Search for Diboson Resonance decaying into pairs of boosted W and Z at $\sqrt{s}$ =13 TeV EXO-15-002

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On behalf of the
Diboson Resonances Group

IIHE CMS meeting: Jamboriihe
2015/12/17

Diboson Resonances Group

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Outline

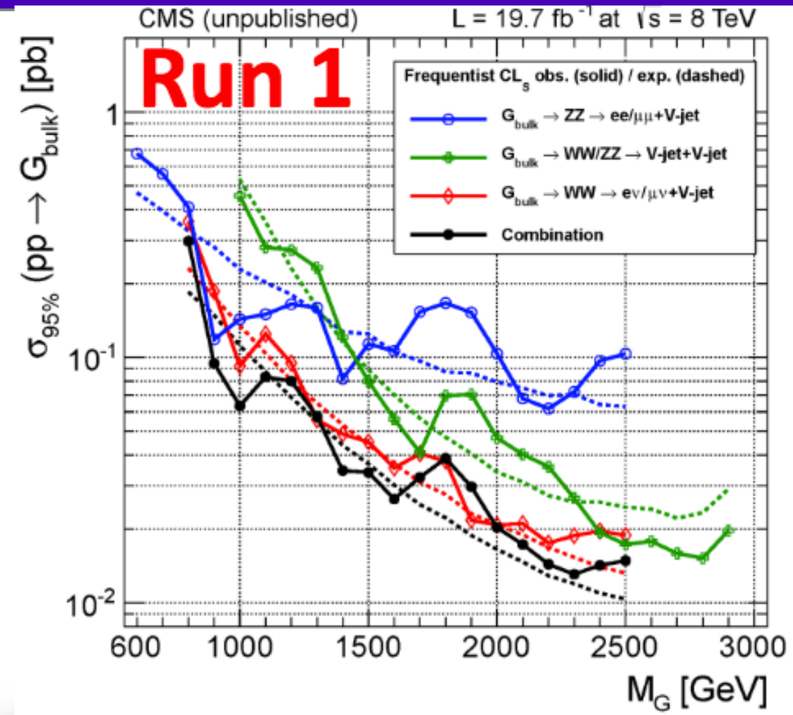
- Introduction
- Pre-selection
- Control plots
- V-tagger validation
- Background estimation
- Systematic uncertainties
- Final limit

Motivation for Diboson Search

Beyond Standard Model

- Many unification attempts
  Hierarchy problem
  - Why is gravity so much weaker?

Motivate the existence of heavy EXOTIC resonances



	Channel	Models
EXOTIC resonance X→ Diboson	WW	Spin-0 Radion Spin-1 HVT (neutral) Spin-2 **Bulk Graviton**¶
	WZ	Spin-1 **HVT** ¶ (charged)
	ZZ	Spin-0 Radion Spin-2 **Bulk Graviton** ¶

¶ For December

Data and simulated samples

Simulated samples

- Spring15 MiniAODv2
- Pileup scenario at 25ns
  - asymptotic_v2

Background samples

- W+Jets(main background)
  - madgraph-pythia8
- TTbar+jets
  - powheg-pythia8
- Single top
  - amcatnlo-pythia8
- WW, WZ, ZZ
  - Powheg(WW)
  - amcatnol-pythia8(WZ, ZZ)

Signal samples

- Bulk graviton, W'(HVT modelB)
  - madgraph

Data

- Run2015D
  - 05Oct2015-v1
  - PromptReco-v4
- Golden JSON
  - 2.198 fb-1
- Jet Energy Corrections:
  - Summer15_25nsV6_DATA

Samples detailed list

- Chapter 3 in the common note
  - AN-15-196

Pre-selection

Muon channel

- HLT_Mu45_eta2p1 or HLT_Mu50_eta2p1
- Tight muon: HighPT ID, relIsoR03 < 0.1, p_T > 53 GeV , |η|<2.1,
- Loose muon (for veto): HighPT ID, relIsoR03 < 0.1, p_T > 20 GeV , |η|<2.4
- Missing E_T > 40 GeV (type I)

Trigger studies for high pT muons, Muon POG, https://indico.cern.ch/event/455179/

Electron channel

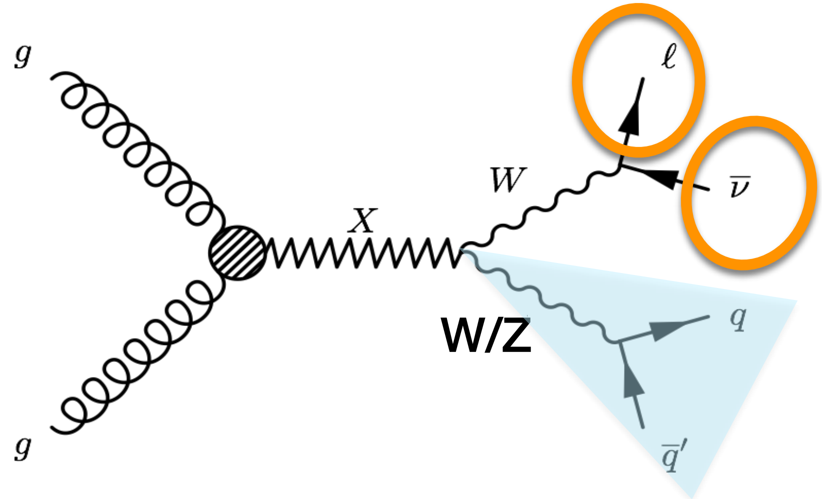
- HLT_Ele105_CaloIdVT_GsfTrkIdT or HLT_Ele115_CaloIdVT_GsfTrkIdT
- Tight electron: HEEP v6.0, p_T > 120 GeV
- Loose electron (for veto): HEEP v6.0
- Missing E_T > 80 GeV (type I)

Electron trigger efficiencies with 25ns data, Wprime meeting, https://indico.cern.ch/event/455047/

Both channels

Noise cleaning filters
AK8 jets, p_T > 200 GeV, Loose ID
AK4 jets (for b-veto), Loose ID
Leptonic W pT > 200 GeV

$\Delta R(l, W_{had}) > \pi/2$
$\Delta R(W_{had}, W_{lep}) > 2$
$\Delta R(W_{had}, \text{missing } E_T) > 2$



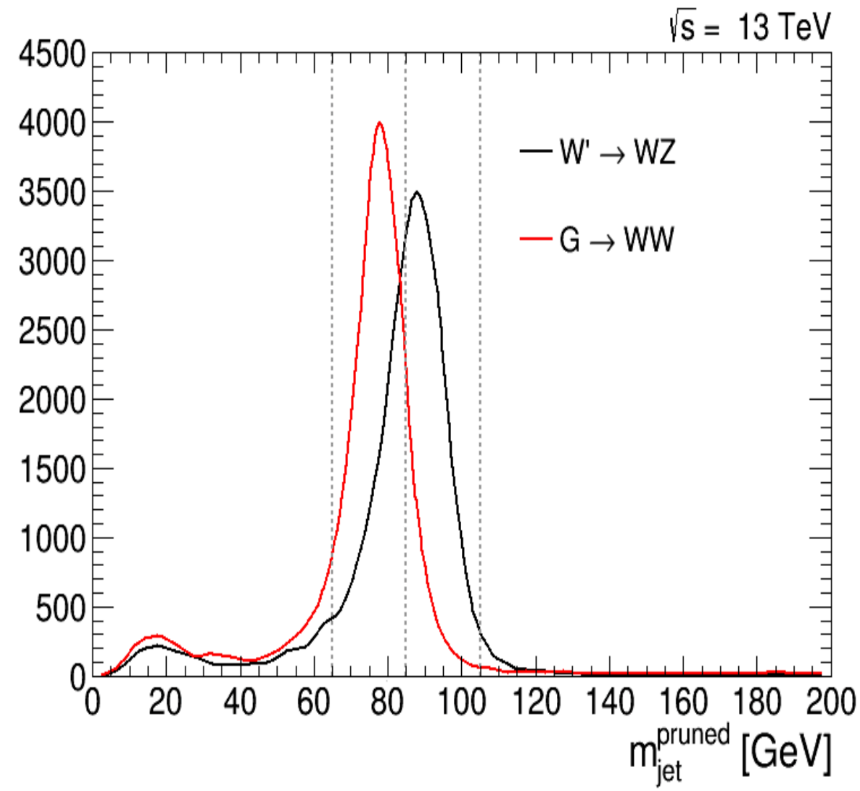
Analysis Strategy

"Bump" search: looking for an excess over the Mvw distributions

Jet pruning

- V-boson mass window
  - 65< M_{pruned} < 105 GeV
  - W-enriched:65-85 GeV
  - Z – enriched:85-105 GeV

Higgs signal region (105-135 GeV) kept blind



Jet substructure

- Discriminate against quark and gluon jet background
- N-subjettiness

HP: $\tau_{21} < 0.6$ LP: $0.6 < \tau_{21} < 0.75$

How to estimate the background contributions

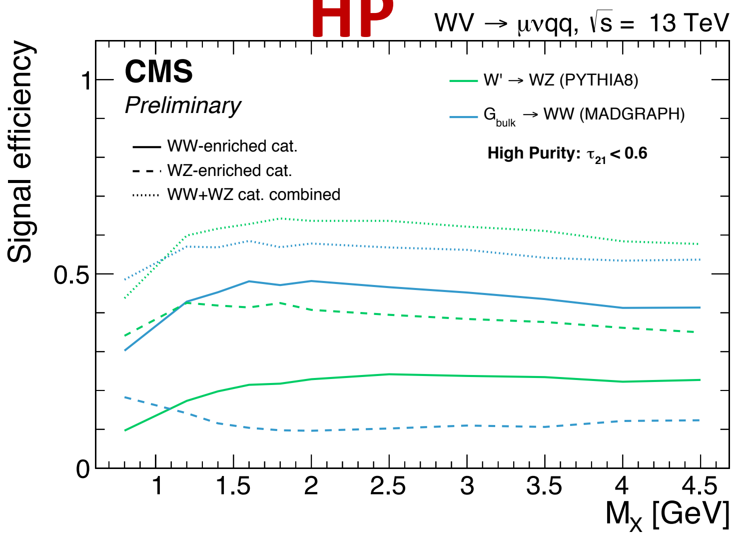
- Minor background: taken from simulation, corrected with scale factors from data
- Wjets: extracted from data

8 signal categories: HP/LP, WW/ WZ, el and muon

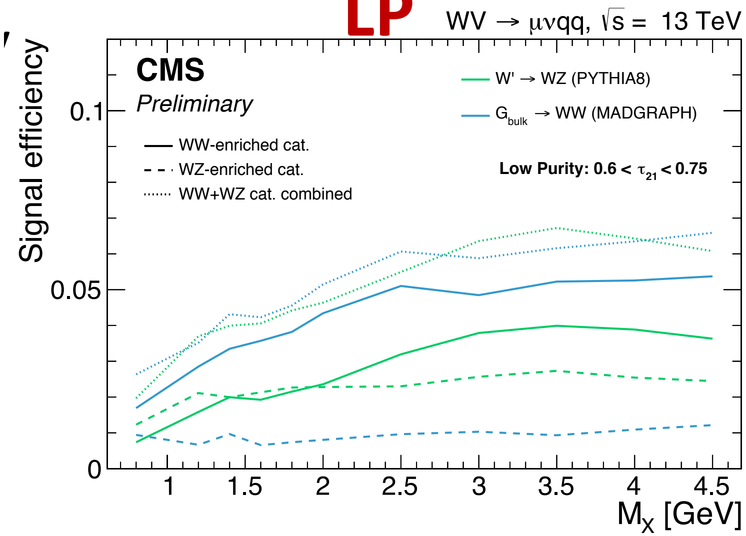
Signal Efficiency(WV in each category)

muon

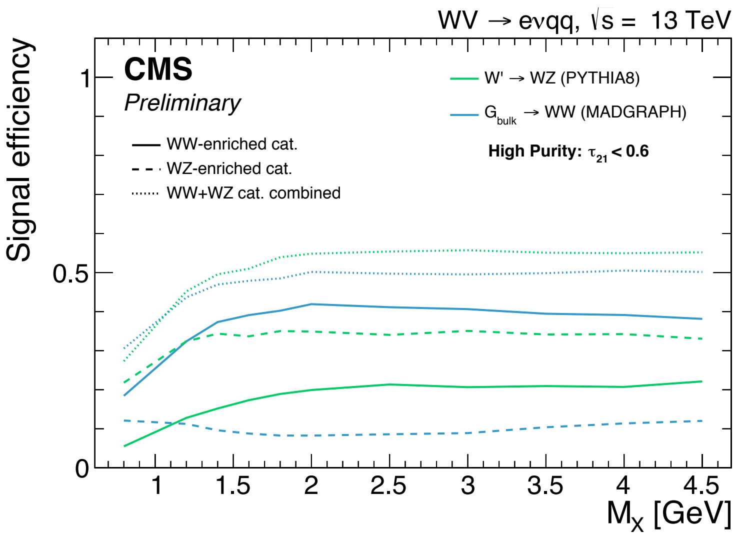
HP

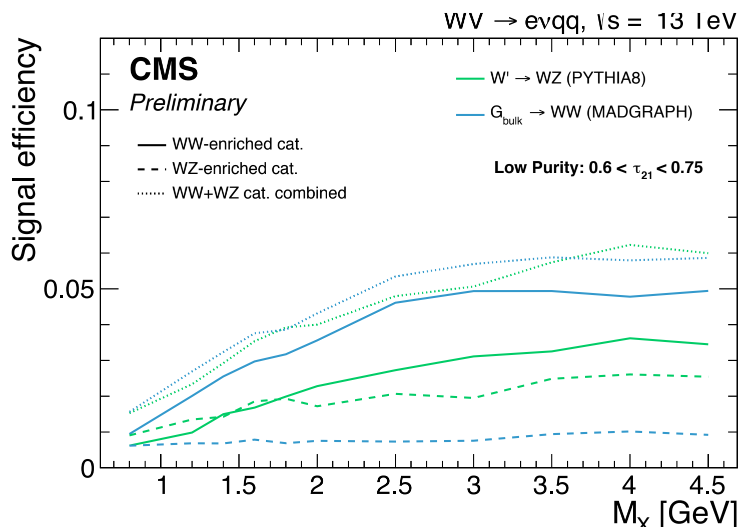


LP



ele



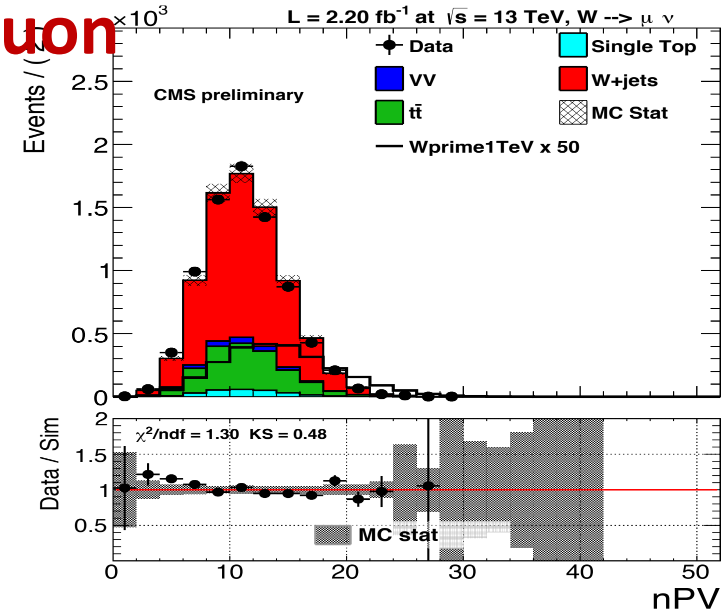


Efficiency of spin-2 G_{bulk} in WW category ~ 2× W'
Efficiency of spin-1 W' in WZ category ~ 3× G_{bulk}

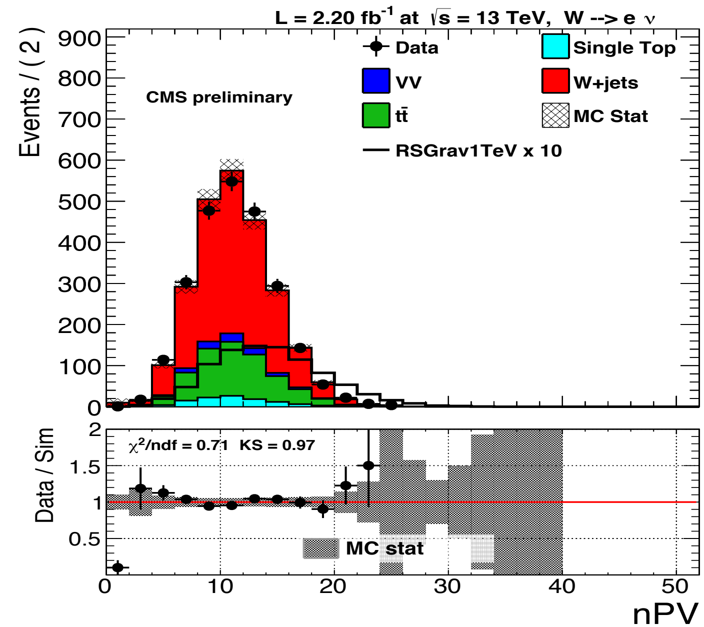
Low signal efficiency in the LP category
-> gain from the combining with HP at high masses where expected background is low

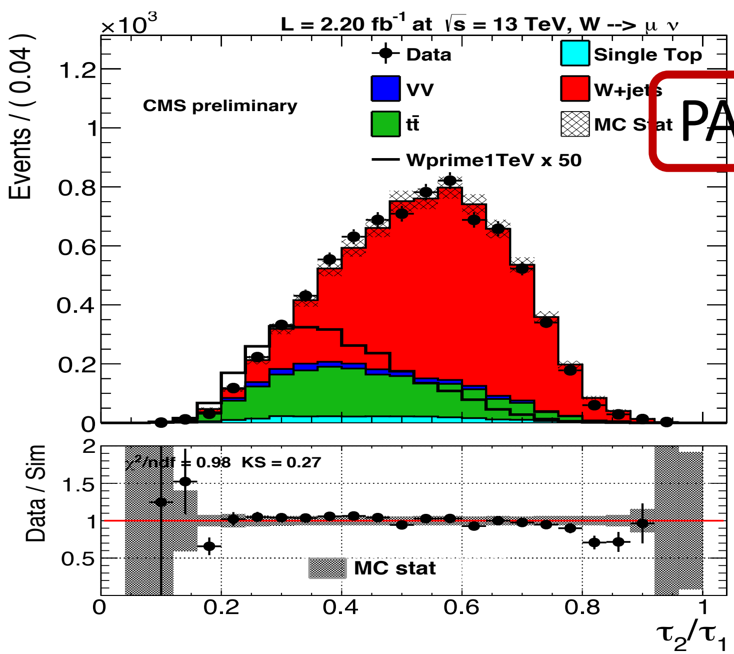
Control Plots in W+jets

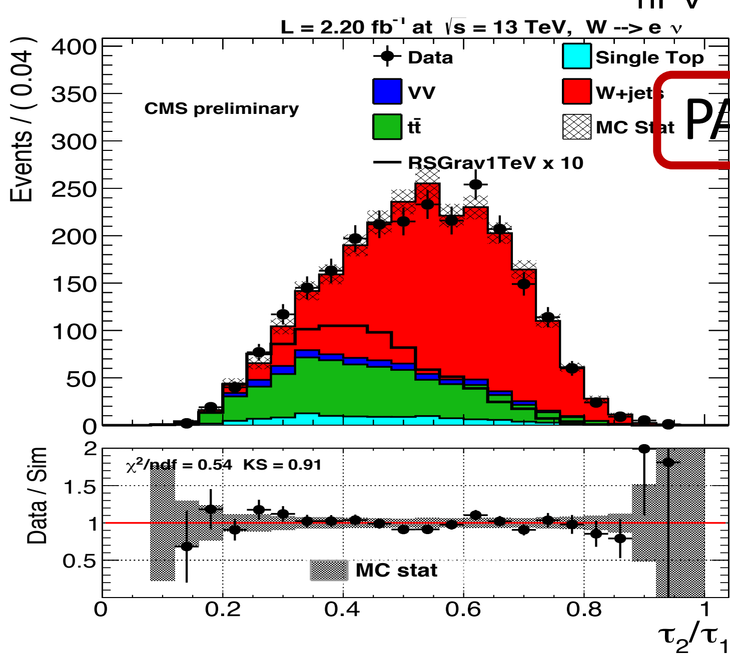
muon



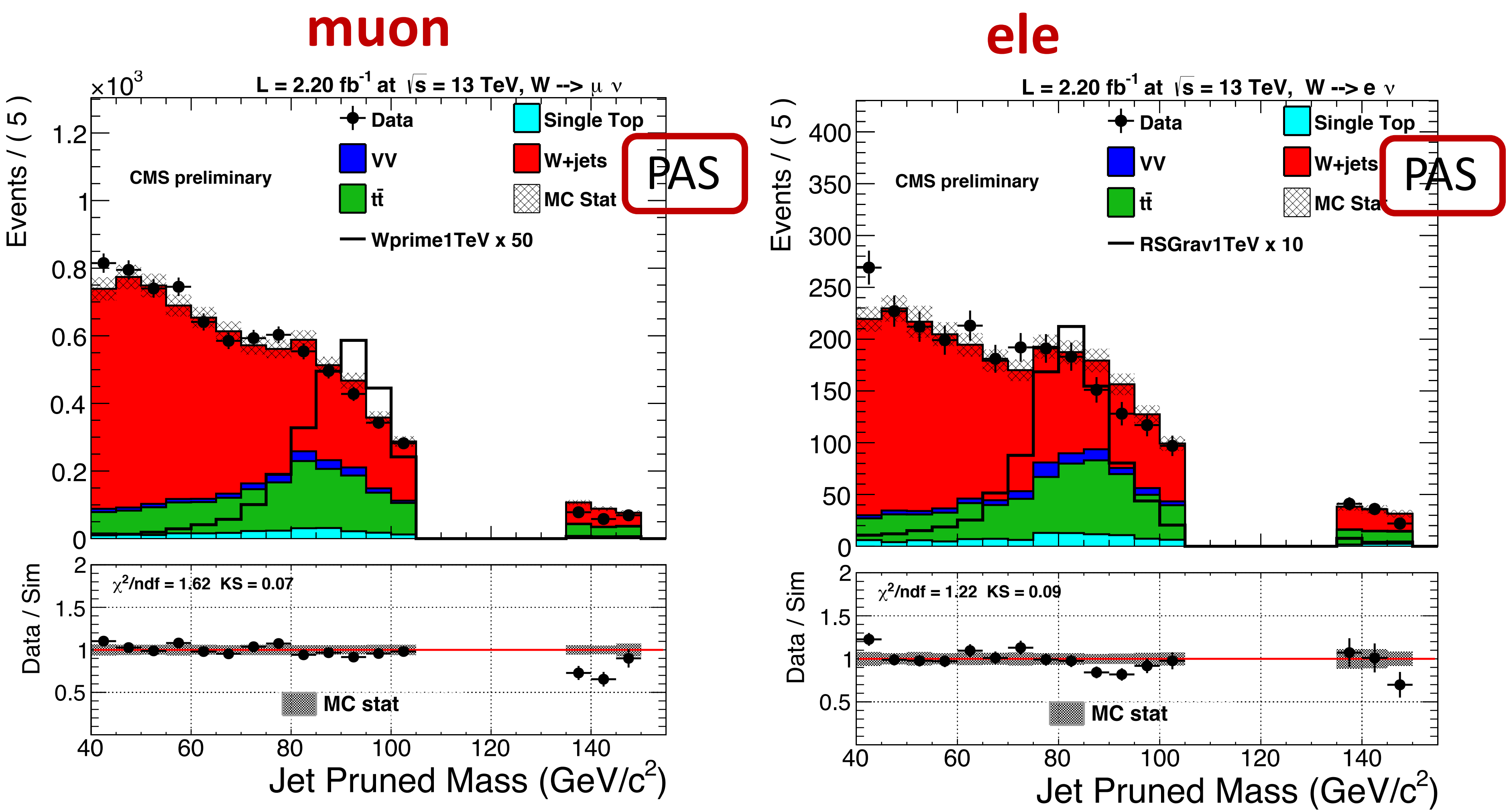
ele







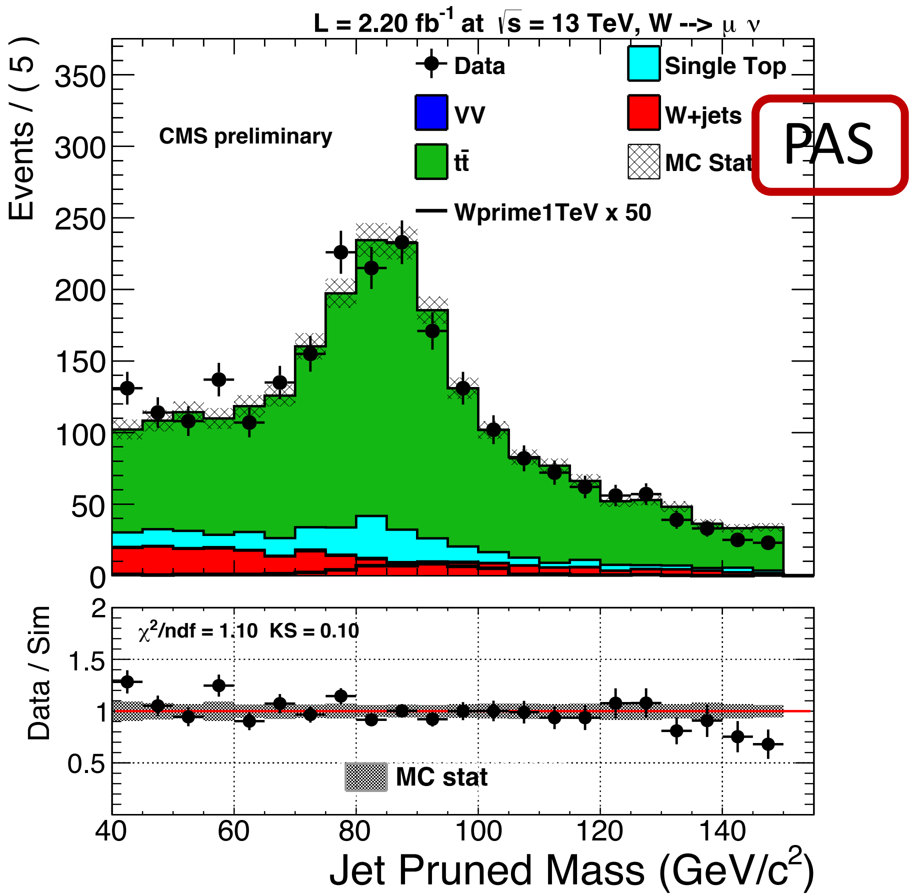
Control Plots in W+jets

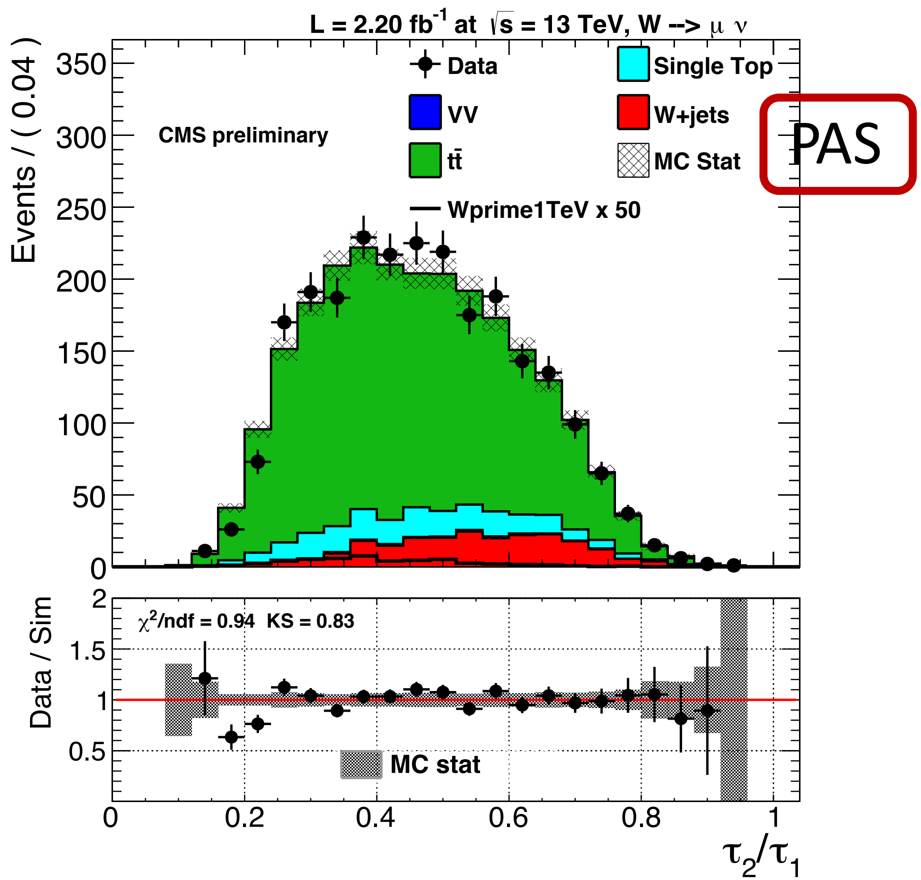


Control Plots in TTbar

Definition: Top-enriched control sample can be naturally obtained by:

- Asking at least one b-tagged jet outside the W-jet (iCSVM)
- Not requiring back to back topology





V-tagger in TTbar

Top Scale factor(TTbar + single Top yield correction)

The top scale factors are just derived by DATA/MC in the signal region.

