Precision top quark physics at a future linear e^+e^- collider

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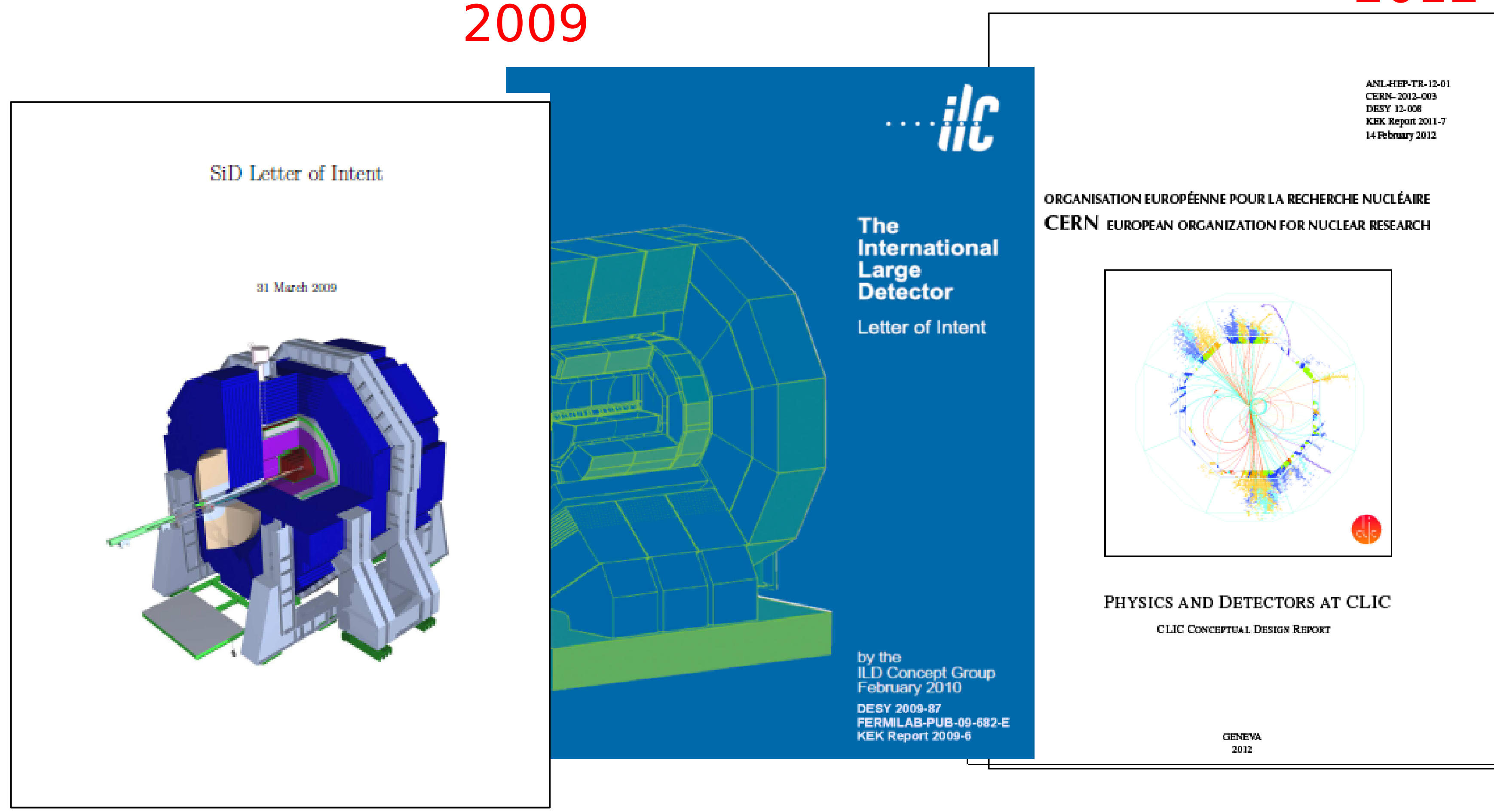
on behalf of the LC community

Outline

- Future e^+e^- colliders
- Detectors
- Top quark mass
- Top quark couplings

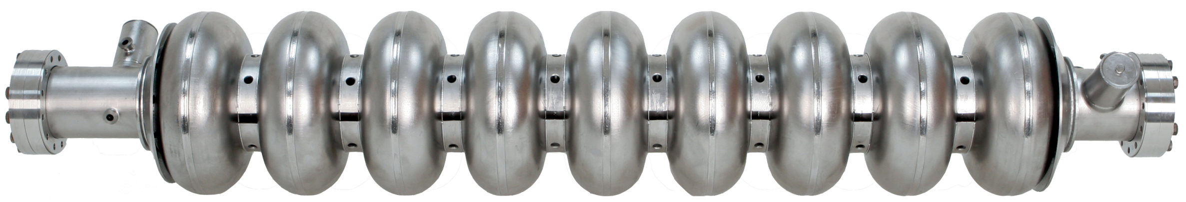
2009 2012

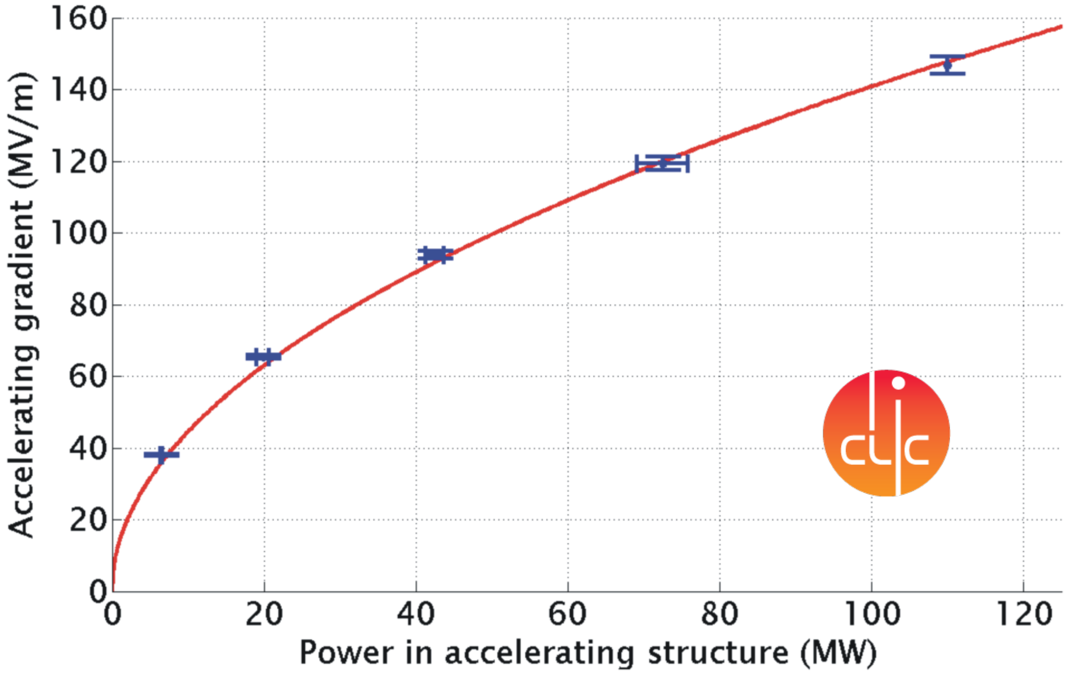


Reference documents prepared by the LC community:
- Tesla TDR (2001) part III on physics
- 2004 Report on the complementarity of LC and LHC
- CLIC physics report
- ILC Reference Design Report (2007): physics and detectors
- Letter Of Intent of the ILC experiments (2009) SiD and ILD
- Conceptual Design Report (2012) of the CLIC detectors
- Soon: Detailed Baseline Design for the ILC experiments

