Les Houches 2019 Experimental summary for SM (Loops/Multilegs)

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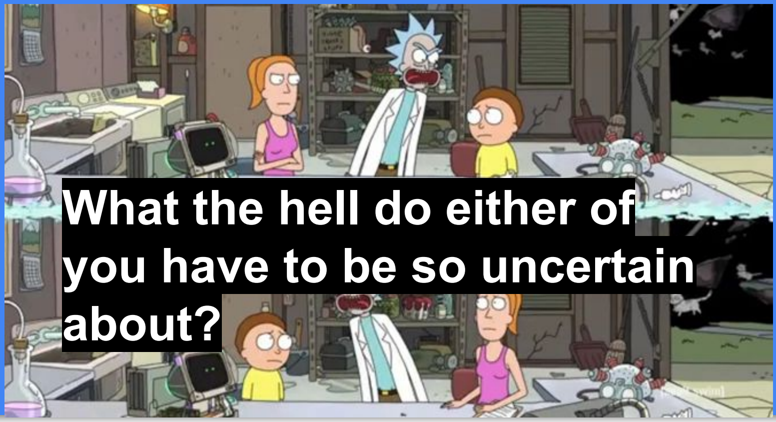
For the SM Loops/Multileg/Jets group

June 19, 2019

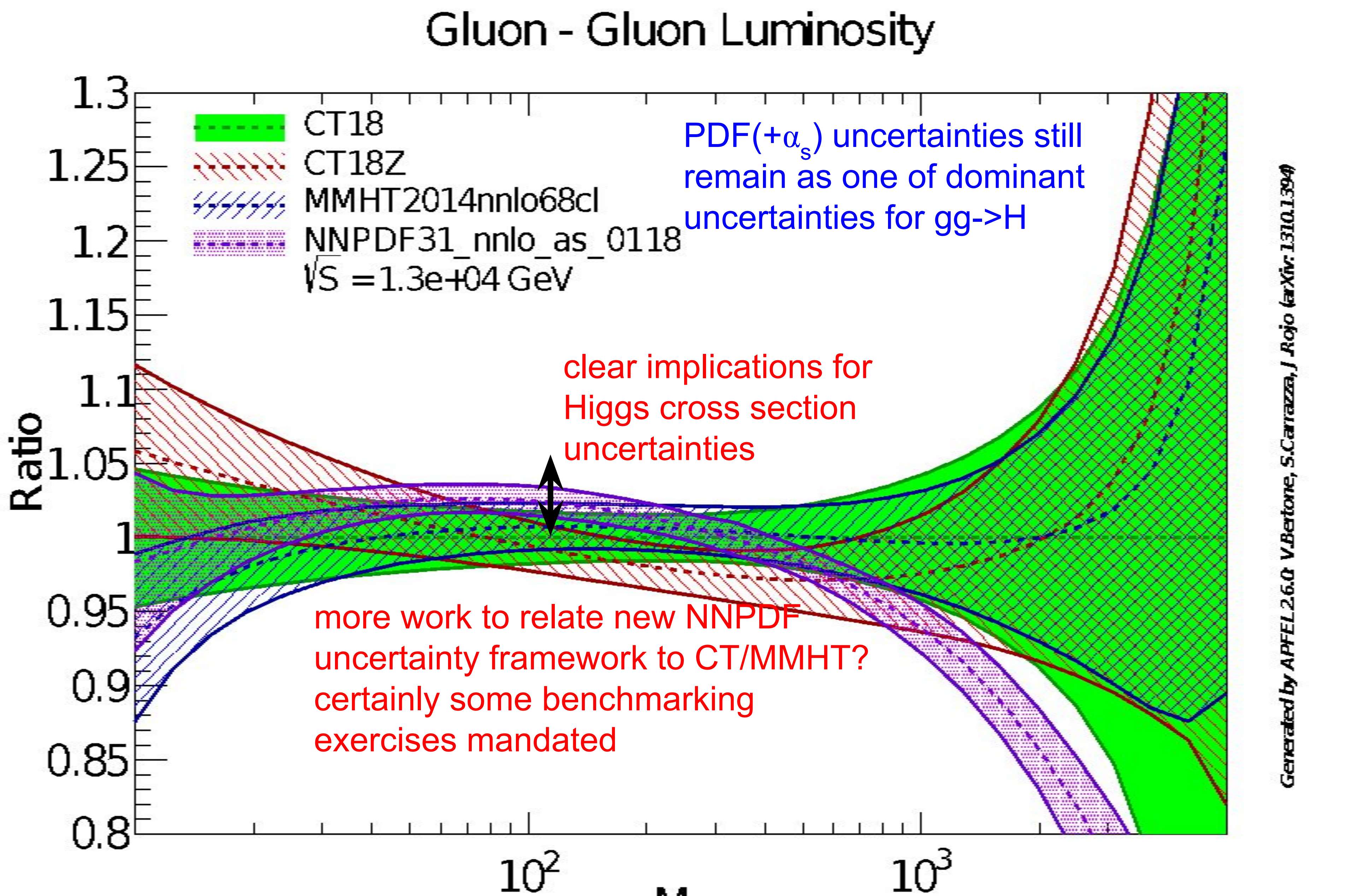
Introduction



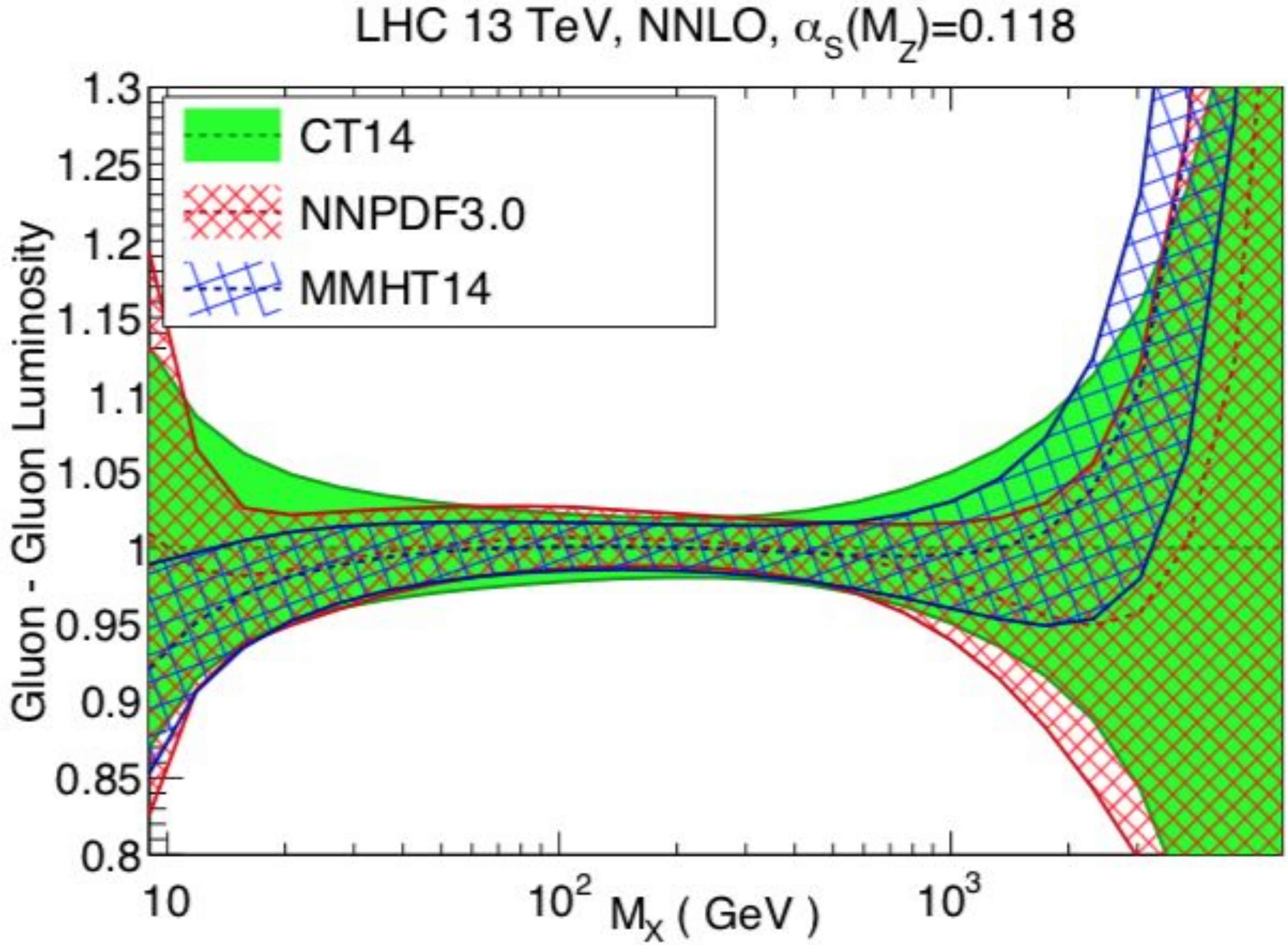
- Photon Isolation (covered in Higgs Theory talk)
- PDF Benchmarking
- Resummation Benchmarking
- Impact of resummation in PDF fits
- Theory Uncertainties in PDF Fits
- Theory Uncertainties: Beyond scale variations?
- Misc. Experiment Theory Issues

