Jets in Higgs Analysis

Conveners:
Daniele del Re (CMS), Bruce Mellado (ATLAS),
Gavin Salam (theory) & Frank Tackmann (theory)

CERN, LPTHE/CNRS (Paris) & Princeton University

7th meeting of the LHC Higgs Cross Section WG
CERN, 5–6 December 2012

Jets play many roles in Higgs searches:

They may come from Higgs decay ($H \to b\bar{b}$)

They may help distinguish different Higgs-production mechanisms (VBF v. gluon-fusion)

They may help distinguish signal from background, e.g. jet bins in $H \to WW$ v. $t\bar{t} \to WWb\bar{b}$

This working group's aims:

Identify where further theory progress needed on jet-related topics. Provide advice and/or prescriptions for uncertainties and central predictions, where possible

Two public subgroup meetings since last plenary

12 October:

https://indico.cern.ch/conferenceDisplay.py?confId=211870

- Presentation of experimental needs
- Analytical theory predictions for $gg \to H$ in 0-jet, 1-jet & VBF bins

29 November:

https://indico.cern.ch/conferenceDisplay.py?confId=218887

- Predictions from latest MC tools for $gg \to H$ with VBF-type selection

Jet issues in Higgs physics

chaired by Daniele Del Re (Universita e INFN, Roma I (IT)), Gavin Phillip Salam (CERN), Frank Tackmann (DESY), Bruce Mellado Garcia (University of Wisconsin (US))

Friday, October 12, 2012 from **15:00** to **18:00** (Europe/Zurich)
at **CERN (4-3-006 - TH Conference Room)**

Video Services EVO Meeting Fri 12/10 from 14:30 to 19:00 : Phone Bridge ID:5934100. More Info

Friday, October 12, 2012

15:00 - 15:15 CMS Report *15'*
Speaker: Pasquale Musella (CERN)
Material: **Slides**

15:25 - 15:40 ATLAS Report *15'*
Speaker: Elisabetta Pianori (University of Warwick (UK))
Material: **Slides**

15:50 - 16:05 Theory uncertainties in Higgs+2 jets *15'*
Speaker: Shireen Gangal
Material: **Slides**

16:15 - 16:35 Discussion on key questions/needs re Higgs+2jets to the MC subgroup *20'*

16:35 - 16:50 Resummation for jet-veto in Higgs + 0 jets *15'*
Speaker: Pier Francesco Monni (ITP, UZH Zuerich)
Material: **Slides**

17:00 - 17:15 Resummation for jet-veto in Higgs + 0 jets *15'*
Speaker: Thomas Becher (University of Bern)
Material: **Slides**

17:25 - 17:40 Resummation for jet-veto in Higgs + 1 jet *15'*
Speaker: Liu Xiaohui
Material: **Slides**

Jet issues in Higgs physics

chaired by Daniele Del Re (Universita e INFN, Roma I (IT)), Gavin Phillip Salam (CERN), Frank Tackmann (DESY), Bruce Mellado Garcia (University of Wisconsin (US))

Thursday, 29 November 2012 from **09:00** to **13:00** (Europe/Zurich)
at CERN **(40-R-D10)**

Manage

Video Services Vidyo public room : Jet_issues_in_Higgs_physics More Info | **Join Now!** | Connect 40-R-D10

Thursday, 29 November 2012

09:00 - 09:30	H+njets with HEJ *30'* Speaker: Jeppe Rosenkrantz Andersen (IPPP, University of Durham (UK)) Material: **Slides**
09:30 - 10:00	H+njets with MINLO *30'* Speaker: Paolo Nason Material: **Slides**
10:00 - 10:30	H+njets with aMC@NLO *30'* Speaker: Stefano Frixione (CERN) Material: **Slides**
10:30 - 11:00	H+njets with Sherpa *30'* Speaker: Marek Schoenherr (University of Durham) Material: **Slides**

Experimental cuts

$H \rightarrow WW$	ATLAS	CMS
2 jets	none	two jets $p_T > 30$ GeV and $\lvert\eta\rvert < 4.7$ $\Delta\eta_{jj} > 3.5$, $m_{jj} > 500$ GeV, central-jet veto (CJV) of 30 GeV anti b tagging
1 jet	1 jet with $p_T > 25(30)$ GeV for $\lvert\eta\rvert < 2.5$ $(2.5 < \lvert\eta\rvert < 4.5)$ anti b tagging	one jet with $p_T > 30$ GeV and $\lvert\eta\rvert < 4.7$ anti b tagging
0 jet	no jet with $p_T > 25(30)$ GeV for $\lvert\eta\rvert < 2.5$ $(2.5 < \lvert\eta\rvert < 4.5)$	no jet with $p_T > 30$ GeV and $\lvert\eta\rvert < 4.7$ anti b tagging

$H \to \tau\tau$	ATLAS		CMS	
2 jet	one jet with pt > 40 GeV	**VBF**: $p_{Tjet\ 2} > 25$ GeV, $\Delta\eta_{jj} > 3$, $m_{jj} > 400$ GeV, anti-b tag	2 jets $p_T > 30$ GeV and $\lvert\eta\rvert < 4.7$	**leptonic**: $\Delta\eta_{jj} > 3.5$, $m_{jj} > 500$ GeV, CJV (30 GeV)
		VH: 30GeV< m_{jj} <160GeV, p_{Tjet2} >25GeV, $\Delta\eta_{jj}$ <2, anti-btag (+ boosted sel veto)		**hadronic**: $\Delta\eta_{jj} > 2.5$, $m_{jj} > 250$ GeV, $p_{TH} > 110$ GeV
1 jets		**boosted**: $p_{T\tau\tau} > 100$ GeV (+ VBF sel veto)	**leptonic**: one jet with p_T >30GeV, $\lvert\eta\rvert$<4.7 and anti-b tag	
		1-jet: veto of the other three, $m_{\tau\tau j} > 225$ GeV	**hadronic**: one jet withp_T >30GeV, $\lvert\eta\rvert$<4.7 and anti-b tag + $p_{TH} > 140$ GeV	
0 jet	none		no jet with p_T >30GeV, $\lvert\eta\rvert$<4.7 used only for normalization purposes	

