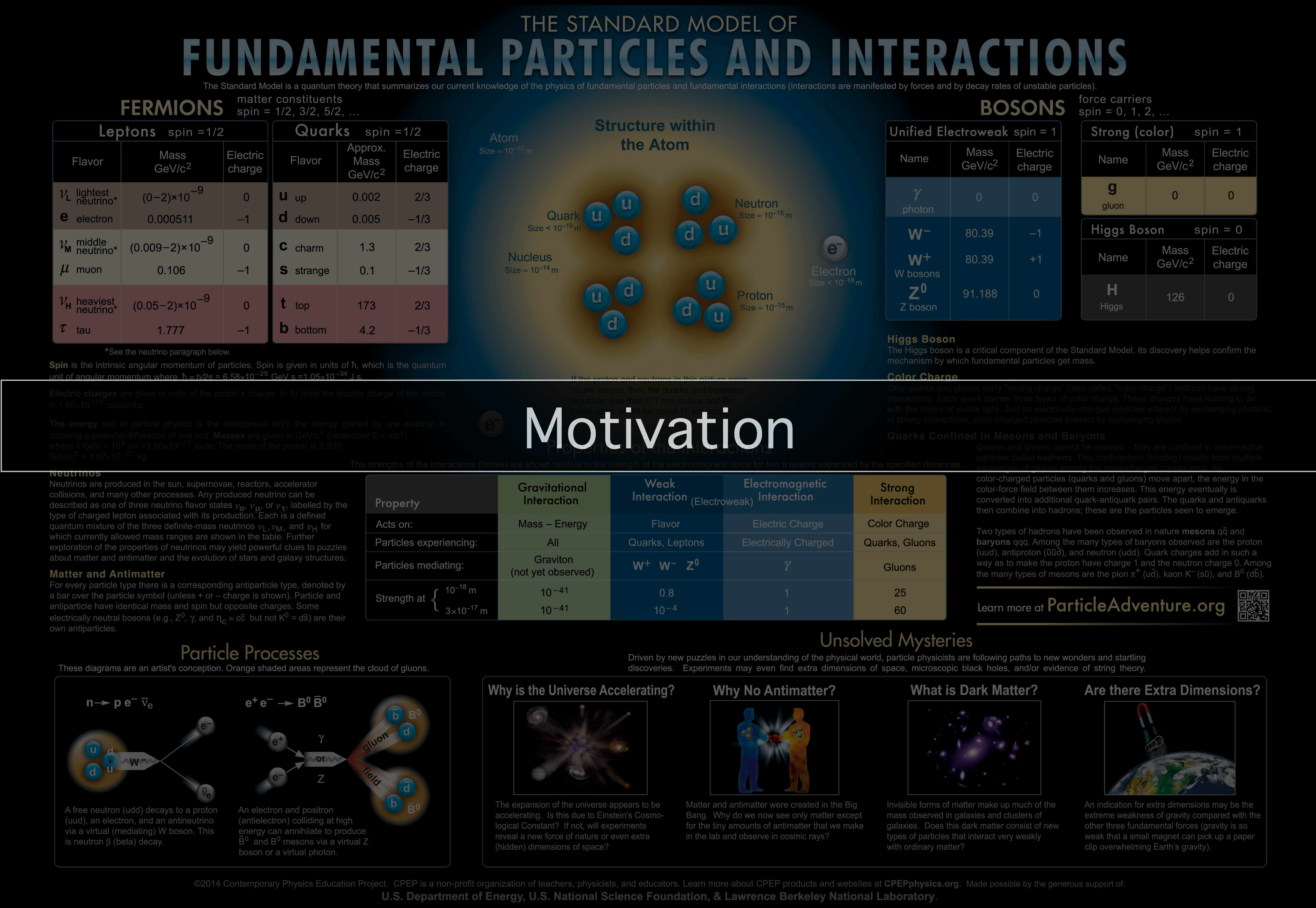
Overview and frontiers in the hunt for Supersymmetry at the LHC

Till Eifert (CERN),
Colloquium, DESY, May 2018

Outline

- **Motivation**
  Why are we looking for physics beyond the standard model?
  What is supersymmetry and why is it interesting?
- **Searching for Supersymmetry at the LHC**
  Brief introduction to the experimental setup.
  Description of a typical supersymmetry analysis.
- **Overview of search program and results**
  How robust are the exclusions?
- **New frontiers**
  complex final states and searches for rare & challenging signatures.
- **Outlook**
  Next steps in the hunt for supersymmetry.

Motivation



THE STANDARD MODEL OF

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a quantum theory that summarizes our current knowledge of the physics of fundamental particles and fundamental interactions (interactions are manifested by forces and by decay rates of unstable particles).

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-2)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-2)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.05-2)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

*See the neutrino paragraph below.

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $=1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The energy unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$) where 1 GeV = 10^9 eV $=1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.

Neutrinos

Neutrinos are produced in the sun, supernovae, reactors, accelerator collisions, and many other processes. Any produced neutrino can be described as one of three neutrino flavor states ν_e, ν_μ, or ν_τ, labelled by the type of charged lepton associated with its production. Each is a defined quantum mixture of the three definite-mass neutrinos ν_L, ν_M, and ν_H for which currently allowed mass ranges are shown in the table. Further exploration of the properties of neutrinos may yield powerful clues to puzzles about matter and antimatter and the evolution of stars and galaxy structures.

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$ but not $K^0 = d\bar{s}$) are their own antiparticles.

Structure within the Atom

If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Higgs Boson spin = 0

Name	Mass GeV/c^2	Electric charge
H Higgs	126	0

Higgs Boson

The Higgs boson is a critical component of the Standard Model. Its discovery helps confirm the mechanism by which fundamental particles get mass.

Color Charge

Only quarks and gluons carry "strong charge" (also called "color charge") and can have strong interactions. Each quark carries three types of color charge. These charges have nothing to do with the colors of visible light. Just as electrically-charged particles interact by exchanging photons, in strong interactions, color-charged particles interact by exchanging gluons.

Quarks Confined in Mesons and Baryons

Quarks and gluons cannot be isolated – they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs. The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge.

Two types of hadrons have been observed in nature **mesons** $q\bar{q}$ and **baryons** qqq. Among the many types of baryons observed are the proton (uud), antiproton ($\bar{u}\bar{u}\bar{d}$), and neutron (udd). Quark charges add in such a way as to make the proton have charge 1 and the neutron charge 0. Among the many types of mesons are the pion π^+ ($u\bar{d}$), kaon K^- ($s\bar{u}$), and B^0 ($d\bar{b}$).

Learn more at ParticleAdventure.org

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

Particle Processes

These diagrams are an artist's conception. Orange shaded areas represent the cloud of gluons.

$n \rightarrow p\, e^-\, \bar{\nu}_e$

A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.

$e^+ e^- \rightarrow B^0 \bar{B}^0$

An electron and positron (antielectron) colliding at high energy can annihilate to produce $\bar{B}^0$ and B^0 mesons via a virtual Z boson or a virtual photon.

Unsolved Mysteries

Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Experiments may even find extra dimensions of space, microscopic black holes, and/or evidence of string theory.

Why is the Universe Accelerating?

The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

Why No Antimatter?

Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

What is Dark Matter?

Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

Are there Extra Dimensions?

An indication for extra dimensions may be the extreme weakness of gravity compared with the other three fundamental forces (gravity is so weak that a small magnet can pick up a paper clip overwhelming Earth's gravity).

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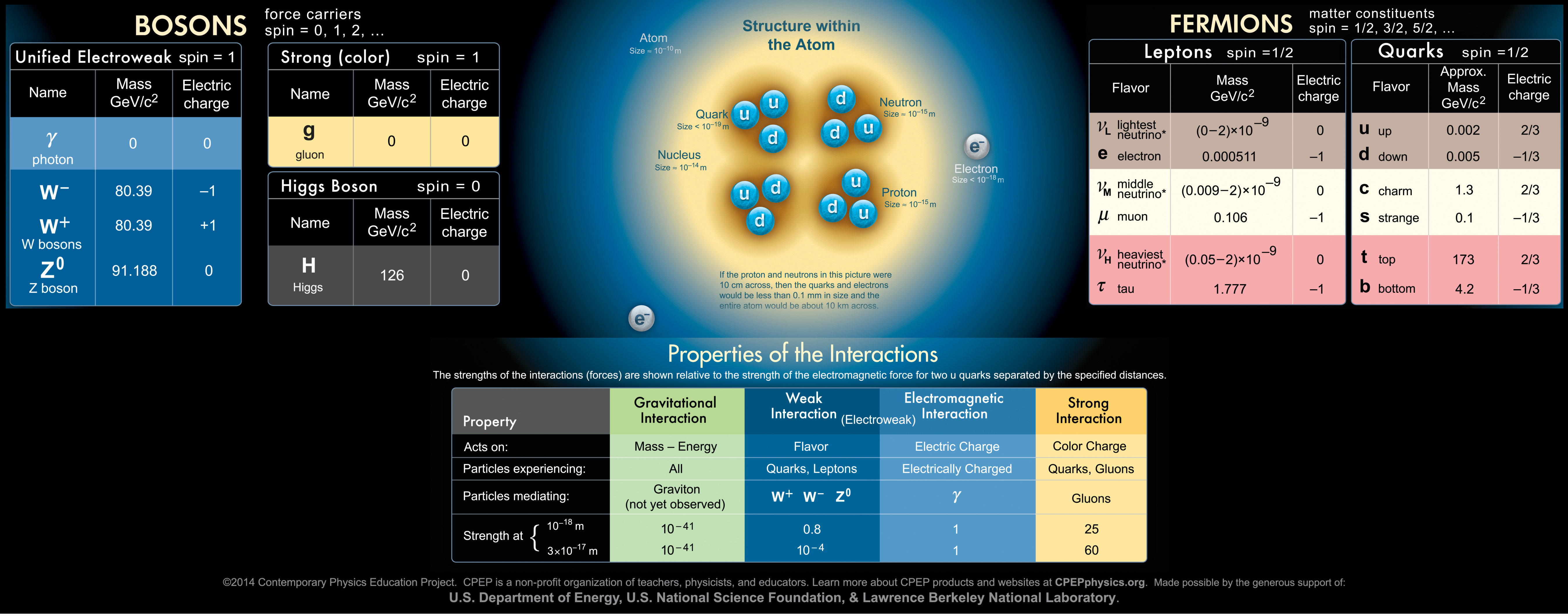
Standard model of particle physics



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Structure within the Atom

Atom
Size ≈ 10^{-10} m

Quark
Size < 10^{-19} m

Nucleus
Size ≈ 10^{-14} m

Neutron
Size ≈ 10^{-15} m

Proton
Size ≈ 10^{-15} m

Electron
Size < 10^{-18} m

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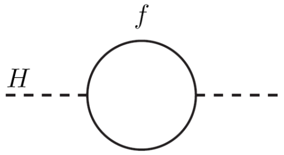
U.S. Department of Energy, U.S. National Science Foundation, & Lawrence Berkeley National Laboratory.

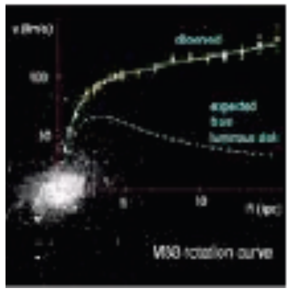
"*We are at a very exciting and puzzling time for particle physics.*"
(F. Gianotti, 2018 CERN New Year presentation.)

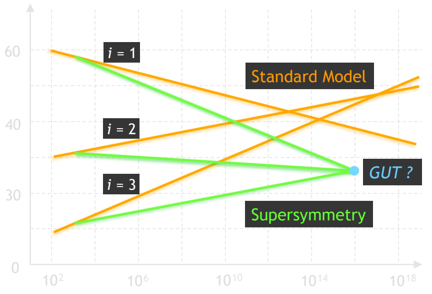
Exciting because the LHC discovered the Higgs boson (2012), the Standard Model is complete and it works beautifully!

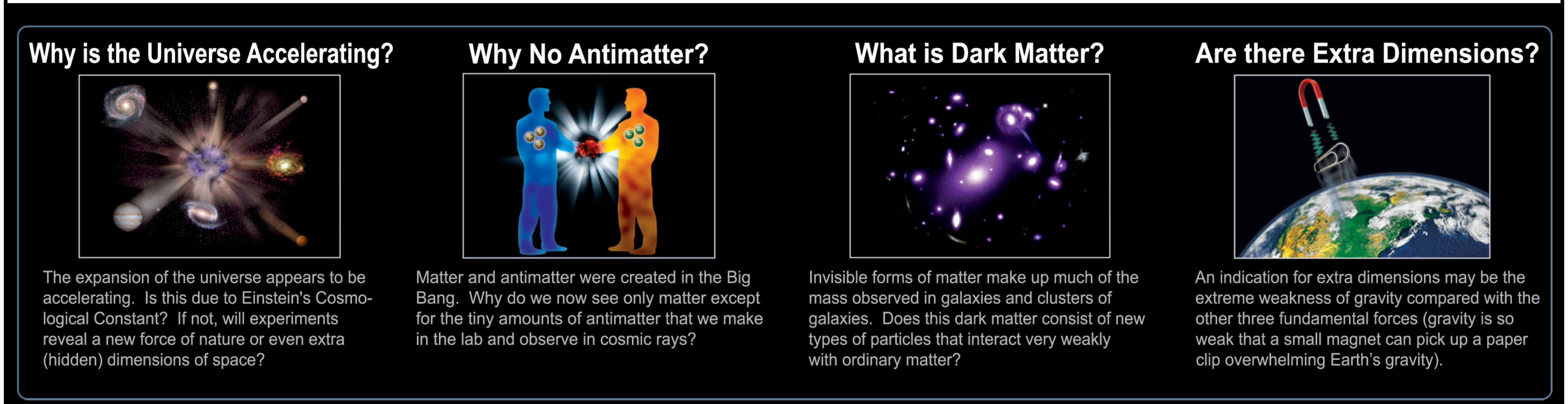
Puzzling because the standard model is not a complete theory of particle physics. Several fundamental questions require physics beyond the standard model.

- Why is the Higgs boson so light?
- What is dark matter?
- What is the origin of the matter-antimatter asymmetry?
- Is there a grand unification of forces?
- How to include neutrino masses and oscillations?
- …









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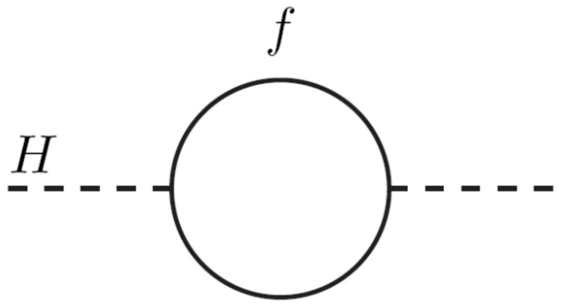
Are there Extra Dimensions?

An indication for extra dimensions may be the extreme weakness of gravity compared with the other three fundamental forces (gravity is so weak that a small magnet can pick up a paper clip overwhelming Earth's gravity).

Strong motivation to search for new physics!

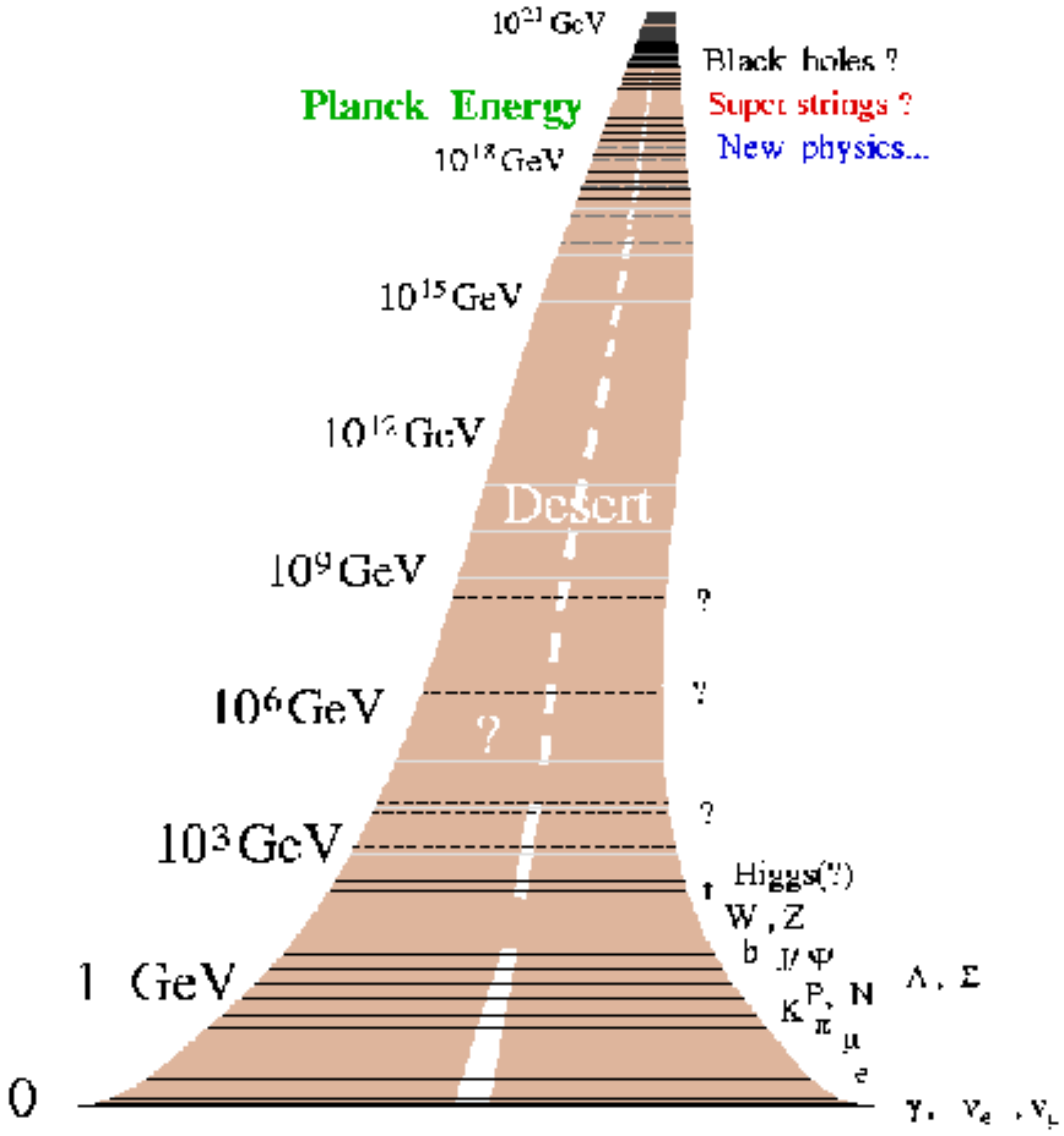
Why is the Higgs boson so light?

Very large quantum loop corrections to Higgs mass in any extension of the Standard Model.



$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2$$

New physics cut-off



Courtesy G. 't Hooft

Why is the Higgs boson so light?

bare mass loop corrections

measured Higgs mass $m_h^2 \approx m_{h\,0}^2 - \Delta m_H^2$

$$(125\ \text{GeV})^2 \overset{?}{=} (10^{19}\ \text{GeV})^2 - (10^{19}\ \text{GeV})^2$$

Requires extremely precise cancelation of bare mass with correction term
"**fine-tuning**"

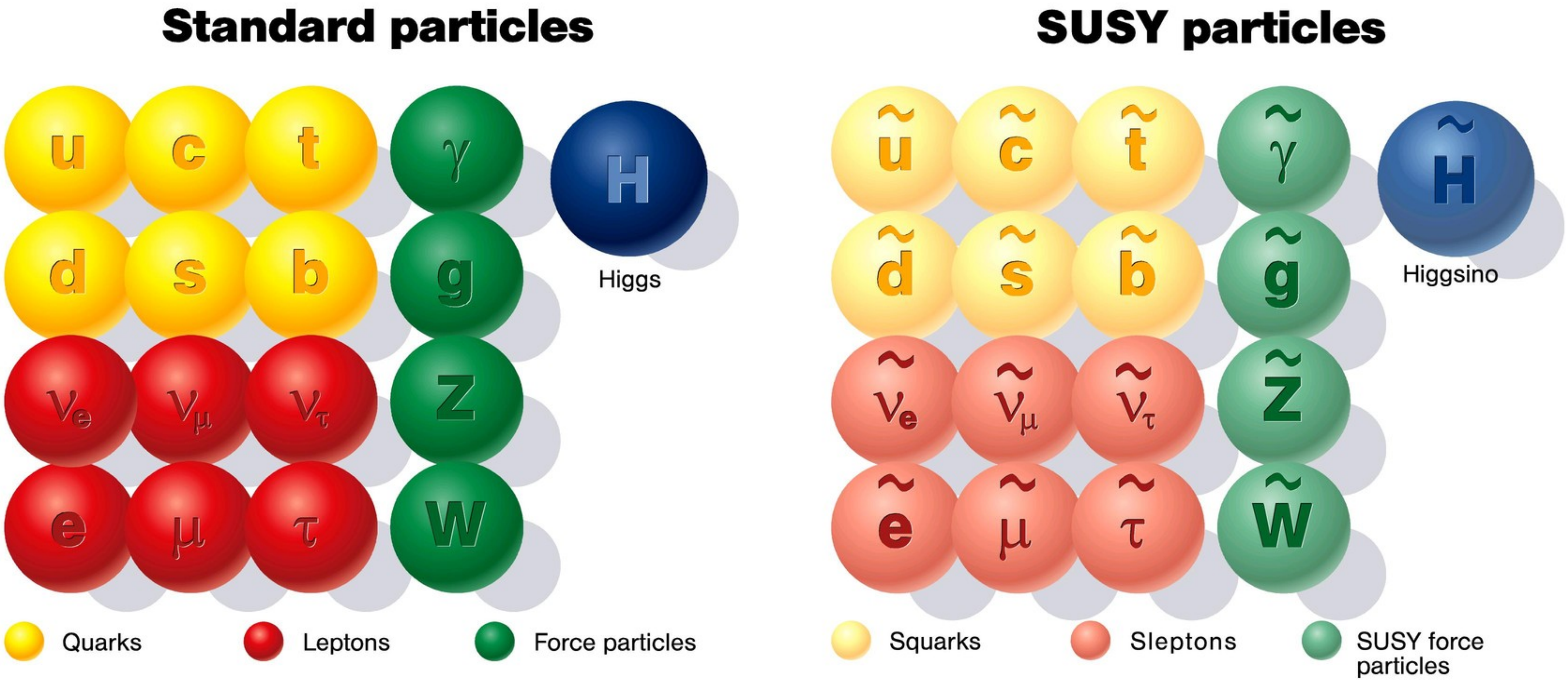
listening to your favorite radio needs the tuned frequency to match that of the radio channel:

radio freq. = 59.058718520915010919812879623498576 12 kHz
tuned freq. = 59.058718520915010919812879623498579 87 kHz

Why is the Higgs boson so much lighter than the Planck mass (or GUT energy, or heavy neutrino mass scale)?

Supersymmetry

Supersymmetry (SUSY):
New symmetry between bosons and fermions.
For every SM particle introduce a supersymmetric partner with Δspin=1/2.



Supersymmetry

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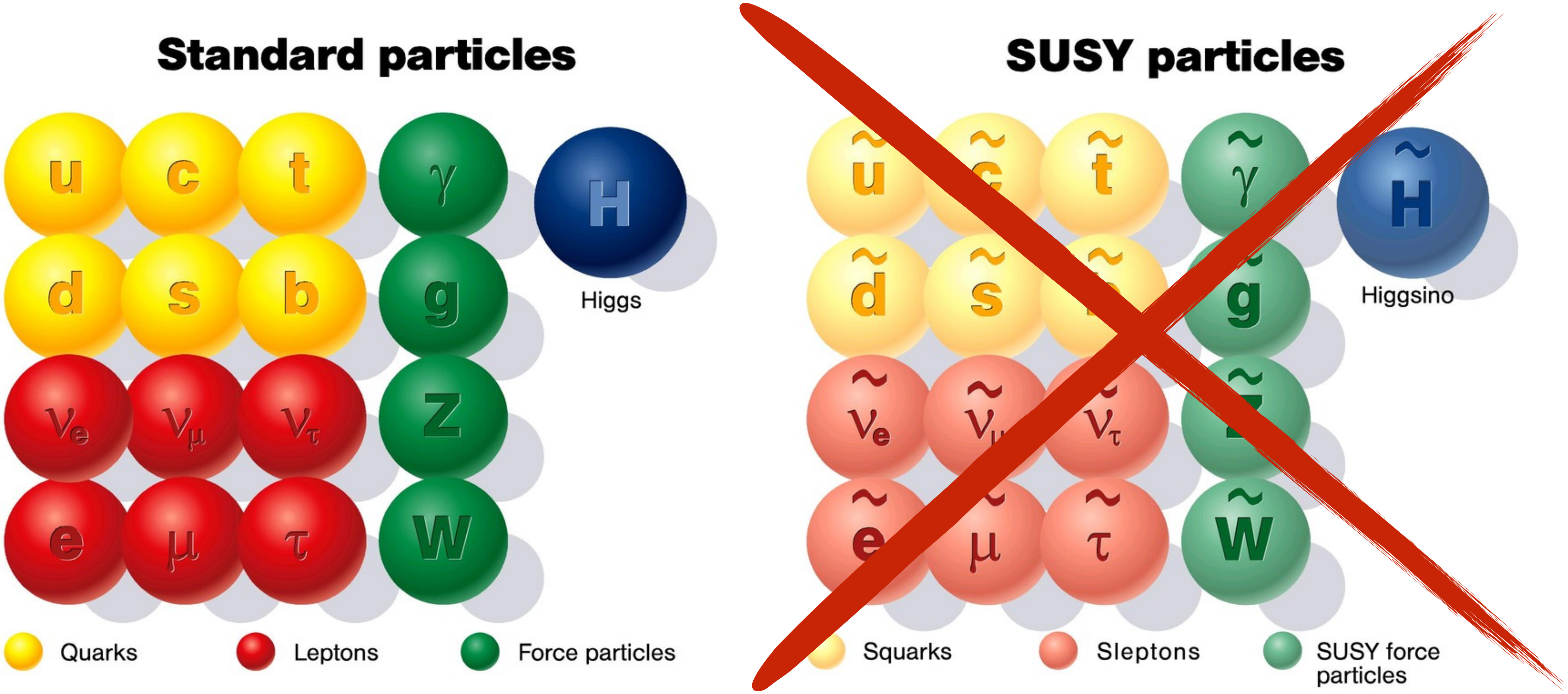
Equal number of bosonic and fermionic states



Supersymmetry

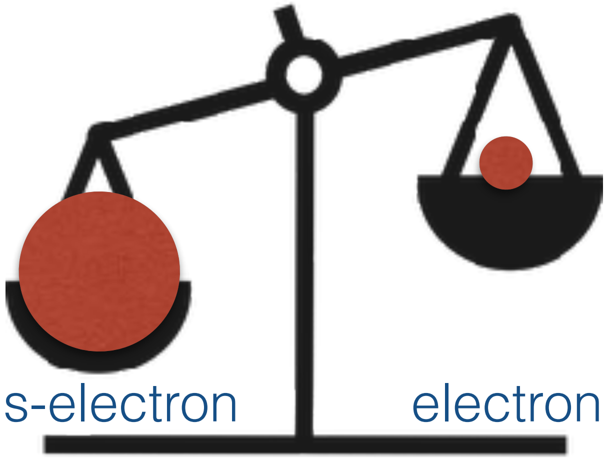
The undiscovered particles in the Minimal Supersymmetric Standard Model (MSSM) [SUSY primer, S. Martin]

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	$+1$	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	-1	$\widetilde{u}_L\ \widetilde{u}_R\ \widetilde{d}_L\ \widetilde{d}_R$	(same)
			$\widetilde{s}_L\ \widetilde{s}_R\ \widetilde{c}_L\ \widetilde{c}_R$	(same)
			$\widetilde{t}_L\ \widetilde{t}_R\ \widetilde{b}_L\ \widetilde{b}_R$	$\widetilde{t}_1\ \widetilde{t}_2\ \widetilde{b}_1\ \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L\ \widetilde{e}_R\ \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L\ \widetilde{\mu}_R\ \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L\ \widetilde{\tau}_R\ \widetilde{\nu}_\tau$	$\widetilde{\tau}_1\ \widetilde{\tau}_2\ \widetilde{\nu}_\tau$
neutralinos	$1/2$	-1	$\widetilde{B}^0\ \ \widetilde{W}^0\ \ \widetilde{H}_u^0\ \ \widetilde{H}_d^0$	$\widetilde{N}_1\ \widetilde{N}_2\ \widetilde{N}_3\ \widetilde{N}_4$
charginos	$1/2$	-1	$\widetilde{W}^\pm\ \ \widetilde{H}_u^+\ \ \widetilde{H}_d^-$	$\widetilde{C}_1^\pm\ \ \widetilde{C}_2^\pm$
gluino	$1/2$	-1	$\widetilde{g}$	(same)
goldstino (gravitino)	$1/2$ $(3/2)$	-1	$\widetilde{G}$	(same)

bino, neutral wino & neutral higgsinos mix to form four neutralinos.

charged wino & charged higgsinos mix to form four charginos.

