STUDIES OF THE STRONG COUPLING

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- Purpose of α_s studies
- Developments since ICHEP1998
  1. New measurements based on four jets:
     - α_s from ALEPH
     - α_s and colour factors from OPAL
  2. Energy dependence from
     - e^+e^- annihilation (JADE & OPAL)
     - hadron collisions (CDF)
  3. Flavour independence (OPAL)
- Status of α_s in Y2K

PA-03c10, abstracts: #114, #115, #162, #251, #1080

PURPOSE OF α_s STUDIES

$n+1$st α_s measurement — why bother?

QCD:

THEORY: SU(N_c) gauge theory with 1(+6) parameter: flavour independent coupling (+ quark masses)
Value of $\alpha_s(M_{Z^0})$ is not predicted by theory

PRACTICE: Theory + phenomenological models uncertainties in theoretical predictions for cross sections are translated into uncertainties of a single parameter

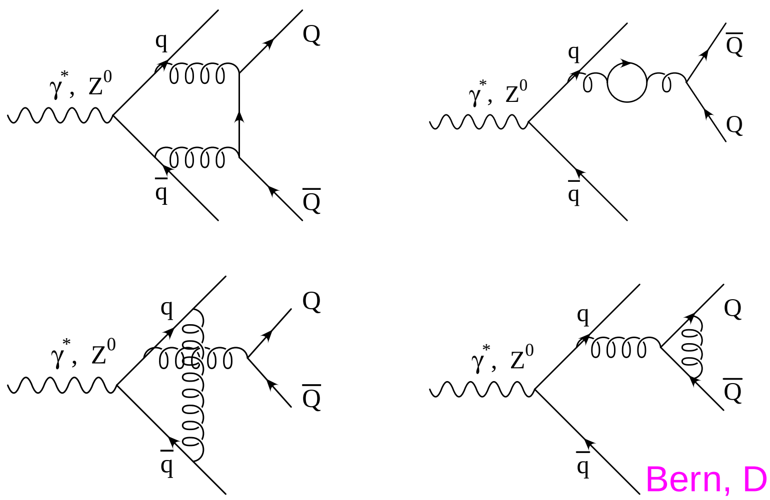
- $\alpha_s(M_{Z^0})$ measurements test "practical QCD"
- Measurements of colour factors, $\alpha_s(Q)$ test SU(N_c) dynamics & particle spectrum
- $\alpha_s^Q(M_{Z^0})$ measurements using flavour tagged samples test assumption of flavour independence

NLO CORRECTIONS TO FOUR-JET OBSERVABLES

$$\langle D\rangle_{\mathrm{LO}} = 0.0216 \leftrightarrow \langle D\rangle_{\mathrm{exp}} = 0.0618 \pm 0.0024$$

$\Rightarrow$ higher order corrections must be large

Loop-corrections for $+\gamma^*,\ Z^0 \to \bar{q}q\bar{Q}Q,\ \bar{q}qgg$:



$+\gamma^*,\ Z^0 \to \bar{q}qgg$

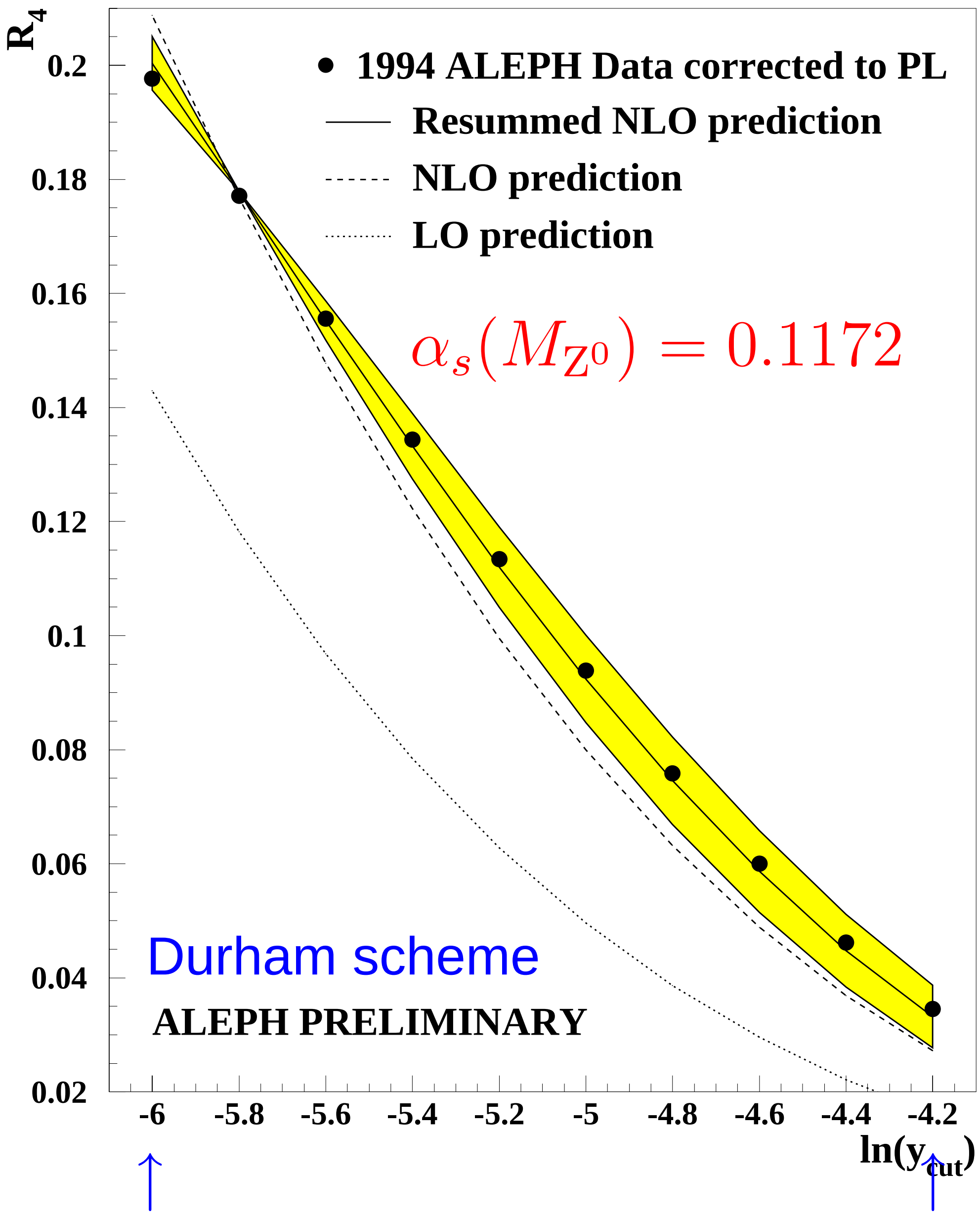
Glover, Miller and Campbell
Bern, Dixon, Kosower and Weinzierl

