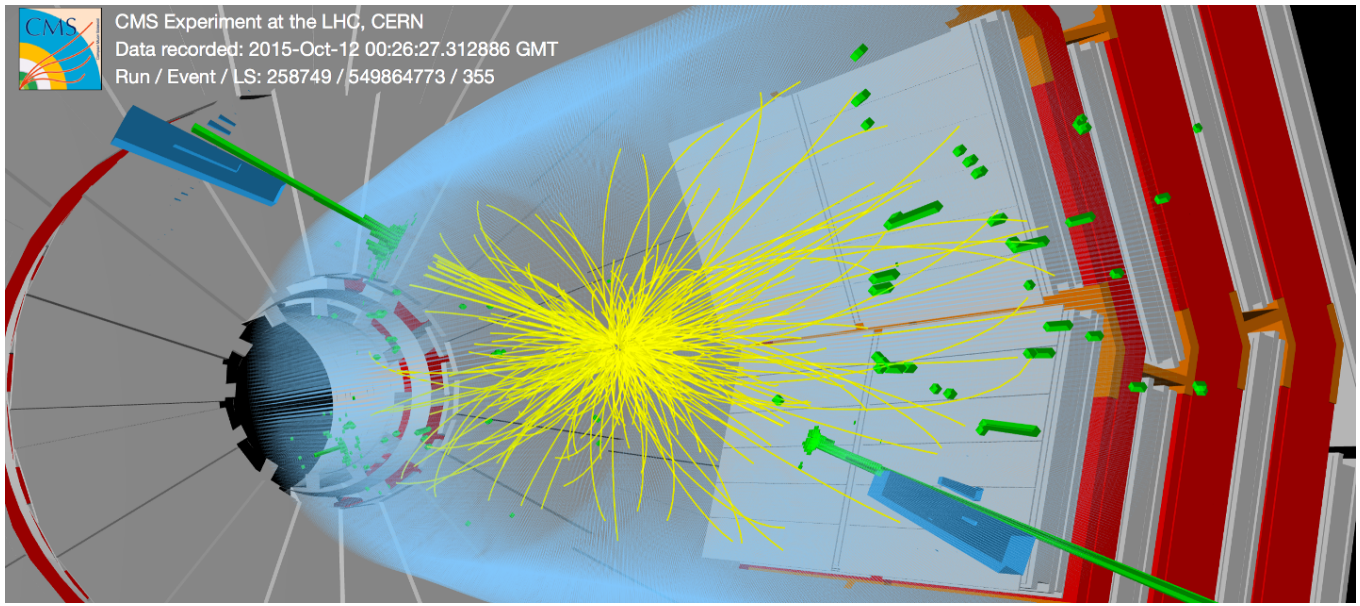
Juska Pekkanen
juska@cern.ch

University of Helsinki & Helsinki Institute of Physics

February 8, 2016

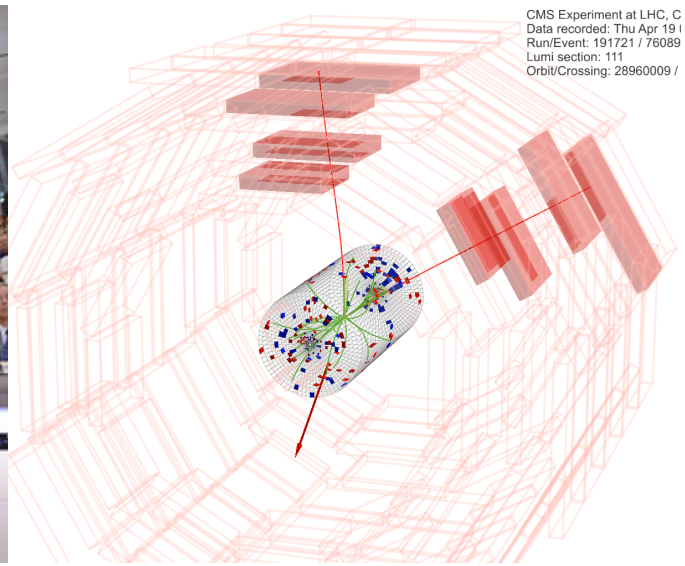
Outline

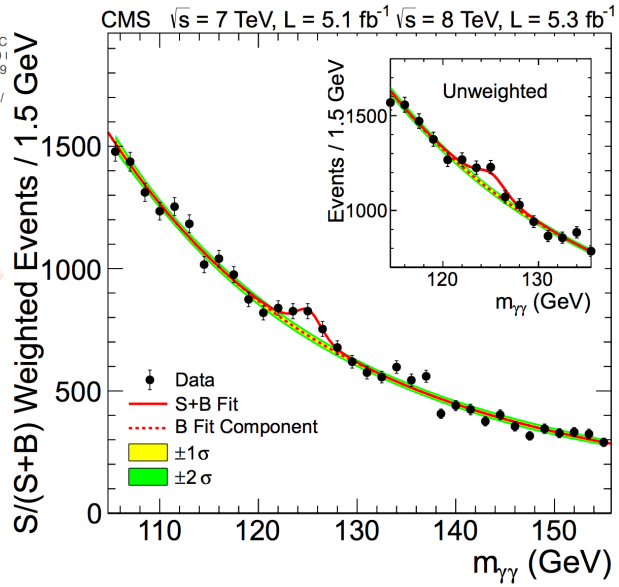
- Motivation for Exotica Searches
- Basic Analysis Strategy
- Dijet Resonance Search
- Diboson Resonance Search
- Conclusions & Outlook



Higgs found, hooray!

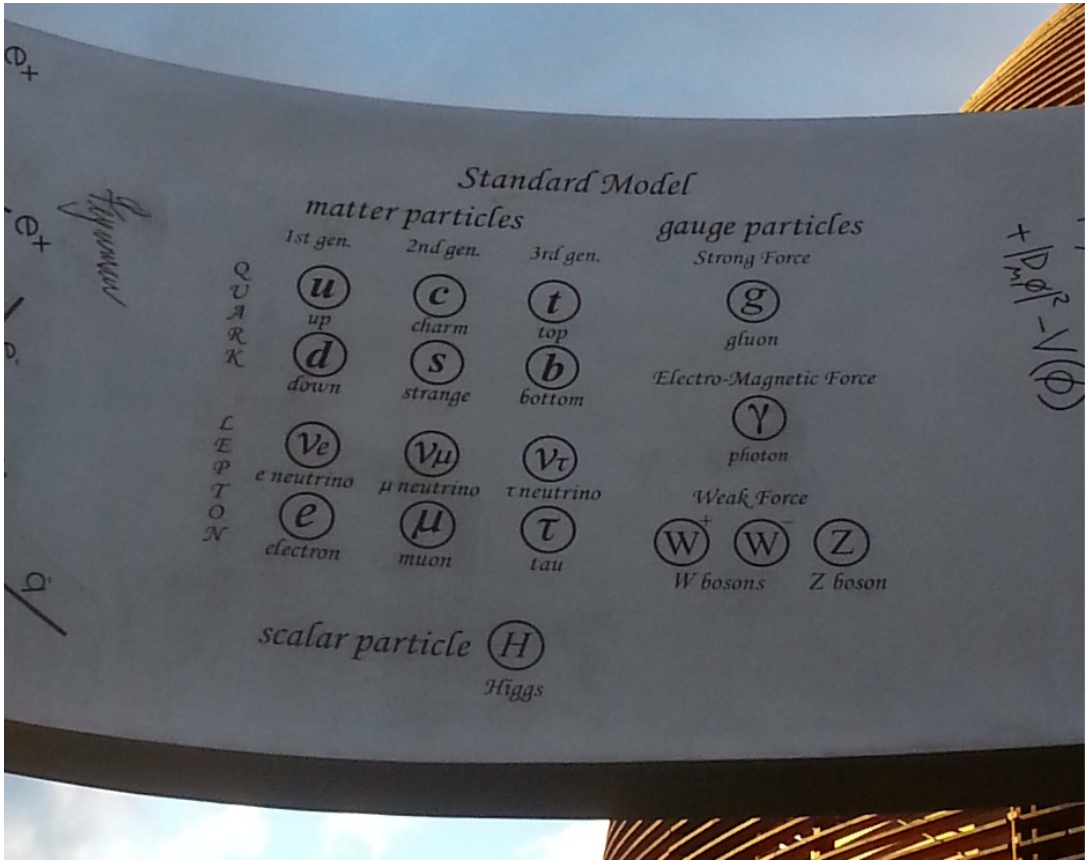
- 'Last piece of Standard Model' found at CERN in 2012
- Studies with 2013 run show no deviance from SM





...but SM is clearly not all that Mother Nature has to hide!

So what else could there be?

