Searches for Diboson Resonances with CMS

Sudha Ahuja, Thiago Tomei

SPRACE

Results Presented In This Talk (1)

Preliminary Results – CMS Collaboration

- *Search for RS Gravitons decaying into a Jet plus MET*,
  EXO-11-061, http://cds.cern.ch/record/1426654
- *Search for exotic VZ resonances decaying into a jet and dileptons with CMS*,
  EXO-11-081, http://cds.cern.ch/record/1444879
- *Search for new resonances decaying to WW → lvqq' in the final state with a lepton, missing transverse energy, and single reconstructed jet*,
  EXO-12-021, http://cds.cern.ch/record/1590301
- *Search for a narrow spin-2 resonance decaying to Z bosons in the semileptonic final state*,
  EXO-12-022, http://cds.cern.ch/record/1596494
- *Search for new diboson resonances in semileptonic and hadronic final states at sqrt(s) = 13 TeV*,
  EXO-15-002, http://cds.cern.ch/record/2117062
- *Search for diboson resonances in the semileptonic X → ZV → llqq final state at sqrt(s) = 13 TeV with CMS*,
  B2G-16-010, http://cds.cern.ch/record/2199611
- *Search for new diboson resonances in the dilepton+jets final state at sqrt(s) = 13 TeV with 2016 data*,
  HIG-16-034, http://cds.cern.ch/record/2243295

Results Presented In This Talk (2)

Published Papers – CMS Collaboration

- *Search for exotic resonances decaying into WZ/ZZ in pp collisions at √s = 7 TeV*, Journal of High Energy Physics **02**, 036 (2013).
- *Search for massive resonances in dijet systems containing jets tagged as W or Z boson decays in pp collisions at √s = 8 TeV,* Journal of High Energy Physics **08**, 173 (2014).
- *Search for massive resonances decaying into pairs of boosted bosons in semi-leptonic final states at √s = 8 TeV,* Journal of High Energy Physics **08**, 174 (2014).
- *Search for narrow high-mass resonances in proton-proton collisions at √s = 8 TeV decaying to Z and Higgs bosons*, Phys. Lett. **B 748**, 255 (2015).
- *Search for heavy resonances decaying to two Higgs bosons in final states containing four b quarks*, Eur. Phys. J. **C 76** (2016) 371.
- *Search for massive resonances decaying into WW, WZ or ZZ bosons in proton-proton collisions at √s = 13 TeV,* Journal of High Energy Physics **03**, 162 (2017).
- *Search for a new scalar resonance decaying to a pair of Z bosons in proton-proton collisions at √s = 13 TeV*, (accepted by JHEP); arXiv:1712.02345.

Published Papers – Others

- *Combination of Run-1 exotic searches in diboson final states at the LHC,* Journal of High Energy Physics **04**, 155 (2016).

Diboson Resonances

Search for X → VV, VH, HH

- V = W or Z boson
- Benchmark models
  - WED radion (HH)
  - WED bulk graviton (ZZ, WW)
  - HVT_B W', Z' (WH, ZH, WW, ZZ)

Can shed light on the electroweak symmetry breaking phenomena

- Is it really just the Higgs, W, Z and photon?

Studied at CMS since beginning of Run 1

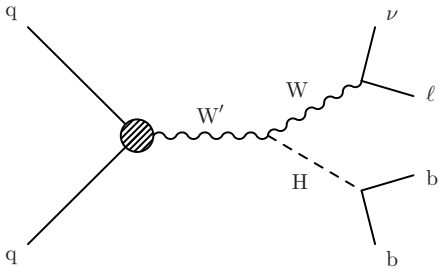
- Coordinated efforts / combinations of all analyses now standard

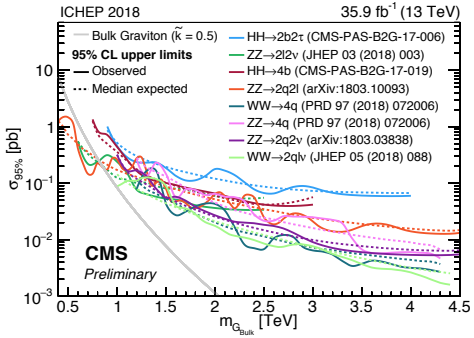
Different channels and different strategies

- Merged jets
- b-tagging
- tau-tagging
- High-energy leptons

Only some analyses shown here!

