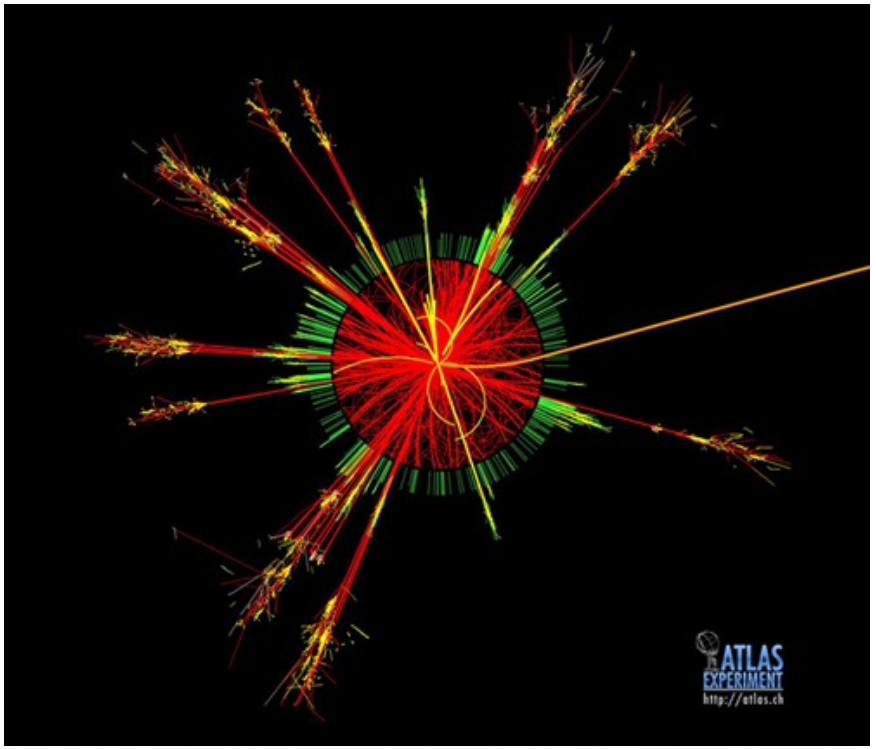
Supersymmetry searches in ATLAS

Basil Schneider on behalf of the ATLAS collaboration
TRIUMF, Canada's national laboratory
for particle and nuclear physics



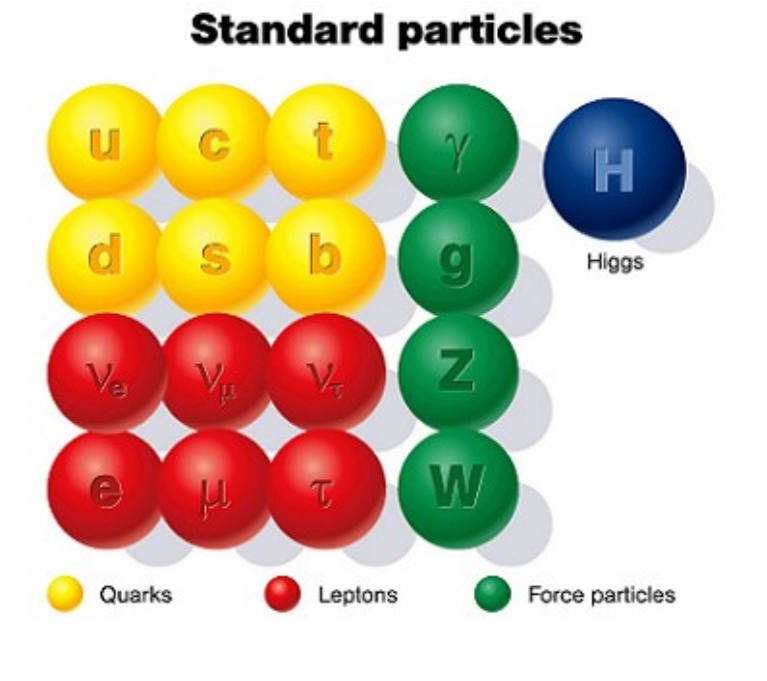
Mitchell Workshop on Collider and Dark Matter Physics
20 May 2015
Mitchell Institute for Fundamental Physics
Texas A&M University

CERN

TRIUMF

ATLAS EXPERIMENT
http://atlas.ch

Standard Model

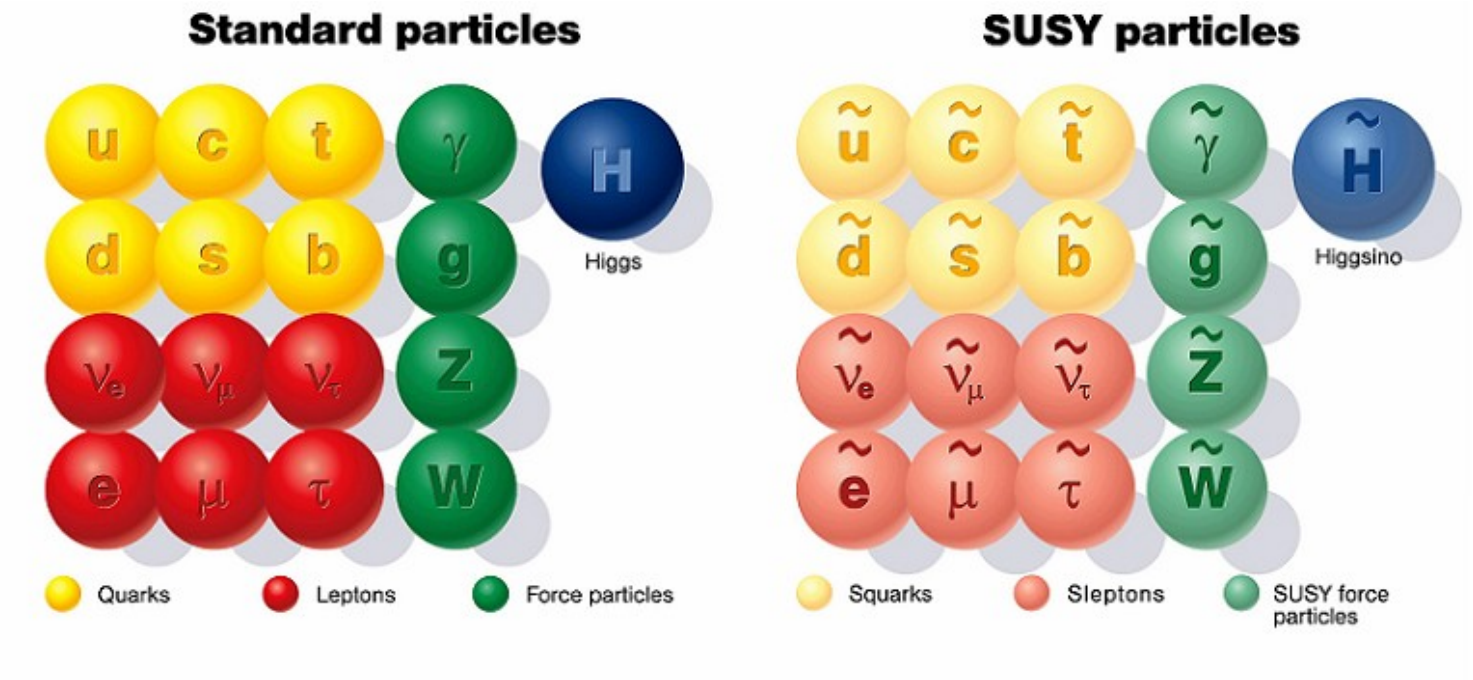


Standard Model (SM) of Particle Physics

very successful description of phenomena at TeV scale, but some shortcomings:

- Higgs mass fine tuned (hierarchy problem)
- No dark matter

Standard Model and Supersymmetry



Standard Model (SM) of Particle Physics

very successful description of phenomena at TeV scale, but some shortcomings:

- Higgs mass fine tuned (hierarchy problem)
- No dark matter

Supersymmetry (SUSY)

unique extension of Poincaré spacetime symmetry

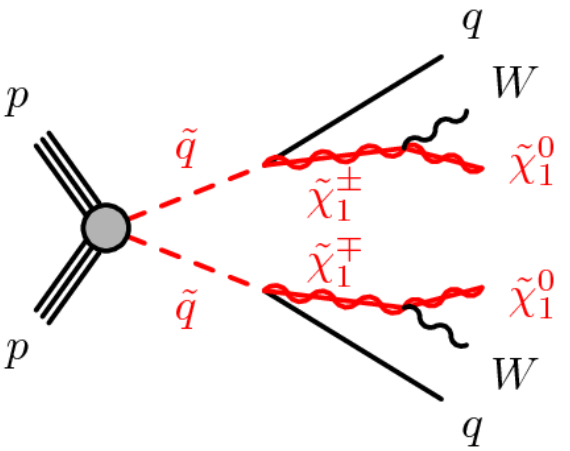
- Solves hierarchy problem in natural way
- Provides excellent dark matter (DM) candidate

SUSY and Dark Matter

- R-Parity: $P_R = (-1)^{3(B-L)+2S}$ (B=baryon number, L=lepton number, S=spin)
- R-Parity conservation → Lepton/Baryon number conservation
- R-Parity conserved to ensure stable proton (actually Lepton or Baryon number conservation is enough → R-Parity violating SUSY models)
- R-Parity conservation → always two SUSY particles in vertex
  → Lightest SUSY particle (LSP) is stable
  → Excellent Dark Matter candidate!

