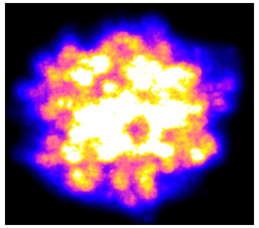
Opportunities of OO and pO collisions at the LHC

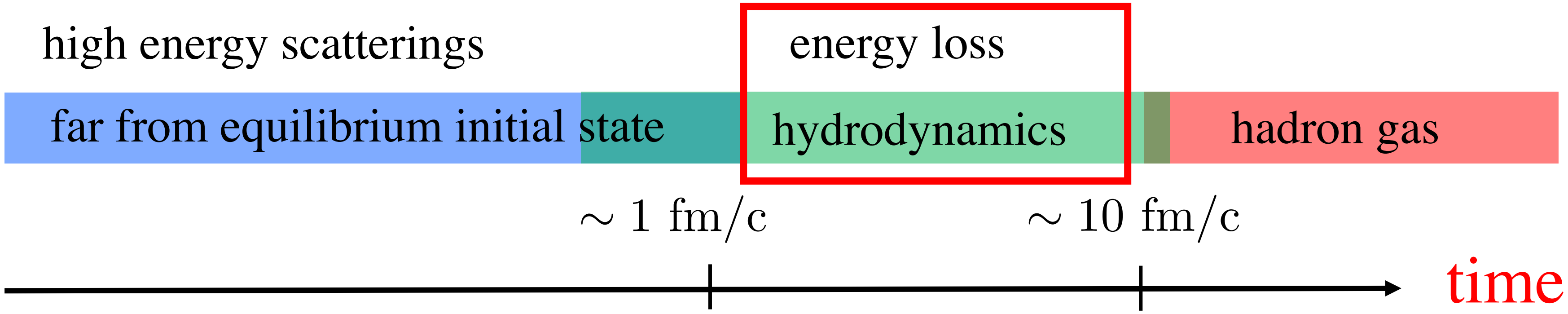
Jasmine Brewer
Aleksas Mazeliauskas
Wilke van der Schee

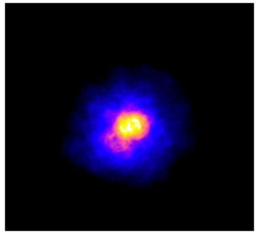
Based on: Brewer, Huss, Mazeliauskas, van der Schee [2108.13434]