- Please see references at the end of the talk





WZ, ZZ Search – 7 TeV Data

One of the first LHC searches
with boosted objects

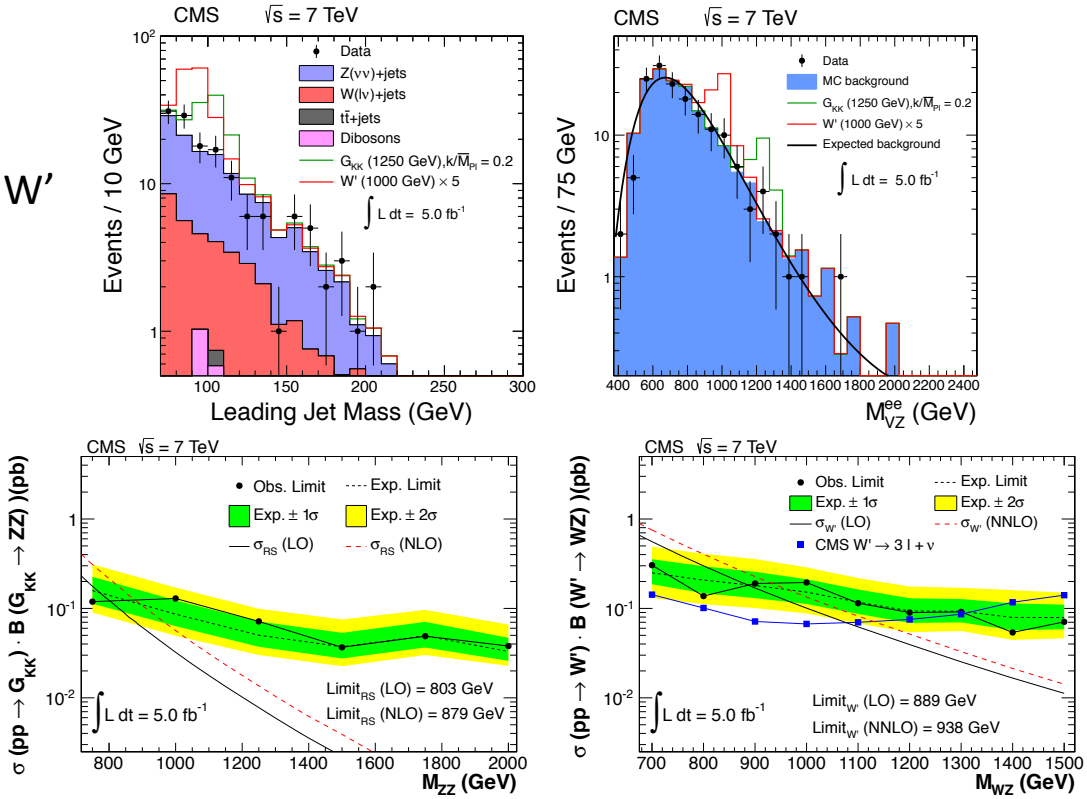
Models: RS1 G_{KK} and sequential W'

Two channels combination:

- $G_{KK} \rightarrow ZZ \rightarrow$
  boosted jet + MET
  - Ph.D. thesis T. Tomei
- G_{KK} / W' $\rightarrow VZ \rightarrow$
  boosted jet + dilepton
  - Ph.D. thesis F. Dias

Simple "jet mass" variable

- PF constituents



WW, WZ, ZZ Search – 8 TeV Data

Integrated effort on diboson searches

Models:

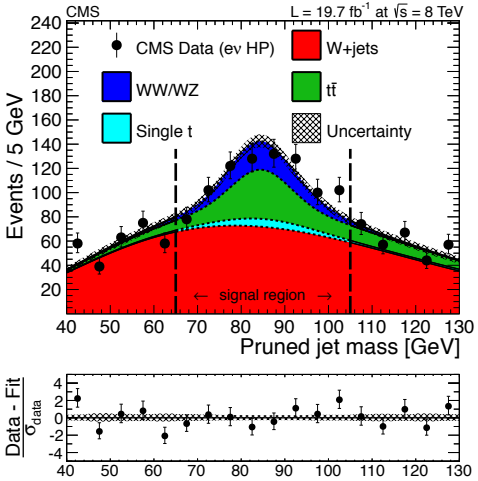
- Bulk graviton G_{bulk}
- HVT model B bosons

