Perturbative and non-perturbative uncertainties in NLO MCs

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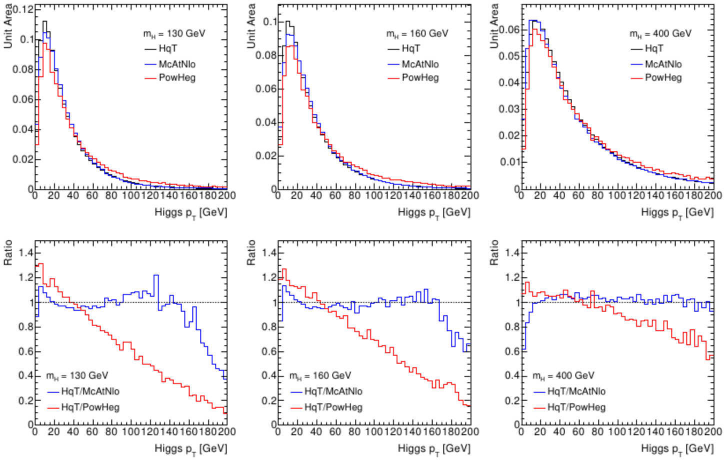
22/11/2011

Introduction



better understand difference between POWHEG and MC@NLO

$\Rightarrow$ treat on same footing

Outline

1. **NLO⊗PS matching**
2. **Perturbative uncertainties**
3. **Non-perturbative uncertainties**
4. **Finite mass effects in Higgs production**
5. **Conclusions**

NLO⊗PS matching – formalities

- fixed order cross section, including subtraction terms $\mathrm{D}^{(\mathrm{S})}$ e.g. CS, FKS

$$\sigma = \int \mathrm{d}\Phi_B \Big[\mathrm{B} + \mathrm{V} + \mathrm{I}\Big] + \int \mathrm{d}\Phi_R \Big[\mathrm{R} - \mathrm{D}^{(\mathrm{S})}\Big]$$

$\Rightarrow \mathbb{S}$

$\Rightarrow \mathbb{H}$

- introduce auxiliary subtraction terms $\mathrm{D}^{(\mathrm{A})}$
  $\rightarrow$ to be used as exponentiation kernels

$$\Delta^{(\mathrm{A})}(t) = \exp\left[-\int_t \mathrm{d}t\,\mathrm{d}z\,\mathrm{d}\phi\,\frac{\mathrm{D}^{(\mathrm{A})}(t,z,\phi)}{B}\right]$$

$$\overline{\mathrm{B}}^{(\mathrm{A})} = \mathrm{B} + \mathrm{V} + \mathrm{I} + \int \mathrm{d}\Phi_1 \Big[\mathrm{D}^{(\mathrm{A})} - \mathrm{D}^{(\mathrm{S})}\Big]$$

- $\mathrm{D}^{(\mathrm{A})}$ and $\mathrm{D}^{(\mathrm{S})}$ need to define identical parton maps, otherwise NLO accuracy for arbitrary observable violated
- $\mathbb{S}$-events include DGLAP resummation, $\mathbb{H}$-events fixed order like

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Special case I – POWHEG

- choose $\mathrm{D}^{(\mathrm{A})} = \mathrm{R}$ implying resumming over the whole phase space

  P. Nason; JHEP11(2004)040

  S. Frixione, P. Nason, C. Oleari; JHEP11(2007)070

- $\mathbb{H}$-events vanish identically, only $\mathbb{S}$-events

- alternatively $\mathrm{D}^{(\mathrm{A})} = f \cdot \mathrm{R}$ with $f = h^2/(h^2 + p_\perp^2)$
  $\rightarrow$ smoothly fade out exponentiation

