Determination of α_s from inclusive jet cross sections

QCD@LHC Workshop, Dresden

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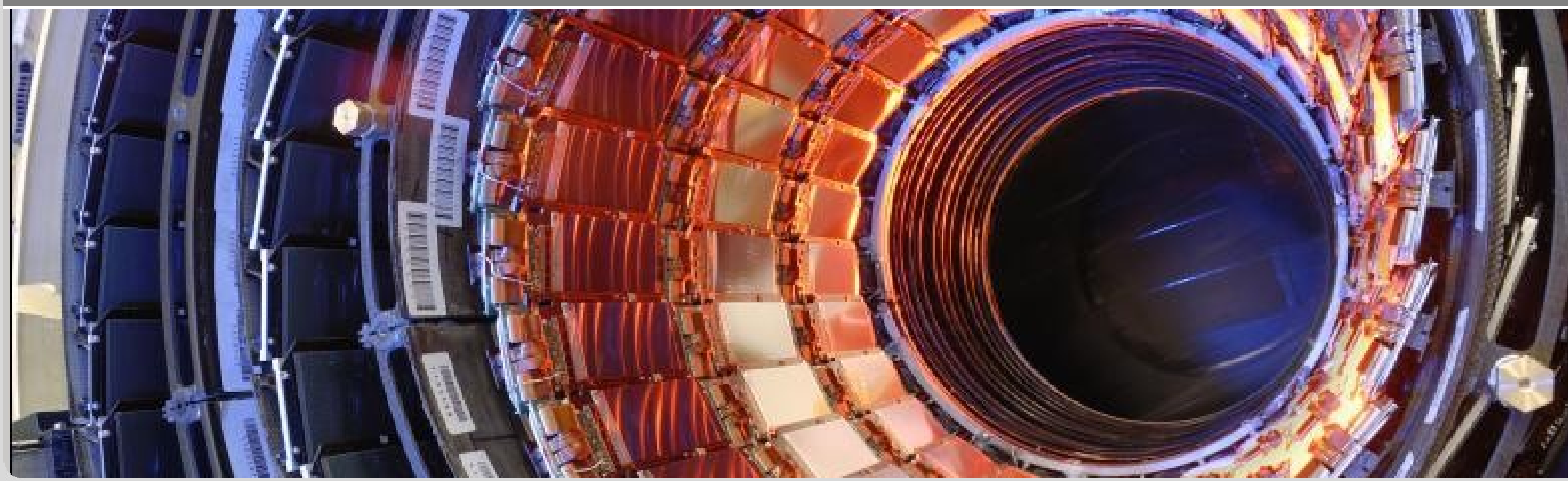

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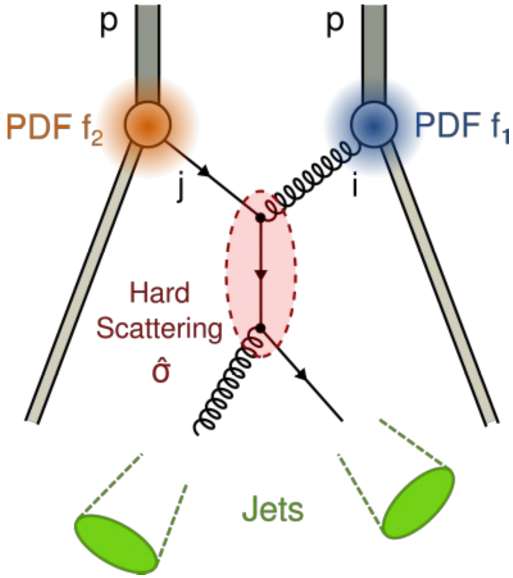
- probing the Standard Model at high precision
  - → $\alpha_s(M_Z)$ among least well known fundamental parameters
  - → $\alpha_s(M_Z)$ relevant for all processes at hadron colliders



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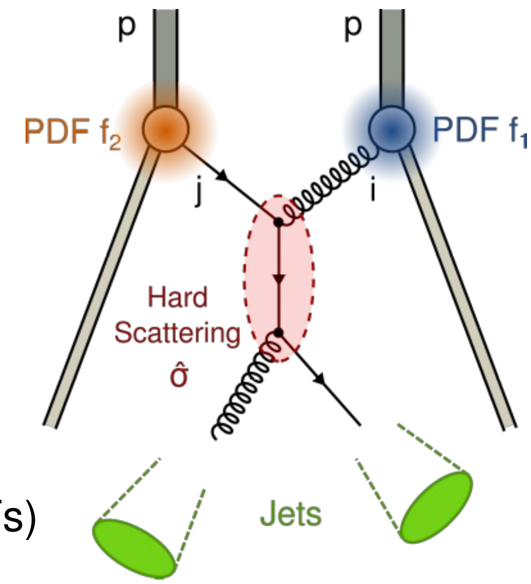

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  - hard parton scattering → strong force at different scales
  - proton structure → **Parton Distribution Functions** (PDFs)
  - **jets** → experimental handle on QCD in the final state

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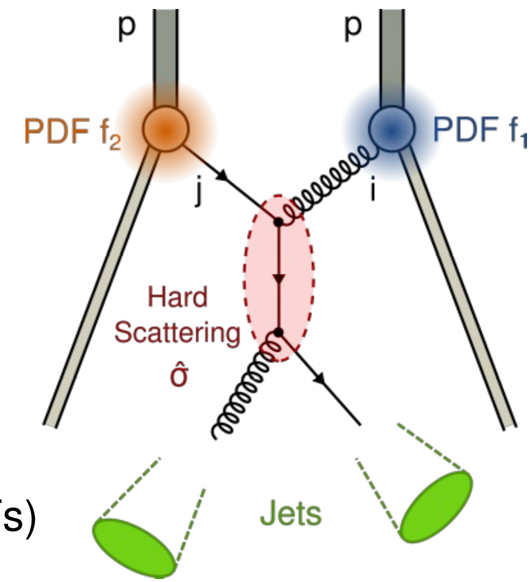

