Discussion:
Physics Benchmarks for Lepton Colliders

Purpose of Benchmarks:

Probe efficacy of Muon Collider (cone angle, bkgnds, pol., L , dE/E , E)

Compare and contrast e+e- and $\mu+\mu-$ machines:

- Energy reach?
- Luminosity?
- polarization?
- dE/E ?

Test physics discovery potential against background and geometry issues

Benchmarks should be robust as the new physics emerges at LHC

Provide useful issues for detector simulation studies

- e.g., how is forward WW fusion impacted by cone blockout?
- how is reconstruction affected by polarization, dE/E?

Discussion points:

(1) Supersymmetry full model simulations

(2) Extra Dimensions: KK Modes (Moose models)

(3) Contact Interactions

(4) Z' Narrow Resonances

(5) WW, WZ , ZZ fusion processes

(6) Higgs and Multi-Higgs (H^0 A^0 Resonances)

(7) Dark Matter (gamma + missing E)

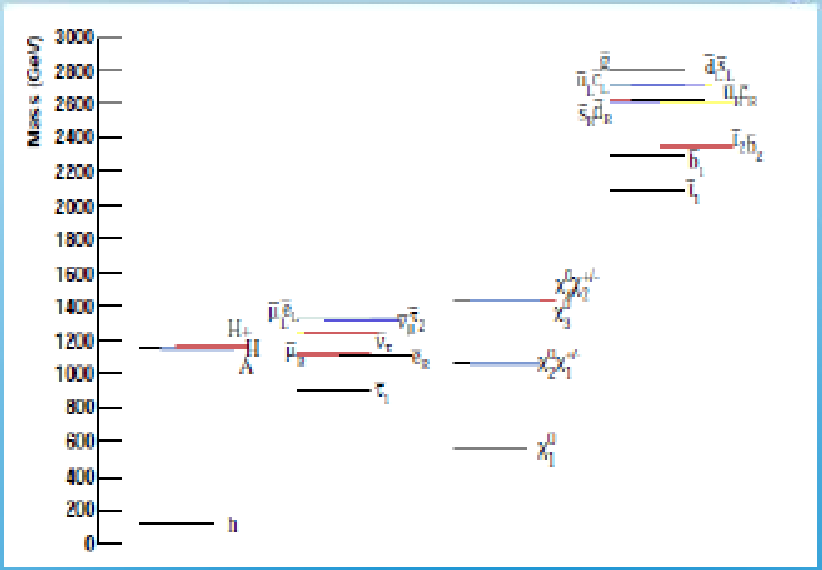
(8) New Strong Dynamics

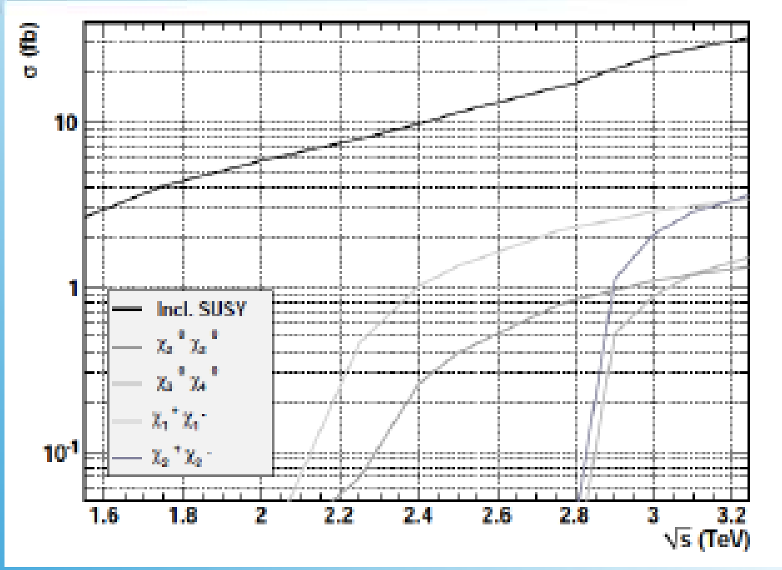
(9) Standard Model Physics

(1) Full Scale SUSY Simulations (M. Battaglia)

Multi-TeV lepton collisions likely to be required by new physics signals at the Tera-scale: essential to understand the intrinsic limitations of e+e- and μ+μ- in terms of practical collision energy (and luminosity);

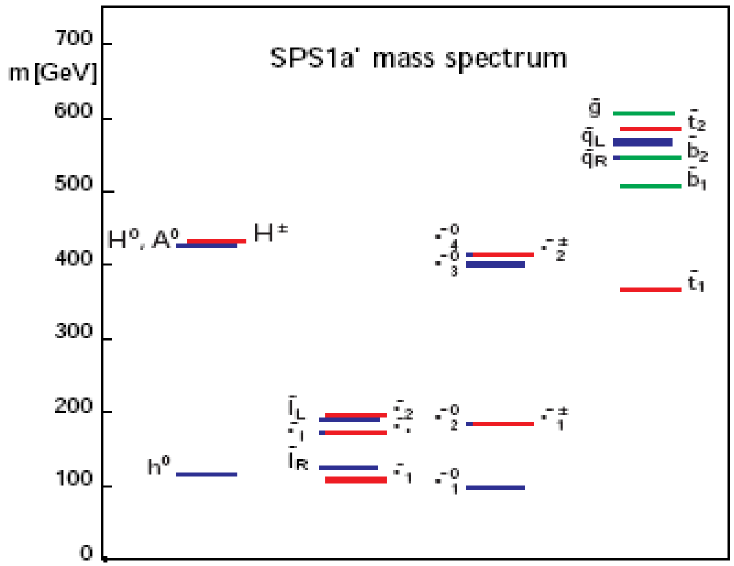
Several scenarios of new physics have thresolds for s-channel particle production extending over considerable energy span: need to evaluate achievable accuracy of measurements within realistic run plan;





Which model(s) to simulate? E.g.:

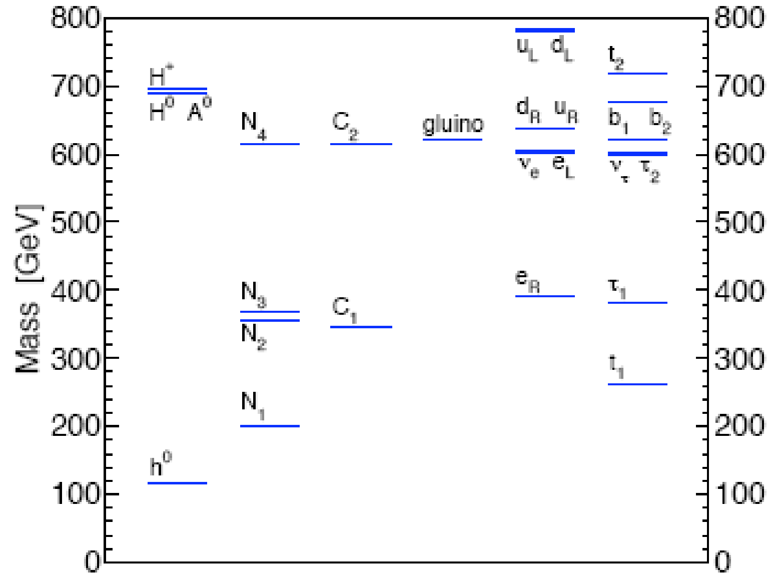
cMSSM ILC Benchmark



Many visible superpartners within reach of the ILC (500 GeV).
All pair production thresholds are below 1.2 TeV.

Compressed SUSY

S. Martin [PR D75:115005,2007]

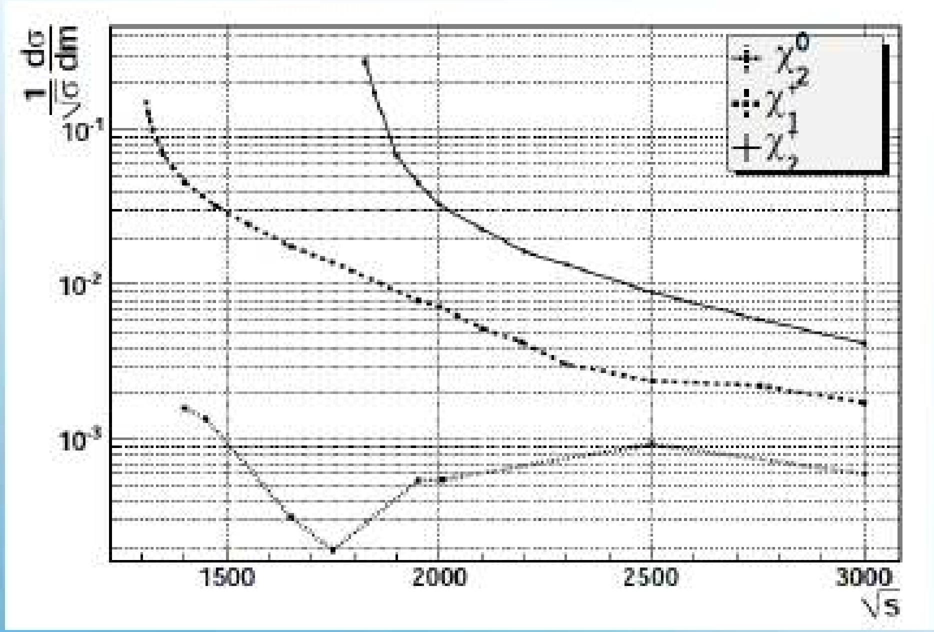


No visible superpartners within reach of the ILC (500 GeV).
All pair production thresholds are below 1.6 TeV.

This is an Industry Standard in e+e- machine studies.

