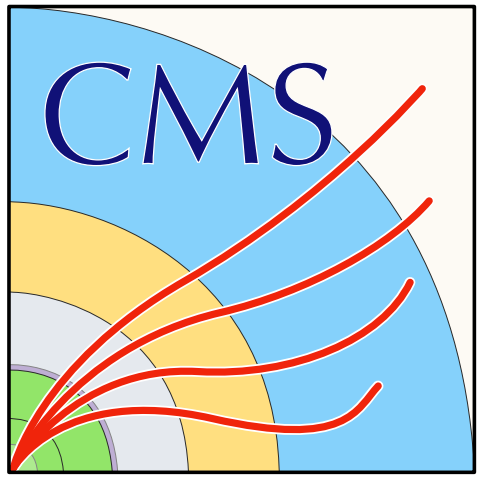
CMS xFitter user report



Toni Mäkelä

xFitter Workshop 26. Feb. 2020

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Outline

1. The evolution of last year's preprints into papers
2. Developments in CMS PDF studies
   - NLO+NLL resummation
3. Developments in CMS PDF studies
   - NLO+NLL resummation
   - SMEFT analysis
4. Issues and wish list for xFitter development

CMS results from the past year

The evolution of last year's preprints into papers

- "Measurement of associated production of a W boson and a charm quark in proton-proton collisions at $\sqrt{s} = 13$ TeV".
  Eur. Phys. J. C79, n. 3, p. 269, 2019.
- "Measurements of normalised multi-differential cross sections for top quark pair production in pp collisions at $\sqrt{s} = 13$ TeV and simultaneous determination of the strong coupling strength, top quark pole mass and parton distribution functions" [CMS-PAS-TOP-18-004, Submitted to Eur. Phys. J.]
- "Measurement of the $t\bar{t}$ production cross section, the top quark mass, and the strong coupling constant using dilepton events in pp collisions at $\sqrt{s} = 13$ TeV"
  Eur. Phys. J. C79, n. 5, p. 368, 2019.

\+ On-going analysis: 13 TeV jet and top production data, yet to be published.

Developments in CMS PDF studies

Our recent studies incorporate

- NLO+NLL resummation
- SMEFT contributions

in the analyses.

These have been implemented using codes that are currently private, so we have a private modified version of xFitter (essentially a new `reaction` as an interface for the SMEFT terms).

$\rightarrow$ Released and possibly merged into master branch once the results of our analysis have been published.

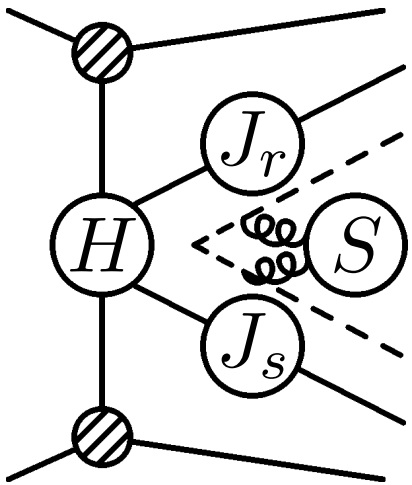
Developments in CMS PDF studies

NLO+NLL resummation

Fixed order NLO: known inadequacies in describing experimental data
Inclusive jet cross-sections contain large logs in radius and threshold p_{T}

- Important to increase accuracy by *renormalization group (RG) improved perturbation theory*

$\rightarrow$ partonic cross-section factorized into hard, jet and soft functions (thm.s proven in EFTs e.g. SCET) and the RG eq. is solved for each, allowing them to be evolved from their characteristic scales μ_H, μ_J, μ_S to a common scale μ.



Developments in CMS PDF studies

NLO+NLL resummation

The theory expression we use in xFitter is then the form

$$\sigma_{\mathrm{SM}} = \sigma_{\mathrm{NLO}} \times NP \times EW \times K$$

- σ_{NLO} = Start with NLO QCD prediction (FastNLO)
- Corrections: NP = Non-perturbative, EW = electro-weak
- Account for threshold and radius resummation by a K-factor:

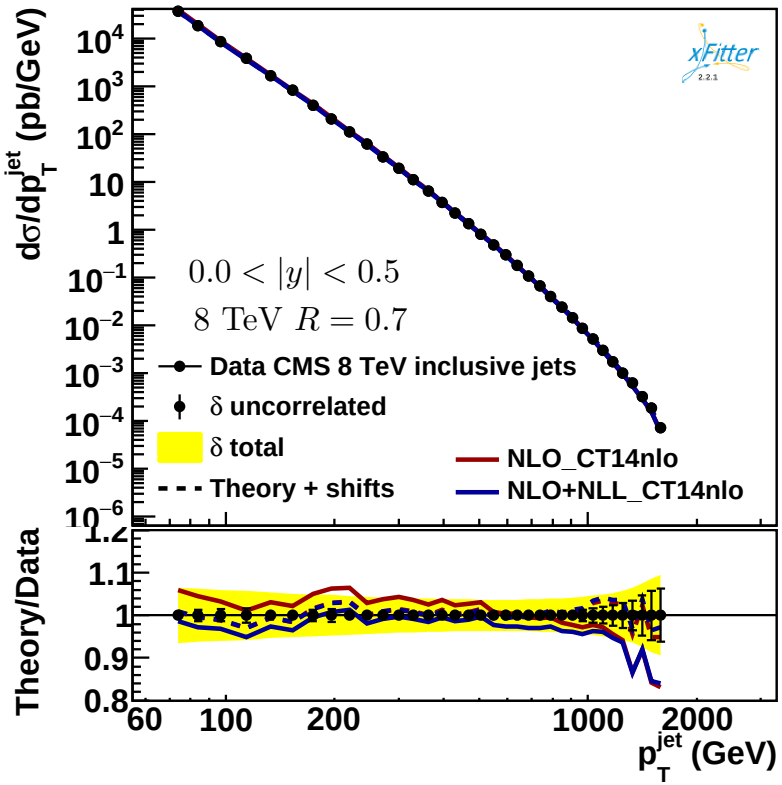
$$K = \frac{\sigma_{\mathrm{NLO}}^{\mathrm{MEKS}} - \sigma_{\mathrm{NLO}}^{\mathrm{sing.}} + \sigma_{\mathrm{NLL}}}{\sigma_{\mathrm{NLO}}^{\mathrm{MEKS}}}$$

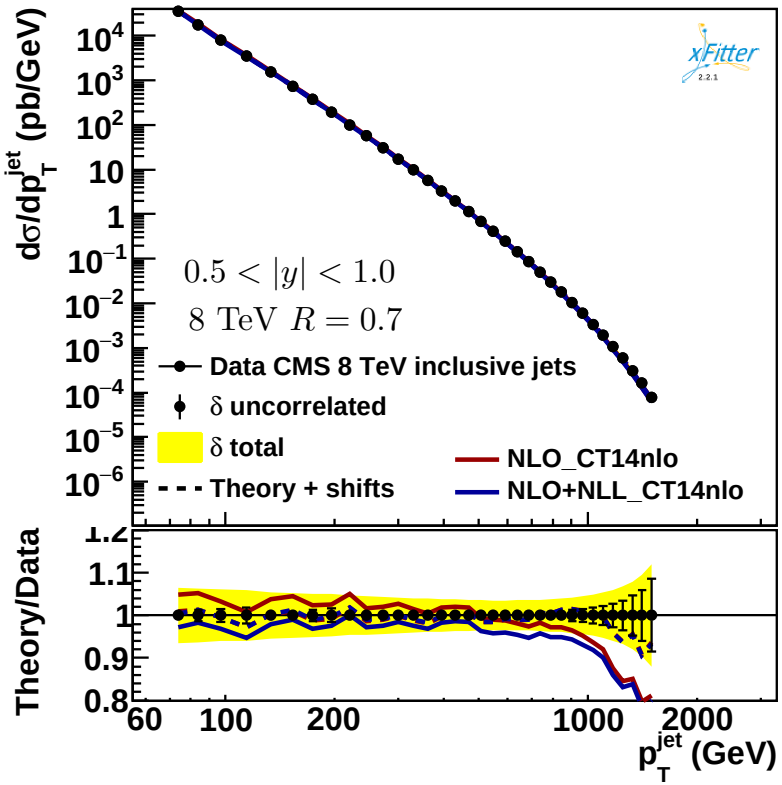
with $\sigma_{\mathrm{NLO}}^{\mathrm{MEKS}}$ from MEKS (1207.0513) $\sigma_{\mathrm{NLO}}^{\mathrm{sing.}}$ and σ_{NLL} from NLL-jet (S-O. Moch, L. Xiaohui), setting $\mu = p_{\mathrm{T}}^{\mathrm{max}}$.

