Theoretical uncertainties in multileg merged calculations

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Contents

Theoretical predictions at hadron level

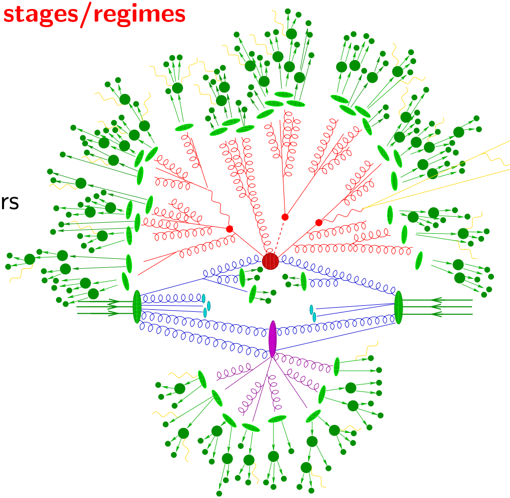
Monte-Carlo event generators built upon factorisation assumptions
⇒ divide calculation into different stages/regimes

Perturbative regimes

- hard interaction
  → fixed-order MEs (LO/NLO)
- parton evolution
  → PDF evolution, parton showers
- QED FSR

Non-perturbative regimes

- PDFs at reference scale
- multiparton interactions
- hadronisation
- hadron decays
  → fit to data



Perturbative uncertainties I

Uncertainties of the hard matrix element:

- arbitrary scales:
  - μ_R from UV regularistion
  - μ_F from factorisation of non-perturbative PDFs
- use that all-orders result independent of these scales $\rightarrow$ variation is an estimate of missing higher-order corrections
- central scale choice arbitrary:
  - choose such that higher order corrections are minimised
- amount of variation arbitrary:
  - customary range $\mu_{R/F} \in [\frac{1}{2}, 2]\, \mu_{R/F}^{\text{def}}$

  $\rightarrow$ can be done using event weights, keeping the kinematics the same
- **$\mu_{R/F}$ independent terms of higher-order corrections cannot be probed**

  $\rightarrow$ (N)NLO might be outside (N)LO uncertainty band

  $\rightarrow$ all-orders result may be outside uncertainty band

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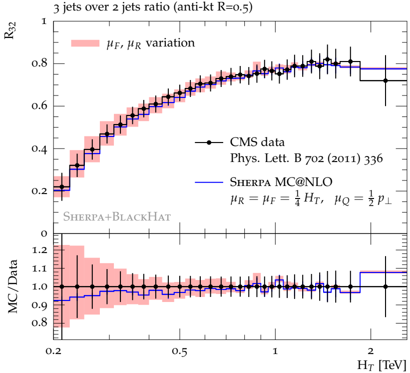
Perturbative uncertainties I

Höche, MS Phys.Rev.D86(2012)094042

MC@NLO di-jet production

perturbative uncertainty estimate:

- $\mu_{R/F}^{\text{def}} = \frac{1}{4}\,H_T$
  $\mu_{R/F} \in [\frac{1}{2}, 2]\,\mu_{R/F}^{\text{def}}$



Perturbative uncertainties I

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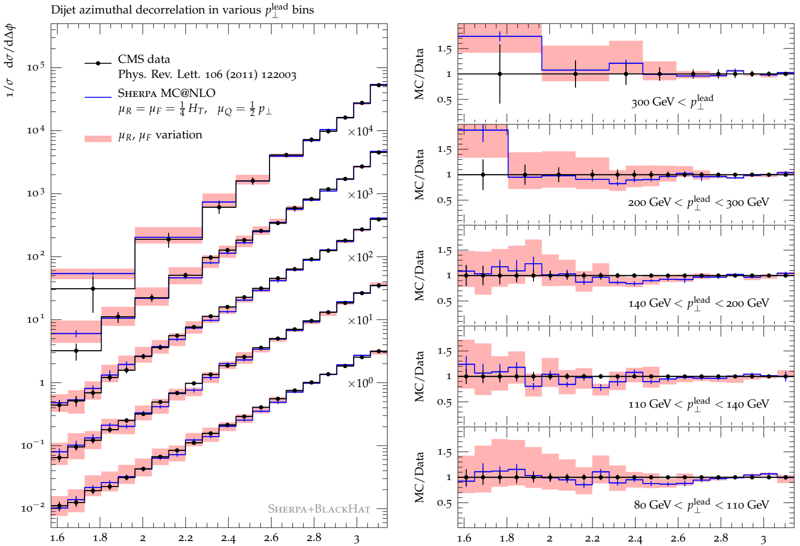

