Working Group 4

BSM: Missing energy and such

Conveners: Jose Santiago
James Wells
Graham Wilson
Filip Moortgat

Program

Experimental session:

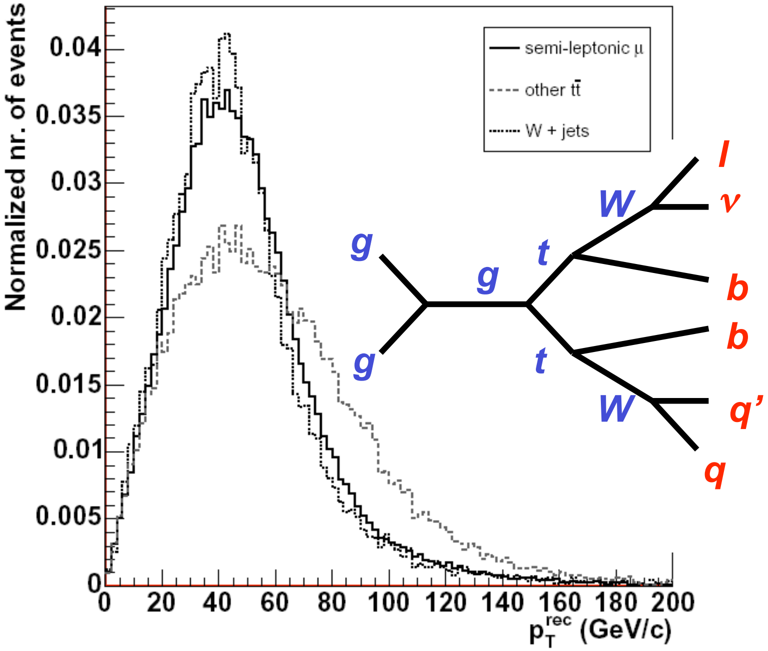
Aspects of measuring missing transverse energy at the LHC
(R.Cavanaugh)
Aspects of measuring missing transverse energy at the ILC
(G. Wilson)

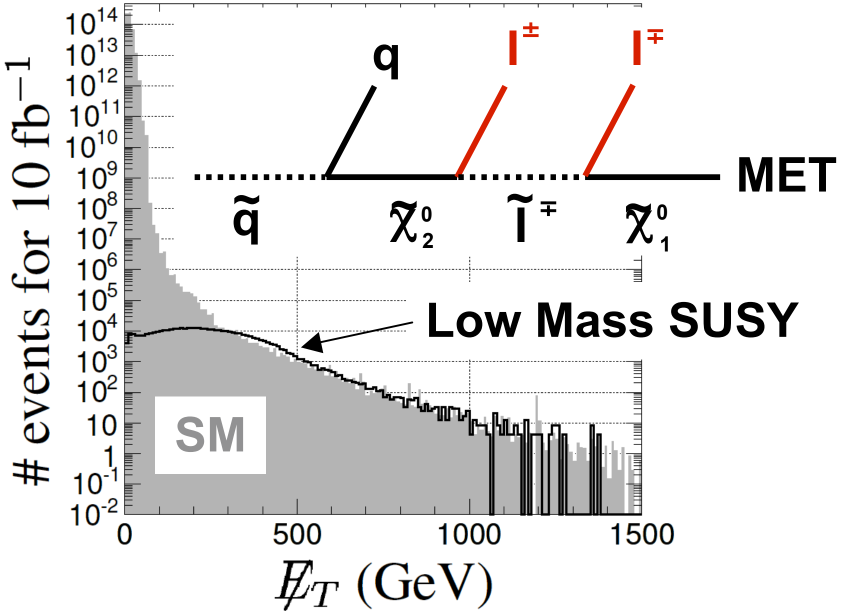
Theory session:

Nearly degenerate gauginos at the LHC and ILC
(K. Wang)
Can the ILC break the remaining MSSM degeneracies from the LHC?
(B. Lillie)
T-parity in Little Higgs models
(R. Hill)
Some complications in analyzing MET
(S. Chang)

Experimental aspects of MET

- "Small" Missing Energy
  - Standard Model Physics
- Experimental Challenge
  - Understanding QCD and other environmental bkgs.
  - good low-energy resolution