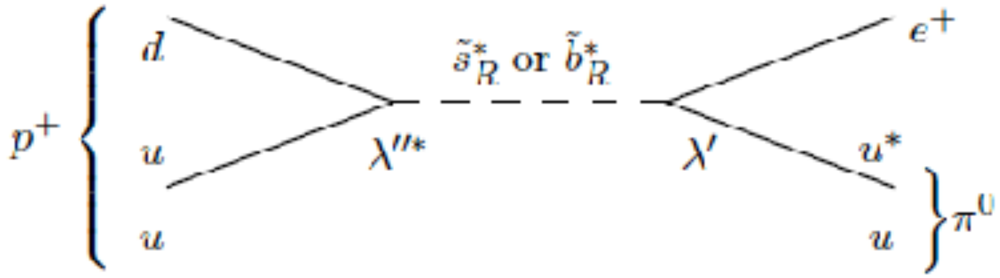
Supersymmetry



Broken symmetry

- Otherwise, m(s-electron) = m(electron), etc.
- Several theories for supersymmetry breaking (gauge mediated, gravity mediated, etc.).
- Minimal supersymmetric standard model (MSSM):
  1 new parameter
  soft supersymmetry breaking (our ignorance!): 124 parameters
  (SM comes with 19 parameters)

SUSY: Lepton (L) and baryon (B) number violation allowed, proton decay



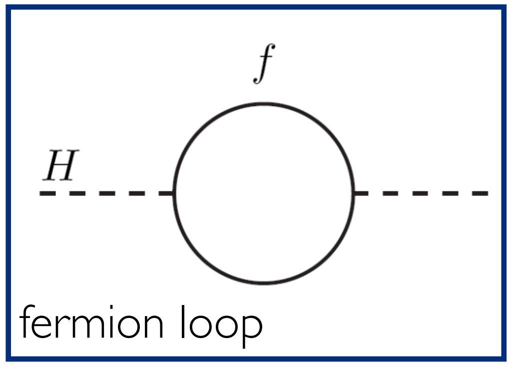
R-parity = +1 (-1) SM (SUSY) particles

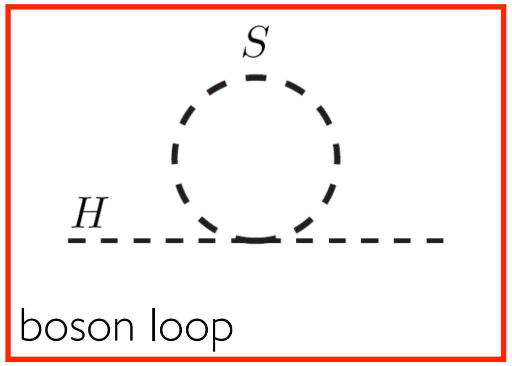
$$P_R = (-1)^{3(\mathrm{B}-\mathrm{L})+2s}$$

R-parity conservation (RPC) implies:

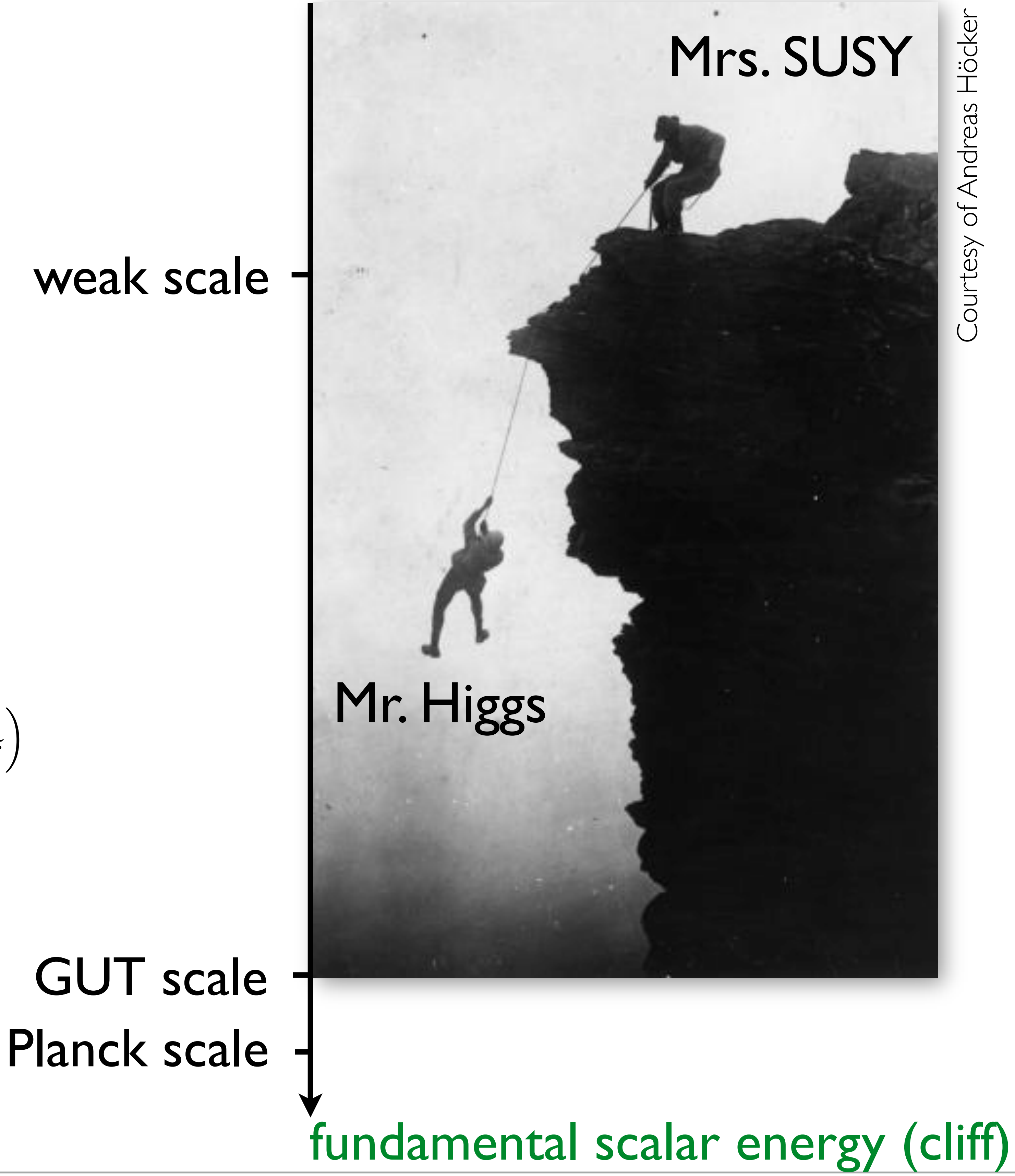
- eliminate B and L number violating terms,
- SUSY production only in even numbers (typically 2),
- lightest supersymmetric particle (LSP) is stable
  if electrically and color neutral then DM candidate, and LSP escapes detection
  → missing (transverse) momentum.

SUSY solution to “Why is the Higgs boson so





fermion and boson loops contribute with different signs to the Higgs radiative corrections; fermion-boson symmetry protects the scalar Higgs.



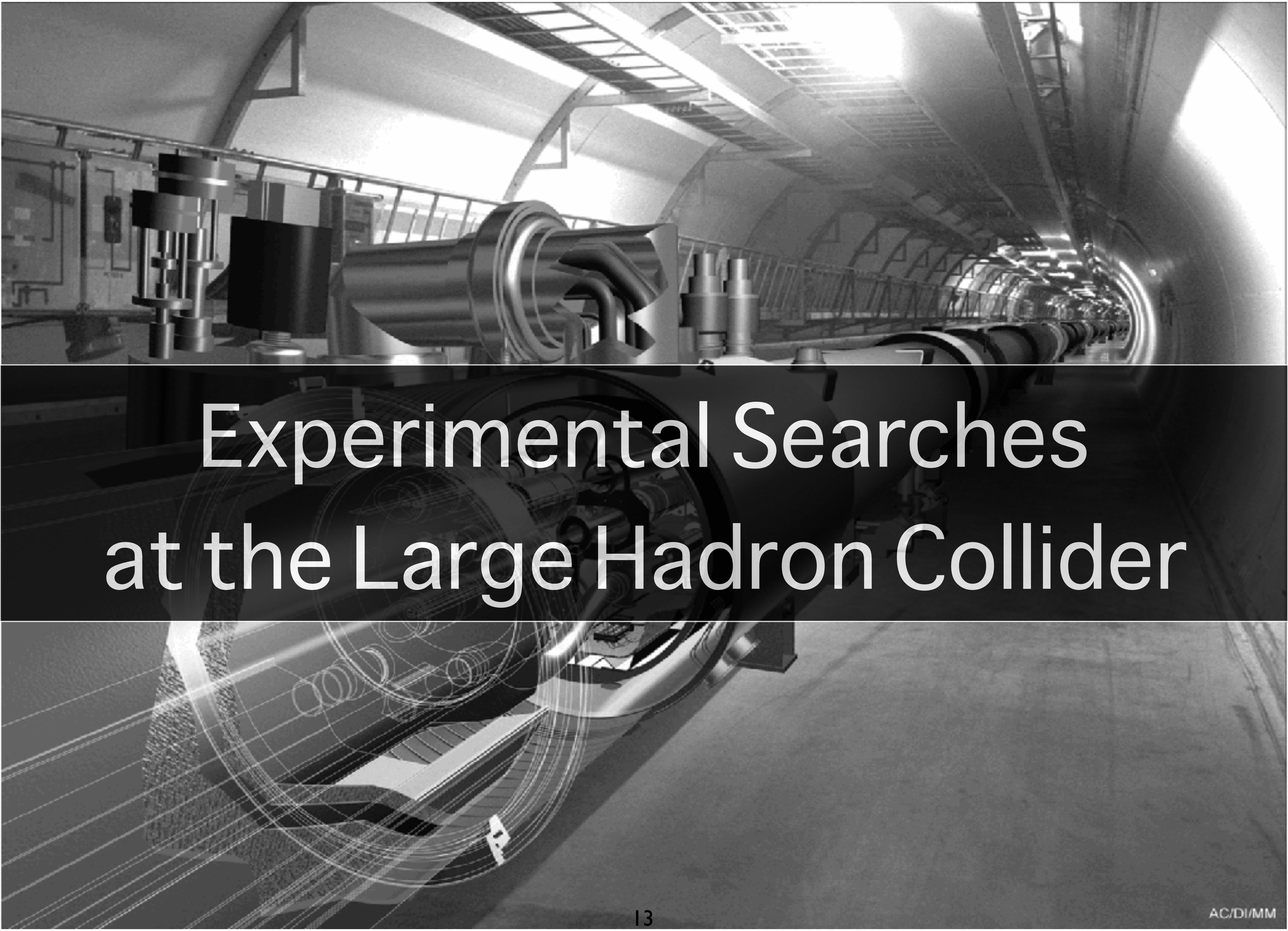
Courtesy of Andreas Höcker

With SUSY:

$$m_h^2 \approx m_{h\,0}^2 + \frac{\lambda_f^2}{8\pi^2} N_c^f \left(m_{\tilde{f}}^2 - m_f^2\right) \ln\left(\Lambda^2/m_{\tilde{f}}^2\right)$$

↑

Ideally, small mass difference btw.
SM and SUSY partner particles.
→ Expect SUSY particles close to weak scale.



Experimental Searches at the Large Hadron Collider

Large Hadron Collider (LHC)

proton-proton (also HI) collisions

Run1: 2010-2012, centre-of-mass energy 7 then 8 TeV

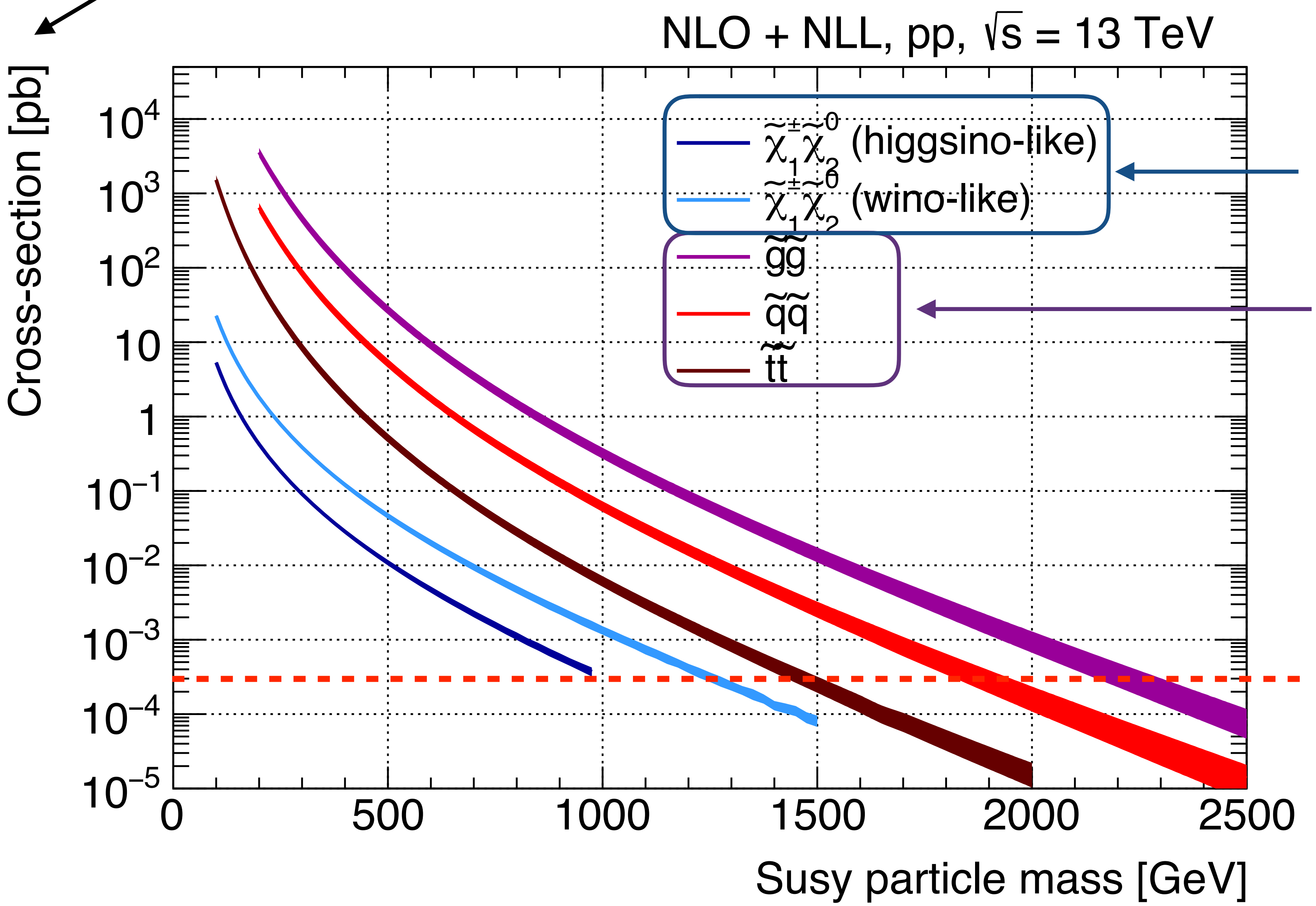
Run2: 2015-2018, centre-of-mass energy 13 TeV

2 general purpose detectors

SUSY particle production

Number of collisions events with SUSY particles

= cross-section (physics) x ∫ luminosity (LHC machine, beam)



SUSY particles w/o color charge, electroweak production

SUSY particles with color charge, strong production

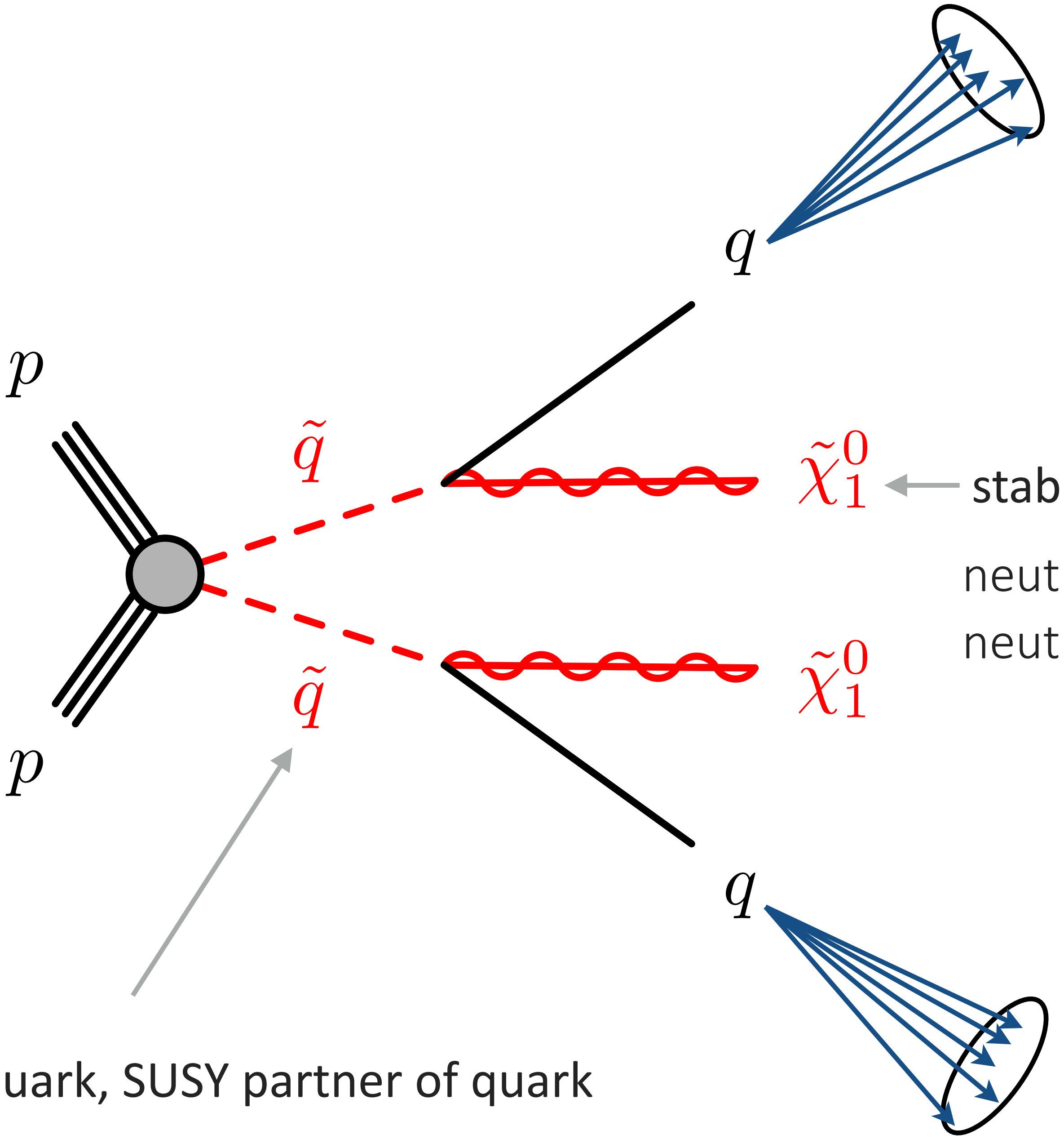
10 events in 2015+2016 LHC dataset (per experiment)

using $\int$luminosity=36 fb^{-1}

SUSY particle cross sections

[NLO + NLL Tool, C. Borschensky et al]

Example squark production and decay



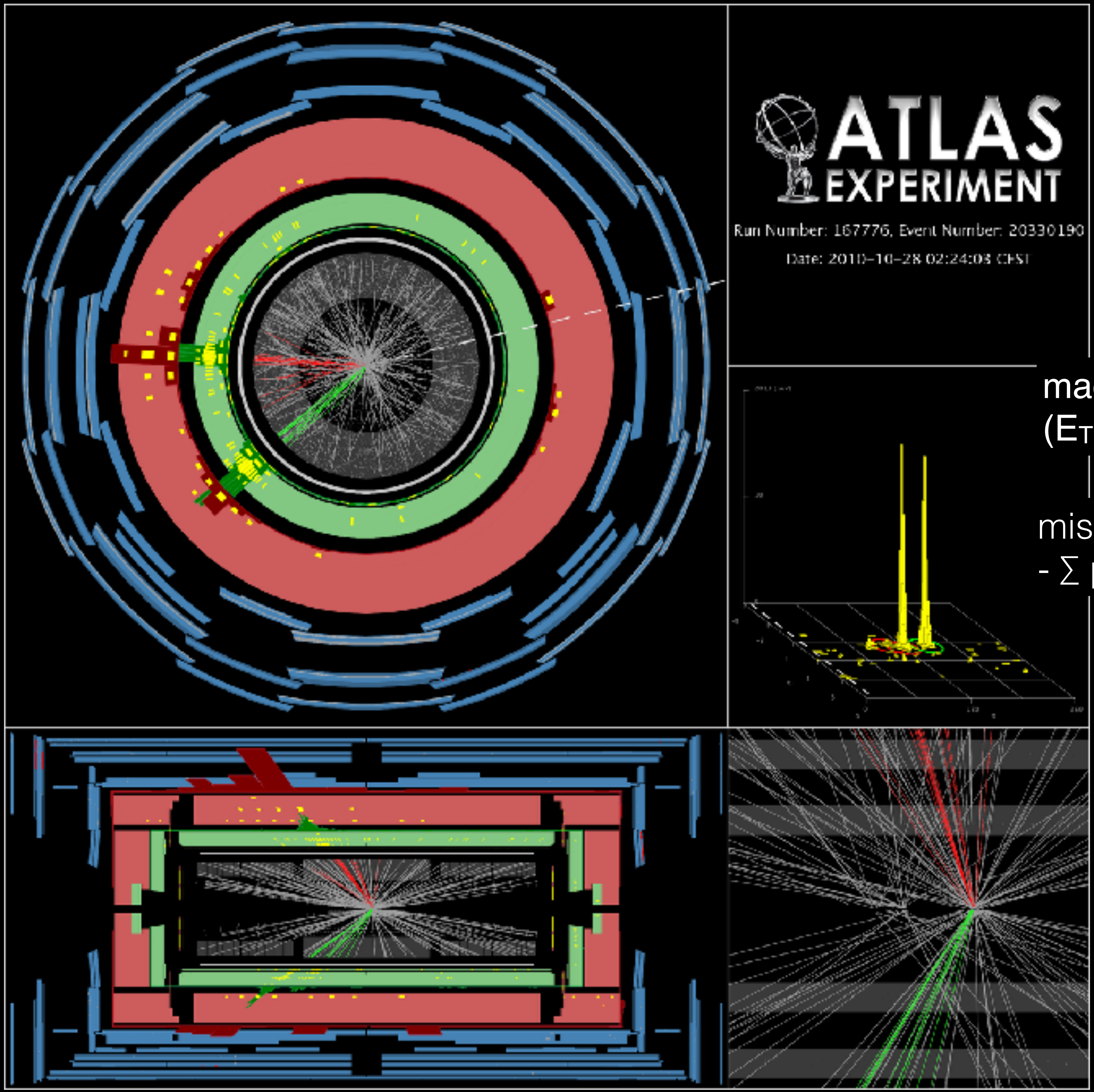
jet = collimated spray of particles

stable Lightest SUSY Particle (LSP) is **dark matter** candidate.

neutral and weakly interacting, behaves like a stable heavy neutrino that will escape the detector without being detected.

squark, SUSY partner of quark

Candidate event picked up in 2010 dataset



Two jets each with transverse momentum (pT) of ~170 GeV

mag(missing transverse momentum) (E_T^{miss}) ~330 GeV.

missing transverse momentum =
$- \sum p_T$(all visible particles in detector)

transverse: momentum along beam direction unknown in initial state in *pp* collisions.

