Updates on triple gauge coupling from WW+WZ semileptonic (lνjj) analysis

Nural Akchurin[1], Jake Anderson[2], Andrew Beretvas[2], Jeffrey Berryhill[2], Pushpa Bhat[2], Chris Clarke[3], Phil Dudero[1], Ricardo Eusebi[4], Dan Green[2], Robert Harr[3], Pratima Jindal[5], Sung-Won Lee[1], Kalanand Mishra[2], Ilya Osipenkov[4], Alexx Perloff[4], Sasha Sakharov[3], Kevin Siehl[3], Andre Sznajder[6], Nhan V. Tran[2], Fan Yang[2], and Francisco Yumiceva[2]

[1] Texas Tech University, Lubbock, Texas, USA
[2] Fermi National Accelerator Laboratory, Batavia, Illinois, USA
[3] Wayne State University, Detroit, Michigan, USA
[4] Texas A&M University, College Station, Texas, USA
[5] University of Nebraska at Lincoln, Nebraska, USA
[6] Universidade do Estado do Rio de Janeiro (UERJ), Brazil

Qialg Li, Zijun Xu, Shuai Liu, Chayanit Asawatangtrakuldee: Peking University

Background material: my presentation in SMP-VV on Apr 20, 2012
https://indico.cern.ch/conferenceDisplay.py?confId=168019

Anomalous gauge couplings

14 independent couplings can completely describe the VWW vertices within the most generic framework of the SM EWK theory consistent with U(1) gauge invariance: 7 each for ZWW and γWW

$$\mathcal{L}_{anom} = ig_{WWZ}\Big[\Delta g_1^Z\left(W_{\mu\nu}^* W^\mu Z^\nu - W_{\mu\nu} W^{*\mu} Z^\nu\right) + \Delta\kappa^Z W_\mu^* W_\nu Z^{\mu\nu} + \frac{\lambda^Z}{M_W^2} W_{\rho\mu}^* W_\nu^\mu Z^{\nu\rho}\Big] + ig_{WW\gamma}\Big[\Delta\kappa^\gamma W_\mu^* W_\nu \gamma^{\mu\nu} + \frac{\lambda^\gamma}{M_W^2} W_{\rho\mu}^* W_\nu^\mu \gamma^{\nu\rho}\Big],$$

- **In reality, only a few of these parameters are experimentally measured**
  - Impose EM invariance $g_1^\gamma = 1$
  - Need CP-odd quantity to measure CP-odd effects: set all tilde-marked and g_4^V to zero (SM values)
  - Assume C- and P-conservation: $g_5^V = 0$
  - After all these assumption we have five independent complex couplings: g_1^Z, κ_γ, κ_Z, λ_γ and λ_Z
- **Experimenters further reduce the number using different schemes**

Different TGC parameterizations

from Yurii Maravin

- LEP parameterization (Δ is defined as a difference from the SM prediction)
  - light Higgs boson scenario

$$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \cdot tan^2\theta_w \quad \text{and} \quad \lambda_Z = \lambda_\gamma = \lambda$$

  - Effectively reduces number of unknown variables to three
    - For Wγ this reduces the number of free parameters to two

Used at Tevatron, and being pursued in CMS WW leptonic analysis. **Implemented in MCFM.**

- Hagiwara-Ishihara-Szalapski-Zeppenfeld (HISZ)
  - Assumes the coupling between SU(2) × U(1) fields and Higgs double are the same

$$\Delta\kappa_Z = \frac{1}{2}\Delta\kappa_\gamma(1 - tan^2\theta_w), \Delta g_1^Z = \frac{\Delta\kappa_\gamma}{2cos^2\theta_w} \quad \text{and} \quad \lambda_Z = \lambda_\gamma = \lambda$$

  - Reduces number of free parameters to two

- Equal coupling relation
  - Two free parameters

$$\Delta g_1^Z = \Delta g_1^\gamma = 0$$

$$\Delta\kappa_Z = \Delta\kappa_\gamma \quad \text{and} \quad \lambda_Z = \lambda_\gamma = \lambda$$

Unitarity: cut-off scale dependence

Any anomalous TGC violates unitarity at sufficiently large energies

Theorists prefer to scale the couplings with energy

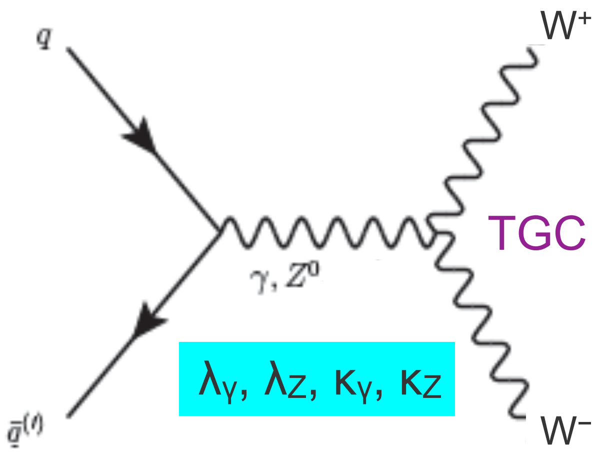
$$\Delta g_1^Z \to \frac{\Delta g_1^Z}{(1+\hat{s}/\Lambda^2)^2}, \qquad \Delta\kappa^{Z/\gamma} \to \frac{\Delta\kappa_1^{Z/\gamma}}{(1+\hat{s}/\Lambda^2)^2}, \qquad \lambda^{Z/\gamma} \to \frac{\Delta\lambda^{Z/\gamma}}{(1+\hat{s}/\Lambda^2)^2},$$

- Tevatron results followed this approach and set limits
  - Several ways to choose Λ (increasing its value makes α_0 limit smaller but at some point unitarity constraint becomes more restrictive than the limit in data itself)
  - Note DØ results have Λ = 500 GeV for early data set, then 750 GeV, with recent results 1.5 TeV
- LEP did not assume any energy dependence and set limits on $\alpha(\hat{s})$

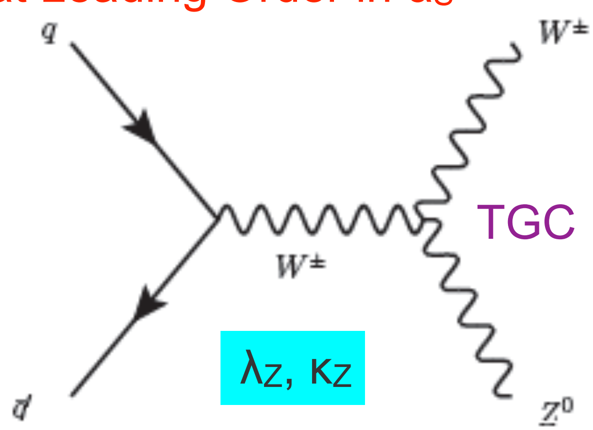
CMS and ATLAS have been following Tevatron approach (although using different scale values). Can set limit for a few different scale values and provide extrapolations.

Accessible in the present analysis

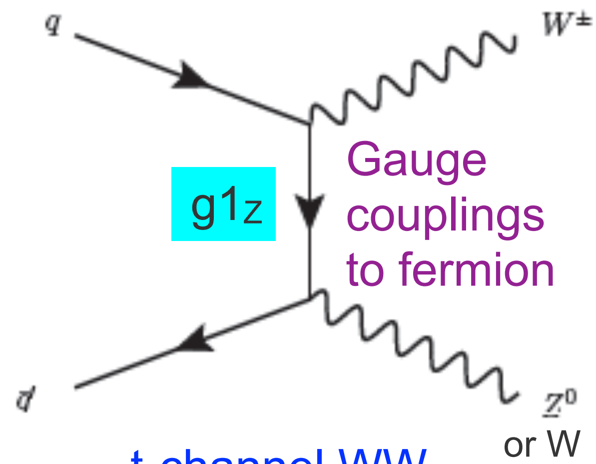
at Leading Order in α_S



s-channel WW production



s-channel WZ production



t-channel WW, WZ production

Our plan:

1.Following LEP and Tevatron, we can set: $\lambda_\gamma = \lambda_Z = \lambda$
Additionally, gauge coupling to fermions are highly constrained, so assume

$$\Delta g_1^Z = 0 \text{ (i.e., SM)} \quad \Longrightarrow \quad \Delta\kappa_Z = -\Delta\kappa_\gamma \cdot tan^2\theta_w$$