Illustrate strength of polarization and energy resolution
in reconstruction and physical parameter determination

Battaglia:



Particle	Mass (GeV)	Born	ISR	ISR+BS	ISR+BS +Bkg	w/ Pol (+0.8/0)	w/ Pol (+0.8/-0.6)
Model I							
$\chi_1^\pm$	643.2	$\pm$ 0.6	$\pm$ 0.6	$\pm$ 0.7	$\pm$ 0.7	$\pm$ 0.5	$\pm$ 0.4
χ_2^0	643.1	$\pm$ 4.3	$\pm$13.8	$\pm$24.1	$\pm$25.6	$\pm$23.9	$\pm$18.1
$\chi_2^\pm$	916.7	$\pm$ 0.8	$\pm$ 0.9	$\pm$ 1.3	$\pm$ 1.4	$\pm$ 1.1	$\pm$ 0.9

arXiv:1104.0523

Battaglia:

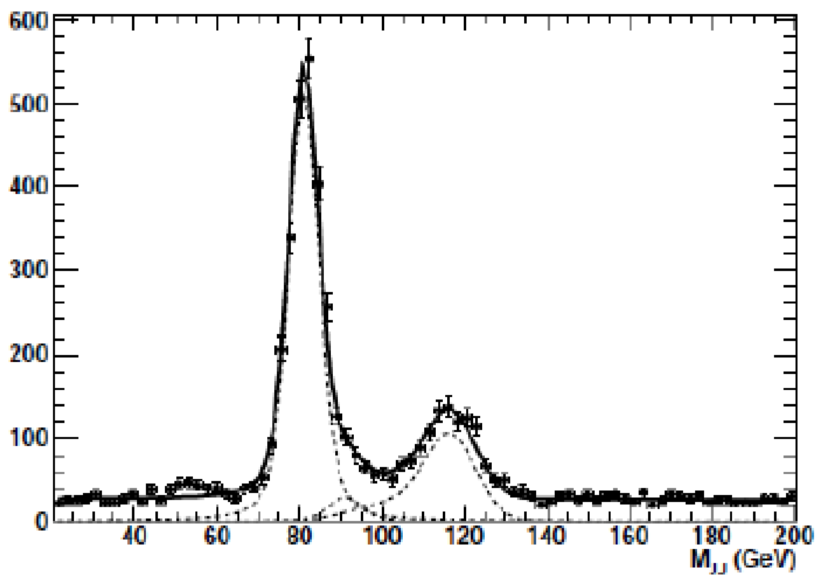
Process	Signature	Detector Challenges	Machine Challenges
$H^0, A^0 \to bb$ $H^+H^- \to tb$	Multi-jets	b tagging δE_{jet} w/ kin fitting	δE_{beam}
Gaugino pairs, $\chi \to W/Z/h$	Multi-jets+ $E_{missing}$	dEjets w/o kin fitting Jet clustering	δE_{beam}, bkg L vs E_{beam} Threshold scan
Slepton pairs	Leptons+ $E_{missing}$	Lepton id δE at high E	L vs E_{beam} Threshold scan Polarisation
Squark pairs	Multi-jets+ $E_{missing}$	δE_{jet} at highest E	
EW observables in $\mu\mu$, bb, tt	Multi-jets, Fwd	b tagging at highest E Quark charge, Fwd	Polarisation, bkg
$\nu\nu H \to \mu\mu$ $\nu\nu H \to bb$	Fwd Fwd b jets	Fwd E reco Fwd b tagging	bkg
$\nu\nu HH \to bbbb$	Fwd b jets	Fwd b tagging, Jet clustering	L, bkg, Polarisation
$\nu\nu WW$ / $\nu\nu ZZ$	Multi-jets Fwd	W/Z separation, Fwd	bkg

Higgs

SUSY Gaugino Pair Production

Battaglia:

- $e^+e^- \to \chi_1^+\chi_1^- \to W^+\chi_1^0 W^-\chi_1^0;\ W \to q\bar{q}'$,
- $e^+e^- \to \chi_2^0\chi_2^0 \to h^0\chi_1^0 h^0\chi_1^0;\ h \to b\bar{b}$,
- $e^+e^- \to \chi_2^+\chi_2^+ \to W^+\chi_2^0 W^-\chi_1^0 \to W^+ h^0\chi_1^0 W^-\chi_1^0;\ h \to b\bar{b},\ W \to q\bar{q}'$,
- $e^+e^- \to \chi_2^+\chi_2^+ \to h^0\chi_1^+ W^-\chi_1^0 \to h^0 W^+\chi_1^0 W^-\chi_1^0;\ h \to b\bar{b},\ W \to q\bar{q}'$,
- $e^+e^- \to \chi_2^+\chi_2^+ \to Z^0\chi_1^+ W^-\chi_1^0 \to Z^0 W^+\chi_1^0 W^-\chi_1^0;\ Z \to q\bar{q},\ W \to q\bar{q}'$,
- $e^+e^- \to \chi_4^0\chi_3^0 \to W^+\chi_1^- W^-\chi_1^+ \to W^+W^-\chi_1^0 W^-W^+\chi_1^0;\ W \to q\bar{q}'$.



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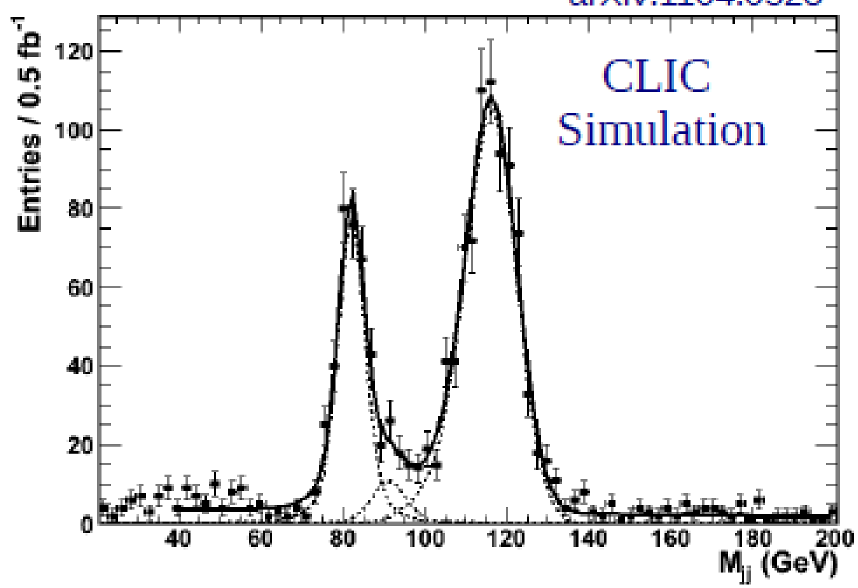


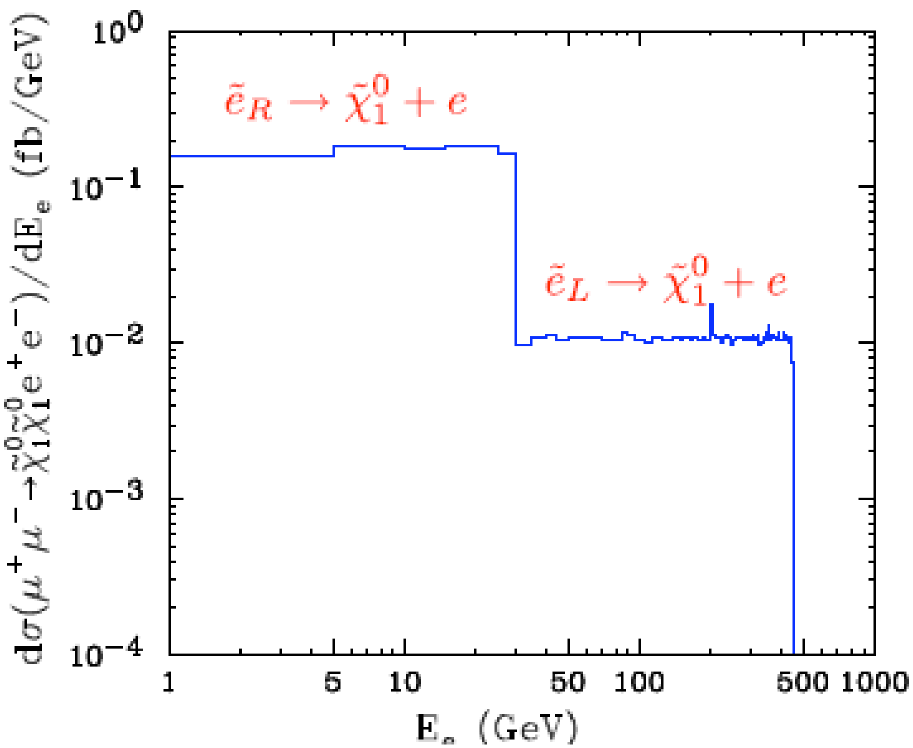
Subset of processes may be particularly illustrative owing to complexity; e.g.

$$\mu^+\mu^- \to \tilde{e}_1^+\tilde{e}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-$$

