New jet cross section measurements in DIS and extraction of α_s

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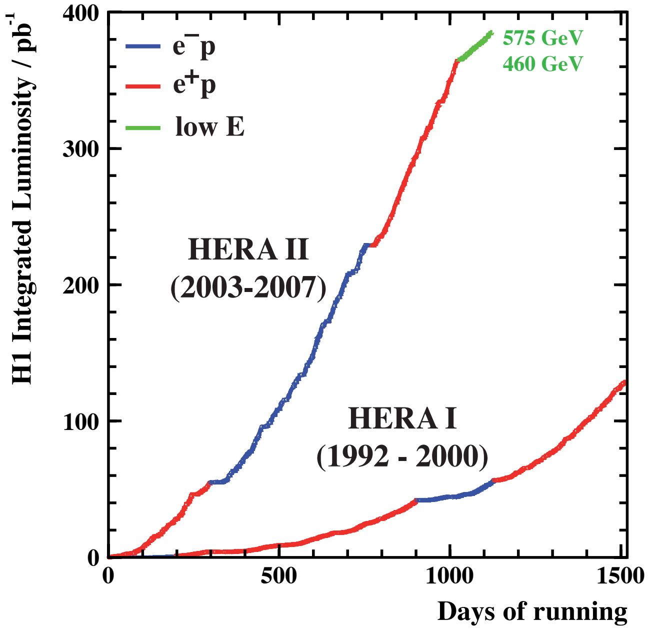
on behalf of the H1 and ZEUS collaborations

Low x 2012

Paphos, Cyprus

Precision Jet Measurements at HERA



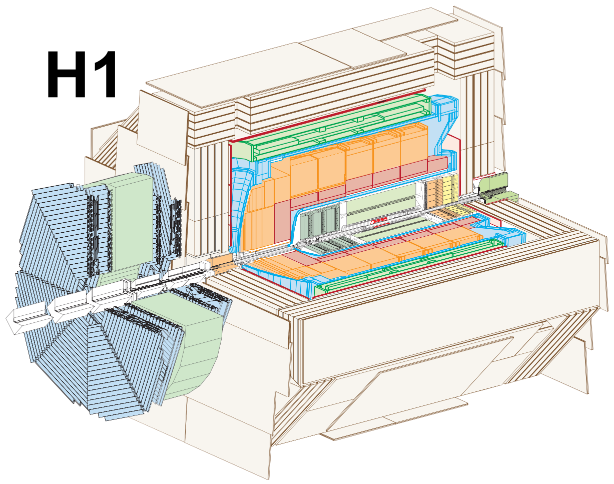
HERA-2 jet measurements

High statistics

L = 300-500 pb^{-1}: small statistical uncertainties, even at high Q^2 and high P_T

Excellent control over systematic uncertainties

H1



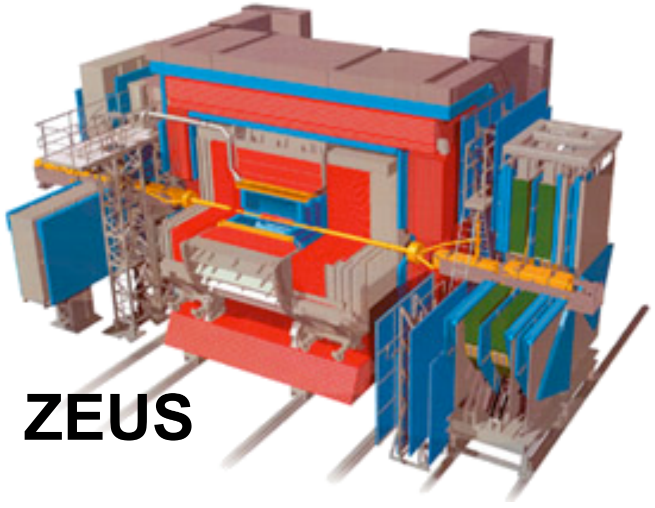
electron measurement: 0.5 – 1% scale uncertainty

jet energy scale: 1% uncertainty!
effect on jet cross sections: 3 – 10%

acceptance correction:
4 – 5% uncertainty

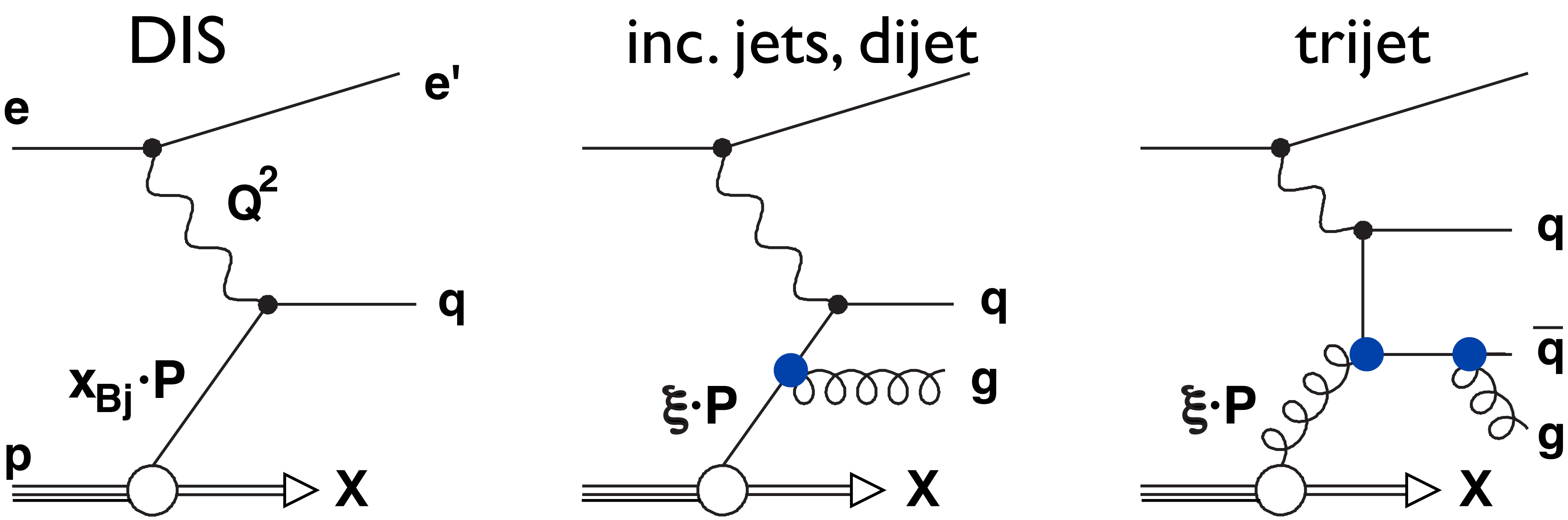
trigger: 1 – 2% normalisation uncertainty

