Search for dark matter with jets and missing transverse energy

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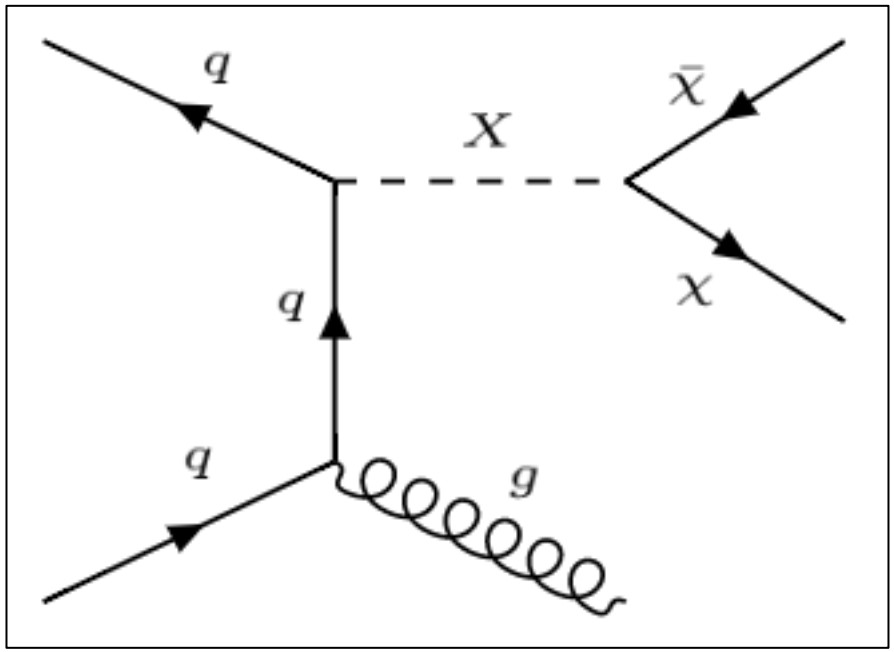
DM WIMP Signal Models

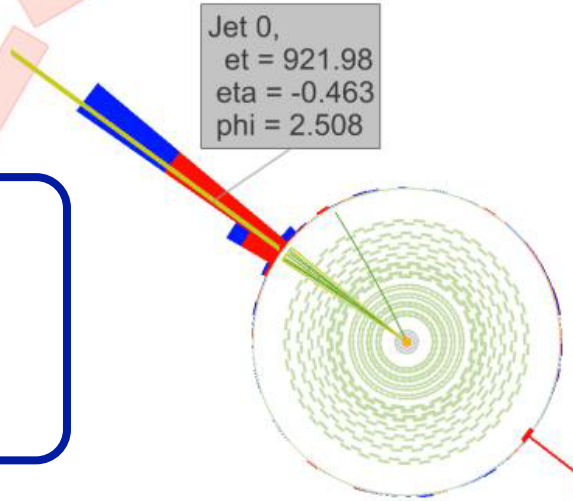


- **Implemented LHC DM Forum** recommendations: Scalar, Pseudo-Scalar, Vector, Axial-Vector models
- **Public results**: performed the **Vector** interpretation in time for the Jamboree approval
- **Exclusion limits** on production cross section in the (m_X ; m_{DM}) plane (assuming $g_{DM}=g_q=1$)
- **Translate** these limits in terms of spin-independent nucleon-DM interaction cross section vs m_{DM}

Signature

JET p_T>100 GeV

KILL INSTRUMENTAL, QCD, TOP
- p_T : $h^{\pm} \geq 10\%$ $h^0 \leq 80\%$
- $\Delta\phi_{Jet,MET} > 0.5$ {4 leading jets pT>30}
- Veto b-tagged jets



PHOTON VETO :
- Isolated γ

KILL V+γ
EXCLUDE MONO-γ

LEPTON VETO :
- Isolated e,μ ; τ

KILL V, V+V, TOP

- MET $\equiv$ MET without μ
- Filters on instrumental and beam noises

Analysis strategy in a nutshell

- **Trigger** on both MET and MHT to reduce the rate while selecting events in the signal region (SR)
- Use "PFMETNoMu" (trigger ; offline) $\Longrightarrow$ define a $Z \rightarrow \mu\mu$ control region (CR) for $Z \rightarrow \nu\nu$ background

- Define several **CR** for data-driven estimations: (di)muon, (di)electron, photon
  $\Longrightarrow$ $Z(\nu\nu)$, $W(l\nu)$ [90% of the total background]
  $\Longrightarrow$ use boson recoil instead of MET
- Calculate **transfer factors** to extrapolate the MET spectrum from CR to SR
- **Transfer factor**s take into account: lepton/photon acceptance/efficiency ; Z/γ, Z/W cross section ratios
- LO MC corrected to NLO (QCD+EW) using k-factors (depending on boson pT)

- Evaluate **uncertainties**
- **Fit** simultaneously the MET spectrum in all CRs to the data
- Compute exclusion **limits** on signal models

Monojet Trigger

[L1]
MET > **50** GeV

→

[CaloMET]
CaloMET > **70** GeV

→

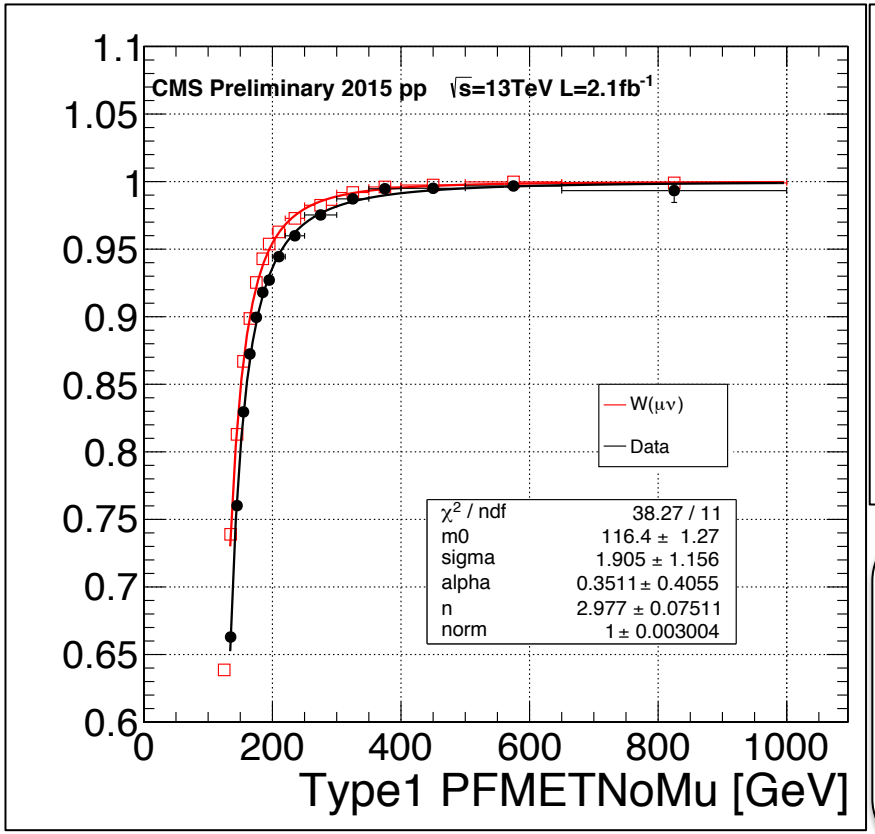
[HBHECleaning]
CaloMET > **60** GeV

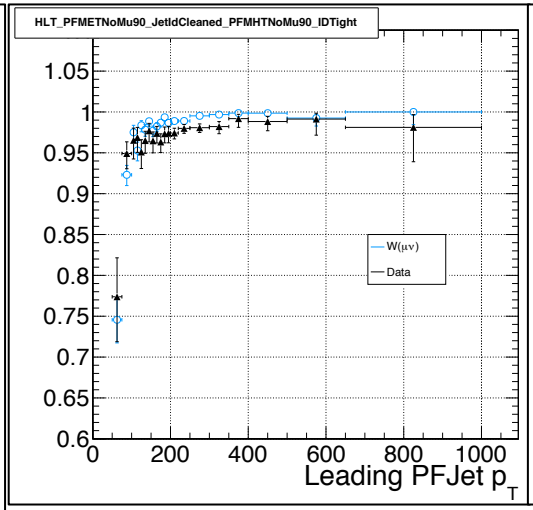
→

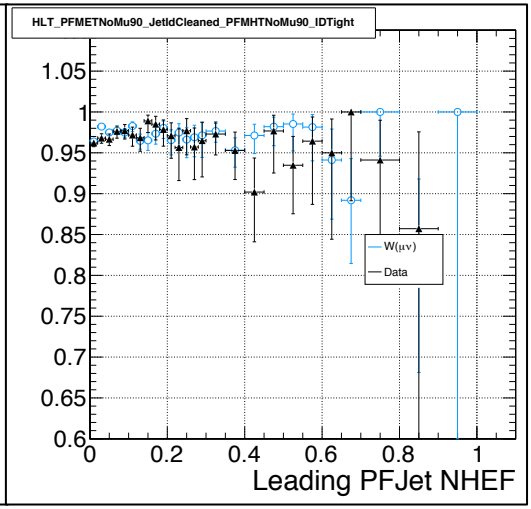
[CaloJets, CaloJet ID Cleaning]
CaloMET > **60** GeV

↓

[PFJets, PFMET]
[PFJet ID & $|\eta|<2.6$ & NHEF > 0.9]
PFMET NoMu > **90**GeV PFMHT NoMu > **90**GeV







- >95% efficient at MET>200GeV
- Some inefficiency remains at low leading jet pT and high NHEF
- Motivated two extra cuts: leading jet pT>100GeV, NHEF<0.8

Control regions

✧ Single muon

- Signal METNoMu trigger
- 1 tight muon, $p_T > 20$ GeV

✧ Single electron

- Single electron trigger
- 1 tight electron, $p_T > 40$ GeV
- MET>50 GeV [suppress QCD]

✧ Double muon

- Signal METNoMu trigger
- 2 loose muons
- ≥1 tight muon pT>20 GeV
- Dimuon mass in [60, 120] GeV

✧ Double electron

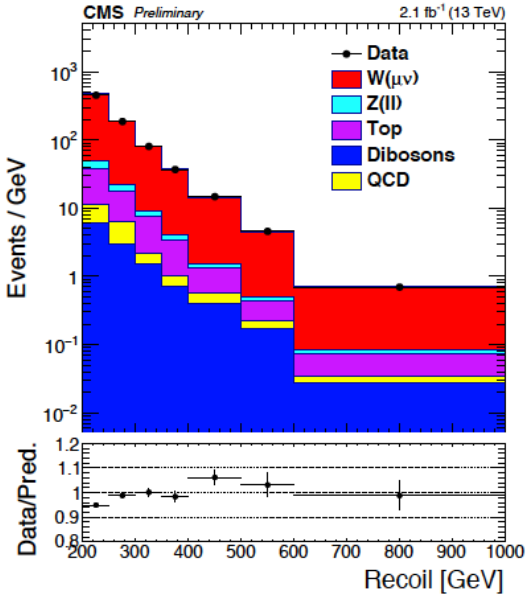
- Single electron trigger
- 2 loose electrons
- ≥1 tight electron
- Dielectron mass in [60, 120] GeV

✧ Single photon

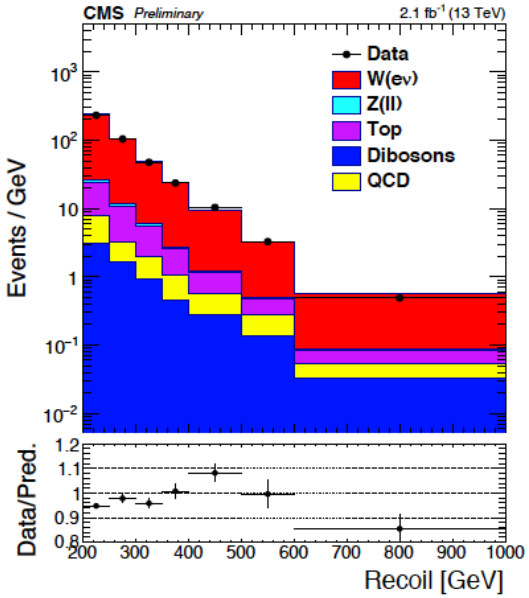
- Single photon trigger
- 1 medium-ID photon
- pT>175 GeV |eta|<1.4442

