

Jets at low and high Q^2 and determination of the strong coupling

Roman Kogler

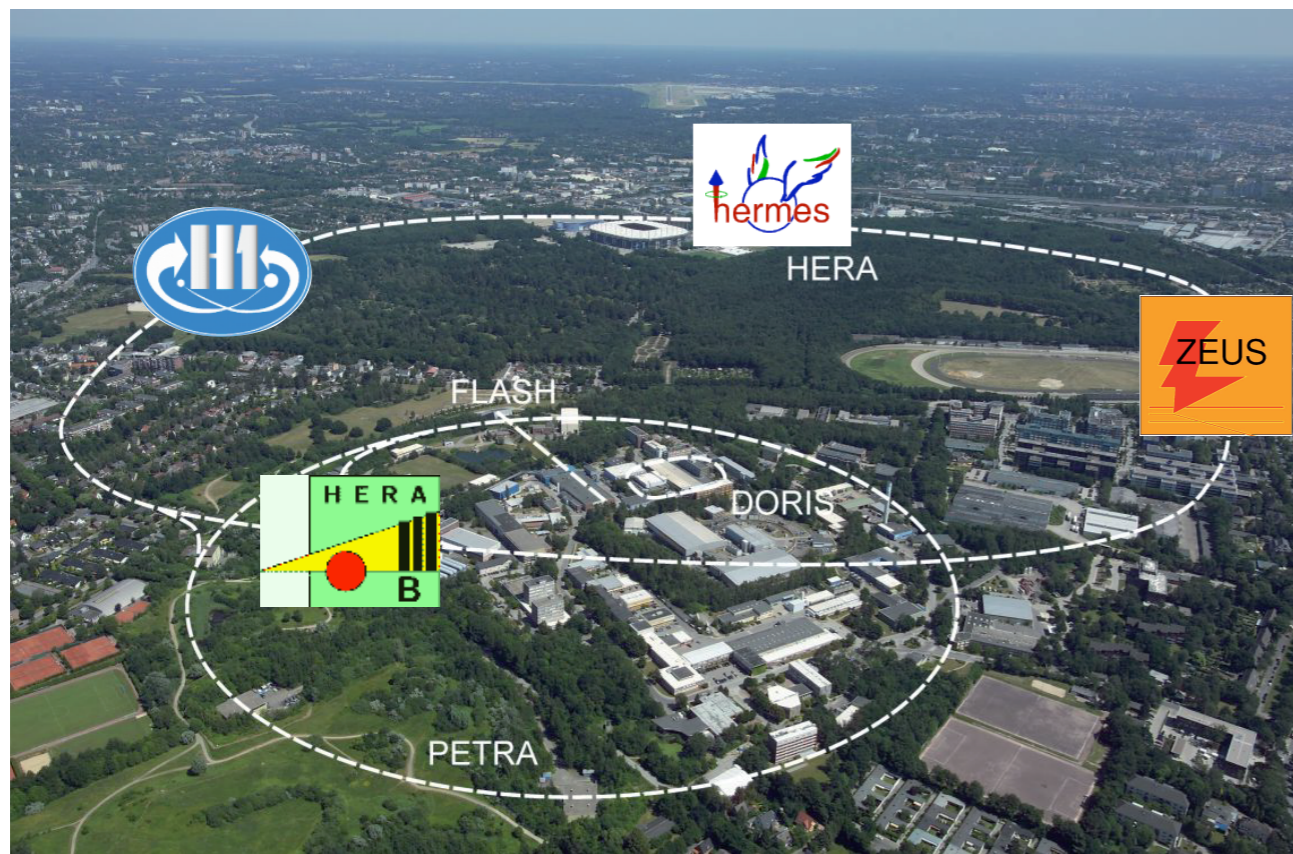
MPI für Physik, München

on behalf of the H1 collaboration



DIS 2010 Florence, April 19-23

The ep collider HERA and H1



HERA

$$E_e = 27.6 \text{ GeV}$$

$$E_p = 920 \text{ GeV}$$

$$\sqrt{s} \approx 320 \text{ GeV}$$

2001-2002 luminosity upgrade

low Q^2 multi-jet analysis:

$$Q^2 < 100 \text{ GeV}^2$$

HERA I

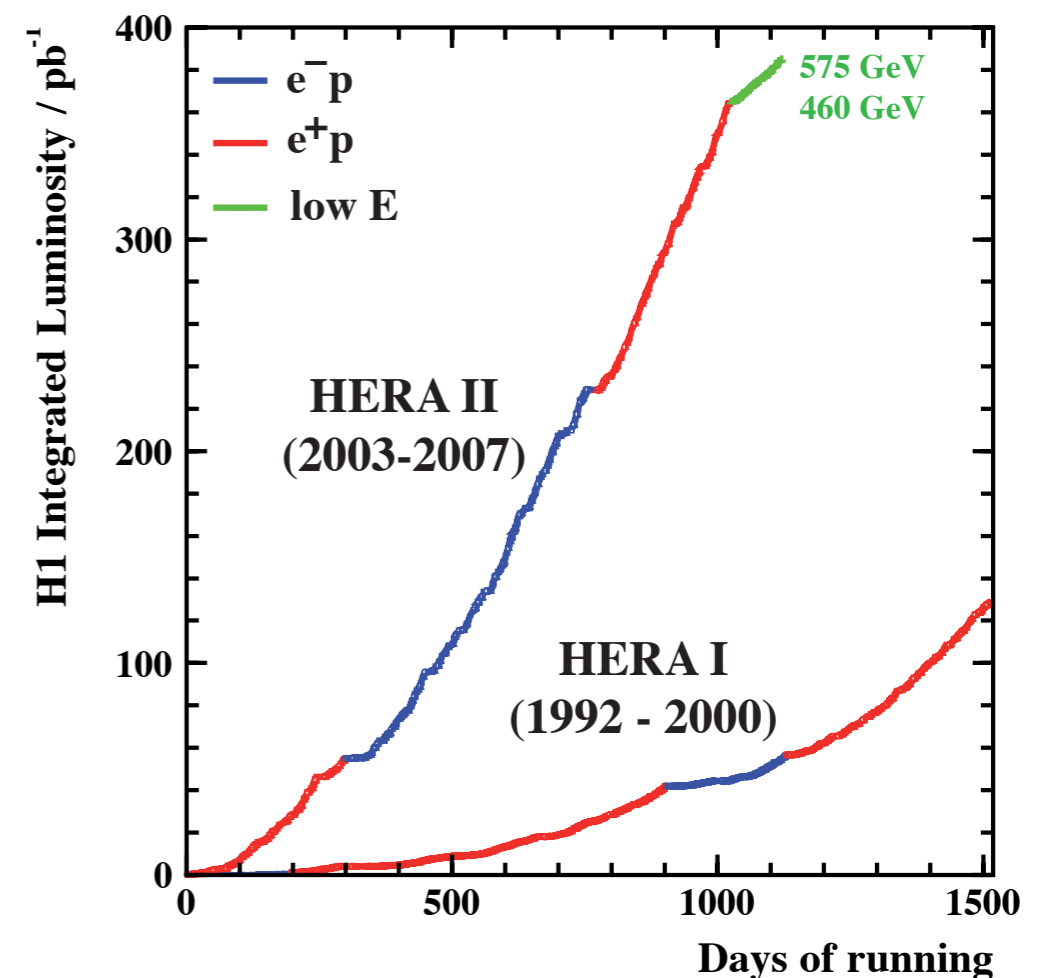
$$L = 44 \text{ pb}^{-1}$$

high Q^2 multi-jet analysis:

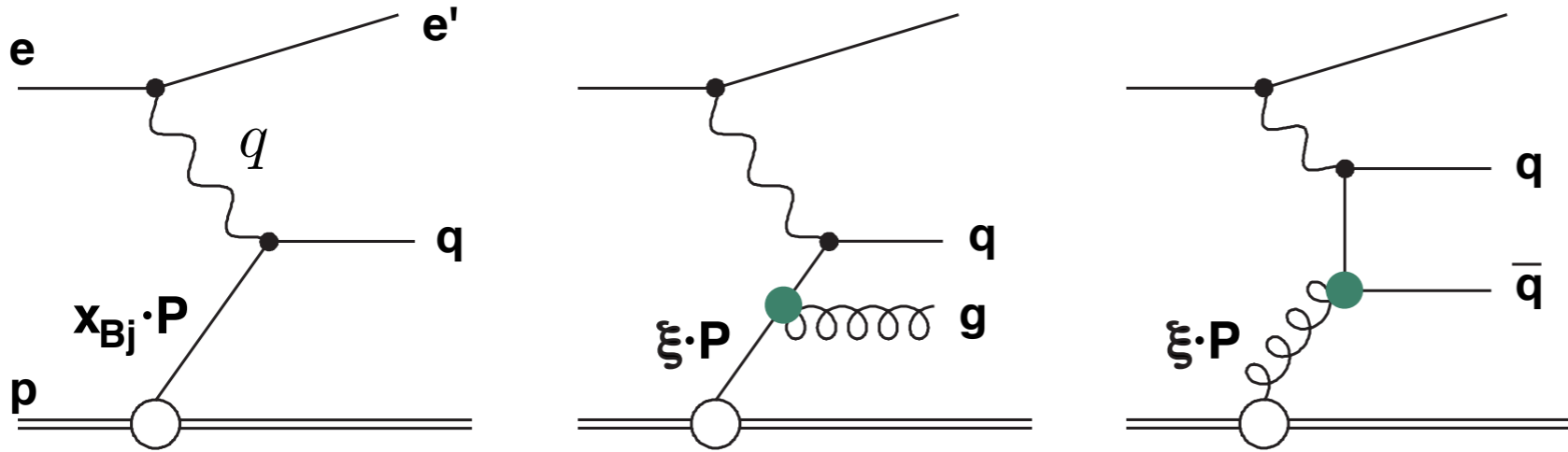
$$Q^2 > 150 \text{ GeV}^2$$

HERA I+2

$$L = 400 \text{ pb}^{-1}$$



Jet Production In DIS



virtuality:

$$Q^2 = -q^2 = -(e - e')^2$$

inelasticity:

$$y = \frac{p \cdot q}{p \cdot k}$$

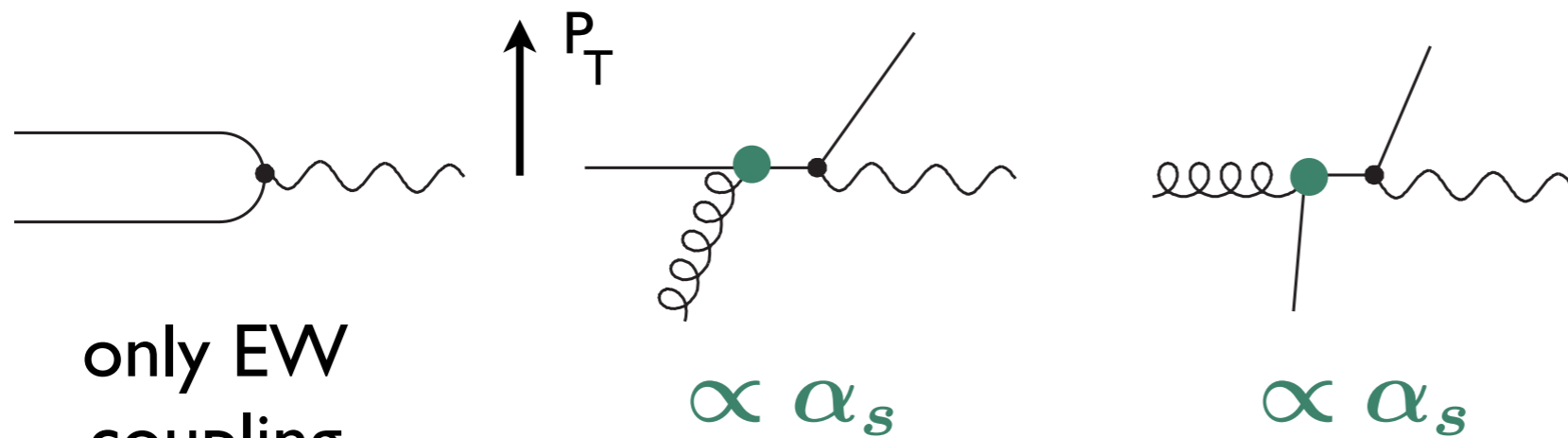
Boost to Breit frame, $2x_{Bj} \cdot p + q = 0$

Bjorken scaling variable:

$$x_{Bj} = \frac{Q^2}{2p \cdot q}$$

Momentum fraction of struck parton (in LO):

$$\xi = \left(1 + \frac{M_{12}^2}{Q^2} \right)$$



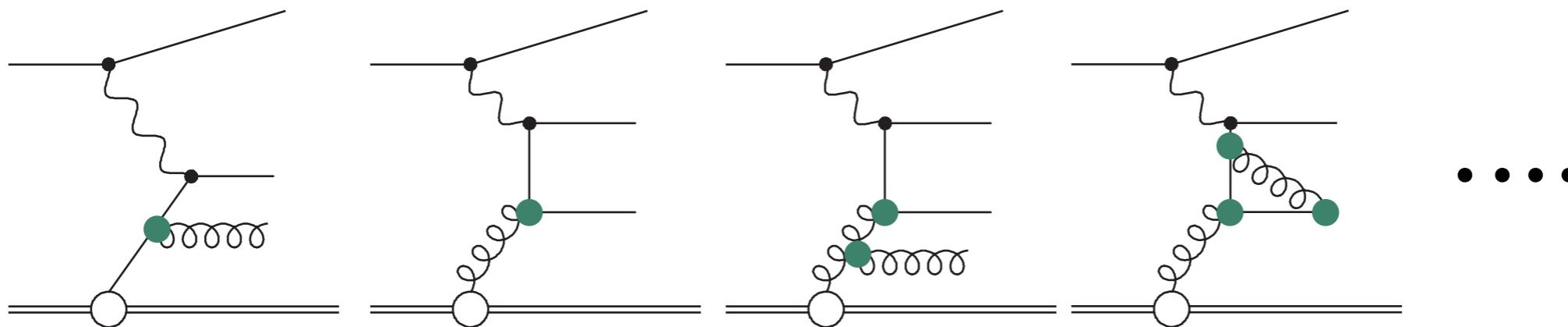
only EW
coupling

$\propto \alpha_s$

$\propto \alpha_s$

Only processes proportional to α_s generate P_T in the Breit frame

Jet Production In DIS



$$\sigma_{\text{njet}} = \sum_{i=q,\bar{q},g} \int_0^1 dx f_i(x, \mu_f) \hat{\sigma}_i(x, \alpha_s^{n-1}(\mu_r), \mu_r, \mu_f) (1 + \delta_{had})$$

$f_i(x, \mu_f)$: PDF of parton i in proton

used here: **CTEQ6.5M**, $\alpha_s(M_Z) = 0.118$

$\hat{\sigma}_i$: partonic cross section, calculated with **NLOJet++**,

MSbar scheme, 5 massless quark flavours,

up to 3-jet cross sections in NLO: $\mathcal{O}(\alpha_s^3)$

choice of scales μ_f and μ_r : two hard scales in DIS: Q and P_T

multijets at low Q^2 : **$Q: 2-10 \text{ GeV}$, $P_T: 5-80 \text{ GeV} \Rightarrow Q/P_T = 0.1 - 2$**

typical: $\mu_f = Q$ $\mu_r = \sqrt{(Q^2 + P_T^2)}/2$

Multi-Jets At Low Q^2

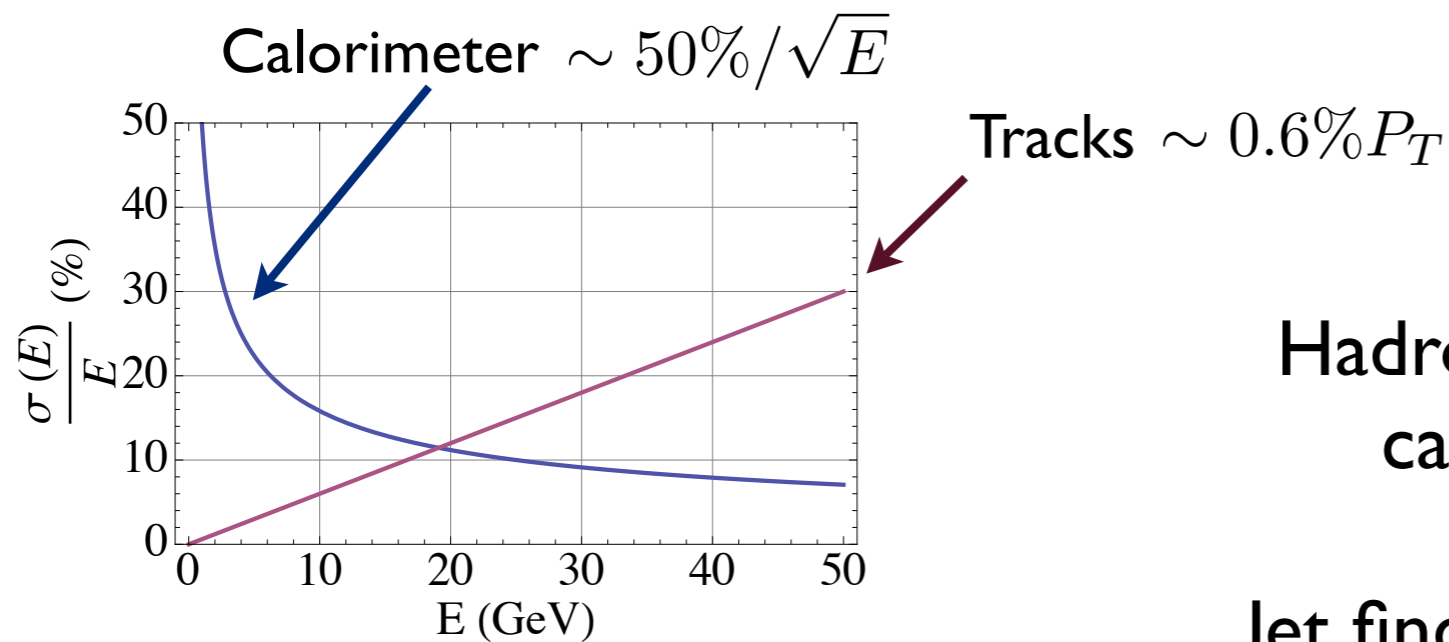
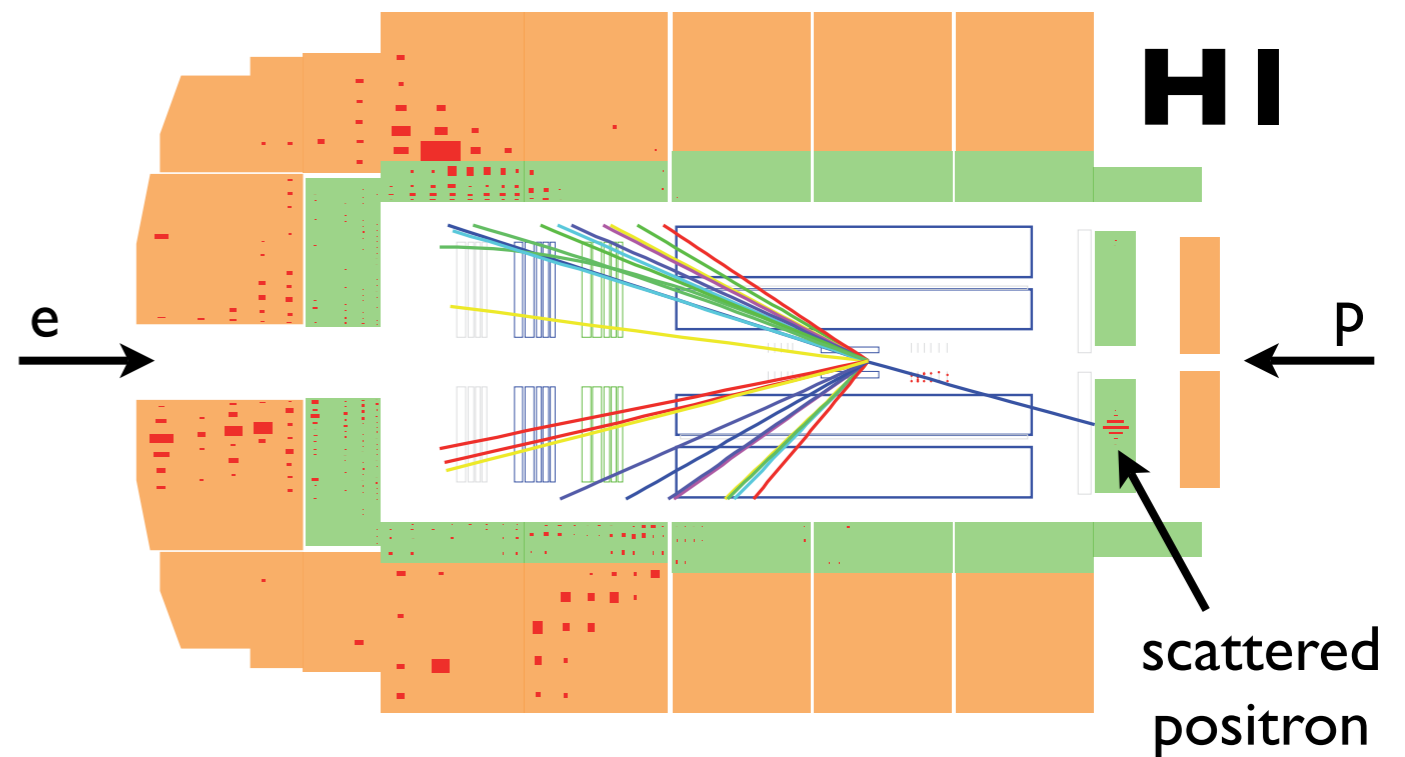
Phase space