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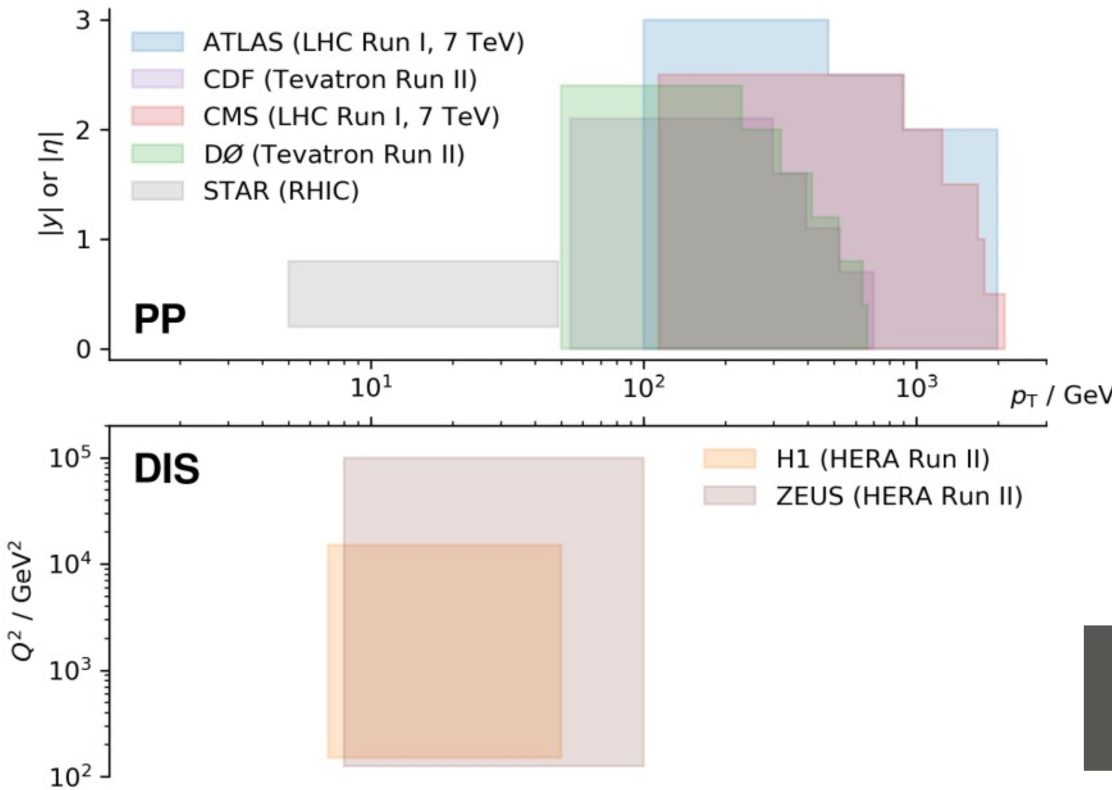
How?

→ determine $\alpha_s(M_Z)$ using **inclusive jet cross sections**

- high production cross section
- definition unambiguous, independent of process and experimental choices
- many measurements available

Data

- jets produced abundently at colliders
- different processes/initial states:
  - → e.g. deep inelastic scattering (**DIS**), proton-(anti)proton collisions (**PP**)
- many measurements available:
  - → e.g. **double-differential inclusive jet** cross section



large and **complementary** phase spaces covered

Challenges

Challenges

theory predictions

$$\sigma_{pp} = \sum_{n}^{\infty} \alpha_s^n(\mu_R^2) \sum_{i,j} \int \mathrm{d}x_1 \, \mathrm{d}x_2 \, f_i(x_1, \mu_F^2) \, f_j(x_2, \mu_F^2) \times \hat{\sigma}_{ij}(x_1 x_2 s, \mu_R^2, \mu_F^2)$$

Challenges

sensitive to
$\alpha_s(M_Z)$

hard process
cross section

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PDF $\alpha_s(M_Z)$ dependence

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convolution with PDFs

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renormalization and factorization scales

processes at different energy scales → RGE, DGLAP evolution

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– fastNLO, APPLgrid

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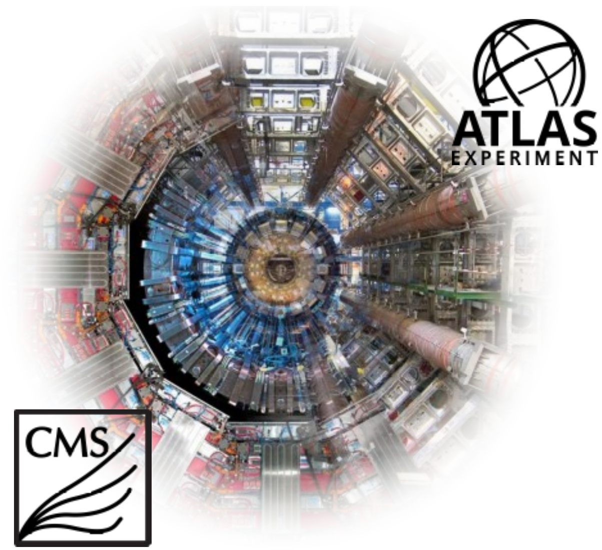
measurements

data from many experiments
– uncertainties
– correlations



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parameter estimation

measurements

consistent treatment of:
- theory predictions
- experimental data
- uncertainties