luminosity: 2 – 2.5% normalisation uncertainty

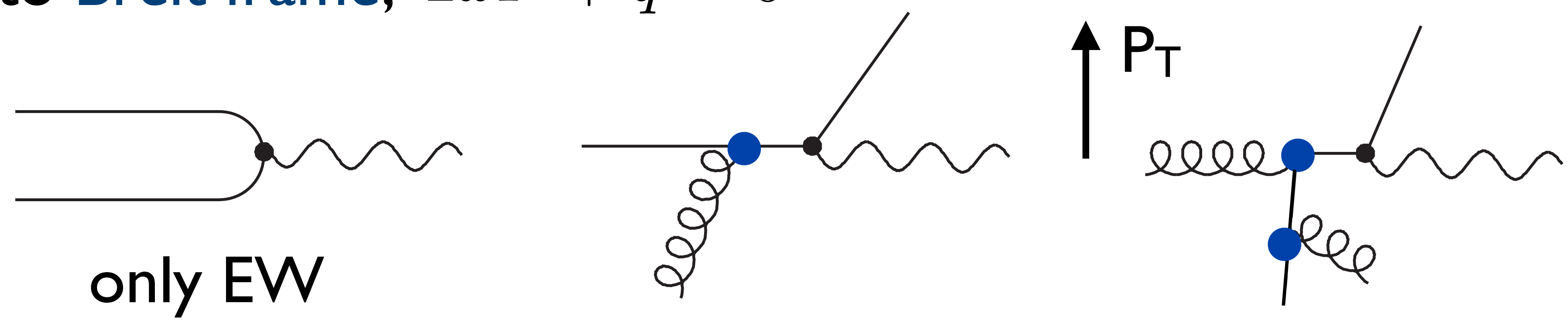


ZEUS

Jet Production in DIS



Boost to Breit frame, $2xP + q = 0$



only EW coupling

$\propto \alpha_s$

$\propto \alpha_s^2$

Momentum fraction of struck parton (in LO): $\xi = x\left(1 + \frac{M_{12}^2}{Q^2}\right)$

Direct sensitivity to α_s and gluon PDF

Observables

Inclusive Jets

each jet above a given P_T requirement contributes to the cross section: large statistics, calculation needs contributions from higher-order configurations

Dijets

events with at least *two jets* above a certain P_T contribute: reduced statistics but NLO calculations have smaller scale dependence

Trijets

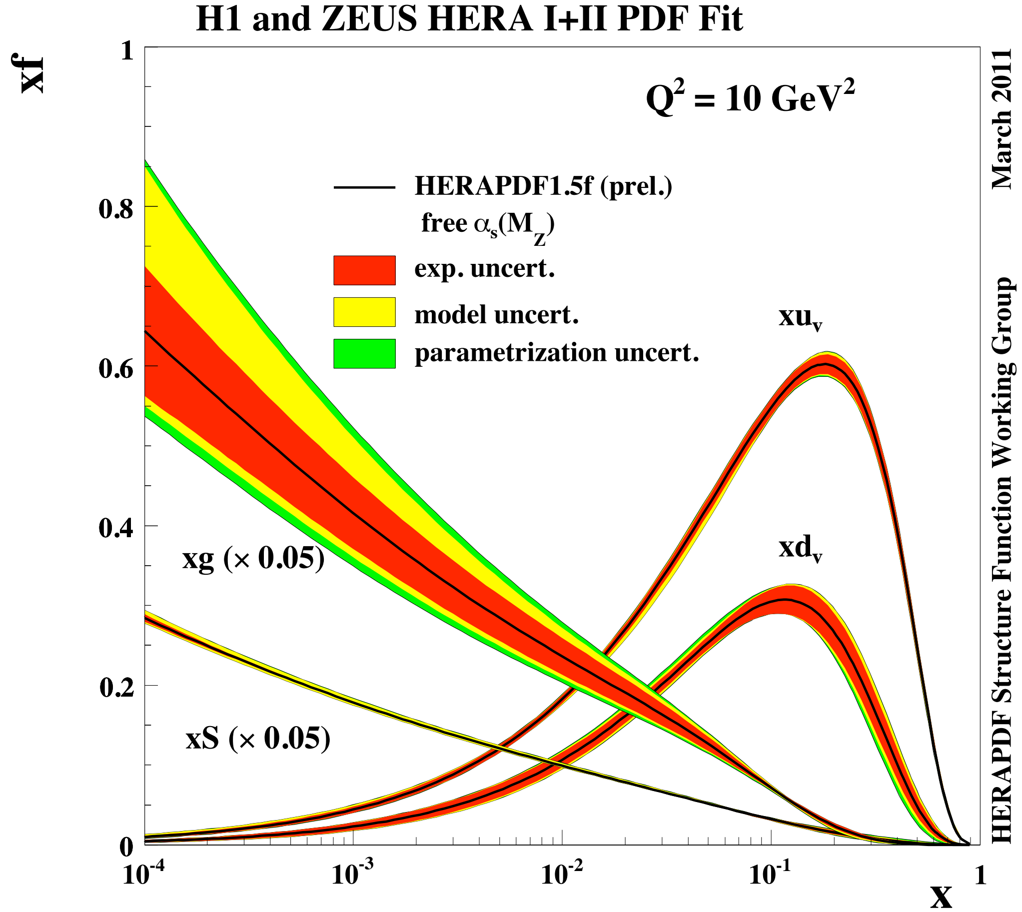
events with at least *three jets* above a certain P_T contribute: smaller statistics and slightly larger experimental uncertainties but high sensitivity to α_s ($O(\alpha_s^2)$ at LO)

