Di-boson resonance searches and Phase 2 upgrade for CMS endcap calorimeter

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Past, Present, and Future Work

Physics analyses:

Run 1

- Mono-photon: SM Z(νν)γ, aTGC, Extra Dimensions, Dark Matter
- High mass SM-like Higgs searches in semi-leptonic channel
- Tri-boson production (WVγ) and search for aQGC
- Heavy resonance searches in semi-leptonic WV channel

Multi-Boson with Jets Analyses

Hardware work - calorimeters:

- Early studies for phase 2 upgrade of CMS forward calorimeter
- R&D – radiation hard scintillating fibers – testbeam program
- Si Pads – timing performance and MIP calibration
- Recently started working on the HGCAL testbeam program at FTBF.

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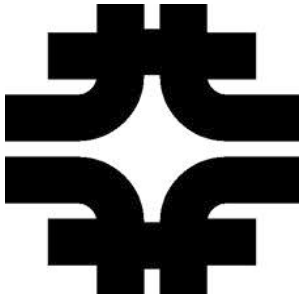
Multi-Boson with Jets Analyses Group at LPC

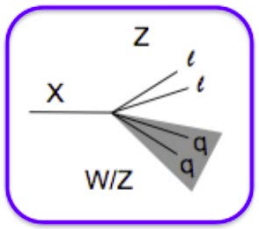


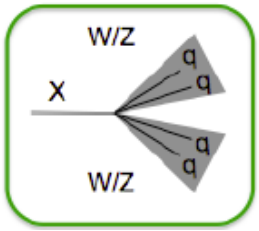
A large analysis group of contributors from around the world

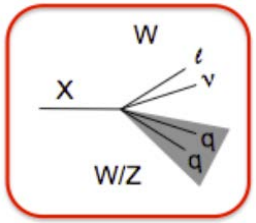
USA, China, Brasil, India, Italy

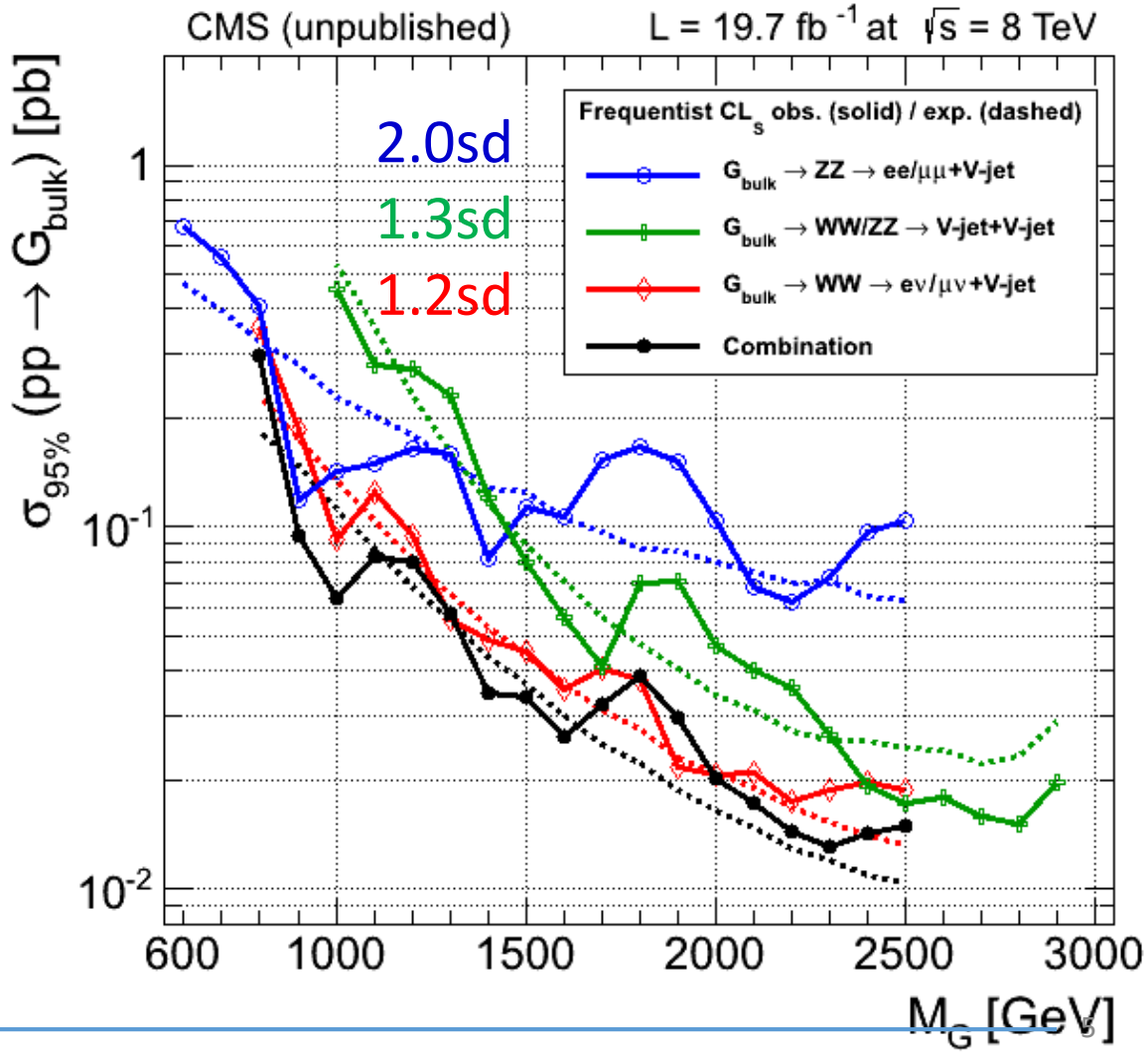
Di-boson resonance searches – Run1 legacy

The 2 TeV "hint" from several di-boson channels. Similar result from ATLAS.