estimate and **analyze**:
- $\alpha_s(M_Z)$
- uncertainty on $\alpha_s(M_Z)$

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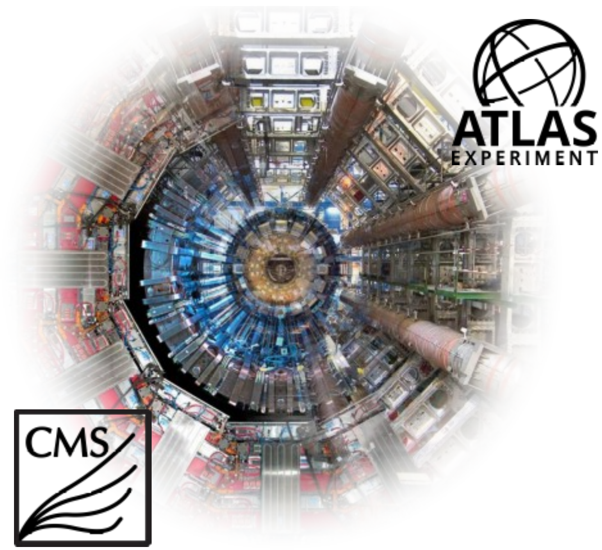
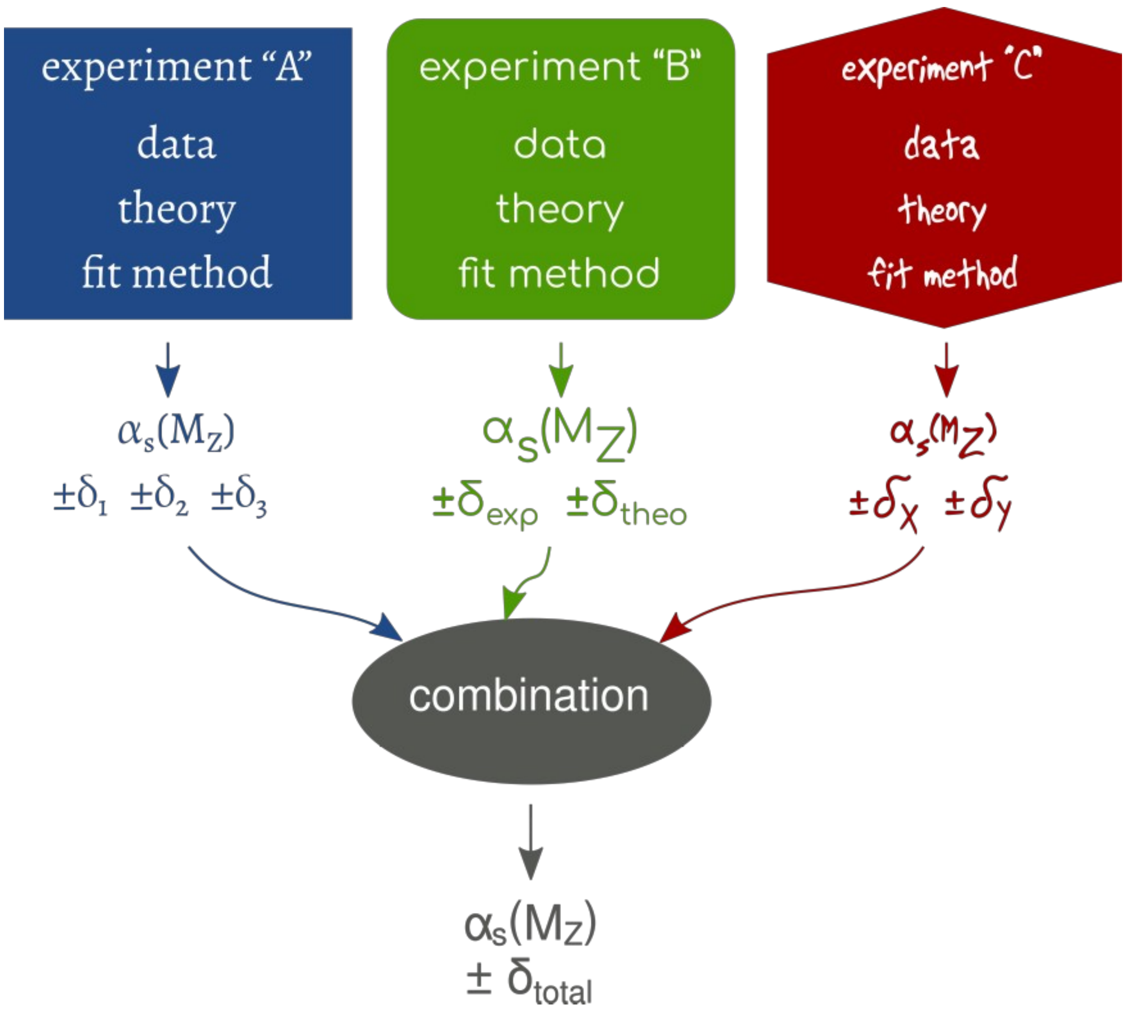


Strategy?

- often: “weighted average” combination of pre-determined values



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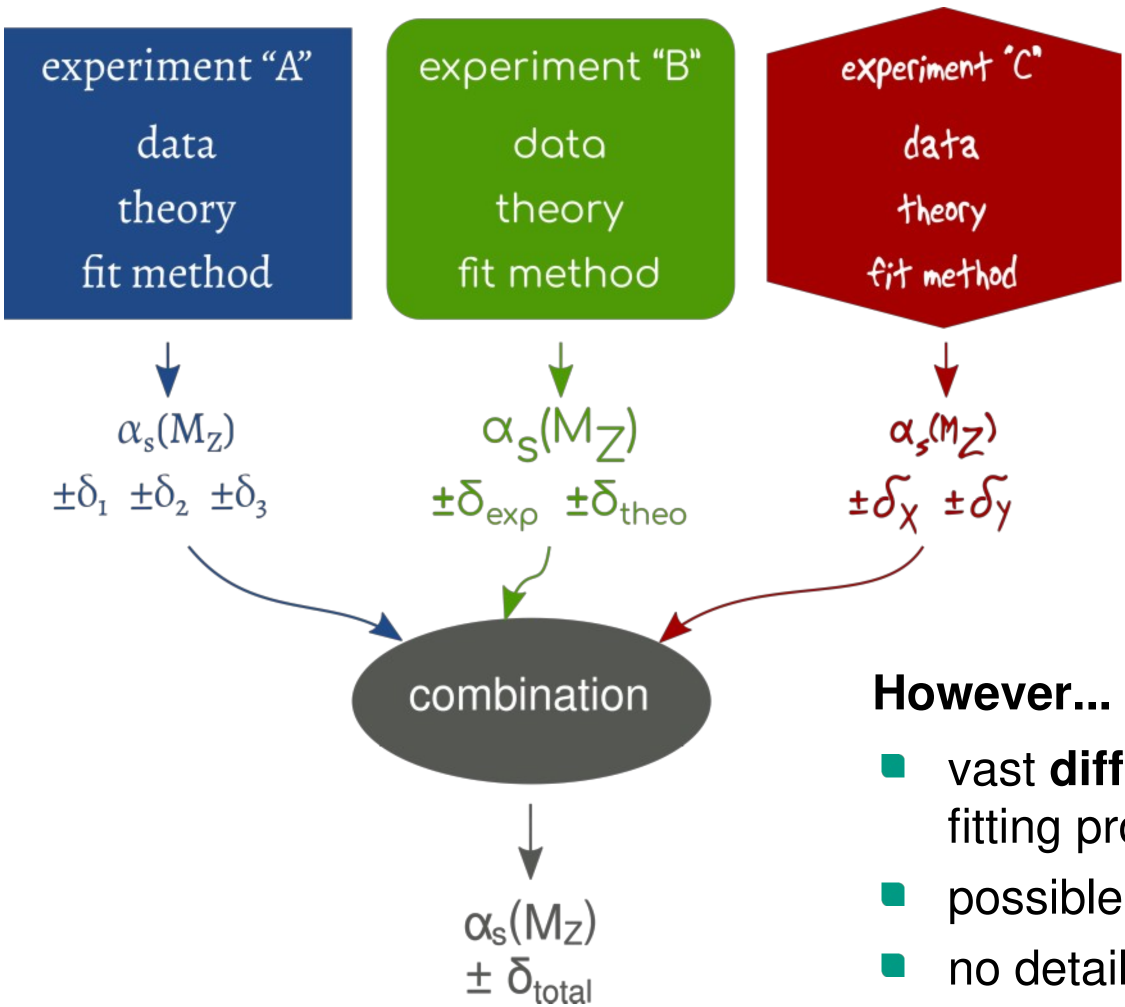
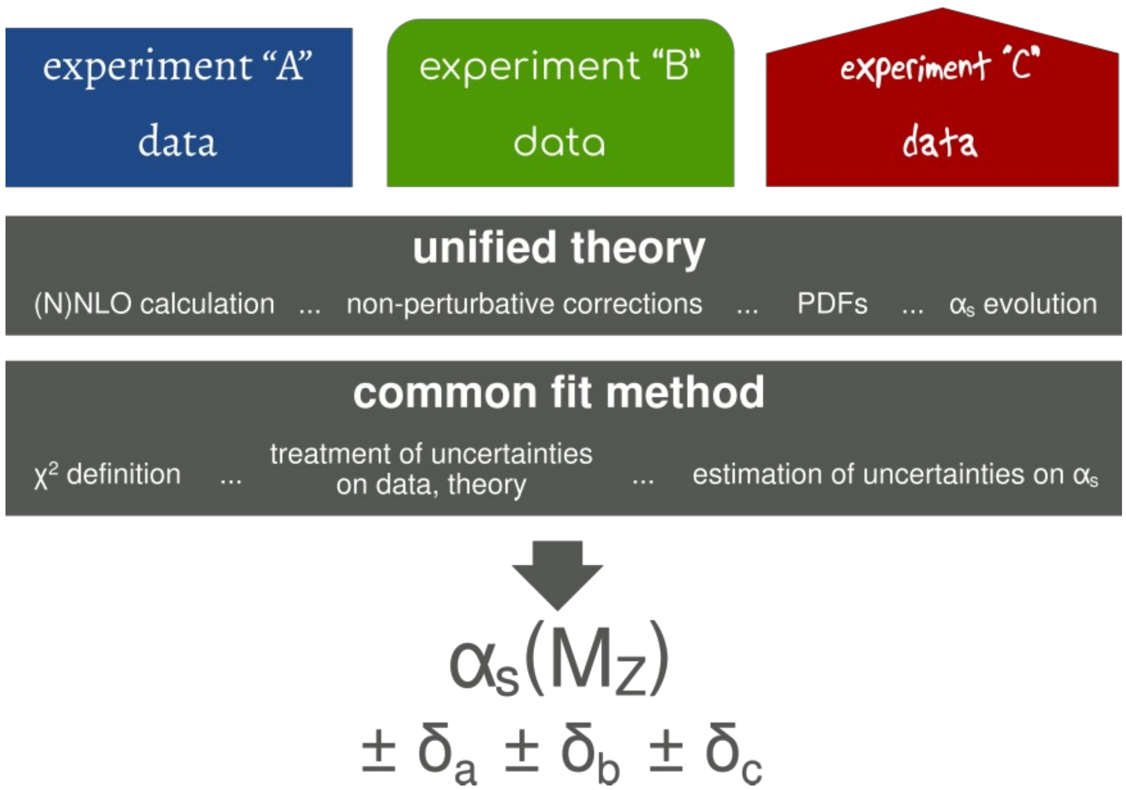


