Determination of α_s at 500 GeV from Event Shapes and Jetrates

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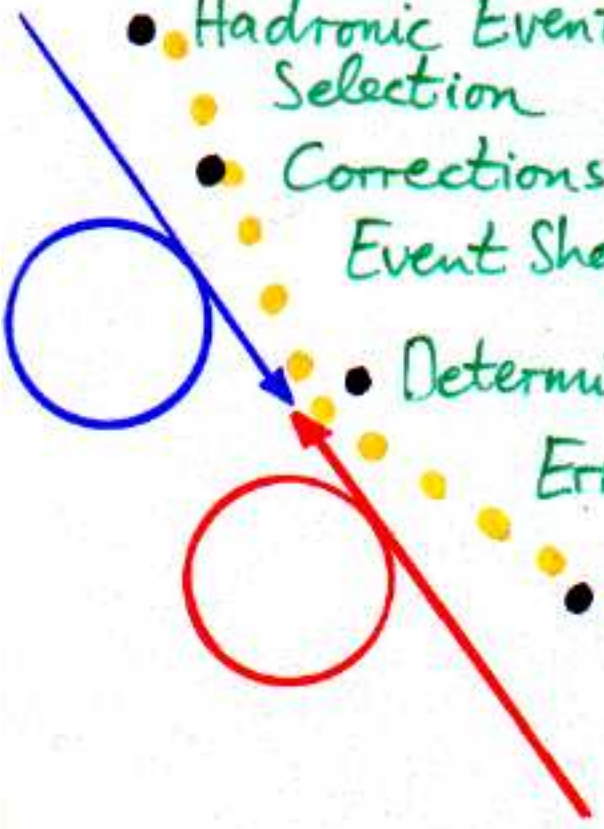
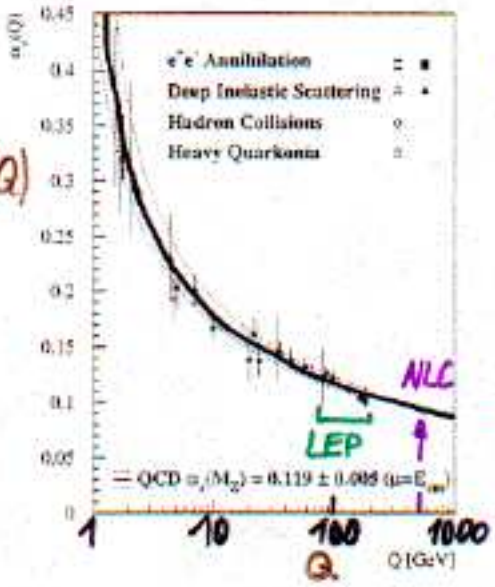
- Why?
- Experimental Complications
- Hadronic Event Selection
- Corrections to Event Shapes
- Determination of α_s
- Error Estimation
- Farther Options
- Conclusions



Why investigating QCD @ 500 GeV

- QCD
  - less precisely surveyed than electroweak sector (even after LEP II)

▶ $\alpha_s(Q)$

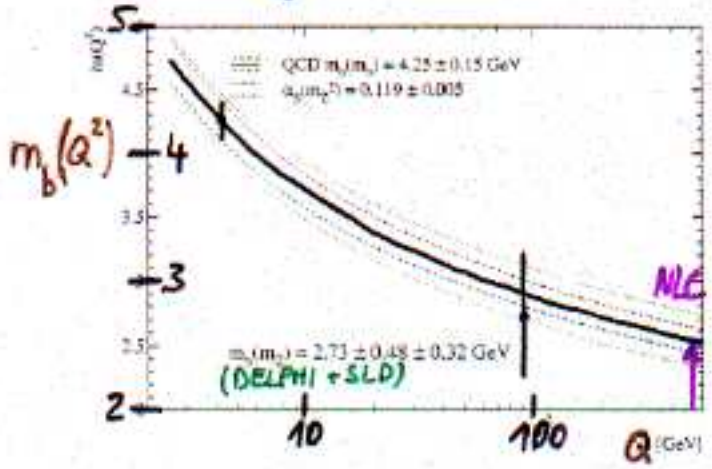


running coupling ↔ asymptotic freedom

⇒ details of running?

▶ running mass

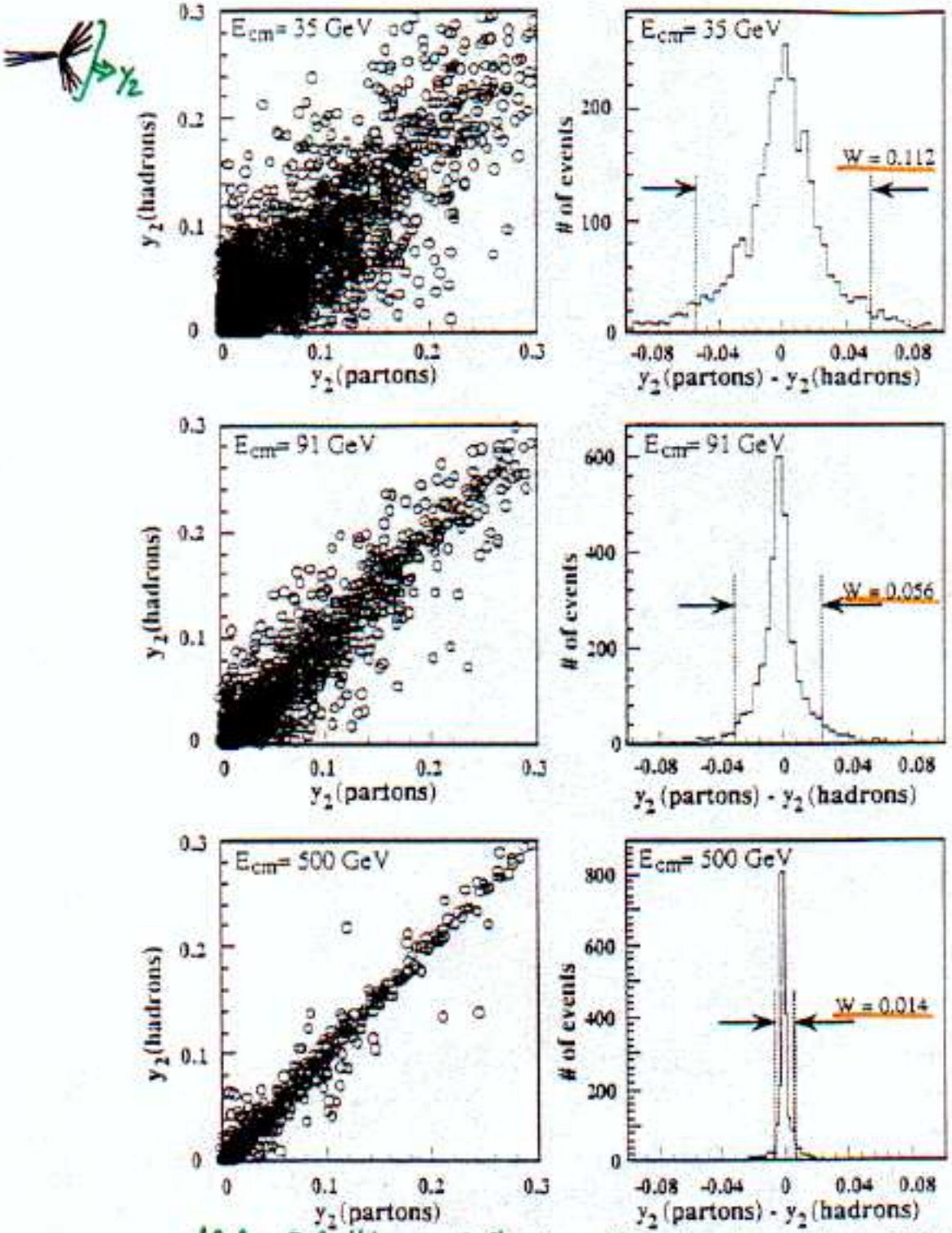
$$\frac{1}{m}\frac{\partial m}{\partial \ln \mu^2} = -\gamma_0 \alpha_s \cdots$$