$$5 \text{ GeV}^2 < Q^2 < 100 \text{ GeV}^2$$

$$0.2 < y < 0.7$$

Reconstruction

Hadronic final state reconstructed with energy flow method:



use best available measurement without double counting

Hadronic final state is measured and calibrated in laboratory frame

Jet finding and clustering performed in Breit frame

Multi-Jets At Low Q^2

Inclusive jets:

$$5 \text{ GeV} < P_T \text{ (Breit)} < 80 \text{ GeV}$$

$$-1 < \eta(\text{lab}) < 2.5$$

2- and 3-jets:

$$M_{12} > 18 \text{ GeV}$$

3-jet sample is a subsample of 2-jet sample

Main experimental uncertainties:

jet energy scale 2% $\rightarrow \Delta\sigma/\sigma = 4 - 10 \%$

acceptance correction $\rightarrow \Delta\sigma/\sigma = 2 - 15 \%$

luminosity measurement $\rightarrow \Delta\sigma/\sigma = 1.5 \%$

positron measurement $\rightarrow \Delta\sigma/\sigma = 2 \%$

Jet Definition:

longitudinally invariant k_T algorithm

inclusive mode, $R_0 = 1$

P_T recombination scheme

Statistics

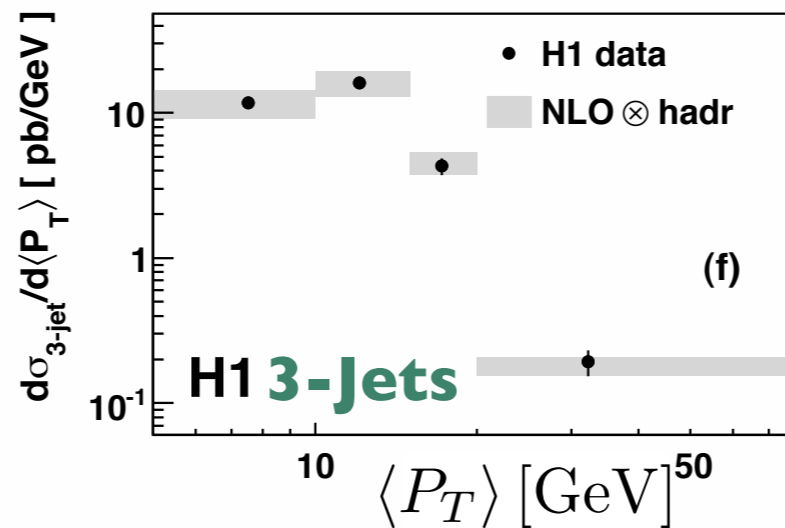
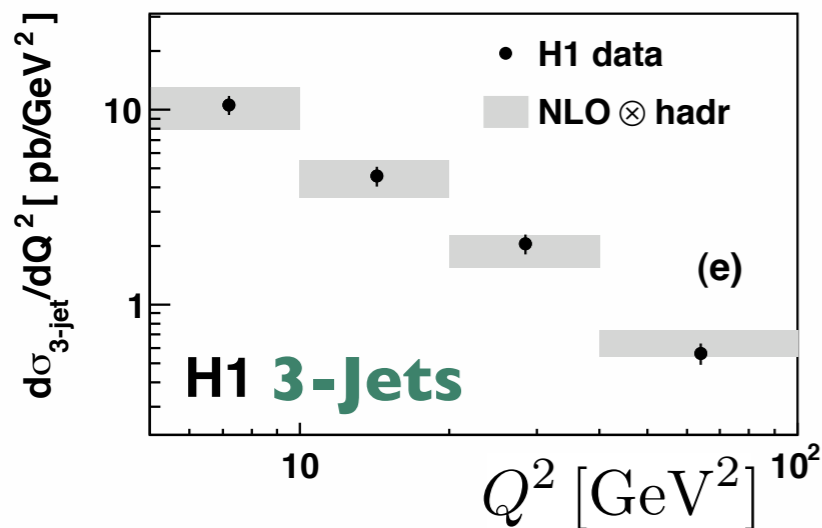
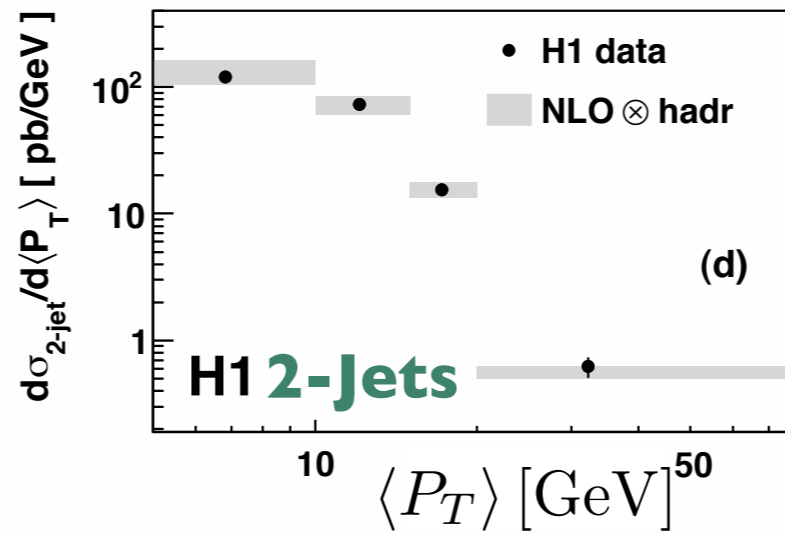
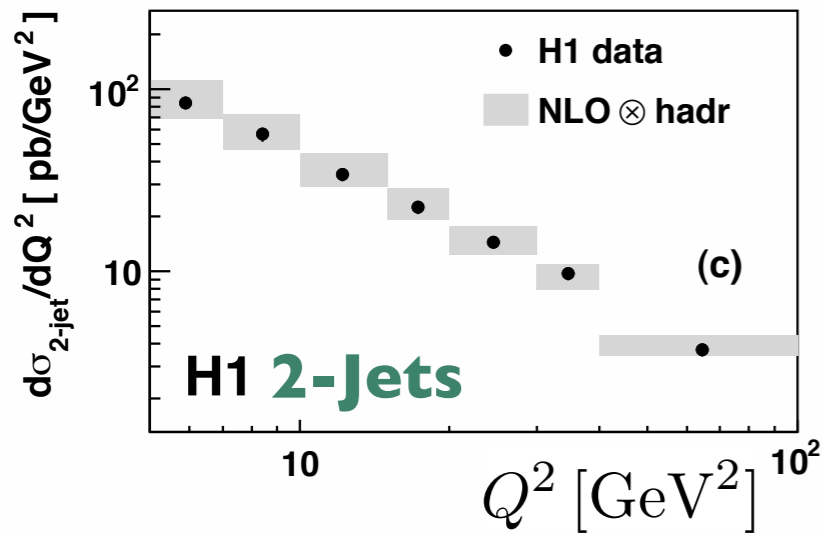
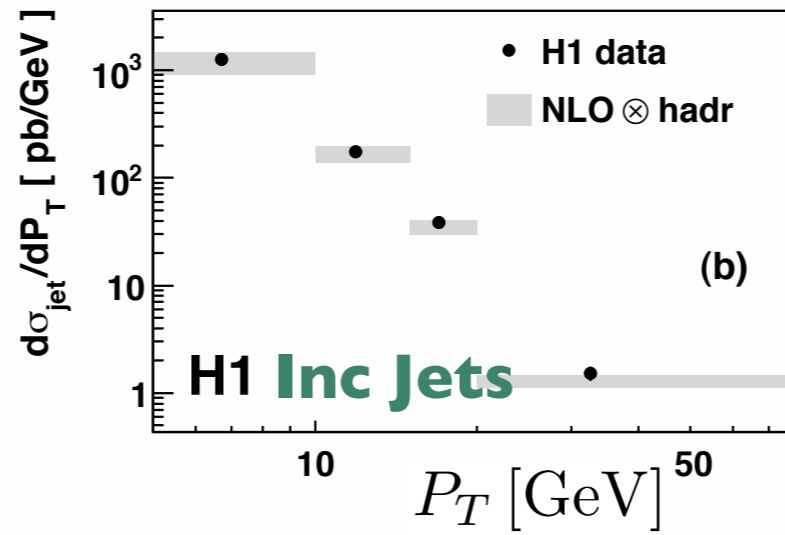
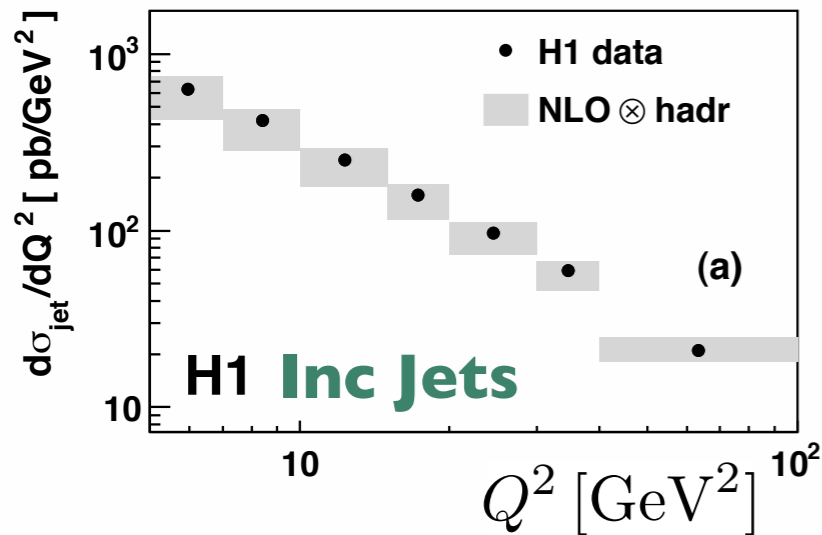
Inclusive Jets: 230.140

