

News on top quark physics and QCD

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Montpellier, 16.11.2003

Contributions:

- **P. Skands:** A new model for multiple interactions
- **S. Moretti:** Higher-order weak contributions to hadronic final states
- **A. Pineda:** Resummation methods at the $t\bar{t}$ threshold
- **A. Hoang:** Three-Loop RGE for the top threshold production current
- **S. Boogert:** Top mass measurements and luminosity spectra

Top quark talks in other groups:

A. Gay: Simulation of $e^+e^- \rightarrow t\bar{t}H$ final results (Higgs)

M. Roth, F. Boudjema: EW radiative corrections to $e^+e^- \rightarrow t\bar{t}H$ (LoopVerein)

Top quark physics

$t\bar{t}$ production at threshold:

$$v \sim \alpha_s \sim 0.1 \ll 1$$

$\Rightarrow t\bar{t}$ system is non-relativistic, provides a testing ground for (NR)QCD.

Goals:

- a determination of m_t (unambiguously defined) with unmatched precision
 $\Delta m_t \approx 100 \text{ MeV}$
- a precise measurement of the top width Γ_t
- a competitive measurement of α_s
- a constraint on the top Yukawa coupling λ_t

$t\bar{t}$ threshold scan

Recall: Recent $t\bar{t}$ threshold scan simulation

(M. Martinez, R. Miquel [hep-ph/0207315]):

Three-parameter fit (m_t , α_s , Γ_t): (only exp. errors)

$$\Delta m_t^{1S} = 19 \text{ MeV}, \quad \Delta \alpha_s = 0.0012, \quad \Delta \Gamma_t = 32 \text{ MeV}.$$

Constraint on λ_t rather weak.

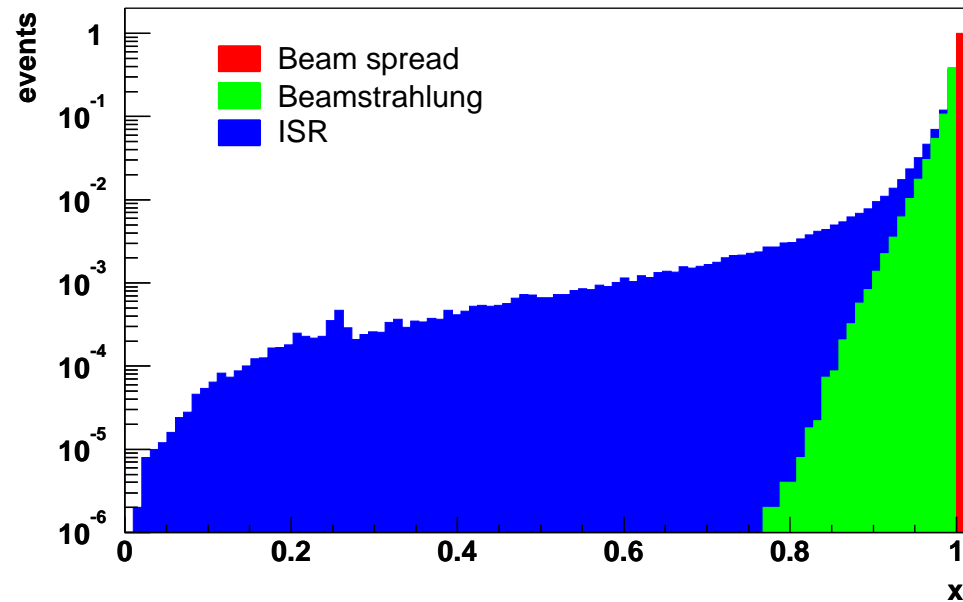
Input of that study:

- $\int \mathcal{L} = 300 \text{ fb}^{-1}$, equally distributed in 9+1 scan points
- **Neglect imperfect reconstruction of luminosity spectrum**
- **α_s and Γ_t require theoretical accuracy of threshold cross section**
 $\sim \Delta\sigma/\sigma = \pm 3\%$

Luminosity spectrum (S. Boogert)

Sources of energy loss:

- Accelerator beam spread ($\sim 0.1\%$)
- Beamstrahlung ($\sim 0.7\%$ at 350 GeV)
- Initial state radiation (calculable in QED)

