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

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Representing

The QCD/$\gamma\gamma$ Working Group

Convenors: A. Brandenburg, PNB,

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Thanks to all the participants!

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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:**

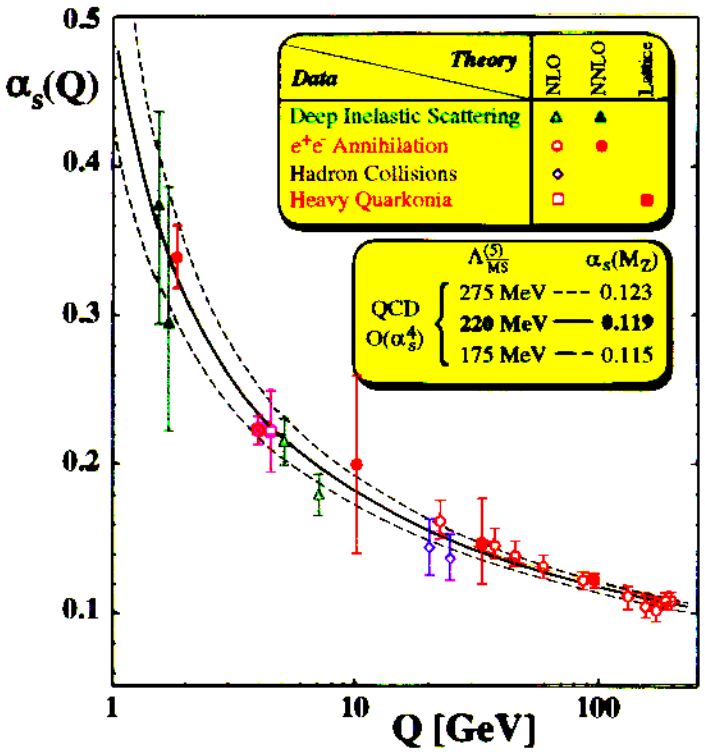
  $\Rightarrow$ longer lever-arm in Q^2

  $\Rightarrow$ α_s measurements with common systematics

  - benefit needs to be quantified

Bethke
Sept. 1998

$\alpha_s(M_Z) = 0.119 \pm 0.004$



RECENT THEORETICAL DEVELOPMENTS

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

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

  important for M_t + α_s determination

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

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

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

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

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

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

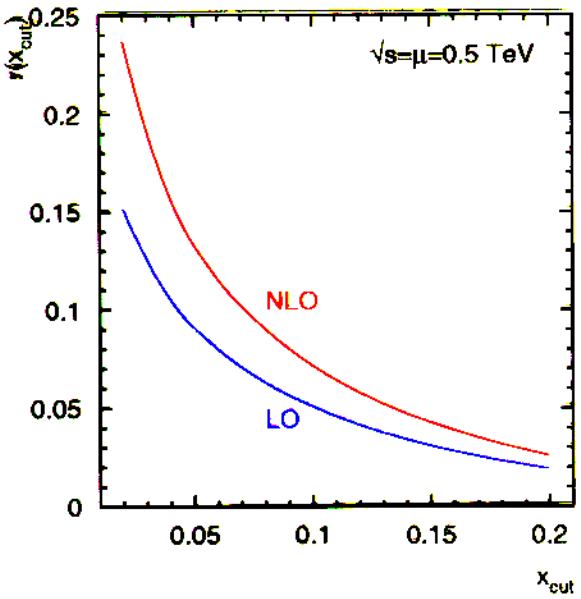
- ***b*-quark forward-backward asymmetry @ 2 loops**