Control regions: Data/MC comparisons

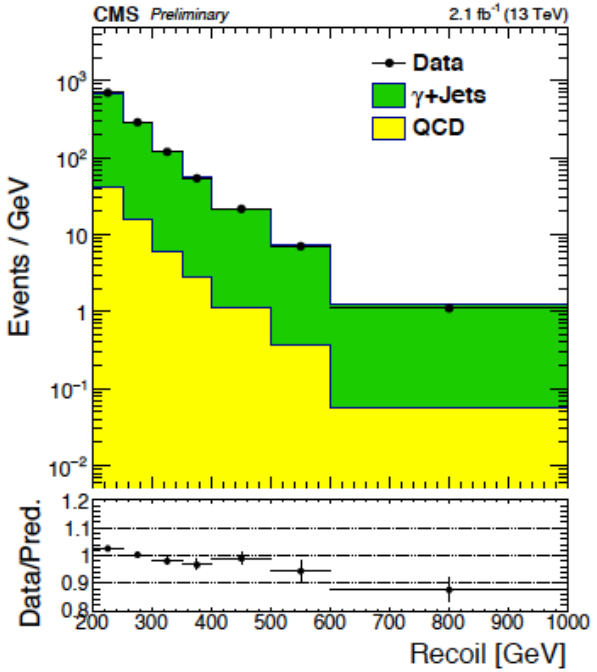
Single Muon



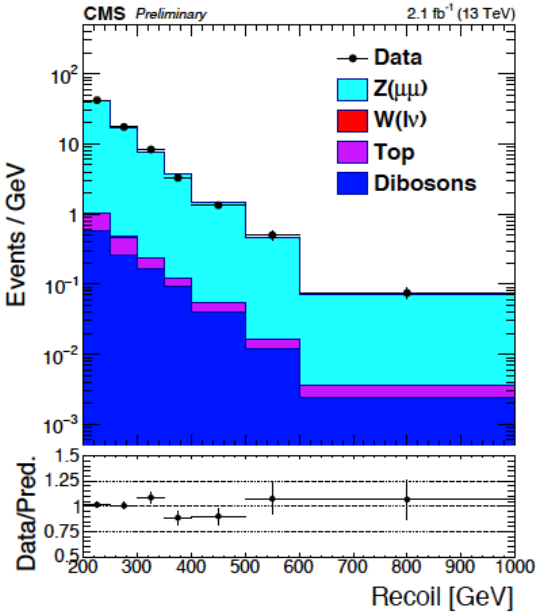
Single Electron



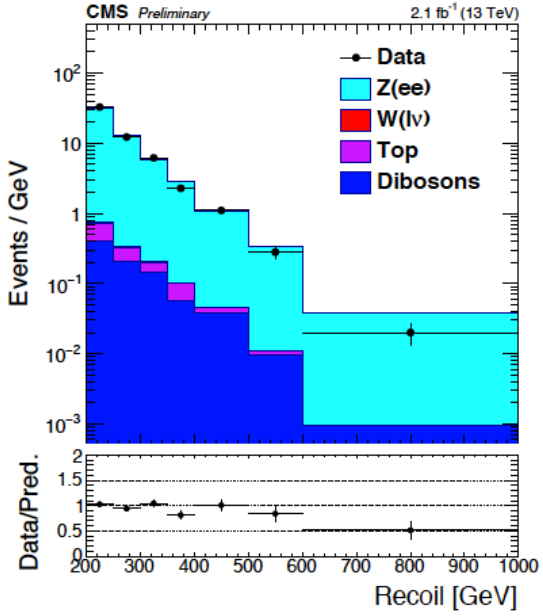
Single Photon



Dimuons



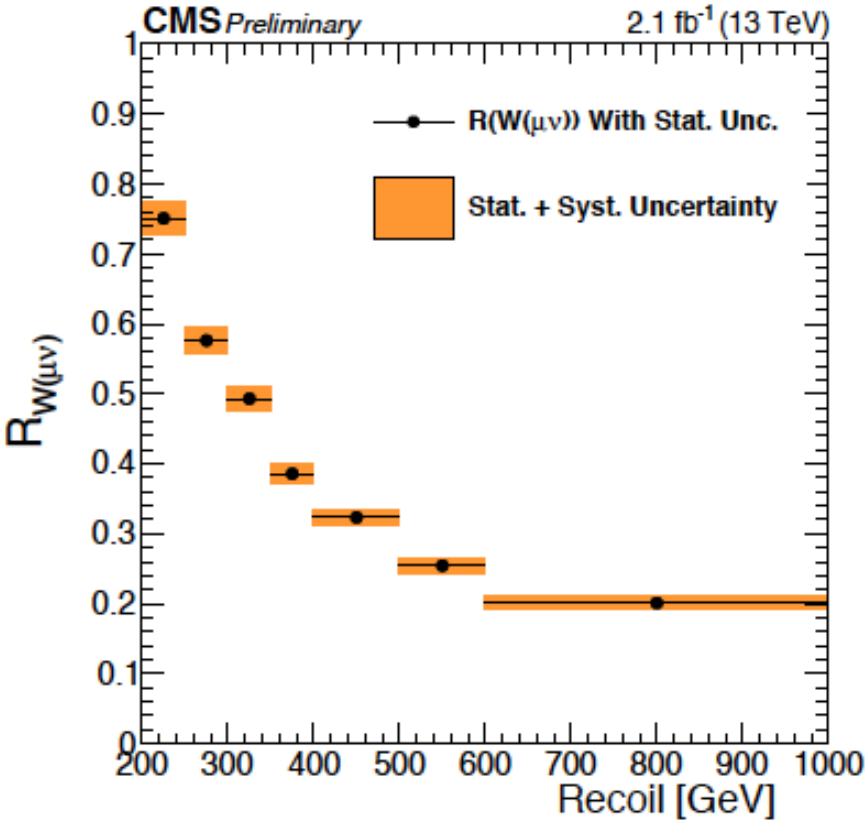
Dielectrons



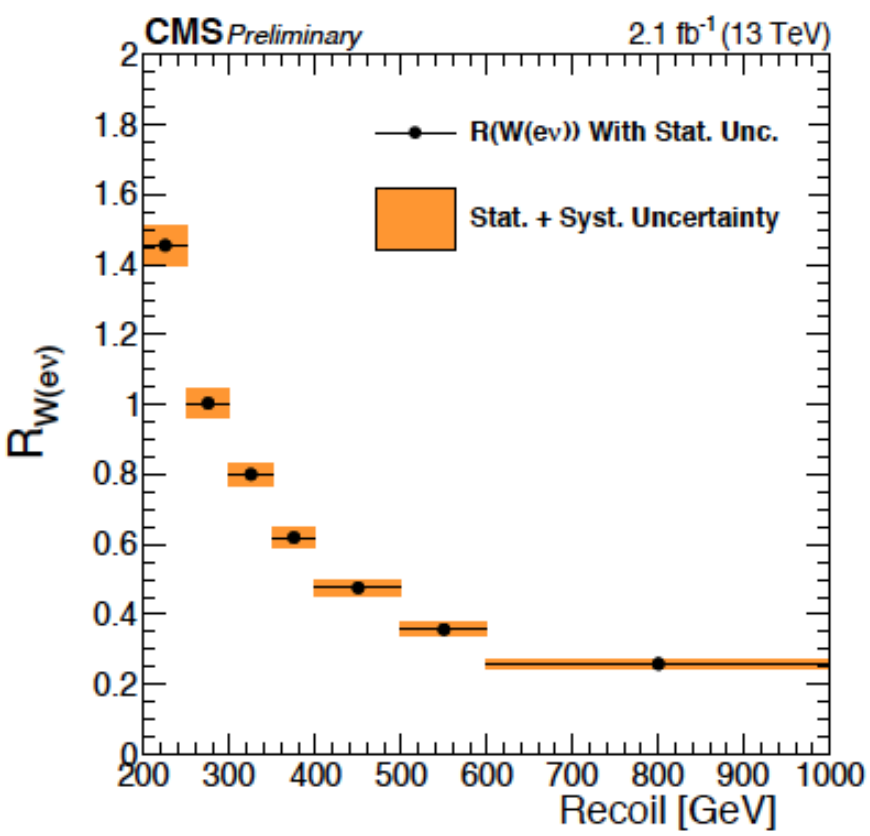
Overall good data/MC agreement in all control regions

Transfer factors : single lepton

Single Muon



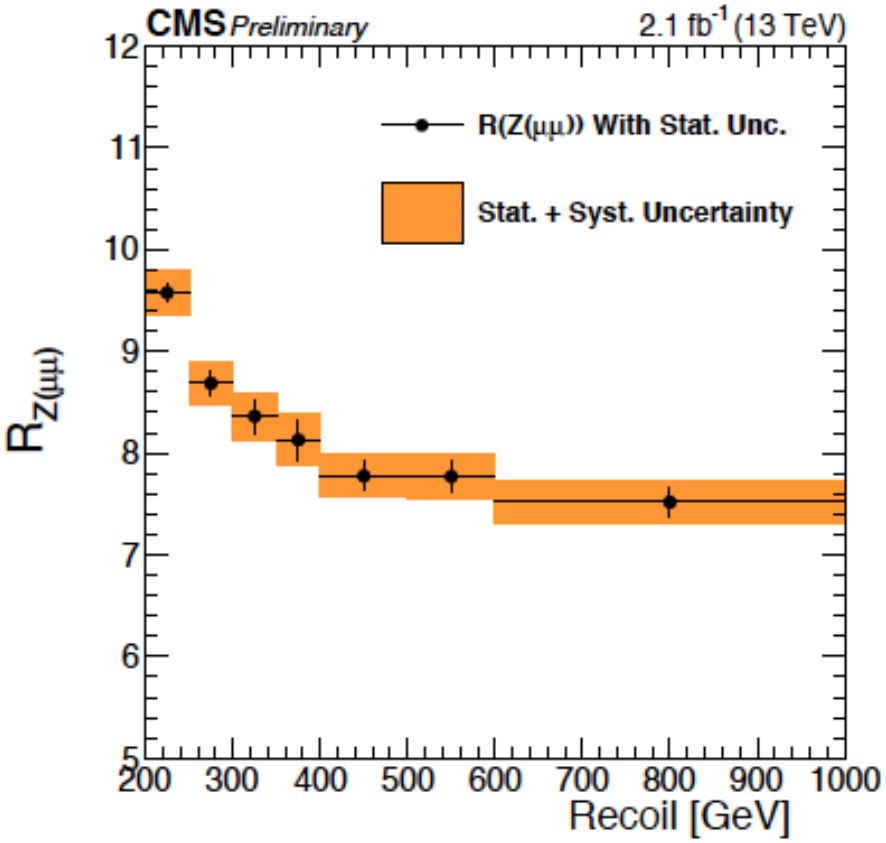
Single Electron



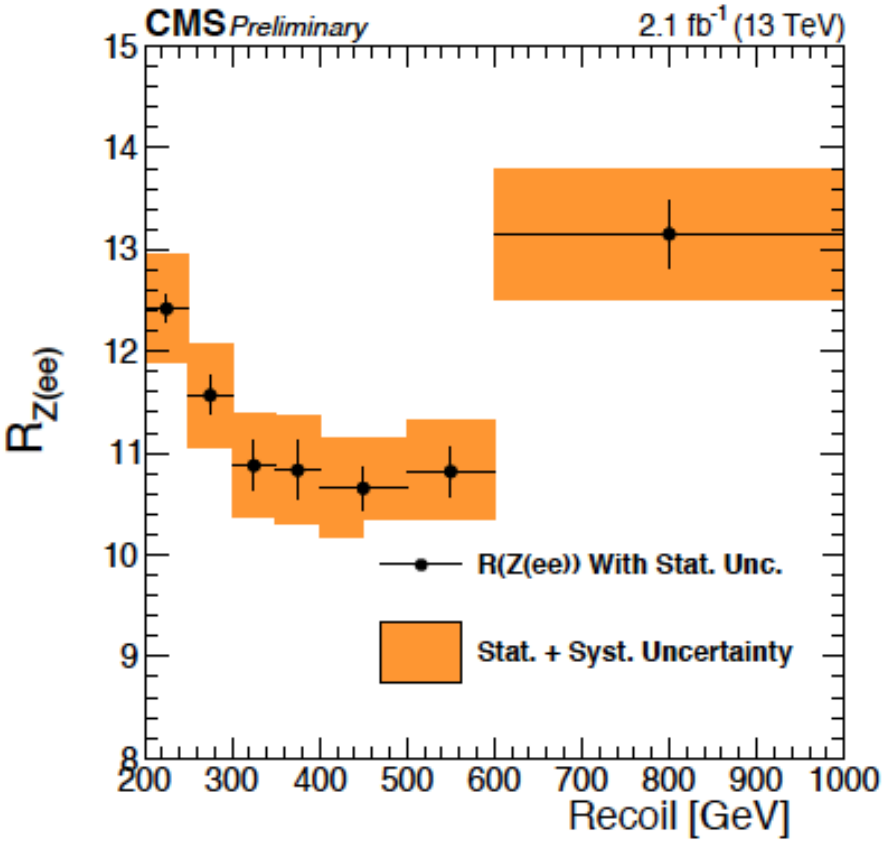
- Lepton acceptance increases at high W pT ⟹ falling shape of the TF

Transfer factors : dilepton

Z(vv) to Z(μμ)

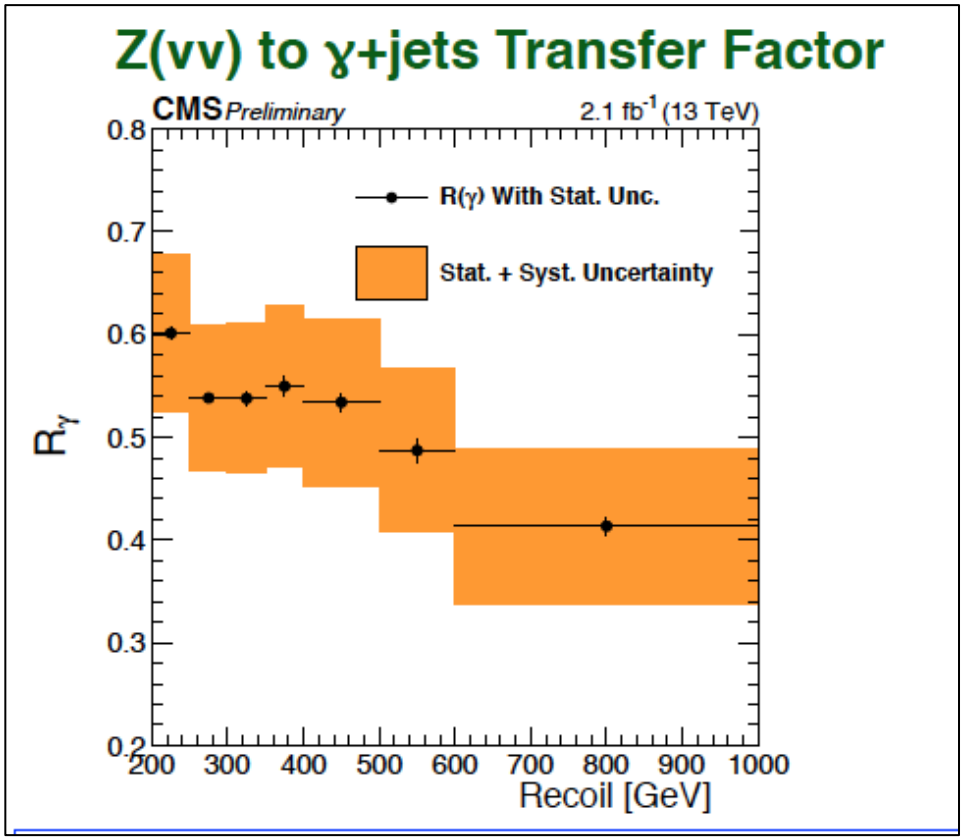


Z(vv) to Z(ee)



- High Z pT ⟹ electrons overlap ⟹ loss of efficiency ⟹ rise of TF in last bin

Transfer factors : single photon

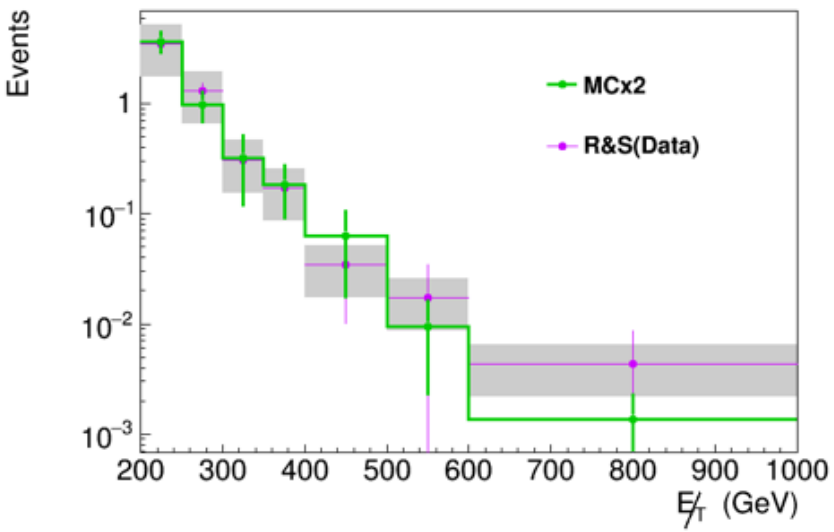


- First bin: photon pT threshold (175GeV) close to MET threshold (200GeV)
- MET resolution effects cause a loss of efficiency on γ+jets events in this bin

QCD data-driven estimation

✧ **Method 1: Rebalance & Smear**

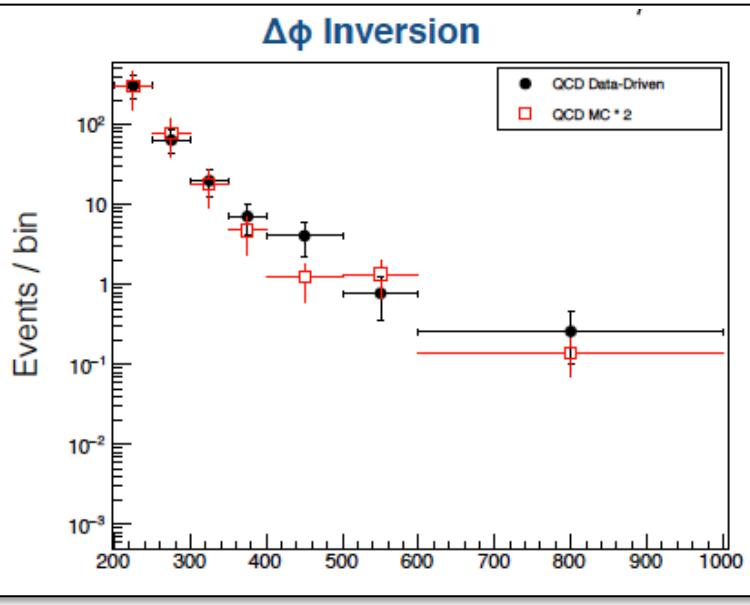
- Rebalance jets in JetHT (QCD-dominated) events to obtain MET=0 using a kinematic fitter
- Smear jet momenta using resolutions
- **This method results in a global scale factor of 2 to be applied on the MC prediction (unc: 50%)**



✧ **Method 2: Δϕ(jet, MET inversion)**

- Define CR by reverting the Δϕ cut
- Measure TF from low Δϕ to high Δϕ region in JetHT data and QCD MC
- Fit TF using exponential functions
- Extract MET spectrum from MET data in CR and reweight them according to the fitted TF

⟹ **This method confirms the scale factor of 2**



Uncertainties

Electroweak backgrounds

✧ Experimental

- Muon efficiency: 1% per muon
- Electron efficiency: 2% per electron
- Lepton veto: 3%
- Photon efficiency: 2%
- Photon purity: 2%

✧ Theoretical

- QCD factorization/renormalization scales: vary by factor 2
- Full NLO EWK corrections