Developments in CMS PDF studies

NLO+NLL resummation

Fixed PDF example 1: 8 TeV NLO vs NLO+NLL





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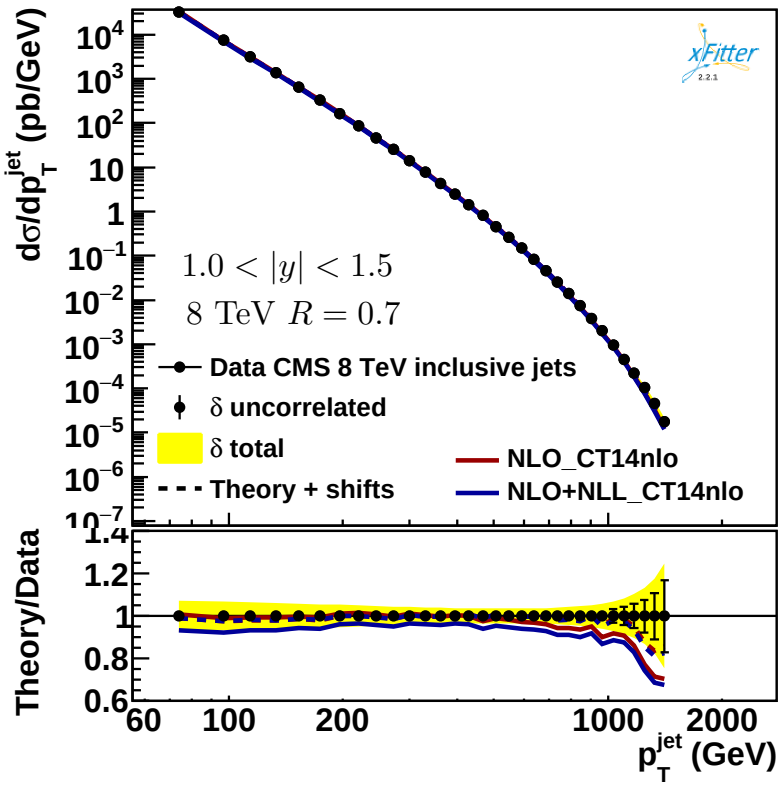
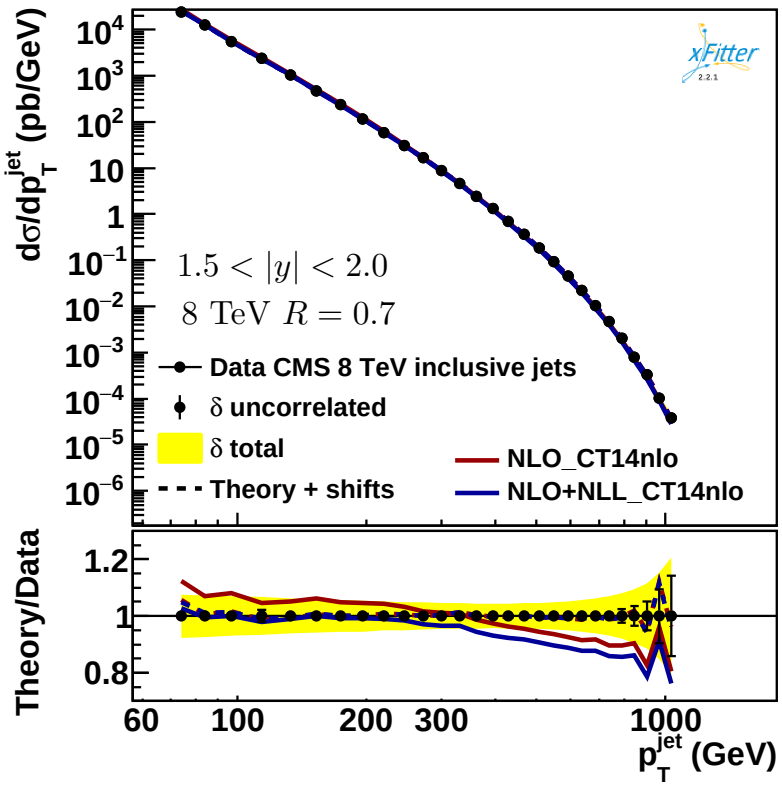
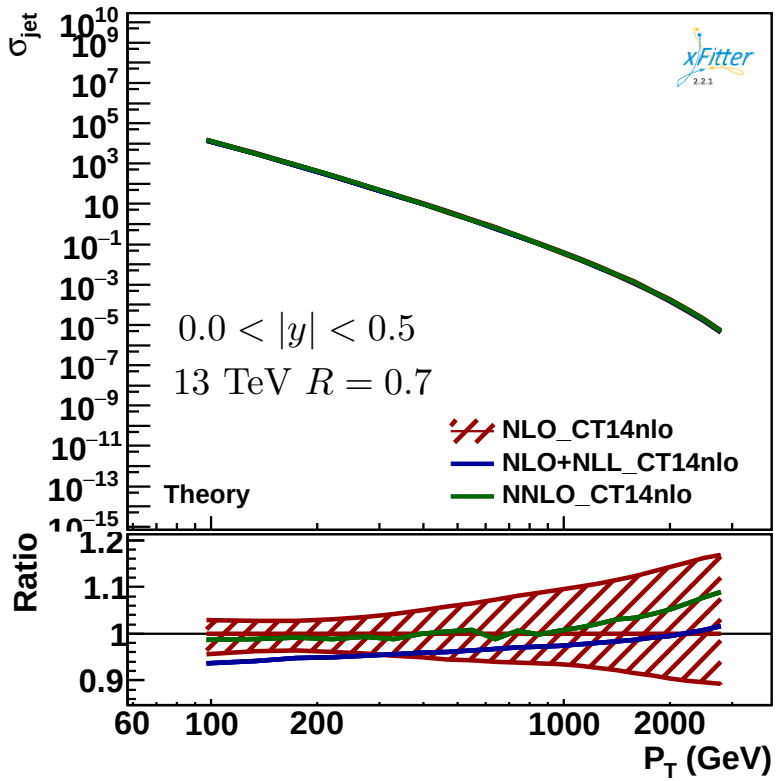