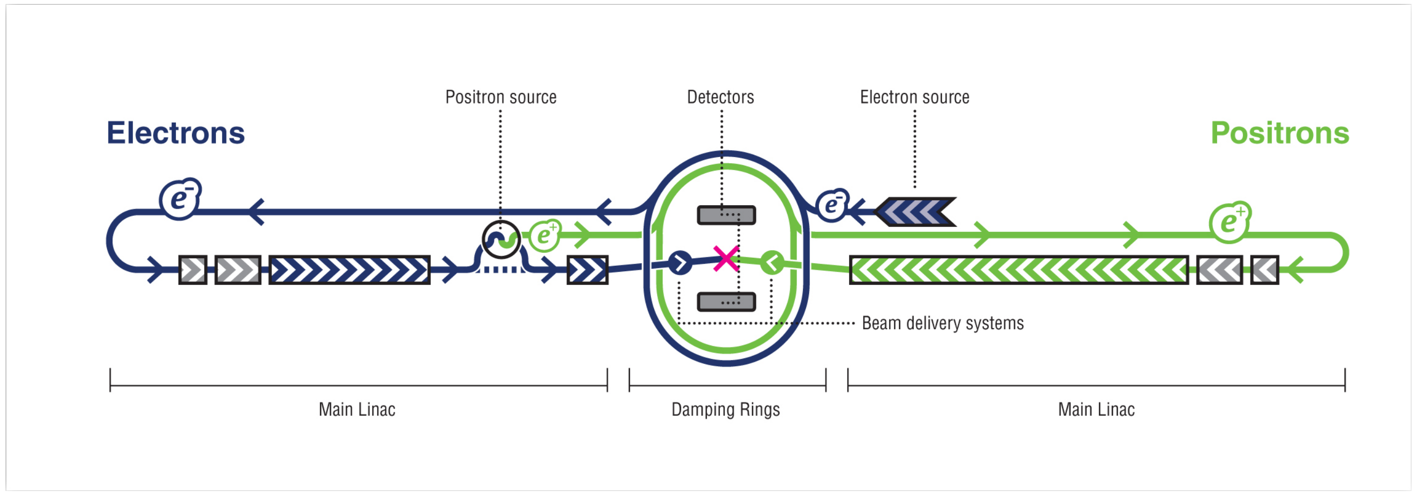
Future e^+e^- colliders

- Superconducting RF cavities are in the industrialization phase and routinely reach gradients well over 30 MV/m. ILC is shovel-ready.
- Still higher gradient (~100 MV/m) can be achieved using drive beam concept. CLIC can open up the multi-TeV regime.





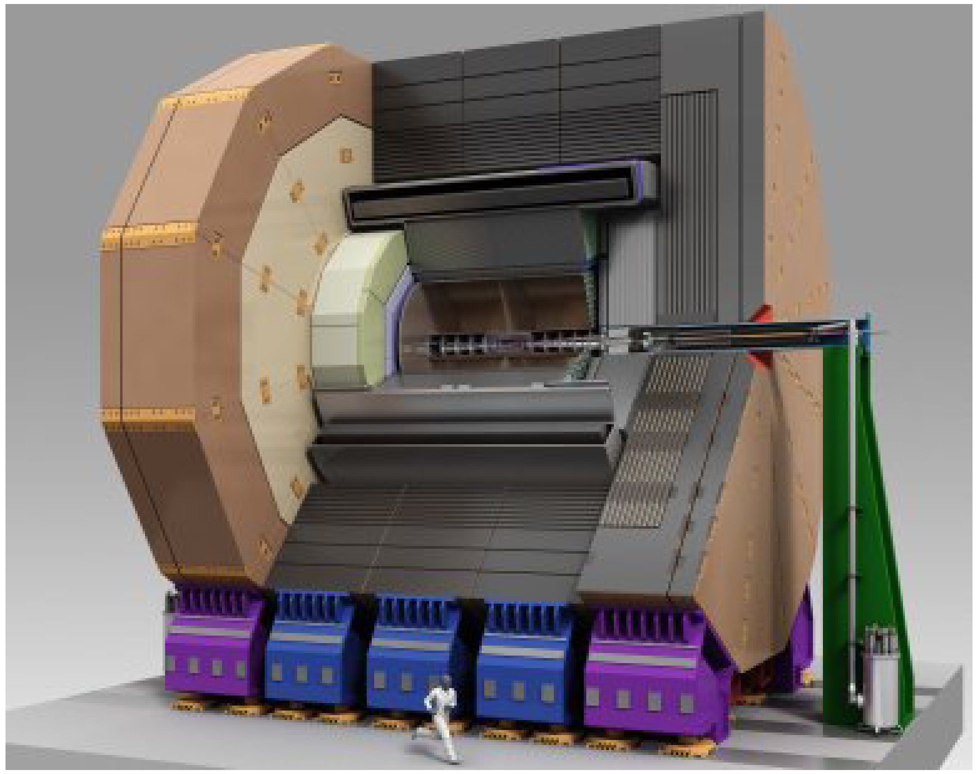
LC technology exists for a low-energy machine (√s ~ 250-500 GeV)
R&D is ongoing for √s ~ 1-3 TeV



R&D around the globe
Non-exhaustive list of test facilities:
ATF@KEK, nm size, low emittance beams
CESR/IT@Cornell (electron cloud)
CTF3@CERN, drive beam
XFEL@DESY, cavities

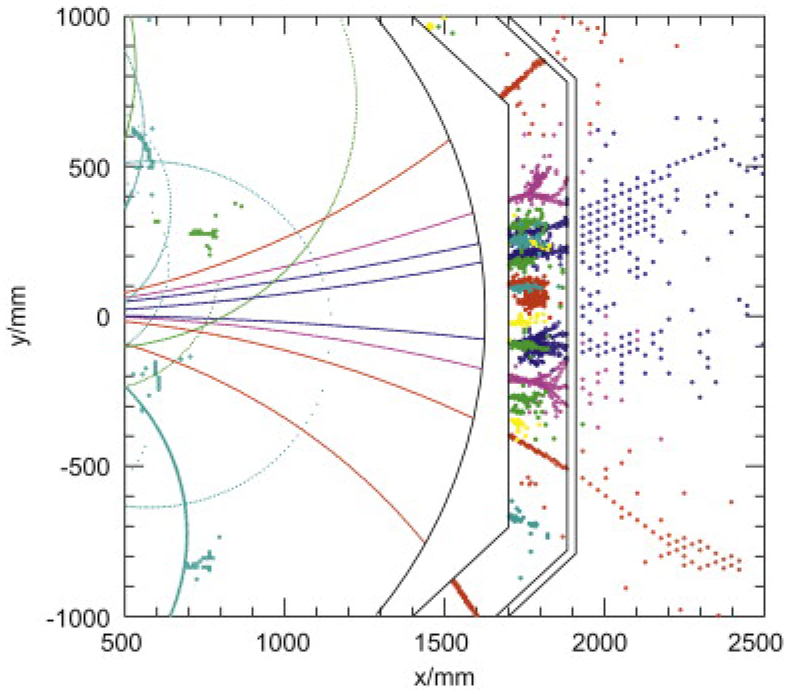
Contributions on 07/07 in TR14:
Steinar Stapnes, the CLIC project
Phil Burrows, beam feedback
Jenny List , polarimetry
Tony Hartin, spin tracking

