Measurement of the Strong Coupling α_S in e^+e^- Annihilation using 4-Jet Events with the OPAL Detector

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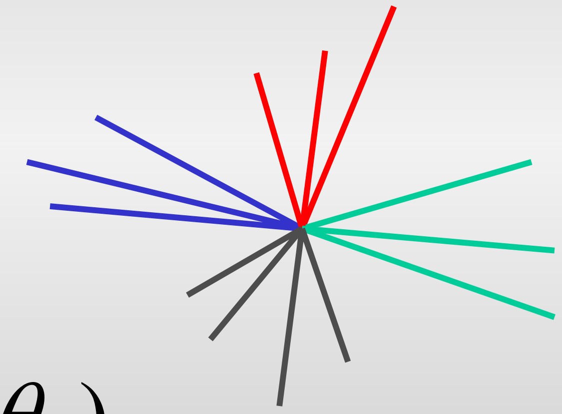
DISCLAIMER: all results presented are preliminary

(sorry, analysis of data below 91 GeV not ready yet)

Introduction

- α_S-measurements using the 4-Jet rate published only for data $\sqrt{s}$ = 91 GeV
- extend analysis to whole available e^+e^- energy-range 91 (14) GeV $\leq \sqrt{s} <$ 209 GeV
- reconstructed particles are combined to jets according to the Durham-scheme:



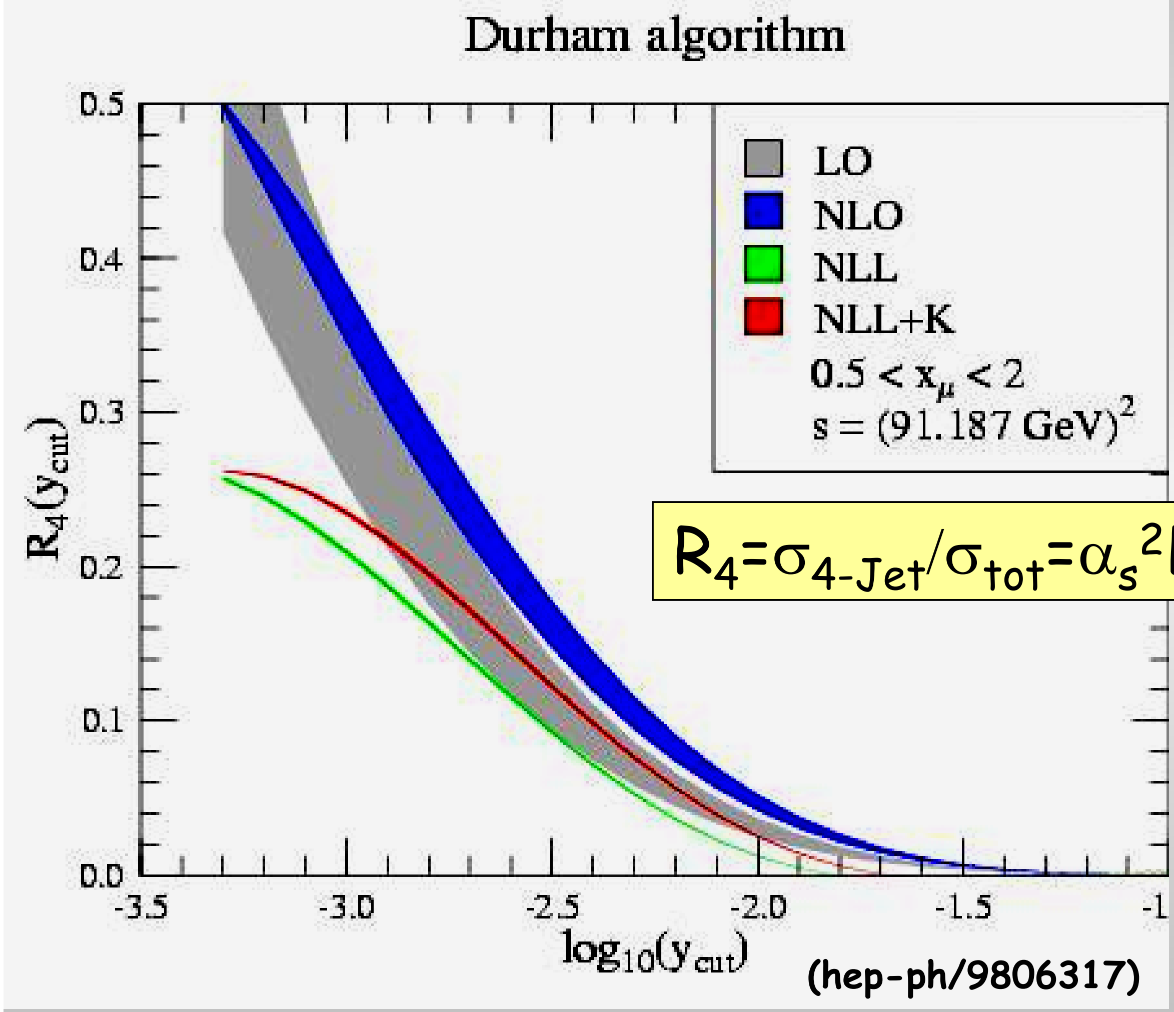
$$y_{ij} = \frac{2\min(E_i^2, E_j^2)}{E_{vis}^2}(1-\cos\theta_{ij})$$

- event is classified as 4-jet event at a certain y_{cut} :

$$y_{34} > y_{cut} > y_{45}$$

- calculate 4-jet-rate as a function of y_{cut}

Theoretical Prediction



(hep-ph/9806317)