- Most prominent Dark Matter candidate: $\tilde{\chi}_1^0$ (neutralino 1 – a WIMP)
- $\tilde{\chi}_1^0$ is the supersymmetric partner of the photon, Z boson and Higgs
- → Mixture of wino, bino and two neutral higgsinos

- Production cross-section of LSP small, but would "observe" LSP as decay product
- Observation of LSP as missing transverse momentum



Mass scale of LSP

Arguments from Particle Physics

- "Classic" naturalness arguments constraints:
  higgsino mass parameter < ~200 GeV
  stop mass < ~1 TeV
  gluino mass < ~3 TeV
- Particles relevant to Higgs potential light, others can be heavy (natural SUSY)
- LSP mass depends on exact mixture of gauginos

Arguments from Cosmology

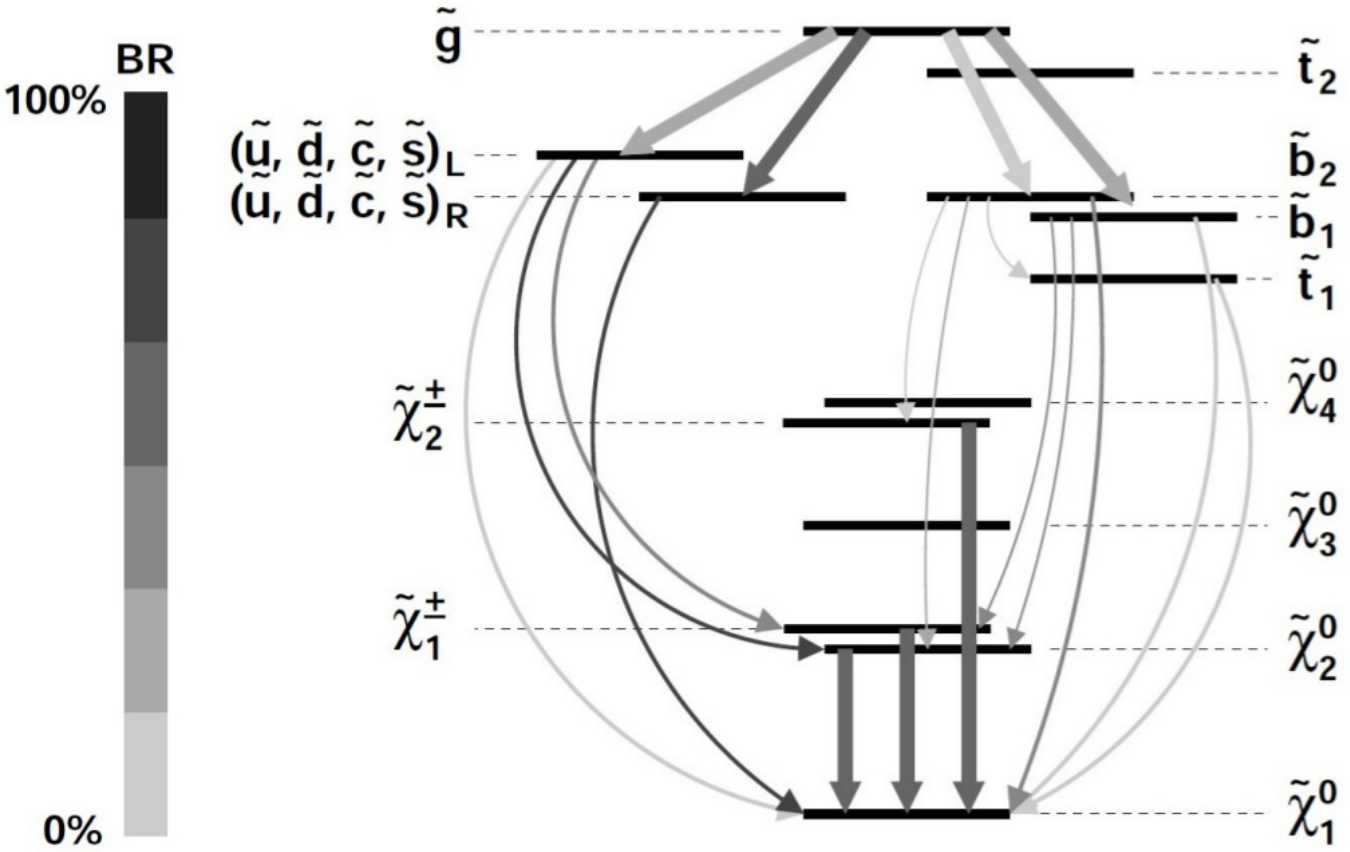
- Assuming thermal equilibrium of DM in early Universe, measuring abundance of DM today
  → DM pair annihilation cross-section
  → DM mass (~ 200 GeV; WIMP miracle)

SUSY particles with mass close to LSP can distort these arguments (Coannihilation-, Well-tempered-scenarios)
→ LSP's of a few TeV possible

SUSY flavours

SUSY spectrum:

- many sparticles with unknown masses
- many decay channels with unknown branching ratios



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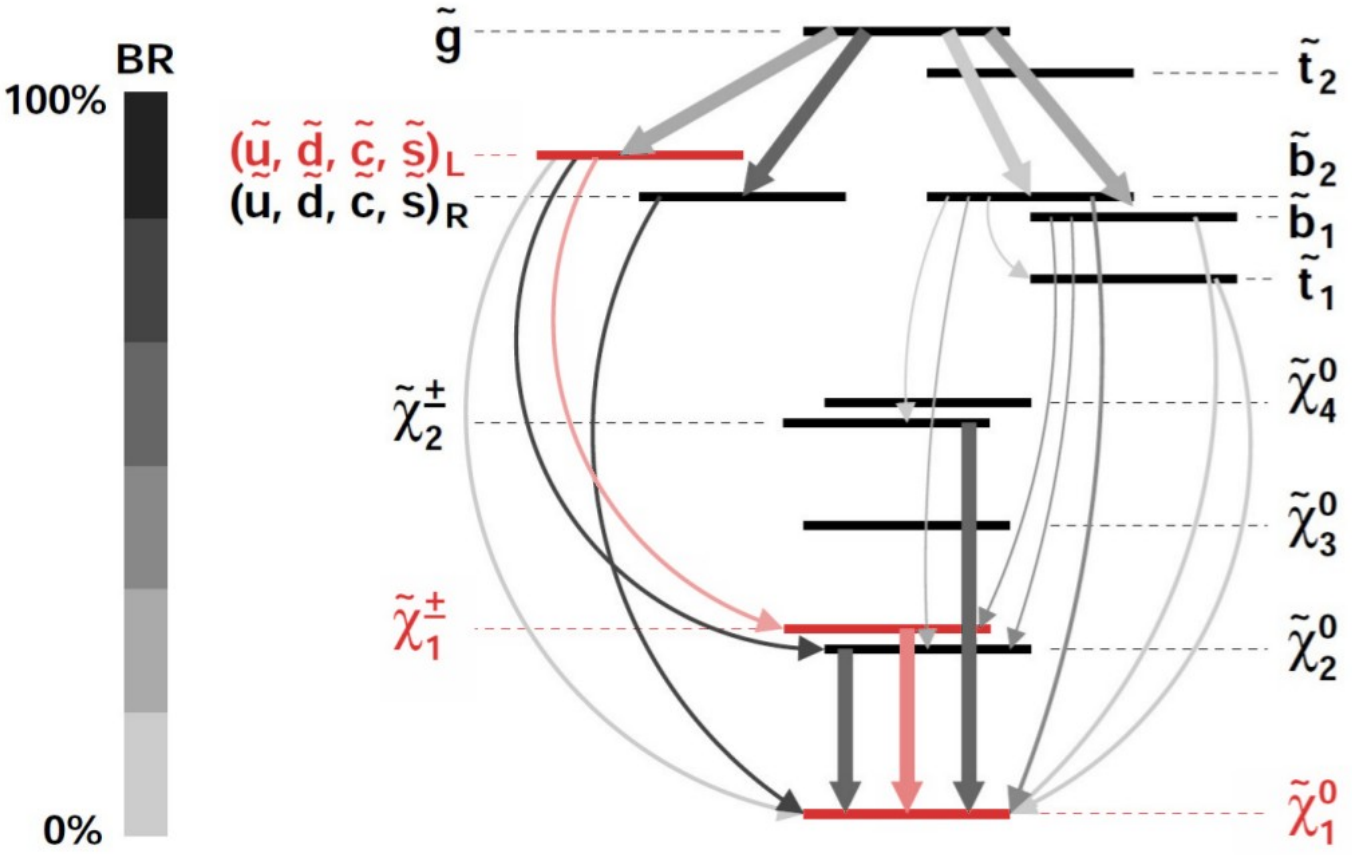
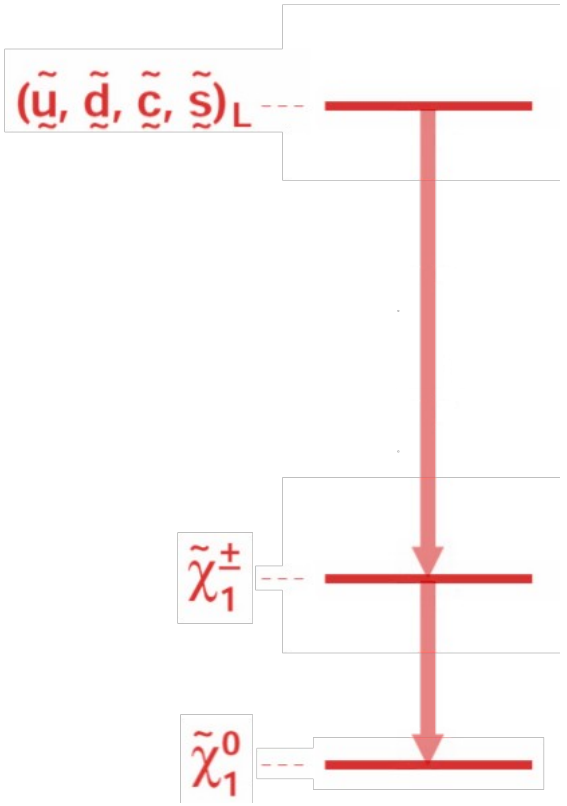
Simplified Model:

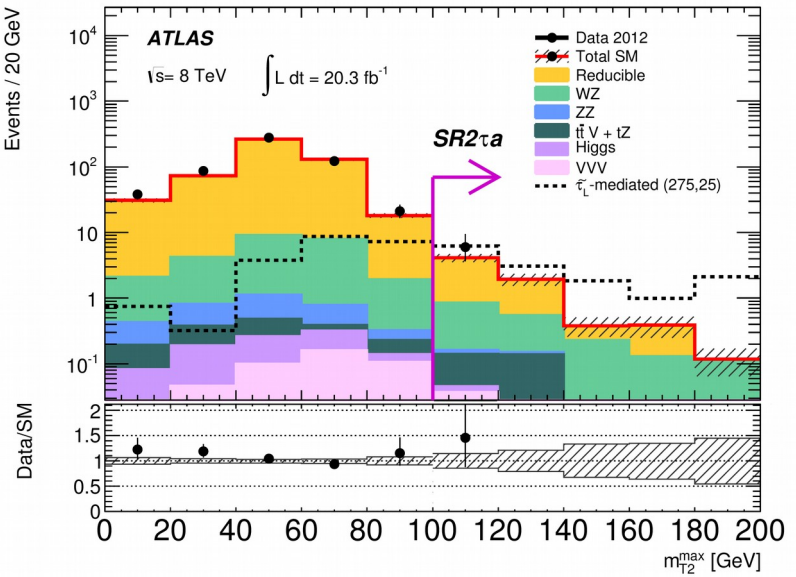
- Study specific chain
- Generalized to full model later

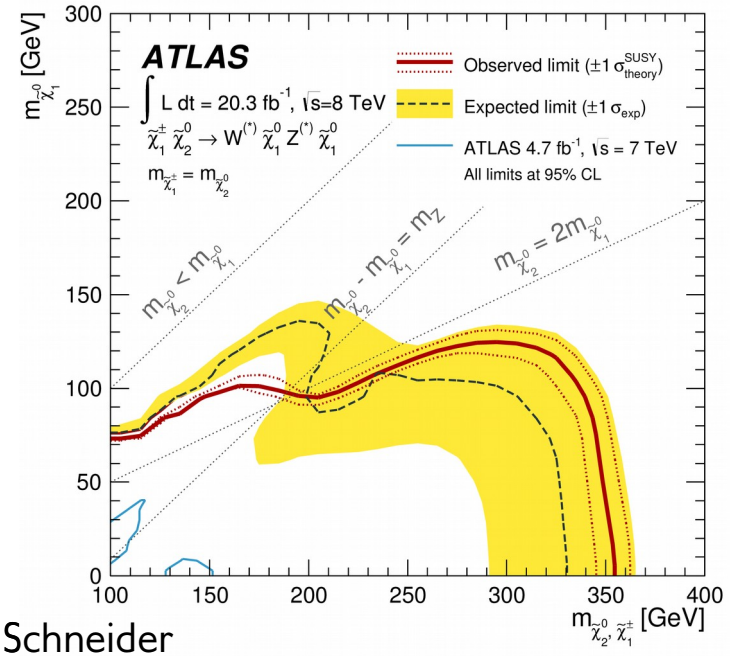




Analysis Strategy

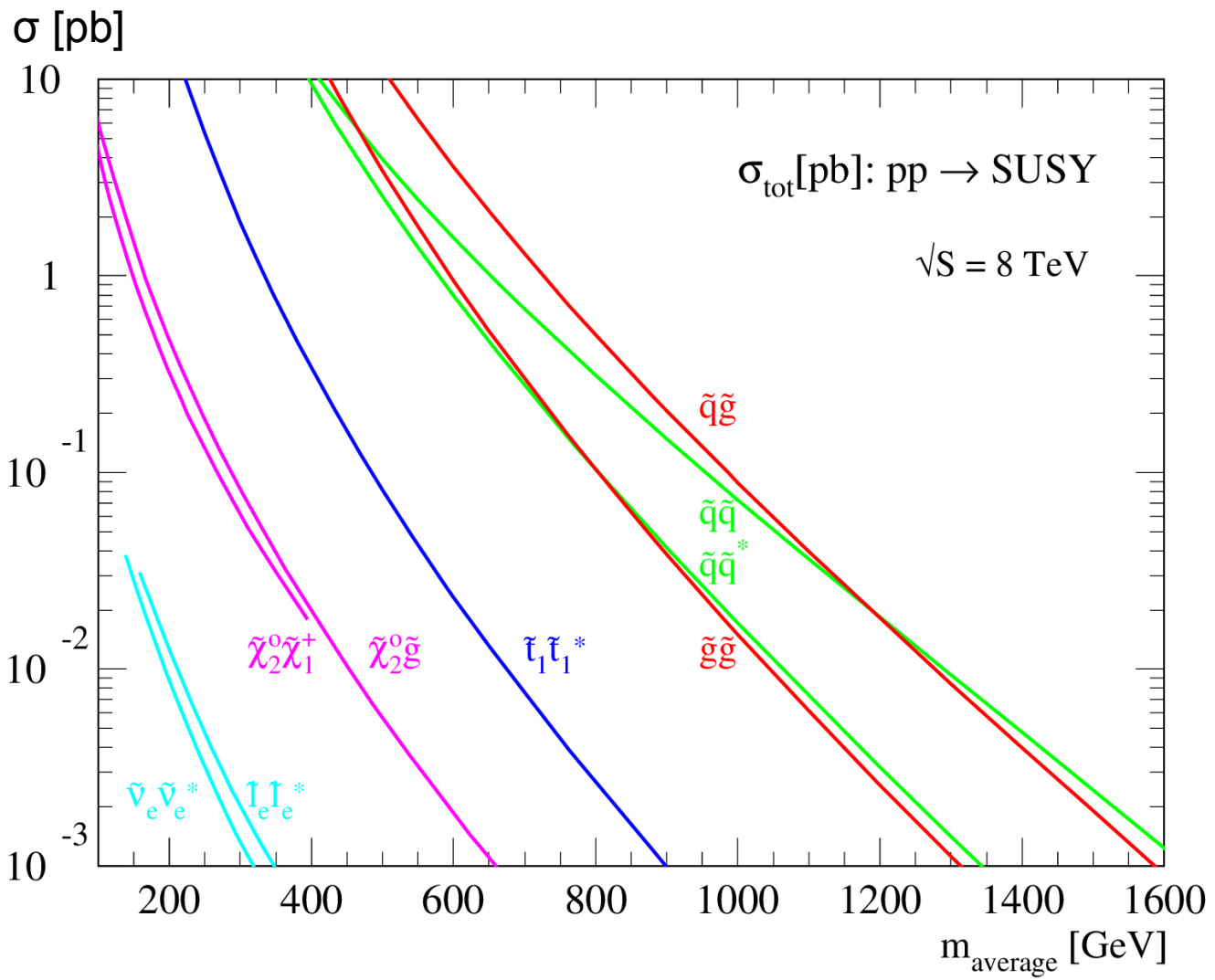
- 8 TeV dataset collected by ATLAS in 2012 corresponding to 20.3 fb^{-1}
- Monte Carlo simulation to generate SM (background) and SUSY (signal) events
- Detector simulation and reconstruction algorithms
- Define signal enhanced region (SR)
  → blinded till analysis is finalized
- SM background coming from real objects taken from Monte Carlo and fitted to data in control regions (CR)
- SM background coming from mis-identified objects measured in data (Matrix Method)
- Validation region (VR) to validate background modeling





- Analysis finalized:
  "open the box", i.e. look at data in SR
- SM null-hypothesis, calculate discovery p-value
- p-value > 5 sigma → declare victory!
- Otherwise, SUSY null-hypothesis and exclude SUSY models at 95 % confidence level
- Combined fit of possibly multiple SR's and all CR's
- Interpolate and draw 2d exclusion contour

Where to expect SUSY?



Inclusive strong production

- targeting 1st and 2nd generation squarks and gluinos
- by far largest cross-sections

3rd generation

- targeting stop and sbottoms
- should be lowest mass squarks for naturalness reasons

