News from Top/QCD

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Program

Top/~~QCD~~ Session

C. Schwinn: Top couling to Higgs and gauge bosons: 6 and 8 fermion final states

S. Boogert: $t\bar{t}$ threshold simulation update

$\longrightarrow$ top couplings in the continuum

$\longrightarrow$ top couplings at the threshold

Program

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C. Schwinn:	Top couling to Higgs and gauge bosons: 6 and 8 fermion final states	$\longrightarrow$ top couplings in the continuum
S. Boogert:	$t\bar{t}$ threshold simulation update	$\longrightarrow$ top couplings at the threshold
M. Schumacher:	Top Yukawa coupling from LC & LHC	$\longrightarrow$ synergy of LHC & ILC

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M. Schumacher:	Top Yukawa coupling from LC & LHC
A. Signer:	Effective theory for unstable particles
M. Slusarczyk:	Two-loop QCD corrections to Γ_t

$\longrightarrow$ top couplings in the continuum

$\longrightarrow$ top couplings at the threshold

$\longrightarrow$ synergy of LHC & ILC

$\longrightarrow$ new conceptual and theoretical developments

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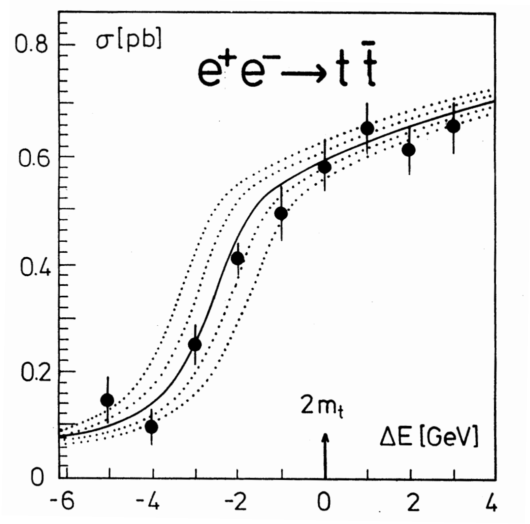
Other Sessions

T. Gehrmann:	$e^+e^- \rightarrow 3$ jets at NNLO	$\longrightarrow$ Loopverein
I. Melo:	Signatures of EWSB in $e^+e^- \rightarrow t\bar{t}\nu\bar{\nu}$	$\longrightarrow$ EW & Altern. Theo.
M. Spira:	SUSY QCD corrections to $e^+e^- \rightarrow t\bar{t}h$	$\longrightarrow$ Loopverein
M. Krämer:	NLO Parton Showers	$\longrightarrow$ Loopverein

Top Yukawa Coupling

Linear Collider

<u>threshold:</u> $\sigma(e^+e^- \to t\bar{t})$ at $\sqrt{s} \approx 350$ GeV



$\rightarrow\ V(r) = -\frac{C_F \alpha_s}{r} - \frac{g_{\rm tth}^2}{r}\, e^{-m_h r}$

$\mathcal{O}(5-10\,\%)$ correction

$\rightarrow\ \delta g_{\rm tth}/g_{\rm tth} = 20 - 50\,\%$

$\delta M_{\rm 1S} \le 50$ MeV, $\delta\Gamma_t \sim 30$ MeV, $\delta\alpha_s \sim 0.001$
($\mathcal{L} = 300\,{\rm fb}^{-1}$, $m_h \lesssim 120$ GeV)
(assumed perfectly known Lumi spectrum)

Martinez, Miquel

- perfect knowledge of luminsity spectrum assumed
- only for light Higgs
- depends on knowledge other parameters, QCD theory
- 1st phase

Top Yukawa Coupling

Linear Collider

threshold: $\sigma(e^+e^- \to t\bar{t})$ at $\sqrt{s} \approx 350$ GeV → difficult, 1st phase

continuum: $\sigma(e^+e^- \to t\bar{t}h) \sim g^2_{\rm tth}$

Br($h \to W^+W^-$)
Br($h \to b\bar{b}$)