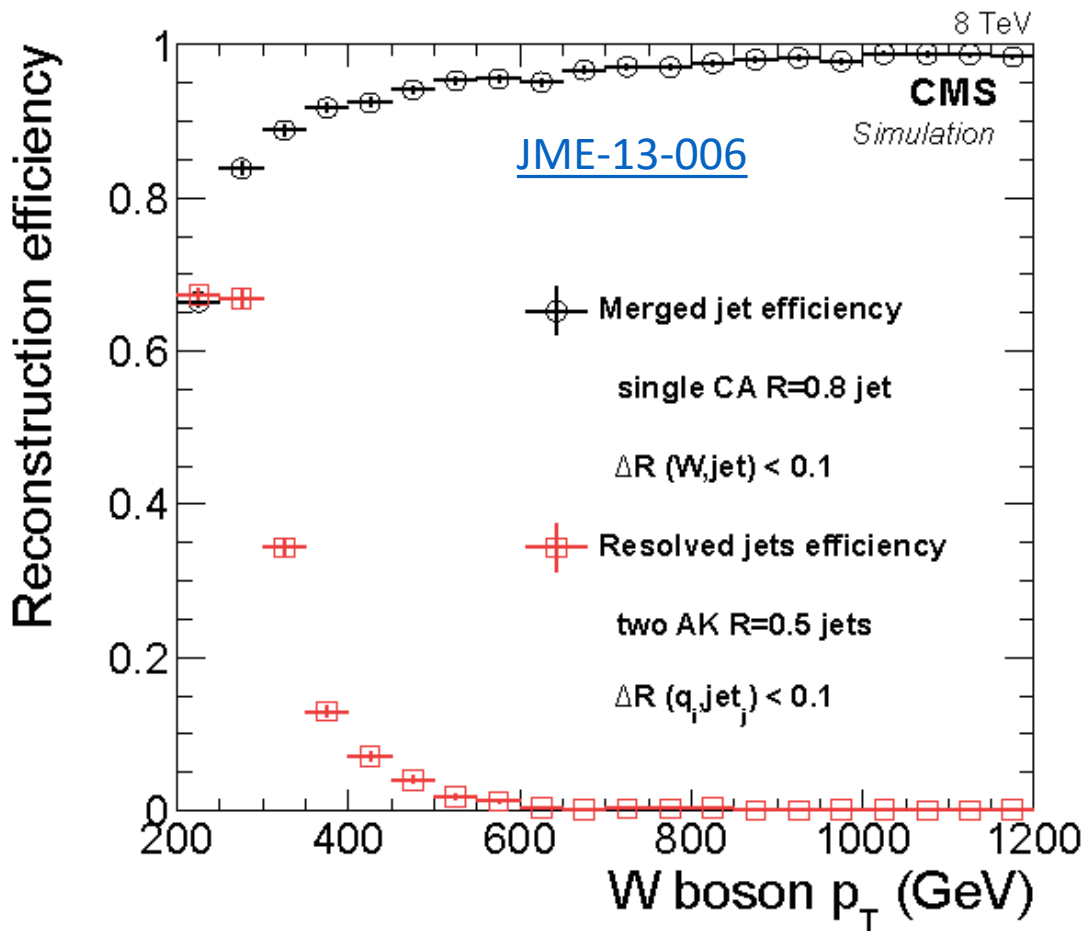


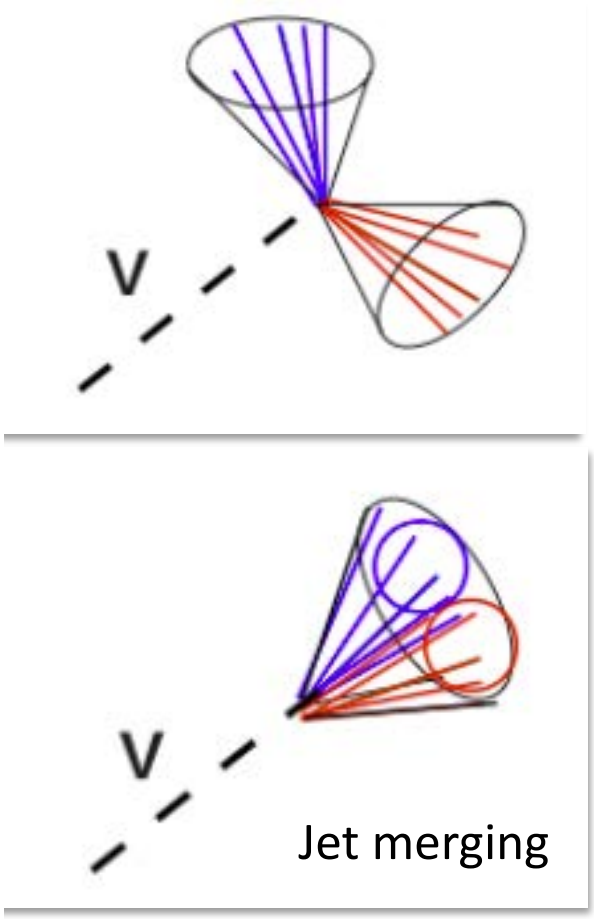






Boosted Topology





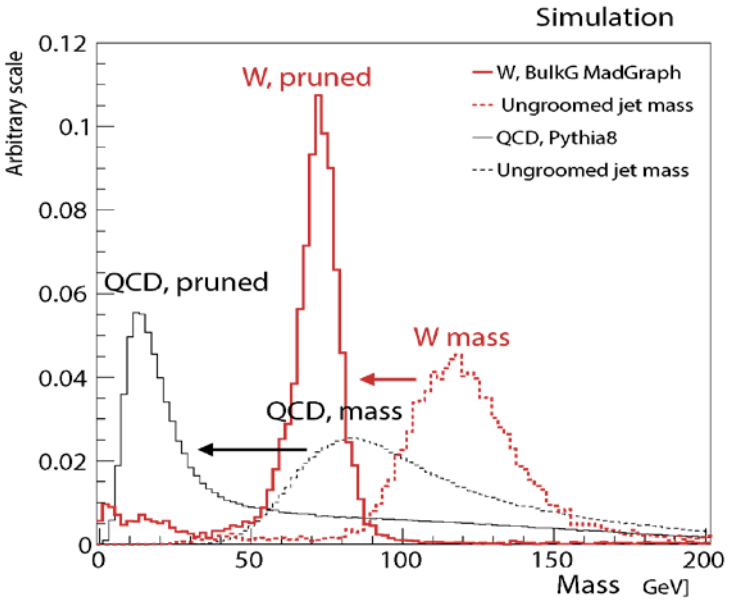
In the searches for resonance with mass heavier that 600 GeV it is critical to use boosted analysis technique.

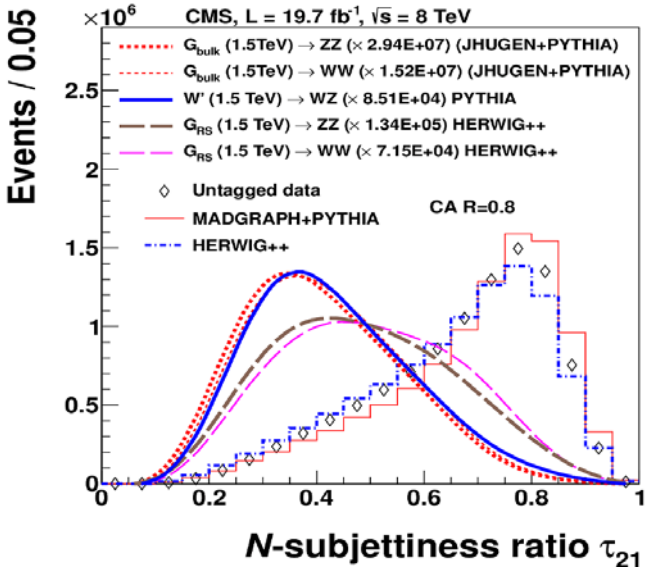
Reconstructing boosted W/Z

Above W,Z p_T>200 GeV quarks merge into R=0.8 jet

- Pruned jet mass (arXiv:0912.0033)
  - Better resolution by elimination soft, large angle radiation and
    - ➢ expected at W/Z mass
- ➢ N-subjettiness (τ_2/τ_1) – provide additional discrimination. Should look like composed of two smaller jets

