An Experimentalist's Appeal to Machine Colleagues Motivated by Theoretical Studies

Basic considerations on LC lumi & energy needs (up to 3 TeV)

Jim Brau

October 19, 2010

Acknowledgements: Konrad Elsener, JoAnne Hewett, John Jaros, Akiya Miyamoto, Francois Richard, Tom Rizzo, Marcel Stanitzki, Mark Thomson

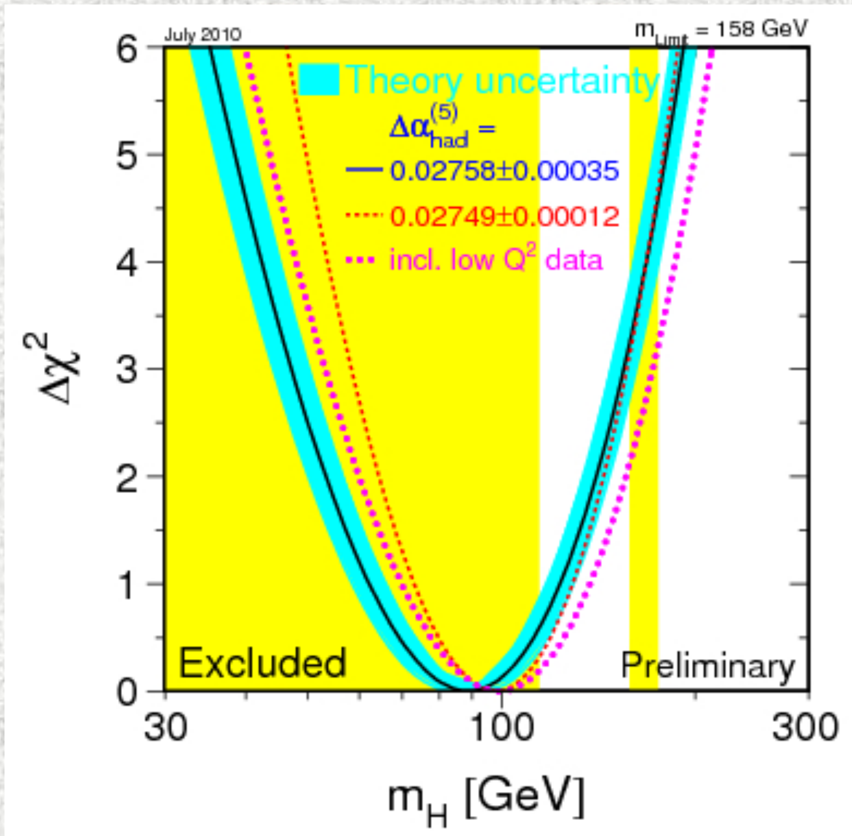
Understanding Matter, Energy, Space and Time: the Case for the Linear Collider

- More than 2700 scientists signed 2003 statement, expressing the world-wide consensus¶ for the linear collider:
  - Understanding the Higgs boson
  - New discoveries beyond the standard model
  - The benefit of precision measurements and the interplay of LHC and LC
  - Cross connections between LC experiments, neutrino and quark studies, cosmological and astrophysical measurements, and high energy nuclear physics

¶ http://physics.uoregon.edu/~lc/wwstudy/lc_consensus.html

The Standard Model Higgs

- Decades of experimentation have established the Standard Model, requiring a light Higgs Boson
- Standard Model describes ElectroWeak observations
  - Mass of gauge bosons requires explanation within the TeV mass scale
  - Higgs Mechanism
    - Minimal solution



Motivation for Linear Collider

- Revolutionary New Physics expected at O(TeV) scale
- LHC has power to initiate discovery of this New Physics,
  but detailed measurements limited compared to LC
- Linear Collider offers added discoveries AND *precise*, model independent measurements
  - Follows established, effective traditions of the field
    - eg. SppS discovered the Z boson, LEP and SLC established its properties in detail
      - Operating at $\sqrt{s} = m_Z$ (& scanning the resonance)
    - SPEAR discovered J/Ψ, Ψ', D's, τ
    - Other examples of electron/hadron machine synergy
- Precision constrains possible explanations, and points the way to deeper understanding

Higgs threshold spin analysis

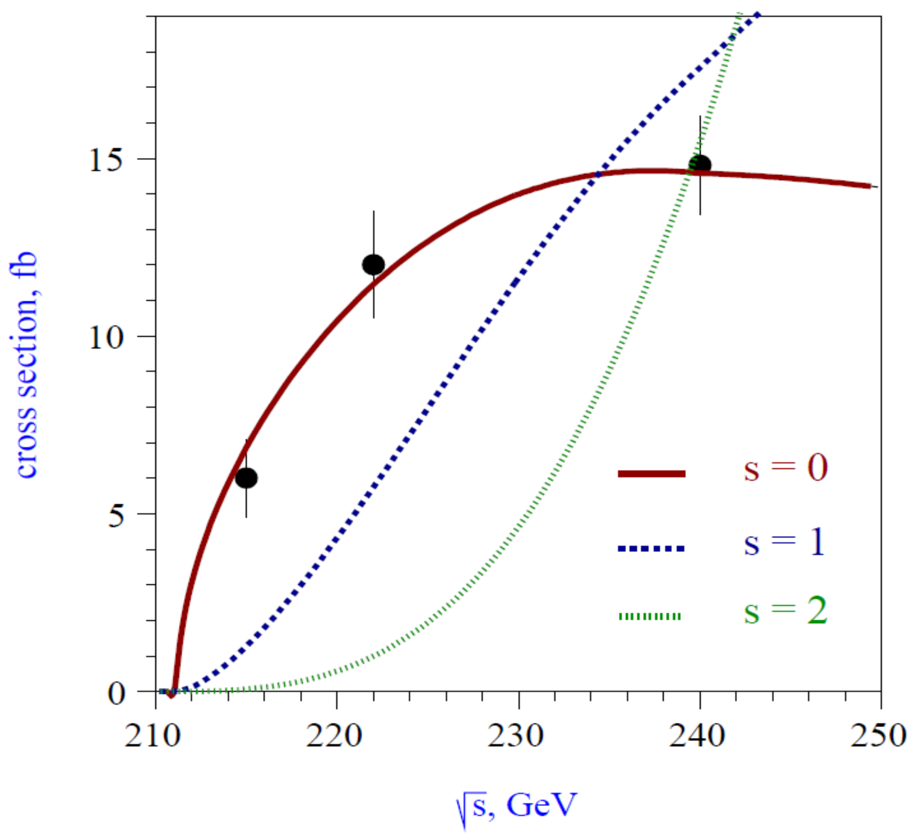


FIGURE 2. The cross sections determined at $\sqrt{s}$ = 215, 222 and 240 GeV (dots) and the predictions for s=0 (full line), s=1 (dashed line) and s=2 (dotted line).

20 fb^{-1} at each energy point

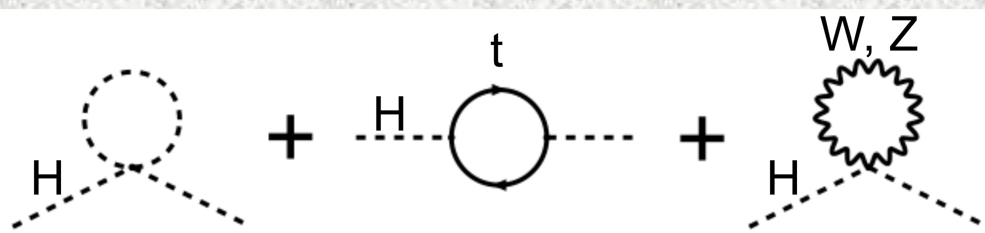
This is an example of the need for good low energy luminosity

hep-ph/0302113 Dova, Garcia-Abia and Lohmann

Failings of the Standard Model

- A light Higgs boson, or its substitute, appears to be needed to explain decades of accumulated experimental data
- Nevertheless, there are also strongly motivated reasons to expect more on the TeV energy scale
  - What resolves the *Hierarchy Problem*?
    - Quantum corrections from loops of particles should naturally drive the Higgs mass to high mass scales, unless New Physics cuts off the corrections

$$M_H^2(p^2) = M_H^2(\Lambda^2) +$$



Quigg, arXiv:0905.3187

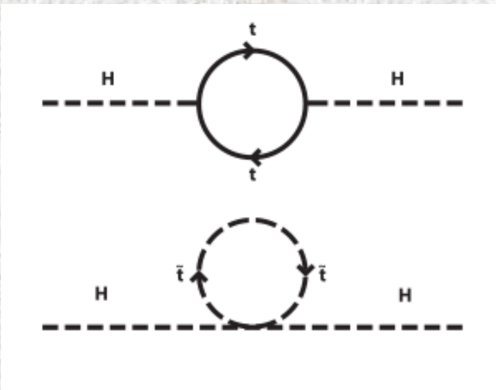
New discoveries beyond the standard model