2. We need to consider a few choices of cutoff scale (Λ): 2 TeV, 7 TeV, 10 TeV.

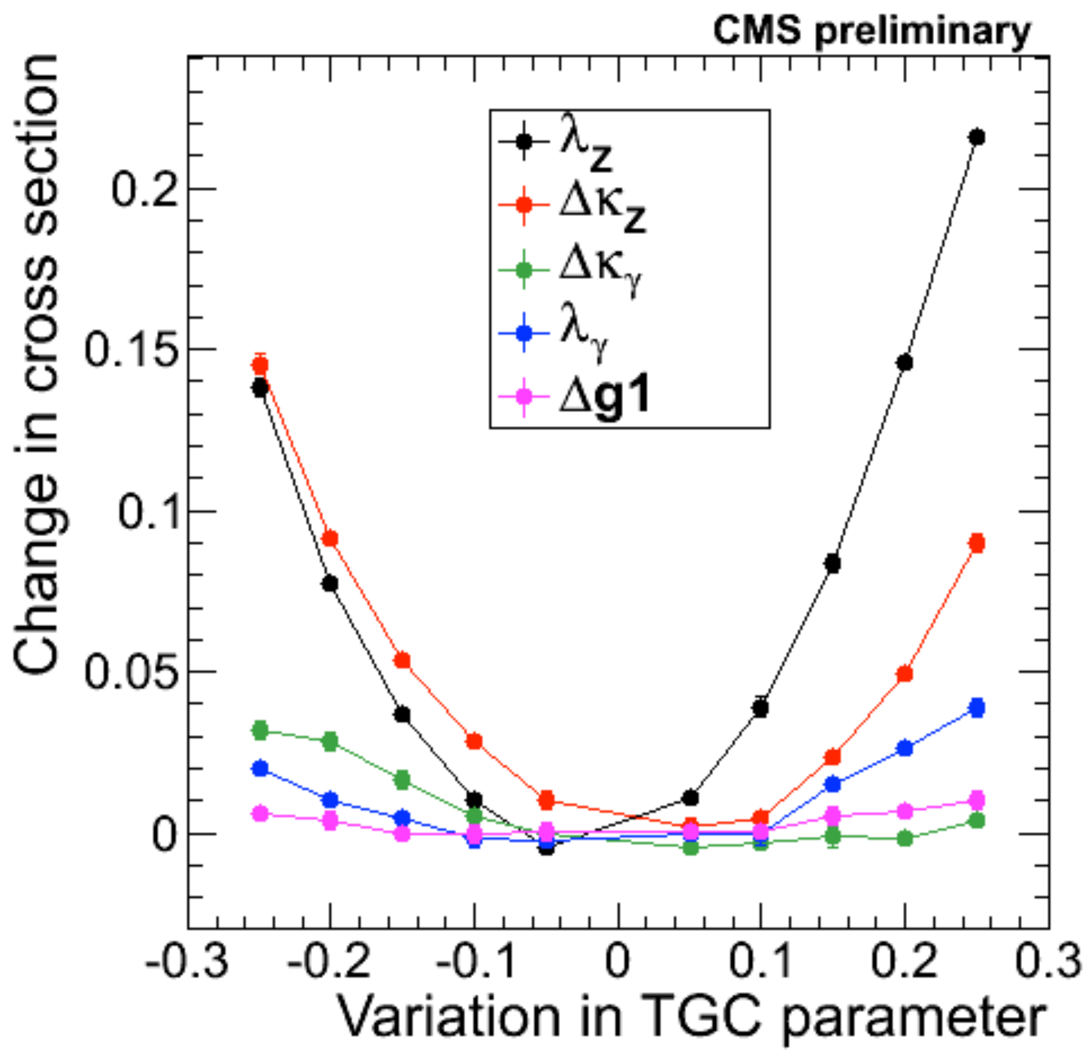
So, we will set limits on aTGC in the (λ, κ) plane. (two independent parameters)

Independent variations of the 5 couplings

- For the feasibility study, I varied each of the 5 couplings independently
  - -highly conservative ⇒ the goal was to determine the ball park estimate
  - -sensitivity estimate is conservative/pessimistic
  - -in actual limit setting, we will vary aTGC parameters in a coordinated way following the scheme described in the previous slide

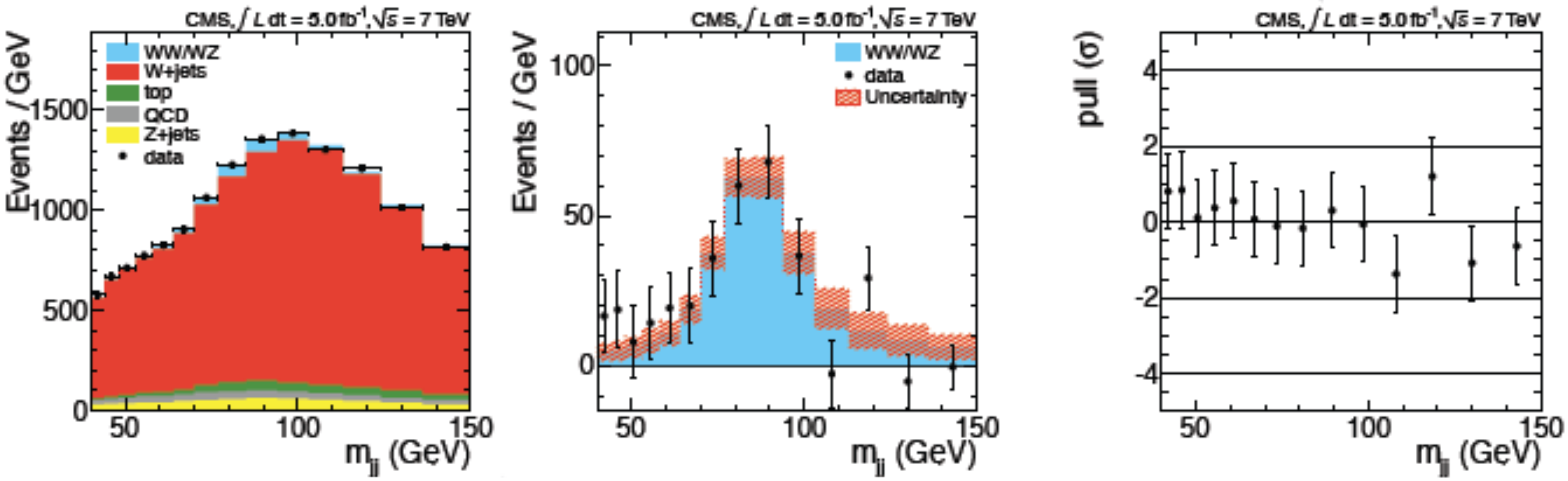
- Plots from the feasibility study are shown in the next slides
  - -chose the cutoff scale Λ = 2 TeV for these studies

aTGC scan: effect on cross section



- Visible change in cross section from change in aTGC parameter.
- We should be sensitive to > 20% change in cross section. See next slide.

Cross section has some information ....



Event category	Measured cross section
μjj	67.11 ± 15.04 pb
ejj	55.00 ± 22.85 pb
μjj,b-tag	70.32 ± 63.16 pb
ejj,b-tag	20.92 ± 51.41 pb
Theory Prediction [4]	65.6 ± 2.2 pb

NLO, MCFM

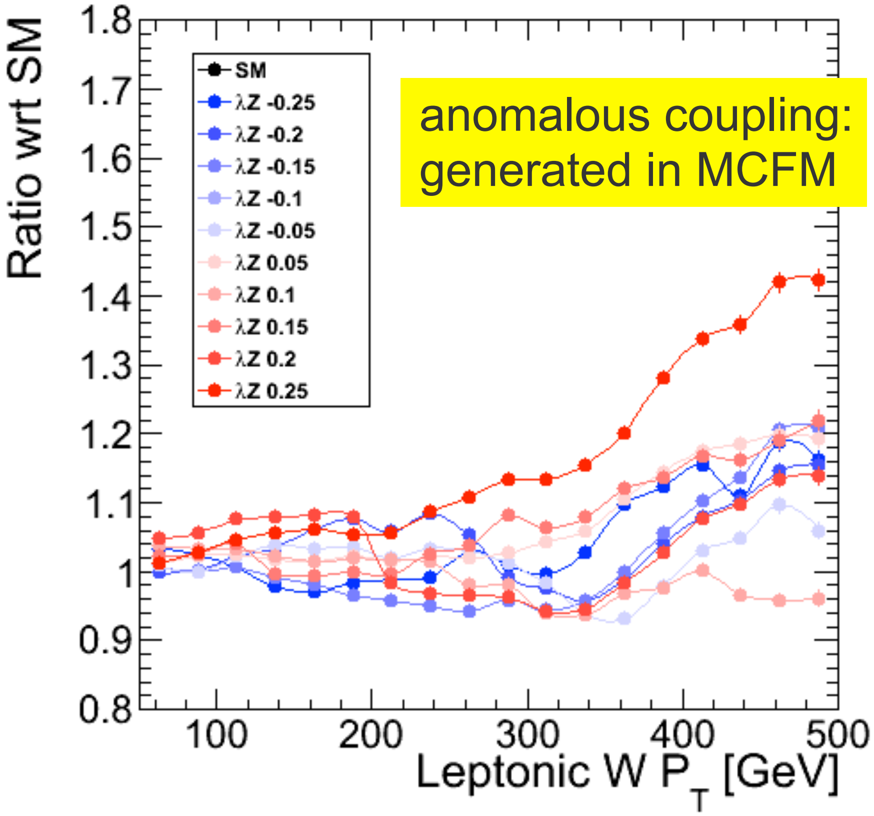
$$\sigma = \frac{N^{\mathrm{Sig}}}{A\,\epsilon\,\mathcal{L}}$$

