QCD AT A HIGH-ENERGY e^+e^- LINEAR COLLIDER

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On behalf of

The European QCD/$\gamma\gamma$ Working Group

LCWS99: Sitges

April 30 1999

MAIN QCD GOALS AT LINEAR COLLIDER

- **Precise test of QCD at highest energies**

In particular:

- **Precise determination of α_s:**

  Event shape observables

  - studied at PETRA, PEP, TRISTAN, SLC, LEP

  $\sigma_{t\bar{t}}$ at and above threshold

  - completely new domain!

- **Combining $\alpha_s(500)$, $\alpha_s(800)$ . . . with low-energy meas.**

  $\Rightarrow$ map out QCD ren. group trajectory

  $\Rightarrow$ constrain 'GUT scale'

  - limited currently by α_s uncertainty

- **Lower-energy running, *eg.* at Z^0, very attractive:**

  $\Rightarrow$ longer lever-arm in Q^2

  $\Rightarrow$ α_s measurements with common systematics

  - benefit needs to be quantified

RECENT THEORETICAL DEVELOPMENTS

- $\sigma_{t\bar{t}}$ **near threshold** **@ NNLO**

  (Beneke, Hoang, Teubner *et al.*)

  important for $M_t + \alpha_s$ **determination**

- $\mathbf{e^+e^-} \to$ **6 jets** **@ LO** **(Moretti)**

  background to $t\bar{t}$, $Z^0(H^0 \to W^+W^-)$ ...

- $\mathbf{e^+e^-} \to X b\bar{b}\, W^+W^-$, $X = H^0, Z^0, g$ **@ LO (Moretti)**

  backgrounds to $t\bar{t}\, H^0$

- $\mathbf{e^+e^-} \to q\overline{q}g$, $g \to b\bar{b}$ **@ NNL** **(Miller, Seymour)**

  background to $Z^0\, H^0$, $t\bar{t}$ ...

- b**-quark forward-backward asymmetry** **@ 2 loops**

  (Seymour)

- $\mathbf{e^+e^-} \to t\bar{t}g$ **@ NLO** **(Brandenburg)**

LINEAR COLLIDER α_s MEASUREMENT

1. Event Shape Observables

- Studied at Snowmass 96 (Burrows *et al.*, SLAC-PUB-7371)
- ECFA/DESY Workshop: O. Biebel
- Statistics:

  $\geq$ 50k $q\bar{q}$ events $\Rightarrow$ $\Delta\alpha_s \leq 0.001$

- Detector systematics:

  currently $\Delta\alpha_s \sim 0.002$

  Excellent tracking + calorimetry $\Rightarrow$ $\Delta\alpha_s \sim 0.001$

- Hadronisation uncertainties $\sim 1/Q$

  At $Q = 500$ GeV $\Rightarrow$ $\Delta\alpha_s < 0.001$

- Limiting precision:

  Higher-order pQCD contributions: $\Delta\alpha_s \sim 0.006$

  $\Rightarrow$ NNLO calculation needed

LINEAR COLLIDER α_s MEASUREMENT

2. Top Quark Observables

- $\sigma_{t\bar{t}}$ **near threshold (Peralta)**

  new NNLO calculations $\Rightarrow$

  reduced correlation $\alpha_s \leftrightarrow M_t$ $\Delta\alpha_s = 0.002$ **(?)**

  PRELIMINARY, NO THEORY UNCERTAINTY

- $\sigma_{t\bar{t}}$ **above threshold (Bernreuther)**

  PRELIMINARY study of NLO calculations

  $\sqrt{s} = 400$ **GeV:** $\Delta\alpha_s = 0.005$

  (theory limiting)

  $\sqrt{s} \geq 500$ **GeV:** $\Delta\alpha_s = 0.012$

  (exp. syst. limiting)

- $e^+e^- \rightarrow t\bar{t}\,g$ **(Brandenburg)**

LINEAR COLLIDER α_s MEASUREMENT

3. Lower-energy running offers new possibilities:

- **Z^0 decay widths: $\Gamma_Z^{had}/\Gamma_Z^{lept}$**

  calculated at NNLO

  current precision, 16M Z^0 at LEP: $\Delta\alpha_s = 0.003$

  100M Z^0 $\Rightarrow$ $\Delta\alpha_s = 0.001$ (?)

  BEWARE: event selection (Mönig *et al.*),

  theory uncertainties?

- **τ decay widths: $\Gamma_\tau^{had}/\Gamma_\tau^{lept}$**

  calculated at NNLO

  current exp. precision, LEP+CLEO: $\Delta\alpha_s = 0.001$

  theoretical uncertainties $\Rightarrow$ $\Delta\alpha_s = 0.003$ (?)

OTHER IMPORTANT TOPICS

- **Limits on new coloured objects (*eg.* gluino)**

  above threshold $\Rightarrow$ modify $\alpha_s(Q)$

- **Limits on anomalous strong top-quark couplings**

  $\Rightarrow$ modify gluon energy in $t\bar{t}g$ events

- **Measurement of Γ_t using $t\bar{t}g$ events**

  $\Rightarrow$ Γ_t affects degree of soft-gluon coherence

- **Polarisation-based asymmetries in $q\bar{q}g$ events:**

  $\vec{P}_e \cdot \vec{k_{q1}} \times \vec{k_{q2}}$ **(CP+ T−)**

  $\vec{P}_e \cdot \vec{k_q} \times \vec{k_{\overline{q}}}$ **(CP− T−)**

  $\Rightarrow$ Search for anomalous final-state interactions

- **Particle multiplicity in heavy- vs. light-quark jets**

  $\Rightarrow$ add long lever-arm to current tests

All warrant updated simulations

- **Colour reconnection and Bose-Einstein correls.**

EVENT SELECTION

- **Multijet $q\bar{q}$ events bgd. to $t\bar{t}$, W^+W^-, $Z^0\ H^0$, ...**

- **Separation of $q\bar{q}$ /$t\bar{t}$ /W^+W^-/$Z^0\ Z^0$ /... not trivial**

- **For QCD studies:** $q\bar{q}$ **/ the rest**

  $t\bar{t}$ **/ the rest**

- **Hawaii 93: kinematic cuts $\Rightarrow$ 83% pure $q\bar{q}$ sample,**

  but with large bias

- **Snowmass 96: eliminate W^+W^- events with right-handed e^- beam**

  $P_e = +90\%$ $\Rightarrow$ **87% pure $q\bar{q}$ sample**

  with zero bias

- **To do:**

  effect of highly efficient b-tag on $q\bar{q}$ /$t\bar{t}$ separation

SUMMARY

- 'QCD events' $\Rightarrow$ background to new physics

  ultimately need to measure and understand them

- Good progress: several new pQCD calculations

- Key QCD meas. exploit high energy + lumi:

  Precise α_s and $\alpha_s(Q^2)$

  $\Rightarrow$ Test QCD at highest Q^2

  $\Rightarrow$ Constrain QCD RGE trajectory + GUT scale

- Low energy running attractive

- Strong overlap of interest with Top Group

- Several important measurements deserve modern simulations