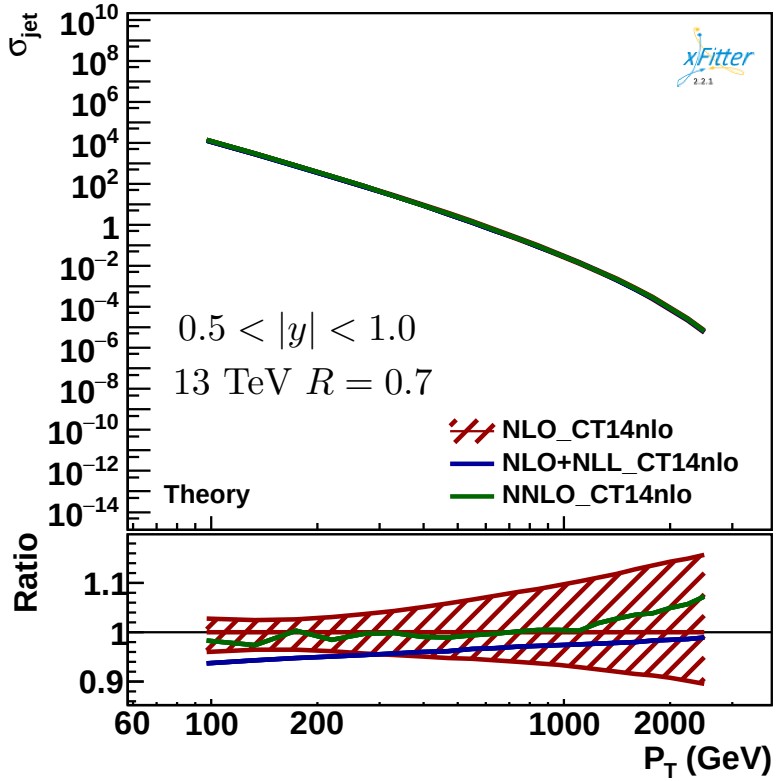


Developments in CMS PDF studies

NLO+NLL resummation

Fixed PDF example 2: 13 TeV NLO vs NLO+NLL vs NNLO





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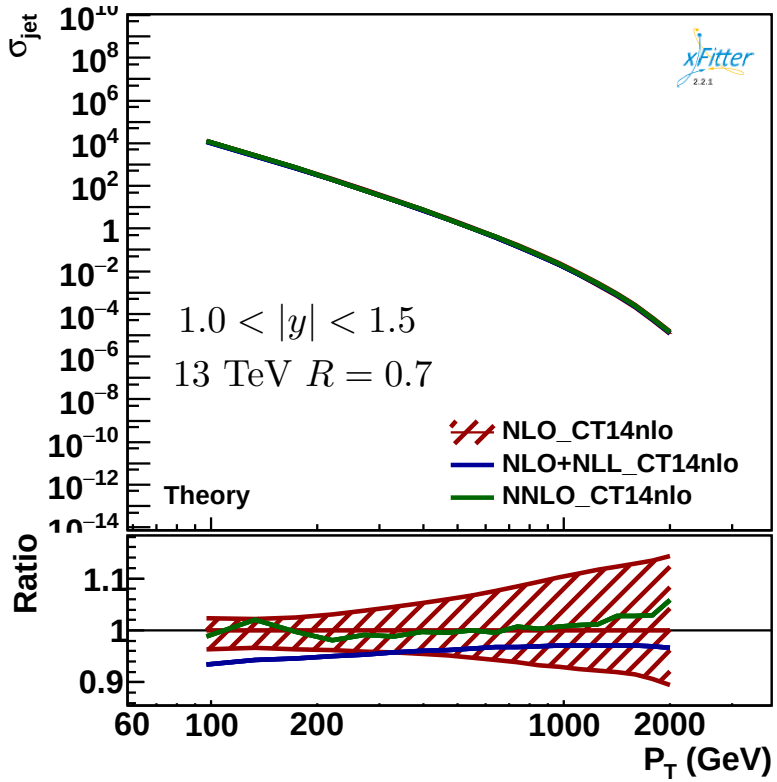
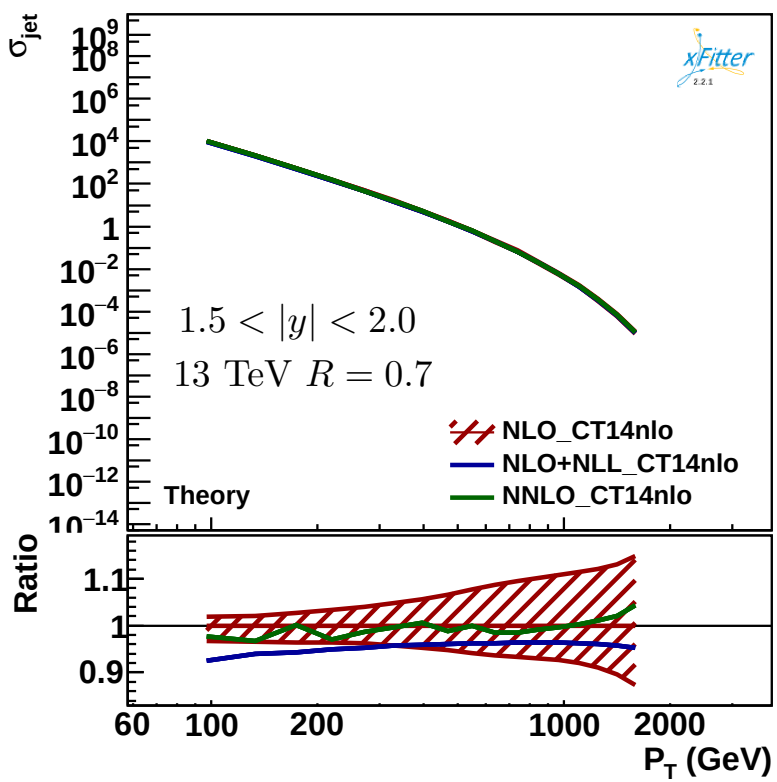




Developments in CMS PDF studies

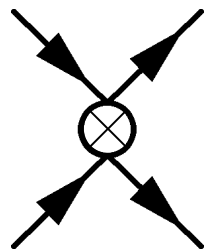
SMEFT analysis

Development with Jun Gao (Shanghai Jiao Tong University): to add contribution from Contact Interactions (CI) (see 1204.4773), we use CIJET (1301.7263) interfaced to xFitter.

$$\sigma_{\text{SMEFT}} = \sigma_{\text{NLO}} \times NP \times EW \times K + CI$$

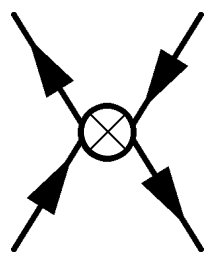
$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + \frac{1}{2\Lambda^2} \sum_n c_n O_n$$

$$O_1 = \underbrace{\delta_{ij}\delta_{kl}}_{\text{colour}} \left(\sum_c^{\text{gen.}} \overline{q}_{Lci} \gamma_\mu q_{Lcj} \sum_d^{\text{gen.}} \overline{q}_{Ldk} \gamma^\mu q_{Ldl} \right)$$



$$O_3 = \delta_{ij}\delta_{kl} \left(\sum_c^{\text{gen.}} \overline{q}_{Lci} \gamma_\mu q_{Lcj} \sum_d^{\text{gen.}} \overline{q}_{Rdk} \gamma^\mu q_{Rdl} \right)$$

$$O_5 = \delta_{ij}\delta_{kl} \left(\sum_c^{\text{gen.}} \overline{q}_{Rci} \gamma_\mu q_{Rcj} \sum_d^{\text{gen.}} \overline{q}_{Rdk} \gamma^\mu q_{Rdl} \right)$$



