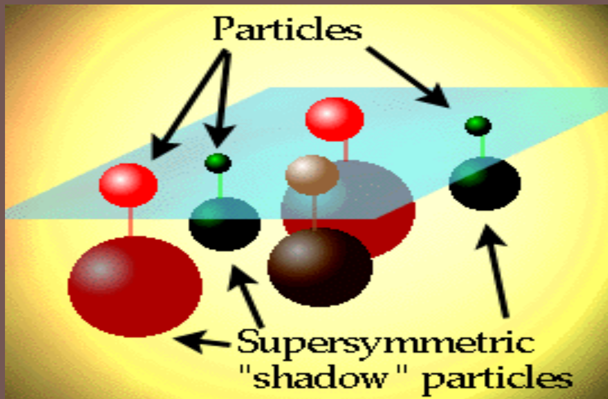

SUSY Search at LHC and beyond

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22 Nov. 2017

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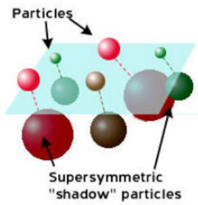
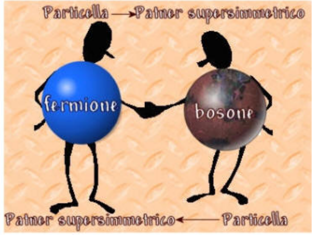
Institute of High Energy Physics
Chinese Academy of Sciences

Outline

- ❑ **SUSY Introduction**
- ❑ **The LHC and ATLAS**
- ❑ **SUSY search strategy**
- ❑ **SUSY search @ LHC**
- ❑ **Longer term prospects @ LHC and Future Colliders (14, 33, 100 TeV)**
- ❑ **Outlook and Summary**





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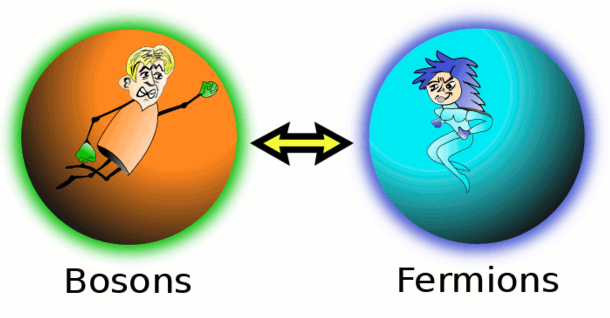


SM and Beyond

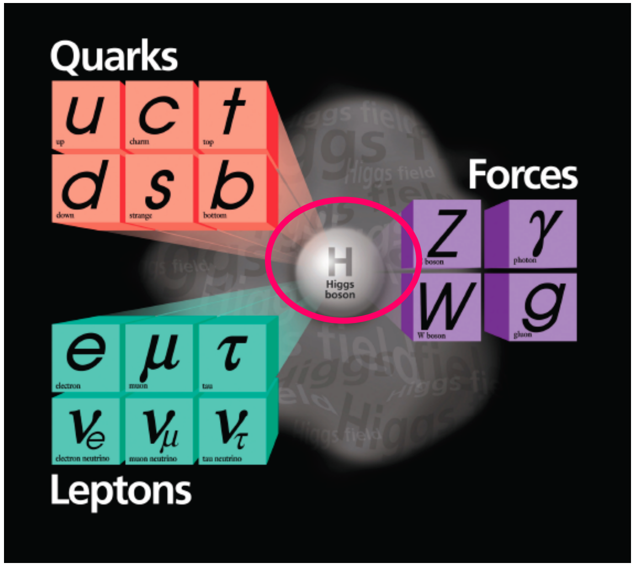


Photo: A. Mahmoud
François Englert

Photo: A. Mahmoud
Peter W. Higgs

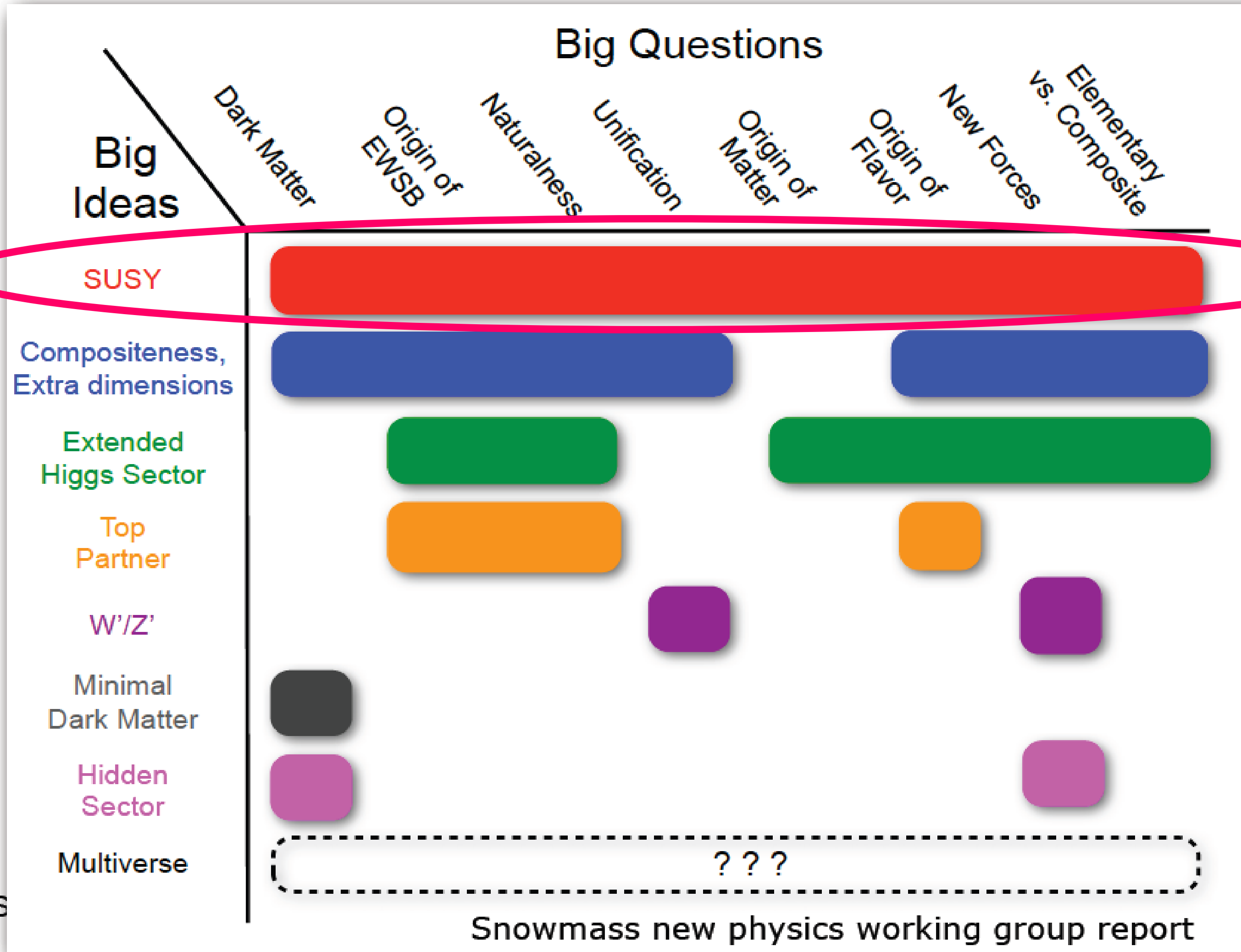
The Nobel Prize in Physics 2013
François Englert, Peter Higgs

- Higgs boson observed, SM fits the experimental data very well → big success in EW scale

- While has problem in Planck scale:
  - Naturalness and "hierarchy" problem
  - Unification of gauge coupling
  - Dark Matter
  - ……

- Need a more fundamental theory in which SM is only a low-energy approximation → **New Physics**

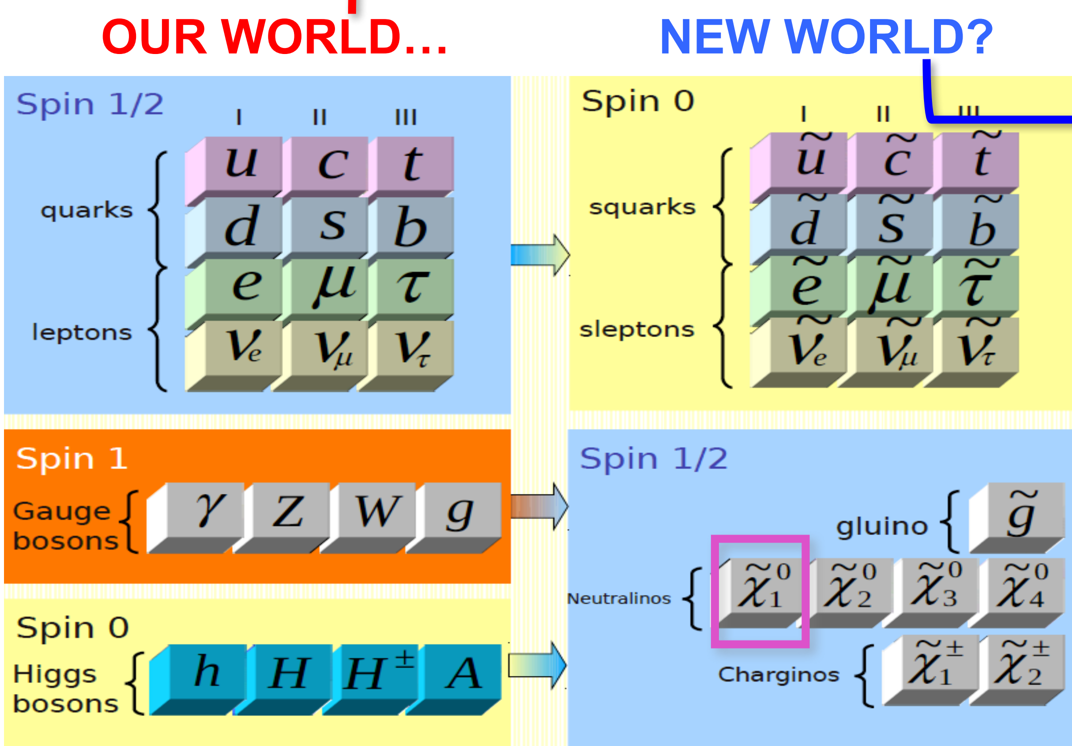
在超出标准模型的新物理模型中，SUSY理论是唯一能够回答绝大多数Big Question的理论

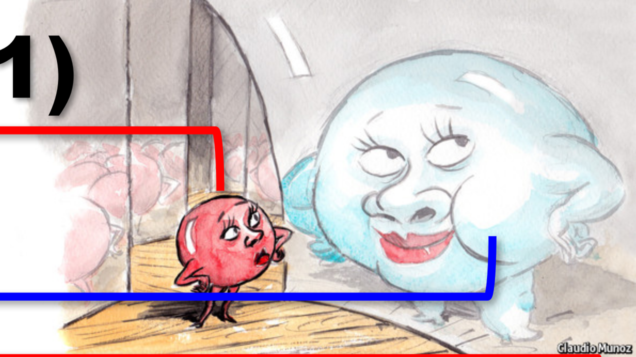


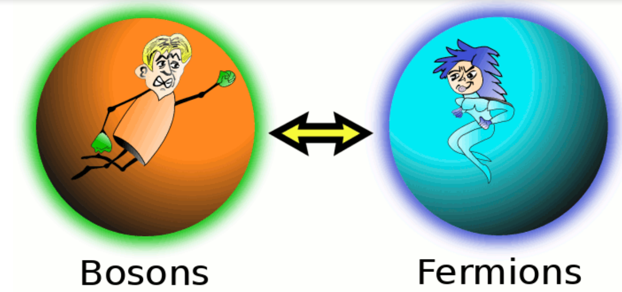
S. S

- **SUSY search is one of the most hot topic at LHC and beyond**

SUSY Introduction (1)



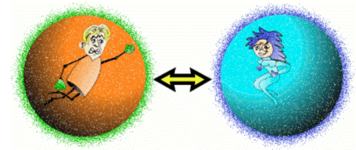




Q |boson> = |fermion>
Q |fermion> = |boson>

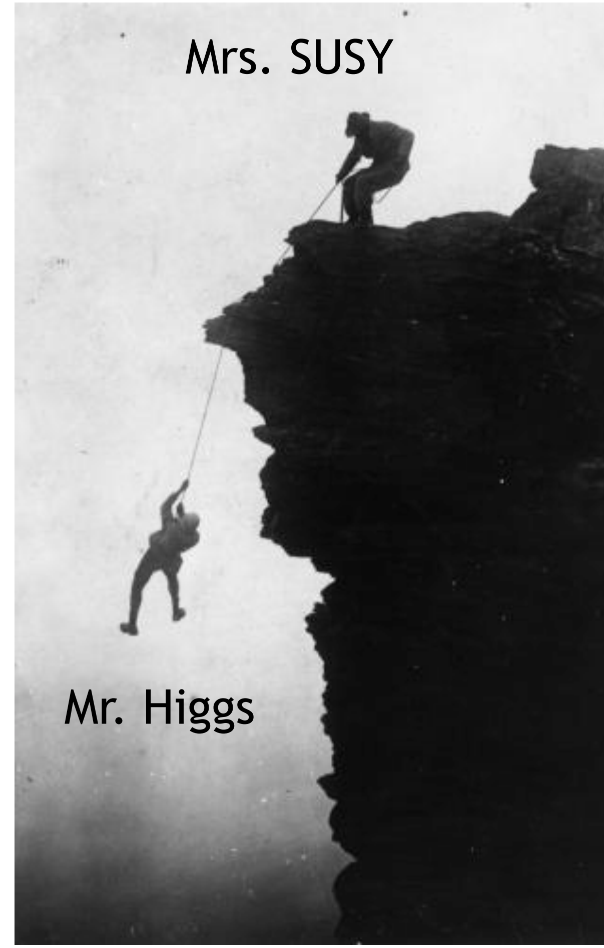
(Julius Wess and Bruno Zumino, 1974)

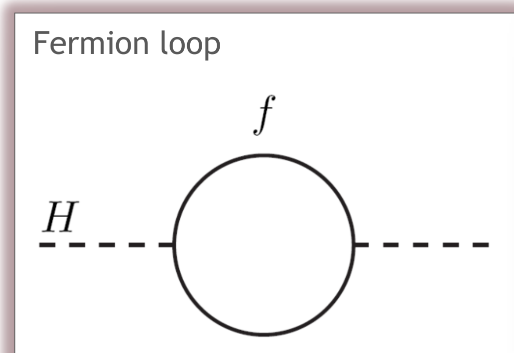
- **Establishes a symmetry between fermions (mater) and bosons (forces)**
  - Each particle has a super-partner
  - Number of elementary particles doubled
  - Spin differs by ½ between SUSY and SM particles
  - Identical gauge numbers and couplings
- **A more fundamental theory: compatible with SM in EW scale, solve most problems in Planck scale**

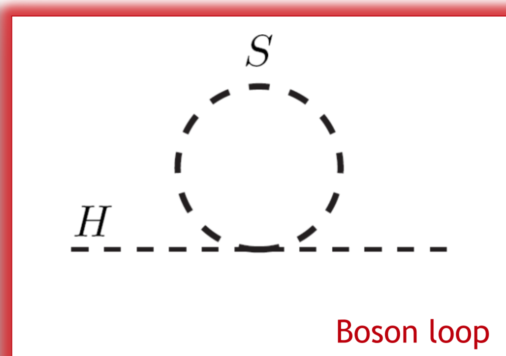


SUSY Introduction (2)

- **Solve hierarchy problem** without "fine tuning"
  - Fermion and boson loops contribute with **different signs** to the Higgs radiative corrections
  - Supersymmetric partner contributions to Higgs mass **cancel** SM contributions



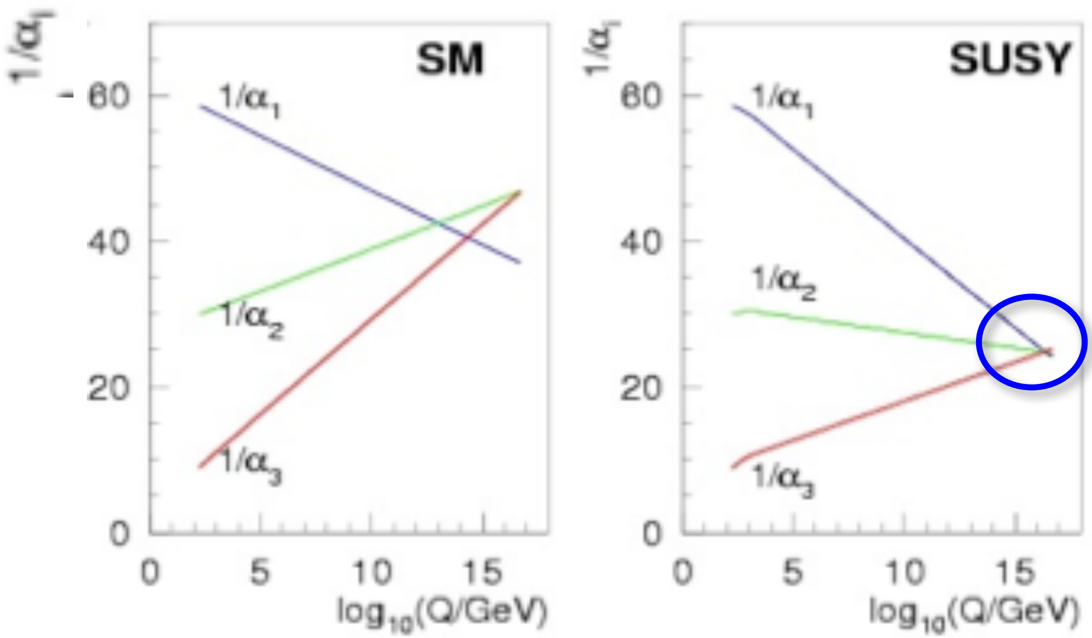




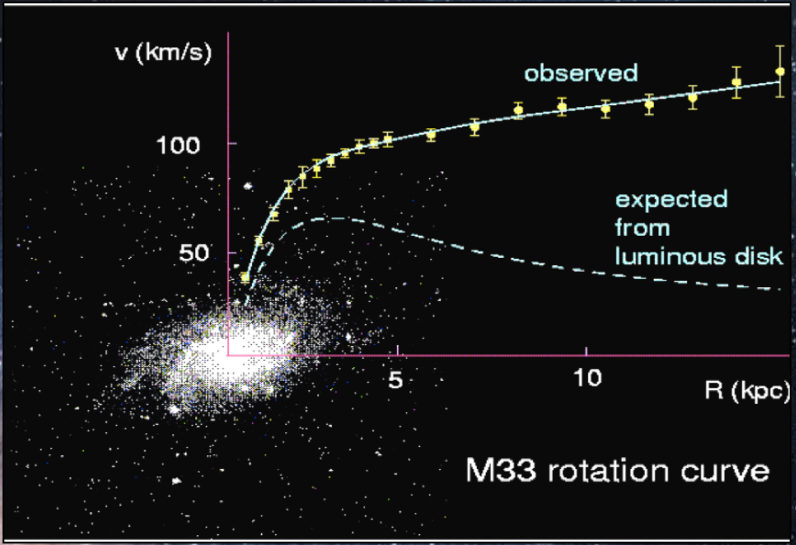
$$M_h^2 = M_{h,tree}^2 + \Delta M_h; \qquad SM : \Delta M_h \sim \Lambda^2; \qquad SUSY : \Delta M_h \sim m_{soft}^2 \log(\Lambda / m_{soft})$$

SUSY Introduction (3)

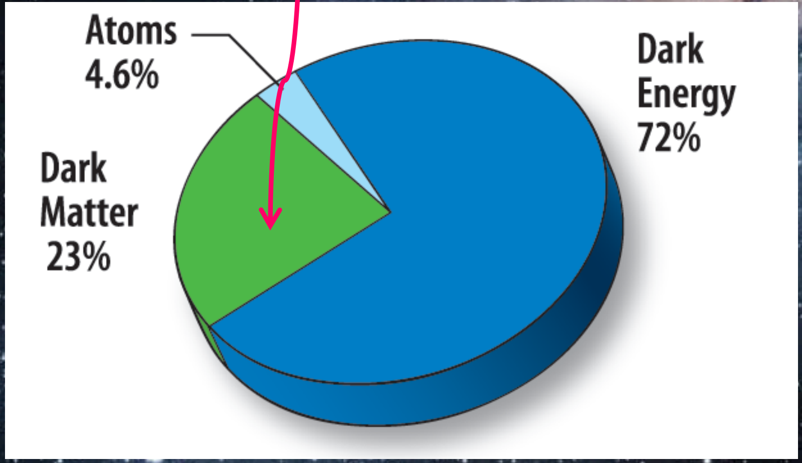
- **Unification of gauge couplings**
  - New particle content changes running of couplings
  - Requires SUSY masses at few TeV



Astronomers found that most of the matter in the Universe must be invisible Dark Matter



‘Supersymmetric’ particles ?



- **SUSY can provide perfect dark mater candidate – WIMP** (lightest neutralino in RPC models)
  - Stable
  - Electrically neutron
  - Same density as DM

$0.094 < \Omega_{CDM}h^2 < 0.136$ **(95% CL)**

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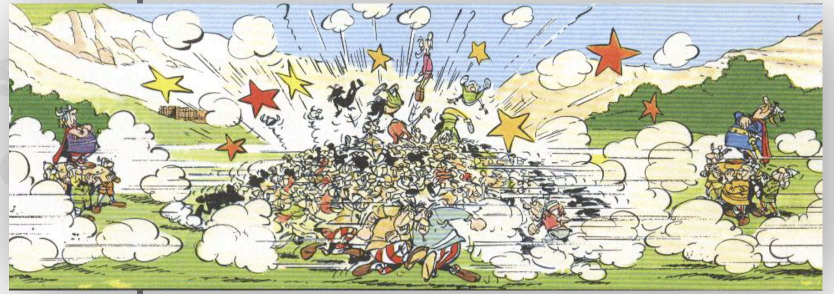
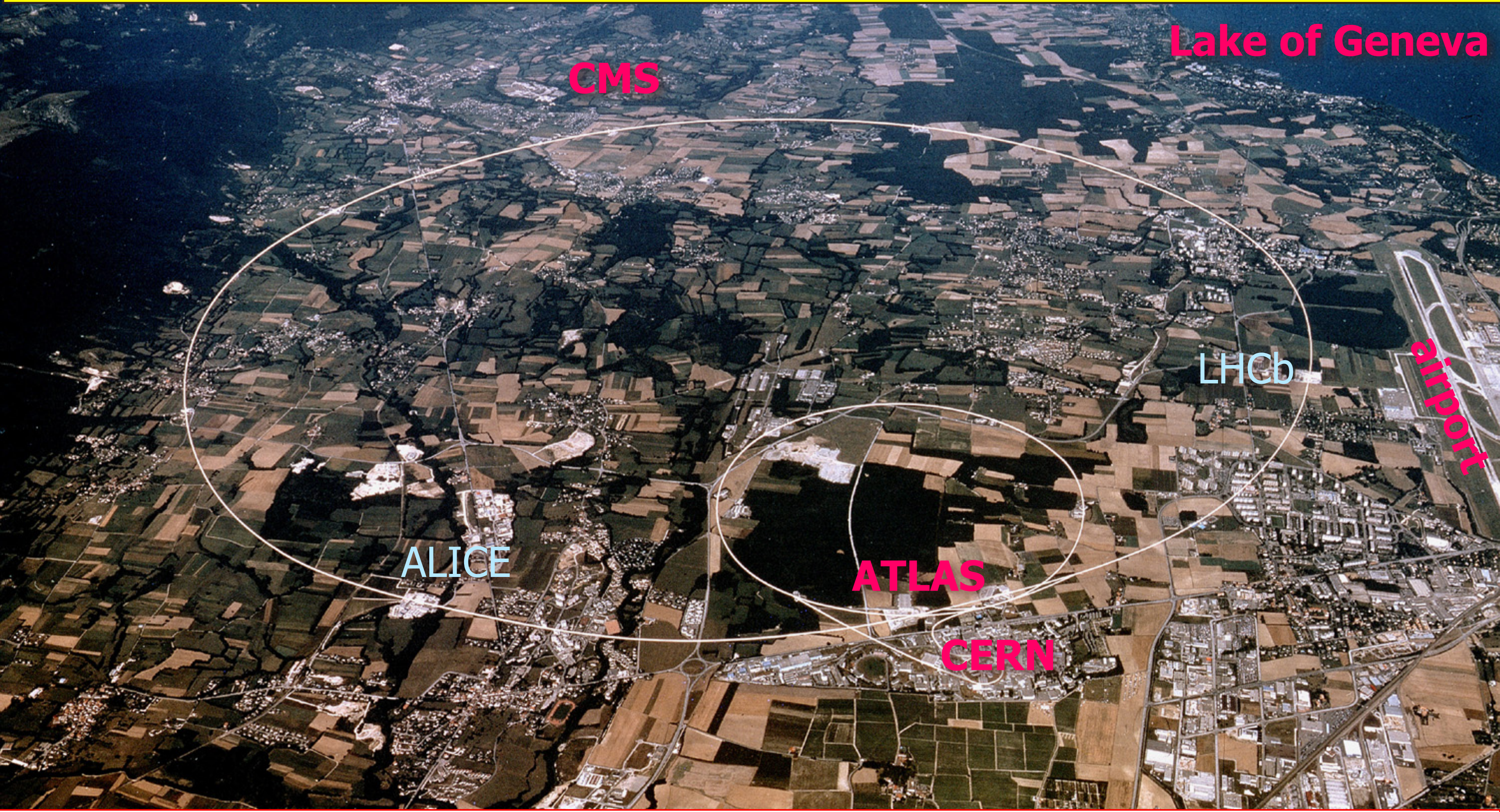
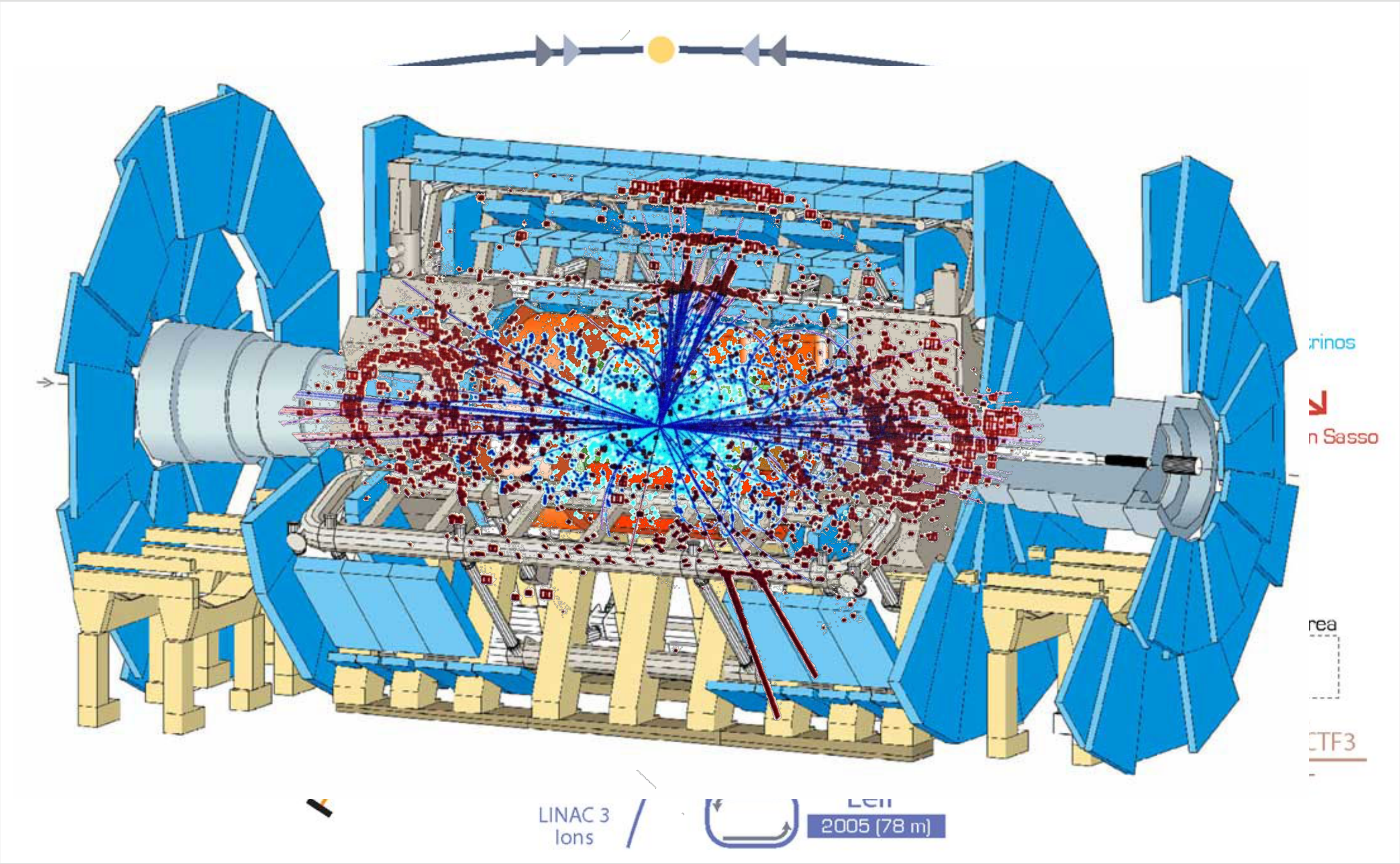


Large Hadron Collider——LHC @CERN, Geneva

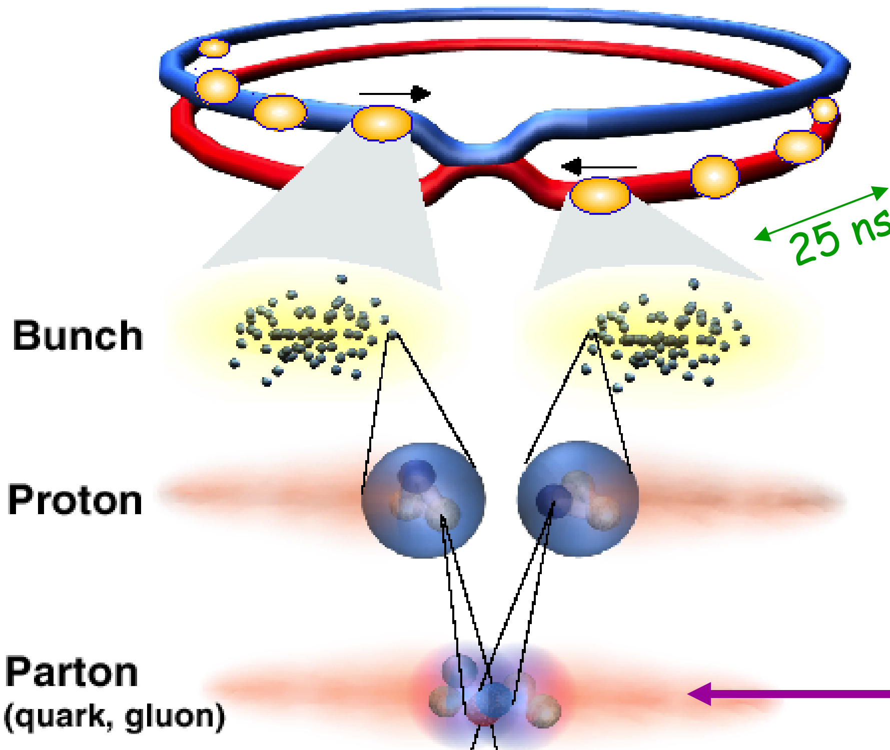


The Large Hadron Collider is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva

CERN's particle accelerator chain



Collisions at LHC



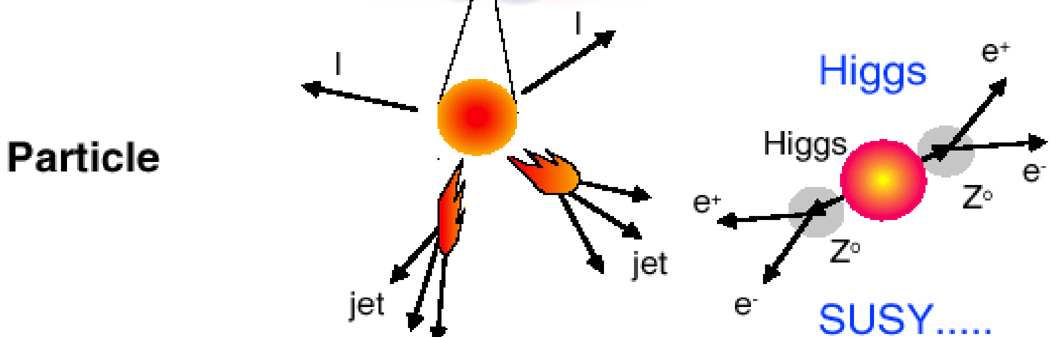
Proton-Proton	2835 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}

Event rate:

$N = L \times \sigma\ (pp) \approx$ 10^9 interactions/s

Mostly soft (low p_T) events

Interesting hard (high-p_T) events are rare

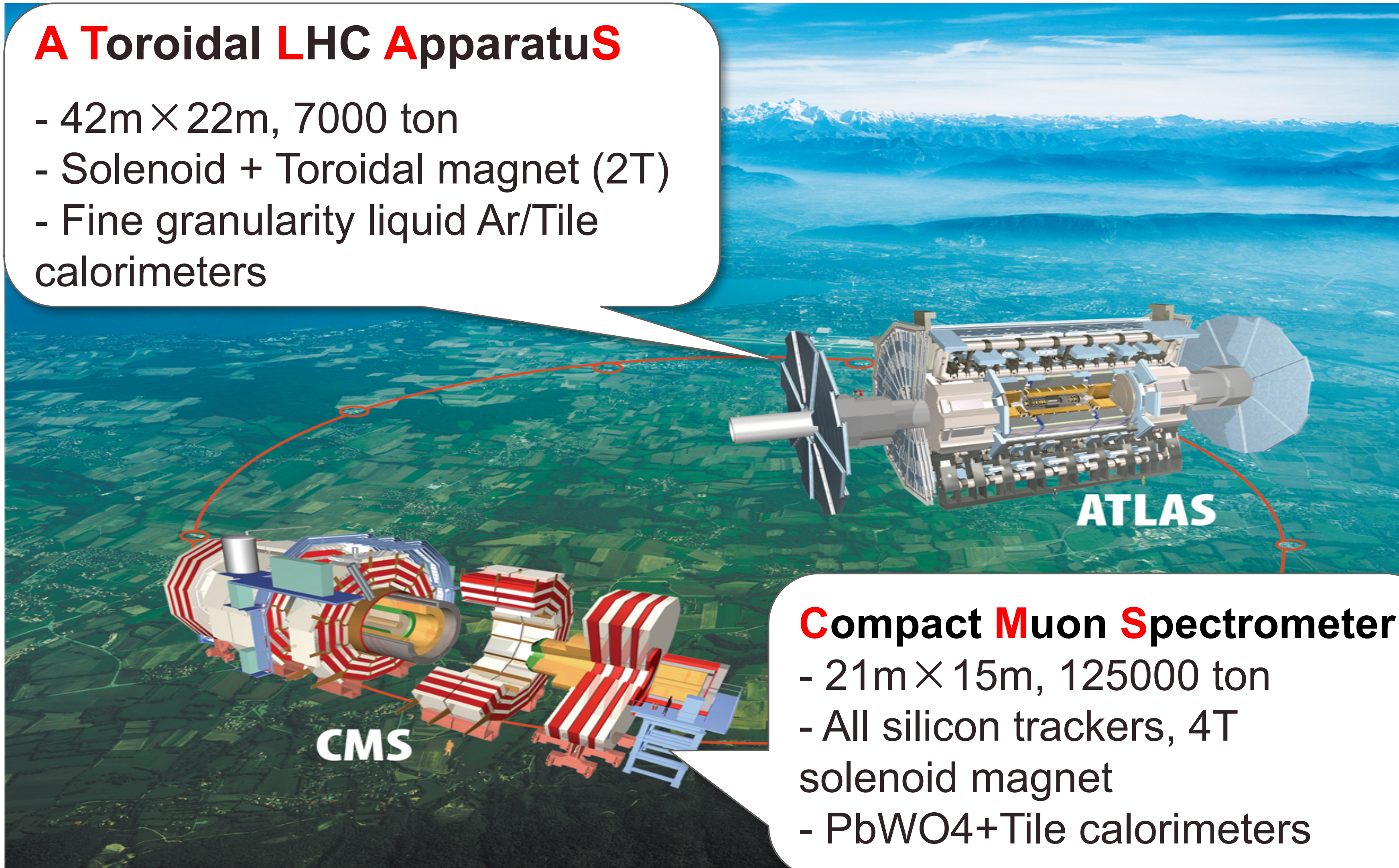


Selection of 1 in 10,000,000,000,000

→ Interesting events are very, very rare
→ One needs highly sophisticated instruments to find them

ATLAS and CMS detector @ LHC

ATLAS and CMS: two multi-purpose detectors @LHC

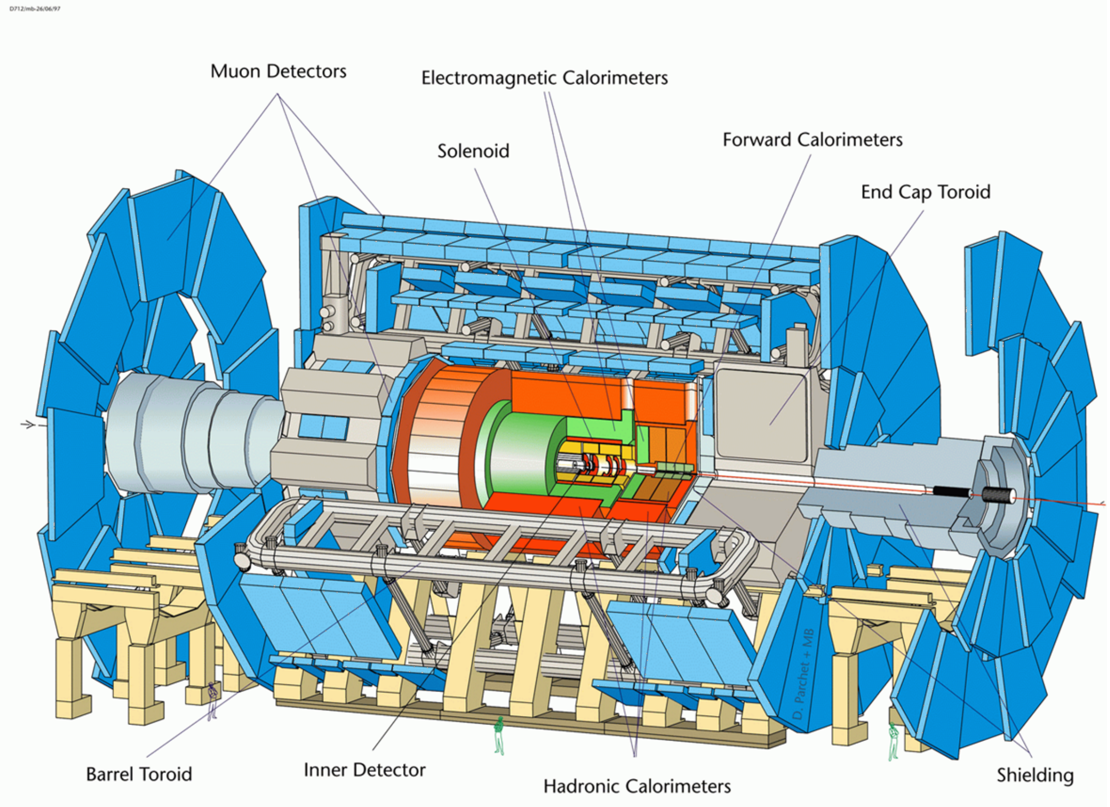


A Toroidal LHC ApparatuS

- 42m×22m, 7000 ton
- Solenoid + Toroidal magnet (2T)
- Fine granularity liquid Ar/Tile calorimeters

Compact Muon Spectrometer

- 21m×15m, 125000 ton
- All silicon trackers, 4T solenoid magnet
- PbWO4+Tile calorimeters