▶ properties of quarks & gluons

⋮

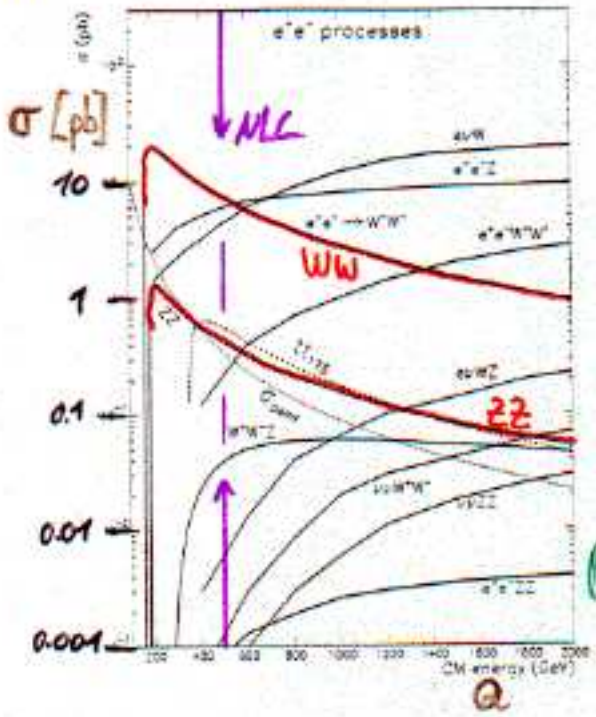
- Non-perturbative (hadronic) effects diminish $\sim \frac{1}{Q}$



(Ref.: S. Bethke in "Physics and Experiments with Linear Colliders")

Experimental Complications

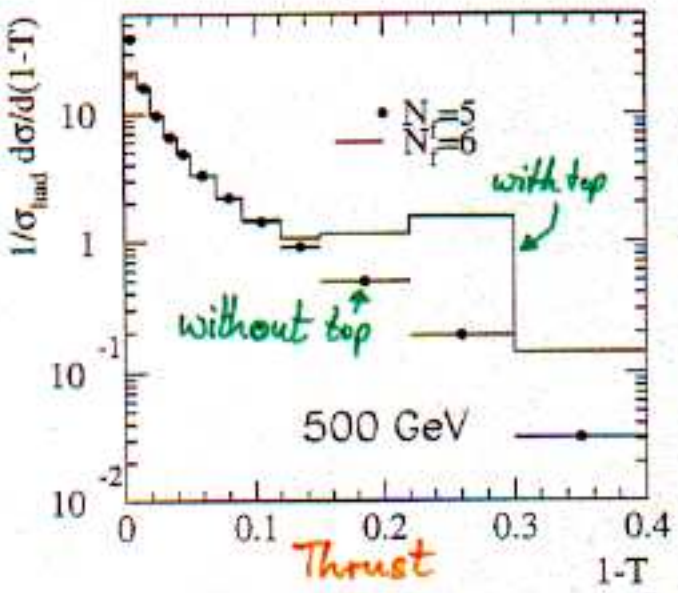
- Background : WW, ZZ production

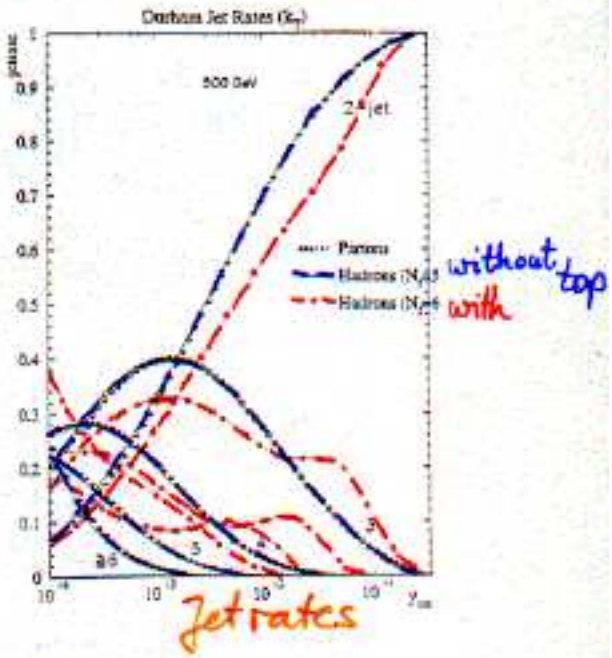


(Ref.: hep-ph/9809220 F. Boudjema)

additionally : $\gamma\gamma$, $\tau\tau$ familiar from LEP II

- QCD Background : $t\bar{t}$ production

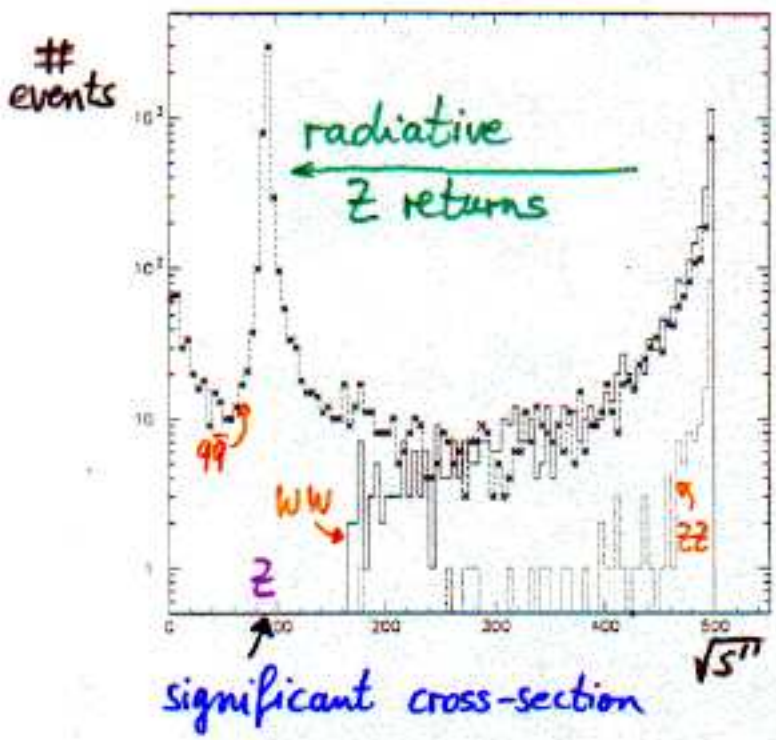




⇒ large distortions due to top

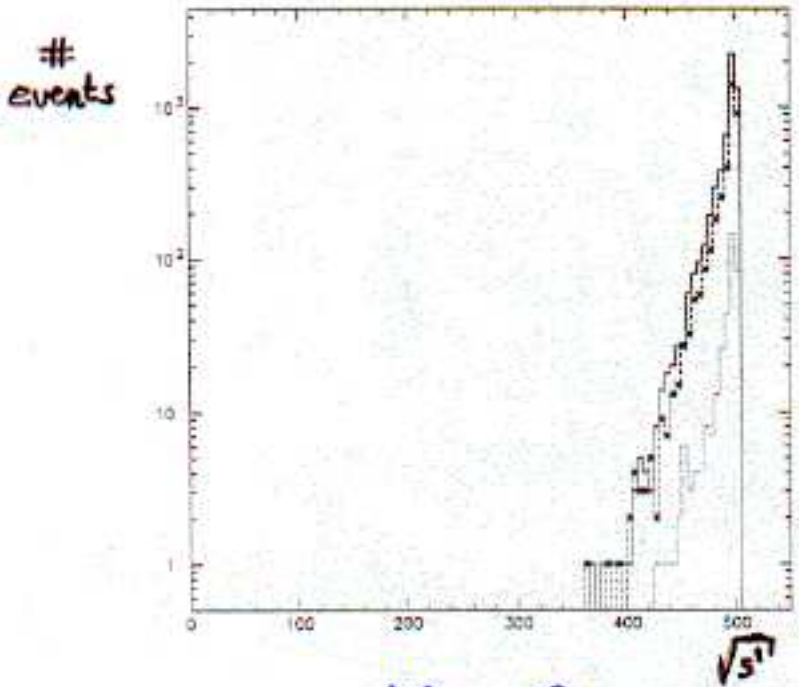
Experimental Complications II

- ISR — familiar since LEP II



significant cross-section

- Beamstrahlung BS



(Ref.: T. Ohl, Circe 1.2β + PYTHIA)

⇒ no problem @ TESLA

Technical Remarks

- Generator studies only: PYTHIA 5.722
  HERWIG 5.9
  ARIADNE 4.8p
  tuned to OPAL data

- excluded $Z \to e^+e^-, \mu^+\mu^-, \tau^+\tau^-, \nu\bar{\nu}$
  $W \to e\nu, \mu\nu$
  (rejectable by: e,μ-Identification, Multiplicity, missing mom.)