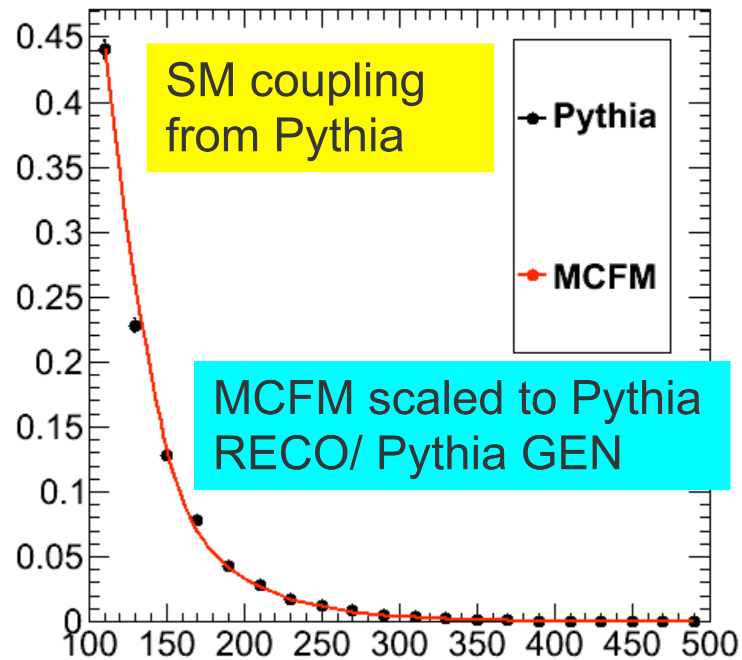
Combining all four channels we obtain:

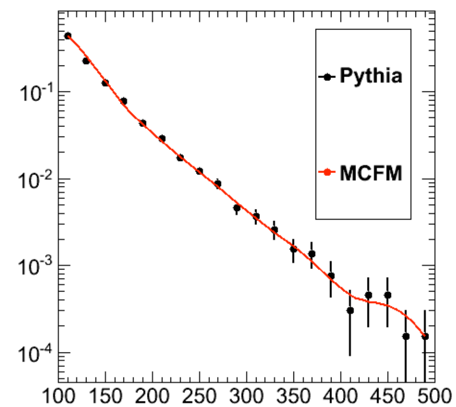
$$\sigma = 61.39 \pm 11.98 \text{ pb}$$

#diboson = 2724 ± 540, MC prediction = 2885

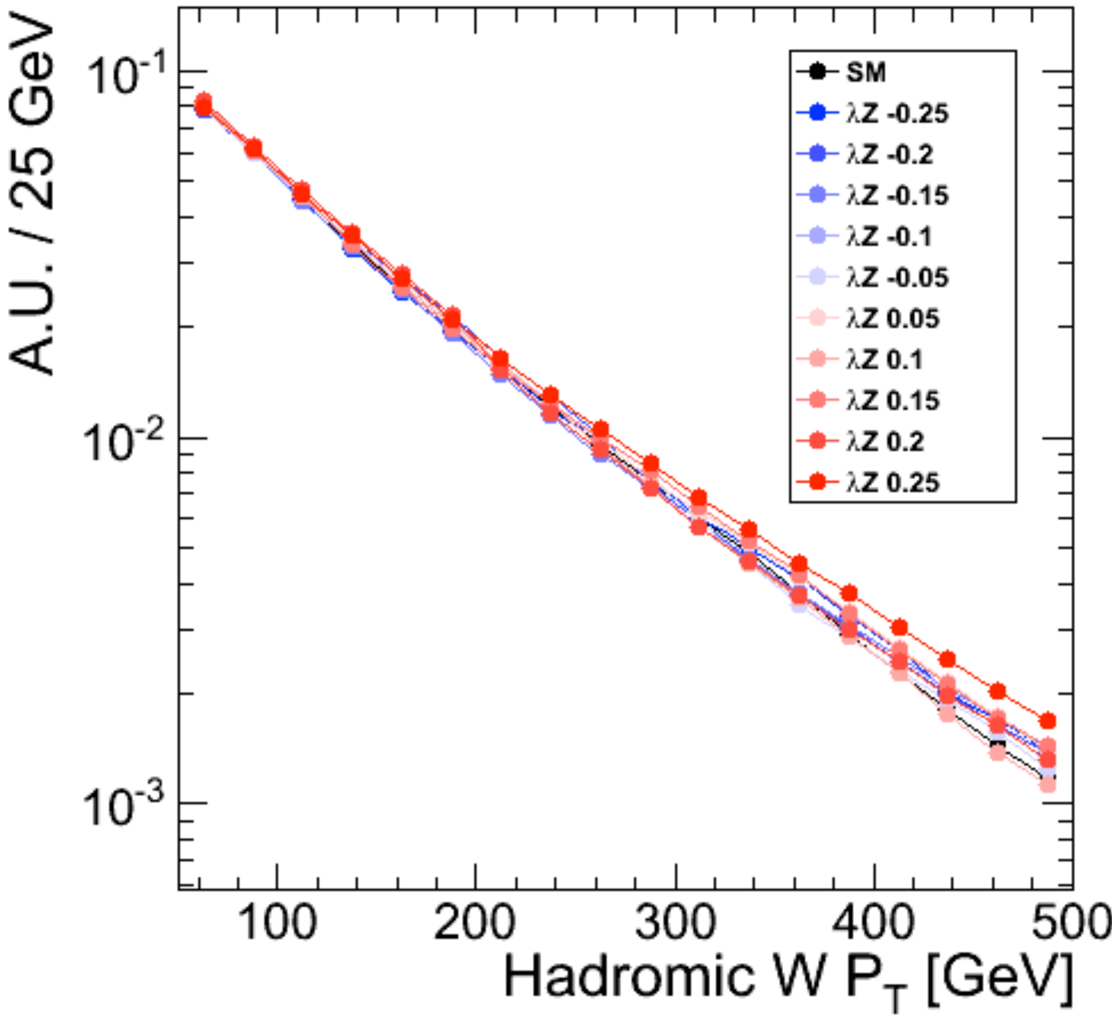
But also get more help from shape ....