Perturbative uncertainties II

- parton showers resum logarithms in their evolution variable t

$$\Delta(t,\mu_Q^2) = \exp\left\{-\int\limits_t^{\mu_Q^2}\mathrm{d}t\int\limits_{z_{\text{min}}}^{z_{\text{max}}}\mathrm{d}z\int\limits_0^{2\pi}\mathrm{d}\phi\,\frac{\alpha_s(\mu_R)}{t}\,\mathcal{K}(t,z,\phi)\right\}$$
$$= \exp\left\{c_1\log^2\frac{t}{\mu_Q^2}+c_2\log\frac{t}{\mu_Q^2}+\ldots\right\}$$

- $t_{\text{max}} = \mu_Q^2$ is the starting scale of the parton shower for this emission
- μ_Q^2 enters the logarithms and plays the role of the resummation scale
- global starting scale μ_Q is a free choice
  starting scales for subsequent emissions fixed by scale of previous emission
- initial state shower replaces the inclusive evolution of the PDF (emissions are integrated over) with its own evolution (emissions are sampled = Monte-Carlo integration)
  $\rightarrow$ choose $\mu_Q \sim \mu_F$ to avoid large logs being left over
- parton shower generates emissions probabilisticly, μ_Q is a phase space cut
  $\rightarrow$ **μ_Q variation cannot be done with event weights, need to rerun**

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$$= \exp\left\{c_1 \log^2 \frac{t}{\mu_Q^2} + c_2 \log \frac{t}{\mu_Q^2} + \ldots\right\}$$

- technically, parton showers are only LL accurate (including the correct leading-colour NLL), however
- choice of μ_R in the shower fixed to $\sim k_\perp$ (prefactor tuned)
  $\rightarrow$ grasp leading terms of higher logarithmic accuracy
  $\Rightarrow$ **parton showers resum better than they should**
- but, contrary to higher logarithmic analytic no counter-terms to preserve them when μ_R is varied
  $\rightarrow$ currently, variation degrades the result
  $\rightarrow$ discussion in LH2013 on how to address this

Perturbative uncertainties II

Additional (descrete) uncertainties

- evolution variable t ($k_\perp$-like, θ-like, Q^2-like, etc.)
  $\rightarrow$ which logarithms are resummed
- recoil strategy
  $\rightarrow$ non-logarithmic corrections, but numerically sizeable/important already at moderate t

$\Rightarrow$ would need to be assessed as well

Parton shower uncertainty assessment only meaningful if (N)LO+PS combination consistent, i.e. same PDFs and values/evolution of α_s in the full partonic calculation.