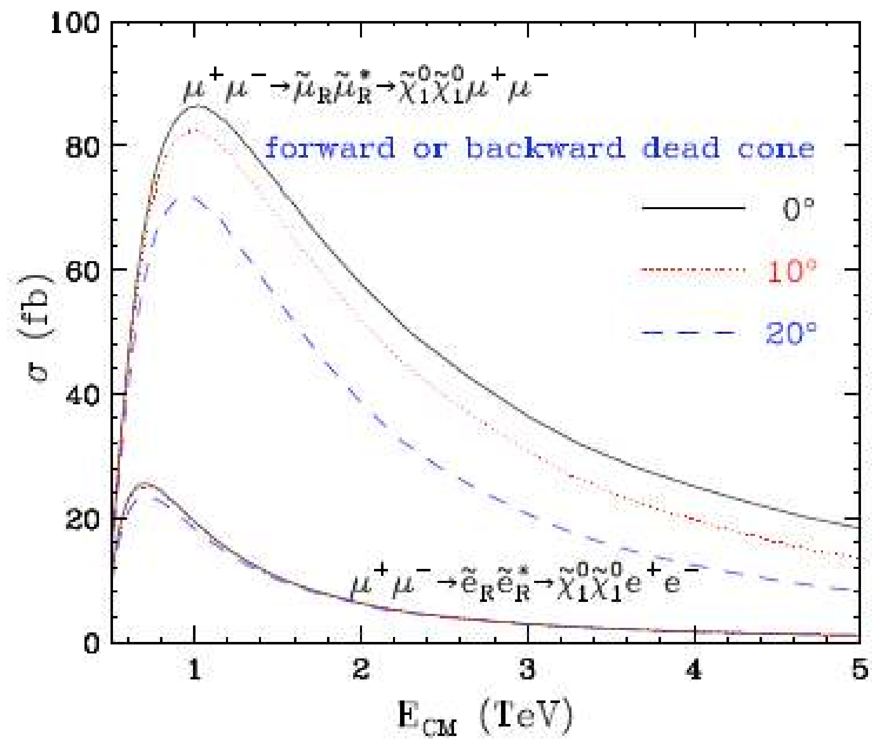
Study advantage of small dE/E in mass determination from sharp kinematic edges:

Kong, Winter (MC)

$m_{\tilde{\chi}_1^0} = 212;\ m_{\tilde{e}_R} = 222;\ m_{\tilde{e}_L} = 374$ GeV



Study severity of forward cone obstruction



(1) SUSY Discussion:

Is there a standard SUSY model for this (as there was in ILC era)?
The electron and muon communities should agree upon this.

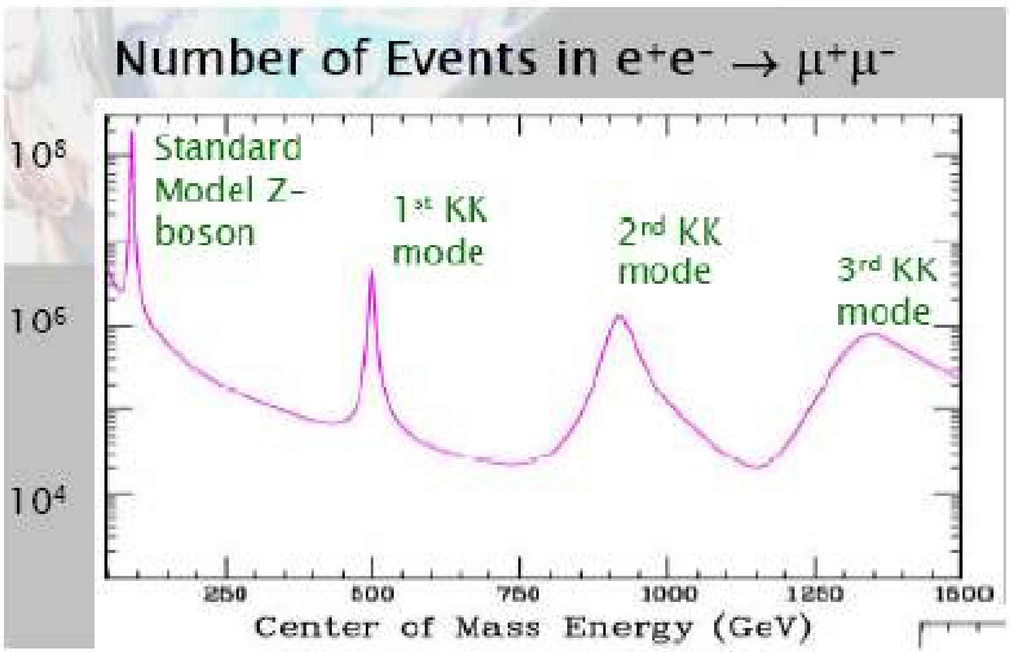
Should we take these models seriously? They are probably not likely to be realistic contenders anymore (e.g., fine tuning), or are they? Robust?

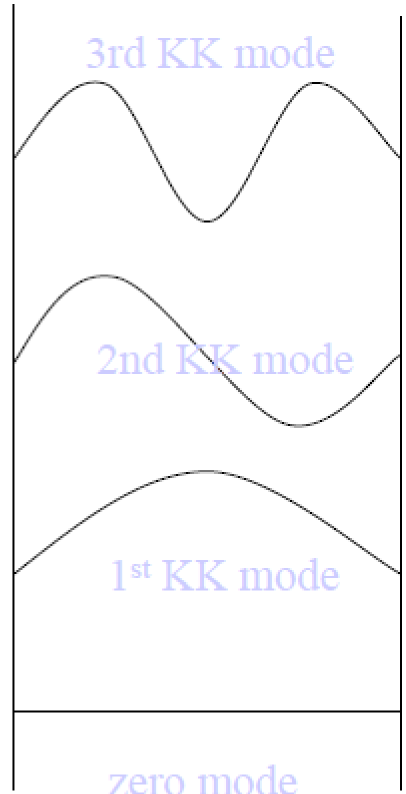
Advantage: they offer rather well defined complex processes worthy of study. Industry standard.

Strategy: Can we abstract generic sub-processes from these models and analyze them to thoroughly in both machines?
(eg, $\mu^+\mu^- \rightarrow \tilde{e}_1^+\tilde{e}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-$

Can the sophisticated analysis software for e+e- be adapted to MC?
Who will undertake this and when?

(2) ED’s, KK Modes, Moose Models

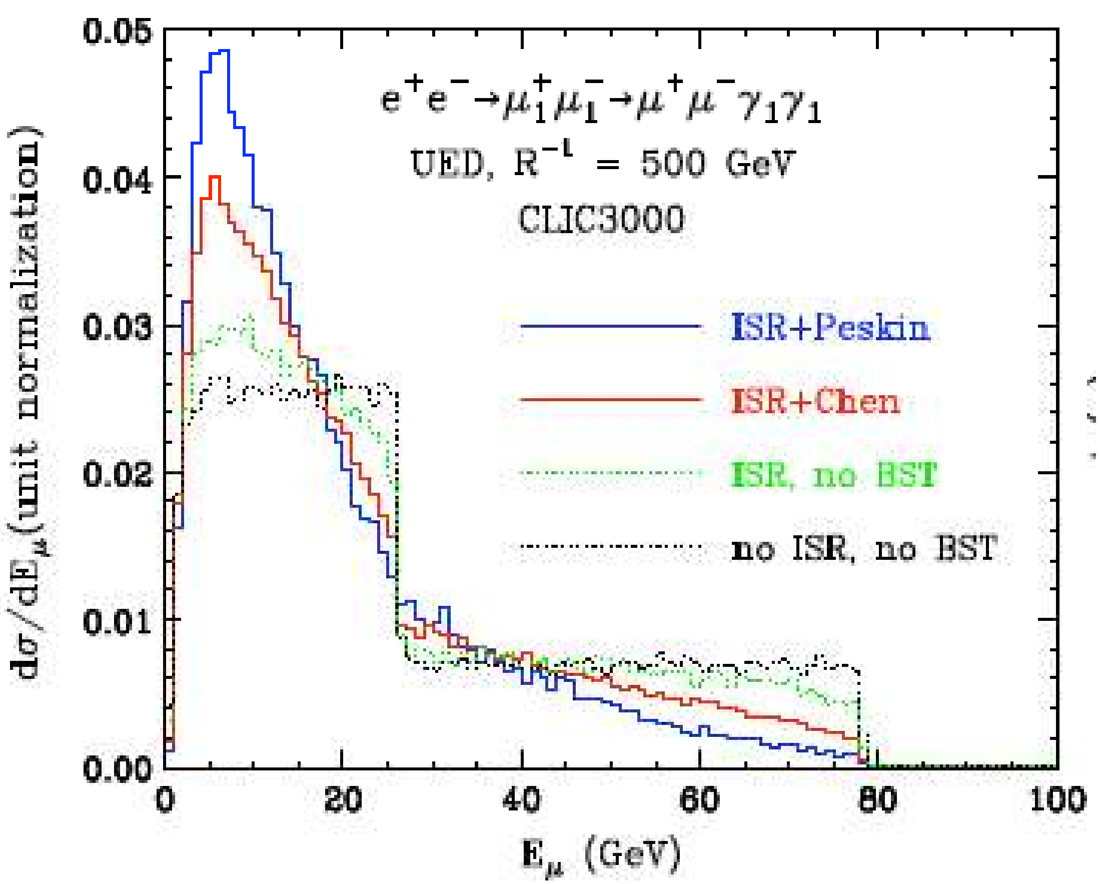




Illustrative benchmark processes involving KK mode production:

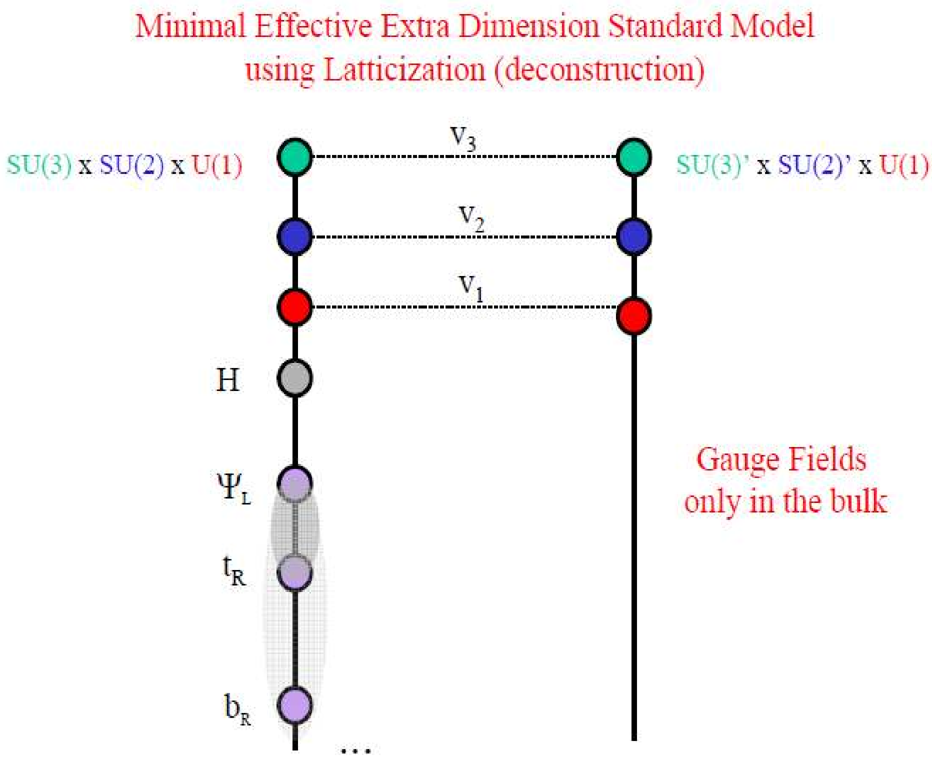
Assess effect of Beamstrahlung , initial state radiation

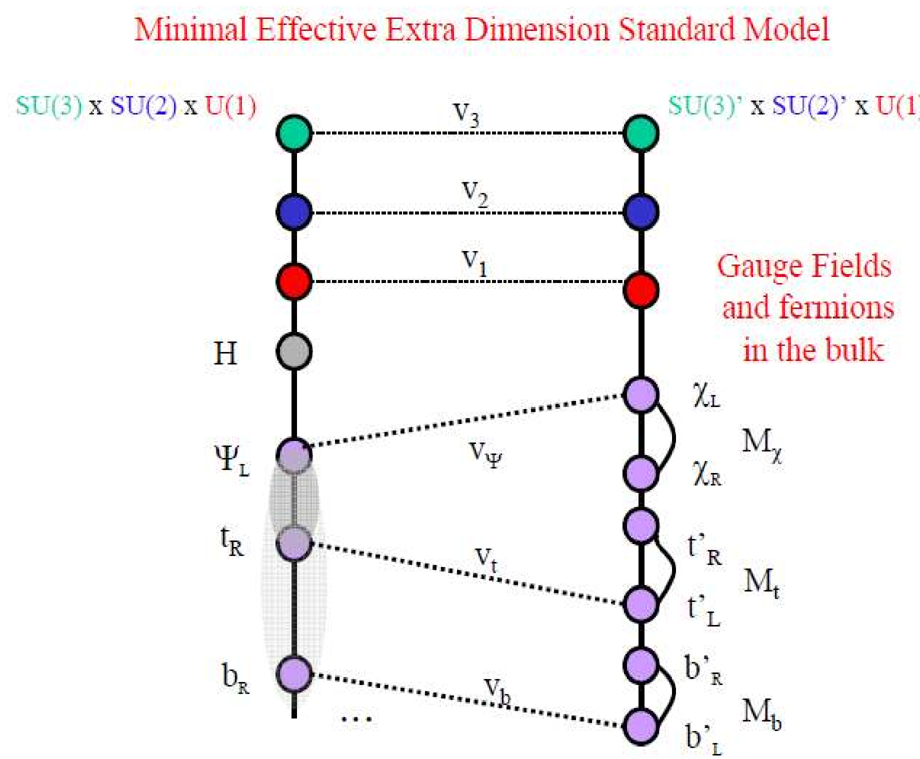
Datta, Kong and Matchev [arXiv:hep-ph/0508161]



Systematize the discussion of models using "deconstruction" (= Moose models)

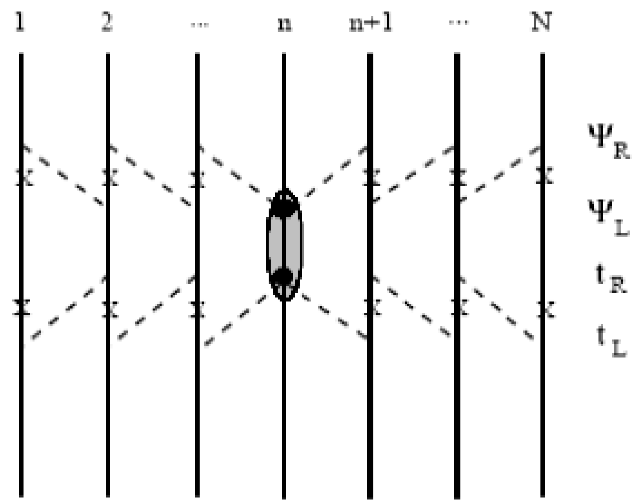
Overlap with generic models, e.g., strong dynamics, Little Higgs



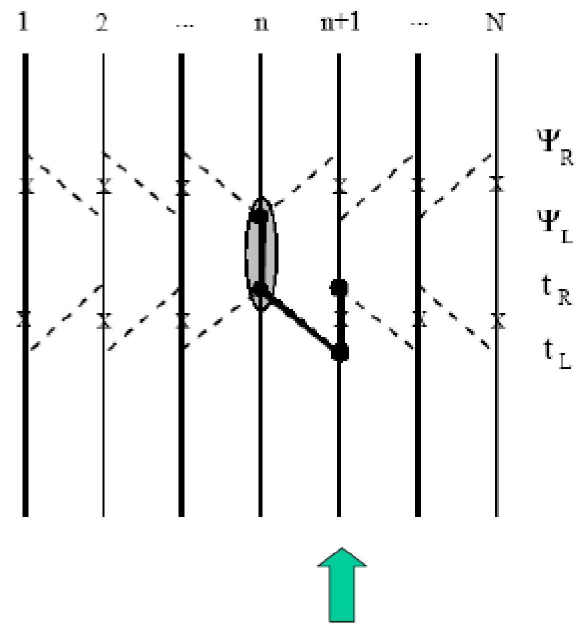


Example: Two dynamical models as deconstructed ED

Higgs is composite: $H \sim \begin{pmatrix} \bar{t}_L t_R \\ \bar{b}_L t_R \end{pmatrix}$



Top Quark Seesaw Model



Chi quarks

Production of pairs of (KK mode) fermions:

Eichten's formula:

$$\sigma_{\mu+\mu- \to e+e-} = \frac{87\ \text{fb}}{s\,/\,(\text{TeV})^2} \qquad R_{\text{process of interest}} = \frac{\sigma_{\text{process of interest}}}{\sigma_{e+e- \to \mu+\mu-}}$$

e.g. R of "chi quarks" = O(1) approximately

If chi quark mass is 1.5 TeV, require a > 3 TeV machine, and approximately N fb^{-1} to produce N pairs!

chi -> t + Z (top seesaw, Little Higgs theories)

Gunion:

A Fourth Generation?

- Precision electroweak, Yukawa perturbativity, ... require $m_{t'}, m_{b'} \lesssim$ 550 GeV.
- LHC will soon either exclude or detect the 4th generation quarks.
- If a 4th generation exists then threshold scans of $b'\overline{b}'$ and $t'\overline{t}'$ production will give the best mass determinations.

  Especially important might be the precise determination of $m_{t'} - m_{b'}$ which will give a crucial contribution to ΔT that might allow a heavier SM-like Higgs boson (as predicted in the MSSM context for a 4th generation).
- Meanwhile, If we see a light SM-like Higgs boson at the LHC with expected rates in the $gg \to h \to WW$ and $gg \to h \to \gamma\gamma$ final states, we will exclude a 4th generation based on non-decoupling loop effects.

  We will also exclude a sequential W' with "SM-like" couplings to the light Higgs.

  Defining ratios relative to SM expectations, R_{WW} and $R_{\gamma\gamma}$, a 4th generation and/or sequentail W' will result in R values substantially > 1.

  These increases derive from the loop triangle diagrams.

  – The $gg \to h$ coupling counts heavy colored fermions in the loop.

cth: I view this as a form of technicolor, m -> 600 GeV

(2) ED’s, KK Modes, Moose Models Questions:

Similar issues as with SUSY models: which models to simulate?
Which sub-processe are optimal benchmarks?

It is unlikely we’ll see the emergence of a full ED. We’ll probe lowest modes, but are these really KK modes of an ED?

Note that many dynamical models have (deconstruction) descriptions In terms of KK modes. At low energies these classes of objects are usually indistinguishable from ED: 4^{th} gen condensation, top seesaw, Little Higgs (anything that can be represented by a Moose = deconstruction).

Perhaps we should enlarge the scope of this benchmark to include Non-SUSY dynamical models? (eg, subsume strong dynamics?)
“Moose Models”?

What do we simulate?

(3) Contact Interactions:

Eichten:

- New interactions (at scales not directly accessible) give rise to contact interactions.

