Top/QCD, EW + Alternative Summary

Frank Simon
MPI for Physics & Excellence Cluster 'Universe'
Munich, Germany

on behalf of the Top/QCD, EW + Alternative Conveners
Juan Fuster, Frank Simon, Martine Bosman,Thomas Teubner , Andre Hoang, Gregory Moreau, Klaus Moenig, Albert de Roeck, Thorsten Ohl, Michael Spira

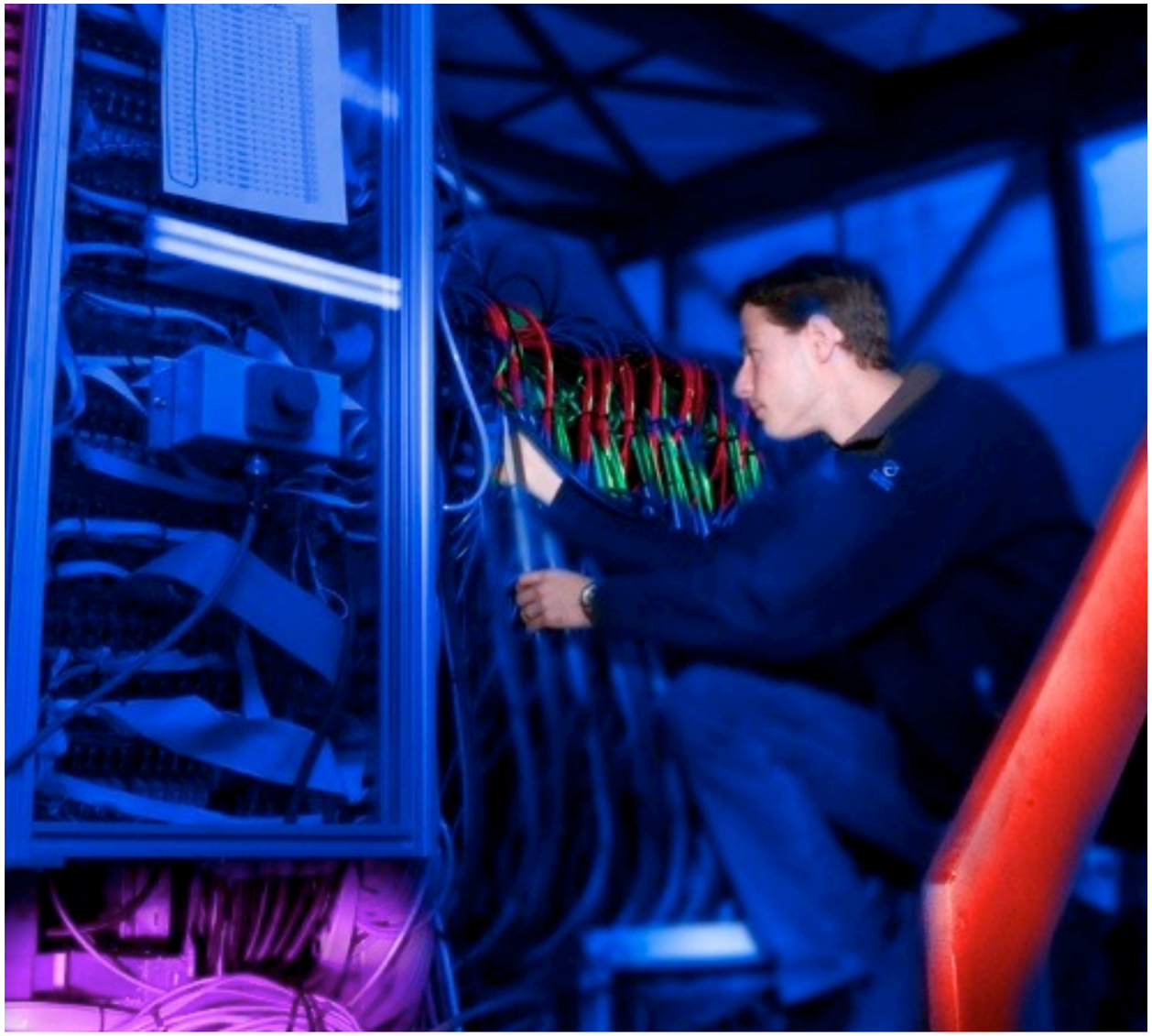
International Workshop on Linear Colliders, Geneva
October 2010

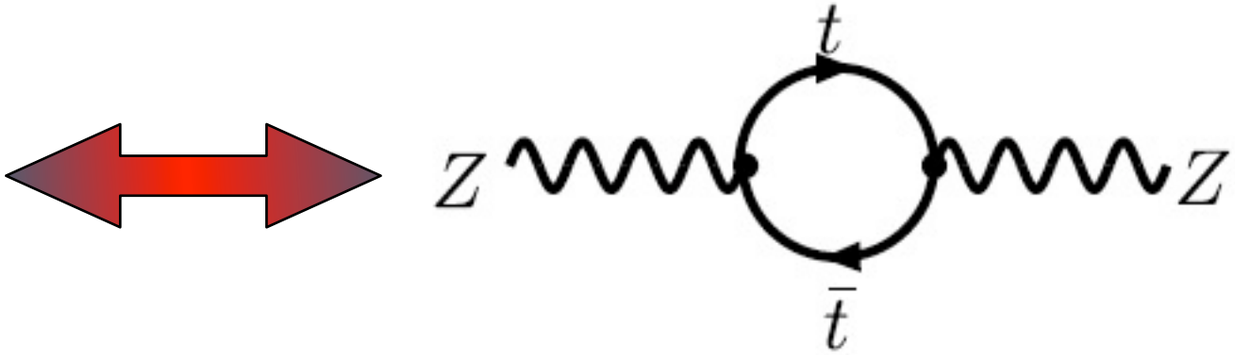
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Excellence Cluster
Universe

Disclaimer

- Very diverse session, from experimental to theoretical aspects, from QCD to extra dimensions and beyond...





... here is a biased experimentalists' perspective.

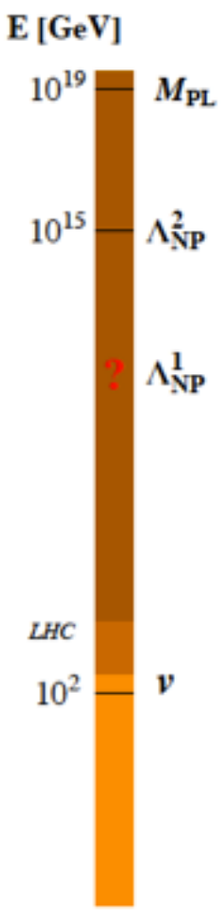
Standard Model and Sensitivity Beyond

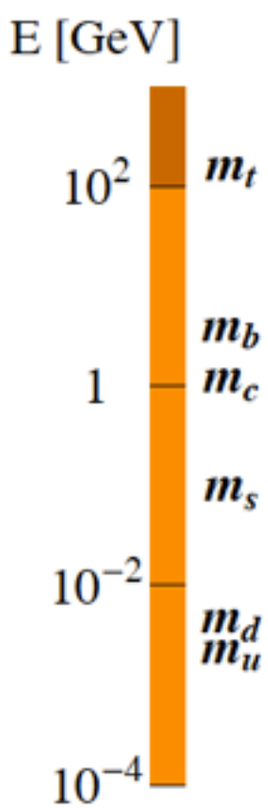
- QCD and electroweak physics are cornerstones of the Standard Model
  - Precision measurements and theory calculations important for further improvement!
    - Important ingredient for MC Generators

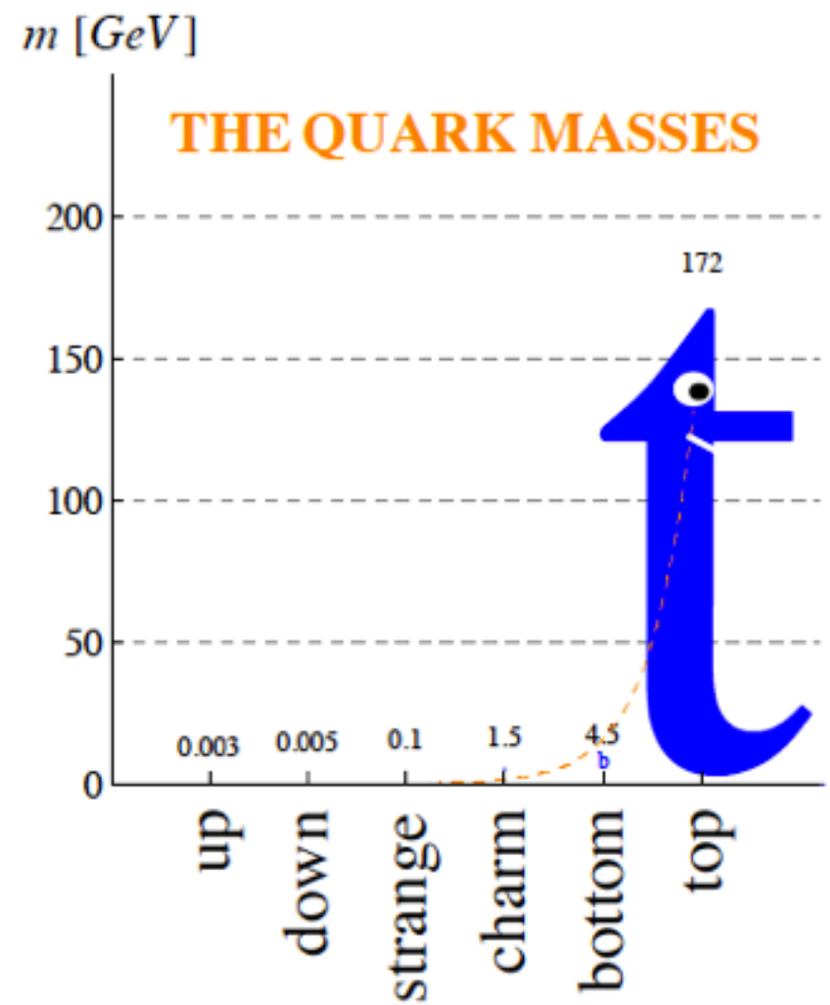
- High precision theory and experiments are already available for a large number of observables
  - Sensitivity for New Physics, well beyond direct collider reach, exists: NP will manifest itself in deviations from expectations
    - Details of observed deviations provide discrimination power between models