used in partonic NLO Monte Carlo programs

DEBRECEN	Z. Nagy and Z. T.
MENLO PARC	L. Dixon and A. Signer
EERAD2	J.M. Campbell, M.A. Cullen and E.W.N. Glover
MERCUTIO	S. Weinzierl and D.A. Kosower

$\Rightarrow$ α_s and colour factor measurements

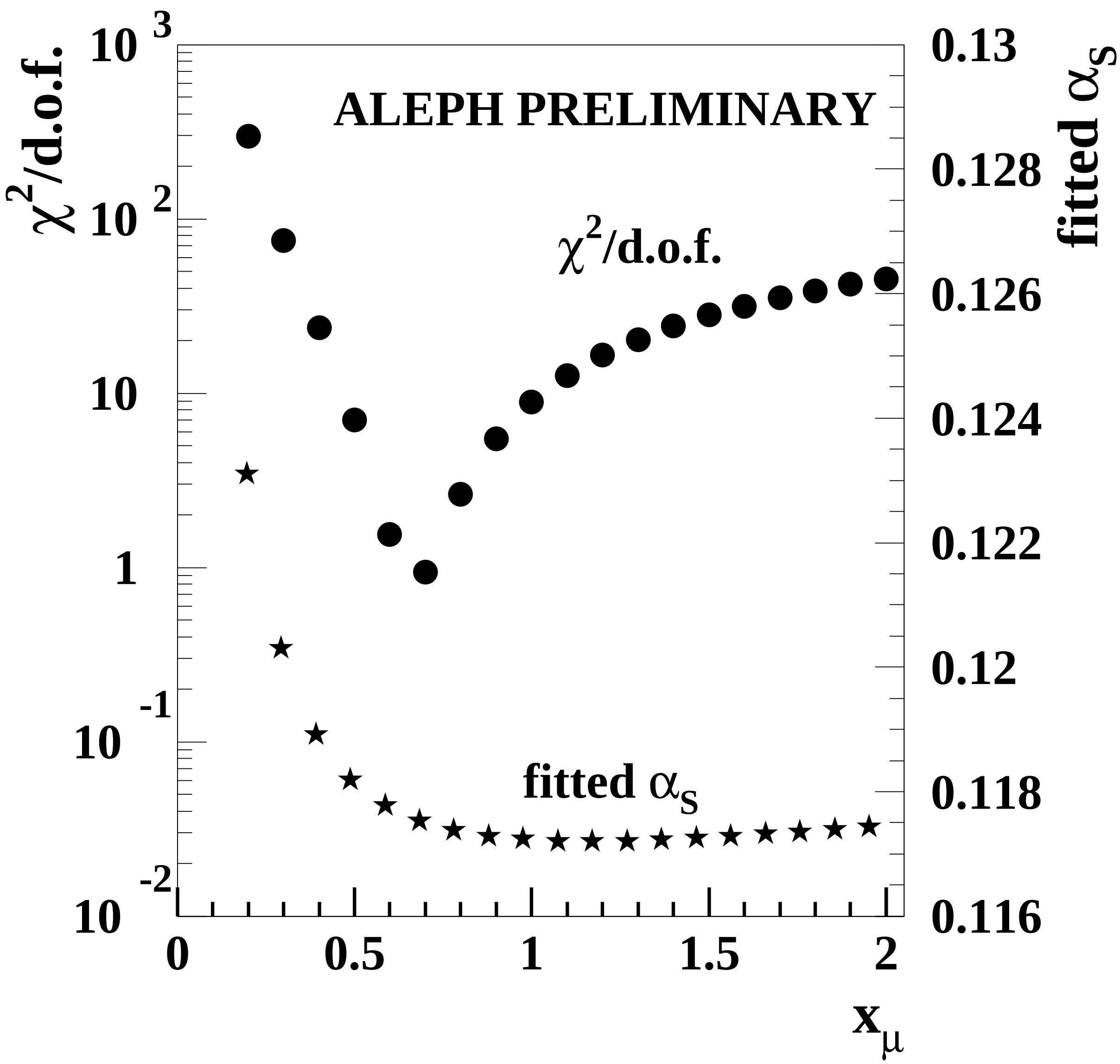
$\alpha_s(M_{Z^0})$ FROM FOUR-JET FINAL STATES OBTAINED WITH ALEPH



$y_{\mathrm{cut}} \simeq 0.0025$ $\quad$ $y_{\mathrm{cut}} \simeq 0.015$

$\frac{\alpha_s(M_{Z^0})}{2\pi} \ln^2 y_{\mathrm{cut}} \simeq 0.5 \Rightarrow$ NLLA is necessary

DEPENDENCE ON THE RENORMALIZATION SCALE



Final result: $\alpha_s(M_{Z^0}) = 0.1172$
$\pm 0.0001(\mathrm{stat.}) \pm 0.0008(\mathrm{had.}) \pm 0.0040(\mathrm{theo.})$