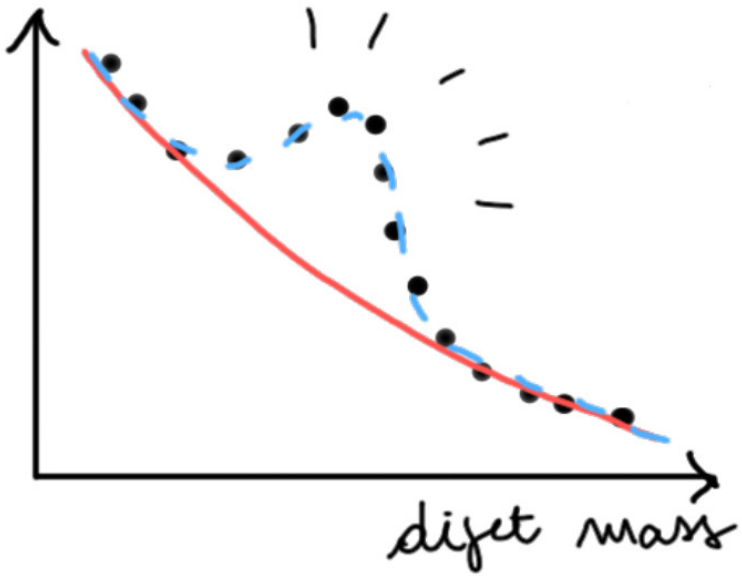


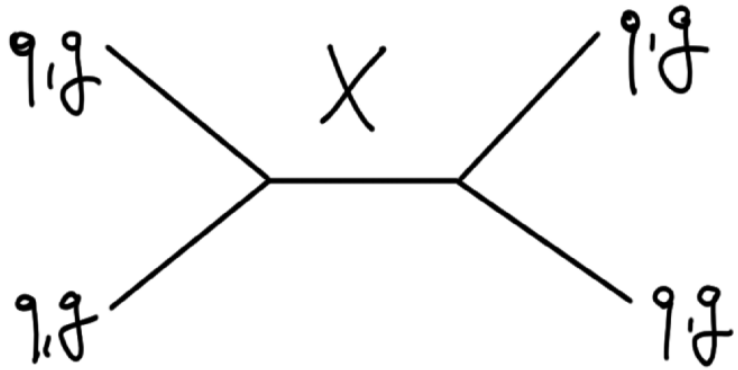
+ ?

We need to look everywhere now!

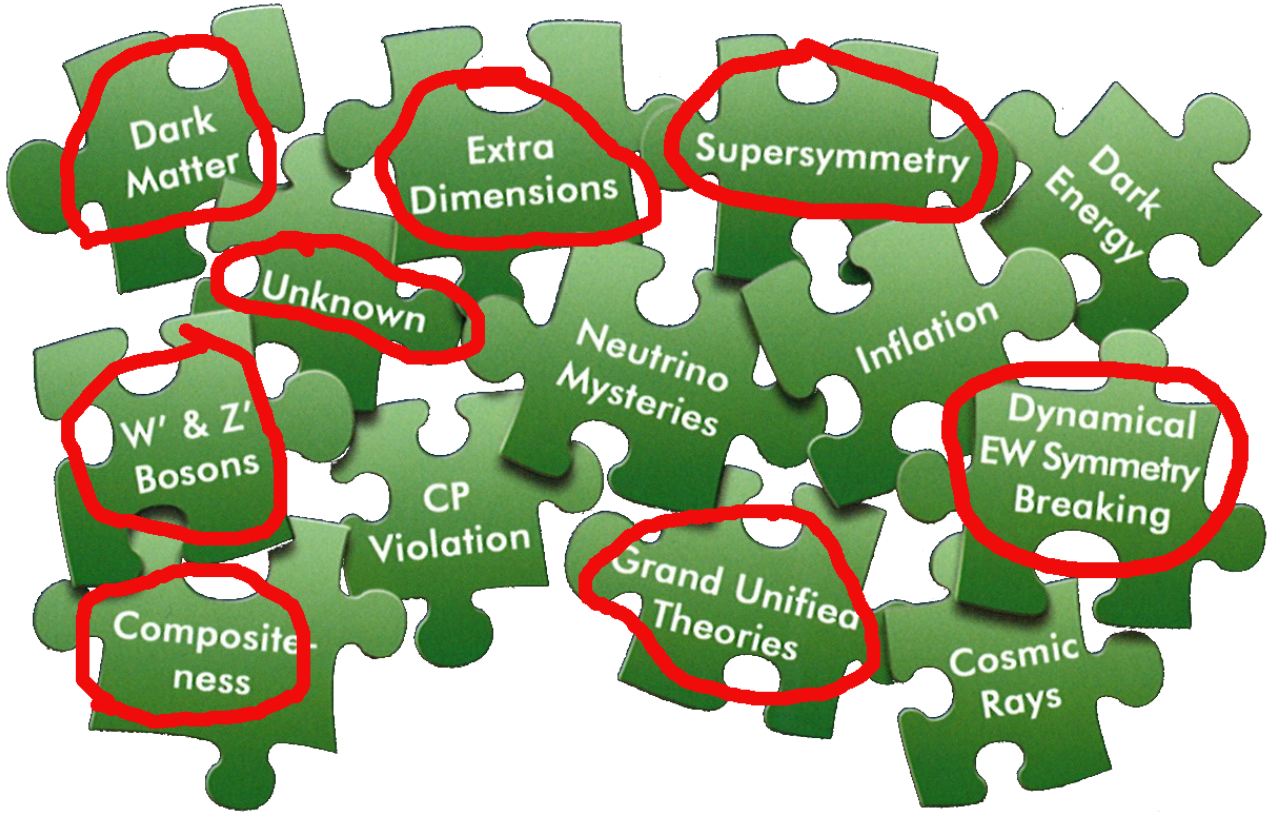
But how to look 'everywhere'?

1. Look for events with objects in back-to-back topology
   → This is how any resonance must decay
2. Reconstruct the invariant mass of the physics objects
3. Fill a histogram with mass spectrum
4. Look for irreguralities in smoothly falling spectrum





Discovery potential of Exotica resonance searches

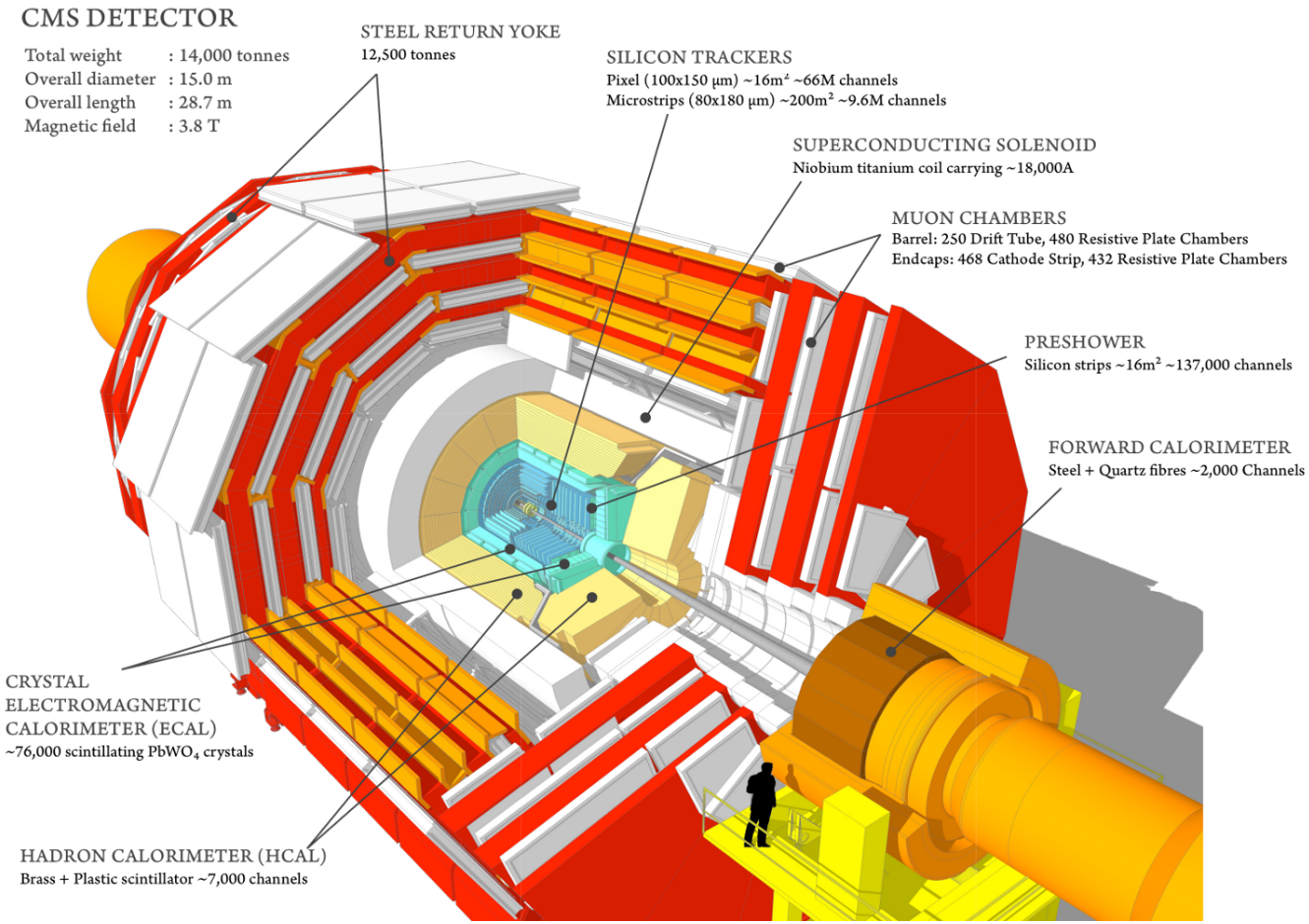


Accessible with Exotica Resonance Searches:

