IWLC2010
"Conclusions from Physics"

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Cambridge

October 22, 2010

CICG Geneva

CERN Geneva

Tomorrow's bright future (e.g., LC) goes through the gateway of "today's" successes: discoveries (e.g., LHC, Tevatron) and R&D.

The most important things that happened this week for the LC might include

… a graduate student pouring through LHC data on a sleepless night in Warsaw.

… an accelerator physicist who just worked out a luminosity improvement technique.

… an LC detector expert who made a breakthrough in design.

Where does Higgs, SUSY, Xdim, etc. fit in?

What'll be most important physics >2020?

No answer can be given now.

What are we doing?

We are showing that LC can make new discoveries* of the leading theories of today beyond the experiments that precede it.

1. Any other attitude (e.g., "who knows, let's see what happens without pre-conceived prejudices") is *too speculative* to support.
2. Knowledge gained through studying concrete "theories of the day" likely will transfer to the study of our theories refined by discoveries of tomorrow.
3. Detectors and accelerator R&D must be guided by our best physics ideas now, with an eye toward inclusiveness to cover the possibilities.
4. This is a time-independent stable strategy to "physics case" studies.

*** "discoveries" is all encompassing (e.g., new particles, new interactions, precision, etc.)**

“Leading Theories of Today”

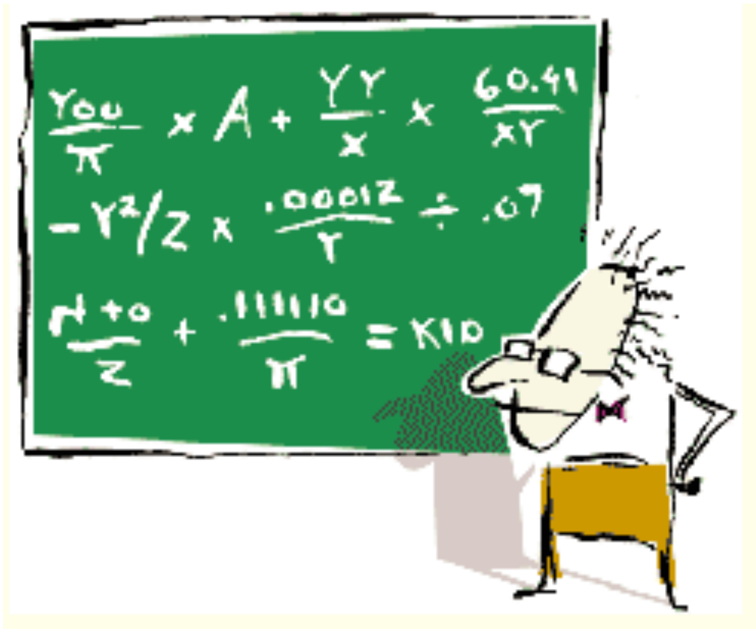
Standard Model

Supersymmetry

Alternatives: Xdims, SCTs, etc.

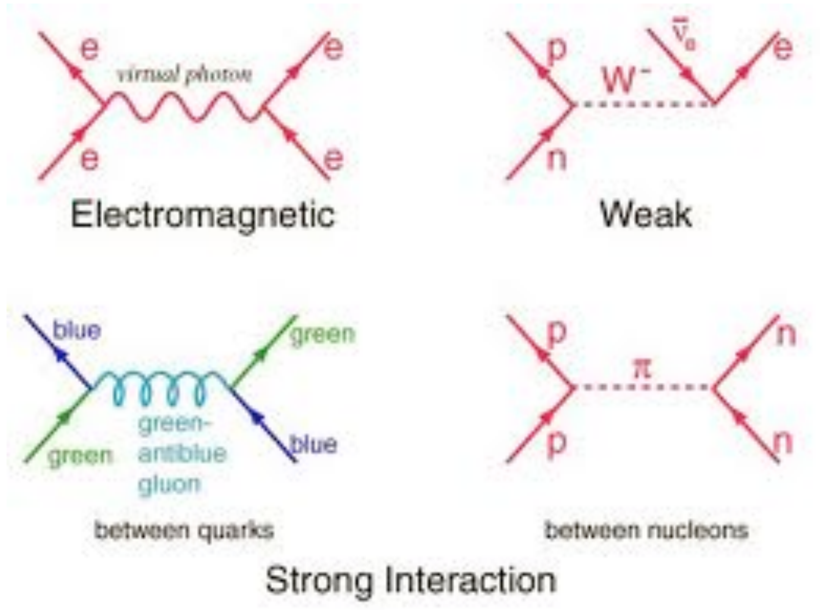
Higgs boson physics

chcr.umich.edu



Please also see ECFA Summary Talks:
Roman Poechl, Higgs
G. Servant, SUSY + Cosmology
C. Royon, Gamma Gamma physics
S. Riemann, Polarisation
M. Weber, Loopverein and generators
F. Simon, Top/QCD Electroweak and Alternatives

Standard Model



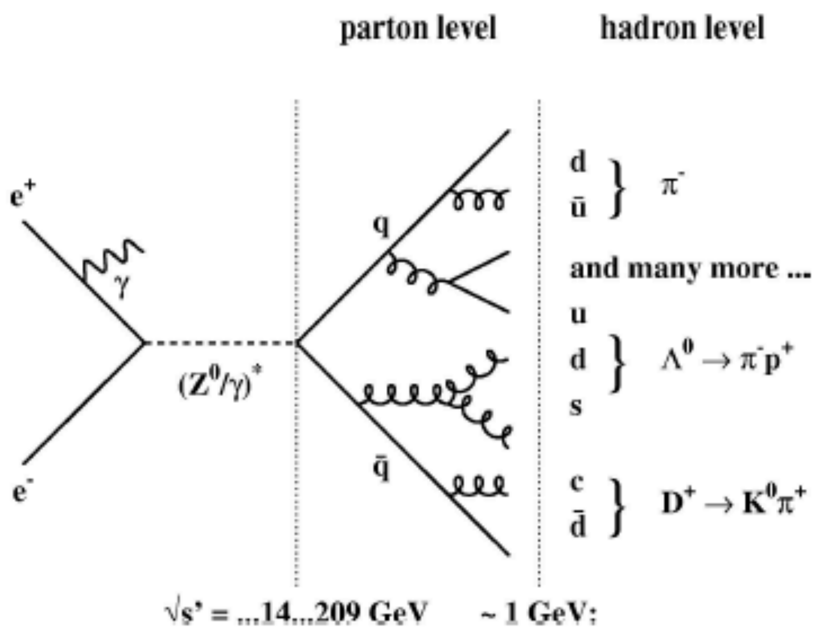
universe-review.ca

Critical to continue our understanding and computations of SM processes for purposes of background subtraction and comparisons for precision analysis.

M. Davier, “News on g-2”
V. Mateu, “Thurst at N3LL with power corrections and a precision global fit for alphas(mZ)”
C. Pahl, “Determination of alpha_s from event shapes”
P. Doublet, “Reconstructing the semileptonic decay channel of the top quark (with ILD)”
M. Peskin, “Top quark antenna splitting function”
B. Jantzen, “Electroweak NLO corrections to top threshold production”
H. Kuehn, “W-Pair production in the TeV region”
Etc.