2-Jets: 31.550

3-Jets: 4.879

Measurements as function of Q^2 , P_T ($\langle P_T \rangle$), ζ

Multi-Jet Cross Sections At Low Q^2



- measurements well described by NLO, $\alpha_s(M_Z) = 0.118$
hadr. corrections 0.9-0.95
(0.8 for 3-jets)

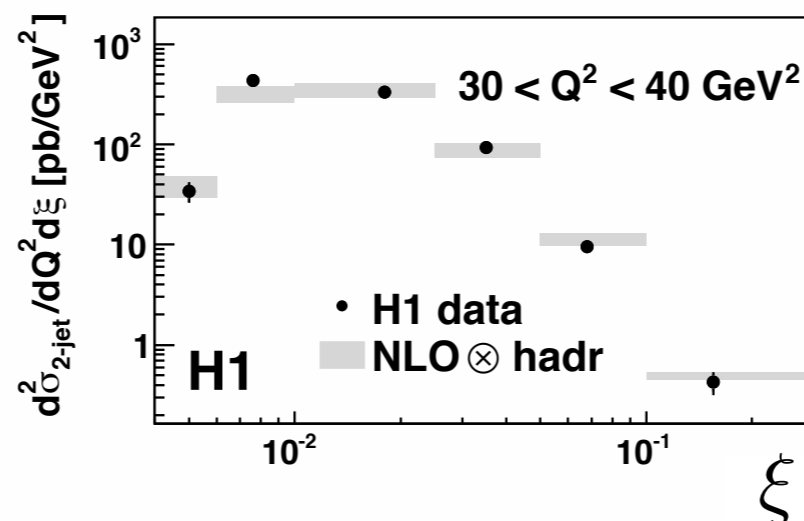
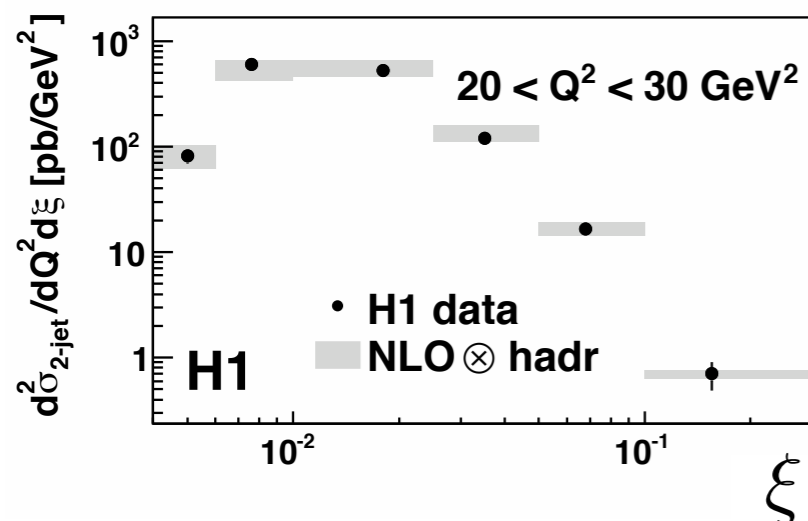
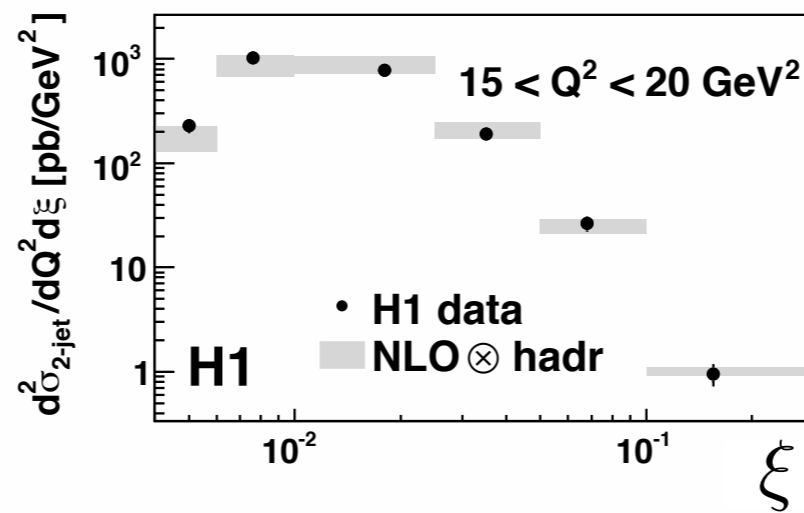
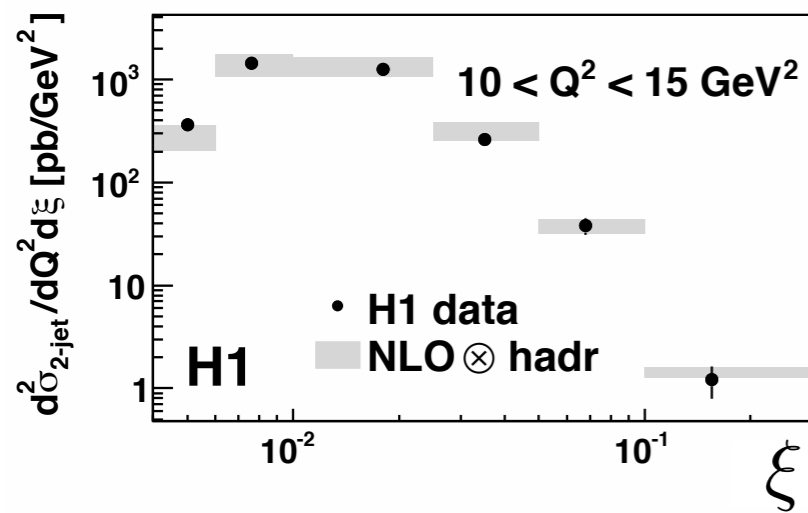
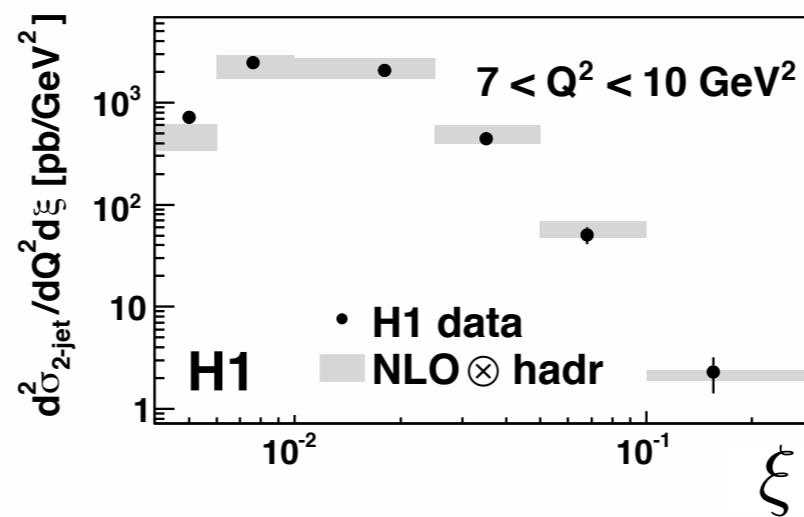
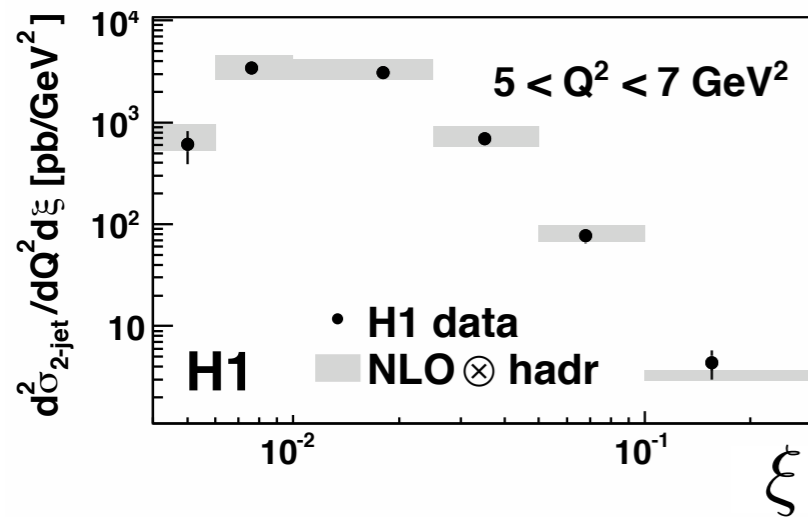
- **exp. uncertainties:**
6-10%

