Measuring hard probe suppression without a measured pp reference

Jasmine Brewer
Aleksas Mazeliauskas
Wilke van der Schee

Based on: Brewer, Huss, Mazeliauskas, van der Schee *(in preparation)*

Opportunities of OO and pO collisions at the LHC

Feb. 4-10, 2021

- Technical feasibility of oxygen at the LHC

Unique opportunities for

- Soft sector
  - Unique geometry, temperature
- High-p_T probes
  - energy loss in small systems
  - constraining nuclear PDFs
- pO for cosmic ray physics

Aleksas Mazeliauskas

Wilke van der Schee

396 registered participants, 186 unique connections per day.

Workshop summary document: arXiv:2103.01939
Slides and recordings: cern.ch/OppOatLHC

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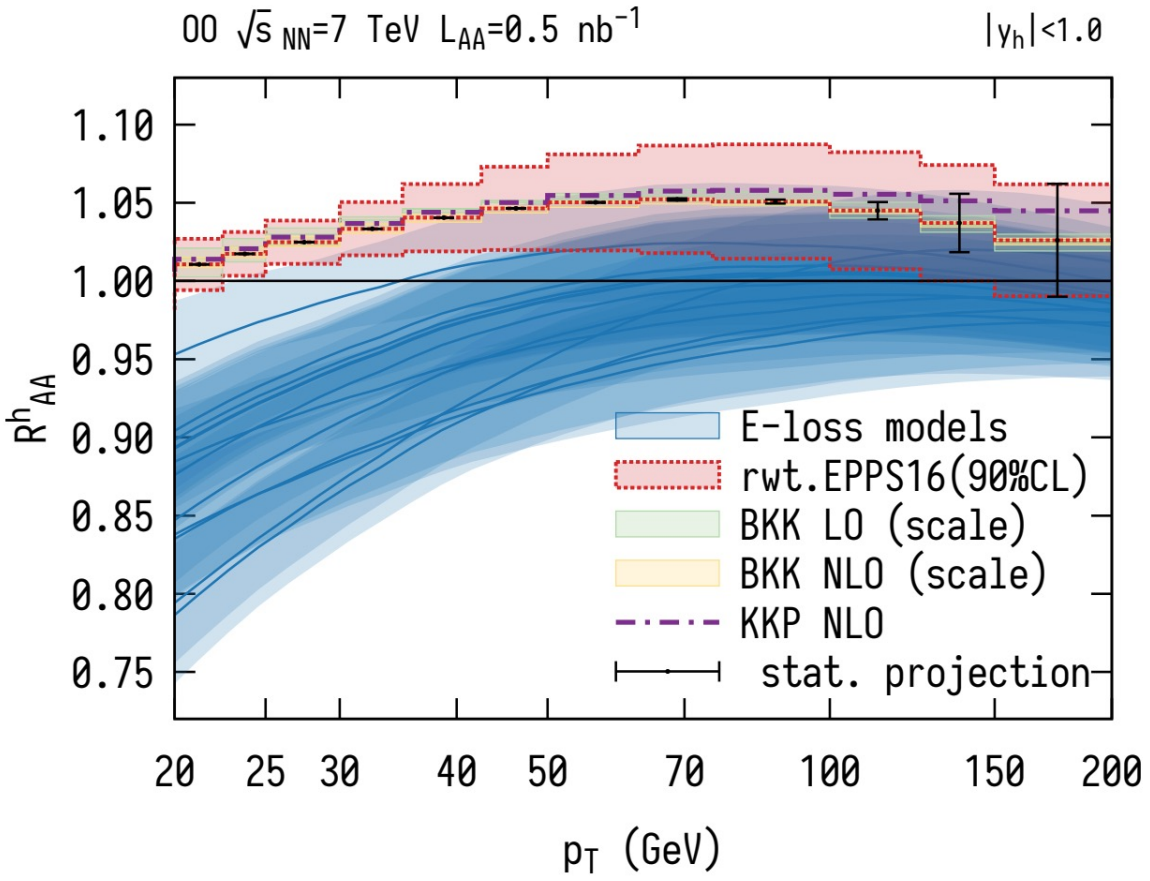
Hard probes measurement projections with oxygen

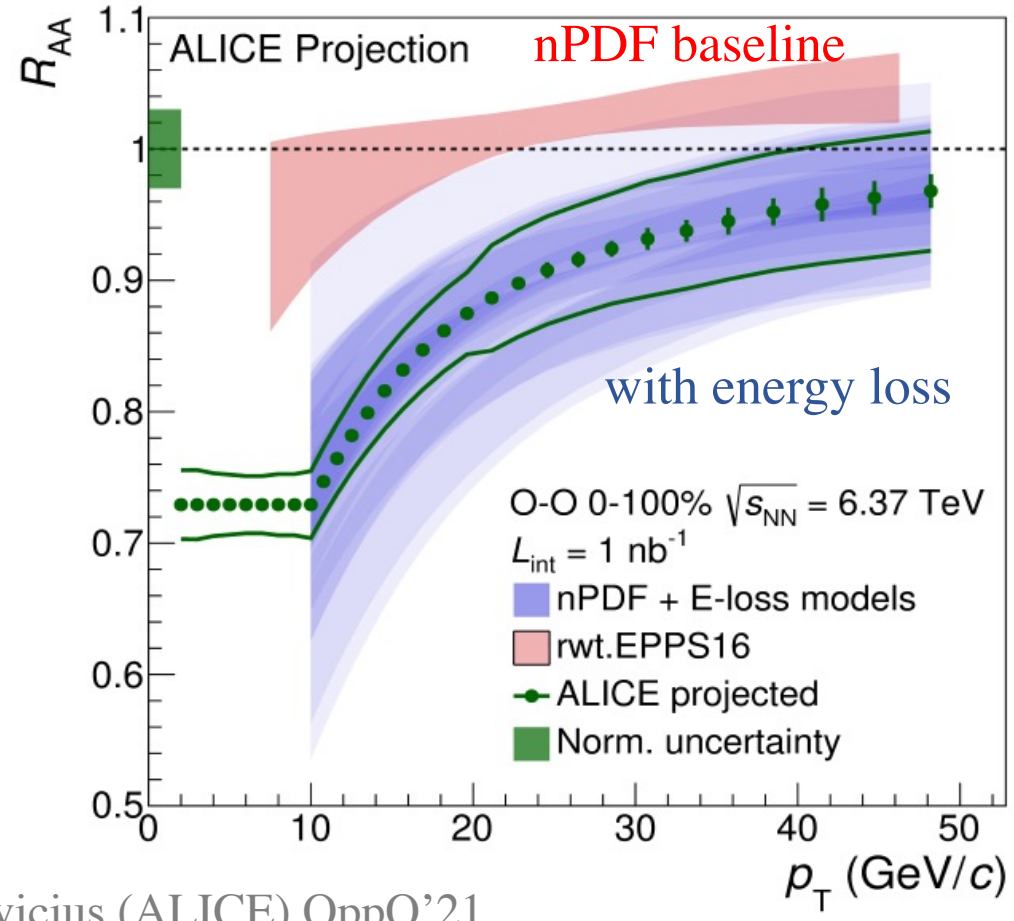


Generally rely on a reference for

Cancellation of pQCD (scale, PDF) uncertainties

Huss et. al. [2007.13754], [2007.13758]

Hard probes measurement projections with oxygen



Vislavicius (ALICE) OppO'21
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Cancellation of experimental systematic uncertainties

