Determination of the strong coupling constant from inclusive jet cross sections

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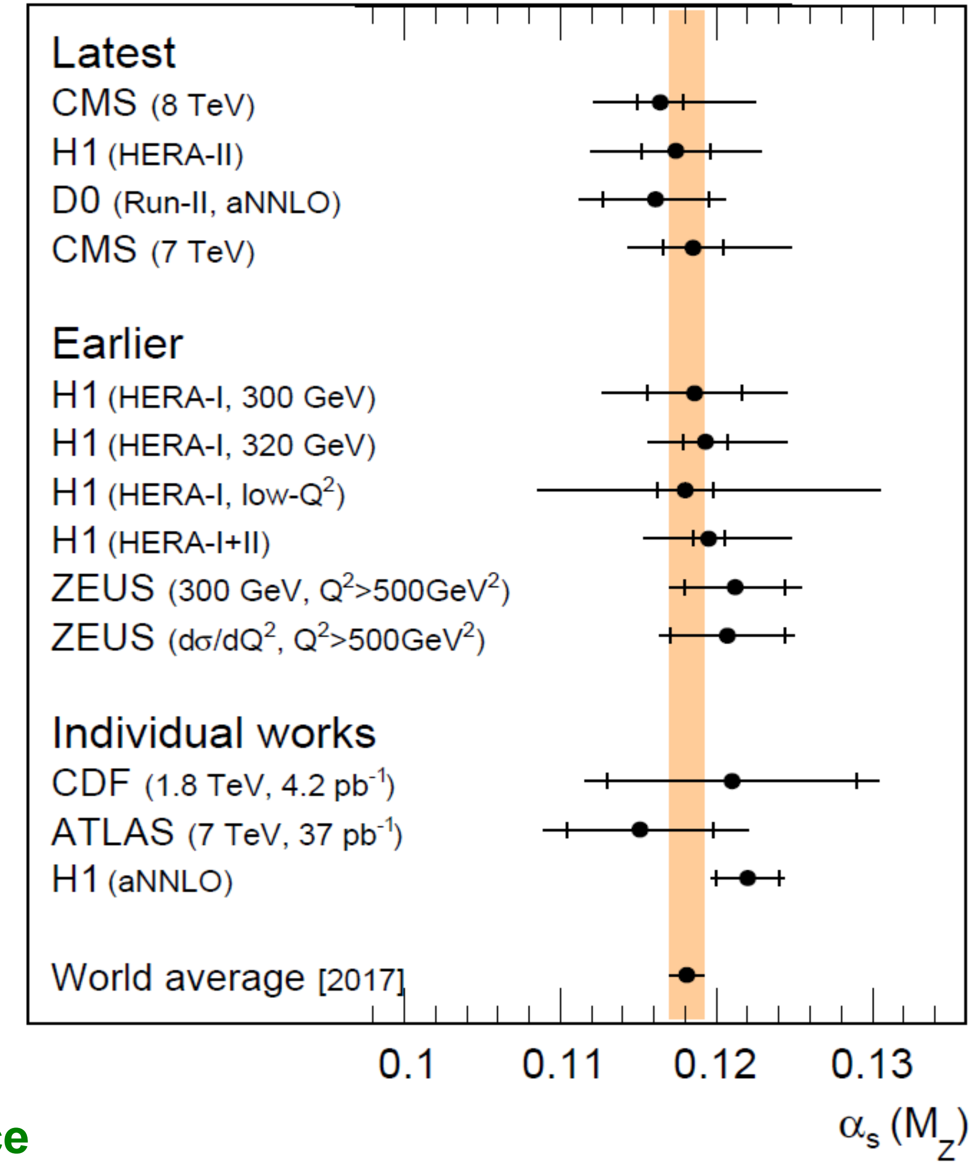
Motivation

- **Why $\alpha_s(M_Z)$?**
  - **Among least known SM parameters**
  - **Important for all processes in hadron-induced collisions**
  - **Needed for QCD precision comparisons**
- **How?**
  - **Start with inclusive jet data**
    - **Wide kinematic range**
    - **Measured in many experiments**
    - **Well defined in fiducial volume of detectors**
  - **Compare to theoretical prediction**
    - **Directly sensitive to $\alpha_s(M_Z)$**
    - **Available at NLO in QCD+EW**
    - **QCD @ NNLO is under way**
    - **Less ambiguous with respect to scale choice**

$\alpha_s(M_Z)$ from inclusive jets



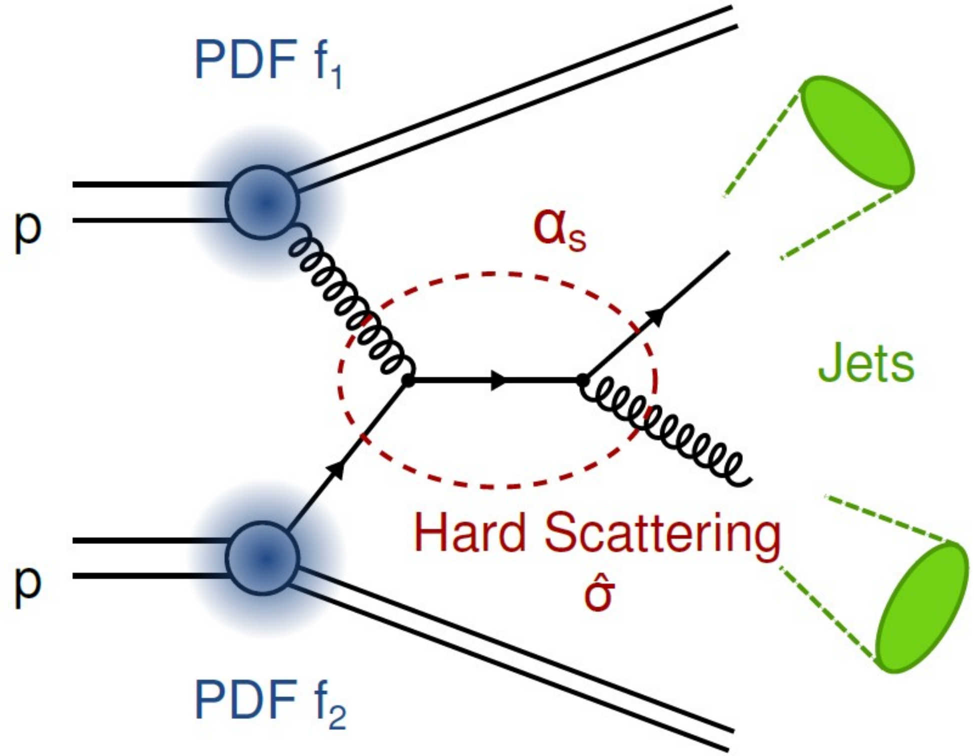
Main ingredients

Data

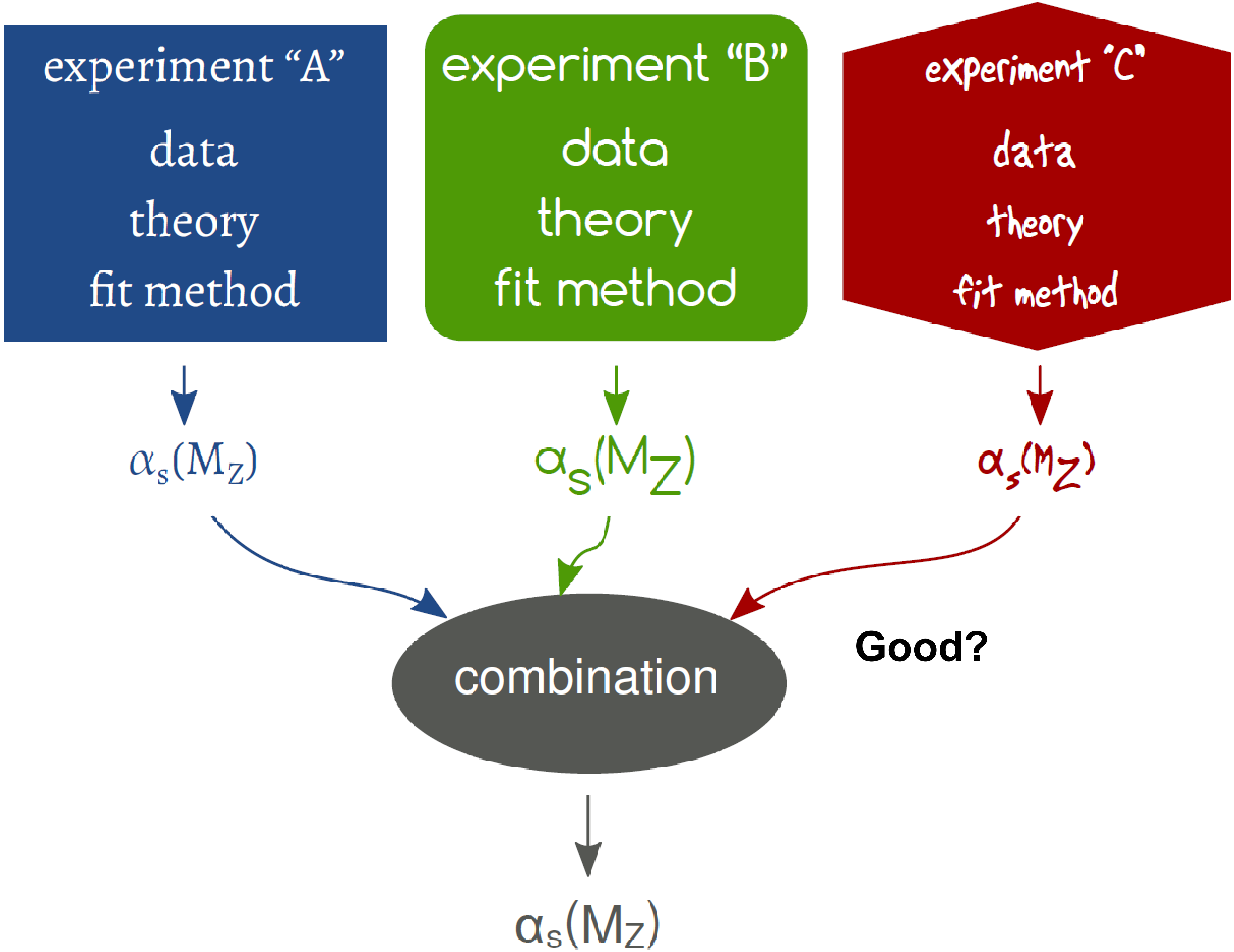
- Abundance of inclusive jet data from various experiments
  - ATLAS, CMS, CDF, D0, H1, ZEUS, STAR, …
- Inclusive jet measurement
  - Phase space, experimental uncertainties, correlations

Theory

- Partonic matrix element $\hat{\sigma}$
  - Sensitive to $\alpha_s(M_Z)$
- Convolution with PDFs
  - Dependence on $\alpha_s(M_Z)$

