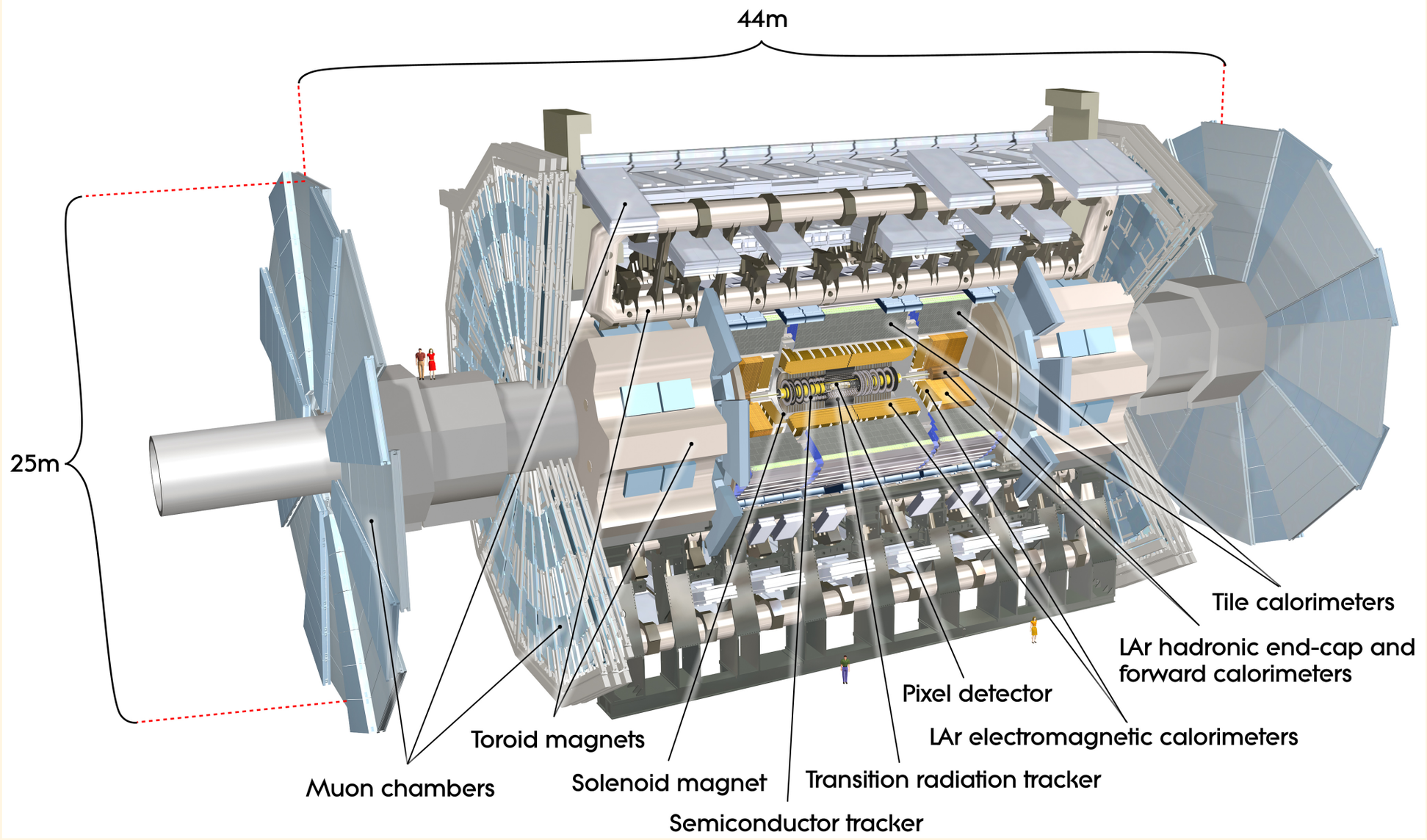
Inclusive searches for squarks and gluinos with the ATLAS detector

Shunsuke Adachi (Univ. of Tokyo)
on behalf of the ATLAS collaboration



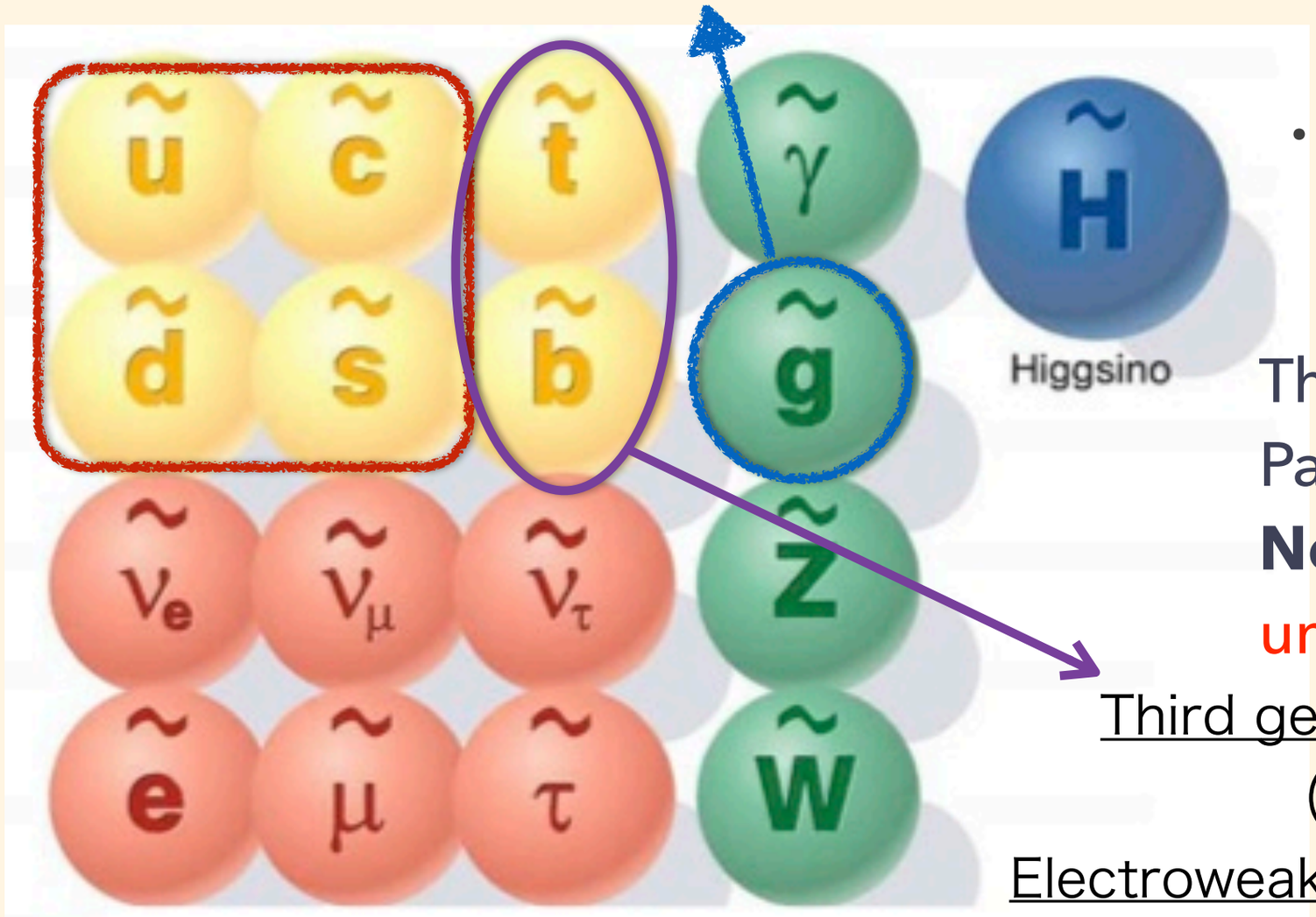
ATLAS detector

- Multi-purpose detector
- Inner tracking detector, Solenoid magnet(2T), Lead/Liquid-argon electromagnetic calorimeter, Steel/Scintillator-tile calorimeter, Toroid magnets, Muon spectrometer (Order from centre)

Supersymmetry

This talk :

Squark $\tilde{q}$ Gluino $\tilde{g}$



Mass eigen states of $\tilde{\gamma}, \tilde{Z}, \tilde{W}, \tilde{H}$

- Charged particles (**"Chargino"**)

$$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$$

- Neutral particles (**"Neutralino"**)

$$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$$

The Lightest Supersymmetric Particle (LSP) is assumed to be **Neutralino**. [Stable particle, undetected]

Third generation squark

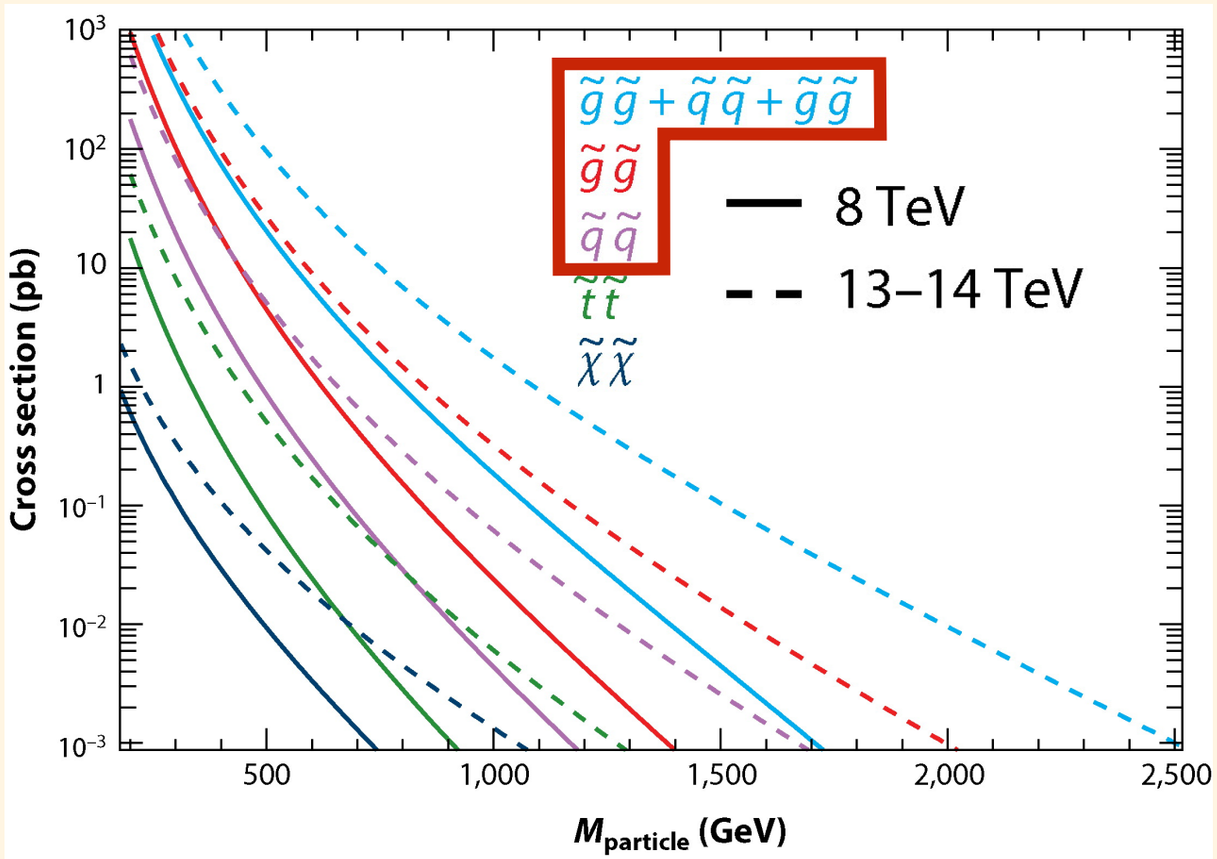
(Thu 24)

Electroweak gaugino & slepton

(Next talk)

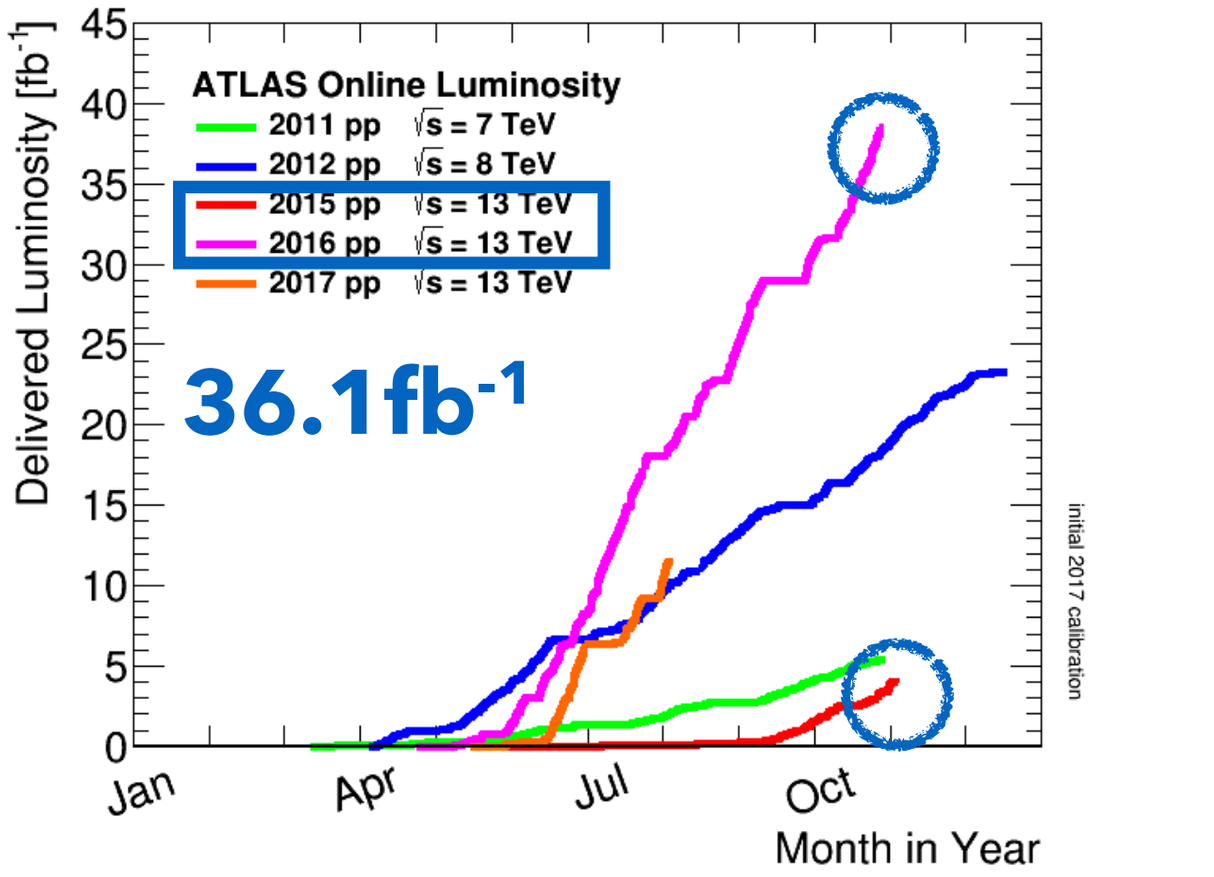
Strong production

Production cross-section



Halkiadakis E, et al. Annu. Rev. Nucl. Part. Sci. (2014)

Luminosity

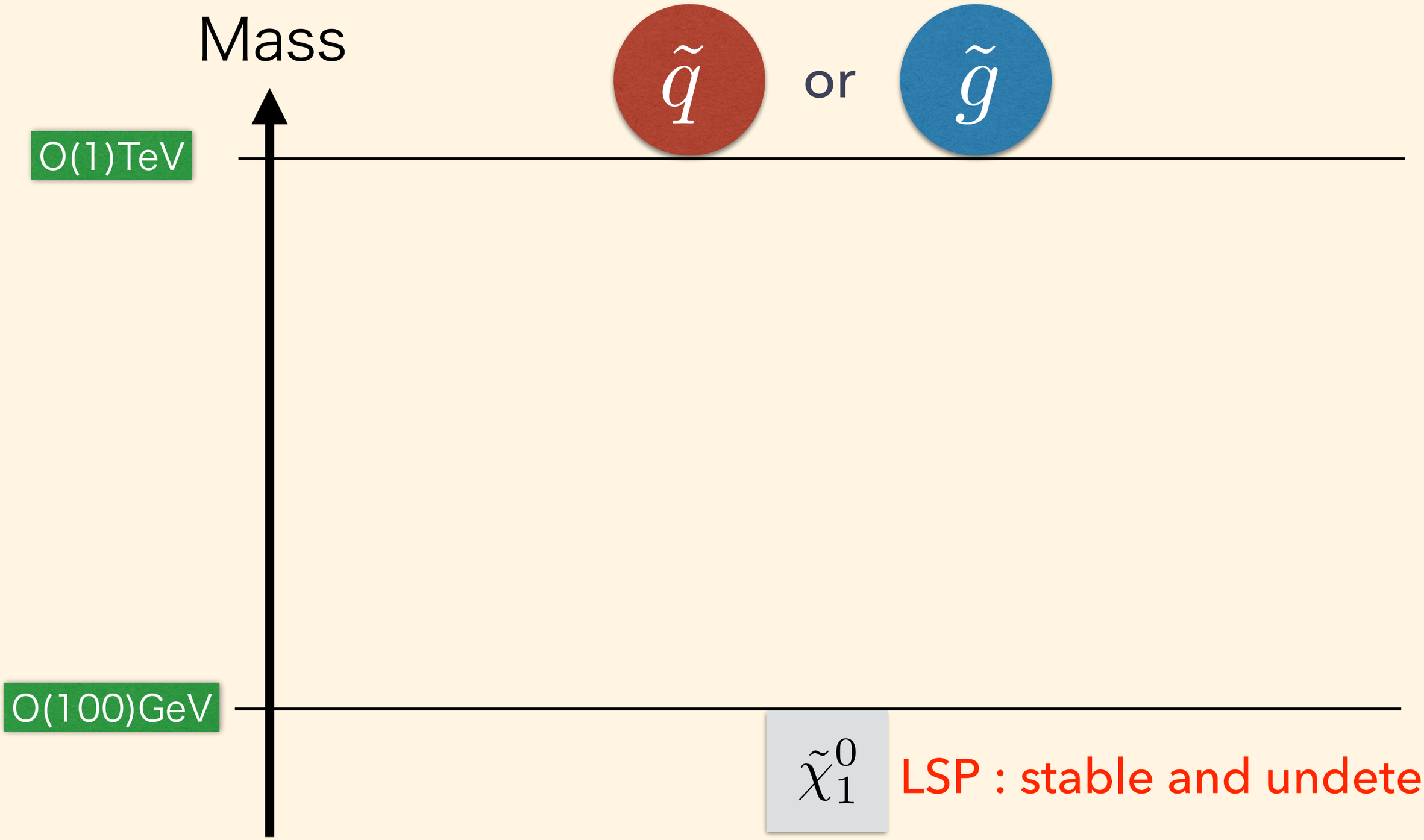


Strong production has larger cross-section at 13TeV than 8TeV.