<table>
<tr><th>H→γγ</th><th>ATLAS</th><th colspan="2">CMS</th></tr>
<tr><td rowspan="2">2 jets</td><td rowspan="2">two jets, $p_{Tjet} > 25$ GeV, $\Delta\eta > 2.8$, $m_{jj} > 400$ GeV, $\Delta\phi_{2j,2\gamma} > 2.6$</td><td rowspan="2">$\Delta\eta>3$, $\Delta\phi_{2j,2\gamma}>2.6$, $Z<2.5$ (*)</td><td>tight: $pt_{jet1,2} > 30$GeV, $m_{jj} > 500$GeV</td></tr>
<tr><td>loose: not tight + $pt_{jet1} > 30$ GeV, $pt_{jet2} > 20$ GeV, $m_{jj} > 250$ GeV</td></tr>
<tr><td>everything else</td><td colspan="3">veto on 2jets + categories based on photon kinematics and properties</td></tr>
</table>

(*) Z = the difference between the average pseudorapidity of the two jets and the pseudorapidity of the diphoton system is required to be less than 2.5

NB: $\Delta\phi_{2j,2\gamma}$ cut acts a bit like a jet veto

Theory for 0-jet bin important for $gg \to H \to WW$

- 0-jet requirement suppresses $t\bar{t} \to WWb\bar{b}$ bkgd by $\sim$ factor 100
- To extract couplings, must know fraction of $gg \to H$ that survives veto

  i.e. has no significant ISR radiation
- But jet veto scale $\sim 25 - 30$ GeV $\ll m_H \longrightarrow$ large logarithms

$$1 - 6\frac{\alpha_s}{\pi} \ln^2 M_H/p_{t,veto} + \dots$$

  cause problems for fixed-order perturbation theory

What are genuine uncertainties in fixed-order calculations?

Total cross section series: $\sigma_{\text{tot}} \simeq \sigma_{\text{LO}}(1 + 10\alpha_s + 36\alpha_s^2 + \cdots)$

Vetoed cross section series: $\sigma_{\text{veto}} \simeq \sigma_{\text{LO}}(1 + 4\alpha_s + 8\alpha_s^2 + \cdots)$

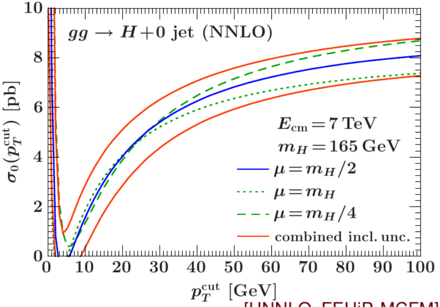
Better-looking perturbative series gives spuriously low scale uncertainties

Stewart–Tackmann '11: write $\sigma_{\text{veto@NNLO}} = \sigma_{\text{tot@NNLO}} - \sigma_{\text{1-jet@NLO}}$

Treat uncertainties in total and 1-jet as uncorrelated.

New procedure. Worthwhile cross-checking with other procedures.

Higgs + 0 Jets



[HNNLO, FEHiP, MCFM]

Stewart & Tackmann '11

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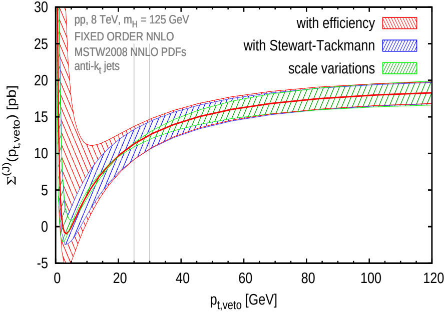


YR2 Stewart & Tackmann

Banfi et al '12

Alternative view: two physical effects

- large K-factor in σ_{tot}
- Sudakov suppression (veto efficiency $= \epsilon = \sigma_{\text{veto}}/\sigma_{\text{tot}}$)

Treat veto efficiency and total cross-section uncertainties as uncorrelated.

Part of issue with jet veto is large logarithms at all orders:

$$\alpha_s^n \ln^{2n} \frac{m_H}{p_{t,\mathrm{veto}}}$$

NLL resummation is remarkably simple: pure Sudakov form factor (no jets = no radiation)

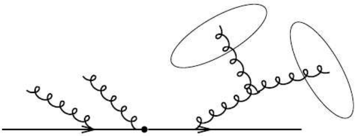
$$\text{veto efficiency } \epsilon(p_t) = \exp\left[\underbrace{Lg_1(\alpha_s L)}_{\mathrm{LL}} + \underbrace{g_2(\alpha_s L)}_{\mathrm{NLL}} + \cdots\right] \qquad L \equiv \ln \frac{m_H}{p_t}$$

resummation functions g_1 and g_2 ≡
those inside Fourier Transform of Higgs p_t resum^n
Banfi, GPS & Zanderighi '12

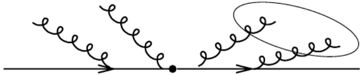
Essentially known since "CAESAR" automated resummation work '03

Story is almost the same at NNLL, i.e. pure Sudakov, plus quasi fixed-order correction

any number of emissions plus
1 gluon splits into two jets



any number of emissions plus
2 gluons clustered into one jet



$$\left(1+\underbrace{f(R)\alpha_s^2(p_{t,\text{veto}})L}_{\text{NNLL}}\right)e^{\left[\underbrace{Lg_1(\alpha_s L)}_{\text{LL}}+\underbrace{g_2(\alpha_s L)}_{\text{NLL}}+\underbrace{g_3(\alpha_s L)}_{\text{NNLL}}+\cdots\right]}$$

4 articles on the subject:
Banfi, GPS & Zanderighi, arXiv:1203.5773; + Monni, arXiv:1206.4998
Becher & Neubert, arXiv:1205.3806
Tackmann, Walsh & Zuberi, arXiv:1206.4312
[Results build on Higgs p_t resum^n of Bozzi et al '03-, Becher & Neubert '10]

Resumming jet veto at NNLL

Story is almost the same at NNLL, i.e. pure Sudakov, plus quasi fixed-order correction

any number of emissions plus
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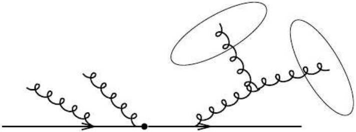

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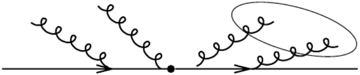

$$\left(\frac{M_H}{p_t}\right)^{f(R)\alpha_s^2(p_{t,\text{veto}})} e^{\left[\underbrace{Lg_1(\alpha_s L)}_{\text{LL}} + \underbrace{g_2(\alpha_s L)}_{\text{NLL}} + \underbrace{g_3(\alpha_s L)}_{\text{NNLL}} + \cdots\right]}$$

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[Results build on Higgs p_t resum^n of Bozzi et al '03-, Becher & Neubert '10]

Current situation:

The 3 groups agree on the NNLL result

BN argue for an all-orders factorization formula ($\simeq$ recipe beyond NNLL)

TWZ argue there are still issues there

One group (BMSZ) has published full NNLL+NNLO numerical predictions.