PDF Benchmarking

Now compare to MMHT2014 and NNPDF3.1



Previous level of agreement



PDF Benchmarking

- Exercise planned to compare fitting methodologies of global PDF sets using common datasets
- Starting from just DIS data and incrementally working up from there
- Goal is to understand role of different methodology etc on the impact of different experimental input
- Particular focus on relative impact of LHC jets vs top data and compatibility of different ttbar observables

Resummation benchmarking: $p_T Z$, $p_T W/p_T Z$

- Benchmarking of analytically resummed $p_T Z$, $p_T W/p_T Z$ is of great interest to experimentalists working on the W mass measurement
  - Has never been done before
  - Study impacts of different possible choices in the calulations
- Benchmarking exercise of the analytic resummed calculations in the precision EW group (not a les Houches project per se, but discussed here for completeness)
  - Benchmarking document:
  - https://indico.cern.ch/event/827617/contributions/3463723/attachments/1864129/3064667/analytic_resum_benchmarking.pdf
  - Participation of 7 groups: CuTe, DYRES, NangaParbat, Radhish, Resbos2, reSolve, SCETlib
- It was agreed to proceed in successive steps of the benchmarking from pure resummation benchmarking to “full resummation+fixed order (FO)” benchmarking
  - 3 step benchmarking

Benchmarking levels

1) Canonical logarithms (as much as possible)
   - Strictly $\ln(Qb_T/b_0)$, $\ln(q_T/Q)$, i.e. $\mu_H = Q_{\rm res} = Q$, $\mu_r = \mu_f = Q$
   - Including b^* or equivalent prescription, but no nonpert. form factor etc.
   - Result in b_T space (if possible)
   - Result in q_T space

2) Nominal, favourite logarithms
   - Including turning off resummation at large q_T, e.g. $Q_{\rm res} = Q/2$, profile scales, $\ln(b_T) \to \ln(1 + b_T)$, etc. ...
   - Result in q_T space

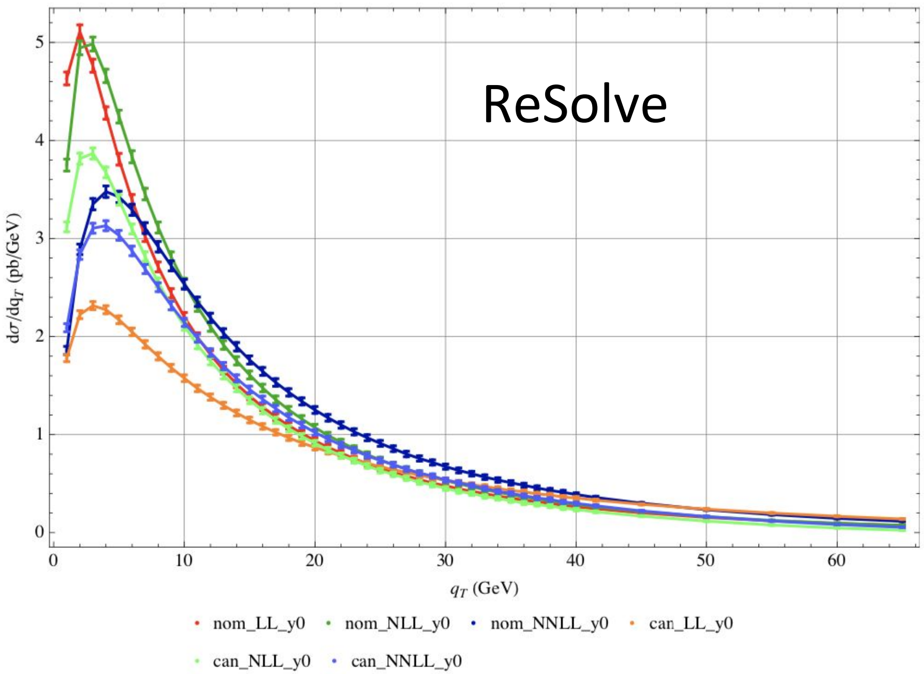
3) Resummation as in 2) plus matching nonsingular FO correction

	Boundary conditions (FO hard, coll., soft)	Anomalous dimensions γ_i	$\Gamma_{\rm cusp}$, β	FO matching (nonsingular)
LL	1	-	1-loop	-
NLL	1	1-loop	2-loop	-
NLL′+NLO$_0$	α_s	1-loop	2-loop	α_s
NNLL+NLO$_0$	α_s	2-loop	3-loop	α_s
NNLL′+NNLO$_0$	α_s^2	2-loop	3-loop	α_s^2
N^{3}LL+NNLO$_0$	α_s^2	3-loop	4-loop	α_s^2

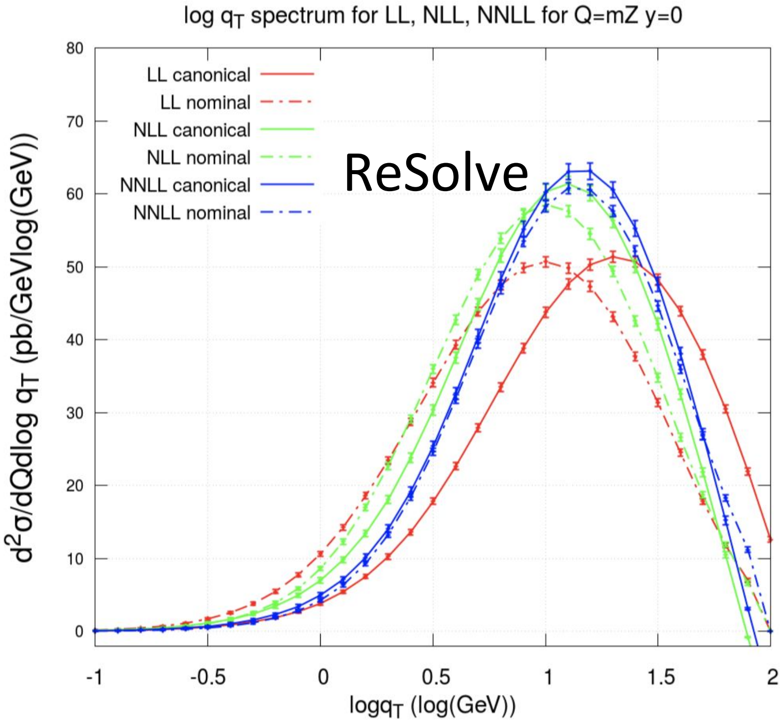
Benchmarking levels

- Benchmarking in qT, log-qT, bT space, etc.