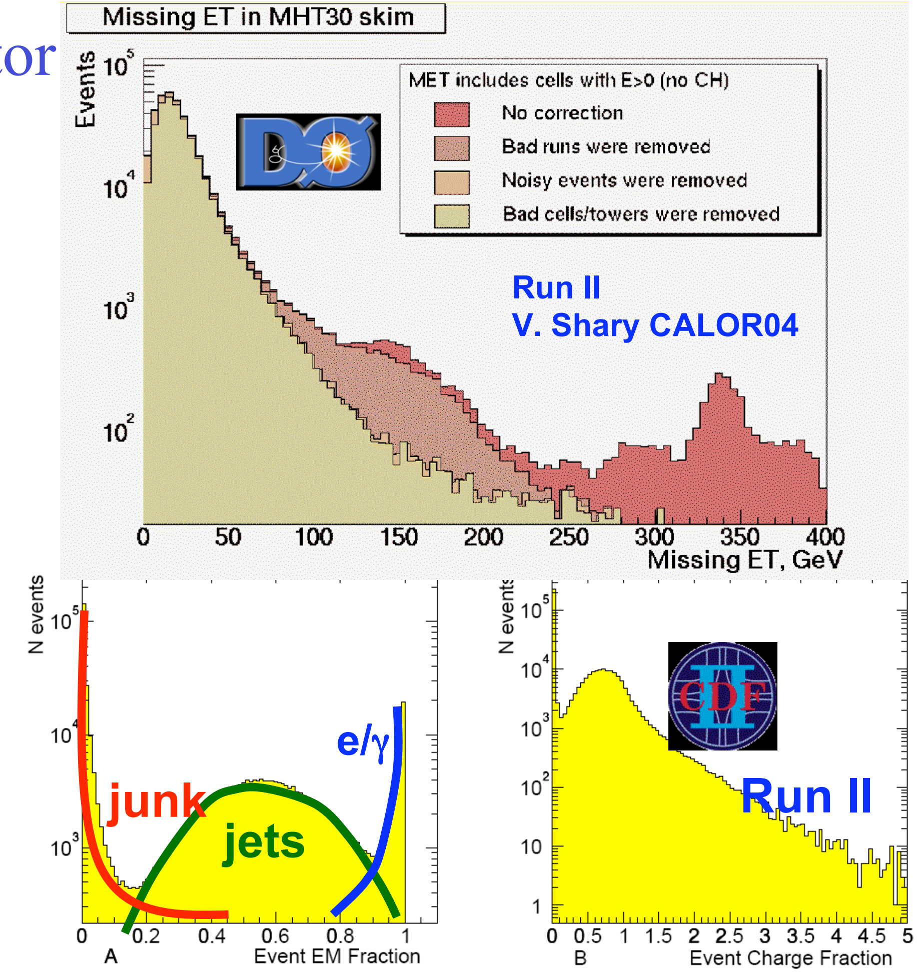


- "Large" Missing Energy
  - New Physics
- Experimental Challenge
  - Understanding Tails!

Rick Cavanaugh

Environmental challenges

- MET is very powerful discriminator for New Physics
  - Difficult part is to convince yourself that there is a real excess!
- Tevatron teaches us
  - MET is not easily understood!
- Collisional backgrounds
  - Pile-up
  - Underlying Event
- Non-collisional backgrounds
  - Beam halo
  - Cosmic muons
- Detector Effects
  - Instrumental Noise
  - Hot/dead channels (DQM)
  - Inter-module calibration



D. Tsybychev, Fermilab-thesis-2004-58

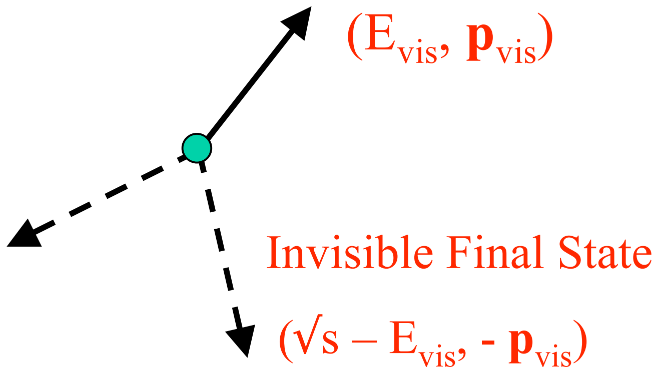
Energy flow for MET

Improving MET using Energy flow:

- Motivation: The energy of a typical jet consists roughly of
  - Charged particles : ~60%
    - Mostly charged pions, kaons and protons, but also some electrons and muons
  - Photons : ~25%
    - Mostly from π^0's, but also some genuine photons (brems,…)
  - Long-lived neutral hadrons : ~10%
    - K^0_L, neutrons
  - Short-lived neutral hadrons, "V^0's" : ~5%
    - $K^0_S \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow \pi^- p$, …, but also γ conversions, and (more problematic) nuclear interactions in the detector material.
- Energy resolution determined (ideally) mostly by
  - the 10% neutral hadrons
  - inefficiencies in charged hadron reconstruction
- Attempt to use Full Detector/Event Information in MET reconstruction
  - Determine MET from calibrated, reconstructed particles

$$\mathbf{E_T^{miss}} = -\sum \mathbf{p_T}(e^\pm, \mu^\pm, \pi^\pm, \gamma, N^o, V^o, etc)$$

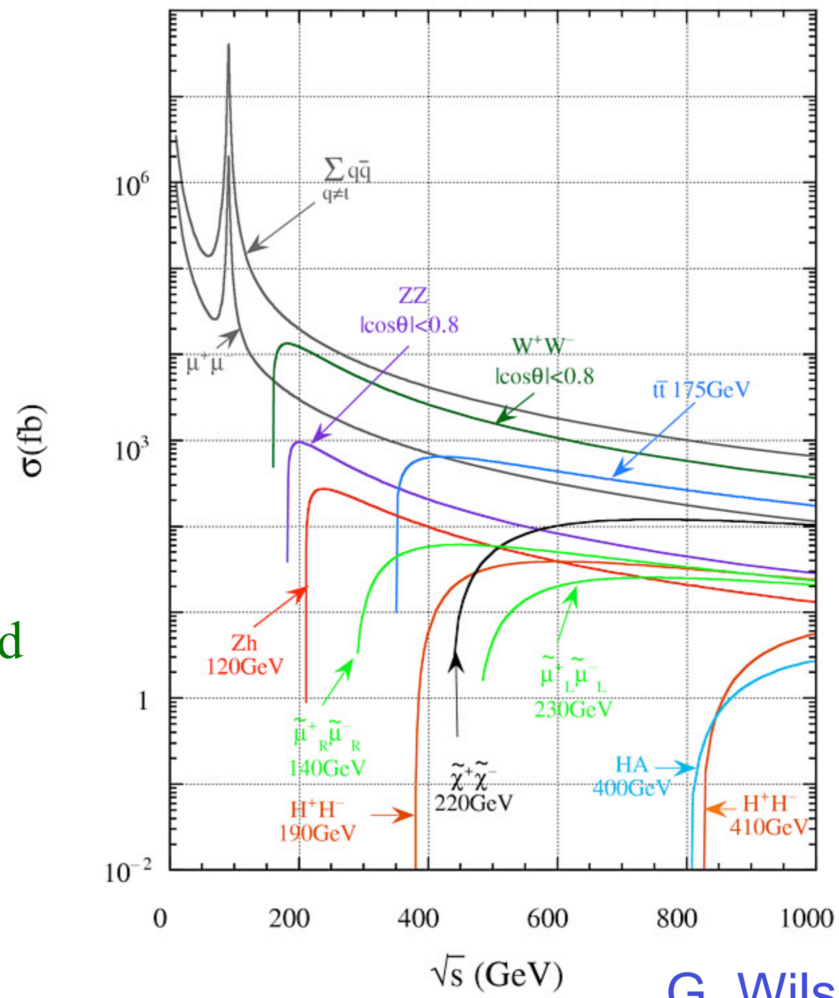
Missing energy at ILC



Sources of fake missing energy:

ILC: Large cross-sections for Bhabha and two-photon processes. Use characteristic electron signatures to reject.

Genuine missing E_T predominates above WW threshold.



G. Wilson

ILC detector requirements

Requirements for an ILC detector:

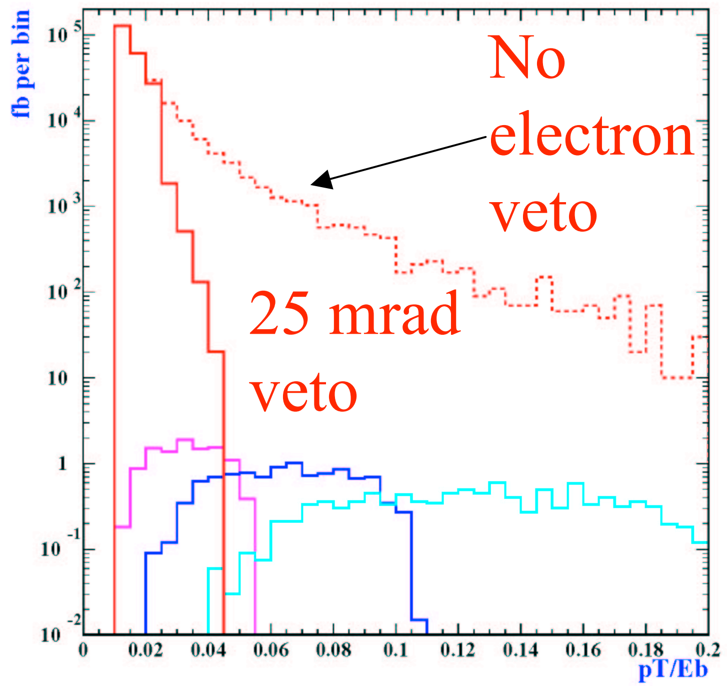
• Hermetic coverage to low angle especially for electrons and photons.

• Robust and accurate measurement of the visible particles.

• Missing E_T resolution in the hadron collider sense is close to irrelevant.

$(M_{smu}-M_{LSP})/M_{smu}$ = 2.8%, 5.6%,11%

$\sqrt{s}$=189 GeV



Red: eeμμ background

1fb/bin signal : smuons (M=90 GeV)

Nearly degenerate gauginos

Kai Wang

Nearly Degenerated Gauginos

$$\Delta = m_{\chi_1^\pm} - m_{\chi_1^0}; \qquad (m_{\chi_2^0}, (m_{\chi_3^0}) \sim m_{\chi_1^\pm})$$

Already studied: Wino LSP in AMSB Feng, Moroi, Randall, Strassler and Su,1999

$M_2 < M_1$, $\Delta \sim m_\pi$

$$\Gamma_{\chi_1^\pm} \sim 10^{-22}\ \mathrm{GeV}$$

signature: Charge track

Cases Studied: well-tempered neutralino Arkani-Hamed, Delgado,Giudice, 2006

- Bino-Wino LSP $M_1 \simeq M_2$, $\Delta \sim \mathcal{O}(\mathrm{GeV})$
- Bino-Higgsino LSP $M_1 \simeq \mu$, $\Delta \sim \mathcal{O}(\mathrm{GeV})$

$$\Gamma_{\chi_1^\pm} \sim 10^{-9}\ \mathrm{GeV}$$

Nearly degenerate gauginos

Results

100fb^{-1}

Processes (fb)	Basic Cuts	η cut	ϵ	M_{JJ} cut	ϵ	p_T^J cut	ϵ	p_T^ℓ
$\chi_1^+\chi_1^- jj$	14.04	6.21	44%	4.67	75%	4.15	89%	1.017
$\chi_1^\pm\chi_2^0 jj$	25.98	6.86	26%	5.41	79%	3.97	73%	2.034
$\chi_1^\pm\chi_1^\pm jj$	15.01	5.66	38%	4.69	83%	3.66	78%	1.764
$\chi_1^\pm\chi_1^0 jj$	2.63	1.05	40%	0.80	76%	0.59	74%	
Total	57.66	19.78		15.57		12.37		4.82
$P_{\text{surv}}\sigma$	47.28	16.22		12.76		10.14		3.95
Zjj (EW)	1404	170	12 %	117.8	69%	87.1	74%	
$P_{\text{surv}}\sigma$	1151.3	139.4		96.6		71.4		
Zjj (QCD)	124.5 pb	3130	2.5%	967.9	31%	519.8	54%	
$P_{\text{surv}}\sigma$	34.8 pb	876.4		271		145.5		
Zjj Total	159.3 pb	1015.8		367.6		216.9		216.9
Wjj (EW)	199.3	37.9	19%	26.6	70 %	19.6	74%	9.12
$P_{\text{surv}}\sigma$	163.4	31.0		21.8		16.1		7.48
Wjj (QCD)	21.4 pb	631.2	2.9%	228.0	36%	121.2	53%	87.63
$P_{\text{surv}}\sigma$	5.99 pb	176.7		63.8		33.9		24.54
Wjj Total	6.15 pb	207.7		85.6		50.0		32.0
Total BG	165.5pb	1192.5		453.2		266.9		248.9
S/B	0.028%	1.36%		2.8 %		3.8%		1.6 %
$S/\sqrt{B}$				6σ		6.2σ		$2.5\ \sigma$