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$$\sigma_{\mathrm{SMEFT}} = \sigma_{\mathrm{NLO}} \times NP \times EW \times K + CI$$

Studied models:

Model CI1 = Pure left-handed:	fit c_1,	$c_3 = 0$,	$c_5 = 0$
Model CI2 = Vector-like:	fit c_1,	$c_3 = 2c_1$,	$c_5 = c_1$
Model CI3 = Axial-vector-like:	fit c_1,	$c_3 = -2c_1$,	$c_5 = c_1$

- For what we show here, Λ is fixed to 10 TeV. In principle the choice affects the running in CIJET calculations, but the values c_i/Λ^2 stay similar if Λ is varied.

$\rightarrow$ Eventually scan for Λ and set limits on CI.

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Developments in CMS PDF studies

SMEFT analysis

Recall the SM factorization:

$$\underbrace{\sigma_{pp\to\text{jet}+X}}_{\text{Experimental data}} = \sum_{ij} \underbrace{f_i(x_1\ ,\mu_F)\ f_j(x_2\ ,\mu_F)}_{\text{Proton structure}} \otimes \underbrace{\hat{\sigma}_{ij}\left(x_1, x_2, \alpha_s(\mu), \frac{Q^2}{\mu_R}, \frac{Q^2}{\mu_F}\right)}_{\text{pQCD}}$$

When probing BSM, we must note that

$$\underbrace{\sigma_{pp\to\text{jet}+X}}_{\text{Experimental data}} = \sum_{ij} \underbrace{\overbrace{f_i(x_1, \mu_F)}^{\text{Determined experimentally!}}\ \overbrace{f_j(x_2, \mu_F)}^{\text{Determined experimentally!}}}_{\text{Proton structure}} \otimes \underbrace{\hat{\sigma}_{ij}\left(x_1, x_2, \alpha_s(\mu), \frac{Q^2}{\mu_R}, \frac{Q^2}{\mu_F}\right)}_{\text{SM+CI}}$$

- The SM results depend on Parton Distribution Functions (PDF), obtained using experimental data in the same kinematic region.
  - → To ensure BSM effects are not absorbed into the PDFs, we must also fit the PDFs and simultaneously when using $\hat{\sigma}_{\text{SM+CI}}$.

Developments in CMS PDF studies

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Use jet cross-sections for simultaneous extraction of PDFs, α_s and CI