Fits of distributions

Hadronisation: Monte Carlo models



Hadronic event in $e^+ e^-$ annihilation

Predictions: Next to Next to Leading Order $O(\alpha_s^3)$

(finished 2008 after 25 years)

$$\frac{1}{\sigma}\frac{d\sigma}{dy}=\frac{dA}{dy}\frac{\alpha_s}{2\pi}+\frac{dB}{dy}\left(\frac{\alpha_s}{2\pi}\right)^2+\frac{dC}{dy}\left(\frac{\alpha_s}{2\pi}\right)^3$$

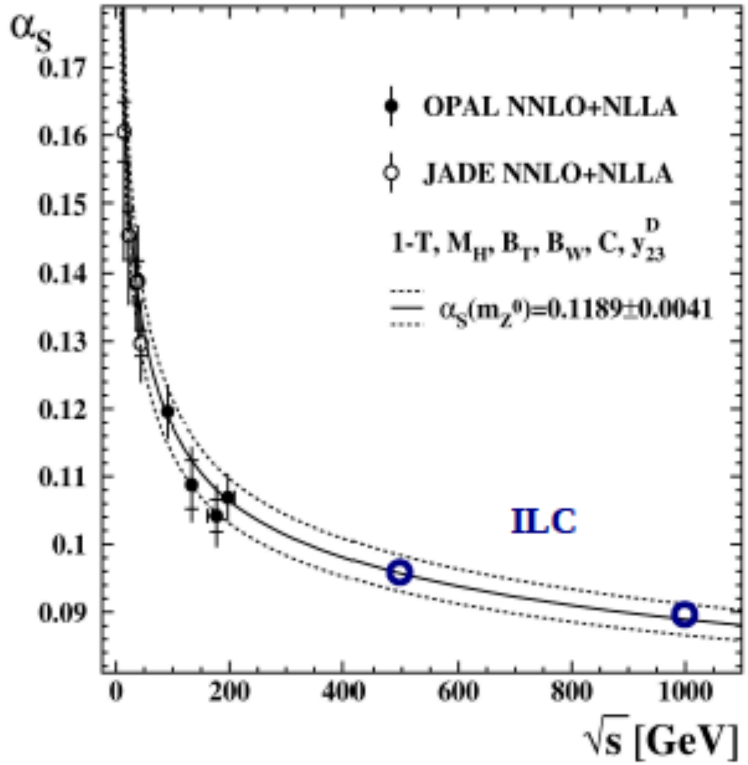
+normalization
+scale dependence (compensation in 2 loops)

optionally:
+**N**ext to **L**eading **L**ogarithmic **A**pproximation (scale compensation in 1 loop)

C. Pahl, "Determination of alpha_s from event shapes"

Summary, ILC

- Uncertainties of $\alpha_s(m_{Z^\circ})$ measurement at 500 GeV:
  - Statistical ~ 0.0001
  - Detector ~ 0.001
  - Background ~ 0.001
  - Hadronisation ~ 0.0001
    partons are almost seen!
  - Scale ~ 0.001
    NNLO very important
- ILC+NNLO = precision

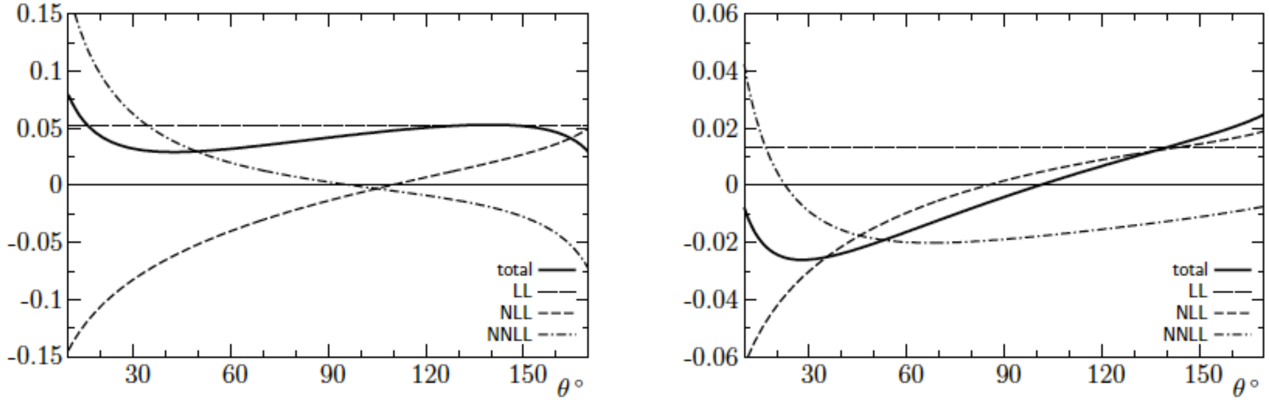


Test of the running of $\alpha_s(\sqrt{s})$: Extended lever arm

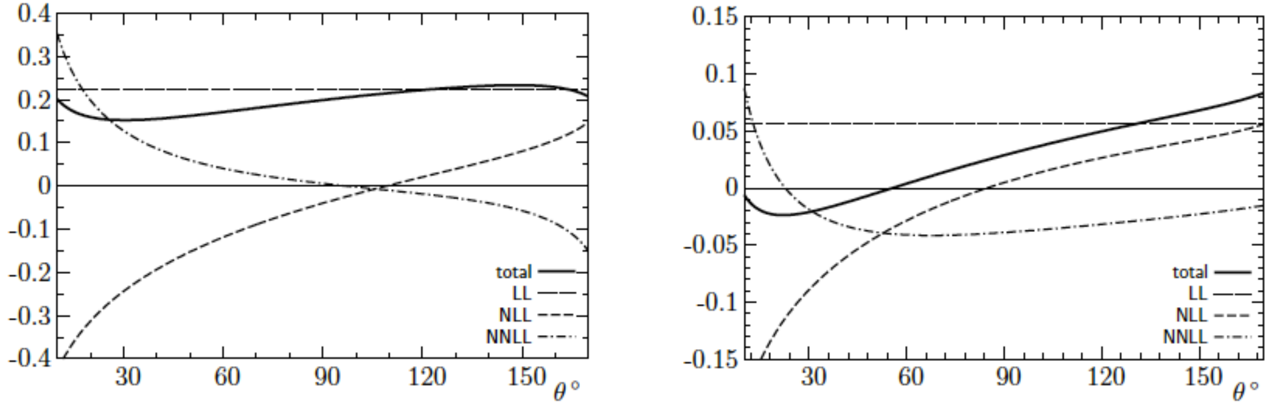
C. Pahl, "Determination of alpha_s from event shapes"

WW production at Linear Collider

2-loop



The two-loop logarithmic corrections to the differential cross section relative to the Born approximation at $\sqrt{s} = 1$ TeV as functions of the production angle fortransverse (left) and longitudinal (right) polarization of the gauge bosons.



The same as above but for $\sqrt{s} = 3$ TeV.

Kuehn, Metzler, Penin, 0709.4055

“Alternatives”

Many interesting ideas of physics beyond the SM that are motivated by problems of today (Hierarchy problem, Dark Matter, etc.)

Telegraph.co.uk

T. Saito, “Extra dimensions and seesaw neutrinos at the ILC”
F. Goertz, “Top pair production within warped models”
A. Pankov, “Identification of extra neutral gauge bosons at a LC with polarised beams”
F. Coradeschi, “Studying new physics with precision ew observables in multi-tev e+e-”
D. Pappadopulo, “T-parity in Little Higgs models”
E. Kato, “Precision measurements of little higgs with t-parity parameters at ILC”
T. Rizzo, “Indirect search reaches for indirect Z’-like objects”
Etc.

