



Search for heavy bosons and lepton flavour violation with dileptons at CMS

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On behalf of the CMS Collaboration

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Heavy Resonances at CMS

- Search for Z' in dilepton channel
 - Bump search in dielectron and dimuon channels (and combination)
 - **EXO-16-031** (2016) **NEW!**
- Search for lepton flavor violation in dilepton channel
 - Heavy particle decays into $e\mu$ final state
 - **EXO-16-001** (2015)
- Search for Z' in ditau channel
 - **EXO-16-008** (2015)
- Search for W'
 - lepton+MET channel: **EXO-15-006** (2015)
 - tau+MET channel: **EXO-16-006** (2015)
- Search for $X \rightarrow Z\gamma$
 - Dilepton+ γ channel: **EXO-16-021** (2012+2015), **EXO-16-034** (2016) **NEW!**
 - Dijet+ γ channel: **EXO-16-025** (2012), **EXO-16-035** (2016)
NEW! **NEW!**

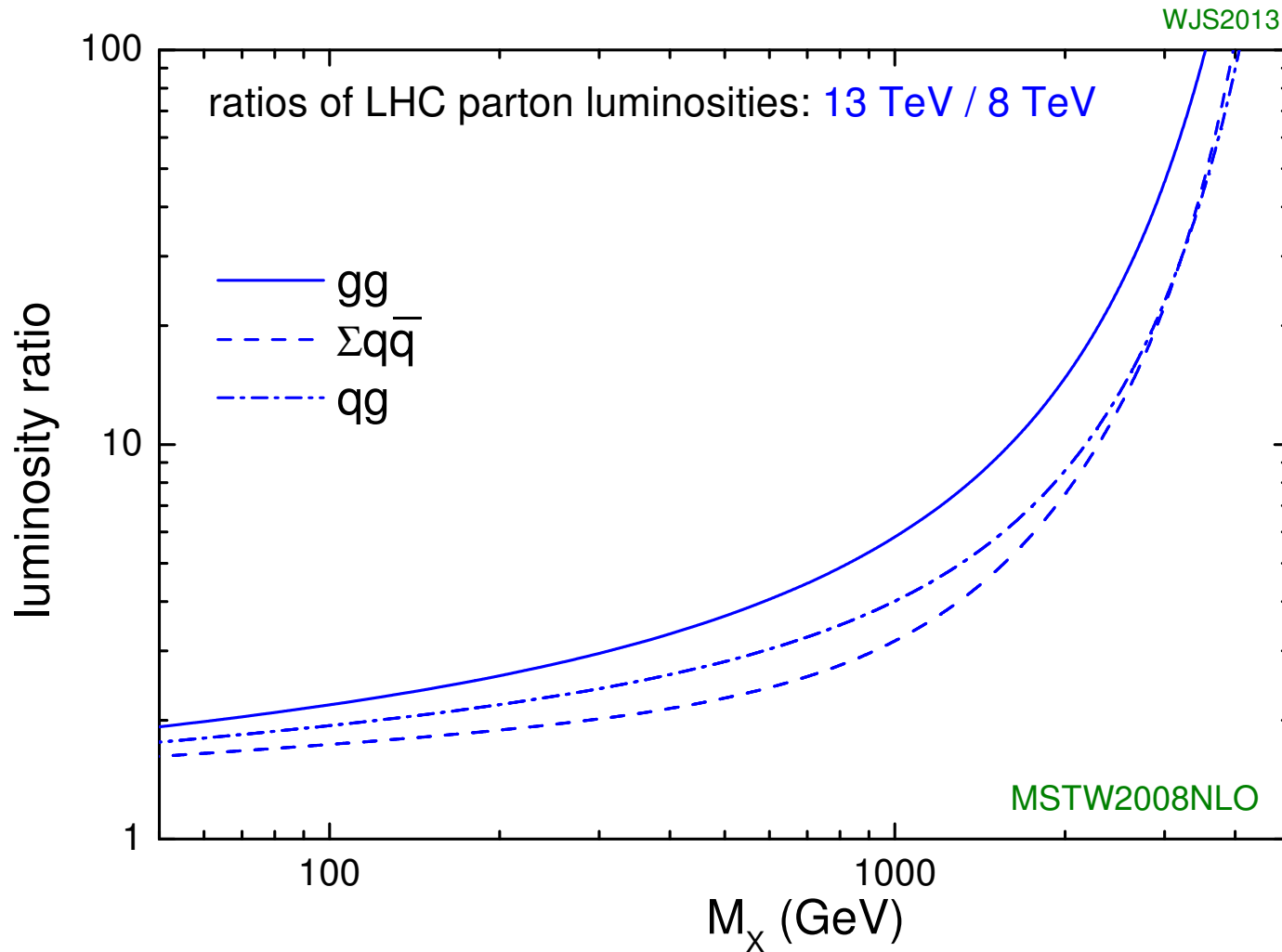


Introduction

- Many BSM models predict the existence of new heavy particles
- The new heavy particles can decay into leptons
 - Provide clean signature with respect to hadronic decay modes
 - But small branching fraction
- Leptonic decay modes are categorized
 - Electron and muon channels (and their combination)
 - Tau channel treated separately
 - Neutrinos leave signature as MET (missing transverse energy)
- Searches probe a large range of energy up to very high mass region
 - From $O(100 \text{ GeV})$ to $O(\text{few TeV})$
- Analyses are usually very sensitive to \sqrt{s}
 - Discovery potential is increased dramatically at 13 TeV
 - 13 TeV results with 2015 dataset defeat 8 TeV already
- In this talk we present **NEW RESULTS** at 13 TeV with 2016 dataset

Luminosity Ratio

J. Stirling

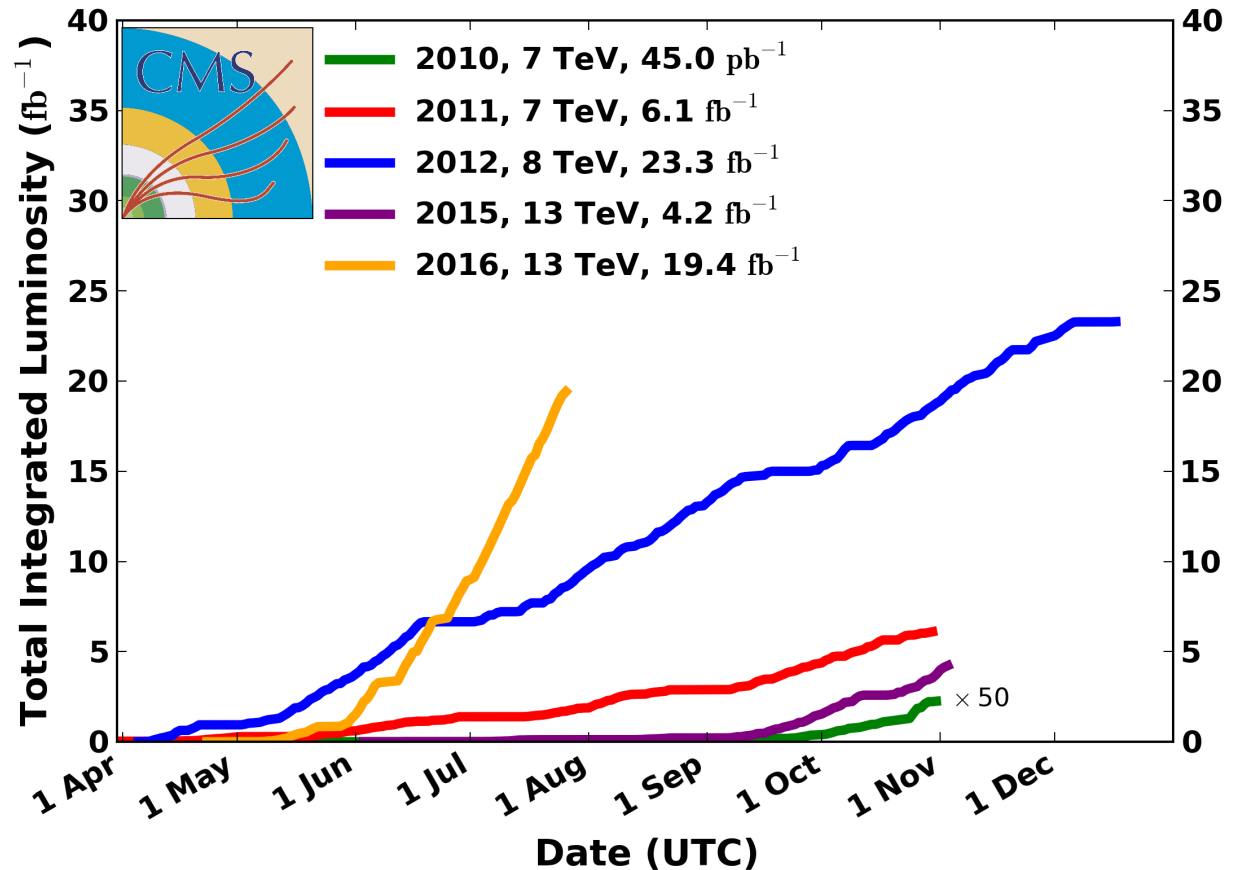




- Successful operation at 13 TeV!

CMS Integrated Luminosity, pp

Data included from 2010-03-30 11:22 to 2016-07-25 21:26 UTC



- Good to use for physics: 13/fb (up to July 15th)
- Preliminary uncertainty on luminosity for 2016 dataset: 6.2%

CMS Detector

Pixels
 Tracker
 ECAL
 HCAL
 Solenoid
 Steel Yoke
 Muons

SILICON TRACKER
 Pixels ($100 \times 150 \mu\text{m}^2$)
 $\sim 1\text{m}^2$ 66M channels
 Microstrips ($50\text{--}100\mu\text{m}$)
 $\sim 210\text{m}^2$ 9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
 76k scintillating PbWO_4 crystals

PRESHOWER
 Silicon strips
 $\sim 16\text{m}^2$ 137k channels

FORWARD CALORIMETER
 Steel + quartz fibres

MUON CHAMBERS
 Barrel: 250 Drift Tube & 500 Resistive Plate Chambers
 Endcaps: 450 Cathode Strip & 400 Resistive Plate Chambers

STEEL RETURN YOKE
 ~ 13000 tonnes

SUPERCONDUCTING SOLENOID
 Niobium-titanium coil
 carrying ~ 18000 A

HADRON CALORIMETER (HCAL)
 Brass + plastic scintillator

Total weight : 14000 tonnes
 Overall diameter : 15.0 m
 Overall length : 28.7 m
 Magnetic field : 3.8 T