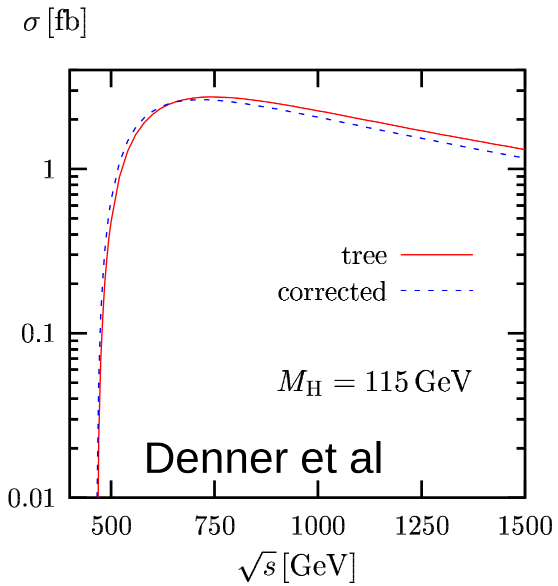
precision: $2 - 5\%$ ($e^+e^- \to Zh$)

$\to$ $\delta g_{\rm tth}/g_{\rm tth} = 5 - 6\,\%$ ($m_h = 120$ GeV)

Gay, Besson, Winter

$\delta g_{\rm tth}/g_{\rm tth} = 10\,\%$ ($m_h = 190$ GeV)

($\sqrt{s} = 800$ GeV , $\mathcal{L} = 1000\,\mathrm{fb}^{-1}$)



- $\sqrt{s} > 500$ GeV crucially needed
- 2nd phase

Top Yukawa Coupling

Linear Collider

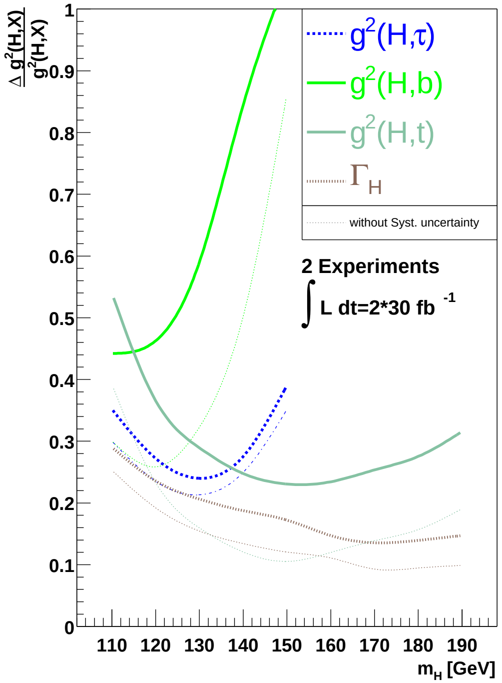
threshold: $\sigma(e^+e^- \to t\bar{t})$ at $\sqrt{s} \approx 350$ GeV $\to$ difficult, 1st phase

continuum: $\sigma(e^+e^- \to t\bar{t}h) \sim g^2_{\mathrm{tth}}$ $\to$ 2nd phase

LHC $gg \to tth$, $h \to W^+W^-$, $h \to b\bar{b}$ (many analyses)

- no absolute measurement of σ_{tot} or $\Gamma(h \to XX)$
  $\to g^2_{tth} \times Br$
- recent analysis: $g_{hW} = g^{\mathrm{SM}}_{hW} \pm 2.5\%$
  $g_{hZ} = g^{\mathrm{SM}}_{hZ} \pm 2.5\%$
  SM particle content
  Dührssen et al.