$$\tau_N = \frac{1}{d_0}\sum_k p_{T,k}\min\{\Delta R_{1,k}, \Delta R_{2,k}, ..., \Delta R_{N,k}\}$$

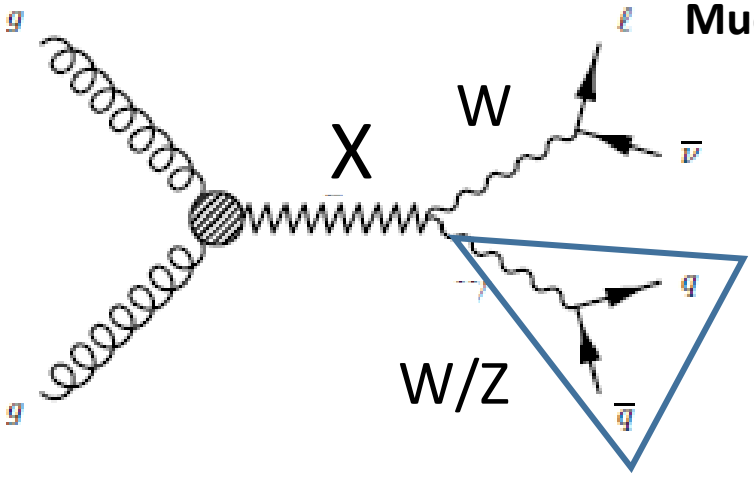




Great expertise is being centered at LPC on techniques for analyses with boosted topology

High Mass analysis details

EXO-15-002



Muon(electron) with pT > 53(120) GeV

Missing transverse energy > 80 GeV

AK8 jet, pT > 200 GeV,
pruned jet mass [65,105]
τ_2/τ_1 categorization:
high purity [0,0.5), low purity [0.5,0.75]

SPRACE-UNESP, PKU, Lyon, INFN Milano, INFN Padova, U Zurich, Fermilab, Buffalo, PHU, CalTech, TTU, Bruxelles

Backgrounds modeling

W+jets – data driven normalization and shape.