- While the standard model with the simplest Higgs boson agrees well with all observations, there are compelling reasons to expect additional new physics
- There are at least two disparate energy scales:
  - the Planck scale at about 10^{19} GeV
  - the electroweak scale at a few hundred GeV
- Also, the strengths of the strong, electromagnetic and weak forces become similar at about 10^{16} GeV suggesting the possibility of grand unification
- These features suggest new physics at TeV scale
  - Candidates: SUSY, extra dimensions, other new particles, …

Supersymmetry

- One of the best motivated theories beyond the Standard Model
- Elegant, unified description of fermions and bosons
  - Matter and forces
  - Could include gravity
  - Predicted by string theory (good or bad?)
- Stabilizes the Higgs mass to the expected low values anticipated by experiments (electroweak parameters), if sparticle masses are O(TeV).
- Every known particle paired with

  yet undiscovered super-partner, and more



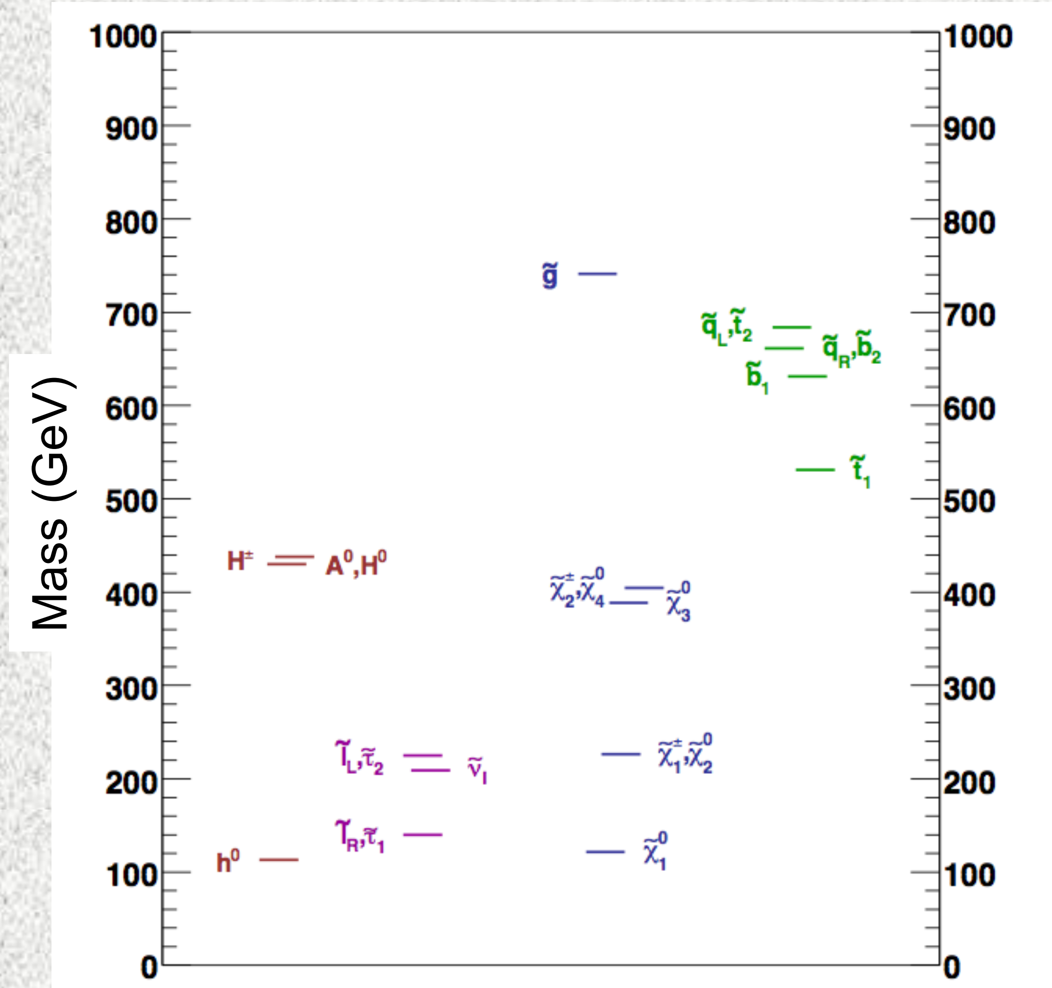
Minimal Supersymmetry

- Light Higgs boson – consistent with indirect measurements
- Natural unification of forces
- Explains Electroweak Symmetry Breaking
- Offers good dark matter candidate

- Many new particles
  - Five Higgs states (h^0, H^0, A^0, H^+, H^-)
  - Superpartners for every known standard model particle

- If Nature has chosen this structure, it will be very difficult to find all of these at the LHC
  - Need linear collider to complete discoveries

Possible Supersymmetry Mass Spectrum

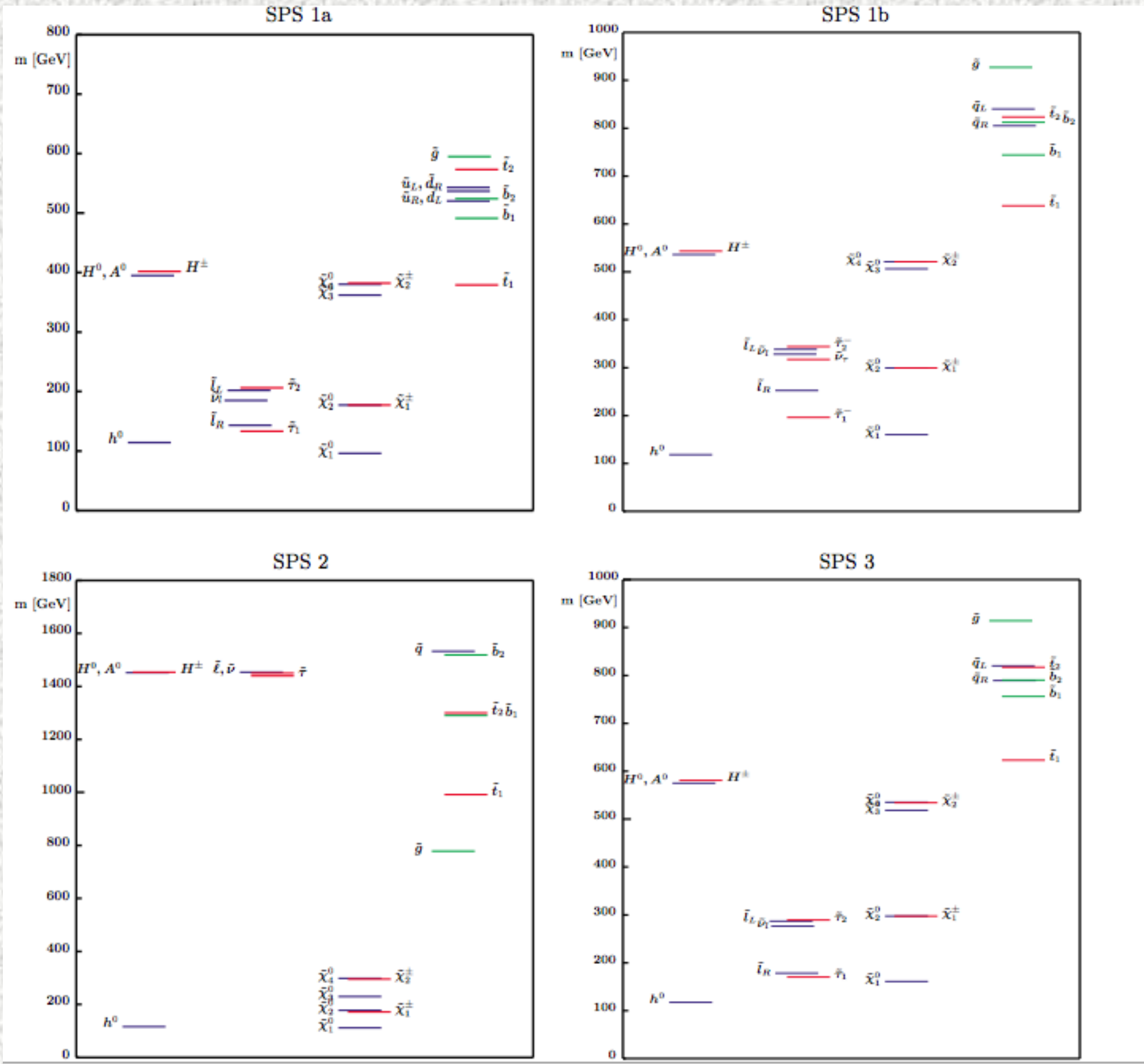


The spectrum at the best-fit CMSSM point, assuming LSP is the lightest neutralino

