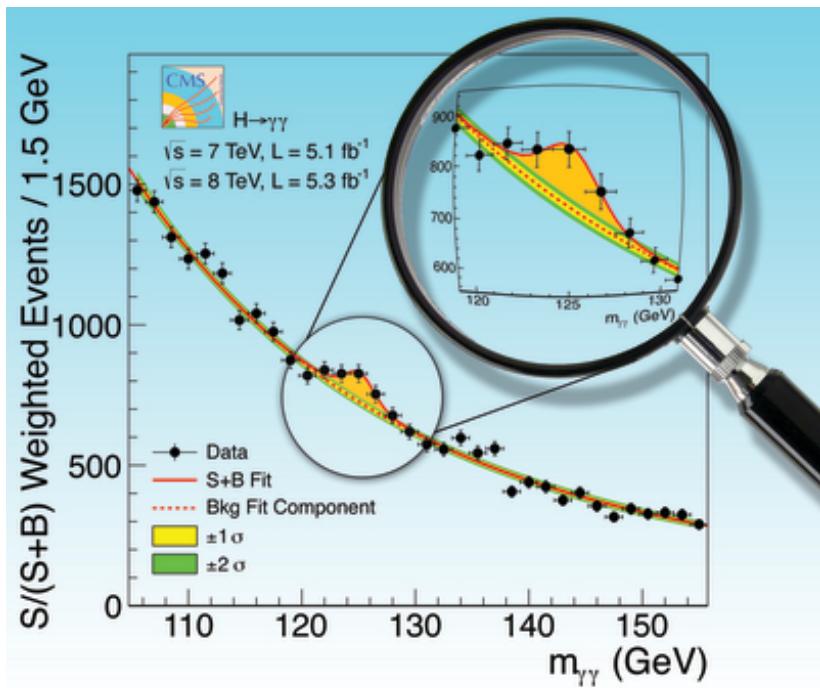


Highlight of LHC Physics

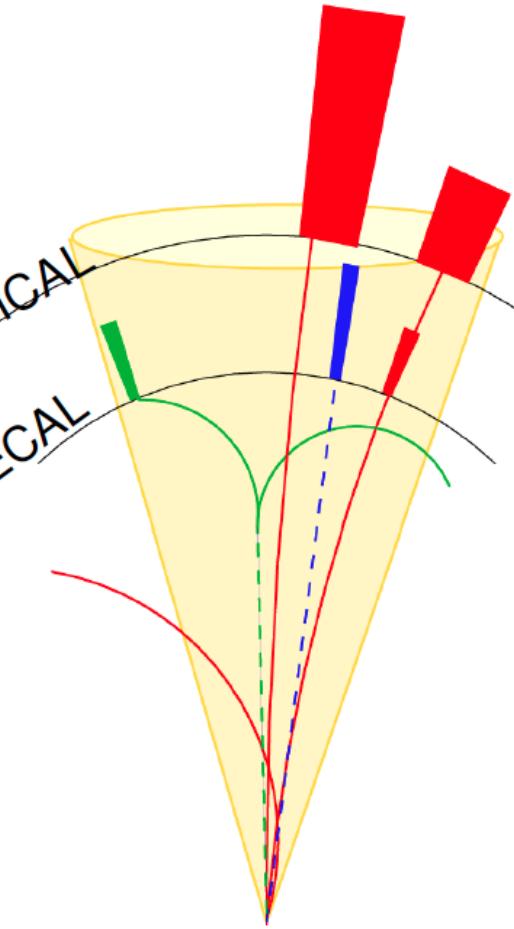


1. Introduction
(kinematics, Luminosity, detector)
2. Standard Model processes
3. The Higgs(-like) boson
- 4A. Supersymmetry with mET
- 4B. Supersymmetry with long-lived particles
5. Extra-dimension & etc
6. Summary

If you have questions even after the school, please send mail to Shoji.Asai@cern.ch

Not Only Scientific results
But also lessons
for experimentalists are listed.

Additional information: Particle flow of CMS



Hadron calorimeter of CMS is thin, energy resolution is not so good.

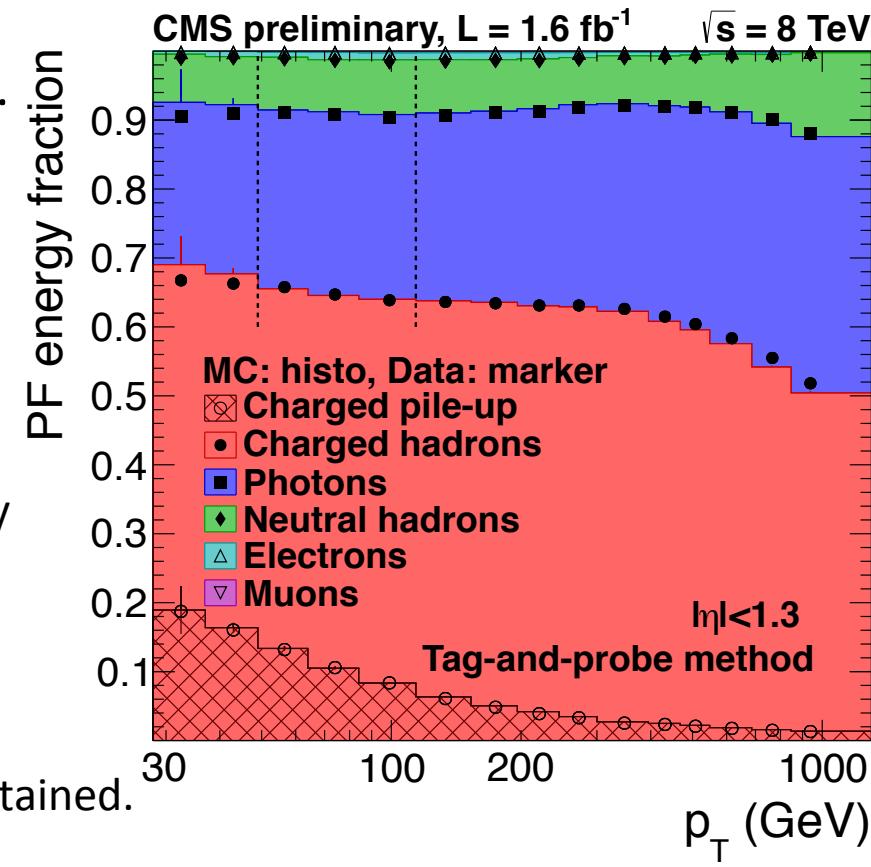
To Solve this problem, tracker information is used.

Charged hadron energy is measured by Tracker,

No use information of Hadron calorimeter.
Energy form only neutral hadrons(n, KL) are used.

Since CMS has strong magnetic field (4T), it is easy to separate neutral hadron from charged hadron,
Now the contribution of Hadron calorimeter is less than 10%, 60-70% is measured by tracker.

The energy resolution of jet similar to ATLAS is obtained.



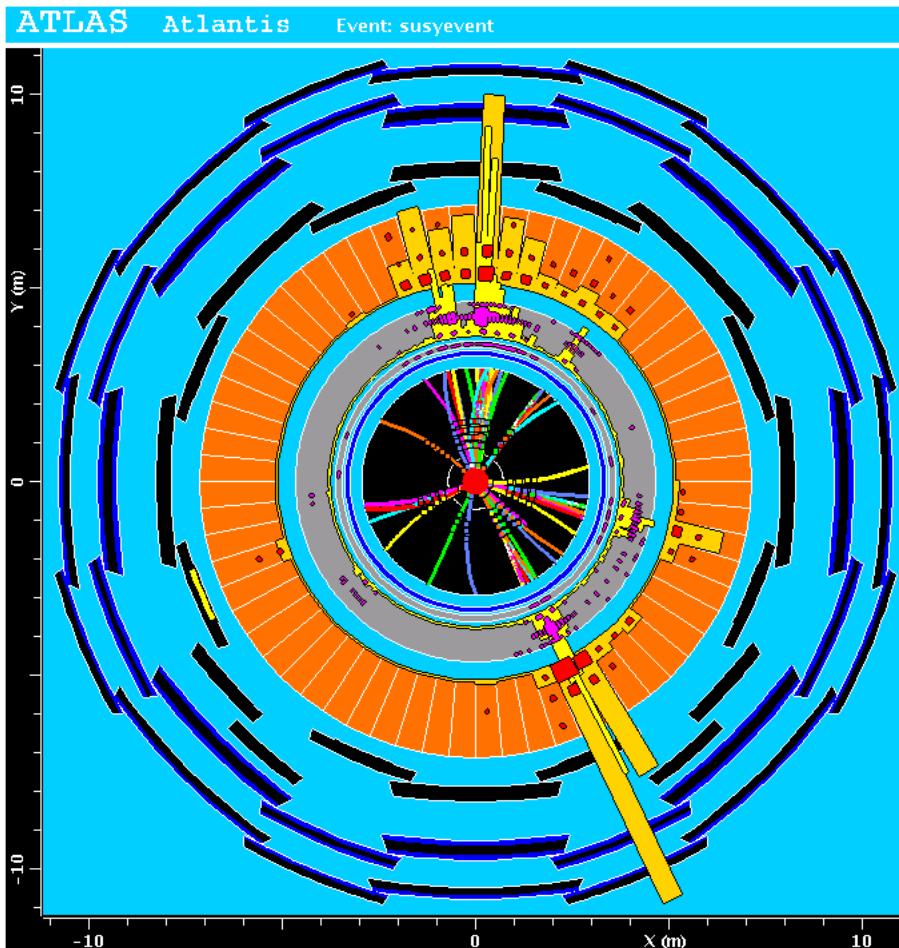
4A. SUSY Searches with mE_T

- (1)Topologies
- (2)Models
- (3)Background
- (4)No lepton mode
- (5)Model less dependence
- (6)One lepton
- (7)3Lepton
- (8)Where is SUSY?

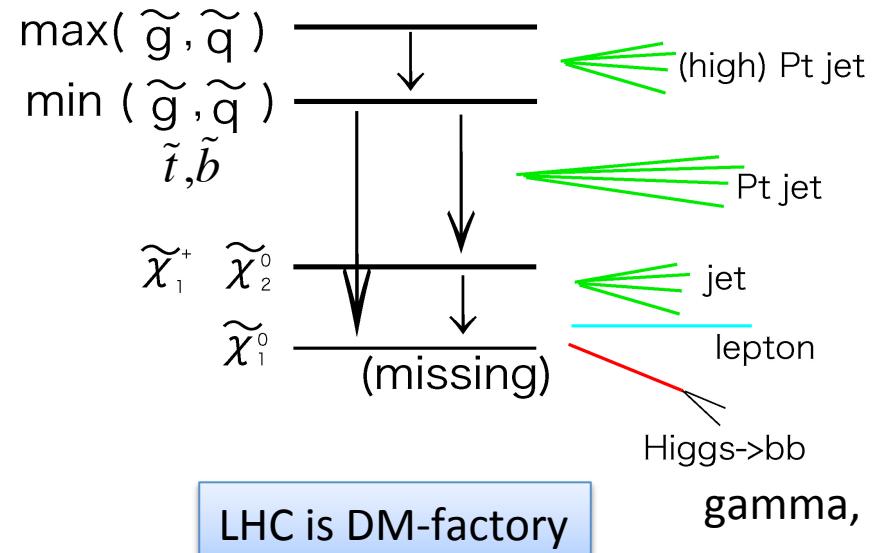
Event Topologies of SUSY Signal @ LHC

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
 $E_T +$ High P_T jets + b-jets
 τ -jets

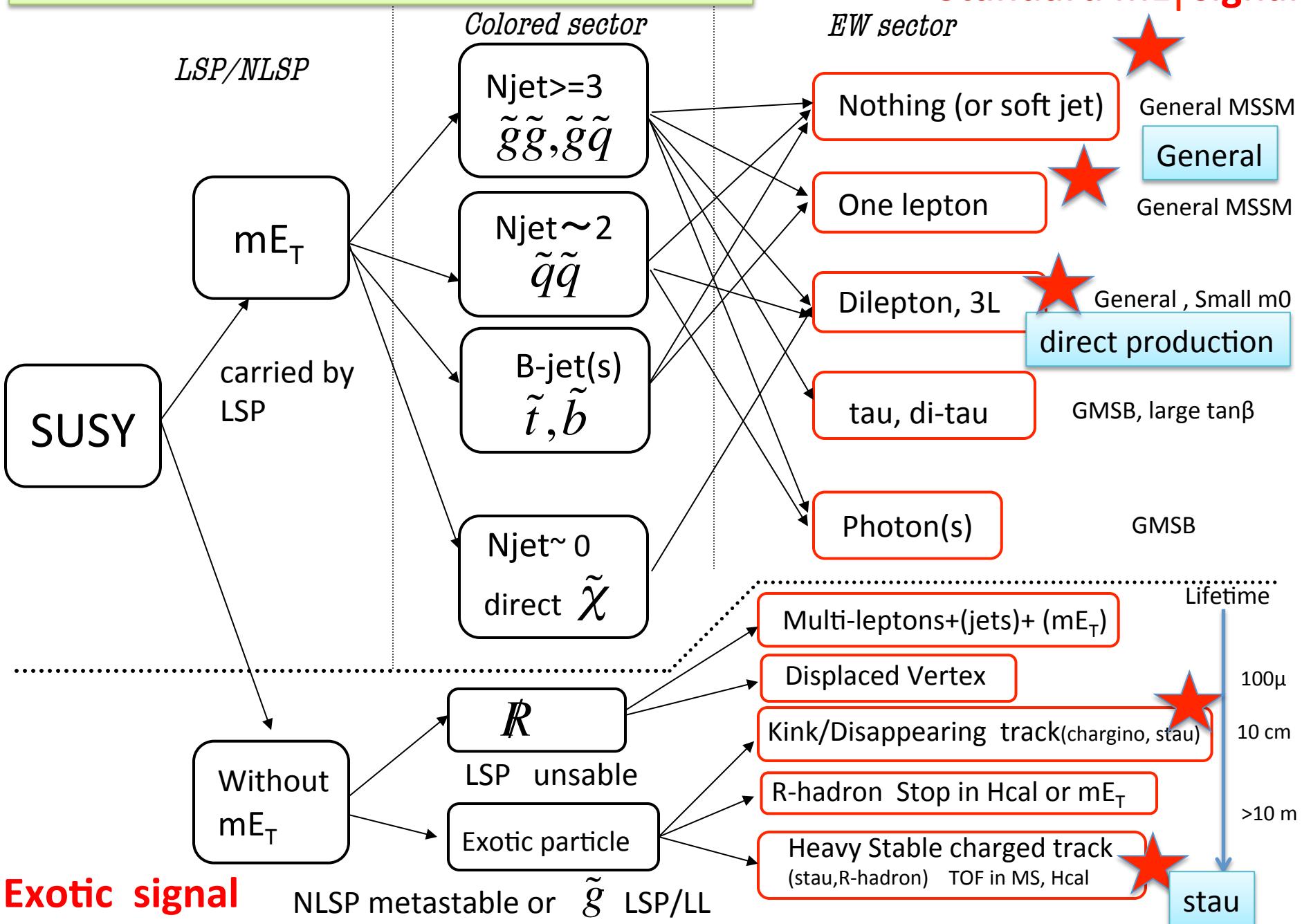
SUSY breaking models have been lectured by Nojiri-san (maybe)

$$m_{susy} = \langle F \rangle / M_{mediation}$$

	mSUGRA	GMSB	AMSB
messenger	Planck scale Physics singlet is introduce by hand $M=M_{pl}, \sqrt{F}=10^{11}$	Messenger sector (No need gravity) $M=10-1000\text{TeV}, \sqrt{F}=10^{5-9}$	Gravity itself simplest $M=M_{pl}, \sqrt{F}=10^{13}$
LSP	neutralino $\sim O(100\text{GeV})$ density ○-△ over close	Gravitino $\sim O(\text{eV-KeV})$ Hot ? X-△	Wino $\sim O(100\text{GeV})$ density ○
FCNC	OK if m_0 (common mass)	OK	if $m_0=0 \rightarrow$ tachion $m_0 >> \text{TeV} \rightarrow$ FCNC OK
Gravitino	100-1000GeV reheating X	<1GeV	10-1000TeV ($\sim m_0$?) reheating ○
Parameter	$m_0, m_{1/2}$, $\text{sign}(\mu), \tan\beta, A$	Λ, M, n $\tan\beta, \text{sign}(\mu), C_{gra}$ Lifetime of NLSP	$m_{3/2} (m_0)$ $\tan\beta, \text{sign}(\mu)$

more detail classification are summarized in this figure:

Standard mE_T signal



General comments on BG processes

BG estimation is crucial for SUSY hunting,
since no peak is expected.

mET is crucial distribution, but mET is also produced by
ν & jet energy resolution(fake mET).

Main BG is W/Z+jets, top pair production
and QCD multijet processes.

(diboson also contributes to search for the EW gaugino
direct production)

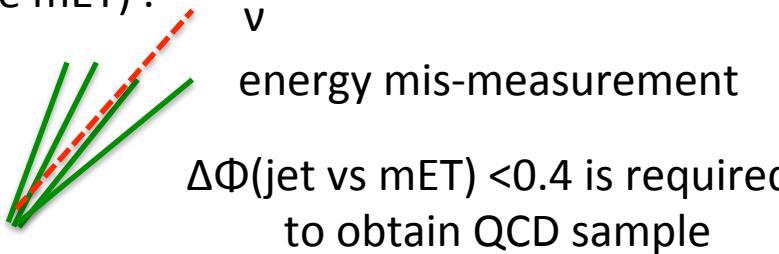
Basic Idea is

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

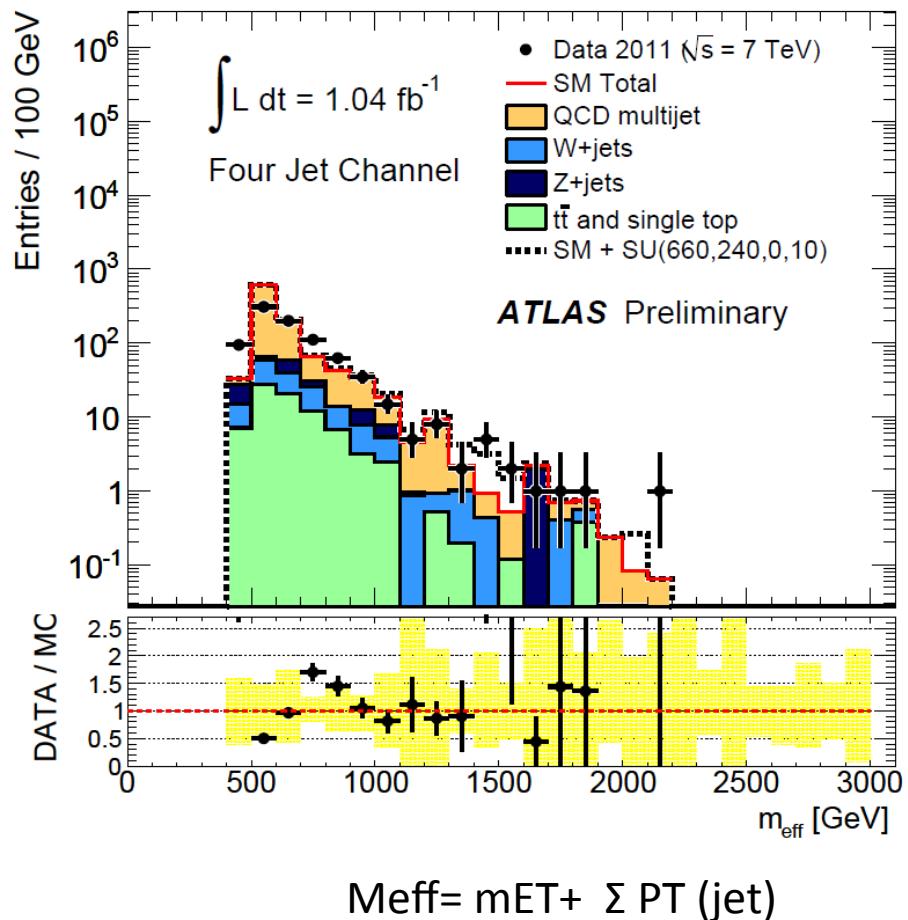
BG1: Control regions (QCD)

QCD multi-jets processes contribute to BG for many SUSY searches, when ν emits in a heavy flavor jet or when jet energy is miss-measured (Fake mET).