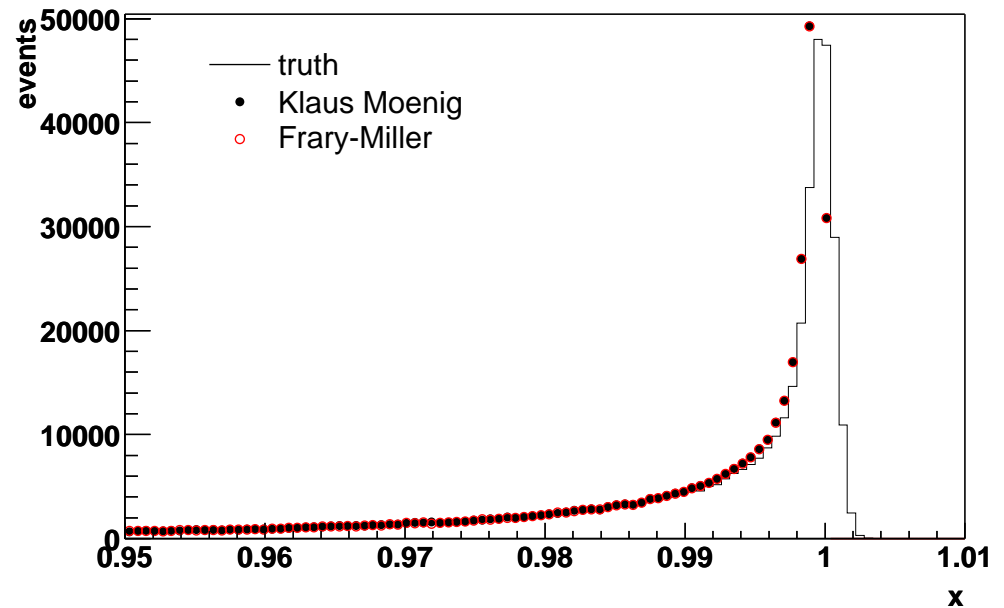
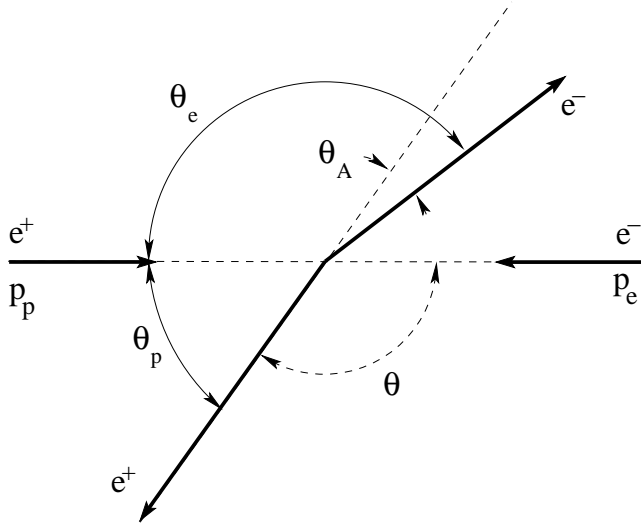


$$x = \sqrt{s'}/\sqrt{s}$$

Reconstruction of luminosity spectrum (S. Boogert)

Approximate reconstruction method: **Bhabha acollinearity**

$$x = 1 - \theta_A/2 \sin \theta \text{ (Frery-Miller); } x = \sqrt{\cot \theta_e \cot \theta_p} \text{ (K. Moenig)}$$



Impact on top quark measurement (S. Boogert)

Compare “fake” threshold data with
Theoretical cross section \otimes
measured luminosity spectrum

Preliminary results:

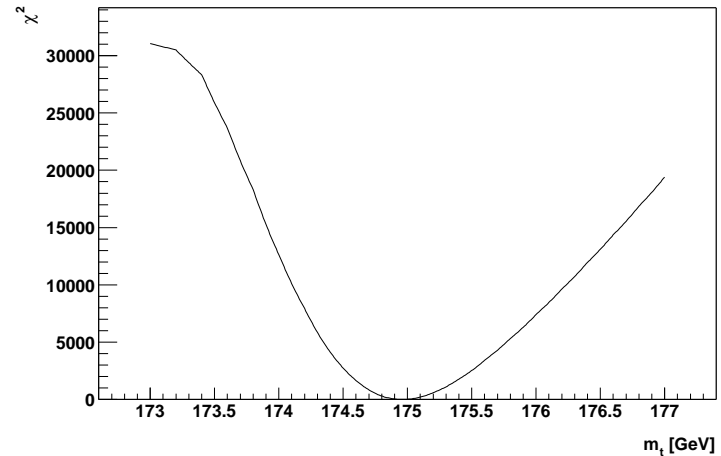
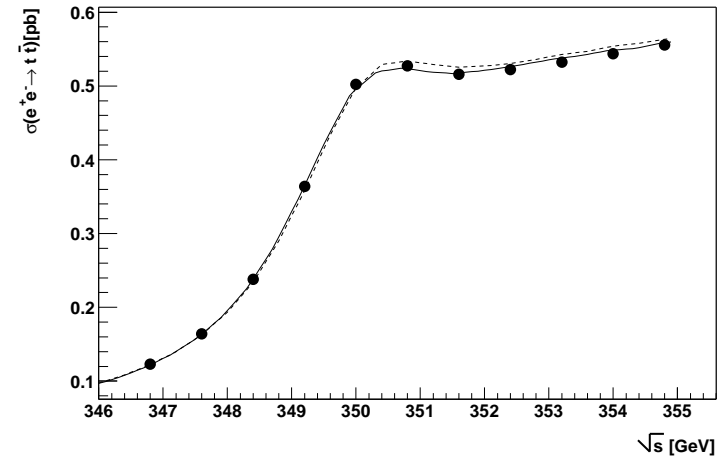
$$m_t = 174.96 \pm 0.02 \text{ (Shift of } -39 \text{ MeV)}$$

$$\alpha_s = 0.1169 \pm 0.0005 \text{ (Shift of } -0.003)$$

$$\Gamma_t = 1.4097 \pm 0.0032$$

Open questions and problems

- asymmetric collisions (beam effects):
how do boosts of c.m. frame affect distributions?
- interpolation limits present analysis;
Toppik too slow!



Threshold cross section: Theory

Recall:

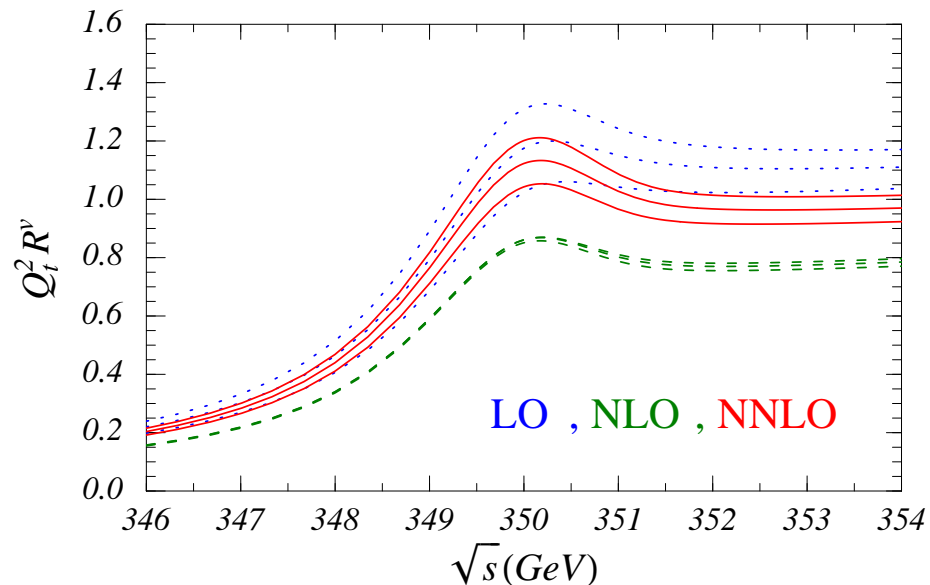
- $(\alpha_s/v)^n$ singularities \Rightarrow breakdown of expansion in number of loops
- $\Gamma_t \approx 1.4 \text{ GeV} \Rightarrow$ nonperturbative effects suppressed