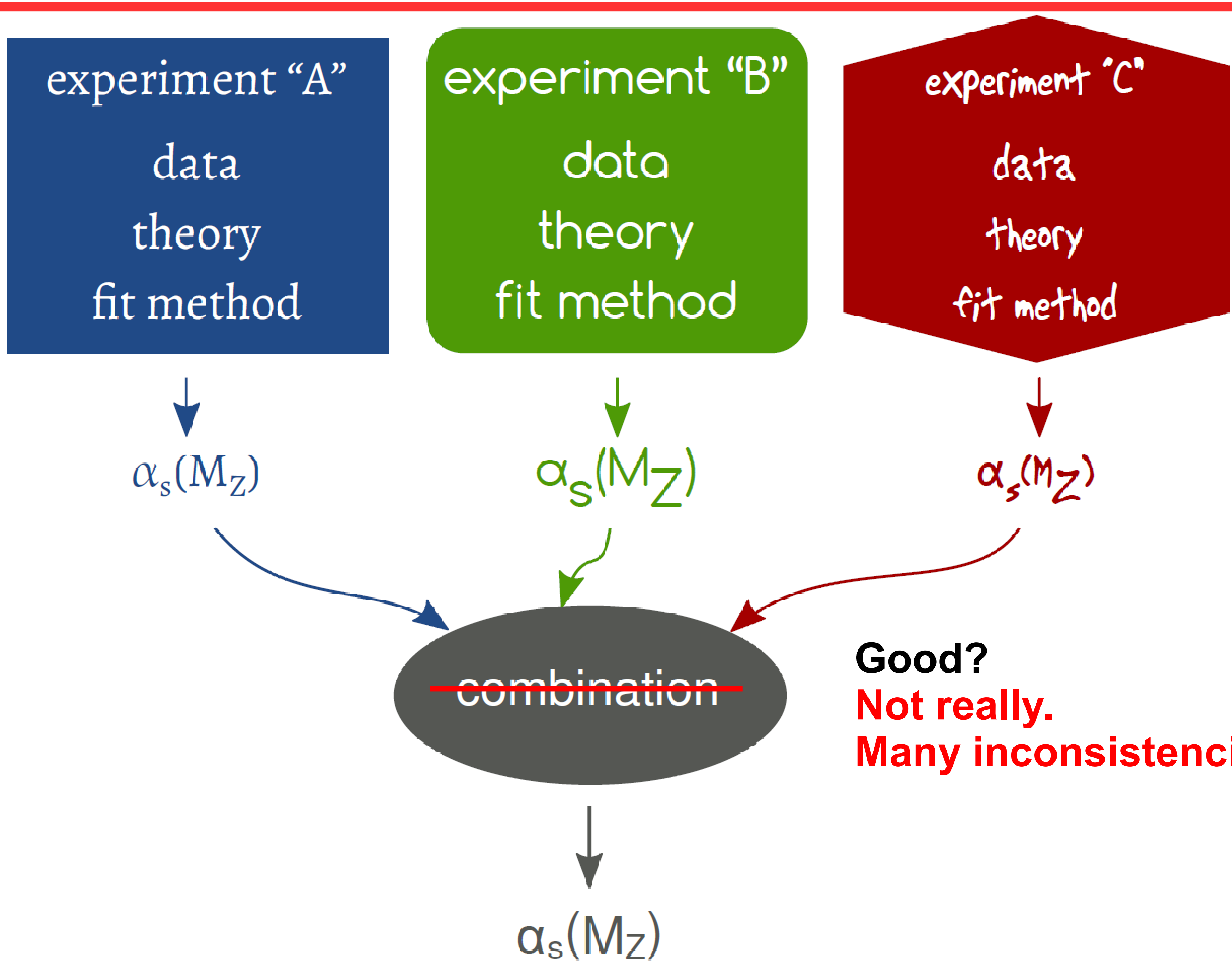


Strategy?



Good?

Strategy?



Good?
Not really.
Many inconsistencies!

Better strategy

experiment "A"
data

experiment "B"
data

experiment "C"
data

consistent theory input

(N)NLO calculation ... non-perturbative corrections ... PDFs ... α_s evolution

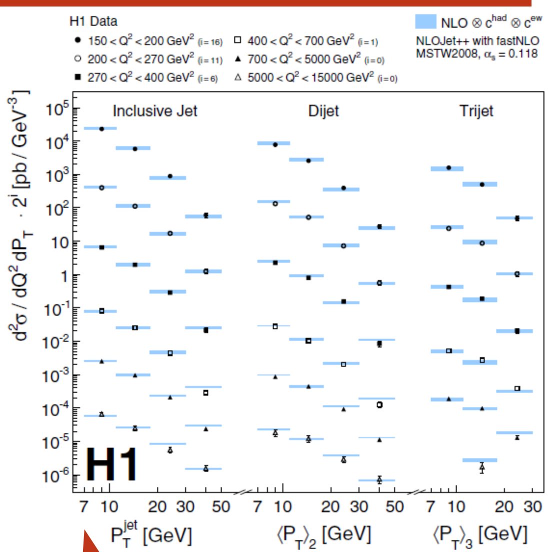
single fit method

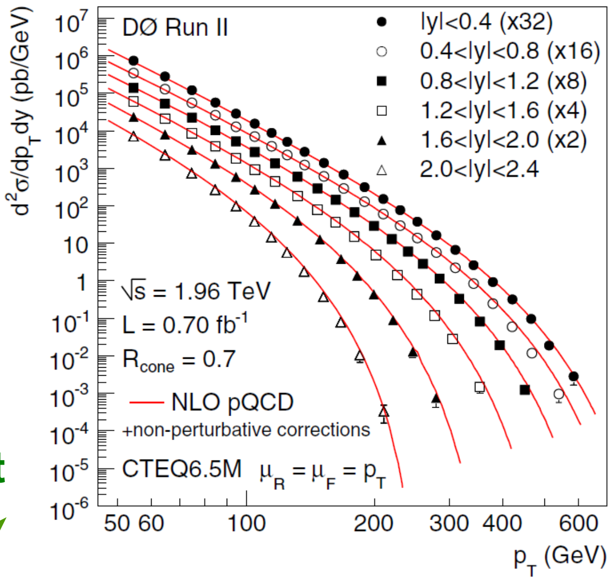
χ^2 definition ... treatment of uncertainties on data, theory ... estimation of uncertainties on α_s

$$\alpha_s(M_Z)$$

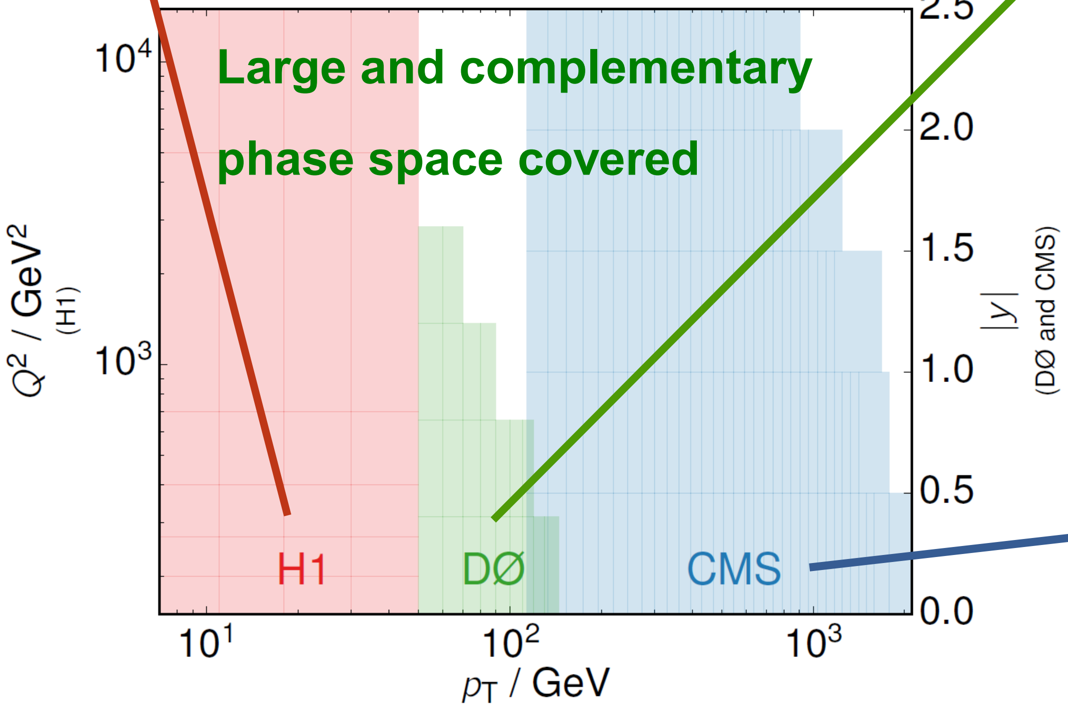
First look: $\alpha_s(M_Z)$ from CMS, D0, H1

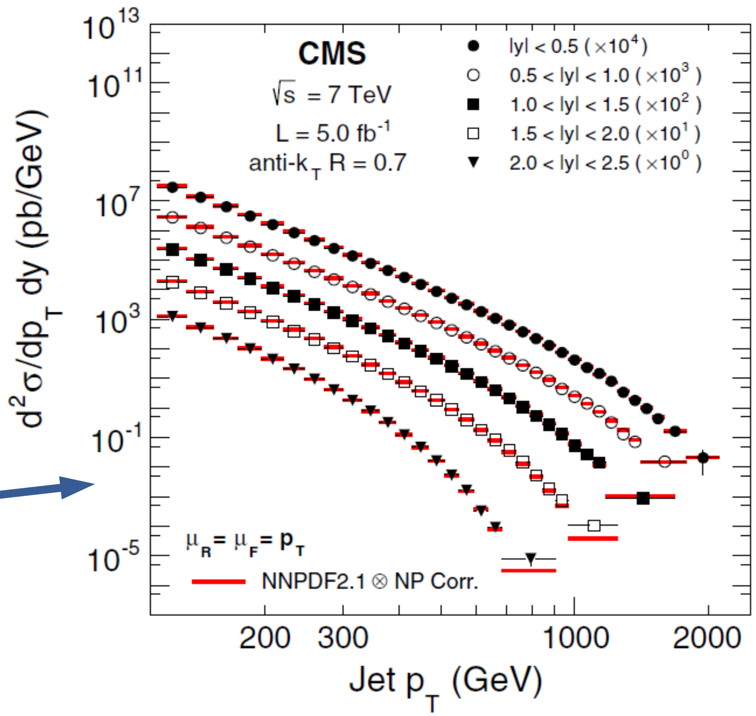
CMS, EPJC 75 (2015) 288.
D0, PRD 80 (2009) 111107.
H1, EPJC 75 (2015) 65.