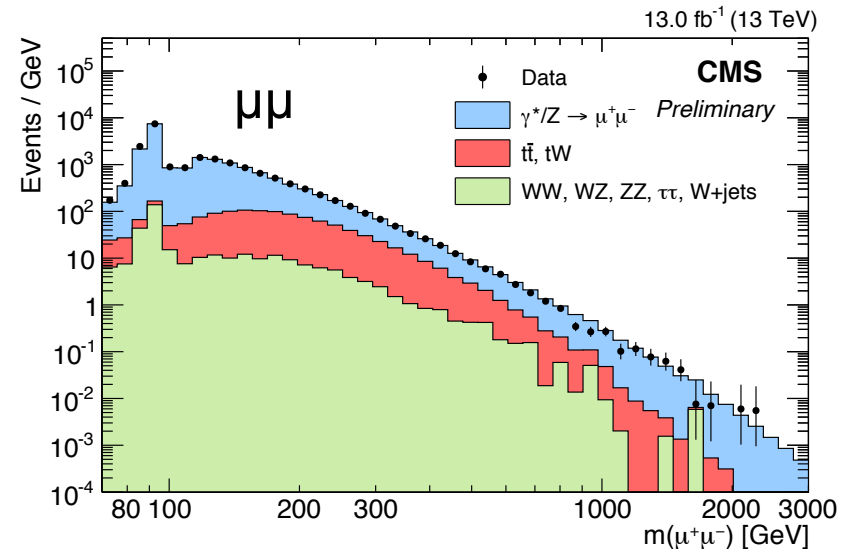
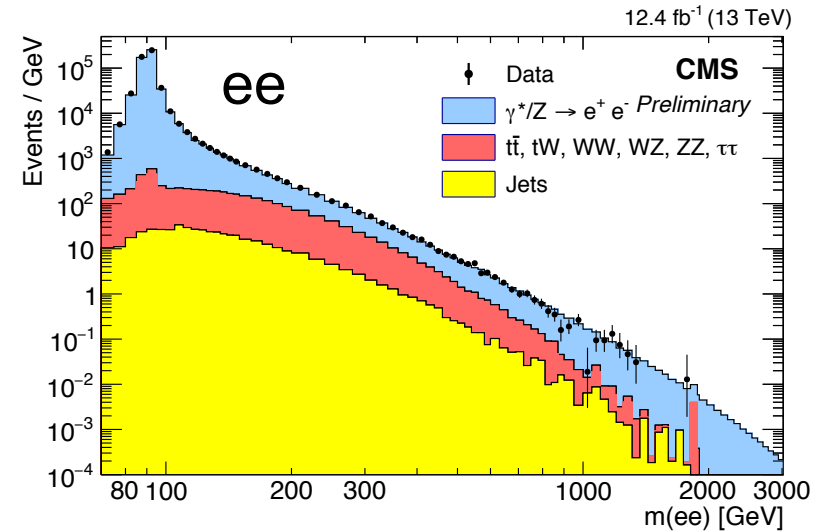


Search for Z' in Dilepton (ee , $\mu\mu$)

NEW!

CMS-PAS-EXO-16-031

- Model independent shape-based search for a narrow resonance
 - Further interpretations of high mass dilepton
- Standard CMS high p_T muon/electron id and event selection are used
 - Isolated e/mu with $p_T > 35/53$ GeV
- Dominant background
 - Drell-Yan, $t\bar{t}$, tW , diboson
 - Jets misidentified as leptons (W +jets, QCD) in the dielectron channel





Search for Z' in Dilepton ($ee, \mu\mu$)

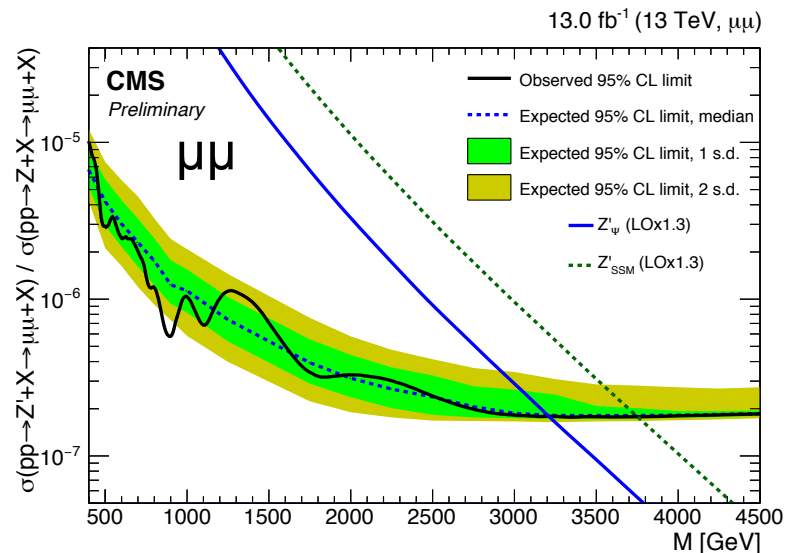
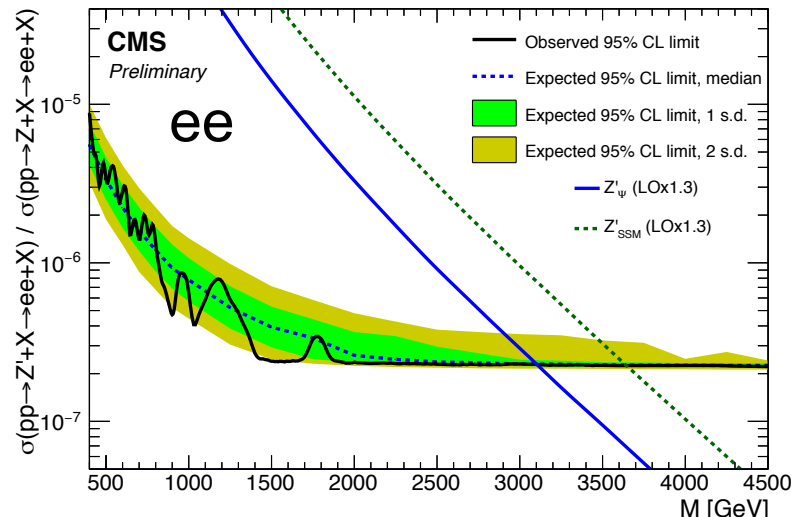
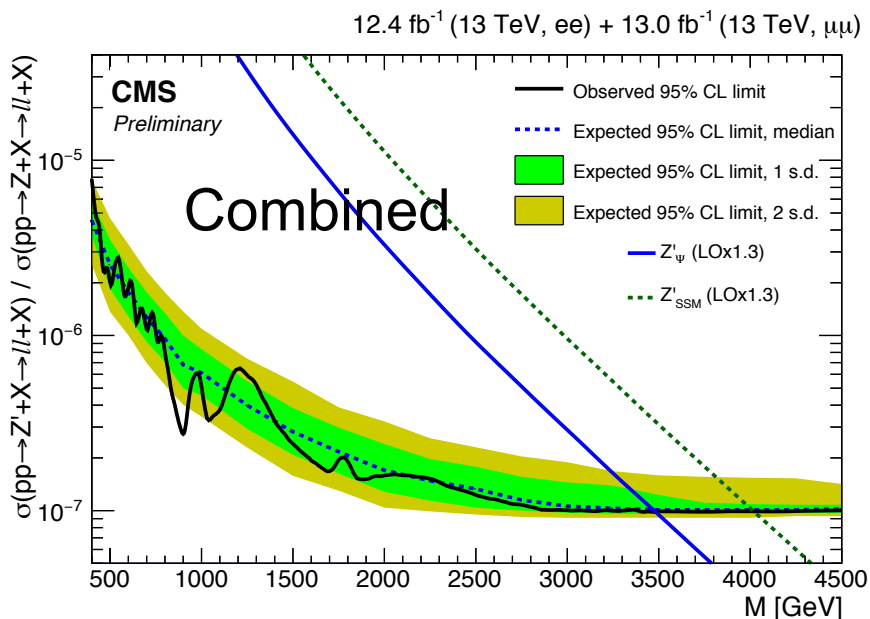
NEW!

CMS-PAS-EXO-16-031

12.4 fb⁻¹ (13 TeV, ee)

• Interpretation

- Limit on the ratio $R_\sigma = \frac{\sigma(pp \rightarrow Z' + X \rightarrow ll + X)}{\sigma(pp \rightarrow Z + X \rightarrow ll + X)}$
- Spin-1 assumed for the new resonance
- Signal with various widths: 0.6% (Z'_ψ), 3% (Z'_{SSM})
- Z'_ψ and Z'_{SSM} exclude < 3.5 TeV and 4.0 TeV

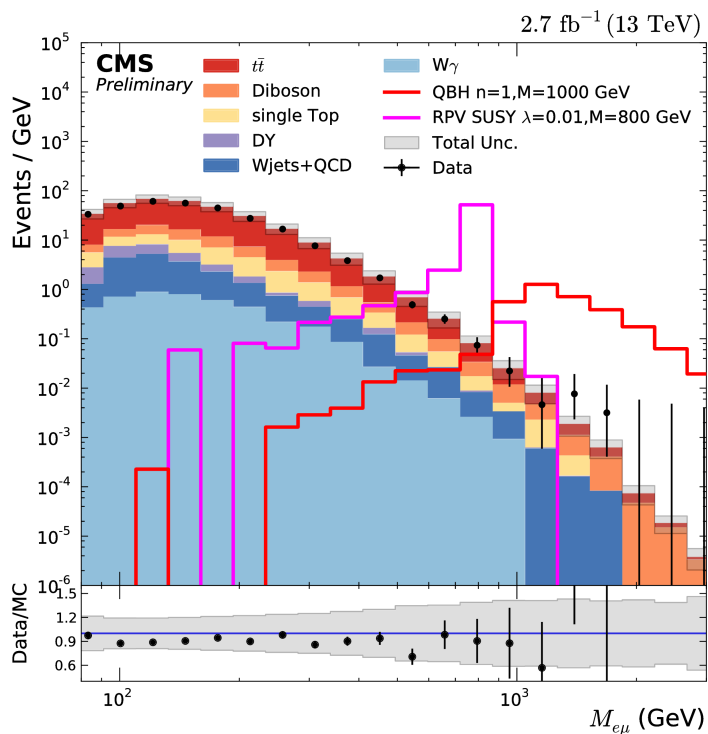




Search for e- μ Resonance

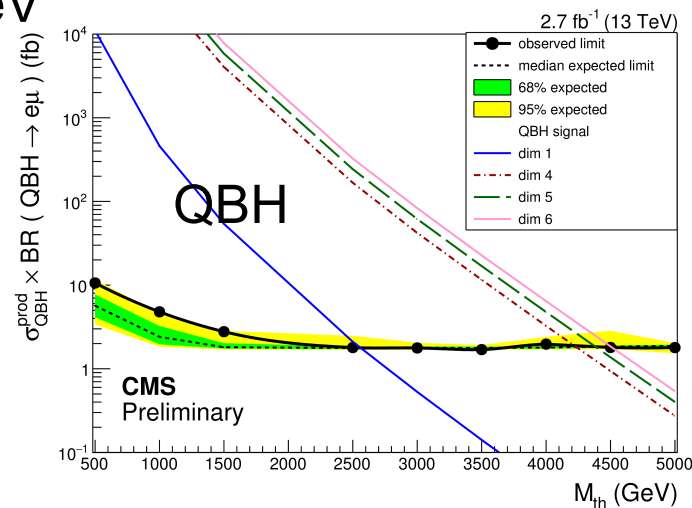
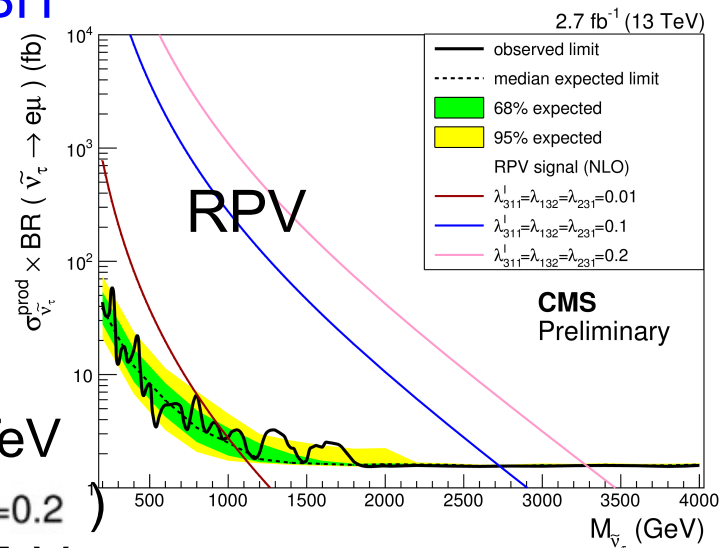
- RPV SUSY with τ sneutrino as LSP and QBH
- Selection
 - Iso. high pT e/ μ with 35/53 GeV
 - Select e- μ pair with highest invariant mass
- Shape based limits