All-hadronic search for squarks and gluinos

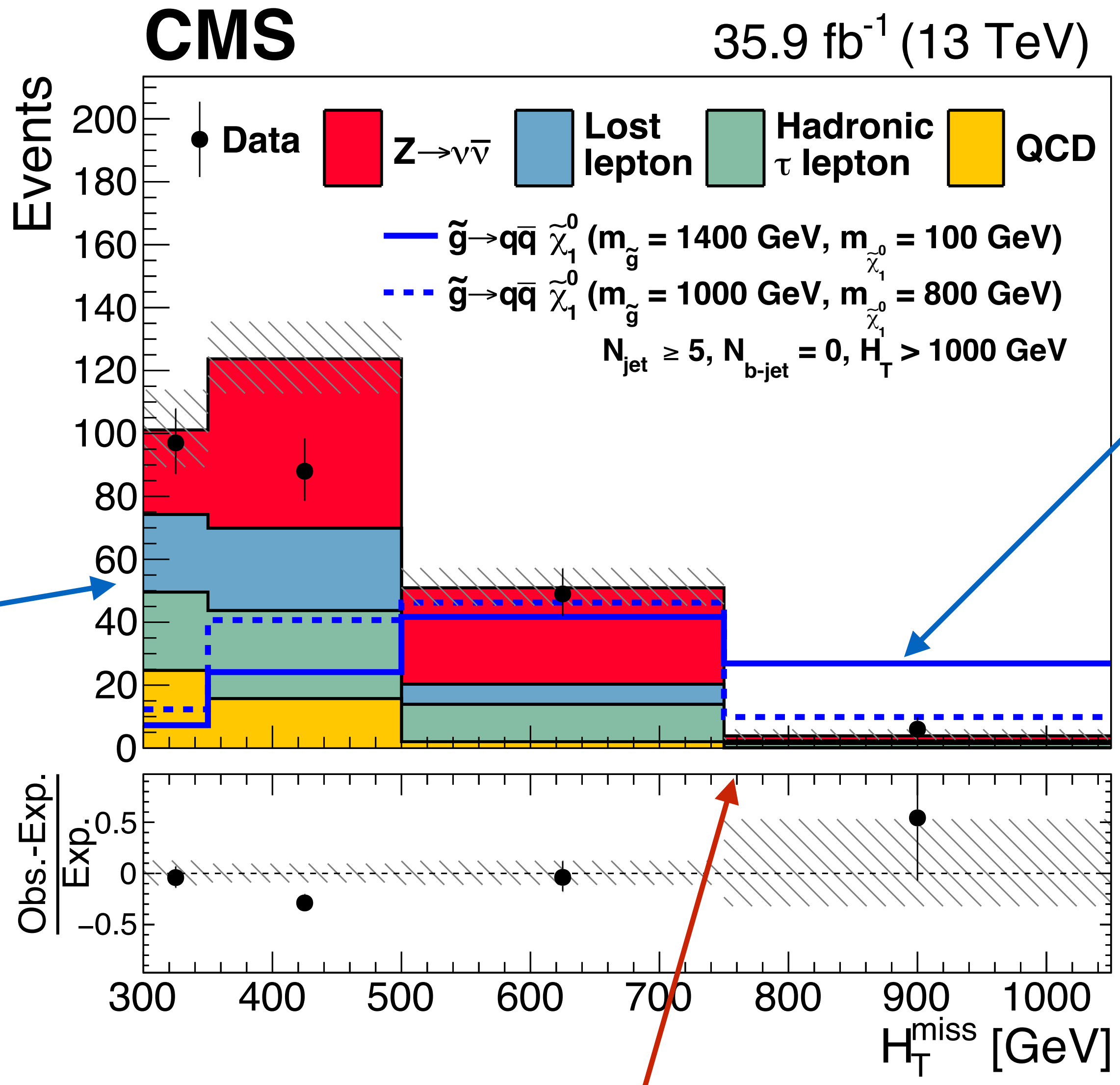
Trigger on missing transverse momentum (E_T^{miss},H_T^{miss})

online selection,
record data on tape

Veto events with identified electrons and muons

Require several jets with high momentum, large E_T^{miss},
large effective mass $m_{eff} = \sum p_T(\text{jets}) + E_T^{miss}$

separate signal
from background



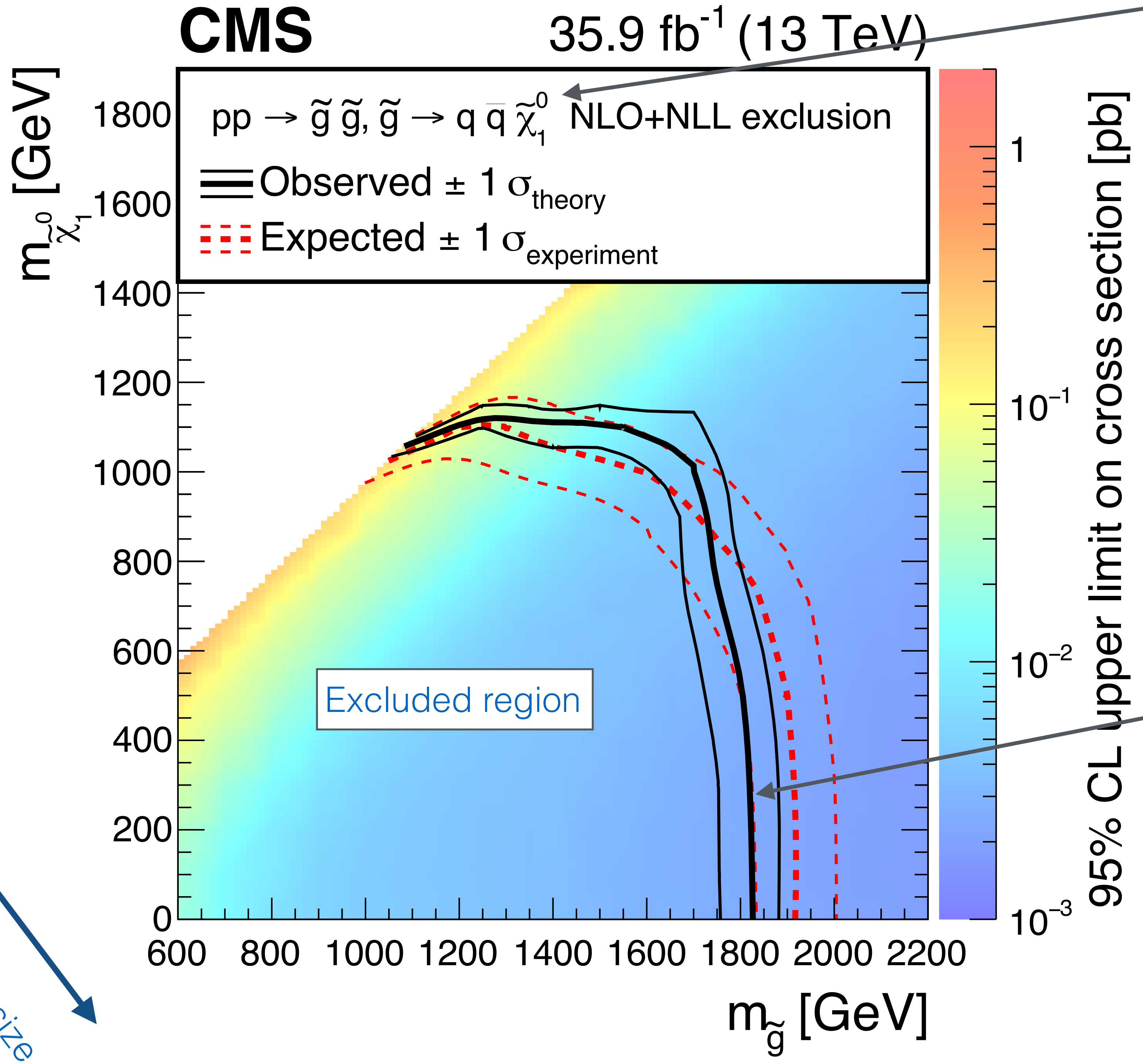
0L + jets with MHT
PRD 96 (2017) 032003

Expectation from a signal model

Critical to have robust
background estimation

Select events with characteristic SUSY signature and unlikely due to background.
Compare event count with background prediction.

Statistical Interpretation



simplified SUSY model

LSP (~DM) mass

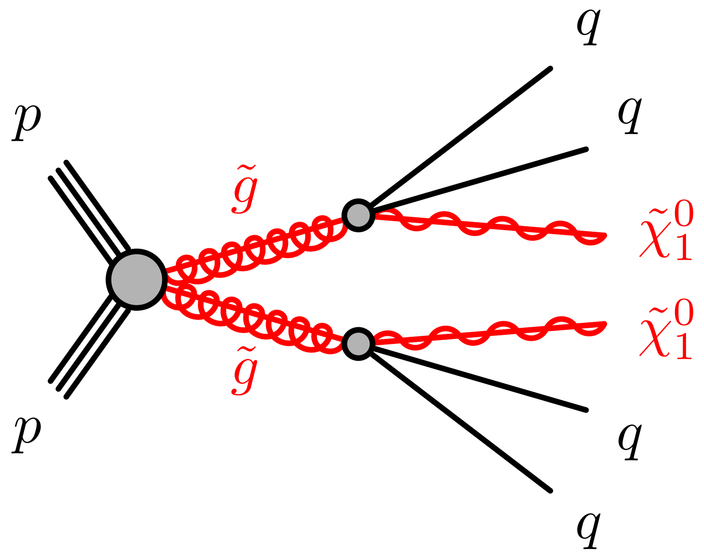
Excluded region

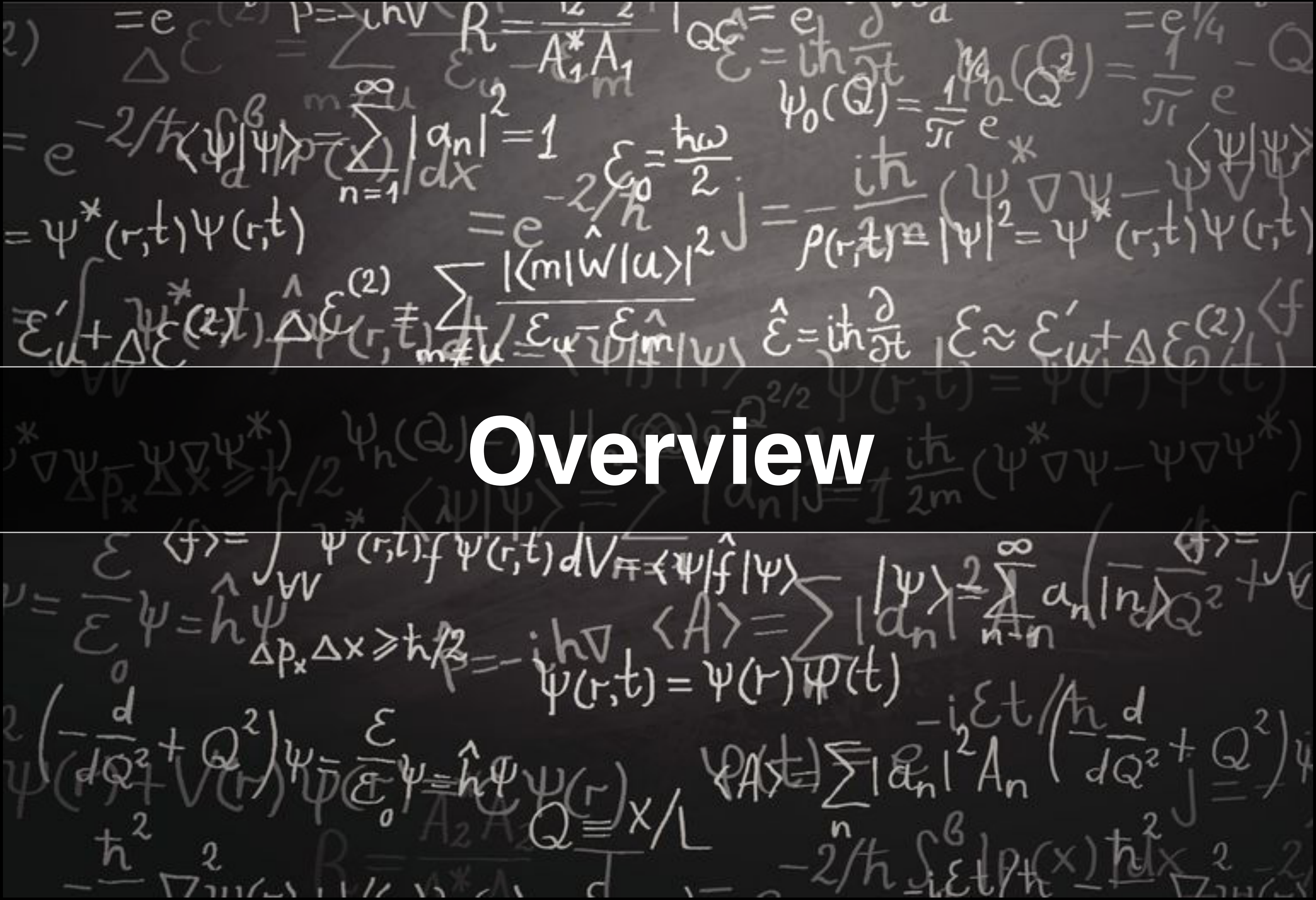
Observed UL @ 95% CL
(pred. cross-section = UL)

gluino mass

jet momenta, size of E_T^{miss}

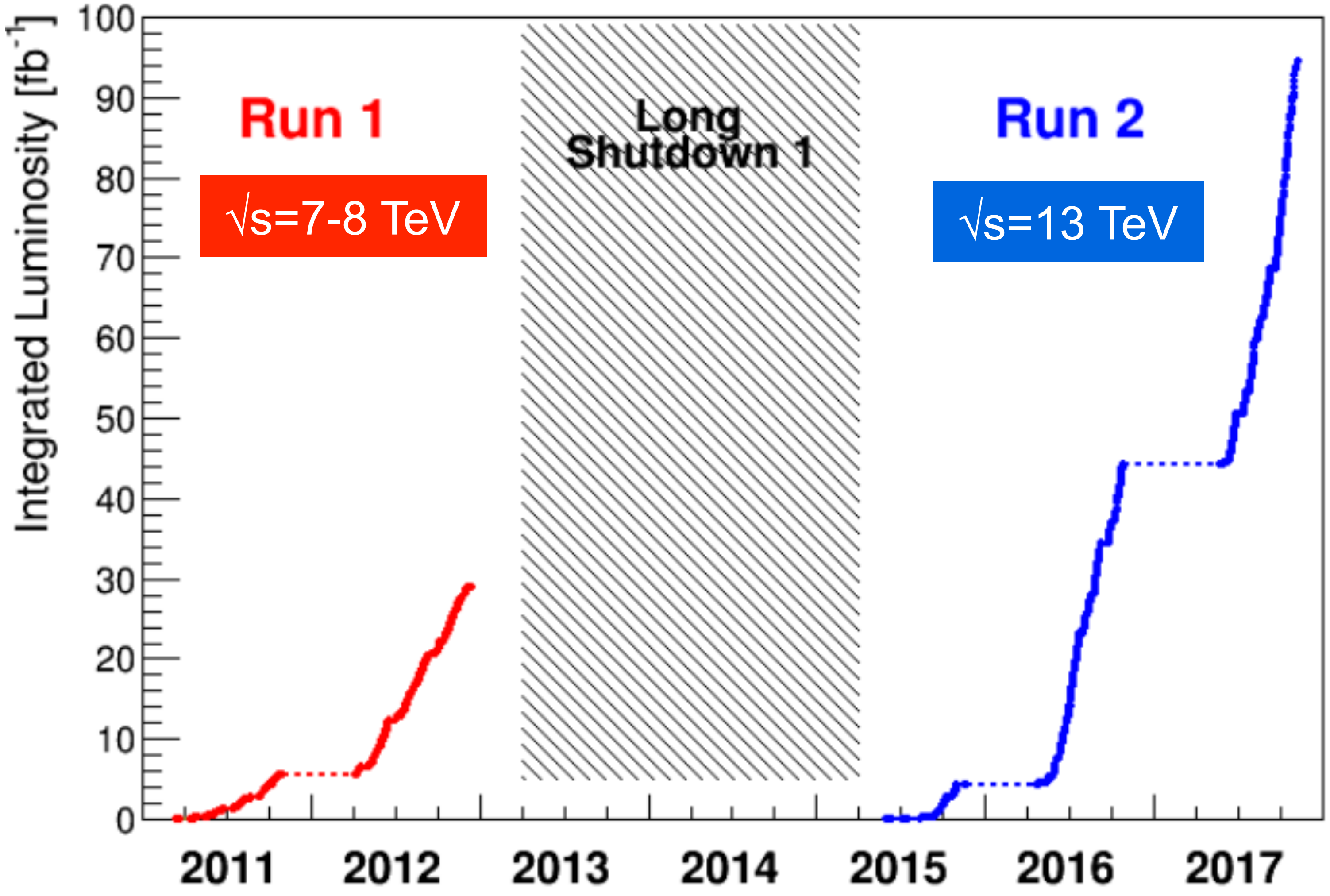
production cross-section





Overview

Huge LHC sample of proton-proton collisions

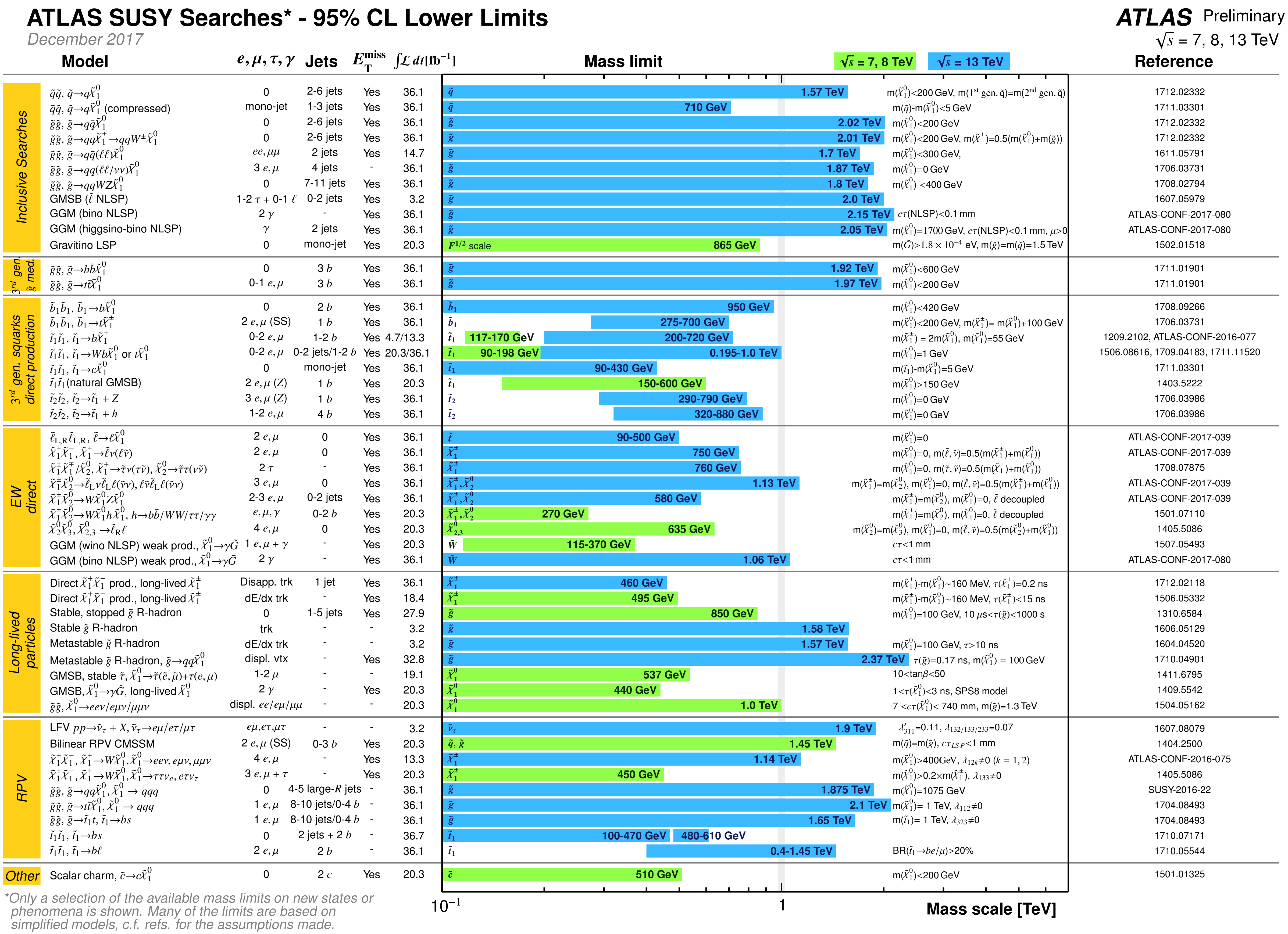


LHC peak luminosity ~2 x 10^{34} cm^{-2}s^{-1} (design 1 x 10^{34})

√s=8 TeV dataset (2012): 5M top quark pairs, 0.4M Higgs bosons, and would expect 2.1M (500) gluino pairs @ 300 GeV (1 TeV) mass,

√s=13 TeV dataset (2015-2017): 75M top quark pairs, 4.5M Higgs bosons, and would expect 30k (90) gluino pairs @ 1 TeV (2 TeV) mass

Large SUSY search program @ LHC



ATLAS SUSY Searches* - 95% CL Lower Limits

December 2017

ATLAS Preliminary

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

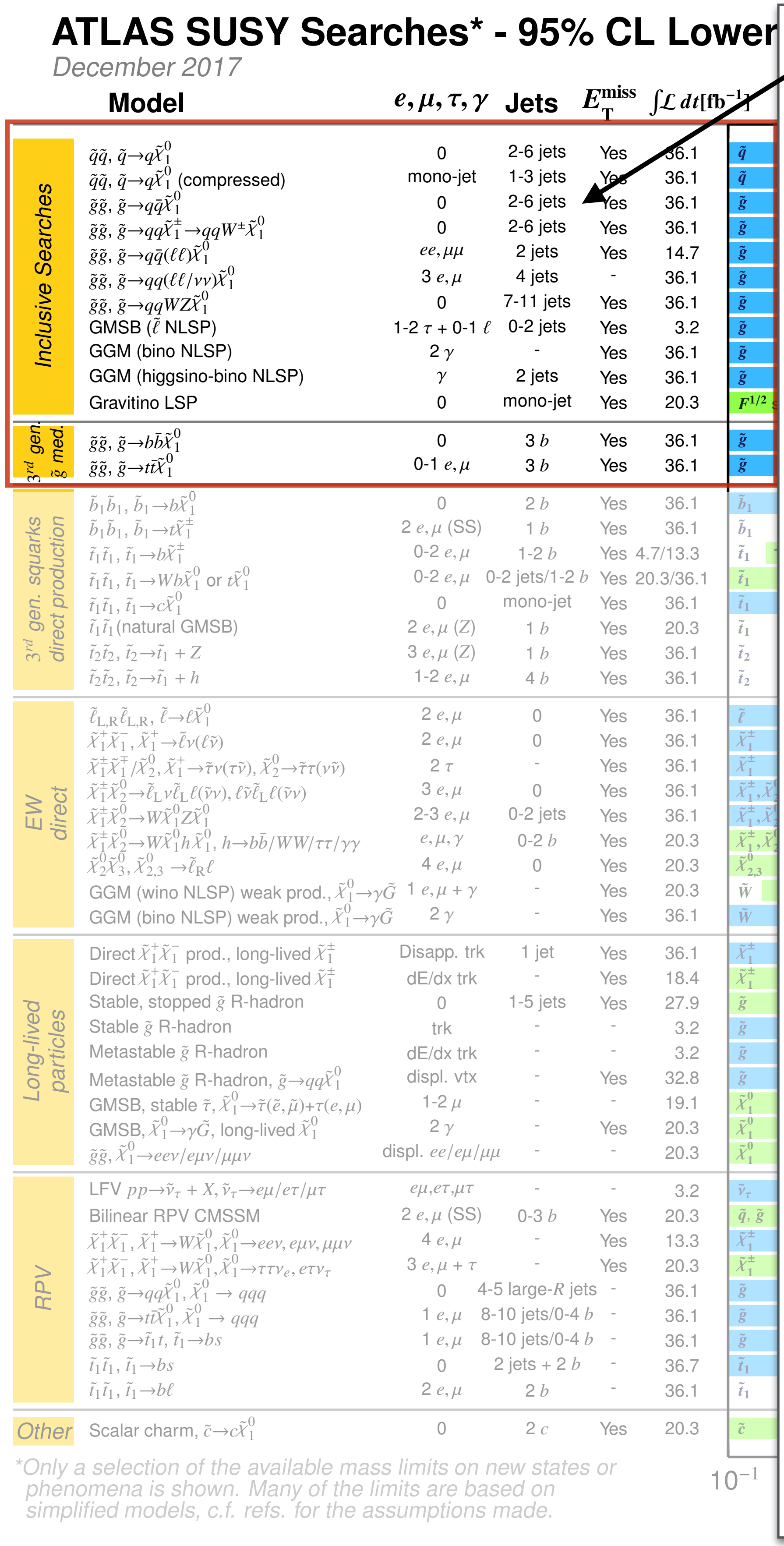
🟩 $\sqrt{s}$ = 7, 8 TeV

🟦 $\sqrt{s}$ = 13 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	🟦 $\tilde{q}$ 1.57 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m(1^{st} gen. $\tilde{q}$)=m(2^{nd} gen. $\tilde{q}$)	1712.02332
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	36.1	🟦 $\tilde{q}$ 710 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<5 GeV	1711.03301
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	🟦 $\tilde{g}$ 2.02 TeV	m($\tilde{\chi}_1^0$)<200 GeV	1712.02332
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	🟦 $\tilde{g}$ 2.01 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	1712.02332
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets	Yes	14.7	🟦 $\tilde{g}$ 1.7 TeV	m($\tilde{\chi}_1^0$)<300 GeV,	1611.05791
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e, μ	4 jets	-	36.1	🟦 $\tilde{g}$ 1.87 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1706.03731
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	🟦 $\tilde{g}$ 1.8 TeV	m($\tilde{\chi}_1^0$) <400 GeV	1708.02794
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	🟦 $\tilde{g}$ 2.0 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	36.1	🟦 $\tilde{g}$ 2.15 TeV	$c\tau$(NLSP)<0.1 mm	ATLAS-CONF-2017-080
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	36.1	🟦 $\tilde{g}$ 2.05 TeV	m($\tilde{\chi}_1^0$)=1700 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2017-080
	Gravitino LSP	0	mono-jet	Yes	20.3	🟩 $F^{1/2}$ scale 865 GeV	m($\tilde{G}$)>1.8×10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	🟦 $\tilde{g}$ 1.92 TeV	m($\tilde{\chi}_1^0$)<600 GeV	1711.01901
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	36.1	🟦 $\tilde{g}$ 1.97 TeV	m($\tilde{\chi}_1^0$)<200 GeV	1711.01901
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	🟦 $\tilde{b}_1$ 950 GeV	m($\tilde{\chi}_1^0$)<420 GeV	1708.09266
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$ 🟦 275-700 GeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}_1^\pm$)= m($\tilde{\chi}_1^0$)+100 GeV	1706.03731
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e, μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 🟩 117-170 GeV 🟦 200-720 GeV	m($\tilde{\chi}_1^\pm$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3/36.1	🟩 $\tilde{t}_1$ 90-198 GeV 🟦 0.195-1.0 TeV	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	36.1	🟦 $\tilde{t}_1$ 90-430 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)=5 GeV	1711.03301
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 🟩 150-600 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$ 🟦 290-790 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1706.03986
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + h$	1-2 e, μ	4 b	Yes	36.1	$\tilde{t}_2$ 🟦 320-880 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1706.03986
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	36.1	🟦 $\tilde{\ell}$ 90-500 GeV	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	36.1	🟦 $\tilde{\chi}_1^\pm$ 750 GeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	🟦 $\tilde{\chi}_1^\pm$ 760 GeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1708.07875
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	36.1	🟦 $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 1.13 TeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	36.1	🟦 $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 580 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	🟩 $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 270 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	🟩 $\tilde{\chi}_{2,3}^0$ 635 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 e, μ + γ	-	Yes	20.3	$\tilde{W}$ 🟩 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	2 γ	-	Yes	36.1	🟦 $\tilde{W}$ 1.06 TeV	$c\tau$<1 mm	ATLAS-CONF-2017-080
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	🟦 $\tilde{\chi}_1^\pm$ 460 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)=0.2 ns	1712.02118
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	🟩 $\tilde{\chi}_1^\pm$ 495 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	🟩 $\tilde{g}$ 850 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	🟦 $\tilde{g}$ 1.58 TeV		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	🟦 $\tilde{g}$ 1.57 TeV	m($\tilde{\chi}_1^0$)=100 GeV, τ>10 ns	1604.04520
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$	displ. vtx	-	Yes	32.8	🟦 $\tilde{g}$ 2.37 TeV	τ($\tilde{g}$)=0.17 ns, m($\tilde{\chi}_1^0$) = 100 GeV	1710.04901
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	19.1	🟩 $\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	🟩 $\tilde{\chi}_1^0$ 440 GeV	1<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	🟩 $\tilde{\chi}_1^0$ 1.0 TeV	7 <$c\tau$($\tilde{\chi}_1^0$)< 740 mm, m($\tilde{g}$)=1.3 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 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	🟩 $\tilde{q}, \tilde{g}$ 1.45 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e, μ	-	Yes	13.3	🟦 $\tilde{\chi}_1^\pm$ 1.14 TeV	m($\tilde{\chi}_1^0$)>400GeV, $\lambda_{12k}\neq0$ ($k = 1, 2$)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 e, μ + τ	-	Yes	20.3	🟩 $\tilde{\chi}_1^\pm$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	36.1	🟦 $\tilde{g}$ 1.875 TeV	m($\tilde{\chi}_1^0$)=1075 GeV	SUSY-2016-22
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e, μ	8-10 jets/0-4 b	-	36.1	🟦 $\tilde{g}$ 2.1 TeV	m($\tilde{\chi}_1^0$)= 1 TeV, $\lambda_{112}\neq0$	1704.08493
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	1 e, μ	8-10 jets/0-4 b	-	36.1	🟦 $\tilde{g}$ 1.65 TeV	m($\tilde{t}_1$)= 1 TeV, $\lambda_{323}\neq0$	1704.08493
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	36.7	🟦 $\tilde{t}_1$ 100-470 GeV 🟦 480-610 GeV		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 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	1710.05544
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	🟩 $\tilde{c}$ 510 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

*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.

