NNLOPS with POWHEG *& MiNLO*

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Outline

- Quick introduction
- MiNLO & NLOPS-merging
  - MiNLO: Multiscale Improved NLO

    [1206.3572]
  - NLOPS merging of X @ NLO and $X+1$ jet @ NLO

    [1212.4504]
- Matching NNLO with PS
  - NNLOPS simulation of Higgs production

    [1309.0017]

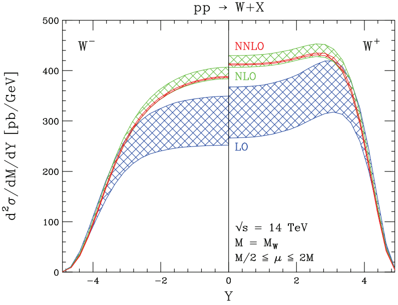
- News in POWHEG BOX

  [powhegbox.mib.infn.it]

Intro

Why NLO is important?

- first order where rates are reliable, and possible to attach sensible theoretical uncertainties
- shapes are, in general, better described
- sometimes corrections are sizeable, rates enhanced, etc.
- in these cases, NNLO is desirable (and lots of progress was done in 2013)



[Anastasiou et al., 0312266]

Limitations:

- Results are at the parton level only (5 final-state jets is the frontier)
- In regions where collinear emissions are important, they fail (no resummation)
  - ☞ desirable to bring NLO accuracy into SMC
    * not trivial, because PS already contains R and V in LL approximation

However, POWHEG and MC@NLO solve this issue

- Choice of scale can become an issue when multijets in the final states
  - ☞ MiNLO originally thought to address this issue

Idea: *Modify* $d\sigma_{\mathrm{SMC}}$ *in such a way that*, expanding in α_{S}, *one recovers the NLO cross section*.

[Nason '04]

$$B(\Phi_n) \quad \Rightarrow \quad \bar{B}(\Phi_n) = B(\Phi_n) + \frac{\alpha_s}{2\pi}\left[V(\Phi_n) + \int R(\Phi_{n+1})\, d\Phi_r\right]$$

$$\Delta(t_{\mathrm{m}}, t) \quad \Rightarrow \quad \Delta(\Phi_n; k_{\mathrm{T}}) = \exp\left\{-\frac{\alpha_s}{2\pi}\int \frac{R(\Phi_n, \Phi'_r)}{B(\Phi_n)}\theta(k'_{\mathrm{T}} - k_{\mathrm{T}})\, d\Phi'_r\right\}$$

POWHEG "master formula" for the hardest emission:

$$d\sigma_{\mathrm{POW}} = d\Phi_n\ \bar{B}(\Phi_n)\left\{\Delta(\Phi_n; k_{\mathrm{T}}^{\mathrm{min}}) + \Delta(\Phi_n; k_{\mathrm{T}})\frac{\alpha_s}{2\pi}\frac{R(\Phi_n, \Phi_r)}{B(\Phi_n)}\, d\Phi_r\right\}$$

+ p_{T}*-vetoing subsequent emissions*, to avoid double-counting.

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- inclusive observables: @NLO
- first hard emission: full tree level ME
- (N)LL resummation of collinear/soft logs

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☞ Notice: when doing $X+$ jet(s) @ NLO, $\bar{B}(\Phi_n)$ is not finite !
↪ need of a generation cut on Φ_n (or variants thereof)
↪ POWHEG for $H + 1$ jet cannot be used for inclusive Higgs production

MiNLO & NLOPS merging

MiNLO: intro

MiNLO: Multiscale Improved NLO [Hamilton,Nason,Zanderighi, 1206.3572]

- goal: method to a-priori choose scales in NLO computation
- relevant for processes with widely different scales (*e.g.* $X+$ jets close to Sudakov regions)

How?

- At LO, the CKKW procedure allows to take these effects into account: modify the LO weight $B(\mathbf{\Phi}_n)$ in order to include (N)LL effects.

$\Rightarrow$ "Use CKKW" on top of NLO computation that potentially involves many scales

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Next-to-Leading Order accuracy needs to be preserved

MiNLO: Multiscale Improved NLO

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Next-to-Leading Order accuracy needs to be preserved

1. Scale dependence shows up at NNLO ["scale compensation"]:

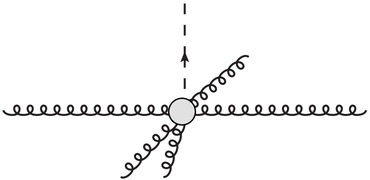
$$O(\mu') - O(\mu) = \mathcal{O}(\alpha_S^{n+2}) \quad \text{if} \quad O \sim \alpha_S^n \quad \text{at LO}$$