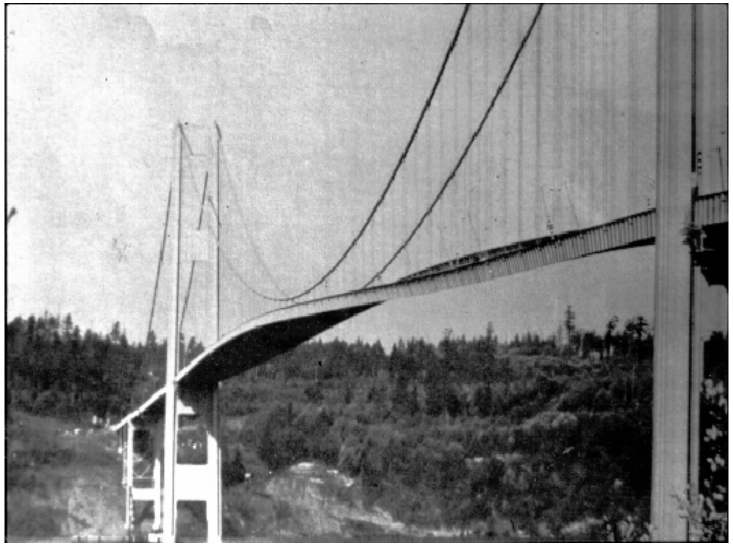
Possible Signals at a Linear Collider

Sensitivity to KK scales that are not (directly) accessible at the LHC (or testable with current EWP measurements) could be possible at ILC due to high precision

De Pree, Sher, hep-ph/0603105

- For brane fermions a 1% measurement of $\sigma_{t\bar{t}}$ could probe KK scales of up to 150 TeV ($\sqrt{s} = 1$ TeV)
- For bulk fermions (depending on bulk masses) sensitivity up to $10 - 15$ TeV is possible by precision measurement of $\sigma_{t\bar{t}}$
- Measurement of A^t_{LR} with sensitivity of 0.2% (several years of ILC running) could probe KK scales of up to 30 TeV for bulk fermions
- Corrections to A^t_{FB} (for bulk fermions) presumably too small also at ILC

Alternatives:
New Resonances



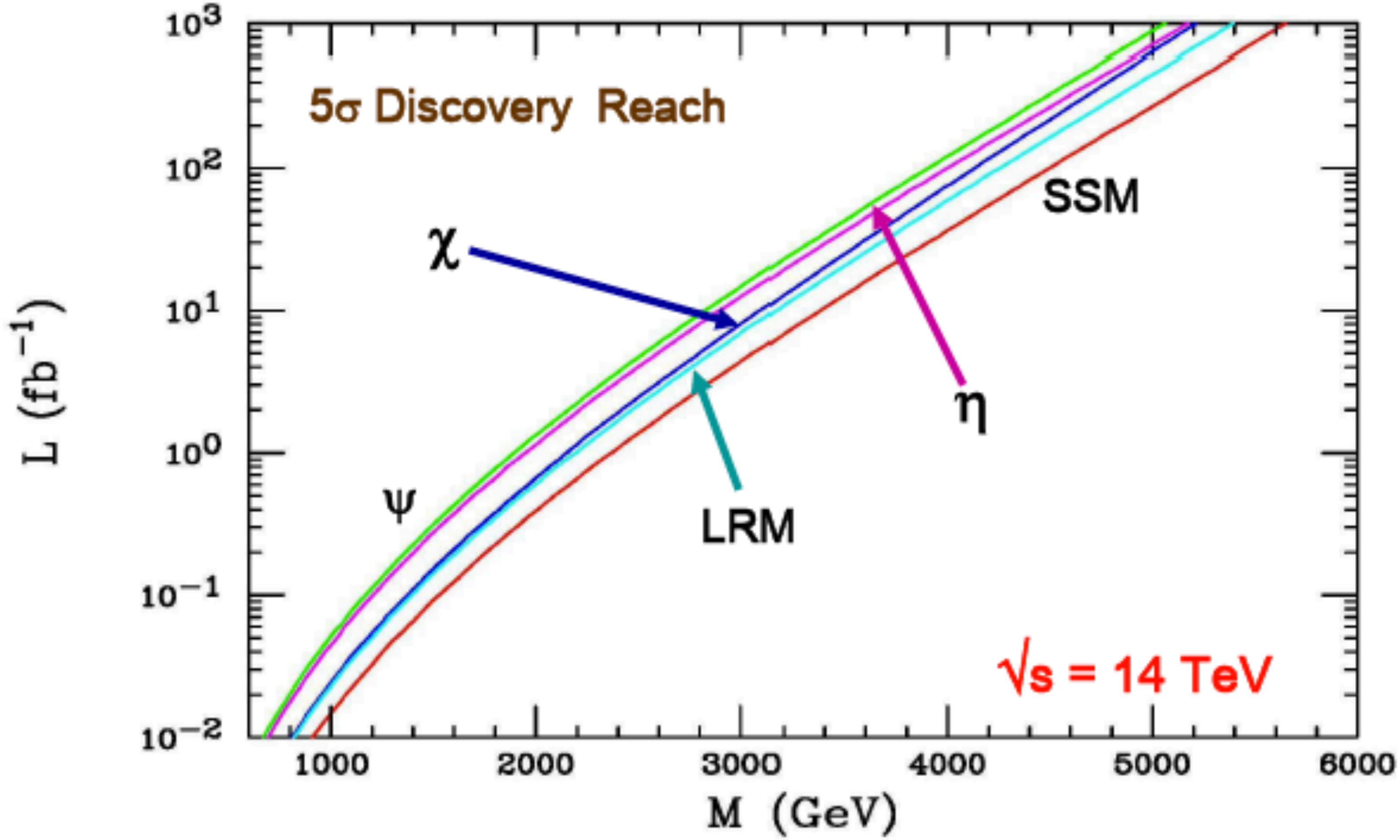
Tacamo bridge resonance

Many ideas of physics beyond the Standard Model have new resonances in the TeV region.

- KK excitations of gravitons and gauge bosons
- "Mesons" of strongly interacting EWSB theories
- Etc.

