Long Lived Particles in Viable SUSY Dark Matter Models

Satoshi Shirai (Kavli IPMU)

Based on

H. Fukuda, N. Nagata, H. Otono, and SS,
"Probing bino–gluino coannihilation at the LHC," Phys.Lett. B748 (2015) 24,
"Probing bino–wino coannihilation at the LHC," JHEP 1510 (2015) 086,
"Cornering Compressed Gluino at the LHC," JHEP 1703 (2017) 025,
"Higgsino Dark Matter or Not," Phys.Lett. B781 (2018) 306

1. SUSY after LHC

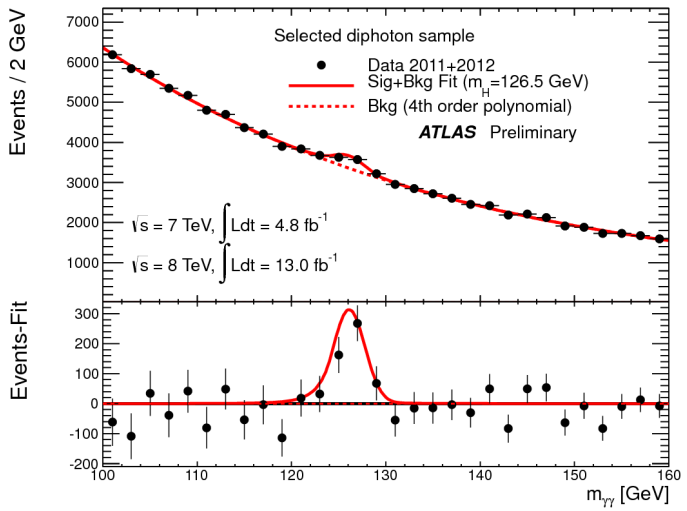
Higgs Mass
Mini-split SUSY
Dark Matter

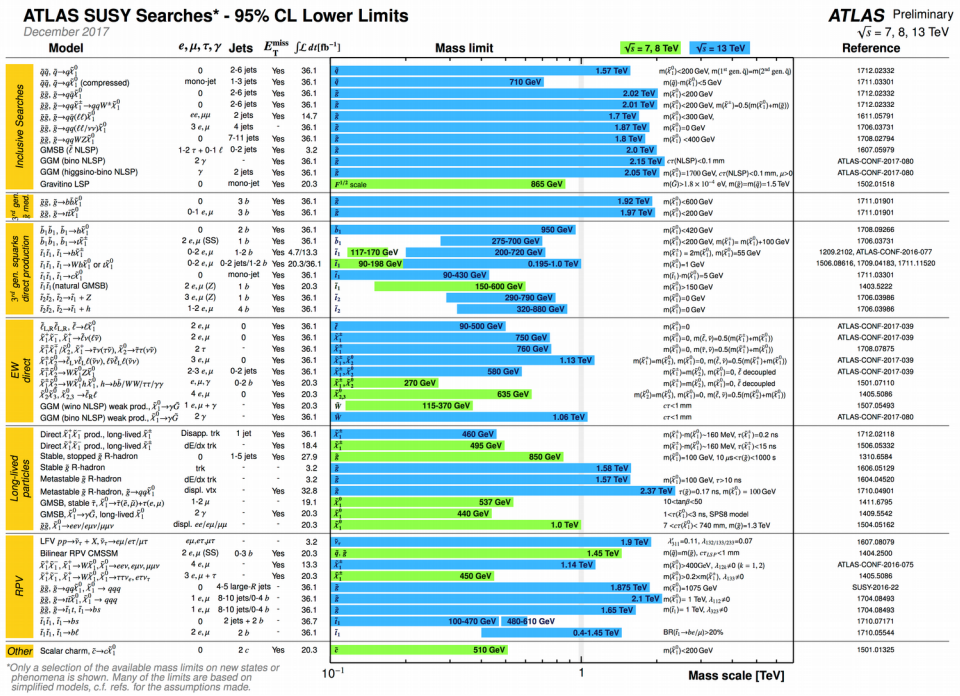
2. Dark Matter Signatures in Mini-Split

Wino
Gaugino coannihilation
Long lived particle signatures

3. Summary

Higgs and SUSY at LHC



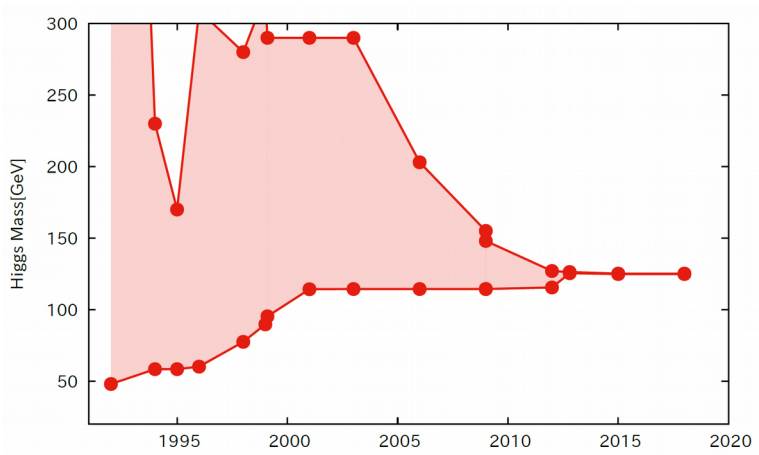


Higgs Discovered!

SUSY Constrained!

Cornering Higgs and SUSY

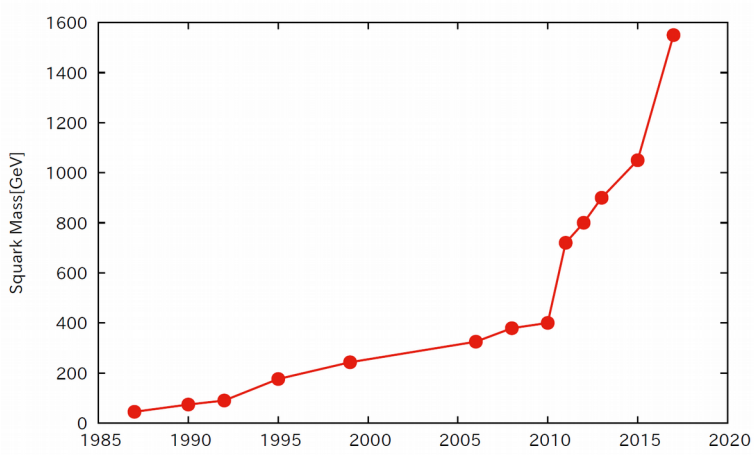
Higgs Mass Range



Year

$m_h = 125.18 \pm 0.16$ GeV

Squark Mass Limit



Year

$m_{\tilde{q}} > 1550$ GeV

SUSY Higgs

Higgs potential

$$V(H) = \frac{\lambda}{2}(HH^\dagger - v^2)^2$$

In MSSM

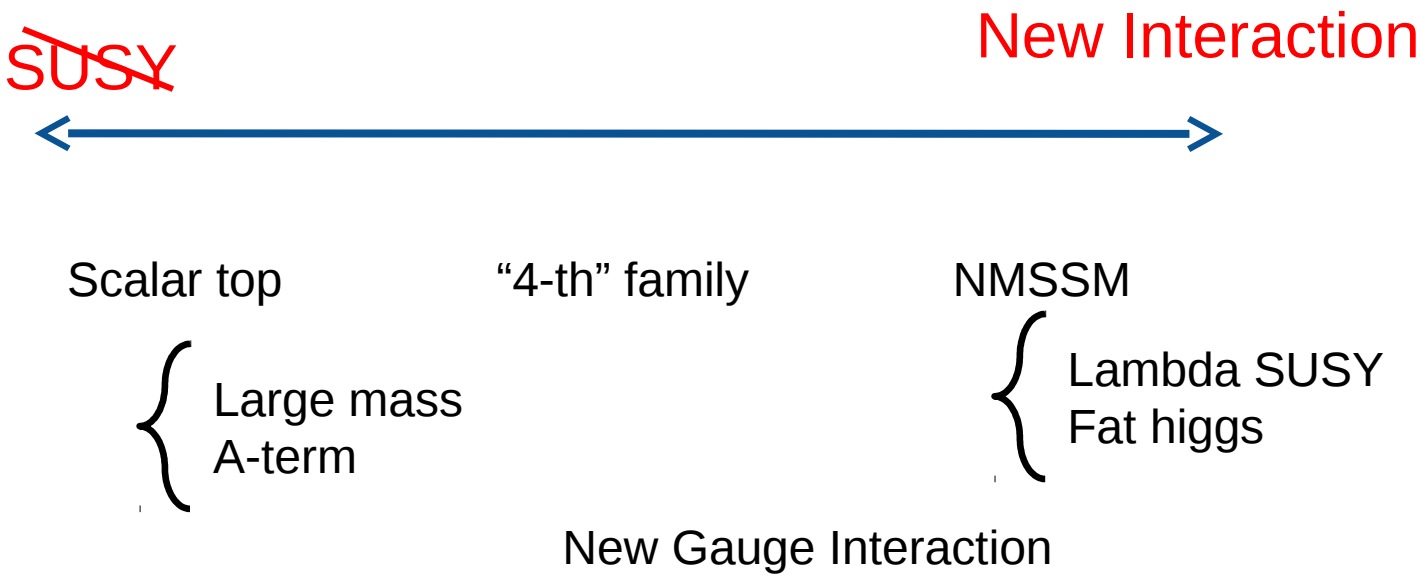
$$\lambda = \frac{1}{4}(g_1^2 + g_2^2)\cos(2\beta)$$