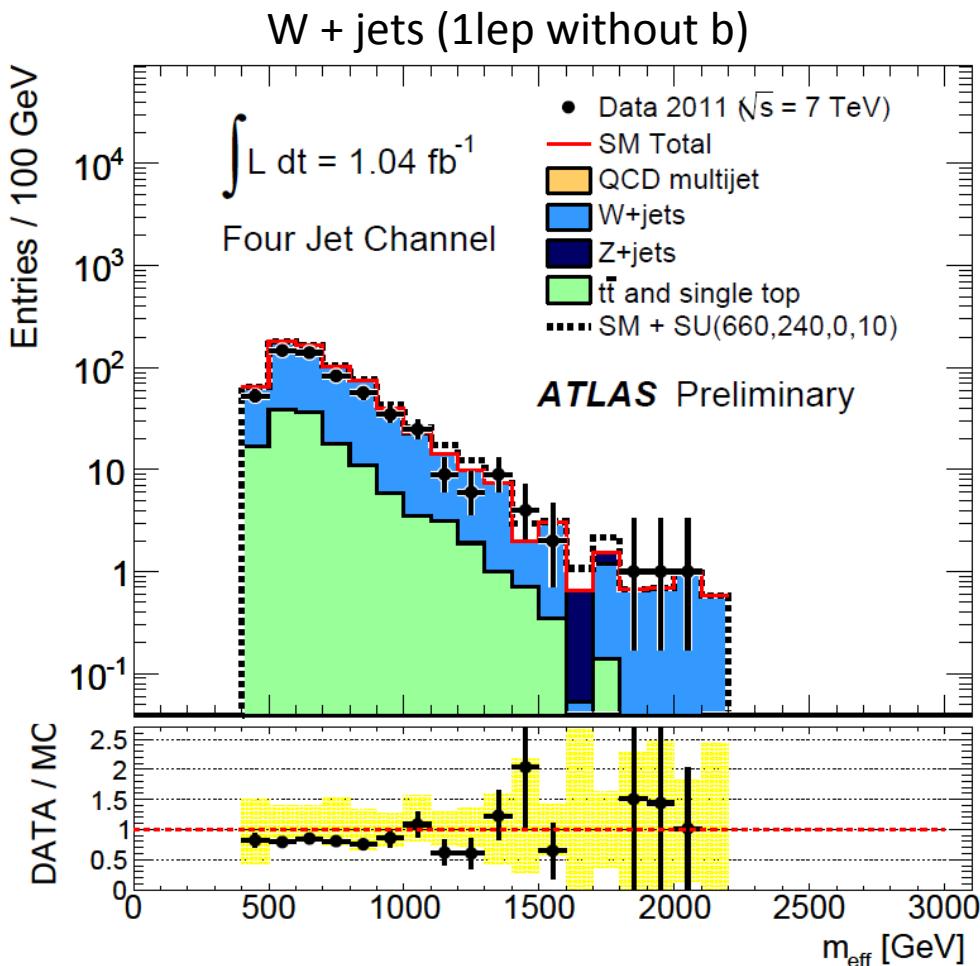


Data is harder than PYTHIA prediction. PYTHIA is parton shower scheme, To produce high PT jet, Q^2 of shower evolution is set high, still not enough, On the other hand, Q^2 is high then too many jets are produced in PYTHIA and there is discrepancy. The other MC also can not reproduce multijet + mET topology.

QCD BG is estimated with real data using this CR



BG2: Control regions (W)



$M_T < M_W$ & no bjets are selected to obtain 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 scale for α_s)

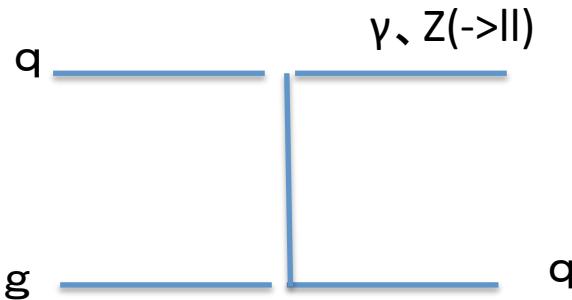
Currently
shape predicted by SHERPA
/Madgraph(CMS) is used
Normalization is determined by data

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 for solid discovery.

BG3: Control regions (Z)

Physics process is the same as W+jets

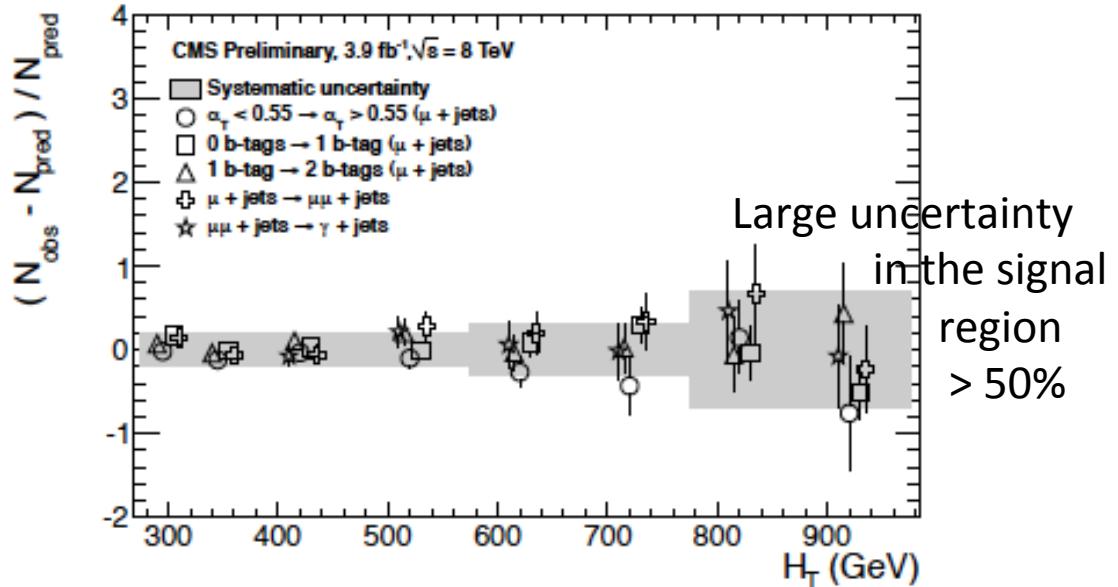
BG ($Z \rightarrow vv$)+Jets
can be estimated
with



Events with high PT jet are expected. we can examine using γ +Jets, $Z(\rightarrow \mu\mu)$ +jets; But stat. is too limited for High Pt

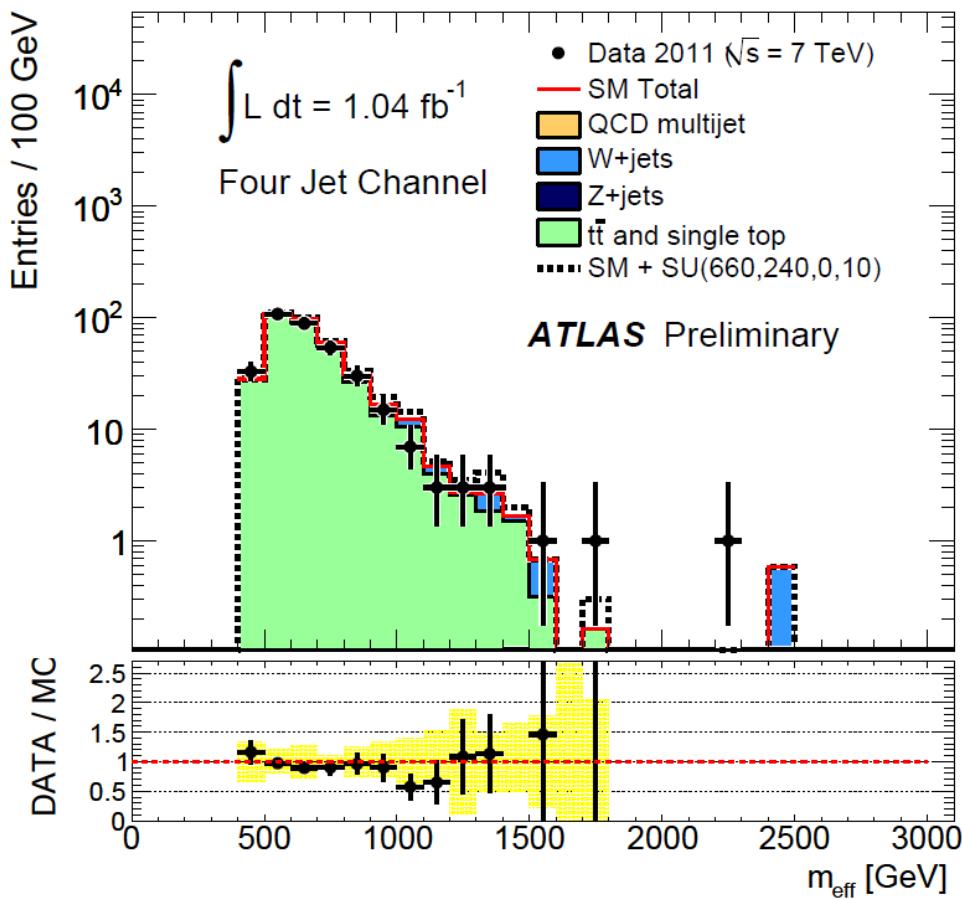
Currently MC produced by ALPGEN/ SHERPA / MADGRAPH(CMS) are used and Normalization has been performed using data(Control region). There are two serious problems:

No body believes MC for such a high end of the kinematics.
depends on PDF, α_s (scale what scale is used),



We need some idea to estimate BG using real data for this region

BG4: Control regions ($t\bar{t}$)



$M_T < M_W$ & bjets are selected to enhance $t\bar{t}$ sample

$t\bar{t}$ is not dominant BG except for mET+bjet analysis, since σ at 7TeV is 170pb.

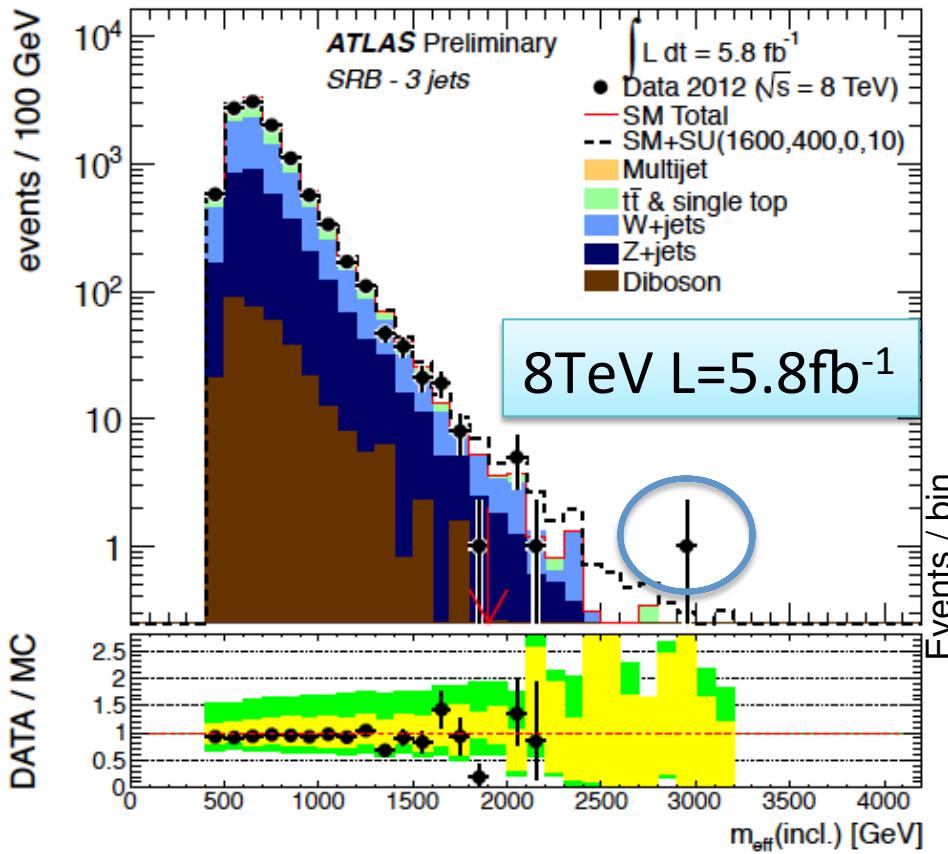
It becomes serious at ECM=14TeV (830pb)

Now basically We use MC even with normalization.

But $t\bar{t}+N\text{jets}$, high m_{eff} regions still need more data and study.

No Lepton mode

At least 3 (high $\text{PT} > 160, 130, 60 \text{ GeV}$) Jets & Large $\text{mET}(>475 \text{ GeV})$ & mET is not direct to jet



$\text{Meff} > 1900 \text{ GeV}$ ($\text{mET}/\text{Meff} > 0.25$)

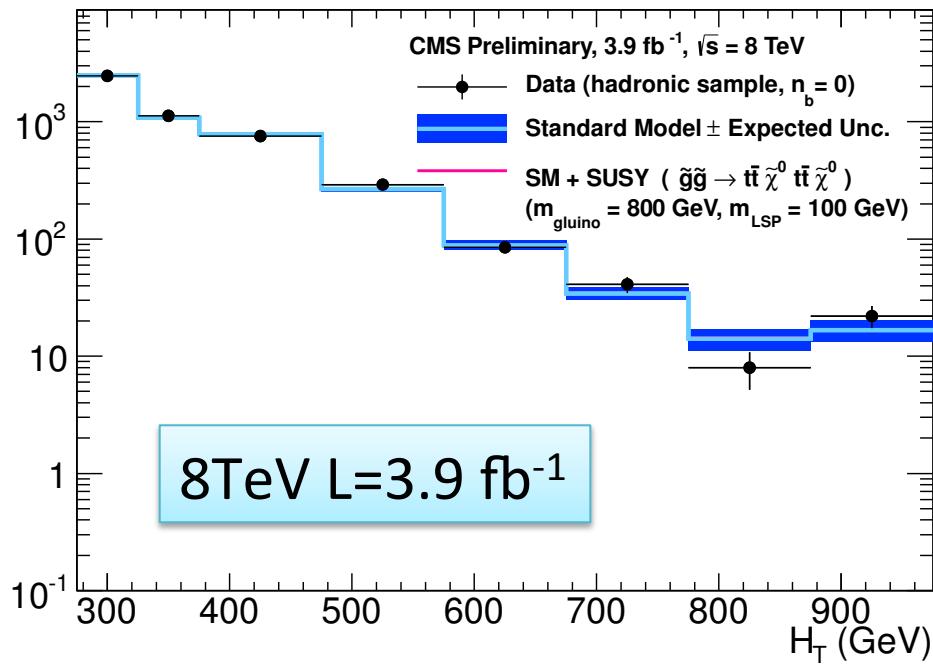
Data 7 event

BG 8.7 ± 3.4 (**Z 5.1** **W 2.7** **t 0.8**)

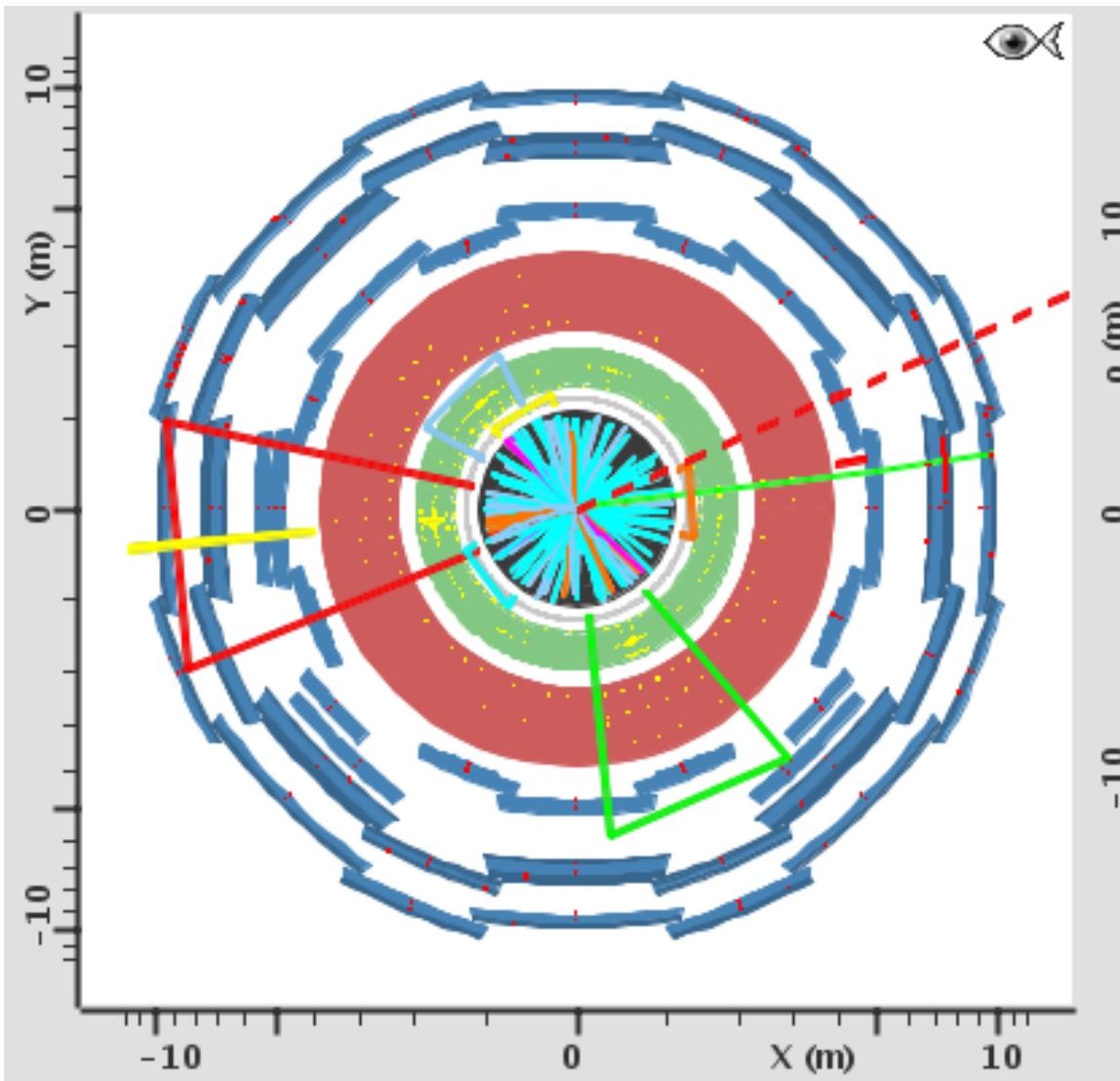
1 candidate in high Meff region

Not only mET but also
Scalar sum of Jet activity(H_T) is useful,
since many jet activity is expected.
 H_T is used in CMS and
 $\text{Meff} = \text{mET} + \sum P_T(\text{jet})$ is used in ATLAS.