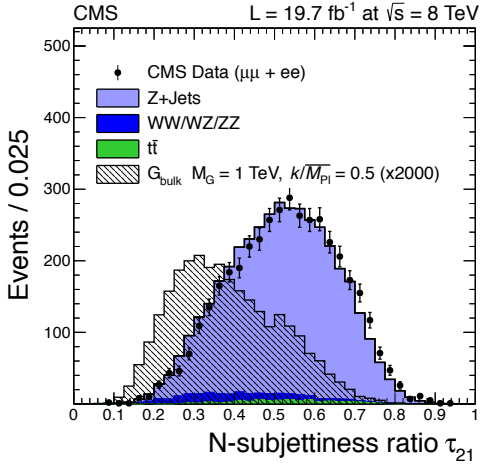
Three channel combination

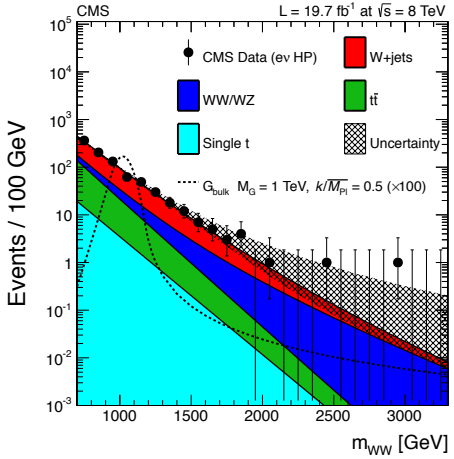
- fully hadronic VV
- semi-leptonic WV
- semi-leptonic ZV

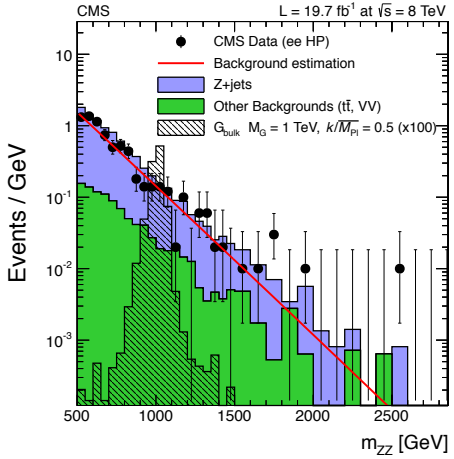
More sophisticated analysis

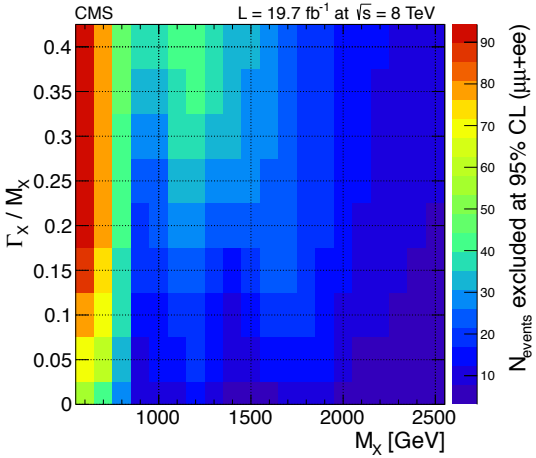
- Pruned mass m_{jet}
- Substructure tau_{21}
  - Categorisation in low and high purity