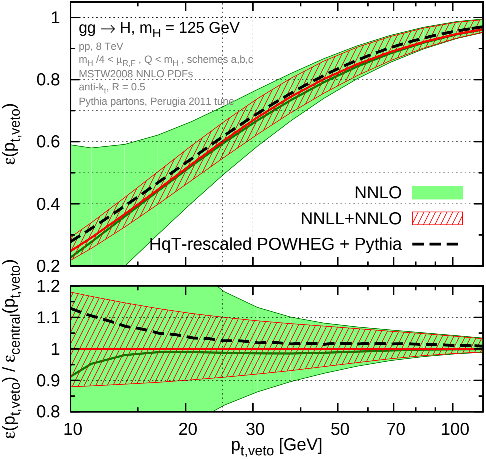
Two groups (BN+Rothen, TWZ+Stewart) have prelim. numerics

[BN numerics shown at last meeting differ from NNLL by constant]

Plan for YR3:

Document the degree of agreement between the groups

Maybe compare final numerical results



NNLL+NNLO compared to NNLO and POWHEG+Pythia (latter tuned/reweighted to HqT)

good agreement!

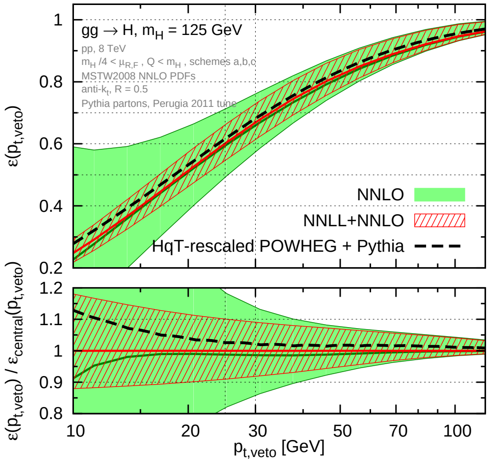
NNLL reduces uncertainties from $\sim 15\% \to \sim 9\%$

[0-jet / $\geq$ 1-jet correlations available too]

public code at

http://jetvheto.hepforge.org

Jet veto efficiency NNLL+NNLO results (BMSZ)



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[0-jet / $\geq$ 1-jet correlations available too]

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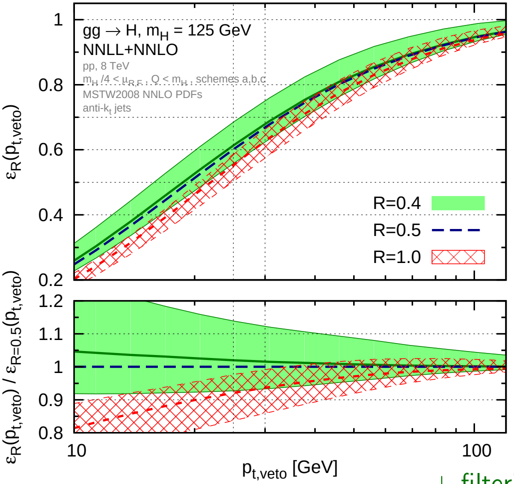
Interim prescription:

- Use these NNLL+NNLO uncertainties in WW 0-jet
- Check central values $\simeq$ your MC



There are all-order terms like $\alpha_s^{n+1} L \ln^n \frac{1}{R}$.

If R is too small these become large.

In practice, choosing $R \sim 1$ reduces uncertainties

Should we resum $\ln R$ terms?

Tackmann, Walsh & Zuberi '12

Should experiments switch to larger R for utmost accuracy?

+ filtering to control UE/pileup dependence

Theory of (exactly) 1-jet bin

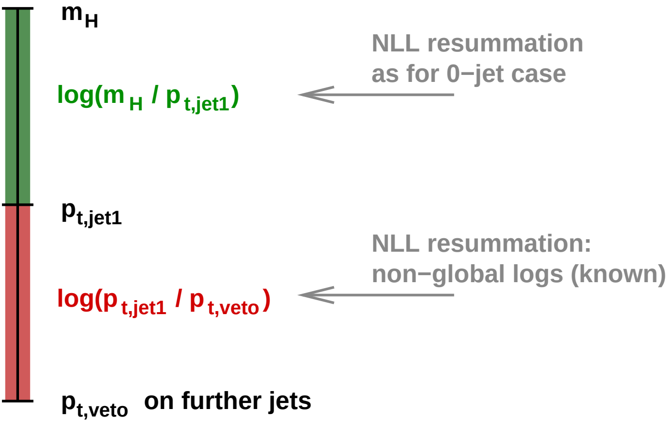
[for WW channel; $\tau\tau$ more complex?]