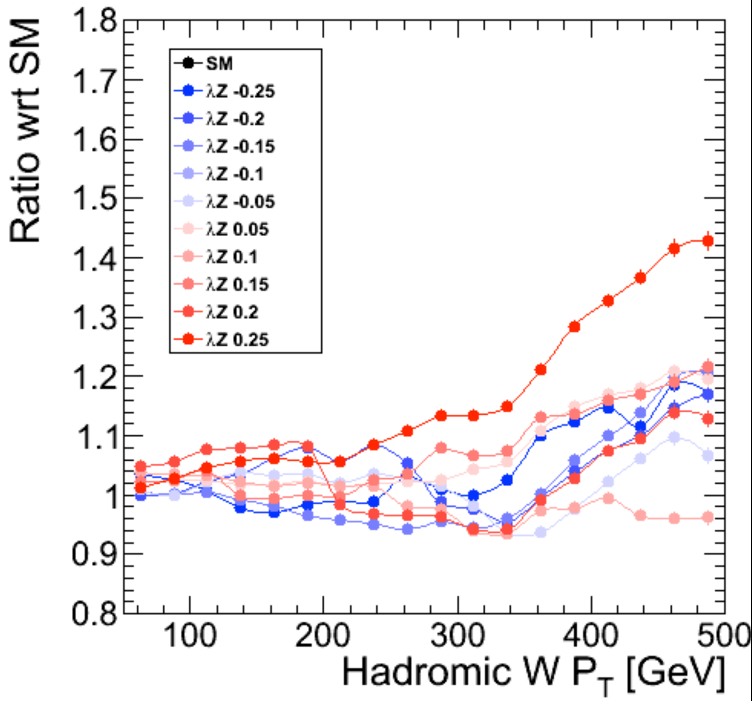






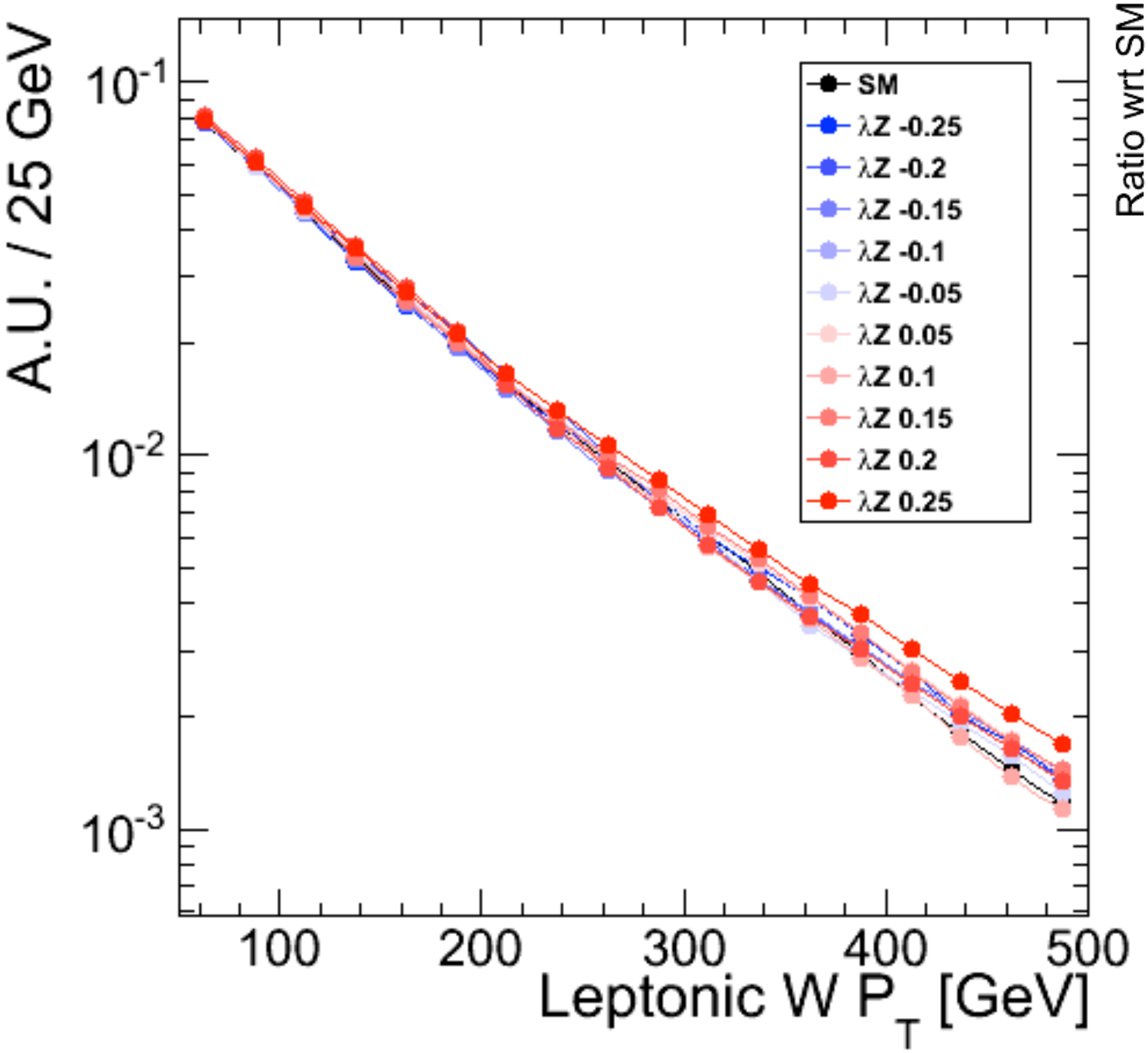
Effect on shape: dijet pT

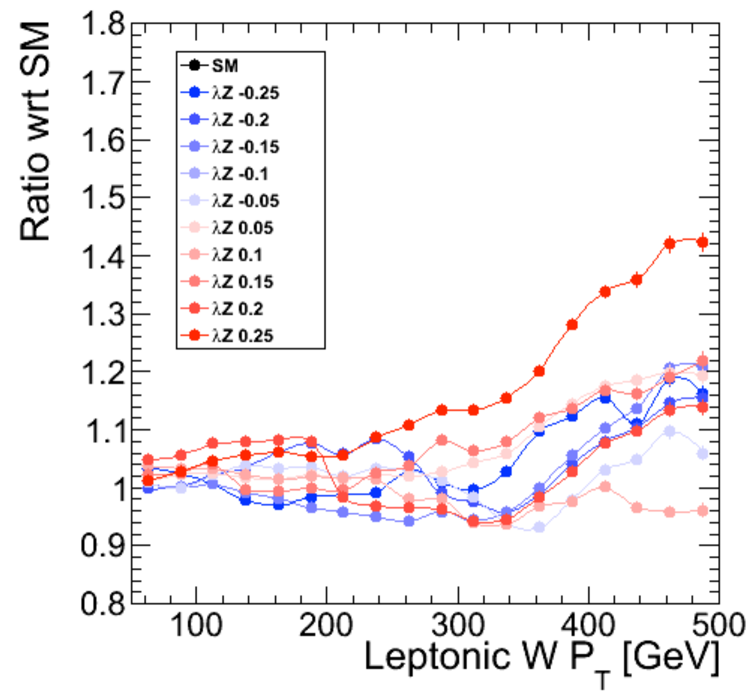




The W pT takes off beyond 200 GeV. Need more MC events in the tail. For this test generated 20k/ sample.

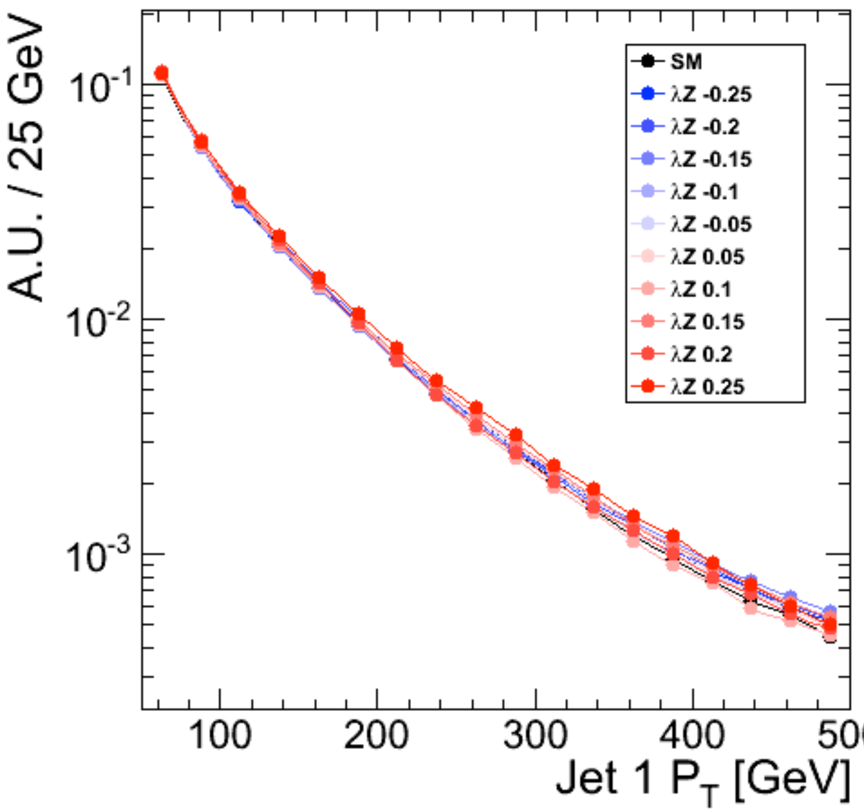
Effect on shape: leptonic W pT

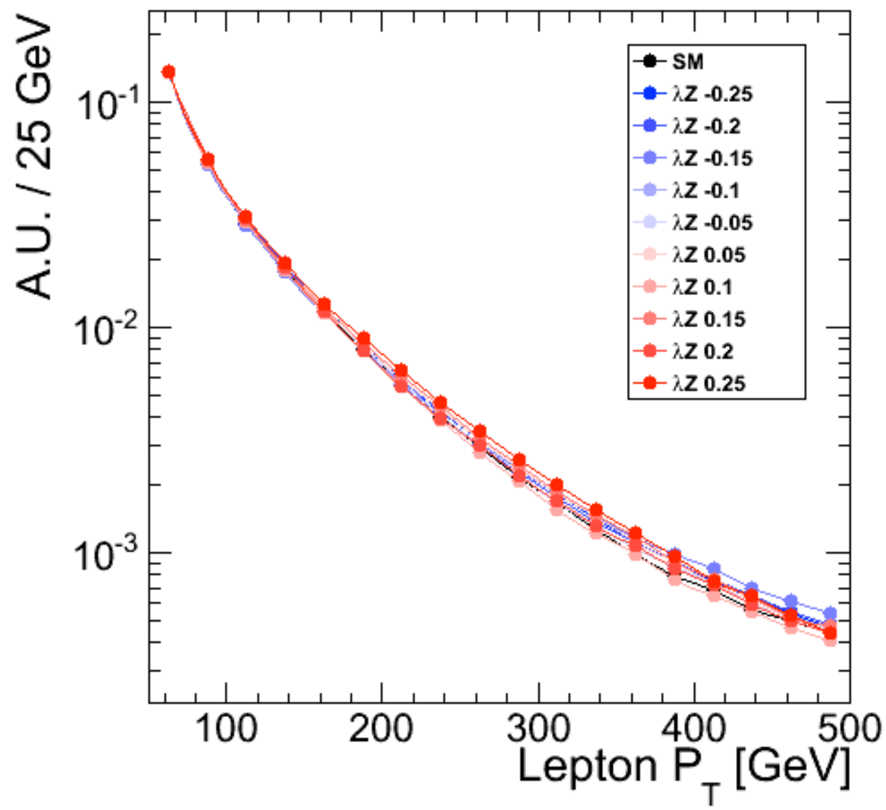




Practically same as hadronic W p_T; highly correlated. Will use one of these (whichever gives better resolution/ agreement with MC) as observable.