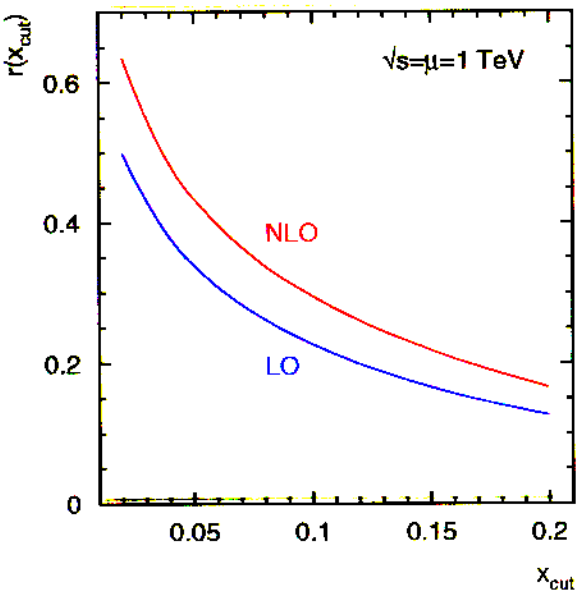
  (Seymour)

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

A. Brandenburg

Results: Fraction $r(x_{cut})$

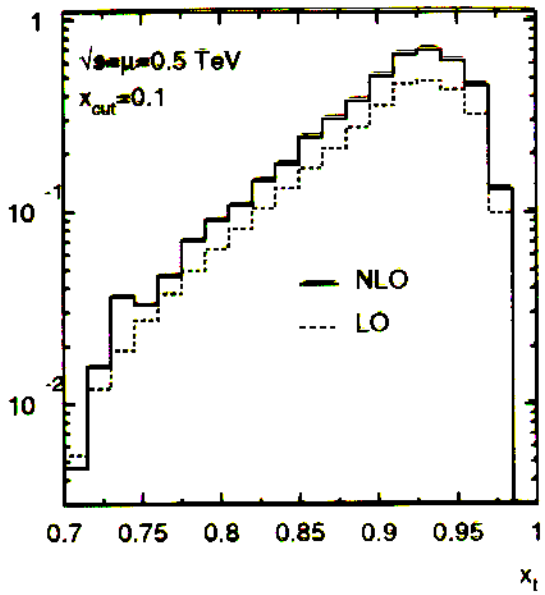




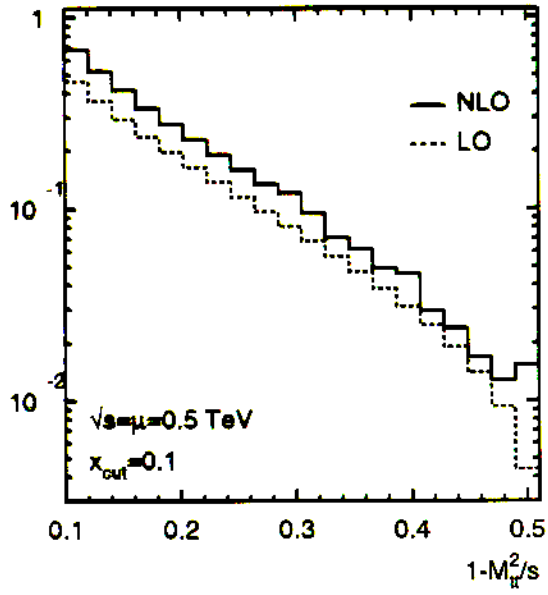
Results: Distributions

Top quark (scaled) energy $x_t = 2E_t/\sqrt{s}$ and (scaled) "gluon energy" $x_g = 1 - M^2_{t\bar{t}}/s$ distributions