LC detectors



LC environment and detector R&D allow for a big leap in performance

- Signal and bkg x-sections of similar magnitude
- Well-defined initial state (CM energy, polarization)
- Triggerless read-out
- Background confined to innermost detectors



Particle Flow: highly granular calorimetry inside a large 3.5-5 Tesla solenoid allows to follow every single visible particle produced in the collisions from the cradle to the grave → best possible estimate of the jet energy: $\Delta E/E \sim 3\text{-}5\%$

Transparent and precise tracking/vertexing:

$\Delta(1/p_T) \sim 10^{-5}\ \mathrm{GeV}^{-1}$

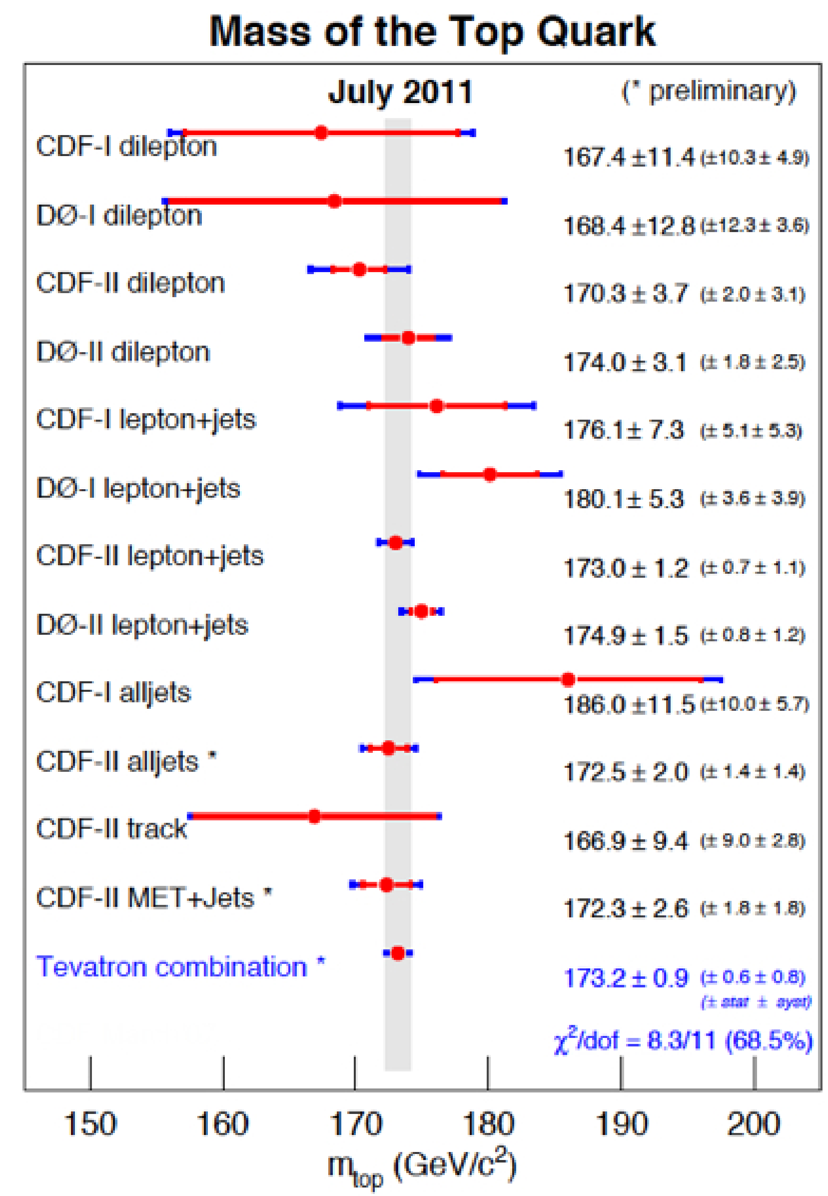
$\Delta(d_0) \sim 5 \oplus 10\text{-}20 / (p \sin^{3/2}\theta)$

Detailed Geant4 model and sophisticated reconstruction software allow realistic estimates of performance

Contributions on 07/07 in TR13:
Tomohiko Tanabe on ILD
Andy White on SiD
Frank Simon on CLIC detectors

Top Quark Mass – Hadron Colliders

Compare the mass of the top quark decay products to a template from a generator and identify the best fit result with the quark pole mass



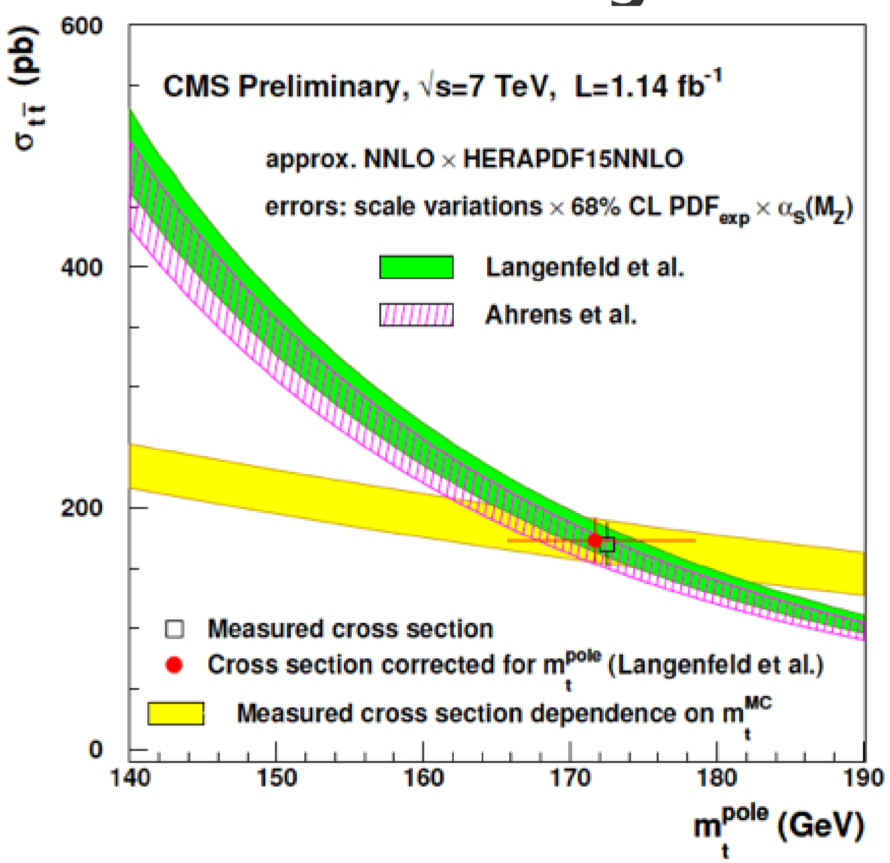
Tevatron: total error below 1 GeV

LHC already systematics dominated:

ATLAS l + jets (1/fb): 174.5 ± 0.6 (stat) ± 2.3 (syst) GeV

CMS μ + jets (5/fb): 172.6 ± 0.4 (stat) ± 1.2 (syst) GeV

Main disadvantage: no rigorous interpretation in

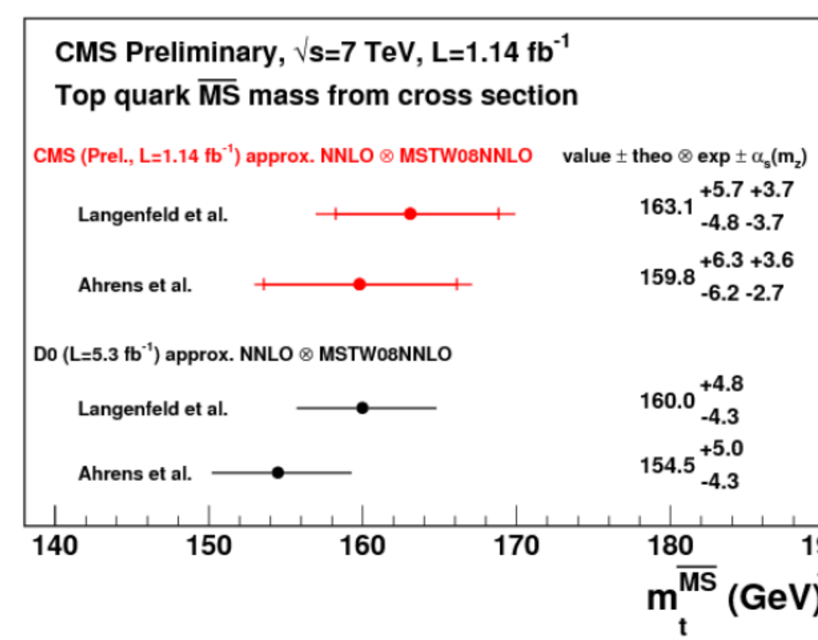


eme

Pair production cross-section measurement at the LHC yields a top quark mass determination

Precision of this procedure seems to be limited:

$$\frac{\Delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} \approx 5\,\frac{\Delta m_t}{m_t}$$