CMS-PAS-EXO-16-001



Exclusion:

- RPV: 3.3 TeV
($\lambda_{311}^1 = \lambda_{132} = \lambda_{231} = 0.2$)
- QBH: 4.5 TeV
($n = 6$)

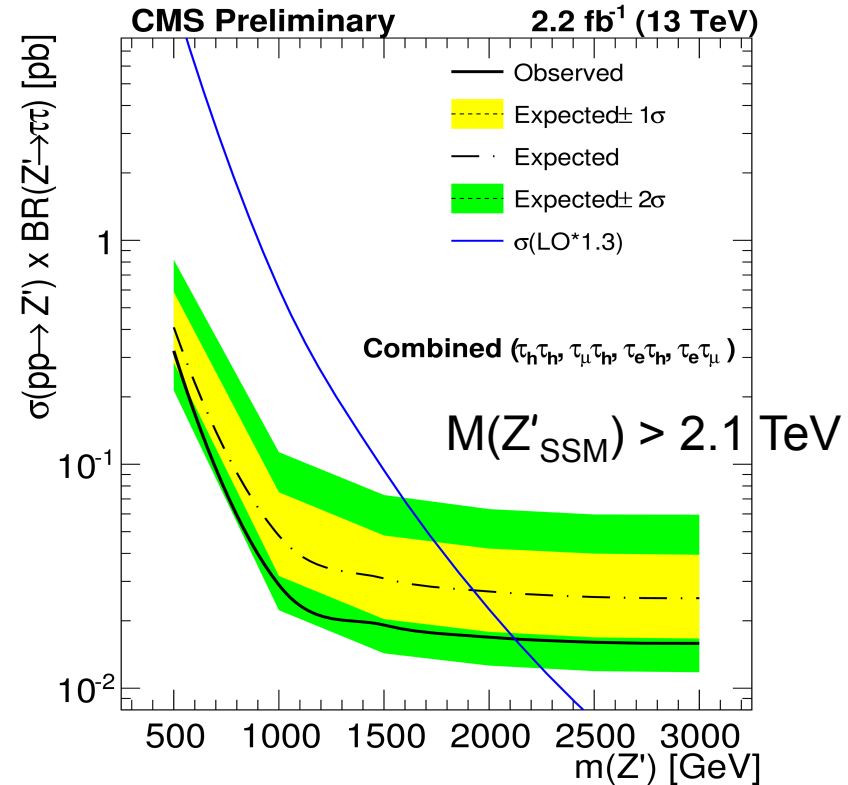
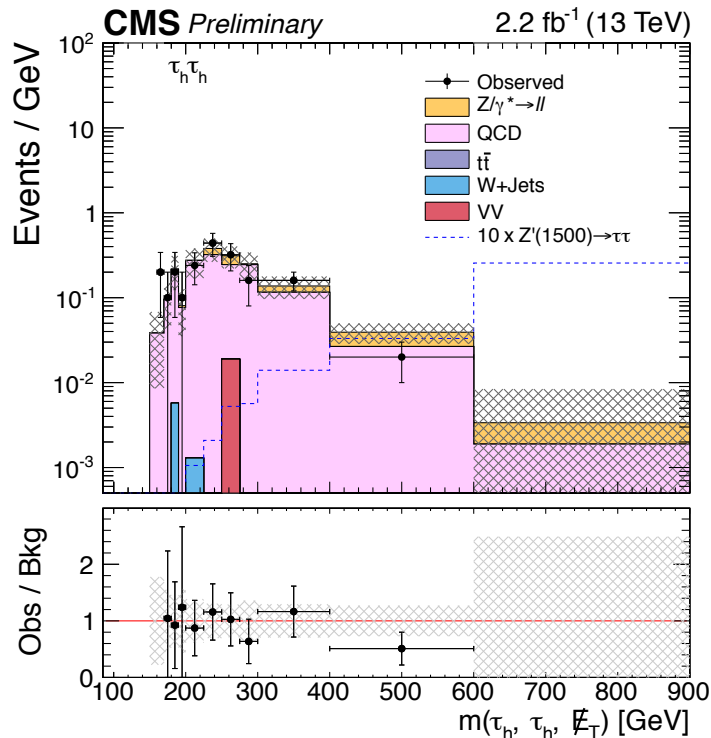


Search for Z' in Ditau

- Consider various channels
 - $T_h-T_h, T_e-T_h, T_\mu-T_h, T_e-T_\mu$
- Main backgrounds: $t\bar{t}$, dibosons, Drell-Yan, multijet from QCD

CMS-PAS-EXO-16-008

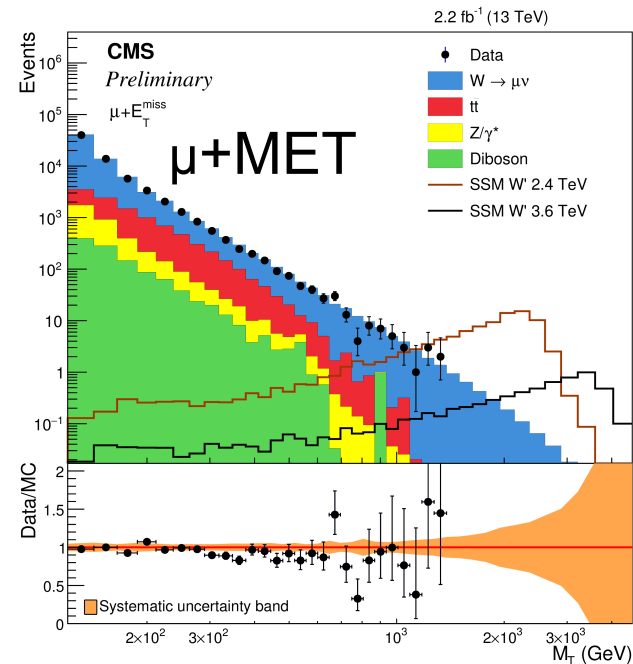
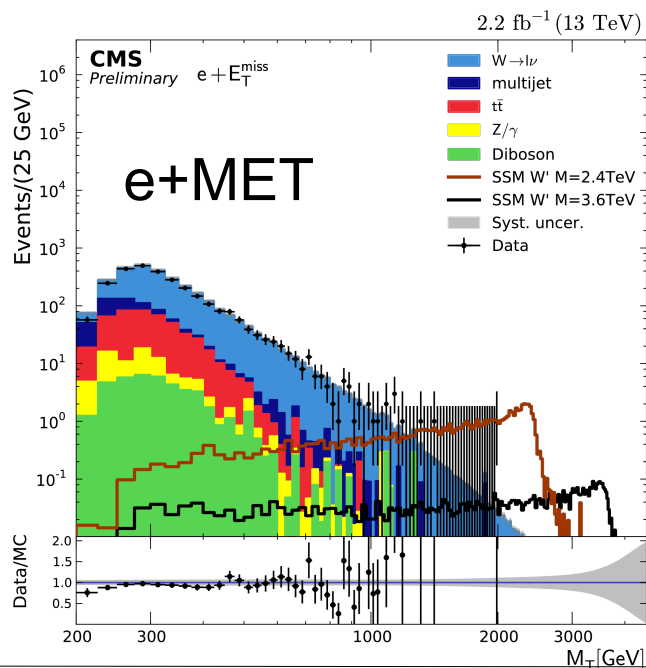
- Selection
 - High iso. pT lepton
 - Back-to-back τ events



Search for $W' \rightarrow \text{lepton} + \text{MET}$ (e or μ)

- New heavy gauge bosons can appear in many BSM models: SSM, RS gravitons, composite Higgs, etc.
- Search strategy $M_T = \sqrt{2p_t^l E_T^{\text{miss}} (1 - \cos \Delta\phi(\vec{p}_t^l, \vec{p}_T^{\text{miss}}))}$
- Event selection
 - One iso. high p_T lepton: $> 130/53$ GeV (e/ μ)
 - Ratio of p_{T_l}/MET : $0.4 < p_{T_l}/\text{MET} < 1.5$ and $|\Delta\phi(p_{T_l}, \text{MET})| > 2.5$
 - Veto on additional leptons with $p_T > 35/25$ GeV

CMS-PAS-EXO-15-006



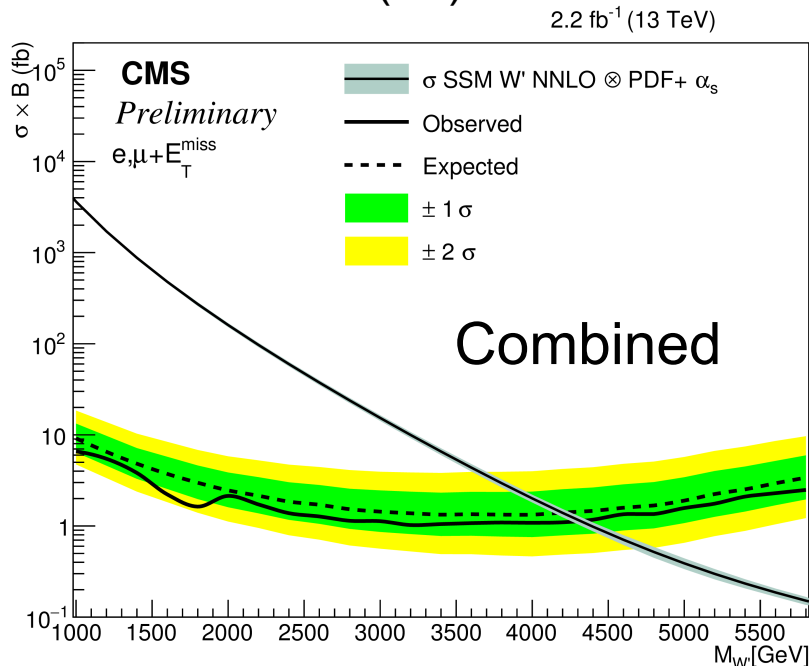


Search for $W' \rightarrow \text{lepton} + \text{MET}$ (e or μ)

