LHC signals for SUSY discovery and measurements

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IFIC Valencia

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Outline

- Introduction
  - ATLAS & CMS detectors
  - Supersymmetry: motivation, framework, final states ...

- LHC discovery potential
  - Background estimation from data
  - Inclusive signatures
  - Discovery reach
  - MSSM Higgs bosons
  - Long-lived particles

- SUSY measurements
  - End-point measurements
  - Spin determination

- Summary & outlook

References
The CMS detector
Supersymmetry (SUSY)

- **Supersymmetry := fundamental global symmetry between fermions-bosons**
  - all SM particles have SUSY-partners with spin difference of $\pm 1/2$

- **Theoretical motivation**
  - Higgs mass stabilisation against loop corrections (fine-tuning problem)
  - SUSY modifies running of SM gauge couplings ‘just enough’ to give Grand Unification at single scale
  - May explain Dark Matter

- **Masses of SM states & SUSY partners cannot be degenerate in mass**
  - Not observed
  - $\Rightarrow$ SUSY must be a broken symmetry at low energy
  - Various possible SUSY SB mechanisms proposed
**SUSY particle spectrum**

![Table](image)

- **R-parity:** \( R = (-1)^{3(B-L)+2s} \)
  - R-parity conservation hinted but *not required* by proton stability
  - not a fundamental symmetry

- **If R-parity is conserved:**
  - SUSY-partners are always produced in pairs (\( R \) is a multiplicative quantum number)
  - Lightest SUSY-particle (LSP) is stable
    - should be colorless and neutral
    - weakly interacting → escapes the detector undetectable → *large missing energy*
    - dark matter candidate

![Diagram](image)
PART I

Discovering Supersymmetry
SUSY model framework

- Minimal SuperSymmetric Standard Model (MSSM) contains >100 free parameters → assume specific physically-motivated model (Θ gravity) for systematic studies

- **Simplest**: minimal SuperGravity (mSUGRA)
  - local SUSY with soft breaking mediated by gravitational interactions
  - universal masses and couplings at GUT scale → 5 free parameters: \( m_0, m_{1/2}, \tan \beta, A_0, \text{sgn}(\mu) \)

Other models also investigated *(not presented here)*

- **GMSB**: gauge messengers; light gravitino LSP
- **AMSB**: anomalies in SUGRA \( \mathcal{L} \); no flavour problem
SUSY signature at LHC

- SUSY search is one of the major topics for LHC
- Focus on the early SUSY searches \( \sim 1 \text{ fb}^{-1} \): one year running at very low luminosity \((10^{31} - 10^{32} \text{ cm}^{-2}\text{s}^{-1})\)
- Relatively large cross sections
- Strongly interacting sparticles (squarks, gluinos) dominate production
- Long cascade decay into the LSP: e.g. lightest neutralino, \(\tilde{\chi}_1^0\)

- 'Golden discovery channel'
  multi jets + missing \(E_T\) + (leptons)
- Other modes also studied: photons, tau leptons, b-jets

Strategy for SUSY searches @ LHC

- Model independent (as possible)
  - theoretically complicated
    - MSSM has > 100 parameters
    - many scenarios: mSUGRA, GMSB, AMSB, ...
    - multi-dimensional parameter space: $m_0$, $m_{1/2}$, $\tan\beta$, ...
  - experimentally rather simple
    - search for multi-jets, large missing $E_T$ and possibly high-$p_T$ leptons

- Data-driven as possible
  - SUSY searches performed with early data at the LHC
    - poor understanding of detector (jet energy scale, fake missing $E_T$, ...)
    - large uncertainty of SM backgrounds, especially in signal region
  - try to estimate dominant background sources using real data wherever possible, instead of believing Monte Carlo estimates

<table>
<thead>
<tr>
<th>Main SM background</th>
</tr>
</thead>
<tbody>
<tr>
<td>top-antitop pairs</td>
</tr>
<tr>
<td>W+jets</td>
</tr>
<tr>
<td>Z+jets</td>
</tr>
<tr>
<td>QCD jets</td>
</tr>
<tr>
<td>diboson processes (ZZ, WW, WZ)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Baseline SUSY cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least 2 high-$p_T$ jets</td>
</tr>
<tr>
<td>High missing $E_T$</td>
</tr>
</tbody>
</table>
  - typically > 100 GeV
  - also > 0.2 $M_{eff}$
| High transverse sphericity (> 0.2) |
| Leptons |
  - either lepton veto |
  - or exactly 1 or 2 leptons |
Background estimation from data