$\to \delta g_{tth}/g_{tth} \sim 12 - 25\%$



Top Yukawa Coupling

LHC & Linear Collider

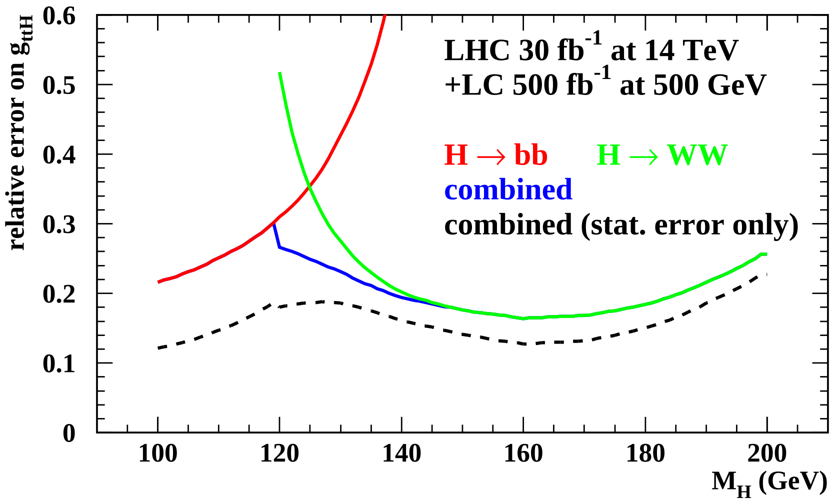
Schuhmacher, Desch

- LC, 1st phase: $\Gamma(h \to b\bar{b})$, $\Gamma(h \to W^+W^-)$
  from $e^+e^- \to Zh$
  use $Z \to l^+l^-$ recoil mass spectrum

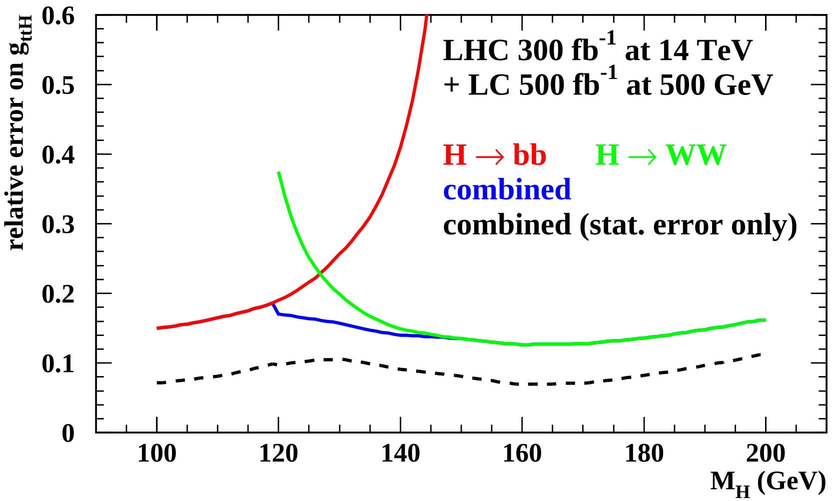
Input

- LHC: $gg \to tth$

$\Rightarrow$ 1st phase measurement



$\delta g_{tth}/g_{tth} = 16 - 27\%$



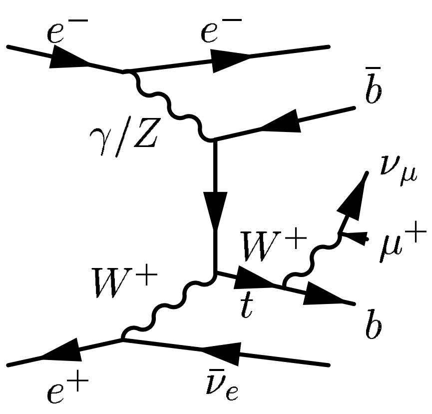
$\delta g_{tth}/g_{tth} = 13 - 17\%$

(incl. systematic errors)

6 and 8 Fermion Final States

$\rightarrow \Gamma_t = 1.4$ GeV: study of fermionic final states in top production

Schwinn



- O'Mega & WHIZARD updates
- single top production: $e^+e^- \rightarrow e\bar{\nu}_e t\bar{b} \quad \rightarrow |V_{tb}|$
  - signal & background diagrams & cuts
  - inconsistencies selecting only top diagrams
  - gauge invariance for small electron scattering angle
  - background $\sim 5\%$ effect after cuts
  - dependence on prescription for finite top lifetime

$\sigma(e^+e^- \rightarrow b\bar{b}e^-\bar{\nu}_e\mu^+\nu_\mu)(fb)$ with $\theta(e^-) > 0.01°$