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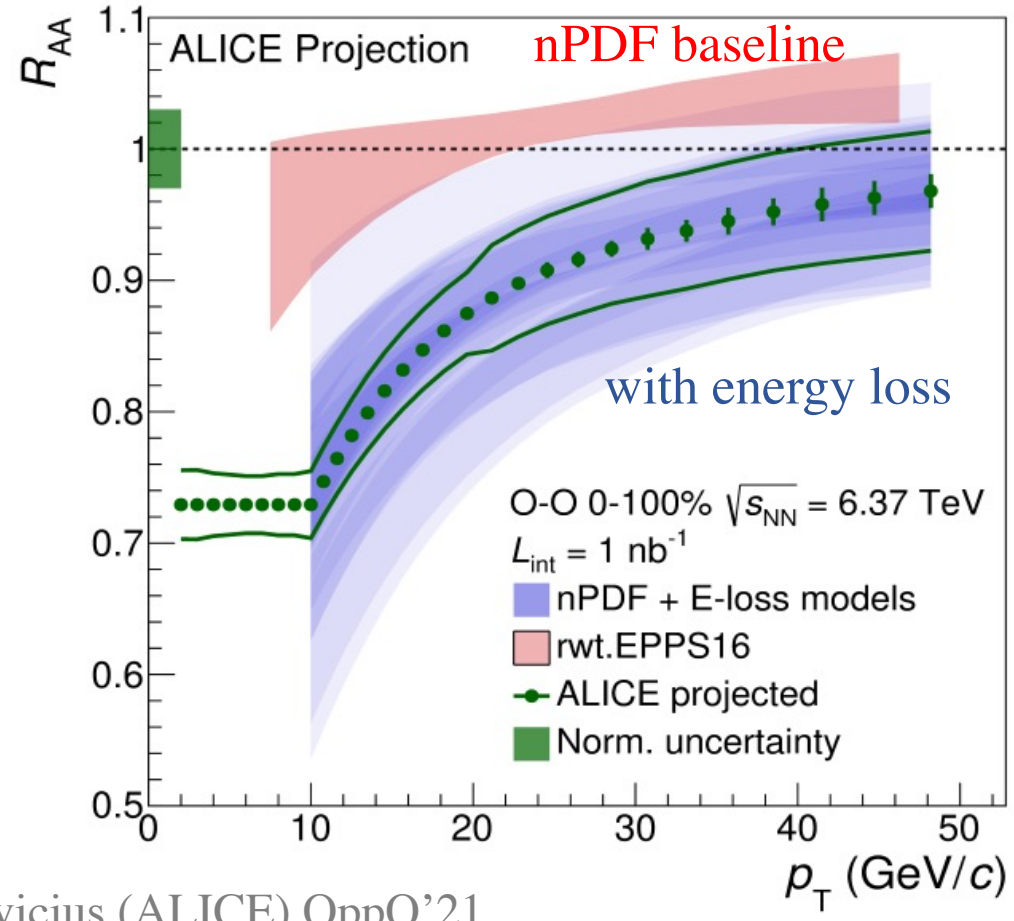

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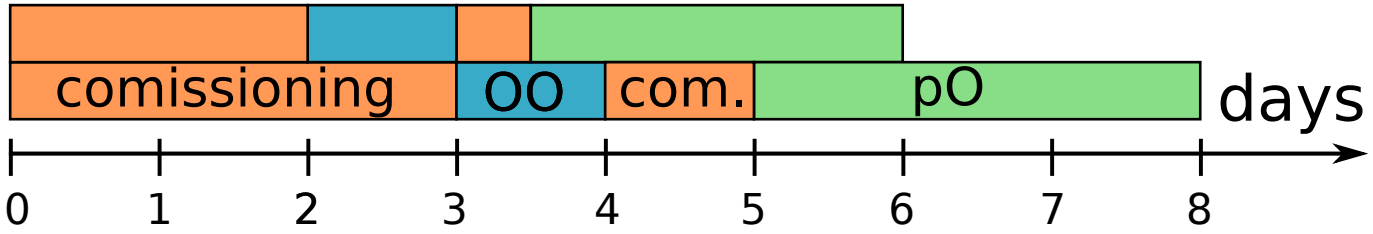
Cancellation of experimental systematic uncertainties

Important both for energy loss (OO) and nPDF constraints (pO)

Paakkinen OppO'21

Precision especially crucial for measuring small effects

Oxygen running in LHC Run 3



p-p	p-Pb	Pb-Pb	O-O	p-O
13.6 TeV	8 TeV	5.02 TeV	6.37 TeV	9 TeV
14 TeV	8.79 TeV	5.52 TeV	7 TeV	9.9 TeV

(Depending on machine condition)

Alemany Fernandez OppO'21
Bruce OppO'21

Planned pp measurements

- Additional commissioning time to change beam energy.
- Additional time for pp reference measurement.

pp references at OO, pO energies likely not possible in a short run

Possibilities for a reference

Constructing a reference

A. Perturbative QCD

B. Interpolation between measurements at nearby energies

Rescale available data at 5.02 with calculated 6.37/5.02 ratio.

Many systematic uncertainties cancel in the ratio

Bypassing the need for a reference at the same energy: mixed-energy ratio

C. Ratios of OO to pp at different center-of-mass energies

Brewer, Huss, Mazeliauskas, van der Schee *(in preparation)*

A. Perturbative QCD

Brewer, Huss, Mazeliauskas, van der Schee *(in preparation)*

Hadron and jet spectra in perturbative QCD

Cross section = Parton distribution functions $\otimes$ Partonic cross section $\otimes$ (fragmentation functions)

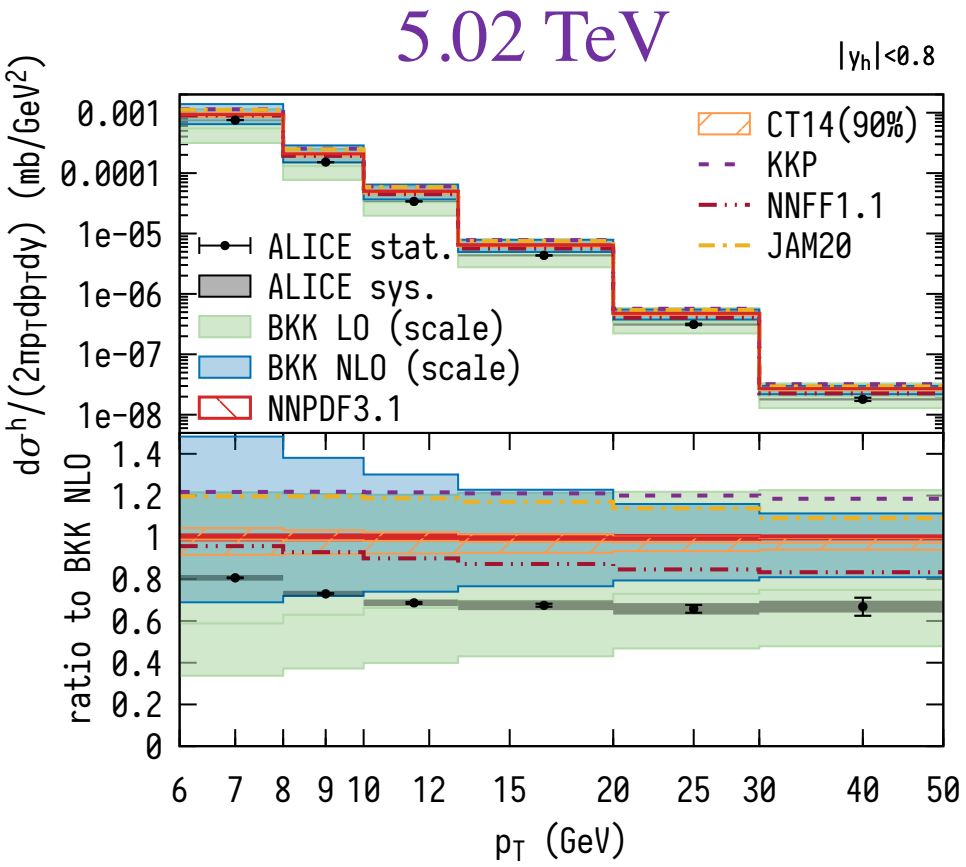
$$\sigma^{\mathrm{had}}(\mu_F, \mu_R) = \mathrm{PDF}(\mu_F) \otimes \hat{\sigma}(\mu_F, \mu_R) \otimes \mathrm{FF}(\mu_F)$$