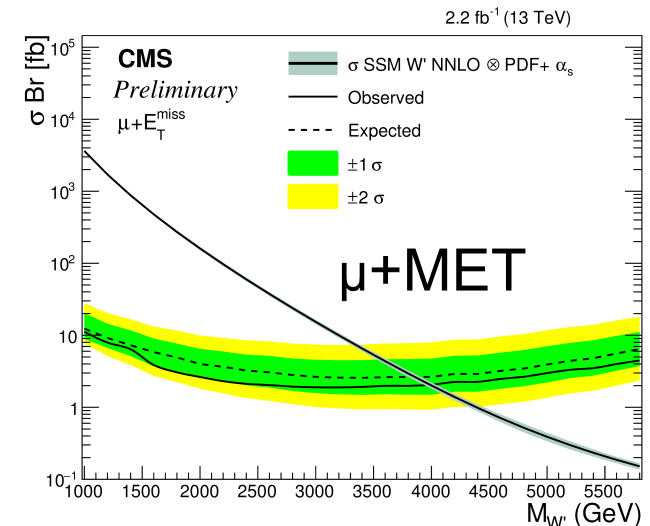
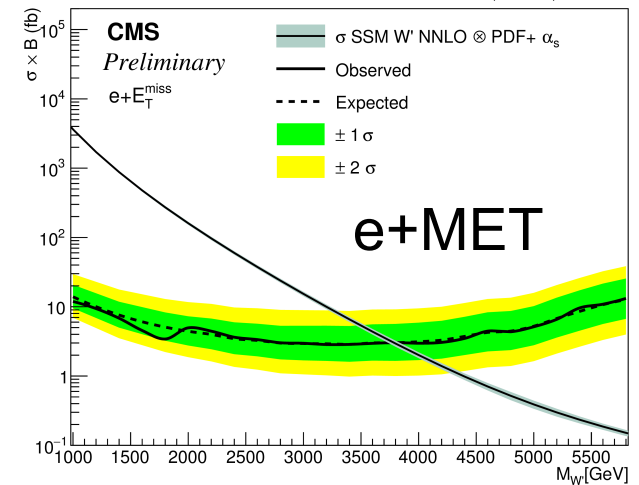


• Interpretations

- Limits are calculated using the full shape of the SSM W' distribution
- Signal acc * eff $\sim 75\%$ at $M(W') = 3 \text{ TeV}$
- Main systematics: acc*eff (3-8%), muon mom. scale (10-20%), luminosity (2.7%)
- Exclude: SSM $M(W')$ below 4.4 TeV



CMS-PAS-EXO-15-006
2.2 fb⁻¹ (13 TeV)



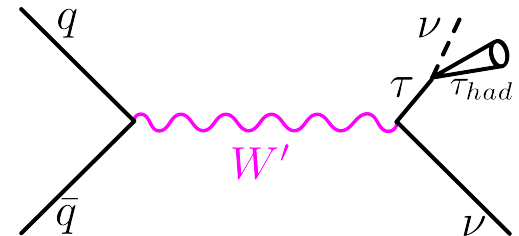
Search for $W' \rightarrow \tau + \text{MET}$

Search strategy

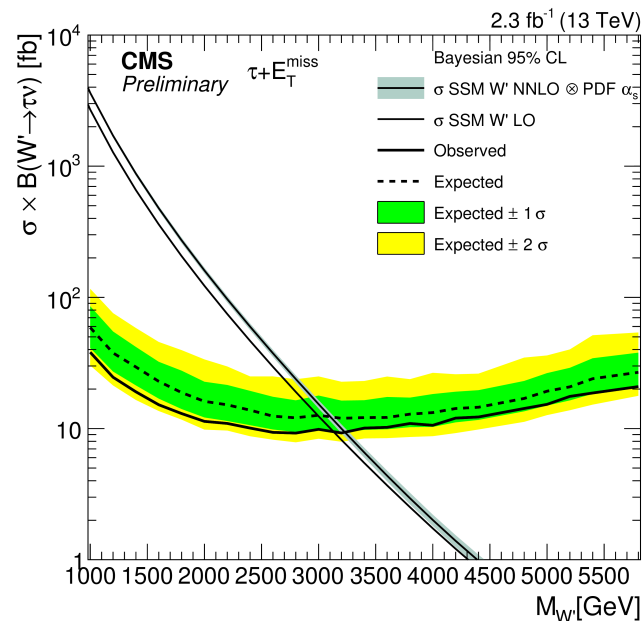
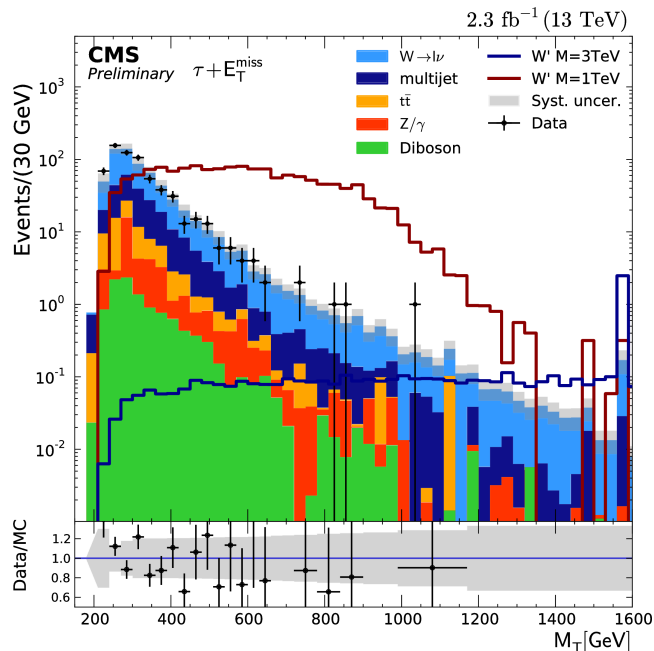
- Similar to $e/\mu + \text{MET}$ channel
- M_T distribution more spread due to two neutrinos
- Kinematic distributions are different

Event selection

- One iso. high p_T hadronic tau: $> 80 \text{ GeV}$
- Ratio of $p_{T_{\tau}}/\text{MET}$: $0.7 < p_{T_{\tau}}/\text{MET} < 1.3$ and $|\text{dphi}(p_{T_{\tau}}, \text{MET})| > 2.4$



CMS-PAS-EXO-16-006



Exclude: SSM
 $M(W')$ below
3.3 TeV



Search for $Z\gamma$ Resonance ($Z \rightarrow \ell\ell$)

NEW!

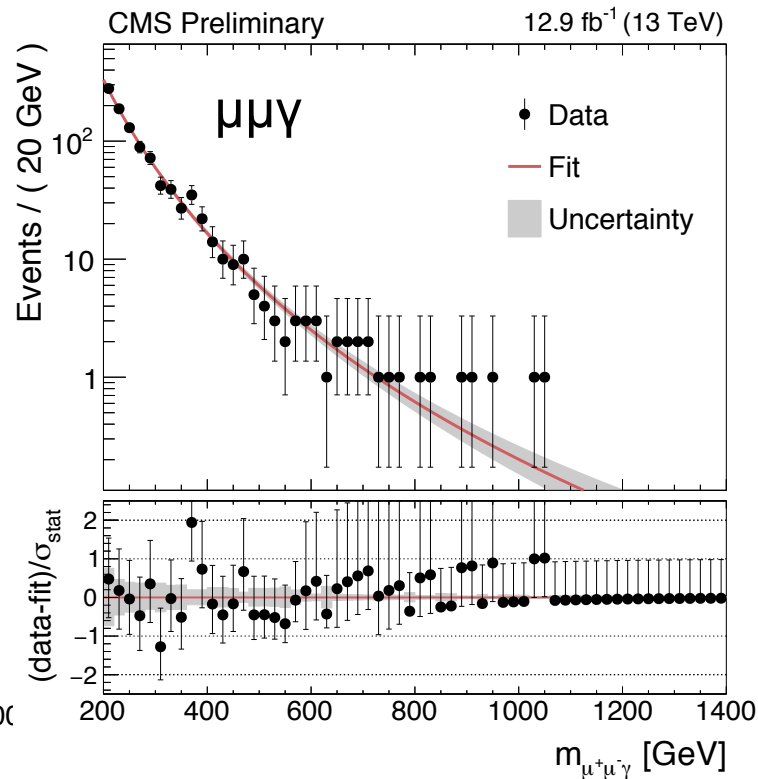
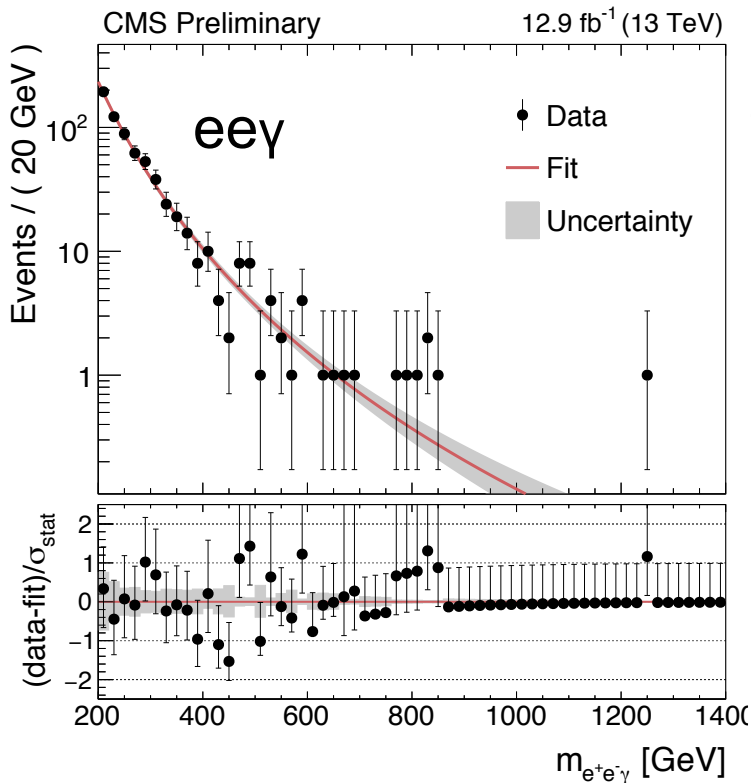
CMS-PAS-EXO-16-034

- Search strategy

- Bump search in $M(Z\gamma)$ spectrum in dilepton channels: $ee\gamma$, $\mu\mu\gamma$
- Search region: $M(Z\gamma) > 300$ GeV
- Fit the data with background model
 - Same technique of diphoton search

Results with new 2016 data

- e/μ $p_T > 25/20$ GeV for leading (subleading)
- $50 < M(Z) < 130$ GeV
- Photon $p_T > 40$ GeV, $dR(\ell, \gamma) > 0.4$
- Photon $p_T > (40/150) \cdot M(Z\gamma)$