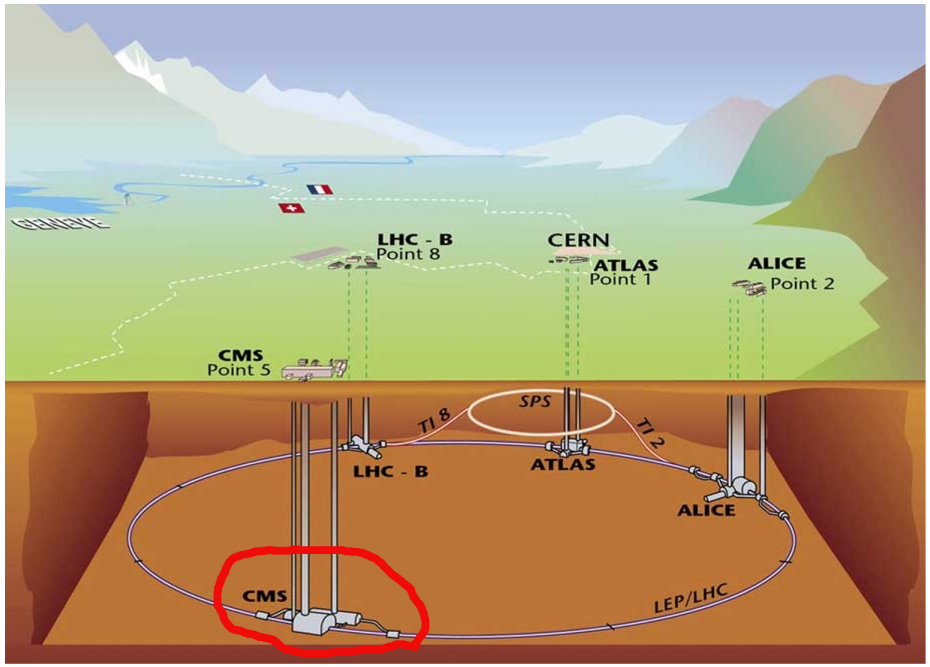
- Excited Quarks
- Scalar Diquarks
- String Resonances
- Z' & W' Bosons
- RS Gravitons
- Color-Octet Scalars
- Axigluons/Colorons
- Supersymmetry
- Dark Matter

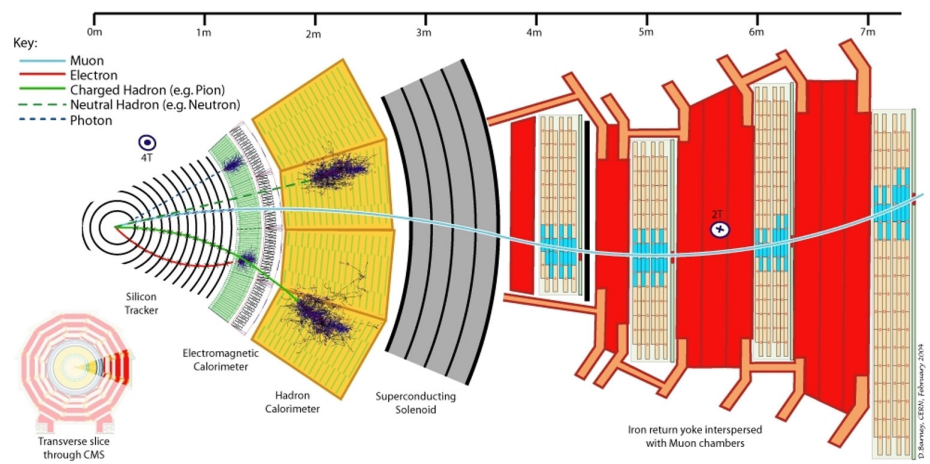
The Compact Muon Solenoid Experiment

- 15x30m multipurpose experiment
- Accurate muon chambers & ECAL
- 3.8T magnetic field
- Particle Flow evt reco



The Compact Muon Solenoid Experiment





Lake Louise Winter Institute 2016
Juska Pekkanen, juska@cern.ch

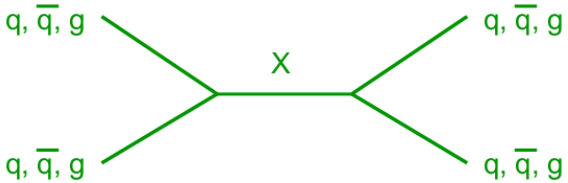
Analyses

1. Dijet Resonance Search

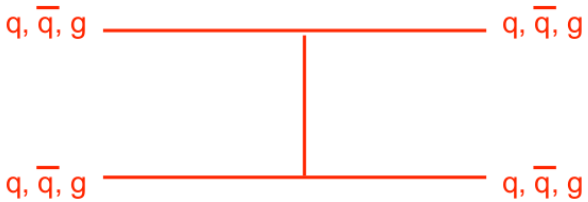
Search for Narrow Resonances Decaying to Dijets

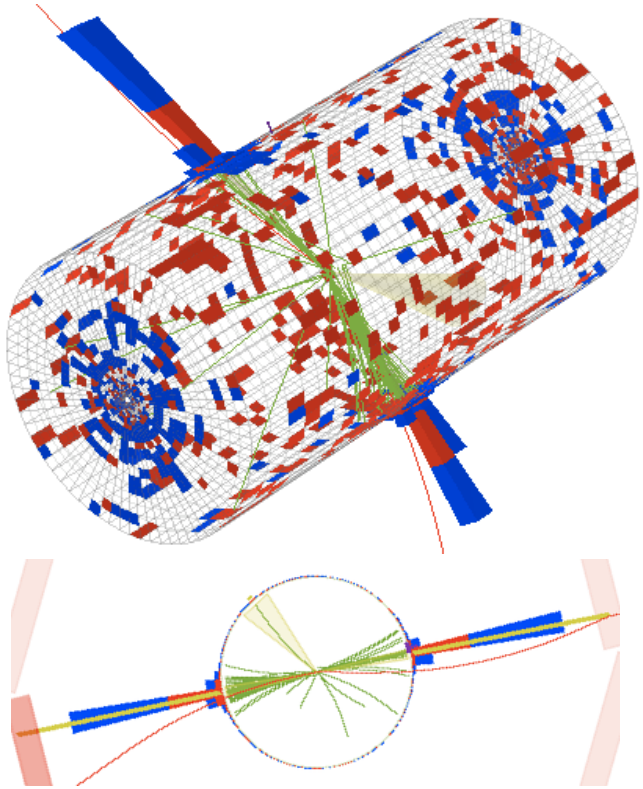
Look at collision events with **dijet topology:**