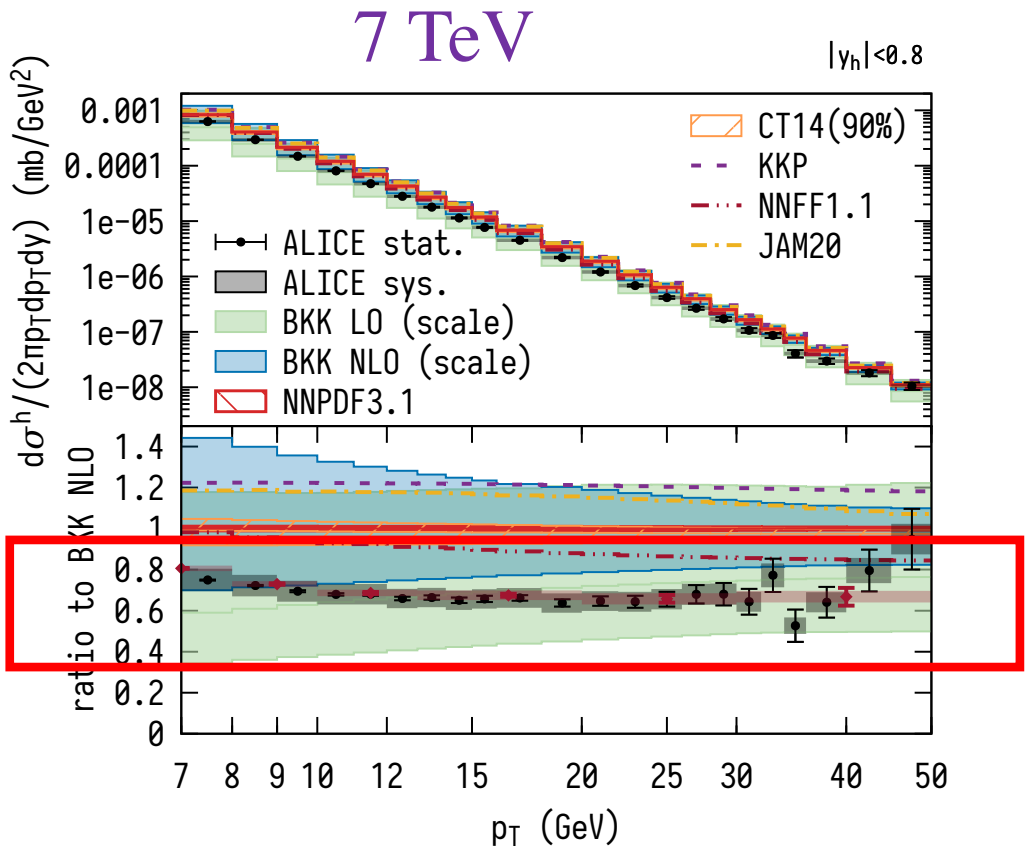
$$\sigma^{\mathrm{jet}}(\mu_F, \mu_R) = \mathrm{PDF}(\mu_F) \otimes \hat{\sigma}(\mu_F, \mu_R)$$

μ_F, μ_R Unphysical scales. Variation used to estimate missing higher order terms in perturbative expansion

pQCD spectra compared to measurements in pp

hadrons





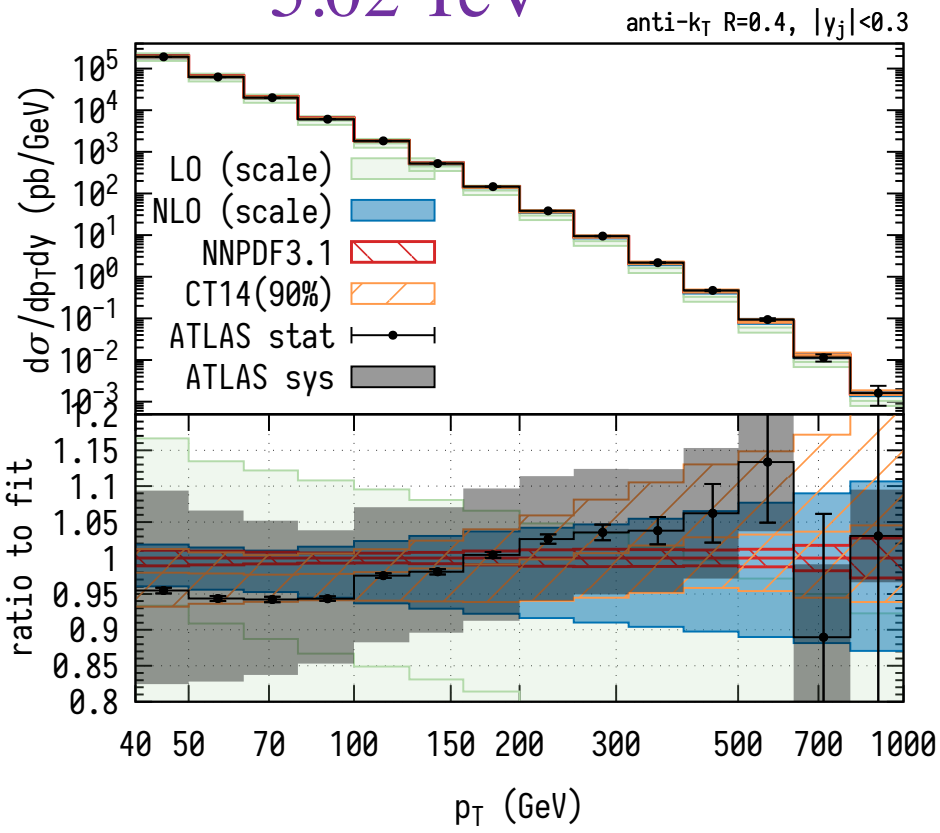
Individual hadron spectra are off but ratio is in agreement with NLO pQCD

pQCD spectra compared to measurements in pp

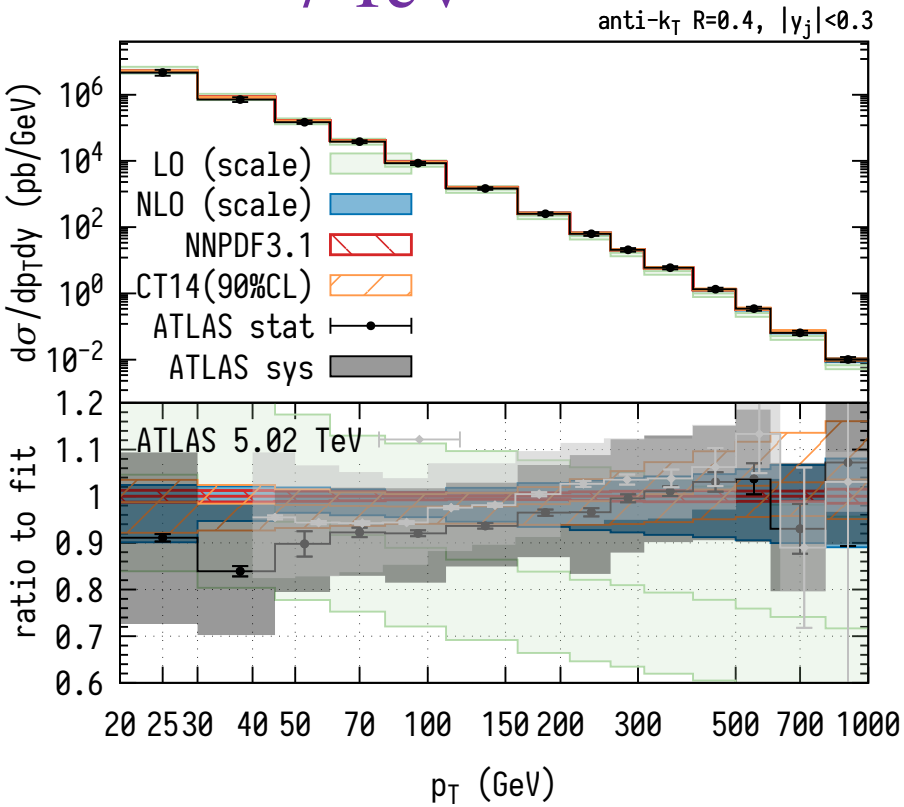
jets

See also extensive study of 2.76 and 7 TeV in ATLAS [1304.4739]