- included $Z \to$ hadrons
  $W \to \tau\nu$, hadrons

- ISR @ NLO in PYTHIA
- BS : Circe 1.28 routines by T. Ohl (TESLA parameters)

- Processes

	$e^+e^- \to q\bar{q}$	$e^+e^-(\gamma) \to q\bar{q}$	$e^+e^-(\gamma) \to W^+W^-$	$e^+e^-(\gamma) \to ZZ$	$e^+e^-(\gamma) \to t\bar{t}$
σ(500 GeV)	2.8 pb	11.6 pb	4.8 pb	0.3 pb	0.3 pb
# events $\int\mathcal{L} = 300$/fb	≈ 900k	≈ 3.6 M	≈ 1.5 M	≈ 90k	≈ 90k

(cross-section from PYTHIA)

Hadronic Event Selection

- Main issue: rejection of W^+W^-, ZZ, $t\bar{t}$

  LEP II experiences ↗

- LEP II: W^+W^- rejection cuts
  - − 4-jet matrix element weight W_4 ☹
  - − $3\to4$-jet flip y_{cut} value y_{34} ☹
  - \+ min(Jetbroadening/Hemisphere) B_{min} ☺
  - \+ mass of W + smallest interjet angle
    - ↳ boost @ 500 GeV ⇒ Hemisphere masses ☹

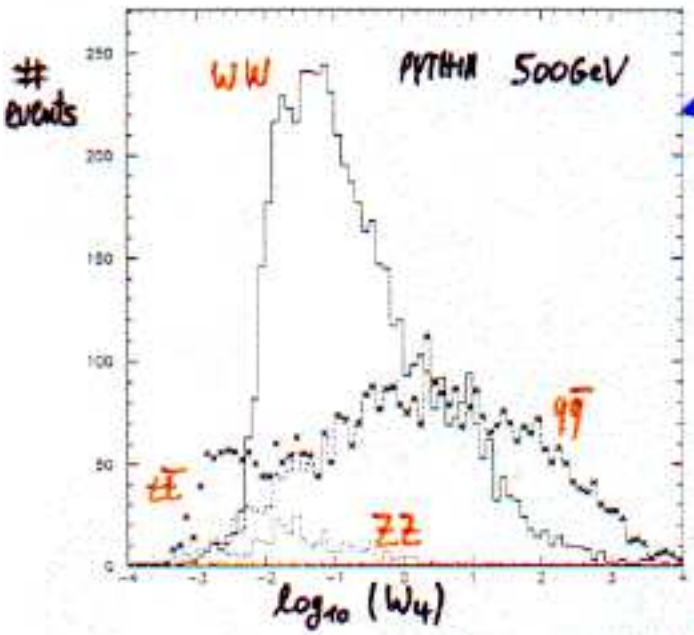
- In addition:
  - \+ polar angle of $\overrightarrow{\text{Thrust}}$ $\cos\theta_{Thrust}$ ☺
  - \+ ISR rejection: $\sqrt{s'} > 0.85\sqrt{s}$

⇒

	LEP II	NLC
typical efficiency	80-90%	>60%
typical purity	75-90%	~90%

Note: Efficiency might be increased without degrading purity

Hadronic Event Selection



← QCD matrix element weight for given 4-jet configuration:

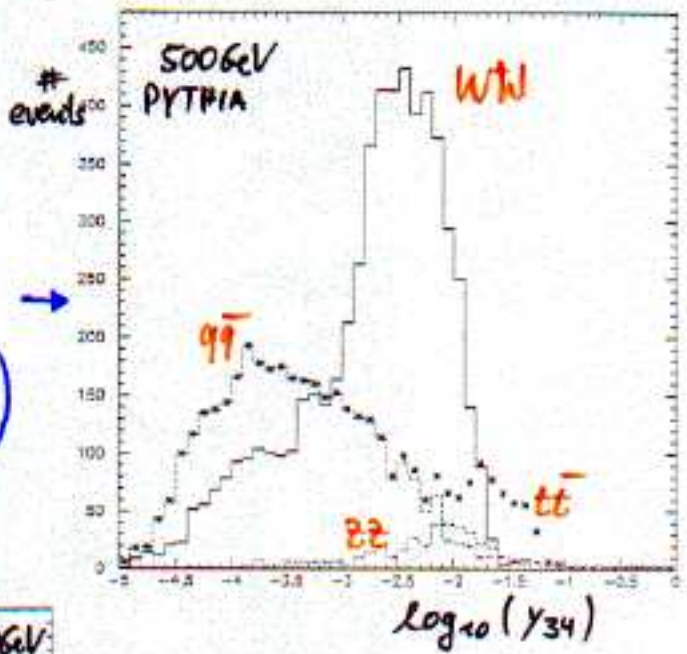
$W_4(\times) < W_4(=)$

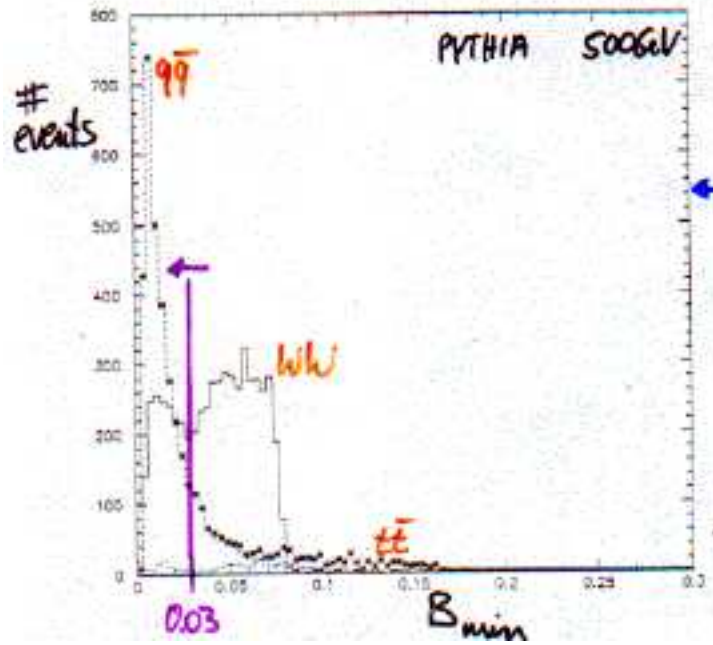
↑ WW @LEP II

↑ qq̄ @LEP II

3+4-jet flip y_{cut} value using Durham: y_{34} →

$y_{34}(\times) > y_{34}(=)$



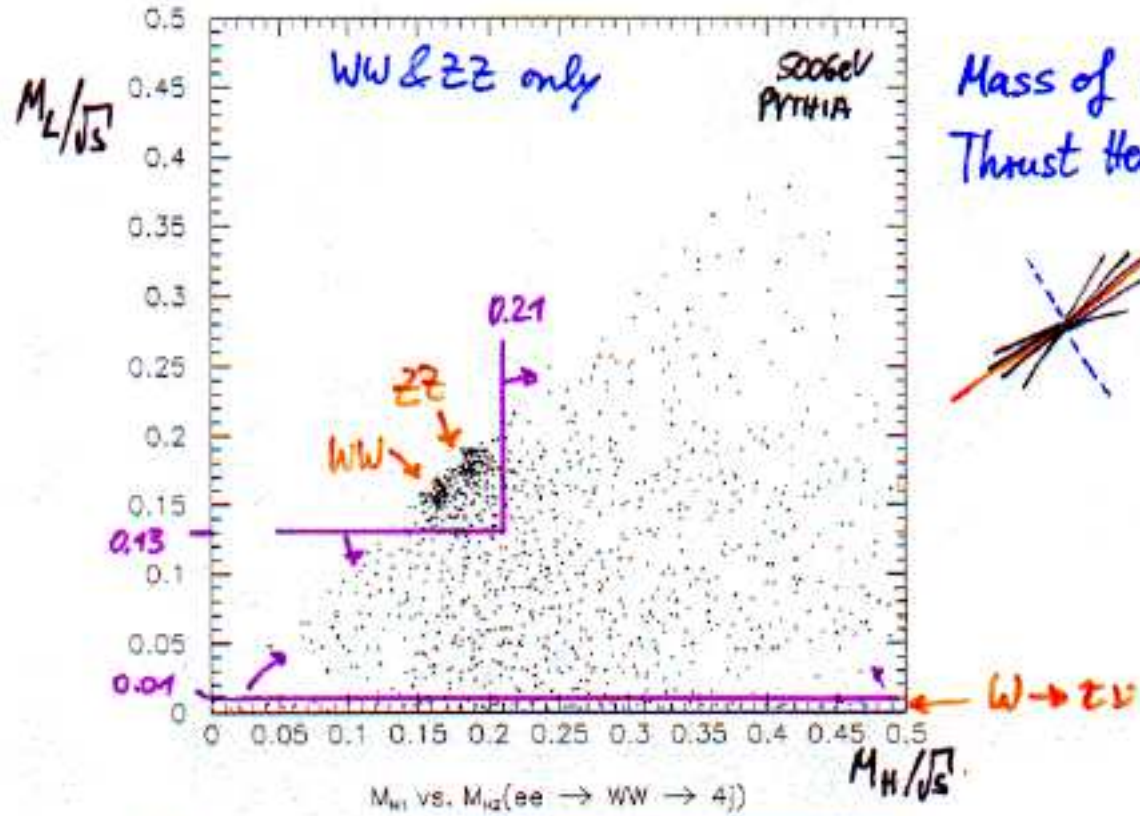


← min of Jetbroadening in each Thrust Hemisphere

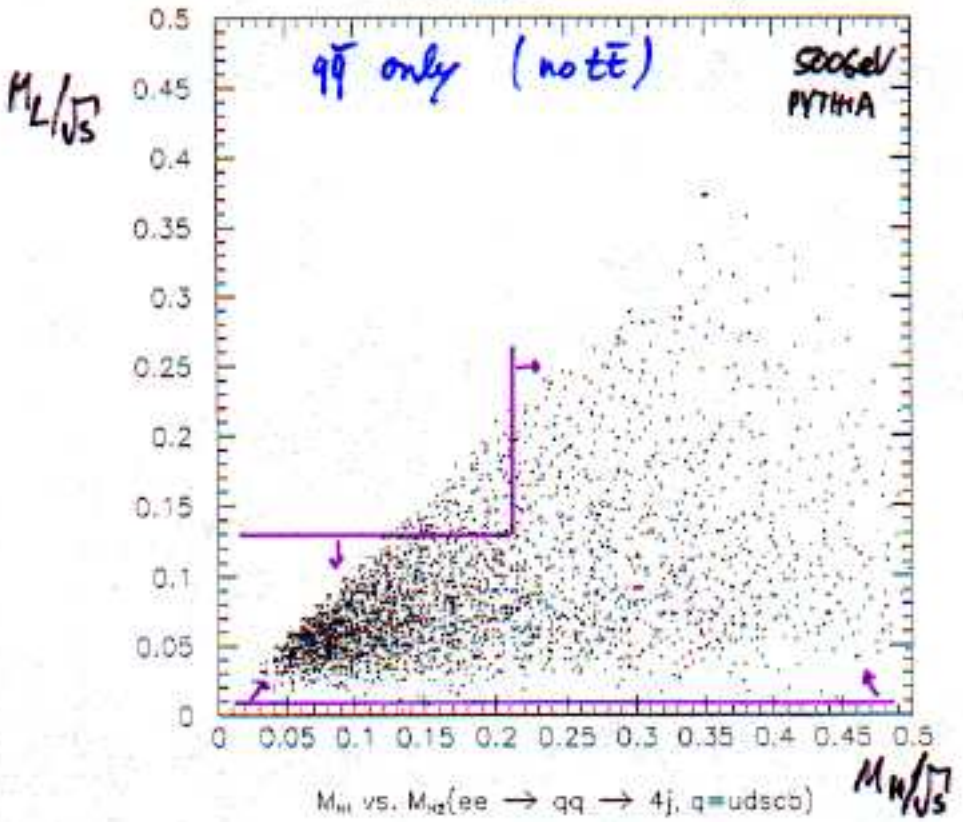
$B_{min} = \min(B_1, B_2)$

⇒ significant WW & $t\bar{t}$ rejection

Hadronic Event Selection

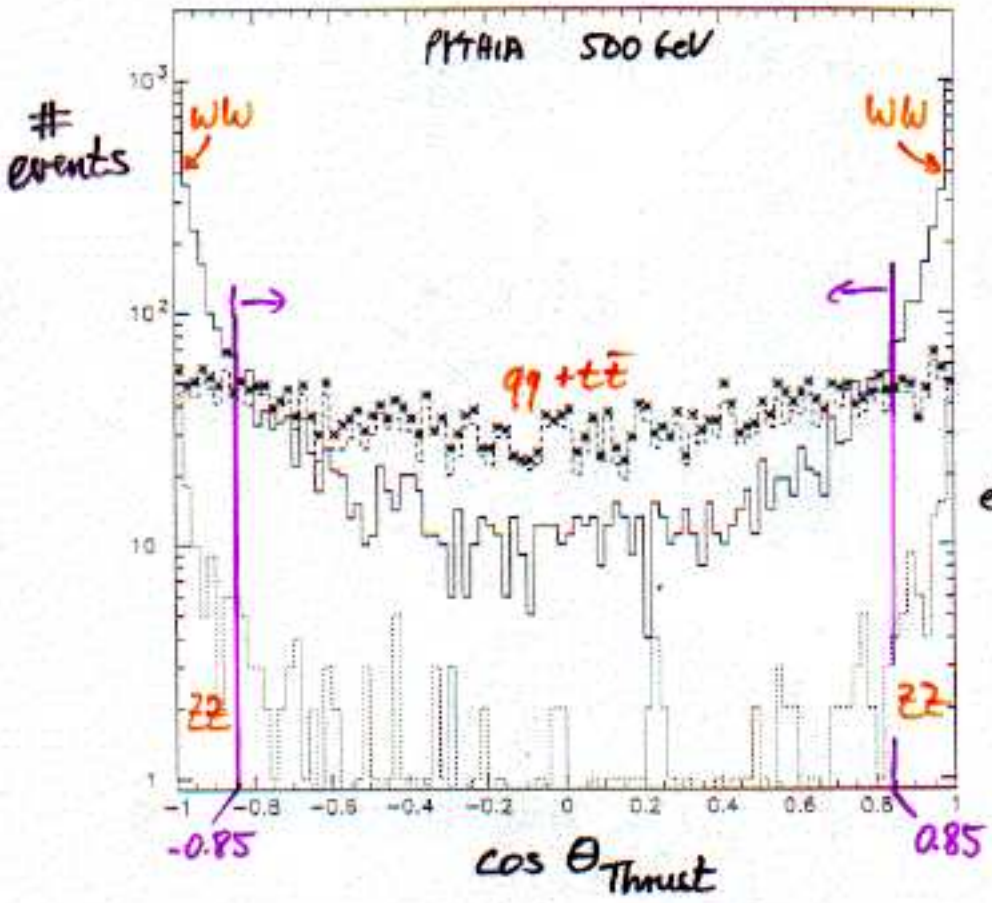


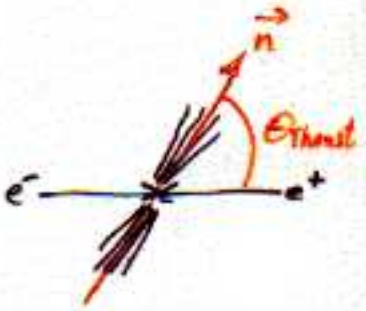
Mass of each Thrust Hemisphere



⇒ significant WW & ZZ rejection

Hadronic Event Selection





⇒ very significant WW & ZZ rejection

loss of $q\bar{q}$ efficiency

Jet rates & Event shapes

- Thrust

$$T = \max_{\vec{n}} \frac{\sum |\vec{p}_i \cdot \vec{n}|}{\sum |\vec{p}_i|}$$

- Heavy Jet mass

$$M_H/\sqrt{s} = \frac{1}{\sqrt{s}} \sqrt{\max\left[\sum_{\vec{p}_i \cdot \vec{n} > 0} (E_i^2 - \vec{p}_i^{\,2}), \sum_{\vec{p}_i \cdot \vec{n} < 0} (E_i^2 - \vec{p}_i^{\,2})\right]}$$

- Total & Wide Jetbroadening

$$B_{1,2} = \frac{\sum_{\vec{p} \cdot \vec{n} \gtrless 0} |\vec{p}_i \times \vec{n}|}{2 \sum |\vec{p}_i|} \quad ; \quad \begin{aligned} B_T &= B_1 + B_2 \\ B_W &= \max(B_1, B_2) \\ B_{min} &= \min(B_1, B_2) \end{aligned}$$

- C Parameter

$$C = \frac{3}{2} \frac{\sum_{i,j} |\vec{p}_i||\vec{p}_j| - (\vec{p}_i \cdot \vec{p}_j)^2 / |\vec{p}_i||\vec{p}_j|}{\sum_{i,j} (|\vec{p}_i|\,|\vec{p}_j|)^2}$$