$$m_h = m_Z \cos(2\beta) \lesssim 91 \text{ GeV}$$

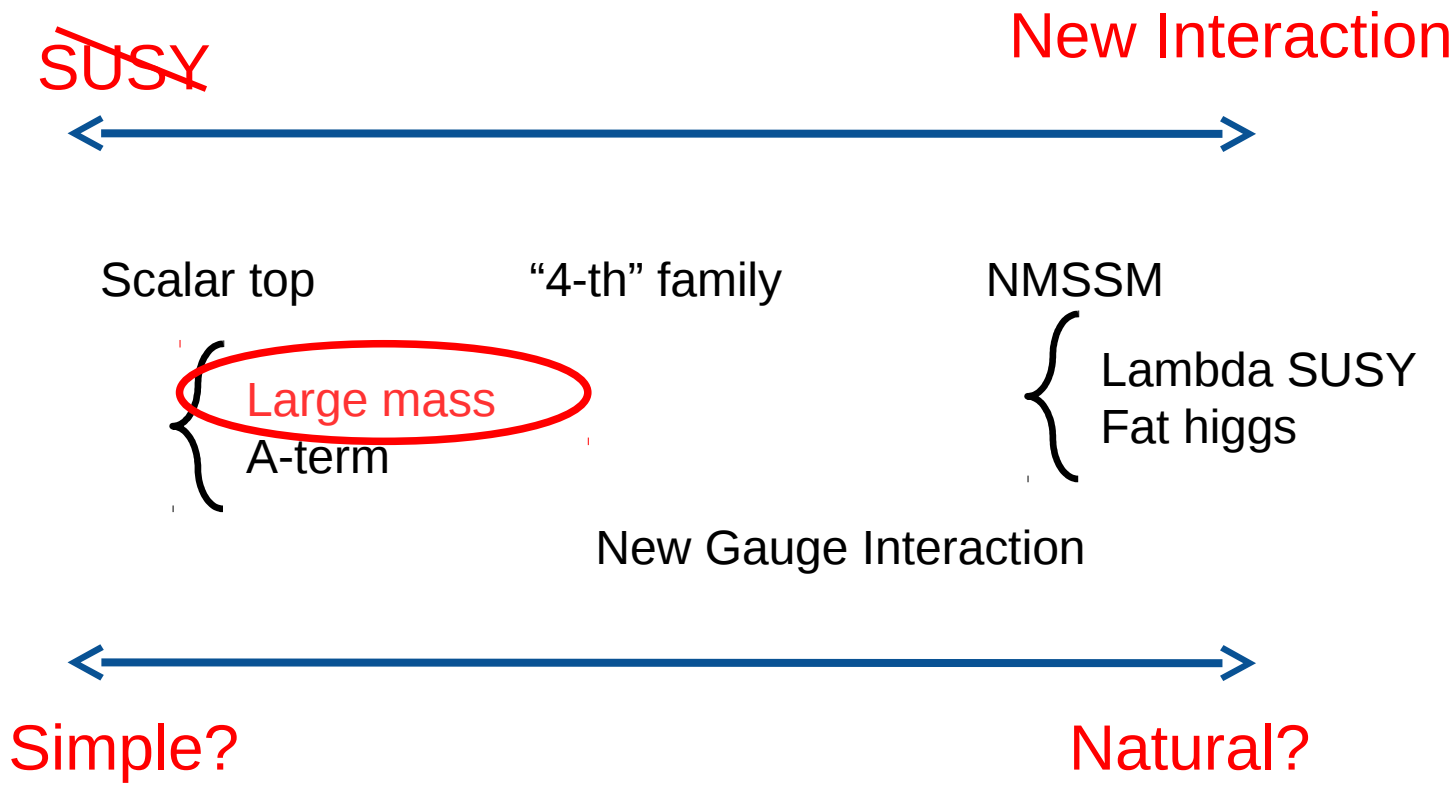
This is clearly less than observed 125 GeV Higgs!

$$\lambda = \lambda_{\text{MSSM}} + \lambda_{\text{SUSY breaking}} + \lambda_{\text{new interaction}}$$