Pushing our knowledge of heavy-ion physics in smaller systems

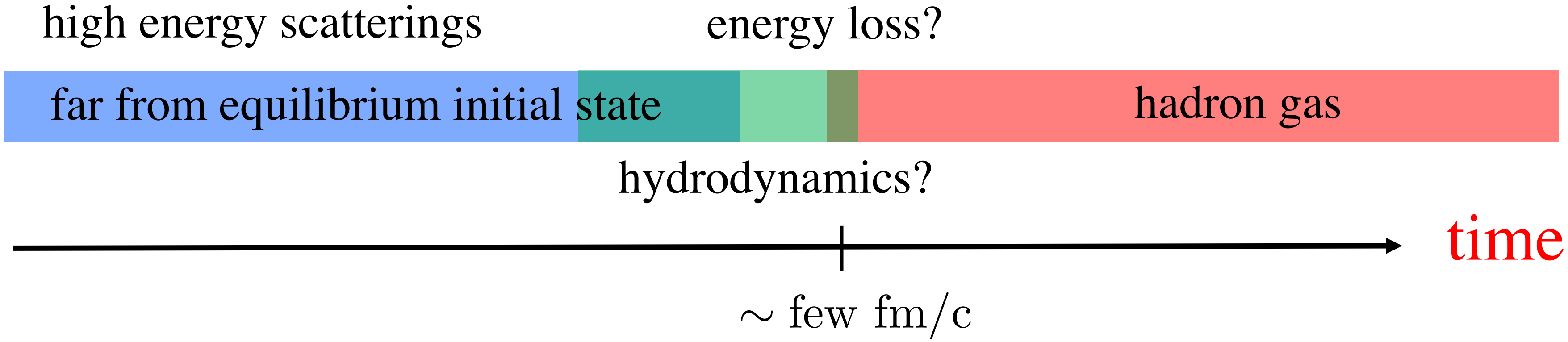


Heavy-ion collisions

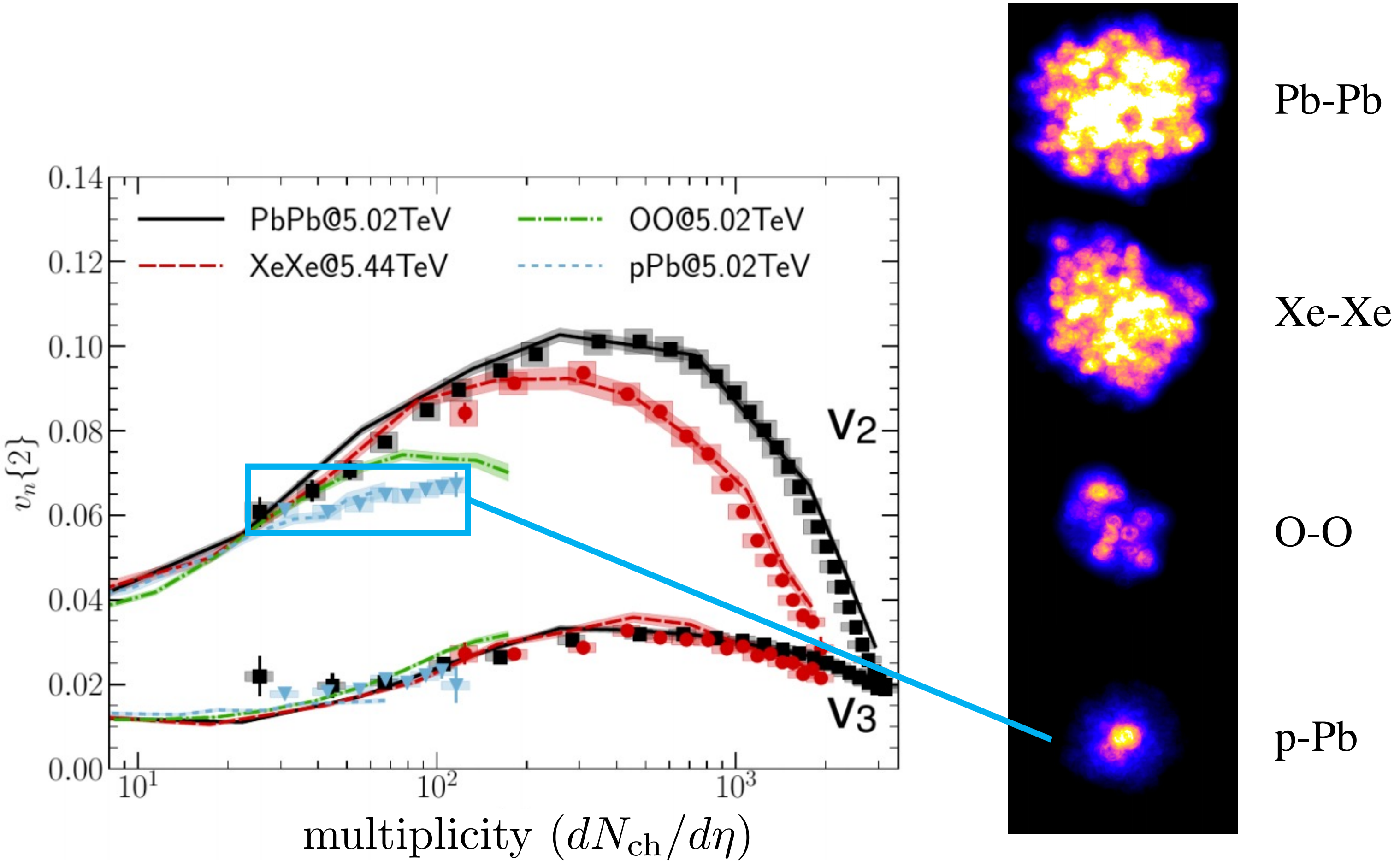




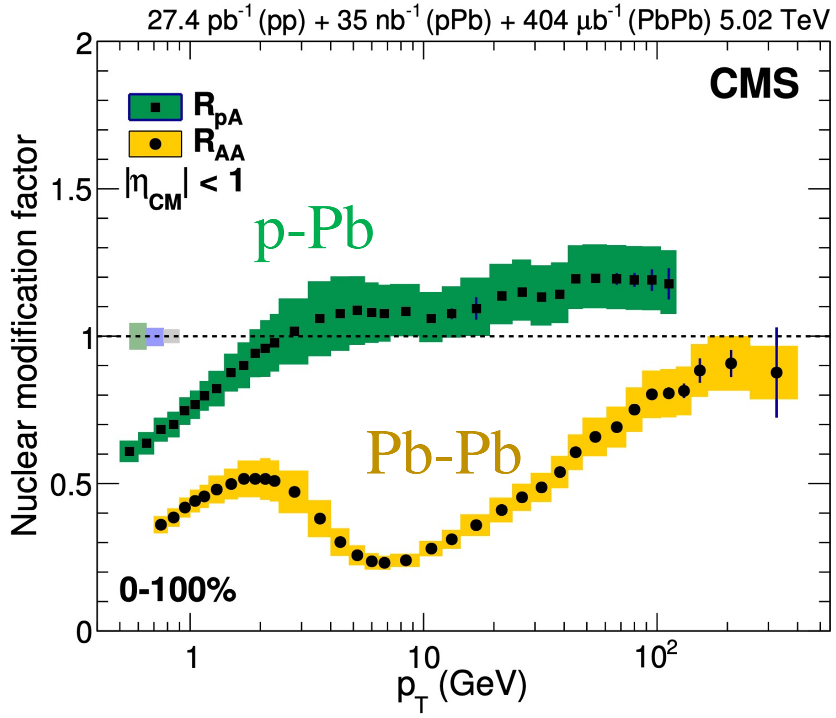
Smaller systems (e.g. p-Pb)



Flow-like correlations in small systems



No observed energy loss



Schenke, Shen, Tribedy [2005.14682], Chun Shen QM'19

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

396 registered participants, 186 unique connections per day.

Workshop summary document: arXiv:2103.01939

Slides and recordings: cern.ch/OppOatLHC

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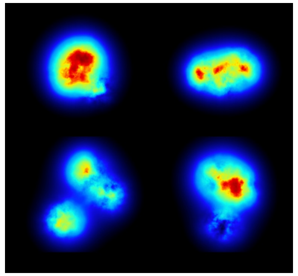
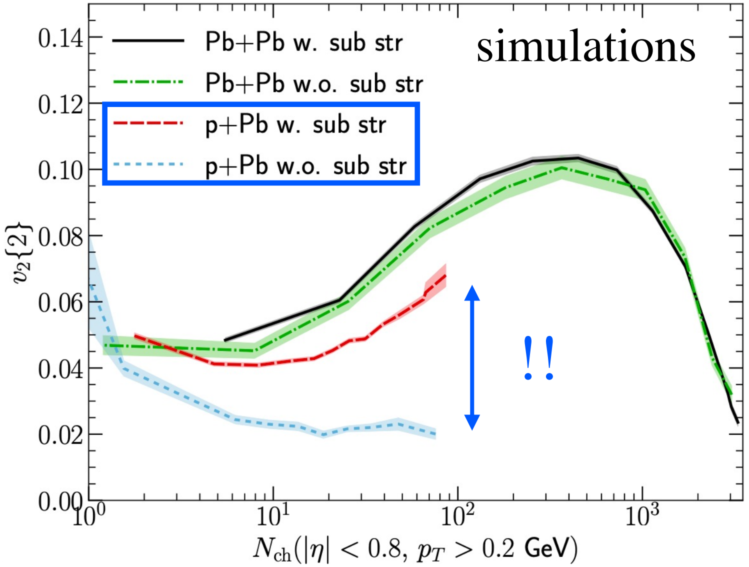
Unique opportunities of oxygen in the soft sector

Better-constrained geometry than pPb

pPb: subnucleonic structure crucial for flow

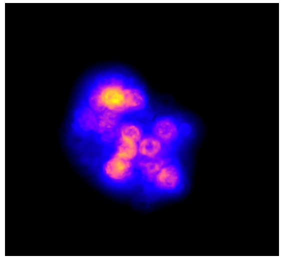


(Bjoern Schenke)



Chun Shen OppO'21

OO: similar multiplicity but heavy-ion-like geometry



Extensive projections by ALICE for short OO/pO run

[ALICE-PUBLIC-2021-004]

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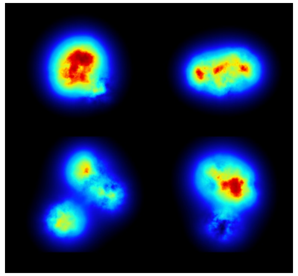

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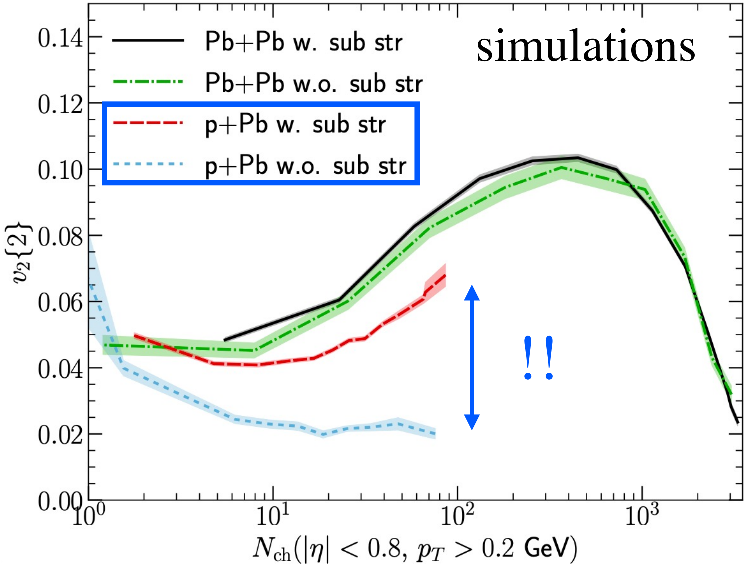

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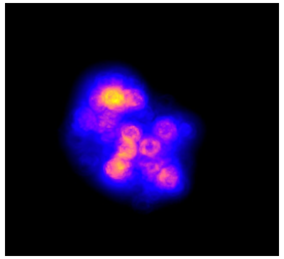
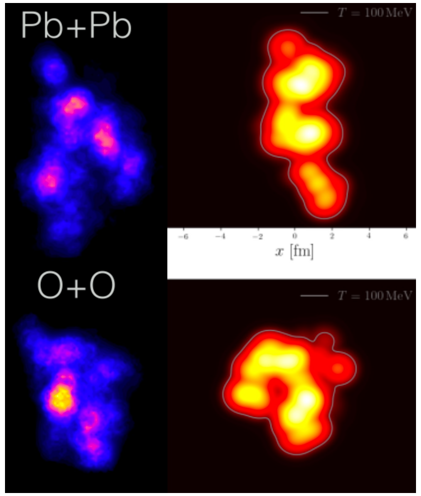