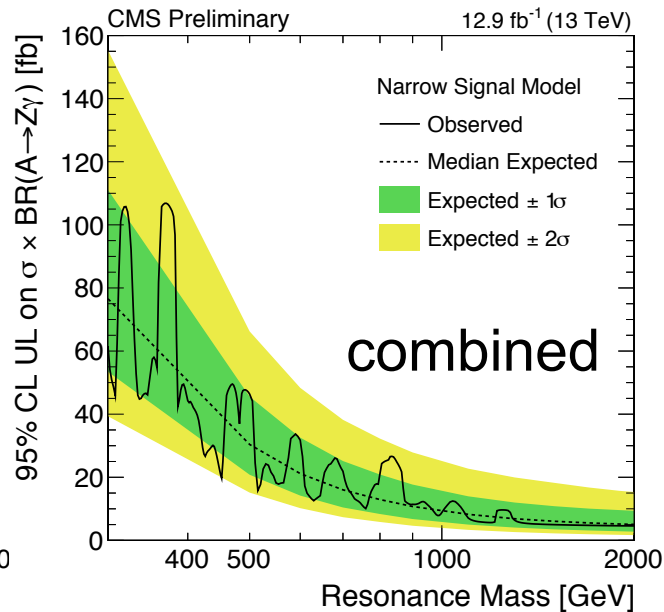
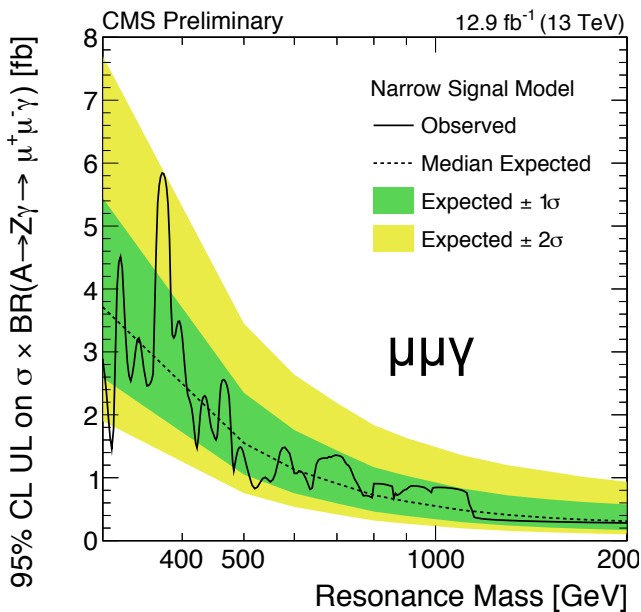
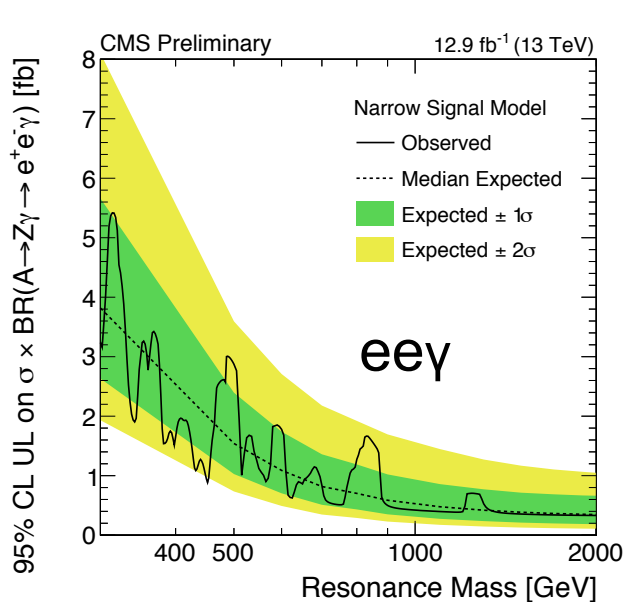
Search for $Z\gamma$ Resonance ($Z \rightarrow \ell\ell$)

NEW!

CMS-PAS-EXO-16-034

- Interpretation

- No significant excess above expected backgrounds is observed
- Limit on $\sigma \times \text{Br}(X \rightarrow Z\gamma \rightarrow \ell\ell\gamma) / \text{Br}(X \rightarrow Z\gamma)$
- Systematic uncertainties: 5% for lepton and photon efficiencies, 3-4% for trigger, $\sim 1\%$ for electron/muon energy/momentum scale corrections





Search for $Z\gamma$ Resonance ($Z \rightarrow qq$)



NEW!

CMS-PAS-EXO-16-025, 035

- Search strategy
 - Bump search in $M(Z\gamma)$ spectrum in dijet channel: Spin-0 $X \rightarrow Z\gamma$, $Z \rightarrow qq$
 - Use boosted topology ($Z \rightarrow J$) and increased branching fraction to improve S/B
 - Exploit b-tagging to further discriminate backgrounds
 - Higher acceptance to compare to dilepton channel: advantage at high mass
- Selection
 - γ $p_T > 170$ (200) GeV for 8 (13) TeV with EB only
 - Z identification
 - Jet $p_T > 170$ (200) GeV for 8 (13) TeV
 - 70 (75) $< M(J) < 110$ (105) GeV for 8 (13) TeV
 - Subjet b-tagging
 - $p_T(\gamma) / M(Z\gamma) > 0.34$



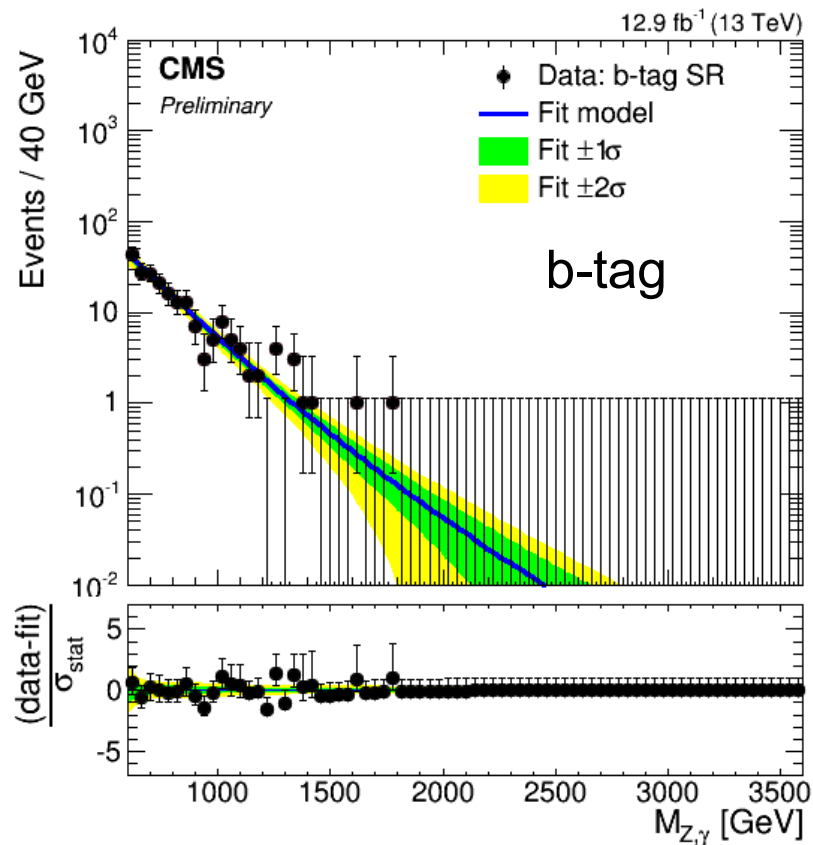
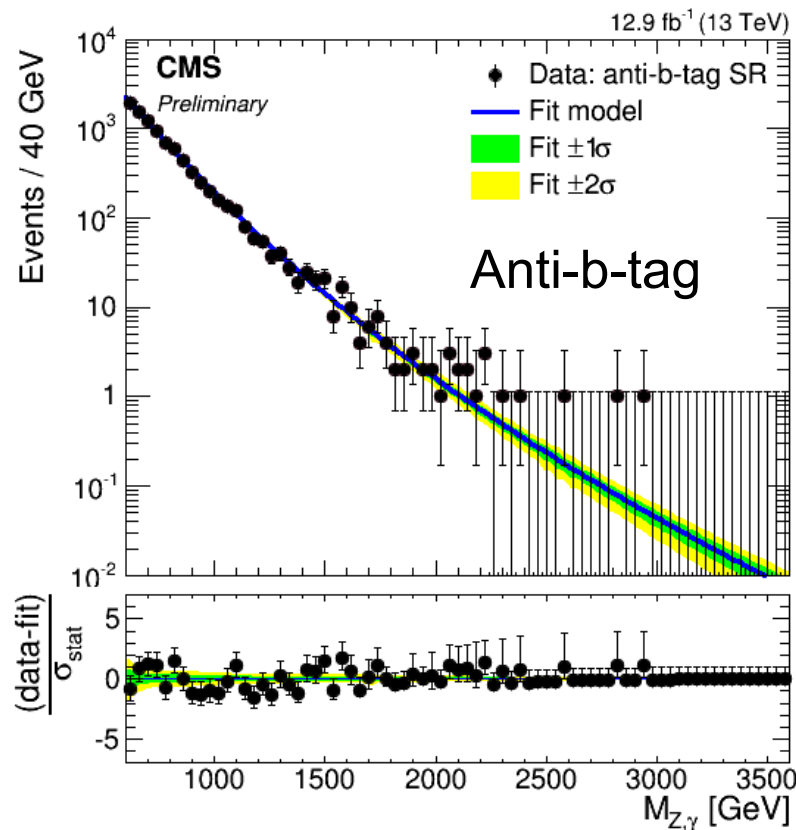
Search for $Z\gamma$ Resonance ($Z \rightarrow qq$)

NEW!

CMS-PAS-EXO-16-025, 035

- Background estimation from smooth fit

$$\frac{dN}{dM_{Z\gamma}} = P_0 \times \left(\frac{M_{Z\gamma}}{\sqrt{s}} \right)^{P_1 + P_2 \times \log\left(\frac{M_{Z\gamma}}{\sqrt{s}}\right)}$$