However...

- vast **differences** in data, theory and fitting procedure
- possible **tensions** can be overlooked
- no detailed uncertainty **breakdown**

Our Strategy

- use data from multiple experiments simultaneously in a consistent fitting procedure



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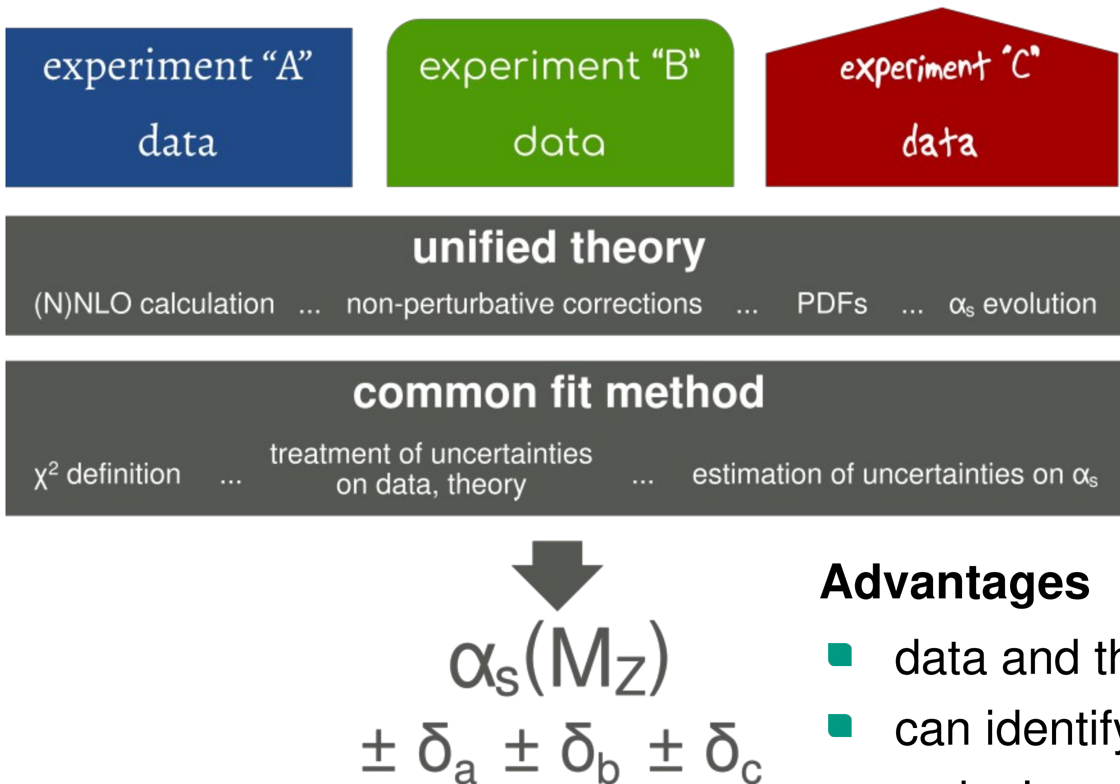

Advantages

- data and theory on **equal footing**
- can identify and characterize **tensions**
- a single uncertainty model
  → uncertainty decomposition possible