  S. Alioli, P. Nason, C. Oleari, E. Re; JHEP04(2009)002

- reintroduction of $\mathbb{H}$-events

Special case II – MC@NLO/aMC@NLO

- choose $\mathrm{D}^{(\mathrm{A})} = \mathrm{B} \cdot \mathcal{K}$ (parton shower kernels) implying resummation exactly as in the parton shower S. Frixione, B. Webber; JHEP06(2002)029
- $\mathrm{B} \cdot \mathcal{K}$ problems with accuracy in the soft limit for non-trivial colour structures (DGLAP only collinear limit, only leading colour)
- MC@NLO/aMC@NLO introduced soft factor to accomodate for this deficiency S. Frixione, P. Nason, B. Webber; JHEP08(2003)007
  $\rightarrow$ not clear whether process independent
- not an issue for ggF because only two coloured external partons
  $\rightarrow$ colour matrix factorises

Special case III – Sherpa-MC@NLO

- choose $\mathrm{D}^{(\mathrm{A})} = \mathrm{D}^{(\mathrm{S})} = B \otimes \tilde{\mathcal{K}}$ (subtraction kernels) implying resumming up to E_{CMS} by explicitely using the parton shower
- Sherpa exponentiates full-colour CS kernels $B \otimes \tilde{\mathcal{K}}$ directly
  $\to$ manifestly grasps soft limit of $N_c = 3$ matrix element
  $\to$ leads to weighted parton shower

  S. Höche, F. Krauss, MS, F. Siegert; arXiv:1111.1220

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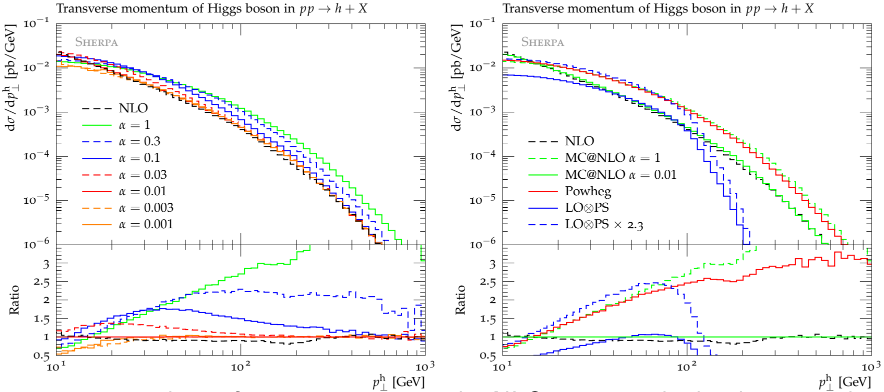
- use dipole phase space constraint α to reduce resummation phase space

  Z. Nagy; PRD68(2003)094002

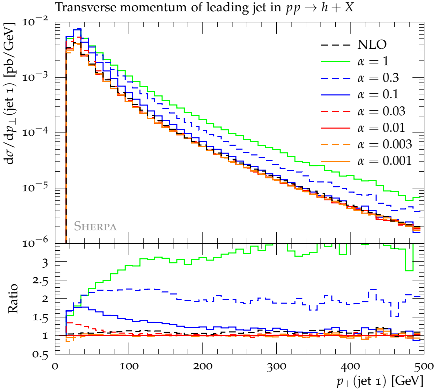
- unfortunately α unphysical, no direct relation to $p_\perp$
  nonetheless implies $p^2_{\perp,\mathsf{max}}(\alpha)$, $p^2_{\perp,\mathsf{max}}(1) = s$ and $p^2_{\perp,\mathsf{max}}(0) = 0$

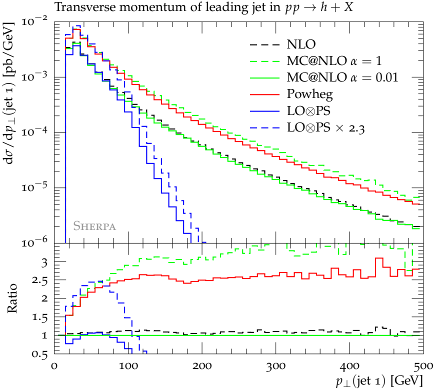
Choice of exponentiated phase space



- results stabilise for small α against the NLO result in the hard region where nothing should be resummed
  $\to$ only $\mathbb{H}$-events contribute there
- for too small α $\mathbb{S}$-events turn negative distorting Sudakov shape
  $\to$ direct result of α being unphysical