- diff. 2-Jetrate from Durham algorithm

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

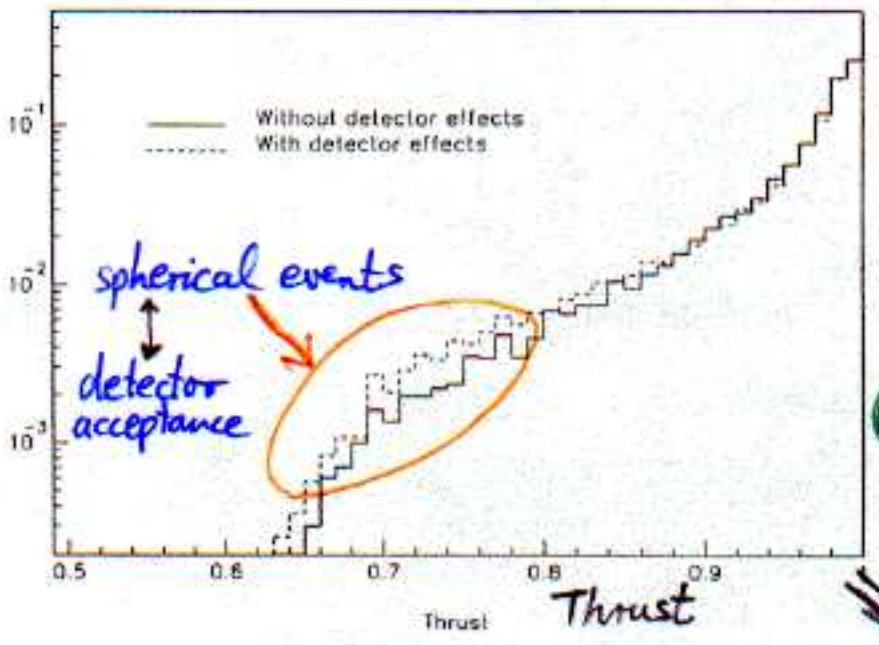
$\Rightarrow$ + routinely used to determine α_s @ LEP II

+ $O(\alpha_s^2)$ + resummed calculations available

Corrections to Observables

- Detector corrections

  not investigated, but



Ref.: G. Azuelos (DESY 92-123A)

small

- Hadronization

  OPAL's tuned parameters

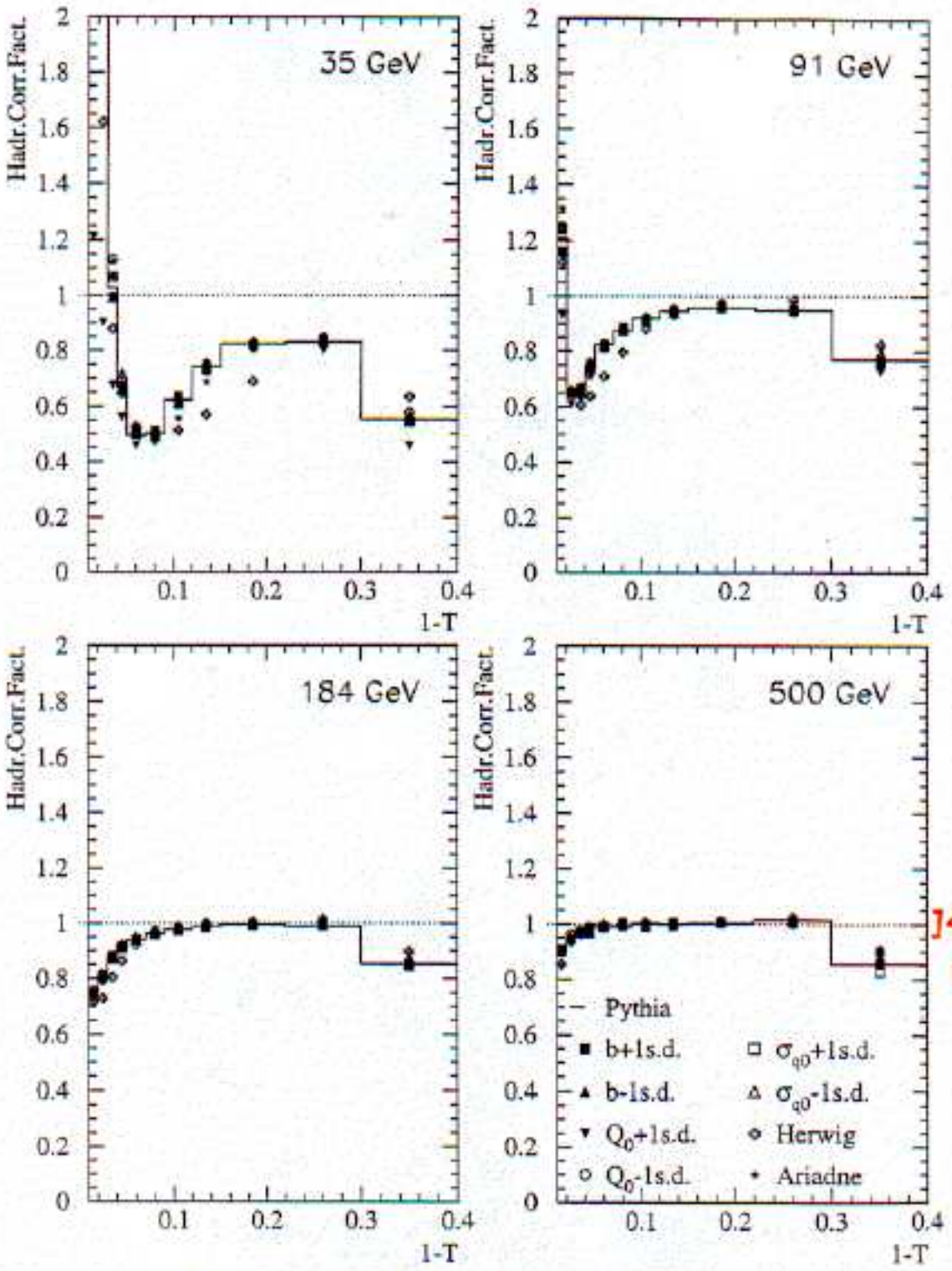
  - Lund sym. fragment. fct. $b = 0.52 \pm 0.04$
  - cut-off for parton shower $Q_0 = 1.9 \pm 0.5$ GeV
  - transverse momentum in fragm. $\sigma_q = 0.40 \pm 0.03$ GeV
  - HERWIG/ARIADNE

  $\Rightarrow$ { tiny hadronization corrections
  negligible parameter dependence

- However: Final MC-tune at end of LEP!

