Resummation Predictions for WW Production at the LHC

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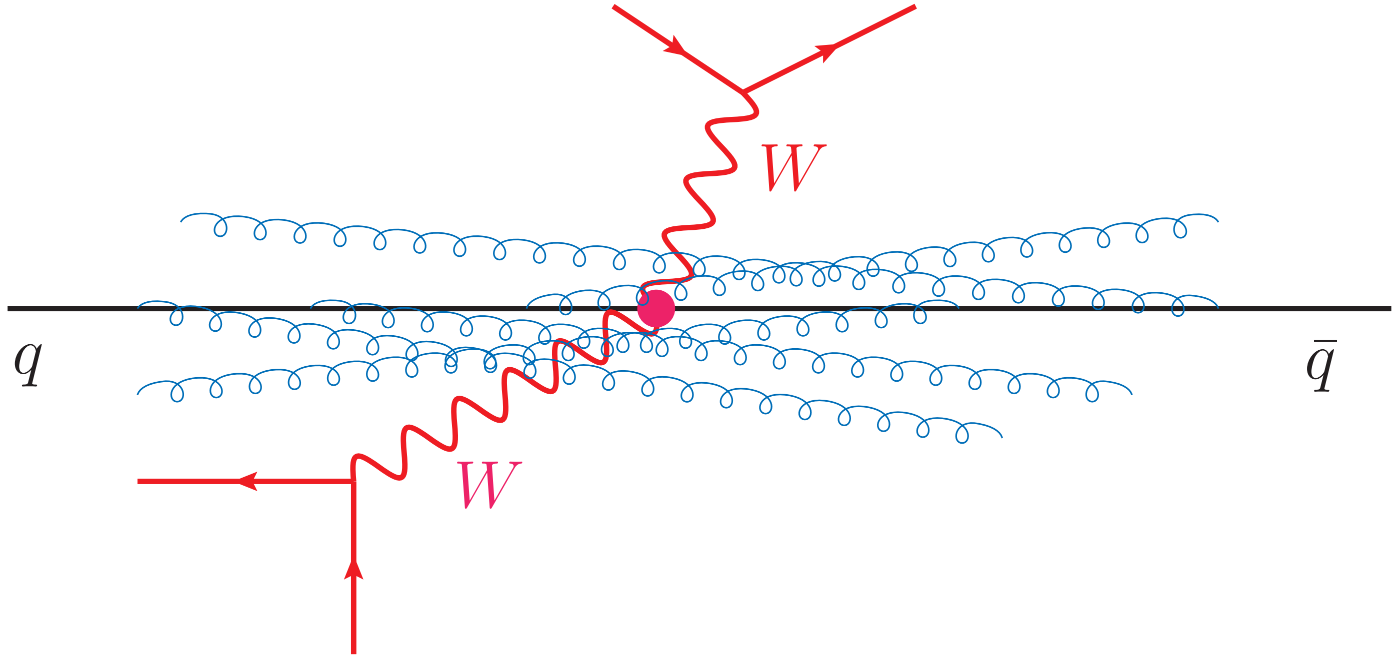

References :

arXiv:1407.4537 : PJ and Takemichi Okui
arXiv:1506.07529 : PJ and Takemichi Okui
arXiv:1509.07118 : PJ, Patrick Meade and Harikrishnan Ramani

A tale of two Ws

NLO

NNLO : 1408.5243
Gehrmann et al.

$\sqrt{s}$	ATLAS σ [pb]	CMS σ [pb]	Theory (MCFM) σ [pb]	σ_{NNLO}
7 TeV	$51.9^{+2.0+3.9+2.0}_{-2.0-3.9-2.0}$ [13]	$52.4^{+2.0+4.5+1.2}_{-2.0-4.5-1.2}$ [14]	$47.04^{+2.02+0.90}_{-1.51-0.66}$	$49.04^{+2.1\%}_{-1.8\%}$
8 TeV	$71.4^{+1.2+5.0+2.2}_{-1.2-4.4-2.1}$ [15]	$69.9^{+2.8+5.6+3.1}_{-2.8-5.6-3.1}$ [16]	$57.25^{+2.35+1.09}_{-1.60-0.80}$	$59.84^{+2.2\%}_{-1.9\%}$

- Process : p p → W W → ℓ ν ℓ ν
- Mild excesses reported by ATLAS <u>and</u> CMS at 7 <u>and</u> 8 TeV measurements.
- Discrepancy reduces slightly at NNLO but does <u>not</u> go away.