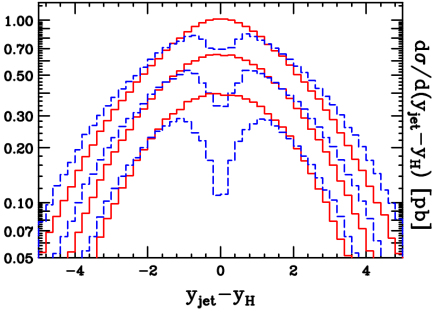
Choice of exponentiated phase space





- same qualitative picture as for $p_\perp^{\mathrm{h}}$
- POWHEG $p_\perp^{\mathrm{jet}}$ has constant offset of $\bar{\mathrm{B}}/\mathrm{B} \approx 2.3$ in high-$p_\perp$ region as hard higher order emissions are unimportant, unlike for $p_\perp^{\mathrm{h}}$

Rapidity separation of Higgs and hardest jet



S. Alioli, P. Nason, C. Oleari, E. Re; JHEP04(2009)002

- $\mathbb{S}$ events suffer from $\bar{\mathrm{B}}/\mathrm{B} \approx 2.3$ K-factor
- shape strongly depends on amount of exponentiated phase space
- again increased jet emission when full phase space exponentiated

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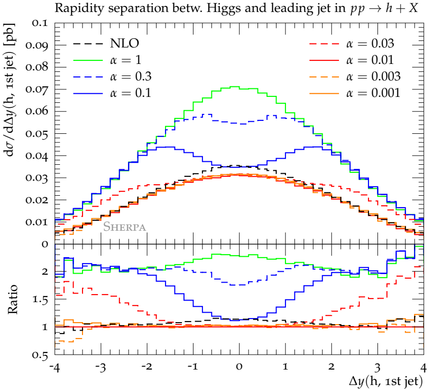

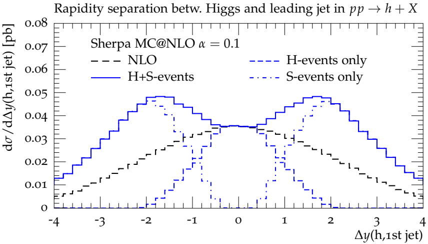

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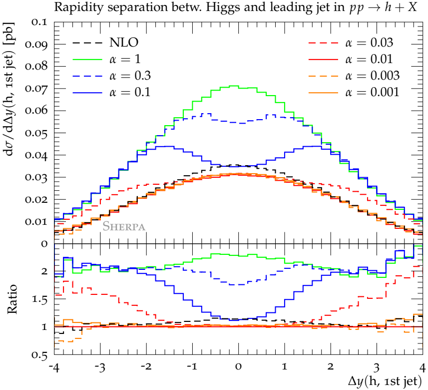