General aim: estimate bkg in a `control’ sample and propagate’ this measurement to the `signal’ sample

- Control region should be as close as possible to signal region
- SUSY contamination should be as low as possible

\[ D = A \times C/B \]

normalisation to data

Replace method in no-lepton mode

- estimate \( E_T^{\text{miss}} \) distribution of \( Z \rightarrow \nu\nu \) from \( p_T(\ell^+\ell^-) \) distribution of \( Z \rightarrow \ell^+\ell^- \)
- apply corrections for lepton reconstruction efficiency and coverage, additional cuts, ...

SUSY mass scale versus $M_{\text{eff}}$

- SUSY mass scale, $M_{\text{SUSY}} :=$ average of squark and gluino masses

$$M_{\text{eff}} \equiv \sum_{i=1}^{4} p_{T}^{\text{jet},i} + \sum_{i=1}^{\text{lep}} p_{T}^{\text{lep},i} + E_{T}^{\text{miss}}$$

- $M_{\text{eff}}$ peak strongly correlated to the SUSY mass scale

- Measurement of $M_{\text{SUSY}}$ feasible with 10 fb$^{-1}$
  - 15% precision for mSUGRA
  - 40% precision for MSSM
  - also possible for GMSB with rapid decays to gravitino LSP
    - significantly increased statistics needed
    - or variables using photon or lepton $p_{T}$

- Total SUSY cross section, $\sigma_{\text{SUSY}}$, can be estimated in a similar way with 10 fb$^{-1}$ with a precision of 15% (50%) in mSUGRA (MSSM)

D R Tovey, PLB 498 (2001) 1
Inclusive search channels

- Lepton multiplicity exclusive (ATLAS) or inclusive (CMS)
- Inclusive in jet multiplicity
- **High missing transverse momentum (> 80-200 GeV)**

<table>
<thead>
<tr>
<th></th>
<th>No jets</th>
<th>1 jet</th>
<th>2 jets</th>
<th>3 jets</th>
<th>4 jets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>lepton veto</strong></td>
<td></td>
<td>split SUSY ✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>1 lepton</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>2 leptons</td>
<td>LFV</td>
<td>LFV</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>3 leptons</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>tau(s)</td>
<td>✔</td>
<td></td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>b-jets</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>photons</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

✔: signatures studied by ATLAS and/or CMS
All-hadronic signature

**ATLAS cuts**

1 fb⁻¹

- **E_T^{miss} + 4 jets**
  - Veto on electrons & muons
  - Δφ(E_T^{miss}, jet₁₋₃) > 0.2 against mismeasured jets (QCD bkg)
  - at least 4 jets with p_T > 50 GeV
  - p_T(jet₁) > 100 GeV
  - E_T^{miss} > max(100 GeV, 0.2M_{eff})
  - transverse sphericity S_T > 0.2

Clear excess of events is visible with 1 fb⁻¹

**CMS Coll., note**

CMS-PAS-SUS-08-005 (2008)

CMS: Further E_T^{miss} clean-up and QCD rejection cuts are applied
Di-leptons plus jets

- Opposite-sign (OS) and same-sign (SS) leptons (e or µ)
- Same flavour and different flavour (lepton flavour violation)

**Os leptons**

**CMS: SS muons, 10 fb^{-1}**

<table>
<thead>
<tr>
<th>Sample(s)</th>
<th>Events</th>
<th>Signif.</th>
<th>Sample</th>
<th>Events</th>
<th>Signif.</th>
<th>Sample</th>
<th>Events</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>1.5</td>
<td>−</td>
<td>LM5</td>
<td>61</td>
<td>14.0</td>
<td>LM10</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>LM1</td>
<td>341</td>
<td>&gt;37.0</td>
<td>LM6</td>
<td>140</td>
<td>22.3</td>
<td>HM1</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>LM2</td>
<td>94</td>
<td>17.6</td>
<td>LM7</td>
<td>82</td>
<td>16.3</td>
<td>HM2</td>
<td>2</td>
<td>1.1</td>
</tr>
<tr>
<td>LM4</td>
<td>90</td>
<td>17.2</td>
<td>LM8</td>
<td>294</td>
<td>35.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ATLAS cuts**

- **MET + 2 SFSS leptons + 4 jets**
  - Exactly two isolated leptons with p_T > 20 GeV
  - at least 4 jets with p_T > 50 GeV
  - p_T(jet_1) > 100 GeV
  - E_T^{miss} > max(100 GeV, 0.2M_{eff})
  - transverse sphericity S_T > 0.2
Other modes: b-jets, taus, ...