J. Ellis, "The Physics Prospects for CLIC," arXiv:0811.1366

We need to be prepared to vary E_{CMS}

A few candidate Supersymmetry Mass Spectra



The benefit of precision measurements and the interplay of LHC and LC

- Two distinct/complementary paths to understanding of the structure of matter, space and time.
  - Direct discovery of new phenomena with operating at the energy scale of the new particles.
  - Inference of new physics through the precision measurement of phenomena at lower energy
- Historical record of these two paths working together to make more complete understanding
  - e^+e^- pointed to top quark, which Tevatron discovered
  - Precision data from both for current Higgs prediction
  - Z discovered at h-coll, precision understanding e^+e^-
  - e^+e^- discoveries of charm, tau, and the gluon

ILC Scope and the RDR

ILCSC "scope document" specifies the requirements, including emphasis on importance of variable energy operation, with good luminosity performance

- Top could be special messenger; 350 GeV scan!
- Polarization very powerful probe!

RDR vs ILC Physics Goals

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%
- The machine must be upgradeable to 1 TeV

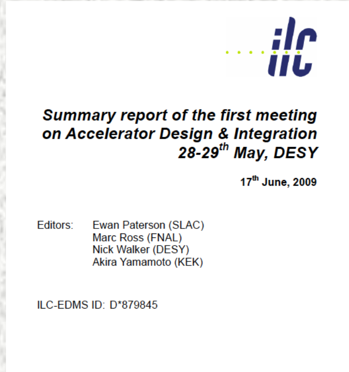
The RDR Design meets these "requirements," including the recent update and clarifications of the reconvened ILCSC Parameters group!

7-Feb-07
GDE/ACFA Closing Beijing
Global Design Effort
6

ILC Design Evolution

- Reference Design Report (RDR) – 2007
  - First detailed technical snapshot, defining in detail the technical parameters and components to guide the development of the worldwide R&D program

- SB2009
  - Proposed set of changes to the baseline aimed at optimizing ILC design for cost, performance and risk.
  - Physics impact studied and commented on by Physics and Detectors Study Group*



ilc

Summary report of the first meeting on Accelerator Design & Integration 28-29th May, DESY

17th June, 2009

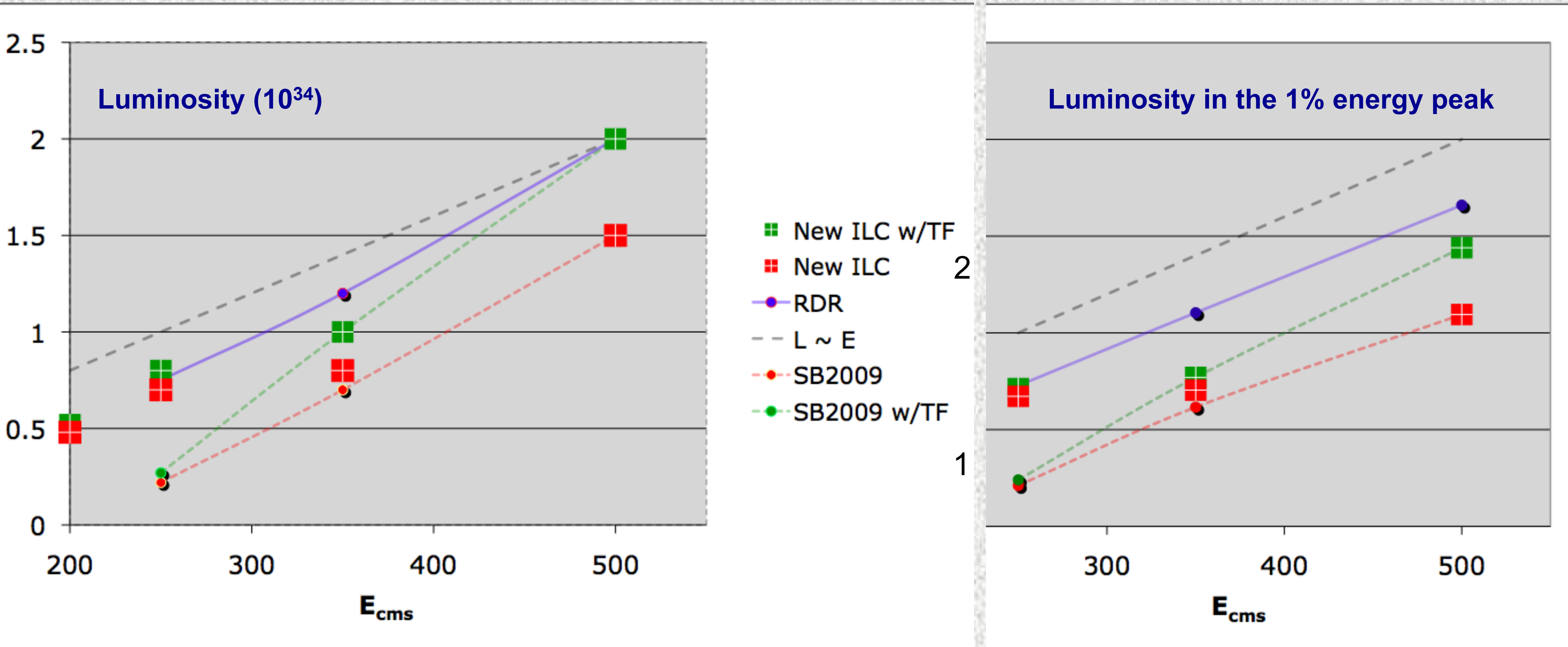
Editors: Ewan Paterson (SLAC)
Marc Ross (FNAL)
Nick Walker (DESY)
Akira Yamamoto (KEK)

ILC-EDMS ID: D*879845

- New ILC Design and Parameters
  - Response to study group's reaction to reduced low energy luminosity – a modified design with new parameters

* T. Barklow, M. Berggren, J. Brau, K. Buesser, K. Fujii, N. Graf, J. Hewett, T. Markiewicz, T. Maruyama, D. Miller, A. Miyamoto, Y. Okada, M. Thomson, G. Weiglein

Recently Updated ILC Machine Parameters



TF = traveling focus

Physics and Detector Studies of New ILC Parameters

- **Effects which have been studied**
  - Luminosity at low E_{cms}
  - Effective luminosity due to Beamstrahlung losses
  - Machine backgrounds
- **Processes to assess impact**

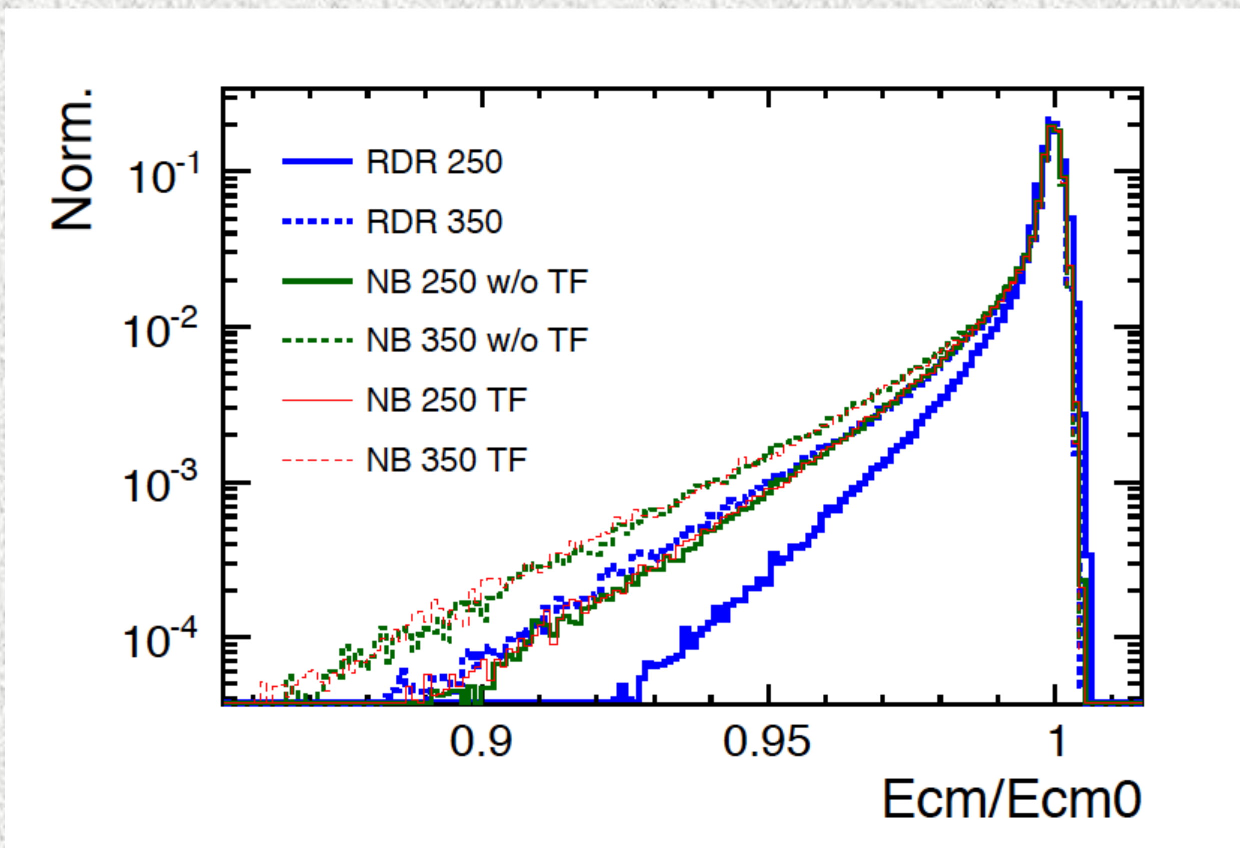
  $e^+e^- \rightarrow Z\ h \rightarrow \mu^+\ \mu^-$ Higgs
  - Higgs mass
  - Higgs cross section
  - Higgs branching ratios - see talk at 1630 today, Hiroaki Ono