Canonical vs. Nominal $Q = m_Z$, $y = 0$



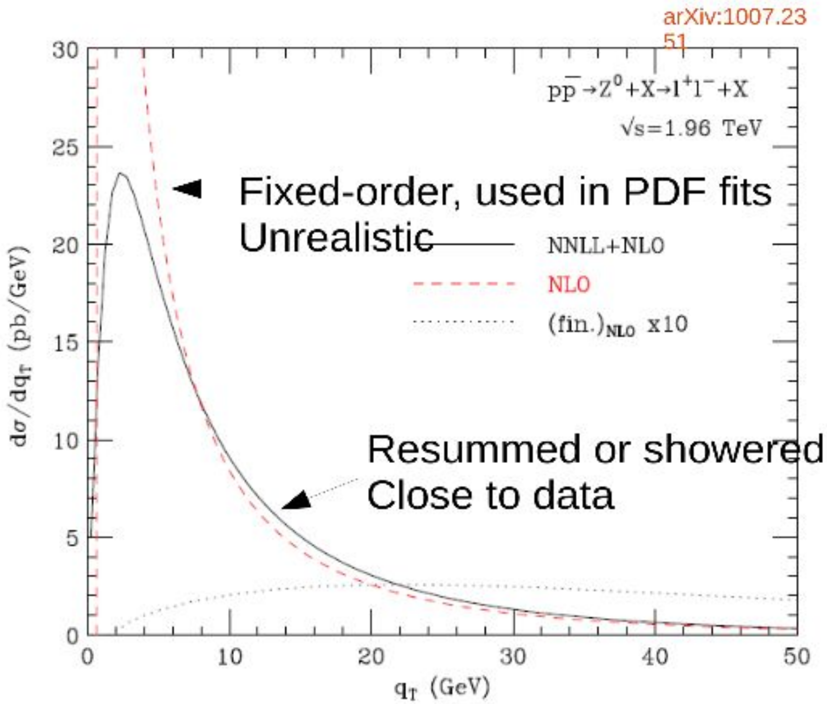
Canonical vs. Nominal $Q = m_Z$, $y = 0$

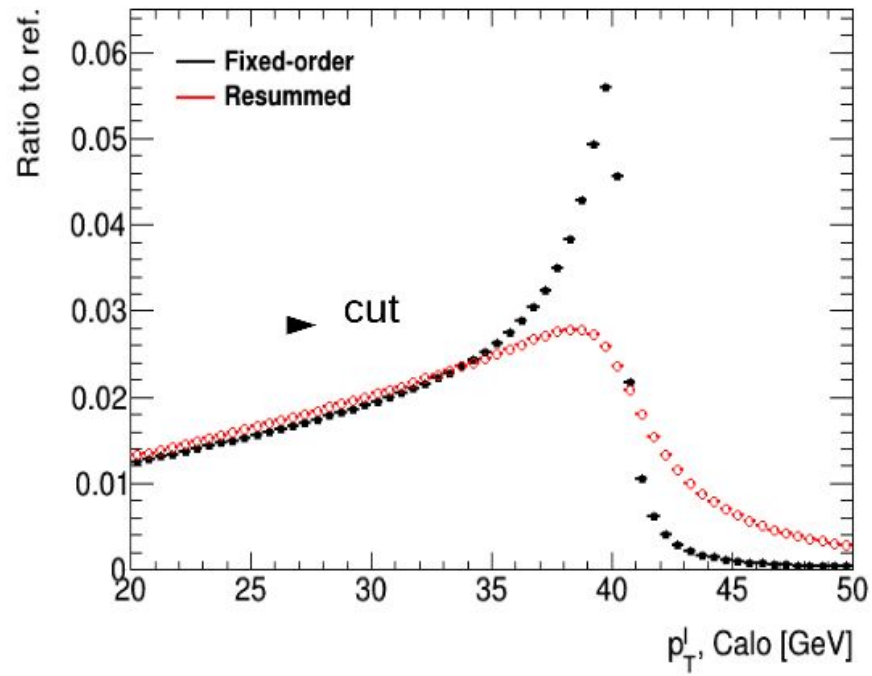


Resummation Impact of PDFs for W/Z Data

Motivation

M. Boonekamp, https://indico.cern.ch/event/801961/contributions/3368455/attachments/1824716/2985820/psKfactors_050419.pdf



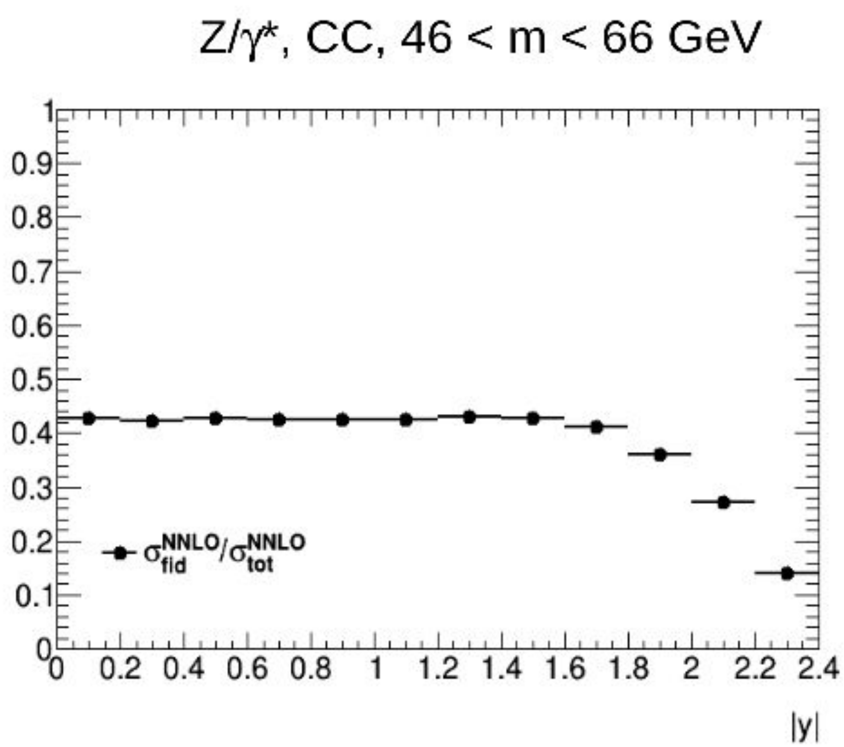


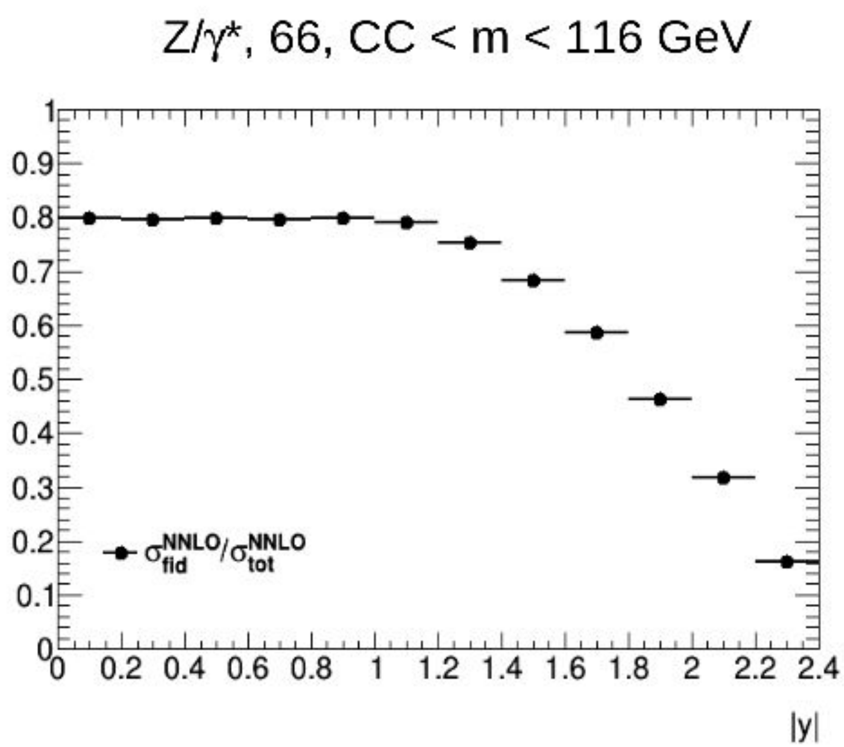
Resummation effects affect the pT distributions, hence the acceptance of fiducial cuts

For same total cross section, fixed-order and resummed ***fiducial*** cross sections differ.

