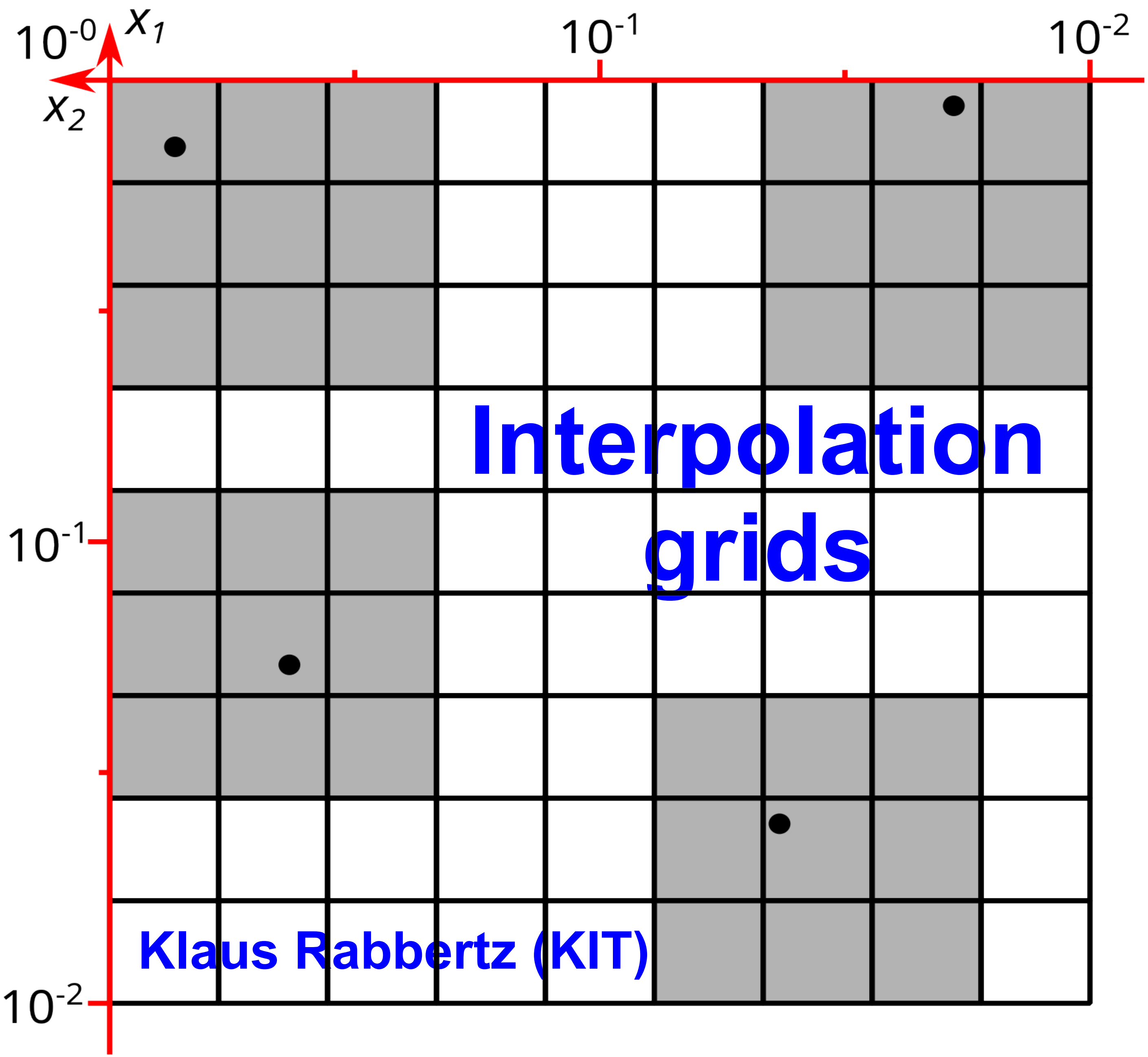
Grids & HighTEA discussion



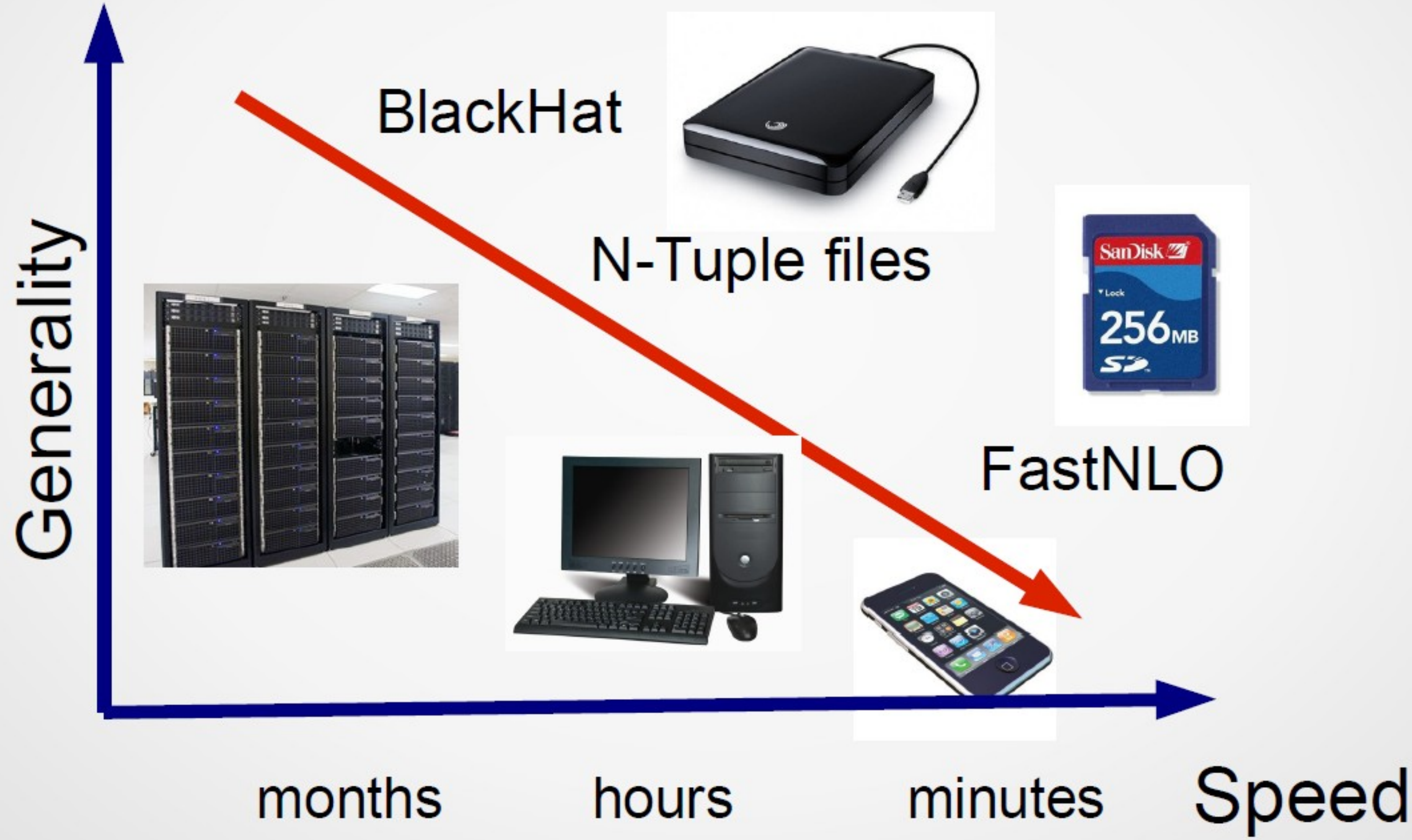
Interpolation grids

Klaus Rabbertz (KIT)

Plot: J. Gäßler

Slide from BlackHat talk 2014

Speed vs Generality

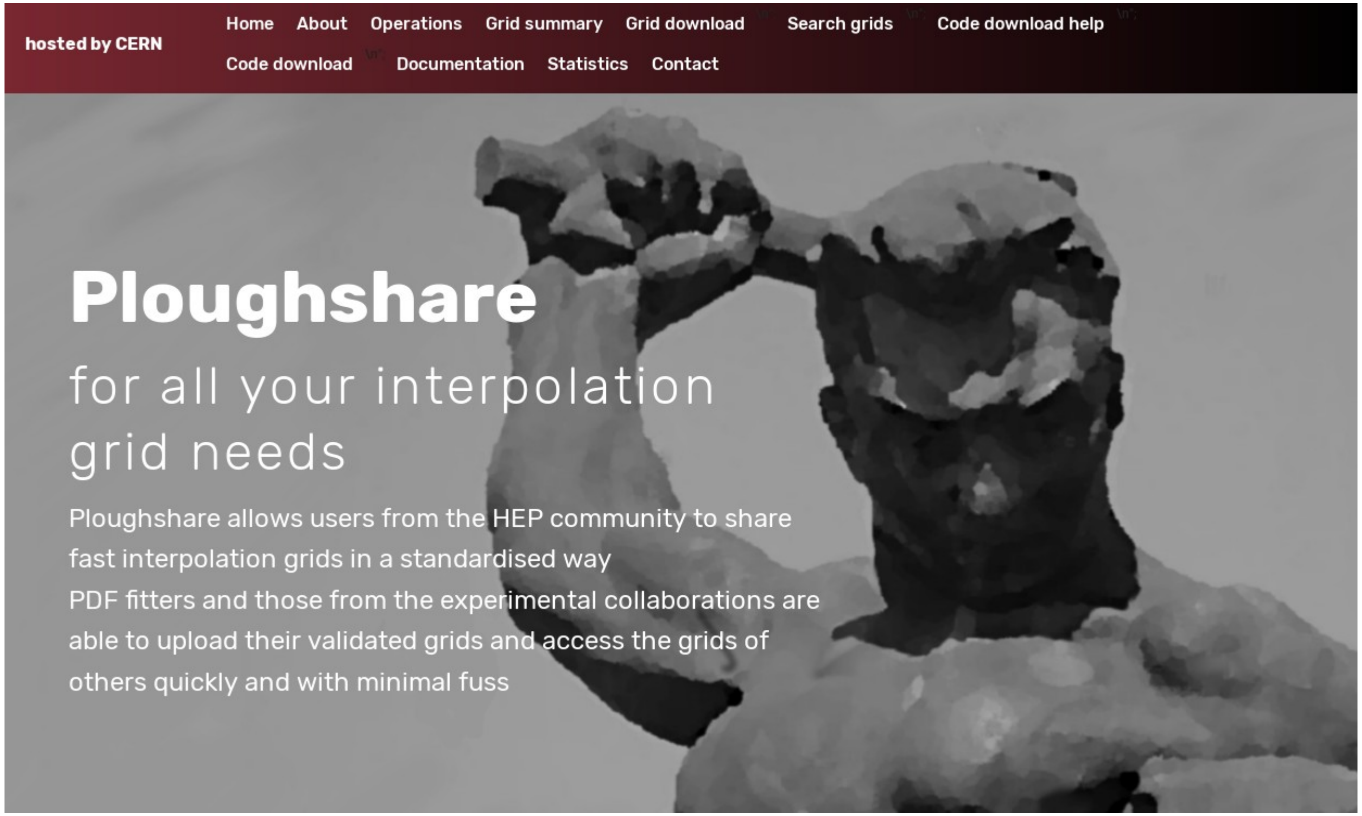


Slide from Daniel Maitre

Loops and Legs 2014, Weimar, 1th May

Jet results

- **Grids at NNLO for DIS jets:**
  - **Eur. Phys. J. C 81 (2021) 10, 957 & Eur. Phys. J. C 79 (2019) 10, 845**
- **Grids at NNLO for pp jets:**
  - **Eur. Phys. J. C 82 (2022) 10, 930**
- **All grids public @ PloughShare**

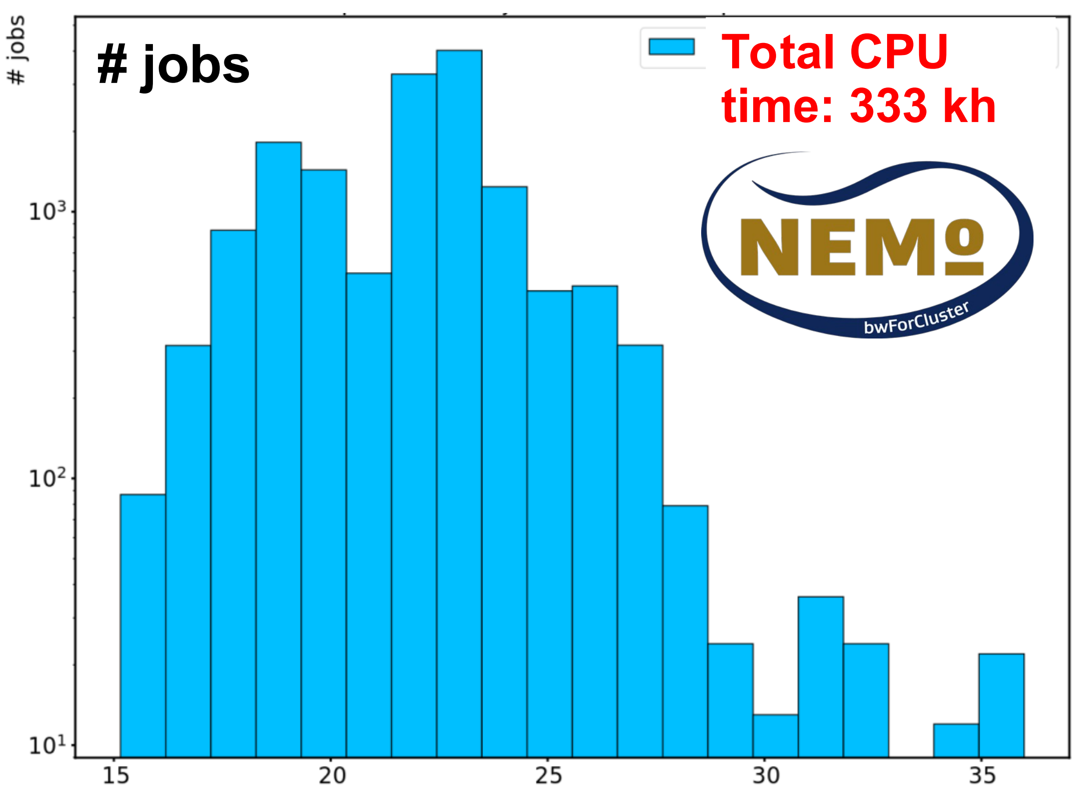


Ingredients

- **Theory: Interface to (v1)**
  - **NNLOJET:** T. Gehrmann et al., RADCOR2017 PoS (2018) 074, arXiv:1801.06415.
  - **Inclusive jets:** J. Currie et al, PRL 118 (2017) 072002; JHEP 10 (2018) 155.
  - **Dijets:** J. Currie et al., PRL 119 (2017) 152001; A. Gehrmann-de Ridder et al., PRL 123 (2019) 102001.
  - **Full-colour NNLO:** X. Chen et al., JHEP09 (2022) 025. **(Not yet included → Lucas)**

- **Tools:**
  - **APPLfast interface:** D. Britzger et al., EPJC 79 (2019) 845, arXiv:1906.05303.
  - **fastNLO:** D. Britzger et al., Proc. DIS2012 (2012) 217, arXiv:1208.3641.
  - **APPLgrid:** T. Carli et al., EPJC 66 (2010) 503, arXiv:0911.2985.
  - **xfitter:** S. Alekhin et al., EPJC 75 (2015) 304, arXiv:1410.4412.