Resonance Signal



QCD Background



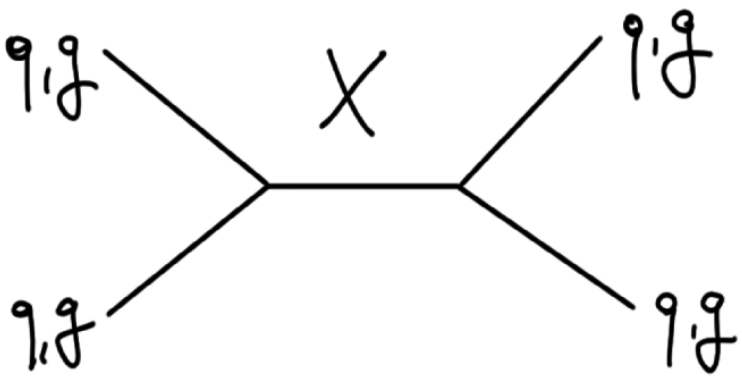


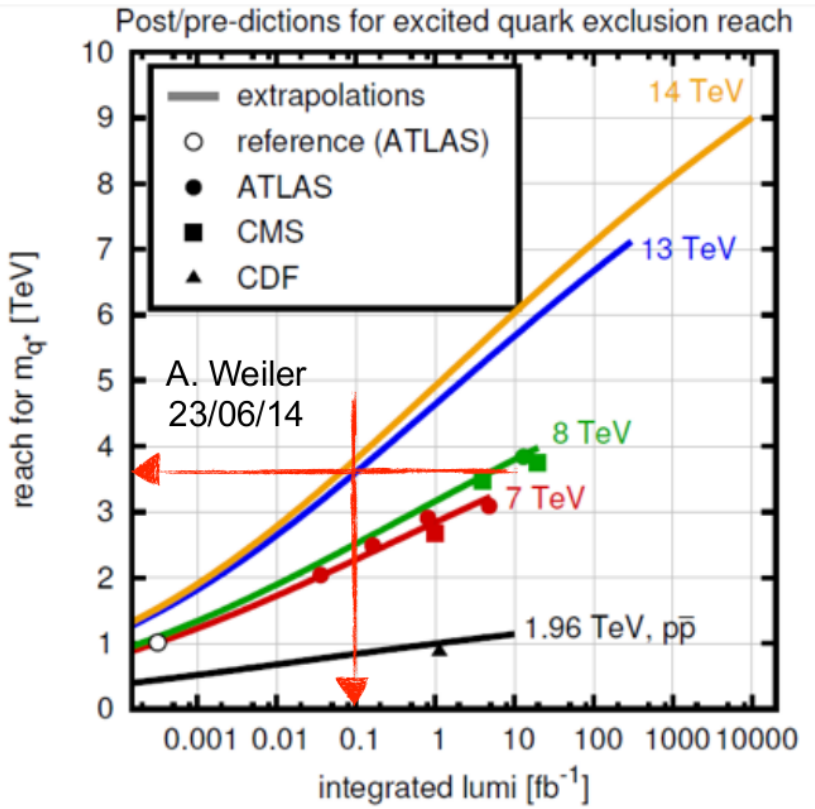
- If a resonance produced from q/g, it must also decay to q/g!
- Use wide jets (Anti-k_T R=1.1) to catch FSR
- Use dijets close to xy-plane to reduce QCD bkg

Motivation for Dijet Analysis

- Simple yet powerful
- Exceptional discovery potential
- Access to $\mathcal{O}$(10 TeV) resonances!
- Only 100 pb^{-1} of data equals Run1 q* cross-section

→ **High-priority CMS Early Analysis**





Analyses

1. Diboson Resonance Search

Search for Resonances Decaying to Pairs of W & Z

- Look at collision events with **Diboson topology**
  - → Choose events with boosted back-to-back V (=W,Z)
- **Semi-Leptonic** VW channel yields jets and leptons
- **Fully hadronic** VV channel yields 2x2 collimated jets

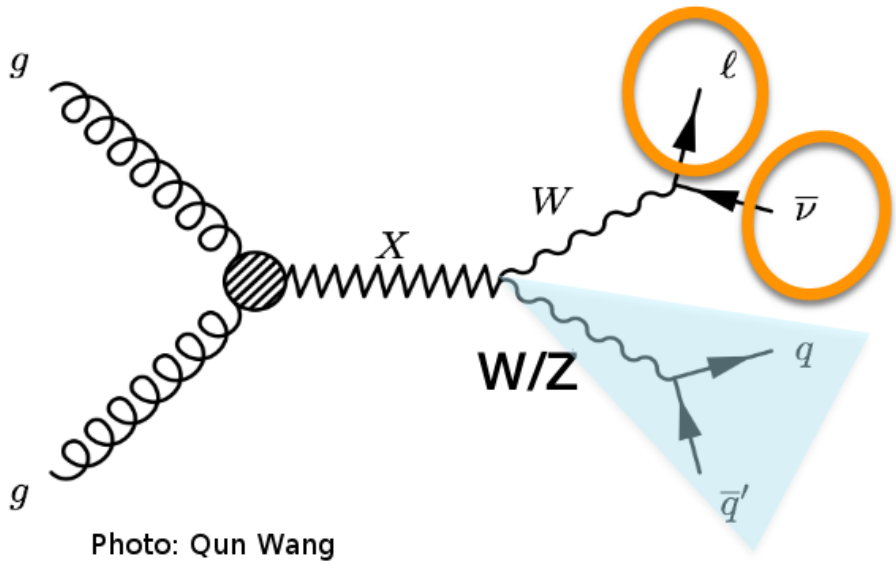


Photo: Qun Wang

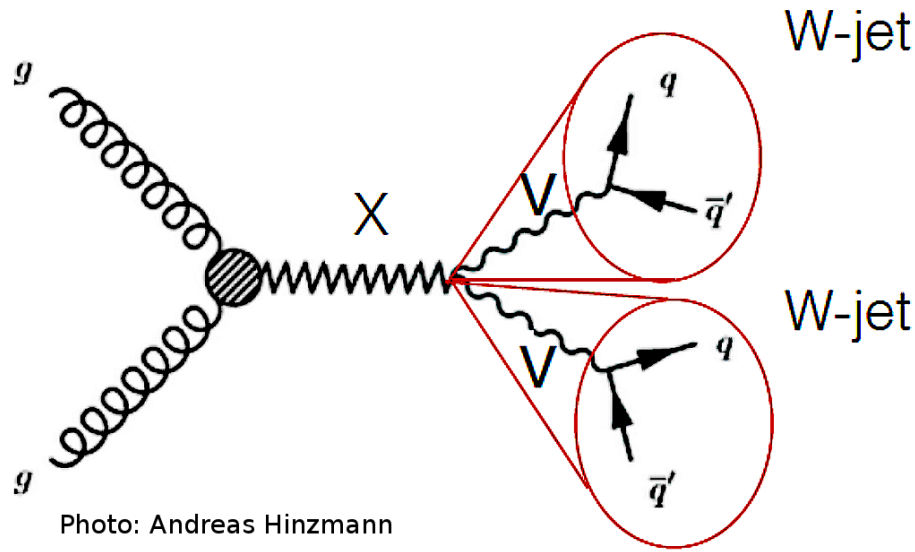
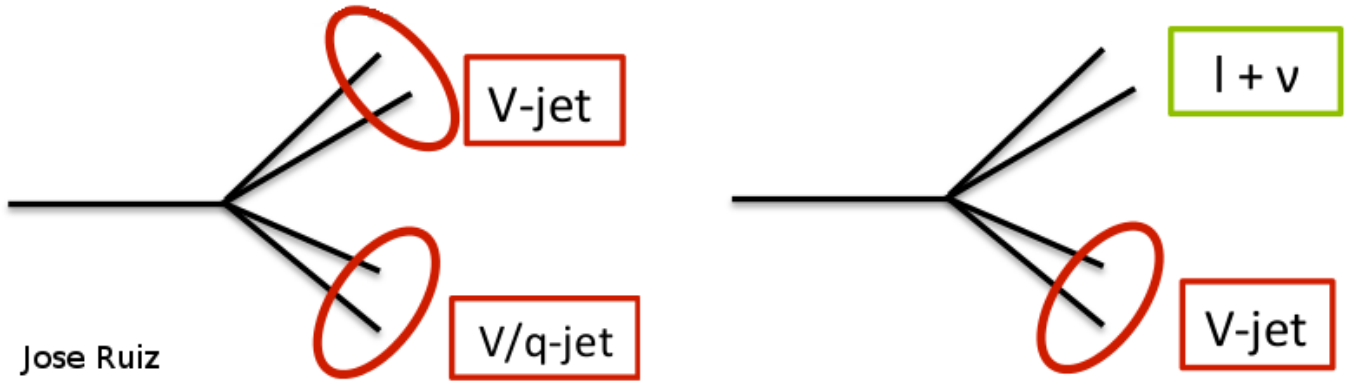


Photo: Andreas Hinzmann

Selecting events with 'V-jets':

- Hadronic W and Z decays result to two overlapping jets
  - → Search for such substructure in dijet events
- V-jets must originate from objects with W or Z mass
  - → Require 'jet pruned mass' $65 < m_{jet} < 105$ GeV



Selecting events in semi-leptonic channel:

- Search for events with W-decay footprint
  - → Require exactly one isolated muon or electron
- Insist the presence of neutrinos
  - → Require $E_T^{miss} > 40$ GeV for muons, $E_T^{miss} > 80$ for electrons

Results - Diboson search

(Warning: a plethora of plots due to combinatorics)