And the classic example of Z' in gauge-extended theories

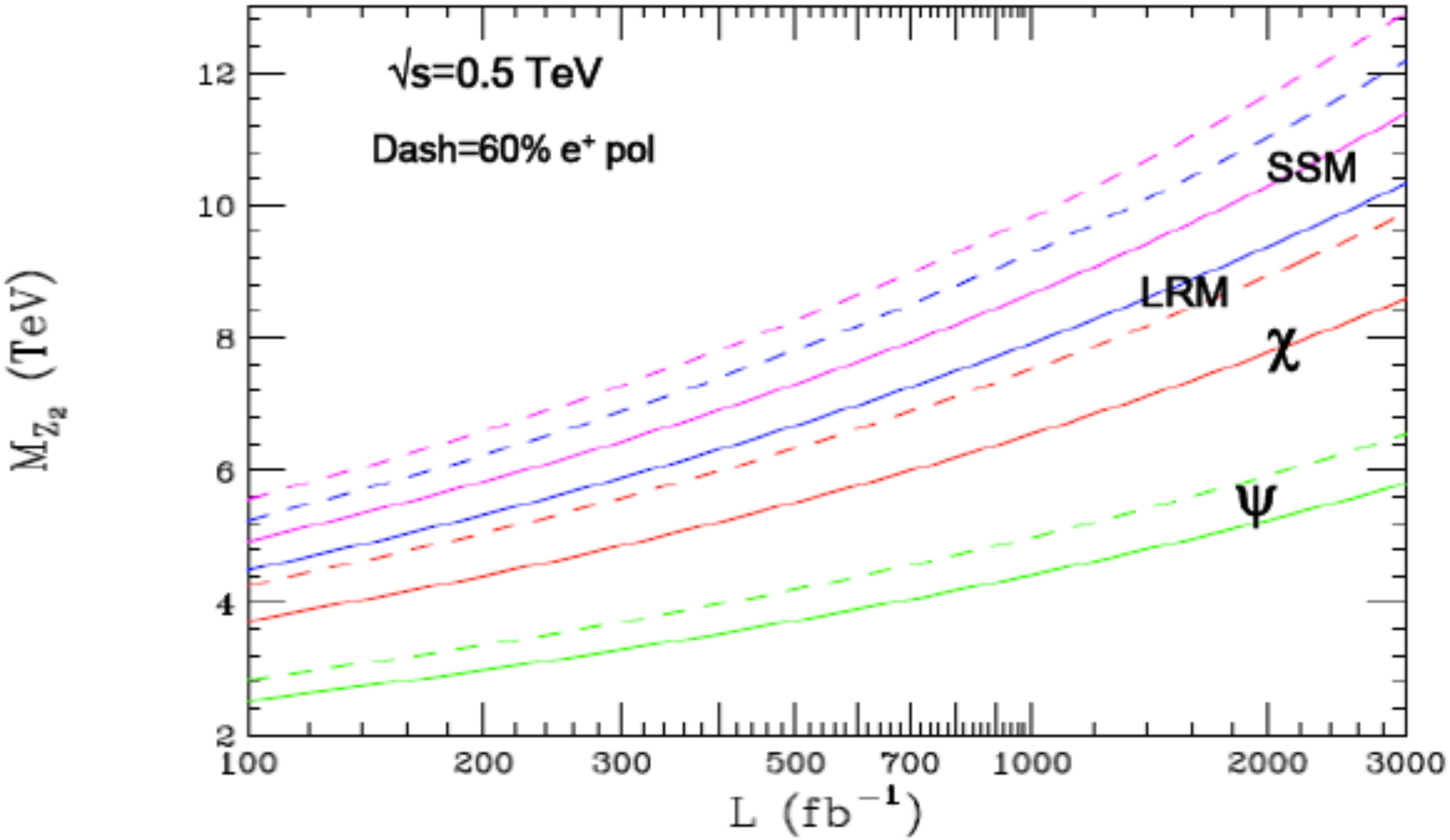
Eventually the 14 TeV LHC will cover the mass range up to ~5-6 TeV for a typical Z' w/ electroweak coupling strength & a luminosity of 1 ab^{-1} …



T. Rizzo, "New Resonances @ ILC/CLIC"

Looking beyond the LHC with e^+e^- colliders

It is well-known that such ‘contact-interaction’ searches are quite sensitive to mass scales far beyond the collider’s √s….