Typical total runtime of a grid production



Total # of ~24h jobs: O(15000)

CPU resources from:
NEMO Freiburg, MPI Munich, CERN Theory

CPU overhead for filling grids: ~ 35%

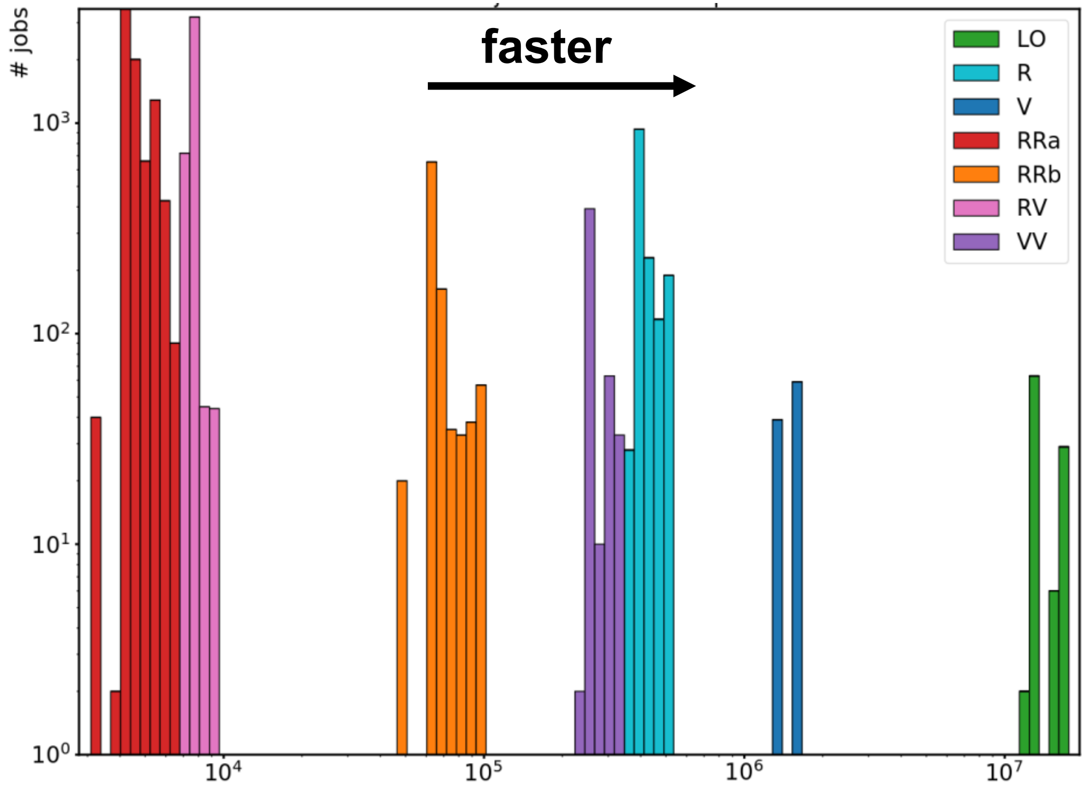
"Events" / hour

RRa, RV: most expensive

LO, NLO, VV: easy

O(10^3-10^4)

O(10^5 - 10^7)