NLL is within straightforward reach for (exclusive) 1-jet bin

"straightforward" means no conceptual issues or new ingredients;
assembling known ingredients correctly still involves hard work

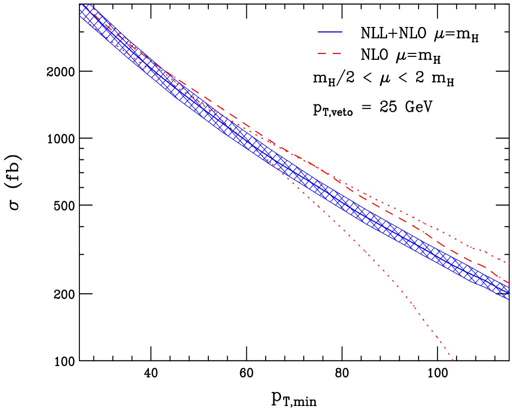
Is $m_H/p_{t,\text{veto}}$ large enough to warrant resumming two sets of logs?

scales for 1−jet bin



Liu & Petriello '12

exclusive 1-jet rate v. $p_{t,min}$ for jet 1



- "Resum logarithms ln $Q/p_{t,\text{veto}}$ [...] where $Q \sim m_H \sim p_{t,\text{jet}}$"
- minimal "NLL_Σ" rather full NLL

  $\alpha_s^n L^{2n} + \alpha_s^n L^{2n-1}$ instead of
  $\exp(\alpha_s^n L^{n+1} + \alpha_s^n L^n)$
  no non-global logs

  e.g. full NNLL+NNLO
  $\sim \text{N}^4\text{LL}_\Sigma$
- A step towards full understanding of 1-jet bin

gluon fusion (ggF) as "background" to VBF 2-jet selection

The Contamination of ggF in VBF (ATLAS)

- Current event selection applies moderate cuts on topological variables. Unlikely that cuts will become much tighter because of loss of signal rate
- **Typical contamination from ggF+2j is ~30%**
  - Contamination gets reduced to about 25% with CJV
- Theory error/systematics on ggF+2j large now:

Source	Error (%)
QCD scale uncertainty	25 (30 with cjv)
Underlying event	30
JES	19

Leading total systematic of ~45% on ggF+2j -> 13% on the extraction of VBF signal (leading systematic)

described by Stefano Frixione in his review

The jets group very recently "commissioned" a comparison of them → understanding the ggF contamination to VBF.

- **aMC@NLO** with Frederix-Frixione ("**FxFx**") merging of H+0/1/2-jet NLO+shower samples. Interfaced with Herwig 6.5
- **Sherpa** with their merging of H+0/1-jet NLO+shower samples plus H+(2/)3-jet LO+shower samples Interfaced with Sherpa shower
- **MINLO/POWHEG**: either H+0, H+1 or H+2-jet NLO+shower samples. Interfaced with Pythia 6.4 (p_t-ordered), Perugia 0 tune
- **HEJ**: high-energy (large-rapidity) approximation for multiple gluon emissions and virtual corrections + exact H+2/3 ME

Most of these tools are fresh off the press

Comparison studies done in a short amount of time

Take following slides as indicative of work in progress rather than final word

Cuts and histograms for comparison study

Simulation & cuts:

- 8 TeV pp collisions, Higgs production by gluon fusion
- Jet-finding with anti-k_t, $R = 0.4$
- At least two jets with $|\eta_j| < 5$, $p_{tj} > 25$ GeV
- VBF cuts: $\Delta y_{jj} > 2.8$, $m_{jj} > 400$ GeV, tagging jets defined as two highest p_t jets; 3rd jet considered if $p_{tj} > 20$ GeV.

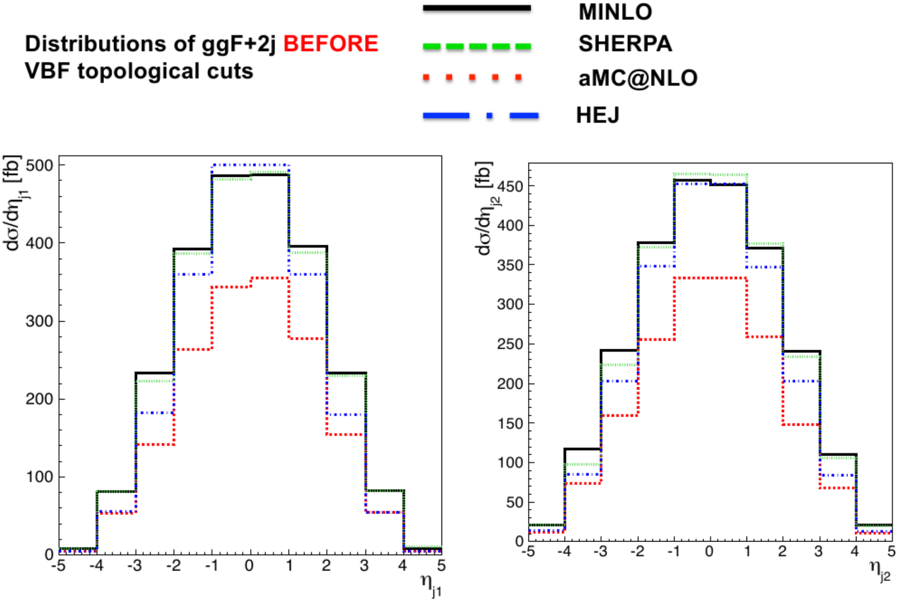
Histograms:

1. p_{tj1}: $25 \ldots 200$ GeV, 25 GeV steps
2. p_{tj2}: $25 \ldots 150$ GeV 25 GeV steps
3. y_{j1}: $-5 \ldots 5$ in steps of 1
4. y_{j2}: $-5 \ldots 5$ in steps of 1
5. $|\Delta y_{jj}|$: $0 \ldots 8$, in steps of 1
6. m_{jj}: $0 \ldots 800$ GeV, 40 GeV steps
7. $\Delta\phi_{jj}$: $0 \ldots \pi$, 10 bins
8. p_{tj3}: $20 \ldots 100$, 10 GeV steps
9. y_{j3}: $-5 \ldots 5$, steps of 1

[10. $\Delta\phi_{jj,\gamma\gamma}$]