2. Away from soft-collinear regions, exact NLO recovered:

$$O_{\mathrm{MiNLO}} = O_{\mathrm{NLO}} + \mathcal{O}(\alpha_S^{n+2}) \qquad [\ i.e.\ \alpha_S^n\ \&\ \alpha_S^{n+1}\ \text{reproduce plain NLO}\ ]$$

From CKKW to MiNLO

- Find "most-likely" shower history (via k_T-algo): $Q > q_3 > q_2 > q_1 \equiv Q_0$



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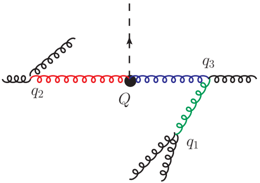

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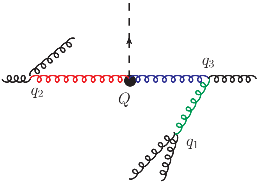

- Evaluate α_S at nodal scales

$$\alpha_S^n(\mu_R)B(\mathbf{\Phi}_n) \Rightarrow \alpha_S(q_1)\alpha_S(q_2)...\alpha_S(q_n)B(\mathbf{\Phi}_n)$$

* scale compensation requires $\bar{\mu}_R^2 = (q_1 q_2 ... q_n)^{2/n}$ in V

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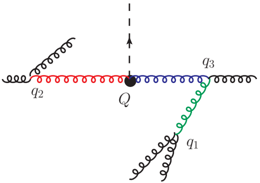

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- Sudakov FFs in internal and external lines of Born "skeleton"

$$B(\mathbf{\Phi}_n) \Rightarrow B(\mathbf{\Phi}_n) \times \{\Delta(Q_0, Q)\Delta(Q_0, q_i)...\}$$

* Upon expansion, $\mathcal{O}(\alpha_S^{n+1})$ (log) terms are introduced, and need to be removed

$$B(\mathbf{\Phi}_n) \Rightarrow B(\mathbf{\Phi}_n)\Big(1 - \Delta^{(1)}(Q_0, Q) - \Delta^{(1)}(Q_0, q_i) + ...\Big)$$

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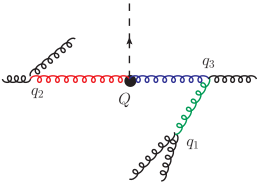

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☞ $X+$ jets cross-section finite without generation cuts
↪ $\bar{B}$ with MiNLO prescription: ideal starting point for NLOPS (POWHEG) for $X+$ jets

MiNLO: example

Example, in 1 line: $H+1$ jet

- Pure NLO:

$$d\sigma = \bar{B}\, d\mathbf{\Phi}_n = \alpha_{\rm S}^3(\mu_R)\Big[B + \alpha_{\rm S}^{\rm (NLO)} V(\mu_R) + \alpha_{\rm S}^{\rm (NLO)} \int d\Phi_{\rm rad} R\Big]\, d\mathbf{\Phi}_n$$

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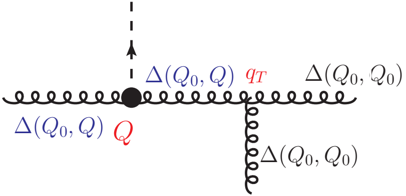
- Pure NLO:

$$d\sigma = \bar{B}\, d\mathbf{\Phi}_n = \alpha_S^3(\mu_R)\Big[B + \alpha_S^{(\mathrm{NLO})} V(\mu_R) + \alpha_S^{(\mathrm{NLO})} \int d\Phi_{\mathrm{rad}} R\Big]\, d\mathbf{\Phi}_n$$

- MiNLO:

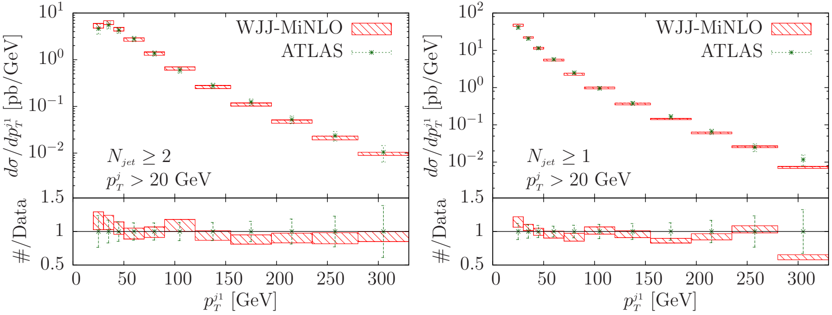
$$\bar{B} = \alpha_S^2(M_H)\alpha_S(q_T)\Delta_g^2(q_T, M_H)\Big[B\left(1 - 2\Delta_g^{(1)}(q_T, M_H)\right) + \alpha_S^{(\mathrm{NLO})} V(\bar{\mu}_R) + \alpha_S^{(\mathrm{NLO})} \int d\Phi_{\mathrm{rad}} R\Big]$$