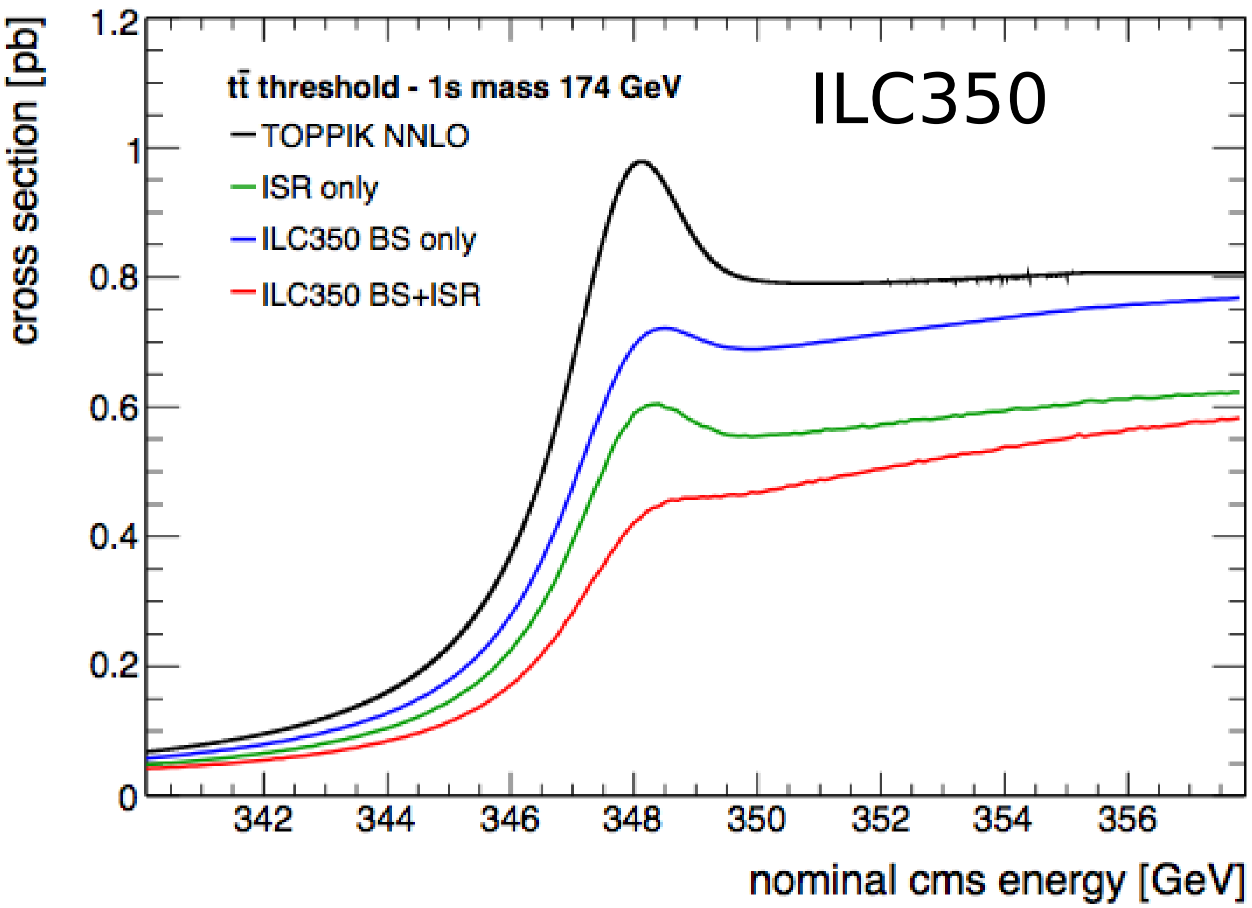


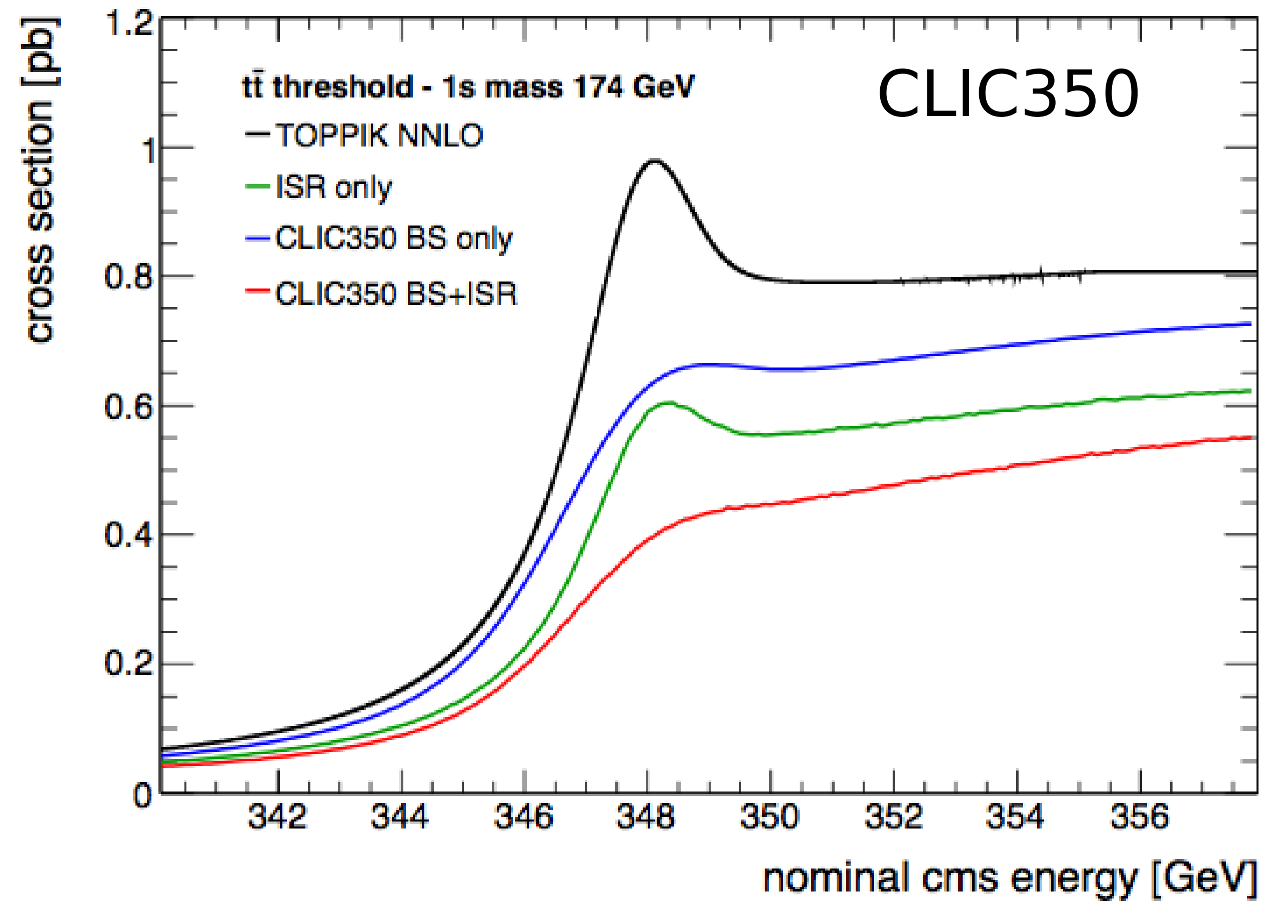
Top quark mass - Threshold Scan at FLC

The shape of the top quark pair production cross section around threshold offers sensitivity to top quark mass, top quark width and the strong coupling constant α_s

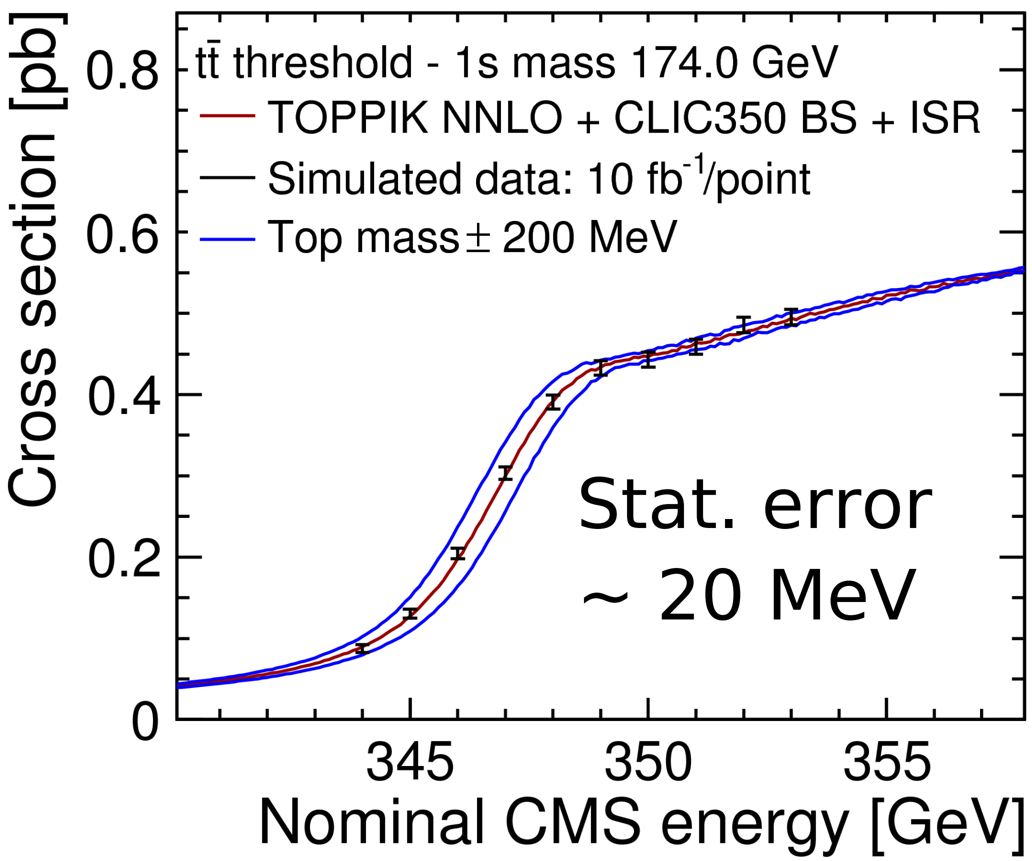
See: Peter Marquard's contribution in this track

Threshold shape is partially washed out by ISR and beam energy spread.
Larger beam energy spread at CLIC has ~15% effect on precison of the fit

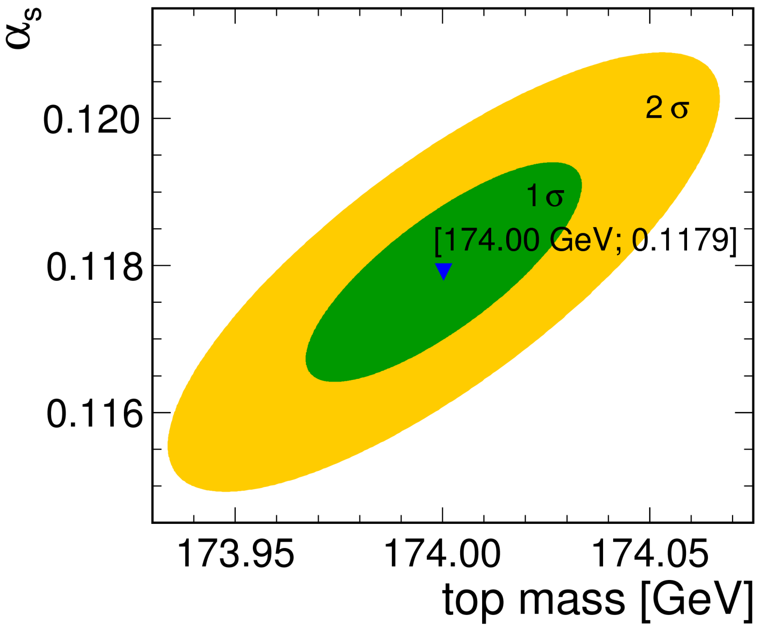




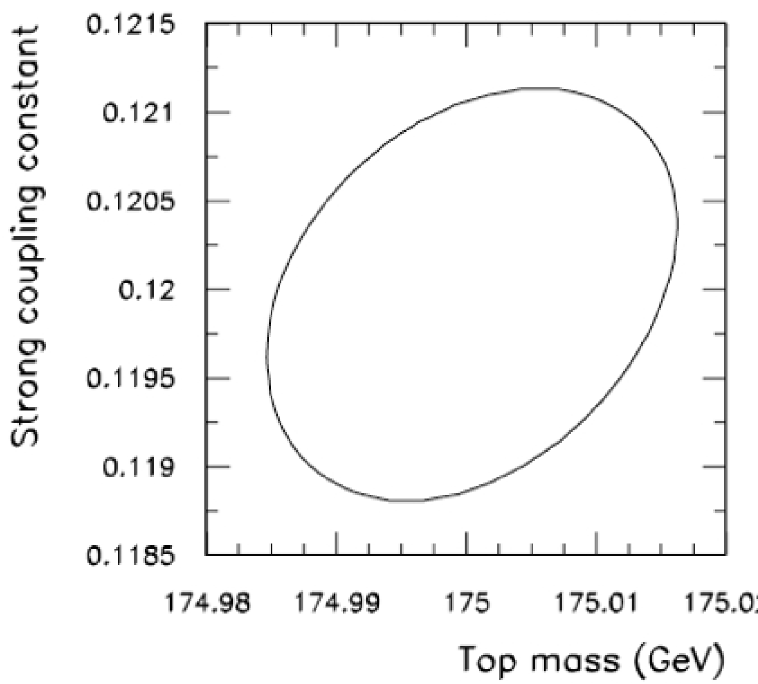
Top quark mass



CLIC preliminary



Martinez, Miquel, EPJ C27, 49 (2003)