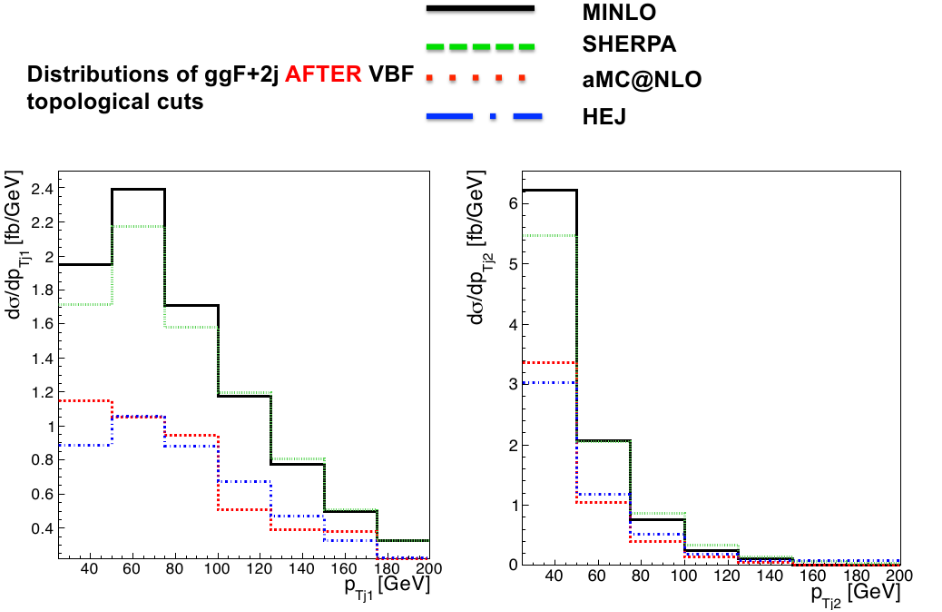
Comparison plots: Sherpa (20 GeV matching); MC@NLO (30 GeV matching); MINLO: Hjj sample; all at parton level, without MPI (UE)

Distributions of ggF+2j **BEFORE** VBF topological cuts



MINLO, Sherpa & HEJ all agree at central jet rapidities; aMC@NLO 25-30% lower

Distributions of ggF+2j AFTER VBF topological cuts

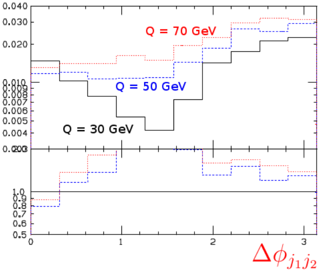


factor 2 difference between aMC@NLO and Sherpa/MINLO, smaller differences between MINLO, Sherpa

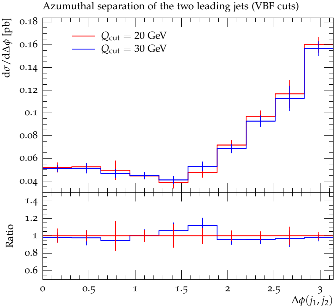
recall Sherpa is H+2@LO, aMC@NLO & MINLO are H+2@NLO

Dependence on matching scale or sample choice

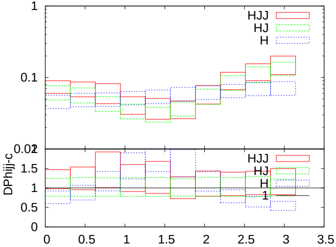
aMC@NLO+FxFx (Frixione)



Sherpa (Schönherr)



POWHEG+MINLO (Nason)



Differences easily summarised in cross-sections

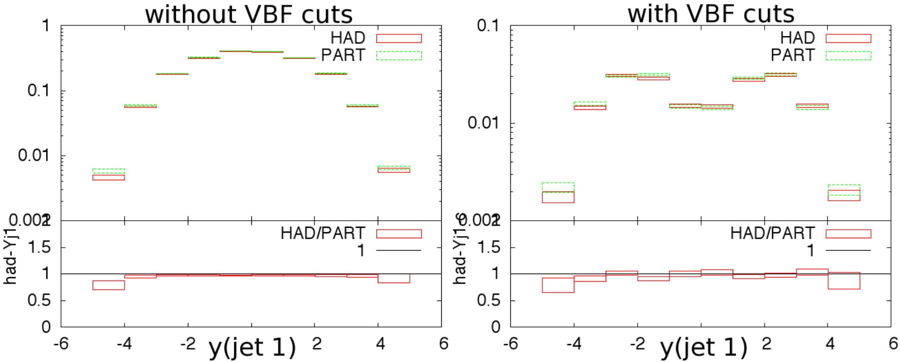
	σ_{tot}	$\sigma_{\text{2-jets}}$	$\sigma_{\text{VBF cuts}}$
aMC@NLO FxFx ($m_Q = 30$ GeV)	13.9 pb	1.65 pb	0.125 pb
Sherpa ($Q_{\text{cut}} = 20$ GeV)	15.2 pb	2.38 pb	0.225 pb
MINLO Hjj	17.8 pb	2.39 pb	0.234 pb
HEJ	—	2.20 pb	0.127 pb

The various differences need understanding

Study needs supplementing with pure NLO H+2 results (e.g. MCFM)
Probably worth examining change of shower in aMC@NLO and MINLO

Impact of UE — is it really 30%?

Impact of UE and hadronisation in MINLO + Pythia



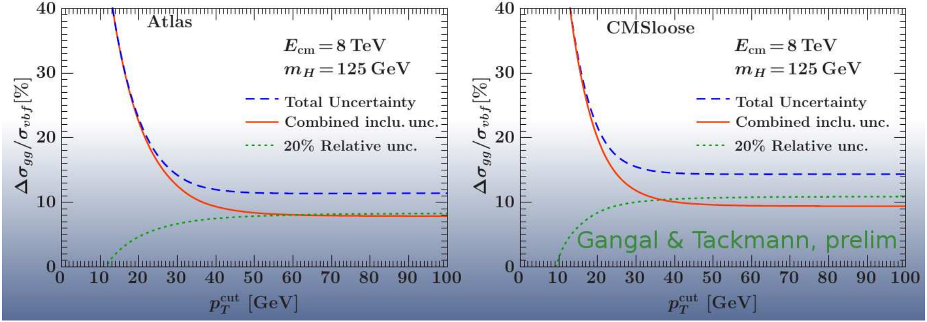
my quick & dirty study: Pythia, scaled to NNLO σ_{tot}, VBF cuts $\to$ UE $\lesssim$ 10%

	partons, no UE	hadrons, no UE	hadrons + UE
Py 6 DW (virt. ord. shower)	0.259 pb	0.243 pb	0.259 pb
Py 6 P2011 (p_t ord. shower)	0.300 pb	0.292 pb	0.318 pb
Py 8 4C (p_t ord. shower)	0.320 pb	0.310 pb	0.330 pb

Does a 3rd-jet veto help disentangle VBF and gluon-fusion?

Normal wisdom says use of a jet veto reduces gluon-fusion “background”.

But (at least in fixed order), it may increase uncertainty on how much gluon-fusion you have.



