# qcd measurement:

Measurement of the ratio of the inclusive 3-jet cross section to the inclusive 2-jet cross section and first determination of the strong coupling constant in the TeV range - CMS Collaboration

Group C

ESHEP2013
CERN - JINR

# Outline



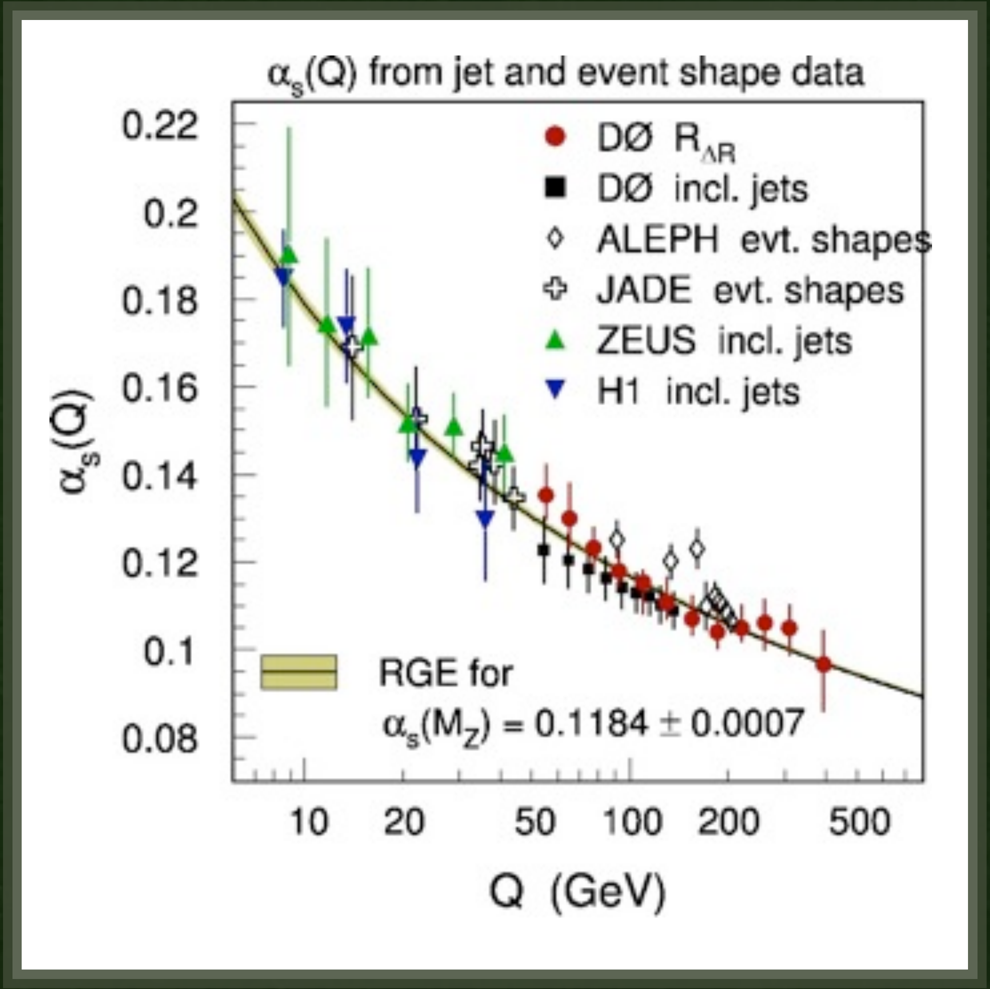
arXiv:1304.7498v1

# Motivation

- QCD predicts that $\alpha_s$ becomes weaker at higher energies:

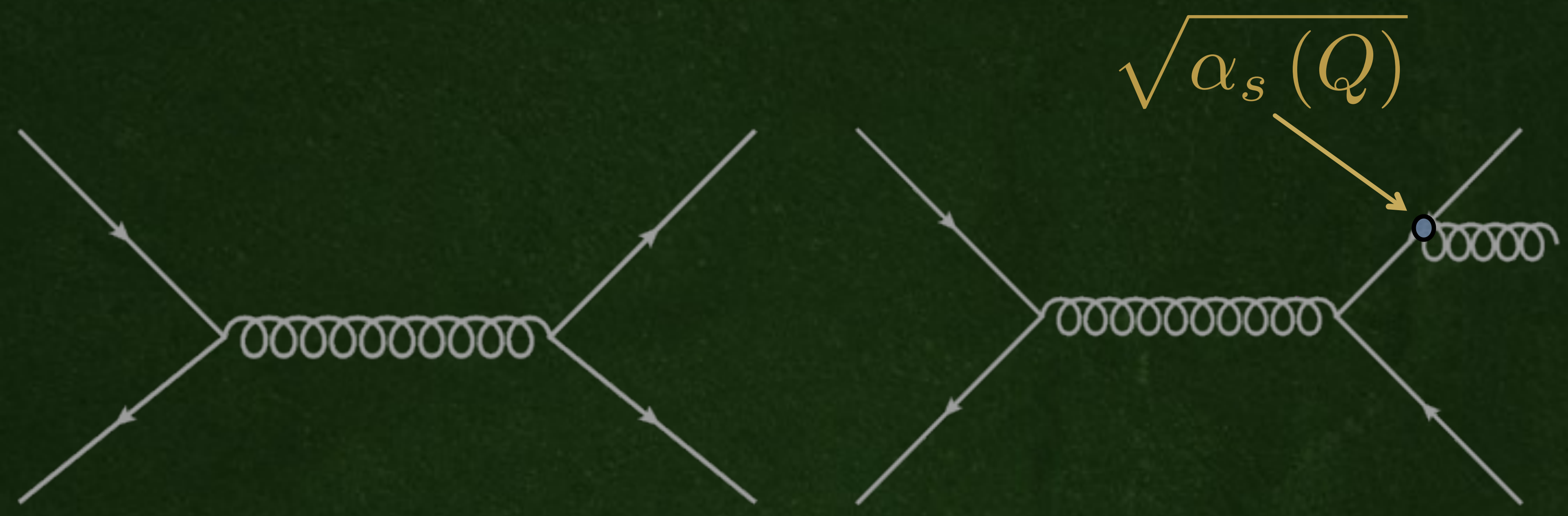
$$\alpha_s(Q) = \frac{\alpha_s(\mu_r^2)}{1 + b_0 \ln\left(\frac{Q}{\mu_r}\right) \alpha_s(\mu_r^2)}$$

