Standard Model

Techniques, Calculations & Phenomenology

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Les Houches, 21st June 2023

Results from the poll

Option 💒 | Option 🪓

15 votes | 0 vote(s)

2 – Option 🏝️

Standard Model Precision Wishlist

- Many new calculations completed in the past two years
  - $2 \to 8$ / $2 \to 9$ @ NLO EW/QCD
  - $2 \to 2$ @ NNLO beyond "standard" (QCD–EW, masses, flavour, fragmentation, …)
  - $2 \to 3$ @ NNLO QCD
  - $2 \to 1$ @ N3LO QCD
- Already new predictions requested (+ exp motivation)
- Extend beyond hadron–hadron collider processes?
  - DIS (EIC); future lepton–lepton colliders; would rely on input from the community!
- Already includes a brief review on current calculational techniques
  - Do we want a similar short review on the state of the art in resummation & PS accuracy & power corrections & …?

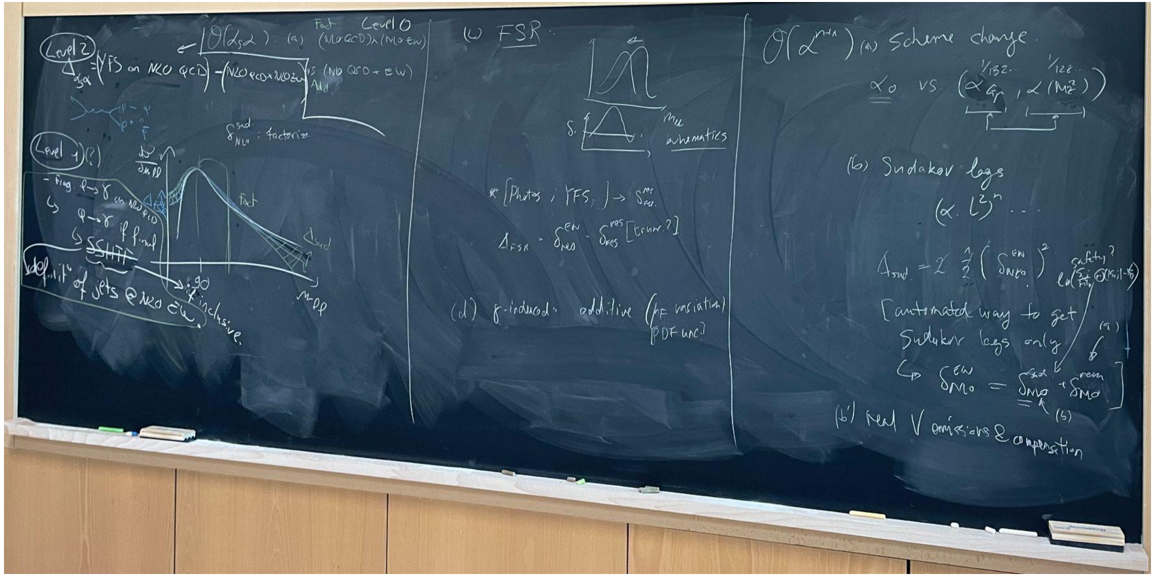
- **Please post your new calculations / requests on #sm-wishlist !**
  (this is very much appreciated…)

Uncertainties for EW corrections (I)

Idea: propose & document a set of prescriptions to estimate EW uncertainties

- scheme variation for the full phase space: α(Gμ) vs. α(Mz)
  - Similar to scale variation in QCD; appropriate for non-enhanced EW corrections
- Sudakov logarithms in high-energy tails exponentiate
  - $\Delta_{\mathrm{Sud}} \simeq (\delta_{\mathrm{NLO}}^{\mathrm{EW}})^2$
  - More refined: first isolate the Sudakov logs from the full NLO EW corrections
- QED FSR corrections close to resonances / shoulders
  - Large corrections mainly from *kinematics*
  - Difference (resummed photons) – (NLO EW)
- Mixed QCD–EW corrections
  - Lv. 0: Difference (NLO QCD + NLO EW) – (NLO QCD × NLO EW)
  - Lv. 1: Difference (fragmentation function l→A, j→A on NLO QCD) – (NLO QCD × NLO EW)
  - Lv. 2: Difference (resummed photons on NLO QCD) – (NLO QCD × NLO EW)

Uncertainties for EW corrections (II)



Electroweak Uncertainties

Les Houches 2023

June 19, 2023

Maybe not a one-size-fits-all procedure but hopefully a useful set of prescriptions to estimate various aspects of theory uncertainties associated with electroweak corrections. If we have enough time, we could see if these ideas can be applied to a concrete example like Drell–Yan produciton at the LHC. This would be a process that exposes almost all of the subtleties that will be discussed in this document.