5.02 TeV



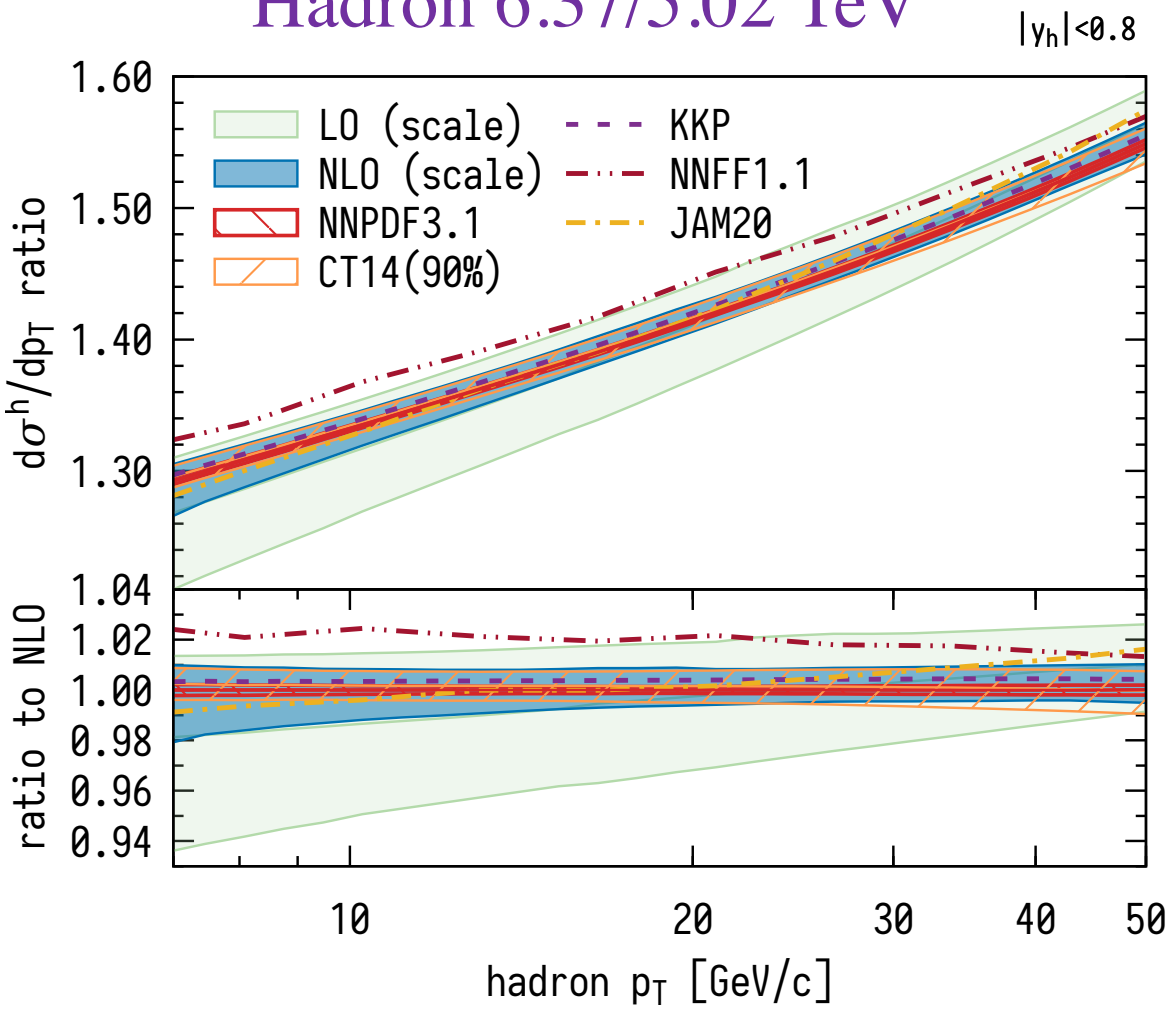
7 TeV



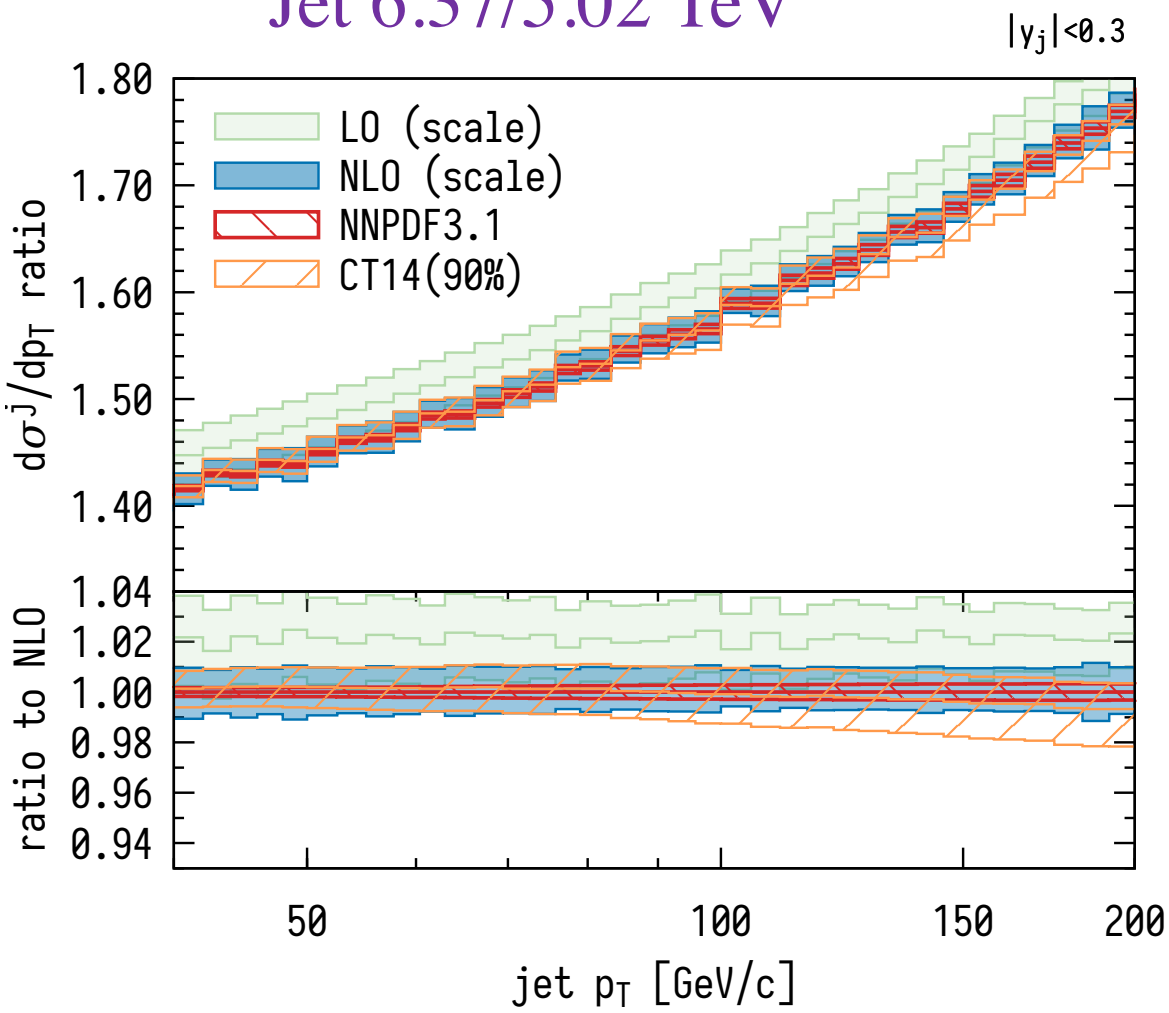
Jet spectra and their ratio agree with NLO pQCD