Normalised Jet Cross Sections

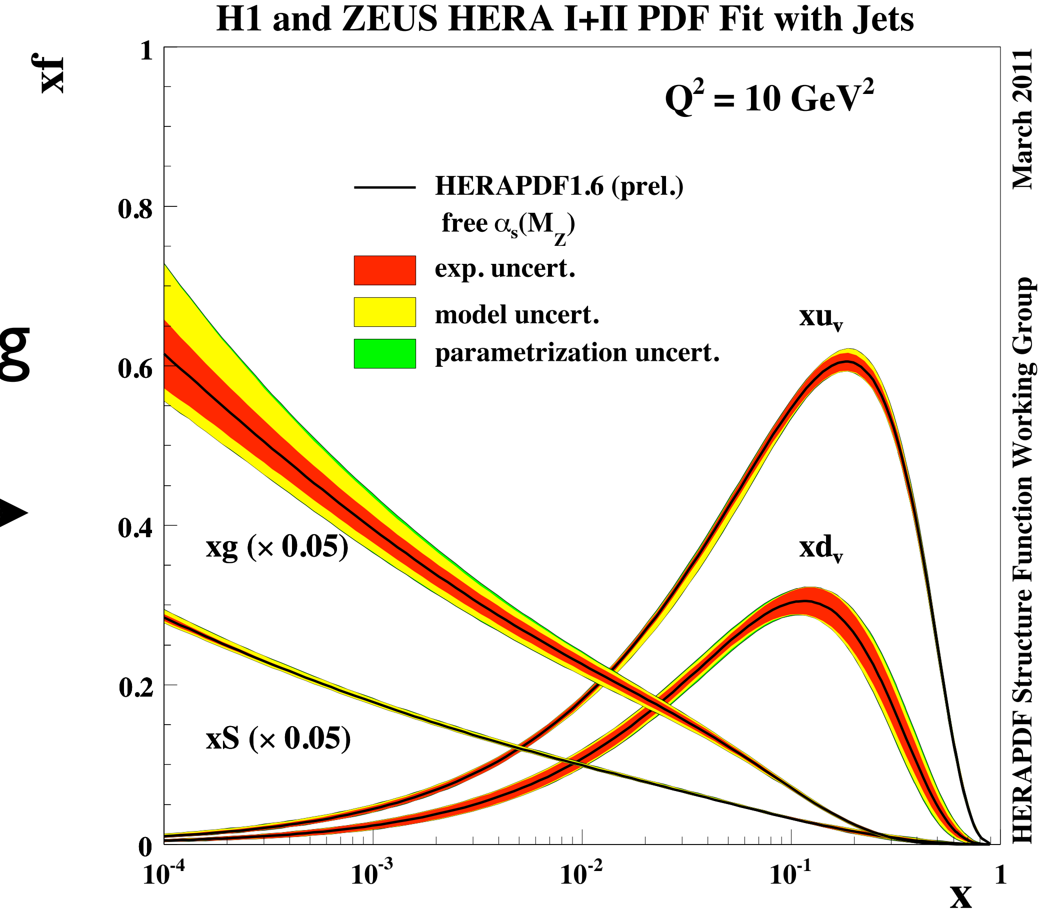
benefit from partial cancellations of experimental and theoretical uncertainties by measurement of σ_{jet}/σ_{NC}

HERA Jet Data in PDF Fits

H1prelim-11-034, ZEUS-Prel-11-001



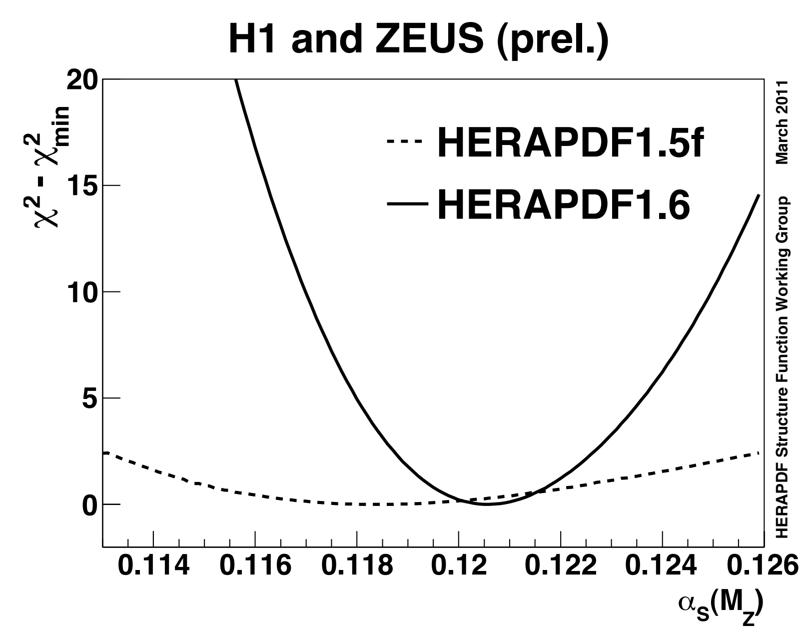
including jets →



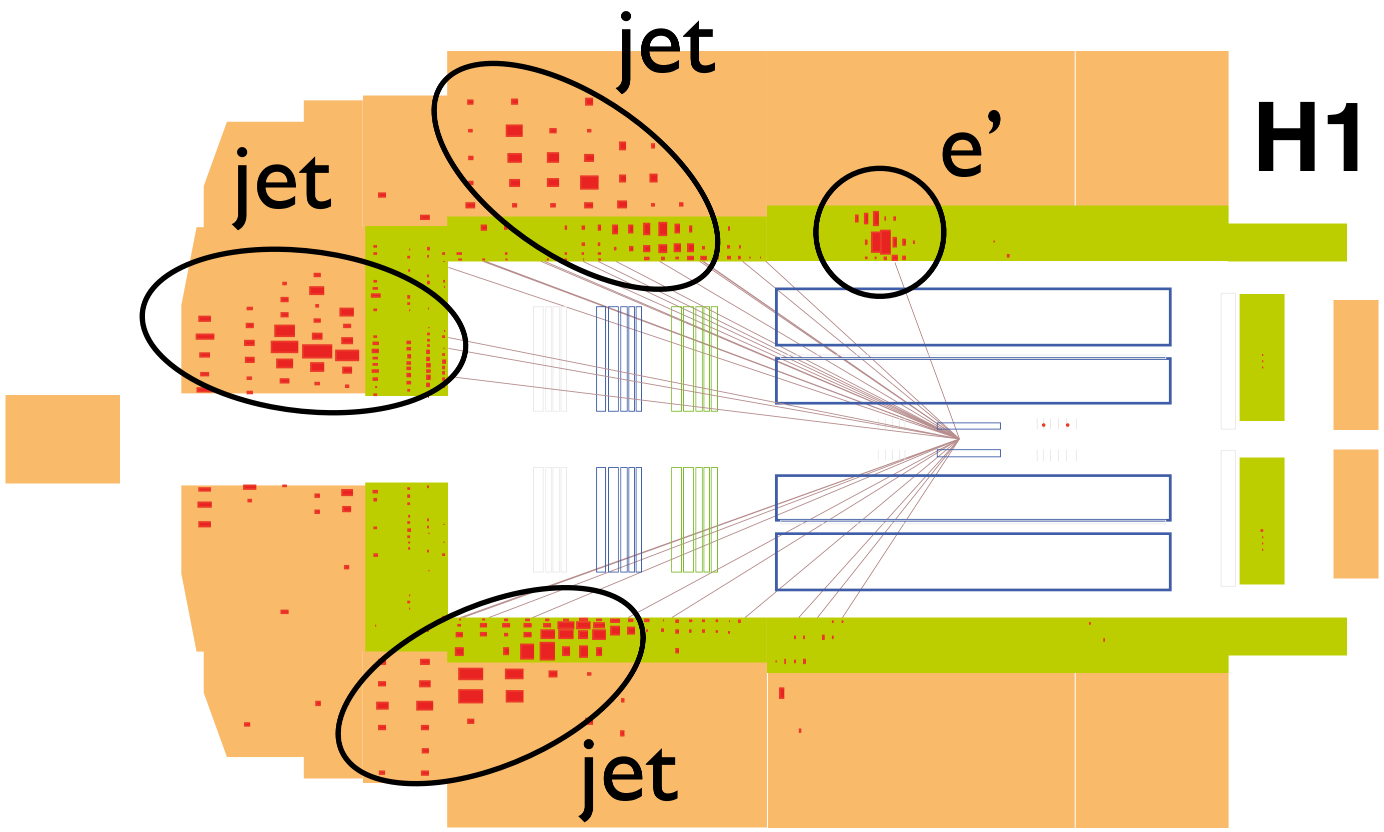
Only inclusive jet cross sections included in HERAPDF fits so far

Large potential shown: correlation between gluon PDF and $\alpha_s(M_Z)$ disentangled

$$\alpha_s(M_Z) = 0.1202 \pm 0.0013(\text{exp.}) \pm 0.0012(\text{had}) \pm 0.0045(\text{scale})$$



Multijet Measurement in DIS



Physical correlations

individual jet measurements are correlated: correlations between individual jets in the inclusive jet sample, dijet events are a subsample of inclusive jets, trijet and dijet events...