Large SUSY search program @ LHC



ATLAS SUSY Searches* - 95% CL Lower

December 2017

	Model	e, μ, τ, γ	**Jets**	E_T^{miss}	$\int \mathcal{L}\, dt[\text{fb}^{-1}]$	
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{q}$
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	36.1	$\tilde{q}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets	Yes	14.7	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e, μ	4 jets	-	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	$\tilde{g}$
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$
	GGM (bino NLSP)	2 γ	-	Yes	36.1	$\tilde{g}$
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	36.1	$\tilde{g}$
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	36.1	$\tilde{g}$
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	0-2 e, μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	36.1	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + h$	1-2 e, μ	4 b	Yes	36.1	$\tilde{t}_2$
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	36.1	$\tilde{\ell}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm}$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}_1^{\pm}$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	36.1	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2$
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 $e, \mu + \gamma$	-	Yes	20.3	$\tilde{W}$
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	2 γ	-	Yes	36.1	$\tilde{W}$
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^{\pm}$
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$	displ. vtx	-	Yes	32.8	$\tilde{g}$
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to eev/e\mu v/\mu\mu v$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$
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	$\tilde{\nu}_\tau$
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e, μ	-	Yes	13.3	$\tilde{\chi}_1^{\pm}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	36.7	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e, μ	2 b	-	36.1	$\tilde{t}_1$
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$

*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.

Searches for squarks and gluinos

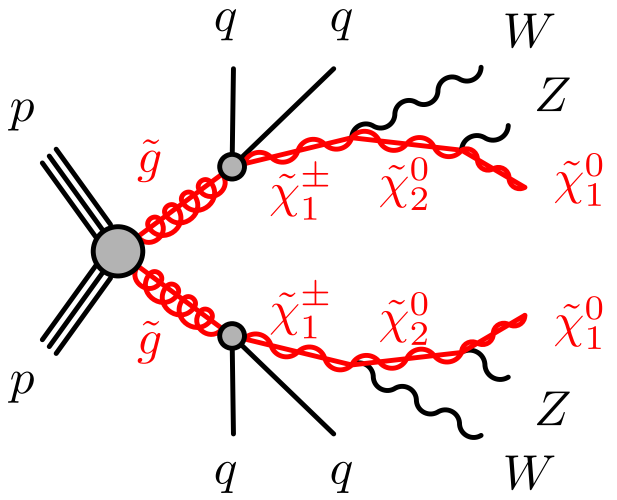
Example diagrams

jets + E_T^{miss}

cascade decays often yield leptons

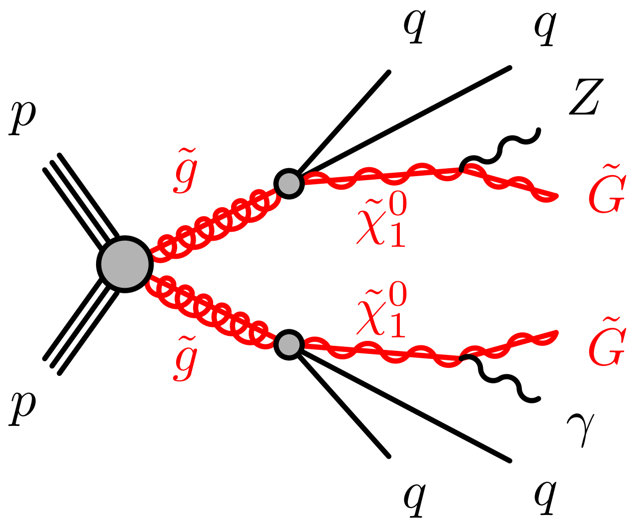
jets + el/mu + E_T^{miss}

jets + tau + E_T^{miss}



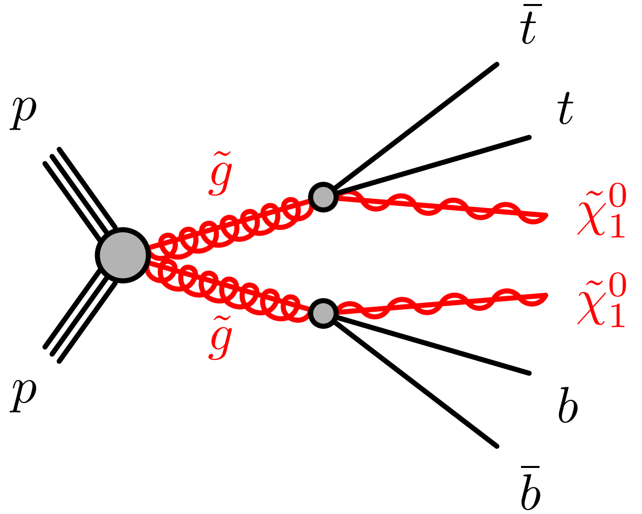
decays to Gravitinos can yield photons

jets + photon(s) + E_T^{miss}

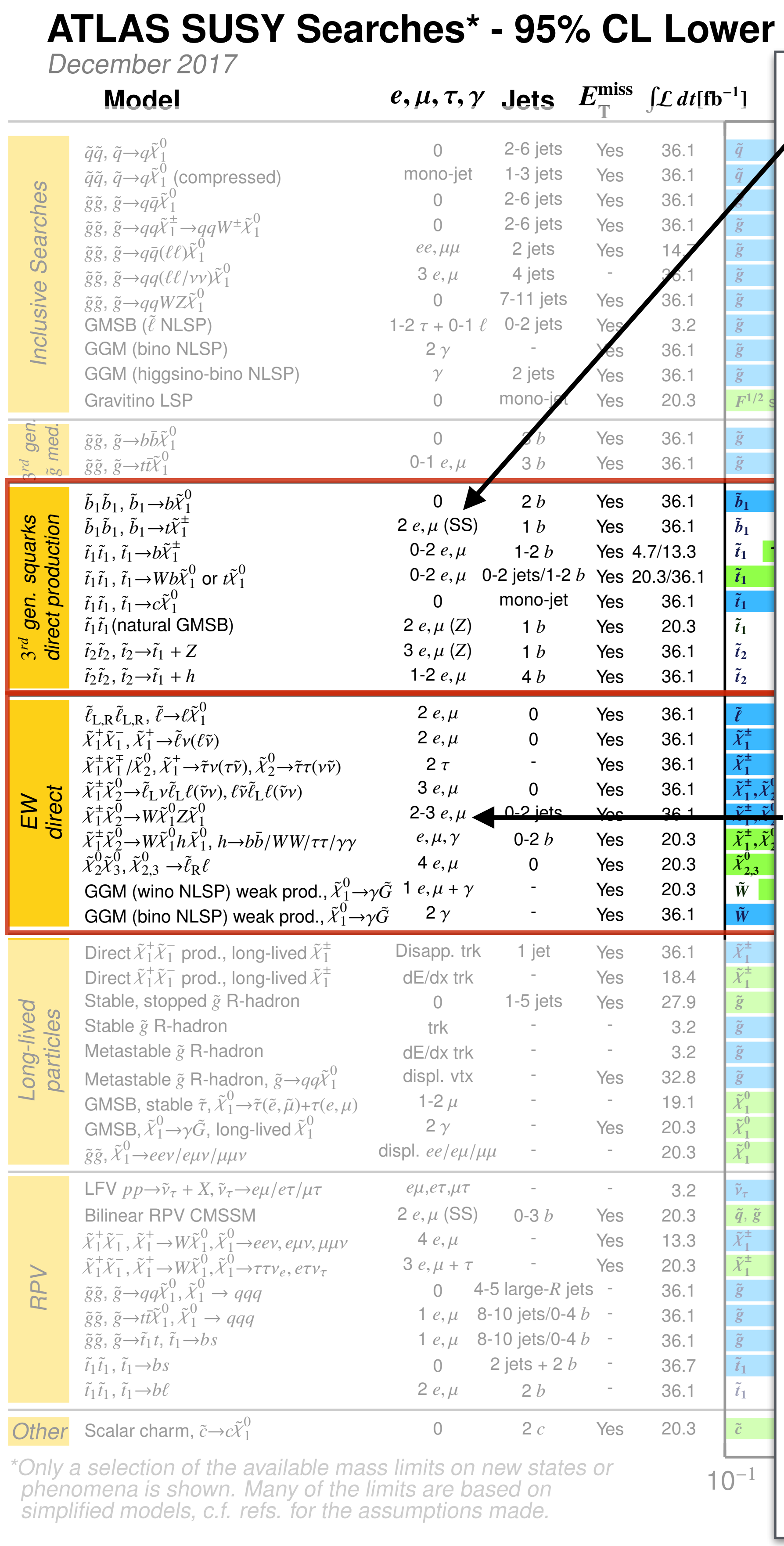


decays can yield top & bottom quarks (natural SUSY)

jets + b-tags + (leptons) + E_T^{miss}



Large SUSY search program @ LHC



ATLAS SUSY Searches* - 95% CL Lower Limits

December 2017

ATLAS Preliminary

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{q}$
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	36.1	$\tilde{q}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets	Yes	14.7	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e, μ	4 jets	-	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	$\tilde{g}$
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$
	GGM (bino NLSP)	2 γ	-	Yes	36.1	$\tilde{g}$
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	36.1	$\tilde{g}$
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	36.1	$\tilde{g}$
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	0-2 e, μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	36.1	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + h$	1-2 e, μ	4 b	Yes	36.1	$\tilde{t}_2$
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	36.1	$\tilde{\ell}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm}$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}_1^{\pm}$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	36.1	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 e, μ + γ	-	Yes	20.3	$\tilde{W}$
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	2 γ	-	Yes	36.1	$\tilde{W}$
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^{\pm}$
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$	displ. vtx	-	Yes	32.8	$\tilde{g}$
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$
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	$\tilde{\nu}_\tau$
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e, μ	-	Yes	13.3	$\tilde{\chi}_1^{\pm}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 e, μ + τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	36.7	$\tilde{t}_1$
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e, μ	2 b	-	36.1	$\tilde{t}_1$
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$

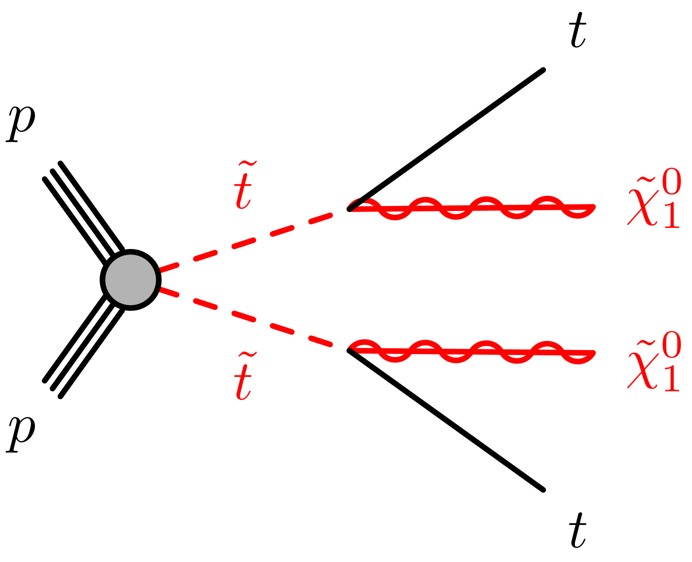
**Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*

Dedicated search program for stop & sbottom production

Example diagrams

top quark pair + E_T^{miss}

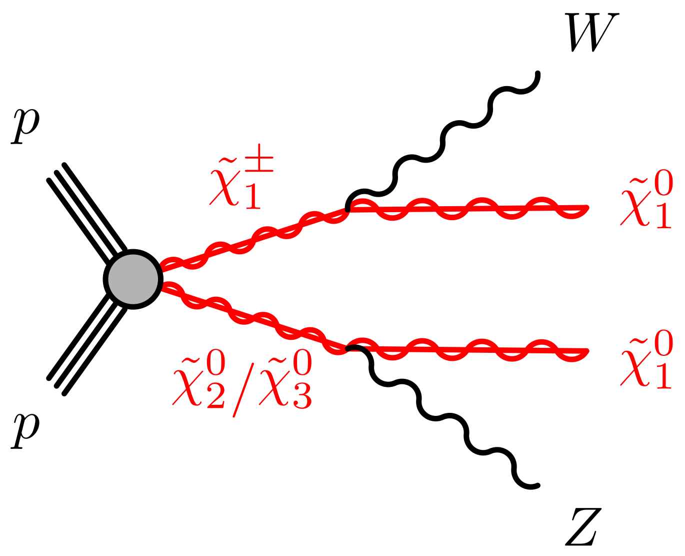
and more complex signatures



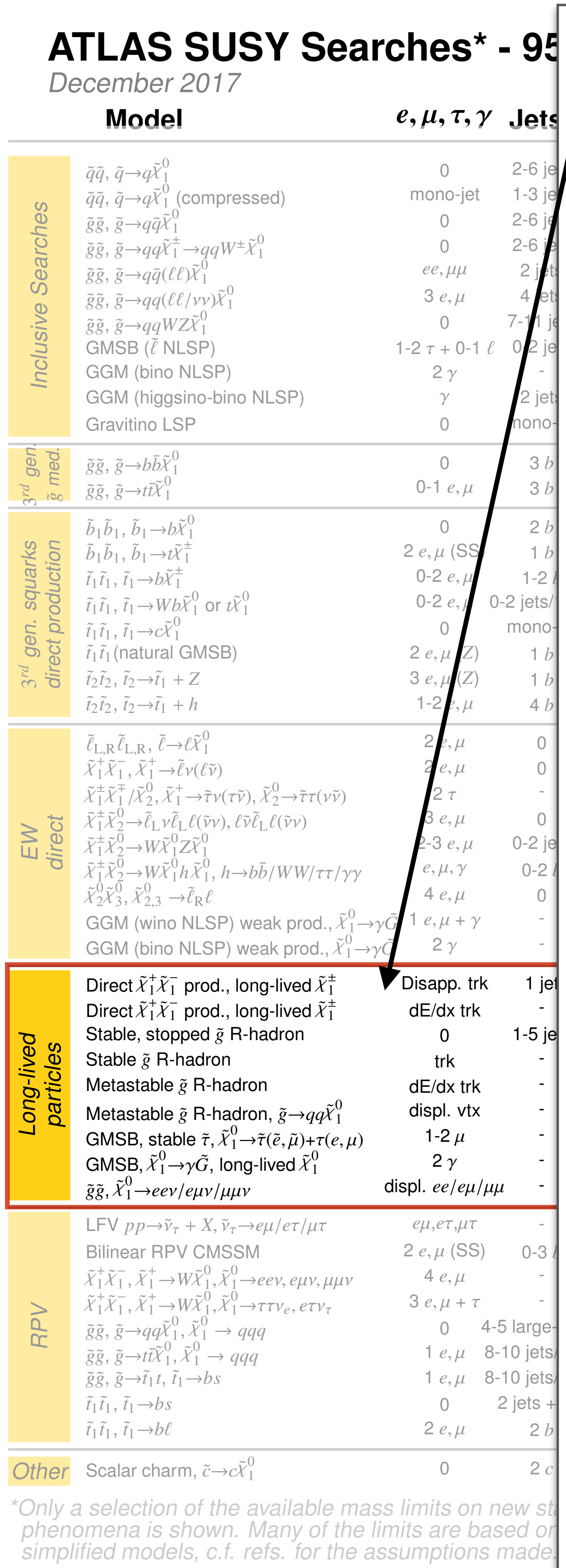
Dedicated search program for electroweak production: charginos, neutralinos, sleptons

di-boson + E_T^{miss}

and more complex signatures



Large SUSY search program @ LHC



ATLAS SUSY Searches* - 95

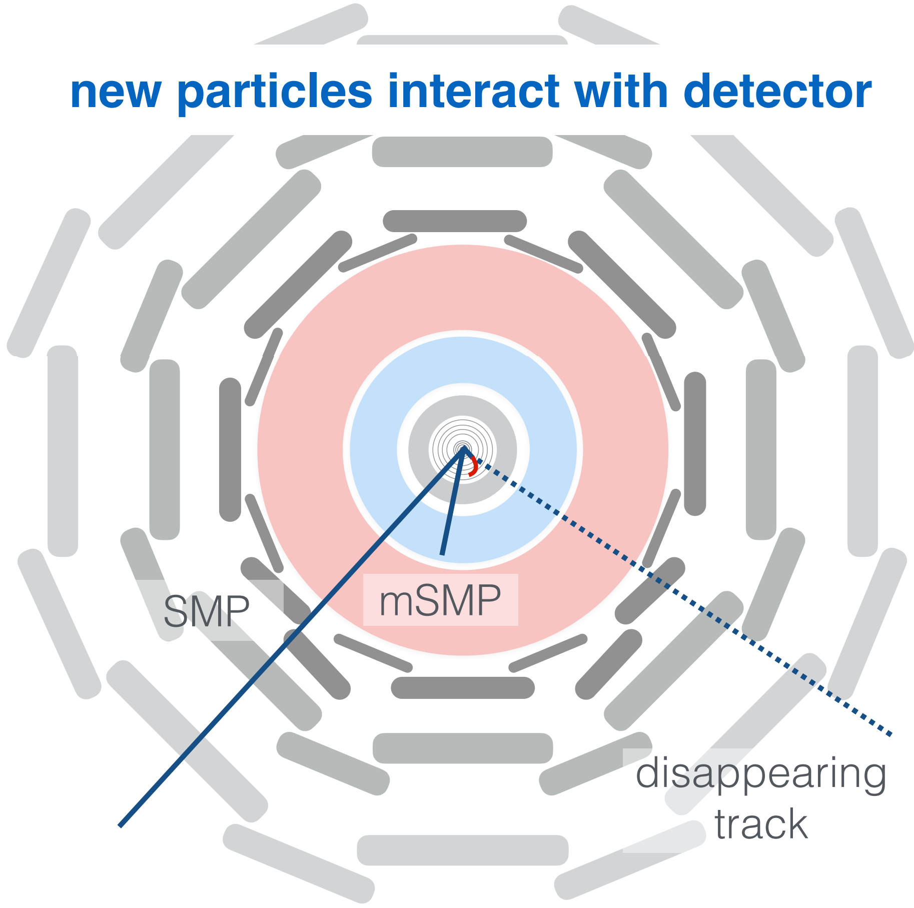
December 2017

	Model	e, μ, τ, γ	Jets
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 je
	$\tilde{q}\tilde{q}, \tilde{q}\rightarrow q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 je
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 je
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	0	2-6 je
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e, μ	4 jets
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qqWZ\tilde{\chi}_1^0$	0	7-11 je
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 je
	GGM (bino NLSP)	2 γ	-
	GGM (higgsino-bino NLSP)	γ	2 jets
	Gravitino LSP	0	mono-
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	1 b
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	0-2 e, μ	1-2 b
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	0	mono-
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\rightarrow\tilde{t}_1 + Z$	3 e, μ (Z)	1 b
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\rightarrow\tilde{t}_1 + h$	1-2 e, μ	4 b
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e, μ	0
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0, \tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu}), \tilde{\chi}_2^0\rightarrow\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 je
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h\rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\rightarrow\tilde{\ell}_R\ell$	4 e, μ	0
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$	1 $e, \mu + \gamma$	-
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$	2 γ	-
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 je
	Stable $\tilde{g}$ R-hadron	trk	-
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\rightarrow qq\tilde{\chi}_1^0$	displ. vtx	-
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0\rightarrow ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-
RPV	LFV $pp\rightarrow\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\rightarrow e\mu/e\tau/\mu\tau$	$e\mu, e\tau, \mu\tau$	-
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow ee\nu, e\mu\nu, \mu\mu\nu$	4 e, μ	-
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow\tau\tau\nu_e, e\tau\nu_\tau$	3 $e, \mu + \tau$	-
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow qqq$	0	4-5 large-
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow qqq$	1 e, μ	8-10 jets/
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow\tilde{t}_1 t, \tilde{t}_1\rightarrow bs$	1 e, μ	8-10 jets/
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow bs$	0	2 jets +
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow b\ell$	2 e, μ	2 b
Other	Scalar charm, $\tilde{c}\rightarrow c\tilde{\chi}_1^0$	0	2 c

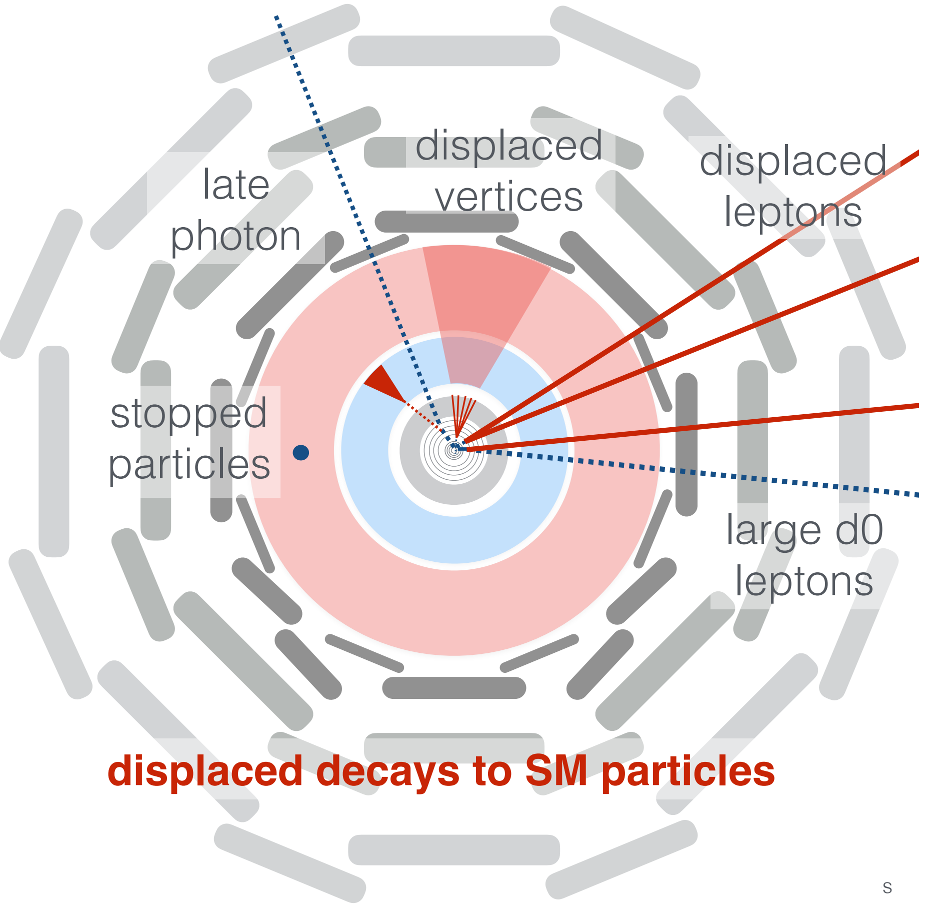
*Only a selection of the available mass limits on new st phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Long-lived particles