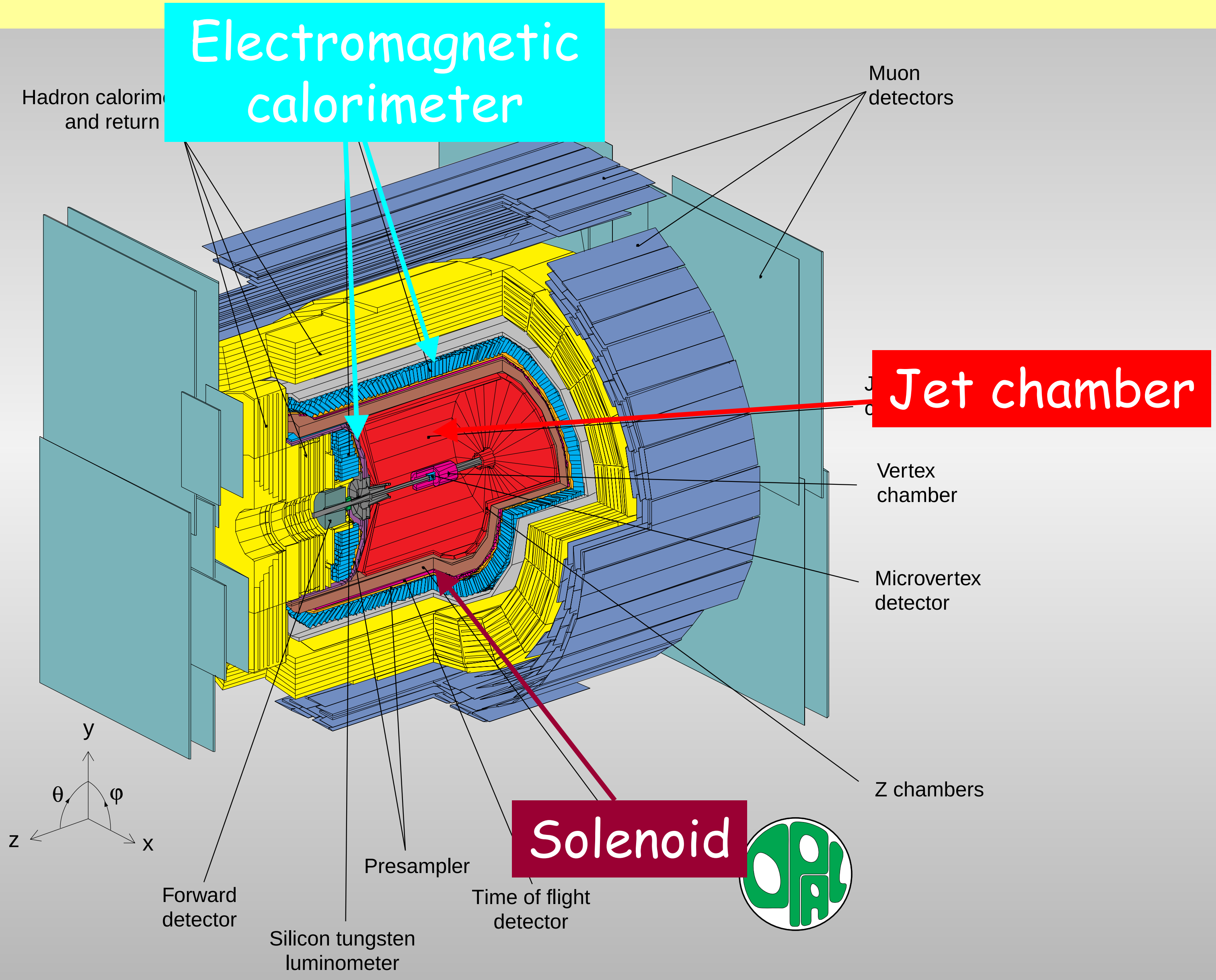
theoretical NLO QCD calculation predicted by Nagy and Trocsanyi (DEBRECEN 2.0)

$$R_4=\sigma_{4\text{-}Jet}/\sigma_{tot}=\alpha_s^2B(y_{cut})+\alpha_s^3C(y_{cut})+O(\alpha_s^4)$$

NLO combined with NLLA calculation by Catani et.al

(k-Factor: higher order contribution to vertex probabilities)

The OPAL Detector


Electromagnetic calorimeter

Jet chamber

Solenoid

Event Selection

$\sqrt{s} > 130$ GeV

- **identification of hadronic events**
  - event multiplicity → track & cluster quality
  - visible energy
  - longitudinal momentum balance
- **removal of events with high Initial State Radiation (ISR)**
  - $\sqrt{s'}$ measured for each event
- **removal of four-fermion background events: hadronic decaying W-pair events**
  - use standard OPAL WW selection procedure
    - likelihood cut for $WW \to qqqq$
    - likelihood cut for $WW \to qql\nu$

$\sqrt{s} > 160$ GeV

OPAL Data Sample

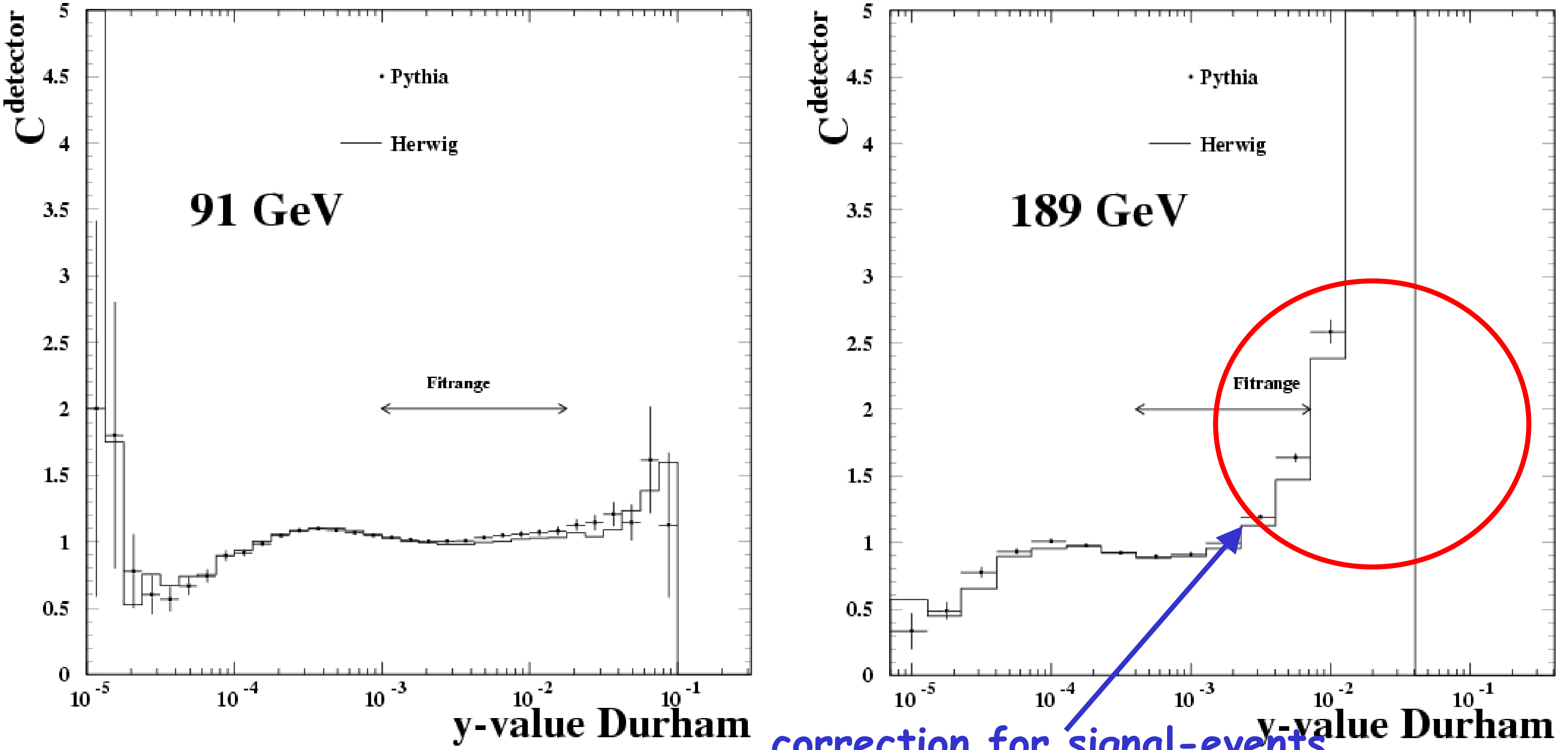
mean √s in GeV	Number of selected events	predicted by Monte Carlo
91.3	397452	396560.0
130.1	318	368.4
136.1	312	329.7
161.3	281	282.4
172.1	218	225.2
182.7	1077	1042.5
188.6	3086	3130.1
191.6	514	472.0
195.5	1137	1161.3
199.5	1090	1030.8
201.6	519	526.5
204.9	1130	1089.6
206.6	1717	1804.1

