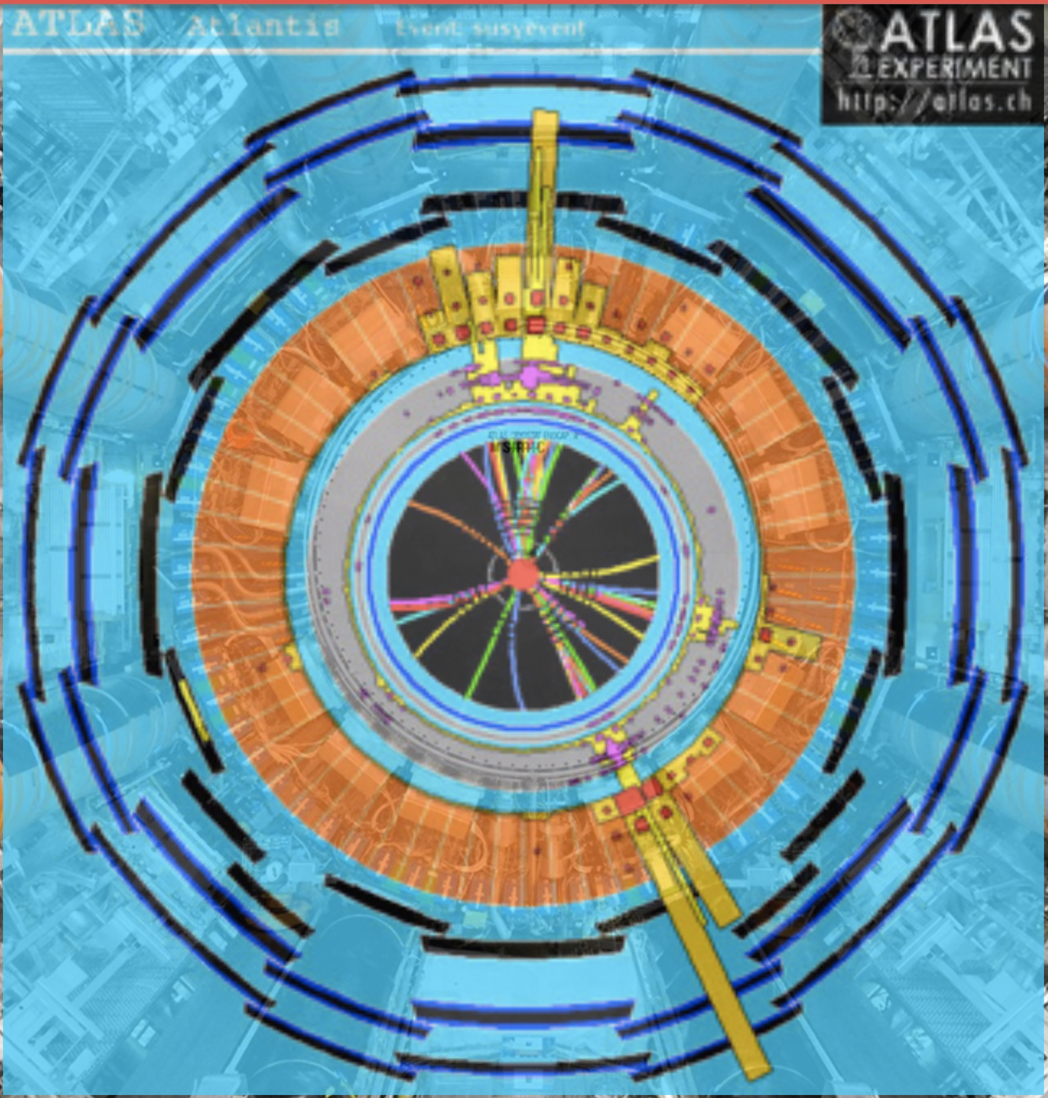
SUSY @ ATLAS



S.Asai（U-Tokyo)

Congratulation!!!!

Francois Englert Peter Higgs and Higgs Boson(s)

Contents

1) ATLAS detector for CMS physicists
2) Introduction; Overview of SUSY searches at ATLAS (Search-Strategy)
3) Some results at 8TeV (with mE_T type)

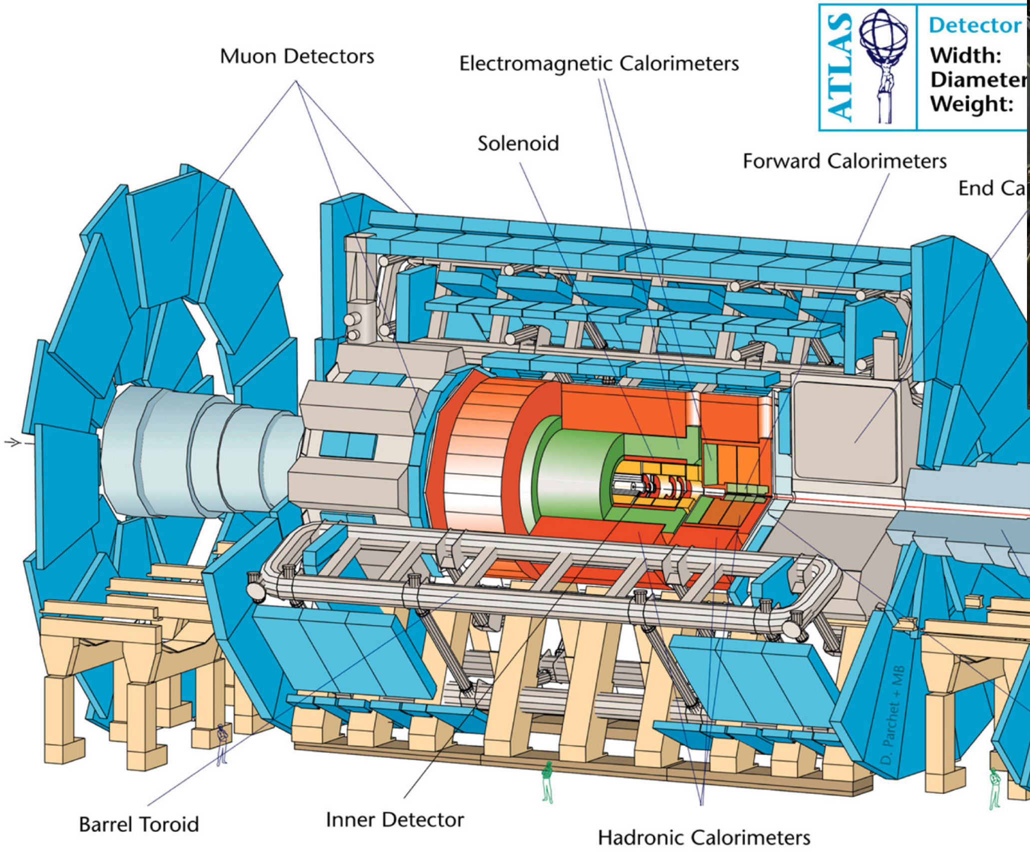
    A) No Lepton multijet mode
    B) One Lepton mode
    C) Interpretations in CMSSM
        & Discussion of possibilities why we can not see SUSY.
    D) Degenerate case
    E) EW gaugino production
    F) Naturalness SUSY (scalar top)

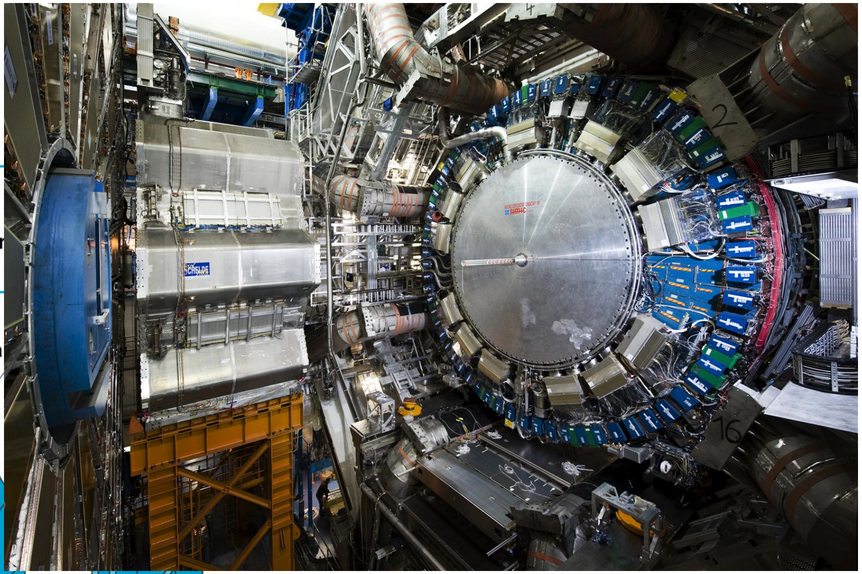
4) Exotic signal (without mE_T case)
    A) Introduction of experimental signature
    B) Results; Kink Track AMSB model

5) Summary and Perspective

It is not complete summary of ATLAS SUSY searches.
(Similar to CMS results)
I Focus on some hints of Next Step of SUSY hinting

1) ATLAS Detector





Resolution
(P_T=100GeV)
e, γ 1.5%
Muon 2-3%
Jets 8%

- Large Detectors since momentum resolution of tracking is $\delta P/P \sim 1/(BL^2)$
- **balance of performance** resolution are good but not specially good for all.
- Accordion Shape of L.Ar calorimeters are used. （**Longitudinal information** & Rad. hard）
- muon system is Large & air-core(less multiple scattering) & toroidal magnet (gain forward)

	ATLAS	CMS
Tracker	B=2T **Large Bore L-> $\delta \sim 1/BL^2$** Si + TRT continuous tracking (we have advantage exotic track)	B=4T Strong B Only Si (semiconductor)
EM cal.	**Accordion Type L.Ar+Lead** 10%/SQRT(E) Fine segment + Layer information	**$PbWO_4$ Scintillator** 3%/SQRT(E) **Excellent E resolution**. not fine segment
Hadron Cal	Thick Iron + scintillator 50%/SQRT(E) Good resolution for Jet	Thin brass + scintillator 100%/SQRT(E) shower escape PFA helps recover of resolution
muon	**Air core Toroidal Manet** multiple-scatter is suppressed low PT muon is detectable. complicated magnetic field	Return yoke of solenoid Strong Magnetic field Good resolution, multiple scattering
Trigger	3 layer Hard + Local Soft + Full Reconst	2 layer Hard + Full Reconst
Summary	Accordion-type L.Ar EM cal. Fine segment muon detec. with Toroidal Magnet B-phys. Exotic track	$PbWO_4$ EM scintillator has excellent energy resolution 4T Solenoid magnet Physics with e/gamma

Production Process at LHC

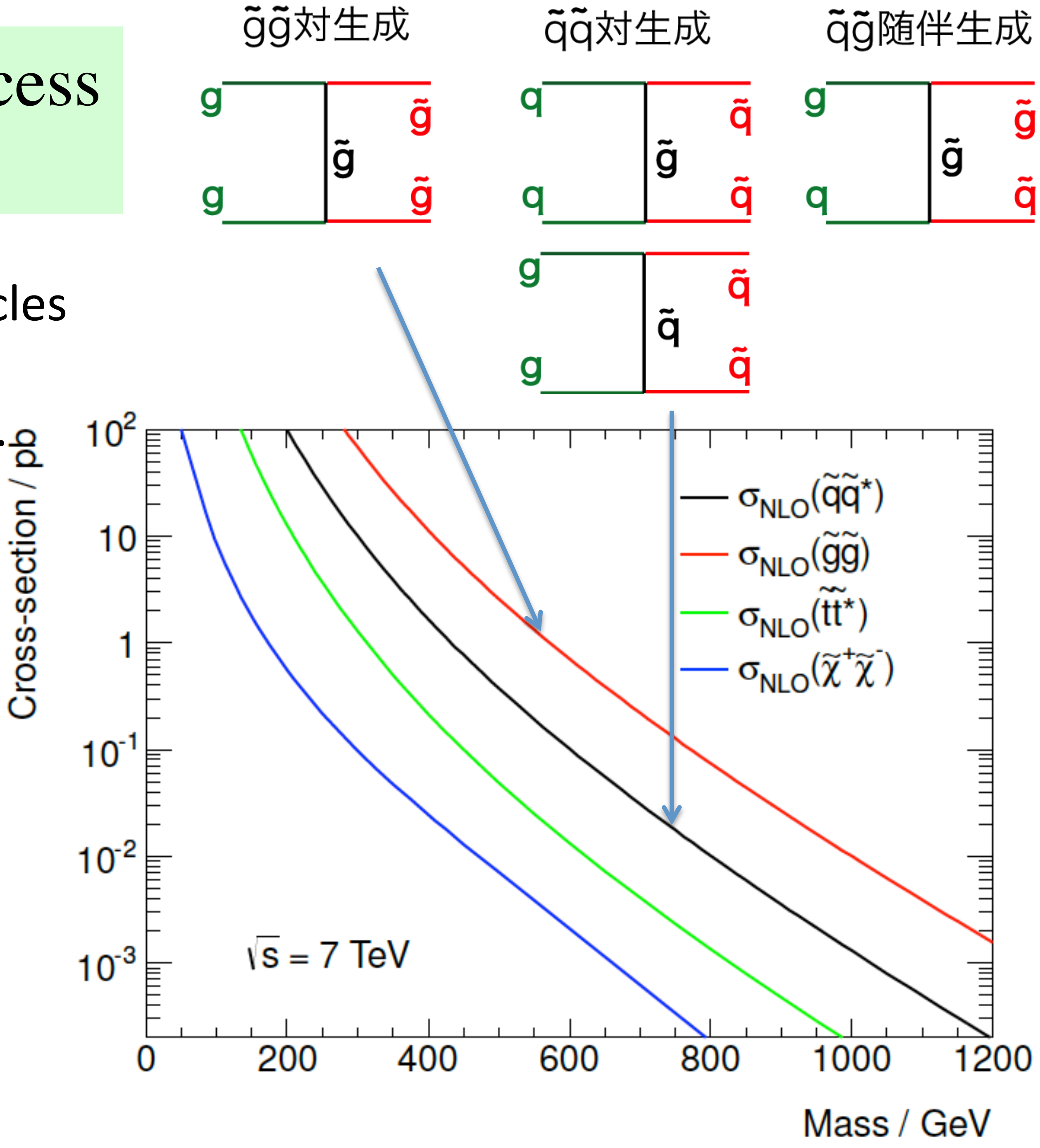
Colored susy particles are pair-produced at LHC dominantly.

Many gluon in Proton

Color factor 8

gluino production is leading.

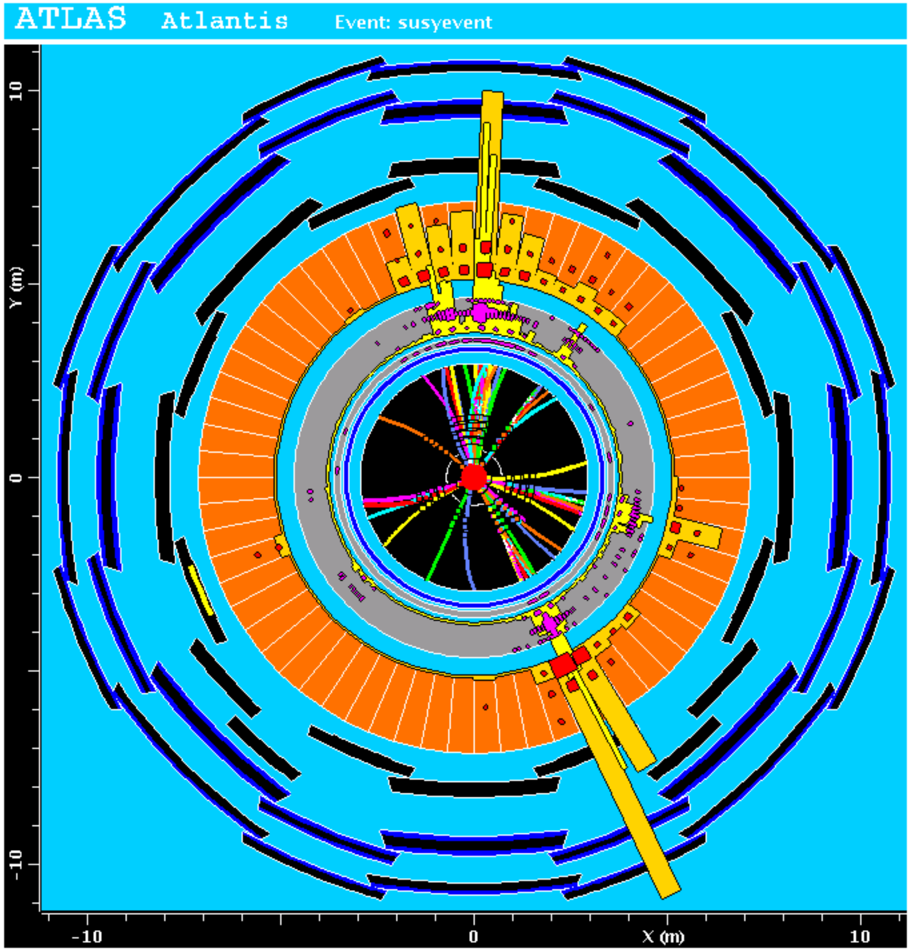
Typical cross-section is O(10) fb for 1TeV SUSY.



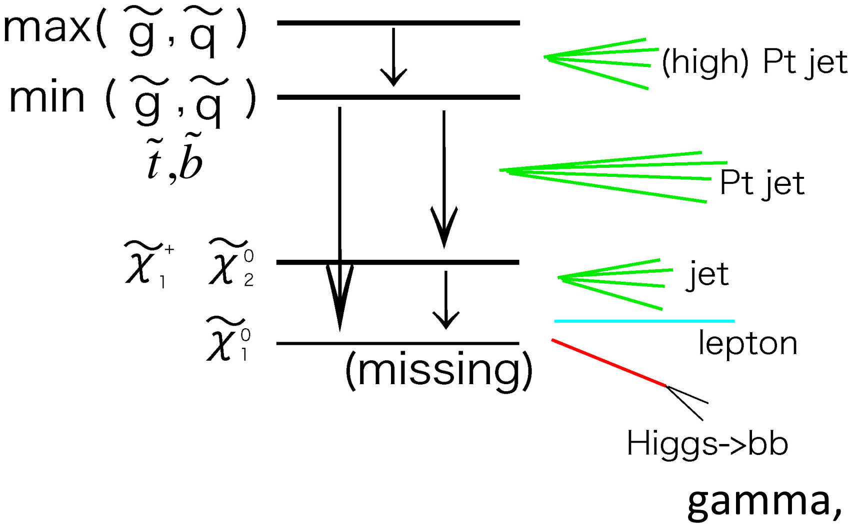
Event Topologies of SUSY Signal @ LHC

SUSY provides various interesting event topologies !!

“Typical” Events topology of SUSY signal is like this



Gluino/squark are produced first, then cascade decay is followed.



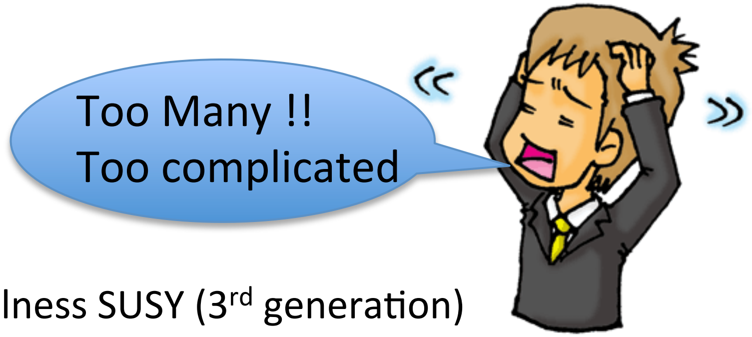
Event topologies of SUSY

multi leptons

$\not{E}_T$ + High P_T jets + b-jets

τ-jets

ATLAS SUSY Study List



Inclusive squark/gluino

0-lepton + 2-6 jets + MET
0-lepton + 7-10 jets + MET Sig.
1-2 leptons + jets + MET
2-lepton + jets + MET *
1-2 taus + jets + MET

Electroweak production

2-leptons + MET
3-leptons + MET
2 taus + MET
1-lepton + 2 b-jets + MET *

Photonic Topologies (GMSB)

photon + lepton + MET
photon + b-jet + MET
2-photons + MET
non-pointing photon
Z(ll) + jets + MET

Naturalness SUSY (3^{rd} generation)

gluino-mediated production

0-1 leptons + ≥3 b-jets + MET
2 SS leptons (+ b-jets) + MET
3-leptons + jets + MET
2 b-jets + 0-jets + MET

direct production

0-leptons + 6-jets (2 b-jets) + MET
1-lepton + 4-jets (2 b-jets) + MET
2-leptons (+ 2 b-jets) + MET
charm / mono-jet + MET
Z(ll) + 2 b-jets + MET

RPV and long lived particles

Disappearing track (AMSB)
Stopped gluino
Long lived slepton
Displaced vertex *
RPV gluino multijet (6,10 jets) *

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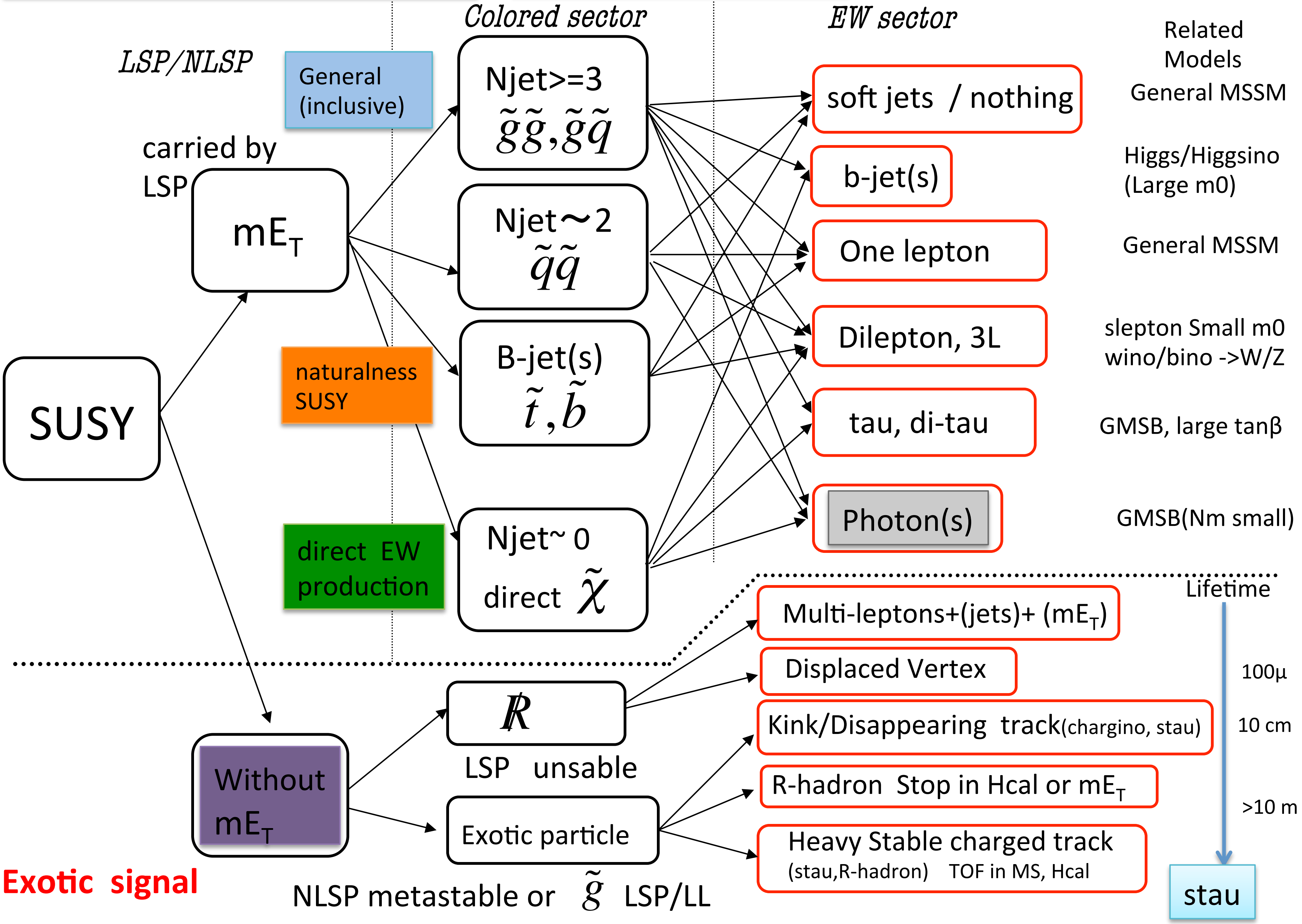
Event topology vs models