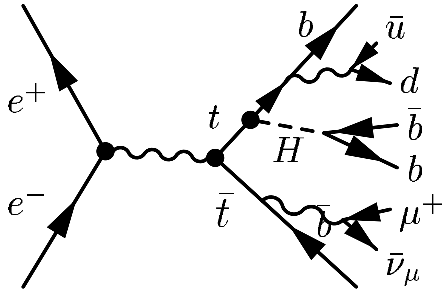
$\sqrt{s}$	Fixed Width	Complex Mass	Fudge Factor	Step Width
500	5.91 (1)	5.92 (2)	5.83 (1)	9.3 (1.9)
800	3.541 (8)	3.549 (8)	3.528 (8)	4.5 (3)
2000	3.62 (2)	3.64 (1)	3.62 (2)	98.0 (4)

6 and 8 Fermion Final States

$\rightarrow \Gamma_t = 1.4$ GeV: study of fermionic final states in top production

Schwinn

- $e^+e^- \rightarrow t\bar{t}h \qquad \rightarrow g^2_{tth}$
  - 6-fermion final state $b\bar{b}b\bar{b}W^+W^-$: $\sim 3\%$
  - 8-fermion final state $< 3\%$ (first studies)



$\rightarrow$ plans: anomalous couplings
QCD effects
polarizations

Unstable Particles

- processes with (near) on-shell massive & unstable particles
  - resonances (Z-pole, n-fermion final states)
  - non-relativistic systems ($t\bar{t}$ threshold, W^+W^-)
  - finite-T QCD

- issues: factorizable vs. non-factorizable,
  on-shell vs. off-shell,
  gauge invariance, double counting,
  scheme-dependence, etc.

- traditional approaches:
  pole scheme — Fadin, Khoze; Denner etal.,. . .
  complex mass scheme — Stuart; Aeppli etal; . . .
  fermion loop scheme,. . . — Beenakker etal

$\rightarrow$ guiding principles: • gauge invariance
• validity for all energies

Unstable Particles

Alternative Approach: Effective Field Theory

Signer

- separation of effects at different length scales

non-resonating $\leftrightarrow$ resonating

$\tau \sim \frac{1}{M}$ $\qquad$ $\tau \sim \frac{1}{\Gamma_t}$

$\Downarrow$ $\qquad$ $\Downarrow$

Wilson coefficients $\qquad$ propagating fields & operators

$$\mathcal{L}_{\rm EFT} \sim \sum_i \, c_i(\mu)\, \mathcal{O}(\phi)(\mu)$$

Unstable Particles

Alternative Approach: Effective Field Theory

- separation of effects at different length scales
- power counting in terms of $\delta = \frac{\Gamma_t}{M} \sim \alpha$
  - unique δ-scaling for field, operators & loops
  - double counting avoided

Unstable Particles

Alternative Approach: Effective Field Theory

- separation of effects at different length scales
- power counting in terms of $\delta = \frac{\Gamma_t}{M} \sim \alpha$
  - unique δ-scaling for field, operators & loops
  - double counting avoided

$\longrightarrow$ gauge invariance “automatic” (on-shell matching, operators)

$\longrightarrow$ exact form of EFT depends on system

$\longrightarrow$ **no** description off resonance (breakdown of δ-expansion)

$\longrightarrow$ gimmicks: • general (Feyman) rules to any order
• factorization scheme & UV-divergences
$\leftrightarrow$ renormalization, anomalous dimensions
$\leftrightarrow$ summation of $\ln(\Gamma/M)$ to all orders

$\longrightarrow$ toy model Signer, Beneke, Chapovsky, Zanderighi
“real” application in progress . . . no free lunch!