More compact, hotter than PbPb at the same multiplicity

- unique constraints on soft sector observables



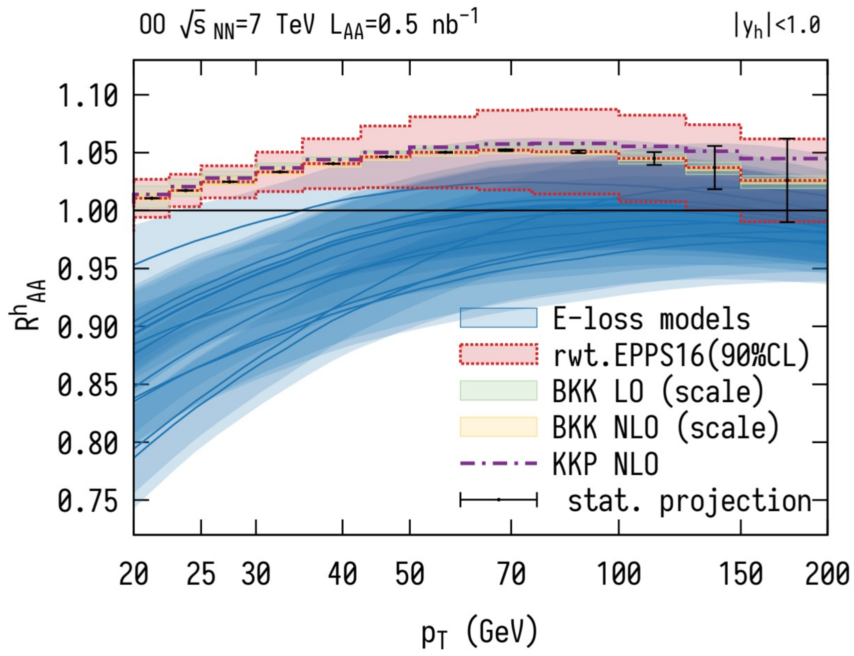
Extensive projections by ALICE for short OO/pO run

[ALICE-PUBLIC-2021-004]

Unique opportunities of oxygen in the hard sector

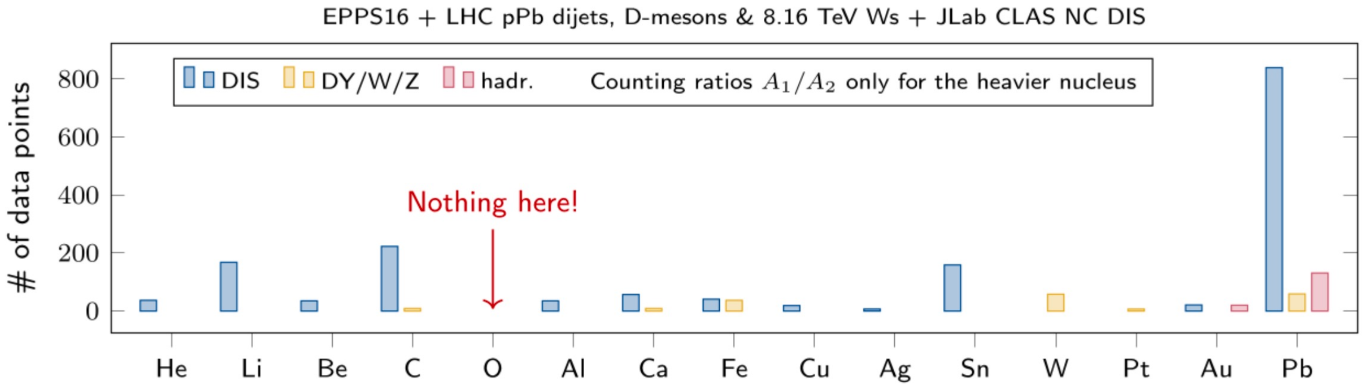
Measuring energy loss in small systems

Huss, Kurkela, Mazeliauskas, Paatelainen, v.d. Schee, Wiedemann [2007.13754], [2007.13758]



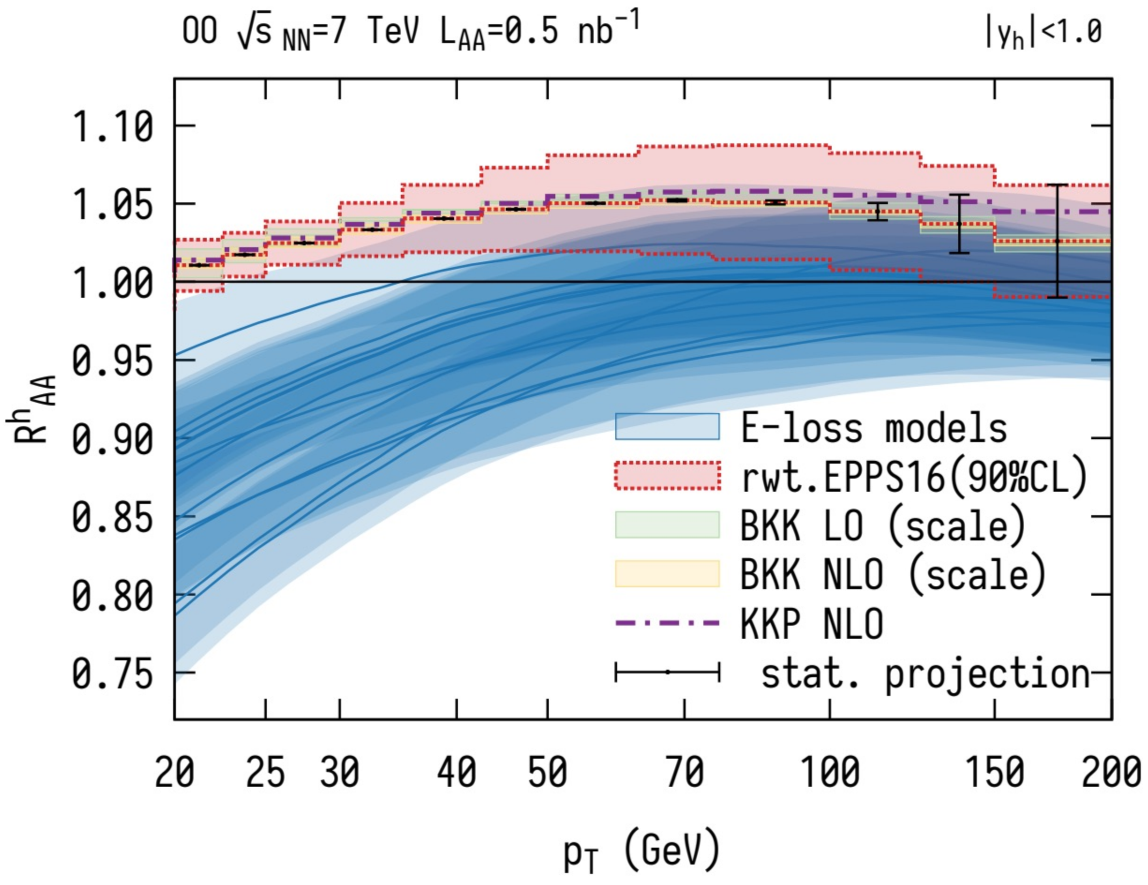
Constraining A-dependence of nuclear PDFs

- Particularly gluons (hadronic data)



Paakkinen OppO'21

Hard probes studies generally rely on a reference



Ratio to pp reference enables..