Standard mE_T signal



Colored sector

EW sector

LSP/NLSP

General (inclusive)

naturalness SUSY

direct EW production

SUSY

carried by LSP

mE_T

Njet>=3 $\tilde{g}\tilde{g},\tilde{g}\tilde{q}$

Njet∼2 $\tilde{q}\tilde{q}$

B-jet(s) $\tilde{t},\tilde{b}$

Njet~ 0 direct $\tilde{\chi}$

Related Models

soft jets / nothing	General MSSM
b-jet(s)	Higgs/Higgsino (Large m0)
One lepton	General MSSM
Dilepton, 3L	slepton Small m0 wino/bino ->W/Z
tau, di-tau	GMSB, large tanβ
Photon(s)	GMSB(Nm small)

Without mE_T

$\not{R}$

LSP unsable

Exotic particle

NLSP metastable or $\tilde{g}$ LSP/LL

Multi-leptons+(jets)+ (mE_T)

Displaced Vertex

Kink/Disappearing track(chargino, stau)

R-hadron Stop in Hcal or mE_T

Heavy Stable charged track (stau,R-hadron) TOF in MS, Hcal

Lifetime

100µ

10 cm

>10 m

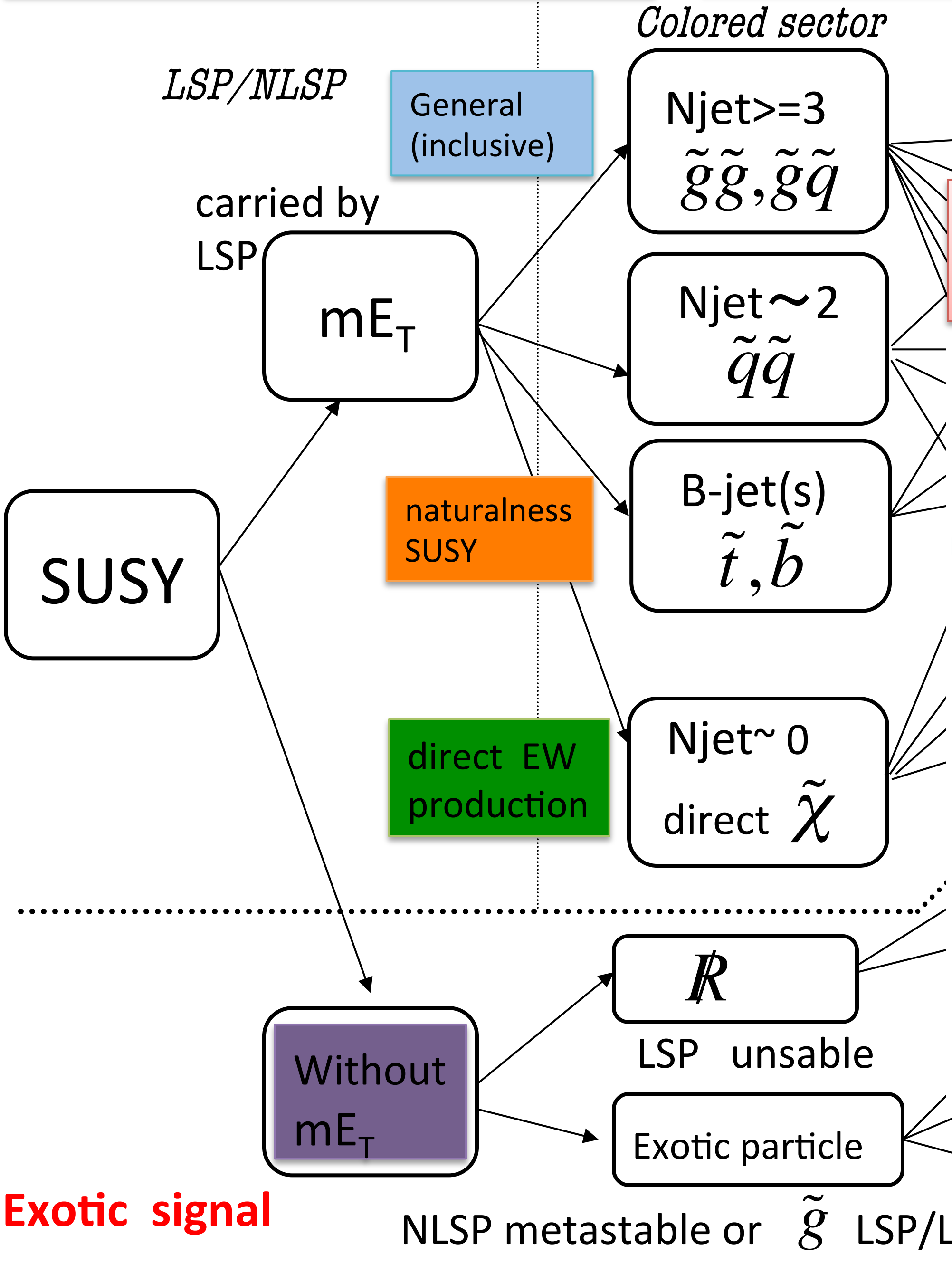
stau

Exotic signal

5 colors show the previous page

Event topology vs models

Standard mE_T signal



Colored sector

EW sector

Related Models

LSP/NLSP

General (inclusive)

carried by LSP

mE_T

SUSY

Njet>=3 $\tilde{g}\tilde{g},\tilde{g}\tilde{q}$

Njet~2 $\tilde{q}\tilde{q}$

B-jet(s) $\tilde{t},\tilde{b}$

naturalness SUSY

direct EW production

Njet~ 0 direct $\tilde{\chi}$

soft jets / nothing

General MSSM

no

One lepton

General MSSM

m0

N/Z

anβ

mall)

....

ne

100μ

.0 cm

>10 m

Still complicated?

Without mE_T

$\not{R}$

LSP unsable

Exotic particle

Heavy Stable charged track (stau,R-hadron) TOF in MS, Hcal

stau

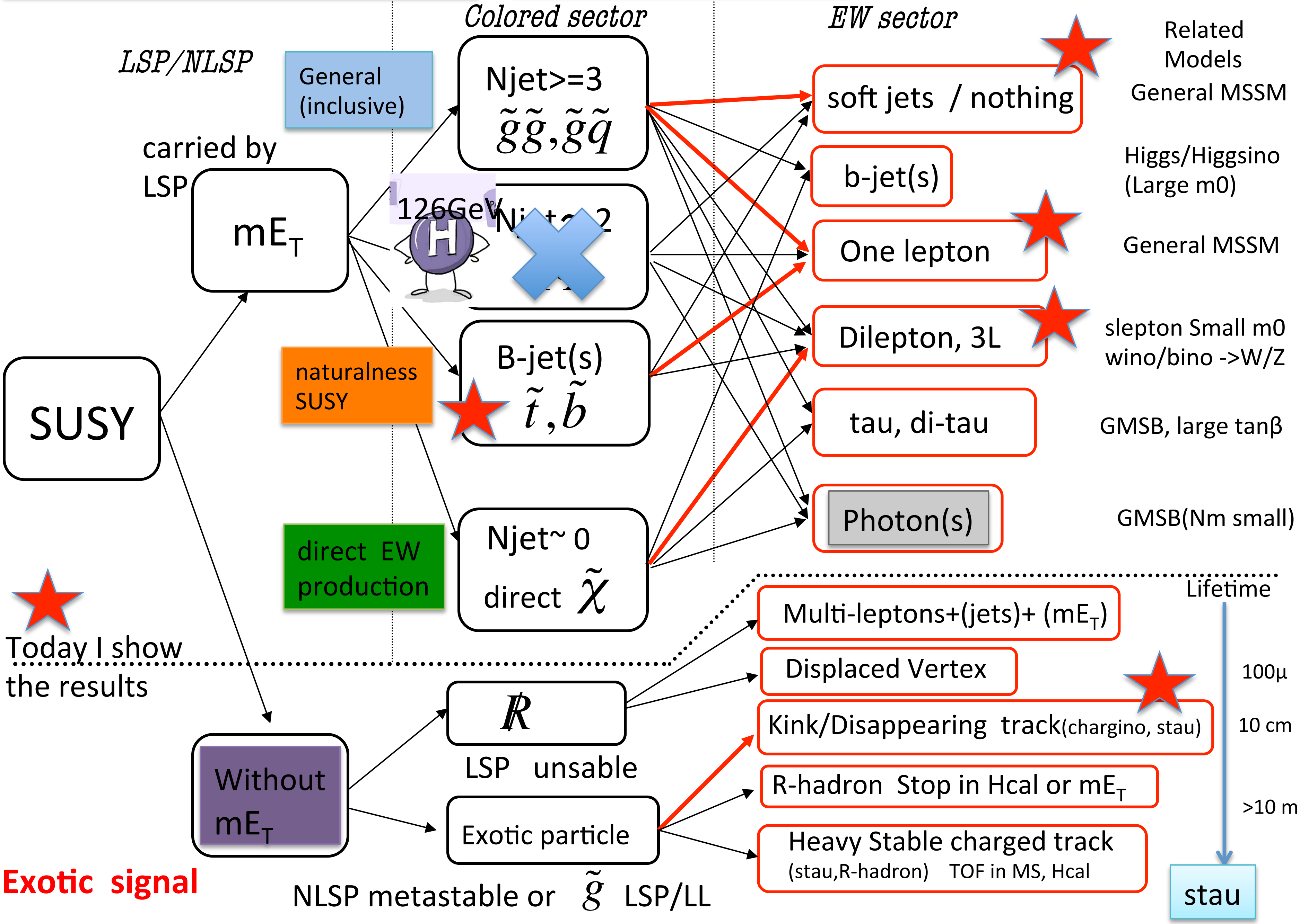
Exotic signal

NLSP metastable or $\tilde{g}$ LSP/LL

5 colors show the previous page

Event topology vs models

Standard mE_T signal



LSP/NLSP

Colored sector

EW sector

Related Models

SUSY

carried by LSP

mE_T

General (inclusive)

naturalness SUSY

direct EW production

Njet>=3
$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}$

126GeV

Njet~2

B-jet(s)
$\tilde{t}, \tilde{b}$

Njet~ 0
direct $\tilde{\chi}$

EW sector	Related Models
soft jets / nothing	General MSSM
b-jet(s)	Higgs/Higgsino (Large m0)
One lepton	General MSSM
Dilepton, 3L	slepton Small m0 wino/bino ->W/Z
tau, di-tau	GMSB, large tanβ
Photon(s)	GMSB(Nm small)

Today I show the results

Without mE_T

$\not{R}$
LSP unsable

Exotic particle

NLSP metastable or $\tilde{g}$ LSP/LL

Multi-leptons+(jets)+ (mE_T)

Displaced Vertex

Kink/Disappearing track(chargino, stau)

R-hadron Stop in Hcal or mE_T

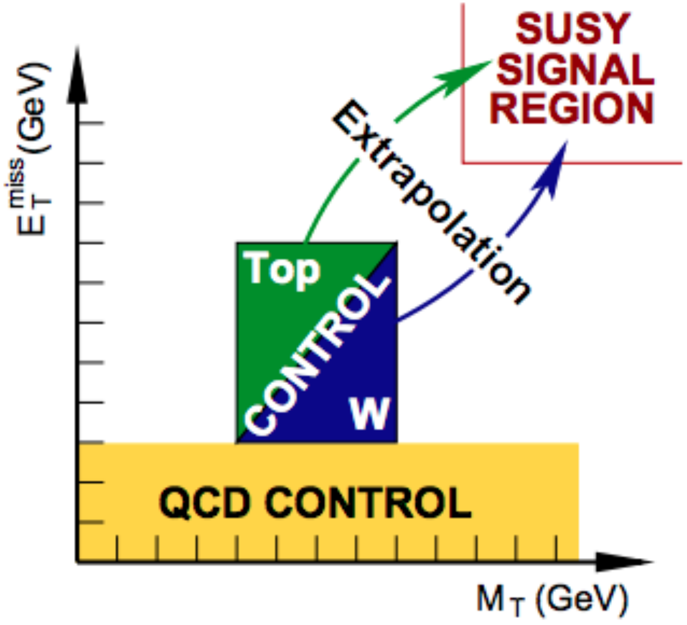
Heavy Stable charged track
(stau,R-hadron) TOF in MS, Hcal

Lifetime
100μ
10 cm
>10 m
stau

Exotic signal

Background Processes and How to estimate?

BG estimation is crucial for SUSY hunting,
because no peak is expected.
It is just discrepancy of distribution;
especially for mET distribution
but mET is also produced by vs
Main BG processes are **W+jets, Z+jets, top pair production.**



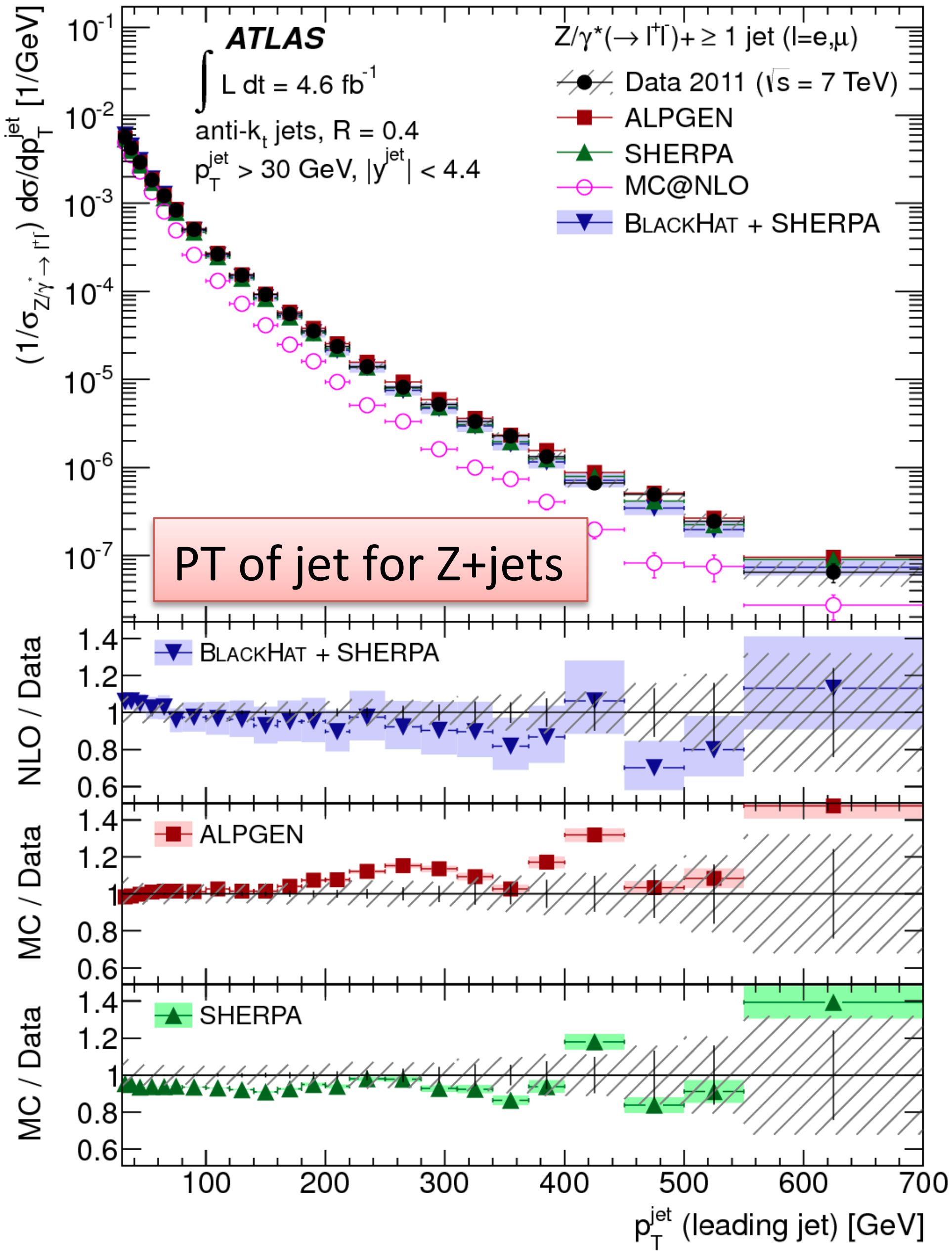
Basic Idea to estimate BG is as follows;

Control regions are defined to enhance the SM BG processes and check the various distributions.

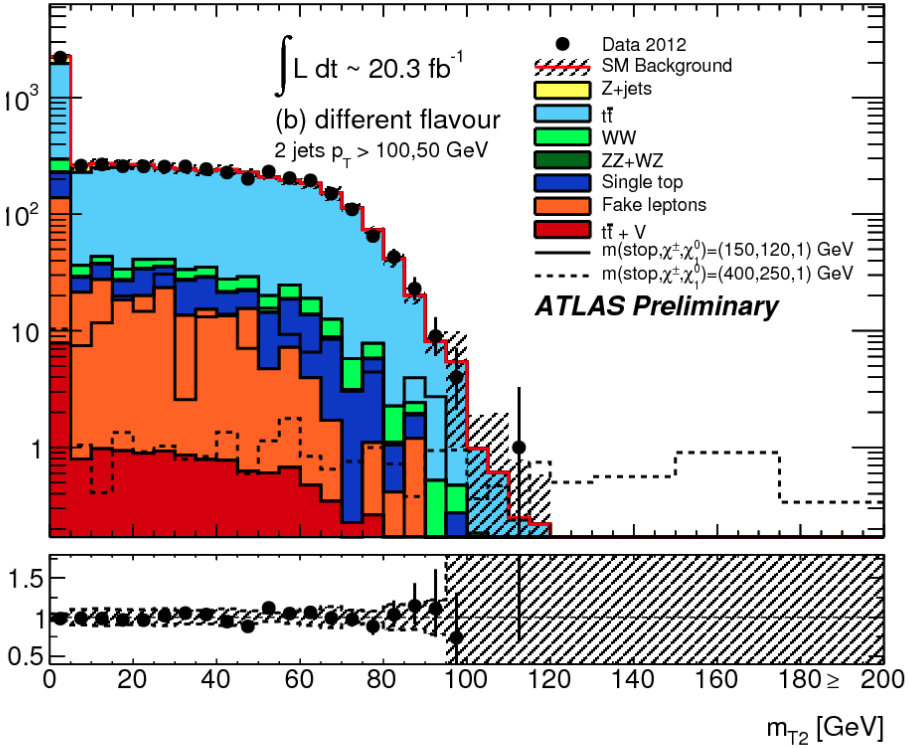
Distributions in CR are extrapolated (with MC) to signal region

Reducible BG (QCD & fake ID) are estimated with data.

We well understand background distributions



PT of jet for Z+jets

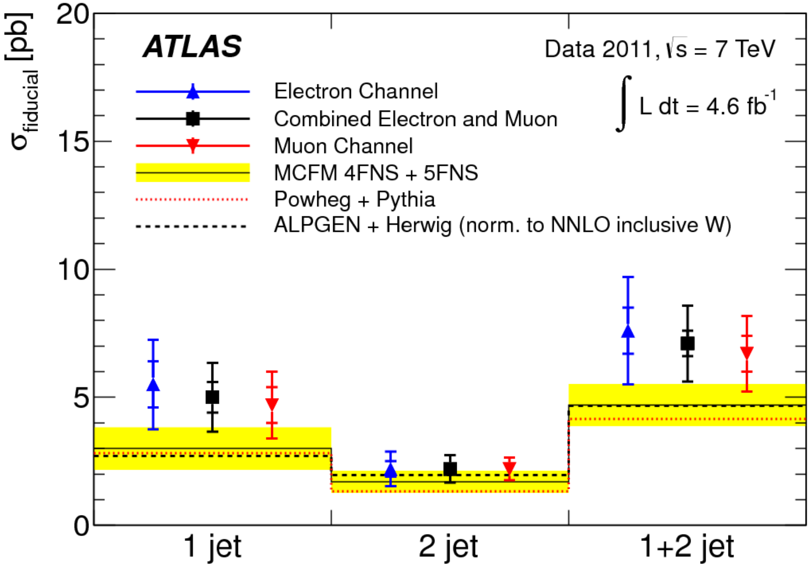


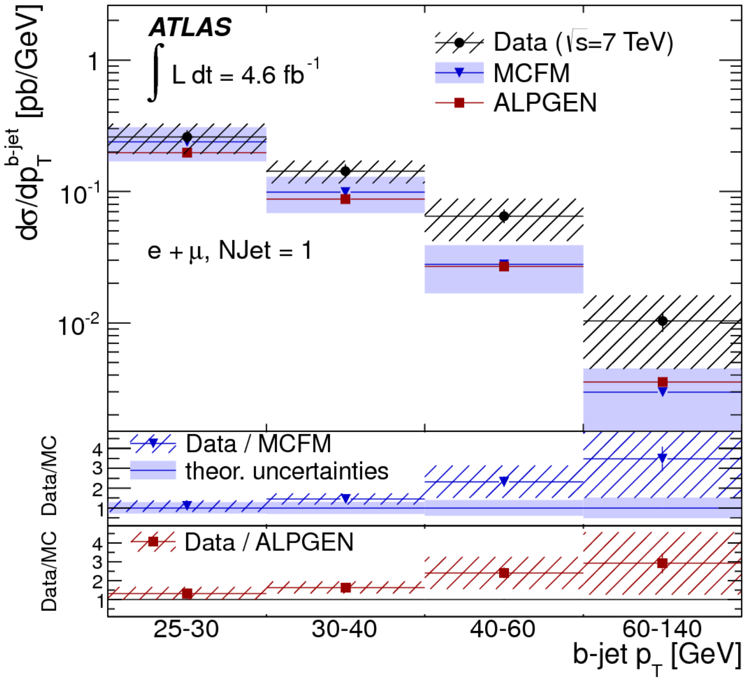
$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\mathrm{miss}} - \mathbf{q}_T)\right)\right]$$

M_T distribution can be used
for W → lepton + neutrino
If two neutrino exists
we use MT 2,
Observed mET is divided into two ν
leptonic decay of top pair is well understood

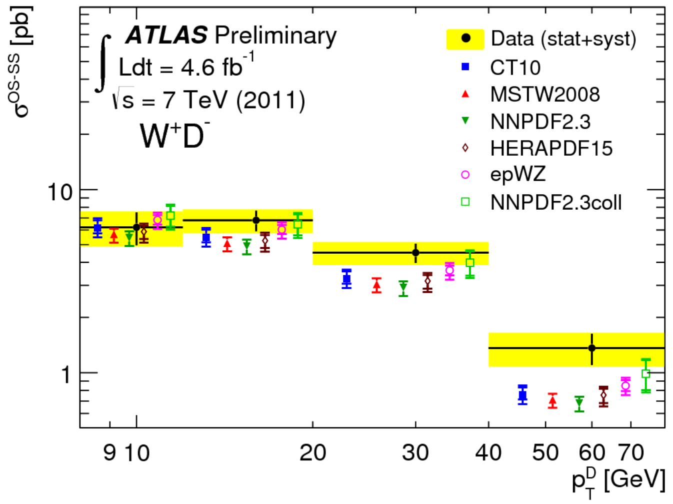
V+b-jet（s） request from Zeyrek-san

8TeV results are still discussing.
Only 7TeV results are public.





(small) Excess is found in "one" b-jets and discrepancy of ratio becomes larger for high PT.
I have discussed with M.Michelangelo more than 10 years ago.
PDF for heavy quark is difficult then factorize betwee ME and PS are difficult to overlap.



[A] No Lepton (multijets) mode

At least 3（high PT > 130,60,60 GeV) Jets
& Large mET(>550 GeV)

At least 5（high PT >
mET(>320Ge

most general inclusive search

ATLAS approach is based on 3 kinematics variables are key

1) Number of Jets

Less Jet multiplicity squark is enhanced, W+jets and Z+jets are main BG
Tight kinematics selections should be required to reduce these BG processes.