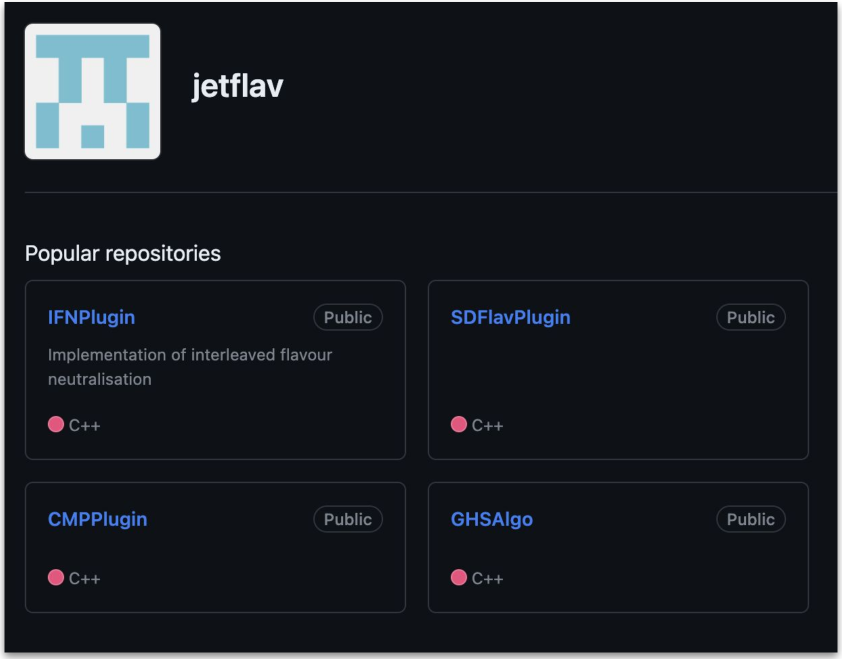
1 Introduction

Typically electroweak parameters are renormalized in a scheme that does not retain a dependence on an unphysical scale, like μ_R in the $\overline{\text{MS}}$ scheme. Moreover, the choice of a scheme is often well motivated, e.g. the coupling associated with Born-level photons are most appropriately renormalized in the α_0 scheme to avoid sensitivity to large logarithms of fermion masses in the final result or the choice of α_{G_μ} in the W-boson couplings absorbs universal higher-order corrections to the ρ parameter into the coupling definition. See for instance the review in Ref. [1] for further details on EW input schemes. As such, an appropriate prescription of estimating higher-order EW corrections becomes much more subtle as naive approaches could potentially overestimate uncertainties by a large amount. This document attempts to highlight the subtleties in estimating such uncertainties and provides prescriptions (of different levels of sophistication) that can be applied to theory predictions.

Jet flavour study (I)

Four flavour-tagging algorithms for anti-kt jets presented during the workshop (check wiki programme for slides).

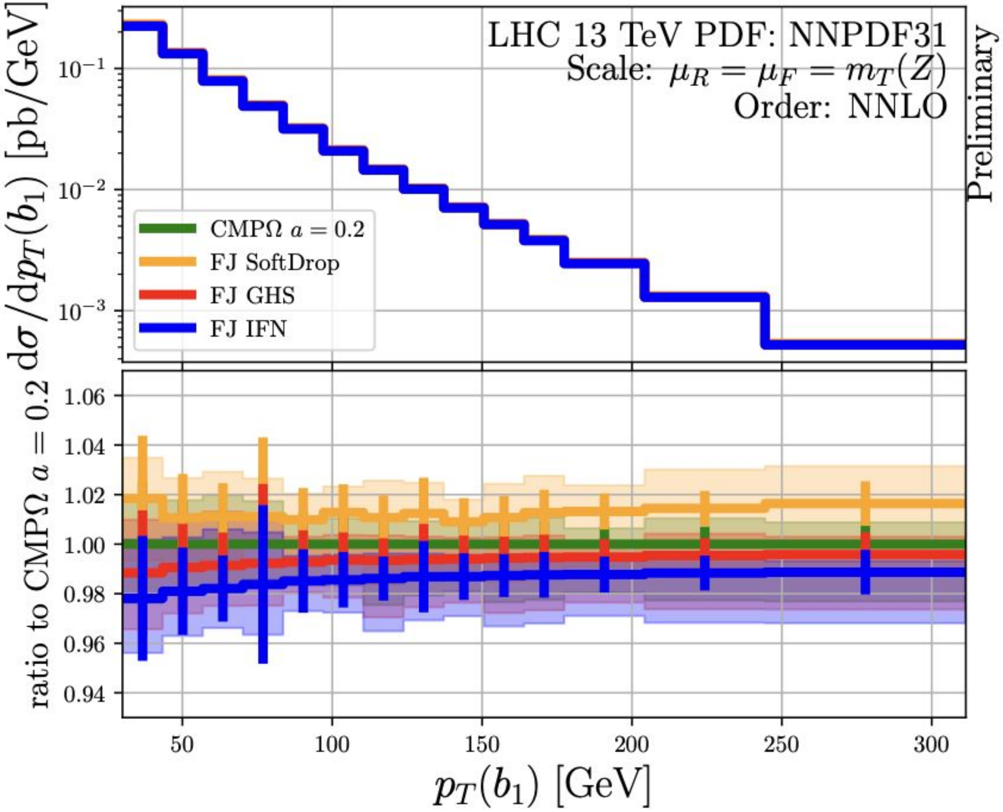
Implementations as fastJet plugins available at:
https://github.com/jetflav



