Searches for heavy resonances decaying to pairs of massive vector bosons in CMS

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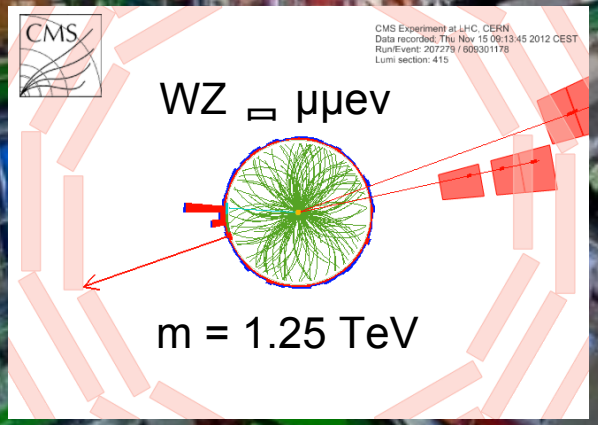
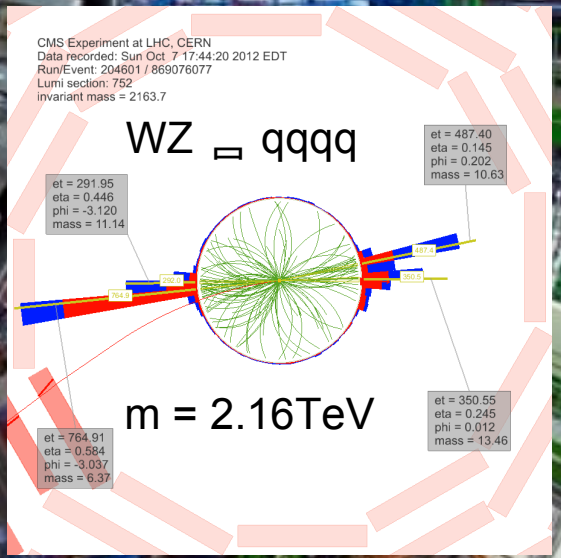
Johns Hopkins

BOOST2013





Reference models considered

- Many extensions of the Standard Model predict heavy resonances decaying to a pair of vector bosons:

$$X \to VV \quad \text{(where } V \text{ is } W \text{ or } Z\text{)}$$

  - Randall-Sundrum Gravitons $G_{\mathrm{RS}} \to WW, ZZ$
  - Original RS1
  - Bulk-graviton with enhanced coupling to WW or ZZ
  - $W' \to WZ$
    - with W' couplings from the extended gauge model
  - Low-Scale Technicolor (LSTC), $\rho_{\mathrm{TC}} \to WZ$
  - SM Higgs, $H \to WW, ZZ$
  - SM Higgs-like boson (in addition to SM Higgs at 125 GeV) used as a reference for high-mass resonances

Final states in play

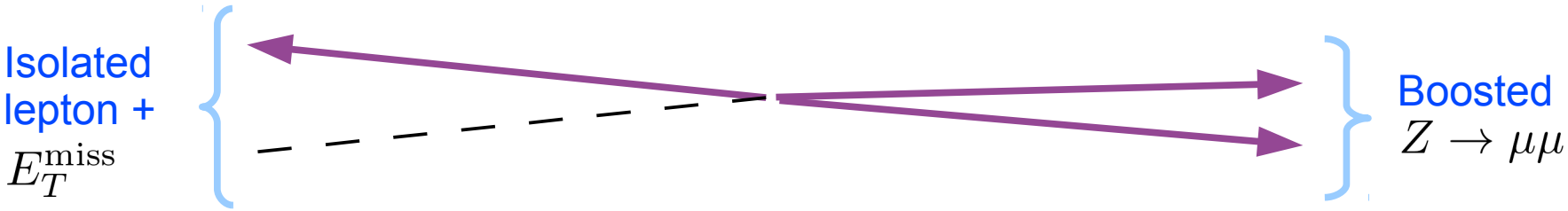
- Covered today (recent 8 TeV results)
  - WZ decaying into leptons
    - $W'/\rho_{\mathrm{TC}} \to WZ \to 3\ell + E_T^{\mathrm{miss}}$ (EXO-12-025)
  - WW, one W decaying leptonically, other hadronically
    - $G_{\mathrm{bulk}} \to WW \to \ell + E_T^{\mathrm{miss}} + \mathrm{jet}$ (EXO-12-021)
  - WW, WZ, ZZ, each V decaying hadronically
    - $G_{\mathrm{RS}} \to WW/ZZ$ and $W' \to WZ$ (EXO-12-024)

- Not covered (7 TeV results, updates in progress)
  - ZZ, WZ, Z decaying to dileptons, V decaying hadronically
    - $G_{\mathrm{RS}} \to ZZ$ and $W' \to WZ$
  - ZZ,one Z decaying to neutrinos, other Z hadronically
    - $G_{\mathrm{RS}} \to ZZ$

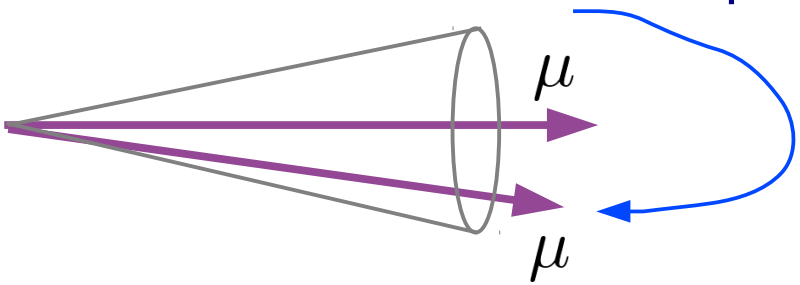
$W'/\rho_{\mathrm{TC}} \to WZ \to 3\ell + E_T^{\mathrm{miss}}$

EXO-12-025

- Two opposite-sign same-flavor leptons in Z mass window
  - Consider both $Z \to \mu\mu$ and $Z \to ee$
- One lepton and E_T^{miss} from $W \to \nu\ell$



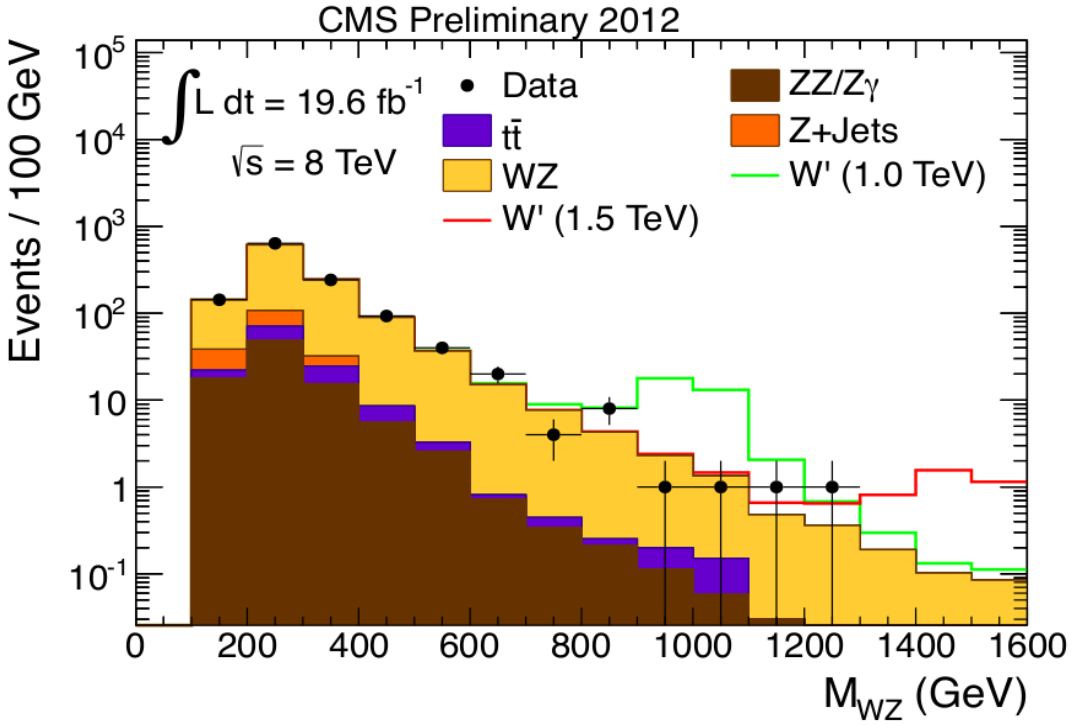
- Special identification+isolation for μ's from (boosted) $Z \to \mu\mu$
  - one muon with relaxed muon system requirements (tracker)
  - isolation: exclude the other muon from particles in the isol. cone

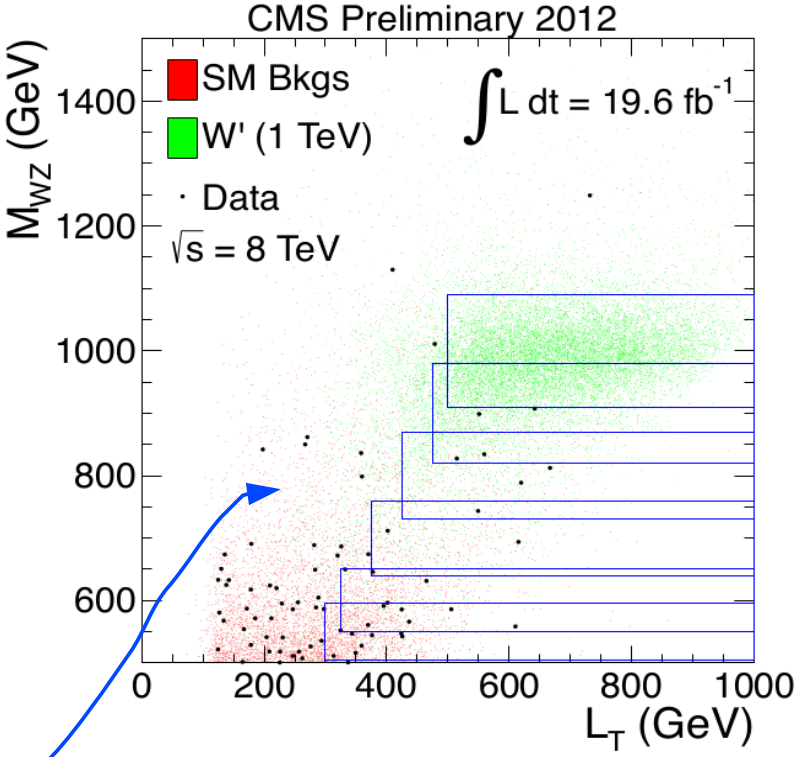


$W'/\rho_{\mathrm{TC}} \to WZ \to 3\ell + E_T^{\mathrm{miss}}$

EXO-12-025

- Compute M_{WZ} taking E_T^{miss} into account
- M_{WZ} and $L_T \equiv \sum p_T(\ell)$ cuts optimized for each signal mass