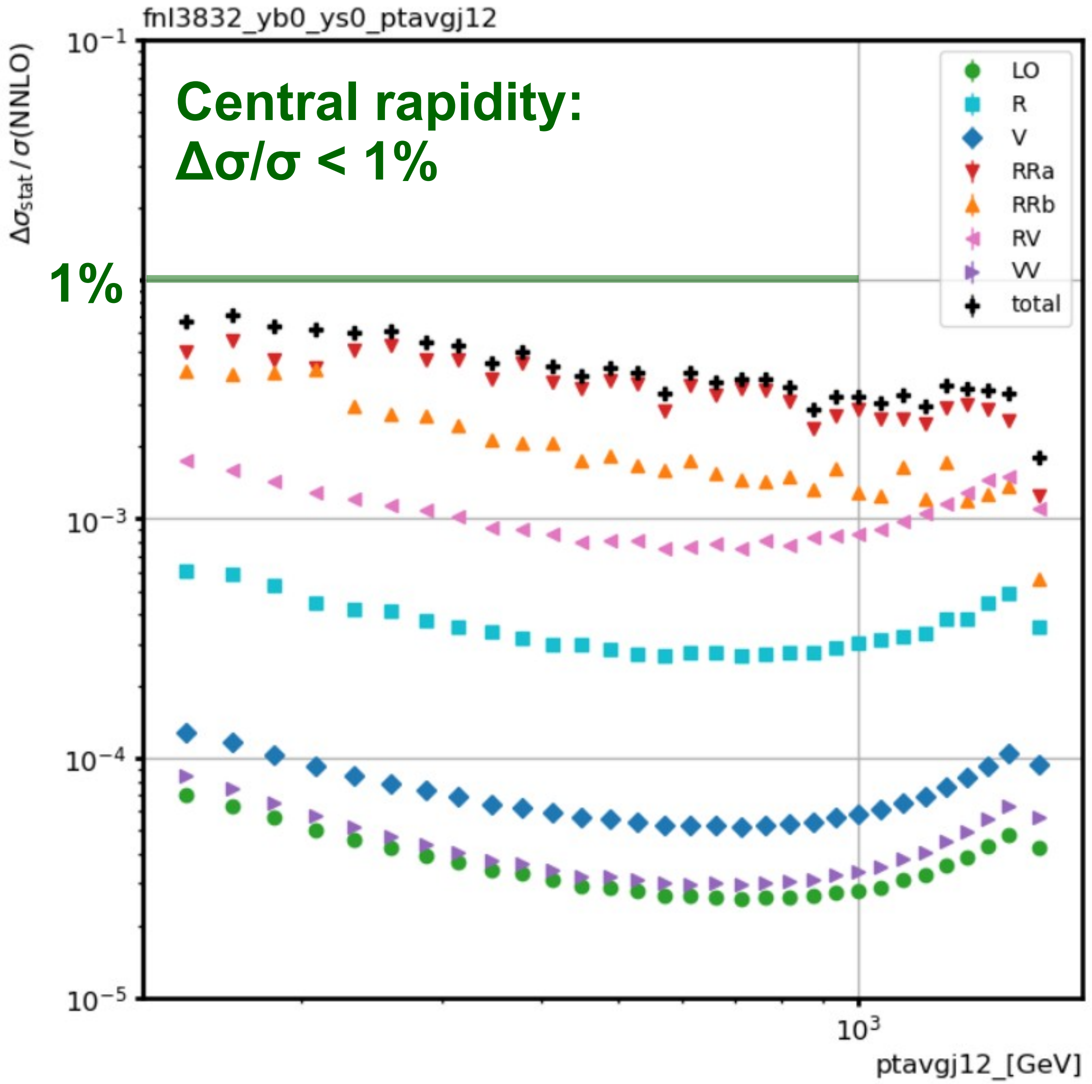


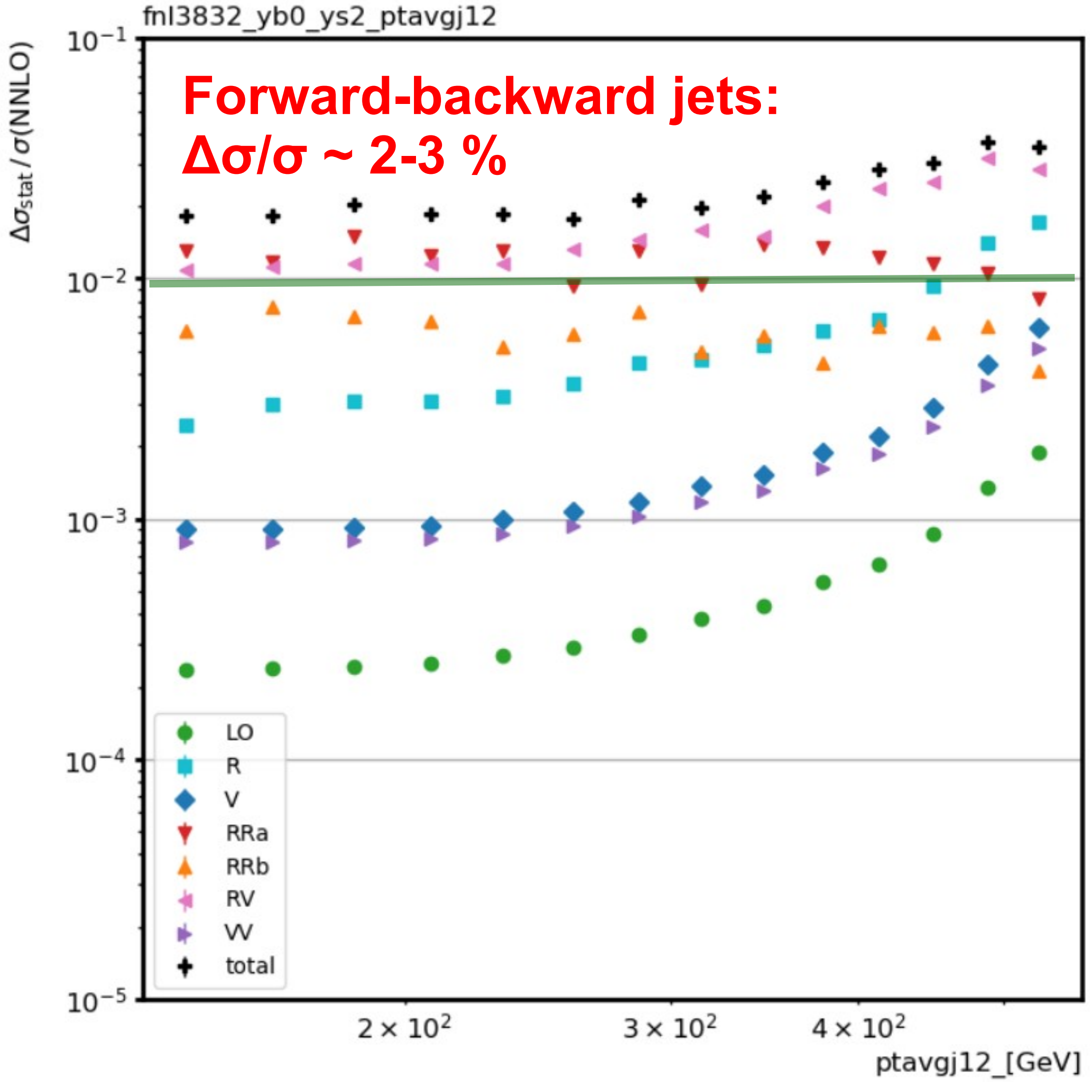
Return on investment

Relative numerical uncertainty of NNLO 3D dijet cross section

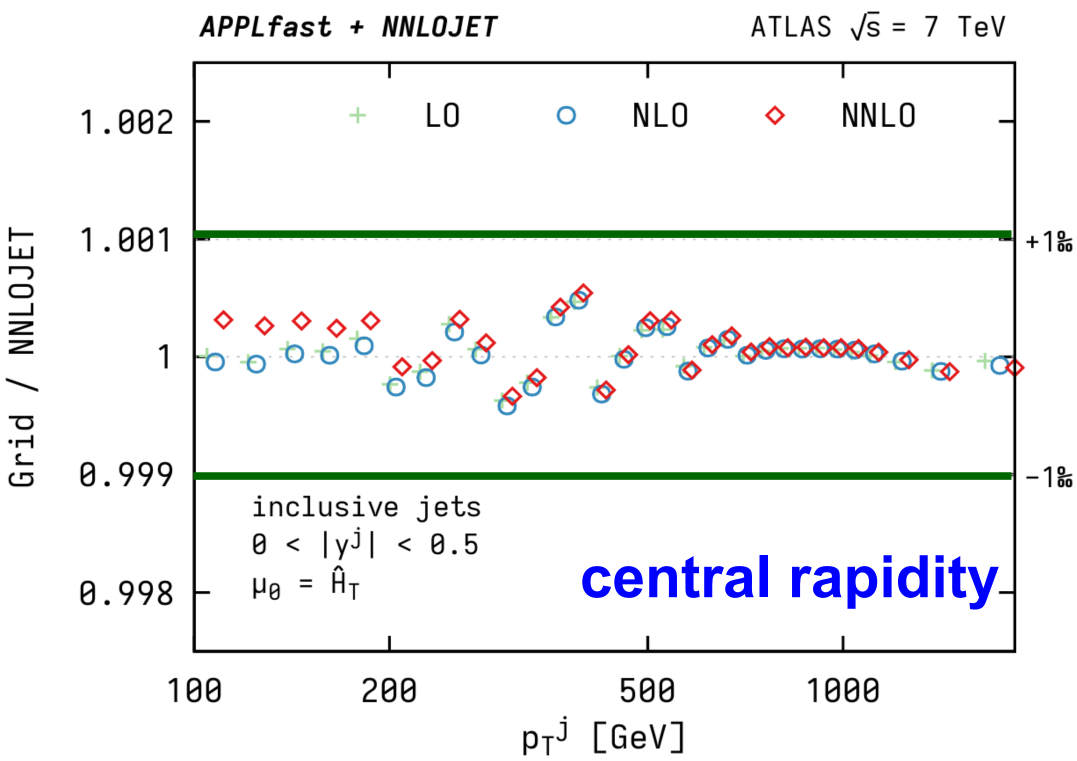
Dominated by RRa and RV channels

Numerical uncertainty provided inside grids



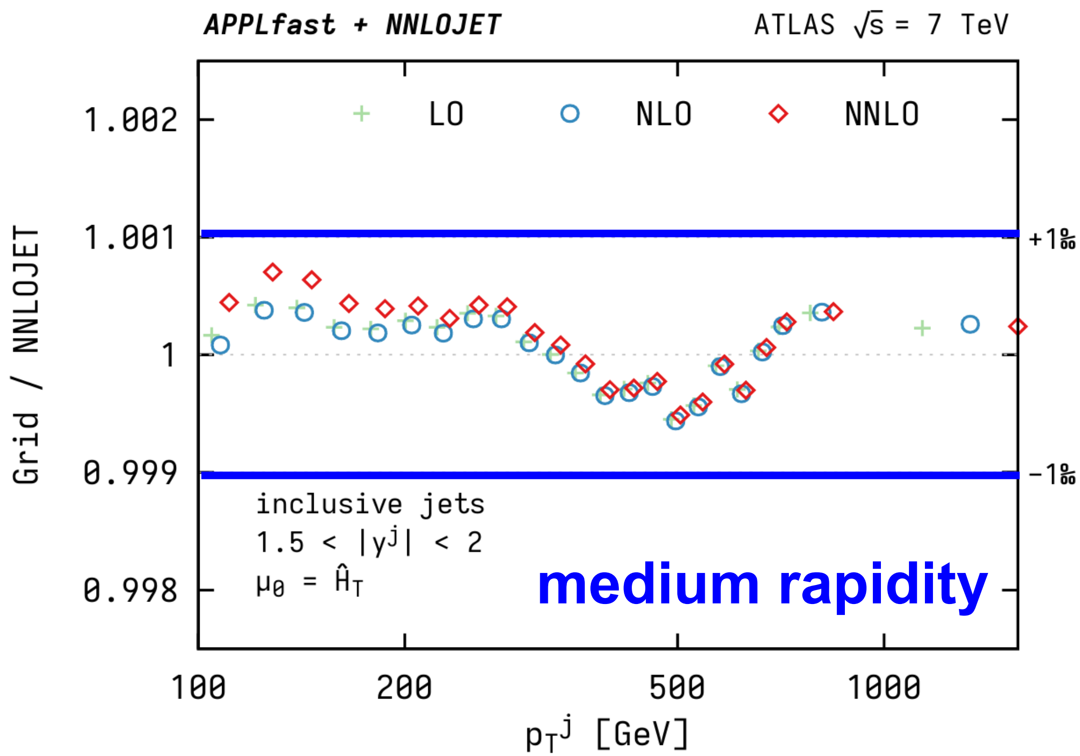


Grid closure vs. NNLOJET



ATLAS inclusive jets at 7 TeV

Generally aim at closure better than 1 ‰ at each level, LO, NLO, NNLO

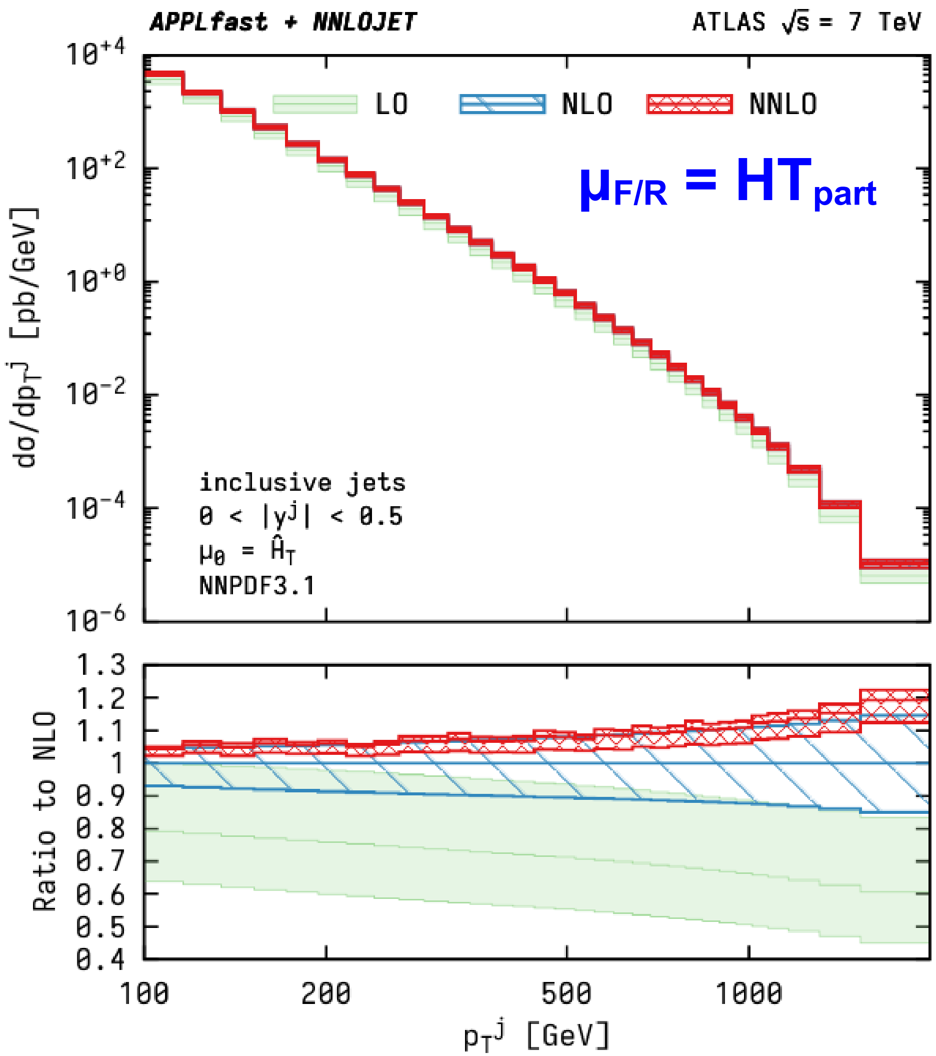


Closure deteriorates somewhat towards phase space limits; exceptionally may exceed 1 ‰ at phase space edges