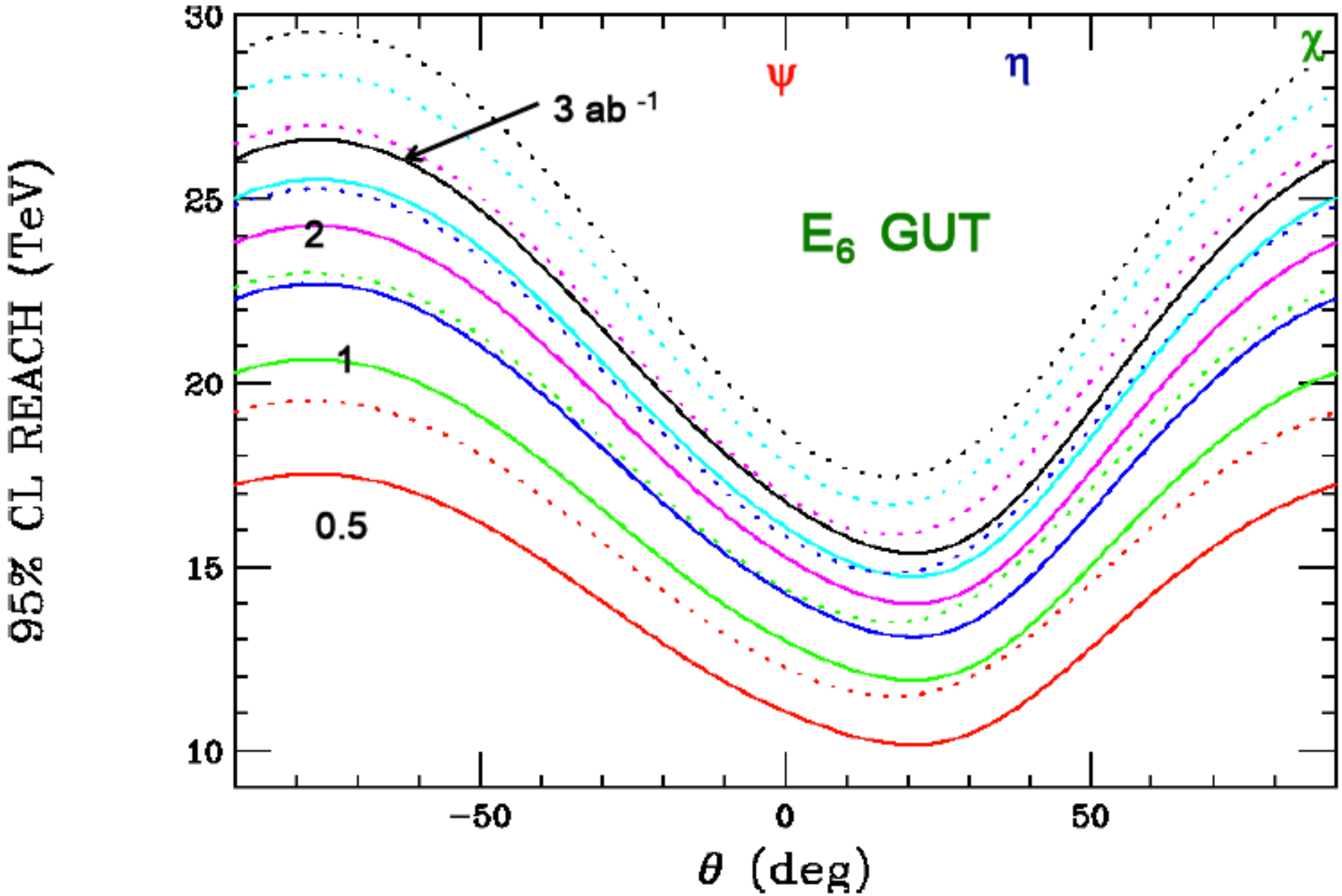


1 ab^{-1} LHC reach

8

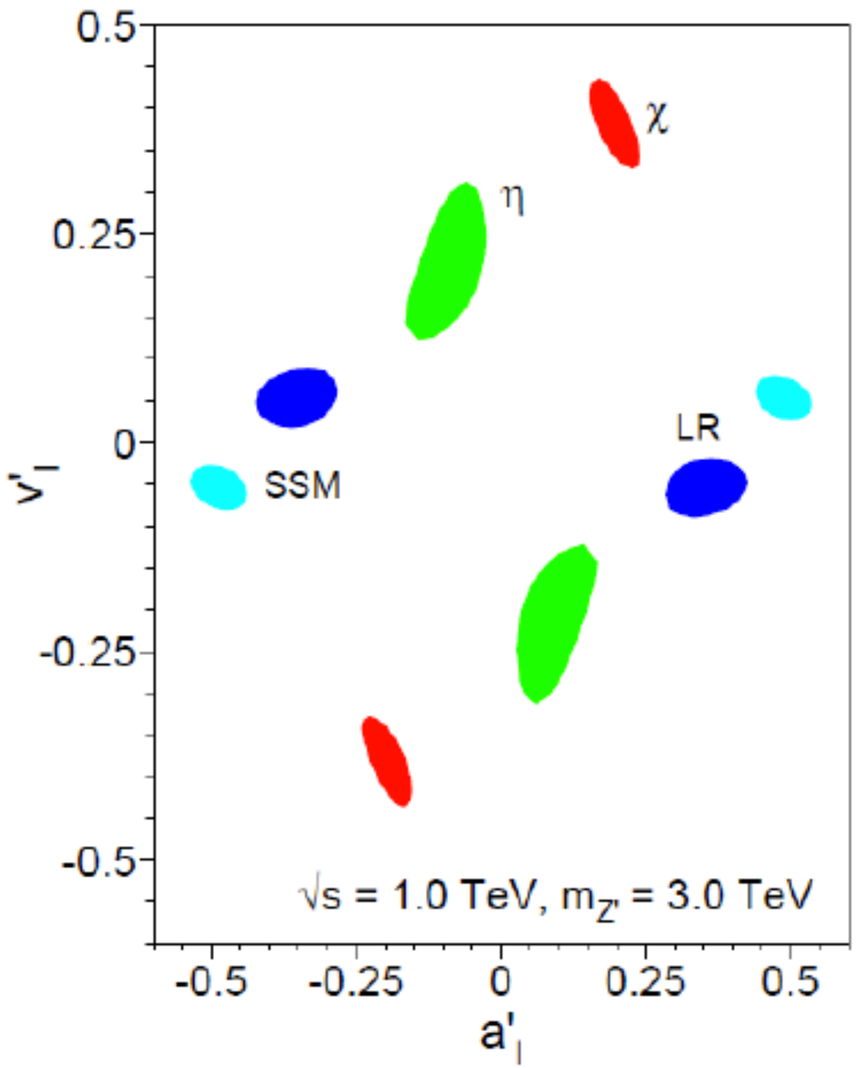
T. Rizzo, “New Resonances @ ILC/CLIC”

√s=3 TeV 95% Exclusion Reach at CLIC



T. Rizzo, "New Resonances @ ILC/CLIC"

ILC Indirect Z' Coupling Determinations



These are well-known for lower energies & one can approximately rescale them to, e.g. , $\sqrt{s}$=2 TeV and $M_{Z'}$ =6TeV with ~4x more luminosity…

We can do even better if $\sqrt{s}$=3 TeV & $M_{Z'}$ =6 TeV!

S. Riemann

20

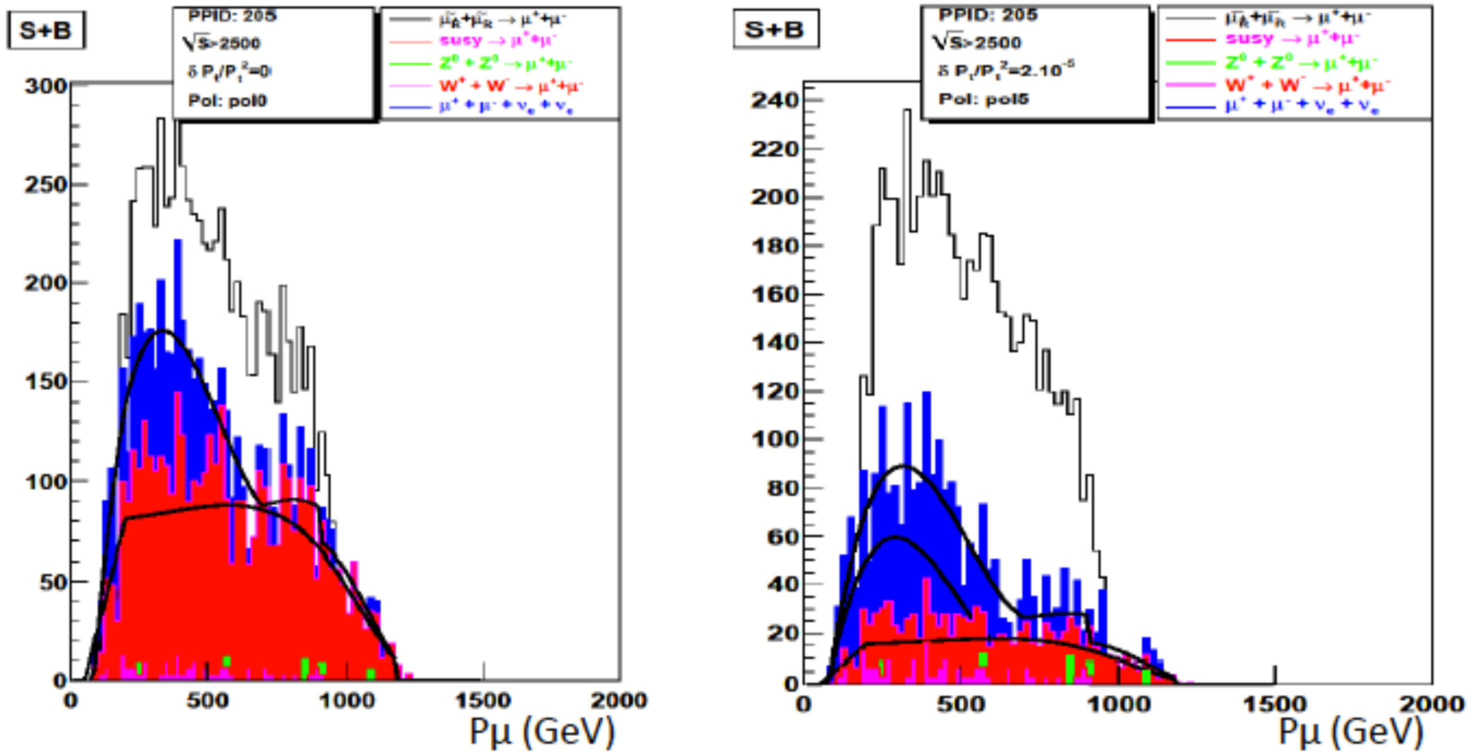
Supersymmetry

Supersymmetry provides a motivated beyond-the-SM scenario that is well-defined and calculable. An ideal new physics scenario to study at LC.

library.thinkquest.org

Z. Rurikova, “Prospects for SUSY for 0.5 to 1 fb-1 with the LHC”
S. Heinemeyer, “SUSY predictions for the ILC”
J. Kalinowski, “DIRAC gauginos and their scalar partners”
J. Conley, “Measuring a light neutralino mass at the ILC”
A. Skachkova, “Stop mass determination at ILC”
G. Moortgat-Pick, “Positron polarization for susy and higgs”
B. Vormwald, “Bilinear R-parity violation at the ILC”
J. List, “SUSY overview at the ILC”
J.-J. Blaising, “Determination of heavy slepton mass at CLIC”
N. Alster, “A study of chargino and neutralino masses … at CLIC”
M. Rauch, “Measuring Unification”
A. Ibarra, “On long-lived staus”
G. Belanger, “On sneutrino dark matter”
P. Sandik, “On SUSY dark matter”
Etc.