The Top Quark: Reaching Across Fields

- The overarching theme of the session: The Top Quark
  - It has color: QCD is important!
  - It is heavy:
    - Connections to EW symmetry breaking in general and to the Higgs
    - Special role in alternative models: potential connections to the hierarchy problem





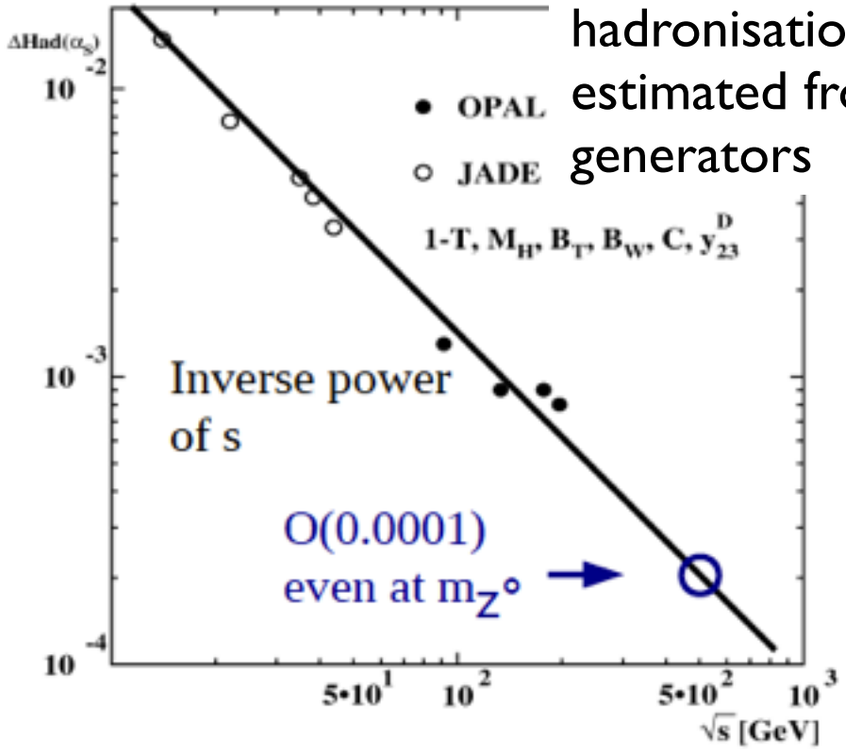


The Strong Coupling Constant α_s

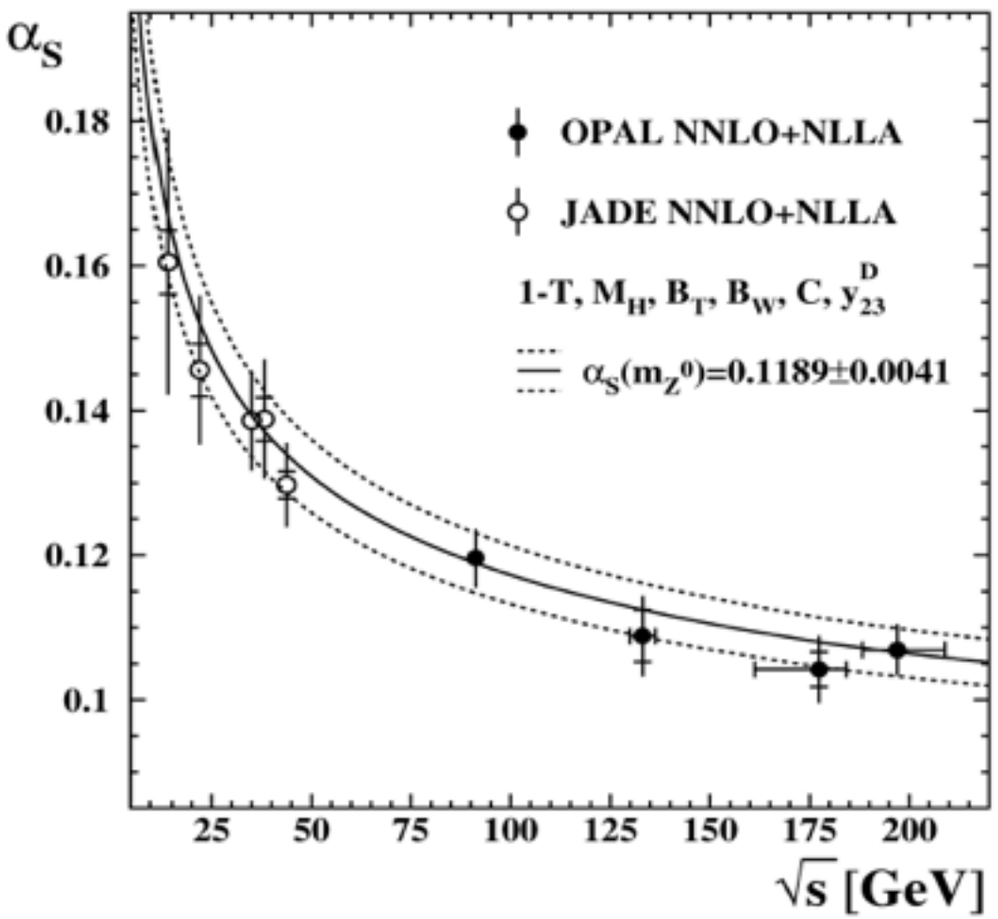
- Measured using event shapes: Thrust et al.

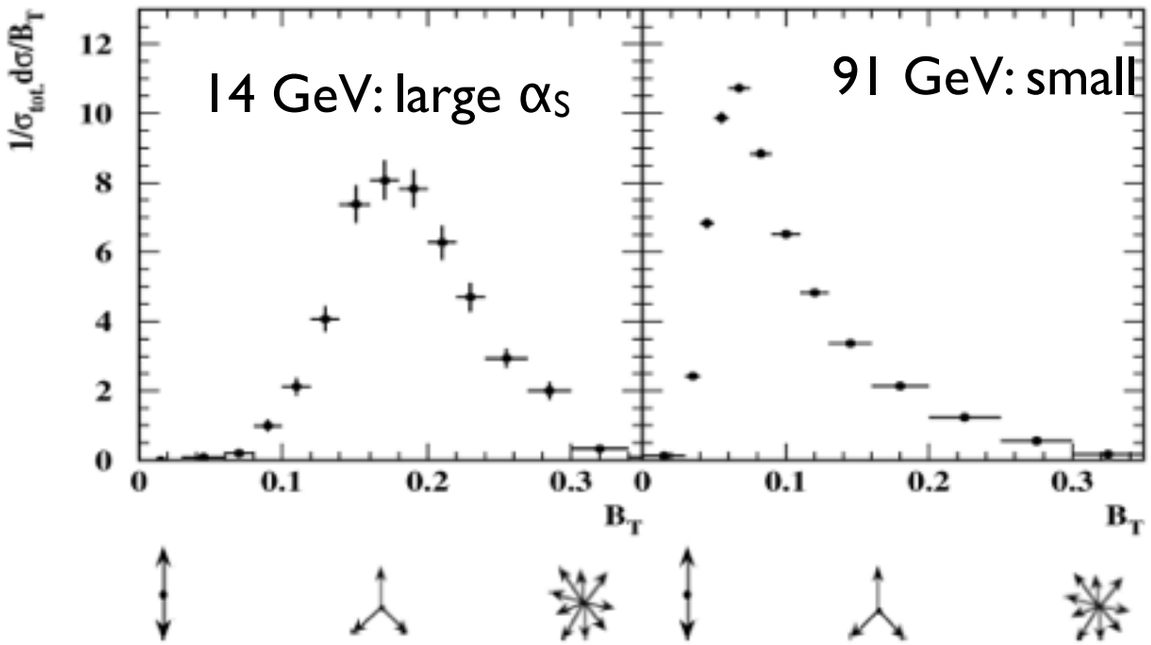
Prospects at a linear collider:

- hadronisation corrections significantly reduced
- uncertainties from uncalculated higher orders significantly reduced



hadronisation uncertainty estimated from different generators





C. Pahl, V. Mateu

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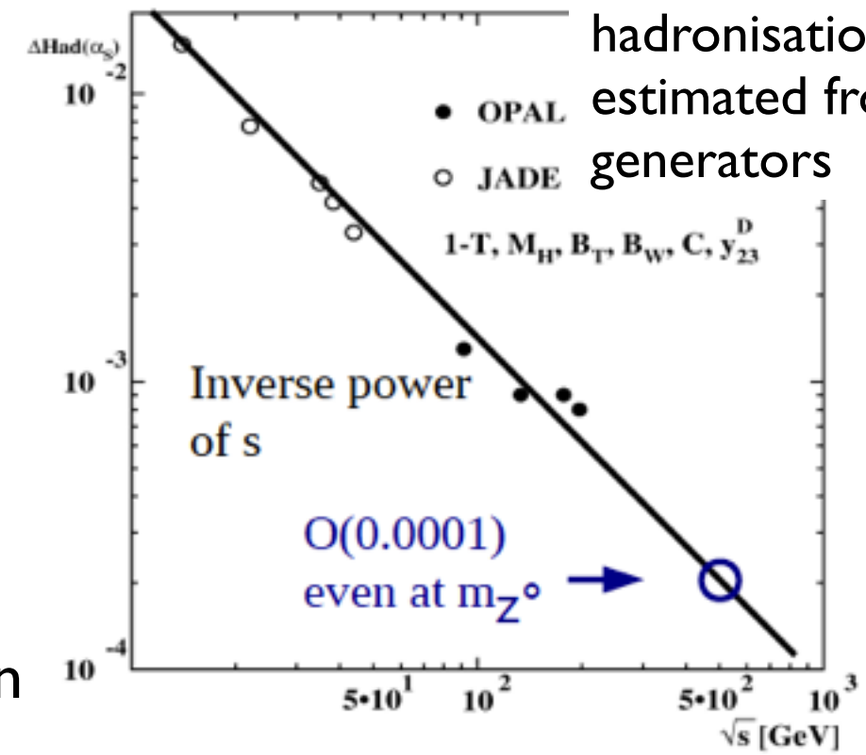
New evaluation without MC:

- Non-perturbative effects from field theory
- Resummation at N^3LL, Renormalon subtraction QED and mass corrections included,...



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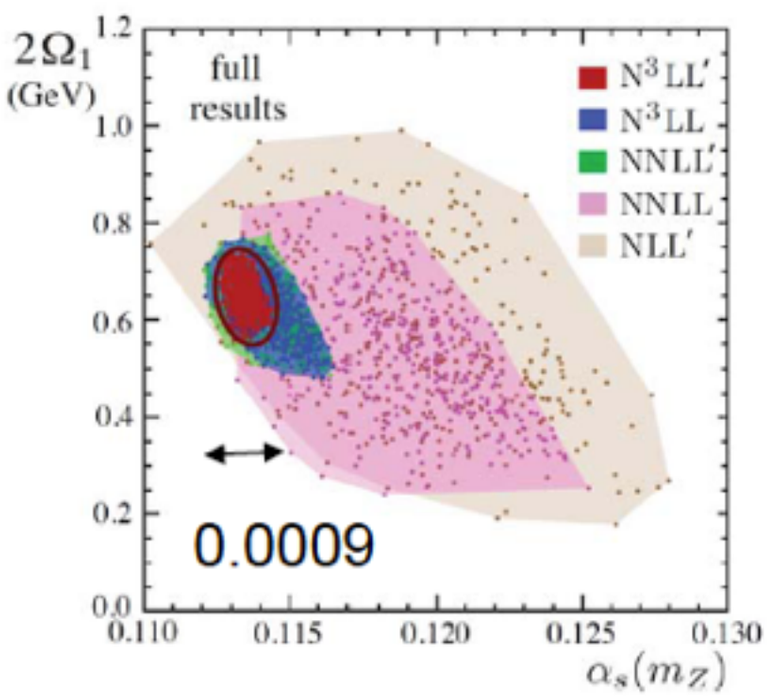
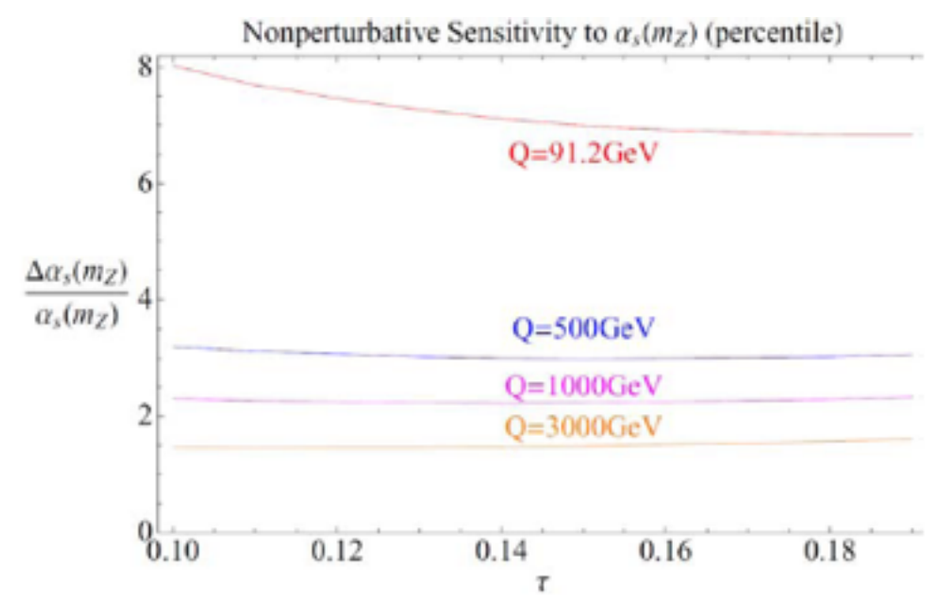


Obtained α_s:
0.1135(9) pert. error

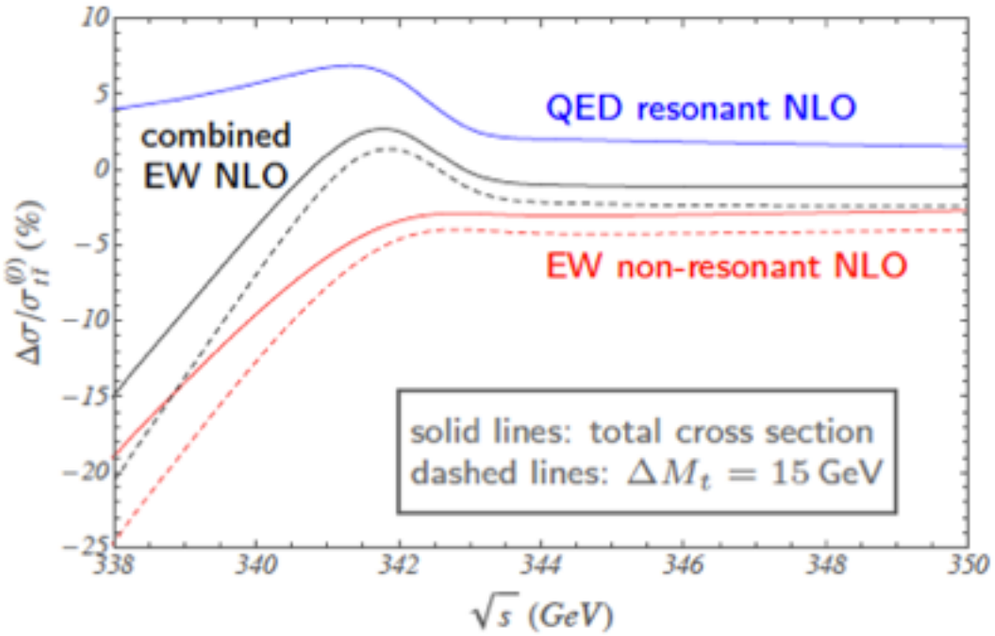
significantly below WA:
0.1183(7)