Top, dibosons, QCD

✧ Experimental

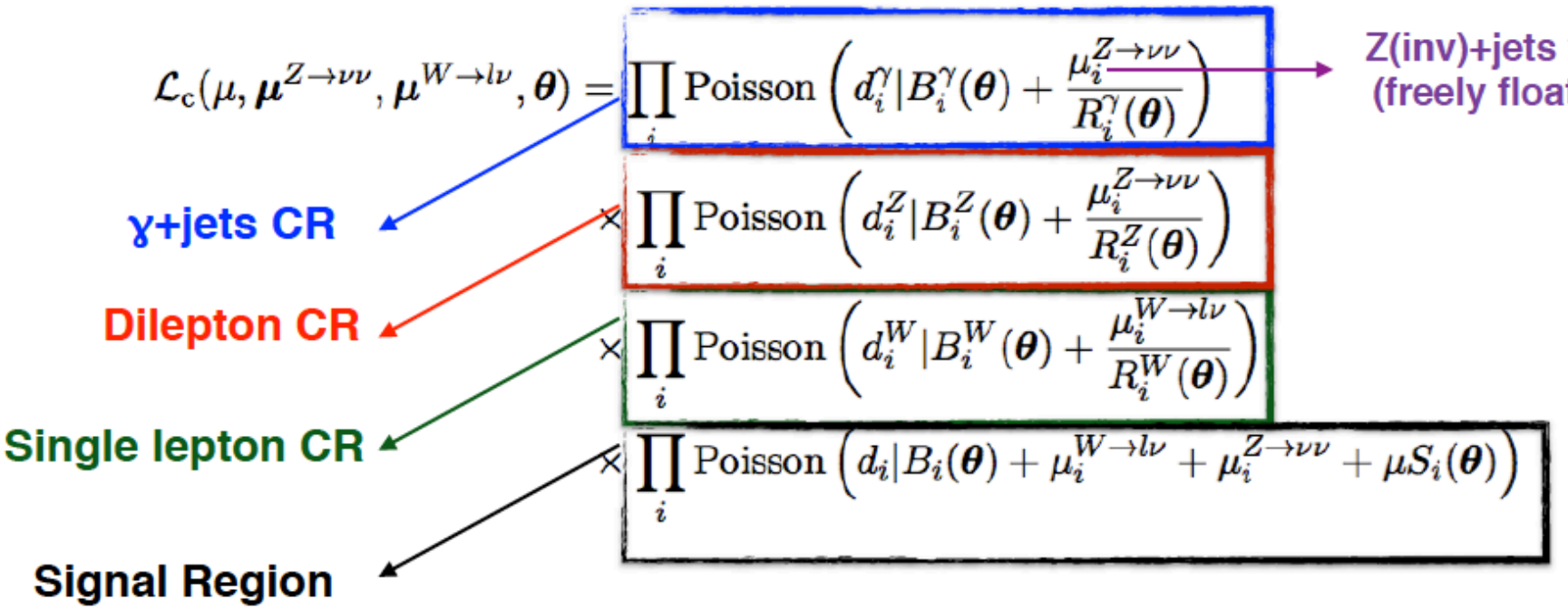
- Luminosity: 12%
- MET (from JEC): 4%
- B-veto: 6% (only on the top background)
- QCD: 50% from data-driven estimation

✧ Theoretical

- Top cross section: 10%
- Diboson cross section: 20%

Fit to the data

Z(vv)+jets and W+jets background extracted through a combined max. likelihood fit of the five control regions and signal region



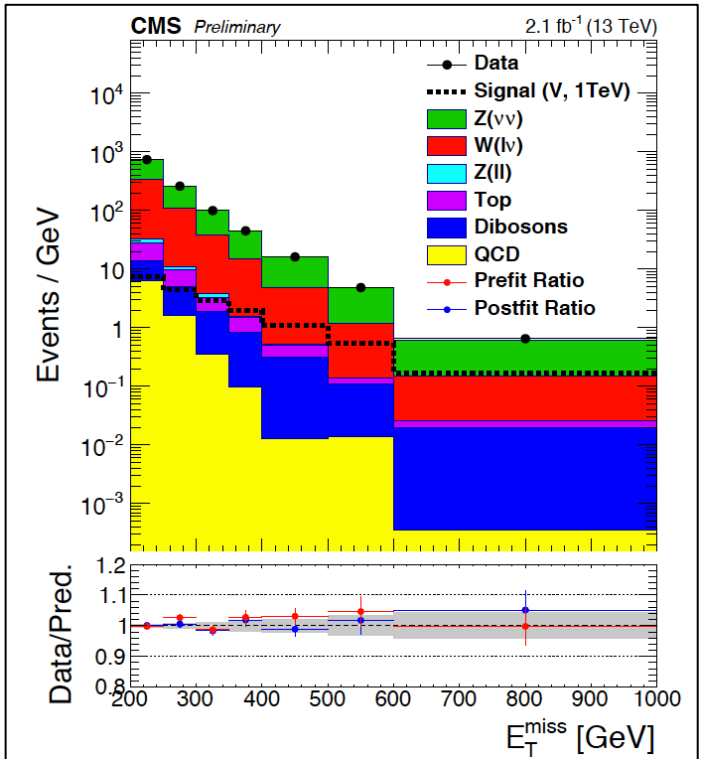
Additional constraint connects the Z(vv)+jets and W+jets estimates

$$\mu_i{}^{W\to l\nu} \to f_i(\boldsymbol{\theta}) \cdot \mu_i{}^{Z\to\nu\nu}$$

Results: MET spectrum

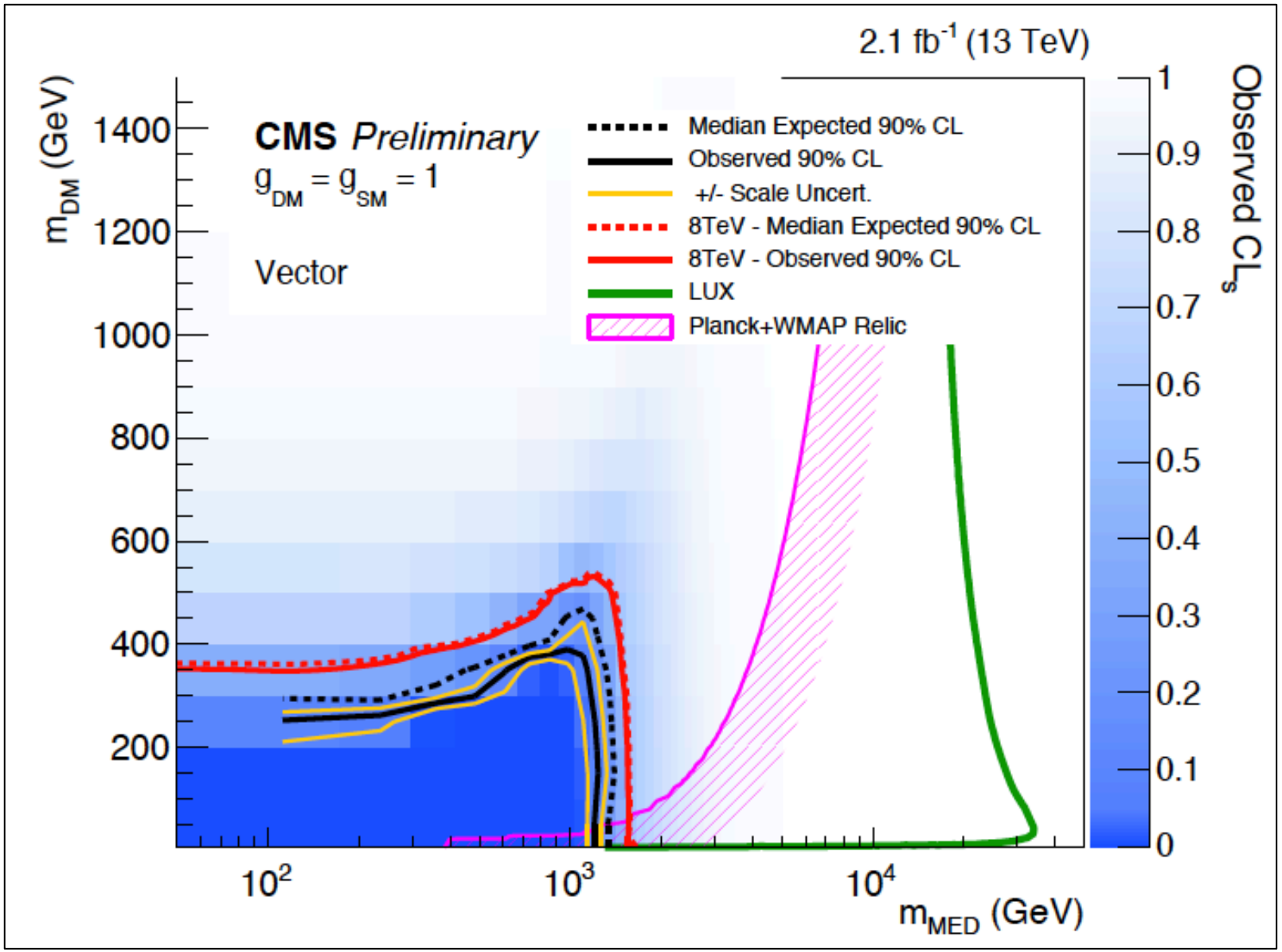
✧ **Post-fit MET spectrum and yields**

- Background-only fit
- Signal point plotted: m_X=1TeV ; m_{DM}=1GeV (dotted line)
- Data/prediction ratio plot: prefit (red), postfit (blue)
- Gray band: post-fit uncertainty on the total background

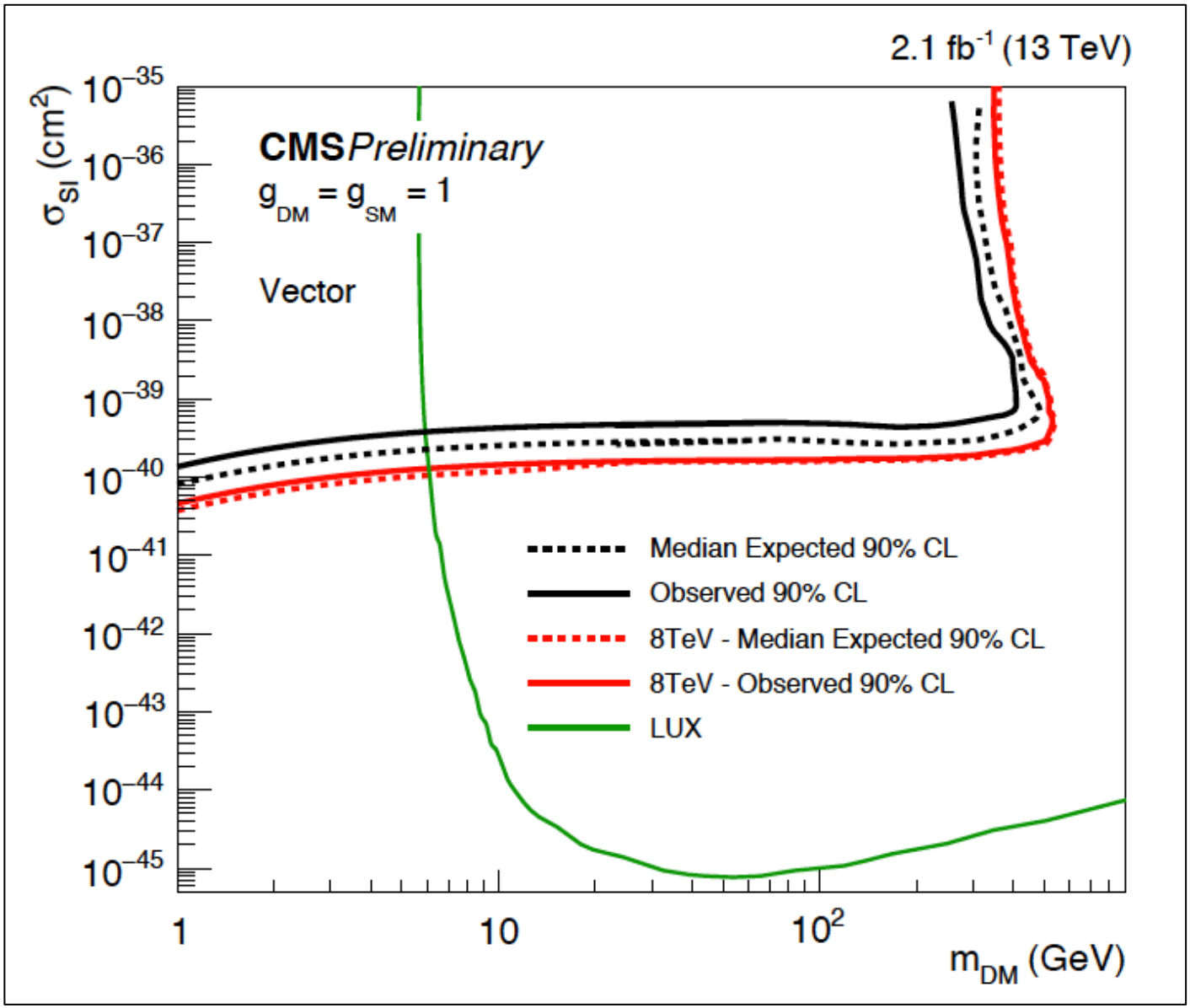


Process	E_T^{miss} [200 – 250] GeV	E_T^{miss} [250 – 300] GeV	E_T^{miss} [300 – 350] GeV	E_T^{miss} [350 – 400] GeV	E_T^{miss} [400 – 500] GeV	E_T^{miss} [500 – 600] GeV	E_T^{miss} [> 600] GeV
$Z(\nu\nu)$ + jets	19651 ± 279	7554 ± 116	3127 ± 55	1470 ± 34	1147 ± 32	357 ± 15	189.0 ± 9.5
$W(l\nu)$ + jets	15555 ± 325	4843 ± 105	1747 ± 44	658 ± 20	433 ± 13	105.0 ± 4.7	48.6 ± 2.7
$Z(ll)$ + jets	257 ± 57	66 ± 15	22.3 ± 4.9	5.1 ± 1.1	3.0 ± 0.7	0.44 ± 0.10	0.12 ± 0.03
Top	705 ± 106	237 ± 35	72.9 ± 10.9	32.1 ± 4.8	18.0 ± 2.7	2.88 ± 0.43	2.47 ± 0.37
Dibosons	373 ± 77	167 ± 34	76 ± 16	37.0 ± 7.6	30.6 ± 6.3	9.4 ± 1.9	7.6 ± 1.6
QCD	313 ± 129	80.5 ± 33.3	17.4 ± 7.2	4.9 ± 2.0	1.30 ± 0.54	1.39 ± 0.57	0.14 ± 0.06
Total	36853	12948	5063	2207	1632	476	247
Observed	36858	13010	4981	2248	1614	484	260