* $\bar{\mu}_R = (M_H^2 q_T)^{1/3}$
* $\log \Delta_f(q_T, Q) = -\int_{q_T^2}^{Q^2} \frac{dq^2}{q^2} \frac{\alpha_S(q^2)}{2\pi}\Big[A_f \log \frac{Q^2}{q^2} + B_f\Big]$
* $\Delta_f^{(1)}(q_T, Q) = -\alpha_S^{(\mathrm{NLO})} \frac{1}{2\pi}\Big[\frac{1}{2} A_{1,f} \log^2 \frac{Q^2}{q_T^2} + B_{1,f} \log \frac{Q^2}{q_T^2}\Big]$
* $\mu_F = Q_0 (= q_T)$

MiNLO: results

VJJ−MiNLO [Campbell,Ellis,Nason,Zanderighi, 1303.5447]



☞ Start from $W + 2$ jets @ NLO, good agreement with data also when requiring $N_{\text{jet}} \geq 1$!

This is not possible with a standard NLO...

[Hamilton et al., 1212.4504]

- Accuracy of BJ+MiNLO for inclusive observables carefully investigated
- BJ+MiNLO describes inclusive boson observables at order α_S (relative to $B + 0j$ at LO)
- However, to reach genuine NLO when inclusive, higher terms must be of relative order α_S^2, *i.e.*
$$O_{\mathrm{BJ+MiNLO}} = O_{\mathrm{B@NLO}} + \mathcal{O}(\alpha_S^{m+2})$$
if O is inclusive (B@LO $\sim \alpha_S^m$).
- “Original MiNLO” contains ambiguous $\mathcal{O}(\alpha_S^{m+3/2})$ terms.
- Possible to improve BJ+MiNLO such that NLO $B + 0j$ (NLO$^{(0)}$) is recovered, without spoiling NLO accuracy for $B + 1j$ (NLO$^{(1)}$) .
  - proof based on careful comparisons of general resummation formula with MiNLO ingredients
  - need to include B_2 in MiNLO-Sudakovs
  - need to evaluate $\alpha_S{}^{(\mathrm{NLO})}$ in BJ+MiNLO at scale q_T, and $\mu_F = q_T$

Effectively it is like if we merged NLO$^{(0)}$ and NLO$^{(1)}$ samples, without merging different samples (no merging scale used).

"Improved" MiNLO & NLOPS merging

- Resummation formula

$$\frac{d\sigma}{dq_T^2 dy} = \sigma_0 \frac{d}{dq_T^2}\Big\{[C_{ga}\otimes f_a](x_A, q_T) \times [C_{gb}\otimes f_b](x_B, q_T) \times \exp S(q_T, Q)\Big\} + R_f$$

- If $C_{ij}^{(1)}$ included and R_f is LO$^{(1)}$, then upon integration we get NLO$^{(0)}$
- Take derivative, then compare with `MiNLO` :

$$\sim \sigma_0 \frac{1}{q_T^2}[\alpha_S, \alpha_S^2, \alpha_S^3, \alpha_S^4, \alpha_S L, \alpha_S^2 L, \alpha_S^3 L, \alpha_S^4 L] \exp S(q_T, Q) + R_f \qquad L = \log(Q^2/q_T^2)$$

- highlighted terms are needed to reach NLO$^{(0)}$:

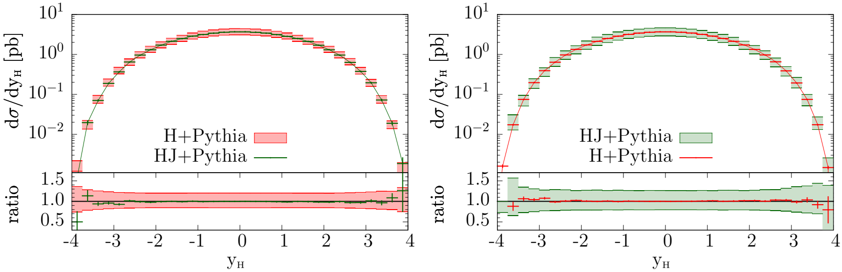
$$\int^{Q^2} \frac{dq_T^2}{q_T^2} L^m {\alpha_S}^n(q_T) \exp S \sim \big(\alpha_S(Q^2)\big)^{n-(m+1)/2}$$

- if I don't include B_2 in `MiNLO` Δ_g, I miss a term $(1/q_T^2)\alpha_S^2 B_2 \exp S$
- upon integration, violate NLO$^{(0)}$ by a term of relative $\mathcal{O}(\alpha_S^{3/2})$
- "wrong" scale in $\alpha_S^{(\mathrm{NLO})}$ in `MiNLO` produces again same error

Alternative proof also available in the paper.