A tale of two Ws

NLO

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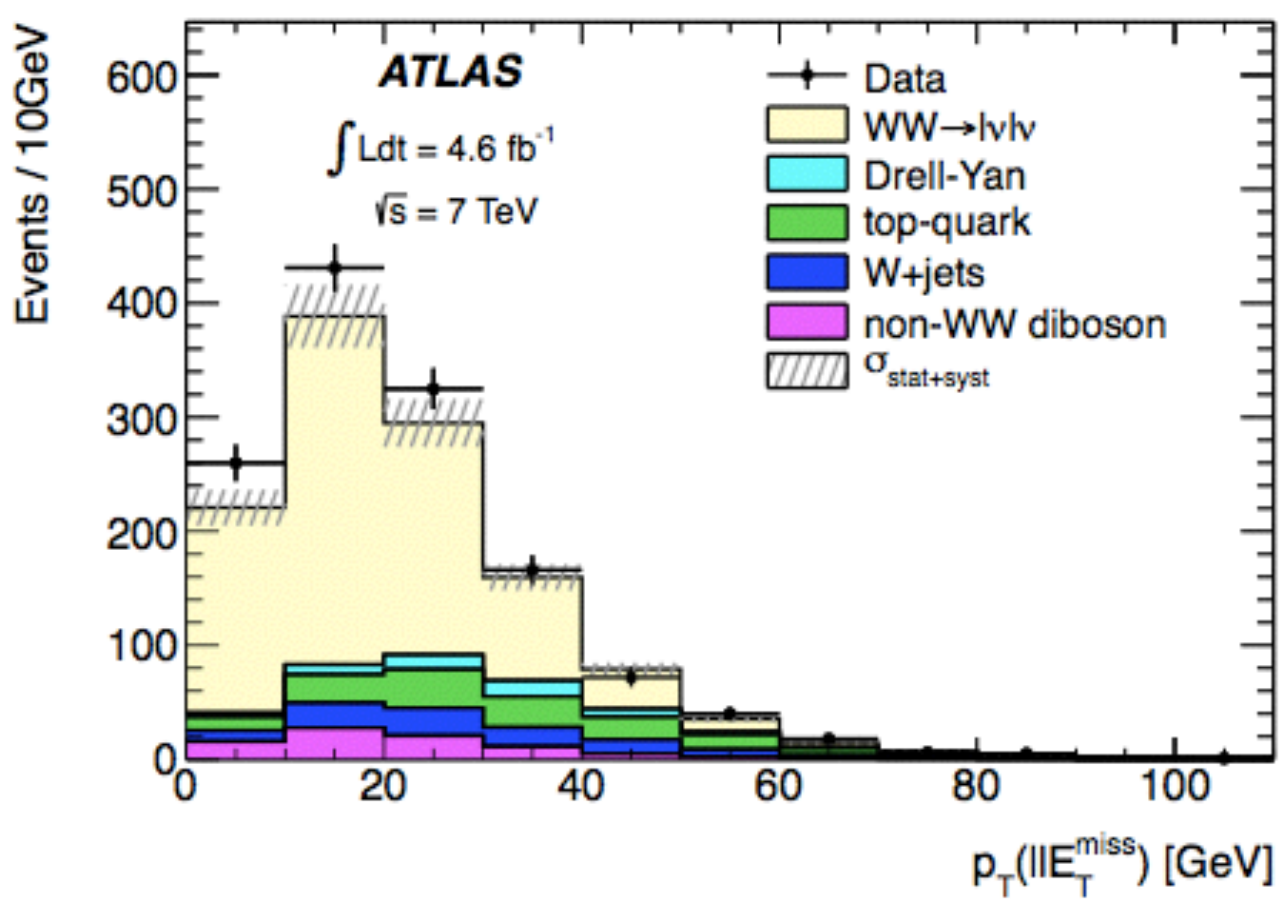
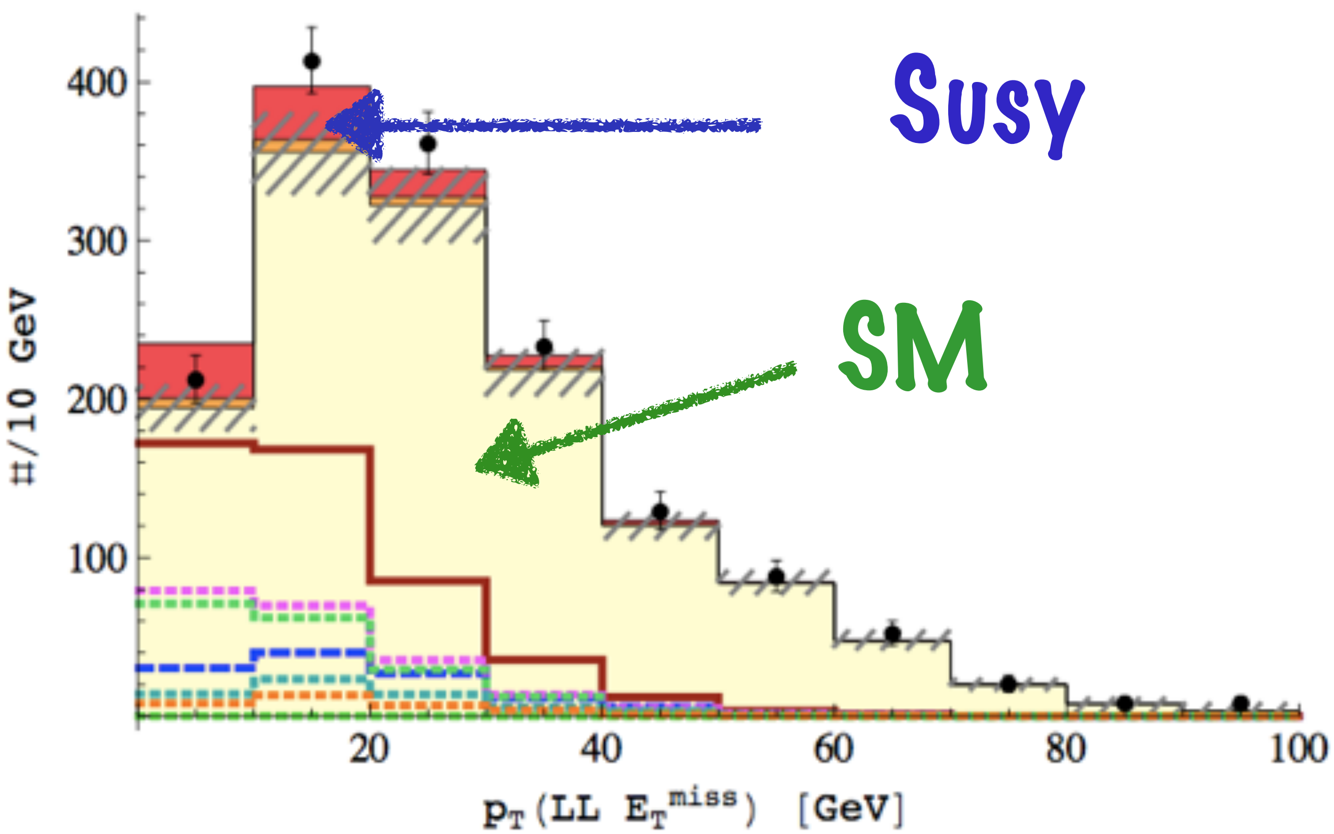
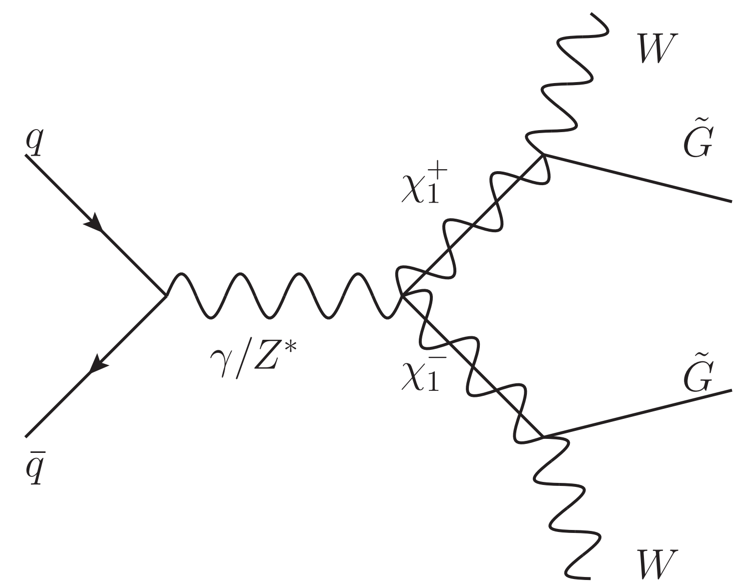
- Discrepancy also exists in shapes.



A tale of two Ws

- New physics hiding in plain sight? ($\ell\,\ell$ + MET final state)
- *Could it be SUSY?*





110 GeV charginos
D. Curtin, PJ, and P. Meade,
Charginos hiding in plain sight
[arXiv:1206.6888]

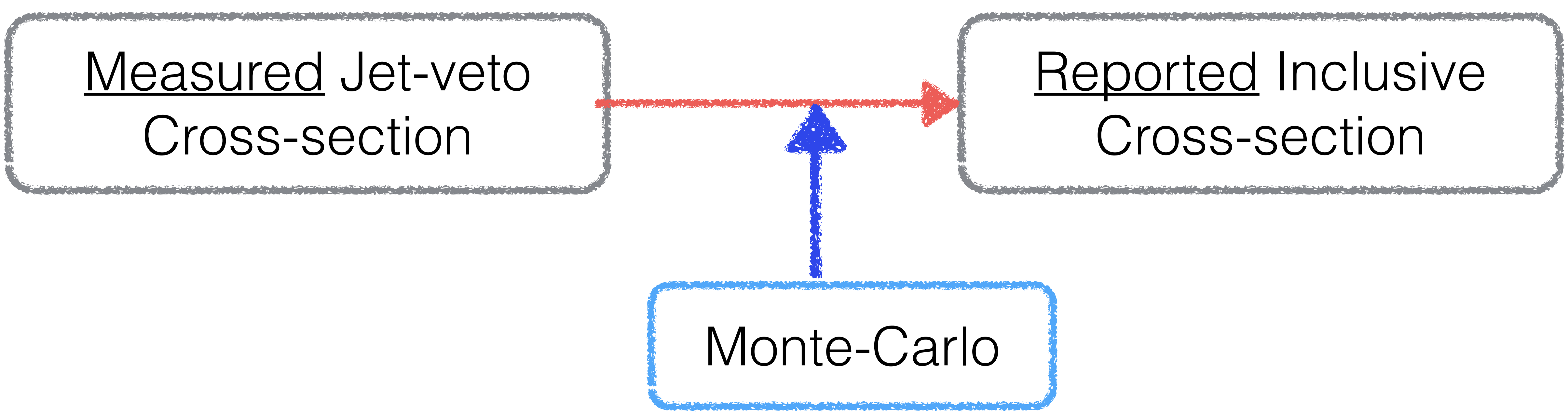
- Any new physics charged under electroweak gauge group could possibly lead to such signatures. Other proposed explanations for the WW excess include sleptons and stops.