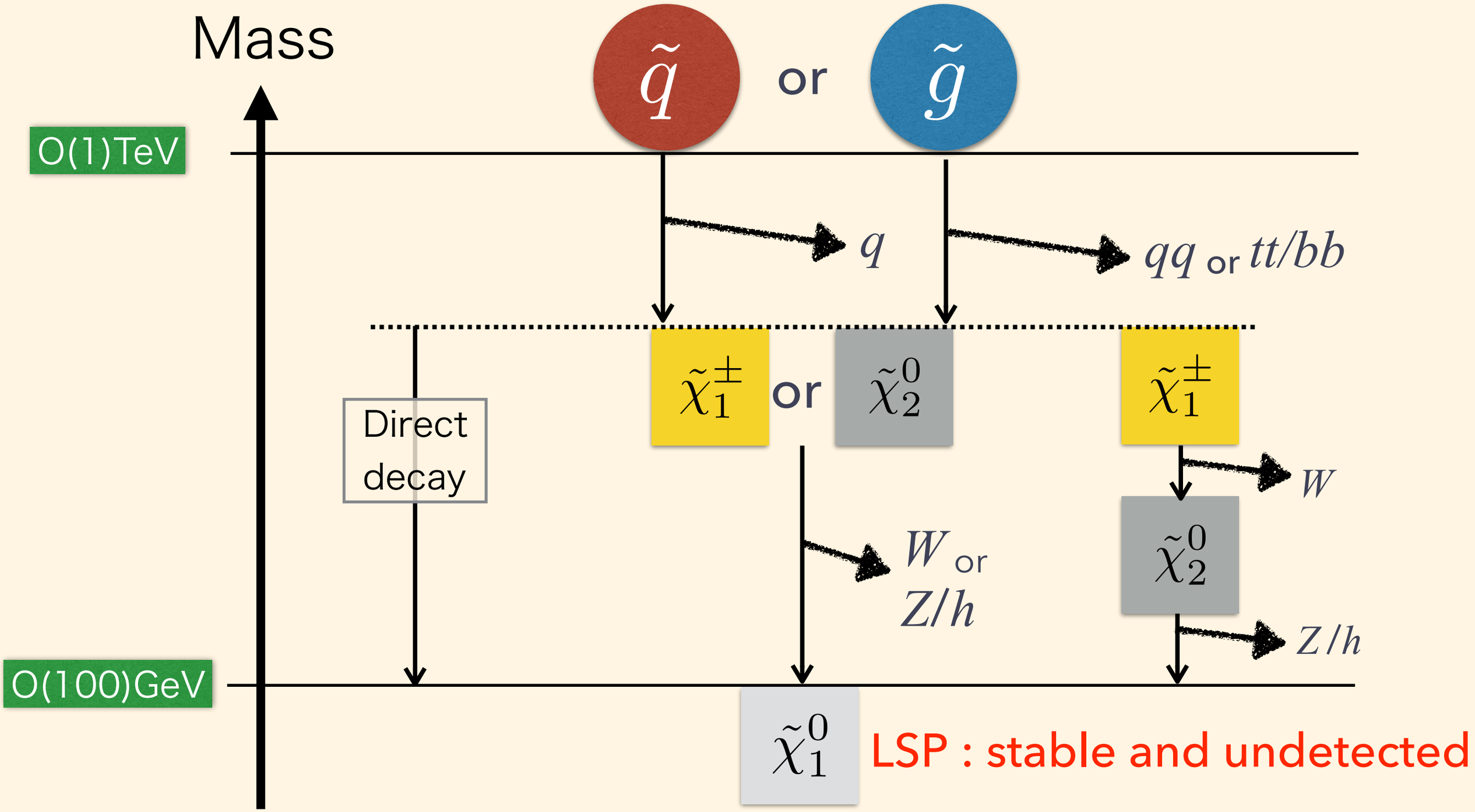
⇒ Important in the early stage of Run2

Result with 2015+2016 data will be shown in this talk

Search strategy



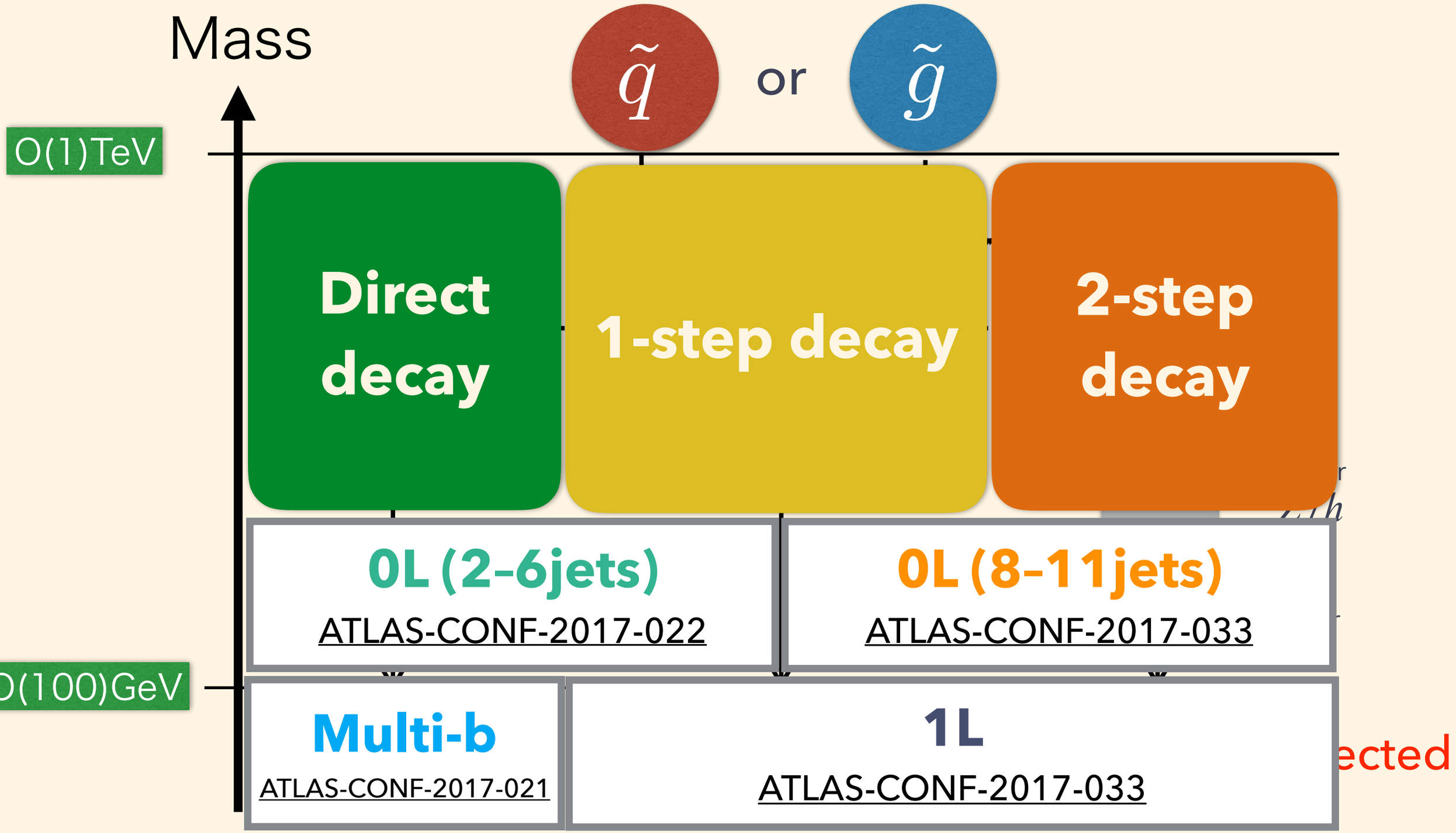
Search strategy



Search strategy

Aiming to cover all possible scenarios, our SUSY searches are based on **topology** in the final state.

"Inclusive search"



0L 2–6jets / 1L 2–6jets

$\tilde{q}$

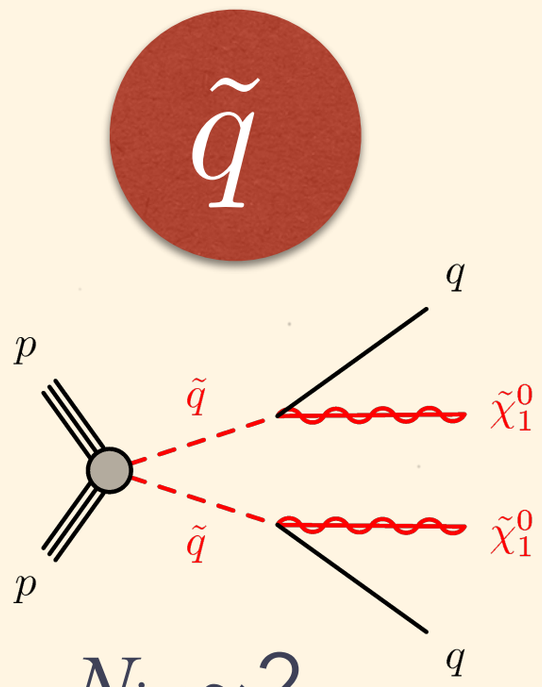
$\tilde{g}$

Direct decay

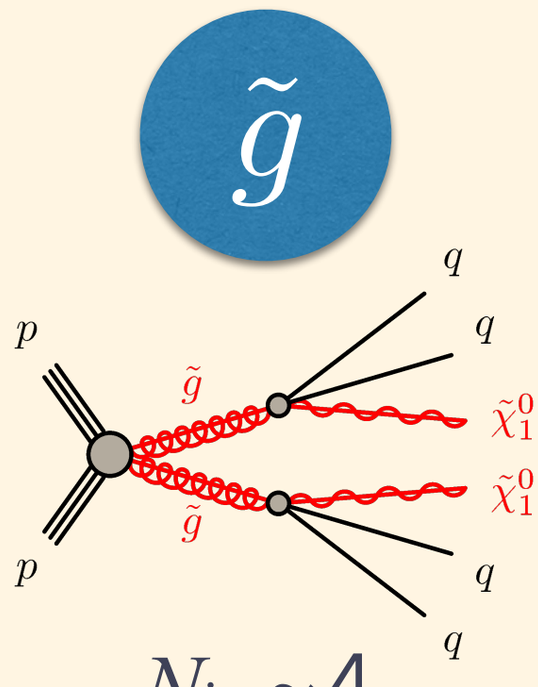
1-step decay

Target decay topology

Direct decay



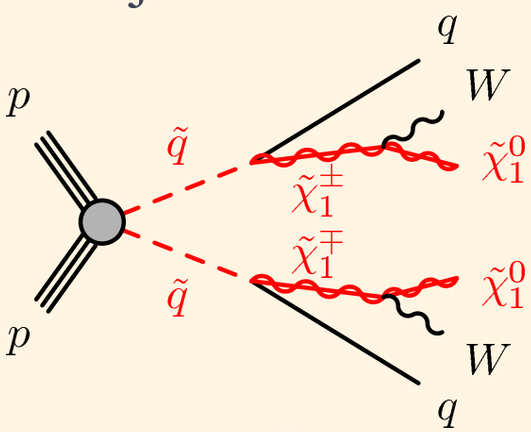
$N_{\text{jet}}\sim 2$



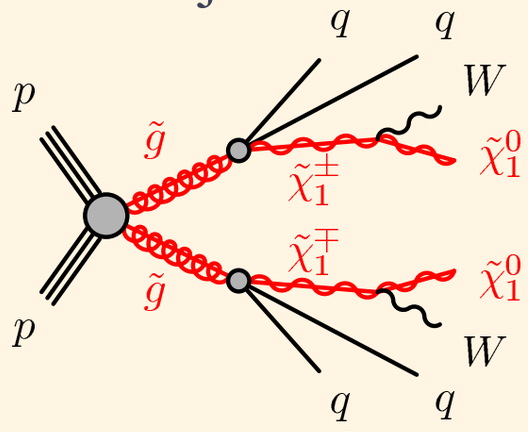
$N_{\text{jet}}\sim 4$

0L can search

1-step decay



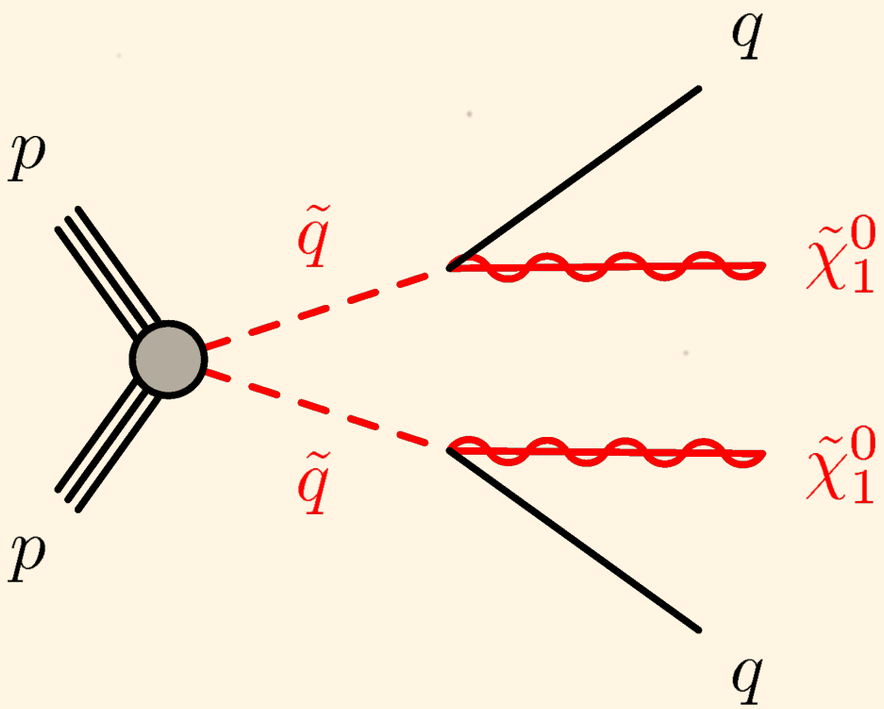
$N_{\text{jet}}\sim 4$



$N_{\text{jet}}\sim 6$

0L & 1L can search

Discriminating variables



- N_{jet} selection for various decays
- Missing transverse momentum from $\tilde{\chi}_1^0$ ($E_{\mathrm{T}}^{\mathrm{miss}}$)
- $m_{eff} = |\vec{E}_T^{miss}| + \sum_j |\vec{p}_T(j)| \propto \Delta Mass(\tilde{q}, \tilde{\chi}_1^0)$

  $|\vec{E}_T^{miss}|$ ⇕ Momentum of $\tilde{\chi}_1^0\tilde{\chi}_1^0$

  $\sum_j |\vec{p}_T(j)|$ ⇕ Momentum of qq

- Masses of SUSY particles are unknown.
- $\Delta M(\tilde{q}, \tilde{\chi}_1^0)$ is smaller. → m_{eff} is smaller.

In order to cover wide mass ranges,

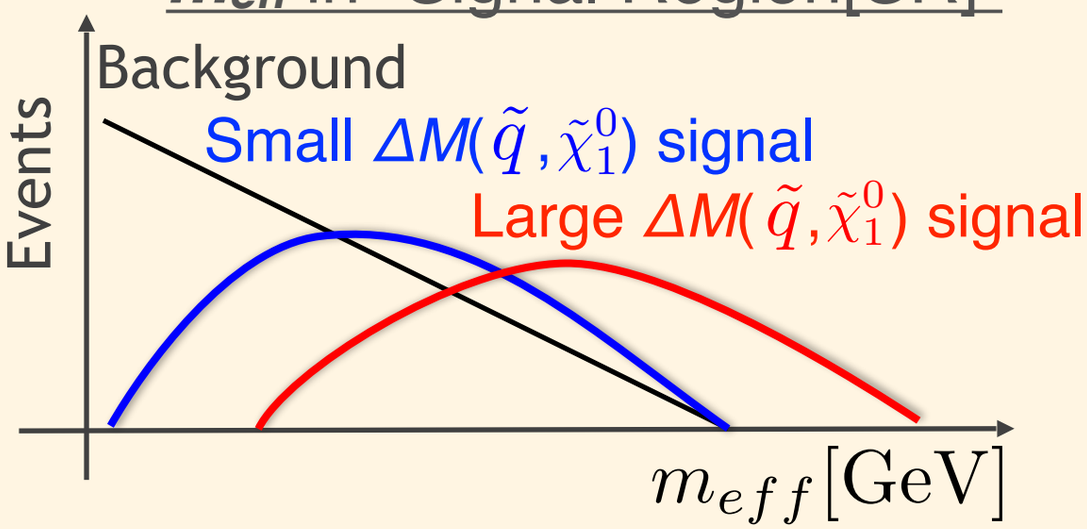
0L : Prepare SRs with different m_{eff} cut.

⇒ N_{jet} cut x m_{eff} cut: **24** SRs are prepared.

1L : Multi-bin fit in m_{eff} shape for each N_{jet}.