Traditional approach: “Fixed-order”

$$\sigma_{t\bar{t}} \sim v \sum_n \left(\frac{\alpha_s}{v} \right)^n \left[1 \text{ (LO)}, \{v, \alpha_s\} \text{ (NLO)}, \{v^2, \alpha_s v, \alpha_s^2\} \text{ (NNLO)}, \dots \right]$$

Teubner, Hoang, Melnikov, Yelkhovsky, Beneke, Signer, Smirnov, Sumino, Nagano, Ota, Yakovlev, Manohar, Stewart

Threshold cross section at NNLO



Large uncertainties in normalization, $(\Delta\sigma/\sigma)^{\text{theory}} \geq 20\%$

Does **not** affect top mass measurement (sensitive to shape)

Large logarithms, $\ln\left(\frac{m_t^2}{E^2}\right) \approx 8$, $\ln\left(\frac{m_t^2}{p^2}\right) \approx \ln\left(\frac{p^2}{E^2}\right) \approx 3.8$

Renormalization Group Improved Approach

Aim: reduce uncertainty in normalization ($\alpha_s, \Gamma_t, \lambda_t$)

Summation of $(\alpha_s \ln v)^n$ terms:

$$\sigma_{t\bar{t}} \sim v \sum_{n,m} \left(\frac{\alpha_s}{v}\right)^n (\alpha_s \ln v)^m \left[1 \text{ (LL)}, \{v, \alpha_s\} \text{ (NLL)}, \{v^2, \alpha_s v, \alpha_s^2\} \text{ (NNLL)}, \dots \right]$$

Uses non-relativistic effective theories of **QCD**

$$\sigma_{t\bar{t}} \propto c(v)^2 \text{Im} G(0, 0, \sqrt{s}) + \dots$$

$$G(0, 0, \sqrt{s}) \sim \int d^4x e^{iq \cdot x} \langle 0 | T \mathbf{J}(x) \mathbf{J}^\dagger(0) | 0 \rangle$$

- Running couplings of potentials in **G** (NNLL completed)
- Wilson coefficient of current **J** only at NLL

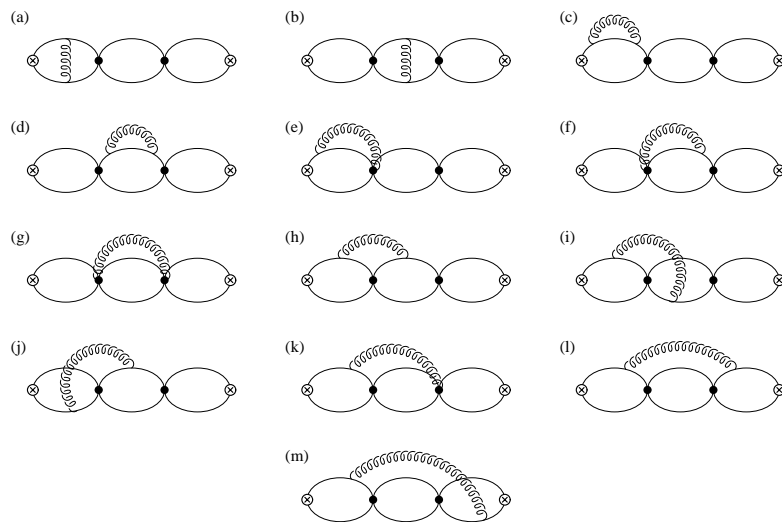
Manohar, Stewart, Hoang; Pineda, Soto, Brambilla, Vairo

Renormalization Group Improved Approach

Running of Wilson coefficient of current \mathbf{J} at NNLL:

Partial result: (Hoang)