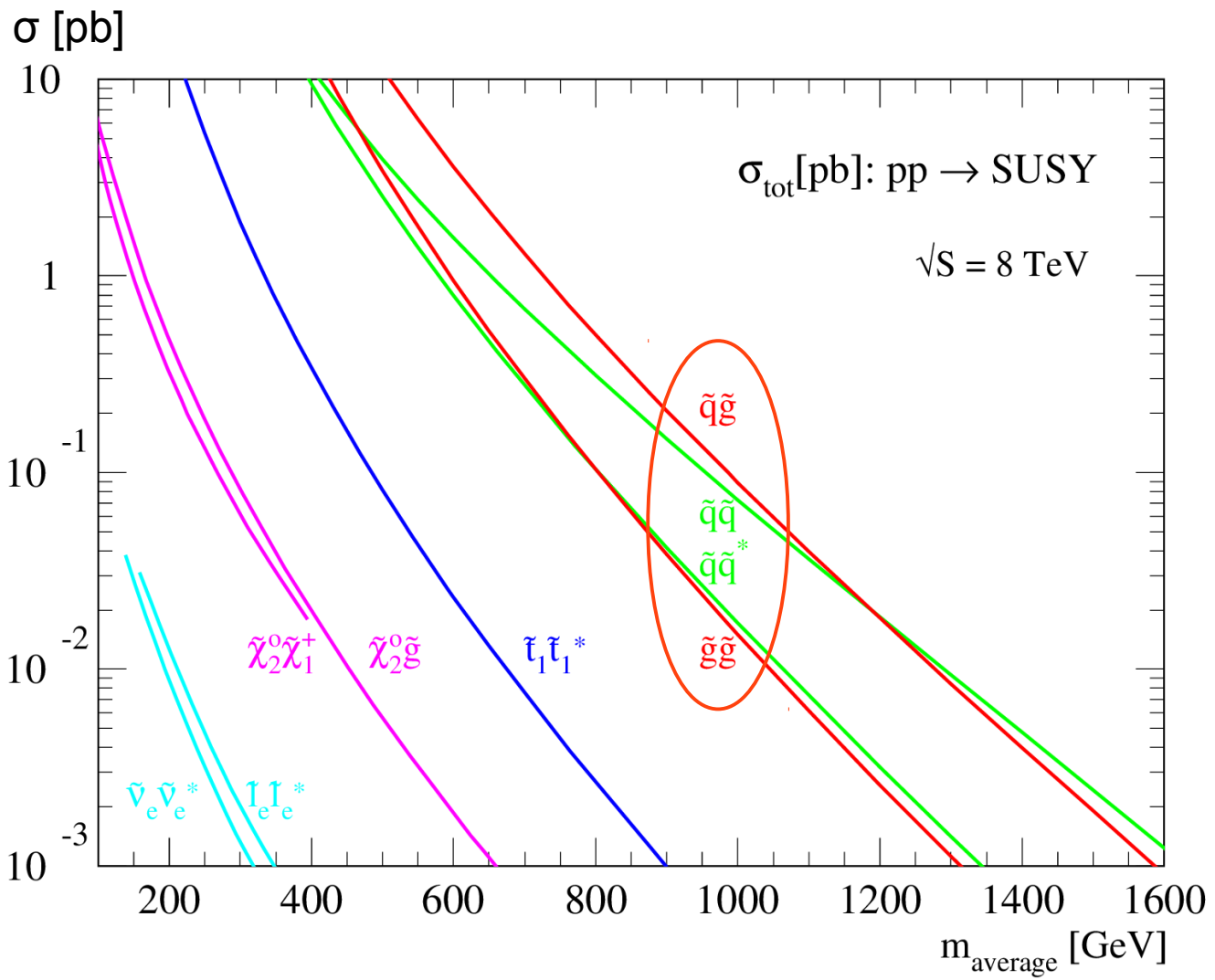
Electroweak

- targeting Electroweakinos, sleptons
- lowest mass particles, clean signature

RPV/LL

- targeting R-Parity violating models and long lived sparticles
- more exotic models

Inclusive strong production



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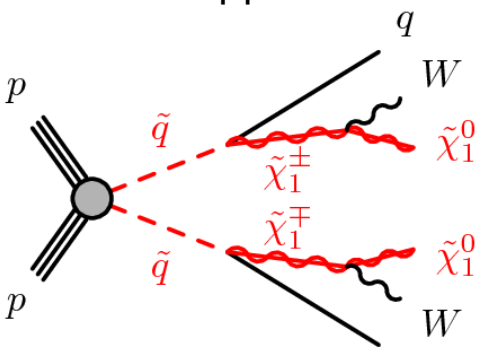
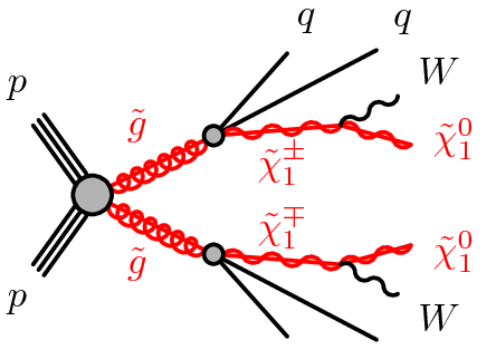
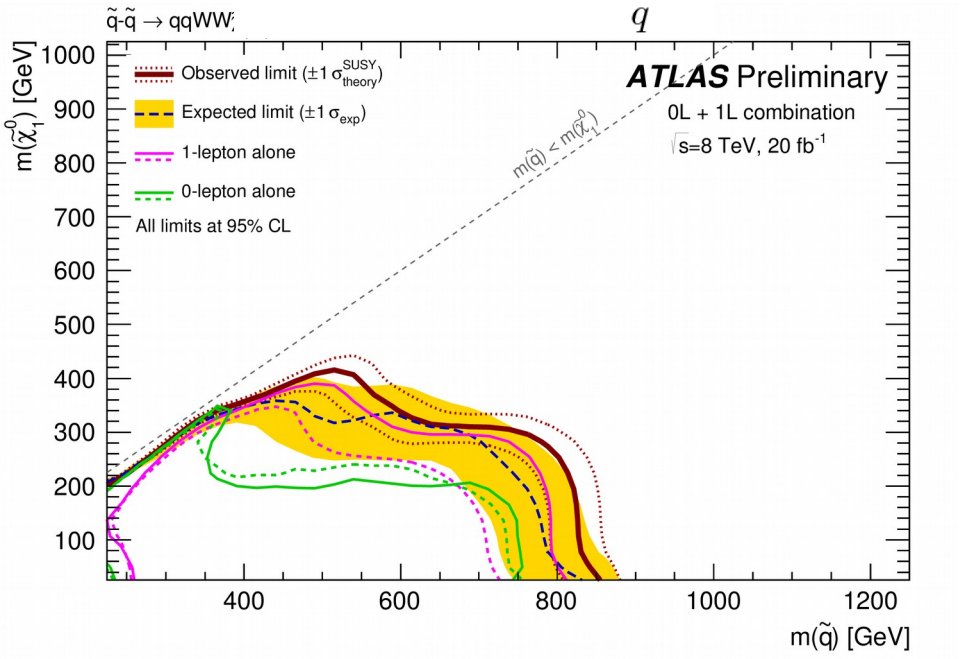
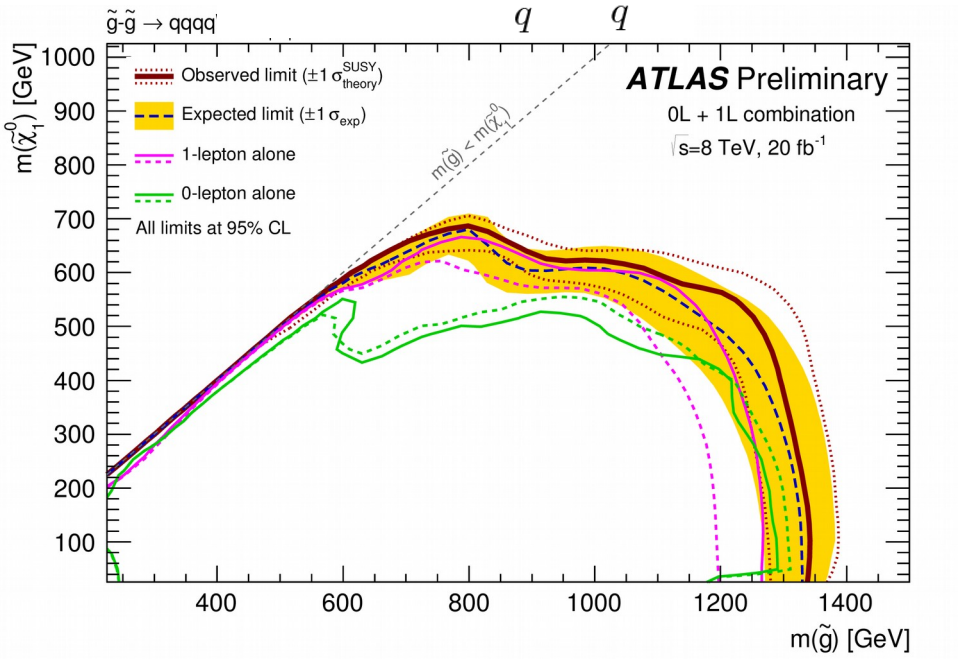
Inclusive search for squarks/gluinos

- Combination of two searches
- Final states with jets, missing transverse momentum and no or one isolated lepton (e/μ)
- $m\left(\tilde{\chi}_1^{\pm}\right) = \frac{1}{2}\left[m\left(\tilde{q}\right) + m\left(\tilde{\chi}_1^0\right)\right]$
- Improvement of approx. 50 GeV; approaching the diagonal





