Physics Landscapes

A.K.A. Beyond the Standard Model

Convenors:

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TeV4LHC Meeting – Brookhaven, February 5, 2005

- **Tao Han (Wisconsin):** *TeV-Scale String Resonances at Hadron Colliders*
- **Yuri Gershtein (Brown):** *Advanced Electron Reconstruction and Tests with D0 Data*
- **Kyoungchul Kong (Florida):** *Search for Level-2 Gauge Bosons of Universal Extra Dimensions at the LHC*
- **Albert de Roeck (CERN):** *Needs for Generators for Signals from Extra Dimensions*

- **Jay Hubisz (Cornell):** *Phenomenology of a Little Higgs Model with T-Parity*
- **Dan Green (FNAL):** *Mass Cuts for the VBF Channel in Higgs Searches*
- **Albert de Roeck (CERN):** *Diffractive Production of Higgs at the LHC*
- **Mu-Chun Chen (BNL):** *Electroweak Fits in Models with Higgs Triplets*

- **Bryan Field (Stonybrook):** *Rare Decays of the Pseudoscalar Higgs*
- **Andreas Birkedal (Florida):** *Collider Phenomenology of Higgsless Models*
- **Bob Kehoe (MSU):** *Disentangling SUSY Signatures at the LHC*
- **Tim Tait (ANL):** *Vectorlike Quarks*

- **Giacomo Polesello (CERN):** *SUSY Searches at LHC - What remains to be studied, and how can the Tevatron help?*
- **Peter Skands (FNAL):** *SUSY Les Houches Accord*
- **Tadas Krupovnickas (BNL):** *mSUGRA Reach for the Tevatron and LHC*

Models of physics at the TeV scale

⋆ **attempt to anticipate new phenomena** *(neutral currents, ...)*

⋆ **guide experimental searches** *(top-quark discovery, ...)*

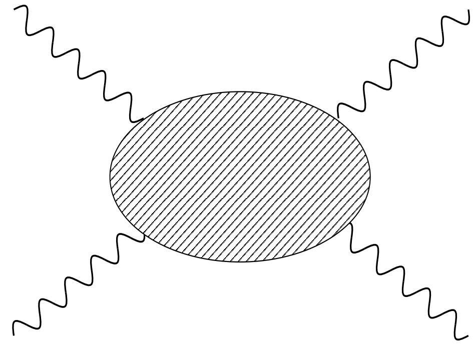
⋆ **try to explain:**

- **observed phenomena** *(dark matter, ν oscillations, ...)*
- **properties of observed particles** *(3 generations, $m_e \ll m_\mu \ll m_\tau$, proton stability, ...)*
- **fine-tuning** *($\langle H \rangle / M_{\rm Planck} \approx 10^{-17}$, $m_t \approx \langle H \rangle$, strong CP problem, ...)*

Many models of physics at the TeV scale despite various severe phenomenological and theoretical constraints.

Testing all of them at the Tevatron and LHC is challenging.

$W_L^+ W_L^-$ scattering:



Perturbatively: $$\sigma\left(W_L^+ W_L^- \to W_L^+ W_L^-\right) \approx \frac{G_F^2\, s}{16\pi}$$

This makes sense only up to $\sqrt{s} \sim 1$ TeV.

At higher energy scales:

⋆ A new particle: Higgs boson

OR

⋆ New strong interactions (perturbative expansion breaks down)

OR

⋆ Quantum field theory description breaks down

Standard Model:

fit to the electroweak data $M_h < 200$ GeV at 95% CL

Physics beyond the standard model changes the fit.

Talk by Mu-Chun Chen:

If in addition to the SM Higgs doublet there is an $SU(2)_W$ triplet scalar, then the upper limit on M_h is completely relaxed (up to the 700 GeV limit from "triviality").