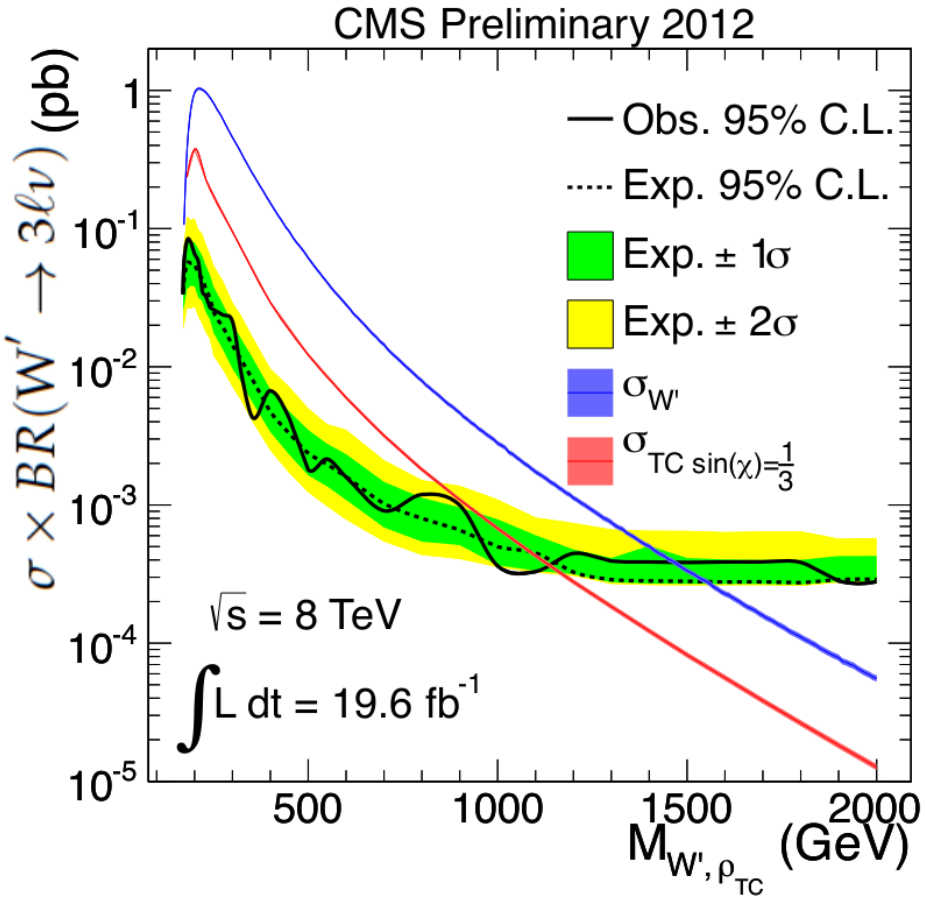


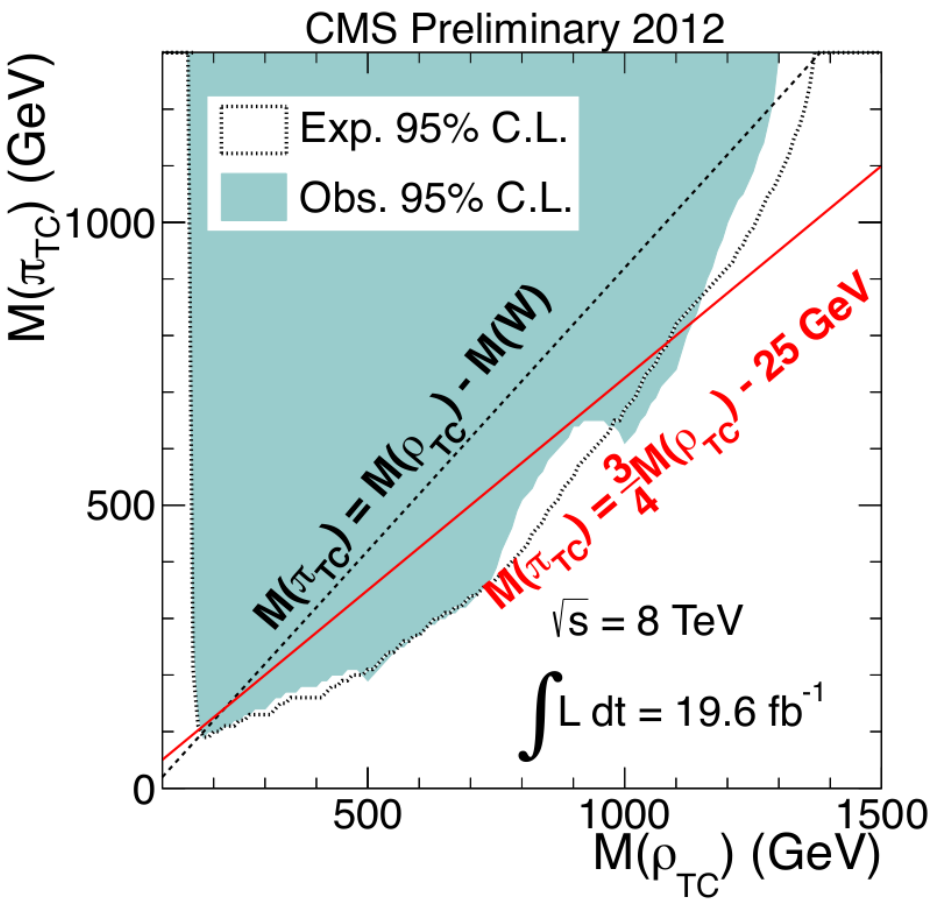
- Count events in each signal box
- Dominant backgrounds are electroweak (e.g WZ), use simulation (with generous systematics)

$W'/\rho_{\mathrm{TC}} \to WZ \to 3\ell + E_T^{\mathrm{miss}}$

EXO-12-025

- Limit: counting experiment in each signal box
- $W' \to WZ$ excluded in range 0.17 to 1.45 TeV
- Most stringent limits on ρ_{TC} to date

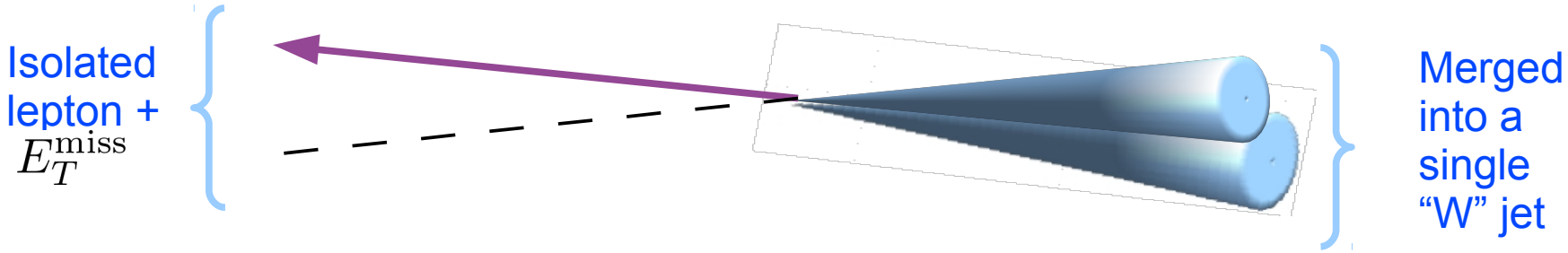




$G_{\mathrm{bulk}} \to WW \to \ell + E_T^{\mathrm{miss}} + \mathrm{jet}$

EXO-12-021

- One $W \to \nu\ell$, the other $W \to jj$
  - one side: isolated lepton + missing energy
  - opposite side: highly boosted $W \to jj$, merged into one jet



- Same as for heavy Higgs, but boost is larger
  (see preceeding talk by Nhan)

- Identify boosted W-jets with "N-subjettiness" variable τ_2/τ_1

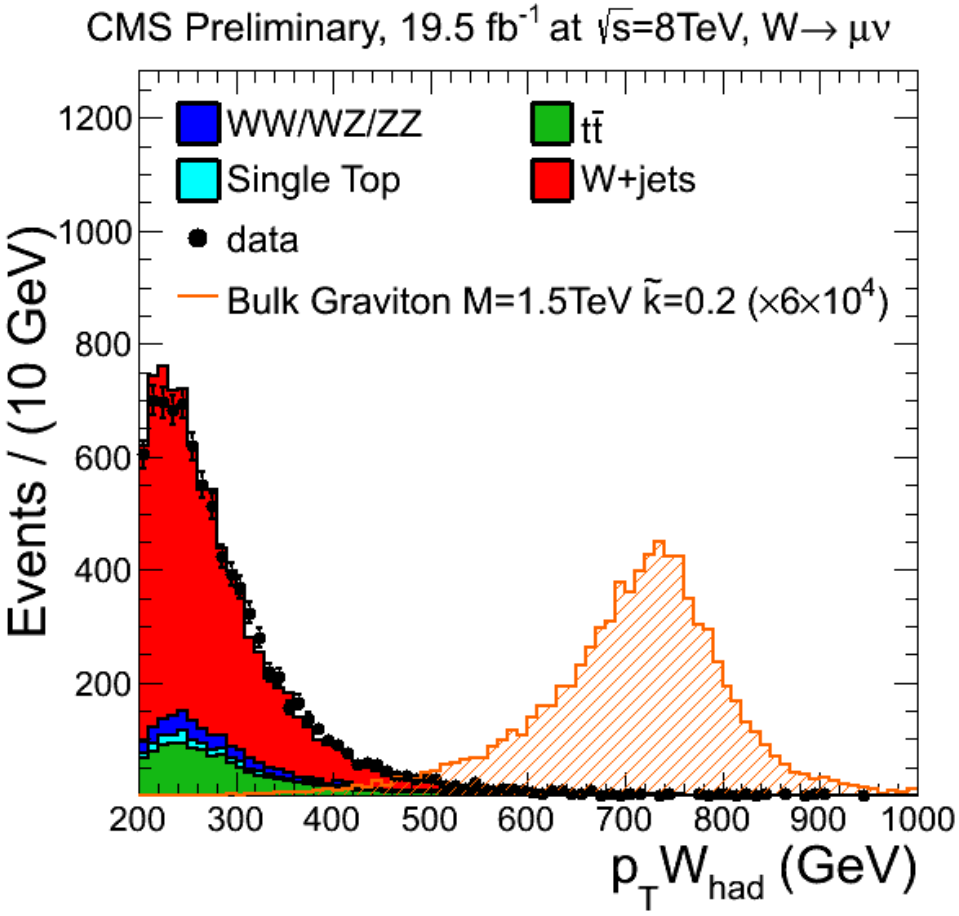
$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1.k}, \Delta R_{2.k}, ..., \Delta R_{N.k}\}$$

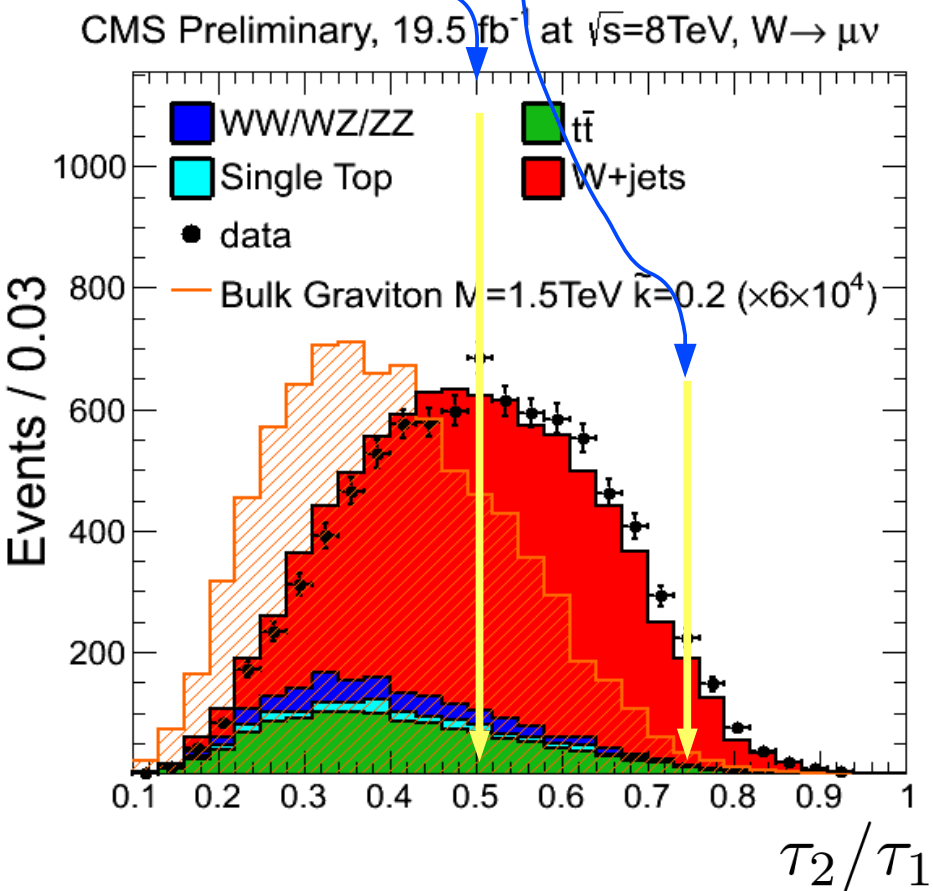
  - τ_2/τ_1 peaks near zero for two subjets

$G_{\text{bulk}} \to WW \to \ell + E_T^{\text{miss}} + \text{jet}$

EXO-12-021

- Require pruned jet mass $65 < m_{\text{jet}} < 105$ GeV
- N-subjettiness: $\tau_2/\tau_1 < 0.5$ (high purity) < 0.75 (low purity)