pQCD predictions for 6.37/5.02 TeV

Hadron 6.37/5.02 TeV



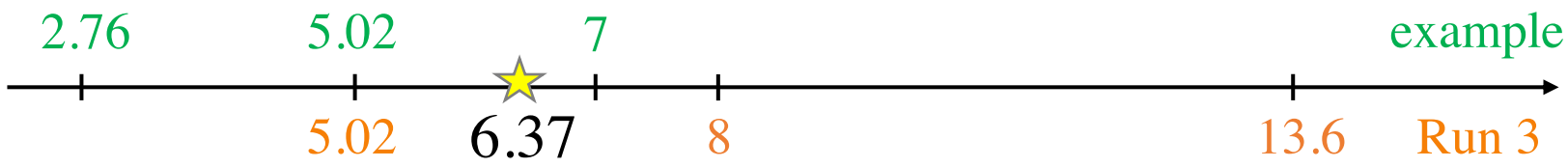
Jet 6.37/5.02 TeV

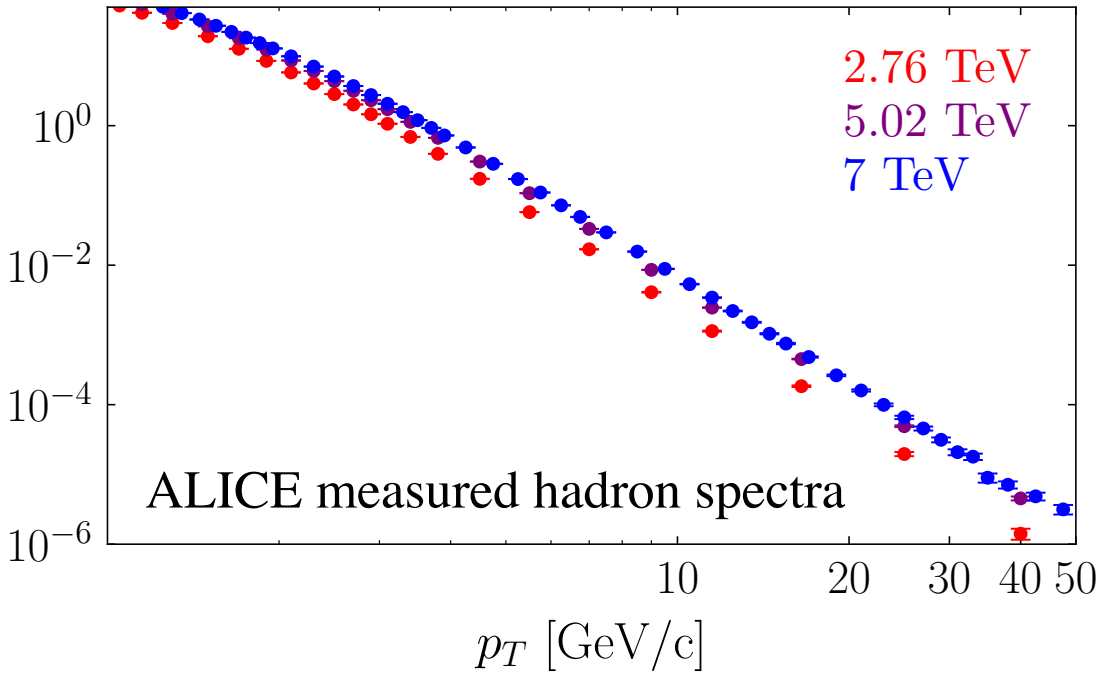


B. Interpolation between measurements at nearby energies

Brewer, Huss, Mazeliauskas, van der Schee *(in preparation)*

Interpolation using global fits of pp spectra





High p_T: $\frac{d\sigma}{dp_T} = A\sqrt{\tilde{s}}^{\beta}\tilde{x}_T^{n(\tilde{x}_T,\sqrt{\tilde{s}})}$

$x_T = 2p_T/\sqrt{s}$

$n \supset \{1, x_T, \log x_T, f(\sqrt{s}), f(\sqrt{s})x_T, f(\sqrt{s})\log x_T\}$

Dependence on

- Functional form
- Data included in the fit
  - $p_T > 7$ GeV (hadrons)
    $p_T > 40$ GeV (jets)

Interpolation using global fits of pp spectra

Fit: maximize (log) likelihood

$$\log \mathcal{L} = -\frac{1}{2} \sum_{\sqrt{s}} (y_{\text{fit}}^{\sqrt{s}} - y_{\text{data}}^{\sqrt{s}}) \cdot (C^{\sqrt{s}})^{-1} \cdot (y_{\text{fit}}^{\sqrt{s}} - y_{\text{data}}^{\sqrt{s}})$$

Covariance matrix

$$(C^{\sqrt{s}})_{ij} = \left(\sigma_{\sqrt{s}}^{\text{stat}}\right)^2 \delta_{ij} + \left(\sigma_{\sqrt{s}}^{\text{lum}}\right)^2 + \left(\sigma_{\sqrt{s}}^{\text{sys}}\right)^2 \delta_{ij}$$

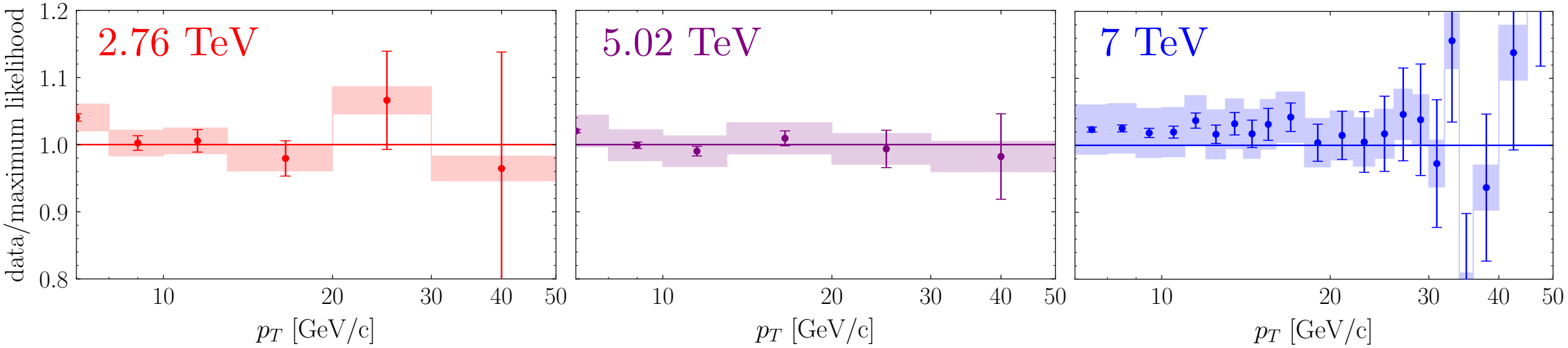
Gaussian statistical uncertainties

Luminosity uncertainty fully correlated at each energy

Consider two cases: other systematics

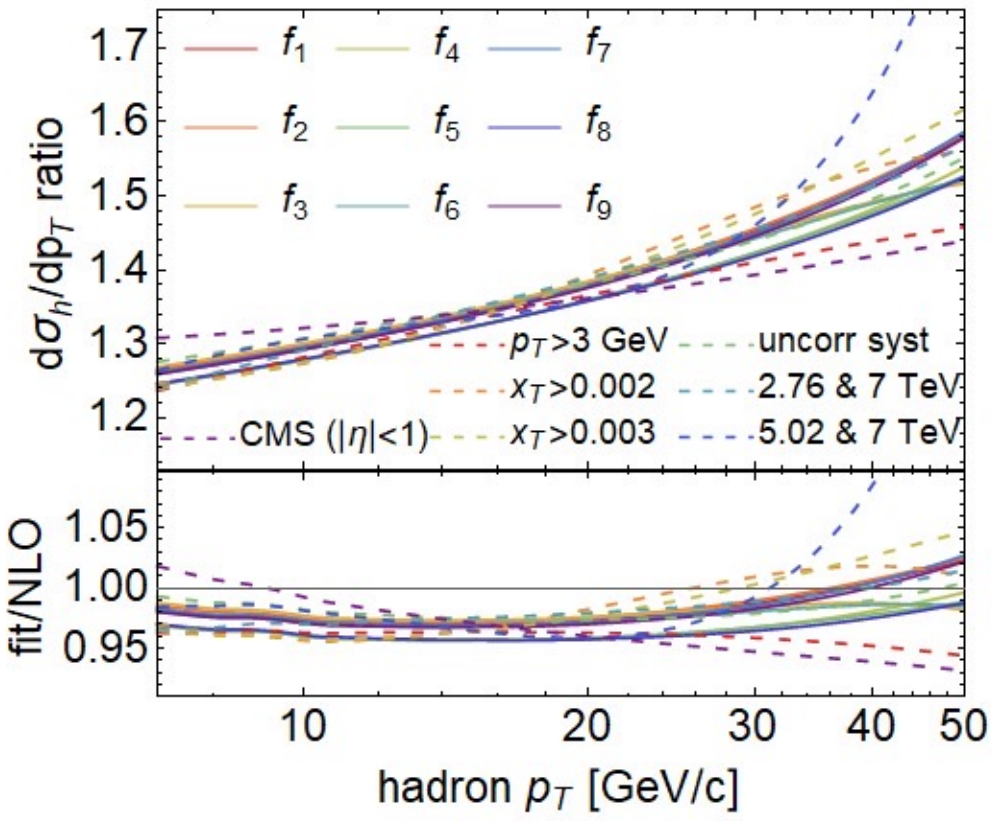
- Fully correlated (cancel)
- Fully uncorrelated