SUSY after 125 GeV Higgs

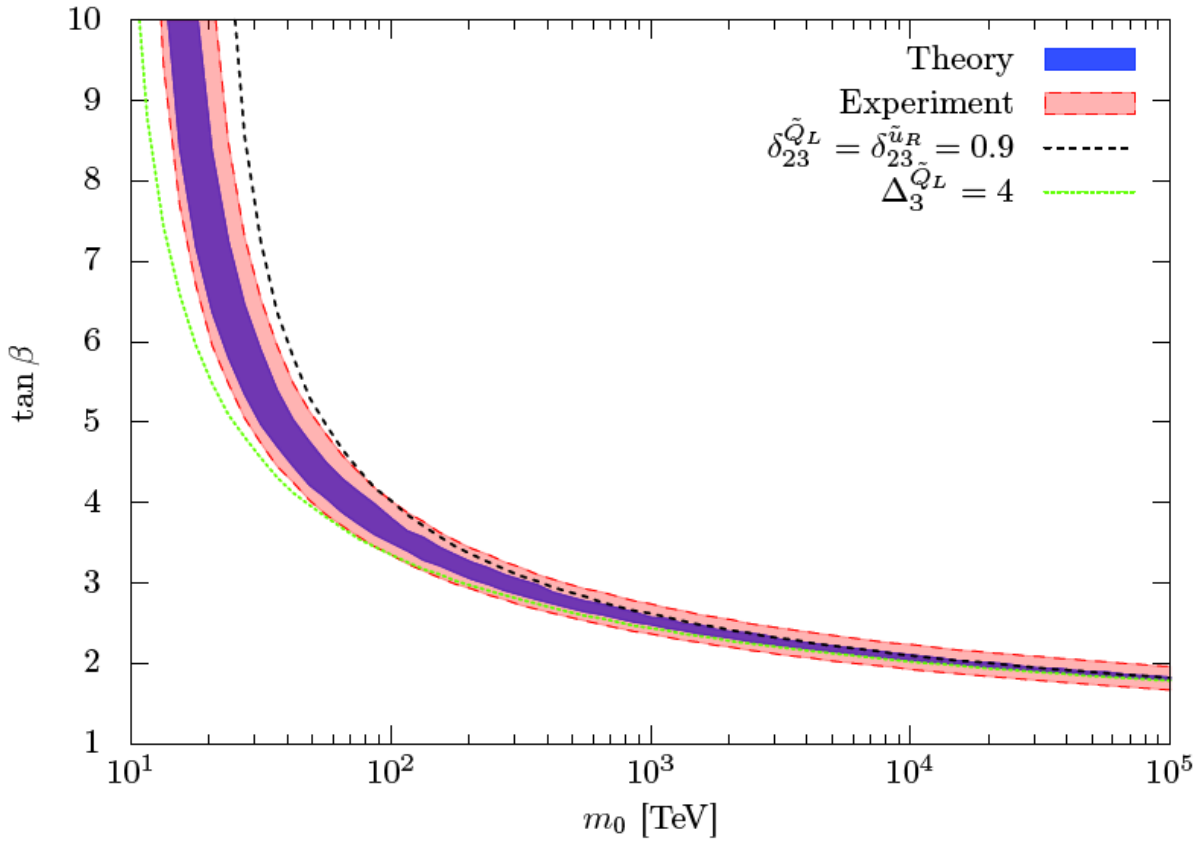


SUSY after 125 GeV Higgs



Higgs Mass from Stop

125 GeV Higgs OK regions



Scalar Mass

Benefit and demerit of SUSY

Benefit

- Hierarchy Problem
- GUT unification
- DM

Possible demerit

- Flavor/CP Problem
- Cosmological Gravitino Problem
- Model building

Mini-Split Mass Spectrum

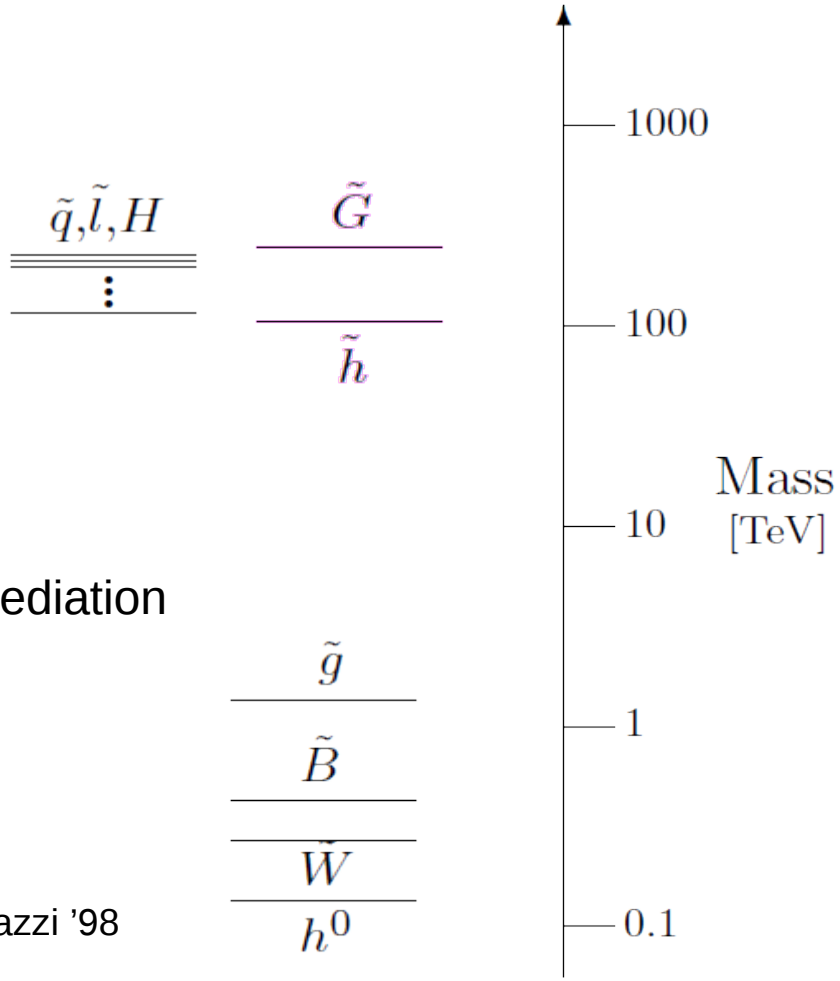
Tree level Gravity Mediation

$$|m_0| \sim |\mu| \sim m_{3/2}$$

Loop suppressed: e.g., Anomaly Mediation

$$M_a \sim \frac{\alpha_a}{4\pi} m_{3/2}$$

Randall, Sundrum '98
Giudice, Luty, Murayama, Rattazzi '98



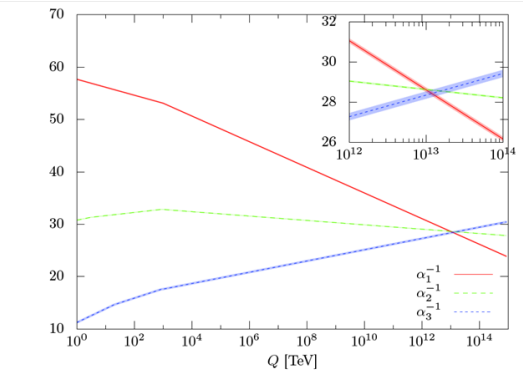
Benefit and demerit of SUSY

Benefit

? • Hierarchy Problem

✓ • GUT unification

✓ • DM



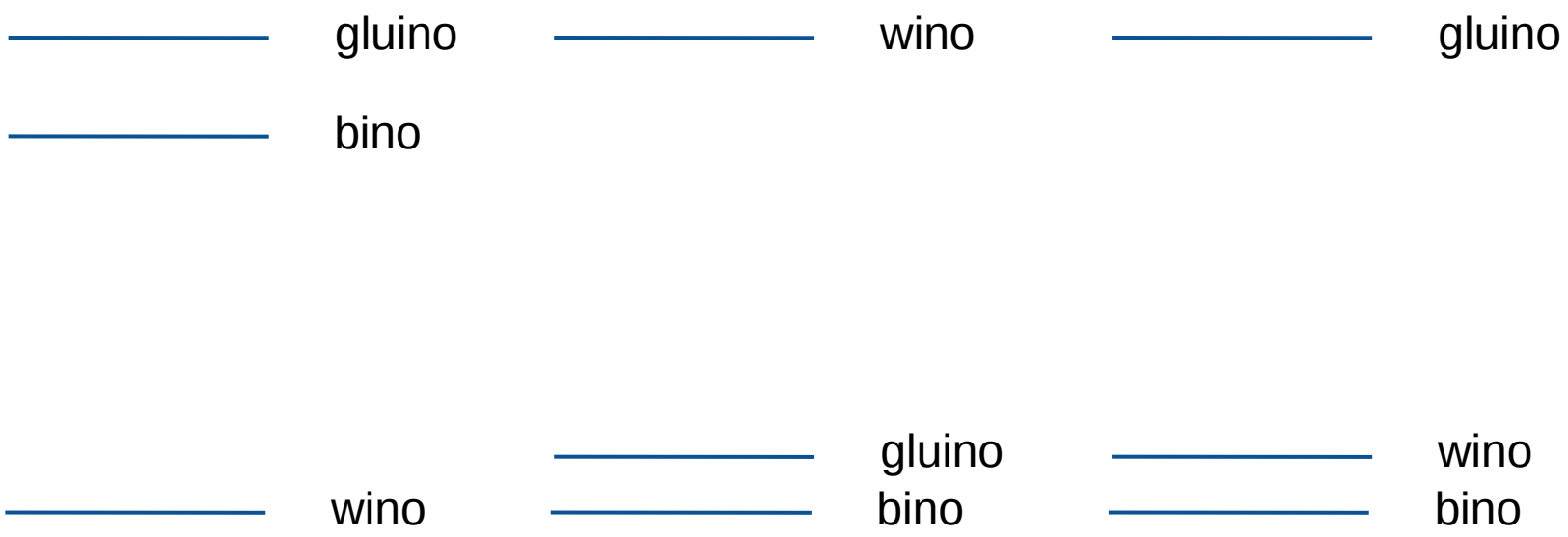
Possible demerit

✓ • Flavor/CP Problem

✓ • Cosmological Gravitino Problem

✓ • Model building

Three Possibilities for DM



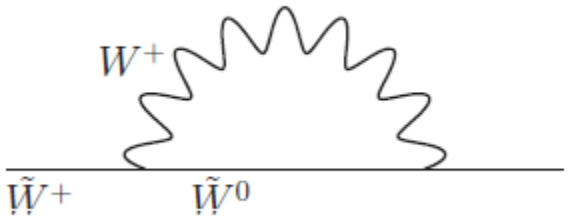
Wino DM

Bino-gluino coannihilation

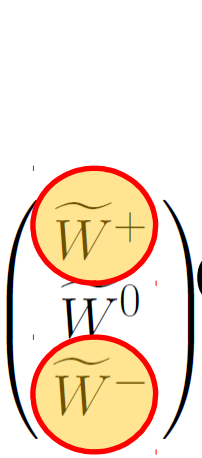
Bino-wino coannihilation

Wino DM case

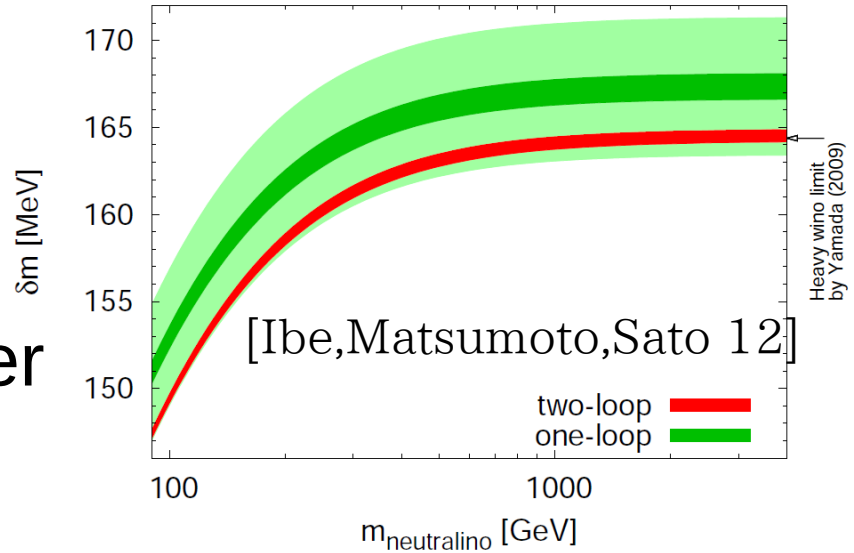
Wino Spectrum



Radiative correction

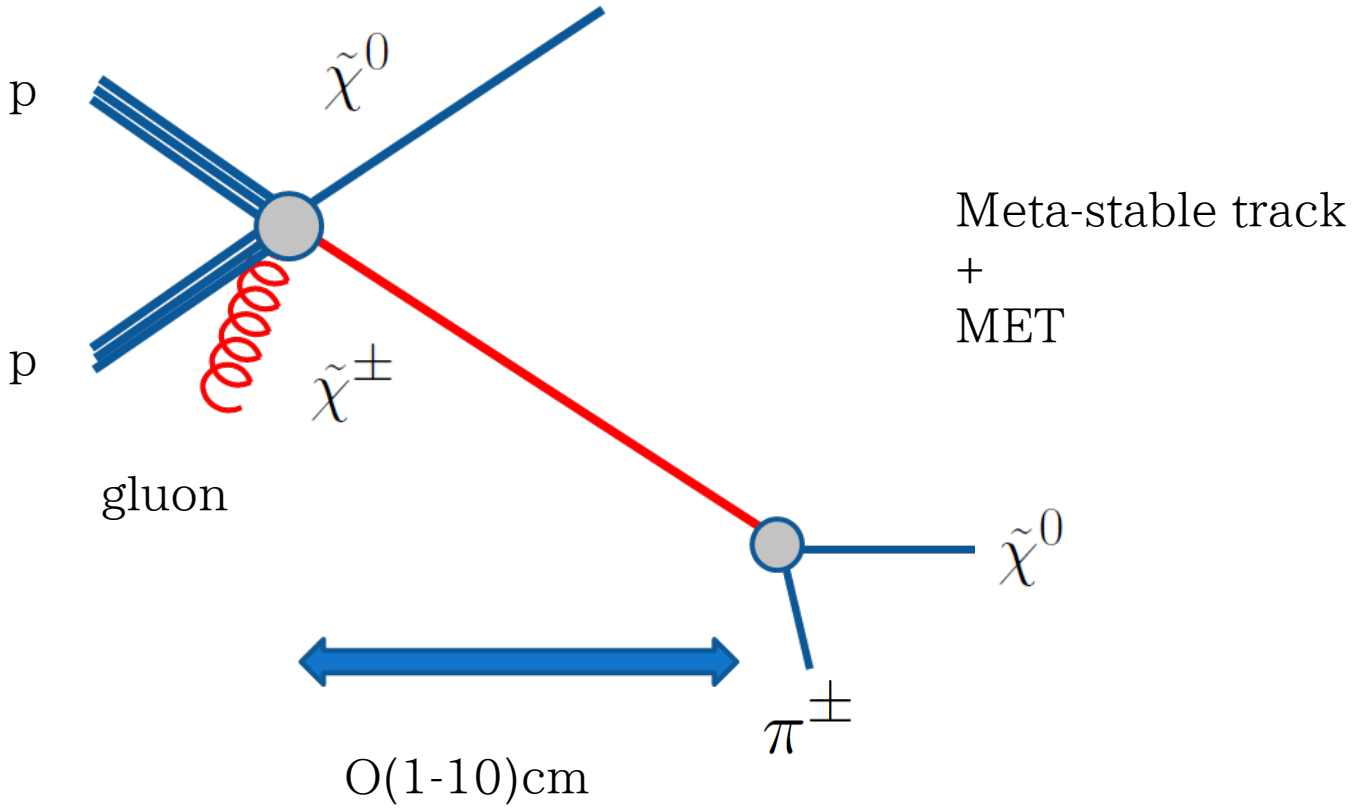


Charged slightly heavier

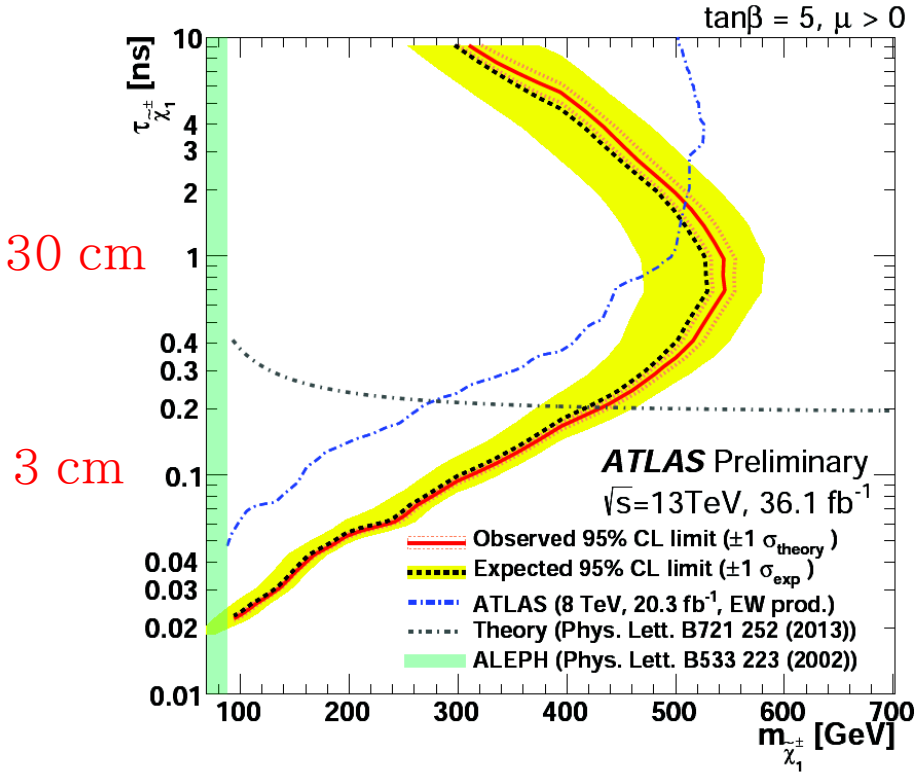


$$c\tau(\widetilde{W}^{\pm} \to \widetilde{W}^0 \pi^{\pm}) \simeq 7 \text{ cm} \left(\frac{\Delta m}{165 \text{ MeV}}\right)^{-3}$$

