MODERN STATUS OF SUPERSYMMETRY SEARCHES AT LHC

A Gladyshev (JINR, Dubna)

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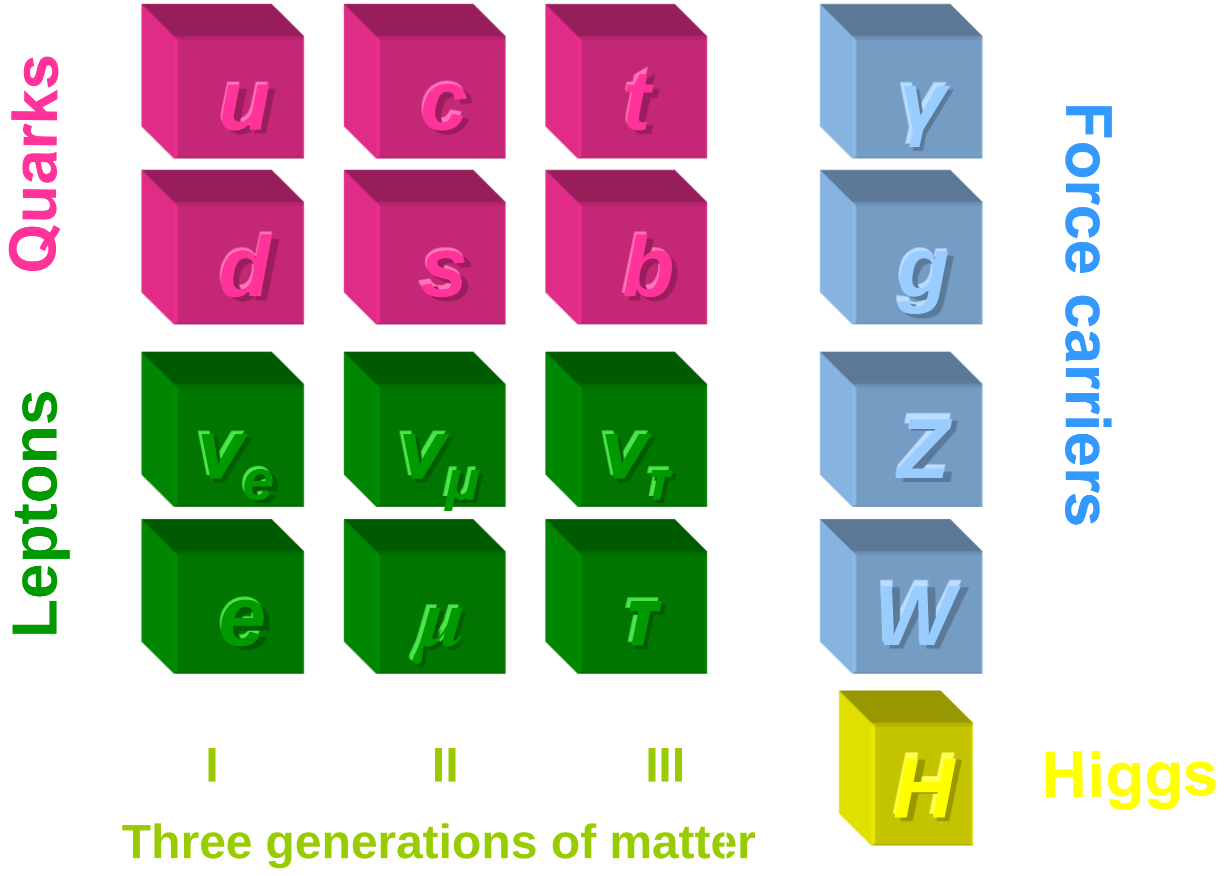
Fundamental Particles



The Standard Model: drawbacks

- Large number of free parameters:
  - gauge coupling constants g_s , g , g'
  - 3×3 matrices of Yukawa coupling constants
  - coupling constant of the Higgs self-interaction
  - the Higgs mass parameter
  - mixing angles and phases

How one can reduce the number of parameters ?

- The choice of the gauge group:

  why there are three independent symmetry groups ?

$$SU(3)_C \times SU(2)_{EW} \times U(1)_Y$$

The Standard Model: drawbacks

- The unification of the strong and electroweak interactions is formal
- Why the «strong» interactions are strong and «weak» ones are weak ?
- Why there are 3 generations of the matter fields ?
- The origin of particle masses: why are particles massive ?
- Why the top-quark is heavy and leptons are light ?
- Is the Higgs boson a fundamental particle ?
- Why the proton charge is equal to the electron charge ?
- How can we include gravity into the theory ?

- The Standard Model has no answers

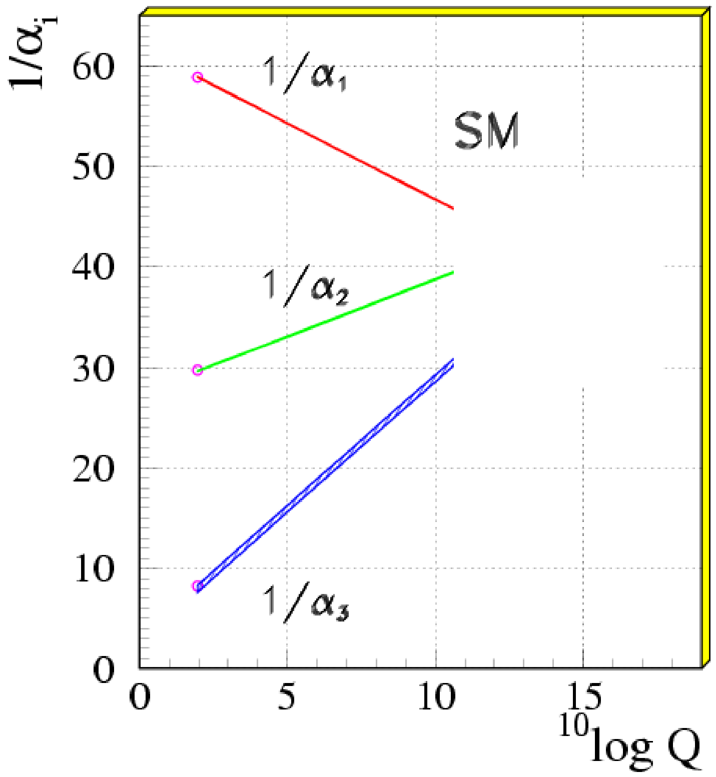
The Standard Model: what to do?

- CONCLUSION: The Standard Model is an effective theory valid within a certain approximation
- WHAT TO DO: consider *more symmetric* theories

- Examples:
  - Grand Unification Theories: The strong, weak and electromagnetic interactions are described by one symmetry group
  - Supersymmetry: Bosons and fermions are described in a common way.

Grand Unification

- The idea of unification is based on the observation that three gauge couplings tends to the same point at high energy



- Evolution equations (SM)

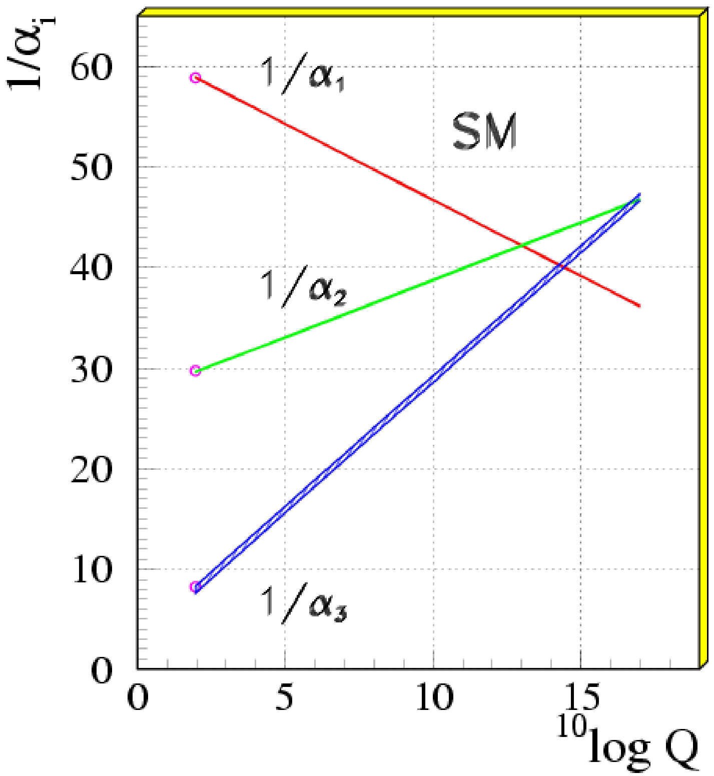
$$\frac{d\tilde{\alpha}_i}{dt} = b_i \tilde{\alpha}_i^2, \quad \tilde{\alpha}_i = \frac{\alpha_i}{4\pi} = \frac{g_i^2}{16\pi^2}, \quad t = \log\frac{Q^2}{\mu^2}$$

$$\frac{1}{\tilde{\alpha}_i} = \frac{1}{\tilde{\alpha}_{0i}} - b_i t$$

$$b_i = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} = \begin{pmatrix} 41/10 \\ -19/6 \\ -7 \end{pmatrix}$$

Grand Unification

- However, there is no Grand Unification at high energies if we use the Standard Model evolution equations for the gauge couplings



- Evolution equations (MSSM)

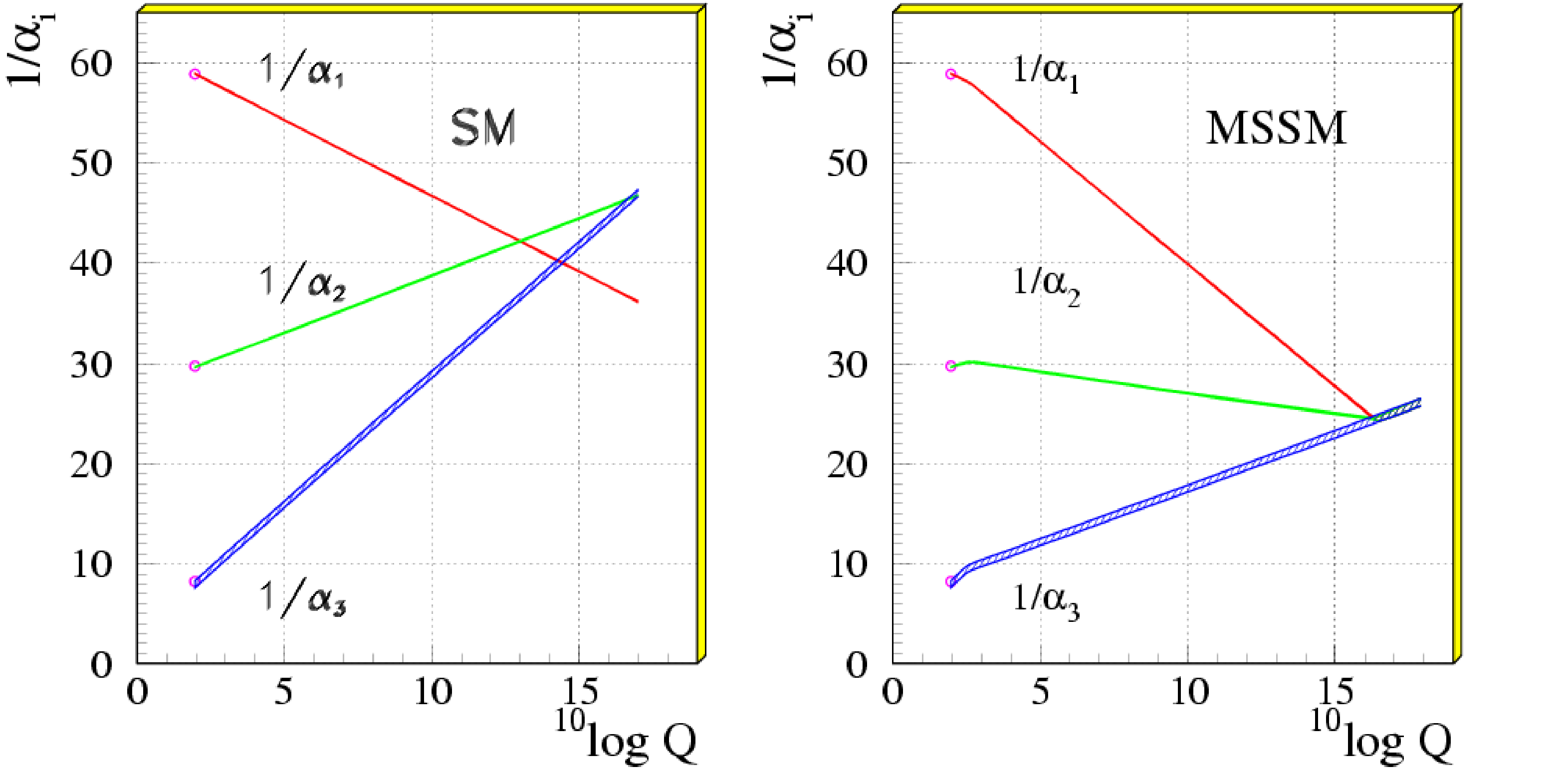
$$\frac{d\tilde{\alpha}_i}{dt} = b_i \tilde{\alpha}_i^2, \quad \tilde{\alpha}_i = \frac{\alpha_i}{4\pi} = \frac{g_i^2}{16\pi^2}, \quad t = \log\frac{Q^2}{\mu^2}$$

$$\frac{1}{\tilde{\alpha}_i} = \frac{1}{\tilde{\alpha}_{0i}} - b_i t$$

$$b_i = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} = \begin{pmatrix} 33/5 \\ 1 \\ -3 \end{pmatrix}$$

Grand Unification

- In the Minimal supersymmetric Standard Model the gauge coupling constants do unify !