Preliminary conclusion shown by Gangal & Tackmann:
in fixed-order calculations, a 3rd (central?) jet veto does not help.

Consequence of ST procedure: uncertainty never lower than for inclusive selection

Related dijet resummations: Forshaw, Seymour & collaborators

Some analyses make use of Multi Variate Analyses (MVAs)
How do we treat theory uncertainties in those cases?

To help make progress with this kind of question:

Can you identify what the MVA is doing?
E.g. show main kinematic distributions after MVA cuts (e.g. $\Delta\phi_{\gamma\gamma,jj}$),
so that it is clear which regions are being affected.

Can MVA be forbidden from going into poorly controlled regions?
[Bernlochner, Gangal, Gillberg & Tackmann]

Significant theory progress on 0-jet bin;
Different groups converging in their understanding
Ideally have statement of where we agree in YR3

First developments on the 1-jet bin

Gluon-fusion contamination of VBF is still an open subject,
comparisons ongoing

A big thanks to all the participants (and my co-conveners), who have contributed figures, numbers, slides, comments!

EXTRAS

Cuts for H $\rightarrow$ WW

ATLAS

- 0 jet and 1 jet category based on Jets reconstructed with the anti-k_t algorithm, $R = 0.4$. Jet $p_T > 25(30)$ GeV for $|\eta| < 2.5$ $(2.5 < |\eta| < 4.5)$.
- For 1-jet category, anti-b tagging applied.
- no 2-jet category any more

CMS

- Jets reconstructed with the anti-k_T algorithm, $R = 0.5$. Jet $p_T > 30$ GeV, $|\eta| < 4.7$
- 0-jet and 1-jet according to above
- 2-jets: $\Delta\eta > 3.5$, $m_{jj} > 500$ GeV, central-jet veto (CJV) of 30 GeV

Cuts for H $\to \tau\tau$

ATLAS — 4 categories: VBF, boosted, VH, 1-jet

- for all, at least one jet with $p_t > 40$ GeV

1. VBF: $p_{t,jet\,2} > 25$ GeV, $\Delta\eta_{jj} > 3$, $m_{jj} > 400$ GeV, anti-b tag
2. boosted: $p_{T,\tau\tau} > 100$ GeV (+ VBF sel veto)
3. VH: 30 GeV $< m_{jj} <$ 160 GeV, $p_{t,jet\,2} > 25$ GeV, $\Delta\eta_{jj} < 2$, anti-b tag (+ boosted sel veto)
4. 1-jet: veto of the other three, $m_{\tau\tau j} > 225$ GeV

CMS — jets defined as $p_T > 30$ GeV, $|\eta| < 4.7$

- leptonic 0 & 1-jet: anti-b tag for 1-jet; 0-jet used just for normalisation
- hadronic 1-jet: as above + $p_{TH} > 140$ GeV
- leptonic 2-jet: $\Delta\eta > 3.5$, $m_{jj} > 500$ GeV, CJV (30 GeV)
- hadronic 2-jet: $\Delta\eta > 2.5$, $m_{jj} > 250$ GeV, $p_{TH} > 110$ GeV

Cuts for H $\to \gamma\gamma$

ATLAS

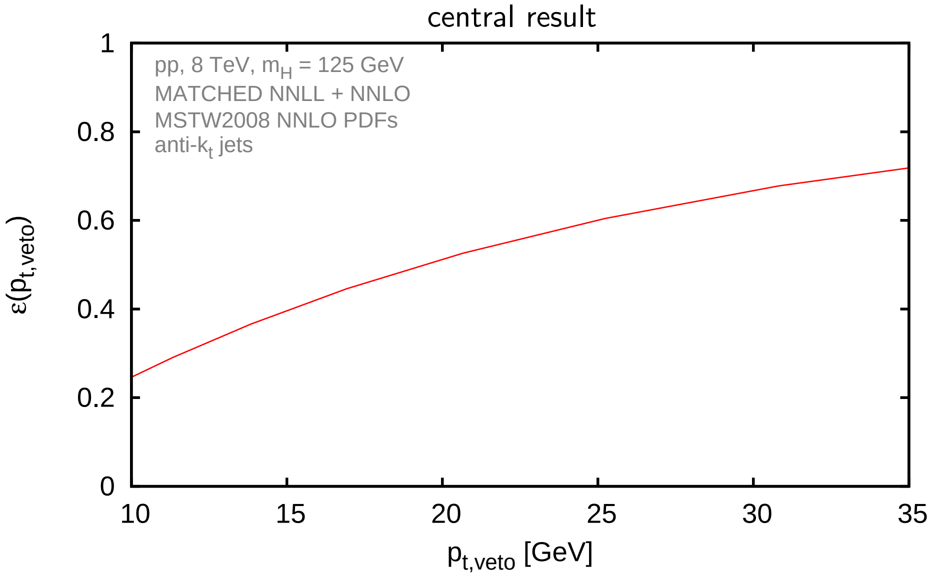
- VBF: two jets, $p_{t,\text{jet}} > 25$ GeV, $\Delta\eta > 2.8$, $m_{jj} > 400$ GeV, $\Delta\phi_{2j,2\gamma} > 2.6$