MiNLO merging: results 1

[Hamilton et al., 1212.4504]



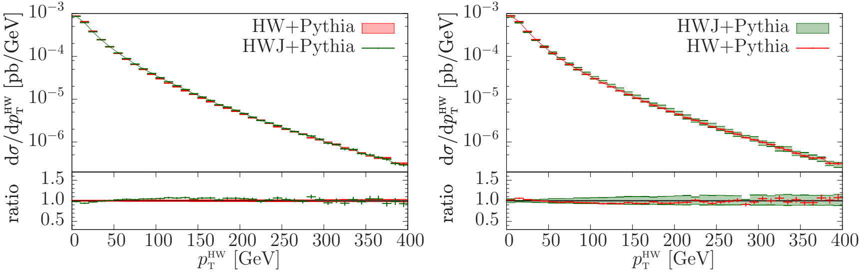
- "H+Pythia": standalone POWHEG ($gg \to H$) + PYTHIA (PS level) [7pts band, $\mu = m_H$]
- "HJ+Pythia": HJ−MiNLO* + PYTHIA (PS level) [7pts band, μ from MiNLO]

✓ very good agreement (both value and band)

☞ Notice: band is $\sim 20 - 30\%$

MiNLO merging: results 2

[Luisoni et al., 1306.2542]



- ✓ good agreement (notice that in `HWJ-MiNLO` this observable is NLO)
- scale dependence in `HW-POWHEG` inherited from fully-inclusive cross-section (no `hfact` used).
- and there is a Sudakov peak (not noticeable in these plots)

NNLO Higgs production matched with PS

NNLO+PS (1)

- HJ−MiNLO* differential cross section $(d\sigma/dy)_{\mathrm{HJ-MiNLO}}$ is NLO accurate

$$W(y) = \frac{\left(\frac{d\sigma}{dy}\right)_{\mathrm{NNLO}}}{\left(\frac{d\sigma}{dy}\right)_{\mathrm{HJ-MiNLO}}} = \frac{c_2\alpha_S^2 + c_3\alpha_S^3 + c_4\alpha_S^4}{c_2\alpha_S^2 + c_3\alpha_S^3 + d_4\alpha_S^4} \simeq 1 + \frac{c_4 - d_4}{c_2}\alpha_S^2 + \mathcal{O}(\alpha_S^3)$$

- thus, reweighting each event with this factor, we get NNLO+PS
  * obvious for y_H, by construction
  * α_S^4 accuracy of HJ−MiNLO* in 1-jet region not spoiled, because $W(y) = 1 + \mathcal{O}(\alpha_S^2)$
  * if we had NLO$^{(0)} + \mathcal{O}(\alpha_S^{2+3/2})$, 1-jet region spoiled because

$$[\mathrm{NLO}^{(1)}]_{\mathrm{NNLOPS}} = \mathrm{NLO}^{(1)} + \mathcal{O}(\alpha_S^{4.5})$$

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* Variants for W are possible:

$$W(y, p_T) = h(p_T)\frac{\int d\sigma_A^{\mathrm{NNLO}}\,\delta(y - y(\mathbf{\Phi}))}{\int d\sigma_A^{\mathrm{MiNLO}}\,\delta(y - y(\mathbf{\Phi}))} + (1 - h(p_T))$$

$$d\sigma_A = d\sigma\ h(p_T), \qquad d\sigma_B = d\sigma\ (1 - h(p_T)), \qquad h = \frac{(\beta m_H)^2}{(\beta m_H)^2 + p_T^2}$$

* $h(p_T)$ controls where the NNLO/NLO K-factor is spread
* with above W, we get $(d\sigma/dy)_{\mathrm{NNLOPS}} = (d\sigma_A/dy)_{\mathrm{NNLO}} + (d\sigma_B/dy)_{\mathrm{HJ-MiNLO}}$

NNLO+PS (2)

In 1309.0017, we used

$$W(y, p_T) = h(p_T) \frac{\int d\sigma^{\rm NNLO} \delta(y - y(\mathbf{\Phi})) - \int d\sigma_B^{\rm MiNLO} \delta(y - y(\mathbf{\Phi}))}{\int d\sigma_A^{\rm MiNLO} \delta(y - y(\mathbf{\Phi}))} + (1 - h(p_T))$$

$$d\sigma_A = d\sigma\, h(p_T), \qquad d\sigma_B = d\sigma\,(1 - h(p_T)), \qquad h = \frac{(\beta m_H)^2}{(\beta m_H)^2 + p_T^2}$$