- The value of $\alpha_s(Q)$ is not fixed by theory
  - Needs to be determined by experiment
- First measurement of $\alpha_s$ in the TeV regime
  - Test of QCD over wide energy range




DØ Collaboration, Phys. Lett. B 718, 56 (2012)

# Measurement of the Strong Coupling

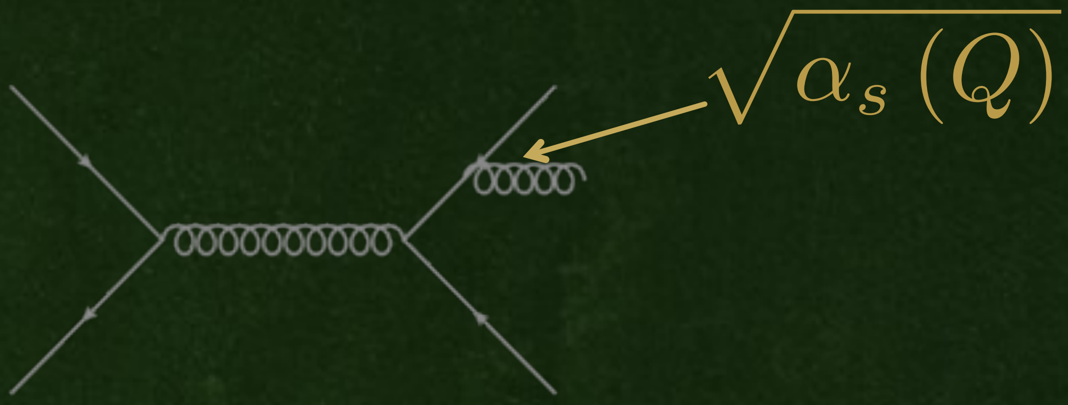



Extra factor of $\alpha_s$ for 3-jet event compared to 2-jet event

$$R_{32} = \frac{inclusive\ 3\ jet\ cross\ section}{inclusive\ 2\ jet\ cross\ section}$$

Many uncertainties (PDF evolution, jet energy scale, luminosity) mostly cancel in the ratio

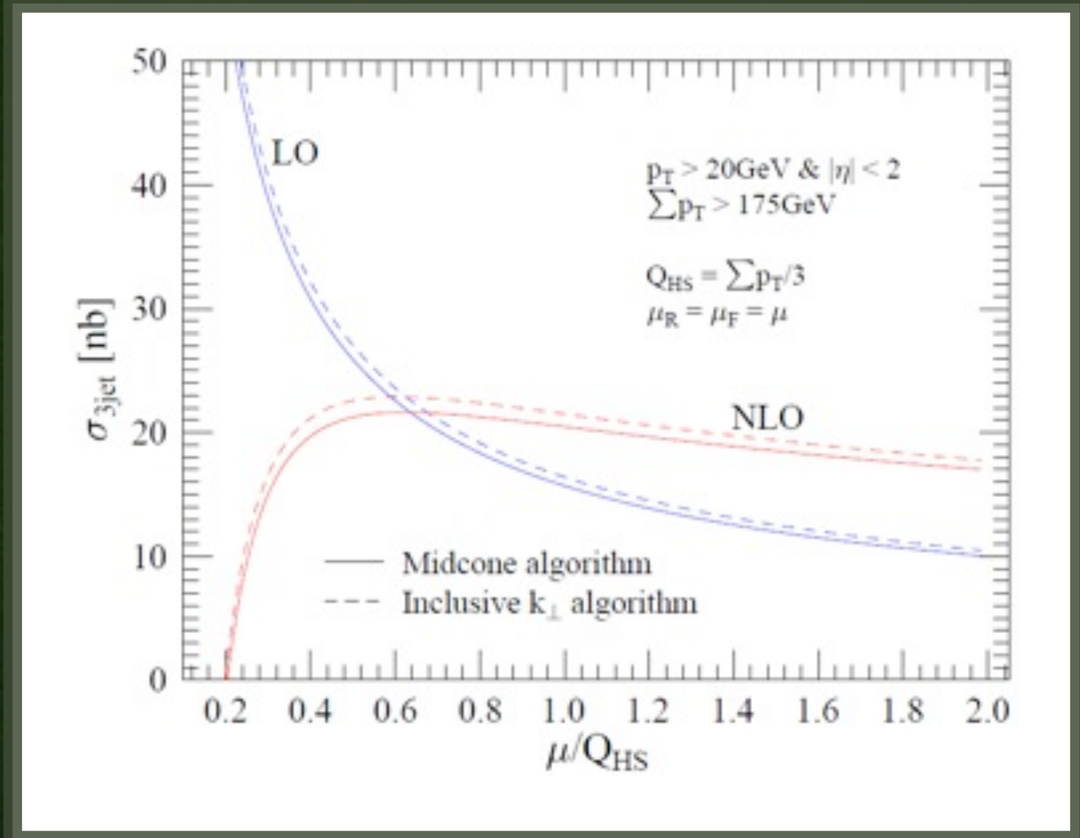
# Choosing the Scales




- Scale Q of process not exactly known
  - Reasonable estimate:

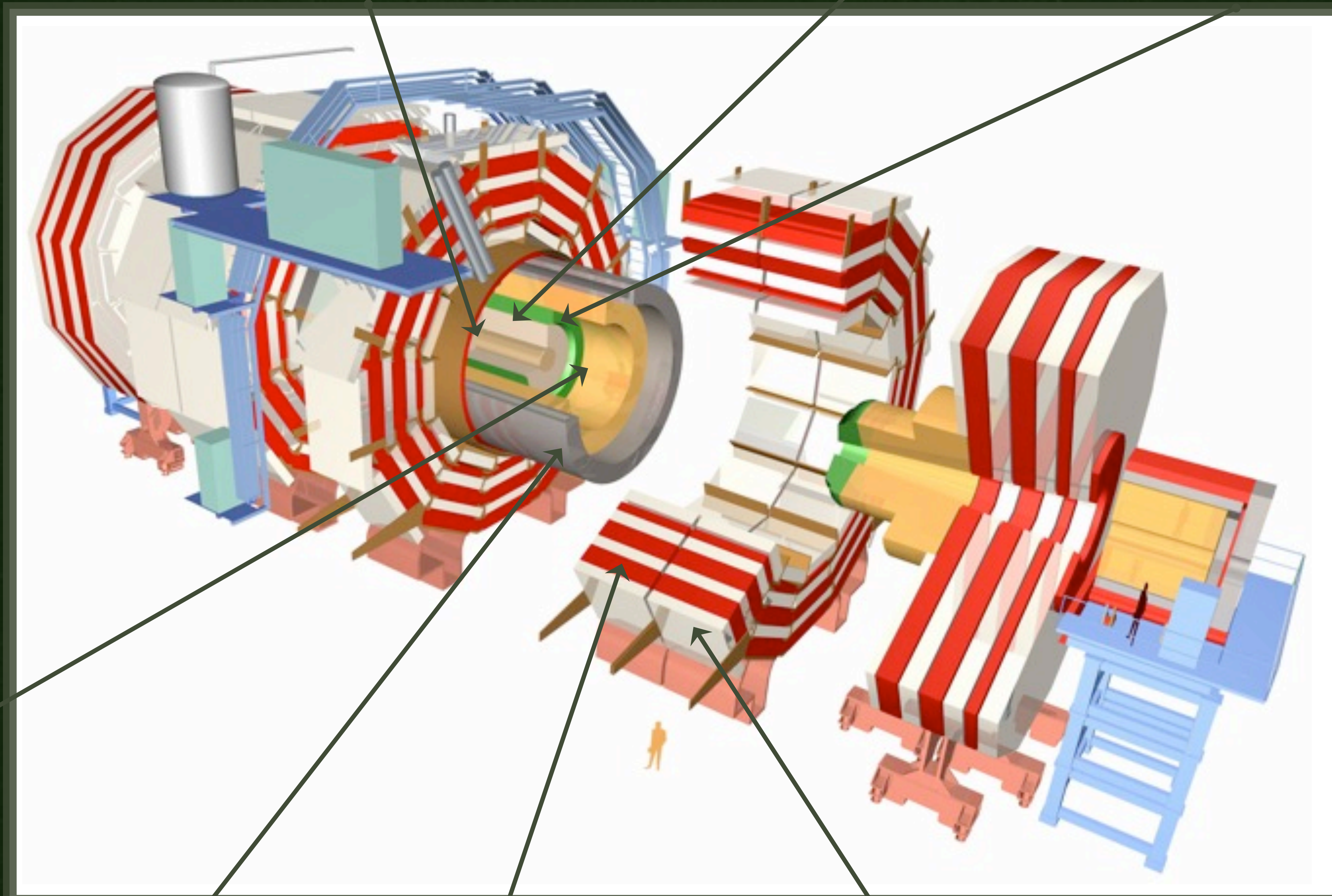
$$Q = \langle p_{T1,2} \rangle = \frac{p_{T1} + p_{T2}}{2}$$

- Renormalization scale $\mu_R$ and factorization scale $\mu_F$ must be chosen
  - Impact on final result
- Constrain $\mu_R = \mu_F = Q = \langle p_{T1,2} \rangle$