- energy points are grouped to four different energy intervals
- calculate luminosity times cross-section weighted average
- fewer energy points with higher statistical precision

Correction for Background and Detector Effects

subtract estimated residual WW-background (~2% - 6%)

- bin-by-bin detector correction: $R^{had}=C^{detector} * R^{det}$

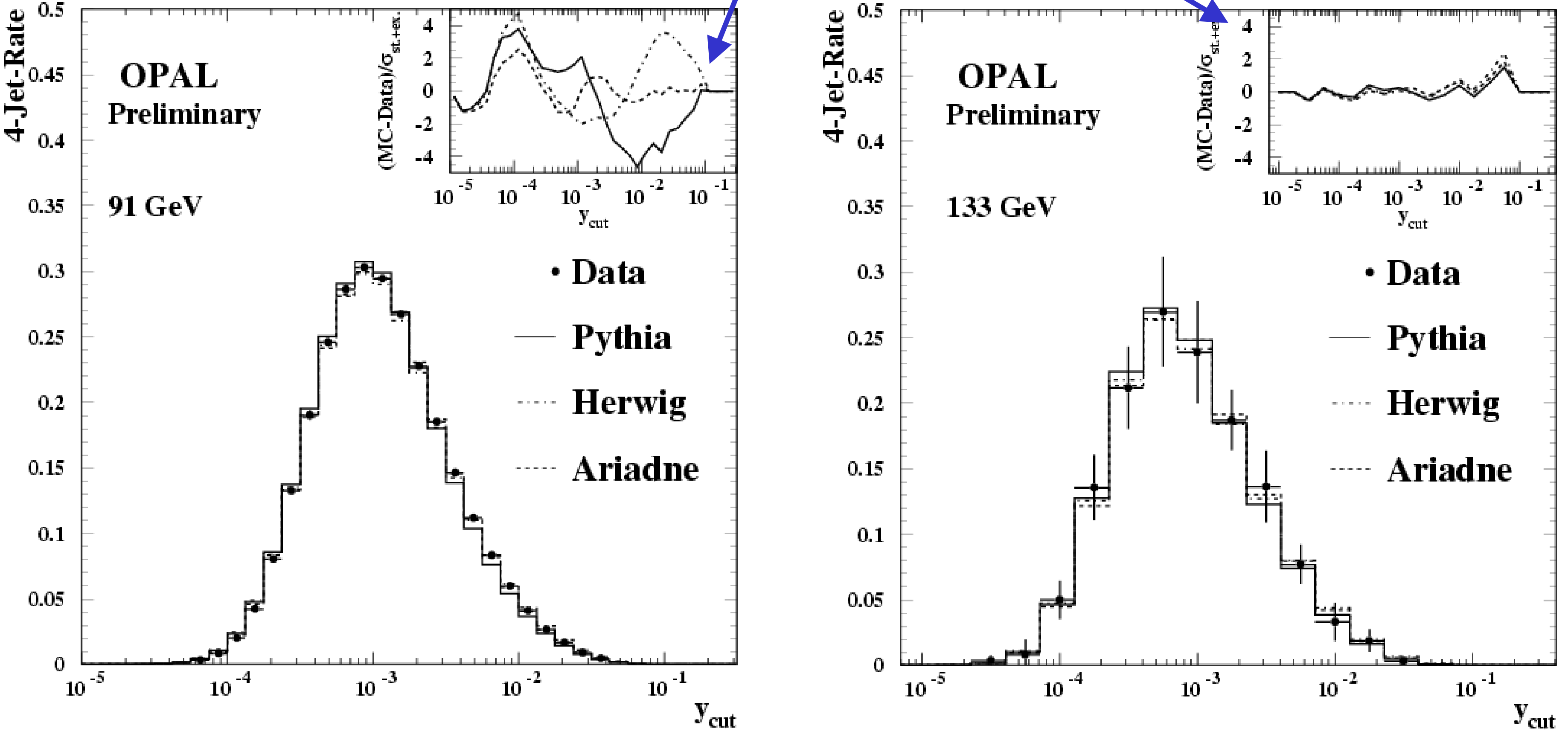


- correction for ISR

correction for signal-events misidentified as W-pair background

Hadron Level Distributions

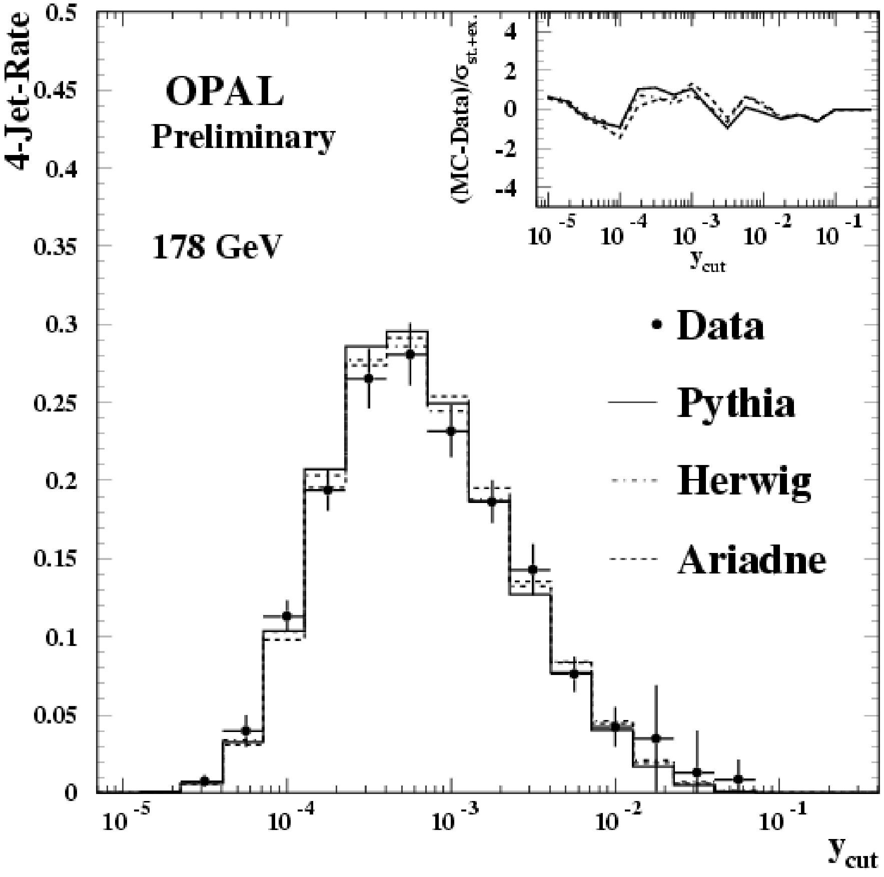
(Monte Carlo-Data)/σ

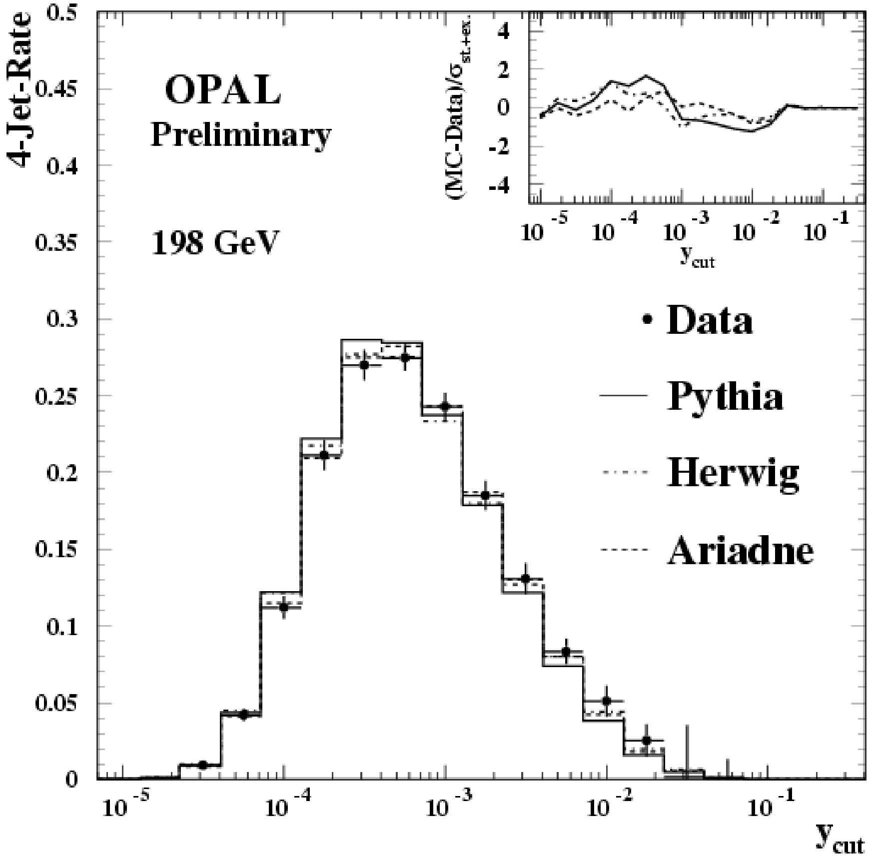


(statistical and experimental error)