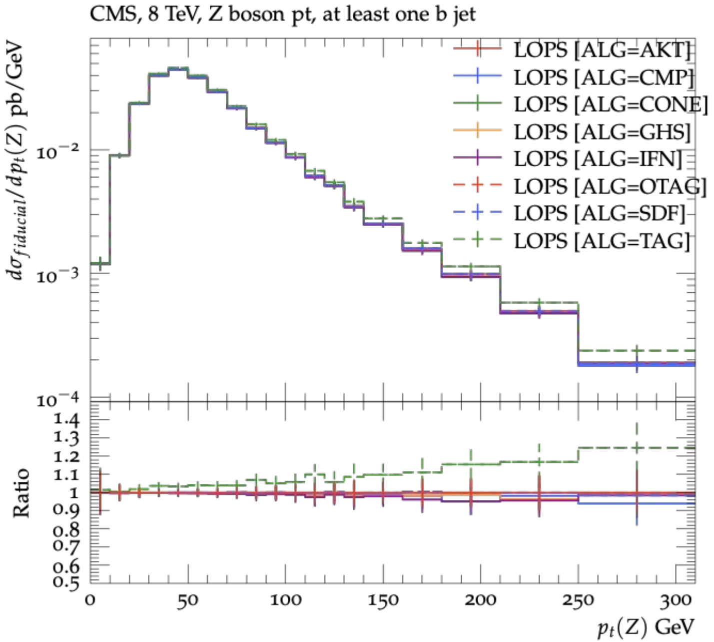
Various studies identified based on fixed-order and NLO+PS predictions
(V+flavour-jet & VH[$\rightarrow$ bb])

$\rightarrow$ jet substructure & Higgs summaries

Jet flavour study (II)



- Z+b-jet @ NNLO QCD using different algorithms
  - Results compatible with each other but differences at the %-level
  - Unfolding corrections to exp. flavour tagging?



aN3LO PDFs & gluon-fusion Higgs production (I)

Prior to the availability of (a)N3LO PDF sets, a separate uncertainty component "PDF-TH" was estimated from the impact of a PDF mismatch at one order lower:

$$\delta(\text{PDF-TH}) = \pm\frac{1}{2}\left|\sigma^{(2)}(\text{PDF}_{\text{NNLO}}) - \sigma^{(2)}(\text{PDF}_{\text{NLO}})\right|$$

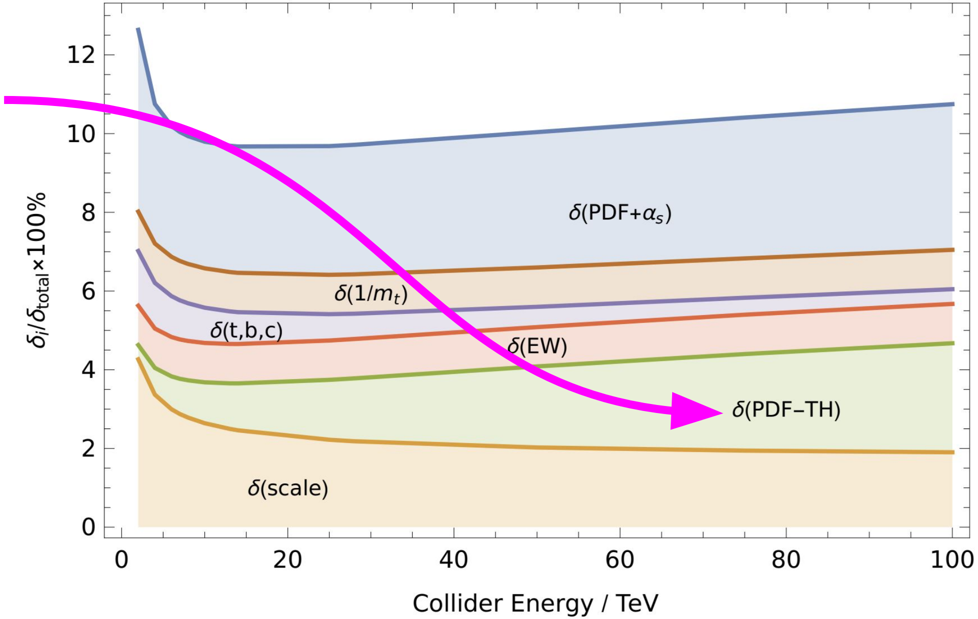
In the following, we focus on the components:

PDF

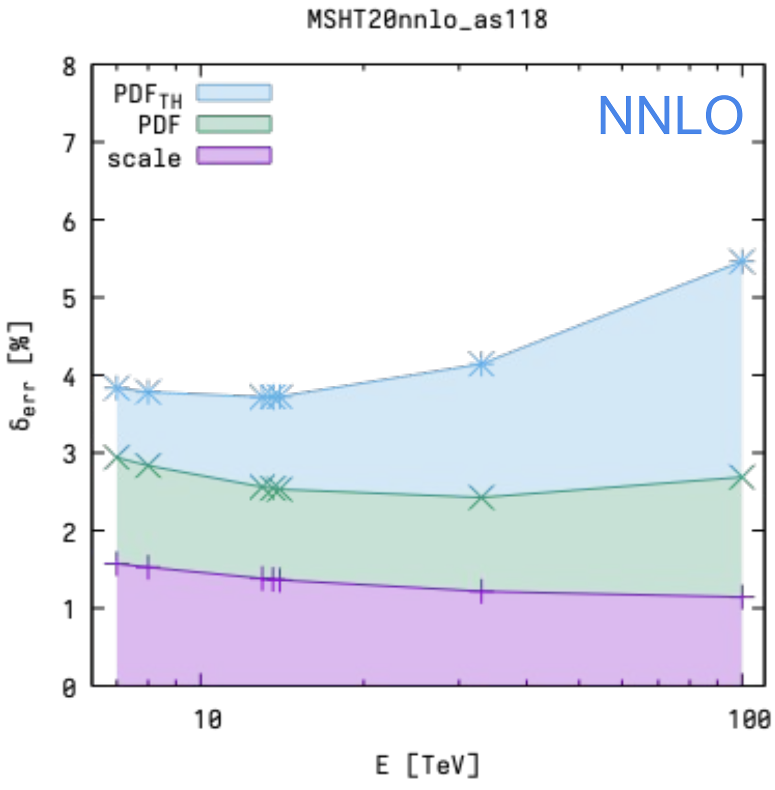
PDF-TH

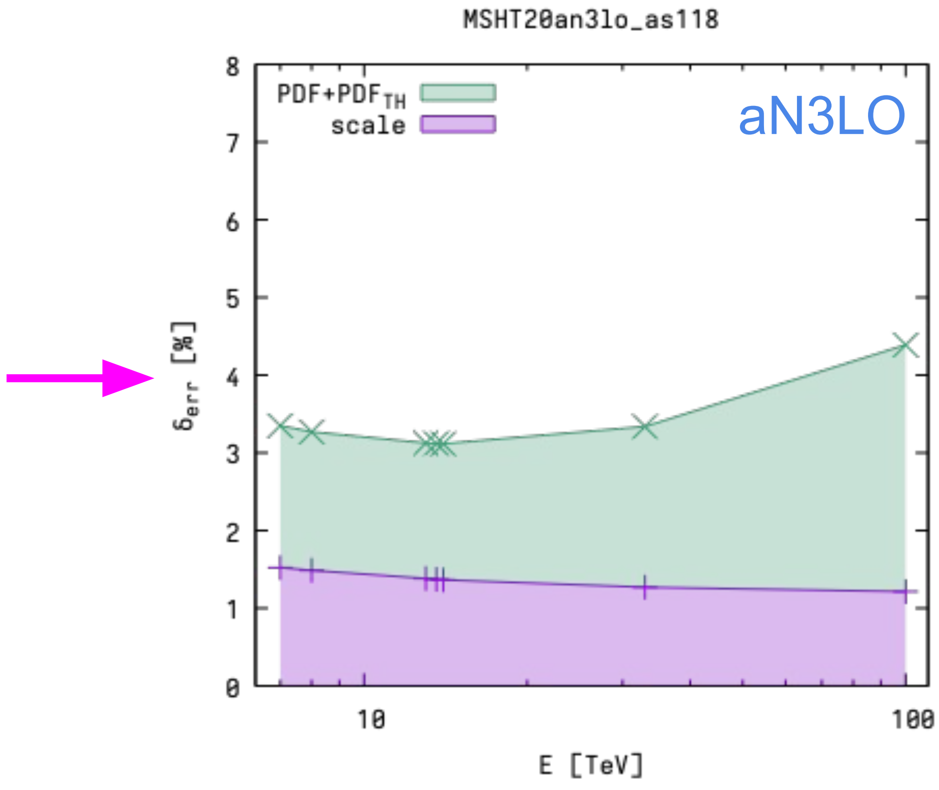
scale

and how the picture changes with aN3LO PDFs

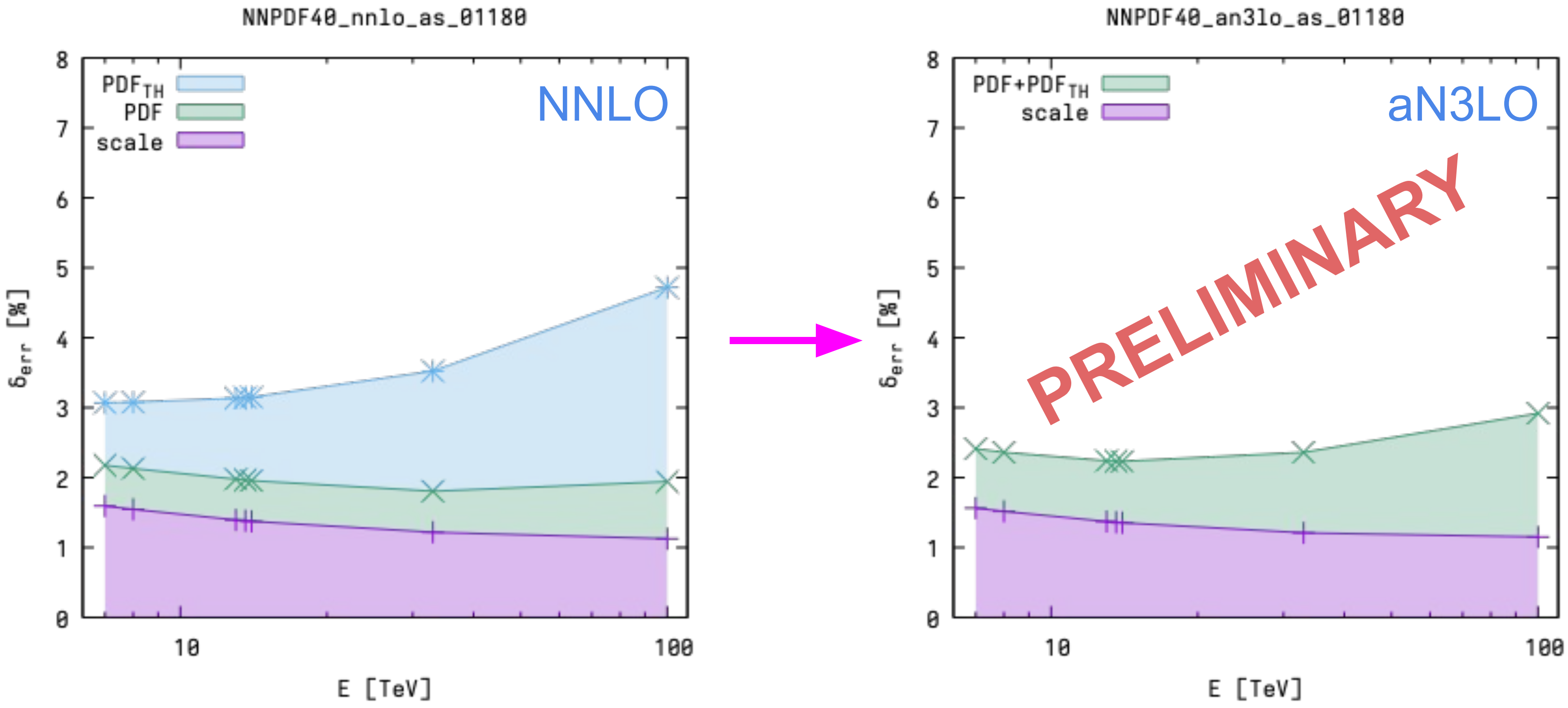


aN3LO PDFs & gluon-fusion Higgs production (II)



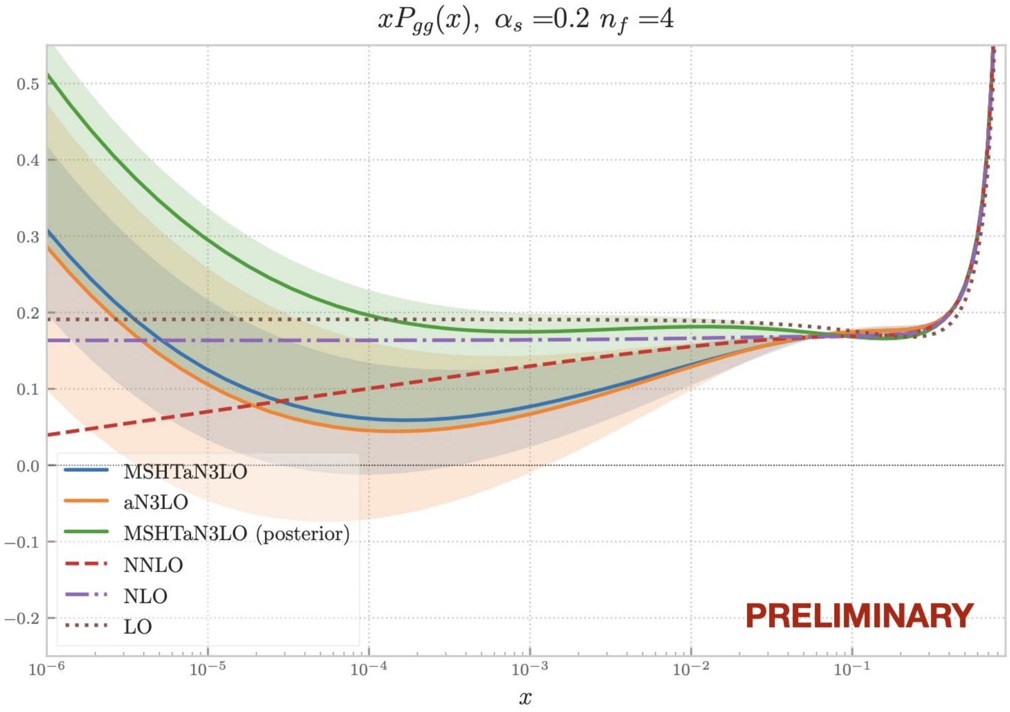


aN3LO PDFs & gluon-fusion Higgs production (III)