Results: exclusion limits on production



Results: exclusion limits on interaction



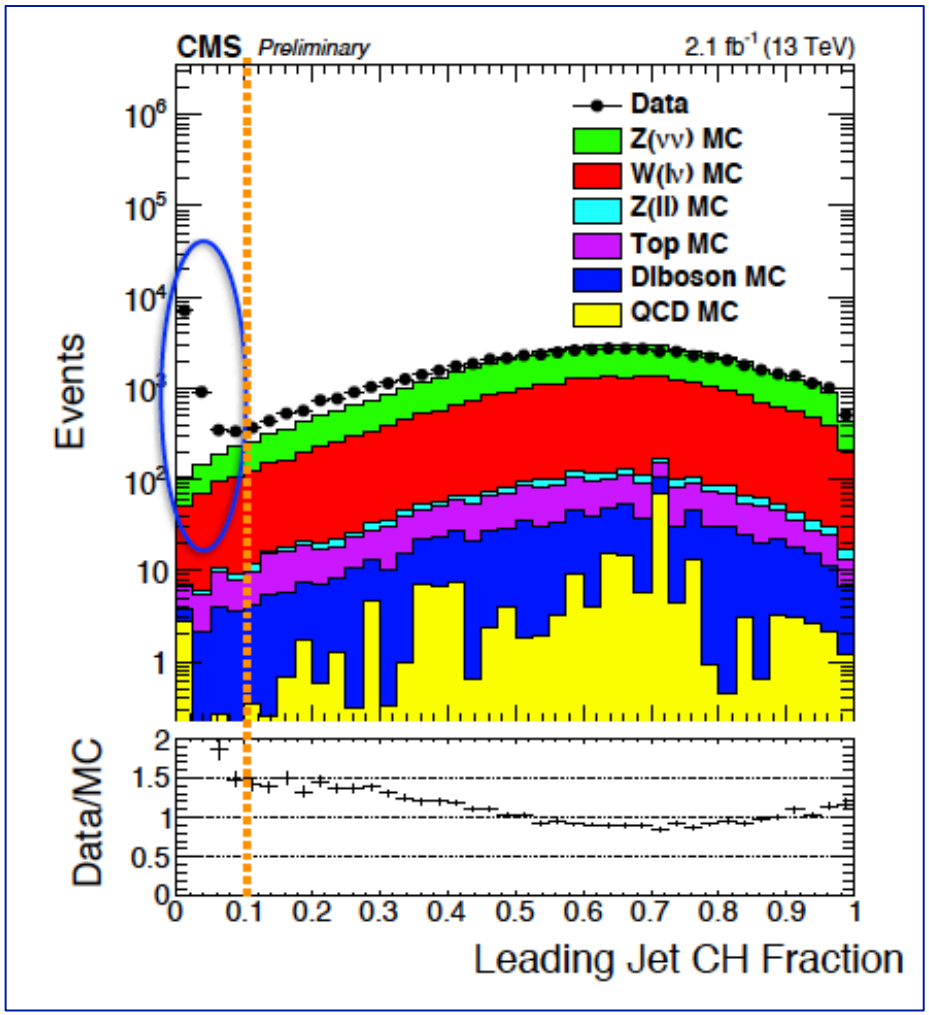
Conclusion

- CMS used 2.1 /fb of 13TeV data to search for DM in a multijets+MET final state
- All backgrounds except top and dibosons are data-driven
- Simultaneous fits in all EWK control regions + backgrounds in signal region

- No significant excess is observed
- Results are interpreted using a simplified model involving a vector mediator
- **Mediator masses up to 1.3TeV are excluded at 90% CL**
- Not enough 13TeV data to reach the best bounds from the 8TeV analysis which exclude vector mediator masses up to 1.6TeV

BACKUP

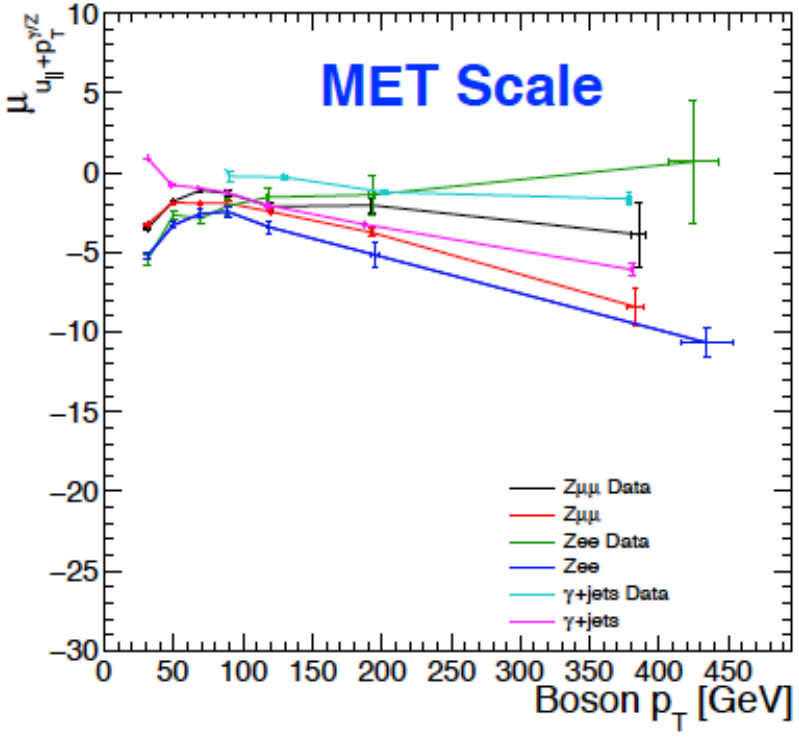
Jets

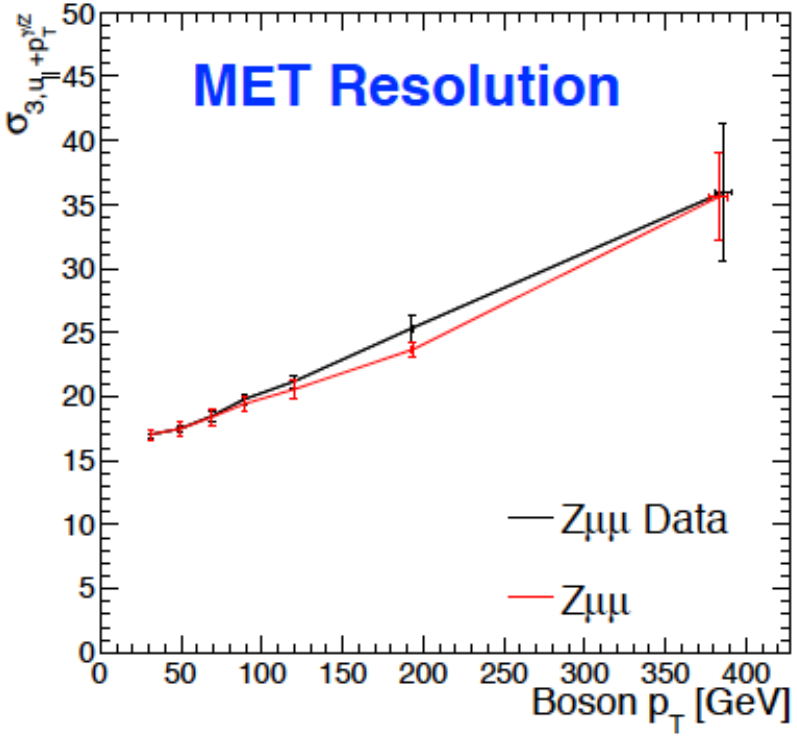


Leading jet : CH fraction > 0.1, NH fraction < 0.8

- kill anomalous noise, mainly beam backgrounds

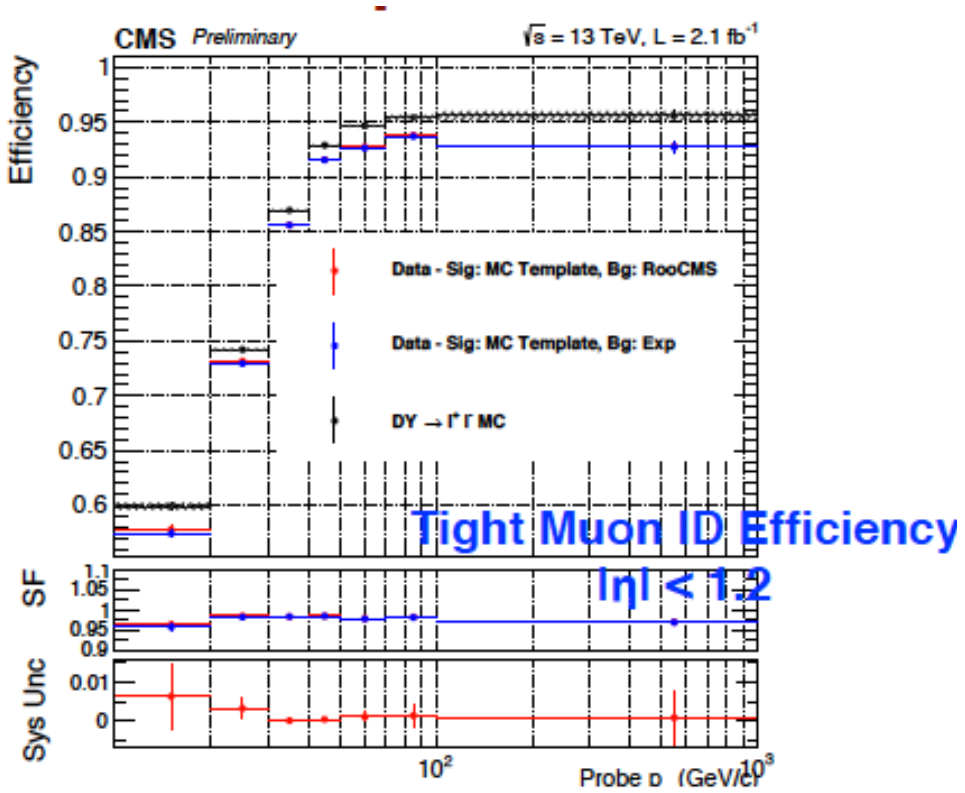
MET

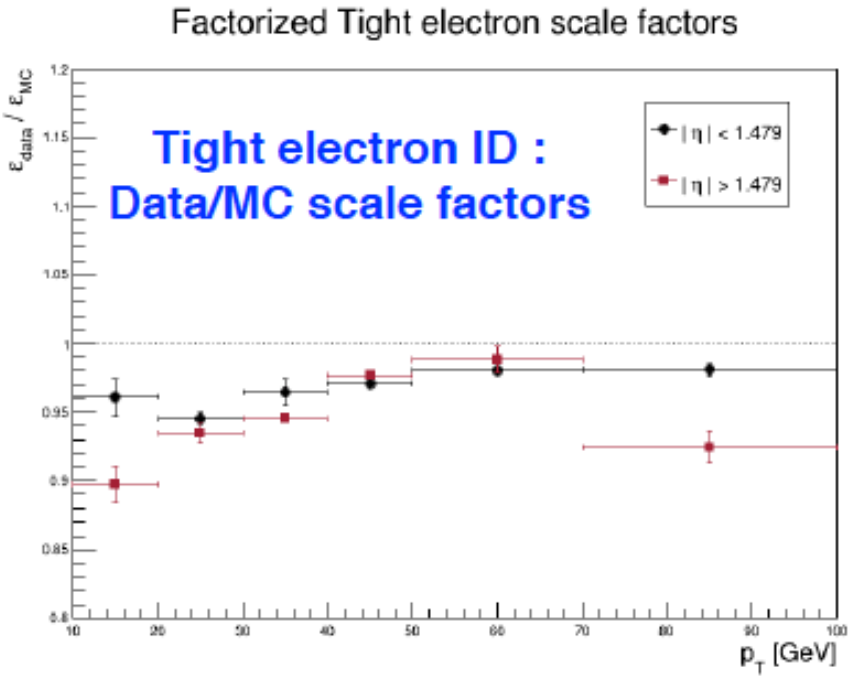




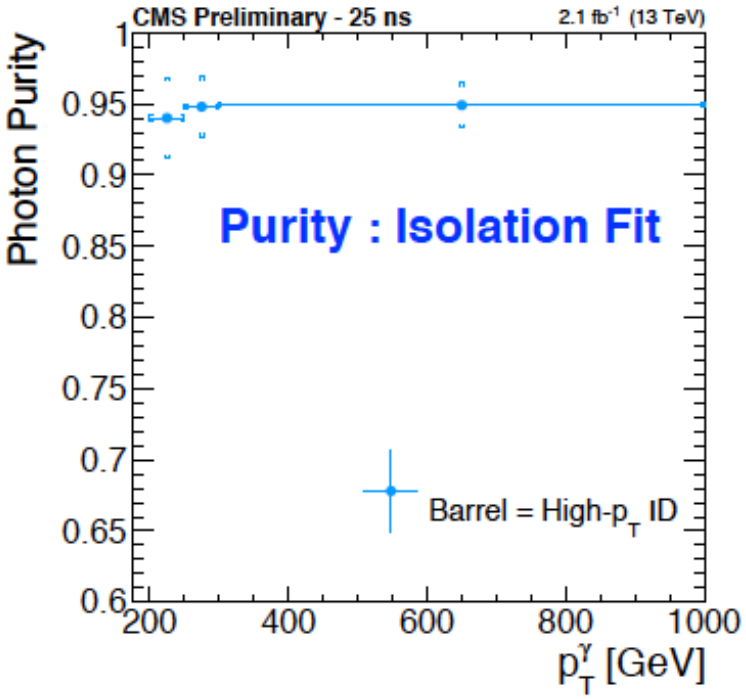
MET response agrees between data and MC at 1-2% level for large MET

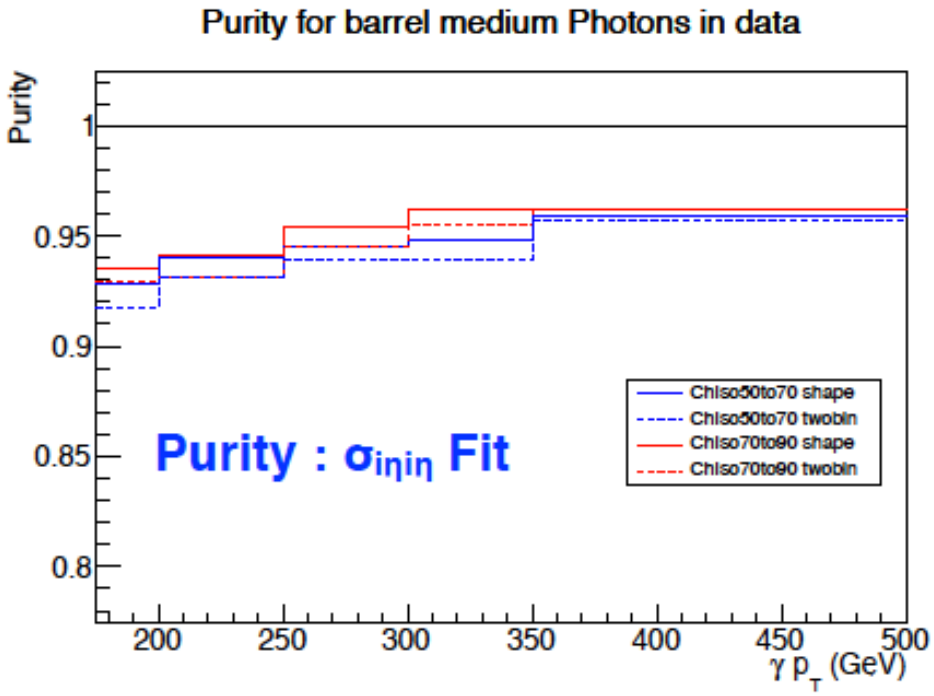
Leptons


CMS Preliminary
√s = 13 TeV, L = 2.1 fb-1
Efficiency
Data - Sig: MC Template, Bg: RooCMS
Data - Sig: MC Template, Bg: Exp
DY → l+ l- MC
SF
Sys Unc
Probe p (GeV/c)
Tight Muon ID Efficiency
|η| < 1.2


Factorized Tight electron scale factors
Tight electron ID :
Data/MC scale factors
| η | < 1.479
| η | > 1.479
pT [GeV]

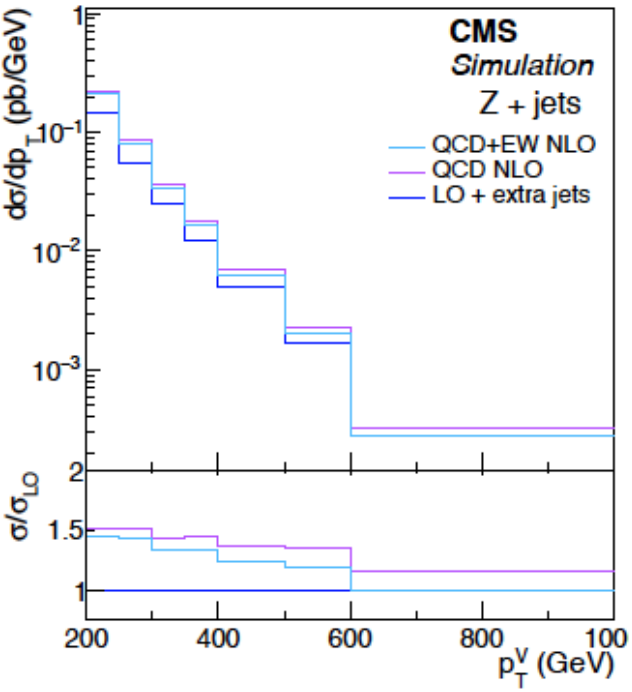
Photons


CMS Preliminary - 25 ns
2.1 fb^{-1} (13 TeV)
Photon Purity
Purity : Isolation Fit
Barrel = High-p$_T$ ID
p$_T^\gamma$ [GeV]