SYSTEMATIC UNCERTAINTIES AND CHECKS

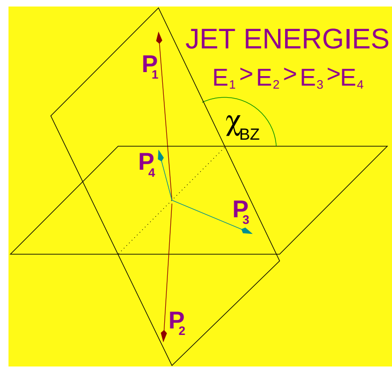
	$\alpha_s(M_Z)$	x_μ	$\Delta\alpha_s$	χ^2/dof	
# Charged tracks = 8	0.11772 ± 0.00013	0.67 ± 0.03	+0.00012	7.2/8	
	0.11736 ± 0.00012	1.	+0.00012	78.3/9	
$\lvert\cos\Theta_T\rvert < 0.9$	0.11769 ± 0.00014	0.65 ± 0.03	+0.00009	8.0/8	
	0.11730 ± 0.00012	1.	+0.00006	82.8/9	
No cut on $\lvert\cos\Theta_T\rvert$	0.11759 ± 0.00013	0.66 ± 0.03	−0.00001	6.9/8	
	0.11723 ± 0.00011	1.	−0.00001	88.2/9	
$E_{neutral} \notin [1,2]$GeV	0.11837 ± 0.00016	0.53 ± 0.02	+0.00077	7.0/8	
	0.11752 ± 0.00011	1.	+0.00028	219.6/9	
Charged Tracks	0.11877 ± 0.00015	0.60 ± 0.02	+0.00077	11.2/8	
	0.11815 ± 0.00012	1.	+0.00091	129.6/9	
HERWIG Hadcorr	0.11693 ± 0.00014	0.61 ± 0.03	−0.00067	15.2/8	
	0.11641 ± 0.00012	1.	−0.00084	127.8/9	
ARIADNE Hadcorr	0.11743 ± 0.00013	0.71 ± 0.03	−0.00017	4.5/8	
	0.11718 ± 0.00012	1.	−0.00006	53.1/9	
PYTHIA,ME	0.12225 ± 0.00015	0.60 ± 0.02	+0.0047	52.0/8	
	0.12160 ± 0.00012	1.	+0.0044	196.2/9	⋆
PYTHIA,Q_0	0.12087 ± 0.00016	0.50 ± 0.02	+0.0033	36.0/8	
	0.11965 ± 0.00012	1.	+0.0024	332.6/9	⋆
Renorm. scale	0.11885 ± 0.00012	0.5	+0.0013	463.9/9	
	0.12123 ± 0.00013	2.	+0.0040	1704.6/9	
1995 Data	0.11783 ± 0.00019	0.66 ± 0.04	+0.00023	12.1/8	
	0.11739 ± 0.00016	1.	+0.00015	57.1/9	⋆

⋆ Not included in final error

SIMULTANEOUS MEASUREMENT OF THE QCD COLOUR FACTORS AND α_s AT OPAL

Observables used:

- D_2 and R_4 for gaining sensitivity to α_s:
- χ_{BZ}, θ^*_{NR}, ϕ_{KSW}, α_{34} for gaining sensitivity to C_F and C_A



Fitted parameters:

$\eta = \frac{\alpha_s C_F}{2\pi}$, $x = \frac{C_A}{C_F}$ and $y = \frac{T_R}{C_F}$

New features:

- Most complete systematics
- Theory is at least NLO
- Simultaneous measurement and use of R_4
- Results are unfolded to usual parameters:

$$C_A = 3.02 \pm 0.25(\mathrm{stat.}) \pm 0.44(\mathrm{syst.})$$

$$C_F = 1.34 \pm 0.13(\mathrm{stat.}) \pm 0.19(\mathrm{syst.})$$

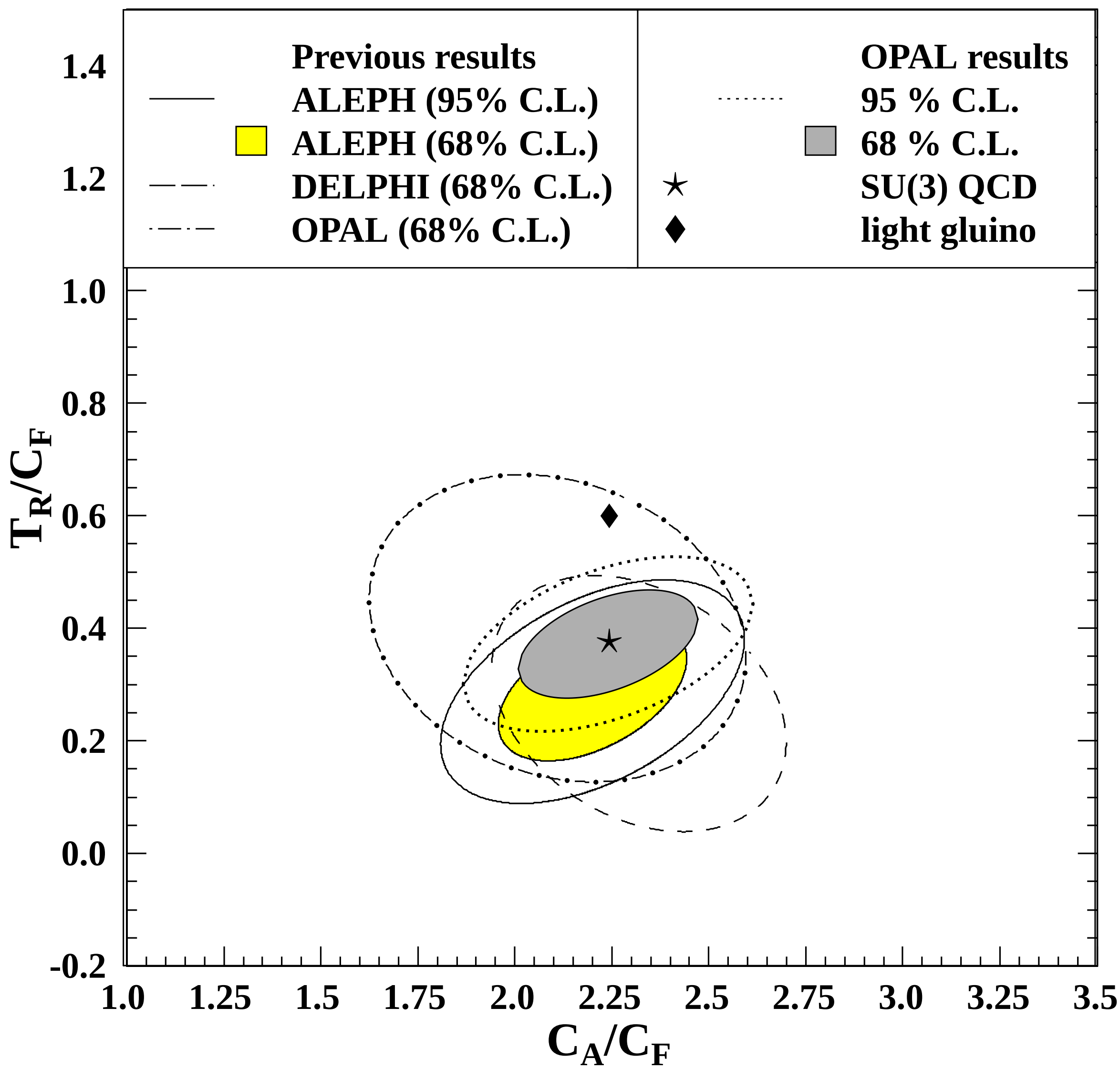
$$\alpha_s = 0.120 \pm 0.011(\mathrm{stat.}) \pm 0.016(\mathrm{syst.})$$

