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 tbar 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 $e^+e^- \longrightarrow t\bar{t}H$ final results (Higgs)

M. Roth, F. Boudjema: EW radiative corrections to $e^+e^- \longrightarrow t\bar{t}H$ (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 (unambigiously defined) with unmatched precision $\Delta m_t \approx 100$ 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 $(m_t,\ \alpha_s,\ \Gamma_t)$**:** (only exp. errors)

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

Constraint on λ_t rather weak.

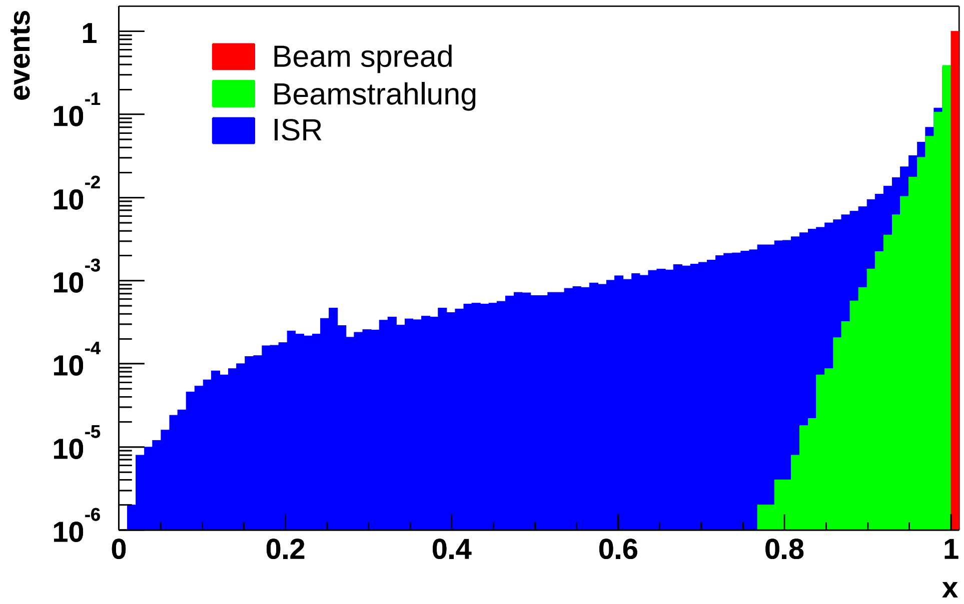
Input of that study:

- $\int \mathcal{L} = 300\ \text{fb}^{-1}$, 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)