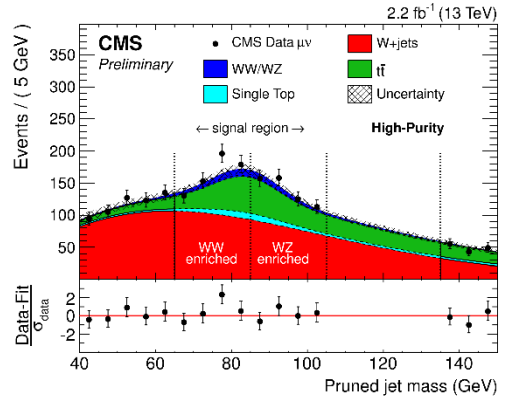
- Normalization in sideband: m_J (40,65), (135,150)
  - ✓ Excluding m_{Higgs} (105-135) region (VH)
- M_{lvJ} shape is derived from low sideband in m_J.

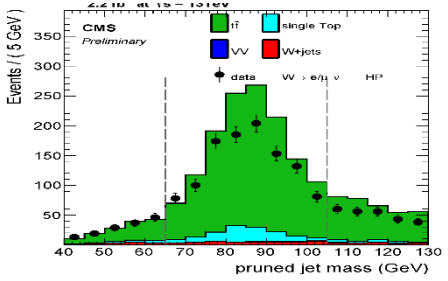
Transfer function from the MC is used (alpha method)

- ✓ Validation - closure test in split low sideband

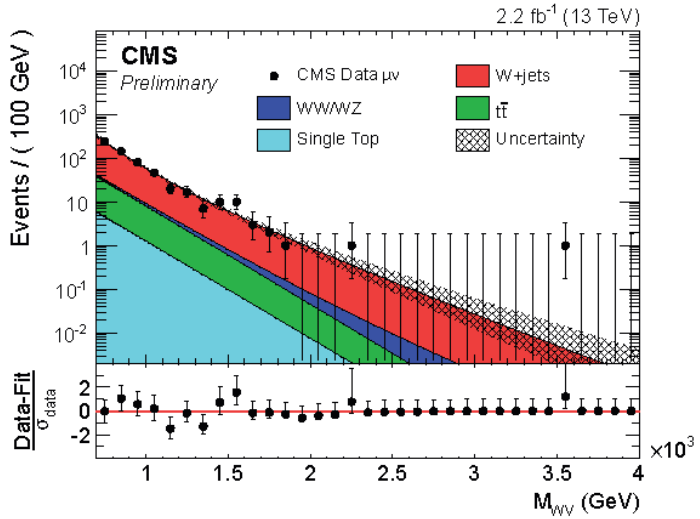
TTbar, single top and WW/WZ/ZZ – prediction from the simulation and applying scale factors (data/MC).

➢ Using *TTbar enriched control region* to derive **various SFs**





W+jets shape – "alpha" method



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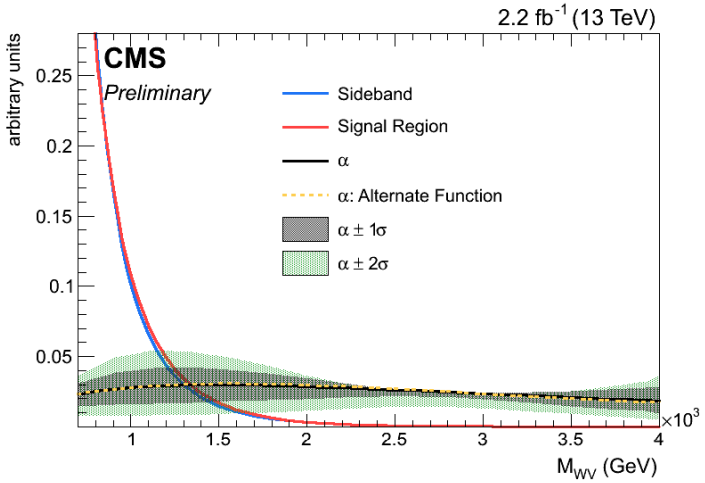