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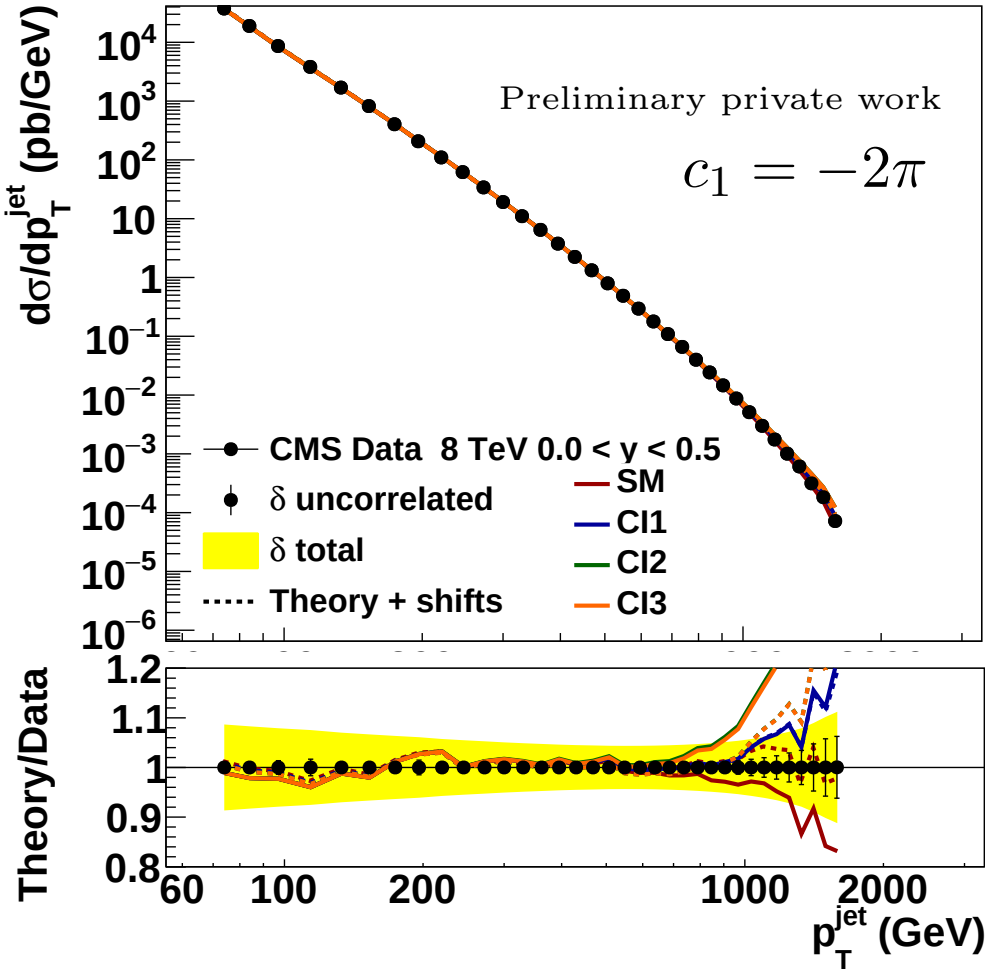
Developments in CMS PDF studies

SMEFT analysis – **Example of CI effects**

- Comparing SM and SM+CI predictions using fixed PDF CT14nlo
- CMS 8 TeV 1609.05331
- With $\Lambda = 10$ TeV, CI manifest as a deviation from SM at $p_{\mathrm{T}}^{\mathrm{jet}} > 1$ TeV
- Constructive/ destructive depending on c_1



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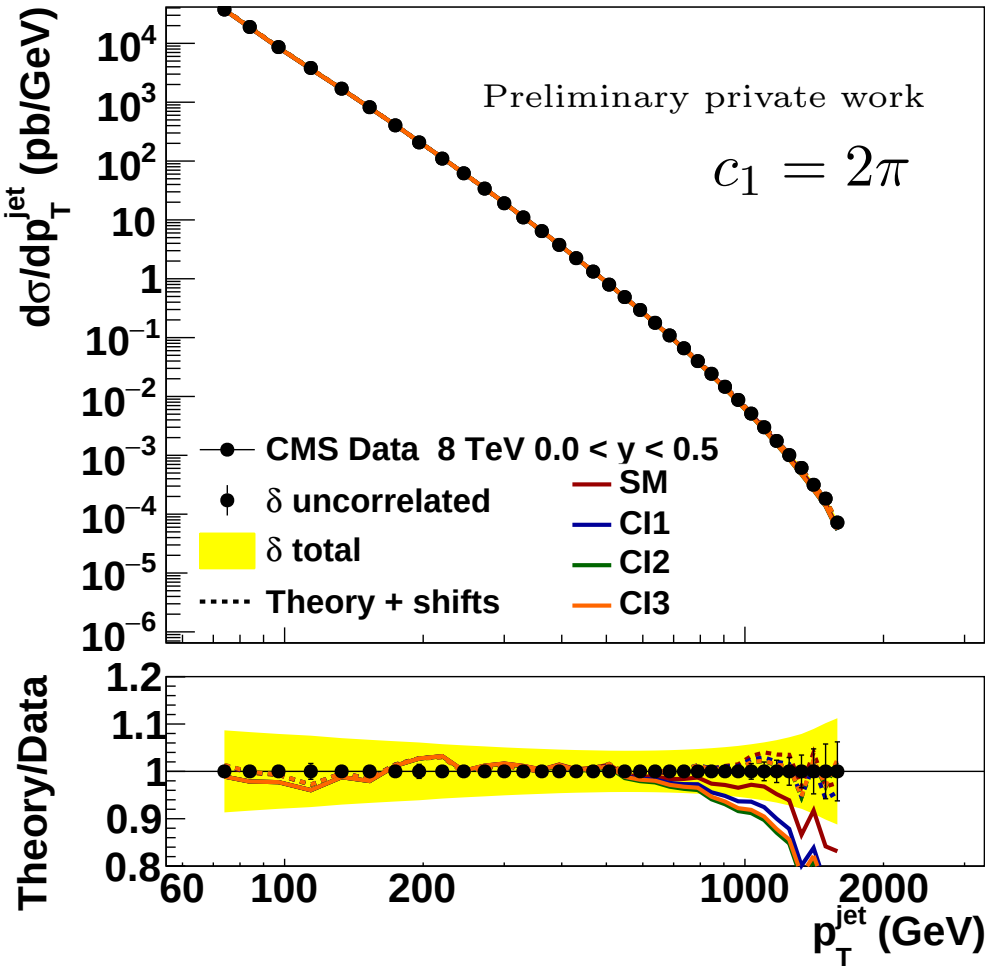