- **theoretical uncertainties:**
dominated by missing higher orders
estimated by variation of μ_f
and μ_r by factors 0.5 and 2

30% at low Q^2, P_T
10% at high Q^2, P_T

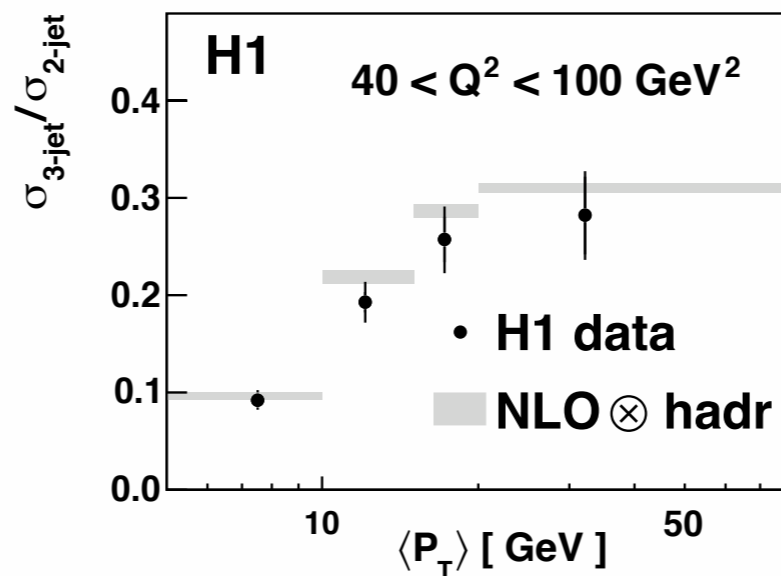
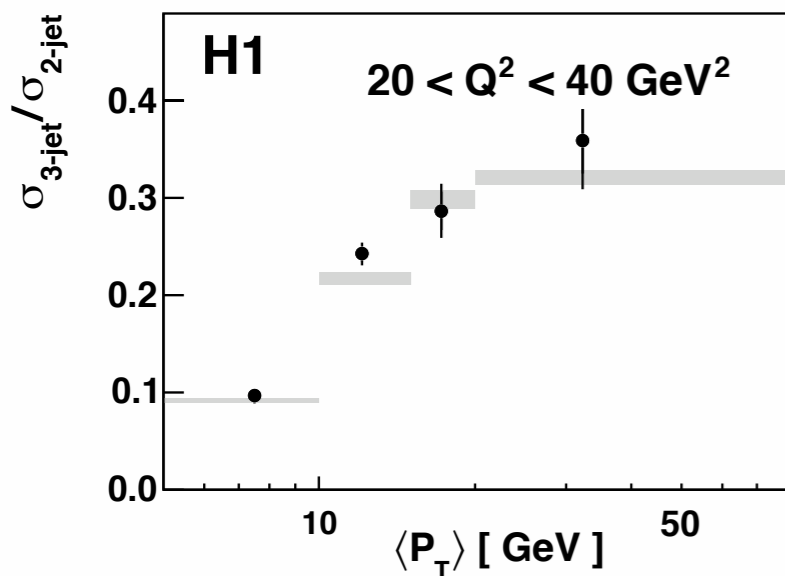
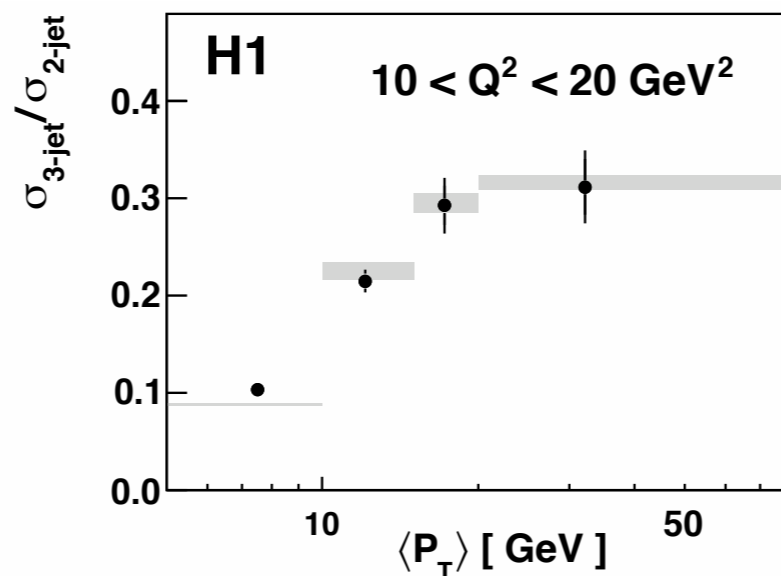
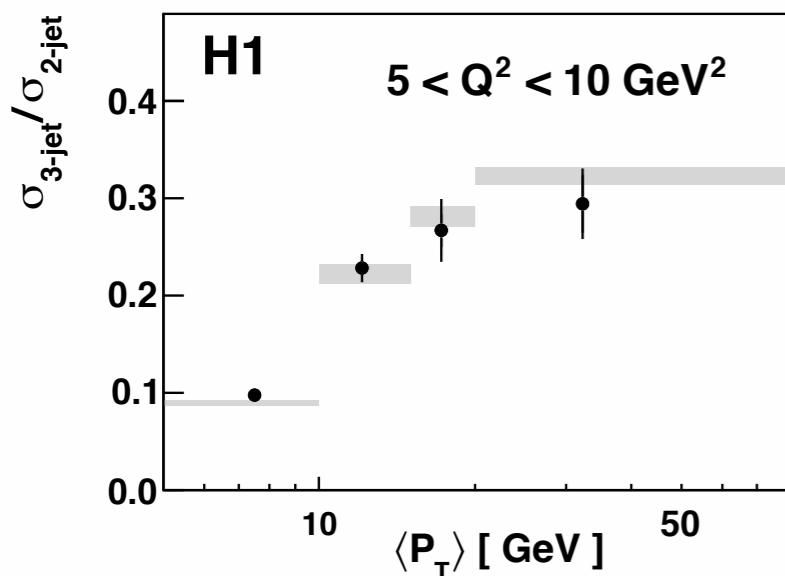
- choice of $\mu_r = \langle P_T \rangle$
disfavoured by data

2-Jet Cross Sections At Low Q^2



- measurements well described by NLO, $\alpha_s(M_Z) = 0.118$
hadr. corrections 0.85-1.05
- statistical uncertainties small even for double-differential cross sections
- theoretical uncertainties larger than experimental ones
- rise of the cross section towards small ξ expected due to increase of gluon density suppressed by cuts on P_T and M_{12}
- test of the gluon density from global analyses and inclusive fits

3-Jet/2-Jet Ratios



- normalisation errors cancel
systematical errors cancel partially
reduced systematical uncertainties by 50%
- **reduced sensitivity to missing higher orders in NLO prediction**
- dominated by statistical uncertainties at large $\langle P_T \rangle$

(9x the statistics from HERA2 data available)

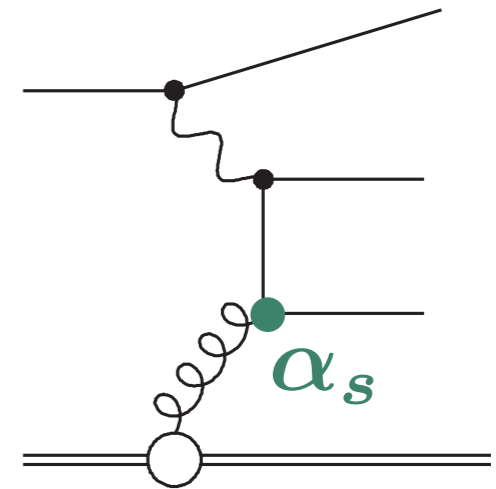
Determination of $\alpha_s(M_Z)$

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

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

⇒ Assign an error due to PDF uncertainty

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



$$\chi^2(\alpha_s) = \underbrace{\vec{V}^T M^{-1} \vec{V}} + \sum_k \epsilon_k^2 \quad M = M^{\text{stat}} + M^{\text{uncorr}}$$

correlated version of $\sim \sum \frac{(\sigma^{\text{exp}} - \sigma^{\text{th}})^2}{\text{err}^2}$