SUSY mechanisms:
- small couplings,
- off-shell decays,
- phase-space suppression



new particles interact with detector



displaced decays to SM particles

Sketches by Michael Adersberger

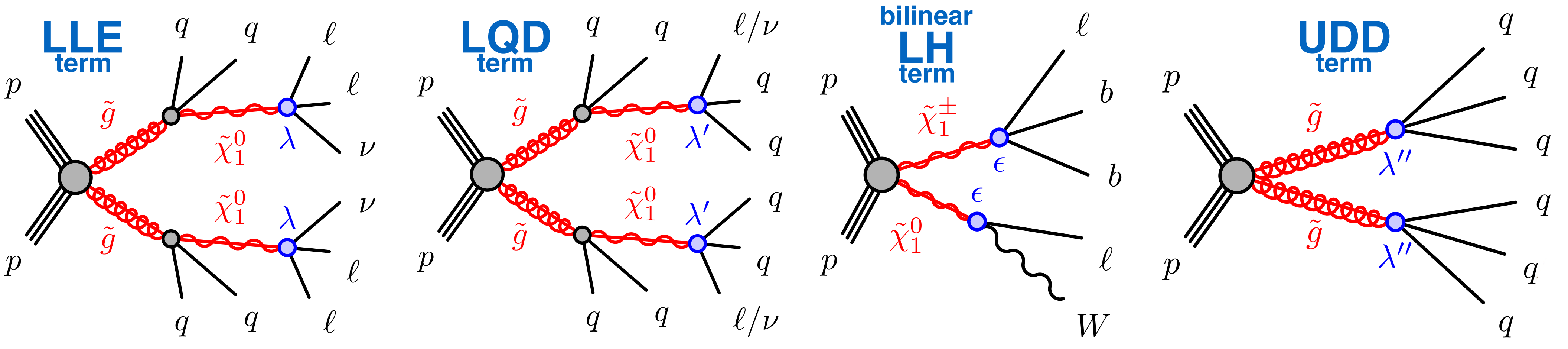
Large SUSY search program @ LHC

ATLAS SU
December 201
Model

***R*-parity violation scenarios**

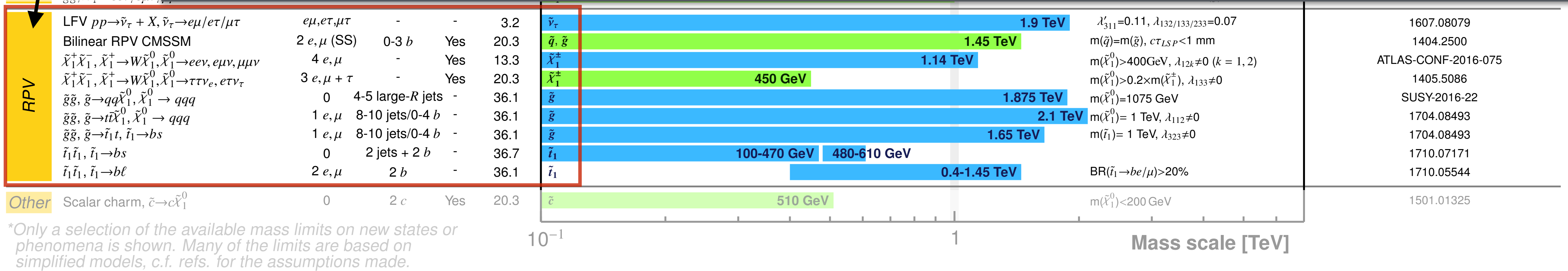
Tree-level terms in SUSY that violate *R*-parity

$$W_{RPV} = \underbrace{\underbrace{\frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c}_{\text{trilinear coupling}} + \underbrace{\kappa_iL_iH_u}_{\text{bilinear coupling}}}_{\text{lepton-number violation}} + \underbrace{\underbrace{\frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c}_{\text{trilinear coupling}}}_{\text{baryon-number violation}}$$



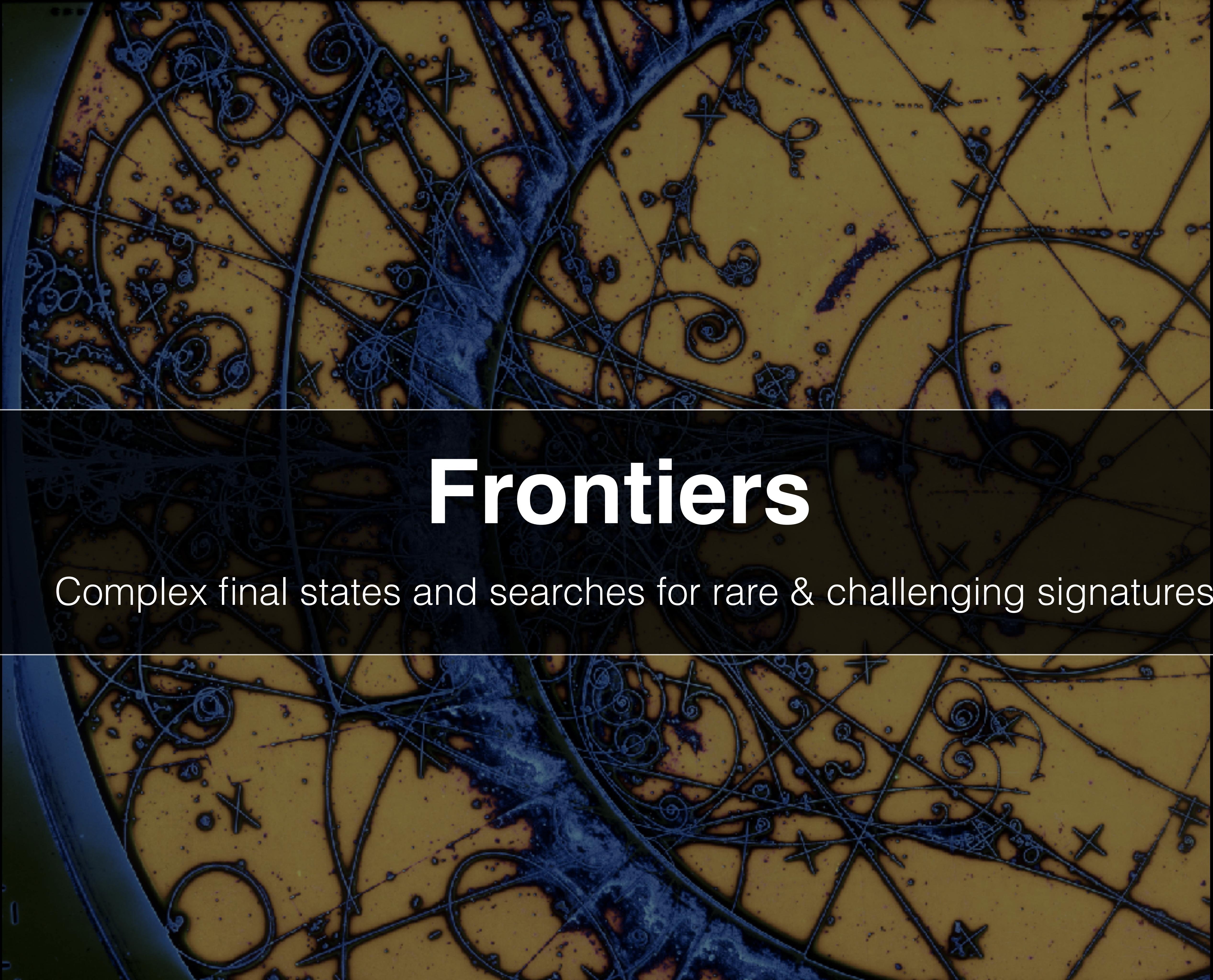
Protect proton decay by e.g. not violating B and L simultaneously.

unstable LSP → no obvious SUSY dark matter candidate,
detector signature w/o E_T^{miss}



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 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.45 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}_1^\pm$ 1.14 TeV	m($\tilde{\chi}_1^0$)>400GeV, $\lambda_{12k}\neq0$ $(k=1,2)$	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to \tau\tau\nu_e, e\tau\nu_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	36.1	$\tilde{g}$ 1.875 TeV	m($\tilde{\chi}_1^0$)=1075 GeV	SUSY-2016-22
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 2.1 TeV	m($\tilde{\chi}_1^0$)= 1 TeV, $\lambda_{112}\neq0$	1704.08493
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1t, \tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 1.65 TeV	m($\tilde{t}_1$)= 1 TeV, $\lambda_{323}\neq0$	1704.08493
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	36.7	$\tilde{t}_1$ 100-470 GeV 480-610 GeV		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 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	1710.05544
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

*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.

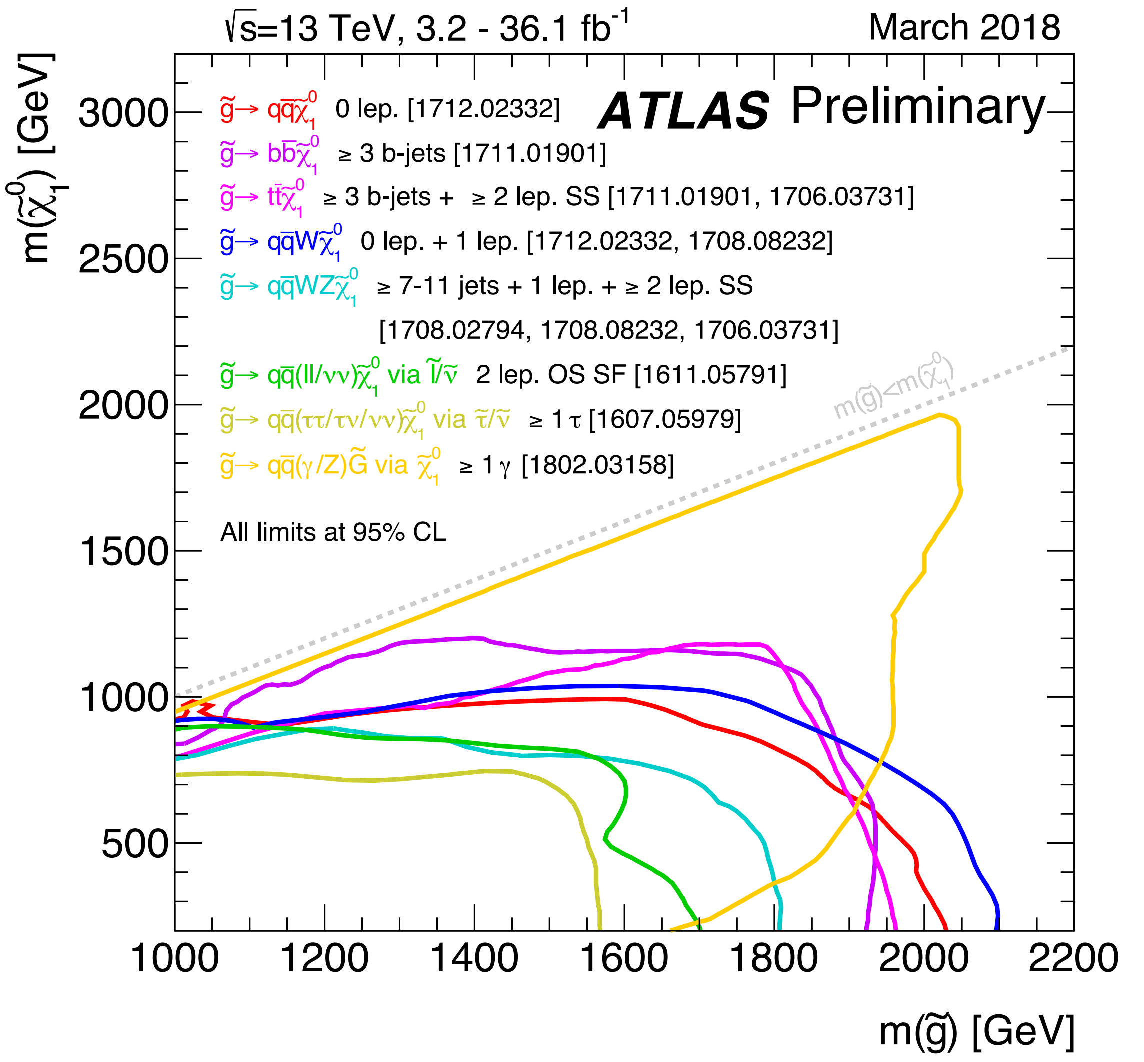


Frontiers

Complex final states and searches for rare & challenging signatures

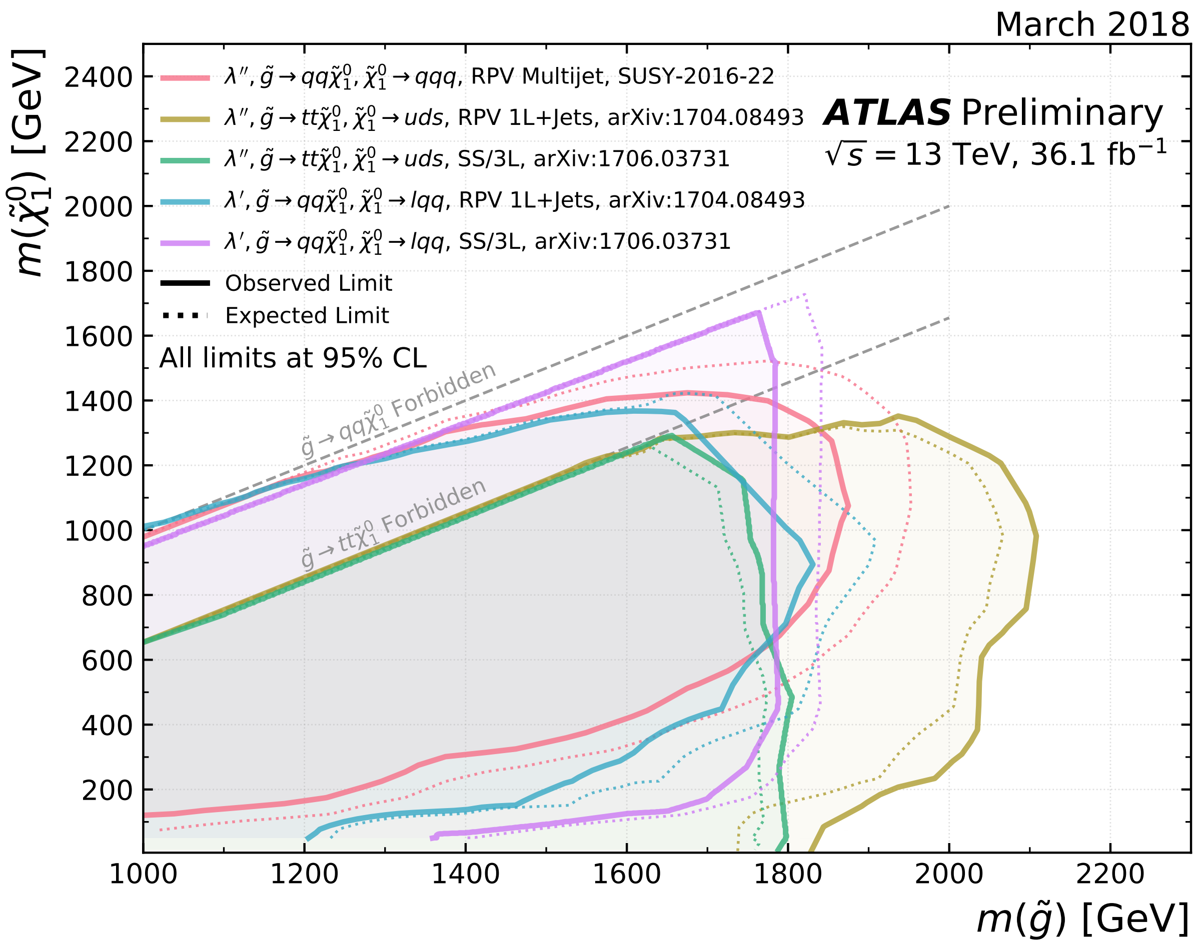
From *R*-parity conserving to *R*-parity violating

Exclusion summary for gluino searches in **RPC** SUSY (with E_T^{miss}) scenarios



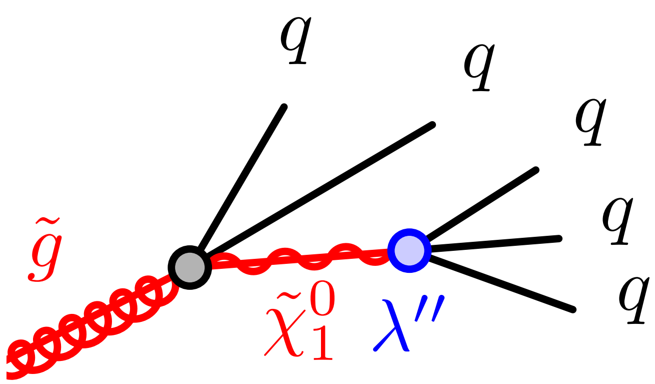
target <u>prompt</u> decays to jets + X + E_T^{miss}

Exclusion summary for gluino searches in **RPV** SUSY (without E_T^{miss}) scenarios



target <u>prompt</u> decays to jets or leptons

From *R*-parity conserving to *R*-parity violating



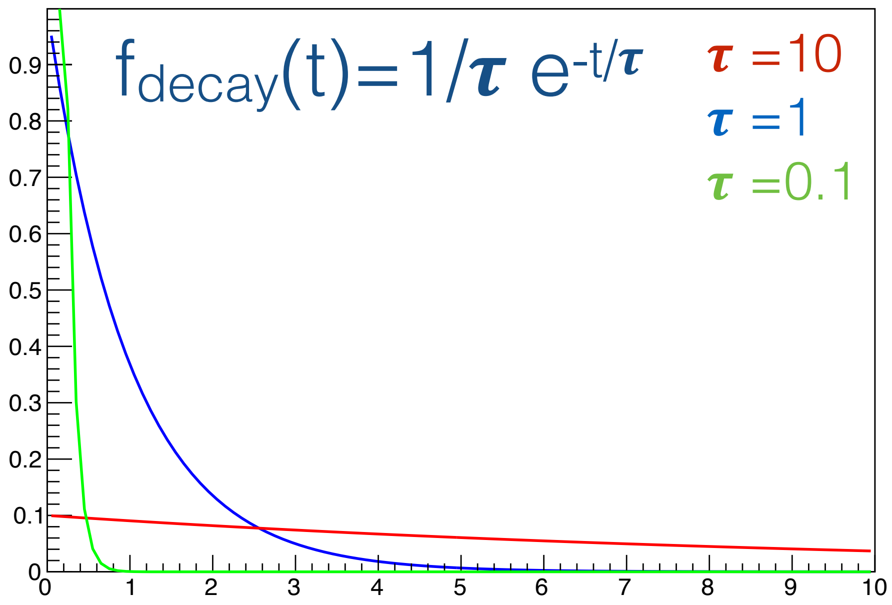
mean decay length for a bino-like lightest neutralino is approximately [Nucl. Phys. B 365 (1991) 597]:

$$L(cm) = \frac{0.9\beta\gamma}{\lambda''^2}\left(\frac{m(\tilde{q})}{100\text{ GeV}}\right)^4\left(\frac{1\text{ GeV}}{m(\tilde{\chi}_1^0)}\right)^5$$

$$\langle L\rangle = \beta\tau = \beta\gamma\tau^0$$

χ_1^0 RPV decay can be non-prompt.

No genuine E_T^{miss}

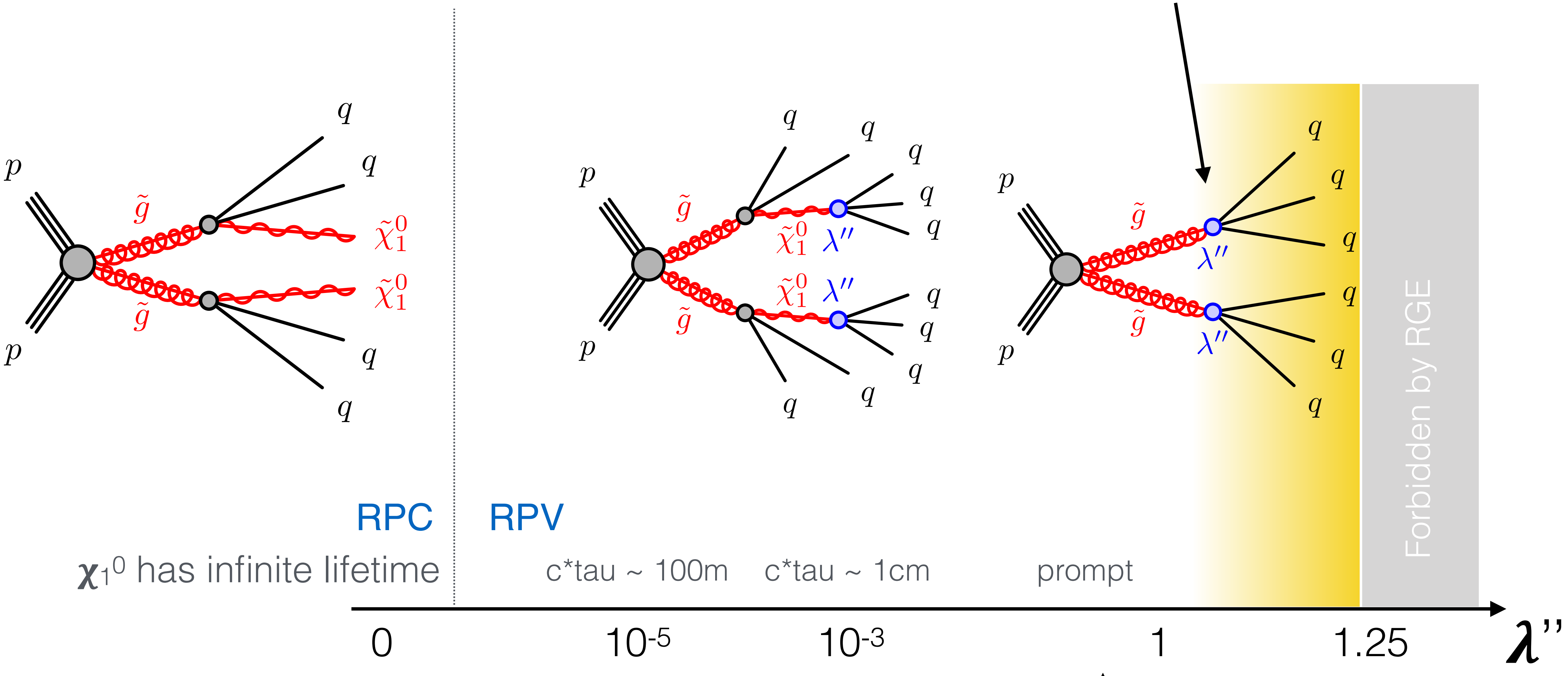


Long-lived particles search program

- typically requires large E_T^{miss} for online event selection (trigger)
- sensitivity above minimal displacement (analysis dependent)

From *R*-parity conserving to *R*-parity violating

RPV coupling large enough to make direct RPV decay competitive



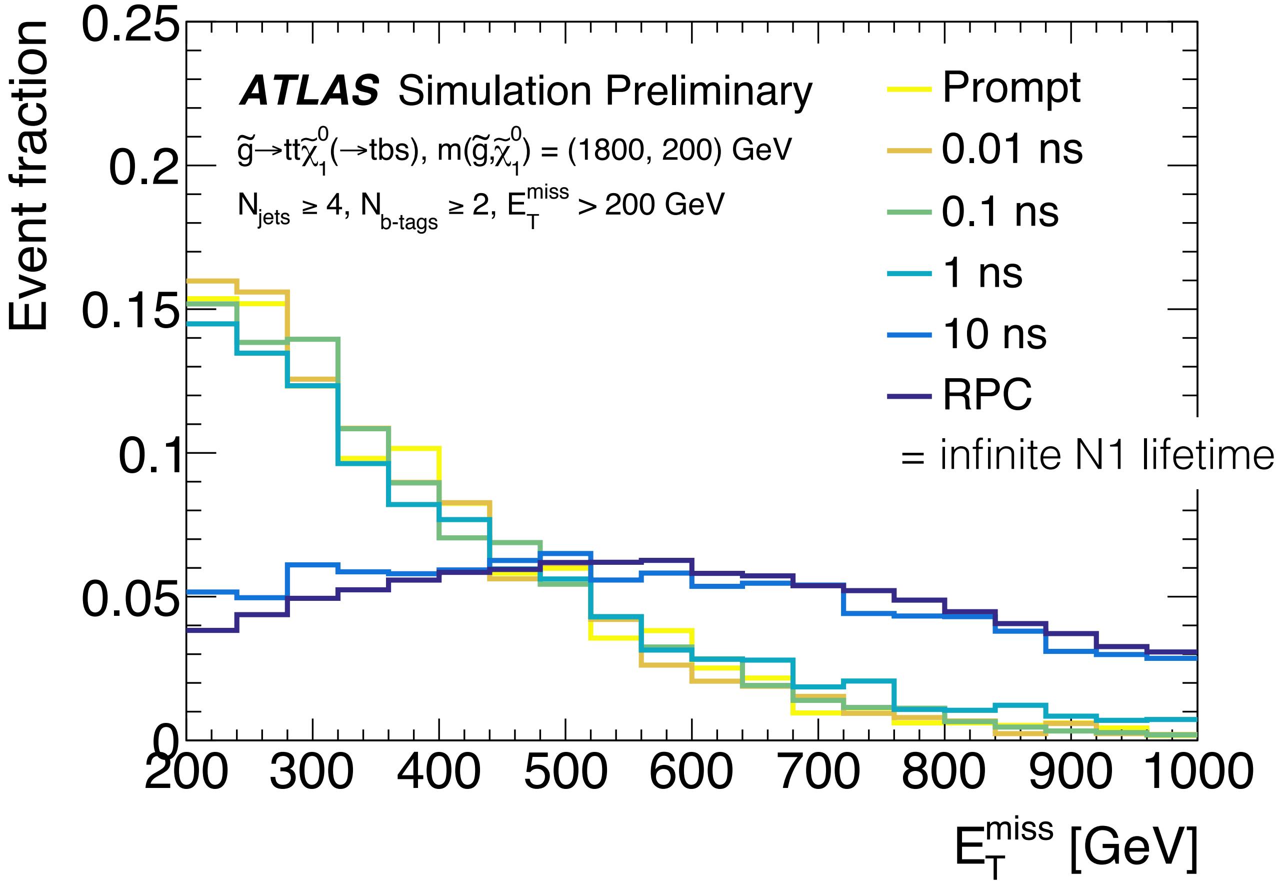
c*tau numbers above approximated using m(squark)=2.5 TeV, m(χ_1^0)=200 GeV

RPC search program

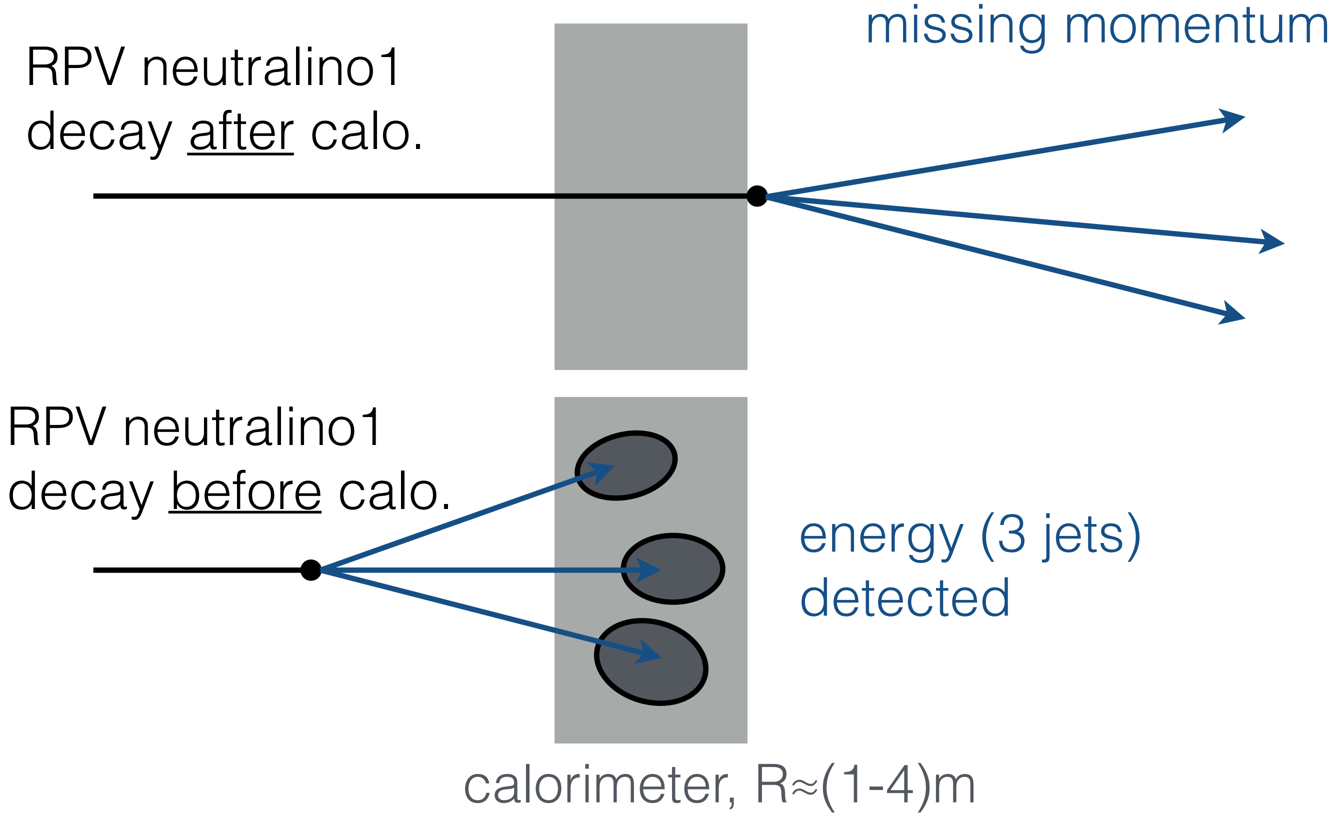
RPV search program

Characteristic observables

ATLAS-CONF-2018-003



Reconstruct jets once neutralino decays are before calorimeter.