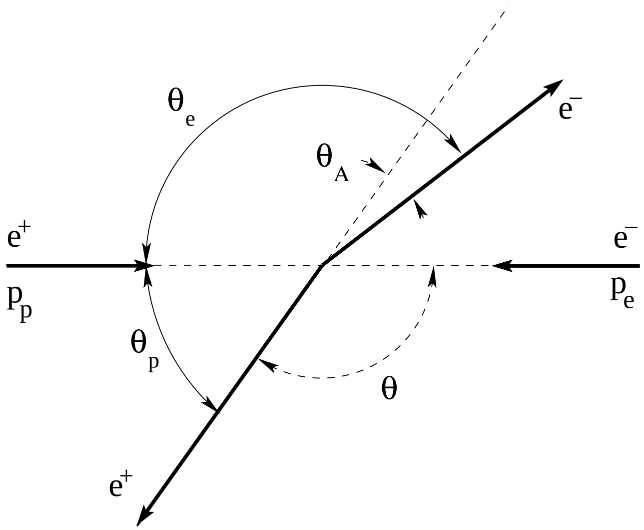


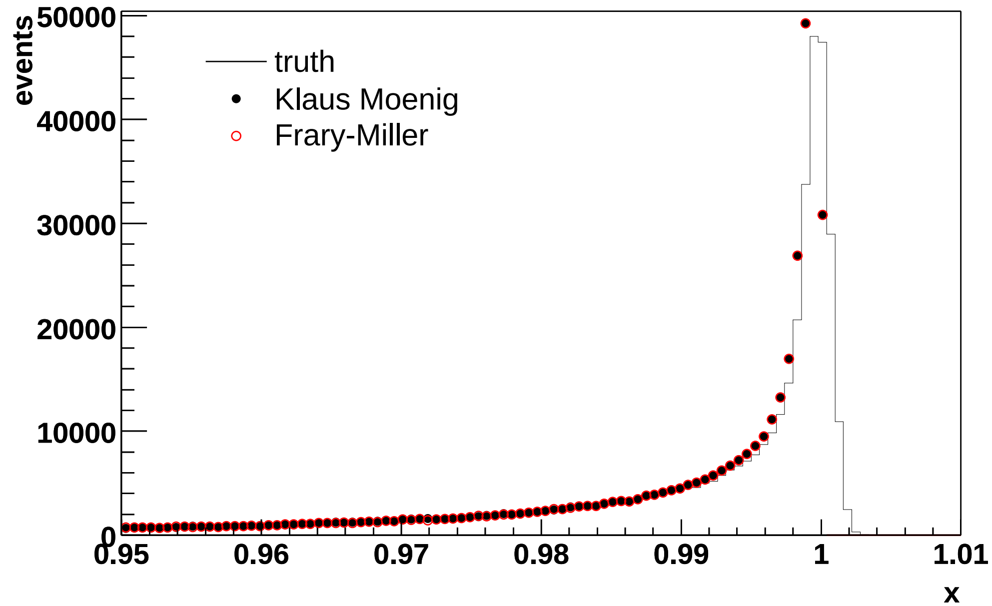
$$x = \sqrt{s'}/\sqrt{s}$$

Reconstruction of luminosity spectrum (S. Boogert)

Approximate reconstruction method: Bhabbha acollinearity

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





Impact on top quark measurement (S. Boogert)

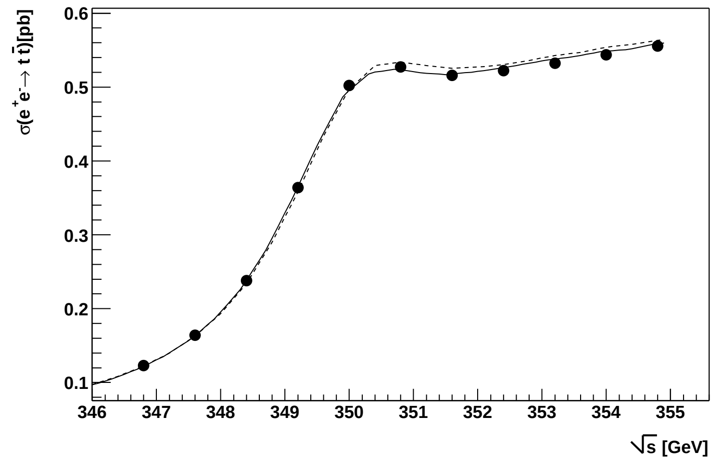
Compare "fake" threshold data with
Theoretical cross section $\otimes$
measured luminosity spectrum

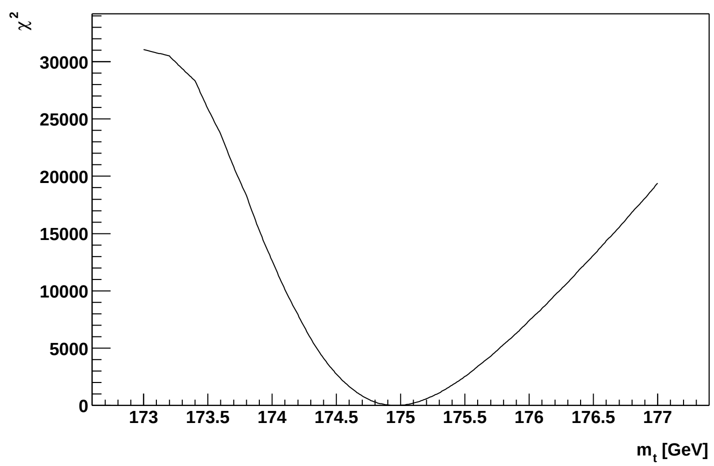
Preliminary results:

$m_t = 174.96 \pm 0.02$ (**Shift** of -39 MeV)

$\alpha_s = 0.1169 \pm 0.0005$ (**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:

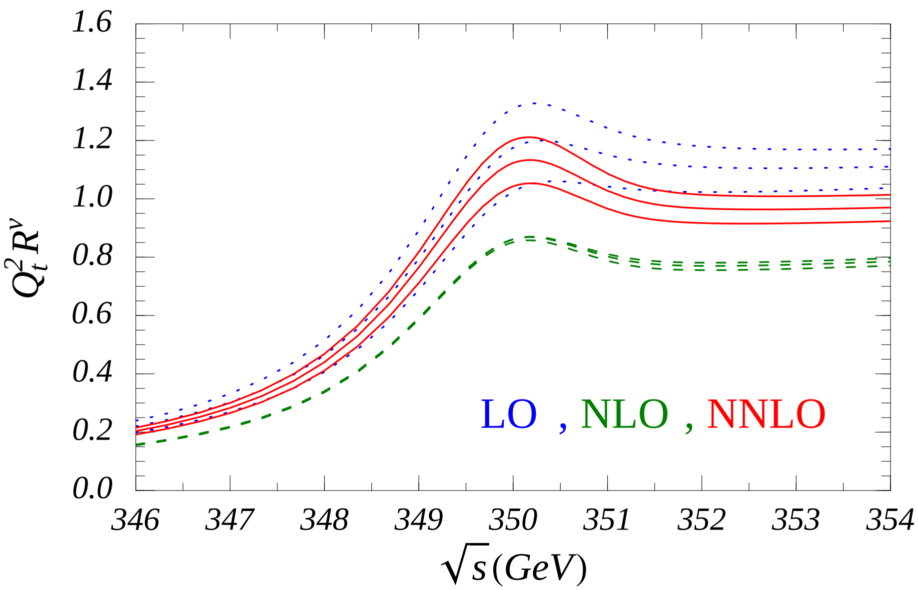
- $(\alpha_s/v)^n$ singularities $\Rightarrow$ breakdown of expansion in number of loops
- $\Gamma_t \approx 1.4\ \text{GeV}$ $\Rightarrow$ nonperturbative effects suppressed

Traditional approach: “Fixed-order”

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

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

Threshold cross section at NNLO



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

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

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

Renormalization Group Improved Approach

Aim: reduce uncertainty in normalization (α_s, Γ_t, λ_t)

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

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

Uses non-relativistic effective theories of QCD

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

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

- Running couplings of potentials in G (NNLL completed)
- Wilson coefficient of current $\mathbf{J}$ only at NLL

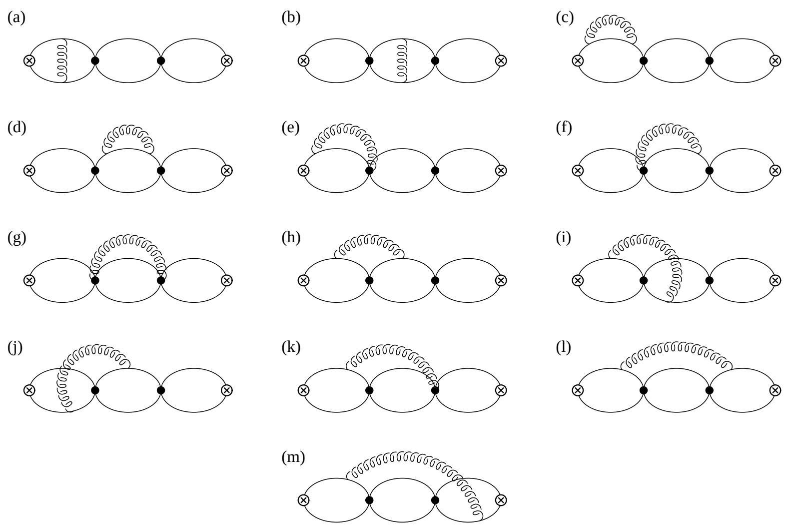
Manohar, Stewart, Hoang; Pineda, Soto, Brambilla, Vairo