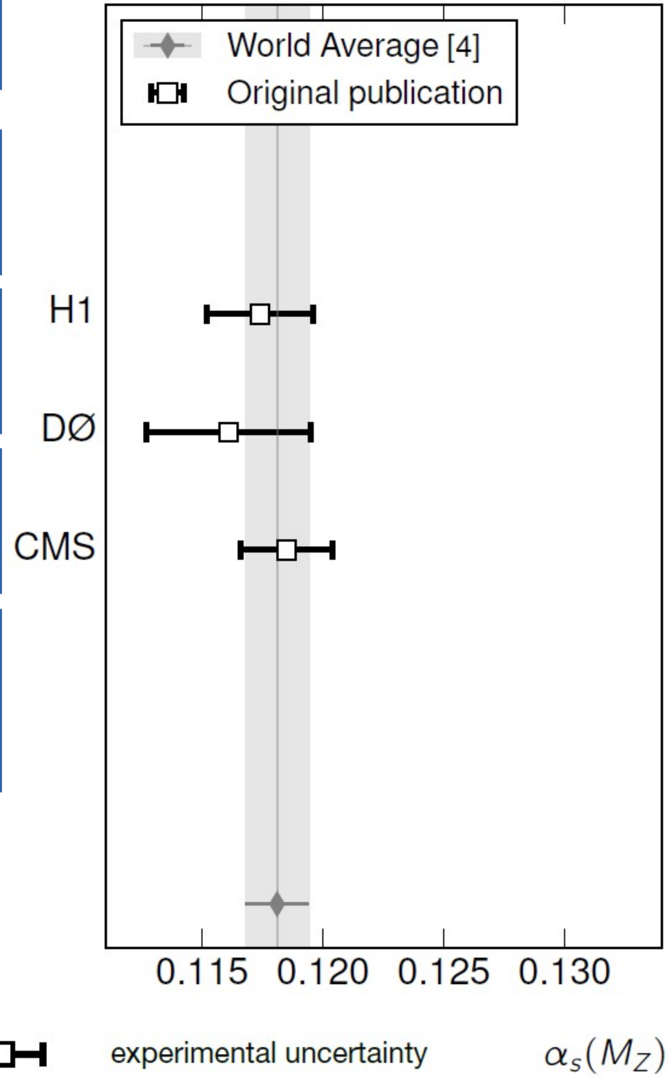
D0 phase space reduced in D0 fit





Comparison of fit setups

H1	DØ	CMS
NLO	approximate NNLO	NLO
direct χ^2 minimization	direct χ^2 minimization	"indirect" χ^2 minimization (fit of parabola to discrete χ^2 points)
conventional χ^2 (**log** data – **log** theory) + relative uncertainties	modified χ^2 + nuisance parameters	conventional χ^2 (data – theory) + absolute uncertainties
linear error propagation	nuisance parameters	• "$\Delta\chi^2 = +1$" • subtraction in quadrature • "offset" method



Could reproduce the original results with → Alpos.

Significant differences in procedures!

- **neglected in naïve combination of results**
- **develop unified fit procedure**

[4] PDG, ChPC 40 (2016) 100001.

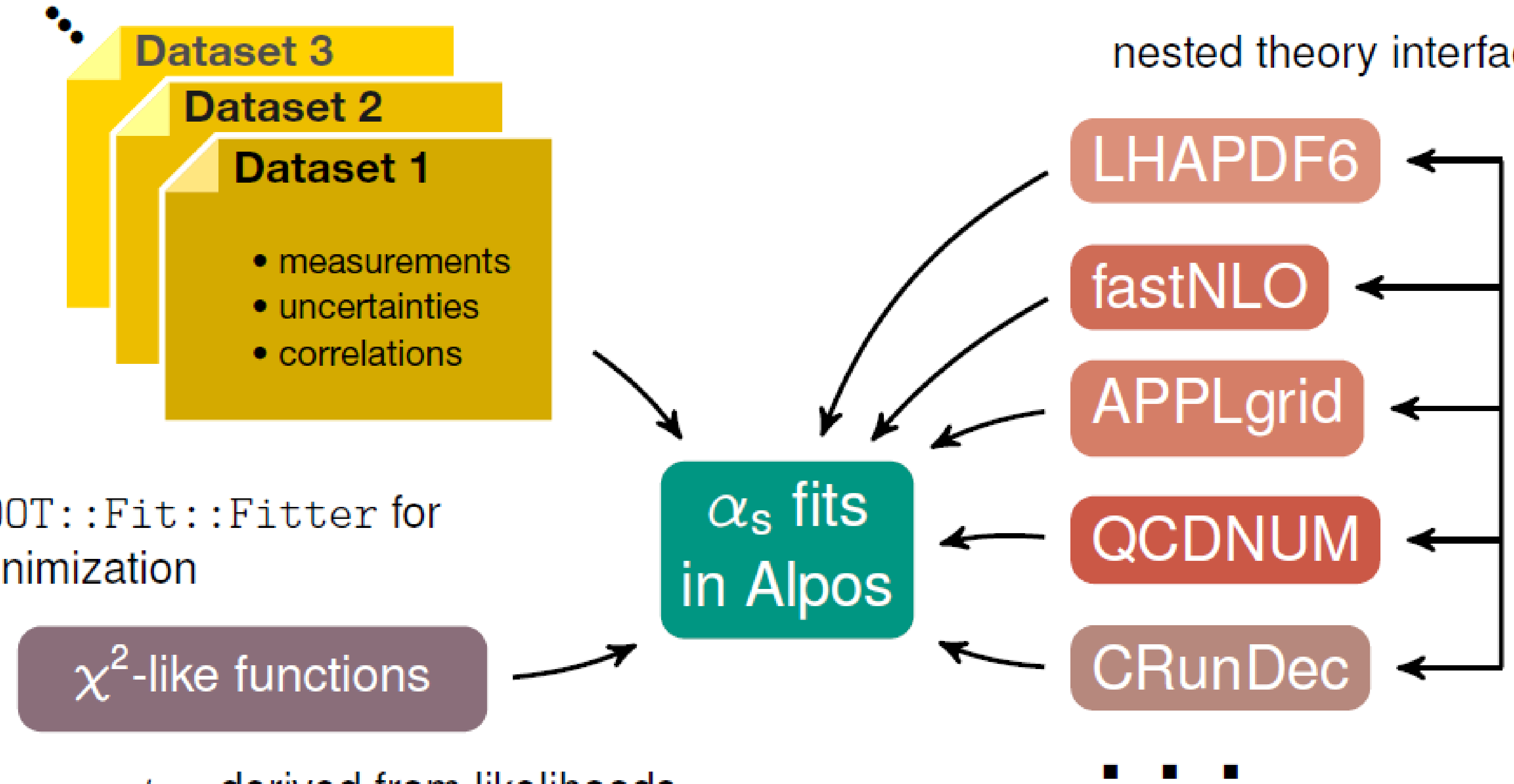
Fitting framework: Alpos

New modular C++ based fitting framework

- used for $\alpha_s(M_Z)$, PDF, and electroweak fits within H1 and CMS

↘ input format: experience with xFitter/HERAFitter

nested theory interfaces ↙



↘ ROOT::Fit::Fitter for minimization

← derived from likelihoods

← multiple models of measurement probability distribution

[https://ekptrac.ekp.kit.edu/svn/Alpos]

Fitting framework: Alpos

New modular C++ based fitting framework

→ E. Eren: CMS jet results, next talk

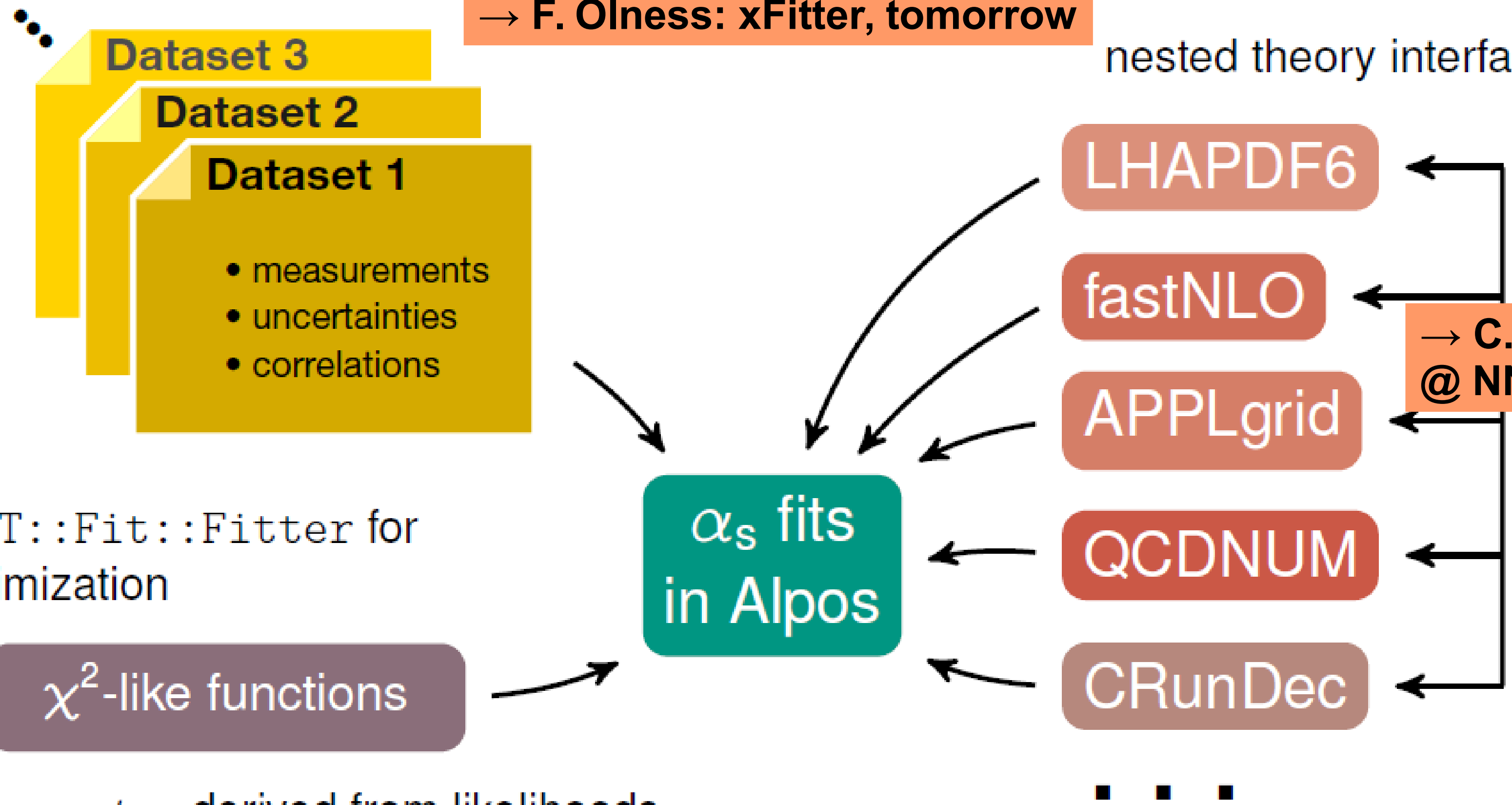
- used for $\alpha_s(M_Z)$, PDF, and electroweak fits within H1 and CMS