Interpolation using global fits of pp spectra

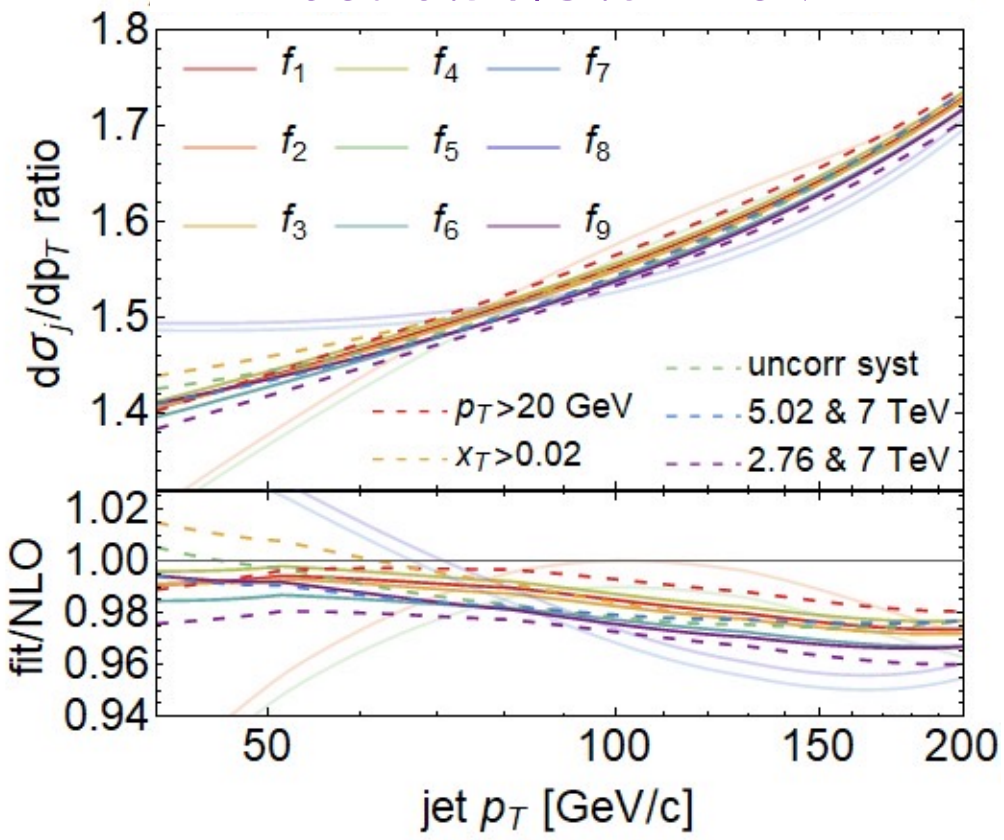


Sensitivity of interpolation to fit forms and assumptions

Hadron 6.37/5.02 TeV

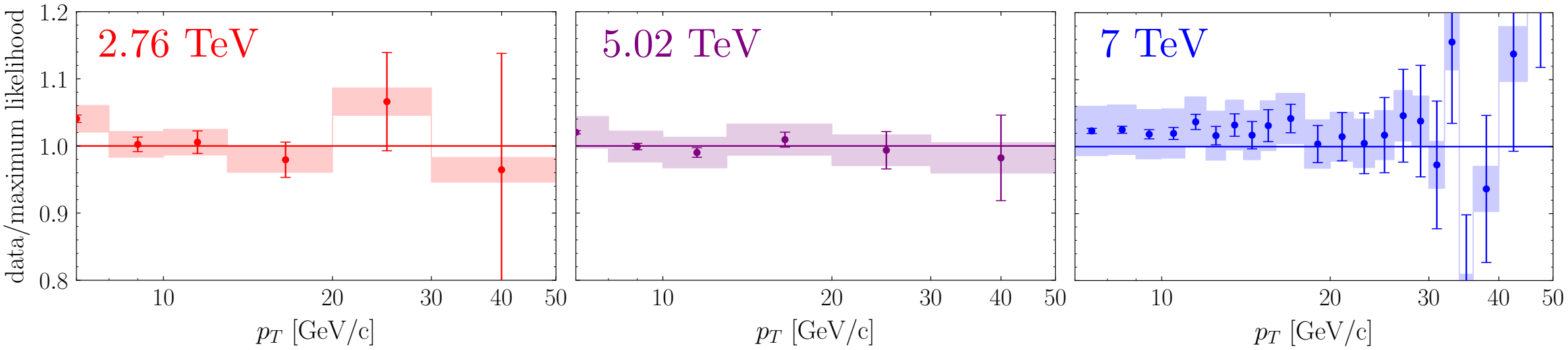


Jet 6.37/5.02 TeV



<5% uncertainty from functional form, but more substantial sensitivity to $p_T^{\min}$

Impact of uncertainties on the anchor energies for interpolation



Sample distribution of fits consistent with data within uncertainties (Markov Chain Monte Carlo)

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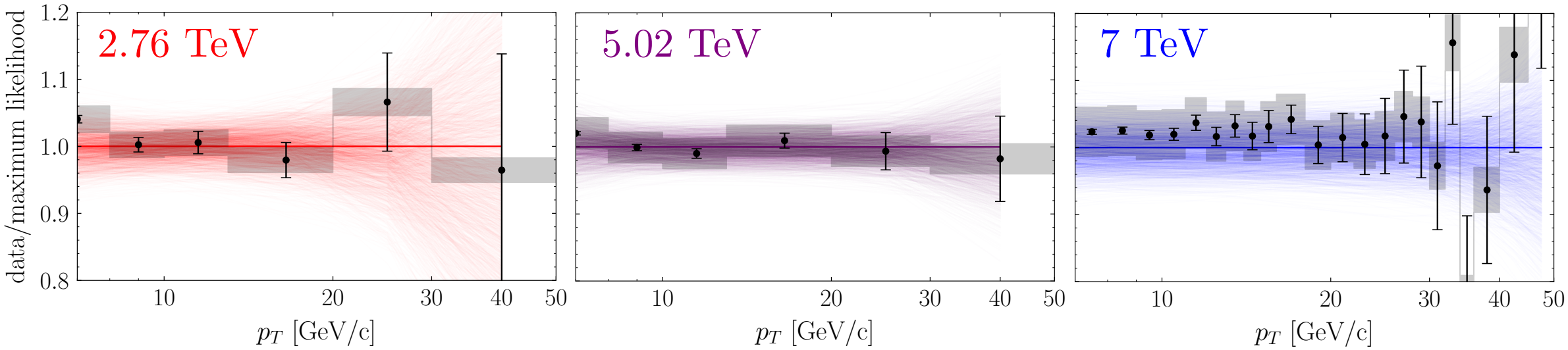
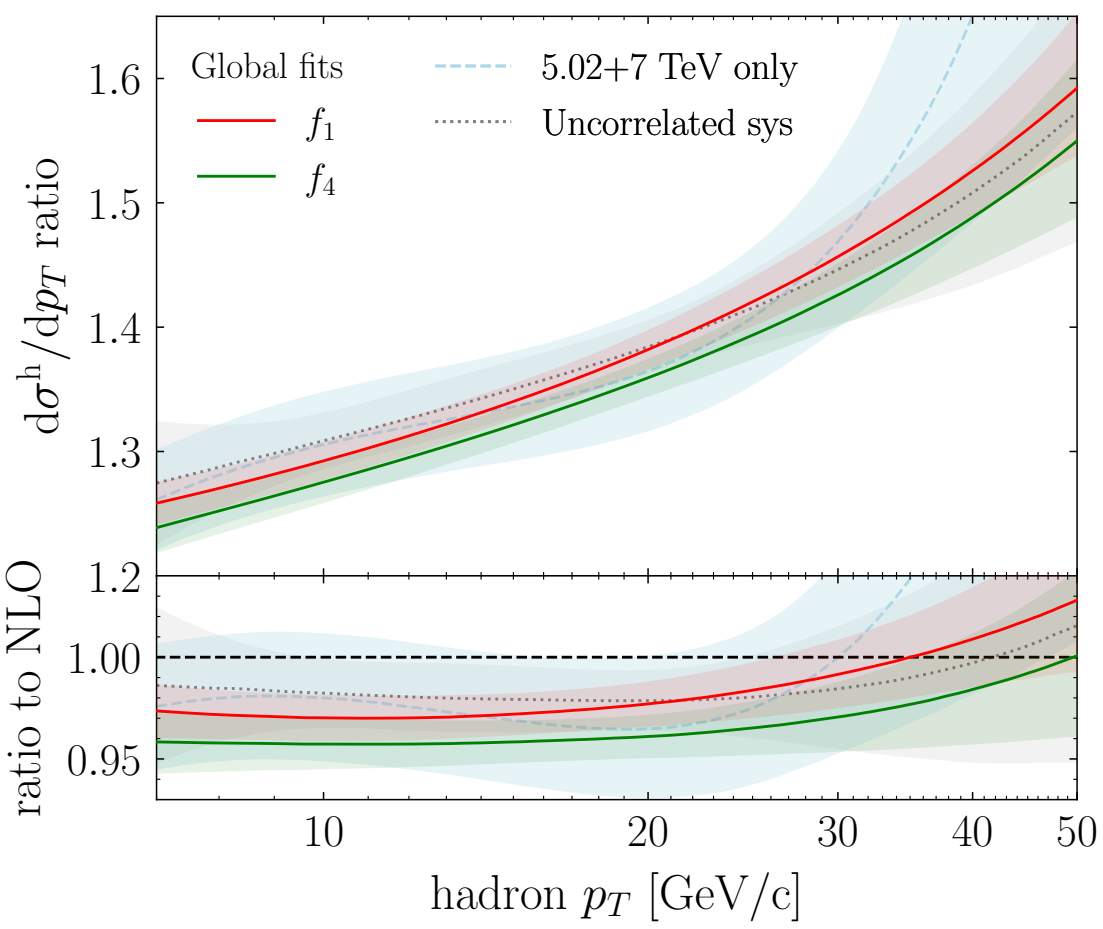