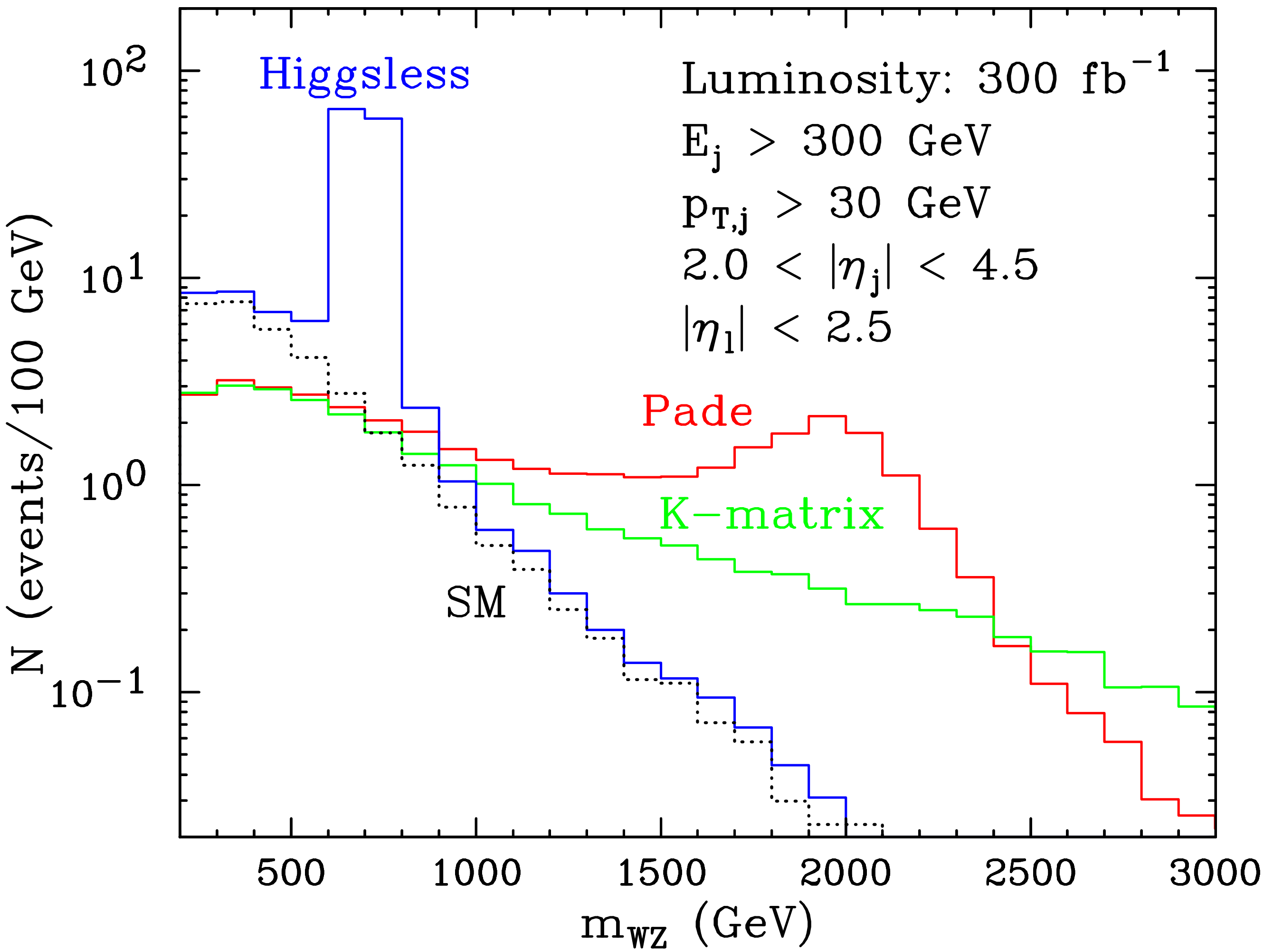
Similar situation if there is a vector-like quark, or a dimension-six operator, or ...

Talk by Andreas Birkedal: **Higgsless Models**

Heavier versions of the W and Z fix the unitarity

LHC is also a "gauge boson collider"!