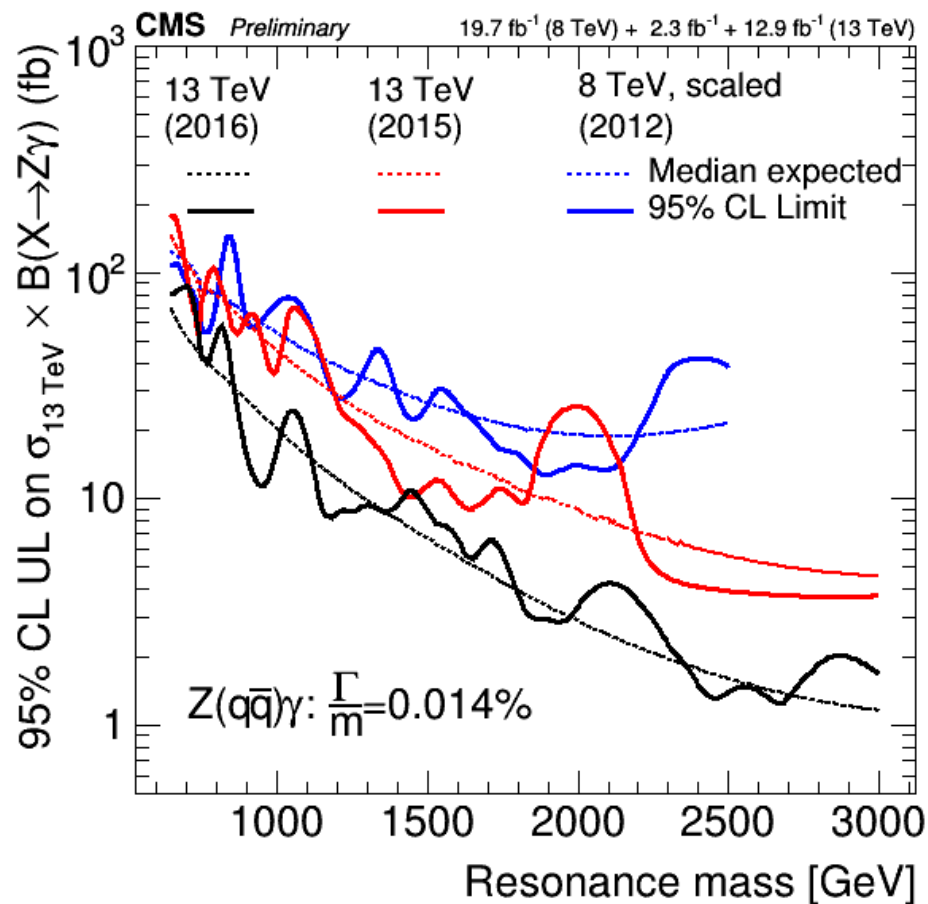
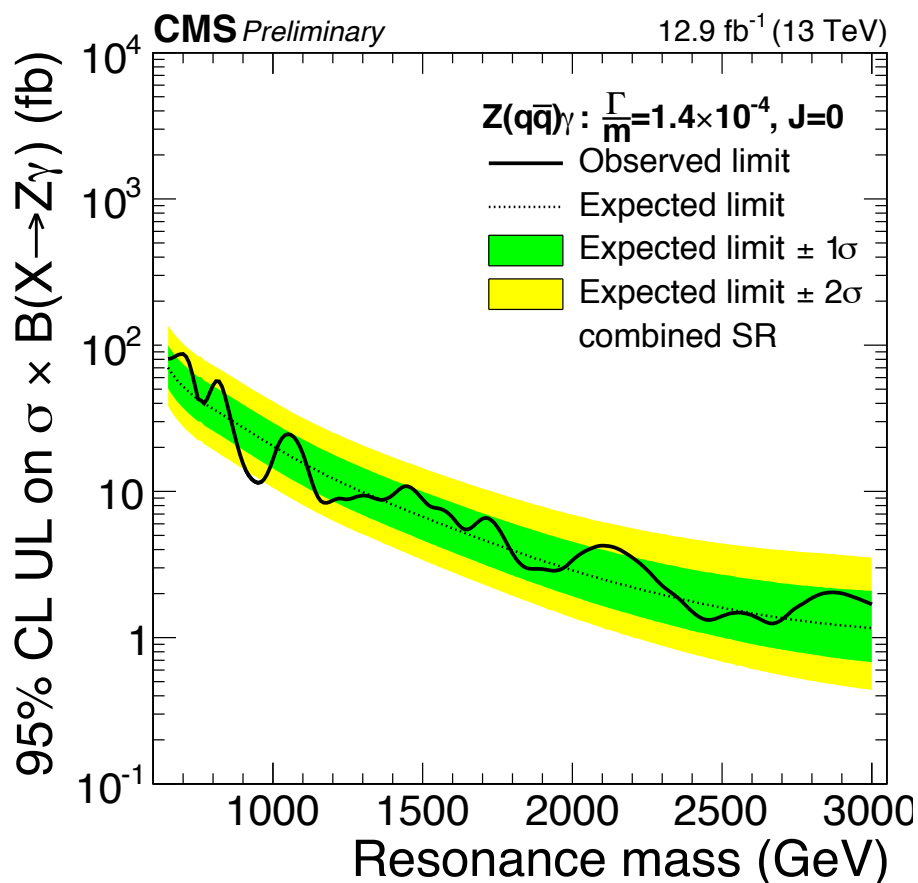


Search for $Z\gamma$ Resonance ($Z \rightarrow q\bar{q}$)

NEW!

CMS-PAS-EXO-16-025, 035

- No significant excess observed
 - Set 95% CL limit





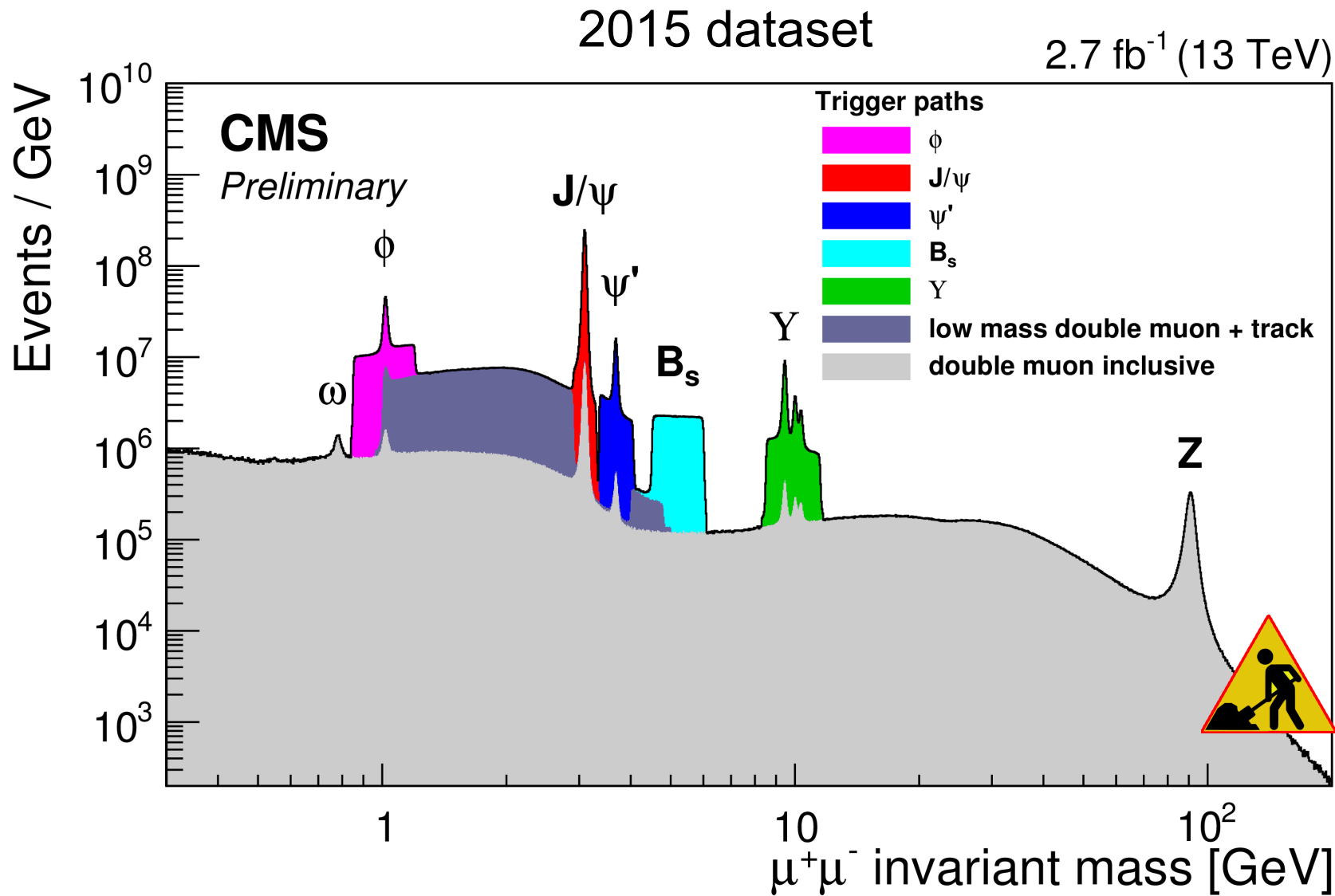
Summary



- Many new searches for BSM physics with heavy resonances in dilepton final state are presented
 - Many new results with 2016 dataset!
 - More can be found here:
 - <http://cms-results.web.cern.ch/cms-results/public-results/publications/>
- Improved limits compared to the previous results
- No significant excess beyond the prediction is observed
- Much more results are coming soon with new data

Stay tuned!

Back Up

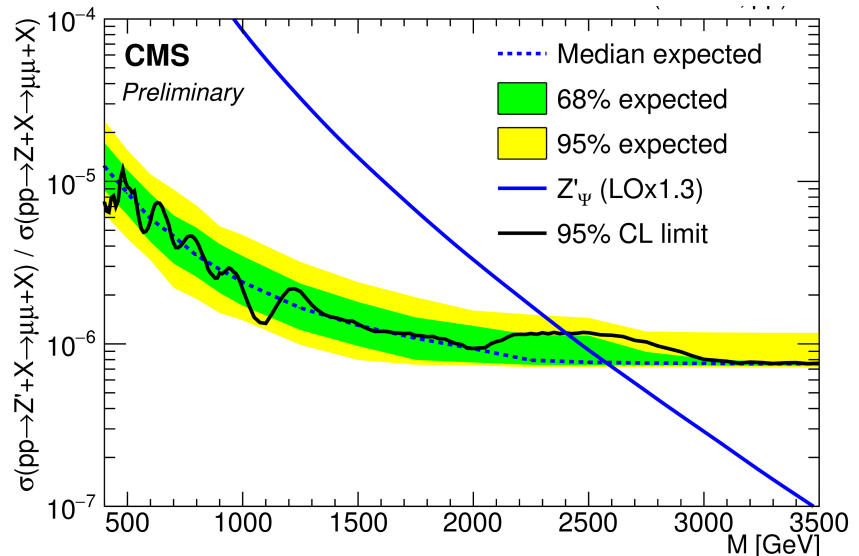
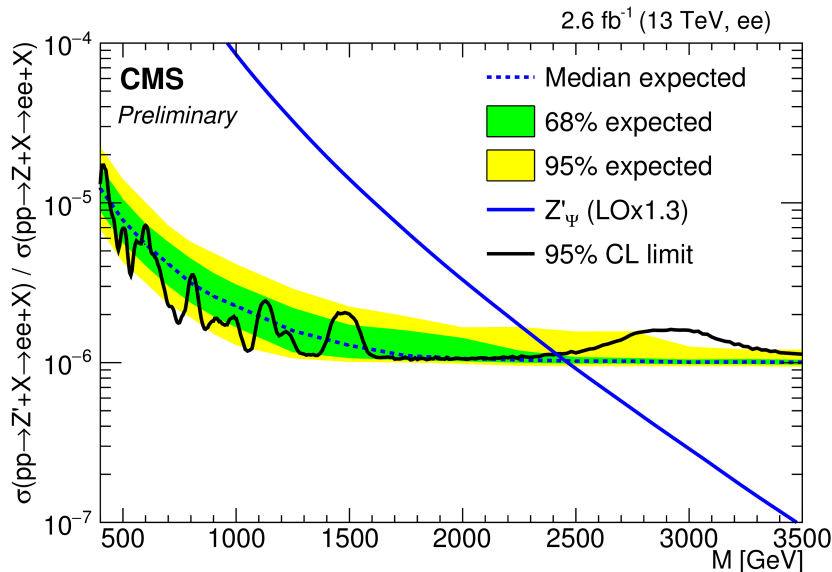
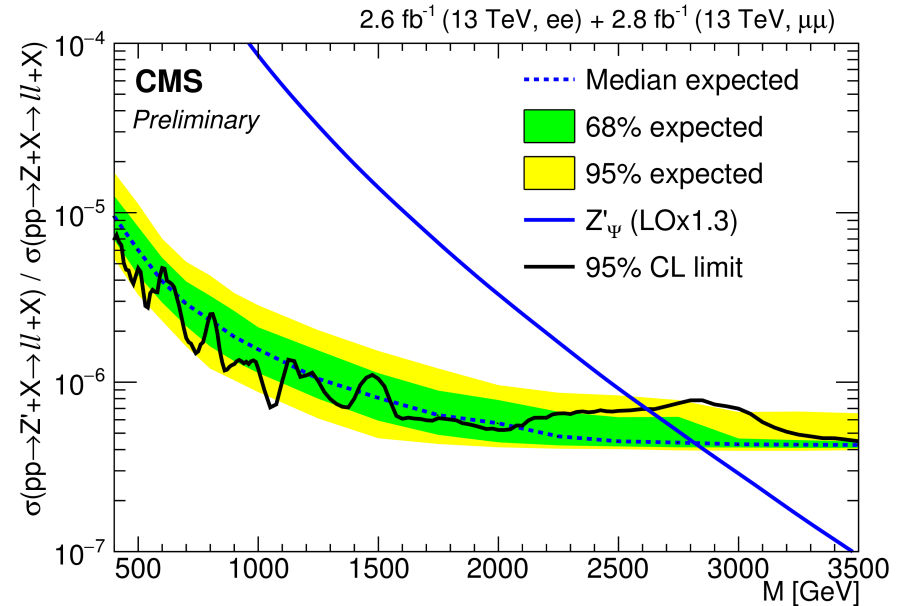