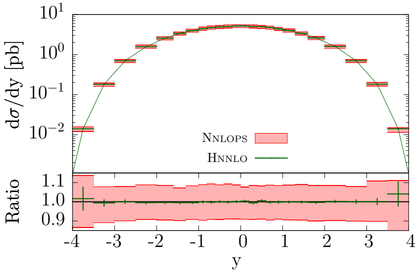
- we get exactly $(d\sigma/dy)_{\rm NNLOPS} = (d\sigma/dy)_{\rm NNLO}$ (no α_S^5 terms)
- we use $h(p_T^{j_1})$

Run details:

- results are for 8 TeV LHC
- scale choices: NNLO input with $\mu = m_H/2$, HJ−MiNLO "core scale" m_H (other powers are at q_T)
- PDF: everywhere MSTW8NNLO
- NNLO always from HNNLO
- events reweighted at the LH level
- plots after $k_{\rm T}$-ordered PYTHIA 6 at the PS level (hadronization and MPI switched off)

NNLO+PS (fully incl.)

- NNLO with $\mu = m_H/2$, HJ-MiNLO "core scale" m_H [NNLO from HNNLO, Catani,Grazzini]
- $(7_{\rm Mi} \times 3_{\rm NN})$ pts scale var. in NNLOPS, 7pts in NNLO

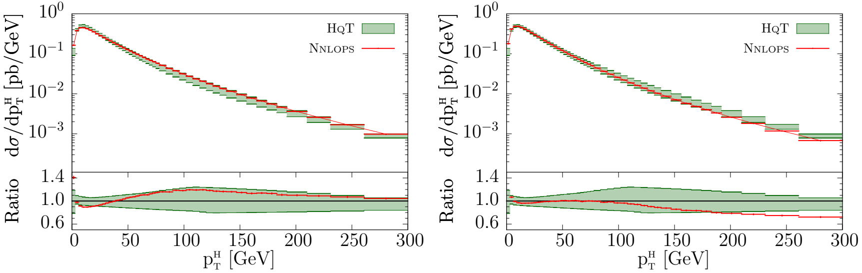


☞ Notice: band is 10%

[Until and including $\mathcal{O}(\alpha_S^4)$, PS effects don't affect y_H (first 2 emissions controlled properly at $\mathcal{O}(\alpha_S^4)$ by MiNLO+POWHEG)]

NNLO+PS (p_T^H)

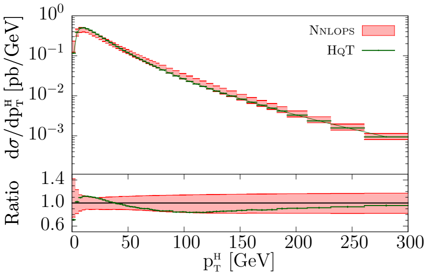
$\beta = \infty$ (W indep. of p_T) $\beta = 1/2$



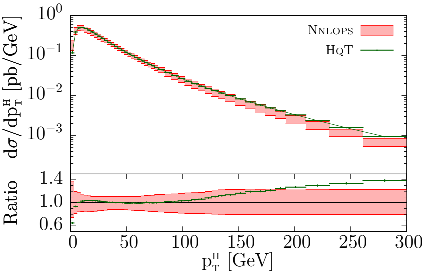
- HqT: NNLL+NNLO, $\mu_R = \mu_F = m_H/2$ [7pts], $Q_{\rm res} \equiv m_H/2$
- ✓ $\beta = 1/2$ & ∞: uncertainty bands of HqT contain NNLOPS at low-/moderate p_T
- $\beta = 1/2$: HqT tail harder than NNLOPS tail ($\mu_{\rm HqT} <$ "$\mu_{\rm MiNLO}$")
- $\beta = 1/2$: very good agreement with HqT resummation ["∼ expected", since $Q_{\rm res} \equiv m_H/2$]

NNLO+PS (p_T^H)