This leads to a small inconsistency when interpreting fiducial cross section measurements in terms of PDFs, which typically use fixed-order predictions

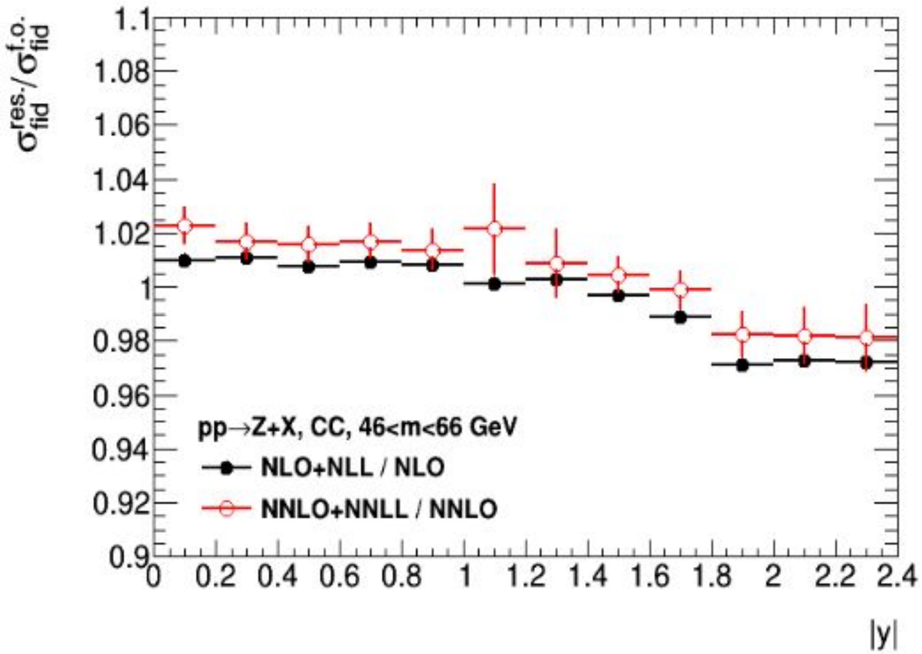
Fixed-order acceptance



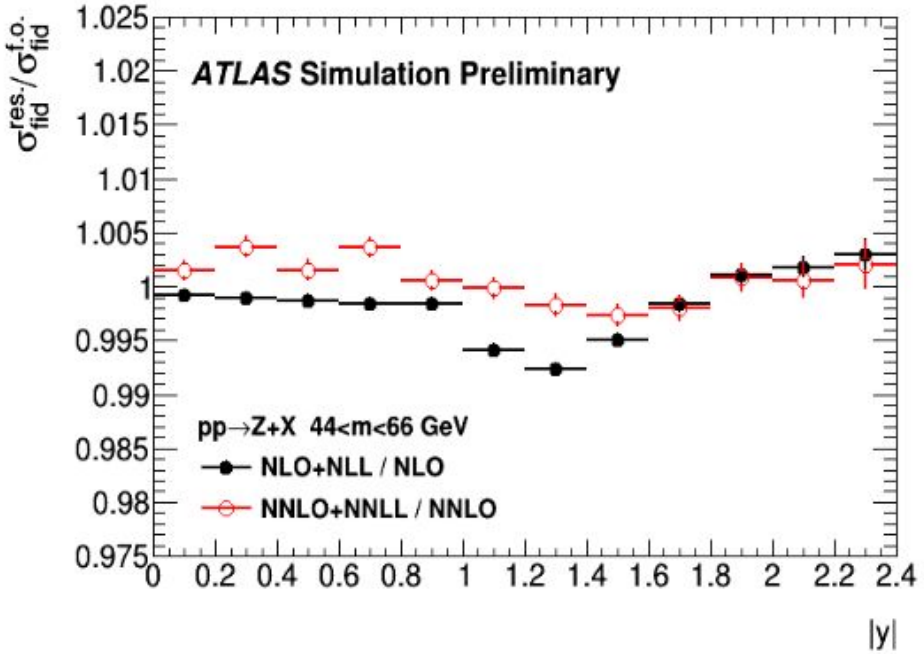


Effect of pT resummation – Z

CC, 46 < M < 66 GeV



CC, 66 < M < 116 GeV



3-4% drop towards high eta

NLL : ~1% dip near |eta|=1.4
Reduced to .5% at NNLL

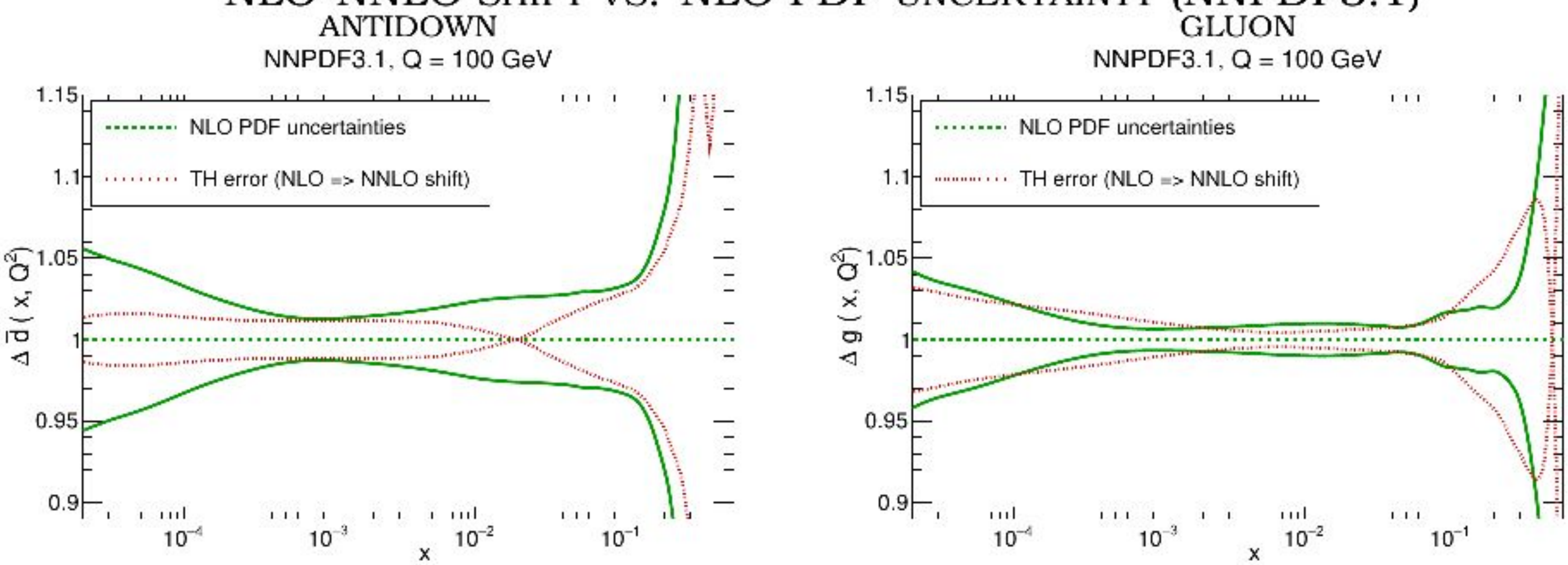
Resummation Impact of PDFs for W/Z Data

- **Bottom line:** Resummation corrections are relevant for predictions of W and Z differential fiducial cross sections (mainly due to lepton pT cuts in fiducial phase space definition)
- Effect may be small in absolute terms, but is relevant compared to the precision of the experimental measurements, in particular for normalized cross sections
- Some further studies will be done to reproduce/study the size of this effect and explore the possibility of including resummed predictions (or at least effective corrections) in global PDF fits

Missing Higher Order Uncertainties in PDFs

THE MISSING HIGHER ORDER UNCERTAINTY ON PDFS
HOW BIG IS IT?