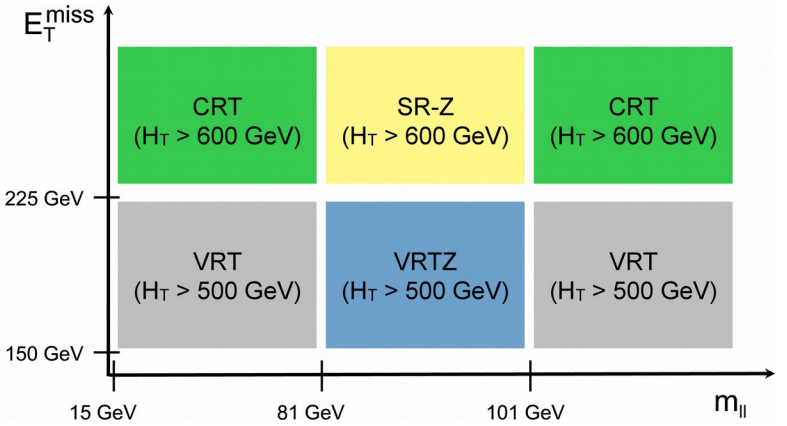


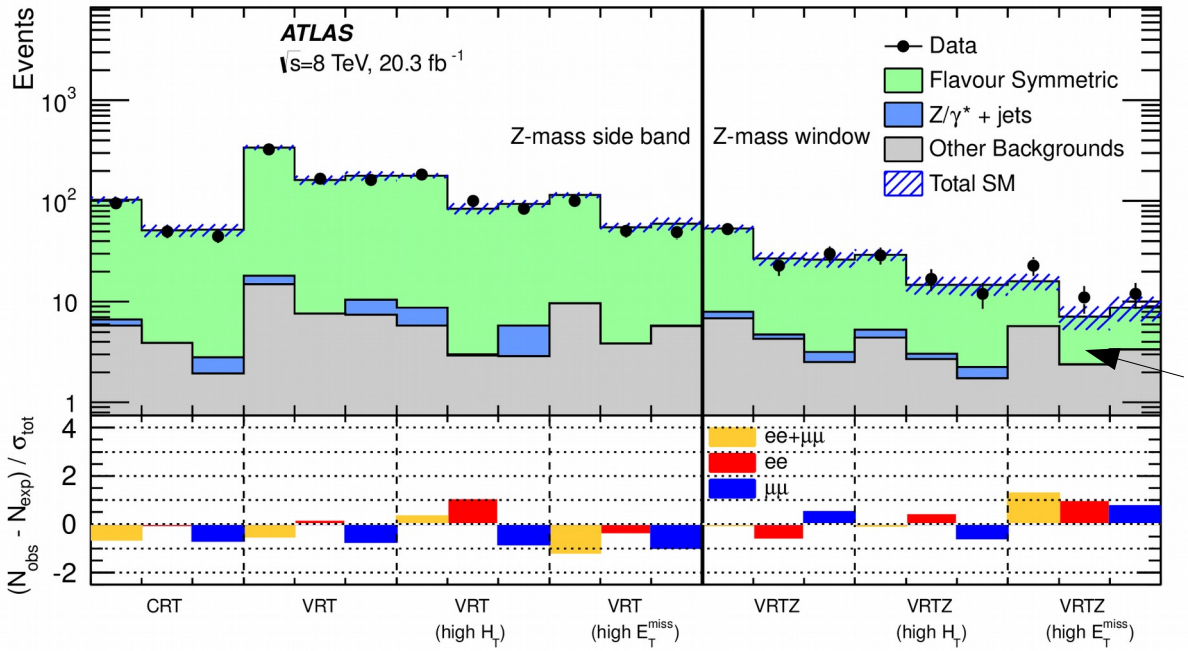


ATLAS-CONF-2015-011

Dileptonic search with Z final state

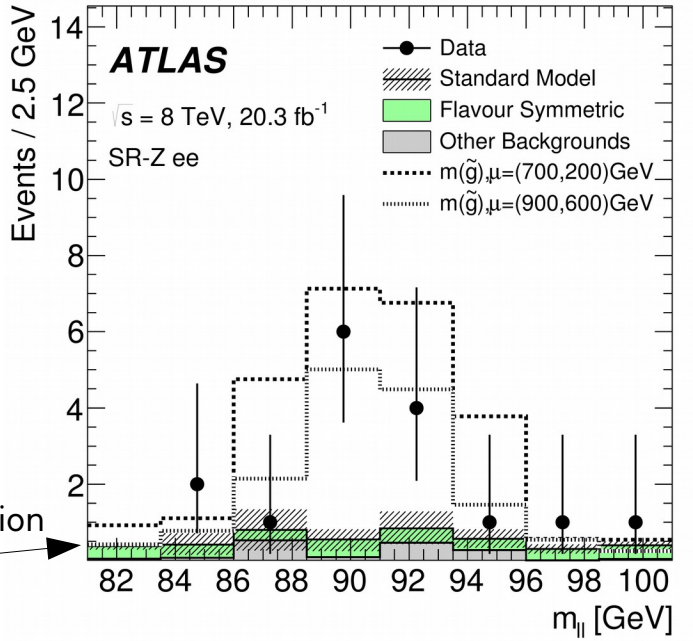
- Search for squarks/gluinos with Z in final state
- Define SR around Z peak
- Scalar sum of jet and lepton p_T's > 600 GeV
- $E_T$miss > 225 GeV
- Measured most important backgrounds in data
- Look at electron and muon channels separately
- → Observe 3 (1.7) sigma overfluctuation in electron (muon) channel
- → Light sbottom? (arXiv:1504.04390 [hep-ph]) → Follow up in run II





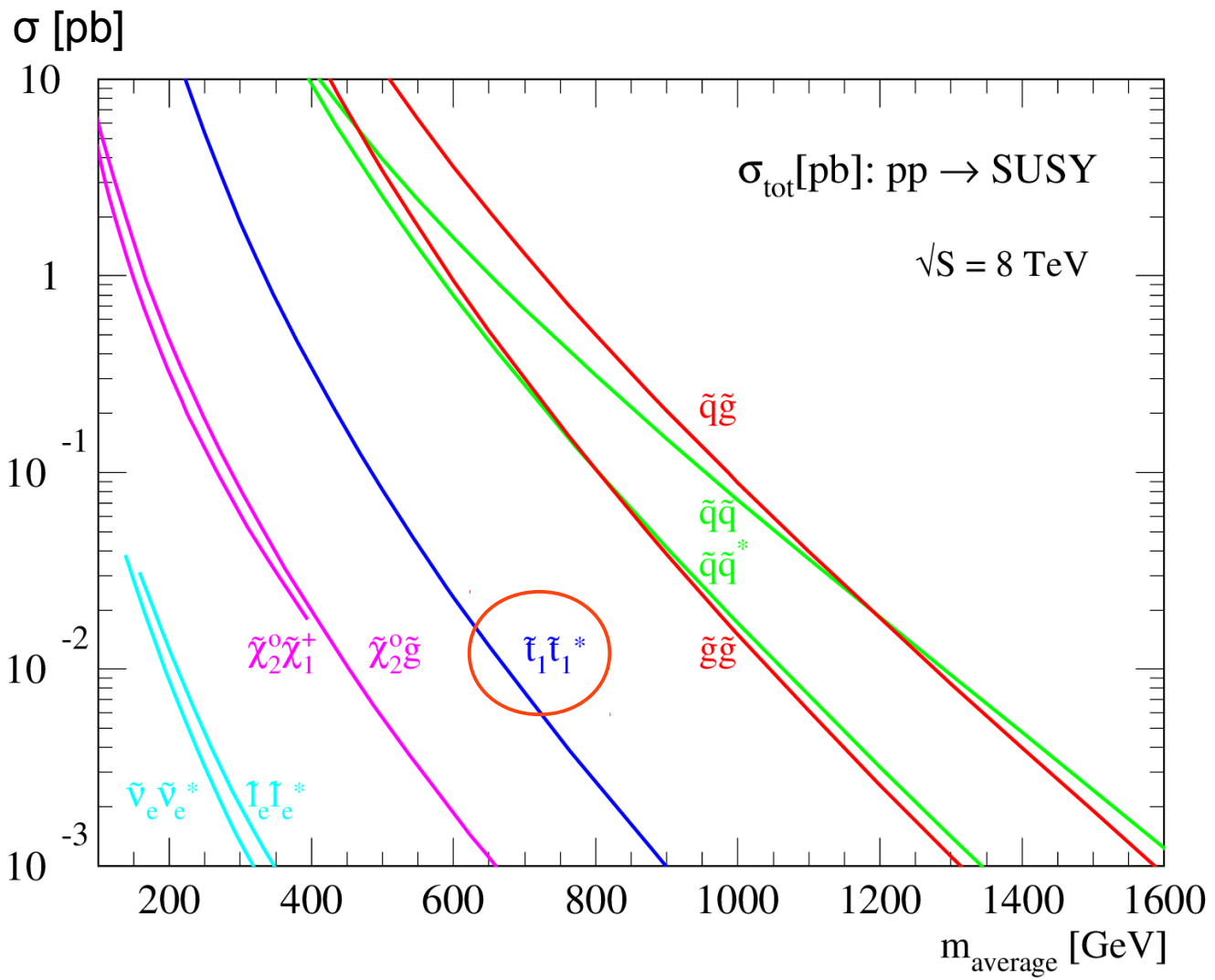
Good agreement in VR

Overfluctuation in SR



503.03290 [hep-ex] (submitted to EPJC)