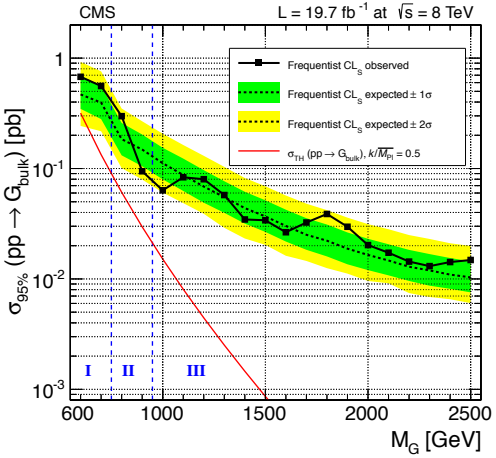




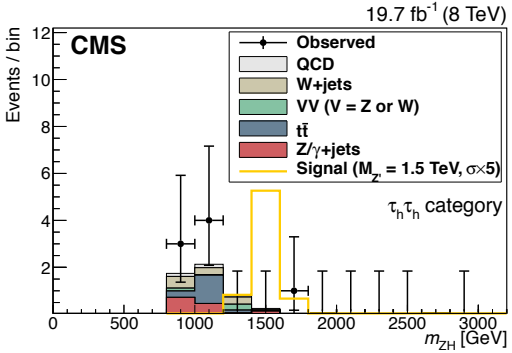

CMS
L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
CMS Data (eν HP)
W+jets
WW/WZ
tt̄
Single t
Uncertainty
G_{bulk} M_G = 1 TeV, $k/\overline{M}_{Pl}$ = 0.5 (×100)
Events / 100 GeV
m_{WW} [GeV]

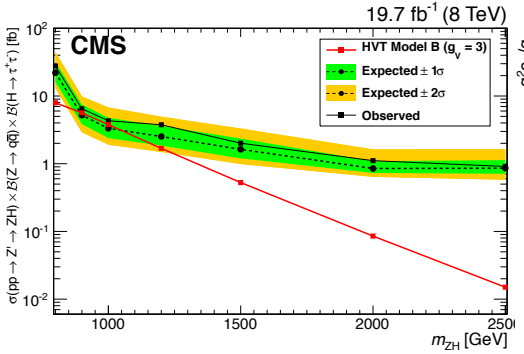

CMS
L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
CMS Data (ee HP)
Background estimation
Z+jets
Other Backgrounds (tt̄, VV)
G_{bulk} M_G = 1 TeV, $k/\overline{M}_{Pl}$ = 0.5 (x100)
Events / GeV
m_{ZZ} [GeV]

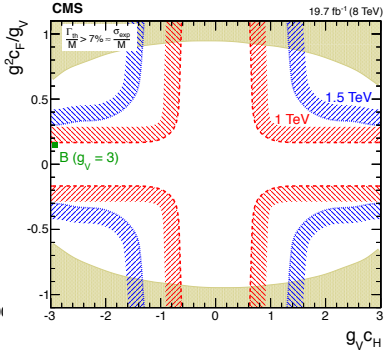

CMS
L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
Γ_X / M_X
M_X [GeV]
N_{events} excluded at 95% CL (μμ+ee)


CMS
L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
Frequentist CL_s observed
Frequentist CL_s expected ± 1σ
Frequentist CL_s expected ± 2σ
σ_{TH} (pp → G_{bulk}), $k/\overline{M}_{Pl}$ = 0.5
I
II
III
$\sigma_{95\%}$ (pp → G_{bulk}) [pb]
M_G [GeV]

ZH Search – 8 TeV Data







Extension to boosted Higgs search

Challenges:

- Fewer events than WW, WZ, ZZ
- Tau ID ~ few tracks in a jet
  - Boosted di-tau ~ regular jet?
- Six-category combination
  - tau_{had} tau_{had}
    - Ph.D. thesis C. Bernardes
  - tau_{lep} tau_{had}, tau_{lep} tau_{lep}

HH Search – 8 TeV Data

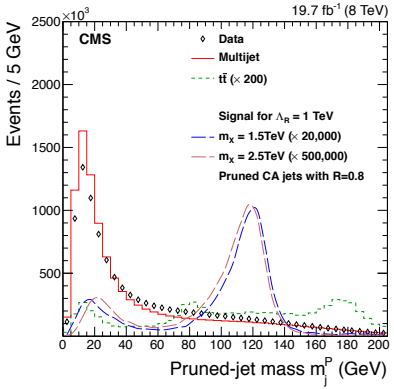
Good training grounds for HHHH coupling at HL-LHC