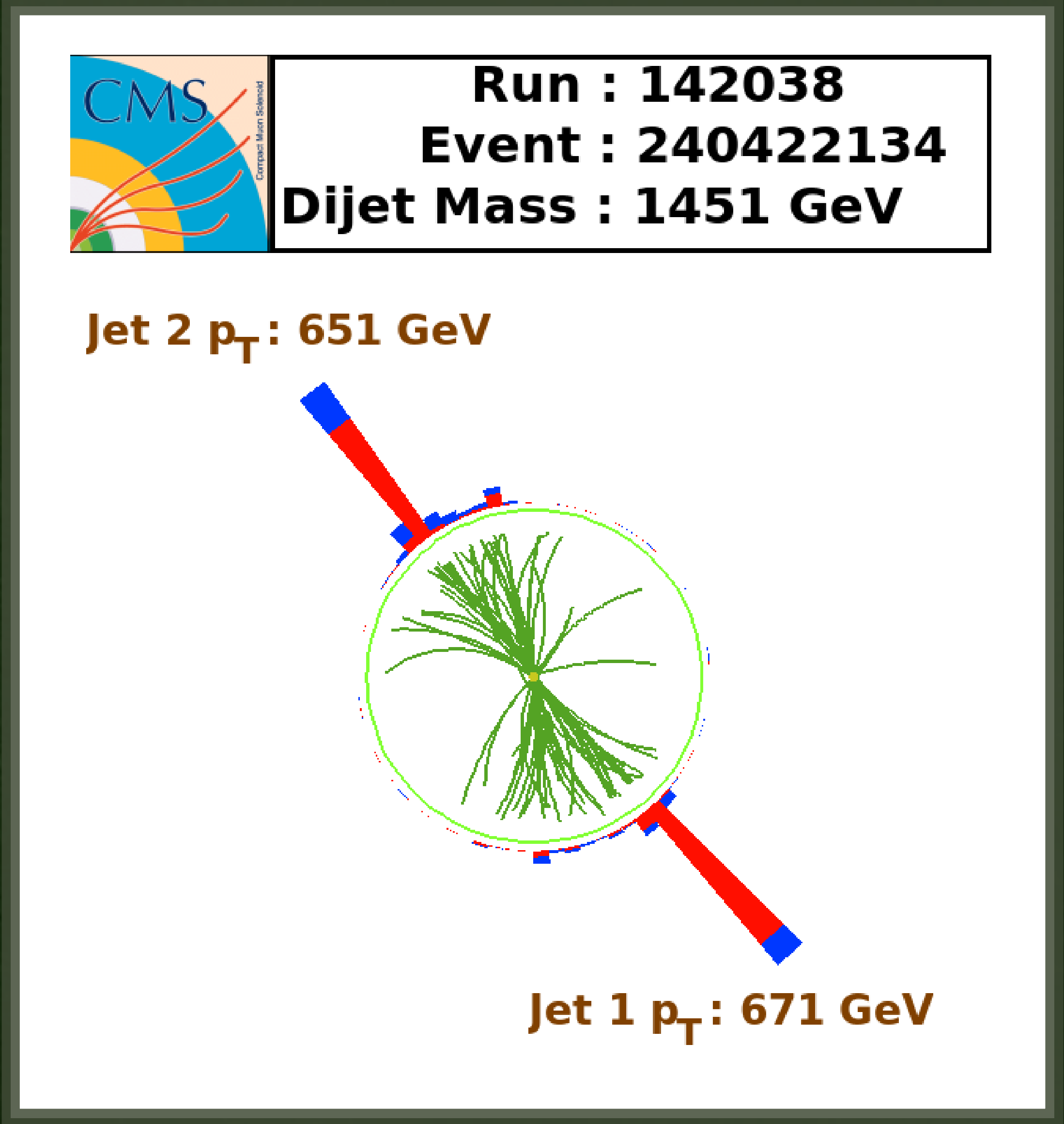

Z. Nagy, Phys. Rev. D68 (2003) 094002

# The CMS Detector



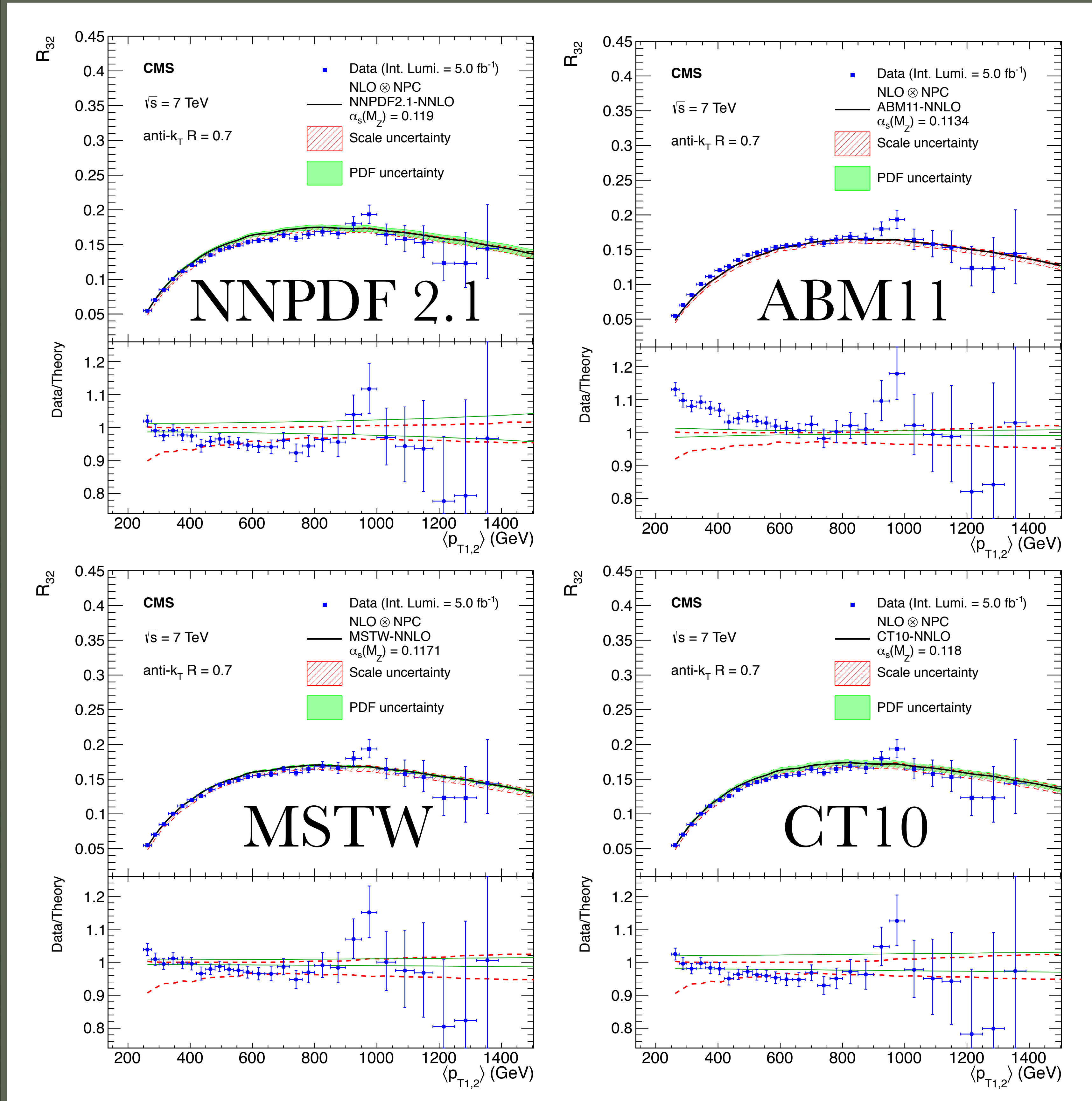
# Event Selection

- Use 5 $fb^{-1}$ of CMS data with $\sqrt{s}$ = 7 TeV recorded in 2011
- Jets are reconstructed using anti-$k_T$ (R=0.7) clustering algorithm
- Select events with ≥2 or ≥3 calibrated jets with
  - High efficiency / high rejection ID criteria for quark/gluon jets (>99% efficient)
  - $p_T > 150$ GeV
  - $|\eta| < 2.5$



