Búsqueda de Supersimetría en el LHC

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Outline

Focus on early data searches: ~ first two years

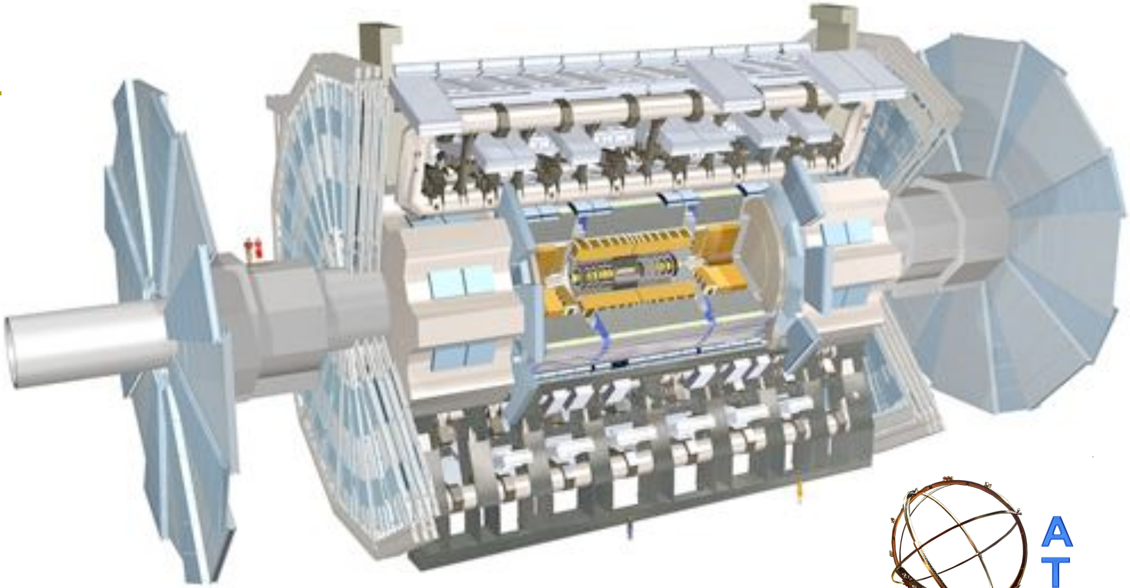
- integrated luminosity from 100 pb^{-1} to 1 fb^{-1}
- presented results for LHC energy $\sqrt{s}$ = 10 TeV & 14 TeV

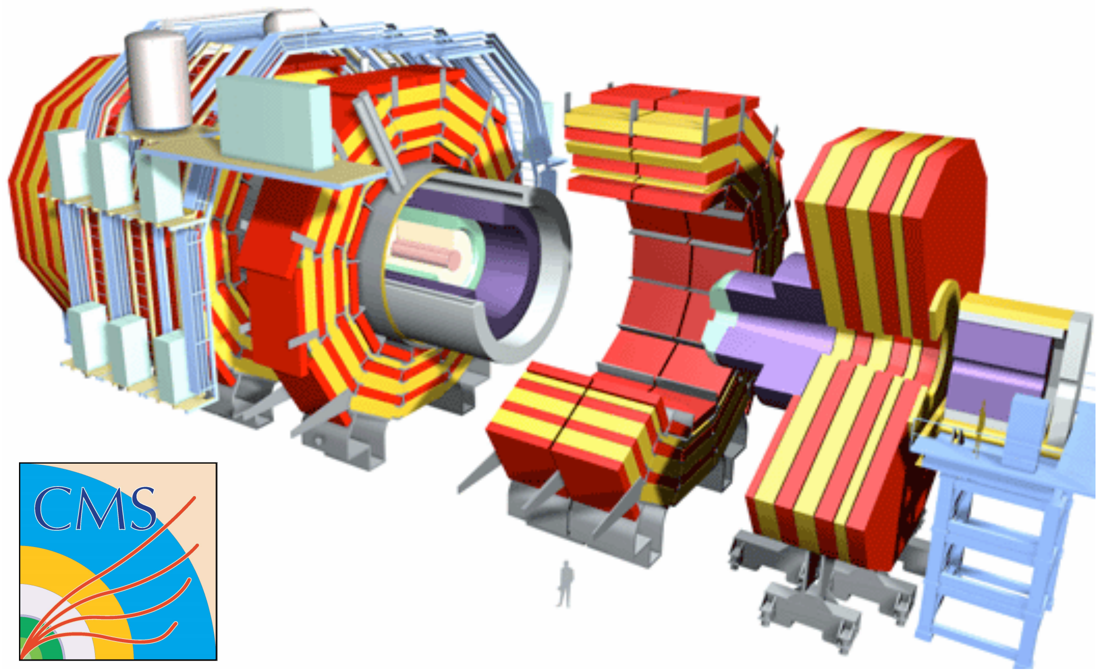
- Introduction
  - ATLAS & CMS detectors
  - Supersymmetry: motivation, framework, final states …
- LHC discovery potential
  - Data-driven background estimation
  - Inclusive signatures
  - Mass measurements from endpoints
  - Discovery reach
  - R-parity violation
- Summary & outlook

