### CMS Physics Results in the LHC Run 2

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ATLA

CMS

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### LHC Performance 2010-2011-2012-2015-2016

### • Amazing performance of the LHC since turn on!



#### What has CMS seen in the pp Run 2 collisions at 13 TeV?

es

Outline of the talk Part 1: precision SM results Part 2: search for direct production of BSM



### Measurements from Run 2

- Many new or precision measurements enabled with large data sets collected in 2016 (~36 fb-1)
  - High expectations for 2017 (~40fb-1) (145 days running) and 2018 (~60fb-1)
- New precision measurements or limits with the Higgs:
  - Differential cross sections
  - Rare decays or not allowed in SM: LFV H  $\rightarrow \tau e/\mu e/\tau \mu$
  - Couplings to vector bosons, quarks and leptons and ttH (H $\rightarrow$ bb/ $\tau\tau$ / $\gamma\gamma$ )
  - HH resonance studies (bb + bb/ $\gamma\gamma/\tau\tau$ )
  - Decays to non-SM particles: H ${\rightarrow}$  invisible or light pseudo- or scalar particles H ${\rightarrow}aa$
- **Top** 
  - New top mass measurement in Lepton+jets and tt+V(W,Z) cross section
- Electroweak production of gauge bosons in VBF
  - W<sup>+</sup>W<sup>+</sup>2j, Z+2j, ZZ+2j
- Many of the results used full 2016 data sample of 35.9 fb<sup>-1</sup>

# Higgs $\rightarrow ZZ \rightarrow 4\ell$ in Run 2





# **Higgs** $\rightarrow \gamma \gamma$ in Run 2

#### CMS-PAS-HIG-017-015



(b)  $N_{jets}$  differential cross-section

# Higgs Couplings Run 1,2 Results





### Higgs $\rightarrow \tau \tau$ in Run 2



### LFV Higgs Decays Run 2



### ttbar Production and top mass in Run 2

#### CMS-PAS-TOP-016-022



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### Higgs Run 2 Results tH, ttH channels CMS-PAS-HIG-017-004/003







# Run 2 Results Z(Z)+2jets channels

#### CMS-PAS-SMP-016-019 **ZZ+2j** EWK production

- MVA to separate QCD bkg. from EW signal using VBF kinematics
- Excellent channel for validation of VBF modeling e.g. jet multiplicity and to set aQGC (WWZZ)

```
Fiducial Selection:

|\eta^{I}| < 2.4 \text{ lep.} P_{t} > 5 \text{GeV} M_{II} > 4 \text{ GeV}

|\eta_{J}| < 4.7 M_{JJ} > 400 \text{GeV} \Delta \eta_{JJ} > 2.4

2jets: P_{t} > 30 \text{GeV}

P_{t}^{I3,4} > 5 \text{GeV} P_{t}^{I1} > 20 \text{GeV} P_{t}^{I2} > 10 \text{GeV}

m_{Z1} > 60 \text{GeV} m_{Z2} < 120 \text{GeV}
```

EWK VBF **ZZ+2j** Cross section  $\sigma(\text{eee})^{\text{fid}} = 0.40^{+0.21}_{-0.16} (\text{stat.})^{+0.13}_{-0.09} (\text{syst.}) \text{ fb}$  $\sigma_{\text{SM}} = 0.29 \pm 0.03 \text{ fb}$ 

| Significance: | Observed: | 2.7 σ        |
|---------------|-----------|--------------|
|               | Expected: | 1.6 <b>o</b> |



QCD bkg. suppression with BDT based jet **gluon-quark** likelihood and event kinematics Excellent channel for validation of VBF modeling: e.g.  $3^{rd}$  jet  $P_T$  and to set aTGC (WWZ)

```
Fiducial Selection:
|\eta^{I}| < 2.4 \text{ lep. } P_t^{I_1} > 30 \text{GeV } P_t^{I_2} > 20 \text{GeV}
|\eta_{J}| < 4.7 \quad M_{JJ} > 200 \text{GeV} \quad \Delta \eta_{JJ} > 2.4
2jets: P_t > 30 \text{GeV}, P_t > 50 \text{GeV}
75 GeV < m_z < 105 \text{GeV}
```

EWK **Z+2j** Cross sections  $\sigma$ (**eejj**) = 552±58 fb  $\sigma_{SM}$  = 543±24 fb

Significance: >> 5  $\sigma$ 





### Search for SUSY EWKinos in Run 2

#### EWK production of chargino-neutralino pair





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### Search for colored SUSY in Run 2





### **SUSY Searches Summary**



#### No sign of SUSY found at the LHC run 1/run 2 probing the TeV scale



### Search for direct production in Run 2

- What else is seen in 2016 Run 2 data ?
- A set of Universal Measurements serving many original phenomenological analysis needs in a variety of models
- Examples of such measurements:
  - Di-boson resonances in VV, Vγ, VH, HH channels
  - ttbar resonances
  - Search for charged higgs H<sup>+/</sup>- (no update from Run2)
  - Z', W', excited quarks, resonance in di-jets
- Many improvements observed in existing Run 2 results compared to Run 1



### Search for Zy resonance

CMS PAS EXO-17-005

- Multiple types of searches performed:
- Low mass: Leptonic search Z(LL)  $\gamma$

Leptonic and hadronic

High mass: boosted hadronic Z decay –  $Z(J)\gamma$  w/ or w/out "J" b-tag – and using the jet substructure techniques