Search for Z' in Dilepton ($ee, \mu\mu$)

- 2015 results

- $M(Z'_{\text{SSM}}) > 3.15 \text{ TeV}$
- $M(Z'_{\psi}) > 2.60 \text{ TeV}$

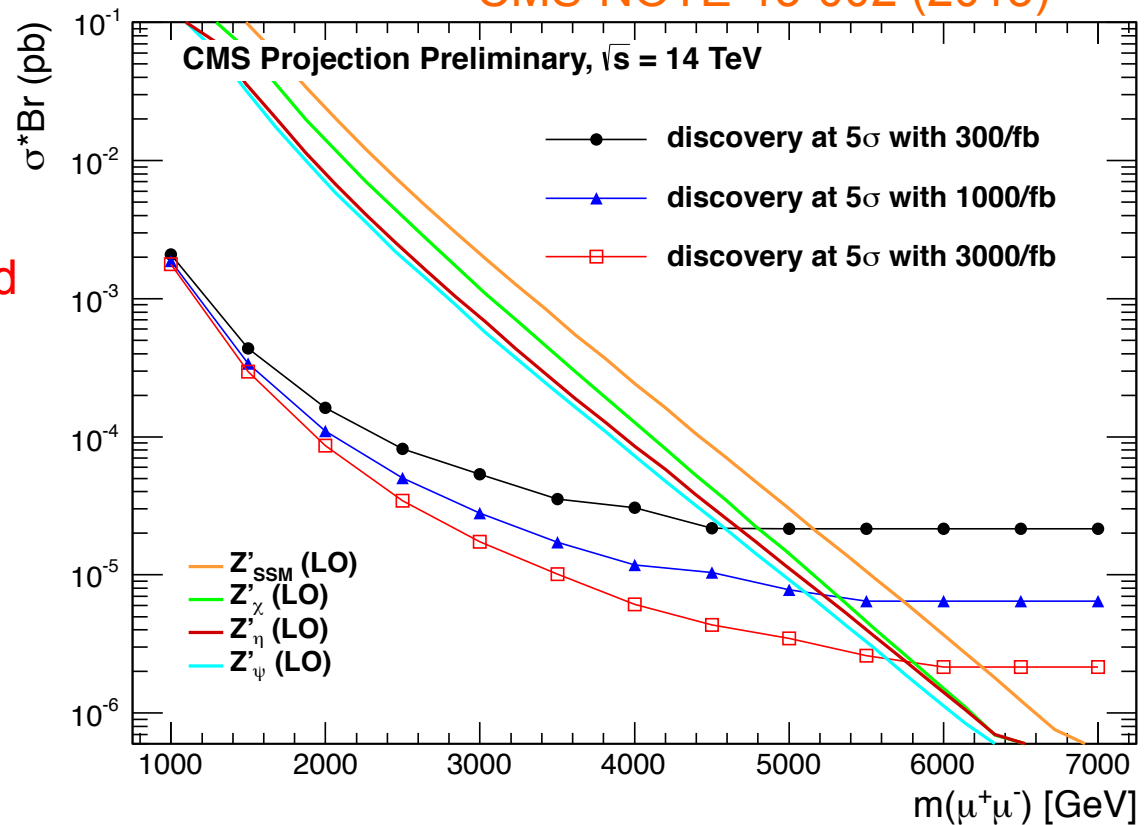
CMS-PAS-EXO-15-005



Z' Projection at 14 TeV

- Projection of discovery reach at 14 TeV with 300, 1000, 3000/fb
- Used in Snowmass white paper
- Studies are based on generator level extrapolations and scaling of 8 TeV results

CMS-NOTE-13-002 (2013)



Important to understand
the future expectation
to decide the detector
upgrade plan

Tau Decays

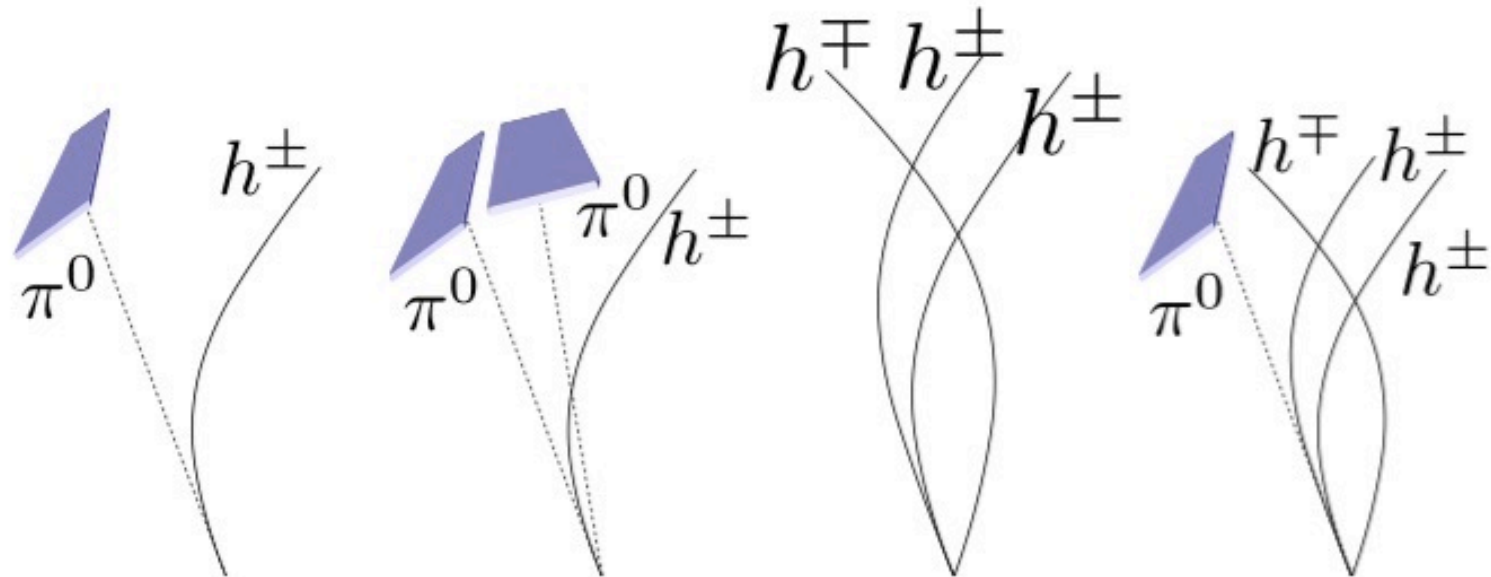


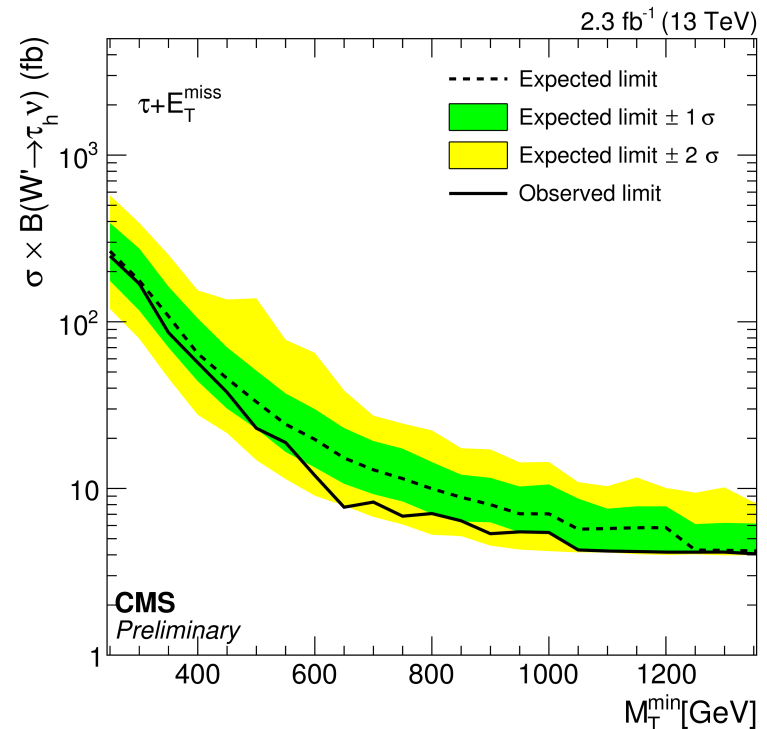
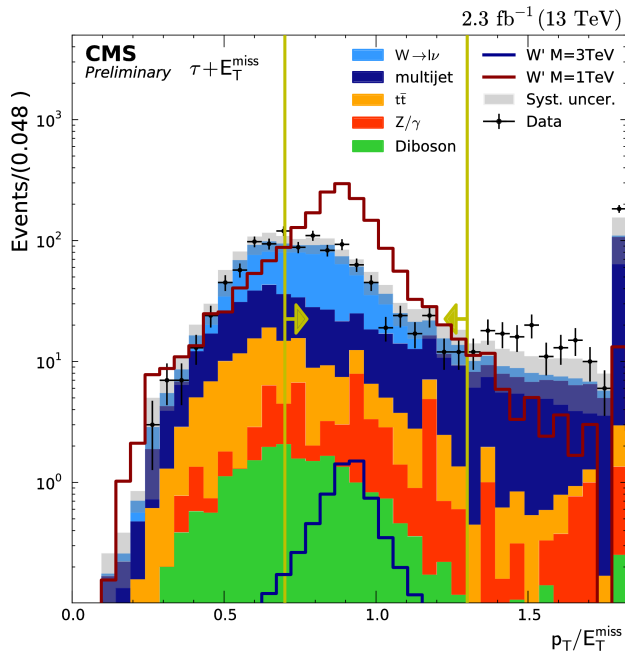
Figure 3: The graphs illustrate the reconstruction of the HPS reconstruction, showing the charged hadrons as lines and the strips from the neutral pions as blue boxes. Considered tau decays: the two left graphs illustrating the decays $\tau \rightarrow h^\pm \pi^0$ ($\mathcal{B} \sim 26\%$) and $\tau \rightarrow h^\pm \pi^0 \pi^0$ ($\mathcal{B} \sim 9.5\%$) would both lead experimentally to a "one-prong" signature. The two graphs on the right lead to an observed "three-prong" signature from the decays $\tau \rightarrow h^\pm h^\pm h^\mp$ ($\mathcal{B} \sim 9.8\%$) and $\tau \rightarrow h^\pm h^\pm h^\mp \pi^0$ ($\mathcal{B} \sim 4.8\%$). Not shown is the one prong decay without a π^0 ($\mathcal{B} \sim 11.6\%$).