Cancellation of pQCD (scale, PDF) uncertainties

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

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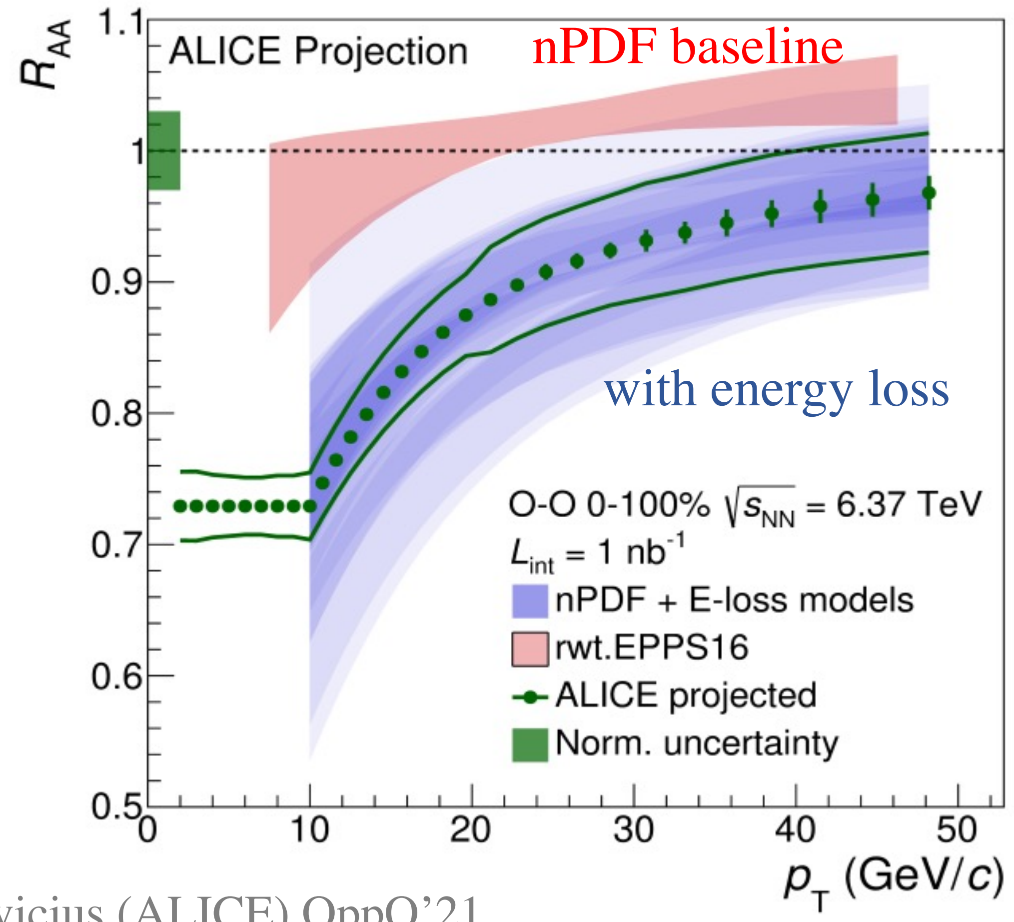

Vislavicius (ALICE) OppO'21
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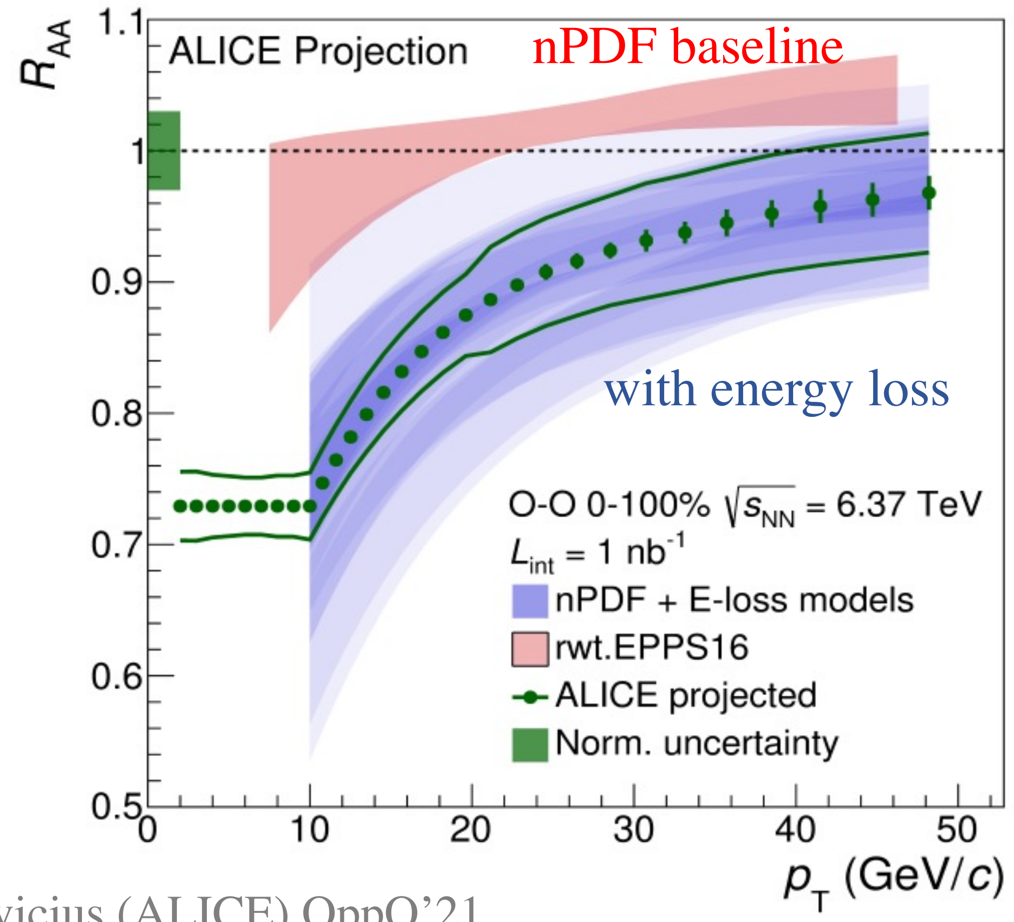


Ratio to pp reference enables..

Cancellation of pQCD (scale, PDF) uncertainties

Cancellation of experimental systematic uncertainties

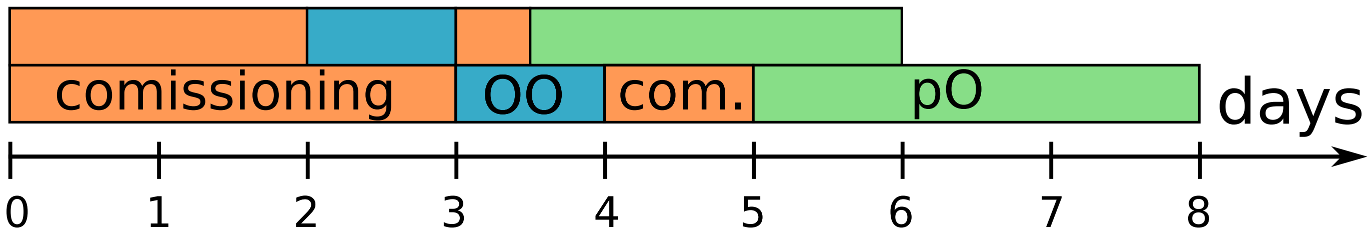
Important both for energy loss (OO) and nPDF constraints (pO)

Paakkinen OppO'21

Vislavicius (ALICE) OppO'21
Huss et. al. [2007.13754], [2007.13758]

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)

Planned pp measurements

Alemany Fernandez OppO'21
Bruce OppO'21

- 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

- Perturbative QCD
- Interpolation between measurements at nearby energies

Construct 6.37/5.02 TeV spectra ratio to scale 5.02 TeV measurement

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

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

Brewer, Huss, Mazeliauskas, van der Schee [2108.13434]