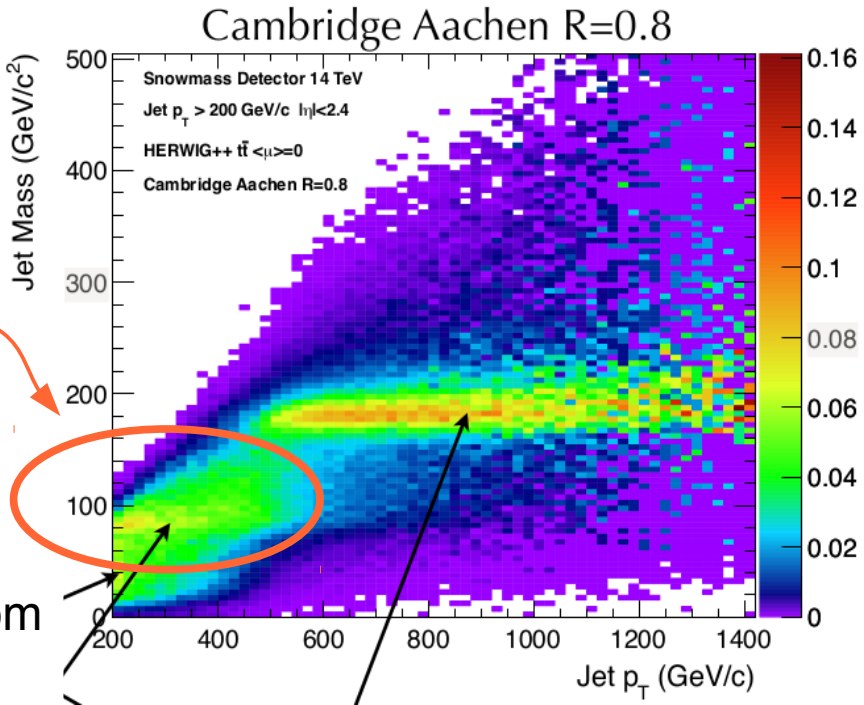
Substructure data/MC scale factor

JME-13-006

- Study performance of W-tagging in data
  - derive data/MC scale factor (SF)
  - error on this "substructure SF" → systematics on the signal!
  - note: *SF is analysis dependent!*

$$\mathrm{SF} \equiv \frac{\varepsilon_{\mathrm{data}}}{\varepsilon_{\mathrm{MC}}}$$

- The only sample of merged hadronic W's is $t\bar{t}$ component of $\ell + \mathrm{jets}$
  - where top is enough boosted that $W \to qq$ merges into one jet
  - but not too boosted so that b-jet merges as well



(plot stolem from Jim Dolen)

Substructure data/MC scale factor

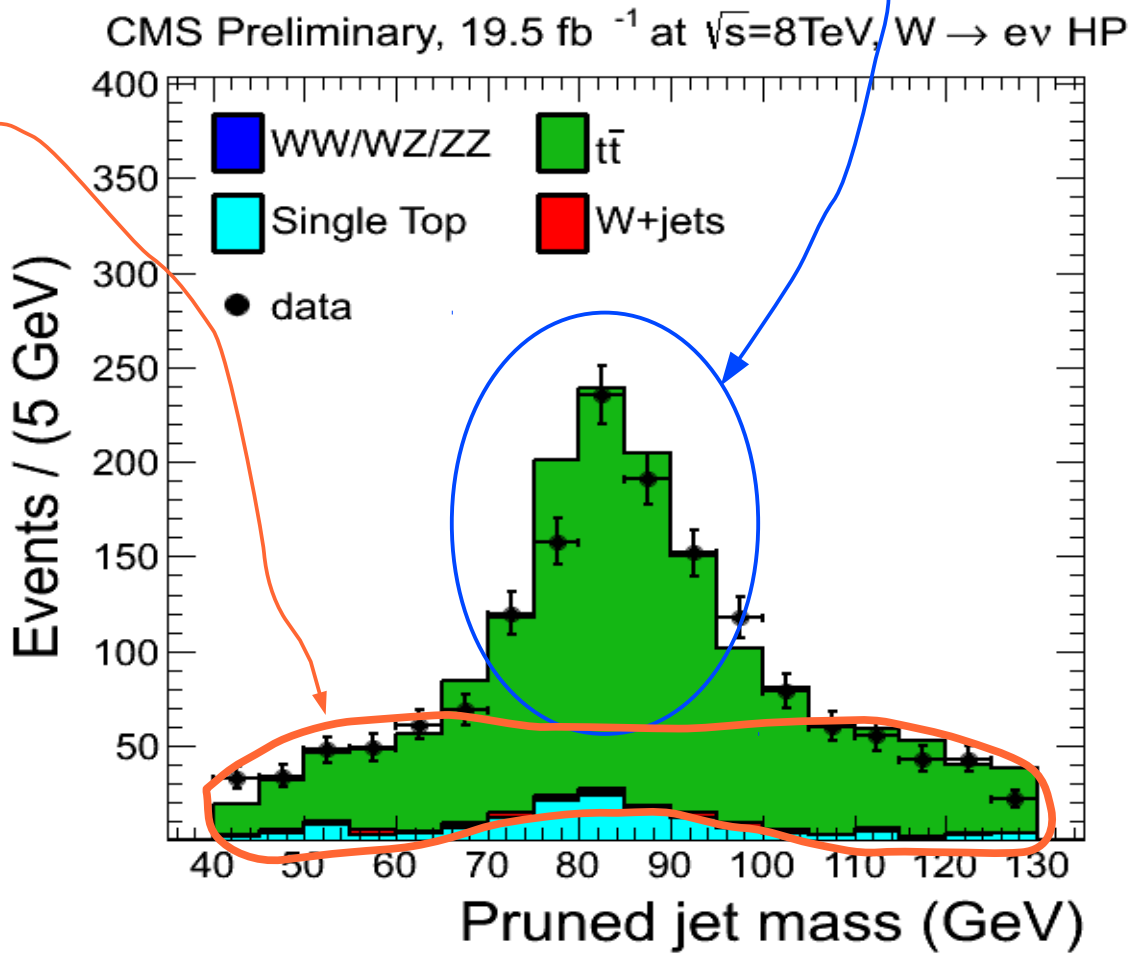
JME-13-006

- Anatomy of the W-peak:

Merged W → qq
This is what we want

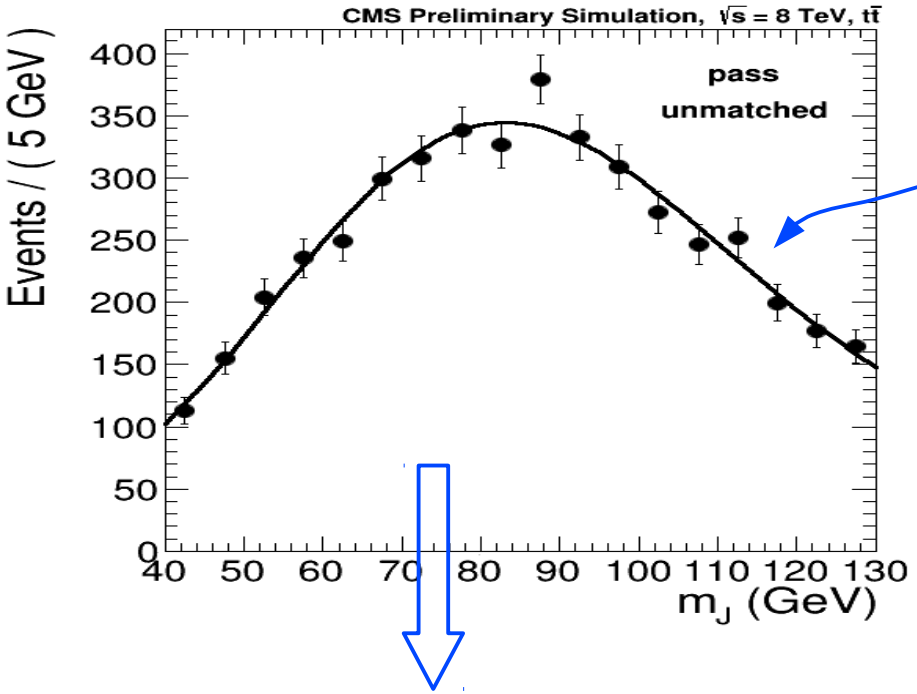
W → qq from $t\bar{t}$
which did not merge.

- "combinatorial background"
- τ_2/τ_1 cut causes it to peak broadly
- needs to be subtracted away (done in the fit)

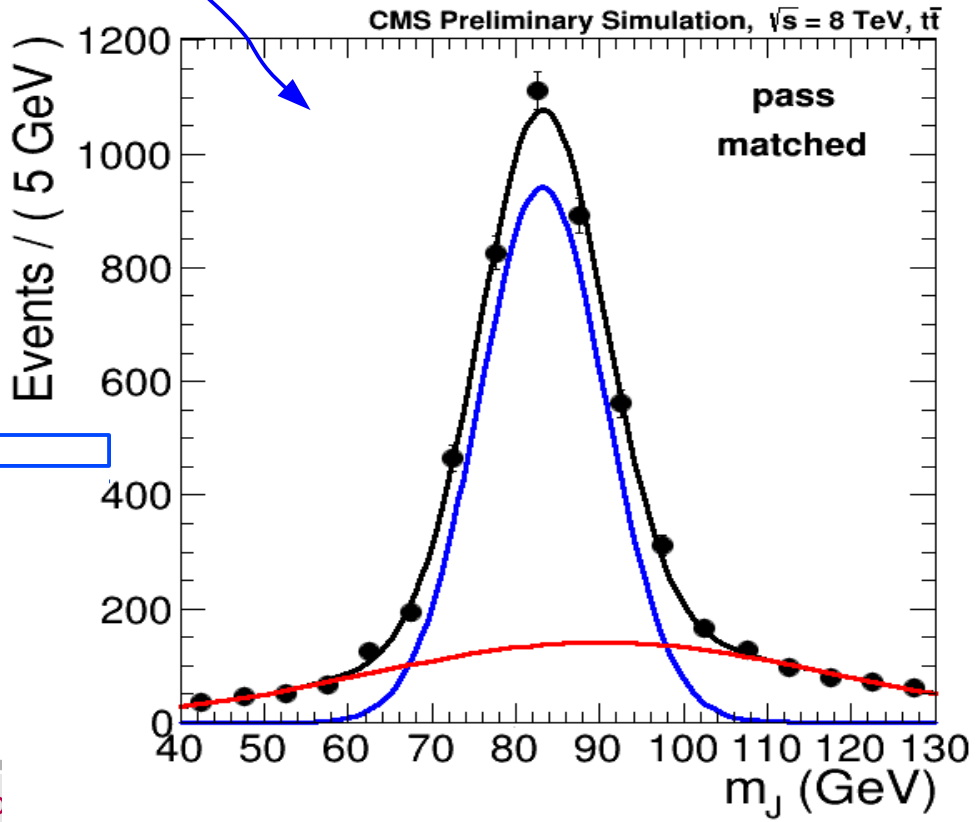


Substructure data/MC scale factor

JME-13-006



- Shape of hadronic W → qq decays from simulation
  - Match W-jet to generator-level W → qq