⇒ N_{jet}=**2,4,6** : **3-4** m_{eff} bins

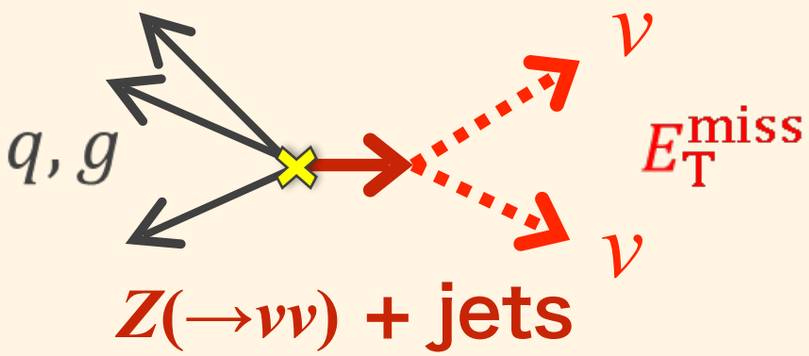
m_{eff} in "Signal Region[SR]"



Background

0L 2–6jets

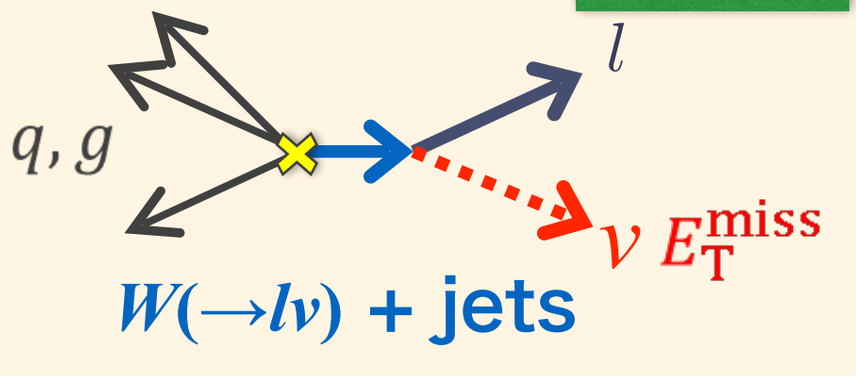
Main BG



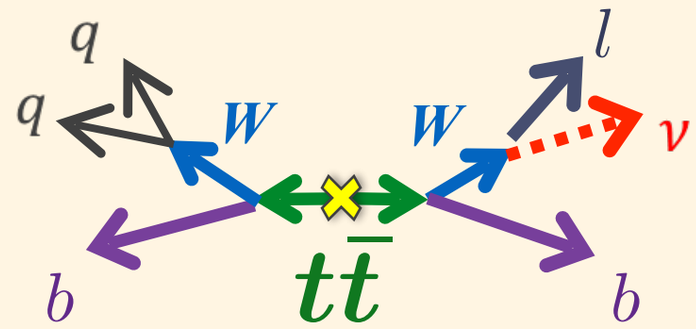
$Z(\rightarrow\nu\nu)$ + jets

1L

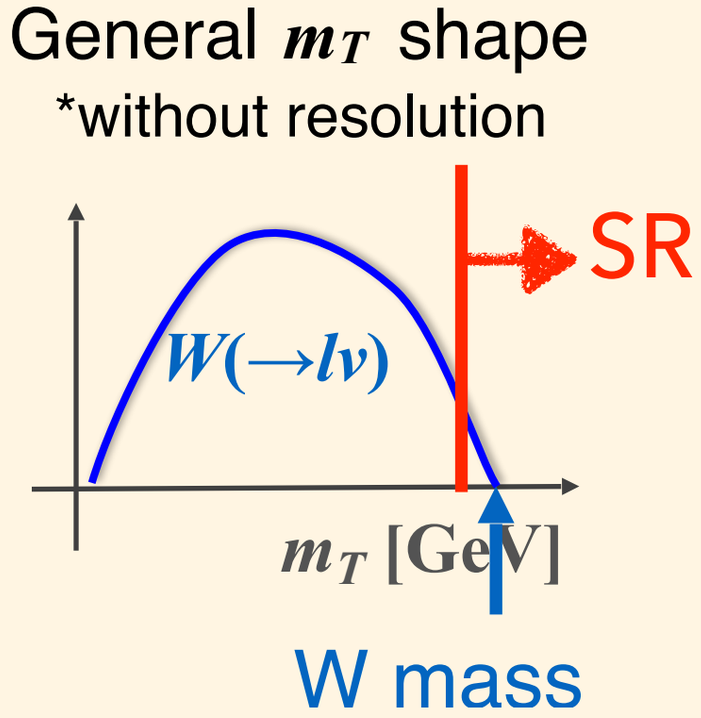
Main BG



$W(\rightarrow l\nu)$ + jets

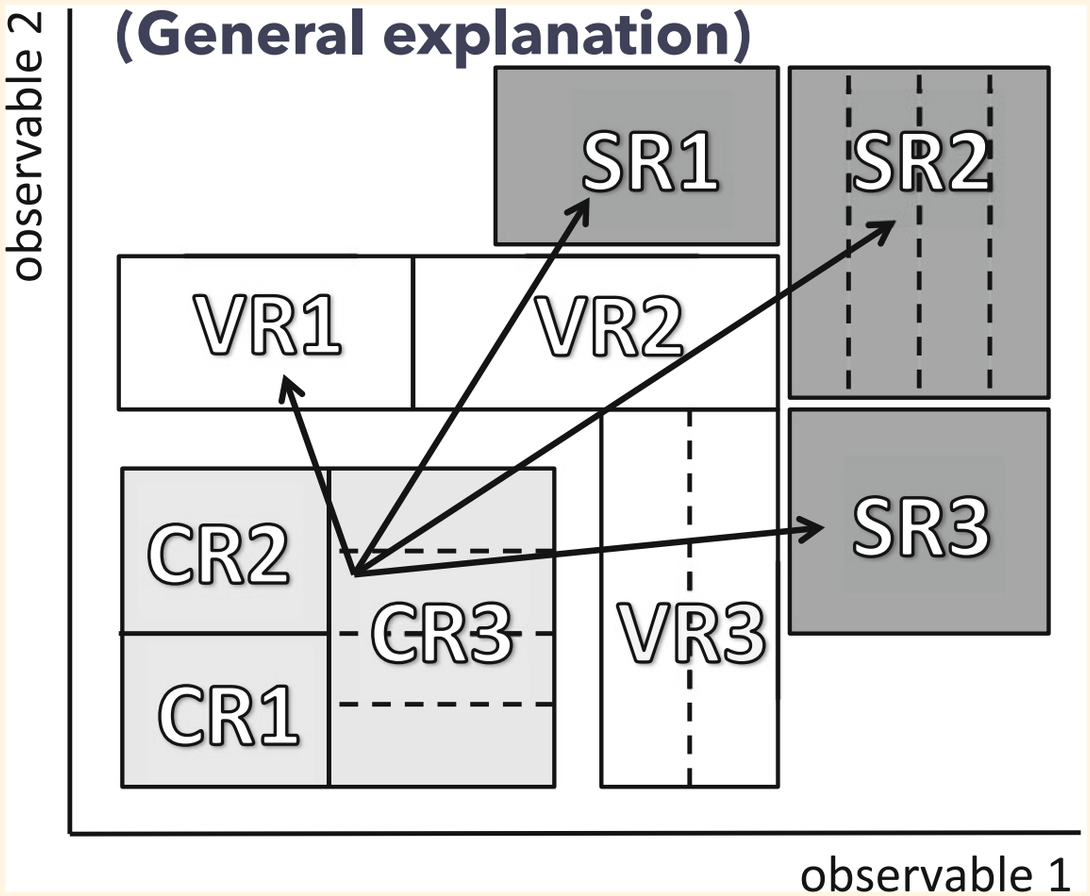


- **0L** & **1L** : High Aplanarity(=more spherical) is required to suppress Z/W+jets.
- **1L** : High m_T(transverse mass) is required to suppress $W\rightarrow l\nu$ coming from **W+jets** / $t\bar{t}$.



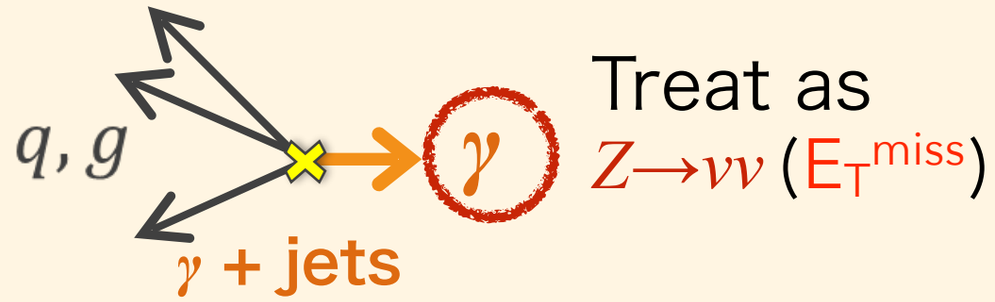
Background estimation

- Typical SUSY searches are performed in the end of kinematics (Ex. in high m_{eff} tail). Thus background estimation is challenging.
- The estimation is done by using **Control Regions**[**CR**].



$$N_{\mathrm{pred,\,SR}} = N_{\mathrm{MC,\,SR}} \times \frac{N_{\mathrm{Data,\,CR}}}{N_{\mathrm{MC,\,CR}}}$$

- **Z+jets in 0L 2–6jets**



γ+jets (require 1γ) : **CR**

Observable 1:Number of γ (*No observable2)

- **W+jets / $t\bar{t}$ in 1L**

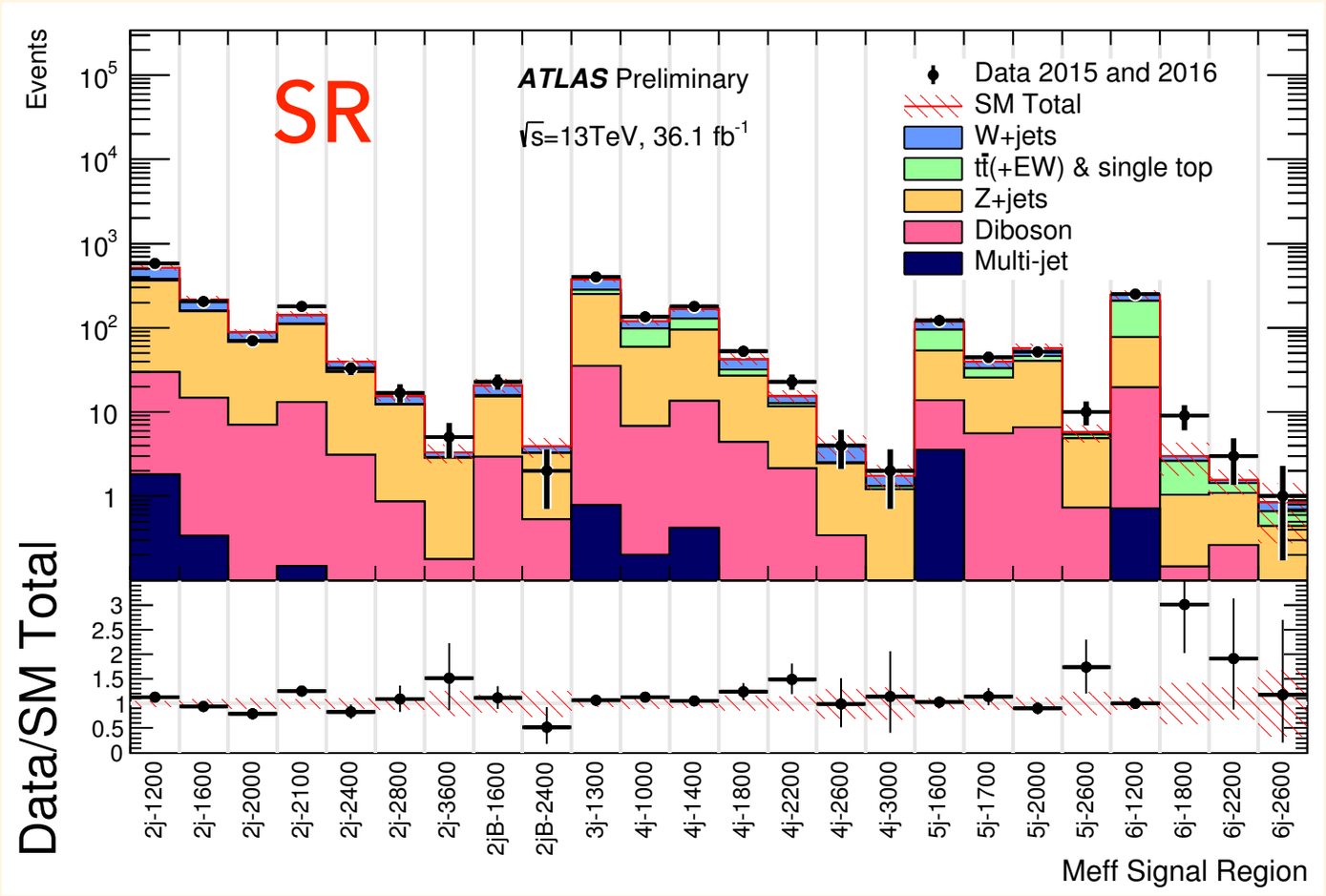
b-veto / b-tag region

Low m_T or low Aplanarity : **CR**

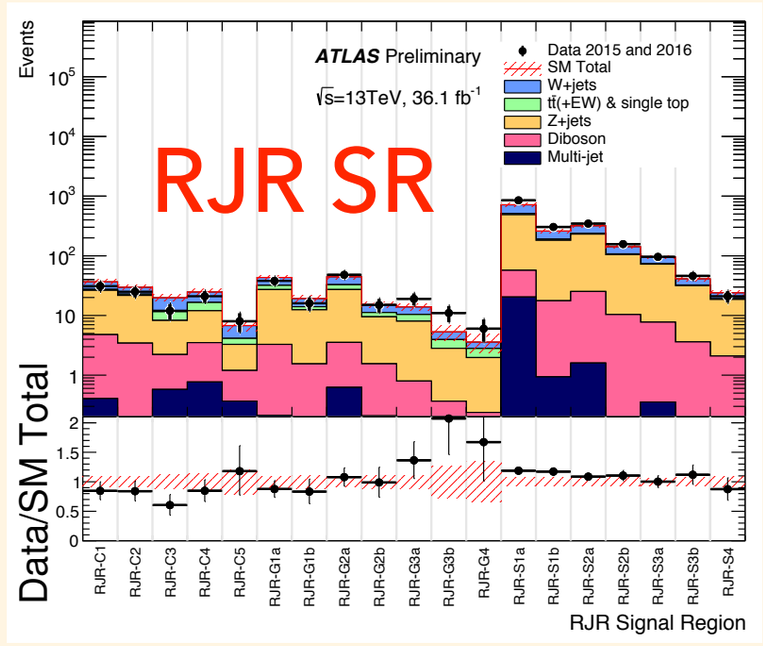
Observable 1 : m_T

Observable 2 : Aplanarity

Fit result : 0L 2-6jets



24 SRs using normal variables



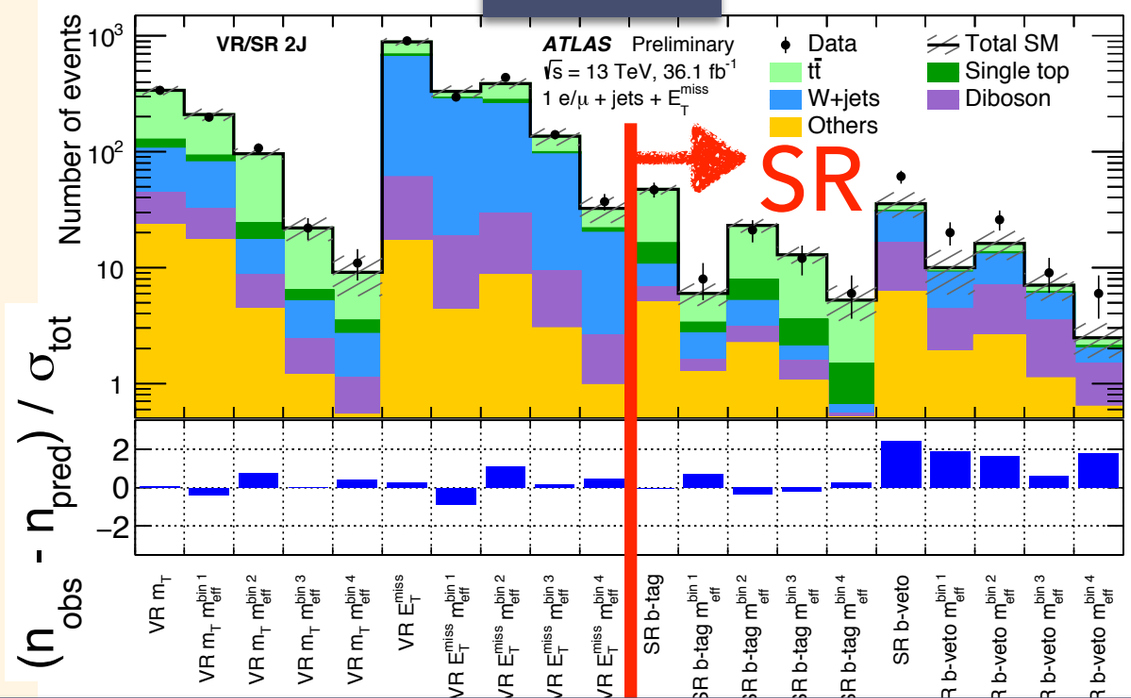
Additionally,
19 SRs using new variables obtained by **Recursive Jigsaw Reconstruction[RJR]** technique are prepared.
This technique improves the sensitivity for small $\Delta M(\tilde{g}, \tilde{\chi}_1^0)$.