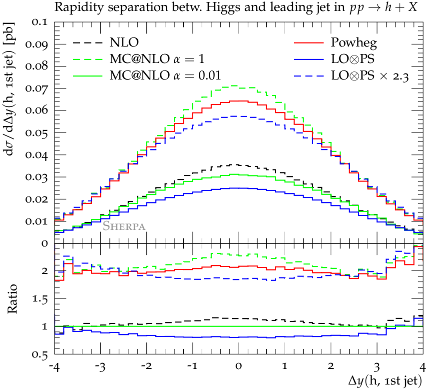

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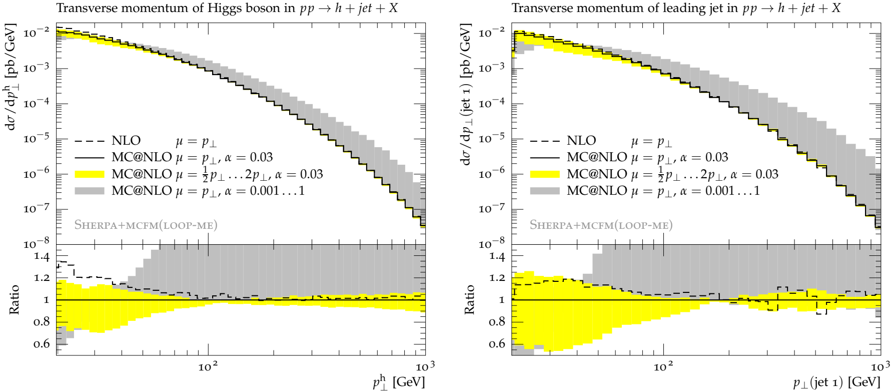
$pp \to h + jet + X \quad (m_t \to \infty)$



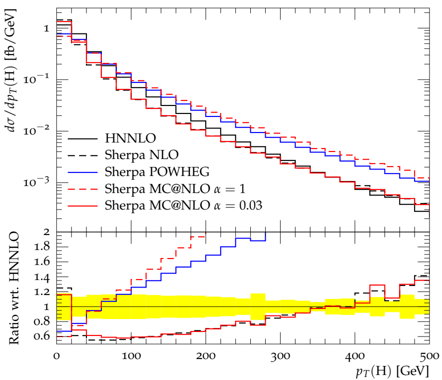
strong dependence on size of resummed phase space

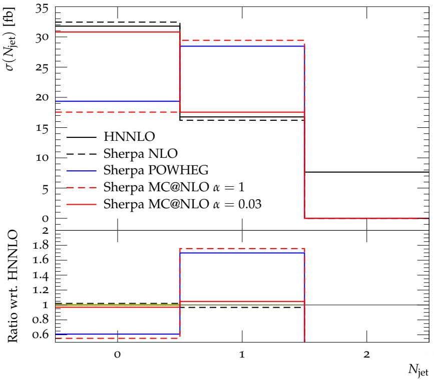
S. Höche, F. Krauss, MS, F. Siegert; arXiv:1111.1220

Uncertainty study for YR2

- process $pp \to h \to e^- \mu^+ \bar{\nu}_e \nu_\mu + X$ (HWW) @ 7TeV
- cuts: as agreed on website, details in YR2
- uncertainties due to scale choice, PDF choics, fragmentation model choice, uncertainties in MPI tuning evaluated separately