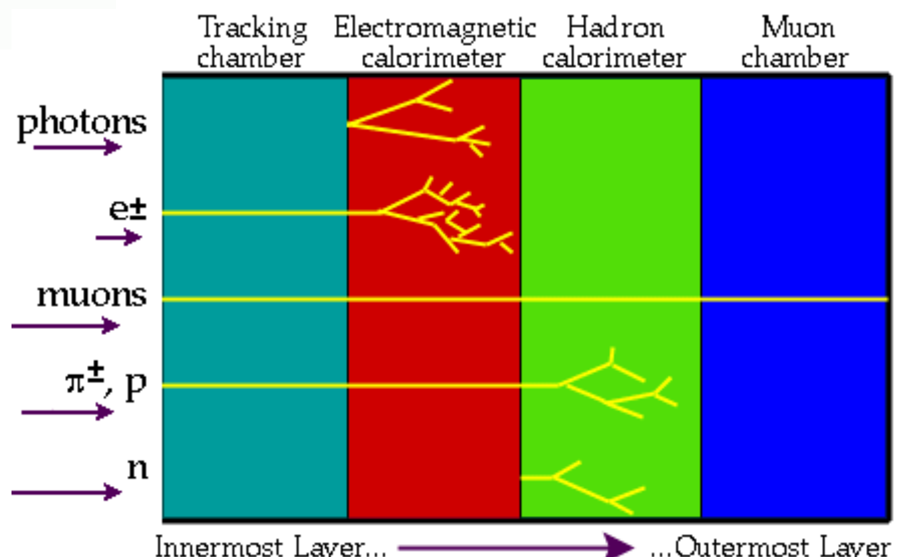


ATLAS

A Toroidal LHC ApparatuS

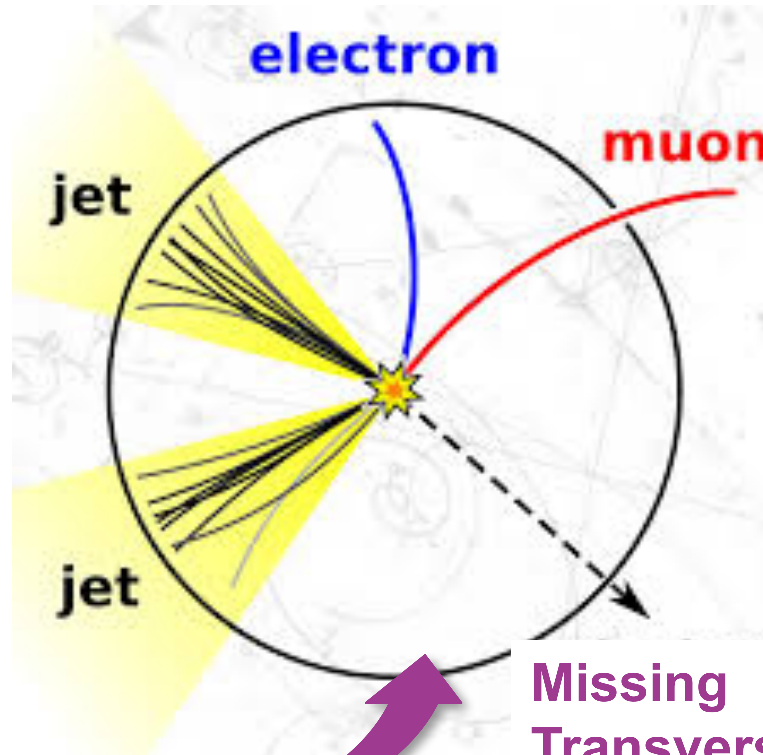
Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~ 10^8 electronic channels
~ 3000 km of cables

- **Tracking (|η|<2.5, B=2T) :**
  - **Si pixels and strips**
  - **Transition Radiation Detector (e/π separation)**
- **Calorimetry (|η|<5) :**
  - **EM : Pb-LAr**
  - **HAD: Fe/scintillator (central), Cu/W-LAr (fwd)**
- **Muon Spectrometer (|η|<2.7) :**
  - **air-core toroids with muon chambers**



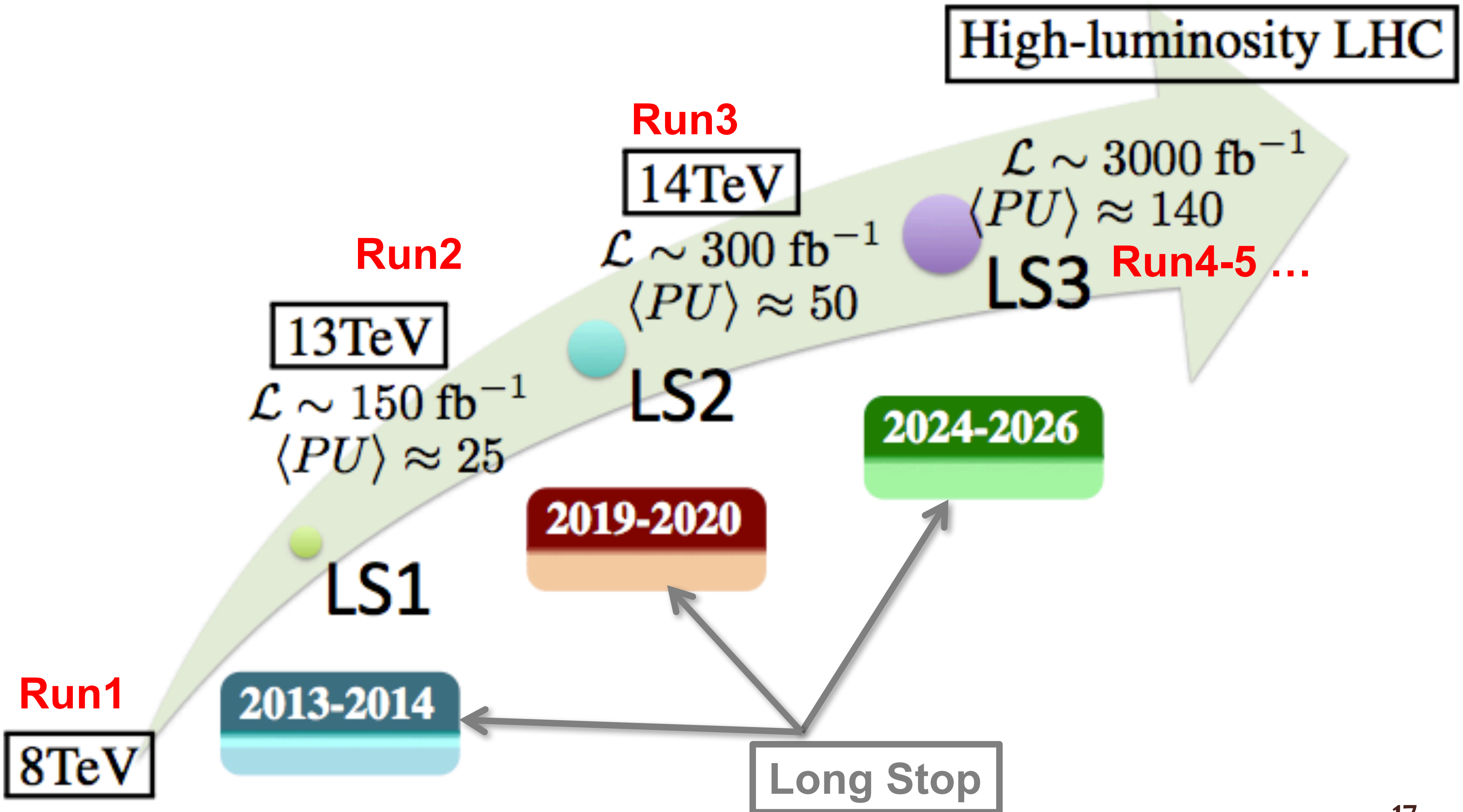
MET: Missing Transverse Energy

- At the LHC an unknown proportion of the energy of the colliding protons escapes down the beam-pipe
- Invisible particles (neutrinos, neutralinos?) are created their momentum can be constrained in **the plane transverse to the beam direction**



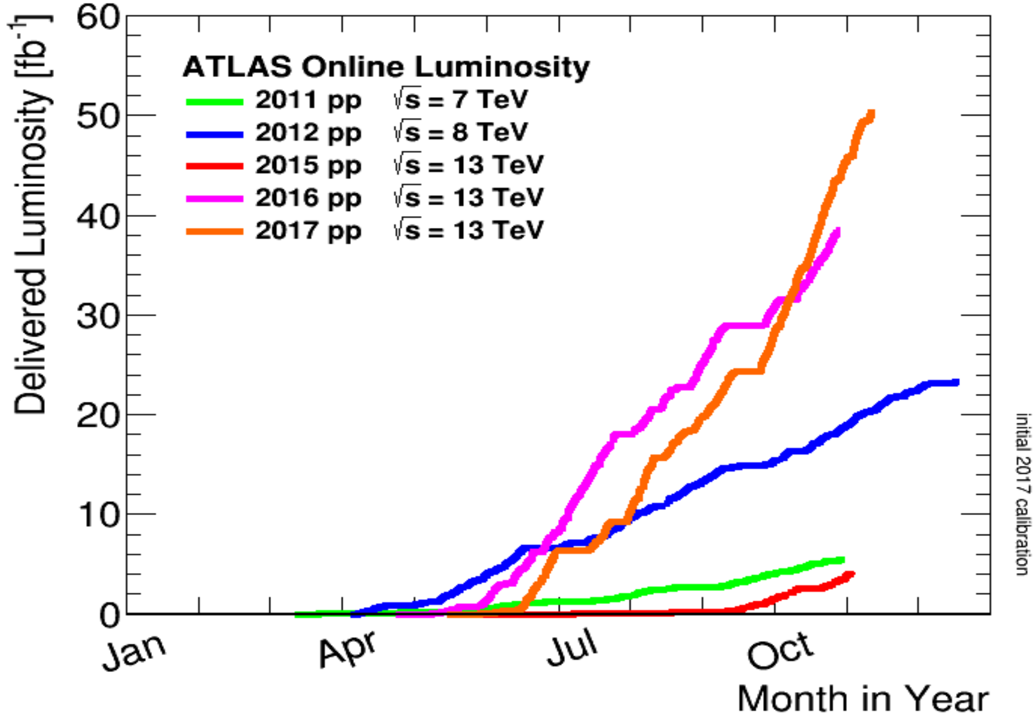
Missing Transverse Energy

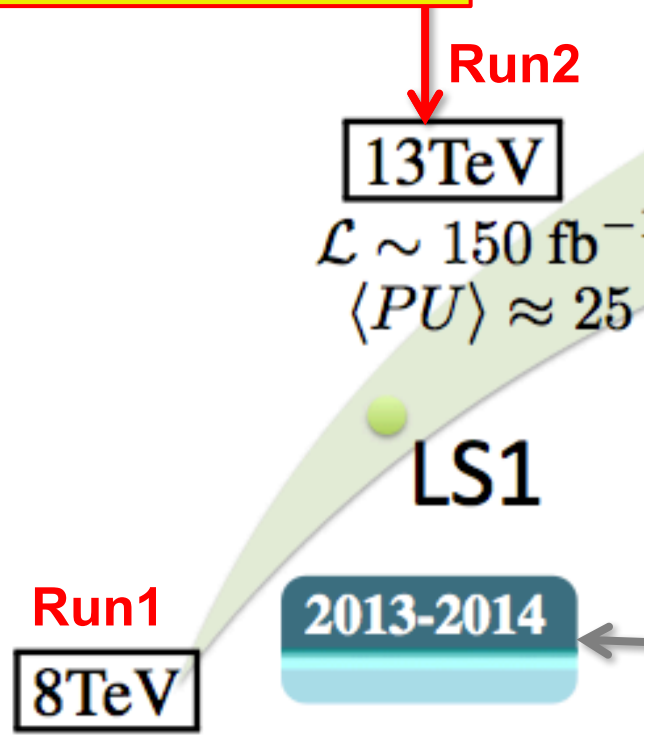
$$E_T^{\text{miss}} = -\sum_i p_T(i)$$


High-luminosity LHC
Run3
14TeV
$\mathcal{L} \sim 3000\ \mathrm{fb}^{-1}$
$\langle PU \rangle \approx 140$
Run2
$\mathcal{L} \sim 300\ \mathrm{fb}^{-1}$
$\langle PU \rangle \approx 50$
LS3
Run4-5 …
13TeV
LS2
$\mathcal{L} \sim 150\ \mathrm{fb}^{-1}$
$\langle PU \rangle \approx 25$
2024-2026
2019-2020
LS1
Run1
2013-2014
8TeV
Long Stop

Since 2010, ATLAS&CMS have invested huge efforts in SUSY search @LHC : Great Luminosity recorded

We are here:
~80 fb^{-1} 13 TeV data
~ 3% of total





Run1:
- ~ 35 pb^{-1} 7 TeV data (2010)
- ~ 5 fb^{-1} 7 TeV data (2011)
- **~ 20 fb^{-1} 8 TeV data (2012)**

Run2:
- **~ 3 fb^{-1} 13 TeV data (2015)**
- **~ 33 fb^{-1} 13 TeV data (2016)**
- **~ 50 fb^{-1} 13 TeV data (2017)**

The results are based on 36 fb^{-1} @ 13 TeV (RUN2 2015-2016)

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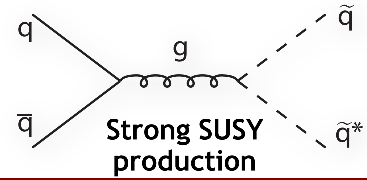
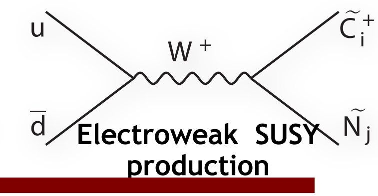
Where do we start?

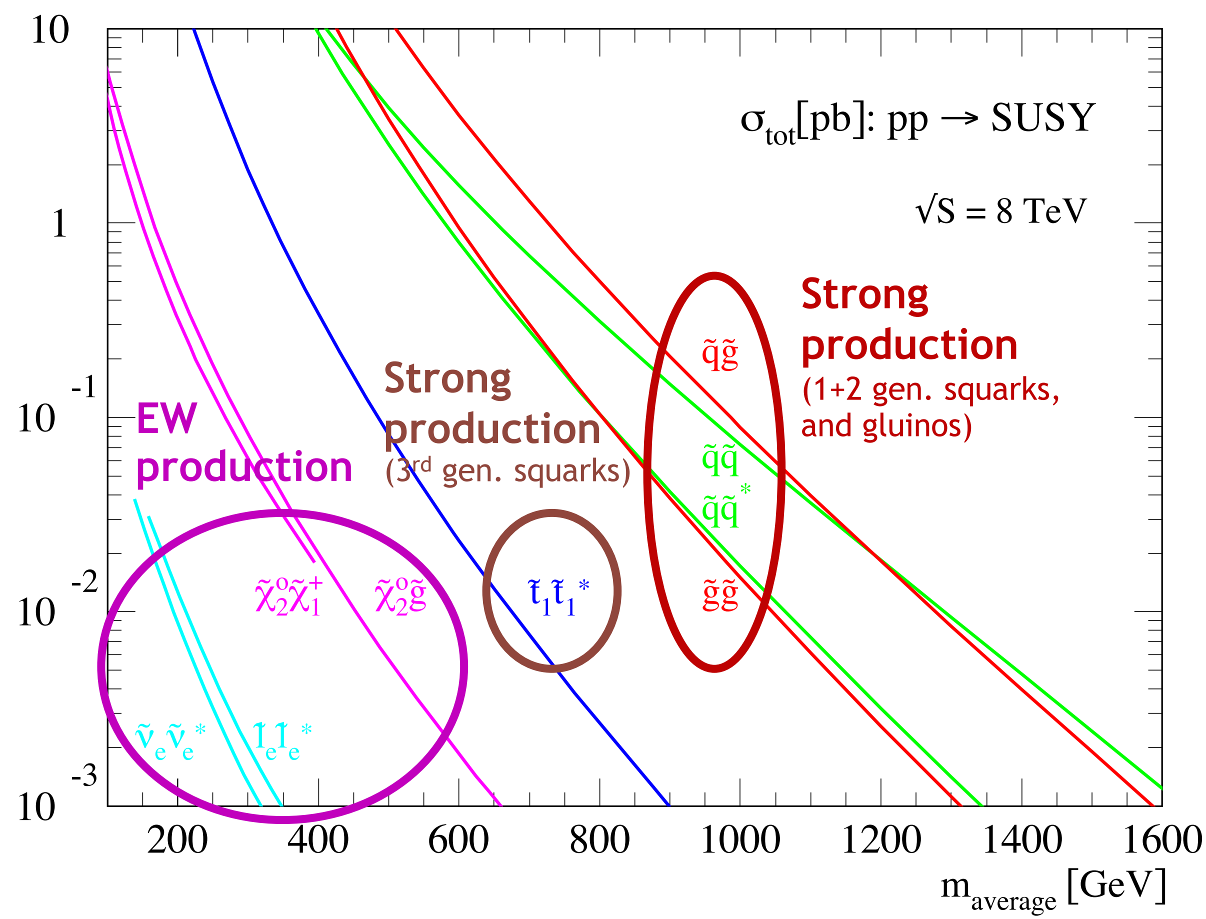
Huge parameter space, but guiding principles





- **Early analyses** dominated by broad and inclusive searches for gluino and squark production
- **Increasing luminosity** gave access to rare production channels. Additional motivation from Natural SUSY paradigm
- If 1st and 2nd squark and gluino is too heavy, EWK SUSY production may dominant in LHC

SUSY searches strategy driven by cross section and luminosity



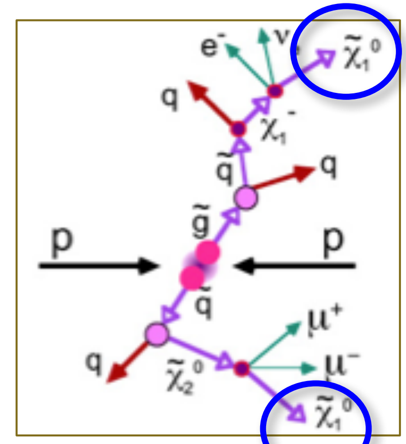
How do we start? - SUSY Signature

- **Conserved R parity (RPC):** (originally introduced for stability of proton)

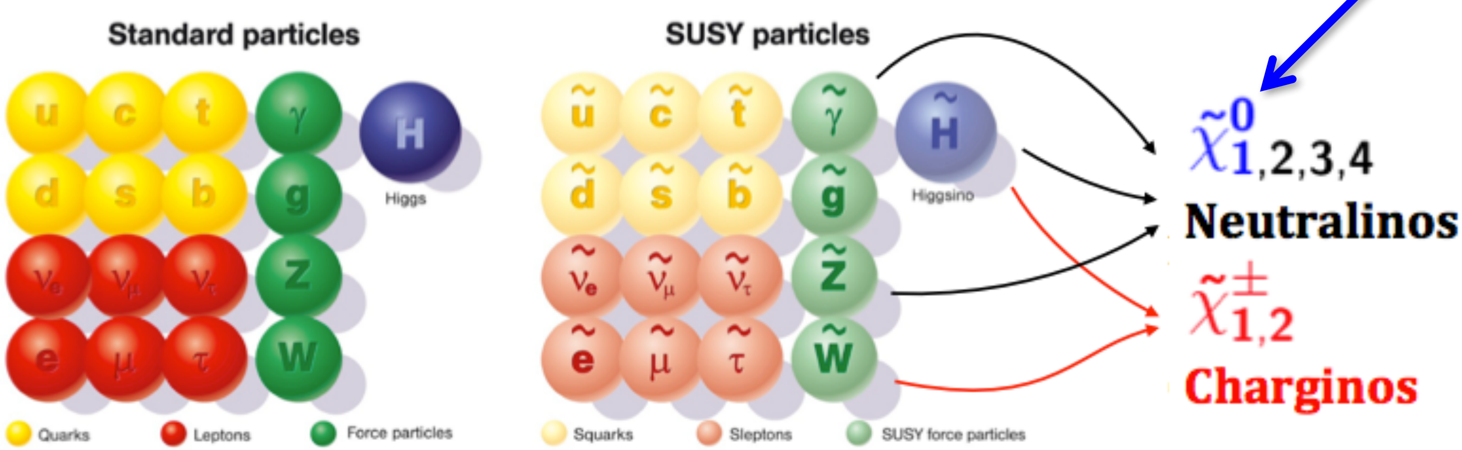
$$R = (-1)^{3(B-L)+2S}$$

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

  – SUSY particles produced/annihilated in pairs
  – Lightest SUSY particle (LSP) stable (DM candidate)
  – Typical signature: jets/leptons/photons + **MET** **(key signature: large MET)**

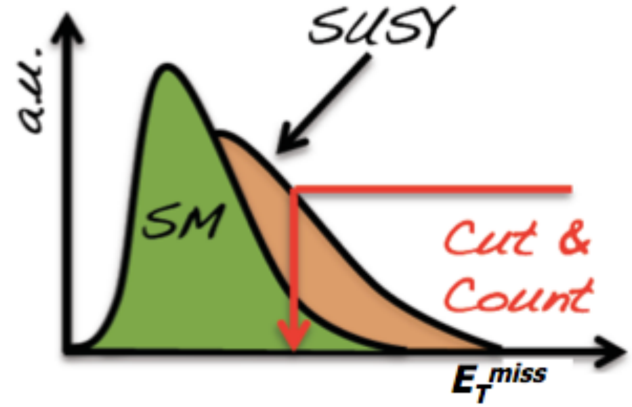


- **Violated R parity (RPV)**: no Dark Matter candidate



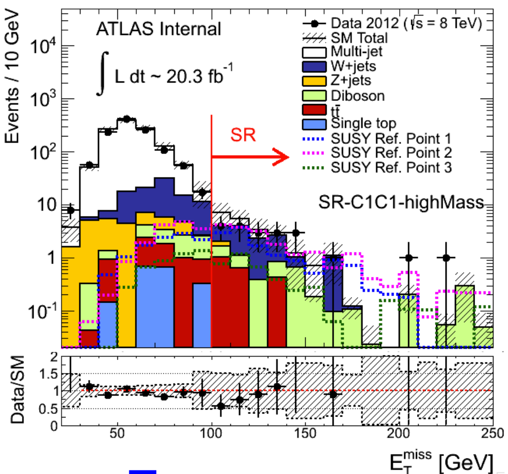
SUSY Signature & Search Strategy

- **SUSY search strategy:** search for deviation from SM
- **SUSY sensitive variables:** Try to establish excess of events in some sensitive kinematic distribution (E_T^{miss}, Meff, mT …)
- **SM background:** SUSY searches rely on accurate modeling of the Standard Model backgrounds

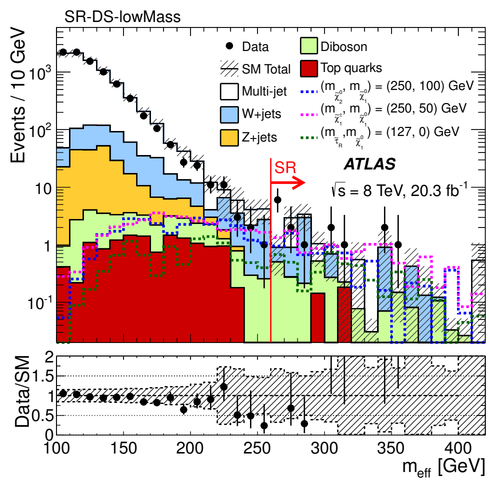


SUSY Sensitive Variables

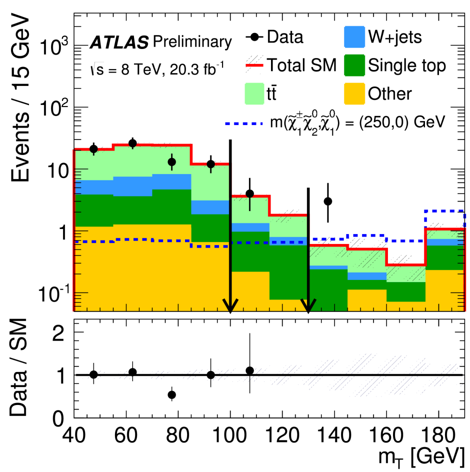
E_T^{miss}



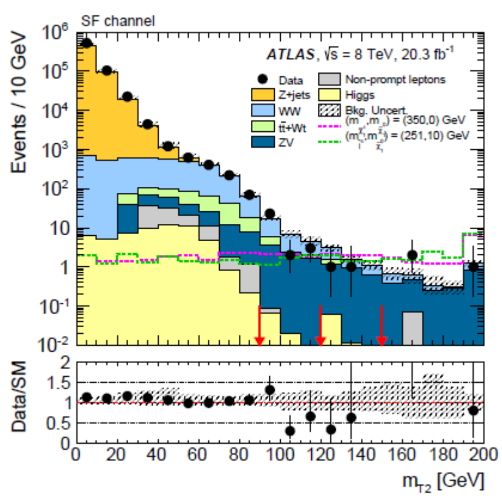
M_{eff}



mT



mT2



- E_T^{miss} from escaping LSP, to suppress bg from mis-measured jets and oth. SM BG
- Related to the sparticle mass scale, like effective mass (**M_{eff}**)

$$M_{\text{eff}} \equiv \sum_{i=1}^{N_{\text{jets}}} p_T^{\text{jet},i} + \sum_{j=1}^{N_{\text{lep}}} p_T^{\text{lep},j} + E_T^{\text{miss}}$$

- **mT, mT2** (stransverse mass): suppress BG with Ws

$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T)\right)\right]$$

- Many others …

SM Background Modeling

Combined fit of all regions and bgs, and including systematic exp. and theory uncertainty as nuisance parameters

Standard Model

Top, multijets
V, *VV*, *VVV*, Higgs
& combinations of these

Reducible backgrounds

Determined from data
Backgrounds and methods depend on analyses

Irreducible backgrounds

- *Dominant sources*:
  - Mulit-jet: data-driven
  - Non-Multi-jet: normalise MC in data control regions
- *Subdominant sources*: MC

blinded

Validation

Validation regions used to cross check SM predictions with data

blinded

Signal regions

SM Background Modeling

Standard Model

Top, multijets
V, *VV*, *VVV*, Higgs
& combinations of th

Irre

Reducible backgrounds

Determined from data
Backgrounds and methods depend on analyses

- **Multijet background**: "ABCD method" or jet smearing method
- **Fake leptons or heavy-flavour jets** determined with "matrix method" in different-purity samples using "real" and "fake" probabilities measured in data.
- **Charge flip rate** measured in Z events

Validation

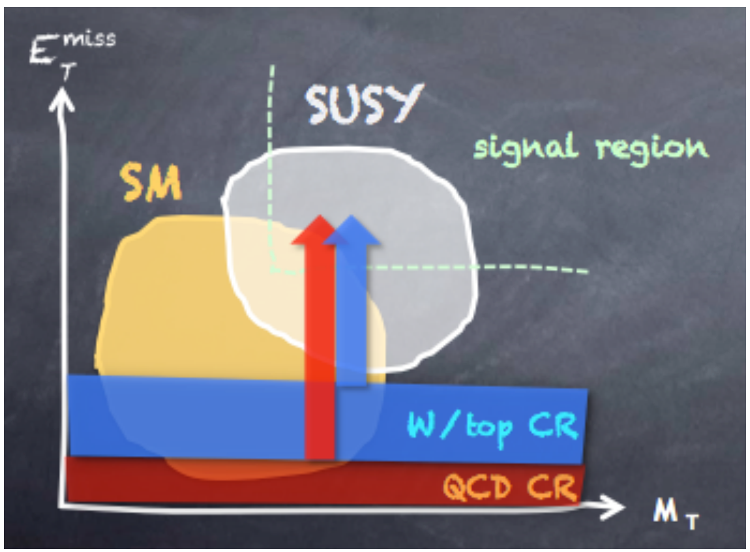
Validation regions use cross check SM predictions with data

Signal regions

blinded

SM Background Modeling

Normalise MC prediction in SRs using dedicated CRs ωιτη transfer factor: *T*



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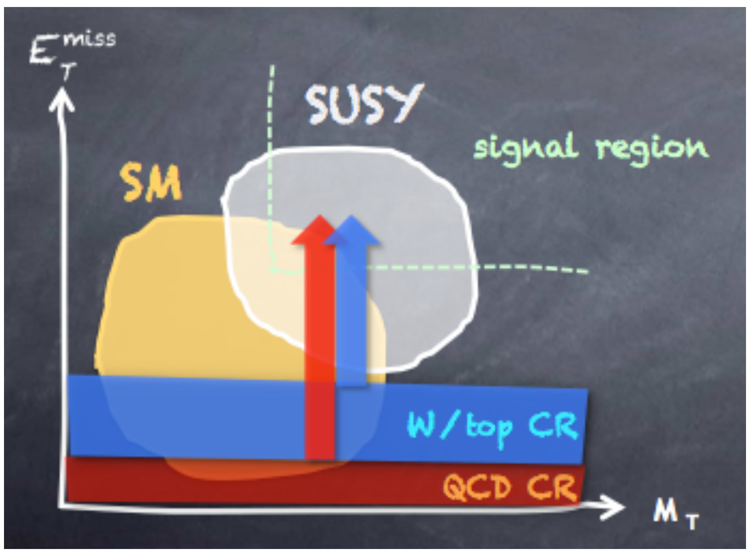

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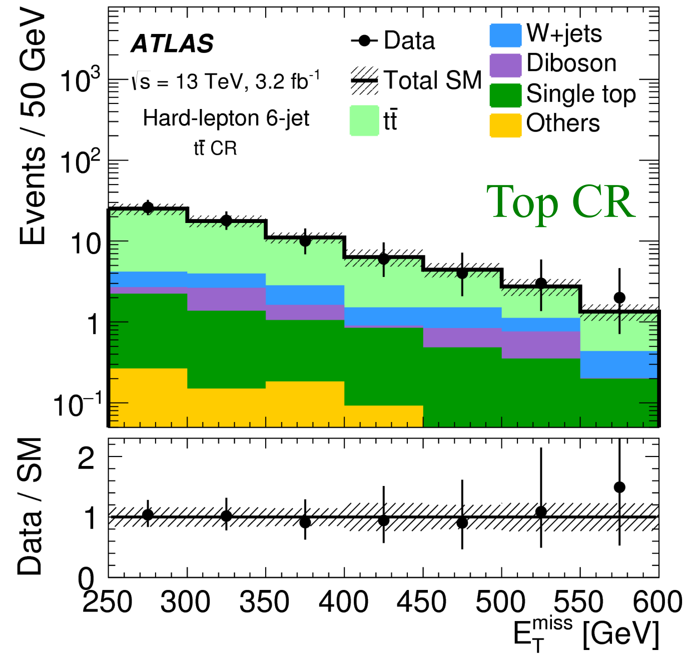
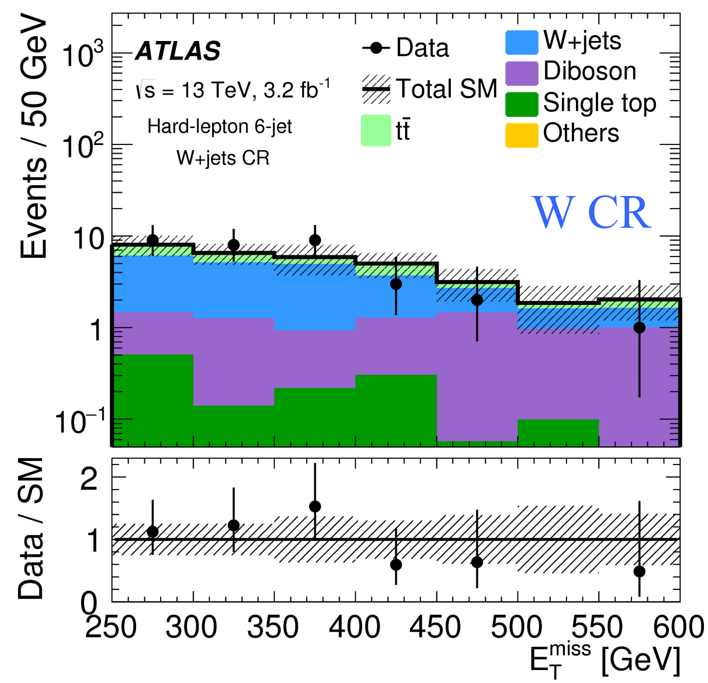
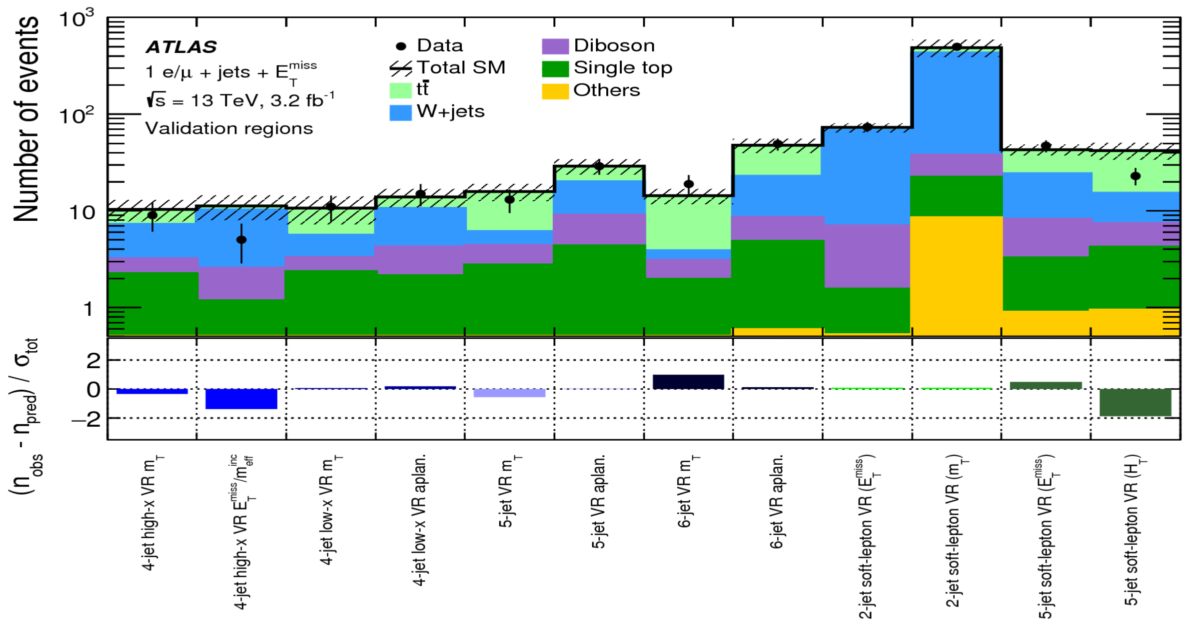




SM Background Modeling



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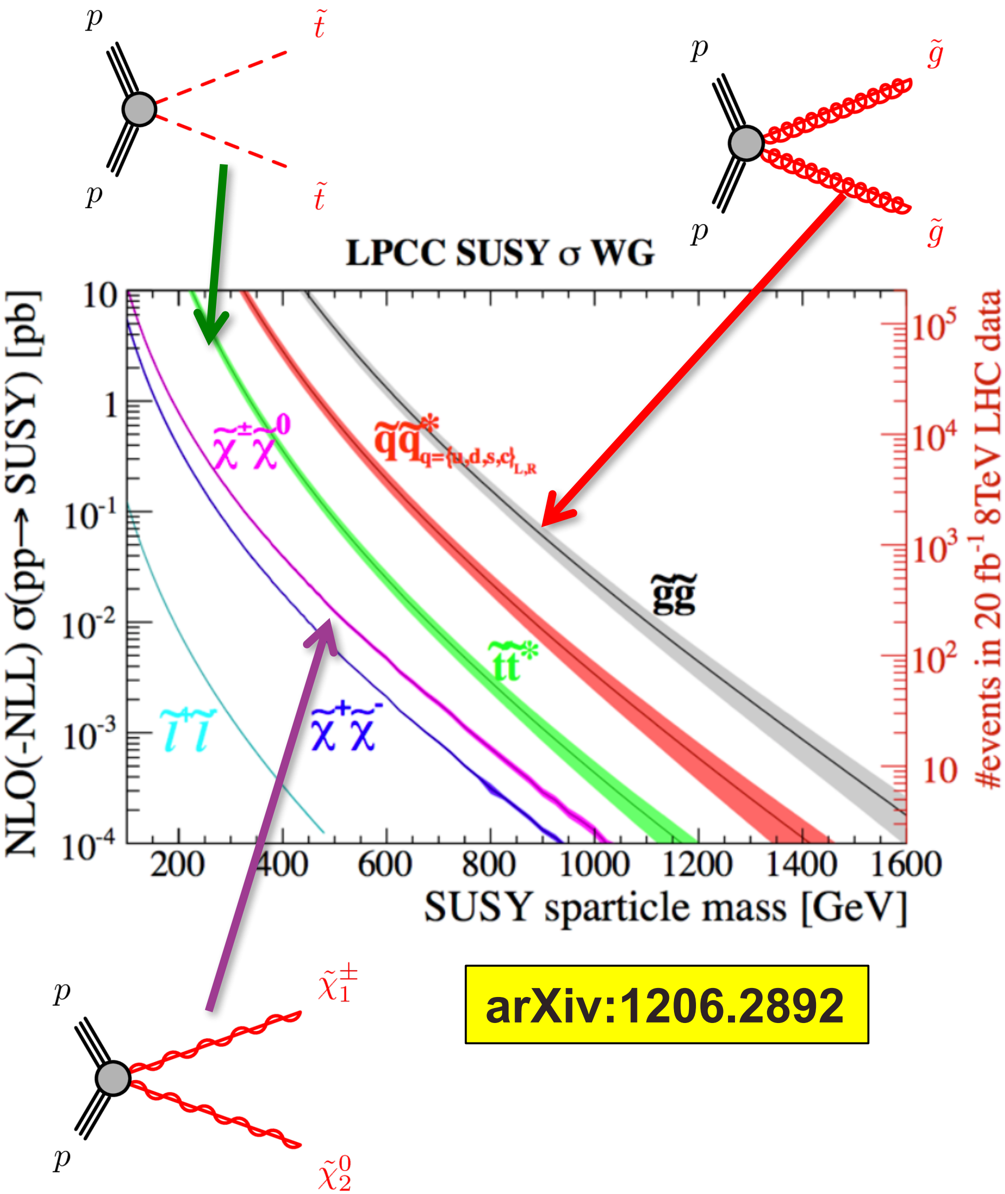
SUSY Search @ LHC

ATLAS public link
CMS public link



arXiv:1206.2892

Strong production:

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

3rd generation:

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

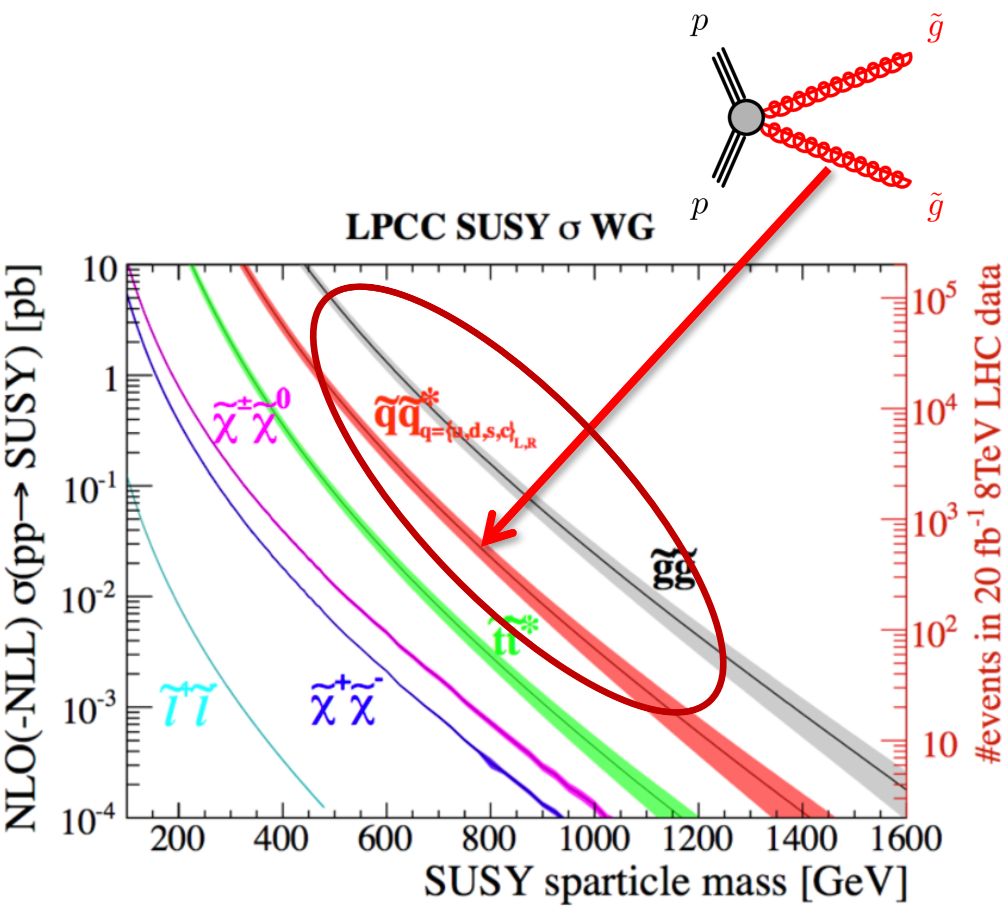
Electroweak production:

- ❑ targeting Electroweakinos, sleptons
- ❑ Lowest mass sparticles, clean signature

RPV/LL:

- ❑ targeting R-parity violating models and long lived sparticles
- ❑ More exotic models

SUSY Search @ LHC



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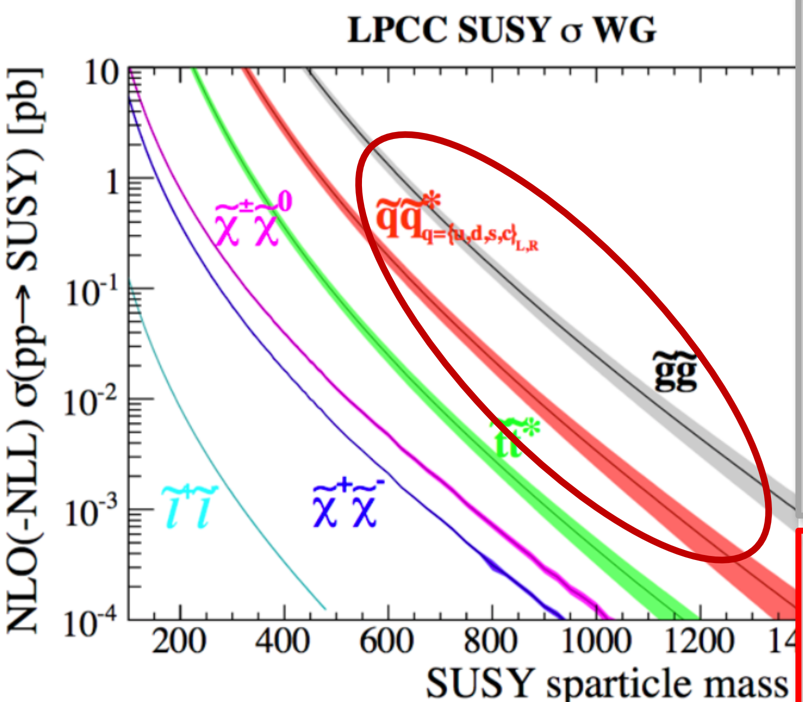
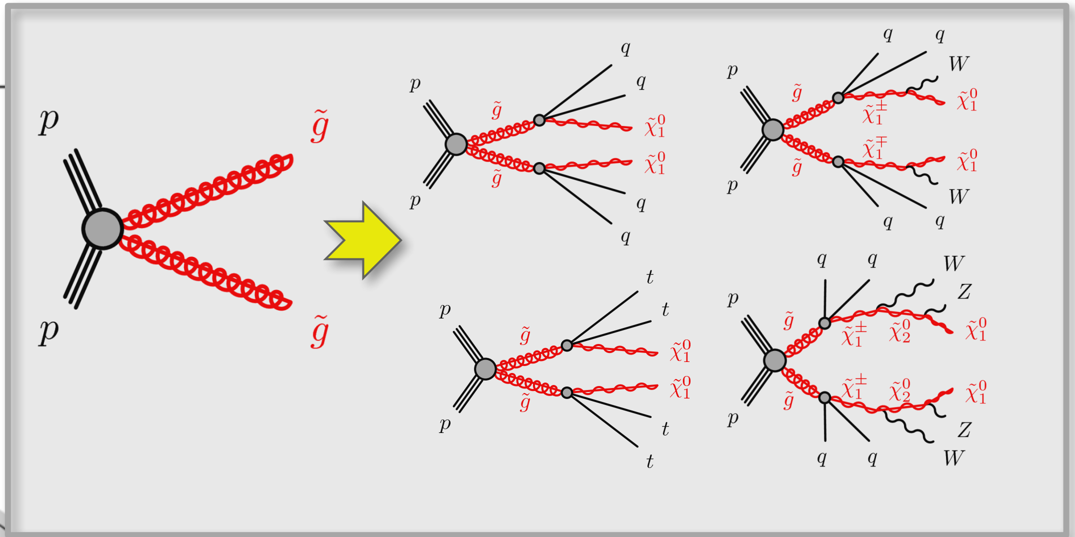
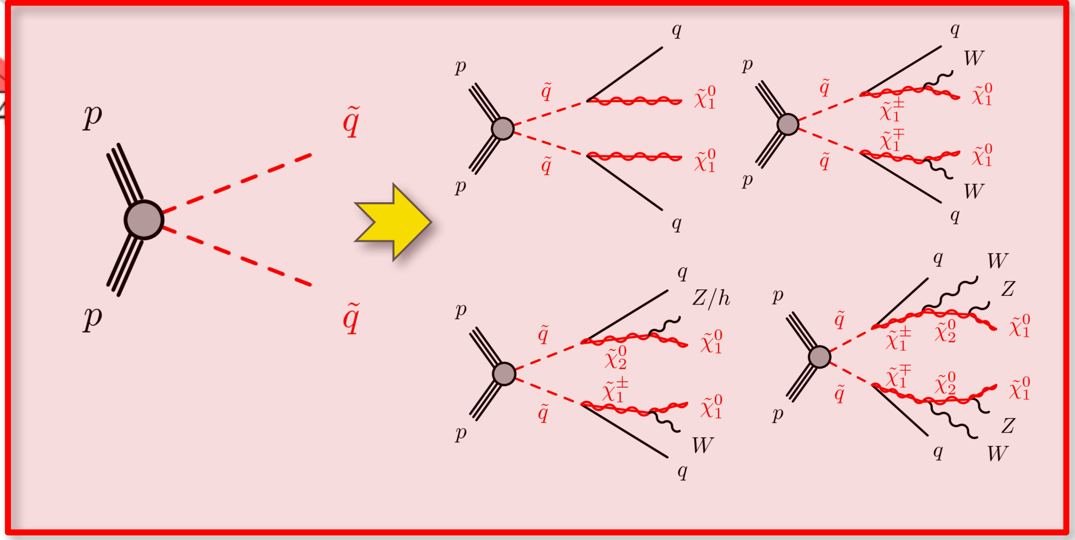
- More exotic models

Electroweakino Production







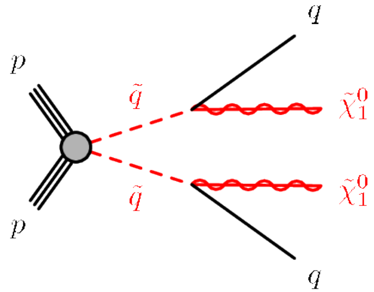
Generic signatures :

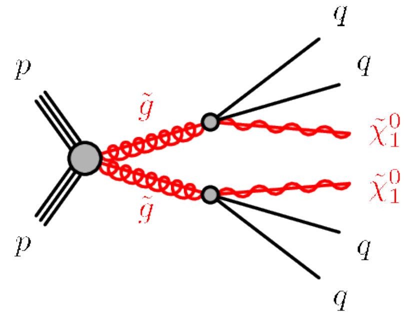
Multi -jets + n_lepton/n_photon (n=0,1, ≥2) + large E_T^{miss} **(0L,1 L, >=2L)**

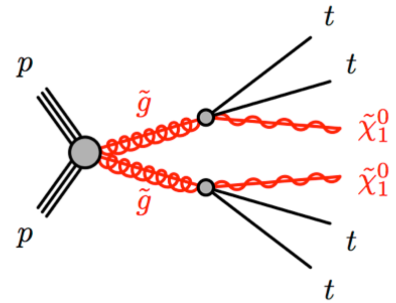
Strong Production: All hadronic

- ATLAS has two searches based on different scenarios: ATLAS-CONF-2017-022(SS,GG), arXiv:1711.01901 (Gtt, Gbb), arXiv:1708.02794 (GG, 7-11jets)
- Signal/BG discrimination based on:
  - **Large/medium mass split: Meff, MET,**
  - **Compressed region: R Jigsaw**
- Huge #signal regions (SRs) defined targeting above different search scenarios and phase space

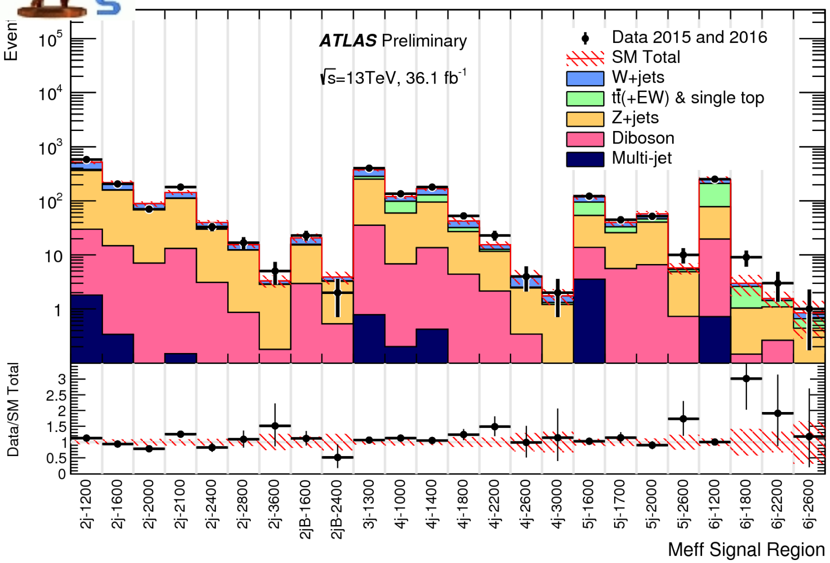
- CMS has several searches based on different kinematics:
  - **H_T^{miss}** (PhysRevD.96.032003):
    - ✓ binned in jet and b-jet multiplicity.
    - ✓ In each bin, bin further in H_T and H_T^{miss}
  - **mT_2 search** (Eur. Phys. J C 77 (2017) 710):
    - ✓ binned in H_T, jet and b-jet multiplicity.
    - ✓ In each bin, look at tails of mT2

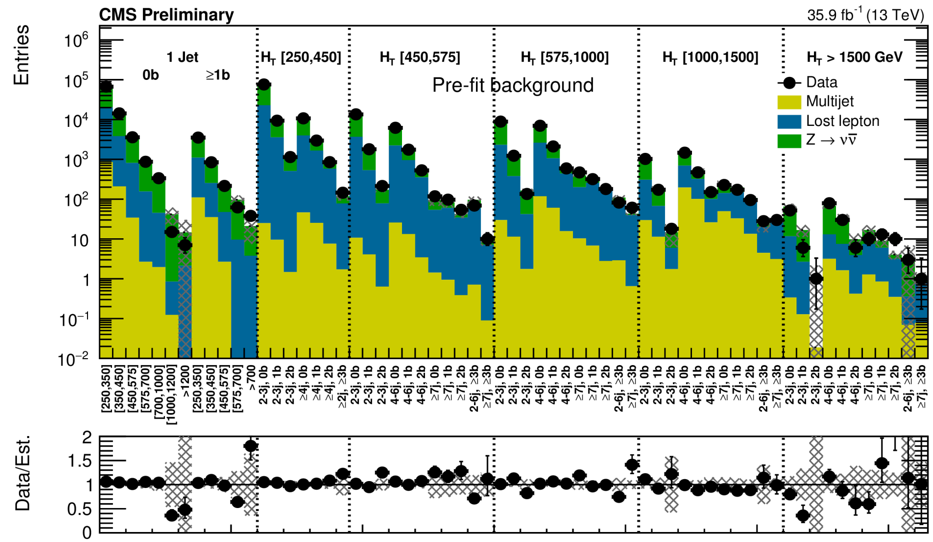


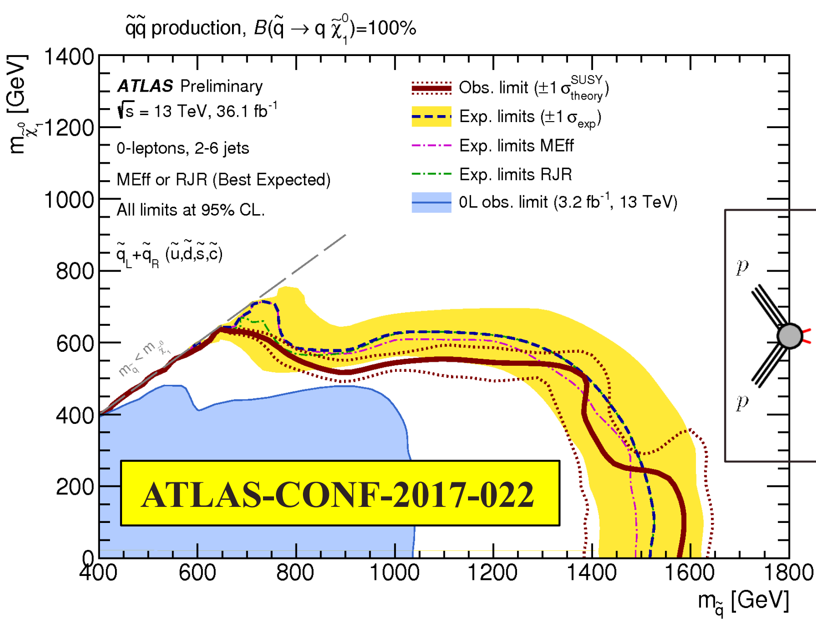


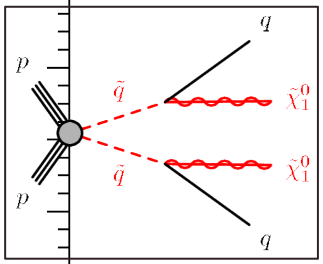


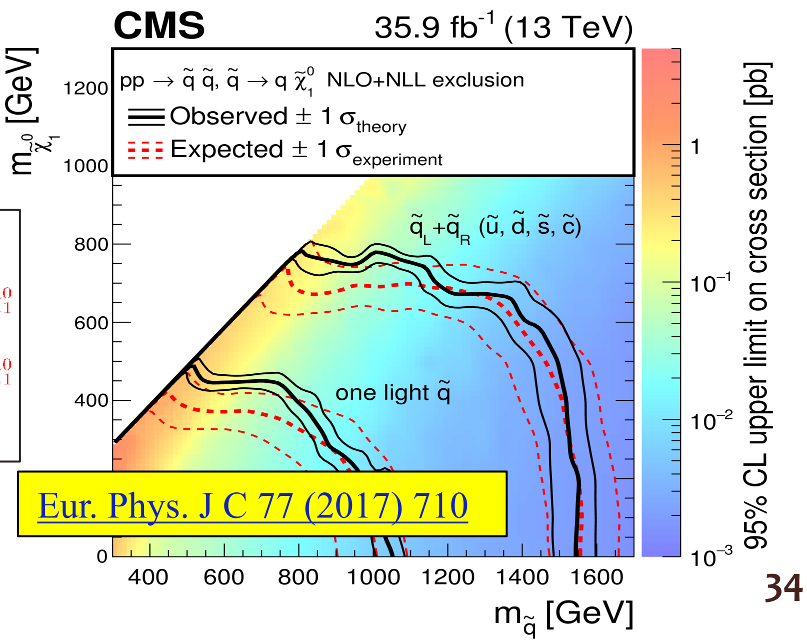
All hadronic: ATLAS | CMS results



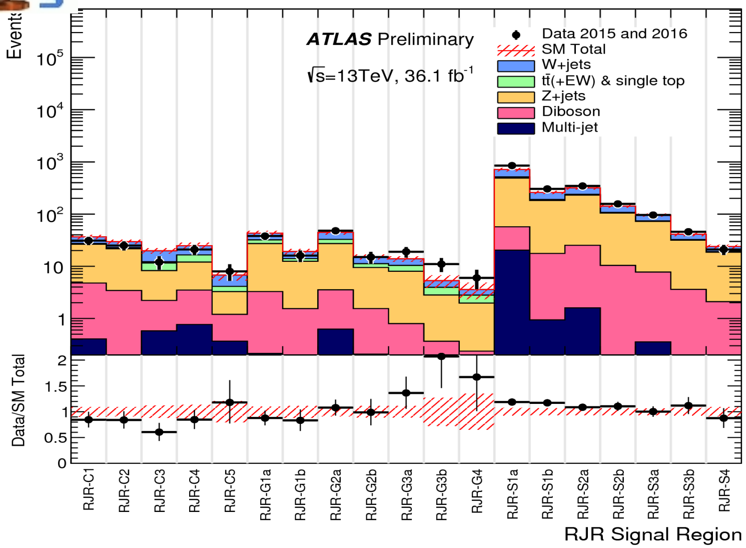


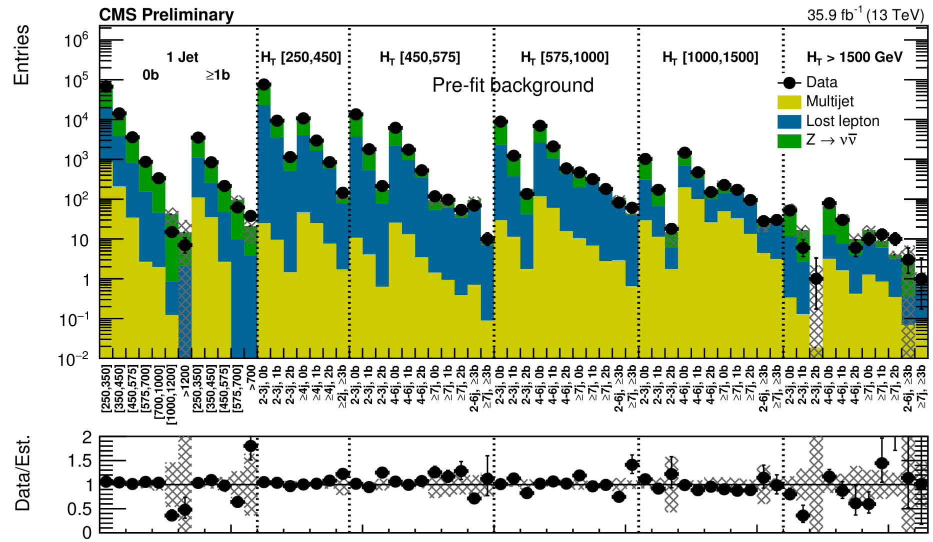


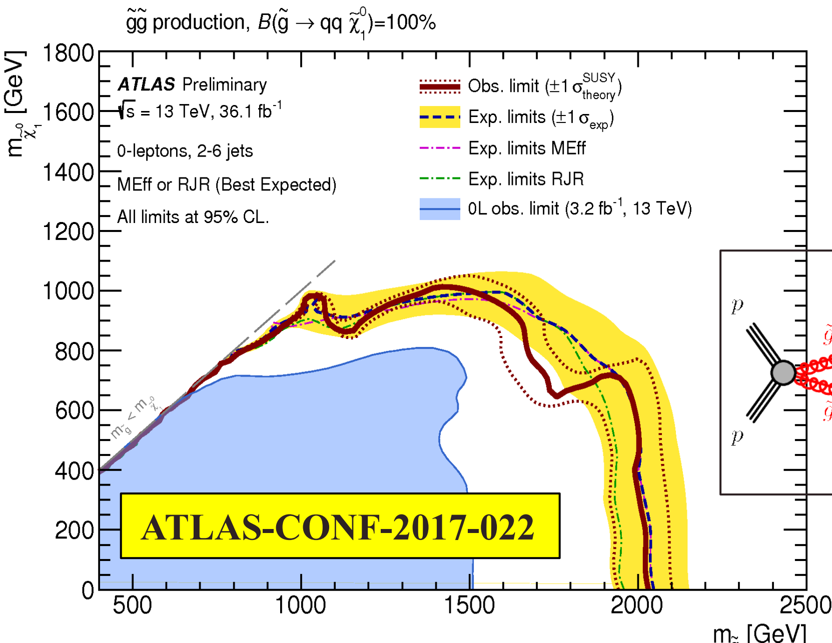


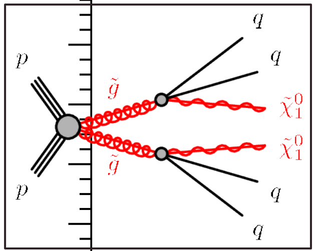


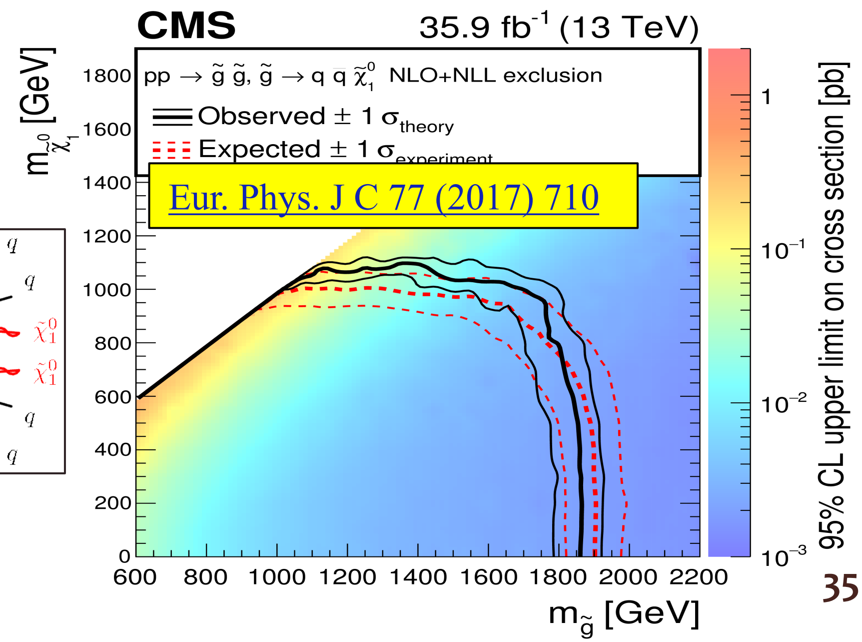
All hadronic: ATLAS | CMS results



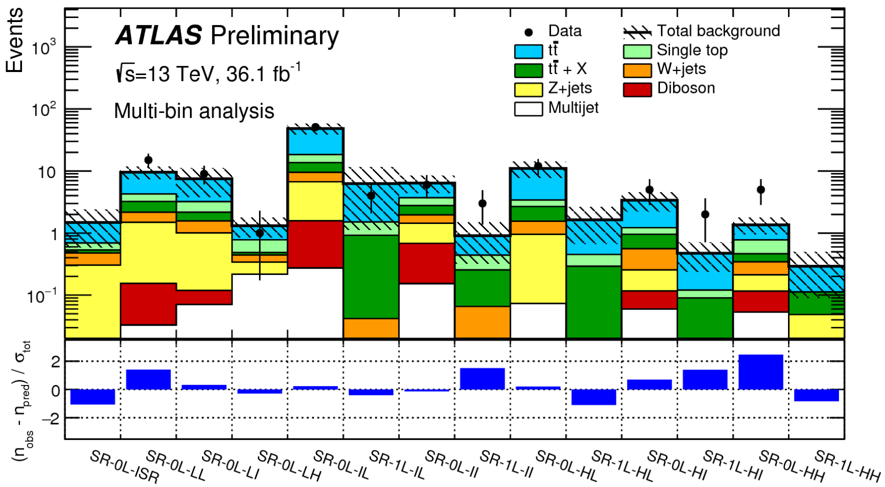


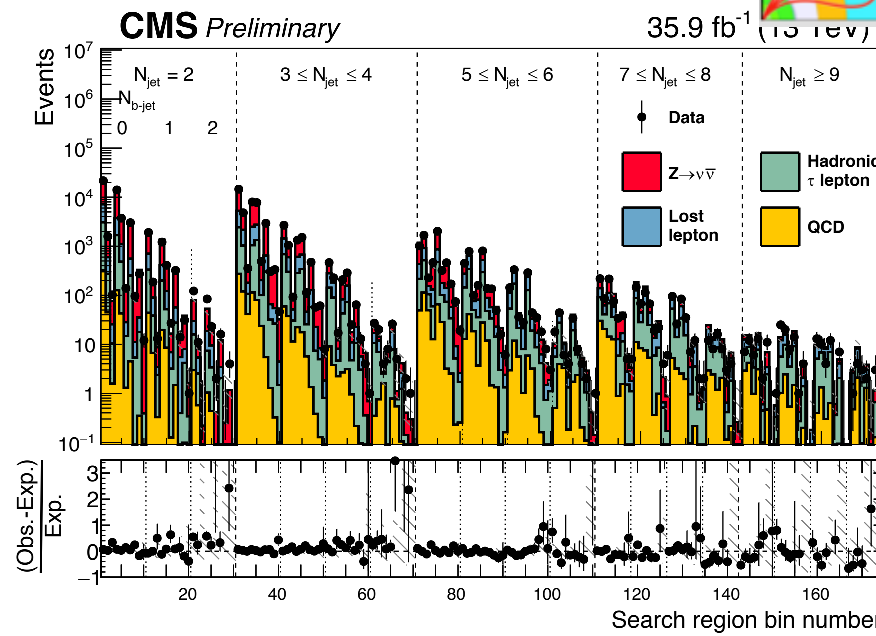


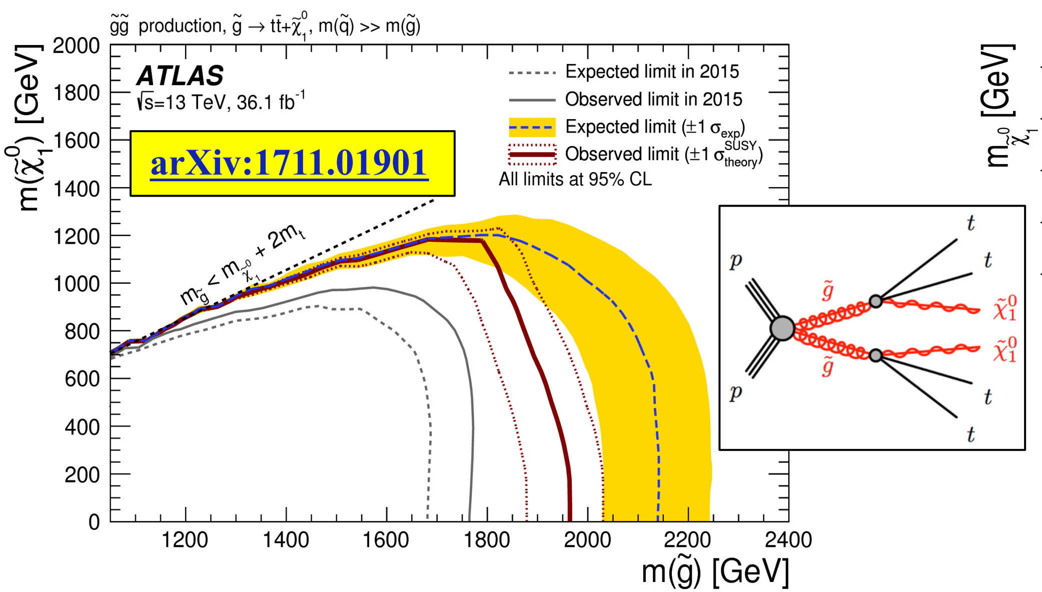


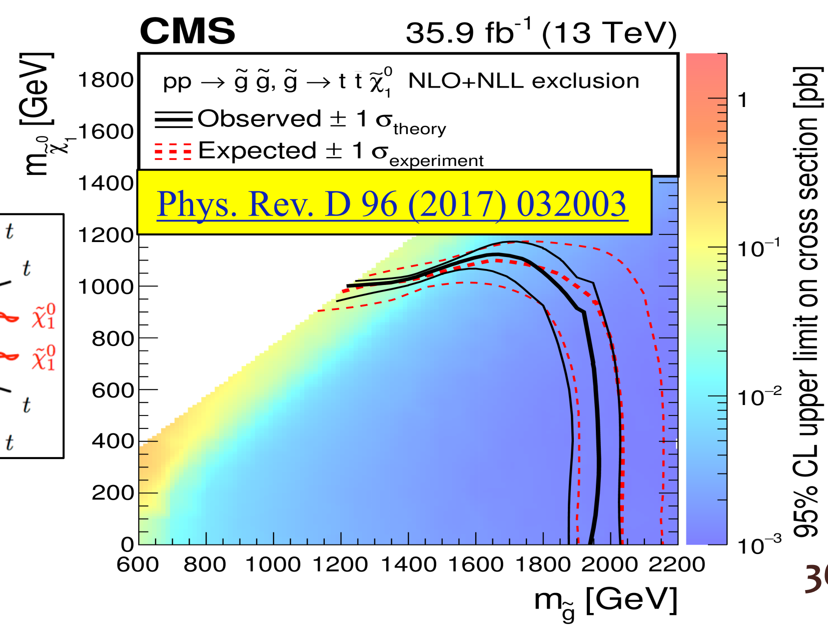


All hadronic: ATLAS | CMS results





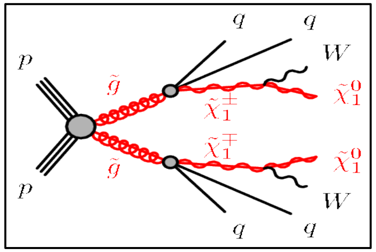


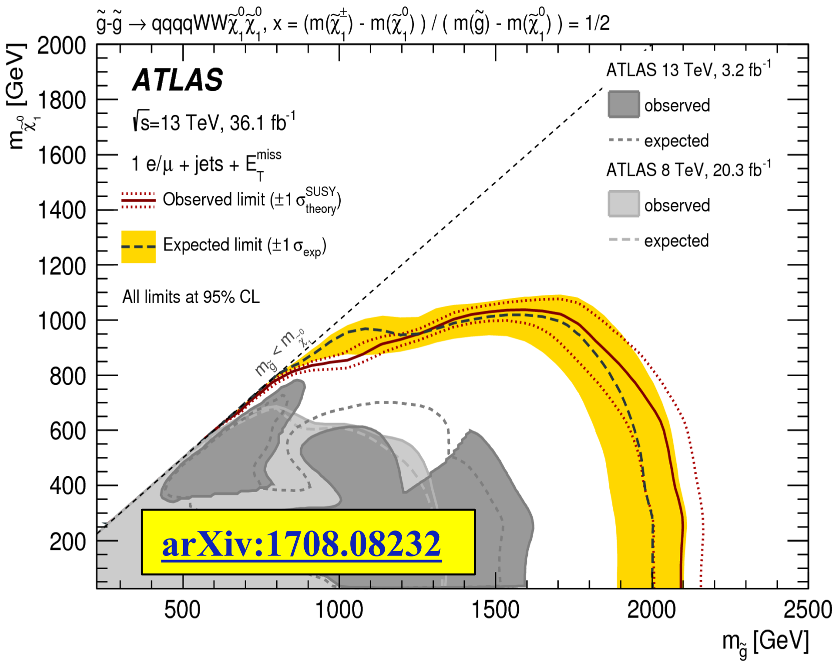


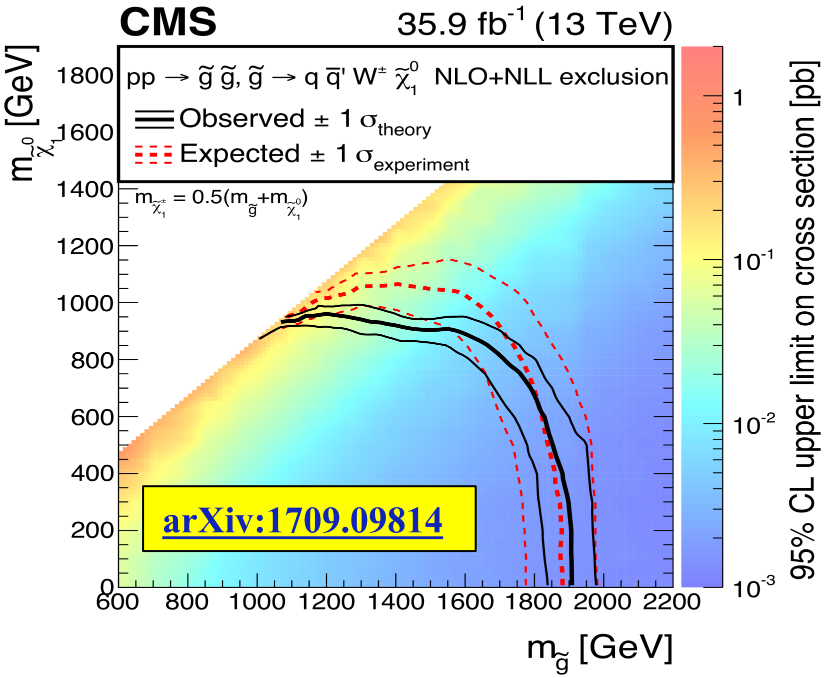
Strong Production: leptonic signatures

- We can use lepton(s) to probe for strong production signals
  - → suppressed hadronic backgrounds
  - → single lepton, OS, SS di-leptons, multi-leptons (+ jets+ MET)

Single Lept.







Strong Production: leptonic signatures

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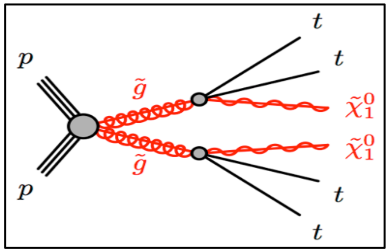
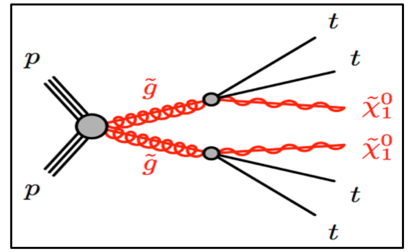
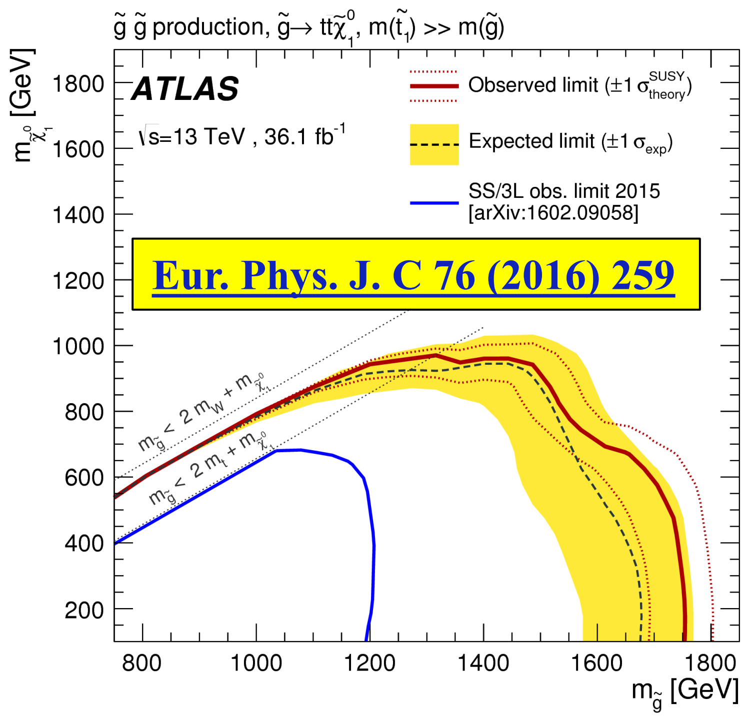
  - → single lepton, OS, SS di-leptons, multi-leptons (+ jets+ MET)



SS Di-lept.