No significant excess

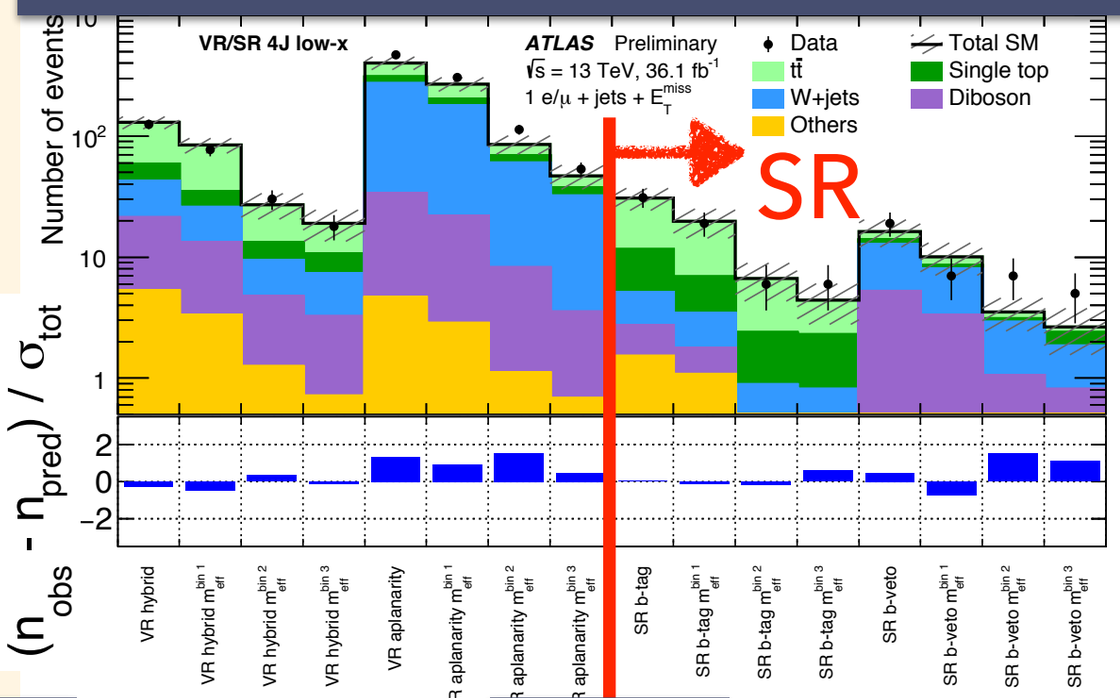
Fit result : 1L 2–6jets

m_{eff} bins × b-tag/b-veto SRs are shown

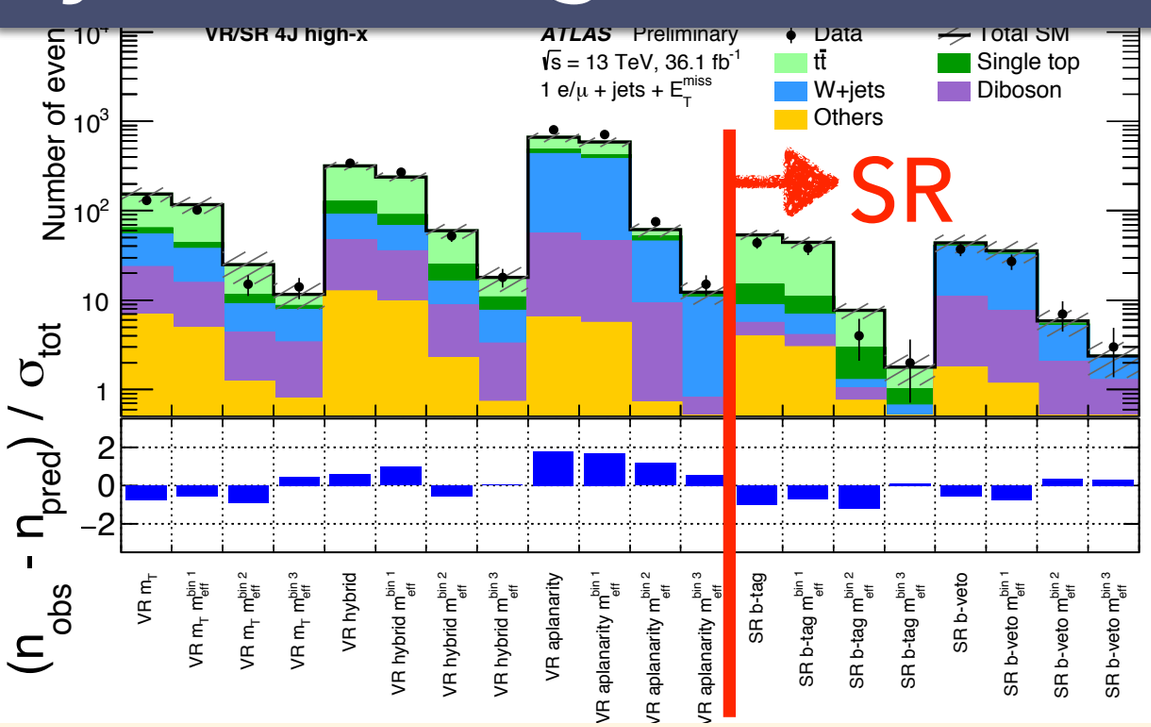
2jets



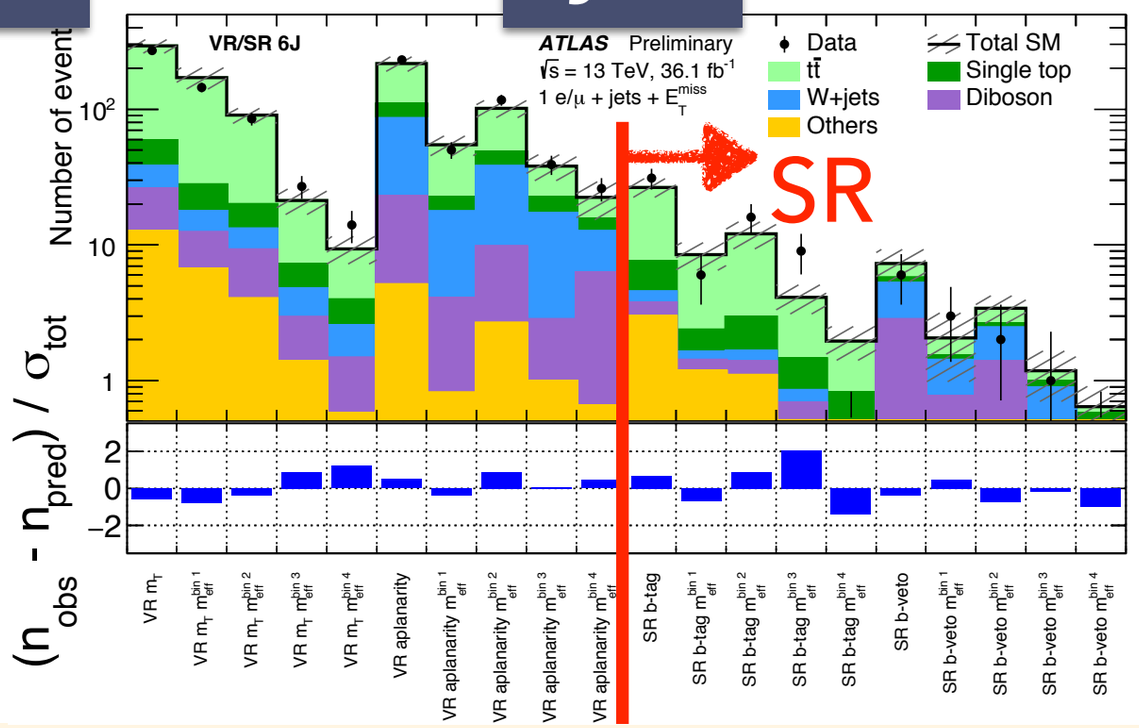
4jets with 150<m_T<450GeV



4jets with high m_T >450GeV

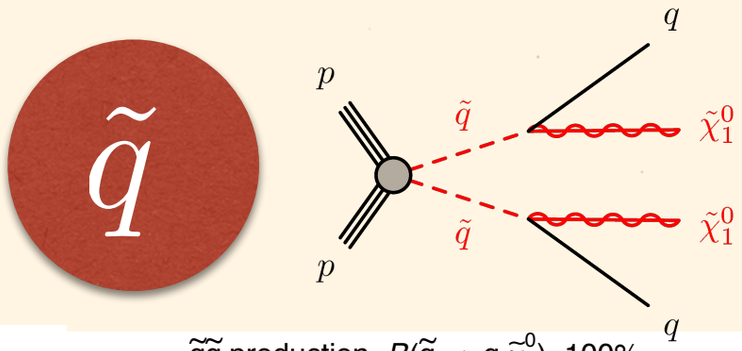


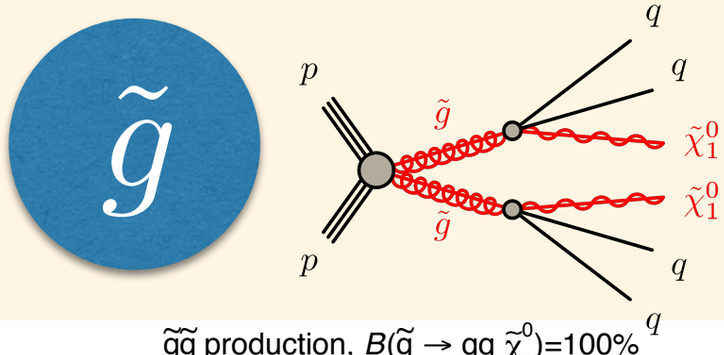
6jets

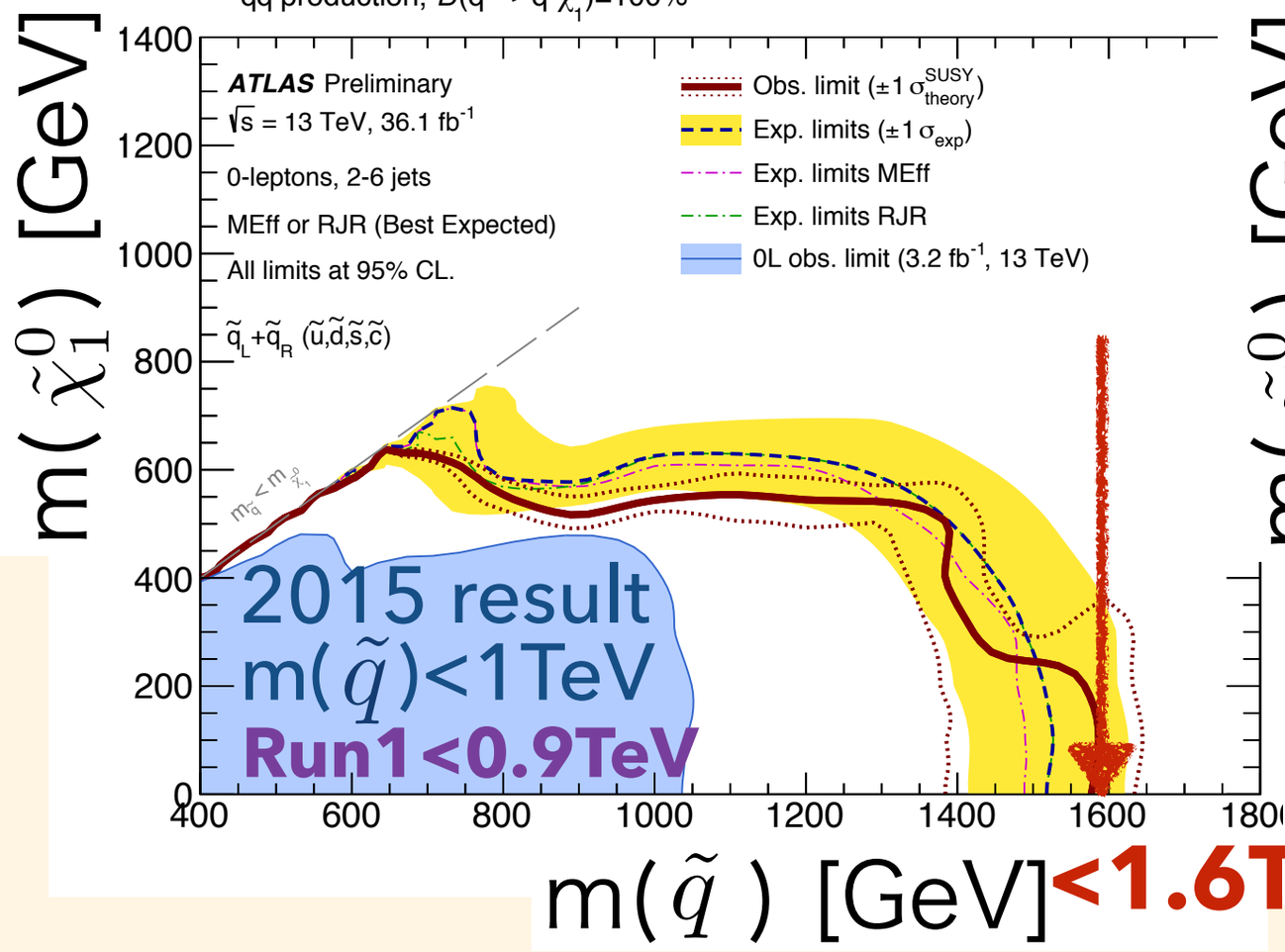


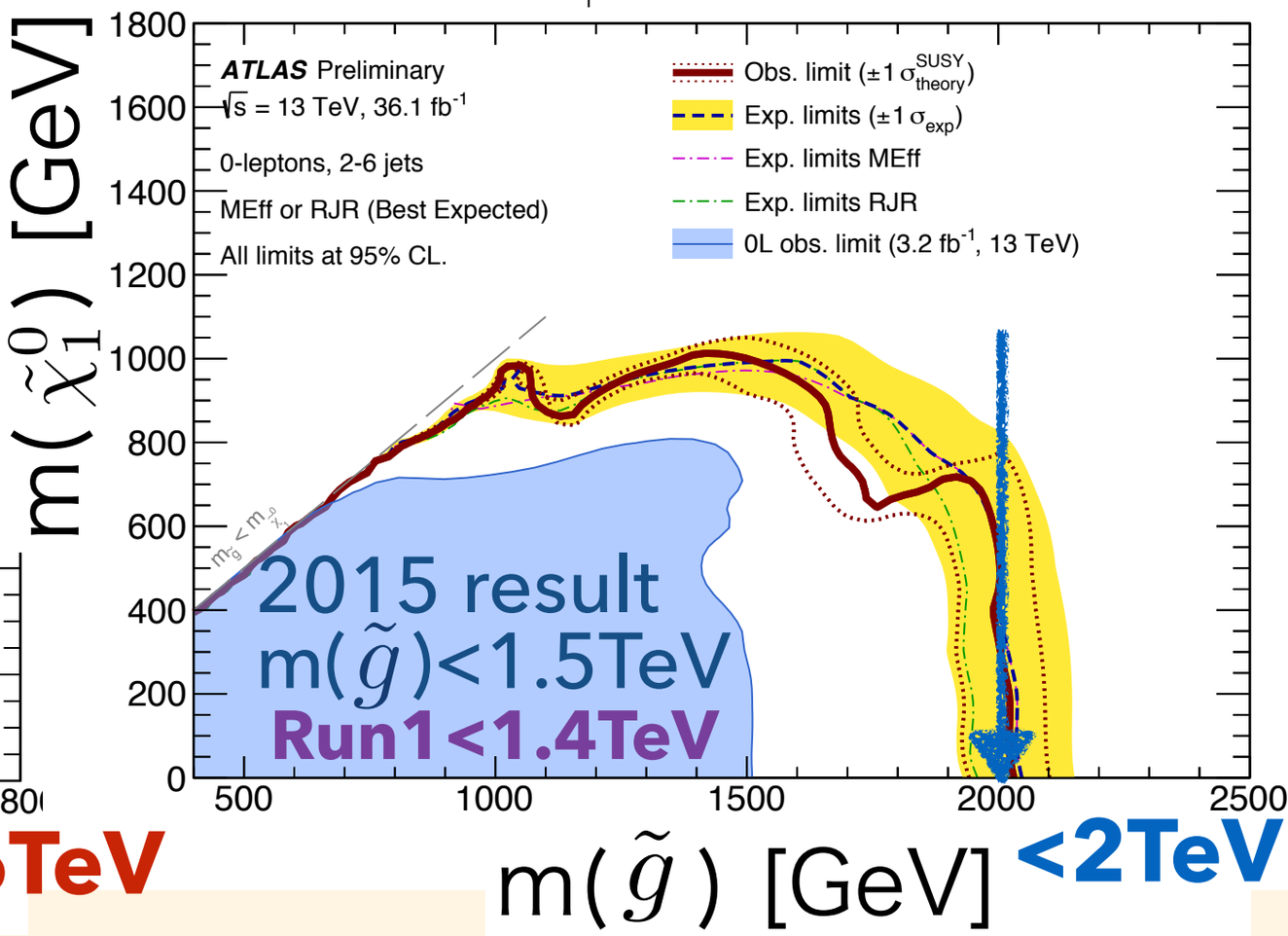
No significant excess

Exclusion limits on Direct decay



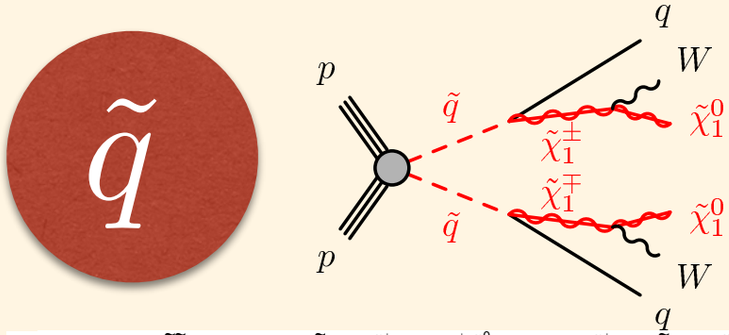


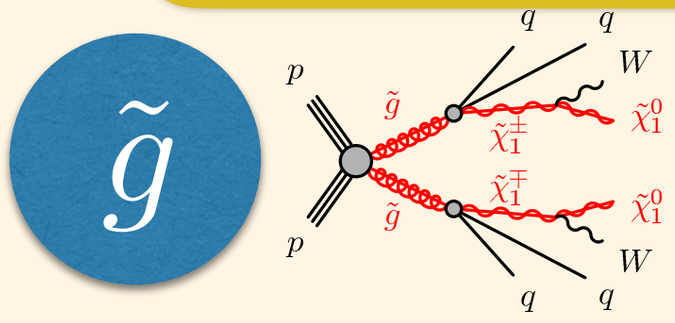


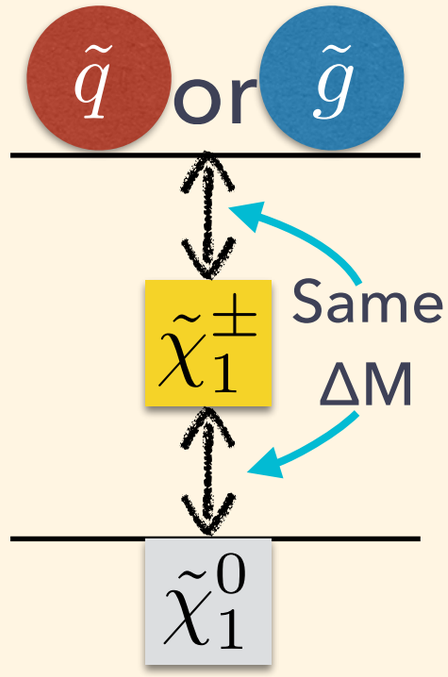


* In **0L** analysis, each point is excluded by the best sensitivity SR in 24+19SRs.