3rd generation squarks



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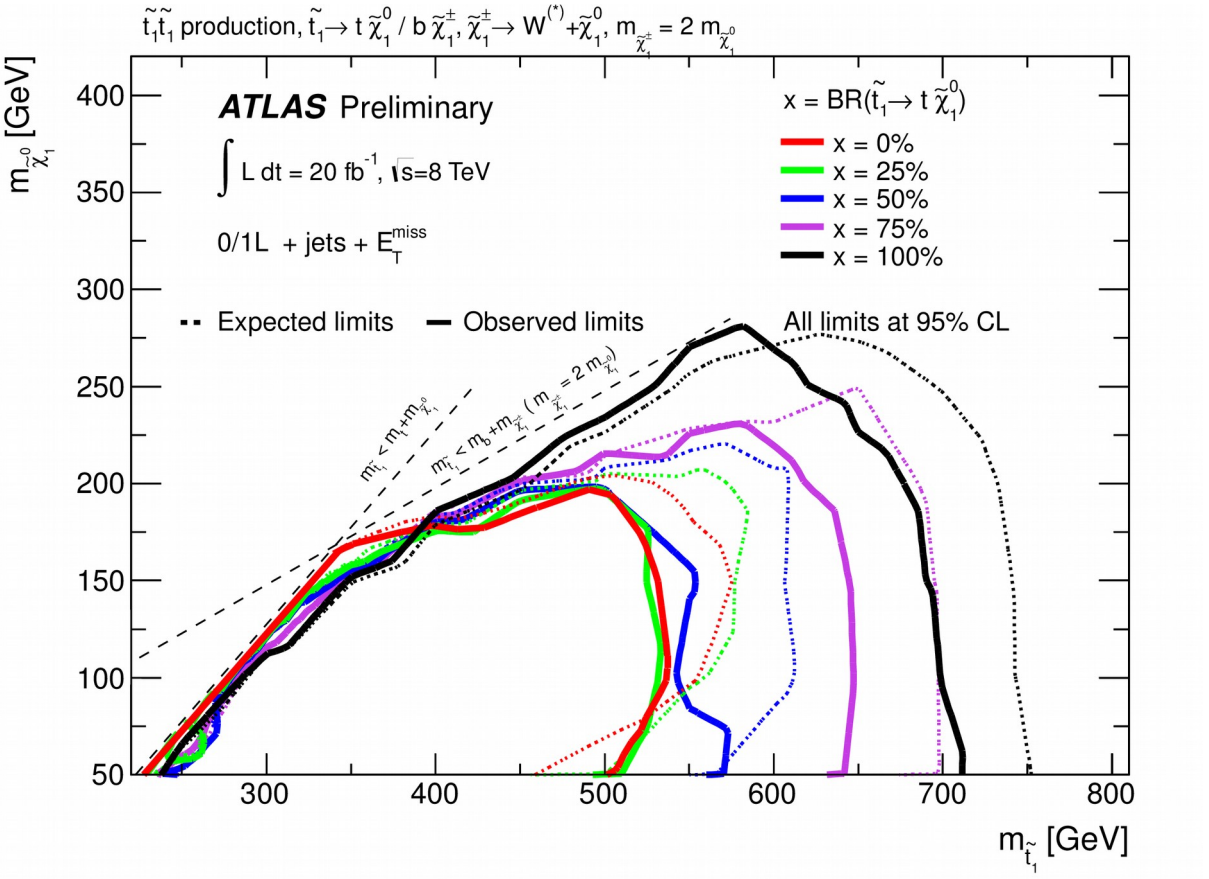
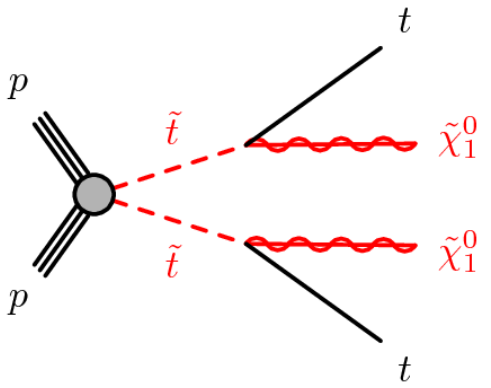
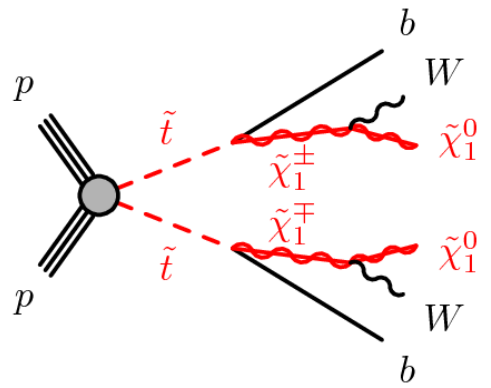
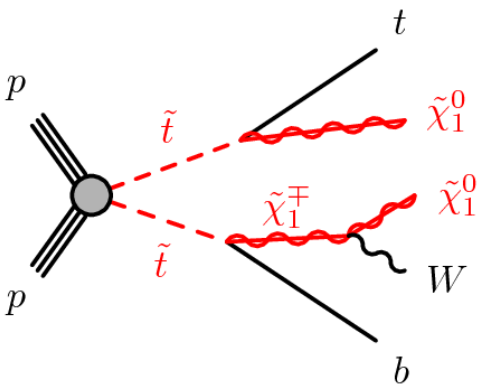
Stop search combination

- Search for a light scalar top → Motivated by naturalness
- Statistic combination of all-hadronic and one lepton search channels
- $m\left(\tilde{\chi}_1^{\pm}\right) = 2m\left(\tilde{\chi}_1^0\right)$
- Exclusion limits set for different branching ratios





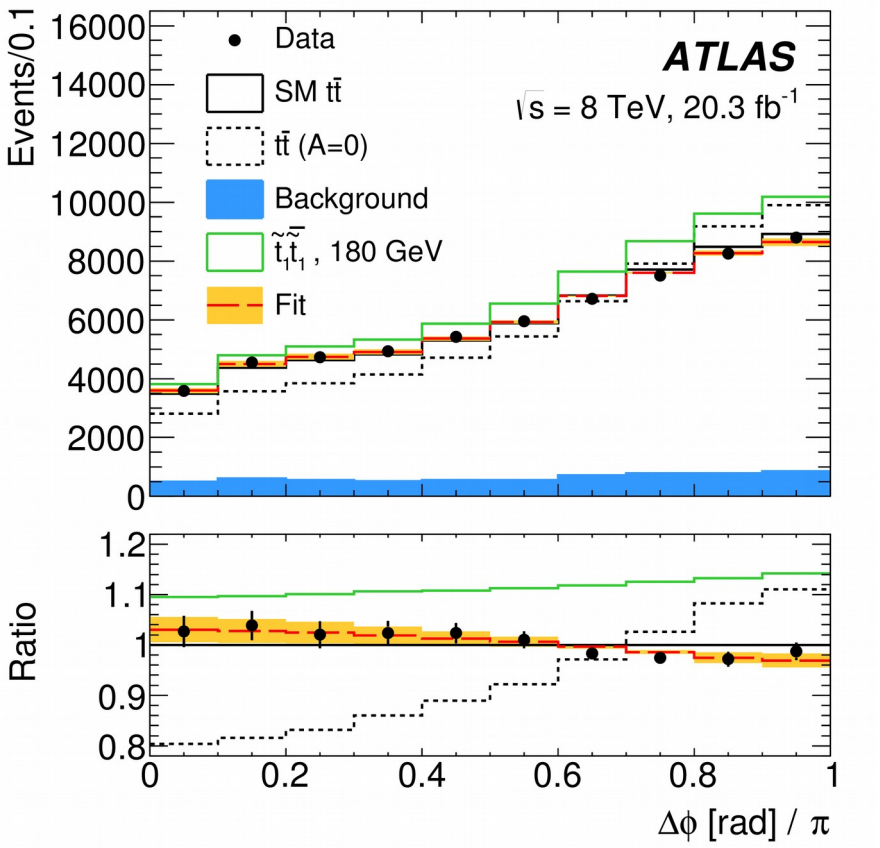


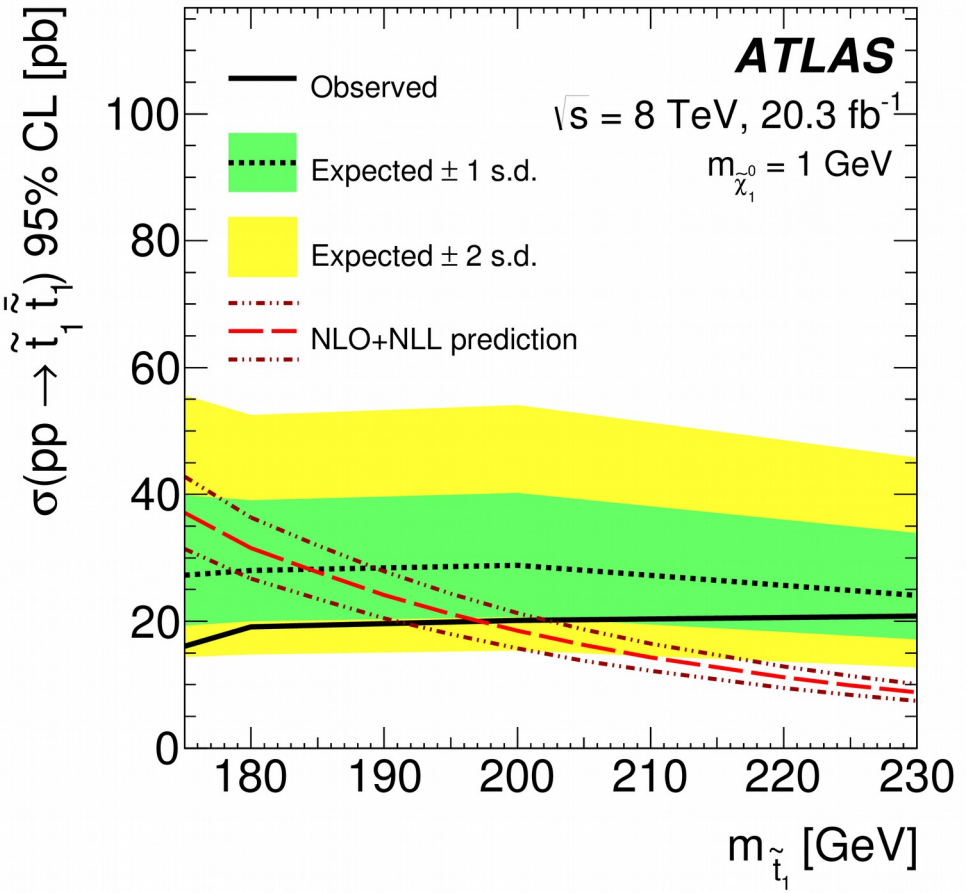


Stealth stop

- Stop with mass close to top could be hidden
- Stop antistop decay could mimic top antitop decay
- Measure top spin correlation
- Measure azimuthal angle ΔΦ and subsequently helicity
- $m_{stop} < 191$ GeV at 95 % CL