$\frac{1}{\sigma_{tot}} \frac{d\sigma(x_{cut}=0.1)}{dx_t}$



$\frac{1}{\sigma_{tot}} \frac{d\sigma(x_{cut}=0.1)}{d(1-M^2_{t\bar{t}}/s)}$



LINEAR COLLIDER α_s MEASUREMENT

1. Event Shape Observables

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

  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

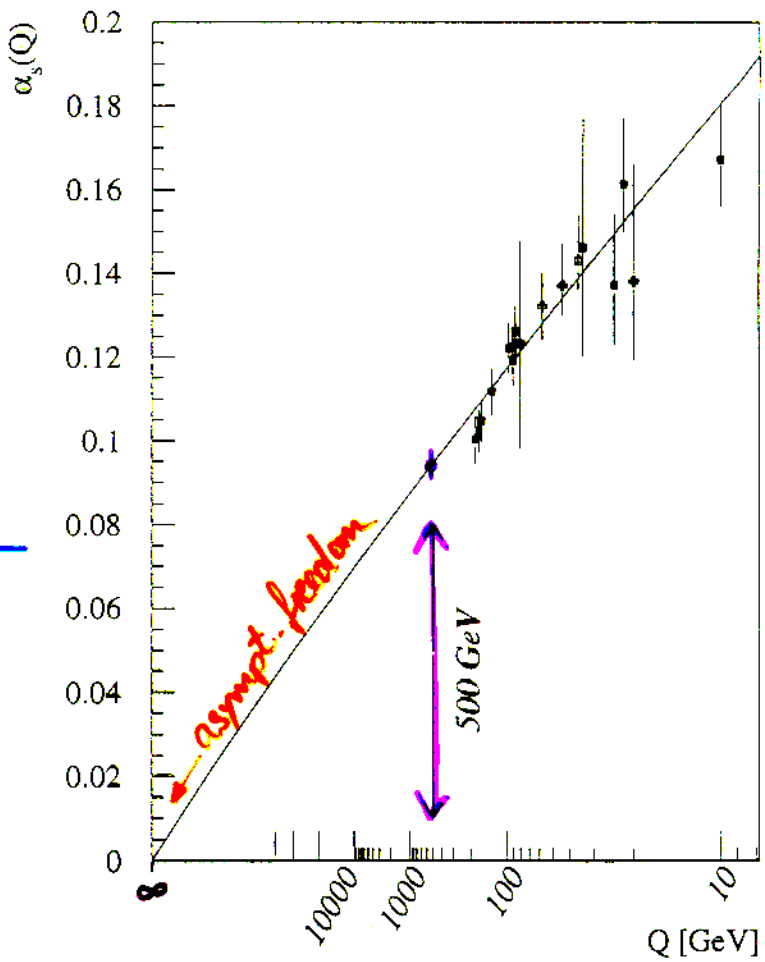
Conclusion

- QCD studies @ MLC : significant test of QCD
  - ⊕ diminished hadronization effects
  - ⊕ net 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



O. Biebel

LINEAR COLLIDER α_s MEASUREMENT

2. Top Quark Observables

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

  new NNLO calculations $\Rightarrow$ **(Peralta)**

  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)

- **$e^+e^- \to t\bar{t}\,g$ (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 $\Rightarrow$ $\Delta\alpha_s = 0.001$ (?)

- **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−)**

  $\vec{P}_e \cdot \vec{k_q} \times \vec{k_{\bar{q}}}$ **(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