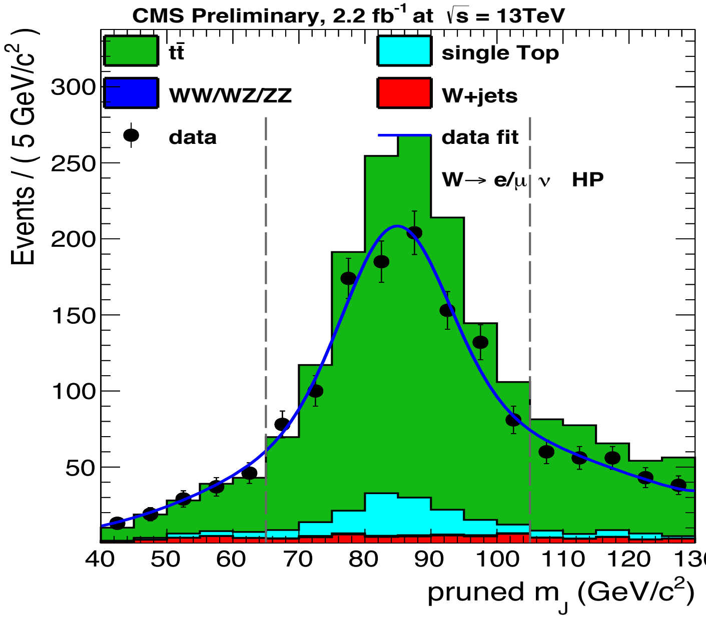
Cut count method: $Sf_{top} = N_{data}/N_{MC}$ (minor background contribution negligible)

Top scale factor	Muon channel	Electron channel	Muon+Electron channels
HP($\tau_{21} < 0.6$)	0.872±0.040	0.833±0.070	0.862±0.035
LP($0.6 < \tau_{21} < 0.75$)	0.787±0.110	0.661±0.200	0.756±0.097
HP($\tau_{21} < 0.45$)	0.847±0.049	0.865±0.084	0.850±0.042
LP($0.45 < \tau_{21} < 0.75$)	0.883±0.059	0.746±0.106	0.870±0.053

Mass scale and resolution

Simultaneous fit of mu and el mJ spectrum

Parameter	Data	simulation	Data/Simulation
$< m >$	84.7±0.4	85.3±0.4	0.992± 0.005
σ	8.2±0.5	7.3±0.4	1.12±0.07

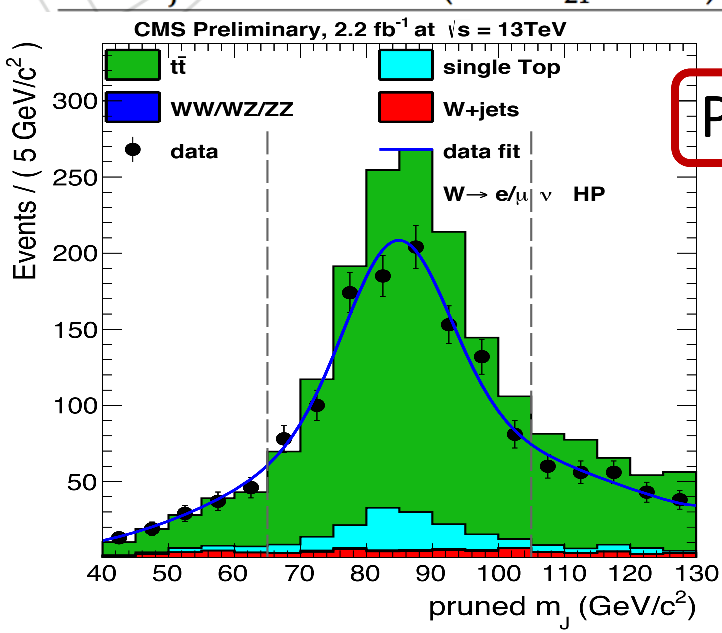


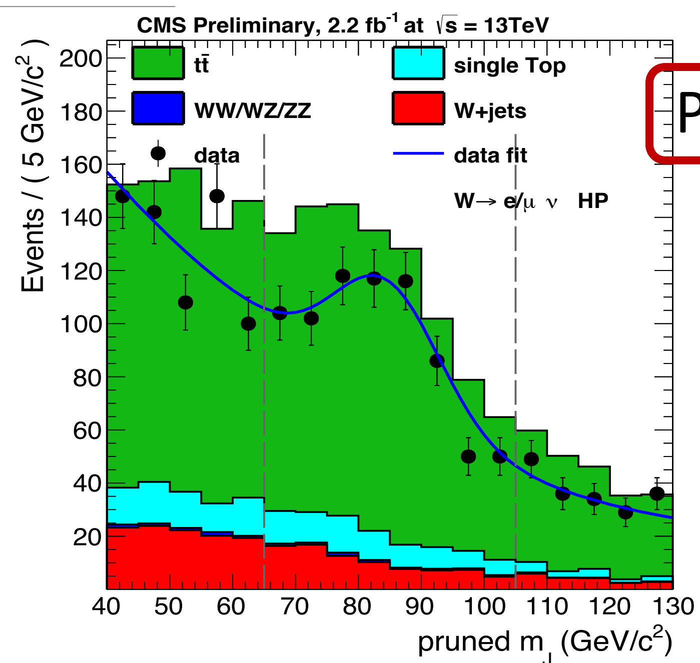
V-tagger in TTbar

W-tagging scale factors

- Consider the TTbar made of 'real' W and 'combinatorial'
- Background(s-top/ WW/ W+jets) are taken from MC
- Pass PDF $f_{pass} = f_{pass}^{W-match} \times \epsilon \times N_W + f_{pass}^{W-nomatch} \times N_2 + F_{pass}^{STop} + F_{pass}^{VV} + F_{pass}^{Wjet}$
- Fail PDF $f_{fail} = f_{fail}^{W-match} \times (1-\epsilon) \times N_W + f_{fail}^{W-nomatch} \times N_3 + F_{fail}^{STop} + F_{fail}^{VV} + F_{fail}^{Wjet}$
- Simultaneous fit data and MC in PASS & FAIL to get SF

Category	Definition	W scale factor
Dijet channel HP	$(\tau_{21} < 0.45)$	0.69 ± 0.14
Dijet channel LP	$(0.45 < \tau_{21} < 0.75)$	1.46 ± 0.38
$\ell\nu$+V-jet channel HP	$(\tau_{21} < 0.6)$	1.03 ± 0.13
$\ell\nu$+V-jet channel LP	$(0.6 < \tau_{21} < 0.75)$	0.88 ± 0.49





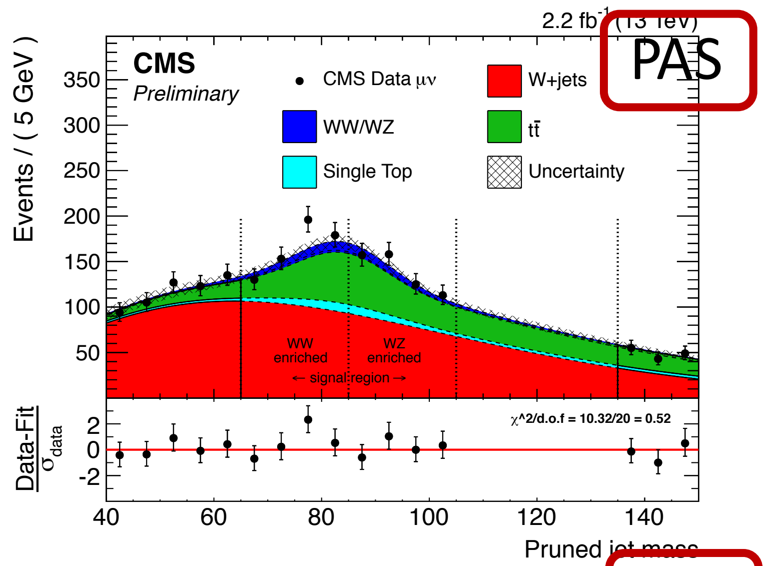
W+jets Background Estimation Yields

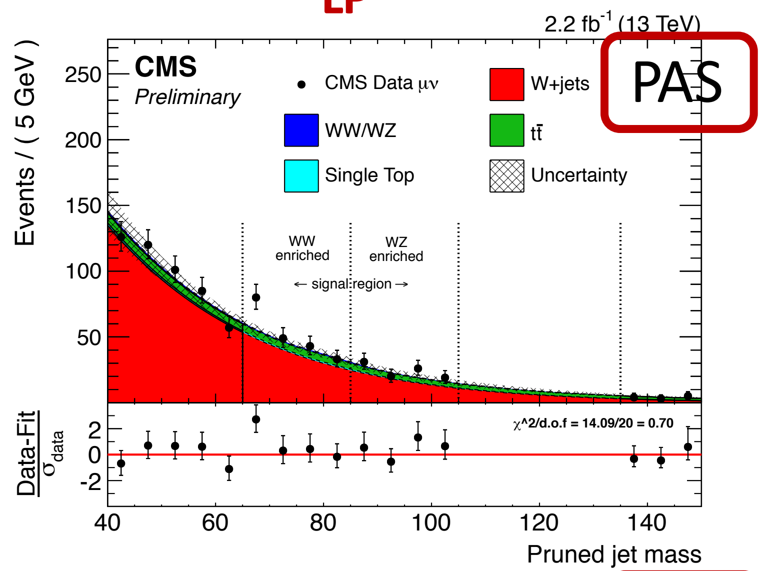
Dominant background is W+jets– Large contribution of ttbar as well

normalization: fit on data sideband in mJ;

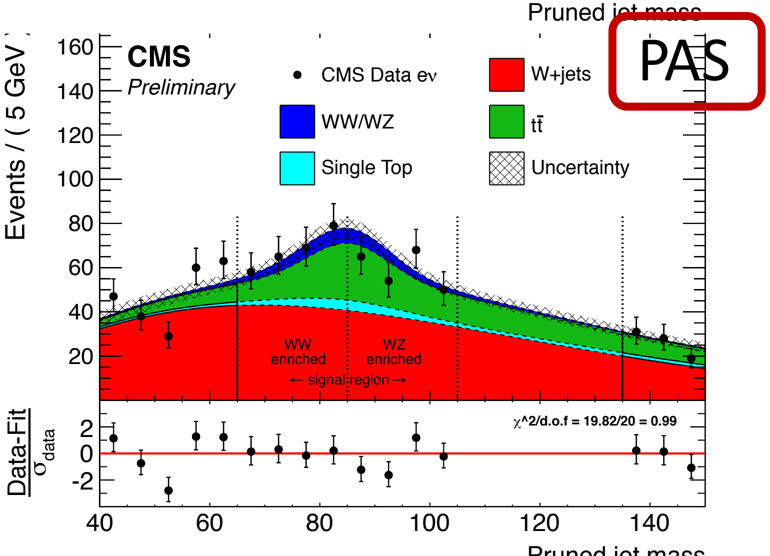
HP **LP**

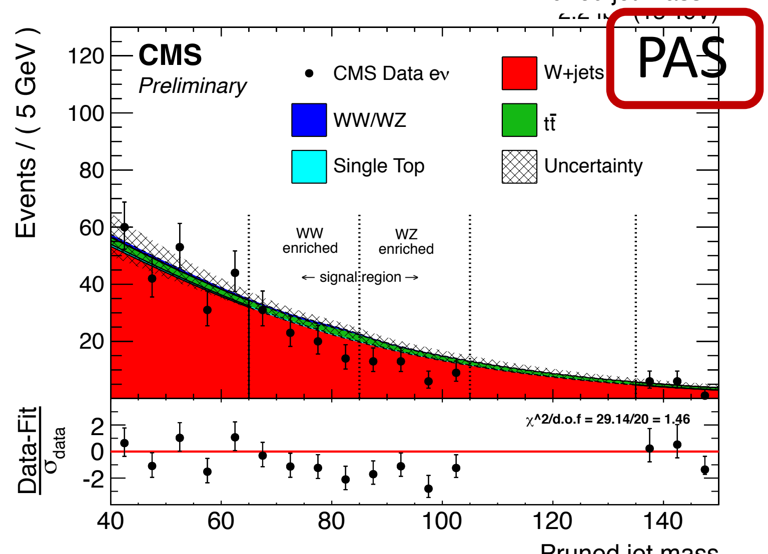
muon





ele



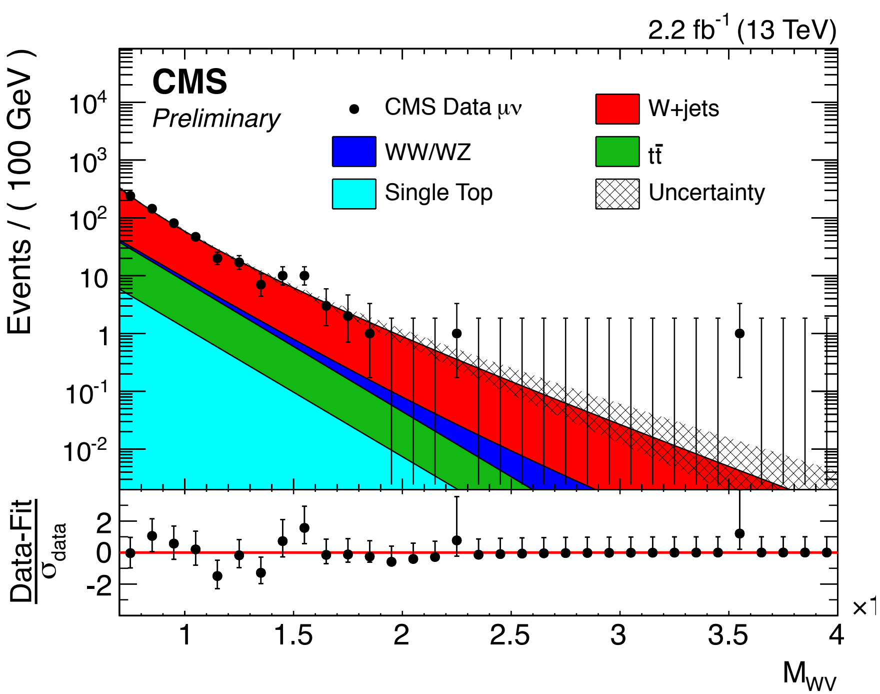


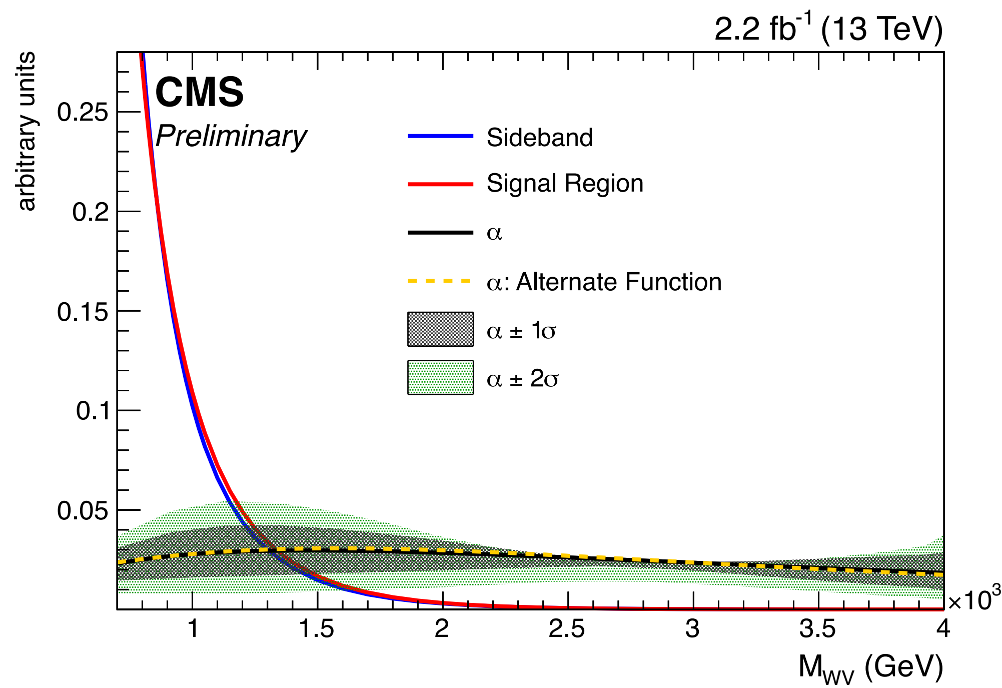
W+jets Background Estimation Shape

Mvw shape: extrapolated from data, from the sideband using alpha function

$$\alpha_{MC}(m_{lvj}) = \frac{F_{MC,SR}(m_{lvj})}{F_{MC,LSB}(m_{lvj})}$$

Muon HP



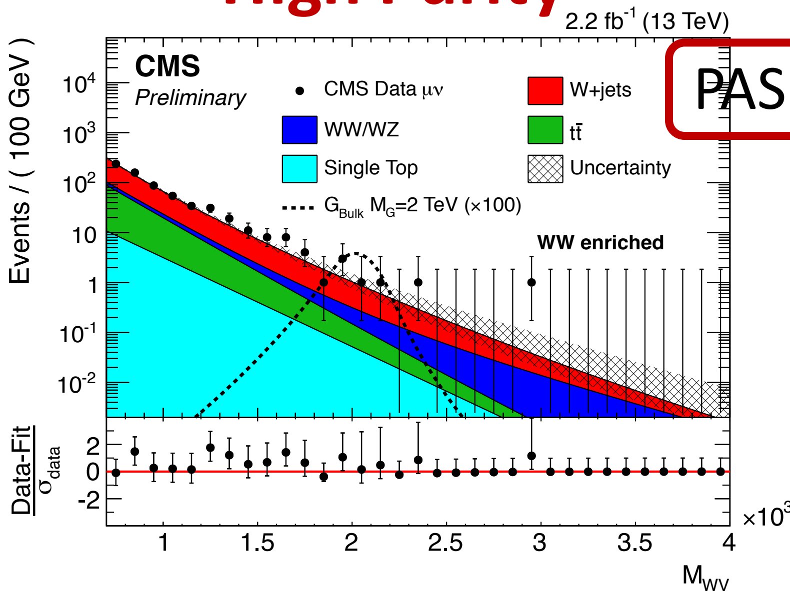


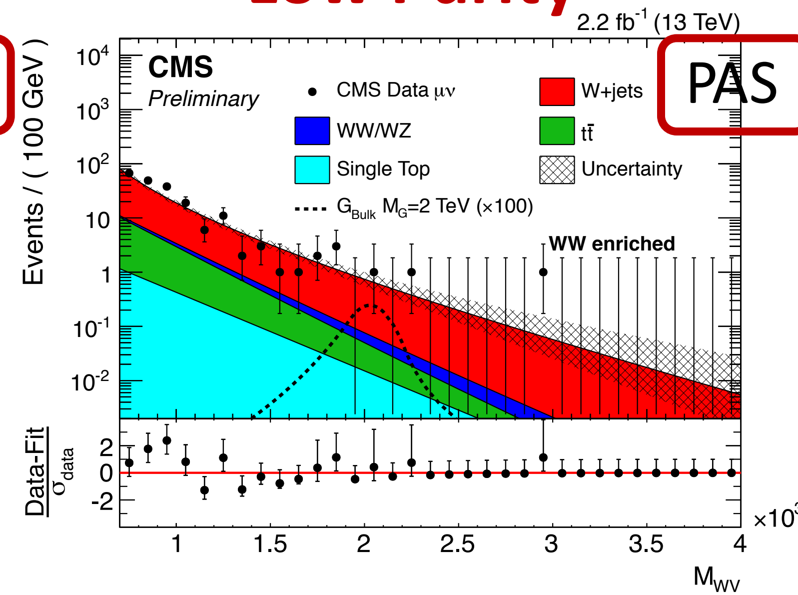
$$F_{ExpN}(x) = e^{c_0 x + n/x}$$

V+jets M_{VV} shape in Signal Region(mu)

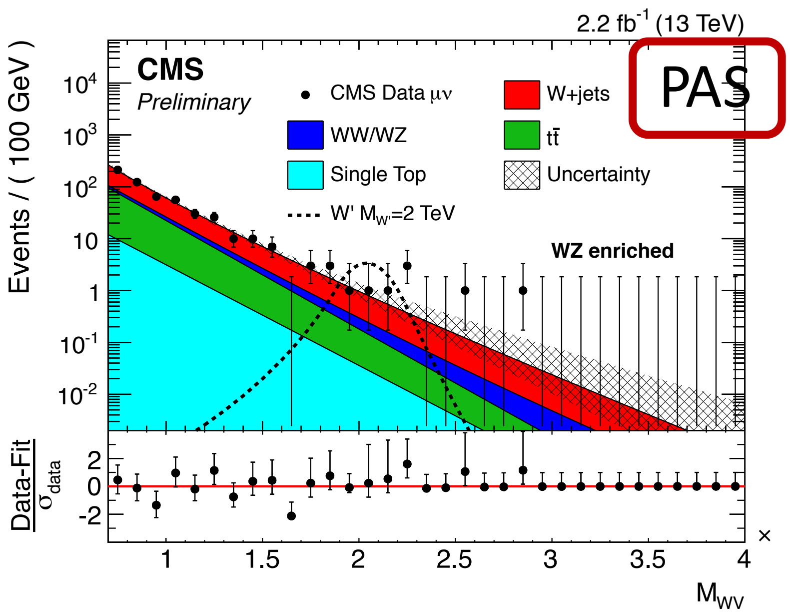
High Purity | Low Purity

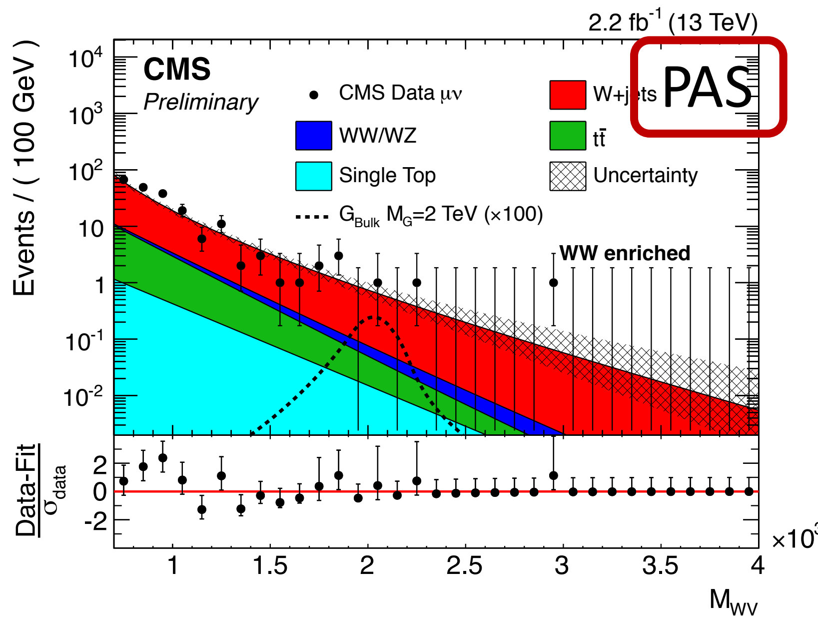
WW category





WZ category





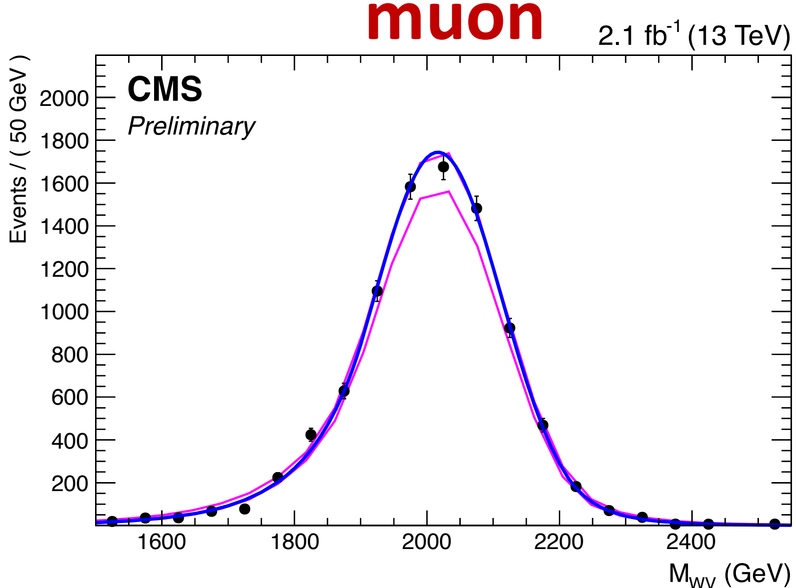
Signal Modelling

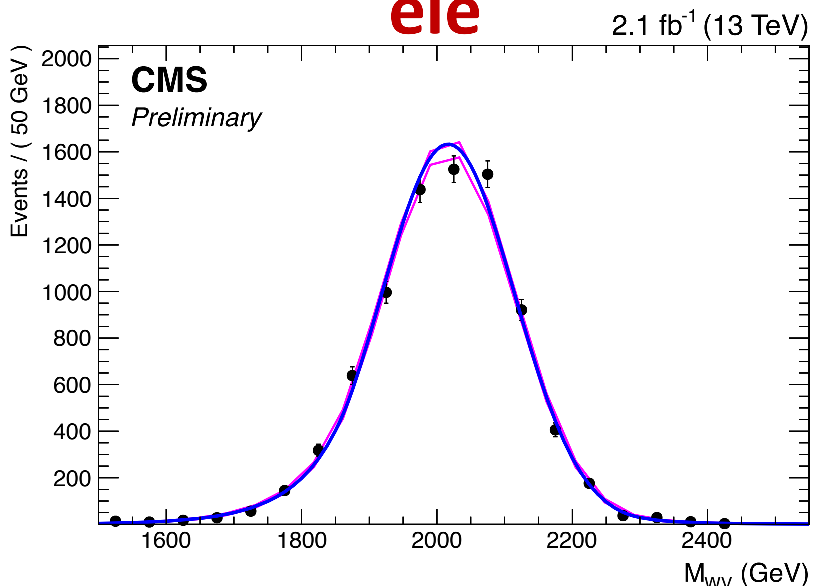
Signal fits are performed with double Crystal-ball function.

muon

ele

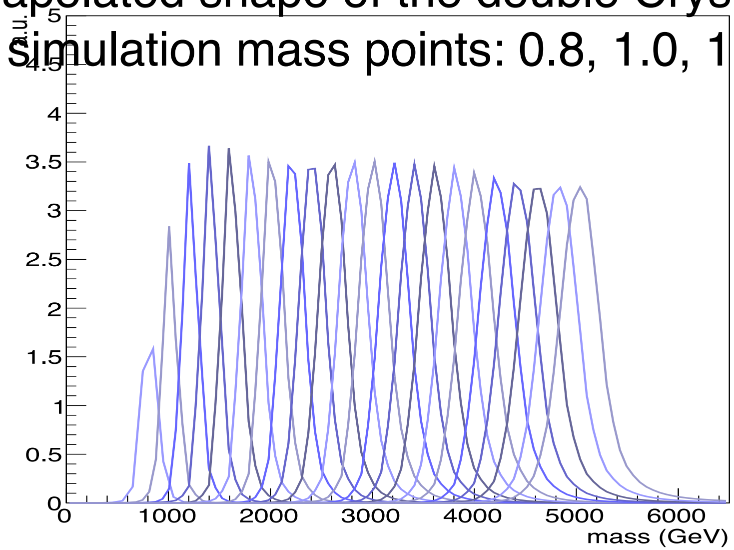
WW

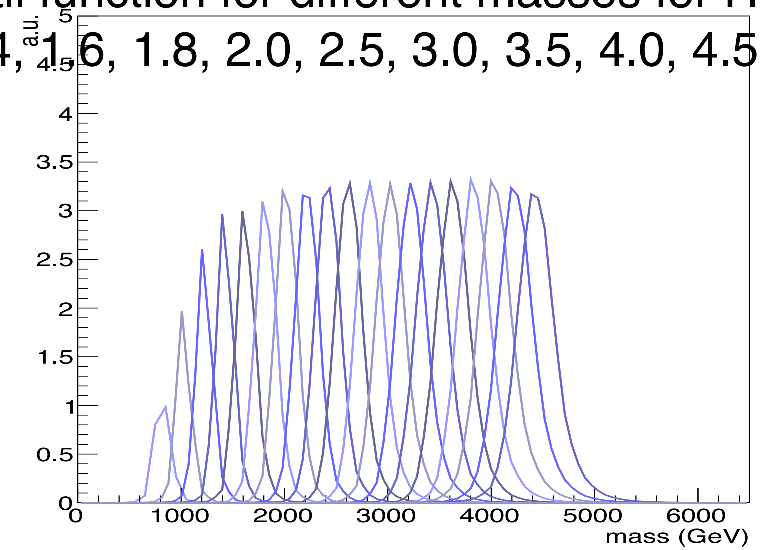




Extrapolated shape of the double Crystal-Ball function for different masses for HP
Full simulation mass points: 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