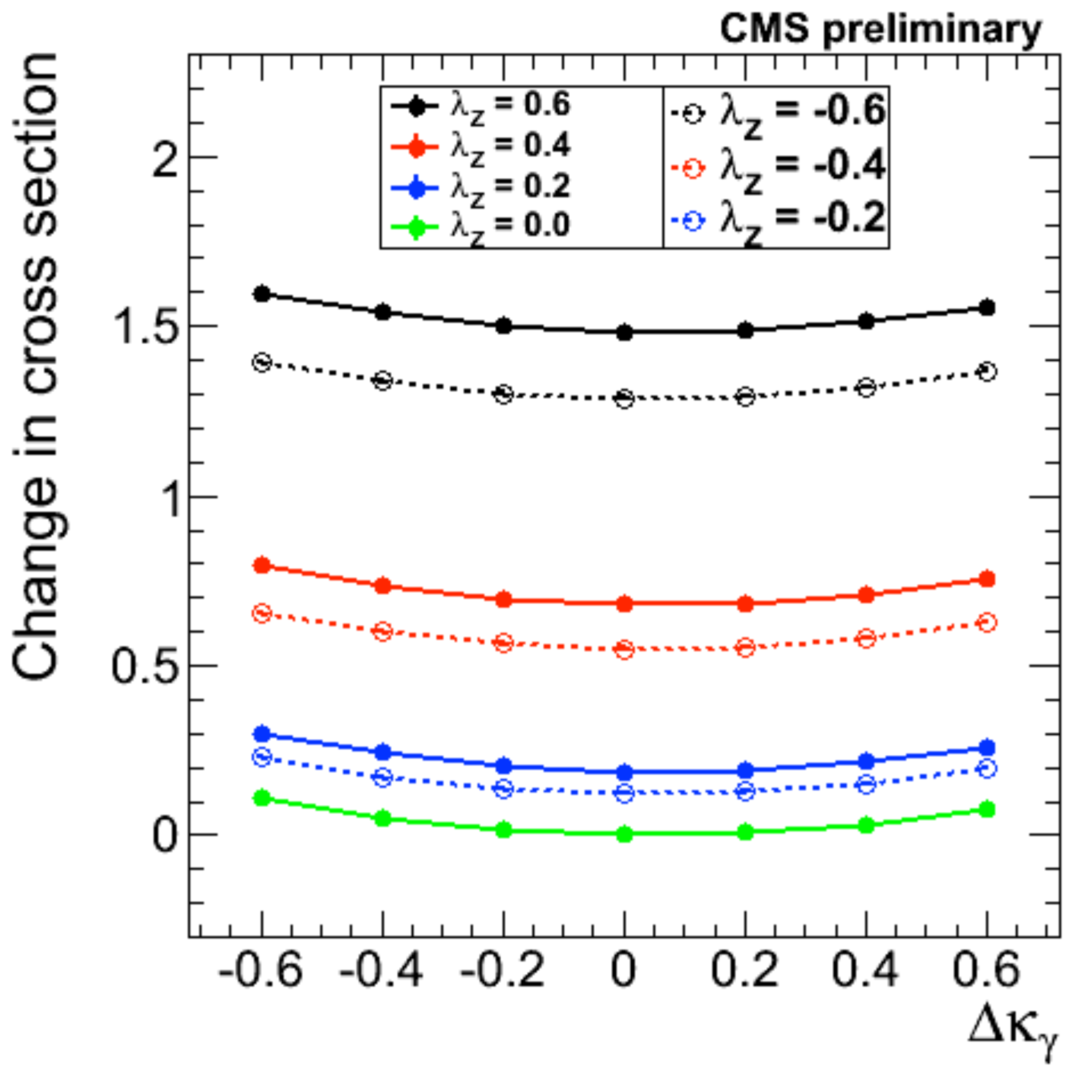
Effect on shape: other variables aren't good





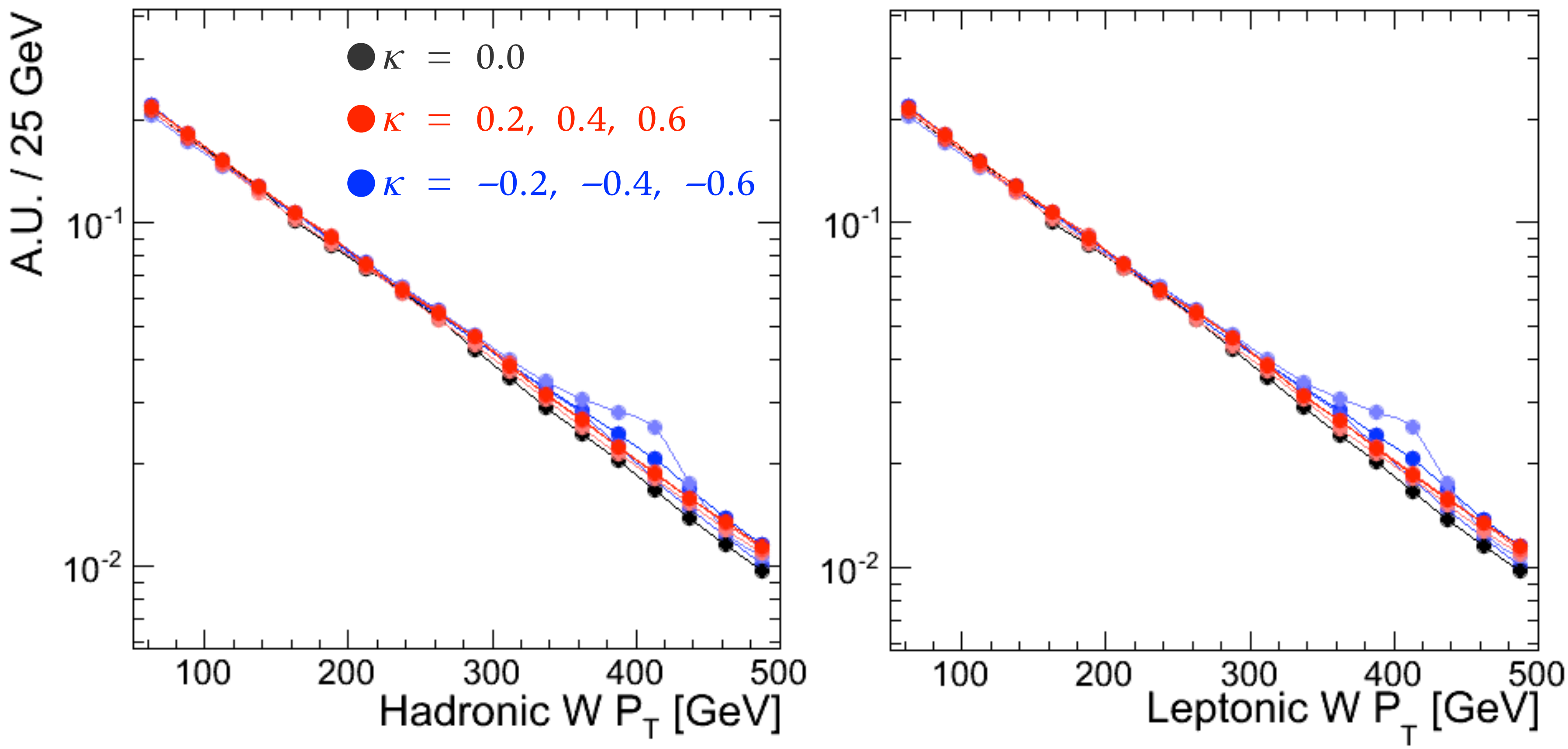
Not very sensitive.