ATLAS & CMS

General-purpose experiments

- very **complex** detectors
- effort needed to **understand** their performance



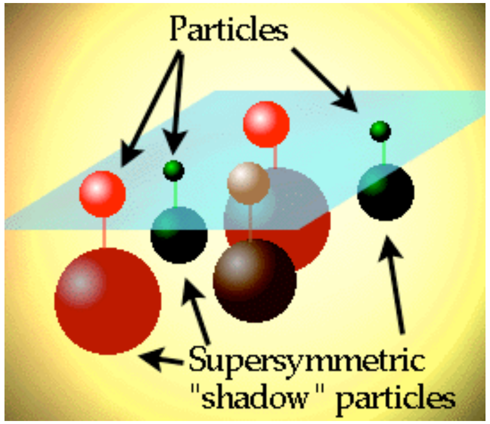


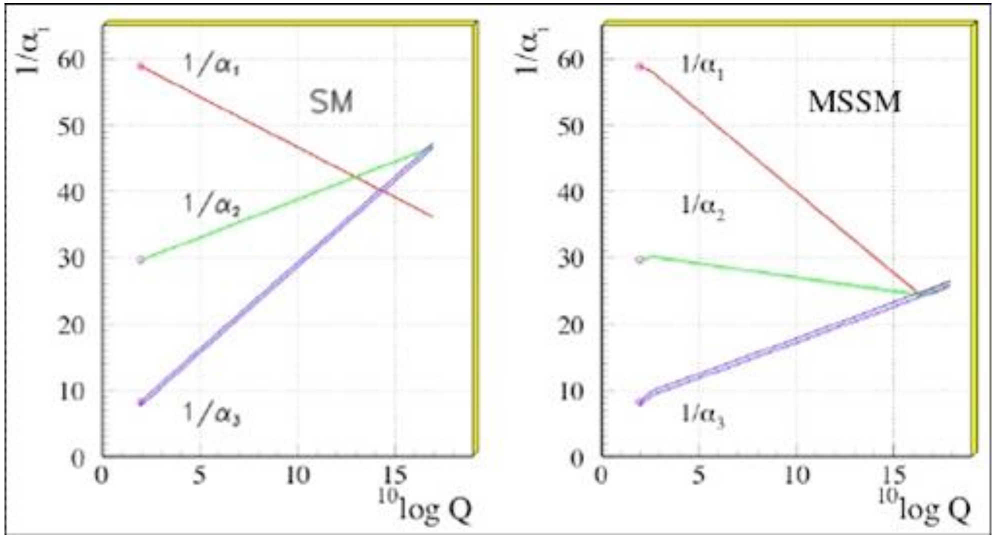
Relevant aspects for SUSY searches

- high quality **lepton** and **jet** measurements
- hermeticity for **missing transverse energy** **(E_T^{miss})** measurements

Supersymmetry (SUSY)

- Supersymmetry := fundamental global symmetry between fermions-bosons
  - all SM particles have SUSY-partners with spin difference of ±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

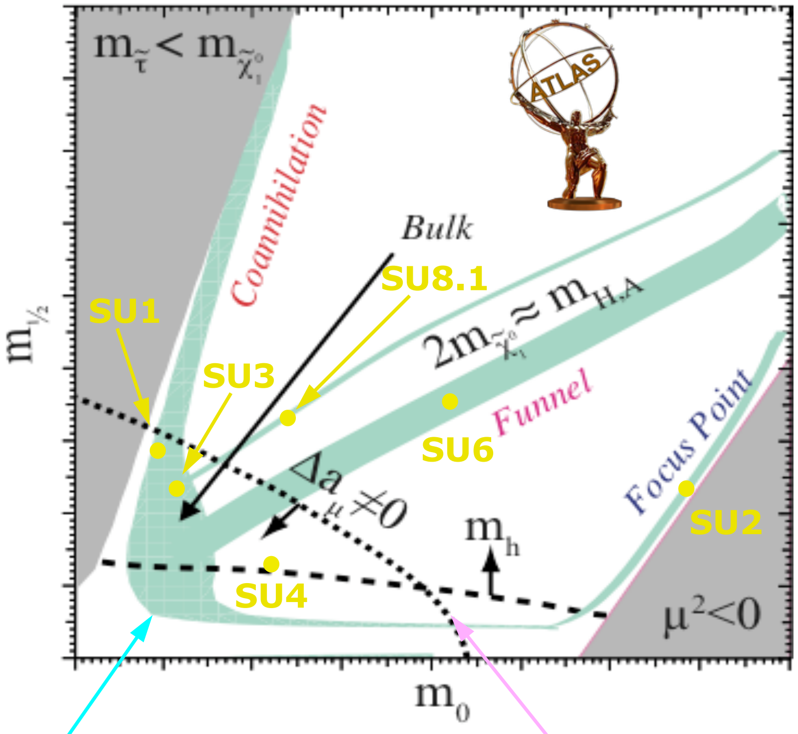




SUSY model framework

- Minimal SuperSymmetric Standard Model (MSSM) contains >100 free parameters
  → assume specific physically-motivated model for systematic studies
- 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, $\mathrm{sgn}(\mu)$
- Other models also investigated *(not presented here)*
  - **GMSB**: gauge messengers; light gravitino LSP
  - **AMSB**: anomalies in SUGRA $\mathcal{L}$; no flavour problem