$WZ \to WZ$:



Minimal Supersymmetric Standard Model

Prototype for new physics

Many in-depth experimental and theoretical studies

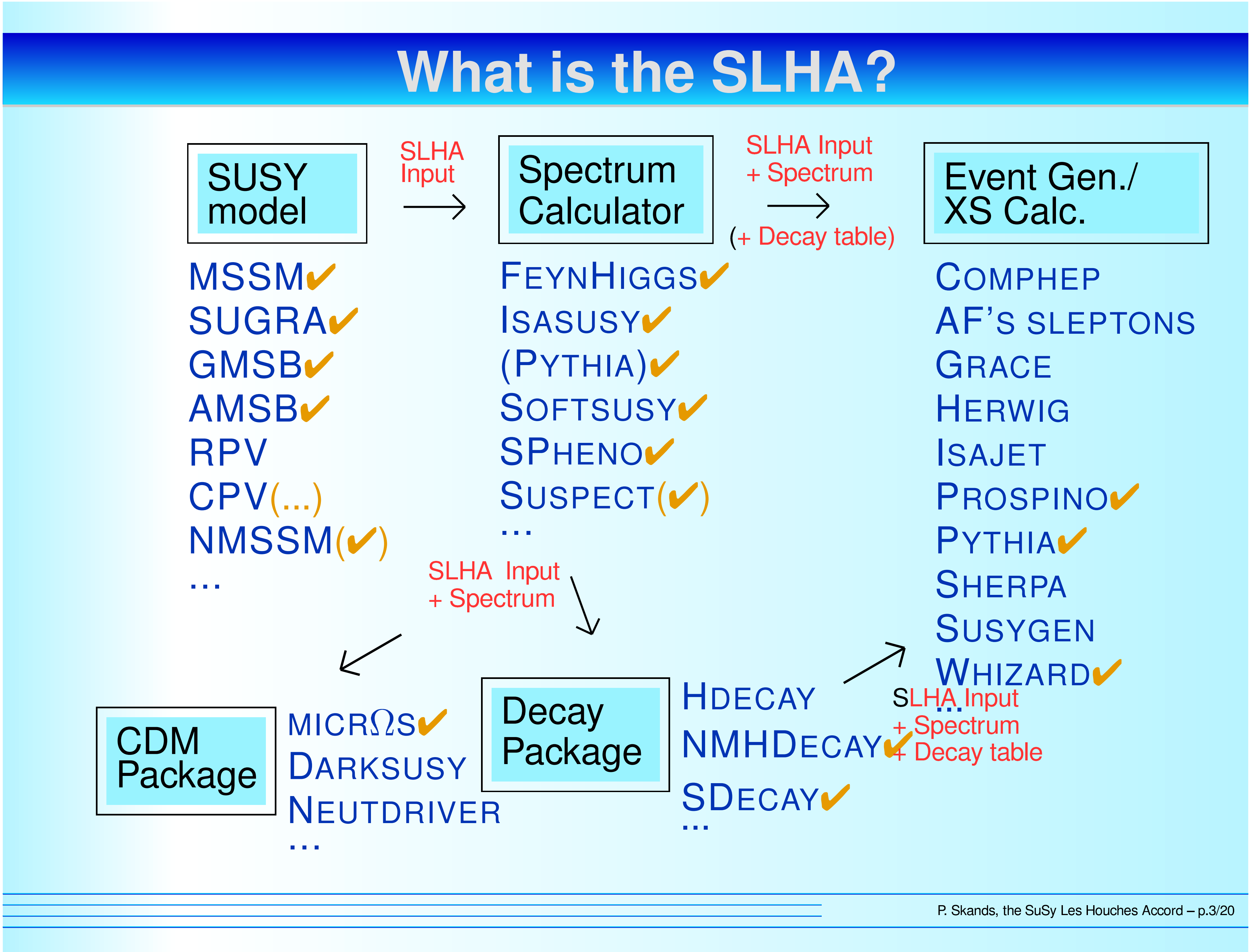
Giacomo Polesello: **SUSY Searches at LHC - What remains to be studied, and how can the Tevatron help?**

Bob Kehoe: **Disentangling SUSY signatures at the LHC**

Bryan Field: **Rare decays of A^0 in the MSSM**

Tadas Krupovnickas: **mSUGRA reach for the Tevatron and LHC**

SUSY Les Houches Accord *(talk by Peter Skands)*



Needs for Generators for Signals from Extra Dimensions

talk by Albert de Roeck)