New results corroborate old studies and extend these findings to a machine with a very different technology

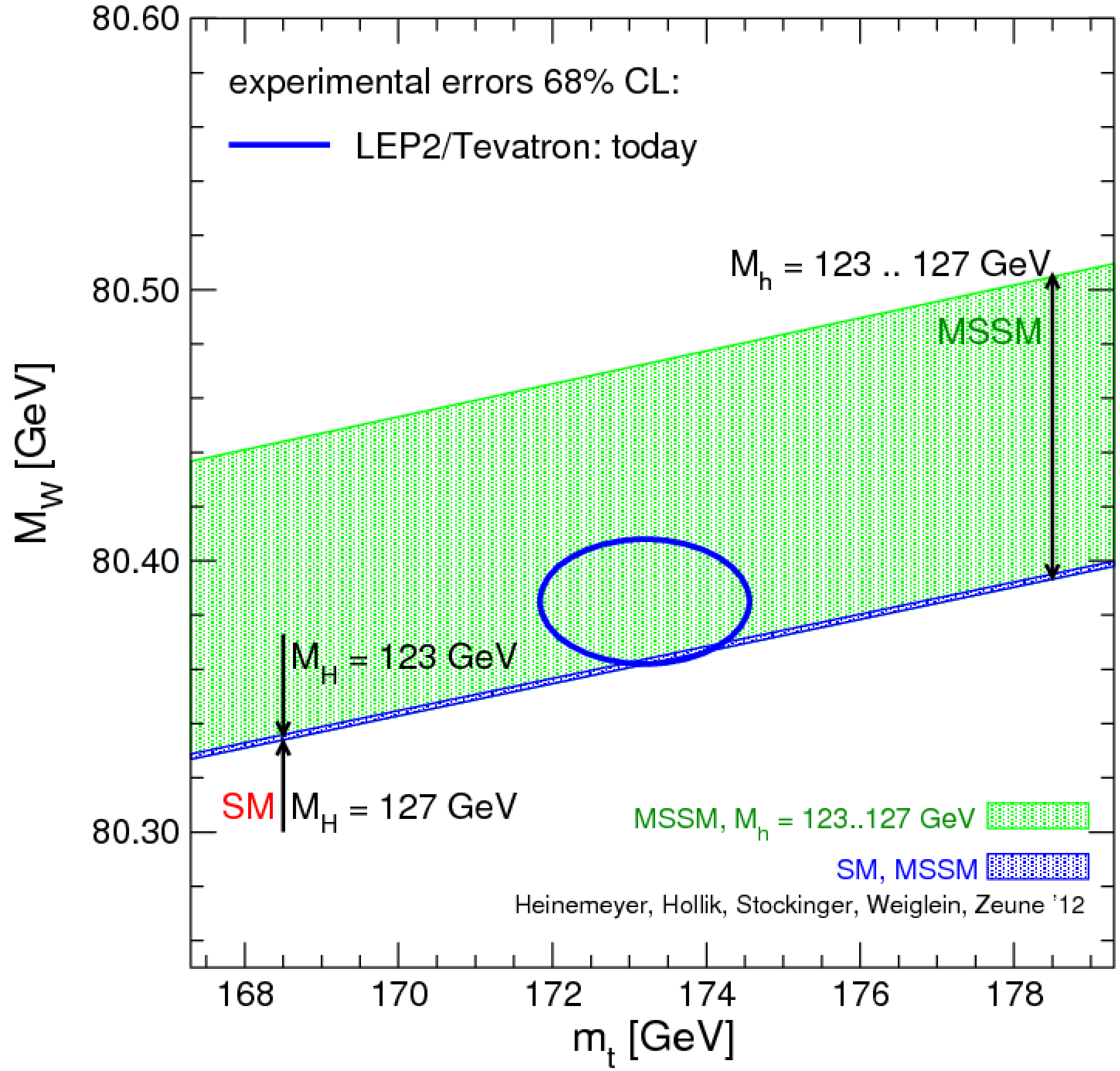
Measurement in the continuum ($\sqrt{s}$ = 500 GeV) is possible with a statistical error ~ 50-100 MeV (ILD/SiD, CLIC CDR). This measurement is affected by the same type of systematic uncertainties as Tevatron/LHC

A precise measurement O(100 MeV) with a rigorous interpretation is achievable at a low energy linear collider

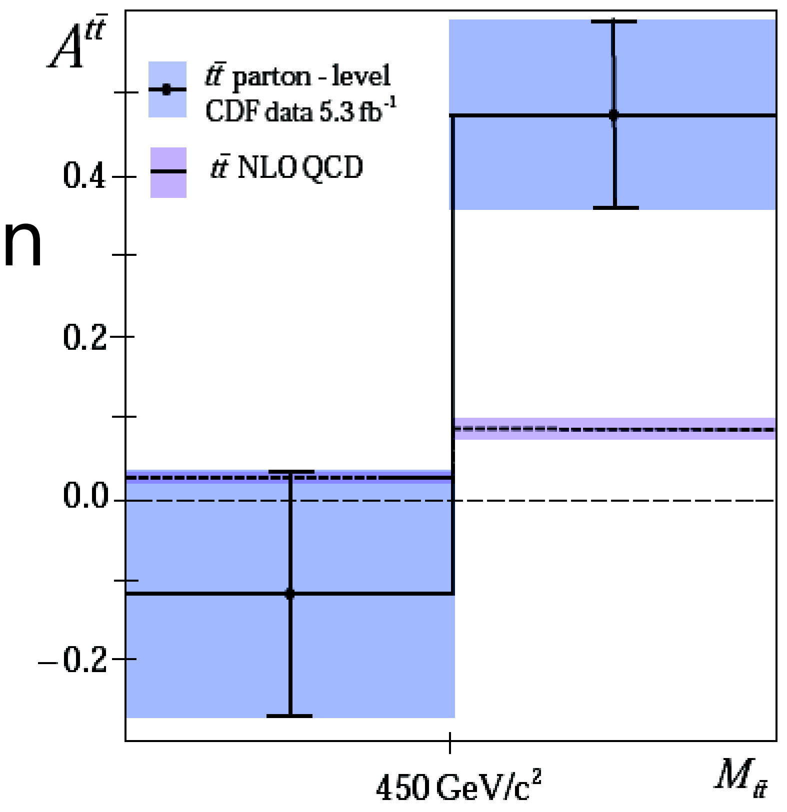
Top quark mass – what do we learn?