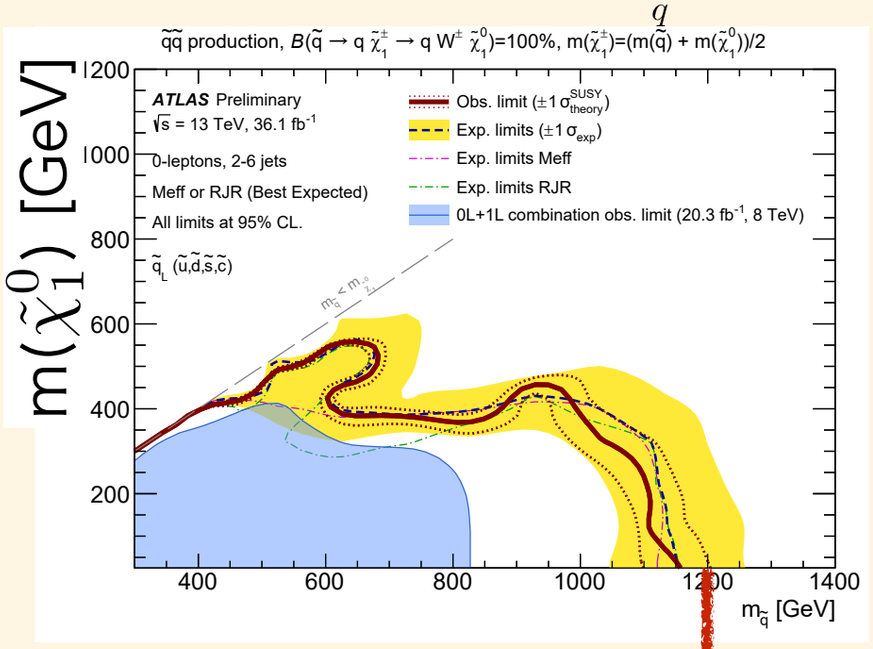
Exclusion limits on 1-step decay

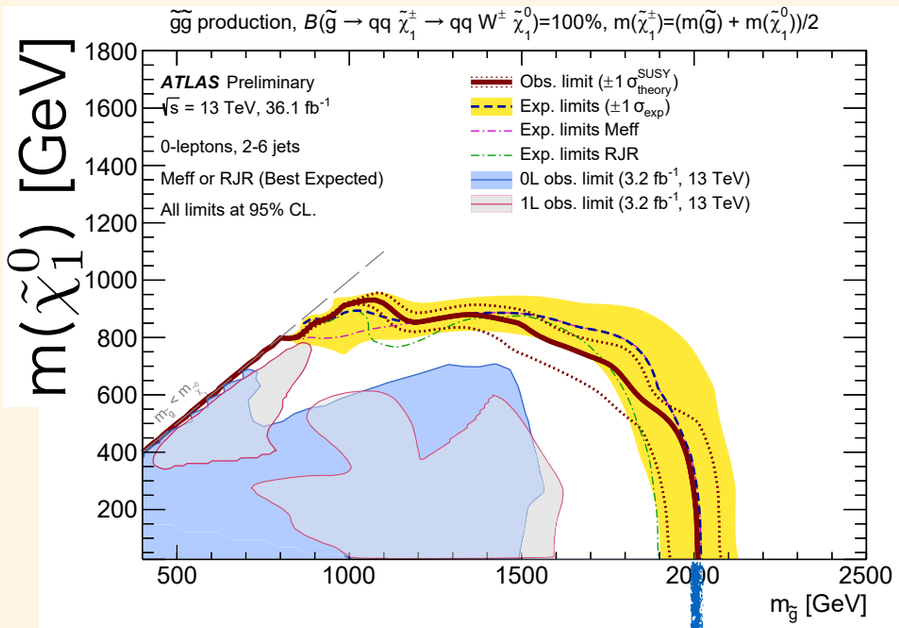




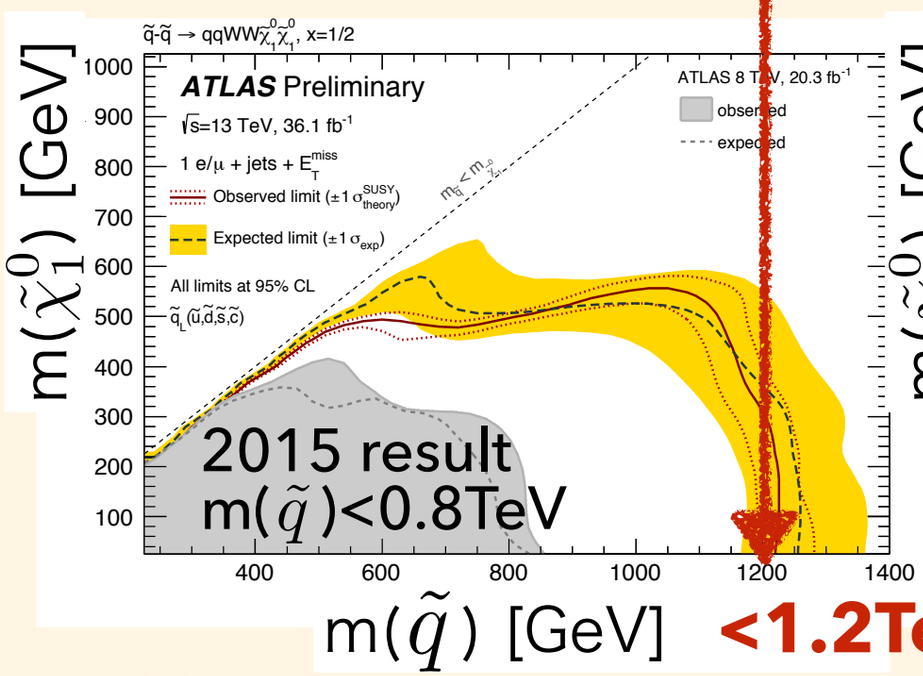


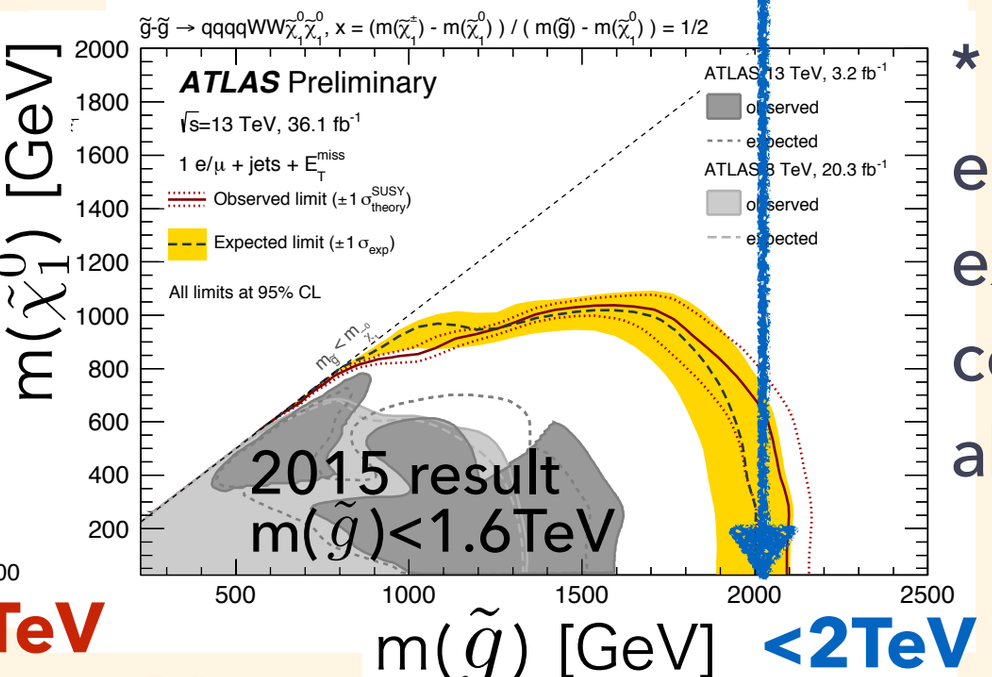
0L





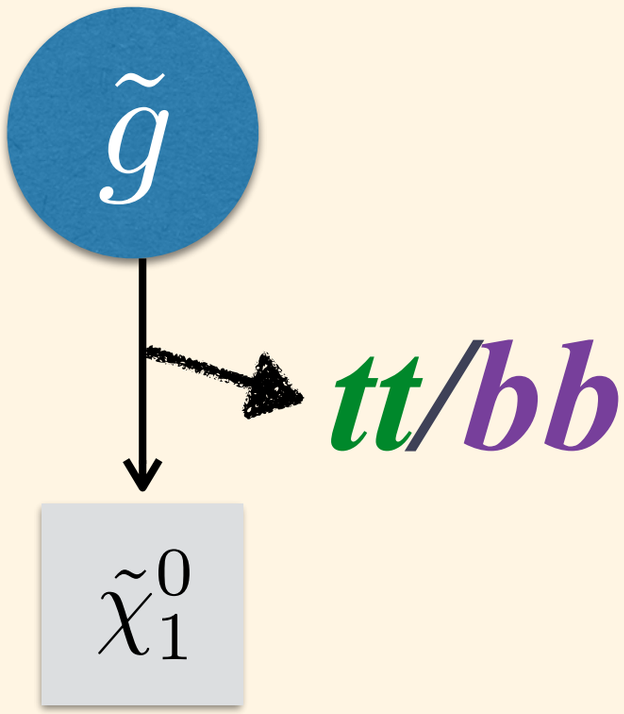
1L





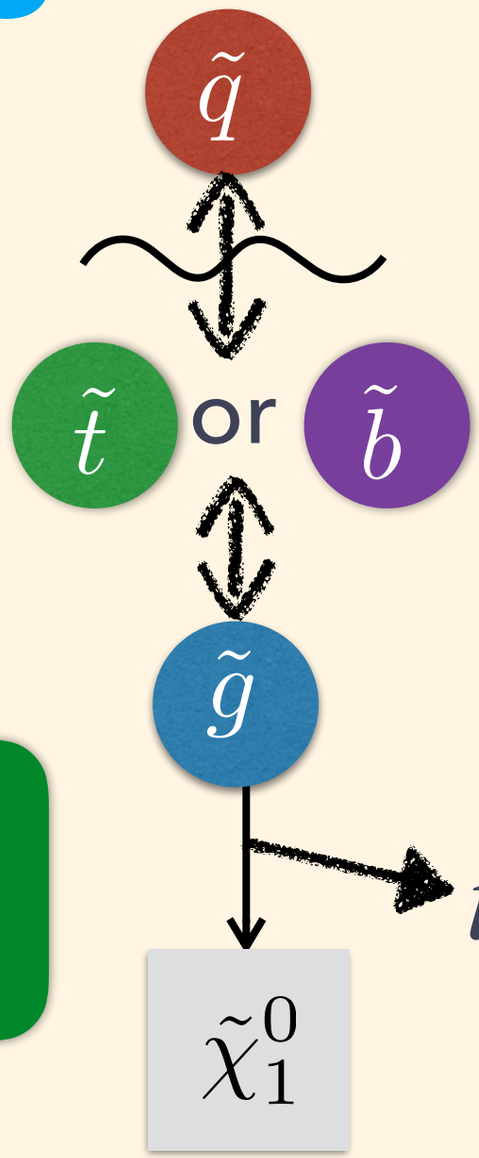
* In **1L** analysis, each point is excluded by combined fit in all of SRs.

Multi-b



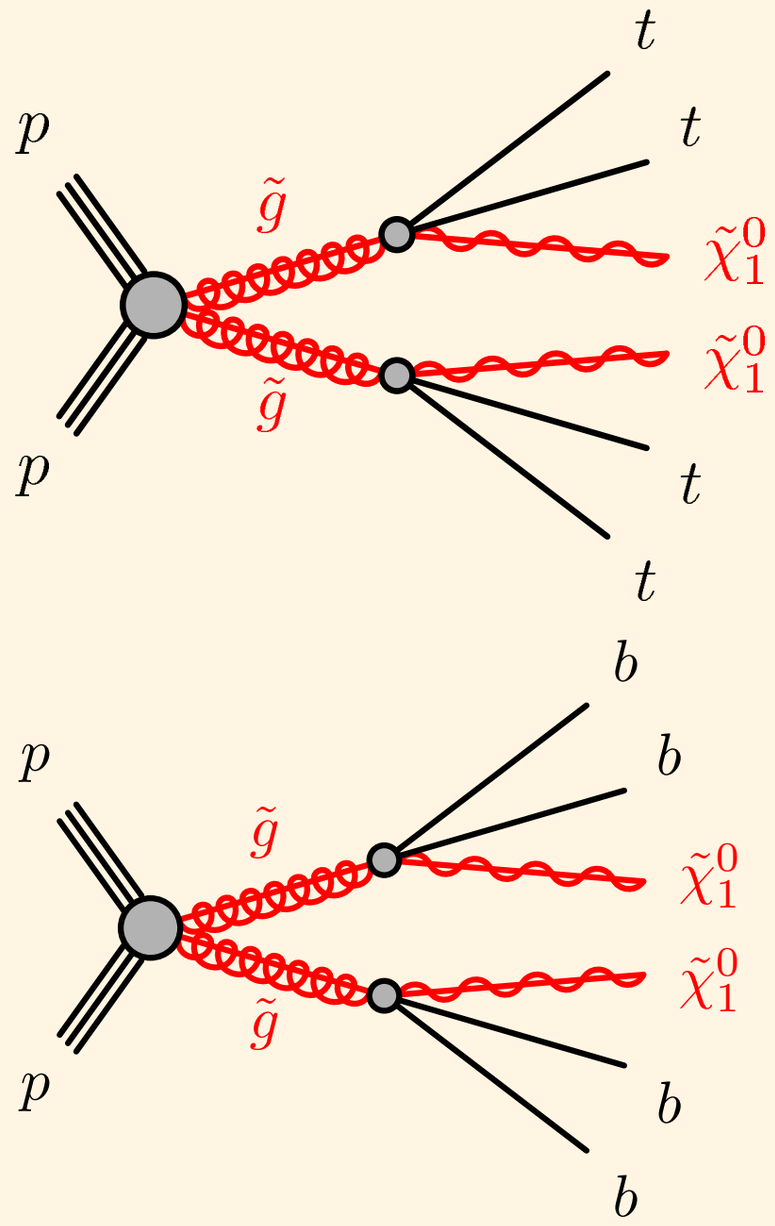
Direct decay

Target decay topology



Well-motivated by "**Naturalness**"

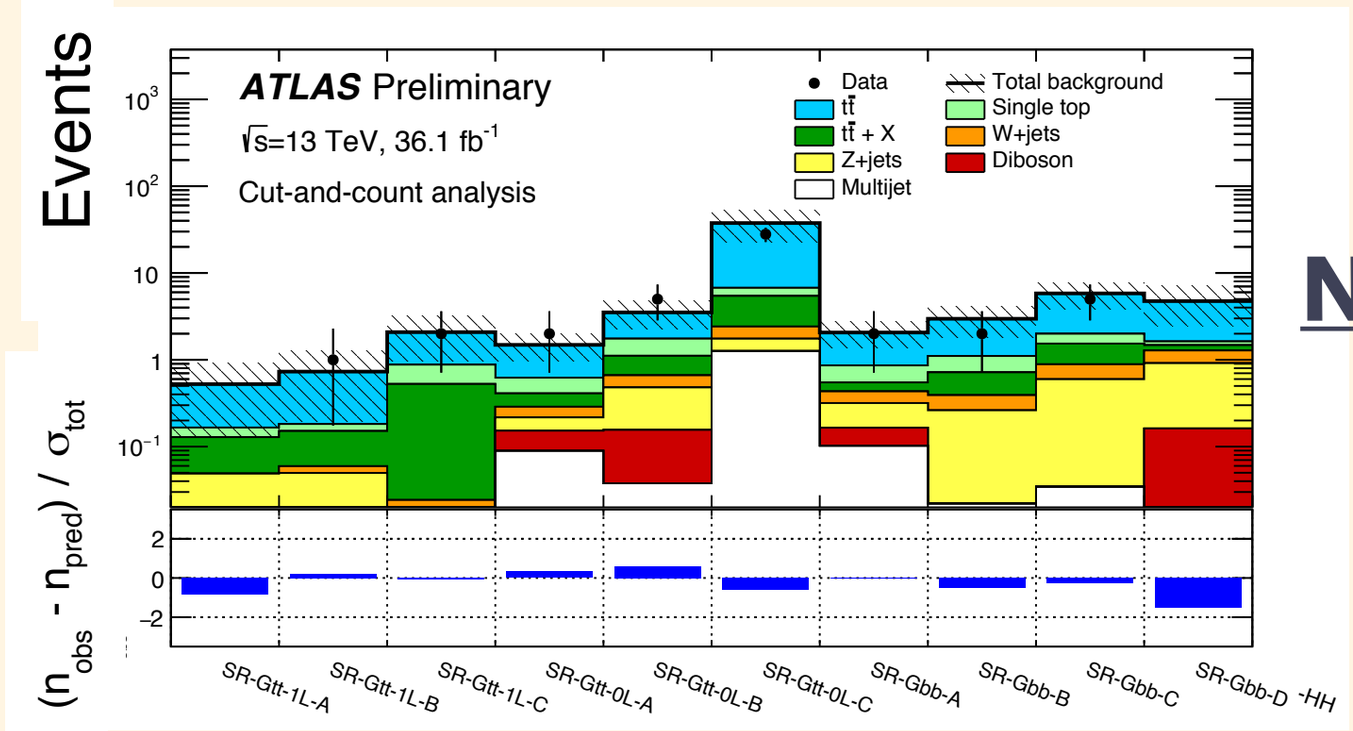
Direct decay



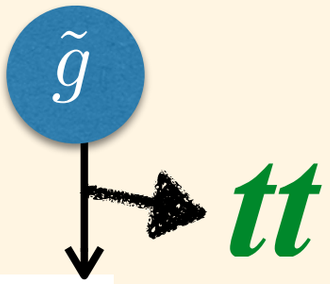
There are **4b** in final state.