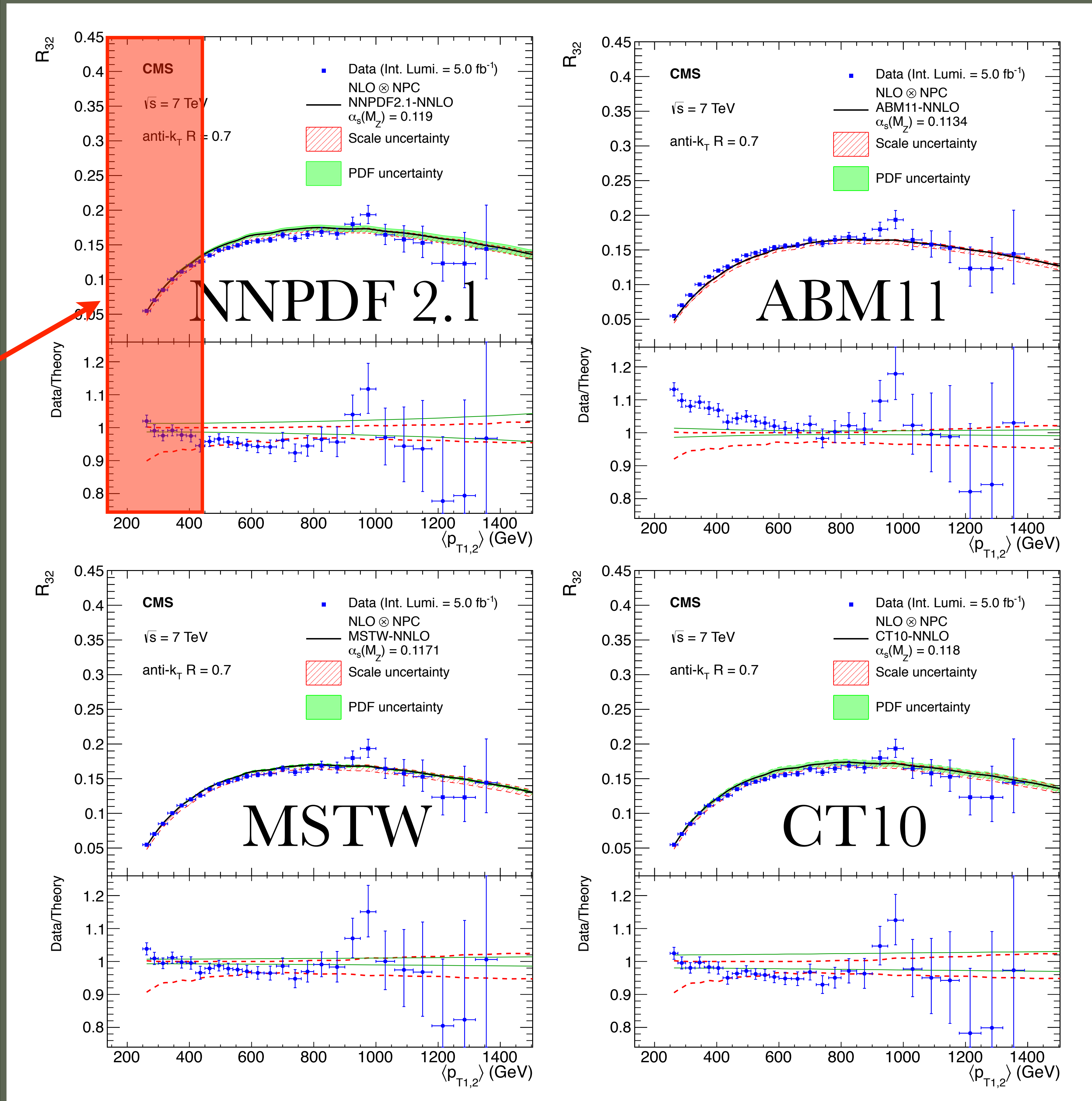
# Theoretical Predictions

- NLOJET++ used to calculate $R_{32}$ using different $\alpha_s$ and parton distribution functions (PDFs)
  - Compare to unfolded data
- $\alpha_s(M_Z)$ is a parameter for the PDFs
- Using four PDFs for comparison:
  - NNPDF 2.1
  - ABM11
  - CT10
  - MSTW08
- Every PDF has different default $\alpha_s(M_Z)$