Variations following the scheme of slide 5



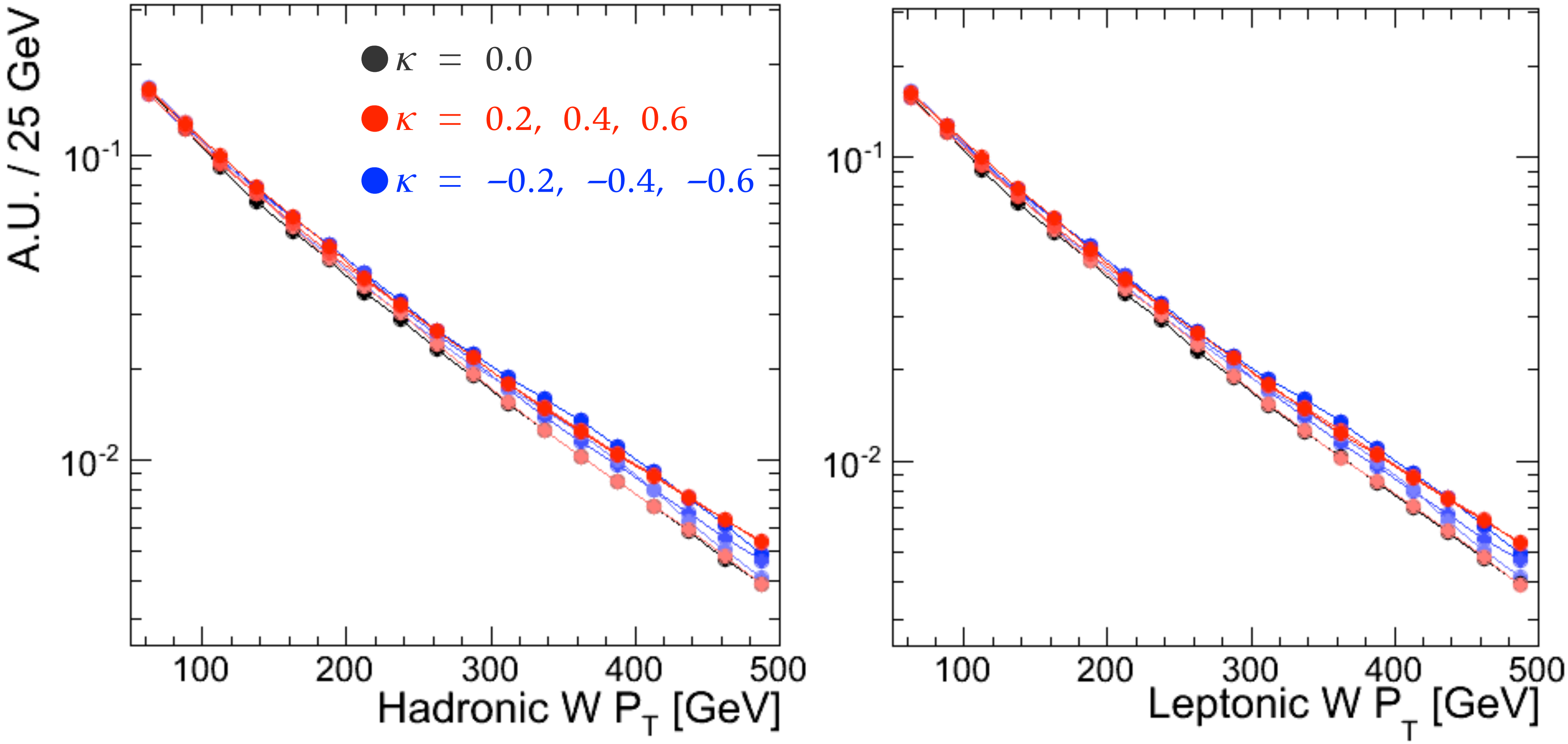
- Generated grid pack for variation in (Λ, $\Delta\kappa$) plane
- 100k events/ sample
- Somewhat larger change in cross section compared to slide 8
- Similar conclusions as before

W pT (Λ=−0.6)



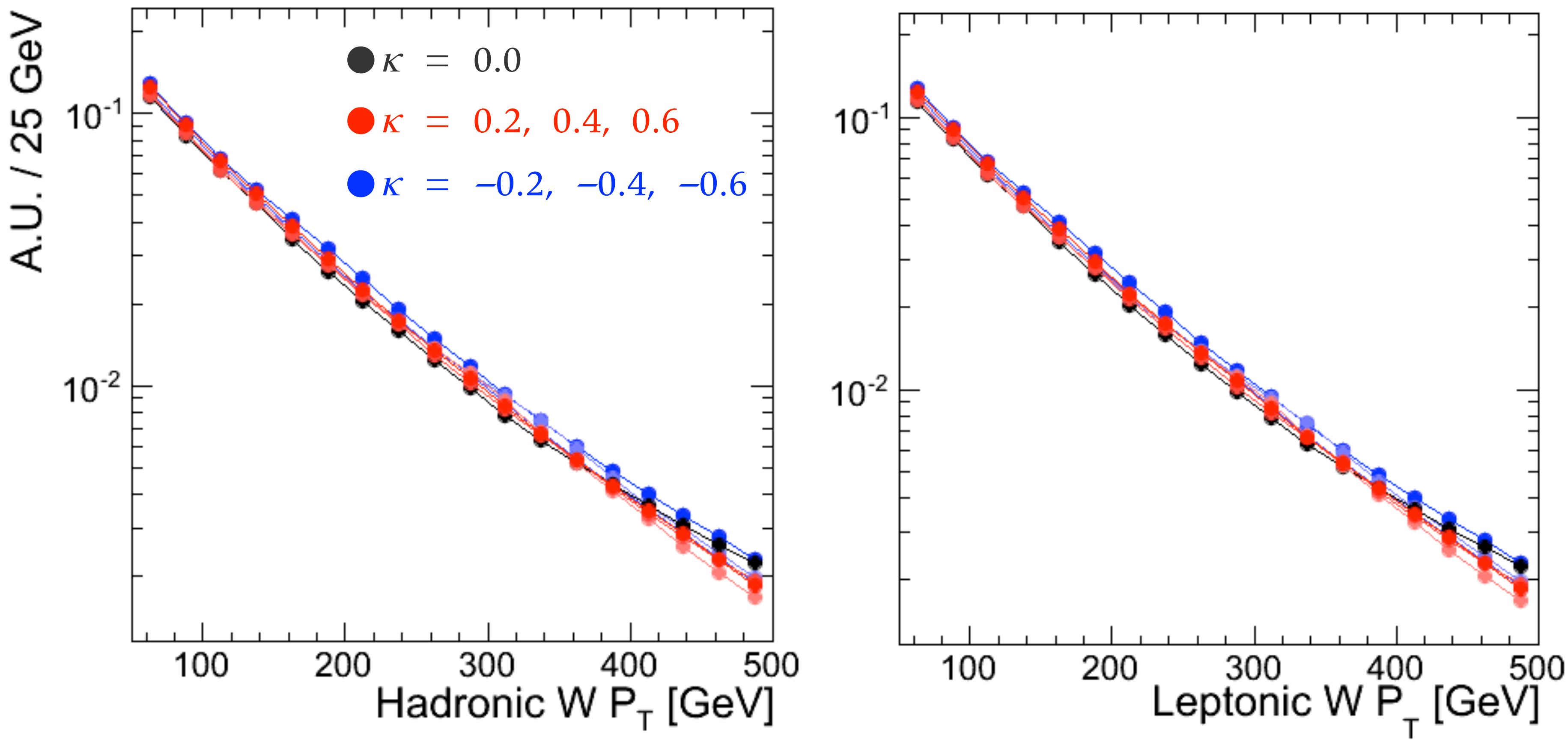
κ = 0.0
κ = 0.2, 0.4, 0.6
κ = −0.2, −0.4, −0.6
A.U. / 25 GeV
10^-1
10^-2
100
200
300
400
500
Hadronic W P_T [GeV]
10^-1
10^-2
100
200
300
400
500
Leptonic W P_T [GeV]

W pT (Λ=−0.4)



A.U. / 25 GeV
κ = 0.0
κ = 0.2, 0.4, 0.6
κ = −0.2, −0.4, −0.6
10^{-1}
10^{-2}
100
200
300
400
500
Hadronic W P_T [GeV]
Leptonic W P_T [GeV]

W pT (Λ=−0.2)



A.U. / 25 GeV
10^{-1}
10^{-2}
κ = 0.0
κ = 0.2, 0.4, 0.6
κ = −0.2, −0.4, −0.6
100
200
300
400
500
Hadronic W P_T [GeV]
10^{-1}
10^{-2}
100
200
300
400
500
Leptonic W P_T [GeV]

Next steps ....

- Proceed to set actual limits
  - -Use the Higgs combination tool as used in HWW and Mjj analyses. Already in the works.

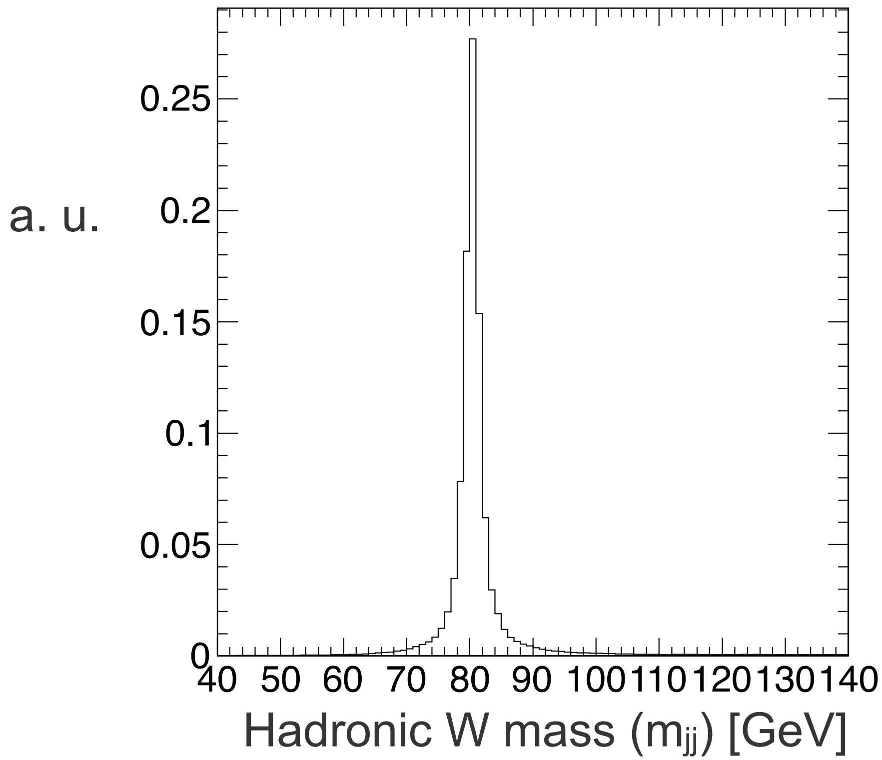
- Try alternative fullSim signal samples of aTGC for cross checks
  - -we have been able to generate MadGraph LHE files for a few benchmark points
  - -fullSim in process, can provide valuable cross checks