Grand Unification

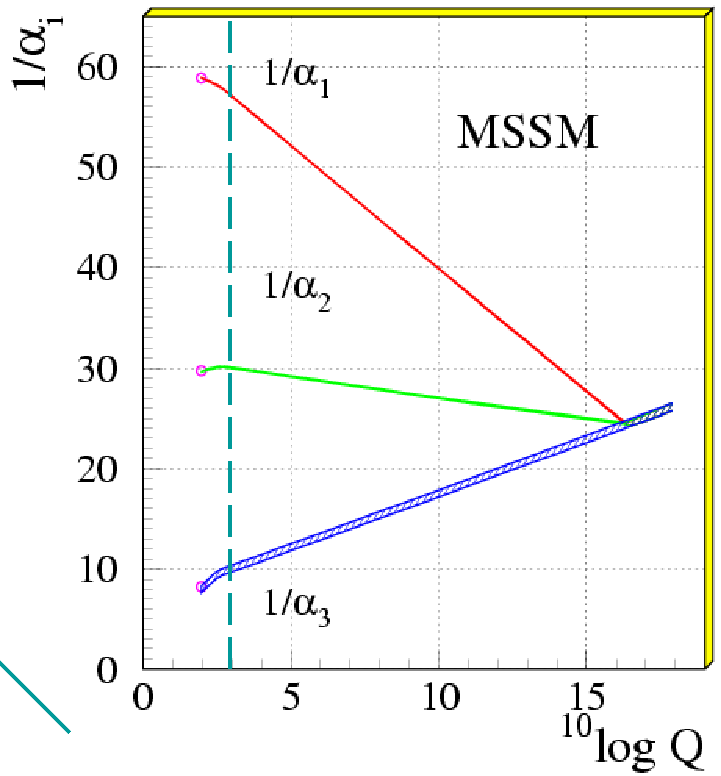
- CONCLUSION: we need supersymmetry for unification

- Initial conditions at low energy are known ('93)

$$\alpha^{-1}(M_Z) = 128.978 \pm 0.027$$
$$\sin^2\theta_{\overline{MS}} = 0.23146 \pm 0.00017$$
$$\alpha_s(M_Z) = 0.1184 \pm 0.0031$$

then we calculate

$$M_{SUSY} = 10^{3.4\pm0.9\pm0.4}\ \text{GeV}$$
$$M_{GUT} = 10^{15.8\pm0.3\pm0.1}\ \text{GeV}$$
$$\alpha^{-1}_{\text{GUT}} = 26.3 \pm 1.9 \pm 1.0$$



- The scale of supersymmetry breaking is $\sim 1\ TeV$

Hierarchy problem

- Hierarchy problem

  Why there are very different energy scales ?

  - Electroweak symmetry breaking scale ($M_W \sim 100\ GeV$)
  - Grand Unification scale ($M_{GUT} \sim 10^{15\text{-}16}\ GeV$)

    or Plank scale ($M_{Pl} \sim 10^{19}\ GeV$)

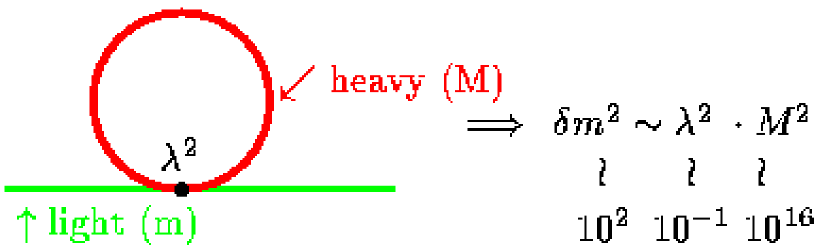
- Possible solution: to postulate the hierarchy.

  Very unnatural !

Hierarchy problem

- Another side of the problem: the hierarchy is destroyed by the radiative corrections

Consider the correction
to the light Higgs boson mass



$$m_H \sim v \sim 10^2\ GeV$$

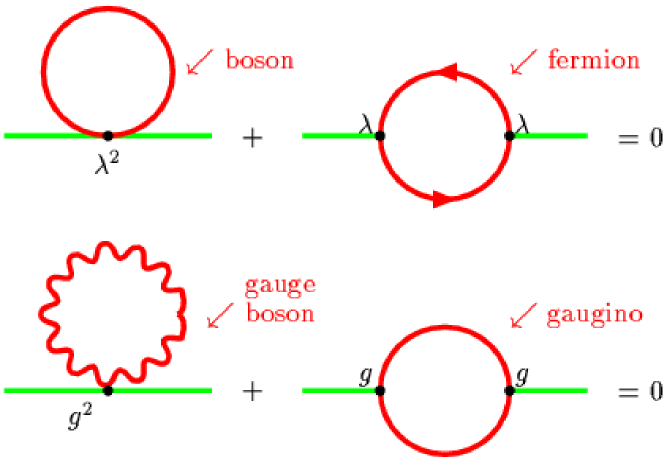
$$M_\Sigma \sim V \sim 10^{16}\ GeV$$

Even if the hierarchy was postulated it is destroyed by radiative corrections (unless they cancel up to 10^{-14})

Hierarchy problem

- Supersymmetry can help to solve the hierarchy problem

- Let us add a «superpartner» - a particle with the same mass but with a different spin. Then the divergency cancells.
- The «accuracy» of cancellation is controlled by the mass-squared difference.



$$m_{boson}^2 - m_{fermion}^2 = M_{SUSY}^2$$

- If the correction is not larger than the mass itself then we have

$$\delta m_h^2 \sim g^2 M_{SUSY}^2 \sim m_h^2 \sim 10^4 GeV \quad \Rightarrow \quad M_{SUSY} \sim 10^3 GeV$$

Supersymmetry: motivations

- Consistency of Grand Unification theory :
  unification of gauge coupling constants
- Solution to the hiearchy problem
- Supersymmetry populates «The Great Desert»: it predicts new particles and their spectrum
- Supersymmetry suggest a solution of the Dark Matter problem
- Radiative electroweak symmetry breaking.
  The Higgs boson mass is calculable.
- Supersymmetry can be tested experimentally

- SUSY is the most popular idea beyond the Standard Model

Supersymmetric SM

- How to construct a supersymmetric model:
  - Define the matter and gauge field content
  - Using the vector superfields construct thefield strength tensor(s)
  - Using the chiral and anti-chiral superfields construct the kinetic terms and the superpotential
  - Write down the full lagrangian in terms of superfields
  - Integrate over grassmanian coordinates
  - Eliminate auxiliary fields using equations of motion
- The result is the lagrangian describing the ordinary fields, the superpartners and their interactions

Minimal SUSY SM (MSSM)

- In supersymmetric theories the number of bosonic degrees of freedom is equal to the number of fermionic degrees of freedom

- In the Standard Model we have
  - 28 bosonic degrees of freedom :

$$(4 + 8) \times 2 \quad + \quad 2 \times 2$$

vector fields (γ,Z,W^+,W^-, gluons) — Higgs boson

  - 90 (96) fermionic degrees of freedom:

$$(6 \times 3 + 3) \times 4 \; + \; 3 \times 2 \; (4)$$

quarks and charged leptons — neutrinos

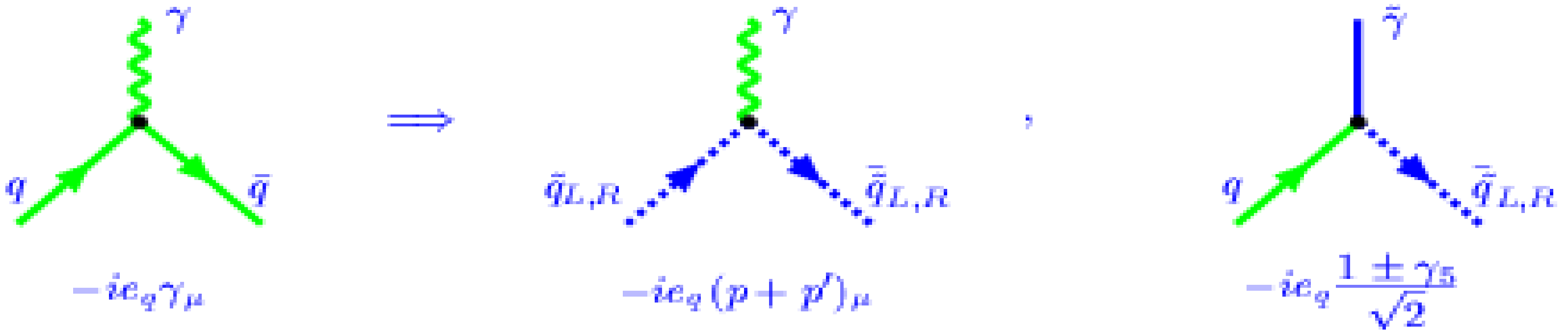
- The Standard Model is not supersymmetric

	Bosons	Fermions	SU(3)	SU(2)	U(1)
Matter fields					
L_i		leptons $L_i = \begin{pmatrix} \nu \\ e \end{pmatrix}_L$	1	2	-1
E_i		$E_i = e_R$	1	1	2
Q_i		quarks $Q_i = \begin{pmatrix} u \\ d \end{pmatrix}_L$	3	2	1/3
U_i		$U_i = u_R$	3*	1	-4/3
D_i		$D_i = d_R$	3*	1	2/3
Gauge fields					
G^a	gluons g^a		8	0	0
V^k	$W^{\pm}, Z$ - bosons		1	3	0
V'	photon γ		1	1	0
Higgs field					
H	Higgs boson $H = \begin{pmatrix} H^+ \\ H^0 \end{pmatrix}$		1	2	-1