Shift of correlated systematic uncertainty k, pull parameter in fit

$$V_i = \underbrace{\sigma_i^{\text{th}} - \sigma_i^{\text{exp}}}_{\text{Bin } i} \left(1 - \sum_k \underbrace{\Delta_{ik} \epsilon_k}_{\text{effect of correlated error k on measurement in bin } i} \right) \quad \sigma_i^{\text{th}} \text{ obtained with } \textit{fastNLO}$$

Bin i

effect of correlated error k on measurement in bin i

Theoretical Uncertainties on $\alpha_s(M_Z)$

α_s is obtained at $\mu_r = \sqrt{(Q^2 + P_T^2)}/2$
evolved with 2-loop solution of RGE to M_Z

⇒ PDF uncertainty

propagated from CTEQ6.5M error set, 2% uncertainty on $\alpha_s(M_Z)$

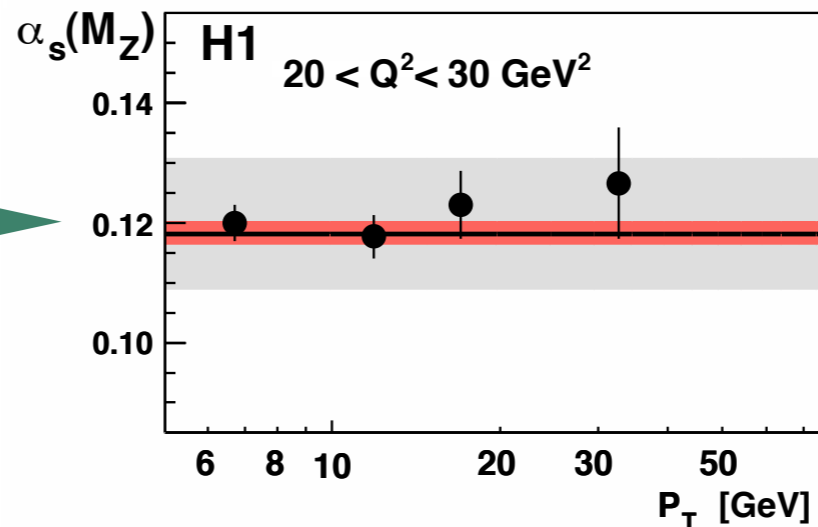
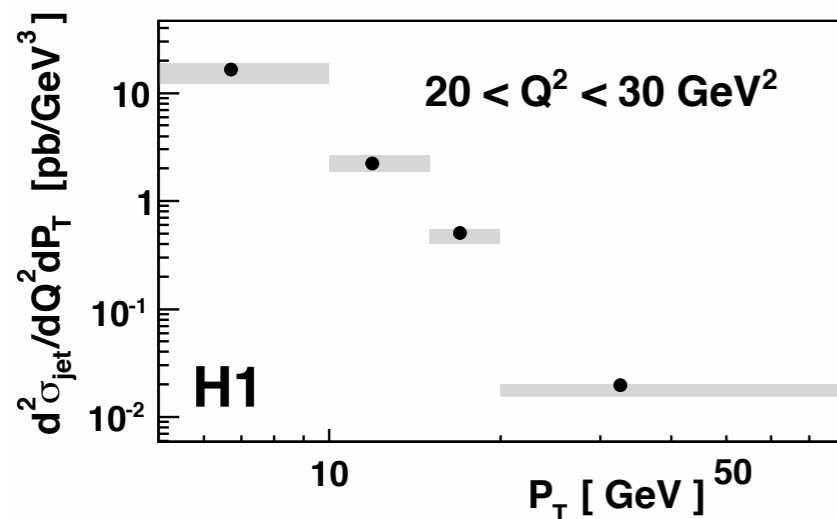
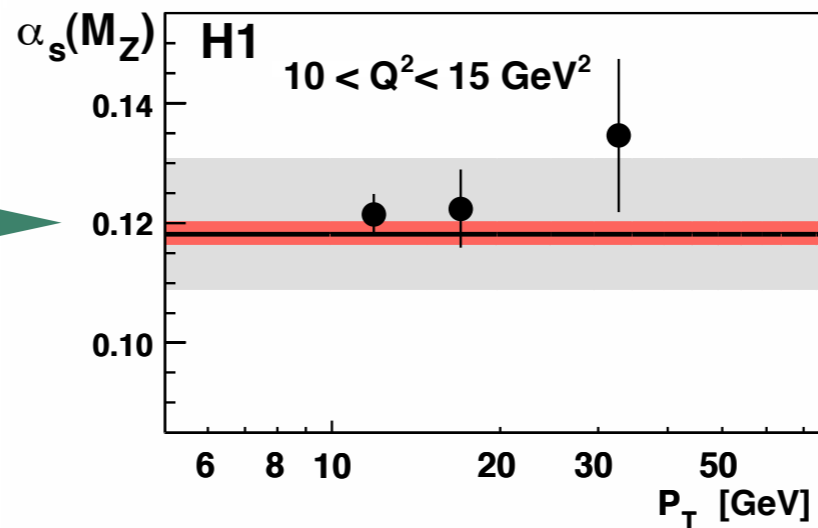
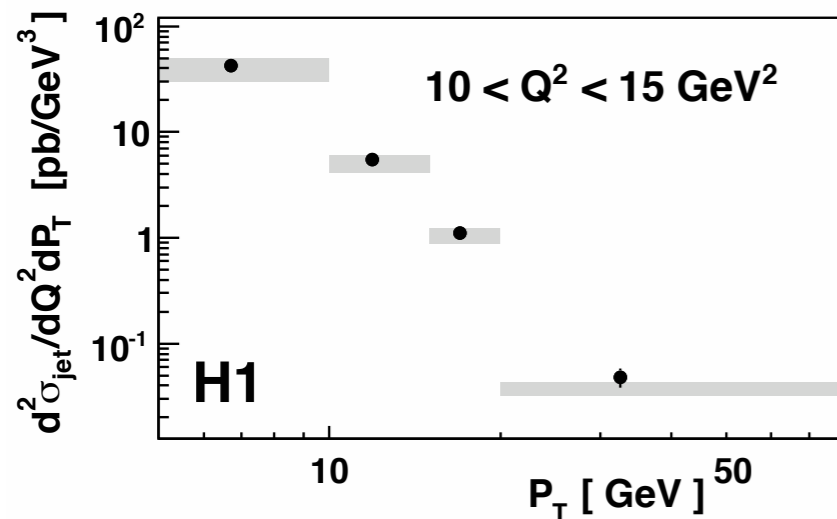
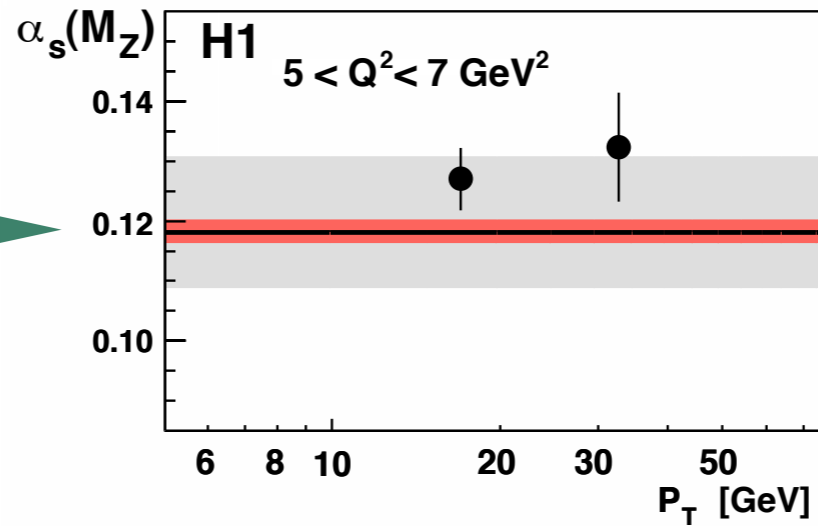
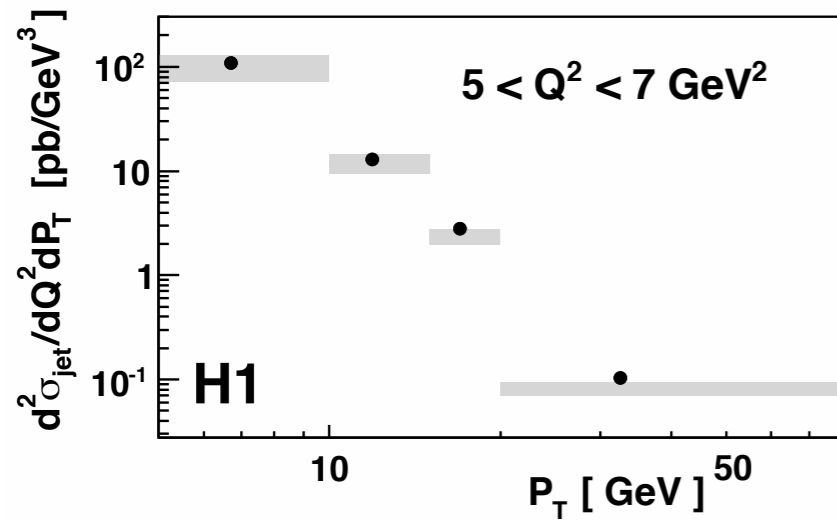
⇒ Hadronisation corrections

obtained with MEPS and CDM models, 1-2% uncertainty on $\alpha_s(M_Z)$

⇒ Missing higher orders

estimated by variation of the scales μ_f and μ_r by factors 0.5 and 2
refit to data points (offset-method), 8% uncertainty on $\alpha_s(M_Z)$