A tale of two Ws

- *Could the WW excess have a QCD explanation?*
- Cross-section reported : p p → W W + X

  X are all hadronic final states i.e. inclusive measurement
- Actual measurement : p p → W W + X’

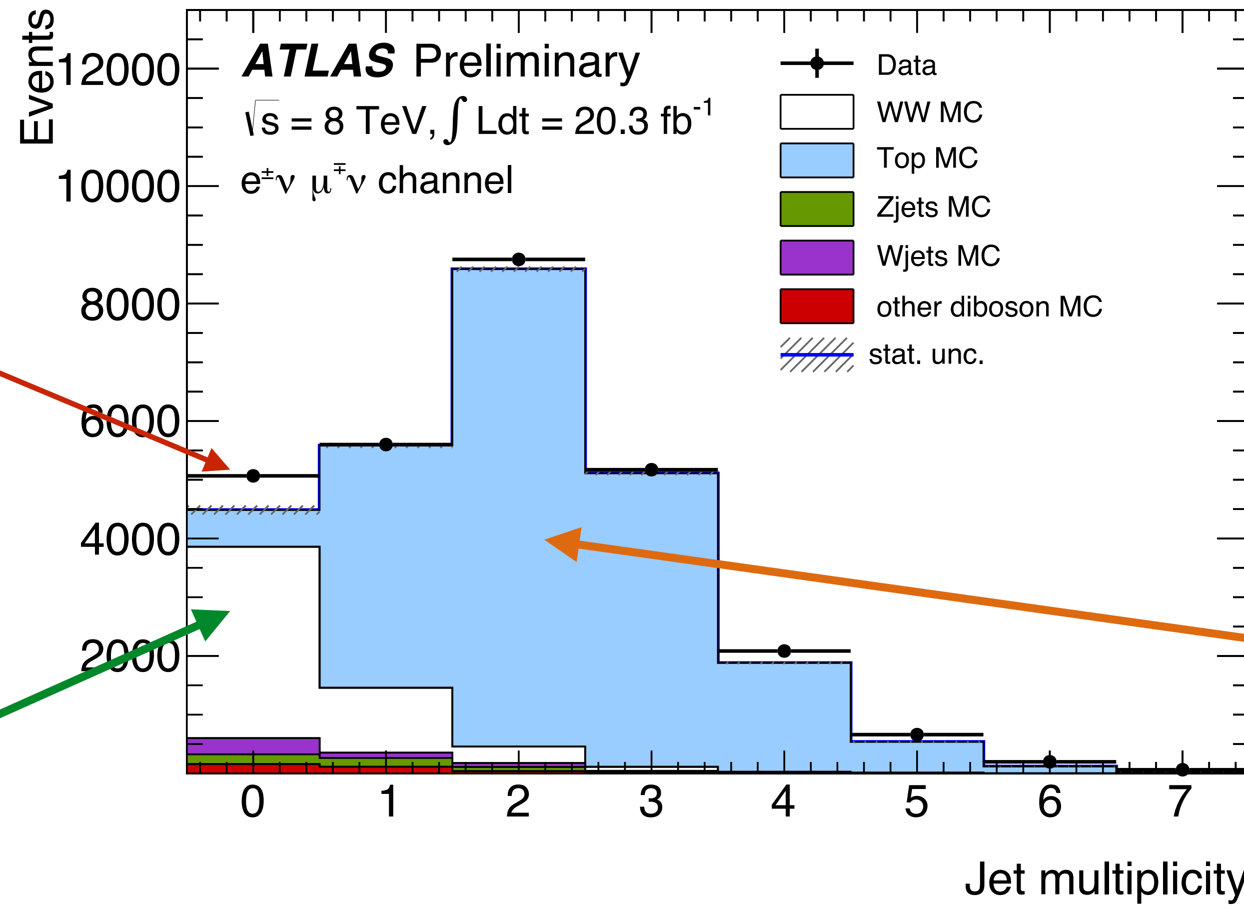
  X’ are some hadronic final states that pass jet-veto condition.



Do we have a good theoretical understanding of MC?

A tale of two Ws

Disagreement in
the 0-jet bin



WW signal

Top background

Measured Jet-veto Cross-section

Reported Inclusive Cross-section

Monte-Carlo

Two methods to test MC

Method I : Jet Veto Resummation

- Origin of large jet veto logs :

$p\,p \rightarrow W\,W$

	Inclusive	Jet-veto
Scales in the problem	M_{WW}	p_T^{veto}, M_{WW}
Logs at higher orders	$\log(M_{WW}/\mu)$	$\log(M_{WW}/\mu)$ $\log(p_T^{veto}/\mu)$
Choice of μ to minimize logs	$\mu \sim M_{WW}$	<u>No choice of μ</u> Large logs of the form $\log(p_T^{veto}/M_{WW})$ remain

Method I : Jet Veto Resummation

- Our approach: Calculate jet-veto cross-section analytically by resummation at NNLL using SCET without relying on MC. *[arXiv:1407.4537 : PJ and T. Okui]*

- Factorization of cross-section :

$$\frac{\mathrm{d}\sigma}{\mathrm{d}M} \sim H(\mu)\, Z_{\mathrm{s}}(\mu,\nu,\bar{\nu})\, B(\mu,\nu)\, \bar{B}(\mu,\bar{\nu})$$

Hard function

Soft function

Beam functions

- Beam functions have divergences (rapidity divergences) which are not regulated by dimensional regularization

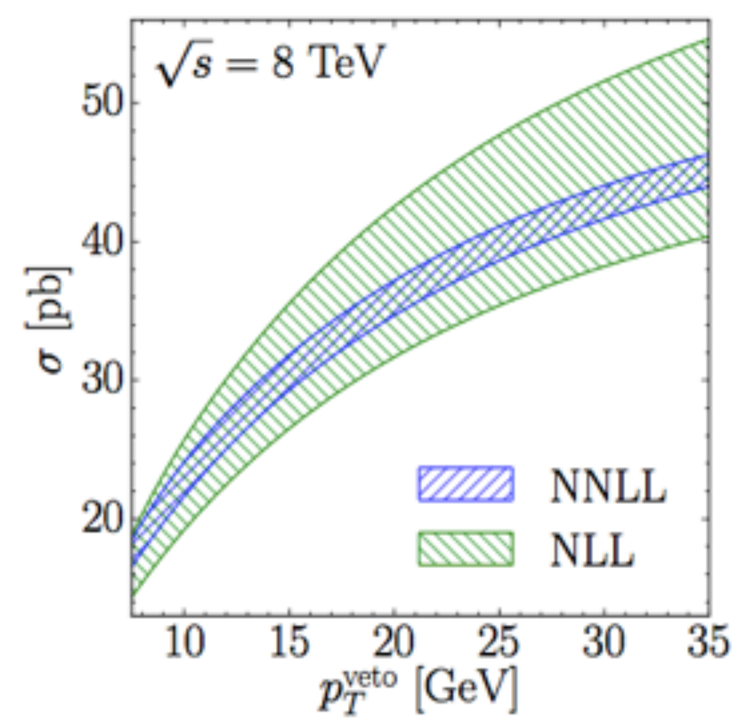
- We introduce the following analytic regulator

$$\left(\frac{\nu}{k_+}\right)^{\alpha}\theta(k_+ - k_-) + \left(\frac{\bar{\nu}}{k_-}\right)^{\bar{\alpha}}\theta(k_- - k_+)$$