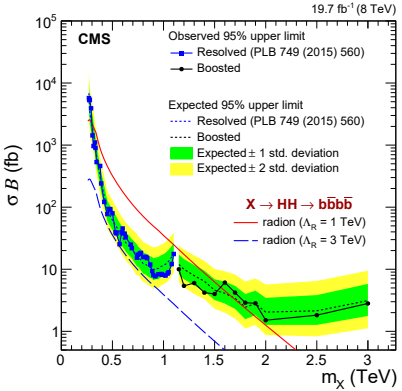
Model: KK radion

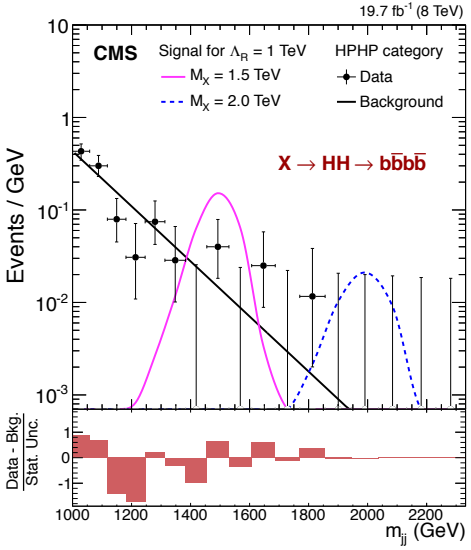
Challenges:

- b-tagging in boosted jet environments
- QCD multijet background

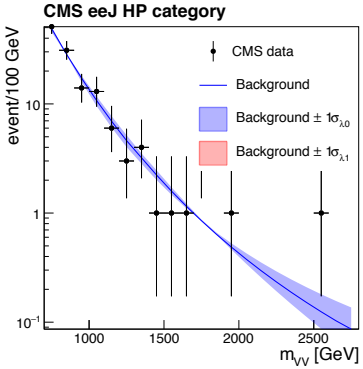
After finishing this analysis with Run-1 data, SPRACE members have been part of the ARC for the Run-2 analyses.

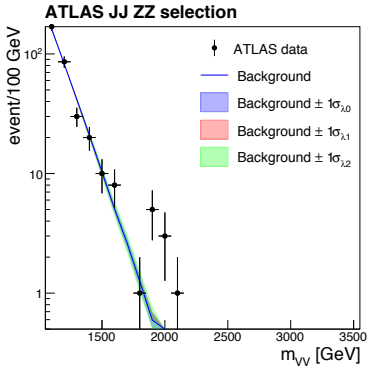


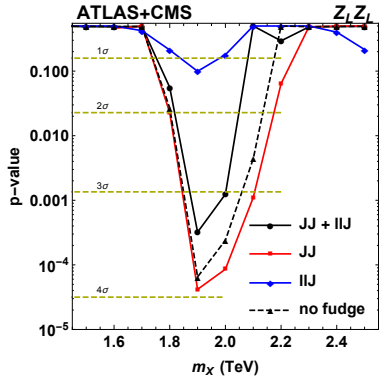


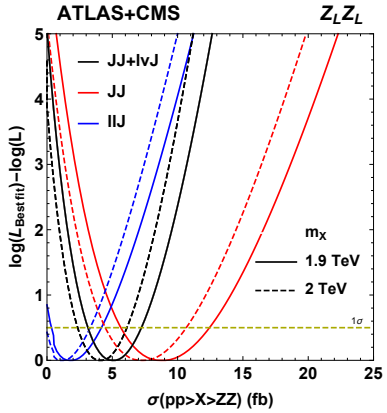


Combination of Run-1 Searches









Pheno. paper by CMS and ATLAS members

- No interest in full joint paper by the experiments.

Interest sparked by the simultaneous excesses around m_{VV} of 1.8—2.0 TeV

- Observed by CMS and ATLAS.

Statistical combination ingredients

- Public data (HEPDATA, plot digitization)
- Background estimation (official, fits)
- Signal benchmarks (official , generation)

Pushed experiments to do Early Analysis of 2015 13 TeV data.

Run-2 Searches – 13 TeV Data (2.3/fb)

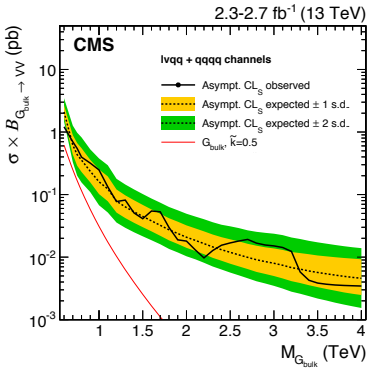
Early Analysis of:

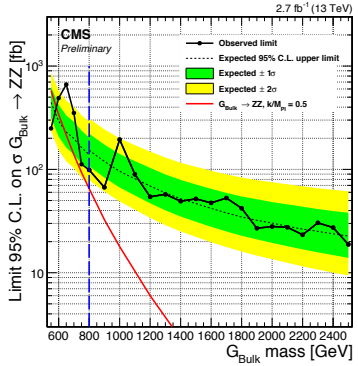
- ❑ X → lvqq (13 TeV)
- ❑ X → jjqq (13 TeV)

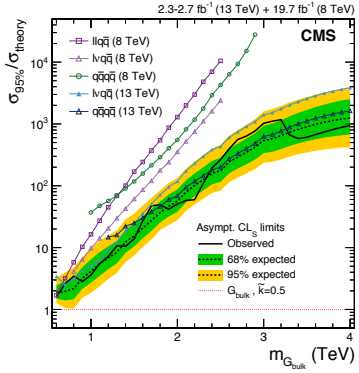
No hint of m_{VV} ~ 1.8—2 TeV excess!

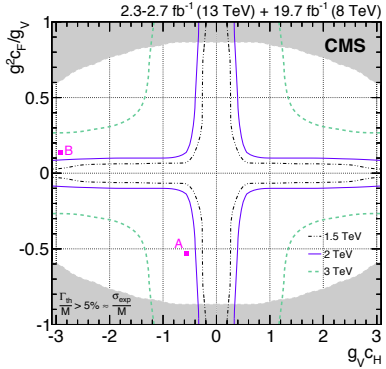
X→ llqq (13 TeV)

- ❑ Both resolved and merged categories
- ❑ Ph.D. thesis J. Cupertino
- ❑ Further confirmation of no excess

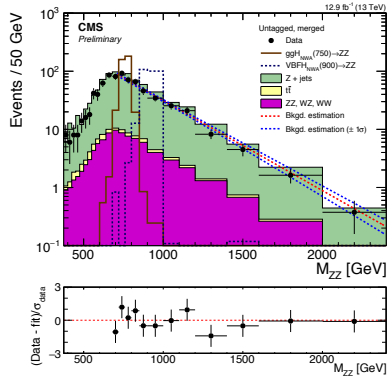


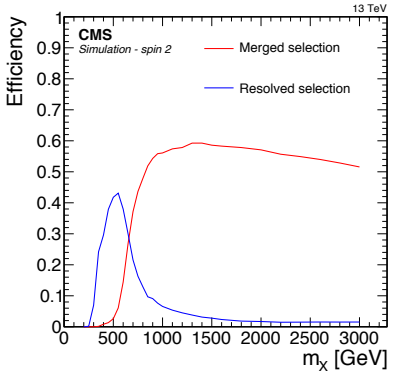


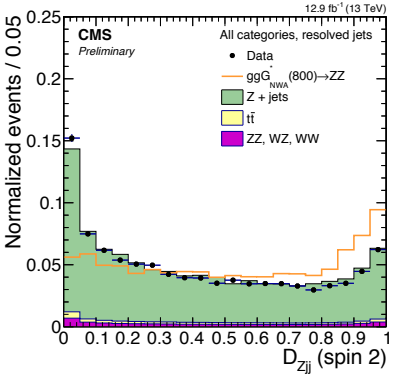


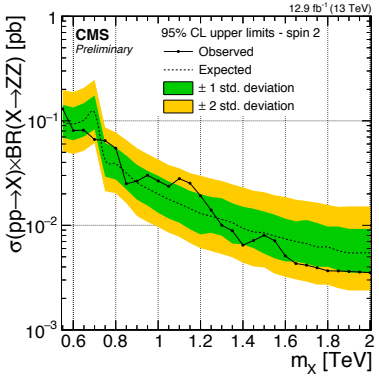


Run-2 Seaches – 13 TeV Data (12.9/fb)









Joint-venture with Higgs group

- 2D-search in (m_{ZZ}, D_{Zjj}) plane

Challenge:

- Calculating D_{Zjj} MELA discriminant with subjets

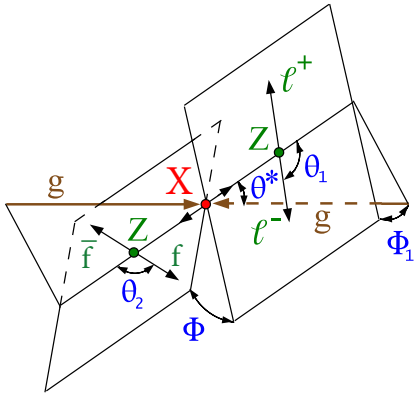
Models:

- Scalar resonance
- WED G_{KK}

$$\mathcal{D}_{\mathrm{Zjj}} = \left[1 + \frac{\mathcal{P}_{\mathrm{Zjj}}(\vec{\Omega}^{X\to 2\ell 2q}|M_{\mathrm{ZZ}})}{\mathcal{P}_{\mathrm{X}\to 2\ell 2\mathrm{q}}(\vec{\Omega}^{X\to 2\ell 2q}|M_{\mathrm{ZZ}})}\right]^{-1}$$

Categorisation

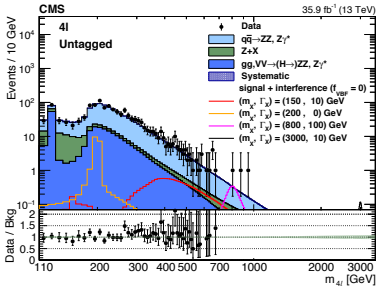
- Jet topologies
  - Resolved
  - Merged
- Purity
  - Untagged
  - b-tagged
  - VBF-tagged

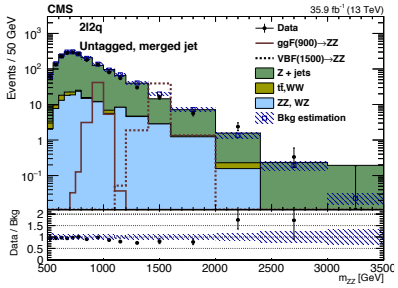


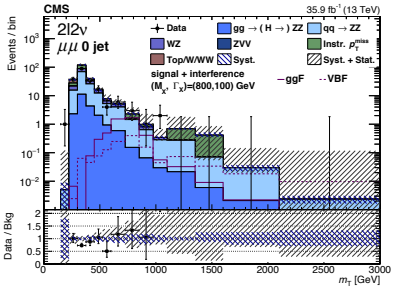
Run 2 Searches – 13 TeV Data (35.9/fb)

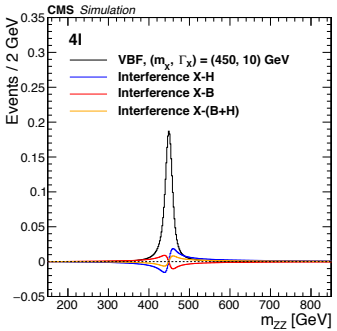
Focus change of the previous analysis

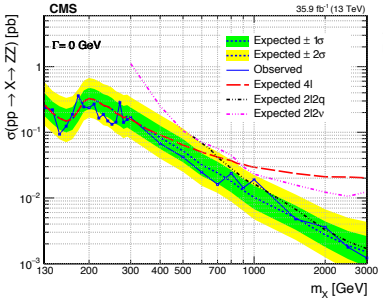
- Scalar resonance only
  - Explicitly considering full VBF production
- Three-channel combination with categories:
  - 4 leptons:
    - VBF, untagged, relaxed ele.
  - llqq:
    - VBF, b-tagged, untagged
  - llvv:
    - VBF, 1+jets, 0-jet
- Full interference effects for 4-lepton channel

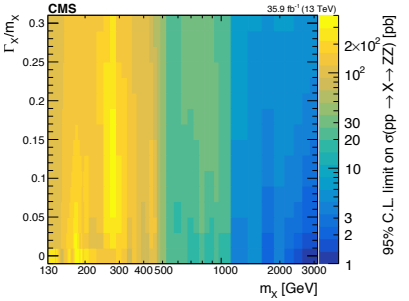












Conclusions

The SPRACE group worked on the diboson resonance searches since the beginning of the CMS experiment.

- Deeply connected with electroweak symmetry breaking
- Even more relevant after Higgs discovery

Solid results obtained for every dataset recorded by CMS.

Took initiative and published a phenomenological combination with ATLAS when there were hints of New Physics.

We now close this chapter of our story and move on the next subject!

SPRACE

Thanks for you attention!

SPECIAL THANKS TO THE ORGANIZERS
SPECIAL THANKS: FAPESP GRANTS
2013/01907-0 AND 2016/15897-4