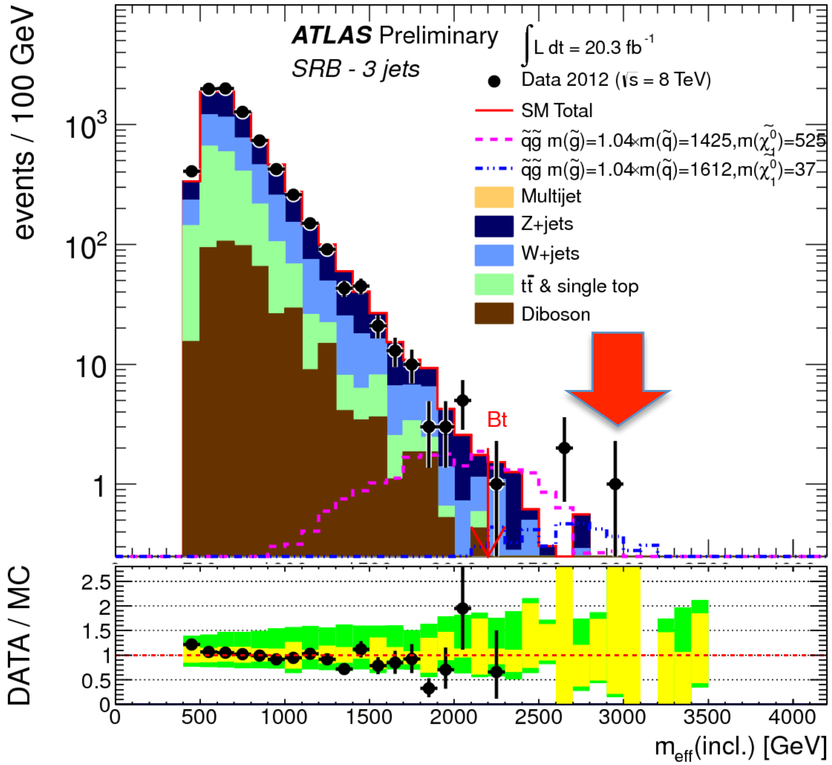
High Jet multiplicity gluino process is enhanced, Higgsino-like gaugino processes are also enhanced. top is the main BG
Relatively loose kinematic selections are possible, since BG is suppressed by jet multiplicity

2) mE_T

3) Not only mET, but also Scalar sum of Jet activity(**H_T**) is useful, since many jet activity is expected for SUSY signal.
H_T is used in CMS (CMS mE_T and H_T are used separately) and
Meff= mET+ ΣP_T (jet) is used in ATLAS.

[A] No Lepton (multijets) mode

At least 3 (high $P_T > 130,60,60$ GeV) Jets
& Large mE_T(>550 GeV)



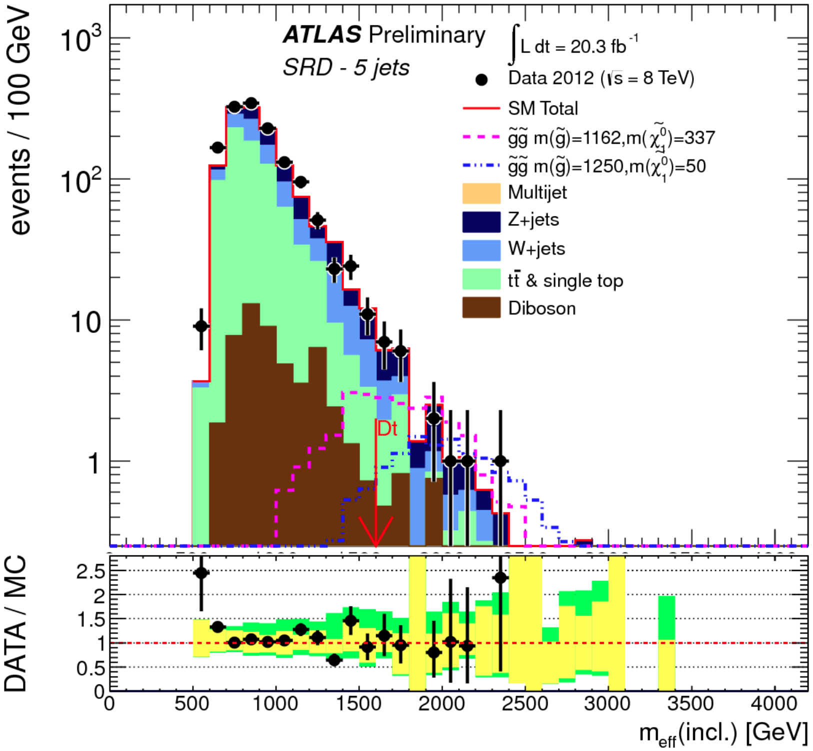
Meff >2200GeV (mET/Meff>0.4)

Data 4 events are observed

BG 2.4 +- 1.4 (**Z 0.2 W 1.6** tt 0.6)

1 candidate in high Meff region

At least 5 (high $P_T > 130,60,60,60,60$GeV)
mE_T(>320GeV)



Meff >1600GeV (mET/Meff>0.2)

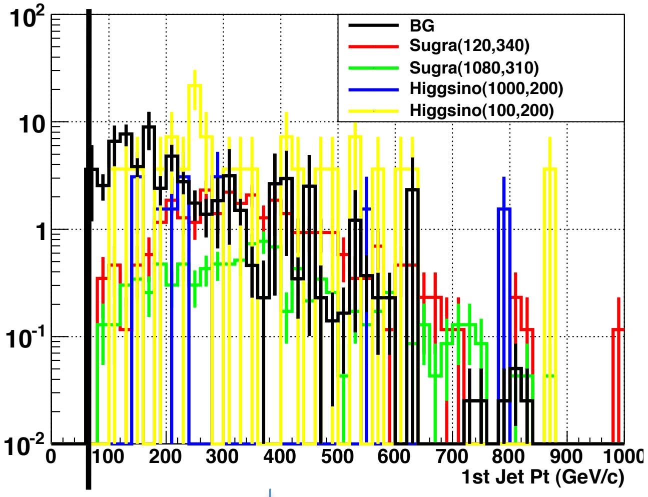
Data 18 events are observed

BG 15 +- 15 (Z 3.8 W 3.3 **tt 5.8**)

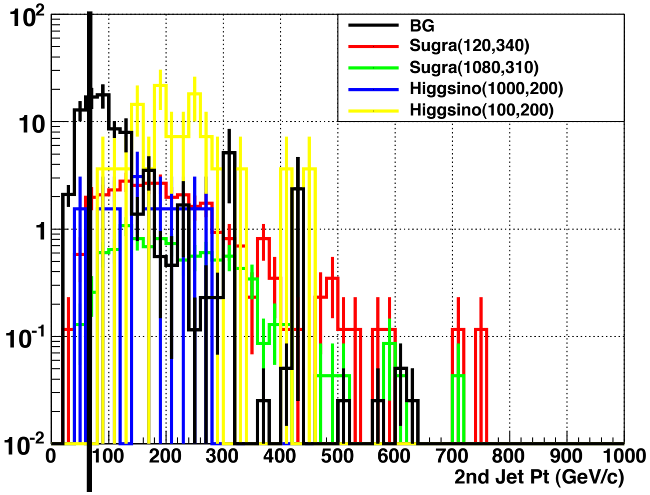
Both Data distributions agree well with SM BG

Jet P_T of W/Z+jets process comparing with signal

< 1st Jet Pt >

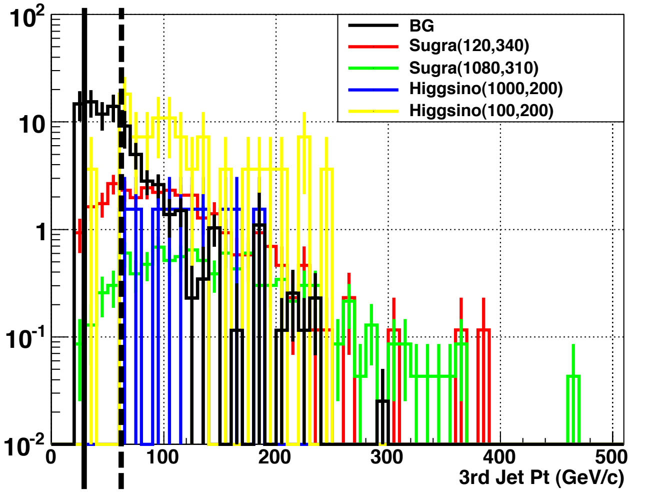


< 2nd Jet Pt >

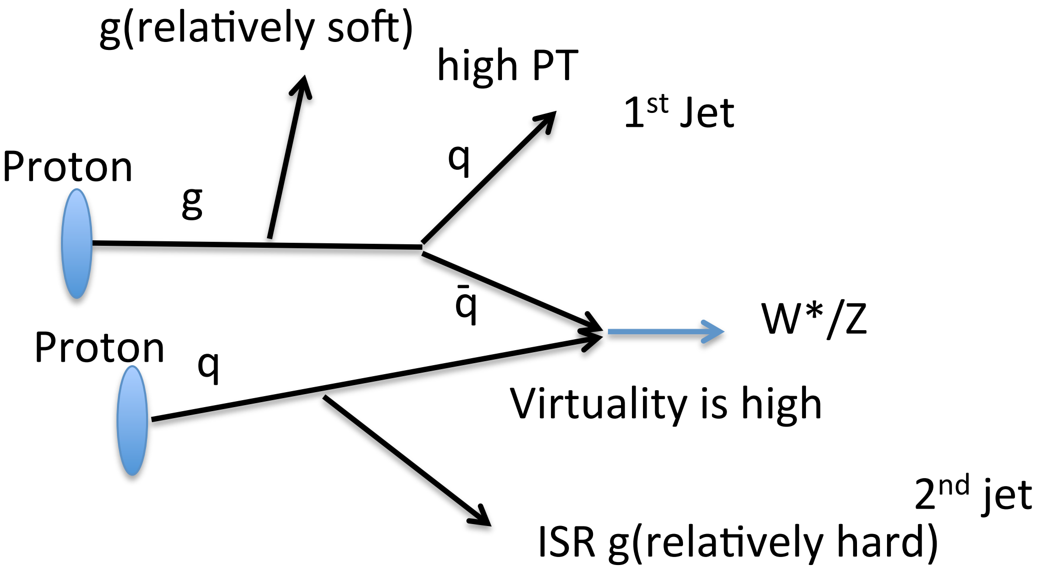


2nd is still hard

< 3rd Jet Pt >



3rd becomes softer



g(relatively soft)

high PT

1st Jet

Proton

g

q

$\bar{q}$

W*/Z

Proton

q

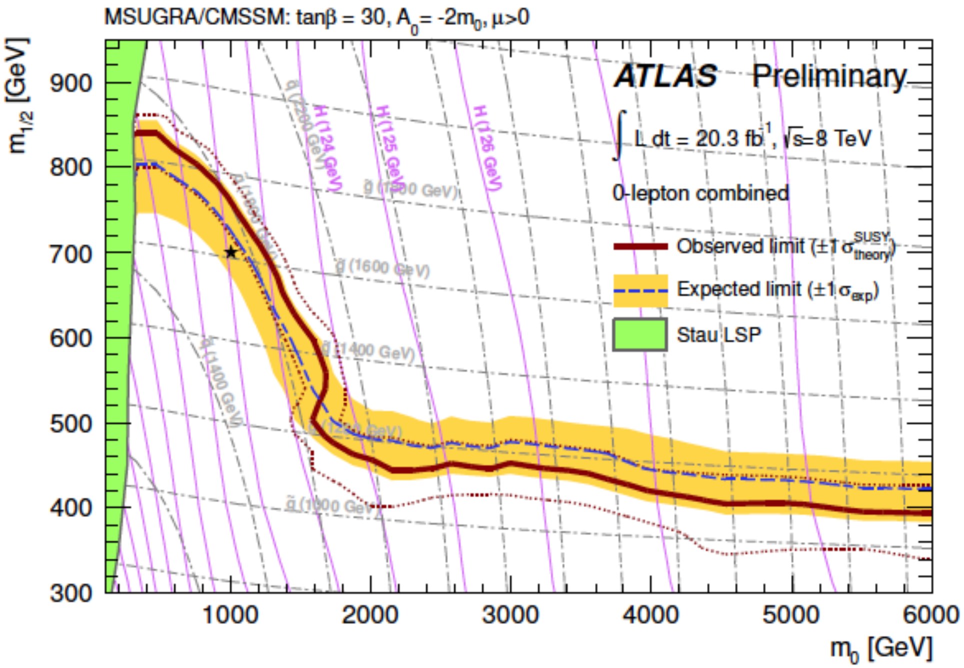
Virtuality is high

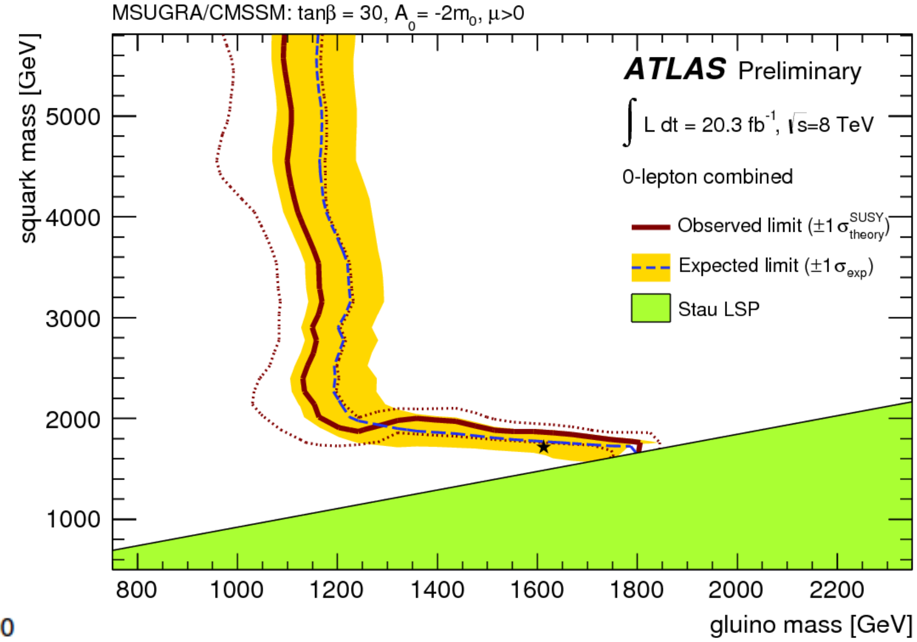
2nd jet

ISR g(relatively hard)

No excess in No lepton mode

Limit within CMSSM model





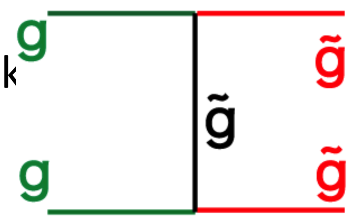
gluino,squark ~ 1.8TeV
gluino ~1.1TeV for Heavy squark

tanβ=30 A0=2m0 can give 126GeV Higgs boson

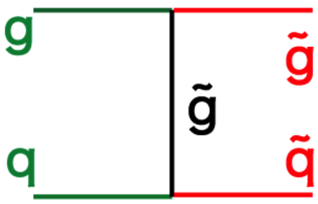
Large m0(heavy squark); only gg->gluino gluino possible at LHC. Since PDF of gluon has steep distribution, heavy gluino σ is seriously suppressed.

Small m0 squark production is possible, valence quark can contribute, and production σ is high for heavy (large x):

g̃g̃対生成



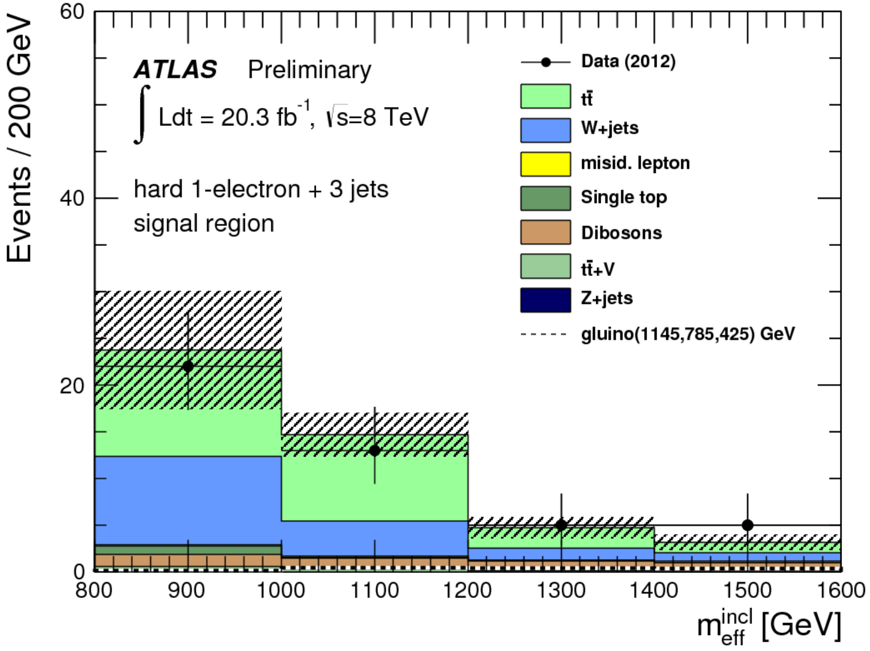
q̃g̃随伴生成



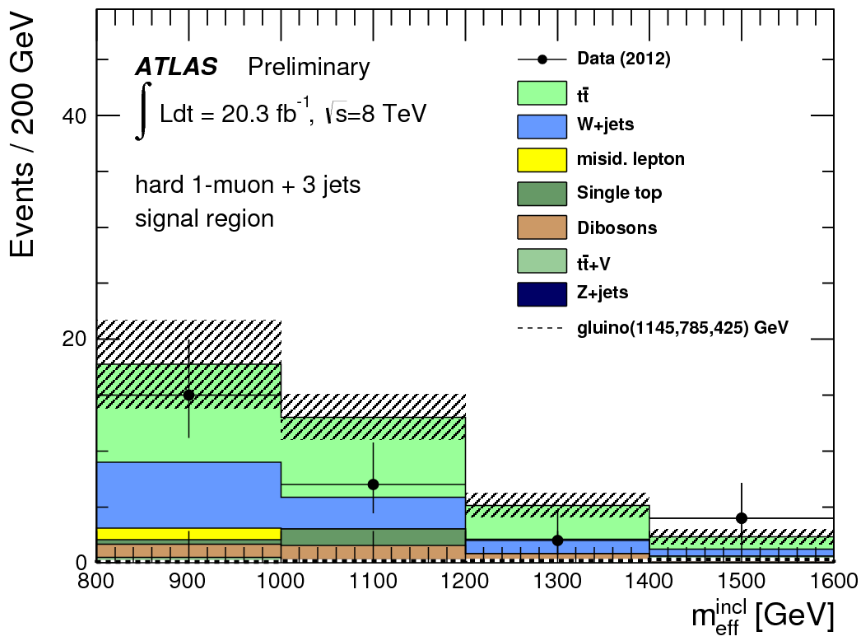
[B] One lepton + mltijets Mode

Electron (PT>25GeV) or muon (PT>25GeV) is required for trigger/ BG suppression
At least 3jets(PT>80,80,30) MET>500GeV MT>150GeV Meff>1400GeV (19 SR are optimized

electron



muon

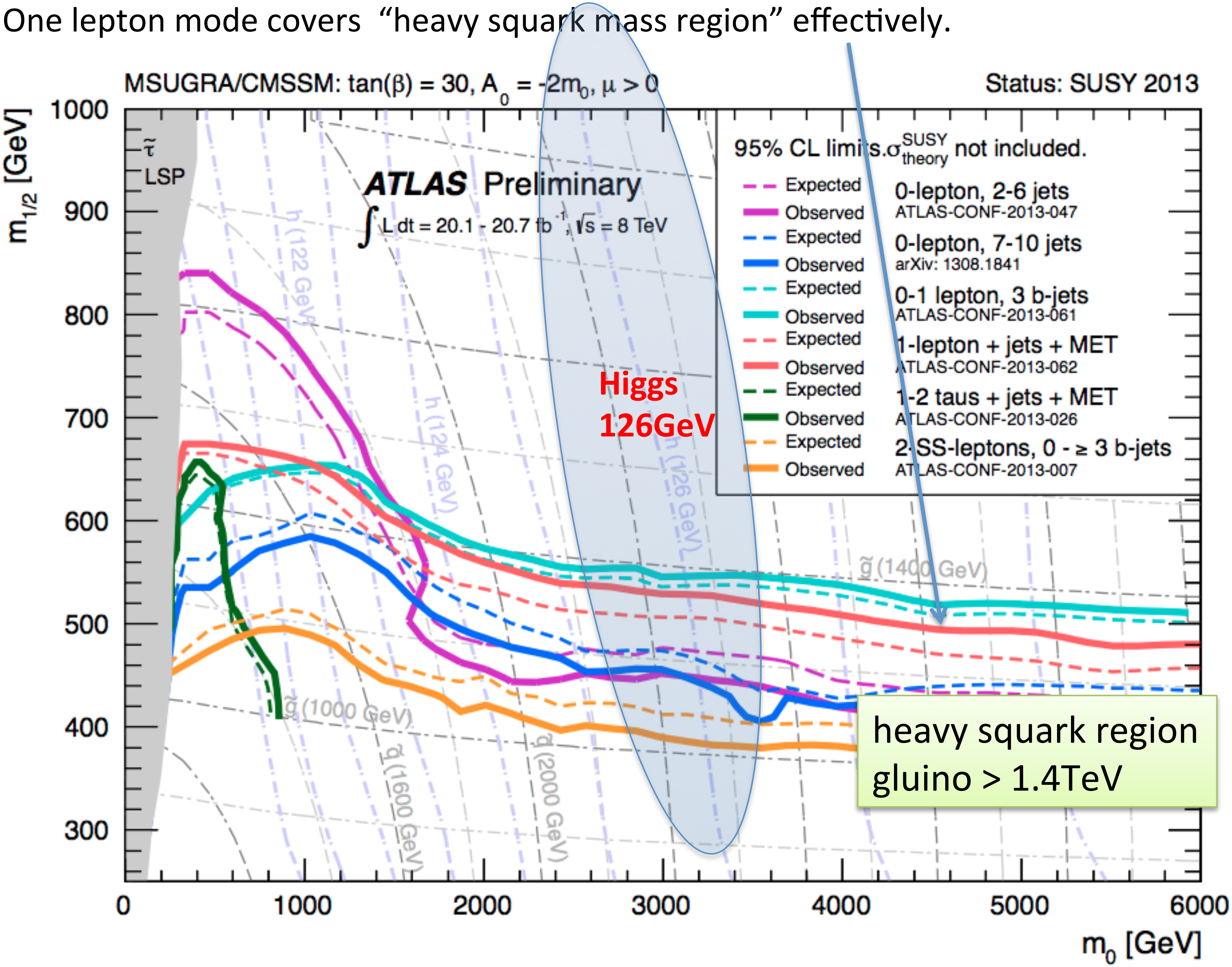


Meff= mET+ Σ P_T (jet) +P_T(lepton)

tt is dominant background processes; both top decay leptonically, and one lepton is not ID (low P_T, not isolated, tau hadronic decay)
One lepton mode is the different topology and different BG processes from no lepton mode

No excess was found in data @ 8TeV

Similar sensitivity for no-lepton and one-lepton modes in many standard SUSY models
One lepton mode covers "heavy squark mass region" effectively.