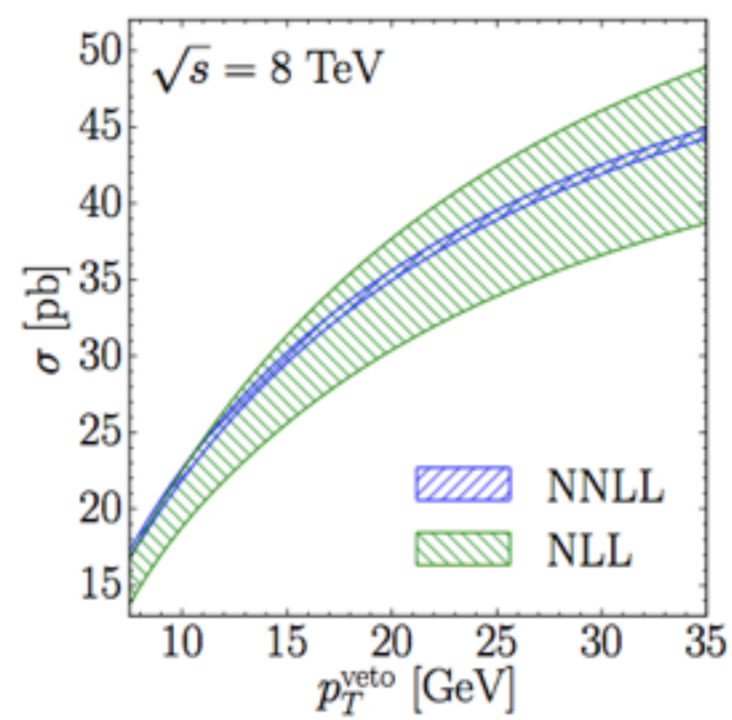
Splits the phase space integrals into regions of different rapidities

Method I : Jet Veto Resummation

- Corresponding to rapidity regulator exists a rapidity renormalization group (RRG) equations, just as there exists RG equations corresponding to dim reg regulator μ.
- Formulation of RRG with analytic regulator had been missing in the literature. We address this issue *[arXiv:1506.07529 : PJ and Takemichi Okui]*.



With RRG



Without RRG

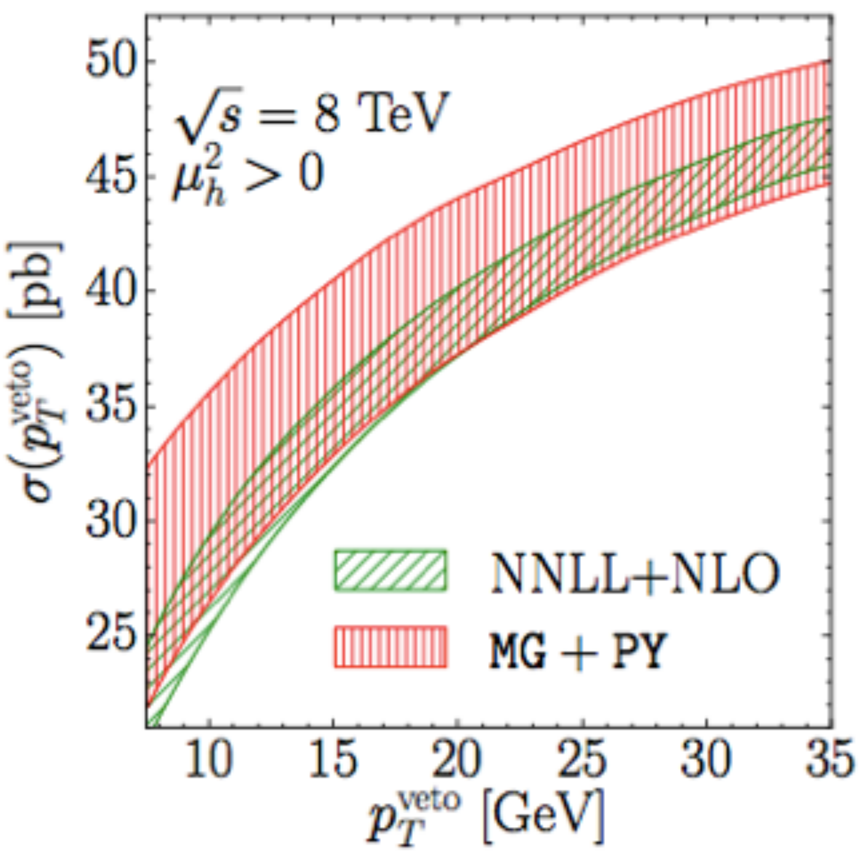
Jet radius
R=1

More robust scale uncertainties using RRG (central value unchanged).