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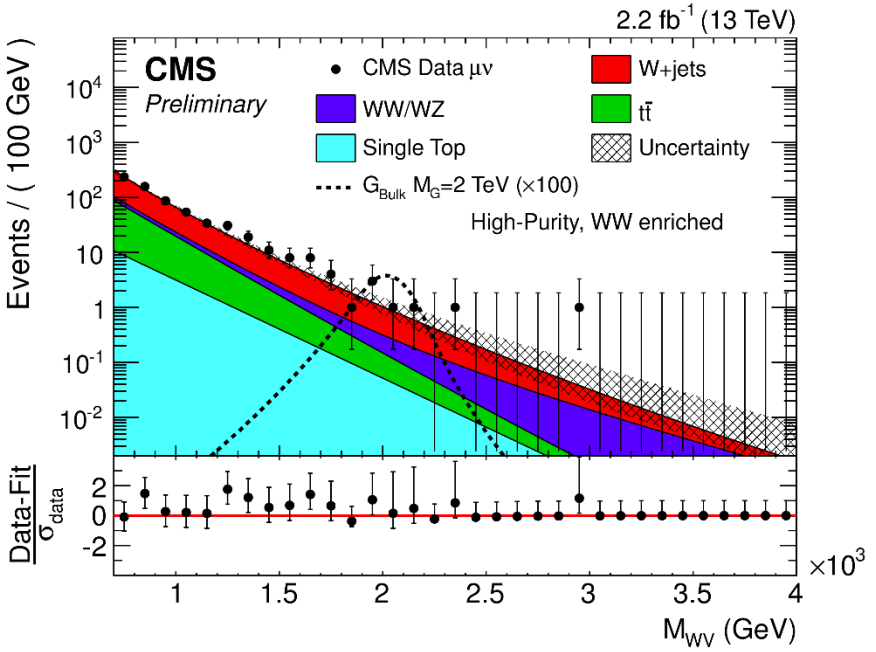
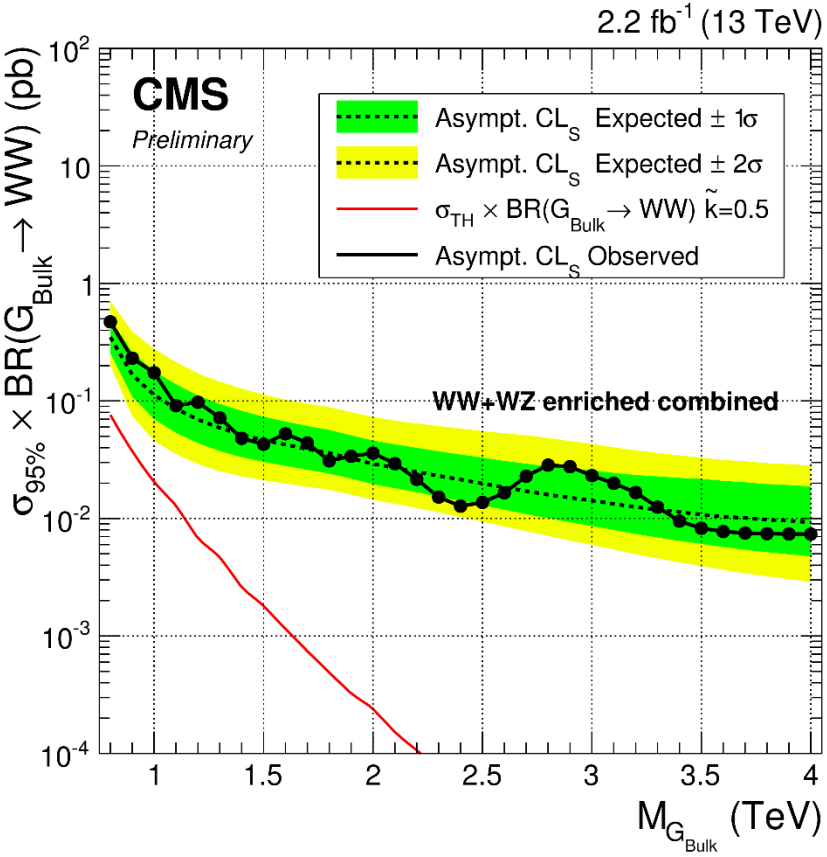


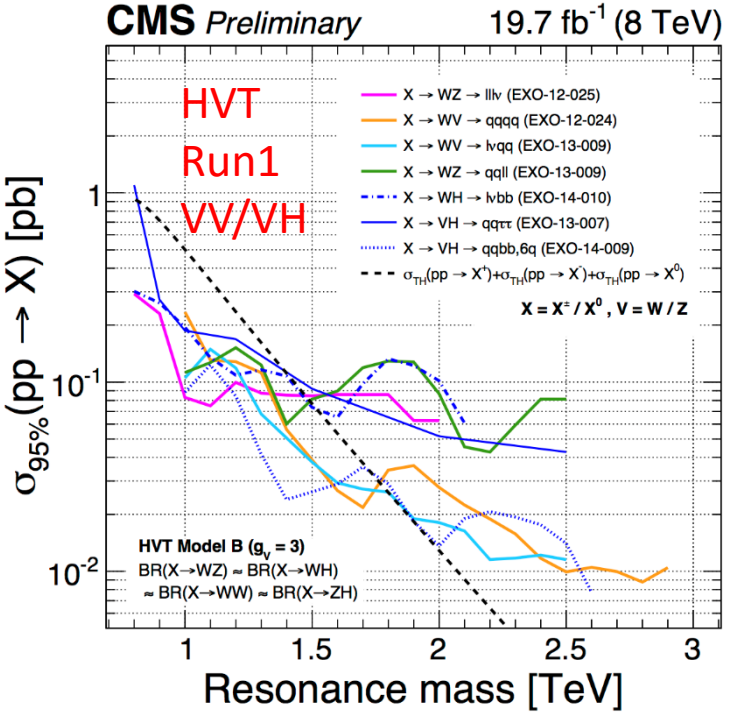
The shape of the W+jets is estimated from the data using transfer function:

$$\alpha_{\mathrm{MC}}(m_{\mathrm{VV}}) = \frac{F^{\mathrm{V+jets}}_{\mathrm{MC,SR}}(m_{\mathrm{VV}})}{F^{\mathrm{V+jets}}_{\mathrm{MC,SB}}(m_{\mathrm{VV}})}$$

Side band in m_J (40,65) is used to predict the contribution in the signal region (65,105) GeV.