NLO-NNLO SHIFT VS. NLO PDF UNCERTAINTY (NNPDF3.1)



- TODAY: NLO PDF & MHOU UNCERTAINTIES COMPARABLE
- NEAR FUTURE: SHOULD WE WORRY ABOUT NNLO MHOU?

THE THEORY COVARIANCE MATRIX

(NNPDF, 2019)

- ASSOCIATE MHOU TO NUISANCE PARAMETER ⇒ THEORY COVARIANCE MATRIX S_{ij}
- $S_{ij} = \frac{1}{N}\sum_k \left(T_i^{(k)} - T_i^{(0)}\right)\left(T_j^{(k)} - T_j^{(0)}\right)$
  $\left(T_i^{(k)} - T_i^{(0)}\right)$: k-TH SHIFT OF i-TH DATAPOINT ABOUT CENTRAL PREDICTION $T_i^{(0)}$.
- SHIFT: GUESS FOR POSSIBLE MHO TERMS ⇒ SCALE VARIATION

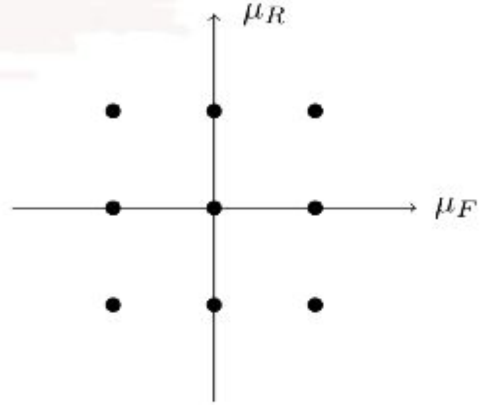
SCALE VARIATION

EXPERIMENTS AND PROCESSES

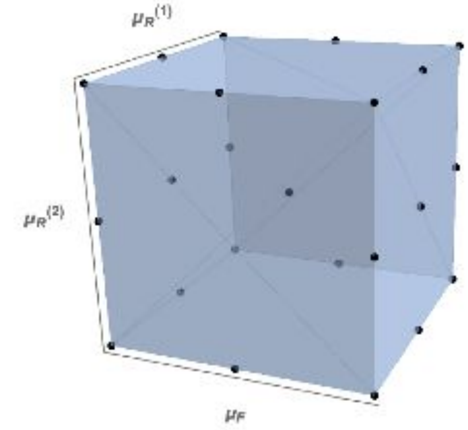
Process Type	Datasets
DIS NC	NMC, SLAC, BCDMS, HERA NC
DIS CC	NuTeV, CHORUS, HERA CC
DY	CDF, D0, ATLAS, CMS, LHCb (y, p_T, M_{ll})
JET	ATLAS, CMS inclusive jets
TOP	ATLAS, CMS total+differential cross-sections

NINE-POINT SCALE VAR.

SAME PROCESS



DIFFERENT PROCESSES



- CLASSIFY DATA INTO PROCESSES
- PICK A SET OF SCALE VARIATIONS
- DECIDE HOW TO CORRELATE SCALE VARIATION BETWEEN DIFFERENT PROCESSES
- RENORMALIZATION ⇒ MATRIX ELEMENT; FACTORIZATION ⇒ EVOLUTION

THE THEORY COVARIANCE MATRIX: CORRELATIONS

- INDEPENDENT NUISANCE PARAMETERS ⇒ TH. AND EXP. ERRORS COMBINE IN QUADRATURE
$\chi^2 = \sum_{i,j=1}^{N_{\rm dat}} \left(D_i - T_i^{(0)}\right) [S + C]_{ij}^{-1} \left(D_i - T_i^{(0)}\right)$

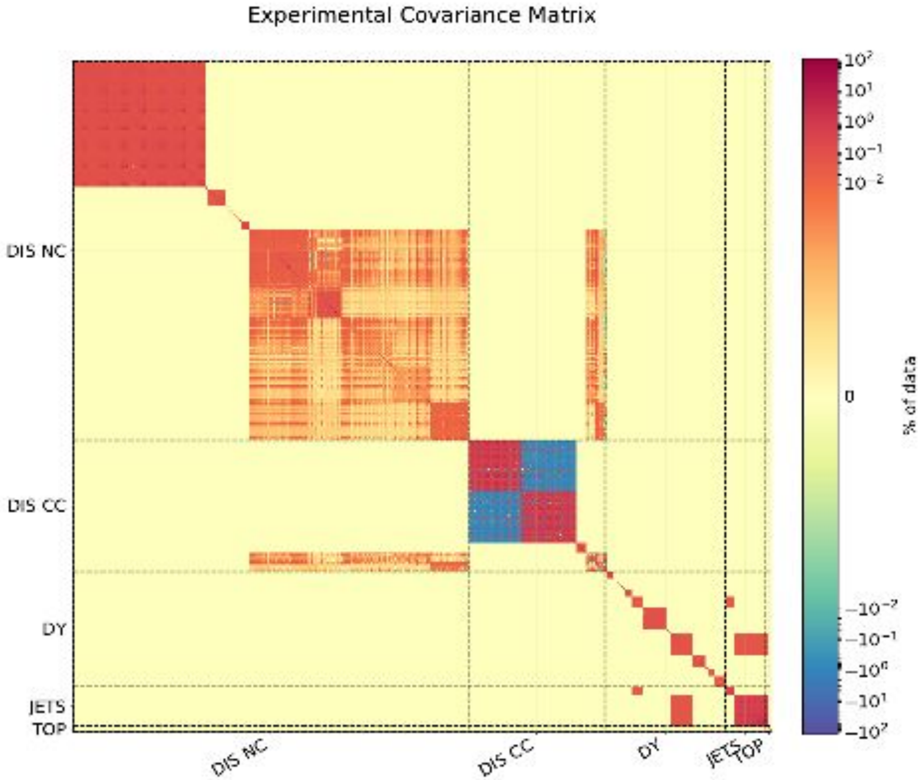
- REN. SCALE ⇒ CORRELATIONS INDUCED BETWEEN EXPERIMENTALLY UNRELATED MEASUREMENTS OF SAME PROCESS