Hadronization Corrections

Correction factors for Thrust

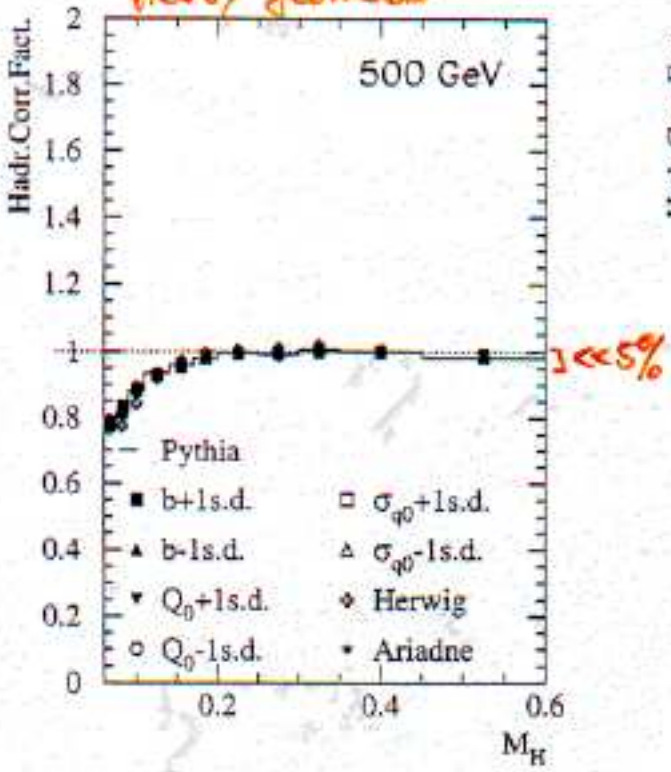


$\lesssim 5\%$ correction

⇒ tiny hadronization corrections @ 500 GeV

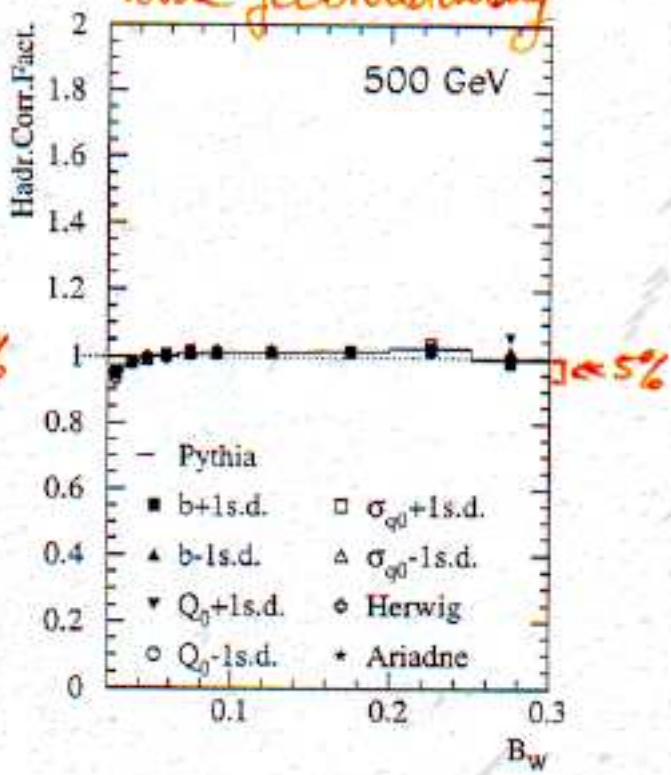
Hadronization Correction Factors

Heavy Jetmass



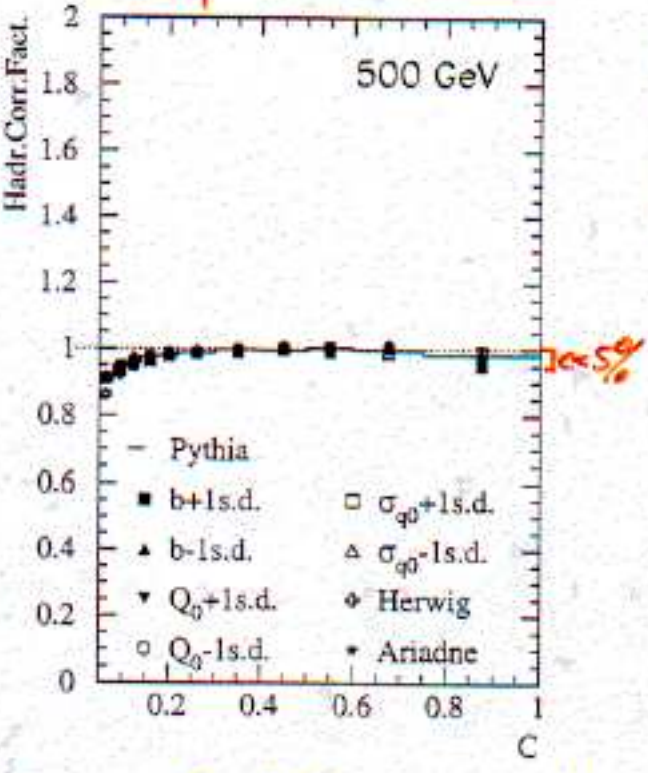
≤5%

Wide Jetbroadening



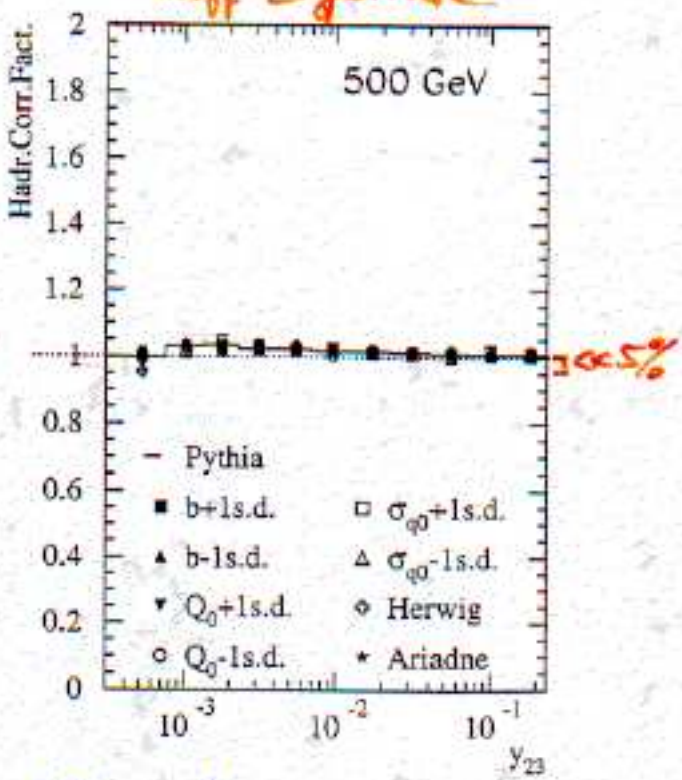
≤5%

C parameter



≤5%

diff. 2-Jetrate

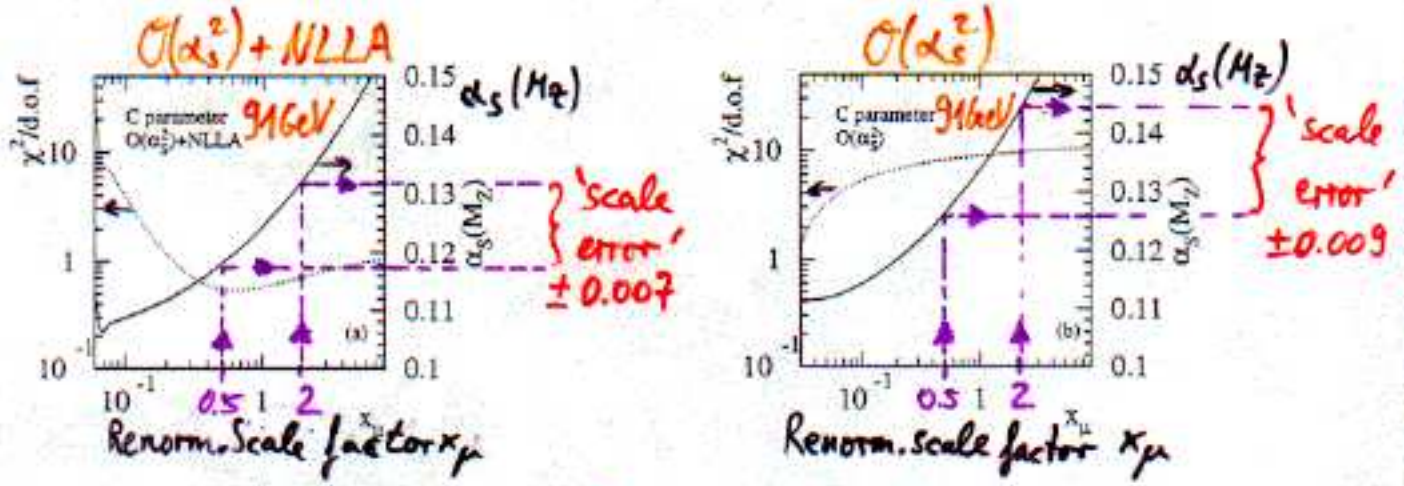


≤5%

⇒ negligible parameter dependence

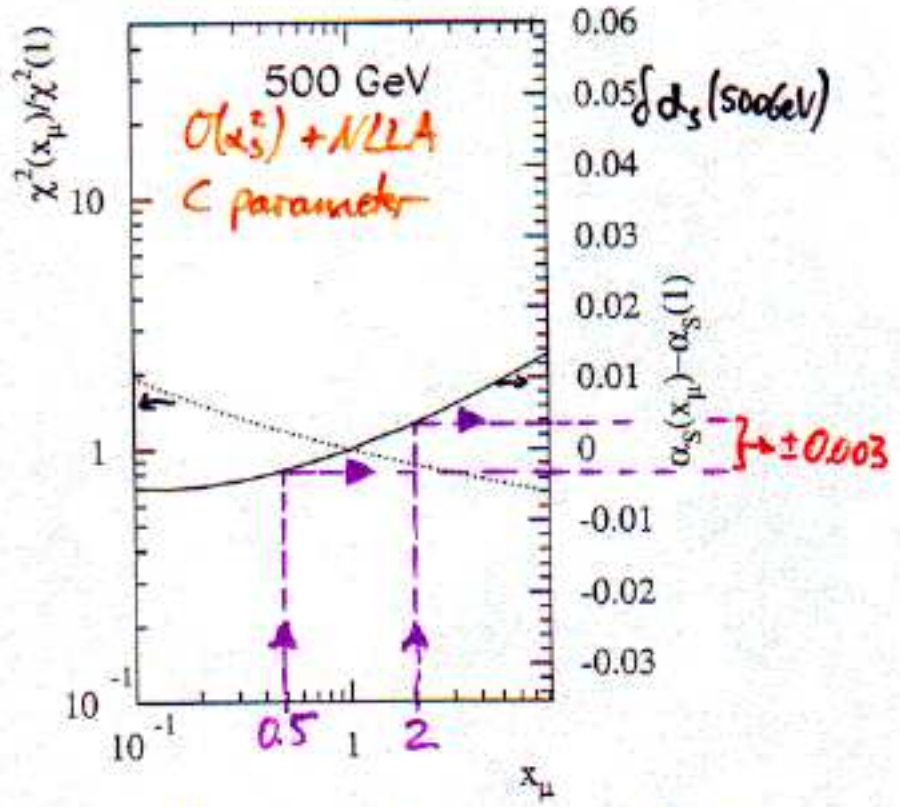
Determination of α_s

- LEP: Improved precision due to resummed calc.