New fitting tool – Alpos

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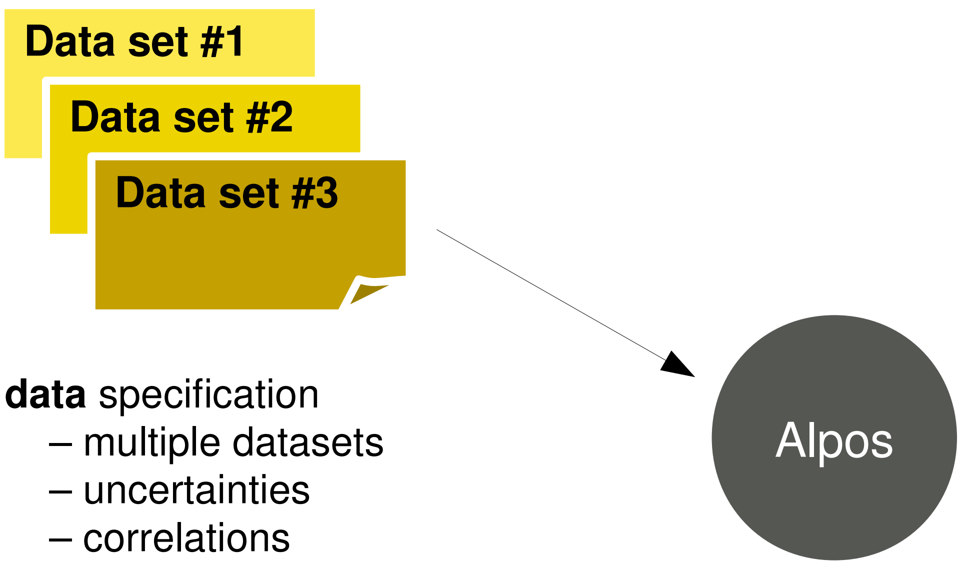
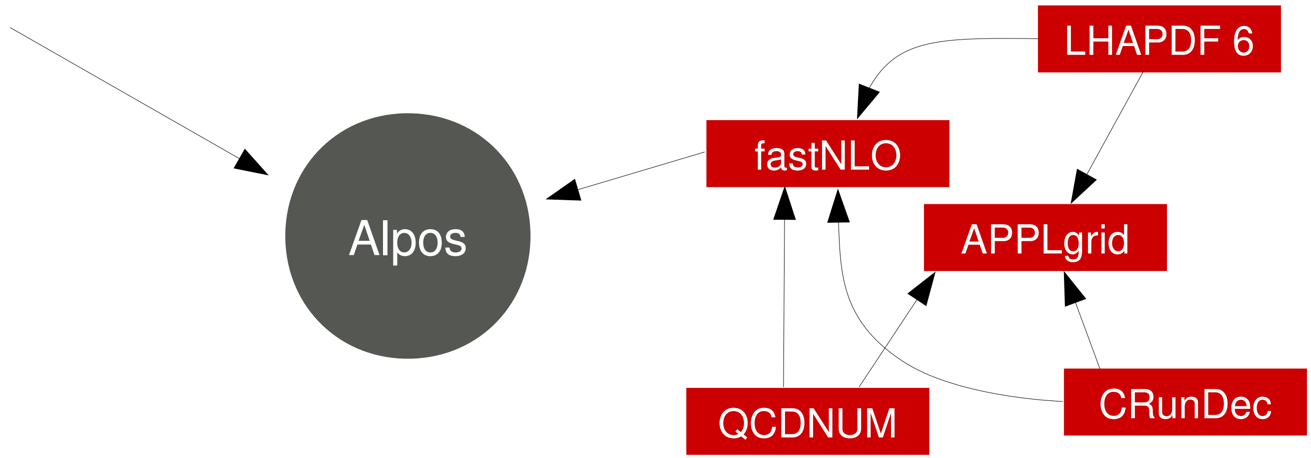


New fitting tool – Alpos

data specification
- multiple datasets
- uncertainties
- correlations



interfaces to many software packages:
- many popular tools supported
- consistent propagation of **shared parameters**

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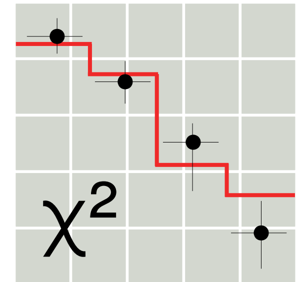
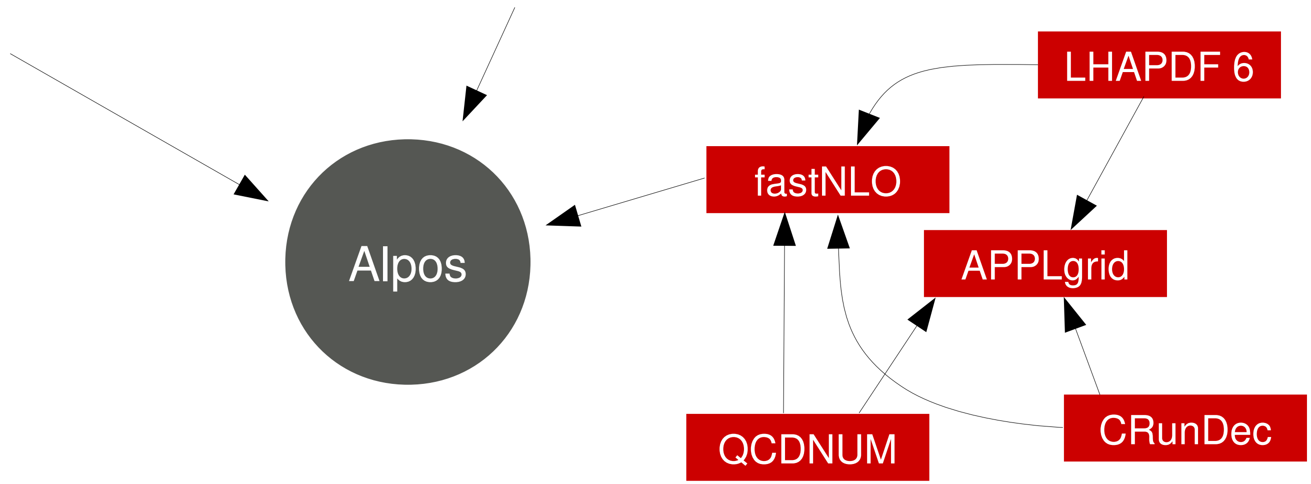


fitting procedure
- multiple χ^2 definitions available
- flexible treatment of uncertainties



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  - hadron-hadron colliders:
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  - lepton-hadron colliders:
    HERA (H1, ZEUS)
  - heavy ion colliders:
    RHIC (STAR)