	Bosons	Fermions	SU(3)	SU(2)	U(1)
Matter fields					
L_i	sleptons $\tilde{L}_i = \begin{pmatrix} \tilde{\nu} \\ \tilde{e} \end{pmatrix}_L$ $\tilde{E}_i = \tilde{e}_R$	leptons $L_i = \begin{pmatrix} \nu \\ e \end{pmatrix}_L$ $E_i = e_R$	1	2	-1
E_i			1	1	2
Q_i	squarks $\tilde{Q}_i = \begin{pmatrix} \tilde{u} \\ \tilde{d} \end{pmatrix}_L$ $\tilde{U}_i = \tilde{u}_R$ $\tilde{D}_i = \tilde{d}_R$	quarks $Q_i = \begin{pmatrix} u \\ d \end{pmatrix}_L$ $U_i = u_R$ $D_i = d_R$	3	2	1/3
U_i			3*	1	-4/3
D_i			3*	1	2/3
Gauge fields					
G^a	gluons g^a	gluino $\tilde{g}^a$	8	0	0
V^k	$W^{\pm}, Z$-bosons photon γ	wino $\tilde{W}^{\pm}$, zino $\tilde{Z}$, photino $\tilde{\gamma}$	1	3	0
V'			1	1	0
Higgs fields					
H_1	Higgs boson $H_1 = \begin{pmatrix} H_1^+ \\ H_1^0 \end{pmatrix}$	higgsino $\tilde{H}_1 = \begin{pmatrix} \tilde{H}_1^+ \\ \tilde{H}_1^0 \end{pmatrix}$	1	2	-1
H_2	Higgs boson $H_2 = \begin{pmatrix} H_2^0 \\ H_2^- \end{pmatrix}$	higgsino $\tilde{H}_2 = \begin{pmatrix} \tilde{H}_2^0 \\ \tilde{H}_2^- \end{pmatrix}$	1	2	1

Minimal SUSY SM (MSSM)

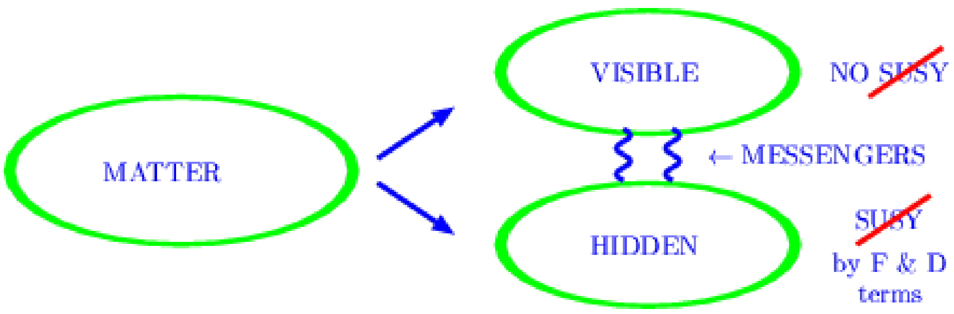
- Consequences of R-parity conservation:
  - Interactions of particles and superpartners are the same (just replace two of the particles in the interaction vertex by superpartners)



  - Superpartners are created in pairs
  - The lightest supersymmetric particle is stable !

Breaking of supersymmetry

- Since superpartners are not observed, in nature supersymmetry can be realised as broken symmetry
- In the MSSM the soft supersymmetry breaking mechanism is used.
- One assumes that breaking takes place in the hidden sector. Mediators of the supersymmetry sbreakin from the hidden sector to the visible one can be
  - Gravitons (SUGRA)
  - Gauge fields
  - Gaugino fields



(the difference is only in details)

Breaking of supersymmetry

- Soft breaking of supersymmetry can be parametrized by additional terms in the lagrangian
  - The mass terms for the scalar components of chiral superfiels $m_{ij}^2 A_i^* A_j$
  - The mass terms for the fermion components of vector superfiels $M\lambda\lambda$
  - Bilenear softsupersymetry breaking term $B_{ij}\mu_{ij}A_i A_j$
  - Trilinear soft supersymetry breaking terms $A_{ijk}\lambda_{ijk}A_i A_j A_k$

- Supersymmetry is broken since components of the same superfield have different masses

Breaking of supersymmetry

- The part of the MSSM lagrangian responsible for supersymmetry breaking reads

$$-L_{SoftBreaking} = \sum_{scalars} m_i^2 |A_i|^2 + \sum_{gauge} M_i(\lambda_i\lambda_i + \bar{\lambda}_i\bar{\lambda}_i)$$
$$+A_U y_U Q_L H_2 U_R + A_U y_D Q_L H_1 D_R + A_U y_L L_L H_1 E_R + B\mu H_1 H_2$$

- Too many free parameters (more than a hundred !)

- Now one can calculate the mass spectrum of superparticles

- Later we will see how to reduce the number of parameters

Constrained MSSM

- Parameters of the Minimal Supersymmetric Standard Model
  - Gauge cuopling constants α_i, i=1,2,3
  - Yukawa coupling constants $y^k_{ab},\ k = U, D, L, (E)$
  - Higgs mixing parameter μ
  - Soft supersymmetry breaking parameters

- The Higgs self-interaction coupling is not arbitrary, it is fixed by supersymmetry.

$$\lambda = \frac{g^2 + g'^2}{8}$$

- The main uncertainty is due to the soft supersymmetry breaking parameters

Constrained MSSM

- Universality hypothesis: soft supersymmetry breaking parameters unify at the scale of Grand Unification

$$-L_{SoftBreaking} = m_0^2 \sum_{scalars} |A_i|^2 + m_{1/2} \sum_{gauge} (\lambda_i \lambda_i + \bar{\lambda}_i \bar{\lambda}_i)$$

$$+A\left(y_t Q_L H_2 U_R + y_b Q_L H_1 D_R + y_L L_L H_1 E_R\right) + B\mu H_1 H_2$$

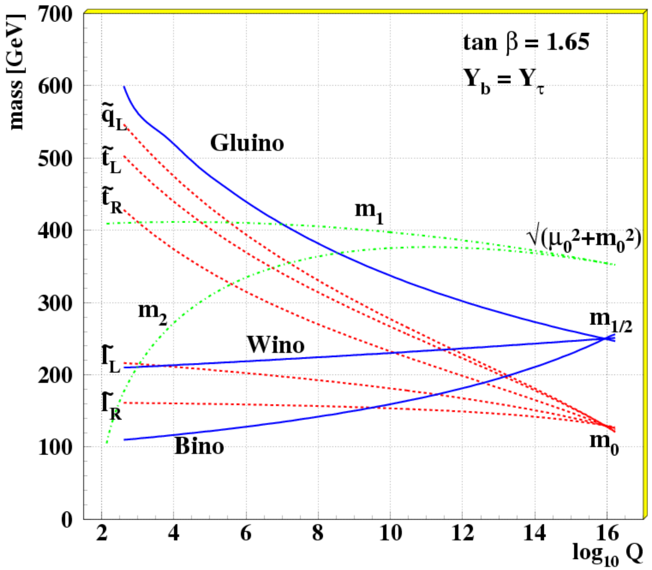
- As a result, MSSM has

  5 free parameters

  $\mu,\ A,\ m_0,\ m_{1/2},\ B(\tan\beta)$

  while the Standard Model has 2 ones

  $m,\ \lambda$



Constrained MSSM

- To make prediction one can choose a certain way
  - Take low-energy values of parameters (superpartners masses, mixing parameters, etc.) and then calculate observables as functions of these values.
  - Take high-energy values of parameters, then using evolution equations find their low-energy values, calculate masses, and then calculate observables. All the calculation now uses a small number of free parameters.
- "Experimental" data are sufficient to find allowed set of parameters

SUSY Dark Matter

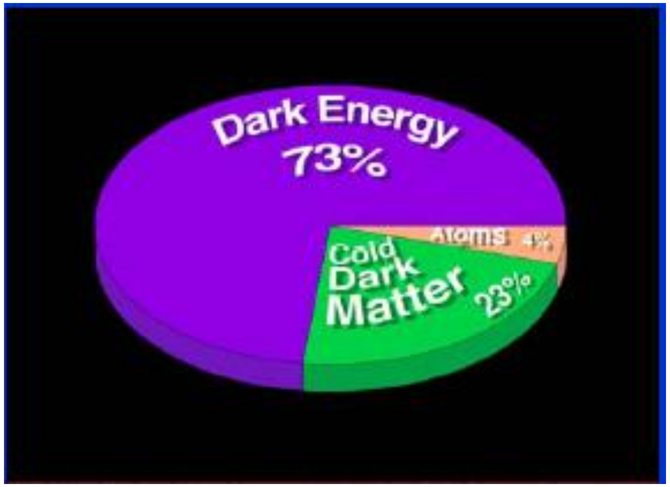
- Dark Matter in the Universe.

  MSSM has a good candidate

  for the WIMP – neutralino –

  a mixture of superpartners

  of photon, Z-boson and Higgses



- Neutral (no electric charge, no colour)
- Weakly interacting (due to supersymmetry)
- Stable (!) if R-parity is conserved
- Heavy enough to account for cold non-baryonic dark matter

SUSY production at colliders

- Supersymmetric particles can be produced at collider if the energy is large enough

$$m_{sparticle} \leq \frac{\sqrt{s}}{2}$$

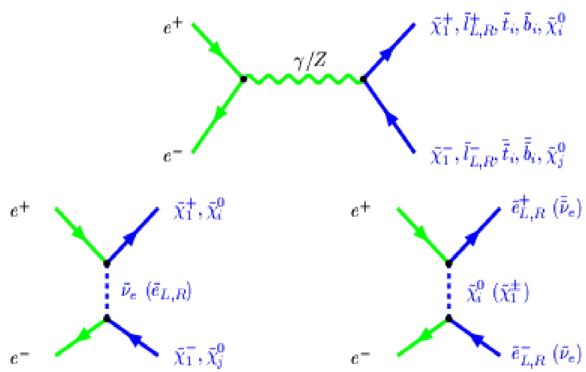
- Production and subsequent decay crucially depends on the model and the mass spectrum

- If the R-parity is conserved only lightest SUSY particles (neutralinos) remain after decays. The main feature is the missing energy taken away by LSP, since they escape detection