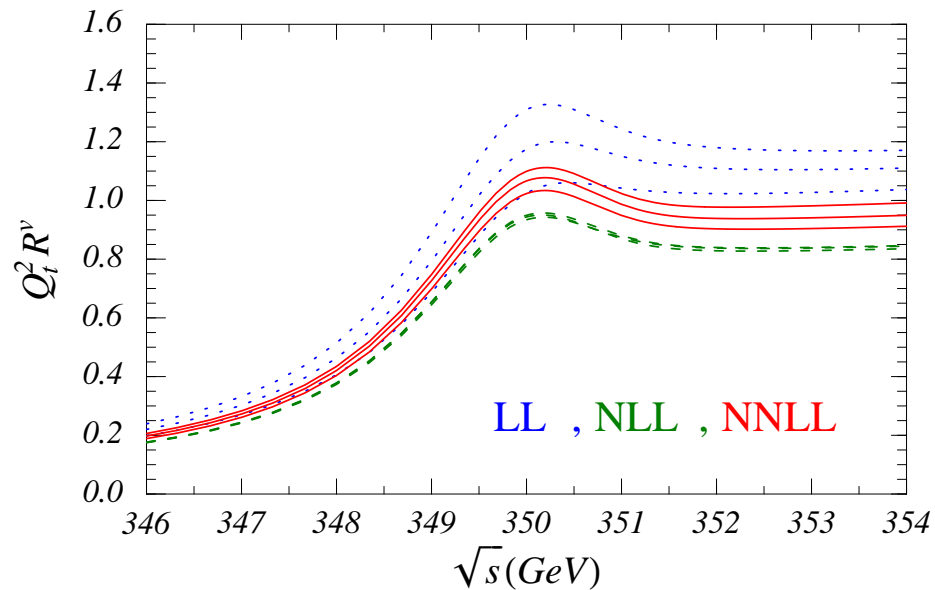
“Non-mixing” contributions to NNLL anomalous dimension



Corrections **large**

Mixing contributions (=higher order running of coefficients in NLL RGE) not completed yet

Threshold cross section at NNLL (A. Hoang)



⇒ Present theoretical accuracy:

$\Delta\sigma/\sigma = \pm 6\%$ (previously $\pm 3\%$).

⇒ **Full NNLL needed**

Threshold cross section at NNLL

$$\sigma_{t\bar{t}} \sim v \sum_n \left(\frac{\alpha_s}{v} \right)^n \left[1 + A\alpha_s^2 \ln v + B\alpha_s^2 \ln^2 v \right. \\ \left. + A'\alpha_s^3 \ln v + B'\alpha_s^4 \ln^2 v + \dots \right]$$

← NLL

← NNLL

A' also computed by [Kniehl, Penin, Smirnov, Steinhauser](#)

Open issues:

- completion of NNLL calculation
- electroweak effects, SM, SUSY (Higgs)
- systematic study of distributions, interconnection, “theory” for unstable particles required

QCD

Recall:

Current accuracy on $\alpha_s(M_Z) \sim 0.003$. Aim:

$$\Delta\alpha_s(M_Z) \lesssim 0.001$$

Current error on $\alpha_s(M_Z)$ dominated by **theoretical uncertainties**.

⇒ Need **2-loop corrections** to $e^+e^- \rightarrow 3$ jets.

Extremely **challenging** calculation, but will be finished in the near future.

Will that be enough?