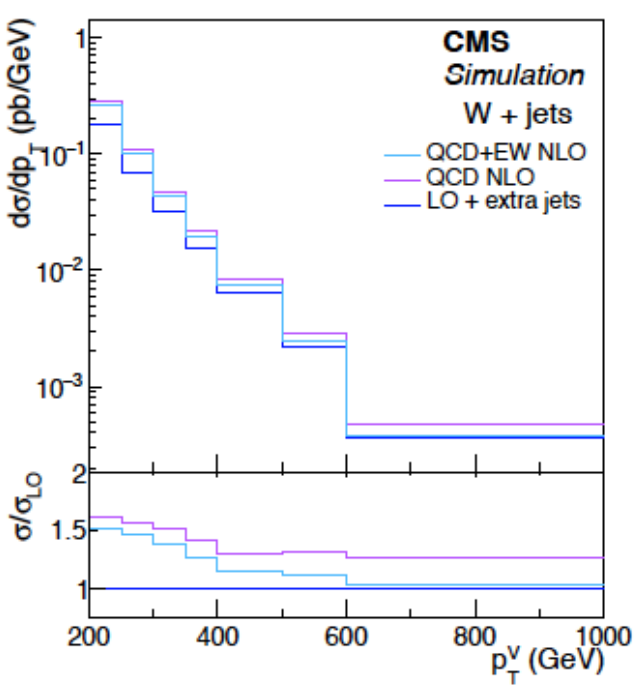

Purity for barrel medium Photons in data
Purity
Purity : $\sigma_{i\eta i\eta}$ Fit
Chiso50to70 shape
Chiso50to70 twobin
Chiso70to90 shape
Chiso70to90 twobin
γ p$_T$ (GeV)

NLO k-factors

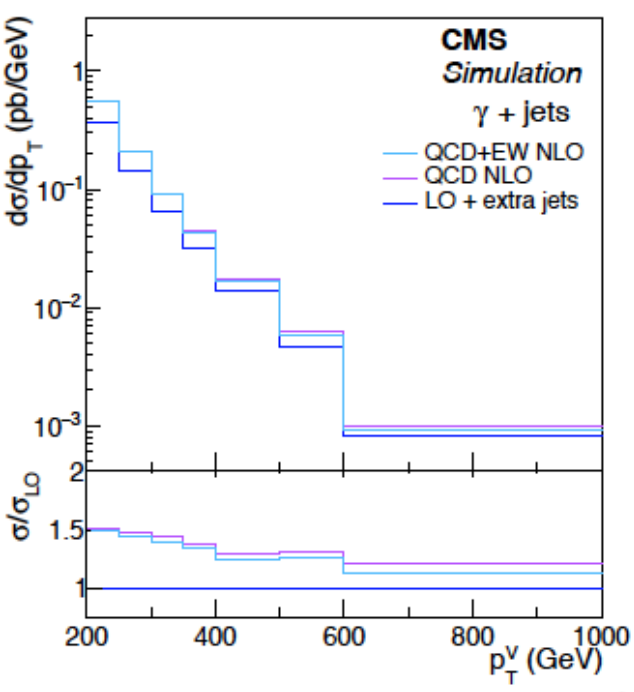
Z+jets



W+jets

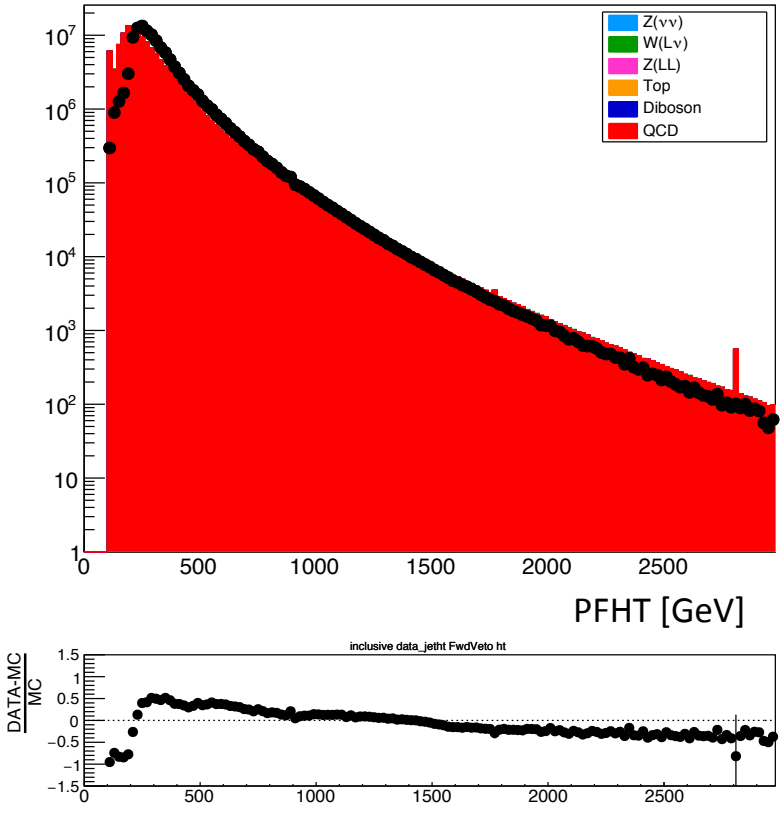


γ+jets

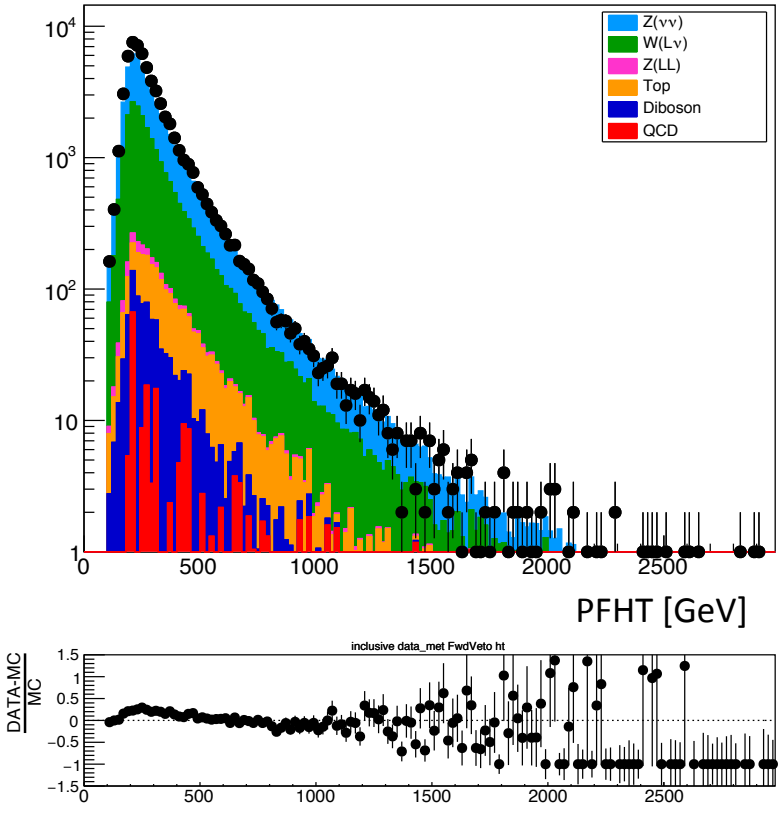


QCD Control Sample: JetHT

Offline HT: JetHT data vs MC ; no $\Delta\phi$ cut



Offline HT: MET data vs MC ; Signal Region



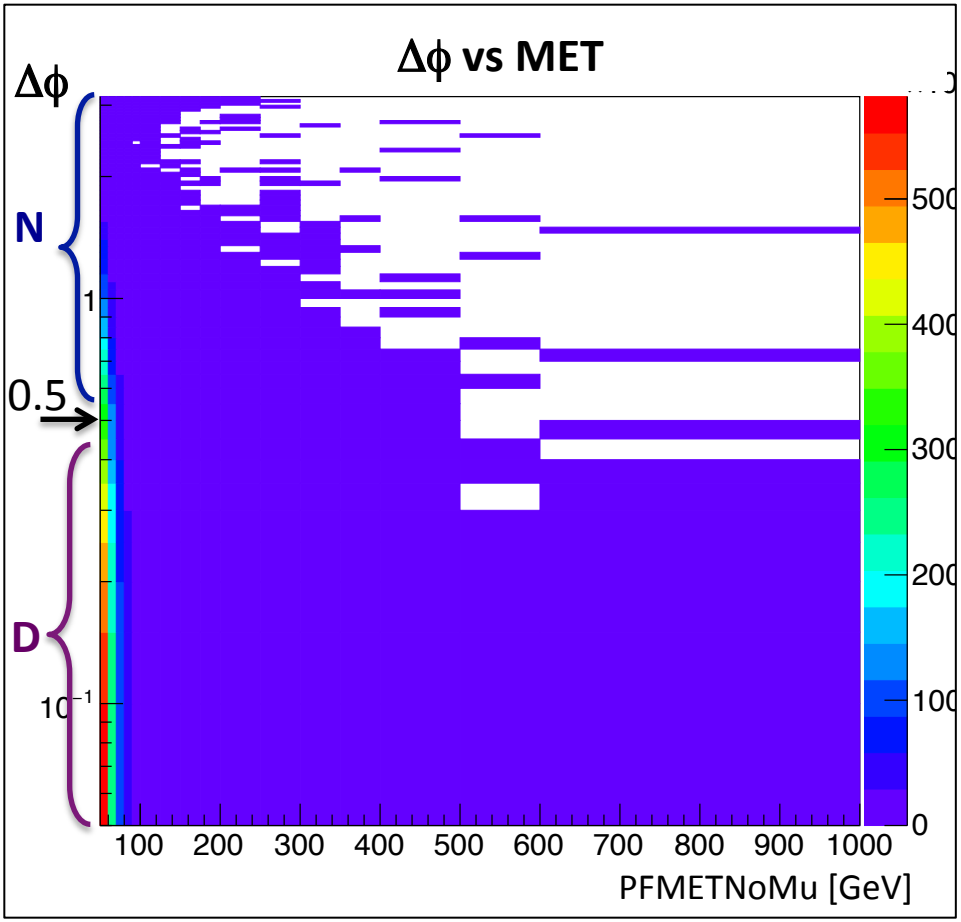
✧ **Combine (un)prescaled pure HLT_PFHT{X} paths**

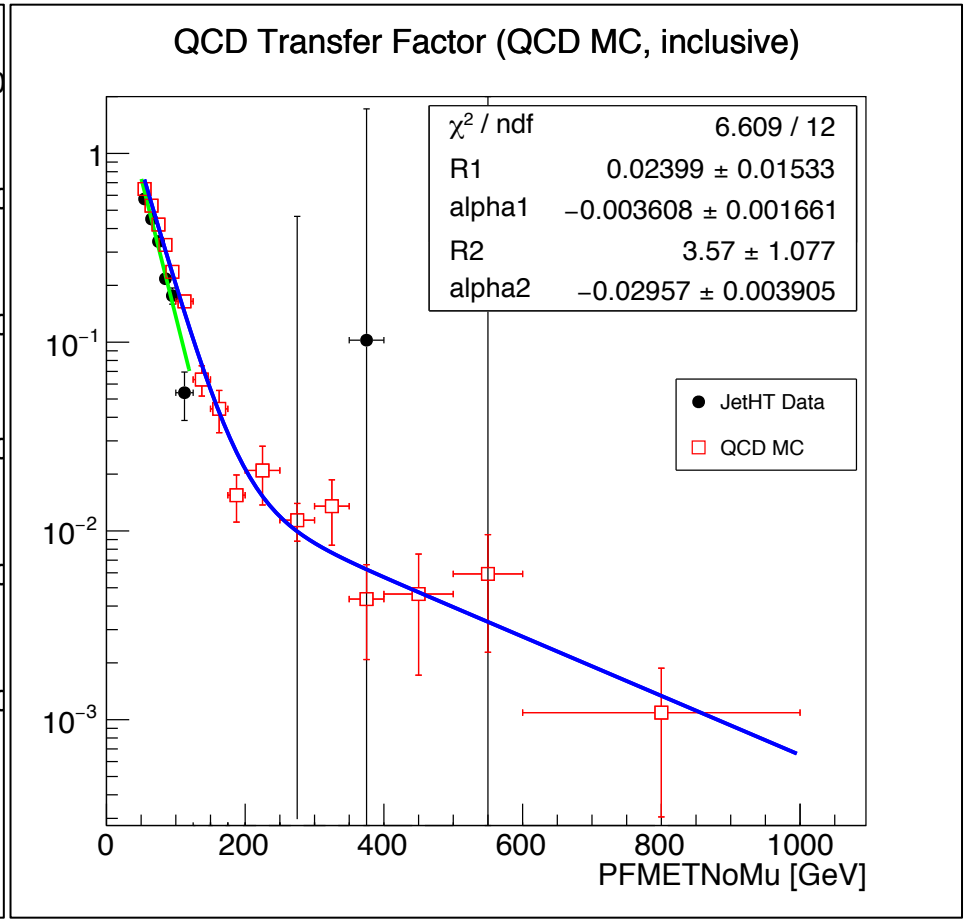
- Define exclusive offline HT bins (rough plateaus)
- Use a single trigger in each HT bin
- Scale up data points by prescale value
- No trigger nor offline HT cut in MC (skim MET>50)

✧ **HT distribution in signal region**

- Important to cover a wide HT spectrum
- Real-MET backgrounds: from 250 to 2000GeV

QCD Transfer factors : standard method





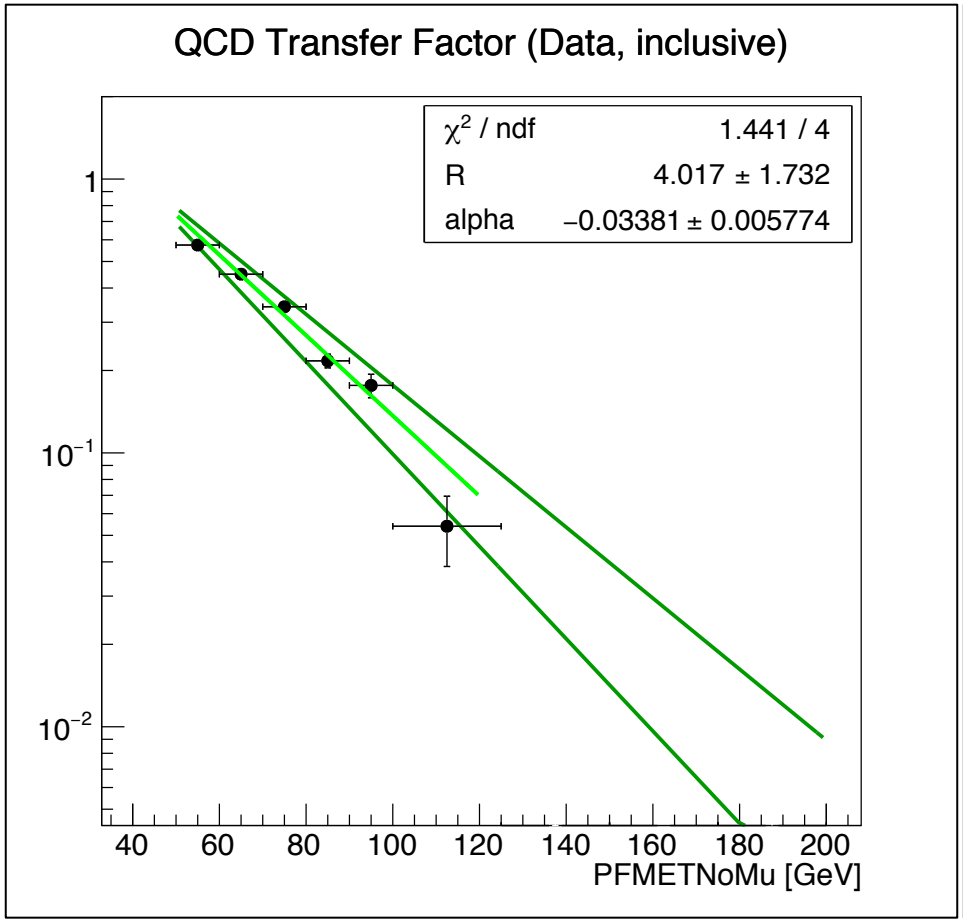
✧ **Compute Transfer Factors in each MET bin**