Renormalization Group Improved Approach

Running of Wilson coefficient of current **J** at NNLL:

Partial result: (Hoang)

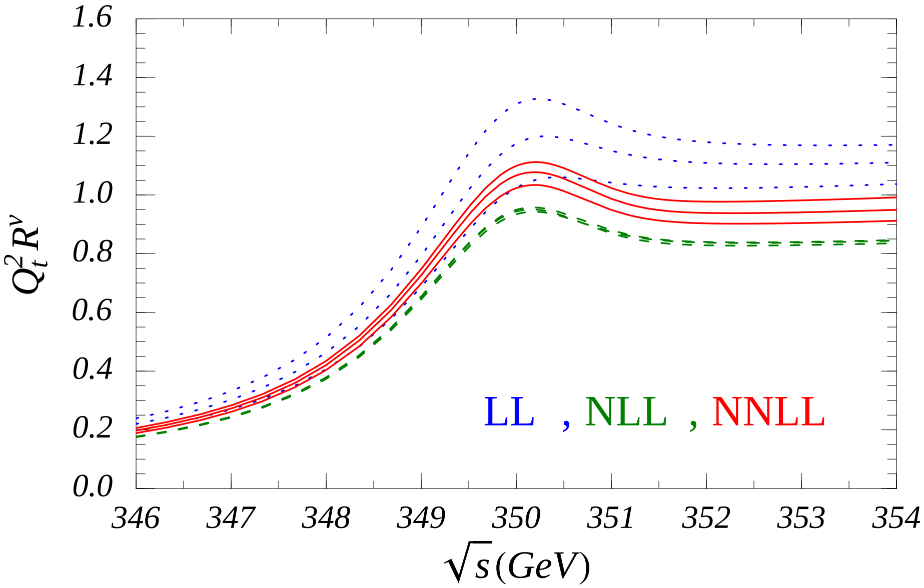
“Non-mixing” contributions to NNLL anomalous dimension



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

$$\sigma_{t\bar{t}} \sim v \sum_n \left(\frac{\alpha_s}{v}\right)^n \Big[1 + A\alpha_s^2 \ln v + B\alpha_s^2 \ln^2 v \qquad \longleftarrow \text{NLL}$$

$$+ A'\alpha_s^3 \ln v + B'\alpha_s^4 \ln^2 v + \ldots \Big] \qquad \longleftarrow \text{NNLL}$$

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:

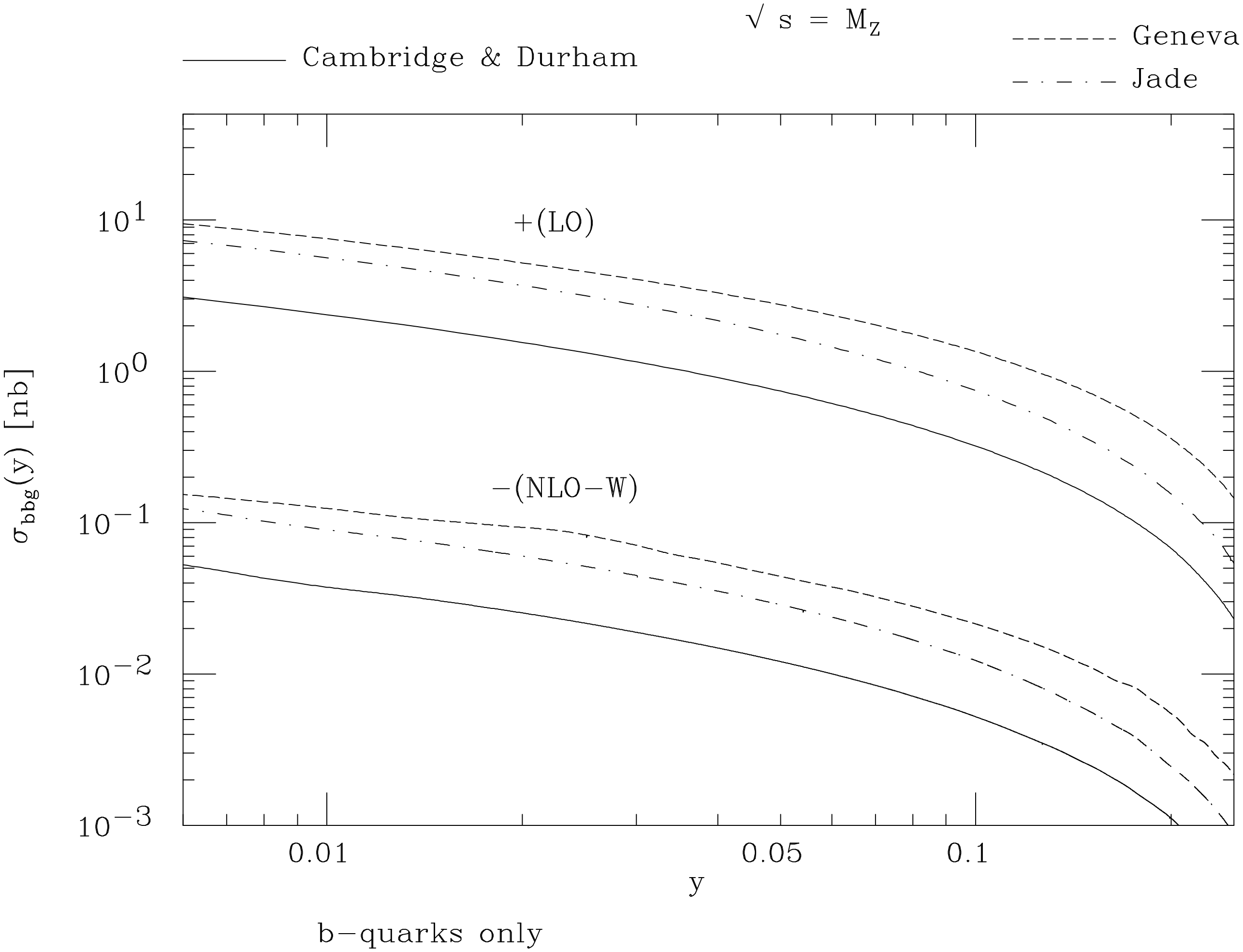
$$\Delta\alpha_s(M_Z) \lesssim 0.001$$

Current error on $\alpha_s(M_Z)$ dominated by **theoretical uncertainties**.
$\Rightarrow$ Need **2-loop corrections** to $e^+e^- \to 3$ jets.
Extremely **challenging** calculation, but will be finished in the near future.
Will that be enough?
Note: $\alpha_s^2 \sim \alpha_{EW}$
$\Rightarrow$ 1-loop electroweak $\sim$ 2-loop QCD
Moreover, EW corrections $\sim \boldsymbol{\alpha_{EW} \ln^2(M_W/\sqrt{s})}$
$\Rightarrow$ At high energies, EW corrections dominate.