Results

Available on the CERN CDS information server

CMS PAS EXO-15-002

CMS Physics Analysis Summary

Contact: cms-pag-conveners-exotica@cern.ch

2015/12/19

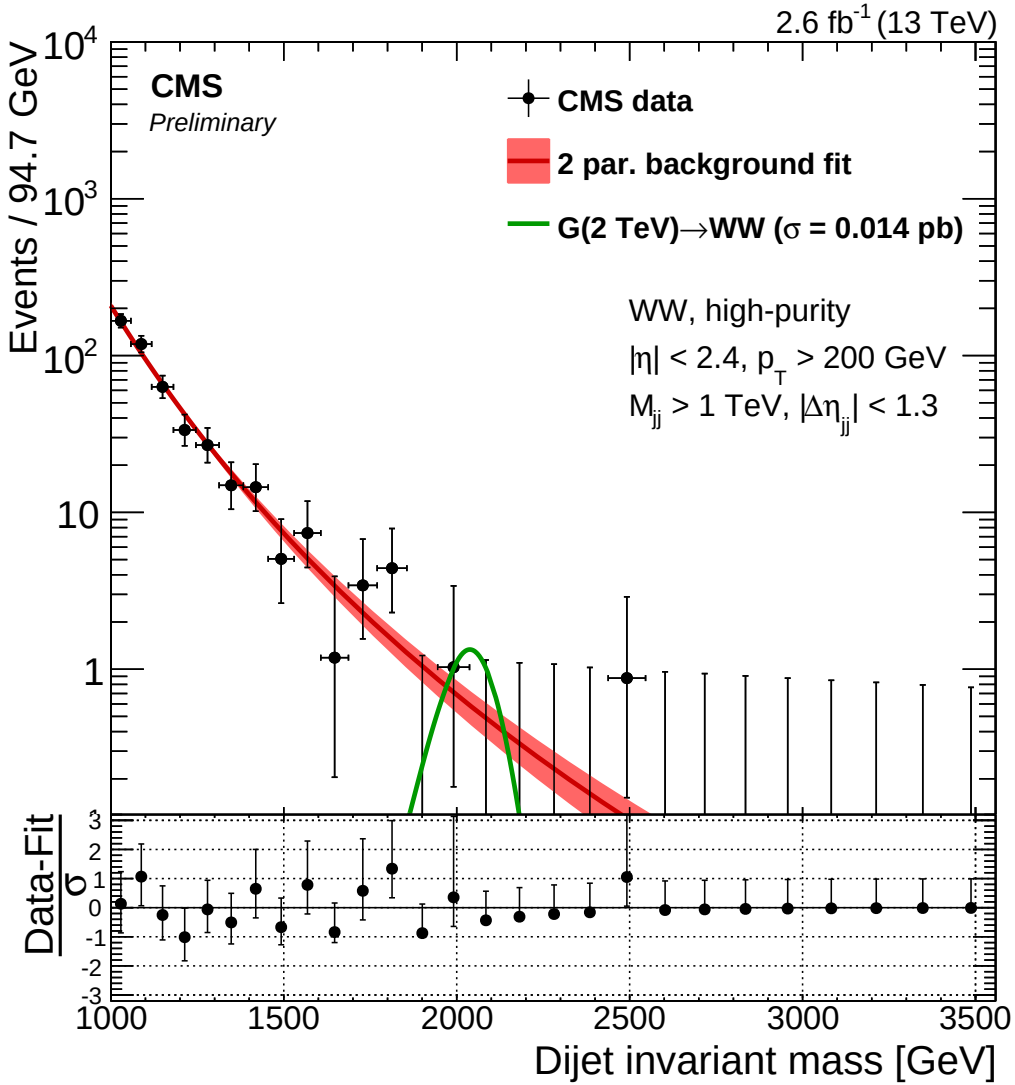
Search for massive resonances decaying into pairs of boosted W and Z bosons at $\sqrt{s} = 13$ TeV

The CMS Collaboration

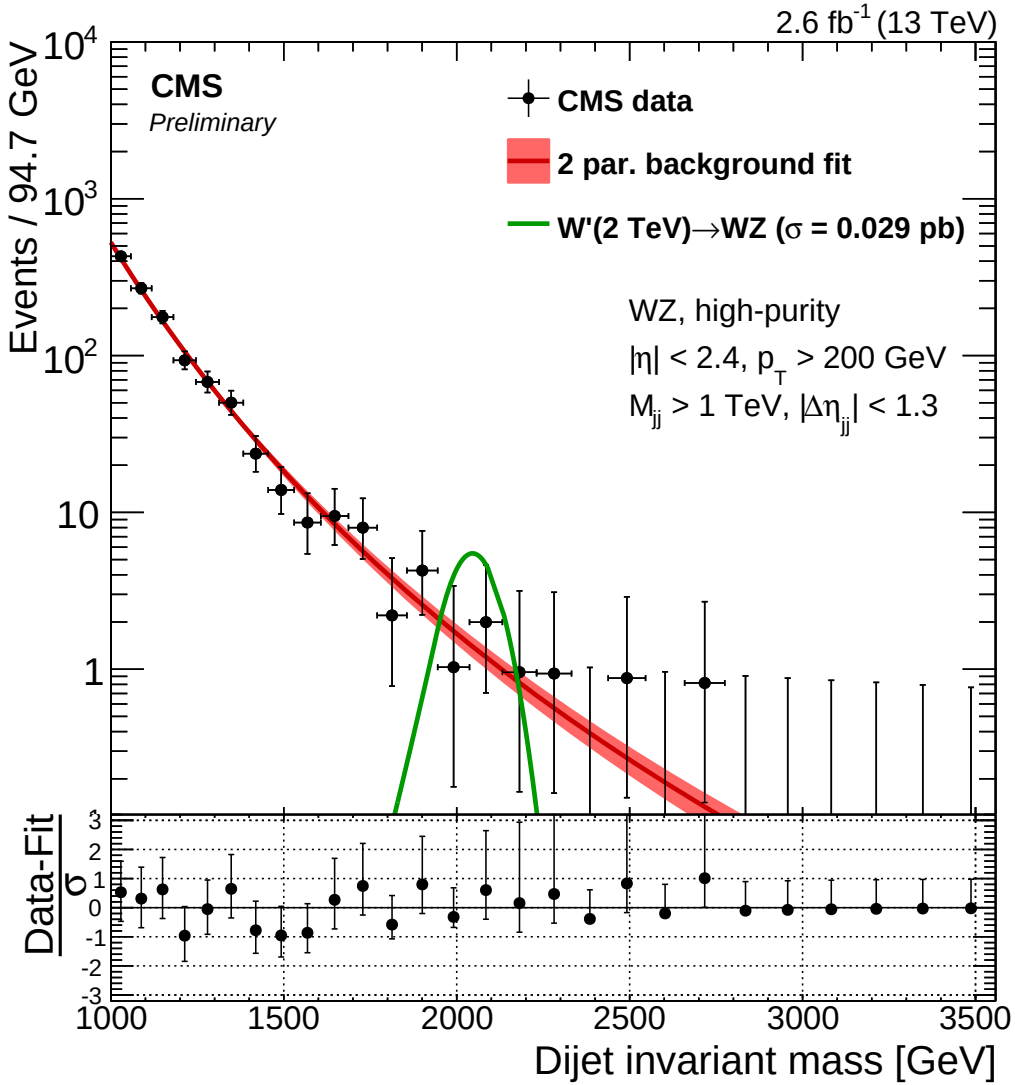
Abstract

A search for massive narrow resonances decaying to pairs of W and Z bosons, based on 2.6 fb^{-1} of pp collision data collected by the CMS experiment at the CERN LHC with a centre-of-mass energy of 13 TeV, is presented. Spin-1 and spin-2 resonances corresponding to masses of at least 0.8 TeV and decaying to WW, WZ, or ZZ, and further to lνqq or qqqq are probed. Cross section and resonance mass exclusion limits are set for various models that predict gravitons and heavy W′ bosons.