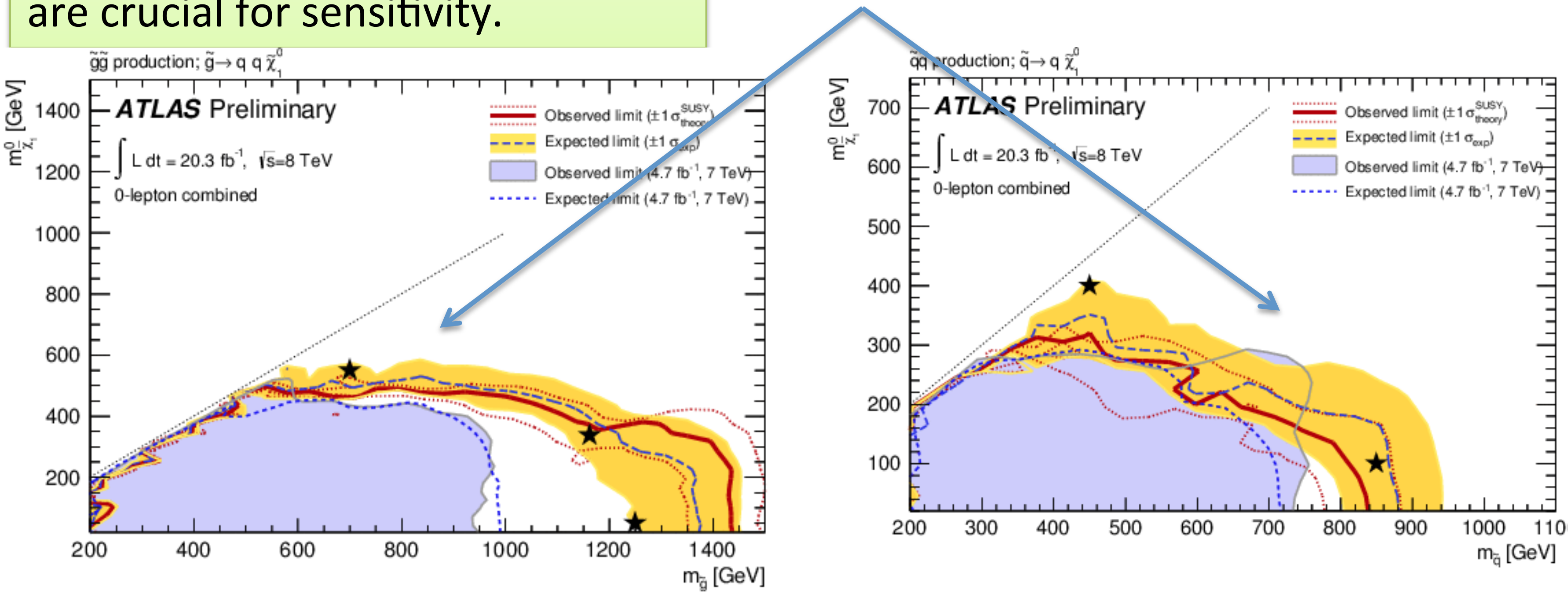


heavy squark region
gluino > 1.4TeV

C) Inclusive results does not depend strongly on SUSY models

Production processes are just strong interaction. σ depends on gluino, squark masses (colored). Not depends on detail of SUSY models. Colored sparticle masses are crucial for sensitivity.

The mass difference between LSP and the produced colored mass(ΔM) is crucial.
ΔM < 500GeV → No sensitivity
No trigger, high background …



There are 4 possibilities why "No SUSY found @ 8TeV LHC"!!!
(1) degenerate spectrum (2) colored sparticles are heavy/ even the EW is still light
(3) No mET (4) NoSUSY (@ TeV scale)

C) Inclusive results does not depend strongly on SUSY models

Production processes are just strong interaction. σ depends on gluino, squark masses (colored). Not depends on detail of SUSY models. Colored sparticle masses are crucial for sensitivity.

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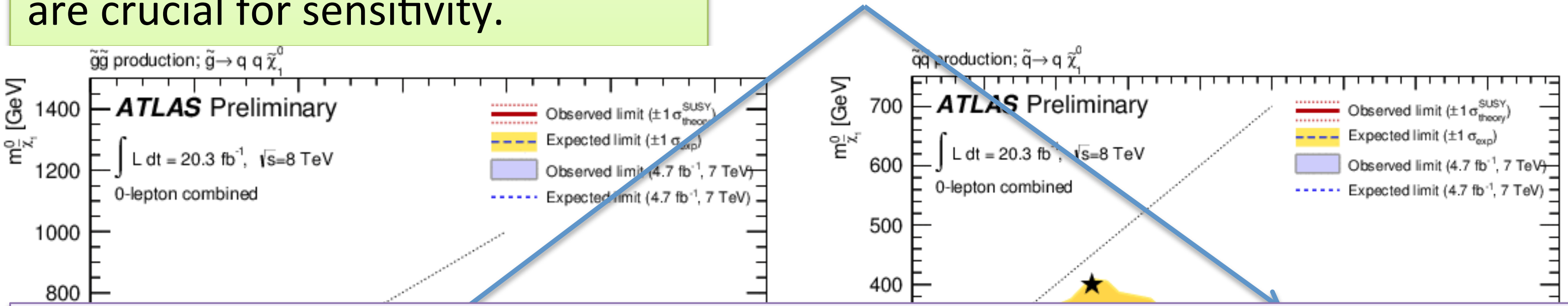


There are 4 possibilities why "No SUSY found @ 8TeV LHC"!!! **Let's examine these 3 possibilities**

(1) degenerate spectrum (2) colored sparticles are heavy/ even the EW is still light (3) No mET

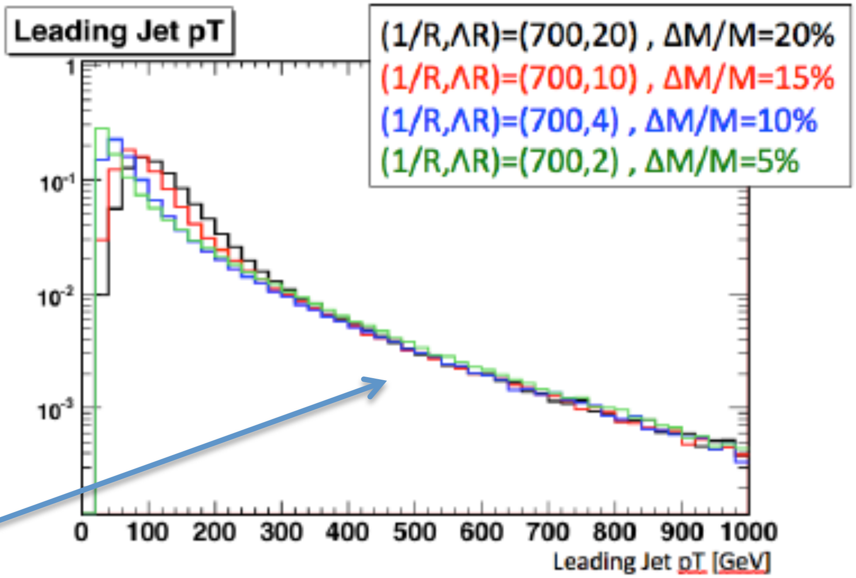
~~(4) NoSUSY (@ TeV scale)~~ ← **defeatism**

(D) Degenerate spectrum (UED,Mirage SUSY)

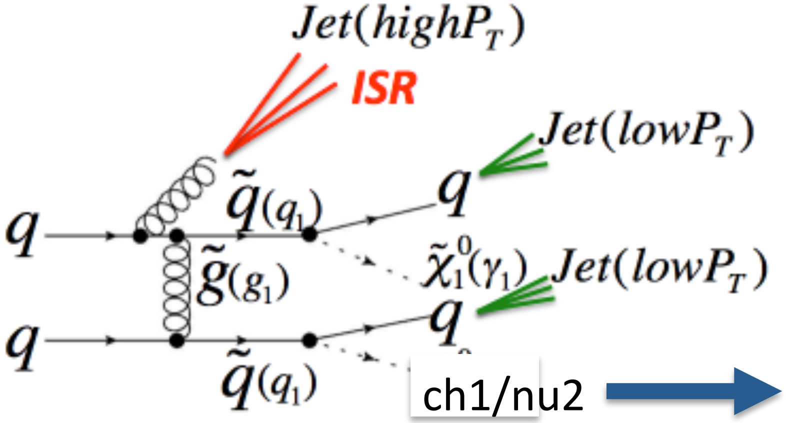
ISR jet is useful for degenerate cases

When heavy particles produce, interaction space should be small, it mean Q^2 of interaction is high
High virtuality is necessary for incoming partons.
It is not new physics. Just QCD.
To make high virtuality state,
the high P_T ISR jet emits.

ISR jet has hard spectrum for heavy particle production,
P_T depends on the mass of produced particles and independent on the decay products.



@10TeV
Pt distribution of the Leading Jet (UED signal)



ch1/nu2 → soft lepton

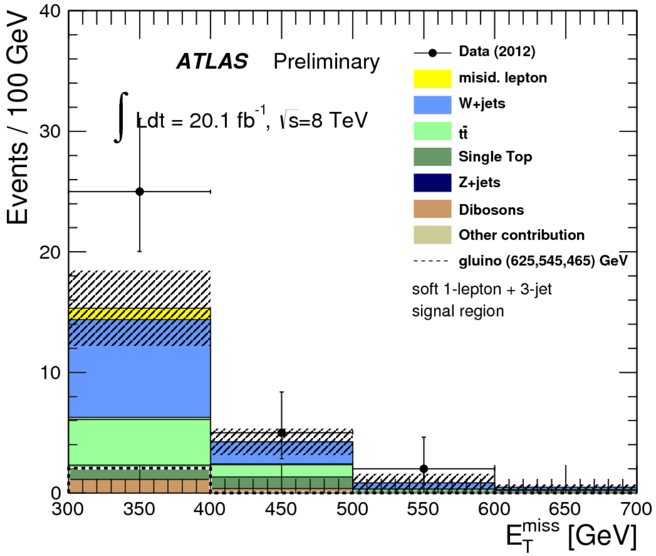
These are soft

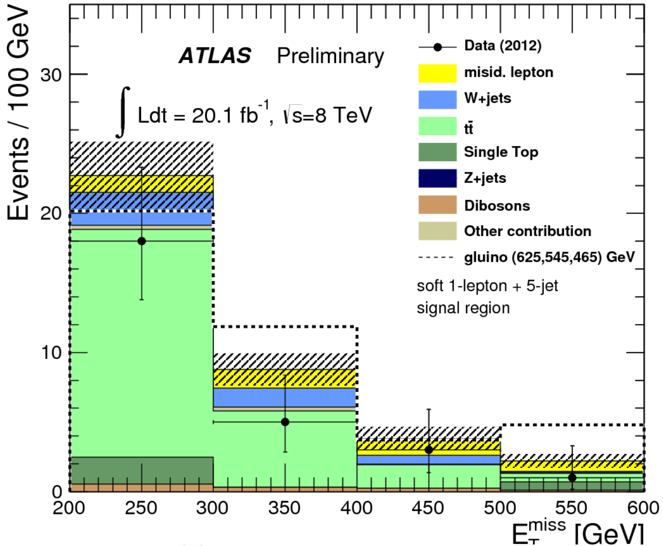
To reduce BG, soft lepton is required

ISR + soft lepton topology for degenerate spectrum

Leading jet (PT> 180 GeV ISR) + Soft Lepton e(PT=10-25GeV) or μ(PT=5-25GeV) from decay products additional jet (PT>25GeV from decay products from decay products

Njets =3,4(W+jets dominant) Njets >= 5 (tt is dominant BG)

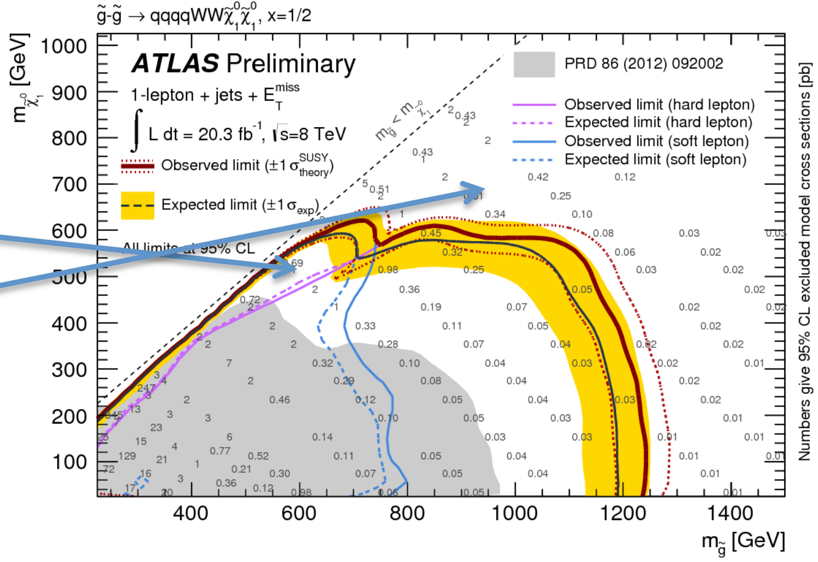




No excess found in high mET region

Degenerated region
is covered gluino< 750 GeV

Still No sensitivity > 750GeV



Need New Idea
for > 750GeV

(E) Heavy colored sparticle case; EW gaugino direct production

"Colored sparticles" become too heavy to be produced at LHC 8 or 14 TeV

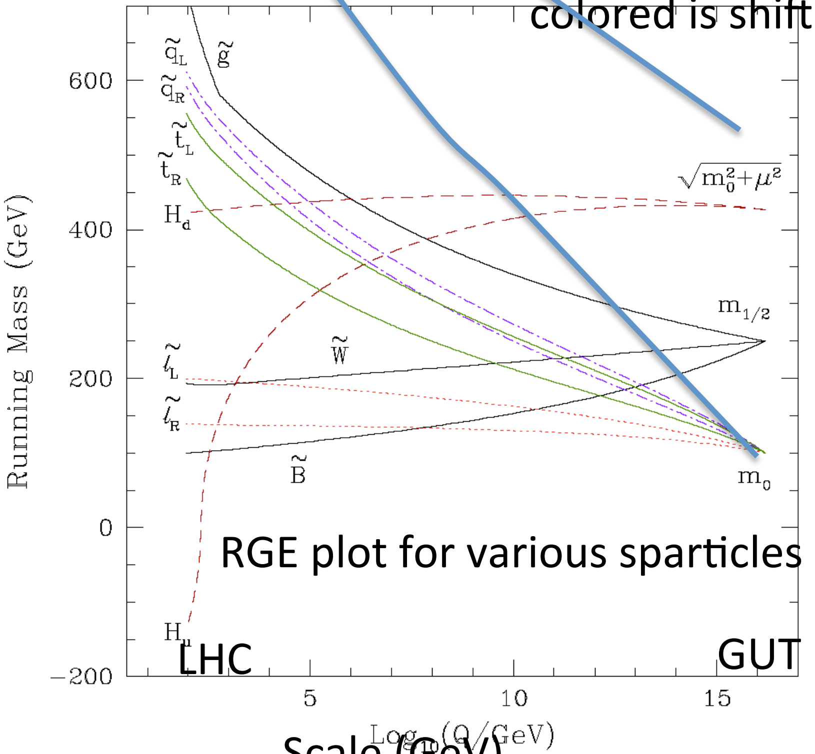
For example

A:Colored sparticle has steep coefficient of RGE
(AMSB model -> I will show later)

B: colored mass is heavy at GUT scale

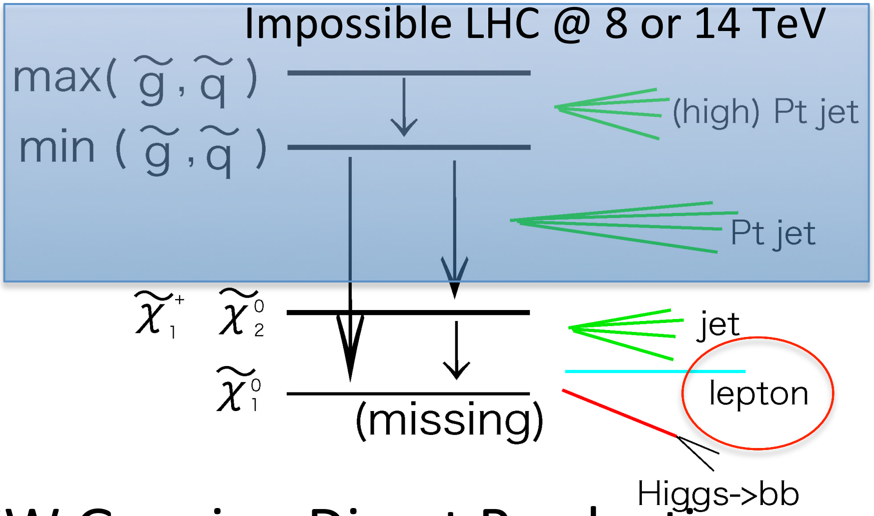
but EW gaugino / Higgsino/ are still light

colored is shifted at GUT scale



RGE plot for various sparticles

Scale (GeV)

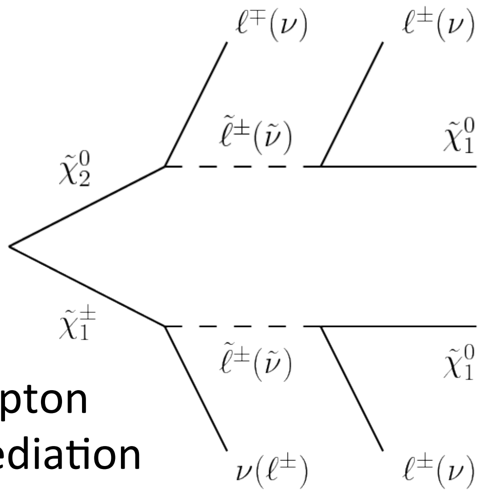


EW Gaugino Direct Production
is only possible for LHC

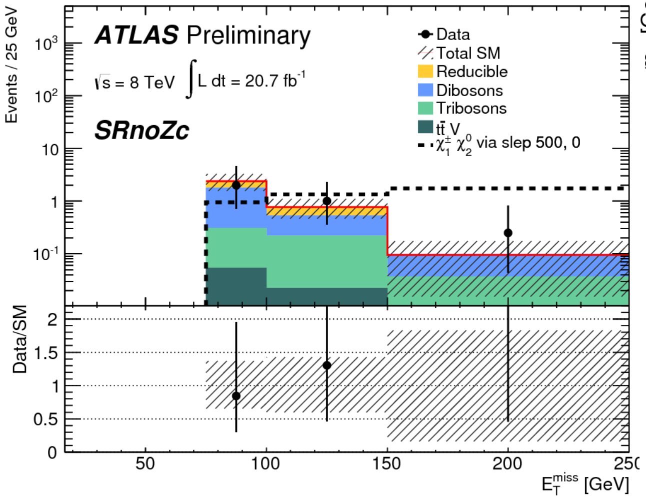
EW direct production ($\chi^{\pm}_1\chi^0_2$) final topology 3 lepton+ mET

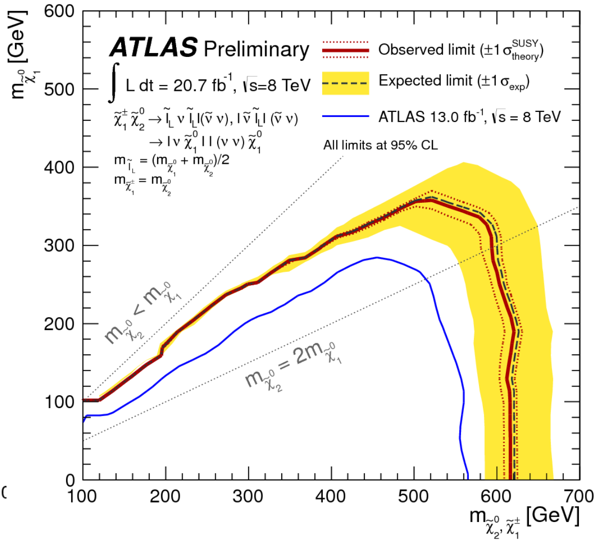
3 lepton & b-jet veto is applied to reduce top BG. MT > 110GeV also reduce top BG

6 signal regions are optimzed

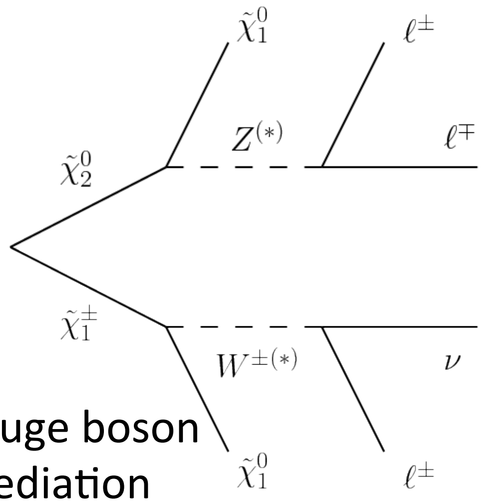


slepton
mediation

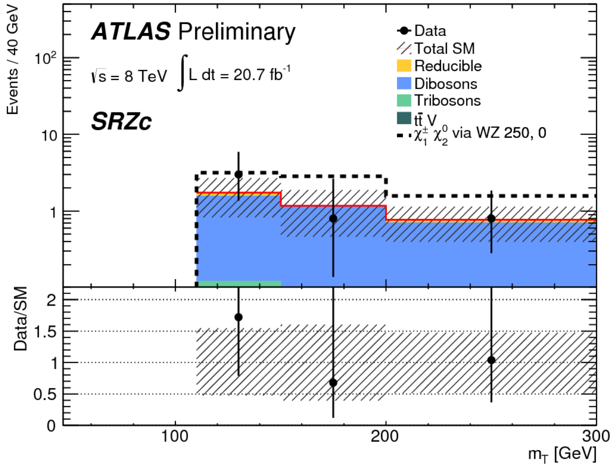


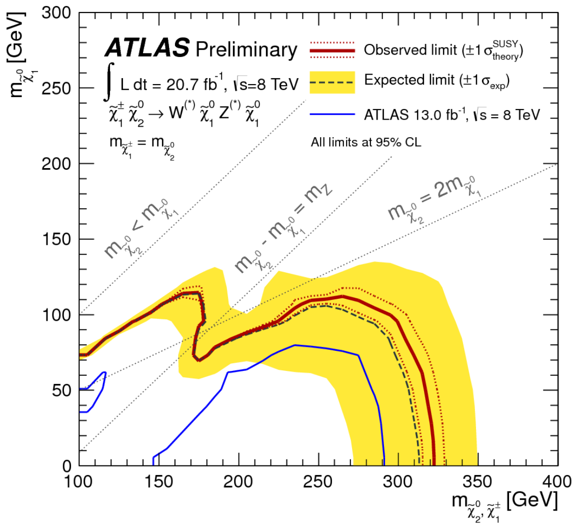


m(SFOS)～Mz



gauge boson
mediation



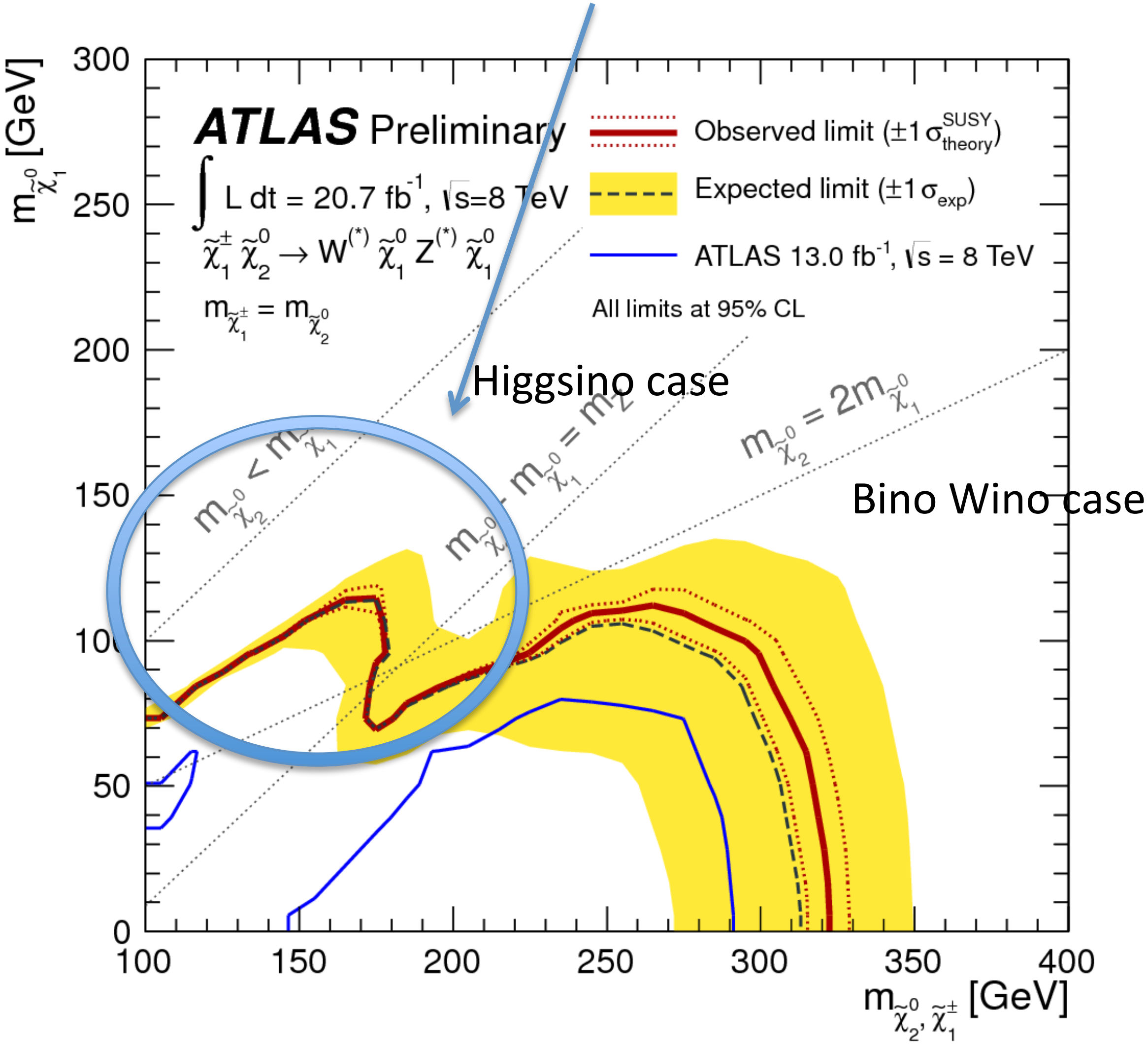


Let's be realistic

Higgs 126GeV ~ large m0(afew -10 TeV) Slepton heavy?