Hadron Level Distributions

good agreement between data and Monte-Carlo models

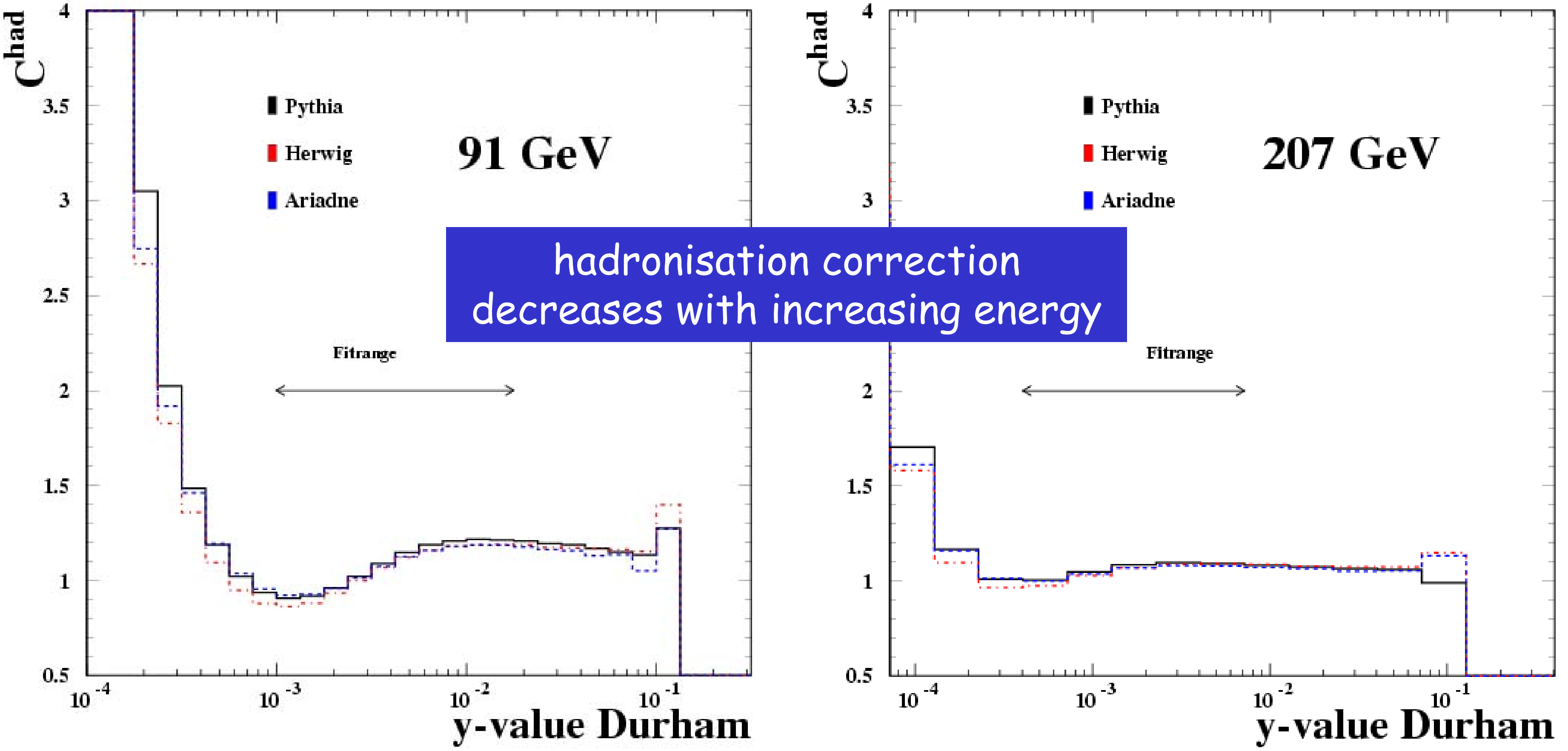




(statistical and experimental error)

Hadronisation Correction

- theoretical prediction without hadronisation ('partonlevel')
- bin-by-bin correction for hadronisation effects



hadronisation correction decreases with increasing energy

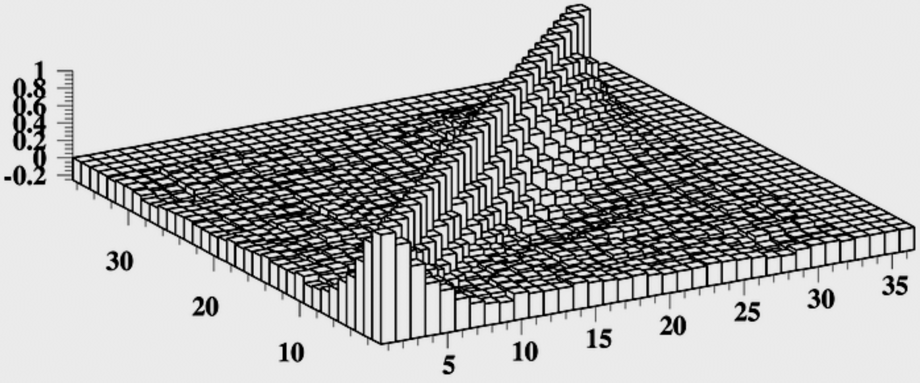
Fitting Procedure

- minimize χ^2 expression with respect to α_S

$$\chi^2 = \sum_{i,j} (x_i - x_i^{theo})(V^{-1})_{ij}(x_j - x_j^{theo})$$

- every event can have entries at several bins
  - bins are correlated → V_{ij} not diagonal