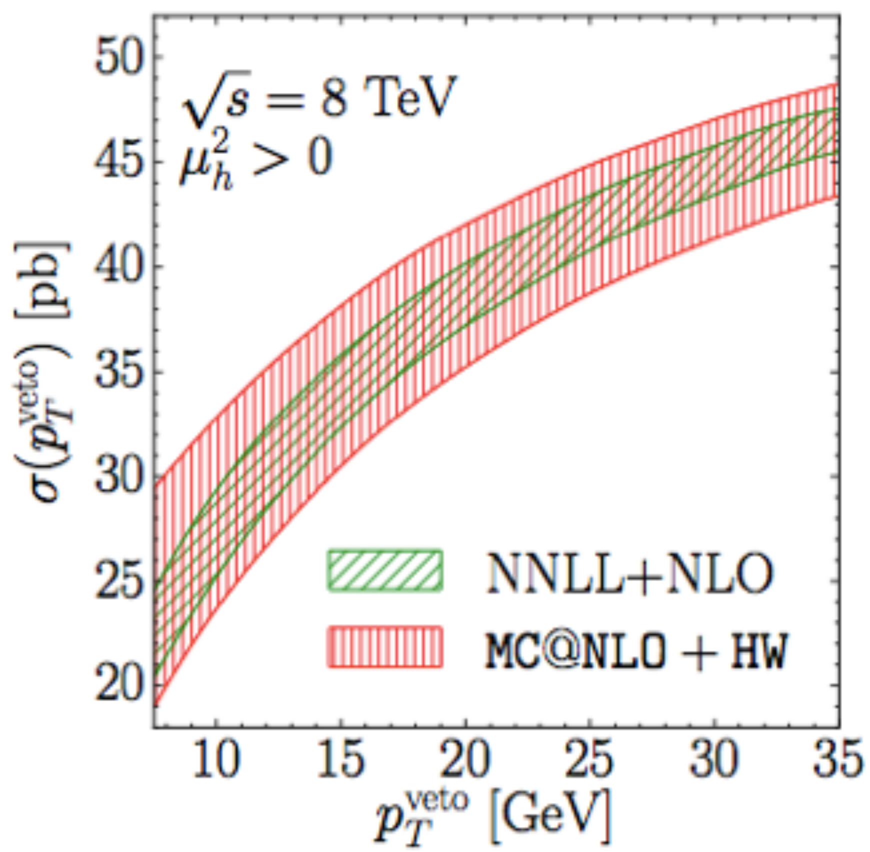
Method I : Jet Veto Resummation

- Comparison with MC+Parton shower

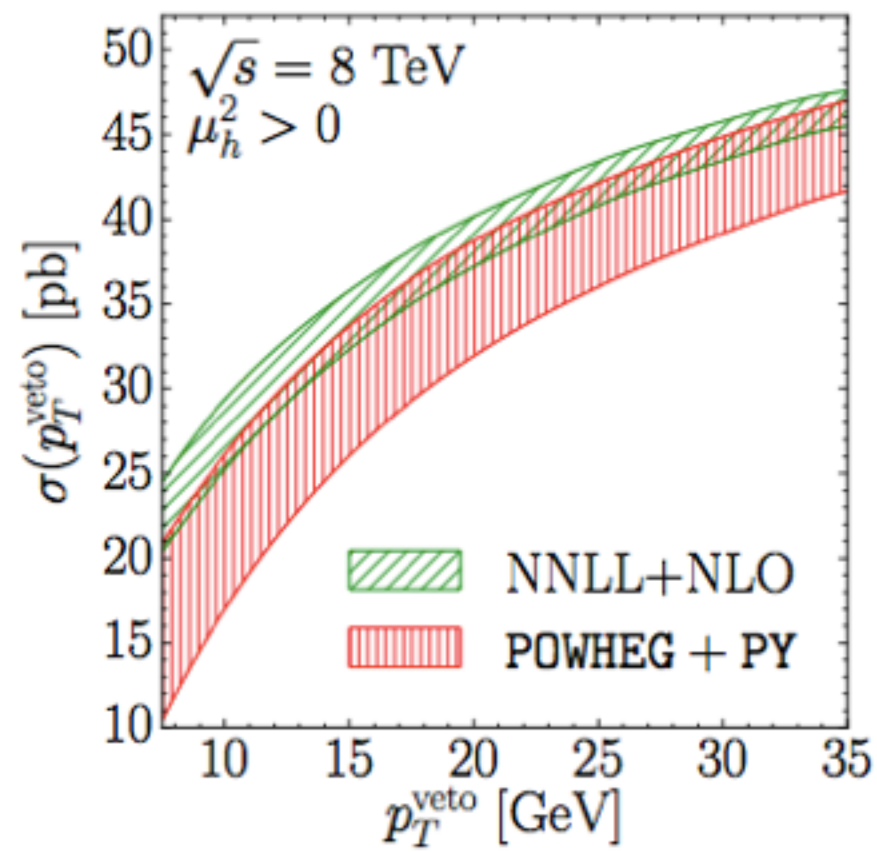
Madgraph
+Pythia



MC@NLO
+Herwig



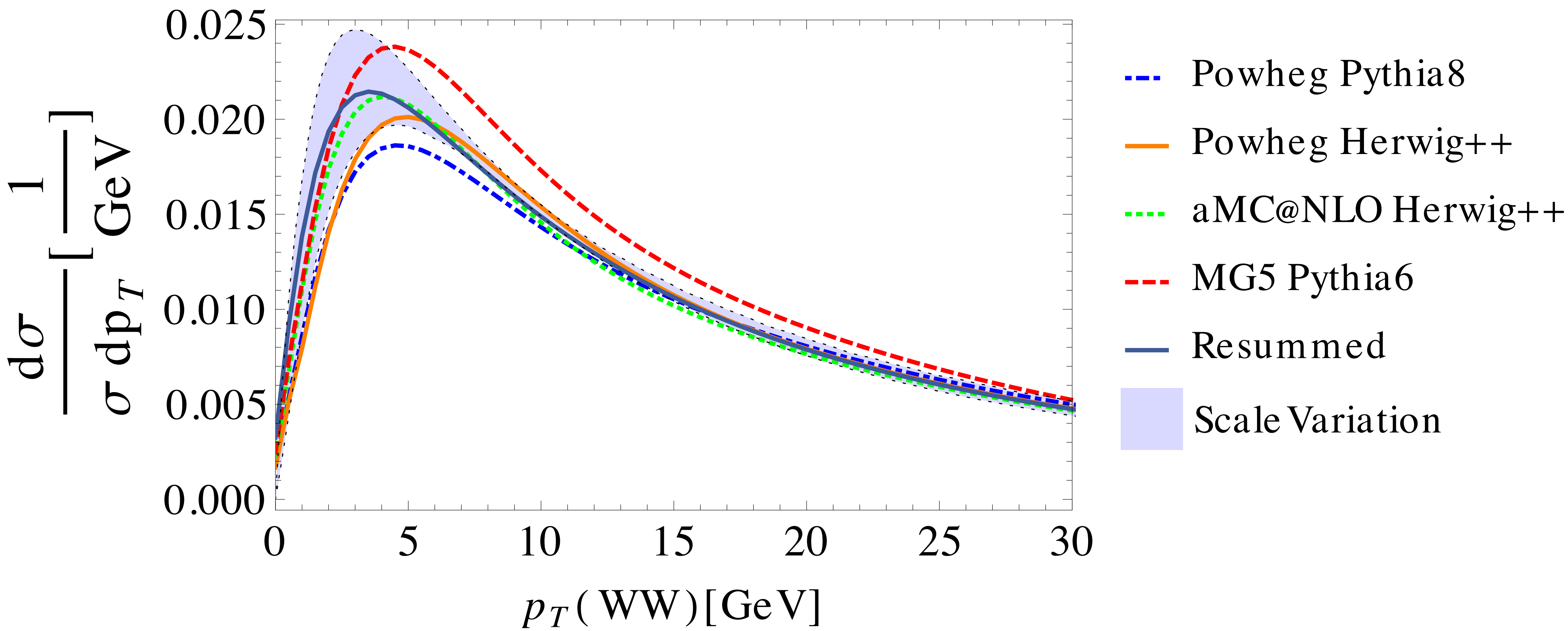
Powheg
+Pythia



*without π^2 Resummation

Method II : p_T Resummation

- Discrepancy between p_T (WW) distribution shapes from NNLL p_T-resummation and MC *[arXiv:1407.4481, P. Meade et al.]*



- Reweight MC :

$$\mathrm{F}[\xi] = \frac{\text{Resummed bin}[\xi]}{\text{MC bin}[\xi]}$$

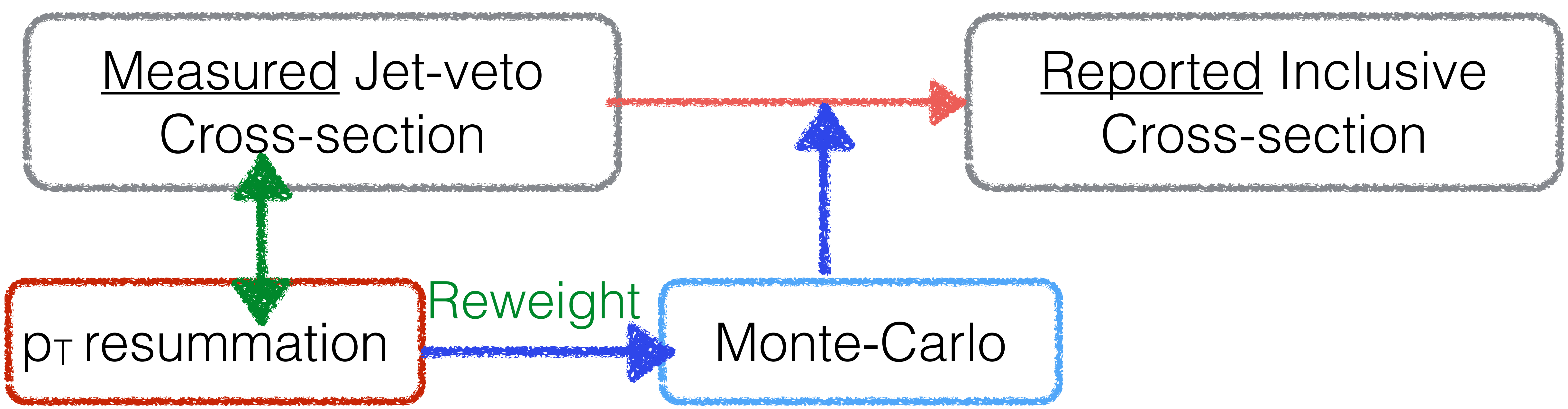
Method II : p_T Resummation

- **New CMS 8 TeV analysis** *[CMS-PAS-SMP-14-016]* reweights MC to correct for the p_T distribution.

$$\sigma_{W^+W^-} = 60.1 \pm 0.9\,(\text{stat.}) \pm 3.2\,(\text{exp.}) \pm 3.1\,(\text{th.}) \pm 1.6\,(\text{lum.})\,\text{pb}.$$

Theory : $59.8^{+1.3}_{-1.1}\,\text{pb}$

- Some correlations between jet-veto and pT of the WW system captured by p_T reweighting technique.