- **CMS**: $h \rightarrow bb$ in cascade decay
- Crucial: b-tagging performance
  - mean efficiency 50%
  - mis-tagging: 1.6% (12%) for $u,d,s,g$ (c-quarks)
- Hemisphere technique applied to reduce combinatorial bkg
- Higgs mass measured: $\pm 7.5$ GeV

- **ATLAS**: $\geq 1 \tau + 4$ jets + $E_{T}\text{miss}$
- $\tau$ reconstruction efficiency estimated from real data by replacing e or $\mu$

<table>
<thead>
<tr>
<th>Sample</th>
<th>$S$</th>
<th>$B$</th>
<th>$S/B$</th>
<th>$S/\sqrt{B}$</th>
<th>$Z_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SU3</td>
<td>259</td>
<td>51</td>
<td>5.1</td>
<td>36.3</td>
<td>12</td>
</tr>
<tr>
<td>SU6</td>
<td>119</td>
<td>51</td>
<td>2.3</td>
<td>16.7</td>
<td>6.8</td>
</tr>
</tbody>
</table>
Discovery reach @ 1 fb$^{-1}$

- **Search for:** $m_{jets} + E_T^{miss} (+ n \text{ leptons})$
- Sensitivity only weakly dependent on $\tan\beta$, $A_0$ & $\text{sgn}(\mu)$
- Best reach achieved with 0-lepton mode
- Significance takes into account systematic uncertainties on bkg estimation
- 1-lepton mode more robust against QCD bkg
- **SUSY @ 2 TeV is accessible with 1 fb$^{-1}$ (1 year of data taking)**
  - result independent of chosen model (mSUGRA, AMSB, ...)
- Caveat: excess of events is not enough
  - possibly other physics beyond the Standard Model
  - further precision measurements required

Random mSUGRA points compatible with low-energy constraints
Long live the sparticle...

- Long-lived particles $\equiv$ they live long enough to pass through detector or decay in it
- Predicted in many SUSY scenarios (GMSB, RPV, ...) and not only!
- Regardless of the model, categorised by event signature
  - Charge: electric? magnetic? colour?
  - Decay length?

Two general cases:

A. Sleptons, R-hadrons  
(heavy slow particles)  
- large ionisation energy loss  
- nuclear int. (R-hadron case)  
- delay (TOF) reconstructed in muon chambers

B. Long-lived neutralino  
(non-pointing photon)  
- decay vertex is somewhere in the inner tracker volume

see e.g. Fairbairn et al, Phys Rept 438 (2007) 1 [hep-ph/0611040]
GMSB: sleptons & neutralinos

- **Slepton NLSP** couples weakly to gravitino
  -> long lifetime
- Detected as heavy, slow-moving muons
- Preselection of slepton-like events at trigger level
- $\beta$ measurement: fast calculation with good resolution in the muon system

- **Neutralino NLSP** $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$
- Selection:
  - one or two non-pointing photons
  - two OS leptons (slepton decay)
  - high $E_T^{\text{miss}}$ (gravitinos)

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R-hadrons

- Massive exotic meta-stable hadrons, formed by gluinos or stops
- **Split SUSY**: if the gluino lifetime is long enough, it will hadronise forming an R-hadron
- Charge can change (`flip`) in hadronic interactions with matter while crossing the detector -> unique signature
- Main background: cosmic muons

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CMS Coll, note
CMS-PAS-EXO-08-003 (2008)