Sample distribution of fits consistent with data within uncertainties (Markov Chain Monte Carlo)

Gives confidence bands on the interpolation

Impact of uncertainties on the anchor energies for interpolation

Hadron 6.37/5.02 TeV



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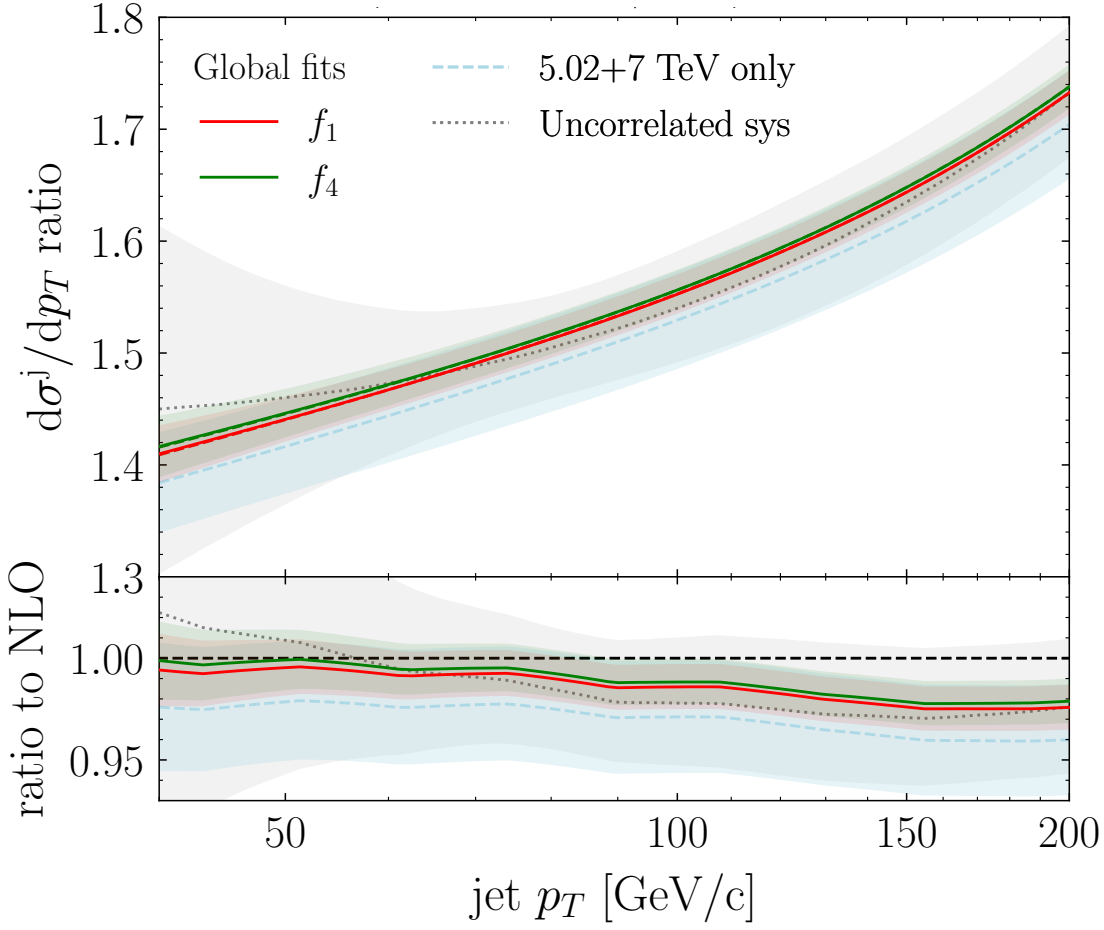


Using three energies gives smaller uncertainties than using two

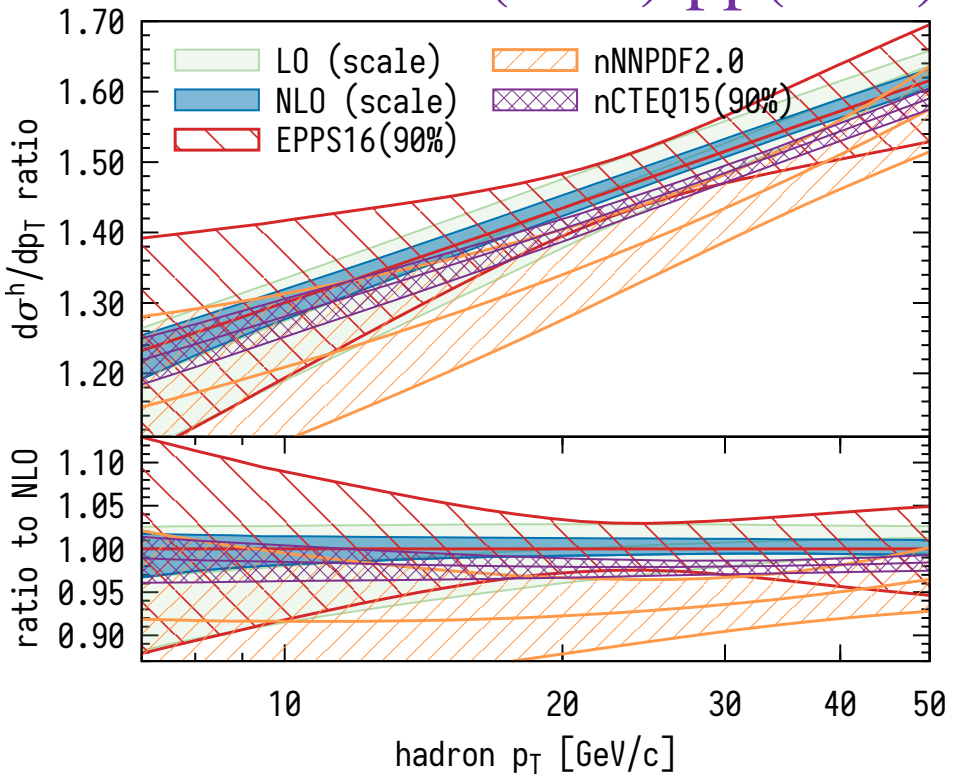
C. Bypassing need for reference with mixed-energy ratios

Brewer, Huss, Mazeliauskas, van der Schee *(in preparation)*

Bypass constructing a reference: OO/pp at different energies

- nPDFs (not pp) are correct baseline for no energy loss
- Comparable uncertainty cancellation to OO/pp at the same energy

Hadron OO(6.37)/pp(5.02)