The Top Decay Width

- SM: Br$(t \to bW) \approx 100\%$ & rare decays

  MSSM: Br$(t \to bH^+) \approx$ several $\%$ $(1 \ll \tan\beta < 100)$

  Br$(t \to \tilde{t}\tilde{\chi}) \lesssim 10\%$

The Top Decay Width

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- Corrections to $\Gamma(t \to bW)$

  $\mathcal{O}(\alpha_s)$: $= -8.4\%$ Jezbek, Kühn

  $\mathcal{O}(\alpha,\text{ew})$: $\simeq -2\%$ Denner, Sack

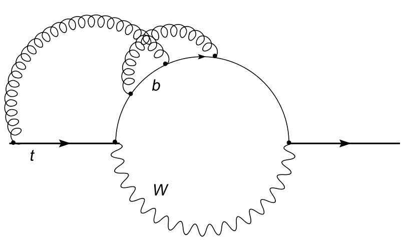
  $\mathcal{O}(\alpha_s^2)$: $\longrightarrow$ required for $t\bar{t}$ threshold at NNLL

  $\rightarrow$ BLM: $\mathcal{O}(\alpha_s^2\beta_0)$ Voloshin, Smith

  $\rightarrow$ $M_W = 0, m_b = 0$ Czarnecki, Melnikov

  $\rightarrow$ $M_W \neq 0, m_b = 0$

  Pade approximation Chetyrkin et al.

$\Pi^{(2)}(q^2) =$ 

$\rightarrow$ expansion for $\frac{q^2}{m_t^2} \ll 1$, $\frac{M_W^2}{q^2} \ll 1$

use $q^2 = m_t^2$, $M_W^2 = 0$

impose analytic properties, cuts

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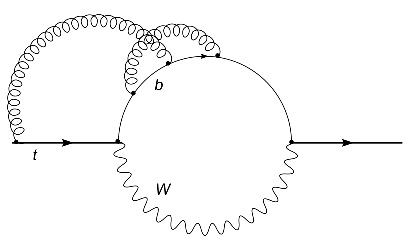
  Br$(t \to \tilde{t}\tilde{\chi}) \lesssim 10\%$

- $\mathcal{O}(\alpha_s^2)$ corrections to $\Gamma(t \to bW)$ $M_W \neq 0, m_b = 0$

  Analytic computation

  Slusarczyk, Czarnecki

$\Pi^{(2)}(m_t^2) =$ 

$\rightarrow$ start with $M_W = 0$ ($\frac{M_W^2}{m_t^2} = 0.213$)

asymptotic expansion in $\frac{M_W^2}{m_t^2}$

use optical theorem

integr. by parts → recurrence relations → master integrals

gaussion elimination → recurrence relations

The Top Decay Width

- SM: Br$(t \to bW) \approx 100\%$ & rare decays

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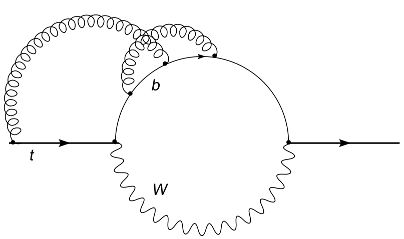
- $\mathcal{O}(\alpha_s^2)$ corrections to $\Gamma(t \to bW)$ $M_W \neq 0, m_b = 0$

  Analytic computation Slusarczyk, Czarnecki

$\Pi^{(2)}(m_t^2) =$ 

$\longrightarrow$ start with $M_W = 0$ ($\frac{M_W^2}{m_t^2} = 0.213$)

asymptotic expansion in $\frac{M_W^2}{m_t^2}$

use optical theorem

$\longrightarrow$ expansion up to $(\frac{M_W^2}{m_t^2})^5$

$\longrightarrow \Gamma(t \to bW) = \Gamma_0\Big[1 + \frac{\alpha_s}{\pi} X_1 + (\frac{\alpha_s}{\pi})^2 15.5(1)\Big]$