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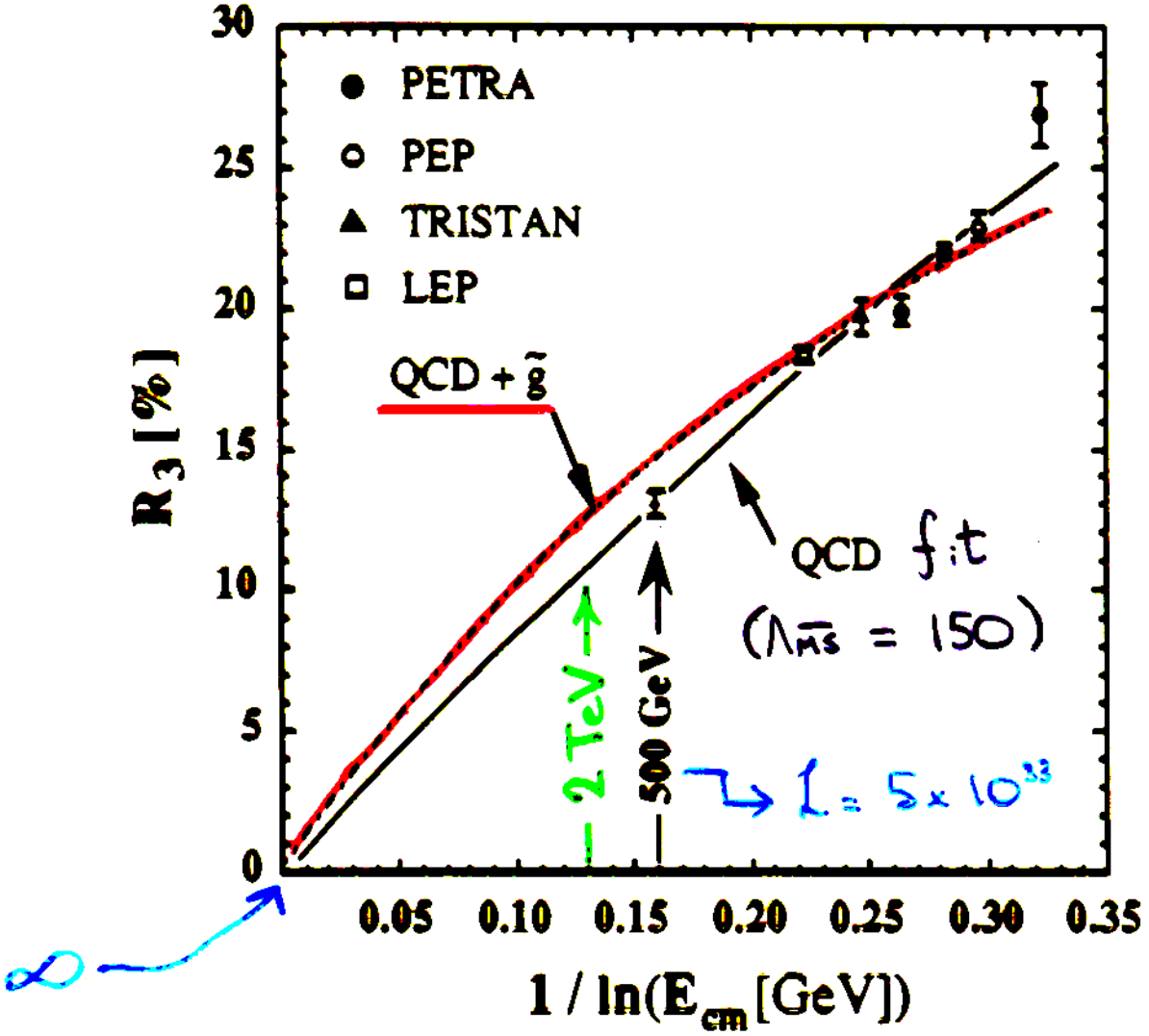


Fig. 4. Three-jet event production rates as a function of $1/\ln(E_{cm})$, measured with the JADE jet finde for a constant jet resolution of $y_{cut} = 0.08$.