  Stau detection (forward electron vetoes)

  Low mass SUSY scenarios study
  - Snowmass SM2 benchmark
    - (m_0 = 100 GeV, $m_{1/2}$ = 250 GeV, tan β = 10, A_0 = 0, and sign μ = +) - similar to SPS1a point

Higgs Mass and Cross Section

- Higgs measurements are best done at E_{cm}=250 GeV
- New Study of Higgs Recoil Mass compares new machine parameters with RDR, and operation @ 350 GeV - Hegne Li



Hengne Li

Higgs Mass and Cross Section

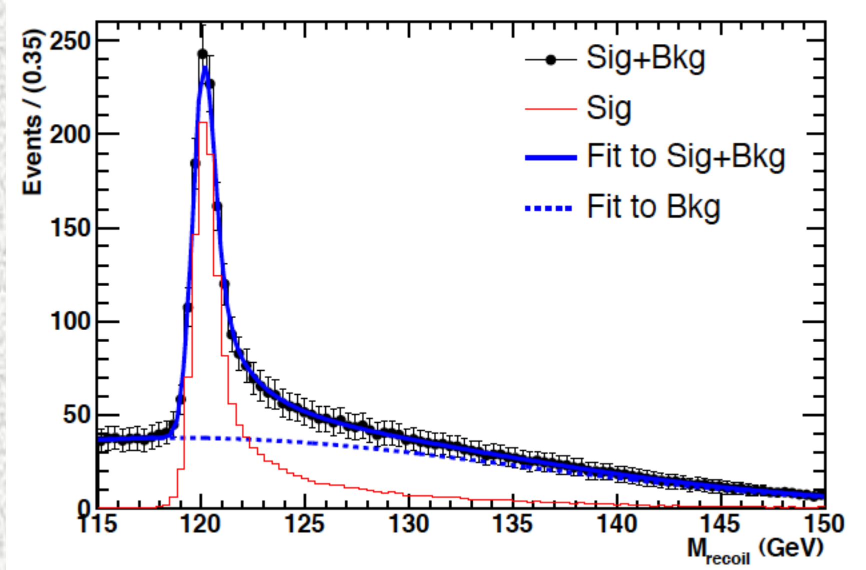
Beam Par	$\mathcal{L}_{int}$ (fb^{-1})	ϵ	S/B	M_H (GeV)	σ (fb) ($\delta\sigma/\sigma$)
RDR 250	188	55%	62%	120.001 ± 0.043	11.63 ± 0.45 (3.9%)
RDR 350	300	51%	92%	120.010 ± 0.087	7.13 ± 0.28 (4.0%)
NB w/o TF 250	175	61%	62%	120.002 ± 0.032	11.67 ± 0.42 (3.6%)
NB w/o TF 350	200	52%	84%	120.003 ± 0.106	7.09 ± 0.35 (4.9%)
NB w/ TF 250	200	63%	59%	120.002 ± 0.029	11.68 ± 0.40 (3.4%)
NB w/ TF 350	250	51%	89%	120.005 ± 0.093	7.09 ± 0.31 (4.4%)

Coupling precision (cross section) better with new parameters than RDR

Higgs precision improvements:

δM: 43 MeV → 29 MeV (wTF)

δσ: 3.9% → 3.4% (wTF)



Low mass SUSY scenarios study

- Study of Snowmass SM2 point (~ SPS1a point)
  - hep-ex/0211002v1, P. Grannis

($m_0 = 100$ GeV, $m_{1/2} = 250$ GeV, $\tan\beta = 10$, $A_0 = 0$, and sign$\mu = +$).

	M	Final state	(BR(%))			
$\tilde{e}_R$	143	$\tilde{\chi}_1{}^0 e$ (100)				
$\tilde{e}_L$	202	$\tilde{\chi}_1{}^0 e$ (45)	$\tilde{\chi}_1{}^\pm \nu_e$ (34)	$\tilde{\chi}_2{}^0 e$ (20)		
$\tilde{\mu}_R$	143	$\tilde{\chi}_1{}^0 \mu$ (100)				
$\tilde{\mu}_L$	202	$\tilde{\chi}_1{}^0 \mu$ (45)	$\tilde{\chi}_1{}^\pm \nu_\mu$ (34)	$\tilde{\chi}_2{}^0 \mu$ (20)		
$\tilde{\tau}_1$	135	$\tilde{\chi}_1{}^0 \tau$ (100)				
$\tilde{\tau}_2$	206	$\tilde{\chi}_1{}^0 \tau$ (49)	$\tilde{\chi}_1{}^- \nu_\tau$ (32)	$\tilde{\chi}_2{}^0 \tau$ (19)		
$\tilde{\nu}_e$	186	$\tilde{\chi}_1{}^0 \nu_e$ (85)	$\tilde{\chi}_1{}^\pm e^\mp$ (11)	$\tilde{\chi}_2{}^0 \nu_e$ (4)		
$\tilde{\nu}_\mu$	186	$\tilde{\chi}_1{}^0 \nu_\mu$ (85)	$\tilde{\chi}_1{}^\pm \mu^\mp$ (11)	$\tilde{\chi}_2{}^0 \nu_\mu$ (4)		
$\tilde{\nu}_\tau$	185	$\tilde{\chi}_1{}^0 \nu_\tau$ (86)	$\tilde{\chi}_1{}^\pm \tau^\mp$ (10)	$\tilde{\chi}_2{}^0 \nu_\tau$ (4)		
$\tilde{\chi}_1{}^0$	96	stable				
$\tilde{\chi}_2{}^0$	175	$\tilde{\tau}_1 \tau$ (83)	$\tilde{e}_R e$ (8)	$\tilde{\mu}_R \mu$ (8)		
$\tilde{\chi}_3{}^0$	343	$\tilde{\chi}_1{}^\pm W^\mp$ (59)	$\tilde{\chi}_2{}^0 Z$ (21)	$\tilde{\chi}_1{}^0 Z$ (12)	$\tilde{\chi}_1{}^0 h$ (2)	
$\tilde{\chi}_4{}^0$	364	$\tilde{\chi}_1{}^\pm W^\mp$ (52)	$\tilde{\nu}\nu$ (17)	$\tilde{\tau}_2 \tau$ (3)	$\tilde{\chi}_{1,2} Z$ (4)	$\tilde{\ell}_R \ell$ (6)
$\tilde{\chi}_1{}^\pm$	175	$\tilde{\tau}_1 \tau$ (97)	$\tilde{\chi}_1{}^0 q\bar{q}$ (2)	$\tilde{\chi}_1{}^0 \ell\nu$ (1.2)		
$\tilde{\chi}_2{}^\pm$	364	$\tilde{\chi}_2{}^0 W$ (29)	$\tilde{\chi}_1{}^\pm Z$ (24)	$\tilde{\ell}\nu_\ell$ (18)	$\tilde{\chi}_1{}^\pm h$ (15)	$\tilde{\nu}_\ell \ell$ (8)