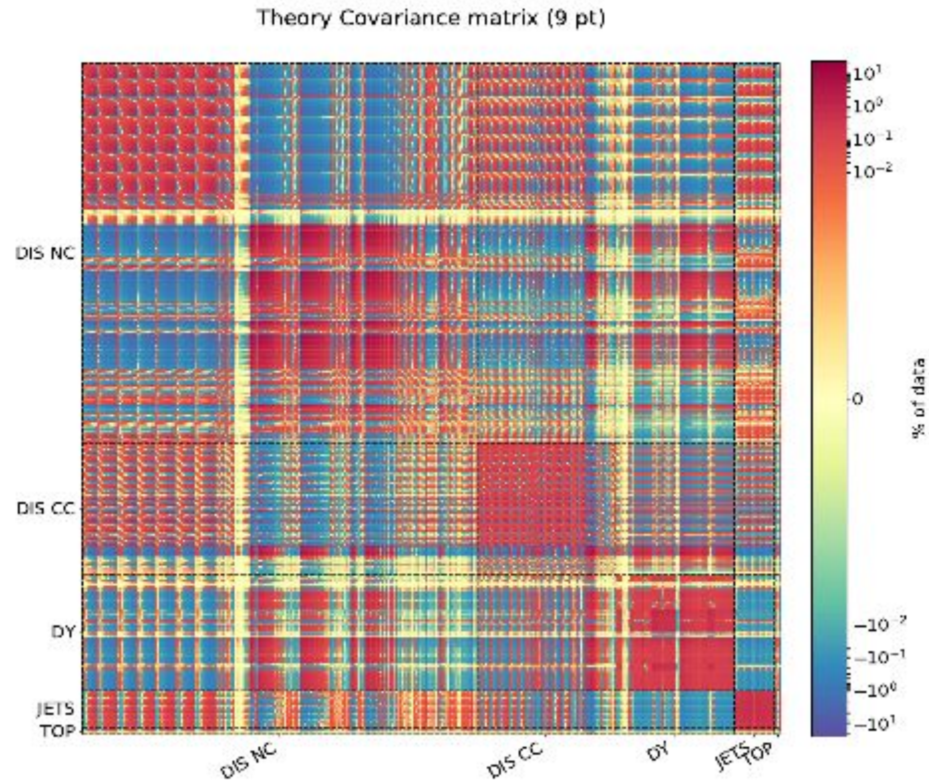
- FACT. SCALE ⇒ CORRELATIONS INDUCED BETWEEN DIFFERENT PROCESSES

THE COVARIANCE MATRIX

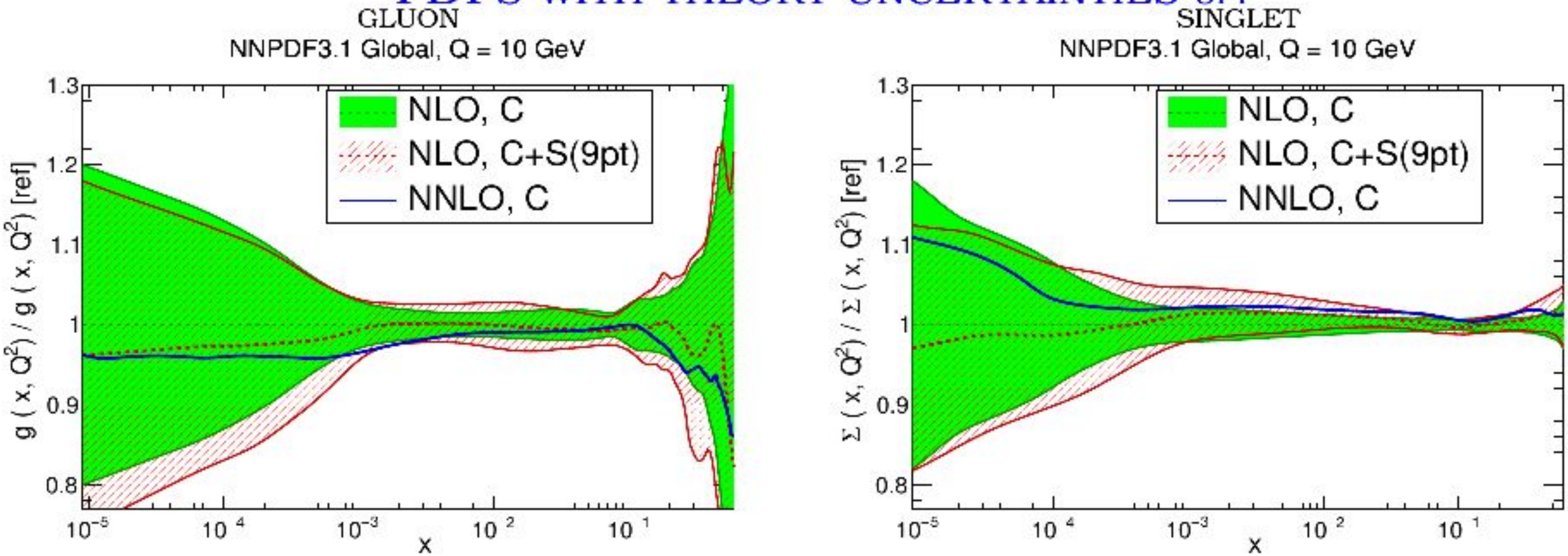
EXPERIMENT

THEORY (9 PT)





PDFs with theory uncertainties 9pt



	C	$C+S^{(3pt)}$	$C+S^{(9pt)}$
χ^2	1.139	1.139	1.109
ϕ	0.314	0.310	0.315

- Fit quality χ^2 improves
- Relative error ϕ on prediction does not change
- Data region: PDF uncertainty almost unchanged
- Extrapolation region: PDF uncertainty significantly increases
- Central value moves towards known NNLO

Equally precise but more accurate result!

Theory Uncertainties, Beyond Scale Variations?

Theory Uncertainties and Correlations.

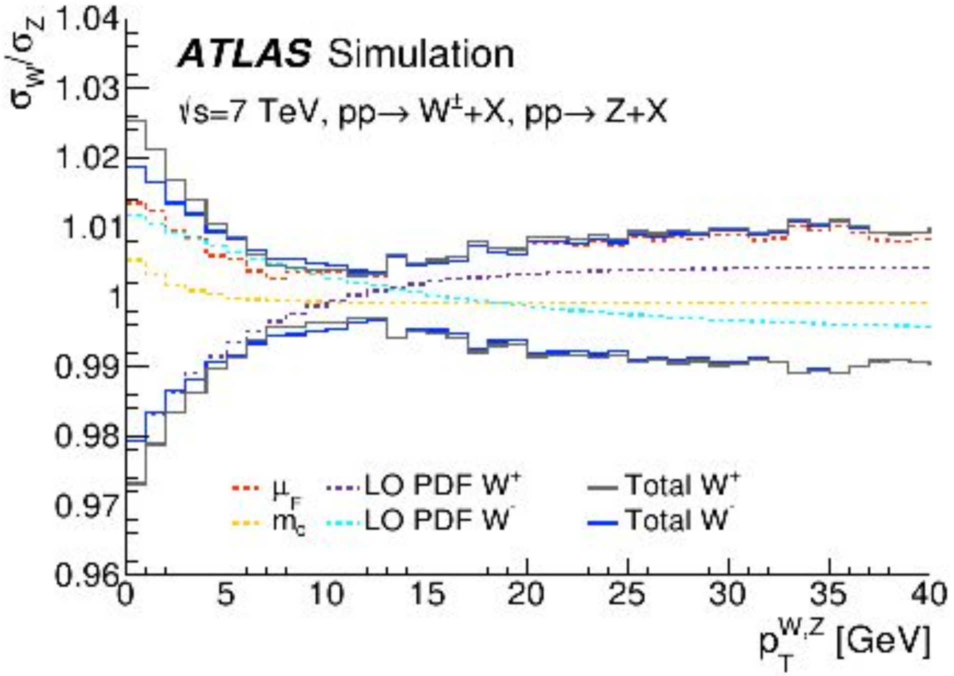
Reliable theory uncertainties are essential for any precision studies and interpretation of experimental measurements

- Especially when theory uncertainties $\gtrsim$ experimental uncertainties
- Correlations can have significant impact
  - In fact, whenever one combines more than a single measurement, one should ask how the theory uncertainties in the predictions for each measurement are correlated with each other
  - Correlations between different points in a spectrum
  - Correlations between processes, observables, ...
- So far we have (mostly) been skirting the issue
  - However, experimentalists have to treat theory uncertainties like any other systematic uncertainty, and in absence of anything better they have to make something up based on naive scale variations
  - In likelihood fits, some (possibly enveloped) scale variation impact will get treated as a free nuisance parameter and floated in the fit

Example: Measurement of the W Mass

Small $p_T^W < 40\,\mathbf{GeV}$ is the relevant region for m_W

- Needs very precise predictions for p_T^W spectrum
- $\simeq 2\%$ uncertainties in p_T^W translate into $\simeq 10\,\mathbf{MeV}$ uncertainty in m_W
- Direct theory predictions for p_T^W are insufficient



⇒ Strategy: Exploit precisely measured Z p_T spectrum to get best possible description for W

- Regardless how precisely $\mathrm{d}\sigma(W)/\mathrm{d}p_T$ can be calculated directly, one always wants to exploit Z data to maximize precision

What About Correlations?