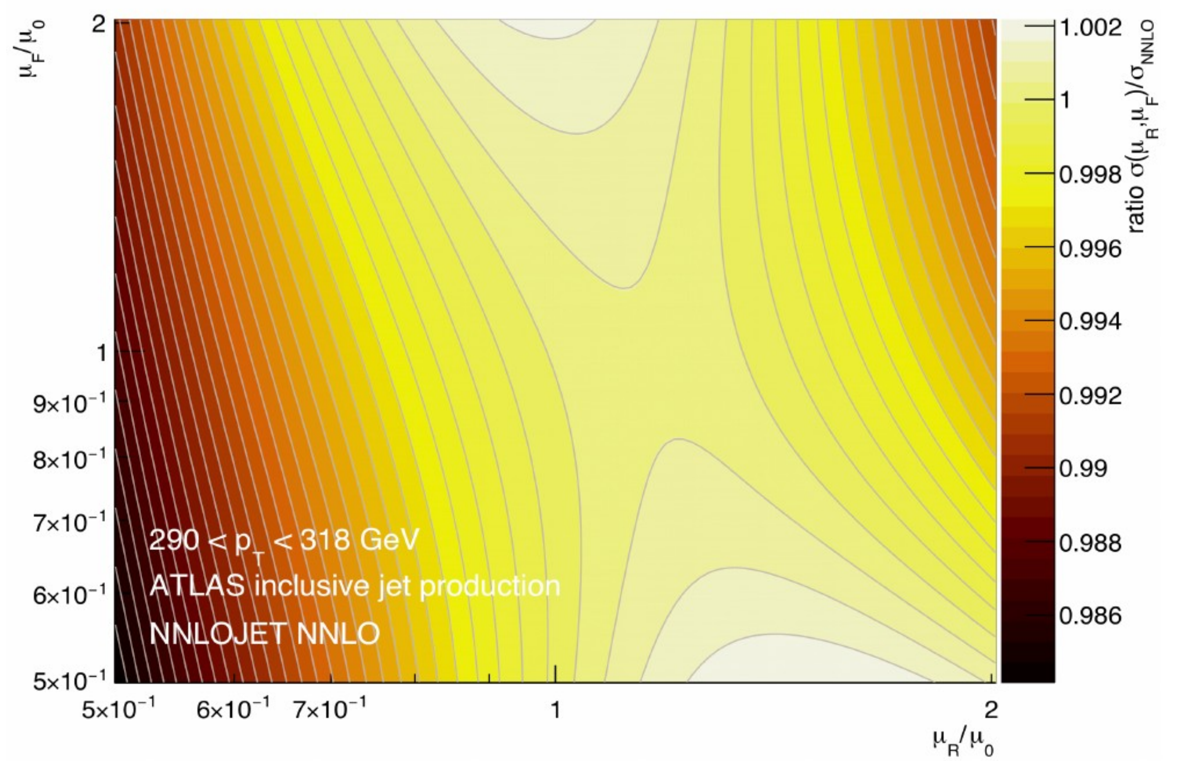
Scale dependence

ATLAS inclusive jets at 7 TeV

Scale uncertainty bands: LO, NLO, NNLO



Full 2-dimensional scale dependence in $\mu_{F/R}$ for each bin



Alternative scale possible: p_{Tjet} instead of HT_{part}

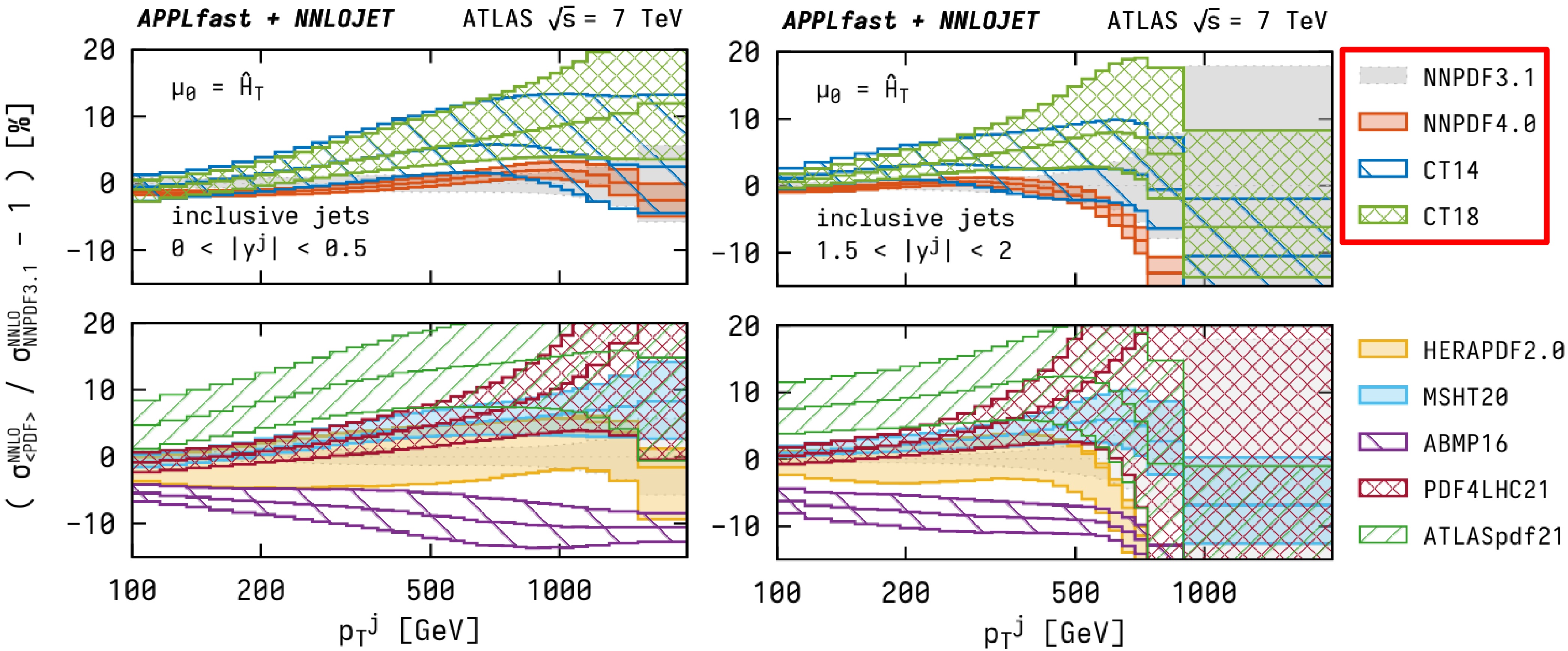
From Snowmass report: arXiv:2203.13923

PDF dependence

ATLAS inclusive jets at 7 TeV

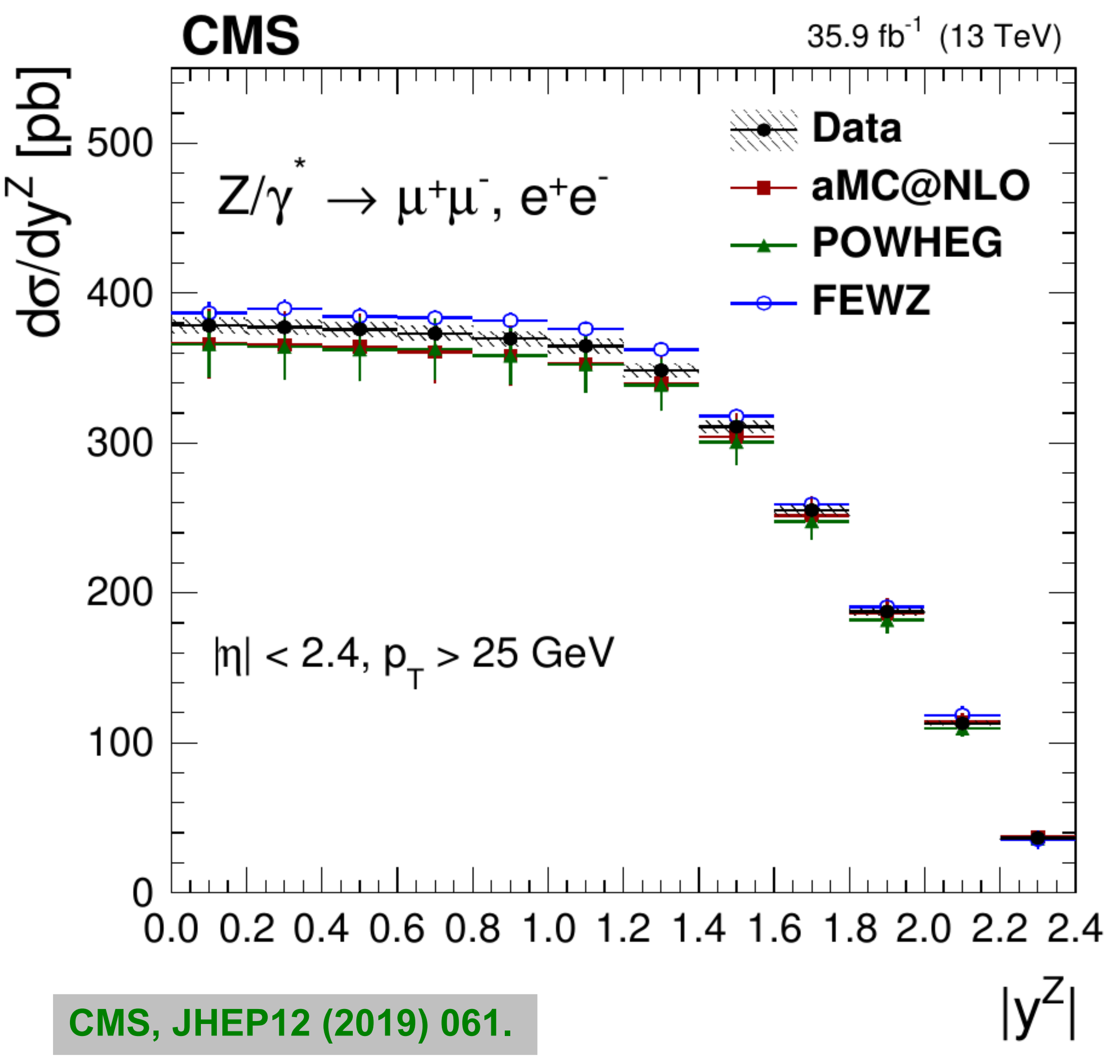
PDF uncertainty bands for selection of 9 PDF sets

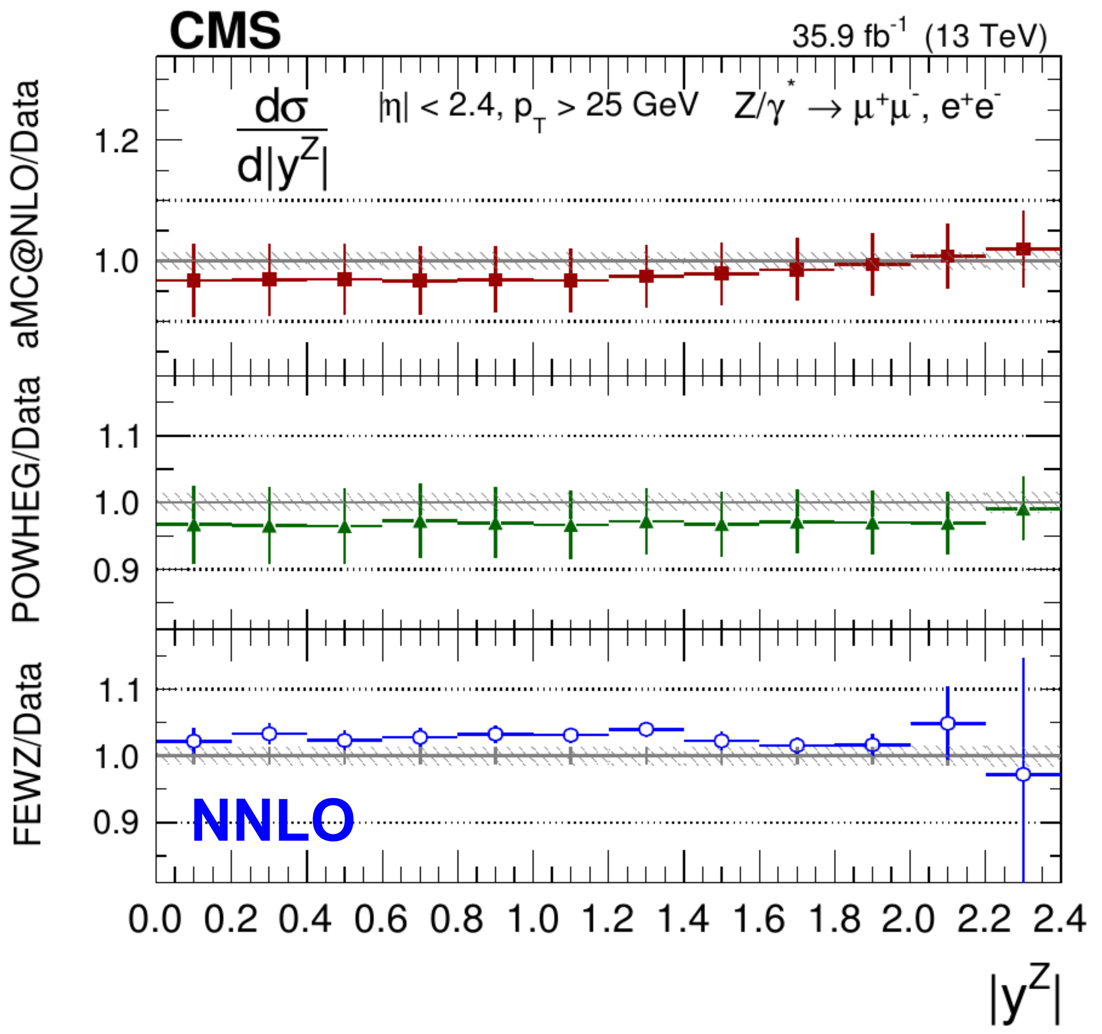
central rapidity — **"Central" PDF: NNPDF3.1** — **medium rapidity**



Observation for ΔPDF: **CT14 → CT18 larger**
NNPDF 3.1 → 4.0 much smaller

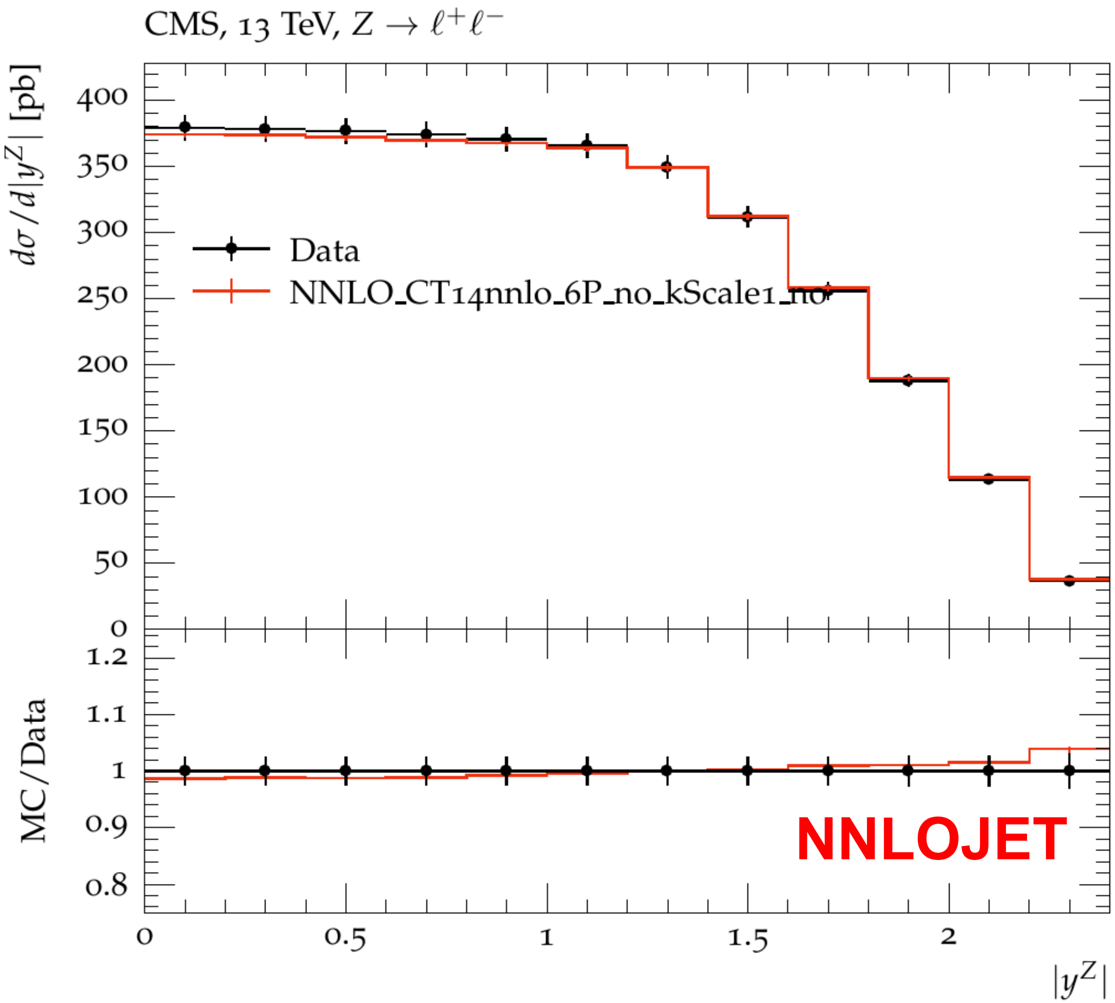
Christiane Mayer: - Establish grid production workflow (LAW) on lxplus
(with A. Huss, KR) - New result for Z+X @ NNLO to compare with CMS

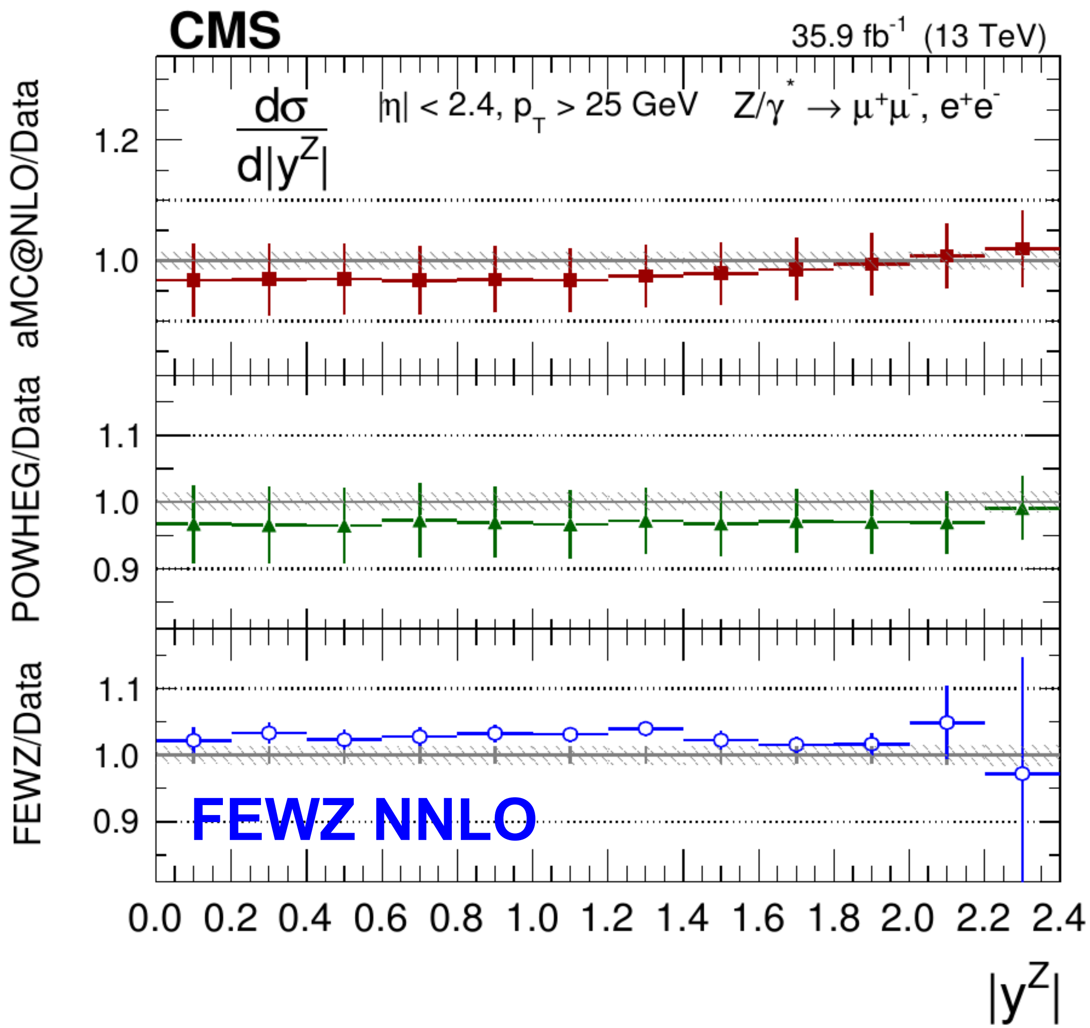




CMS, JHEP12 (2019) 061.