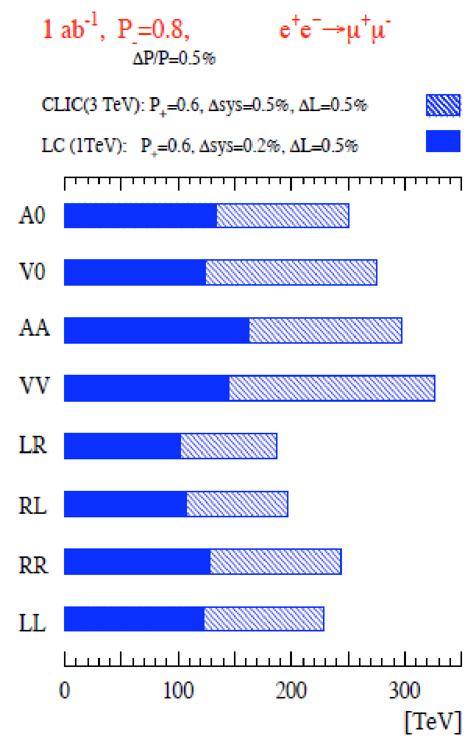
$$\mathcal{L} = \frac{g^2}{\Lambda^2}(\bar{\Psi}\Gamma\Psi)(\bar{\Psi}\Gamma'\Psi)$$

- Muon collider is sensitive to contact interaction scales over 200 TeV as is CLIC.
- Cuts on forward angles for a muon collider not an issue.
- Polarization useful to disentangle the chiral structure of the interaction. (CLIC)

good benchmark process

Muon Collider Study
E.Eichten, S.~Keller, [arXiv:hep-ph/9801258]

CLIC Study



(3) Contact Interactions Questions:

Contact interactions should be easy to treat fully and are potentially Illustrative of polarization (chiral contact terms), geometry (cone obstruction) and energy reach Issues.

Include quasielastic ops with mu+mu -> light f + f
mu+mu -> top + top
mu + mu -> WW, ZZ, etc.

Does more work remain to be done here? (beyond Eichten + Keller)

Gunion: (4)

Z' s, KK excitations, etc.

First, let me paraphrase Langackers Physics Report. Z' includes new resonances associated with a gauge symmetry, KK excitations, etc.

- A new $U(1)'$ gauge symmetry is one of the best motivated extensions of the standard model.
- For example, $U(1)'$ s occur frequently in superstring constructions.
- If there is supersymmetry at the TeV scale, then both the electroweak and Z' scales are usually set by the scale of soft supersymmetry, so it is natural to expect $M_{Z'}$ in the TeV range.
- TeV-scale $U(1)'$ s (or Kaluza-Klein excitations of the photon and Z) frequently occur in models of dynamical symmetry breaking, Little Higgs models, and models with TeV^{-1}-scale extra dimensions.

Eichten:

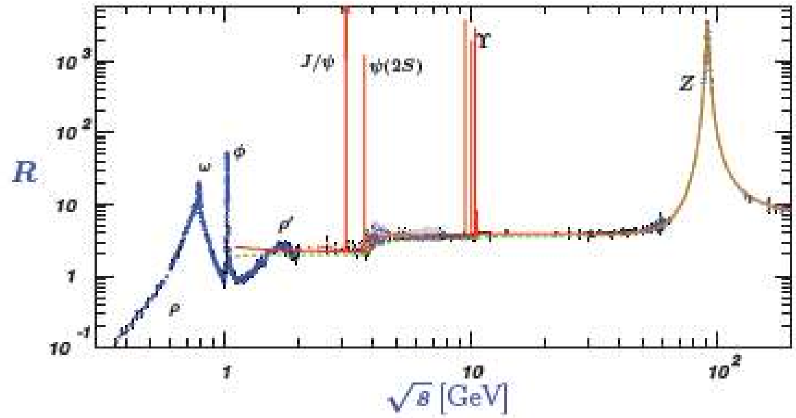
S Channel Resonances

- Universal behavior for s-channel resonance

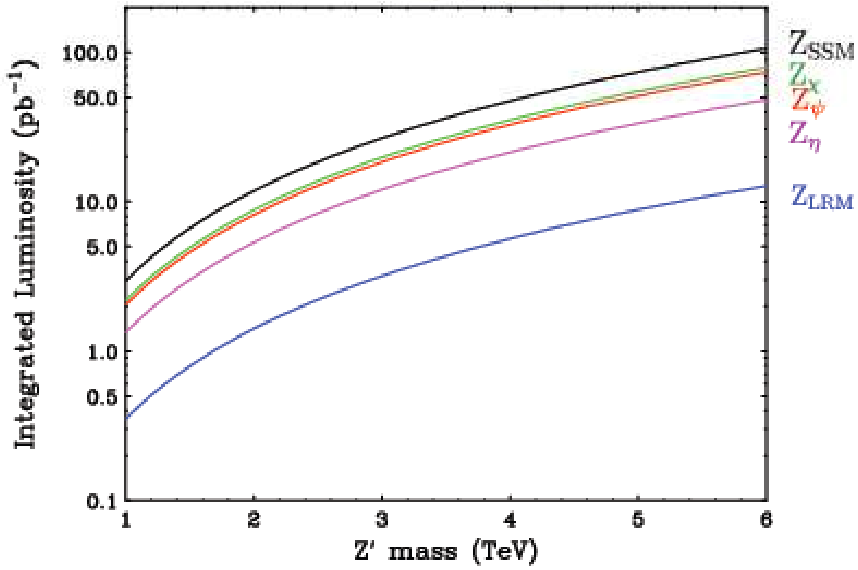
$$\sigma(E) = \frac{2J+1}{(2S_1+1)(2S_2+1)}\frac{4\pi}{k^2}\left[\frac{\Gamma^2/4}{(E-E_0)^2+\Gamma^2/4}\right]B_{in}B_{out}$$

Convolute with beam resolution ΔE.
If $\Delta E \ll \Gamma$

$$\boxed{R_{\text{peak}} = (2J+1)3\frac{B(\mu^+\mu^-)B(visible)}{\alpha^2_{\text{EM}}}}$$



- Can use to set minimum required luminosity for a muon collider:
  - Likely new physics candidates:
    - scalars: h, H^0, A^0,...
    - gauge bosons: Z′
    - new dynamics: bound states
    - ED: KK modes
  - Example – new gauge boson: Z′
    - SSM, E6, LRM
    - 5σ discovery limits: 4-5 TeV at LHC (@ 300 fb^{-1})



The integrated luminosity required to produce 1000 $\mu^+\mu^-$ -> Z′ events on the peak

> Minimum luminosity at Z′ peak:
> $\mathcal{L}$ = 0.5-5.0 x 10^{30} cm^{-2} sec^{-1}
> for M(Z′) -> 1.5-5.0 TeV

(4) S-channel Resonances Questions:

My personal view: This may the single most important issue governing the possibility of having a muon collider. It is also likely to be ruled in or out by LHC soon. If Z' exists we can contemplate a low luminosity first MC (e.g., Neuffer's talk)

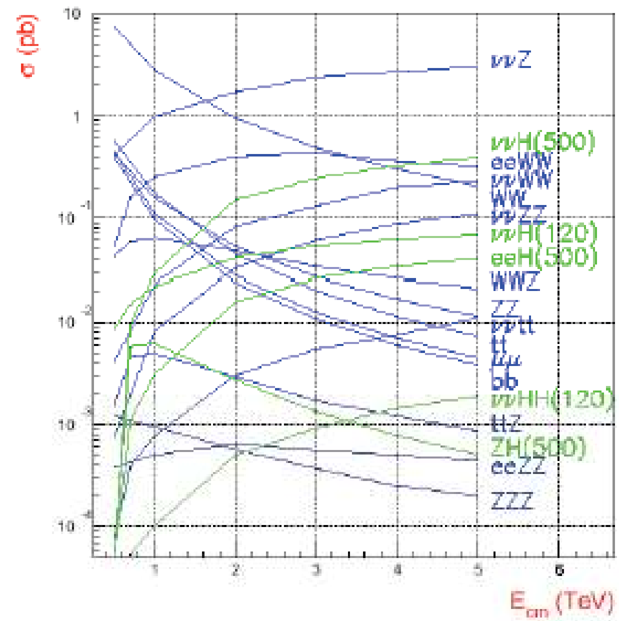
Many Z's to study; various final states, compelled in some models

Study dependence of sensitivity vs parameters, eg, Γ/M and Br's.

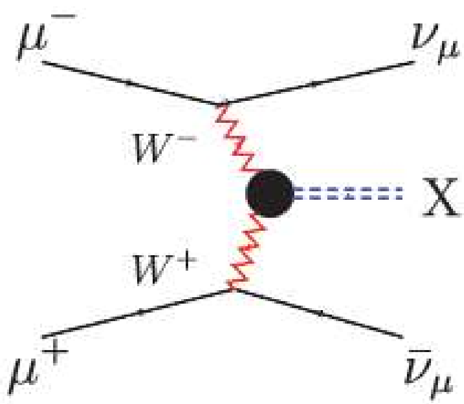
(5) Fusion Processes

Eichten:

CLIC (or MC e<->μ)



- For $\sqrt{s}$ > 1 TeV - Fusion Processes
  - Large cross sections
  - Increase with s.
  - Important at multi-Tev energies
  - $M_X^2 < s$
  - Backgrounds for SUSY processes
  - t-channel processes sensitive to angular cuts



$$\sigma(s) = C \ln(\frac{s}{M_X^2}) + \ldots$$

- An Electroweak Boson Collider

Gunion:

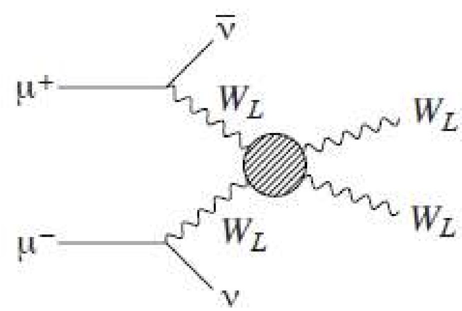
No Higgs or Higgs-like states: the Strongly-Interacting Electroweak Scenario

Much of the following material is based on papers by the Muon-Quartet (Barger, Berger, Gunion, Han).