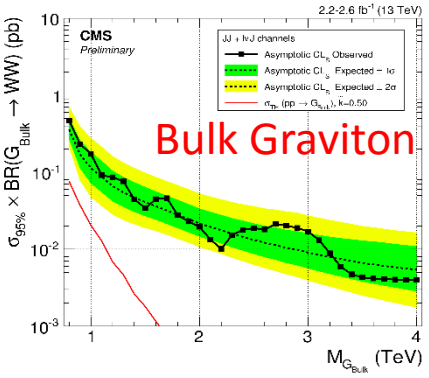
Limits on heavy resonance production cross section

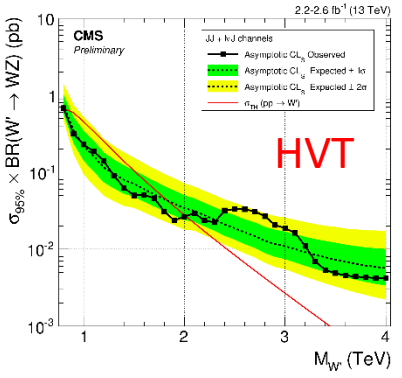




Semi-leptonic WV + hadronic VV

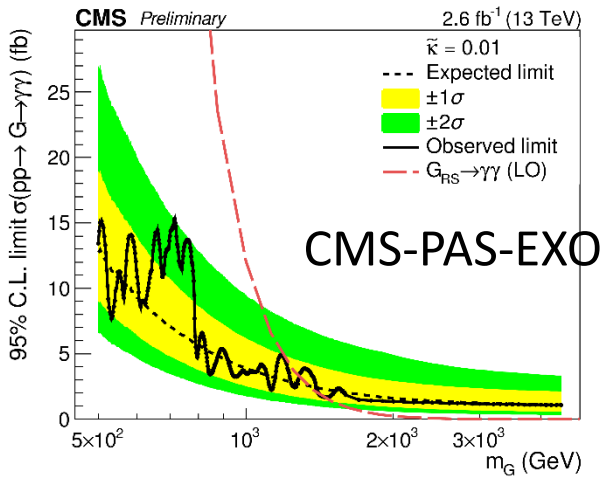
No significant excess is observed, thus we derived upper cross section limits for few benchmark models (Bulk Graviton, HVT)



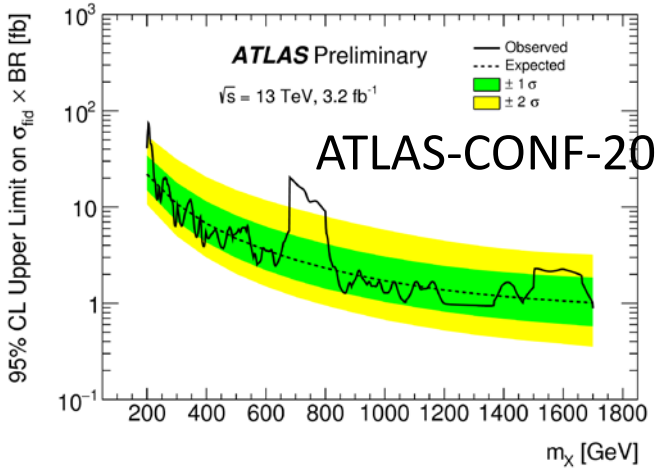


“Low” mass extension

- The CMS and ATLAS experiments recently released preliminary results which exhibit an excess at ~750GeV in the diphoton invariant mass