Note: $\alpha_s^2 \sim \alpha_{EW}$

⇒ 1-loop electroweak \sim 2-loop QCD

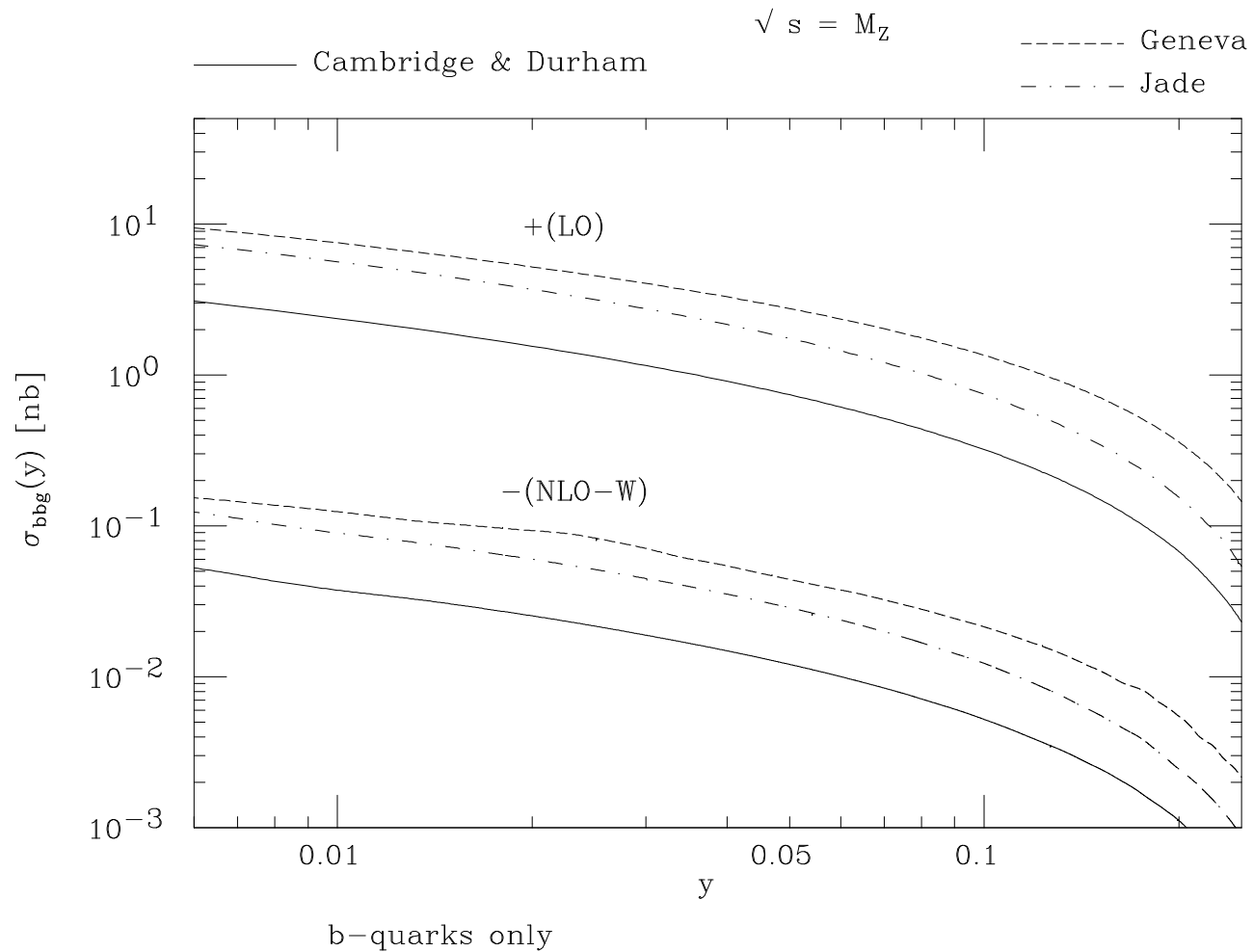
Moreover, EW corrections $\sim \alpha_{EW} \ln^2(M_W/\sqrt{s})$

⇒ At high energies, EW corrections dominate.

Factorisable EW corrections recently computed by **Maina, Moretti, Ross**.