LHC Signals

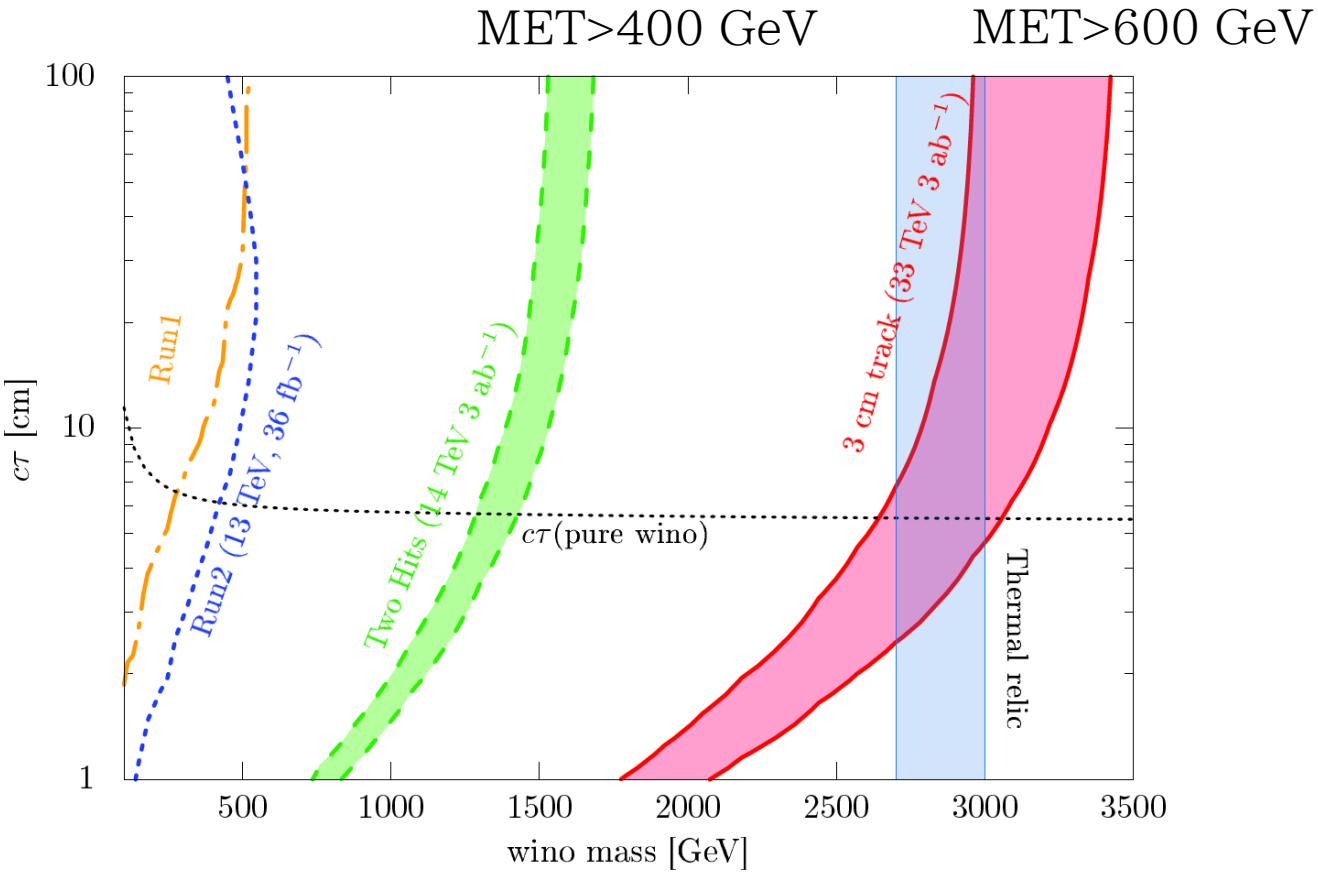

p
p
$\tilde{\chi}^0$
$\tilde{\chi}^{\pm}$
gluon
$\tilde{\chi}^0$
$\pi^{\pm}$
O(1-10)cm
Meta-stable track
+
MET

Current Constraint(wino)