All PDFs at NNLO

Excluded from analysis



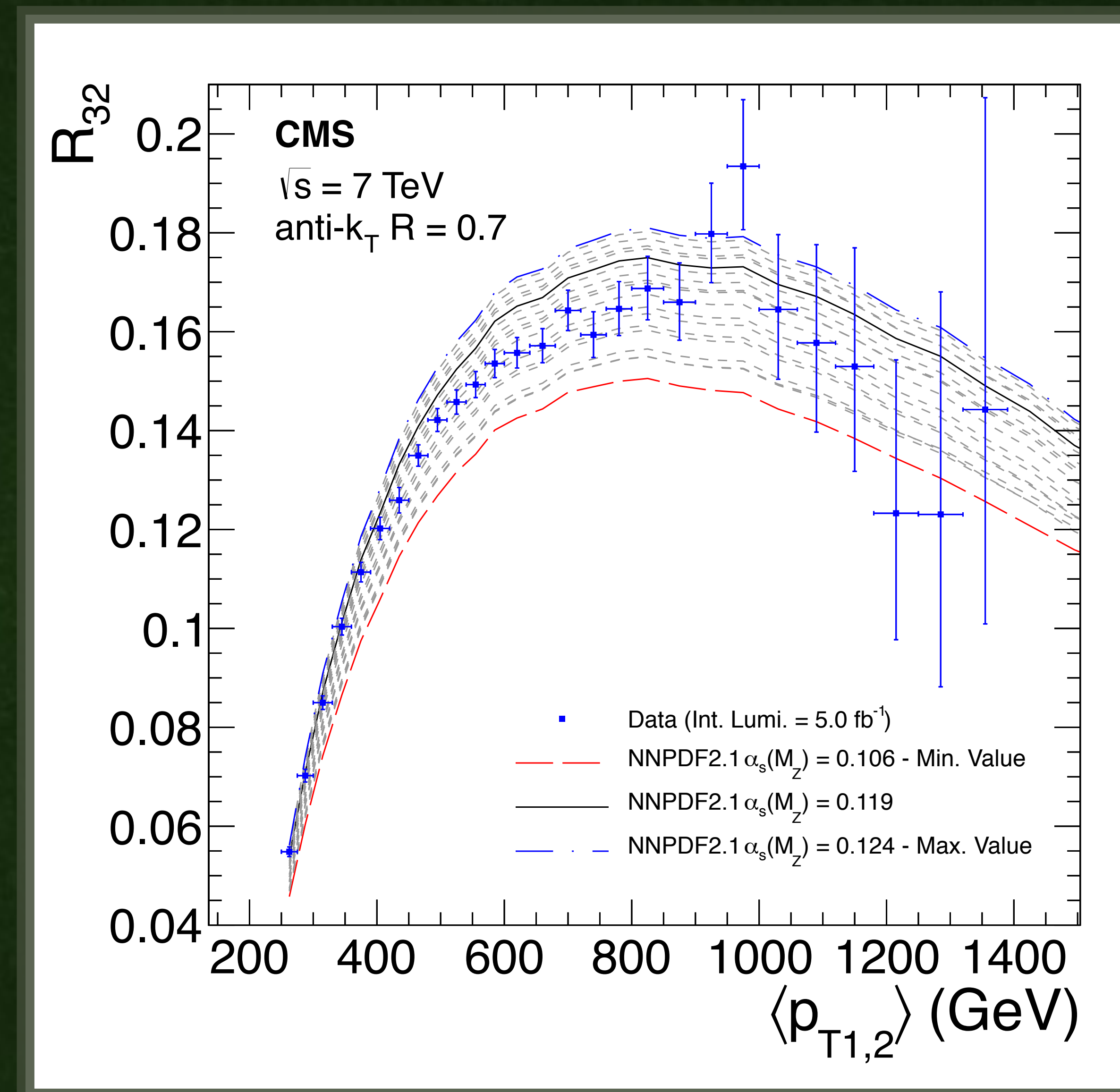

All PDFs at NNLO

# Sources of Systematic Uncertainties

- Experimental
  - Jet Energy Scale (JES)
  - Unfolding:
    - Insufficient knowledge of the simulation of jet $\langle p_{T1,2} \rangle$ spectra
    - Observed difference between MC and data in $\langle p_{T1,2} \rangle$ resolution
- Theoretical
  - NNPDF 2.1 uncertainties
  - Renormalization and factorization scales
    - Systematics established with 0.5μ and 2μ variations

# Extracting $\alpha_s(M_Z)$

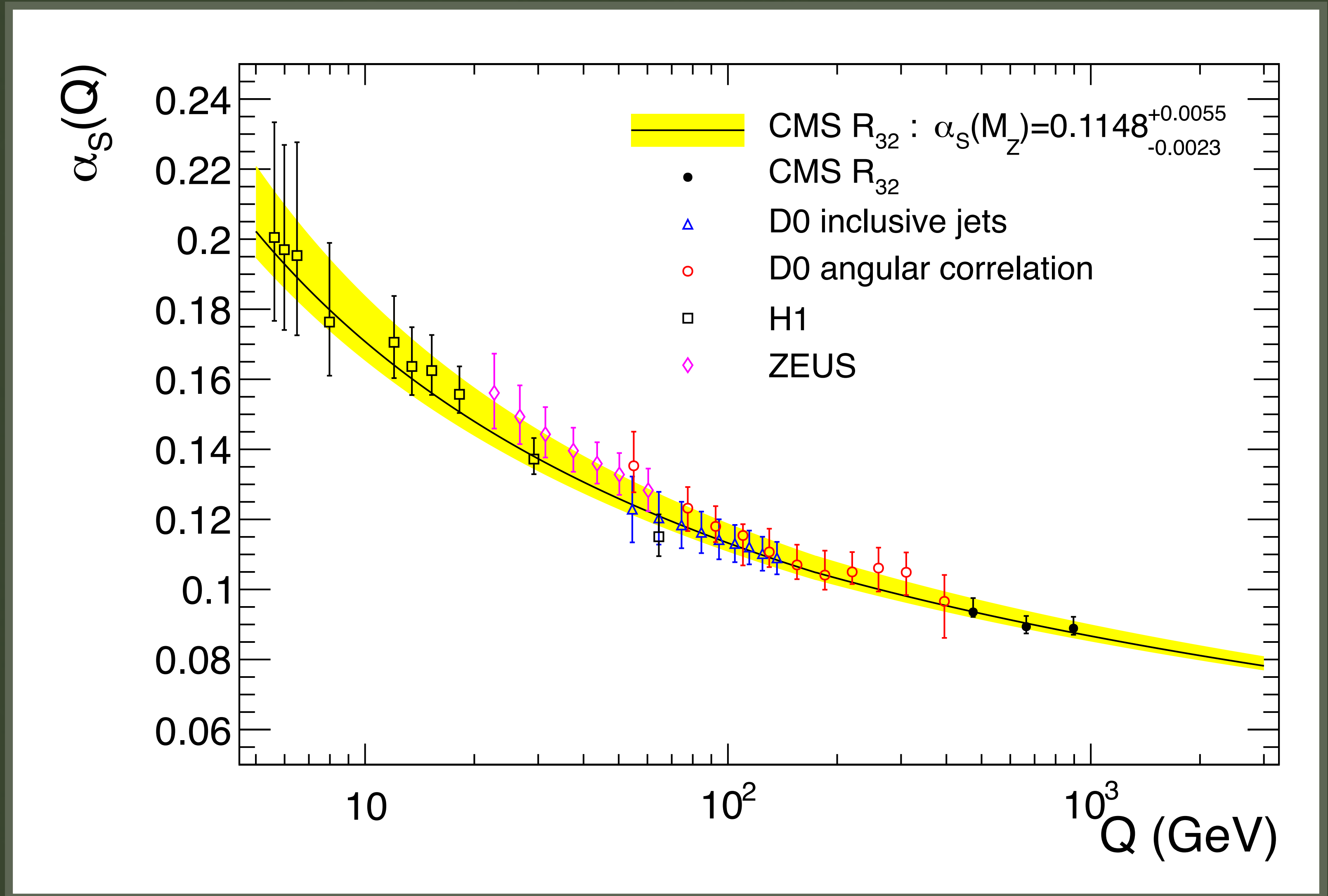
- $\alpha_s(M_Z)$ predictions varied using NNPDF2.1
- $\alpha_s(M_Z)$ variations fit to data to minimize $\chi^2/N_{dof}$