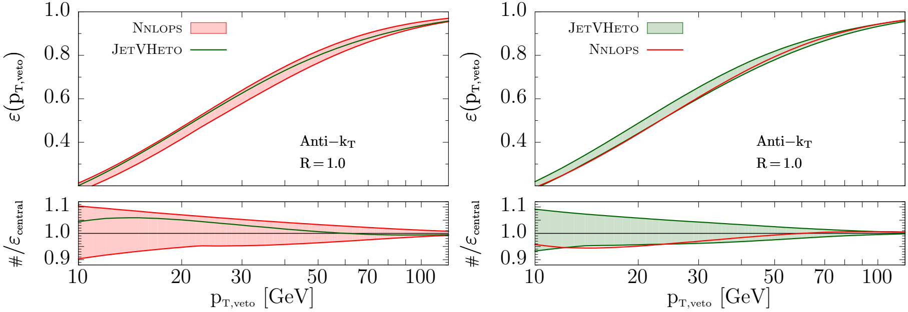
$\beta = \infty$ (W indep. of p_T)



$\beta = 1/2$



- HqT: NNLL+NNLO, $\mu_R = \mu_F = m_H/2$ [7pts], $Q_{\rm res} \equiv m_H/2$
- $\beta = 1/2$: NNLOPS tail $\rightarrow$ NLOPS tail [$W(y, p_T \gg m_H) \rightarrow 1$]
  larger band (affected just marginally by NNLO, so it's $\sim$ genuine NLO band)

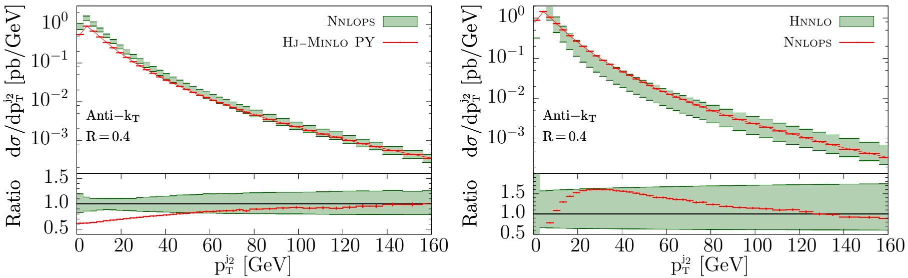


$$\varepsilon\left(p_{\mathrm{T,veto}}\right) = \frac{\Sigma(p_{\mathrm{T,veto}})}{\sigma^{\mathrm{tot}}} = \frac{1}{\sigma^{\mathrm{tot}}}\int d\sigma\, \theta\left(p_{\mathrm{T,veto}} - p_{\mathrm{T}}^{\mathrm{j_1}}\right)$$

- `JetVHeto`: NNLL resum, $\mu_R = \mu_F = m_H/2$ [7pts], $Q_{\mathrm{res}} \equiv m_H/2$, (a)-scheme only
- nice agreement, differences never more than 5-6 %

☞ Separation of $H \to WW$ from $t\bar{t}$ bkg: x-sec binned in N_{jet}
0-jet bin ⇔ jet-veto accurate predictions needed !

NNLO+PS (p_T^{j2})



- This is LO (and $\mu_{\rm NNLO} = m_H$)
- as expected, at high $k_{\rm T}$, NNLOPS reproduces the underlying HJ−MiNLO (which for j_2 means HJ−POWHEG)
- at small p_T ($\lesssim m_H/2$), effect of $W(p_{T,j_1})$ noticeable (j_1 just harder than j_2)
- scale variation in NNLOPS greatly underestimated (usual effect with POWHEG in "NLO-jet" region; here even more pronounced, since NNLO-reweighted)

POWHEG-BOX status update

POWHEG BOX: technical improvements

* V2 ready, new processes and new developments there.

* MiNLO will be the default for $X+$jets processes.

Automation:

- Interface to MadGraph 4 [Frederix]: automatically builds subprocesses list, B, B_{ij}, $B^{\mu\nu}$, R and large-N Born color structures.
  - Used to build the code for Hj and Hjj [Campbell, Ellis, Frederix, Nason, Oleari], with virtuals from MCFM.
- interface to GoSam [Luisoni, Nason, Oleari, Tramontano]: automatically write the code for 1-loop amplitudes, and interface it via BLHA
  - Used to study VH and VHj

PDF and scale uncertainties:

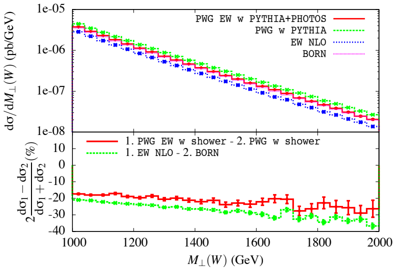
- Generate MC samples for different scale choices, and, even more, for different PDFs, is very time consuming
- Primitive reweighting facility now superseded by new mechanism [Hamilton,Nason,ER]
  - we need some feedback

Complicated processes & parallelization:

- Possible to run POWHEG BOX in parallel. Not only event generation, but also grid computation.
- details in repository [Parallel-grids]