- Model jet mass in $t\bar{t}$ by narrow + wide components

Substructure SF

JME-13-006

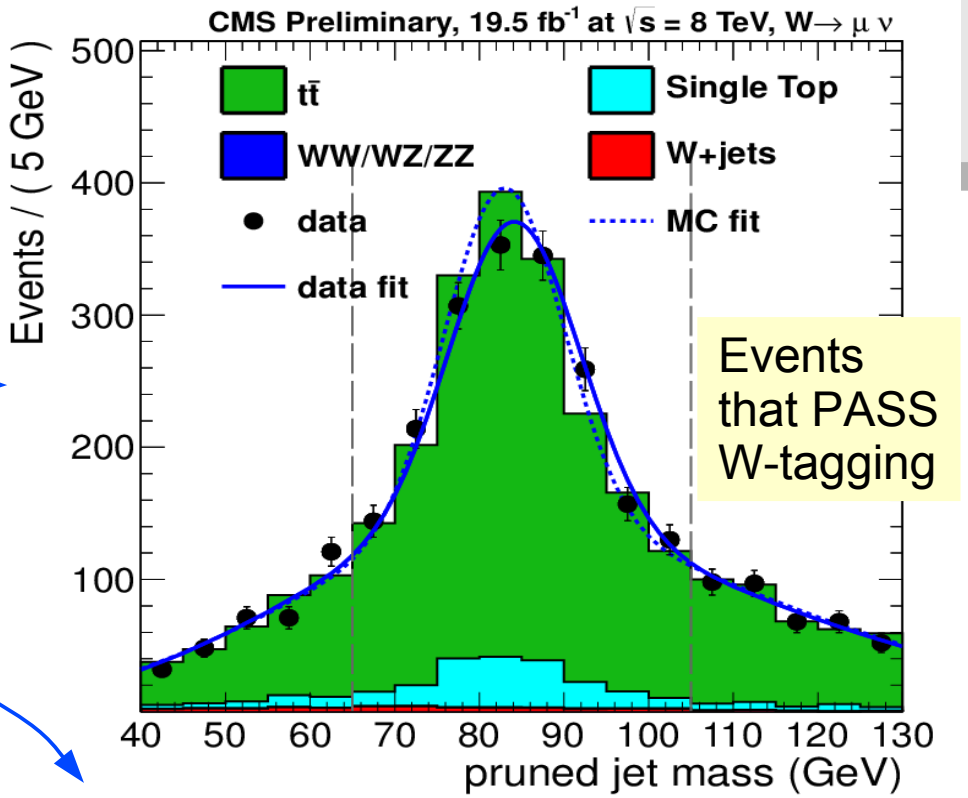
- Simultaneous fit to events that pass and fail W-tagging, in $\mu + \text{jets}$ and $e + \text{jets}$
- Efficiency in data:

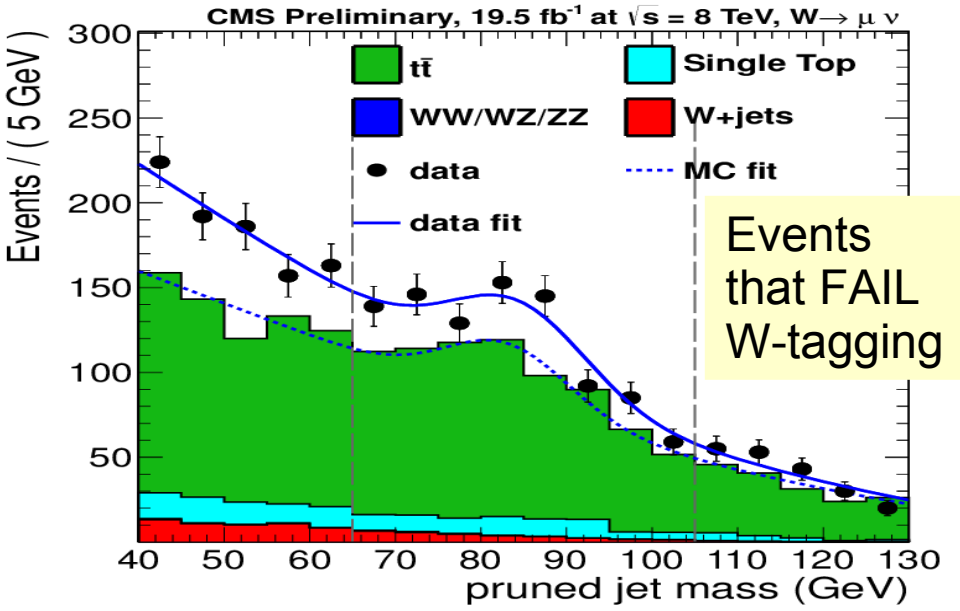
$$\varepsilon_{\text{data}} = \frac{N_{\text{pass}}}{N_{\text{pass}} + N_{\text{fail}}}$$

- High and low purity:

$$\text{SF}_{W\text{tag}} = 0.93 \pm 0.08$$
$$\text{SF}_{W\text{tag}} = 1.10 \pm 0.30$$

- Use MC to extrapolate to higher $p_T(\text{jet})$



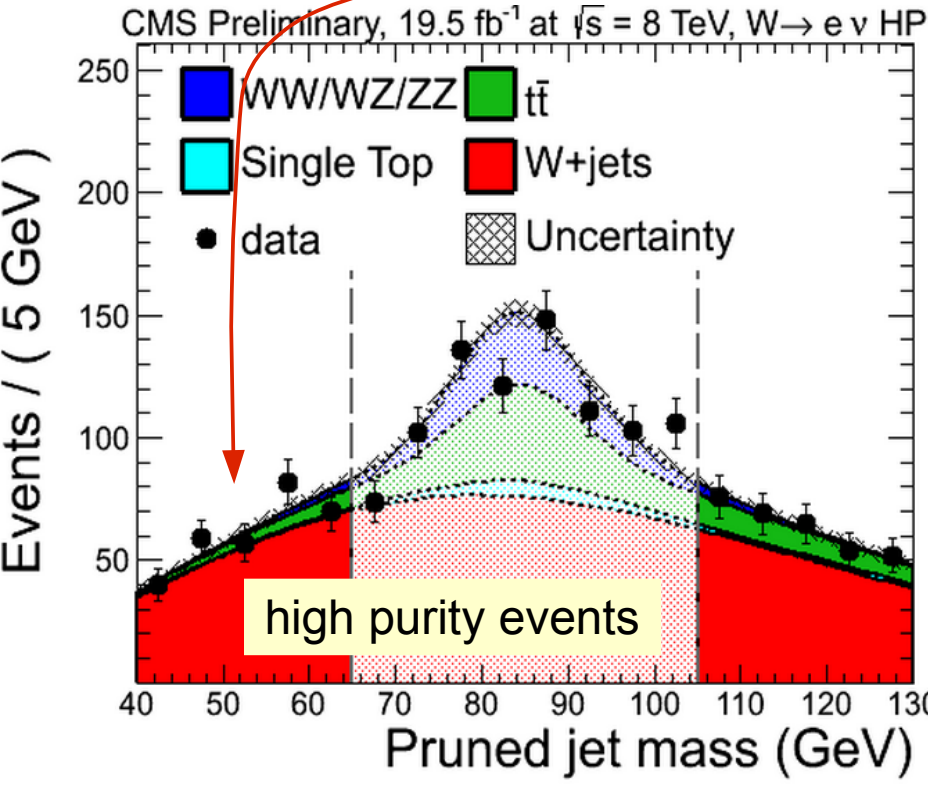


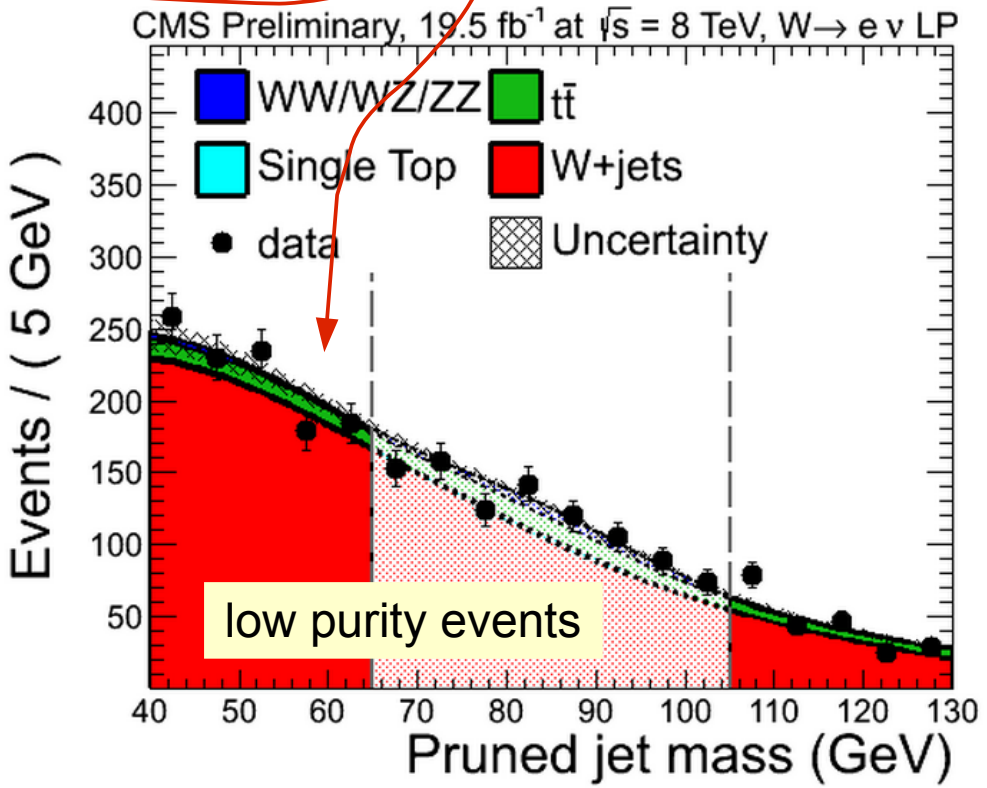
$G_{\text{bulk}} \to WW \to \ell + E_T^{\text{miss}} + \text{jet}$

EXO-12-021

(details in Nhan's talk)

- Backgrounds:
  - W+jets (dominant) – data driven
  - WW + WZ, $t\bar{t}$ and single top – mainly from simulation
- W+jets: obtain m_{WW} from scaled m_{jet} sidebands