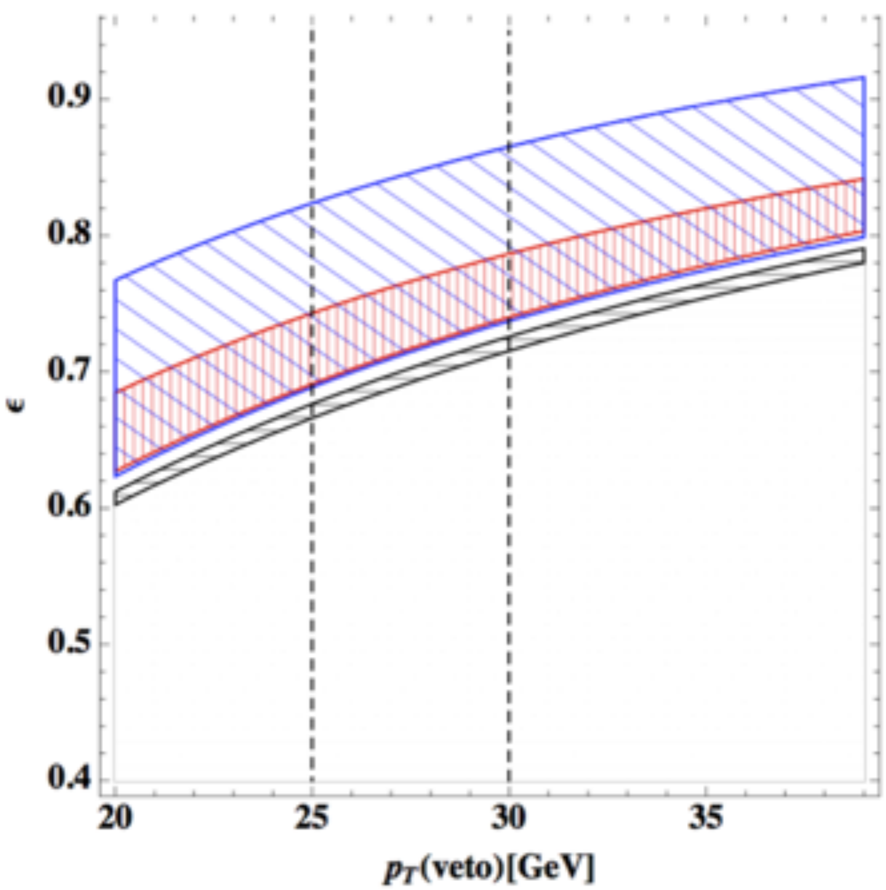


Comparison of two methods

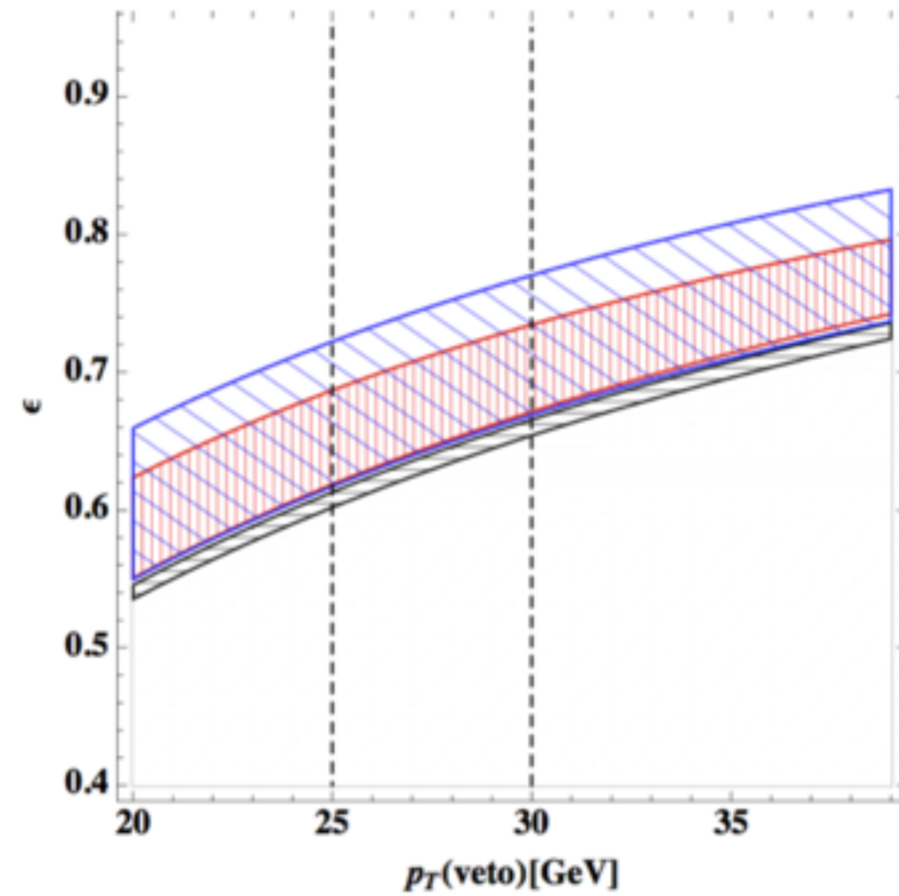
- Jet-veto resummation : Guaranteed to get the correct total jet-veto cross-section but provides no information on the p_T shape.
- p_T resummation : Guaranteed to get the correct p_T shape for the total cross-section but relies on MC for jet-binning.
- Main source of discrepancy between two methods (~ 5-9%) is that *method I* employs π^2 resummation which also increases the inclusive cross-section while *method II* fixes the inclusive cross-section to fixed-order.
- Incidentally, increase in cross-section from π^2 resummation effect in *method I* is very similar to that from NNLO.

Comparison of two methods

- For apples to apples comparison, use the same PDFs, scales, etc. *[arXiv:1509.07118 : PJ, Patrick Meade and Harikrishnan Ramani]*



8 TeV



14 TeV

JetVetoResummation

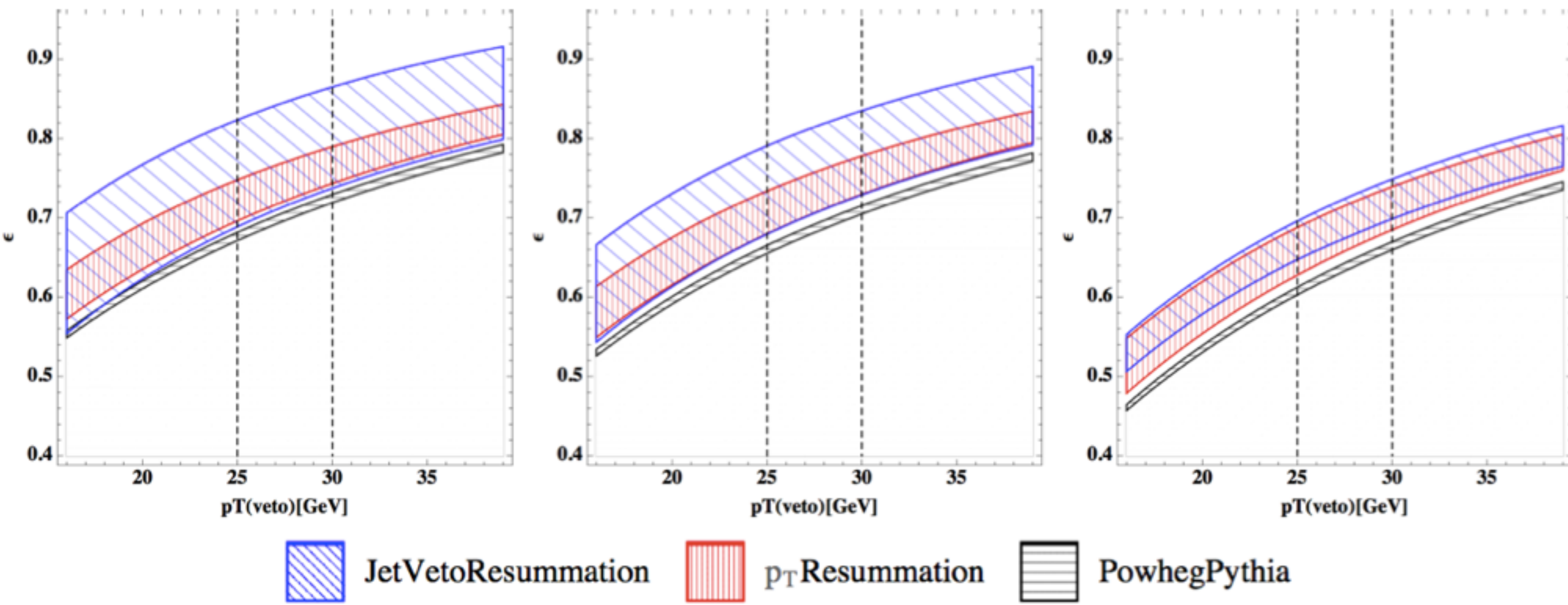
p_TResummation (MC reweighted with p_T of WW)

PowhegPythia

Comparison of two methods

- Better agreement between the two methods for large R.

