

#### The standard model, supersymmetry and CMS

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#### Introduction



- The standard model
- Supersymmetry
- Initial issues
- Constraining our models
- Signals of supersymmetry
- SUSY at CMS

### The standard model



- Majority of evidence so far in good agreement with standard model predictions,
  - Electroweak Precision Observables [EWPO]
     (anomalous magnetic moment of electron, M<sub>t</sub>, M<sub>w</sub>)
  - Rare Decays (B-physics)
- Evidence for discrepancies and limitations,
  - Anomalous magnetic moment of the muon a<sub>μ</sub>
  - Relic  $\Omega_{CDM}$
  - Quadratic divergences in radiative corrections to m<sub>H</sub>

## Supersymmetry



- Superpartners with  $\Delta s = \frac{1}{2}$
- Must be a broken symmetry,
  - No observations of these particles yet
  - Need to introduce new mass terms to the lagrangian

$$q \rightarrow \tilde{q}$$
 $l \rightarrow \tilde{l}$ 
 $v \rightarrow \tilde{v}$ 
 $W^{\pm} \rightarrow \tilde{W}^{\pm}, Z^{0} \rightarrow \tilde{Z}$ 
 $g \rightarrow \tilde{g}$ 
 $Y_{W} \rightarrow \tilde{B}$ 
 $H \rightarrow \tilde{H}$ 
 $\tilde{W}^{\pm}, \tilde{B} \rightarrow \tilde{\chi}^{0}$ 
 $\tilde{W}^{\pm}, \tilde{H} \rightarrow \tilde{\chi}^{\pm}$ 

### Initial issues



- Similar problem to SM parameters
- Get 19 → 104< (depending on symmetry breaking mechanism) parameters
- 3 problems,
  - Motivation for fine tuning (same as SM)
  - Enormous parameter space computational issues
  - No predictive ability

#### The MSSM



- Many parameters, but can still realise "appealing" behaviour of SUSY
- Relax constraints on baryon and lepton number conservation
- Enforce R-parity, defined as  $R = (-1)^{3(B-L)+2S}$
- B,L: baryon-, lepton- number, S: spin
- R<sub>SM</sub>=+1, R<sub>SUSY</sub>=-1, leads to *only* pair-production
- LSP particle is stable  $\rightarrow \Omega_{\text{CDM}}$  candidate!

### Further constraints

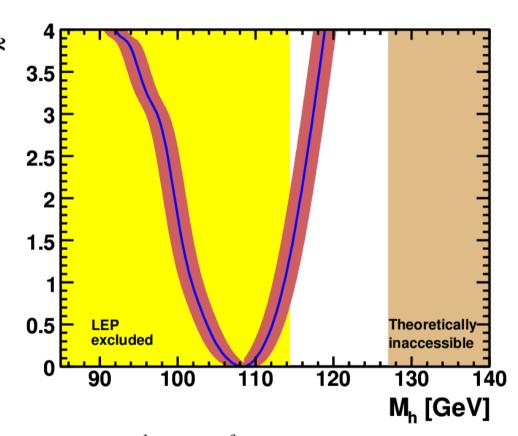


- Would be good to make predictions
  - Insist on universality at the GUT scale i.e.
    - Gaugino masses  $M_1 = M_2 = M_3 = m_{1/2}$ - Sfermion masses  $A_b = A_t = A_\tau = A_0$
- Require two more parameters for the higgs sector
  - tan(β) ratio of Higgs field vacuum expection
  - Sign of μ Higgs mixing parameter
- Results in the constrained MSSM (CMSSM)
- Have reduced SUSY to 4 parameters and a sign

### Making predictions



- Essential that one doesn't get too hung up on the theory...
- Look at how EWPOs (m<sub>Z</sub>, m<sub>W</sub>, etc.) and rare decays (BR(b→sγ), etc.) can constrain our parameter space
- Do a multi-parameter fit,
   minimising a global χ² function



$$\chi^{2} = \sum_{i}^{N} \frac{(C_{i} - P_{i})^{2}}{\sigma(C_{i})^{2} + \sigma(P_{i})^{2}} + \sum_{i}^{M} \frac{(f_{SM_{i}}^{obs} - f_{SM_{i}}^{fit})}{\sigma(f_{SM_{i}})^{2}} + \dots$$