Most stringent limits on production **of spin-0** resonance to date in a broad range

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## Search for VV,qV All-Hadronic Resonance

CMS PAS B2G-17-001

### Models: Graviton, heavy spin-1 boson and excited quarks

Decay channels: WW, WZ, ZZ, (qW, qZ), with bosons reconstructed as 1 super-jet









### Search for VV,qV All-Hadronic Resonance

CMS PAS B2G-17-001

### Models: Graviton, heavy spin-1 boson and excited quarks Decay channels: WW, WZ, ZZ, (qW, qZ)





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### Search for VH Resonance

#### CMS PAS B2G-17-002





### Search for HH Resonance

#### Models: low/high mass HH narrow spin-0,2 resonances Decay channels: HH (HH→bbtt/bbWW)

#### CMS PAS B2G-16-026

Radion ( $\Lambda_{\rm B} = 3 \text{ TeV}$ )

Observed 95% upper limit

Expected 95% upper limit

Expected limit  $\pm 1$  std. deviation Expected limit  $\pm 2$  std. deviation

2500

Bulk KK graviton ( $\kappa/\overline{M_{Pl}} = 0.1$ )

Expected limit ± 1 std. deviation

Expected limit ± 2 std. deviation

2500

Observed 95% upper limit

Expected 95% upper limit

3000

3000

M(X) [GeV]

M(X) [GeV]

35.9 fb<sup>-1</sup> (13 TeV)

35.9 fb<sup>-1</sup> (13 TeV)

#### Decay channels: HH (HH→bbbb)

2000

2000





### Search for ttbar Resonances

CMS PAS EXO-16-015

### Search for ttbar resonances in semi-leptonic and all-hadronic final states using jet substructure



Also, Limit on KK gluon G<sub>KK</sub> in RS model: ~3.3 TeV at 95% CL

# Search for Extra Gauge Bosons W', Z'

CMS PAS EXO-15-006 CMS PAS EXO-16-031

### Analyses based on techniques used Run 1



### Search for Extra Gauge Boson W'<sub>R</sub>





Limit on W'<sub>R</sub> (tb): ~3.4-3.5 TeV depending on the  $v_R$  mass Limit on  $W'_{R}$  as a function of the coupling Strength to L- and R-handed fermions

# Search for new physics in di-jets

CMS PAS EXO-16-056





- Many more new and interesting results from Run 2 which I had no time to discuss :
- In particular:
- Mono-jet, mono-Higgs, mono-V, DM searches, and heavy fermions, RPV, Vector-Like-Quarks, etc.
- More information on CMS twiki with <u>CMS Preliminary Public Results</u>



### **CONCLUSIONS**

- Many precise and important measurements from Run2 already available:
  - Higgs boson, Top quark and gauge boson measurements

 No signs of physics beyond standard model yet, but Run2 continues; improved limits on new particles produced directly can be used to further constrain the model building !

### • The well known open questions still remain!

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### **Additional Slides**

### Search for VV Resonances in Semileptonic

CMS PAS B2G-16-020 CMS PAS B2G-16-022 CMS PAS B2G-16-023



G<sub>bulk</sub> and W' Limits: Upper Limit on production x-section 32

M<sub>G<sub>Bulk</sub></sub> (TeV)

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model

### **New Physics Searches Summary**

**Beyond 2 Generations** 

#### **Exotic Particles**



#### No new physics found at the LHC run 1/run 2 probing the TeV scale

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# Search for new physics in di-jets

CMS PAS EXO-16-056



DM interpretation for Dirac DM with  $g_{q}$ =0.25 and  $g_{DM}$ =1.0



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### Single or Pair Production of VLQ CMS PAS B2G-16-019 CMS PAS B2G-17-007

- Vector-Like-Quark in many models
  - T<sub>5/3</sub> pair production, with T->tW decays (Same Sign leptons)
- T<sub>2/3</sub> single production, with T->Zt decay (Z->II, t->hadrons) processes with Wb, Zb, Zt possible



Limits placed on T2/3 quark mass:

Exclusion up to 1.35 - 1.45 TeV depending on the width for left-handed T(b) Exclusion up to 0.85 - 0.95 TeV depending on the width for right-handed T(t) For Z'->Tt , Exclusion of Z'(T) mass range 1.5-2.5 (0.7-1.5) TeV



Limits placed on T5/3 quark mass:

1.16 TeV (for right handed chirality) with 1.2 TeV expected 1.10 TeV (for leftt handed chirality) with 1.15 TeV expected



### Single or Pair Production of VLQ CMS PAS B2G-17-003 CMS PAS B2G-17-007

- Vector-Like-Quark in many models
  - T<sub>2/3</sub> pair production, with T->tW decays (semi-leptonic)
- T<sub>2/3</sub> single production, with T->Zt decay (Z->II, t->hadrons) processes with Wb, Zb, Zt possible



35.9 fb<sup>-1</sup> (2016, 13 TeV)

Limits placed on T2/3 quark mass:

Exclusion up to 1.35 - 1.45 TeV depending on the width for left-handed T(b) Exclusion up to 0.85 - 0.95 TeV depending on the width for right-handed T(t) For Z'->Tt, Exclusion of Z'(T) mass range 1.5-2.5 (0.7-1.5) TeV



Limits placed on T2/3 quark mass: 1.30 TeV with 1.28 TeV expected