different initial state

different experimental setups

large phase space covered

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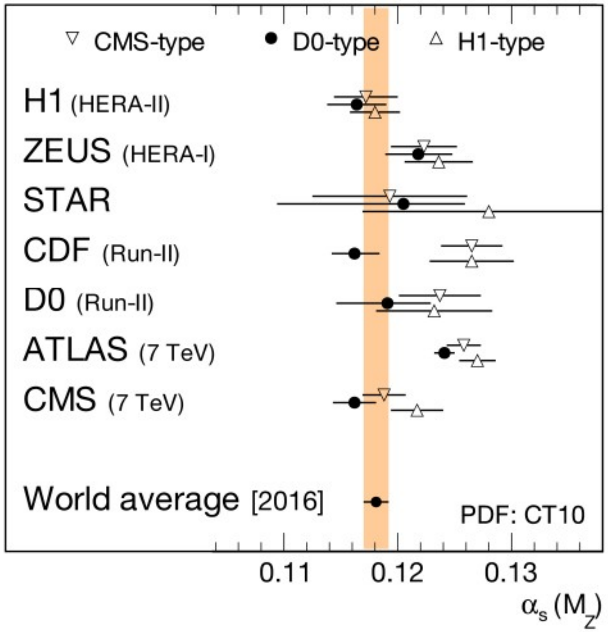
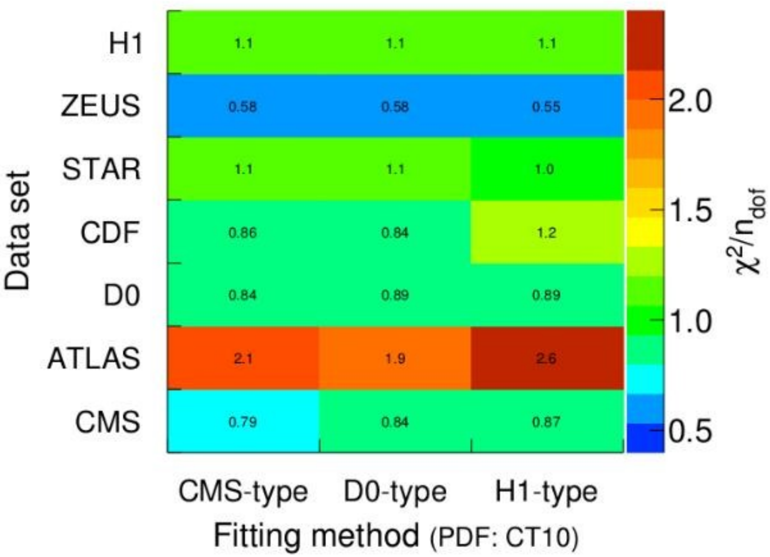
- starting point: three **published $\alpha_s(M_Z)$ determinations**
  - CMS — V. Khachatryan et al. "Constraints [...] and extraction of the strong coupling constant [...] at $\sqrt{s}$ = 7 TeV", *Eur. Phys. J. C* **75** (2015), p. 288. arXiv: 1410.6765 [hep-ex]
  - DØ — V.M. Abazov et al. "Determination of the strong coupling constant [...] at $\sqrt{s}$ = 1.96 TeV", *Phys. Rev. D* **80** (2009), p. 111107. arXiv: 0911.2710 [hep-ex]
  - H1 — V. Andreev et al. "Measurement [...] and determination of the strong coupling constant α_s", *Eur. Phys. J. C* **75** (2015), p. 65. arXiv: 1406.4709 [hep-ex]

Collaboration fit methods

- take published $\alpha_s(M_Z)$ determinations from **CMS**, **DØ** and **H1** collaborations
- **reimplement** methods in our own framework
  → *bonus*: can also apply to **other data**
- methods give mostly consistent results
  - *nevertheless*: variations exist
  - not always covered by uncertainties
- χ^2 / $n_{\text{degrees of freedom}}$ as fit quality indicator
  - especially high (low) values for ATLAS (ZEUS)





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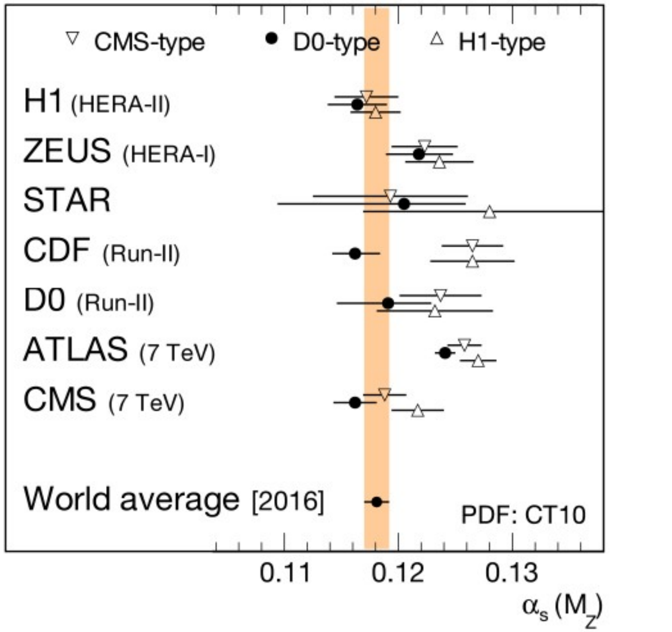
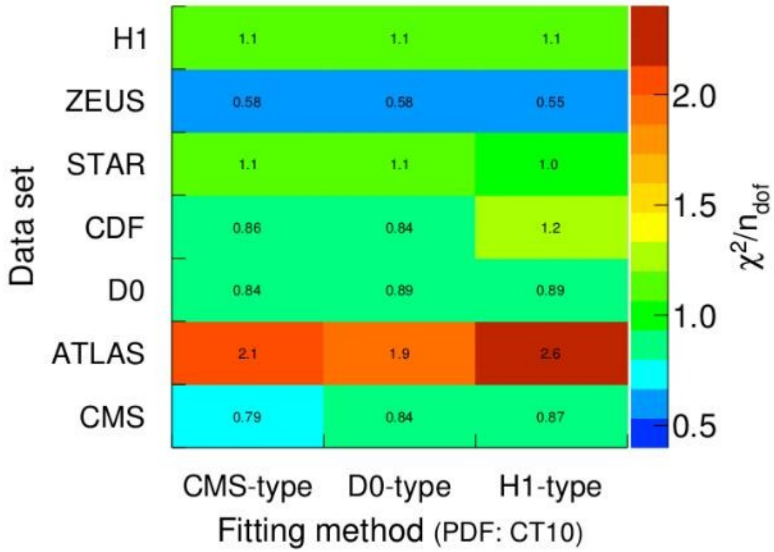
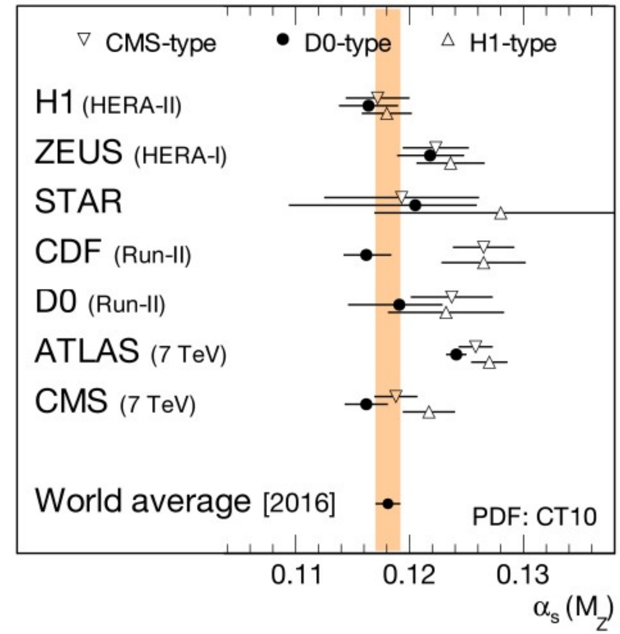
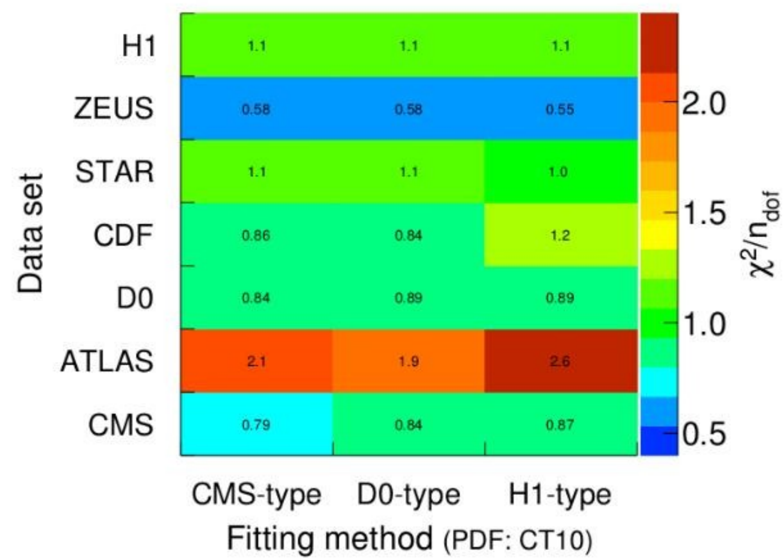