WW





Systematic Uncertainties(1)

Background normalization

- W+jets normalization uncertainty —> driven by amount of data in sideband
- TTbar and Single Top normalization —> uncertainty in the scale factor derived in top-enriched control sample
- VV normalization —> uncertainty in the V-tagging scale factor derived in top-enriched control sample

Source	W+jets	$t\bar{t}$	Single Top	VV
Luminosity	-	5%	5%	5%
Cross section	-	-	5%	3%
V-tagging eff. (HP/LP)	-	-	-	13%/49%
W+jets normalization	See Tab.6	-	-	-
W+jets shape	See Sec. 7.1.1	-	-	-
$t\bar{t}$ normalization (HP/LP)	-	5%/14% (μ) 8%/30% (e)	5%/14% (μ) 8%/30% (e)	-
Trigger	-	1% (μ) 1% (e)	1% (μ) 1% (e)	1% (μ) 1% (e)
Lepton identification	-	1% (μ) 3% (e)	1% (μ) 3% (e)	1% (μ) 3% (e)

Summary of background uncertainties

W+jets M_{WV} shape

1. uncertainties in the **M_{WV} shape in sideband** driven by amount of data → correlated between m_{jet}^{pruned} categories
2. uncertainties in the **alpha shape** driven by W+jets MC statistics → uncorrelated between m_{jet}^{pruned} categories
3. uncertainties due to the **choice of the function** taken into account inflating 1) and 2) by $\sqrt{2}$

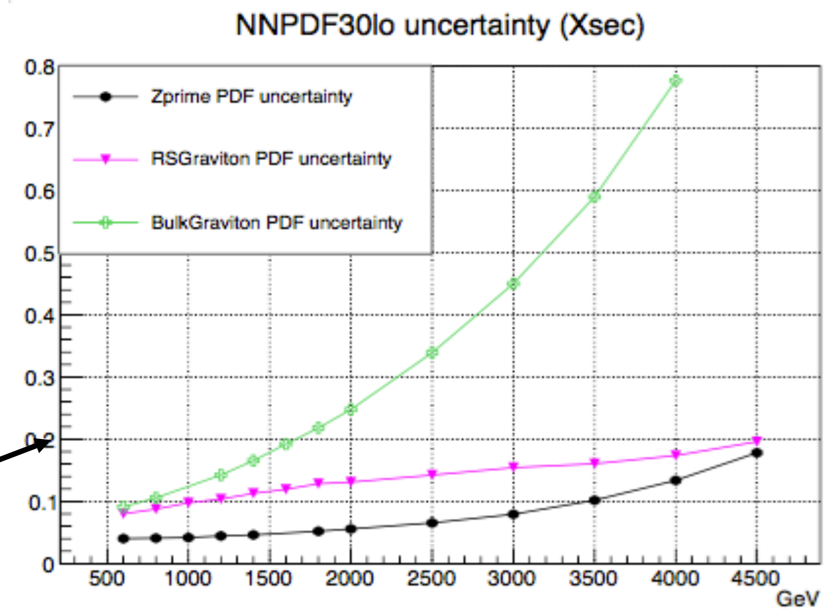
Systematic Uncertainties(2)

- Most important sources for signal normalization:
  - Jet energy scale: 3-12%
  - Jet mass scale: 1-10%
  - Jet mass resolution: 1-5%
  - V-tagging efficiency scale factors: 13/49% for HP/LP

Summary of signal uncertainties

Source	Signal Normalization		Mean m_{WW} Shape		Width m_{WW} Shape	
	$\mu\nu$+jet	$e\nu$+jet	$\mu\nu$+jet	$e\nu$+jet	$\mu\nu$+jet	$e\nu$+jet
Muon Energy Scale	0.7%	–	0.1%	–	0.5%	–
Electron Energy Scale	–	0.2%	–	0.1%	–	0.1%
Muon Energy Resolution	0.1%	–	0.1%	–	0.1%	–
Electron Energy Resolution	–	0.1%	–	0.1%	–	0.1%
Trigger	1%	1%	–		–	
Lepton identification	1%	3%	–		–	
Luminosity	5%				–	
b-tag selection	0.2%				–	
W-tagging eff. (HP/LP)	13%/49%		–		–	
Jet Energy Scale	See Tab. 8				1.3%	[2%-3%]
Jet Energy Resolution	See Tab. 8				0.1%	3%
PDF uncertainties	See Sec. 7.7		–		–	

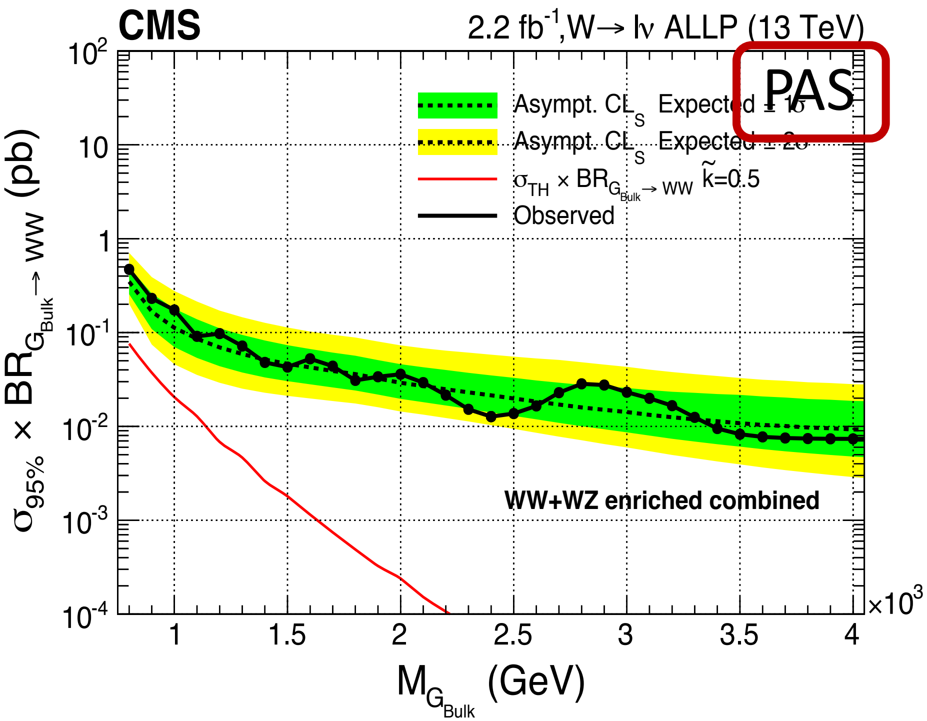
- Extrapolation uncertainties for V-tagging SF at high p_T comparing PYTHIA8 and HERWIG++ signal samples
  - compare selection efficiency of each mass point wrt 600 GeV (p_T 200-300 GeV)
  - Found 1-4% differences in signal efficiency
- PDF uncertainties on signal xsec
  - 10-40% for Bulk Graviton signal in [0.5, 3]TeV



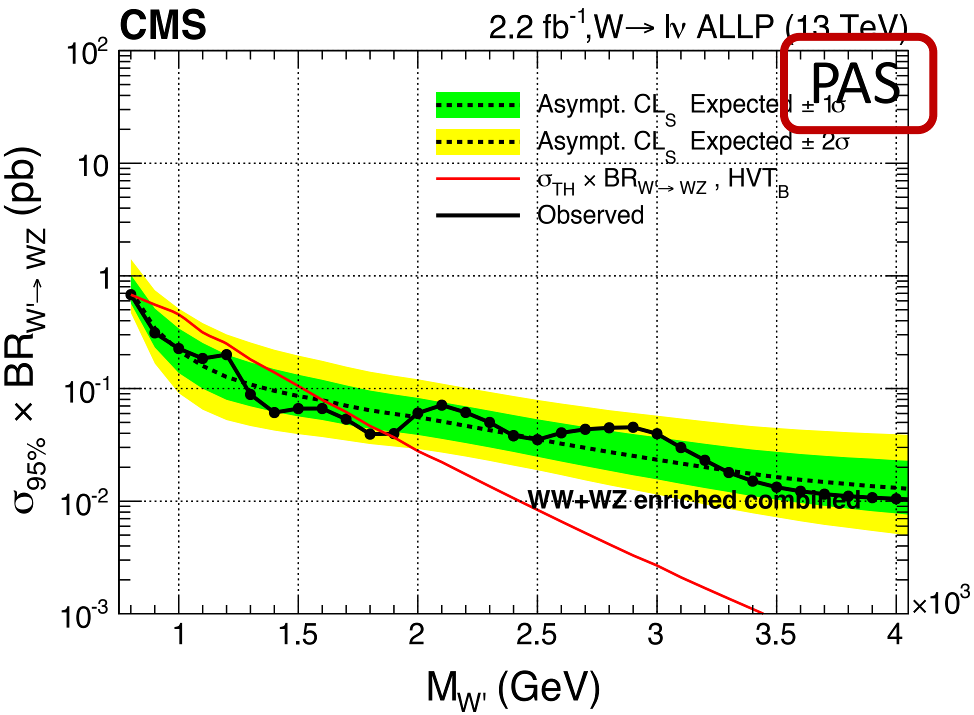
Limits

Combined Limits

Use the Higgs combination tool and Asymptotic CL_s method to compute the upper limits.



Graviton

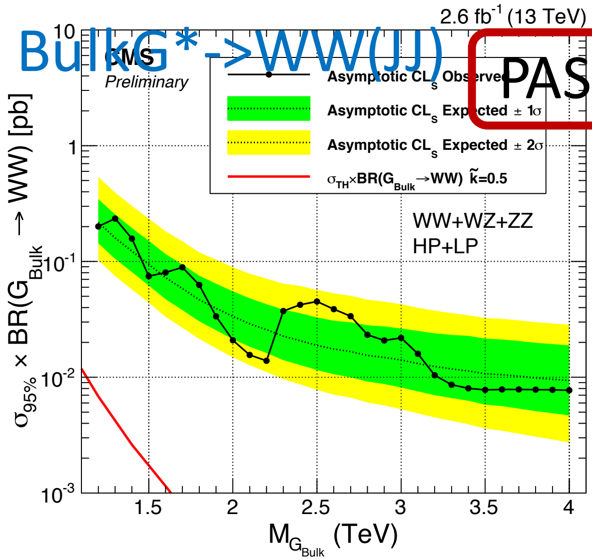


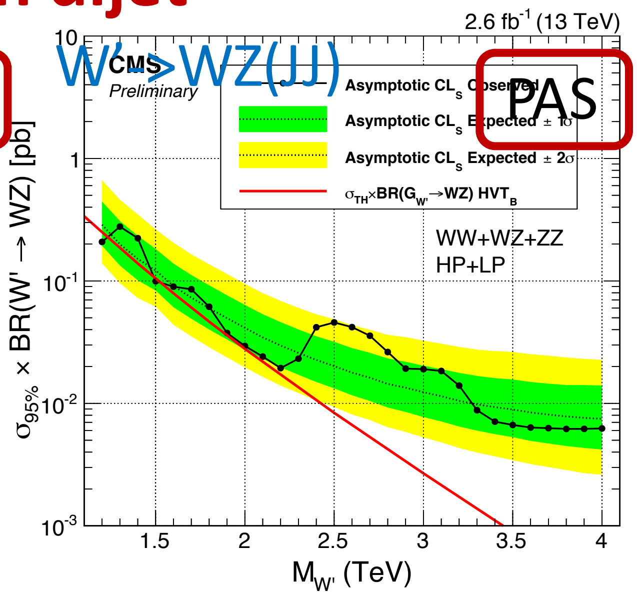
Wprime

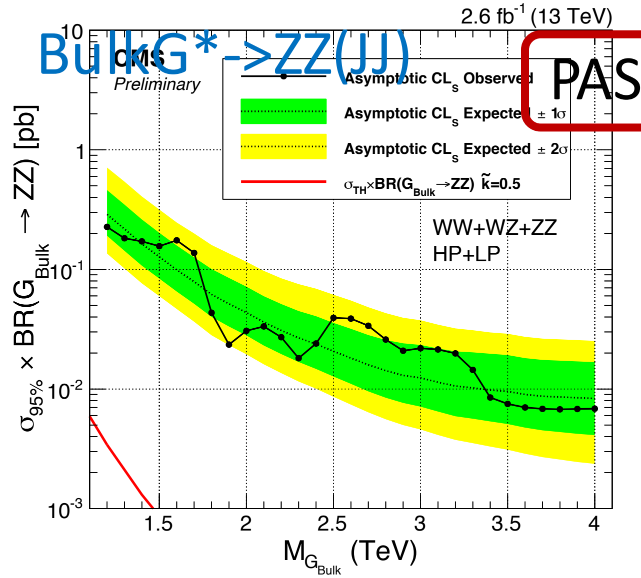
The achieved sensitivity is not sufficient to exclude Bulk Graviton model. For HVT model B of a charged spin-1, it's excluded for the masses below 1.8TeV

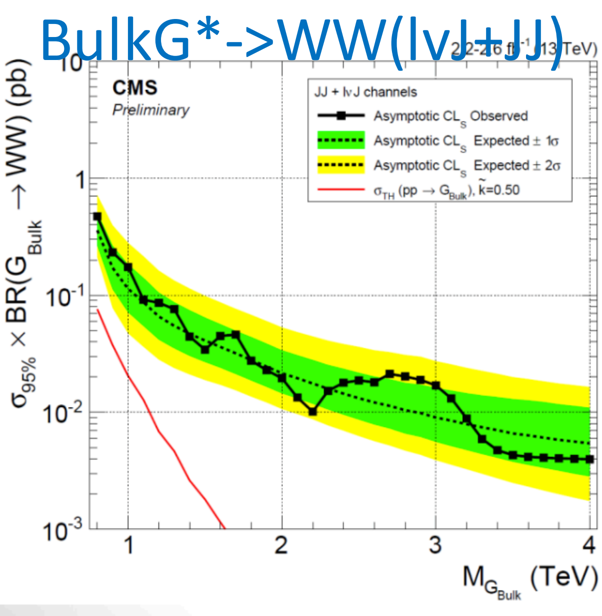
Limits

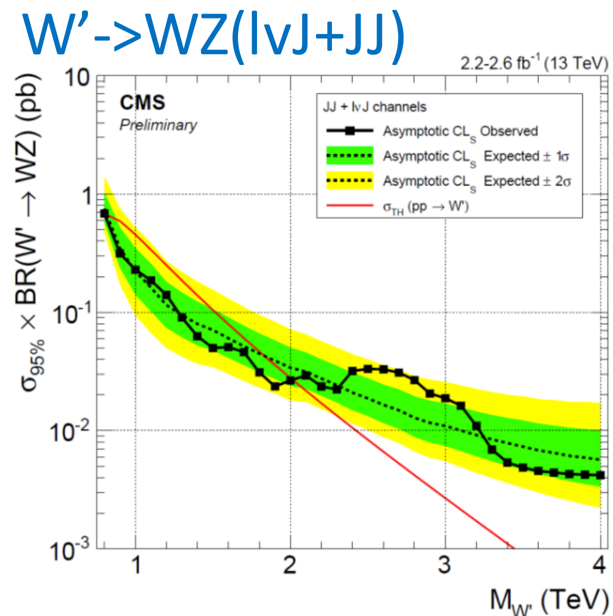
Combined Limits on dijet

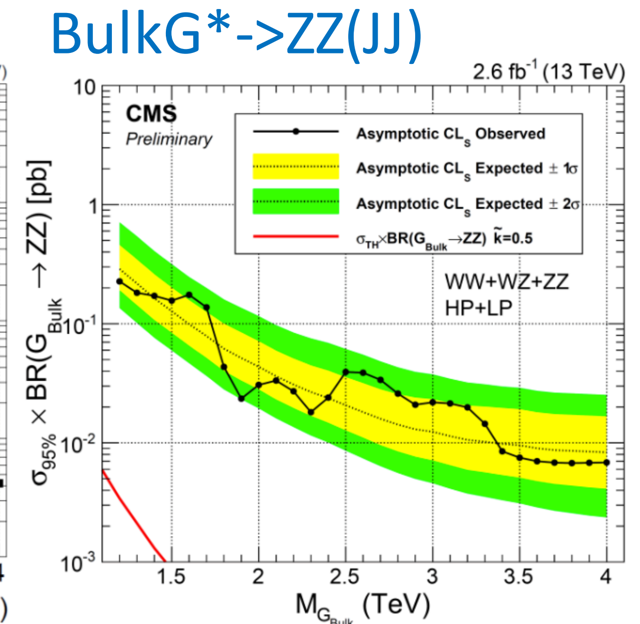






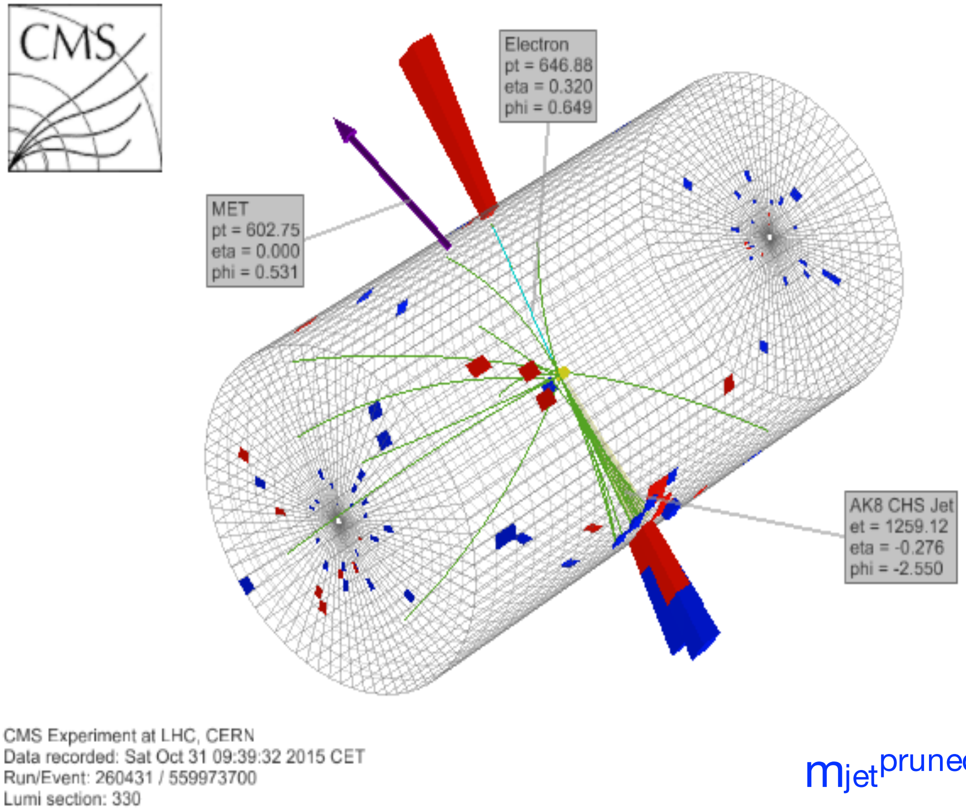


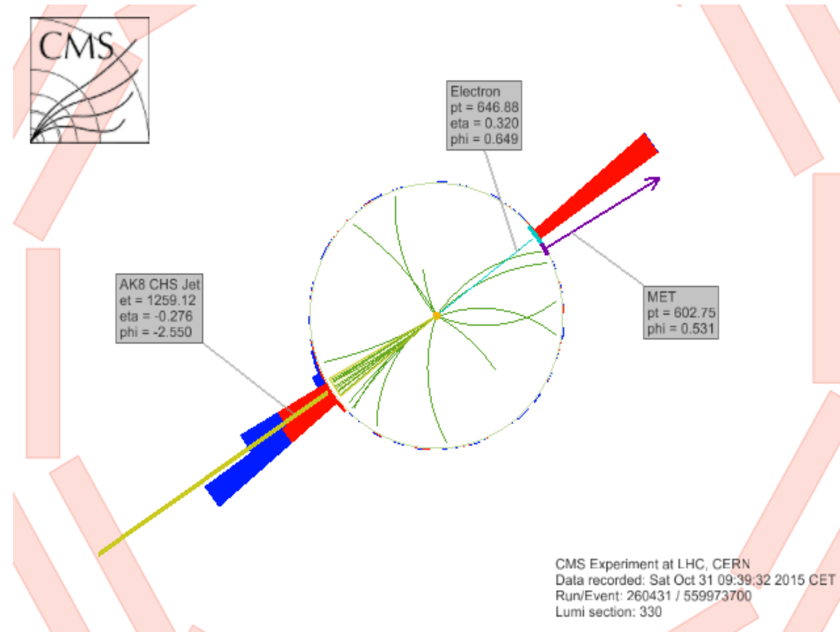




Event Display

Single Electron HP-WW





m_{jet}^{pruned} = 68.7 GeV

AK8 jet mass = 135.6 GeV

AK8 jet p_T = 1.31 TeV

W_{lept} p_T = 1.34 TeV

M_{WW} = 2.78 TeV

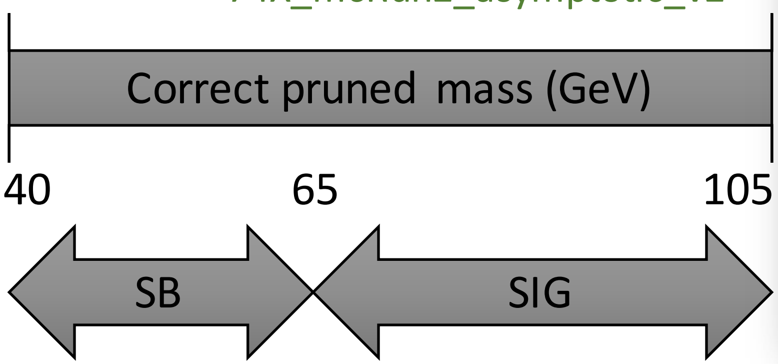
Summary

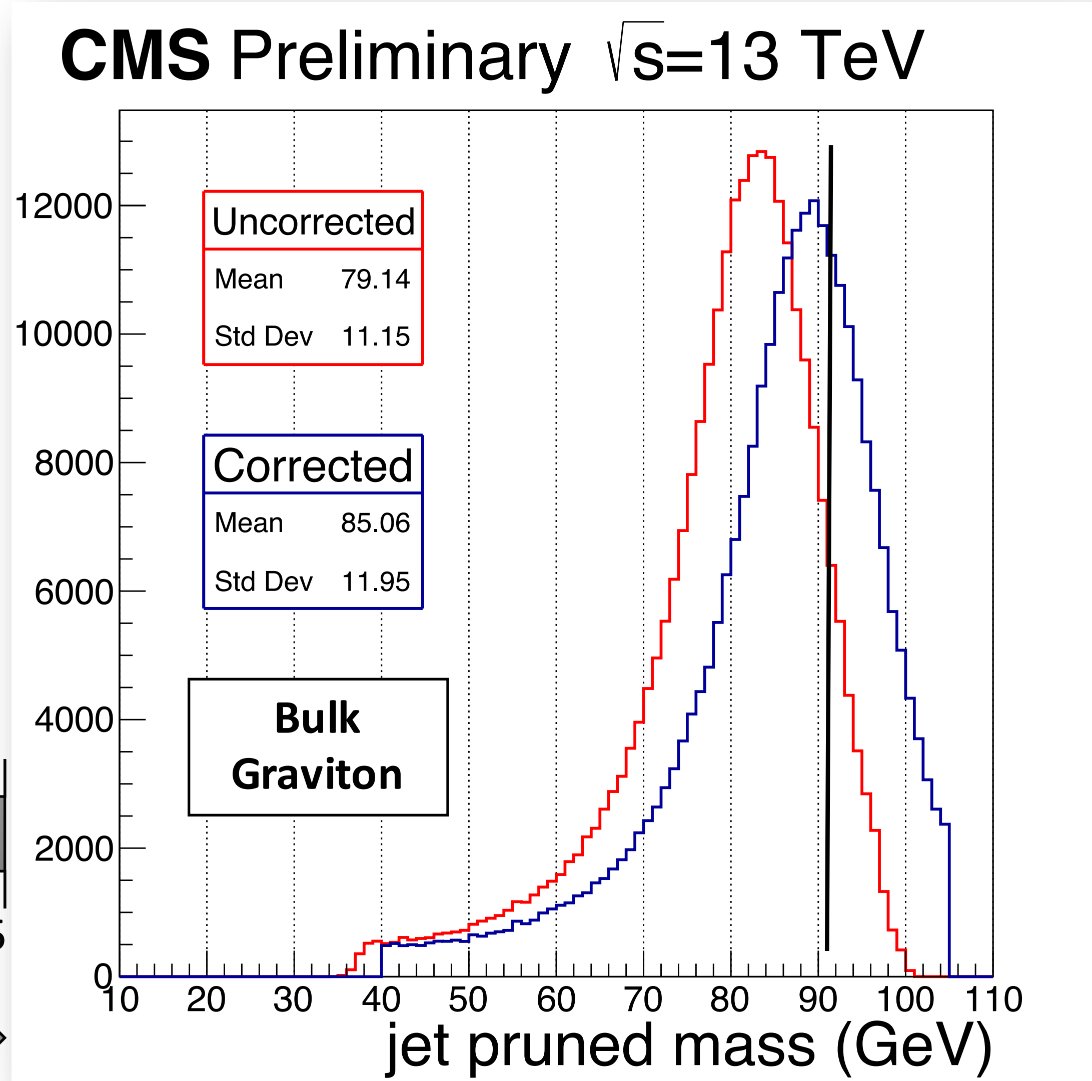
- Di-boson search surpasses Run 1 sensitivity above 1.7 TeV
- Combined significance in region of interest 1.7-2.0 is below 2 sigma
- Highest combined significance at 2.8-3.0 TeV of 2.8 sigma reduced to 1.6 sigma including LEE
- Most stringent limit on W'->WZ of 2.0 TeV set by this search
- The final analysis and combination is scheduled as a paper for Moriond.
- The data to be taken in 2016 will finally unravel what is happening around M_{VV} =2 TeV, observed in many channels.