Both Data distribution agree well with BG



Candidate event (Hardest)



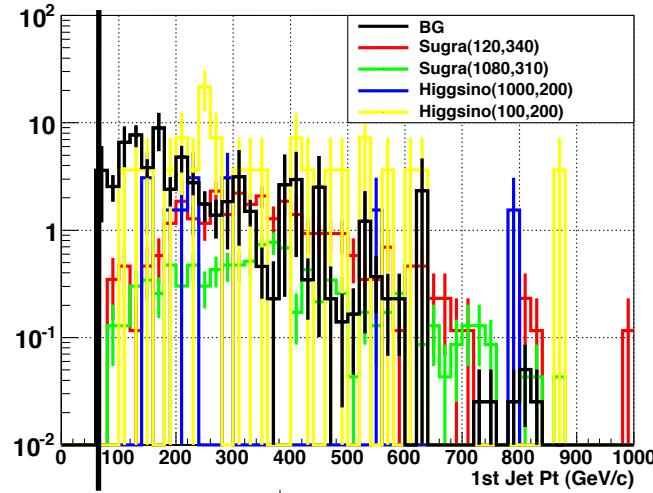
$M_{eff}(4j) = 2992 \text{ GeV}$
 $MET = 1170 \text{ GeV} \quad \phi=0.4$

2 high PT ($>150\text{GeV}$) Jets
pT=1335 GeV eta=0.96 phi=3.05
pT=530 GeV eta=-1.26 phi=-1.17
pT=112 GeV eta=-0.38 phi=2.34
pT=21GeV eta=0.13 phi=0.07

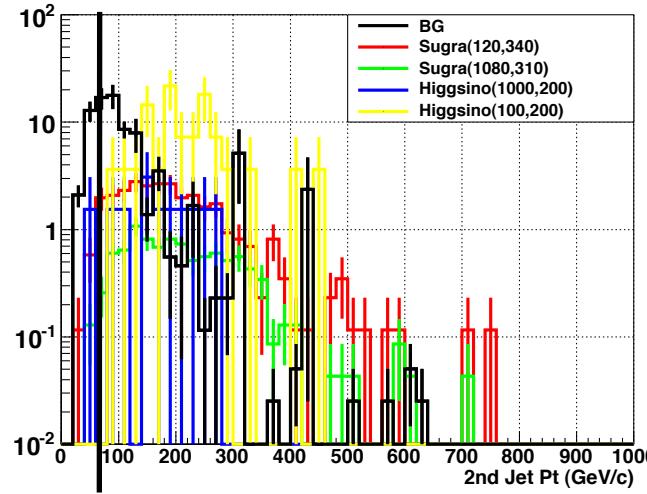
3,4 th is soft ? maybe W+jets
in the next page

Jet PT of W+jets process comparing with signal

$< 1^{\text{st}} \text{ Jet Pt} >$

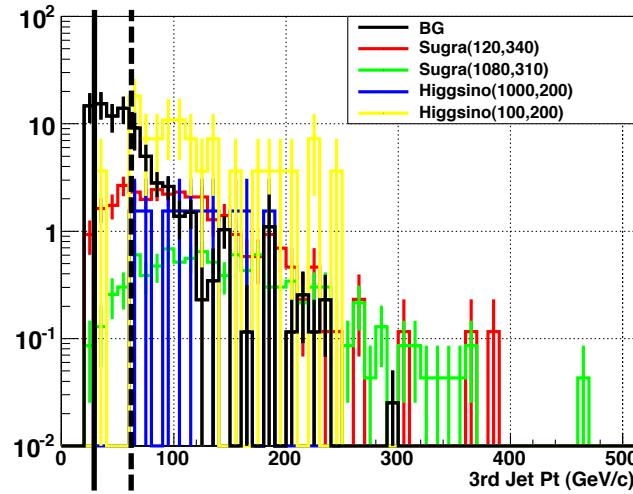


$< 2^{\text{nd}} \text{ Jet Pt} >$

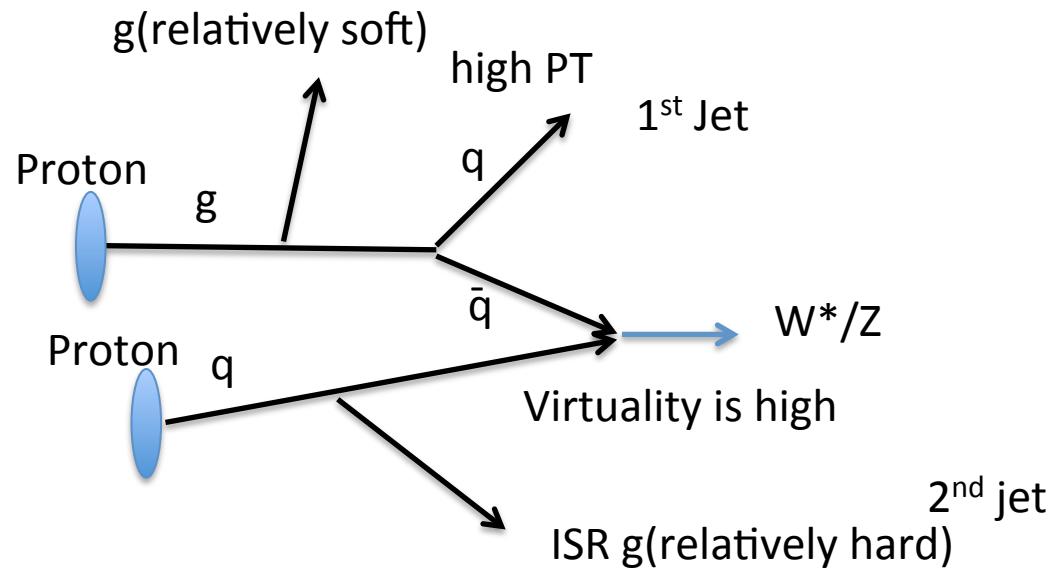


2nd is still hard

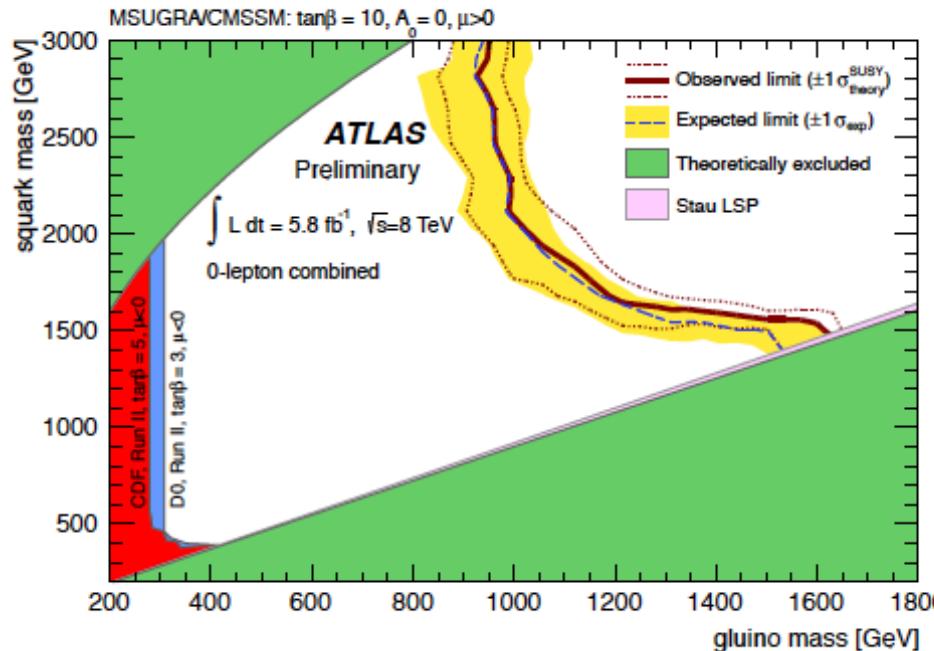
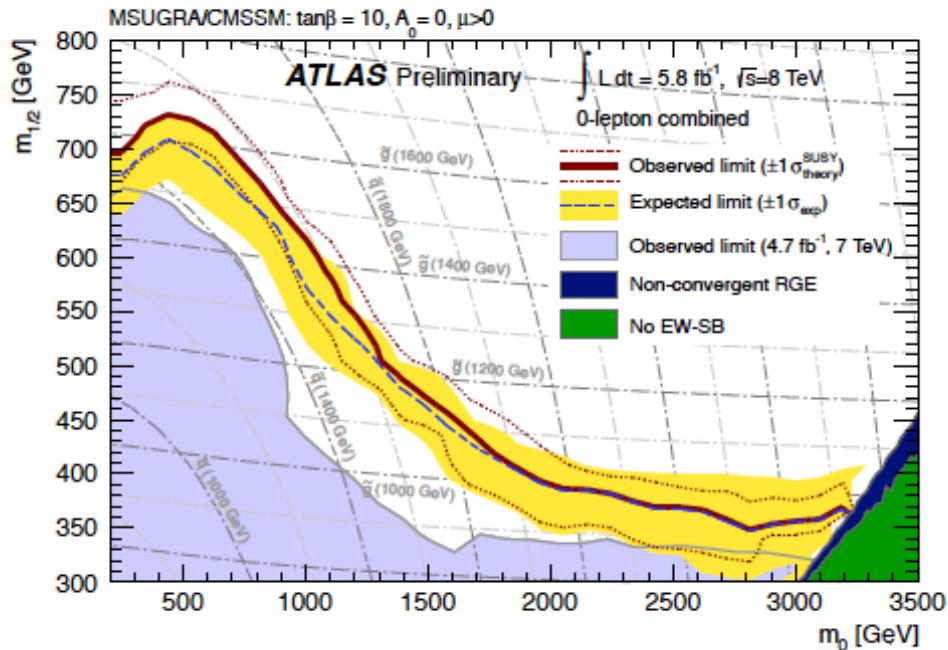
$< 3^{\text{rd}} \text{ Jet Pt} >$



3rd becomes softer



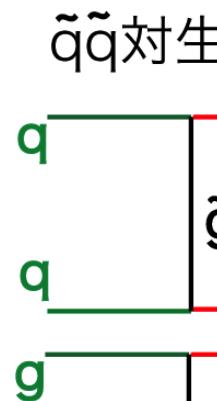
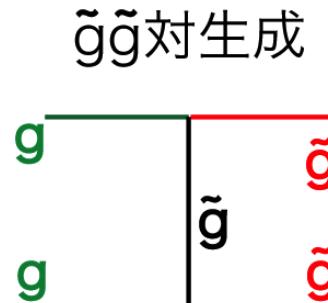
Limit within CMSSM model



heavy squark means that only $gg \rightarrow \text{gluino}$ gluino possible at LHC. Since PDF for high x gluon has steep distribution, heavy gluino σ is seriously suppressed.

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

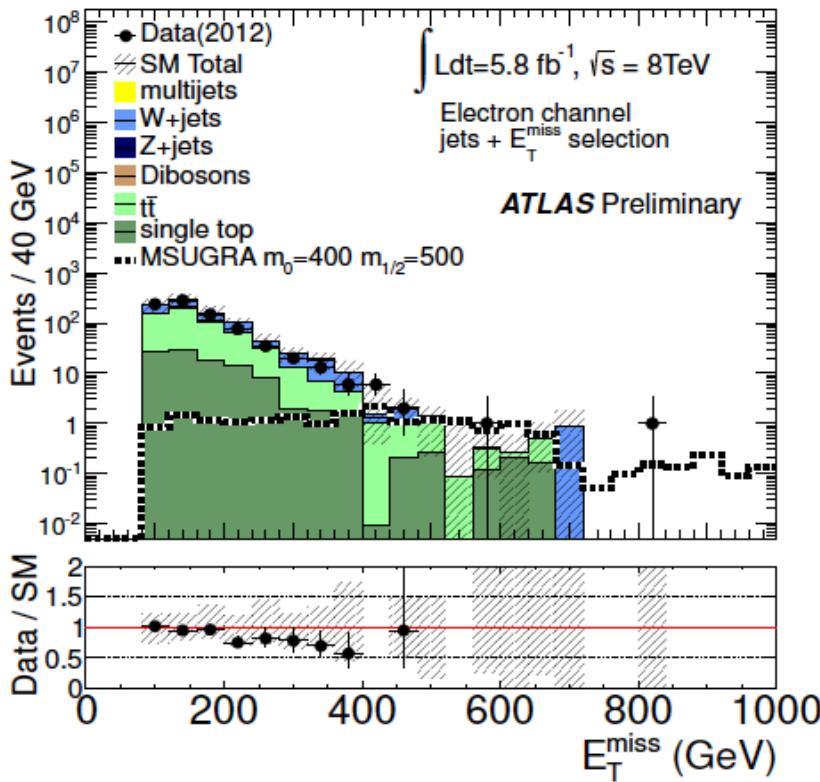
gluino,squark $\sim 1.5 \text{ TeV}$
gluino 950 GeV for Heavy squark



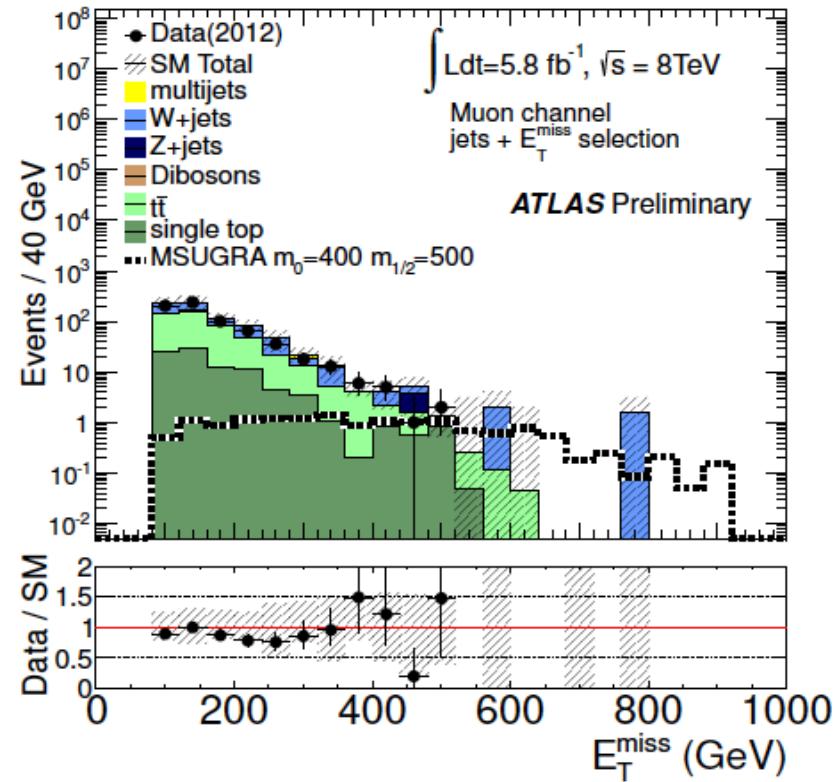
One lepton Mode

Electron (PT>25GeV) or muon (PT>20GeV) is required for trigger/ BG suppression
 At least 4jets(PT>80 GeV) MET>250GeV MT>100GeV Meff>800GeV

electron



muon

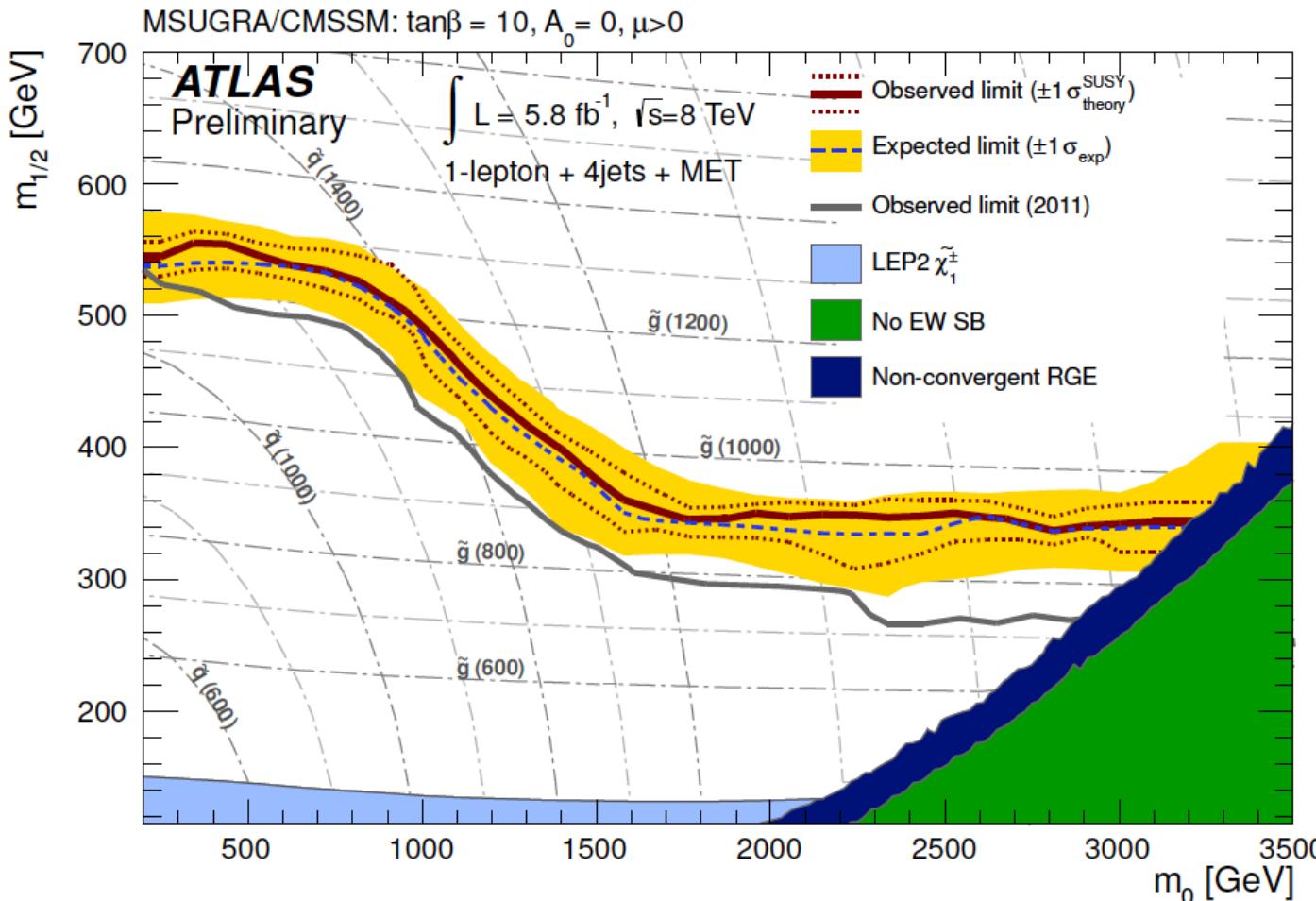


$$M_T \equiv \sqrt{2E_T^{\text{miss}} p_T^\ell [1 - \cos(\Delta\phi_{\ell, E_T^{\text{miss}}})]}.$$