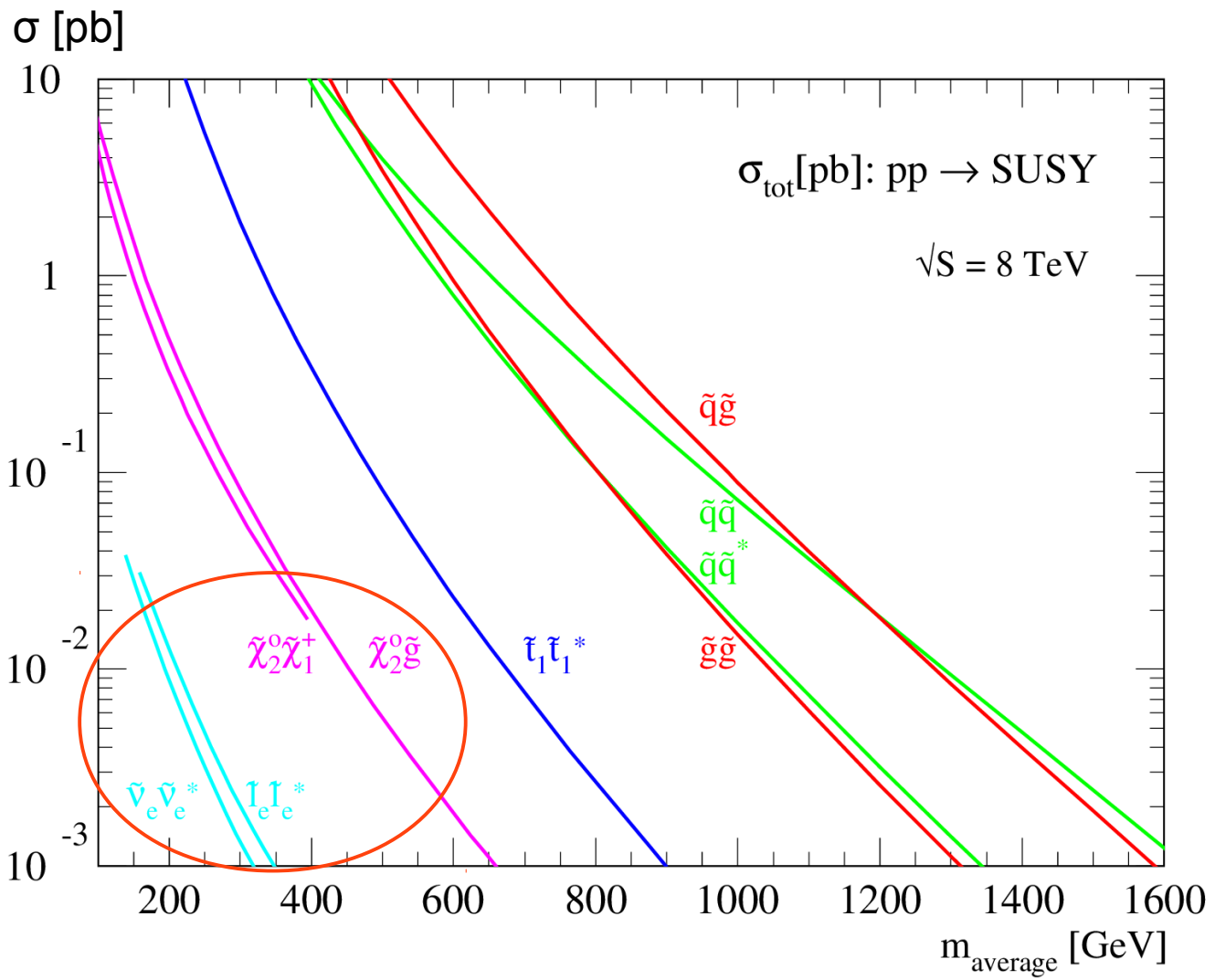
$$\tilde{t}\bar{\tilde{t}} \rightarrow t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$$





Phys. Rev. Lett. 114, 142001 (2015)

Electroweak production



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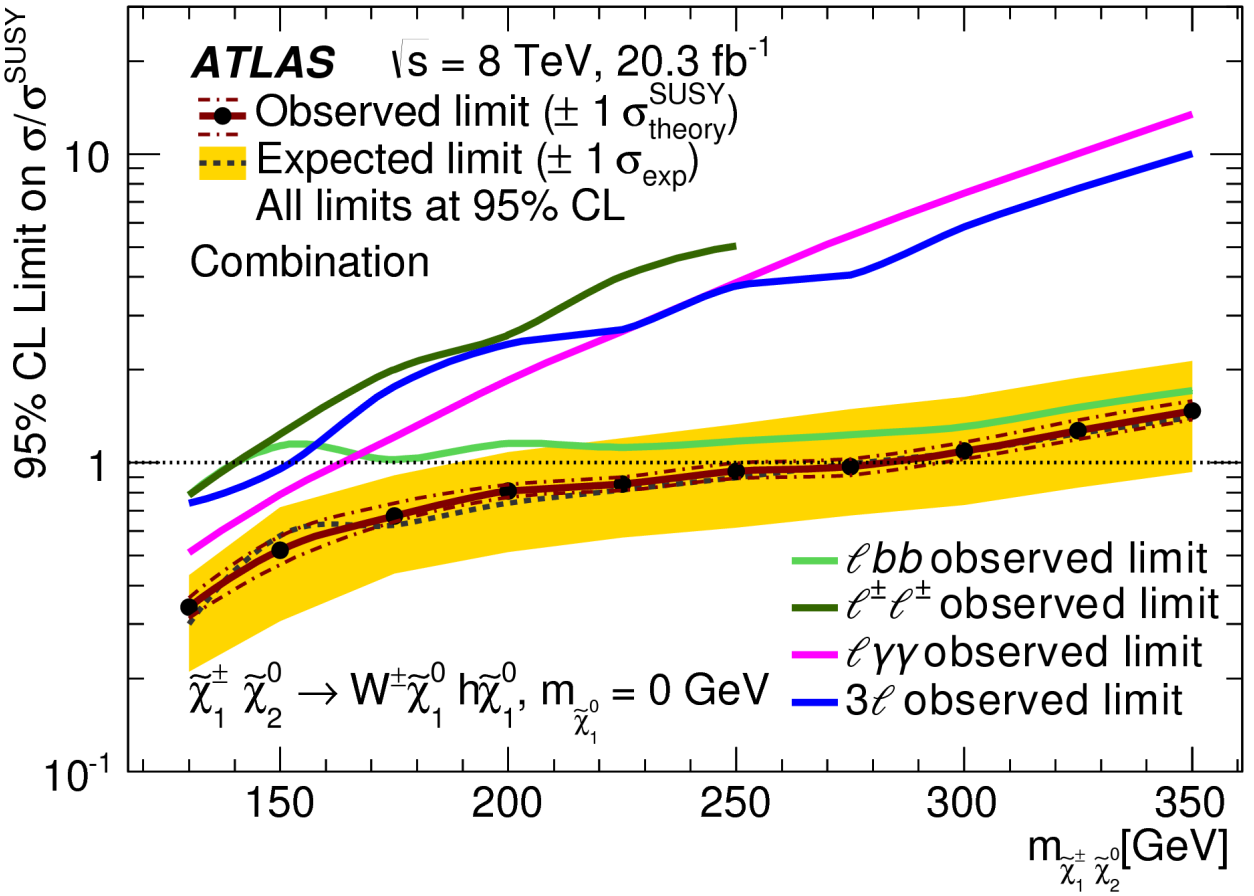
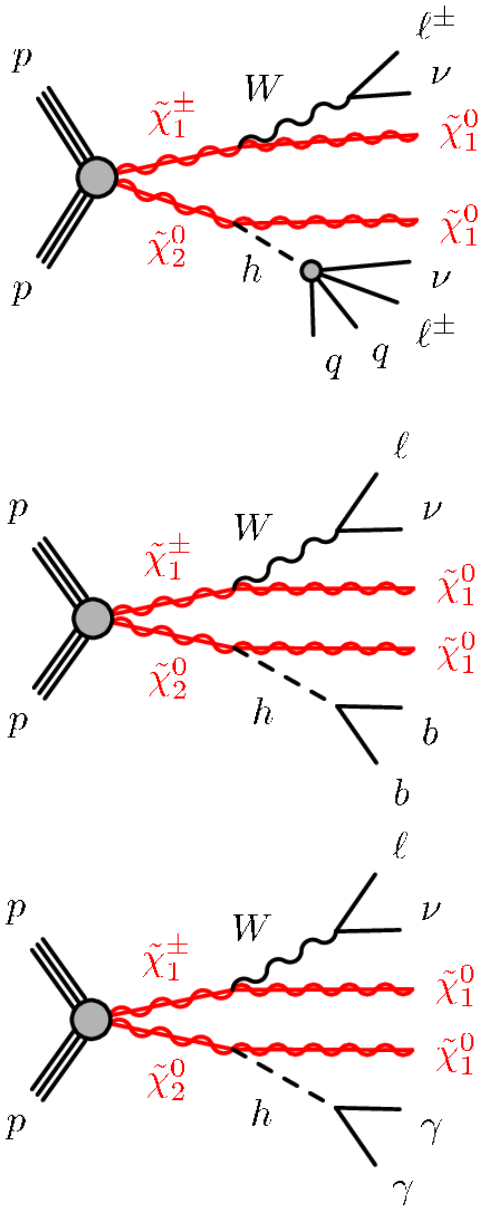
Sparticles decaying via Higgs

- Chargino 1 Neutralino 2 associated production
- Decay via Higgs and W bosons
- Higgs decays to b quarks, photons or W bosons
- Different final states combined