Backup

Corrected Pruned Jet Mass

- AK8PFchs JEC
  - On Data
    - L2Relative, L3Absolute, L2L3Residual
    - Local database
      Summer15_25nsV6_DATA
  - On MC
    - L2Relative, L3Absolute
    - Global tag
      74X_mcRun2_asymptotic_v2

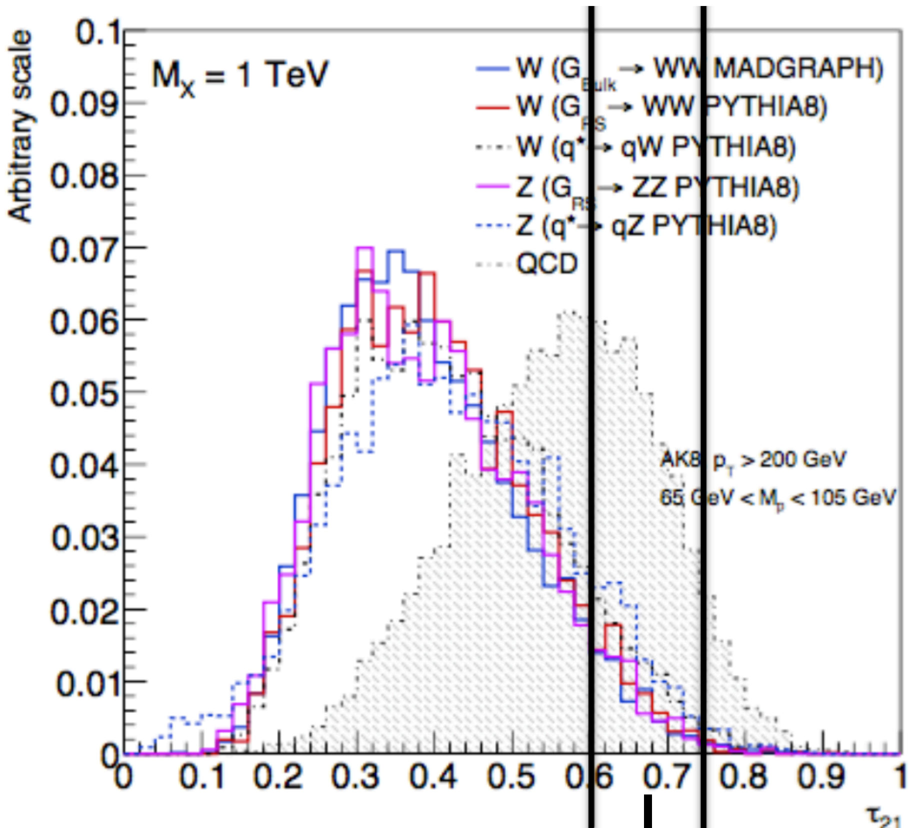




Analysis Strategy

4 signal categories

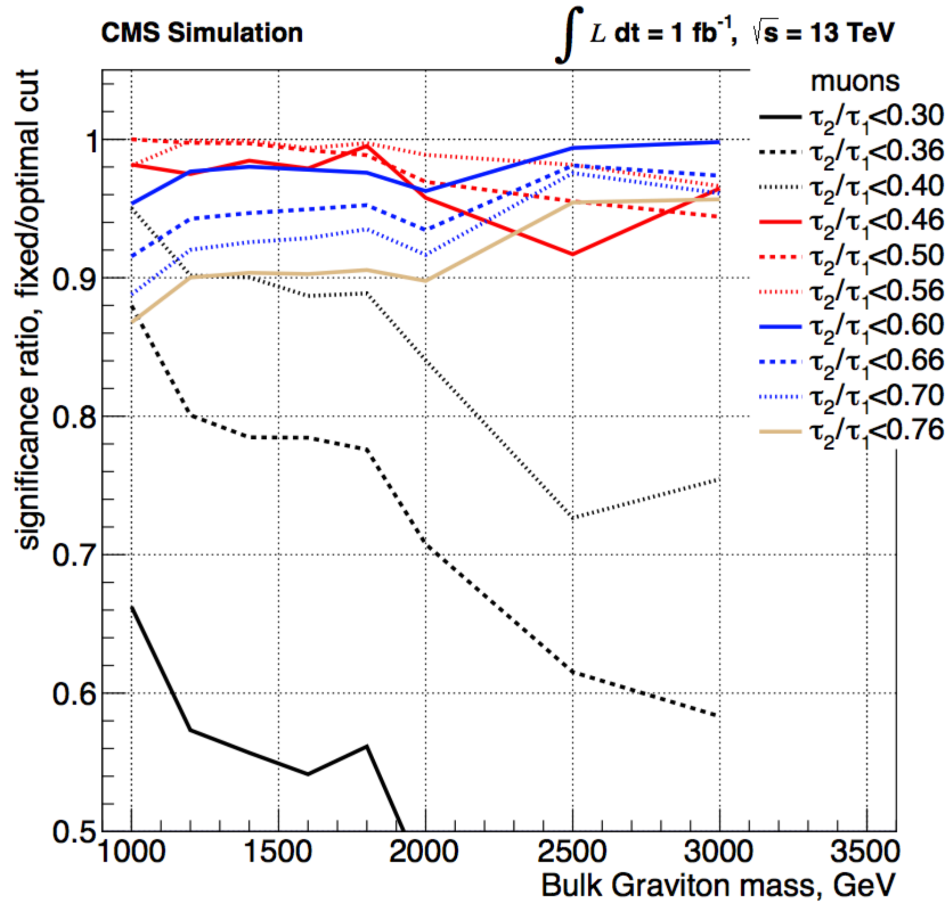
HP/LP: WW, WZ



High purity

Low purity

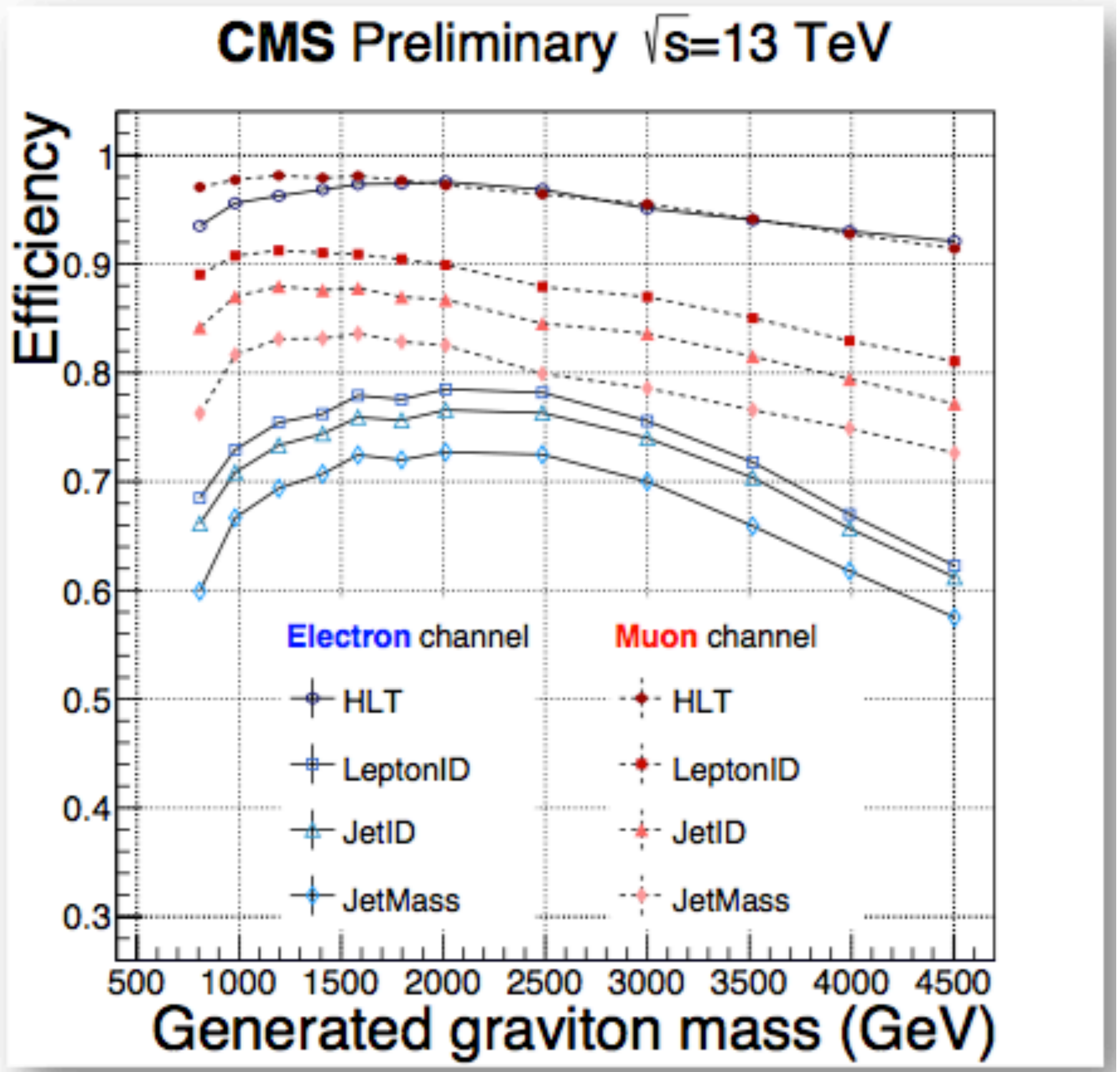
Tau21 cut optimization in VW



Best working point @ 0.6

Efficiency of Bulk Graviton Signal

- HLT + Lepton ID
  - Electron channel
    - ❑ 78% @ 2.0 TeV
  - Muon channel
    - ❑ 90% @ 1.2 TeV
- Full selection
  - Electron channel
    - ❑ 67% @ 2.5 TeV
  - Muon channel
    - ❑ 75% @ 1.6 TeV