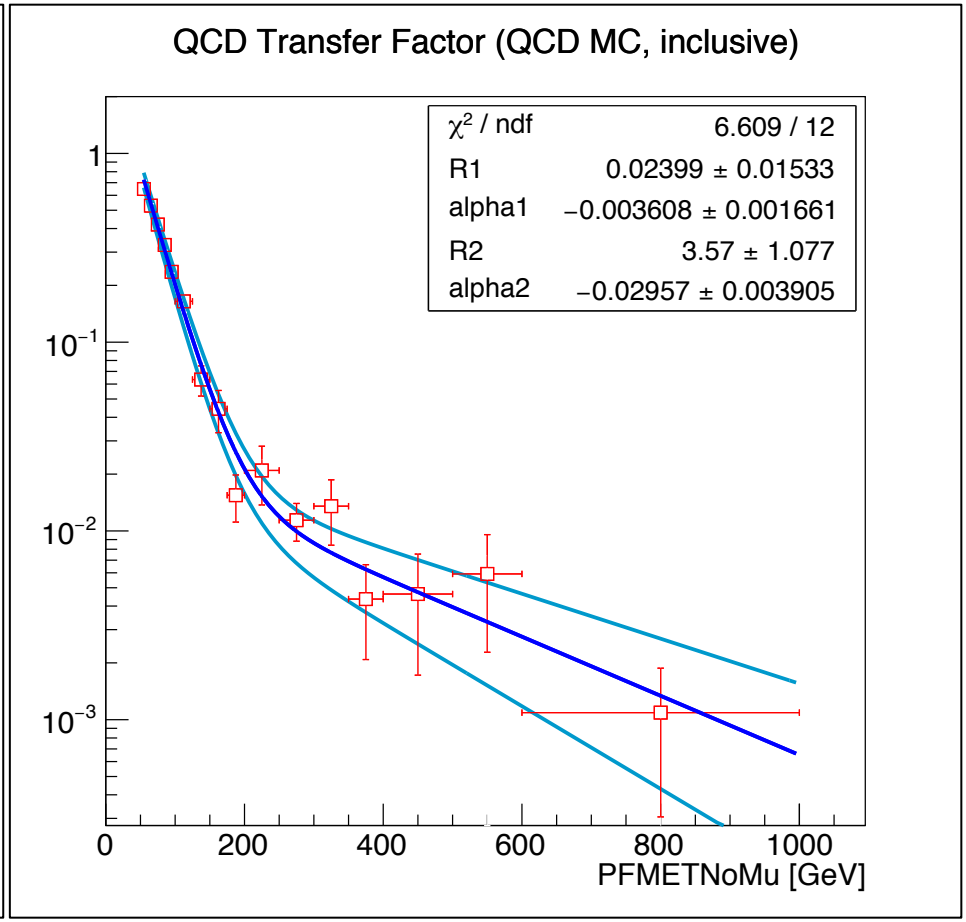
- For each MET Bin: TF = N/D
- Integral above the Δϕ cut / Integral below cut

✧ **Fit Transfer Factor**

- In Data: Single Exponential
- In MC : Double Exponential
- Combine one exp from MC and the exp from Data
- Obtain TF function of MET

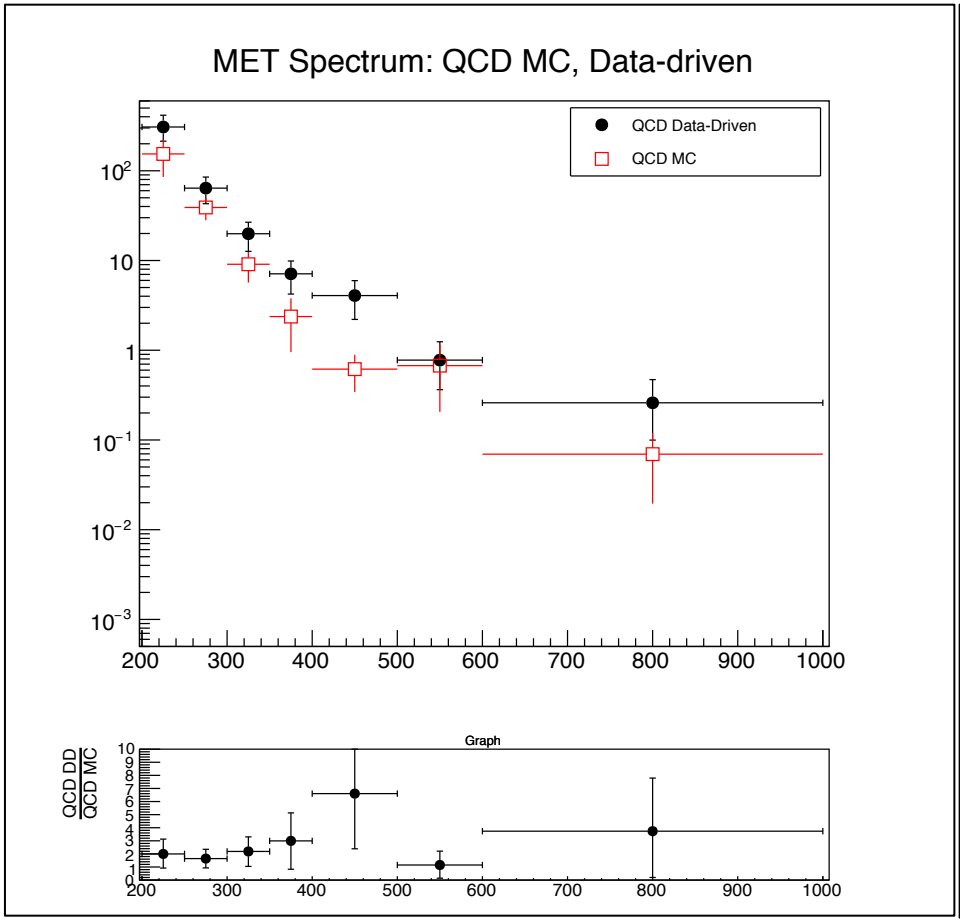
QCD Fit uncertainties

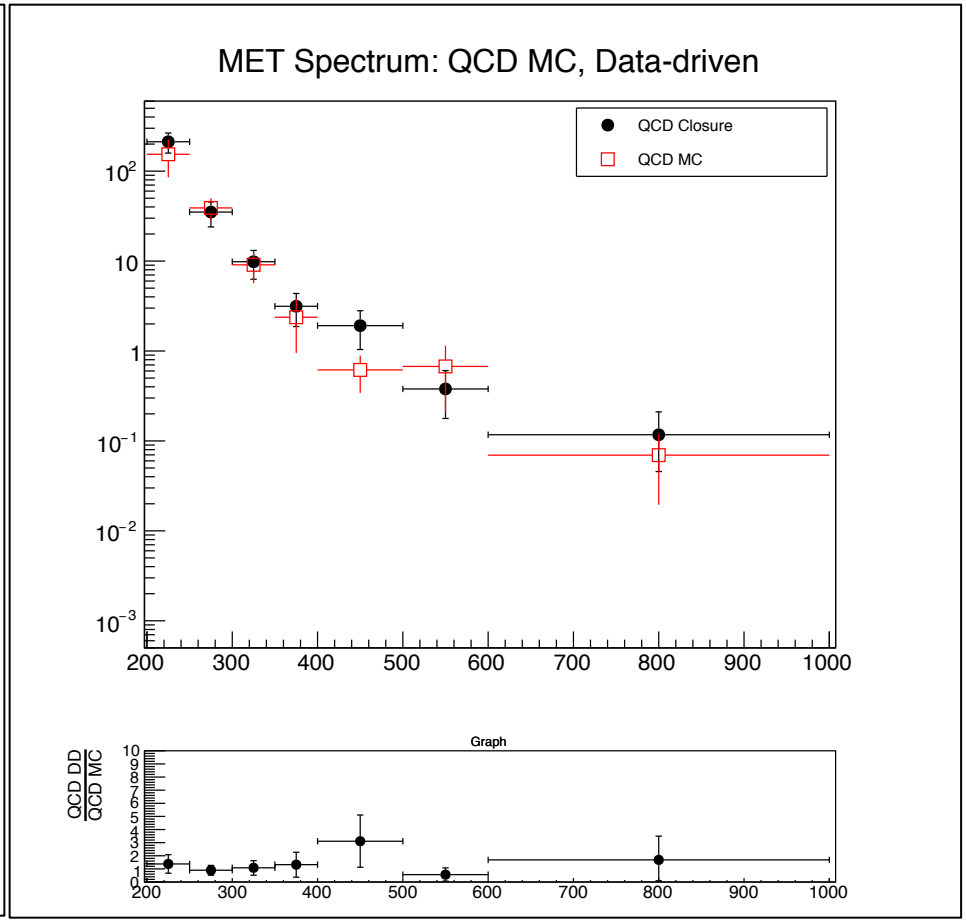




- Use fit function values and errors at each x-axis position to build up/down graphs
- Fit the shifted up/down graphs
- Obtain two additional functions
- Re-evaluate the MET spectrum using these up/down functions

QCD Prediction and Closure Test





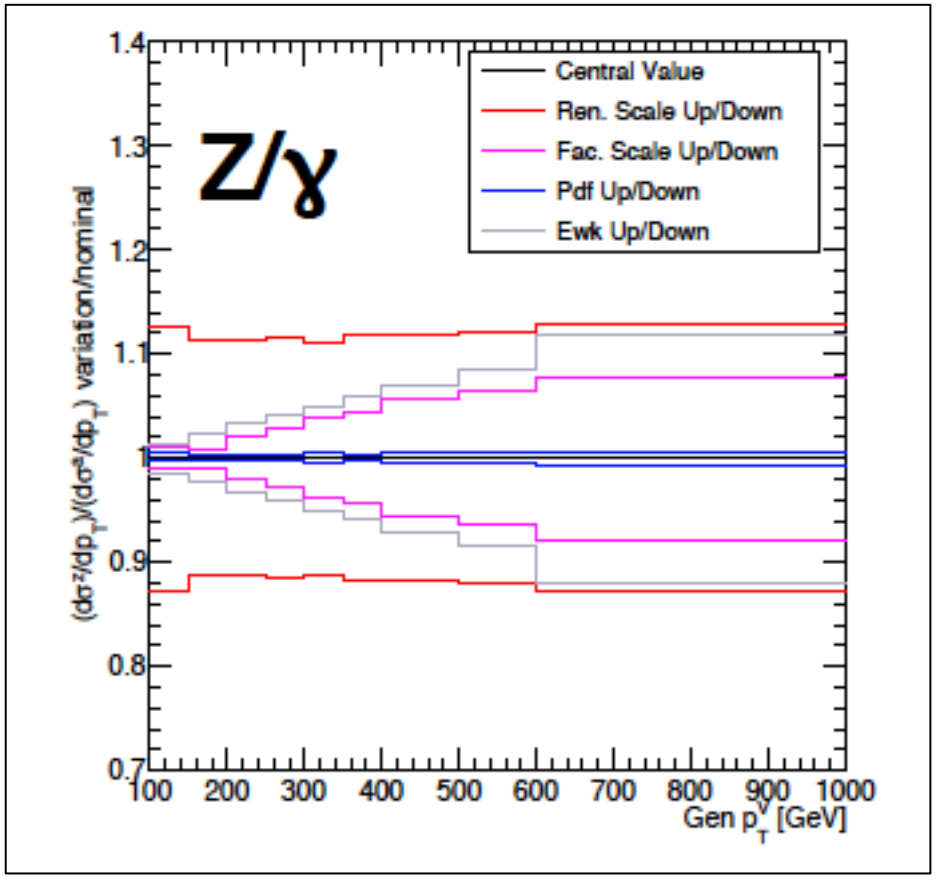
✧ QCD prediction

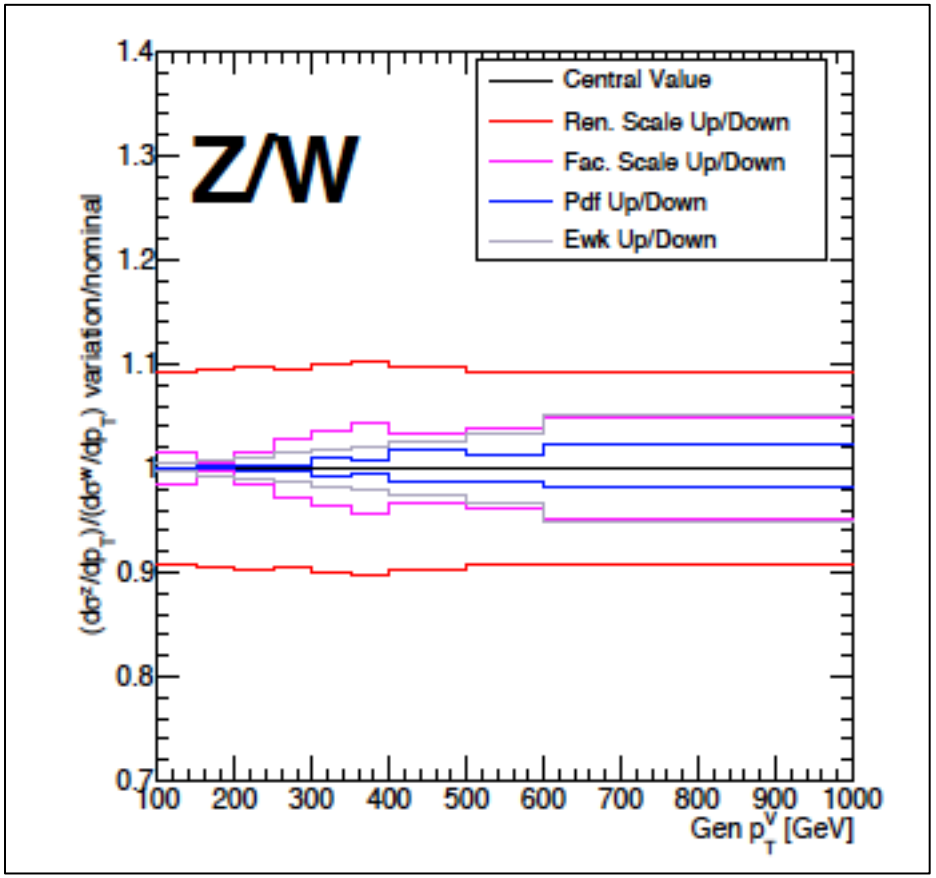
- Produce MET spectrum from MET data at low $\Delta\phi$
- Apply event weight using TF(MET) function
- Obtain the data-driven spectrum in signal region
- Propagate fit uncertainties into error bars here

✧ Closure test

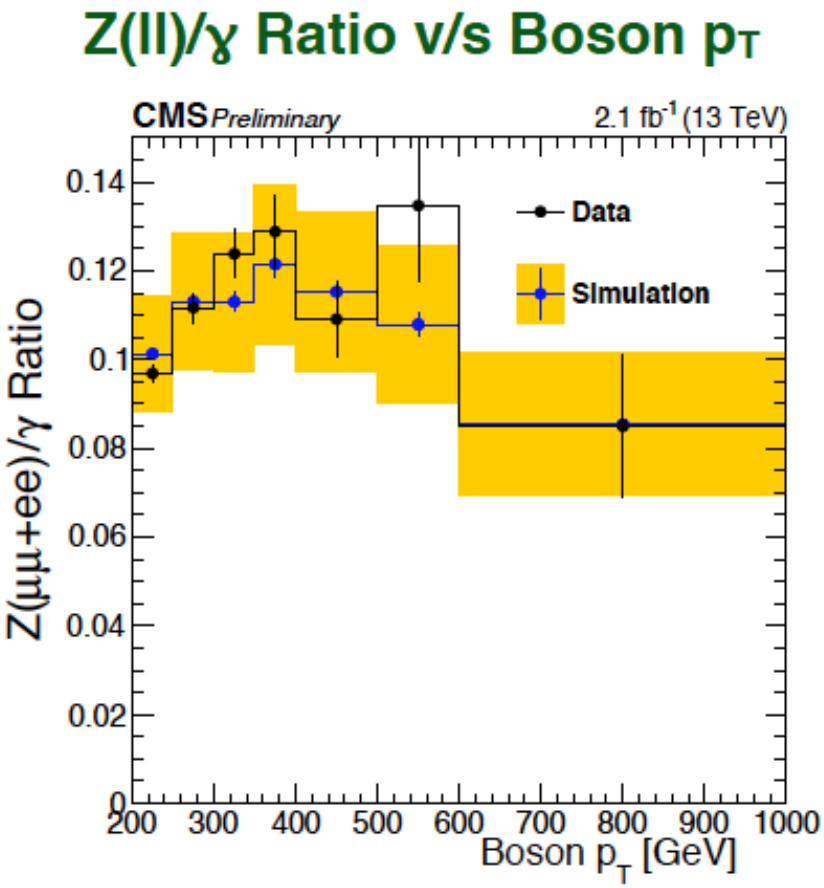
- Produce MET spectrum from QCD MC at low $\Delta\phi$
- Apply event weight using TF(MET) function
- Test pure MC TF function, then MC+Data combination
- Good closure except in the [400 ; 500] GeV bin