Main differences

- χ^2 definition
  - *in particular*: uncertainty model
- χ^2 minimization strategy
- treatment of PDF α_s dependence
- final uncertainty estimation





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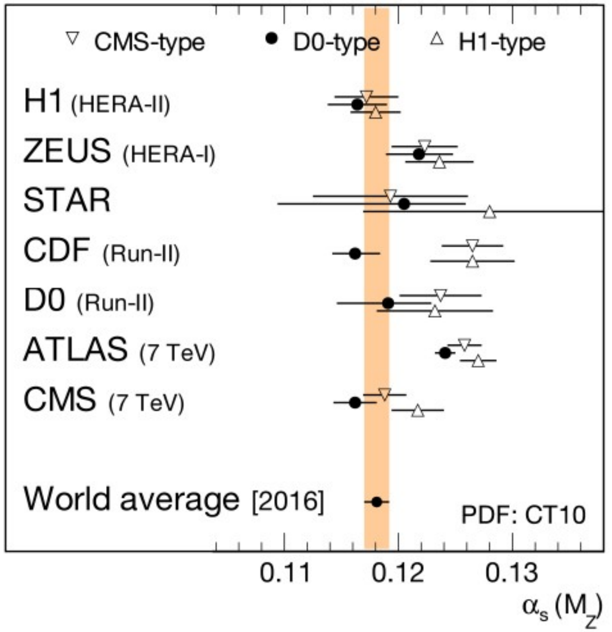

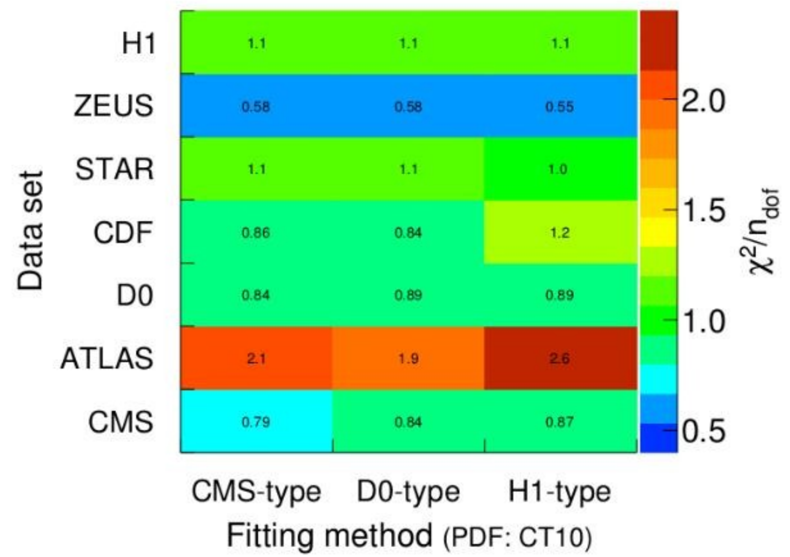

Common fit method

- fit all data sets with a **consistent fitting method**
  - direct minimization of χ^2 quantity:

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

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well-suited for data spanning
multiple orders of magnitude

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uncertainties in χ^2 definition

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from non-perturbative effects

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additional uncertainties on $\alpha_s(M_Z)$ by **refitting** with parameter variations:

choice of PDF set

choice of PDF $\alpha_s(M_Z)$

"scale" (missing higher orders)

Correlations

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experimental

within individual datasets

- provided by collaborations

across datasets:

- assumed to be negligible

← different kinematic ranges, experimental techniques

← third-party studies did not identify any relevant sources of correlation

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from PDFs

- uncertainties are obtained from variations of the PDF parameters (*NNPDF*: from an ensemble of PDF replicas)

→ correlations between observable bins

- variations (replicas) evaluated for all datasets simultaneously

→ correlations between observable bins both **within** and **across** datasets

from non-perturbative effects

within individual datasets

- as recommended by collaborations

across datasets:

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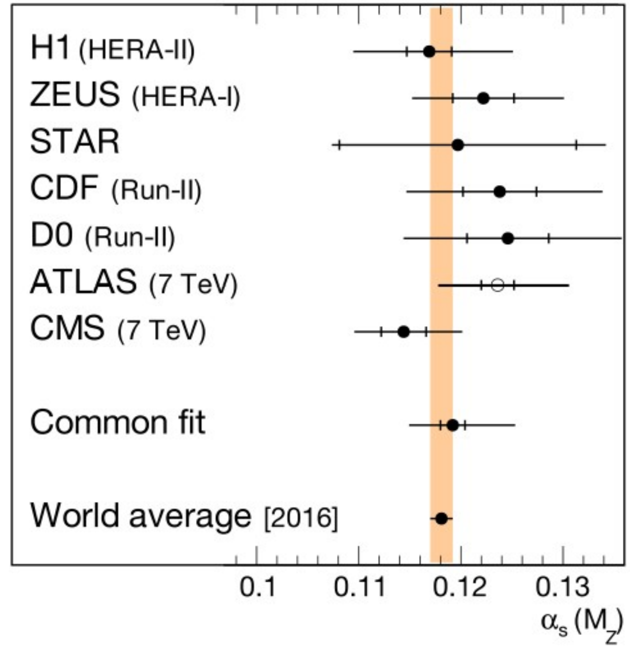
← estimated using different methods and different MC event generators