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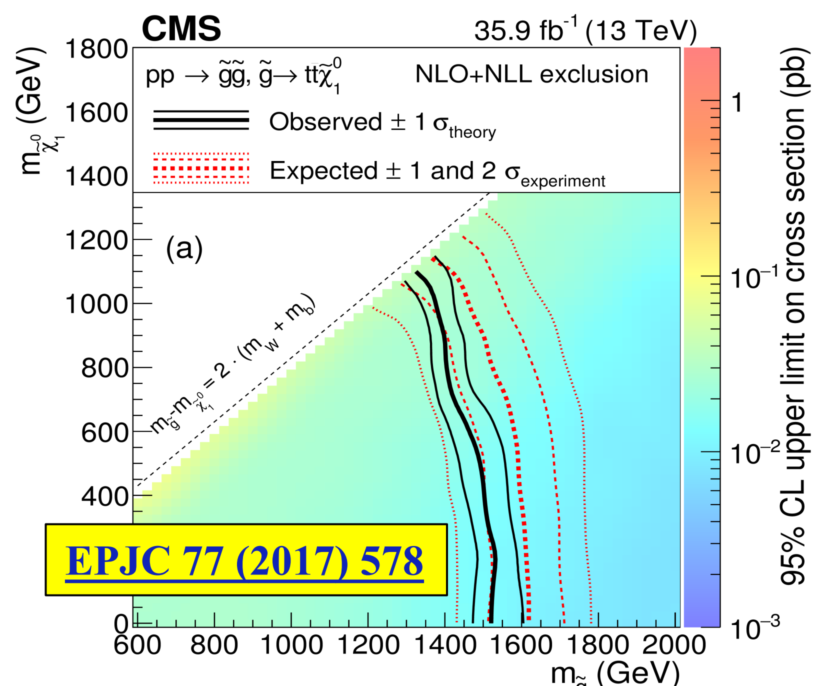
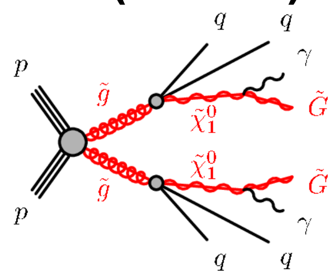


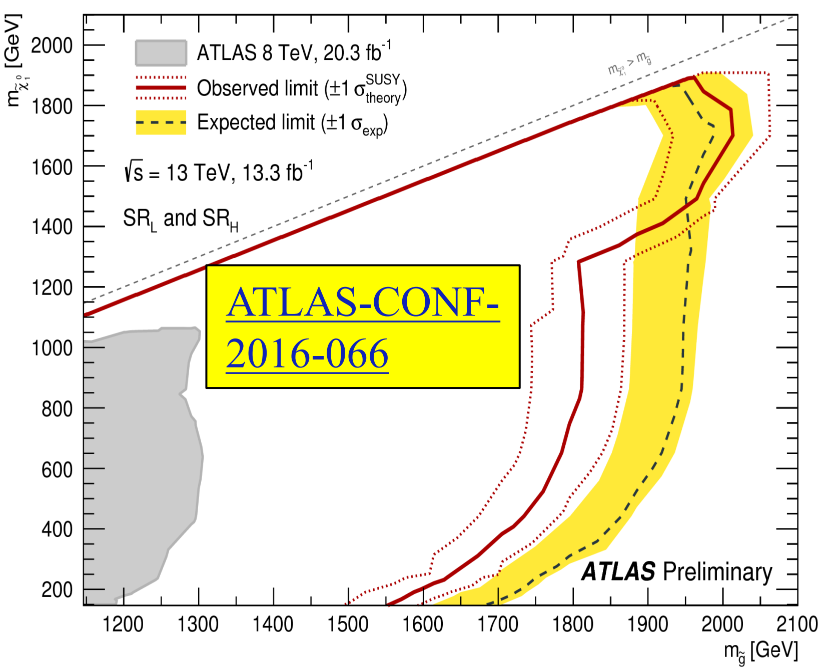
EPJC 77 (2017) 578

Strong Production: photonic signatures

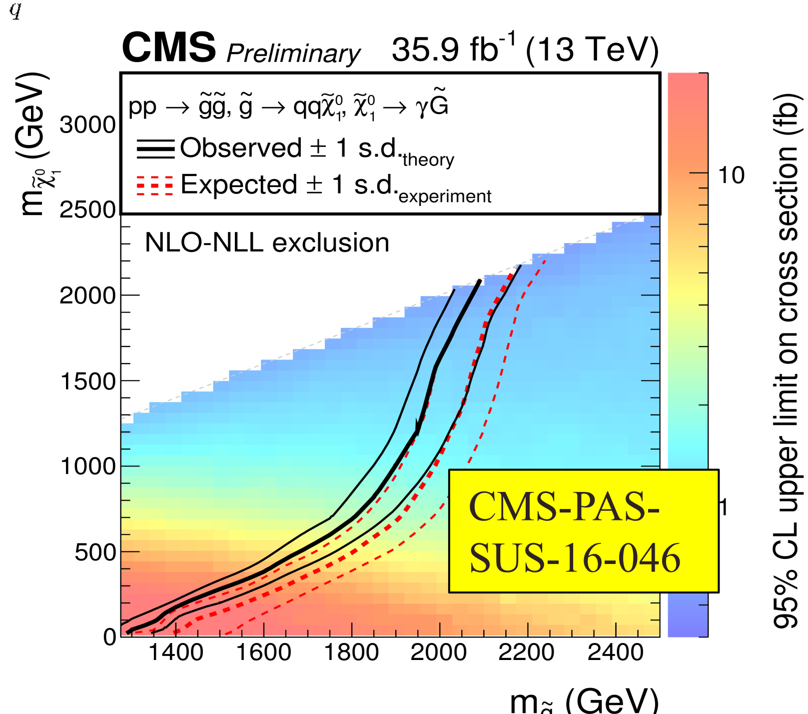
- We can use photon(s) to probe for strong production signals
  - → suppressed hadronic backgrounds
  - → N-photons + jets+ MET (N >= 1)



photons

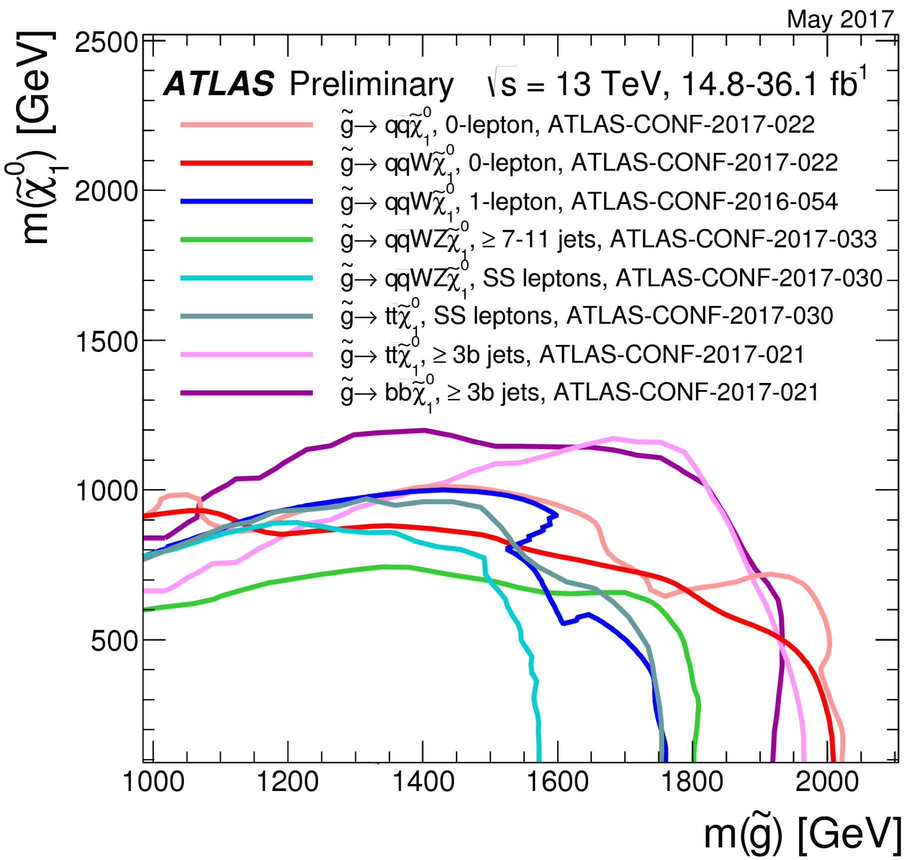


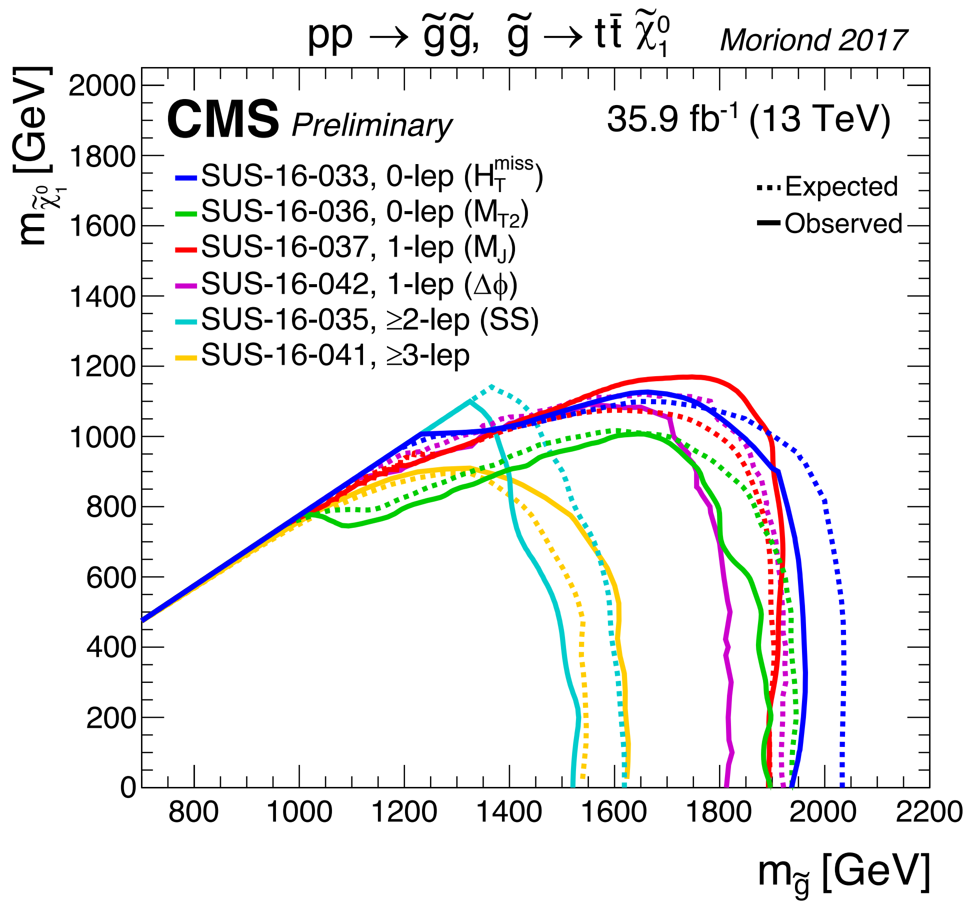
ATLAS-CONF-2016-066



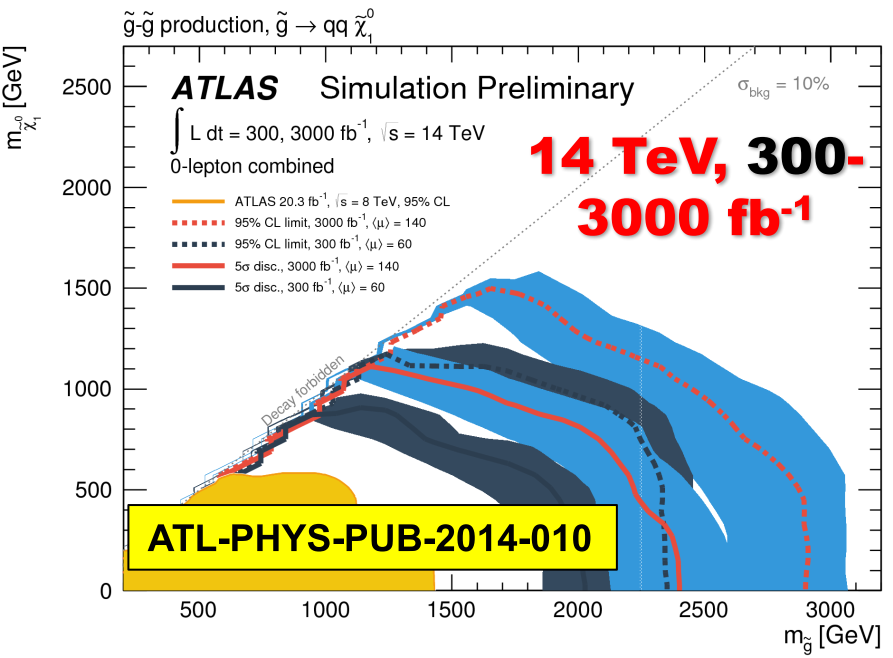
CMS-PAS-SUS-16-046

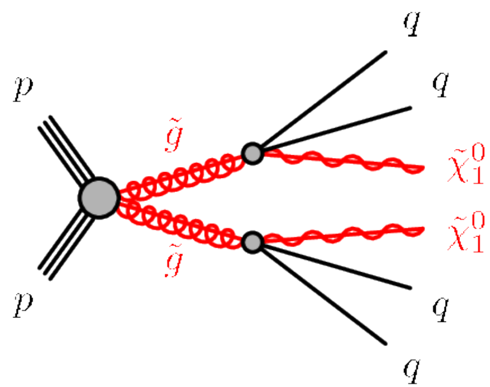
Strong Production *(summary)*

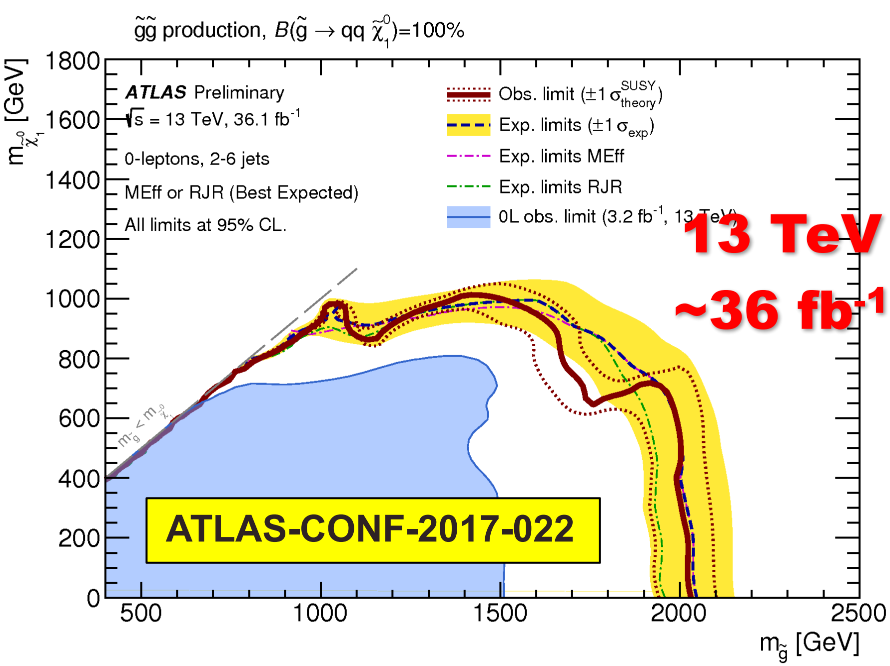




Prospects at HL-LHC



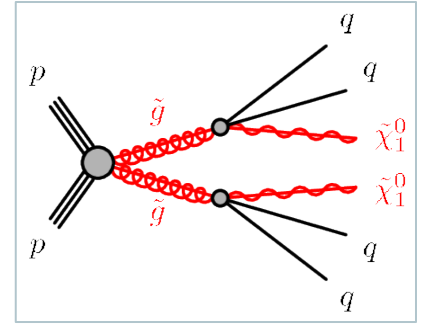


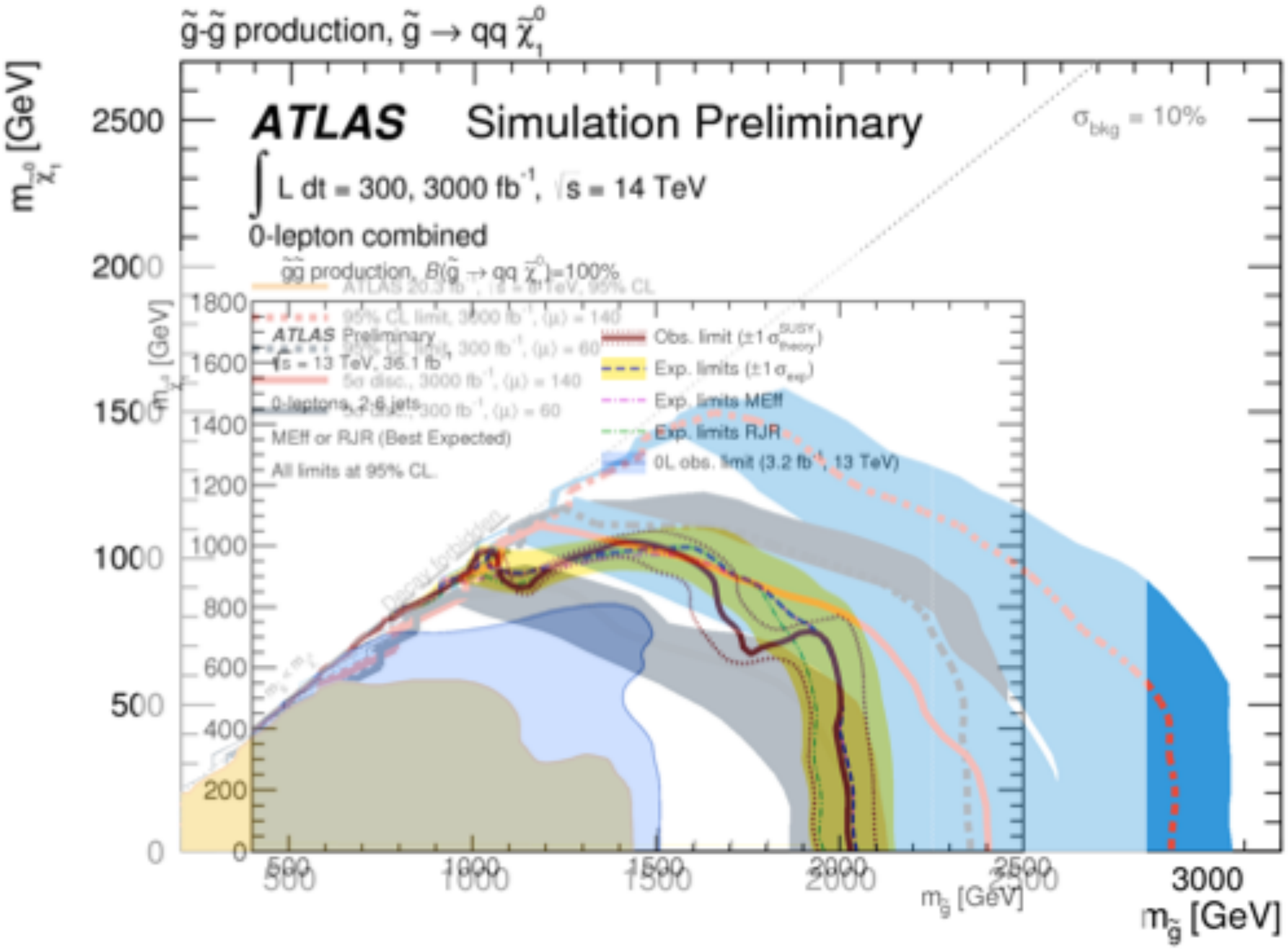


For exclusions:

- Gluinos: ~ 2 TeV now
- 2.5 TeV @ 300 fb-1
- 3 TeV @ 3000 fb-1

Places to hunt for SUSY?

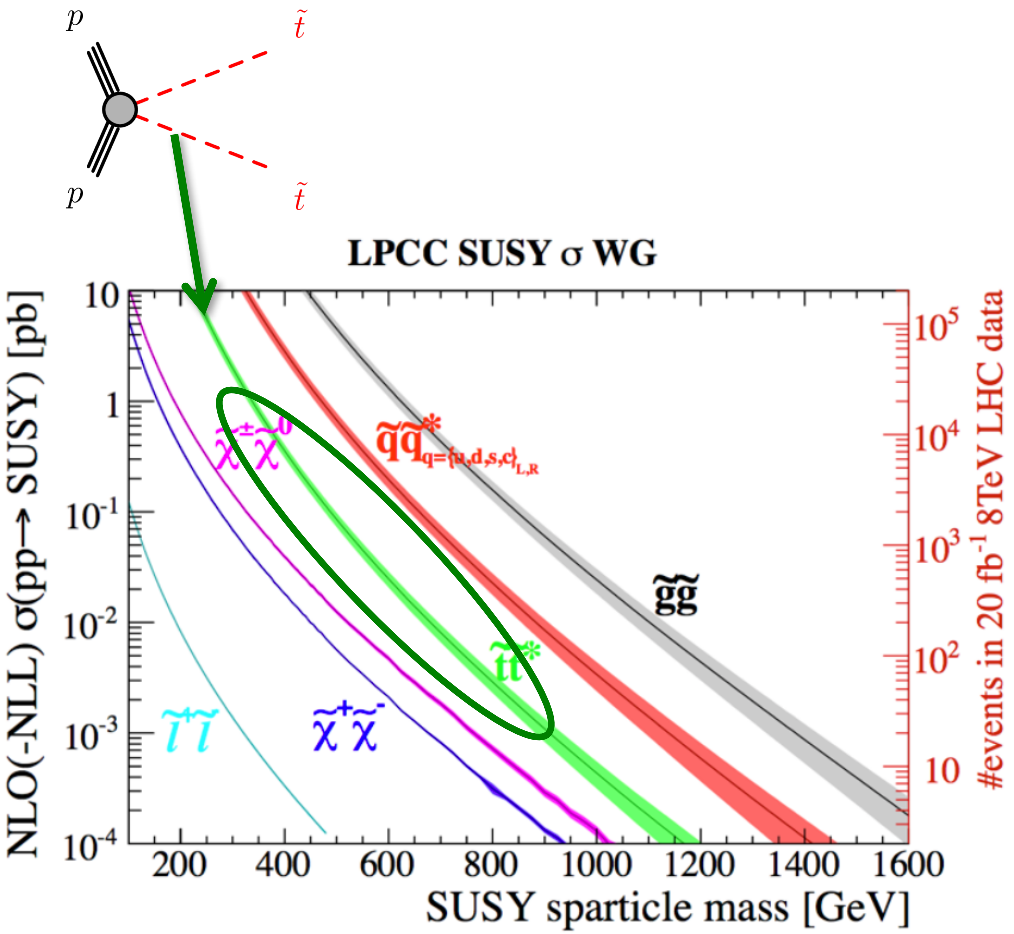




For discovery potential:

- **We explored 85% of our mass reach (2 → 2.5 TeV)**
- **with a small window remaining between 1 — 2 TeV**
- **300/fb 5σ discovery case is practically excluded**

SUSY Search @ LHC



Strong production:

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

3rd generation:

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

Electroweak production:

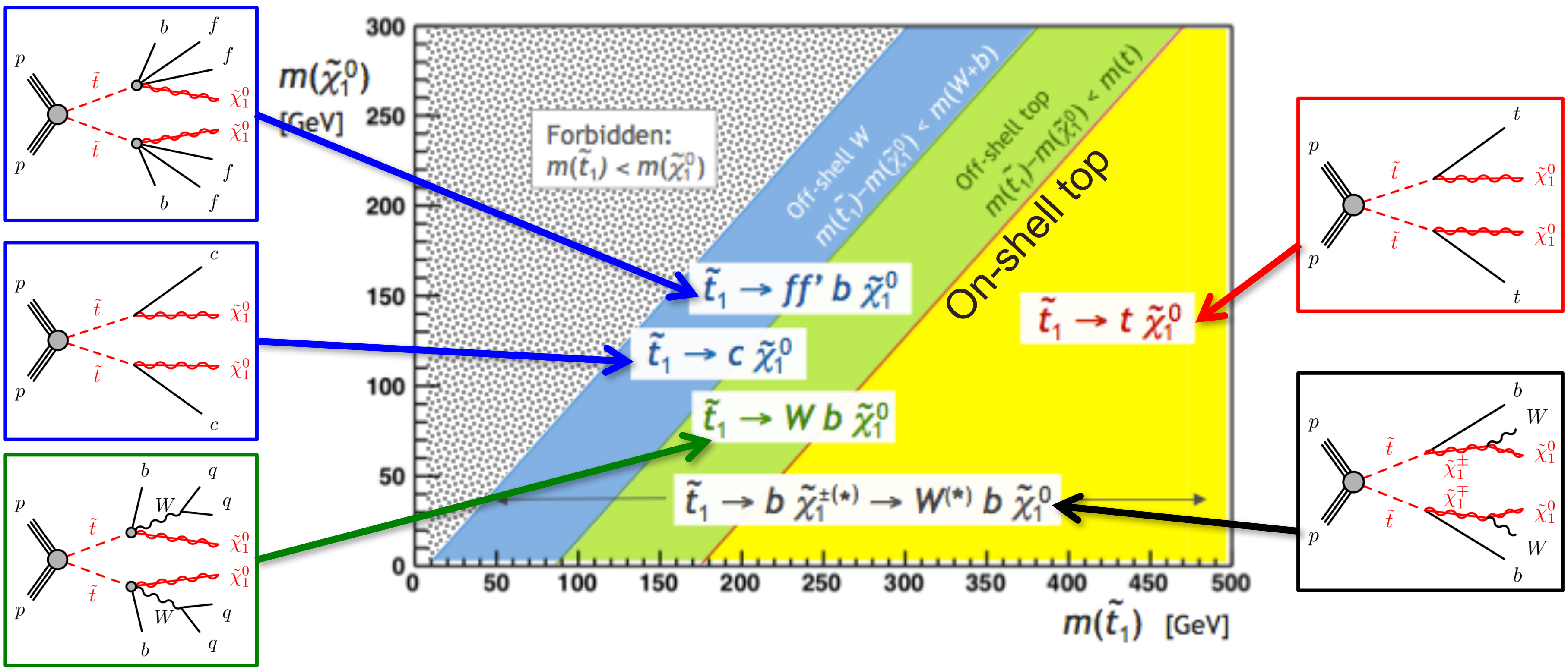
- targeting Electroweakinos, sleptons
- Lowest mass sparticles, clean signature

RPV/LL:

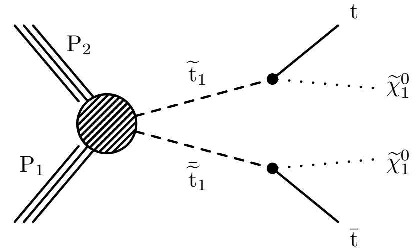
- targeting R-parity violating models and long lived sparticles
- More exotic models

3rd Generation: stop

- Search for stop directly from ~t~t production
- Large spectrum of possible stop decays, covering range from low to heavy stop mass, various decay modes.

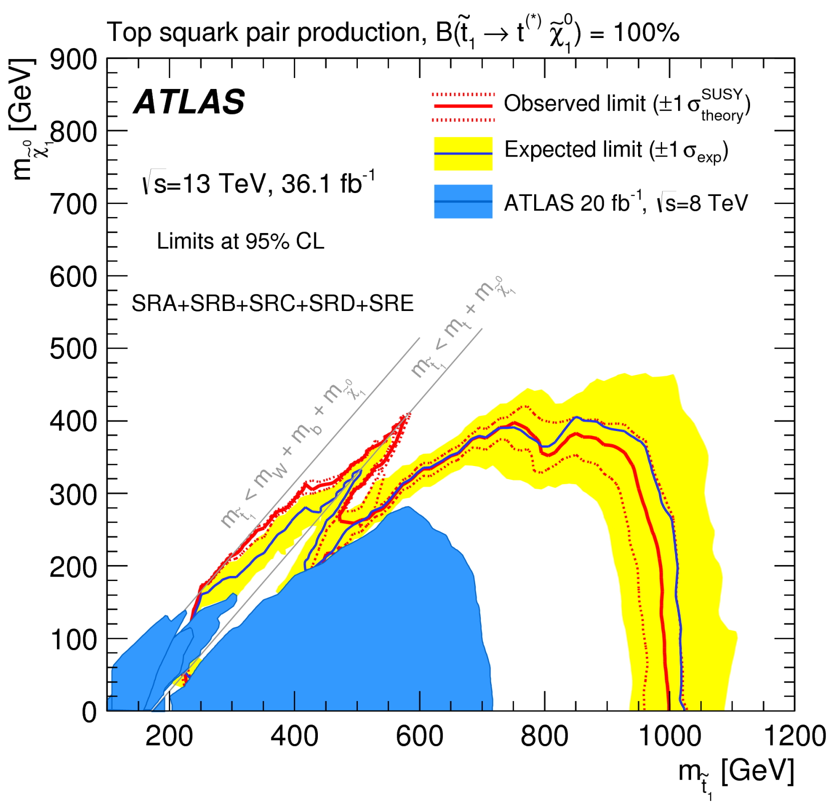


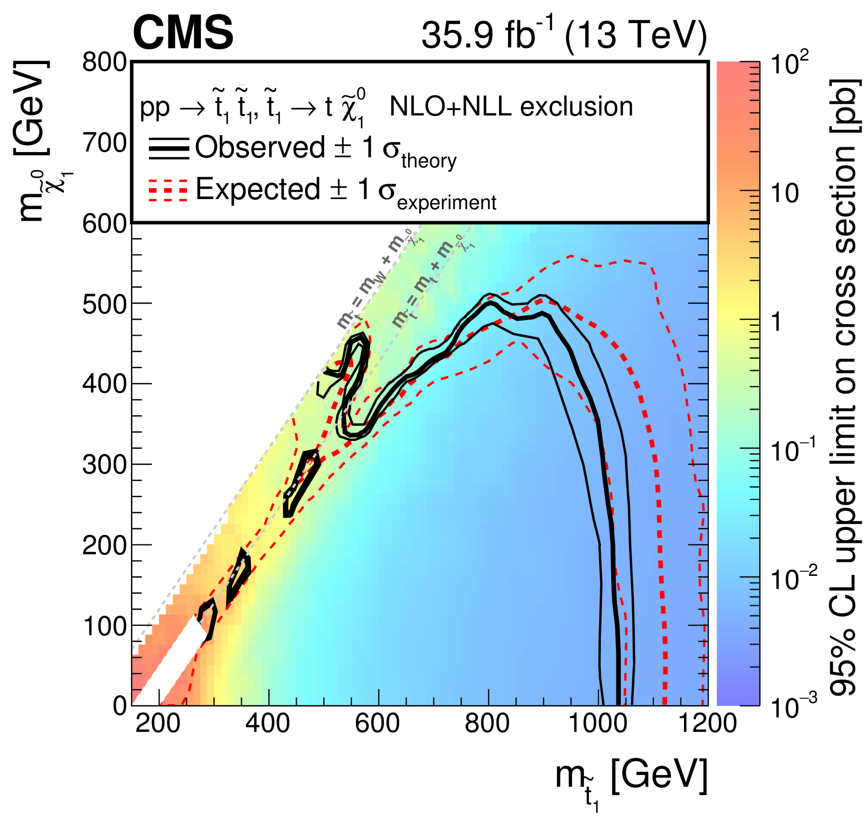
3rd Generation: stop (fully hadronic)



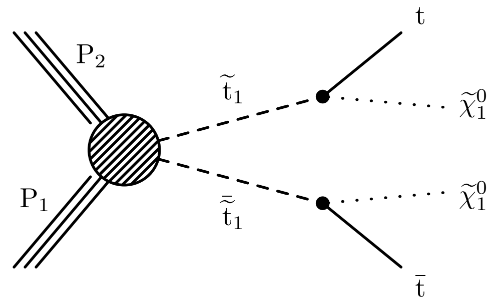
arXiv:1709.04183

JHEP 10 (2017) 005



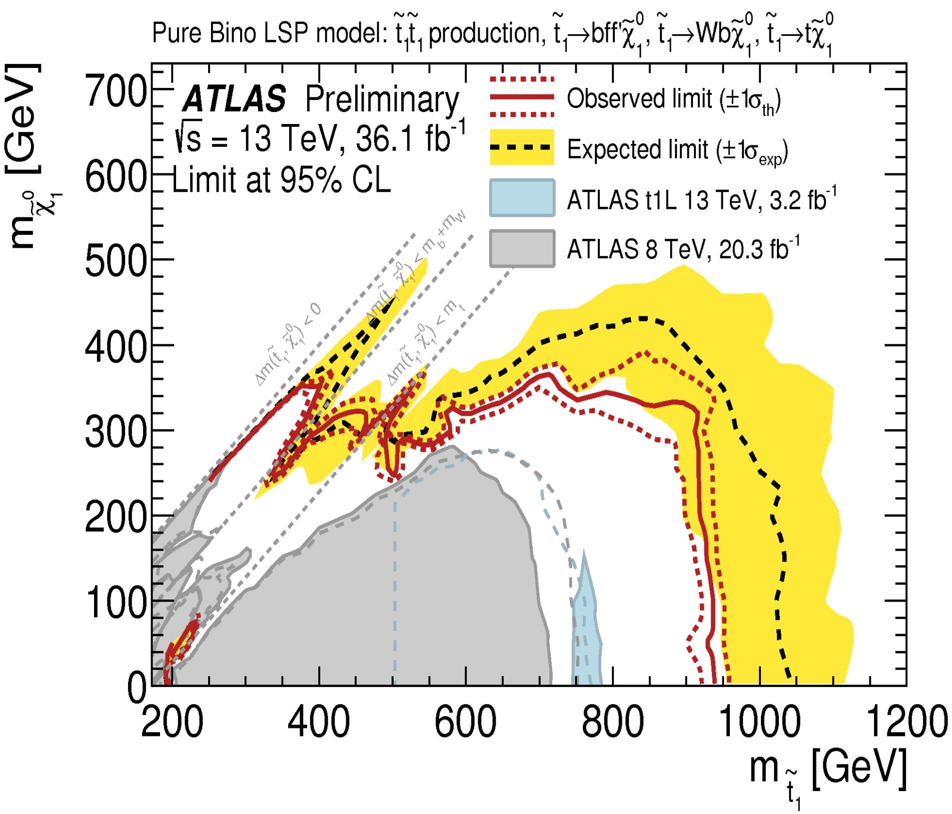


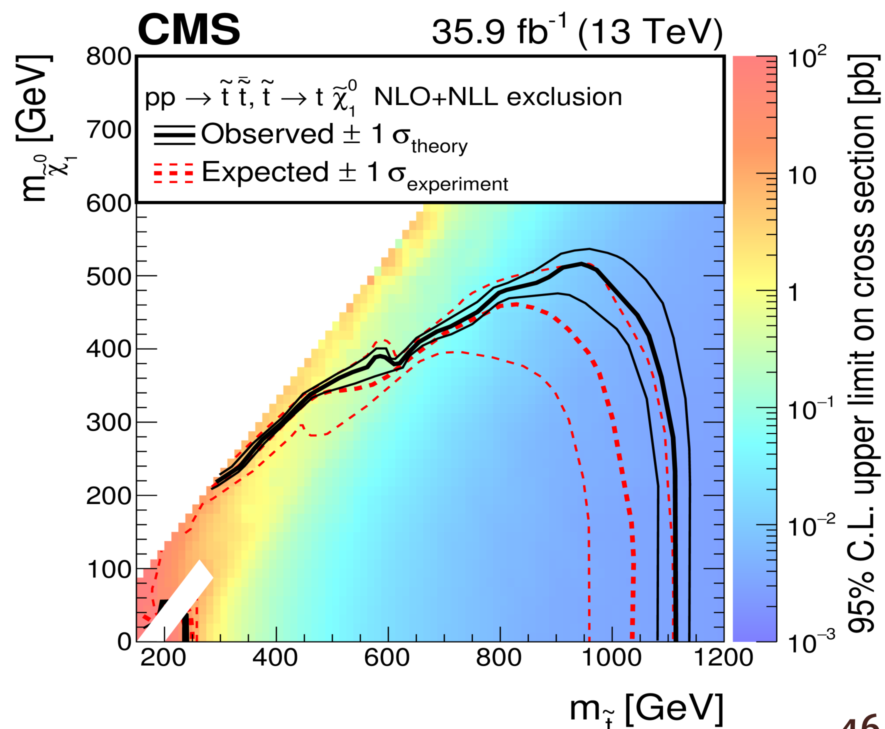
3rd Generation: stop (leptonic)



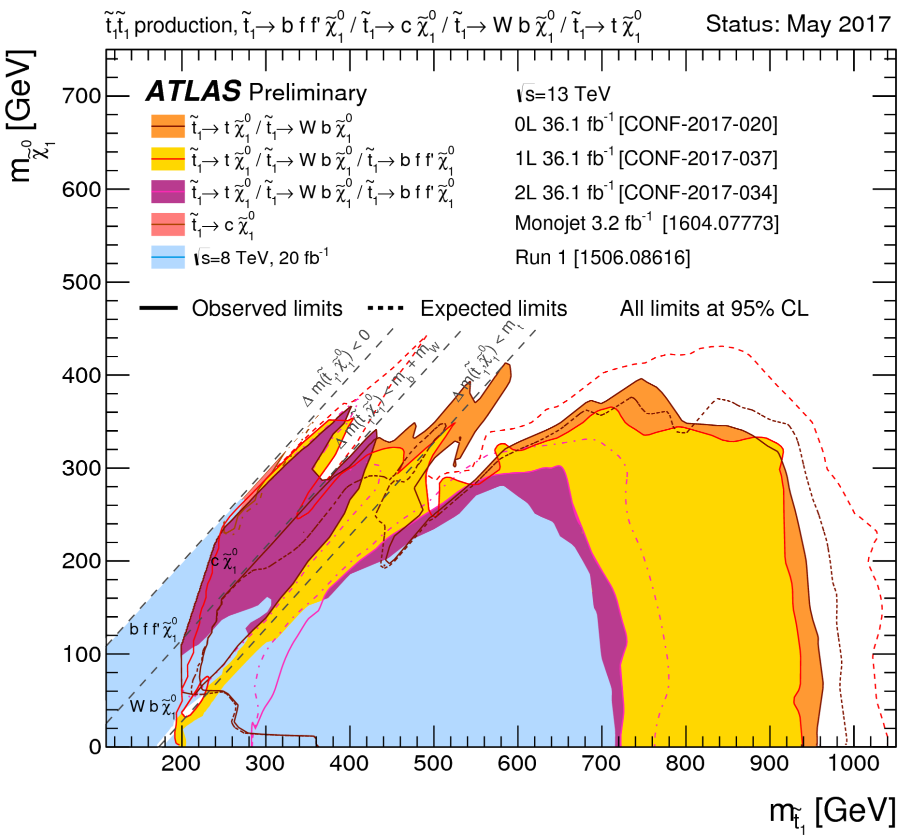
ATLAS-CONF-2017-037

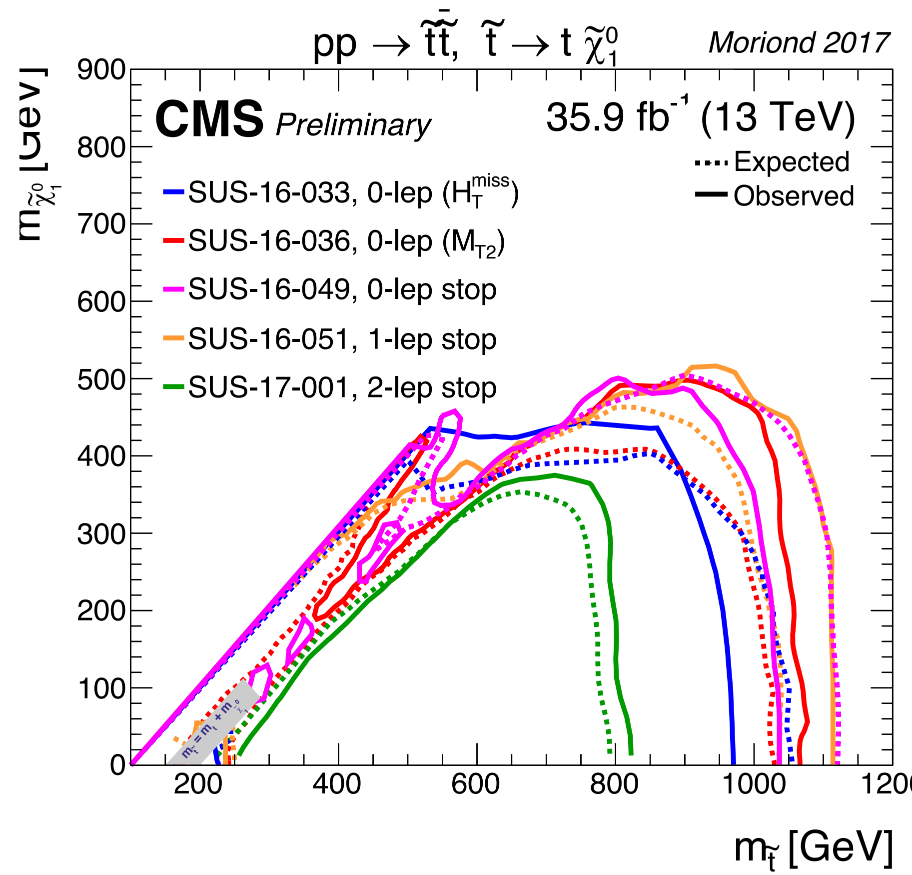
JHEP10(2017)019





3rd Generation *(summary)*

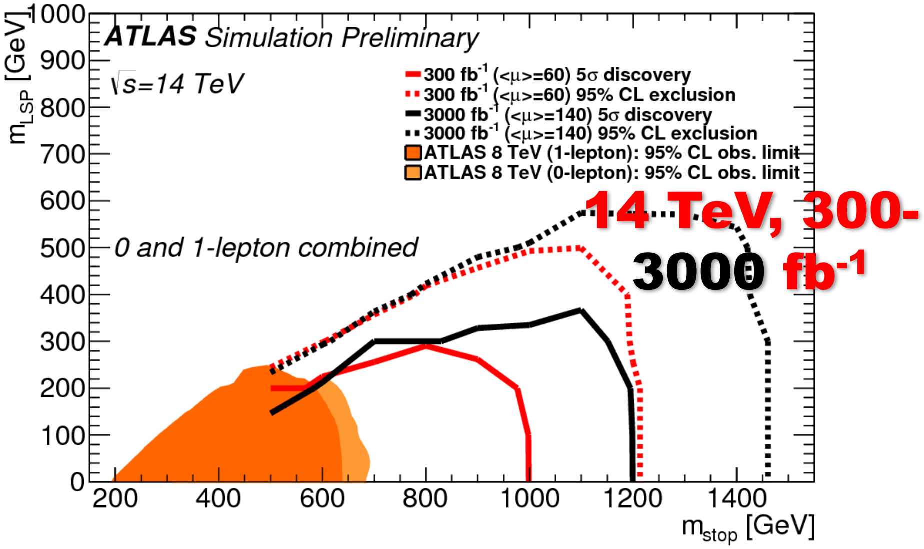


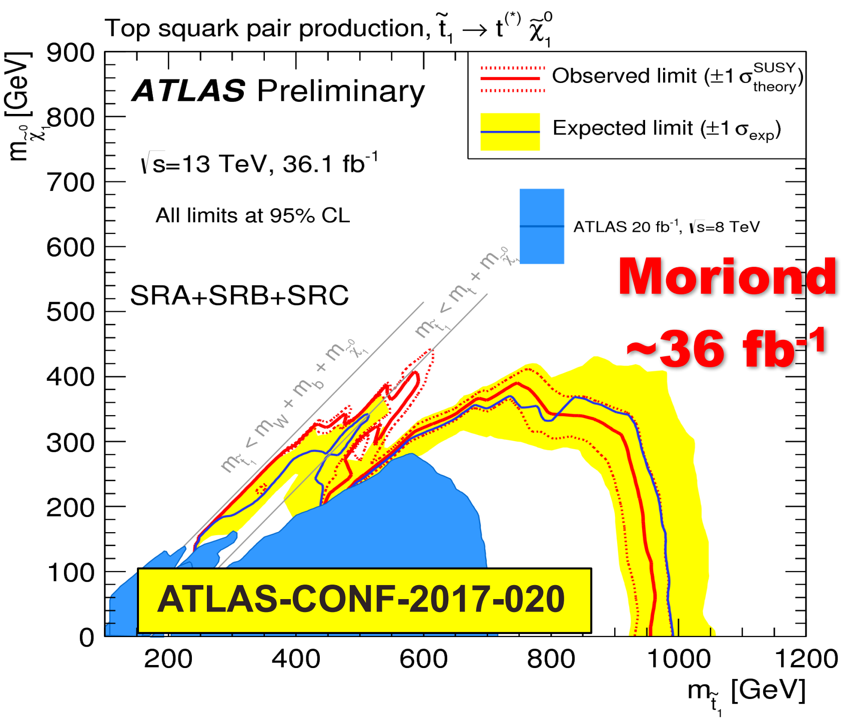


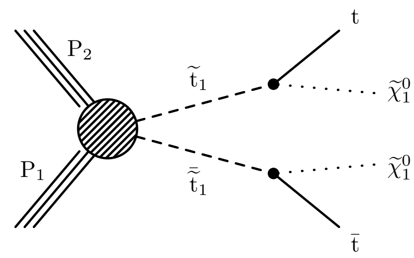
- ❑ **For bottom squarks: exclusion limits beyond 1 TeV (CMS-PAS-SUS-16-032)**
- ❑ **Still <600 GeV for compressed region, also for stop→charm+MET (ATLAS-CONF-2017-038)**