→ reduced scale uncertainty

- 500 GeV



apparently:
smaller uncertainty
but:
no gain in precision
needed:
$O(\alpha_s^3)$ calculation

⇒ choice of renormalization scale
⇝ dominating error contribution

Error estimation

- Assumptions:
  - 10^7 sec @ $\mathcal{L} = 3 \cdot 10^{34}/s \cdot cm^2$ → $\int \mathcal{L} \approx 300/fb$
  - 65% selection efficiency → ~ 500k $e^+e^- \to q\bar{q}$
  - 'perfect detector'
  - fit to PYTHIA distributions

- Error contributions to $\alpha_s(M_Z)$ ($1\text{-}T, M_H, B_T, B_W, C, \chi_{23}$)

⊕ stat.: ≈ 0.0001

⊕ expt'l: ± 0.001 ... 0.006 taken from LEP II (might suffer from low LEP II statistics)

⊕ hadr.: ±0.0006 ... 0.0015 Q_0 dominates

[HERWIG +0.017 ... +0.025 tune?]

ARIADNE −0.004 ... +0.001

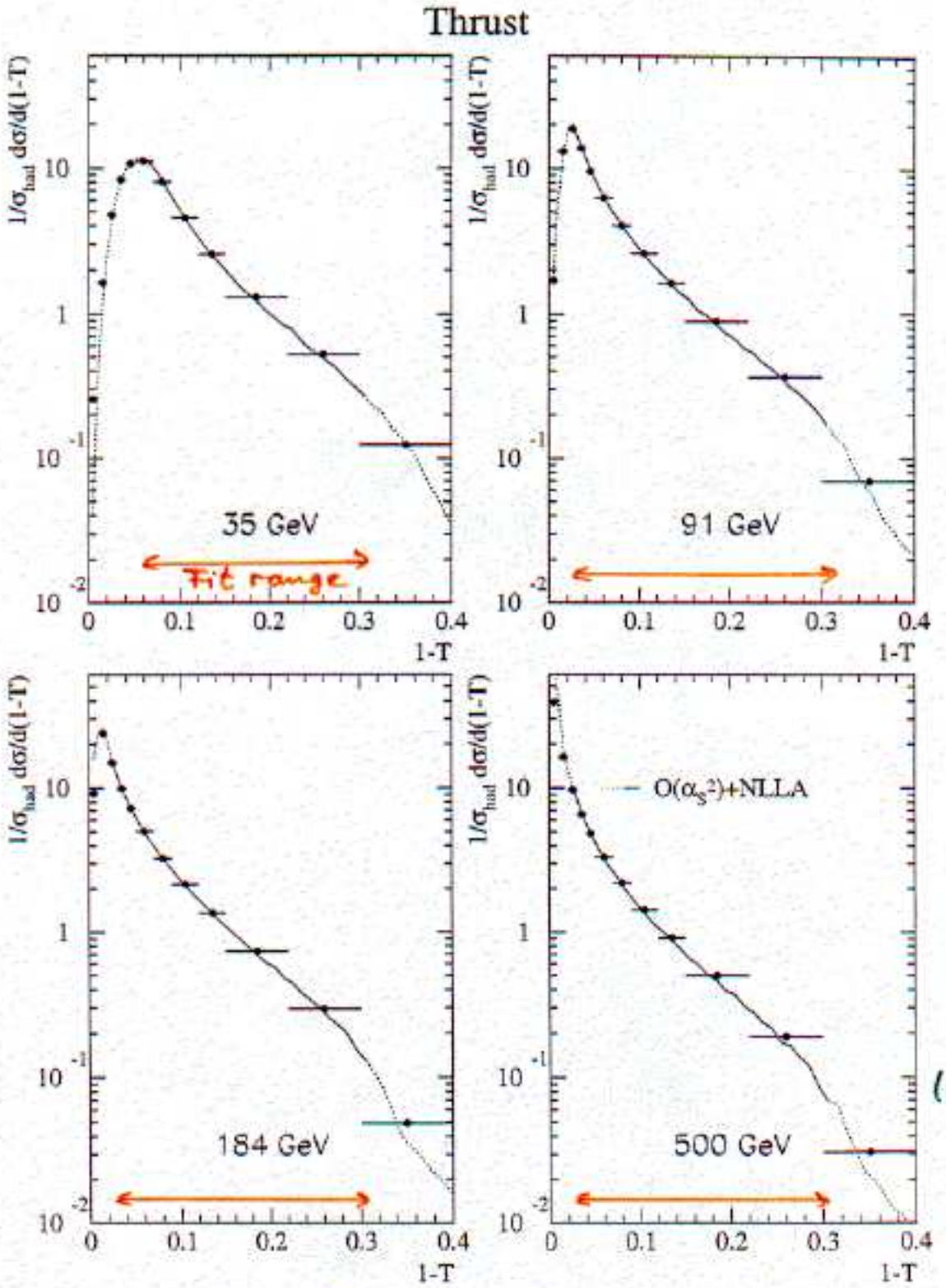
⊕ ren. scale x_{μ^2} α_s^2 ± 0.001 ... 0.004

⇒ total $\delta\alpha_s(M_Z) \approx 0.004$ (cp. 0.006 @ LEP using event shapes)

$\hat{=}$ $\delta\alpha_s(500\,GeV) = 0.0025$

Note: Gain in precision by $O(\alpha_s^3)$ calc. only!

α_s Fits to Event shapes

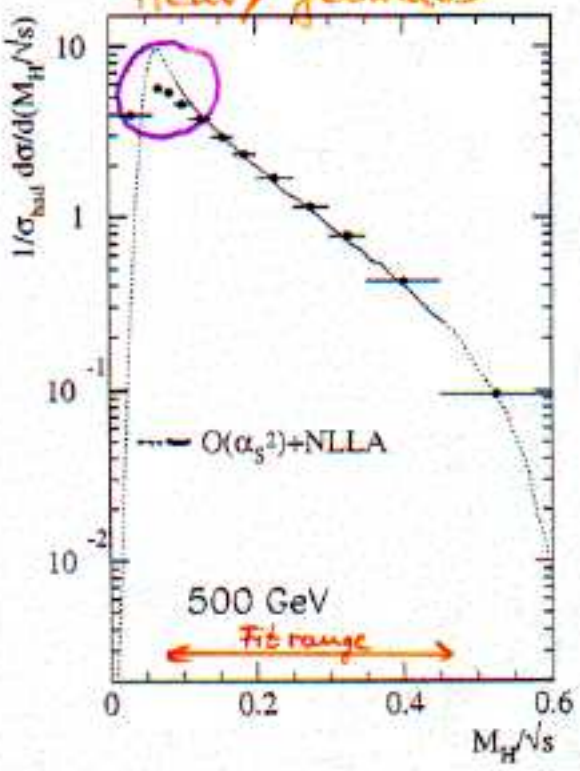


(whiggle due to technical problem)