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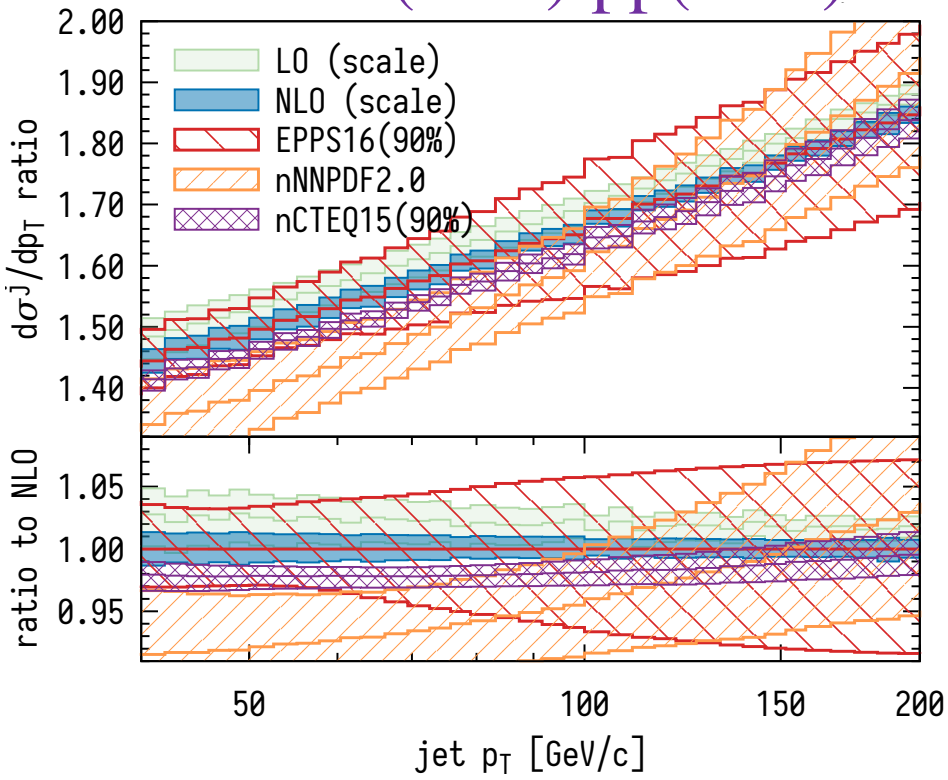


pO is crucial for constraining nPDFs

Summary

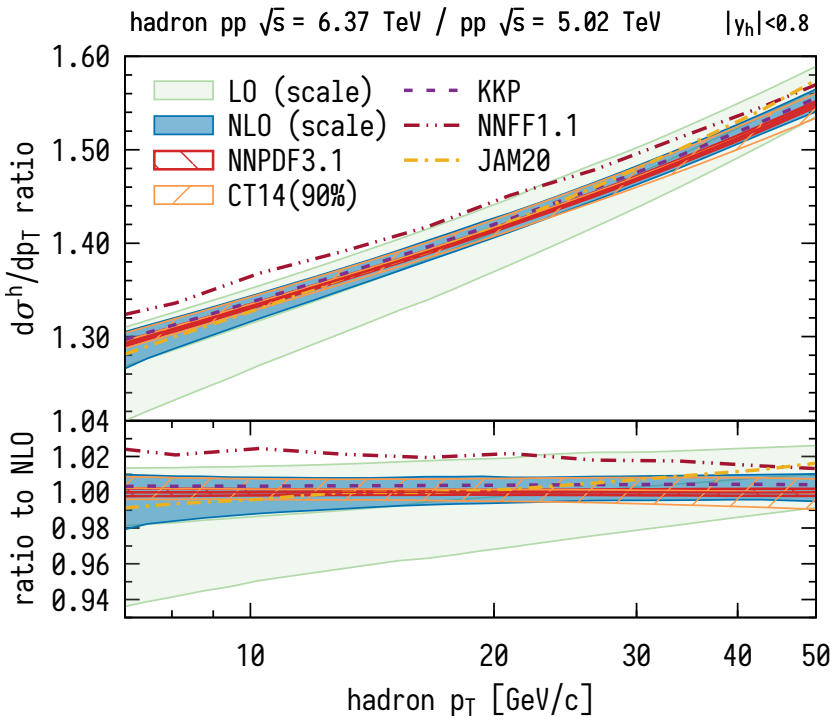
~ few-5% uncertainties on constructing a reference either from pQCD or from data-driven interpolation

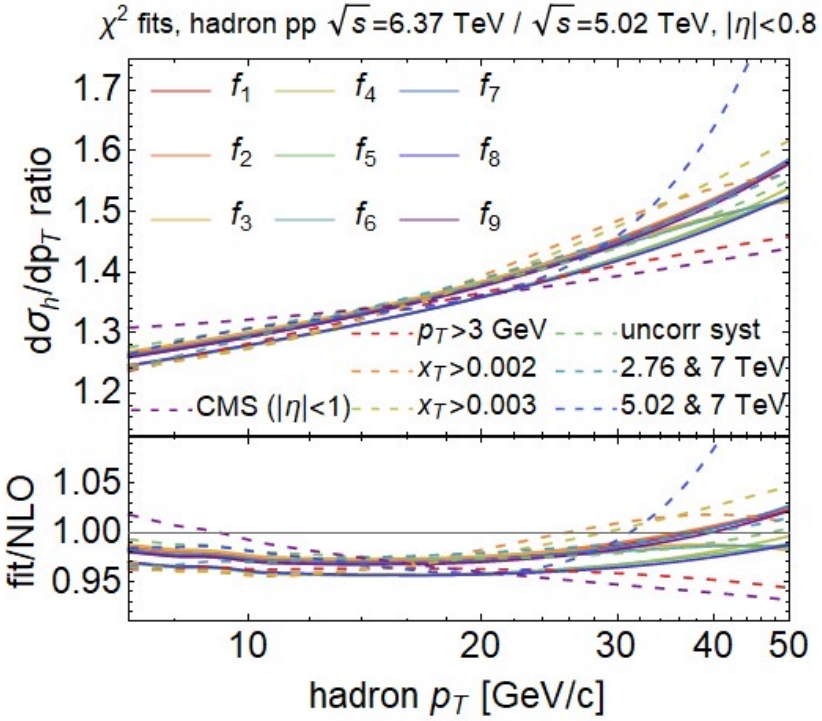
- pQCD has few-% uncertainties, but is not identical to interpolation
- Can pp measurement at 13.6 TeV be used in reference interpolation?

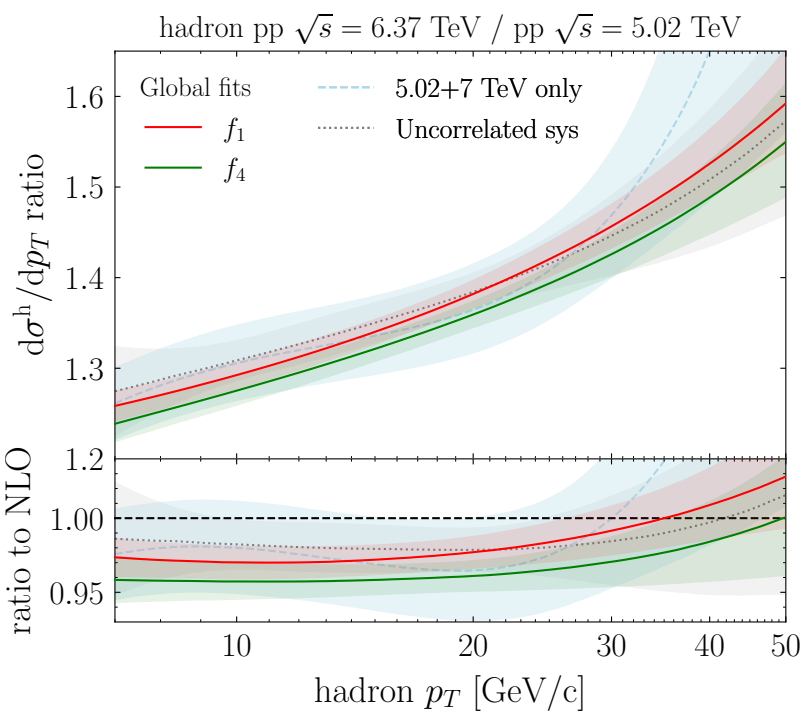
Ratios of OO and pp measurements at different center-of-mass energy

- To what extent can experimental systematics be cancelled in OO and pp at different energies?
- Oxygen nPDF constraints crucial for measuring energy loss. Can mixed-energy ratios provide comparable constraints compared to pO reference?

Uncertainties in constructing pp reference: hadrons







Uncertainties in constructing pp reference: jets