qualitative picture – no mass scale

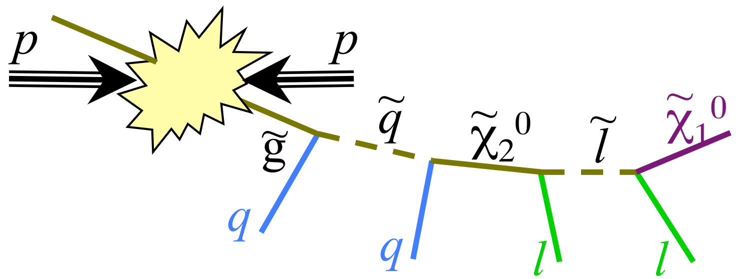


WMAP constraints on neutralino relic density

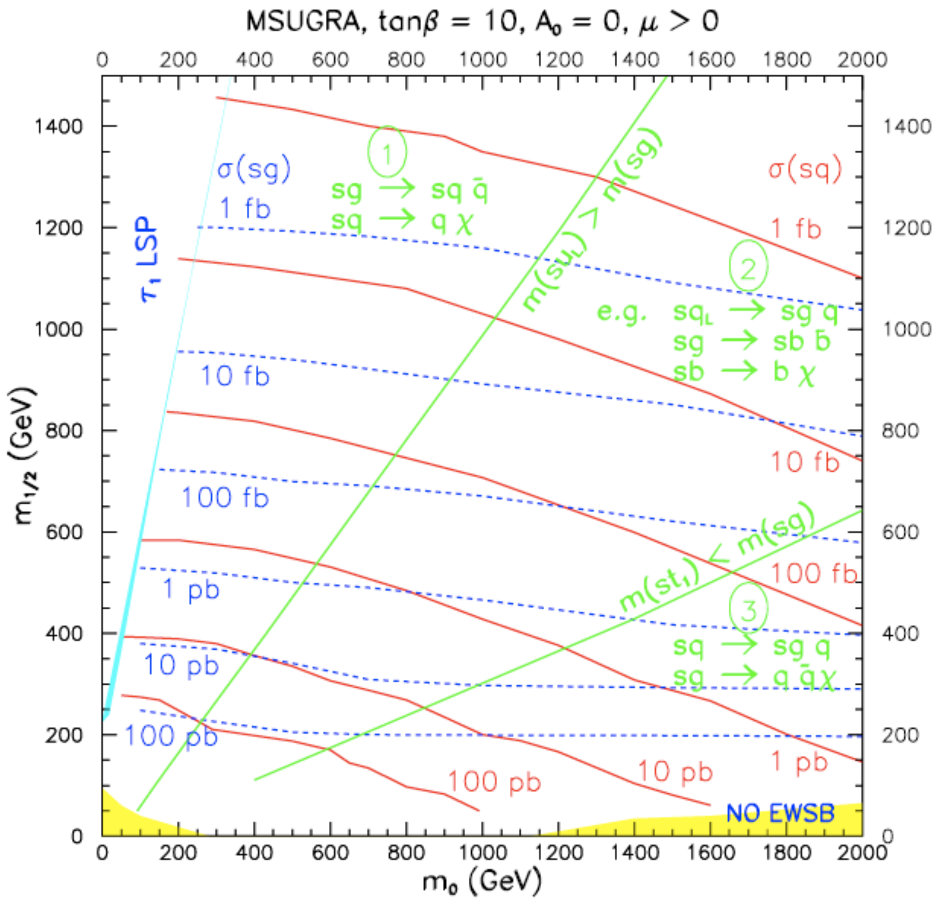
$(g-2)_\mu$ measurements

SUSY signature at LHC

- Relatively large cross sections at the LHC
- Strongly interacting sparticles (squarks, gluinos) dominate production
- Long cascade decay into the LSP: e.g. lightest neutralino, $\tilde{\chi}_1^0$



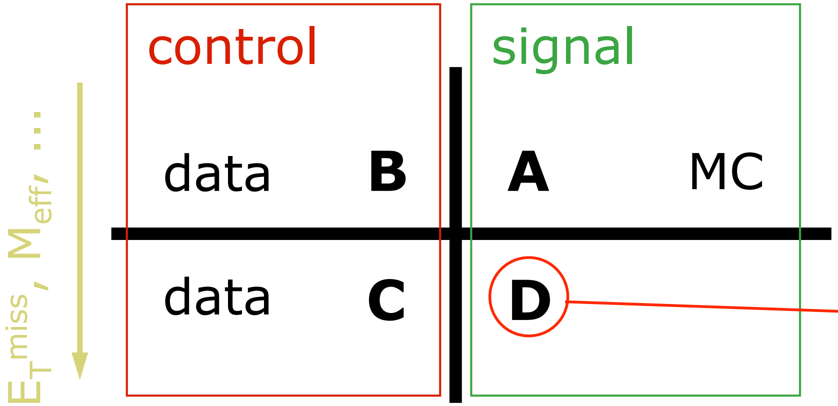
- **'Golden discovery channel'**
  multi jets + missing E_T
  + (leptons)
- Other modes also studied:
  photons, tau leptons, b-jets
- Main background:
  QCD dijets, top-pairs, W/Z + jets



CMS Coll., J. Phys. G **34** (2007) 995

Background estimation from data

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



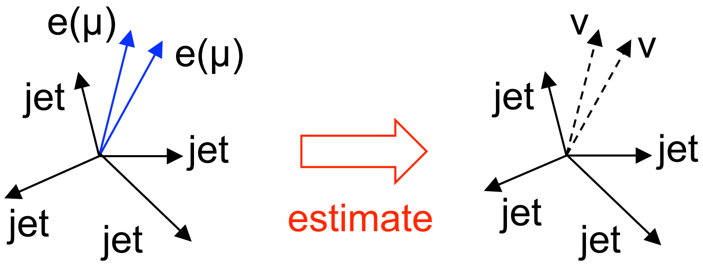
- Control region should be as close as possible to signal region
- SUSY contamination should be as low as possible