Correlations only come from common sources of uncertainties

✓ "Straightforward" for unc. due to input parameters ($\alpha_s(m_Z)$,)

Scale variations are inherently ill-suited for correlations

✗ Scales are not physical parameters with an uncertainty that can be propagated

  ✗ They are not the underlying source of uncertainty

  ✗ Scale variation reduces at higher order not because the scales become better known but because the cross section becomes less dependent on them

✗ A priori, scale variations do not imply true correlations between different kinematic regions or different processes

✗ Taking an envelope is not a linear operation and so does not propagate

⇒ In my mind, trying to decide how to (un)correlate scale variations in the end only treats a symptom, but not the actual problem

A Possible Solution.

$$\sigma = c_0 + \alpha_s(\mu)[c_1 + \alpha_s(\mu)\, c_2 + \cdots]$$

Identify the actual source of uncertainty

- The unknown higher-order corrections: $\alpha_s(\mu)\, c_2 + \cdots$

Parametrize and vary the unknown

- We often know quite a lot about the general structure of c_2
  - μ dependence, color structure, partonic channels, kinematic structure, ...
- Suitably parametrize the missing pieces
  - Simplest case: c_2 is just a number
  - More generally, have to parametrize an unknown function
- Common/independent pieces between different predictions determine the correlations between them

Theory Nuisance Parameters.

Perturbative series at leading power is determined to all orders by a coupled system of differential equations (RGEs)

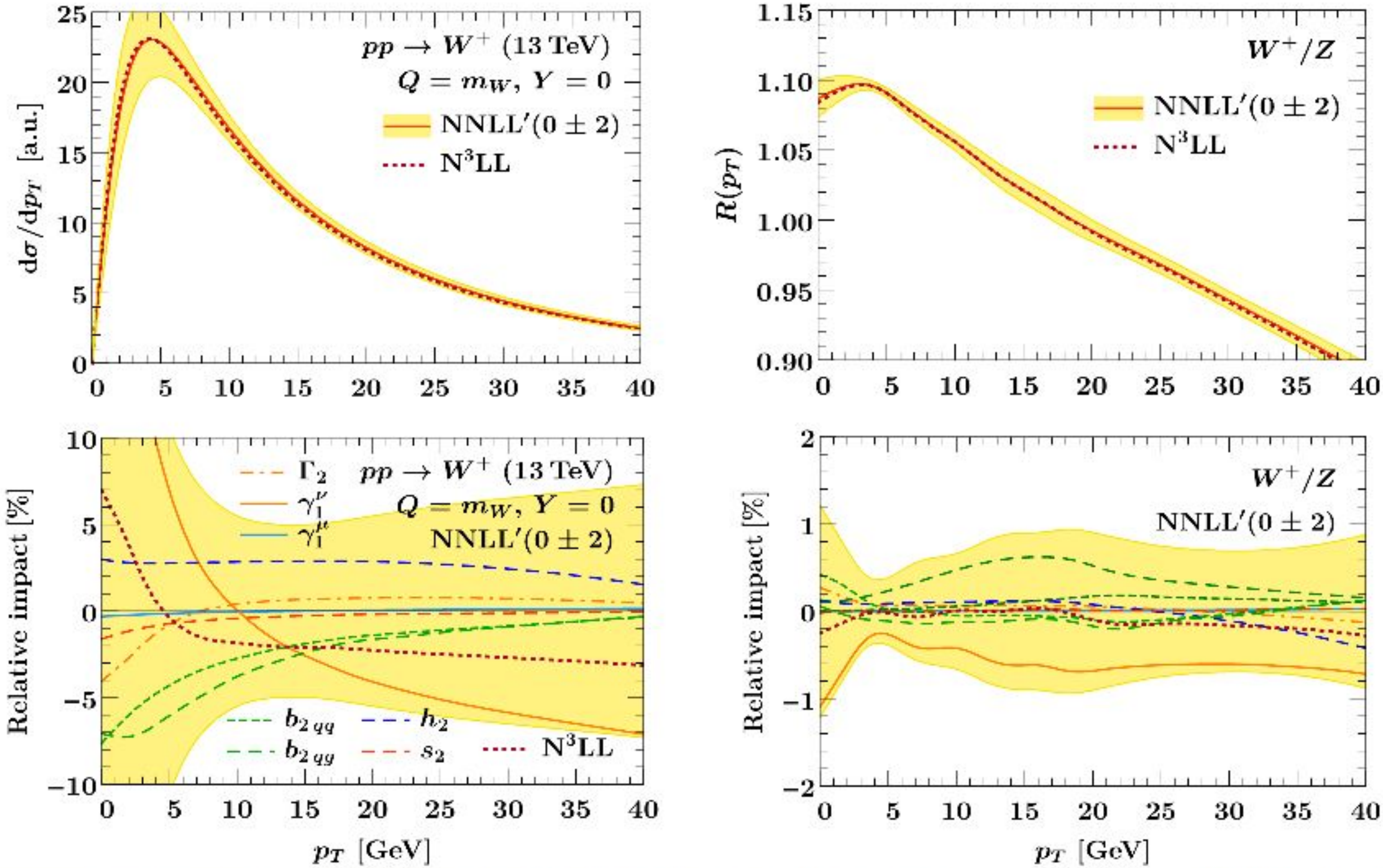
→ Each resummation order only depends on a few semi-universal parameters

→ Unknown parameters at higher orders are the actual sources of perturbative theory uncertainty

	boundary conditions			anomalous dimensions			
order	h_n	s_n	b_n	γ_n^h	γ_n^s	Γ_n	β_n
LL	h_0	s_0	b_0	–	–	Γ_0	β_0
NLL′	h_1	s_1	b_1	γ_0^h	γ_0^s	Γ_1	β_1
NNLL′	h_2	s_2	b_2	γ_1^h	γ_1^s	Γ_2	β_2
N^3LL'	h_3	s_3	b_3	γ_2^h	γ_2^s	Γ_3	β_3
N^4LL'	h_4	s_4	b_4	γ_3^h	γ_3^s	Γ_4	β_4

- Basic Idea: Use them as theory nuisance parameters
  - ✓ Vary them independently to estimate the theory uncertainties
  - ✓ Impact of each independent nuisance parameter is fully correlated across all kinematic regions and processes
  - ✓ Impact of different nuisance parameters is fully uncorrelated
- Price to Pay: Calculation becomes quite a bit more complex

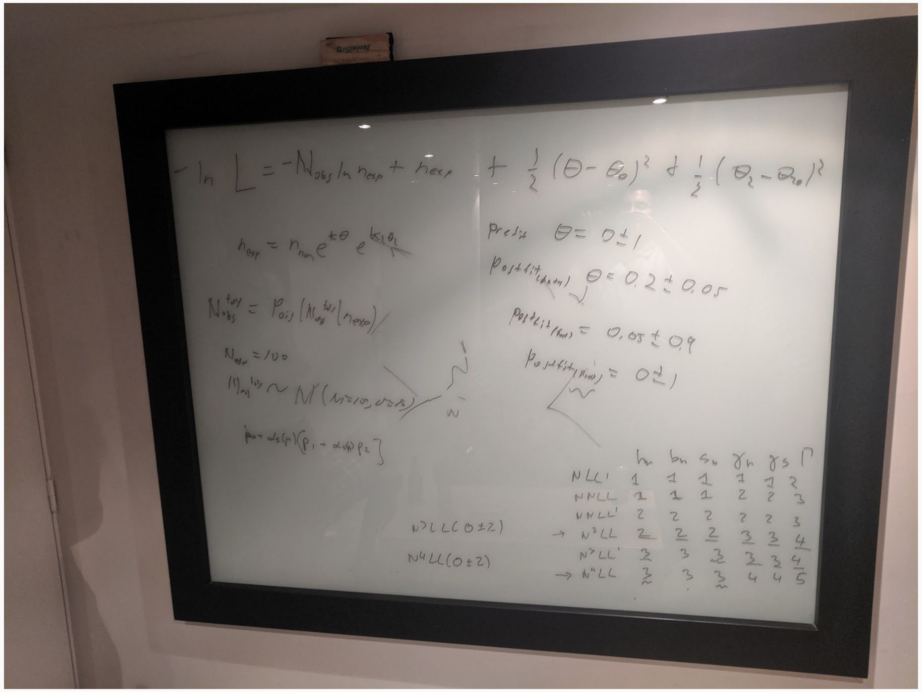
W vs. Z.