POWHEG BOX: other news

- EW processes ($VVjj$, $\ell\ell jj$) [Jaeger, Zanderighi, ...]
  - last month: $ZZjj$, also with anomalous couplings [Jaeger, Karlberg, Zanderighi, '13]
- DM+monojet [Haisch,Kahlhoefer, ER]
- NLO QCD and NLO EW, for DY [Bernaciak,Wackeroth'12 - Barze et al'12-'13]



- we started looking into problem with top p_T in $t\bar{t}$

Conclusions

- MiNLO & improved MiNLO:
  - original motivation: assign scales and Sudakov FF in $B+n$ jets NLO computations
  - ideal as starting point for POWHEG
  - $B+1$ jet "improved" MiNLO allows to merge NLO$^{(0)}$ and NLO$^{(1)}$ samples, without the need of a merging scale
    - ☞ merging for higher multiplicity requires further study
- NNLOPS:
  - MiNLO allows to define a procedure to reach NNLOPS
  - Shown first results for Higgs production
    - ☞ NNLOPS doable for DY and $H+V$; more to learn ?

- Progress in POWHEG BOX:
  - list of processes steadily increasing
  - towards automation (via interfaces to MG4 / GoSam / ...?)
  - several technical improvements to keep up with theoretical and experimental needs
    $\hookrightarrow$ V2 essentially ready

Conclusions

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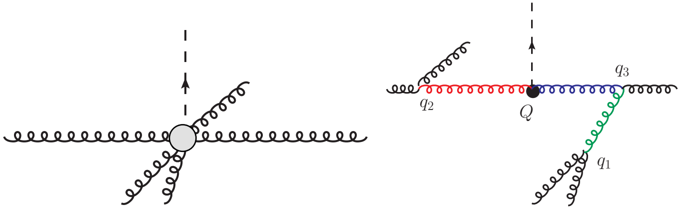
Thanks for your attention!

Backup 1: CKKW in a nutshell

- ME weight $B(\mathbf{\Phi}_n) \Rightarrow$ "most-likely" shower history (via k_T-algo): $Q > q_3 > q_2 > q_1 \equiv Q_0$



- New weight:

$$\alpha_S^5(Q)B(\mathbf{\Phi}_3) \quad \rightarrow \quad \alpha_S^2(Q)B(\mathbf{\Phi}_3)\frac{\Delta_g(Q_0,Q)}{\Delta_g(Q_0,q_2)}\frac{\Delta_g(Q_0,Q)}{\Delta_g(Q_0,q_3)}\frac{\Delta_g(Q_0,q_3)}{\Delta_g(Q_0,q_1)}$$
$$\Delta_g(Q_0,q_2)\Delta_g(Q_0,q_2)\Delta_g(Q_0,q_3)\Delta_g(Q_0,q_1)\Delta_g(Q_0,q_1)$$
$$\alpha_S(q_1)\alpha_S(q_2)\alpha_S(q_3)$$

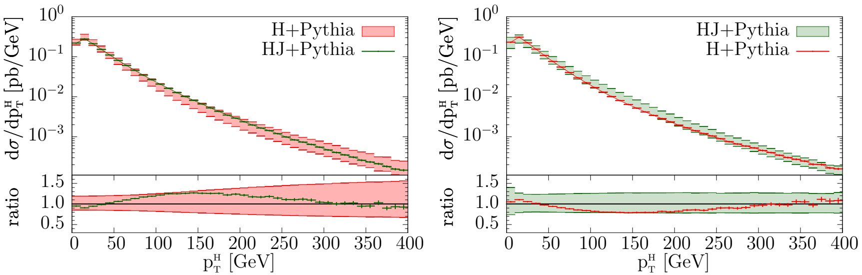
where typically

$$\log \Delta_f(q_T,Q) = -\int_{q_T^2}^{Q^2}\frac{dq^2}{q^2}\frac{\alpha_S(q^2)}{2\pi}\left[A_{1,f}\log\frac{Q^2}{q^2} + B_{1,f}\right]$$

- Fill phase space below Q_0 with vetoed shower

Backup 2: MiNLO merging, other results

[Hamilton et al., 1212.4504]



- Good agreement
- At high p_T, bands as expected (LO vs NLO)
  (`POWHEG` $(gg \to H)$ with `hfact` $= m_H/1.2$, YR2)