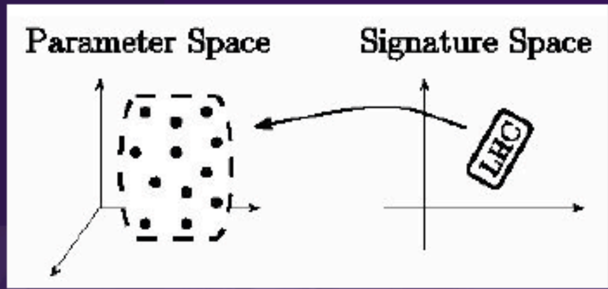
Table: Summary Table for Invisible Channels, all numbers are in fb unless noted explicitly, η, M_{JJ} and p_T^J cuts

LHC inverse problem

LHC Inverse problem

Arkani-Hamed, Kane, Thaler, Wang hep-ph/0512190

- How to map from observables to a Lagrangian?
- What is the nature of the inverse mapping?
- Each parameter can be well measured, but many islands can be degenerate!



Simulated ~40k points in parameter space

Found ~300 degeneracies

Expect ~30 model points consistent with any "generic" set of data

Ben Lillie

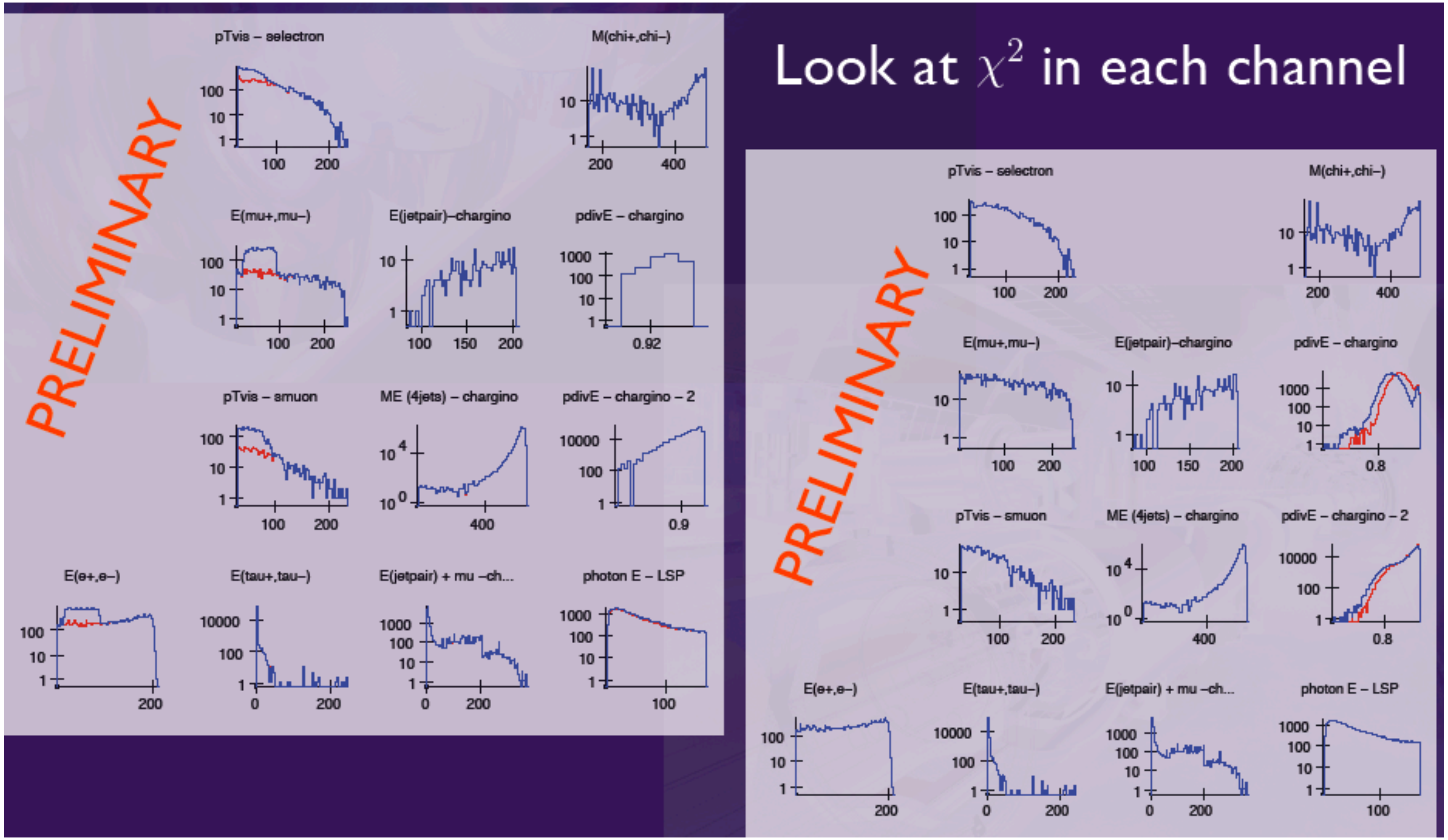
What about the ILC?