CMS-PAS-EXO-15-004



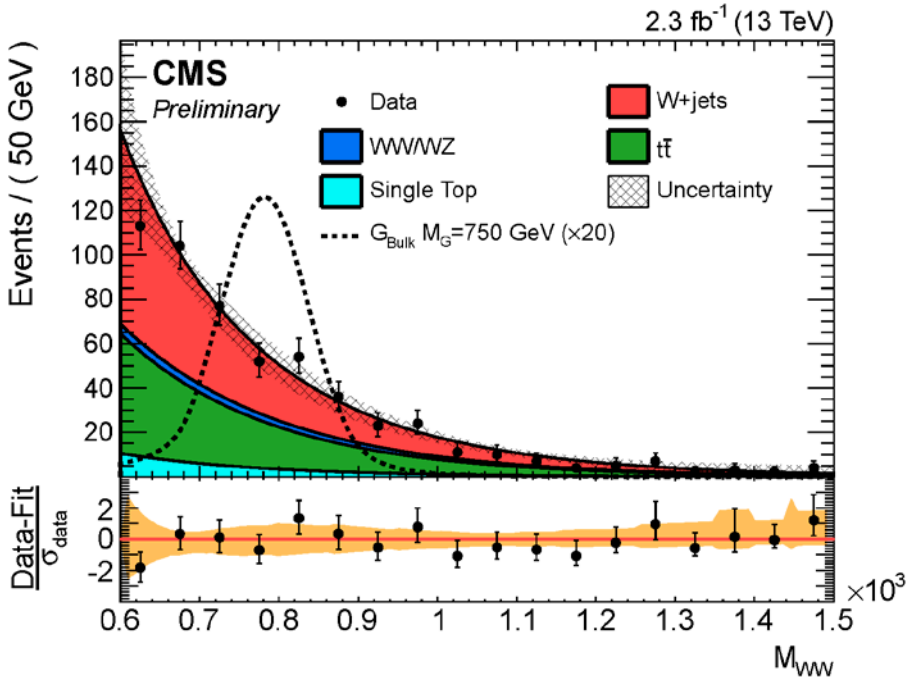
ATLAS-CONF-2015-081

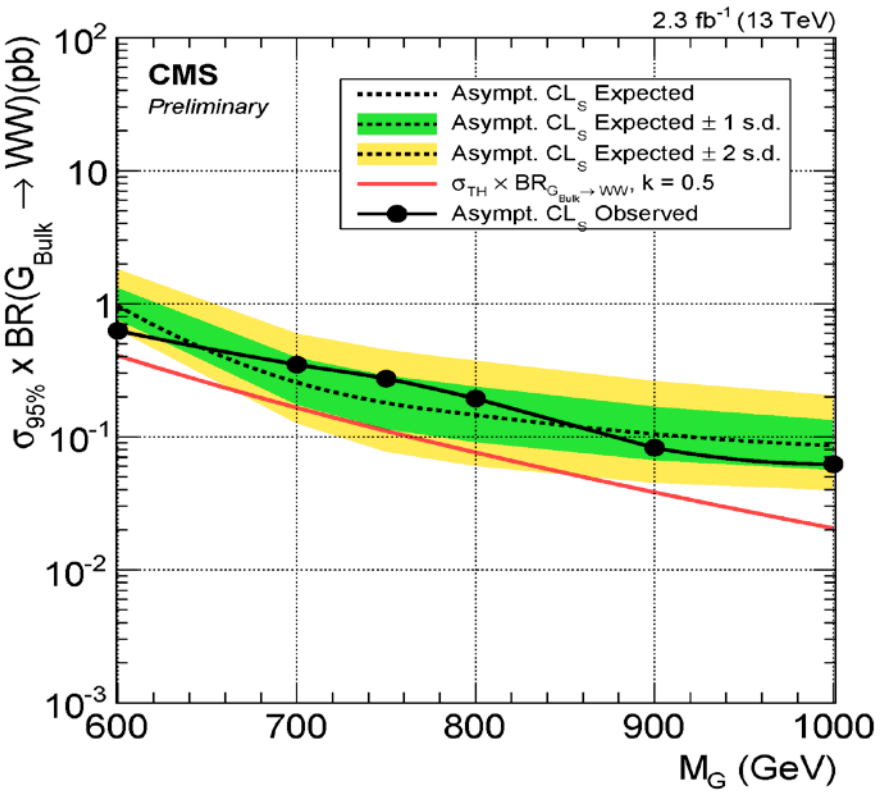
Theory community suggest possible final states of γγ, Zγ, ZZ, WW

Low mass extension of the EXO-WV analysis focuses on probing the 600-1000 GeV mass range, and being optimized for X->WW channel

Low mass resonance searches

B2G-16-004





- Use HLT trigger with lower p_T
- Lepton identification for lower p_T
- Re-optimized τ_2/τ_1 selection

No significant excess is observed, thus we derived upper cross section limits for Bulk Graviton production in the WW decay channel.

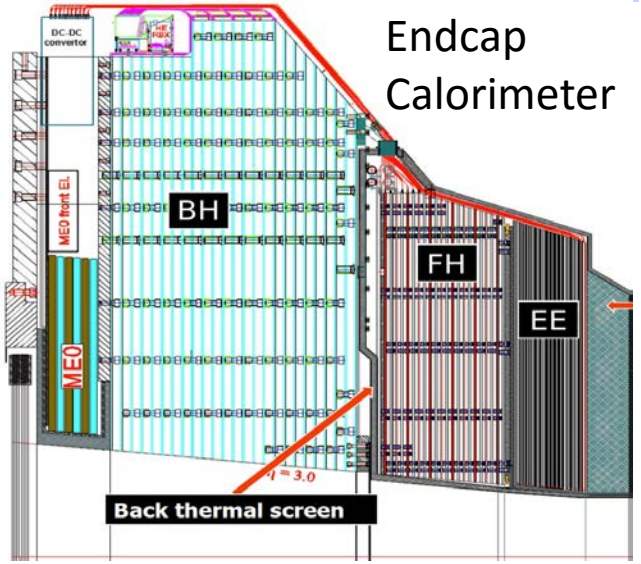
2016 will be very exciting year. We except to collect significantly more data. Incorporate the latest developments in the analysis techniques.

The CMS HGC design fro Phase2 upgrade

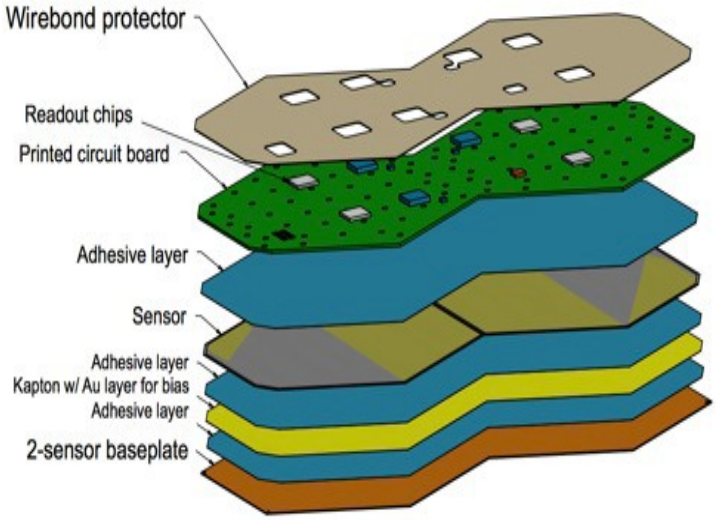
System divided into three parts:

- EE – Silicon with tungsten absorber 28 sampling layers – 25 Xo + ~1.3 λ
- FH – Silicon with brass or steel absorber 12 sampling layers – 3.5 λ
- BH – Scintillator with brass or steel absorber 11 layers – 5.5 λ

EE and FH are maintained at – 30C, BH is at room temperature



Endcap Calorimeter



Construction:

- Hexagonal Si-sensors built into modules
- Modules with a W/Cu base plate and PCB readout board.
- Modules mounted on copper cooling plates to make wedge-shaped cassettes
- Cassettes inserted into absorber structures at integration site (CERN)

Large international collaboration.