→ D. Britzger: DIS jet fits @ NNLO, yesterday

↘ input format: experience with xFitter/HERAFitter

→ F. Olness: xFitter, tomorrow

nested theory interfaces ↙



→ C. Gwenlan: Usage @ NNLO, yesterday

↘ ROOT::Fit::Fitter for minimization

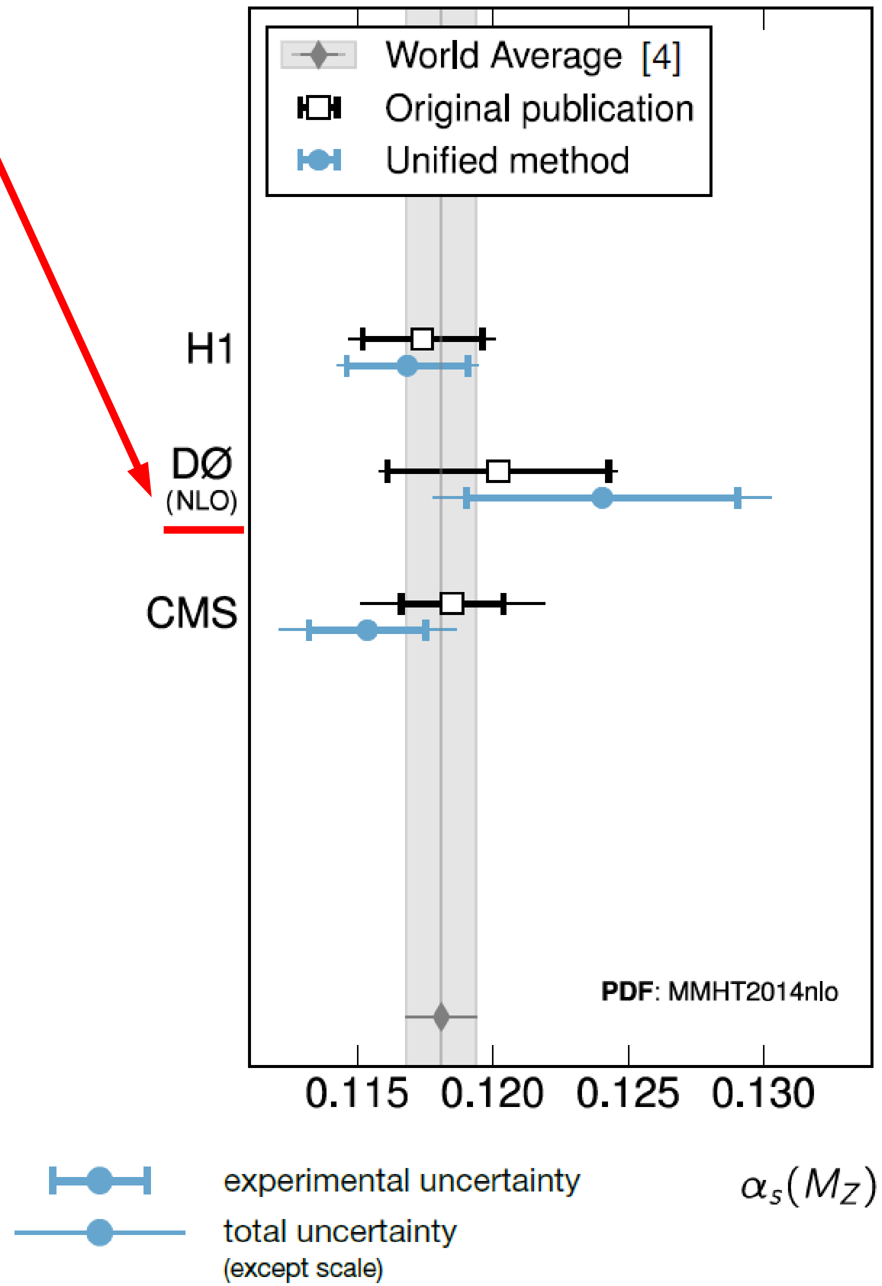
← derived from likelihoods

← multiple models of measurement probability distribution

[https://ekptrac.ekp.kit.edu/svn/Alpos]

Unified fit procedure (1)

theory predictions	consistent (N)NLO
$\alpha_s(M_Z)$ extraction procedure	direct χ^2 minimization
χ^2 definition	conventional χ^2 (**log** data – **log** theory) + relative uncertainties
PDF and non-perturbative uncertainties	included in χ^2 definition
PDF $\alpha_s(M_Z)$ dependence	additional uncertainty on $\alpha_s(M_Z)$

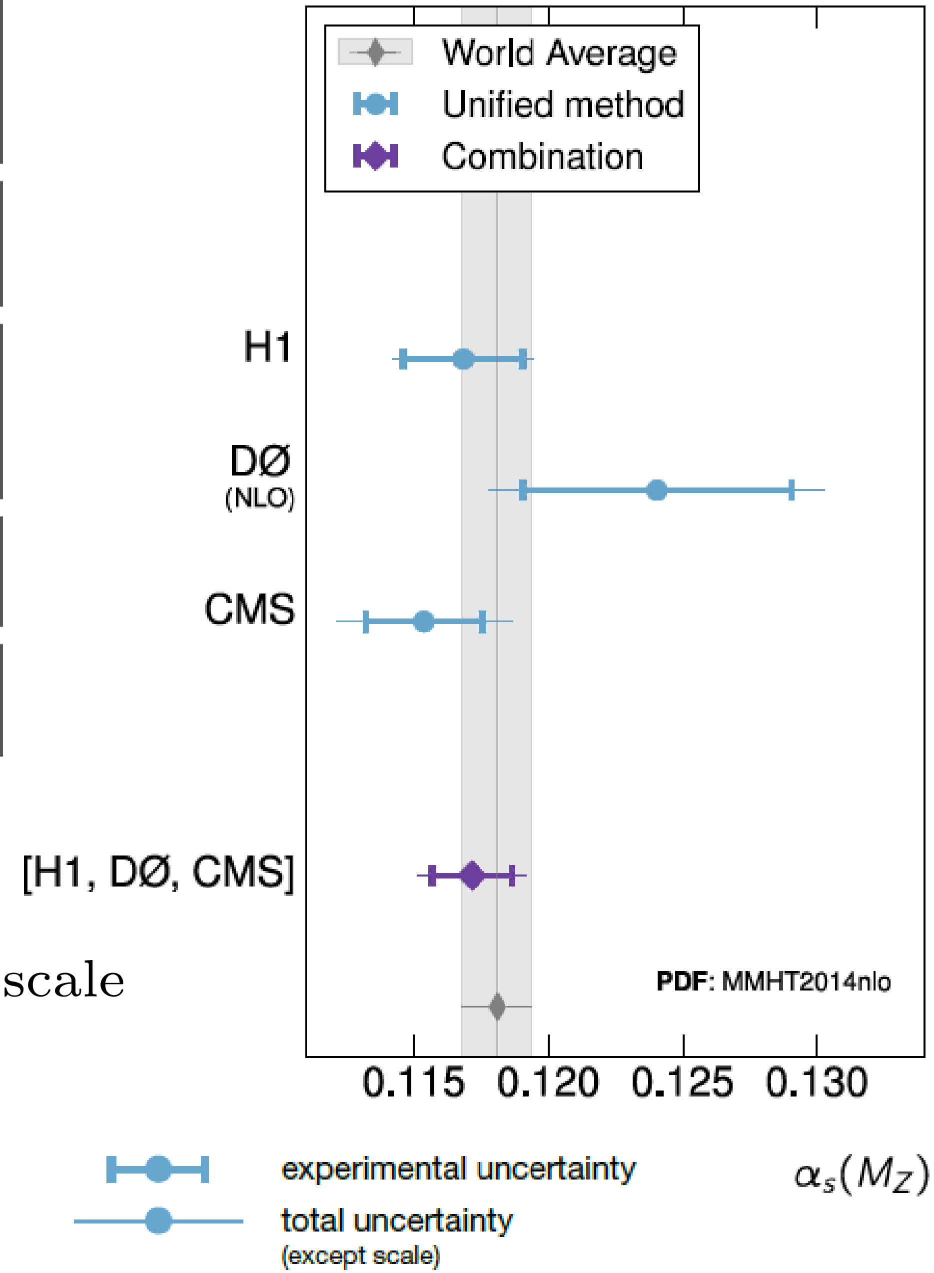


Results using unified fit procedure:

- **compatible with published values within uncertainties**
- **more consistent comparison**
- **simultaneous fit**

Unified fit result (1)

theory predictions	consistent (N)NLO
$\alpha_s(M_Z)$ extraction procedure	direct χ^2 minimization
χ^2 definition	conventional χ^2 (**log** data – **log** theory) + relative uncertainties
PDF and non-perturbative uncertainties	included in χ^2 definition
PDF set+$\alpha_s(M_Z)$ dependence	additional uncertainty on $\alpha_s(M_Z)$



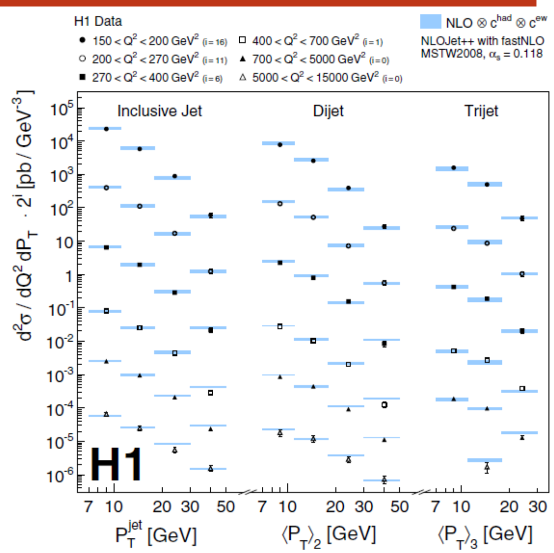
Result of simultaneous fit:

$$\alpha_s(M_Z) = 0.1172(15)_{\text{exp}}\,(14)_{\text{theo w/o scale}}\,(50)_{\text{scale}}$$

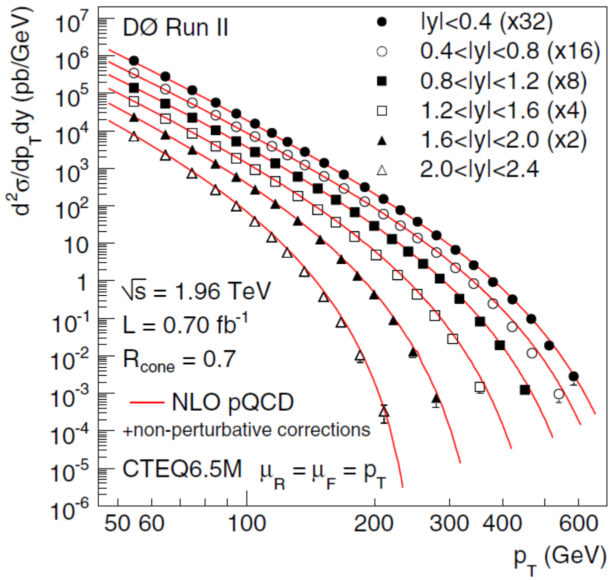
$$[\chi^2_{\text{min}}/\text{ndf} = 152/178 = 0.86]$$