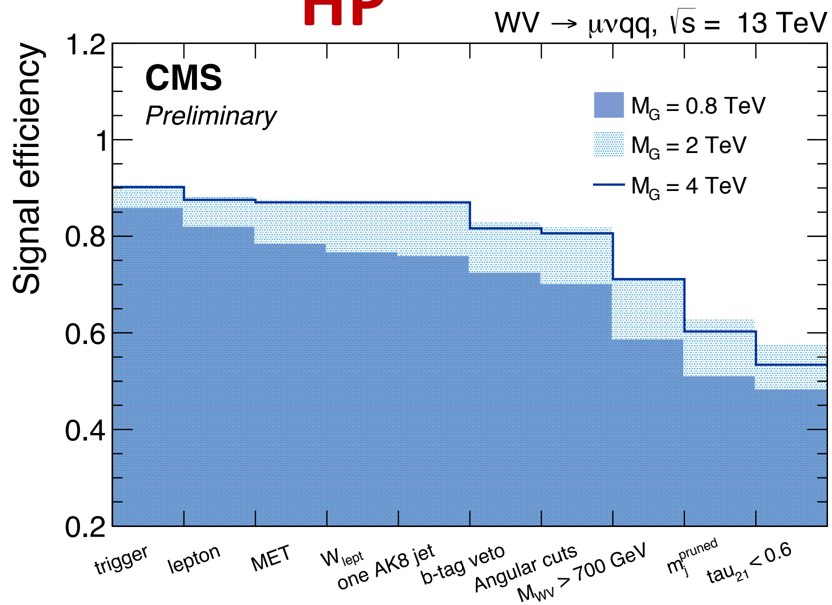


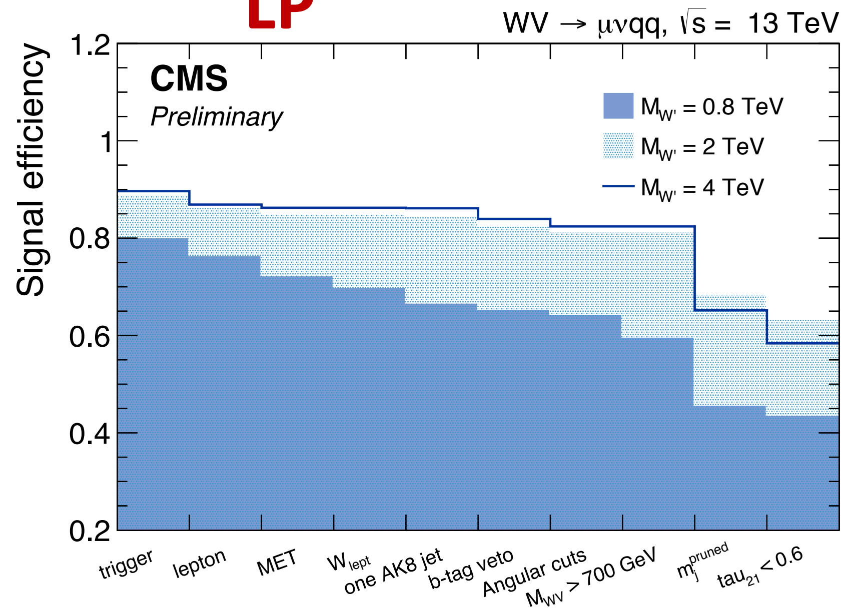
Signal Efficiency after Each Selections

HP

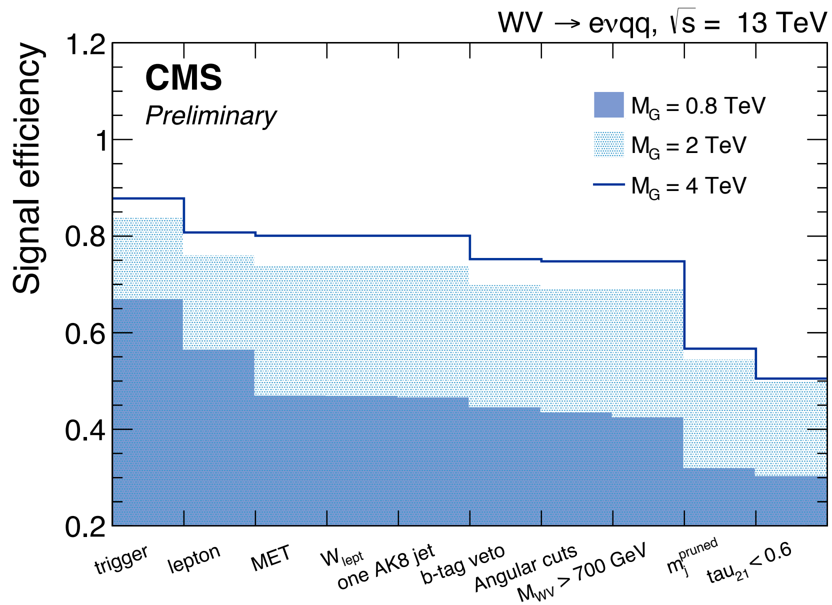
LP

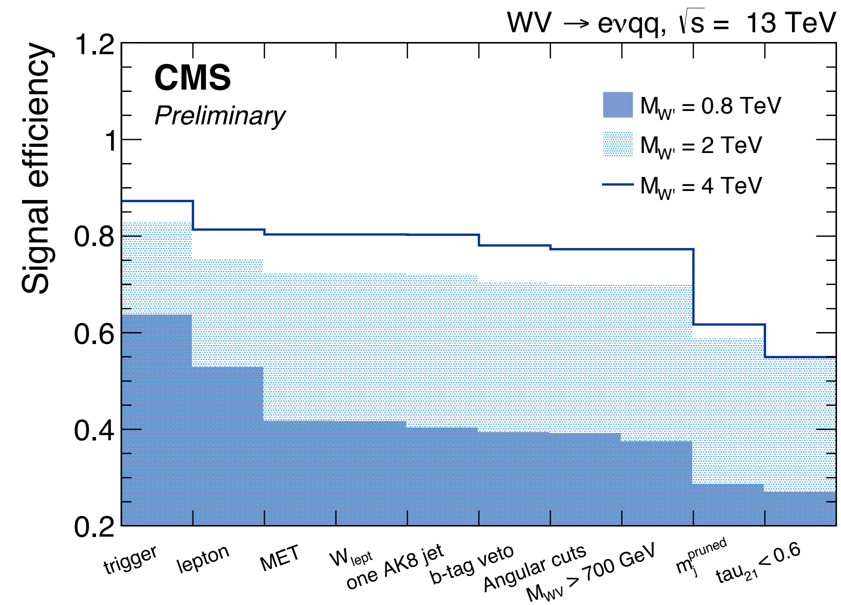
muon



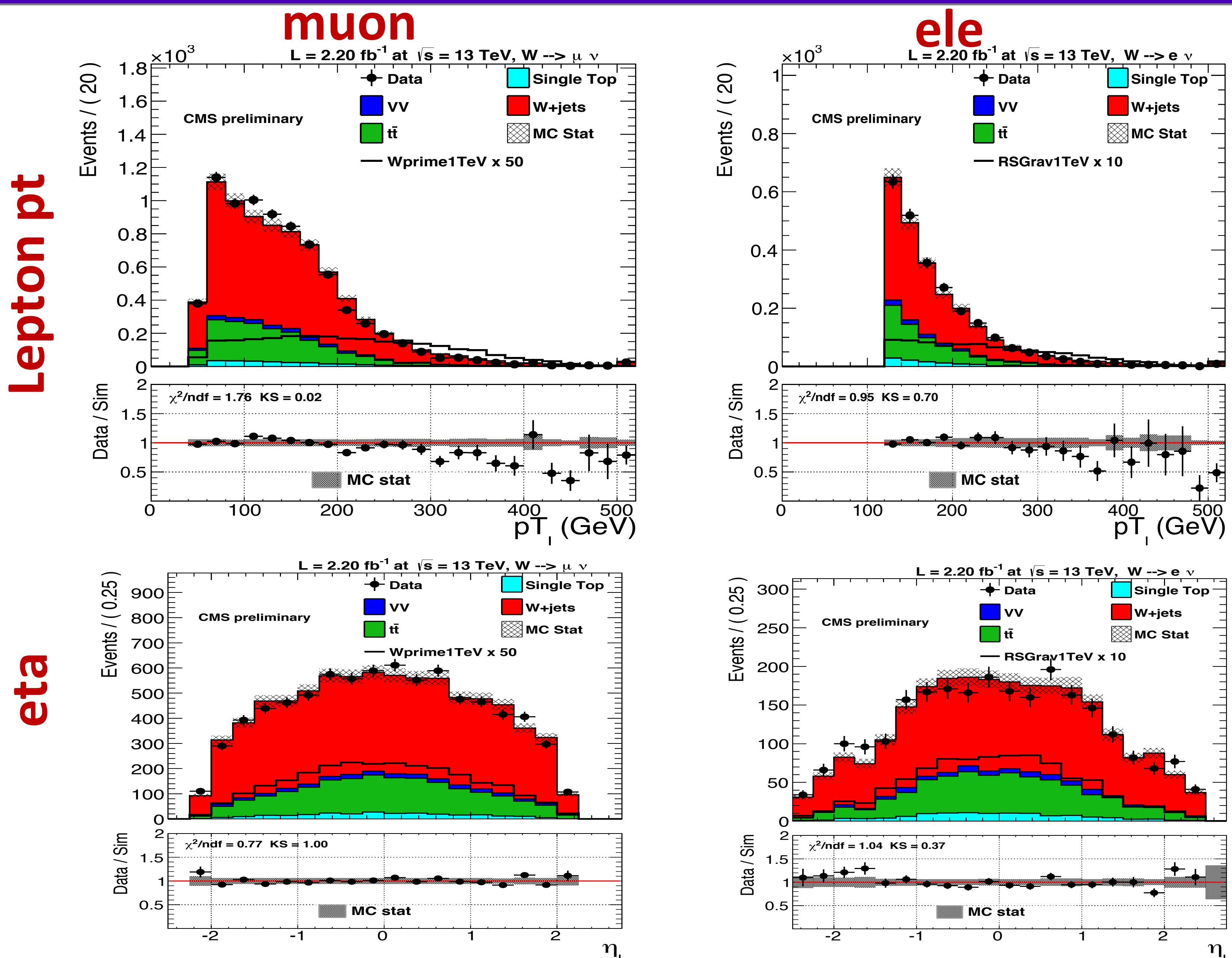


ele

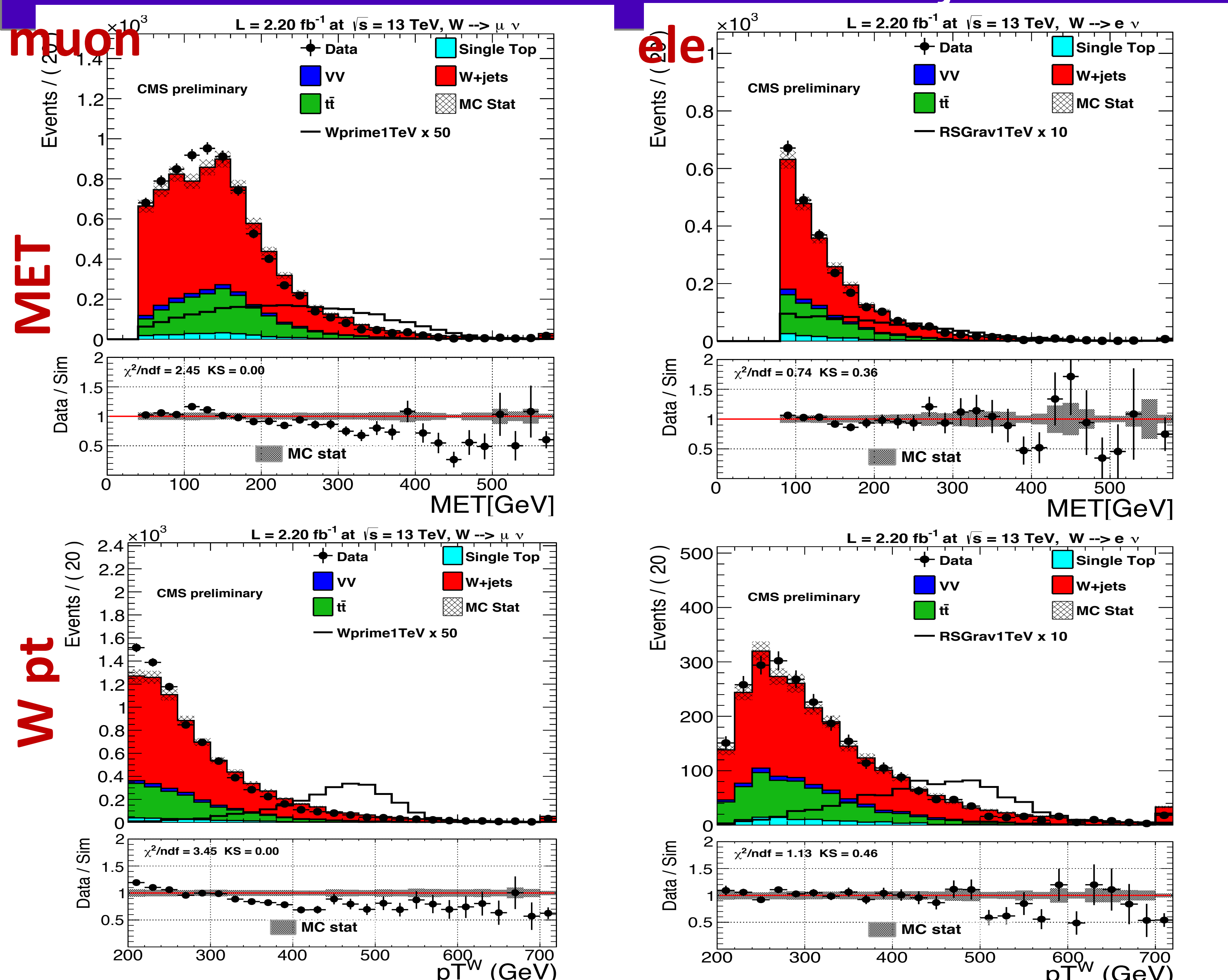




Control Plots in W+jets

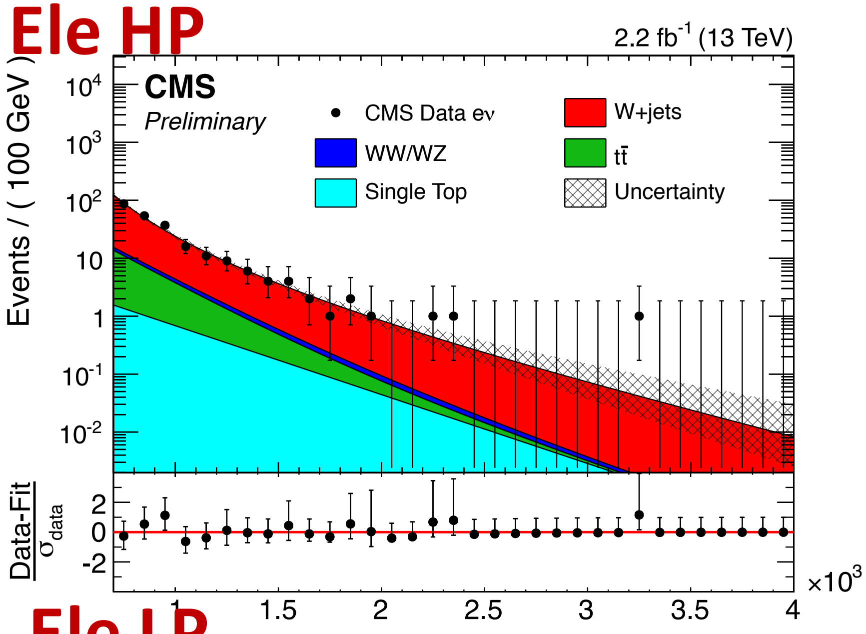


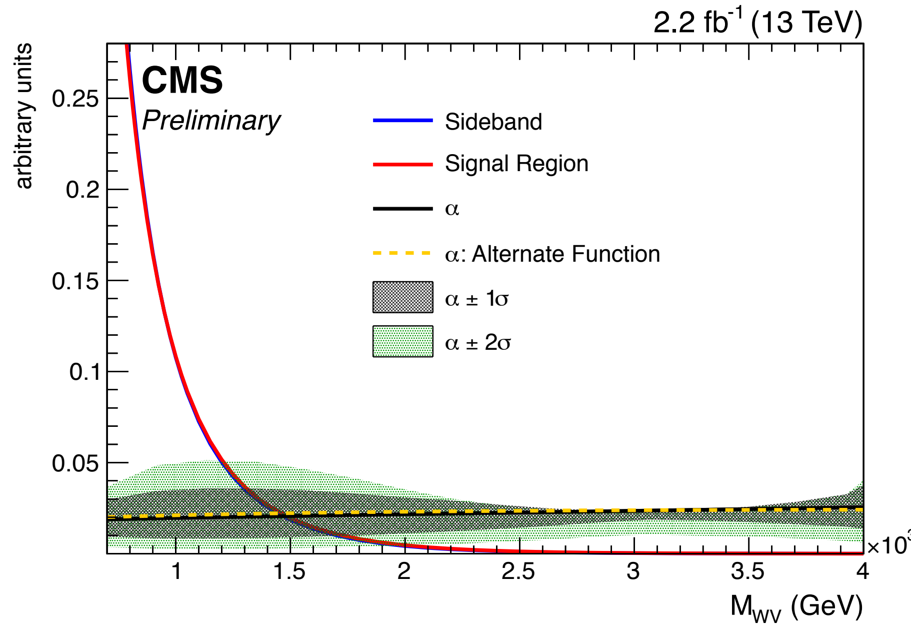
Control Plots in W+jets



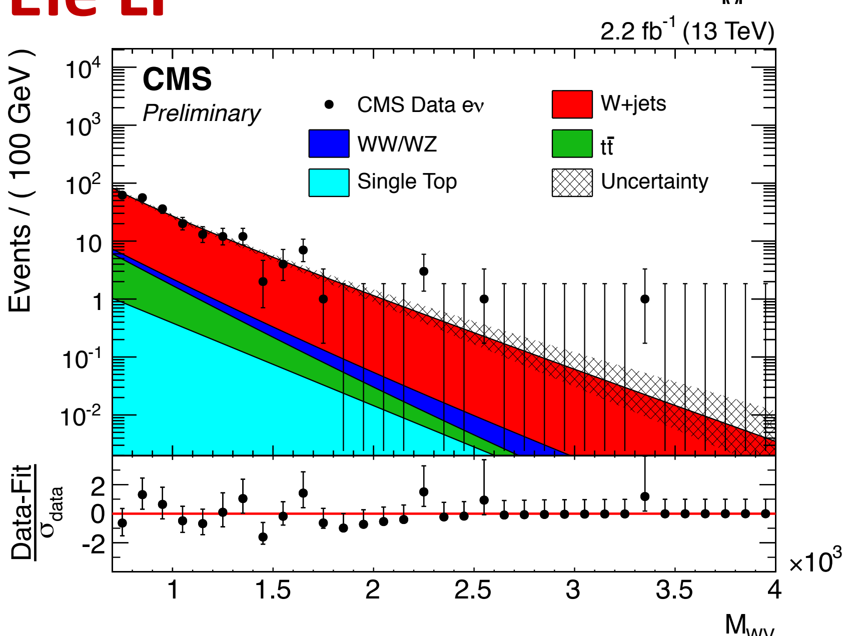
V+jets M_{VW} shape in Signal Region

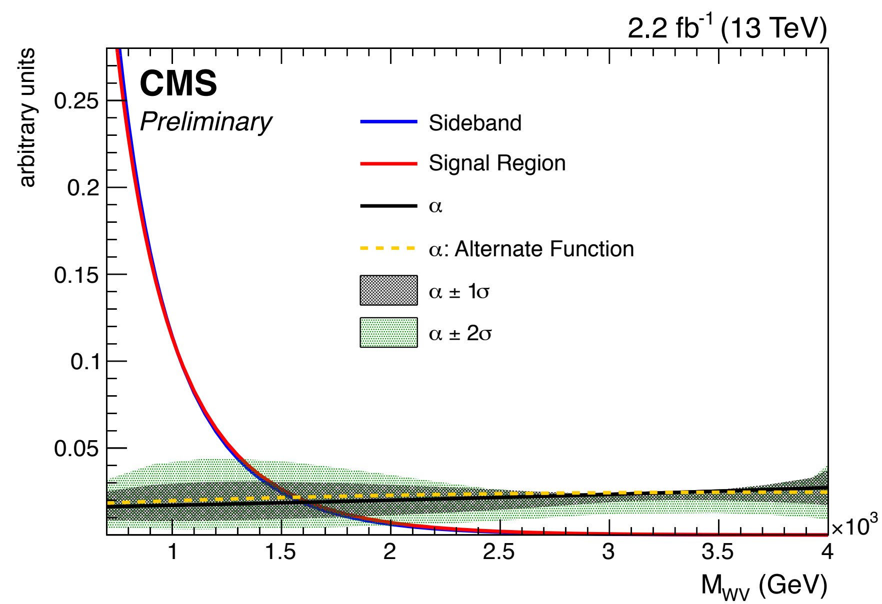
Ele HP





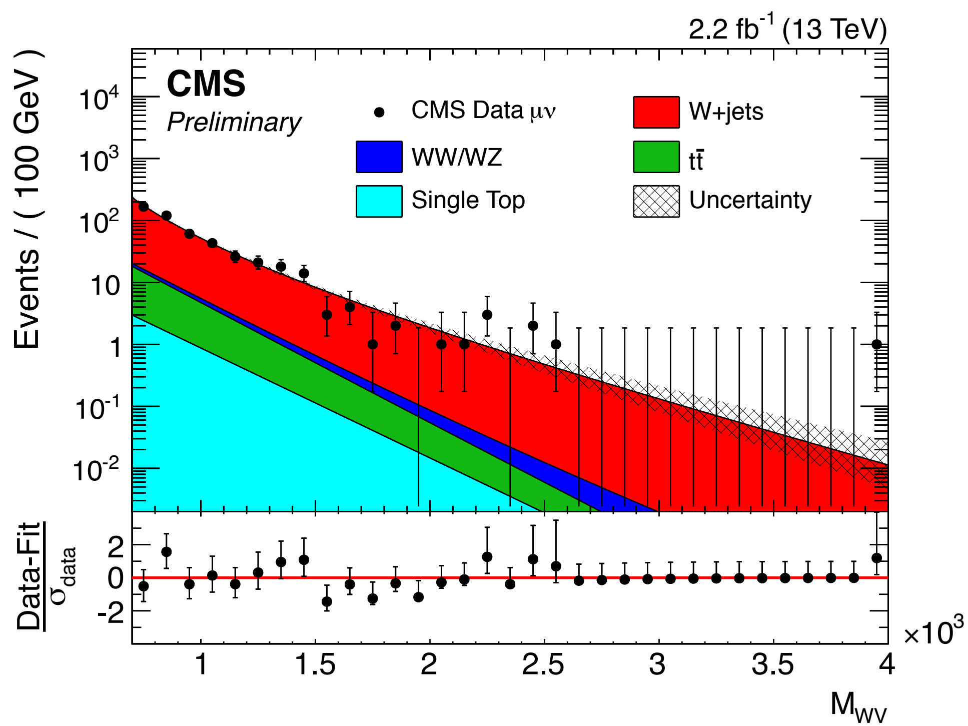
Ele LP

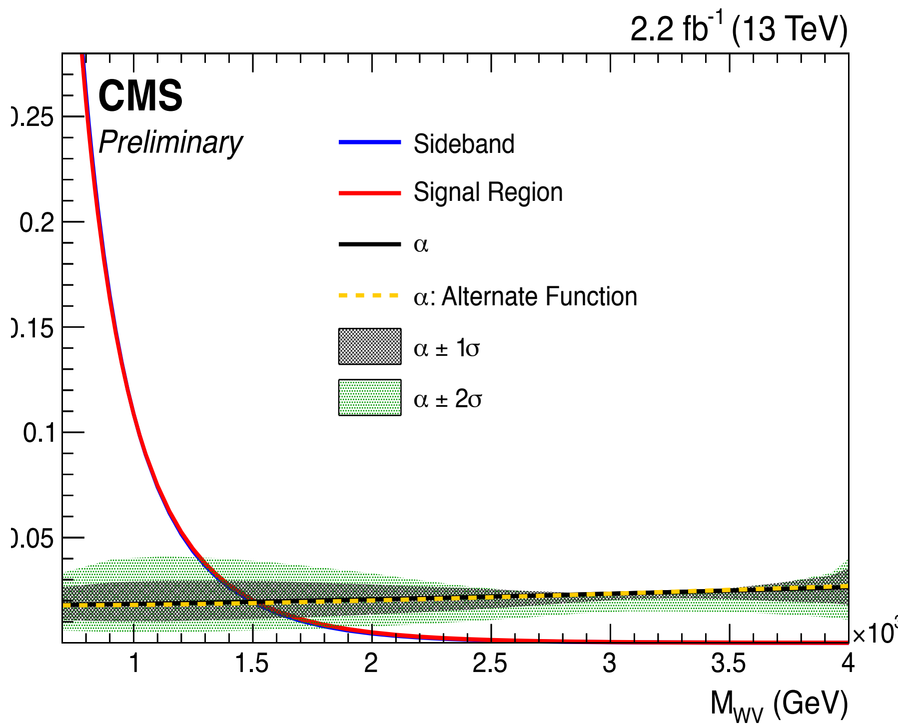




V+jets M_{VW} shape in Signal Region

Mu LP





Closure check on alpha-method

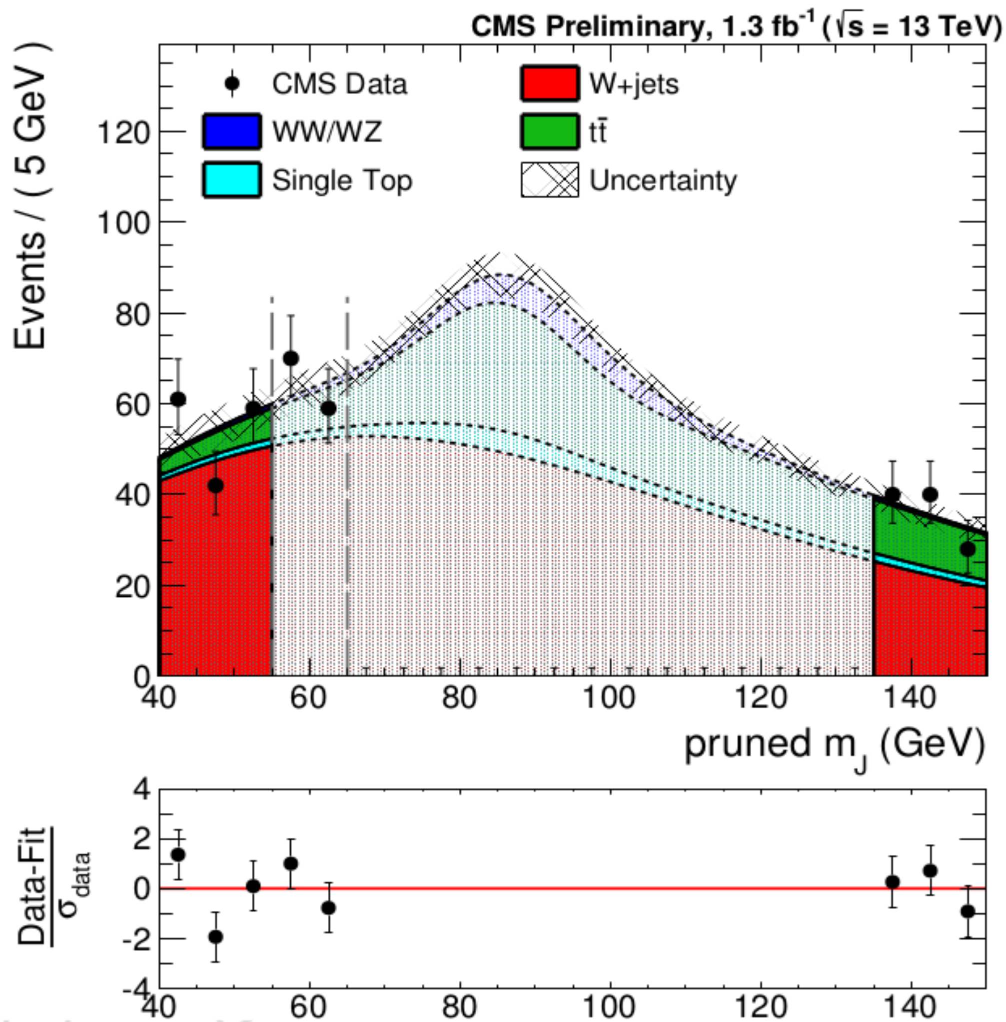
Closure check:

- Split the low sideband in two region (A and B)

- Use region A as sideband, region B as signal region

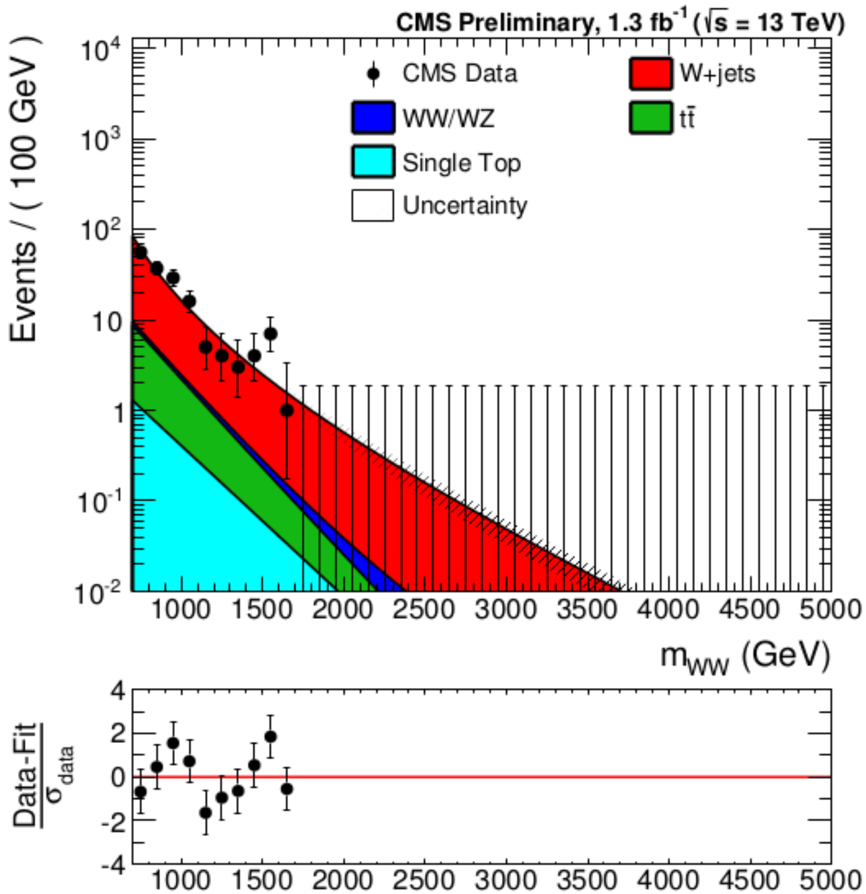
- Check the extrapolation of W+jets from region A to region B

(electron and muon channel merget together due to the low statistics of the sideband alone)

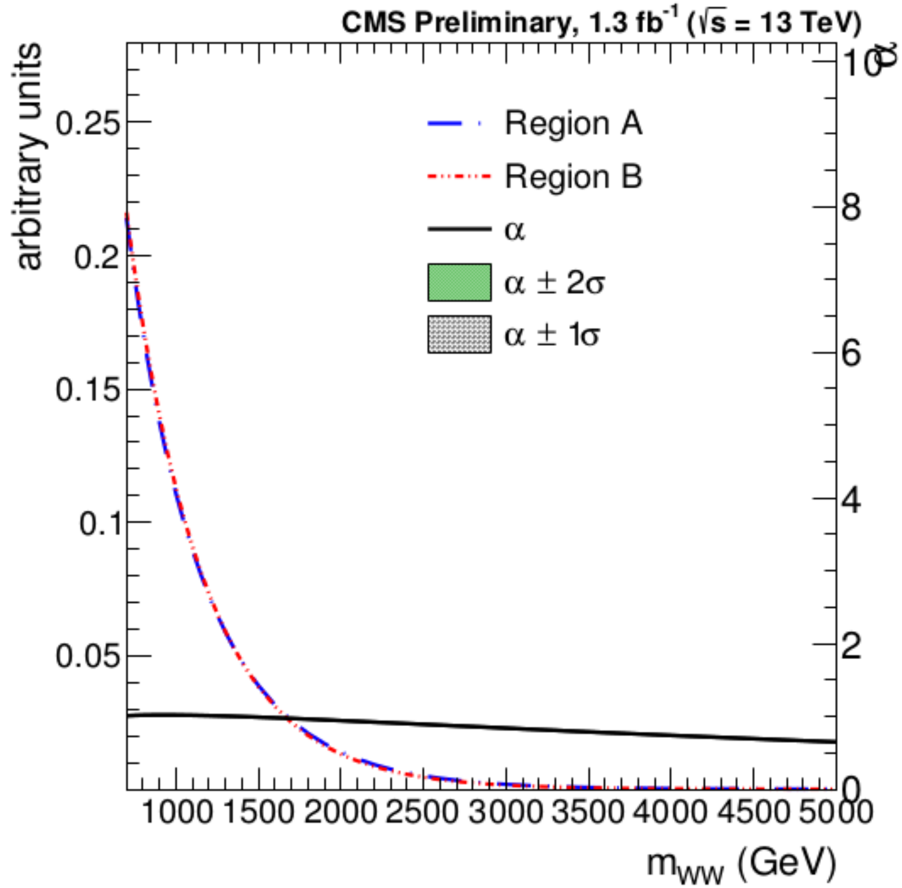


Closure check: sideband fit and alpha

Fit Mvw distribution in data, in region A, subtracting minor backgrounds, to extract W+jets shape



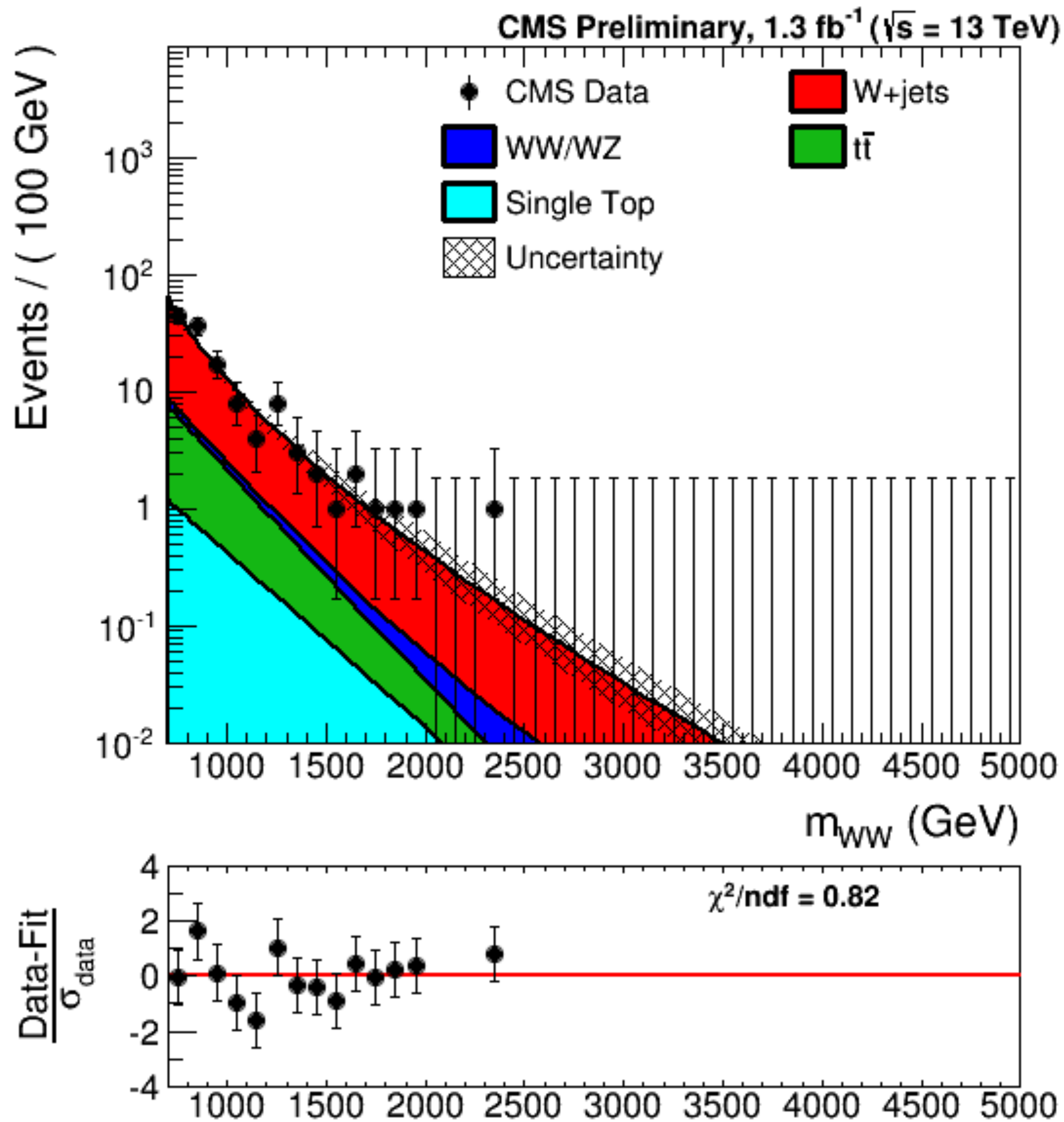
Alpha-function: MC ratio region B/region A of Mvw shape of W+jets



Closure check: extrapolation to Region B

W+jets (region B) =
Alpha * W+jets (region A)

→ final background prediction in region B

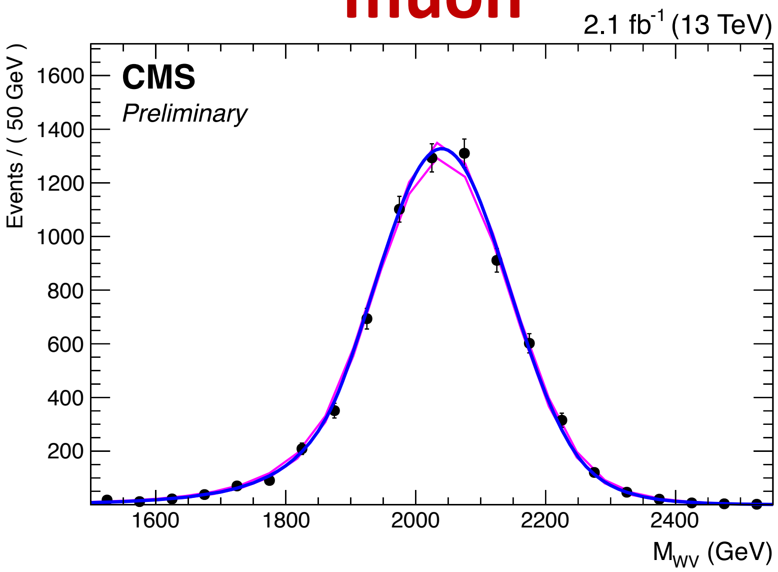


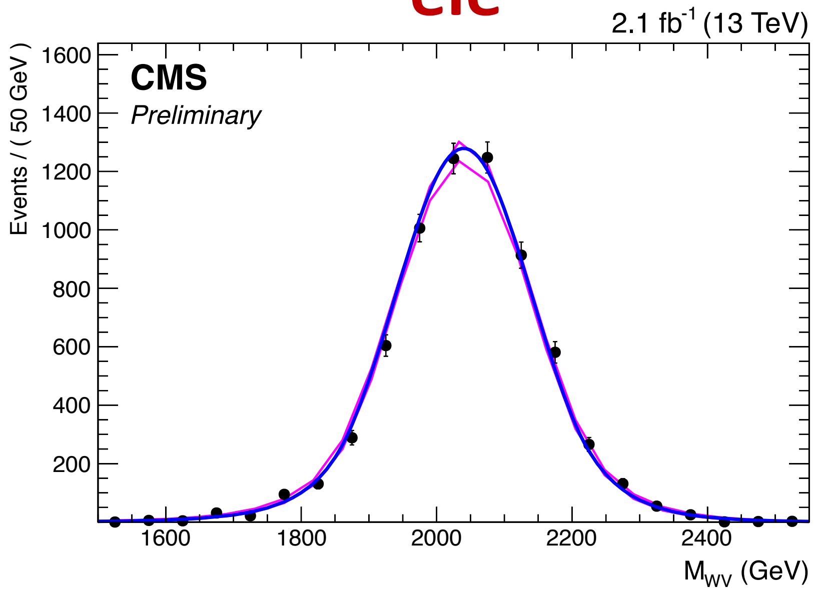
Signal Modelling

Signal fits are performed with double Crystal-ball function.

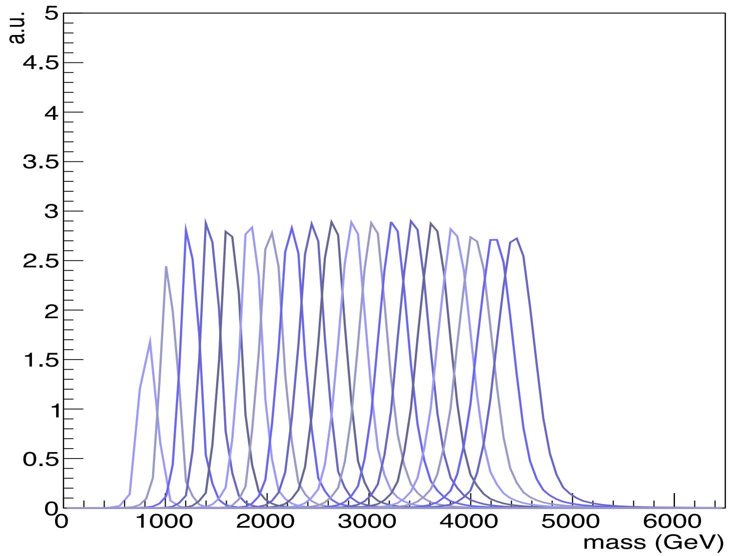
muon **ele**

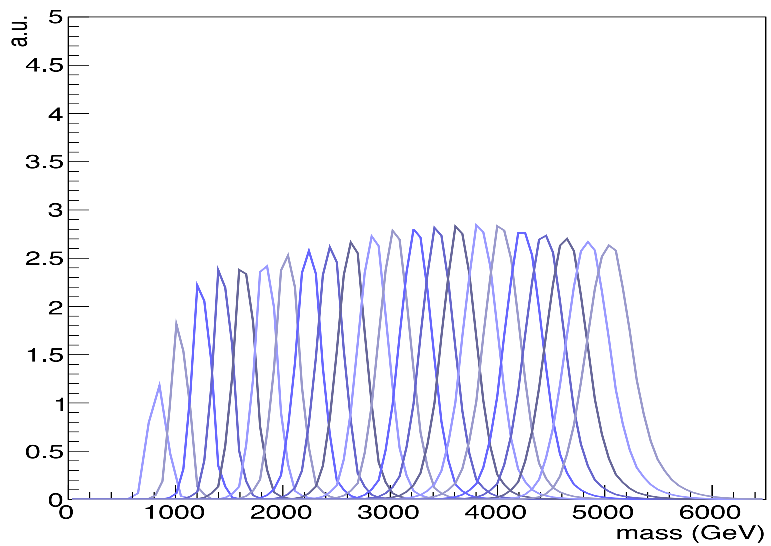
WZ





WZ





Statistical interpretation

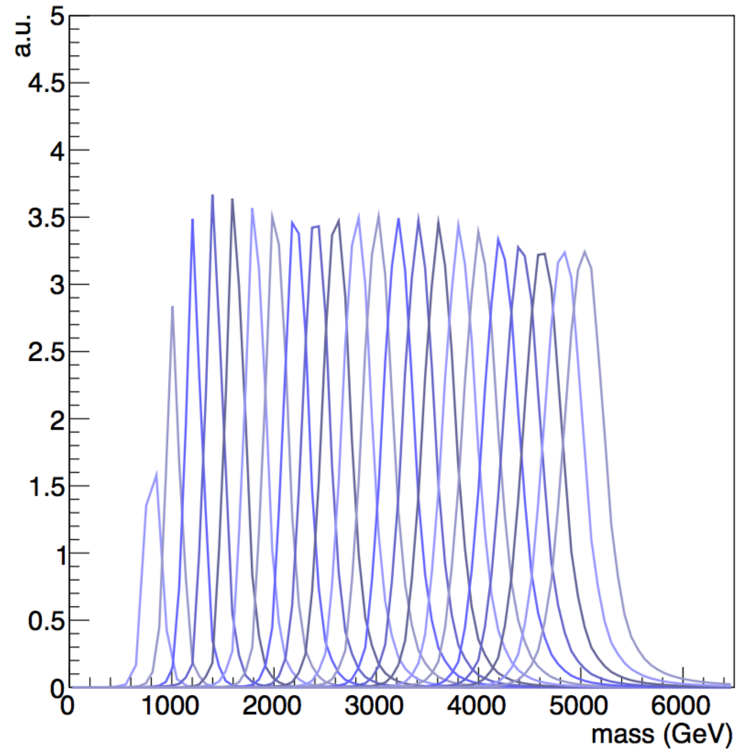
- No deviation from the standard model prediction is observed in the final Mwv distributions in any of the categories

- We set 95% CL upper limits on the two production cross-section of a narrow resonance:

  spin-2 Bulk Graviton-> WW

  spin-1 W'->WZ in the context of the HVT model B

- Since MC available for only few mass points we interpolate the Crystall-Ball parameters and the signal efficiency to predict the shape and normalization of the intermediate mass points



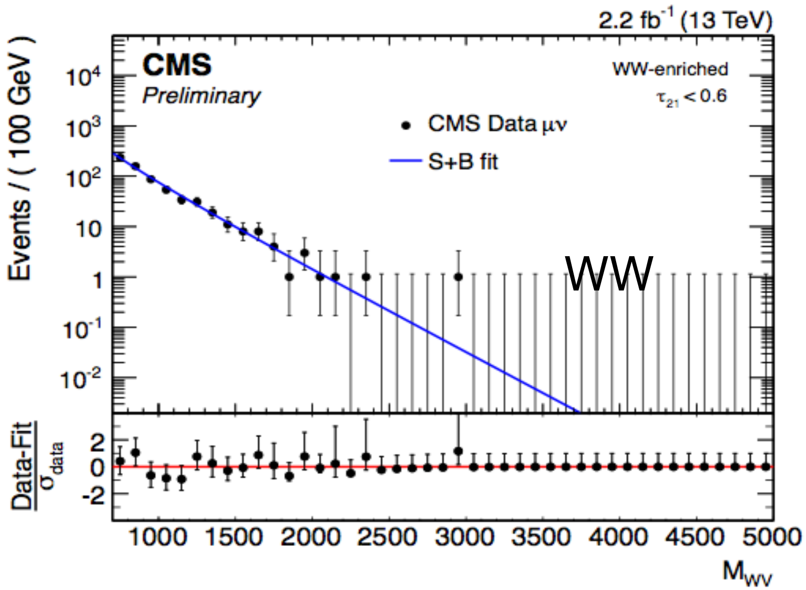
Additional checks

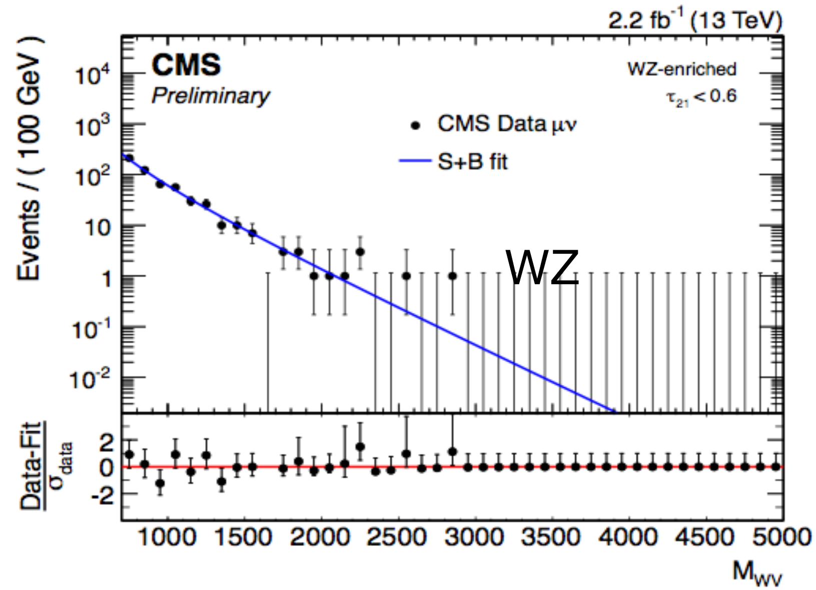
- Run expected limits estimating the shape directly from the signal region (as in VV analysis) using an exponential with tail and assuming
  - fully **uncorrelated** shapes between the pruned jet mass categories
    - fit different parameters in each category
  - completely **correlated** shapes between the pruned jet mass categories
    - force same parameters in different categories
- Compare the results with default alpha method where in the different categories we assume
  - same M_{VV} distribution in low sideband
  - different alpha shapes
- Run the check for muon channel only in the HP category

Dijet methon (post-fit)