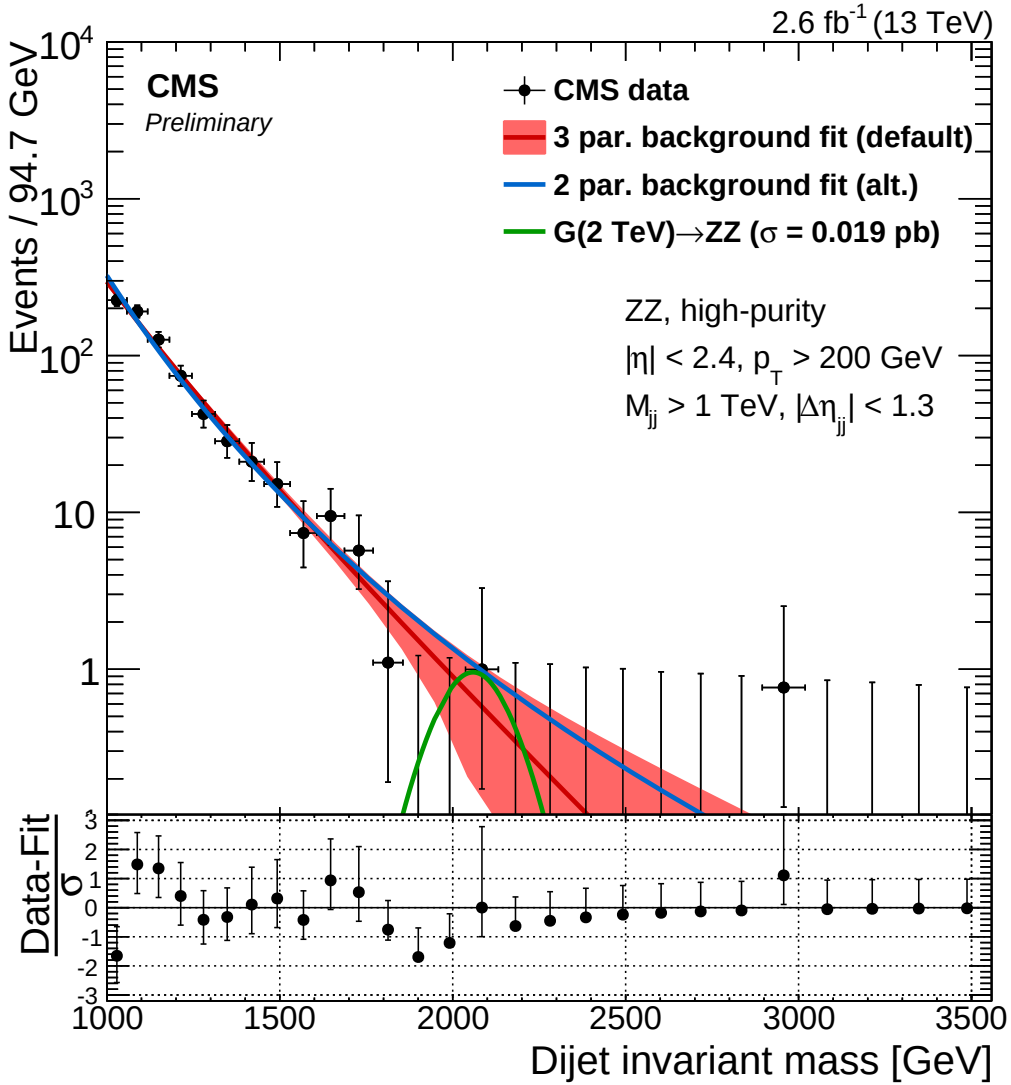
Diboson WW Hadronic



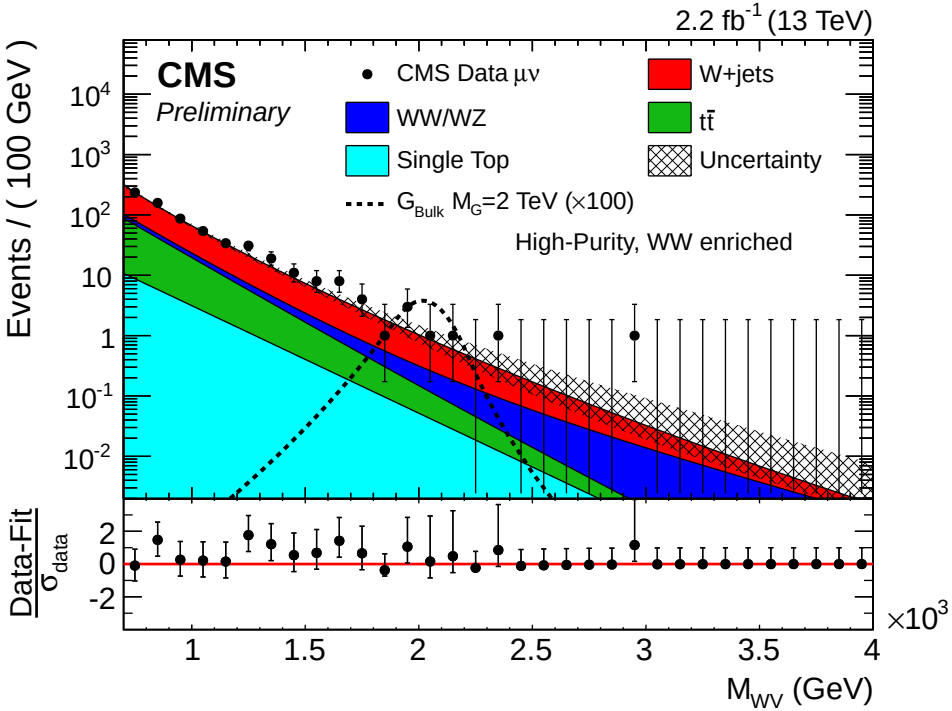
Diboson WZ Hadronic

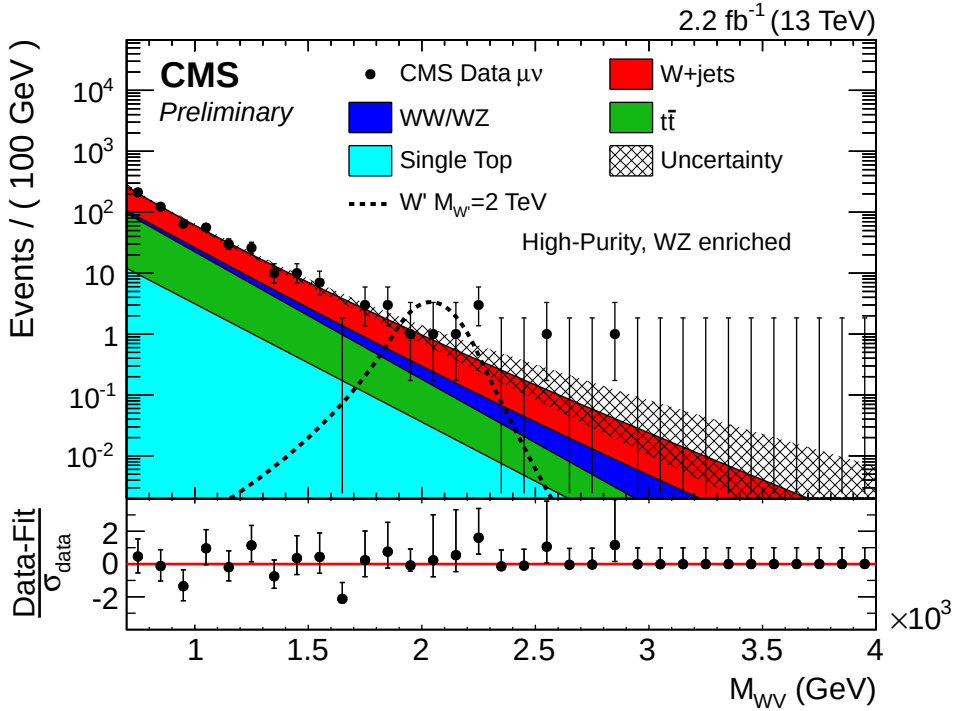


Diboson ZZ Hadronic



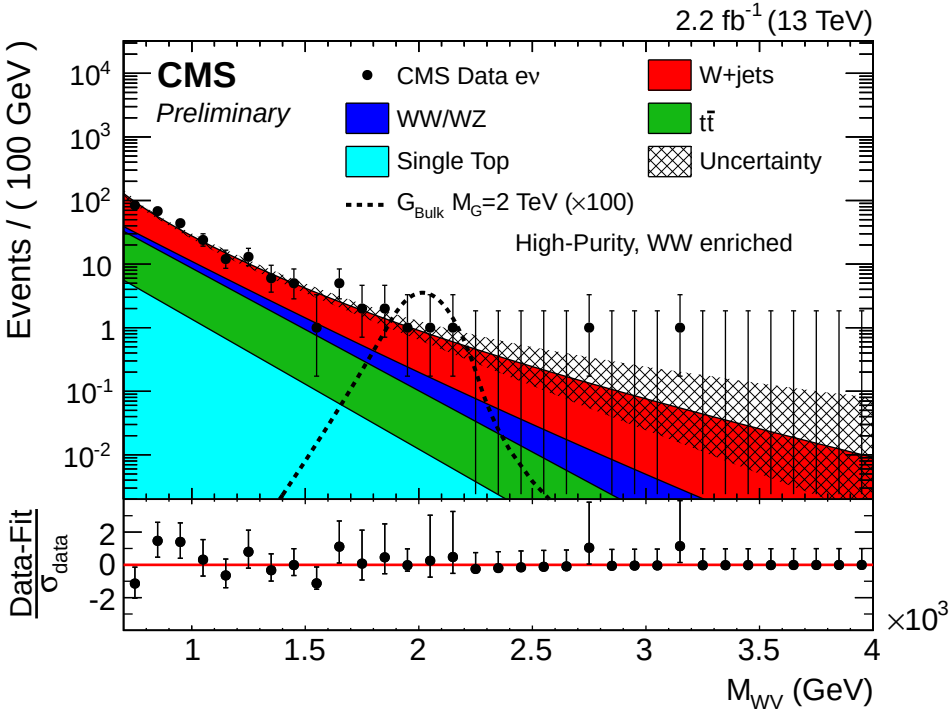
Diboson VW Semi-Leptonic, muon channel

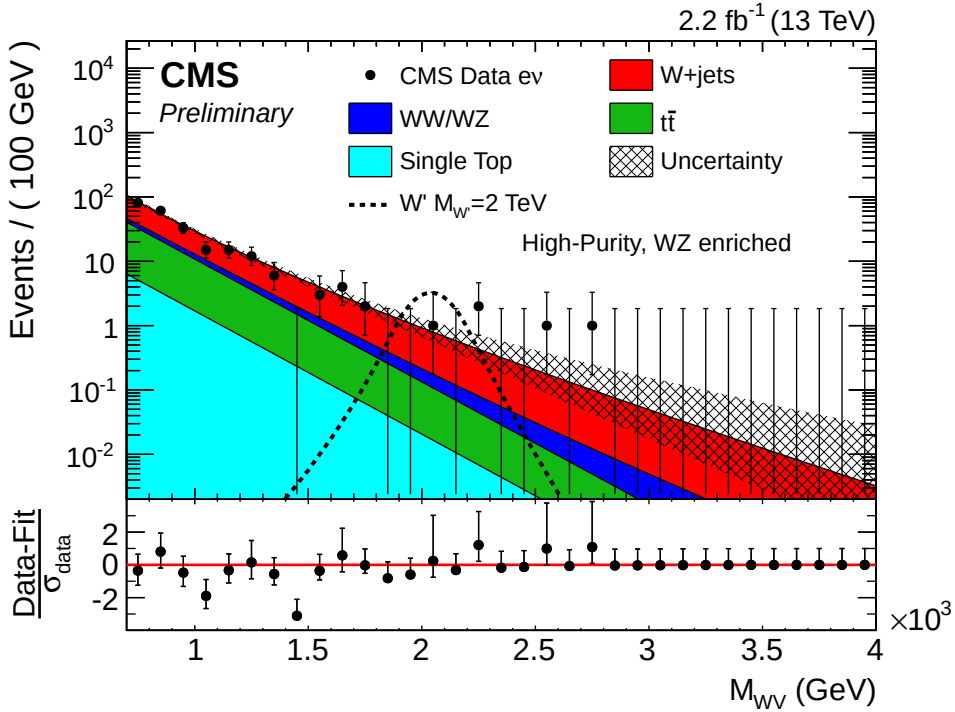




Left: WW $\rightarrow \mu\nu$ + W-jet enriched
Right: WZ $\rightarrow \mu\nu$ + Z-jet enriched

Diboson VW Semi-Leptonic, electron channel

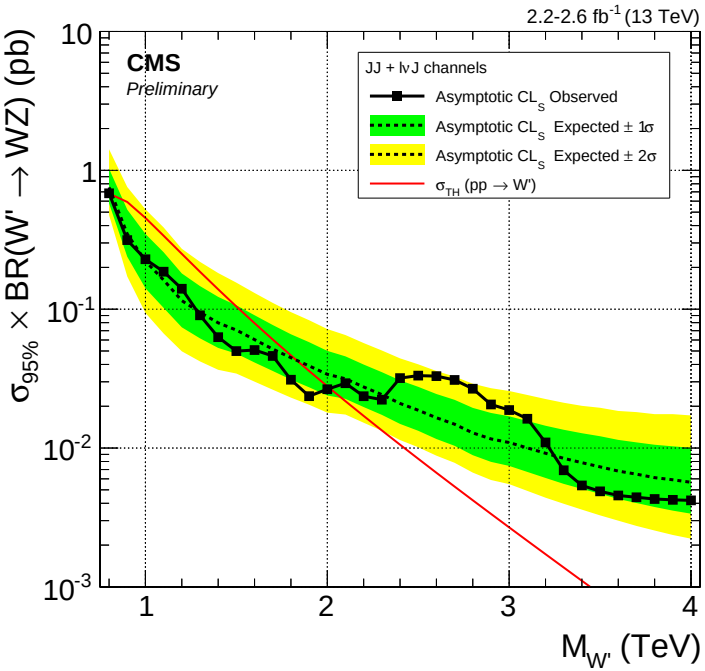




Left: WW $\rightarrow e\nu$ + W-jet enriched
Right: WZ $\rightarrow e\nu$ + Z-jet enriched

Diboson Search Conclusions

- More sensitive than Run 1 above 1.7 TeV
- No signs of excess at 2 TeV
  - $\rightarrow$ ... but wait for 2016 results!
- New limits for gluon fusion production in 3 final states
- New mass limit for HVT (B) $\rightarrow$ W' > 2 TeV (Drell-Yan)
- Highest significance 2.8 σ at 3 TeV (1.6 σ with LEE)



Model	95% excl. σ (800-4000 GeV)
HVT (B) $\rightarrow$ W'	755–5.7 fb
$G_{bulk} \rightarrow WW$	472–4.0 fb
$G_{bulk} \rightarrow ZZ$	227–6.8 fb

Results - Dijet search

Results