D. Savoiu, Master's thesis, IEKP-KA/2016-25, KIT

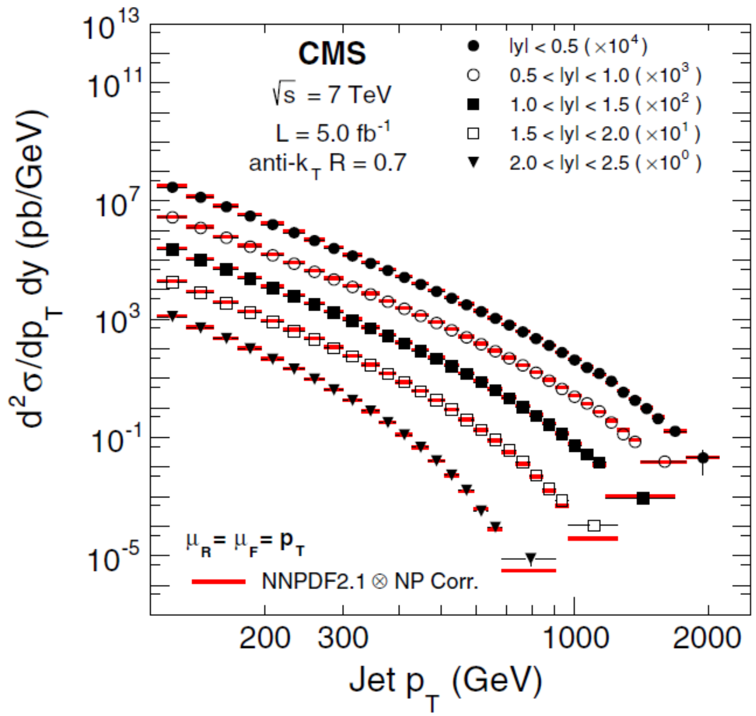
datasets



H1 Data
NLO ⊗ c^had ⊗ c^ew
NLOJet++ with fastNLO
MSTW2008, αs = 0.118
Inclusive Jet
Dijet
Trijet
H1
d²σ / dQ²dP_T · 2^i [pb / GeV⁻³]
P_T^jet [GeV]
⟨P_T⟩_2 [GeV]
⟨P_T⟩_3 [GeV]

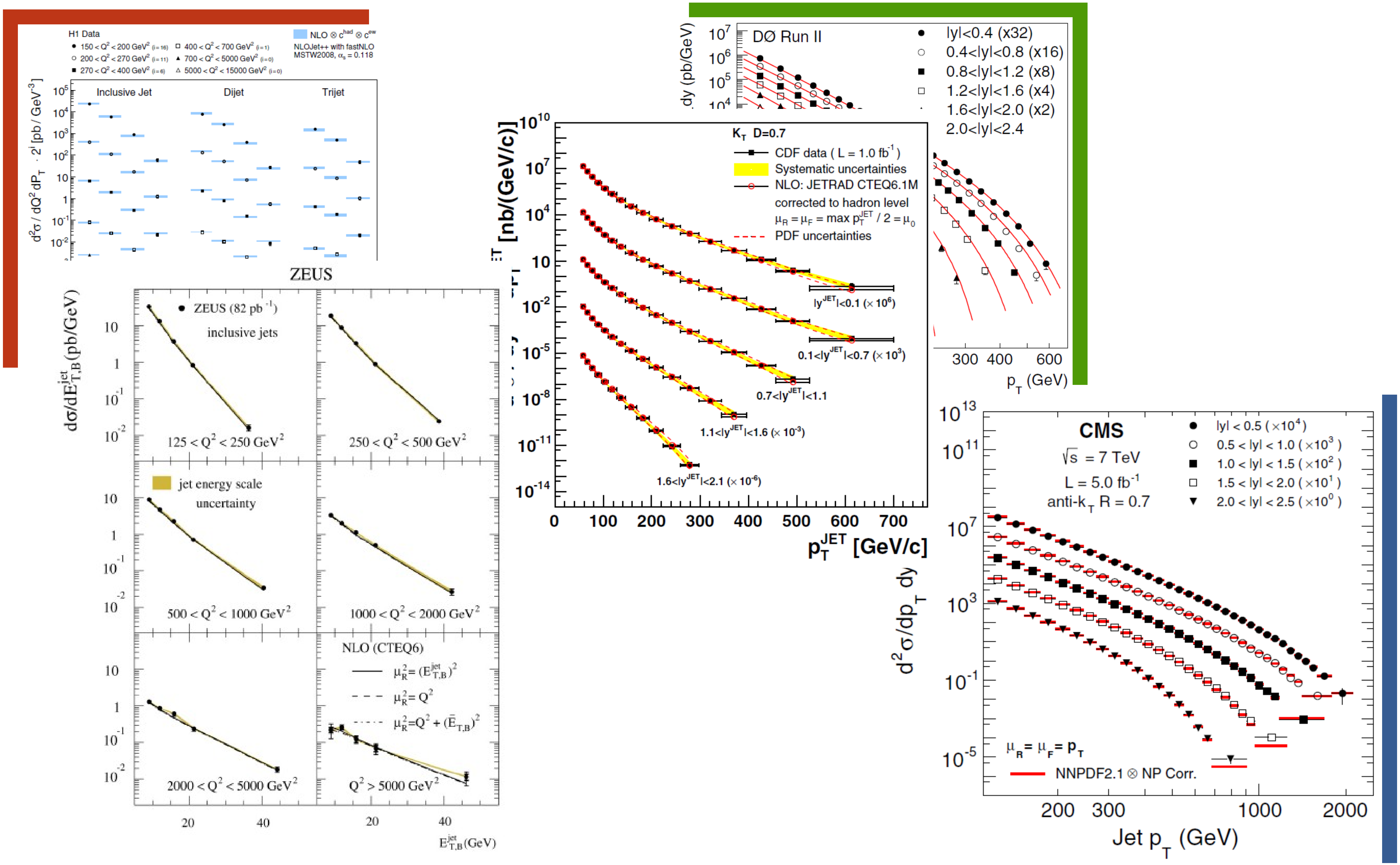


DØ Run II
|y|<0.4 (x32)
0.4<|y|<0.8 (x16)
0.8<|y|<1.2 (x8)
1.2<|y|<1.6 (x4)
1.6<|y|<2.0 (x2)
2.0<|y|<2.4
√s = 1.96 TeV
L = 0.70 fb⁻¹
R_cone = 0.7
NLO pQCD
+non-perturbative corrections
CTEQ6.5M μ_R = μ_F = p_T
d²σ/dp_Tdy (pb/GeV)
p_T (GeV)

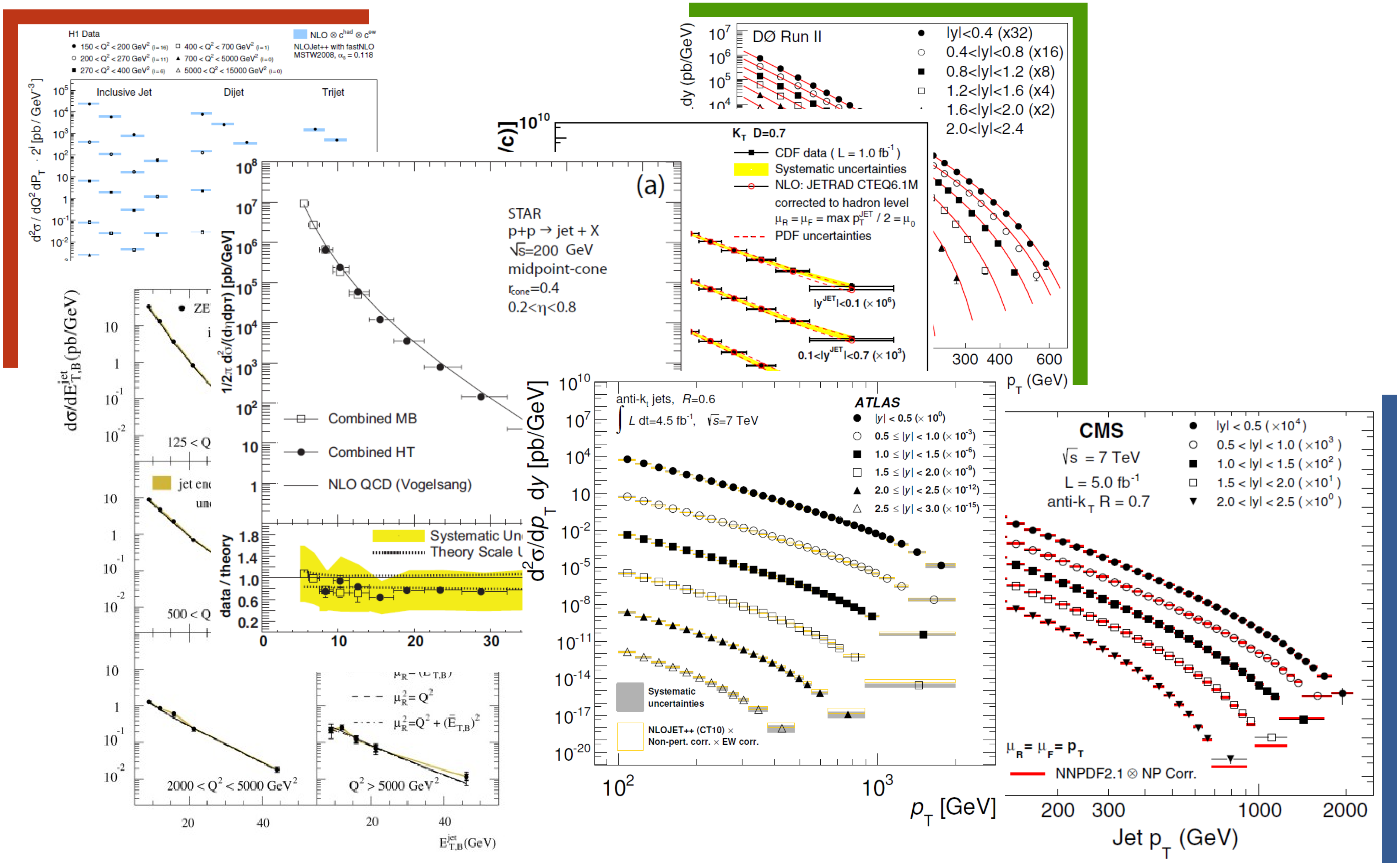


CMS
√s = 7 TeV
L = 5.0 fb⁻¹
anti-k_T R = 0.7
|y| < 0.5 (×10⁴)
0.5 < |y| < 1.0 (×10³)
1.0 < |y| < 1.5 (×10²)
1.5 < |y| < 2.0 (×10¹)
2.0 < |y| < 2.5 (×10⁰)
μ_R = μ_F = p_T
NNPDF2.1 ⊗ NP Corr.
d²σ/dp_T dy (pb/GeV)
Jet p_T (GeV)