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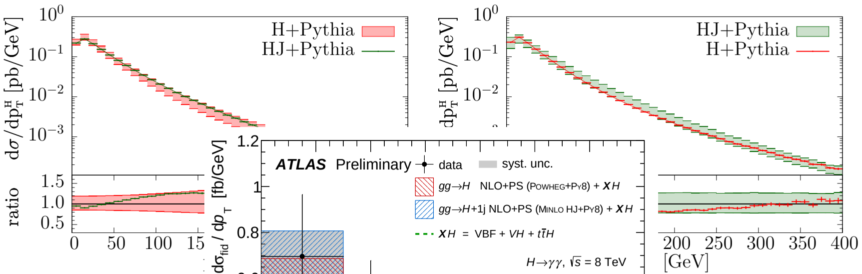
[Hamilton et al., 1212.4504]



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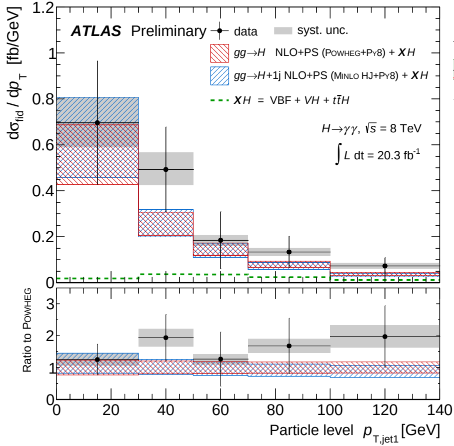

Backup 3: MiNLO details

MiNLO: All α_S in Born term are chosen with CKKW (local) scales $q_1, ..., q_n$

$$\alpha_S^n(\mu_R)B \Rightarrow \alpha_S(q_1)\alpha_S(q_2)...\alpha_S(q_n)B$$

- Normal NLO structure ($\mu = \mu_R$):

$$\sigma(\mu) = \underbrace{\alpha_S^n(\mu)B}_{\text{Born}} + \underbrace{\alpha_S^{n+1}(\mu)\Big(C + nb_0\log(\mu^2/Q^2)B\Big)}_{\text{Virtual}} + \underbrace{\alpha_S^{n+1}(\mu)R}_{\text{Real}}$$

- Explicit μ dependence of virtual term as required by RG invariance:

$$\alpha_S^n(\mu')B = \Big[\alpha_S(\mu)\ -nb_0\alpha_S^{n+1}(\mu)\log(\mu'^2/\mu^2)\Big]B + \mathcal{O}(\alpha_S^{n+2})$$

$$\text{Virtual}(\mu') = \text{Virtual}(\mu)\ +\alpha_S^{n+1}(\mu)nb_0\log(\mu'^2/\mu^2)\ B + \mathcal{O}(\alpha_S^{n+2})$$

$\Rightarrow \sigma(\mu') - \sigma(\mu) = \mathcal{O}(\alpha_S^{n+2})$

- In MiNLO "scale compensation" kept if

$$\Big(C + nb_0\log(\mu_R^2/Q^2)B\Big) \Rightarrow \Big(C + nb_0\log(\bar{\mu}_R^2/Q^2)B\Big)$$

with $\bar{\mu}_R^2 = (q_1 q_2 ... q_n)^{2/n}$

Backup 4: MiNLO details

Few technicalities for original MiNLO:

- $\mu_F = Q_0$ (as in CKKW)
- Cluster with CKKW also V and R kinematics
  - Actual implementation uses FKS mapping for first cluster of $\mathbf{\Phi}_{n+1}$
  - Ignore CKKW Sudakov for 1^{st} clustering of $\mathbf{\Phi}_{n+1}$ (inclusive on extra radiation)
- Some freedom in choice of $\alpha_S^{(\mathrm{NLO})}$ (entering V, R and $\Delta^{(1)}$):
  * suggested average of LO α_S
  * not free for "improved" `MiNLO`
- Used full NLL-improved Sudakovs (A_1, B_1, A_2)

Improved MiNLO: where are terms coming from when differentiating resum. formula?

$1/q_T^2$, always from integration in Sudakov
α_S from $C^{(0)} \times B_1$, ...
α_S^2 from $C^{(0)} \times B_2$, ...
...
$\alpha_S L$ from A_1 term in exponent
$\alpha_S L^2$ from A_2 term in exponent
...

Backup 5: NNLOPS

p_T^H spectrum:

- "$\mu_{\mathrm{HJ-MiNLO}} = m_H, m_H, p_T$"
- At high p_T, $\mu_{\mathrm{HJ-MiNLO}} = p_T$
- If $\beta = 1/2$, `NNLOPS` $\longrightarrow$ `HJ-MiNLO` at high p_{T}
- NNLO/NLO ~ 1.5, because HNNLO with $\mu = m_H/2$, $\mu_{\mathrm{HJ-MiNLO,core}} = m_H$