Low mass SUSY scenarios run allocations

Beams	Energy	Pol.	$\int \mathcal{L}dt$	$[\int \mathcal{L}dt]_{equiv}$	Comments
e^+e^-	500	L/R	335	335	Sit at top energy for sparticle masses
e^+e^-	M_Z	L/R	10	45	Calibrate with Z's
e^+e^-	270	L/R	100	185	Scan $\widetilde{\chi}_1^0\ \widetilde{\chi}_2^0$ threshold (L pol.) Scan $\widetilde{\tau}_1\ \widetilde{\tau}_1$ threshold (R pol.)
e^+e^-	285	R	50	85	Scan $\widetilde{\mu}_R^+\ \widetilde{\mu}_R^-$ threshold
e^+e^-	350	L/R	40	60	Scan $t\bar{t}$ threshold Scan $\tilde{e}_R\ \tilde{e}_L$ threshold (L & R pol.) Scan $\widetilde{\chi}_1^+\ \widetilde{\chi}_1^-$ threshold (L pol.)
e^+e^-	410	L	60	75	Scan $\widetilde{\tau}_2\ \widetilde{\tau}_2$ threshold Scan $\widetilde{\mu}_L^+\ \widetilde{\mu}_L^-$ threshold
e^+e^-	580	L/R	90	120	Sit above $\widetilde{\chi}_1^\pm\ \widetilde{\chi}_2^\mp$ threshold for $\widetilde{\chi}_2^\pm$ mass
e^-e^-	285	RR	10	95	Scan with e^-e^- collisions for $\tilde{e}_R$ mass

sparticle	δM end point	δM scan	δM combined
$\tilde{e}_R$	0.19	0.02	0.02
$\tilde{e}_L$	0.27	0.30	0.20
$\widetilde{\mu}_R$	0.08	0.13	0.07
$\widetilde{\mu}_L$	0.70	0.76	0.51
$\widetilde{\tau}_1$	$\sim 1-2$	0.64	0.64
$\widetilde{\tau}_2$	–	1.1	1.1
$\widetilde{\nu}_e$	~ 1	–	~ 1
$\widetilde{\nu}_\mu$	7?	–	7?

sparticle	δM end point	δM scan	δM combined
$\widetilde{\nu}_\tau$	–	–	–
$\widetilde{\chi}_1^0$	0.07	–	0.07
$\widetilde{\chi}_2^0$	$\sim 1-2$	0.12	0.12
$\widetilde{\chi}_3^0$	8.5	–	8.5
$\widetilde{\chi}_4^0$	–	–	–
$\widetilde{\chi}_1^\pm$	$\sim 1-2$	0.18	0.18
$\widetilde{\chi}_2^\pm$	4	–	4

hep-ex/0211002v1, P. Grannis

1000 fb^{-1} equivalent luminosity (scaled by L ~ E) required to achieve physics program

Low mass SUSY scenarios run allocations

Beams	Energy	Pol.	$\int \mathcal{L}dt$	$[\int \mathcal{L}dt]_{\rm equiv}$	Comments
e^+e^-	500	L/R	335	335	Sit at top energy for sparticle masses
e^+e^-	M_Z	L/R	10	45	Calibrate with Z's
e^+e^-	270	L/R	100	185	Scan $\widetilde{\chi}_1{}^0\ \widetilde{\chi}_2{}^0$ threshold (L pol.) Scan $\widetilde{\tau}_1\ \widetilde{\tau}_1$ threshold (R pol.)
e^+e^-	285	R	50	85	Scan $\widetilde{\mu}_R{}^+\ \widetilde{\mu}_R{}^-$ threshold
e^+e^-	350	L/R	40	60	Scan $t\bar{t}$ threshold Scan $\tilde{e}_R\ \tilde{e}_L$ threshold (L & R pol.) Scan $\widetilde{\chi}_1{}^+\ \widetilde{\chi}_1{}^-$ threshold (L pol.)
e^+e^-	410	L	60	75	Scan $\widetilde{\tau}_2\ \widetilde{\tau}_2$ threshold Scan $\widetilde{\mu}_L{}^+\ \widetilde{\mu}_L{}^-$ threshold
e^+e^-	580	L/R	90	120	Sit above $\widetilde{\chi}_1{}^\pm\ \widetilde{\chi}_2{}^\mp$ threshold for $\widetilde{\chi}_2{}^\pm$ mass
e^-e^-	285	RR	10	95	Scan with e^-e^- collisions for $\tilde{e}_R$ mass

sparticle	δM end point	δM scan	δM combined
$\tilde{e}_R$	0.19	0.02	0.02
$\tilde{e}_L$	0.27	0.30	0.20
$\widetilde{\mu}_R$	0.08	0.13	0.07
$\widetilde{\mu}_L$	0.70	0.76	0.51
$\widetilde{\tau}_1$	$\sim 1-2$	0.64	0.64
$\widetilde{\tau}_2$	–	1.1	1.1
$\widetilde{\nu}_e$	~ 1	–	~ 1
$\widetilde{\nu}_\mu$	7?	–	7?

sparticle	δM end point	δM scan	δM combined
$\widetilde{\nu}_\tau$	–	–	–
$\widetilde{\chi}_1{}^0$	0.07	–	0.07
$\widetilde{\chi}_2{}^0$	$\sim 1-2$	0.12	0.12
$\widetilde{\chi}_3{}^0$	8.5	–	8.5
$\widetilde{\chi}_4{}^0$	–	–	–
$\widetilde{\chi}_1{}^\pm$	$\sim 1-2$	0.18	0.18
$\widetilde{\chi}_2{}^\pm$	4	–	4

hep-ex/0211002v1, P. Grannis

1000 fb^{-1} equivalent luminosity (scaled by L ~ E) required to achieve physics program

One of Many Possible Scenarios for CLIC Operation

Model	K'
$m_{1/2}$	1300
m_0	1001
$\tan\beta$	46
sign(μ)	–
m_t	175
Masses	
$\lvert\mu(m_Z)\rvert$	1420
h	123
H	1161
A	1153
$H^\pm$	1164
χ	554
χ_2	1064
χ_3	1430
χ_4	1437
$\chi_1^\pm$	1064
$\chi_2^\pm$	1435
g	2820
e_L, μ_L	1324
e_R, μ_R	1109
ν_e, ν_μ	1315
τ_1	896
τ_2	1251
ν_τ	1239
u_L, c_L	2722
u_R, c_R	2627
d_L, s_L	2723
d_R, s_R	2615
t_1	2095
t_2	2366
b_1	2297
b_2	2349

Energy	L (ab^{-1})	P	Comments
3.0	2.0	-	Determine kin. Endpoints + Higgs
2.7	0.3	+0.8	Scan μ_R and e_R
2.5	0.3	-0.8	Scan χ^+ and τ_1
2.5	0.4	+0.8	Scan μ_R and e_R
2.2	0.7	-0.8	Scan χ^+ , τ_1, μ_R and e_R
2.0	0.5	-0.8	Scan τ_1
3.0	1.0	-0.8/+0.8	Study SUSY processes with pol.

Particle	Mass Accuracy (GeV)
$\chi^\pm_1$	± 4.3
$\mu^\pm_R$	± 6.2
$\tau^\pm_1$	± 6.7
χ^0_1	± 4.0

M. Battaglia and J.J. Blaising

Consider High Mass SUSY Scenario

(also studied Minimal Universal Extra Dimensions (MUED) Benchmark Point)