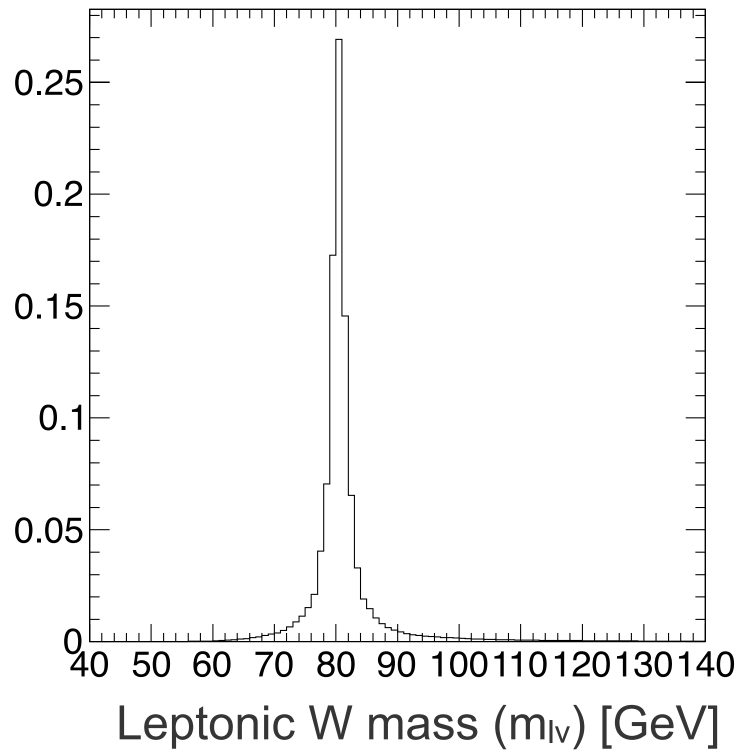
Aim to have the limits and full documentation next week.
Cross-checks using fullSim will come later.

backup slides

Diboson lineshape

In order to get NLO shapes, we generated diboson samples using MCFM. But diboson m_{jj} shape is almost a delta function. Smearing this by detector resolution will get us a Gaussian shape which is not good. Need to explore some data driven shape.





Dataset & MC samples: use full 2011 data

Data

Dataset name	Run range
/EG/Run2010A-Apr21ReReco-v1/AOD /Mu/Run2010A-Apr21ReReco-v1/AOD	136033 - 144114
/Electron/Run2010B-Apr21ReReco-v1/AOD /Mu/Run2010B-Apr21ReReco-v1/AOD	144919 - 149442
/SingleElectron/Run2011A-May10ReReco-v1/AOD /SingleMu/Run2011A-May10ReReco-v1/AOD	160431 - 163869
typo ~~/ElectronHad/~~ Run2011A-PromptReco-v4/AOD /SingleMu/Run2011A-PromptReco-v4/AOD	165088 - 167913
/SingleElectron/Run2011A-05Aug2011-v1/AOD /SingleMu/Run2011A-05Aug2011-v1/AOD	170826 - 172619
/SingleElectron/Run2011A-PromptReco-v6/AOD /SingleMu/Run2011A-PromptReco-v6/AOD	172620 - 173692
/SingleElectron/Run2011B-PromptReco-v1/AOD /SingleMu/Run2011B-PromptReco-v1/AOD	175832 - 180252

Triggers

For electron use:
Ele_25/32/35_WmT40/50

For muons:
IsoMu_24 || IsoMu_17 ||
Mu_20 || Mu30 || Mu40

Fall 11 MC: Processed in CMSSW 4_2_X

sample
/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/TTJets_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v2/AODSIM
/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/Tbar_TuneZ2_s-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/Tbar_TuneZ2_t-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/Tbar_TuneZ2_tW-channel-DS_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/T_TuneZ2_s-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/T_TuneZ2_t-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/T_TuneZ2_tW-channel-DS_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WW_TuneZ2_7TeV_pythia6_tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WZ_TuneZ2_7TeV_pythia6_tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM

Event selection and quality cuts

Table 6: Summary of selection criteria.

$W \to \ell\nu$ selection	Jet selection
Single lepton trigger	$p_T^{jet} > 35$ GeV
High-quality lepton ID and isolation	$\Delta\eta_{jj} < 1.5$
Muon (electron) $p_T > 25(35)$ GeV	dijet $p_T > 20$ GeV
$\not{E}_T > 25(30)$ GeV for muon (electron) samples	$\Delta\phi(\not{E}_T, \text{lead jet}) > 0.4$
W transverse mass > 50 GeV	
Second lepton veto	

- ✦Studied in detail
- ✦Improve the signal to background ratio, reduce syst uncertainty
- ✦Will show distribution of some of these variables later

Signal and background expectation

Signal Efficiency x Acceptance x BR

Signal	Cross section [4]	$A \times \varepsilon$ (ejj)	$A \times \varepsilon$ (ejj,b-tag)	$A \times \varepsilon$ (μjj)	$A \times \varepsilon$ (μjj,b-tag)
WW	47.0 ± 2.0	3.039×10^{-3}	3.163×10^{-4}	5.918×10^{-3}	5.864×10^{-4}
WZ	18.6 ± 1.0	1.608×10^{-3}	3.760×10^{-4}	3.220×10^{-3}	7.760×10^{-4}
Diboson	65.6 ± 2.2	2.633×10^{-3}	3.332×10^{-4}	5.153×10^{-3}	6.402×10^{-4}

total = 0.88% including the BR (~11% for each lepton, 67% jj)

Back-of-the-envelop calculation: expect 65 pb x 5 fb^{-1} x 0.88 ≈ 2800 diboson events

Background rate

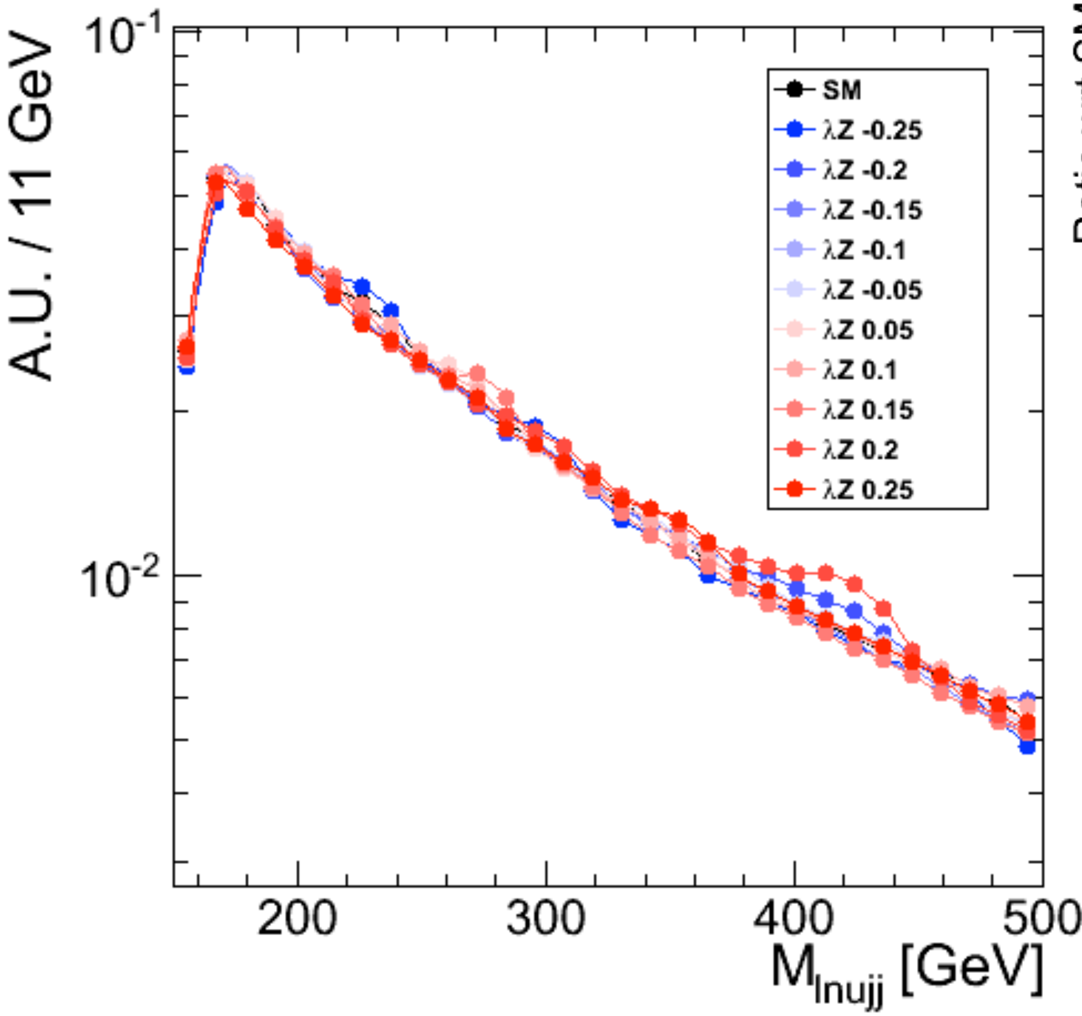
Process	cross section
W plus jets	(NLO) 31314 pb ± 5% [23]
$t\bar{t}$	(NLO) 163 pb ±7% [24]
Single top	(NNLO) [25–27] ± 5%
Drell-Yan plus jets	(NLO, $m_{ll} > 50$ GeV) 3048 pb ± 4.3% [23]
Multijet	$\not{E}_T$ fit in data ± 50% (100%) for electron (muon)