$G_{\text{bulk}} \to WW \to \ell + E_T^{\text{miss}} + \text{jet}$

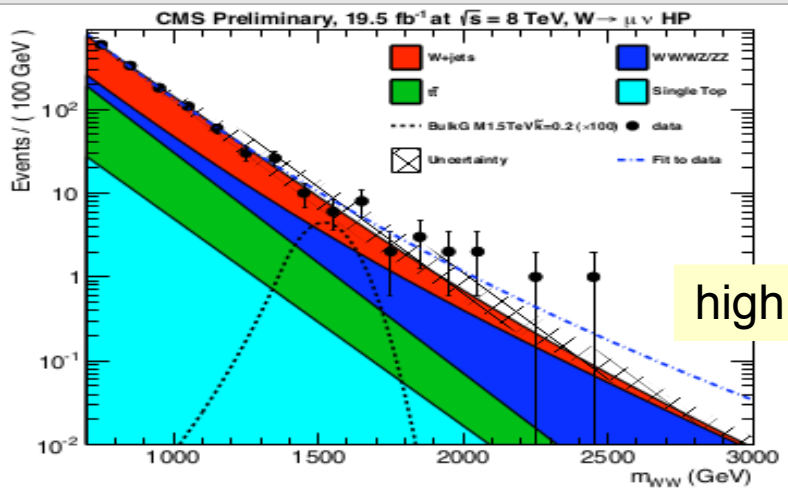
EXO-12-021

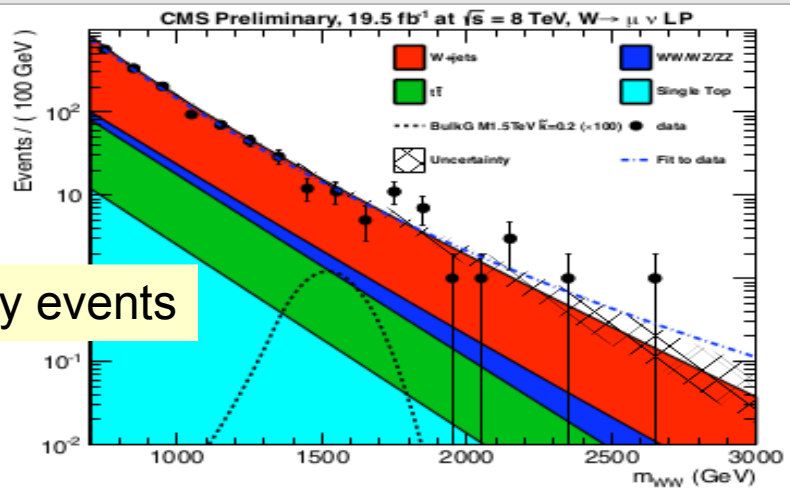
high purity events

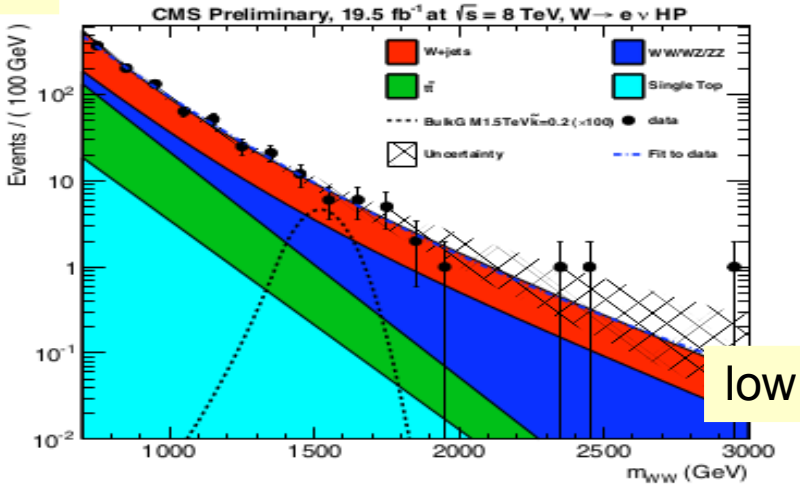
low purity events

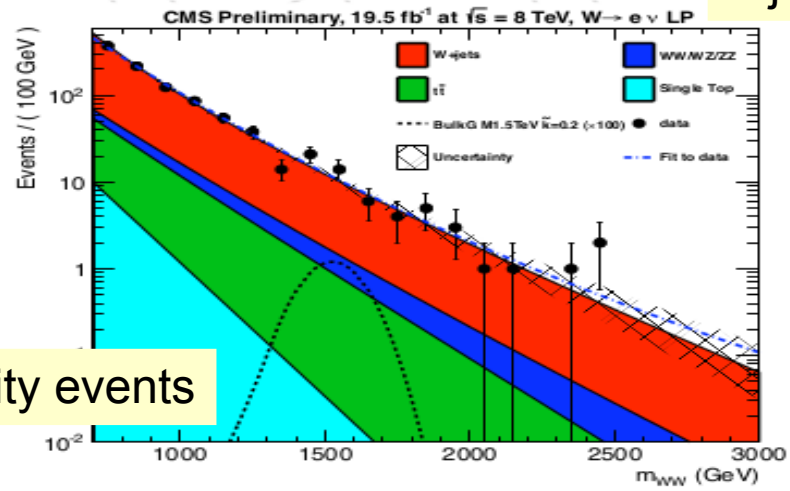
muon + jets

electron + jets



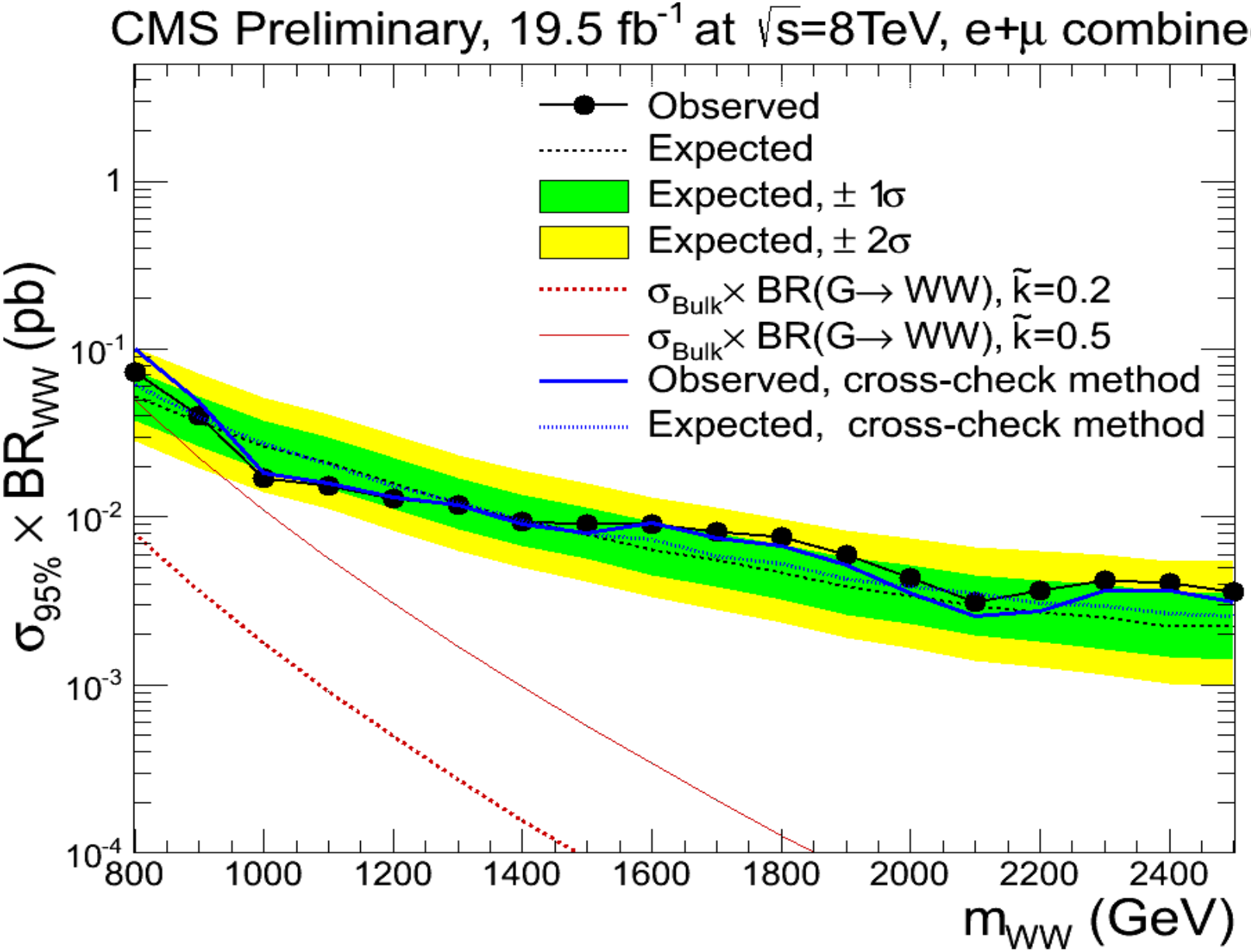






$G_{\mathrm{bulk}} \to WW \to \ell + E_T^{\mathrm{miss}} + \mathrm{jet}$

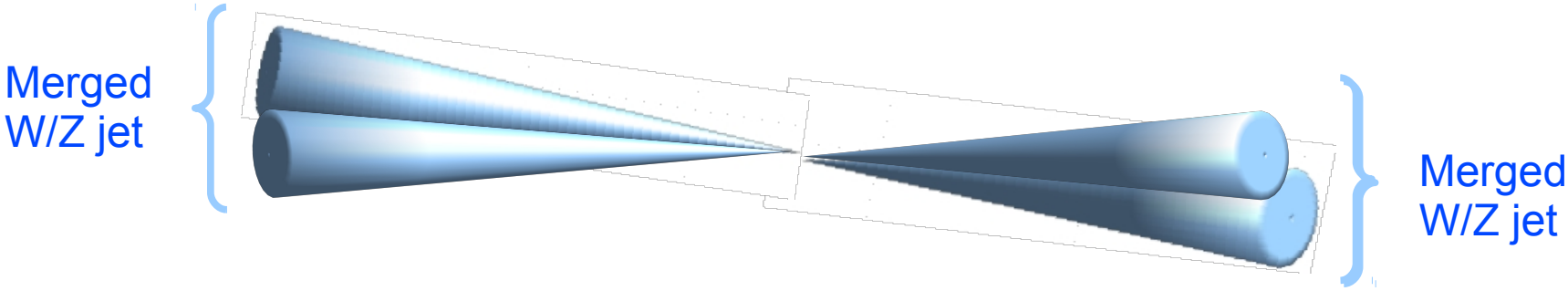
EXO-12-021



$G_{\mathrm{RS}} \to WW/ZZ$ and $W' \to WZ$ in di-jets

EXO-12-024

- Fully hadronic decays $W \to jj$ and $Z \to jj$
  - boosted → merge in a single jet
  - QCD background suppressed by $|\eta_1 - \eta_2| < 1.3$

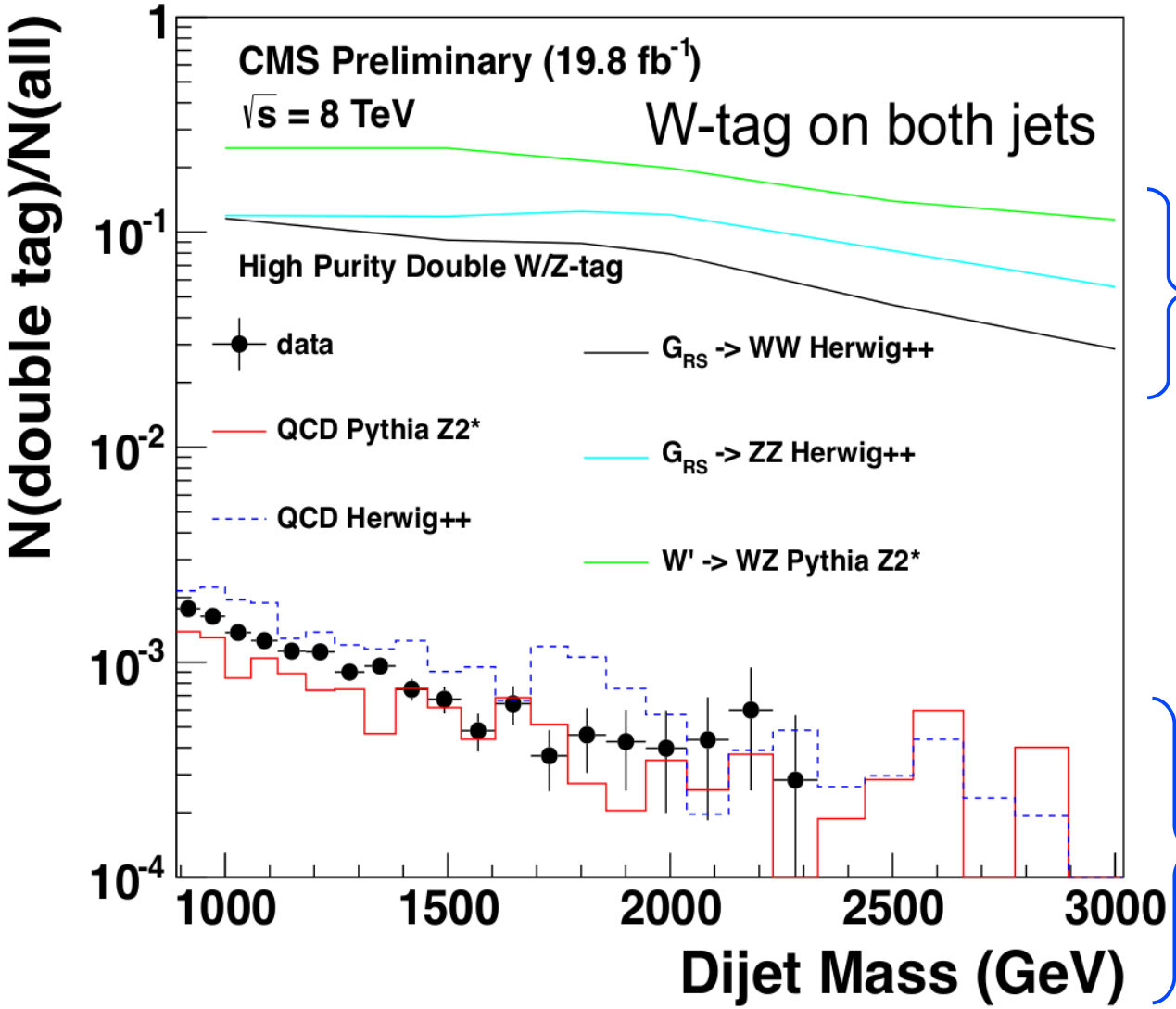


- Each jet is required to pass the "W/Z-tagger"
  - pruned jet mass: $70 < M_{\mathrm{jet}} < 100$ GeV
  - N-subjettiness: $\tau_2/\tau_1 < 0.5$ (high purity) < 0.75 (low purity)
  - (consistent with l+jets)