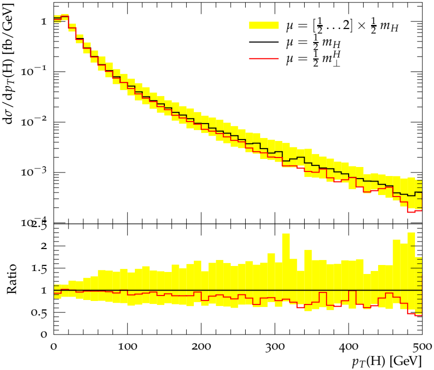
Scale uncertainties

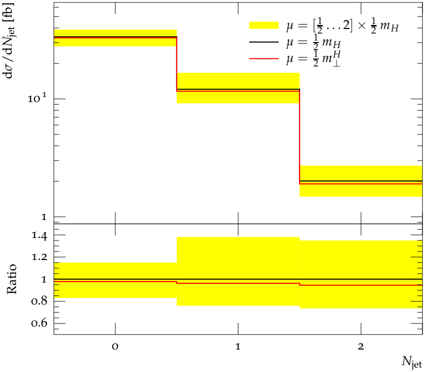




- same differences as before

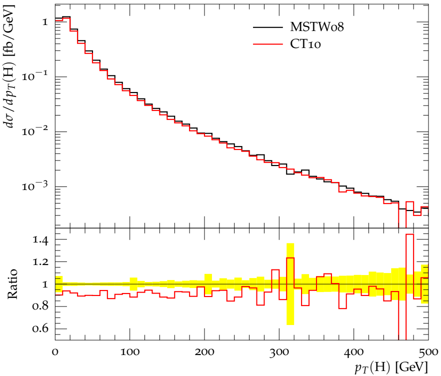
Scale uncertainties

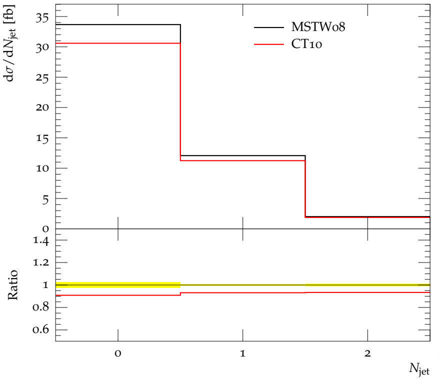




- HEFT coupling $\propto \alpha_s^2(\frac{1}{2}\, m_H)$ always taken non-dynamical
- minor dependence on functional form $(m_H \leftrightarrow m_\perp^H)$
- large uncertainty due to canonical scale variation

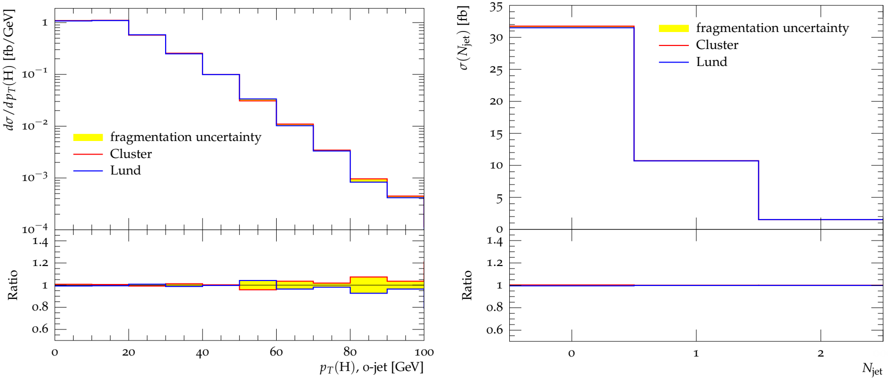
PDF uncertainties





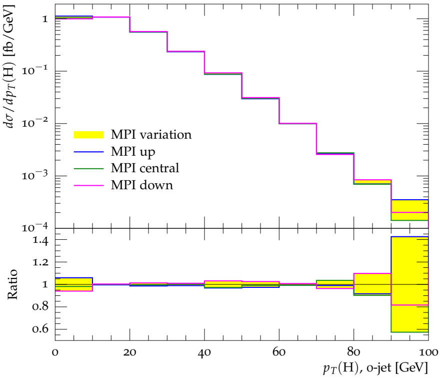
- MSTW2008NLO and CT10 sets with corresponding α_s parametrisation
- effects mainly the overall normalisation

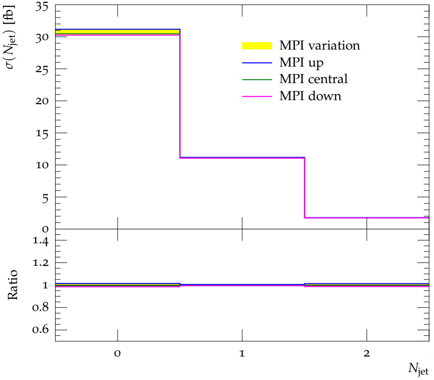
Fragmentation model uncertainties



- both models tuned to LEP data
- negligible dependence on fragmentation model variation