Experimental effects

correlations may change due to the detector resolution: introduces migrations between different jet samples

Regularised Unfolding

Migration matrix $\mathbf{A}$ describes the detector response

$$\mathbf{m} = \mathbf{A} \cdot \mathbf{x}$$

$\mathbf{m}$: measured distribution (detector level)

$\mathbf{x}$: true distribution (particle level)

Perform unfolding by analytic minimisation of

$$\chi^{\mathbf{2}} = \frac{\mathbf{1}}{\mathbf{2}}(\mathbf{m} - \mathbf{A}\mathbf{x})^{\mathbf{T}}\mathbf{V}^{-\mathbf{1}}(\mathbf{m} - \mathbf{A}\mathbf{x})^{\mathbf{T}} + \tau^{\mathbf{2}} \cdot \mathbf{L}$$

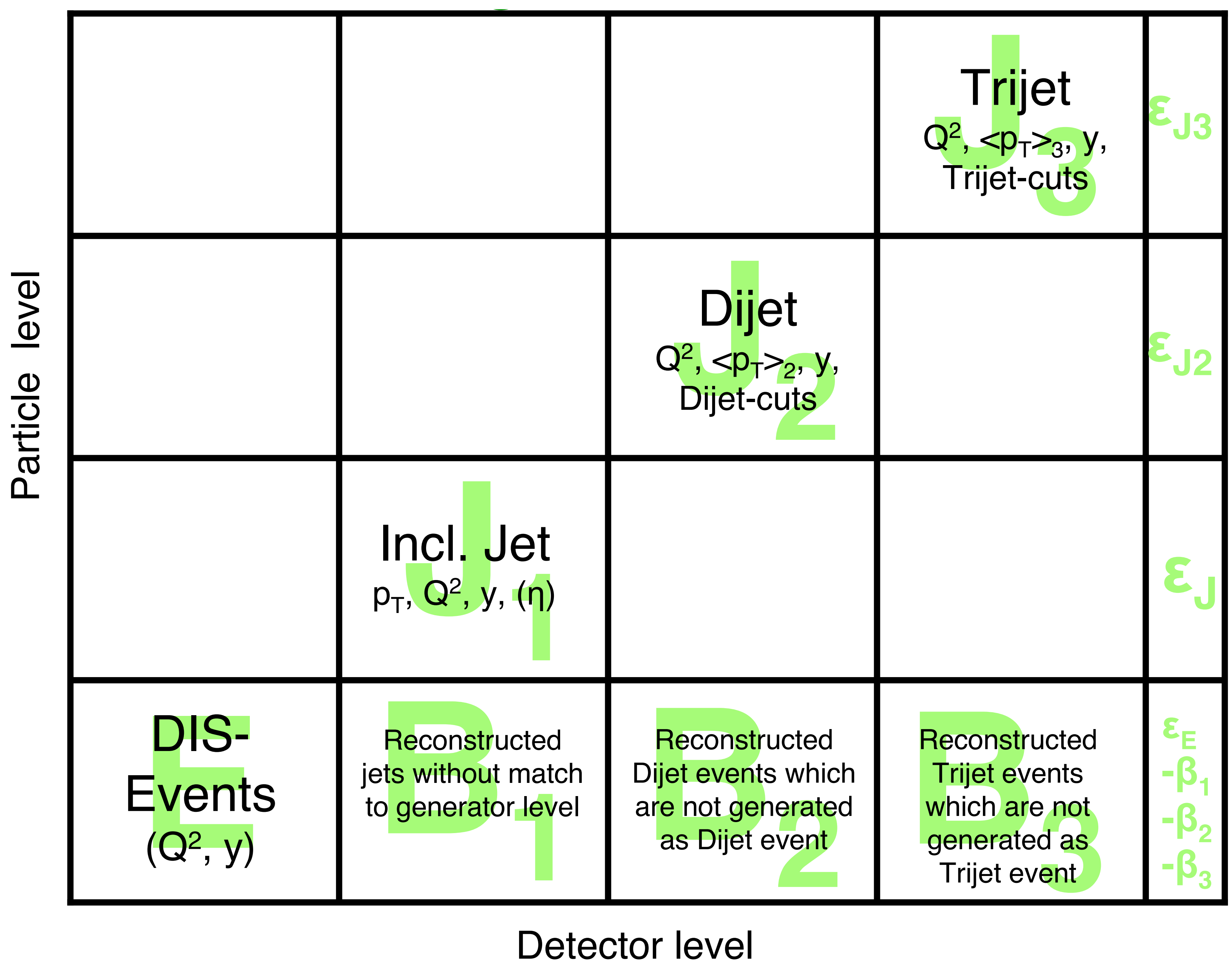
TUnfold (S. Schmitt), arXiv:1205.6201

Regularisation parameter $\boldsymbol{\tau}$ suppresses large fluctuations

Correlation of datasets contained in covariance matrix $\mathbf{V}$

Possibility to unfold four measurements at once:
NC DIS, inclusive jet, dijet and trijet cross sections