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

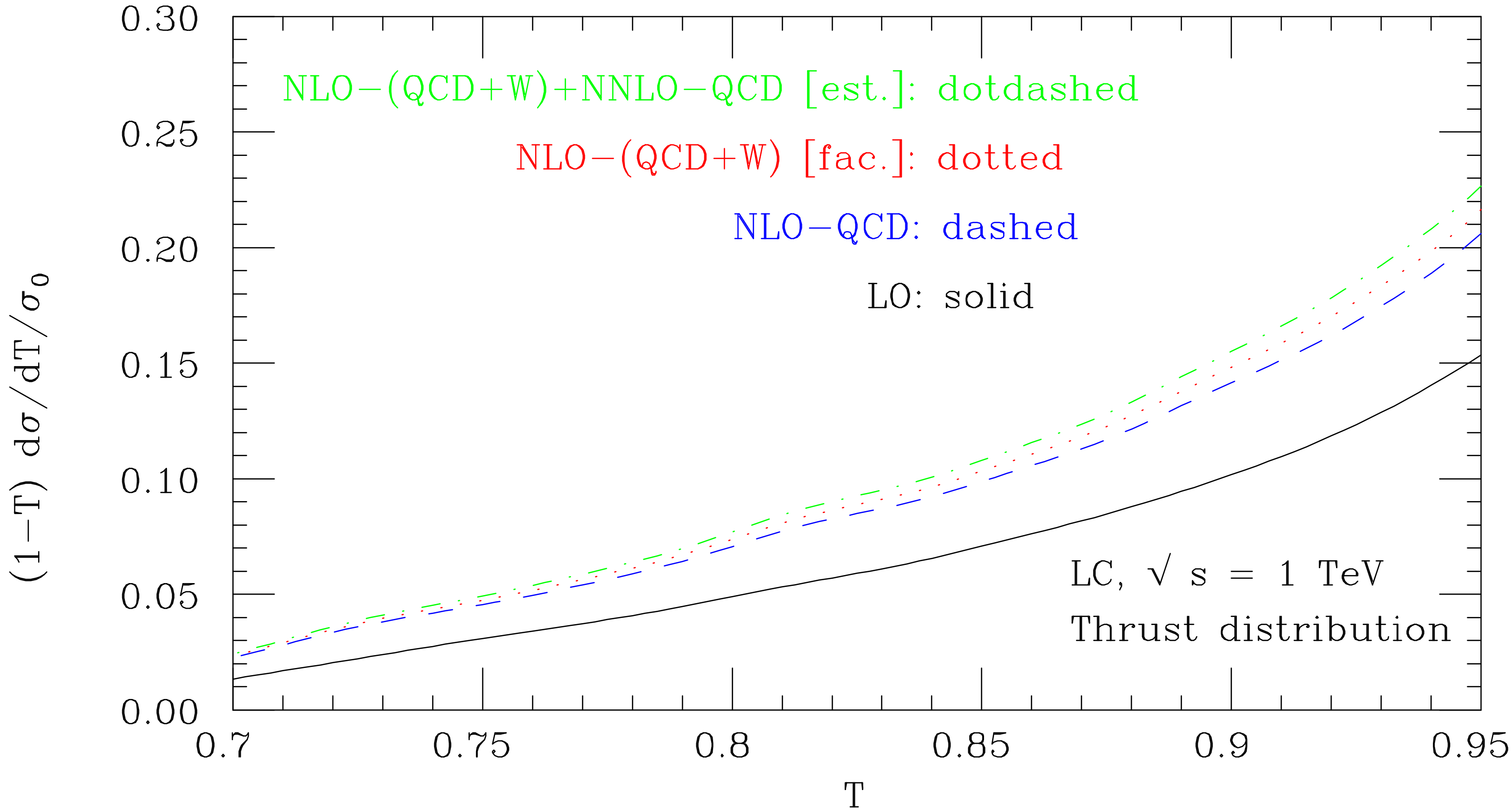
Electroweak corrections to $e^+e^- \to 3$ jets

S. Moretti



Electroweak corrections to $e^+e^- \to 3$ 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 $e^+e^- \to 3$ 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 .