more datasets



Add more datasets



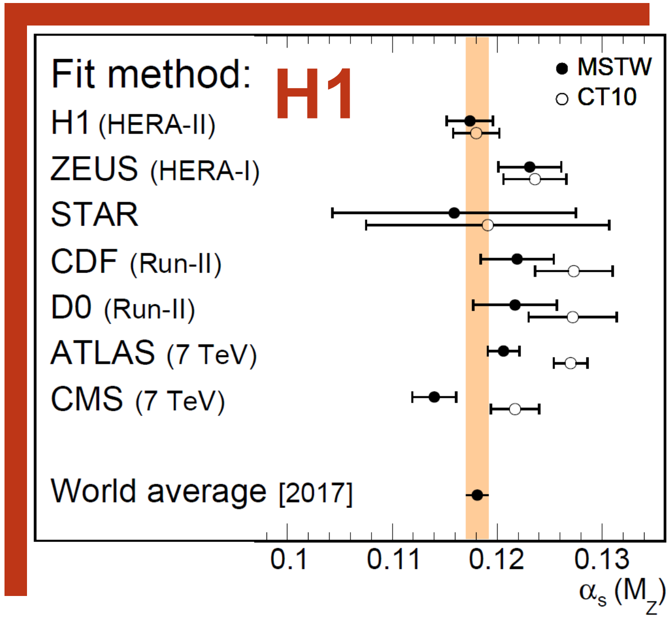
Add more datasets

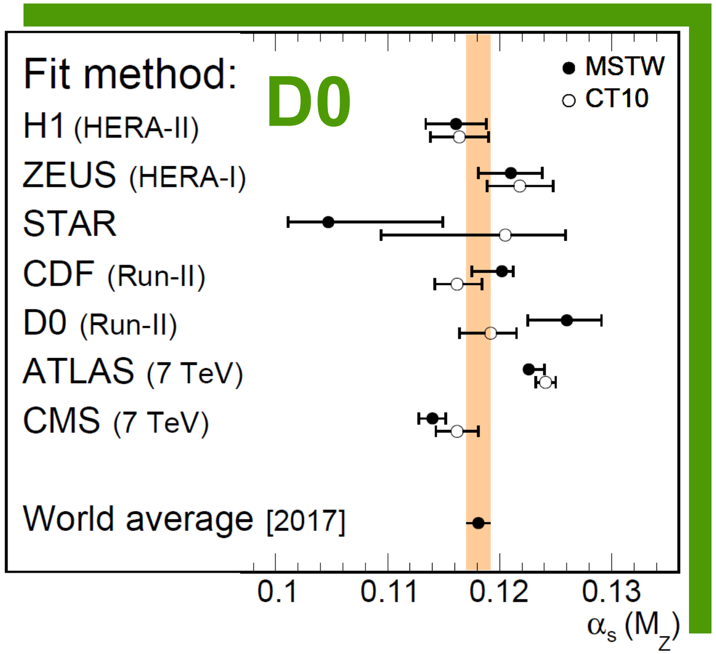
Definition and kinematic range of inclusive jet data sets

Data	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]	No. of points	jet algorithm	p_T-range [GeV]	Other kinematic ranges
H1 [2]	0.319	0.35	24	k_t (R=1.0)	$7 < p_T < 50$	$150 < Q^2 < 15\,000\,\mathrm{GeV}^2$ $0.2 < y_{DIS} < 0.7$ $-1.0 < \eta^{jet}_{lab} < 2.5$
ZEUS [4]	0.318	0.082	30	k_t (R=1.0)	$E_T > 8$	$Q^2 > 125\,\mathrm{GeV}^2$ $\lvert\cos\gamma_h\rvert < 0.65$ $-2.0 < \eta^{jet}_{lab} < 1.5$
STAR [7]	0.20	0.0003	9	midp. (R=0.4)	$7.6 < p_T < 48.7$	$0.2 < \eta < 0.8$
CDF [5]	1.96	1.0	76	k_t (R=0.7)	$54 < p_T < 527$	$\lvert y\rvert < 2.1$
D0 [1]	1.96	0.7	110	midp. (R=0.7)	$50 < p_T < 665$	$\lvert y\rvert < 2.0$
ATLAS [6]	7	4.5	140	anti-k_t (R=0.6)	$100 < p_T < 1992$	$\lvert y\rvert < 3.0$
CMS [3]	7	5.0	133	anti-k_t (R=0.7)	$114 < p_T < 2116$	$\lvert y\rvert < 3.0$

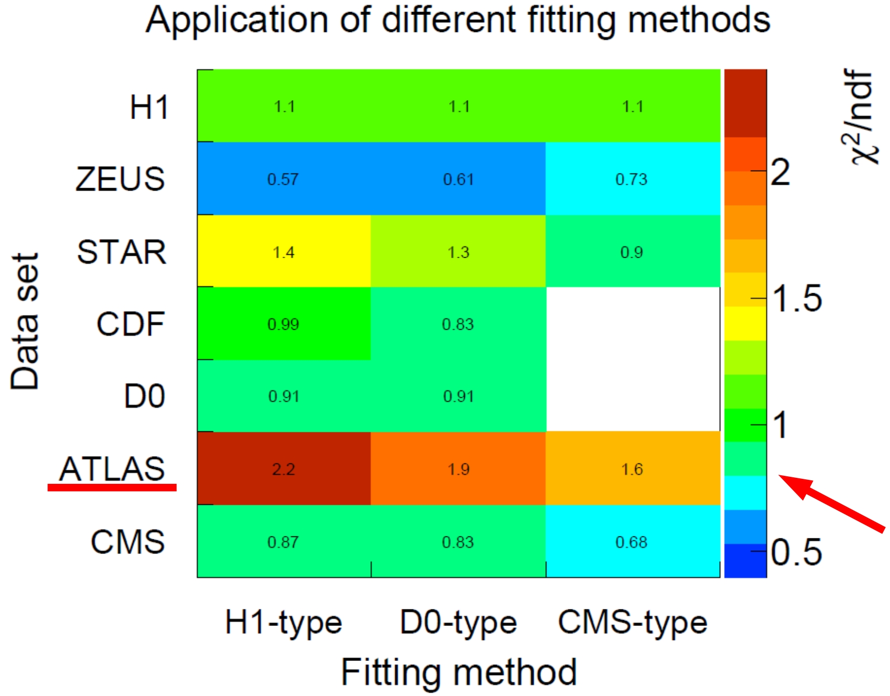
[1] D0, PRD 80 (2009) 111107,
[2] H1, EPJC 75 (2015) 65,
[3] CMS, EPJC 75 (2015) 288,
[4] ZEUS, NPB 765 (2007) 1,
[5] CDF, PRD 75 (2007) 092006,
[6] ATLAS, JHEP 02 (2015) 153,
[7] STAR, PRL 97 (2006) 252001.

Original fit procedures





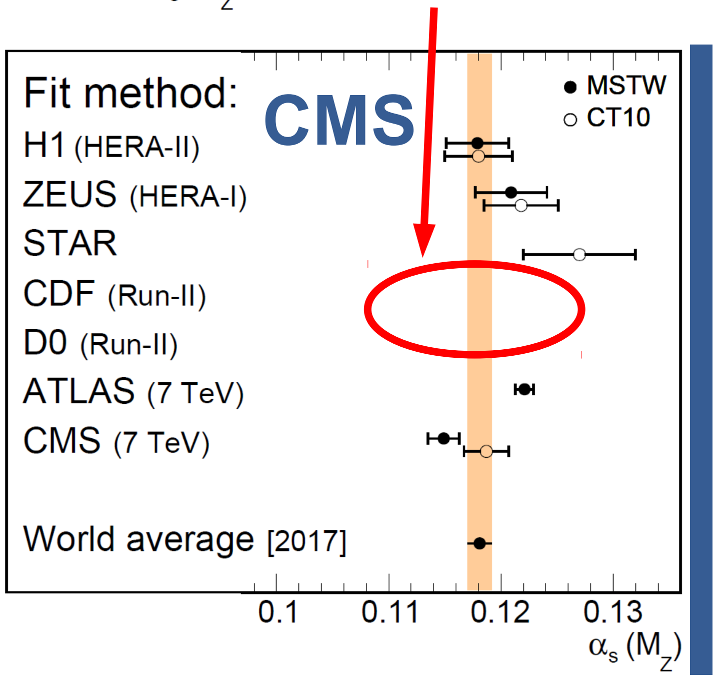
Experimental uncertainties only



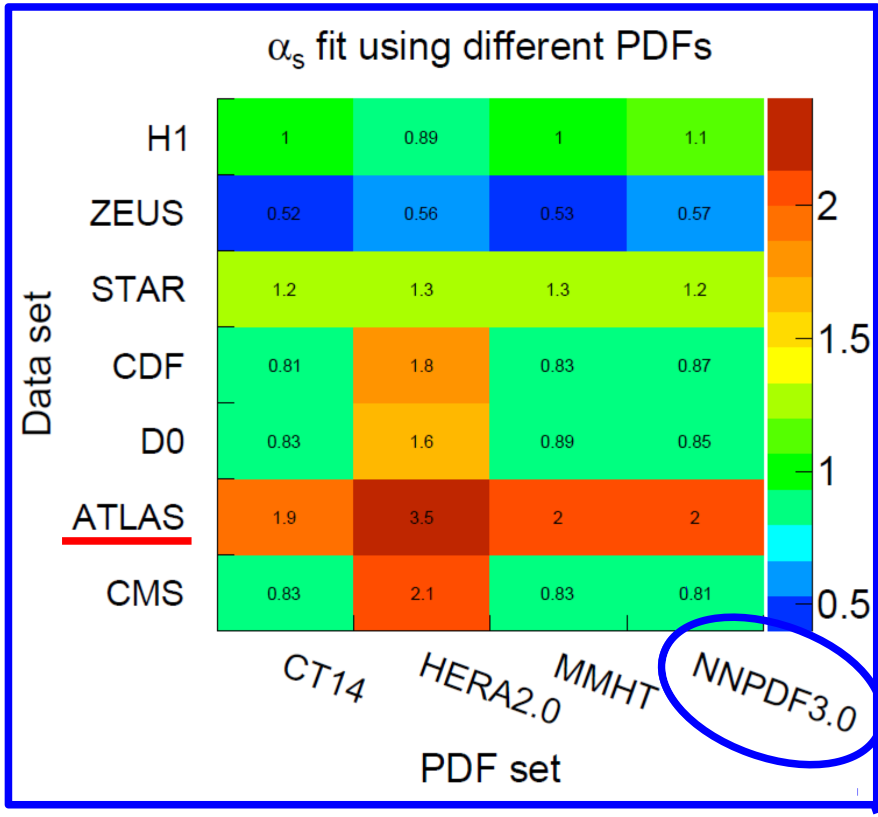
→ J. Dandoy: ATLAS 8TeV jets, this session