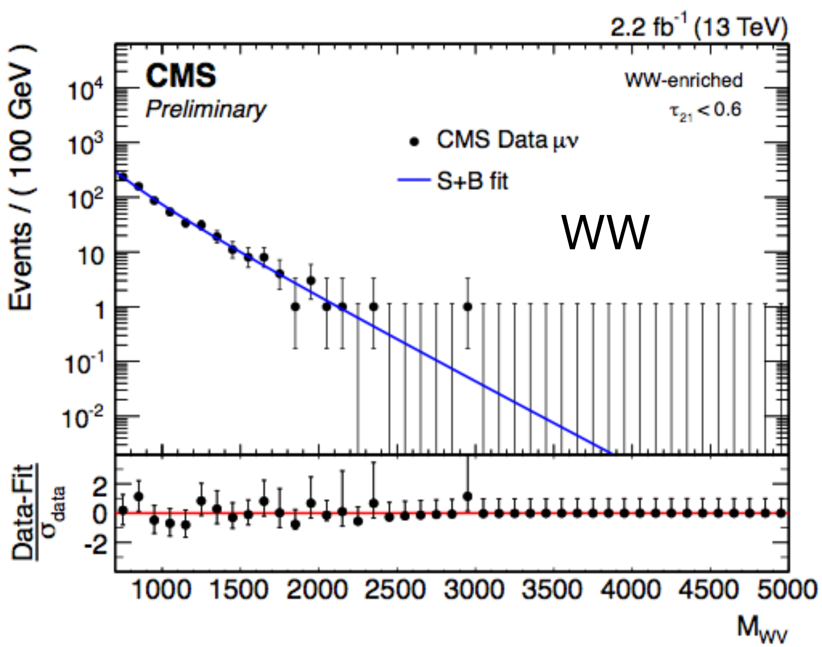
p38

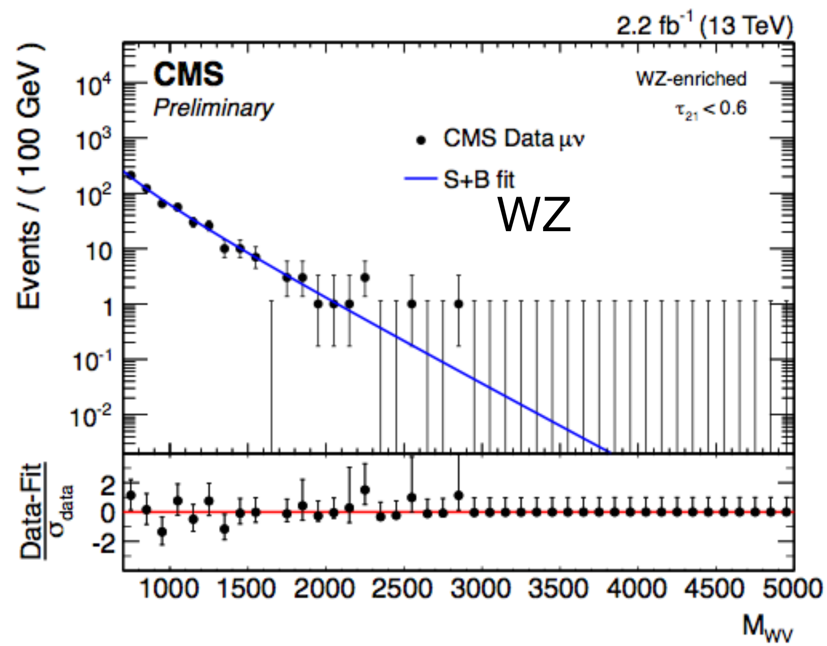
uncorrelated shapes



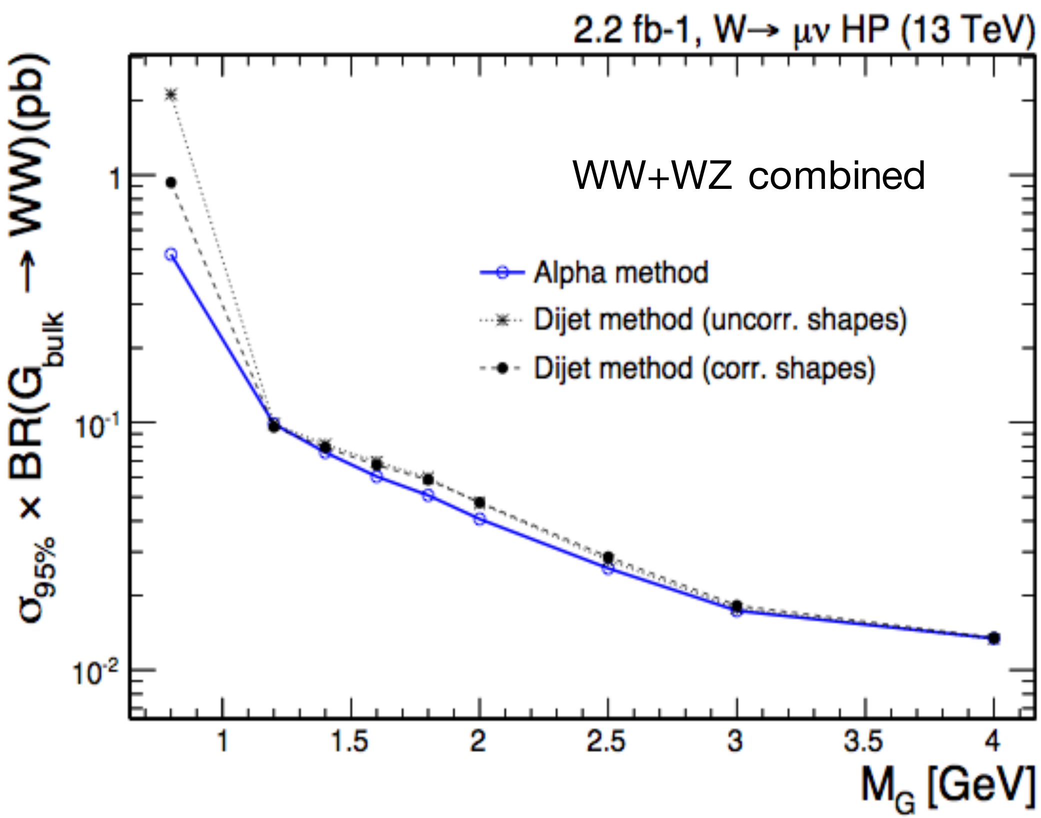


correlated shapes





Compare Expected Limits



- The different methods give consistent results
- The additional information from data in sideband contained in the alpha method give better constraint on the shape in signal region (especially at low masses)

Post-fit uncertainties

What we have now in the datacards

```
Deco_WJets0_xww_sb_lo_from_fitting_el_HP_mlvj_13TeV_eig0 param 0.0 1.4
Deco_WJets0_xww_sb_lo_from_fitting_el_HP_mlvj_13TeV_eig1 param 0.0 1.4
Deco_WJets0_xww_sb_lo_from_fitting_el_HP_mlvj_13TeV_eig2 param 0.0 1.4
```
→ sideband fit

```
Deco_WJets0_xww_sim_el_HPW_mlvj_13TeV_eig0 param 0.0 1.4
Deco_WJets0_xww_sim_el_HPW_mlvj_13TeV_eig1 param 0.0 1.4
Deco_WJets0_xww_sim_el_HPW_mlvj_13TeV_eig2 param 0.0 1.4
Deco_WJets0_xww_sim_el_HPW_mlvj_13TeV_eig3 param 0.0 1.4
```
→ alpha

→ For a parameter A of the pdf, this means:

- use the a-priori information on the parameter
  - use A as initial value with its uncertainty σA
- assign a gaussian prior for σA with central value = 0
  - if gauss width = 1: constrain the parameter to vary inside the uncertainty of the a-priori fit
  - if gauss width = 1.4: constrain the parameter to vary inside a larger uncertainty of what obtained a-priori

→ In the next slides study post-fit uncertainties and expected limits for different values of the gauss width

- run MaxLikelihood fit for one datacard (ex: 2 TeV BulkG in HP-WW category)
- run diffNuisances.py script

Post-fit uncertainties

- Results with gauss width σ_{input} = 1.4

shift, relative post-fit uncertainty

```
Deco_WJets0_xww_sb_lo_from_fitting_mu_HP_mlvj_13TeV_eig0 * +0.20, 0.72 *
Deco_WJets0_xww_sb_lo_from_fitting_mu_HP_mlvj_13TeV_eig1   +0.00, 0.99
Deco_WJets0_xww_sb_lo_from_fitting_mu_HP_mlvj_13TeV_eig2 * -0.82, 0.71 *

Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig0               * +0.11, 0.84 *
Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig1                 -0.23, 0.97
Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig2               * +0.41, 0.93 *
Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig3                 -0.03, 0.99
```

Post-fit expected limit:
r < 1.8359

- Results with gauss width σ_{input} = 1.0

shift, relative post-fit uncertainty

```
Deco_WJets0_xww_sb_lo_from_fitting_mu_HP_mlvj_13TeV_eig0 * +0.24, 0.80 *
Deco_WJets0_xww_sb_lo_from_fitting_mu_HP_mlvj_13TeV_eig1   +0.00, 0.99
Deco_WJets0_xww_sb_lo_from_fitting_mu_HP_mlvj_13TeV_eig2 * -0.88, 0.79 *

Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig0               * +0.11, 0.88 *
Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig1                 -0.24, 0.98
Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig2               * +0.44, 0.95 *
Deco_WJets0_xww_sim_mu_HPW_mlvj_13TeV_eig3                 -0.03, 0.99
```

Post-fit expected limit:
r < 1.7266

→ When changing from 1.4 to 1.0:

- expected limits improve of ~6%
- data in signal region constrain parameters from 1-1.3 σ_{input} down to 0.8-0.95 σ_{input}

Post-fit uncertainties

- Compare with normalization uncertainties
  - fix shape parameters —> set uncertainty to very low value (σ_{input} = 0.001)
  - and change for example the uncertainty on the W+Jets normalization

- W+Jets normalization unc. = 5% (original value from sideband fit)

shift, relative post-fit uncertainty

```
CMS_xww_WJ_norm_mu_HPW_13TeV +0.69,0.82
```

Post-fit expected limit:
r < 1.4180

- W+Jets normalization unc. = 1%

shift, relative post-fit uncertainty

```
CMS_xww_WJ_norm_mu_HPW_13TeV +0.21, 0.99
```

Post-fit expected limit:
r < 1.3945

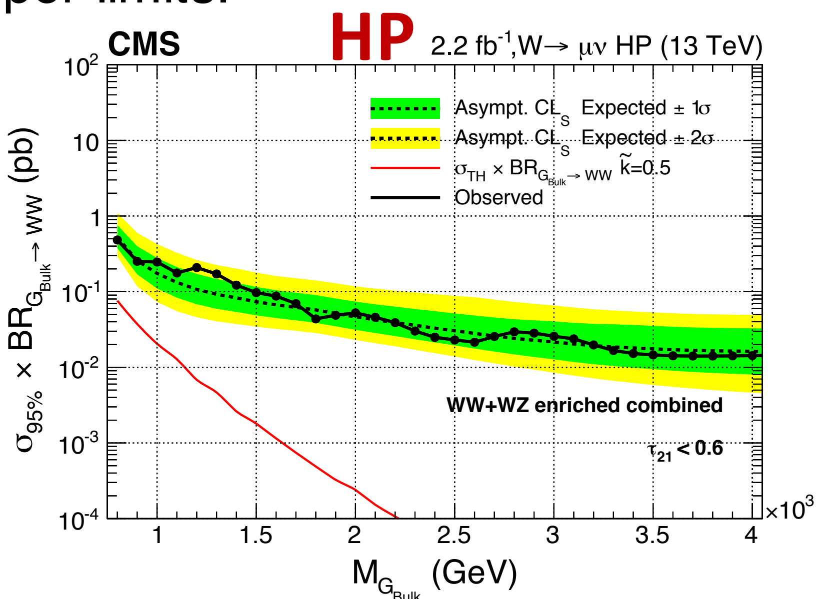
⟶ When changing from 5% to 1%:

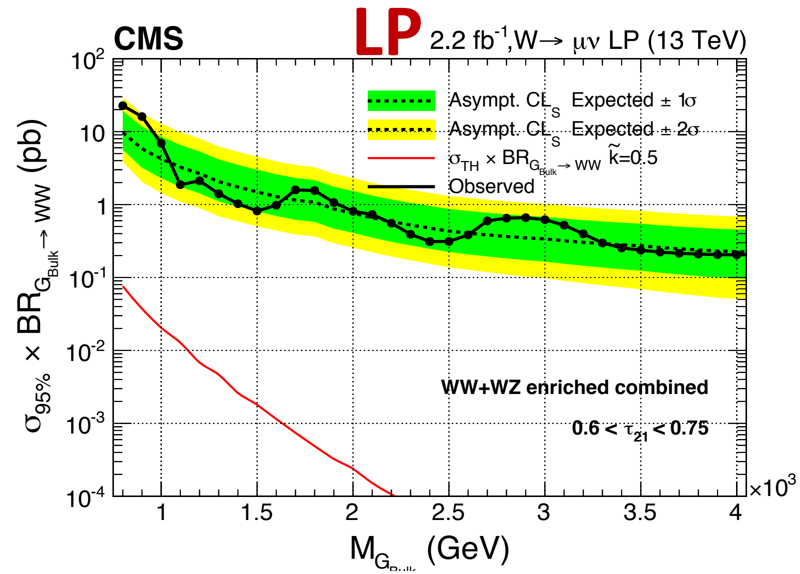
- expected limits improve of ~2%
- data in signal region do not constrain the initial parameter

Limits(Bulk Graviton)

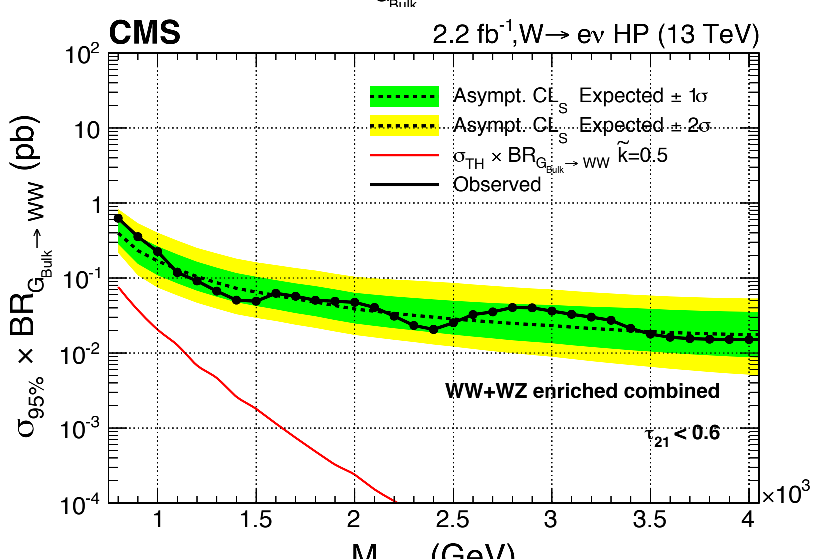
Use the Higgs combination tool and Asymptotic CLs method to compute the upper limits.

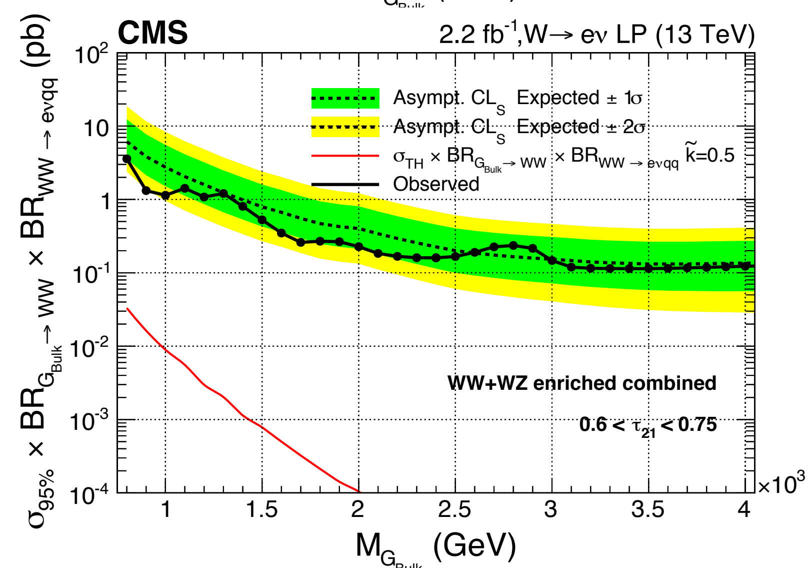
muon



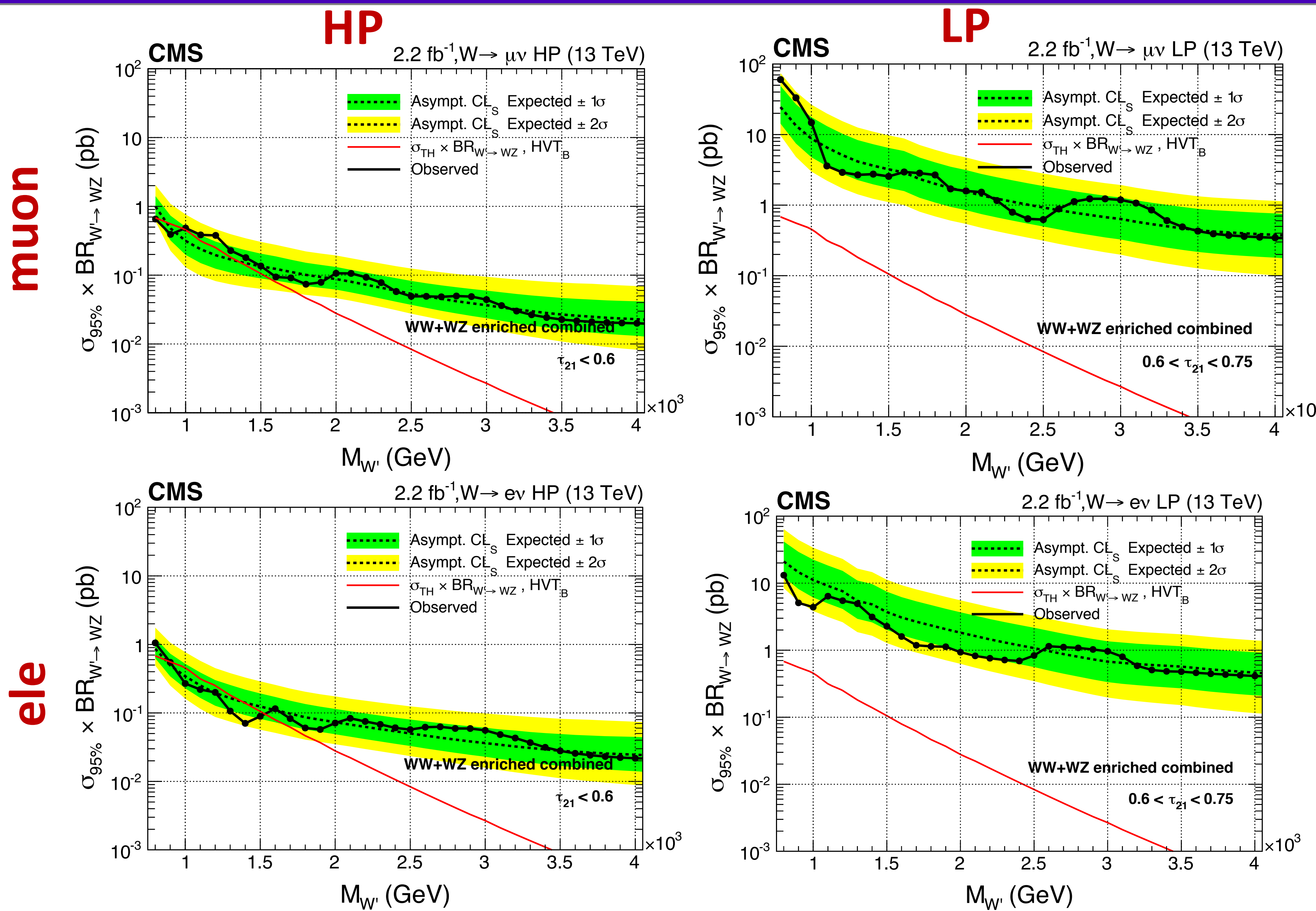


ele





Limits(W')

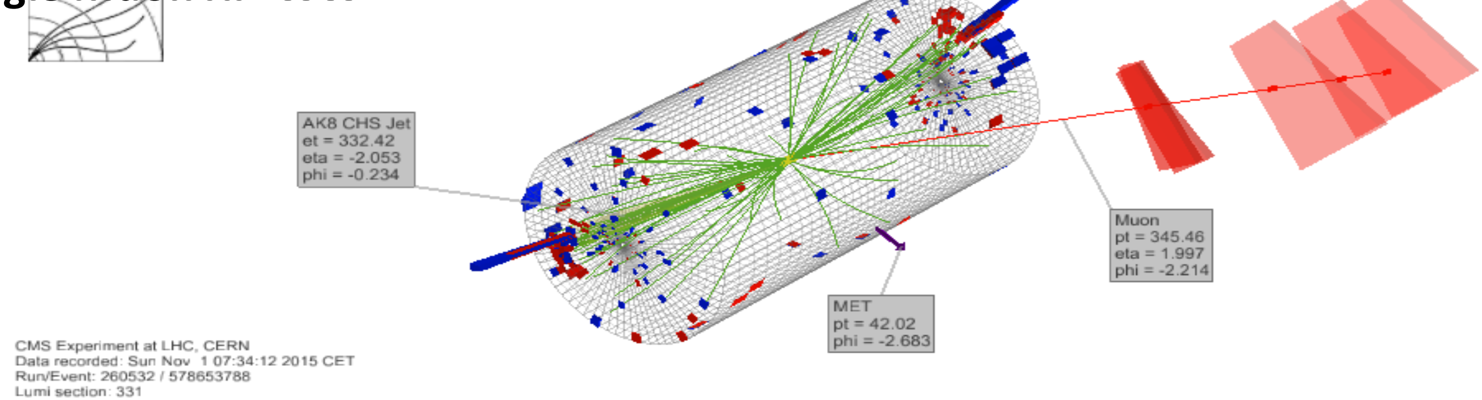

HP
LP
muon
ele
CMS
2.2 fb^{-1},W→ μν HP (13 TeV)
2.2 fb^{-1},W→ μν LP (13 TeV)
2.2 fb^{-1},W→ eν HP (13 TeV)
2.2 fb^{-1},W→ eν LP (13 TeV)
Asympt. CL$_S$ Expected ± 1σ
Asympt. CL$_S$ Expected ± 2σ
$\sigma_{TH} \times BR_{W' \to WZ}$, HVT$_B$
Observed
WW+WZ enriched combined
τ_{21} < 0.6
0.6 < τ_{21} < 0.75
$\sigma_{95\%} \times BR_{W' \to WZ}$ (pb)
$M_{W'}$ (GeV)
×10^3

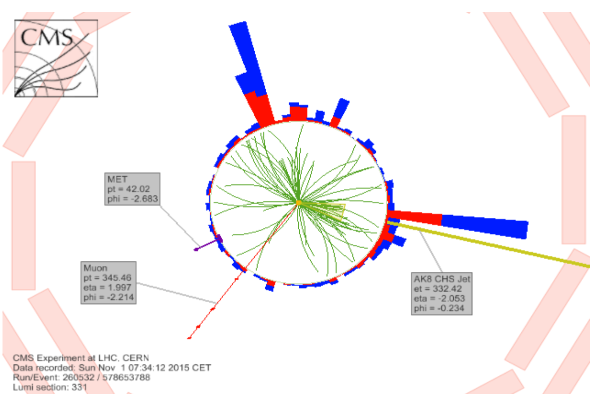
Event Display

In the next slides event display and properties of the events in the region ~ 2.8-3.2 TeV

dataset	HP WW-enriched	HP WZ-enriched	LP WW-enriched	LP WZ-enriched
SingleMuon	1	1	1	1
SingleElectron	2	1	0	1

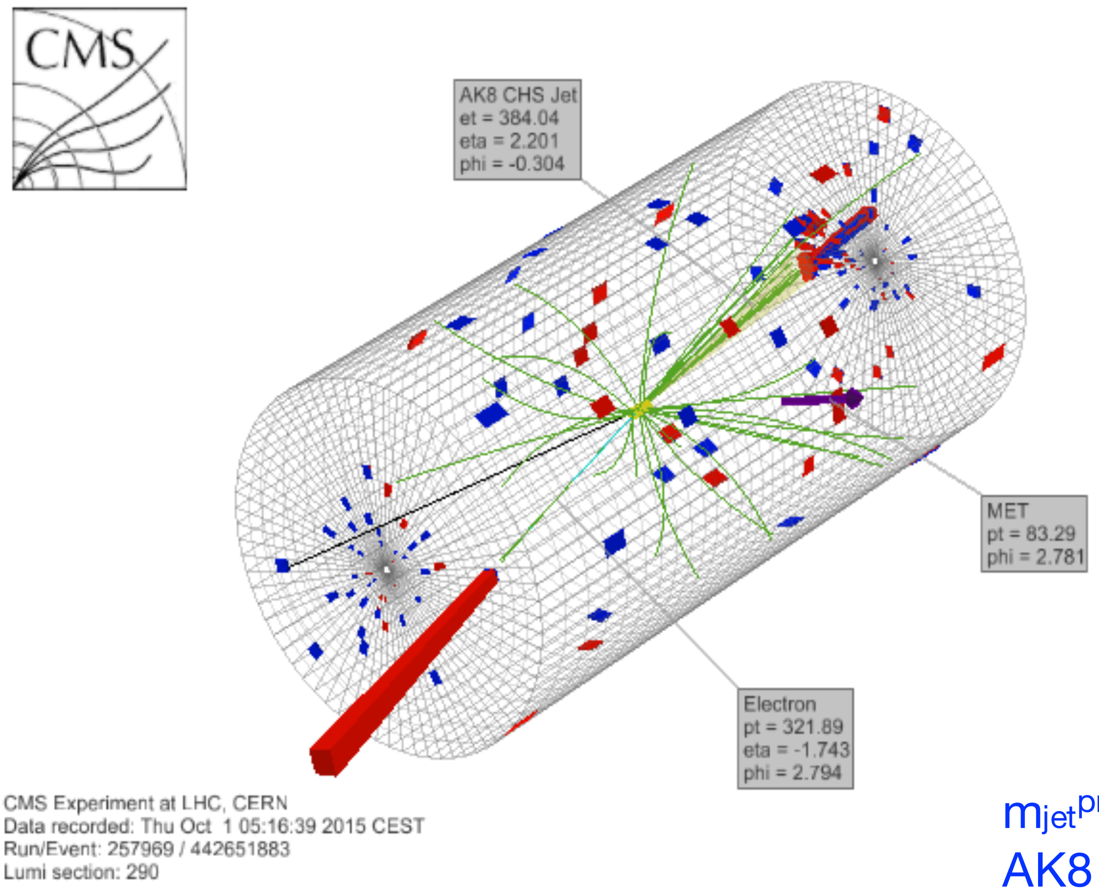
Single Muon HP-WW

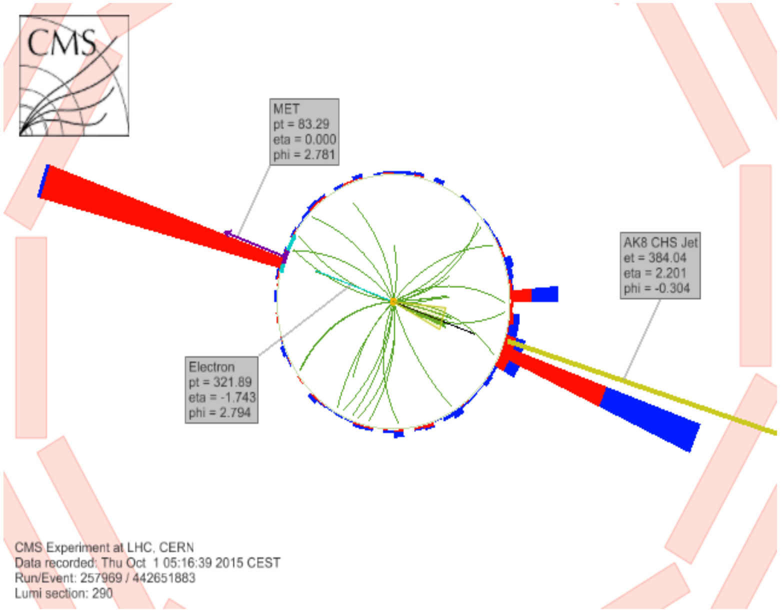




m_{jet}^{pruned} = 78.6 GeV
AK8 jet mass = 108.7 GeV
AK8 jet p_T = 0.37 TeV
W_{lept} p_T = 0.44 TeV
M_{WW} = 2.97 TeV