$$\alpha_S(M_Z) = 0.1148 \pm 0.0014(\text{exp.}) \pm 0.0018(\text{PDF})^{+0.0050}_{-0.0000}(\text{scale})$$

$$\text{World Average: } \alpha_S(M_Z) = 0.1184 \pm 0.0007$$

# Conclusion

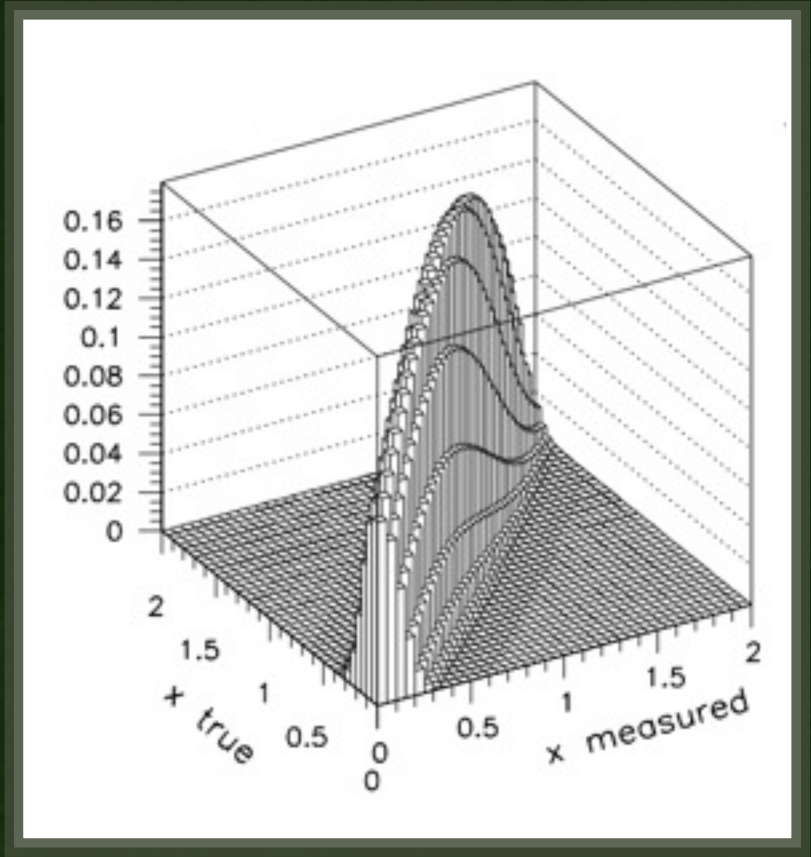



- Extrapolated $\alpha_s(Q)$ plotted against
  - $\alpha_s(Q)$ measurements at CMS at high Q
  - DØ, H1 & ZEUS measurements of $\alpha_s(Q)$ at lower Q
- Provides $\alpha_s(Q)$ measurement at unexplored scales

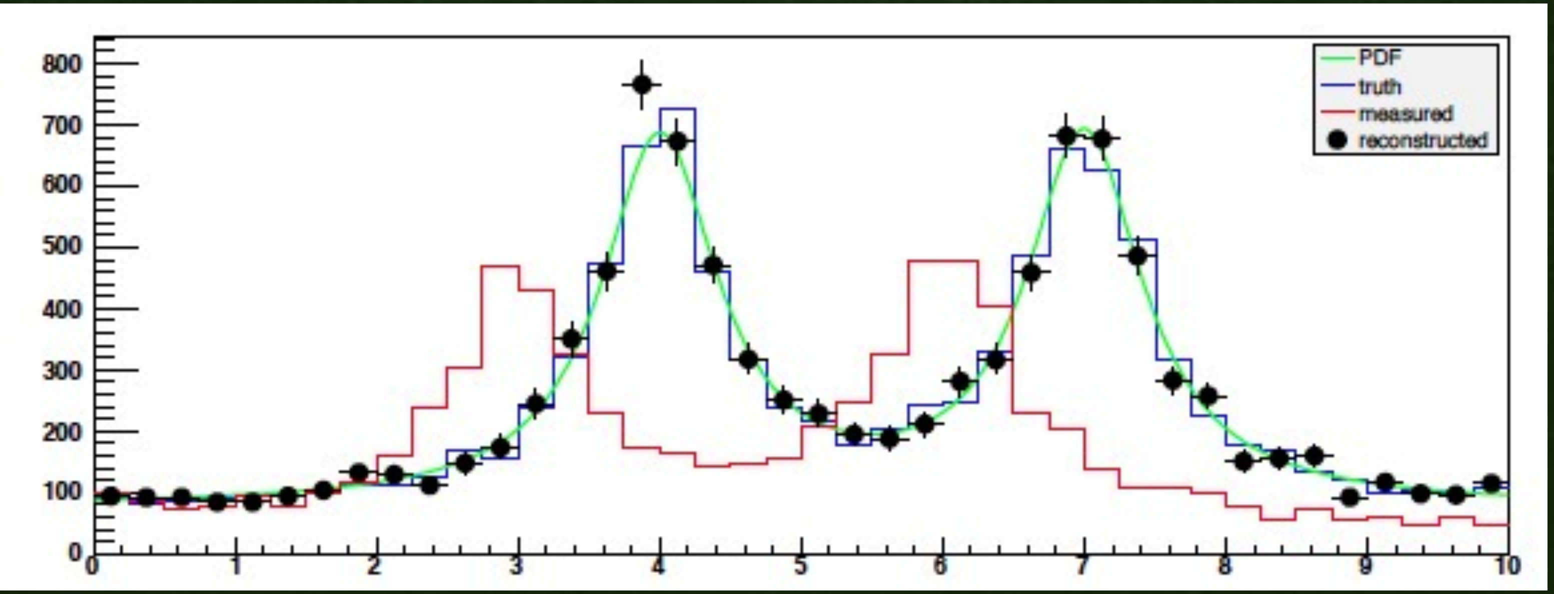
# Backup

# Bayesian Unfolding

- Method to separate the detector response from the distribution to get a spectrum that is closest to the true one
- Corrects for detector smearing effects
- Particle-level results