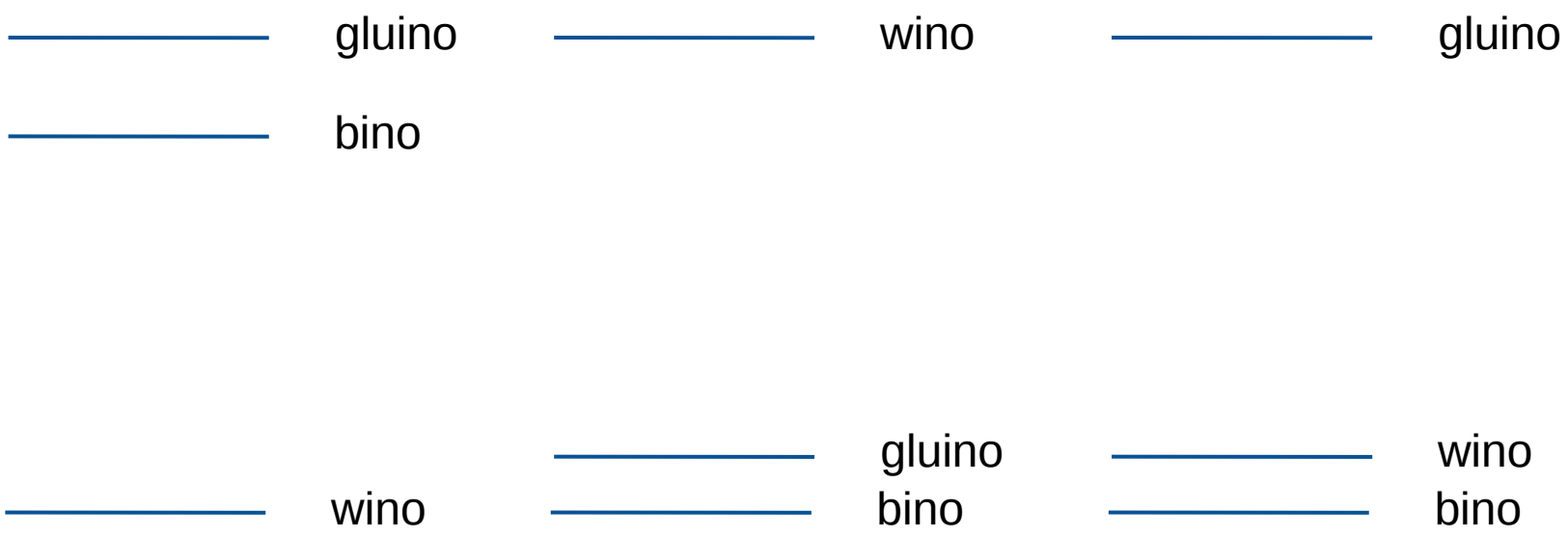


MET + disappearing track

Prospects for Wino



Three Possibilities for DM



Wino DM

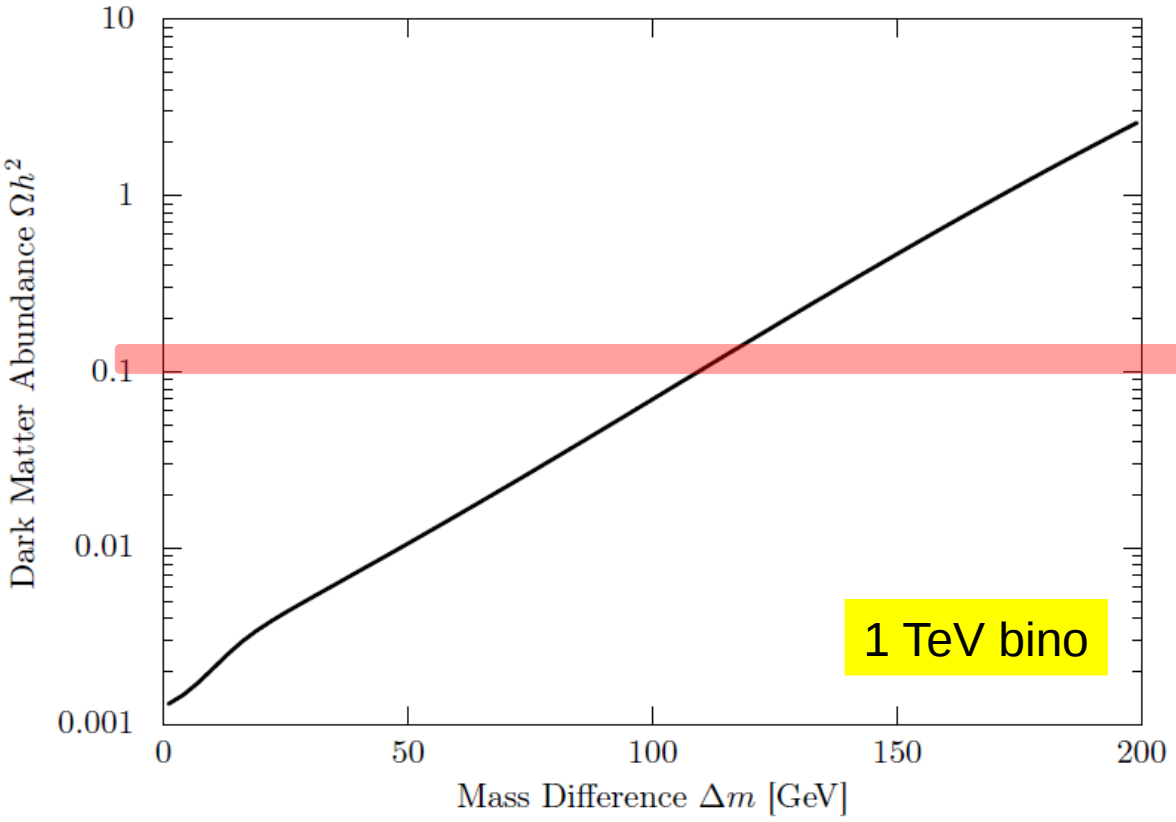
Bino-gluino coannihilation

Bino-wino coannihilation

Bino-Gluino Coannihilation

Bino-Gluino Coannihilation 1

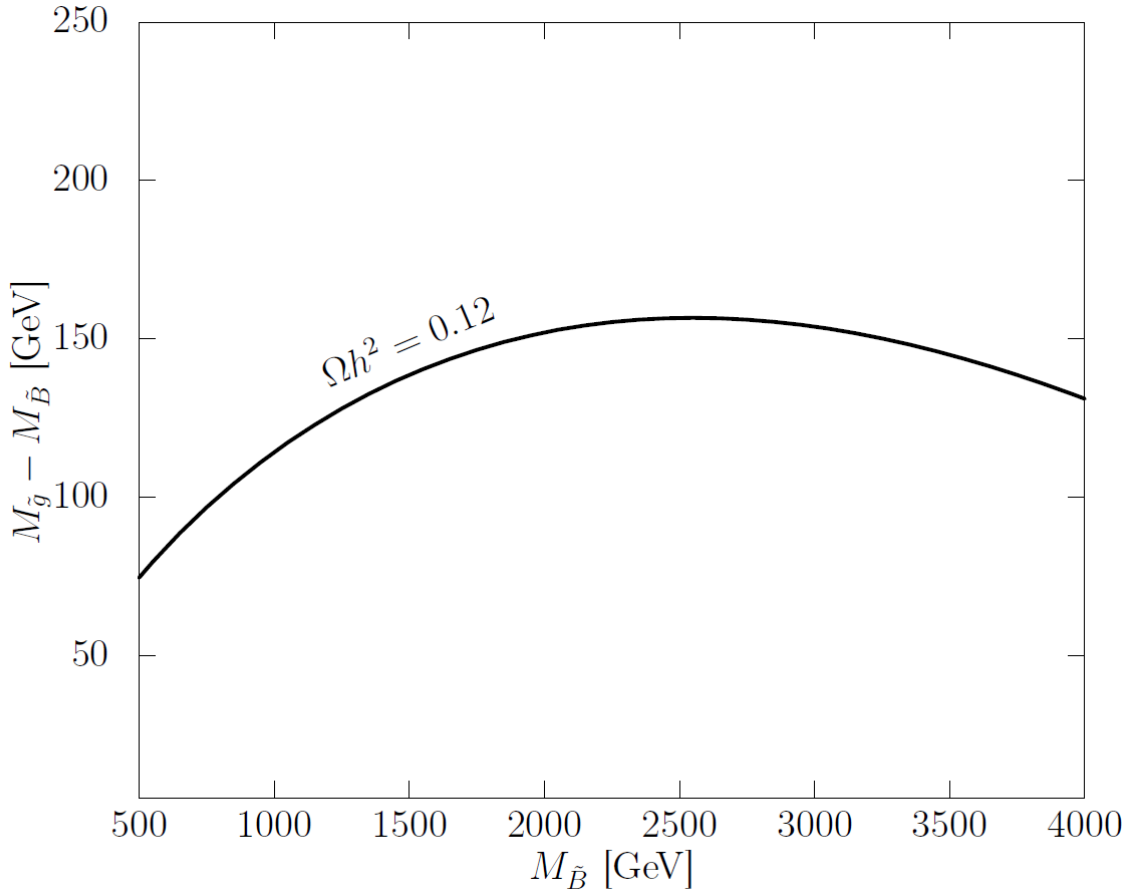
Dark matter abundance



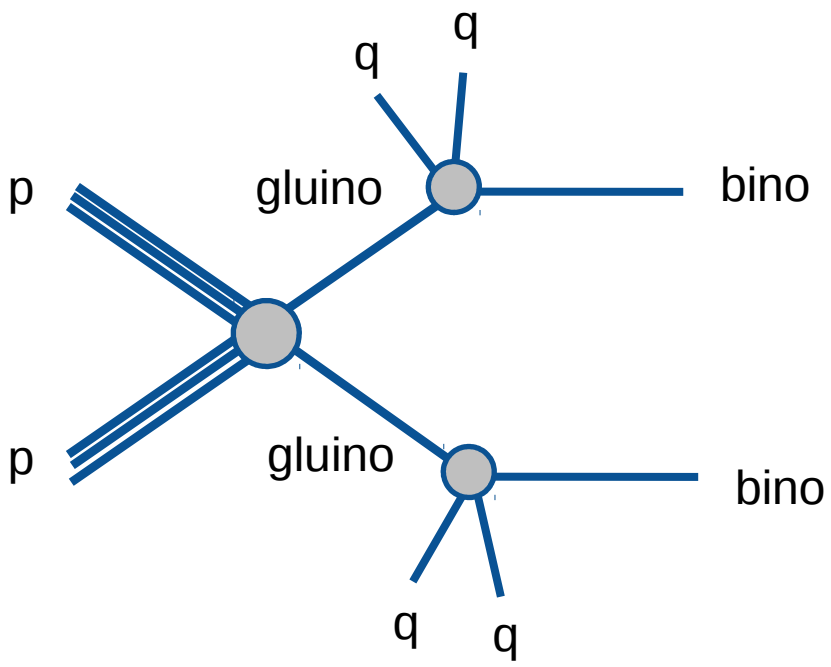
Observed DM

Gluino-bino mass difference

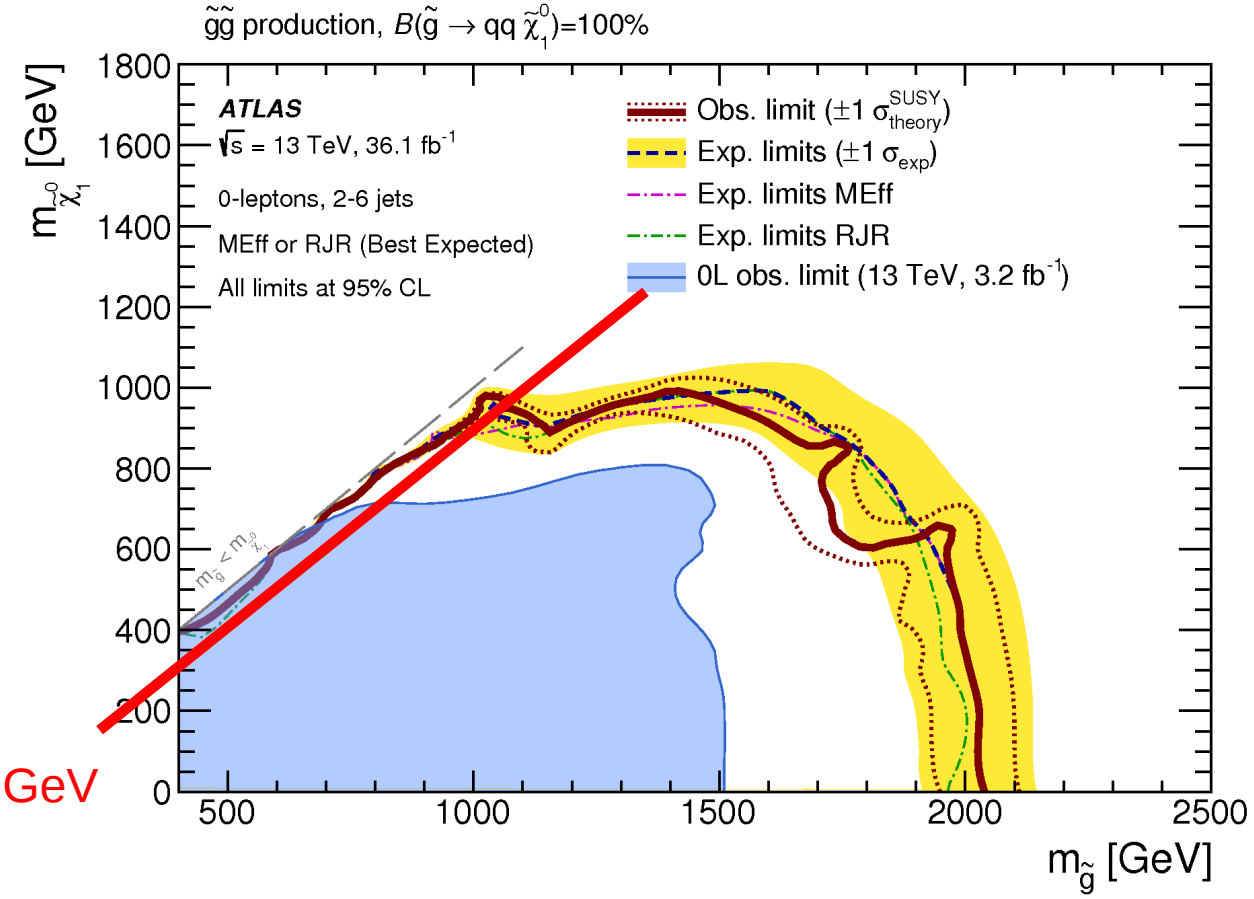
Gluino Coannihilation



LHC Signals

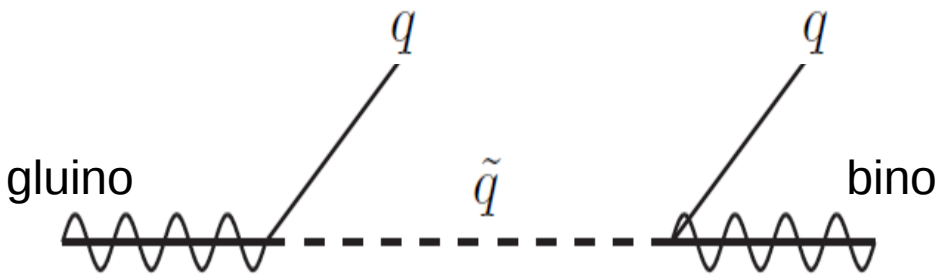


Prompt Decay Case



Mass diff. = 100 GeV

Bino-Gluino Interaction



Bino-gluino interaction is suppressed by sfermion mass

Long-lived gluino

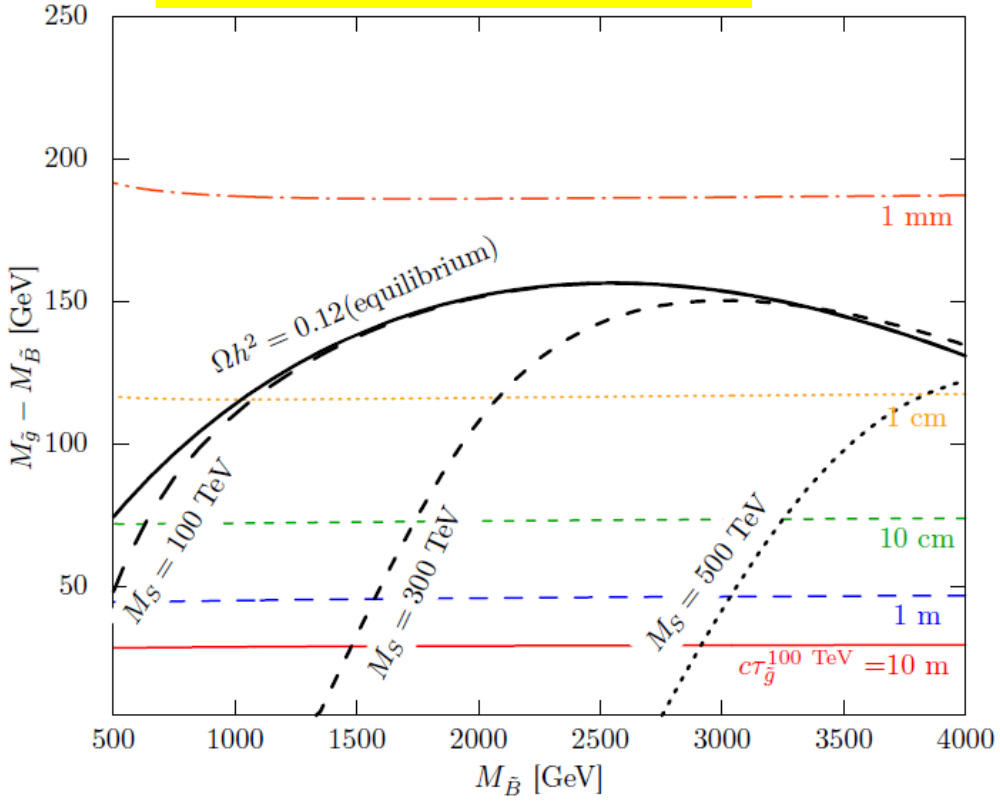
$$c\tau_{\tilde{g}} = O(1)\left(\frac{\Delta m}{100\ \mathrm{GeV}}\right)^{-5}\left(\frac{M_s}{100\ \mathrm{TeV}}\right)^{4}\ \mathrm{cm}$$

Too heavy sfermion prevents coannihilation

$$M_s \lesssim 250\left(\frac{M_{\mathrm{bino}}}{1\ \mathrm{TeV}}\right)^{3/4}\ \mathrm{TeV}$$