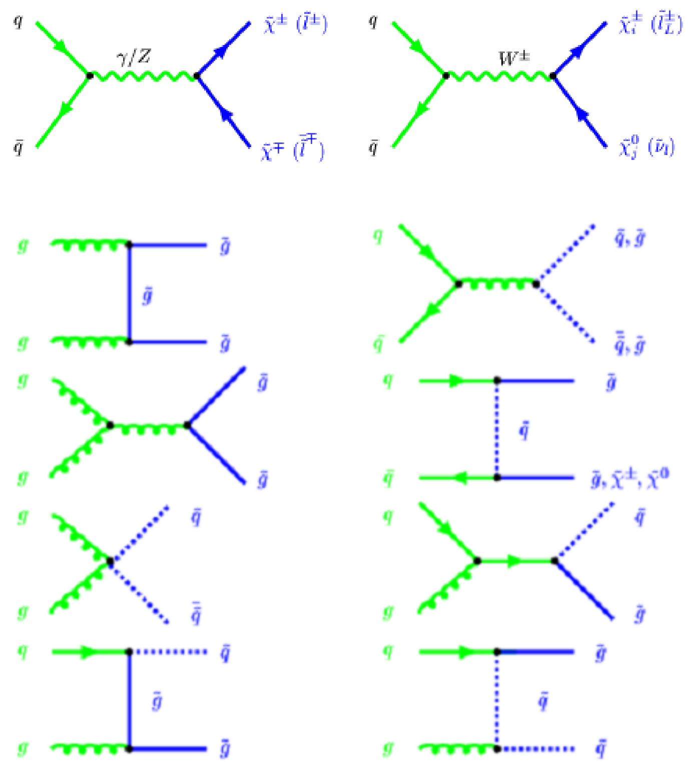
SUSY production at colliders

- Processes of creation of supersymmetric particles

- e^+e^- colliders

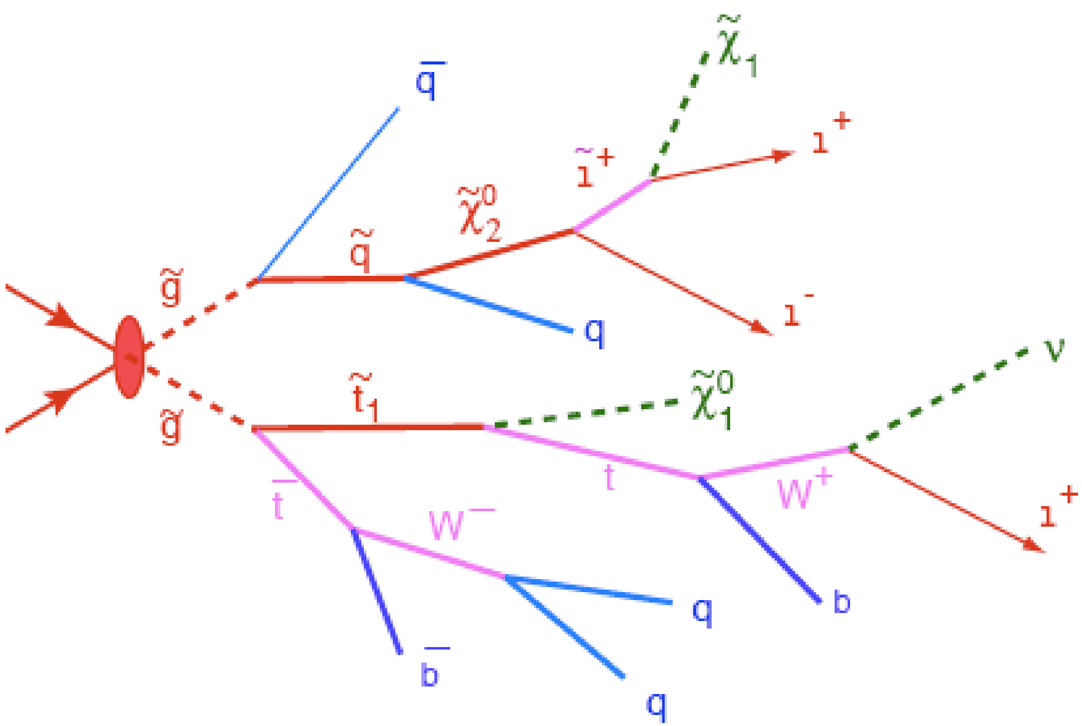


- Hadron colliders



SUSY events signatures

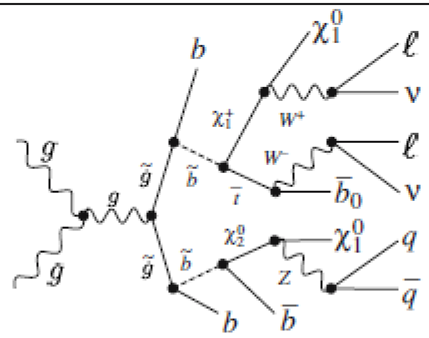
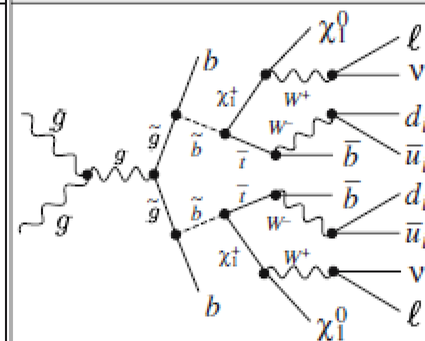
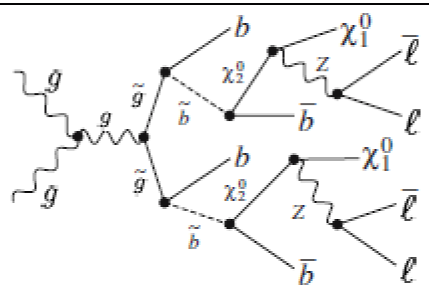
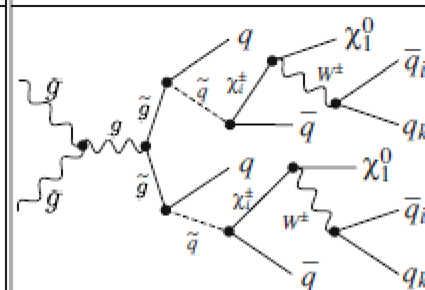
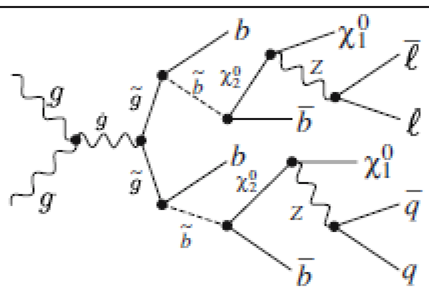
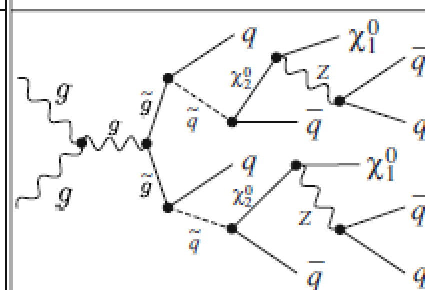
- Missing Energy: from LSP
- Multi-Jet: from cascade decay (gaugino)
- Multi-Leptons: from decay of charginos/neutralios



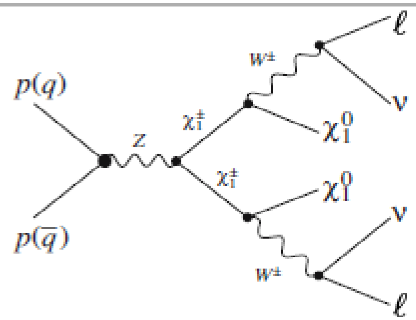
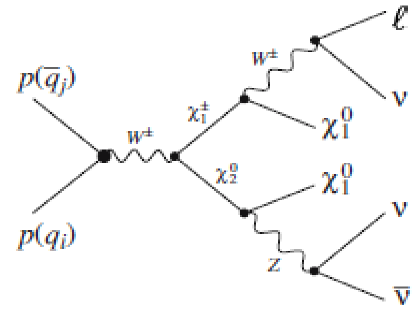
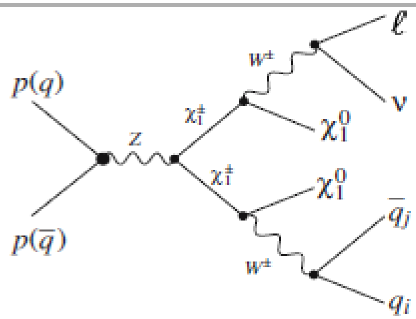
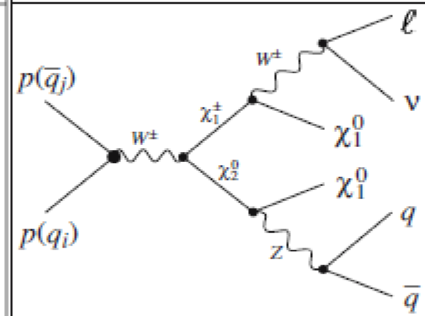
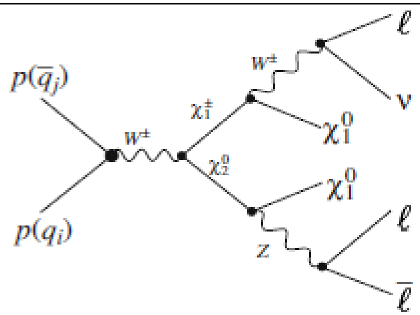
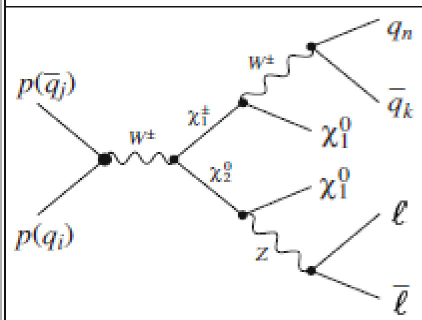
SUSY events signatures

Production	Main decay mode	Signature
$\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}$	$\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ $q\bar{q}'\tilde{\chi}_1^\pm$ $g\tilde{\chi}_1^0$ $\left.\right\} m_{\tilde{q}} > m_{\tilde{g}}$ $\tilde{q} \to q\tilde{\chi}_i^0$ $\tilde{q} \to q'\tilde{\chi}_i^\pm$ $\left.\right\} m_{\tilde{g}} > m_{\tilde{q}}$	$\not\!\!E_T$ + multijets (+ leptons)
$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0\ell^\pm\nu, \tilde{\chi}_2^0 \to \tilde{\chi}_1^0\ell\ell$	Trilepton + $\not\!\!E_T$
	$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 q\bar{q}', \tilde{\chi}_2^0 \to \tilde{\chi}_1^0\ell\ell$	Dileptons + jet + $\not\!\!E_T$
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	$\tilde{\chi}_1^+ \to \ell\tilde{\chi}_1^0\ell^\pm\nu$	Dilepton + $\not\!\!E_T$
$\tilde{\chi}_i^0\tilde{\chi}_i^0$	$\tilde{\chi}_i^0 \to \tilde{\chi}_1^0 X, \tilde{\chi}_i^0 \to \tilde{\chi}_1^0 X'$	Dilepton + jet + $\not\!\!E_T$
$\tilde{t}_1\tilde{t}_1$	$\tilde{t}_1 \to c\tilde{\chi}_1^0$	Two noncollinear jets + $\not\!\!E_T$
	$\tilde{t}_1 \to b\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 q\bar{q}'$	Single lepton + $\not\!\!E_T$ + $b's$
	$\tilde{t}_1 \to b\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \to \tilde{\chi}_1^0\ell^\pm\nu$	Dilepton + $\not\!\!E_T$ + $b's$
$\tilde{\ell}\tilde{\ell}, \tilde{\ell}\tilde{\nu}, \tilde{\nu}\tilde{\nu}$	$\tilde{\ell}^\pm \to \ell^\pm\tilde{\chi}_i^0, \tilde{\ell}^\pm \to \nu_\ell\tilde{\chi}_i^\pm$	Dilepton + $\not\!\!E_T$
	$\tilde{\nu} \to \nu\tilde{\chi}_1^0$	Single lepton + $\not\!\!E_T$

SUSY events signatures

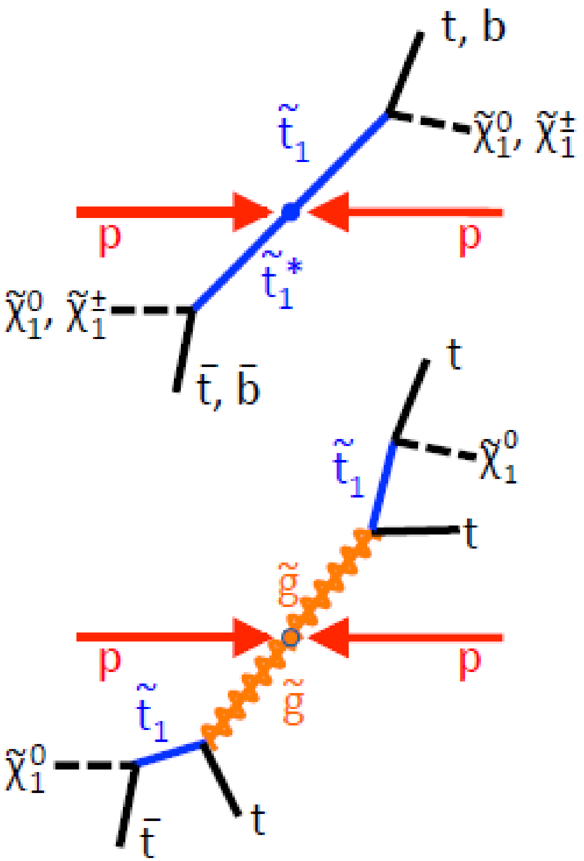
Process	Final state	Process	Final state
	2ℓ 2ν $6j$ $\not{E}_T$		2ℓ 2ν $8j$ $\not{E}_T$
	4ℓ $4j$ $\not{E}_T$		$8j$ $\not{E}_T$
	2ℓ $6j$ $\not{E}_T$		$8j$ $\not{E}_T$

SUSY events signatures

Process	Final states	Process	Final states
	2ℓ 2ν $\not{E}_T$		ℓ 3ν $\not{E}_T$
	ℓ ν $2j$ $\not{E}_T$		ℓ ν $2j$ $\not{E}_T$
	3ℓ ν $\not{E}_T$		2ℓ $2j$ $\not{E}_T$