Note- polarization plays important role in signal or S/B enhancement

Other New Physics At CLIC

- Other new physics at CLIC could demand running at variable energies

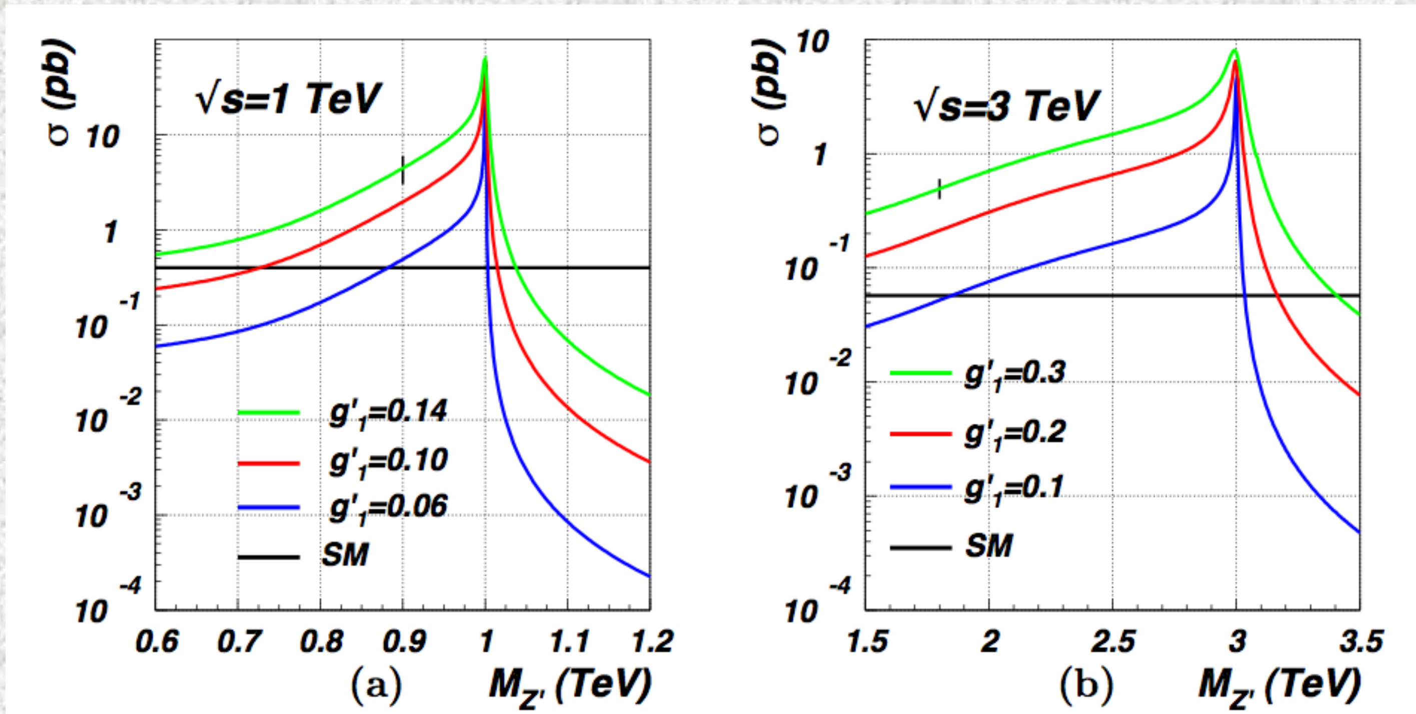
  - New Heavy Gauge Bosons (Z’,W’)
  - Extended Higgs Sector (eg. Charged Higgs)
  - Extra Dimensions
  - Universal Extra Dimensions
  - Fourth generation of fermions
  - Other known possibilities, or the unexpected

Low-energy extension of SM: Z'

minimal B−L low-energy extension of SM

$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$

Extra gauge boson, the Z'



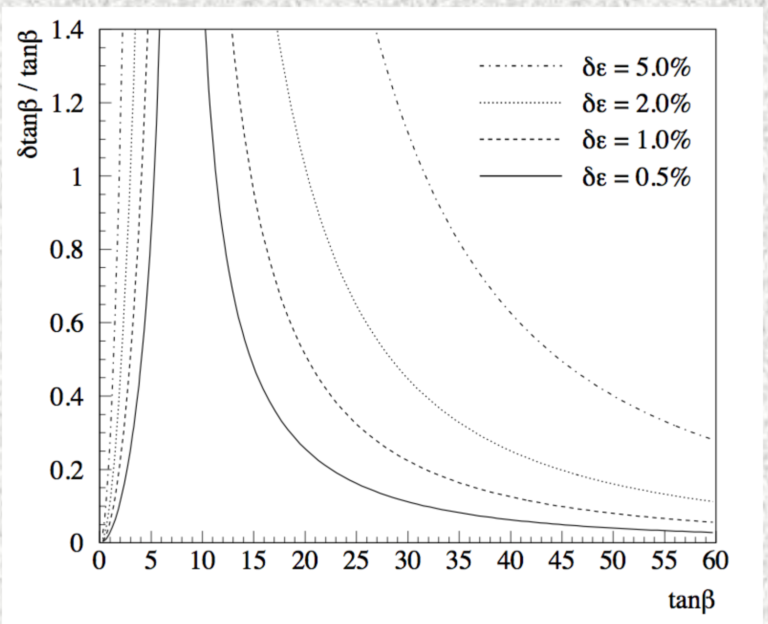
With a known value for $M_{Z'}$ (e.g., from LHC), one could extract g_1' from a line shape fit of the cross section at a LC.

L. Basso, A. Belyaev, S. Moretti and G. M. Pruna arXiv:0903.4777

We need to be prepared to vary E_{CMS}

Extended Higgs Sector

- A minimal extension of the Higgs sector (5 Higgs bosons)
  - Light SM-like Higgs (h^0)
  - Heavy CP-even neutral Higgs (H^0)
  - CP-odd, neutral Higgs (A^0)
  - Two charged Higgs (H^+, H^-)
  - two more parameters
    - Ratio (tan β) of vacuum expectation values and mixing angle α.
      - energy scan of $e^+e^- \rightarrow H^+H^-$ sensitive to value of tan β esp. for large tan β



A. Ferrari, LC-PHSM-2003-051
Equal √s steps 0.8 – 3.5 TeV

We need to be prepared to vary E_{CMS}

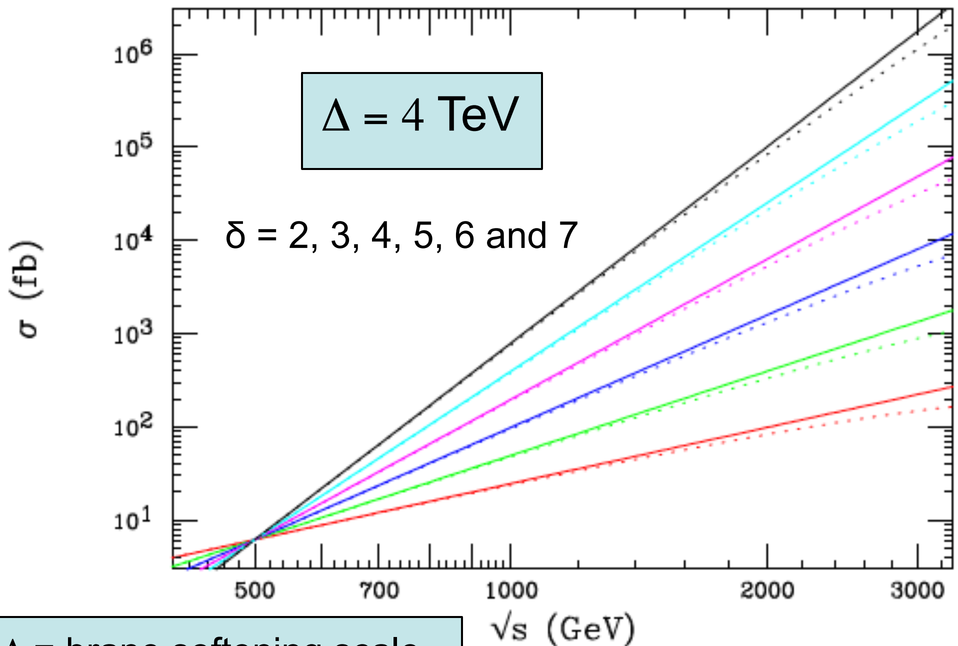
Extra Dimensions

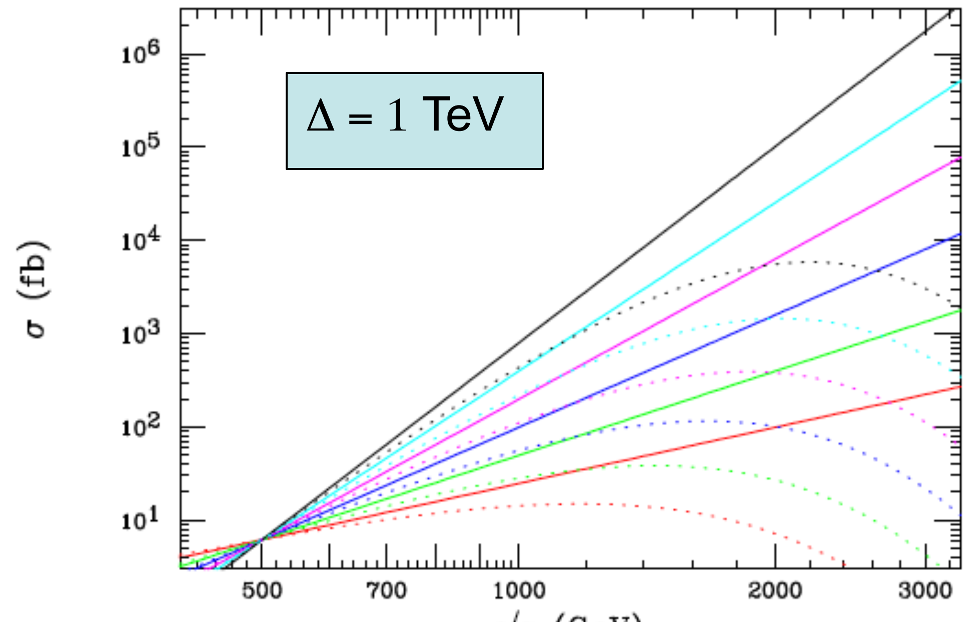
- Is the solution to the Hierarchy Problem found in the presence of large extra dimensions?
  - N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Rev. D 59, 086004 (1999) [arXiv:hep- ph/9807344] and Phys. Lett. B 429, 263 (1998) [arXiv:hep-ph/9803315]
- If yes, this suggests existence of excitations in the extra dimensions,
- But the details depend on the nature of the extra dimensions
  - Rigid or Soft Branes?
  - Warped extra dimensions?
  - L. Randall and R. Sundrum, Phys. Rev. Lett. 83, 3370 (1999) [arXiv:hep-ph/ 9905221]
  - …