RESULTS FOR x AND y

NLO corrections stabilize the results for y and does not affect x:

$$T_R/C_F = 0.37 \pm 0.04(\mathrm{stat.}) \pm 0.05(\mathrm{syst.})$$

$$C_A/C_F = 2.25 \pm 0.08(\mathrm{stat.}) \pm 0.13(\mathrm{syst.})$$



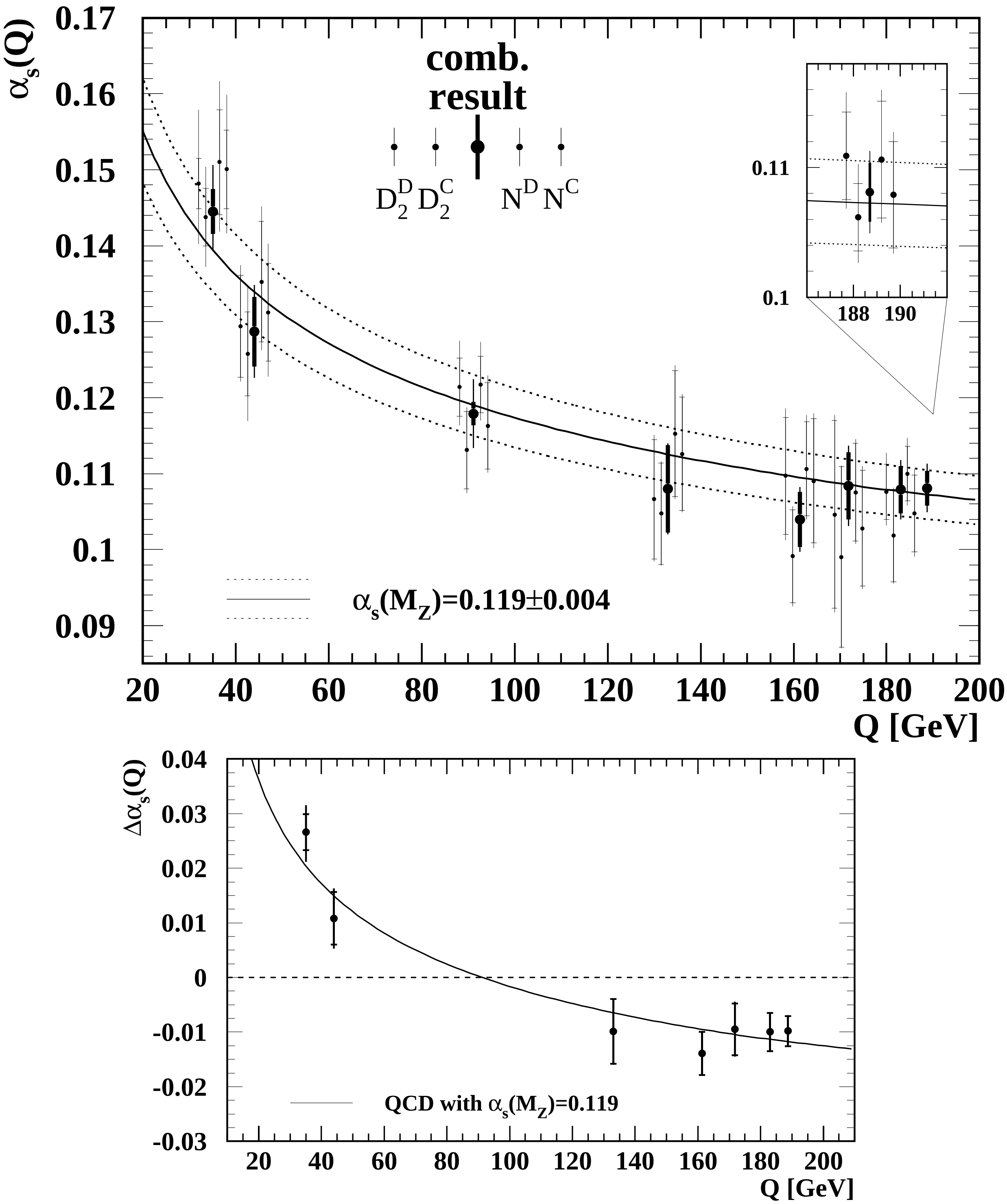
SYSTEMATIC UNCERTAINTIES

	η	x	y	χ^2/d.o.f.
Standard analysis	0.0256±0.0003	2.25±0.08	0.37±0.04	98.5/79
Charged track only	0.0257±0.0003	2.24±0.08	0.37±0.04	127.1/79
Cluster only	0.0256±0.0003	2.25±0.08	0.38±0.04	124.2/79
$\lvert\cos\theta_{thrust}\rvert < 0.7$	0.0256±0.0003	2.26±0.08	0.38±0.04	117.9/79
$N_{ch} \geq 8$	0.0256±0.0003	2.25±0.08	0.37±0.04	98.3/79
Detector effects	$\Delta\eta = 0.0000$	$\Delta x = 0.004$	$\Delta y = 0.002$	
HW-ME+JT-PS*	0.0256±0.0003	2.19±0.08	0.34±0.04	534.1/79
JT-ME($a + 1\sigma$)+JT-PS*	0.0258±0.0003	2.15±0.08	0.33±0.04	97.5/79
JT-ME($\sigma_q - 1\sigma$)+JT-PS*	0.0257±0.0003	2.16±0.08	0.33±0.03	156.5/79
JT-ME*+HW-PS	0.0246±0.0003	2.31±0.08	0.39±0.04	112./79
JT-ME*+JT-PS($a + 1\sigma$)	0.0253±0.0003	2.28±0.08	0.37±0.04	106.6/79
JT-ME*+JT-PS($\sigma_q - 1\sigma$)	0.0253±0.0003	2.28±0.08	0.37±0.04	106.1/79
JT-ME*+JT-PS($Q_0 + 1\sigma$)	0.0252±0.0003	2.29±0.08	0.37±0.04	101.1/79
JT-ME*+JT-PS($udsc$)	0.0260±0.0003	2.19±0.07	0.33±0.03	173.1/79
Hadronization	$\Delta\eta = 0.0003$	$\Delta x = 0.043$	$\Delta y = 0.016$	
$x_\mu = 1.0$ in angular corr. and				
$x_\mu = 0.5$ in R_4 and D_2	0.0235±0.0003	2.40±0.08	0.28±0.03	118.0/79
$x_\mu = 2.0$ in R_4 and D_2	0.0271±0.0003	2.14±0.08	0.42±0.04	103.7/79
$x_\mu = 1.0$ in R_4 and D_2 and				
$x_\mu = 0.5$ in angular corr.	0.0256±0.0003	2.25±0.08	0.37±0.03	98.2/79
$x_\mu = 2.0$ in angular corr.	0.0257±0.0003	2.24±0.08	0.37±0.04	99.0/79
R-matching for D_2	0.0281±0.0005	2.06±0.09	0.40±0.03	103.4/79
Theoretical uncertainty	$\Delta\eta = 0.0013$	$\Delta x = 0.096$	$\Delta y = 0.038$	
$0.8 < C_i^{tot} < 1.2$	0.0255±0.0002	2.28±0.06	0.39±0.03	339.6/96
Fit range	$\Delta\eta = 0.0001$	$\Delta x = 0.033$	$\Delta y = 0.013$	
5-parton background	0.0257±0.0003	2.18±0.08	0.34±0.04	112.5/79
5-parton background	$\Delta\eta = 0.0001$	$\Delta x = 0.070$	$\Delta y = 0.039$	
Total systematic error	$\Delta\eta = 0.0013$	$\Delta x = 0.130$	$\Delta y = 0.053$	

JET STUDIES WITH JADE AND OPAL: $\alpha_s(Q)$ FROM e^+e^--ANNIHILATION

- Study of jet rates using four different jet-finders — JADE, Durham, Cambridge and cone — at nine different collision energies between 35 and 189 GeV
- Similarity of JADE and OPAL is utilized to perform a uniform α_s-analysis over a wide energy range
- New analysis of JADE data using modern theoretical input
- Energy dependence is compatible with three-loop running with $\chi^2/$d.o.f. = 7.85/7
- Competitive α_s result from running, $\alpha_s(M_{\mathrm{Z}^0}) = 0.1187^{+0.0034}_{-0.0019}$