**Mesino**: \( \tilde{t}q \)
**Sbaryon**: \( \tilde{t}qq \)

**R-meson**: \( gqq \)
**R-baryon**: \( gqqq \)
**R-Gluino-ball**: \( \tilde{g} \)

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PART II

SUSY Measurements
Exclusive studies

- SUSY events contain two LSPs which escape the detector
  - reconstruction of mass peaks impossible
- Mass measurement strategy
  - apply kinematics on long decay chains to link endpoints with combinations of masses
  - measure endpoints (edges, thresholds) in invariant mass distributions
- $\tilde{g}, \tilde{b}_1, \tilde{b}_2$ masses: near di-lepton endpoint
- $\tilde{\chi}^0_1, \tilde{\chi}^0_2, \tilde{t}_R, \tilde{q}_L, \tilde{q}_R$ masses: kinematic endpoints and stransverse mass $M_{T2}$ (variant of $M_T$ for two-body decays)
- Comments:
  - cuts applied depend on the SUSY mass scale; has to be known from $M_{\text{eff}}$ distribution
  - method does not depend on underlying model (pure kinematics)

<table>
<thead>
<tr>
<th>Related edge</th>
<th>Kinematic endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l^+l^- $ edge</td>
<td>$(m_{ll}^{\text{max}})^2 = \frac{1}{(\tilde{\chi} - \tilde{l})(\tilde{\chi} - \tilde{\chi})}$</td>
</tr>
<tr>
<td>$l^+l^- q $ edge</td>
<td>$(m_{lq}^{\text{max}})^2 = \max \left( \frac{(\tilde{q} - \tilde{\chi})(\tilde{q} - \tilde{\chi}) - (\tilde{l} - \tilde{\chi})(\tilde{l} - \tilde{\chi})}{\xi^2} \right)$</td>
</tr>
<tr>
<td>$X q $ edge</td>
<td>$(m_{Xq}^{\text{max}})^2 = X + (\tilde{q} - \tilde{\chi}) \left[ \frac{\tilde{X} + X - \tilde{\chi}}{2} \right] / (2\tilde{\xi})$</td>
</tr>
<tr>
<td>$l^+l^- $ threshold</td>
<td>$(m_{lq}^{\text{min}})^2 = \left{ \frac{2(\tilde{q} - \tilde{\chi})(\tilde{q} - \tilde{\chi}) - 16\tilde{X}^2}{4\tilde{\xi}} \right}$</td>
</tr>
<tr>
<td>$l^\pm_{\text{near}} q $ edge</td>
<td>$(m_{l_{\text{near}}q}^{\text{max}})^2 = \frac{(\tilde{q} - \tilde{\chi})(\tilde{l} - \tilde{\chi})}{\tilde{\xi}}$</td>
</tr>
<tr>
<td>$l^\pm_{\text{far}} q $ edge</td>
<td>$(m_{l_{\text{far}}q}^{\text{max}})^2 = \frac{(\tilde{q} - \tilde{\chi})(\tilde{l} - \tilde{\chi})}{\tilde{\xi}}$</td>
</tr>
<tr>
<td>$l^\pm q $ high-edge</td>
<td>$(m_{l_{\text{q(high)}}}^{\text{max}})^2 = \max \left( m_{l_{\text{near}}q}^{\text{max}} m_{l_{\text{far}}q}^{\text{max}} \right)$</td>
</tr>
<tr>
<td>$l^\pm q $ low-edge</td>
<td>$(m_{l_{\text{q(low)}}}^{\text{max}})^2 = \min \left( m_{l_{\text{near}}q}^{\text{max}} m_{l_{\text{far}}q}^{\text{max}} \right)$</td>
</tr>
<tr>
<td>$M_{T2} $ edge</td>
<td>$\Delta M = m_{\tilde{\chi}^0_1} - m_{\tilde{\chi}^0_1}$</td>
</tr>
</tbody>
</table>

$\tilde{\chi} = m_{\tilde{\chi}^0_1}^2, \tilde{l} = m_{\tilde{t}_R}^2, \tilde{q} = m_{\tilde{q}_L}^2$ and $X$ is $m_h^2$ or $m_{Z}^2$