CERN-PH-EP/2015-317
2015/12/04

CMS-EXO-15-001

Search for narrow resonances decaying to dijets in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$

The CMS Collaboration*

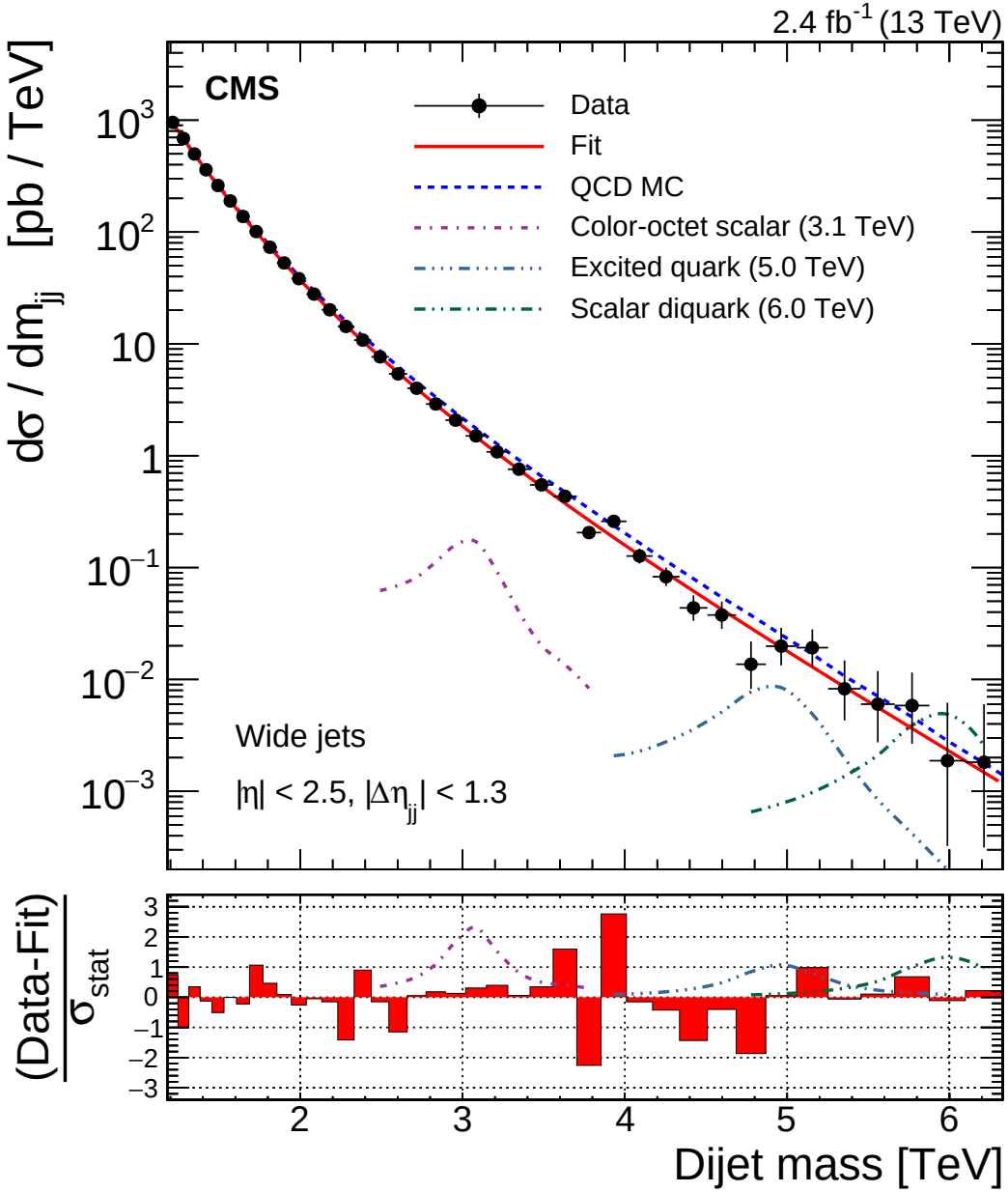
Abstract

A search for narrow resonances in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$ is presented. The invariant mass distribution of the two leading jets is measured with the CMS detector using a data set corresponding to an integrated luminosity of $2.4\,\text{fb}^{-1}$. The highest observed dijet mass is 6.1 TeV. The distribution is smooth and no evidence for resonant particles is observed. Upper limits at 95% confidence level are set on the production cross section for narrow resonances with masses above 1.5 TeV. When interpreted in the context of specific models, the limits exclude string resonances with masses below 7.0 TeV, scalar diquarks below 6.0 TeV, axigluons and colorons below 5.1 TeV, excited quarks below 5.0 TeV, color-octet scalars below 3.1 TeV, and W′ bosons below 2.6 TeV. These results significantly extend previously published limits.