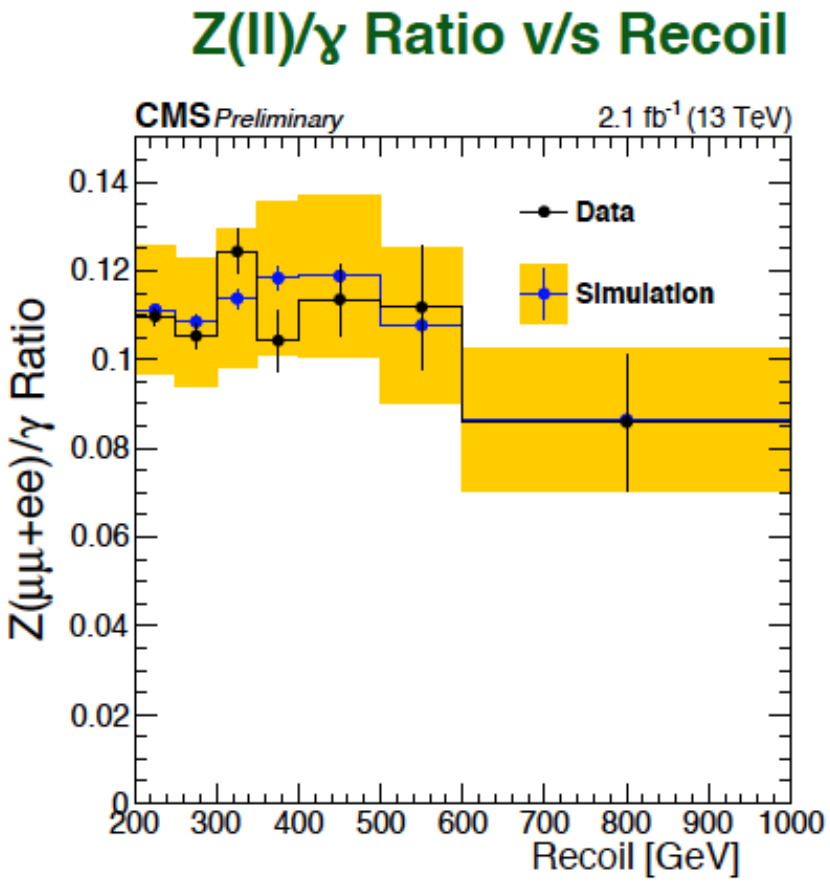
Cross section ratios





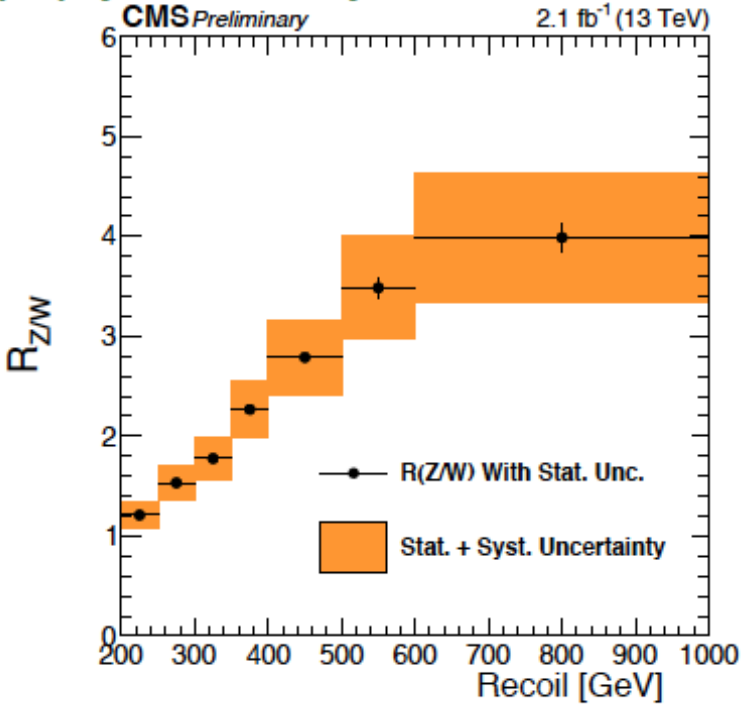
Cross section ratios: validation in data