C. Pahl, V. Mateu

Understanding the Top

- New calculations at the top threshold region: $e^+e^- \to W^+W^-b\bar{b}$

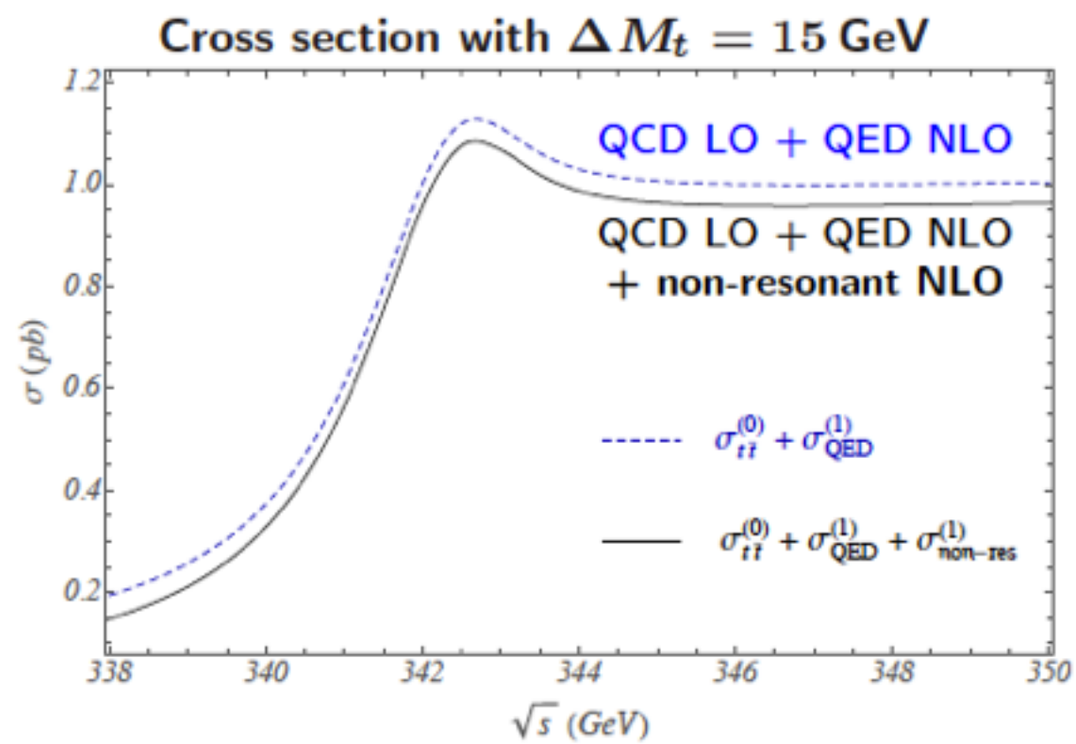


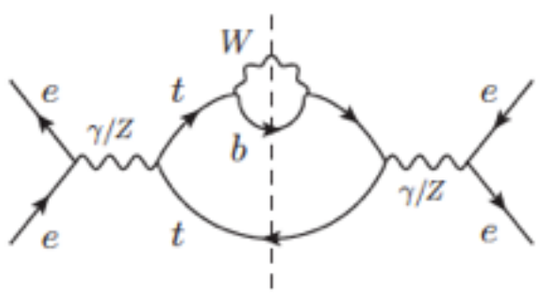
relative size of different contributions to the cross section

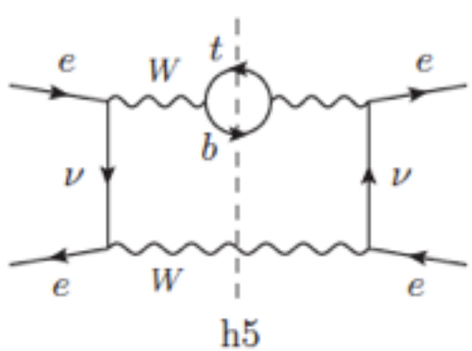
QED resonant correction

EW non-resonant NLO corrections (new!)

(cut on reco t mass)





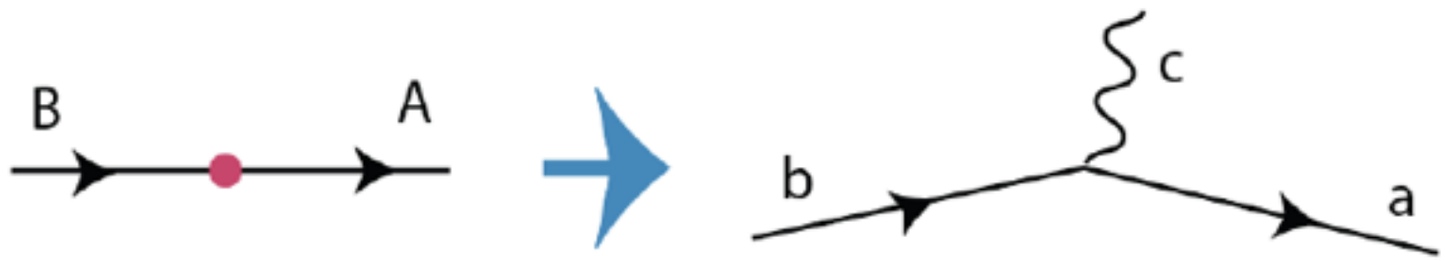


example for non-resonant cut diagrams

B. Jantzen

Bringing the Top into MC

- Parton showers are crucial in MC: Renewed interest
- The goal: correct color correlations + spin dynamics
- The tool: Antenna showers - 2 → 3 process



- The promise: treat massive quarks, mandatory for the top quark (up to now: all quarks were treated massless)

Here are the 3-body matrix elements $\mathcal{O} \to t(a)g(c)\overline{q}(b)$ of this operator:

$$
\begin{aligned}
i\mathcal{M}(t_L g_L \overline{q}_L) &= -\sqrt{2}ig\left\{\frac{\langle a^\flat b\rangle}{[a^\sharp c]}\left(\frac{[a^\sharp ac\rangle}{s_{ac}-m^2}-\frac{[a^\sharp bc\rangle}{s_{bc}}\right)\right. \\
&\qquad \left. +\langle a^\flat c\rangle\langle cb\rangle\left(\frac{1}{s_{ac}-m^2}+\frac{1}{s_{bc}}\right)\right\} \\
i\mathcal{M}(t_L g_R \overline{q}_L) &= \sqrt{2}ig\frac{\langle a^\flat b\rangle[cab\rangle}{\langle bc\rangle}\frac{1}{s_{ac}-m^2} \\
i\mathcal{M}(t_R g_L \overline{q}_L) &= -\sqrt{2}ig\frac{m}{\langle a^\sharp a^\flat\rangle[a^\flat c]}\left\{\frac{\langle a^\sharp c\rangle[a^\flat(a+c)b\rangle}{s_{ac}-m^2}\right. \\
&\qquad \left. +\frac{\langle bc\rangle[a^\flat(b+c)a^\sharp\rangle}{s_{bc}}\right\} \\
i\mathcal{M}(t_R g_R \overline{q}_L) &= \sqrt{2}ig\frac{m}{\langle a^\sharp a^\flat\rangle\langle bc\rangle}\langle a^\sharp b\rangle\frac{[cab\rangle}{s_{ac}-m^2}
\end{aligned}
$$

Larkoski and I feel that this is a promising strategy for generating spin-aware antenna showers with top quarks. Much work remains to be done. Wish us luck !

M. Peskin

Measuring the Top

- ILC can provide significant improvements of top couplings in synergy with LHC

Operators with two 3rd generation quarks + two leptons

	$t\bar{b}e_i\bar{\nu}_j$	$t\bar{t}e_i\bar{e}_j$	$t\bar{t}\nu_i\bar{\nu}_j$	#		$t\bar{b}e_i\bar{\nu}_j$	$t\bar{t}e_i\bar{e}_j$	$t\bar{t}\nu_i\bar{\nu}_j$	#
$O_{\ell q}^{ji33}$	–	✔	✔	6	O_{qe}^{3ij3}	–	✔	–	6
$O_{\ell q'}^{j33i}$	✔	–	✔	6	O_{qde}^{ji33}	✔	–	–	9
O_{eu}^{ji33}	–	✔	–	6	$O_{\ell qe}^{ji33}$	✔	✔	–	9
$O_{\ell u}^{j33i}$	–	✔	✔	6	$O_{q\ell e}^{3ij3}$	✔	✔	–	9

ILC benefits

- operators only tested at ILC: $O_{\ell q}$, O_{eu}, $O_{\ell u}$, O_{qe}
- better precision for other ones: $O_{\ell qe}$, $O_{q\ell e}$

- Combine Wt_Lb_L from LHC single top with Zt_Lt_L from ILC: increase in sensitivity to NP

