What will LC tell us on Top / QCD ?

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1. Within the SM
2. Beyond the SM

Top-quark is now the only quark whose property is not well-known yet

The 3rd generation is a copy of the 1st & 2nd. ?

If you believe so, GO TO 1.
If not, GO TO 2.

QCD is part of SM, so → 1.

1. Within the SM.

What do we need for more precise tests of the SM?

Important parameters: m_t, α_s

At present $\Delta m_t^{exp} = 4.3$ GeV

$\Delta\alpha_s(M_Z) = 0.003$

Why do we need to know them more precisely? Weiglein

- EW precision tests and Higgs-boson mass prediction
- Testing the idea of GUT

The most precise EW formula: M_W–M_Z relation

$$M_W^2(1 - M_W^2/M_Z^2) = \frac{\pi\alpha}{\sqrt{2}G_F}(1 + \Delta r)$$

Δr is known at complete two-loop level plus leading three-loop

If m_t is measured with $\Delta m_t = 1.5$ GeV,
M_W can be calculated with $\Delta M_W = 9$ MeV

↕ c.f.

$\Delta M_W^{exp} \sim 7$ MeV
at LC

Very precise test!

They will also give a strong constraint on MSSM.

How to determine m_t at LC?

Threshold behavior of $\sigma(e\bar{e} \to t\bar{t})$

Steinhauser.

↑

$t\bar{t}$ rest frame

Non-relativistic QCD

Computing QCD potential, fitting $\sigma(e\bar{e} \to t\bar{t})$, we can expect

$\Delta m_t^{exp} \simeq 80$ MeV

This technique is also applicable to b & C quark system

In order to perform those analyses with small systematic errors, careful studies of

Beam spread. Beamstrahlung. Initial-state radiation

are required

Boogert

By parametrizing them as $p(x)$, cross sections are given by

$$\sigma(\sqrt{s}) = \int_0^1 dx\, p(x)\, \sigma'(x\sqrt{s})$$

Final goal is: $\Delta m_t \sim 48$ MeV

$\Delta \alpha_s \sim 0.0017$.

Measuring α_s, we need QCD higher order corrections

Weinzierl

$$e\bar{e} \to q\bar{q} \to 3 \text{ jets}$$

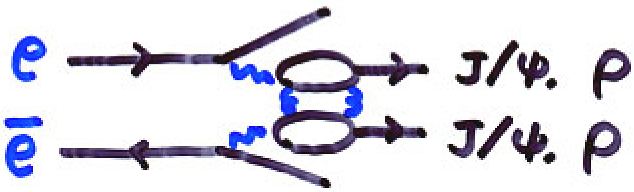
NNLO calculations are in progress, which need not only Two-loop amplitude. but also $\sigma^{1\text{-loop}}(4\text{jets})$ and $\sigma^{Born}(5\text{jets})$ for IR-div. cancellation

LC offers a good opportunity also for Traditional physics "Pomeron"

Wallon

Pomeron is "something" exchanged in NN forward scattering, which has vacuum quantum number.

In terms of QCD, they correspond to double gluon exchange



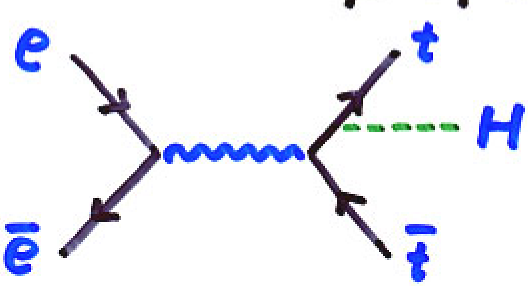
A test of soft IR part of QCD

Measuring $t\bar{t}H$ coupling is also important

Besson

↓

A test of SM-vertex proportional to m_t



$\Delta g_{ttH} / g_{ttH} \sim 15\%$ for $m_H < 200$ GeV

$\sim 5\%$ for $m_H = 120$ GeV

after a careful
study of possible background.
($\sqrt{s} = 800$ GeV)

2. Beyond the SM

Top-quark mass is even close to the EW breaking scale

↑

An indication that top-quark has some information which the other quarks do not have?

↓ This leads us to

Testing top-quark couplings

One good signal is CP violation
∵ CP-violation in the SM occurs at three loop level.