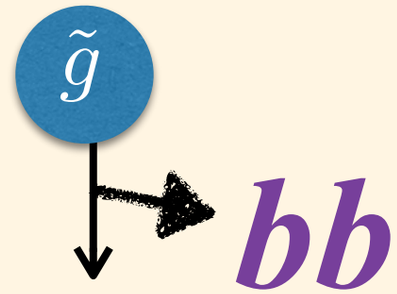
Special analysis with requirement on $N_{b\text{-}jet}$

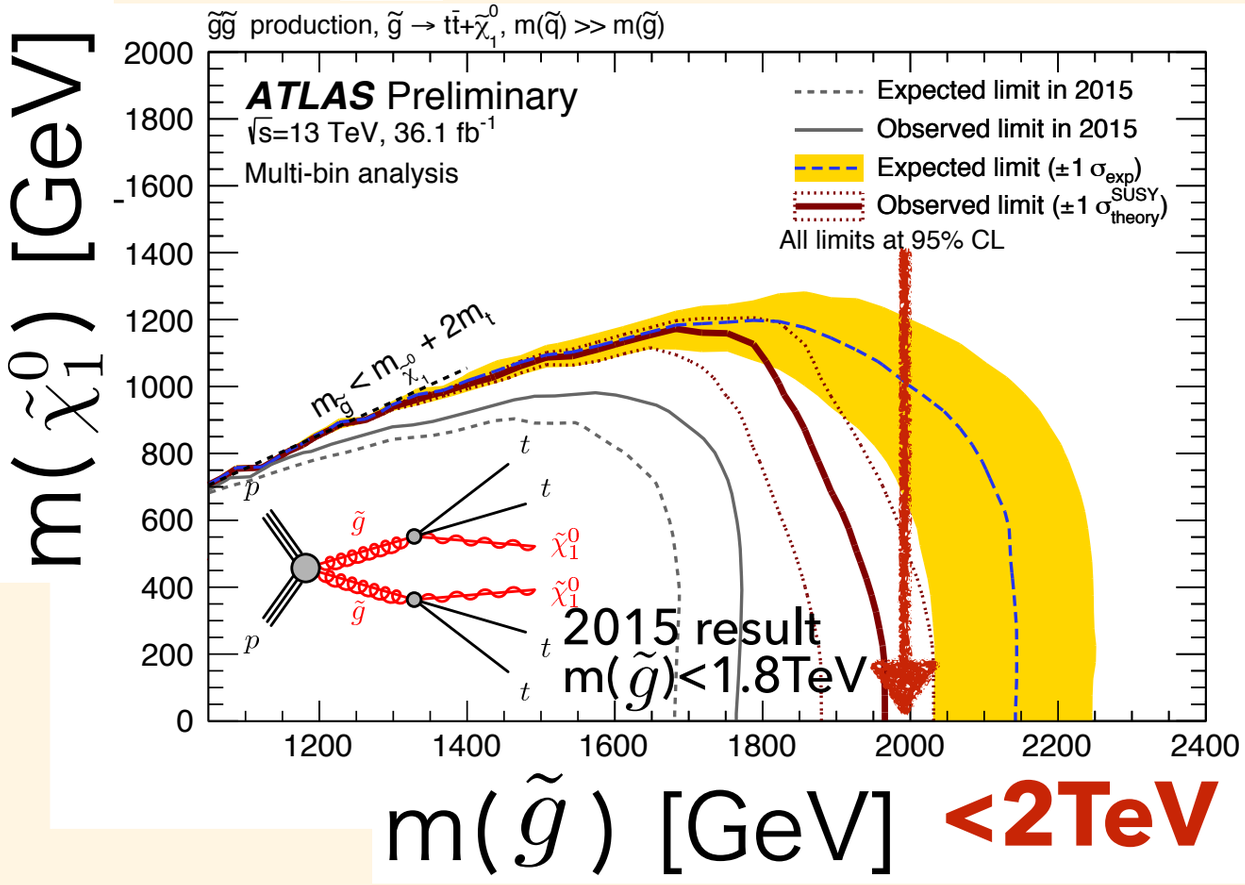
Fit result & Exclusion limits

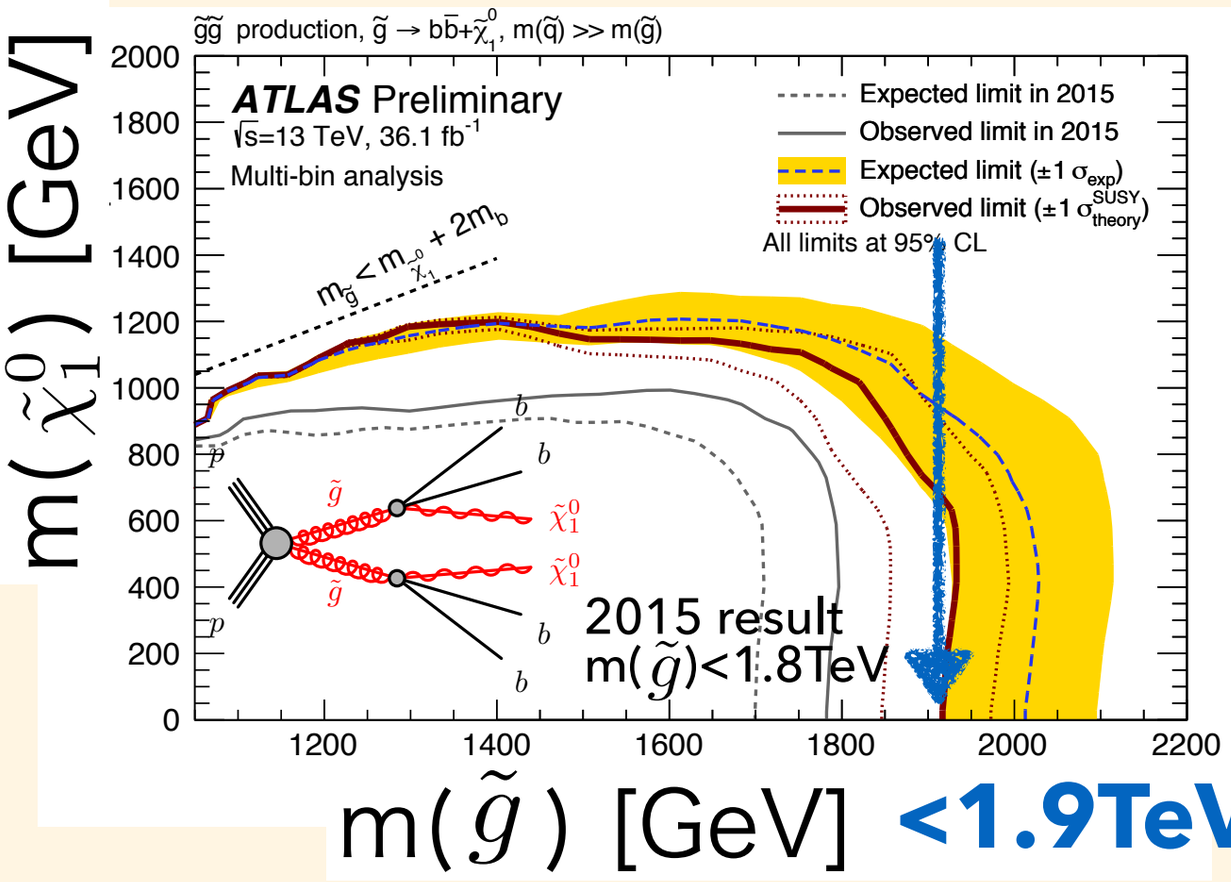


No significant excess









0L 8–11jets / 1L 9jets

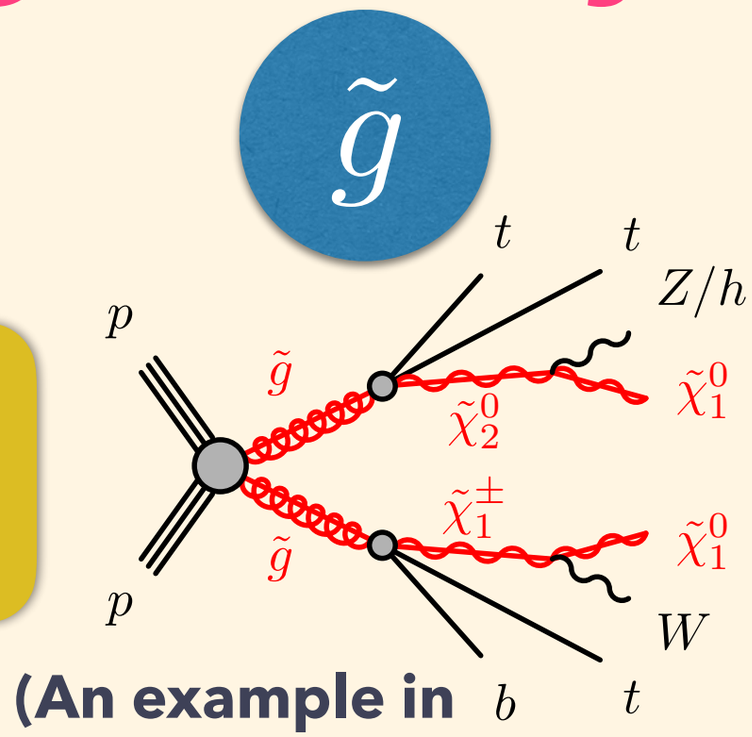
$\tilde{g}$

1-step decay

2-step decay

Target decay topology

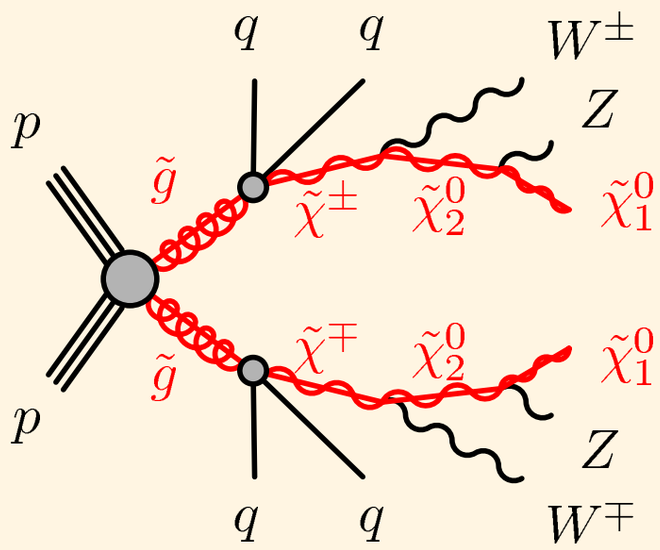
1-step decay



(An example in pMSSM process)

- pMSSM process with fixed parameters.
  - Bino LSP
  - **Higgsino-dominated** multiplet at intermediate mass between $\tilde{g}$ and LSP.
- $\tilde{g} \to tt\tilde{\chi}_2^0$ / $tb\tilde{\chi}_1^\pm$ decay is enhanced by **Higgsino**.

2-step decay



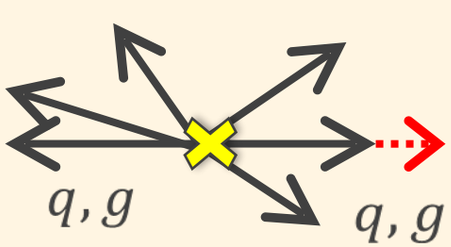
- Simplified model
- 2-step decay makes many particles in final states.

SR & Background

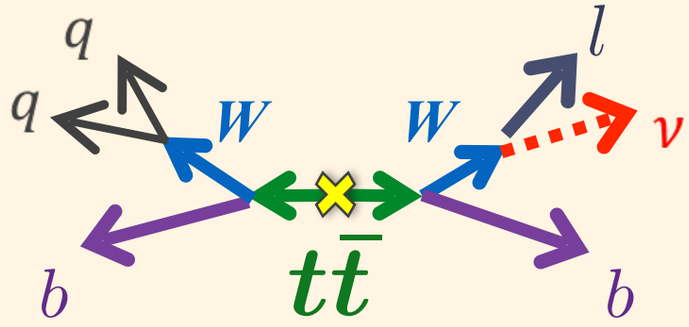
0L 8–11jets

- Split SRs by N_{jet} : $N_{\mathrm{jet}} \geqq 7,8,9,10,11$

Main BG



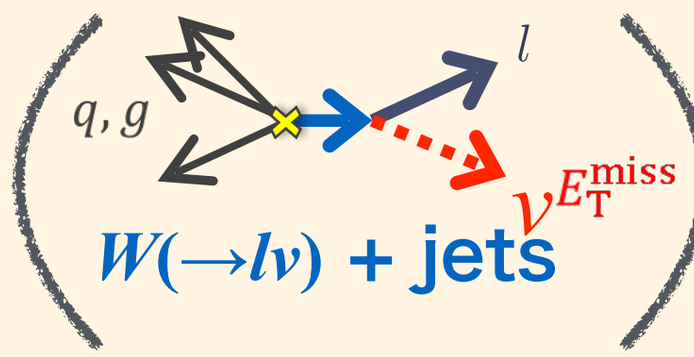
by energy mis-measured Multi-jet



1L 9jets

- One SR $N_{\mathrm{jet}} \geqq 9$

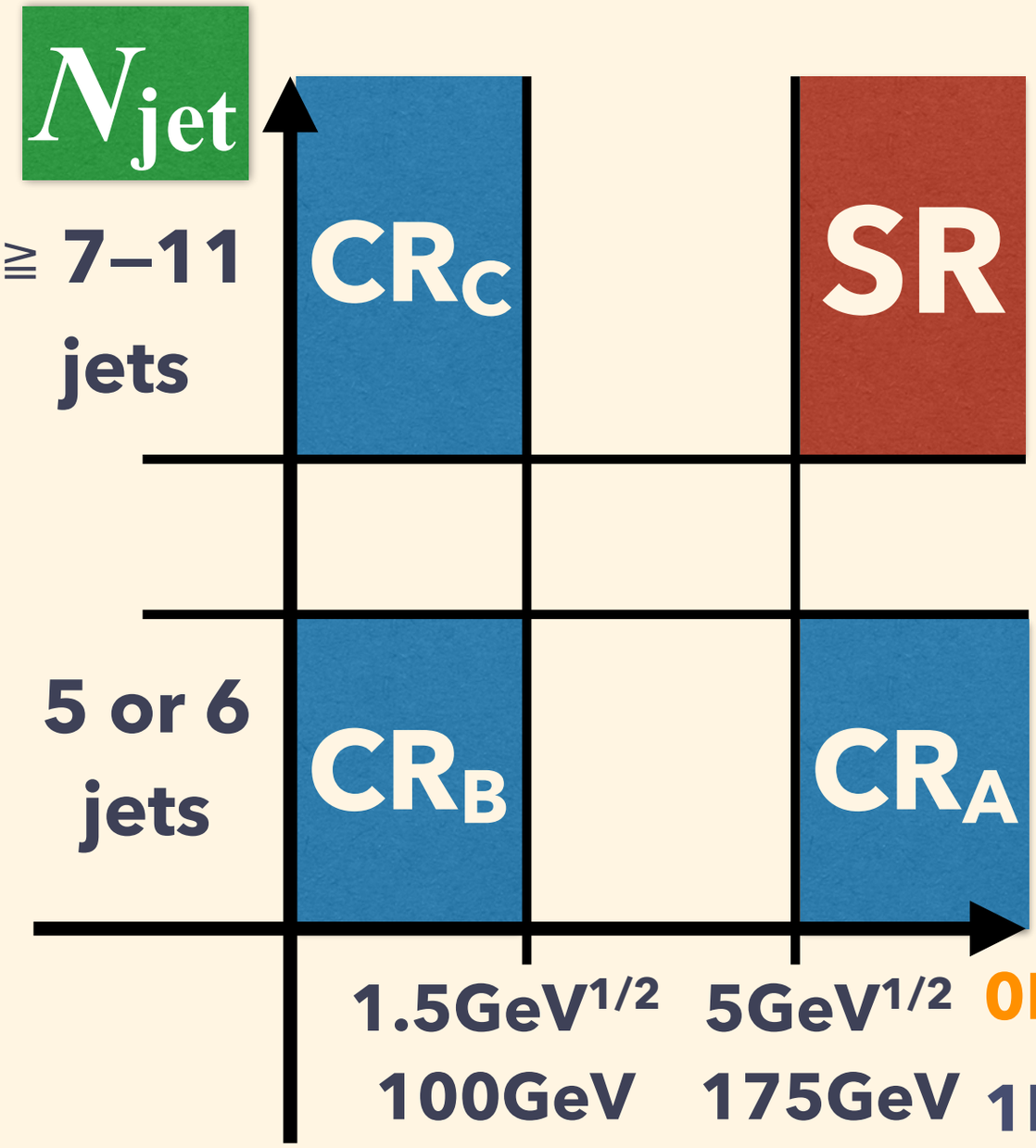
Main BG



High jet multiplicity can remove SM background much.
But it's difficult to estimate it with MC.