$\alpha_s(Q)$ FROM DIFFERENTIAL TWO-JET RATES AND MEAN JET MULTIPLICITIES

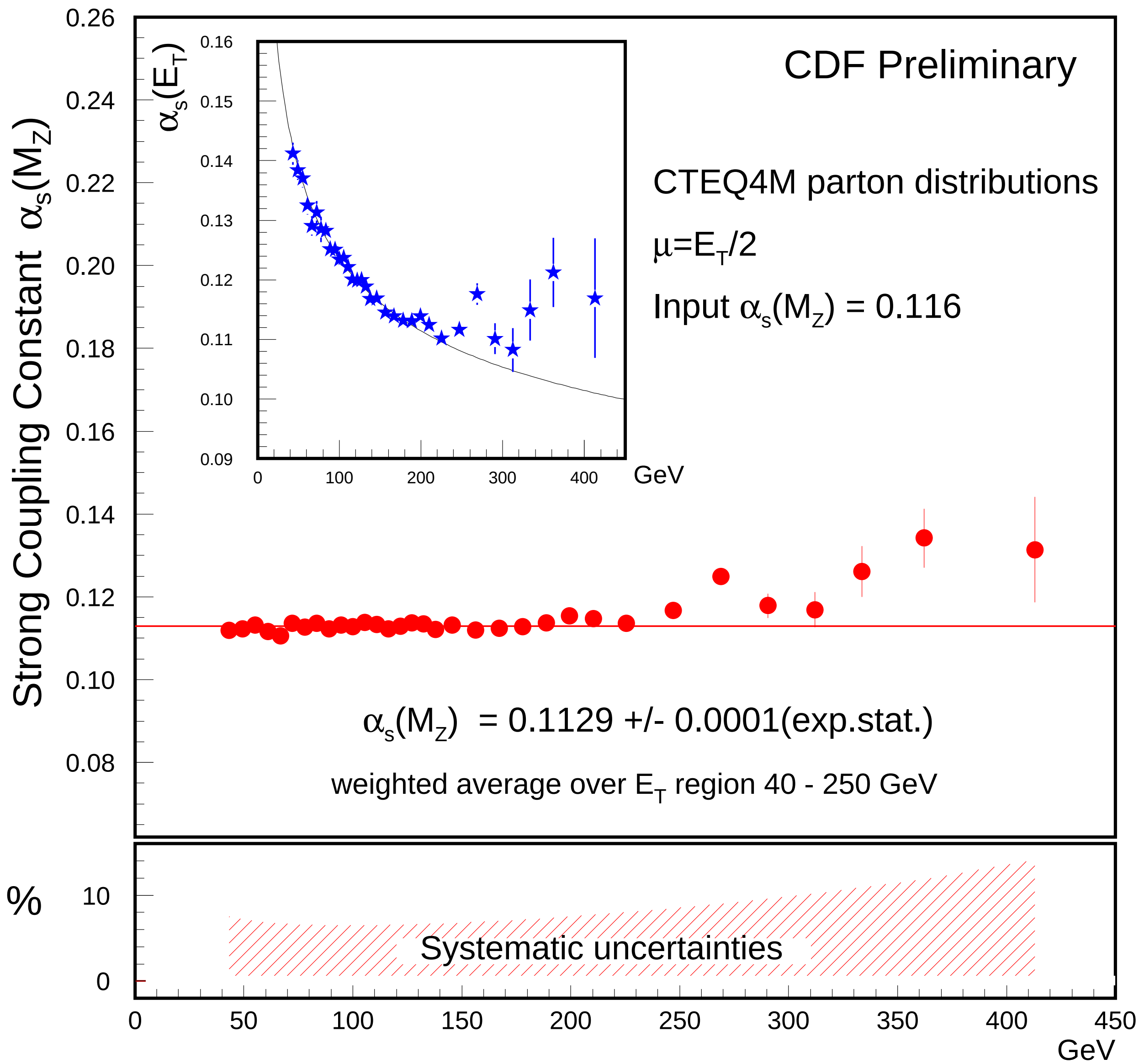


$$\Delta\alpha_s(Q) = \alpha_s(Q) - \alpha_s(M_{Z^0})$$

$\alpha_s(Q)$ FROM CDF

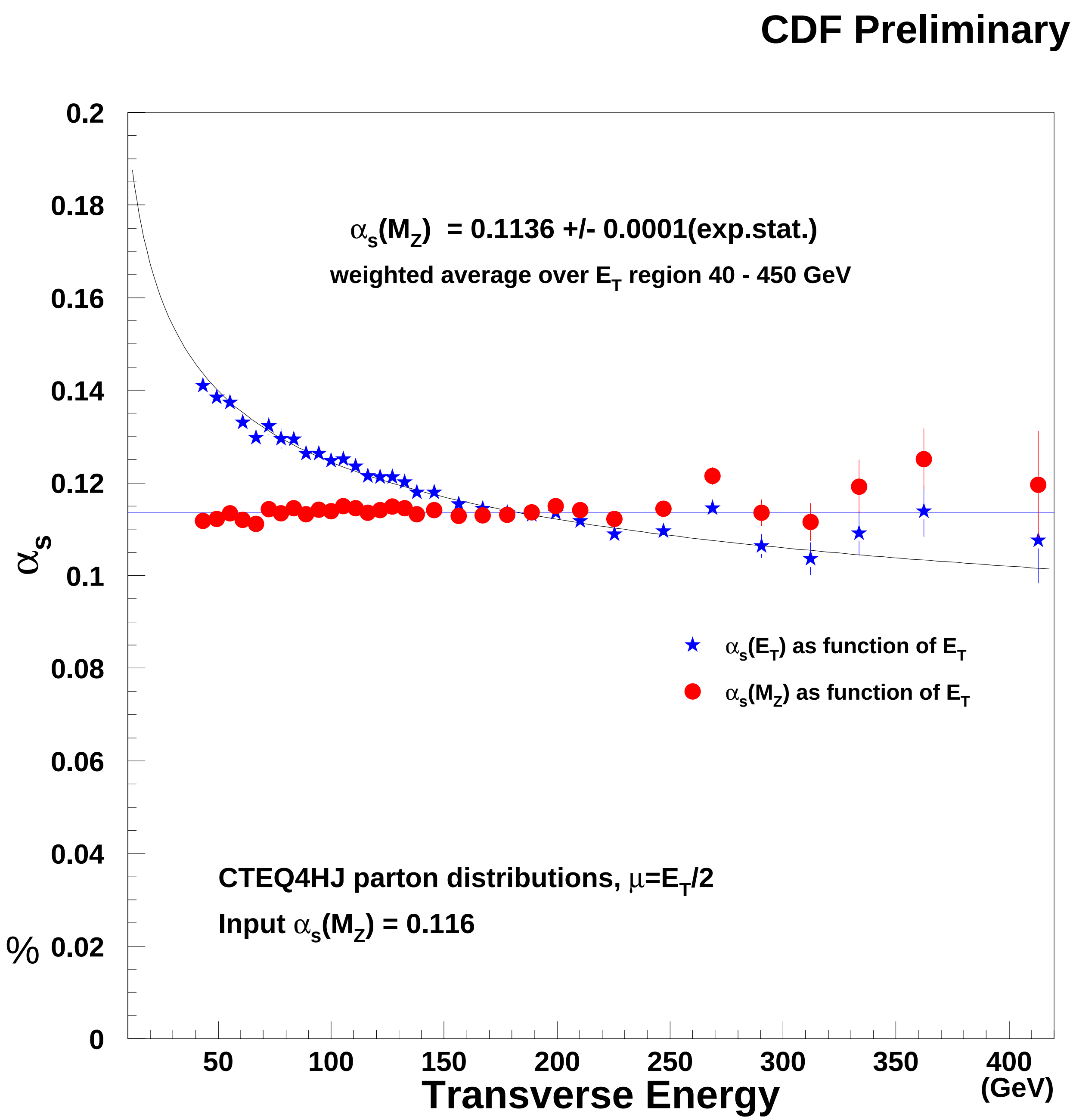
- First α_s measurement at the TEVATRON based upon inclusive jet cross section
- CDF run 1B, 87 pb^{-1} in 33 $E_\perp$ bins
- Discrepancies with theory in the high $E_\perp$ region
  ...could be accommodated by modifications of parton distribution functions (CTEQ4HJ)
- $\alpha_s(Q)$ from $Q =$ 40 to 450 GeV in a single experiment
  $\alpha_s(M_{Z^0}) =$
  $0.1129 \pm 0.0001(\mathrm{stat.})\,^{+0.0078}_{-0.0089}(\mathrm{syst.})$

$\alpha_s(Q)$ FROM CDF WITH CTEQ4M



Flavour-threshold-like deviation from three-loop running above 250 GeV, and α_s in PDF and measured is not quite consistent