Search for $W' \rightarrow \tau + \text{MET}$

• Interpretation

CMS-PAS-EXO-16-006

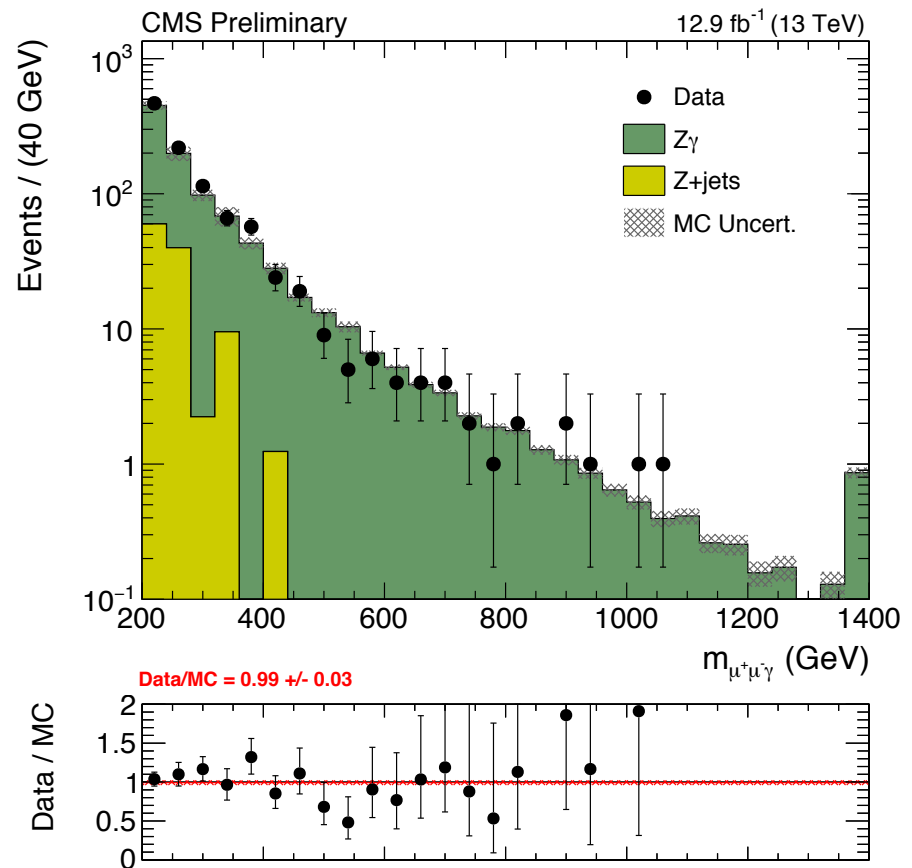
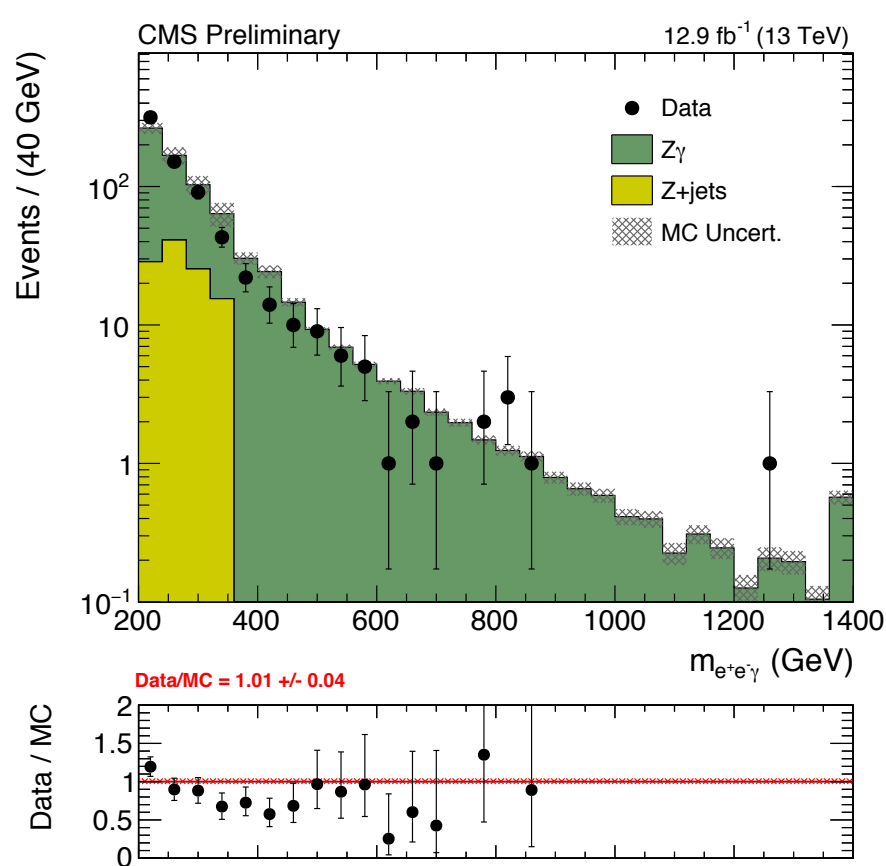
- Limits are calculated using the full shape of the SSM W' distribution Due to large tail at low M_T
- Signal $\text{acce} \times \text{eff} \sim 23\%$ at $M(W') = 3 \text{ TeV}$
- Main systematics: $\text{acc} \times \text{eff}$ (25%), τ mom. scale (3%), luminosity (4.6%), fake (50%)
- Exclude: SSM $M(W')$ below 3.3 TeV



Search for $Z\gamma$ Resonance ($Z \rightarrow \ell\ell$)

CMS-PAS-EXO-16-034

- $M(Z\gamma)$ invariant mass distribution after full event selection





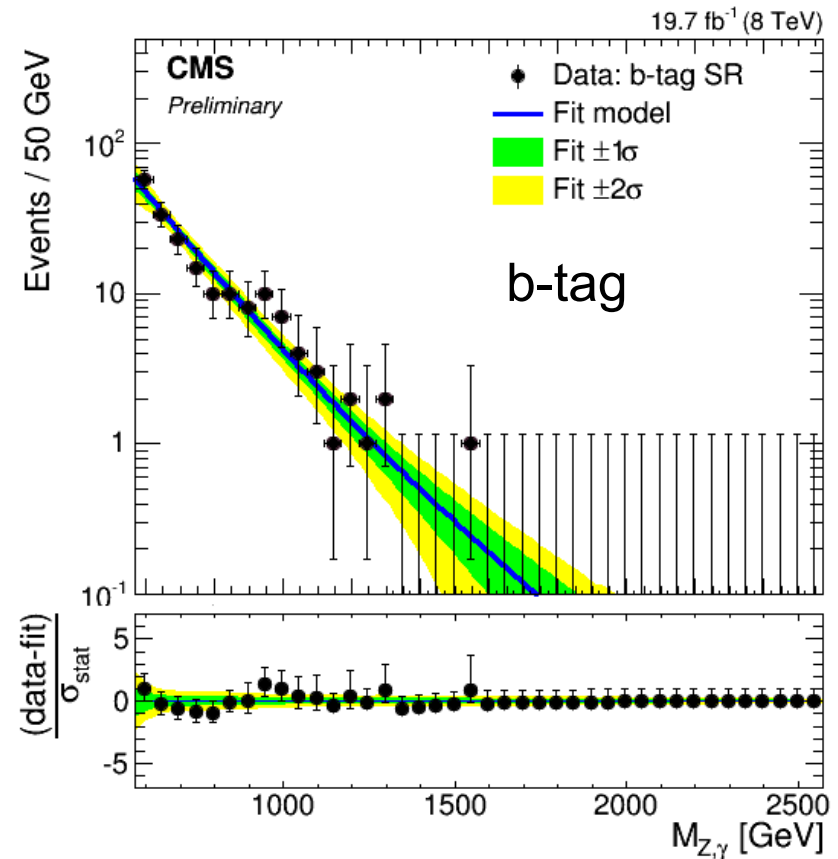
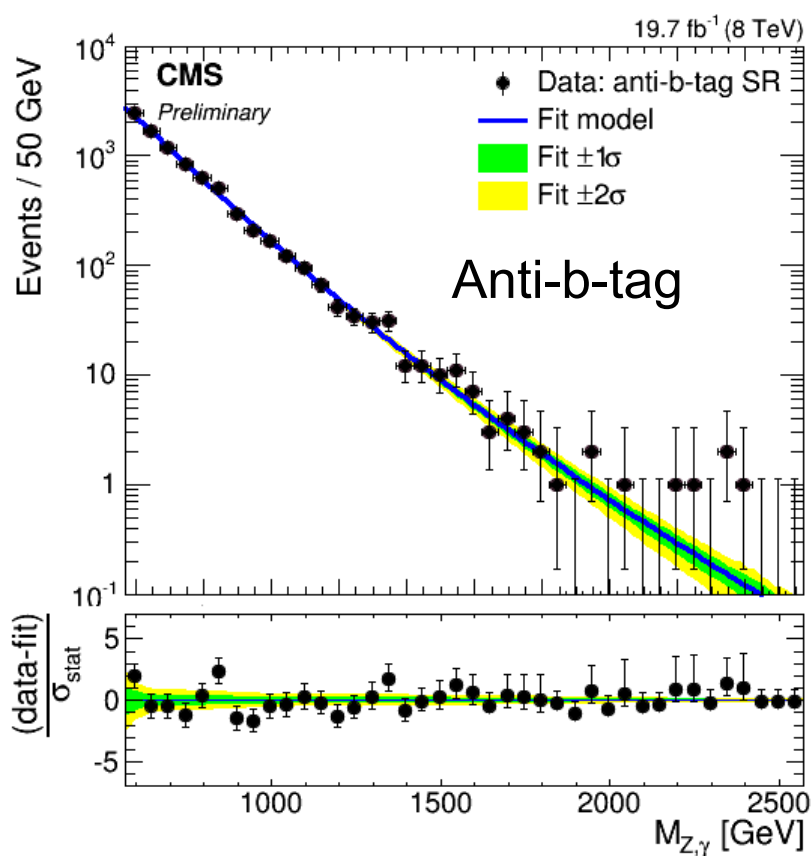
Search for $Z\gamma$ Resonance ($Z \rightarrow qq$)

NEW!

CMS-PAS-EXO-16-025

- Background estimation from smooth fit

$$\frac{dN}{dM_{Z\gamma}} = P_0 \times \left(\frac{M_{Z\gamma}}{\sqrt{s}} \right)^{P_1 + P_2 \times \log\left(\frac{M_{Z\gamma}}{\sqrt{s}}\right)}$$





Search for $Z\gamma$ Resonance ($Z \rightarrow q\bar{q}$)

NEW!

CMS-PAS-EXO-16-025, 035

- No significant excess observed
 - Set 95% CL limit