$G_{RS} \to WW/ZZ$ and $W' \to WZ$ in di-jets

EXO-12-024

- Fraction of events passing two-"W/Z-tag" requirement



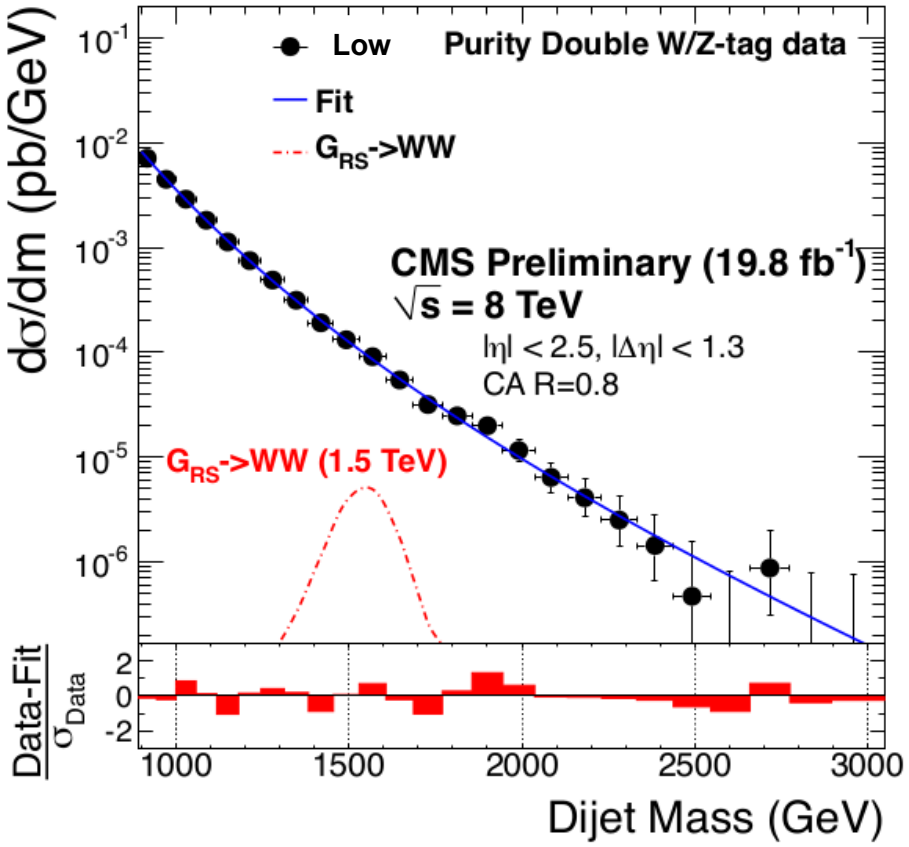
Various signal models

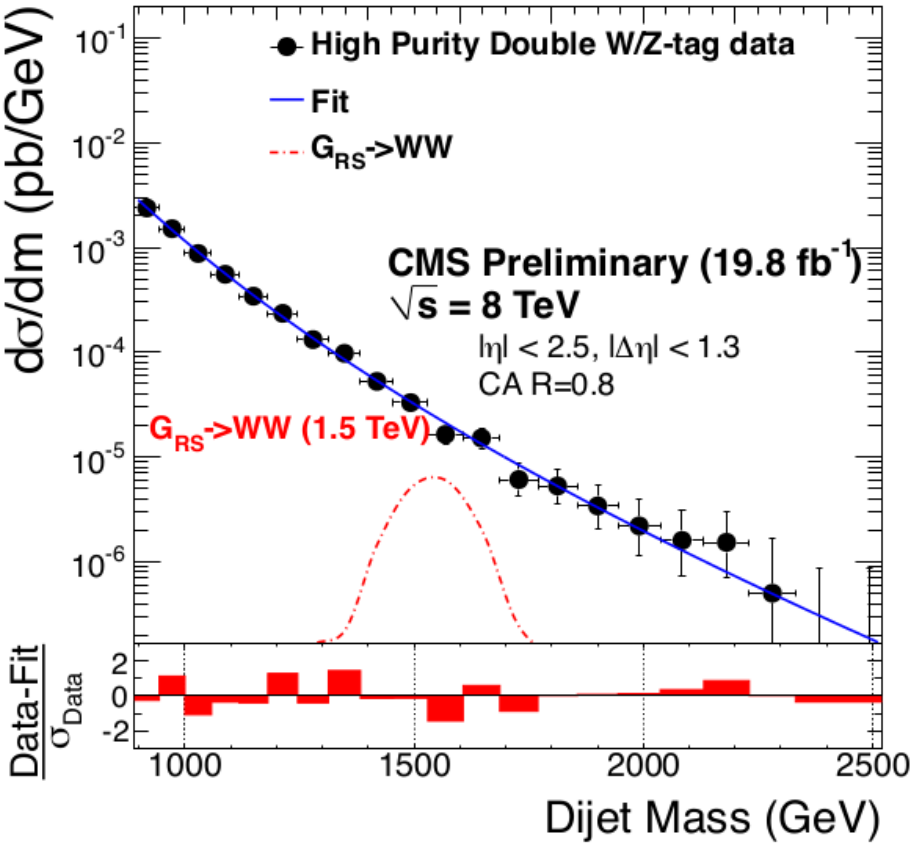
QCD (the only relevant background)

$G_{RS} \to WW/ZZ$ and $W' \to WZ$ in di-jets

EXO-12-024

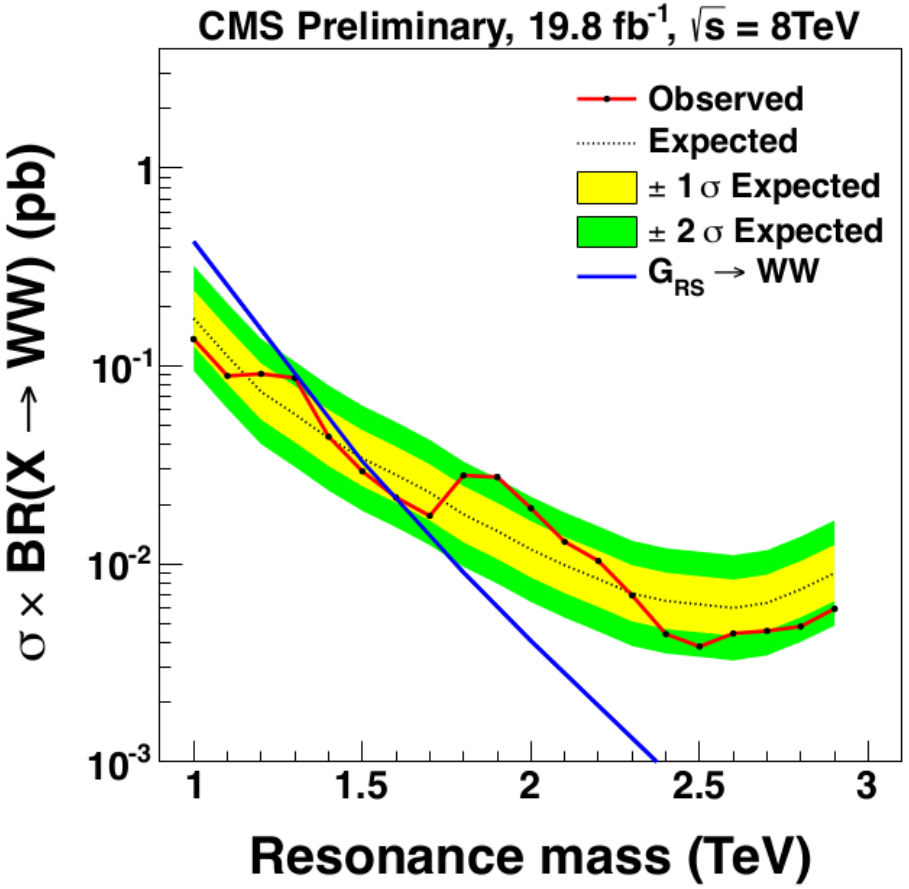
- Background: smooth fit (S+B) to data (no need for BG MC)
- Simultaneous fit to high-purity ($\tau_2/\tau_1 < 0.5$) and low-purity ($0.5 < \tau_2/\tau_1 < 0.75$) data

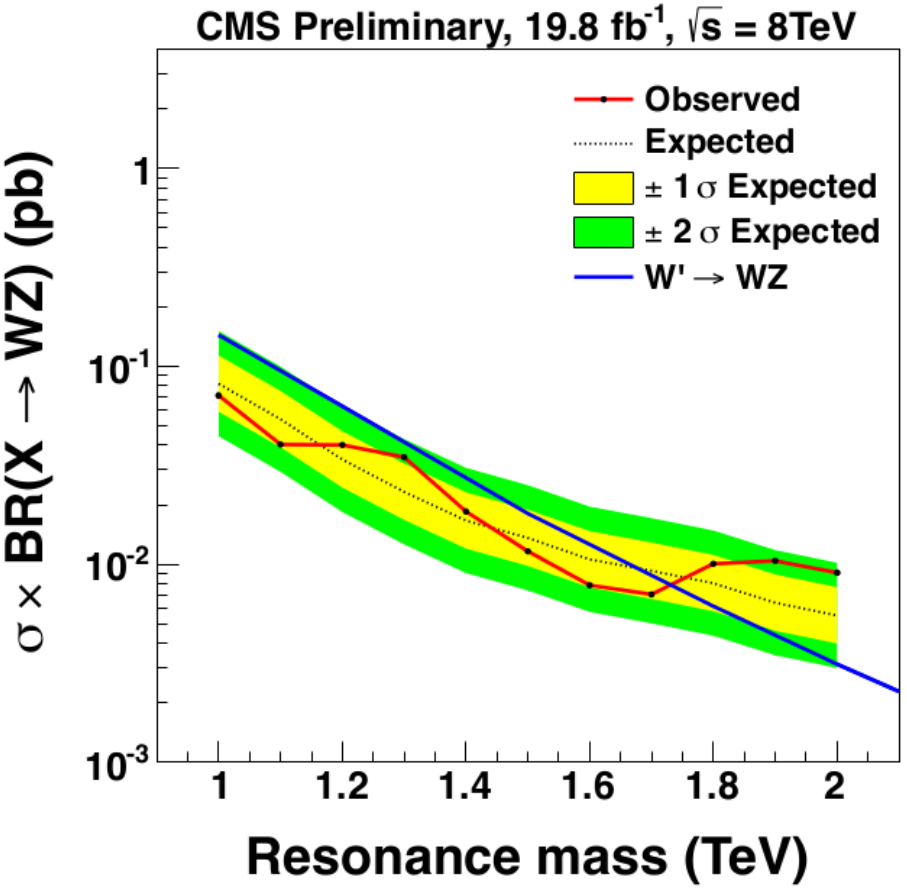




$G_{RS} \to WW/ZZ$ and $W' \to WZ$ in di-jets

EXO-12-024



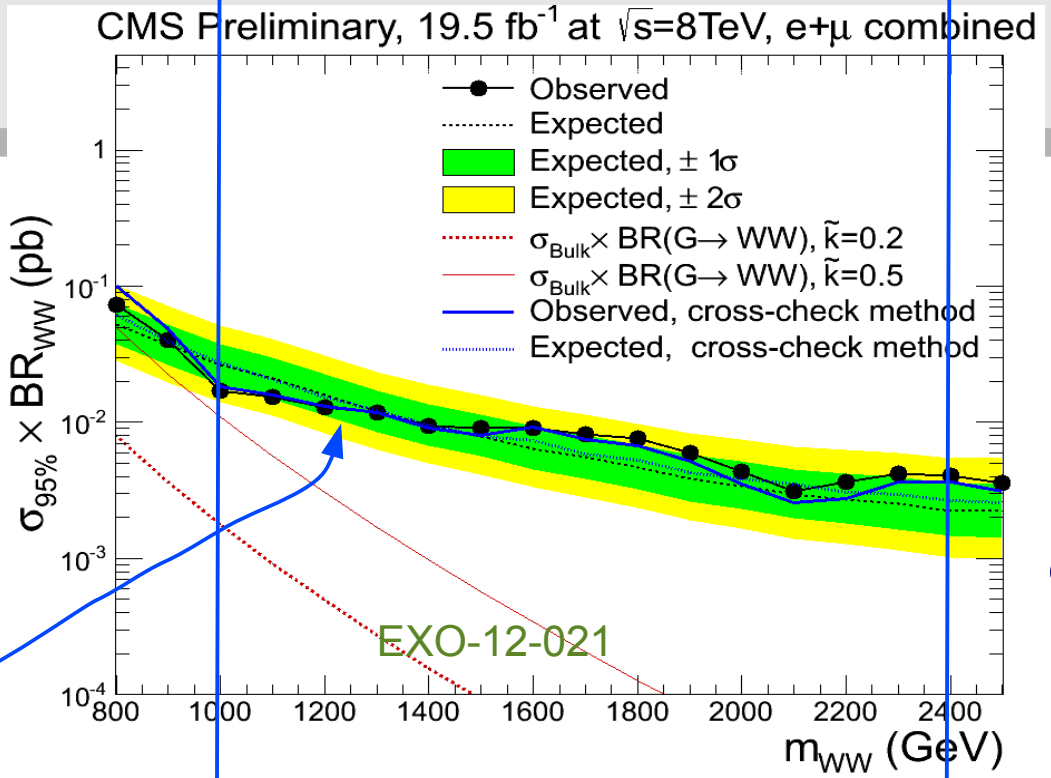


- G_{RS1} (k/MPL=0.1) → WW(ZZ) excluded in mass range 1.0 to 1.59(1.17) TeV
- W' → WZ excluded in mass range 1.0 to 1.73 TeV
- q* → qW(qZ) excluded in mass range 1.0 to 3.23(3.00) TeV