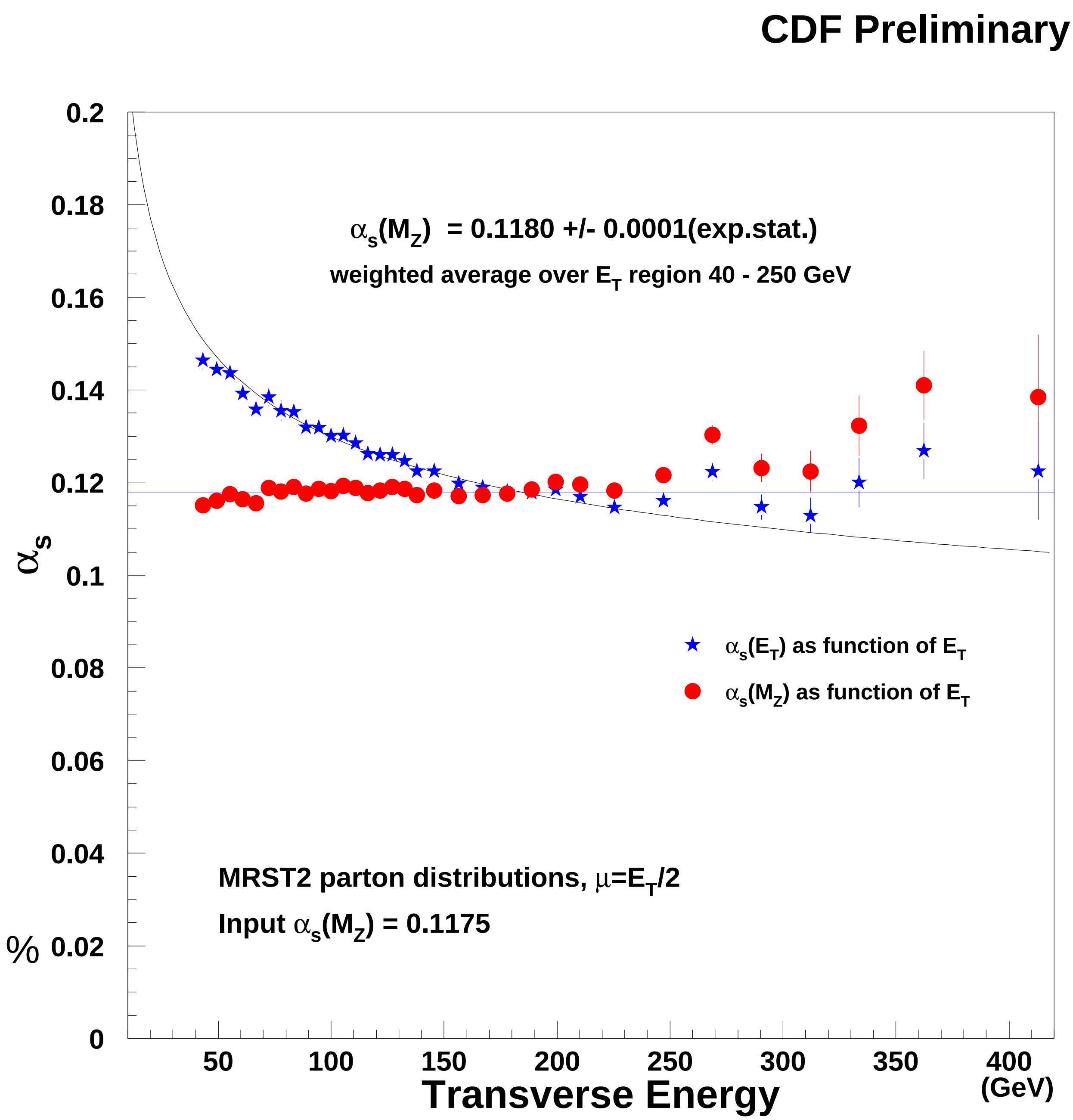
$\alpha_s(Q)$ FROM CDF WITH CTEQ4HJ



Compatible with three-loop running between 40 and 450 GeV, but

α_s in PDF and measured is not quite consistent

$\alpha_s(Q)$ FROM CDF WITH MRST2



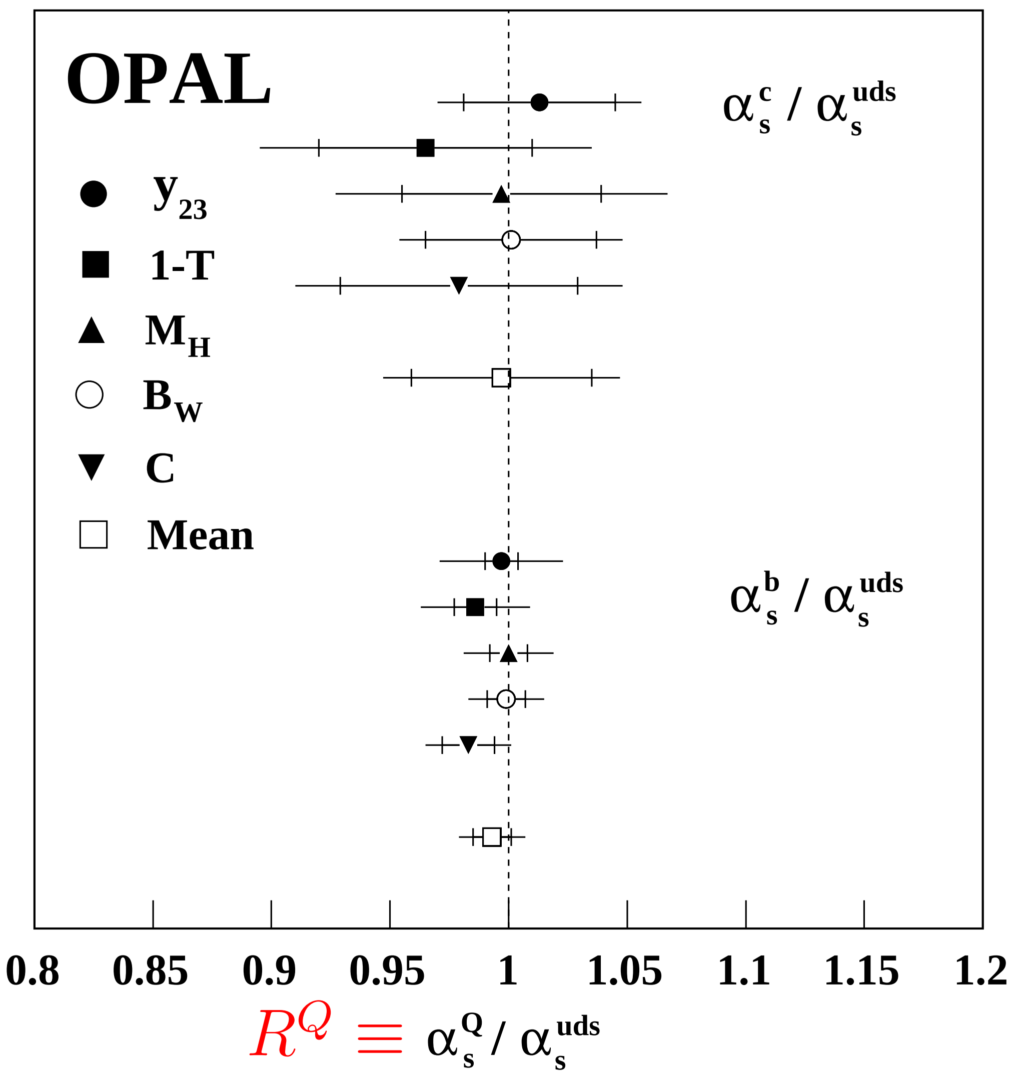
α_s in PDF and measured is consistent, but flavour-threshold-like deviation from three-loop running above 250 GeV