Unfolding of Jet Multiplicities



Migration Matrix

Multidimensional unfolding in Q^2, P_T and y

Full treatment of migrations between jet observables

Normalisation preserved with inclusive NC DIS events

Detector response obtained from simulation

Dimension:
about 600 x 2200 bins

MC Test

Performance test:
Test unfolded result w.r.t. MC truth

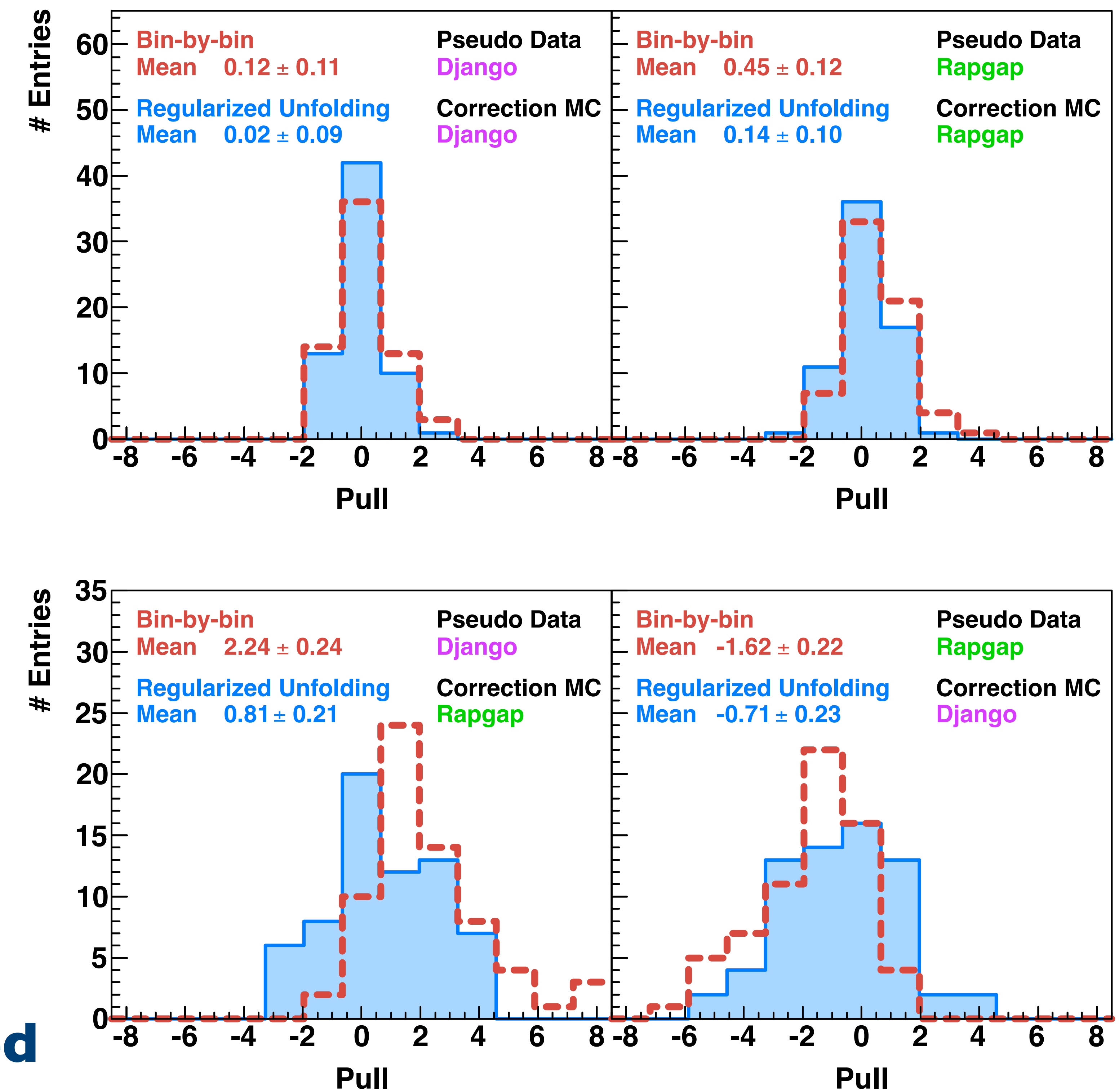
Pull distribution:

$$P_i = \frac{x_i^{\mathrm{unfold}} - x_i^{\mathrm{true}}}{\delta_i^{\mathrm{unfold}}}$$

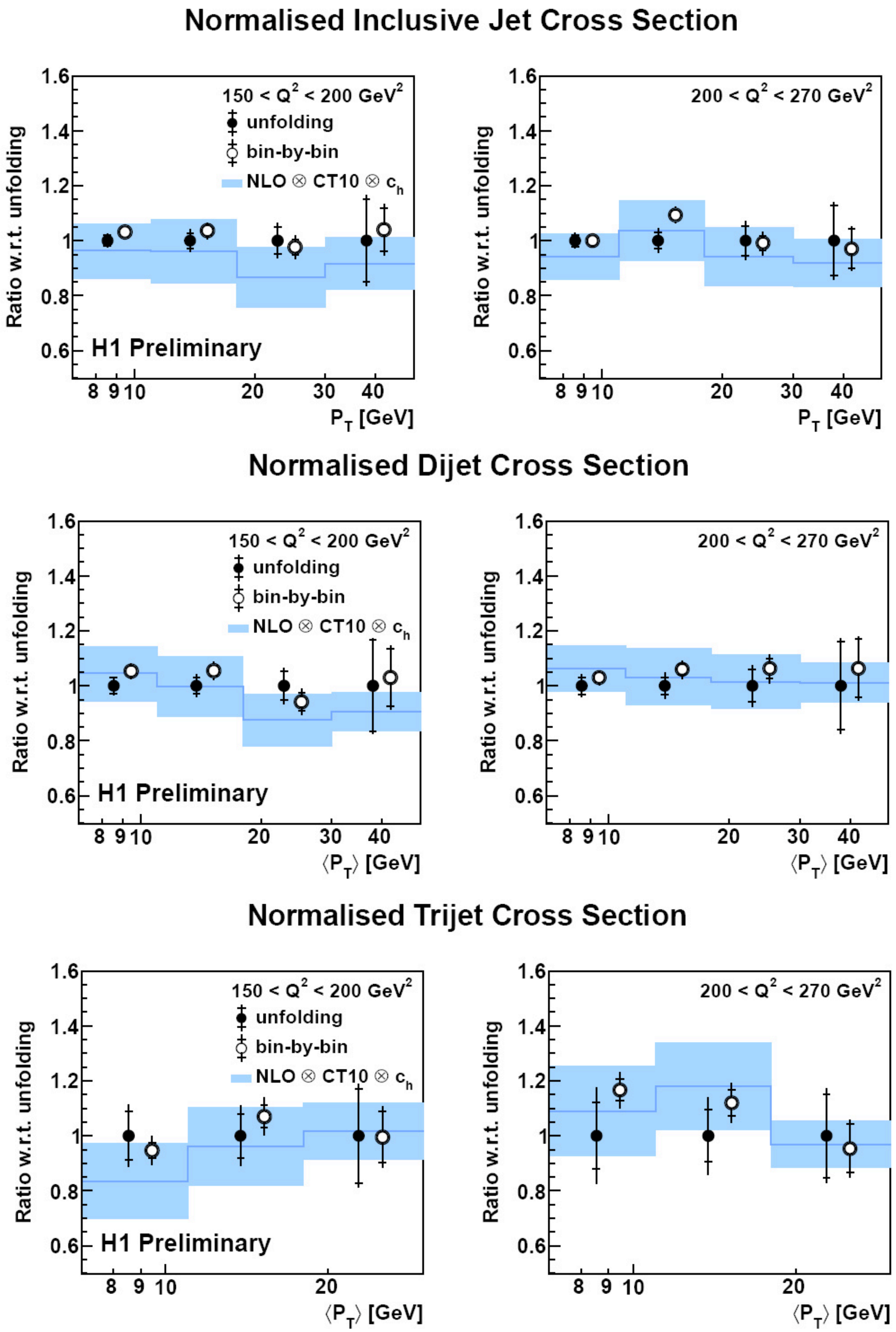
Two theo. models:
Djangoh (CDM)
Rapgap (MEPS)