$e^+e^- \rightarrow \gamma + G$

- by measuring the γG cross section at different centre-of-mass energies, one can disentangle the Planck scale and the number of extra dimensions δ simultaneously

Solid lines - Rigid Branes; **Dotted lines – Soft Branes**





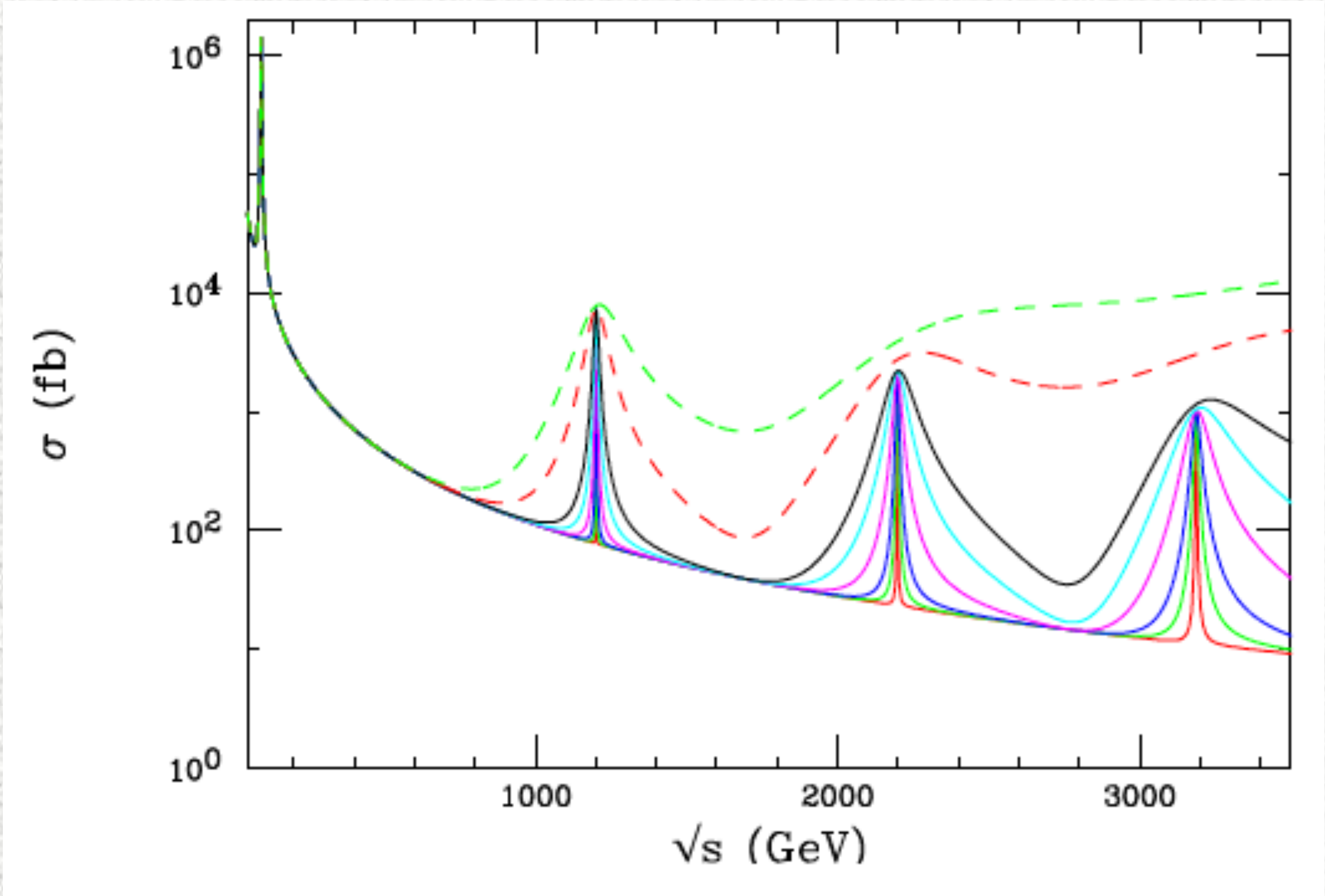
Δ = brane softening scale

CLIC Physics Working Group, hep-ph/0412251;
H. Murayama and J. Wells, hep-ph/0109004

Notice – falling cross section

Kaluza-Klein Graviton Excitations

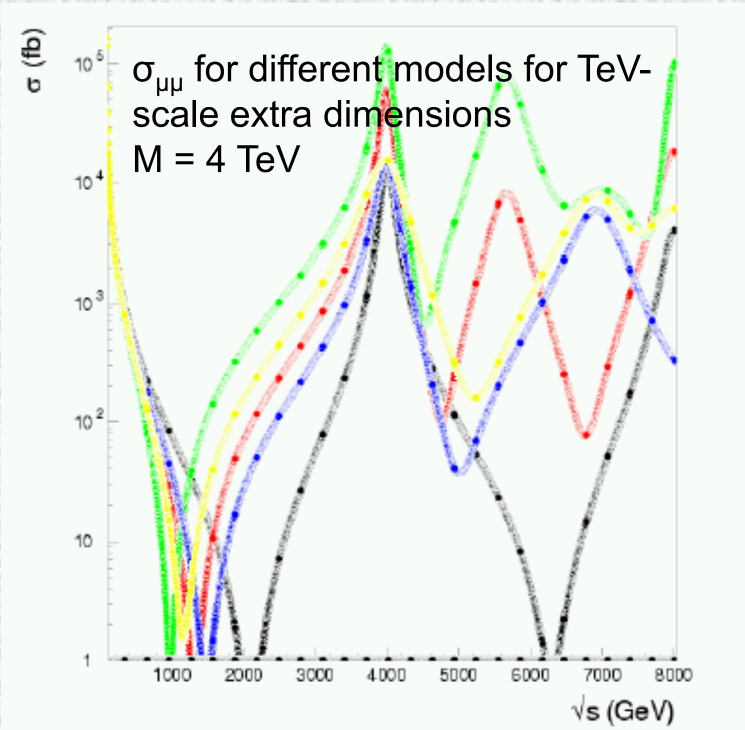
The spectrum of Kaluza-Klein graviton excitations produced in
a Randall- Sundrum model in the process $e^+e^- \rightarrow \mu^+\mu^-$,
showing different possibilities for their decay widths

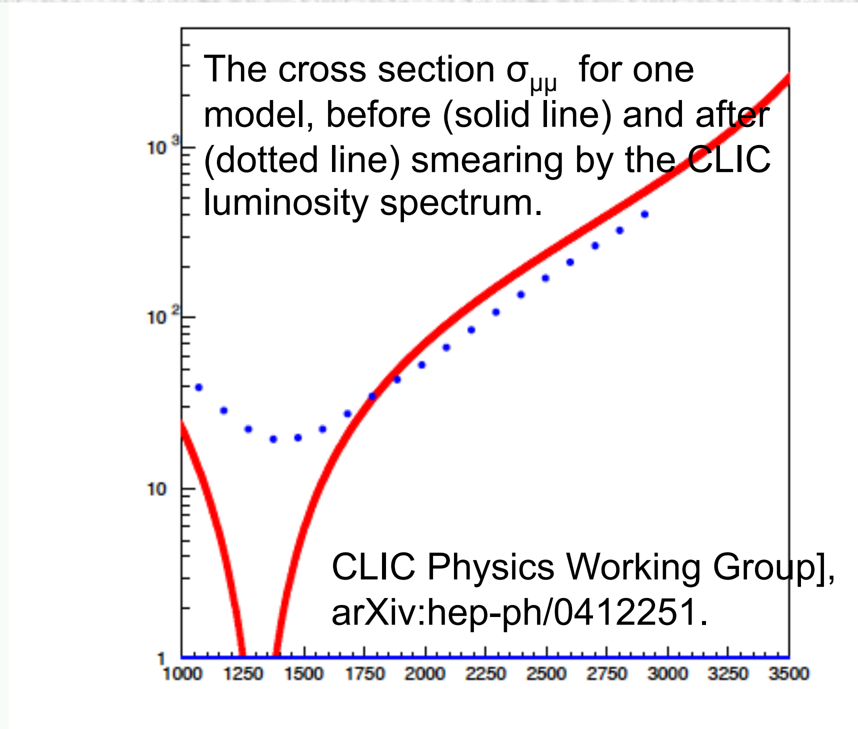


CLIC Physics Working Group, arXiv:hep-ph/0412251.