ATL-PHYS-PUB-2013-011

Prospects at HL-LHC







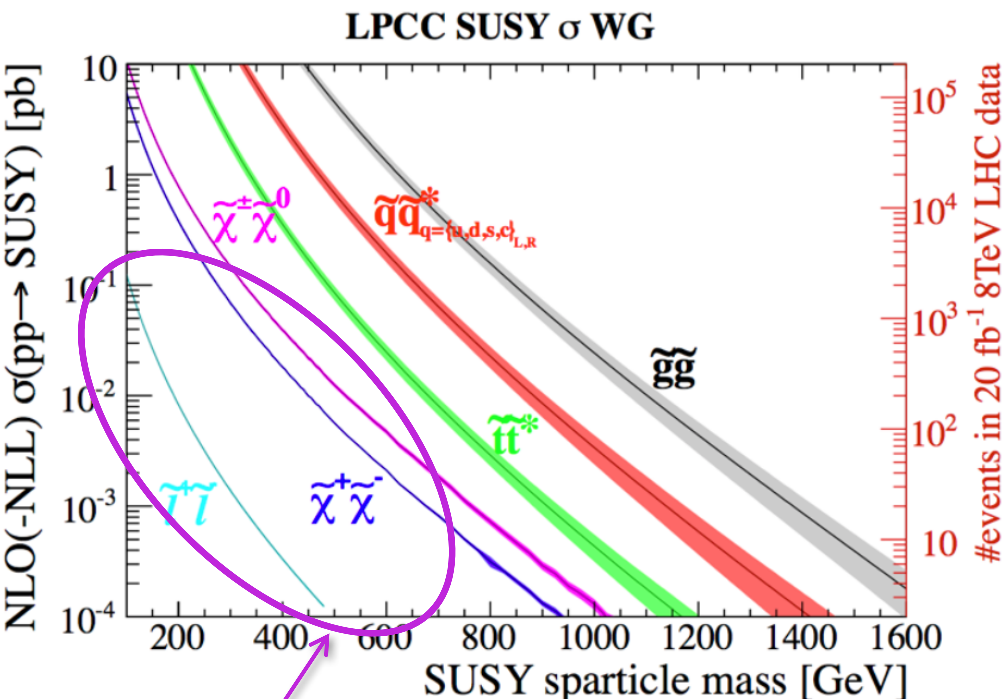
For exclusions (all hadronic):

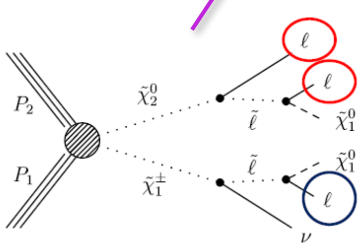
- stop: ~ 1 TeV now
- 1.2 TeV @ 300 fb-1
- 1.4 TeV @ 3000 fb-1

For discovery:

- 1.0 TeV @ 300 fb-1
- 1.2 TeV @ 3000 fb-1

SUSY Search @ LHC





Strong production:

- ❑ targeting gluinos and 1st and 2nd gene...
- ❑ ...
- 3r...
- ❑ ...ttoms
- ❑ Should be lowest mass squarks for naturalness reasons

If coloured sparticles much heavier than EW partners, EWK prod. will be dominant at LHC

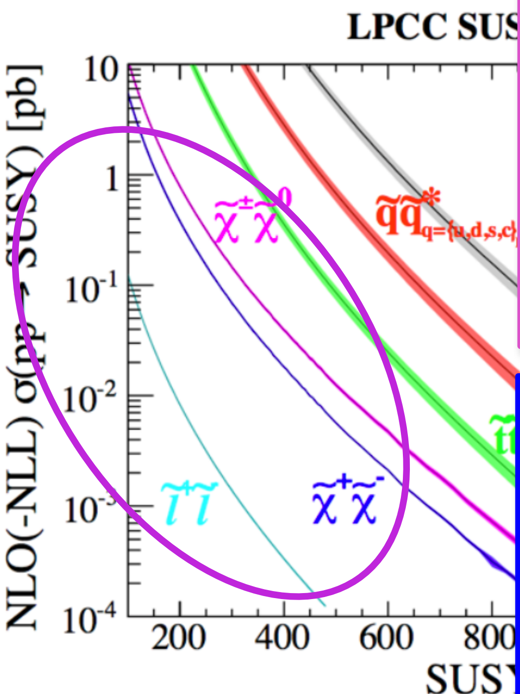
Electroweak production:

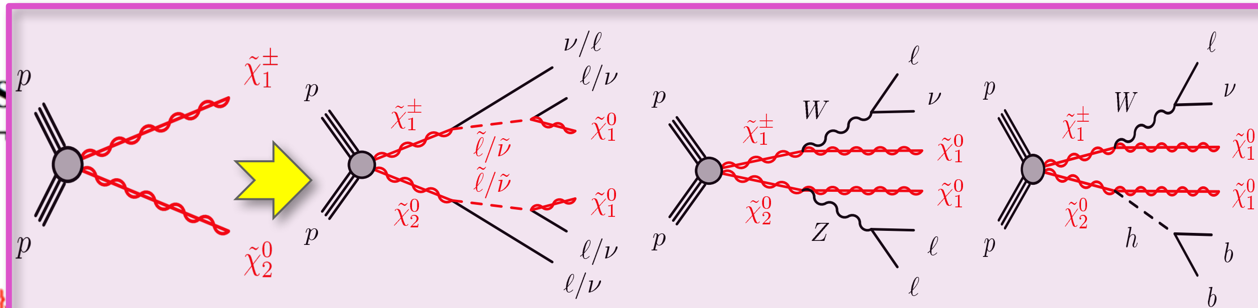
- ❑ targeting Electroweakinos, sleptons
- ❑ Lowest mass sparticles, clean signature(multi-lept, Low jet act)

RPV/LL:

- ❑ targeting R-parity violating models and long lived sparticles
- ❑ More exotic models

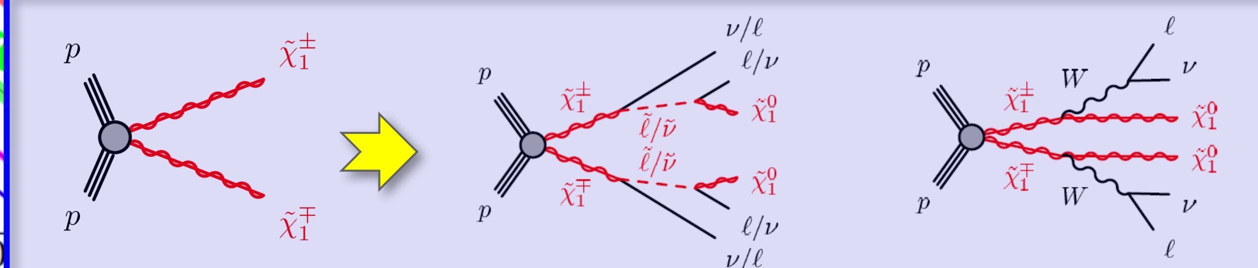
Electroweakino Production





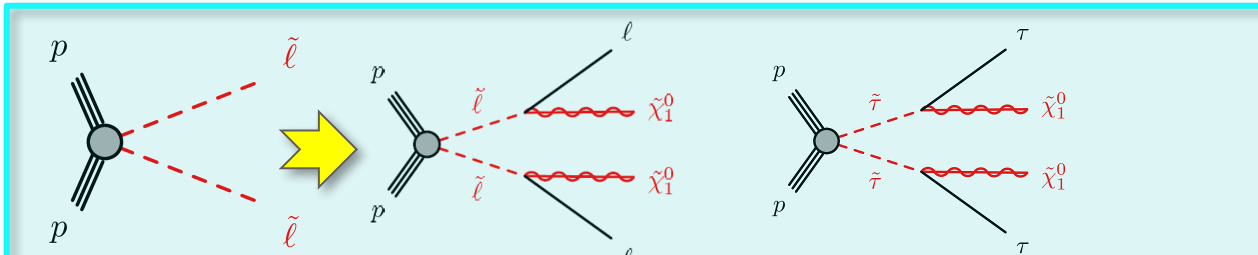
ATLAS: ATLAS-CONF-2017-039, ATLAS-CONF-2017-035, JHEP 04 (2014)169

CMS: CMS-PAS-SUS-16-039, CMS-PAS-SUS-17-004



ATLAS: ATLAS-CONF-2017-039, ATLAS-CONF-2017-035, JHEP 05 (2014)071

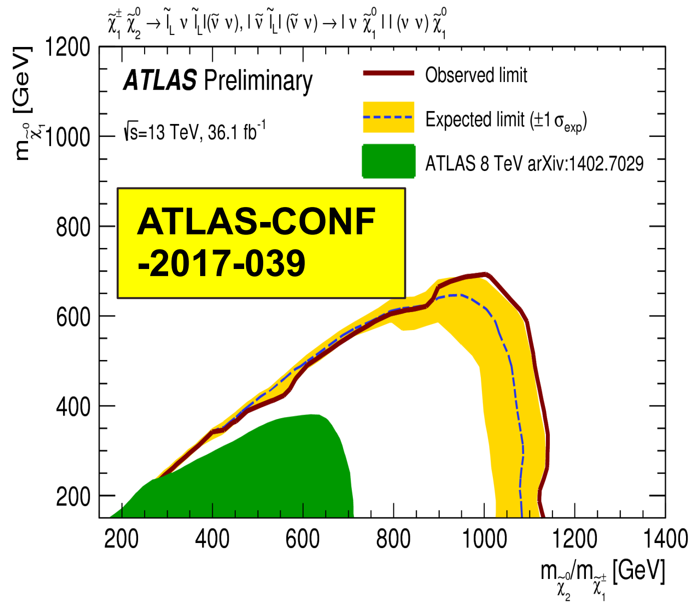
CMS: EPJC 74 (2014) 3036

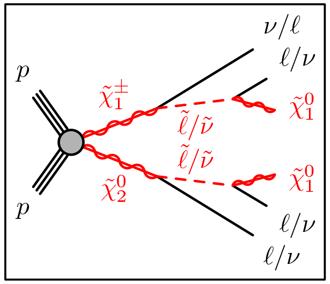


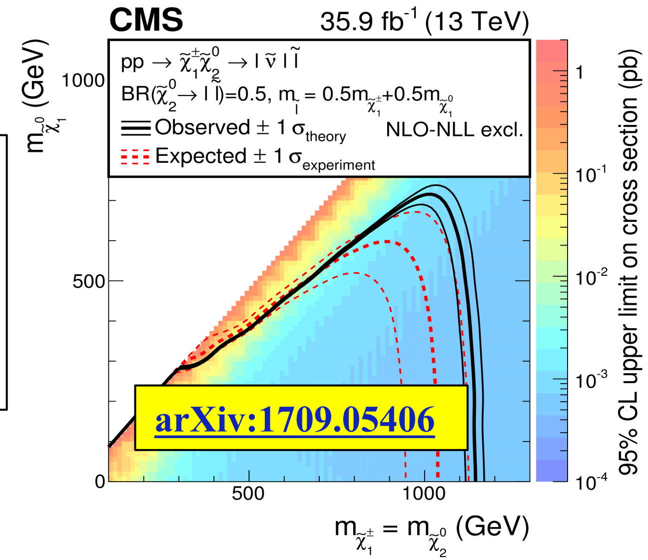
ATLAS: 2l (e/μ): ATLAS-CONF-2017-039; ≥2τ:Phys. Rev. D 93, 052002 (2016)

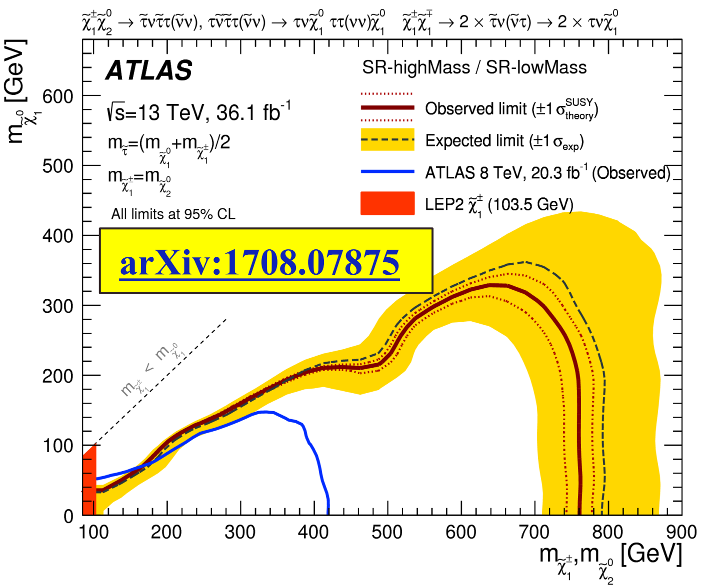
CMS: EPJC 74 (2014) 3036

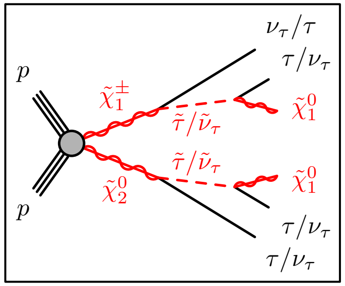
Chargino-Neutralino Pairs: via sleptons

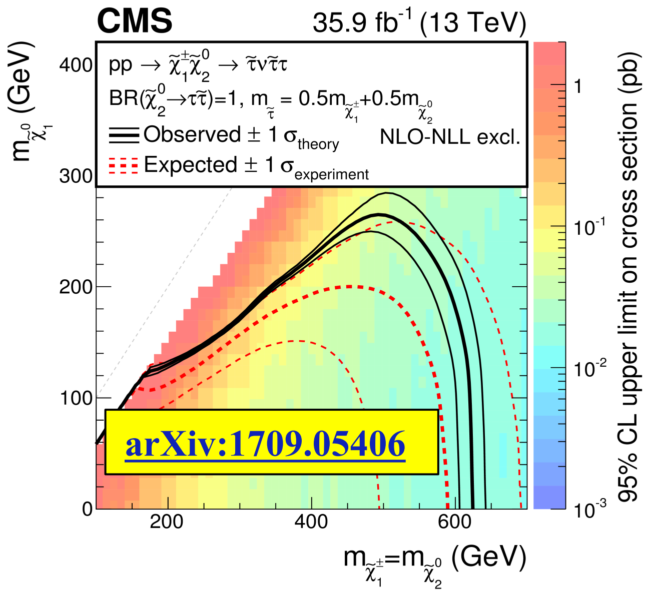






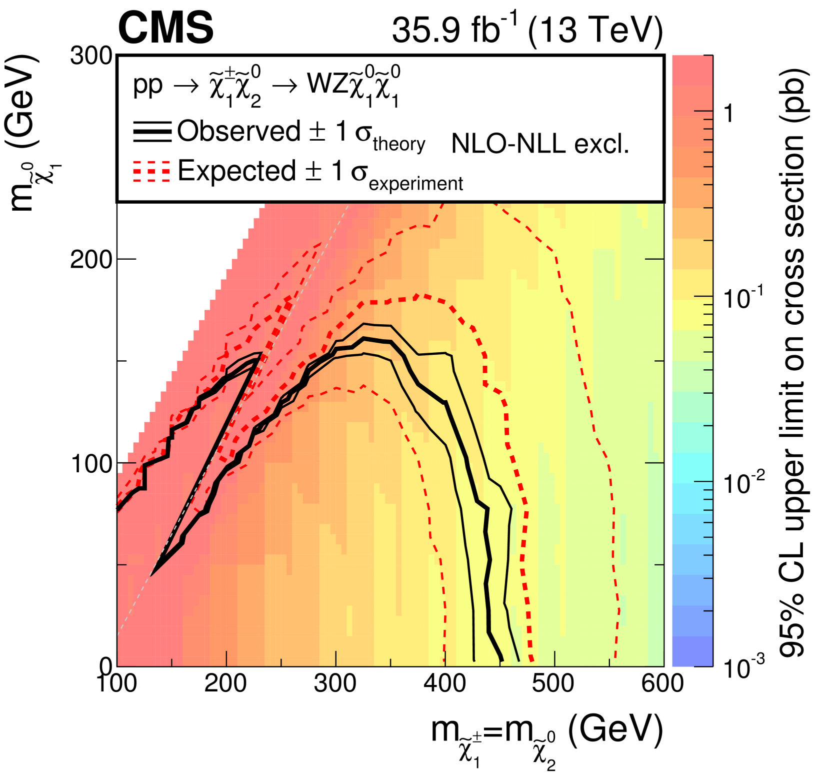


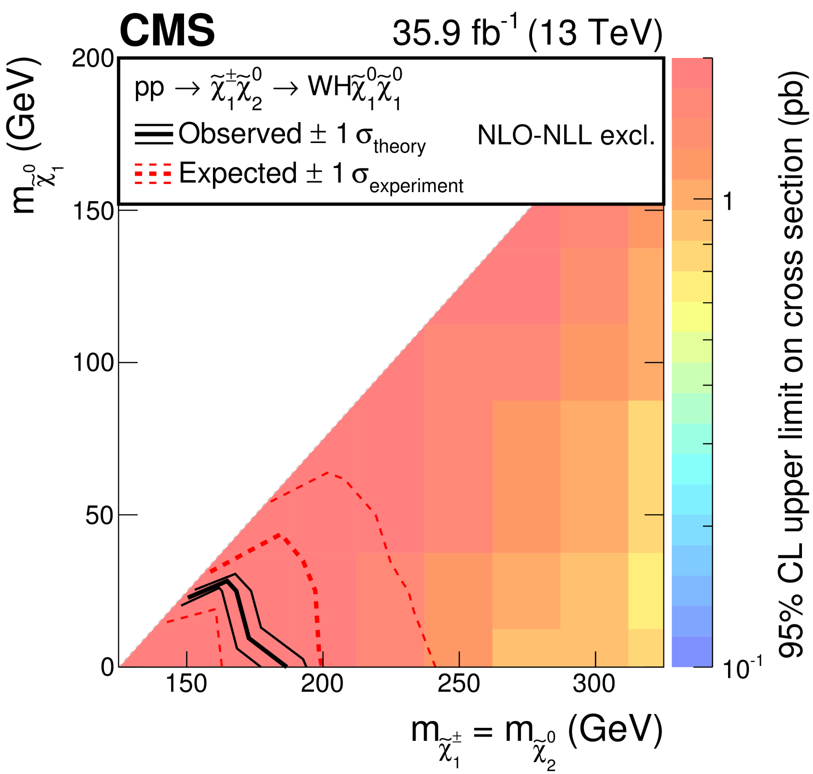


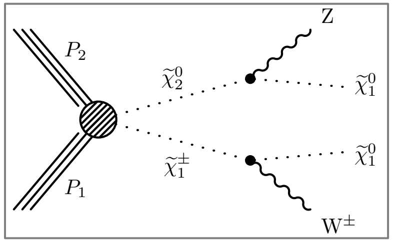


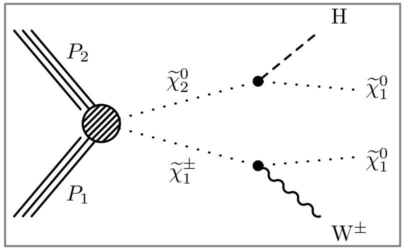
Chargino-Neutralino Pairs: via WZ or WH

arXiv:1709.05406

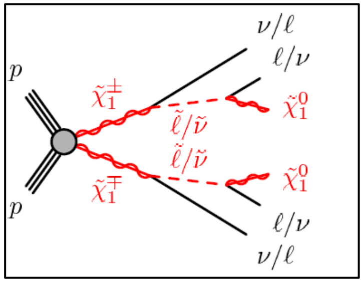


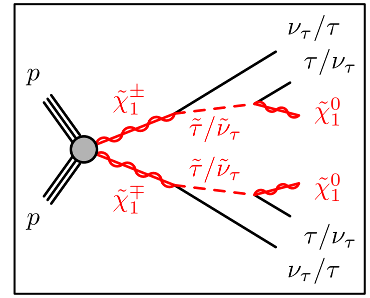


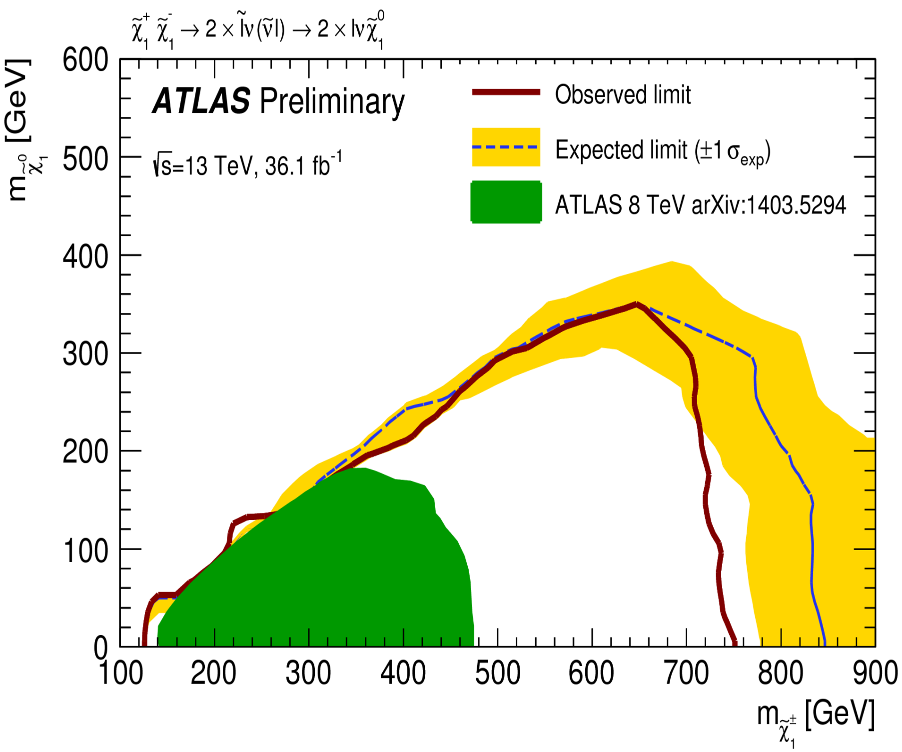


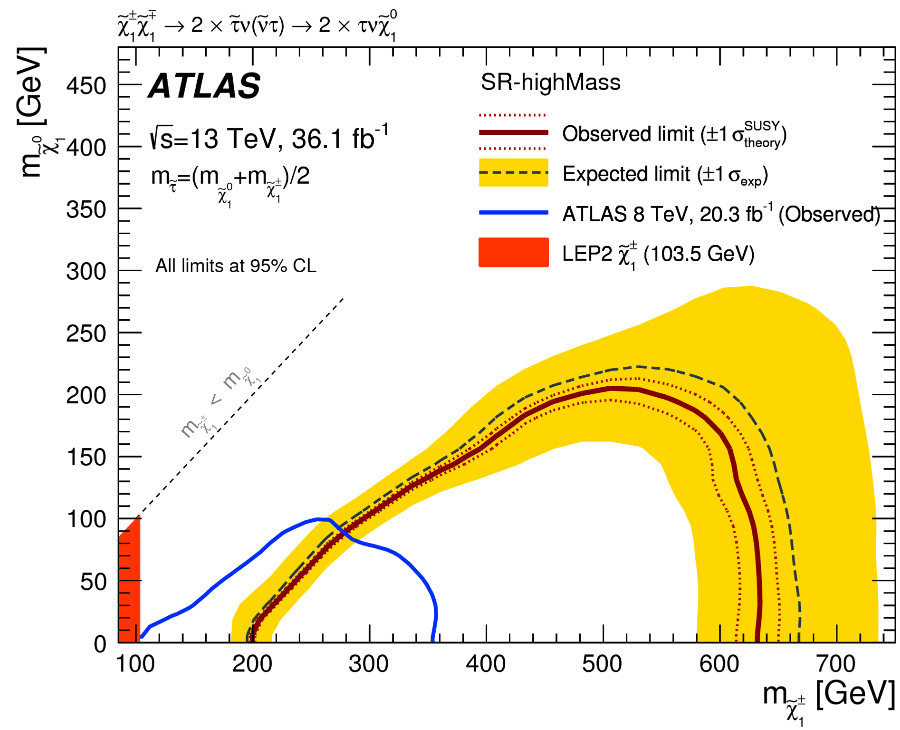


Chargino-Chargino Pairs: via sleptons





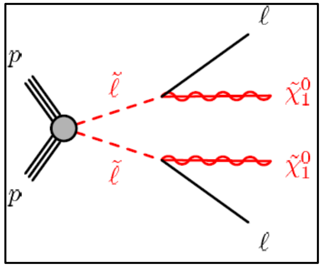


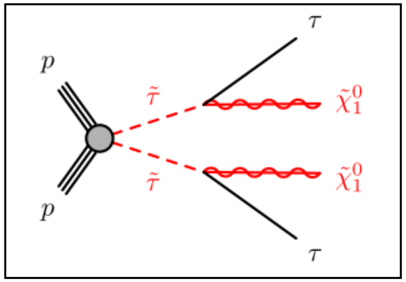


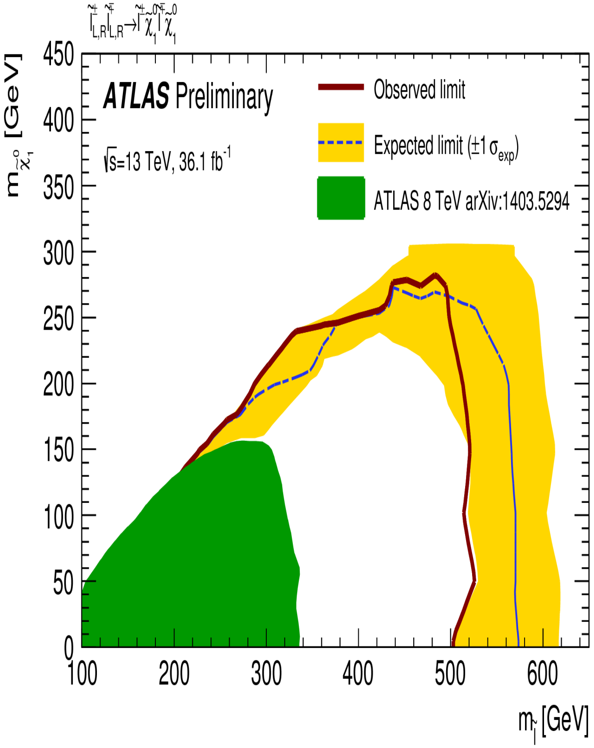
ATLAS-CONF-2017-039

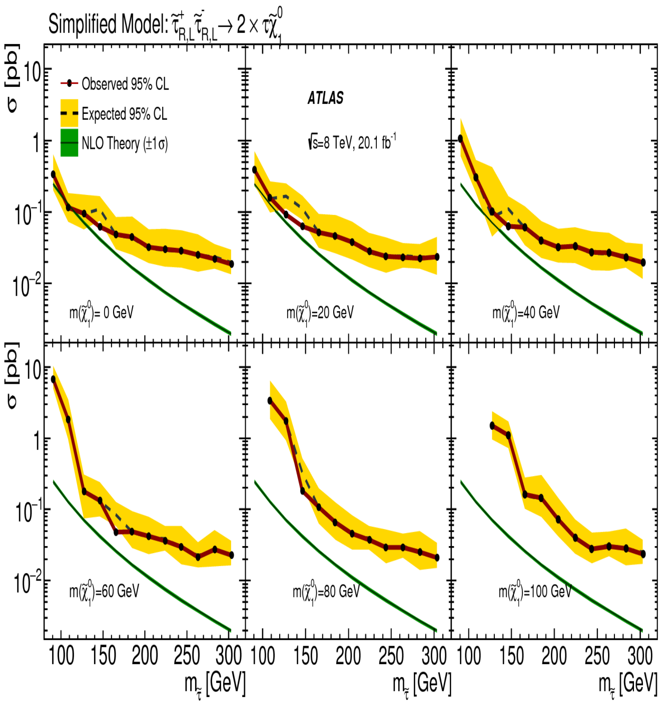
[arXiv:1708.07875]

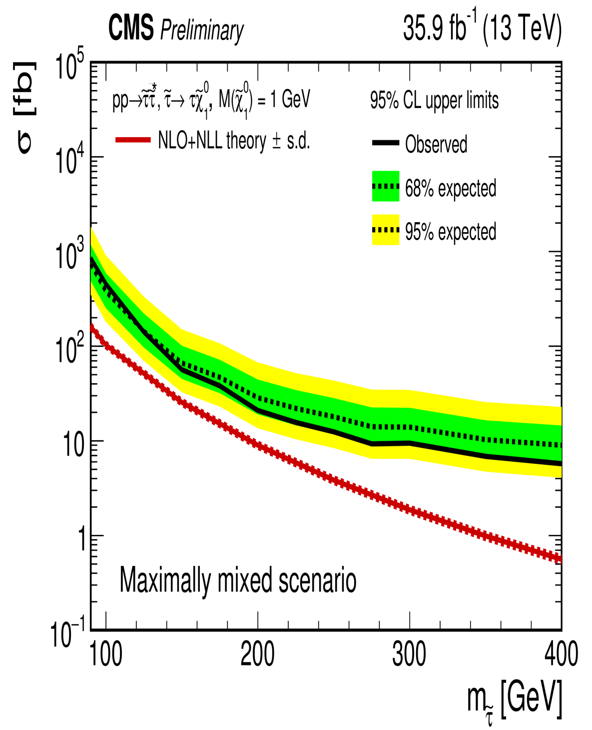
Direct slepton pair











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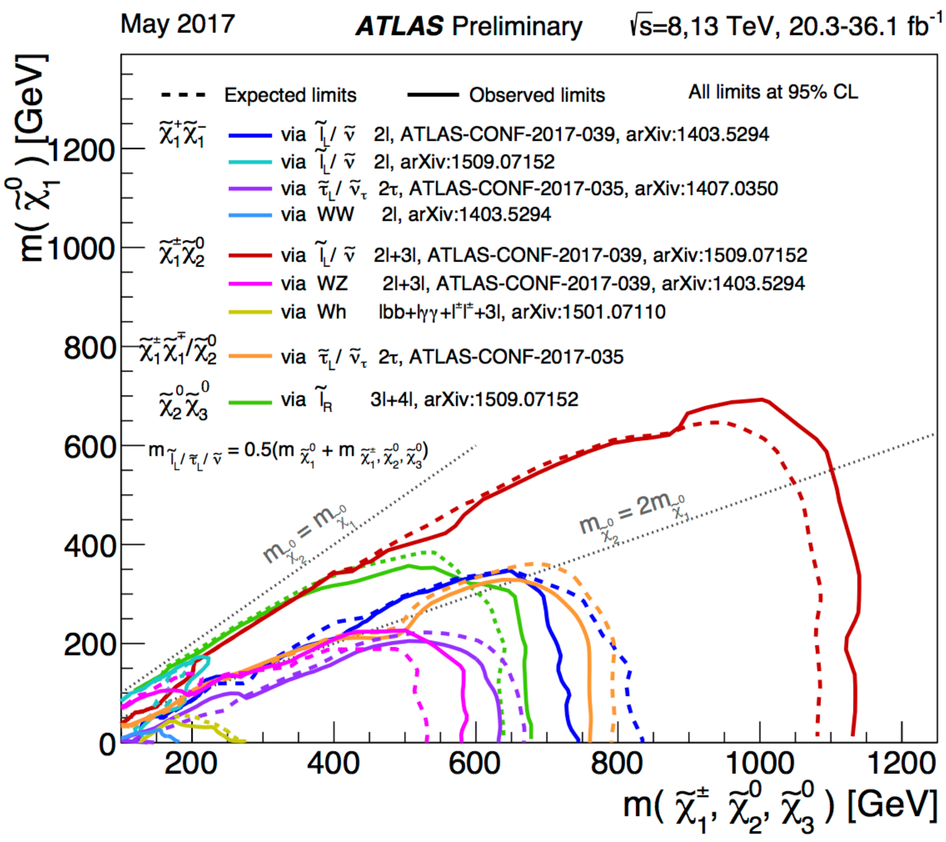
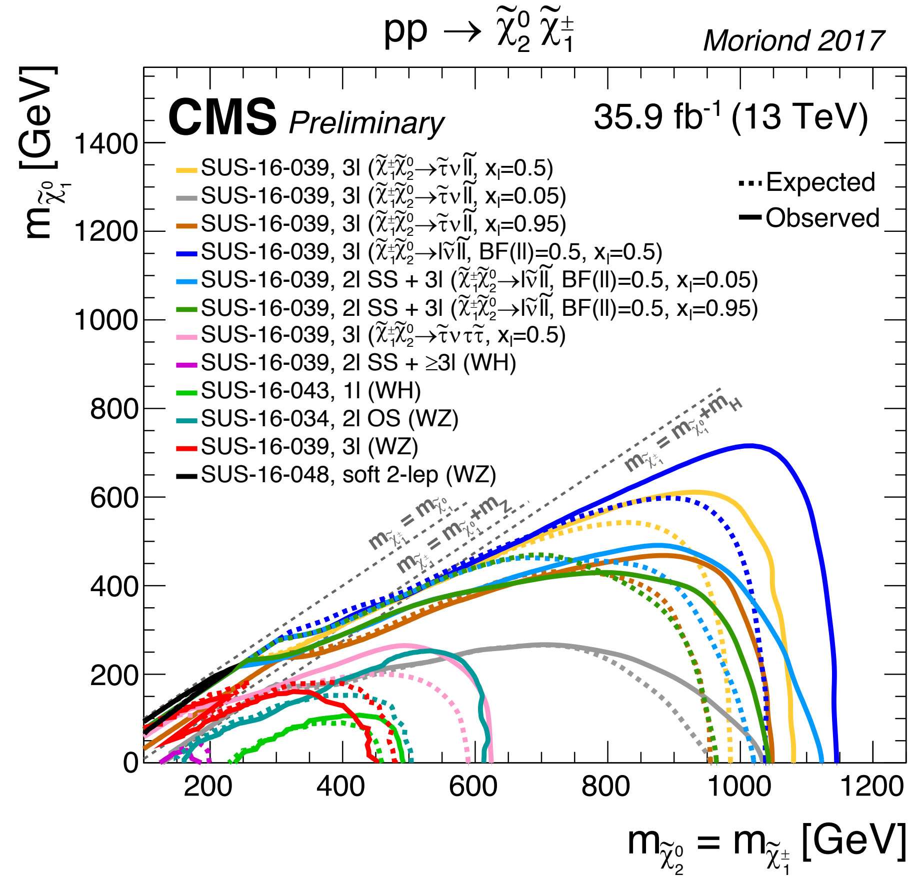
Phys. Rev. D 93, 052002 (2016)

CMS-PAS-SUS-17-003

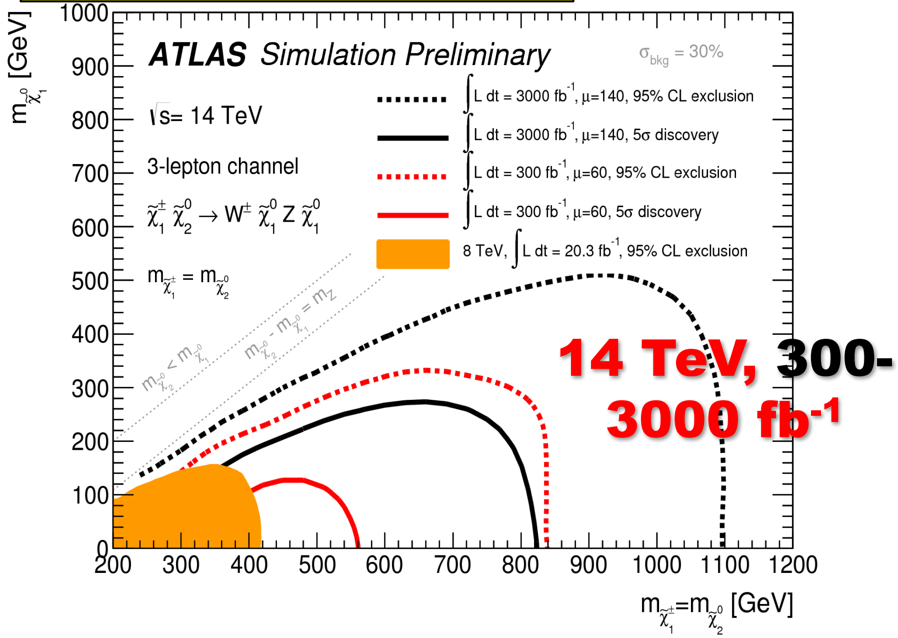
EWK Production *(summary)*

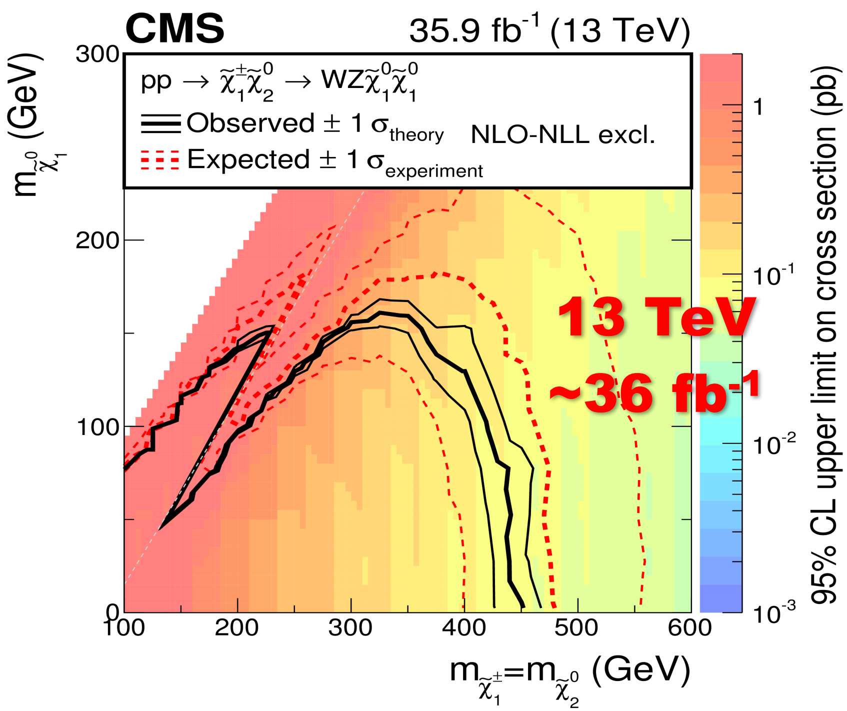




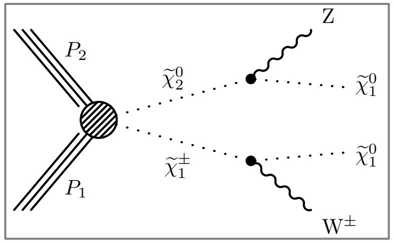
- Powerful exclusions in decays via sleptons (C1/N2 up to 0.6-1.1 TeV)
- Exclusions is not so large in decays via bosons (up to 150-400 GeV)
- Mass limit on selectron/smuon up to 500 GeV, not yet on staus

ATL-PHYS-PUB-2014-010





Prospects at HL-LHC



For exclusions:

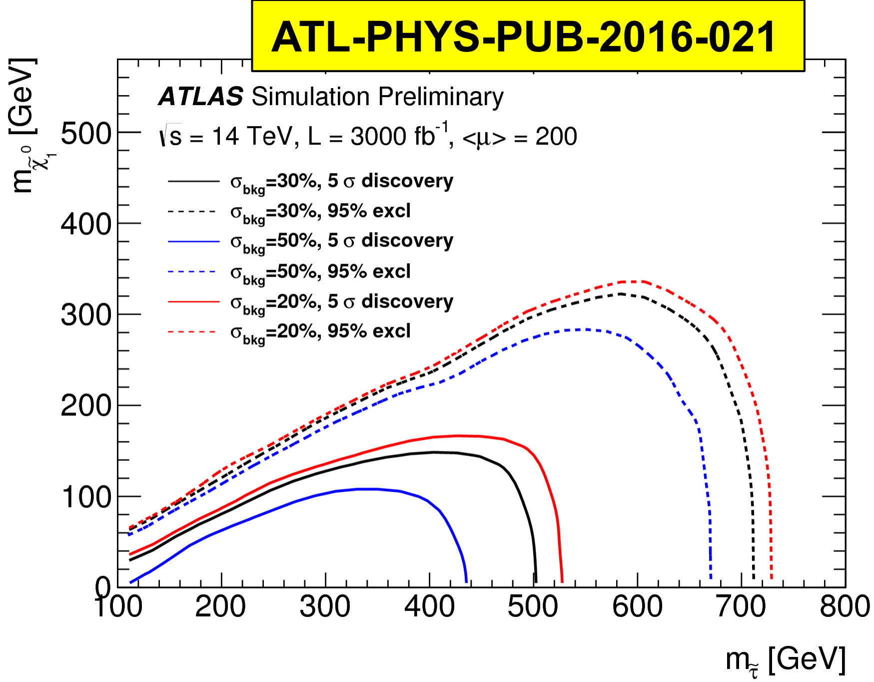
- chargino: ~ 0.45 TeV now
- 0.8 TeV @ 300 fb-1
- 1.1 TeV @ 3000 fb-1

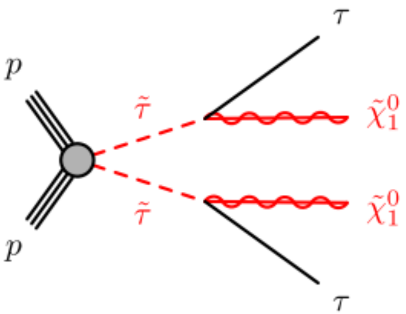
For discovery:

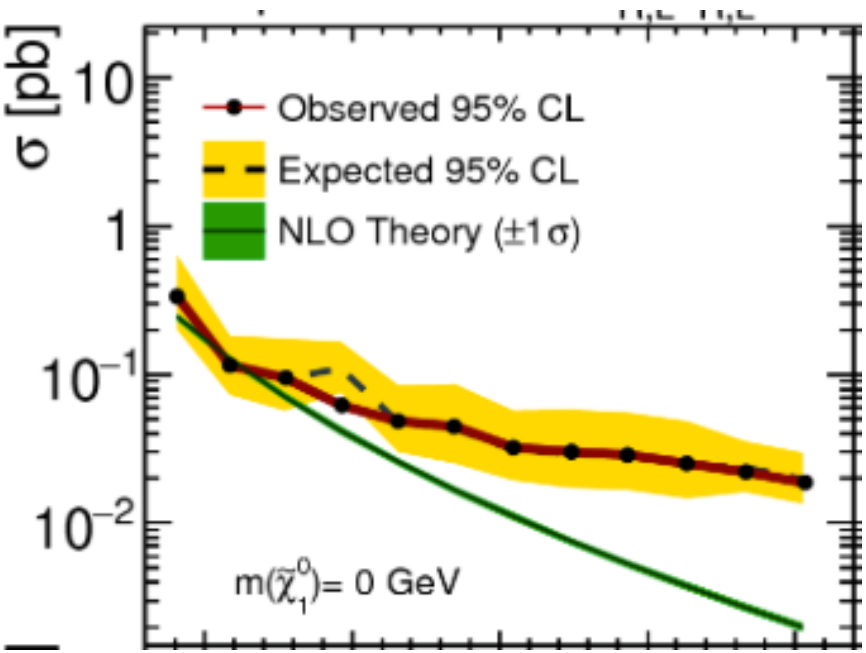
- 0.55 TeV @ 300 fb-1
- 0.8 TeV @ 3000 fb-1

Some room for discovery

Direct stau







100 GeV

For exclusions:

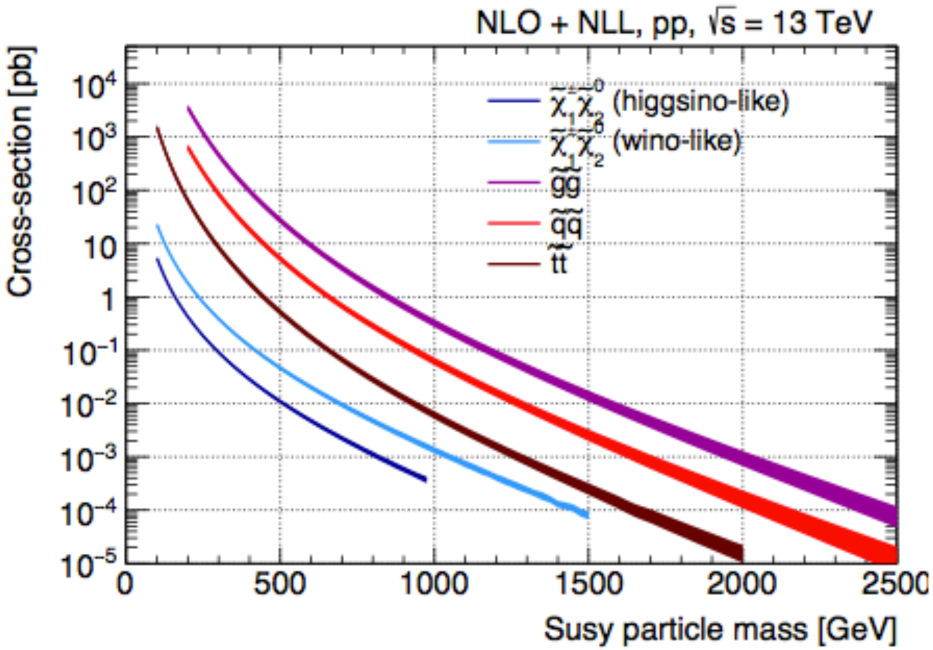
- stau: ~ 0.1 TeV now
- 0.7 TeV @ 3000 fb-1

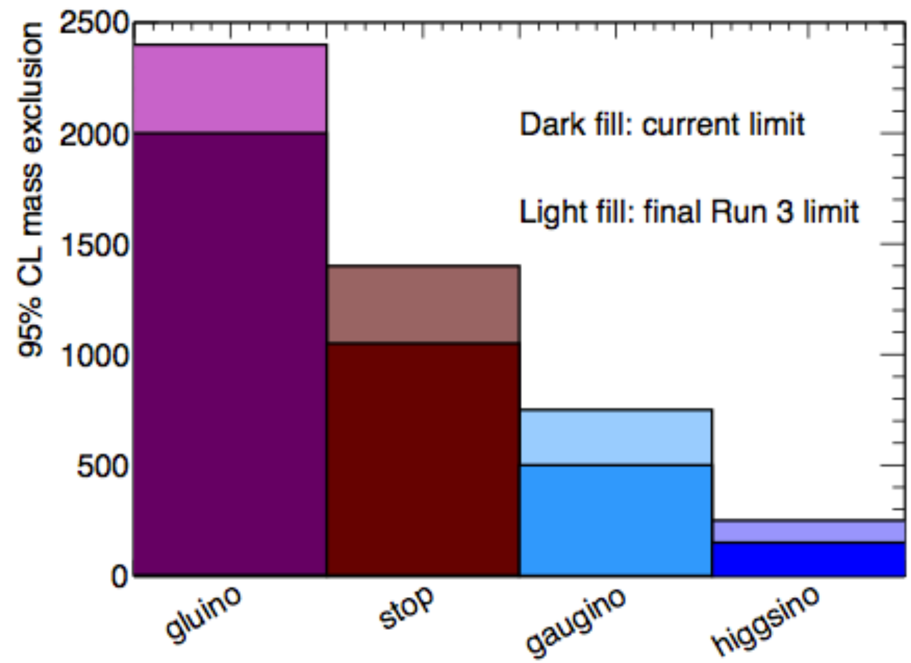
For discovery:

- 0.5 TeV @ 3000 fb-1

Very promising at LHC

2015+2016 – A milestone for SUSY





This means:

- **We explored 85% of our mass reach for gluino pair production, about 75% for stop**
- **~60% for gauginos, and just above 50% for higgsinos**

Outline

- SUSY Introduction
- The LHC and ATLAS
- SUSY search strategy
- SUSY search @ LHC
- **Longer term prospects @ LHC and Future Colliders (14, 33, 100 TeV)**
- Outlook and Summary

Prospects at Future Proton Colliders

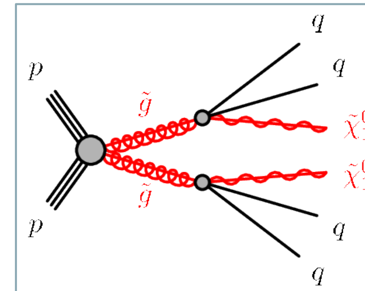
Machine	$\sqrt{s}$	Final Integrated Luminosity
LHC Phase I	14 TeV	300 fb^{-1}
HL-LHC or LHC Phase II	14 TeV	3000 fb^{-1}
HE-LHC	33 TeV	3000 fb^{-1}
VLHC	100 TeV	3000 fb^{-1}

arXiv:1311.6480, 1406.4512, 1410.6287

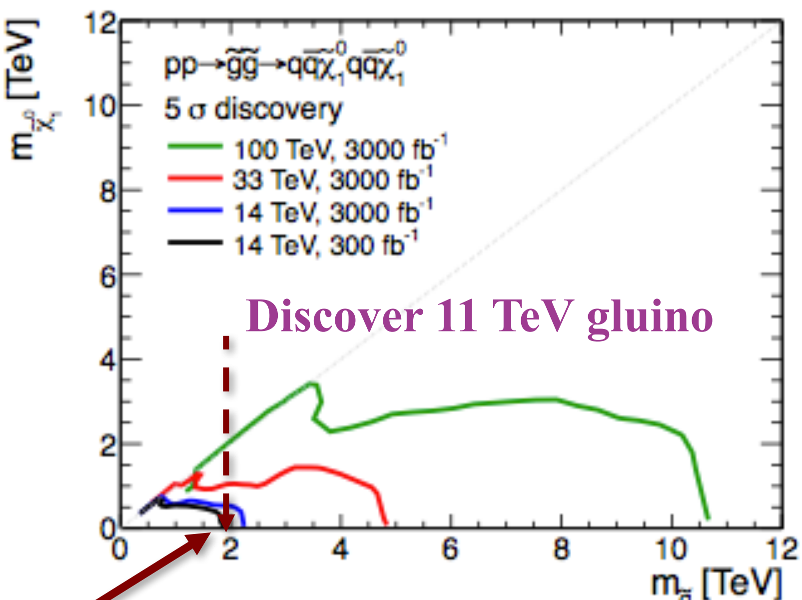
- **Long term prospects for 4 collider scenarios have been studied (14, 33, 100 TeV @3000 fb^{-1})**
- **Use same search strategy as 8-13TeV @LHC**
- **Use simple analysis strategies, avoid assumption on detector design, pileup sensitivity, etc**

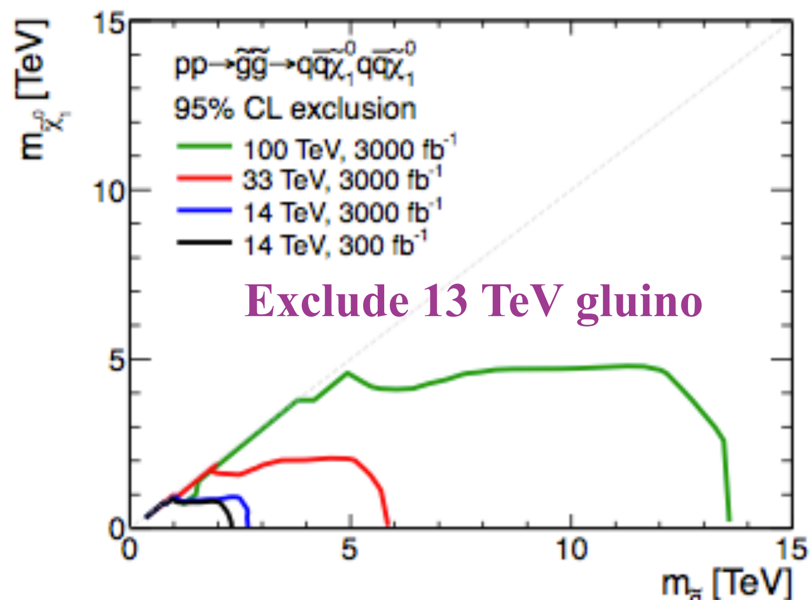
Gluino pair (Gqq) – light flavor

- Search for gluinos with fully hadronic final states
- Discover (Exclude) 11 (13) TeV gluino
- Increasing the center-of-mass energy has a tremendous impact on the experimentally available parameter space (~5 x beyond 14 TeV @100 TeV)



arXiv:1311.6480



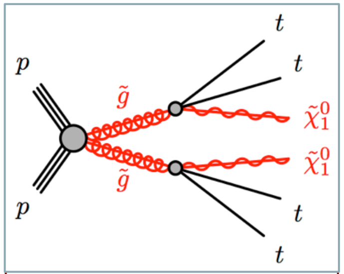


LHC 13 TeV limit ~2 TeV

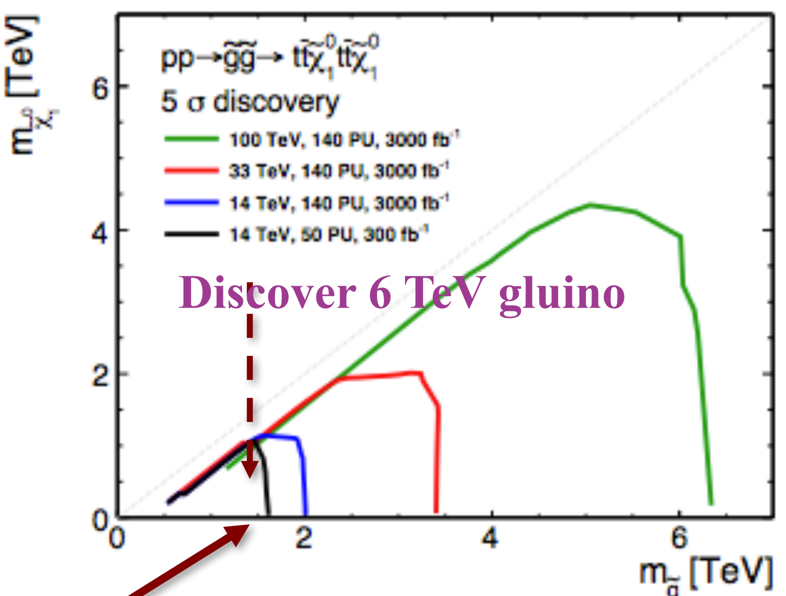
20% systematic uncertainty, no pileup

Gluino pair (Gtt) – heavy flavor

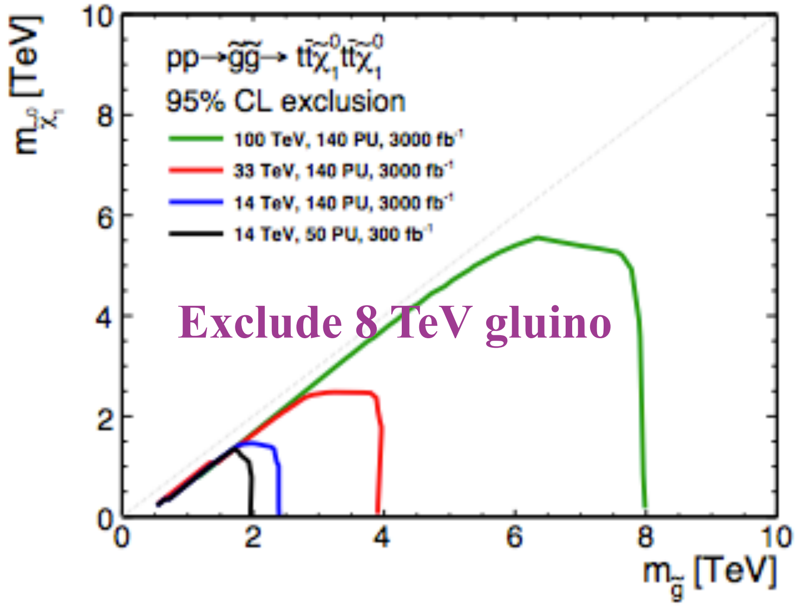
- Search for gluinos with Same Sign 2 lepton, 2b-jets, large missing transverse momentum
- Discover (Exclude) 6 (8) TeV gluino
- Increasing the center-of-mass energy has a tremendous impact on the experimentally available parameter space (~3 x beyond 14 TeV @100 TeV)



arXiv:1311.6480



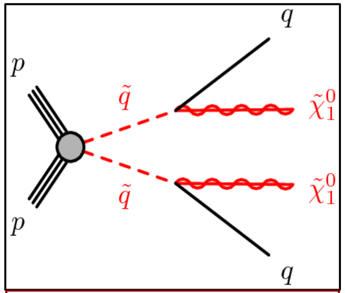
LHC 13 TeV limit ~1.5 TeV



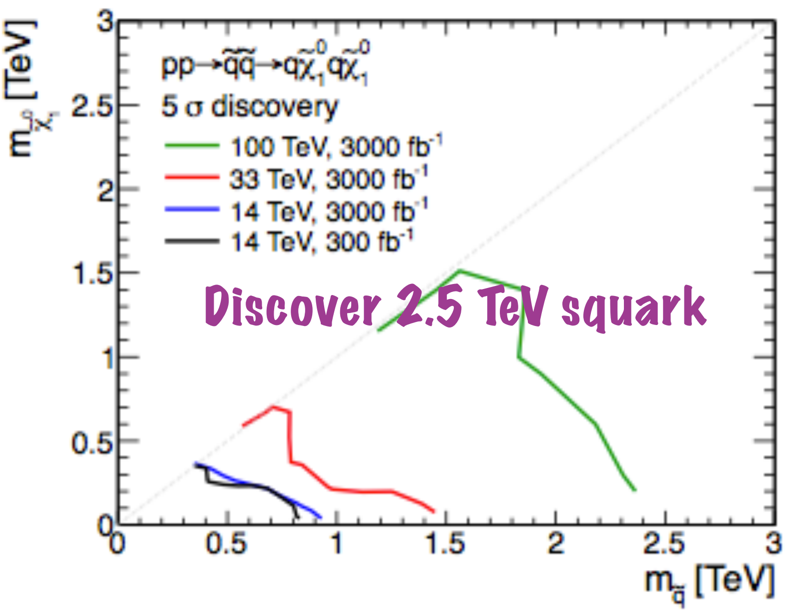
20% systematic uncertainty, no pileup

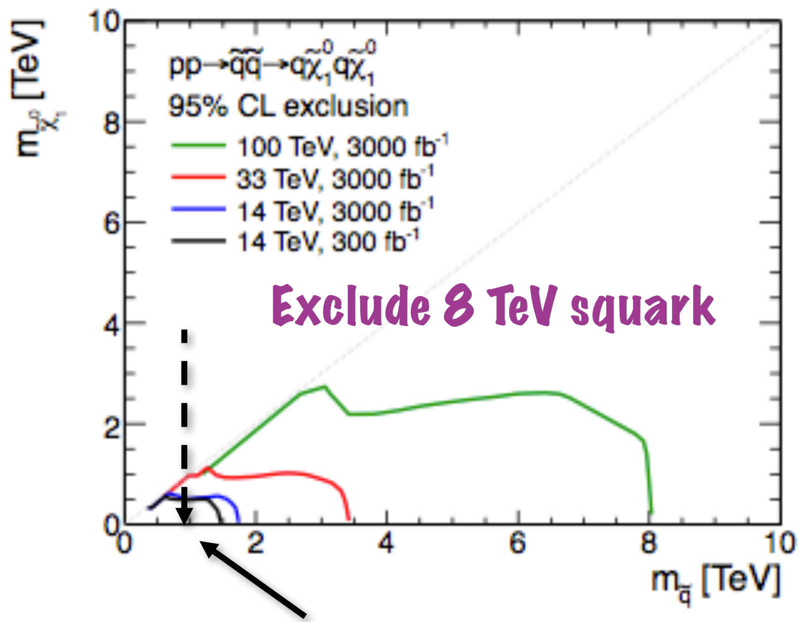
Squark pair

- Search for squarks with no lepton, multi-jets, large missing transverse momentum
- Signal to BG discrimination based on: MET, HT (Σjet pt)
- Discover (Exclude) 2.5 (8) TeV squark
- Increasing the center-of-mass energy has a tremendous impact on the experimentally available parameter space (~3 x beyond 14 TeV @100 TeV)



arXiv:1311.6480



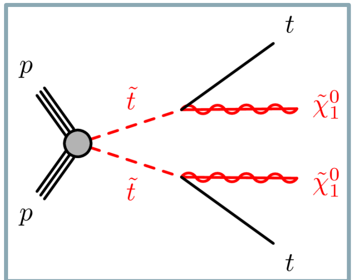


20% systematic uncertainty, no pileup

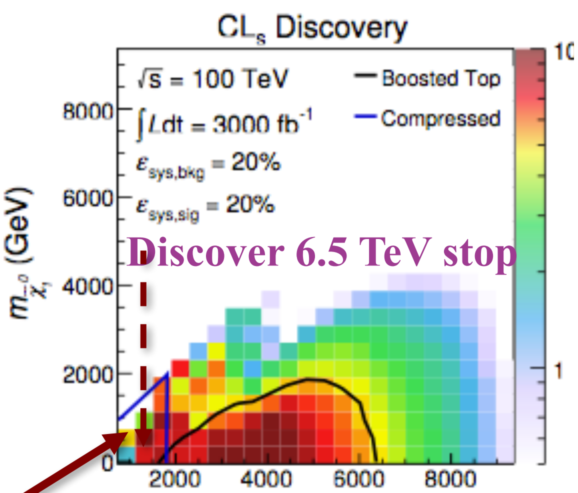
LHC 13 TeV limit ~1 TeV

Stop pair

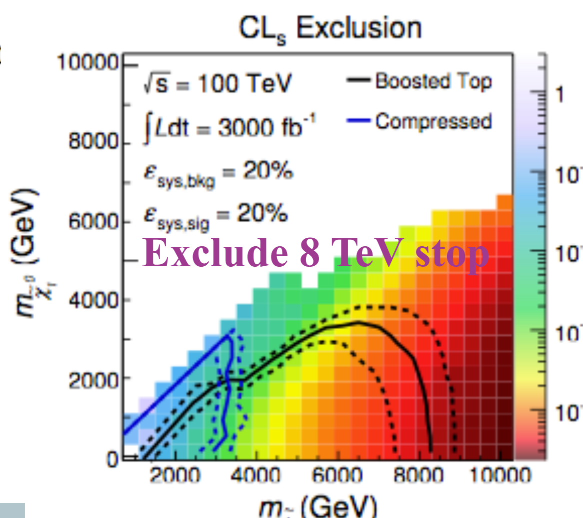
- Search for stop with on-shell top decay @ 100 TeV
- Tops are very boosted at 100 TeV, the search strategy with isolated leptons, b-tags or top-tagging are sensitive to detector granularity/performance, pileup conditions etc. → So use simple handles with hard jets, MET and muon-in-jet
- Two scenarios with high mass stop and compressed region designed
- Discover (Exclude) 6.5 (8) TeV stop @100TeV



arXiv:1406.4512



LHC 13 TeV limit ~1 TeV



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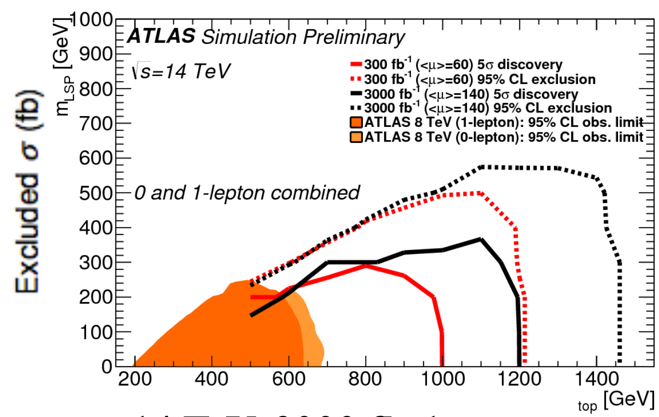
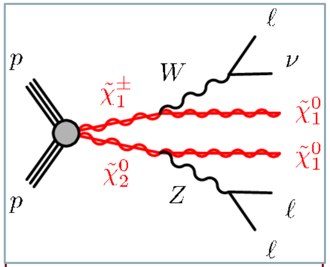


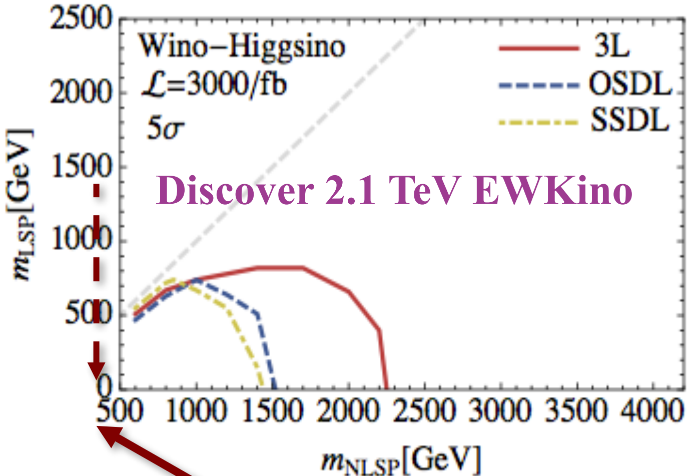
14 TeV, 3000 fb-1: Exclude 1. 4 TeV stop

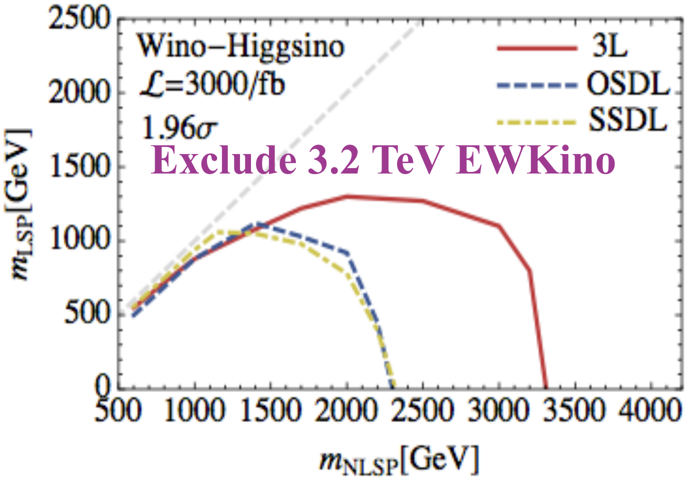
EWK Signature

- Increasing bounds on colored SUSY particles, maybe only electroweakinos in the low energy spectrum. LHC has limited reach for direct produced EWK particles
- Potential search for electroweakinos with multi-lepton signatures: 3L || OS2L || SS2L @100 TeV
- Discover (Exclude) 2.1 (3.2) TeV electroweakinos for wino NLSP



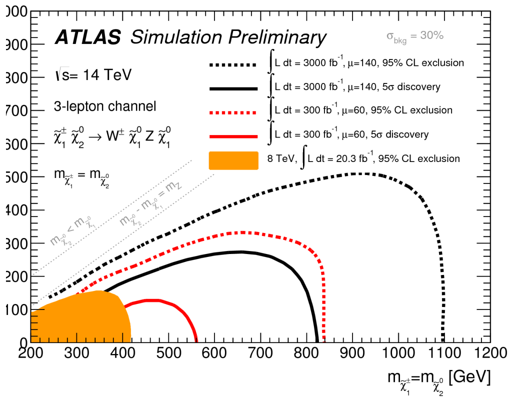
arXiv:1410.6287





LHC 8 TeV limit ~0.45 TeV

ATL-PHYS-PUB-2013-011



14 TeV, 3000 fb-1:
Exclude 1. 1 TeV EWKino

Outline

- ❑ SUSY Introduct
- ❑ The LHC and A
- ❑ SUSY search s
- ❑ SUSY search @
- ❑ Longer term p
  LHC and Futur
  (14, 33, 100 Te

- ❑ **Outlook and Summary**

Summary and Outlook

- [LHC 13 TeV ~36 fb^{-1}] In canonical scenarios, sensitivity is achieved to ~2 TeV gluinos, ~1 TeV stops and ~400-1000 GeV EWKinos
- [LHC 14 TeV ~3000 fb^{-1}] Discovery potential up to 2.2 TeV gluinos, 1.2 TeV stop and 800 GeV EWKinos
- [100 TeV ~3000 fb^{-1}] Discover (Exclude) 11 (13) TeV gluino, 6.5 (8) TeV stop, 2.1 (3.2) TeV EWKinos
- LHC is a discovery machine, new physics may come at any time , stay tuned!

Thanks for your attention!

ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

ATLAS Preliminary

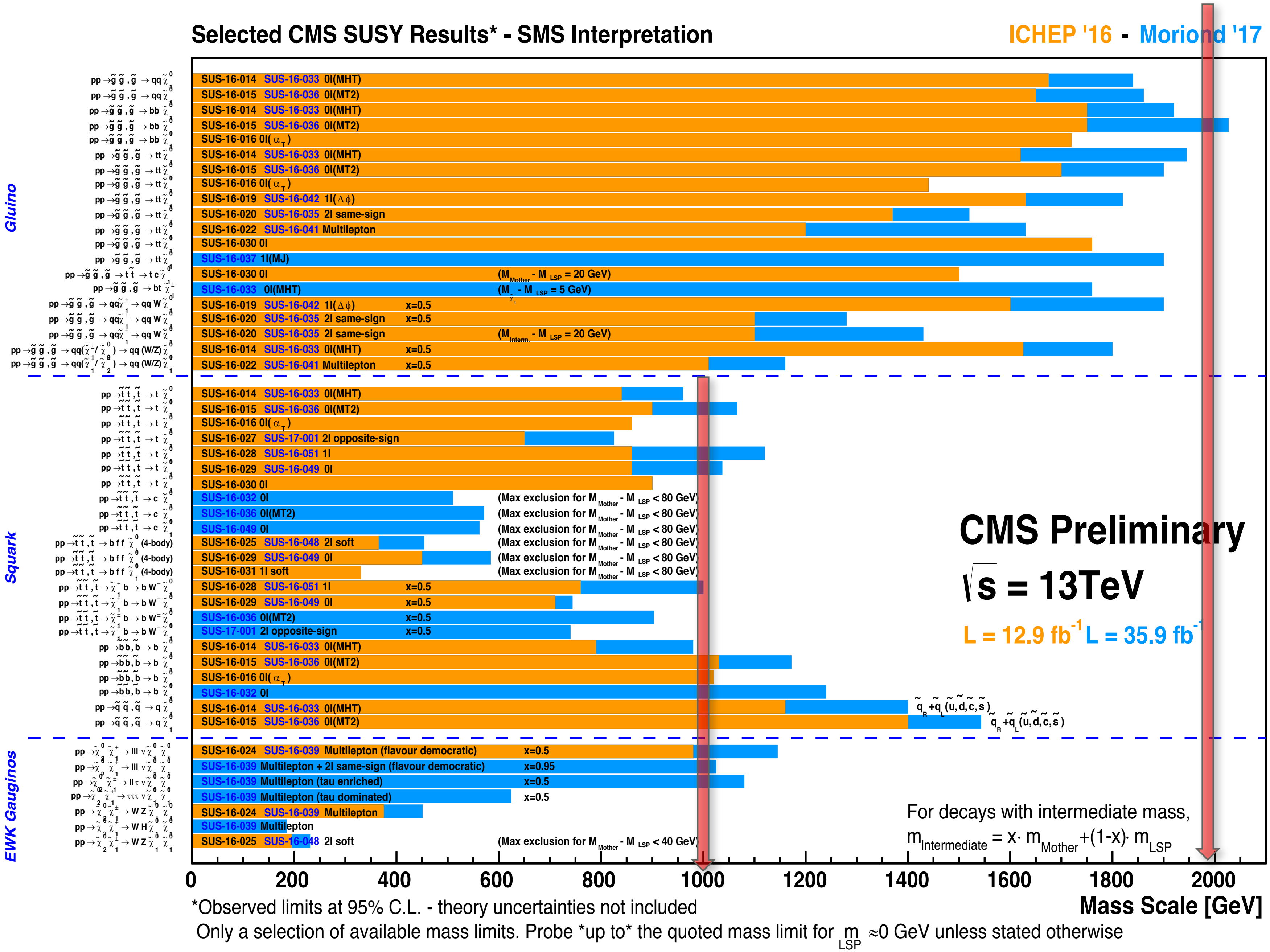
$\sqrt{s}$ = 7, 8, 13 TeV

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

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$		Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$	1.85 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q},\ \tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	36.1	$\tilde{q}$	1.57 TeV	$m(\tilde{\chi}^0_1)$<200 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2017-022
	$\tilde{q}\tilde{q},\ \tilde{q}\to q\tilde{\chi}^0_1$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$	608 GeV	$m(\tilde{q})-m(\tilde{\chi}^0_1)$<5 GeV	1604.07773
	$\tilde{g}\tilde{g},\ \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	36.1	$\tilde{g}$	2.02 TeV	$m(\tilde{\chi}^0_1)$<200 GeV	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g},\ \tilde{g}\to qq\tilde{\chi}^{\pm}_1\to qqW^{\pm}\tilde{\chi}^0_1$	0	2-6 jets	Yes	36.1	$\tilde{g}$	2.01 TeV	$m(\tilde{\chi}^0_1)$<200 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}^0_1)+m(\tilde{g}))$	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g},\ \tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}^0_1$	3 e,μ	4 jets	-	36.1	$\tilde{g}$	1.825 TeV	$m(\tilde{\chi}^0_1)$<400 GeV	ATLAS-CONF-2017-030
	$\tilde{g}\tilde{g},\ \tilde{g}\to qqWZ\tilde{\chi}^0_1$	0	7-11 jets	Yes	36.1	$\tilde{g}$	1.8 TeV	$m(\tilde{\chi}^0_1)$ <400 GeV	ATLAS-CONF-2017-033
	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	3.2	$\tilde{g}$	1.65 TeV	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.37 TeV	$m(\tilde{\chi}^0_1)$<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde{g}$	1.8 TeV	$m(\tilde{\chi}^0_1)$>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g},\ \tilde{g}\to b\bar{b}\tilde{\chi}^0_1$	0	3 b	Yes	36.1	$\tilde{g}$	1.92 TeV	$m(\tilde{\chi}^0_1)$<600 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g},\ \tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	Yes	36.1	$\tilde{g}$	1.97 TeV	$m(\tilde{\chi}^0_1)$<200 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g},\ \tilde{g}\to b\bar{t}\tilde{\chi}^+_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.37 TeV	$m(\tilde{\chi}^0_1)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1,\ \tilde{b}_1\to b\tilde{\chi}^0_1$	0	2 b	Yes	36.1	$\tilde{b}_1$	950 GeV	$m(\tilde{\chi}^0_1)$<420 GeV	ATLAS-CONF-2017-038
	$\tilde{b}_1\tilde{b}_1,\ \tilde{b}_1\to t\tilde{\chi}^{\pm}_1$	2 e,μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$	275-700 GeV	$m(\tilde{\chi}^0_1)$<200 GeV, $m(\tilde{\chi}^{\pm}_1)=m(\tilde{\chi}^0_1)$+100 GeV	ATLAS-CONF-2017-030
	$\tilde{t}_1\tilde{t}_1,\ \tilde{t}_1\to b\tilde{\chi}^{\pm}_1$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	117-170 GeV; 200-720 GeV	$m(\tilde{\chi}^{\pm}_1)=2m(\tilde{\chi}^0_1)$, $m(\tilde{\chi}^0_1)$=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1,\ \tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$	90-198 GeV; 205-950 GeV	$m(\tilde{\chi}^0_1)$=1 GeV	1506.08616, ATLAS-CONF-2017-020
	$\tilde{t}_1\tilde{t}_1,\ \tilde{t}_1\to c\tilde{\chi}^0_1$	0	mono-jet	Yes	3.2	$\tilde{t}_1$	90-323 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}^0_1)$=5 GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-600 GeV	$m(\tilde{\chi}^0_1)$>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	$m(\tilde{\chi}^0_1)$=0 GeV	ATLAS-CONF-2017-019
	$\tilde{t}_2\tilde{t}_2,\ \tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	Yes	36.1	$\tilde{t}_2$	320-880 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	ATLAS-CONF-2017-019
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R},\ \tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0	Yes	36.1	$\tilde{\ell}$	90-440 GeV	$m(\tilde{\chi}^0_1)$=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	$\tilde{\chi}^{\pm}_1$	710 GeV	$m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^{\pm}_1)+m(\tilde{\chi}^0_1))$	ATLAS-CONF-2017-039
	$\tilde{\chi}^{\pm}_1\tilde{\chi}^{\mp}_1/\tilde{\chi}^0_2,\ \tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu}),\ \tilde{\chi}^0_2\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}^{\pm}_1$	760 GeV	$m(\tilde{\chi}^0_1)$=0, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}^{\pm}_1)+m(\tilde{\chi}^0_1))$	ATLAS-CONF-2017-035
	$\tilde{\chi}^{\pm}_1\tilde{\chi}^0_2\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu),\ \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	36.1	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$	1.16 TeV	$m(\tilde{\chi}^{\pm}_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^{\pm}_1)+m(\tilde{\chi}^0_1))$	ATLAS-CONF-2017-039
	$\tilde{\chi}^{\pm}_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1Z\tilde{\chi}^0_1$	2-3 e,μ	0-2 jets	Yes	36.1	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$	580 GeV	$m(\tilde{\chi}^{\pm}_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, $\tilde{\ell}$ decoupled	ATLAS-CONF-2017-039
	$\tilde{\chi}^{\pm}_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1h\tilde{\chi}^0_1,\ h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$	270 GeV	$m(\tilde{\chi}^{\pm}_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}^0_2\tilde{\chi}^0_3,\ \tilde{\chi}^0_{2,3}\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}^0_{2,3}$	635 GeV	$m(\tilde{\chi}^0_2)=m(\tilde{\chi}^0_3)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^0_2)+m(\tilde{\chi}^0_1))$	1405.5086
	GGM (wino NLSP) weak prod., $\tilde{\chi}^0_1\to\gamma\tilde{G}$	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$	115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}^0_1\to\gamma\tilde{G}$	2 γ	-	Yes	20.3	$\tilde{W}$	590 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^{\pm}_1$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}^{\pm}_1$	430 GeV	$m(\tilde{\chi}^{\pm}_1)-m(\tilde{\chi}^0_1)$~160 MeV, $\tau(\tilde{\chi}^{\pm}_1)$=0.2 ns	ATLAS-CONF-2017-017
	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^{\pm}_1$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}^{\pm}_1$	495 GeV	$m(\tilde{\chi}^{\pm}_1)-m(\tilde{\chi}^0_1)$~160 MeV, $\tau(\tilde{\chi}^{\pm}_1)$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	850 GeV	$m(\tilde{\chi}^0_1)$=100 GeV, 10 μs<$\tau(\tilde{g})$<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	$m(\tilde{\chi}^0_1)$=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}^0_1\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}^0_1$	537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	20.3	$\tilde{\chi}^0_1$	440 GeV	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	$\tilde{\chi}^0_1$	1.0 TeV	7 <$c\tau(\tilde{\chi}^0_1)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g},\ \tilde{\chi}^0_1\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}^0_1$	1.0 TeV	6 <$c\tau(\tilde{\chi}^0_1)$< 480 mm, $m(\tilde{g})$=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 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
	$\tilde{\chi}^+_1\tilde{\chi}^-_1,\ \tilde{\chi}^+_1\to W\tilde{\chi}^0_1,\ \tilde{\chi}^0_1\to ee\nu,e\mu\nu,\mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}^{\pm}_1$	1.14 TeV	$m(\tilde{\chi}^0_1)$>400GeV, $\lambda_{12k}\neq0$ (k = 1, 2)	ATLAS-CONF-2016-075
	$\tilde{\chi}^+_1\tilde{\chi}^-_1,\ \tilde{\chi}^+_1\to W\tilde{\chi}^0_1,\ \tilde{\chi}^0_1\to\tau\tau\nu_e,e\tau\nu_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}^{\pm}_1$	450 GeV	$m(\tilde{\chi}^0_1)>0.2\times m(\tilde{\chi}^{\pm}_1)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g},\ \tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g},\ \tilde{g}\to qq\tilde{\chi}^0_1,\ \tilde{\chi}^0_1\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.55 TeV	$m(\tilde{\chi}^0_1)$=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g},\ \tilde{g}\to t\bar{t}\tilde{\chi}^0_1,\ \tilde{\chi}^0_1\to qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$	2.1 TeV	$m(\tilde{\chi}^0_1)$= 1 TeV, $\lambda_{112}\neq0$	ATLAS-CONF-2017-013
	$\tilde{g}\tilde{g},\ \tilde{g}\to\tilde{t}_1t,\ \tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$	1.65 TeV	$m(\tilde{t}_1)$= 1 TeV, $\lambda_{323}\neq0$	ATLAS-CONF-2017-013
	$\tilde{t}_1\tilde{t}_1,\ \tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$	410 GeV; 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1,\ \tilde{t}_1\to b\ell$	2 e,μ	2 b	-	36.1	$\tilde{t}_1$	0.4-1.45 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}^0_1$	0	2 c	Yes	20.3	$\tilde{c}$	510 GeV	$m(\tilde{\chi}^0_1)$<200 GeV	1501.01325

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.