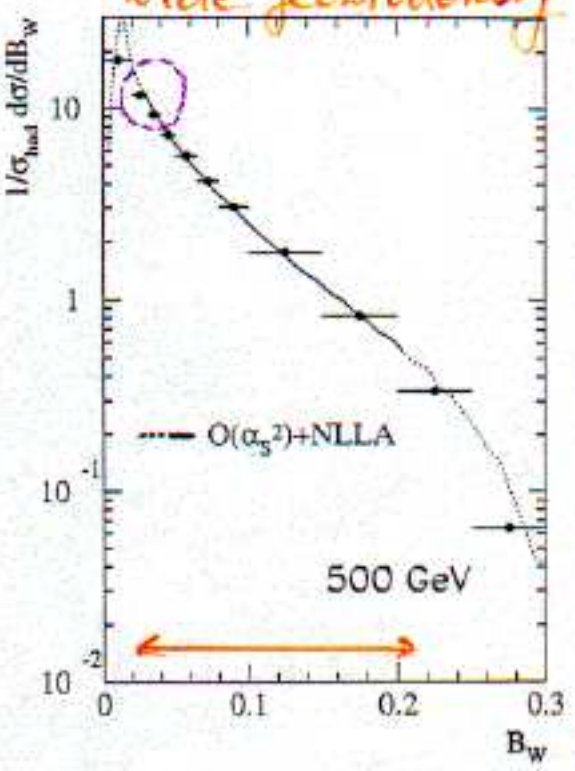
⇒ adequate fit over large energy range

α_s Fits to Event shapes

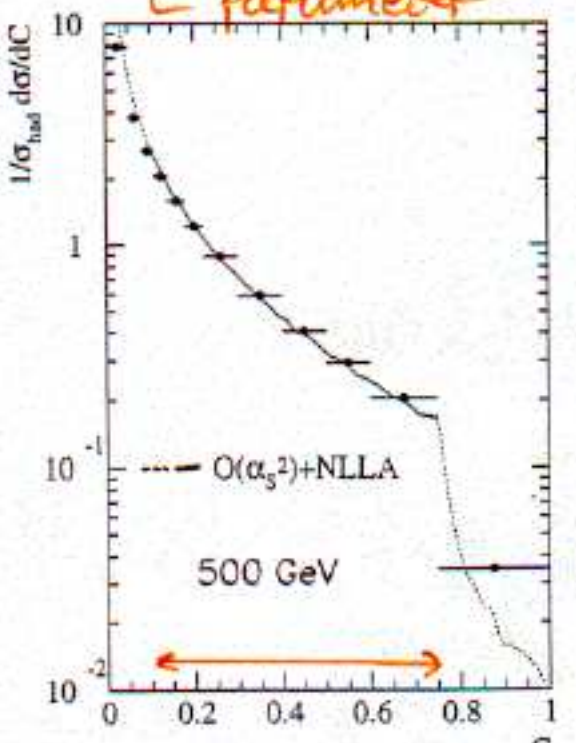
Heavy Jetmass



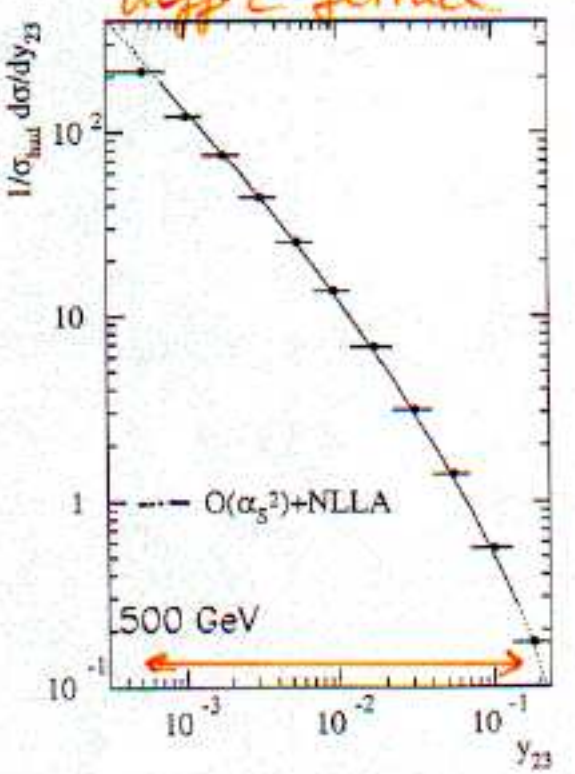
Wide Jetbroadening



C parameter



diff 2-Jetrate



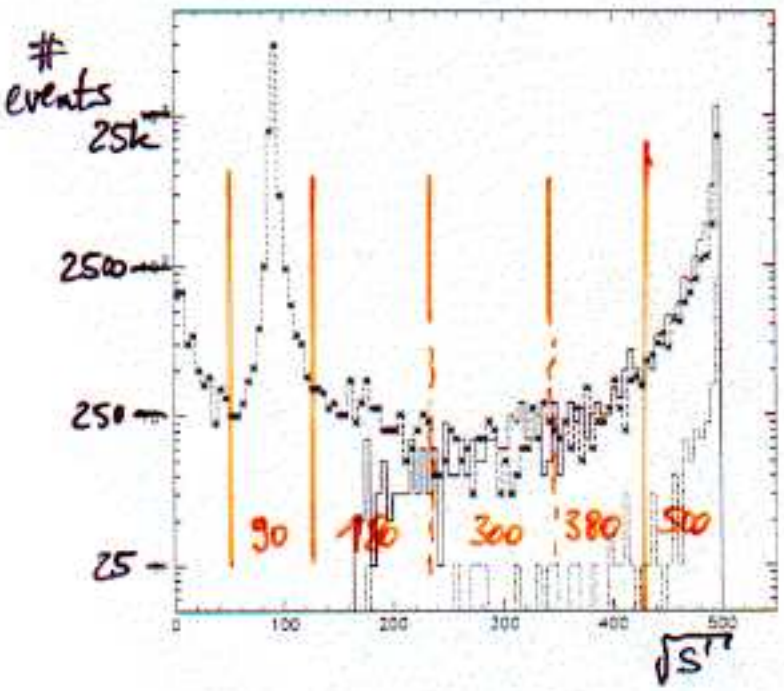
⇒ adequate fits but experience problems at small values

Further QCD Options

- Determine α_s (91 ... 500 GeV)

  using ISR + BS + FSR

  ⇝ running of α_s from a single experiment



⇝ requires very efficient WW rejection

+ more statistics

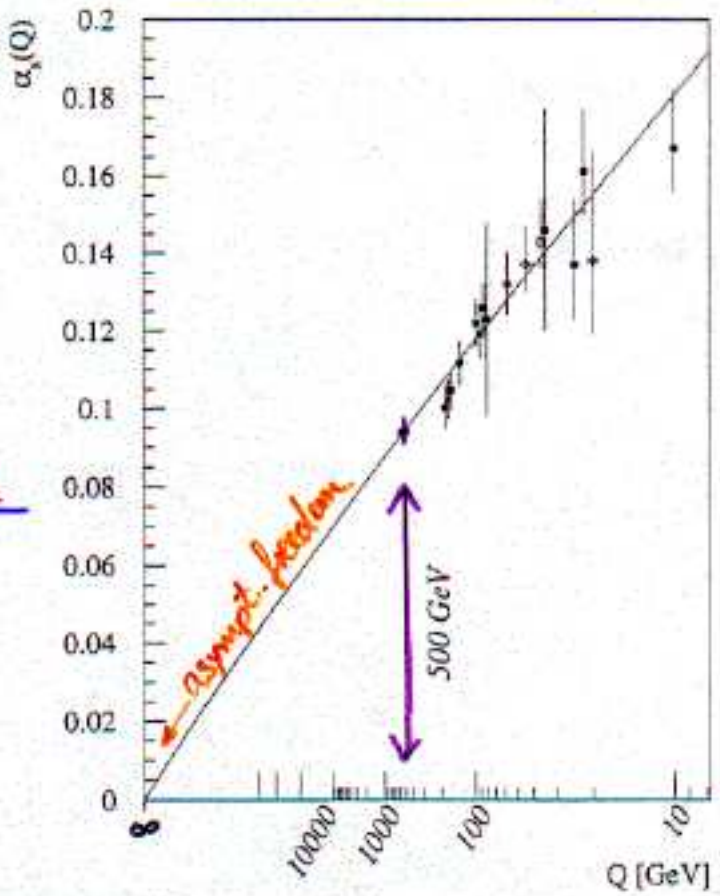
- Mass effect for b and t quarks

...

Conclusion

- QCD studies @ MLC : significant test of QCD
  - ⊕ diminished hadronization effects
  - ⊕ not statistics limited
  - ⊕ ISR + BS + FSR : window to lower energies
  - ⊖ fight WW, ZZ, $t\bar{t}$ background
  - ⊖ ISR + BS : dominating cross-section
  - ⊖ systematics (theory) limited
- Precision on α_s after ~ 1yr at high lumi

$\delta\alpha_s(500\,GeV) \simeq 0.0025$

- Another big step towards

Asymptotic Freedom