- If no Higgs boson exists with $m_H < 600$ GeV, then, naively, partial wave unitarity of $W_L W_L \to W_L W_L$ will be violated at large s_{WW}.
  The $W_L W_L \to W_L W_L$ scattering amplitude behaves as

$$A \sim \begin{cases} m_H^2/v^2 & \text{if light Higgs}, \\ s_{WW}/v^2 & \text{if no light Higgs}. \end{cases} \quad (1)$$

  Understanding the manner in which unitarity violation is avoided at high energies will be crucial.
- $W_L W_L \to W_L W_L$ scattering will be probed via



Gunion:

- Energy reach is a critical matter here with subprocess energies $\sqrt{s_{WW}} \gtrsim$ 1.5 TeV is needed to probe strong WW scattering.
  Since $E_\mu \sim$ (3–5)E_W, this condition implies

$$\sqrt{s_{\mu\mu}} \sim (3\text{–}5)\sqrt{s_{WW}} \gtrsim 4 \text{ TeV}\,. \qquad (2)$$

- The ultimate goal is to determine all the different weak isospin amplitudes, in terms of which the physical scattering amplitudes can be written as

$$\begin{aligned}
\mathcal{M}(W_L^+W_L^- \to Z_LZ_L) &= \frac{1}{3}[T(0) - T(2)] \\
\mathcal{M}(Z_LZ_L \to W_L^+W_L^-) &= \frac{1}{3}[T(0) - T(2)] \\
\mathcal{M}(W_L^+W_L^- \to W_L^+W_L^-) &= \frac{1}{6}[2T(0) + 3T(1) + T(2)] \\
\mathcal{M}(Z_LZ_L \to Z_LZ_L) &= \frac{1}{3}[T(0) + 2T(2)] \\
\mathcal{M}(W_L^\pm Z_L \to W_L^\pm Z_L) &= \frac{1}{2}[T(1) + T(2)] \\
\mathcal{M}(W_L^\pm W_L^\pm \to W_L^\pm W_L^\pm) &= T(2)\,.
\end{aligned}$$

Overlap with New Strong Dynamics:
Top Seesaw has a very heavy (TeV), broad composite Higgs accessible
In the fusion production WW -> Higgs (Chivukula, Dobrescu, Georgi, Hill)

Mass matrix for $t - \chi$ system is,

$$-\left(\overline{t_L}\ \ \overline{\chi_L}\right)\begin{bmatrix} 0 & \mu \approx 600\, GeV \\ m \approx 1\, TeV & M \approx 4\, TeV \end{bmatrix}\begin{pmatrix} t_R \\ \chi_R \end{pmatrix} + \text{h.c.}$$

Diagonalized:

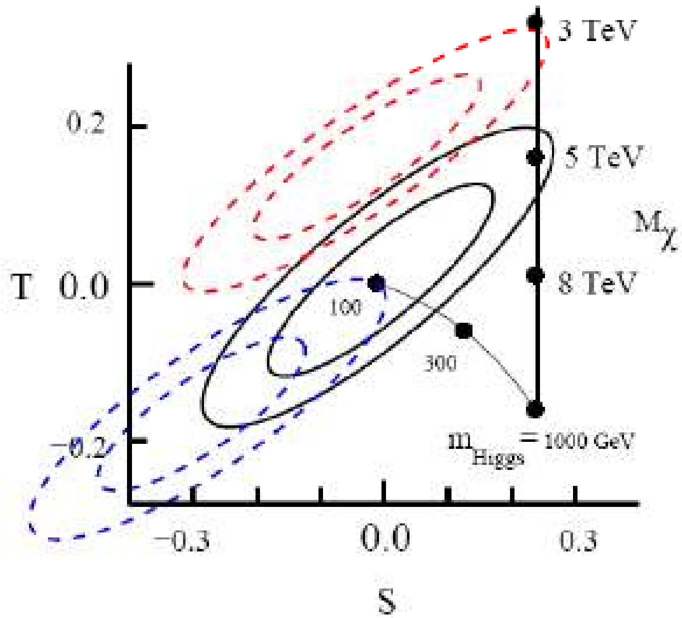
$$\begin{aligned} m_t &\approx \frac{\mu m}{M} \\ m_\chi &\approx M \end{aligned}$$

1998: Top Seesaw DOA (outside of the S-T ellipse $\sim 4\sigma$. (Chivukula, Dobrescu, Georgi, Hill)

1999: S-T error ellipse shifts along major axis tow: upper right (predicted by the theory!).

2001: Inconsistencies in data; keep only leptons $\rightarrow$ Top Seesaw consistent and SM ruled out at $\sim 2\sigma$!!

Theory consistent for natural values of its paramet at the 2σ level (He, CTH, Tait)



(5) Fusion Processes Questions:

Fully simulate measurement of broad heavy TeV scale Higgs

Probe energy reach and detector geometry (forward cone).

List of candidate fusion processes? E.g. q qbar production

(6) Higgs and MultiHiggs

Eichten:

- Various processes available for studying the Higgs at a multi-TeV muon collider
  - *Associated production: Zh^0*
    - R ~ 0.12
    - *search for invisible h^0 decays*
  - Higgsstrahlung: $t\bar{t}h^0$
    - R ~ 0.01
    - measure top coupling
  - W*W* fusion (m_h = 120 GeV)
    - $\nu_\mu \bar{\nu}_\mu h^0$: R ~ 1.1 s ln(s) (s in TeV^2)
    - $\nu_\mu \bar{\nu}_\mu h^0 h^0$: measure Higgs self couplings

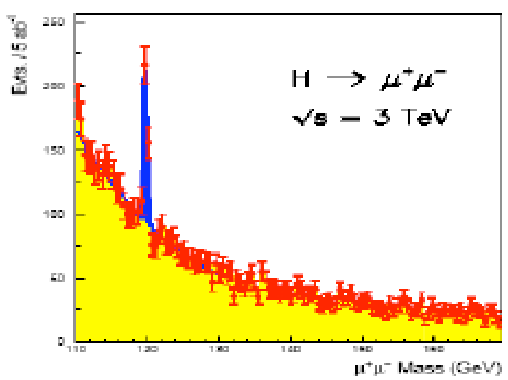
MC or CLIC:

needs 10 ab^{-1}

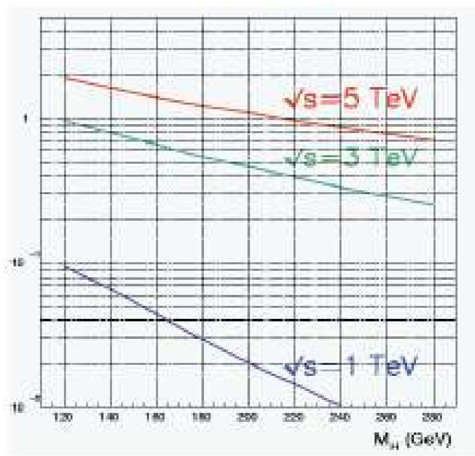
MC or CLIC:

good benchmark process

m(H) = 120 GeV



$\sigma(\mu^+\mu^- \to \nu\,\bar{\nu}\,h^0h^0)$ (fb^{-1})



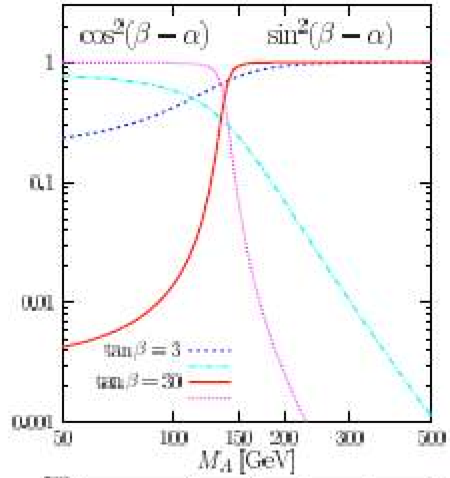
Eichten:

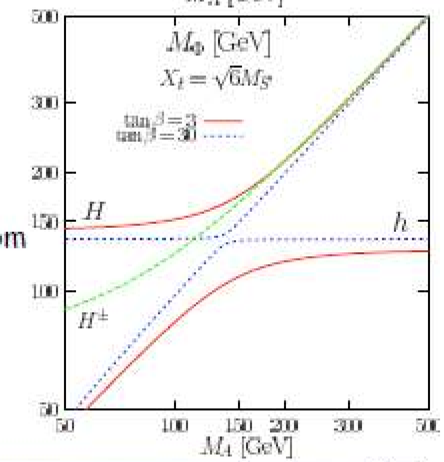
- Five scalar particles: h^0, H^0, A^0, $H^\pm$
- Decay amplitudes depend on two parameters: (α, β)

	$\mu^+\mu^-, b\bar{b}$	$t\bar{t}$	ZZ, W^+W^-	ZA^0
h^0	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$
H^0	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos(\beta-\alpha)$	$-\sin(\beta-\alpha)$
A^0	$-i\gamma_5\tan\beta$	$-i\gamma_5/\tan\beta$	0	0

$$\tan 2\alpha = \frac{M_A^2 + M_Z^2}{M_A^2 - M_Z^2}\tan 2\beta.$$

- decoupling limit $m_{A^0} \gg m_{Z^0}$:
  - h^0 couplings close to SM values
  - H^0, $H^\pm$ and A^0 nearly degenerate in mass
  - H^0 small couplings to VV, large couplings to ZA^0
  - For large $\tan\beta$, H^0 and A^0 couplings to charged leptons and bottom quarks enhanced by $\tan\beta$. Couplings to top quarks suppressed by $1/\tan\beta$ factor.