arXiv:hep-ph/9509307

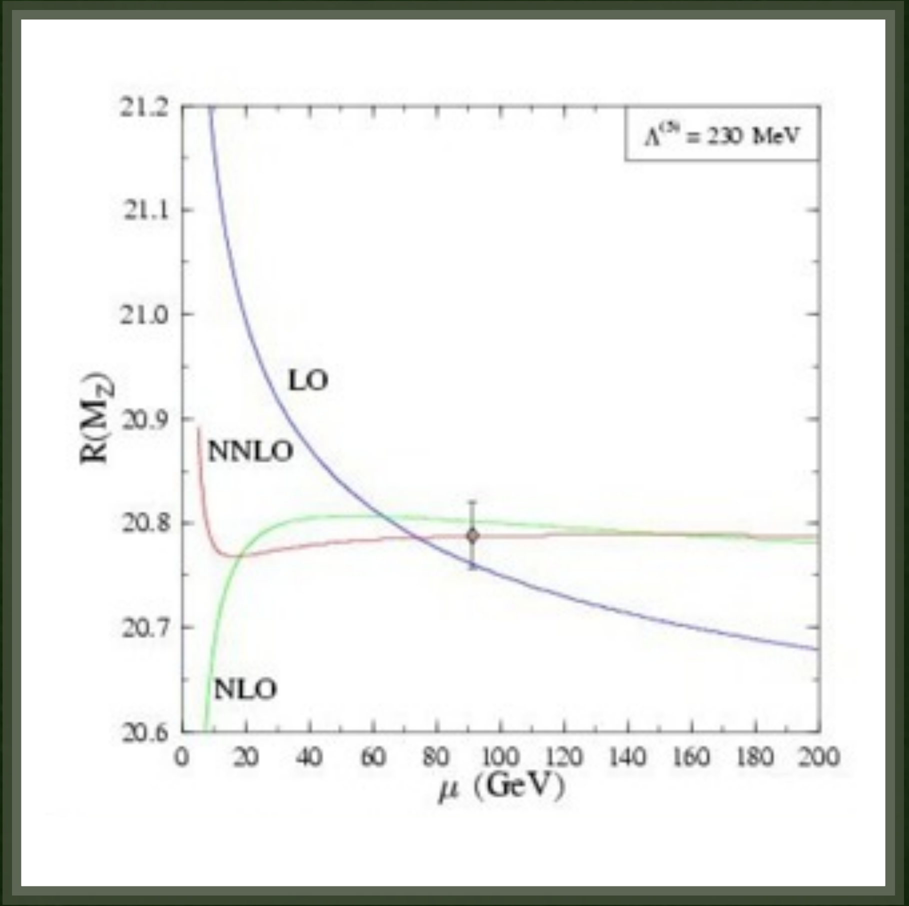


# Renormalization Scale

- Quarks have masses
  - Approximate symmetry
  - Need renormalization of divergences

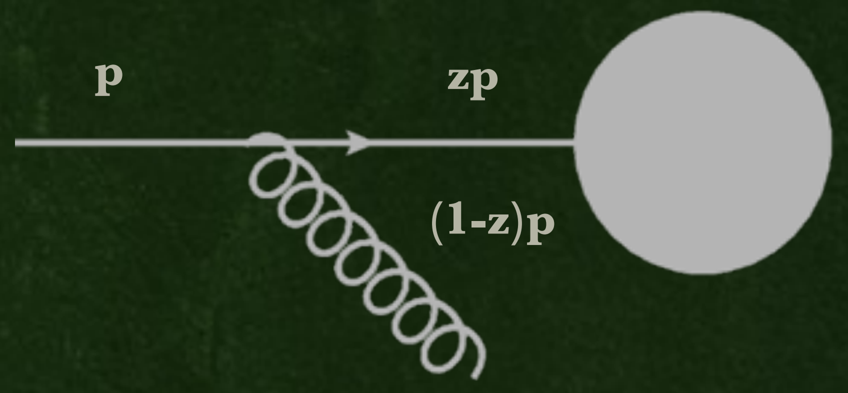
$$R(Q^2) \to R\left(\frac{Q^2}{\mu_R^2}\right)$$

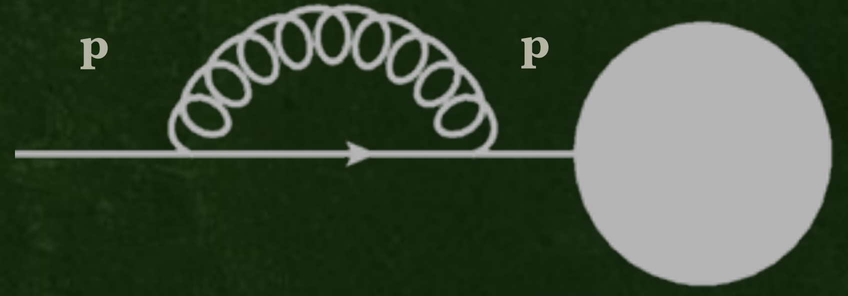
- Renormalization scale $\mu_R$ is an arbitrary, non-physical parameter
  - Measurement cannot depend on $\mu_R$
  - Calculations in pQCD will depend on choice of $\mu_R$
  - Systematic uncertainty



# Factorization Scale

- In initial state, soft and collinear gluon radiation is not cancelled by extra loop diagrams
  - Need another arbitrary scale $\mu_F$
- Divergences can be factorized into PDFs
- Factorization theorem:
  - Long distance physics in PDFs depends on $\mu_R$
  - Short distance physics depends on $\mu_F$ *and* $\mu_R$



# Triggers

- 3 single-jet triggers used at various $p_T$ ranges
- The highest threshold trigger used is unprescaled through 2011
- All triggers fully efficient above indicated offline cut

| HLT pT threshold (GeV) | 190 | 240 | 370 |
|---|---|---|---|
| Luminosity (1/fb) | 0.15 | 0.51 | 5.0 |
| Offline $\langle p_{T1,2} \rangle$ cut (GeV) | 215 | 269 | 409 |