Perturbative uncertainties II

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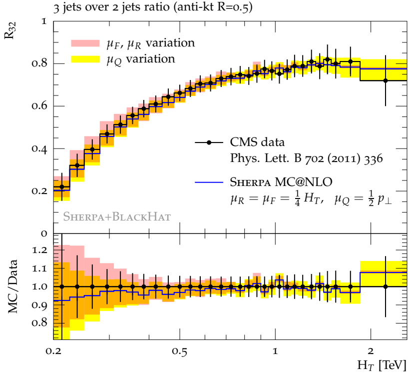
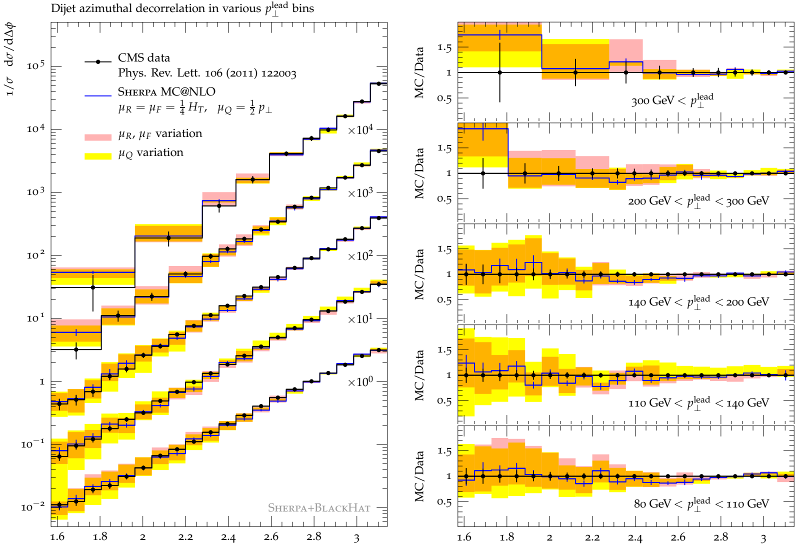


Perturbative uncertainties II

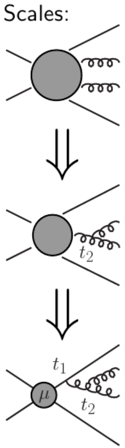


Perturbative uncertainties in merged samples

- consistent combination of fixed-order and parton shower
- scale choice

$$\alpha_s(\mu_R^{\text{def}})^{n+k} = \alpha_s^k(\mu_R^{\text{core}}) \prod_{i=0}^{n} \alpha_s(t_i)$$

  to (N)LO accuracy in (N)LO merging necessary
  to preserve resummation behaviour
- can vary μ_R in NLO merging, necessitates counterterm
- similar considerations for μ_F
- resummation of parton shower unchanged
  → same considerations for μ_Q apply
  → one global μ_Q
  parton shower of n-jet configuration fixed to start at t_n
- merging scale Q_{cut}:
  residual dependence beyond formal accuracy → uncertainty
  → vary within region such that parton shower approximation still sensible
  → changes the range of (N)LO acc.,
  cannot be done via event weights

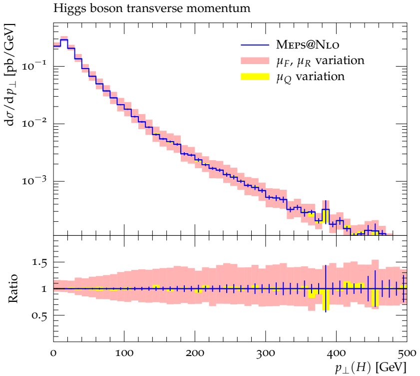


Perturbative uncertainties in merged samples

MEPS@NLO Higgs+jets production

perturbative uncertainty estimate:

- $\mu_{core}^{\text{def}} = m_h$
  $\mu_{R/F} \in [\frac{1}{2}, 2]\,\mu_{R/F}^{\text{def}}$
- $\mu_{Q}^{\text{def}} = m_h$
  $\mu_Q \in [\frac{1}{\sqrt{2}}, \sqrt{2}]\,\mu_{Q}^{\text{def}}$
- $Q_{\text{cut}} = 20$ GeV
  $Q_{\text{cut}} \in [15, 30]$ GeV
  be aware:
  different curves have different accuracies in the region 15-30 GeV



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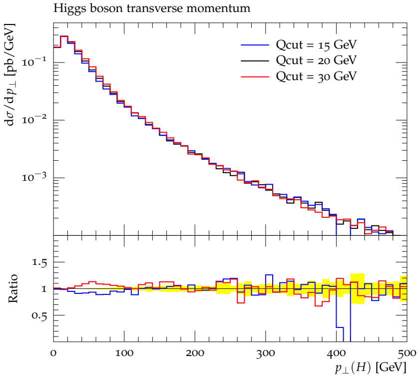