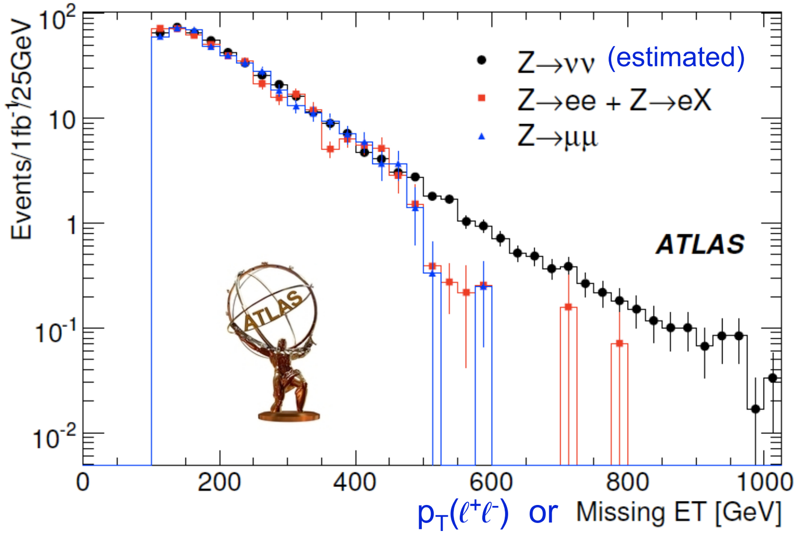
D = A × C/B

normalisation to data

Replace method in no-lepton mode

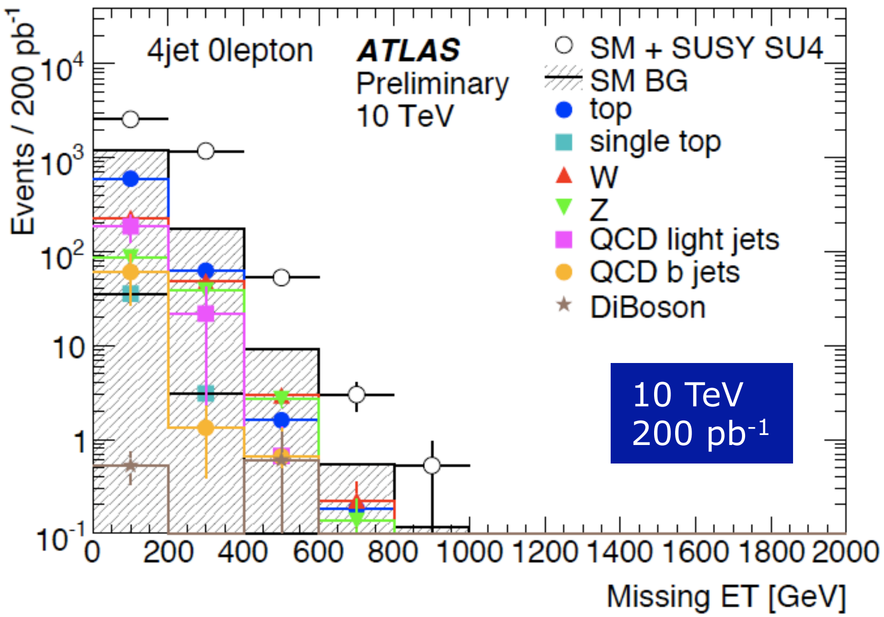
- estimate E_T^{miss} distribution of $Z \to \nu\nu$ from $p_T(\ell^+\ell^-)$ distribution of $Z \to \ell^+\ell^-$
- apply corrections for lepton reconstruction efficiency and coverage, additional cuts, …



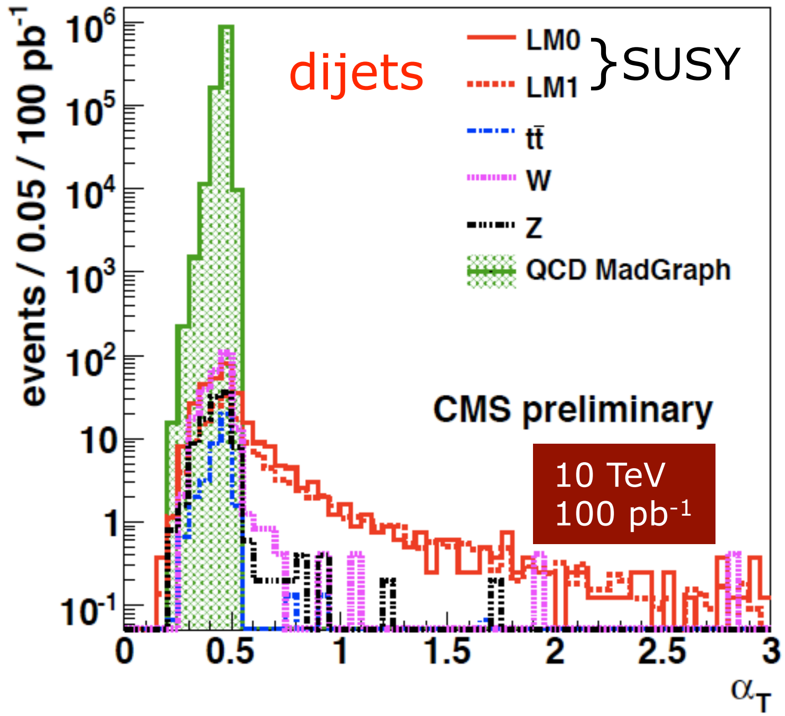


ATLAS Coll, arXiv:0901.0512 (2008)

All-hadronic signature



ATLAS Coll, ATL-PHYS-PUB-2009-084 (2009)



CMS Coll., CMS-PAS-SUS-09-001 (2009)

ATLAS

- **Veto on electrons & muons**
- $\Delta\varphi(E_T^{miss}, jet_{1-3}) > 0.2$ against mismeasured jets (QCD bkg)

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

CMS

- Also applicable in higher jet multiplicities (3…6)
- No explicit dependence on calorimeter-based $\mathbf{E_T^{miss}}$

$$a_{\rm T} = \frac{1}{2}\frac{H_{\rm T} - \Delta H_{\rm T}}{\sqrt{H_{\rm T} - H_{\rm T}^{\rm miss}}}, \quad H_T = \sum_{i=1}^{n} p_{\rm T}^{{\rm jet},i}$$