Comparison:
Unfolded results with results obtained bin-wise derived correction factors

⇒ Unfolding less biased

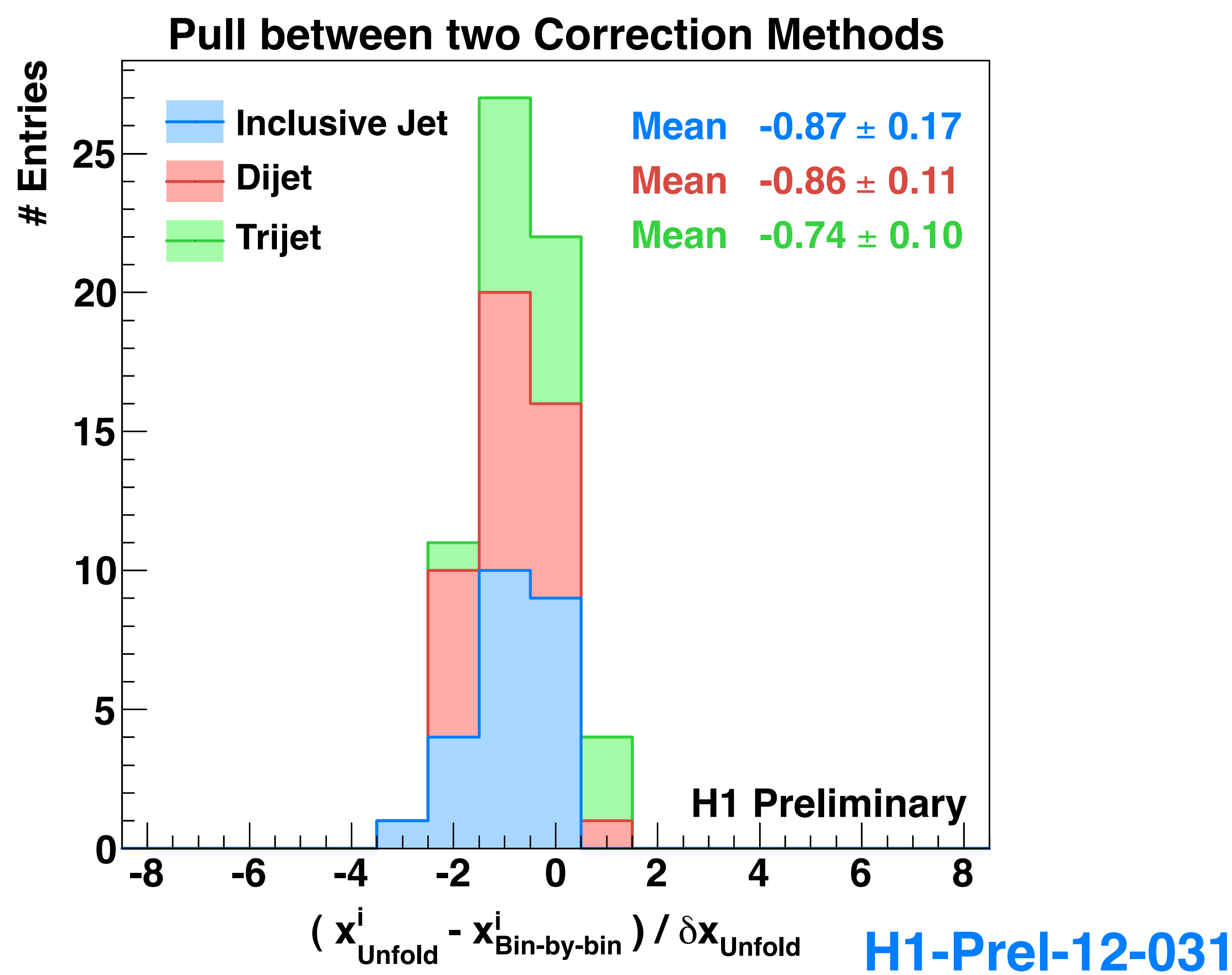


Comparison to “bin-by-bin”



Performance on data

- bin-by-bin result gives slightly higher cross section (~0.8σ)
- larger stat. error - but full covariance matrix available