Model Counting at the ILC

242 Models
165 Pairs

- 500 GeV:
  - 20 models with selectrons & smuons.
  - 28 models with staus, 7 of which also have selectrons/smuons
  - 53 models with charginos, 2 of which also have selectrons/ smuons,
  - 8 of which also have staus
  - 99 models with only LSP (lightest neutralino)
  - 36 models with no kinematically accessible sparticles
- 1 TeV:
  - 116 models with selectrons & smuons
  - 125 models with staus, 55 of which also have selectrons/smuons
  - 25 models with first chargino, 16 models with second chargino; 12 of which
  - also have selectrons/smuons, 15 of which also have staus
  - 1 model with only LSP (lightest neutralino)
  - 1 model with no kinematically accessible sparticles

Preliminary results



T-parity in Little Higgs models

Richard Hill

can define an internal "T" parity

[V,V]~V, [V,A]~A, [A,A]~V

V→+V ← unbroken "vector" generators

A→-A ← broken "axial" generators

why an exact parity might be nice

- forbids large nonstandard EW effects
- organizing principle for models

what it might imply

- missing energy signature ?
- dark matter candidate ?

T parity violation

given a parity: we can define it, but is it respected by the dynamics ?

T parity from an internal symmetry

[V,V]~V, [V,A]~A, [A,A]~V

V→+V — unbroken "vector" generators

A→-A — broken "axial" generators

- as in QCD, topological interaction breaks this internal parity

T parity from "identical" sectors

$$\delta\left[\Gamma'(\Phi_1) \pm \Gamma'(\Phi_2)\right] \sim \int \epsilon(dA)^2 \pm \epsilon(dA)^2$$

- if sectors are really identical, then they give identical (not cancelling) anomalies

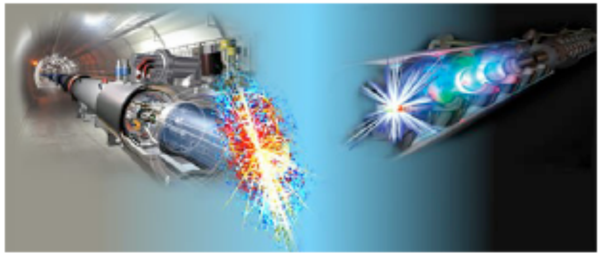
In both cases, the decays of "lightest T odd particle" must proceed through the topological interaction ⇒ distinct signatures !

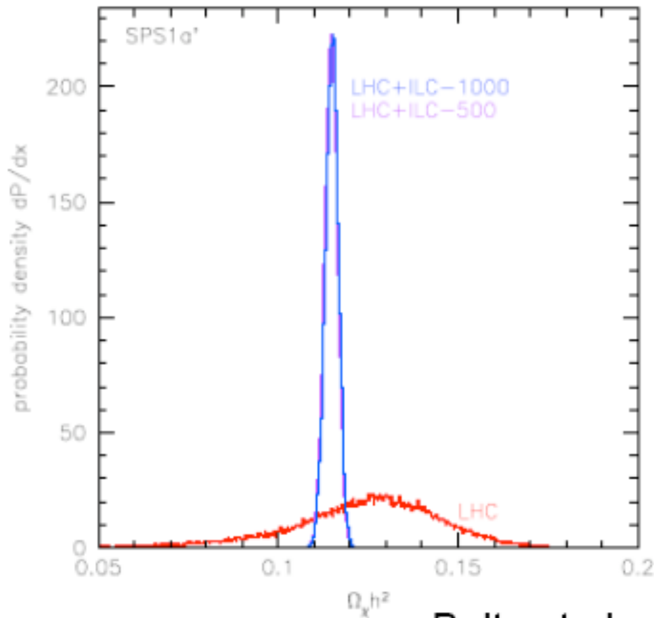
T parity violated

- is electroweak symmetry broken by fermion condensation ? weakly coupled composite higgs an important case to investigate
  - can look a lot like a SM higgs
- even without mention of fermions, need to worry about anomalies in a little higgs model
- T parity generally violated
  - hard to find dark matter candidate or missing energy signal in gauge/higgs sector of composite models
- topological interactions offer exciting probe of UV completion

Spencer Chang

- Within a BTSM model
  - Discovery of new states (e.g. Superpartners)
- Is missing particle a WIMP?
  - Enough information to predict relic abundance?
- Cosmologically, LHC lacking… ILC combination ideal (Matchev et.al., Baltz et.al.)