aN3LO PDFs & gluon-fusion Higgs production (IV)

With two independent aN3LO sets, a more detailed look into approximated splitting functions



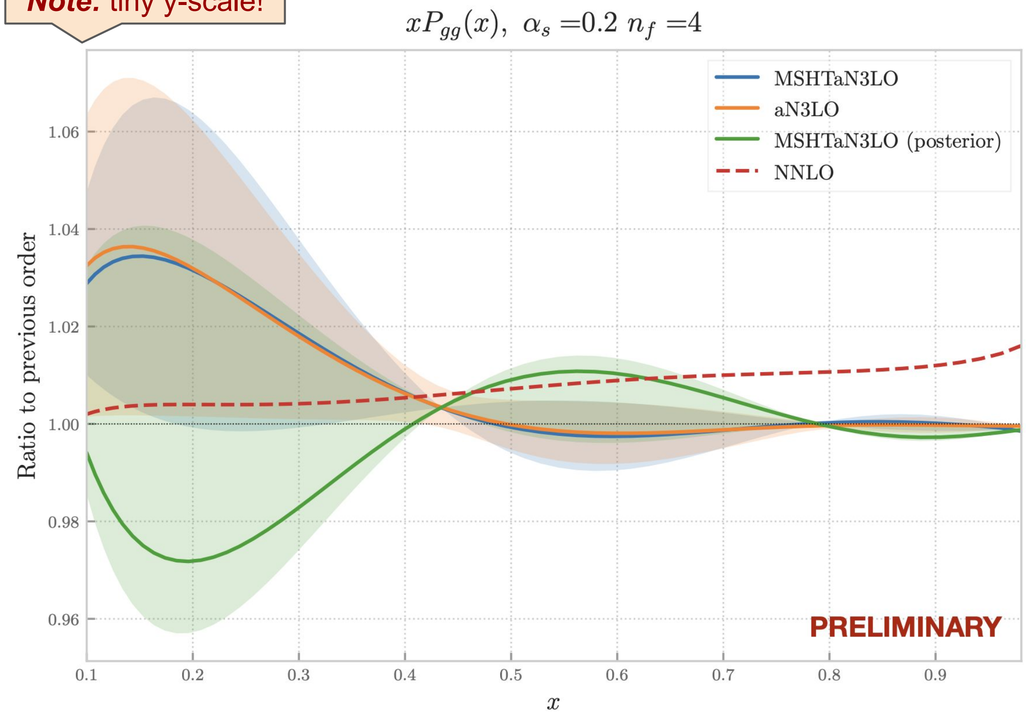
MSHT (prior) ≃ **NNPDF**

MSHT (posterior) shifts within uncertainty band
(absorbs some low-x logs?)