Naturalness means Higgsino |μ| is also light.

-> neutralino 2 & chargino mass is relatively close to neutralino 1

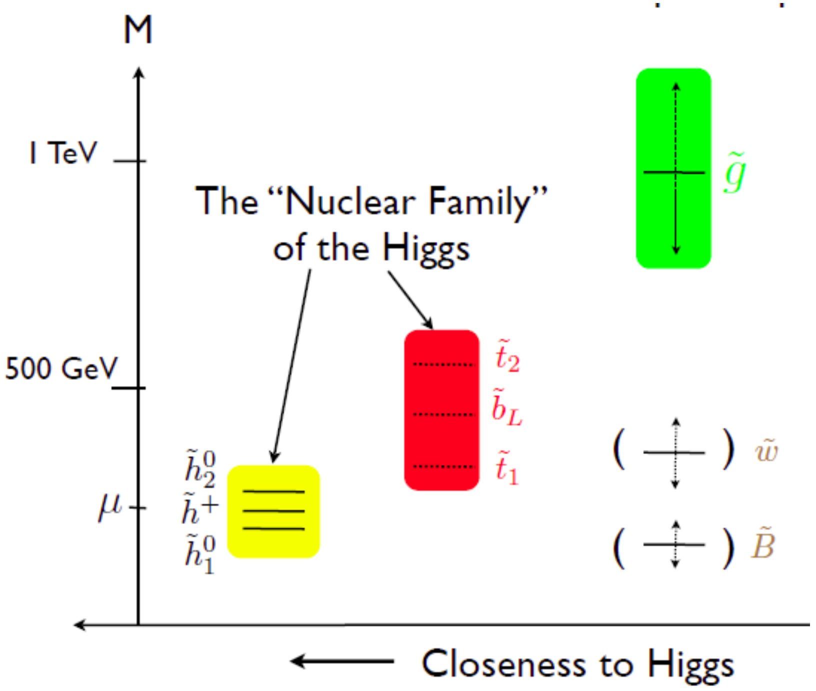


Higgsino case

Bino Wino case

We need new idea for EW production processes

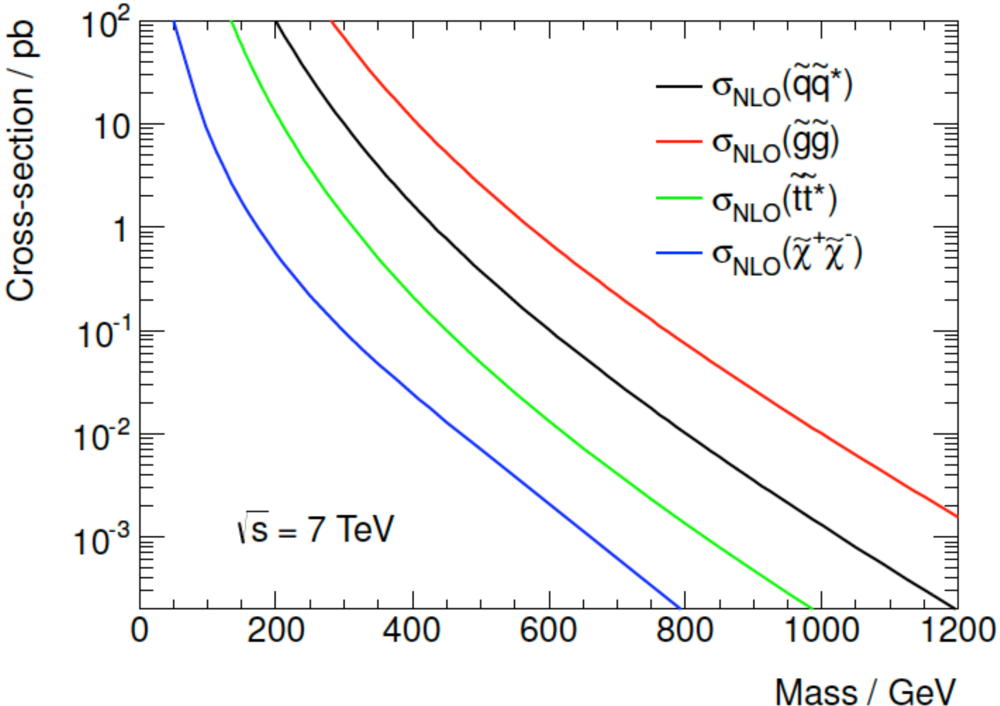
F) Naturalness SUSY signal (stop / Higgsino)



To avoid fine tuning of Higgs potential, both stop and Higgsino mass should be close to EW scale.

And scalar top becomes light because of the following two reasons.

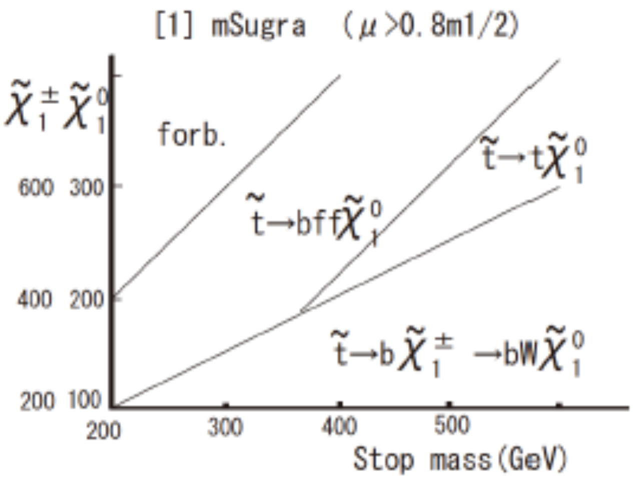
1) Large (negative) radiative correction of Yukawa- Higgs coupling
2) L and R mixing due to A term



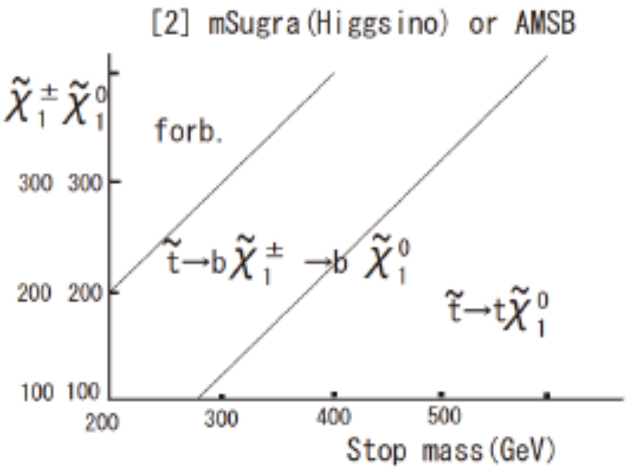
Stop should be light !!
cross-section is ~ 10 fb for 600GeV.
Not so high.
Dedicated analyses are necessary.

Decay pattern and event topologies

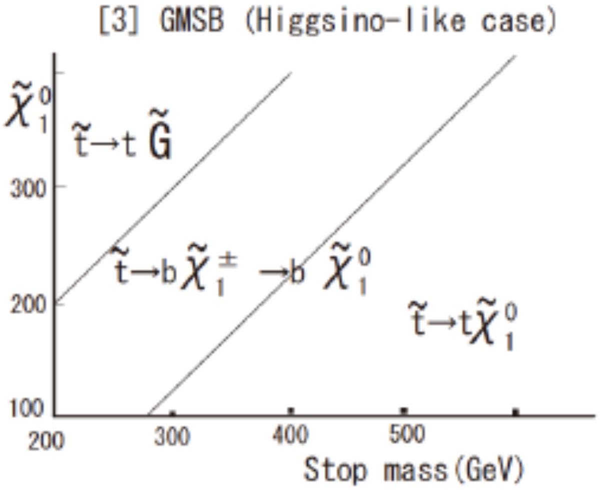
Various decay patterns are possible depending mass relation to chargino/neutralino



[1] mSugra (μ>0.8m1/2)



[2] mSugra (Higgsino) or AMSB



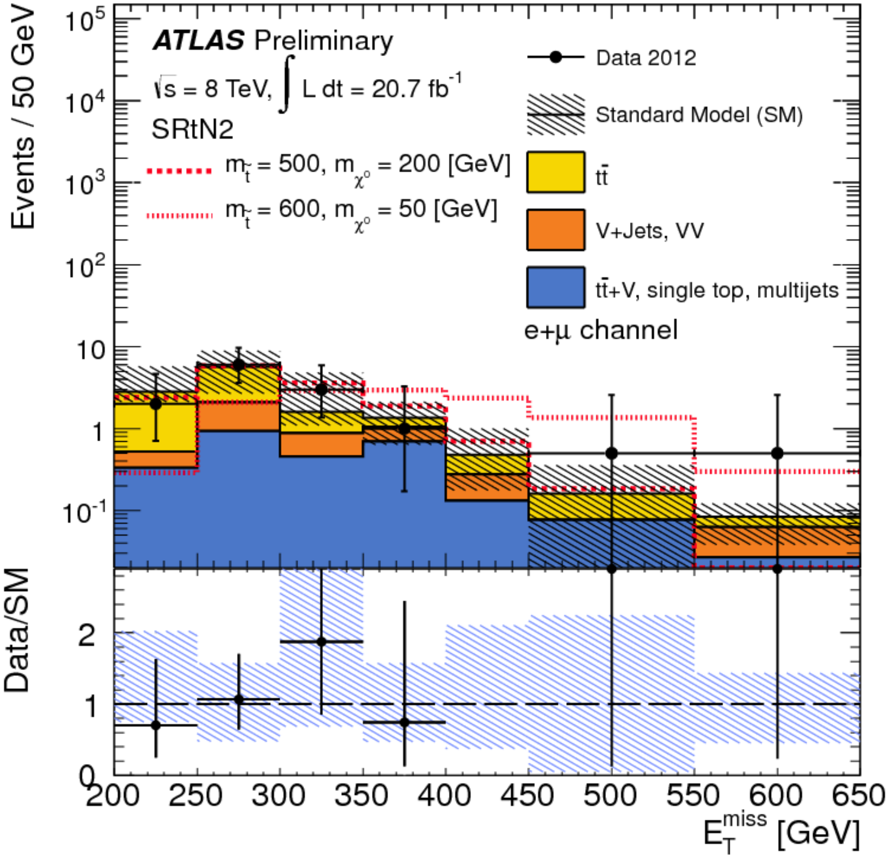
[3] GMSB (Higgsino-like case)

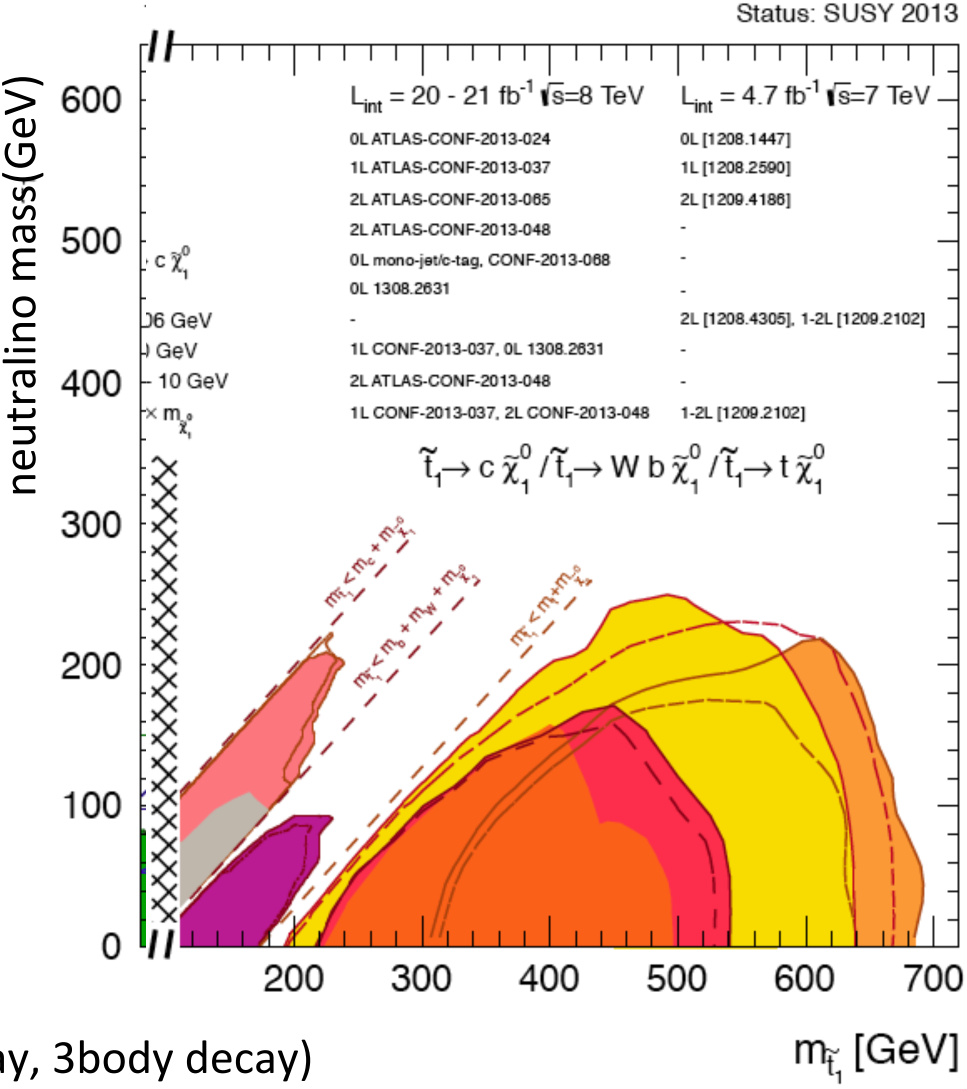
Possible event topologies are summarized in this table. Decay pattern vs topologies
1,2 b-jets are required in "jets"

	0-lep 6-jets	1-lep 4-jets	2-lep 2-jets	0-lep 2-jets	2/3-lep (Z) 3-jets
t+N1	○	○	△		
b+C1	△	○	○	○	
b+W+N1	△	○	○		
c+N1				○ (c-tag)	
b+f+f'+N1	△	○(?)		○(?)	
b+C1/t+N1 (GMSB)	△				○

1-lepton + 2b + 4 jets + MET

top pair is dominate BG and is reduced by MT2 and high mET are required.





If mass difference is small,
sensitivity becomes worse (charm decay, 3body decay)
If neutralino mass is lighter than 200GeV, Lower limit on stop > 600GeV

4) SUSY with Exotic signature

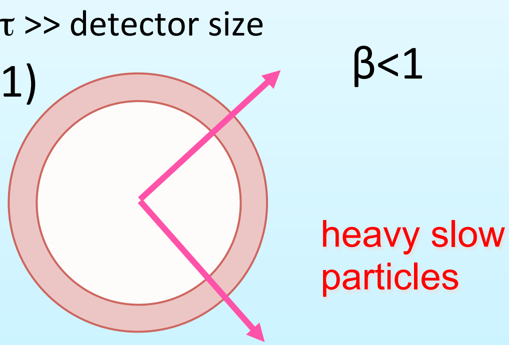
Motivation

no mET signature should be covered

(1) AMSB Wino LSP chargino life cτ= 1-10 cm
(2) GMSB stau NLSP stable in detector or decay in ID
(3) SPLIT SUSY (m0>1000TeV) gluino → R-hadron
(4) R-parity violation If coupling is small displaced vertex

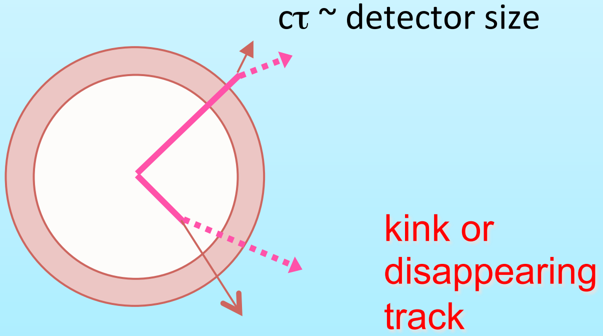
Signatures

(A) Heavy charged particles (GMSB stau, R-hadron)
    (A1) dE/dx energy loss in the semiconductor ,
    (A2) TOF information in Cal. or muon system (β< 1)



(B) Decay in flight (AMSB wino, GMSB stau)
    (B1) Kink/Disappearing track in tracking system

    (B2) neutralino decay with long-life
    displaced vertex is found

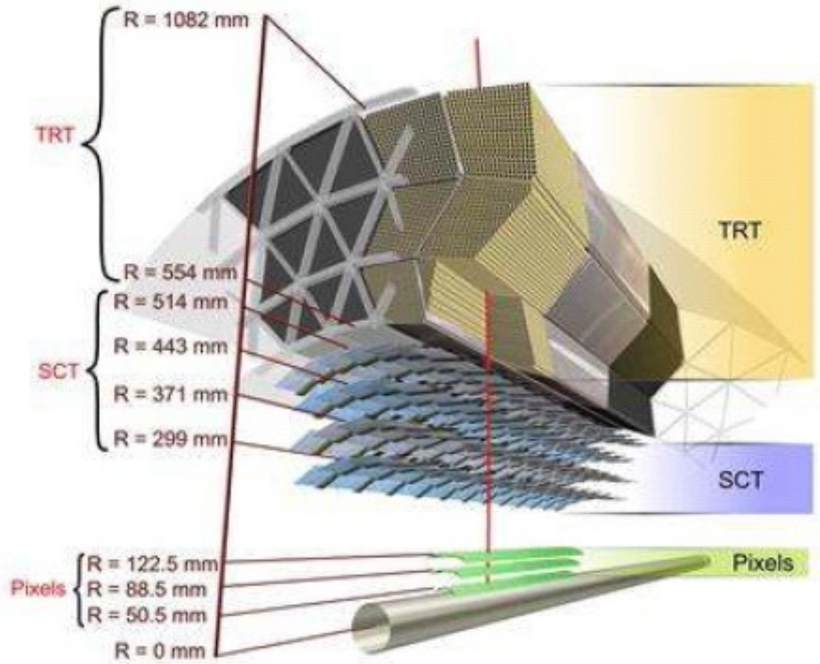


(C) stau and R-hadron(both neutral and charged)
stop in the dense material (Hadron calorimeter)
dedicated trigger is necessary to catch decay.

A) Let’s summarize methods as function of lifetime

cτγ 0.1mm 100mm 1000mm ∞

	Displaced Vertex	dE/dx in Pixel (β<1)	short High P track in Pixel/ SCT (β~1)	Kink / Disappearing TRT (β~1)	Time of Flight In Calorimeter (β<1)	Time Of Flight In Muon Spec. (β<1)	Stop in Calorimeter (β<1)
RPV	✓						
AMSB			✓	✓			
LL Stau		✓	✓	✓	✓	✓	✓
R-had		✓			✓	✓	✓

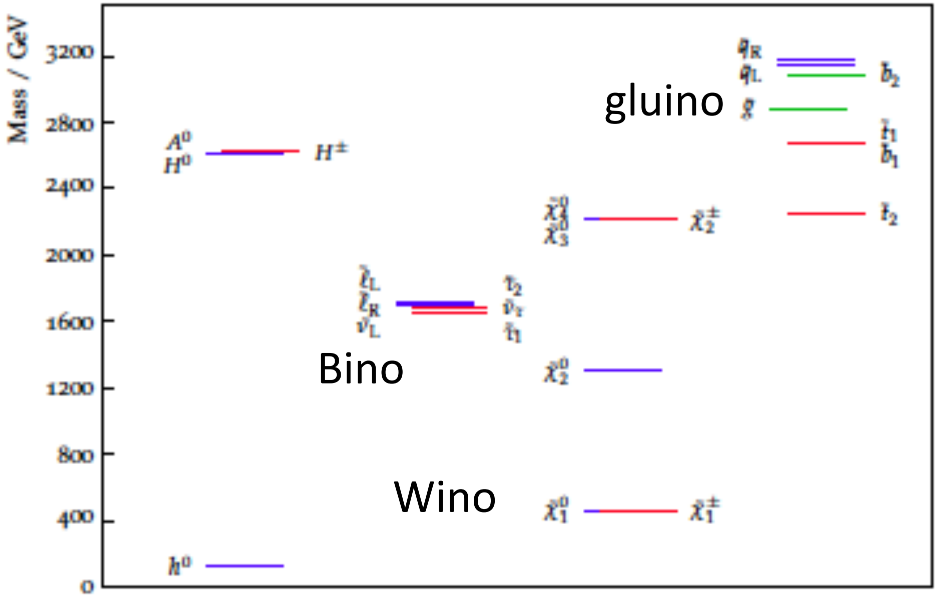


Radius of each detector

	ATLAS	CMS
Vertex	0.1mm	0.1mm
Pixel or SCT	5-50cm	5-100cm
TRT	50-100cm	No
Hcal	2-4m (Δ t~1nsec)	1.5-2.5m
μ	5-10m(Δ t~1nsec)	4-6m

Hadronic calorimeter Fe or Brass
Depth 1m time resolution ～1nsec

B) Anomaly Mediated SUSY Breaking Long-lived chargino

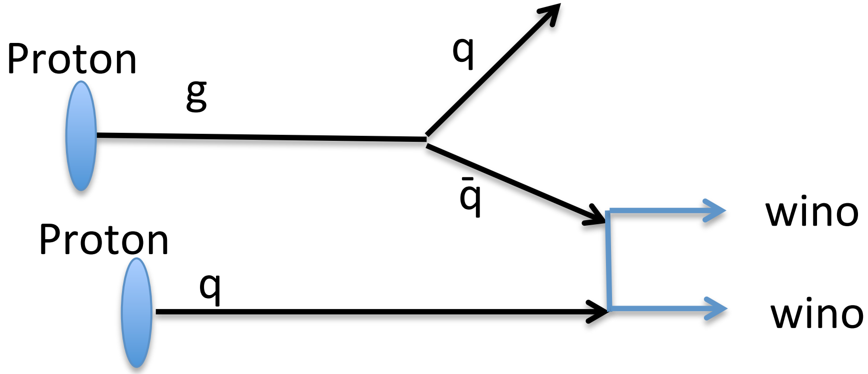


AMSB is one of the simplest & promising model in which SUSY breaking is mediated by quantum loop

Bino:Wino:gluino ~ 3:1:7

Gluino is heavy
On the other hand,
Chargino is still light

126GeV
Higgs
can be explained
naturally.



Wino Pair (+-, +0) productions have large cross-section and also high PT jet (ISR) is expected since LHC is gluon quark collider.

Monojet topology + Wino signal is signature

BUT the similar SM process gg->qZ -> q νν (monojet) has large cross-section:
We need additional signatures of AMSB to reduce this BG process.