Hadron and jet spectra in perturbative QCD

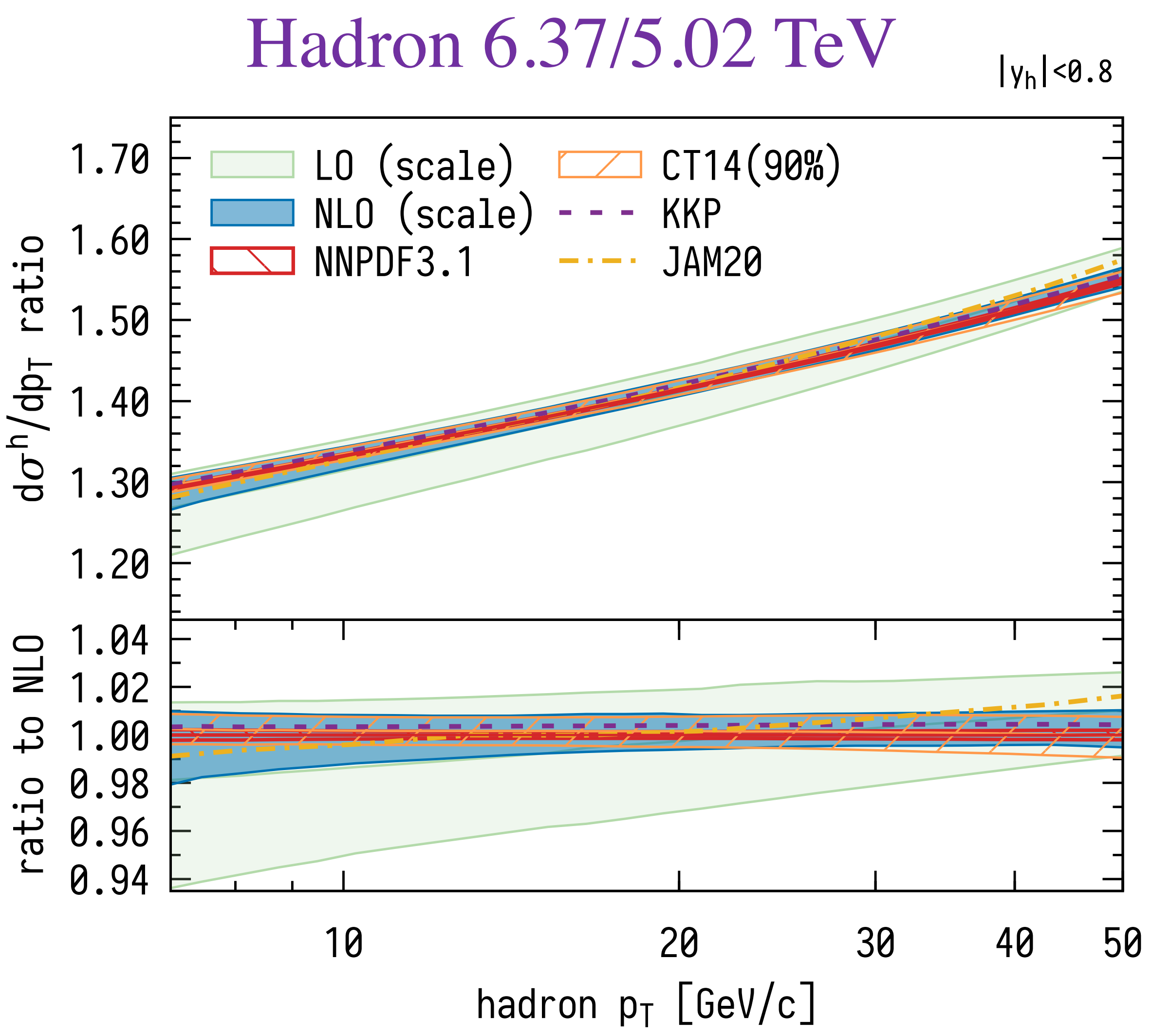
Cross section $=$ Parton distribution functions $\otimes$ Partonic cross section $\otimes$ (fragmentation functions)

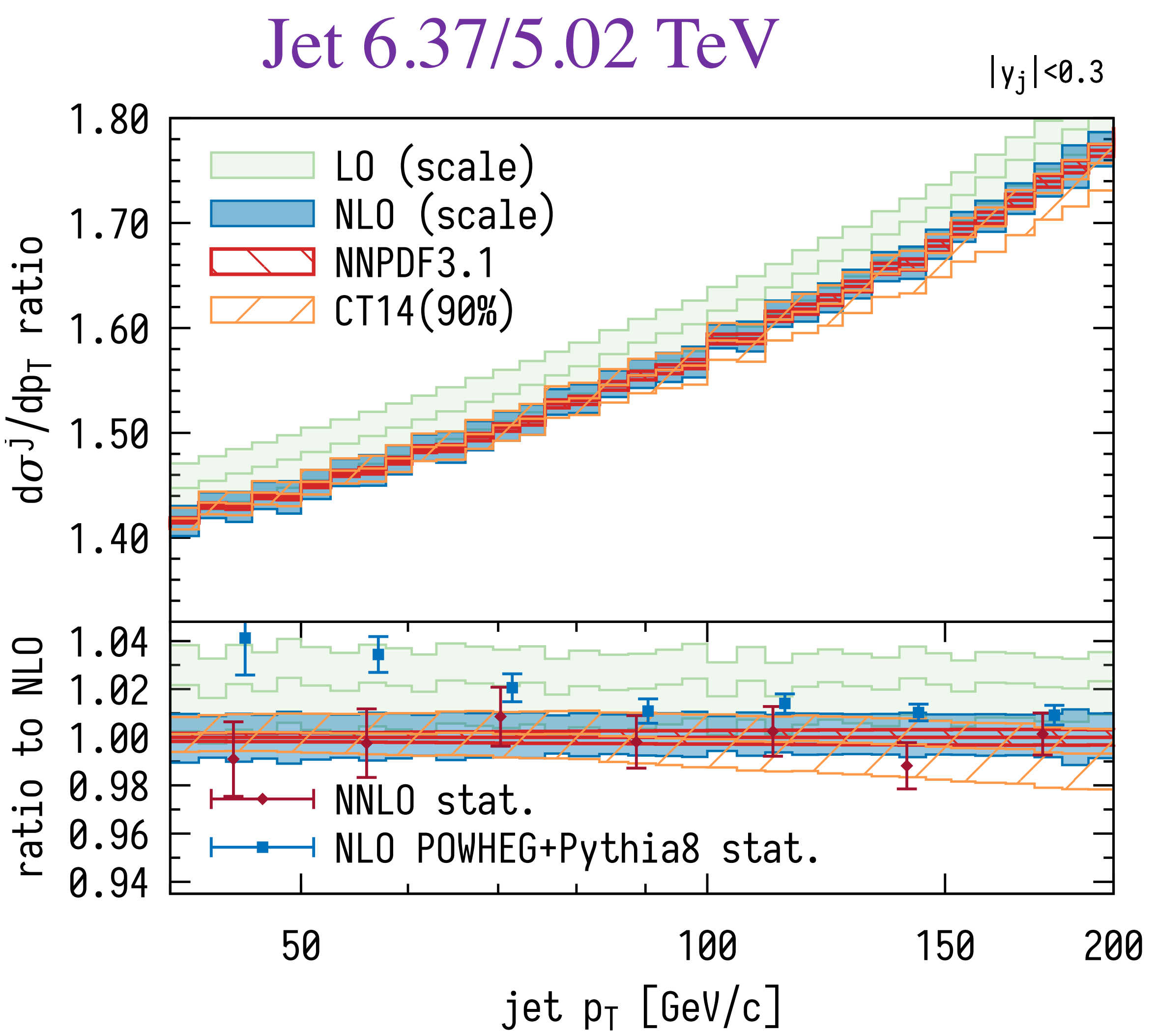
$$\sigma^{\text{had}}(\mu_F, \mu_R) = \text{PDF}(\mu_F) \otimes \hat{\sigma}(\mu_F, \mu_R) \otimes \text{FF}(\mu_F)$$