RPV neutralino1
decay after calo.

missing momentum

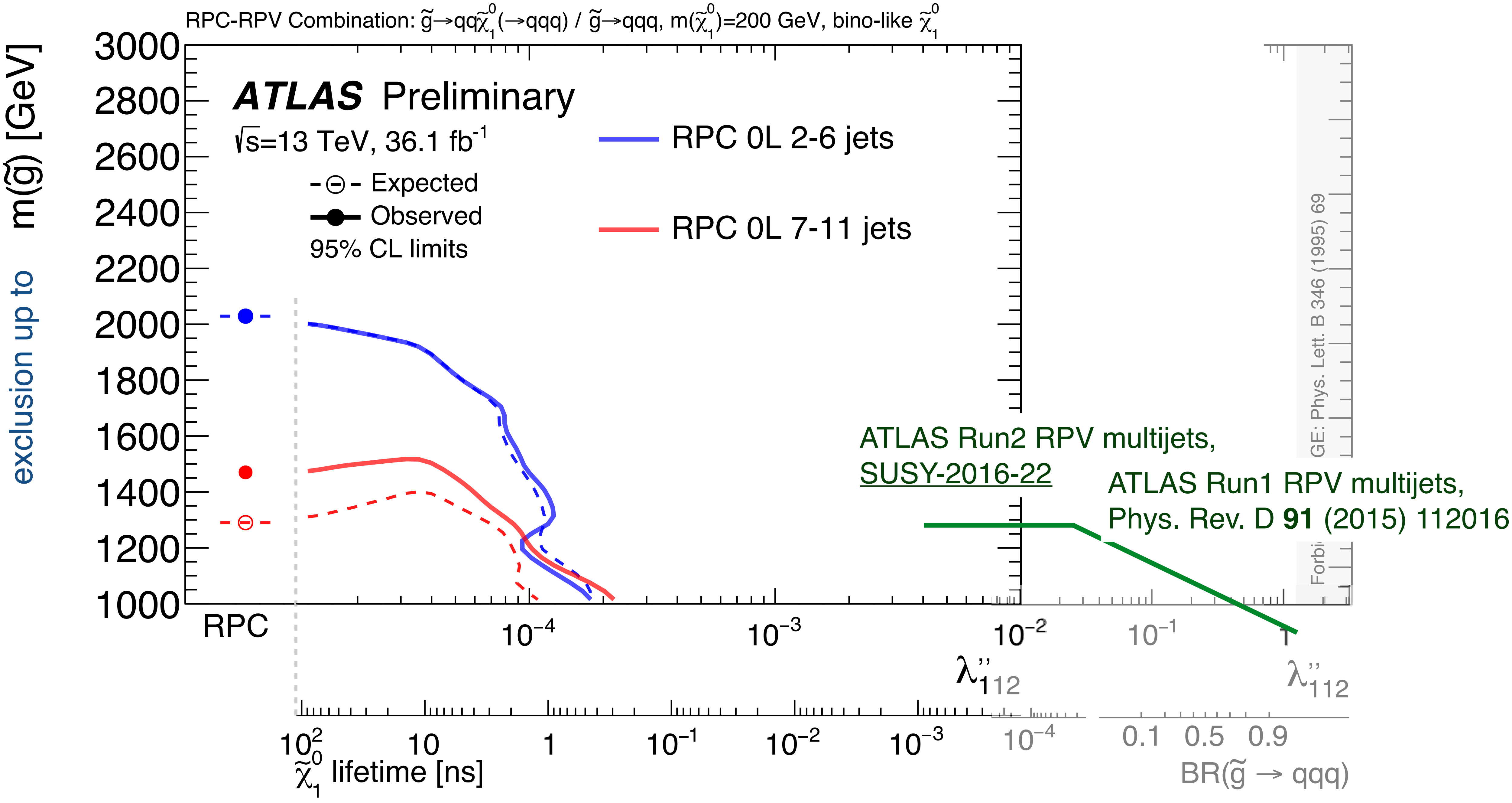
RPV neutralino1
decay before calo.

energy (3 jets)
detected

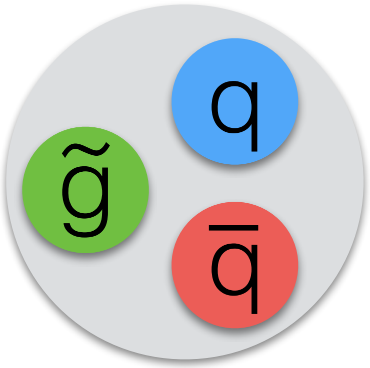
calorimeter, R≈(1-4)m

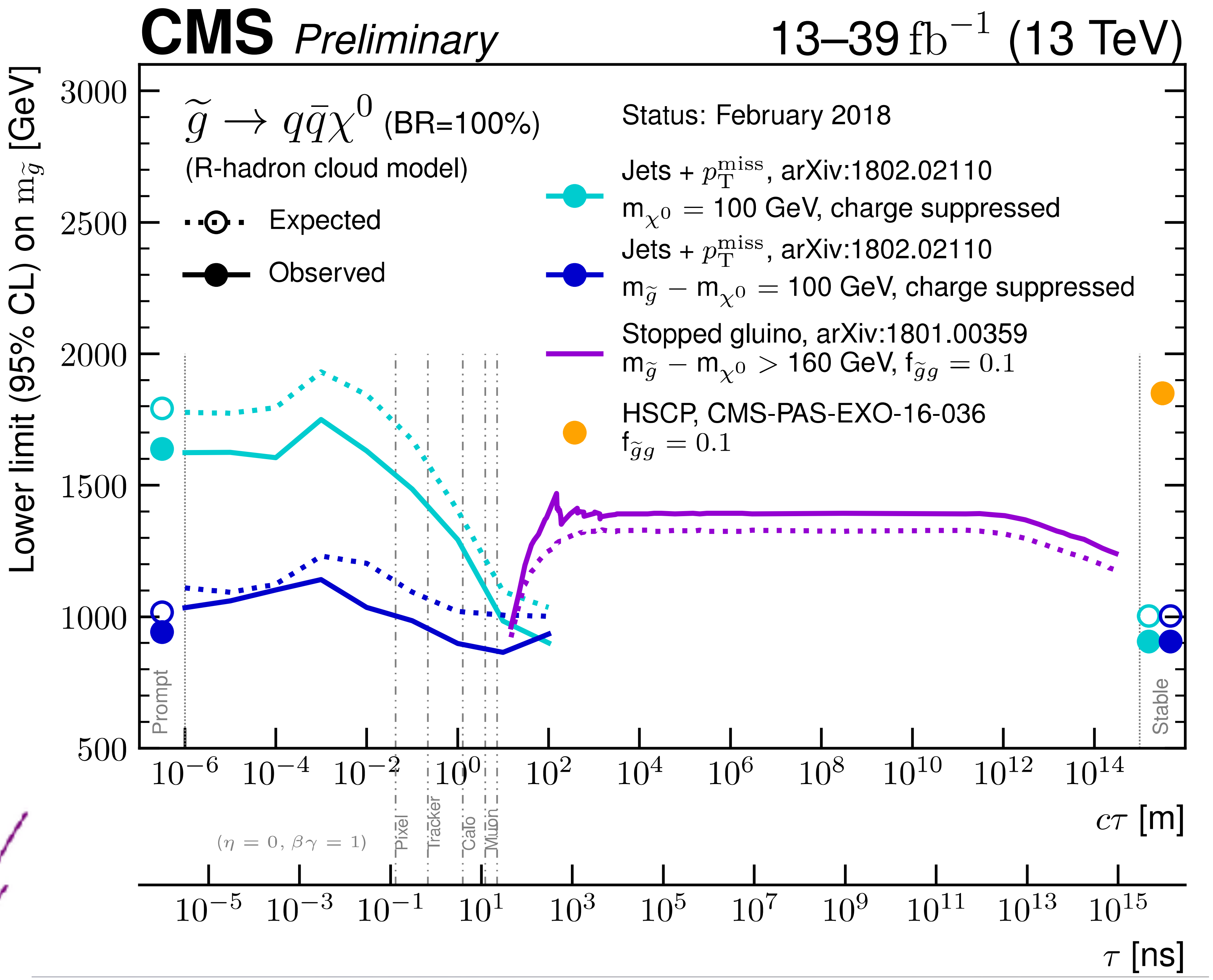
From *R*-parity conserving to *R*-parity

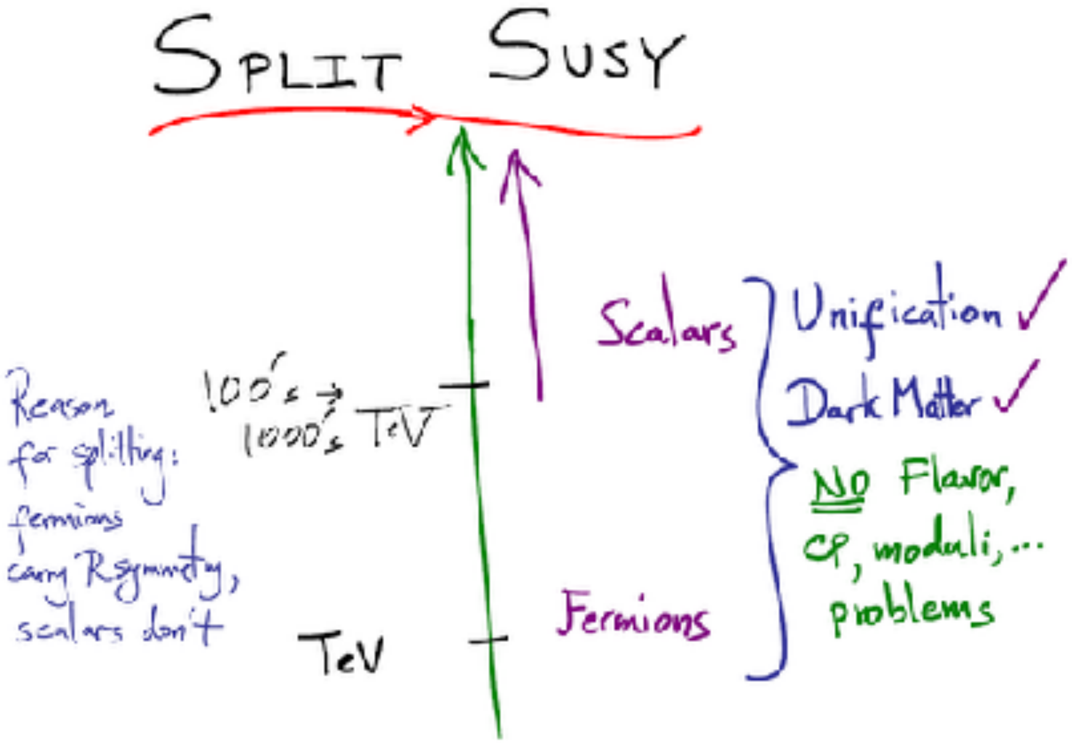
ATLAS-CONF-2018-003



R-hadron scenario

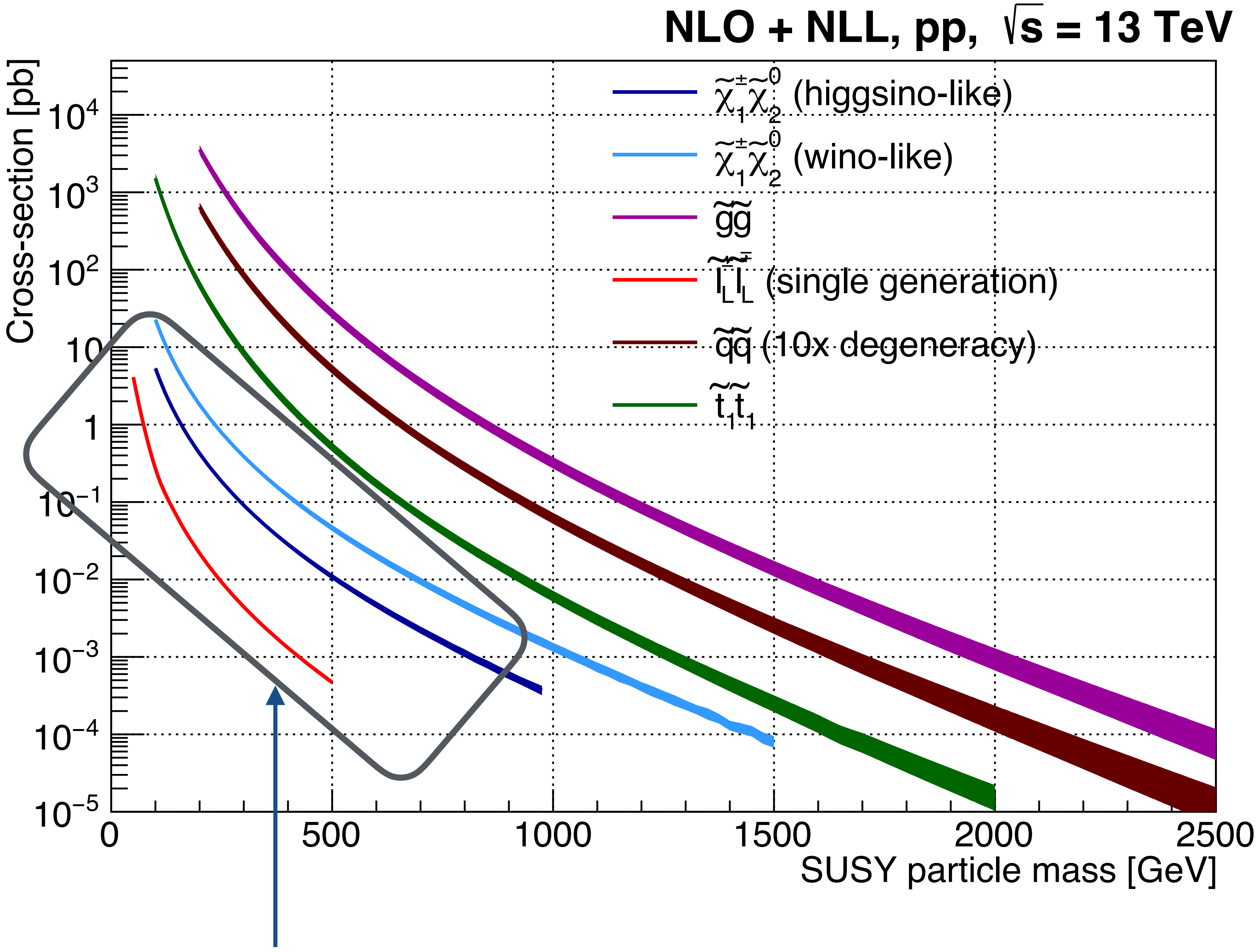






From Arkani-Hamed's talk

Frontier: Low rates



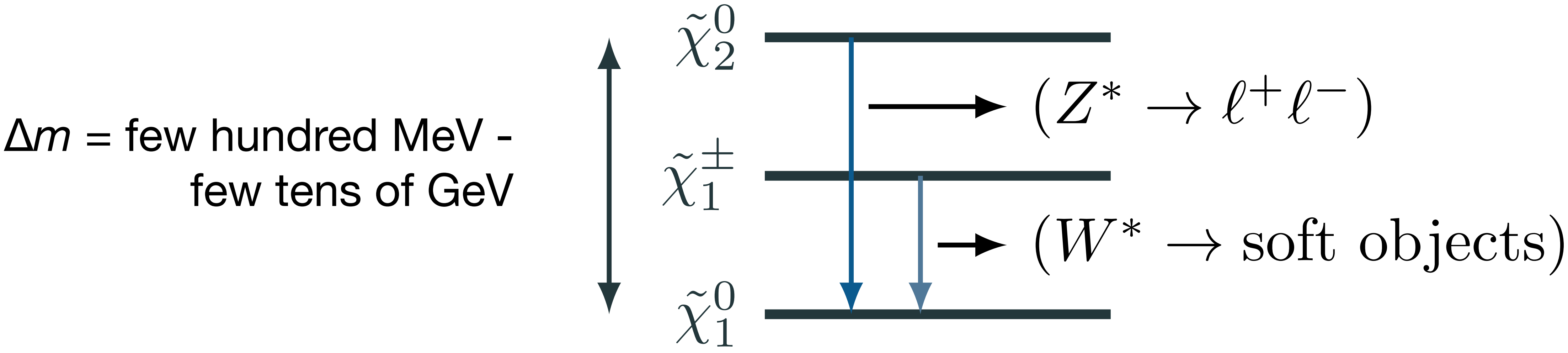
Production cross section of SUSY particles
w/o color charge, **electroweak production**

Compressed electroweak spectrum

Dark matter: co-annihilation is compression

Naturalness requires Higgsinos near weak-scale

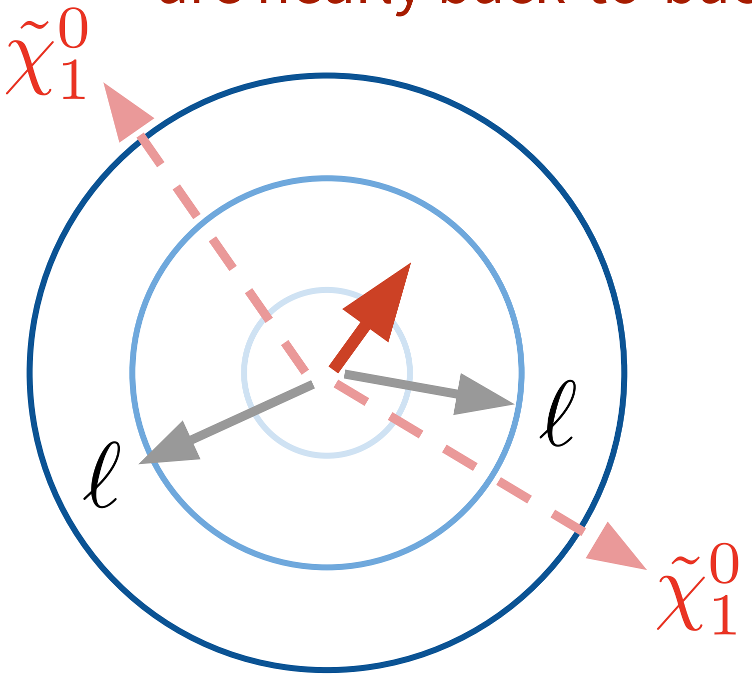
Higgsinos realised as multiplet of neutralinos & charginos



Challenge to reconstruct intra-Higgsino soft decay products

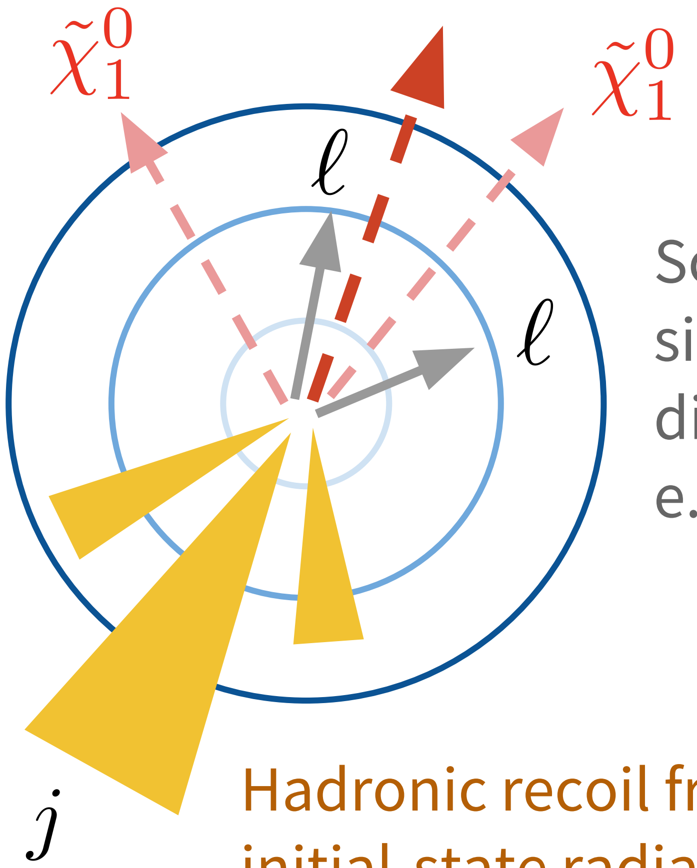
Strategy: initial-state-radiation (ISR)

Low missing E_T as LSPs are nearly back-to-back



Leptons too soft to pass lepton triggers

Trigger on missing E_T by boosting LSPs



Soft dileptons allow signal-background discrimination e.g. m(ll), mT2

Hadronic recoil from initial-state radiation (ISR)

Guidice et al [1004.4902], Gori et al [1307.5952], Han et al [1401.1235], Baer et al [1409.7058], Barr et al [1501.02511]. . .