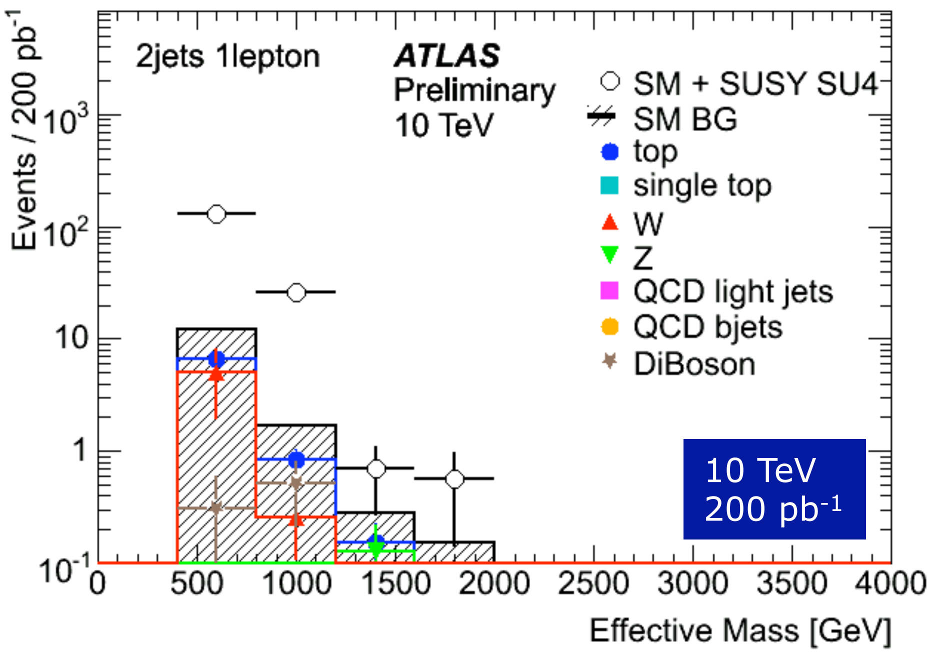
Excess of events visible with 100 pb^{-1}

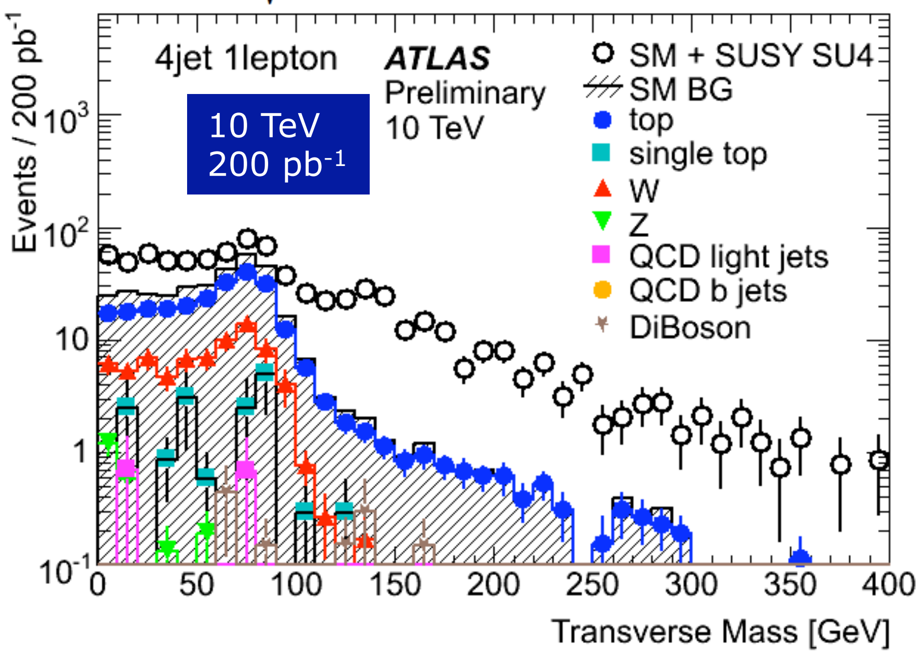
Inclusive one-lepton mode

MET + 1 lepton + 2-4 jets

- lower cross section; better background control
- ttbar dominant; W+jets at high MET
- use low-M_T region for normalisation and shape in signal region
- cut M_T >100 GeV suppresses effectively the background from top-pairs and W production

$$M_T = \sqrt{2 \cdot P_T^{\mathrm{lep}} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos\Delta\phi)}$$

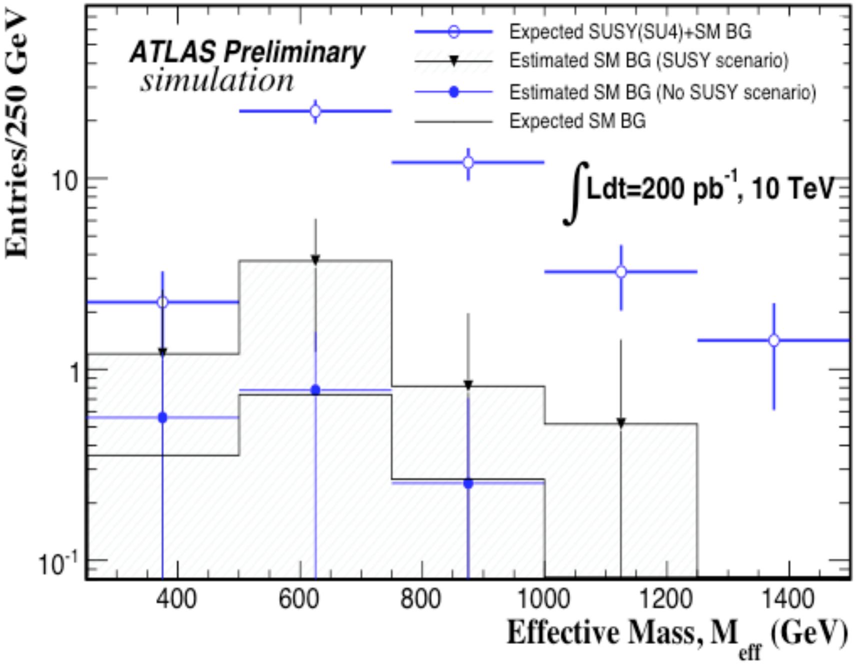




ATLAS Coll, ATL-PHYS-PUB-2009-084 (2009)