aN3LO PDFs & gluon-fusion Higgs production (V)

With two independent aN3LO sets, a more detailed look into approximated splitting functions

Note: tiny y-scale!

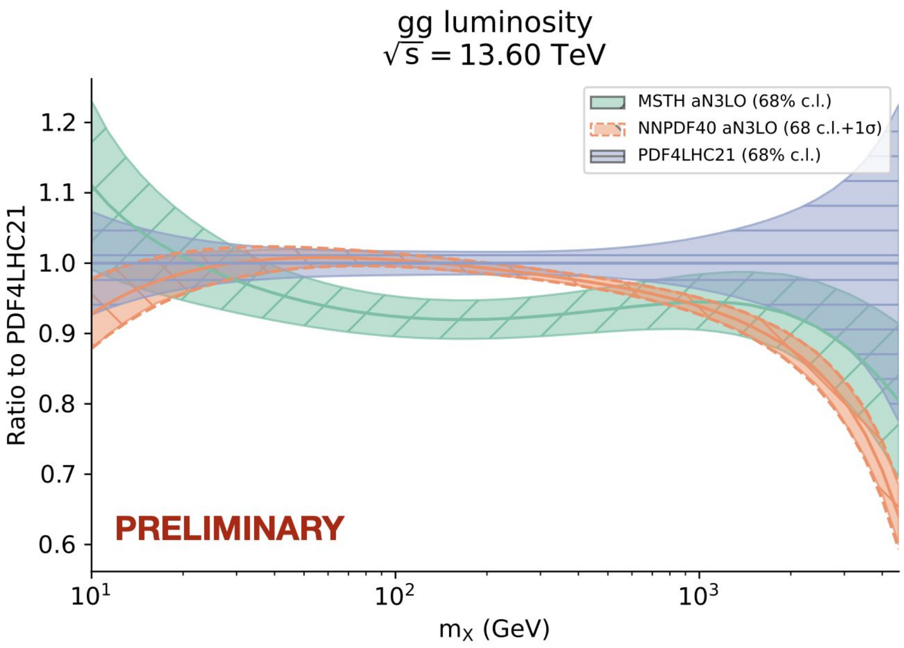


MSHT (prior) ≃ **NNPDF**

MSHT (posterior) shifts within uncertainty band

aN3LO PDFs & gluon-fusion Higgs production (VI)

Some differences between aN3LO sets by **MSHT** & **NNPDF** in gg luminosity

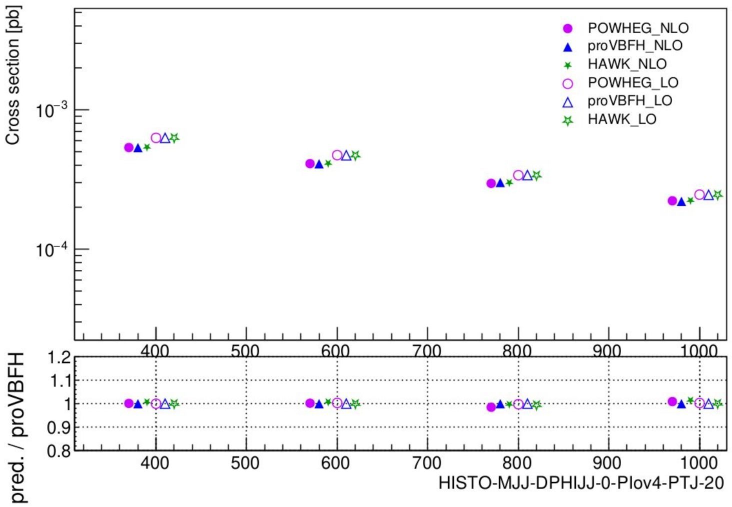


Followup studies:

- Understand origin of differences
  (impact from prior → posterior?
  treatment of MHO uncertainties
  & other N3LO inputs?
  difference in methodology? …)
- Compare evolution of toy PDFs
- Cross-section level comparisons
- …

VBF studies (I)

- Update @ 13.6 TeV for Higgs XSWG
  - Phase-space selection and binning (done) LINK
    (aligned with VBF/VBS simplified fiducial volume)
  - State-of-the-art @ fixed-order
    - Validation on-going (looks good)
    - Inclusion of non-factorizable corrections
    - Interference with irreducible background



  - Recommendation for PS uncertainties based on findings of [Buckey et al.; 2105.11399]
    - Add a few generator/shower/matching combinations …
      → expectation: things are still under control
  - A glance at non-perturbative aspects …
    → expectation: …