Christiane Mayer: **- Nicely agrees with CMS data**
(with A. Huss, KR) - Slightly lower than FEWZ





Christiane Mayer: https://cds.cern.ch/record/2856036

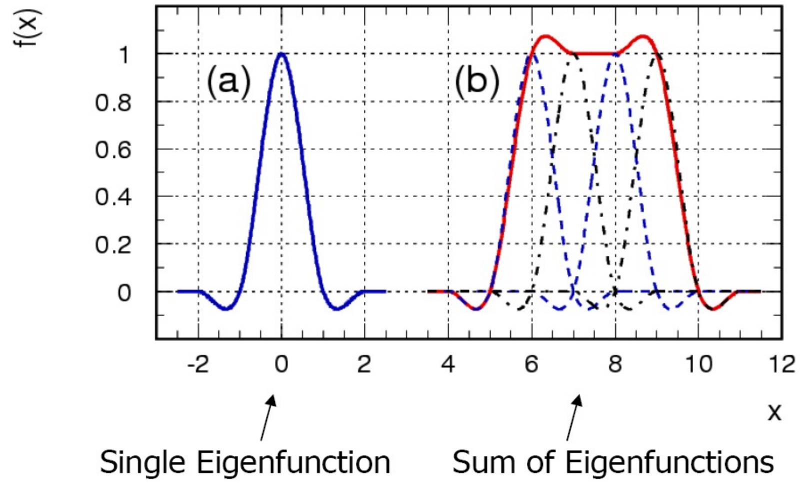
Questions

Backup Slides

Interpolation concept

Implemented in APPLgrid & fastNLO

Use interpolation kernel



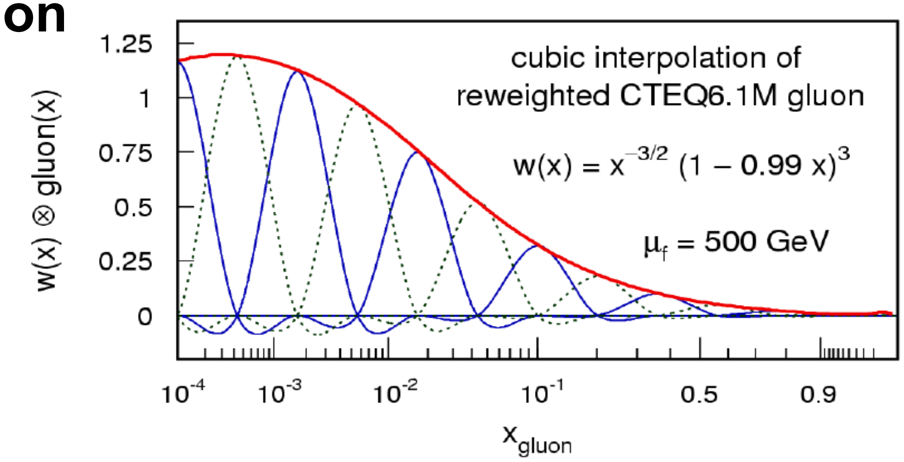
- Introduce set of n discrete x-nodes, x_i's being equidistant in a function f(x)
- Take set of Eigenfunctions $E_i(x)$ around nodes x_i

→ Interpolation kernels

- Actually a rather old idea, see e.g. C. Pascaud, F. Zomer (Orsay, LAL), LAL-94-42

→ Single PDF is replaced by a linear combination of interpolation kernels

$$f_a(x) \cong \sum_i f_a(x_i) \cdot E^{(i)}(x)$$



→ Then the integrals are done only once

→ Afterwards only summation required to change PDF

Tabulate the convolution of the perturbative coefficients with the interpolation kernel

Inclusive jet datasets

- **Seven inclusive jet datasets from ATLAS & CMS, 2D in p_T and y**
  - **Four centre-of-mass energies, three jet radii R**
  - **Two central scales for $\mu_{R/F}$**

Sample plots in this talk

Data	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]	no. of points	anti-k_T R	kinematic range [GeV]	fiducial cuts	$\mu_{R/F}$-choice
CMS [30]	2.76	0.00543	81	0.7	$p_T^{jet} \in [74, 592]$	$\lvert y\rvert < 3.0$	p_T^{jet}, $\hat{H}_T$
ATLAS [28]	7.0	4.5	140	0.6	$p_T^{jet} \in [100, 1992]$	$\lvert y\rvert < 3.0$	p_T^{jet}, $\hat{H}_T$
CMS [31]	7.0	5.0	133	0.7	$p_T^{jet} \in [114, 2116]$	$\lvert y\rvert < 3.0$	p_T^{jet}, $\hat{H}_T$
ATLAS [32]	8.0	20.3	171	0.6	$p_T^{jet} \in [70, 2500]$	$\lvert y\rvert < 3.0$	p_T^{jet}, $\hat{H}_T$
CMS [33]	8.0	5.6 19.7	248	0.7	$p_T^{jet} \in [21, 74]$ $p_T^{jet} \in [74, 2500]$	$\lvert y\rvert < 4.7$	p_T^{jet}, $\hat{H}_T$
ATLAS [34]	13.0	3.2	177	0.4	$p_T^{jet} \in [100, 3937]$	$\lvert y\rvert < 3.0$	p_T^{jet}, $\hat{H}_T$
CMS [35]	13.0	36.3 33.5	2×78	0.4 0.7	$p_T^{jet} \in [97, 3103]$	$\lvert y\rvert < 2.0$	p_T^{jet}, $\hat{H}_T$

Dijet datasets

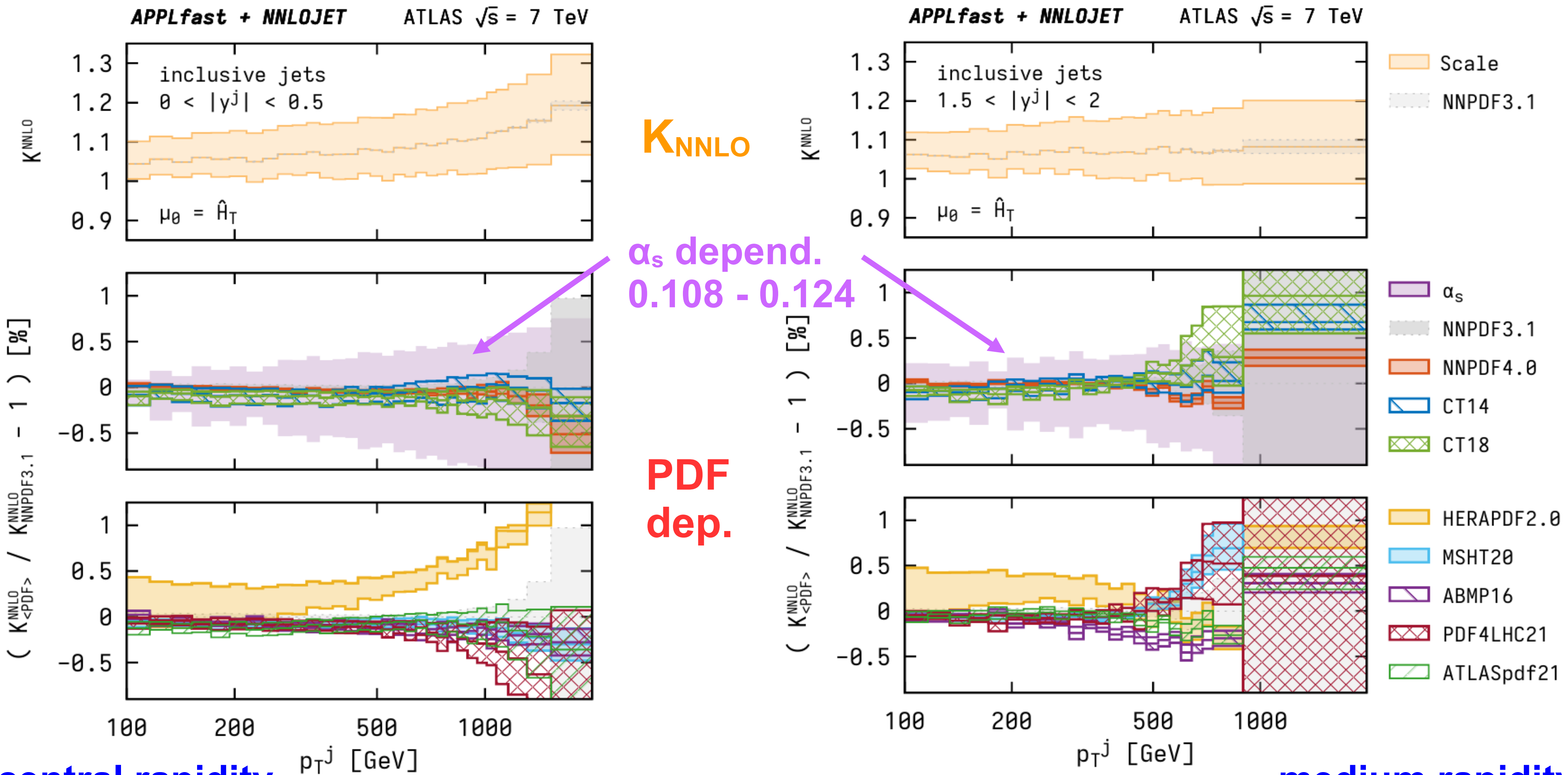
- **Four dijet datasets from ATLAS & CMS, 2D in m_{12} and y* or y_{max}, or 3D in <p_{T12}>, y*, y_b**
  - **Three centre-of-mass energies, three jet radii R**
  - **One central scale for $\mu_{R/F}$, except for 3D data with two**

Sample plots in this talk

Data	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]	no. of points	anti-k_T R	kinematic range [GeV]	fiducial cuts	$\mu_{R/F}$-choice
ATLAS [55]	7.0	4.5	90	0.6	$m_{12} \in [260, 5040]$	$\|y_1\|, \|y_2\| < 3.0$ $[p_{T,1}, p_{T,2}] > [100, 50]$GeV $y^* < 3.0$	m_{12}
CMS [31]	7.0	5.0	54	0.7	$m_{12} \in [197, 5058]$	$\|y\| < 5.0$ $[p_{T,1}, p_{T,2}] > [60, 30]$GeV $\|y_{max}\| < 2.5$	m_{12}
CMS [49]	8.0	19.7	122	0.7	$\langle p_{T1,2}\rangle \in [133, 1784]$	$\|y\| < 5.0$ $p_{T,1}, p_{T,2} > 50$GeV $\|y_1\|, \|y_2\| < 3.0$	$p_{T,1}\exp(0.3\, y^*)$ m_{12}
ATLAS [34]	13.0	3.2	136	0.4	$m_{12} \in [260, 9066]$	$\|y_1\|, \|y_2\| < 3.0$ $p_{T,1}, p_{T,2} > 75$GeV $\langle p_{T1,2}\rangle > 100$GeV $y^* < 3.0$	m_{12}