ED Monte Carlo Generators

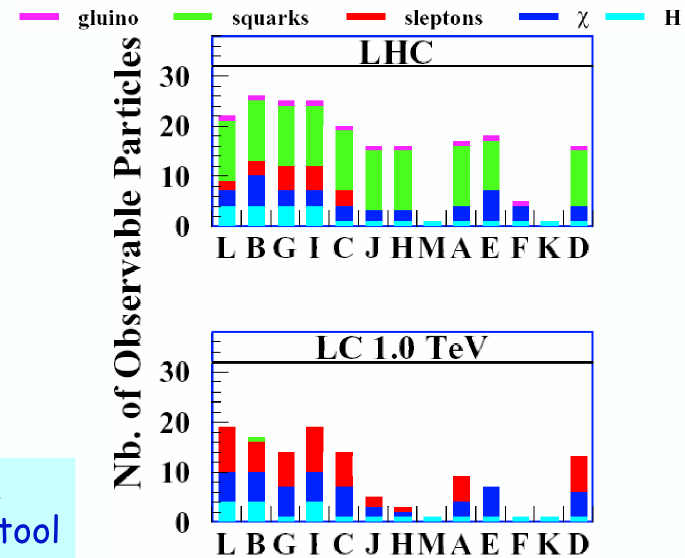
Monte Carlo Generators for LHC (Tevatron) analyses

- RS included in standard working horses HERWIG and PYTHIA
  - Spin correlations not complete in PYTHIA e.g. for $G \to \gamma\gamma$ ZZ, WW (now added: Pythia version 6.226)
- ADD: several private codes for both the graviton radiation and graviton exchange processes, for PYTHIA or HERWIG
  - Recently improved by SHERPA which contains complete ADD FeynmanRules (Gleisberg, Kraus, Matchev) $\to$ now used in ATLAS/CMS
- UEDs exist in a private code for COMHEP (Matchev et al.)
- Wish: have processes combinable with main working horse MCs, at present PYTHIA and HERWIG. Thanks to the Les Houches accord(*) of 2001, an agreed exchange format exists in the Monte Carlo world such that one can think of a tool kit of ED processes to be combined with these MCs for the fragmentation/ hadronization (which is done e.g. for SM and SUSY processes)

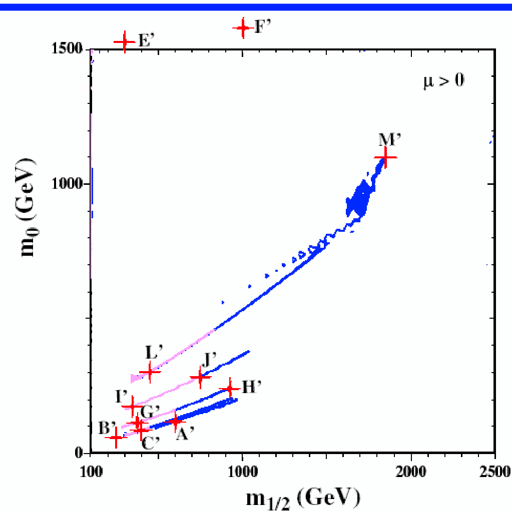
(*) GENERIC USER PROCESS INTERFACE FOR EVENT GENERATORS.
E. Boos et al. Workshop on Physics at TeV Colliders, Les Houches, 2001. hep-ph/0109068

Benchmarks for EDs: The SUSY example

- A number of SUSY (msugra and other) benchmark points to study LHC/LC sensitivity (Battaglia et al, Allanach et al,…)
- Take into account direct searches at LEP and Tevatron, BR ($b \to s\gamma$), g_μ-2 (E821), Cosmology: $0.09 \leq \Omega_\chi h^2 \leq 0.13$



Allowed regions in the M_0-$M_{1/2}$ plane



ISASUGRA as common tool

Very useful for comparisons of analyses, common studies, LHC/ILC studies

We would benefit strongly from defining common ED benchmarks! Working group?

This is a tricky thing to do ...