Multi-parton interaction uncertainties

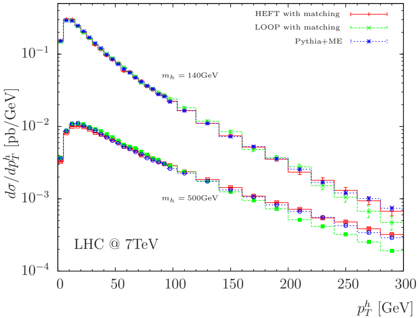




- tune to LHC UE data, Les Houches type variation (± 10% activity)
- small dependence on MPI variation
- Sherpa MPI model known to have too small hard, jet-like component

Finite mass effects in Higgs production

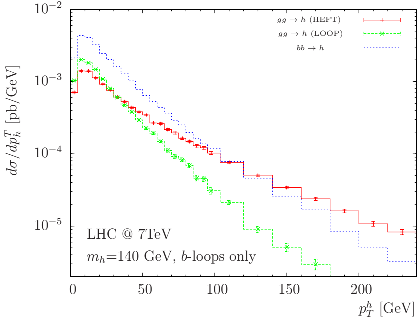
- study of the effects of finite quark masses in Higgs production in merged samples J. Alwall, Q. Li, F. Maltoni; arXiv:1110.1728



- in SM Higgs production effects are small, visible only at high $p_\perp^h$

Finite mass effects in Higgs production

- effects of finite quark in top-phobic scenarios
  → coupling only through b-quark loop   J. Alwall, Q. Li, F. Maltoni; arXiv:1110.1728



- much larger effects, strong shape dependence

  ⇒ multijet merging works fine with loop-induced processes

Conclusions

- investigated structural differences of NLO⊗PS algorithms
- crucial to have consistent framework for both POWHEG and (SHERPA-)MC@NLO
  $\rightarrow$ important to have identical scales in fixed order and resummed parts
- differences between POWHEG and MC@NLO induced by amount of phase space used for resummation
- $\mathbb{S}$-events accompagnied by additional $\bar{\mathrm{B}}/\mathrm{B}$ K-factor, contrast to $\mathbb{H}$-events
  $\rightarrow$ uncontrolled NNLO terms
- only emissions with $p_\perp < \mu_F$ should be resummed, otherwise issues with the argument of leading logarithm
  $\rightarrow$ uncontrolled terms to all orders
- exponentiation kernels need to converge onto $N_c = 3$ ME, otherwise mismatch in soft emissions
  $\rightarrow$ NLO accuracy spoiled

Conclusions

- systematically investigated theoretical uncertainties in ggF
- largest uncertainty from canonical scale variation
  $\rightarrow \approx 40\%$
- functional form of central scale and PDF choice comparable in size
  $\rightarrow \approx 10\%$
- non-perturbative uncertainties small
  $\rightarrow < 5\%$
- MPI uncertainty suffers from deficiencies of model

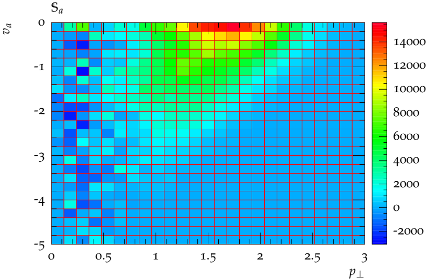
- m_t mass effects in ggF small in merged samples,
  m_b much larger, but only in absence of top loop

Thank you

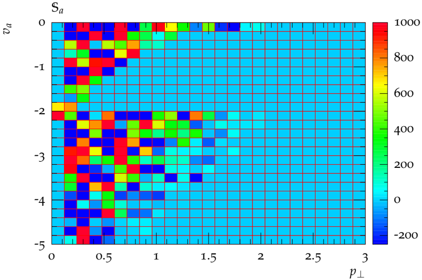
Unphysicality of α

- distribution of $\mathbb{S}$-events in v_a-$p_\perp$-plane

$\alpha = 1$



$\alpha = 0.01$



$\rightarrow$ cut in α implies cut in $p_\perp$ but also removes bits that should be exponentiated

- regions $> \alpha$ filled by opposite dipole