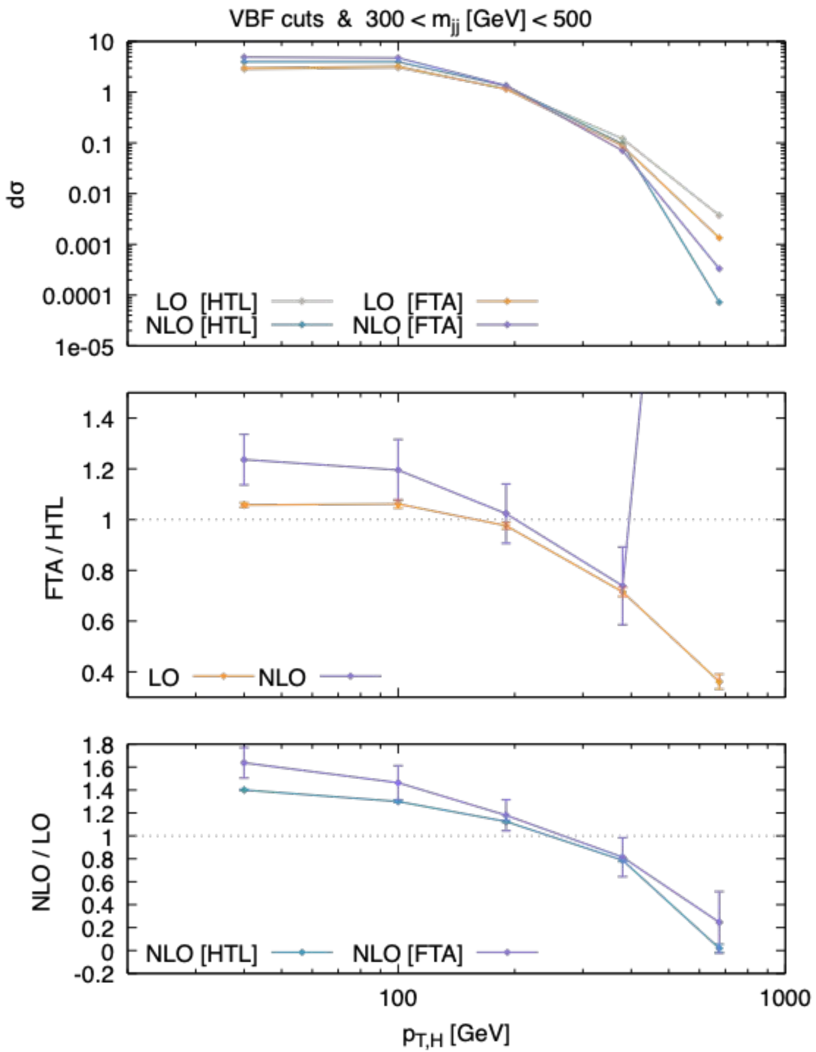
- ggH contamination into VBF phase space
  (ongoing study with debugging happening @ Les Houches!)

VBF studies (II)

- Study top-mass effects in ggH with VBF cuts

- HEJ: Impact from high-energy logs?

→ Higgs summary



Event files & Interpolation Grids

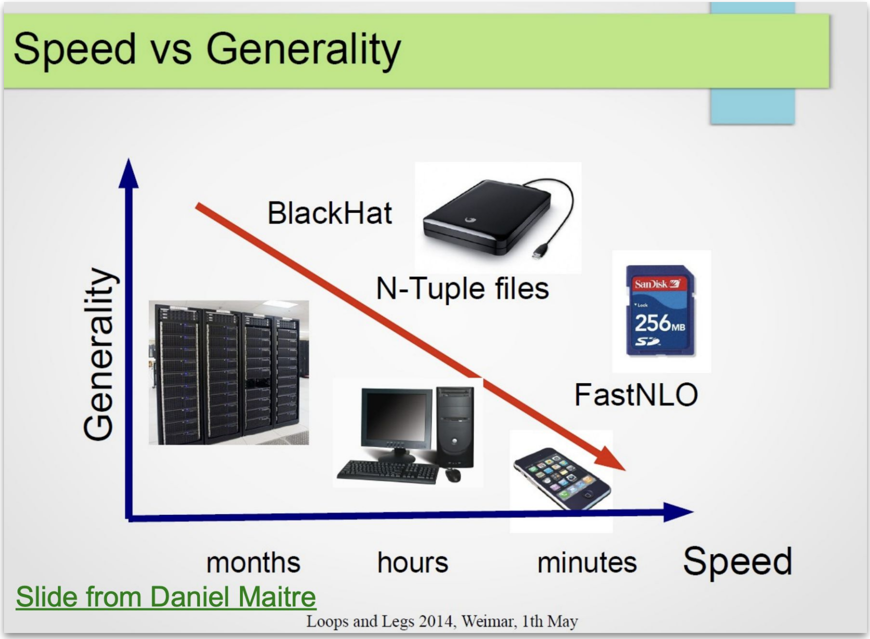
Discussed two approaches for dissemination of theory calculations

HighTea

R.Poncelet

Precomputed “theory events” that can be analyzed with a simple but flexible interface.

Storage efficiency through (partial) unweighting; possibilities to combine with the positive-weight cell resampler?



APPLfast

K.Rabbertz, L.Kunz

Predefined histogram bins for efficient re-evaluation using different PDF param. Indispensable in PDF fits.