calculate covariance matrix using many Monte Carlo subsamples



covariance matrix at 91 GeV

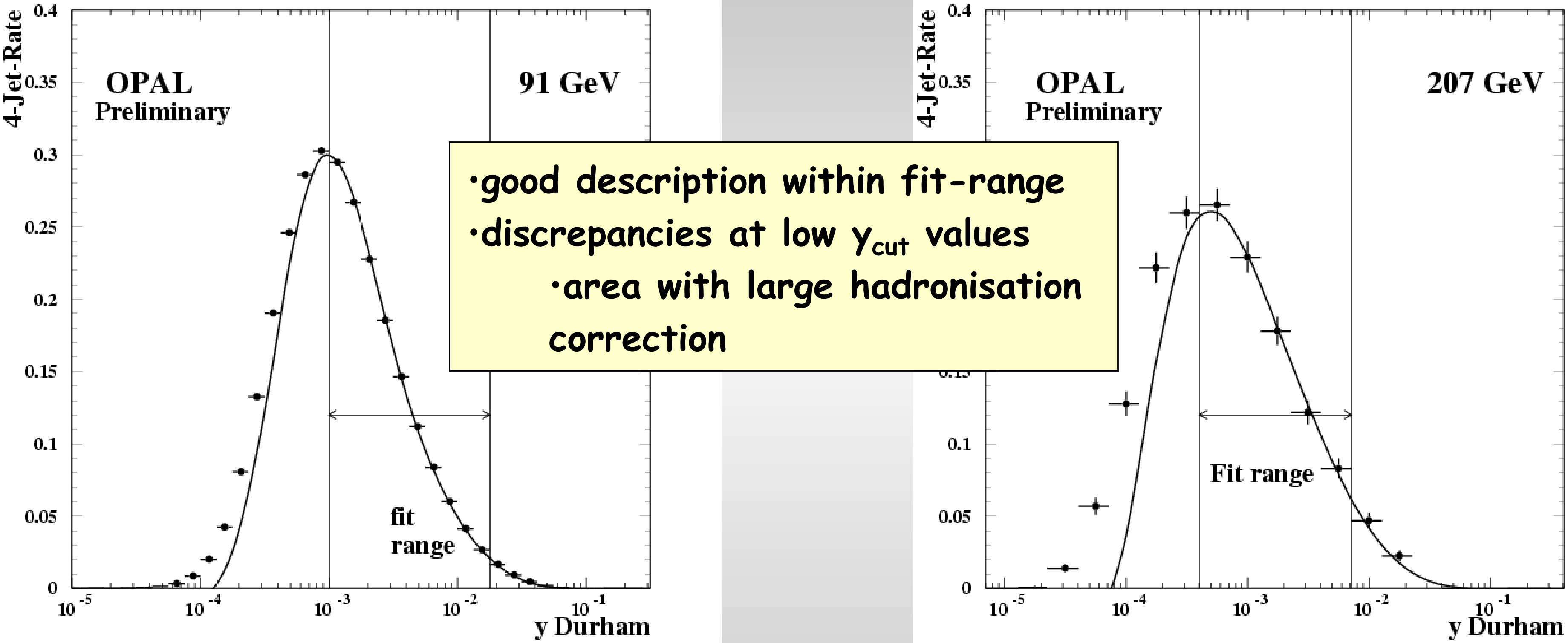
Systematic Variations

- experimental uncertainties

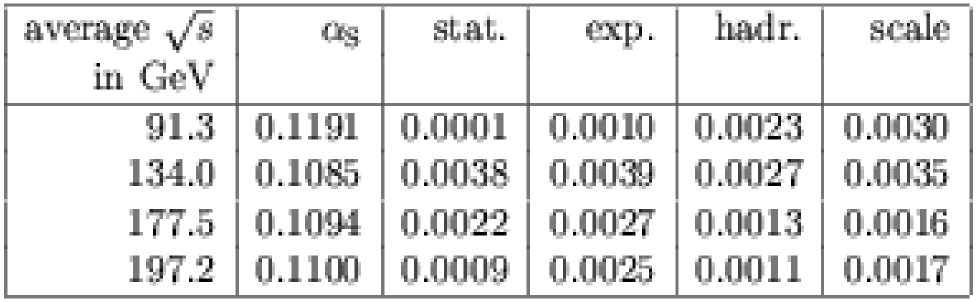
  selection of tracks and clusters, correction for detector effects, cut on $\cos\theta_T$

  selection of non-ISR events ($\sqrt{s} > 91$ GeV), correction for four-fermion BG ($\sqrt{s} > 160$ GeV)
- hadronization uncertainties
  - use Herwig and Ariadne instead of Pythia
- missing higher order terms
  - vary renormalsation scale $x_\mu = \mu/\sqrt{s}$ from 0.5 to 2.0

Fit to the Distribution



- good description within fit-range
- discrepancies at low y_{cut} values
  - area with large hadronisation correction

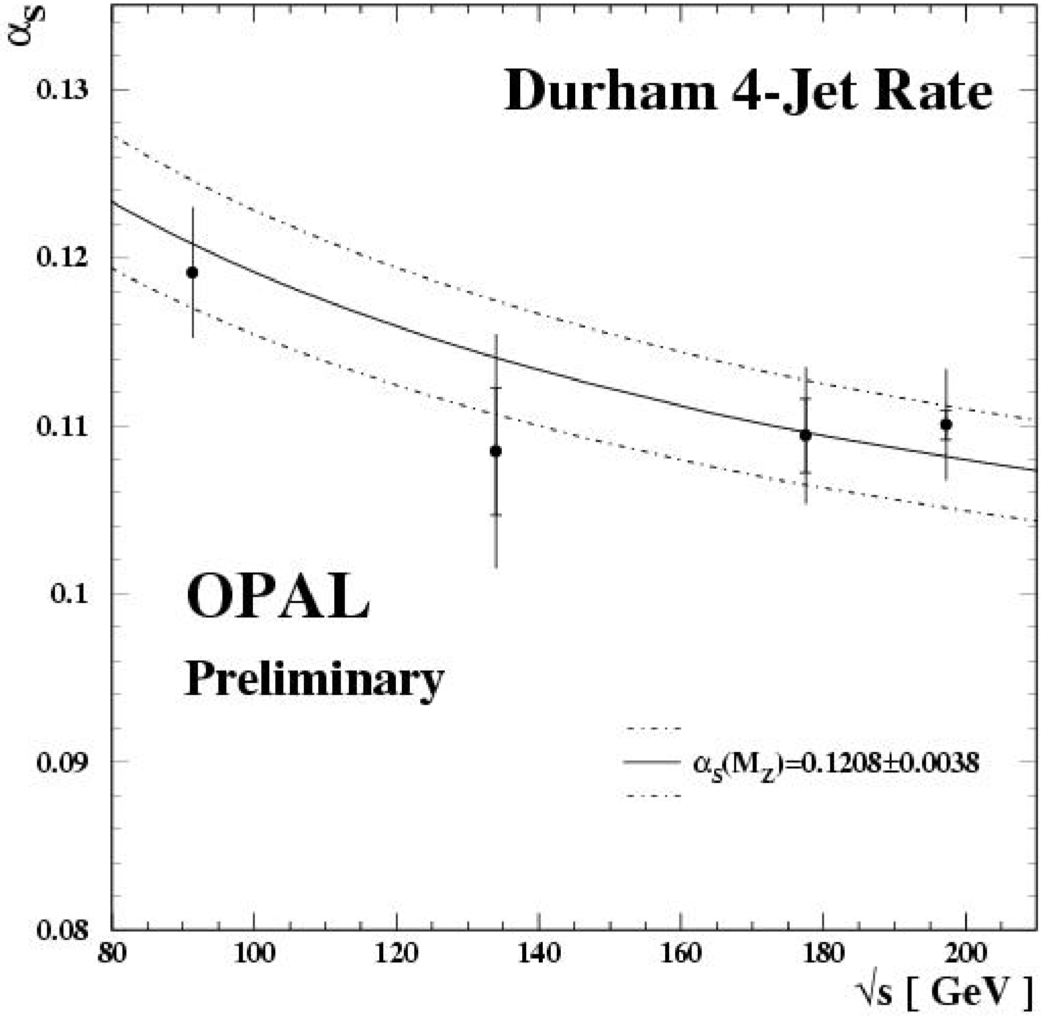


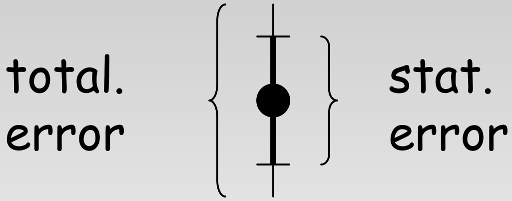
average $\sqrt{s}$ in GeV	α_S	stat.	exp.	hadr.	scale
91.3	0.1191	0.0001	0.0010	0.0023	0.0030
134.0	0.1085	0.0038	0.0039	0.0027	0.0035
177.5	0.1094	0.0022	0.0027	0.0013	0.0016
197.2	0.1100	0.0009	0.0025	0.0011	0.0017

with increasing energy:

- experimental error increases
- hadr. and scale error decreases

'Running' of α_s





the energy dependence of α_s is consistent with the expectation from QCD

Combination to Single α_S Value

- evolve the fitted values to common scale M_Z (two Loop)

  (assuming validity of QCD)
- calculate combined value with correlated errors
  - follow approach suggested by the LEP QCD WG

    (calculate weights from covariance matrix)

$$\boxed{\begin{aligned}\alpha_S(M_{Z^0}) = 0.1208 \pm 0.0006(\text{stat.}) \pm 0.0021(\text{exp.})\\ \pm 0.0019(\text{had.}) \pm 0.0024(\text{scale})\end{aligned}}$$

LEP 1 data dominates result with ~50%

(133 GeV < 1%, 177 GeV ~ 16%, 198 GeV ~ 34%)

Summary & Further Plans

- first measurement of α_S using the 4-Jet event rate and NLO+ NLLA theory prediction above 91 GeV
- evolution of α_S with √s is consistent with QCD
- combination of α_S result in:

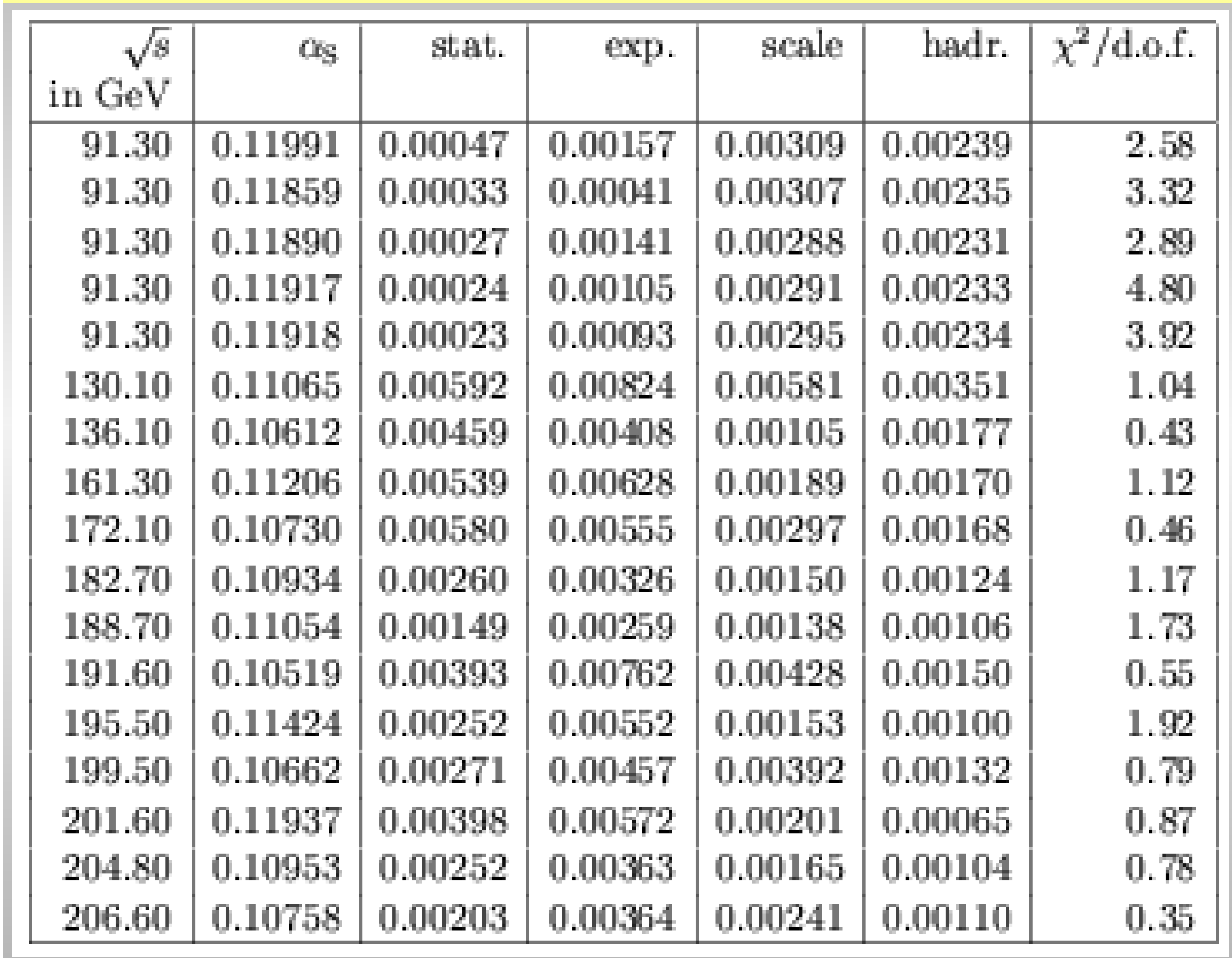
$$\boxed{\alpha_S(M_{Z^0}) = 0.1208 \pm 0.0038(\text{tot.})}$$

- consistent with the world average
- similar analysis at ALEPH: α_S= 0.1170±0.0013 (M_Z only)

future plans:

- extend analysis to energy range below M_Z
- measure α_S with other four-jet type event shapes (D-Parameter, Thrust-Minor)