Non-perturbative uncertainties

- only phenomenological models for non-perturbative physics (Had/UE), or parametrisation (PDF at reference scale)
  $\rightarrow$ unclear in how far they describe all aspects of the physics process
  $\rightarrow$ **different models/parametrisations should be taken for unc.**
- models fitted to data
  $\rightarrow$ has statistical interpretation within a given (parameter) model
  $\rightarrow$ use PDF eigenvectors or model eigentunes to estimate uncertainties

  Richardson, Winn EPJC72(2012)2178
- PDF uncertainty on hard ME can be assessed using event weights
- Had/UE uncertainties cannot be assessed using weights as the event structure changes (UE scatters and primordial Hadrons are probabilistic)
  $\rightarrow$ **need to rerun**
- cumbersome for $>$15 parameters
  $\rightarrow$ simplified idea discussed in LH2011
  $\rightarrow$ vary MPI activity in transverse region $\pm$ 10% (consistent with data) changes the overall MPI activity

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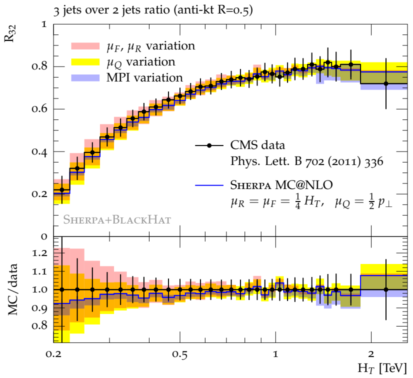
non-pert. uncertainty estimate:

- MPI activity in tr. region $\pm$ 10%



Non-perturbative uncertainties

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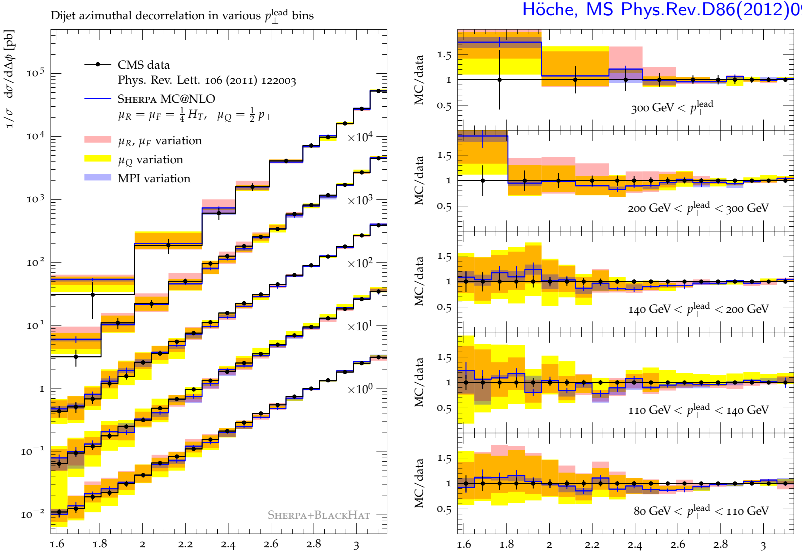

How to combine them (?)

- no statistical interpretation of uncertainty estimate of a perturbative calculation, scale independent terms cannot be included
- uncertainties on fits to data can be interpreted statistically, however have to consider that model is incomplete (no first principles)
  $\rightarrow$ vary the model/parametrisation
- total uncertainty – how to combine them:
  - envelope?
    $\rightarrow$ minimal solution (underestimation very likely)
  - add in quadrature?
    $\rightarrow$ seems like good solution in between extremes
  - add linearly?
    $\rightarrow$ maximal solution (very conservative, overestimation likely)
- not all theoretical uncertainties can be assessed using event weights
  $\rightarrow$ need to rerun (at least) for parton shower, hadronisation, multiparton interaction uncertainties

Thank you for your attention!