$\downarrow$

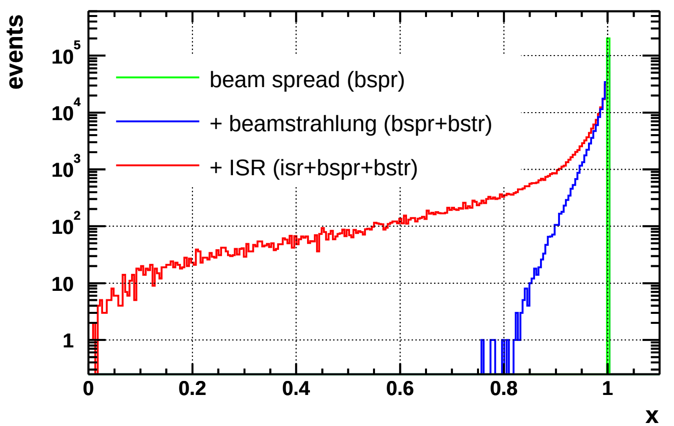
-2.15%

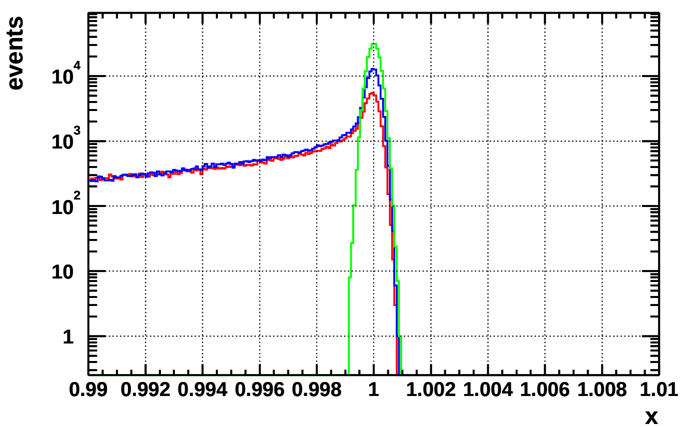
Top-Antitop Threshold

$\sigma(e^+e^- \to t\bar{t})$ at $\sqrt{s} \approx 350$ GeV $\Rightarrow m_t,\, \alpha_s,\, \Gamma_t,\, (g_{tth})$

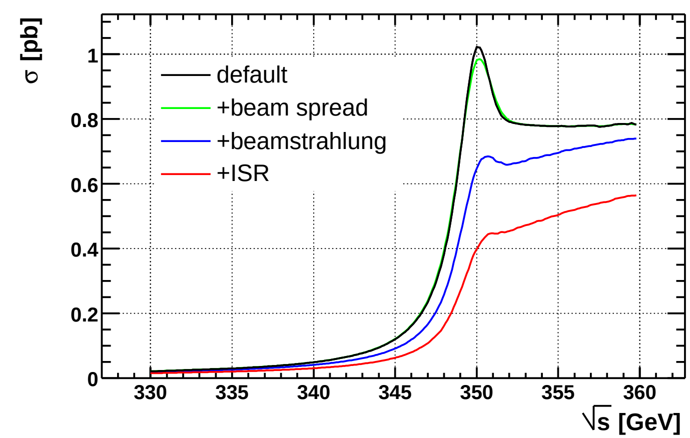
Influence of Luminosity spectrum

Boogert





$$\sigma(s) = \int_0^1 dx\, L(x)\, \sigma^0(x^2 s)$$



Top-Antitop Threshold

$\sigma(e^+e^- \to t\bar{t})$ at $\sqrt{s} \approx 350$ GeV $\Rightarrow m_t, \alpha_s, \Gamma_t, (g_{tth})$

Influence of Luminosity spectrum Boogert

previous WS's:
- measurement of $L(x)$ (excl. beam energy spread)
  - $\rightarrow$ Bhabba accollinearity
  - $\rightarrow$ accelerator & beam simulations
- TOPPIK interpolation

this WS:
- beam energy spread included (cold & warm designs)
- $L(x)$ parametrized (σ, a_0, a_2, a_3)

Top-Antitop Threshold

$\sigma(e^+e^- \to t\bar{t})$ at $\sqrt{s} \approx 350$ GeV $\Rightarrow m_t, \alpha_s, \Gamma_t, (g_{tth})$