Stacked Signal + Background



Left: Signal + backgrounds without polarization. Right: with (e^-80, e^+0) polarization; Signal x 1.8 and background x0.2; upper edge better preserved from WW bkg. Background modeled for background subtraction

J-J.Blaising(LAPP/IN2P3), October 2010 IWLC10 14

Table of Results

Data Set	√S> (GeV)	$\delta pt/pt^2$ ($x10^{-5}$ GeV^{-1})	Polarization (e^- / e^+)	BX Capability	M (GeV)	M ^{o} (GeV)
S	2950	0	0/0	1	1106.3±2.9	558.8±1.3
S	2500	0	0/0	1	1098.8±2.6	555.4±1.2
S	2500	2	0/0	1	1104.6±2.9	560.0±1.7
S	2500	6	0/0	1	1098.8±3.1	559.1±3.6
S	2500	20	0/0	1	1107.5±4.2	575.7±5.3
S(G4+R)	2500	2	0/0	1	1107.2±2.8	560.1±2.2
S+B	2500	2	0/0	1	1107.4±20.2	533.8±13.1
S+B	2500	2	80/60	1	1101.7±13.5	536.7±5.5
S+B	2500	2	80/60	5	1102.4±12.9	548.9±7.1
S+B	2500	2	80/60	20	1104.6±12.8	551.1±7.1

When $\delta pt/pt^2$ increases, S/B decreases, δm increases; for $\delta pt/pt^2 > 10^{-4}$, efficiency corrections are large ,introducing significant systematic errors.

B modeling/subtraction increases δm; it can be improved using polarization.

γγ-> hadron decrease S/B; up to 20 BX time stamping (10 nsec); there is no significant δm degradation.

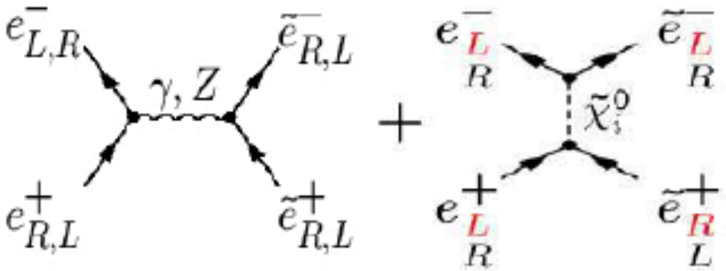
J-J.Blaising(LAPP/IN2P3), October 2010 IWLC10 17

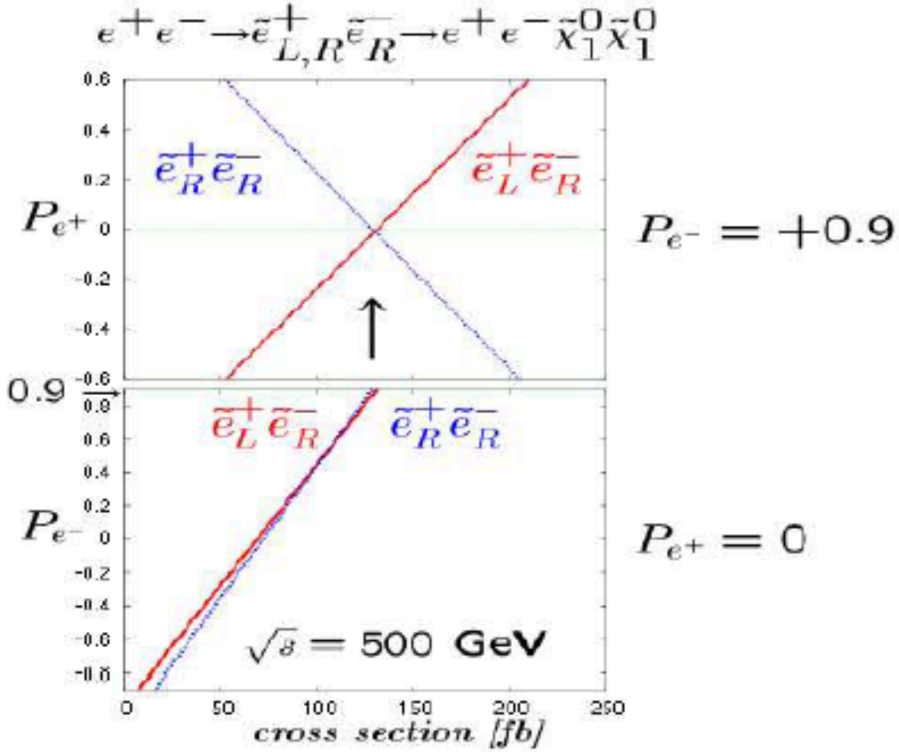
J.-J. Blaising, "Determination of heavy smuon and selectron mass at CLIC"

Slepton 'chiral' quantum numbers

- Association of chiral electrons to scalar partners $e^-_{L,R} \leftrightarrow \tilde{e}^-_{L,R}$ and $e^+_{L,R} \leftrightarrow \tilde{e}^+_{R,L}$:

s-channel t-channel





1. separation of scattering versus annihilation channel
2. test of 'chirality': only $\tilde{e}^+_L\tilde{e}^-_R$ may survive at P(e-) > 0 and P(e+) > 0 !

(90%, 60%):200 fb/50 fb factor ~4, (90%,30%):175 fb/75 fb factor~2.3, (90%,22%): ~1.6

- *Even high P(e-) not sufficient, P(e+) is substantial!*

G. Moortgat-Pick, "Polarized positrons for Higgs and SUSY"

Reminder: background suppression

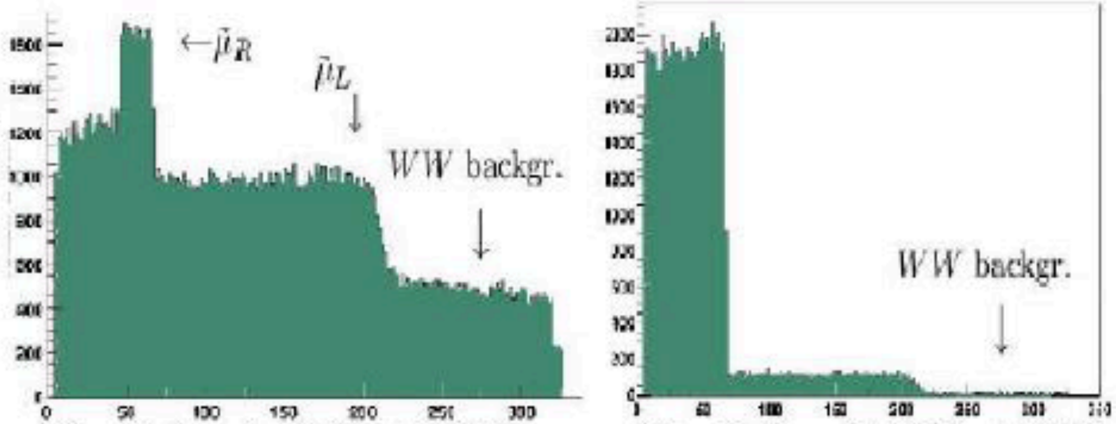
- To optimize threshold scans: precise continuum measurements important!
- Worst SM background is WW-pair production
  - e.g. $e^+e^- \rightarrow \tilde{\mu}^+_{L,R}\tilde{\mu}^-_{L,R}$

Muon energy spectrum: $\mu^+\mu^-$ events (incl. W^+W^-) at $\sqrt{s} = 750$ GeV

- Strong WW-backgr.:
  - all edges observable only with P(e-) and P(e+)
  - at 65 GeV and 220 GeV

S / B = 0.07 (+80%,0)

S / B= 0.46 (+80%,-80%)



$(P_{e^-}, P_{e^+}) = (-80\%, +80\%)$ $(P_{e^-}, P_{e^+}) = (+80\%, +80\%)$

G. Moortgat-Pick, "Polarized positrons for Higgs and SUSY"

Higgs Boson Physics

Eckkller.com

One of most significant physics motivations for the linear collider Is the ability to study Higgs boson(s) very precisely.