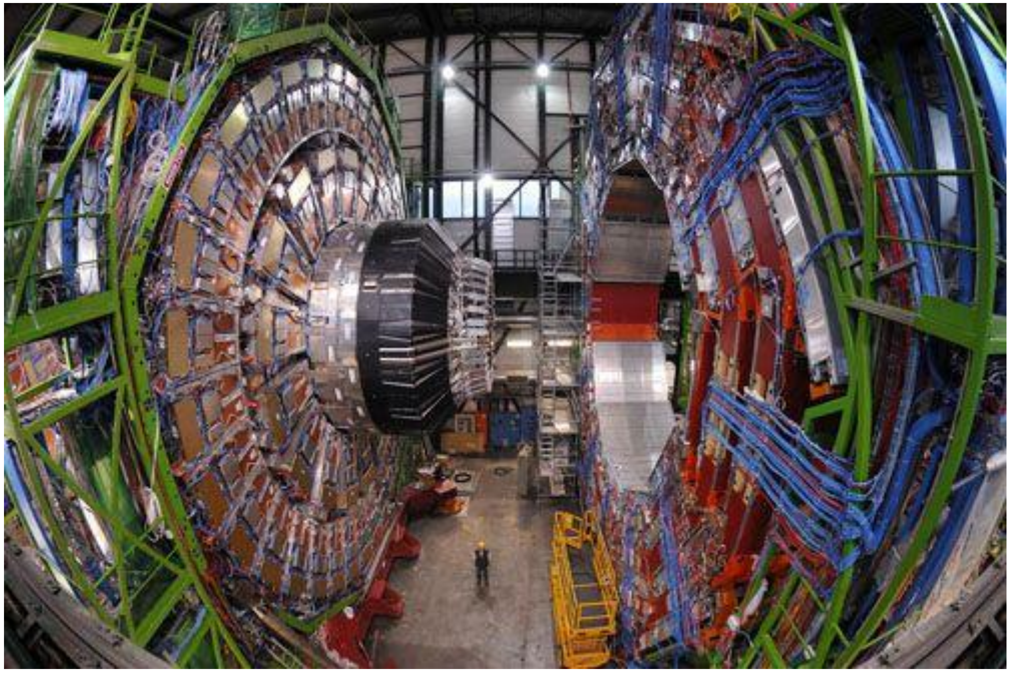
Stop production

- Top squarks can be produced at LHC by either direct production or gluino mediated production
- Final state with several top or bottom quarks and neutralinos
- Signature: b-jets, E_T, one or several leptons, light jets



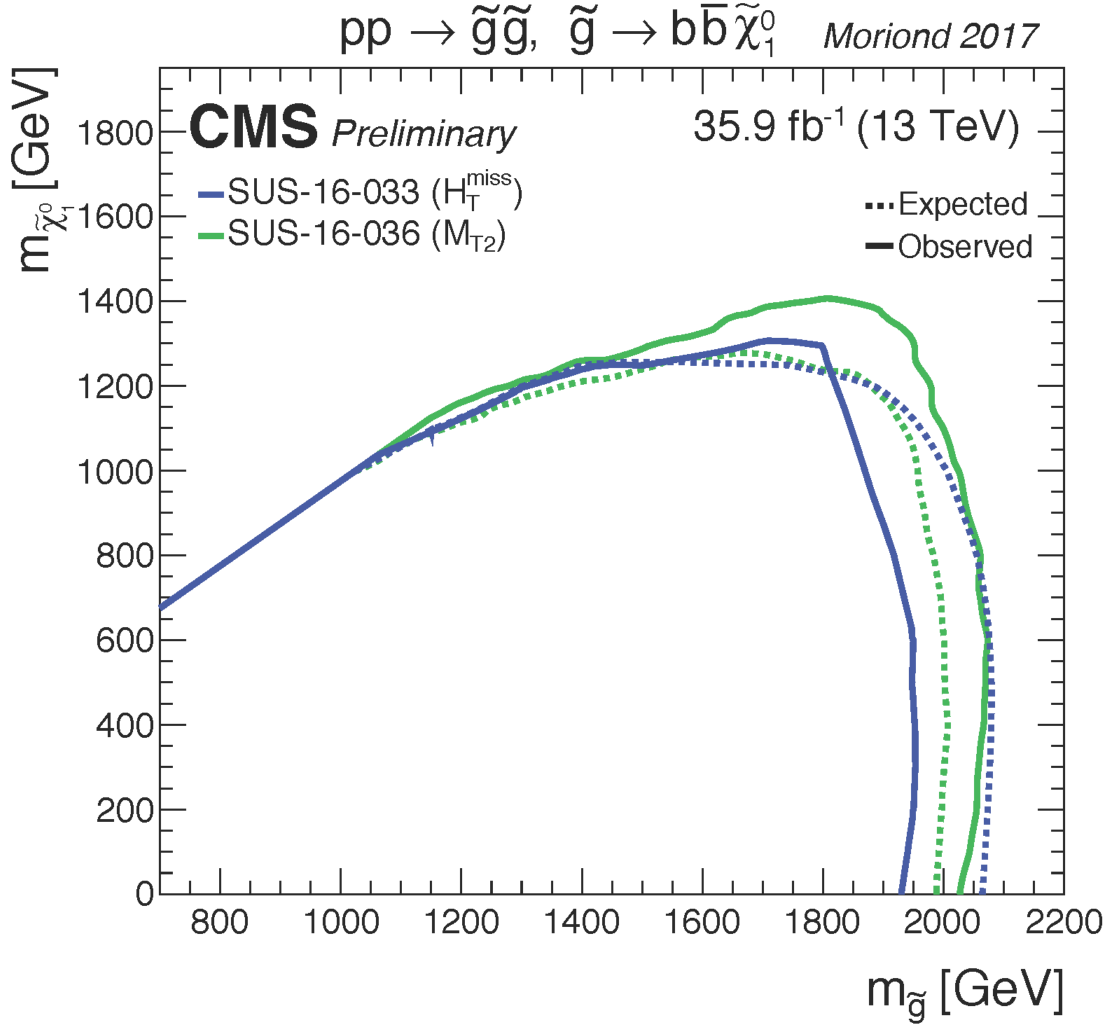
SUSY searches at CMS

- CMS is a particle detector designed to see a wide range of particles and phenomena produced in high-energy collisions in the LHC.