Selected CMS SUSY Results* - SMS Interpretation
ICHEP '16 - Moriond '17
Gluino
SUS-16-014 SUS-16-033 0l(MHT)
SUS-16-015 SUS-16-036 0l(MT2)
SUS-16-014 SUS-16-033 0l(MHT)
SUS-16-015 SUS-16-036 0l(MT2)
SUS-16-016 0l(α_T)
SUS-16-014 SUS-16-033 0l(MHT)
SUS-16-015 SUS-16-036 0l(MT2)
SUS-16-016 0l(α_T)
SUS-16-019 SUS-16-042 1l($\Delta\phi$)
SUS-16-020 SUS-16-035 2l same-sign
SUS-16-022 SUS-16-041 Multilepton
SUS-16-030 0l
SUS-16-037 1l(MJ)
SUS-16-030 0l ($M_{Mother} - M_{LSP}$ = 20 GeV)
SUS-16-033 0l(MHT) ($M - M_{LSP}$ = 5 GeV)
SUS-16-019 SUS-16-042 1l($\Delta\phi$) x=0.5
SUS-16-020 SUS-16-035 2l same-sign x=0.5
SUS-16-020 SUS-16-035 2l same-sign ($M_{Interm.} - M_{LSP}$ = 20 GeV)
SUS-16-014 SUS-16-033 0l(MHT) x=0.5
SUS-16-022 SUS-16-041 Multilepton x=0.5
Squark
SUS-16-014 SUS-16-033 0l(MHT)
SUS-16-015 SUS-16-036 0l(MT2)
SUS-16-016 0l(α_T)
SUS-16-027 SUS-17-001 2l opposite-sign
SUS-16-028 SUS-16-051 1l
SUS-16-029 SUS-16-049 0l
SUS-16-030 0l
SUS-16-032 0l (Max exclusion for $M_{Mother} - M_{LSP}$ < 80 GeV)
SUS-16-036 0l(MT2) (Max exclusion for $M_{Mother} - M_{LSP}$ < 80 GeV)
SUS-16-049 0l (Max exclusion for $M_{Mother} - M_{LSP}$ < 80 GeV)
SUS-16-025 SUS-16-048 2l soft (Max exclusion for $M_{Mother} - M_{LSP}$ < 80 GeV)
SUS-16-029 SUS-16-049 0l (Max exclusion for $M_{Mother} - M_{LSP}$ < 80 GeV)
SUS-16-031 1l soft (Max exclusion for $M_{Mother} - M_{LSP}$ < 80 GeV)
SUS-16-028 SUS-16-051 1l x=0.5
SUS-16-029 SUS-16-049 0l x=0.5
SUS-16-036 0l(MT2) x=0.5
SUS-17-001 2l opposite-sign x=0.5
SUS-16-014 SUS-16-033 0l(MHT)
SUS-16-015 SUS-16-036 0l(MT2)
SUS-16-016 0l(α_T)
SUS-16-032 0l
SUS-16-014 SUS-16-033 0l(MHT)
SUS-16-015 SUS-16-036 0l(MT2)
EWK Gauginos
SUS-16-024 SUS-16-039 Multilepton (flavour democratic) x=0.5
SUS-16-039 Multilepton + 2l same-sign (flavour democratic) x=0.95
SUS-16-039 Multilepton (tau enriched) x=0.5
SUS-16-039 Multilepton (tau dominated) x=0.5
SUS-16-024 SUS-16-039 Multilepton
SUS-16-039 Multilepton
SUS-16-025 SUS-16-048 2l soft (Max exclusion for $M_{Mother} - M_{LSP}$ < 40 GeV)
CMS Preliminary
$\sqrt{s}$ = 13TeV
L = 12.9 fb^{-1} L = 35.9 fb^{-1}
For decays with intermediate mass,
$m_{Intermediate} = x \cdot m_{Mother} + (1-x) \cdot m_{LSP}$
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

The journey into new physics territory has just only begun (only using 2% data), and for sure, exciting times are ahead of us!

J Blaeu 1664

ATLAS IHEP Team Members

Total of 43 members:
13 physicist staff
8-10 Post-doc
16 PhD students
4 engineer staff

Staffs: Joao Guimaraes da Costa, Xuai Zhuang, Hongbo Zhu, Yaquan Fang, Xinchou Lou, Qun Ouyang, Feng Lu, Lianyou Shan, Zhijun Liang, Yanping Huang, Da Xu, Xin Shi

General Management and Boards

Xinchou Lou	ATLAS ITK Steering Committee member
Xuai Zhuang	ATLAS CB Chair Advisory Group member (2016 - 2018)

Detector Operations and R&D

JuanAn Pascual	Pixel DAQ coordinator (2016.5 – 2018.1)
JuanAn Pascual	Deputy Run Coordinator (2017.11 – 2018. 10)
Jason Mansour	Inner detector online and DAQ coordinator

Physics and Performance

Xuai Zhuang	EWK SUSY Group Convener (2015.4 - 2016.4)
Joao Costa	HWW Group Convener (2016.4 - 2017.3)
Yanping Huang	Photon ID group convener (2016. 10 - now)

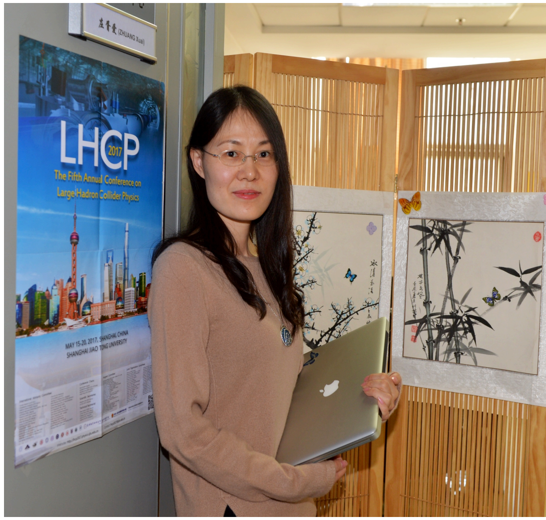
Recent group activities

- **Detector Upgrade**
  - Phase II ITK strip upgrade
- **Detector operation, Core software and Performance**
  - Pixel Detector DAQ and Operations, offline studies
  - Inner detector data quality and tracking CP
  - Photon ID
  - Tau reconstruction and data quality
  - Second vertex finder
  - MET performance
- **Physics Analysis**
  - Higgs: $H\rightarrow\gamma\gamma$, $Z\gamma$, WW, bb, ttH(bb), di-Higgs in $WW\gamma\gamma$, WWWW, bbbb
  - New resonance search: $\gamma\gamma$, $Z\gamma$
  - SUSY searches ：di-tau, 1L, SS/2L&3L, tau+jets
  - SM measurement: $Z\gamma$ VBS, Z+jet

IHEP SUSY Group

2 graduated this year

Staffs



Xuai ZHUANG Shan JIN Da XU Feng LU

Postdoc + students

Mohamad Kassem AYOUB Huan REN Huajie Cheng Peng Zhang Yang Liu Chenzheng Zhu

SUSY Search Topics @ IHEP

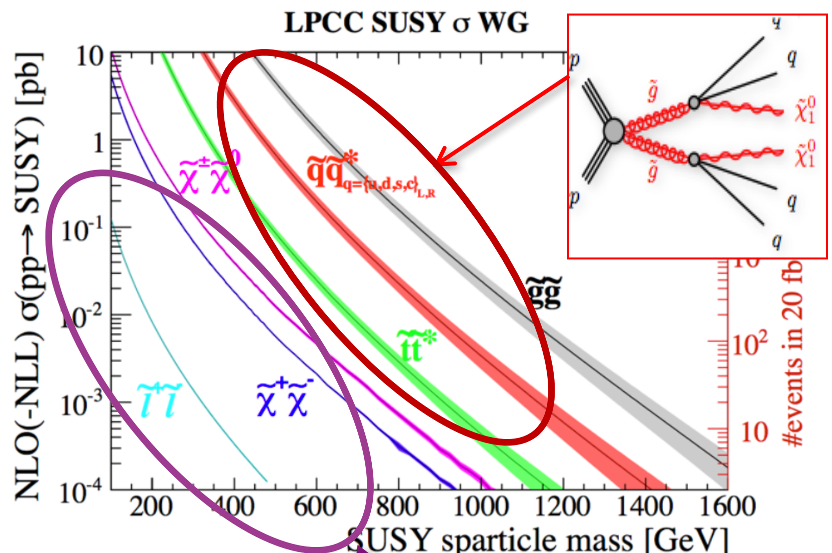
Strong production: targeting gluino and squarks (Inc. 3rd gen. squarks)

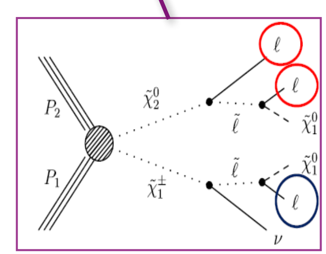
- ❑ Generic signatures :
  Multi -jets + n_lepton/n_photon(n=0,1, ≥2) + large E_T^{miss} (0L,**1 L, >=2L**)
- ❑ **IHEP topics:**
  - ② **** 1L +jets +MET (Run1+Run2)***
  - ③ **SS/3L +jets +MET (Run2)**
  - ④ **Tau +jets +MET (Run1)**

Weak production: targeting charginos, neutralinos and slepton

- ❑ Generic signatures:
  low–jet multiplicity + ≥ 2leptons + large E_T^{miss} (2/3/4L, **>=2tau**)
- ❑ **IHEP topic:**
  - ① **** >=2tau+MET (Run1 + Run2)***

- ****Analysis Contacts***
- **very wide coverage on SUSY search from IHEP: strong + EW**





SUSY models: good sale in market

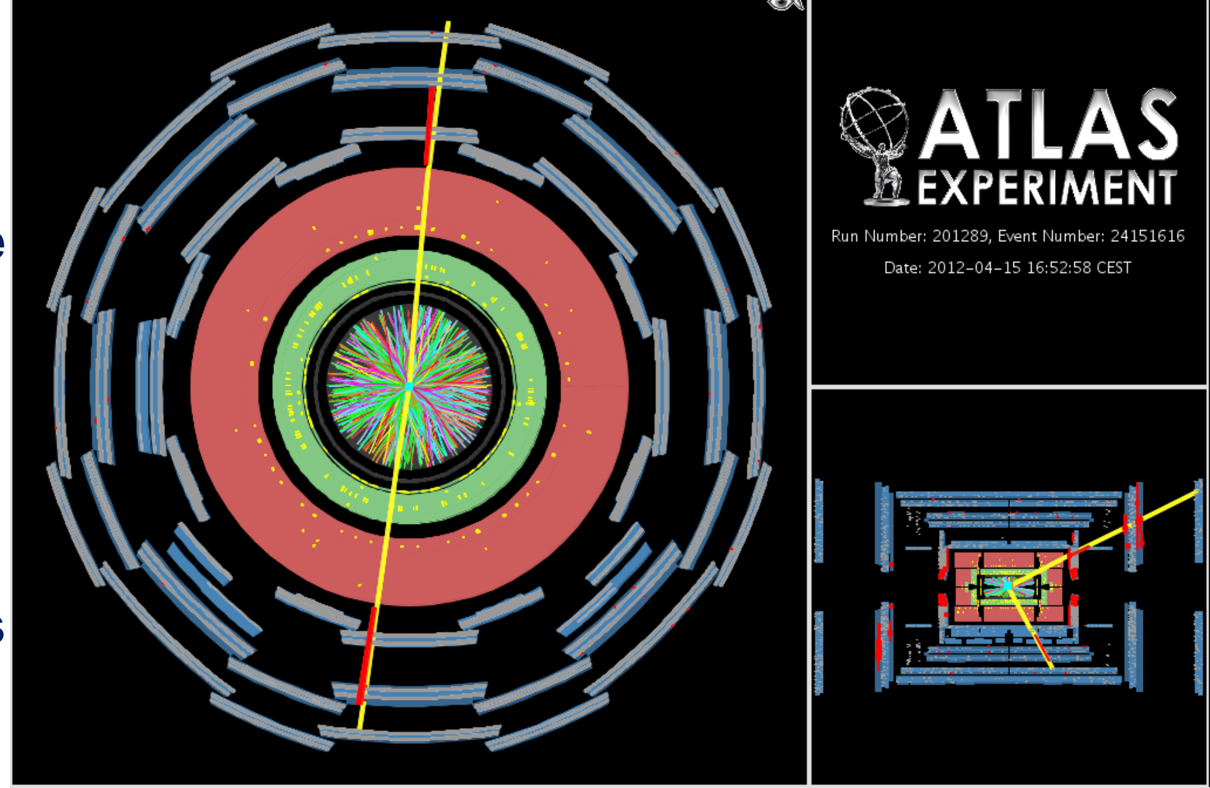
- Simplified Models:
  - Not really a model (Br~100%, most masses fixed at high scales)
  - Important tool for interpretation
- Phenomenological models:
  - pMSSM: captures "most" of phenomenologic features of R-parity conserving MSSM
    - 19 free parameters: M1,M2,M3 ; tan β, μ and $m_{A;}$ 10 sfermion mass parameters; A_t, A_b and A_τ
    - Comprehensive and computationally realistic approximation of the MSSM with neutralino LSP
  - GGM (gravitino)
- Complete SUSY models: mSUGRA, GMSB …

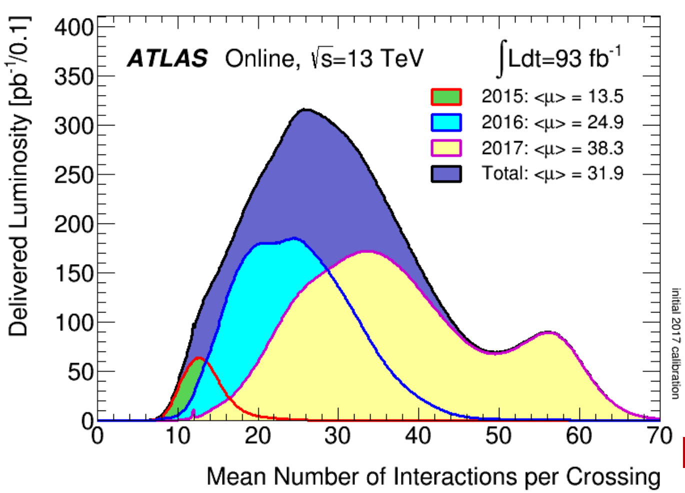
A change of perspective

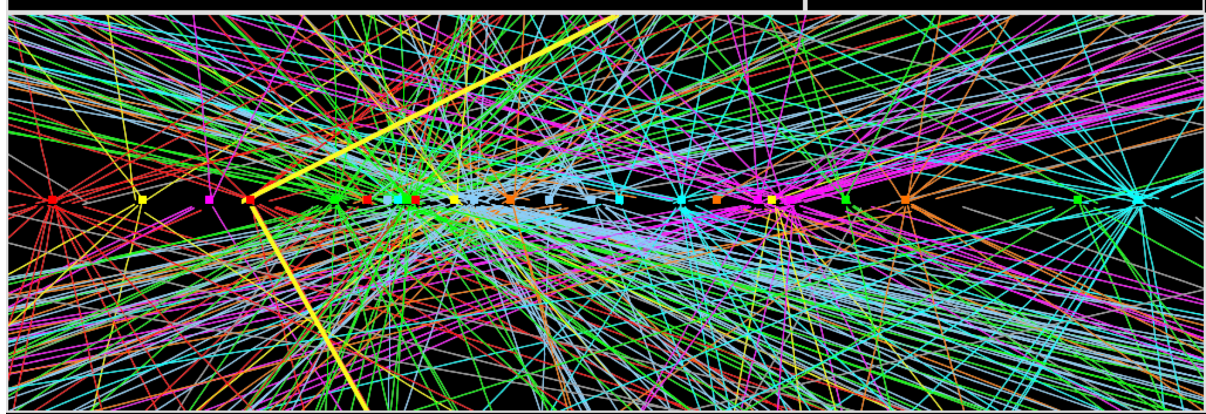
- Develop more complex analysis (compressed, small cross section …)
- Are there topologies of strong production (including 3rd gen.) not covering?
  - PRV signatures? Long-lived signatures? …
- EW signatures have still more room to be discovered
  - Significant gain in sensitivity still expected for conventional C1N2 via WZ, WH decay
  - No proven sensitivity yet in run2 for a number of well-motivated signatures: direct stau, C1C1 via WW … (PhysRevD.93.052002)
  - Higgsino LSP signatures
  - RPV signatures of EW production
  - …

Excellent LHC performance is a (nice) challenge for the experiment:

- **Trigger**
- **Pile-up**
- **Maintain accuracy of the the measurements in this environment**

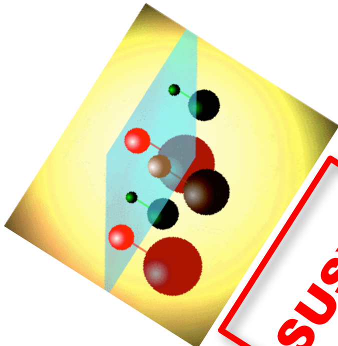




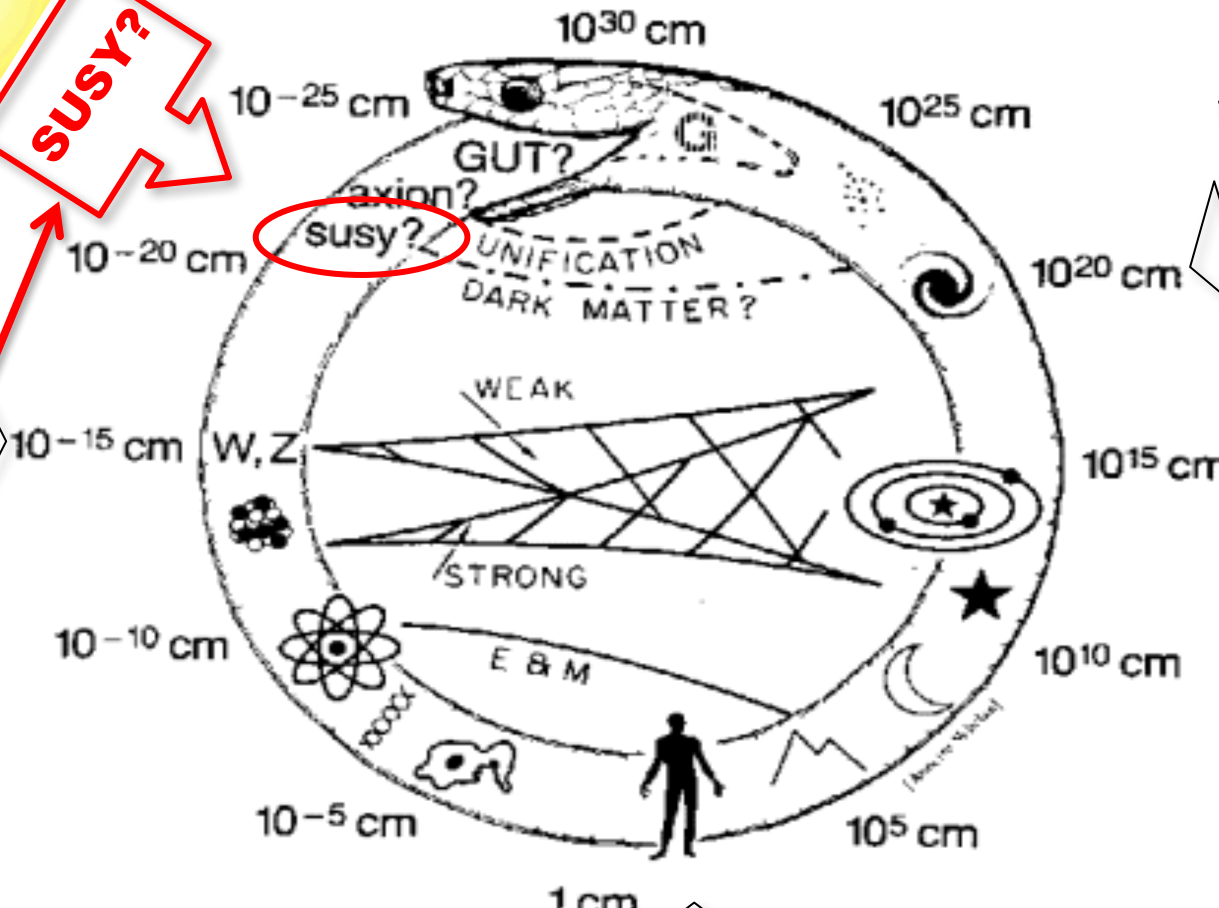


Inner Detector for a Z → μμ event with 25 primary vertices

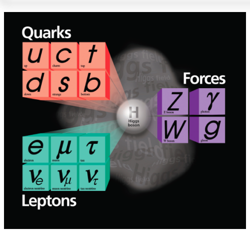
希腊神话中的怪物“Uroboros”与格拉肖的“宇宙圈”



SUSY?



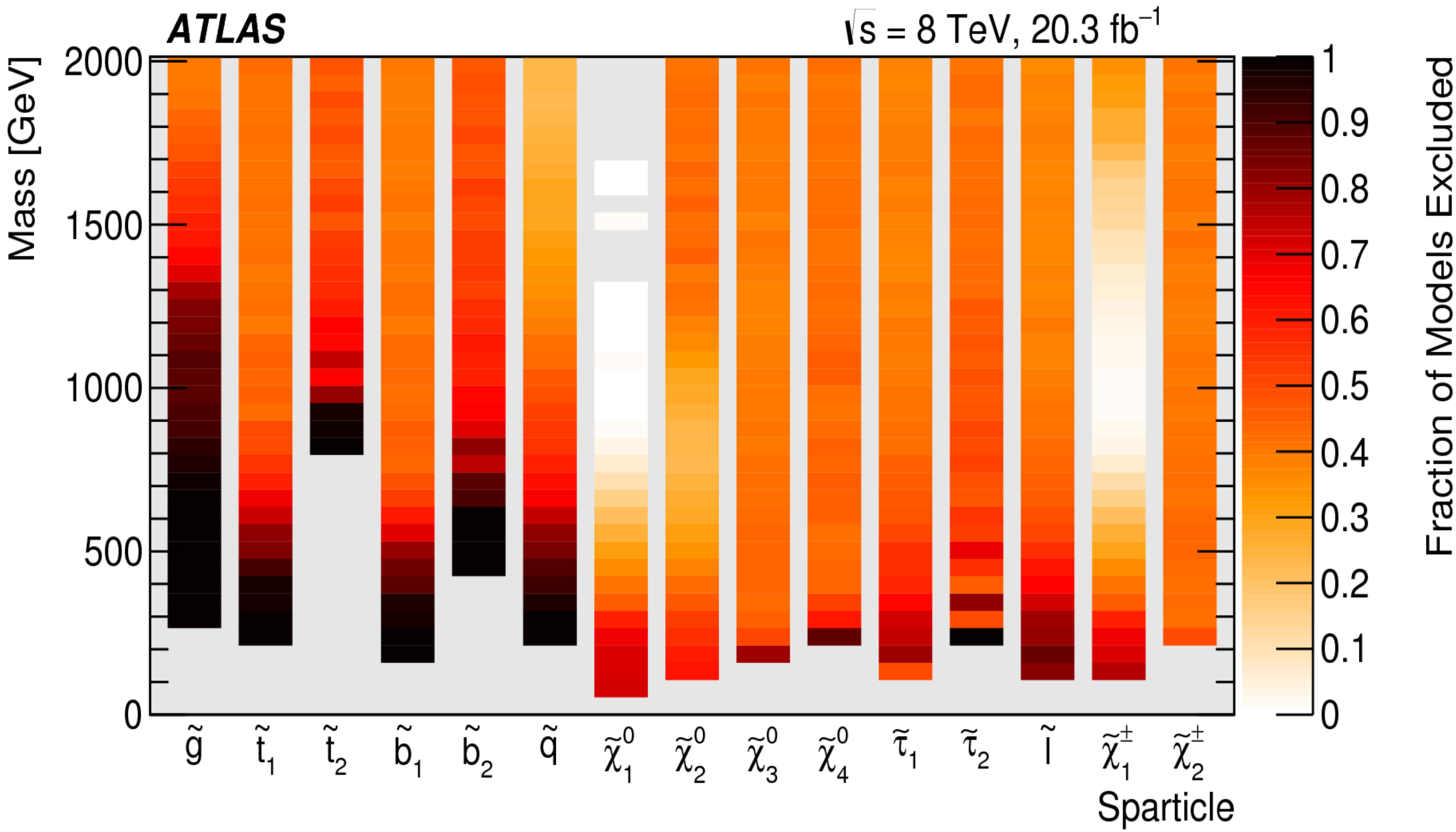
粒子“微观世界”，强弱相互作用主导，理论模型是标准模型



引力主导，爱因斯坦的广义相对论

引力和电磁力占主导地位

An attempt to map out the SUSY model space with all the ATLAS analyses, giving an impression of where SUSY could still hide …



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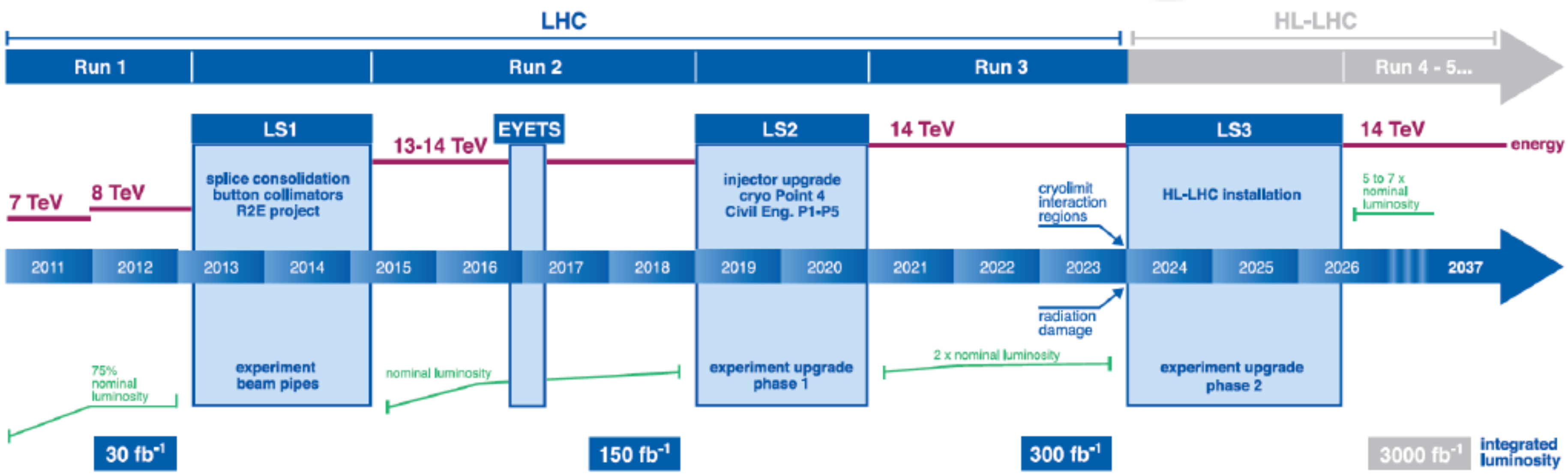
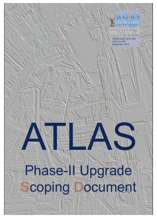
LHC / HL-LHC Plan

High Luminosity LHC





ATLAS Phase-0

New inner pixel layer
Detector consolidation
2015: FTK deployment

ATLAS Phase-1

Improve L1 Trigger, NSW and LAr electronics to cope with higher rates

ATLAS Phase-2

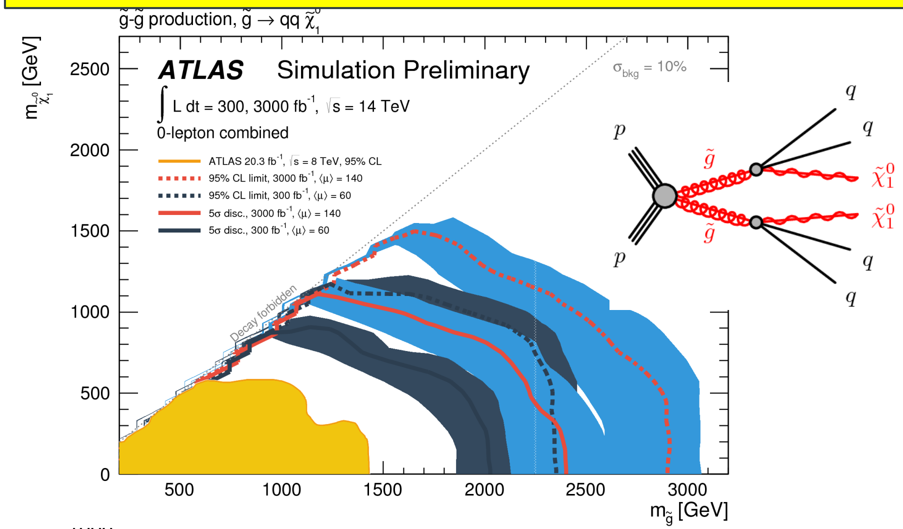
Prepare for 140-200 pile-up events
Replace Inner Tracker
New L0/L1 trigger scheme
Upgrade muon/calorimeter electronics
Upgrade of DAQ detector readout

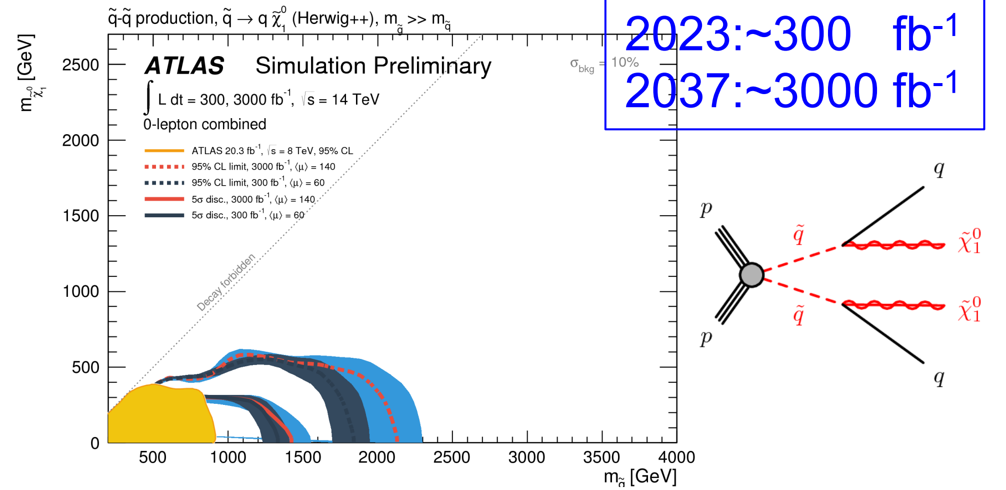
Long term prospects

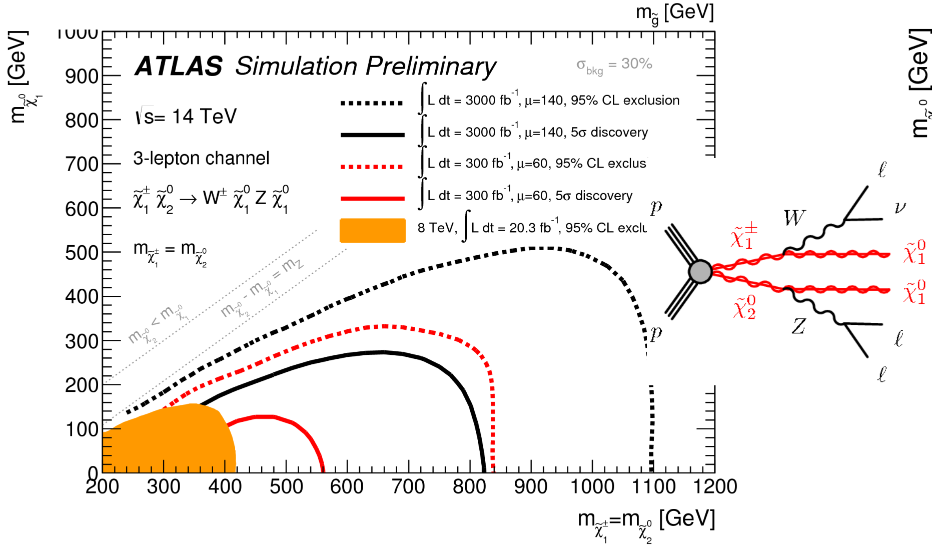
ATL-PHYS-PUB-2014-010

- ATLAS studied long term prospects for the (HL-)LHC with 300, 3000 fb^{-1}@14TeV
- Discovery potential up **to 2.5 TeV gluinos, 1.3 TeV squarks/sbottom and 800 GeV Electroweakinos, 500 GeV stau (IHEP)**

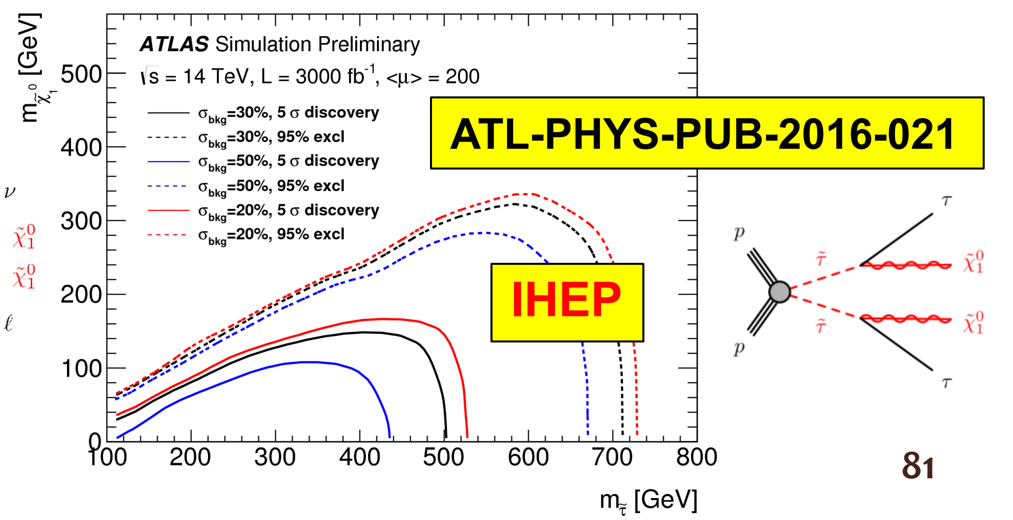
2023:~300 fb^{-1}
2037:~3000 fb^{-1}



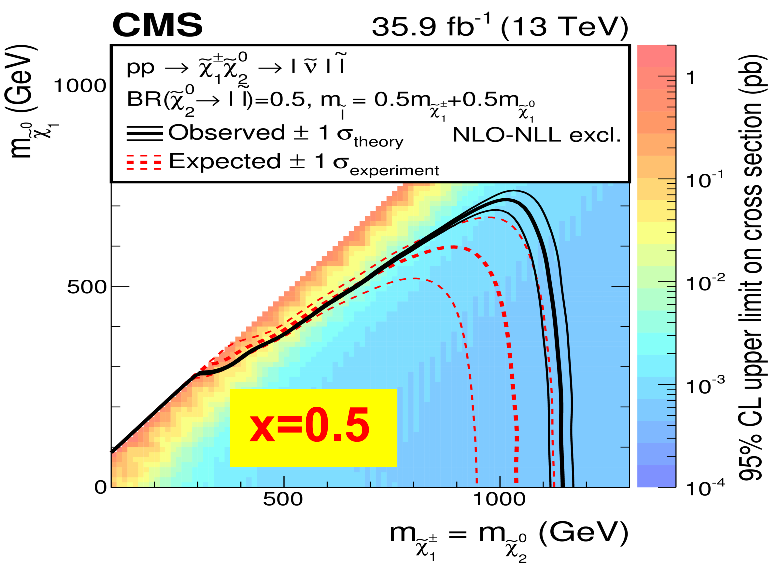


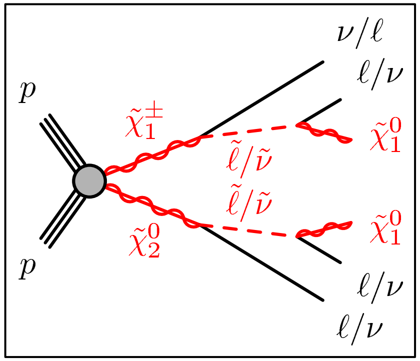


ATL-PHYS-PUB-2016-021

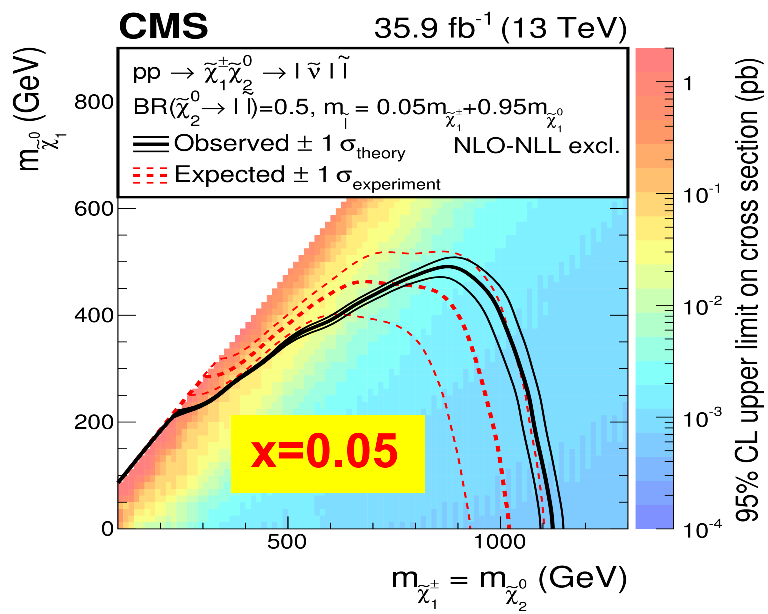


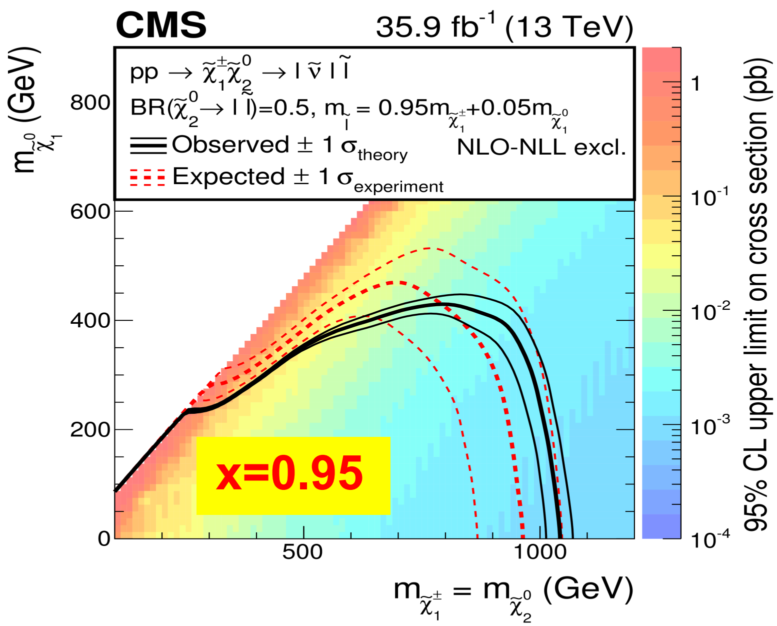
C1N2 via slepton: dependent with x





arXiv:1709.05406

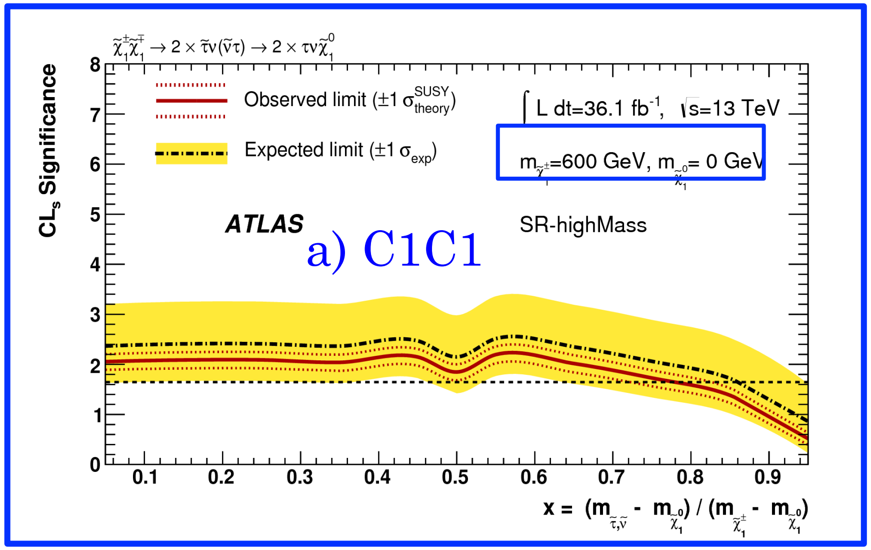


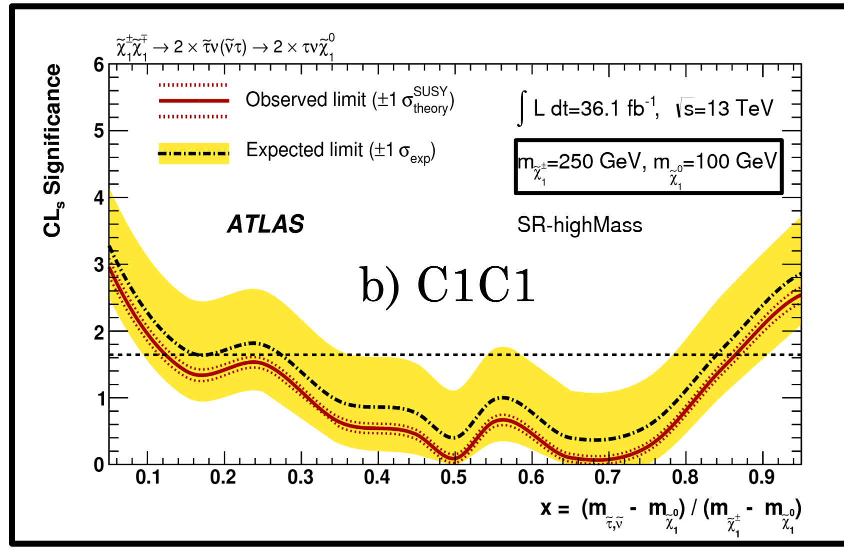


The CLs significance as a function of x

arXiv:1708.07875

$$m(\tilde{\tau}_L) = m(\tilde{\chi}_1^0) + x \cdot \left(m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0)\right)$$