Not really new: ATLAS 7 TeV data do not fit well for any method

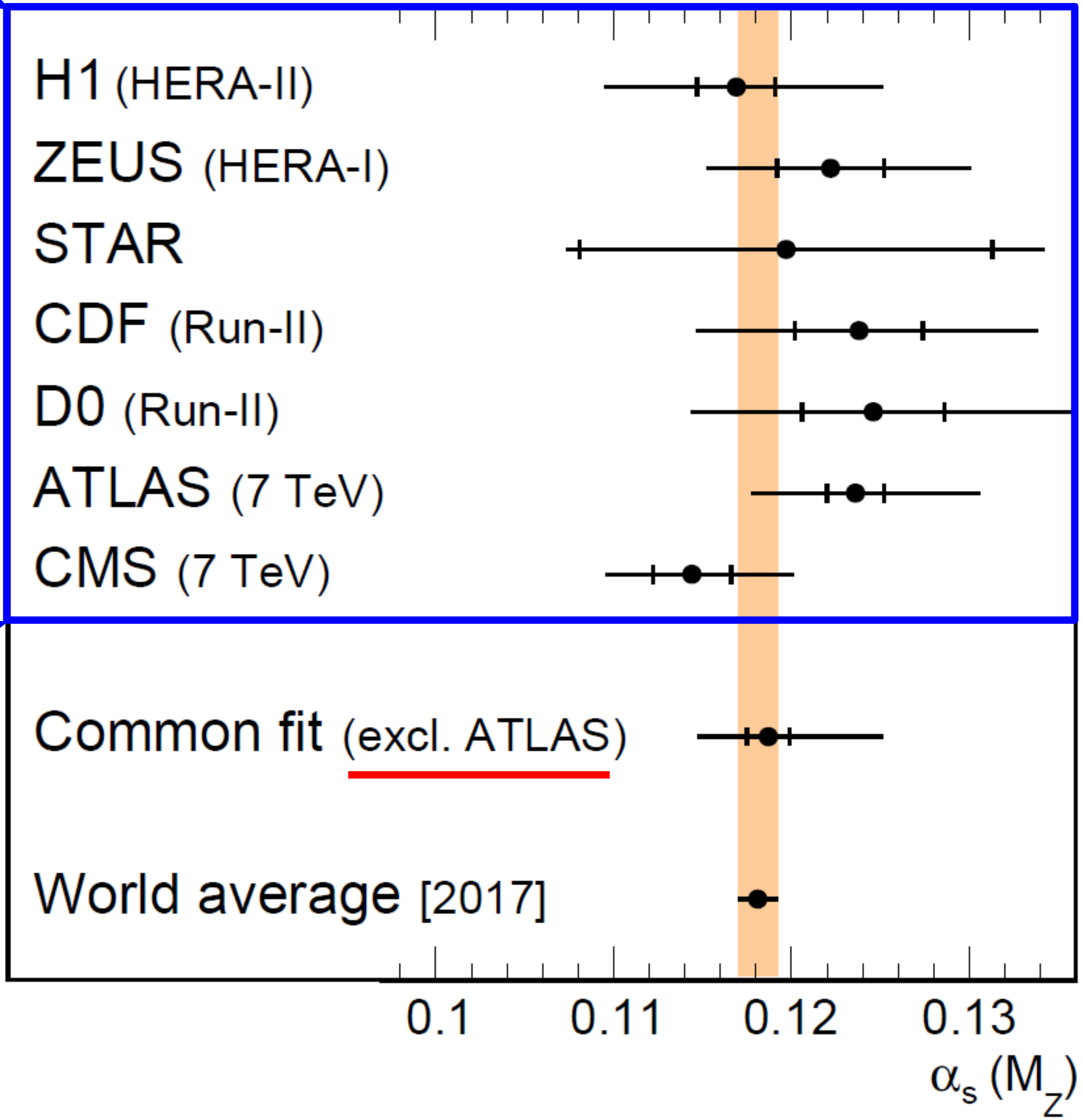
Cannot be fitted for these PDFs with this method



Unified fit procedure (2)



Experimental & total uncertainties



Same issue with ATLAS 7 TeV here
→ final result without

Assumed correlations between datasets:
experimental: uncorrelated
theoretical: correlated (except NP)

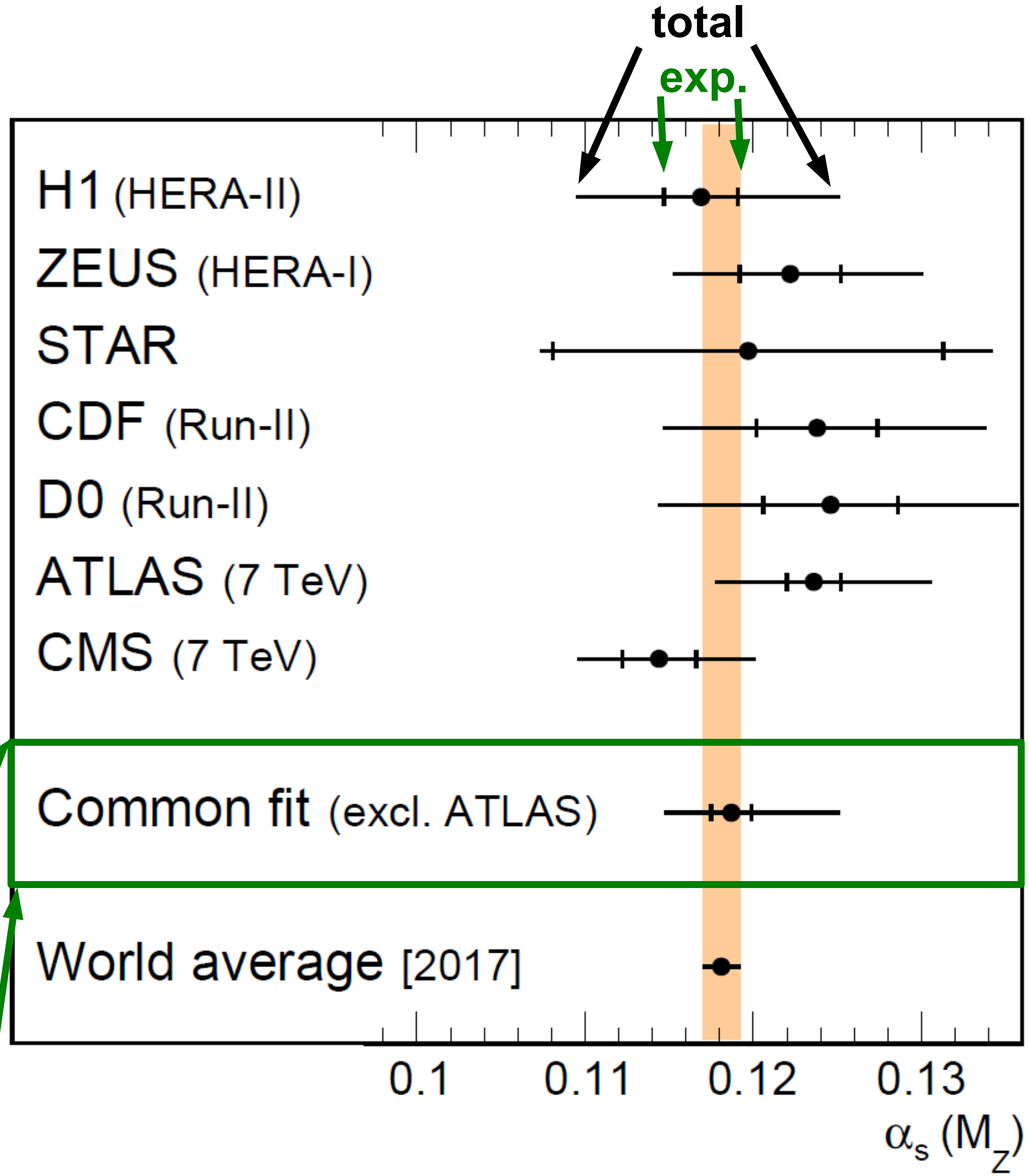
Unified fit result (2)

Simultaneous fit to H1, ZEUS, STAR, CDF, D0, and CMS

- consistent result
- reduced experimental uncertainty
- scale uncertainty (NLO) dominating in full uncertainty breakdown

$$\alpha_s(M_Z) = 0.1187(\pm 12)_{\mathrm{exp}}\,(\pm 5)_{\mathrm{NP}}\,(\pm 6)_{\mathrm{PDF}}\,\left({}^{+18}_{-3}\right)_{\mathrm{PDFset}}\,\left({}^{+11}_{-8}\right)_{\mathrm{PDF}\alpha_s}\,\left({}^{+59}_{-38}\right)_{\mathrm{scale}}$$

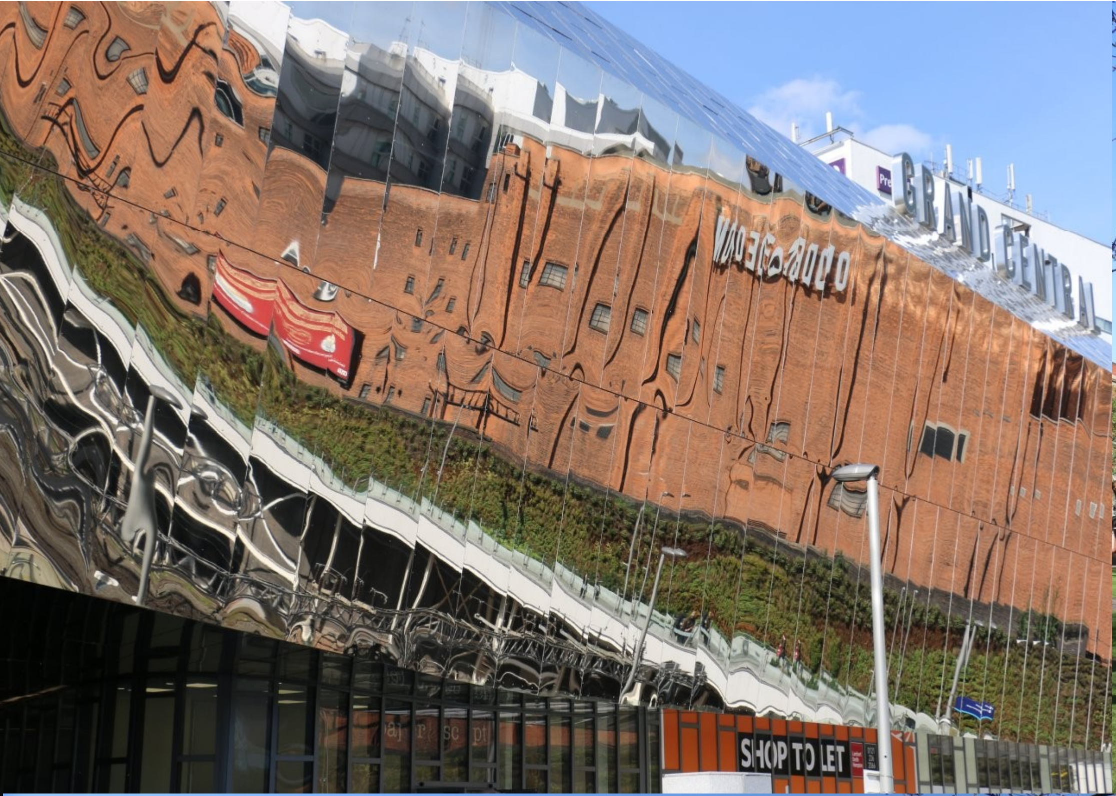
$$[\chi^2_{\mathrm{min}}/\mathrm{ndf} = 0.87]$$



Summary & Outlook

- Reproduced published $\alpha_s(M_Z)$ fit results exactly
- Developed a unified, more robust fit procedure
- Implemented in flexible way within Alpos project [https://ekptrac.ekp.kit.edu/svn/Alpos]
- Open for further participation
- Use better theory, in particular NNLO
- Add further datasets & observables
- Perform phenomenological studies on correlations, scales, NP corrections, ...

Thank you for your attention!