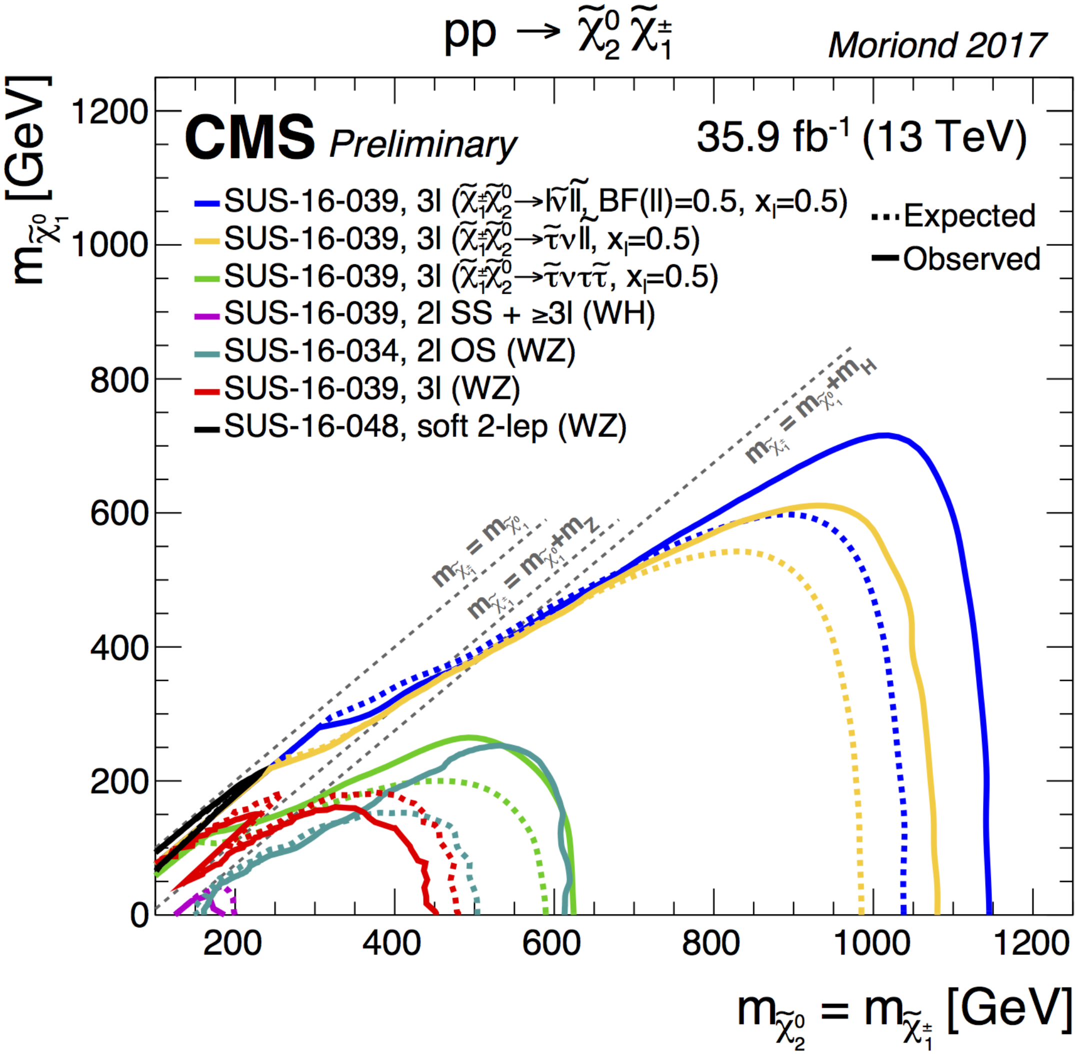
SUSY searches at CMS

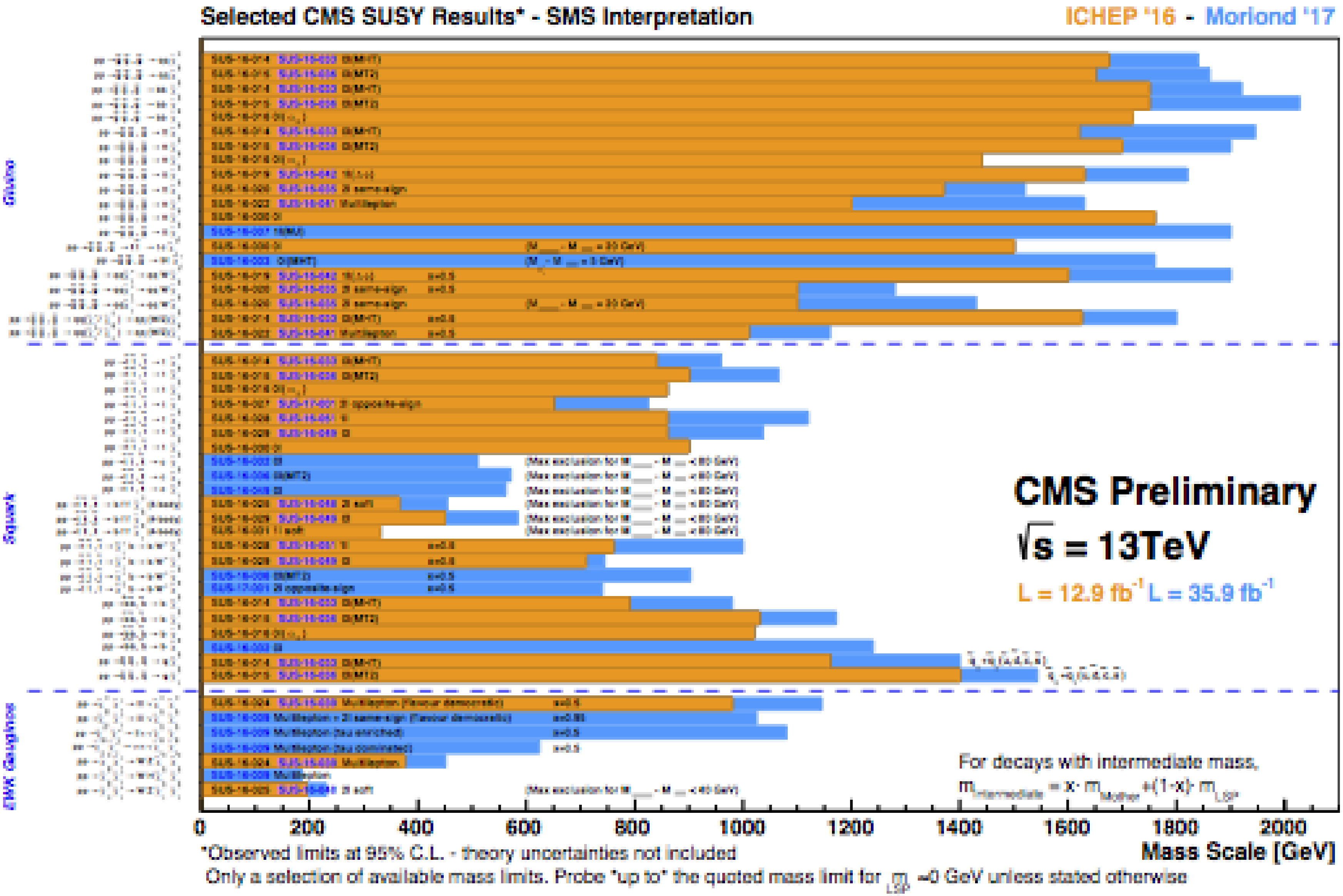
- Limits on gluino pairs to 4 bottoms



SUSY searches at CMS

- Limits on chargino/neutralino production

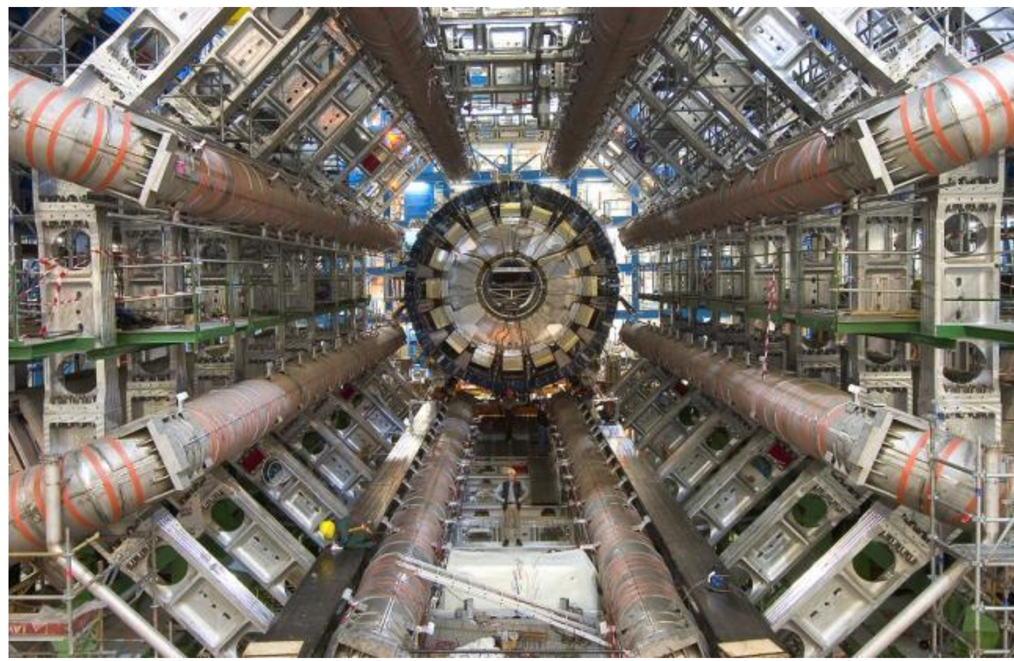



Selected CMS SUSY Results* - SMS Interpretation
ICHEP '16 - Moriond '17
Gluino
Squark
EWK Gauginos
CMS Preliminary
√s = 13TeV
L = 12.9 fb⁻¹ L = 35.9 fb⁻¹
For decays with intermediate mass,
m_intermediate = x· m_Mother + (1-x)· m_LSP
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Mass Scale [GeV]
*Observed limits at 95% C.L. - theory uncertainties not included
Only a selection of available mass limits. Probe "up to" the quoted mass limit for m_LSP =0 GeV unless stated otherwise

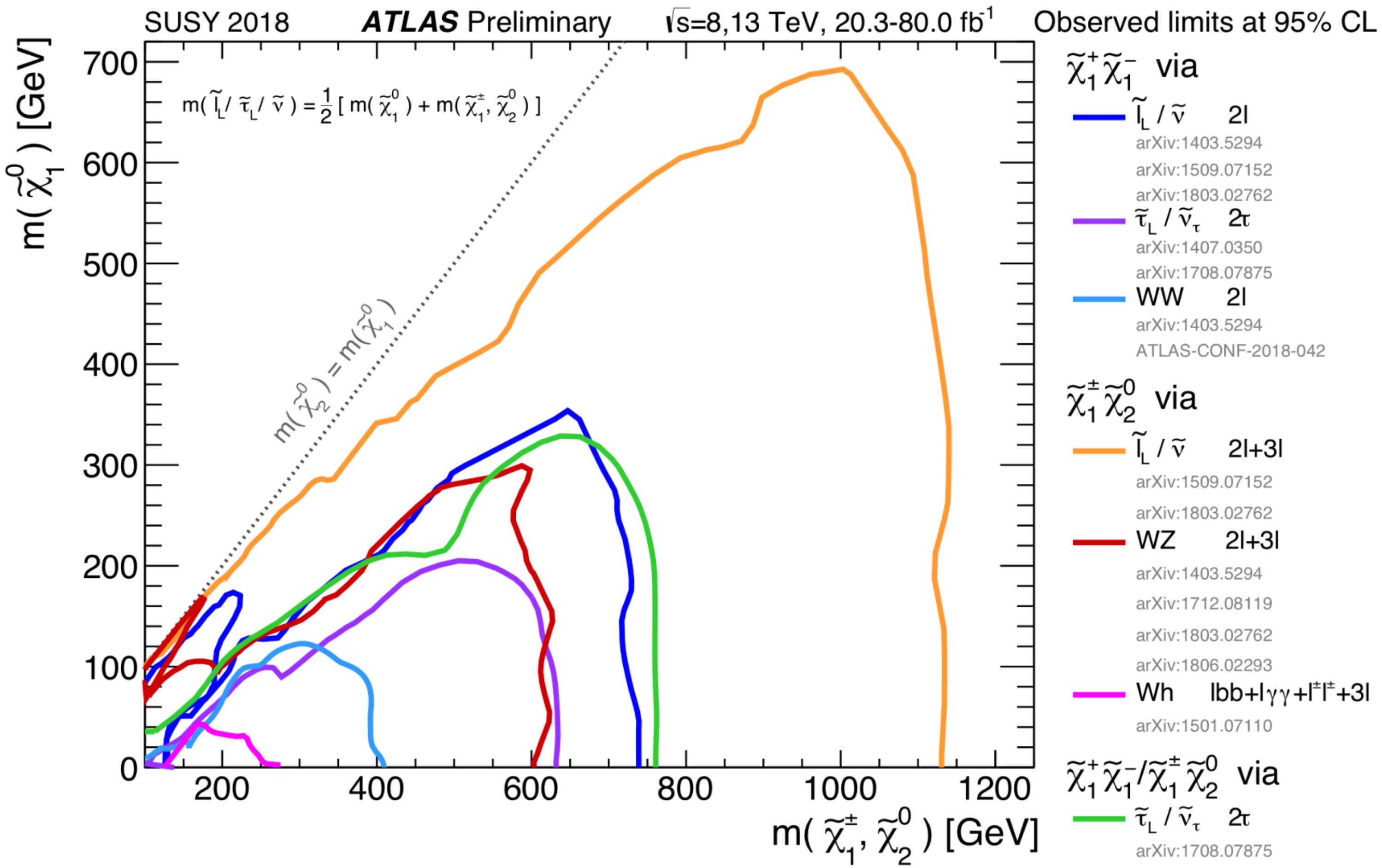
SUSY searches at ATLAS

- ATLAS is one of general-purpose detectors at the LHC. It studies a wide range of physics, from the search for the Higgs boson to extra dimensions and particles that could make up dark matter.