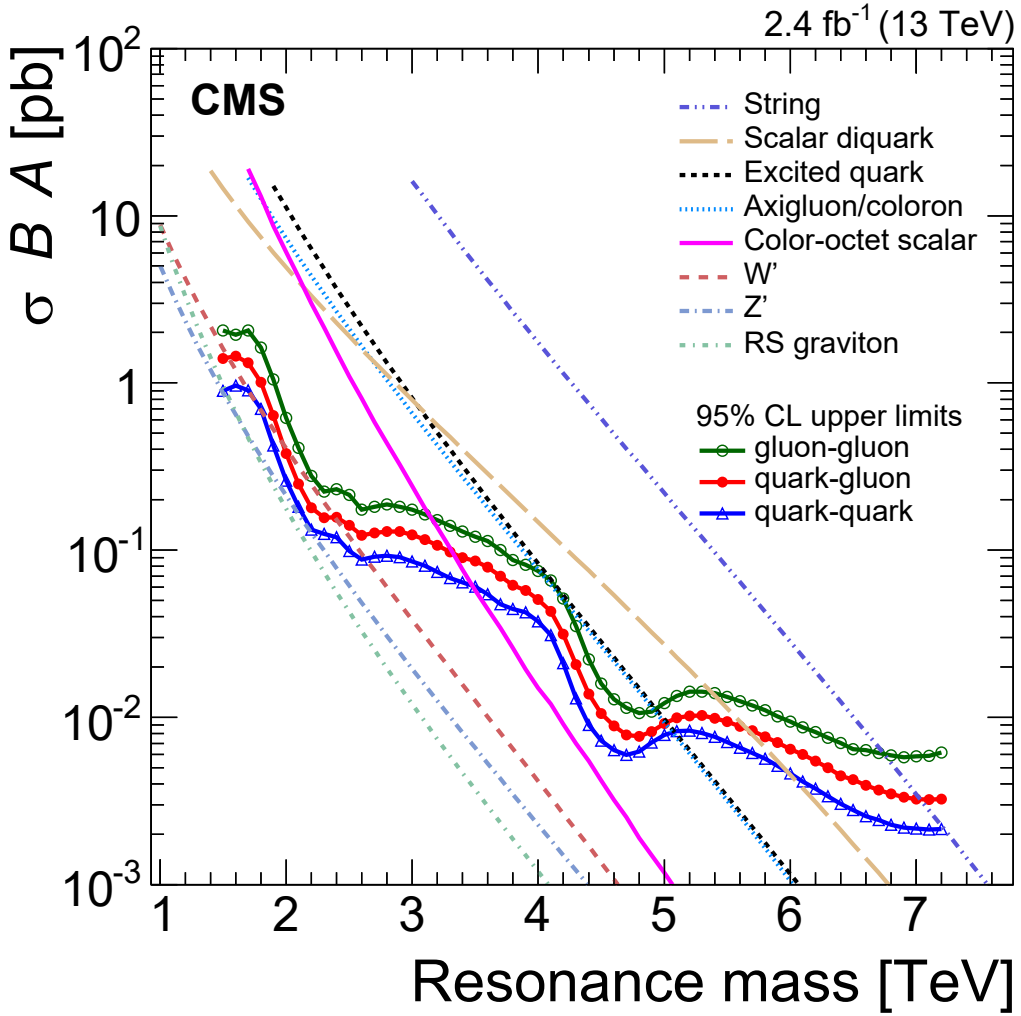
Submitted to Physical Review Letters

World's 1st public new physics search result at 13 TeV

Results


2.4 fb^{-1} (13 TeV)
CMS
Data
Fit
QCD MC
Color-octet scalar (3.1 TeV)
Excited quark (5.0 TeV)
Scalar diquark (6.0 TeV)
Wide jets
$|\eta| < 2.5$, $|\Delta\eta_{jj}| < 1.3$
$d\sigma / dm_{jj}$ [pb / TeV]
$\frac{(Data-Fit)}{\sigma_{stat}}$
Dijet mass [TeV]

Results


2.4 fb-1 (13 TeV)
CMS
σ B A [pb]
String
Scalar diquark
Excited quark
Axigluon/coloron
Color-octet scalar
W'
Z'
RS graviton
95% CL upper limits
gluon-gluon
quark-gluon
quark-quark
Resonance mass [TeV]

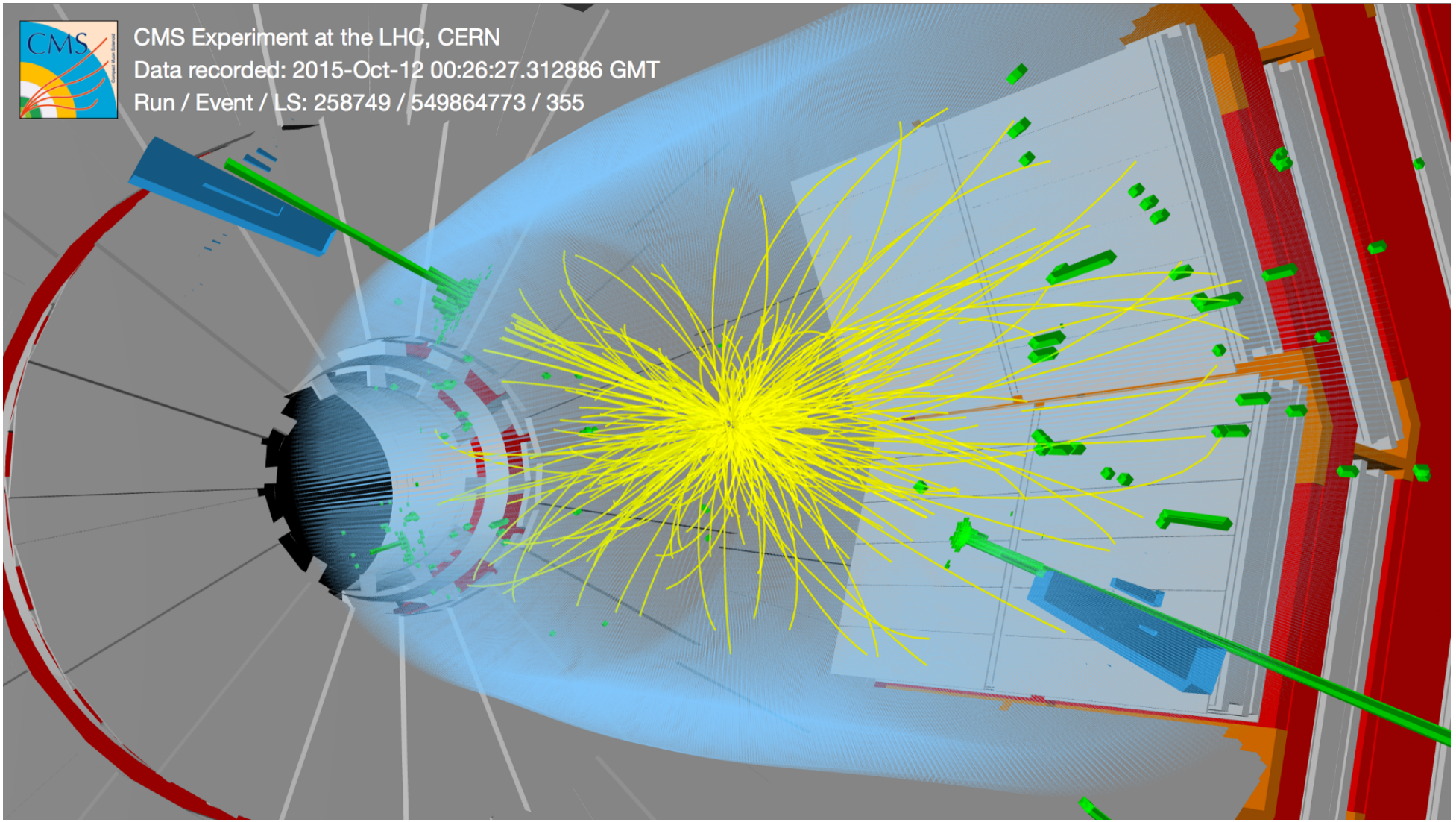
Results

Narrow Resonance Model	Mass Limits (TeV)			
	CMS Run 1 (20 fb^{-1})		CMS Run 2 (2.4 fb^{-1})	
	Observed	Expected	Observed	Expected
String Resonance (S)	5.0	4.9	7.0	6.9
Scalar Diquark (D)	4.7	4.4	6.0	6.1
Axigluon (A) / Coloron (C)	3.7	3.9	5.1	5.1
Excited Quark (q*)	3.5	3.7	5.0	4.8
Color Octet Scalar (S8)	2.7	2.6	3.1	3.3
Heavy W (W')	1.9, 2.0-2.2	2.2	2.6	2.3
Heavy Z (Z')	1.7	1.8	--	--
RS Graviton (G)	1.6	1.3	--	--

Giulia D'imperio

- Limits extended for 6 models
- Confirmation from Atlas shortly after

Event With Highest M_{jj} Observed at 6.14 TeV



Conclusions

- Resonance searches probe various BSM models
- First results show no indications of resonances
- Previous limits significantly exceeded in many channels
- Dijet search at 750 GeV with 'data scouting' underway
- More results by Moriond, more data by summer