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

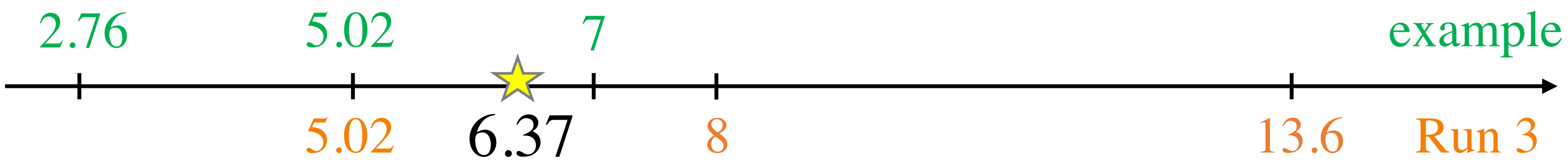
μ_F, μ_R Unphysical scales. Variation used to estimate missing higher order terms in perturbative expansion

pQCD predictions for 6.37/5.02 TeV





Interpolating between measurements at nearby energies



Fit spectra at high p_T: $$\frac{d\sigma}{dp_T} = A\sqrt{\tilde{s}}^{\beta}\,\tilde{x}_T^{\,n(\tilde{x}_T,\sqrt{\tilde{s}})} \qquad x_T = 2p_T/\sqrt{s}$$

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

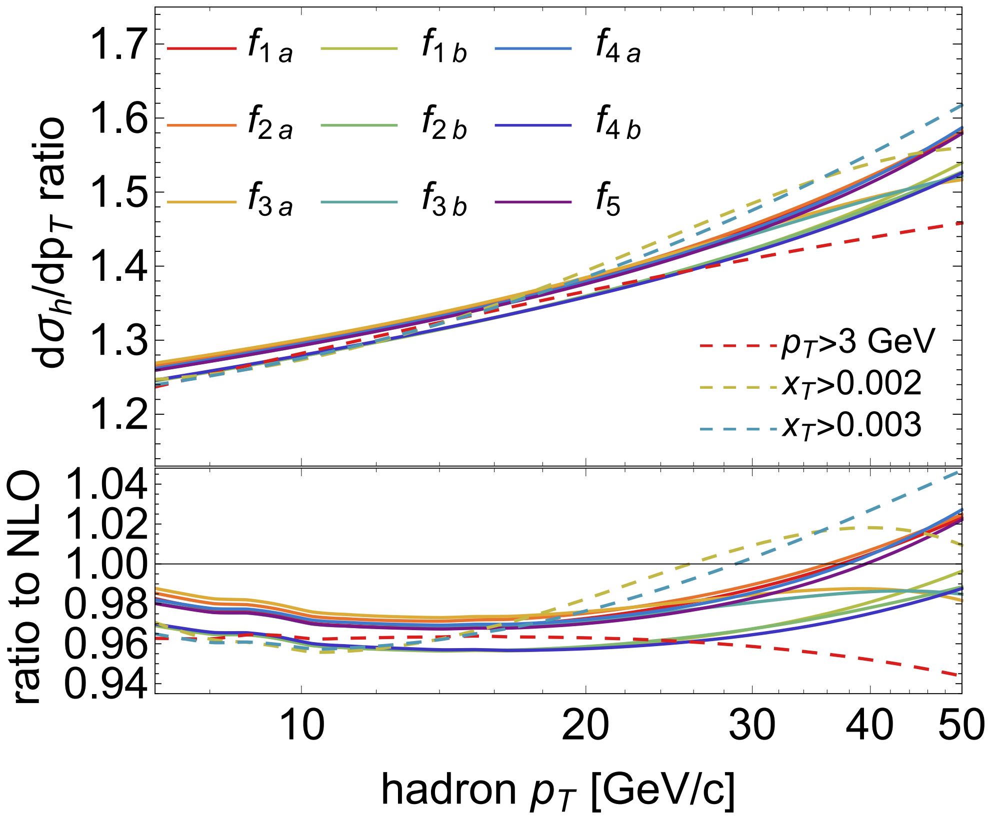
Consider interpolation uncertainties from

- Functional form and data included in the fit
- Measurement uncertainties at anchor energies

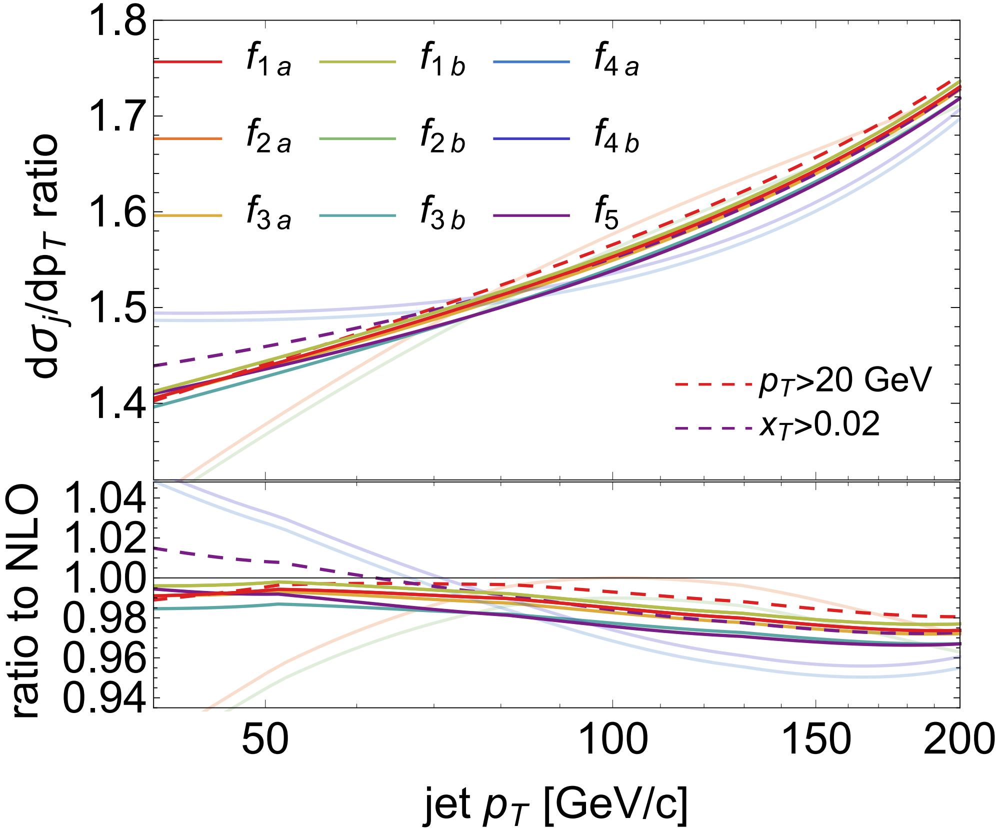
Brewer, Huss, Mazeliauskas, van der Schee [2108.13434]

