SUPERSYMMETRIC MODELS AND THEIR SIGNATURES AT THE LARGE HADRON COLLIDER: AN OVERVIEW OF THE PROJECT

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The research project in a nutshell

Chain from Theory to Experiment in High Energy Particle Physics

Experiment

- LHC is running
  - Proton Proton collider
  - 14 Tev in 2011
  - Study properties of Brout-Englert-Higgs boson
  - Also Beyond Standard Model physics

Theory

- Supersymmetry is the leading candidate in BSM physics
- Many models for supersymmetry lead to different signatures

Study well motivated susy models
and
Identify specific signals for the LHC

A wide project

Expertise

- Some already present at VUB
- Collaboration with ULB, UCL, KUL . . .
- Hire new researcher

Plan of the talk

- Scan the steps of the chain
- Steps are tightly connected one to the other
- Important to have such a research chain at work in Belgium

What is Supersymmetry ?

Supersymmetry

Symmetry which maps bosons in fermions and viceversa

$$Q \mid \text{boson} \rangle = \mid \text{fermion} \rangle \qquad Q \mid \text{fermion} \rangle = \mid \text{boson} \rangle$$

$$\{Q_\alpha, Q^\dagger_{\dot\alpha}\} = 2\sigma^\mu_{\alpha\dot\alpha} P_\mu$$
$$\{Q_\alpha, Q_\beta\} = \{Q^\dagger_{\dot\alpha}, Q^\dagger_{\dot\beta}\} = 0$$
$$[P^\mu, Q_\alpha] = [P^\mu, Q^\dagger_{\dot\alpha}] = 0$$

- Irreducible representations of supersymmetry algebra are supermultiplets
- Supermultiplets contains bosons and fermions
- Superpartners have the same mass and quantum numbers
- Chiral superfields

$$\Phi = (\phi, \psi)$$

- Vector superfields

$$V_{Sfield} = (\lambda, A_\mu)$$

MSSM AND ITS VIRTUES

- Matter and vector fields become supersymmetric

$$\text{Matter} \Rightarrow \text{ Chiral superfields } (\phi, \psi)$$

$$\text{Vector} \Rightarrow \text{Vector superfields } (\lambda, A^\mu)$$

- Doublet of Higgs chiral superfields

$$h \Rightarrow H_1, H_2$$

- Special ultraviolet finiteness properties (no quadratic divergencies)
- Address the hierarchy problem $M_{planck} \gg\gg M_{\text{weak}}$
- Better GUT unification
- Natural Dark Matter candidate
- Included in unification theories
  - Local supersymmetry includes gravity (Supergravity)
  - Superstring theory

Basic of Susy phenomenology: susy breaking

- Supersymmetry not realized at low energies

SUSY MUST BE BROKEN!!

- Soft susy breaking $\equiv$ No quadratic divergencies

Supersymmetry must be broken softly

$$\mathcal{L} = \mathcal{L}_{MSSM} + \mathcal{L}_{soft}$$

- $\mathcal{L}_{soft}$ = Soft terms

$m_s \lambda_\alpha \lambda^\alpha$ Gaugino mass

$m_s^2 \phi^\dagger \phi$ Scalar mass

$A\phi^3$ A - term

$\vdots$

- Superpartners get masses of order supersymmetry breaking scale m_s
- m_s should be larger than EW scale
- We expect low energy supersymmetry breaking

Aspects of MSSM and soft terms

- Much of collider physics is determined by the Lightest Supersymmetric Particle (LSP)

Z_2 symmetry: R-parity

- Forbids lepton and baryon violating terms
- LSP stable $\Rightarrow$ Dark matter candidate

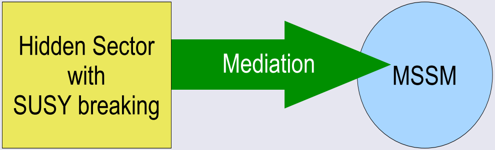
Problematic Issues

- $O(100)$ free parameters
- Flavour problem
- CP problem

These issues should be addressed in a theoretical framework for supersymmetry breaking that gives prediction for the soft terms!!!