Allanach et al., JHEP 09 (2000) 004
Dilepton endpoint

\[ \tilde{\chi}_2^0 \rightarrow \tilde{l}^\pm l^\mp \rightarrow \tilde{\chi}_1^0 l^\pm l^\mp \]

\[ M_{\ell\ell}^{\text{max}} = \sqrt{\frac{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{l}}^2)(M_{\tilde{l}}^2 - M_{\tilde{\chi}_1^0}^2)}{M_{\tilde{l}}^2}} \]

\[ m_{\ell\ell}^{\text{max}} (TH) = 78.15 \text{ GeV} / c^2 \]

- Event selection:
  - 2 OS isolated leptons with \( p_T > 10 \text{ GeV} \), \( |\eta| < 2.4 \)
  - at least 3 jets with \( p_T > 30 \text{ GeV} \), \( |\eta| < 3 \)
  - \( p_T^{j1} > 120 \text{ GeV}, p_T^{j2} > 80 \text{ GeV} \)
  - \( E_T^{\text{miss}} > 200 \text{ GeV} \)

- Background
  - Flavour-symmetric: SF & DF
  - Flavour-asymmetric: SF dileptons only
  - Fake leptons

\[ m_{ee}^{\text{max}} = 77.90 \text{ GeV} / c^2 \]

\[ \Delta m_{ee}^{\text{max}} = \pm 1.07 (\text{stat.}) \pm 0.36 (\text{syst.}) \text{ GeV} / c^2 \]

\[ m_{\mu\mu}^{\text{max}} = 78.03 \text{ GeV} / c^2 \]

\[ \Delta m_{\mu\mu}^{\text{max}} = \pm 0.75 (\text{stat.}) \pm 0.18 (\text{syst.}) \text{ GeV} / c^2 \]
Adding the squarks

- Di-lepton edge starting point for reconstruction of decay chain
- Make invariant mass combinations of leptons and jets
- Gives multiple constraints on combinations of four masses
- Sensitivity to individual sparticle masses

<table>
<thead>
<tr>
<th>Endpoint</th>
<th>SU3 truth</th>
<th>SU3 measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\ell\ell q}^{\text{max}}$</td>
<td>501</td>
<td>$517 \pm 30 \pm 10 \pm 13$</td>
</tr>
<tr>
<td>$m_{\ell\ell q}^{\text{min}}$</td>
<td>249</td>
<td>$265 \pm 17 \pm 15 \pm 7$</td>
</tr>
<tr>
<td>$m_{\ell q}^{\text{max}}$</td>
<td>325</td>
<td>$333 \pm 6 \pm 6 \pm 8$</td>
</tr>
<tr>
<td>$m_{\ell q}^{\text{(low)}}$</td>
<td>418</td>
<td>$445 \pm 11 \pm 11 \pm 11$</td>
</tr>
</tbody>
</table>

with 1 fb$^{-1}$

mSUGRA masses/parameters determination

Measurement of mass combinations - `endpoints'

\[ m_{\ell\ell q}^{\text{max}}, m_{lq(\text{high})}^{\text{max}}, m_{\ell\ell q}^{\text{min}} \ldots \]

Sparticles masses determination with high uncertainty even for SU3 (optimum case)

\[ \delta m(\tilde{\chi}_1^0) = 70\% \quad \delta m(\tilde{q}) = 15\% \]
\[ \delta m(\tilde{\chi}_2^0) = 30\% \quad \delta m(\tilde{\ell}) = 50\% \]

mSUGRA parameters determination:
- \( m_0, m_{1/2} \) at 1–3%
- \( \tan\beta, A_0 \) only order of magnitude
- \textit{BUT}: Higgs width measurement
- \( \tan\beta \) determination

1 fb\(^{-1}\)

Fitting mass combinations with Sfitter program

<table>
<thead>
<tr>
<th></th>
<th>SPS1a</th>
<th>error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m_0 )</td>
<td>100</td>
<td>1.2 (1%)</td>
</tr>
<tr>
<td>( m_{1/2} )</td>
<td>250</td>
<td>1.0 (0.4%)</td>
</tr>
<tr>
<td>( \tan\beta )</td>
<td>10</td>
<td>0.9 (9%)</td>
</tr>
<tr>
<td>( A_0 )</td>
<td>-100</td>
<td>20 (20%)</td>
</tr>
</tbody>
</table>

If \( \text{sgn}(\mu) \) fixed

300 fb\(^{-1}\)

For a more precise parameter determination, SLHC, ILC is needed

For a more precise parameter determination, SLHC, ILC is needed

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What about the (SUSY) Higgs bosons?