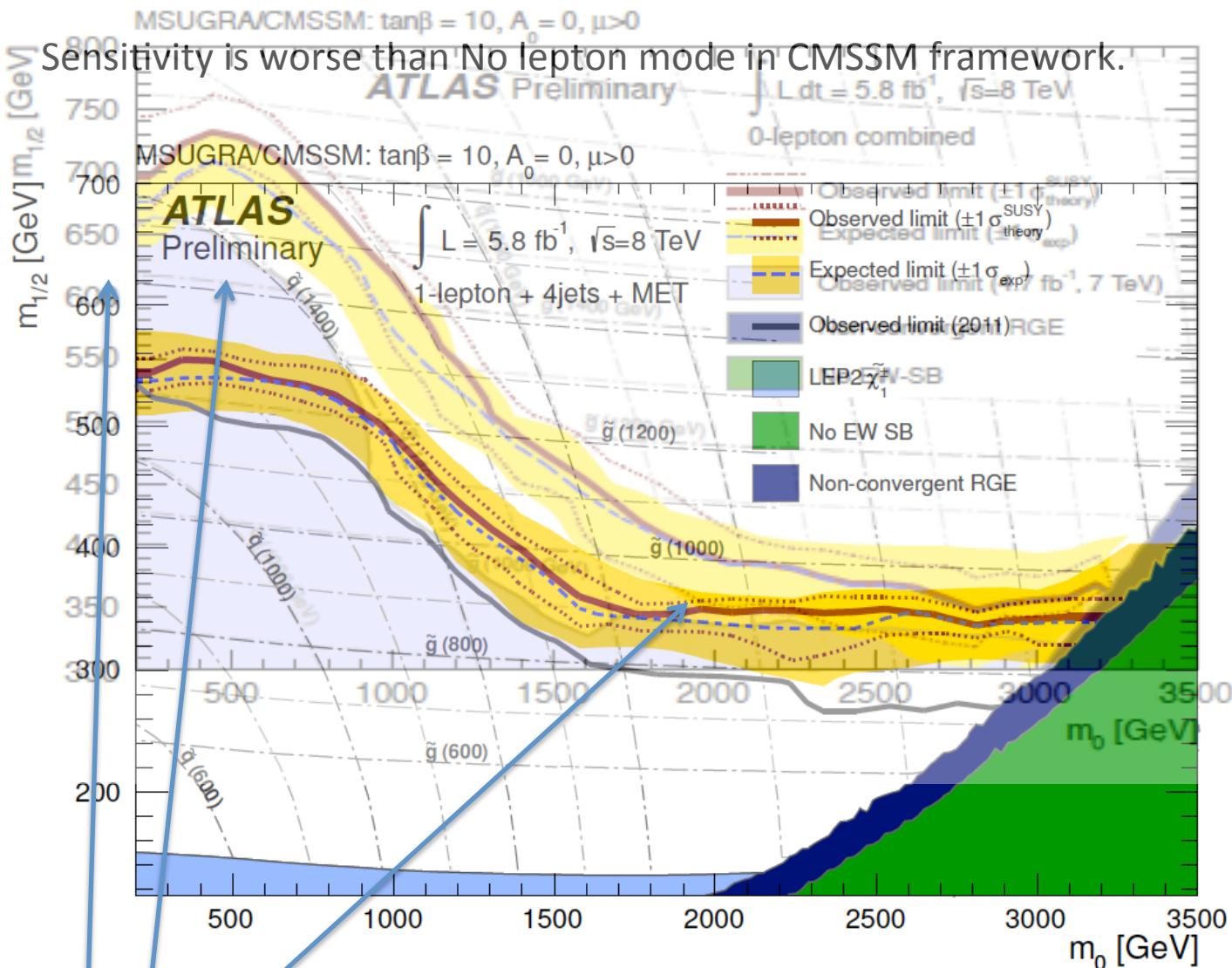
tt is dominant background processes; No excess was found in data @ 8TeV ($L=5.8\text{fb}^{-1}$)

Limit in CMSSM framework for one lepton mode

Sensitivity is worse than No lepton mode in CMSSM framework:
But similar



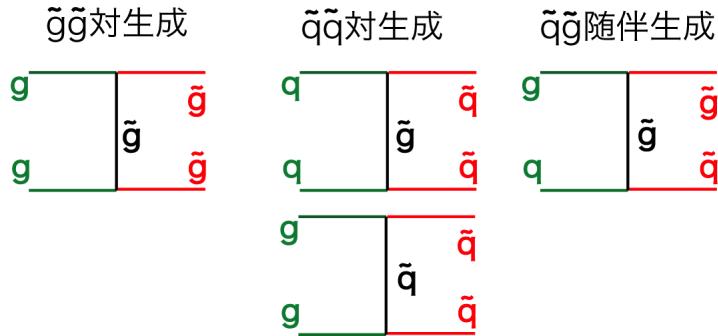
Topology & BG are different! No Lepton mode W,Z
One Lepton mode tt -> complementary analysis



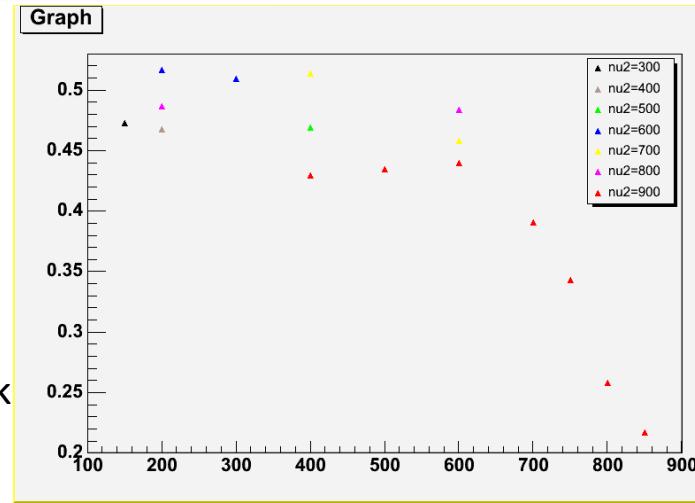
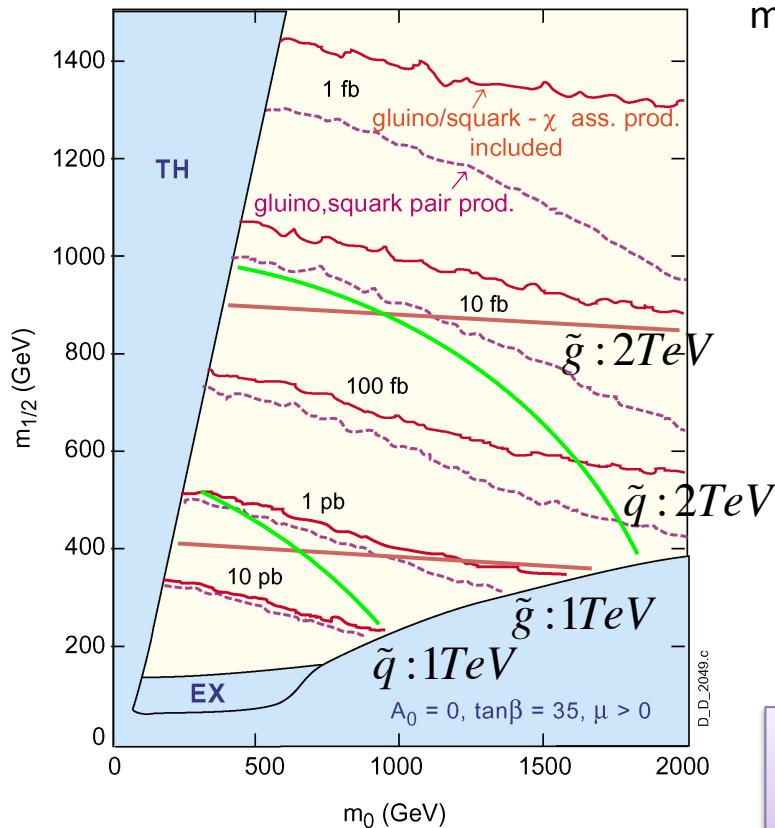
Let's superimpose
no lepton results

- ◎ Similar large m_0 : Spectrum is relatively compressed \rightarrow Lepton help sensitivity
- ◎ relatively Small m_0 Large $m_{1/2}$ enhance mET \rightarrow No lepton has good sensitivity
- ◎ Small m_0 Lepton branching increase, No lepton mode sensitivity becomes worse

LHC results does not depend strongly on SUSY models



Production process is just strong interaction.
It depend on gluino,squark mass.



LSP mass (GeV) for Gluino mass 1TeV

Distribution does not strongly depend on the the other SUSY parameters.

(-> Not so large on Efficiency/ BG)
Main difference comes from the mass difference between LSP and the produced colored mass.

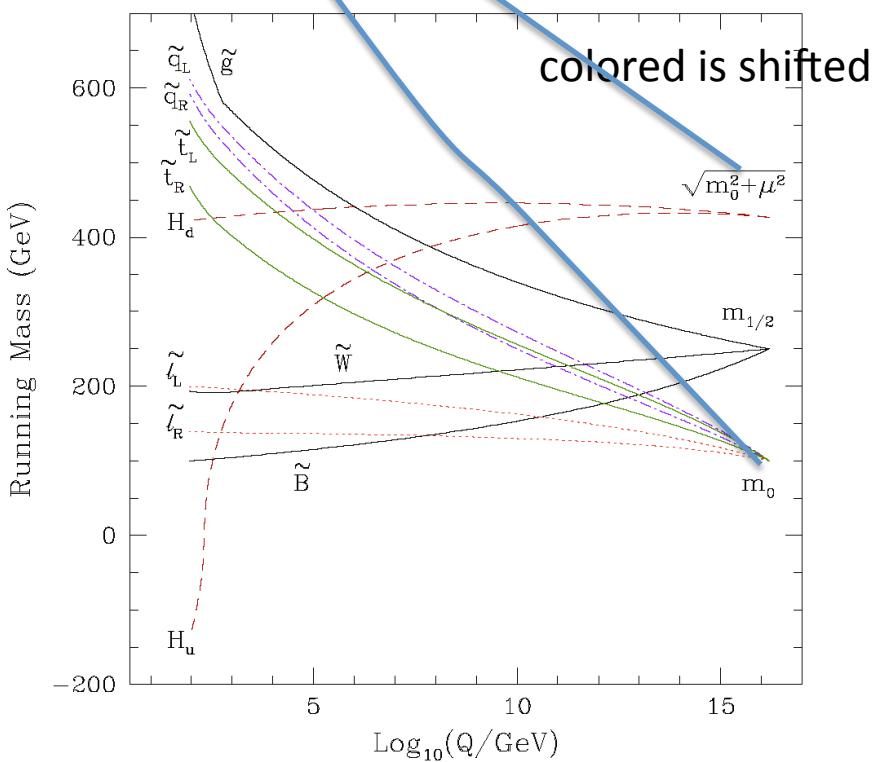
$$\Delta M(\text{coloured vs LSP}) = 400\text{GeV} (@ 14\text{TeV})$$

mass difference between LSP and colored mass is crucial: $\Delta M < 300\text{GeV} \rightarrow$

No SUSY found @ LHC (1) heavy colored (2) degenerate (3) No mET (4) NoSUSY @ 1TeV scale $\rightarrow 10\text{TeV}$?

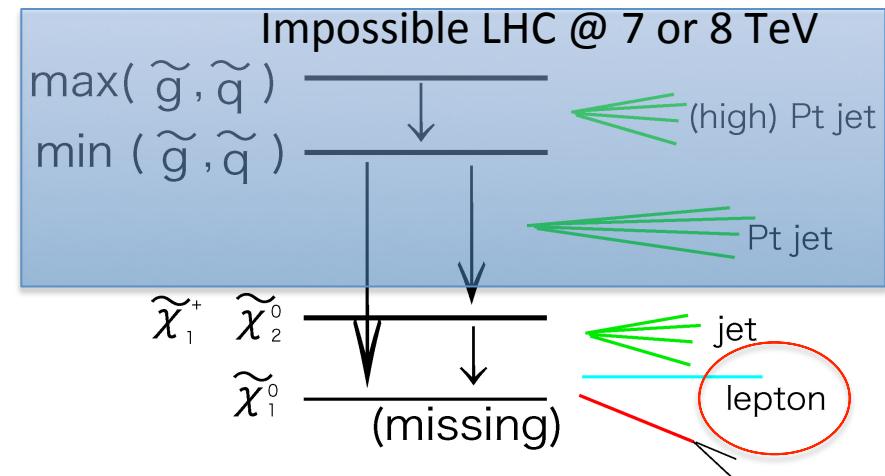
(1) Heavy colored particle

(1) Heavy Colored particles are heavy at LHC (especially for LHC 8TeV)
 but EW gaugino / Higgsino/ are still light
 LHC phenomenology EW gaugino direct production



A: Colored particle has steep coefficient of RGE
 (AMSB model \rightarrow I will show in LL)

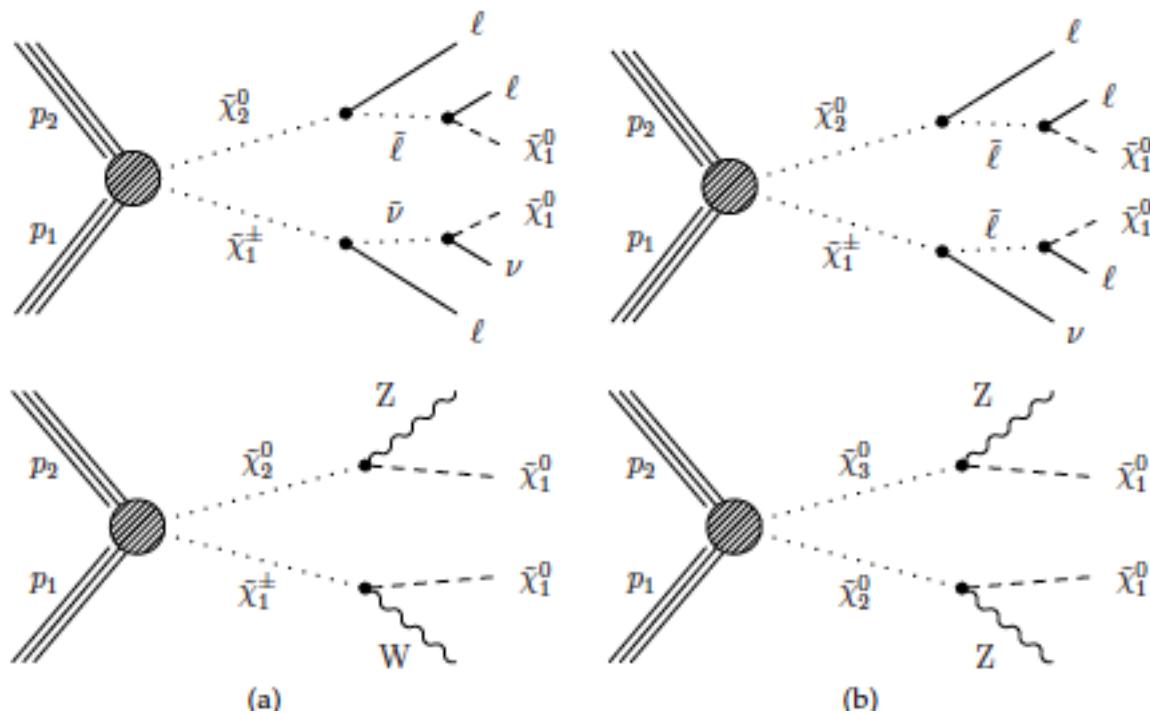
B: colored mass is heavy at GUT scale



Gaugino Direct Production
 is only possible signal.

Heavy colored particle 3/2 lepton modes

chargino1 + neutralino2 \rightarrow lepton pairs + mET (no requirement on jet)



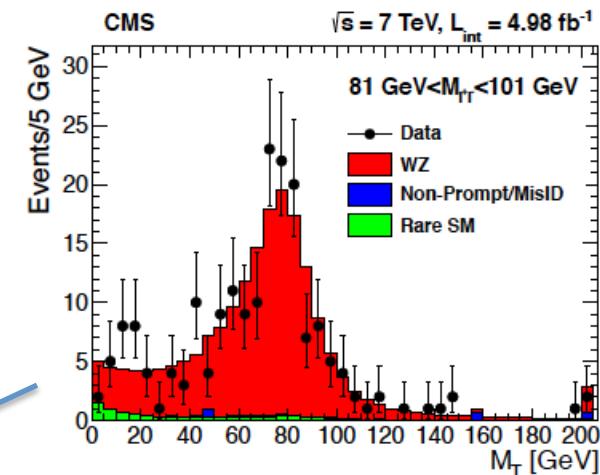
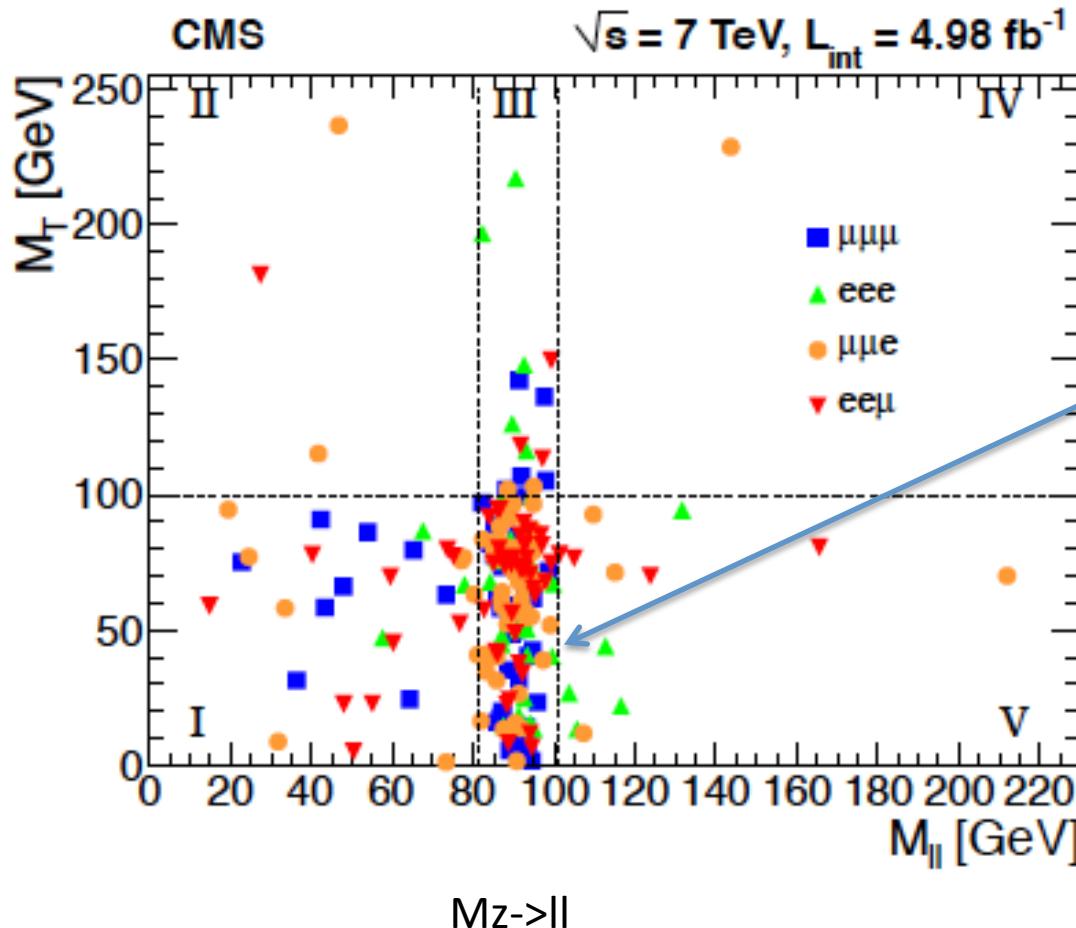
If slepton is lighter than ch1/nu2,
branching fraction
including lepton
increases significantly.