FLAVOUR INDEPENDENCE OF α_s

Improvement over previous OPAL analyses:

- Larger event sample ($2.5\times\ b$, $33\times\ c$)
- Improved b and uds tagging, b-purity 96 %
- NLO theory

G. Rodrigo, A. Santamria and M. Bilenky
W. Bernreuther, A. Barndenburg and P. Uwer
P. Nason and C. Oleari

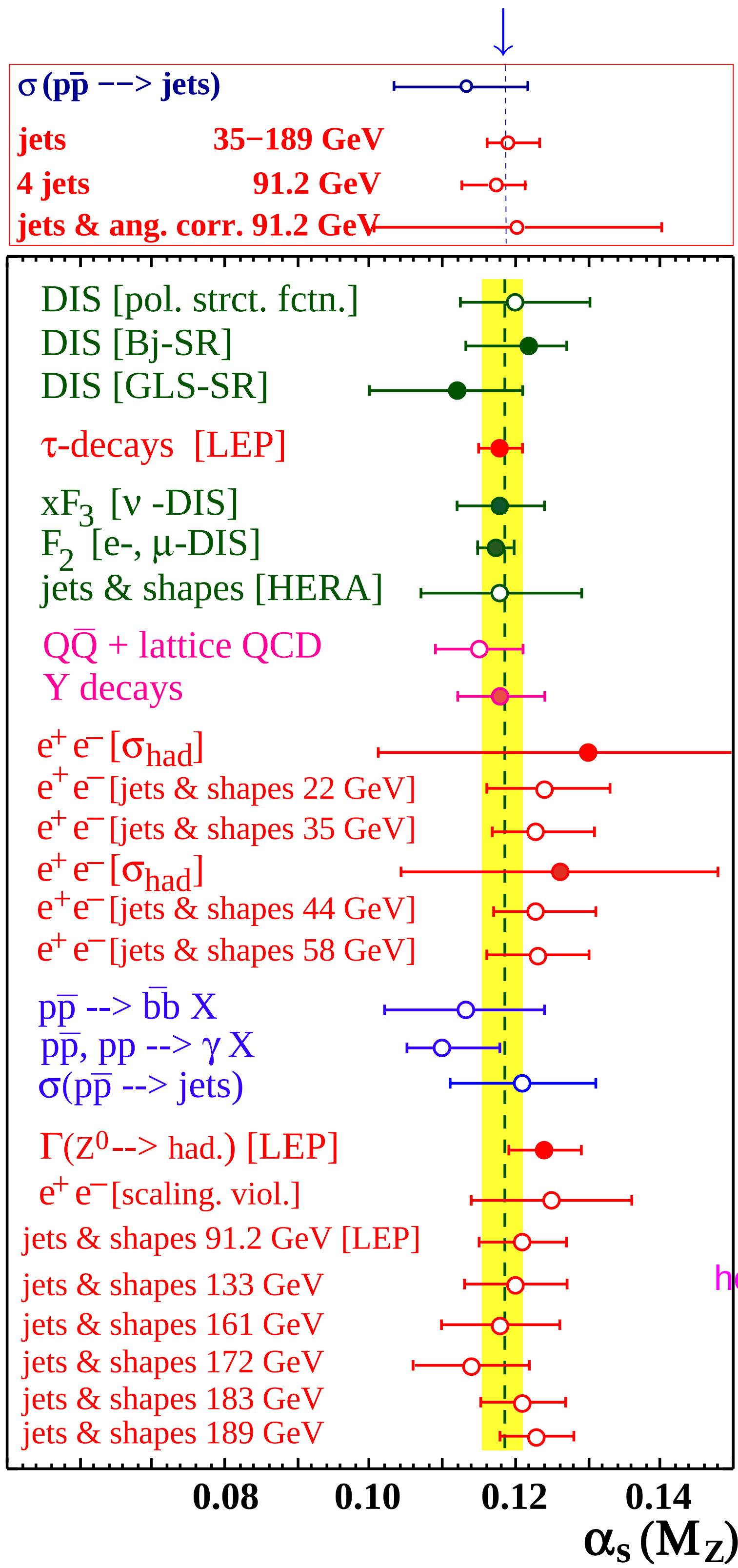


$$R^c = 0.997 \pm 0.038(\text{stat.}) \pm 0.030(\text{syst.}) \pm 0.012(\text{theo.})$$

$$R^b = 0.993 \pm 0.008(\text{stat.}) \pm 0.006(\text{syst.}) \pm 0.011(\text{theo.})$$

WORLD SUMMARY OF α_s-MEASUREMENTS

$$\alpha_s(M_{Z^0}) = 0.1184 \pm 0.0031$$



Bethke

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based on

NNLO