# Signs of supersymmetry

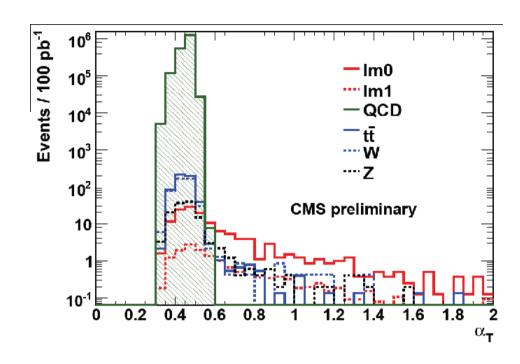


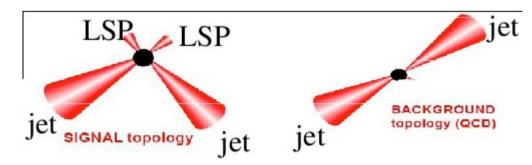
- What specific signals could one get from SUSY at the LHC?
  - Same Sign Dilepton
    - Suppressed in SM so a low background channel
    - Main background is QCD Dijet, top quark, electroweak boson production
  - Opposite Sign Dilepton
    - e.g.  $\tilde{\chi}_2^0 \rightarrow l \, l \, \tilde{\chi}_1^0$
    - Linear rise with invariant mass of leptons, with a cut-off at the kinematic limit (characterised by  $m_{\tilde{\chi}^0_-} m_{\tilde{\chi}^0_-}$ )
    - Can calculate the position of this cut off beforehand

# Signs of SUSY - ME<sub>T</sub>



- Both signals also have missing E<sub>T</sub> (LSP escaping)
- Can parametrise this with α<sub>T</sub>, the "balance" of the event jets
- Allows for effective cuts on the SM background



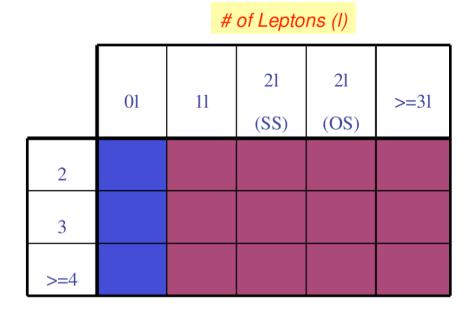


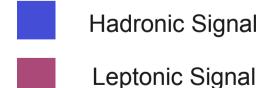
#### SUSY at CMS

# of Jets + # Photons



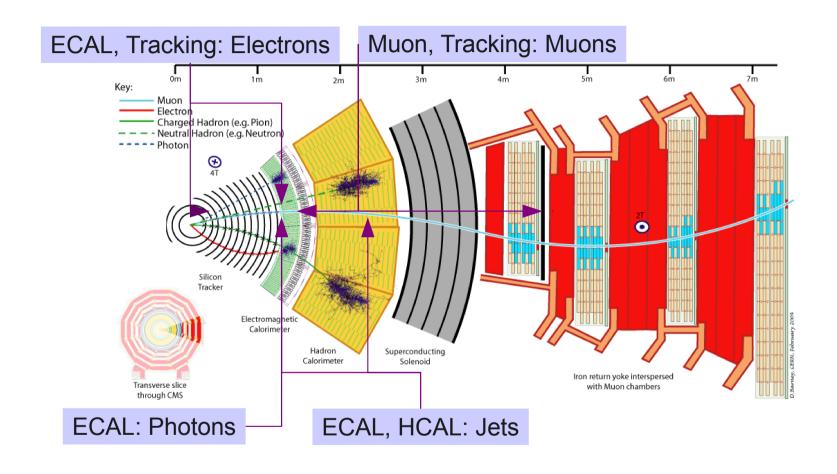
- Missing  $E_T$  don't need absolute  $\sqrt{s}$
- Cuts in place to eliminate main background
- Several leptonic signals
   → ECAL plays an
   important role
- Ol events have the highest cross-section





### SUSY at CMS (2)





Can see that SUSY requires analysis of data from all the different components of CMS

## Summary



- Can phenomenologically motivate constraints on general SUSY
- Have well defined signals for SUSY at CMS
- For particular models can generate likelihood functions to limit parameter space
- Good prospects for the understanding of new physics at the LHC