Bino-Gluino Coannihilation

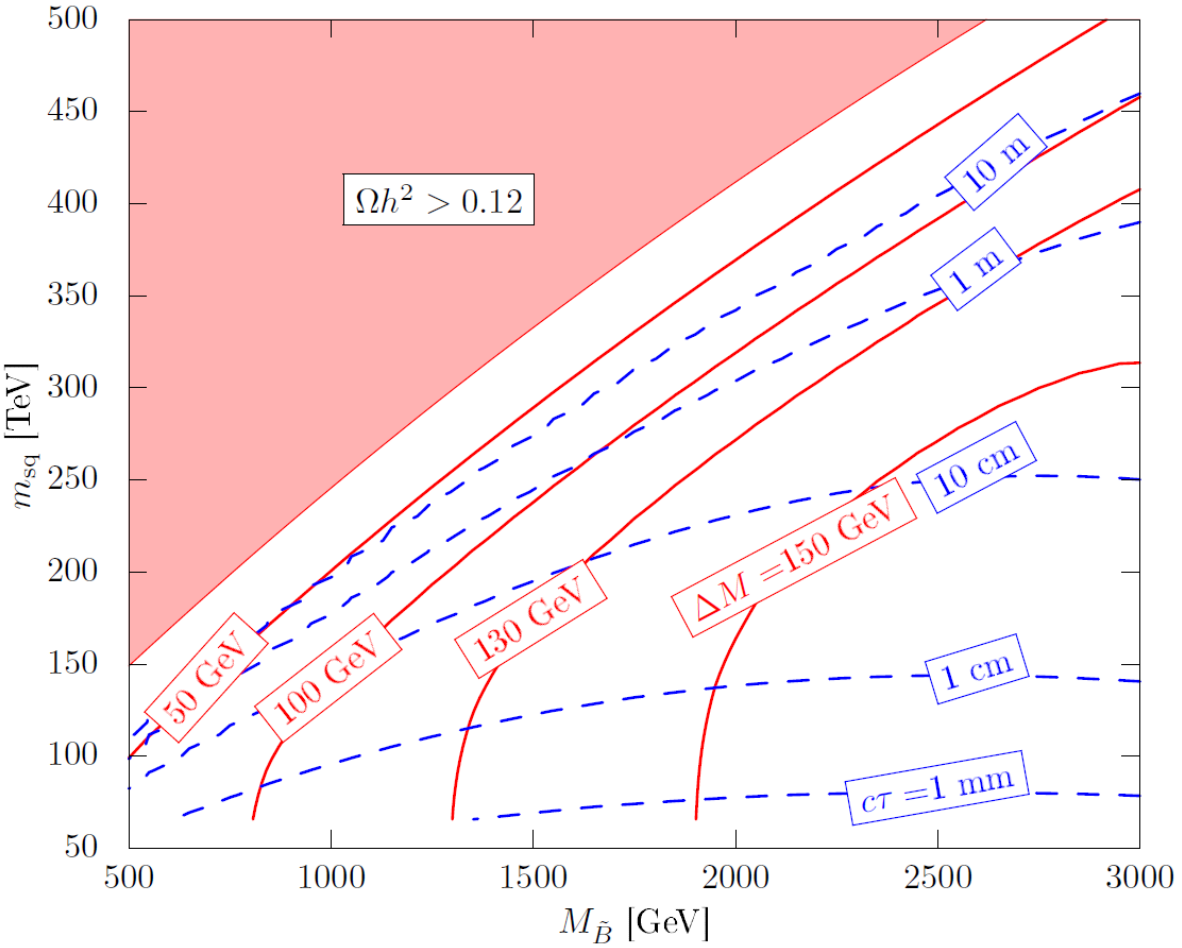
Required mass difference



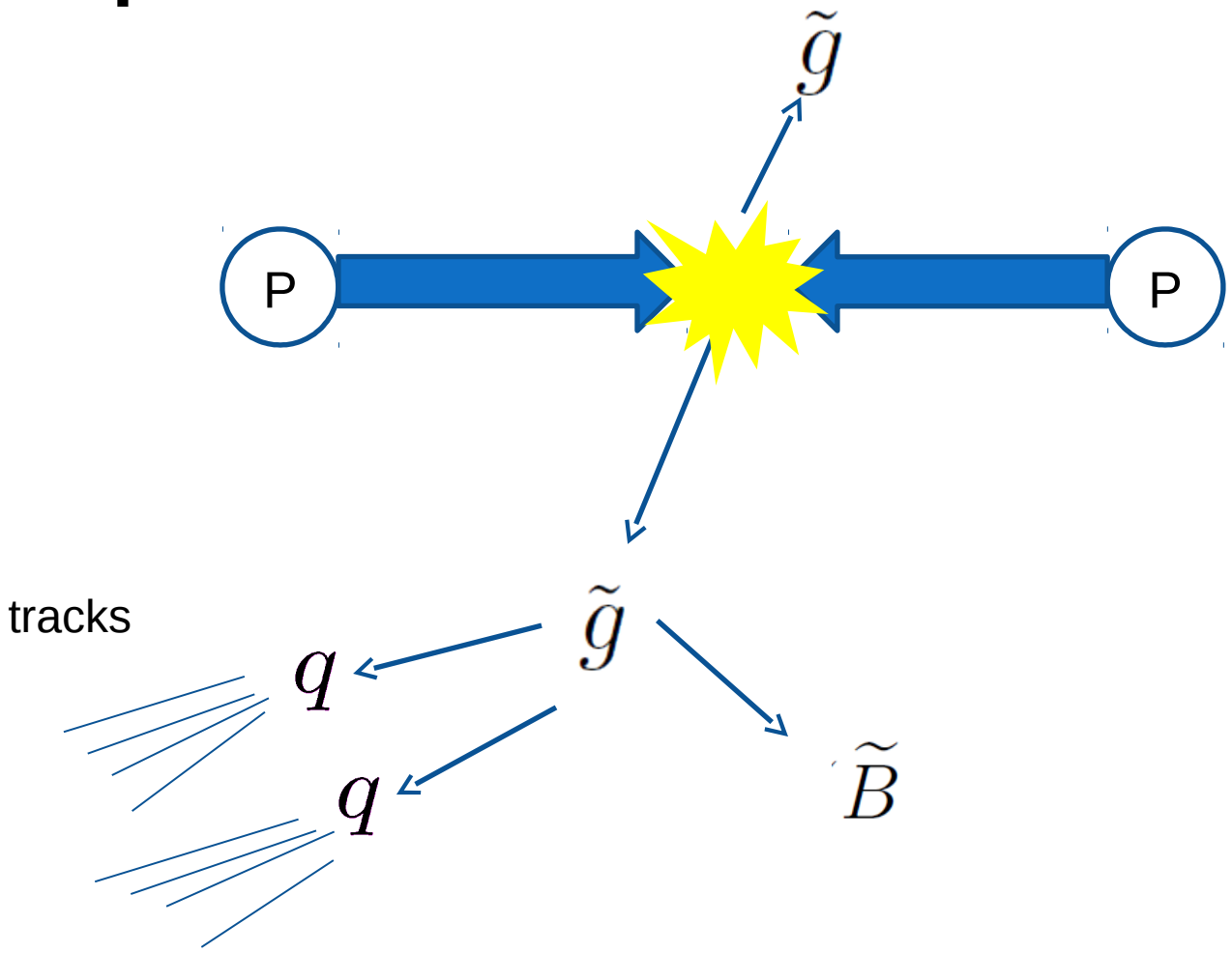
E.g.,
For 100 TeV sfermion,

Mass diff. ~ 100 GeV
Decay length ~ cm

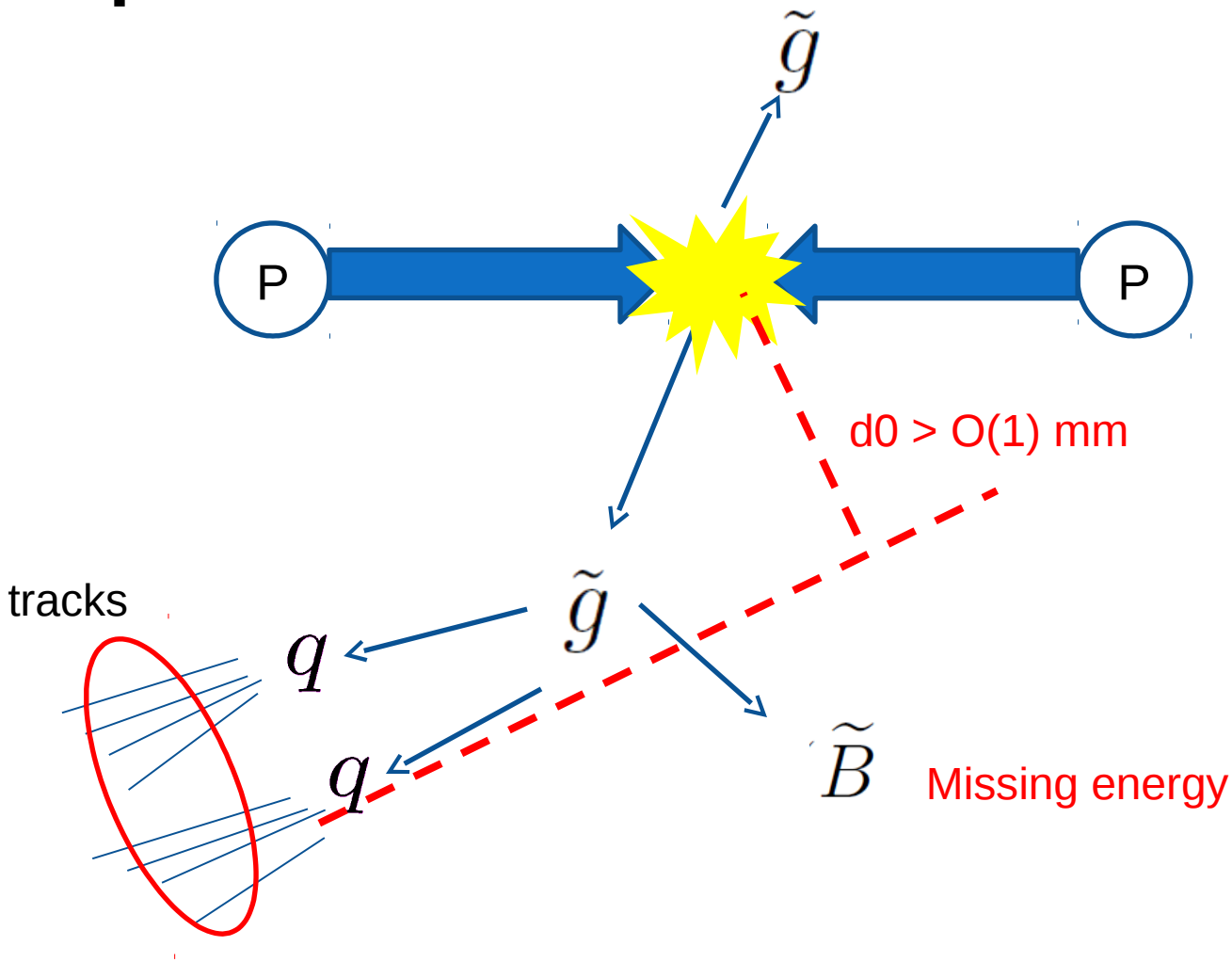
Bino-Gluino Coannihilation 2



Displaced Vertex



Displaced Vertex



ATLAS DV Search

[ATLAS, PRD 97 052012]

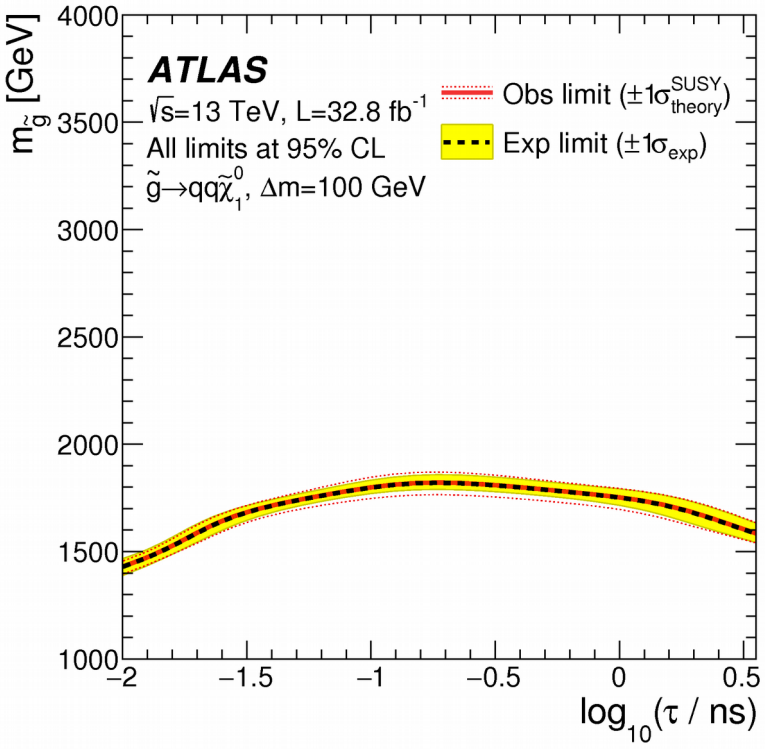
13 TeV 32.8 fb-1

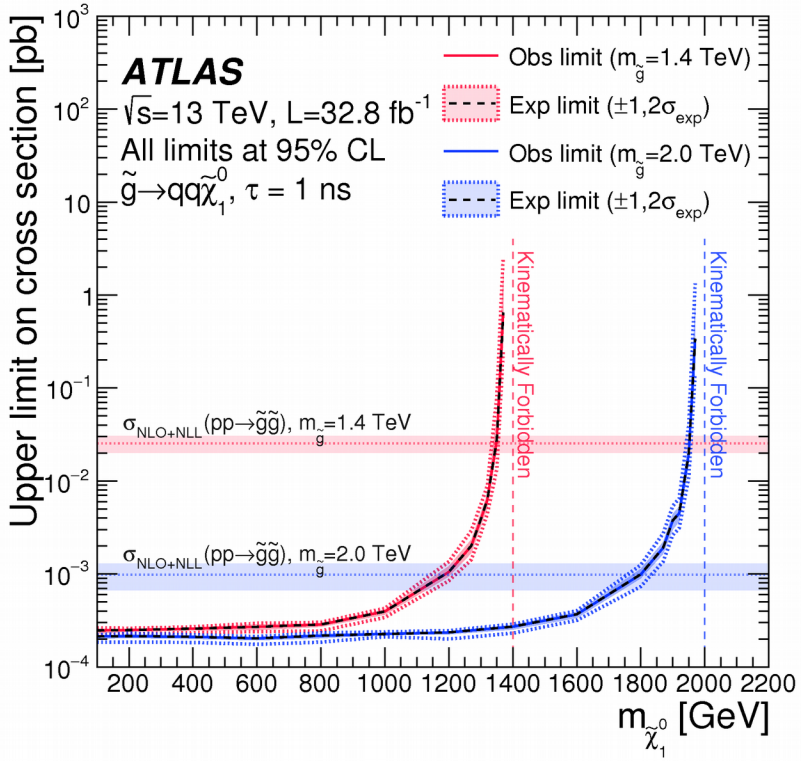
- MET trigger + event filer > 250 GeV
- DV with impact parameter > 2 mm