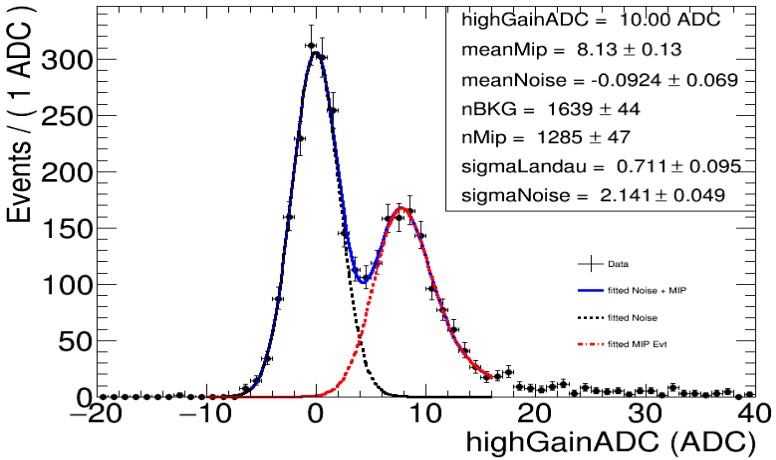
On US side: Alabama, Baylor, Boston, Brown, Carnegie Mellon, Fairfield, Fermilab, Florida International, Florida State, Florida Tech, Iowa, Kansas State, Maryland, Minnesota, MIT, Northwestern, Rochester, Texas Tech, UC Davis, UC Santa Barbara

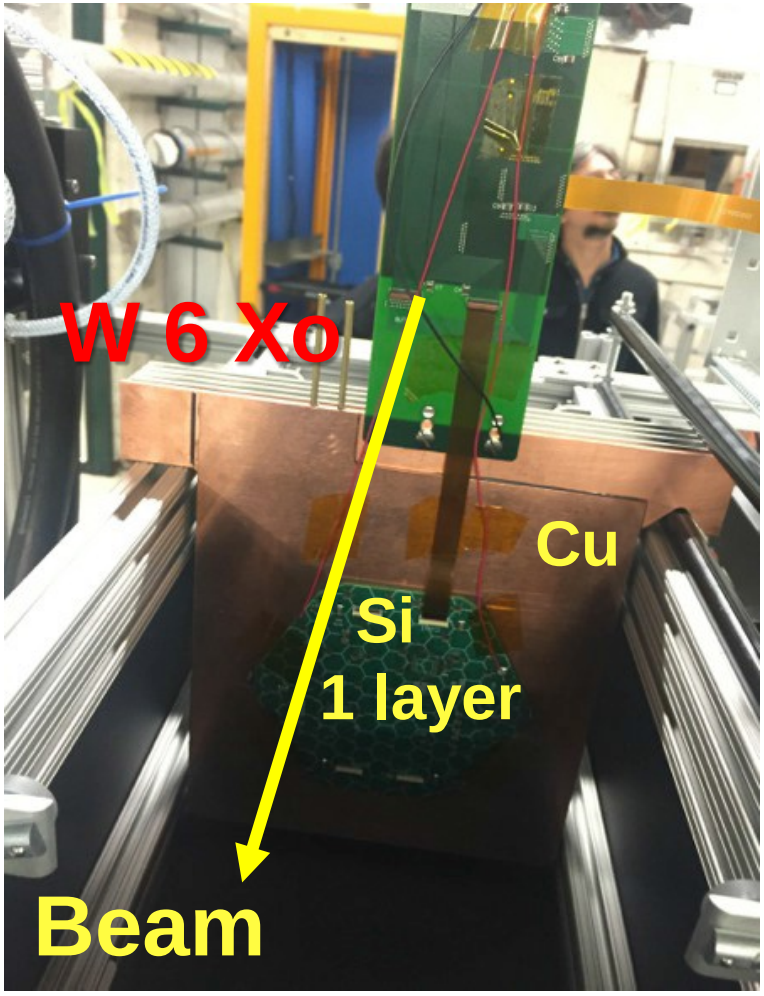
The test beams at Fermilab

March 25 - April 5	Single layer with $6X_0$ absorber
May 18 – 31	Up to 28 layers with $25X_0$ absorber

- **Goals:**
  - Measure energy response
  - Measure time and position resolutions
  - Compare to simulation
  - Test the proposed design of compact module

MIP calibration with 120 GeV pions (high gain)





Summary

- It is very exciting time for the HEP research program
  - ✓ looking forward to continue with the **heavy resonance searches** and the **phase 2 upgrade work**.

- Working at LPC as a resident is a great advantage
  - LPC is the place where the experts are brought together.
  - One benefits a lot from the talks, seminars, workshops organized at the Center.
  - Excellent local computing facility