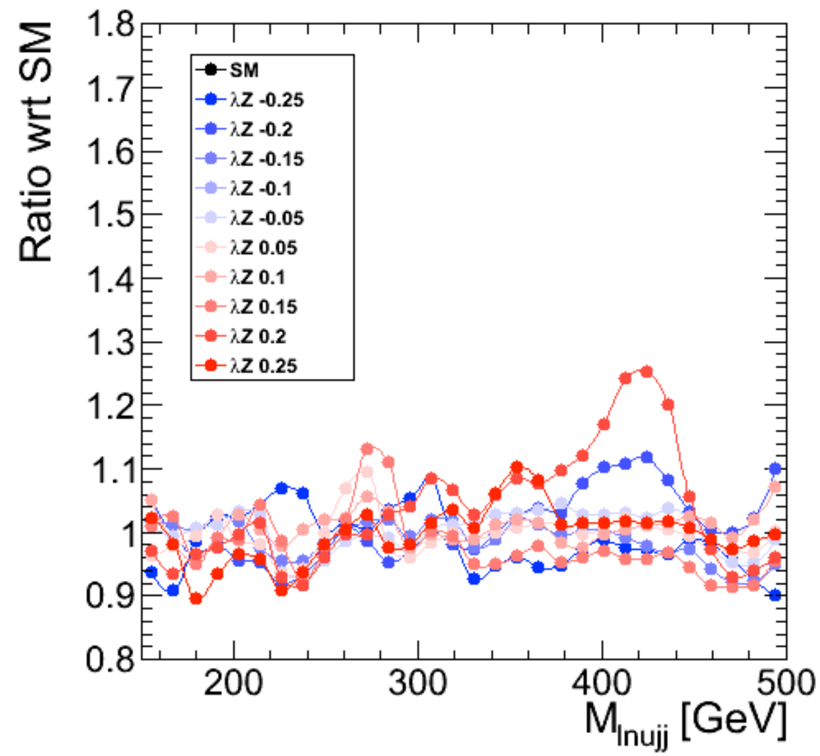
Fit results table

Bin	Muons, non-b-tagged		Electrons, non-b-tagged	
	Predicted	Extracted	Predicted	Extracted
Dibosons	1697	1736 ± 389	867	727 ± 302
Multijet	123	119 ± 317	2610	3204 ± 867
Single Top	653	652 ± 33	332	332 ± 17
$t\bar{t}$	1679	1666 ± 117	963	953 ± 67
W+Jets	76129	67674 ± 586	37137	32706 ± 850
Drell-Yan+Jets	3610	3613 ± 155	1487	1485 ± 64
Total Yields	83891	75460	43396	39407
Data	—	75419	—	39365

Bin	Muons, b-tagged		Electrons, b-tagged	
	Predicted	Extracted	Predicted	Extracted
Dibosons	211	226 ± 203	110	35 ± 86
Multijet	16	16 ± 42	171	231 ± 78
Single Top	1220	1219 ± 60	618	626 ± 31
$t\bar{t}$	3206	3192 ± 191	1846	1976 ± 104
W+Jets	5082	5082 ± 206	2551	2693 ± 107
Drell-Yan+Jets	206	206 ± 9	857	858 ± 37
Total Yields	9941	9941	6153	5648
Data	—	9940	—	5695

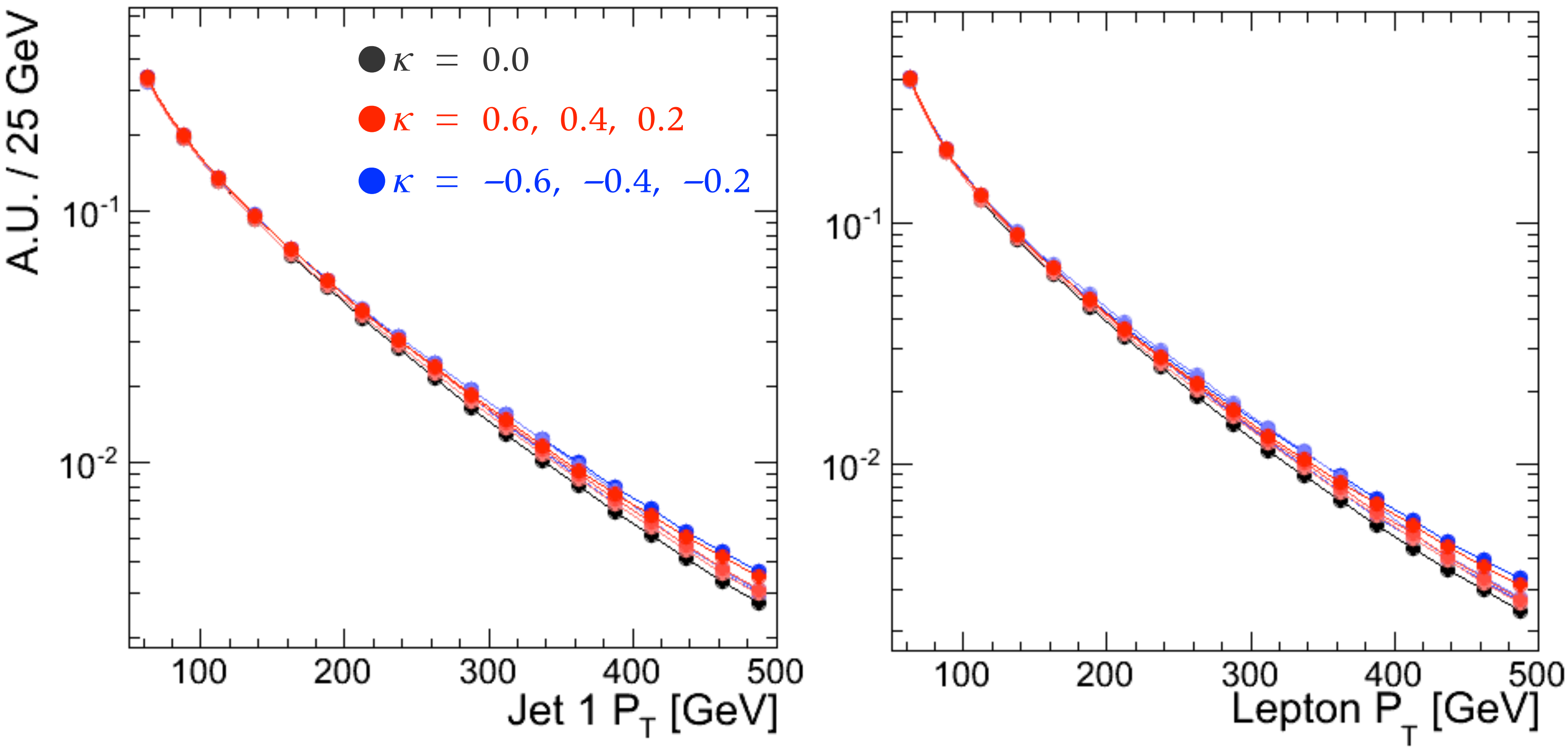
WW invariant mass





Harder to interpret the effect. Perhaps more sensitive to cutoff scale. Also, the agreement between data and main background MC is not good.

Leading jet and lepton p_T ($\Lambda = -0.6$)



Agreement between fullSim LO and MCFM

- The MCFM is parton-level NLO generator
  - -no hadronization, no detector simulation
  - -our standard diboson (WW and WZ) samples are fully simulated in Pythia at LO
  - -the agreement between the two in W pT is good (I am working on the comparison plots). Can be seen in the Mjj paper.
  - -data-MC agreement for W+jets background is also good in shape. Normalization determined by dijet mass fit (slide 8).

•For high p_T (> 100 GeV) no need to re-weight the MCFM for detector effects. Will revisit it if needed.