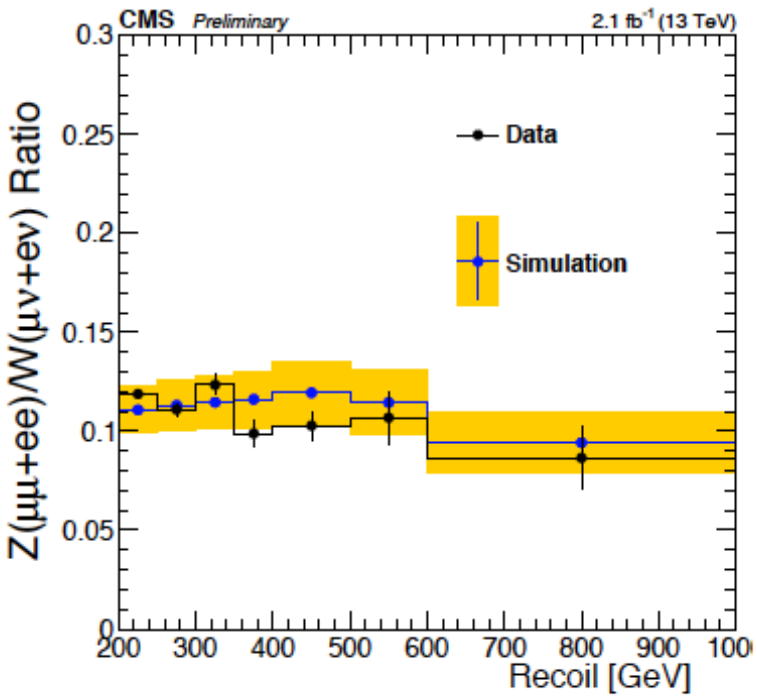


Z/W constraint

Z(vv)+jets ↔ W+jets Transfer Factor

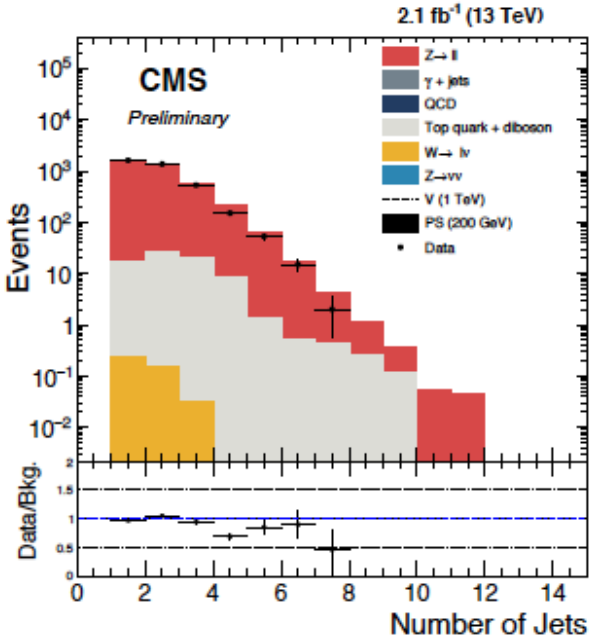


Validation with Z(ll)/W(lv) Events in Data

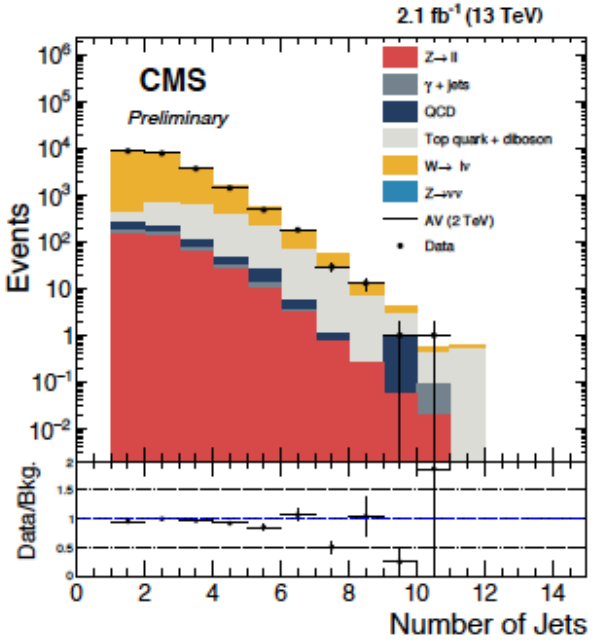


Control region: #Jets

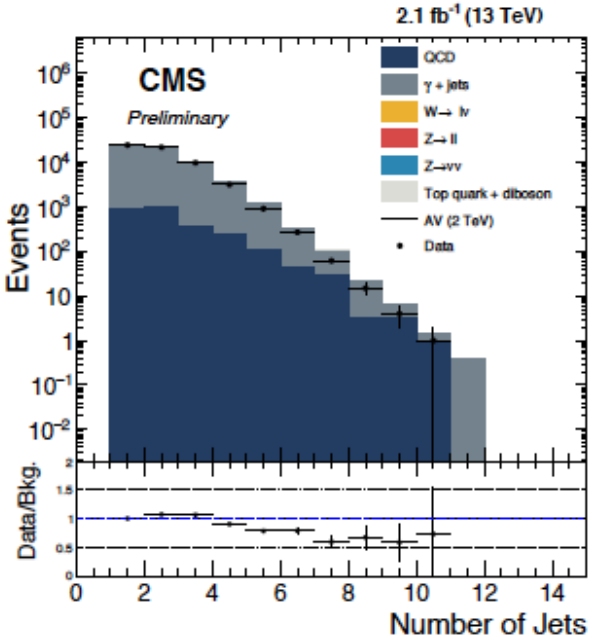
Z(μμ) Events



W(eν) Events

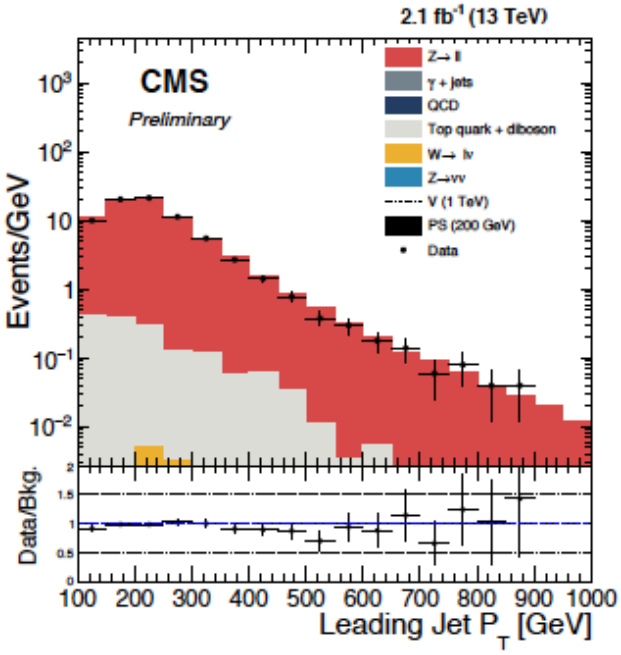


γ+jets Events

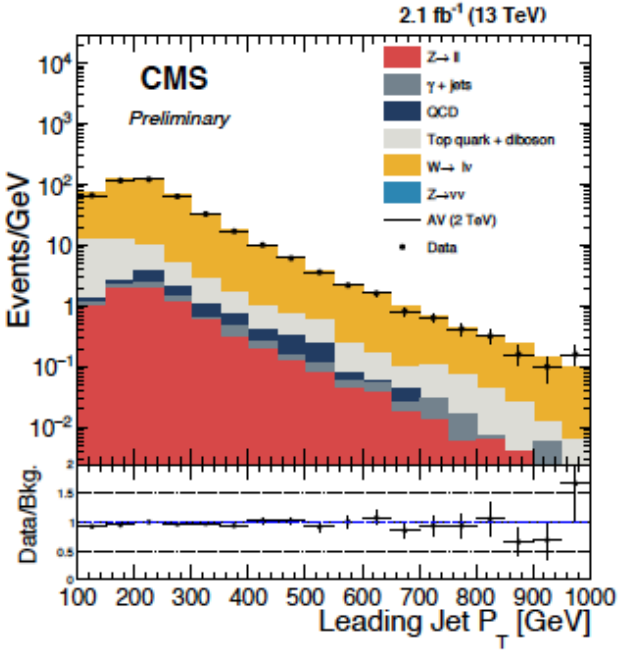


Control region: Leading jet pT

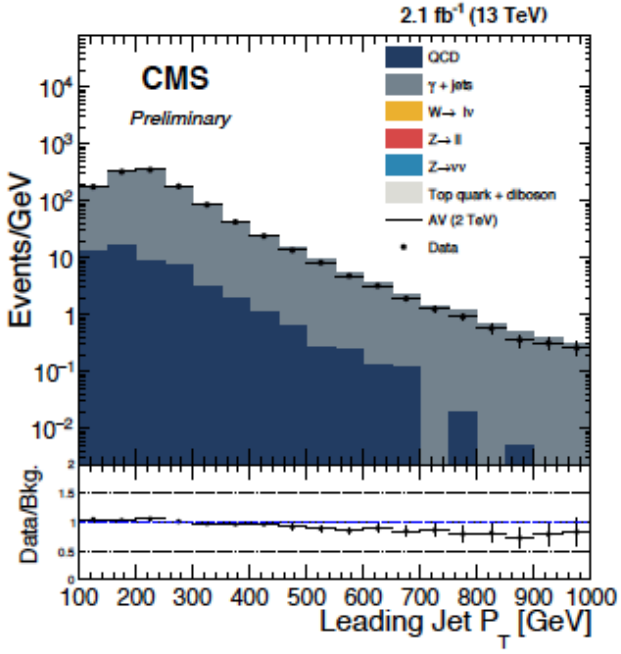
Z(μμ) Events



W(eν) Events

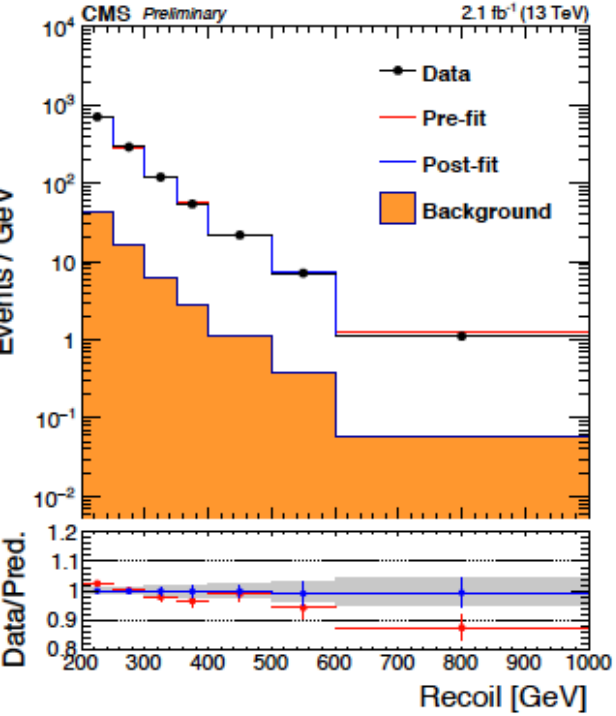


γ+jets Events

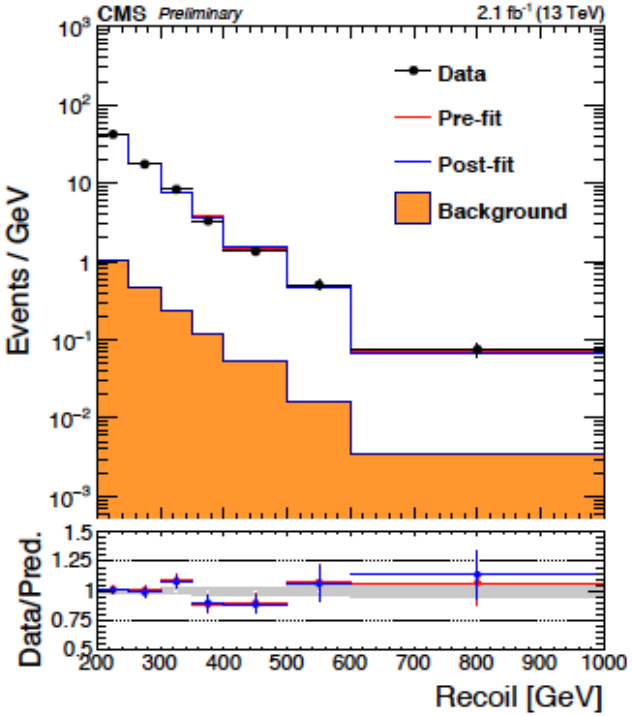


Control regions: postfit recoil

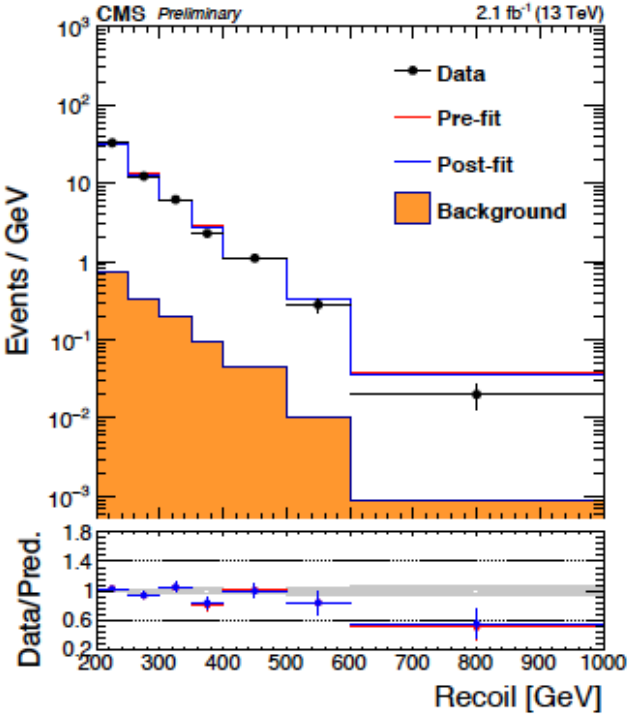
Photons



Dimuons

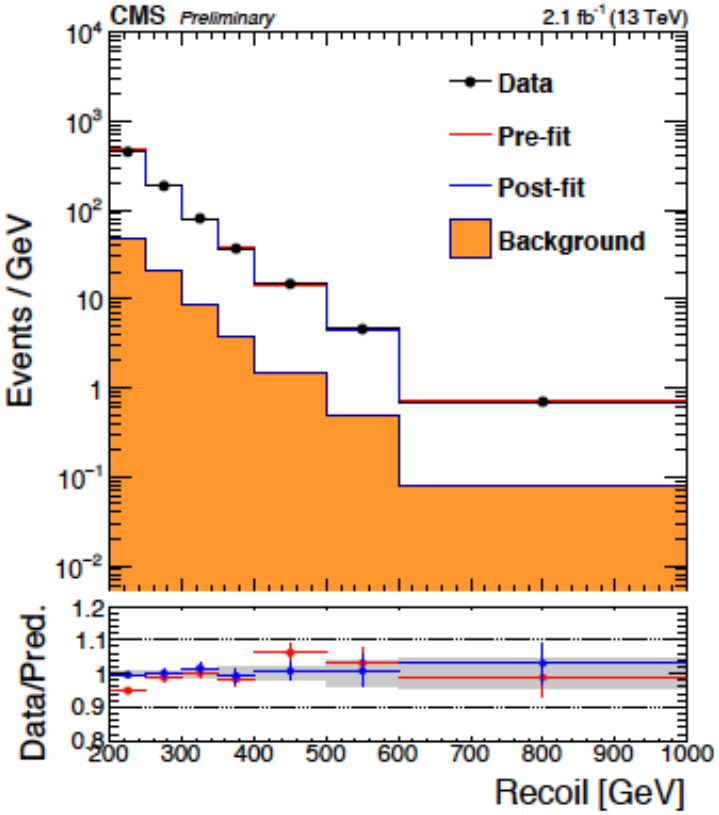


Dielectrons

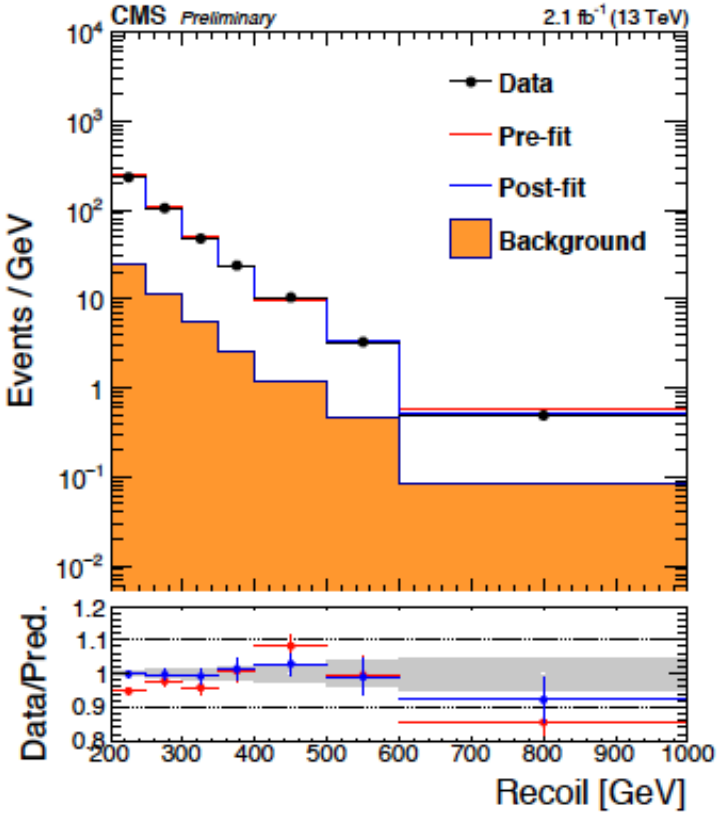


Control regions: postfit recoil

Single Muon

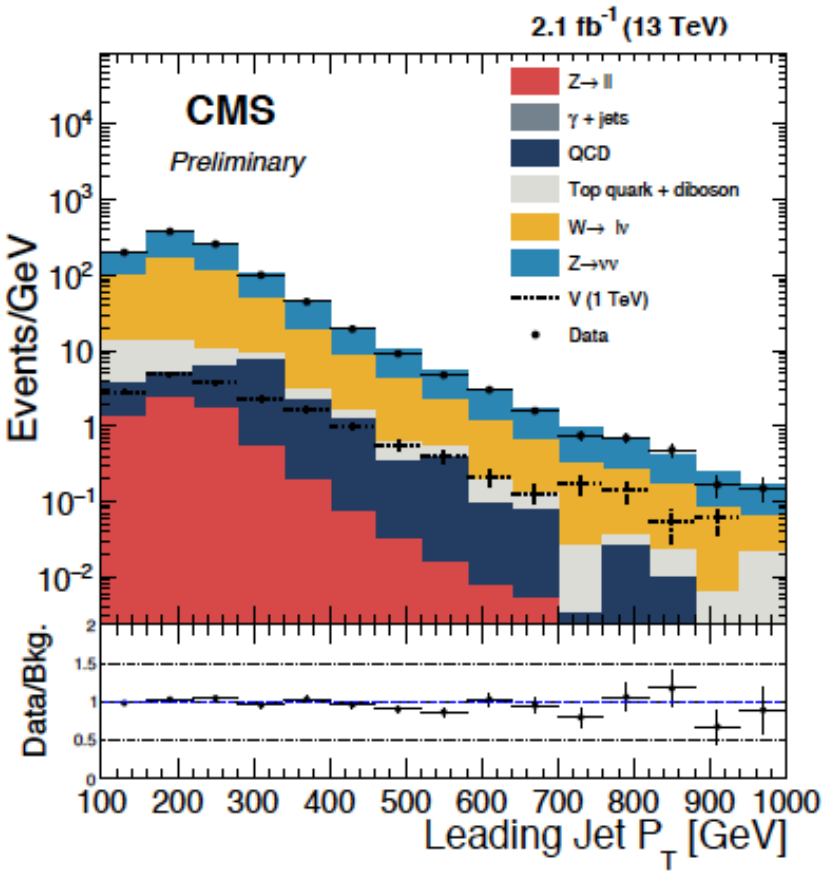


Single Electron

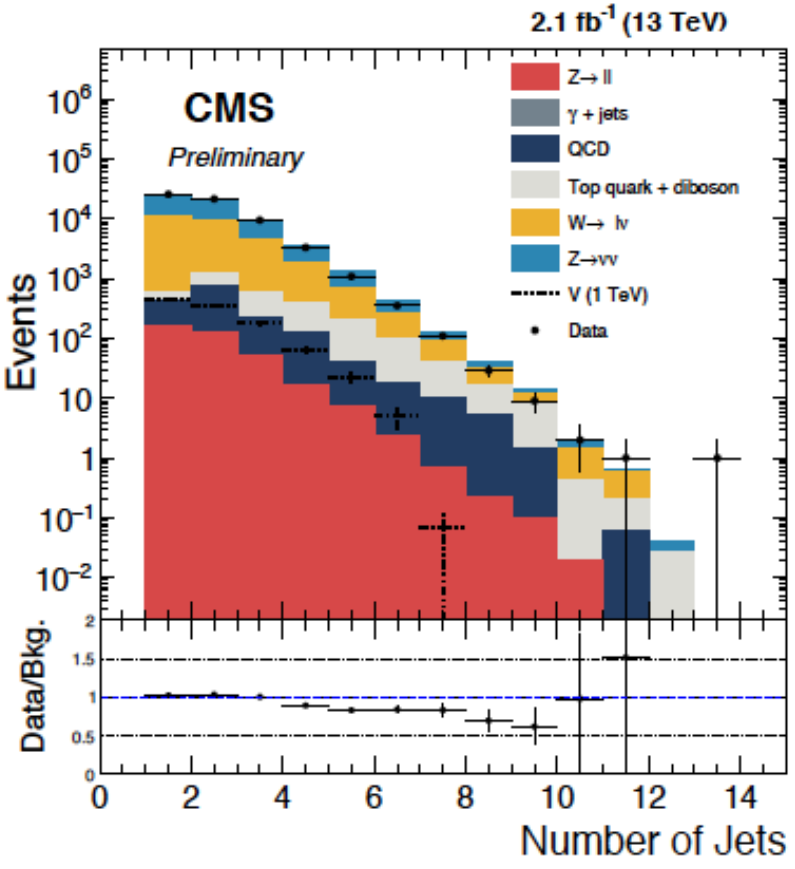


Signal region: postfit distributions

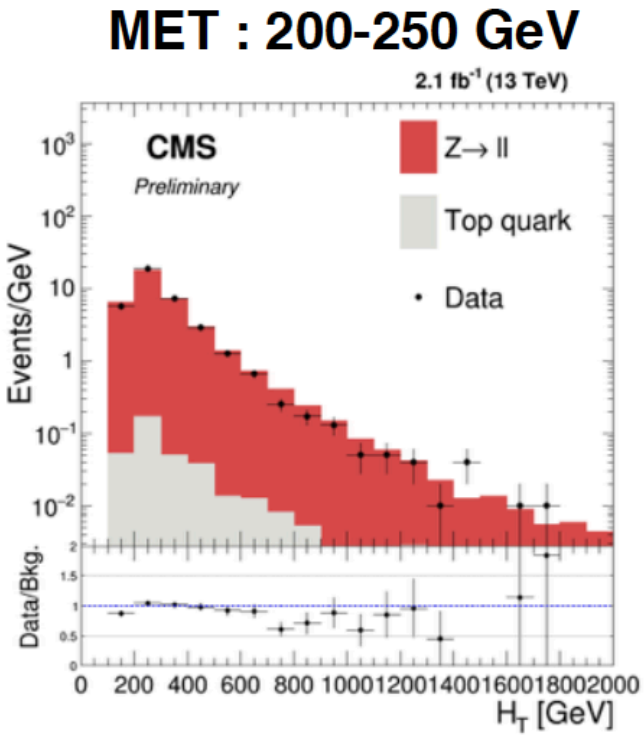
Post-fit Leading Jet p_T

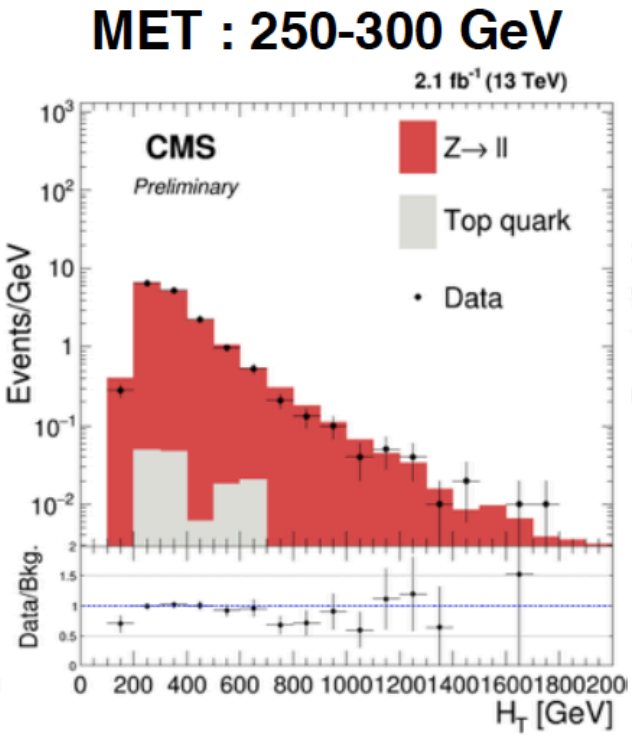


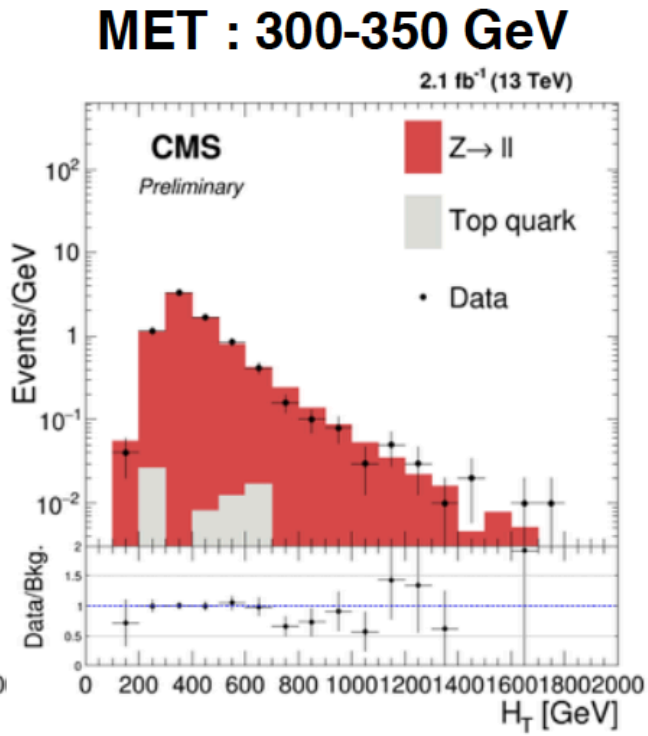
Post-fit Number of Jets



Signal region: postfit distributions







Limits: Axial-Vector mediator