ATLAS EXPERIMENT

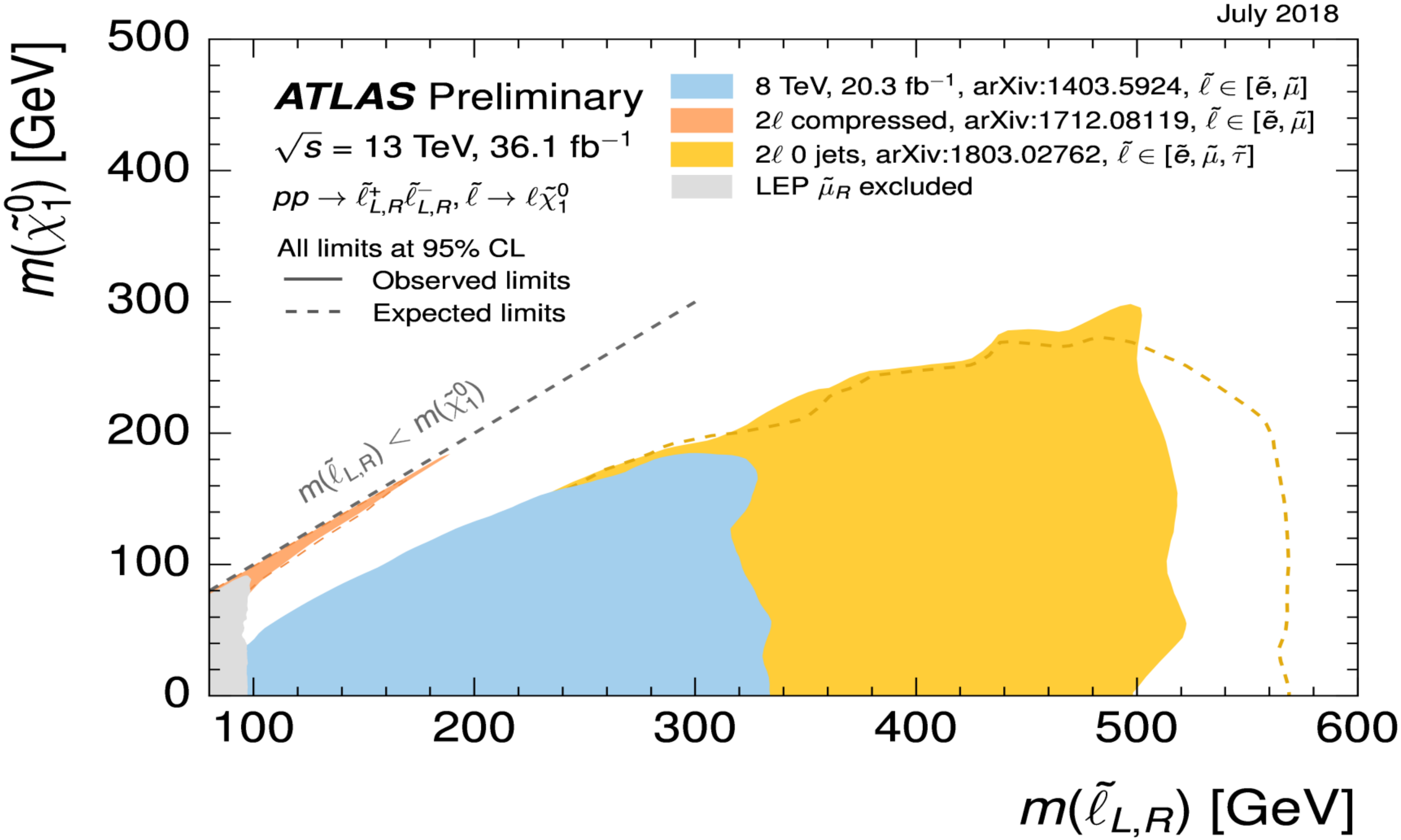


SUSY searches at ATLAS



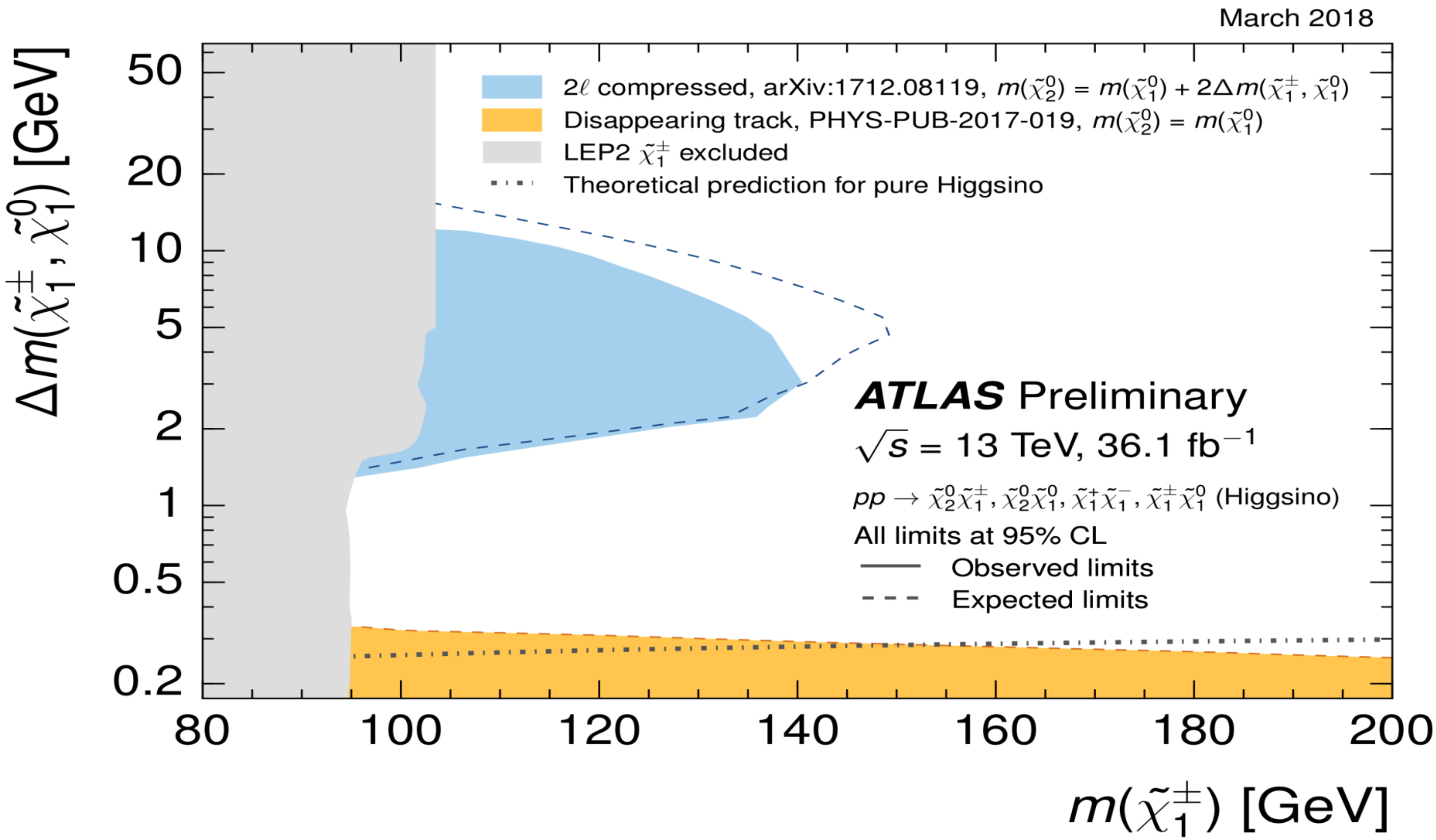
- The 95% CL exclusion limits on $\chi_1^+\chi_1^-$ and $\chi_1^\pm\chi_2^0$ production

SUSY searches at ATLAS



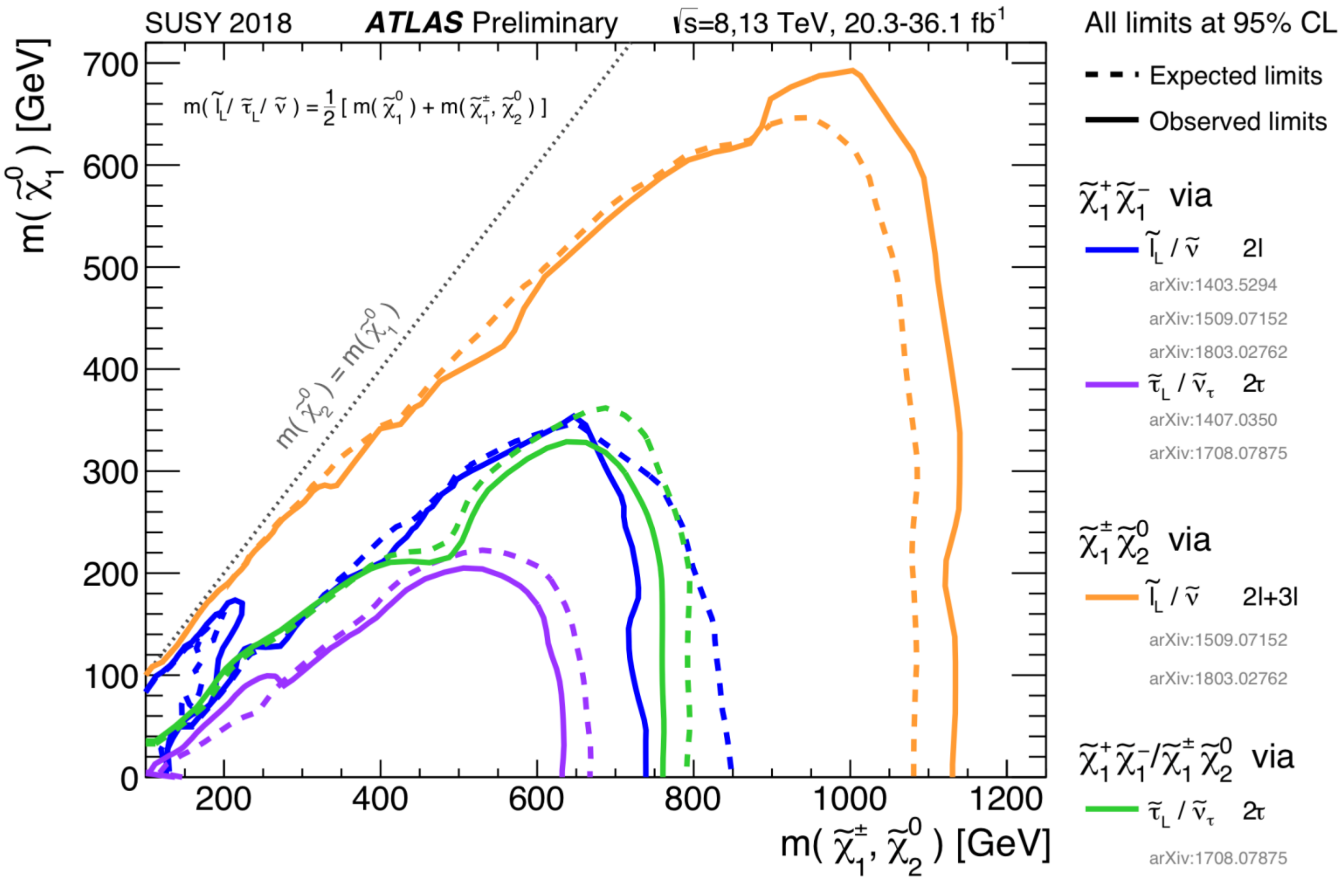
- Exclusion limits at 95% CL based on 13 TeV data for different analyses probing the direct production of sleptons

SUSY searches at ATLAS



- Exclusion limits at 95% CL for higgsino pair production

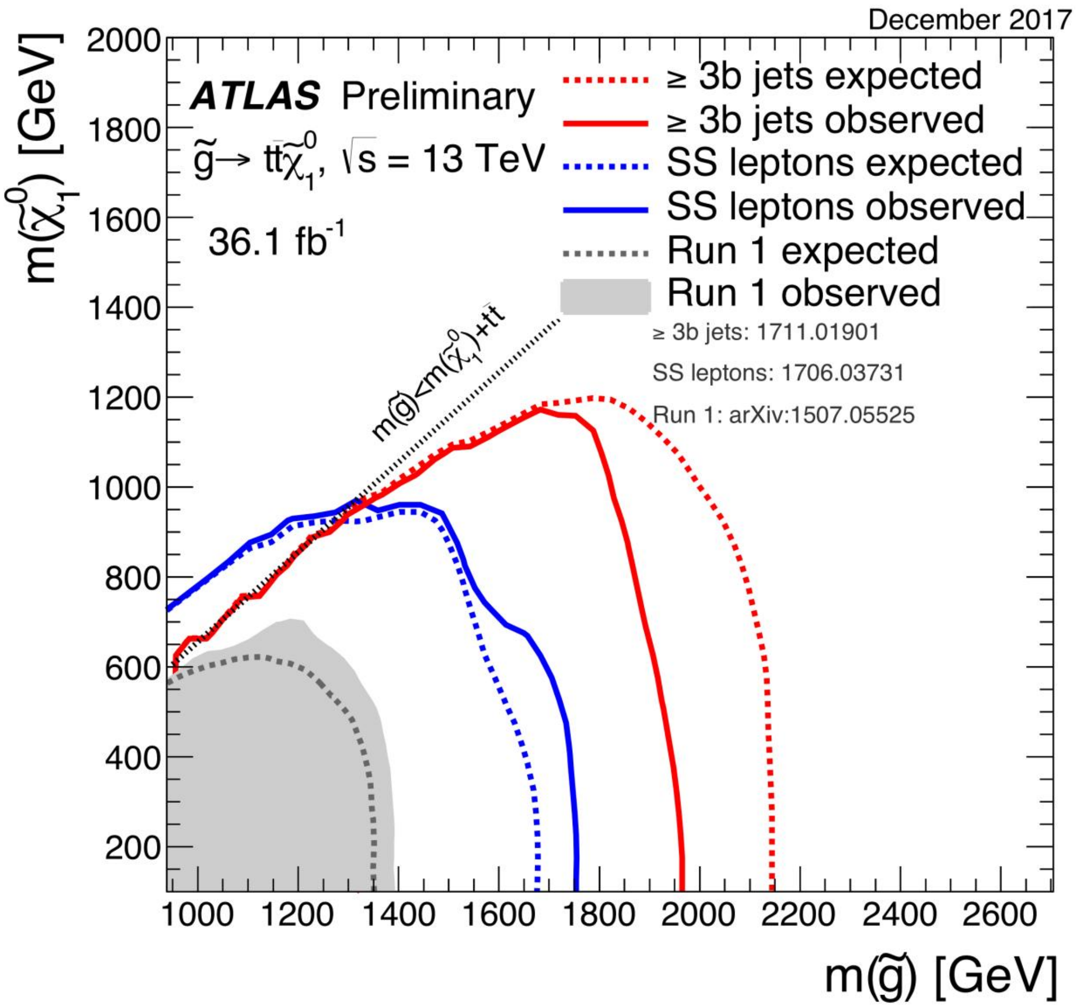
SUSY searches at ATLAS



- The 95% CL exclusion limits on $\chi_1^+\chi_1^-$ and $\chi_1^\pm\chi_2^0$ production with ℓ-mediated decays

SUSY searches at ATLAS

- Exclusion limits at 95% CL based on 13 TeV data in for the Gtt simplified model where a pair of gluinos decays promptly via off-shell top squarks to four top quarks and two lightest neutralinos.