MEDIATION OF SUPERSYMMETRY BREAKING

STANDARD PARADIGM: MEDIATION OF SUSY BREAKING



- Gravity mediation
- Gauge mediation

GAUGE MEDIATION

- Low energy supersymmetry breaking
- Solves the susy flavour problem
- Predictive mass spectrum and soft terms (No gravity)

$\Rightarrow$?? What is the phenomenological output of such models ?? $\Leftarrow$

Particle spectra and Cross section

Theoretical models give (as functions of fewer parameters) at the supersymmetry breaking scale:

- Superpartner particle spectrum (in MSSM 32 distinct masses of undiscovered particles)
- Mixing angles

These parameters are RG evolved at the ElectroWeak scale to obtain effective Lagrangian and then

- Physical masses and mixing angles
- Cross sections
- Decay widths
- Dark matter abundance

These features are constrained by cosmology and by LEP bounds

Montecarlo simulations of LHC collision

- FeynRules to calculate Feynman rules
- MadGraph/MadEvent to simulate collision events
- Output of MadGraph/MadEvent is interfaced with the simulation of the detector
- Reconstruction tools to reconstruct particles observed in the final state

Benchmark points

- Too large parameter space for a complete scan
- Proceed via benchmark points
- Ex: Constrained MSSM
  - All soft parameters as functions of 4 continuos + 1 discrete parameters

EXPERIMENTAL ISSUES

- Susy can be missing energy (LSP is typically neutralino)
- In model of gauge mediation gravitino is the LSP
- $\Rightarrow$ Decay of NLSP to Gravitino could be detected

- Important to extract susy from the SM background
- Kinematic topology can indicate supersymmetry
- Identify optimal event variables

WorkPlan

First stage: General Gauge Mediation (GGM)

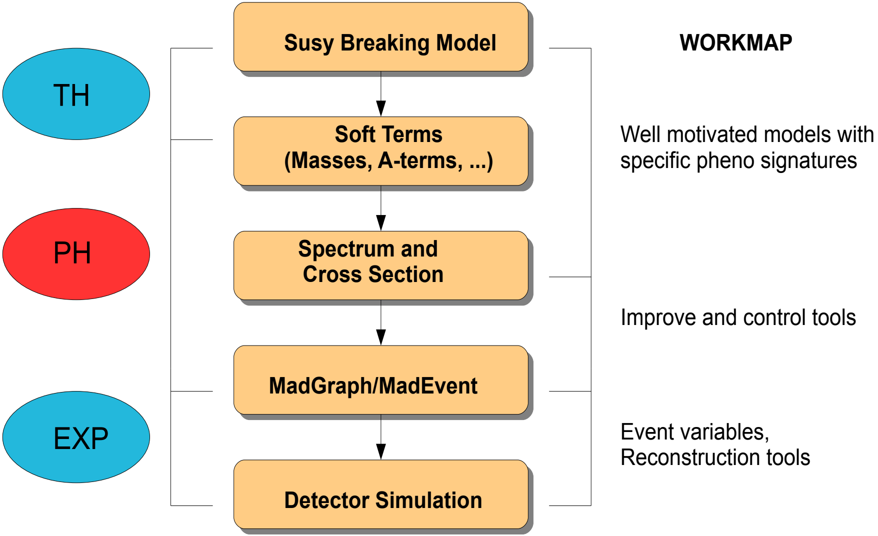
- GGM is a general framework for gauge mediation
- All soft terms determined by 6 parameters
- 6-dimensional parameter space still has to be fully explored
- Can have unusual NLSP (chargino, sneutrino)
- $\Rightarrow$ Can lead to unusual signatures at the LHC

Explore phenomenology of GGM,
from theory to LHC detectors

Parallel workplan

- Well motivated models and model-independent analysis
- Develope computational tools (Implement Gravitino physics in MadGraph)
- Method to estimate SM backgrounds distribution from collision data

SUMMARY



TH
PH
EXP
Susy Breaking Model
Soft Terms
(Masses, A-terms, ...)
Spectrum and
Cross Section
MadGraph/MadEvent
Detector Simulation
WORKMAP
Well motivated models with
specific pheno signatures
Improve and control tools
Event variables,
Reconstruction tools