Measure fundamental parameters of the Standard Model as precisely as possible

If (now that?) a Higgs-like object is observed, use precise measurements of the masses of the top quark, the W boson and the new state to test internal consistency of the Standard Model

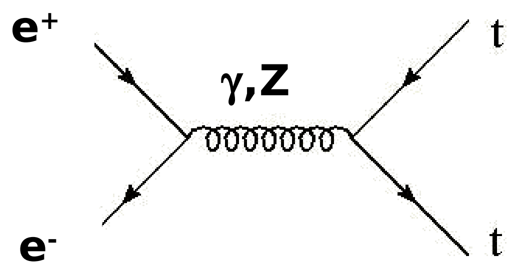


Top quark couplings

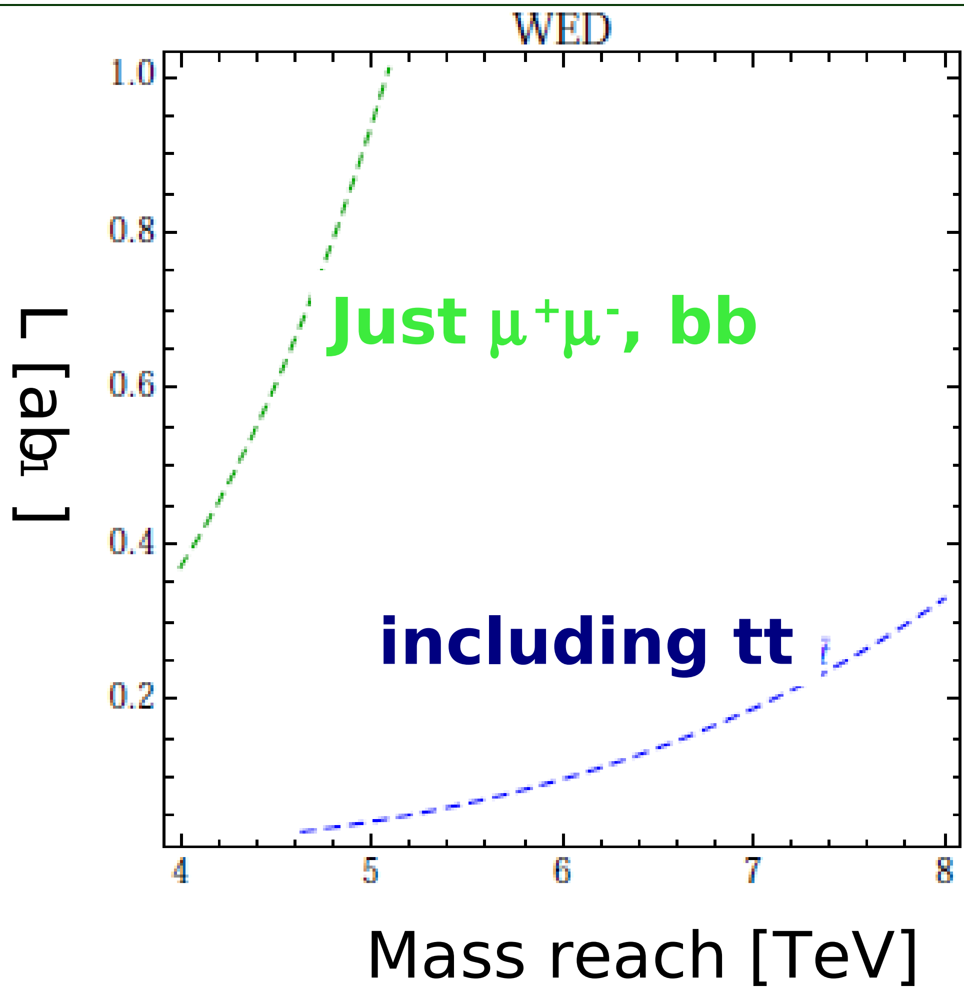


Asymmetries in the production of third generation quarks has been an interesting area for decades

The CDF collaboration, "*Evidence for a Mass Dependent Forward-Backward Asymmetry in Top Quark Pair Production*," Phys.Rev.D83 (2011).



tt production at a LC:
σ~0.6 pb
at √s = 500 GeV
~0.2 pb
at √s = 1 TeV
~0.1 pb
at √s = 3 TeV



Detailed study of tt production at LC may greatly enhance the sensitivity to BSM physics

Example: Warped Extra Dimensions at LC 3 TeV

F. Corradeschi, LCWS10, arXiv:1202.0660
M. Battaglia, LCWS11

Top quark couplings

$$\Gamma^{\mu}_{t\bar{t}(\gamma,Z)} = ie\left[\gamma^{\mu}\left[F^{\gamma,Z}_{1V} + F^{\gamma,Z}_{1A}\gamma^{5}\right] + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}\left[F^{\gamma,Z}_{2V} + F^{\gamma,Z}_{2A}\gamma^{5}\right]\right]$$

Parton-level studies show how measurements on tt production at LC (σ, A_{FB}, A_{LR}, ...) can constrain the form factors F

Form factor	SM value	LC prospects $\sqrt{s}$ = 500 GeV
F_{1V}^{Z}	1	1.9%
F_{1A}^{Z}	1	1.6%
$F_{2V}^{\gamma,Z} = (g-2)^{\gamma,Z}_{t}$	0	1.1%
Re F_{2A}^{γ}	0	0.7%
Re d_t^{γ}	0	4%
Re F_{2A}^{Z}	0	0.8%
Re d_t^{Z}	0	5%
Im F_{2A}^{γ}	0	0.8%
Im F_{2A}^{Z}	0	1.0%

TESLA TDR, to be explored in complete studies with detailed simulation

Control over beam polarization is vital!!

Top quark couplings

Fully hadronic $t\bar{t}$ events are a benchmark channel in SiD and ILD LOI

Basic selection:

- visible energy
- number of (charged) particles
- y_{min} (6 jets)
- W-boson mass
- b-tagging

Efficiency: 51%

Purity: 69 %

Kinematic fit:

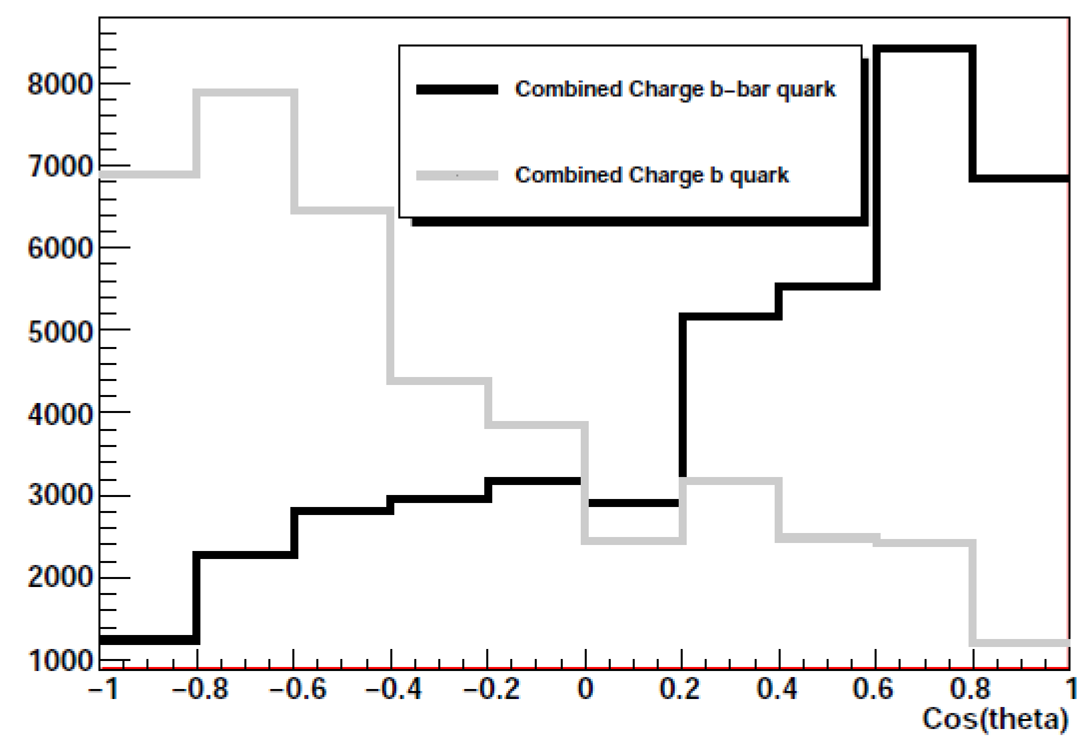
- $m_t = m_t$
- $m_W = 80.4$ GeV
- $E_{vis} = 500$ GeV
- $P_x = P_y = P_z = 0$