H. Ono, “Higgs branching ratios”
M. Weber, “Higher-order corrections to Higgs Pheno at ILC”
F. Staub, “The Higgs masses in the NMSSM at one and two loop level”
R. Yonamine, “e+e- to ttH”
J. Tian, “Higgs self-coupling analysis”
Y. Takubo, “Anomalous Higgs coupling study in H to WW*”
H. Tabassam, “Prospects for the top Yukawa coupling from e+e- to ttbar higgs”
R. Rattazzi, “Composite Higgs dynamics with a better chance at ILC/CLIC than LHC”
H. Videau, “Higgs to tau tau”
R. Poeschl, “Higgs prospects for DBDs”
A. Weiler, “Buried/charming Higgs”
M. Spira, “Susy higgs yukawa couplings to bottom quarks at NNLO”
M. Battaglia, “New from the Higgs at the ILC/CLIC”
S. Biswal, “Anomalous Higgs interactions especially HVV vertex”
D. Harada, “Higgs boson pair production in new models at colliders”
M. Battaglia, “A study of e+e- to H0 A0 -> bbbb at 3 TeV at CLIC”

Also discovery!

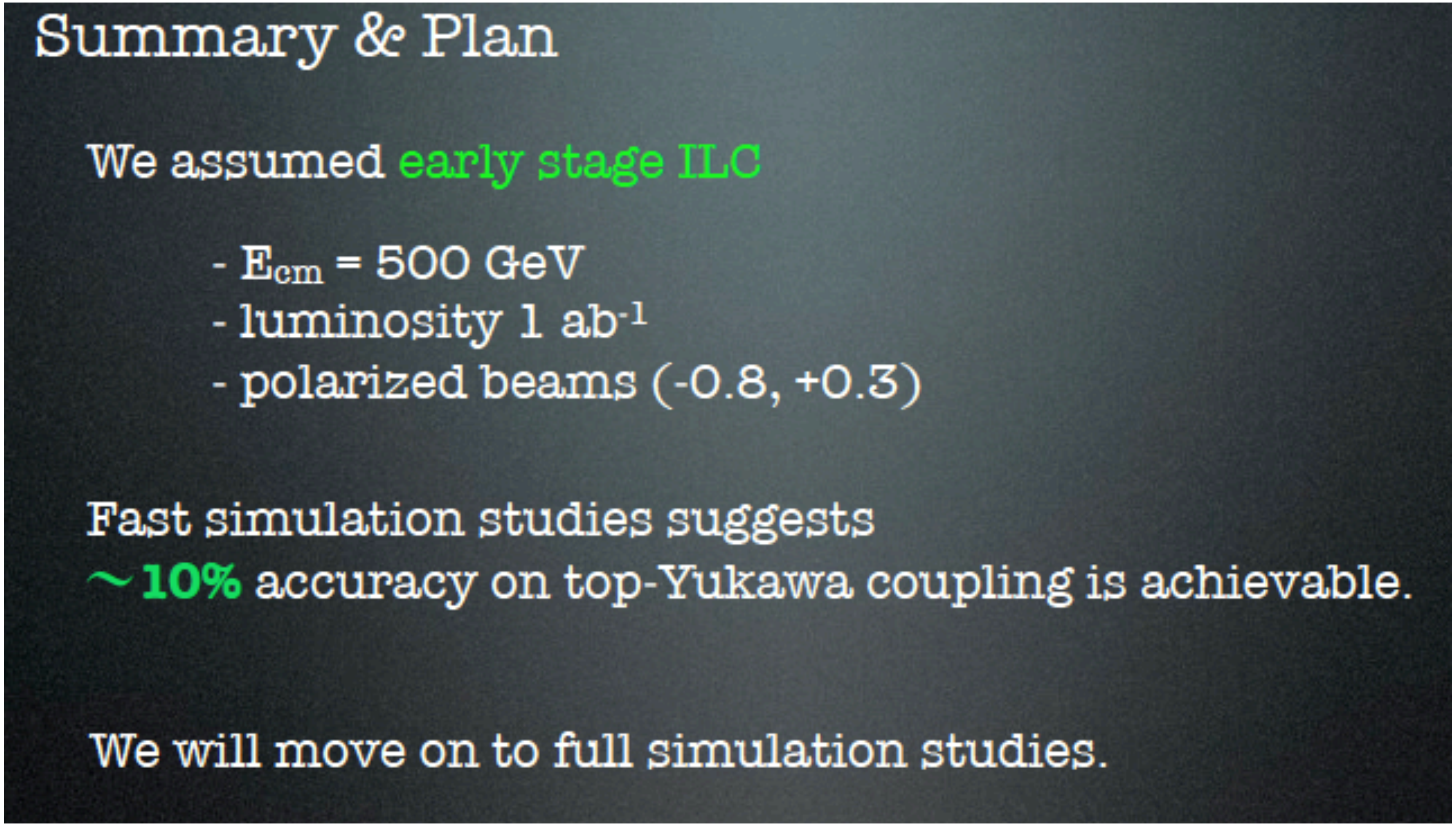
Semi-Leptonic Channel

- $e^+ e^- \rightarrow \bar{t}tH \rightarrow \bar{b}W^- bW^+ \bar{b}b$
- Focus on semi-leptonic final state with one W decaying into lepton and neutrino and other W decaying into light jets
- Final state is 1 lepton, missing energy, 6 Jets with 4 b-jets
- Remove the leptons and force remaining particles into 6-jets (JetFinder Algorithm)
- High momentum Lepton and large missing momentum signature

Reconstruction shown and final results soon.

H. Tabassam, "Prospects for the top Yukawa from e+e- to ttbar h"

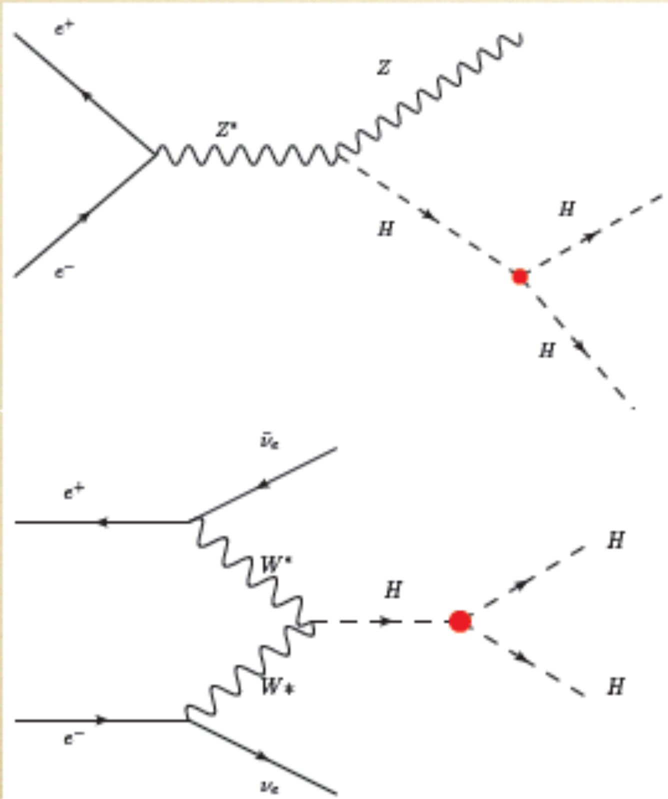
Another interesting study on this question:

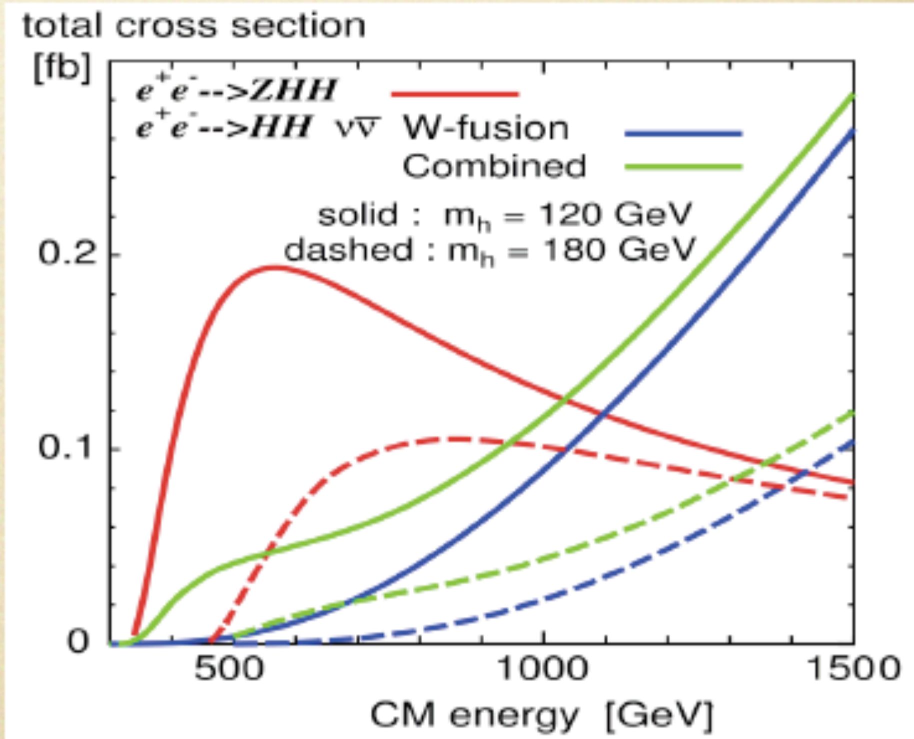


R. Yonamine, "Measurement of Top-Yukawa coupling at the early stage ILC"

Measurement of the trilinear Higgs self-coupling @ ILC

- double Higgs-strahlung (dominate at lower energy)
- WW fusion (dominate at higher energy)





J. Tian, "Study of Higgs Self-Couplings at ILC"

status of the simulation (preliminary)

$e^+ + e^- \rightarrow ZHH \quad e^+ + e^- \rightarrow \nu\nu HH \quad M(H) = 120\text{GeV} \quad \int Ldt = 2\text{ab}^{-1}$

Energy (GeV)	Modes	Fast Simulation	Full Simulation
500	$ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b})$	2.5σ	3.6σ
500	$ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	0.8σ	1.3σ
500	$ZHH \rightarrow (q\bar{q})(b\bar{b})(b\bar{b})$	2.0σ	2.0σ
500	$ZHH \rightarrow (q\bar{q})(b\bar{b})(WW^*)$	0.05σ	-
1,000	$\nu\bar{\nu}HH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	2.5σ	-

- from LCWS2010, full simulations of llHH and ννHH were investigated (today's topic)
- qqHH analysis was presented at ALCPG09 by Takubo-san.
- improvement in full simulation comes from b tagging and background specification.

Events
Sgl vs. bkg

4.93 vs. 0.50

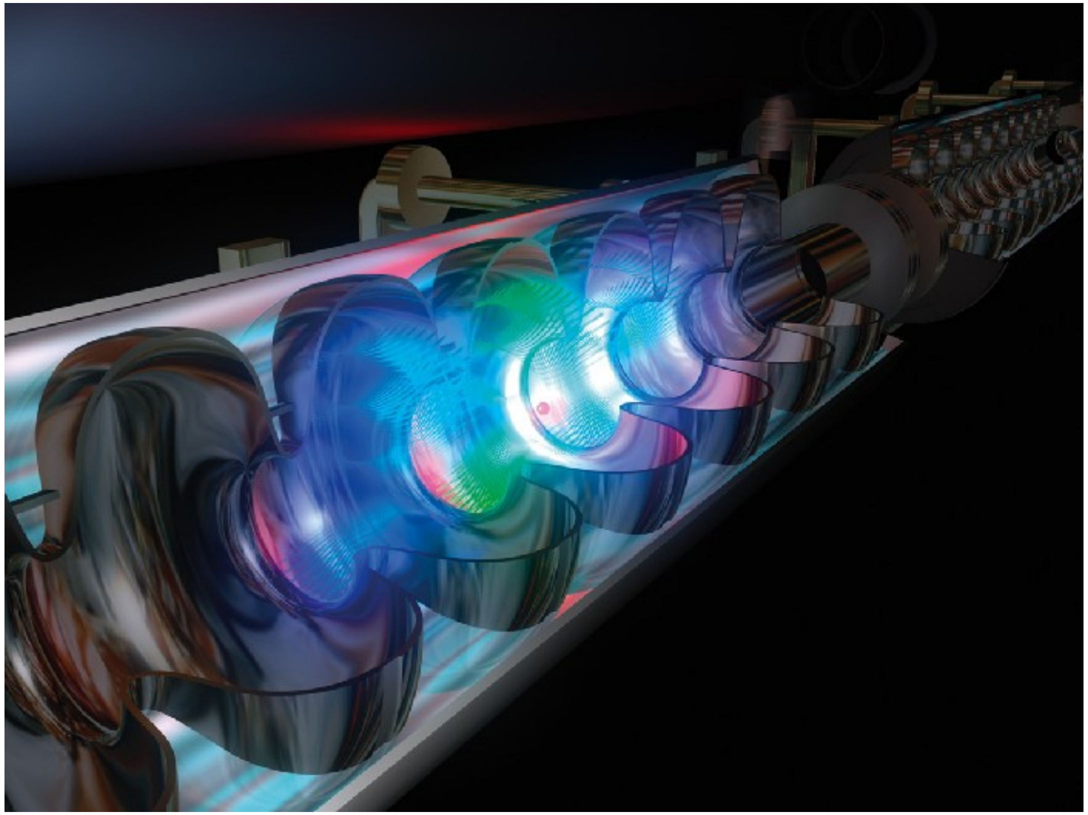
1.9 vs. 0.9

J. Tian, "Study of Higgs Self-Couplings at ILC"

Conclusions

Significant activity in the "Physics" work of Linear Colliders

Doing our part to make the case to be prepared for LC running and for showing why we need a Linear Collider.



desy.de

2010 Physics Conclusion:
LC has promise to make revolutionary discoveries through production of new states and through precision analysis.