Interpolation Grids (I)

Dataset	Theory
CDF Z differential	Sherpa+Vrap
D0 Z differential	Sherpa+Vrap
[D0 W electron asymmetry]	MCFM+FEWZ
D0 W muon asymmetry	MCFM+FEWZ
ATLAS low-mass DY 7 TeV	MCFM+FEWZ
ATLAS high-mass DY 7 TeV	MCFM+FEWZ
ATLAS W, Z 7 TeV ($\mathcal{L} = 35$ pb^{-1})	MCFM+FEWZ
ATLAS W, Z 7 TeV ($\mathcal{L} = 4.6$ fb^{-1}) (*)	MCFM+FEWZ
CMS W electron asymmetry 7 TeV	MCFM+FEWZ
CMS W muon asymmetry 7 TeV	MCFM+FEWZ
CMS DY 2D 7 TeV	MCFM+FEWZ
LHCb $Z \to ee$ 7 TeV	MCFM+FEWZ
LHCb $W, Z \to \mu$ 7 TeV	MCFM+FEWZ
[ATLAS W 8 TeV] (*)	MCFM+DYNNLO
ATLAS low-mass DY 2D 8 TeV (*)	MCFM+DYNNLO
ATLAS high-mass DY 2D 8 TeV (*)	MCFM+FEWZ
CMS W rapidity 8 TeV	MCFM+FEWZ
LHCb $Z \to ee$ 8 TeV	MCFM+FEWZ
LHCb $W, Z \to \mu$ 8 TeV	MCFM+FEWZ
[LHCb $W \to e$ 8 TeV] (*)	MCFM+FEWZ
ATLAS $\sigma^{tot}_{W,Z}$ 13 TeV (*)	MCFM+FEWZ
LHCb $Z \to ee$ 13 TeV (*)	MCFM+FEWZ
LHCb $Z \to \mu\mu$ 13 TeV (*)	MCFM+FEWZ

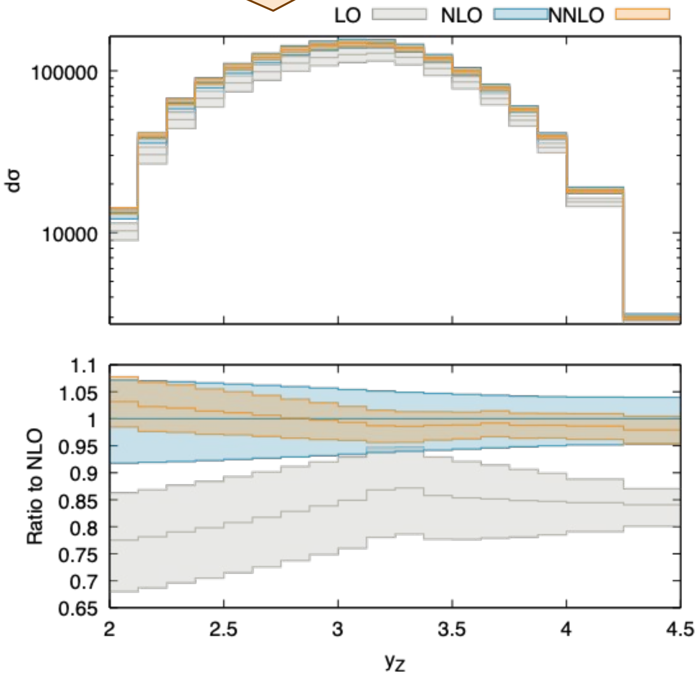
So far, all Drell–Yan processes (& PT[V]) included in PDF fits employ:
(NLO tables) × (NNLO K-factors)

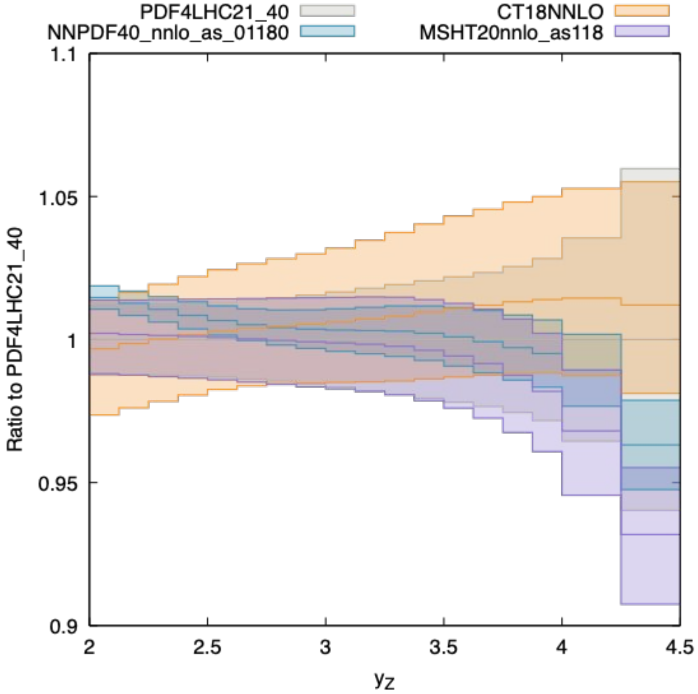
- extend all to NNLO grids
  benchmark & compare different libraries:
  APPLgrid, fastNLO, PineAPPL
- how stable are the K-factors?
- what is the impact on PDF fits?
- …

Interpolation Grids (II)

- non-flat K-factor
- Usage of inclusive N3LO K-factor tricky?

LHCb $Z \to ee$ 13 TeV (*)
LHCb $Z \to \mu\mu$ 13 TeV (*)





spread between PDF sets up to ~ 5%
(K-factors much smaller)

Conclusion / Summary

- Fruitful exchange on various aspects of Standard Model phenomenology
- New projects started & good progress on on-going projects

We hope to see many of you again for the next councelling retreat in 2025!