J. A. Aguilar-Saavedra, H. Tabassam

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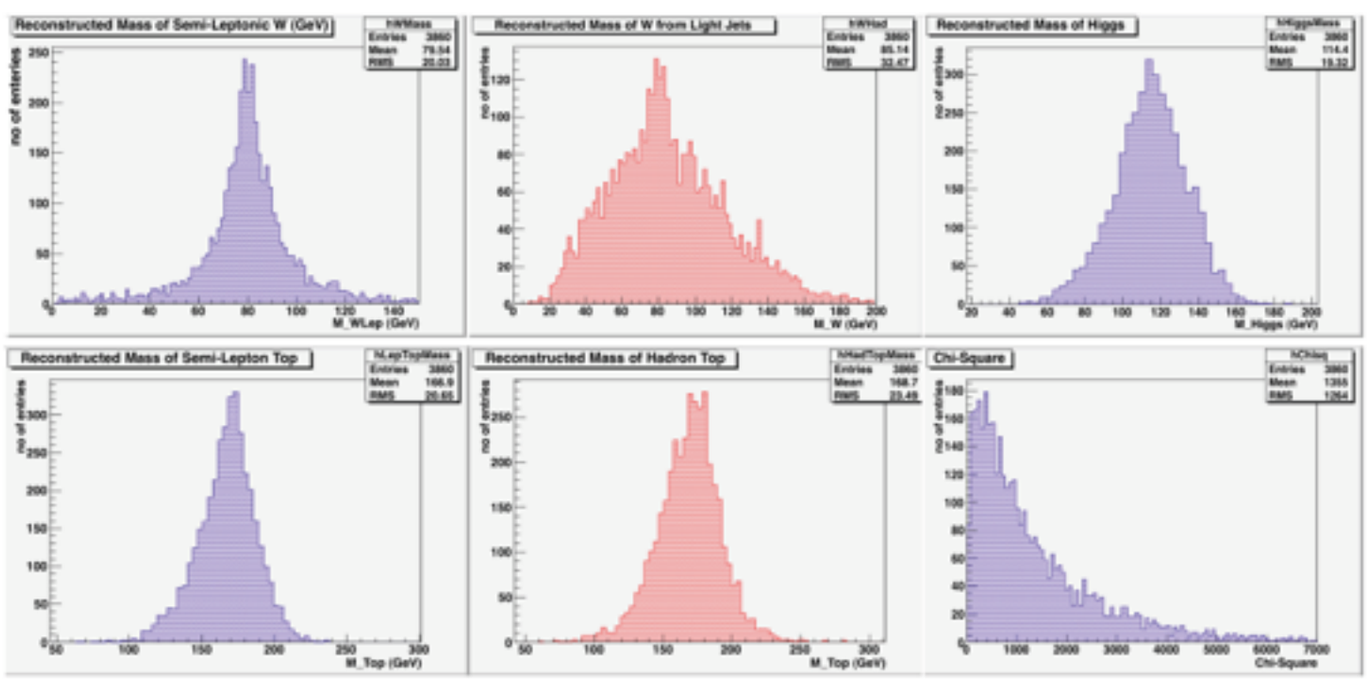
- Combine Wt_Lb_L from LHC single top with Zt_Lt_L from ILC: increase in sensitivity to NP
- Simulation study of Top-Yukawa Coupling at 500 GeV:



$$e^+e^- \to t\bar{t}H \to W^+bW^-\bar{b}b\bar{b}$$

semileptonic mode: one W decays into lν, with l = e, μ

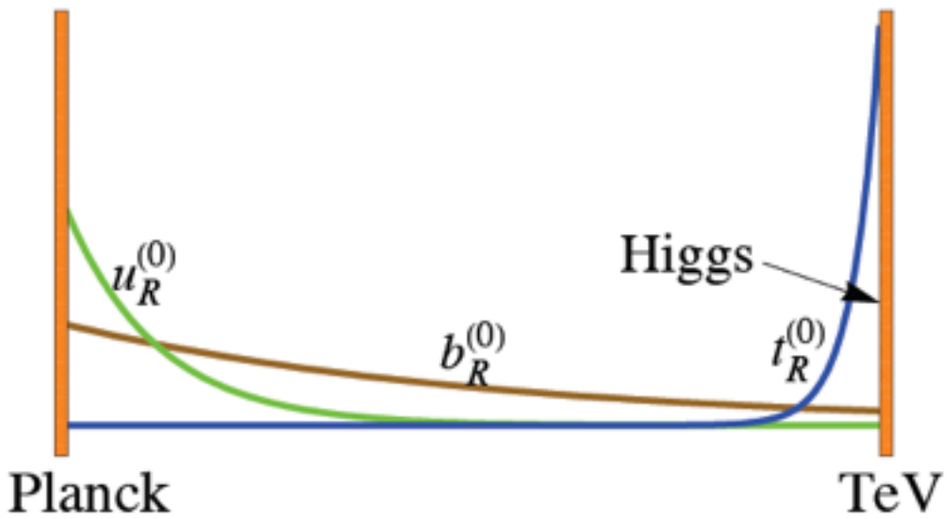
Final state:

1 lepton, missing energy, 6 jets (4 b-jets)

J. A. Aguilar-Saavedra, H. Tabassam

The Top as a Window to Extra Dimensions

- Warped XD (RS) - Models provide the possibility to address unexplained hierarchies:



Expect sizable effects in couplings involving third generation quarks

But: Corrections to A_{FB} at Tevatron are quite small

High precision by ILC for σtt and A_{LR} :
Sensitivity to KK scales of 150 TeV (brane fermions), 30 TeV (bulk fermions)

F. Goertz, P. Doublet

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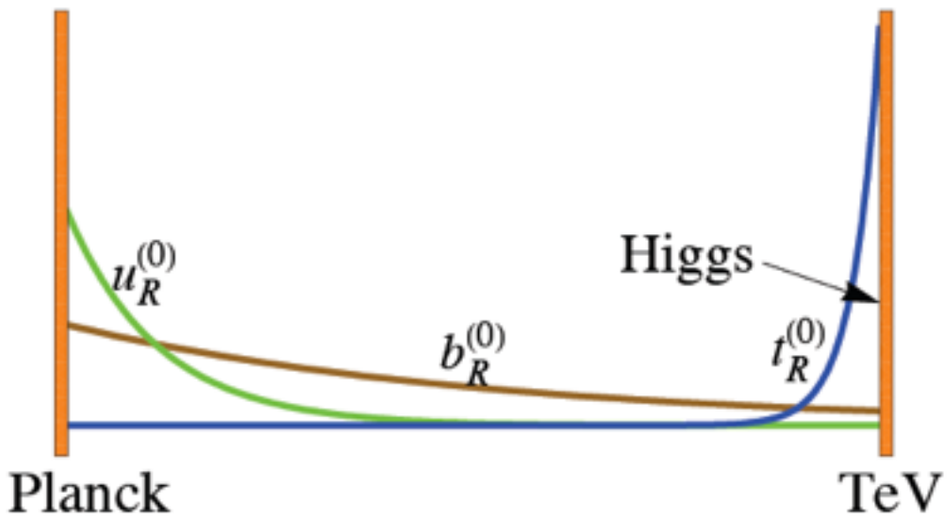

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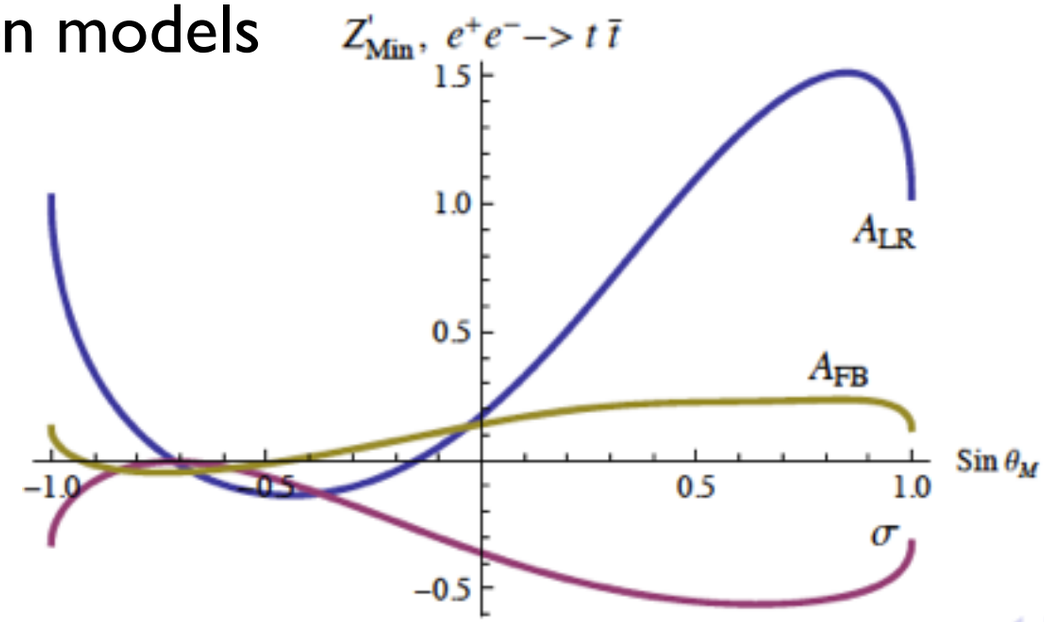
- A full simulation study of the measurement of left ($g_Z(t_L)$) and right ($g_Z(t_R)$) top couplings to the Z: Sensitive to wXD via Z-Z_{KK} mixing
- Simulated in ILD: 500 fb^{-1} at 500 GeV $e^+e^- \to t\bar{t} \to bl\nu\,\bar{b}q\bar{q}'$
  - Full reconstruction using PandoraPFA, detailed study of lepton selection efficiency