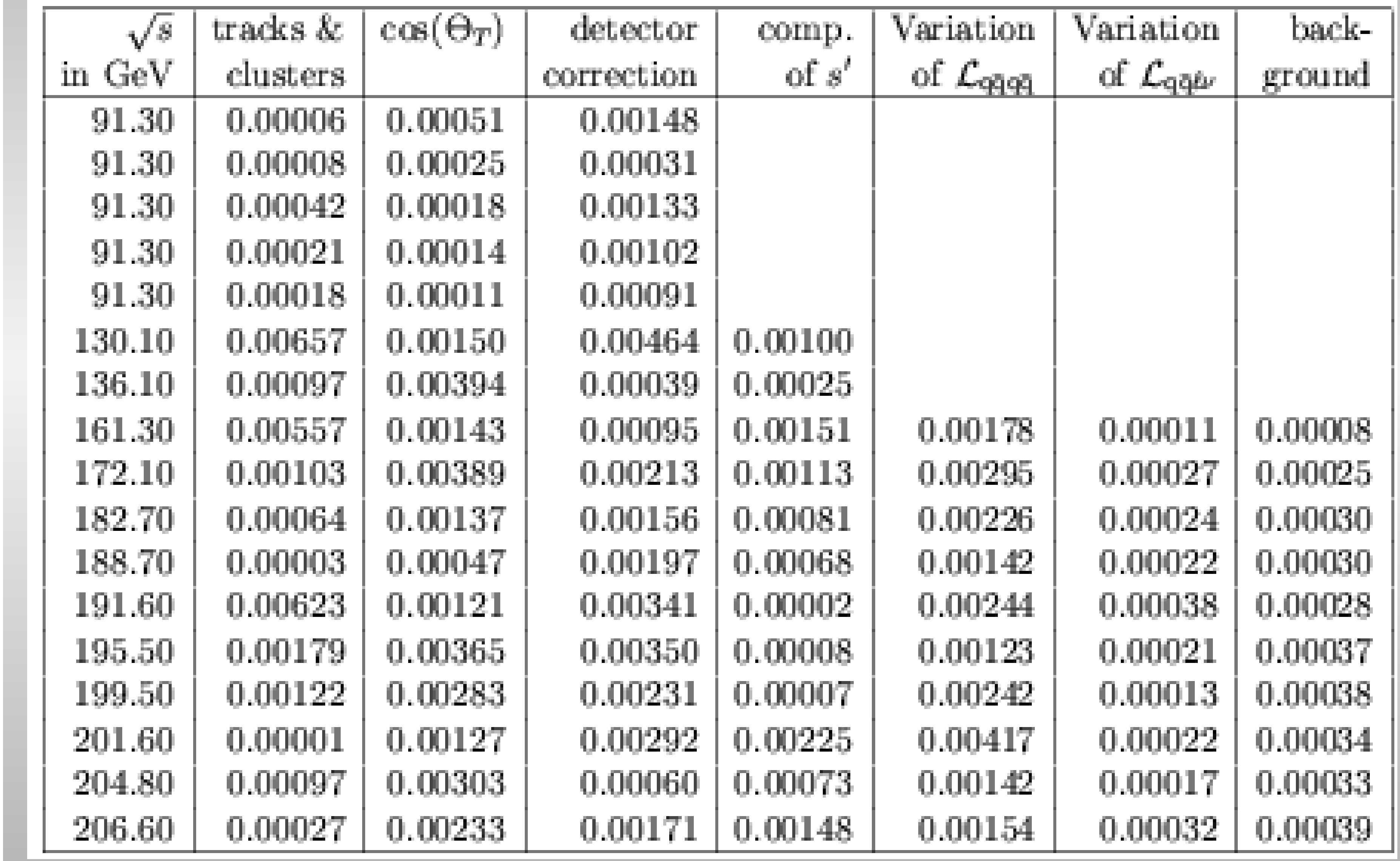
Result for the Energy Points



$\sqrt{s}$ in GeV	α_S	stat.	exp.	scale	hadr.	χ^2/d.o.f.
91.30	0.11991	0.00047	0.00157	0.00309	0.00239	2.58
91.30	0.11859	0.00033	0.00041	0.00307	0.00235	3.32
91.30	0.11890	0.00027	0.00141	0.00288	0.00231	2.89
91.30	0.11917	0.00024	0.00105	0.00291	0.00233	4.80
91.30	0.11918	0.00023	0.00093	0.00295	0.00234	3.92
130.10	0.11065	0.00592	0.00824	0.00581	0.00351	1.04
136.10	0.10612	0.00459	0.00408	0.00105	0.00177	0.43
161.30	0.11206	0.00539	0.00628	0.00189	0.00170	1.12
172.10	0.10730	0.00580	0.00555	0.00297	0.00168	0.46
182.70	0.10934	0.00260	0.00326	0.00150	0.00124	1.17
188.70	0.11054	0.00149	0.00259	0.00138	0.00106	1.73
191.60	0.10519	0.00393	0.00762	0.00428	0.00150	0.55
195.50	0.11424	0.00252	0.00552	0.00153	0.00100	1.92
199.50	0.10662	0.00271	0.00457	0.00392	0.00132	0.79
201.60	0.11937	0.00398	0.00572	0.00201	0.00065	0.87
204.80	0.10953	0.00252	0.00363	0.00165	0.00104	0.78
206.60	0.10758	0.00203	0.00364	0.00241	0.00110	0.35

χ^2-value from statistical error only

Experimental Uncertainties



$\sqrt{s}$ in GeV	tracks & clusters	$\cos(\Theta_T)$	detector correction	comp. of s'	Variation of $\mathcal{L}_{qqqq}$	Variation of $\mathcal{L}_{qq\ell\nu}$	back-ground
91.30	0.00006	0.00051	0.00148				
91.30	0.00008	0.00025	0.00031				
91.30	0.00042	0.00018	0.00133				
91.30	0.00021	0.00014	0.00102				
91.30	0.00018	0.00011	0.00091				
130.10	0.00657	0.00150	0.00464	0.00100			
136.10	0.00097	0.00394	0.00039	0.00025			
161.30	0.00557	0.00143	0.00095	0.00151	0.00178	0.00011	0.00008
172.10	0.00103	0.00389	0.00213	0.00113	0.00295	0.00027	0.00025
182.70	0.00064	0.00137	0.00156	0.00081	0.00226	0.00024	0.00030
188.70	0.00003	0.00047	0.00197	0.00068	0.00142	0.00022	0.00030
191.60	0.00623	0.00121	0.00341	0.00002	0.00244	0.00038	0.00028
195.50	0.00179	0.00365	0.00350	0.00008	0.00123	0.00021	0.00037
199.50	0.00122	0.00283	0.00231	0.00007	0.00242	0.00013	0.00038
201.60	0.00001	0.00127	0.00292	0.00225	0.00417	0.00022	0.00034
204.80	0.00097	0.00303	0.00060	0.00073	0.00142	0.00017	0.00033
206.60	0.00027	0.00233	0.00171	0.00148	0.00154	0.00032	0.00039