Sensitivity of interpolation to fit forms and assumptions

Hadron 6.37/5.02 TeV

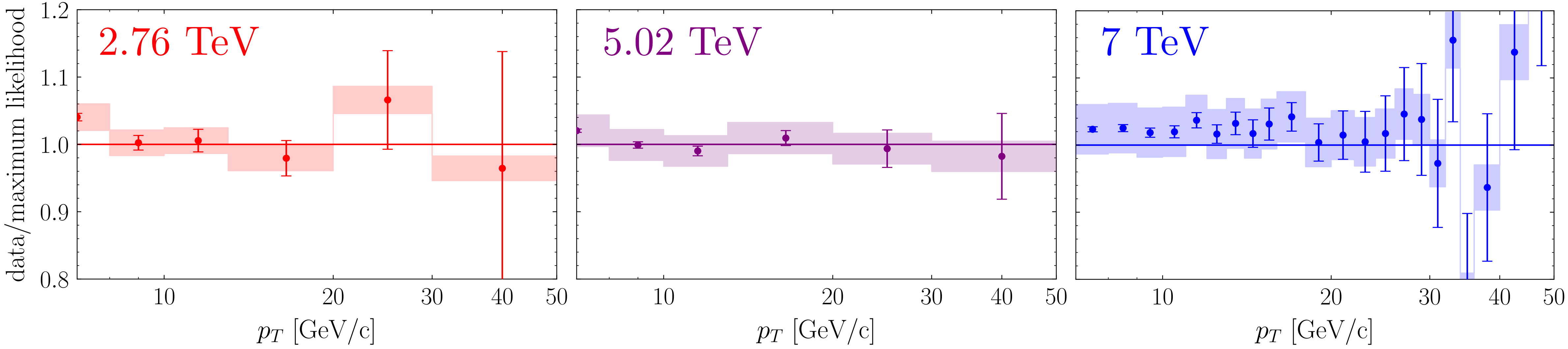


Jet 6.37/5.02 TeV



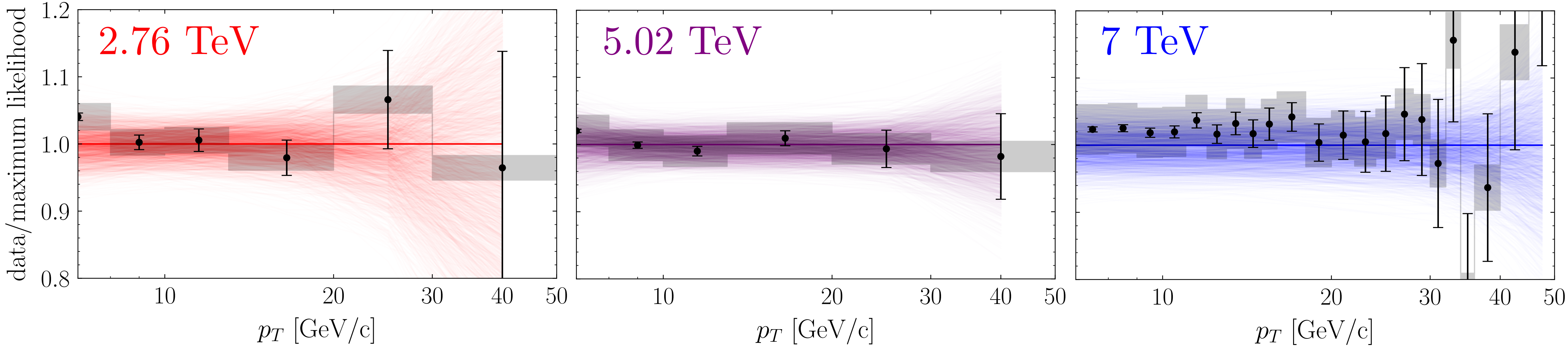
<5% uncertainty from functional form, but more substantial sensitivity to $p_T^{\min}$

Impact of uncertainties on the anchor energies for interpolation



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

Impact of uncertainties on the anchor energies for interpolation



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

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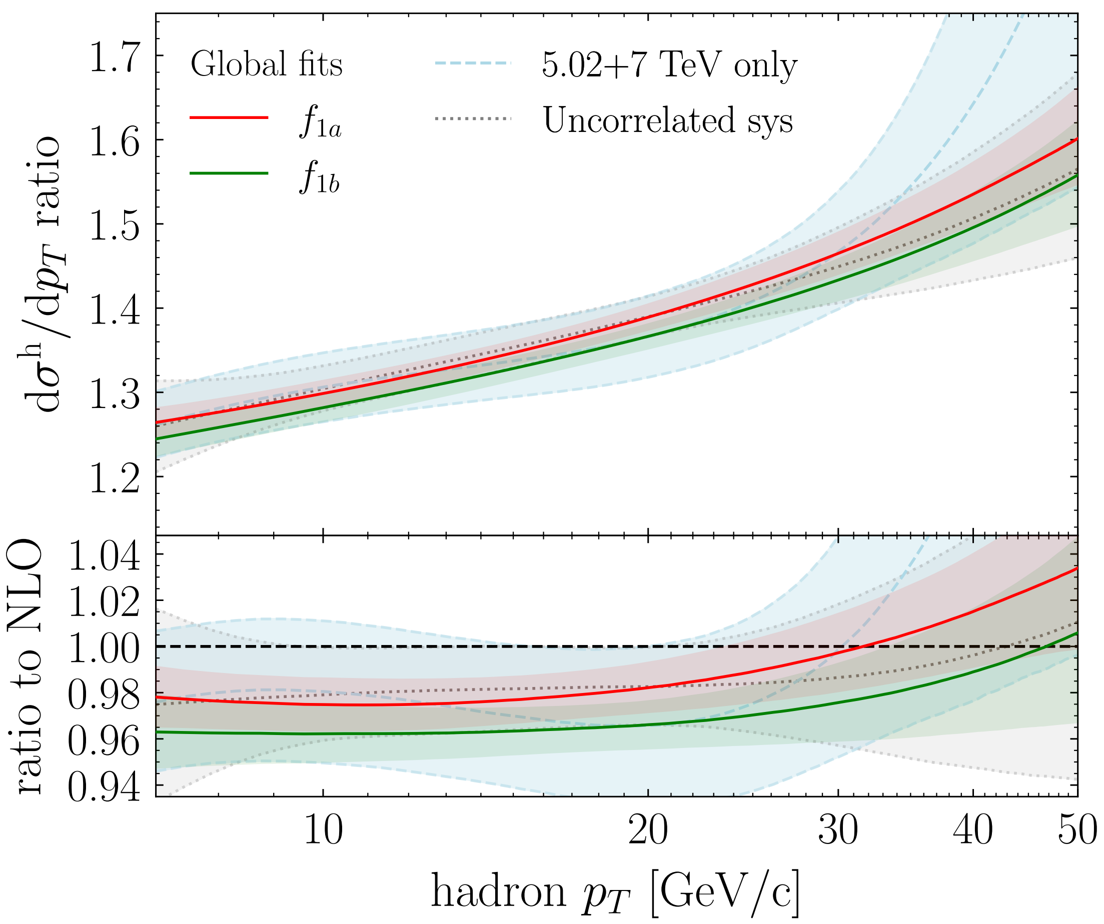

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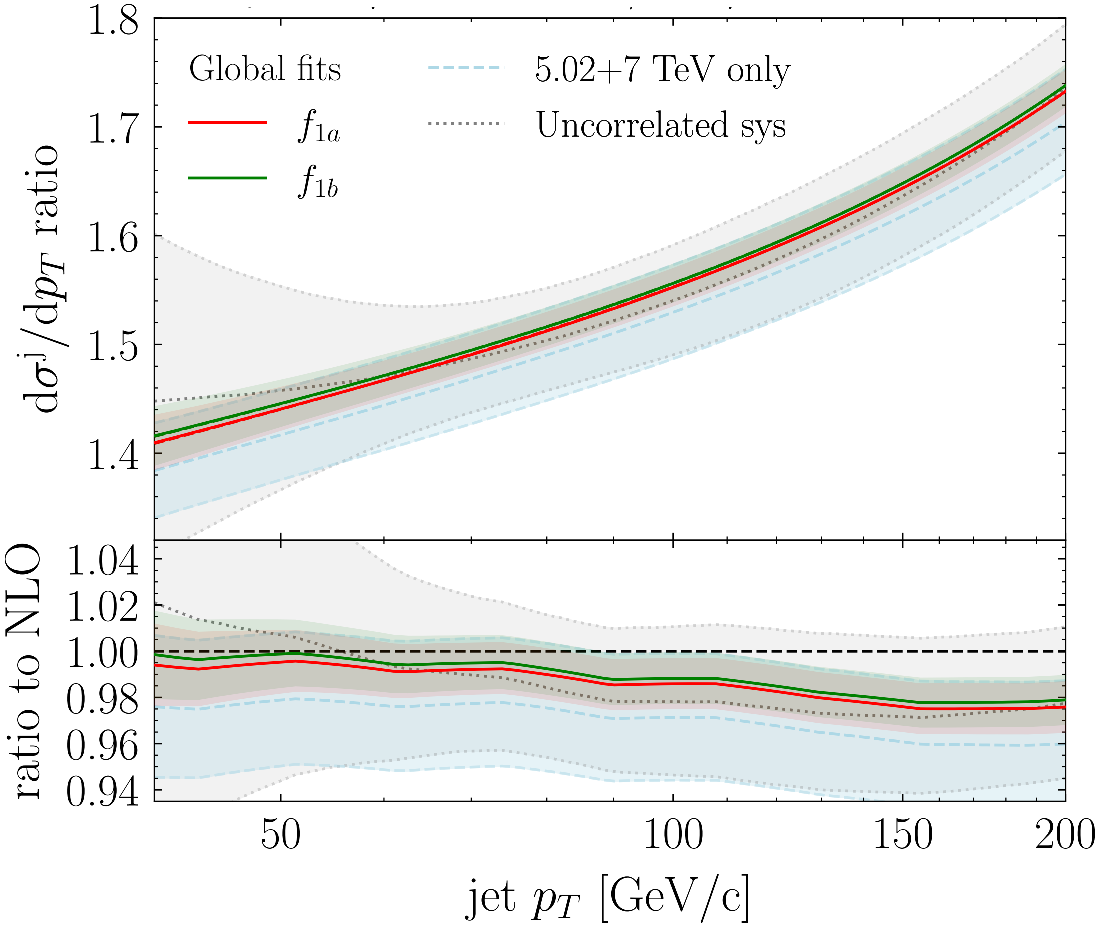