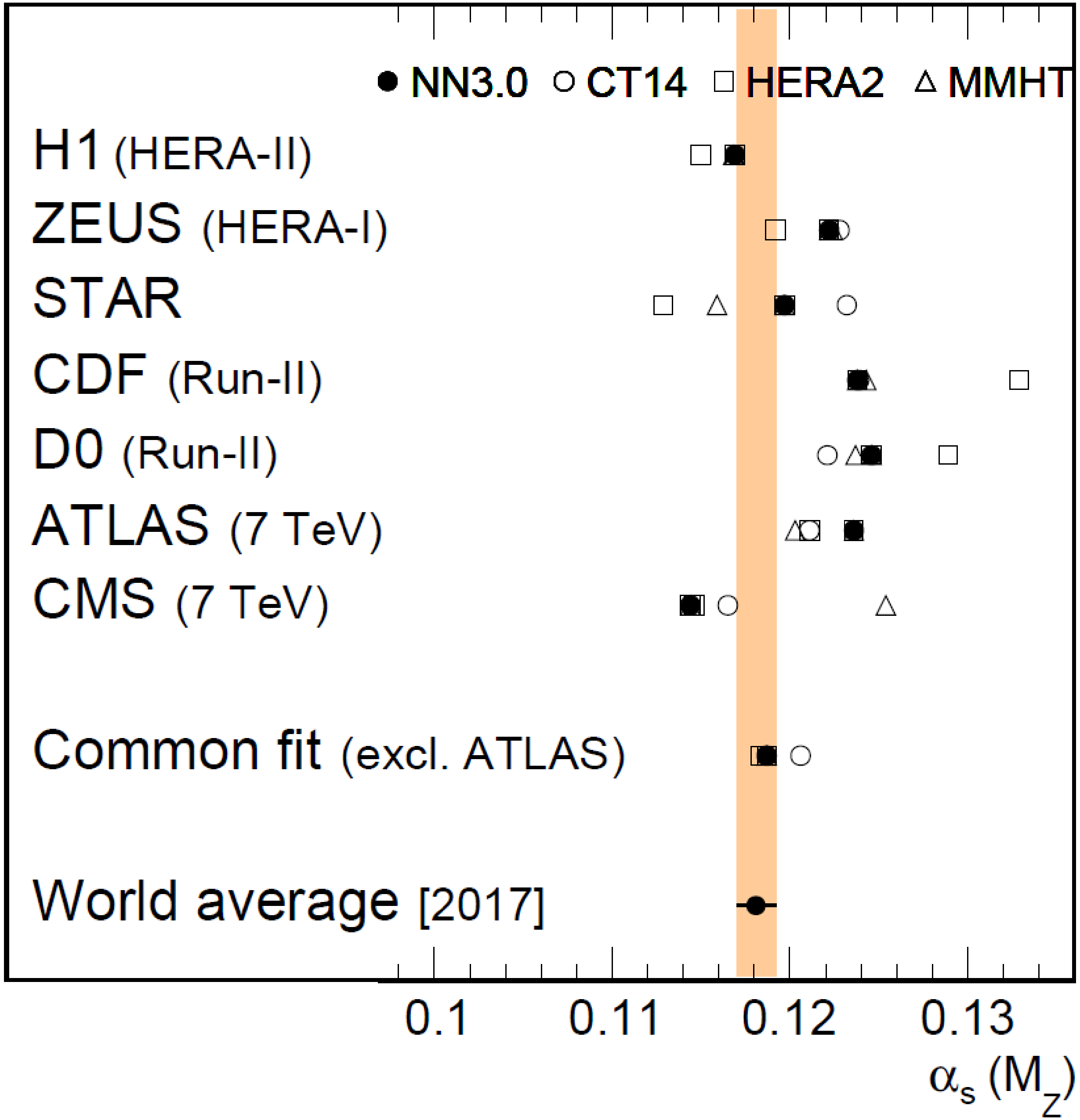

GRAND CENTRAL
SHOP TO LET



Thank you
Birmingham
GRAND CENTRAL
SHOP TO LET

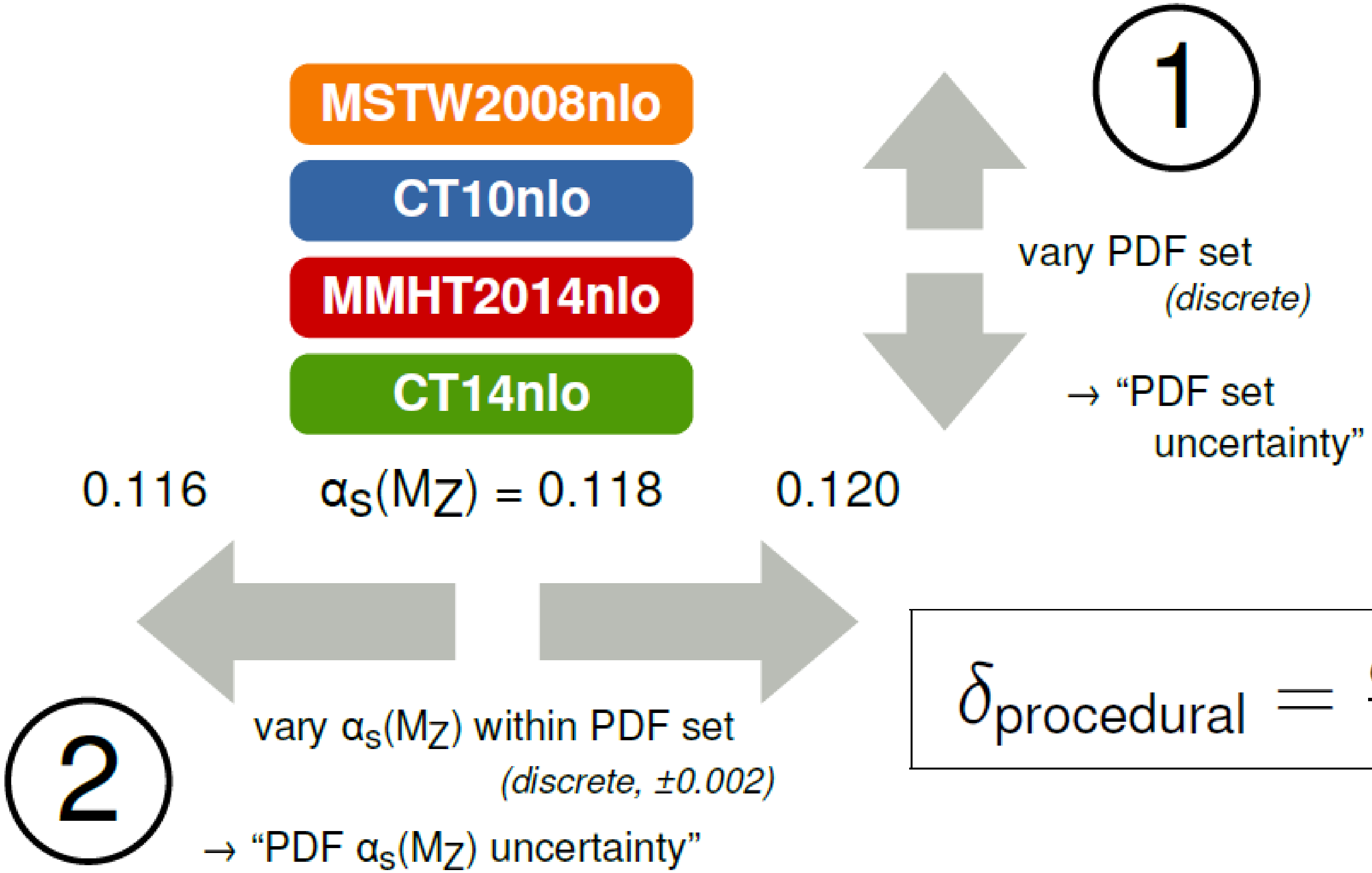
Backup

PDF dependence



Additional “PDF” uncertainties

- additional PDF-related procedural uncertainties arise in addition to “PDF uncertainties” themselves:
  1. choice of PDF set
  2. choice of $\alpha_s(M_Z)$ assumed when fitting PDF



$$\delta_{\text{procedural}} = \frac{\alpha_s^{(\text{max})} - \alpha_s^{(\text{min})}}{2}$$

Method comparison

H1 fit methodology

$$\chi^2_{\text{H1}} \rightarrow \sum_{ij} (\ln m_i - \ln t_i) \left[\mathbf{V}^{-1}_{(\text{rel})} \right]_{ij} (\ln m_j - \ln t_j)$$

- iterative χ^2 minimization (*MINUIT*)
  - determine central value with experimental uncertainties only
  - assume PDF without $\alpha_s(M_Z)$ dependence; use MSTW2008nlo with $\alpha_s(M_Z) = 0.118$
- additional theory uncertainties: NP corr., PDF, PDF $\alpha_s(M_Z)$, PDF set, μ_r, μ_f
  - obtained through additional fits / linear error propagation

DØ fit methodology

$$\chi^2_{\text{DØ}} \rightarrow \sum_i \frac{\left[m_i - t_i \frac{1 + \sum_k \delta_{ik}^{(\text{NP})} \left(\alpha_k^{(\text{NP})} \right) + \sum_l \delta_{il}^{(\text{PDF})} \left(\alpha_l^{(\text{PDF})} \right)}{1 + \sum_j \delta_{ij} (\varepsilon_j)} \right]^2}{\sigma^2_{i,\text{stat}} + \sigma^2_{i,\text{uncorr}}}$$

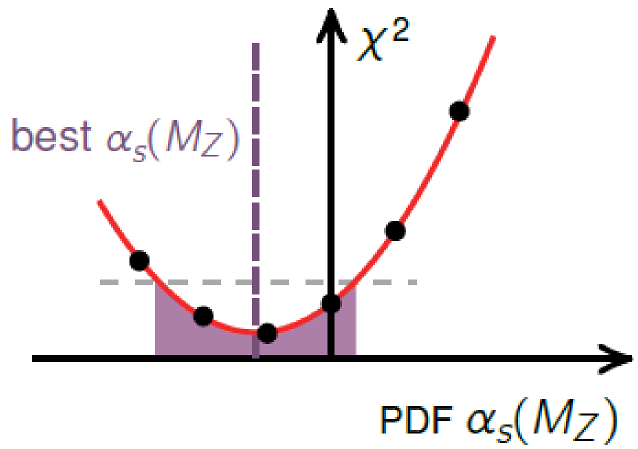
- iterative χ^2 minimization (*MINUIT*)
  - one nuisance parameter for each PDF eigenvector and each NP correction factor
  - interpolate cross section predictions obtained for PDFs assuming different values of $\alpha_s(M_Z)$
- aNNLO (NLO predictions with threshold corrections + NNLO PDFs)
- 88 out of 110 data points excluded $\leftarrow$ correlations with MSTW2008 PDFs

Method comparison

CMS fit methodology

$$\chi^2_{\mathrm{CMS}} \to \sum_{ij}(m_i - t_i)\left[(\mathbf{V}_{\mathrm{exp}} + \mathbf{V}_{\mathrm{PDF}})^{-1}\right]_{ij}(m_j - t_j)$$

- χ^2 is evaluated for each PDF in an $\alpha_s(M_Z)$ series
  - resulting $(\chi^2, \alpha_s(M_Z))$ points are assumed to lie on a parabola
  - fit of second-degree polynomial function $\to$ central value and uncertainty on $\alpha_s(M_Z)$
- PDF: CT10nlo (results are also provided for MSTW2008 and NNPDF21)
- NP uncertainties obtained by performing additional fits with correlated variation of theory



Fit methods **differ significantly**!

$\to$ “naive” combination of results (weighted average) not very conclusive

$\to$ need to extract $\alpha_s(M_Z)$ using measurements from all experiments in a **unified** fit procedure