Kaluza-Klein Excitations

Examples of models with one or more TeV-scale extra dimensions

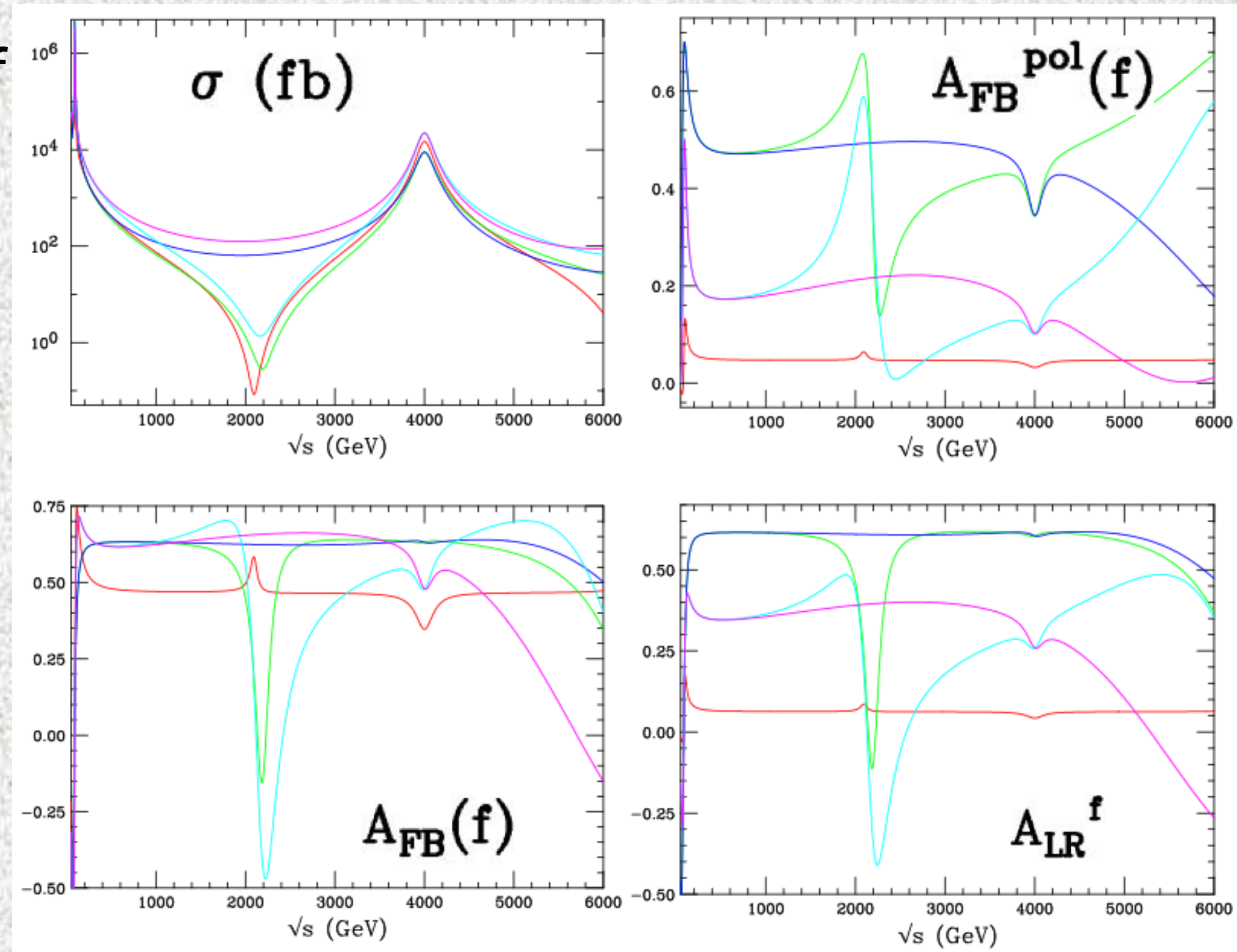




The positions of peaks, dips and corresponding cross sections and widths uniquely reveal the extra-dimensional model.

Resolving Degenerate KK Excitations

- Kaluza-Klein excitations of standard model gauge fields likely unresolvable by the LHC (eg M ~ 4 TeV) – Z' like
- Linear Collider operating below the resonance can resolve and interpret them with measurements of
  - $\sigma_{ff}(\sqrt{s})$
  - A_{FB}, A_{LR}, A_{FB}^{pol}



$e^+e^- \to \mu^+\mu^-\ b\bar{b}$ and $c\bar{c}$ for two alternative model of extra dimensions; red muons, b green(blue), c cyan(magenta) for 'conventional' (AS).
T. Rizzo, Phys Rev D61, 055005 (2000)

We need to be prepared to vary E_{CMS}

SUSY or UED? Which is It?

- SUSY and UED can produce similar looking spectra
  - Distinctions: KK towers, spin, extended Higgs sector/ gaugino states
- Example - level 1 KK muons $e^+e^- \rightarrow \mu_1^+ \mu_1^-$
  compared to smuon production: $e^+e^- \rightarrow \tilde{\mu}^+\tilde{\mu}^-$
- Threshold scan will establish spin
  - determines the masses
  - confirms the particle nature (spin)
    - UED cross sections rise at threshold $\propto \beta$
    - Supersymmetry threshold onset is $\propto \beta^3$

We need to be prepared to vary E_{CMS}

M.Battaglia, A. Datta, A. De Roeck, K. Kong, T. Matchev, JHEP 07(2005)033

Fourth Generation

- A fourth generation of fermions has not been ruled out.
- Mass theoretically limited to < 1 TeV
  - M.S. Chanowitz, M. A. Furman and I. Hinchliffe, *Nucl. Phys. B153 (1979) 402.*
- LHC may discover a 4^{th} generation, but the leptons will be very difficult for a hadron machine (remember the tau)
- Thresholds scans would offer discovery potential and powerful information on 4^{th} generation particle properties

We need to be prepared to vary E_{CMS}

CLIC Physics Requirements and Benchmark Processes

- LCD Note 2010- DRAFT
- Update DRAFT List of Requirements for the CLIC accelerator, 13 Oct 2010
- following discussions involving M. Battaglia, J.J. Blaising, K. Elsener, G. Giudice, L. Linssen, D. Schlatter, D. Schulte, F. Teubert, J. Wells (CERN)

- 6. Requirements for lower energies, after operation of the 3 TeV CLIC
  - Threshold scans are expected to be necessary, if possible down to energies around $\sqrt{s}$ = 1TeV. They will be performed within the luminosity budget and running period mentioned above (3-5 ab^{-1} in 6-10 years). Cross sections for scans will be exceedingly small near threshold. Therefore, luminosity will remain a crucial parameter for operation at lower energies. For the threshold scans, the peak luminosity rather than the total luminosity will be relevant.

  - Typically, the luminosity within 1% of the c.m. energy is required to be less than 40% reduced at 1.5 TeV c.m., and less than 60% reduced at 1 TeV c.m. Pending further studies, the requirements on beam energy accuracy and beam polarisation are the same as for the 3 TeV CLIC.

The future is uncertain. But we must be prepared!

- We expect the LHC to start clarifying the physics landscape
- Until then, keep an open mind: many solid reasons suggest a need to operate below the full energy of the collider
- Nature may provide unanticipated discoveries, and the variable $\sqrt{s}$ capability could be a critical tool to elucidate the new physics
- We must design and construct our future linear colliders with the capability to lower the center of mass energy without significant loss of luminosity
- More quantitative work on the physics requirements of luminosity versus energy is needed

"I never said half the things I really said."