Inclusive multi-lepton signatures

1. Opposite sign dileptons (OS)+ MET + 2-4 jets
   - non-resonant (produced through neutralino decay)
   - **same flavoured leptons**
   - [ATLAS Coll., ATL-PHYS-PUB-2009-084 (2009)]
2. Same sign dileptons (SS) + MET + 2 jets
   - low SM background contribution (if fakes are kept under control)
   - [ATLAS Coll., ATL-PHYS-PUB-2009-085 (2009)]
3. Trileptons + 1 jet
   - less dependence on MET
   - requiring MET gives sensitivity to gaugino direct production
   - [ATLAS Coll., arXiv:0901.0512 (2008)]



ATLAS Coll, ATL-PHYS-PUB-2009-085 (2009)

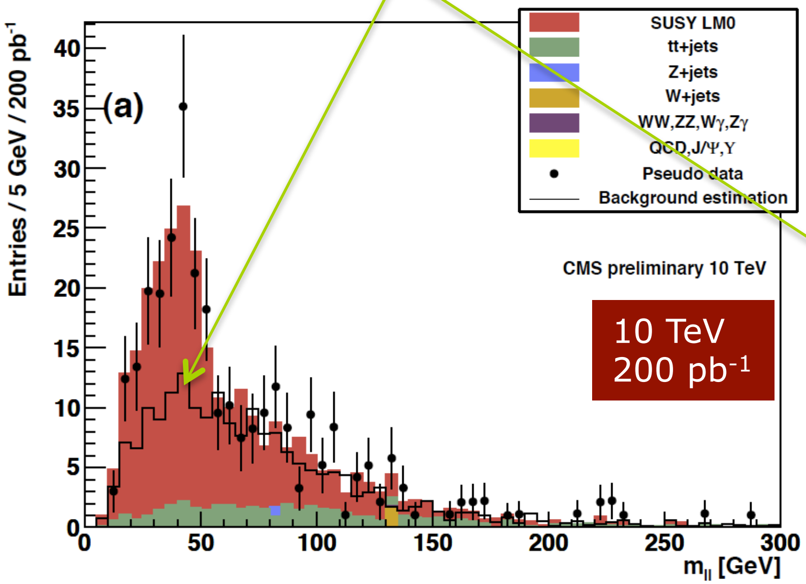
Opposite-sign dileptons (e or μ)

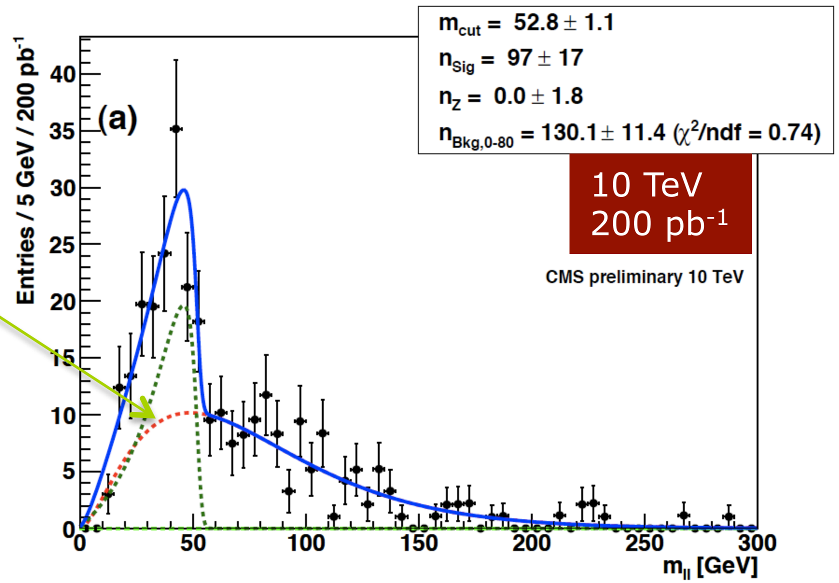
Determination of sparticle properties

➔ edges in mass distributions in leptonic final states

- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+\ell^-$ and $\tilde{\chi}_2^0 \to \tilde{\ell}^+\ell^-$
- Z/γ → e+e−, μ+μ− suppressed by E_T^{miss} + jets requirement
- flavour-symmetric bkg extrapolated from opposite flavour distribution

CMS Coll., CMS-PAS-SUS-09-002 (2009)



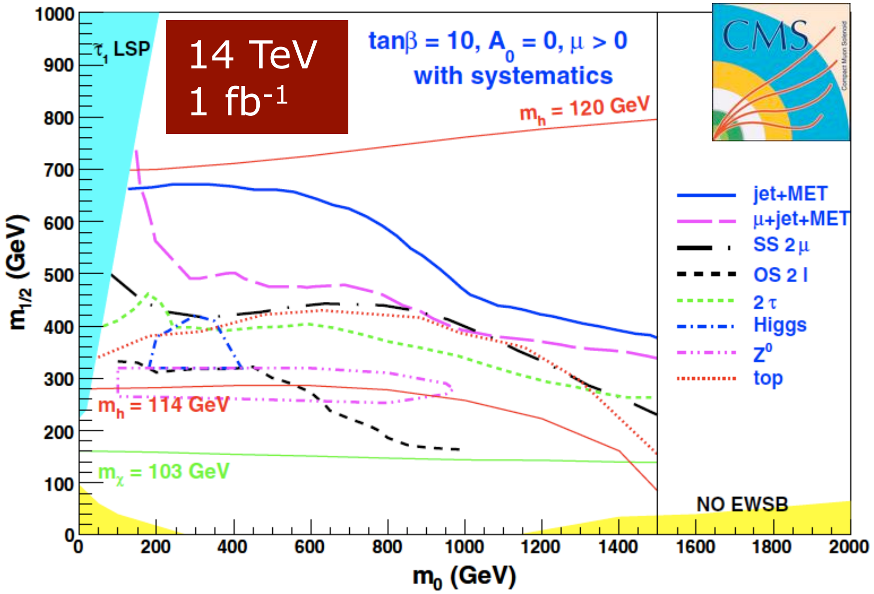


Significant excess of OSSF leptons over backgrounds

Depending on model, endpoint in the invariant mass distribution may be determined with 3–3.5% precision with 200 pb^{-1} (1.5–2.5% with 10 fb^{-1})