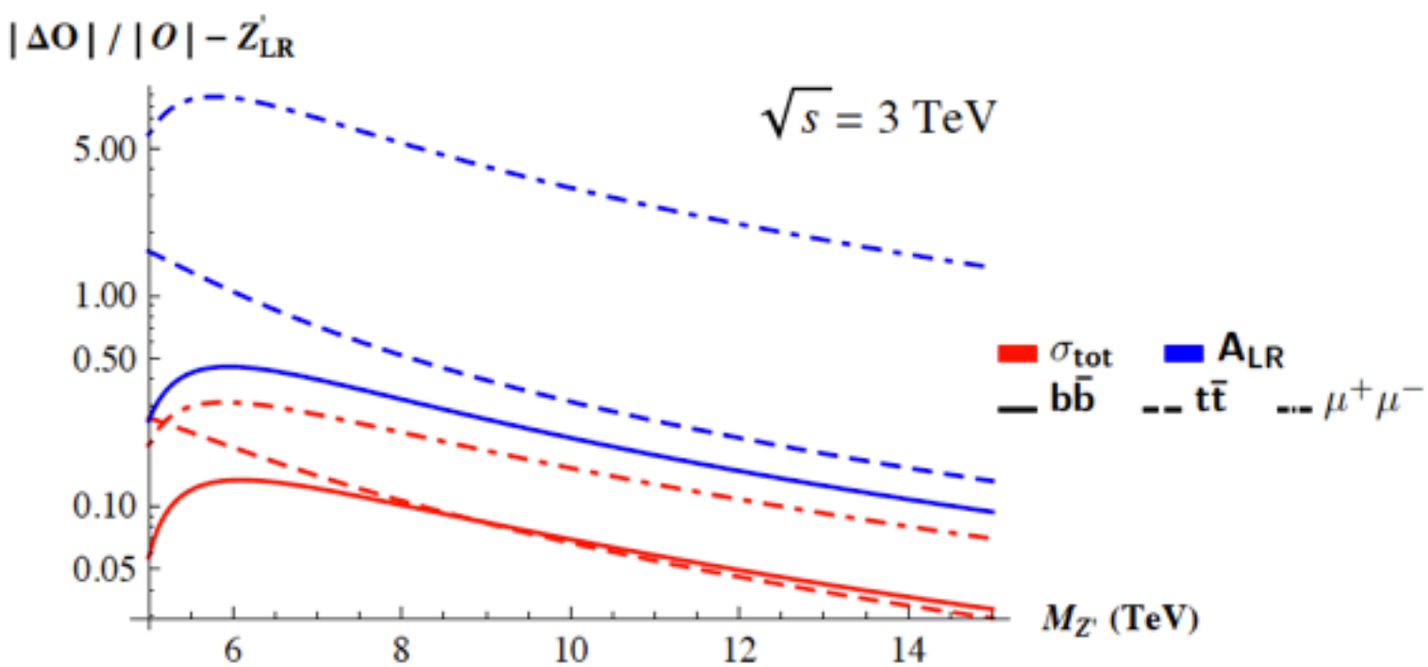
- Promising first results: Expected precision Δσ/σ ~ 0.4% (stat) unpolarized
  $\Delta A_{LR}/A_{LR}$ ~ 0.7% (stat)

F. Goertz, P. Doublet

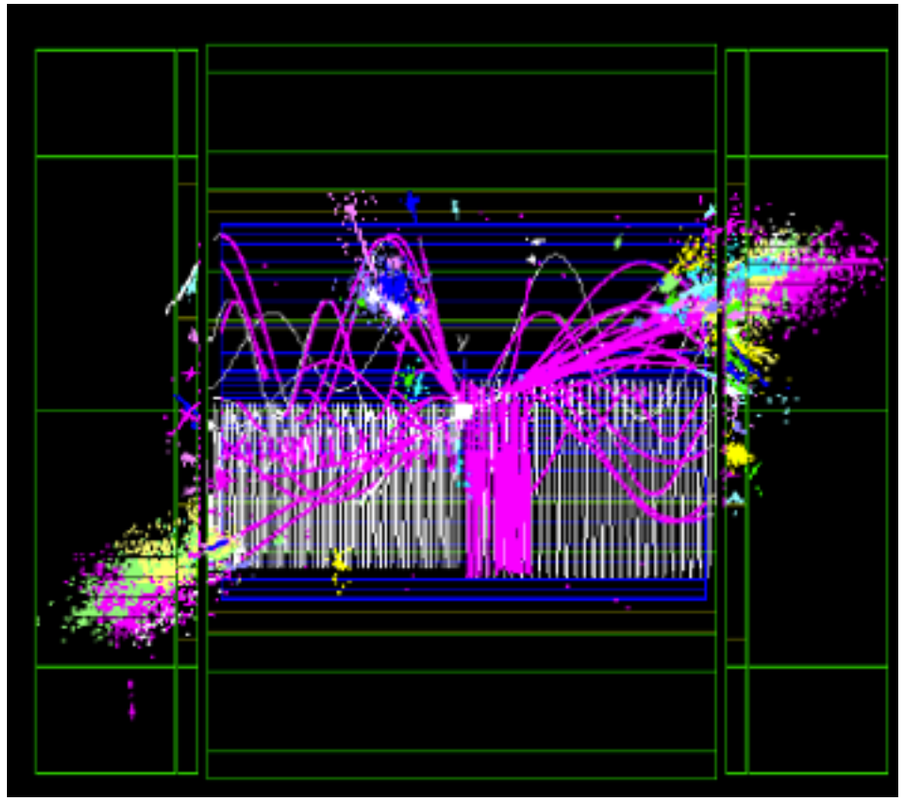
The Top as a Window to Massive Gauge Bosons

- Precision measurements of various two-fermion final states at CLIC provide sensitivity far beyond the direct reach of colliders and discrimination power between models





First CLIC full detector studies beginning



F. Coradeschi

EW Observables Beyond the SM

- Direct observation of a heavy resonance at LHC would demand a follow-up with e^+e^- colliders, similar to the Z at LEP/SLD, with polarization
  - High statistics expected
  - Potential for discovery of new particles in the decay products
- For states beyond the direct reach of a LC: Reasonable determination of spin and couplings possible up to 6 TeV through indirect measurements

T. Rizzo, T Saito

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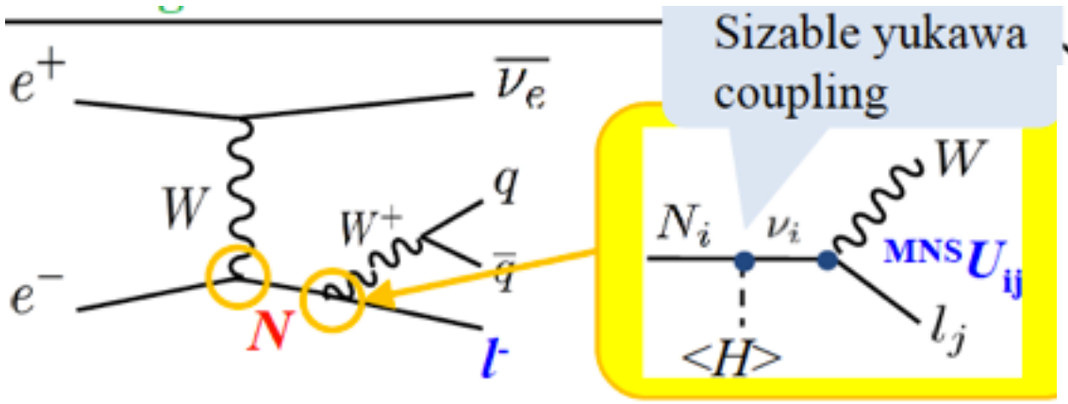
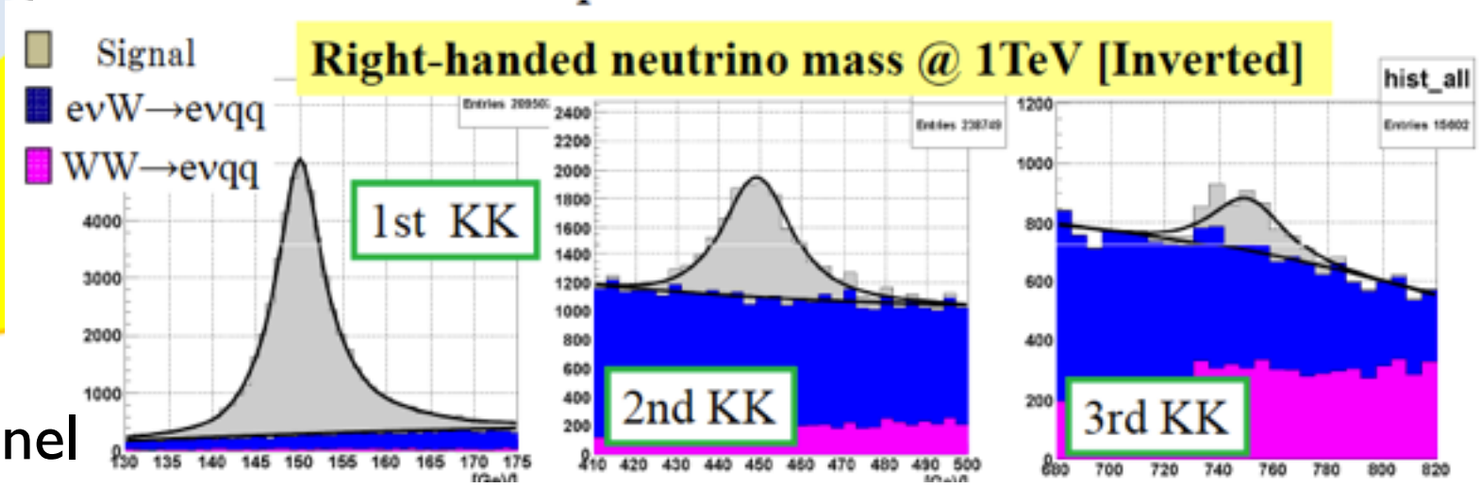
- Potential to see heavy right-handed Neutrinos: di-jet + lepton + missing energy