Decay in TRT or SSD (High Pt track > 100GeV &

Chargino is Long-Lived

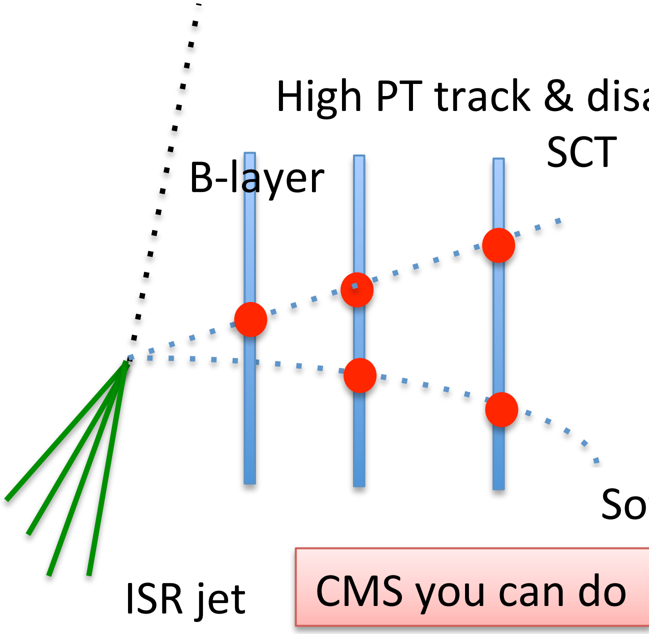
since cτγ ~0(10cm), reasonable number of Chargino decays in TRT (R=50-100cm)

Wino is LSP/NLSP

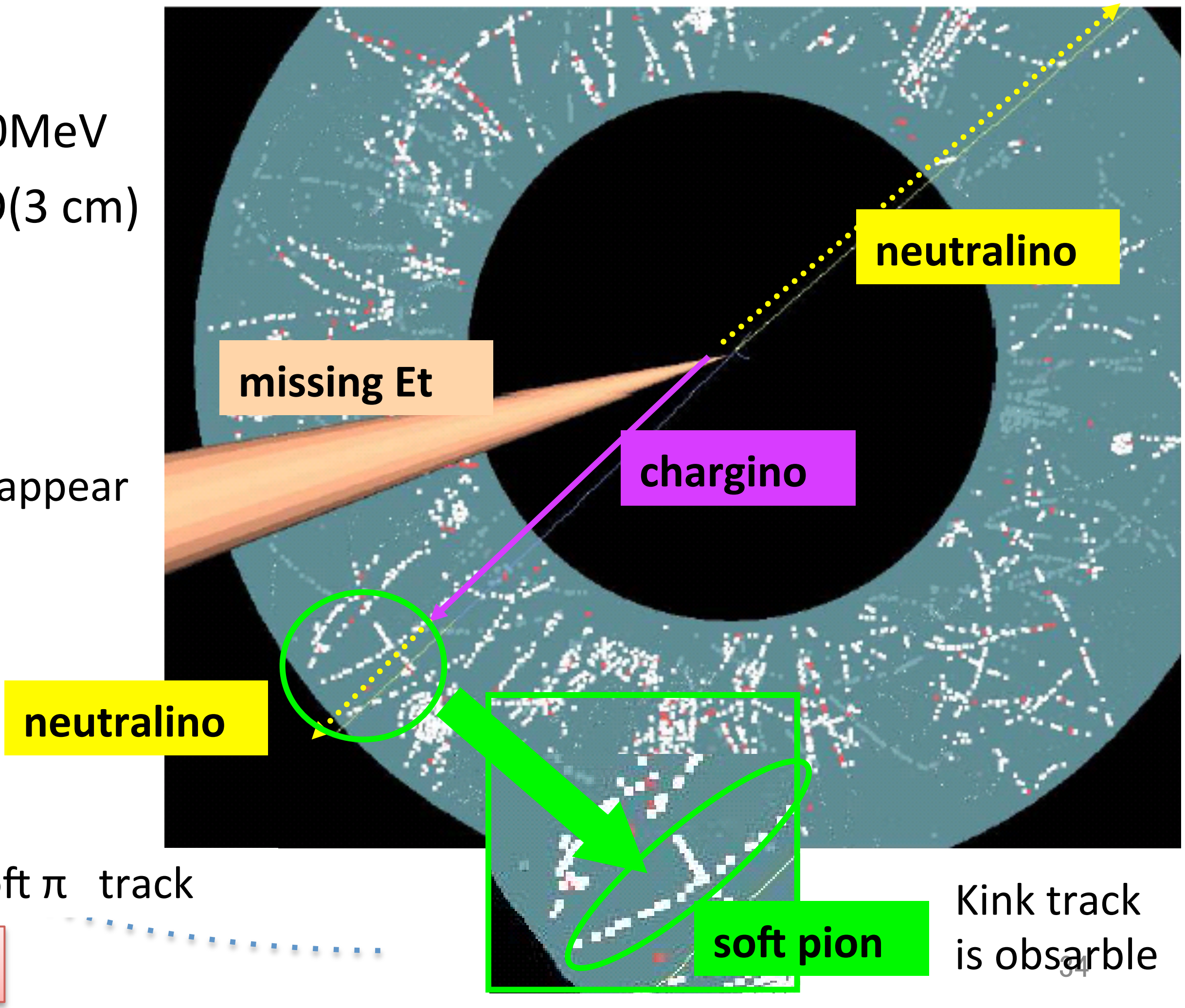
$\Delta m(\text{wino}^{+} - \text{wino}^{0}) \sim$ 150-170MeV

Predictable and lifetime cτ~O(3 cm)

Charged Wino decays in ID:



This is the Simulated Events



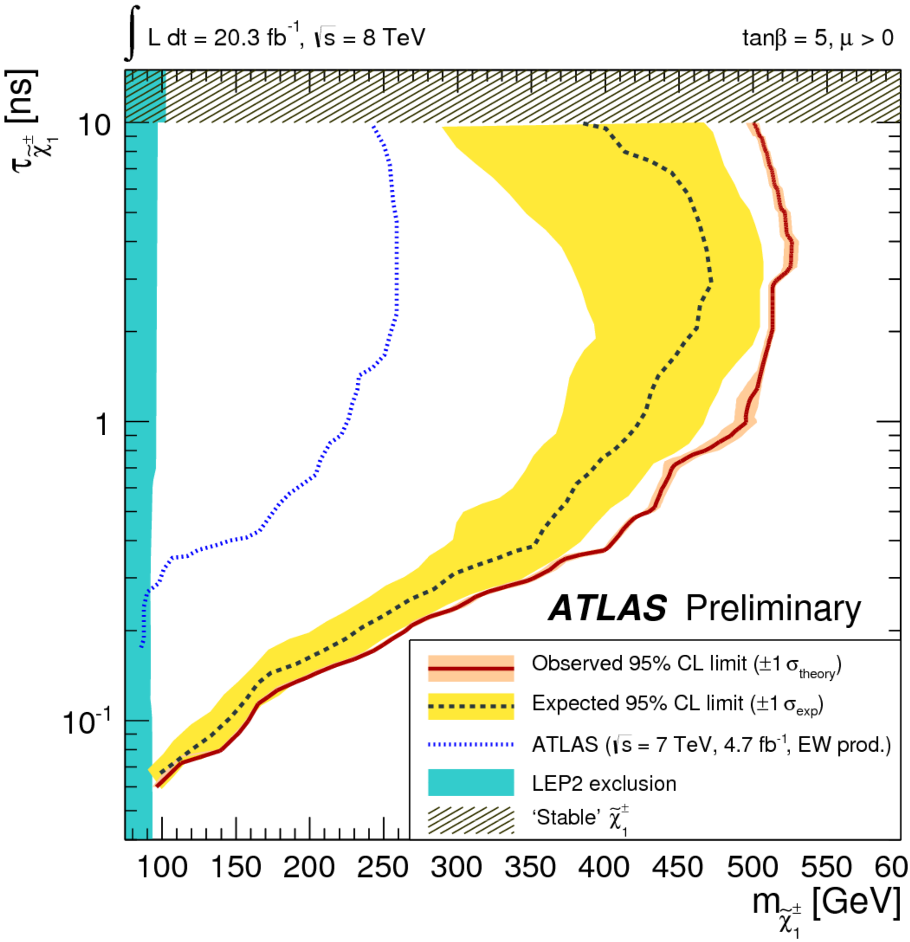
Kink track is obsarble

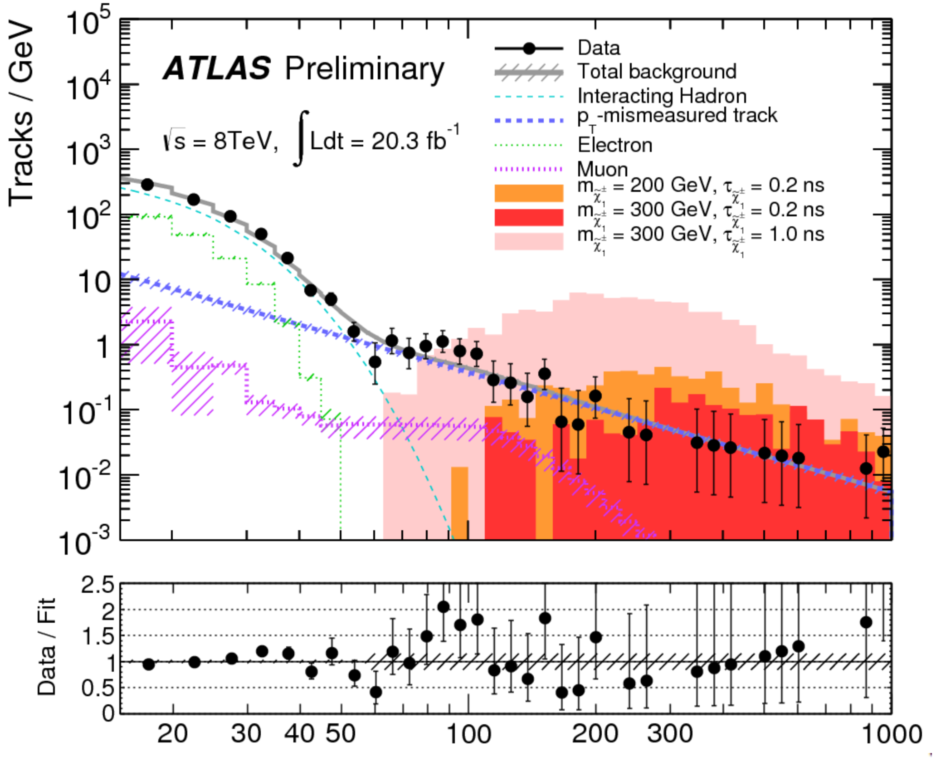
Results at 8TeV

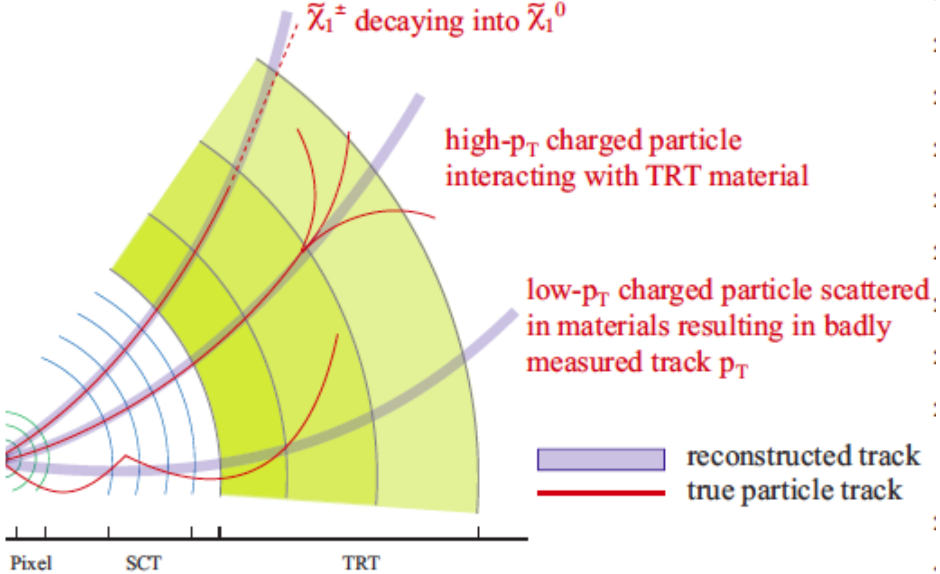
Badly reconstructed track is BG for high Pt region

Track interacting material is BG for middle Pt

These are estimated (fitted) by the real data







Results at 8TeV

Badly reconstructed track is BG for high Pt region

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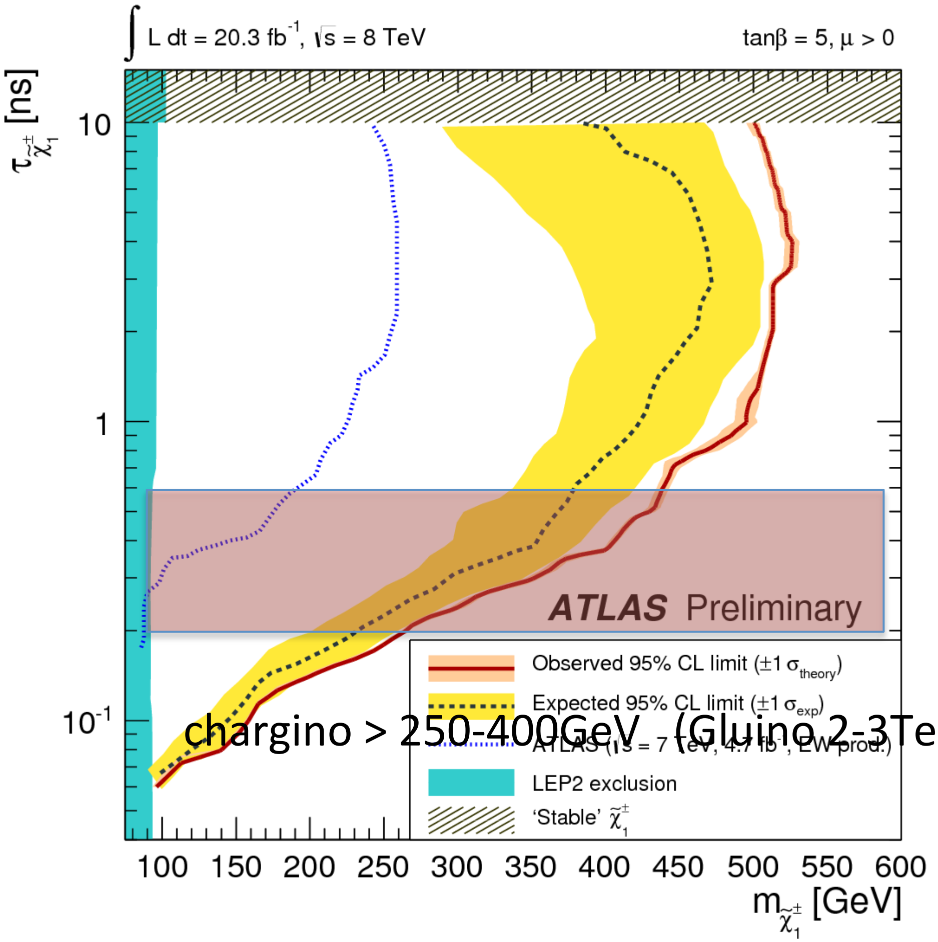
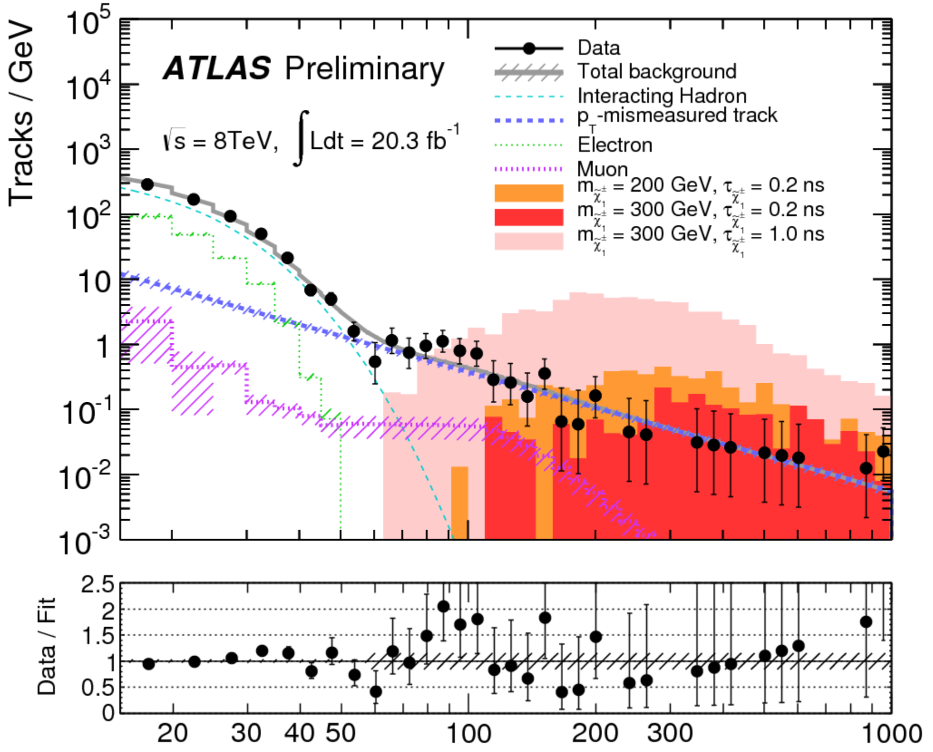
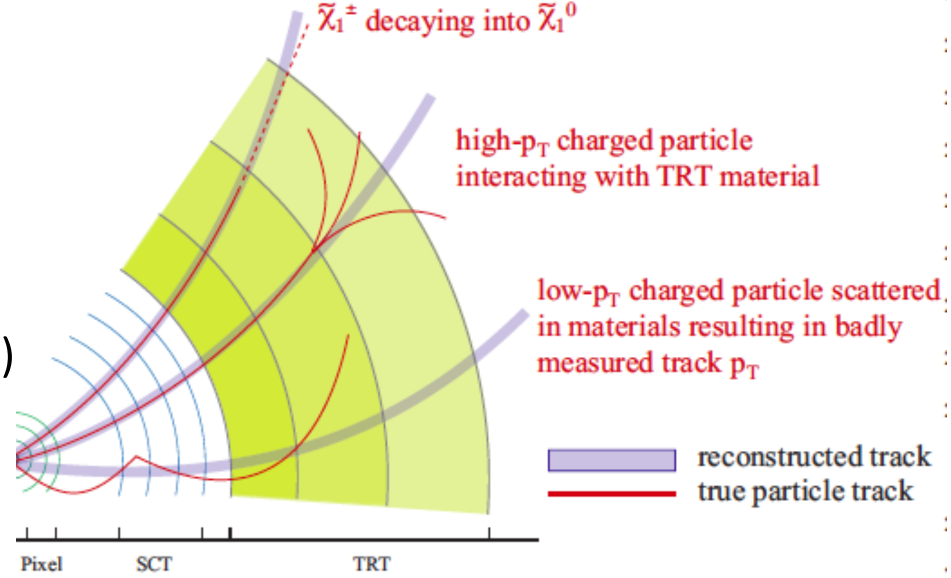
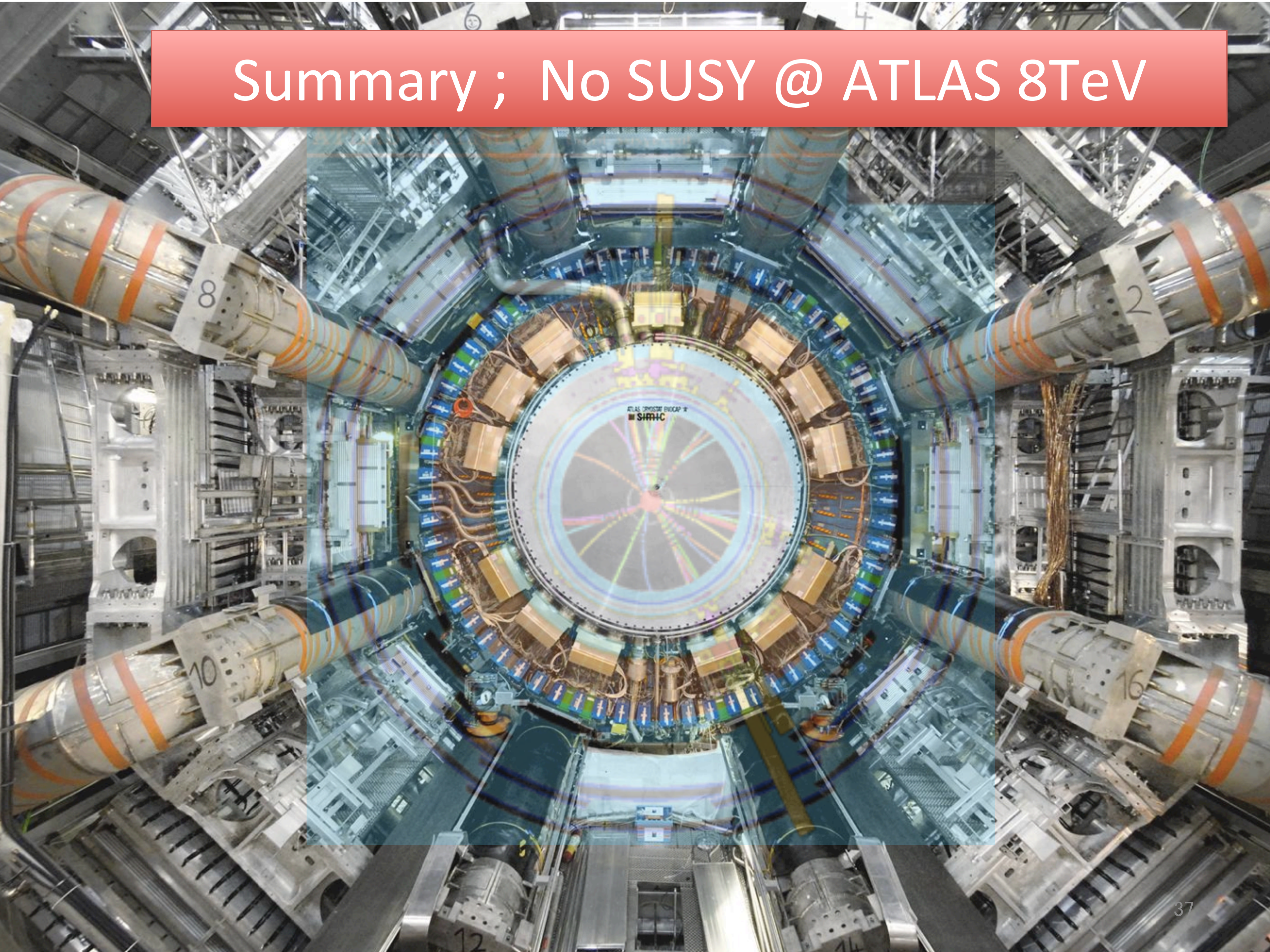


chargino > 250-400GeV (Gluino 2-3TeV)

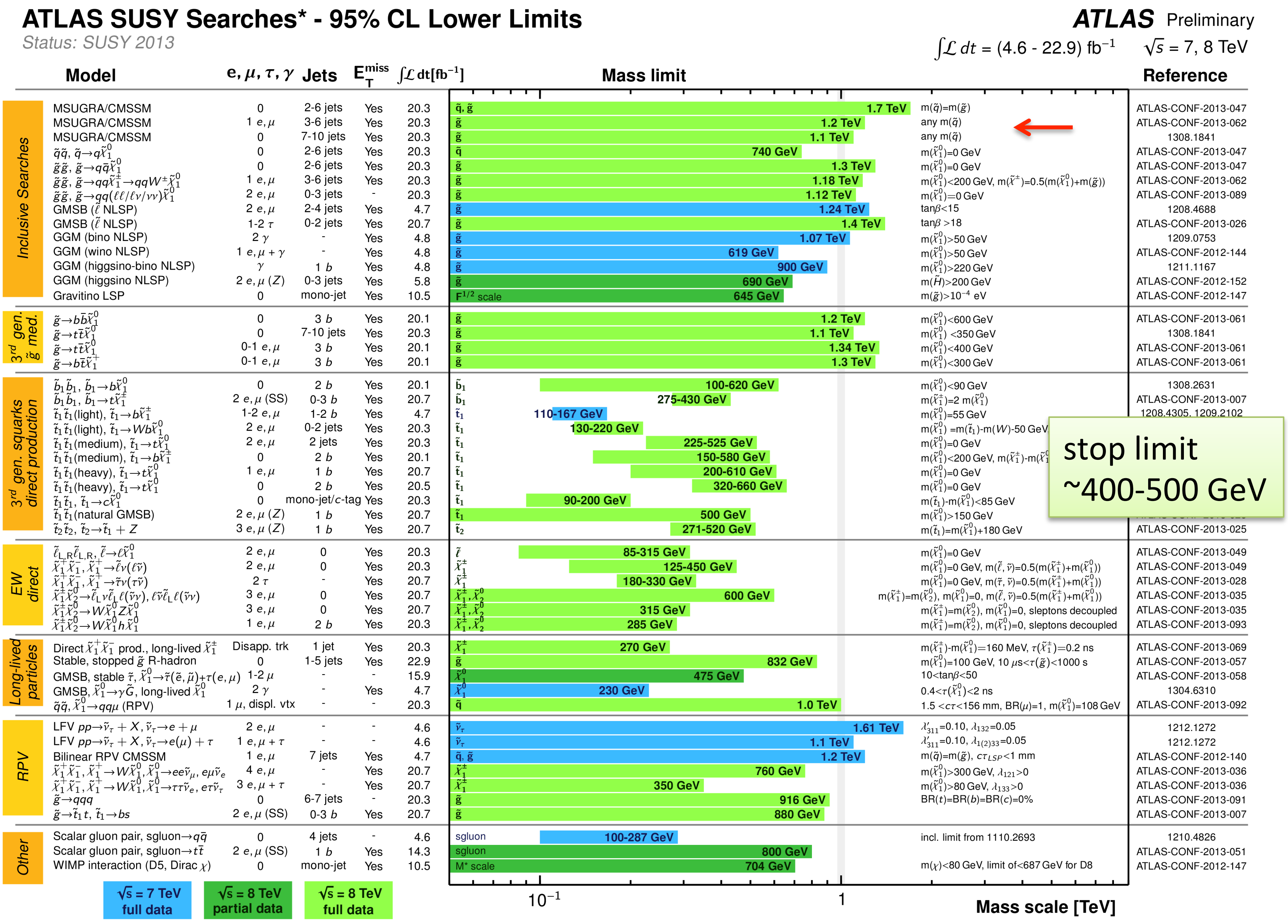




Summary ; No SUSY @ ATLAS 8TeV



No excess was found for all SUSY searches



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

$\int\mathcal{L}\,dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 7, 8 TeV