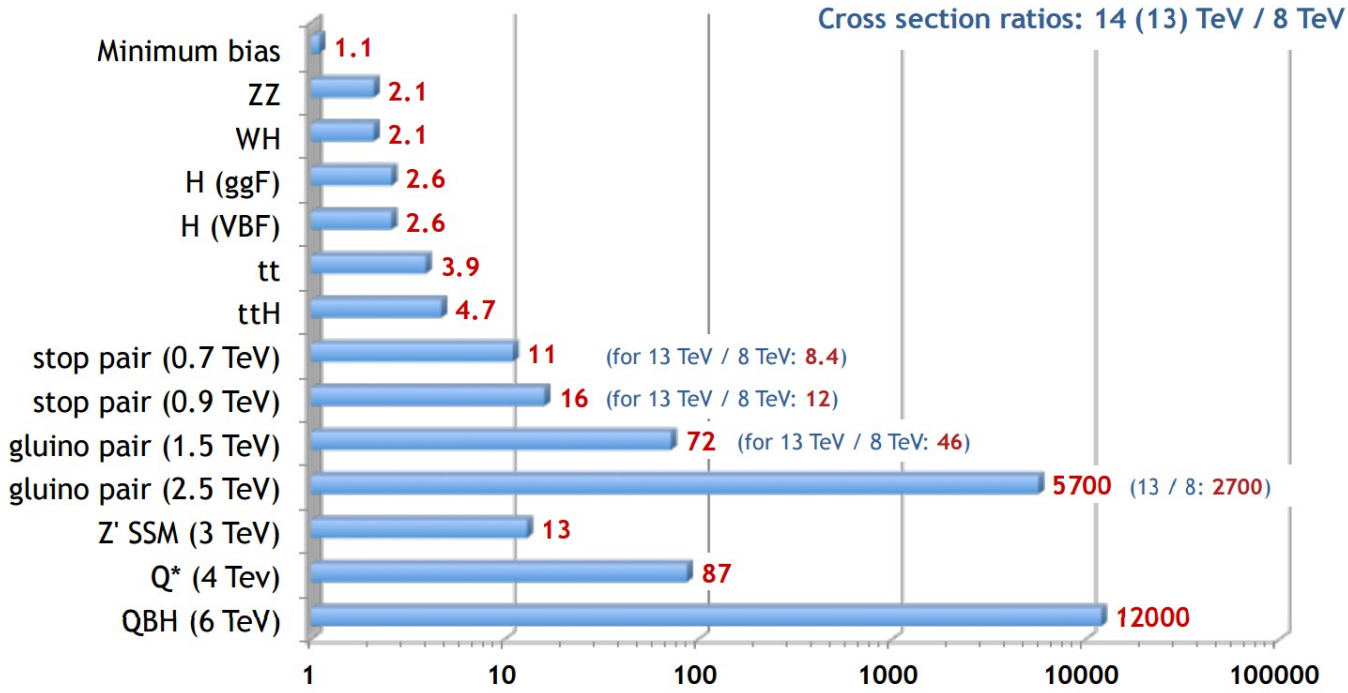


arXiv:1501.07110 [hep-ex] (accepted by EPJC)

What about the near future?

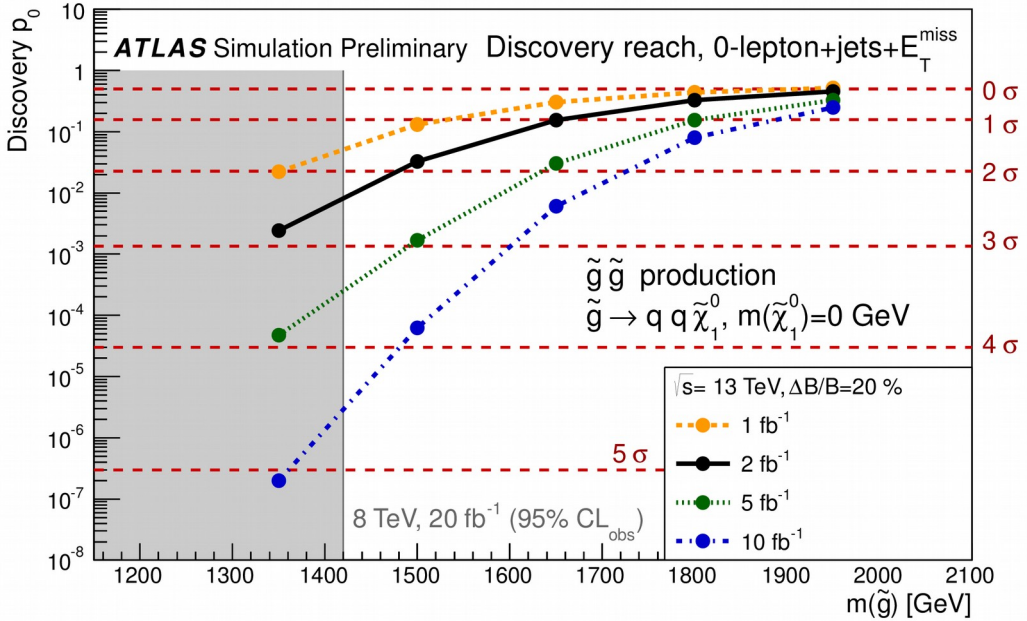
- Haven't found SUSY yet, but run II just ahead
- 13 TeV collisions planned to start in ~ 1 month!
- First collisions at 900 GeV taken place 2 weeks ago!
- Large increase in cross-section for many sparticles
- Some searches have sensitivity with a few fb^{-1}
- First SUSY publications this year?

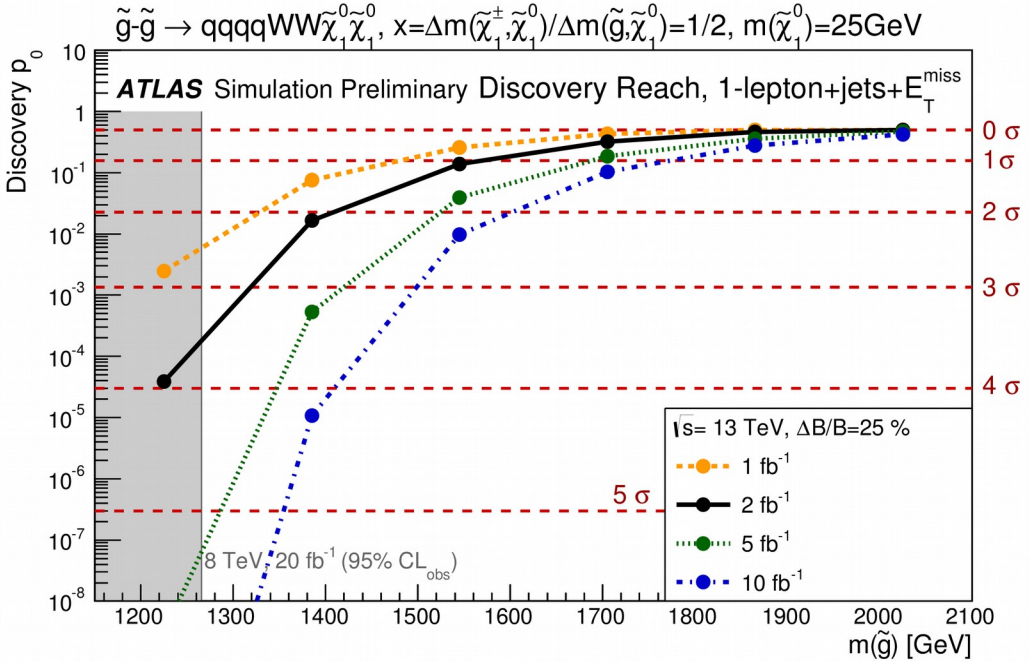
	Tevatron run II	LHC run I	LHC run II
Collsion energy	1.96 TeV	7/8 TeV	13 TeV
Luminosity/$10^{32}cm^{-2}s^{-1}$	4	70	160
Integrated Lumi/fb^{-1}	10	25	120
Pileup	8	21	45



Prospects

- Estimate discovery reach at 13 TeV for 1, 2, 5 and 10 fb^{-1}
- Searches for squark/gluino production in 0 and 1 lepton final states show increased sensitivity already with low amount of data
- Estimates use simple searches, sophisticated analyses will have increased sensitivity
- Depending on model, extended reach compared to run I already with a few fb^{-1} possible!





ATL-PHYS-PUB-2015-005

Conclusions

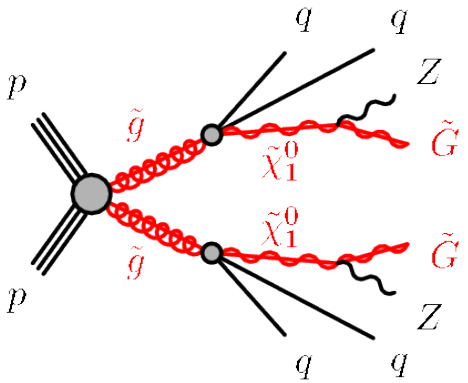
- ATLAS collected ~20 fb^{-1} of data at 8 TeV for 2012
- Many different SUSY searches carried out
- Analysis teams looked at data in many different ways
- Almost all run I data analyses published
- Presented many different analyses, searching for squarks/gluinos, 3rd generations sparticles or electroweakly produced gauginos

- No hints of SUSY found
- Exclusion limits for several models set
- Parameter space for natural SUSY getting smaller
- Still room for natural SUSY with DM candidate

- Run 2 just around the corner
- Big increase of cross-section for certain SUSY particles
- Hint of SUSY might already show up with few fb^{-1}!
  → Stay tuned!

Backup

Dileptonic search with Z final state



Channel	SR-Z ee	SR-Z μμ	combined
Observed events	16	13	29
Expected background events	4.2 ± 1.6	6.4 ± 2.2	10.6 ± 3.2
Flavour-symmetric backgrounds	2.8 ± 1.4	3.3 ± 1.6	6.0 ± 2.6
Z/γ* + jets	0.05 ± 0.04	0.02 + 0.03 – 0.02	0.07 ± 0.05
Rare top	0.18 ± 0.06	0.17 ± 0.06	0.35 ± 0.12
WZ/ZZ diboson	1.2 ± 0.5	1.7 ± 0.6	2.9 ± 1.0
Fake leptons	0.1 + 0.7 – 0.1	1.2 + 1.3 – 1.2	1.3 + 1.7 – 1.3