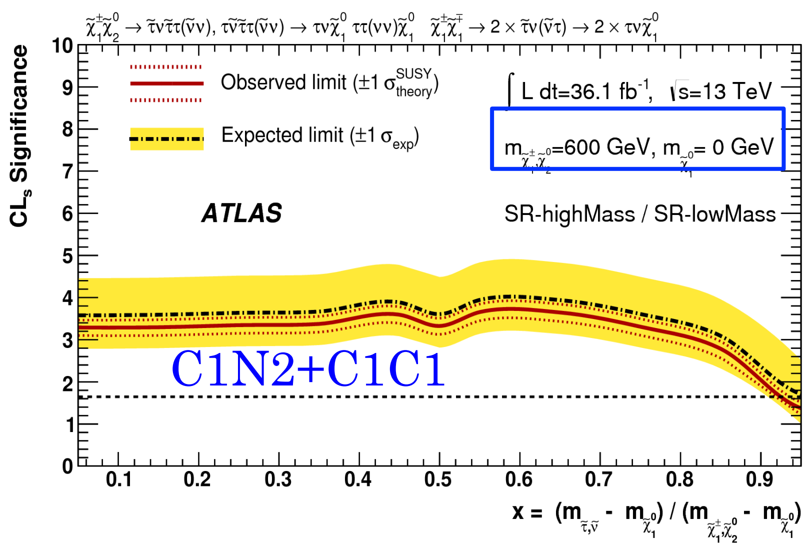
a) **When only C1C1 production is considered, the benchmark scenario with <u>large mass-splitting</u> (600,0) can be excluded for x up to 0.75. For larger values of x, the pT spectra of the tau from the chargino decay become very soft.**

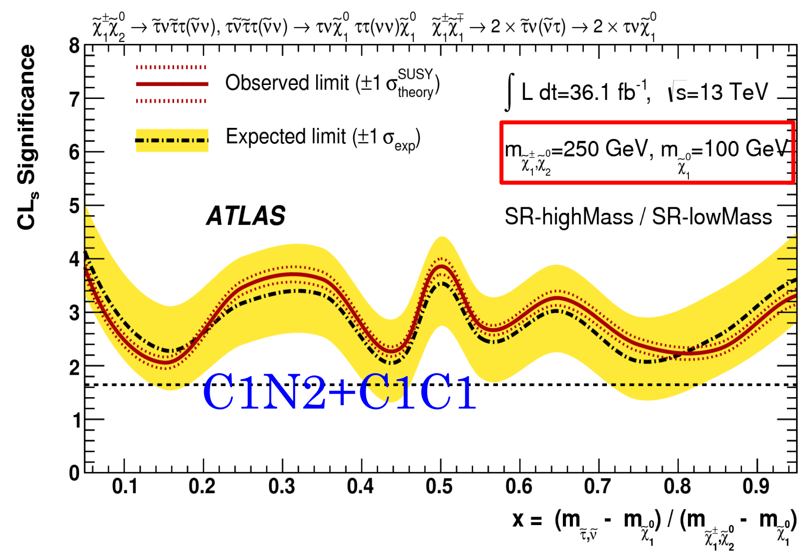
b) **The <u>compressed benchmark scenario</u> (250,100) can only be excluded for the extreme cases with x = 0.05 or x = 0.95 since the mT2 requirement is more effective for models with large mass-splittings between C1 or the staus and N1.**

The CLs significance as a function of x

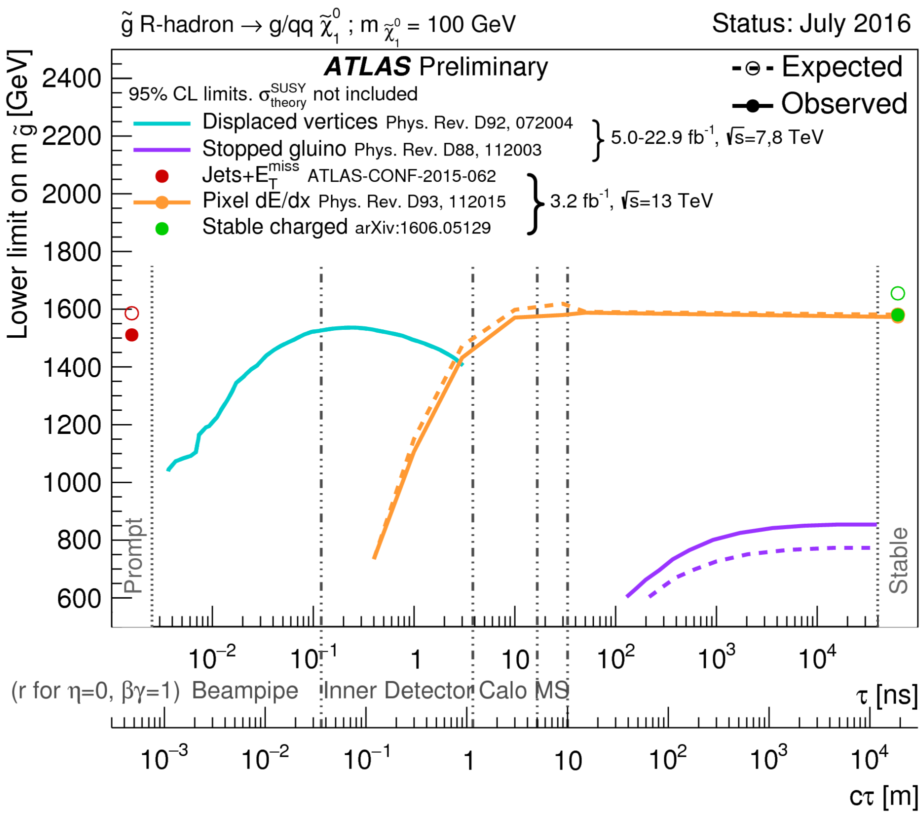
arXiv:1708.07875

$$m(\tilde{\tau}_L) = m(\tilde{\chi}_1^0) + x \cdot \left(m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0)\right)$$

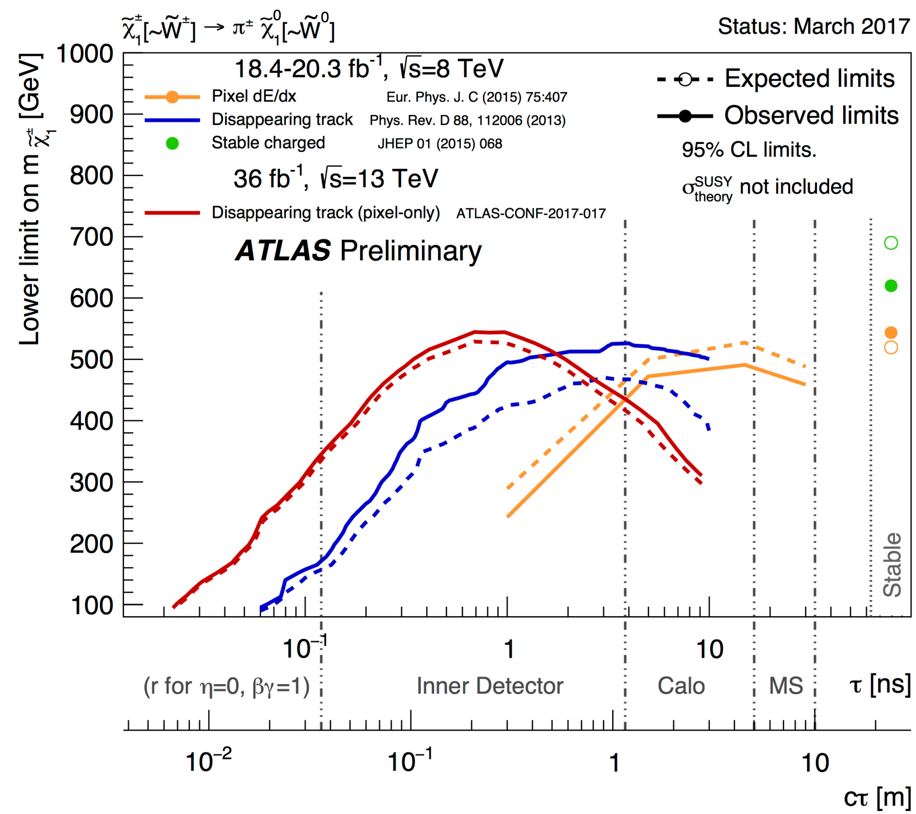




- **For combined production of C1C1 and C1N2, the same general features are observed, but due to the higher signal yields with respect to C1C1 production alone, both benchmark scenarios can be excluded for all considered values of x.**

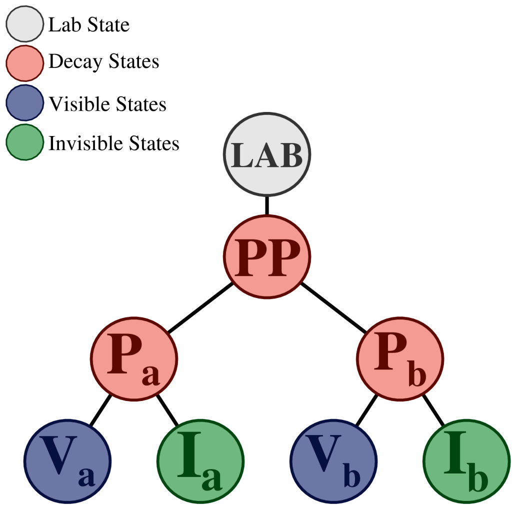


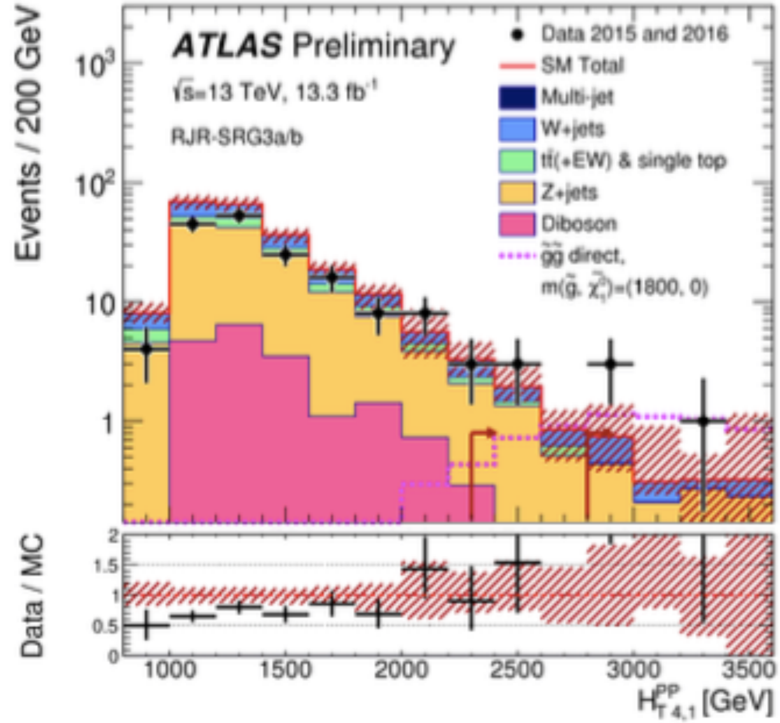
$\tilde{g}$ R-hadron → g/qq $\tilde{\chi}^0_1$; m $\tilde{\chi}^0_1$ = 100 GeV
Status: July 2016
ATLAS Preliminary
Expected
Observed
95% CL limits. σ^{SUSY}_{theory} not included
Displaced vertices Phys. Rev. D92, 072004
Stopped gluino Phys. Rev. D88, 112003
5.0-22.9 fb^{-1}, $\sqrt{s}$=7,8 TeV
Jets+E_T^{miss} ATLAS-CONF-2015-062
Pixel dE/dx Phys. Rev. D93, 112015
Stable charged arXiv:1606.05129
3.2 fb^{-1}, $\sqrt{s}$=13 TeV
Lower limit on m $\tilde{g}$ [GeV]
Prompt
Stable
(r for η=0, βγ=1) Beampipe
Inner Detector
Calo
MS
τ [ns]
cτ [m]



$\tilde{\chi}^\pm_1[\sim\tilde{W}^\pm] \rightarrow \pi^\pm \tilde{\chi}^0_1[\sim\tilde{W}^0]$
Status: March 2017
18.4-20.3 fb^{-1}, $\sqrt{s}$=8 TeV
Pixel dE/dx Eur. Phys. J. C (2015) 75:407
Disappearing track Phys. Rev. D 88, 112006 (2013)
Stable charged JHEP 01 (2015) 068
36 fb^{-1}, $\sqrt{s}$=13 TeV
Disappearing track (pixel-only) ATLAS-CONF-2017-017
ATLAS Preliminary
Expected limits
Observed limits
95% CL limits.
σ^{SUSY}_{theory} not included
Lower limit on m $\tilde{\chi}^\pm_1$ [GeV]
Stable
(r for η=0, βγ=1)
Inner Detector
Calo
MS
τ [ns]
cτ [m]

RJigsaw





the complementary search using the **Recursive Jigsaw Reconstruction (RJR) techniques** in the construction of a discriminating variable set (‘RJR-based search’). By using a dedicated set of selection criteria, the RJR-search improve the sensitivity to supersymmetric models with small mass splittings between the sparticles (models with compressed spectra).

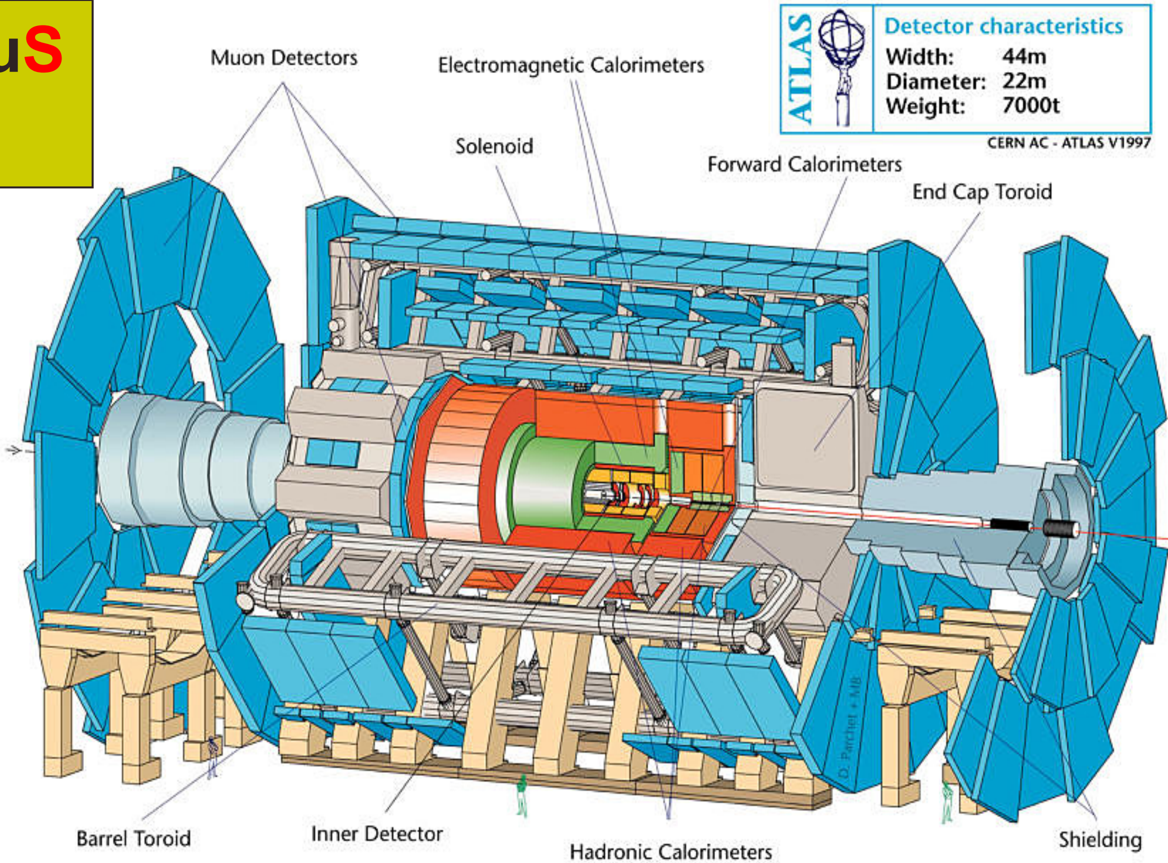
Recursive jigsaw reconstruction

- based on assumption of decay tree
- fix set of rules to resolve combinatorics and unknowns in invisible system
- can form set of variables in the rest frame of each level in the decay tree

A Toroidal LHC ApparatuS

- 42m × 22m, 7000 ton

- **Inner Detector (2T solenoid, |η|<2.5):**
  $\sigma_{p_t}/p_t \approx 0.05\%/GeV \times p_t \oplus 1\%$
- **Calorimetry:**
  - * electromagnetic, |η|<3.2
    $\sigma_E/E \approx 10\%\sqrt{GeV}/\sqrt{E} \oplus 0\%$
  - * hadronic (central, |η|<1.7)
    $\sigma_E/E \approx 50\%\sqrt{GeV}/\sqrt{E} \oplus 3\%$
  - * hadronic (endcaps, 1.7<|η|<3.2)
    $\sigma_E/E \approx 60\%\sqrt{GeV}/\sqrt{E} \oplus 3\%$
  - * hadronic (forward, 3.2<|η|<4.9)
    $\sigma_E/E \approx 100\%\sqrt{GeV}/\sqrt{E} \oplus 5\%$
- **Muon system (~4T toroid, |η|<2.7):**
  $\sigma_{p_t}/p_t \approx 10\%$ for $p_t(\mu) \approx 1$ TeV/c



- **Inner Detector:** Highly segmented silicon strips, determine very accurately charged particles trajectories
- **Solenoid Magnet:** Solenoid coil that generates a 2T magnetic field in the region of the Inner Detector
- **Electromagnetic Calorimeter:** Electron and photon energies are measured through electromagnetic showers
- **Hadronic Calorimeter:** Hadrons interact with dense material and produce a shower of charged particles
- **Toroid Magnets:** 8 toroidal coils that create a 0,4T magnetic field in the area of the Muon Spectrometer
- **Muon Spectrometer:** Muons traverse the rest of the detector and are measured in its outer layers

Data-driven background estimation

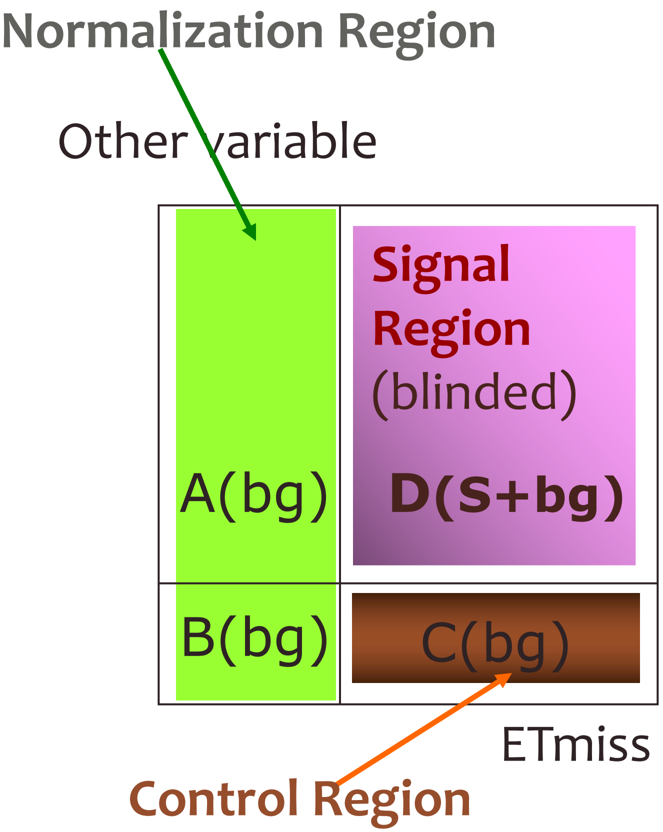
"ABCD" Method

One approach to data-driven bg ***estimation*** is to use uncorrelated model-independent variables to *extrapolate* the background from a background-dominated control region to the signal region.

Nbg in signal region D = (A/B)*C

Normalize Factor

Control Sample



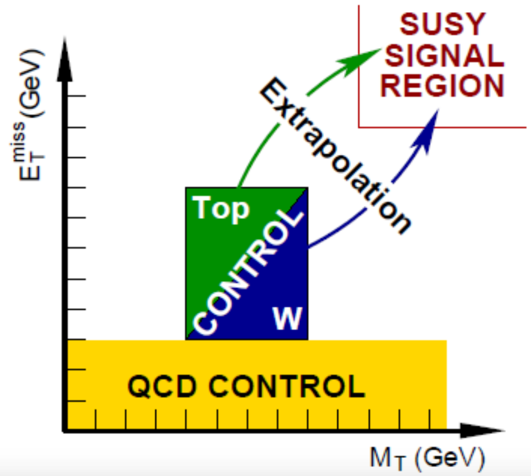
Key points:

- <u>The two variables</u> should have good discrepancy and uncorrelated
- <u>Control Sample selection:</u> enough statistics;lower susy contamination; unbiased estimation of SM background
- <u>Normalization region selection:</u> enough statistics;lower susy contamination; flat ratio(A/B) distribution with ETmiss

Background Estimation Strategy

ATLAS-CONF-2013-062

- **W/Z/ttbar background (dominant)**
- **Semi-data driven approach**
- **Normalize MC to Data in W/T-CR**
- **Extrapolate to SR using MC: assuming shape is described correctly**
- **Extrapolation done in simultaneous fit.**



$$N^{SR}_{pred_j} = (N^{CR_i}_{data} - N^{CR_i}_{other\ bkg}) \times \frac{N_{pred}(MC^j, SR)}{N_{pred}(MC^j, CR_i)}$$
$$= (N^{CR_i}_{data} - N^{CR_i}_{other\ bkg}) \times C^j_{CR_i \to SR}$$

- QCD background (small bg)
- Fullly-data driven approach
- Measure real and fake efficiencies in QCD-CRs
- Apply Matrix Method to get contribution in SR

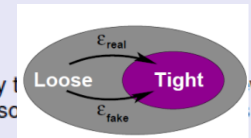
$$\text{QCD BG} = \frac{1}{1/\epsilon_{fake} - 1/\epsilon_{real}} \cdot N_{fail} - \frac{1/\epsilon_{real} - 1}{1/\epsilon_{fake} - 1/\epsilon_{real}} \cdot N_{pass}$$

N_{pass}: Events passing the signal selection cuts (*tight*)

N_{fail}: Events satisfying relaxed lepton isolation criteria but not passing the signal selection cuts (*loose-but-not-tight*)

ϵ_{real}: Probability t... vent passes also...

ϵ_{fake}: Probability that a loose QCD event passes also the tight selection cuts



Other small BGs (diboson, single top etc) are directly estimated from MC.

Gluino-Neutralino Signature

Impact of Systematic Uncertainties

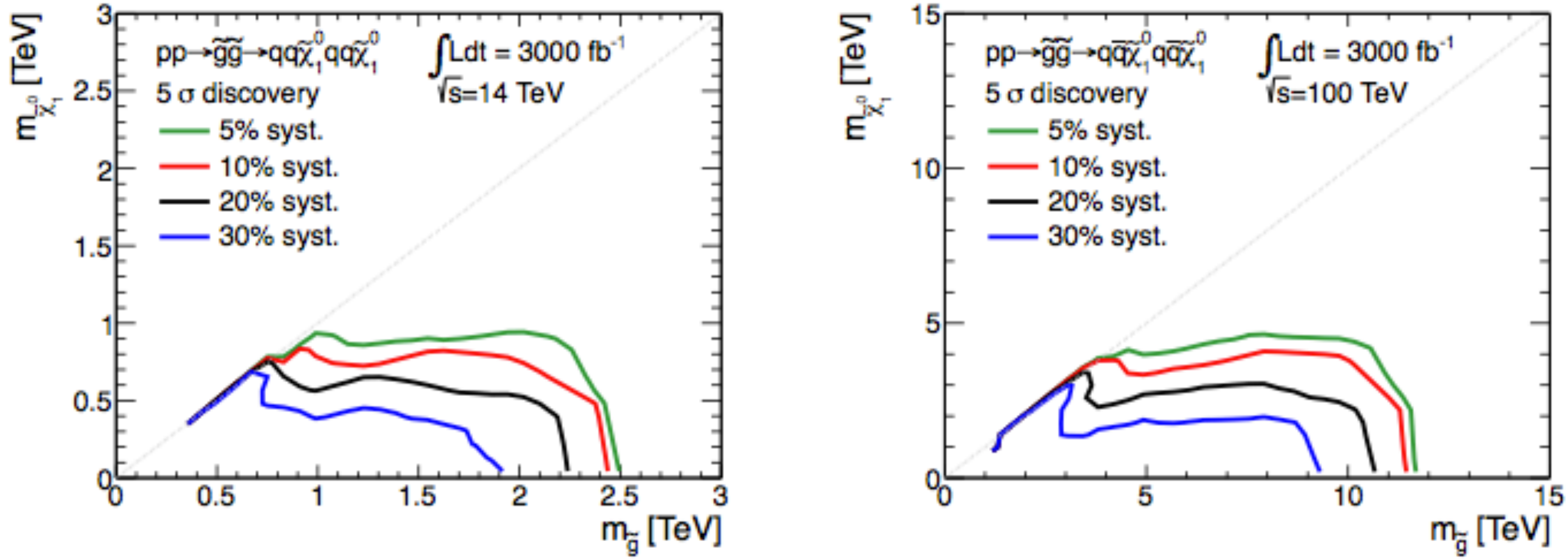


Figure 12: Expected 5σ discovery contours for the $\sqrt{s} = 14$ TeV LHC [left] and a 100 TeV proton collider [right] with 3000 fb^{-1}. The different curves correspond to various assumptions for the systematic uncertainty on the background: 5% [green], 10% [red], 20% [blue], and 30% [black].

- It is likely that the experiments will significantly reduce these uncertainties with larger datasets and an improved understanding of their detectors
- Varying the systematic background uncertainty from 30% to 5%, the discovery reach increases by roughly 600 GeV (3.4 TeV) in m(~g) at 14 TeV (100 TeV) and the coverage in LSP direction is roughly doubled

Impact of Pileup

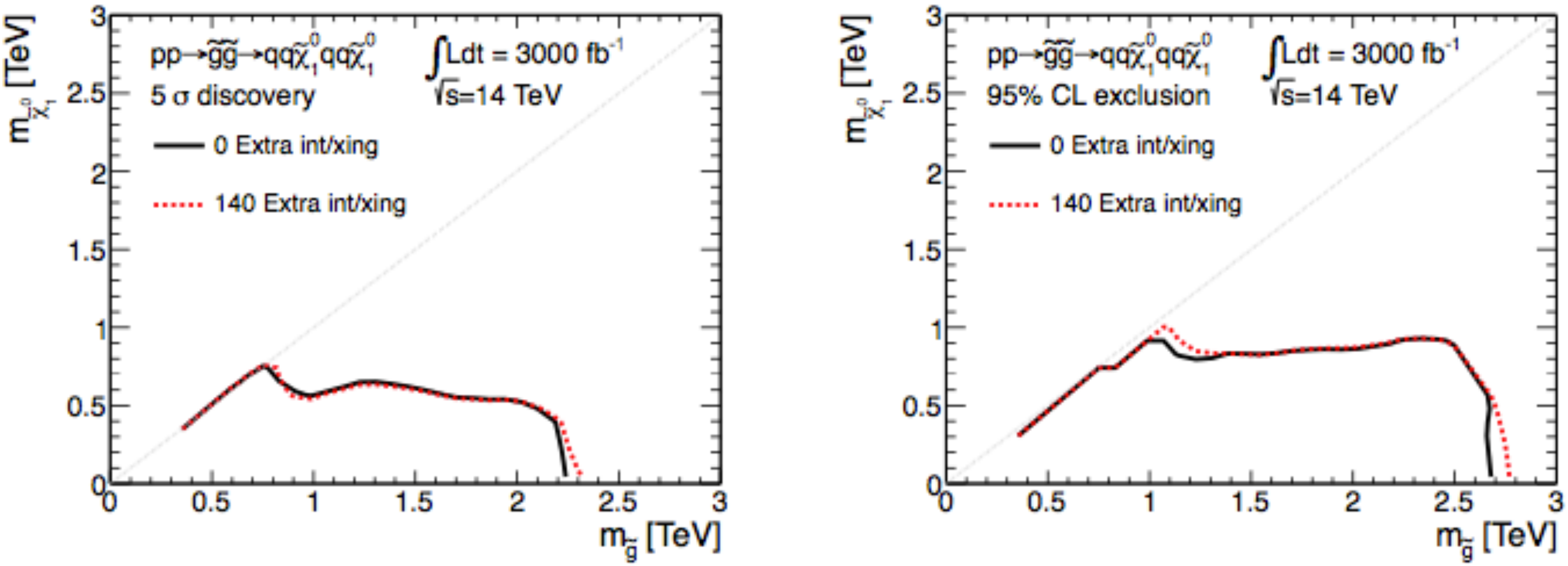


Figure 14: Discovery contours [right] and expected limits [left] for the analyses performed with [red, dotted] and without [black, solid] pileup at the 14 TeV LHC with 3000 fb^{-1} integrated luminosity.

- Compared the results with 140 additional minimum-bias interactions
- The Delphes based Snowmass simulation includes a pileup suppression algorithm that primarily impacts the Emiss resolution (Snowmass detector:ArXiv:1309.1057)
- Given that the HT and ETmiss distributions are effectively unchanged, it is not surprising that the results are very similar with and without pileup

Interpretation strategy

Based on the number of observed, expected events in all regions with all uncertainties: Probability density function (PDF)

Likelihood function: $L(\mu,\theta)$

μ: signal strength (POI);

θ: nuisance parameters(NP)

Profile Likelihood: constrain uncertainty (NP) as part of a likelihood fit

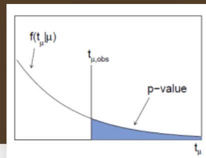
Construct test statistics t_μ based on likelihood ratio λ:

$$\tilde{\lambda}(\mu) = \begin{cases} \frac{L(\mu,\hat{\hat{\theta}}(\mu))}{L(\hat{\mu},\hat{\theta})} & \hat{\mu} \geq 0, \\ \frac{L(\mu,\hat{\hat{\theta}}(\mu))}{L(0,\hat{\hat{\theta}}(0))} & \hat{\mu} < 0 \end{cases}$$

$$t_\mu = -2\ln\lambda(\mu)$$

Find the observed test statistic for tested μ: $t_{\mu,obs}$

Construct the PDF of test statistic t_μ: generate toy Monte Carlo or using asymptotic formula



From the constructed distribution of test statistic for s+b, find the p-value of the observation

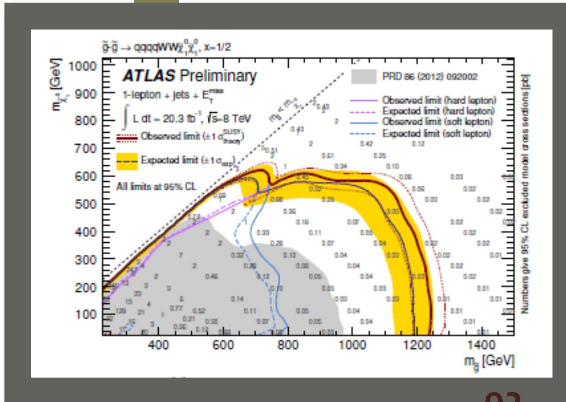
$$p_\mu = \int_{t_{\mu,\mathrm{obs}}}^{\infty} f(t_\mu|\mu)\, dt_\mu$$

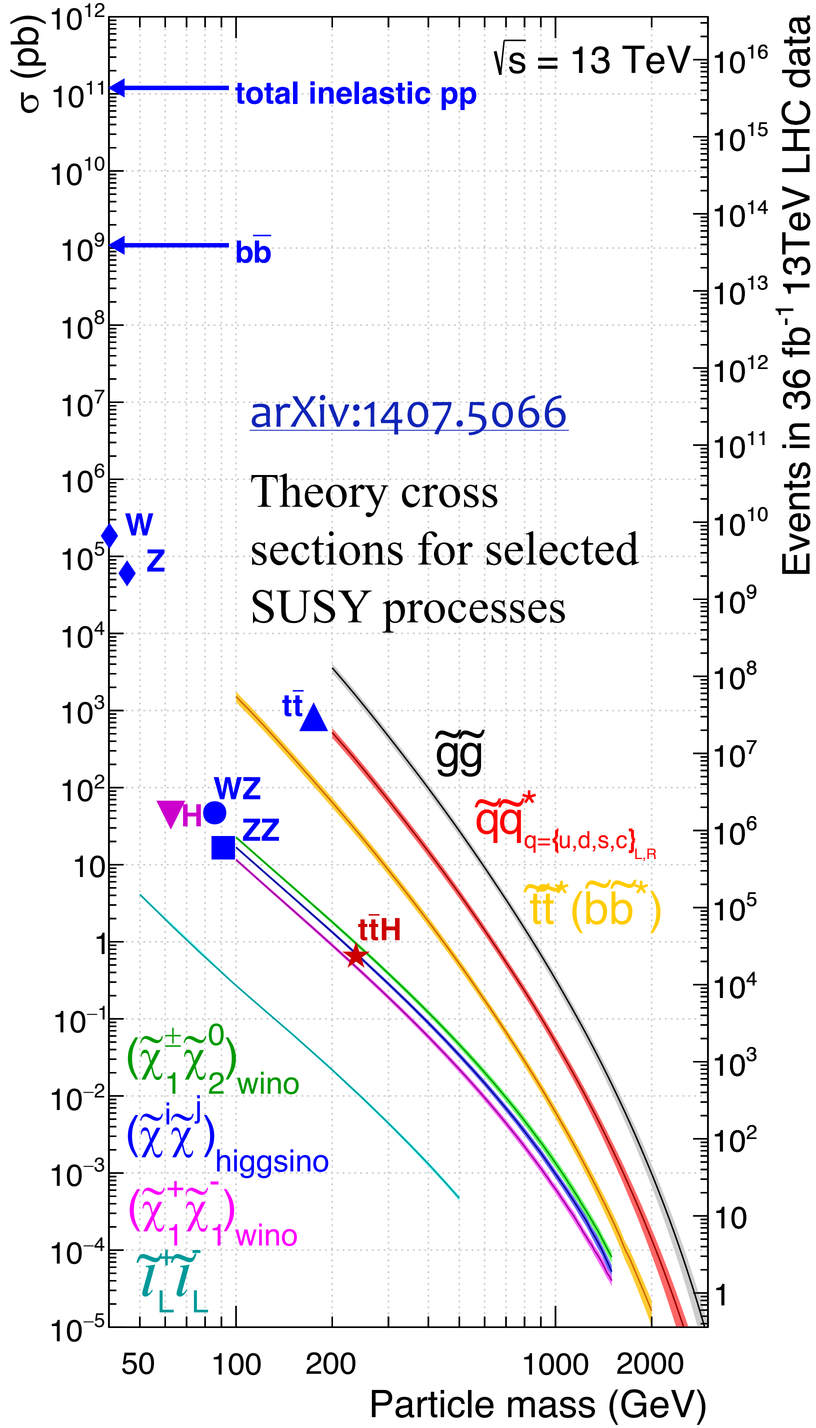
If CLs<0.05: the value of signal is excluded at 95% CL……….

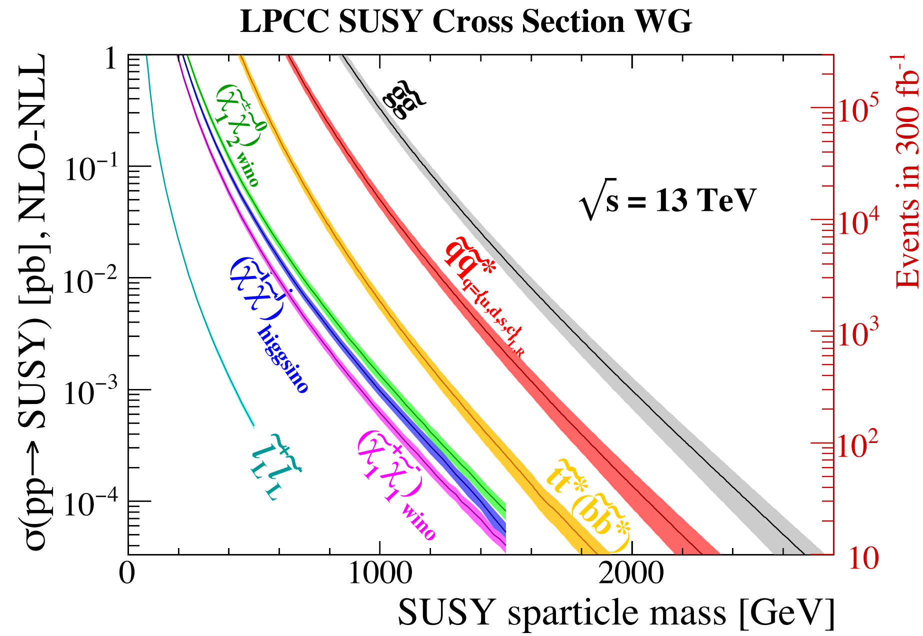
$$\mathrm{CL_s} = \frac{\mathrm{CL_{s+b}}}{\mathrm{CL_b}} = \frac{p_{s+b}}{1-p_b}$$

The above check has been done for each signal grid points on the SUSY model.

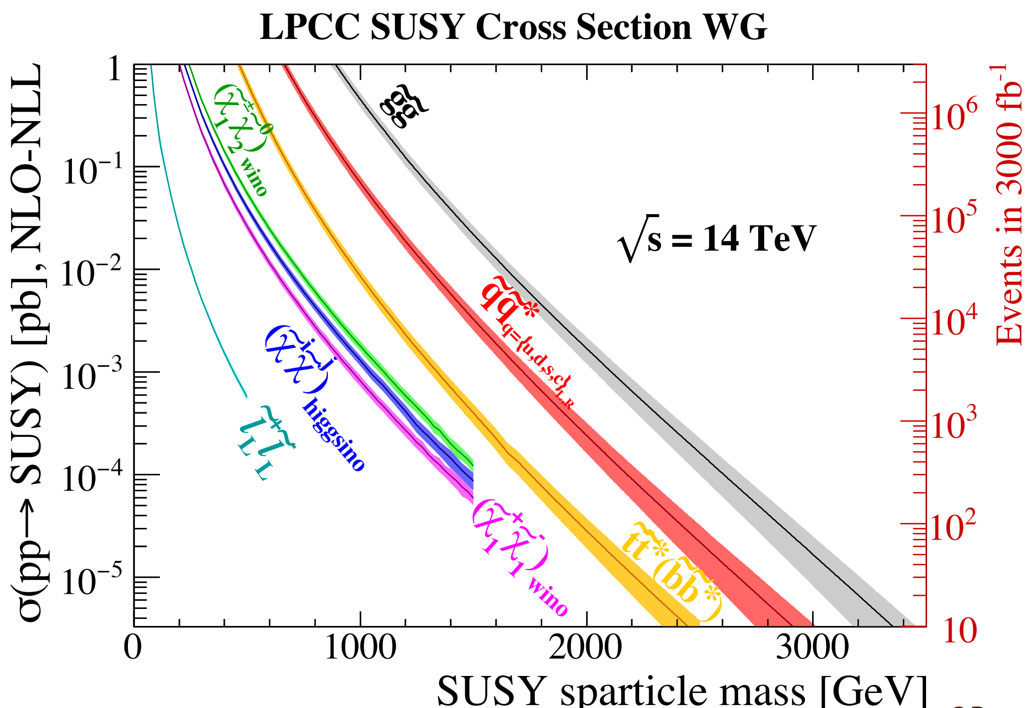
The line can be drawn for the area where points are excluded







https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1407.5066



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1407.5066