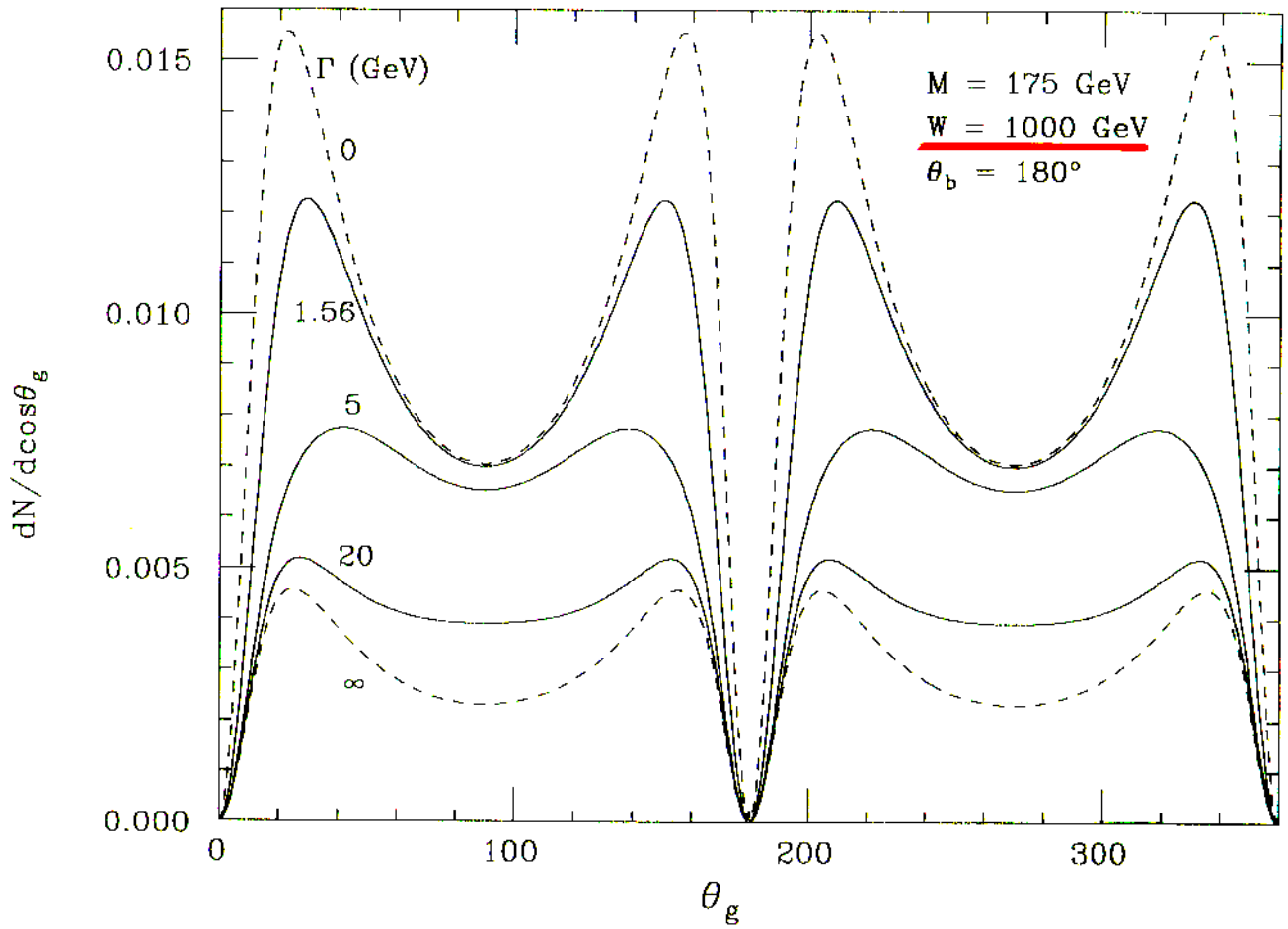
Light gluinos: $N_f \longrightarrow N_f + 3N_{\tilde{g}}$

Precision (probably) limited by LOWER ENERGY DATA!

L. Orr et al.

Update: $m_t = 175$ GeV

$\theta_b = 180^\circ$



Emission Δ of 5 GeV gluons

Realistic simulation needed!

=> $\Delta\Gamma_t$

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' ⇒ 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 $\alpha_s(Q^2)$

  ⇒ Test QCD at highest Q^2

  ⇒ Constrain QCD RGE trajectory + GUT scale

- **Low energy running attractive**

- **Strong overlap of interest with Top Group**

- **Several important measurements deserve modern simulations**