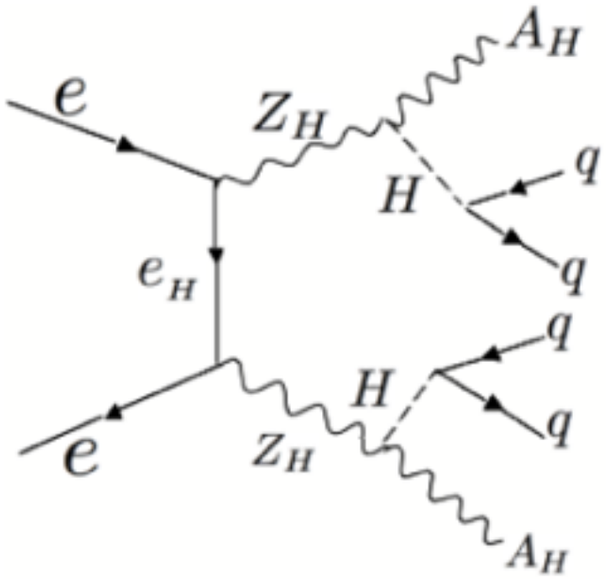


- Clean measurement in electron channel
- Model identification by adding tau channel (more challenging!)

T. Rizzo, T Saito

Alternative Higgses and other Beasts

- Little Higgs with T Parity
  - Results in new heavy gauge bosons A_H (dark matter candidate), W_H, Z_H: Accessible at linear colliders



for models with mass scales of a few 100 GeV: cross sections ~ 100 fb

➪ Challenging analysis, large SM Background

E. Kato, A. Weiler, M. Redi, D. Pappadopulo

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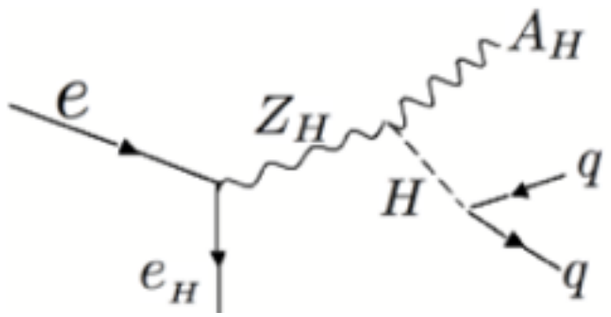

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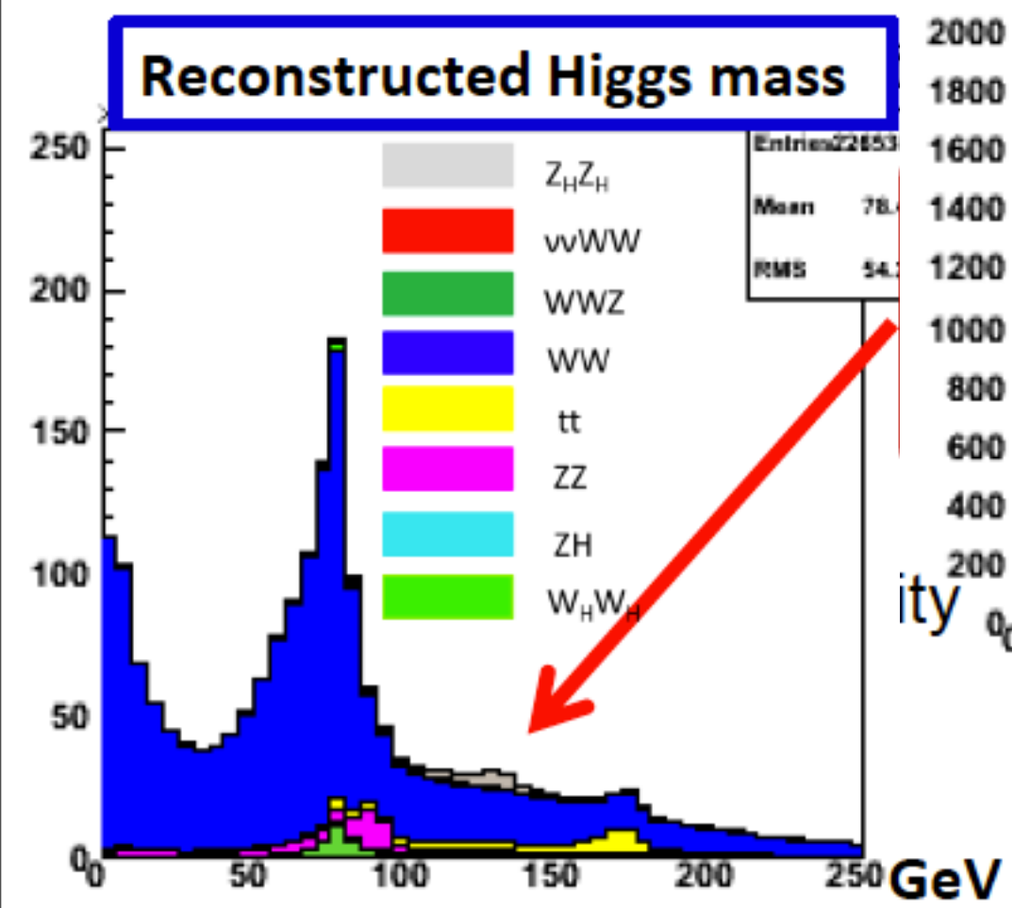

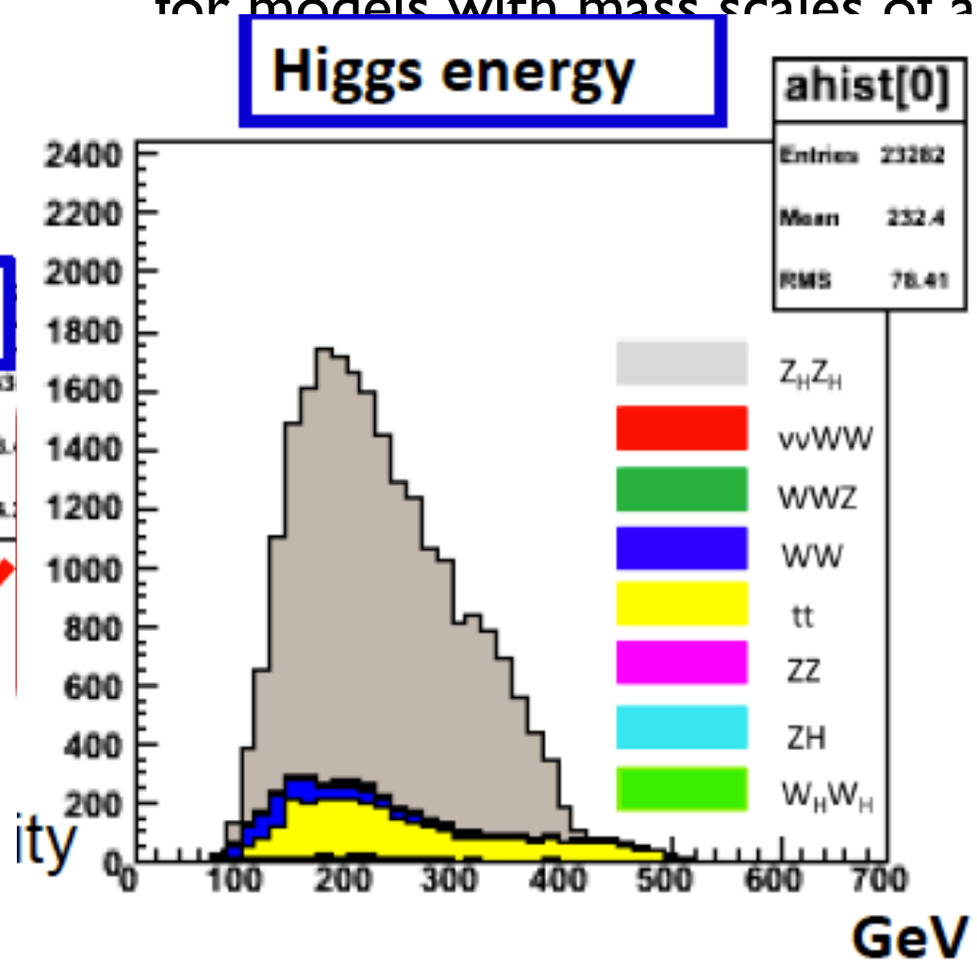

ity

ıckground

high purity is reachable with b tagging, rejection of isolated leptons, and acoplanarity requirements