Influence of Luminosity spectrum

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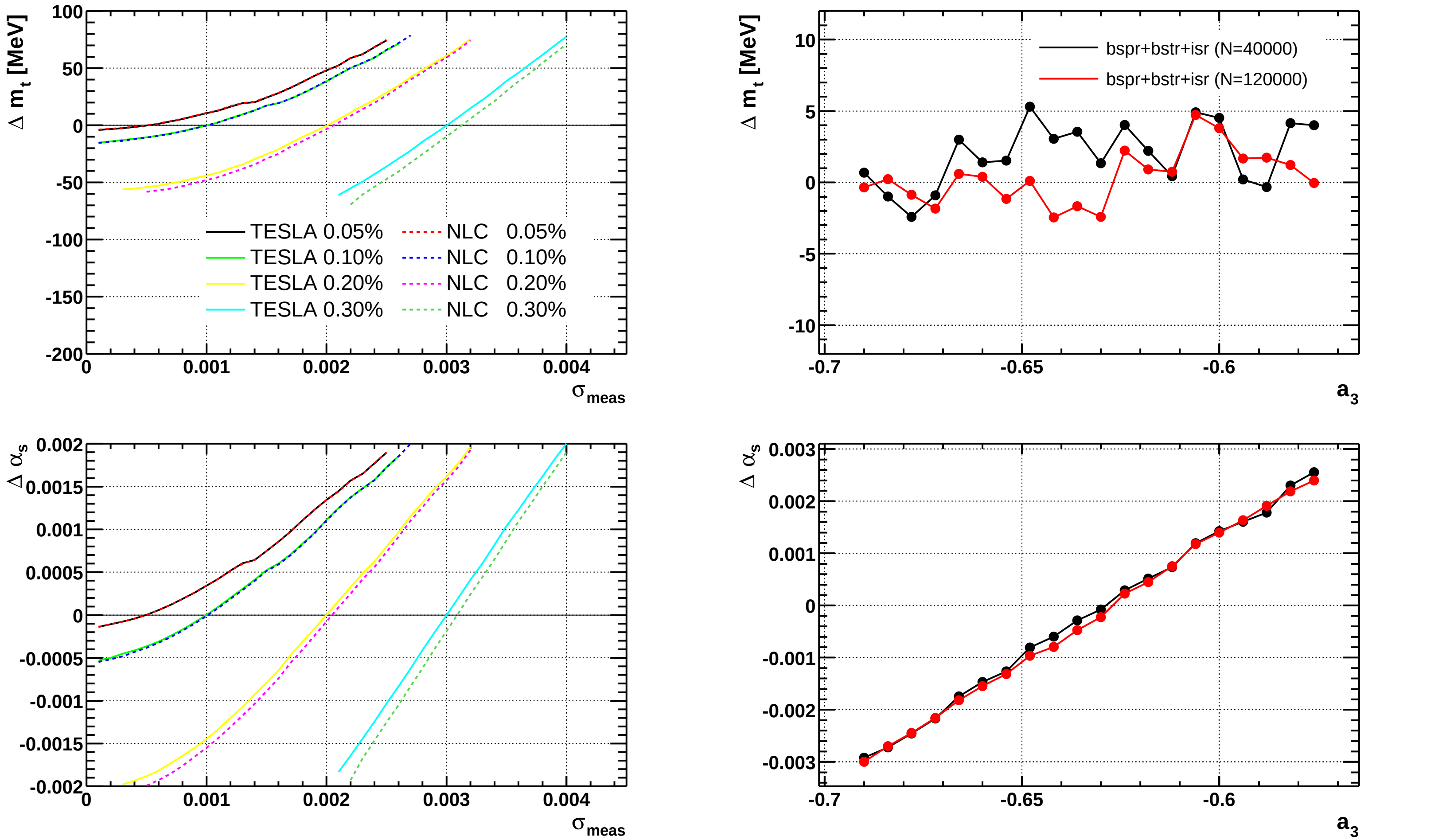

Top-Antitop Threshold

$\sigma(e^+e^- \to t\bar{t})$ at $\sqrt{s} \approx 350$ GeV $\quad \Rightarrow m_t,\, \alpha_s,\, \Gamma_t,\, (g_{tth})$

Influence of Luminosity spectrum

Boogert

$\rightarrow \quad \Delta m_t \approx -50$ MeV (Paris numbers)

$\Delta\alpha_s \approx -0.0017$ MeV

$\Delta\Gamma_t \approx -13$ MeV

. . . things to think of:

- optimized scan strategy
- top event generator
  - A_{FB}, distributions, cuts
  - electroweak corrections $\leftrightarrow$ unstable particles
- other thresholds

Final Words

- Plenty of problems to work on in SM top precision physics !

  NO Free Lunches !

  Kein Freibier !