K factor robustness

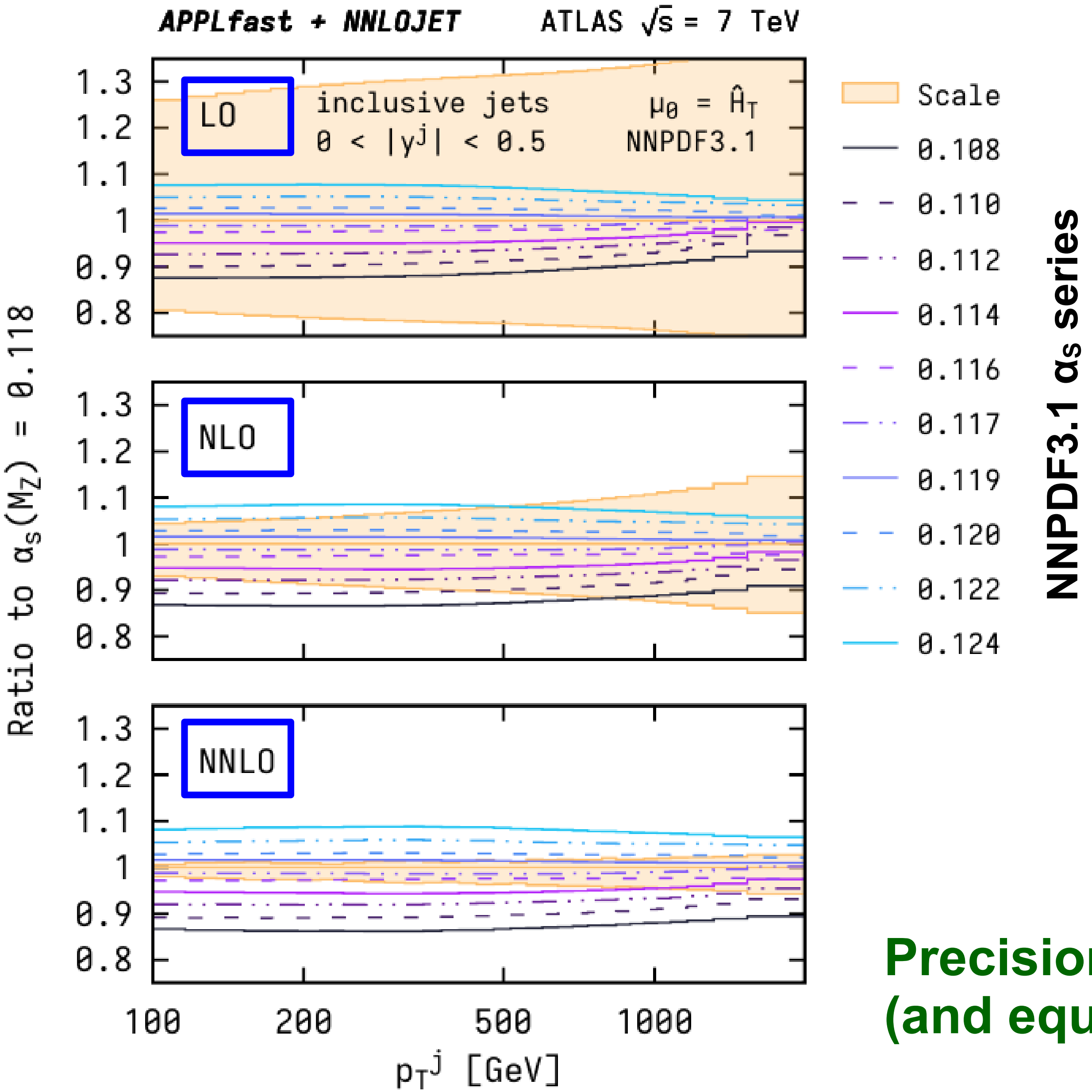
Dependence of K_{NNLO} on: α_s **– negligible**
most PDF sets – ~ 0.5%
exceptionally (HERAPDF) – ~ 1%



central rapidity **medium rapidity**

α_s dependence

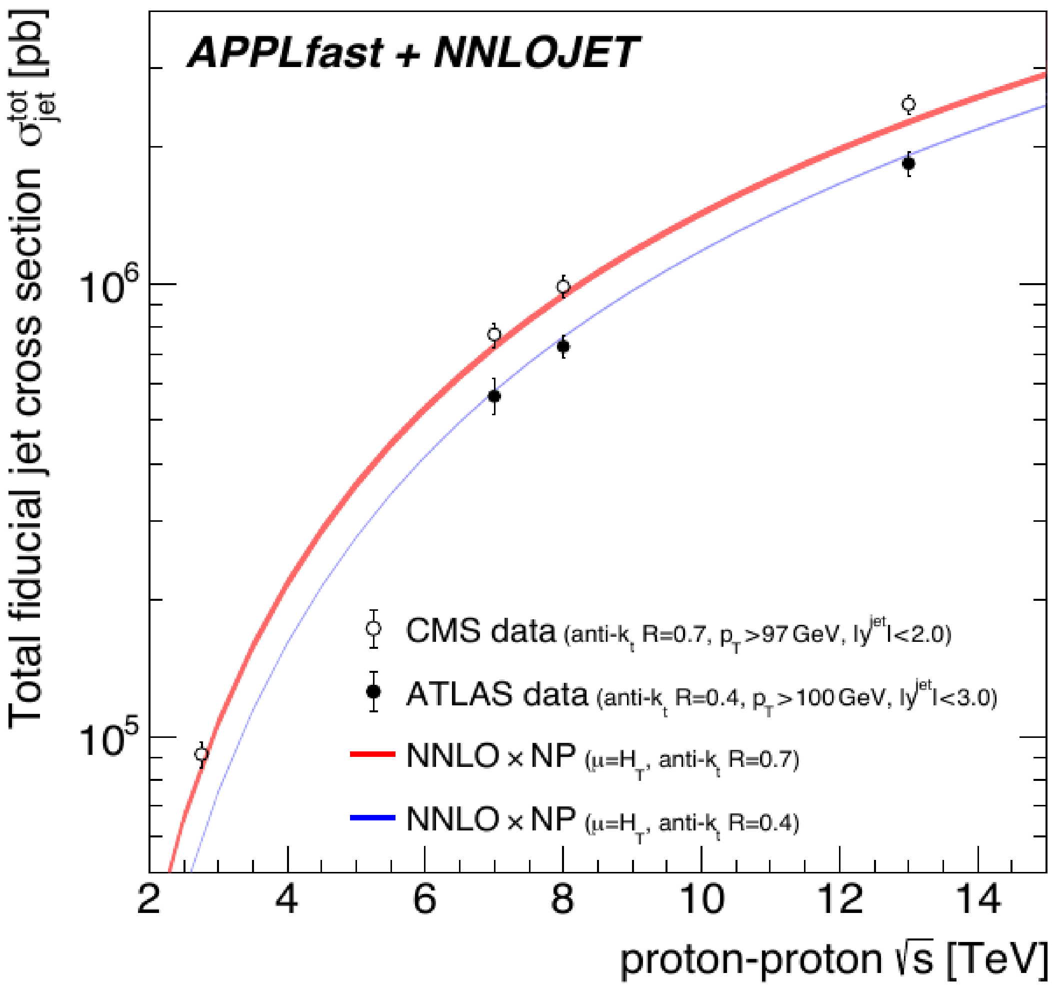
ATLAS inclusive jets at 7 TeV



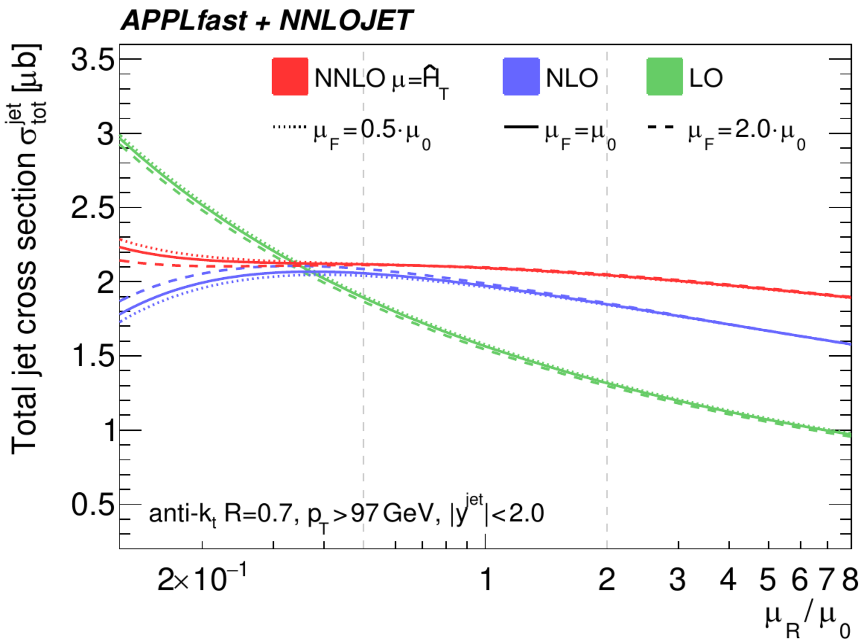
Scale uncertainty versus α_s dependence (0.108 – 0.124) at each order

Precision determinations require NNLO (and equally accurate data!)

Total inclusive jet cross section



- **Closest possible definition with most cms energies**
  - **ATLAS:** R=0.4, p_T > 100 GeV, |y| < 3
  - **CMS:** R=0.7, p_T > 97 GeV, |y| < 2
- **Only 13 TeV grid used here with E_{cms} extrapolation**



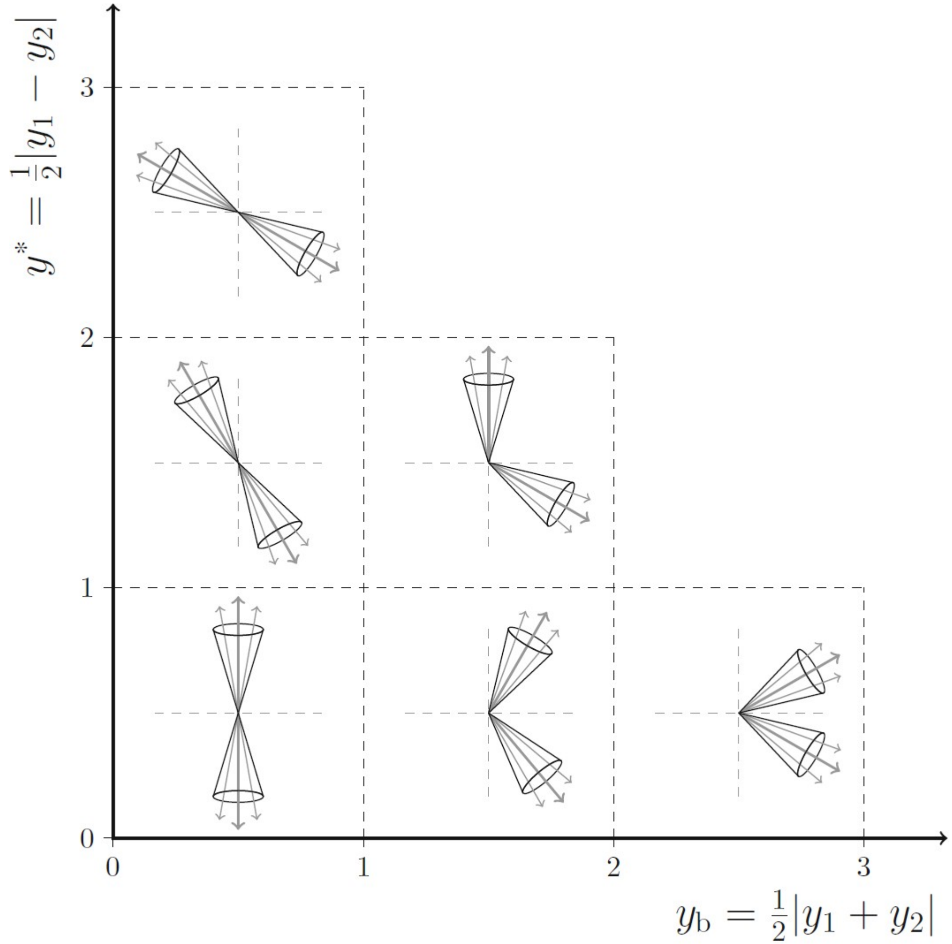
Scale dependence for CMS

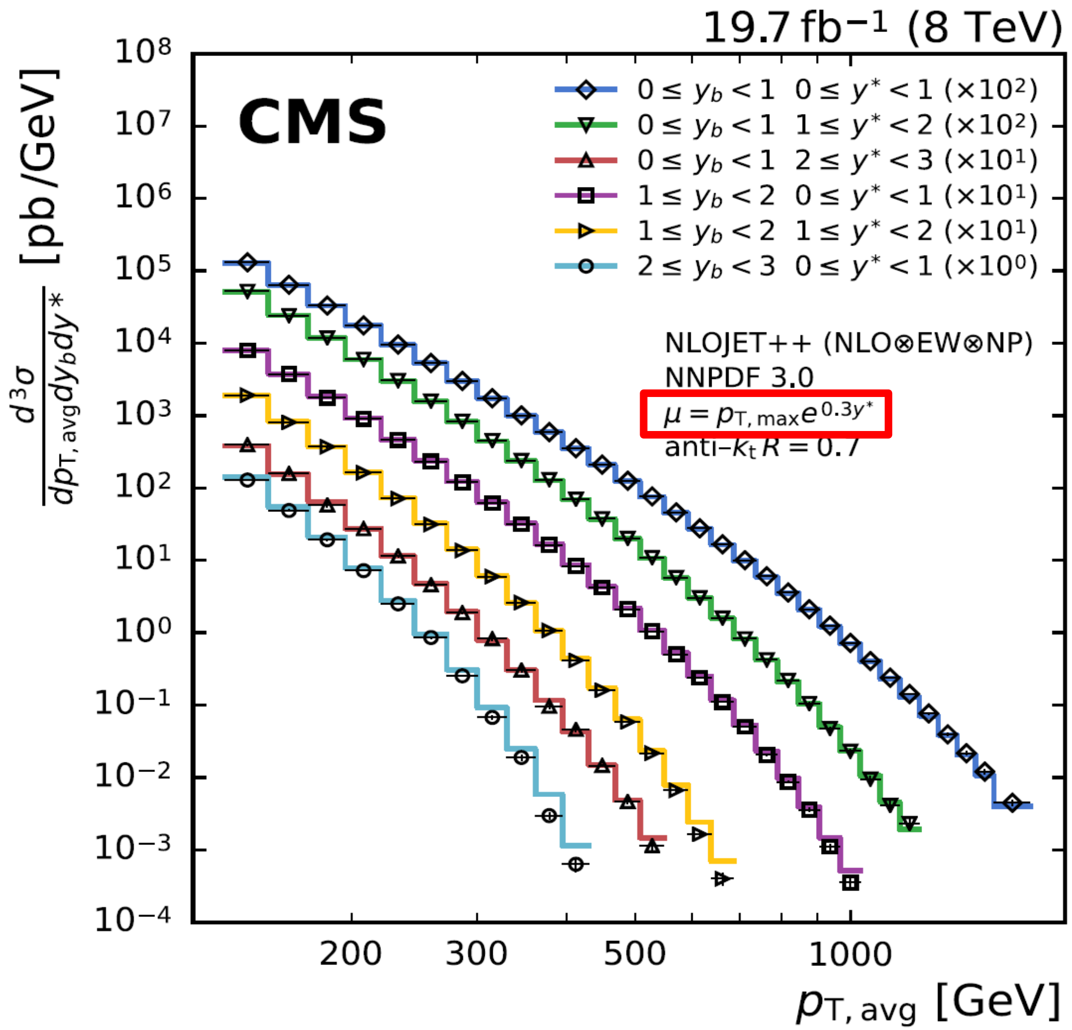
Triple-differential dijets

Most measurements done with respect to dijet mass and either max. rapidity $|y|_{max}$ (CMS) or rapidity separation y^* (ATLAS). One CMS result 3D in p_{T12}, y^*, y_b:

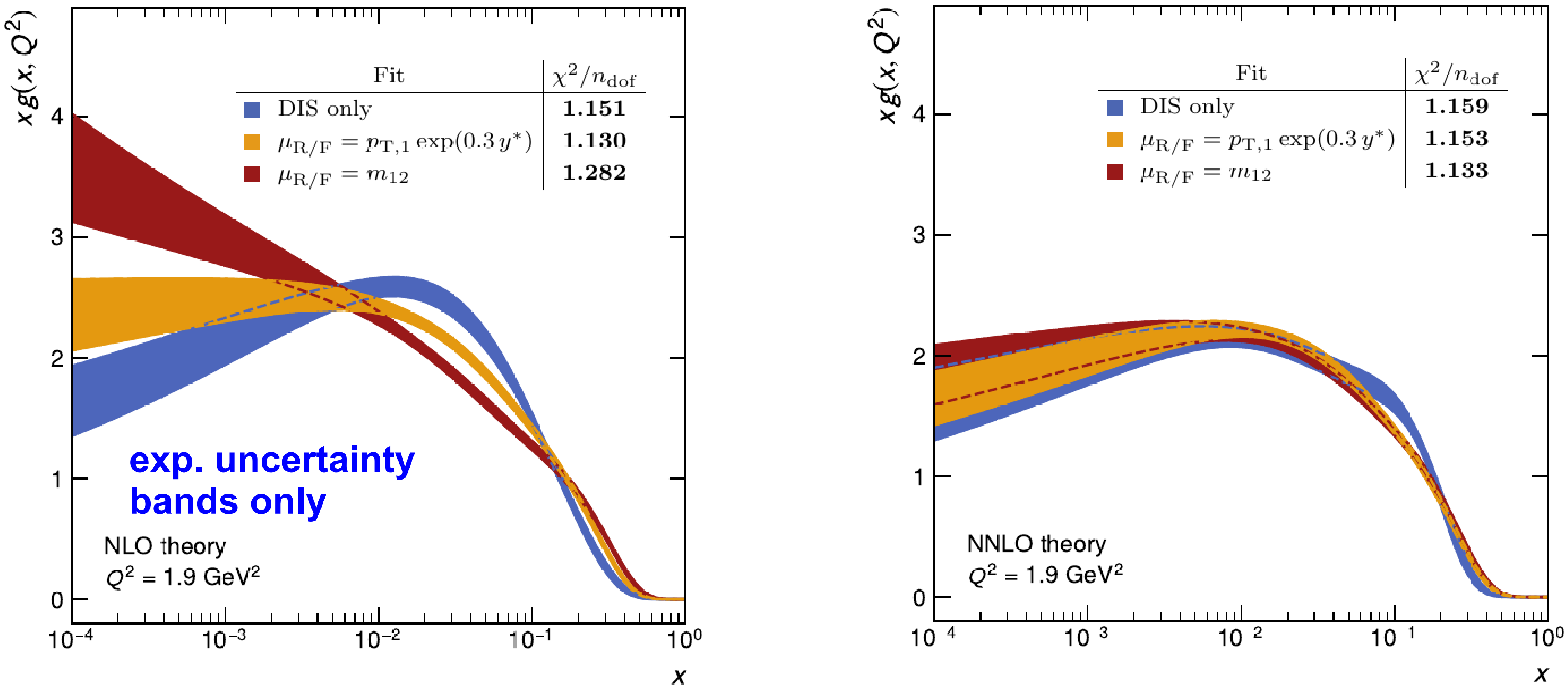
$$\frac{d^3\sigma}{dp_{\mathrm{T,avg}}\,dy_b\,dy^*} \propto \alpha_s^2$$

Illustration of dijet event topologies





Gluon from 13-parameter PDF fit with xfitter for two central scale choices

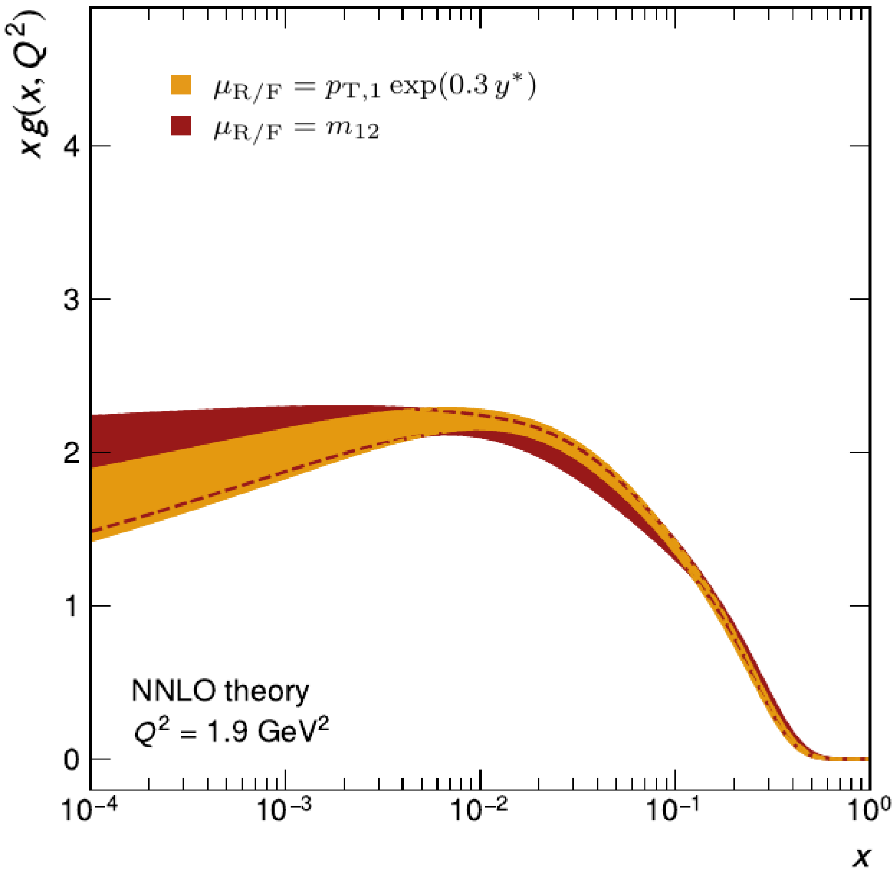


Left: NLO Significant differences between central scale definitions

Right: NNLO Much improved agreement between scales

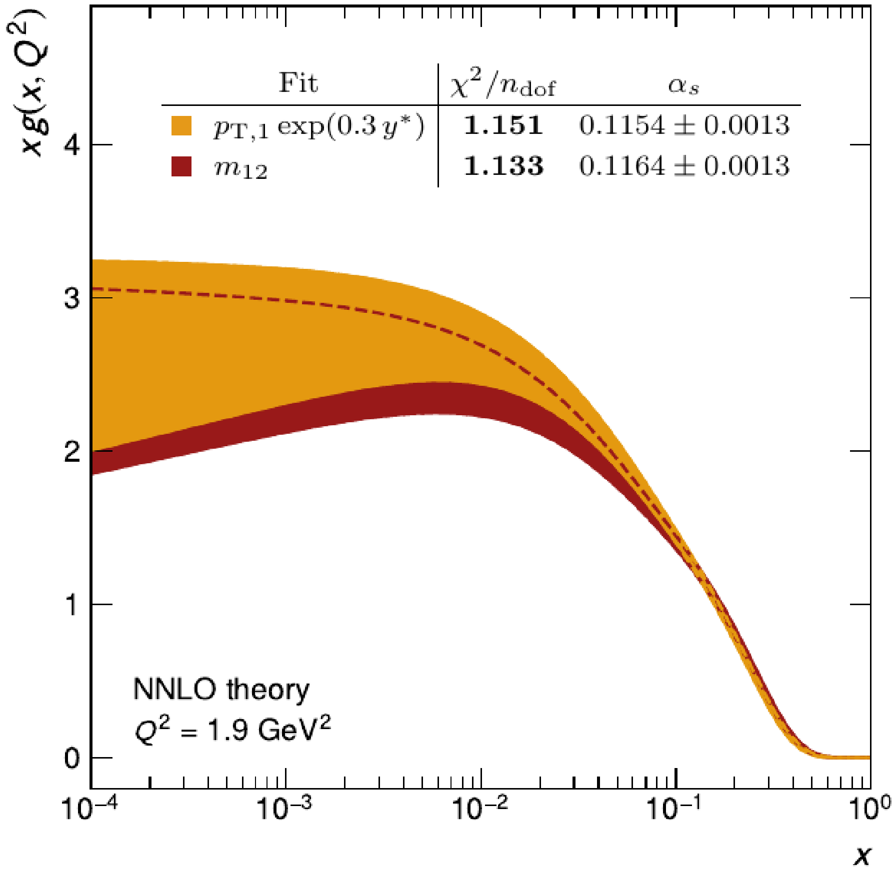
Scale varied fits & PDF+α_s fit

Gluon from 13-parameter PDF fit with scale variation band at NNLO



Much reduced scale dependence

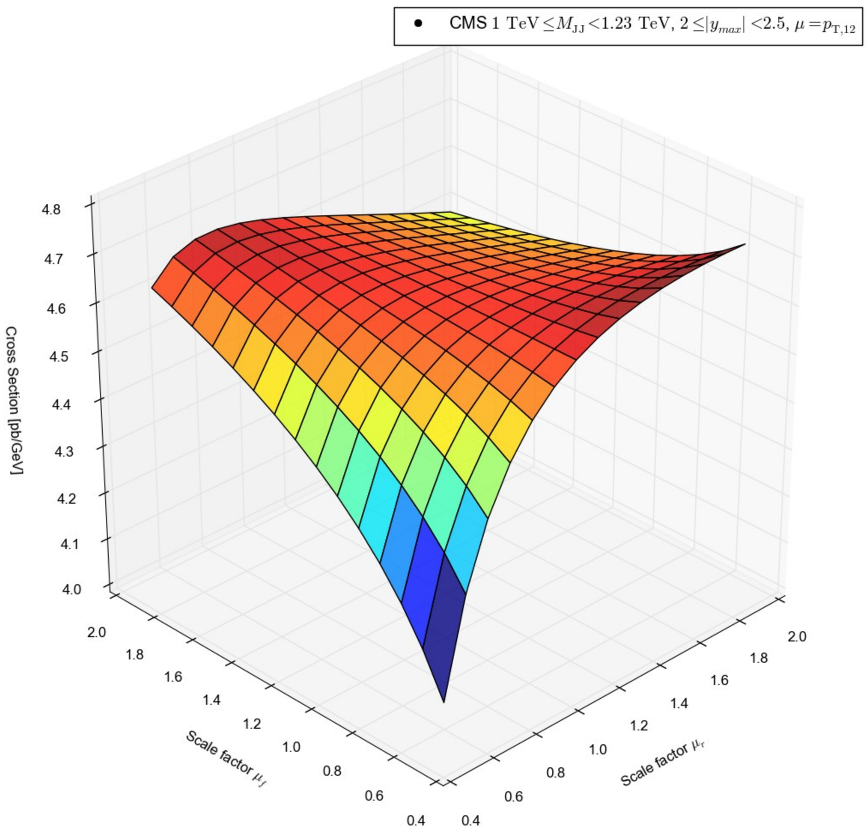
Gluon from 14-parameter PDF fit at NNLO with free α_s



Consistent results between scales

Demo plot using Python extension

- Python extension available
  - … [--enable-pyext]
- Easy example plotting 2D scale dependence:



Setup Python with fastNLO

```
#! /usr/bin/env python2

from fastnlo import fastNLOLHAPDF

import matplotlib
import matplotlib.pyplot as plt
from matplotlib import cm
from mpl_toolkits.mplot3d import axes3d
import numpy as np
```

Select table, PDF & mem.

```
fnlo = fastNLOLHAPDF('fnlotable.tab')
fnlo.SetLHAPDFFilename('CT10nlo.LHgrid')
fnlo.SetLHAPDFMember(0)
```

Define μ_r, μ_f ranges

```
mufs = np.arange(0.1, 1.5, 0.10)
murs = np.arange(0.1, 1.5, 0.10)
xs = np.zeros((mufs.size, murs.size))
```

Loop over μ_r, μ_f

```
for i, muf in enumerate(mufs):
    for j, mur in enumerate(murs):
        fnlo.SetScaleFactorsMuRMuF(mur, muf)
        fnlo.CalcCrossSection()
        xs[i][j] = np.array(fnlo.GetCrossSection())[0]
```