Battaglia:

SUSY Heavy Higgs Production

CLIC CDR H Benchmark	CLIC CDR χ Benchmark
MSSM model with non-unified gaugino masses	cMSSM model
M_1=780 GeV, M_2=940 GeV, M_3=540 GeV m_0 = 303 GeV, A_0 = -750 GeV, tan β = 24, μ>0	$m_{1/2}$=966 GeV, m_0 = 800 GeV, A_0 = 0, tan β = 51, μ<0
M_A = 902.6 GeV M_H = 902.4 GeV M_{H+} = 906.3 GeV	M_A = 742.8 GeV M_H = 742.0 GeV M_{H+} = 747.6 GeV

Determine M(A), Γ(A) from fit to bb invariant mass distribution

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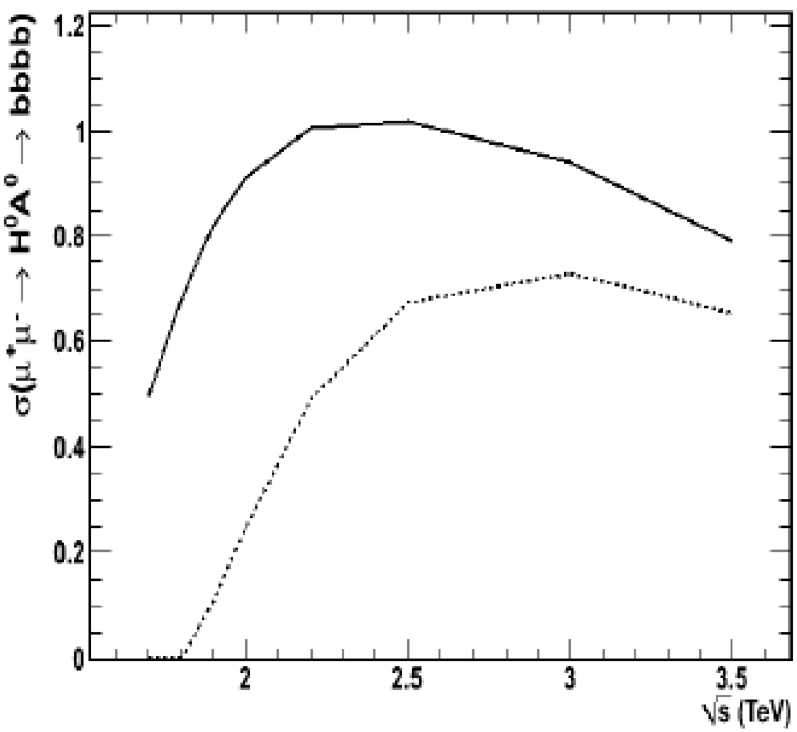
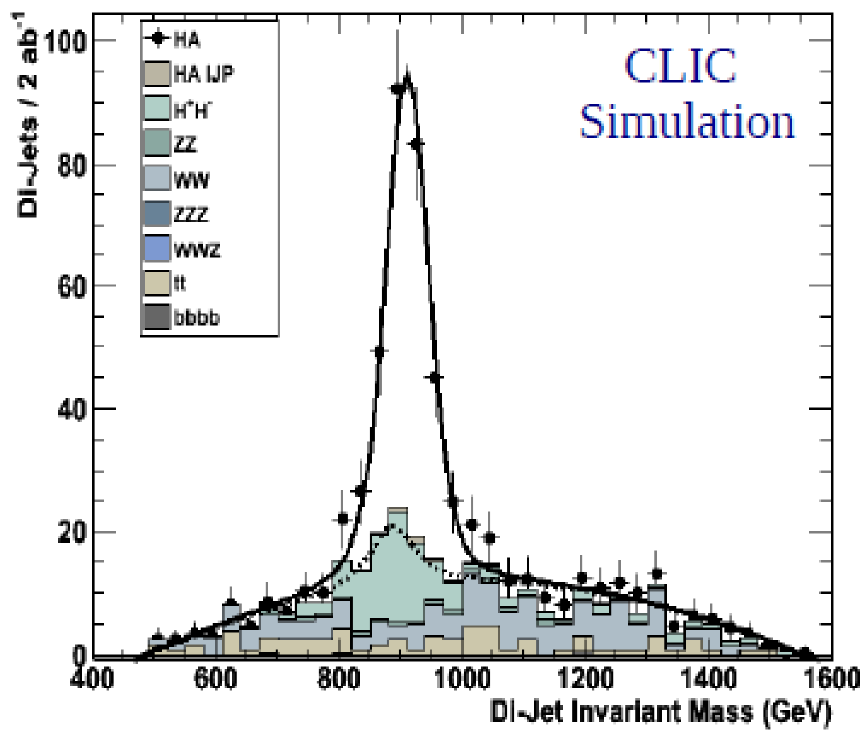
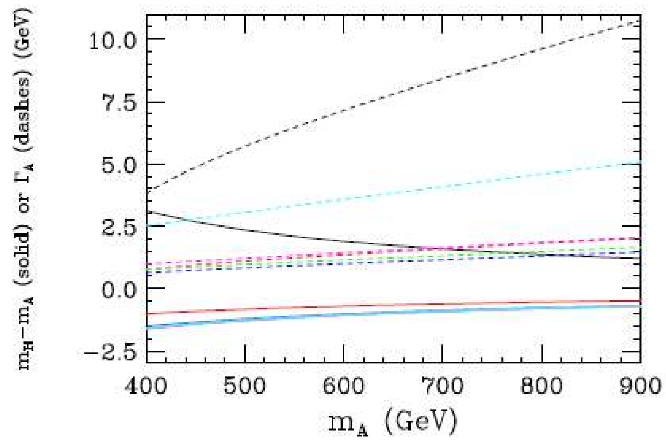
SUSY Heavy Higgs Production

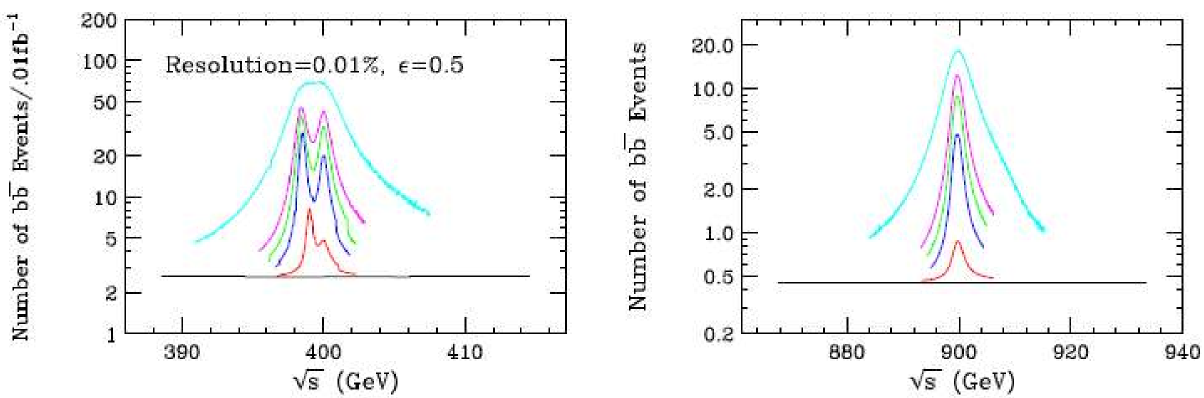




Higgs and MultiHiggs: H^0 A^0 Resonances (Gunion, Han, Cline)

Gunion:





Separating A from H. Beamstrahlung=0.01%, bremsstrahlung included. $L = .01$ fb^{-1} at any given $\sqrt{s}$. Ok for $m_A = 400$ GeV; Impossible for $m_A = 900$ GeV.

Higgs and MultiHiggs H^0 A^0 Resonances (Gunion, Han, Cline)

Gunion:

- Energy reach is a critical matter here with subprocess energies $\sqrt{s_{WW}} \gtrsim$ 1.5 TeV is needed to probe strong WW scattering.
  Since $E_\mu \sim$ (3–5)E_W, this condition implies

$$\sqrt{s_{\mu\mu}} \sim (3\text{–}5)\sqrt{s_{WW}} \gtrsim 4 \text{ TeV}\,. \qquad (2)$$

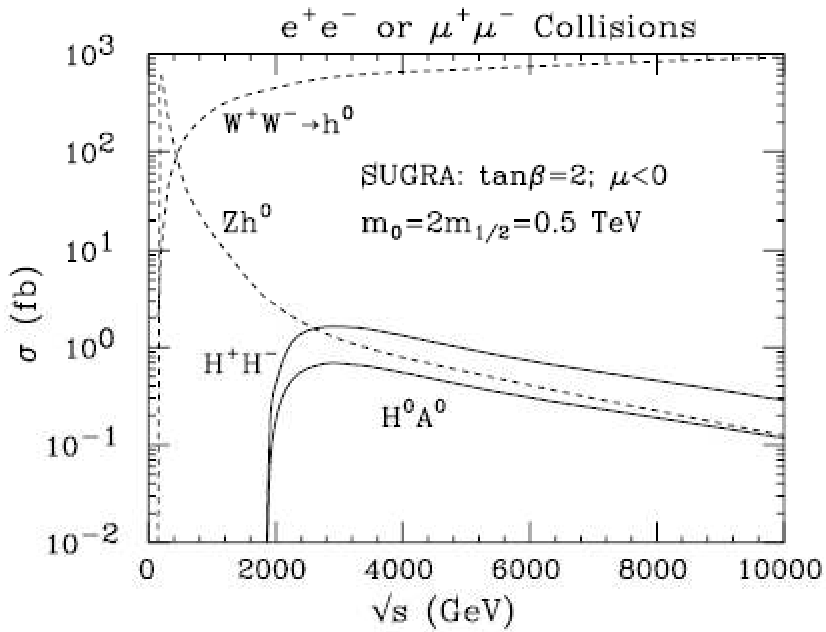
- The ultimate goal is to determine all the different weak isospin amplitudes, in terms of which the physical scattering amplitudes can be written as

$$\begin{aligned}
\mathcal{M}(W_L^+W_L^- \to Z_LZ_L) &= \frac{1}{3}[T(0) \;-\; T(2)] \\
\mathcal{M}(Z_LZ_L \to W_L^+W_L^-) &= \frac{1}{3}[T(0) \;-\; T(2)] \\
\mathcal{M}(W_L^+W_L^- \to W_L^+W_L^-) &= \frac{1}{6}[2T(0) \;+\; 3T(1) \;+\; T(2)] \\
\mathcal{M}(Z_LZ_L \to Z_LZ_L) &= \frac{1}{3}[T(0) \;+\; 2T(2)] \\
\mathcal{M}(W_L^\pm Z_L \to W_L^\pm Z_L) &= \frac{1}{2}[T(1) \;+\; T(2)] \\
\mathcal{M}(W_L^\pm W_L^\pm \to W_L^\pm W_L^\pm) &= T(2)\,.
\end{aligned}$$

Separating A from H. Beamstrahlung=0.01%, bremsstrahlung included. L = .01 fb^{-1} at any given $\sqrt{s}$. Ok for m_A = 400 GeV; Impossible for $m_A = 900$ GeV.