(1) $e\bar{e}$ collision

Since $t\bar{t}$ is produced via s-channel γ, Z exchange and $m_e/\sqrt{s}$ is negligible, initial $|e\bar{e}\rangle$ is CP even

↓

We have to make CP-odd observable from final-state products:

$$e\bar{e} \to t\bar{t} \to \ell^{\pm}X,\ \ell^{+}\ell^{-}X,\ bX$$

CP violation could occur in

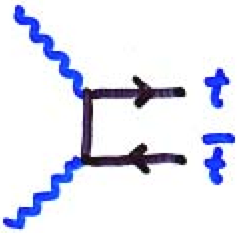
$t\bar{t}\gamma/Z$, tbW couplings.

If $|g_{non\text{-}SM}/g_{SM}| \gtrsim 0.05$, we have good chances to detect them.

The use of polarized beams is effective

Many authors

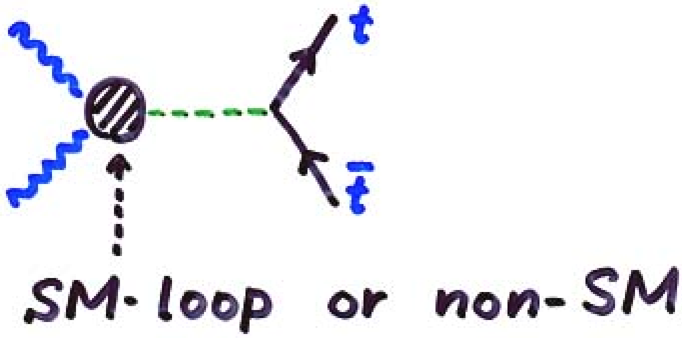
(2) $\gamma\gamma$ collision



Initial state can be CP odd

We can make a CP violating asymmetry without studying final top-quark distributions.

Also, we could study Higgs coupling:



Asakawa
Hioki
($\gamma\gamma$ session)

$\sqrt{s_{\gamma\gamma}}$ is not a constant, so calculations are more complicated.

Similar precision is expected for some coupling determination.

★ $e\bar{e}$ & $\gamma\gamma$ will work complementary to each other

One useful tool for analyses :

Decoupling theorem

Grzadkowski - Z.H., Rindani

Generally,

$$Q = Q_{SM} + C_P Q_P + C_D Q_D + O(C^2_{P,D})$$

C_P: non-SM parameter in Production vertex

C_D: non-SM parameter in Decay vertex

For example,

Final-lepton-energy distribution

$$\frac{d\sigma}{dE_\ell} = \left(\frac{d\sigma}{dE_\ell}\right)_{SM} + C_P\left(\frac{d\sigma}{dE_\ell}\right)_P + C_D\left(\frac{d\sigma}{dE_\ell}\right)_D$$

However. Angular distribution is

$$\frac{d\sigma}{d\cos\theta_\ell} = \left(\frac{d\sigma}{d\cos\theta_\ell}\right)_{SM} + C_P\left(\frac{d\sigma}{d\cos\theta_\ell}\right)_P$$

That is. C_D term decouples !

This decoupling theorem is applicable to any initial state

$$e\bar{e},\ \gamma\gamma,\ pp \to \overset{(-)}{t}X \to \ell^{\pm}X'$$

Through this theorem, we will be able to study C_P part and C_D part separately.

Refs.

hep-ph 0208079

9911505, 0112361

0002006

Another useful tool :

Optimal-observable analysis

3. Optimal-Observable Analysis

How can we determine several unknown parameters simultaneously?

$\Longrightarrow$ **Optimal-observable method** Atwood. Soni Davier et al. Diehl. Nachtmann. Gunion et al.

Brief summary of this method: Suppose we have a distribution

$$\frac{d\sigma}{d\phi}(\equiv \Sigma(\phi)) = \sum_i c_i f_i(\phi) \quad + O(c_i^2)$$

where $f_i(\phi)$ are calculable functions, and c_i are the parameters we try to determine.

Determining c_i

$\Longrightarrow$ We make weighting functions $w_i(\phi)$ which satisfies :

$$\int w_i(\phi)\Sigma(\phi)d\phi = c_i$$

The one which minimizes the statistical uncertainty of c_i is

$$w_i(\phi) = \sum_j X_{ij} f_j(\phi)/\Sigma(\phi)\,,$$

where X is the inverse matrix of

$$M_{ij} \equiv \int \frac{f_i(\phi) f_j(\phi)}{\Sigma(\phi)} d\phi$$

This X gives

$$\Delta c_i = \sqrt{X_{ii}\, \sigma_T / N}\,,$$

σ_T: Total cross section; N: Number of events

Finally,

Top-quark is a standard quark?

↓

(I guess) Many people will say

"Yes, we believe so"

However "No" must be a much much more exciting answer!

(We can write many paper!)

We hope LC will be able to give a clear answer in the near future!

Merci beaucoup!