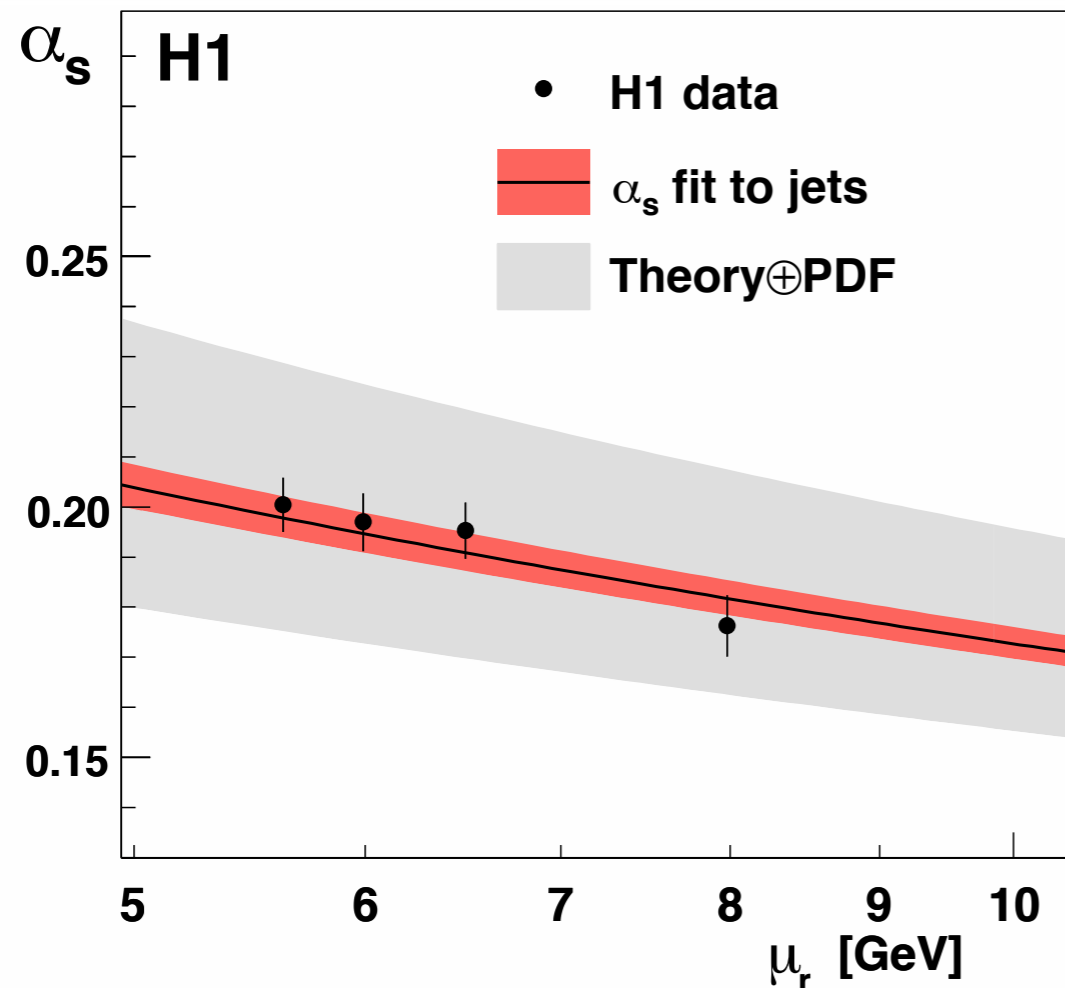
$\alpha_s(M_Z)$ Fits from Inclusive Jets



- fits performed for all 22 individual data points (only 11 shown)
- k-factors σ_{NLO}/σ_{LO} very large in some regions (>2.5), those data points were excluded from fit
- error bar: exp. uncertainties
- inner red band: simultaneous fit to all data points with experimental errors
- outer grey band: PDF, hadronisation and beyond NLO uncertainties

$\alpha_s(\mu_r)$ Determination from Low Q^2 Jets

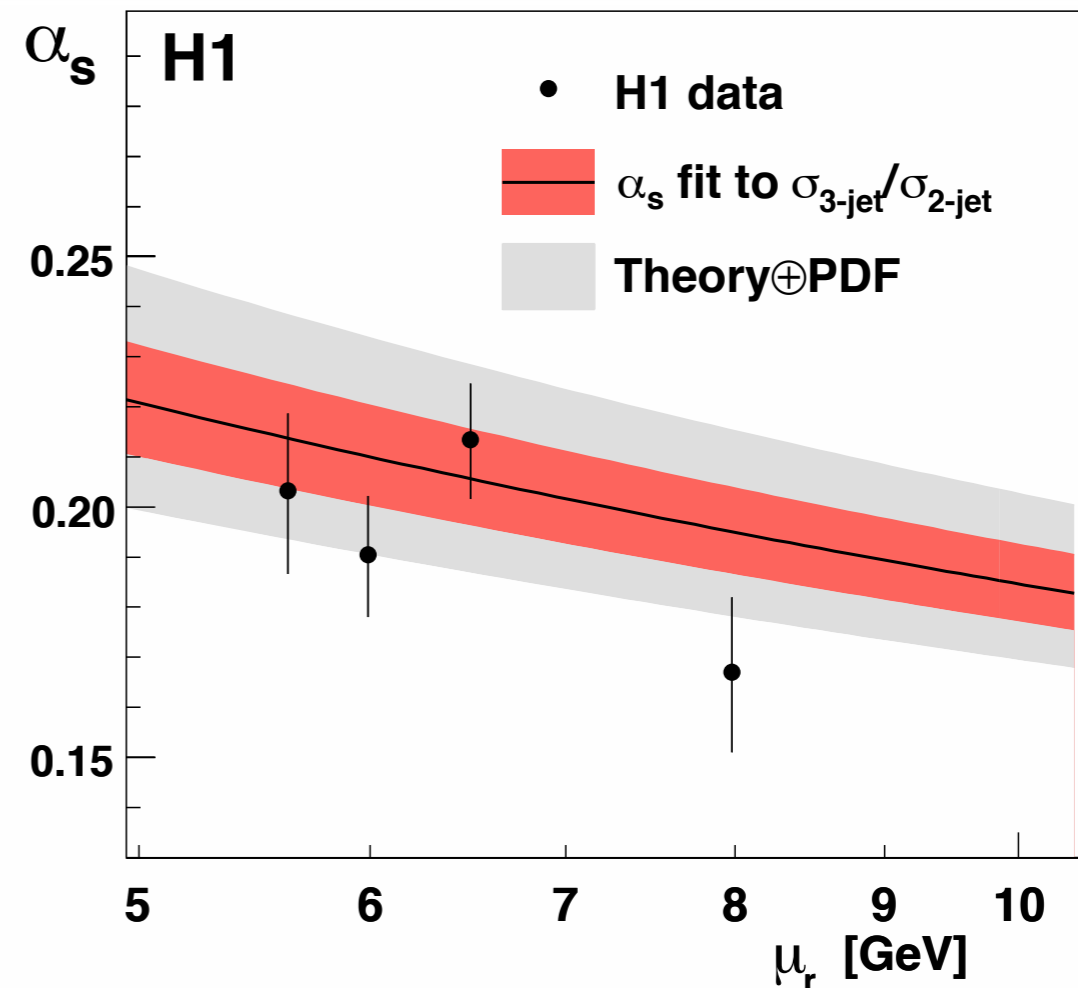
α_s from Jet Cross Sections



- Simultaneous fit to all 62 measurements of inclusive, 2- and 3-jet cross sections
- result dominated by theoretical uncertainty, missing higher orders

NNLO calculations needed

α_s from 3-Jet to 2-Jet Ratio



- Simultaneous fit to all 14 3-jet/2-jet measurement points
- reduced systematical and theoretical uncertainties, dominated by statistics

more data needed

Multijets at high Q^2 and $\alpha_s(\mu_r)$

Phase space:

$$150 \text{ GeV}^2 < Q^2 < 15.000 \text{ GeV}^2$$

$$0.2 < y < 0.7$$

Inclusive jets:

$$7 \text{ GeV} < P_T \text{ (Breit)} < 50 \text{ GeV}$$

$$-0.8 < \eta(\text{lab}) < 2$$

2- and 3-jets:

$$M_{12} > 16 \text{ GeV}$$

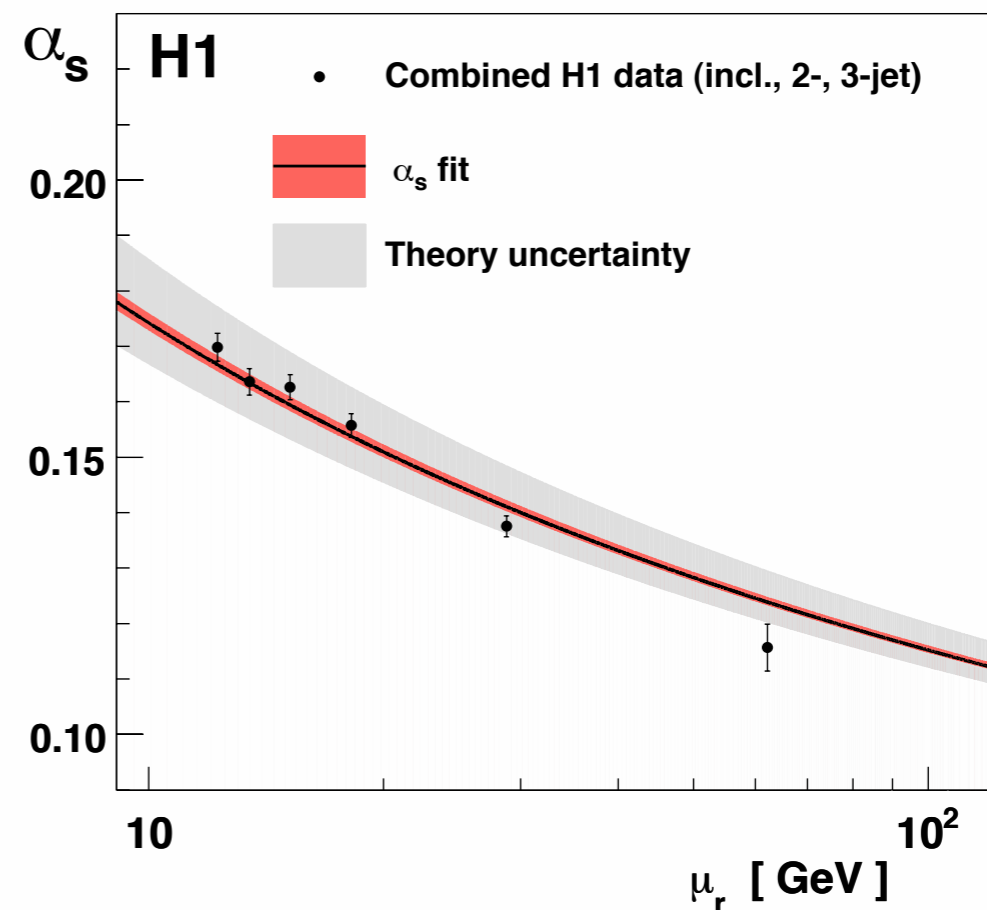
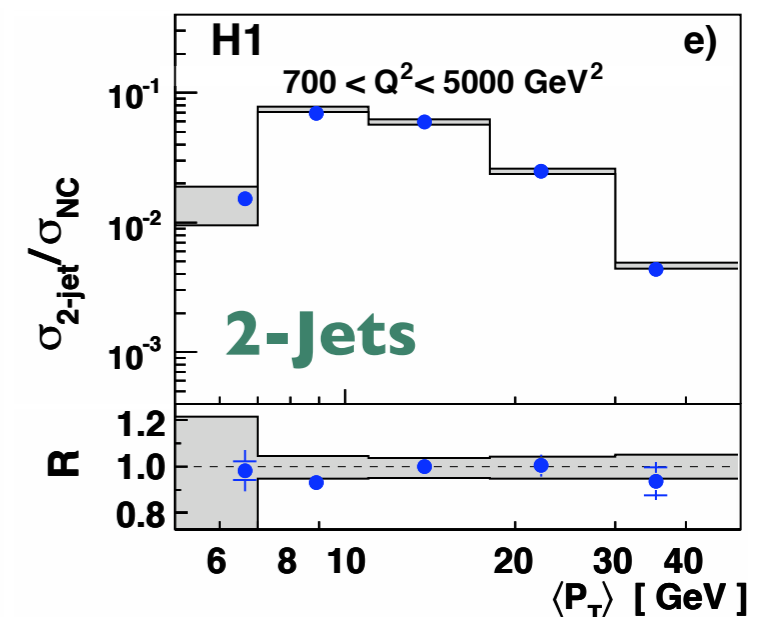
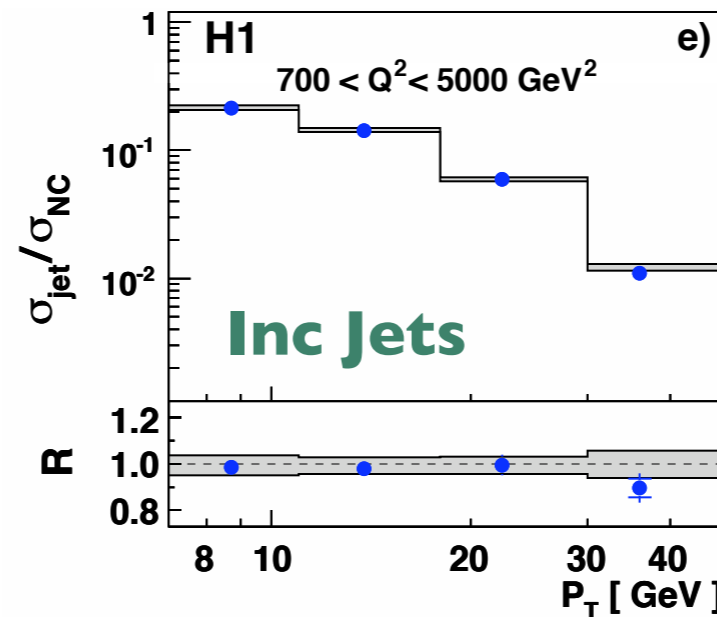
cross sections **normalised** to

DIS cross section

smaller theoretical uncertainties,
still larger than exp. uncertainties,

very precise $\alpha_s(M_Z)$

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Running of $\alpha_s(\mu_r)$

Multijets at low Q^2

$$\alpha_s(M_Z) = 0.1160 \pm 0.0014(\text{exp.})_{-0.0077}^{+0.0093}(\text{th.}) \pm 0.0016(\text{pdf})$$

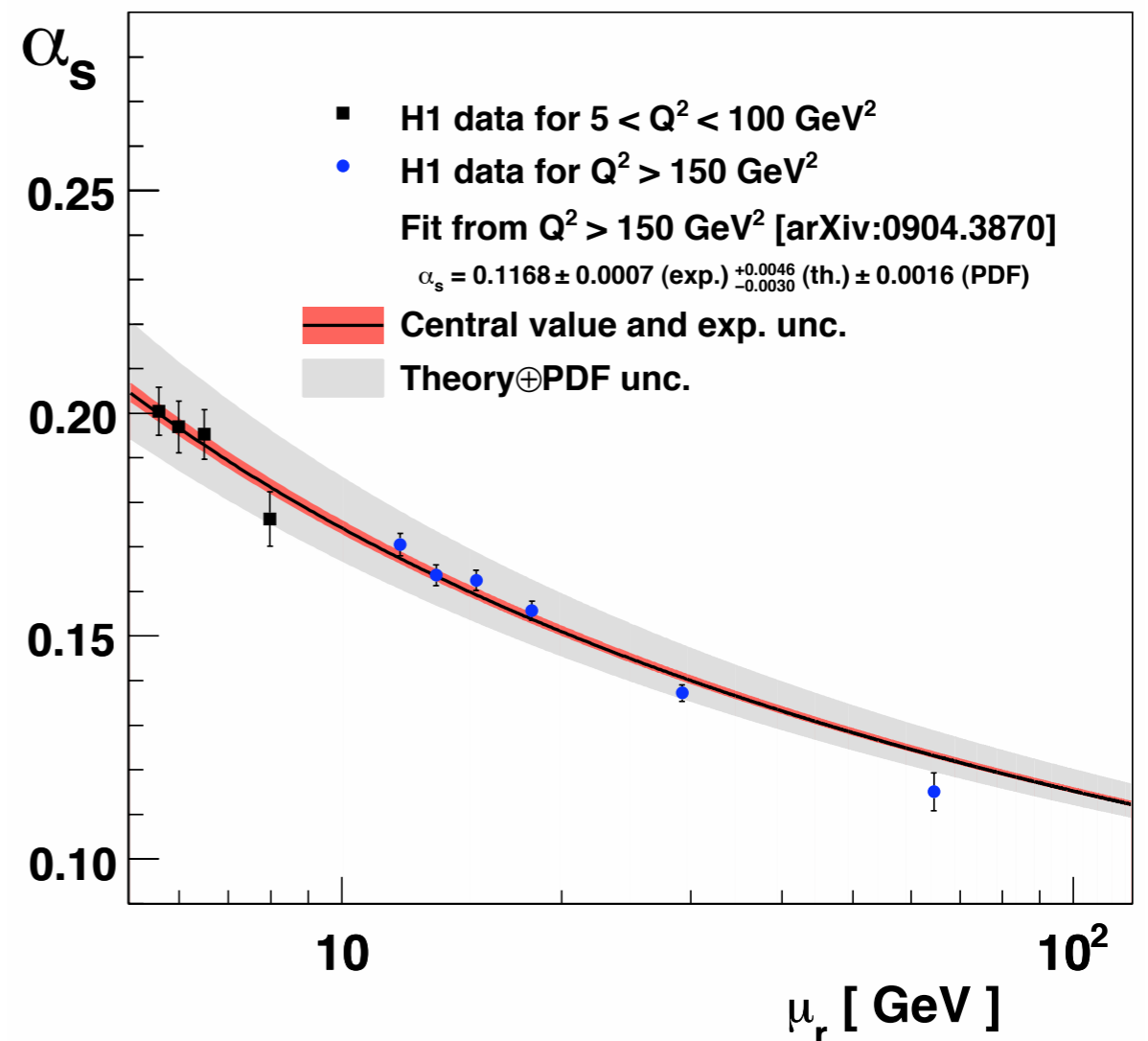
Multijets at high Q^2

$$\alpha_s(M_Z) = 0.1168 \pm 0.0007(\text{exp.})_{-0.0030}^{+0.0046}(\text{th.}) \pm 0.0016(\text{pdf})$$

Theoretical uncertainty extrapolated down from high Q^2 determination with 2-loop solution of RGE

Good agreement between extracted $\alpha_s(\mu_r)$ at low and high Q^2

Running of the strong coupling tested for scales between 6 - 70 GeV



Summary

Multijet cross sections at low and high Q^2 in agreement with NLO predictions

Low Q^2 multi-jets:
theoretical uncertainties
dominated by missing
higher orders
NNLO needed

Low Q^2 3j/2j ratio:
limited by statistics
analysis of HERA2 data
in progress

High Q^2 multi-jets:
precise determination via
normalised cross sections
analysis to measure normalised and jet cross sections
with improved experimental uncertainties in progress