MSSM is one model with many parameters, while extra dimensions are used in many different models

Universal Extra Dimensions

All Standard Model particles propagate in $D \geq 5$

Momentum conservation $\Rightarrow$ KK parity is conserved

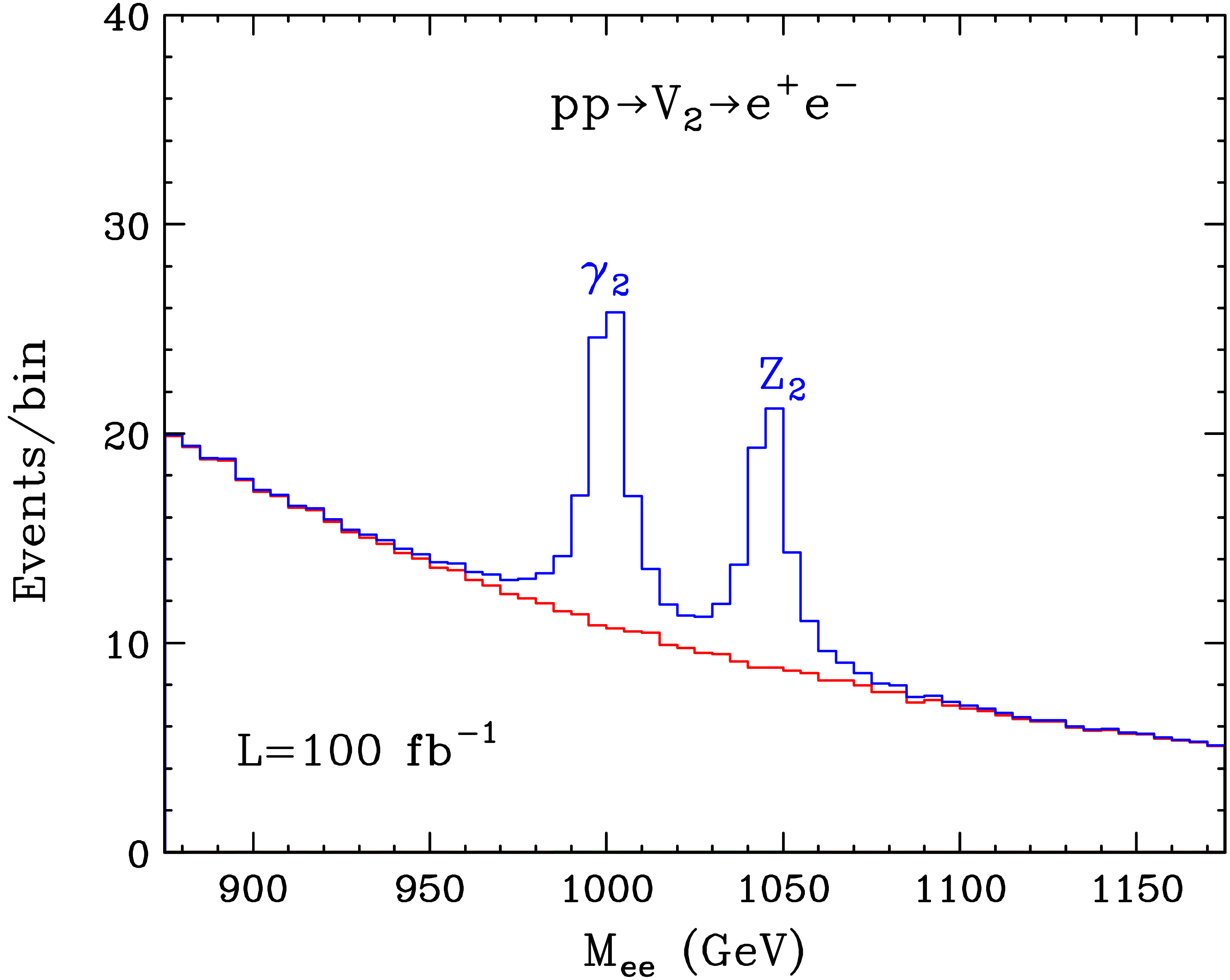
- Bounds from one-loop shifts in M_W/M_Z and other observables: $\dfrac{1}{R} \gtrsim 300\ \mathrm{GeV}$

- Pair production of level-1 Kaluza-Klein modes at the Tevatron and LHC, followed by cascade decays

  $\rightarrow$ similar with MSSM (somewhat degenerate spectrum).

Talk by Kyoungchul Kong:

Level-2 Gauge Bosons of Universal Extra Dimensions at the LHC



talk by Jay Hubisz: **Phenomenology of a Little Higgs Model with T-Parity**

T-parity is similar with R-parity (in MSSM) and KK parity (in UED)

Search for heavy vector-like quarks, gauge bosons (pair produced) and weak triplet scalars.