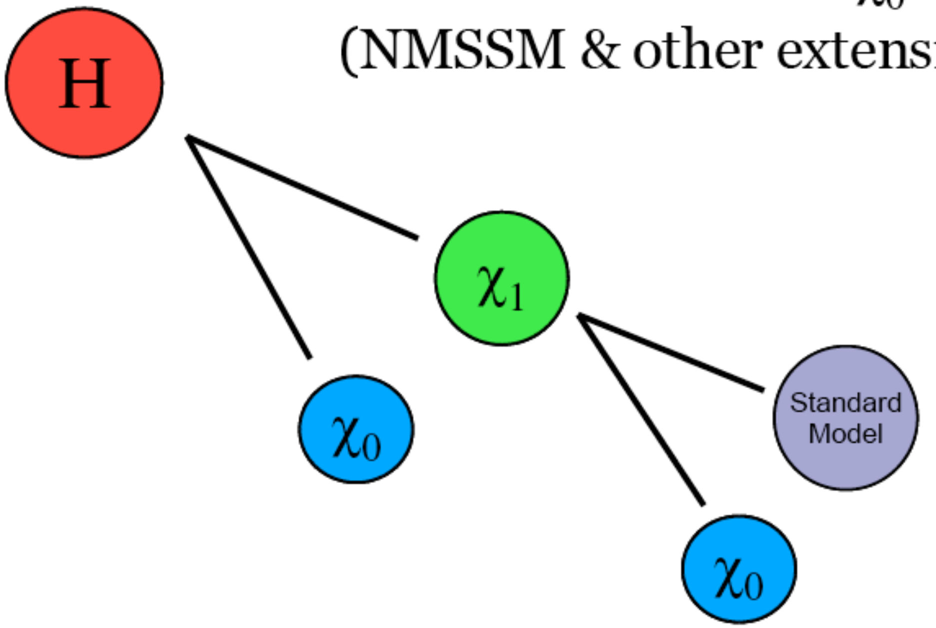


Baltz et.al.

Model Under Investigation

For motivation, see Carlos, Tim, Jack's talks in this workshop

MSSM
+
new neutralino χ_0
(NMSSM & other extensions)

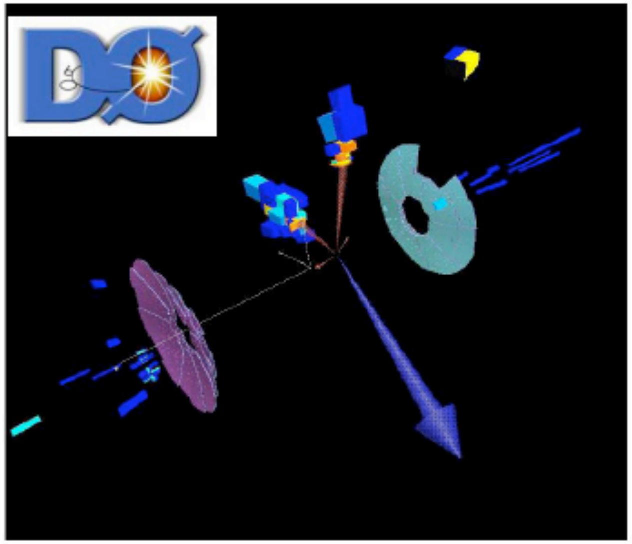


Nonstandard decays should be into neutral states, neutralinos?

Invisible $2\chi_0$ decay strongly constrained

Impact on SUSY pheno

- Dominant singlino LSP implies longer cascades
- Longer cascades mean more visible energy (jets, leptons) and reduced missing energy
- Tevatron searches normally expect:
  - Squark$\rightarrow$ jet + MET
  - Gluino$\rightarrow$ 2jets + MET
- Effects degrade search esp. with optimized MET cuts



Other possibilities

- Other new LSPs: e.g. RH sneutrino
- Highly displaced vertices from weak R-parity violation
  - UDD leading to $h \rightarrow 2\chi_1 \rightarrow 6$ (displaced?) jets
  - Hidden Valley Models (Strassler et.al.)
- R-parity violation into neutrinos: Fake Dark Matter
- Analysis issues suggest a need for a global analysis that is adaptable and not wedded to a model (MARMOSET?)
- Cautious analysis is best – i.e. Avoid model priors until necessary

Summary & questions

Question to answer:

What can the LHC learn us in preparing for the ILC?
(with 10 fb^{-1}ud)

"fb-1ud" = inverse femtobarn of understood data

- Given that LHC = coloured particles
  ILC = electroweak particles

- How much can we deduce in a model independent way?