Otherwise, WZ+mET
topology is dominant,
BG WZ is also large

Heavy colored particle 3/2 lepton modes

chargino1 + neutralino2 \rightarrow lepton pairs + mET (no requirement on jet)

at least 3 leptons ($>20, 10, 8$ GeV) HT(sum of Jet PT) < 200 GeV to reduce top

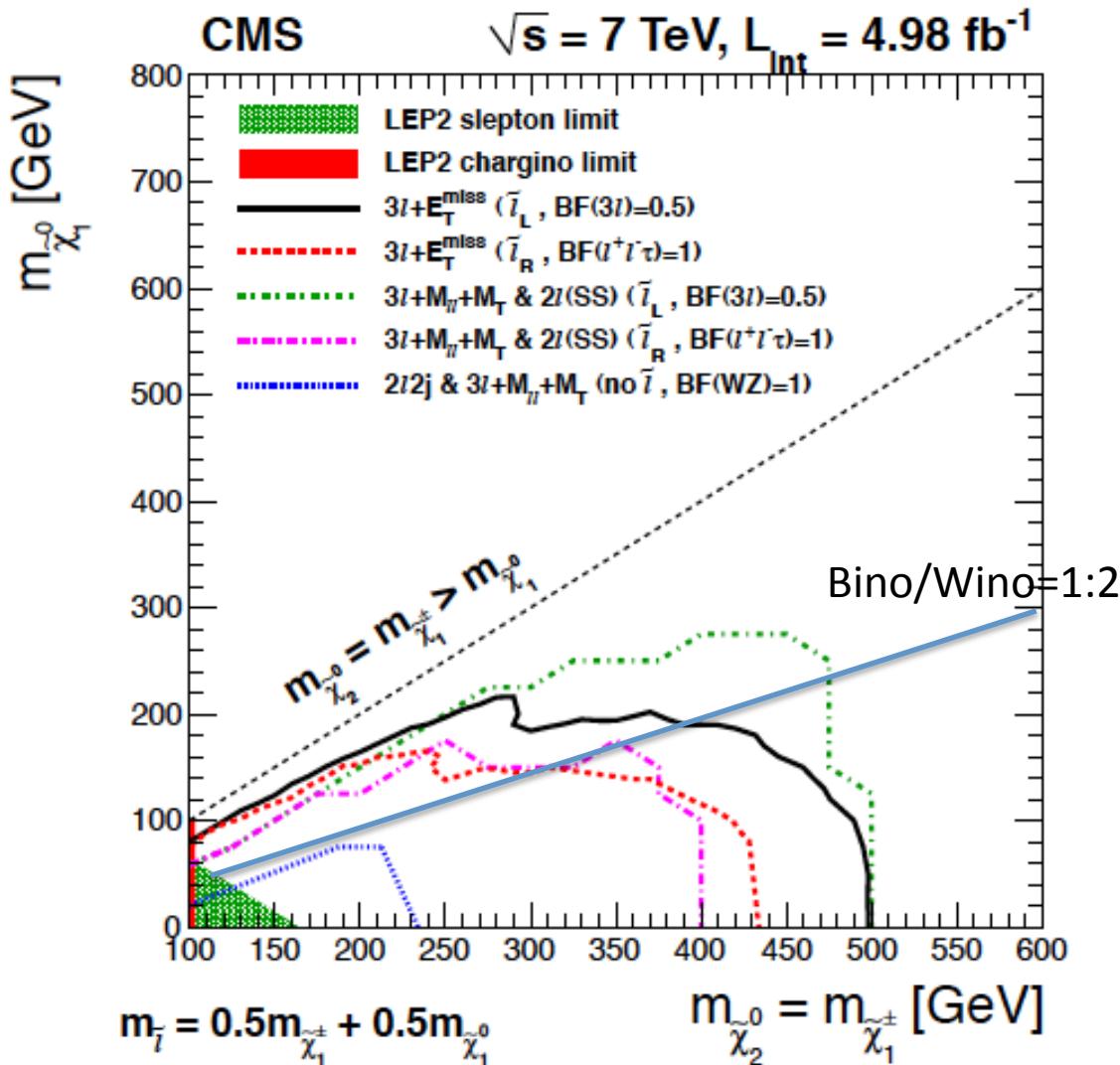


$$M_T \equiv \sqrt{2E_T^{\text{miss}} p_T^\ell [1 - \cos(\Delta\phi_{\ell, E_T^{\text{miss}}})]}.$$

Signal is expect for all regions
When $\Delta m(\text{ch1}/\nu\text{2} \text{ vs } \nu\text{1})$ is large, III,IV,V are sensitive:

No excess was found:

Heavy colored particle 3/2 lepton modes



If slepton contribution is small
No limit is obtained.

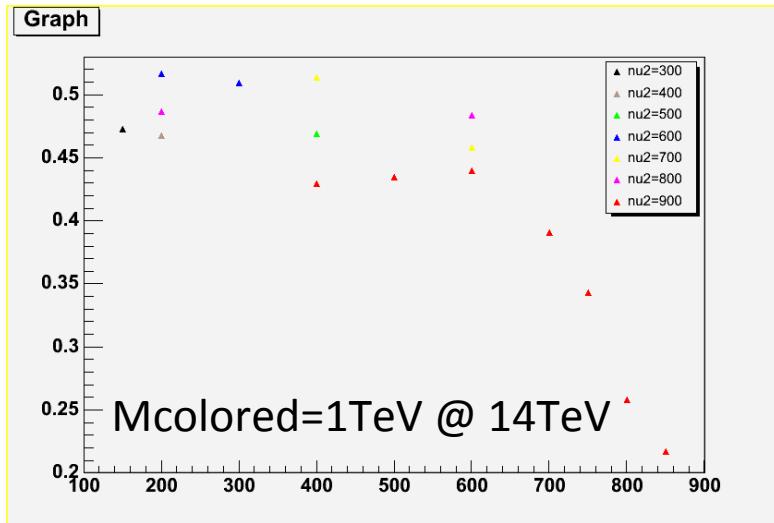
$\text{Br}(3L) = 50\%$ case
 $M(\text{char1}, \nu 2) > 400 \text{ GeV}$ for
 $M(\nu 1) = 1/2 M$

Higgsino case
(Branching lepton decreases
 ΔM decrease)
No limit is set

Since LHC is $p+p$, $q\bar{q}$ is sea quark.
 $q + q\bar{q} \rightarrow \text{Wino Zino}$
is suppressed

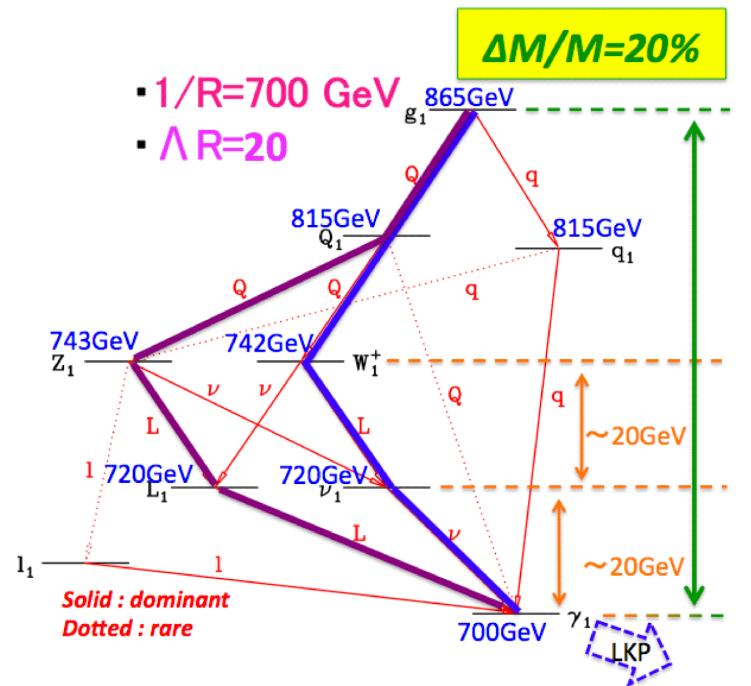
**Need new idea
for Ch1Nu2 study**

(2)Degenerate case (UED,Mirage SUSY)



If $\Delta M/M < 30\%$ (Degenerated mass spectrum)
current susy hunting is not valid.

The mirage SUSY models or the UED model:
New physics scale is close to TeV.
Degenerate spectrum is expected.



This shows the mass spectrum for UED model

When mass spectrum become degenerate,
the SM particles emitting from cascade decay becomes soft and sensitivity(trigger)
is seriously loosen.

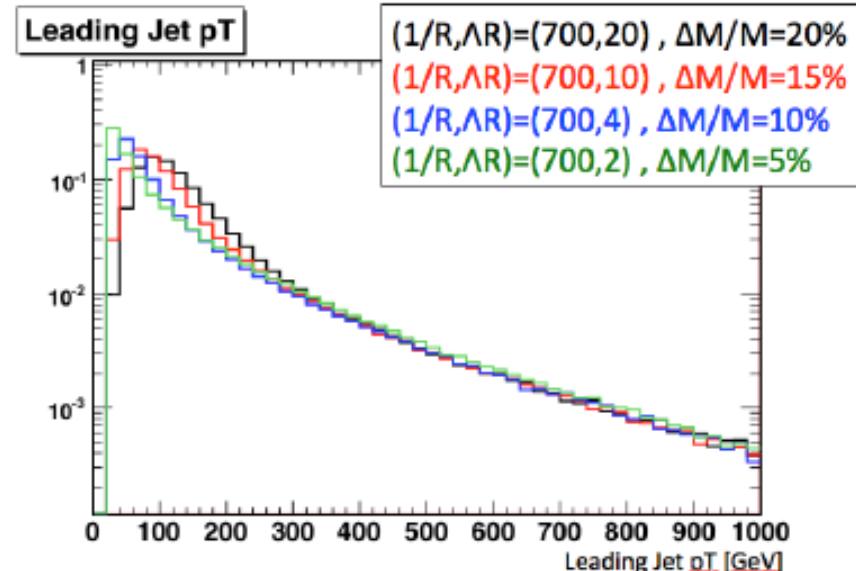
ISR jet is useful for degenerate cases

When heavy particles (high Q^2) produce,
high virtuality is necessary for incoming partons

It is not new physics. Just QCD.

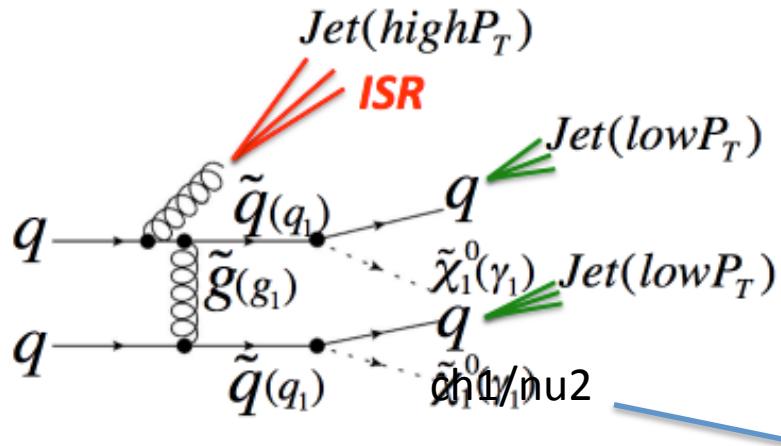
To make high virtuality state,
the high PT ISR jet is emitted.

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



@10TeV

Pt distribution of the Leading Jet (UED signal)



Various mass difference case are shown.

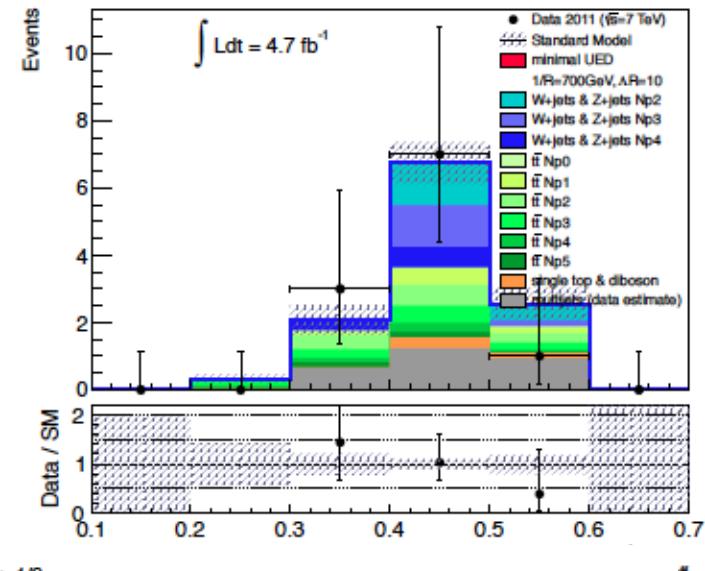
- (1) Hard spectrum is expected
- (2) Independent on the mass differences

soft lepton

To reduce BG, soft lepton

Basic selection for the ISR +soft lepton

	2-jets channel
Lepton p_T	$7 < p_T^e < 25 \text{ GeV}$, $6 < p_T^\mu < 20 \text{ GeV}$
E_T^{miss}	$> 250 \text{ GeV}$
m_T	$> 100 \text{ GeV}$
$E_T^{\text{miss}} / m_{\text{eff}}$	> 0.3
N_{jet}	≥ 2
jet p_T	$> 130, 25 \text{ GeV}$

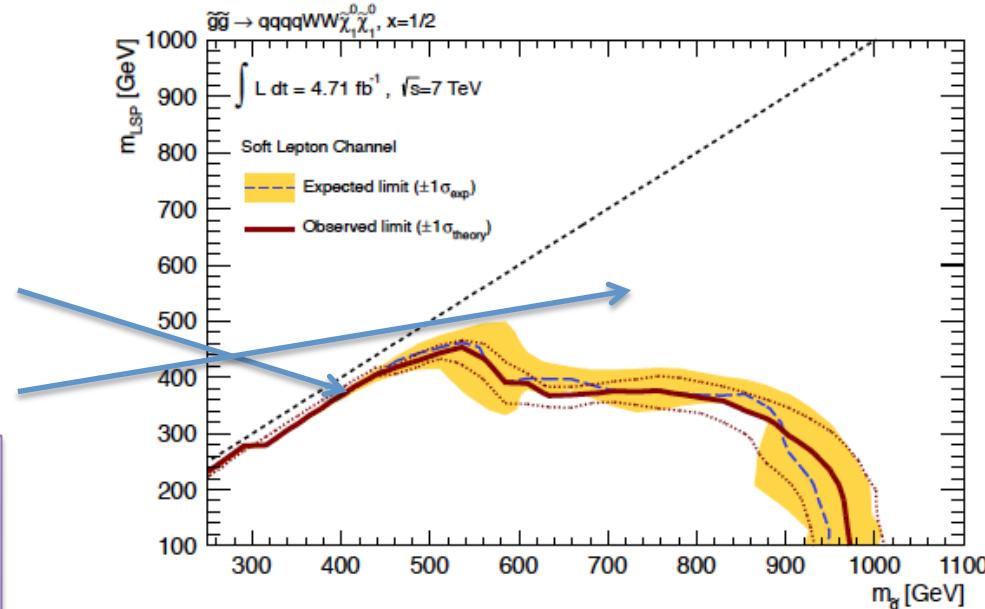


No excess found

Degenerated region
is covered gluino < 550GeV

Still No sensitivity > 550GeV

Need New Idea/data
for > 550GeV



No excess was found for all SUSY searches

ATLAS SUSY Searches* - 95% CL Lower Limits (Status: SUSY 2012)

Inclusive searches

MSUGRA/CMSSM : 0 lep + j's + $E_{T,\text{miss}}$	$L=5.8 \text{ fb}^{-1}$, 8 TeV [ATLAS-CONF-2012-109]	1.50 TeV	$\tilde{q} = \tilde{g}$ mass	
MSUGRA/CMSSM : 1 lep + j's + $E_{T,\text{miss}}$	$L=5.8 \text{ fb}^{-1}$, 8 TeV [ATLAS-CONF-2012-104]	1.24 TeV	$\tilde{q} = \tilde{g}$ mass	$\int L dt = (1.00 - 5.8) \text{ fb}^{-1}$
Pheno model : 0 lep + j's + $E_{T,\text{miss}}$	$L=5.8 \text{ fb}^{-1}$, 8 TeV [ATLAS-CONF-2012-109]	1.18 TeV	\tilde{g} mass ($m(\tilde{q}) < 2 \text{ TeV}$, light $\tilde{\chi}_1^0$)	$\sqrt{s} = 7, 8 \text{ TeV}$
Pheno model : 0 lep + j's + $E_{T,\text{miss}}$	$L=5.8 \text{ fb}^{-1}$, 8 TeV [ATLAS-CONF-2012-109]	1.38 TeV	\tilde{q} mass ($m(\tilde{q}) < 2 \text{ TeV}$, light $\tilde{\chi}_1^0$)	
Gluino med. $\tilde{\chi}^\pm (\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^\pm)$: 1 lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-041]	900 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 200 \text{ GeV}$, $m(\tilde{\chi}^\pm) = \frac{1}{2}(m(\tilde{\chi}_1^0) + m(\tilde{g}))$)	
GMSB : 2 lep (OS) + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [Preliminary]	1.24 TeV	\tilde{g} mass ($\tan\beta < 15$)	
GMSB : 1-2 τ + 0-1 lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-112]	1.20 TeV	\tilde{g} mass ($\tan\beta > 20$)	
GGM : $\gamma\gamma + E_{T,\text{miss}}$	$L=4.8 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-072]	1.07 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) > 50 \text{ GeV}$)	

3rd gen. squarks
gluino mediated

$\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ (virtual b) : 0 lep + 1/2 b-j's + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$, 7 TeV [1203.6193]	900 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 300 \text{ GeV}$)	
$\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ (real b) : 0 lep + 3 b-j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [1207.4686]	1.02 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 400 \text{ GeV}$)	
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 1 lep + 1/2 b-j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [1207.4686]	1.00 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) = 60 \text{ GeV}$)	
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 2 lep (SS) + j's + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$, 7 TeV [1203.6193]	710 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 150 \text{ GeV}$)	
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 3 lep + j's + $E_{T,\text{miss}}$	$L=5.8 \text{ fb}^{-1}$, 8 TeV [ATLAS-CONF-2012-105]	850 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 300 \text{ GeV}$)	
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 0 lep + multi-j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-108]	760 GeV	\tilde{g} mass (any $m(\tilde{\chi}_1^0) < m(\tilde{g})$)	
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 0 lep + 3 b-j's + $E_{T,\text{miss}}$	$L=5.8 \text{ fb}^{-1}$, 8 TeV [ATLAS-CONF-2012-103]	1.00 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 300 \text{ GeV}$)	
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 0 lep + 3 b-j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [1207.4686]	940 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 50 \text{ GeV}$)	
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (real t) : 0 lep + 3 b-j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [1207.4686]	820 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) = 60 \text{ GeV}$)	

3rd gen. squarks
direct production

$bb, b_1 \rightarrow b\tilde{\chi}_1^0$: 0 lep + 2-b-jets + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-106]	480 GeV	\tilde{b} mass ($m(\tilde{\chi}_1^0) < 150 \text{ GeV}$)	
$bb, b_1 \rightarrow t\tilde{\chi}_1^{\pm}$: 3 lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-108]	380 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^{\pm}) = 2m(\tilde{\chi}_1^0)$)	
$t\bar{t}$ (very light), $t \rightarrow b\tilde{\chi}_1^{\pm}$: 2 lep + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [CONF-2012-059]	135 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^{\pm}) = 45 \text{ GeV}$)	
$t\bar{t}$ (light), $t \rightarrow b\tilde{\chi}_1^{\pm}$: 1/2 lep + b-jet + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [CONF-2012-070]	120-173 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^{\pm}) = 45 \text{ GeV}$)	
$t\bar{t}$ (heavy), $t \rightarrow b\tilde{\chi}_1^{\pm}$: 0 lep + b-jet + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [1208.1447]	380-465 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^{\pm}) = 0$)	
$t\bar{t}$ (heavy), $t \rightarrow b\tilde{\chi}_1^{\pm}$: 1 lep + b-jet + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [CONF-2012-073]	230-440 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^{\pm}) = 0$)	
$t\bar{t}$ (heavy), $t \rightarrow b\tilde{\chi}_1^{\pm}$: 2 lep + b-jet + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [CONF-2012-071]	298-305 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^{\pm}) = 0$)	
$t\bar{t}$ (GMSB) : $Z(\rightarrow ll) + b\text{-jet} + E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$, 7 TeV [1204.6736]	310 GeV	\tilde{t} mass ($115 < m(\tilde{\chi}_1^0) < 230 \text{ GeV}$)	