Efficiency: 31%

Purity: 86%

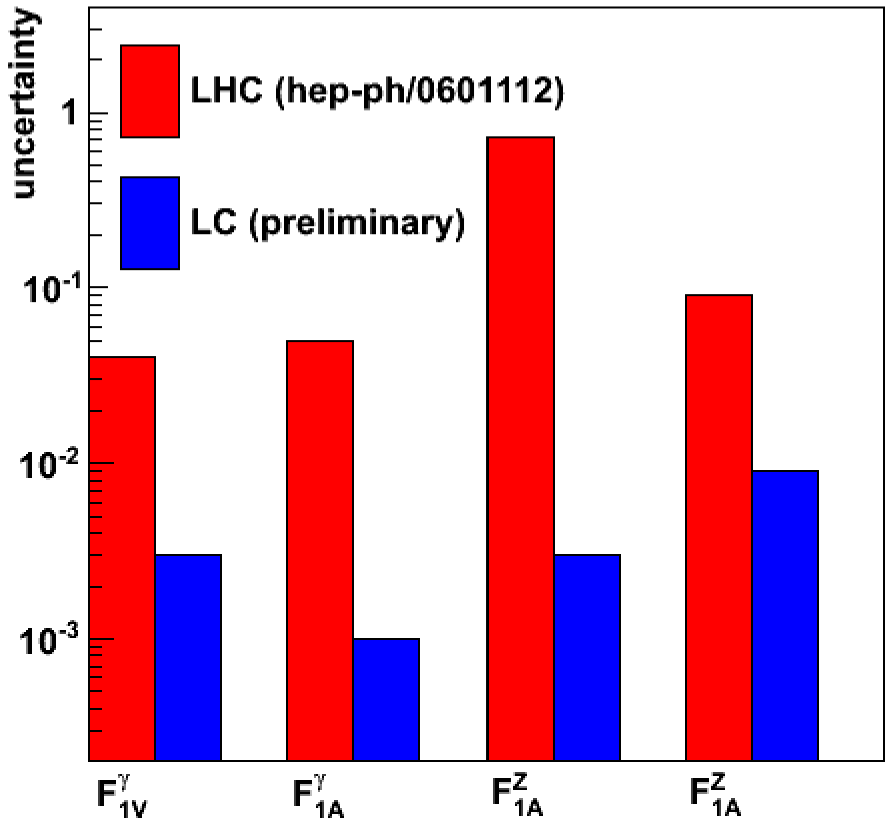
Excellent flavour tagging, vertex charge and jet charge determination allow to reconstruct the A_{FB}^{tt} (and that of b-quarks in tt events) to ~5%

Lepton + jets final state offers better distinction of t and t directions



Work in progress

Revisiting the parton-level study for the Dedailed Baseline Design



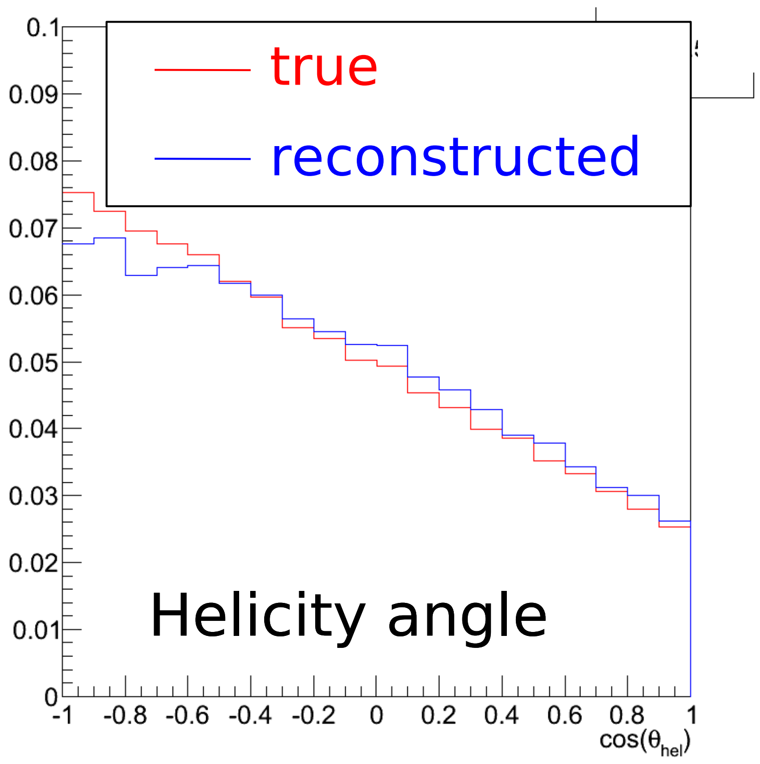
LAL/IFIC preliminary

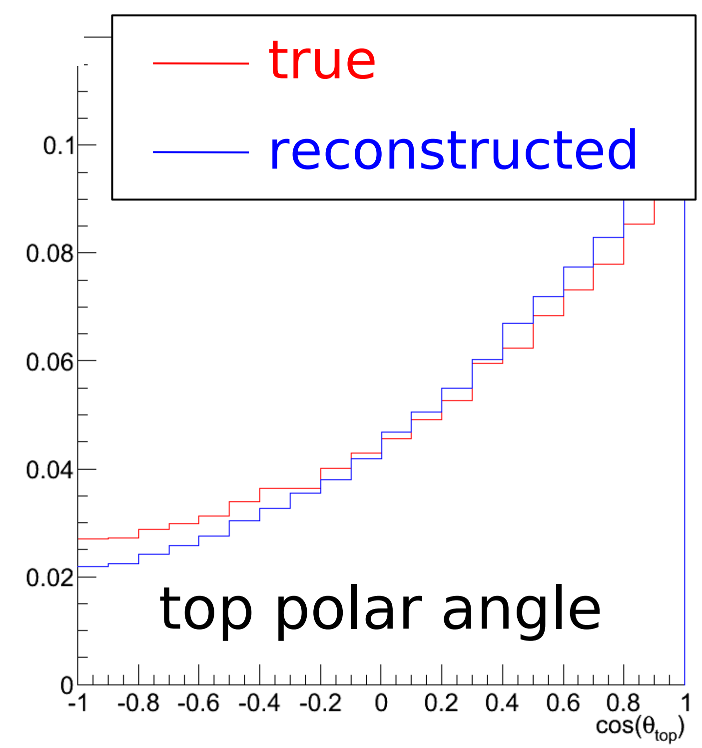
Assumptions:

LC: √s = 500 GeV, L = 500/fb
P(e⁻) = 80%, P(e⁺)=30%

LHC: 14 TeV, 300/fb

LAL/IFIC preliminary





Full simulation in ILD concept to understand experimental challenges and estimate systematic errors. Preliminary: migrations due to ambiguities in tt reconstruction can be controlled at an LC

Summary

New results from detailed studies on two highlights of the LC precision top quark physics program:

- $\Delta m_t \sim$ 100 MeV

Threshold scan yields a precise top quark mass measurement in a well-defined scheme

Continuum measurement yields a similar statistical precision

- $\delta F_{1V}^{\gamma,Z}, \delta F_{1A}^{\gamma,Z}$ ~1%

Polarization allows to disentangle γ and Z

Couplings to Z and characterized couplings at the % level

A_{FB}(tt) to 5% in fully hadronic final state! Much better in lepton+jets (preliminary)

More results expected soon!!