⇒ Data-driven estimation is necessary.

Background estimation (ABCD method)



- Background in SR is predicted by extrapolating in **a specific variable** and N_{jet} 2D plain (**only data**).

*** H_T = Σ jet p_T**

0L $E_T^{miss}/\sqrt{H_T}$

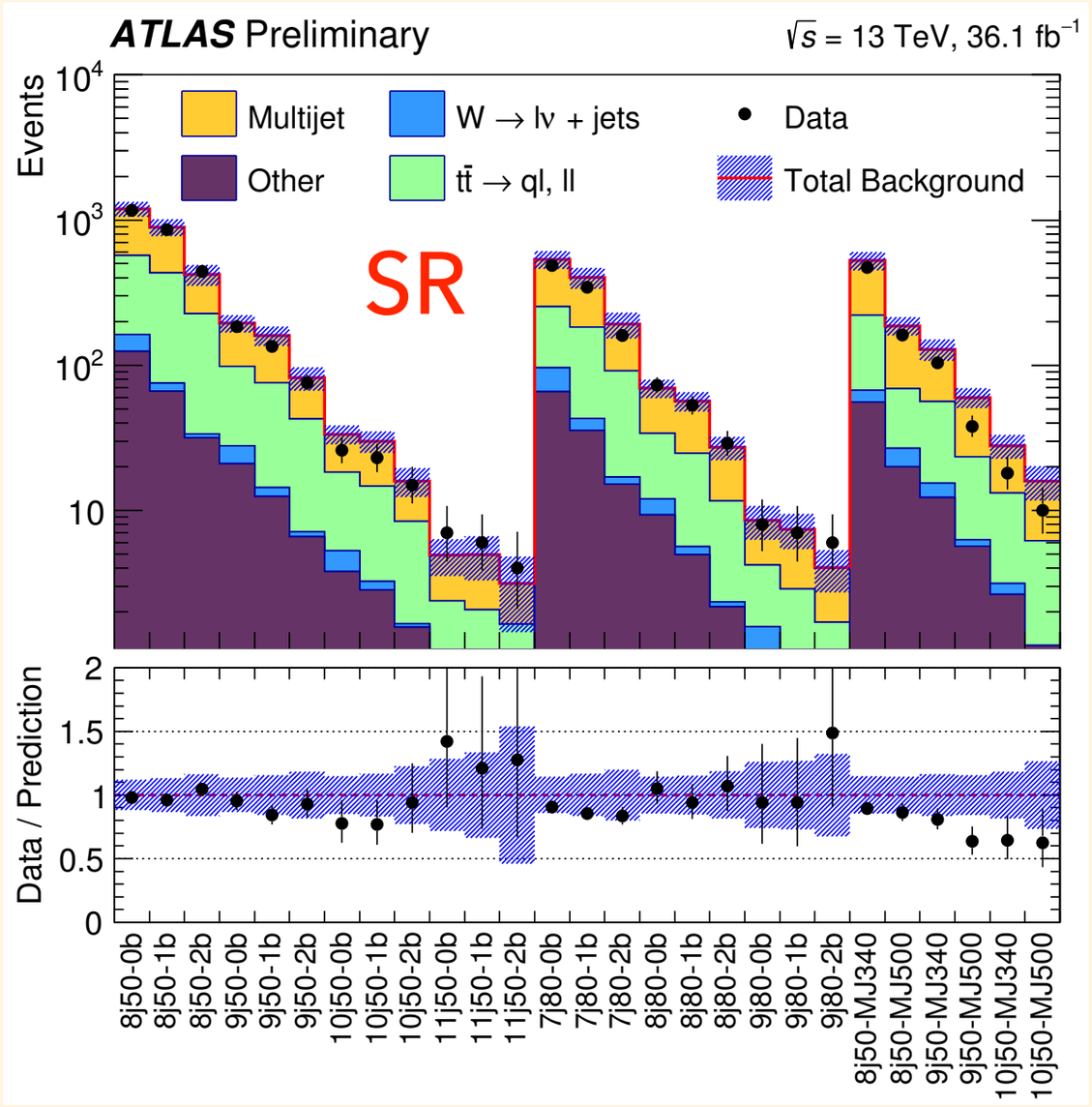
1L m_T

× N_{jet}

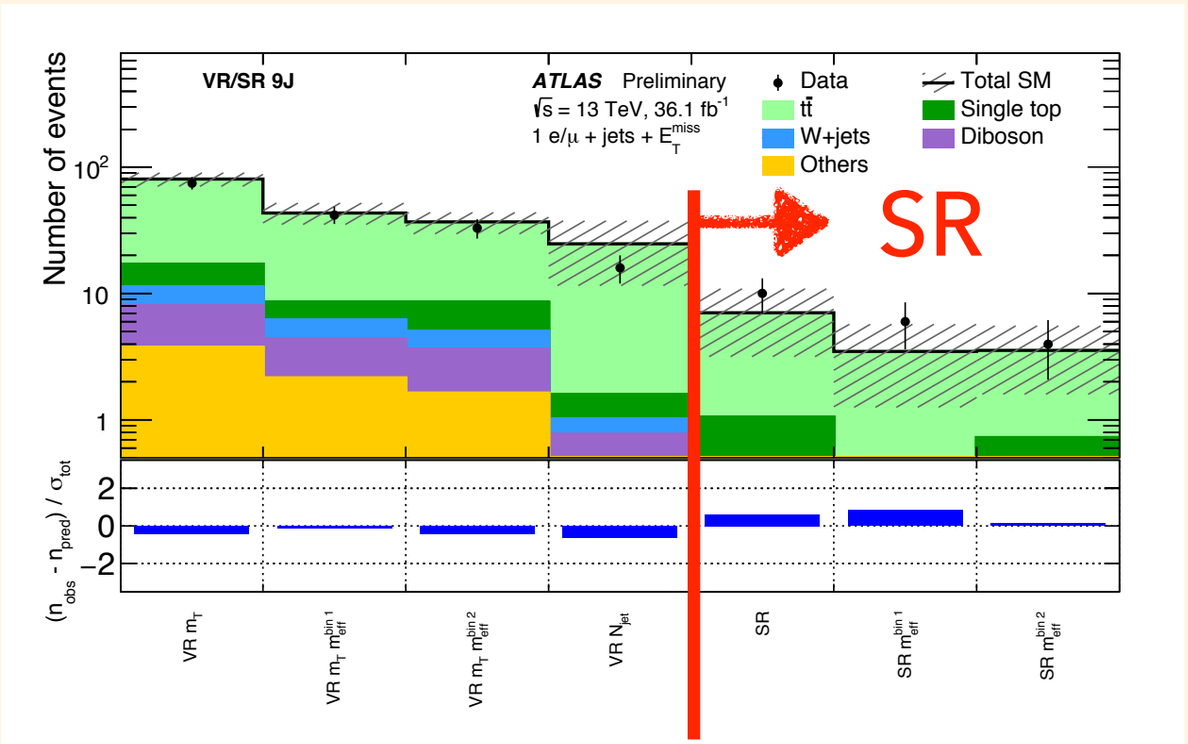
- **1L** estimates $t\bar{t}$ / **W+jets** in b-tag/b-veto region, respectively.

$$N_{\mathrm{pred,\ SR}} = N_{\mathrm{Data,\ CR_C}} \times \frac{N_{\mathrm{Data,\ CR_A}}}{N_{\mathrm{Data,\ CR_B}}}$$

Fit result : 0L 8–11jets / 1L 9jets



27 SRs (Inclusive selections on N_{jet} and $N_{\text{b-jet}}$)



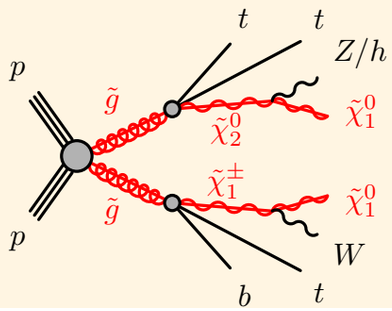
m_{eff}-bin SRs (Exclusive selections)

(Multi-bin fit is done in m_{eff})