EW direct

$l_1 l_1, l_1 \rightarrow \tilde{\chi}_1^{\pm}$: 2 lep + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [CONF-2012-076]	93-180 GeV	\tilde{l} mass ($m(\tilde{\chi}_1^{\pm}) = 0$)	
$\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow l\bar{v}(l\bar{v}) \rightarrow l\bar{v}\tilde{\chi}_1^0$: 2 lep + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [CONF-2012-077]	120-330 GeV	$\tilde{\chi}_1^{\pm}$ mass ($m(\tilde{\chi}_1^0) = 0, m(\tilde{l}) = \frac{1}{2}(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0))$)	
$\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow 3(l\bar{v} + v\bar{2}\tilde{\chi}_1^0)$: 3 lep + $E_{T,\text{miss}}$		60-500 GeV	$\tilde{\chi}_1^{\pm}$ mass ($m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0) = 0, m(\tilde{l})$ as above)	

Long-lived particles

AMSB (direct $\tilde{\chi}_1^{\pm}$ pair prod.) : long-lived $\tilde{\chi}_1^{\pm}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-111]	210 GeV	$\tilde{\chi}_1^{\pm}$ mass ($1 < \tau(\tilde{\chi}_1^{\pm}) < 10 \text{ ns}$)	
Stable \tilde{g} R-hadrons : Full detector	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-075]	985 GeV	\tilde{g} mass	
Stable \tilde{t} R-hadrons : Full detector	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-075]	683 GeV	\tilde{t} mass	
Metastable \tilde{g} R-hadrons : Pixel det. only	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-075]	910 GeV	\tilde{g} mass ($ \tau(\tilde{g}) > 10 \text{ ns}$)	

RPV

RPV : stable $\tilde{\tau}$	$L=1.1 \text{ fb}^{-1}$, 7 TeV [1109.3089]	1.32 TeV	$\tilde{\nu}_{\tau}$ mass ($\lambda_{311}^{+} = 0.10, \lambda_{312}^{+} = 0.05$)	
Bilinear RPV : 1 lep + j's + $E_{T,\text{miss}}$	$L=1.0 \text{ fb}^{-1}$, 7 TeV [1109.6606]	760 GeV	$\tilde{q} = \tilde{g}$ mass ($c\tau_{\text{LSP}} < 15 \text{ mm}$)	
BC1 RPV : 4 lep + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-035]	1.77 TeV	\tilde{g} mass	
RPV $\tilde{\chi}_1^0 \rightarrow q\bar{q}u : \mu + \text{heavy displaced vertex}$	$L=4.4 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-113]	700 GeV	\tilde{q} mass ($3.0 \times 10^{-5} < \lambda_{211}^{+} < 1.5 \times 10^{-5}, 1 \text{ mm} < c\tau < 1 \text{ m}, \tilde{g} \text{ decoupled}$)	
Hypercolour scalar gluons : 4 jets, $m_{\tilde{g}} = m_{\tilde{q}}$	$L=4.6 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-110]	100-287 GeV	s gluon mass (incl. limit from 1110.2693)	
Spin dep. WIMP interaction : monojet + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-084]	709 GeV	M* scale ($m_{\tilde{g}} < 100 \text{ GeV}$, vector D5, Dirac χ)	
Spin indep. WIMP interaction : monojet + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$, 7 TeV [ATLAS-CONF-2012-084]	548 GeV	M* scale ($m_{\tilde{g}} < 100 \text{ GeV}$, tensor D9, Dirac χ)	

stop limit
300-400GeV Now

10⁻¹

1

10

Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena shown.

All limits quoted are observed minus 1.5 theoretical signal cross section uncertainty.

4B SUSY with Exotic signature

Motivation

no mET signature should be covered

- (1) AMSB Wino LSP chargino life $c\tau = 1-10 \text{ cm}$ Wino $\Omega \ll 1$
- (2) GMSB stau NLSP stable in detector or decay in ID Gravitino DM
- (3) SPLIT SUSY ($m_0 > 1000 \text{ TeV}$) gluino $\rightarrow R\text{-hadron}$
- (4) R-parity violation If coupling is small displaced vertex

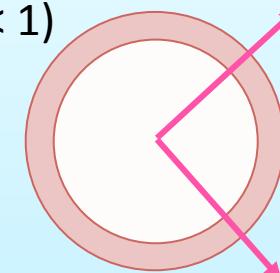
Signatures

(A) Heavy charged particles (GMSB stau, R-hadron)

(A1) dE/dx energy loss in the semiconductor , $c\tau \gg \text{detector size}$

(A2) TOF information in Cal. or muon system ($\beta < 1$)

$\beta < 1$



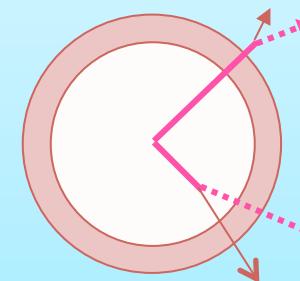
(B) Decay in flight (AMSB wino, GMSB stau)

(B1) Kink/Disappearing track in the continuous tracking system (ATLAS)

heavy slow particles

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

$c\tau \sim \text{detector size}$



(C) stau and R-hadron(both neutral and charged)

stop in the dense material (Hadron calorimeter)

kink or
disappearing
track

dedicated trigger is necessary to catch decay.

methods as function of lifetime

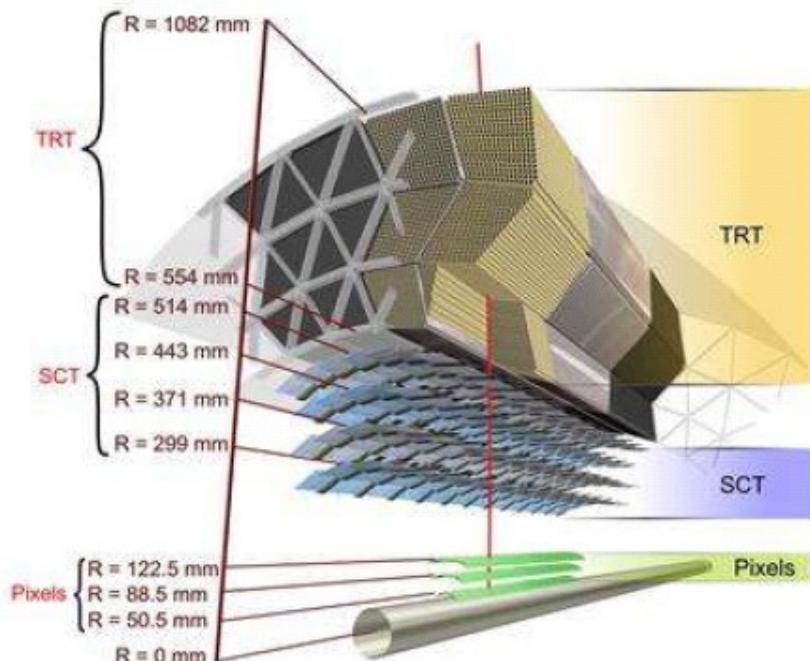
cty 0.1mm

100mm

1000mm

∞

	Displaced Vertex	dE/dx in Pixel	Kink / Disappearing	dE/dx in TRT	Time of Flight In Calorimeter	Time Of Flight In Muon Spectrometer	Stop in Calorimeter
RPV	✓		✓				
AMSB		✓?	✓	★			
Stau LL		✓	★	✓	✓	✓	✓
R-had	?	✓			✓	✓	✓

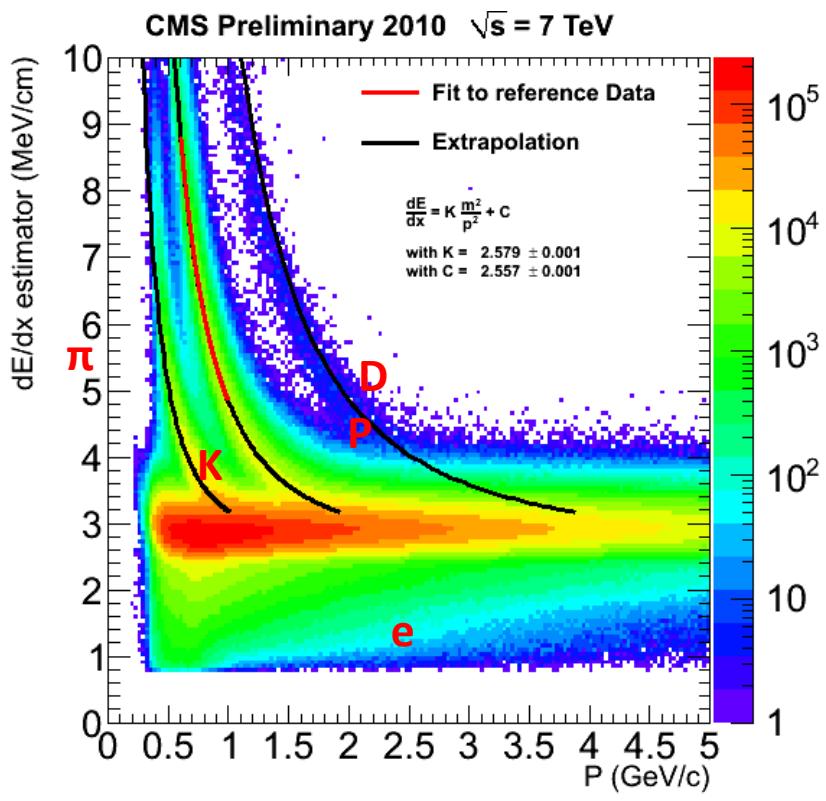


Radius of each detector

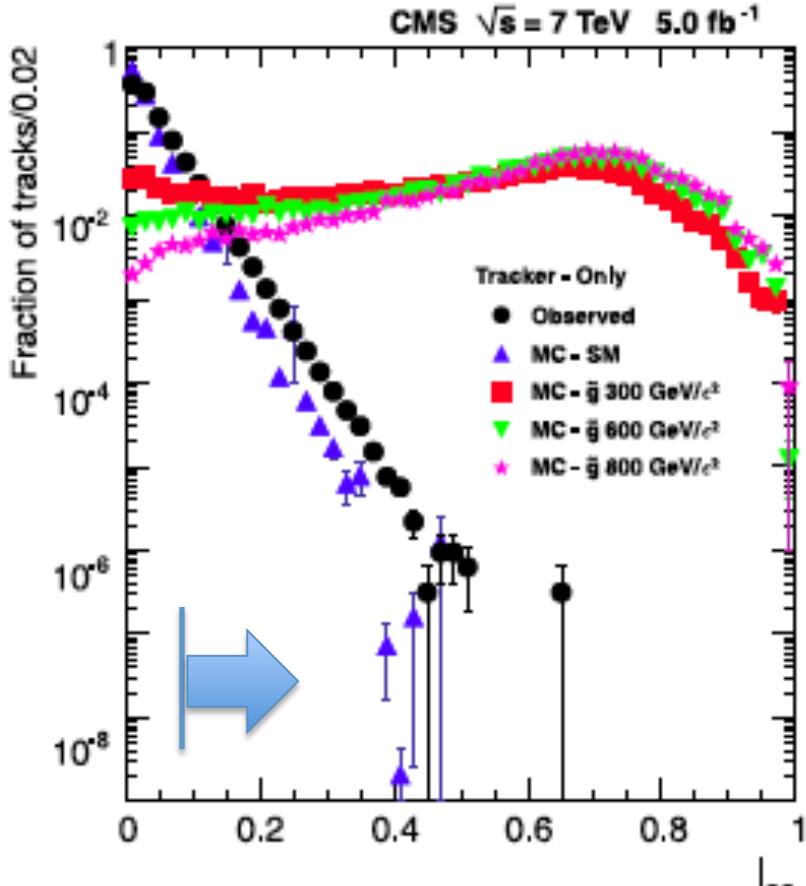
	ATLAS	CMS
Vertex	0.1mm	0.1mm
Si (dE/dx)	5-10cm	5-100cm
TRT	50-100cm	No
Hcal	2-4m ($\Delta t \sim 1\text{nsec}$)	1.5-2.5m
μ	5-10m($\Delta t \sim 1\text{nsec}$)	4-6m

Hadronic calorimeter Fe or Brass
Depth 1m time resolution $\sim 1\text{nsec}$

(A1) dE/dx in Si tracker



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



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

P_i 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 $\beta=1$ is assumed for this calculation.

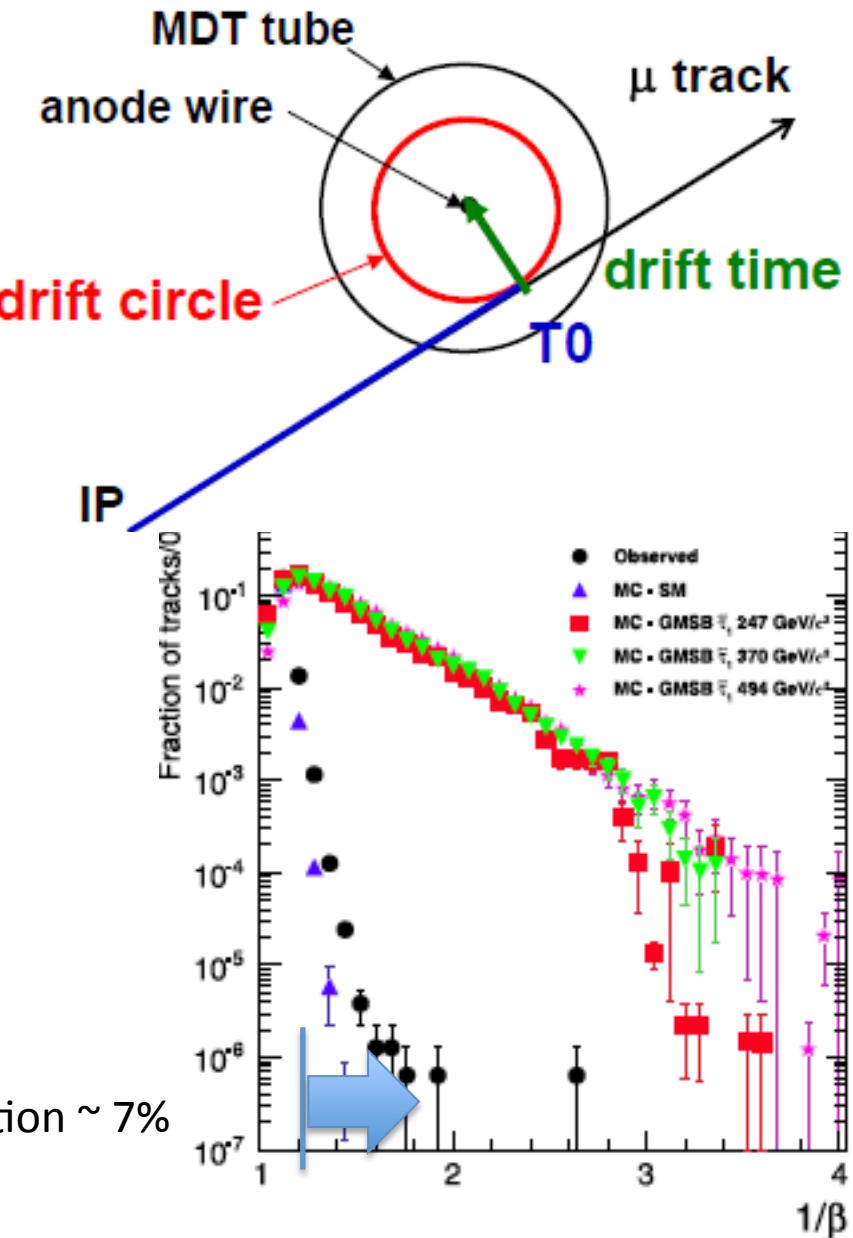
For the particle with $\beta < 1$,
drift circle become wrong.

Then the χ^2 becomes worse, since the
calculated drift is worse.

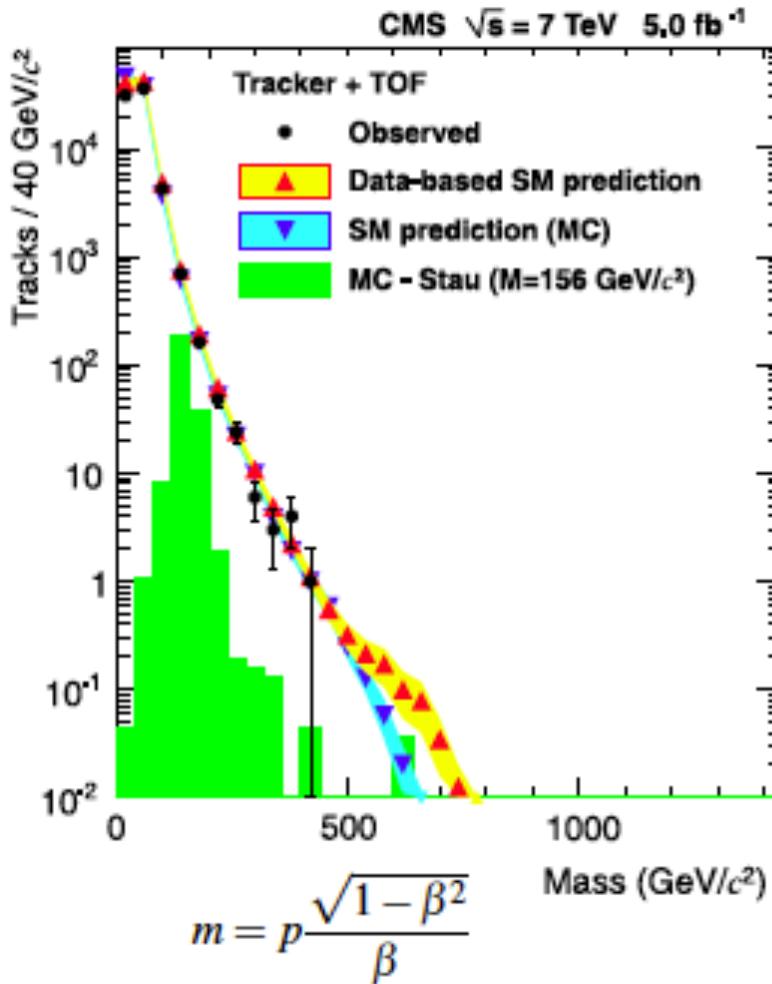
T_0 is fitted to obtain best χ^2

$\beta = 0.3 - 0.95$

β resolution $\sim 7\%$

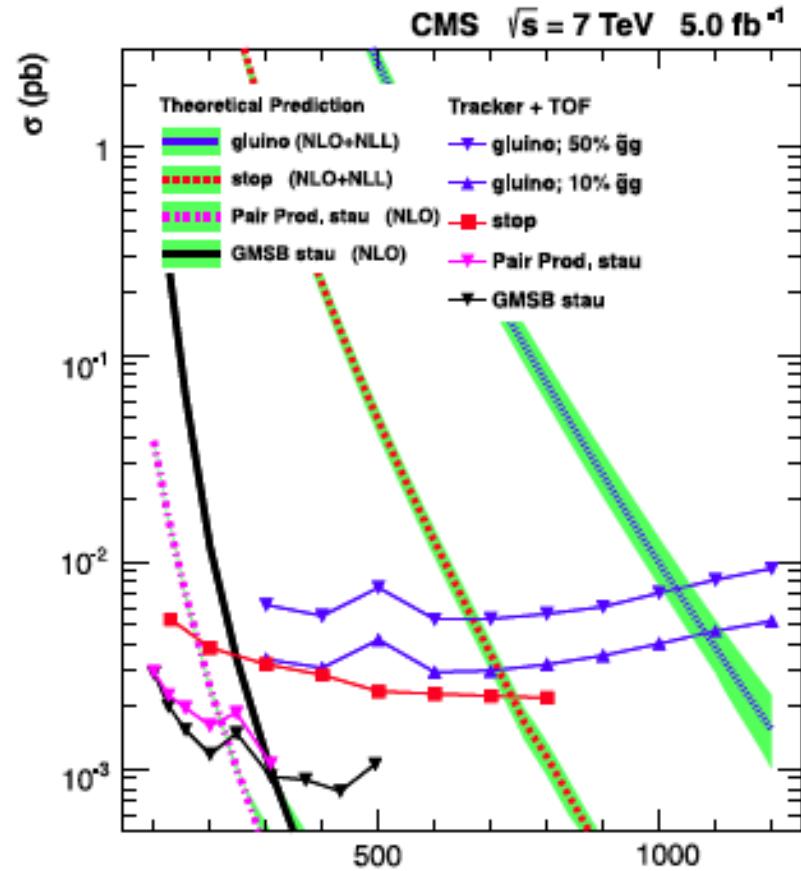


(A1) dE/dx in ID + (A2) muon TOF (I)