5σ discovery reach

- Sensitivity weakly dependent on tanβ, A_0 & sgn(μ)
- Significance takes into account systematic uncertainties on bkg estimation
- Best reach achieved with 0-lepton mode
- 1-lepton mode more robust against QCD bkg



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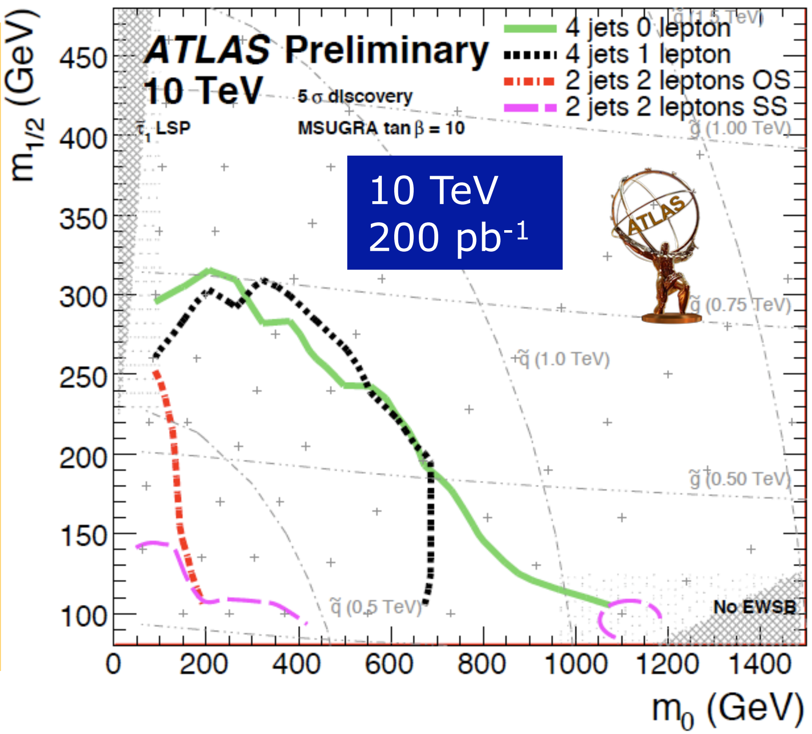


ATLAS Coll, ATL-PHYS-PUB-2009-084

- SUSY scale of 2 TeV accessible with 1 fb^{-1} @ 14 TeV
- With only 200 pb^{-1} of *well understood* data @ 10 TeV, the LHC can go beyond the reach of the Tevatron
- Caveat: excess of events is not enough
  - possibly other physics beyond the Standard Model
  - further precision measurements required

R-parity violation (RPV)

- *R*-parity: $R = (-1)^{3(B-L)+2s}$ $\rightarrow$ $R = \begin{cases} +1, \text{ for SM particles} \\ -1, \text{ for superpartners} \end{cases}$

L-number violating terms; bilinear terms; *B*-number violating term

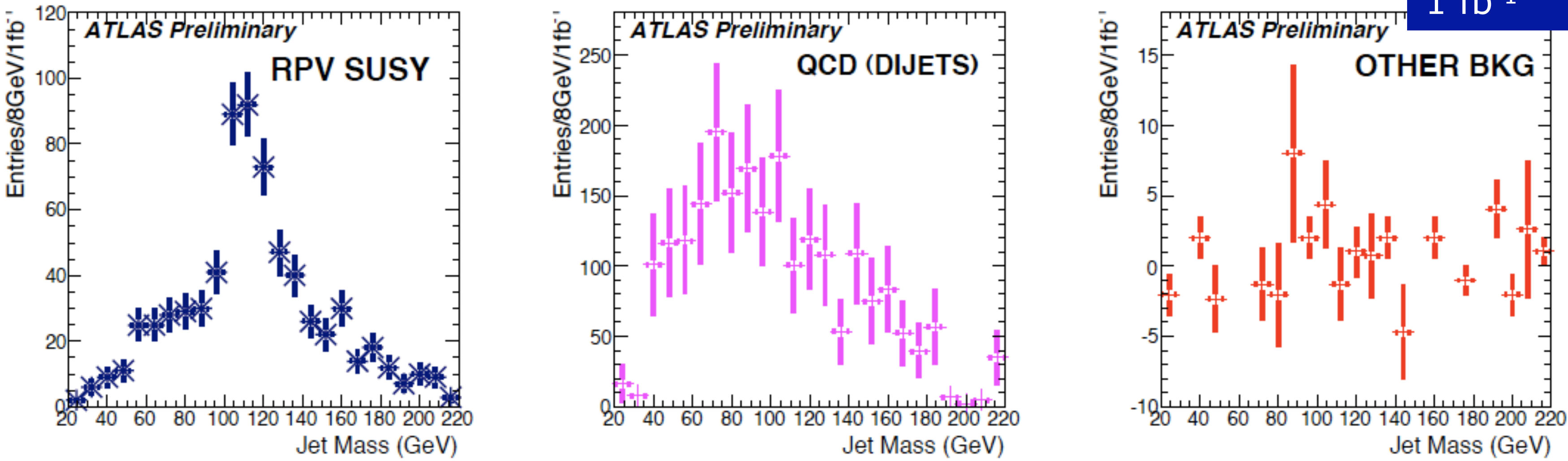
$$W_{RPV} = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}_k^C + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}_k^C + \varepsilon_i\hat{L}_i\hat{H}_u + \lambda''_{ijk}\hat{U}_i^C\hat{D}_j^C\hat{D}_k^C$$