- Supersymmetry requires two Higgs doublets $\Rightarrow$ five physical states
  - three neutral: two CP-even ($h$ and $H$) and one CP-odd ($A$)
  - two charged: $H^+$, $H^-$
- The lightest Higgs, $h$, can be discovered in the whole ($m_A$, $\tan\beta$) plane
  - however, indistinguishable from a light SM Higgs
  - discovery of other (heavy) Higgs bosons (SUSY) should be necessary
- Searches for MSSM Higgs boson
  - decay modes: $h/H/A \rightarrow \tau\tau$, $h/H/A \rightarrow \mu\mu$
  - charged Higgs: $H^\pm \rightarrow \tau\nu$, $H^\pm \rightarrow t\bar{b}$
- Measurement of Higgs properties with 300 fb$^{-1}$:
  - mass ($\sim 0.1\%$)
  - width / $\tan\beta$ (5–10\%)
  - couplings ($\sim 20\%$)
  - spin / CP
Is it Supersymmetry?

- Angular distributions in sparticle decays ➔ charge asymmetry in lepton-jet invariant mass distributions
- Charge asymmetry reflects the primary production asymmetry between squarks and anti-squarks (LHC: proton–proton collider)
- Consider usual two-body slepton decay chain
  - charge asymmetry of lq pairs sensitive to spin of $\tilde{\chi}_2^0$
  - shape of dilepton invariant mass spectrum is an indication of slepton spin
  - results consistent with spin-$\frac{1}{2}$ $\tilde{\chi}_2^0$ and spin-0 slepton

$$A^\pm = \frac{N(l^+ q) - N(l^- q)}{N(l^+ q) + N(l^- q)}$$

Q: How do we know that a SUSY signal is really due to SUSY?
Other models (e.g. UED with Kaluza-Klein parity) can mimic SUSY mass spectrum

A: Measure spin of new particles!

See next talk for more on SUSY look-alikes...

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Recap: What LHC can(not) tell us about SUSY?

- **SUSY discovery potential**
  - SUSY @ 1 TeV with 0.1 fb\(^{-1}\) – could be first discovery
  - SUSY @ 2 TeV with 1-10 fb\(^{-1}\) – within 1 year of data taking
  - SUSY @ 5 TeV – may need SLHC

- **Measurement of effective mass → mass scale, total SUSY cross section**

- **Endpoint measurements**
  - sparticle masses at 10% level
  - model parameters at 1 – 10% level (assuming specific model!)

- **How can we distinguish various SUSY models?**
  - \(E_T^{\text{miss}}\) spectrum → \(R\)-parity
  - hard photons, NLSPs, long-lived gluinos → GMSB, split SUSY
  - \(\tau\) leptons → large \(\tan\beta\)

- **Higgs sector**
  - discovery of SM Higgs: observable for the whole allowed mass range
  - additional Higgs bosons from the MSSM can be discovered on a large fraction of the parameter space
  - measurement of Higgs bosons properties is possible with 300 fb\(^{-1}\)
    - masses, total width, ratios of couplings, spin / CP properties

- **And what it cannot tell us ...**
  - observe and measure the full gaugino spectrum (in particular charginos)
  - constrain model parameters to < 1%
  - define directly the nature of neutralino & chargino (higgsino / bino / wino -like?)
Outlook: SUSY / Dark Matter @ LHC

- Discovery: search for deviation from SM in inclusive signatures like **missing energy + jets (+leptons)**
  - Inclusive studies: establish SUSY discovery
  - Exclusive studies: rough determination of model parameters
- Scheme developed for SUSY, but applicable to other BSM scenarios, e.g. UED, T-parity Little Higgs, ...
- **LHC should discover general WIMP dark matter**, but it is non-trivial to prove that it has the right properties
  - **SLHC, ILC**: extend discovery potential of LHC
    - improve on LHC capability of identifying DM model
    - more precise determination of model parameters
- **Complementarity between LHC and cosmo/astroparticle experiments**
  - uncorrelated systematics
  - measure different parameters
- In the following years we expect a continuous interplay between particle physics experiments (LHC, SLHC, ILC) and astrophysical/cosmological observations
  - either for model exclusion or discovery of New Physics