- Mass of DV > 10 GeV
- # of tracks >4

without DV BG O(10^5)

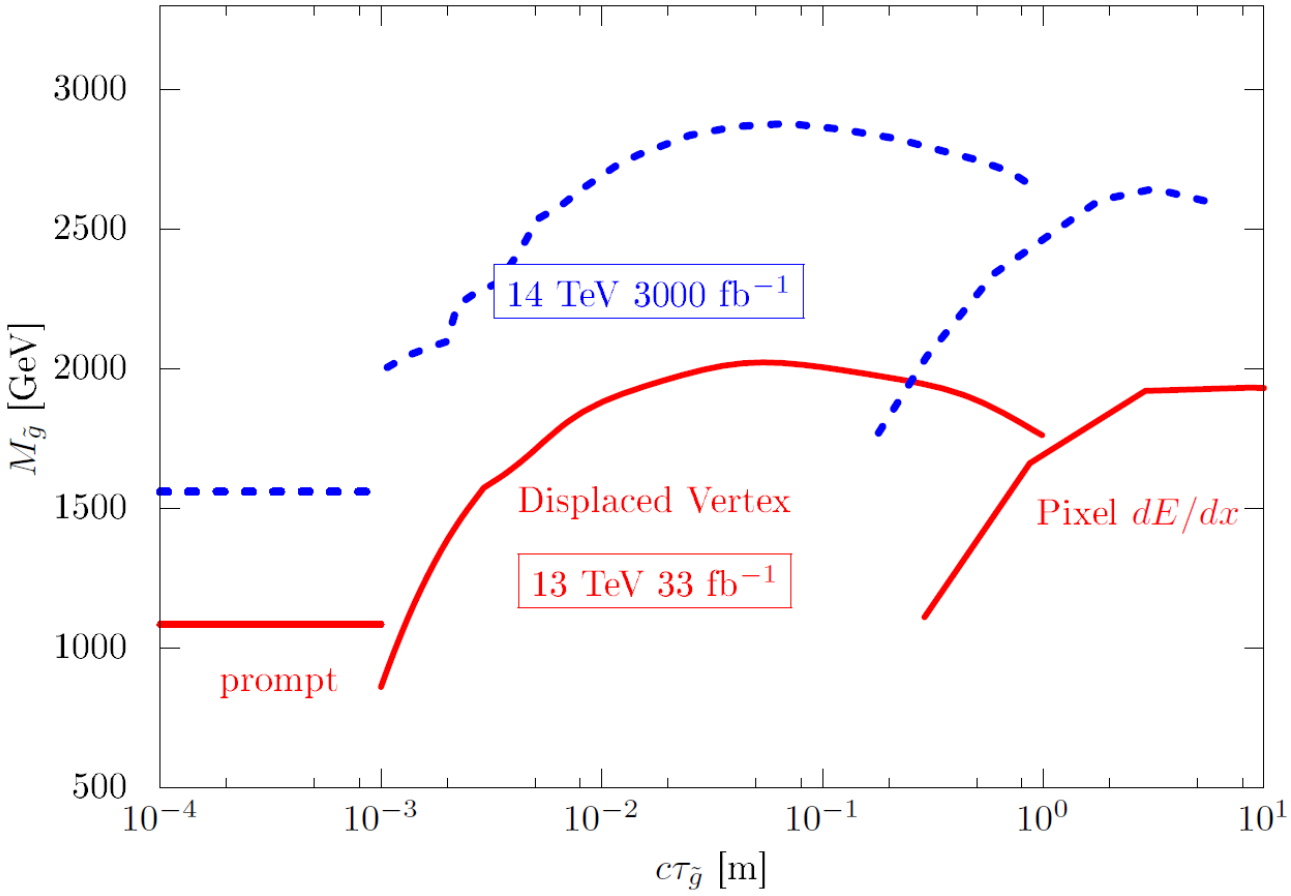
Selection	Subregion	Estimated	Observed
Event preselection $n_{trk} = 3,\ m_{DV} > 10$ GeV			3093
Event preselection $n_{trk} = 4,\ m_{DV} > 10$ GeV	VRLM	9 ± 2	9
	VRM	$150\ ^{+60}_{-30}$	177
Event preselection $n_{trk} \geq 5,\ m_{DV} > 10$ GeV	5-tracks	$2.2\ ^{+2.8}_{-0.9}$	1
	6-tracks	$0.6\ ^{+0.6}_{-0.2}$	1
	≥7-tracks	$1\ ^{+3}_{-1}$	3
	Total	$4.2\ ^{+4.1}_{-1.4}$	5
Full SR selection	*Total*	$0.02\ ^{+0.02}_{-0.01}$	0