Using three energies gives smaller uncertainties than using two

Uncertainties of constructing a pp reference

~ 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
- Uncertainties on interpolation require fitting with 3 energies

Brewer, Huss, Mazeliauskas, van der Schee [2108.13434]

Bypassing the need for a reference with mixed-energy ratios

nPDFs (not pp) are correct baseline for no energy loss

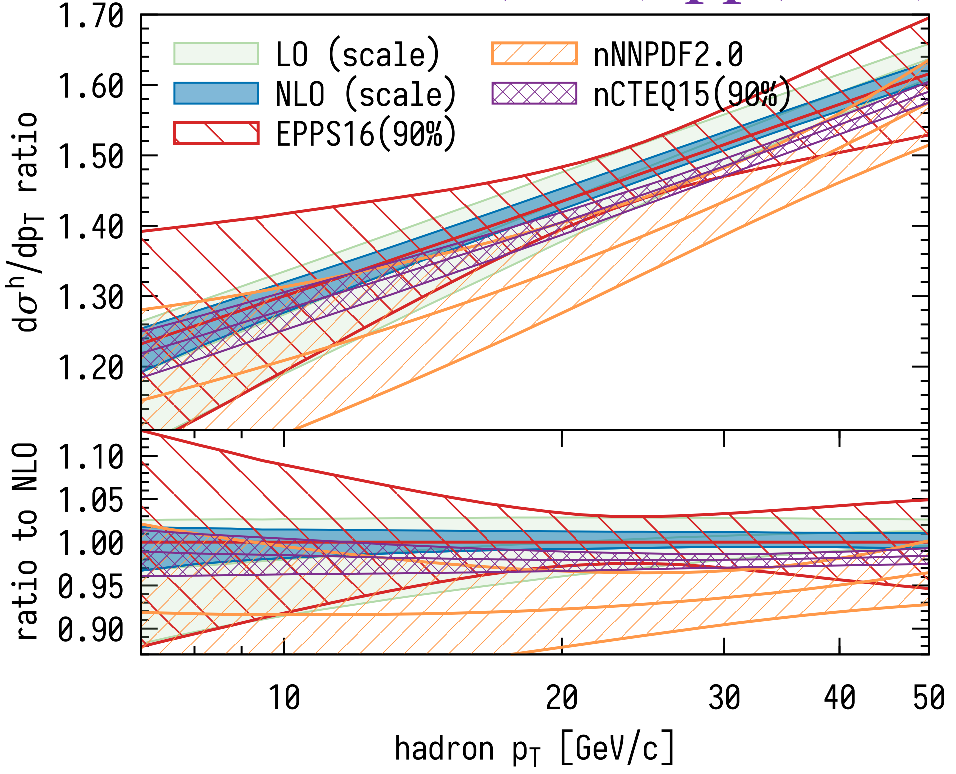
Ratio to pp important to cancel pQCD scale uncertainties
and experimental systematic uncertainties

Is it crucial to take the ratio with pp at the same energy?

Brewer, Huss, Mazeliauskas, van der Schee [2108.13434]

Bypass constructing a reference: OO/pp at different energies

Hadron OO(6.37)/pp(5.02)



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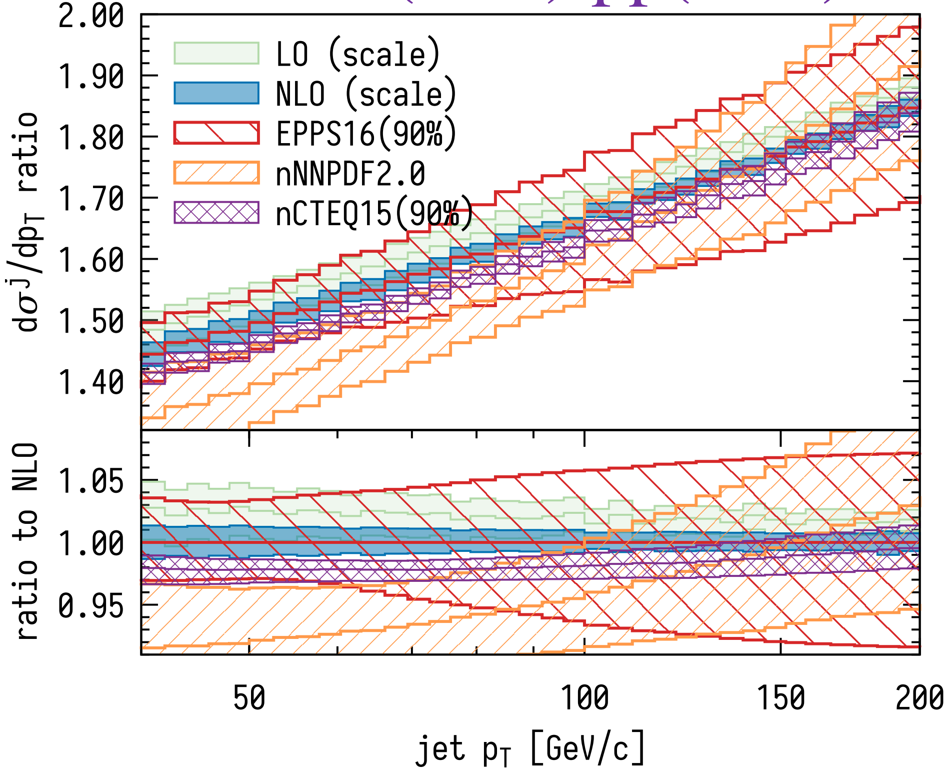

Comparable uncertainty cancellation to OO/pp at the same energy, and much smaller than nPDF uncertainty

pO is crucial for constraining nPDFs

Oxygen provides unique physics opportunities

Flow:

- Unique geometry/ temperature for the same multiplicity

Hard probes:

- Possibility to measure energy loss in small systems
- Important constraints on nPDFs (especially gluons) in light nuclei

Opportunities for hard probes measurements without a pp reference

- Systematic study of uncertainties of constructing a reference from pQCD or interpolation
- Ratio of oxygen and pp spectra at different energies: good cancellation of pQCD scale uncertainties. nPDF uncertainties dominant
  - Cancellation of experimental systematics?