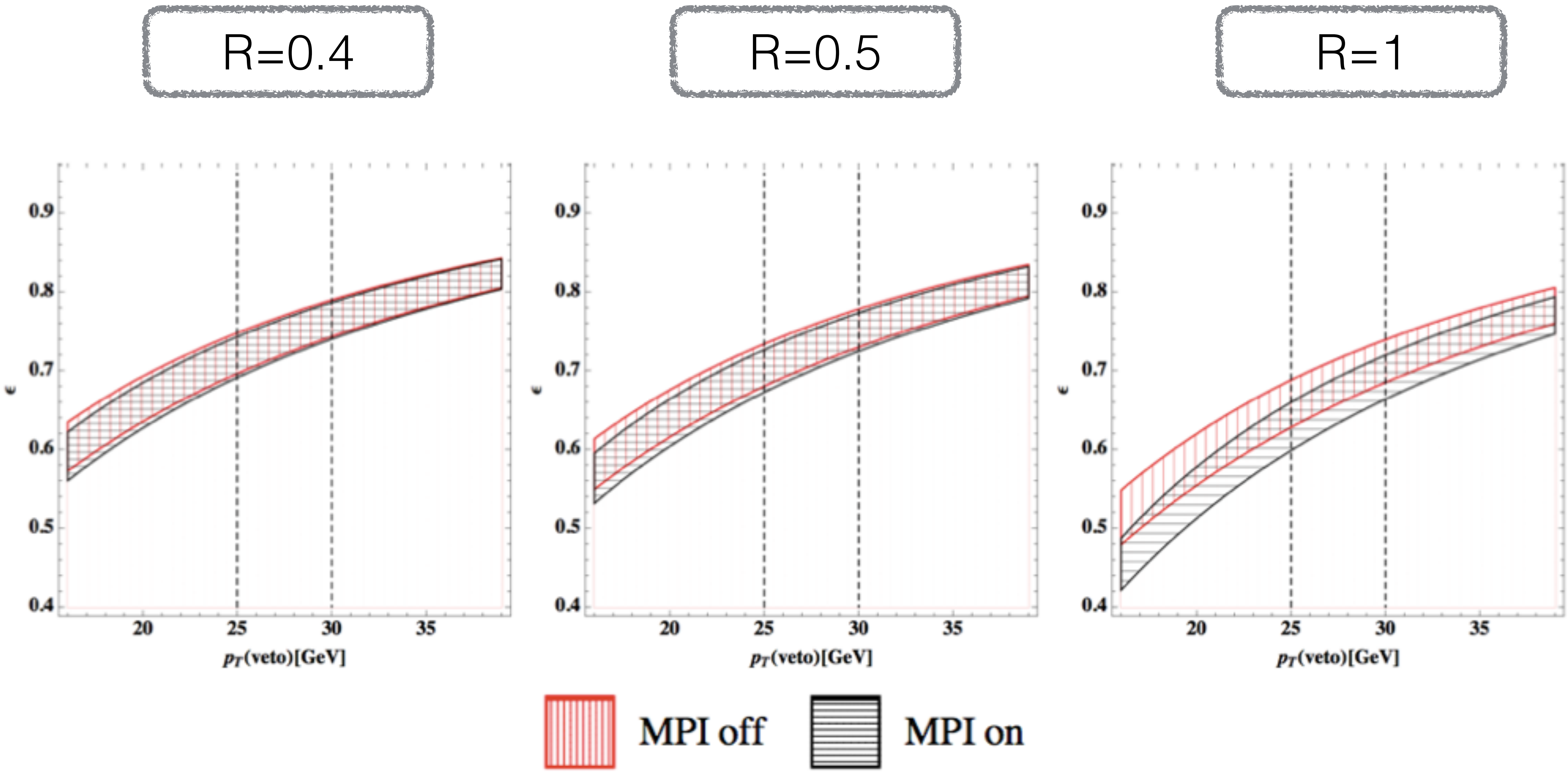
R=0.4 R=0.5 R=1



(MC reweighted with p_T of WW)

Comparison of two methods

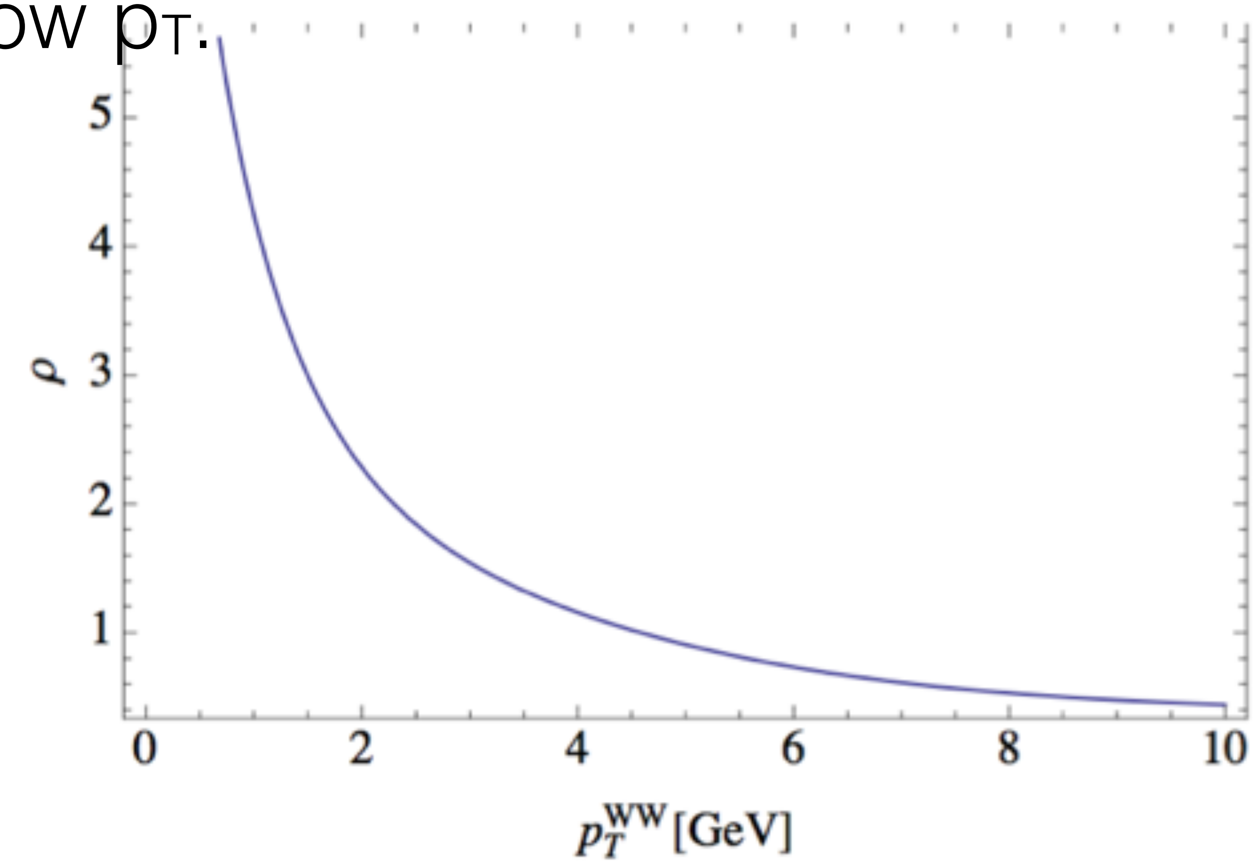
- But MPI effects also big at large R.