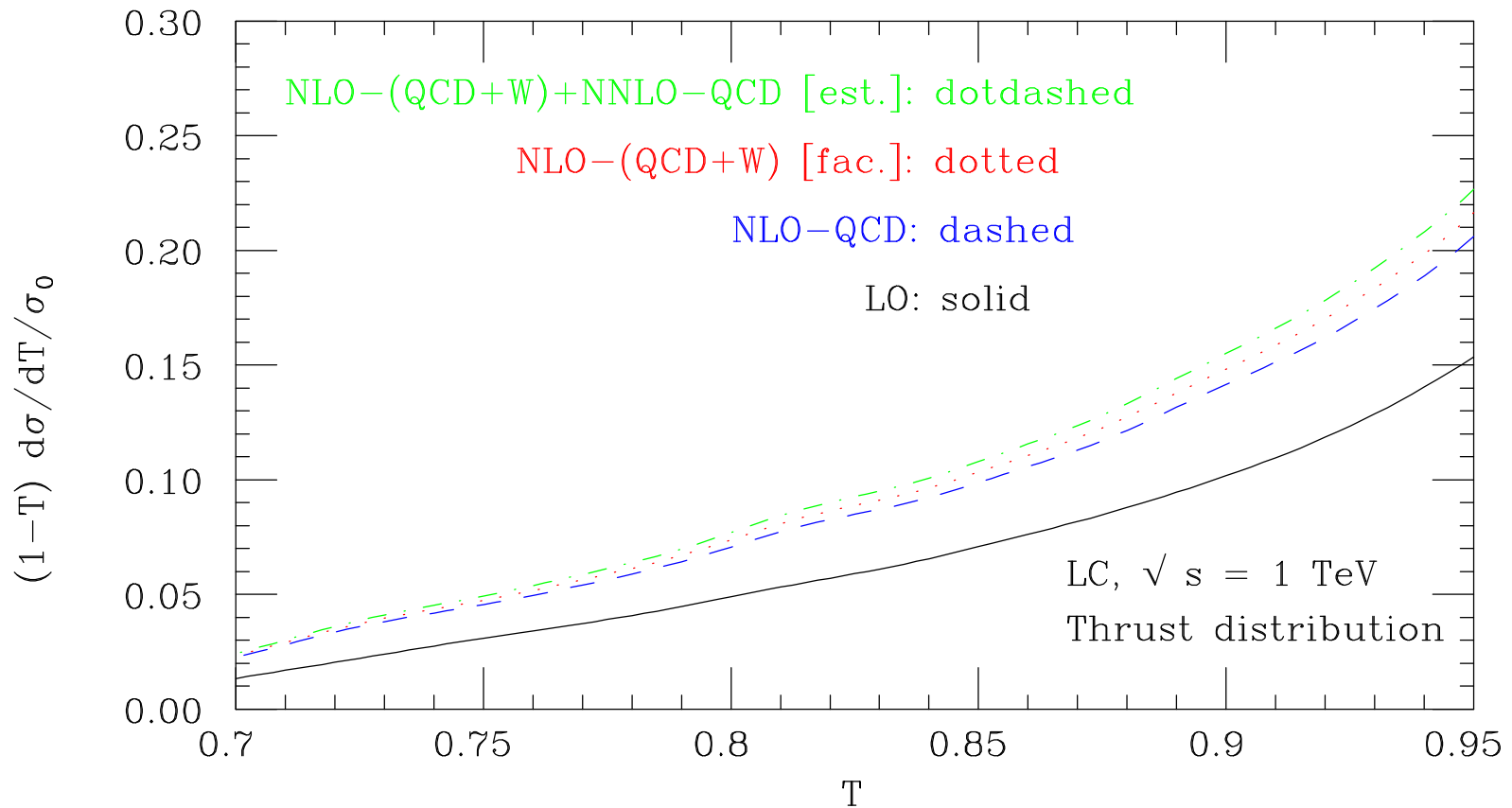
Electroweak corrections to $e^+e^- \rightarrow 3$ jets

S. Moretti



Electroweak corrections to $e^+e^- \rightarrow 3$ jets: Thrust

S. Moretti



Multiparticle interactions

P. Skands, T. Sjöstrand

- At an LC, $\gamma\gamma$ collisions will probe hadronic substructure of photon and present backgrounds for other processes
- multiple interactions of partons in γ are possible
- **Question:** What are the PDFs for a proton or γ with 1 valence quark, 2 sea quarks and 5 gluons kicked out?
- Define probability $f_{i_1, \dots, i_n}(x_1, \dots, x_n, Q_1, \dots, Q_n)$ to find flavours i_1, \dots, i_n with momenta x_1, \dots, x_n in hadron/ γ probed at scales Q_1, \dots, Q_n ,
- we know the case $n = 1$
- Model f by imposing a set of physically well motivated constraints and fix parameters by comparing to an enormous amount of data from DIS and hadron-hadron collisions.
- The new model is available in **PYTHIA 6.3**

Conclusions

- **$t\bar{t}$ threshold scan**: first steps taken to implement “realistic” luminosity spectrum measurement.
- **Theory**: New 3-loop computation of anomalous dimension of $t\bar{t}$ current. Updated theoretical uncertainty $\Delta\sigma/\sigma = \pm 6\%$. Full NNLL calculation needed to improve on this.
- **QCD** : 1-loop electroweak corrections to $e^+e^- \rightarrow 3 \text{ jets}$ have to be included together with 2-loop **QCD** corrections at Giga-Z and in particular at high energies to allow for precise measurement of α_s .