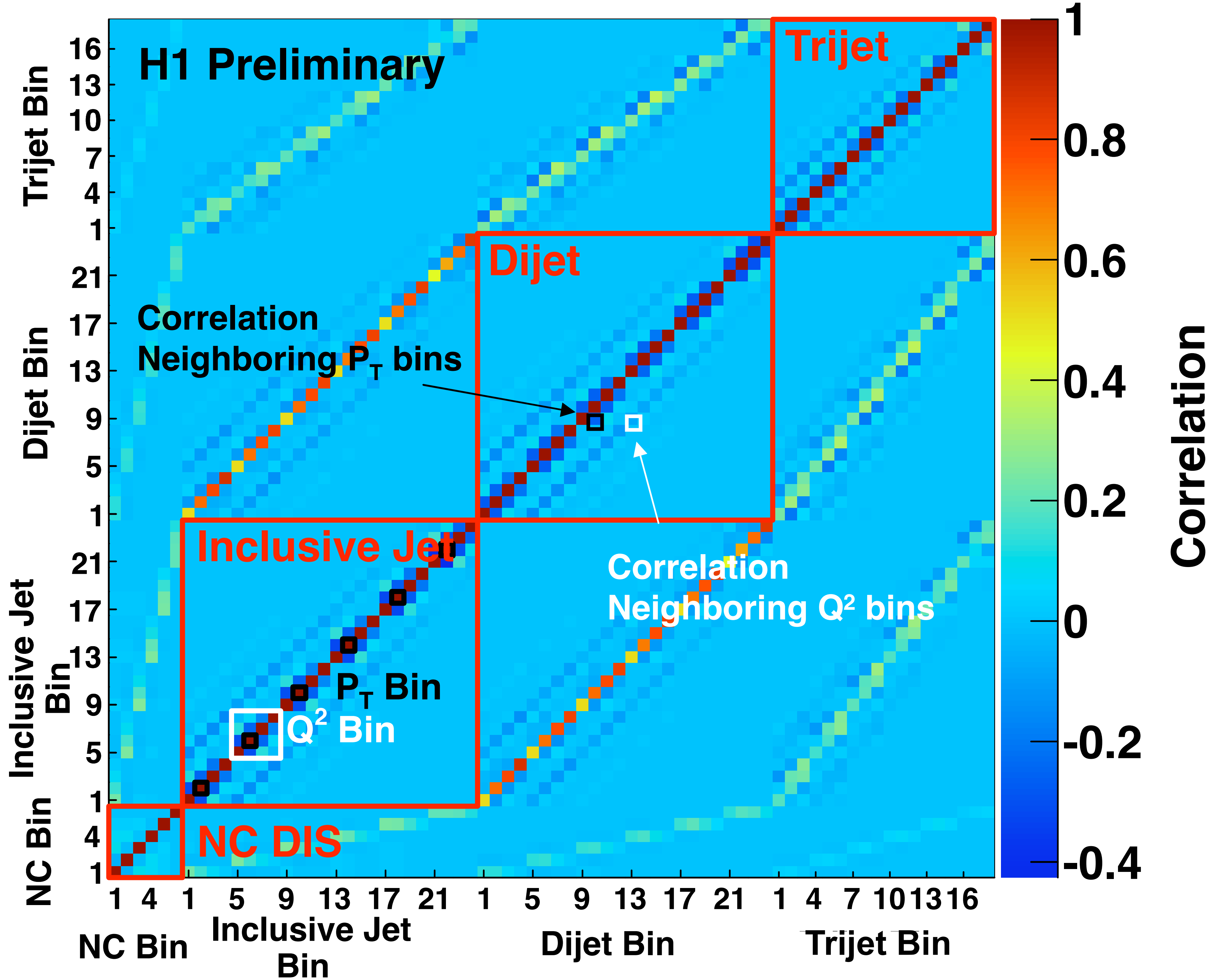


Unfolded Correlation Matrix

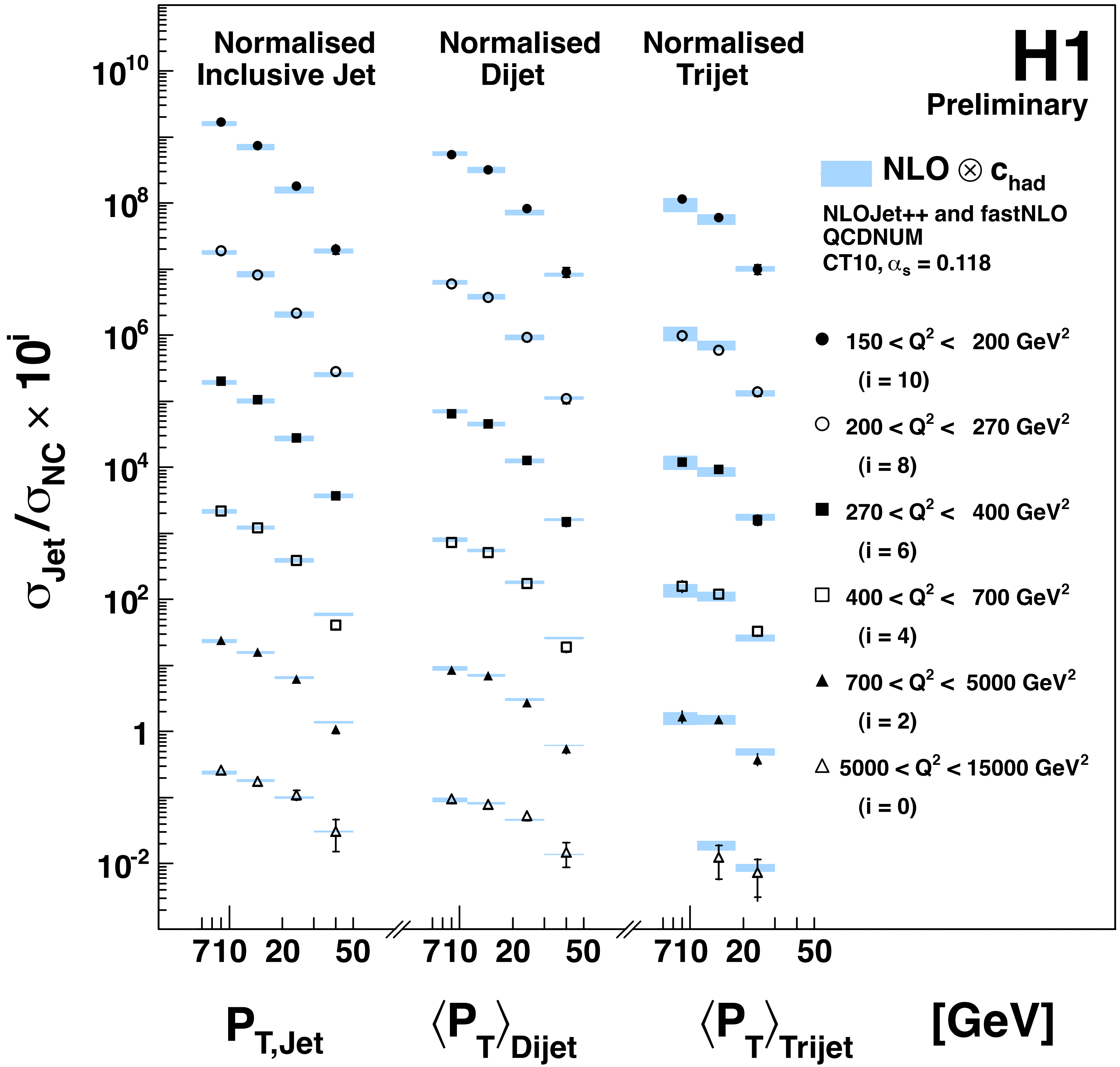
Full, partly anti-correlated, covariance matrix available after unfolding

Normalisation of individual measurements possible using full error propagation

Valuable information for QCD fits



Normalised Multijet Cross Sections



NLO Calculation

NLOJet++ and QCDNUM corrected for hadronisation effects

Scale choice:

$$\mu_f^2 = Q^2$$

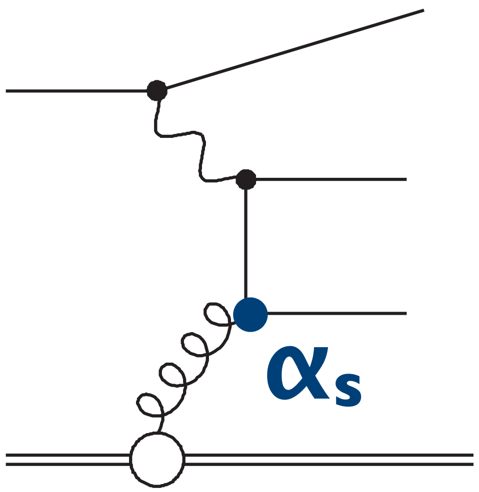
$$\mu_r^2 = \frac{1}{2}(Q^2 + P_T^2)$$

H1-Prel-12-031

Determination of $\alpha_s(M_Z)$

NLO calculation depends on PDF and $\alpha_s(M_Z)$

⇒ Keep PDF fixed and fit $\alpha_s(M_Z)$



Hessian method: Minimise $\chi^2(\alpha_s)$

$$\chi^2(\alpha_s) = \boldsymbol{u}^T \boldsymbol{V}^{-1} \boldsymbol{u} + \sum_k \epsilon_k^2$$

$$u_i = \sigma_i^{\mathrm{exp}} - \sigma_i^{\mathrm{theo}}(\alpha_s, \mathrm{pdf}) \left(1 - \sum_{\mathrm{k}} \Delta_{\mathrm{ik}} \epsilon_{\mathrm{k}}\right)$$