- Comparing two WW searches

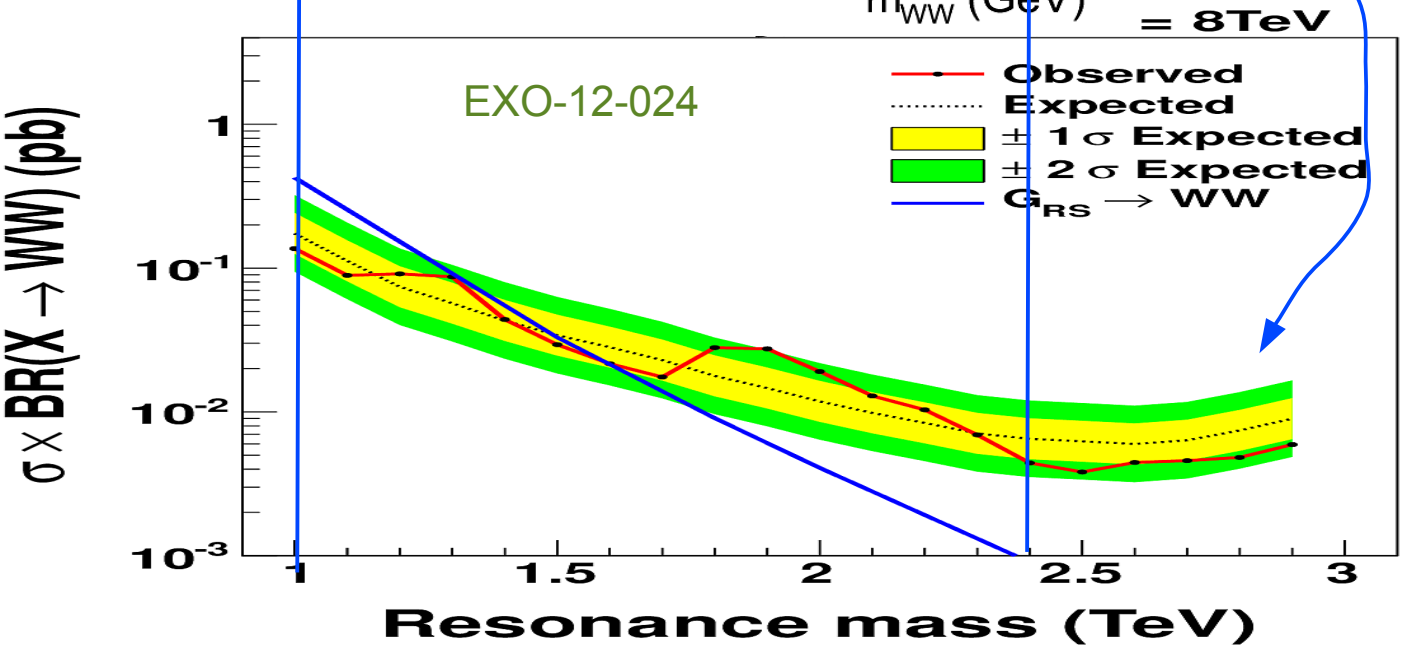
  (please ignore theory curves)

- Plan to combine the two analyses



l+jets search does better for most of the mass range

Dijet search goes to higher masses

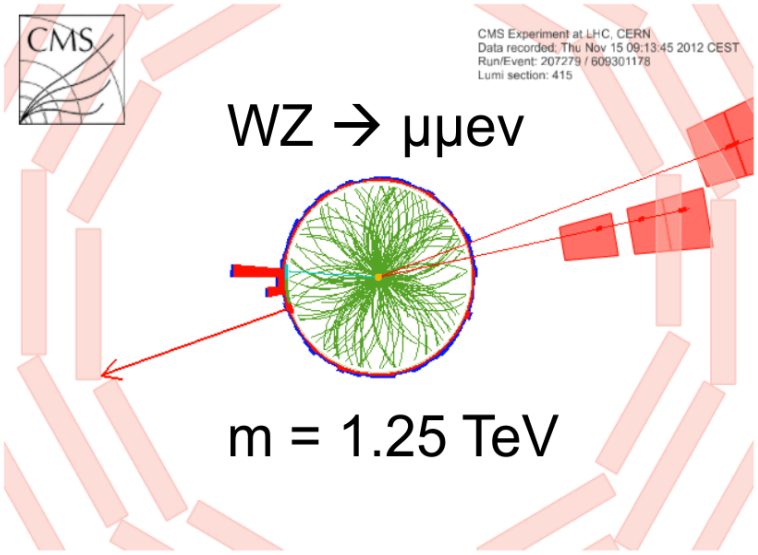


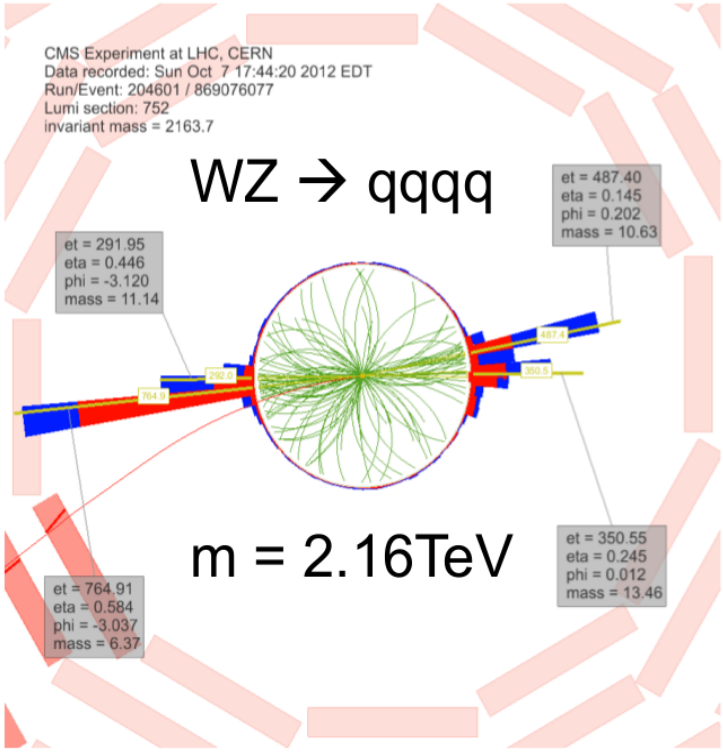
Where we are now

- CMS has a broad program of searches to VV resonances
- We are getting a handle on how to deal with boosted objects
  - special isolation of leptons from Z's (and tops)
  - substructure for merged jets from W and Z (and tops)
- Deploying these tools in analyses – several results are the best of its kind
  - most stringent limits on
    - $G_{RS1}(k/M_{\mathrm{PL}} = 0.1) \rightarrow WW\ (ZZ)$
    - ρ_{TC} and $W' \rightarrow WZ$
    - $q* \rightarrow qW\ (qZ)$ (not a topic of this talk, though...)

Where we are going

- Aim at covering all possible final states for best sensitivity over the full mass range
  - Most stringent limits to date in all final states (WW, ZZ, WZ)
  - Plan to update all 7 TeV searches
  - Combine 8 TeV searches (synchronize models across analyses)
- No excess so far, but stay tuned!

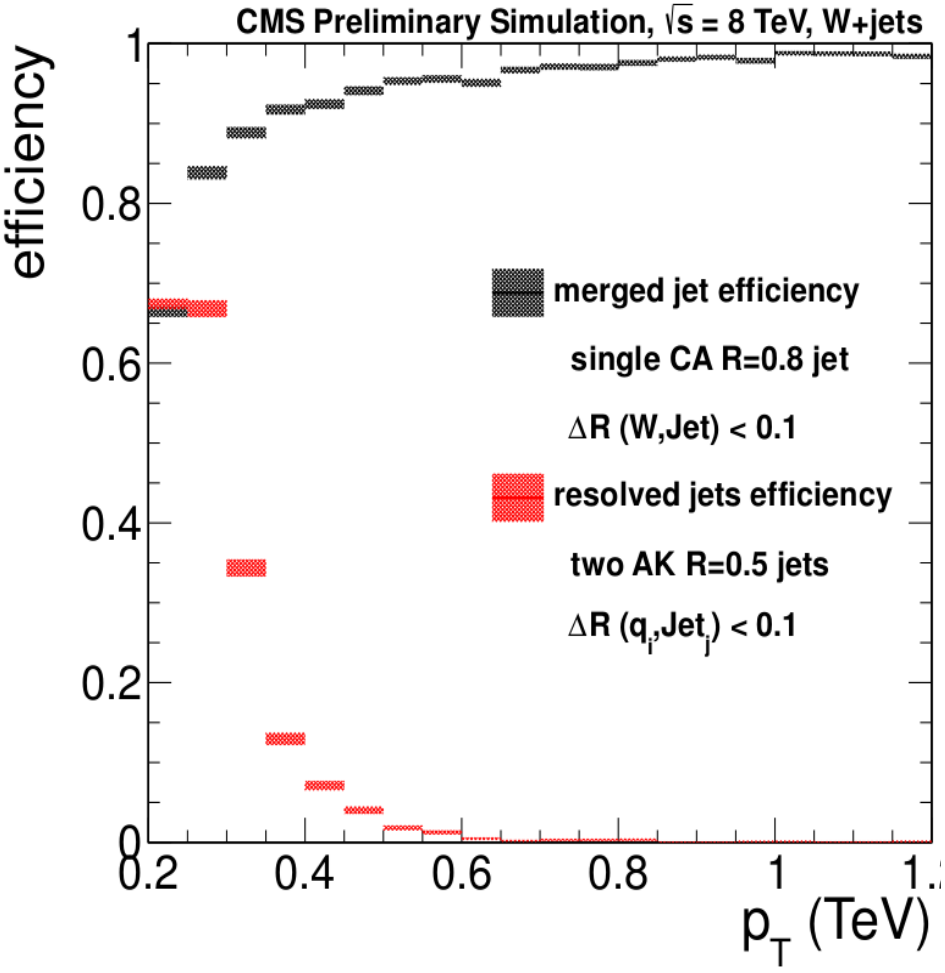


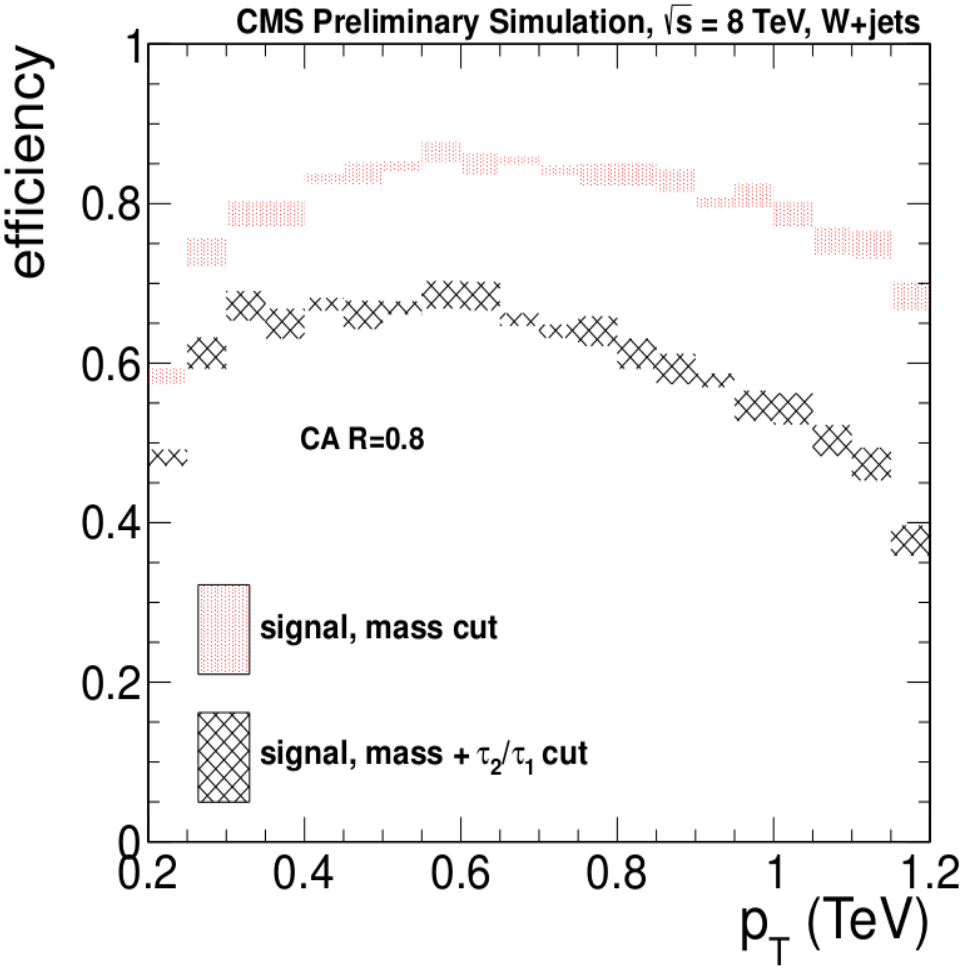


BACKUP MATERIAL

W-tagging efficiency

- Efficiency to reconstruct a W as a single CA8 jet.
- Once we have a W in a CA8, efficiency to pass W-tagging