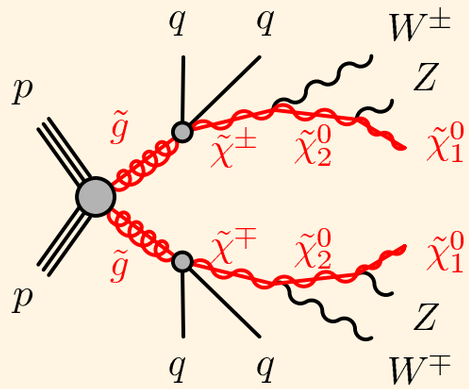
No significant excess

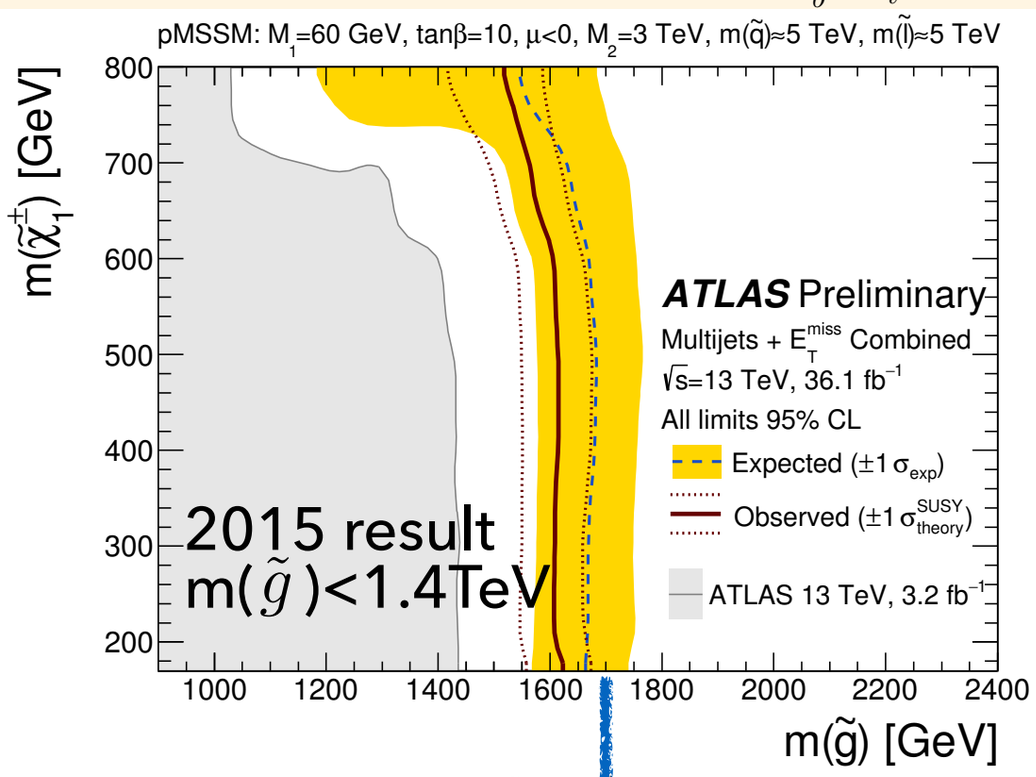
Exclusion limits

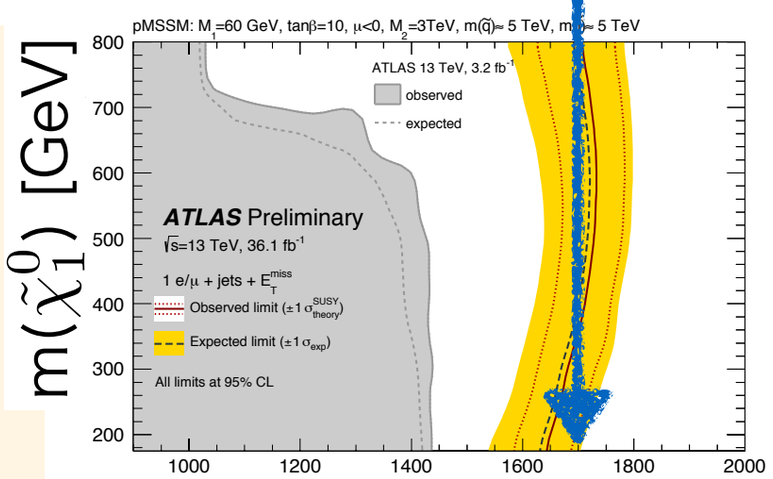
1-step decay



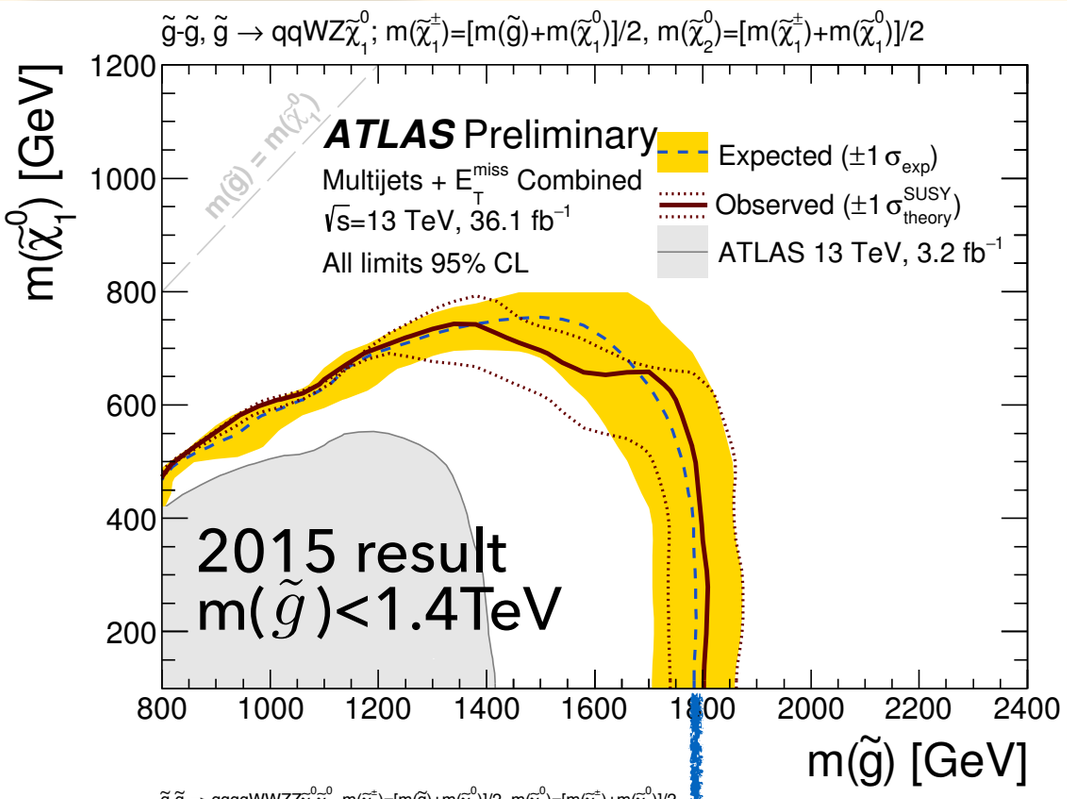
2-step decay

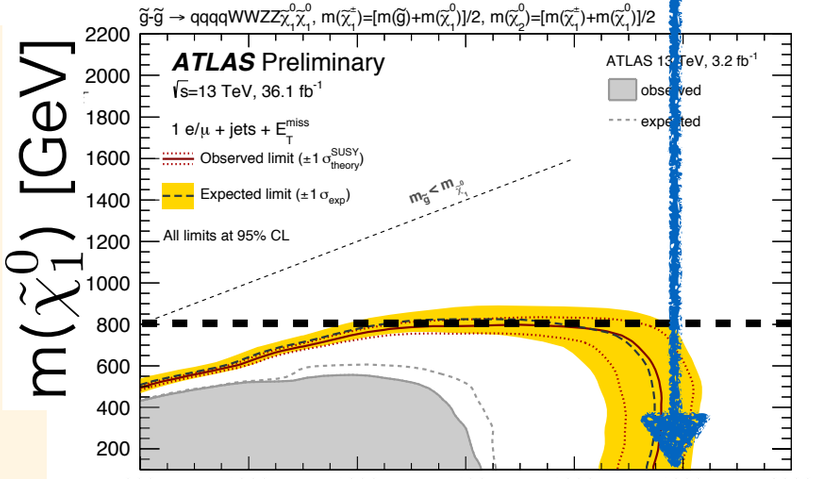




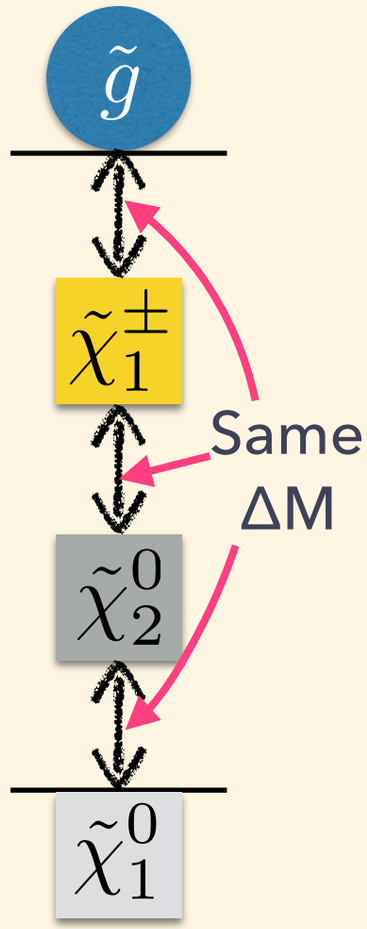


m($\tilde{g}$) [GeV] **<1.7TeV**



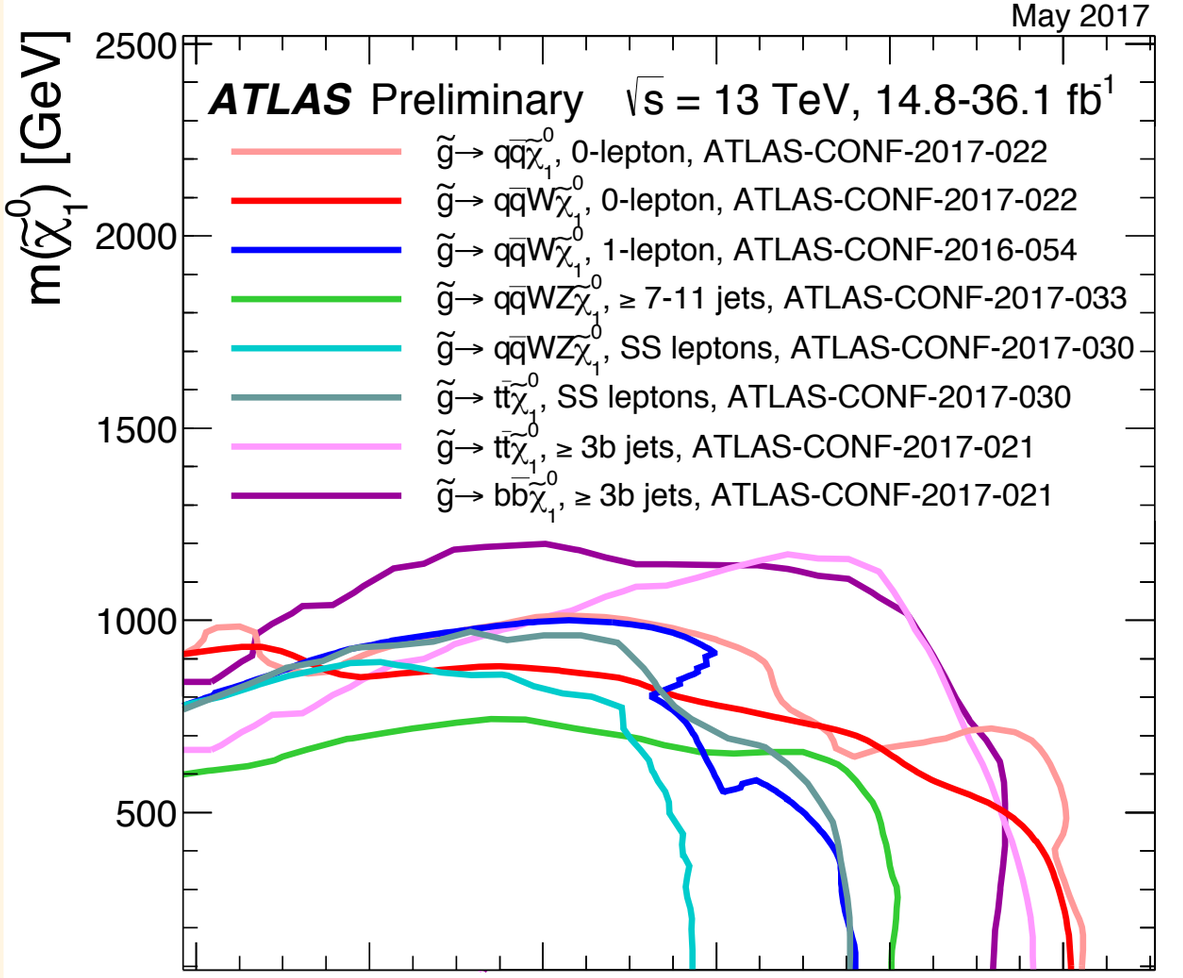


m($\tilde{g}$) [GeV] **<1.8TeV**



Summary

- At ATLAS experiment, Squark and Gluino are searched widely.
- In order to cover various mass spectrum and various number of decay steps, analysis is separated by N_{jet} and other object in the final states.



Summary plot of exclusion limits in strong production
(1L is old result with only 14.8fb^{-1})

- There is **no significant excess** in strong production search.
- **Squark** mass is excluded up to **1.2–1.6 TeV** in 0–2 steps decay.
- **Gluino** mass is excluded up to **1.7–2TeV** in 0–2 steps decay.

Backup

Recent results in strong production

Dataset : 36.1fb^{-1} in 2015+2016

Direct decay | **1-step decay** | **2-step decay**

0L (2–6jets)
ATLAS-CONF-2017-022

0L (8–11jets)
ATLAS-CONF-2017-033

Multi-b
ATLAS-CONF-2017-021

1L
ATLAS-CONF-2017-033

Same-sign 2L / 3L
arXiv:1706.03731

Long lived particle

Displaced vertex
ATLAS-CONF-2017-026

Gluino is long-lived particle

R-parity violation

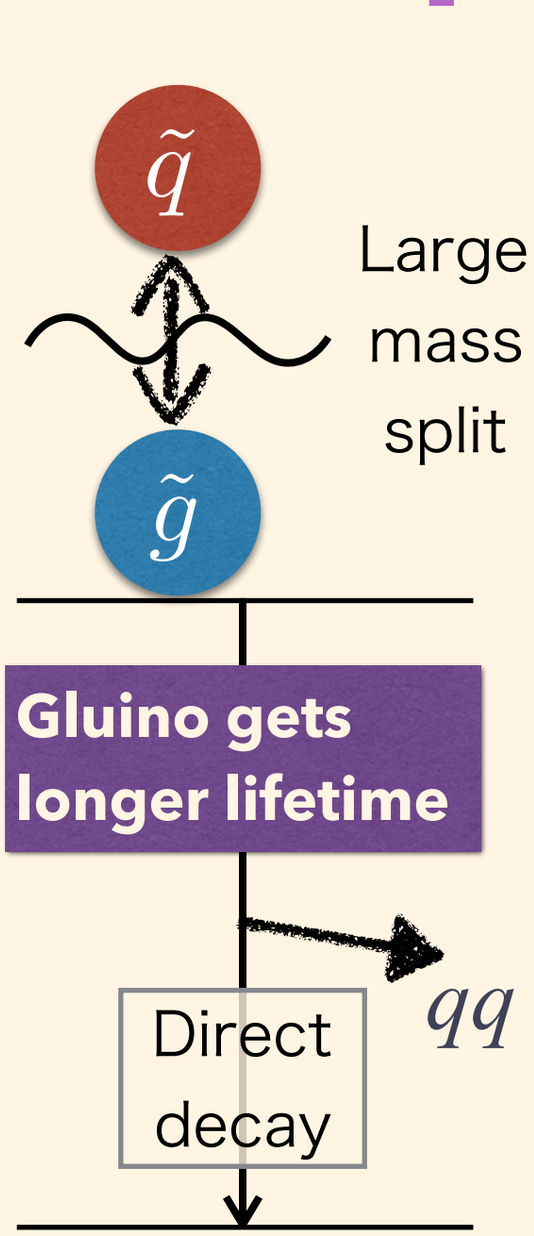
R-parity violating 1L
arXiv:1704.08493

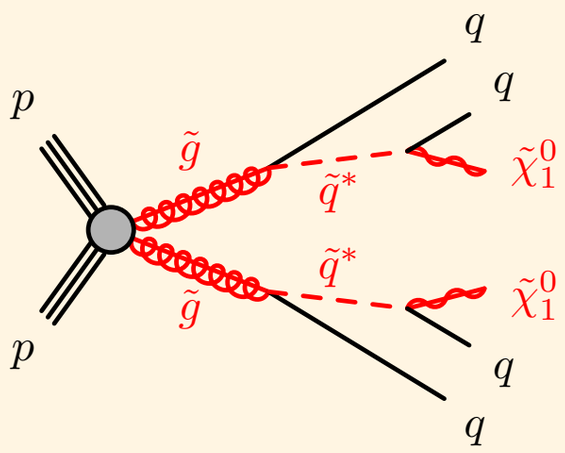
No LSP in final states

Displaced vertex 0L

Long lived particle

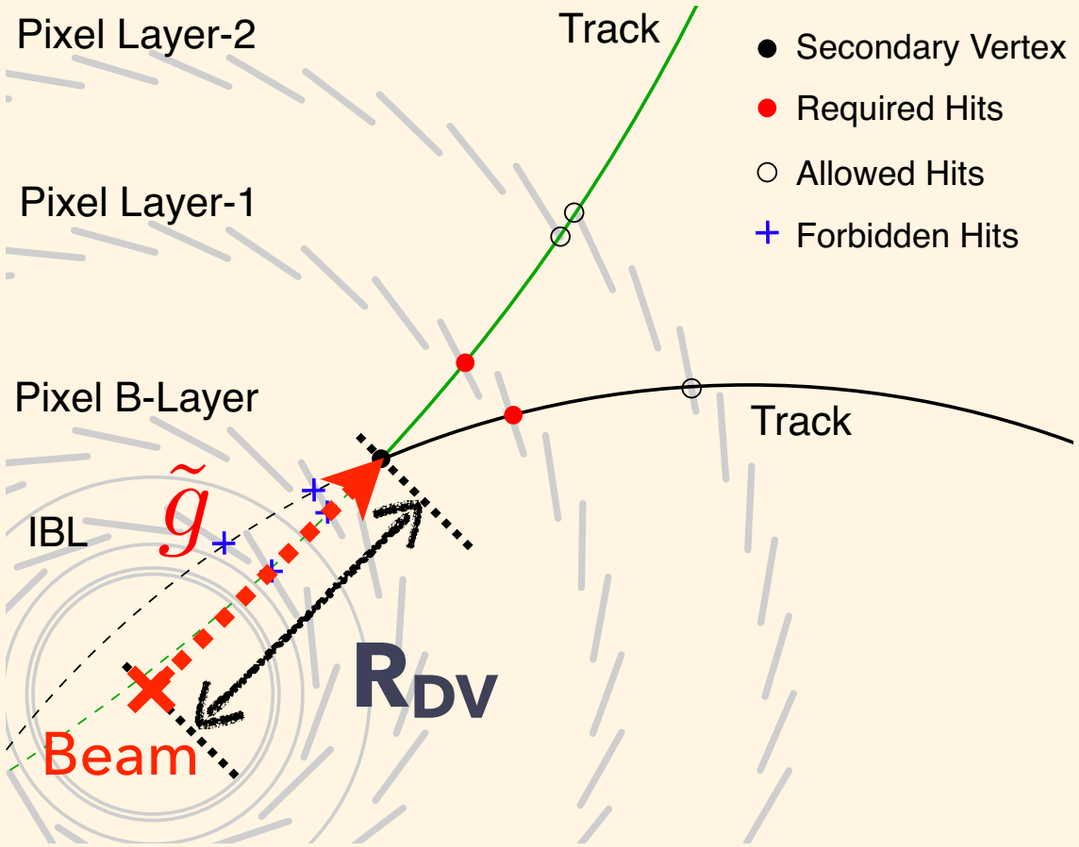
Displaced vertex

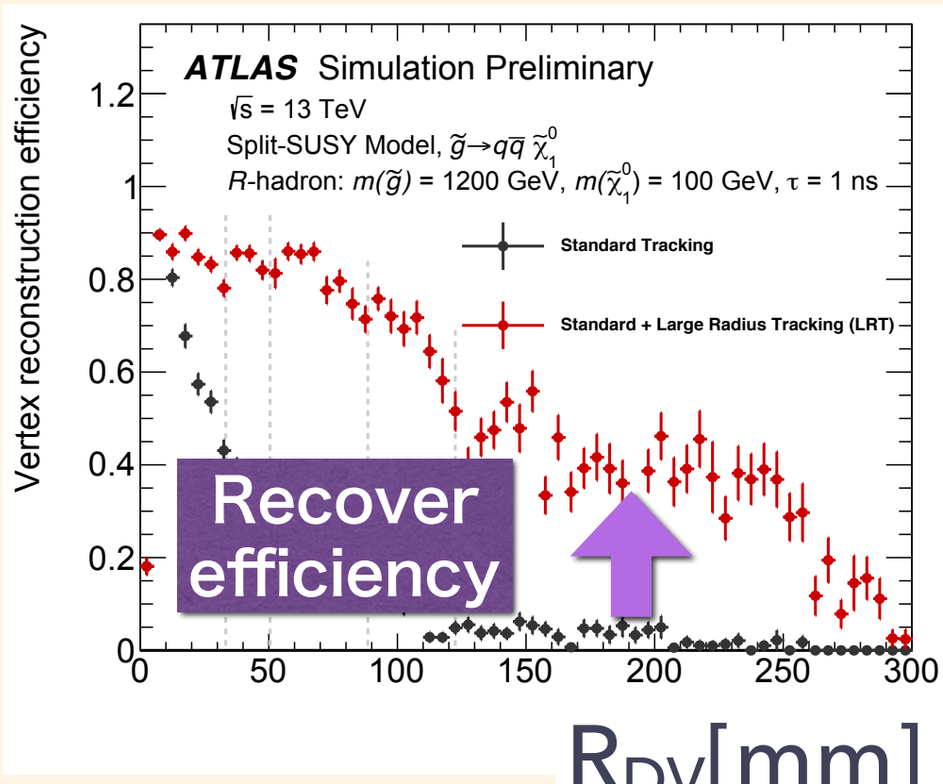




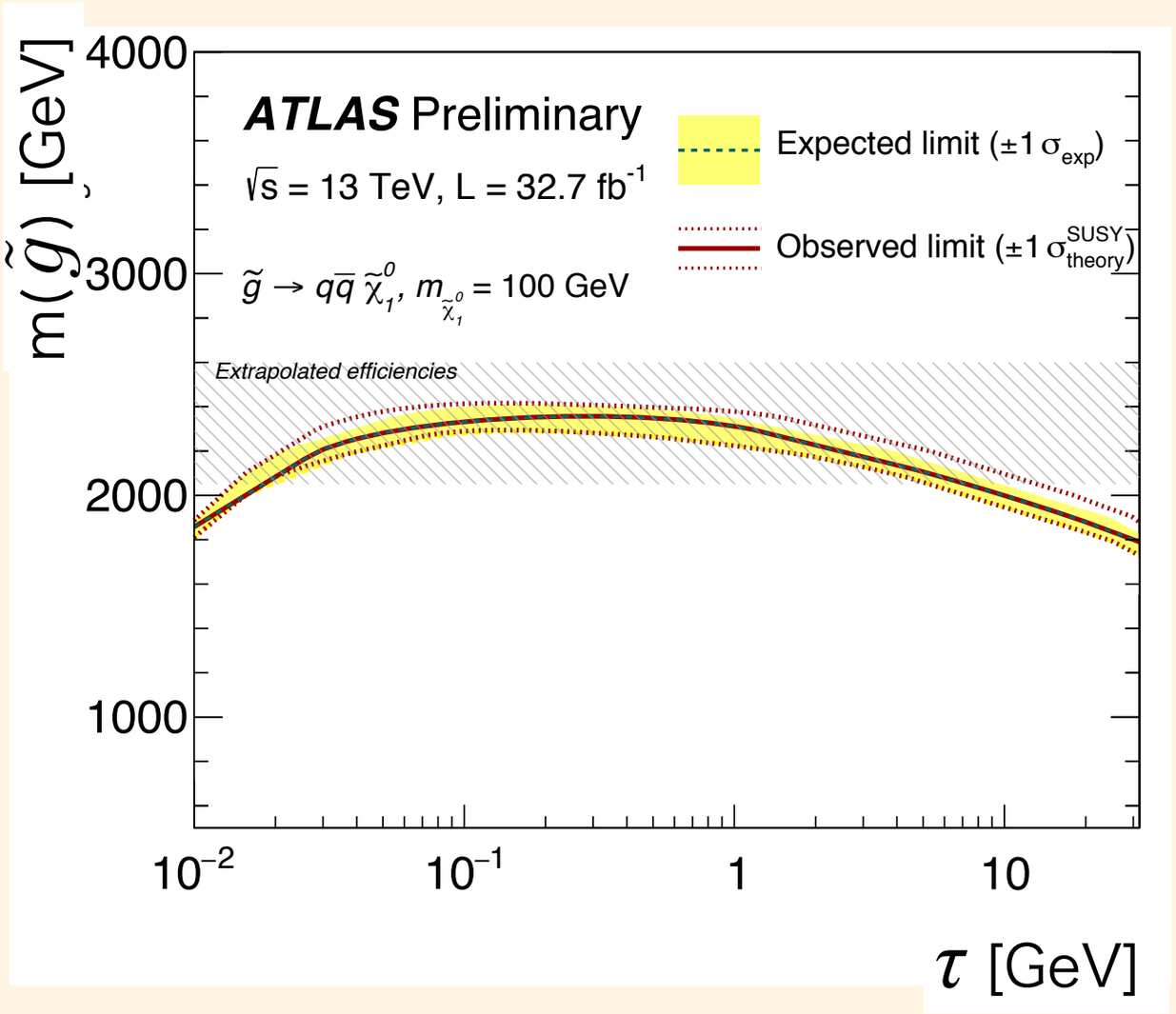
- Virtual squark $\tilde{q}^*$ makes gluino long-lived.
- Gluino decay makes displaced vertex and it cannot reconstructed by normal tracking algorithm.

⇒ Need special tracking algorithm to recover efficiency.





Fit result : Displaced vertex

Selection	Sub-Region	Estimated	Observed
Event pre-selection $n_{trk} = 3$, $m_{DV} > 10$ GeV			3093
Event pre-selection $n_{trk} = 4$, $m_{DV} > 10$ GeV	VRLM	**9 ± 2**	**9**
	VRM	**150 ± 60**	**177**
Event pre-selection $n_{trk} \geq 5$, $m_{DV} > 10$ GeV	5-tracks	**2.2 ± 2.8**	**1**
	6-tracks	**0.6 ± 0.6**	**1**
	≥7-tracks	**1 ± 3**	**3**
	Total	**4.2 ± 4.1**	**5**
Full SR selection	**Total**	**0.02 ± 0.02**	**0**

0 event observed