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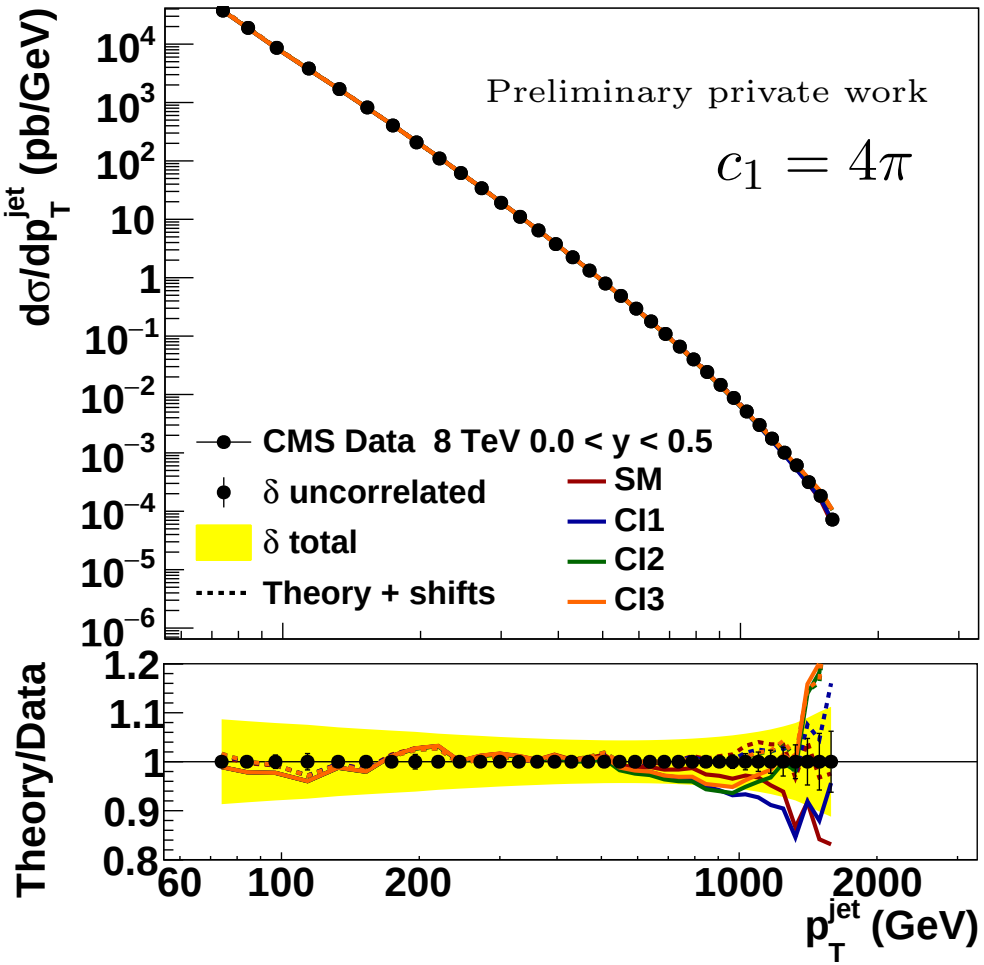

Issues with master

or "our wish list" for future development in xFitter

- When fitting α_s, we sometimes need boundaries for some PDF parameters to stabilize MINUIT. However, The `Hesse` or `Pumplin` error bands cannot be computed then. It'd be nice if this was fixed.
- It would be nice to have FastNLO available at NNLO. Currently we use K-factors for higher orders.
- MCFM already exists at NNLO, but there is no xFitter interface yet.
- Question: has the equivalence of χ^2 between master and older versions, e.g. 2.0.0, been validated?

Thanks for your attention!