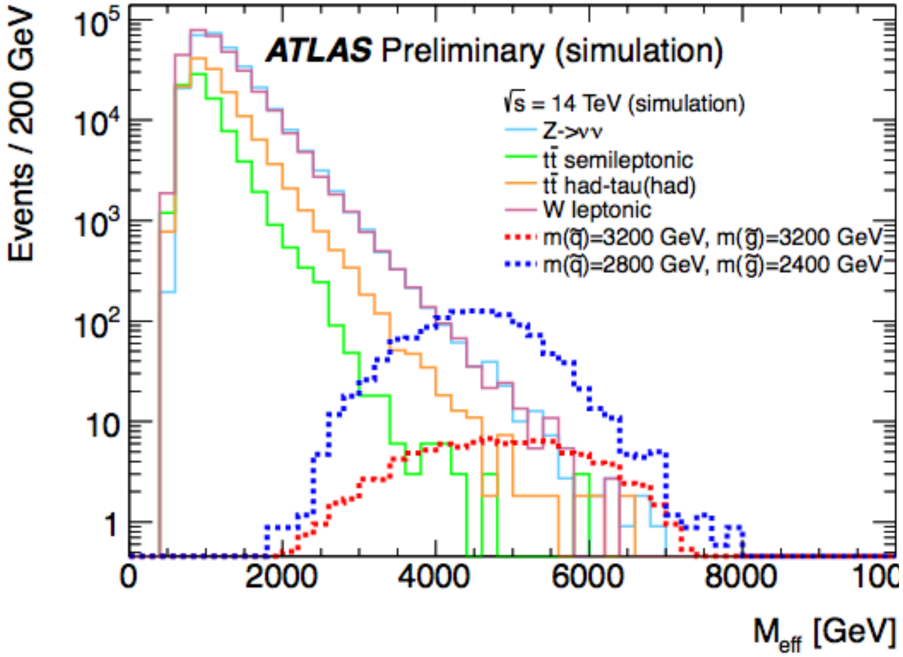
	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	m($\tilde{q}$)=m($\tilde{g}$)	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any m($\tilde{q}$)	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any m($\tilde{q}$)	1308.1841
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{q}$	740 GeV	m($\tilde{\chi}^0_1$)=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}^0_1$)=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^\pm_1\to qqW^\pm\tilde{\chi}^0_1$	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	m($\tilde{\chi}^0_1$)<200 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}^0_1$)+m($\tilde{g}$))	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	m($\tilde{\chi}^0_1$)=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e,μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	tanβ >18	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	4.8	$\tilde{g}$	1.07 TeV	m($\tilde{\chi}^0_1$)>50 GeV	1209.0753
	GGM (wino NLSP)	1 $e,\mu+\gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	m($\tilde{\chi}^0_1$)>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	m($\tilde{\chi}^0_1$)>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	m($\tilde{H}$)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	m($\tilde{g}$)>10^{-4} eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}^0_1$	0	3 b	Yes	20.1	$\tilde{g}$	1.2 TeV	m($\tilde{\chi}^0_1$)<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	m($\tilde{\chi}^0_1$) <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	m($\tilde{\chi}^0_1$)<400 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}^+_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}^0_1$)<300 GeV	ATLAS-CONF-2013-061
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	m($\tilde{\chi}^0_1$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}^\pm_1$	2 e,μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$	275-430 GeV	m($\tilde{\chi}^\pm_1$)=2 m($\tilde{\chi}^0_1$)	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}^\pm_1$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	m($\tilde{\chi}^0_1$)=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}^0_1$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-220 GeV	m($\tilde{\chi}^0_1$) =m($\tilde{t}_1$)-m(W)-50 GeV,	
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}^0_1$	2 e,μ	2 jets	Yes	20.3	$\tilde{t}_1$	225-525 GeV	m($\tilde{\chi}^0_1$)=0 GeV	
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}^\pm_1$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	m($\tilde{\chi}^0_1$)<200 GeV, m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$	
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}^0_1$	1 e,μ	1 b	Yes	20.7	$\tilde{t}_1$	200-610 GeV	m($\tilde{\chi}^0_1$)=0 GeV	
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}^0_1$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	m($\tilde{\chi}^0_1$)=0 GeV	
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)<85 GeV	
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$	500 GeV	m($\tilde{\chi}^0_1$)>150 GeV	
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$	271-520 GeV	m($\tilde{t}_1$)=m($\tilde{\chi}^0_1$)+180 GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	85-315 GeV	m($\tilde{\chi}^0_1$)=0 GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}^\pm_1$	125-450 GeV	m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{\ell}$, $\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	ATLAS-CONF-2013-049
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}^\pm_1$	180-330 GeV	m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{\tau}$, $\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	ATLAS-CONF-2013-028
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.7	$\tilde{\chi}^\pm_1$, $\tilde{\chi}^0_2$	600 GeV	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-2013-035
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1Z\tilde{\chi}^0_1$	3 e,μ	0	Yes	20.7	$\tilde{\chi}^\pm_1$, $\tilde{\chi}^0_2$	315 GeV	m($\tilde{\chi}^\pm_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, sleptons decoupled	ATLAS-CONF-2013-035
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1h\tilde{\chi}^0_1$	1 e,μ	2 b	Yes	20.3	$\tilde{\chi}^\pm_1$, $\tilde{\chi}^0_2$	285 GeV	m($\tilde{\chi}^\pm_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, sleptons decoupled	ATLAS-CONF-2013-093
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}^\pm_1$	270 GeV	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=160 MeV, τ($\tilde{\chi}^\pm_1$)=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$	832 GeV	m($\tilde{\chi}^0_1$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}^0_1\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}^0_1$	475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	4.7	$\tilde{\chi}^0_1$	230 GeV	0.4<τ($\tilde{\chi}^0_1$)<2 ns	1304.6310
	$\tilde{q}\tilde{q}$, $\tilde{\chi}^0_1\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, m($\tilde{\chi}^0_1$)=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	1 e,μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$	1.2 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to ee\tilde{\nu}_\mu$, $e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.7	$\tilde{\chi}^\pm_1$	760 GeV	m($\tilde{\chi}^0_1$)>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to\tau\tau\tilde{\nu}_e$, $e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.7	$\tilde{\chi}^\pm_1$	350 GeV	m($\tilde{\chi}^0_1$)>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e,μ (SS)	1 b	Yes	14.3	sgluon	800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	m(χ)<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

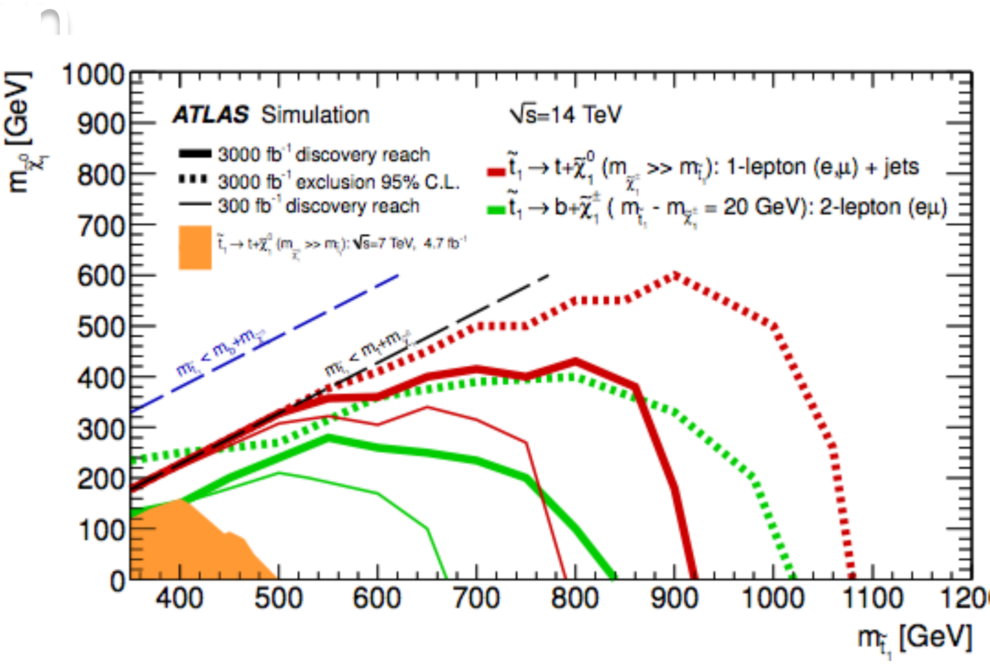
stop limit

~400-500 GeV

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Never give up, we have 14TeV

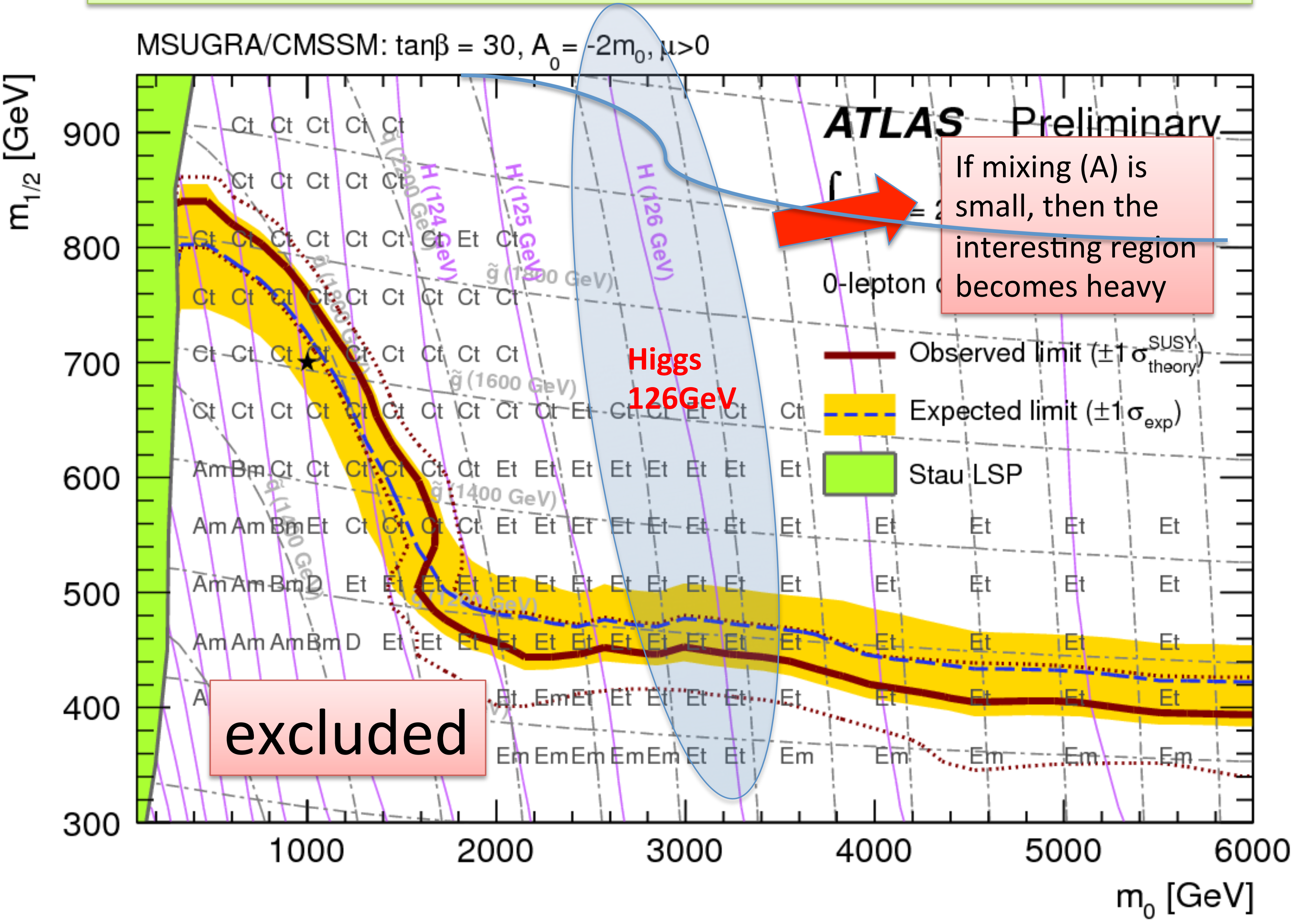




We can cover gluino/squark upto ~ 3TeV
stop 600-700 GeV

1) Boost up EW gaugino direct production, 2) Understand BG at high end
3) degenerate case

Interesting SUSY parameters predicted by Higgs 125.5GeV will be covered



If mixing (A) is small, then the interesting region becomes heavy

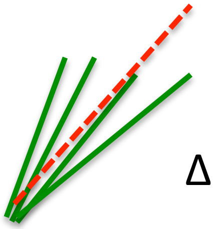
Higgs 126GeV

excluded

Additional slide

BG1: Control regions (QCD)

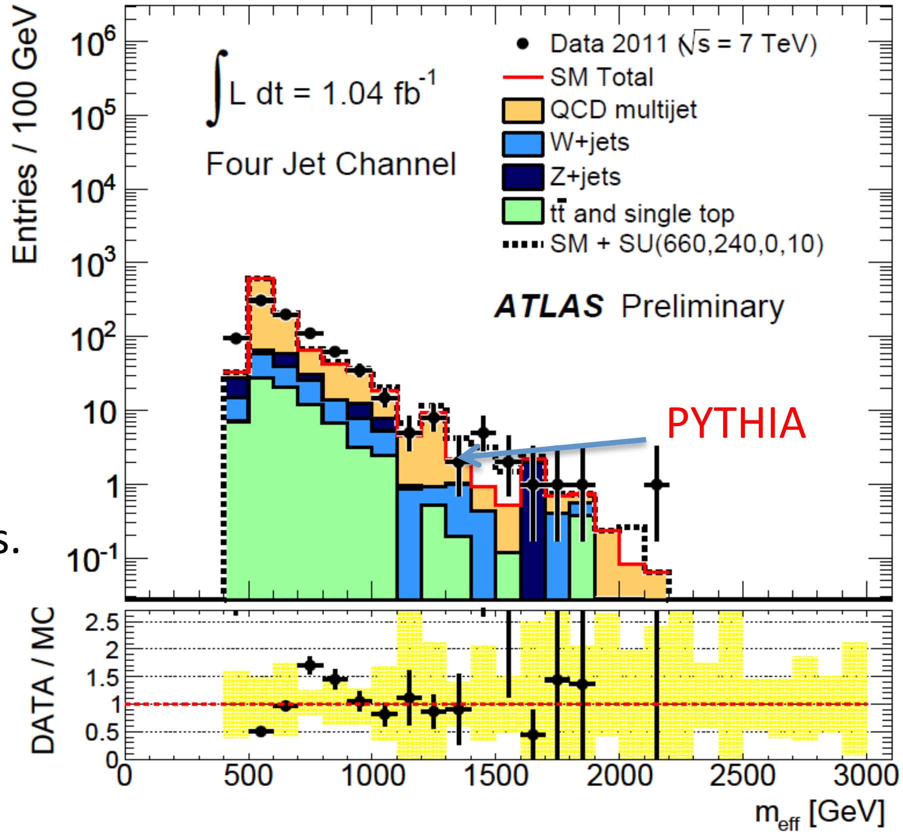
QCD multi-jets processes becomes BG
when ν emits in a heavy flavor jet
or when jet energy is miss-measured
(Fake mET) .



ν

energy mis-measurement

ΔΦ(jet vs mET) <0.4 is required
to enhance QCD processes.



PYTHIA

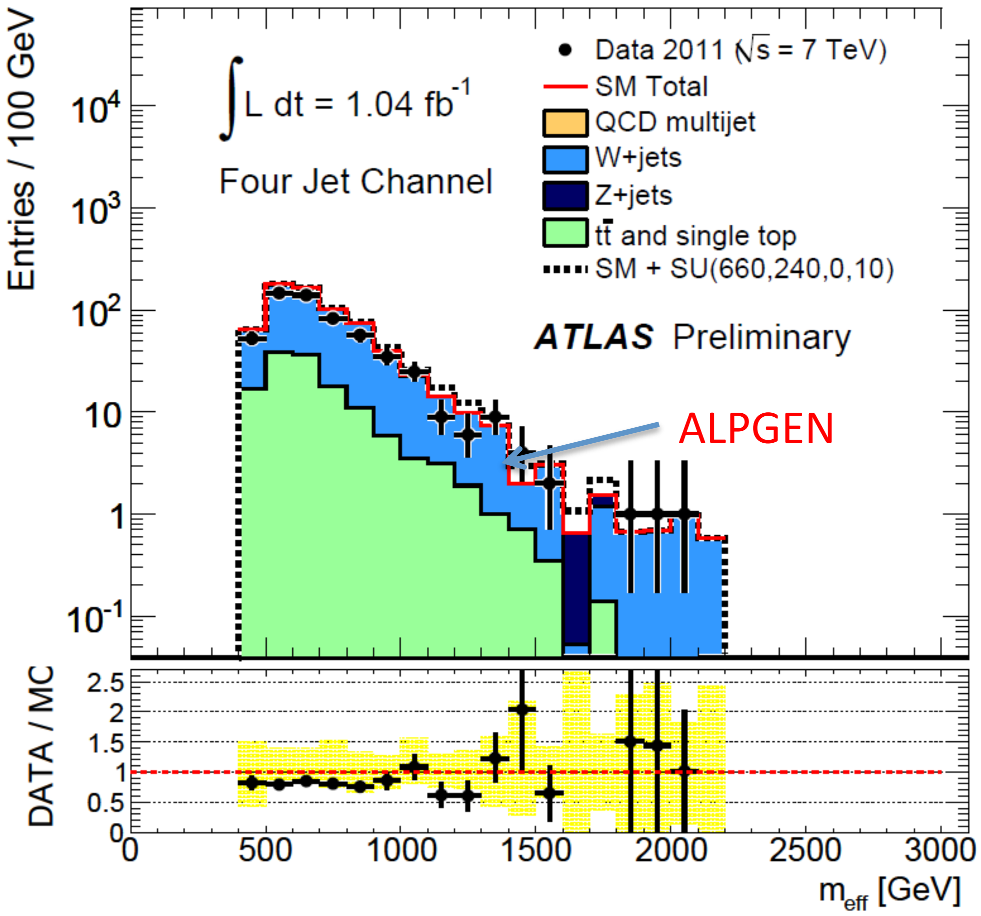
Meff= mET+ Σ PT (jet)

Data is harder than PYTHIA prediction.
PYTHIA is parton shower scheme,
To produce high PT jet, Q^2 of shower
evolution is set high, still not enough,
On the other hand, Q^2 is high
then too many jets are produced in PYTHIA
and there is discrepancy.
The other MC also can not reproduce
multijet + mET topology.

QCD BG is estimated
with real data using this CR

BG2: Control regions (W)

W + jets (1lep without b)



ALPGEN

$$M_T \equiv \sqrt{2E_T^{miss} p_T^{\ell}[1-\cos(\Delta\phi_{\ell,E_T^{miss}})]}.$$

M_T< Mw & no bjets are required to select W+jets sample.
Blue shows the simulated W+jets BG.

MC is produced with ALPGEN.

Slop is slightly different: Data is harder
SHERPA is better to reproduce a shape.
(Not physics, just different scale for αs)

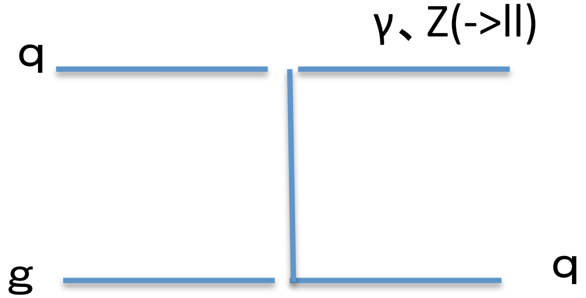
Currently
shape predicted by SHERPA /Madgraph(CMS) is used
Normalization is determined by data

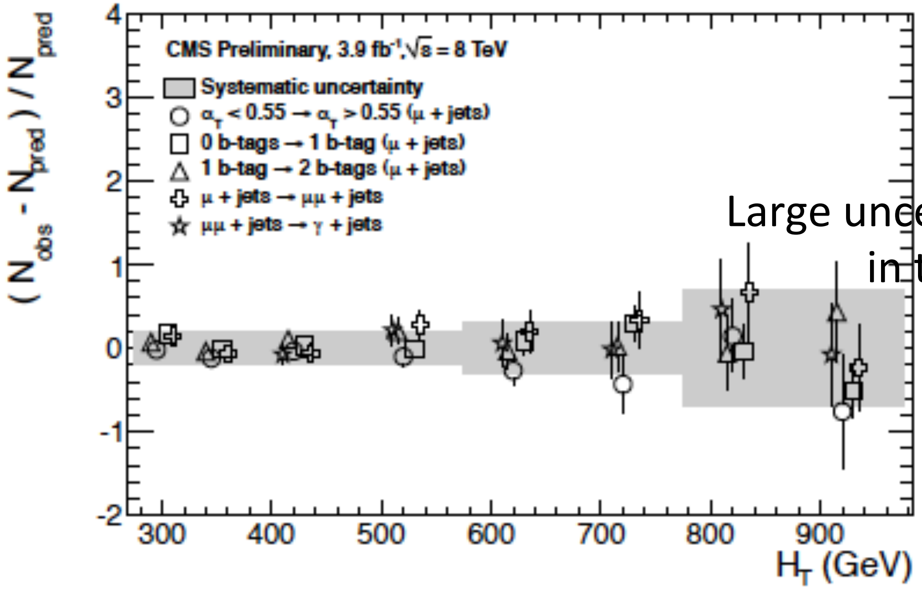
BUT Nobody can believe shape of MC in high mET/HT region. We need some idea to estimate BG using real data for this region.

BG3: Control regions (Z)

Physics process is the same as W+jets

BG (Z->νν)+Jets can be estimated with





Large uncertainty in the signal region > 50%

Events with high PT jet are expected.

we can examine using γ+Jets, Z(→μμ)+jets; But stat. is too limited for High Pt

Currently MC produced by ALPGEN/ SHERPA / MADGRAPH(CMS) are used and Normalization has been performed using data(Control region).