NB: $\Delta\phi_{2j,2\gamma}$ cut a bit like a 3rd jet veto

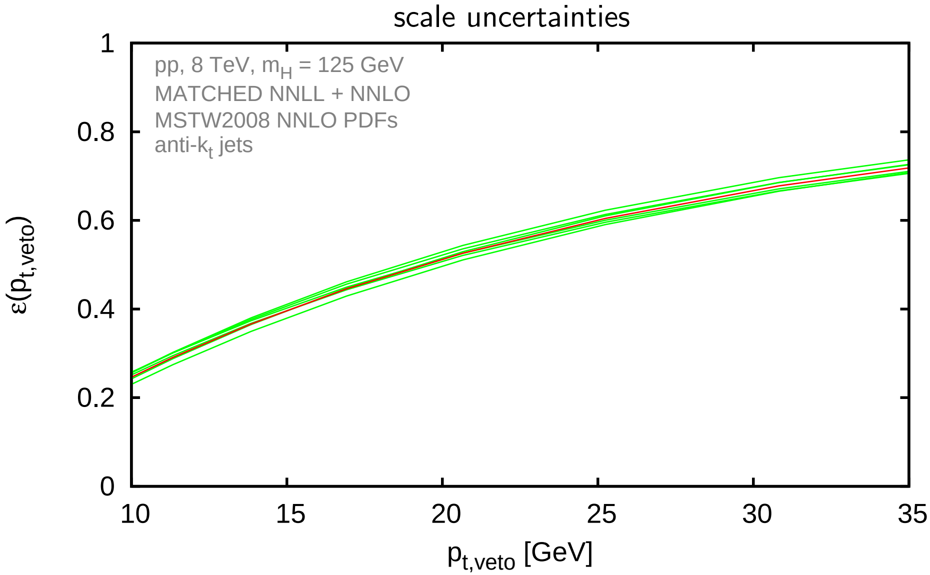
CMS — 2 categories in 2-jet bin

- tight: $p_{t,\text{jet }1,2} > 30$ GeV, $m_{jj} > 500$ GeV, $\Delta\eta > 3$
- loose: not tight $+$ $p_{t,\text{jet }1} > 30$ GeV, $p_{t,\text{jet }2} > 20$ GeV, $m_{jj} > 250$ GeV, $\Delta\eta > 3$
- for both: $\Delta\phi_{2j,2\gamma} > 2.6$, the difference between the average pseudorapidity of the two jets and the pseudorapidity of the diphoton system is required to be less than 2.5

Different uncertainty contributions at NNLO + NNLL

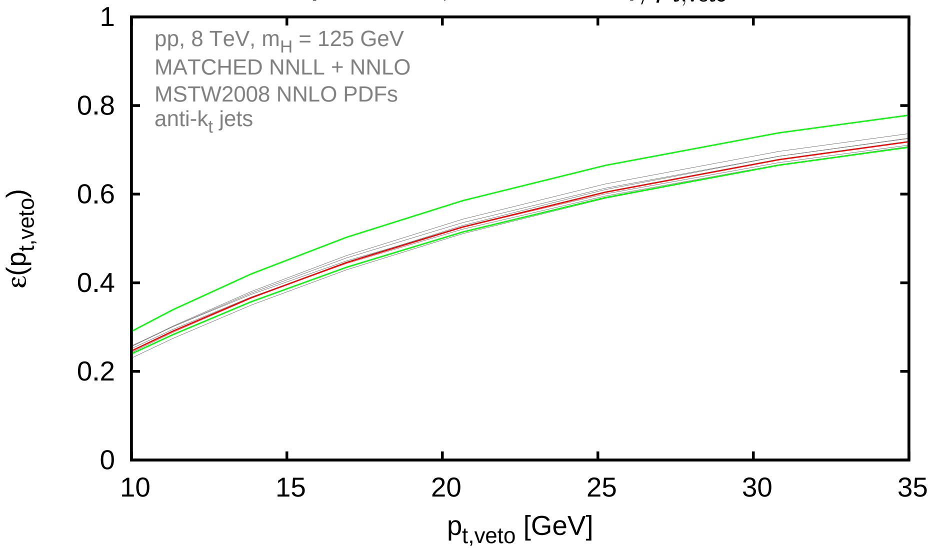


Different uncertainty contributions at NNLO + NNLL

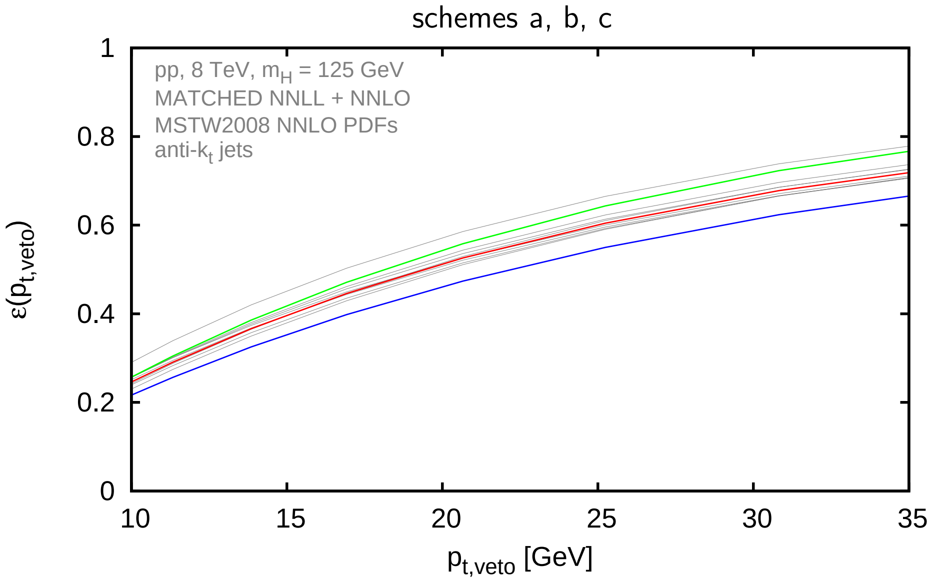


Different uncertainty contributions at NNLO + NNLL

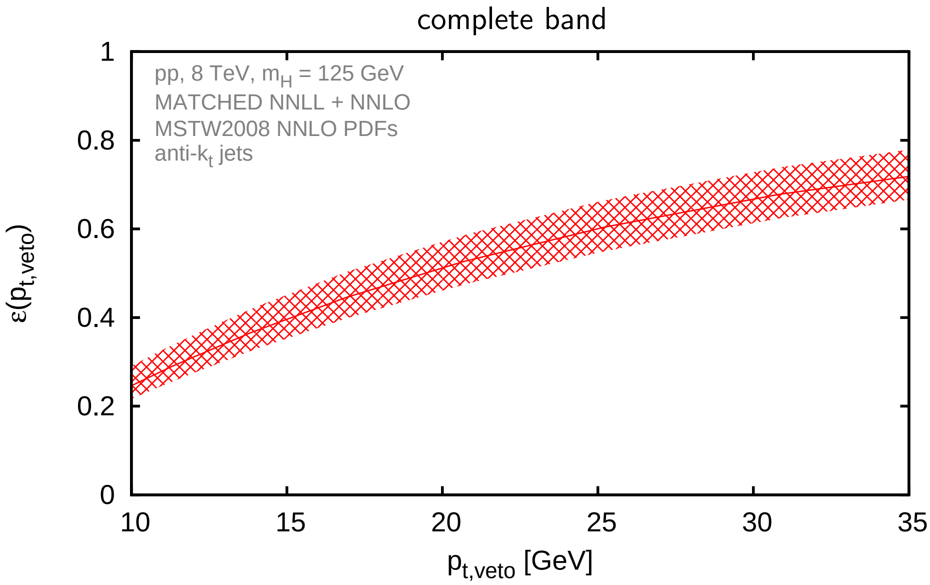
Q variation, with $L = \ln Q/p_{t,\text{veto}}$