PT>50GeV
las>0.05
 $1/\beta > 1.05$

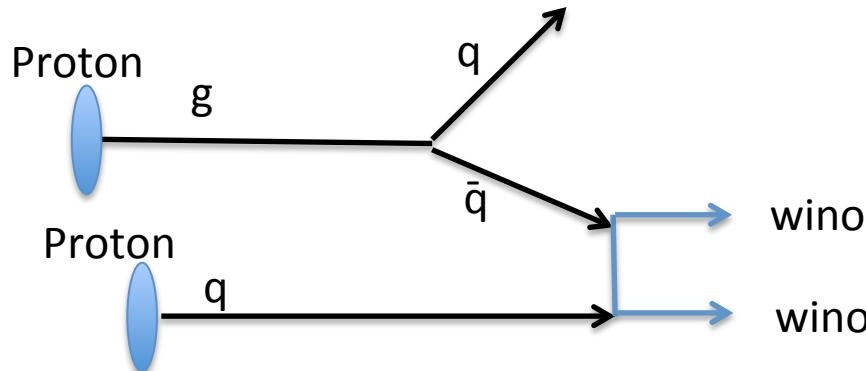
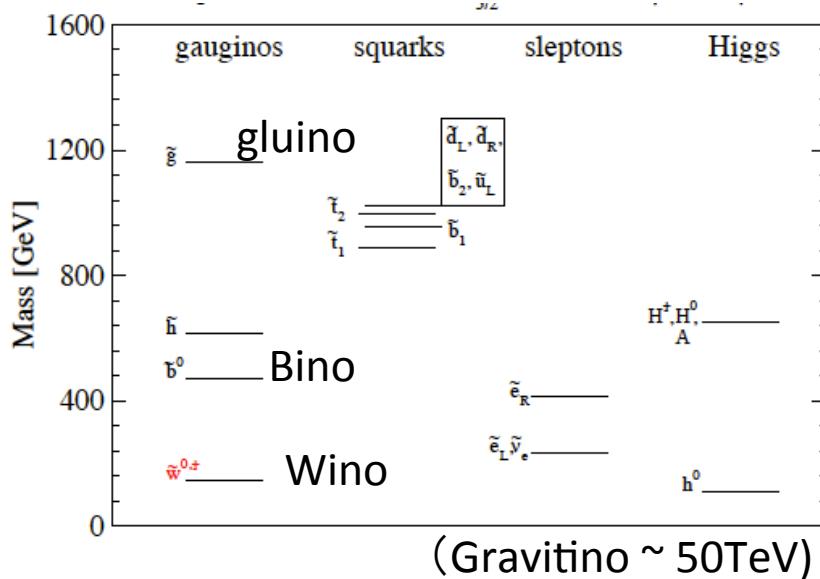
Data 72079 events
BG 88010+- 8800(sys) event
BG is estimated assuming that PT, dE/dx and $1/\beta$ are independent



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

direct production

Anomaly Mediated SUSY Breaking Long-lived ch1



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

Bino:Wino:gluino $\sim 3:1:7$

Gluino is heavy and cross-section @7-8 TeV is small.
On the other hand, Chargino is still light

Wino Pair (+-, +0) productions have large cross-section (factor 1000) 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 $gg \rightarrow qZ \rightarrow qvv$ (monojet) has large cross-section:
We need additional signatures of AMSB to reduce this BG process.

Decay in TRT (ATLAS has continuous tracking)

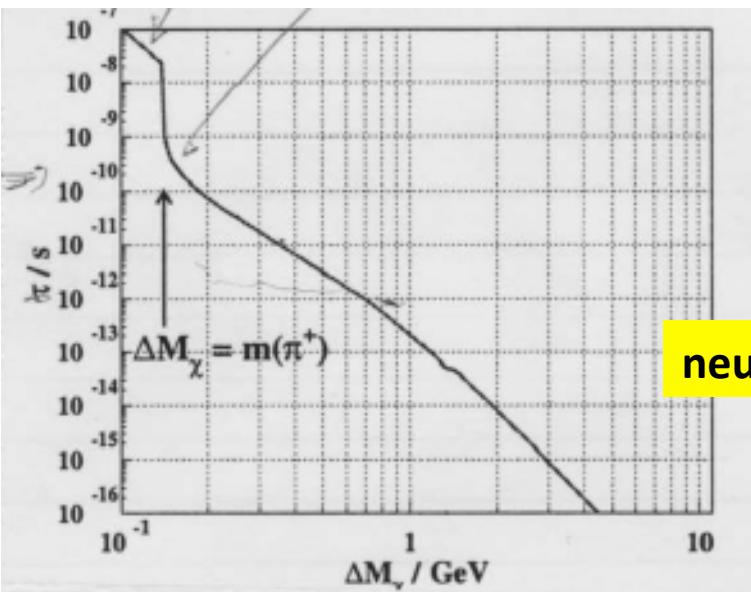
Chargino is Long-Lived

Wino is LSP/NLSP

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

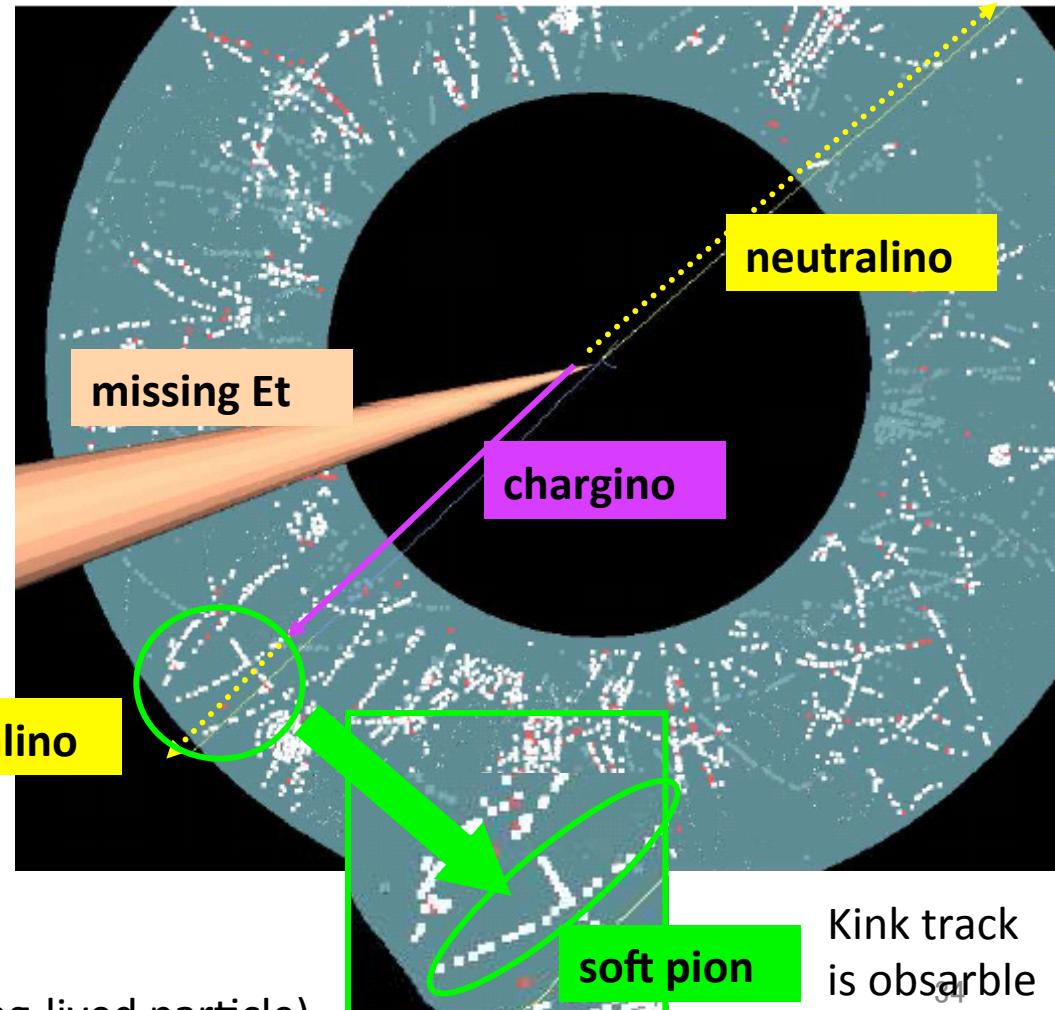
Predictable and lifetime $c\tau \sim O(3\text{ cm})$

Charged Wino decays in ID:



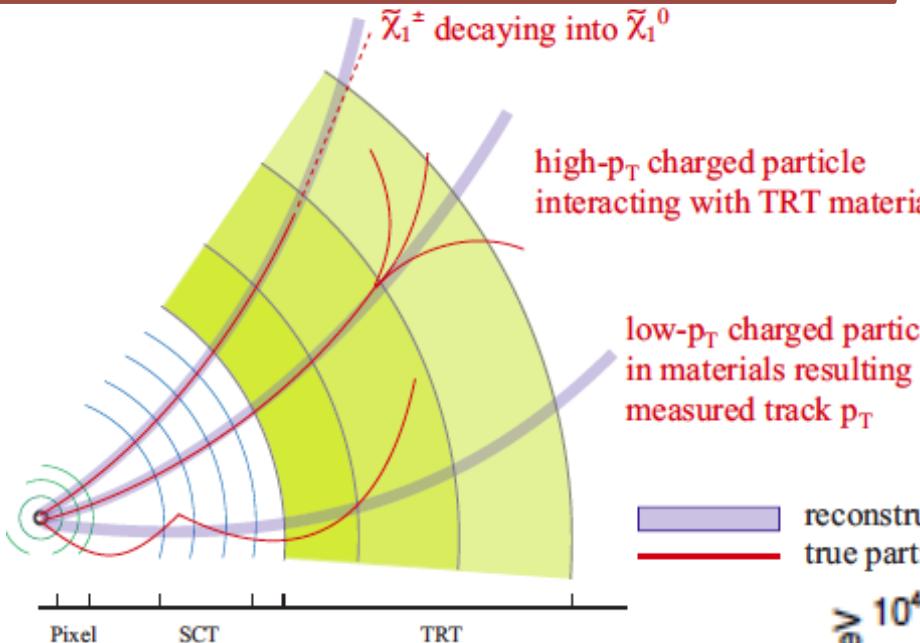
since $c\tau \sim 0(10\text{cm})$, reasonable number of Chargino decays in TRT ($R=50-100\text{cm}$)

This is the Simulated Events



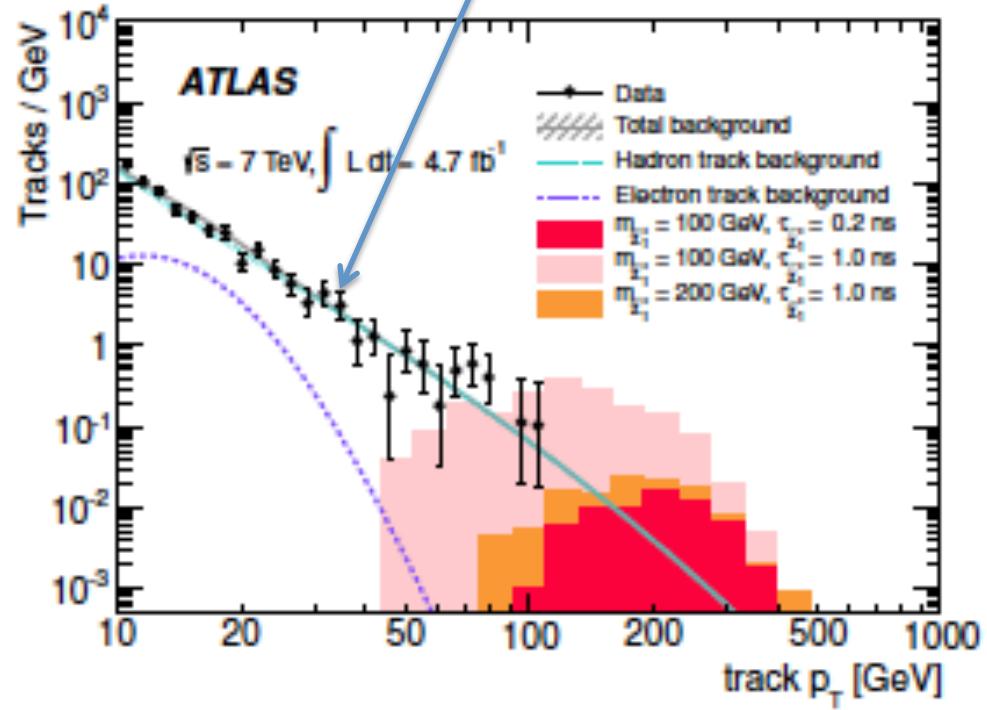
Let's discuss in 4B (SUSY with Long-lived particle)

Kink/disappearing track

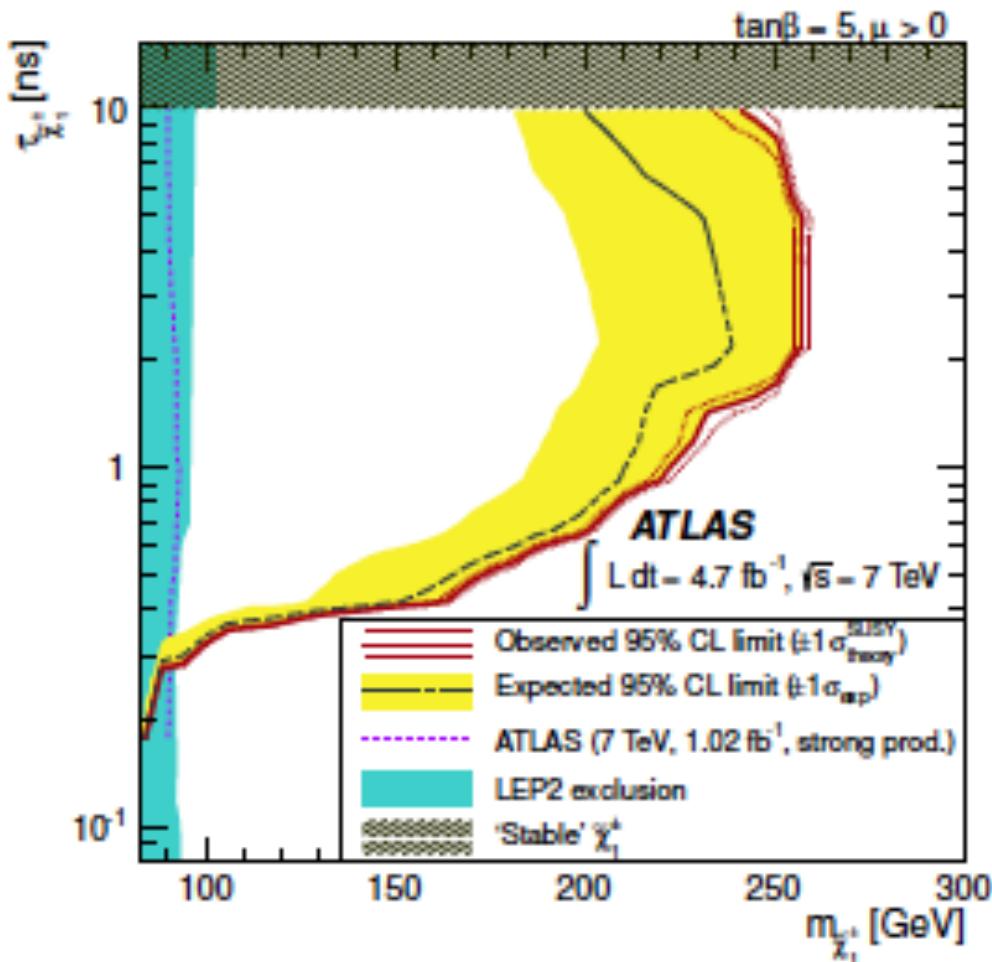


Badly reconstructed track is BG for high Pt region
Track interacting material is BG for middle Pt region
These are estimated (fitted) by the real data

No excess was found in high PT region



Kink/disappearing track



Current Limit on Wino is 92GeV obtained at OPAL. (I have set 12 years ago)
Now We obtain new limit using disappearing track search.
New Lower limit $> 200 \text{ GeV}$ $\tau > 0.8 \text{ nsec}$
 $> 250 \text{ GeV}$ for $\tau > 2 \text{ nsec}$

I have new idea to extend sensitivity for short lifetime case

5. 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

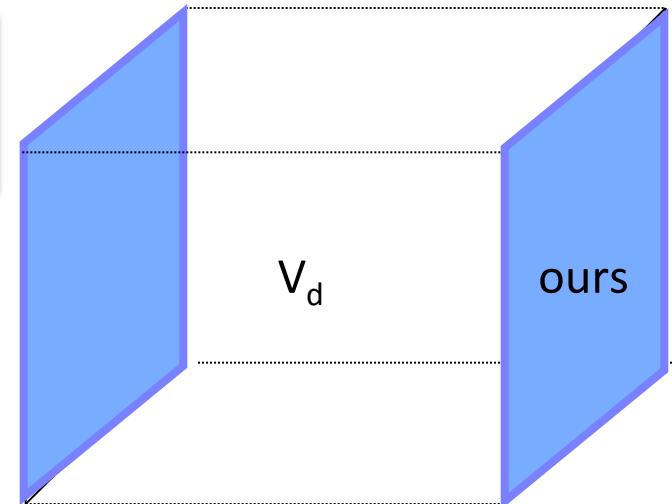
(1) Large Volume : ADD model Large Extra Dimension flat space

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

When $M_D = 1 \text{ TeV}$

$d=2 \quad R \sim 10^{12} \text{ fm} \sim 1 \text{ mm}$

$d=6 \quad R \sim 100 \text{ fm}$



Light KK Graviton ($d=2 \quad 1/R = 10^{-4} \text{ eV}$) $d=6 \quad 1/R = 7 \text{ MeV} \rightarrow$ Many KK state

$1/R \ll \text{TeV G}$: 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 \rightarrow sensitivity becomes worse

Expected Event Topology @ LHC

Graviton emission (monojet, $\gamma + \text{missing}$)