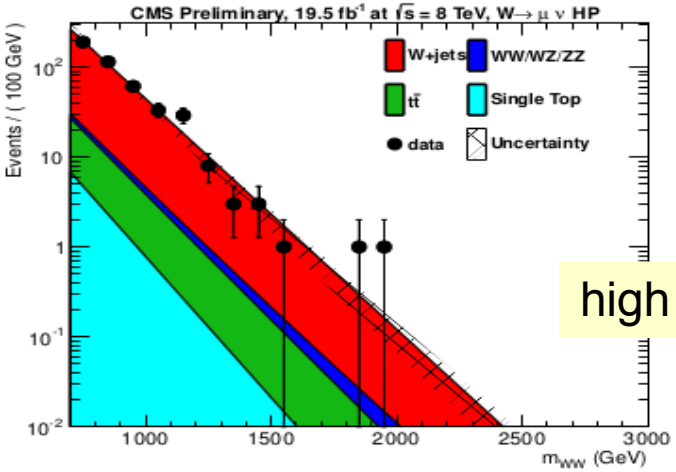
Fits to $F_{data,SB}(m_{WW})$

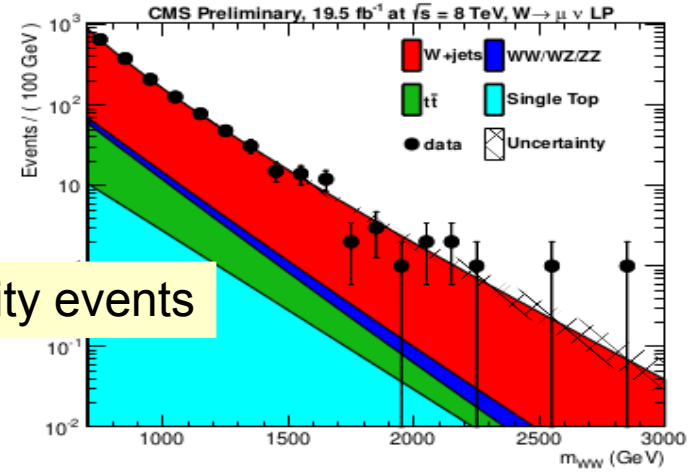
high purity events

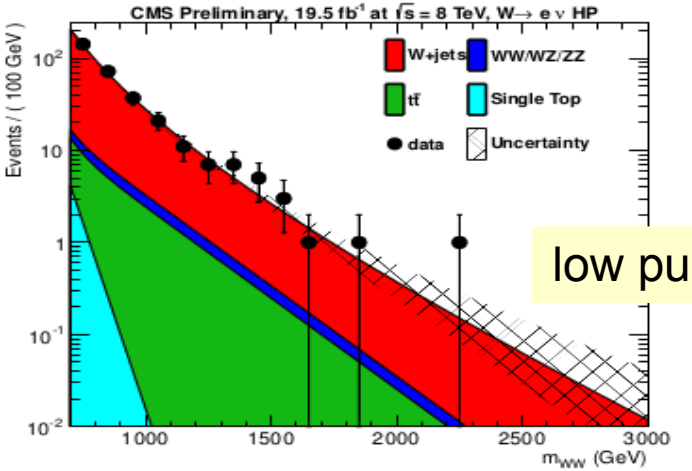
low purity events

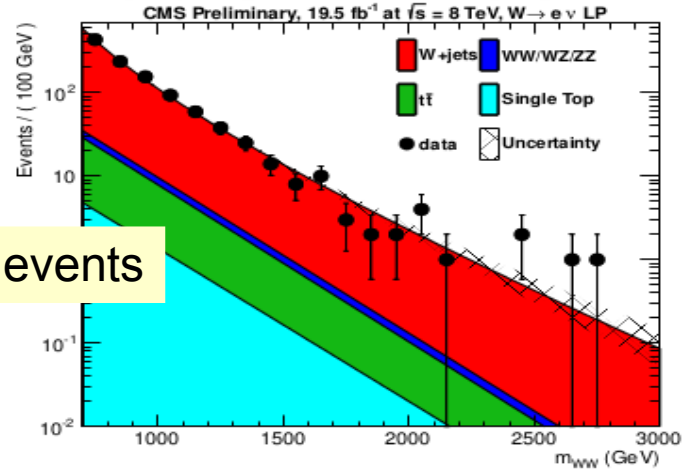
muon + jets

electron + jets

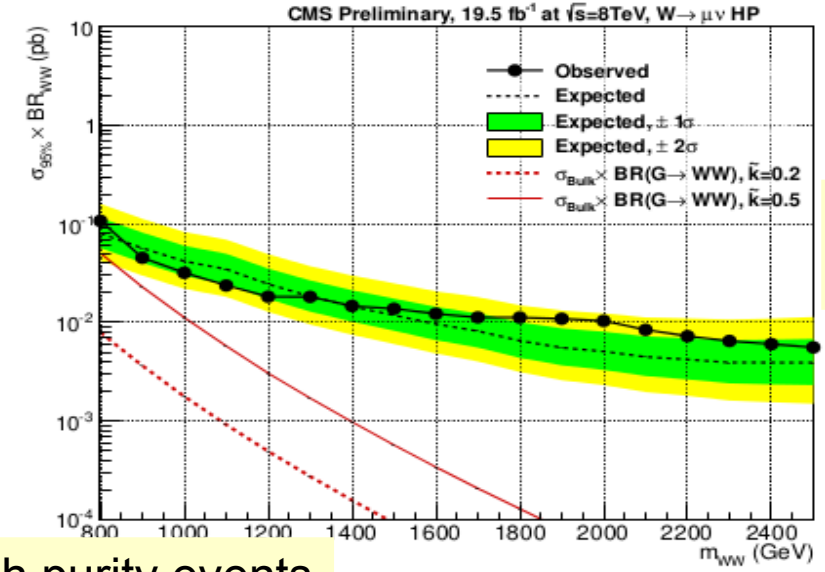




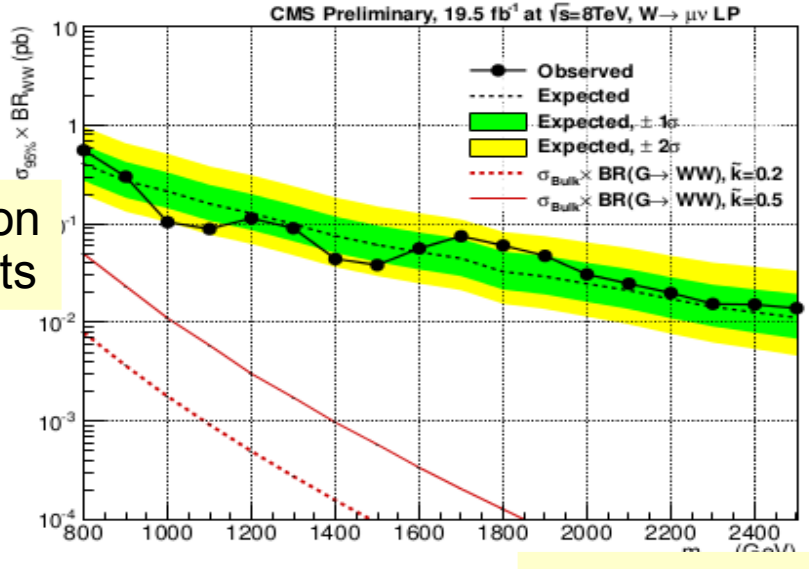




$G_{\mathrm{RS}} \to WW \to \ell + E_T^{\mathrm{miss}} + \mathrm{jet}$

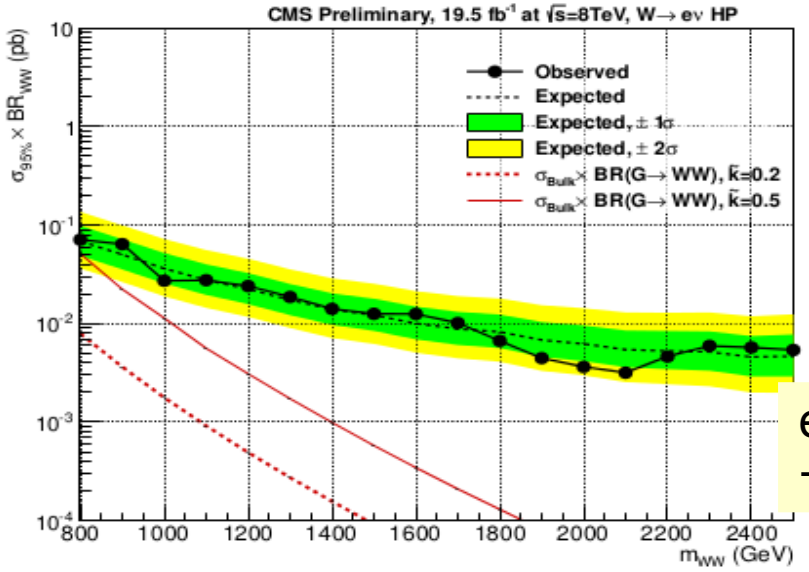


high purity events

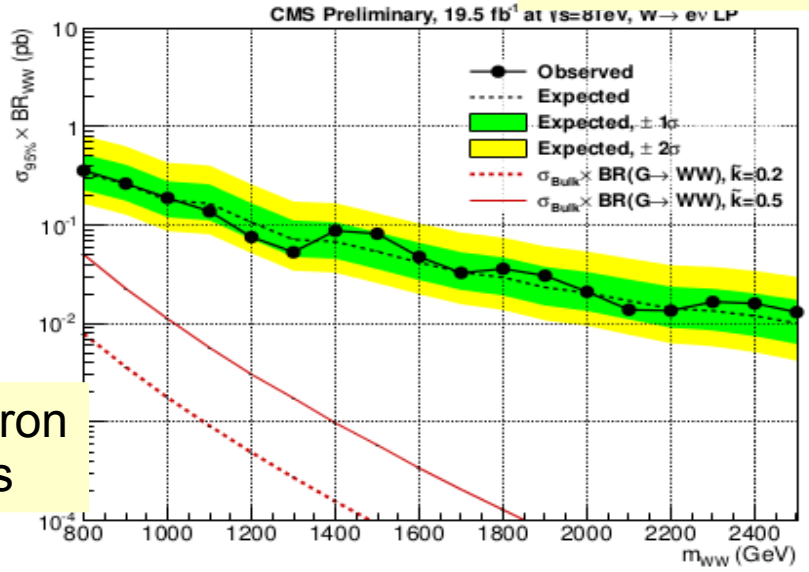


muon + jets

low purity events



electron + jets



Complementarity

- Most stringent limits to date in all final states WW, ZZ, WZ (,qW, qZ)
- Compare analyses sensitivity in 2-D plane of coupling k/M_{PL} and mass of RS1 Graviton
- Different channels are complementary
- Plan to combine all 8 TeV results