$pp \to W^+$ (13 TeV)
$Q = m_W$, $Y = 0$
NNLL′(0 ± 2)
N³LL
dσ/dp_T [a.u.]
W^+/Z
NNLL′(0 ± 2)
N³LL
R(p_T)
Γ_2
γ_1^ν
γ_1^μ
$pp \to W^+$ (13 TeV)
$Q = m_W$, $Y = 0$
NNLL′(0 ± 2)
b_2 qq
b_2 qg
h_2
s_2
N³LL
Relative impact [%]
p_T [GeV]
W^+/Z
NNLL′(0 ± 2)
Relative impact [%]
p_T [GeV]

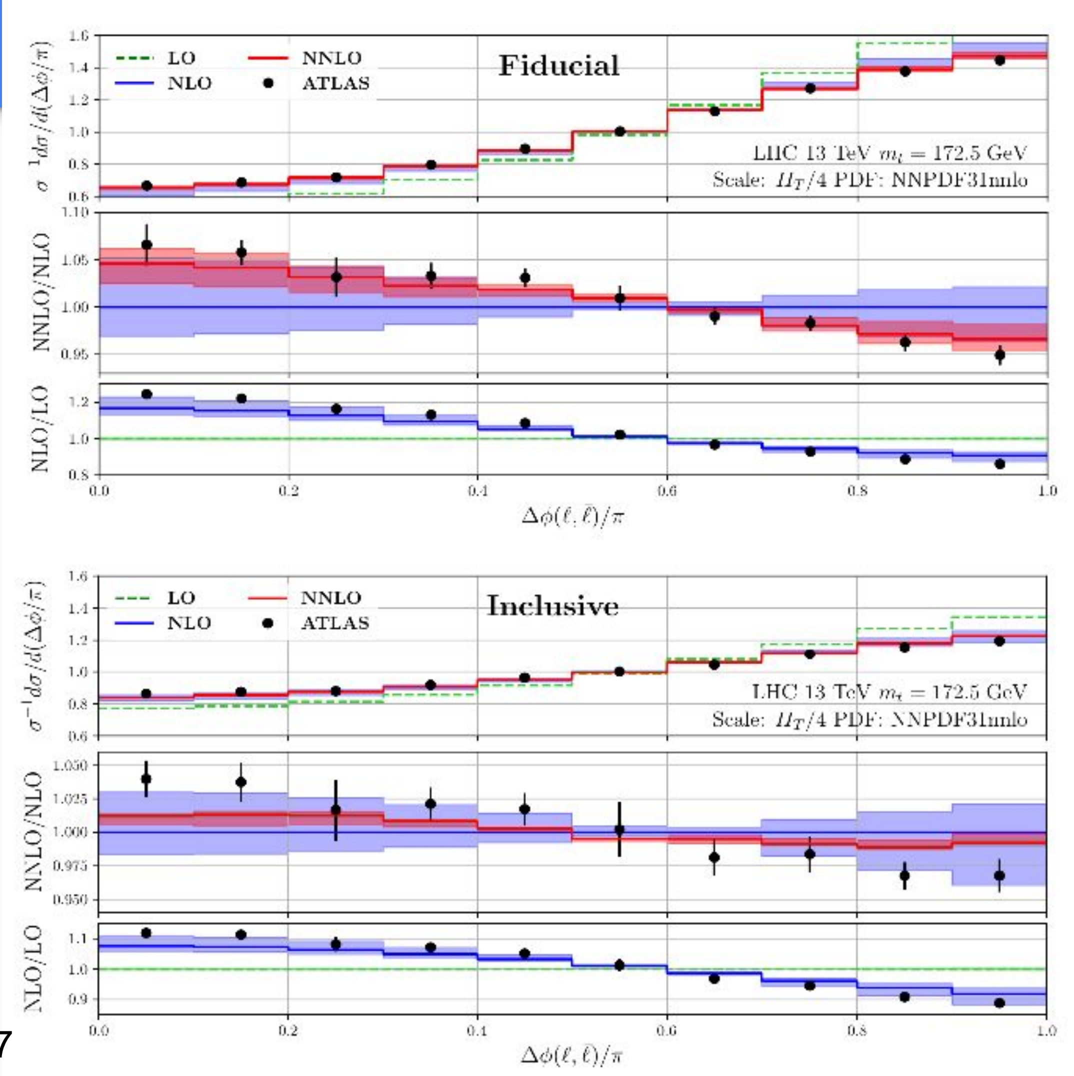
Theory Nuisances: Next Steps

- Significant interest in ATLAS and CMS to adopt this procedure for future mW measurements
- Easiest path likely through differential reweighting of Monte Carlo from existing generators
- As initial exercise for Les Houches, set up maximum likelihood fits with representative toy data for Z and/or W pT distributions



Misc. Issues: Fixed Order Comparisons in ttbar (Spin correlation example)

- Comparisons to top data at fixed order involves non-trivial unfolding to parton level with associated model dependencies
- Unfolding to inclusive phase space can introduce additional model dependence/issues

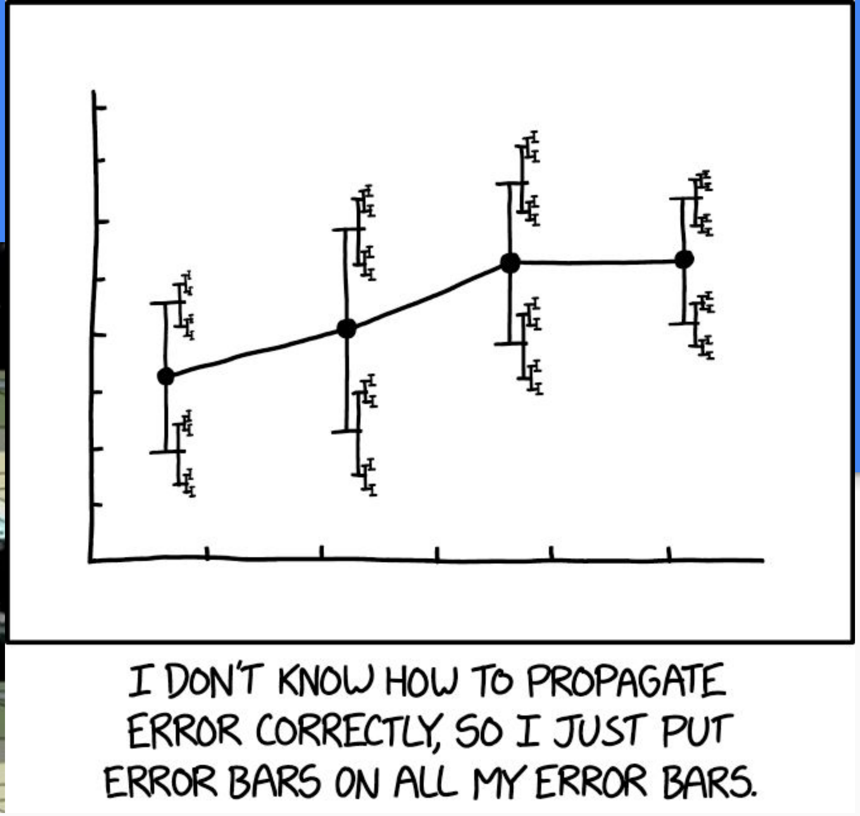


arXiv:1901.05407

Additional topics

- Continuation of precision jet study from Les Houches 2017
- Better determination of uncertainties
- Better understanding of effects at small jet radius

Conclusions



- Missing higher orders
  - Scale choices/variation scheme
  - Something else?
  - Correlations?
- PDFs
- Resummation effects
- (Shower uncertainties? Monte Carlo Uncertainties?)
- Unknown Unknowns?