Gunion:

- Pair production at high $\sqrt{s}$ is a good discovery option. Below is an illustration for $m_A \sim m_H \sim 1$ TeV. Need $\sqrt{s} \gtrsim 2.4 m_A$ and $L = 100 - 1000$ fb^{-1} (detailed study needed).



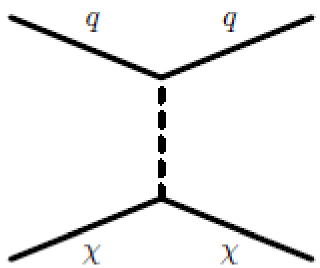
- Both of the above options would be good in the case of a general two-Higgs-doublet model.

(6) Higgs and Multi-Higgs Questions:

This requires thought about strategy and where it fits in the larger framework.

(7) Dark Matter at Colliders

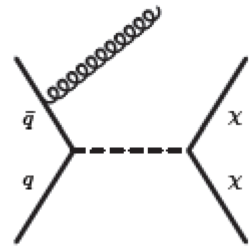
Fox:



Direct detection

Look down

Low rate, low energy recoil events in underground labs



Mono-jet + $\not{E}_T$

Collider searches

Look small

Missing energy events at colliders

Fox: LEP can place bounds on DM-electron coupling

Alternative avenue of attack, "cleaner" environment

Hadrophobic DM proposed as explanation of DAMA

Equal couplings to quarks and leptons?

Mono-jets $\longleftrightarrow$ Mono-photons (Z's ?)

$$q \leftrightarrow \ell$$

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{\ell}\gamma^\mu\ell)}{\Lambda^2}, \qquad \text{(vector, } s\text{-channel)}$$

$$\mathcal{O}_S = \frac{(\bar{\chi}\chi)(\bar{\ell}\ell)}{\Lambda^2}, \qquad \text{(scalar, } s\text{-channel)}$$

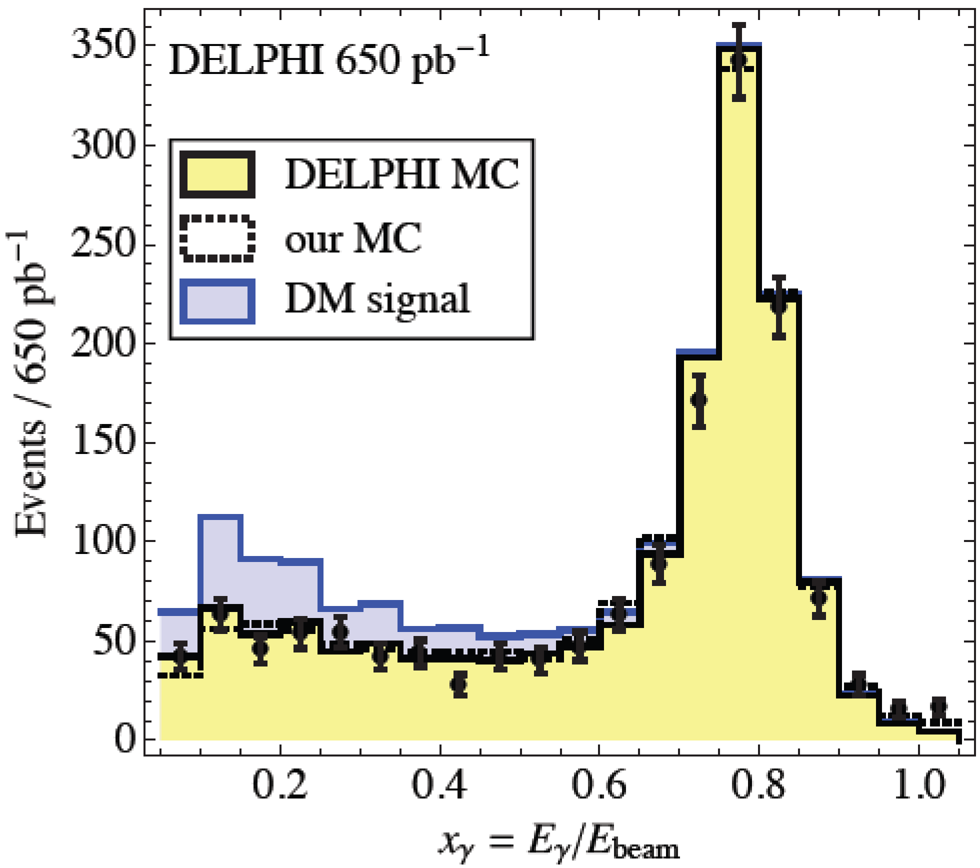
$$\mathcal{O}_A = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{\ell}\gamma^\mu\gamma_5\ell)}{\Lambda^2}, \qquad \text{(axial vector, } s\text{-channel)}$$

$$\mathcal{O}_t = \frac{(\bar{\chi}\ell)(\bar{\ell}\chi)}{\Lambda^2}, \qquad \text{(scalar, } t\text{-channel)}$$

"Dark Matter contact terms" with associated radiated gauge boson

Fox:

LEP is cleaner, use spectral information



(7) Dark Matter Questions:

Need to study and generate basic plots for high energy lepton colliders. We need this paper asap.

γ + missing ET, and Z + missing ET

Is this a subset of contact terms?

High energy machine may produce the mediator.

Urgently needs a study; this is a sexy topic.

New Strong Dynamics (Martin)

Standard Model and other issues (eg, QCD Giele and Stavenga)

Ayres Freitas, Tao Han, E.E.: A first pass at benchmarks

Eichten:

Final states	Exp. considerations	Theo. considerations	
$\ell^+\ell^-$, $\ell = e,\ \mu,\ \tau$	Ecal, μ-chamber; τ-tagging at HE	Contact interaction	Z'
$q\bar{q}$, $q = u,\ c,\ s,\ b$	Hcal, b-tagging at HE	Contact interaction	
$\gamma\gamma$	Ecal	QED	KK mode
$\gamma + \not{E}$	Ecal, missing energy	missing mass/dark matter	
$W^+W^- \to q\bar{q}', q\bar{q}'$	Hcal: M_W-reconstruct	New resonances	
$W^+W^- \to \ell\bar{\nu}, q\bar{q}'$	$\not{E}$, M_W-reconstruct	New resonances	Strong Dynamics
$ZZ \to q\bar{q}, q\bar{q}$	Hcal: M_Z-reconstruct	New resonances	
$ZZ \to \ell^+\ell^-, \nu\bar{\nu}$	Ecal; $\not{E}$	New resonances	
$t\bar{t} \to bW^+\ \bar{b}W^+$	E,Hcal, b-tagging, mass reconstruct	New heavy quarks	4th Generation, Little Higgs Models
ZHH	multiple $b\bar{b}$	Higgs self coupling	
$W^+W^- \to HH$	multiple $b\bar{b}$	Higgs self coupling	
$\nu\bar{\nu}W^+W^- \to 4j + \not{E}$	Hcal: M_W-reconstruct	WW scattering	
$\nu\bar{\nu}ZZ \to 4j + \not{E}$	Hcal: M_Z-reconstruct	WW scattering	Strong Dynamics
$\nu\bar{\nu}t\bar{t}$	Hcal: m_t-reconstruct	$WW \to t\bar{t}$	
$\tilde{\chi}_i\tilde{\chi}_j$	leptons, jets+$\not{E}$	SUSY	
$\tilde{\ell}_i\tilde{\ell}_j$	leptons+$\not{E}$	SUSY	SUSY
$\tilde{q}_i\tilde{q}_j$	jets+$\not{E}$	SUSY	

Is this the top five?

Process	Observables	Experimental considerations	Theoretical considerations	Strategy
Z'	M, Γ couplings final states	energy scale = M ? beam energy resolution initial state polarization ? cone size	coupling strength L – R chiral compelling models	first priority if confirmed at LHC; may enable low-L machine
WW fusion	M couplings states?	beam energy initial state polarization cone size !	coupling strength strong dynamics (broad TeV scale Higgs)	High priority if no low mass Higgs at LHC
SUSY	many states decay chains m's, Br's, σ's	beam energy resolution initial state polarization missing ET cone size	Mainstream theory perturbative dynamics MSSM or else?	Simply depends upon confirmation at LHC
Dark Matter	γ or Z + missing ET	cms frame is known initial state polarization? missing ET cone size	Very interesting how powerful are limits? Need the paper asap !	High priority appears easy to dc
Contact Term				