Comparison of two methods

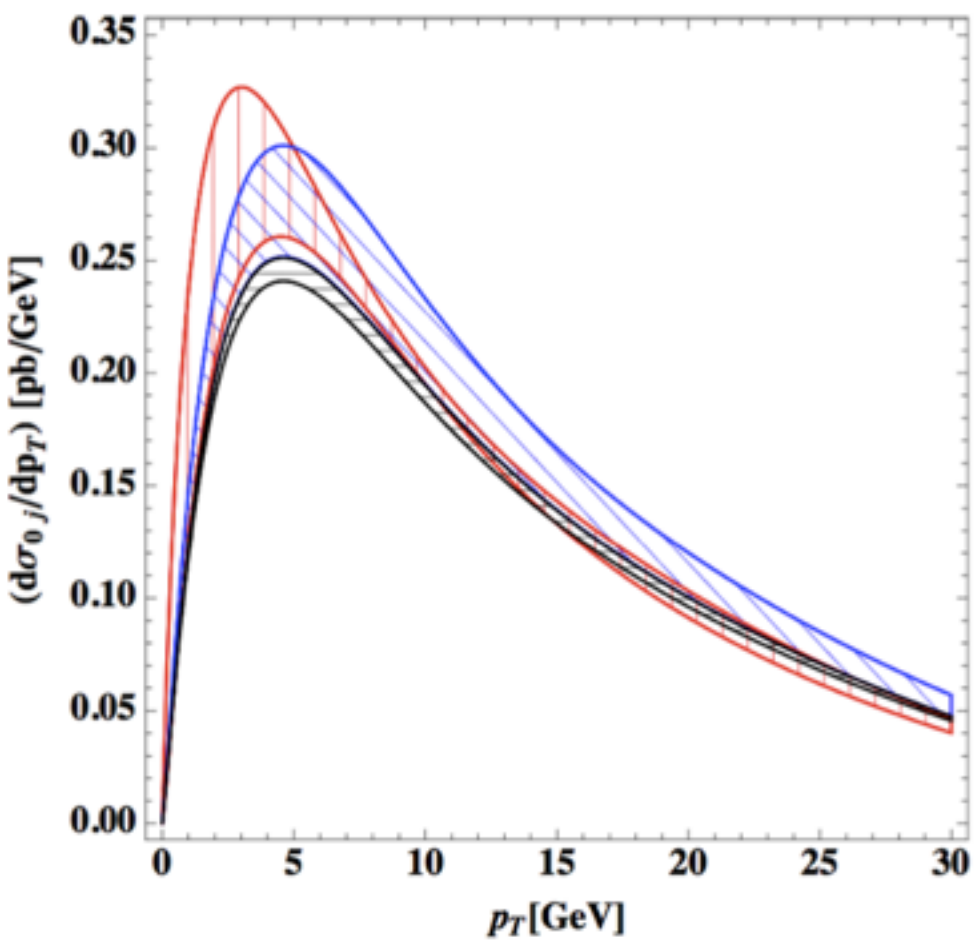
- Inspired by p_T-reweighting technique, we consider a new reweighting technique using of p_T of the leading jet instead of p_T of the WW system.
- The basic idea is to get the p_T shape of WW in the 0-jet bin using jet-veto resummation relying on the correlation between p_T(WW) and p_T(leading jet).
- However, correlation worsens at low p_T.

$$\rho(p_T) = \frac{\langle |p_T^j(p_T) - p_T| \rangle}{p_T}$$

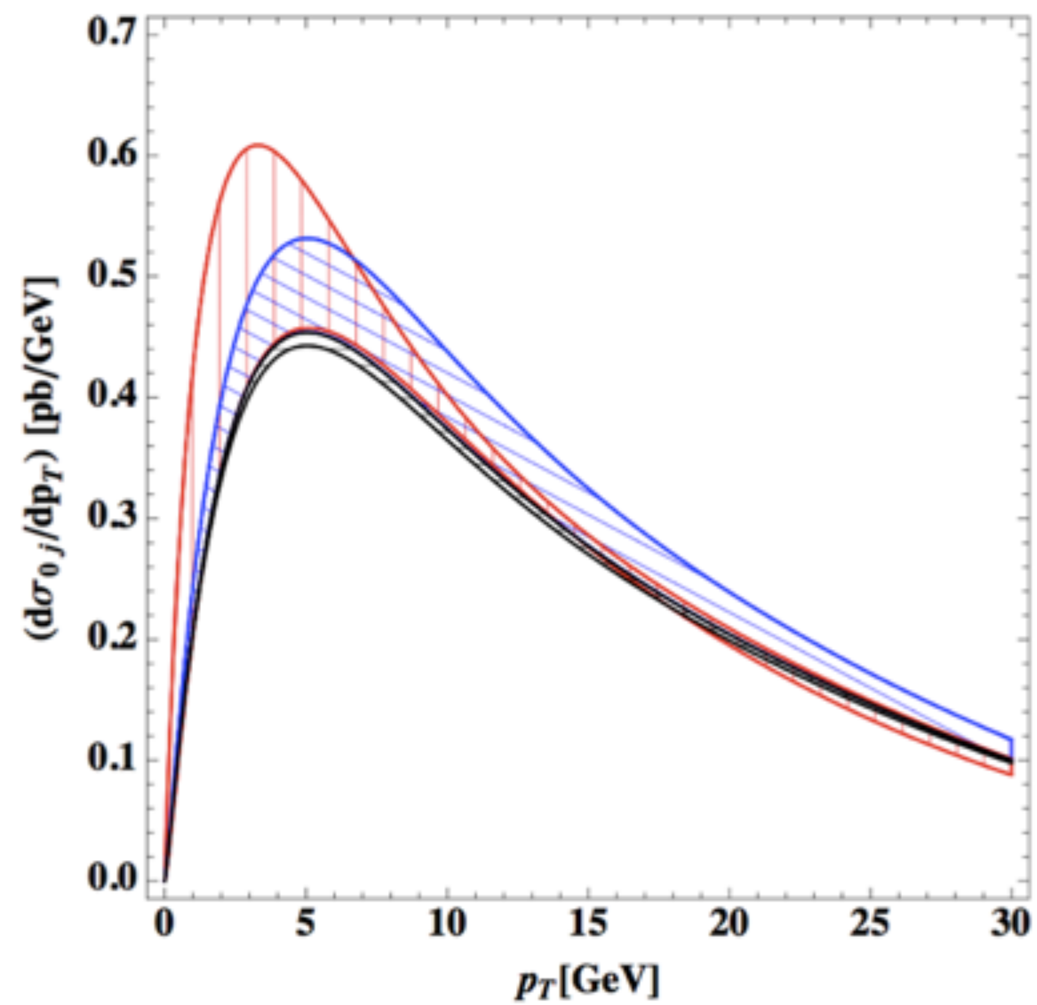


- Also, non-perturbative and MPI effects at low p_T lead to large uncertainties.
- Therefore, we simply use <u>two-bin reweighting</u> in p_T of the leading jet.

Comparison of two methods



8 TeV



14 TeV

JetVetoResummation (MC reweighted with p_T of leading jet)

p_TResummation (MC reweighted with p_T of WW)

PowhegPythia

Summary

- WW is an important background for Higgs studies and new physics searches.
- Jet veto in WW channel is often essential for suppressing top backgrounds.
- Jet veto logs can be large and need to be resummed.
- Two methods for resummation : Jet-veto resummation and p_T resummation followed by reweighting.
- Good agreement between two methods demonstrated and a new reweighting technique proposed.
- Analysis should be extended to other diboson channels for better understanding.