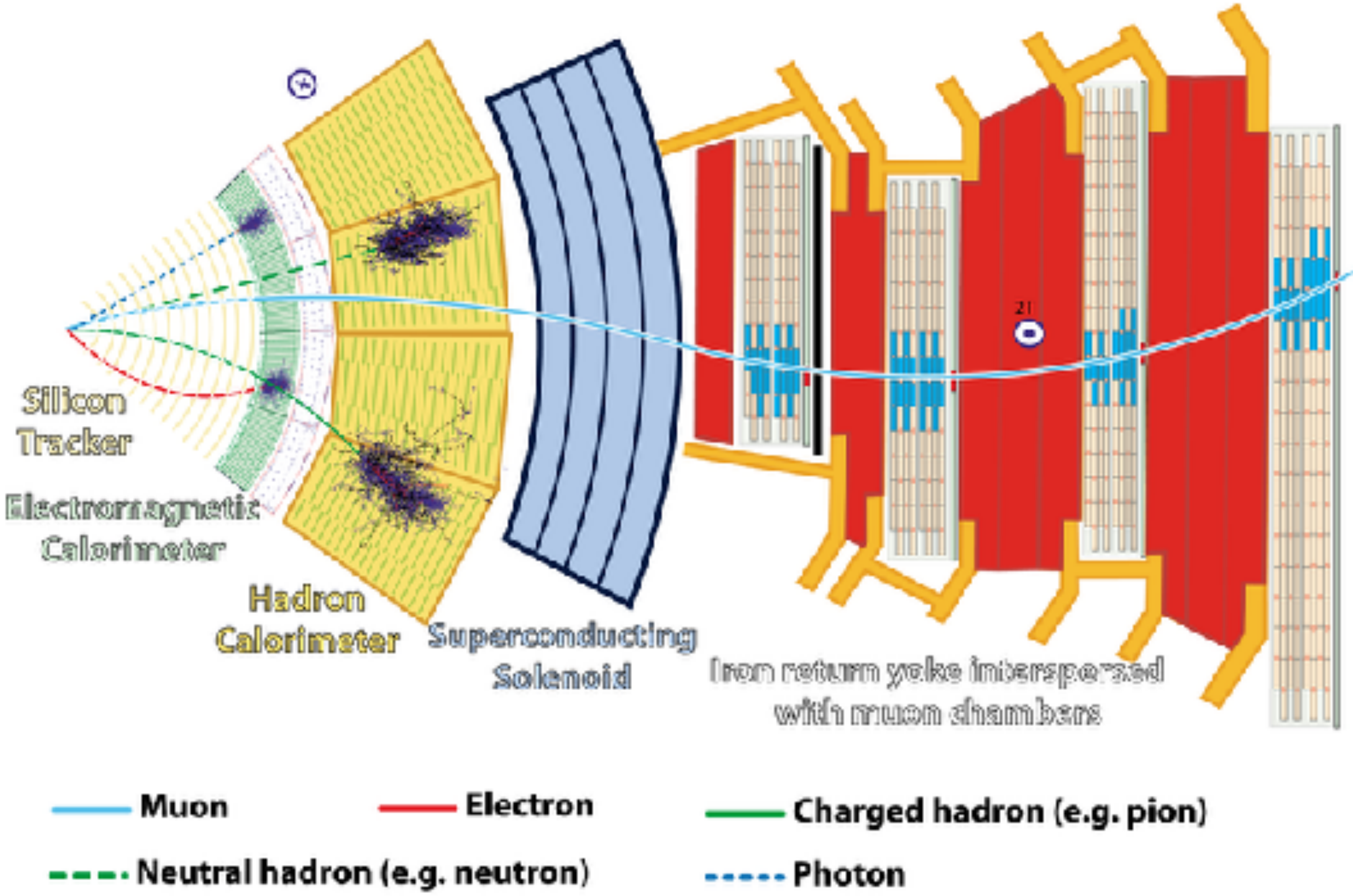
Adopted by ATLAS [1712.08119] and CMS [1801.01846] 13 TeV, 36.1 fb^{-1}

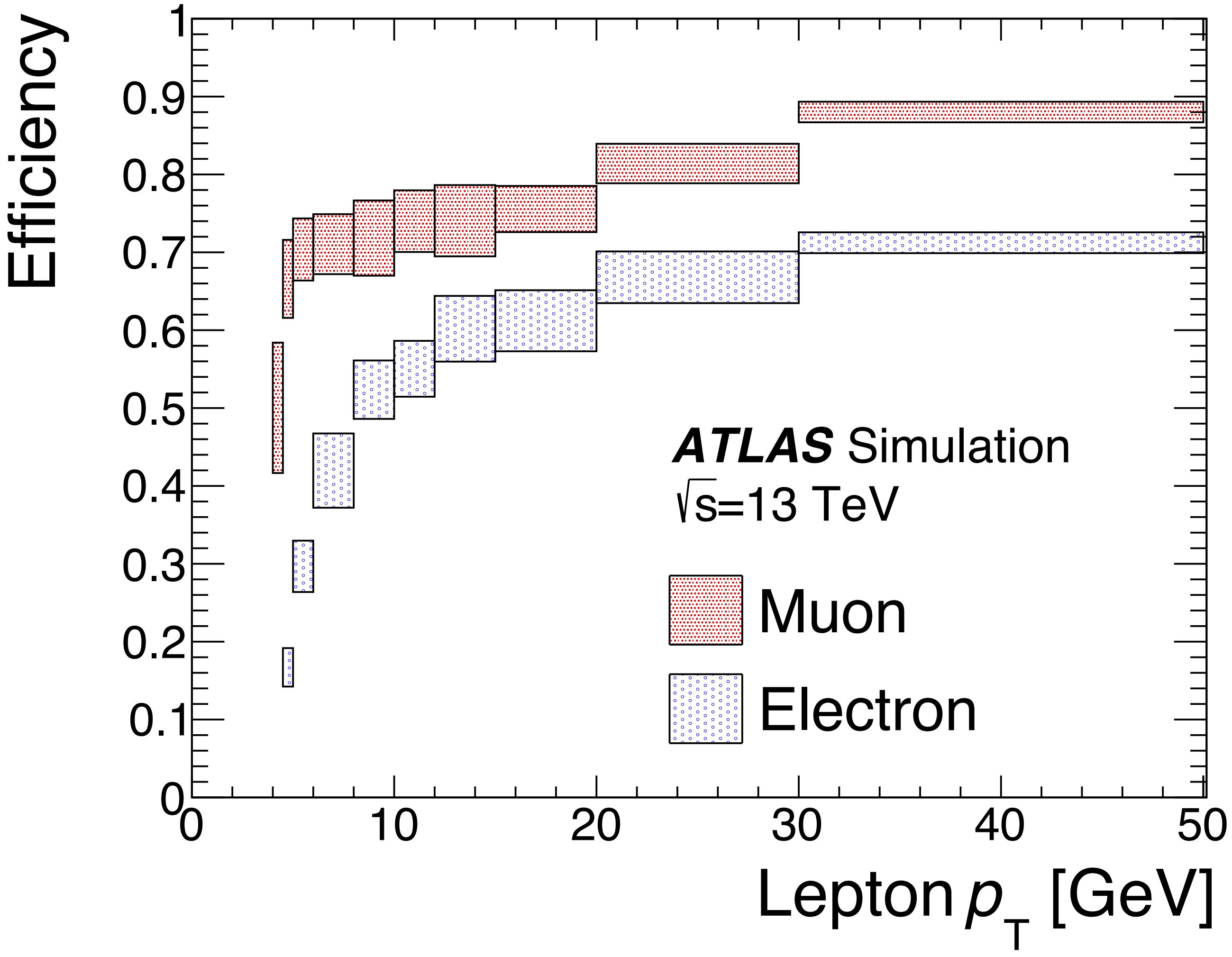
Sketches by Jesse Liu

Detector challenges

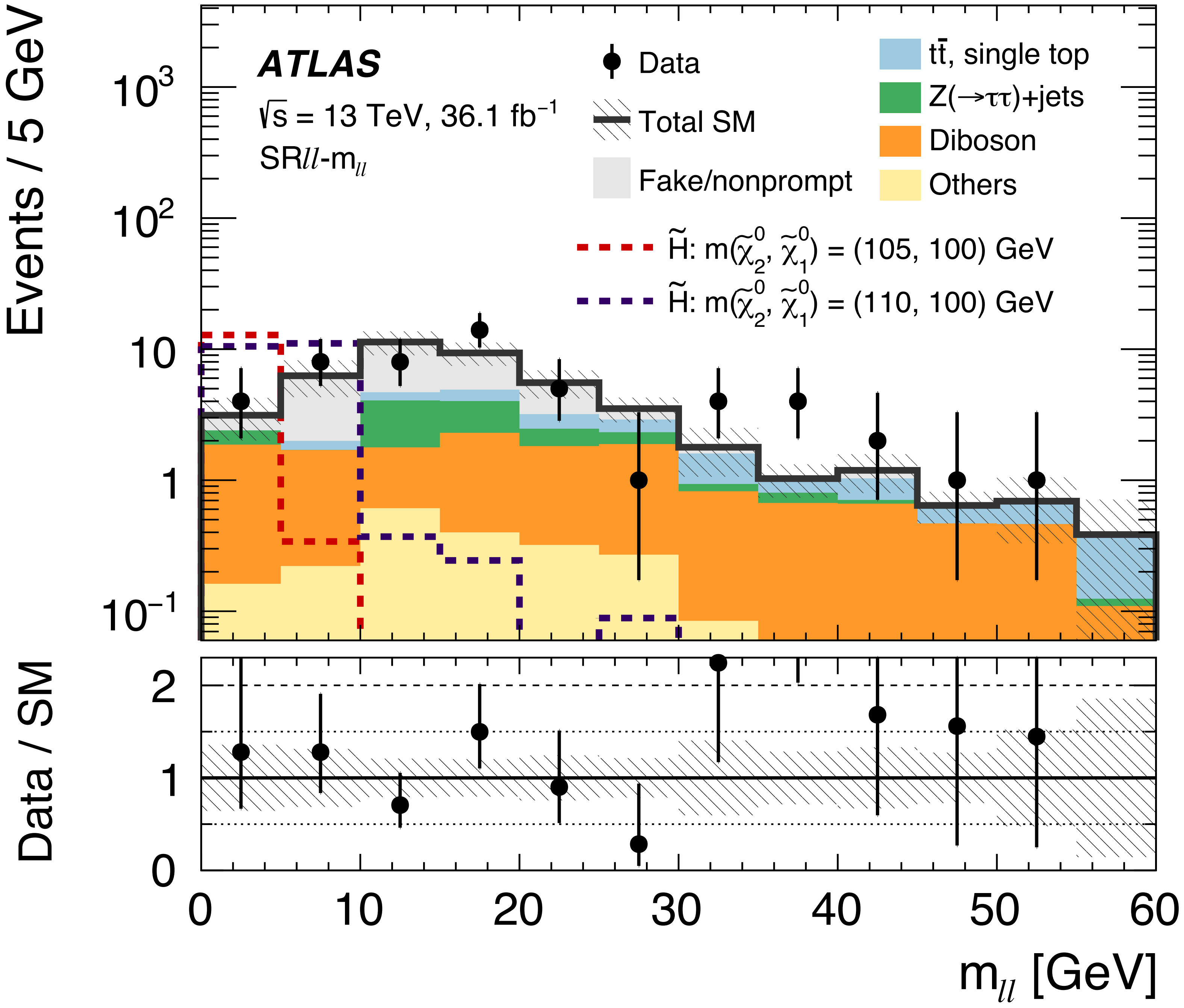
Muon energy loss in calorimeter ~ 3 GeV

Electron cluster reconstruction in calorimeter, ≳ 5 GeV





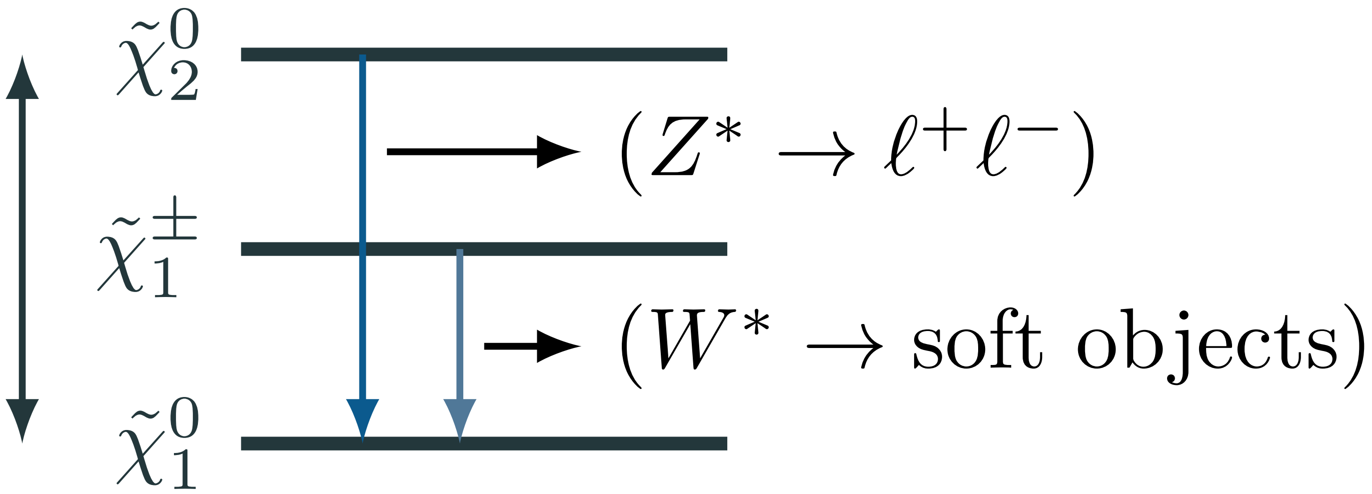
Inspecting data

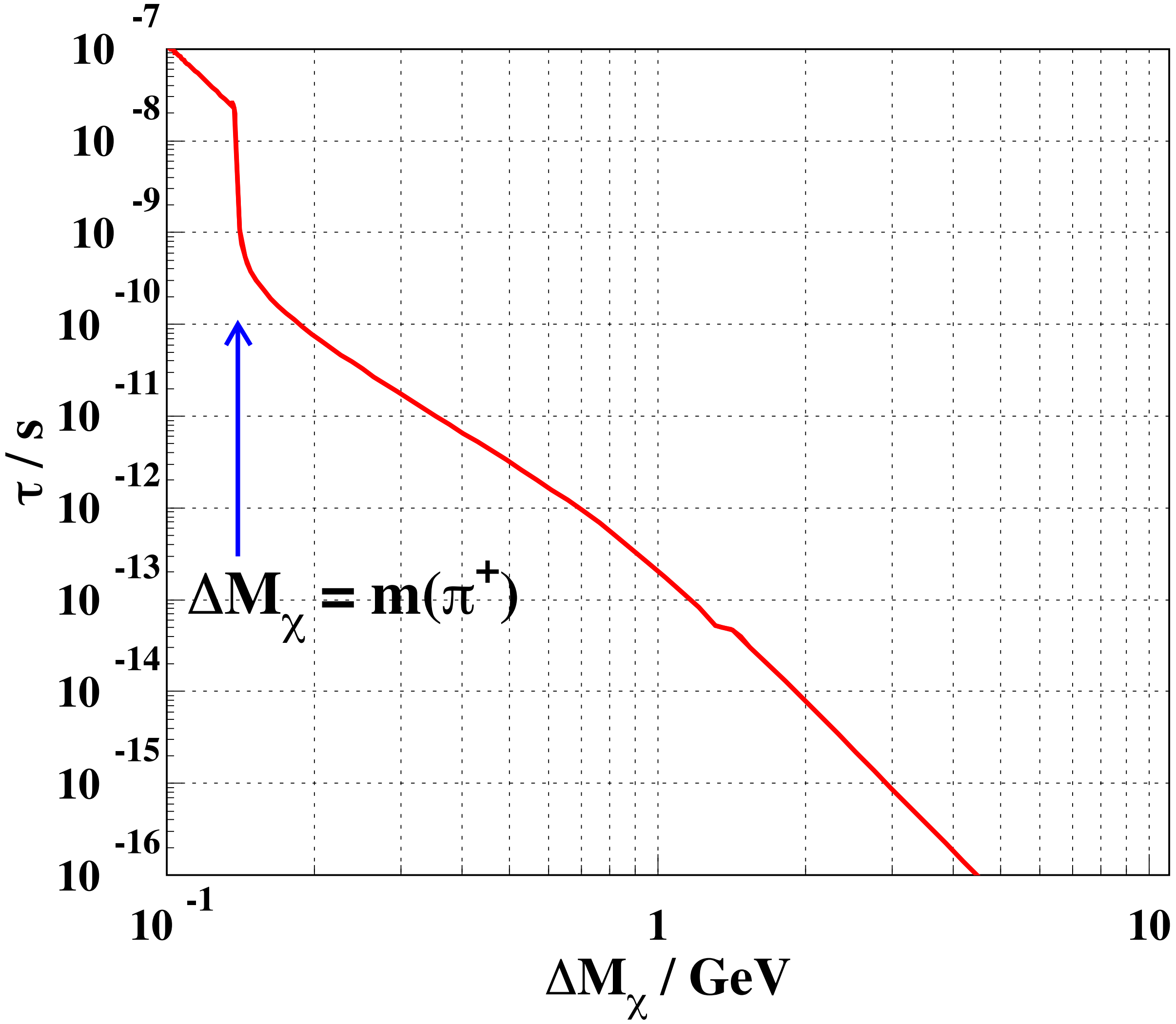


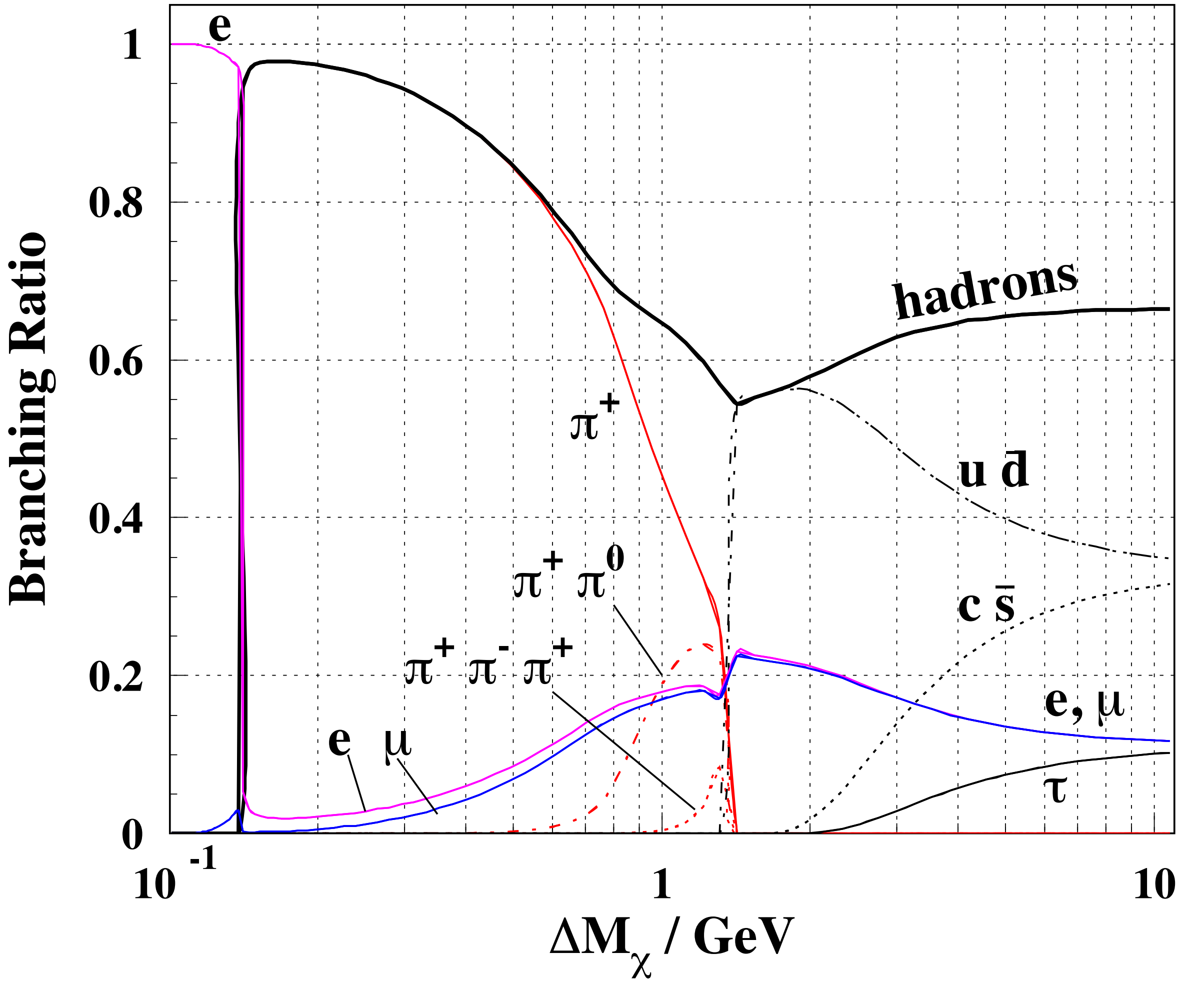
Signal has kinematic endpoint $m_{ll} < \Delta m(\chi^0{}_2, \chi^0{}_1)$

Ultra compressed spectrum

Δ*m* = few hundred MeV



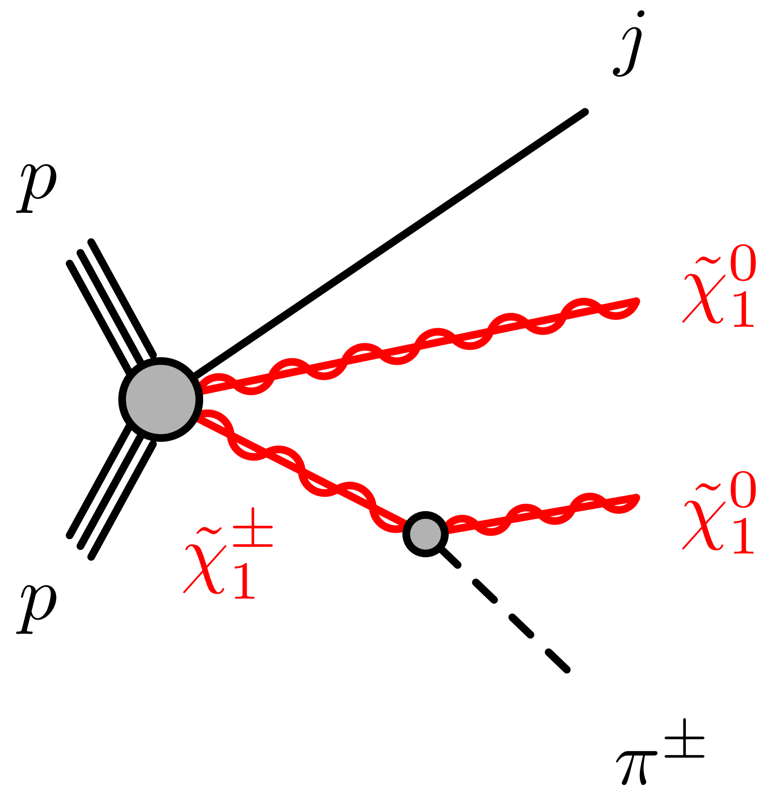


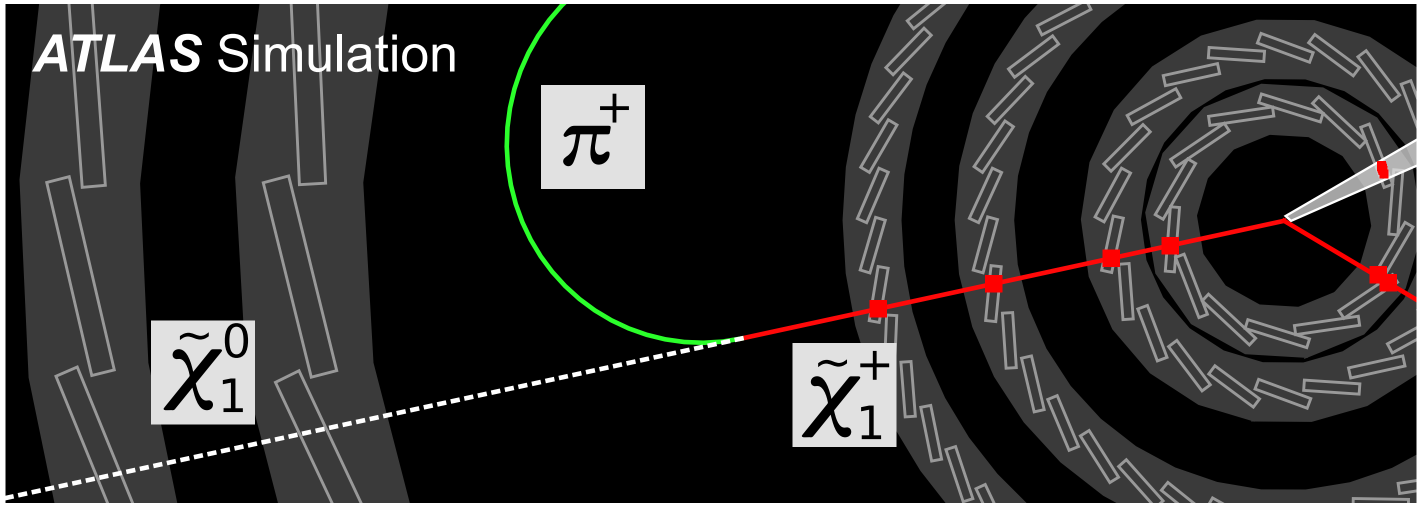


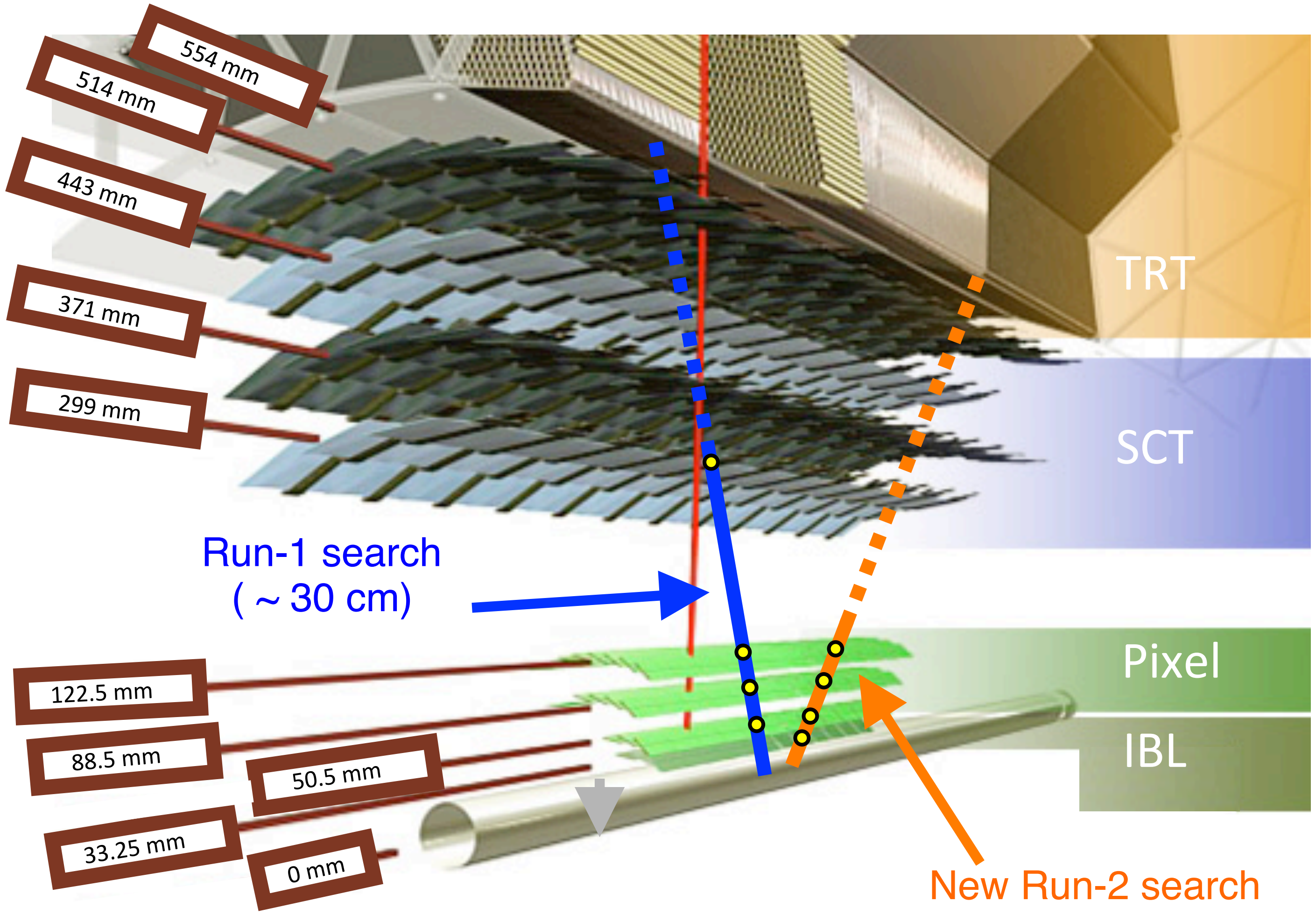
Journal of High Energy Physics, Volume 2003, JHEP03(2003)

Disappearing track

Hadronic recoil (ISR), trigger!