Spin measurements at the LHC would be useful to distinguish between these models (see talk by G. Polessello).

There is no such thing as a "model independent" analysis, but one can study generic features of large classes of models.

Strategy: assume that new particles will be discovered one at a time $\rightarrow$ analyze models that include the SM $+$ one new particle.

Spin: a good theoretical discriminant

New fermions, gauge bosons, scalars, ...

Vector-like quarks

$q_L\,,\,q_R$: same gauge charges

Predicted in many models:

- "Top-quark seesaw" model (Dobrescu, Hill, 1997)

  $\rightarrow$ Higgs doublet is composite

- "Little Higgs" models (Arkani-Hamed et al, 2002)

  $\rightarrow$ no quadratic divergences at 1-loop

- "Beautiful mirrors" (Choudhury, Tait, Wagner, 2001)

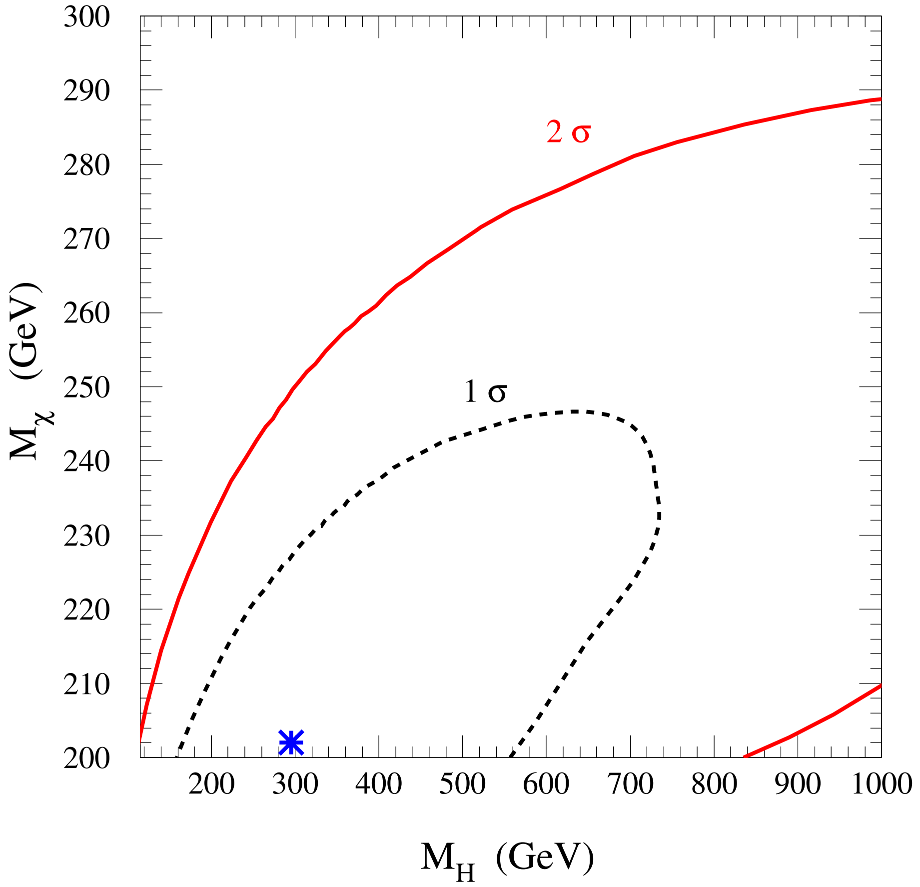
  $\rightarrow$ explains $A^b_{\rm FB}$;

  $\rightarrow$ signal in Run II: $b' \rightarrow bZ$ for $m_{b'} < 300$ GeV

Standard Mirrors: Best Fit

Talk by Tim Tait

$$M_1 = 200 \text{ GeV} \qquad Y_2 = 143 \text{ GeV}$$
$$m_H = 295.4 \text{ GeV} \qquad \sin^2\theta_L^b = 0.00811$$
$$\alpha_s(M_Z) = 0.116$$



New neutral gauge bosons (Z')

Consider an $SU(3)_C \times SU(2)_W \times U(1)_Y \times U(1)_z$ gauge symmetry spontaneously broken down to $SU(3)_C \times U(1)_{\rm em}$ by the VEVs of a doublet H and an $SU(2)_W$-singlet scalar, φ.