- What can we learn apart from ILC energy scale --
are there other things that one would like to know?
(detector design?)

LHC 4 ILC ?

LHC : gluon factory

colored states:
squarks, gluinos, etc.

+ R-parity

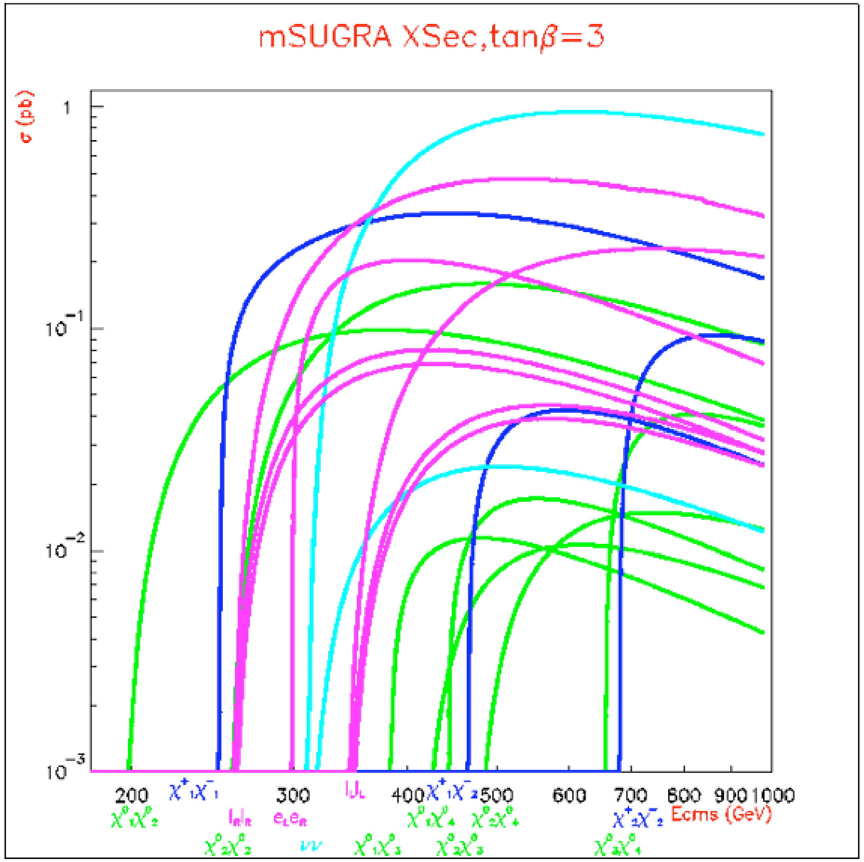
?

ILC : electron factory

charginos, neutralinos,
sleptons, etc.

Not at all trivial.
New ideas needed!

Is the LHC going to reliable tell us something about this?



Questions 2

G. Wilson

- Suppose:
  - –A light Higgs is found. Consistent with SM, SUSY.
  - –Only a jets+MET signal is found at LHC.
- What is the minimum √shat involved in the signal ?
  - –Can we estimate the e^+e^- production threshold reliably ?
- Can the signal be produced in e^+e^- (does it couple to the γ, W, Z, h) ?
  - –Presumably no info will be available.
  - –If it's a gluino, e^+e^- is probably irrelevant for direct tests ...
- Is there ANY robust logical inference on the masses of lighter particles that can be made, e.g. M_{LSP} ???

We may find that LHC can't tell very much of value in diagnosing this new physics.
And that ILC at any energy may not be a useful diagnostic tool for certain hadron collider signatures.

Outlook

I have seen people interested in:

• extrapolating ILC relevant information from
CMS TDR / ATLAS notes (latter still ongoing)

e.g. qqH, H to invisible

• studying techniques for global, model independent analysis of the first data to deduce the underlying model

• …

If you want to contribute: please contact the conveners!

Prediction is very hard, especially about the future

Yogi Berra