- Experimental uncertainty obtained by $\chi^2 = \chi^2_{\mathrm{min}} + 1$
- Theoretical uncertainty obtained by offset method:
  - Repeat fit for μ_r and μ_f varied by a factor of 1/2 and 2
- PDF uncertainty calculated with PDF eigenvalues
- Consistency with PDF sets with varied $\alpha_s(M_Z)$ checked

Determination of $\alpha_s(M_Z)$

Normalized Inclusive Jet

$$\alpha_s = 0.1197 \pm 0.0008\,(\text{exp}) \pm 0.0014\,(\text{PDF}) \pm 0.0011\,(\text{had}) \pm 0.0053\,(\text{theo})$$

$$\chi^2 / \text{ndf} = 28.7/23 = 1.24$$

Normalized Dijet

$$\alpha_s = 0.1142 \pm 0.0010\,(\text{exp}) \pm 0.0016\,(\text{PDF}) \pm 0.0009\,(\text{had}) \pm 0.0048\,(\text{theo})$$

$$\chi^2 / \text{ndf} = 27.0/23 = 1.17$$

Normalized Trijet

$$\alpha_s = 0.1185 \pm 0.0018\,(\text{exp}) \pm 0.0013\,(\text{PDF}) \pm 0.0016\,(\text{had}) \pm 0.0042\,(\text{theo})$$

$$\chi^2 / \text{ndf} = 12.0/16 = 0.75$$

Good χ^2/ndf for each individual observable

Tension between α_s from dijets and inclusive/trijets observed, but α_s values well within theoretical uncertainties

Combined Fit

$$\alpha_s = 0.1177 \text{ +/- } 0.0008\,(\text{exp})$$

$$\chi^2 / \text{ndf} = 104.608 / 64 = 1.634$$

Fit to all data points

Relatively large χ^2/ndf

Combined Fit

Largest benefit is from a combined fit

simultaneous fit to normalised inclusive jet, dijet and trijet cross sections

Sensitivity to higher orders

theoretical uncertainty estimated by variation of scale

use k-factor as indicator for higher order contributions

$$k = \sigma_{\mathrm{NLO}}/\sigma_{\mathrm{LO}}$$

range of k-factor: $1.05 < k < 1.45$

Restrict analysis to $k < 1.3$

faster convergence of perturbative series

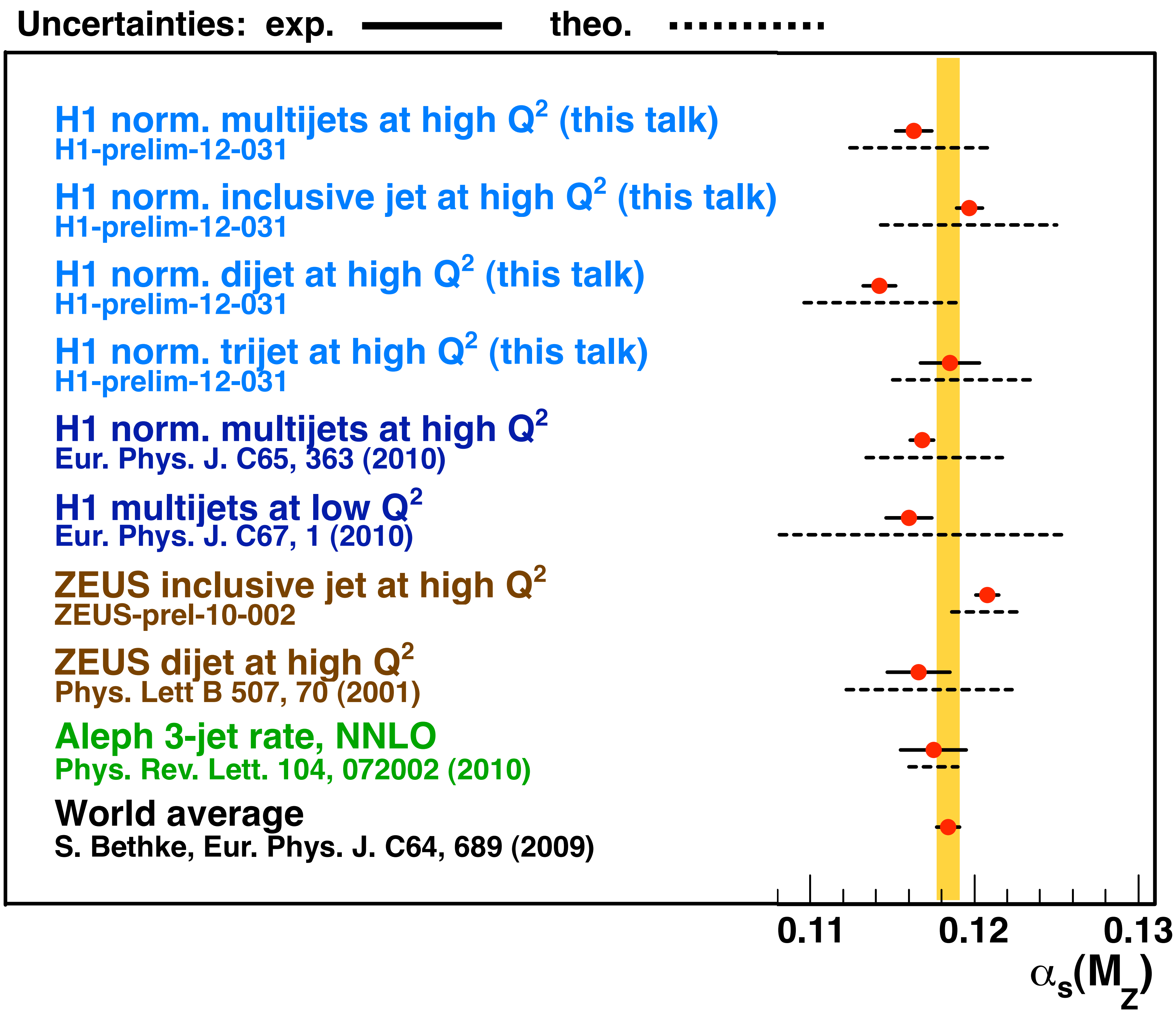
trade-off between number of data points and smaller theoretical uncertainty

Normalized Multijet (k-factor < 1.3)

$$\alpha_s = 0.1163 \pm 0.0011\ (\mathrm{exp})\ \pm 0.0014\ (\mathrm{PDF})\ \pm 0.0008\ (\mathrm{had})\ \pm 0.0039\ (\mathrm{theo})$$

$\chi^2 / \mathrm{ndf} = 53.2 / 41 = 1.30$ (much better χ^2/ndf)

Comparison of $\alpha_s(M_Z)$ Values



Summary

Regularised Unfolding of Jet Multiplicities

- multi-dimensional unfolding of various measurement simultaneously
- full covariance matrix and robust estimation of systematic uncertainties

Precision Measurement of Multijet Production at high Q^2

- absolute and normalised cross sections
- important testing ground for pQCD calculations
- input for future QCD analyses

Determination of α_s

- using unfolded measurements with full covariance matrix
- dominated by theoretical uncertainty