Plot

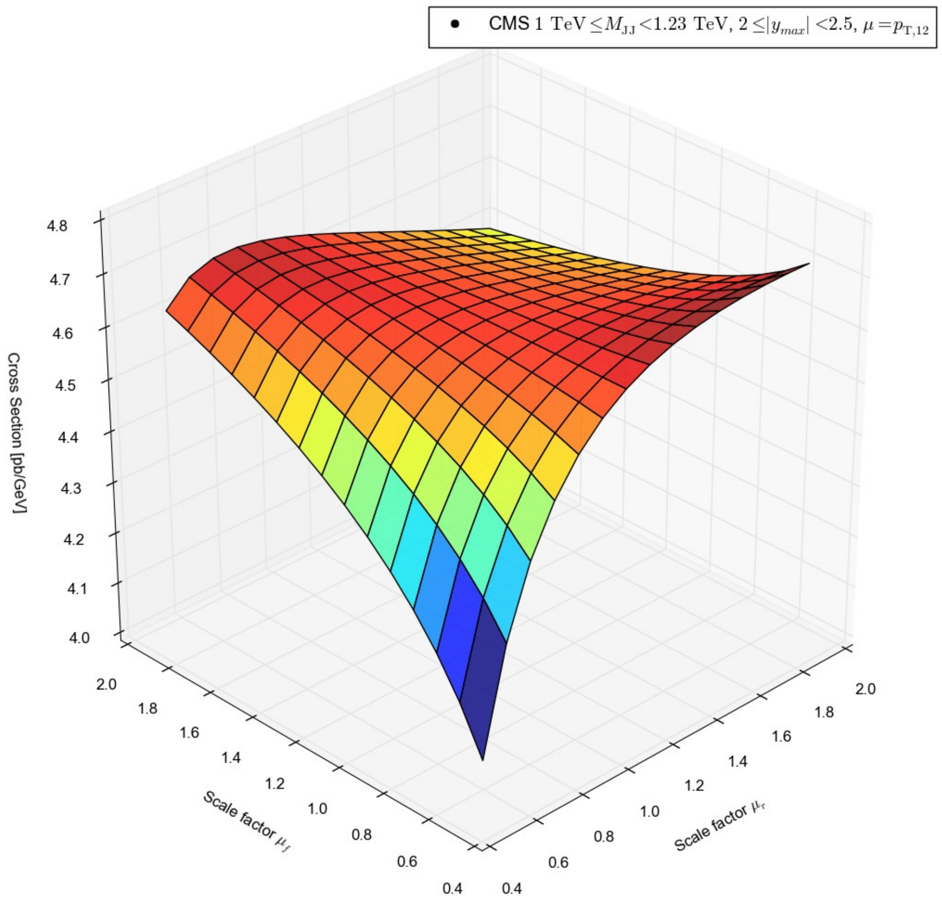
```
fig = plt.figure(figsize=(13,13))

… plotting details
ax.set_ylabel('Scale factor $\mu_F$')
ax.set_xlabel('Scale factor $\mu_R$')
ax.set_zlabel('Cross Section [pb/GeV]')
plt.show()
… plotting details
```

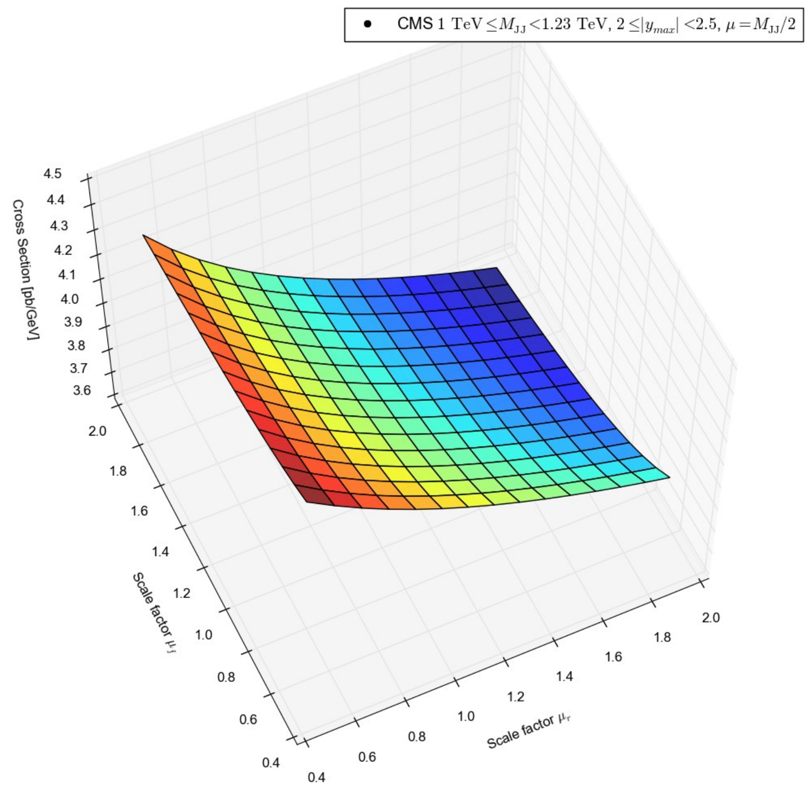
Extra slide: CMS dijet mass

Central scale: μ = <pT$_{1,2}$>

Outer |y_{max}| bin!



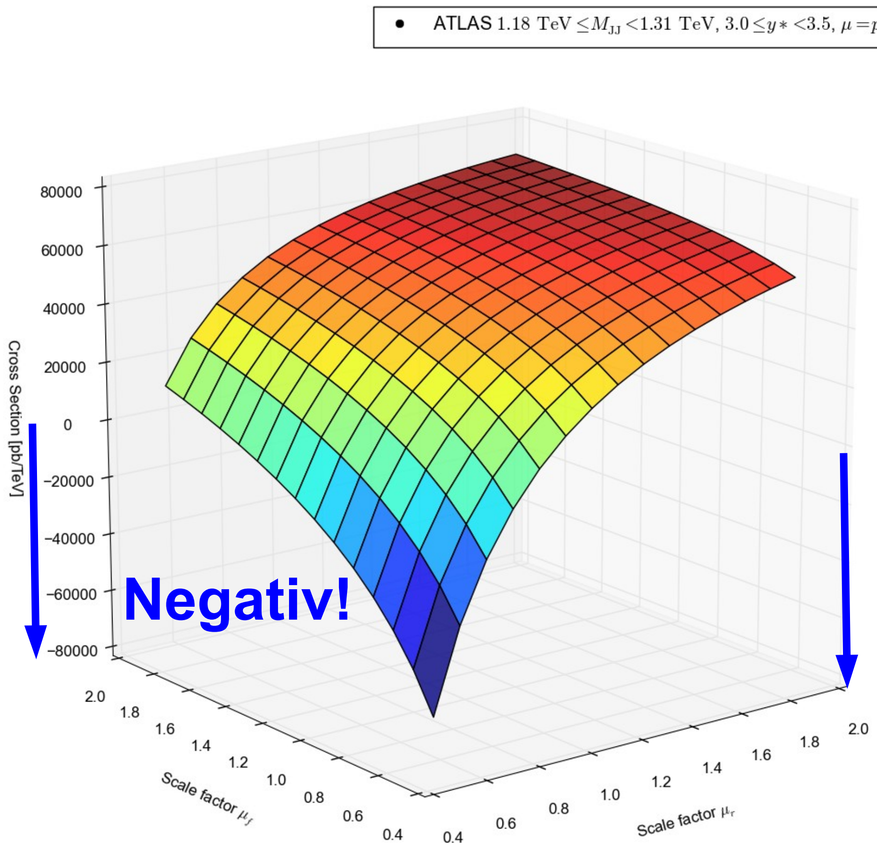
Central scale: μ = M$_{JJ}$/2



Grids allow plotting full 2D (μ_R,μ_F) dependence

Central scale: μ = pT_{max}

Outer y* bin!

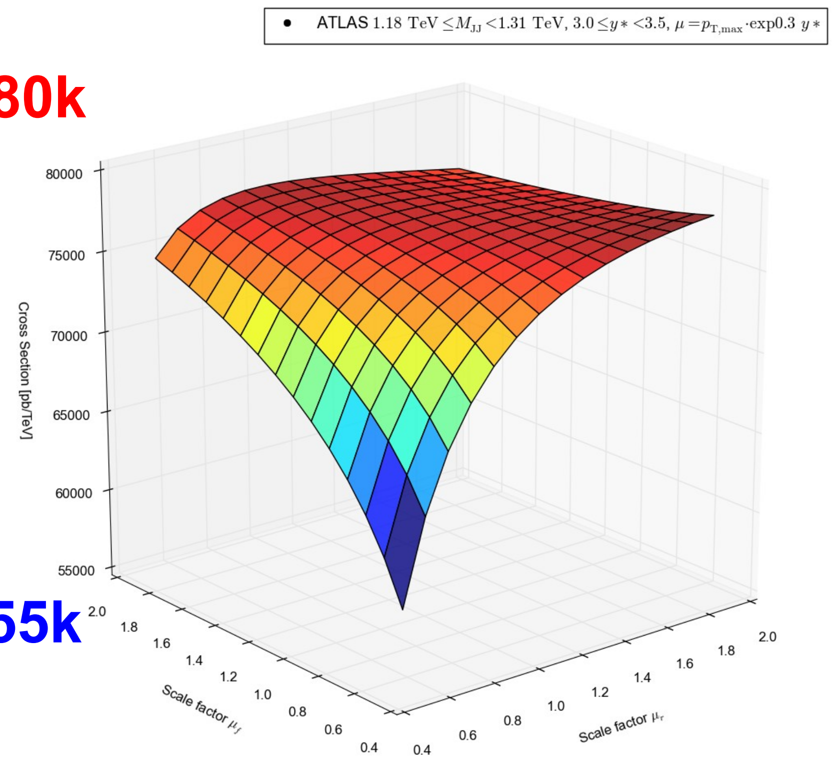


+80k

-80k

Negativ!

Central scale: μ = pT_{max} · exp(0.3 y*)



+80k

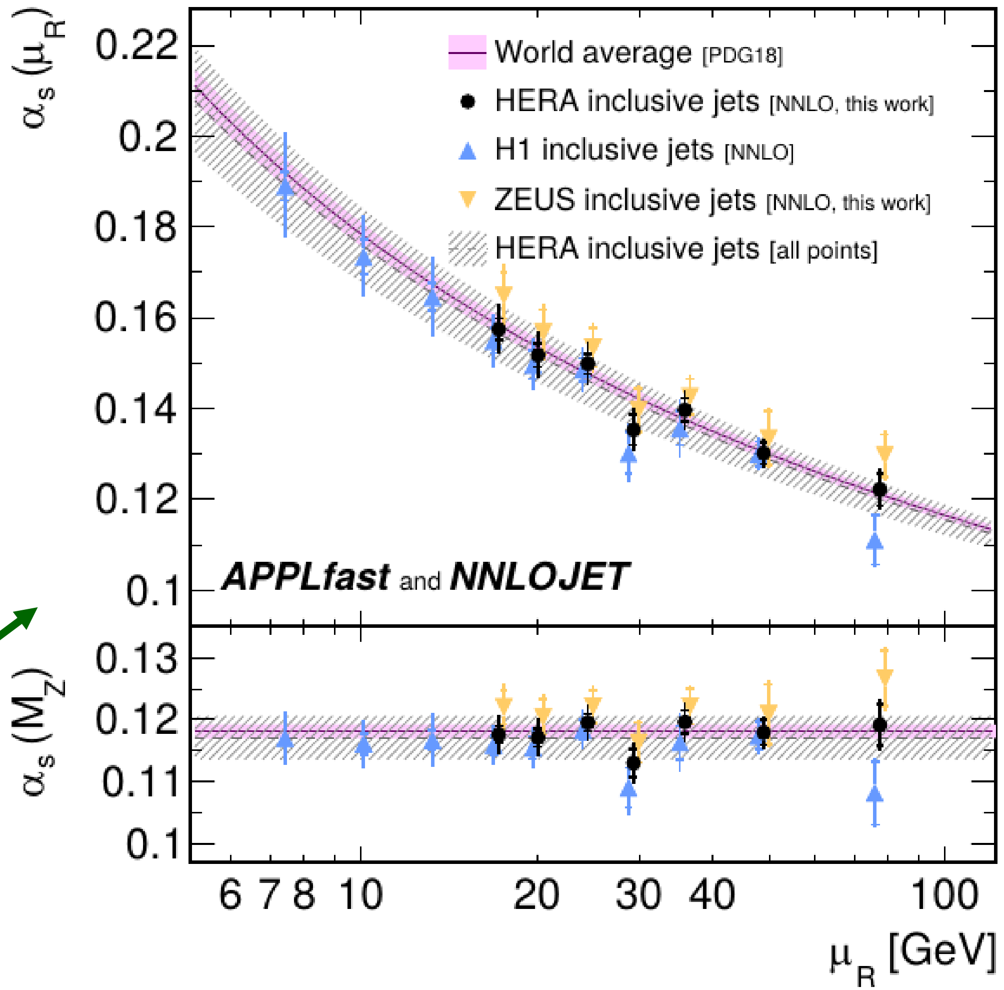
+55k

Grids allow plotting full 2D (μ_R,μ_F) dependence

Successfully used for jets at NNLO in DIS:

- **H1,** **EPJC 77 (2017) 791; Err. EPJC 81 (2021) 738.**
- **APPLfast,** **EPJC 79 (2019) 845; Err. EPJC 81 (2021) 957.**
- **HERAPDF2.0Jets,** **EPJC 82 (2022) 243.**

Example:
Running of α_s from inclusive jets



Interpolation grids available on:
https://ploughshare.web.cern.ch