ATLAS SUSY Searches* - 95% CL Lower Limits

July 2018

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

Legend: $\sqrt{s}$ = 7, 8 TeV (green); $\sqrt{s}$ = 13 TeV (blue)

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	$\tilde q\tilde q$, $\tilde q\to q\tilde\chi^0_1$	0	2-6 jets	Yes	36.1	$\tilde q$ [2×, 8× Degen.] 0.9 1.55	m($\tilde\chi^0_1$)<100 GeV	1712.02332
		mono-jet	1-3 jets	Yes	36.1	$\tilde q$ [1×, 8× Degen.] 0.43 0.71	m($\tilde q$)-m($\tilde\chi^0_1$)=5 GeV	1711.03301
	$\tilde g\tilde g$, $\tilde g\to q\bar q\tilde\chi^0_1$	0	2-6 jets	Yes	36.1	$\tilde g$ 2.0	m($\tilde\chi^0_1$)<200 GeV	1712.02332
						$\tilde g$ Forbidden 0.95-1.6	m($\tilde\chi^0_1$)=900 GeV	1712.02332
	$\tilde g\tilde g$, $\tilde g\to q\bar q(\ell\ell)\tilde\chi^0_1$	3 e,μ	4 jets	-	36.1	$\tilde g$ 1.85	m($\tilde\chi^0_1$)<800 GeV	1706.03731
		$ee,\mu\mu$	2 jets	Yes	36.1	$\tilde g$ 1.2	m($\tilde g$)-m($\tilde\chi^0_1$)=50 GeV	1805.11381
	$\tilde g\tilde g$, $\tilde g\to qqWZ\tilde\chi^0_1$	0	7-11 jets	Yes	36.1	$\tilde g$ 1.8	m($\tilde\chi^0_1$) <400 GeV	1708.02794
		3 e,μ	4 jets	-	36.1	$\tilde g$ 0.98	m($\tilde g$)-m($\tilde\chi^0_1$)=200 GeV	1706.03731
	$\tilde g\tilde g$, $\tilde g\to t\bar t\tilde\chi^0_1$	0-1 e,μ	3 b	Yes	36.1	$\tilde g$ 2.0	m($\tilde\chi^0_1$)<200 GeV	1711.01901
		3 e,μ	4 jets	-	36.1	$\tilde g$ 1.25	m($\tilde g$)-m($\tilde\chi^0_1$)=300 GeV	1706.03731
3^{rd} gen. squarks direct production	$\tilde b_1\tilde b_1$, $\tilde b_1\to b\tilde\chi^0_2/t\tilde\chi^\pm_1$		Multiple		36.1	$\tilde b_1$ Forbidden 0.9	m($\tilde\chi^0_1$)=300 GeV, BR($b\tilde\chi^0_1$)=1	1708.09266, 1711.03301
			Multiple		36.1	$\tilde b_1$ Forbidden 0.58-0.82	m($\tilde\chi^0_1$)=300 GeV, BR($b\tilde\chi^0_1$)=BR($t\tilde\chi^\pm_1$)=0.5	1708.09266
			Multiple		36.1	$\tilde b_1$ Forbidden 0.7	m($\tilde\chi^0_1$)=200 GeV, m($\tilde\chi^\pm_1$)=300 GeV, BR($t\tilde\chi^\pm_1$)=1	1706.03731
	$\tilde b_1\tilde b_1$, $\tilde t_1\tilde t_1$, $M_2 = 2\times M_1$		Multiple		36.1	$\tilde t_1$ 0.7	m($\tilde\chi^0_1$)=60 GeV	1709.04183, 1711.11520, 1708.03247
			Multiple		36.1	$\tilde t_1$ Forbidden 0.9	m($\tilde\chi^0_1$)=200 GeV	1709.04183, 1711.11520, 1708.03247
	$\tilde t_1\tilde t_1$, $\tilde t_1\to Wb\tilde\chi^0_1$ or $t\tilde\chi^0_1$	0-2 e,μ	0-2 jets/1-2 b	Yes	36.1	$\tilde t_1$ 1.0	m($\tilde\chi^0_1$)=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde t_1\tilde t_1$, $\tilde H$ LSP		Multiple		36.1	$\tilde t_1$ 0.4-0.9	m($\tilde\chi^0_1$)=150 GeV, m($\tilde\chi^\pm_1$)-m($\tilde\chi^0_1$)=5 GeV, $\tilde t_1\approx\tilde t_L$	1709.04183, 1711.11520
			Multiple		36.1	$\tilde t_1$ Forbidden 0.6-0.8	m($\tilde\chi^0_1$)=300 GeV, m($\tilde\chi^\pm_1$)-m($\tilde\chi^0_1$)=5 GeV, $\tilde t_1\approx\tilde t_L$	1709.04183, 1711.11520
	$\tilde t_1\tilde t_1$, Well-Tempered LSP		Multiple		36.1	$\tilde t_1$ 0.48-0.84	m($\tilde\chi^0_1$)=150 GeV, m($\tilde\chi^\pm_1$)-m($\tilde\chi^0_1$)=5 GeV, $\tilde t_1\approx\tilde t_L$	1709.04183, 1711.11520
	$\tilde t_1\tilde t_1$, $\tilde t_1\to c\tilde\chi^0_1$ / $\tilde c\tilde c$, $\tilde c\to c\tilde\chi^0_1$	0	2c	Yes	36.1	$\tilde t_1$ 0.85	m($\tilde\chi^0_1$)=0 GeV	1805.01649
						$\tilde t_1$ 0.46	m($\tilde t_1$,$\tilde c$)-m($\tilde\chi^0_1$)=50 GeV	1805.01649
		0	mono-jet	Yes	36.1	$\tilde t_1$ 0.43	m($\tilde t_1$,$\tilde c$)-m($\tilde\chi^0_1$)=5 GeV	1711.03301
	$\tilde t_2\tilde t_2$, $\tilde t_2\to\tilde t_1 + h$	1-2 e,μ	4 b	Yes	36.1	$\tilde t_2$ 0.32-0.88	m($\tilde\chi^0_1$)=0 GeV, m($\tilde t_1$)-m($\tilde\chi^0_1$)= 180 GeV	1706.03986
EW direct	$\tilde\chi^\pm_1\tilde\chi^0_2$ via WZ	2-3 e,μ	-	Yes	36.1	$\tilde\chi^\pm_1/\tilde\chi^0_2$ 0.6	m($\tilde\chi^0_1$)=0	1403.5294, 1806.02293
		$ee,\mu\mu$	≥ 1	Yes	36.1	$\tilde\chi^\pm_1/\tilde\chi^0_2$ 0.17	m($\tilde\chi^\pm_1$)-m($\tilde\chi^0_1$)=10 GeV	1712.08119
	$\tilde\chi^\pm_1\tilde\chi^0_2$ via Wh	$\ell\ell/\ell\gamma\gamma/\ell bb$	-	Yes	20.3	$\tilde\chi^\pm_1/\tilde\chi^0_2$ 0.26	m($\tilde\chi^0_1$)=0	1501.07110
	$\tilde\chi^\pm_1\tilde\chi^\mp_1/\tilde\chi^0_2$, $\tilde\chi^+_1\to\tilde\tau\nu(\tau\tilde\nu)$, $\tilde\chi^0_2\to\tilde\tau\tau(\nu\tilde\nu)$	2 τ	-	Yes	36.1	$\tilde\chi^\pm_1/\tilde\chi^0_2$ 0.76	m($\tilde\chi^0_1$)=0, m($\tilde\tau,\tilde\nu$)=0.5(m($\tilde\chi^\pm_1$)+m($\tilde\chi^0_1$))	1708.07875
						$\tilde\chi^\pm_1/\tilde\chi^0_2$ 0.22	m($\tilde\chi^\pm_1$)-m($\tilde\chi^0_1$)=100 GeV, m($\tilde\tau,\tilde\nu$)=0.5(m($\tilde\chi^\pm_1$)+m($\tilde\chi^0_1$))	1708.07875
	$\tilde\ell_{L,R}\tilde\ell_{L,R}$, $\tilde\ell\to\ell\tilde\chi^0_1$	2 e,μ	0	Yes	36.1	$\tilde\ell$ 0.5	m($\tilde\chi^0_1$)=0	1803.02762
		2 e,μ	≥ 1	Yes	36.1	$\tilde\ell$ 0.18	m($\tilde\ell$)-m($\tilde\chi^0_1$)=5 GeV	1712.08119
	$\tilde H\tilde H$, $\tilde H\to h\tilde G/Z\tilde G$	0	$\geq 3b$	Yes	36.1	$\tilde H$ 0.13-0.23 0.29-0.88	BR($\tilde\chi^0_1\to h\tilde G$)=1	1806.04030
		4 e,μ	0	Yes	36.1	$\tilde H$ 0.3	BR($\tilde\chi^0_1\to Z\tilde G$)=1	1804.03602
Long-lived particles	Direct $\tilde\chi^+_1\tilde\chi^-_1$ prod., long-lived $\tilde\chi^\pm_1$	Disapp. trk	1 jet	Yes	36.1	$\tilde\chi^\pm_1$ 0.46	Pure Wino	1712.02118
						$\tilde\chi^\pm_1$ 0.15	Pure Higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde g$ R-hadron	SMP	-	-	3.2	$\tilde g$ 1.6		1606.05129
	Metastable $\tilde g$ R-hadron, $\tilde g\to qq\tilde\chi^0_1$		Multiple		32.8	$\tilde g$ [$\tau(\tilde g)$ =100 ns, 0.2 ns] 1.6 2.4	m($\tilde\chi^0_1$)=100 GeV	1710.04901, 1604.04520
	GMSB, $\tilde\chi^0_1\to\gamma\tilde G$, long-lived $\tilde\chi^0_1$	2 γ	-	Yes	20.3	$\tilde\chi^0_1$ 0.44	1<$\tau(\tilde\chi^0_1)$<3 ns, SPS8 model	1409.5542
	$\tilde g\tilde g$, $\tilde\chi^0_1\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde g$ 1.3	6 <$c\tau(\tilde\chi^0_1)$< 1000 mm, m($\tilde\chi^0_1$)=1 TeV	1504.05162
RPV	LFV $pp\to\tilde\nu_\tau + X$, $\tilde\nu_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	3.2	$\tilde\nu_\tau$ 1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde\chi^\pm_1\tilde\chi^\mp_1/\tilde\chi^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0	Yes	36.1	$\tilde\chi^\pm_1/\tilde\chi^0_2$ [$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$] 0.82 1.33	m($\tilde\chi^0_1$)=100 GeV	1804.03602
	$\tilde g\tilde g$, $\tilde g\to qq\tilde\chi^0_1$, $\tilde\chi^0_1\to qqq$	0	4-5 large-R jets	-	36.1	$\tilde g$ [m($\tilde\chi^0_1$)=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde g$ [λ''_{112}=2e-4, 2e-5] 1.05 2.0	m($\tilde\chi^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde g\tilde g$, $\tilde g\to tbs$ / $\tilde g\to t\bar t\tilde\chi^0_1$, $\tilde\chi^0_1\to tbs$		Multiple		36.1	$\tilde g$ [λ''_{323}=1, 1e-2] 1.8 2.1	m($\tilde\chi^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde t\tilde t$, $\tilde t\to t\tilde\chi^0_1$, $\tilde\chi^0_1\to tbs$		Multiple		36.1	$\tilde g$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05	m($\tilde\chi^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde t_1\tilde t_1$, $\tilde t_1\to bs$	0	2 jets + 2 b	-	36.7	$\tilde t_1$ [qq, bs] 0.42 0.61		1710.07171
	$\tilde t_1\tilde t_1$, $\tilde t_1\to b\ell$	2 e,μ	2 b	-	36.1	$\tilde t_1$ 0.4-1.45	BR($\tilde t_1\to be/b\mu$)>20%	1710.05544

10^{-1} 1 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Summary of SUSY searches

- A broad range of searches for SUSY have been performed by CMS and ATLAS for increased sensitivity with partial 2018 data set
- Experiments performed a large set of analyses almost synchronously with data taking
- The mass limits pushed up to more than 2 TeV (gluinos) and more than 1 TeV (stops)
- Some limits depend on additional assumptions on the mass of the intermediate states

- Much larger data sets will be available during the rest of Run2, and we are looking forward to seeing first significant deviations from the SM predictions!

THANK YOU FOR ATTENTION !

12th APCTP – BLTP JINR Joint Workshop

"Modern problems in nuclear and elementary particle physics"

August 20 – 24, 2018, Busan, Republic of Korea