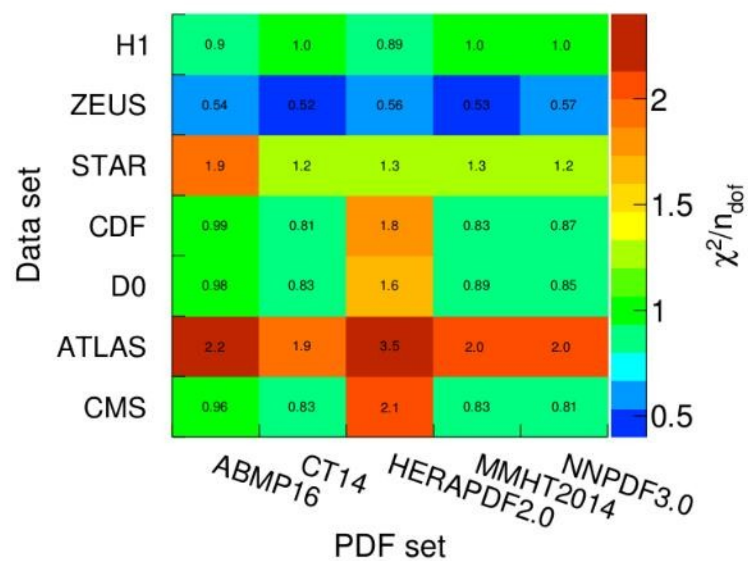
Results at NLO

- re-fit all data sets with our **common fit method**
  - enable determination using **all*** data sets simultaneously:

$$\alpha_s(M_Z) = 0.1192 \quad (12)_{exp} \quad (5)_{NP} \quad (7)_{PDF} \quad (5)_{PDF\ \alpha_s} \quad (11)_{PDF\ set} \quad \left({}^{+59}_{-38}\right)_{scale}$$



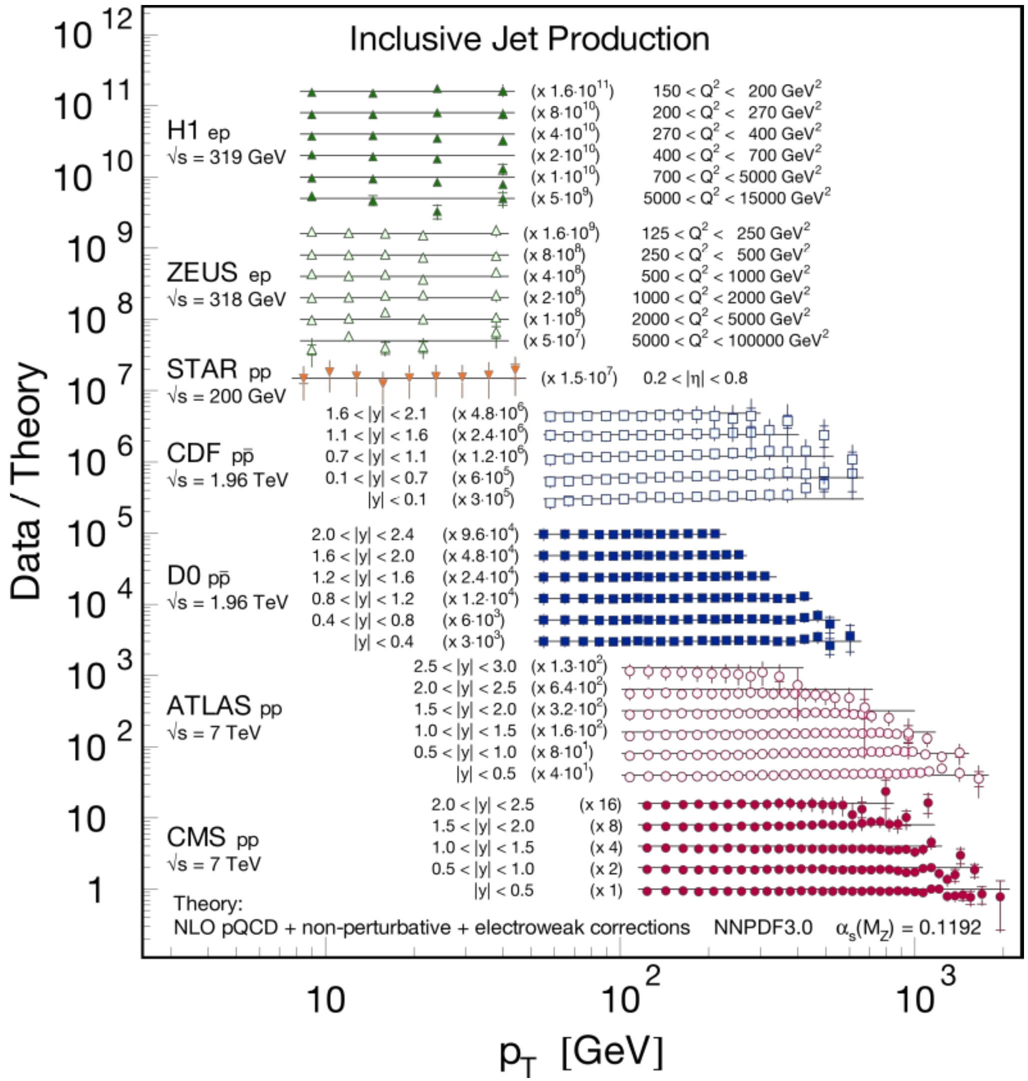
- χ^2/n_{dof} as fit quality indicator
  - HERAPDF2.0 → consistently higher values for all data sets except H1, ZEUS, STAR
  - confirm high (low) values for ATLAS (ZEUS)



*) conservative option: ATLAS data not included in common fit
disclaimer: did not check decorrelation schemes proposed by ATLAS for the 8, 13 TeV data

Status of inclusive jet production

- data is well described by theory at NLO, *but*: missing higher orders cause of largest uncertainty
  - → working on theory predictions at **NNLO**
- probe of QCD across **>3 orders of magnitude** in p_T
- promising tool for understanding experimental data
  - → preparation for studies involving PDFs,
  - → in particular, simultaneous PDF+$\alpha_s(M_Z)$ determinations



Summary

- systematic study of $\boldsymbol{\alpha_s(M_Z)}$ at **NLO** using **inclusive jet** cross sections from multiple experiments:

  ATLAS, CDF, CMS, DØ, H1, STAR, ZEUS

- **consistent** handling of data and theory in a single **common fitting procedure**
  - implemented in new fitting tool **Alpos** → **flexible** data/uncertainty specification, **fastNLO** interface

- determination of $\alpha_s(M_Z)$ at NLO in a **simultaneous** fit to a well-understood data subset:

  $$\alpha_s(M_Z) = 0.1192 \quad (12)_{\mathrm{exp}} \quad \left(^{+60}_{-41}\right)_{\mathrm{theo}}$$

  - largest uncertainty → “scale” (missing higher orders in perturbation theory)

- all components in place for a determination at **NNLO**, as soon as theory becomes available

- pre-print available (`arxiv.org/abs/1712.00480`), submitted for publication