E. Kato, A. Weiler, M. Redi, D. Pappadopulo

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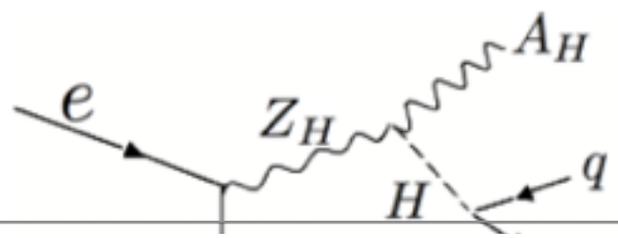

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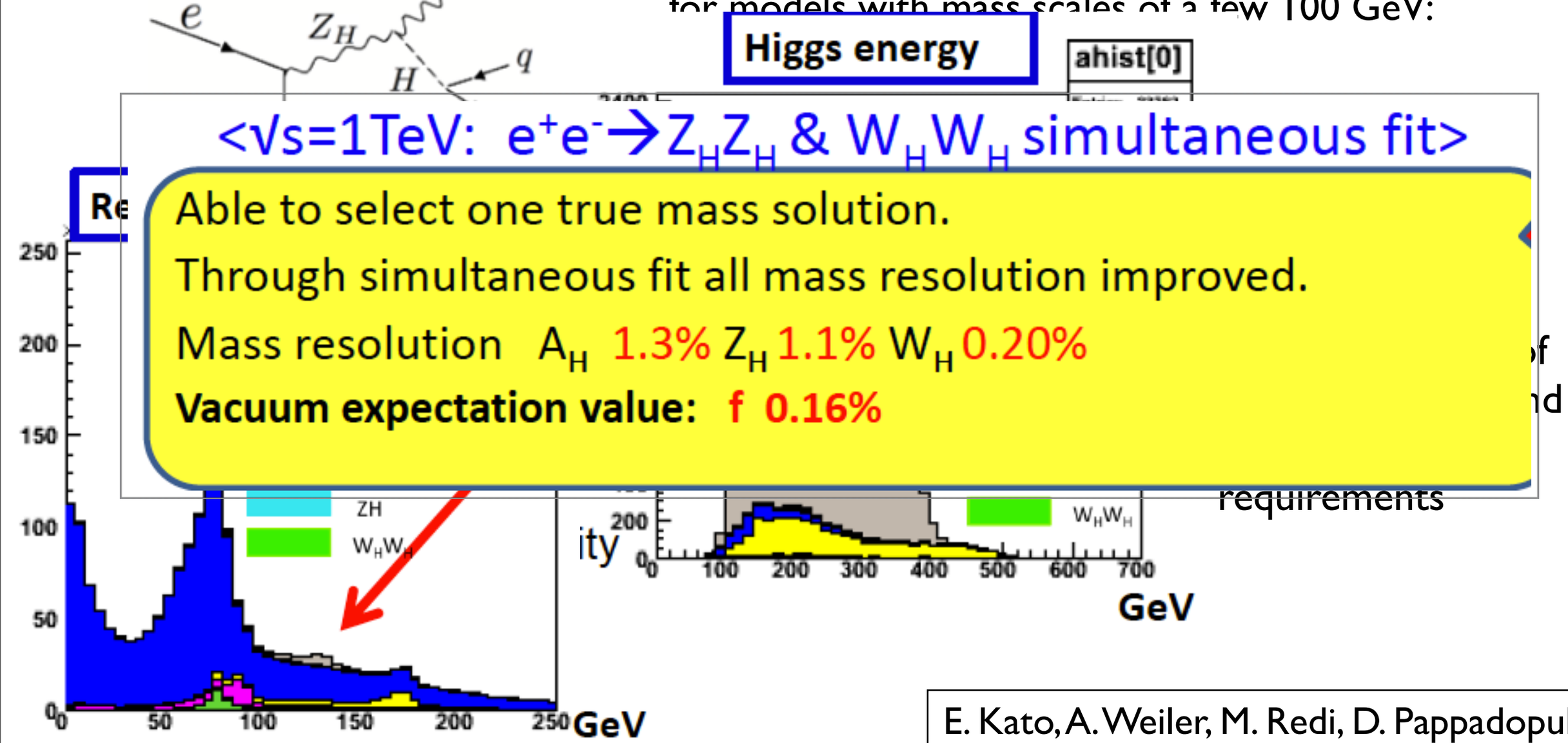


<Vs=1TeV: $e^+e^- \rightarrow Z_H Z_H$ & $W_H W_H$ simultaneous fit>

Able to select one true mass solution.

Through simultaneous fit all mass resolution improved.

Mass resolution A_H 1.3% Z_H 1.1% W_H 0.20%

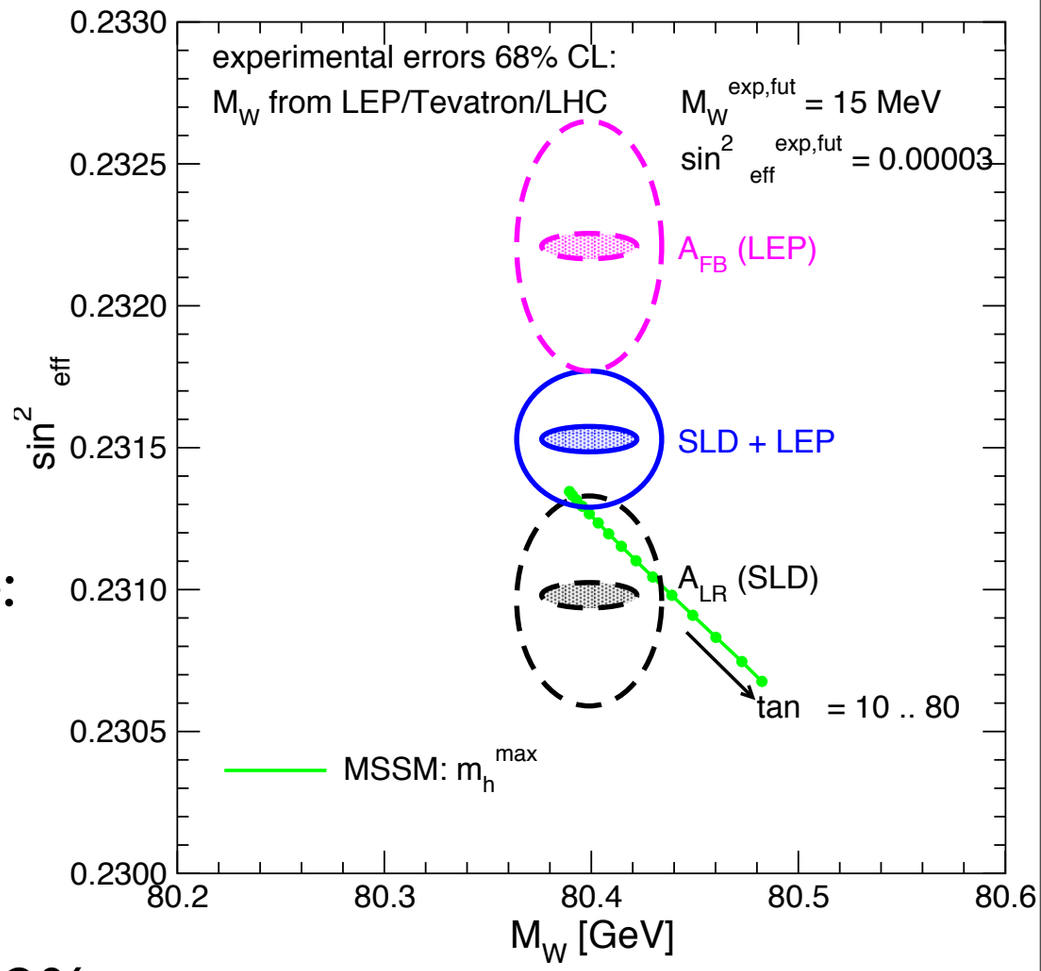
Vacuum expectation value: f 0.16%

requirements

E. Kato, A. Weiler, M. Redi, D. Pappadopulo

The Importance of Polarization

- Polarized $e^{\pm}$ beams required for many EW precision studies
  - Both at the Z pole ("Giga-Z") and at high Energy
- Some effects can only be achieved with polarized e- and e+:
  - access to specific triple gauge coulings
  - accuracy in ΔA_{LR} (important for many studies!)
  - precision measurements on $\sin 2\theta_{eff}$ at the Z-pole: potential to clarify LEP / SLD measurements



- New strawman baseline design foresees $P(e^+)$~22%:
  - can be compensated in some cases by achieving $P(e^-)$=90%, but not in all cases
- Explore possibilities to increase $P(e^+)$ to 30% or more

G. Moortgat-Pick

Summary

- QCD and EW Physics form the Foundation of the Standard Model: Theoretical & experimental advances are of key importance (and interesting!)

- A Linear Collider is an excellent tool for precision measurements in that area:
  - Direct measurements, Top physics and other studies provide access also to phenomena (far) beyond the Standard Model