Single Electron HP-WW





m_{jet}^{pruned} = 72.1 GeV

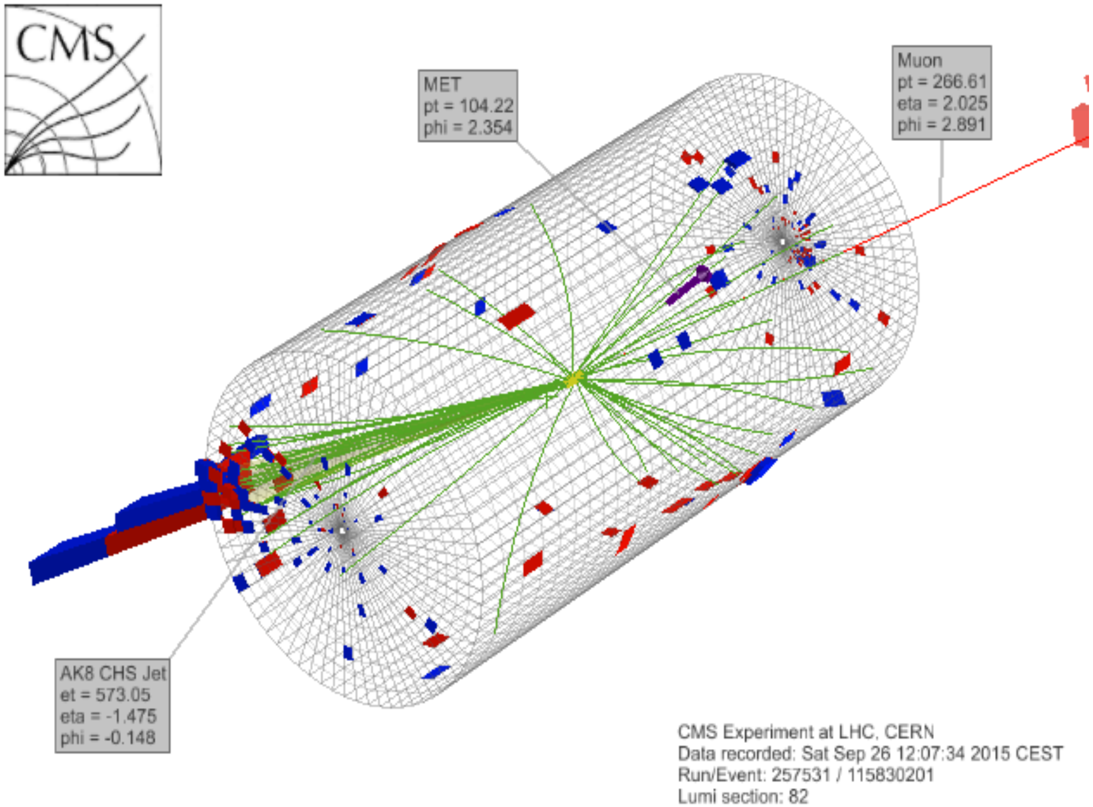
AK8 jet mass = 113.5 GeV

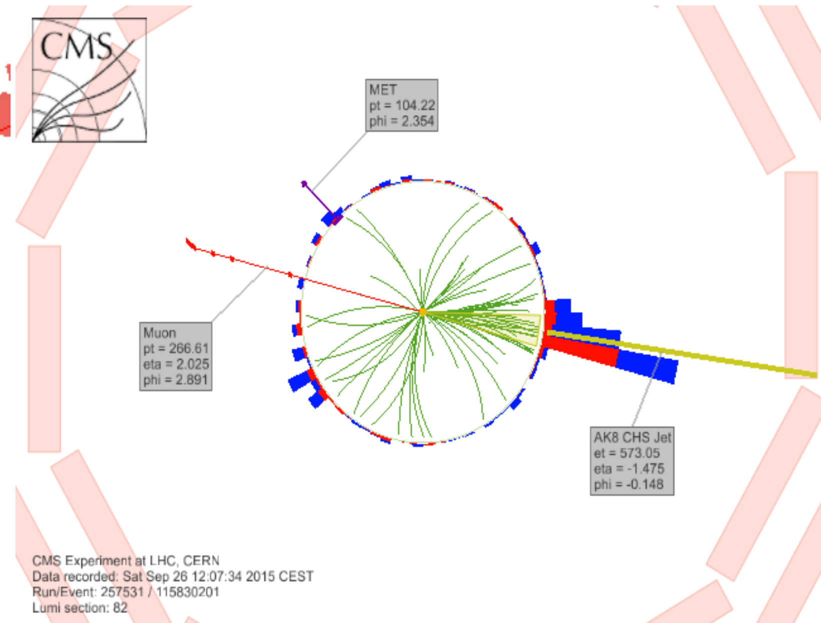
AK8 jet p_T = 0.43 TeV

W_{lept} p_T = 0.46 TeV

M_{WW} = 3.12 TeV

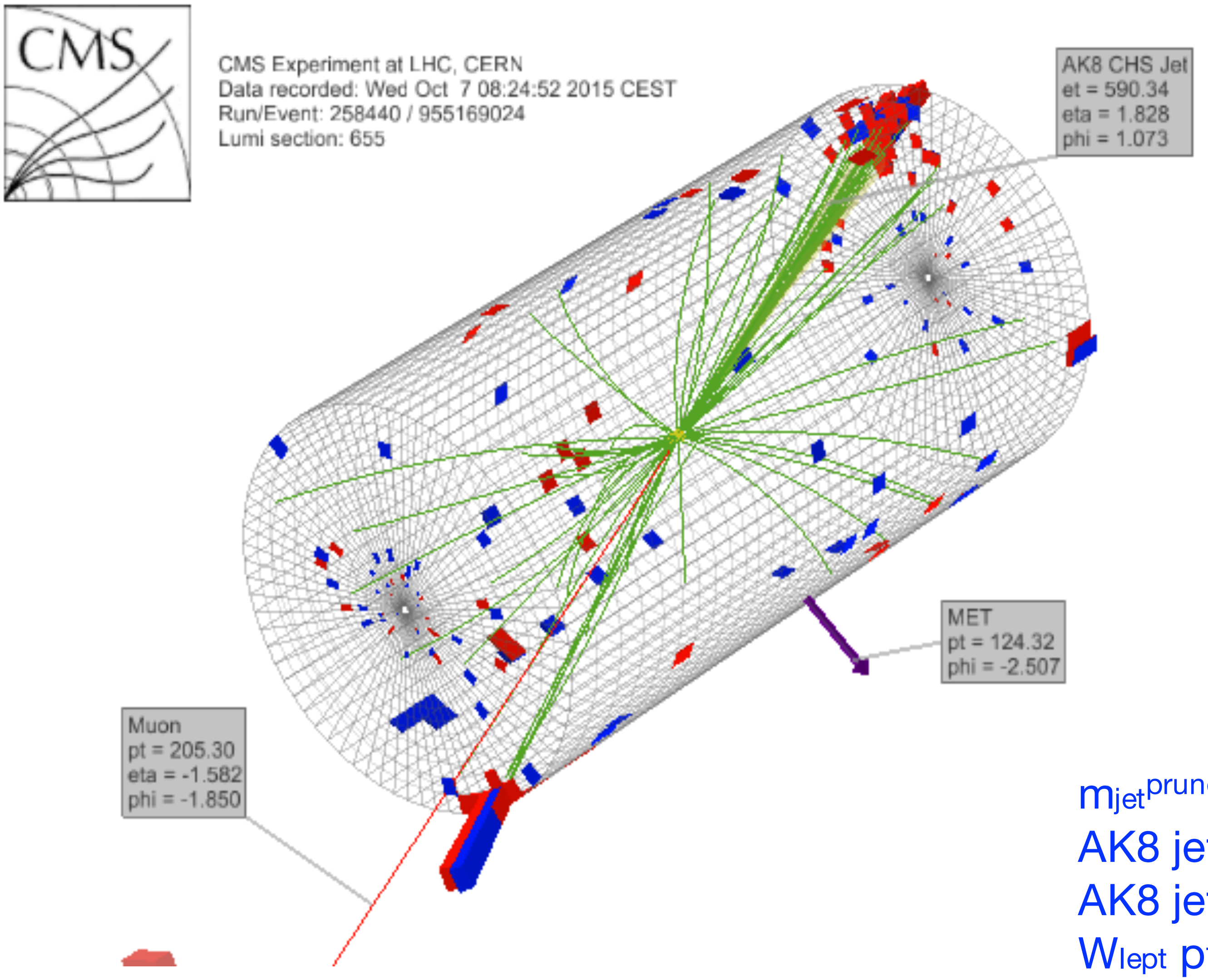
Single Muon LP-WW





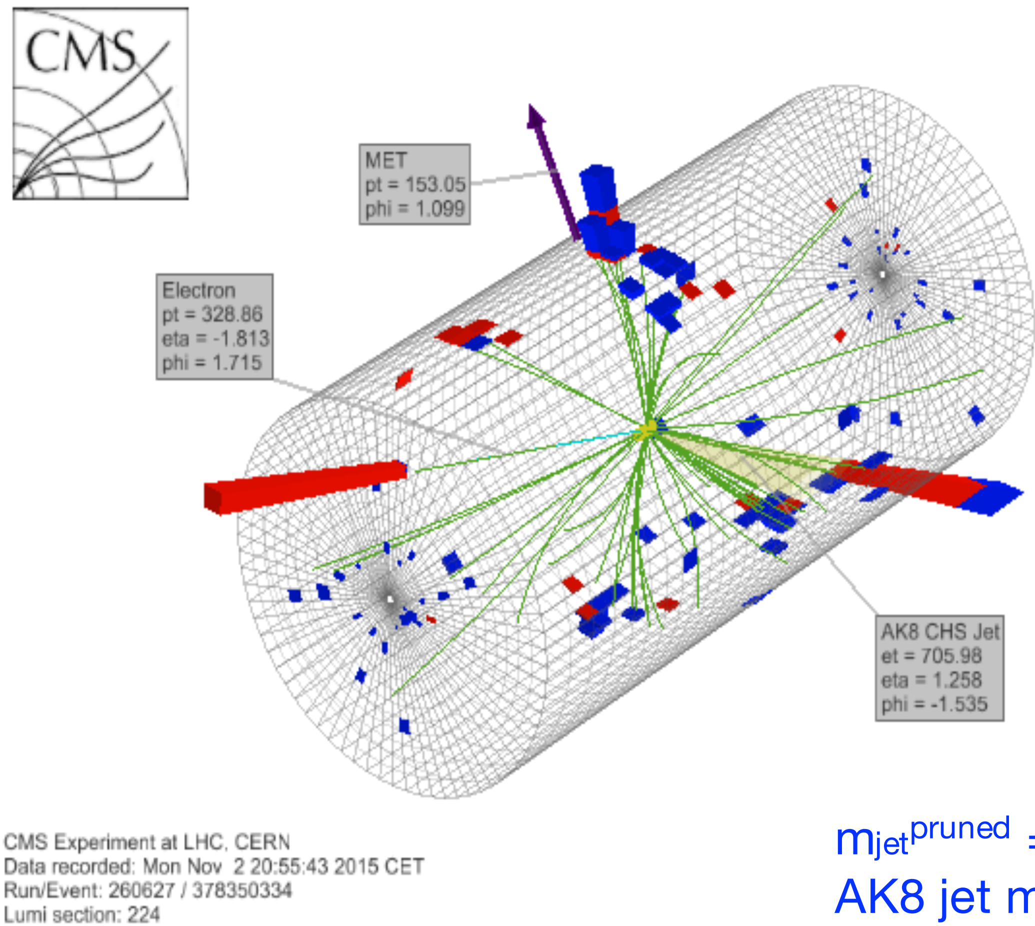
m_{jet}^{pruned} = 71.4 GeV
AK8 jet mass = 115.4 GeV
AK8 jet p_T = 0.63 TeV
W_{lept} p_T = 0.42 TeV
M_{WW} = 2.95 TeV

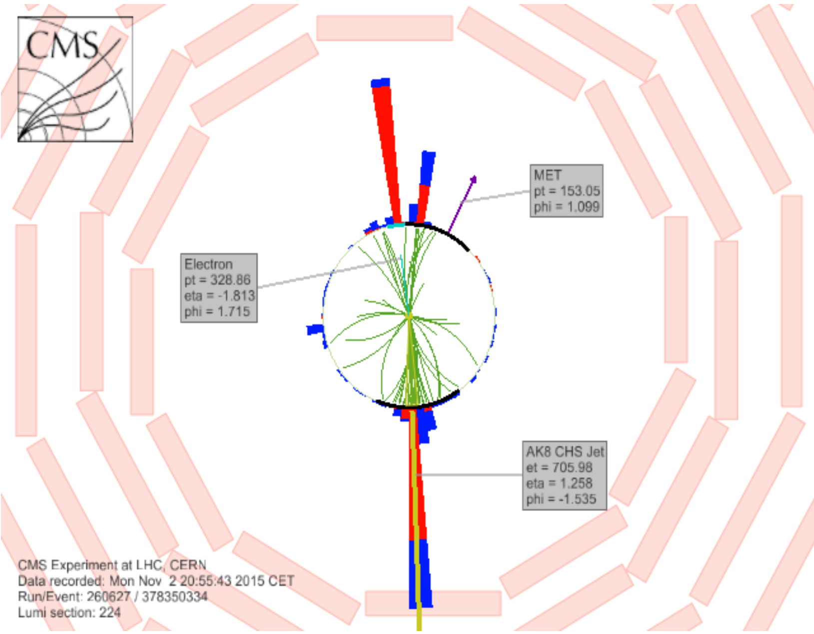
Single Muon HP-WZ



m_{jet}^{pruned} = 86.5 GeV
AK8 jet mass = 128.6 GeV
AK8 jet p_T = 0.67 TeV
W_{lept} p_T = 0.37 TeV
M_{WW} = 2.82 TeV

Single Electron HP-WZ





m_{jet}^{pruned} = 102.2 GeV

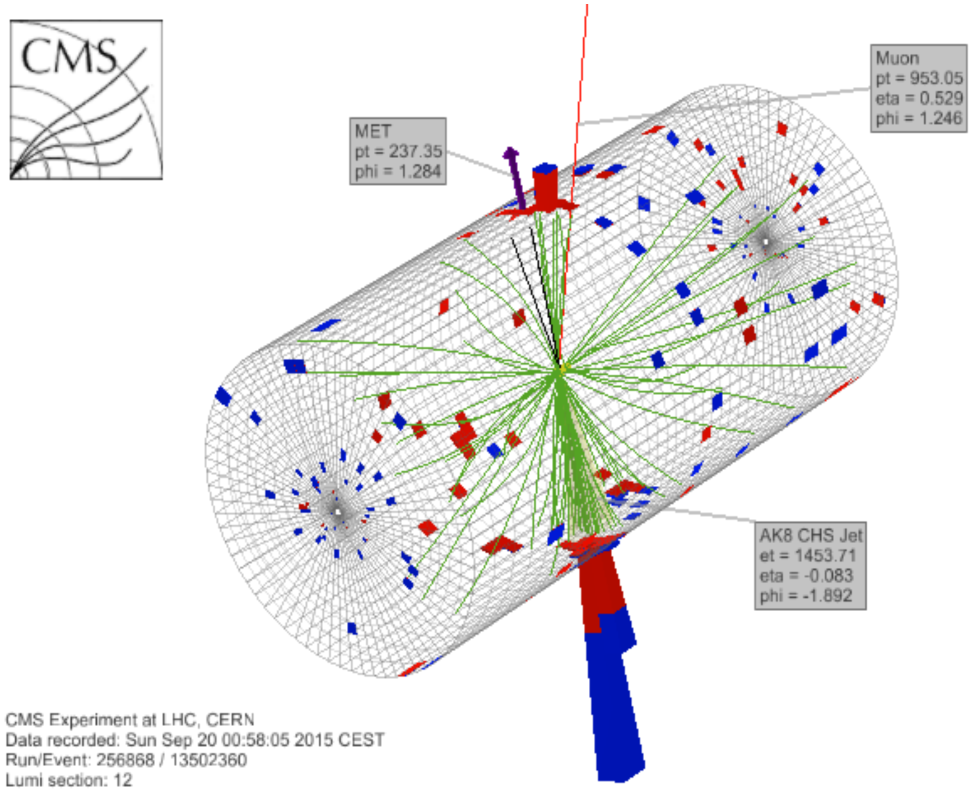
AK8 jet mass = 127.0 GeV

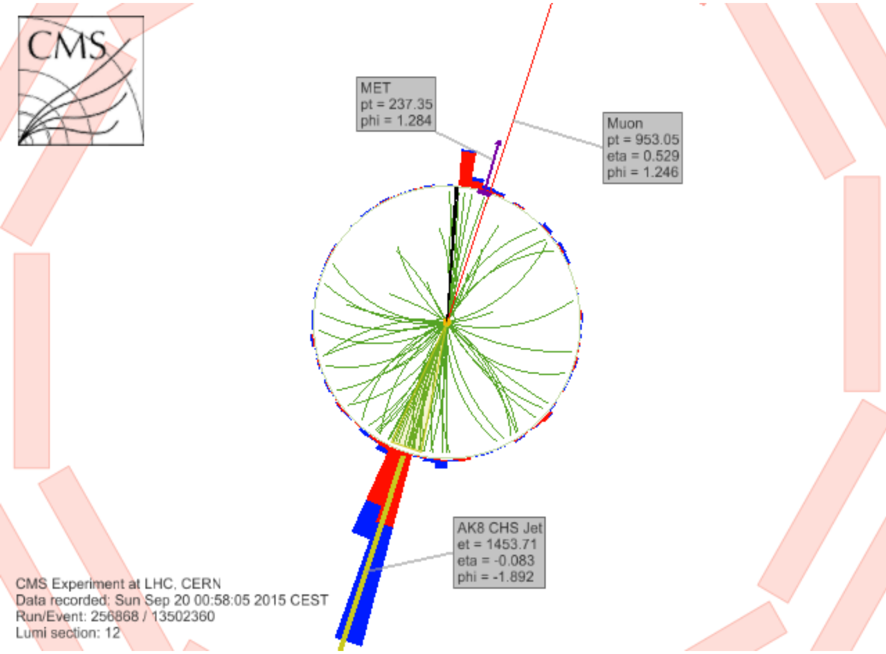
AK8 jet p_T = 0.69 TeV

W_{lept} p_T = 0.46 TeV

M_{WW} = 2.76 TeV

Single Muon LP-WZ





m_{jet}^{pruned} = 94.3 GeV

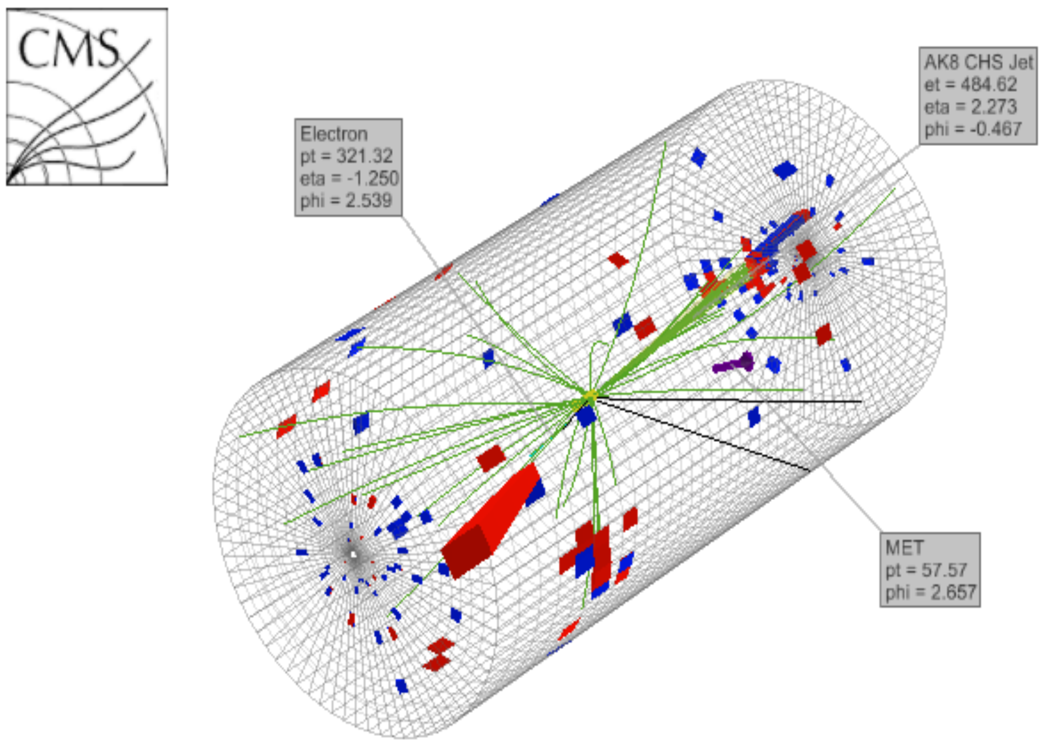
AK8 jet mass = 326.9 GeV

AK8 jet p_T = 1.47 TeV

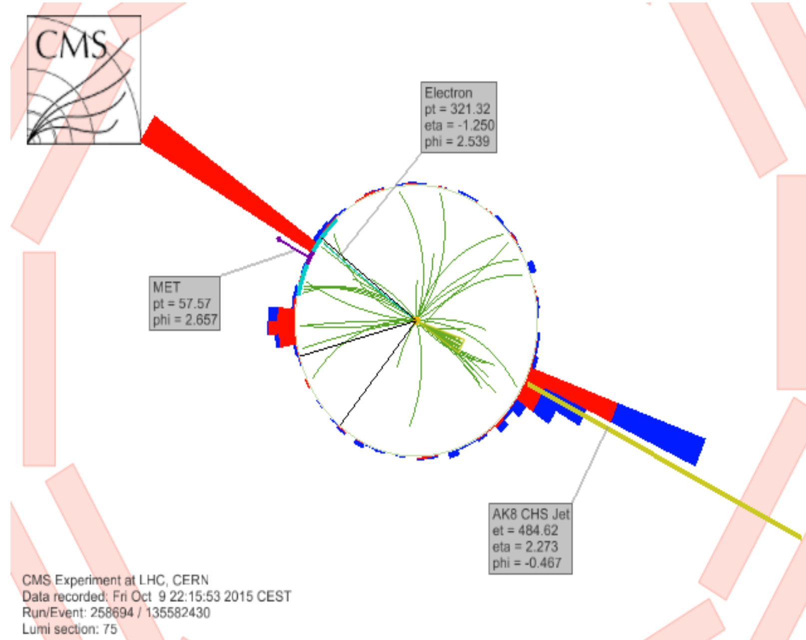
W_{lept} p_T = 1.26 TeV

M_{WW} = 2.87 TeV

Single Electron LP-WZ

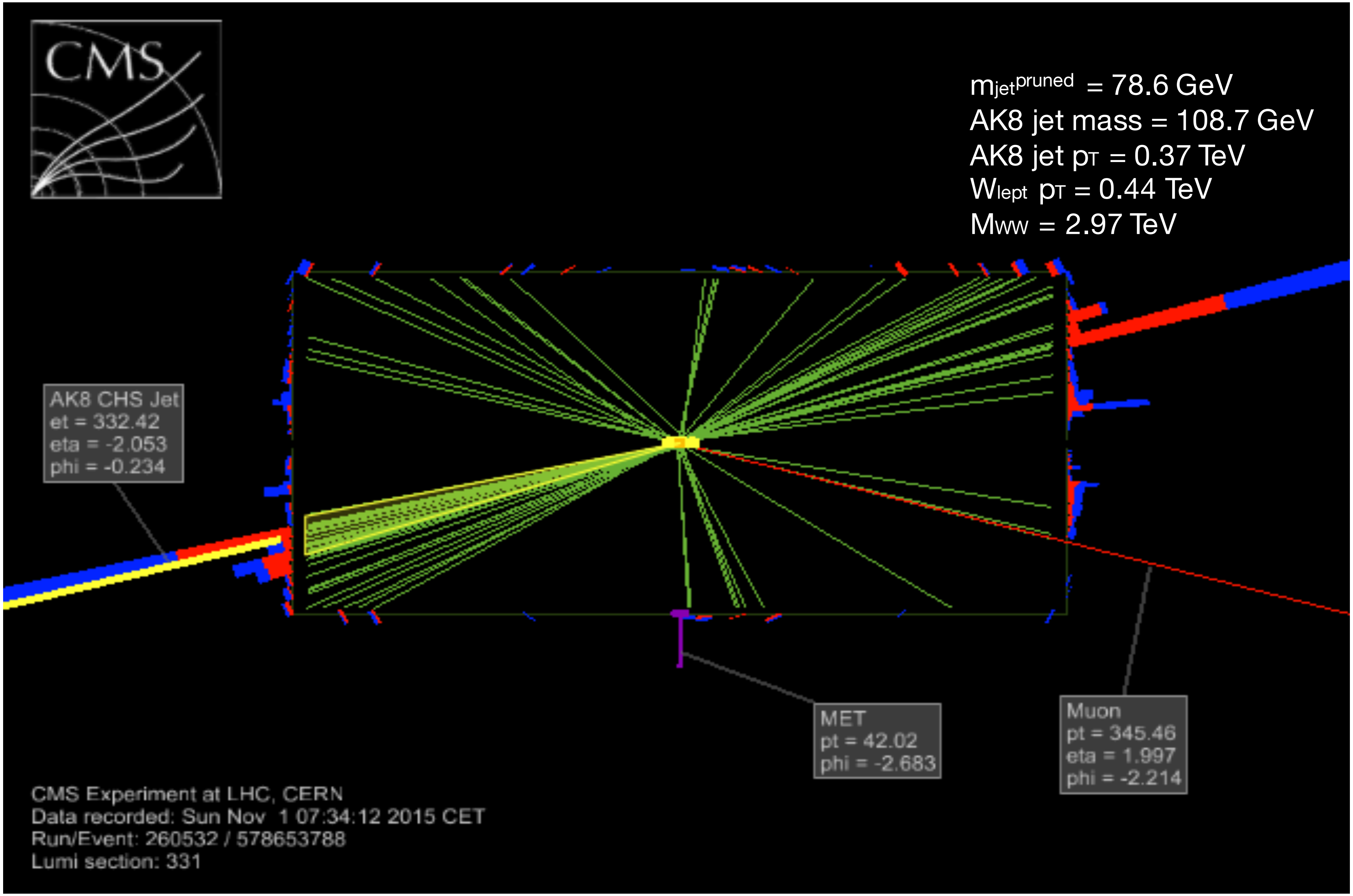


CMS Experiment at LHC, CERN
Data recorded: Fri Oct 9 22:15:53 2015 CEST
Run/Event: 258694 / 135582430
Lumi section: 75

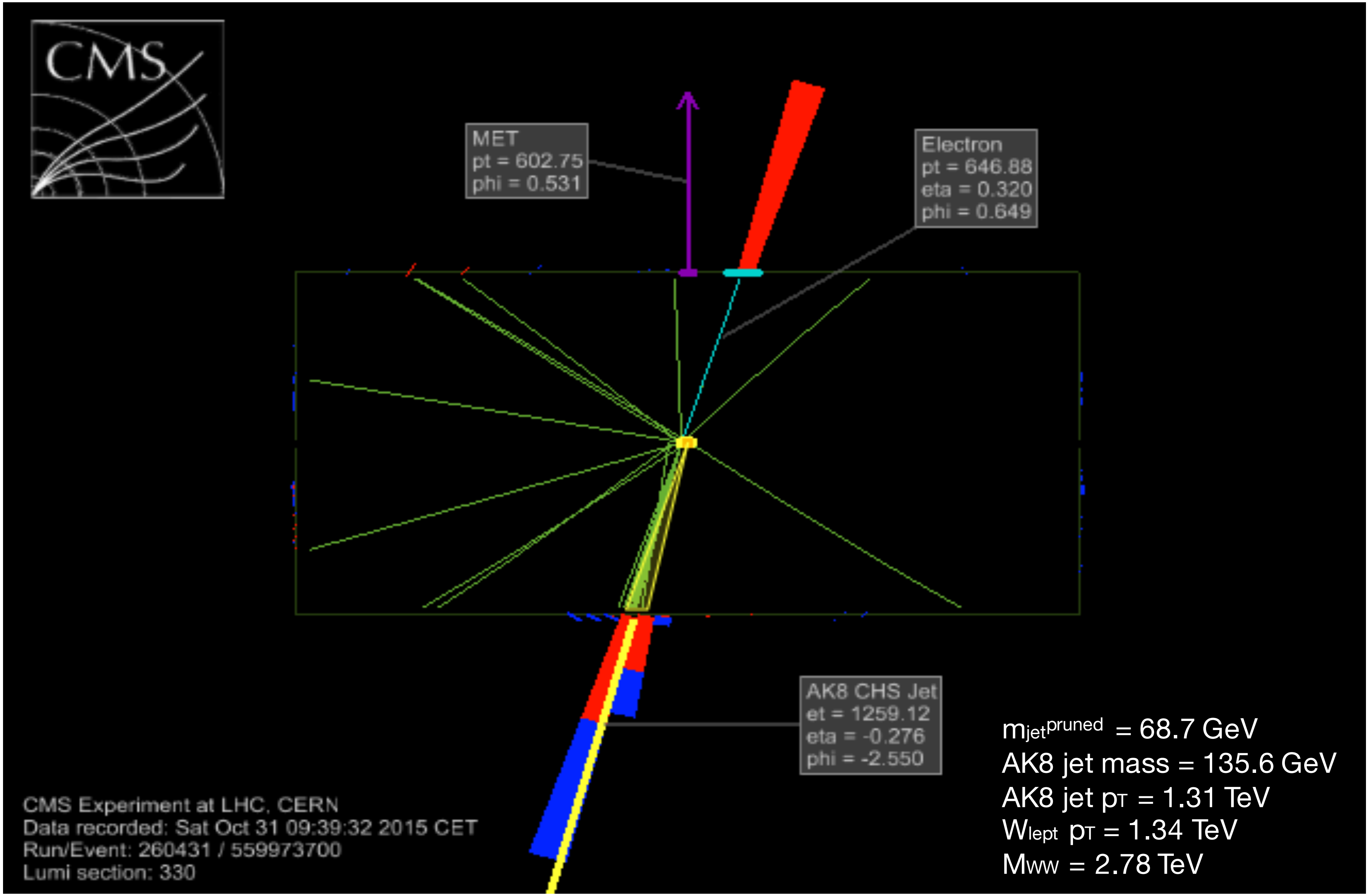


m_{jet}^{pruned} = 100.4 GeV
AK8 jet mass = 140.2 GeV
AK8 jet p_T = 0.55 TeV
W_{lept} p_T = 0.44 TeV
M_{WW} = 2.84 TeV