The mass and couplings of the Z' boson are described by the following parameters:

• gauge coupling g_z

• VEV v_φ

• $U(1)_z$ charge of the Higgs doublet, z_H

• fermion charges under $U(1)_z$ – constrained by anomaly cancellation conditions and requirement of fermion mass generation

Z' searches at the Tevatron:

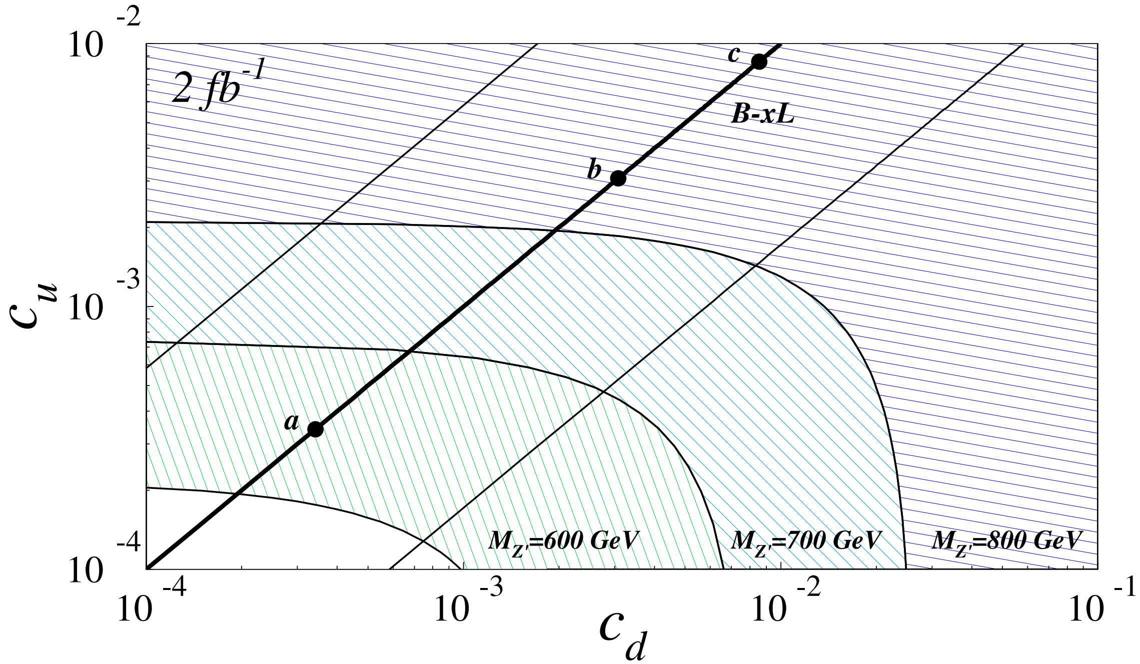
(M. Carena, A. Daleo, B. Dobrescu, T. Tait, hep-ph/0408098)

A user-friendly parametrization:

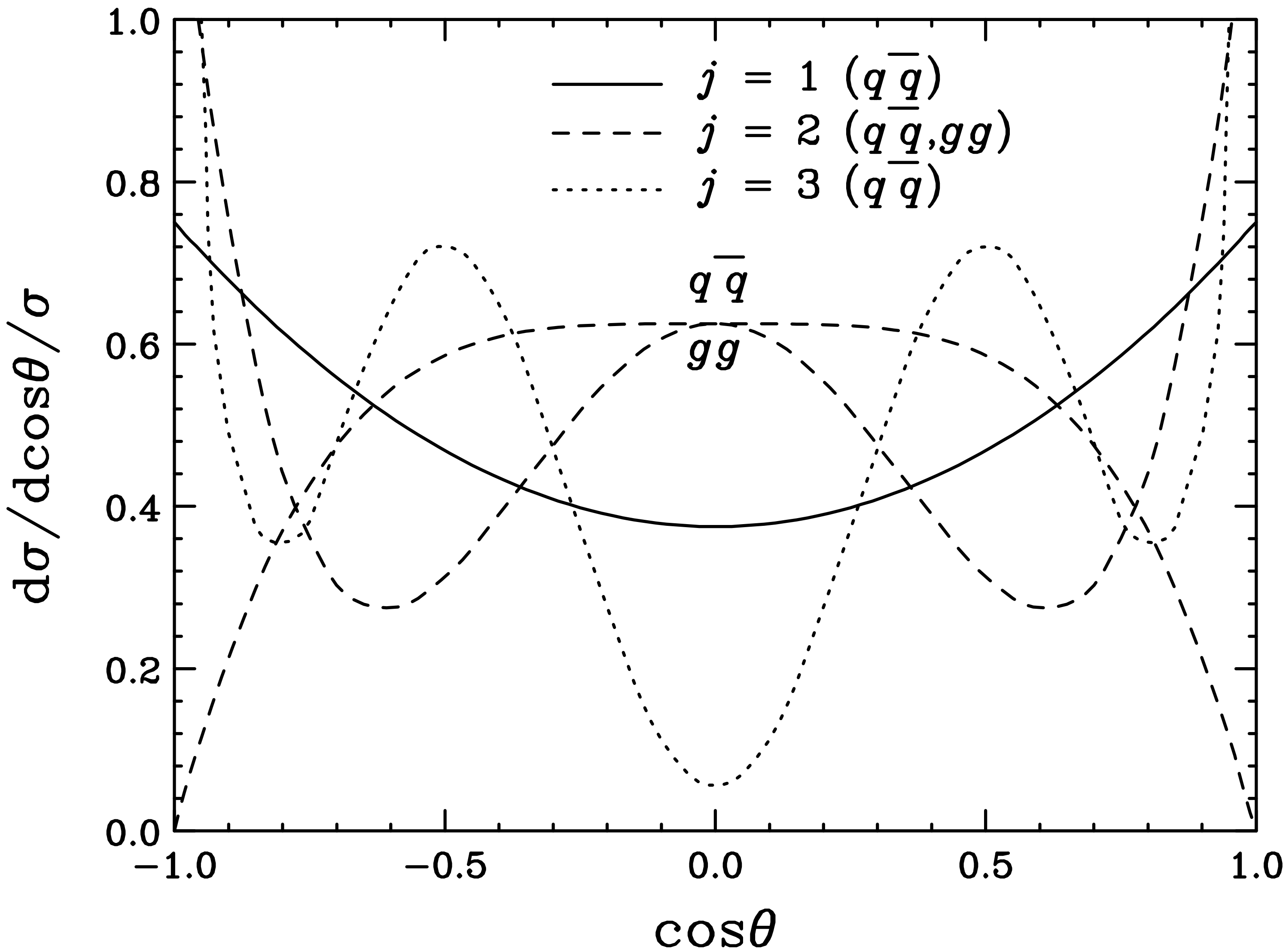
$$\sigma^{Z'} = \frac{\pi}{48\,s}\left[c_u\, w_u\left(\frac{M_{Z'}^2}{s}, M_{Z'}^2\right) + c_d\, w_d\left(\frac{M_{Z'}^2}{s}, M_{Z'}^2\right)\right]$$

$w_{u(d)}$ include PDF's and QCD

$c_{u,d} = g_z^2\,(z_q^2 + z_{u,d}^2)\,\mathrm{Br}(Z' \to l^+ l^-)$



Look for higher spin states in the angular distribution:



Experimental issues

Yuri Gershtein: Advanced Electron Reconstruction – use CMS algorithm with D0 data. It is hard to know the material precisely.

High event rate complicates the triggers
(no triggers for stable charged particles, displaced vertices, inclusive $\not\!\!E_T$)

Dan Green: one could test basic event selections using known SM processes. If you want to find a Higgs signal in VBF, then find first the Z signal in the same channel.

Albert De Roeck: diffractive Higgs process could provide spin and parity information. Predictions are hard to make, it would help to measure $p\bar{p}->p\bar{p}+2\gamma$ or $p\bar{p}+\eta_c$ at the Tevatron.

Bob Kehoe: multijet backgrounds – “fake everything”. Think about what can be done with the first fb^{-1}.

...

Conclusions

There is a lot of work to be done:

- Analyze as many models as possible, from theoretical constraints all the way to full detector simulations.

- Study generic new particles and signals

- ATLAS and CMS are going to be the most complex experiments ever performed.

The exploration of the energy frontier leads necessarily to discoveries!