- Proton stability → either *B* or *L* can be violated (*not both!*)
- Phenomenological consequences
  - LSP may be charged (e.g. stau, sleptons)
  - LSP is not stable ➔ no missing energy, if LSP decays in the detector
- What about dark matter (DM)?
  - constraints on neuralino relic densities do *not* apply, if LSP lifetime << age of Universe
  - non-SUSY particles may account for DM *(axions, KK gravitons,…)*
  - possible DM candidates in SUSY with RPV:
    - gravitino NLSP with lifetime much longer than the age of the Universe
    - cosmologically long-lived axino LSP or neutralino LSP (split SUSY)

RPV SUSY in ATLAS

- Baryon number violation ATLAS Coll, ATL-PHYS-PUB-2009-076
  - Coupling $\lambda''_{112} \neq 0$ ➔ $\tilde{\chi}_1^0 \rightarrow qqq$
  - Looking at the substructure of the resulting single collimated jet using the k_T *algorithm*
  - Neutralino mass peak clearly seen over background (mainly QCD dijets) with 1 fb^{-1}

10 TeV
1 fb^{-1}

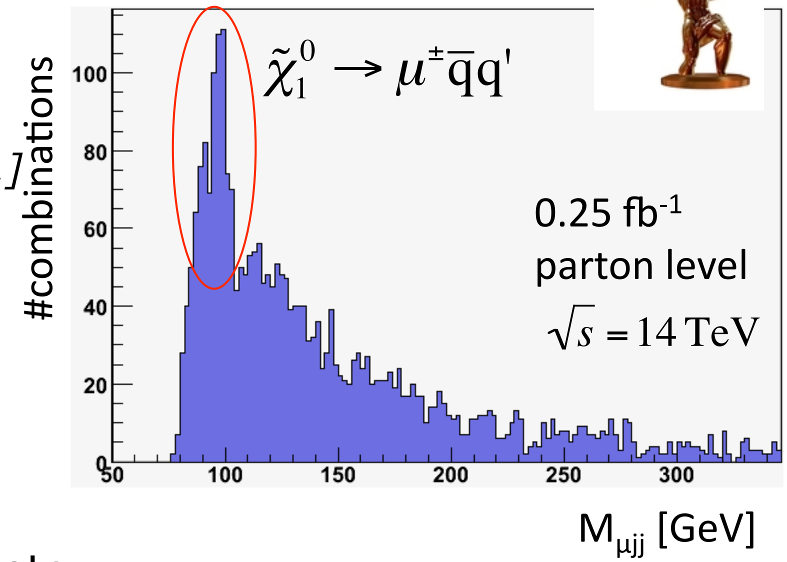


- Lepton number violation: currently under study in ATLAS
  - various inclusive signatures: leptons + MET, leptons + jets, …
  - different types of LSP: sneutrino, stau, **neutralino** *(see next slide)*
  - both **prompt** and **delayed** LSP decays

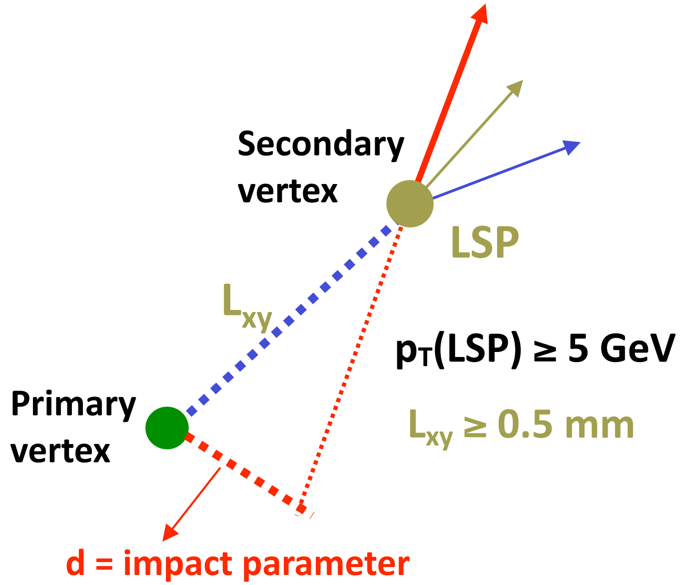
Bilinear RPV studies @ IFIC

- Why bilinear RPV (bRPV)?
  Predicts neutrino masses and mixings
  - *[deCampos, Hirsch, Diaz, Porod, Romao, Valle, …]*
  - collider signatures sensitive to neutrino mixing parameters, e.g.:

$$\tan^2\theta_{atm} \approx \frac{BR(\tilde{\chi}_1^0 \to \mu^\pm W^\mp)}{BR(\tilde{\chi}_1^0 \to \tau^\pm W^\mp)}$$



- Selection criteria for $\tilde{\chi}_1^0 \to \mu W \to \mu qq$
  - one isolated high-p_T muon & two high-p_T jets
  - high effective mass & transverse sphericity
  - moderate cut on missing E_T
  - $|M_{jj}-M_W| < 5$ GeV
- Neutralino mass peak visible over SM and SUSY combinatoric background in $M_{\mu jj}$ distribution with ~1 fb-1 @ 10 TeV
- LSP lifetime: cτ = 530 μm
  → secondary vertex tagging possible



Emma Torró, V.A.M., Carmen García, ATL-COM-PHYS-2009-543

Conclusions

- **Low mass SUSY may be within LHC reach with O(100 pb^{-1})**
- Knowledge of SM background crucial for early discovery ➔ data-driven analyses
- Clean experimental signatures to be explored first
  - Greatest potential from 0-lepton channel, but 1-lepton and dilepton modes more robust
  - Endpoint measurements in leptonic signatures may constrain mass spectra already with 200 pb^{-1}
- **R-parity violating scenarios may be also probed early on**