Single Muon HP-WW

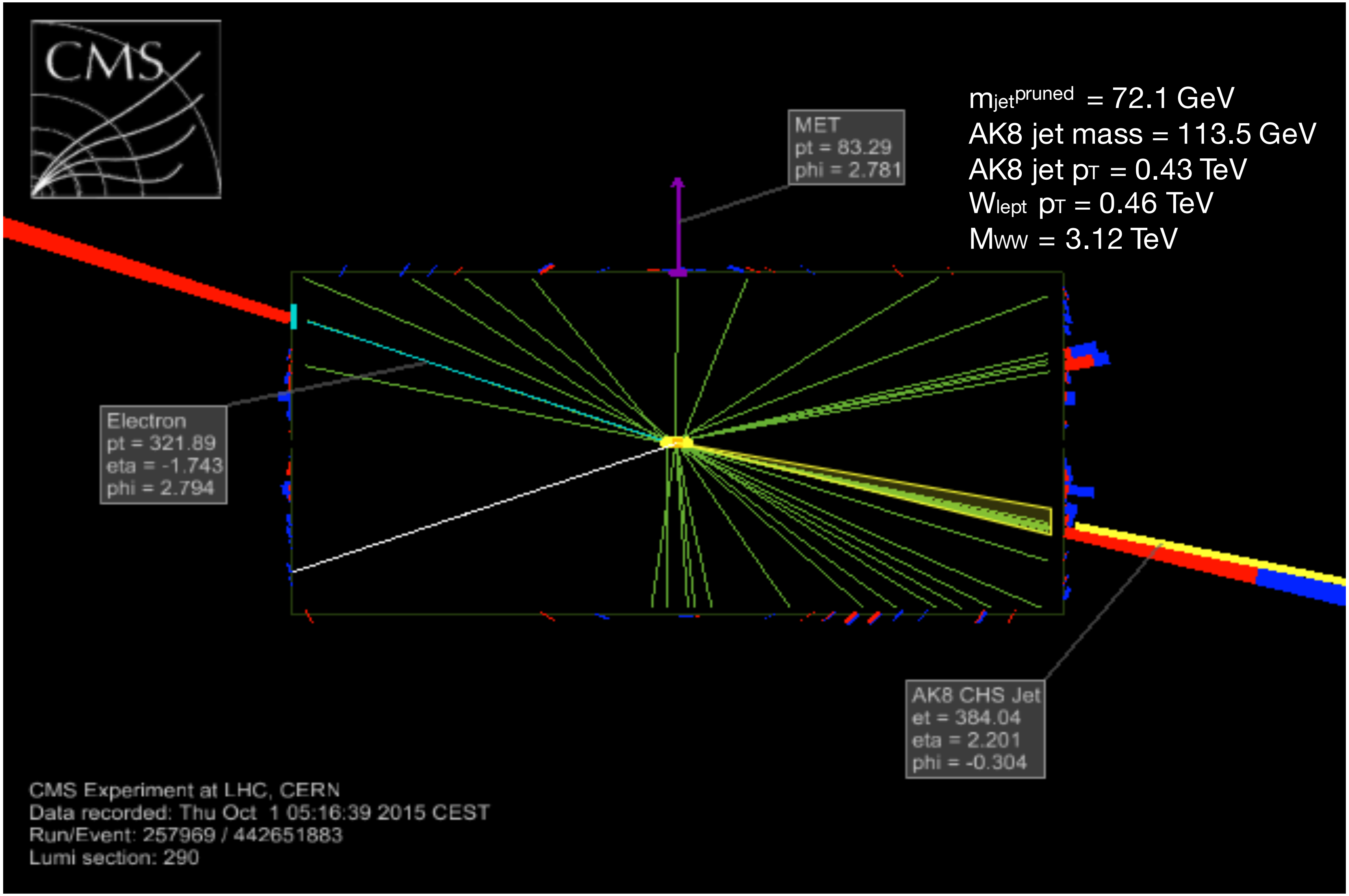


Single Electron HP-WW

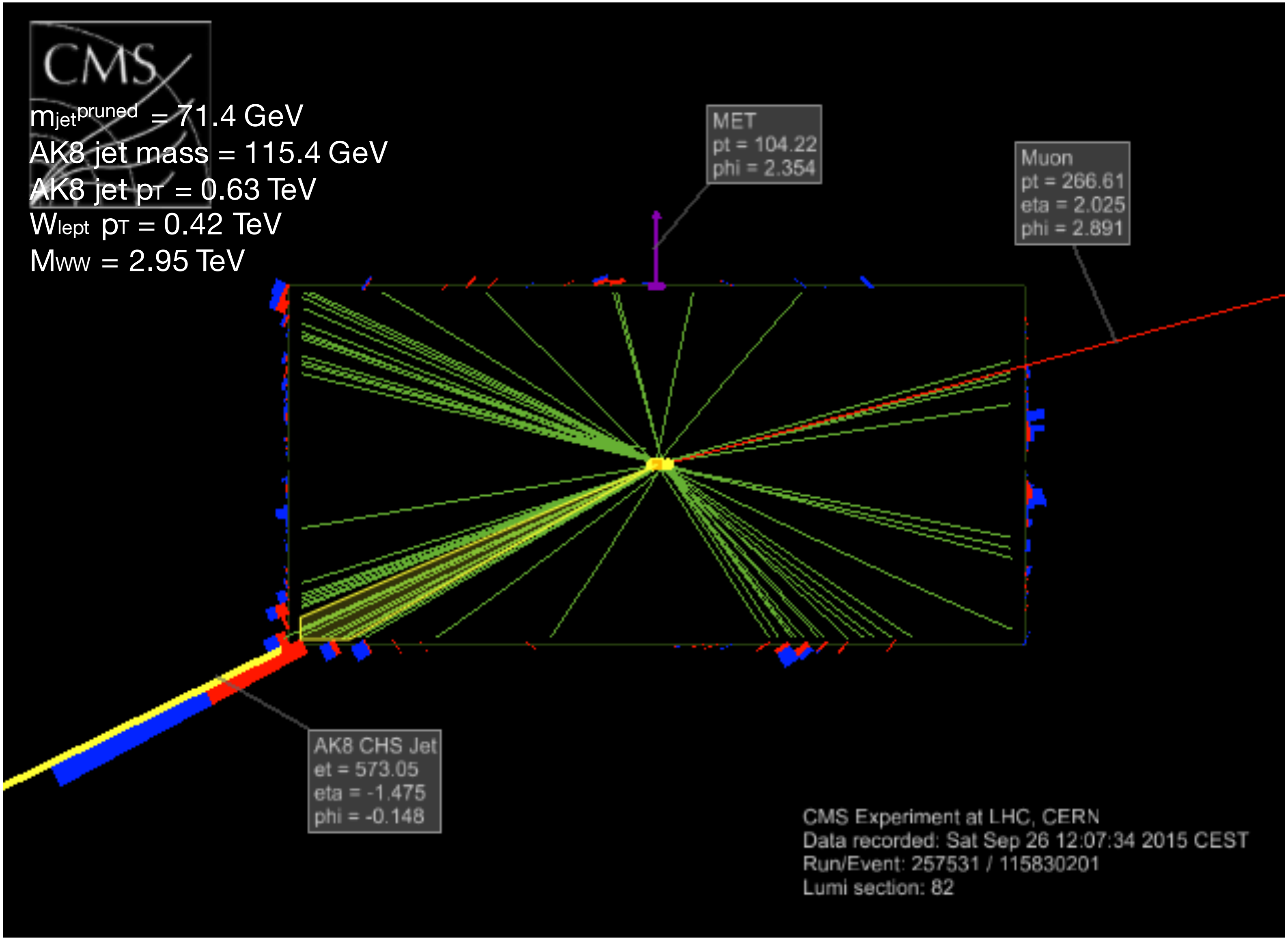


m_{jet}^{pruned} = 68.7 GeV
AK8 jet mass = 135.6 GeV
AK8 jet p_T = 1.31 TeV
W_{lept} p_T = 1.34 TeV
M_{WW} = 2.78 TeV

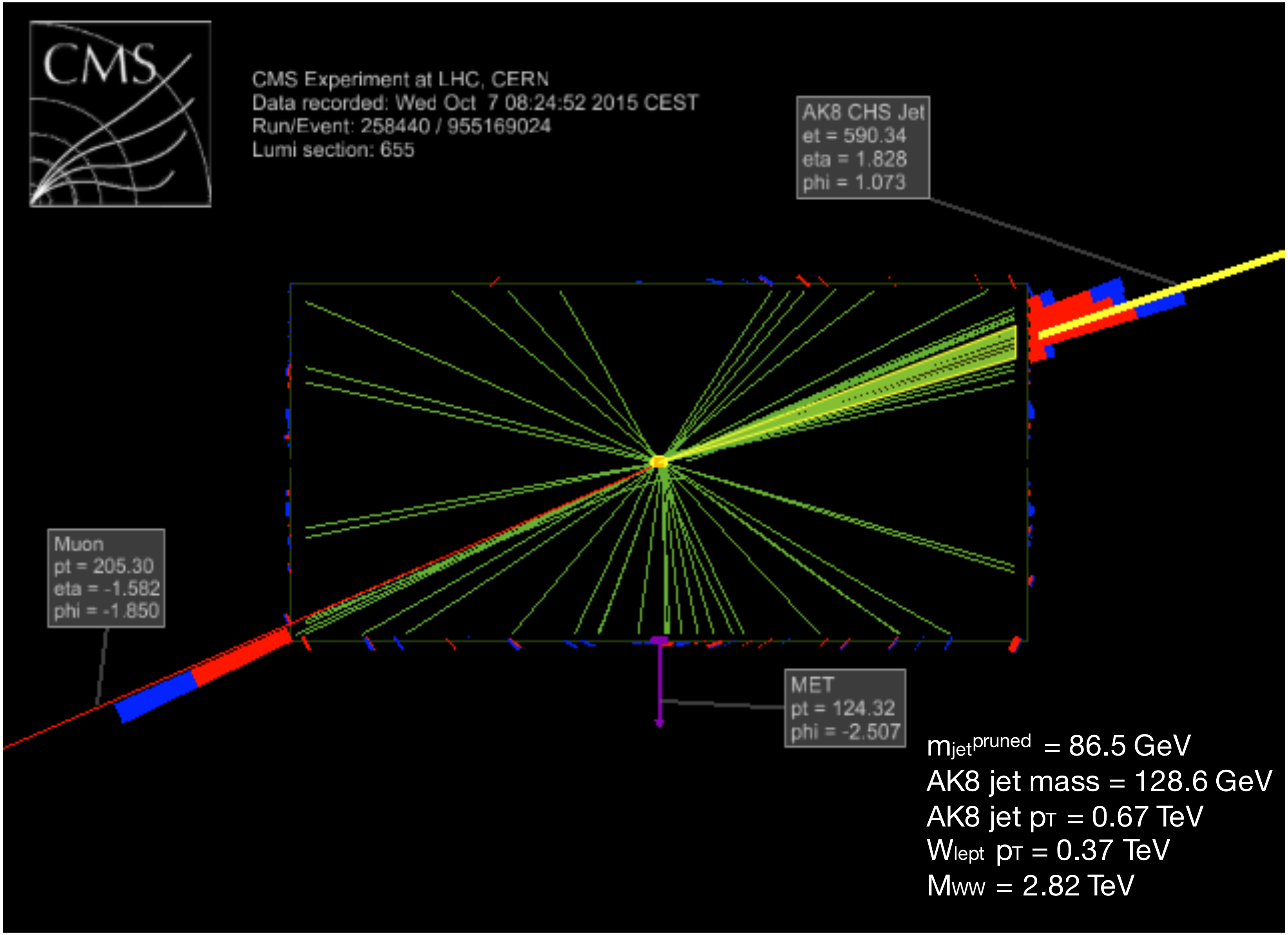
Single Electron HP-WW



Single Muon LP-WW

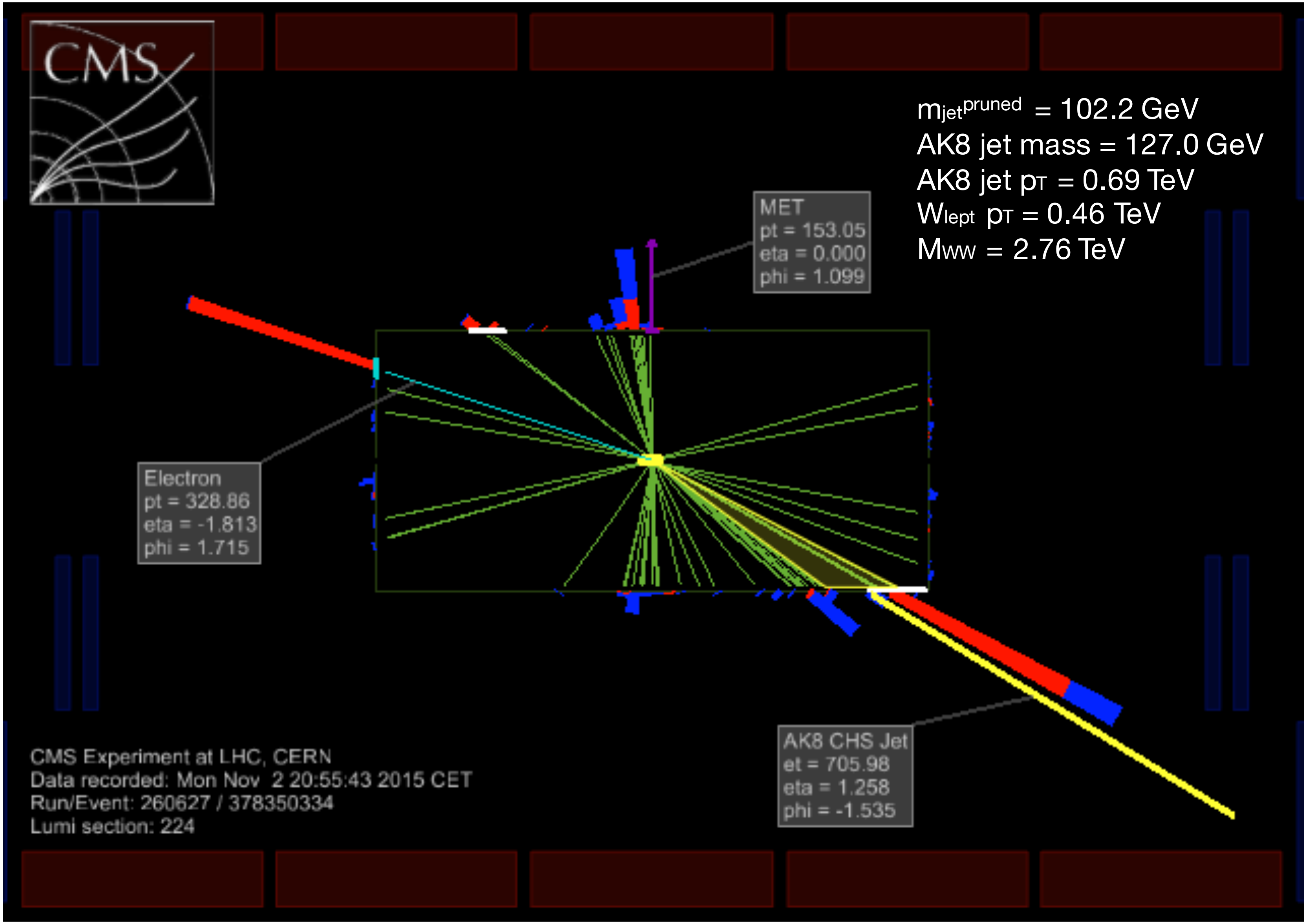


Single Muon HP-WZ

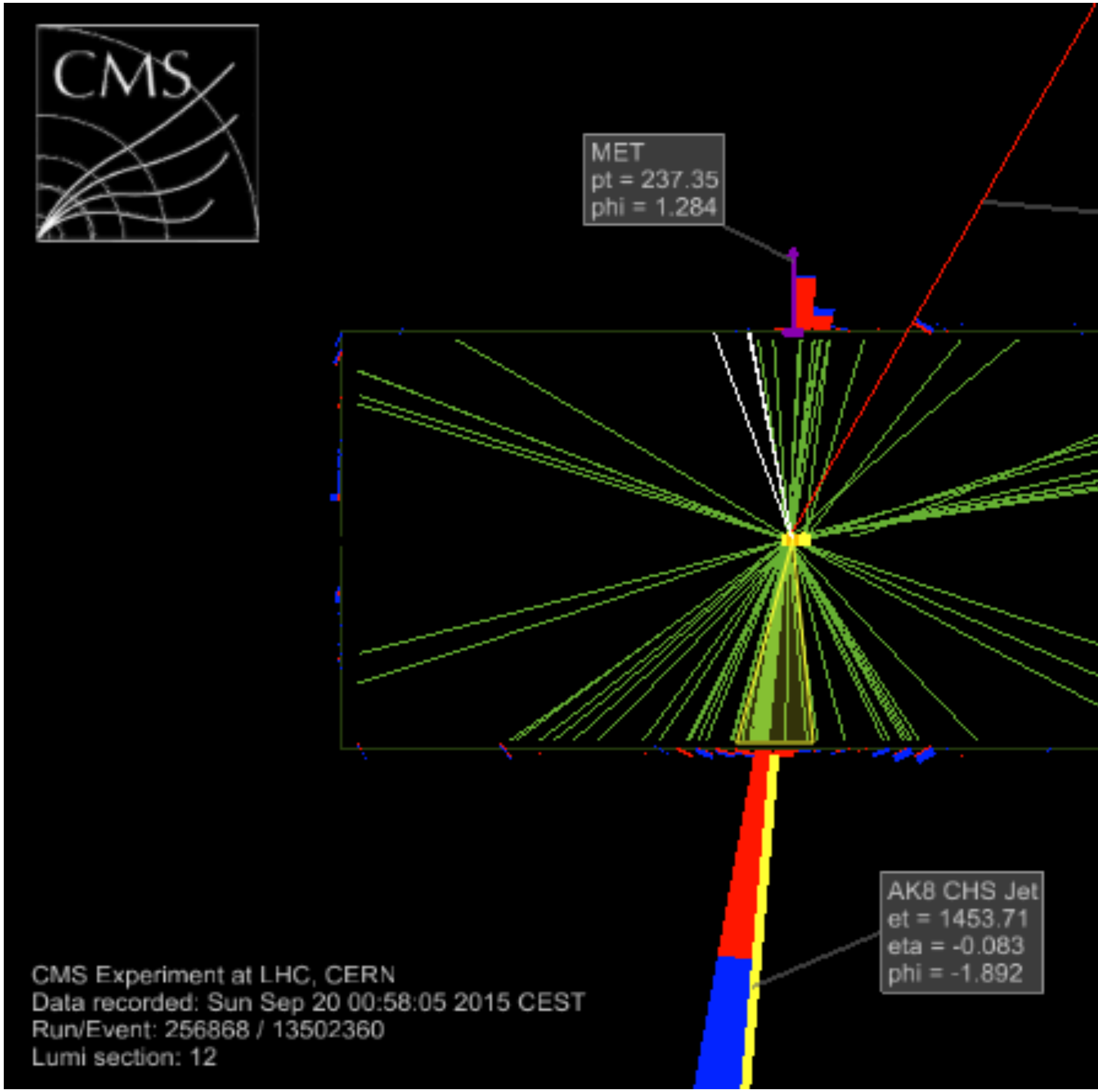


m_{jet}^{pruned} = 86.5 GeV
AK8 jet mass = 128.6 GeV
AK8 jet p_T = 0.67 TeV
W_{lept} p_T = 0.37 TeV
M_{WW} = 2.82 TeV

Single Electron HP-WZ

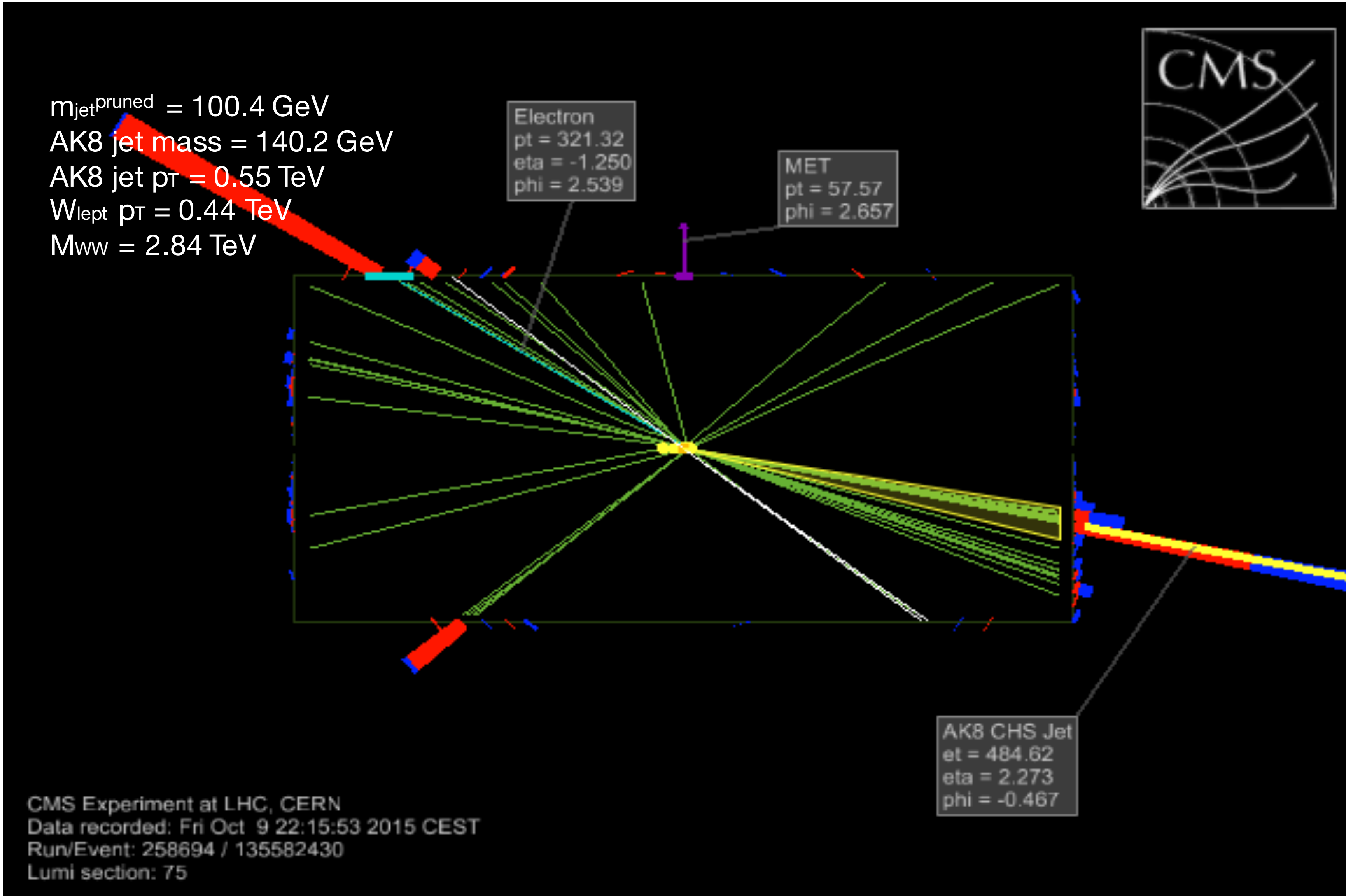


Single Muon LP-WZ



m_{jet}^{pruned} = 94.3 GeV
AK8 jet mass = 326.9 GeV
AK8 jet p_T = 1.47 TeV
W_{lept} p_T = 1.26 TeV
M_{WW} = 2.87 TeV

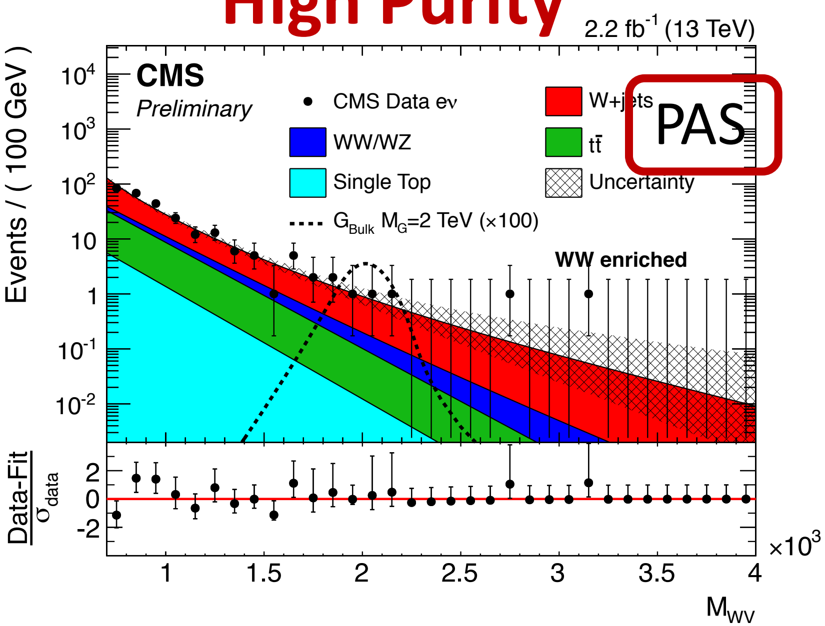
Single Electron LP-WZ



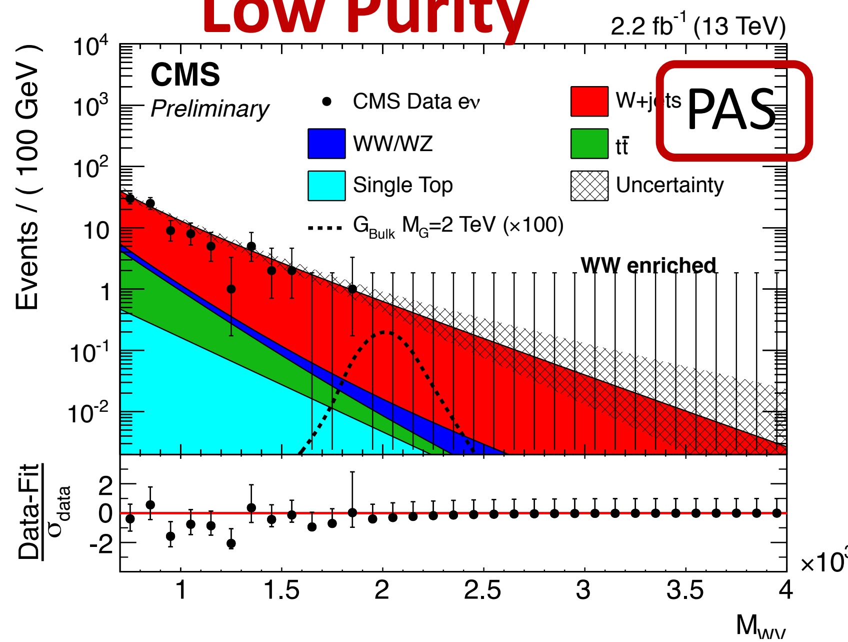
V+jets M_{VV} shape in Signal Region(el)

WW category

High Purity



Low Purity



WZ category