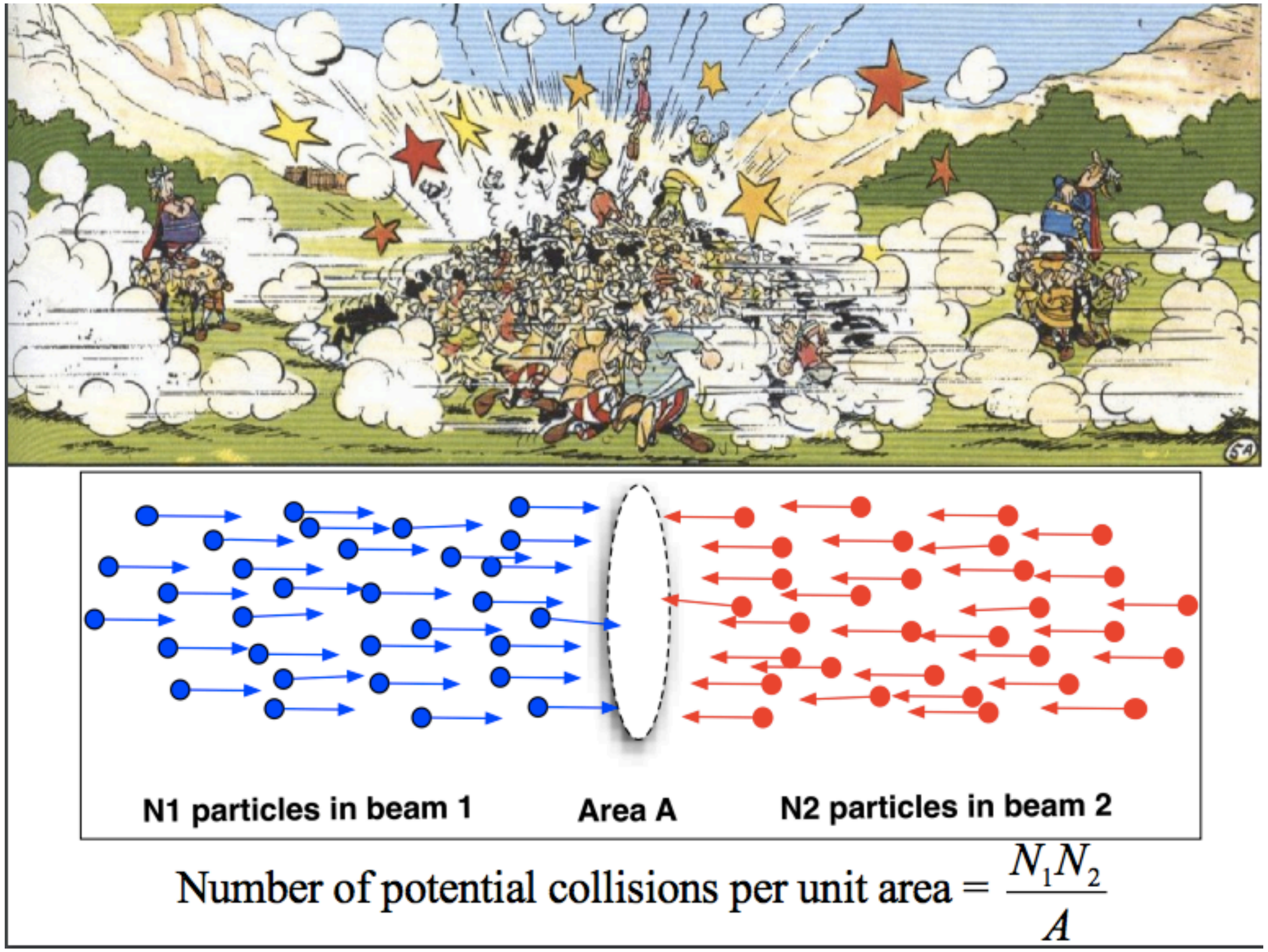
Run-1 search
(~ 30 cm)

New Run-2 search
(~ 12 cm)

Experimental challenge: ***pileup***

Many *pp* interactions (i.e. collisions) in the same bunch crossing = pileup.

Average of 38 collisions per crossing in 2017.

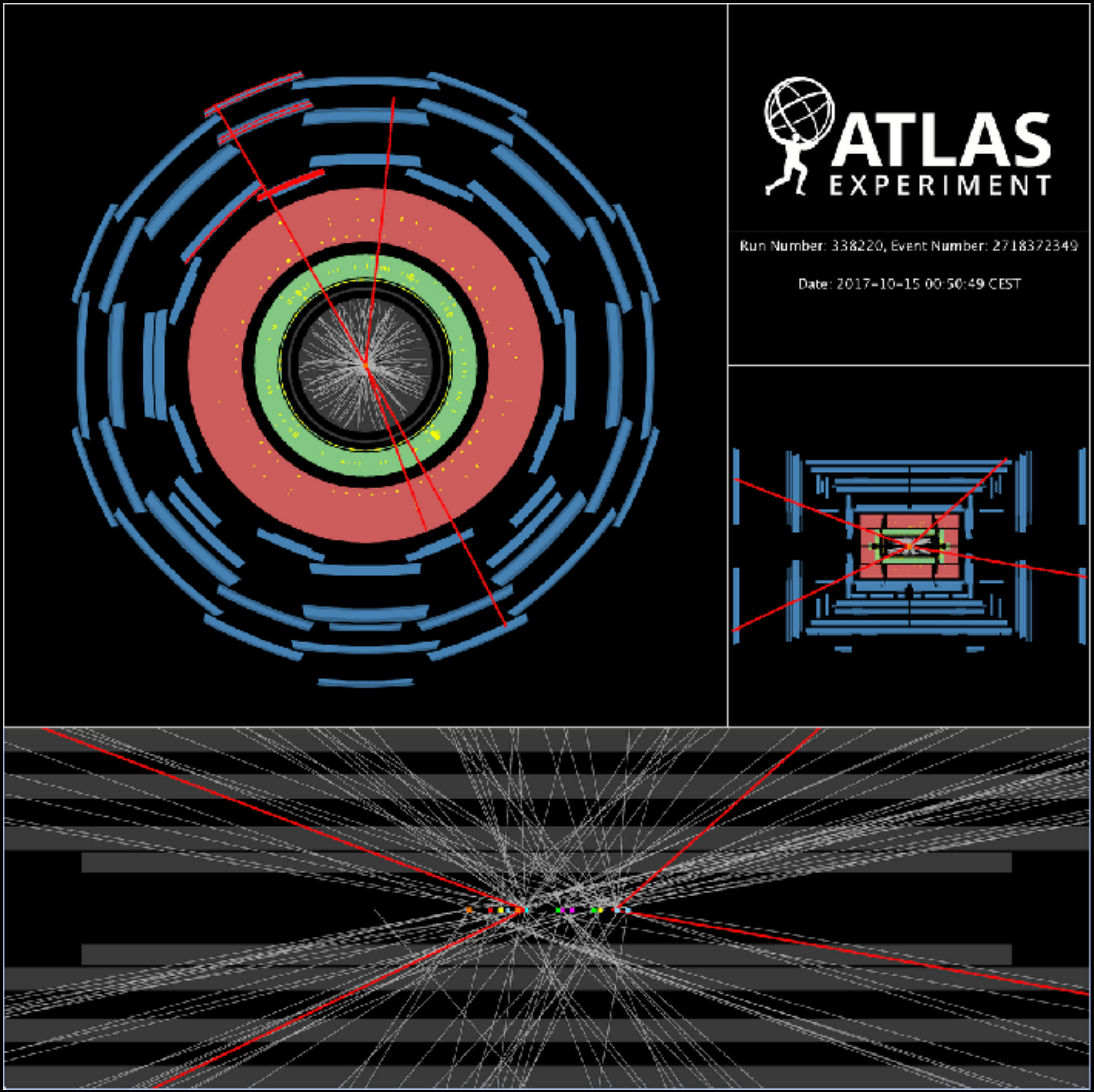


Many charged soft particles that leave hits in inner-detector.

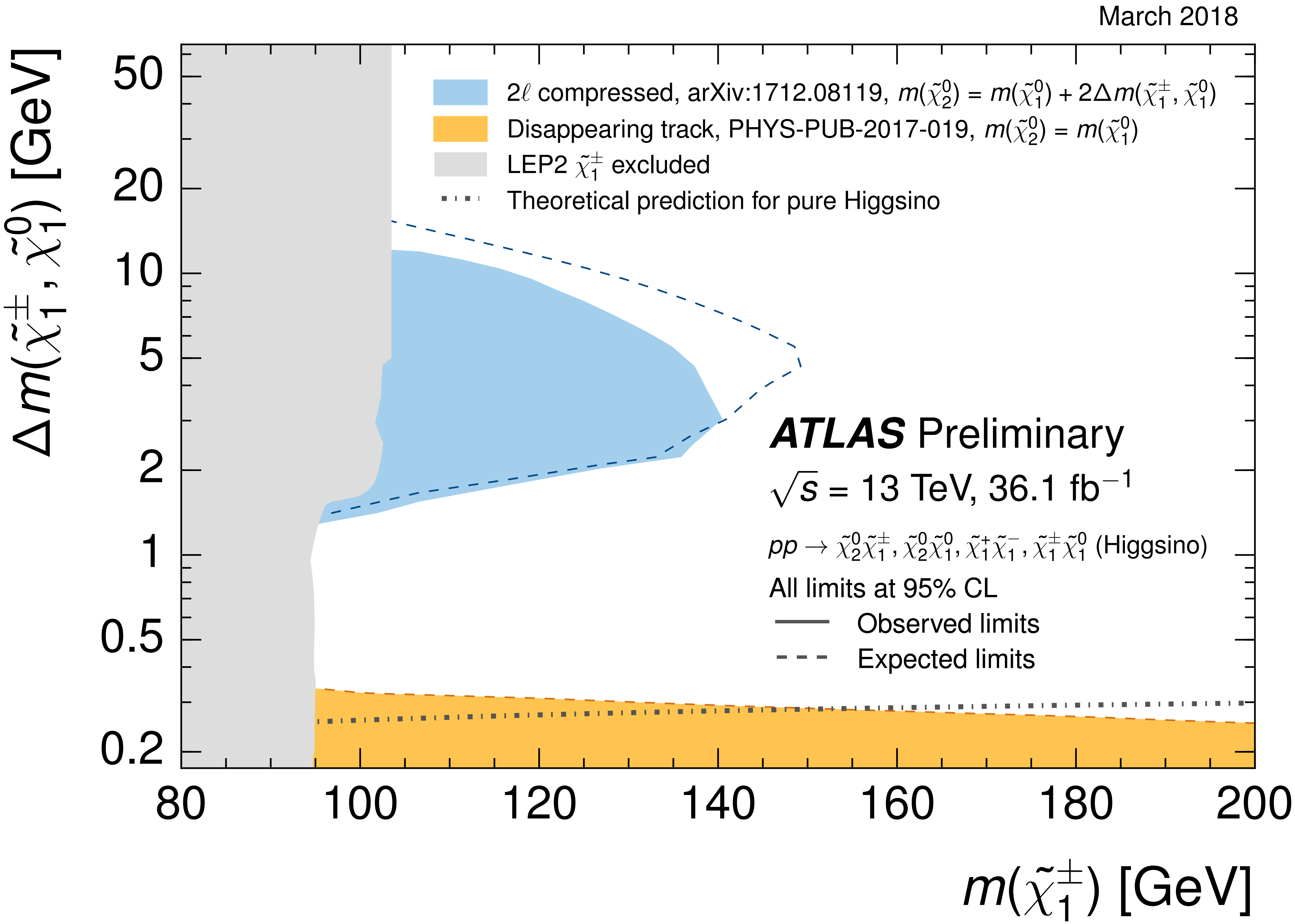
Challenge for disappearing track (random hits bkg), and many other areas!

High pileup event display

ATLAS 2017 collision data event with **two Z-boson** candidates each decaying to two muons and originating from well separated *pp* interactions in the same LHC bunch crossing. The production vertices of the two Z boson candidates are separated by 67 mm.



Hadron collider extends nearly 20 years old LEP limits

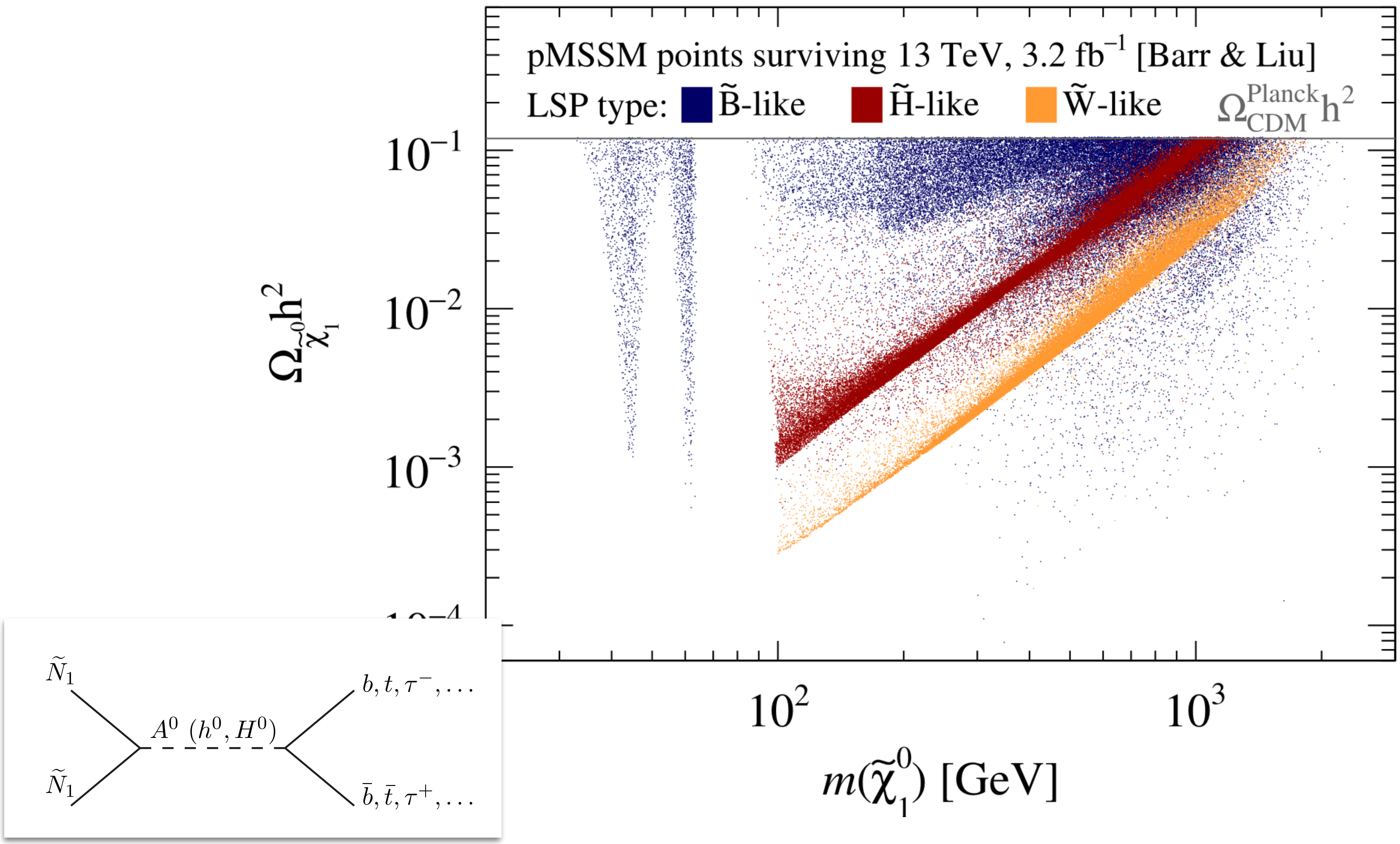


Outlook

Next steps in the hunt for supersymmetry.

SUSY comes with Dark Matter WIMP

Neutralino dark matter: composition controls relic abundance



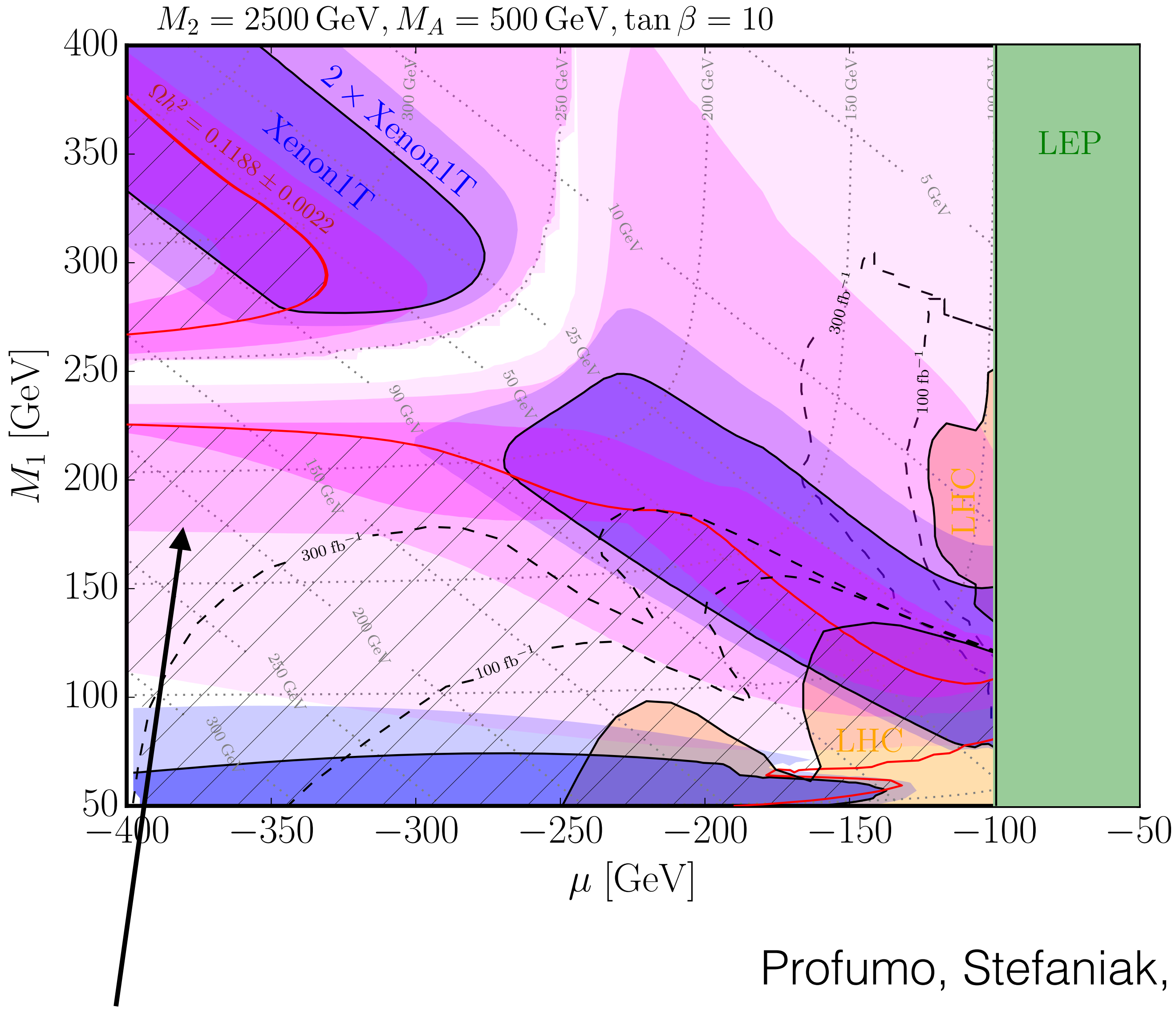
Barr & Liu [1608.05379]

Bino dark matter annihilation suppressed, other processes ensure $\Omega_{\tilde\chi_1^0} \leq \Omega^{\text{Planck}}_{\text{CDM}}$

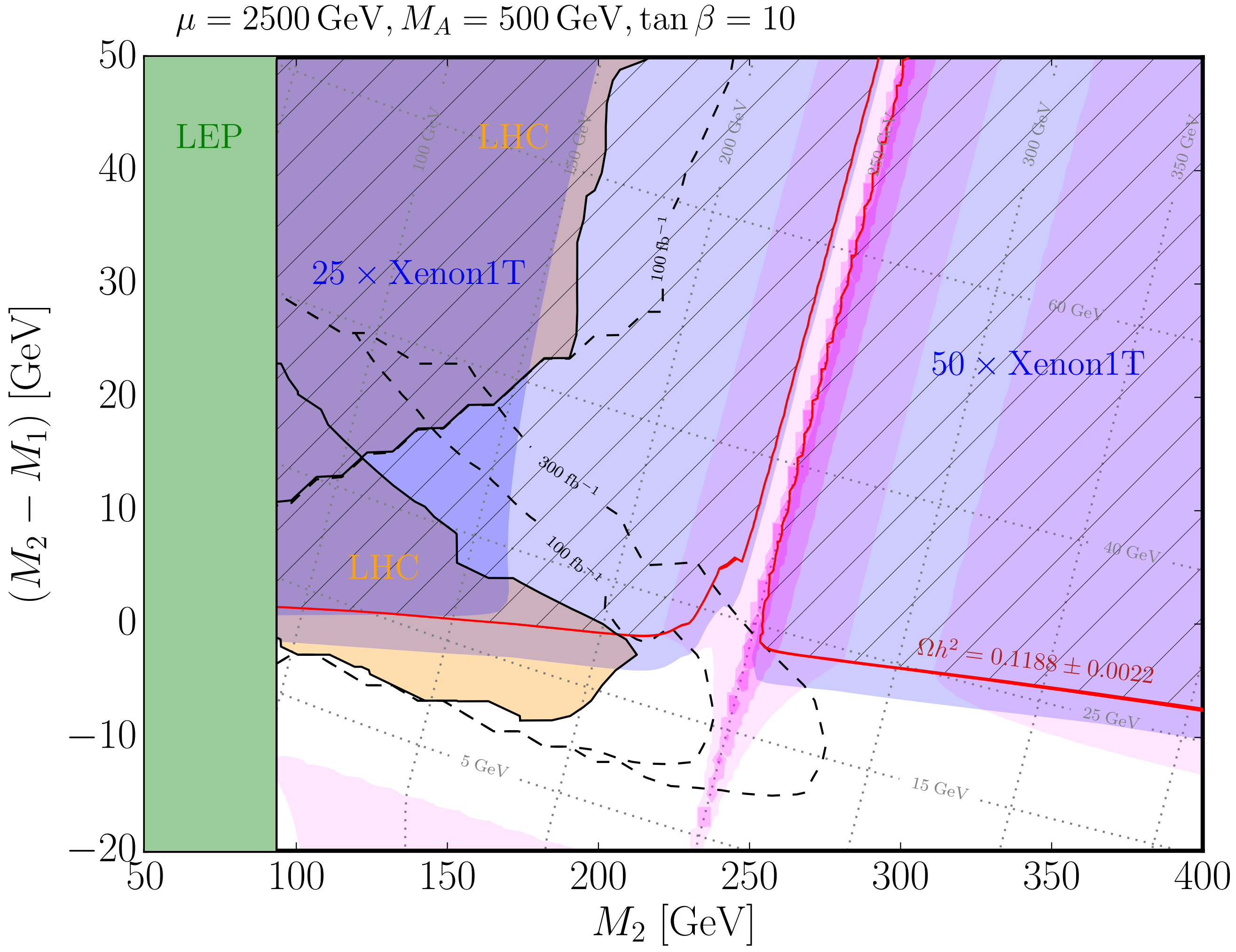
Higgsino & wino dark matter bands: mass controls abundance $\Omega_{\tilde\chi_1^0} h^2 \sim \langle \sigma v \rangle^{-1} \sim m^2_{\tilde\chi_1^0}$

Well Tempered Neutralino

well-tempered bino-Higgsino neutralino



well-tempered bino-wino neutralino



Profumo, Stefaniak, Haskins [1706.08537]

Projected limits from **DM indirect** detection experiments scaled by current limit is scaled by factors of 10, 100 and 1000, with high to low opacity.

For large μ values direct detection quickly becomes ineffective.

Complementarity of dark matter programs

Estimates of future LHC sensitivity at 95% CL

	~35 ifb 13 TeV	**Run2 (140 ifb) 13 TeV**	**Run3 (~300 ifb) 13/14 TeV**	**HL-LHC (3000 ifb) 13/14 TeV**
gluino	2 TeV (prel.)	~2.3 TeV (my est.)	2.4 TeV (upgrade), 2.4/2.6 TeV (my est.)	2.9 TeV (upgrade), 2.9/3.1 TeV (my est.)
squark (x8) decoupled	1.5 TeV (prel.)	1.75 TeV (my est.)	1.9/2.0 TeV (my est.)	2.3/2.4 TeV (my est.)
stop	1-1.1 TeV (prel.)	~1.3 TeV (my est.)	1.4x TeV (my est.)	1.85 TeV (my est.)
wino C1N2 to WZ bino	~600 GeV (prel.)	670 GeV (my est.)	780 GeV (my est.), 750 GeV (CMS est.), 840 GeV (upgrade)	1150 GeV (my est.), 1.2 TeV (CMS est.), 1.1 TeV (upgrade)
wino C1C1 to WW bino	225 GeV (based on x-section ratio for 180 GeV Run1)	~320 GeV (my est.)	380-400 GeV (my est.)	~630 GeV (my est.)
wino LSP, pixel-trklet	420 GeV (prel.)	580 GeV (my est.)	680 GeV (my est.)	1030 GeV (my est.)
higgsino LSP, DM=3-20 GeV	150 GeV	200-250 GeV (my est.)	250-300 GeV (my est.)	450-500 GeV (my est.)
higgsino LSP, DM=0.3-3 GeV	?			
slepton (sel, smu)	~500 GeV (prel.)	670 GeV (my est.)		
stau	?			700 GeV (upgrade)

Summary

Harvesting large LHC dataset
wide Supersymmetry search program; so far no clear sign of new physics.

SUSY frontiers at LHC

Complex scenarios: new clever ideas, sophisticated analysis techniques.

(uncovered signatures .. long-lived, *R*-parity violating, etc.)

Electroweak SUSY production, complementing dark matter direct & indirect detection

(analysed ~1% of the expected LHC p-p dataset)

A very exciting and puzzling time for particle physics.