Different uncertainty contributions at NNLO + NNLL



Different uncertainty contributions at NNLO + NNLL



Resummation accuracy: know the fine print

There are two widely-used definitions of "NLL", "NNLL", etc.:

[+ minor variants; no good naming convention]

- "minimal" : $\Sigma = \sum_n \underbrace{\alpha_s^n L^{2n}}_{\mathrm{LL}_\Sigma} + \underbrace{\alpha_s^n L^{2n-1}}_{\mathrm{NLL}_\Sigma} + \underbrace{\alpha_s^n L^{2n-2}}_{\mathrm{NNLL}_\Sigma} + \cdots$

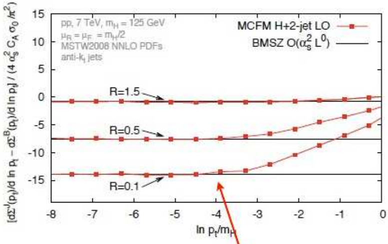
  for $L \sim 1/\sqrt{\alpha_s}$, $\mathrm{N}^p\mathrm{LL}_\Sigma$ uncertainty is $\mathcal{O}\left(\alpha_s^{(p+1)/2}\right)$

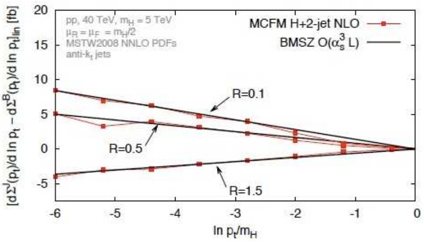
- "full": $\Sigma = \exp\left[\sum_n \underbrace{\alpha_s^n L^{n+1}}_{\mathrm{LL}} + \underbrace{\alpha_s^n L^{n}}_{\mathrm{NLL}} + \underbrace{\alpha_s^n L^{n-1}}_{\mathrm{NNLL}} + \cdots\right]$

  for $L \sim 1/\alpha_s$, $\mathrm{N}^p\mathrm{LL}$ uncertainty is $\mathcal{O}\left(\alpha_s^p\right)$

As an example, "full" NNLL (+ NNLO) $\sim$ "minimal" $\mathrm{N}^4\mathrm{LL}_\Sigma$

Check against MCFM [Campbell, Ellis, Williams '10]





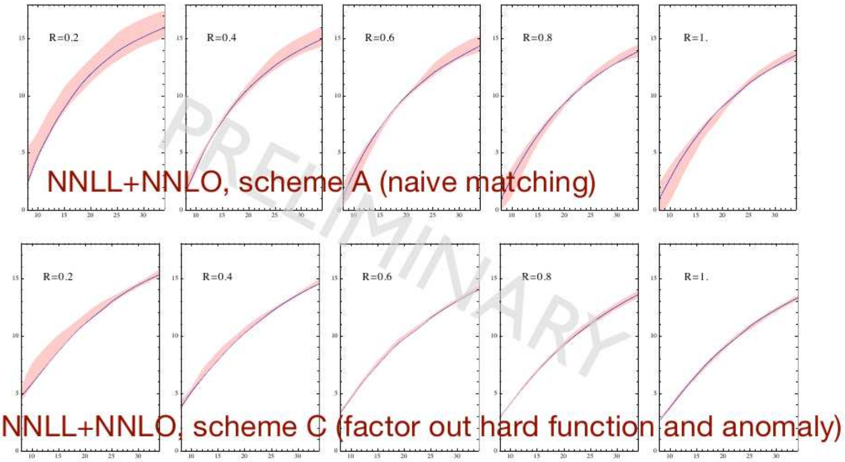
- Difference between log-distributions in $p_{t,\text{Higgs}}$ and $p_{t,\text{veto}}$ at order $\mathcal{O}(\alpha_s^2)$ against MCFM's H+2j@LO

$$\Delta\left(\frac{d\Sigma_2(p_t)}{d\ln p_t}\right) \sim \alpha_s^2 L^0$$

- Difference between log-distributions in $p_{t,\text{Higgs}}$ and $p_{t,\text{veto}}$ at order $\mathcal{O}(\alpha_s^3)$ against MCFM's H+2j@NLO

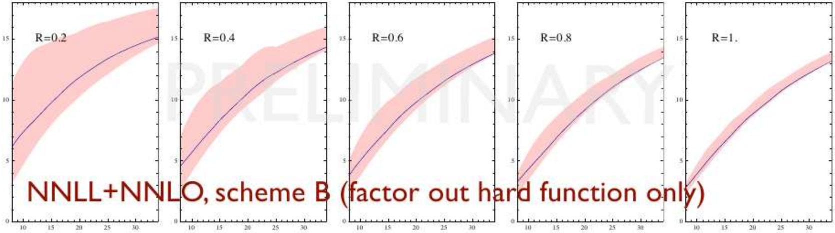
$$\Delta\left(\frac{d\Sigma_3(p_t)}{d\ln p_t}\right) \sim \alpha_s^3 L^2 + \alpha_s^3 L + \alpha_s^3 L^0$$

10



- Small scale dependence in A, very small scale uncertainty in scheme C
- Cancellation of scale dependence between resummed result and matching correction.

Becher



- Large scale uncertainty at small *R*, in contrast to the other schemes.
- Given the differences among schemes, it is not straightforward to assign theoretical uncertainty at low *R*

Becher

Practical stability of Sherpa results

with VBF cuts:

$$\sigma = .225^{+0.074}_{-0.055}(\mu_{R/F})\,^{+0.010}_{-0.005}(\mu_Q)\,^{+0.003}_{-0.009}(Q_{\text{cut}})\,^{+0.000}_{-0.013}(\text{Nmax})\pm 0.004(\text{stats})pb$$