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)

$$\Lambda = \overline{M_{Pl}} \exp(-\pi k R)$$

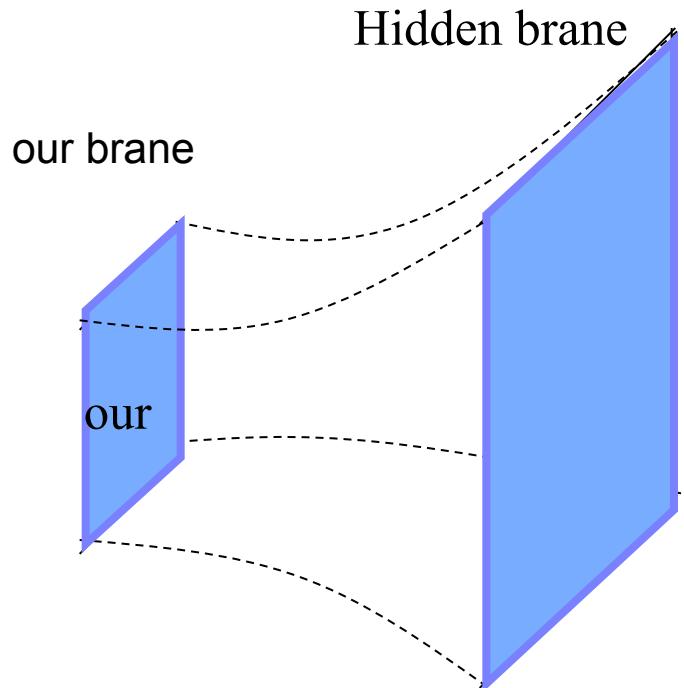
when R (distance between two brane) $\sim 12/k$

$\pi k R \sim 40$ then $\Lambda \sim 1 \text{ TeV}$

KK Graviton

Coupling parameter $c = \sqrt{8\pi} k / M_{Pl} = 0.01 - 0.1$

$M_n = k x_n \exp(-k r \pi)$ ($x_n = 3.83, 7.02, \dots$ for $n=1, 2, \dots$)



Event topology @ LHC

KK-Graviton exchange high mass lepton resonance,

 high mass $\gamma\gamma$ resonance

KK gluon exchange high mass top pair resonance

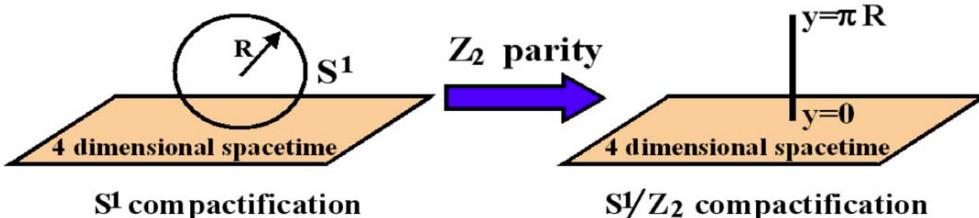
(3) Universal Extra dimension

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

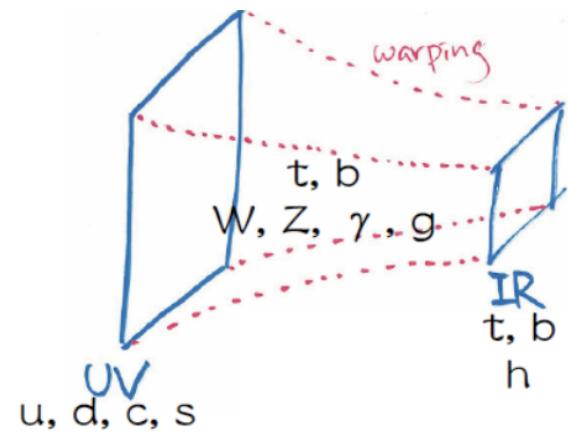
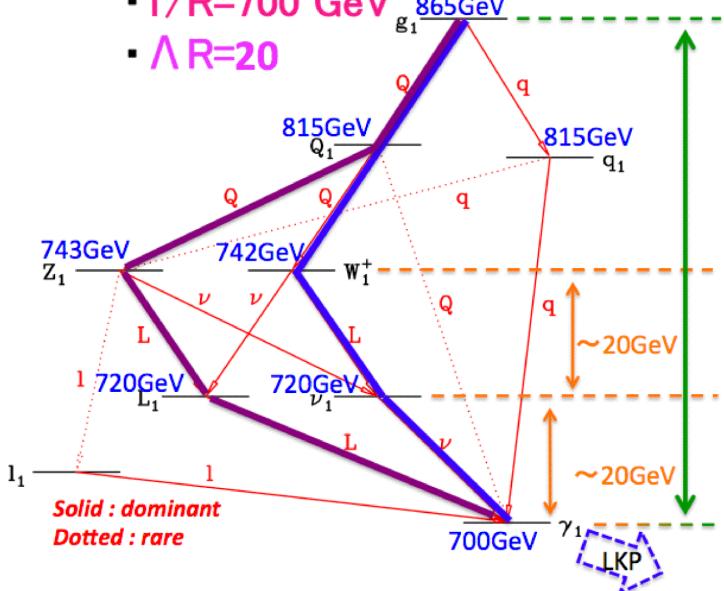
KK Parity SM KK even 1st KK odd



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($1\rightarrow t\bar{t}$) (Gauge Boson has KK state
fermion is on brane with Higgs)

- $1/R = 700 \text{ GeV}$
- $\Delta R = 20$

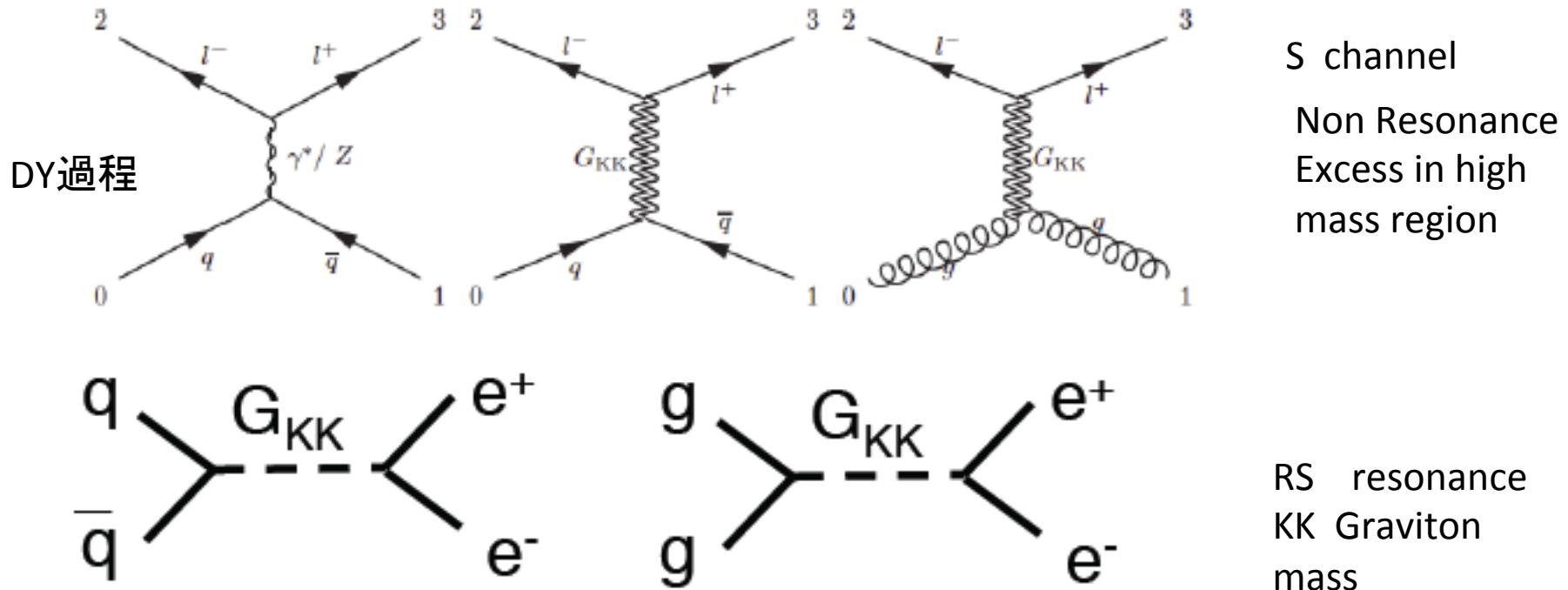


Observed event topologies are summarized here

	ADD (Graviton)			RS		UED	comment
topology	emission	s-chan	t-channel	Graviton	gluon		
Simple	monojet	○					simple
	$\gamma + \text{missing}$ (monoy)	○					simple
	$e^+e^- \mu^+\mu^-$ non-reso resonance		○				DY BG
	$\gamma\gamma$ non-reso resonance		○		○		Z', W'
	$\mu\mu$ (SS)			○			BG free
	2jets	○	○	△	△		difficult
	boosted top				○		subjet
	multi-object w/o lep with lepton		○				QCD BG
	mET+Lepton+jets		△			○	SUSY-like
	mET with Photon		△			○	GMSUSY

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

[B] $e^+e^- \mu^+\mu^-$ pair (non-reso, reso)



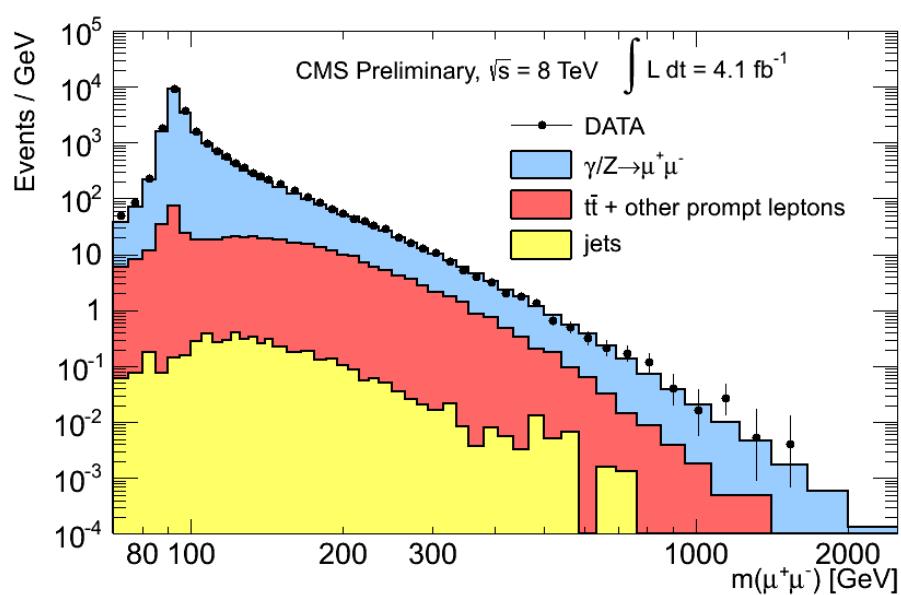
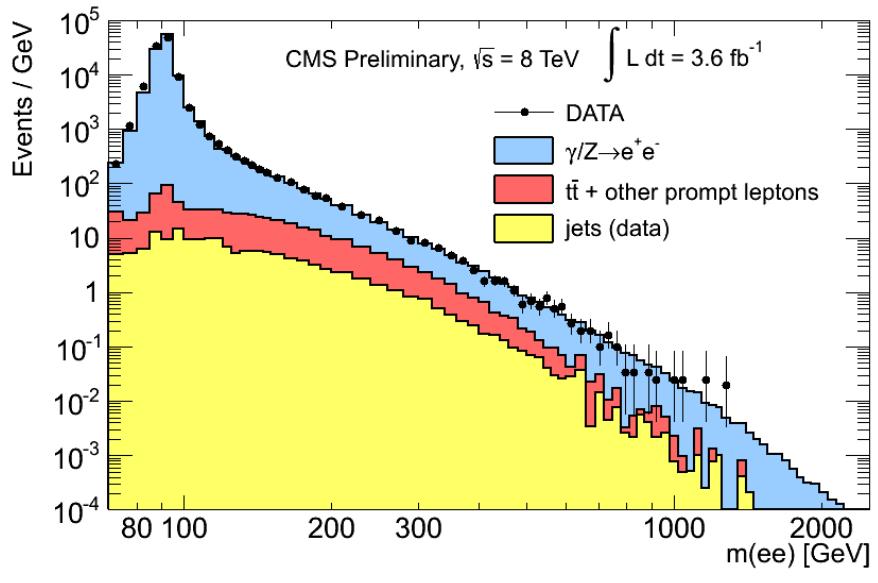
Lepton universality is violated in Detector response

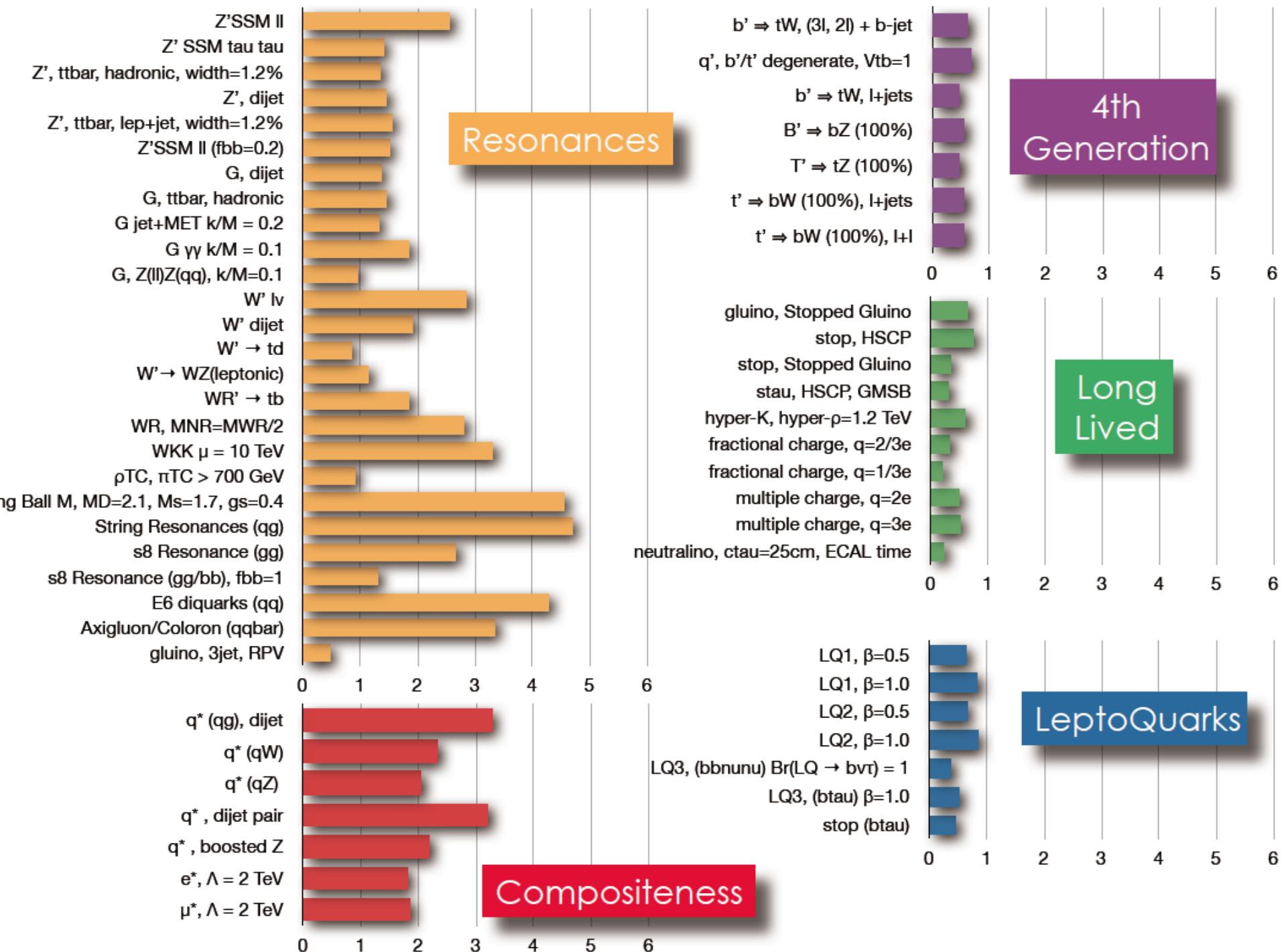
e : fake probability 10^{-4} resolution becomes better $\Delta E/E \sim 1/\sqrt{E}$

μ : fake probability 10^{-5} resolution becomes worse $\Delta P/P \sim P$

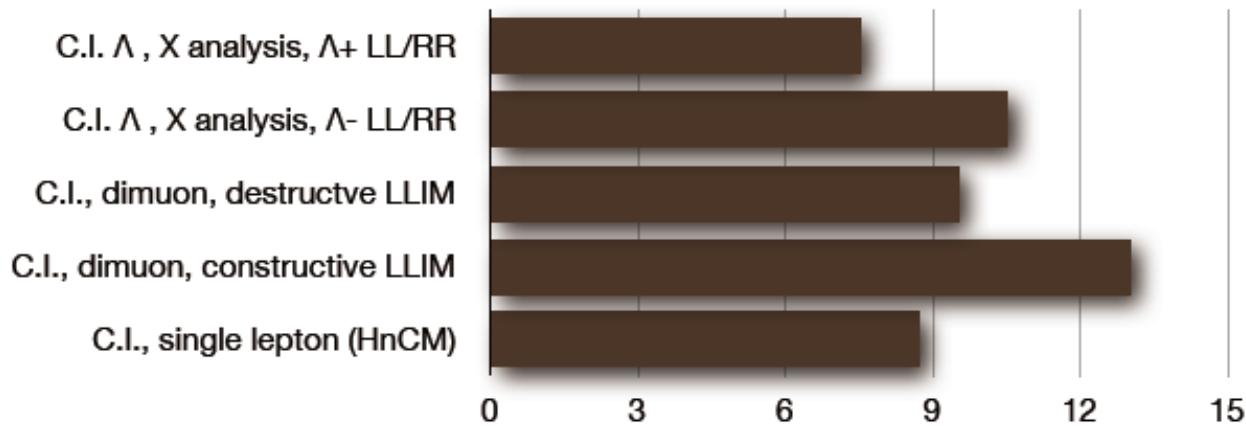
-> electron is useful for resonance search, Non-resonance : muon is more reliable

No Excess was found in resonance/Non-resonance

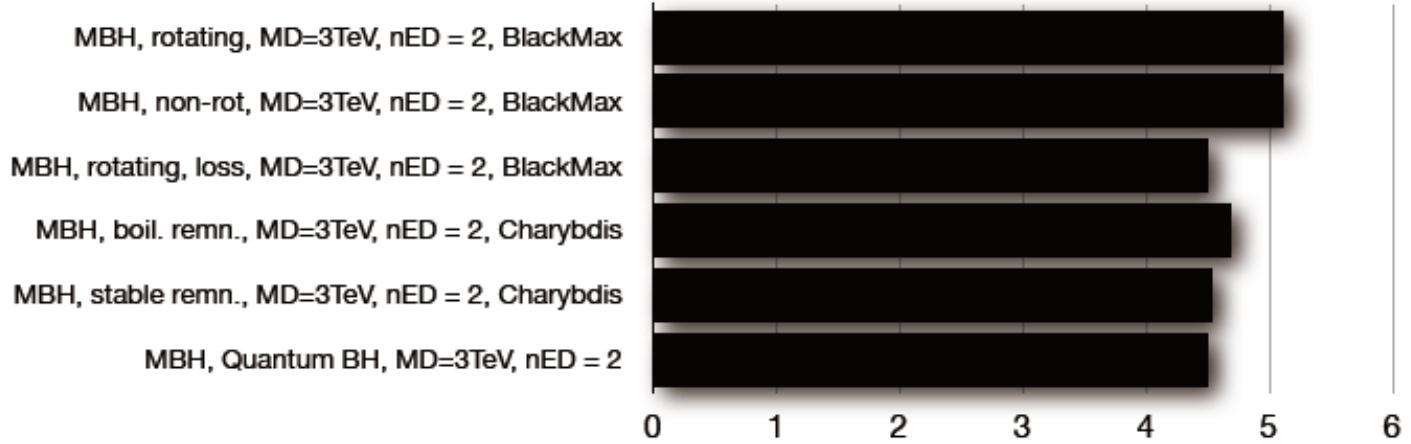




Contact Interaction



Black Holes



Summary

No BSM is found



8TeV Full data
13-14TeV