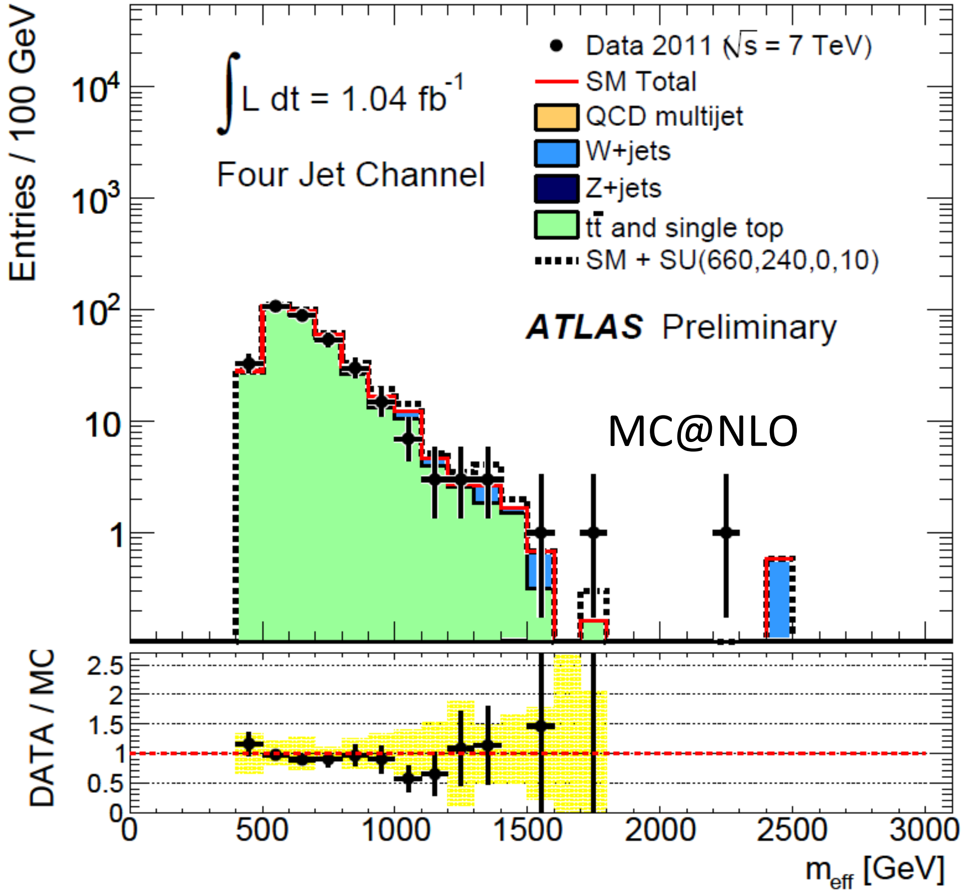
There are two serious problems:

No body believes MC for such a high end of the kinematics.

depends on PDF, αs(scale what scale is used),

Problem
We need some idea to estimate for high mET & HT region

BG4: Control regions (tt)



MC@NLO

Data agree well

M_T< M_W & bjets are selected to enhance tt sample

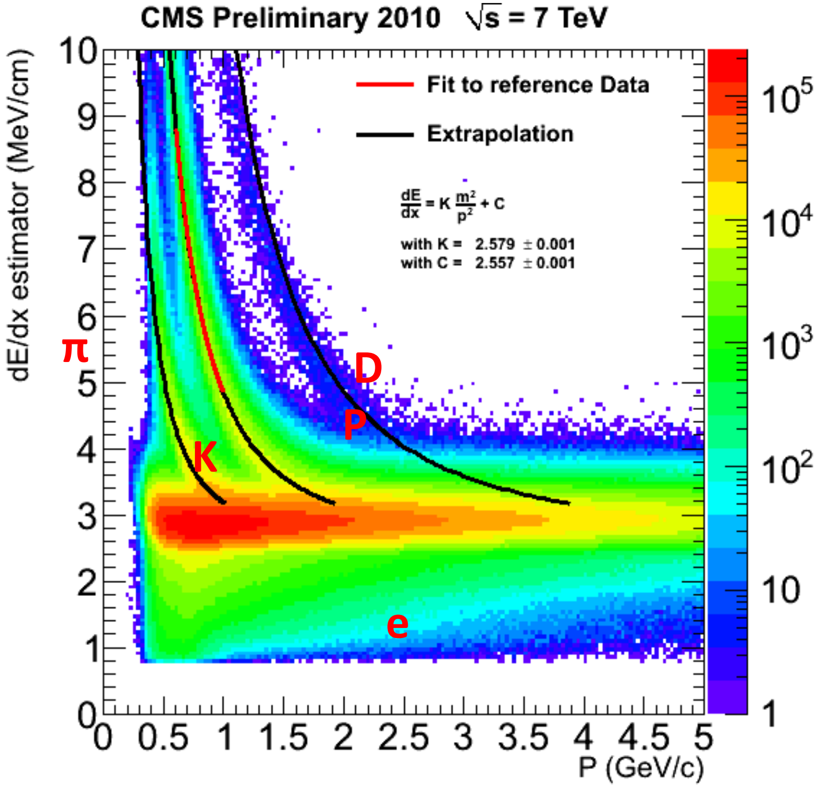
tt is not dominant BG except for mET+bjet analysis, since σ at 7TeV is 170pb.

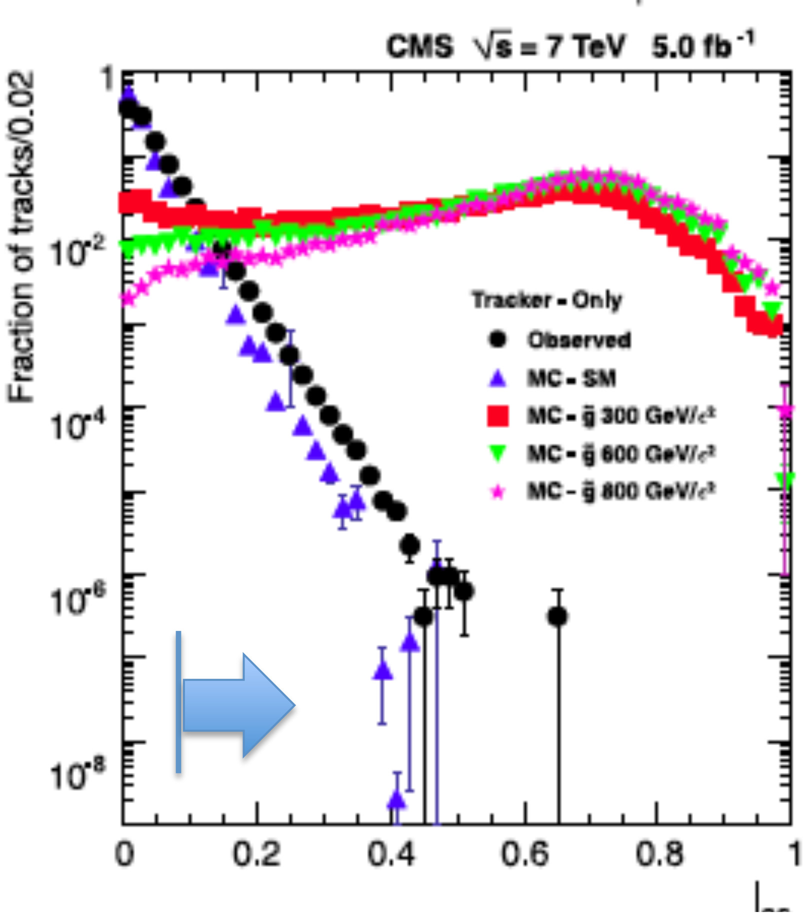
It becomes serious at ECM=14TeV (830pb)

Now basically We use MC even with normalization.

Problem
tt+Njets,
"Additional Njets" is key
still need more data and study

(A1) dE/dx in Si tracker



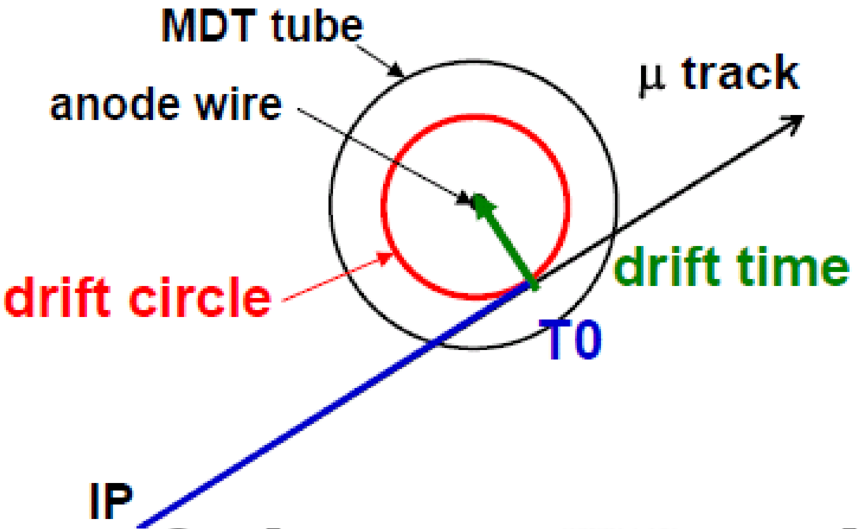


$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right)^2 \right] \right),$$

Ionization energy loss dE/dX ~$1/\beta^2$
We can use this information to search for heavy stable particles.

Pi is the probability
for a minimum–ionizing particle (MIP) to produce a charge smaller or equal to the **i**–th
charge measurement for the observed path length in the detector

(A2) TOF information using muon

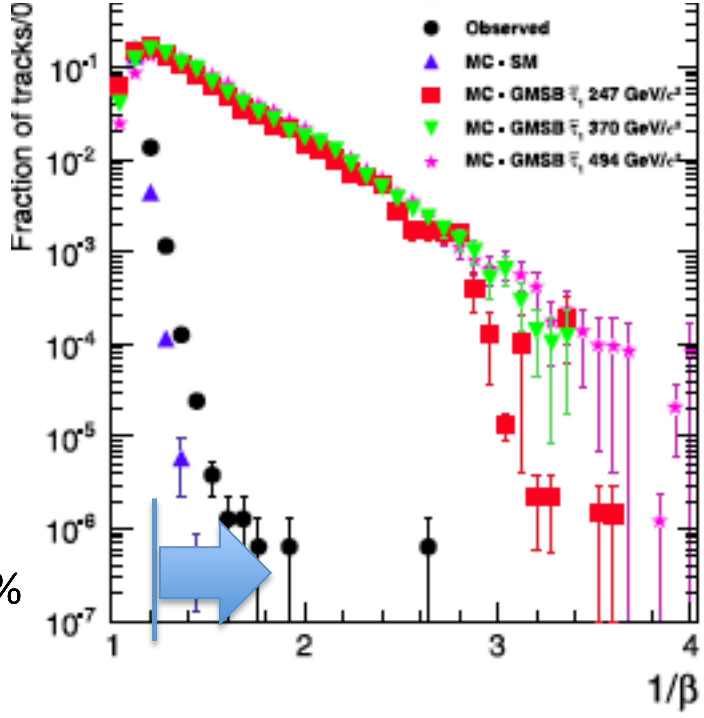


drift time = TDC output time
- T_0(flight time from IP)
drift circle = function(drift time)
Then the position is determined.

But β=1 is assumed for this calculation.
For the particle with β<1,
drift circle become wrong.

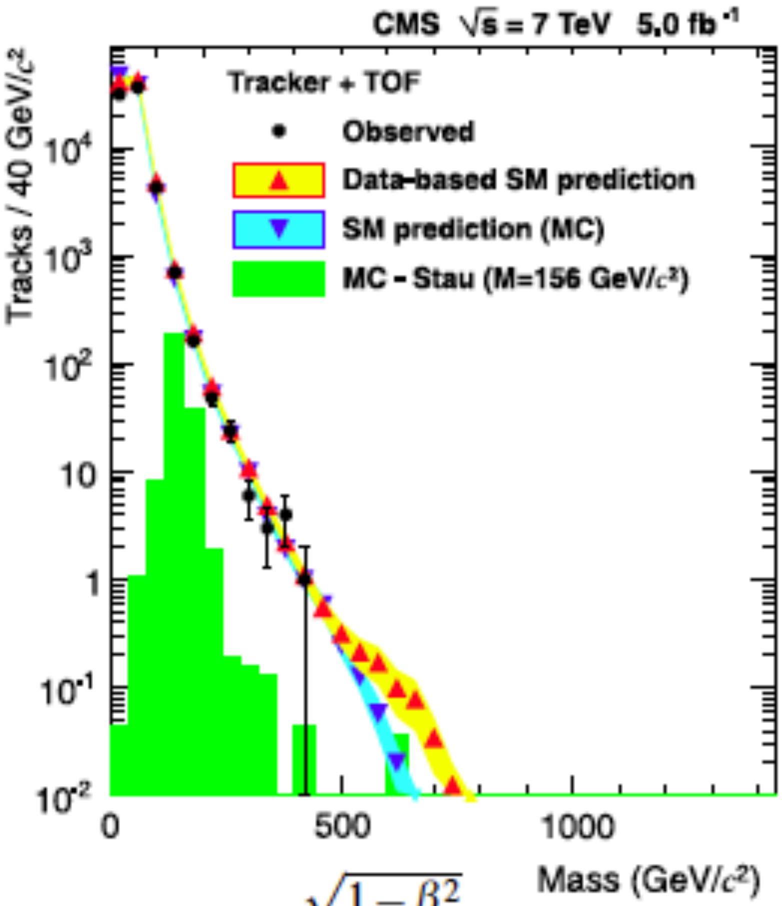
Then the chi^2 becomes worse, since the calculated drift is worse.
T0 is fitted to obtain best chi^2

β＝0.3-0.95

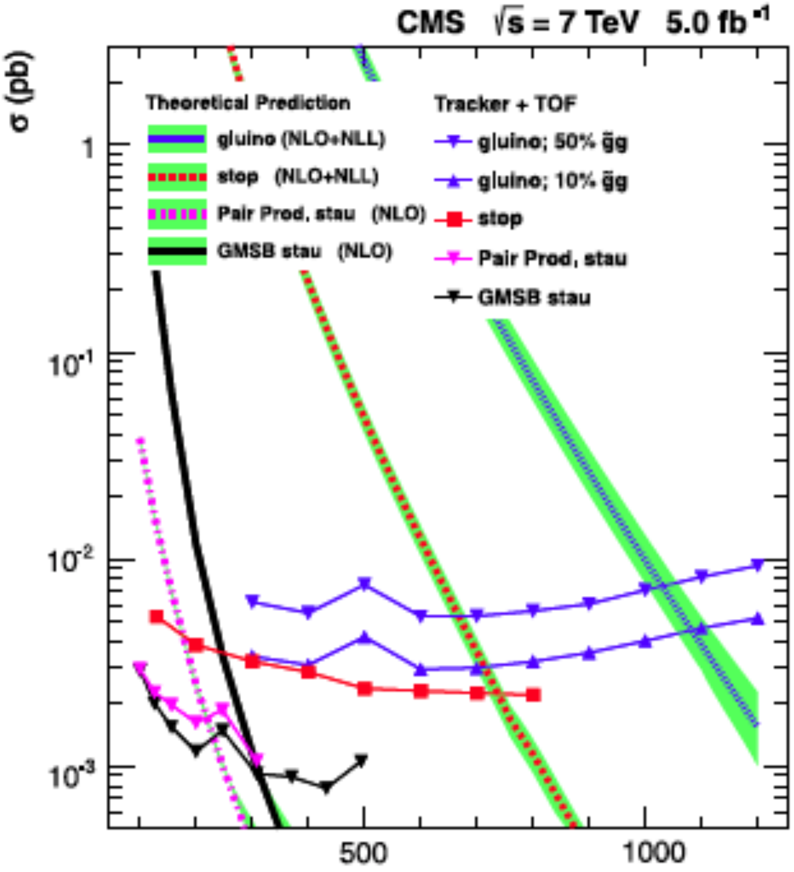


β resolution ~ 7%

(A1) dE/dx in ID + (A2) muon TOF (I)



$$m = p\frac{\sqrt{1-\beta^2}}{\beta}$$



314GeV is excluded (95%CL)
for stable stau.
direct production

PT>50GeV
Ias>0.05
1/β> 1.05

Data 72079 events
BG 88010+- 8800(sys) event
BG is estimated assuming that PT, dE/dx and 1/β are independent

Extra-dimension

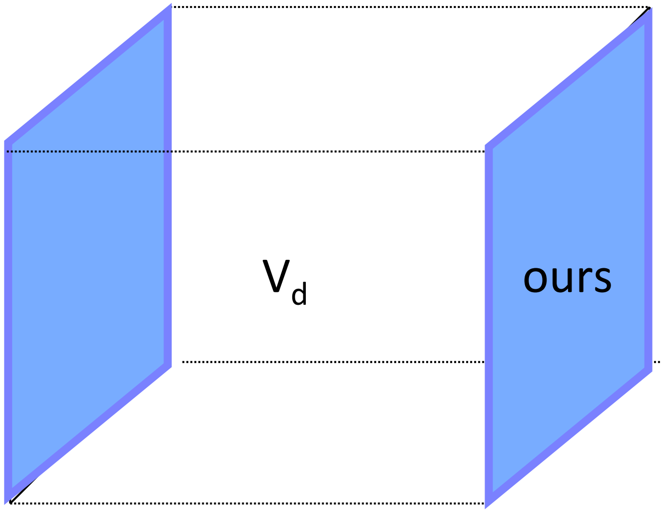
Why   is topics of extra-dimension selected for exotic searches?

No I am a mad (bad?)   physicist !!!

ED models provide various event topologies!!!

Lesson
Do not believe theorists!!
New particles searches should be based on topologies. ED & SUSY provide ….

（1）Large Volume ： ADD model
Large Extra Dimension flat space



$$(M_{pl}/\sqrt{8\pi})^2 = V_d M_D^{2+d}$$ （ADD）

When M_D=1TeV

d=2 R～10^{12}fm ~ 1mm
d=6 R～100 fm

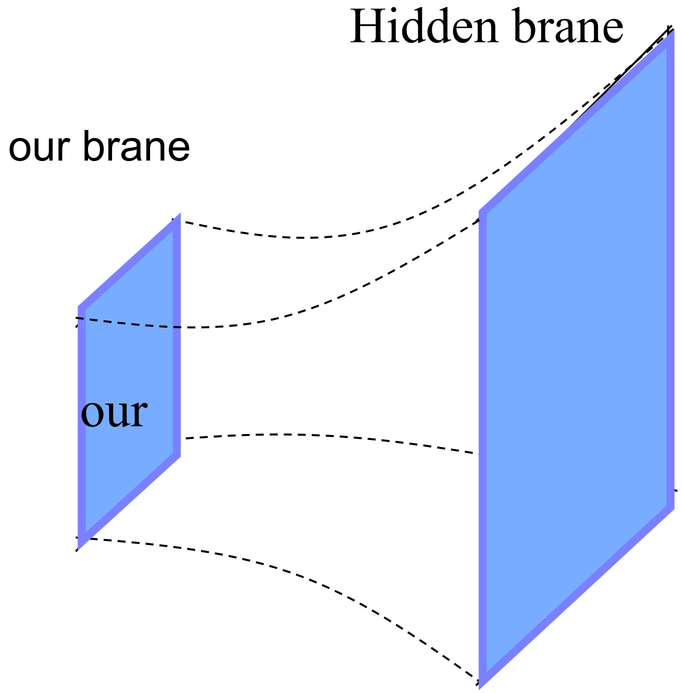
Light KK Graviton (d=2 1/R= 10^{-4} eV d=6 1/R= 7MeV) → Many KK state

1/R << TeV G： Many KK state contribute and sum of these contributions becomes large: Gravity coupling is enhanced and proportional to energy.

For Large d, number of KK state decreases quickly -> sensitivity becomes worse

Expected Event Topology @ LHC
Graviton emission (monojet, γ＋missing)
Graviton exchange (high mass lepton pair, high mass jet pair)
BH, Stringball, 2jet

（2）Curved space （RS-I）



in the curved space-time (k: curvature)

$$\Lambda = \overline{M}_{Pl}\exp(-\pi kR)$$

when R(distance between two brane)～12/k
πkR～40 then Λ～1TeV

KK Graviton

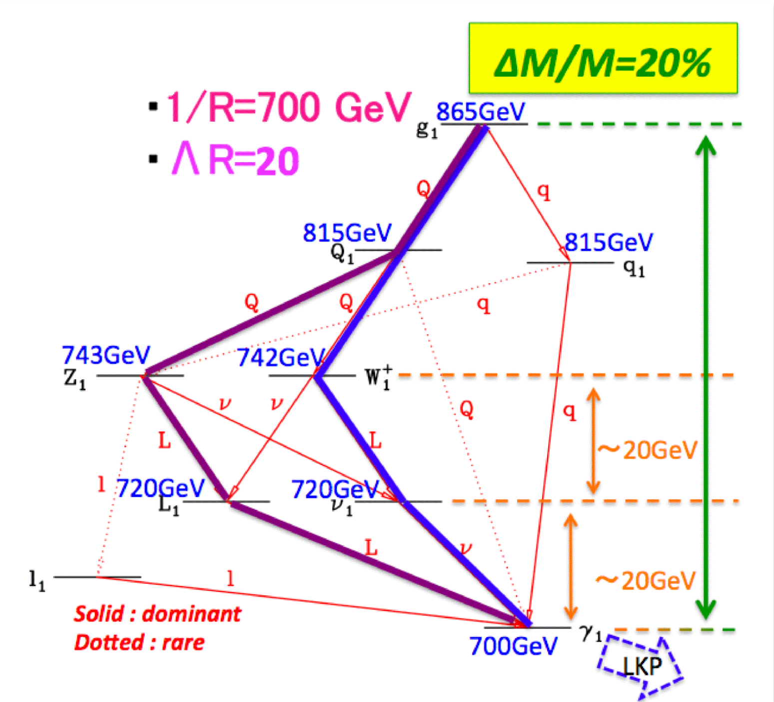
Coupling parameter $c=\sqrt{(8\pi)}k/M_{Pl}=0.01\text{-}0.1$
$M_n = kx_n\exp(-kr\pi)$ (x_n =3.83,7.02… for n=1,2…)

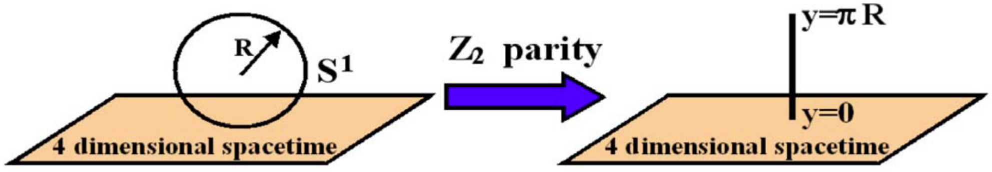
Event topology @ LHC
KK-Graviton exchange high mass lepton resonance,
high mass γγ resonance
KK gluon exchange high mass top pair resonance

(3) Universal Extra dimension

All particles(not only graviton, but all SM) can travel in bulk of extra dimension

All SM particles has KK
KK parity exists with some boundary condition
KK Parity   SM KK even   1st KK odd

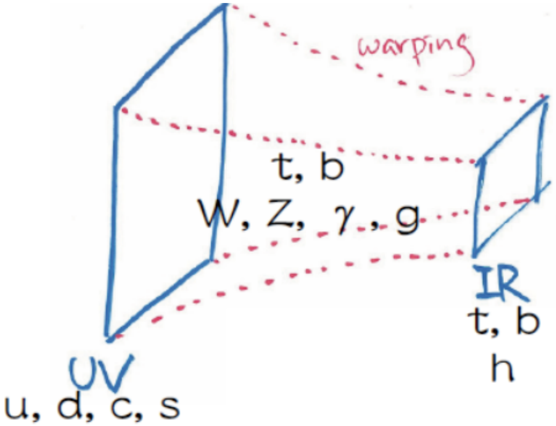




S^1 compactification

S^1/Z_2 compactification

Event topology @ LHC
1) KK photon is LKKP (DM   0.7-1.5TeV)
SUSY-like signal , but degenerated spectrum
0th order all KK particles has 1/R
2) gluon(1)->tt   (Gauge Boson has KK state
fermion is on brane with Higgs)



Observed event topologies are summarized here

topology

Simple

compli-
cated

	ADD (Graviton)			RS		UED	**comment**
	emission	s-chan	t-channel	Graviton	gluon		
monojet	○						simple
γ+missing (monoγ)	○						simple
e^+e^- $\mu^+\mu^-$ non-reso		○					DY BG
resonance				○			Z’,W’
γγ non-reso		○					
resonance				○			
μμ (SS)			○				BG free
2jets		○	○	△	△		difficult
boosted top					○		subjet
multi-objcet w/o lep			○				QCD BG
with lepton			○				
mET+Lepton+jets			△			○	SUSY-like
mET with Photon			△			○	GMSUSY

○ good △ we will see excess, but not leading channel