Bino-Gluino Interaction

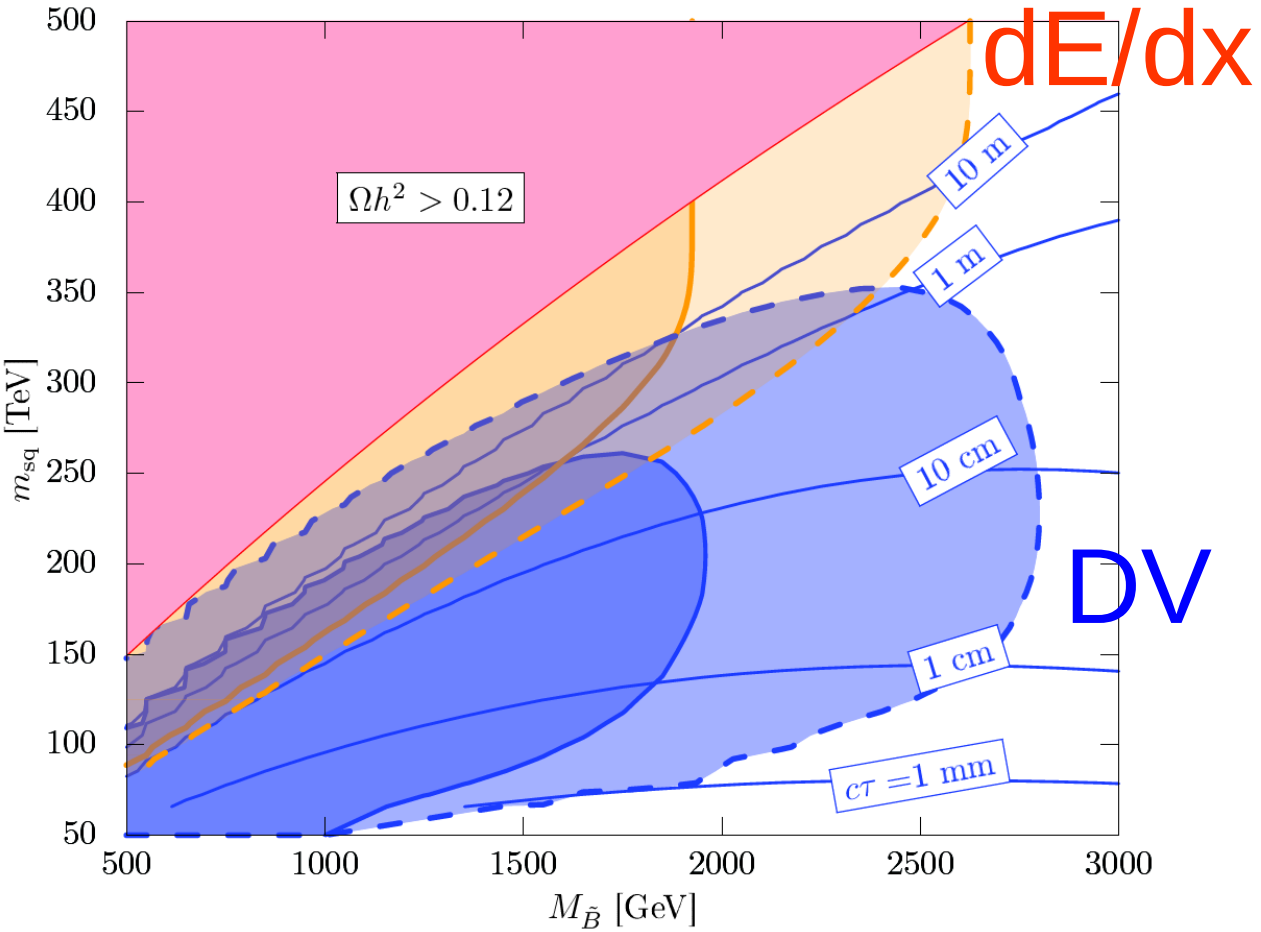




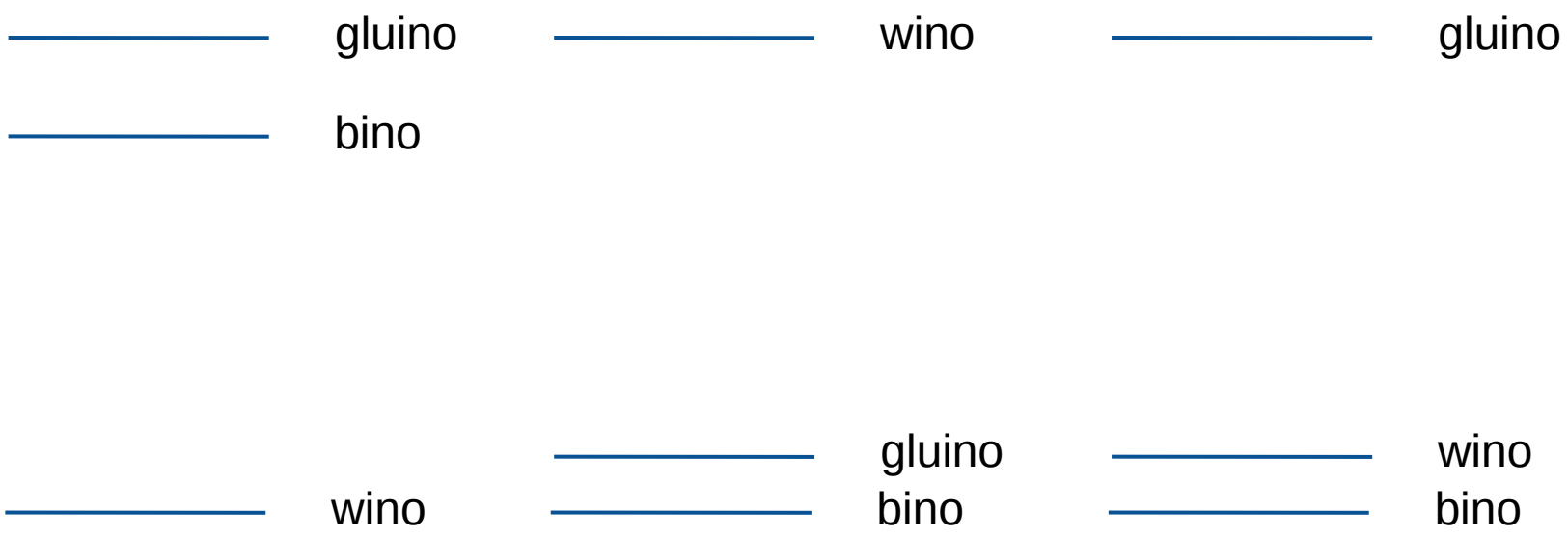
Prospects


3000
2500
2000
1500
1000
500
$M_{\tilde{g}}$ [GeV]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
$c\tau_{\tilde{g}}$ [m]
14 TeV 3000 fb^{-1}
Displaced Vertex
13 TeV 33 fb^{-1}
Pixel dE/dx
prompt

Bino-Gluino Prospects



Three Possibilities for DM



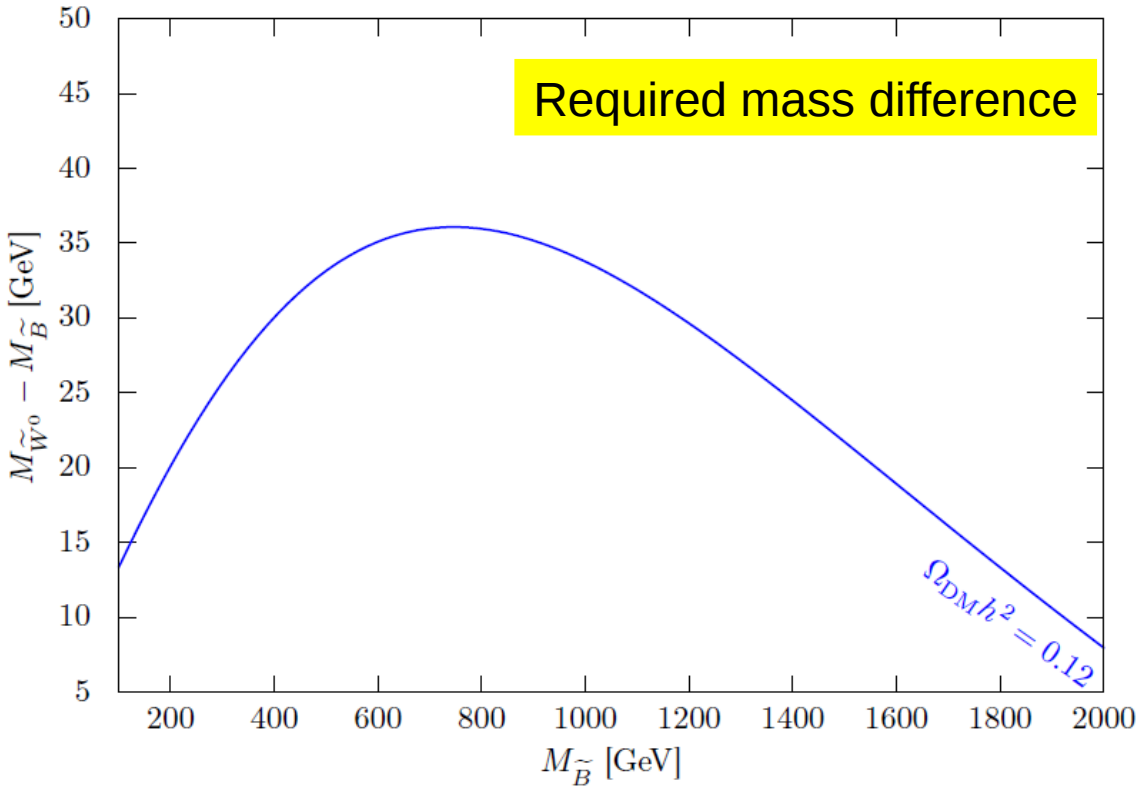
Wino DM

Bino-gluino coannihilation

Bino-wino coannihilation

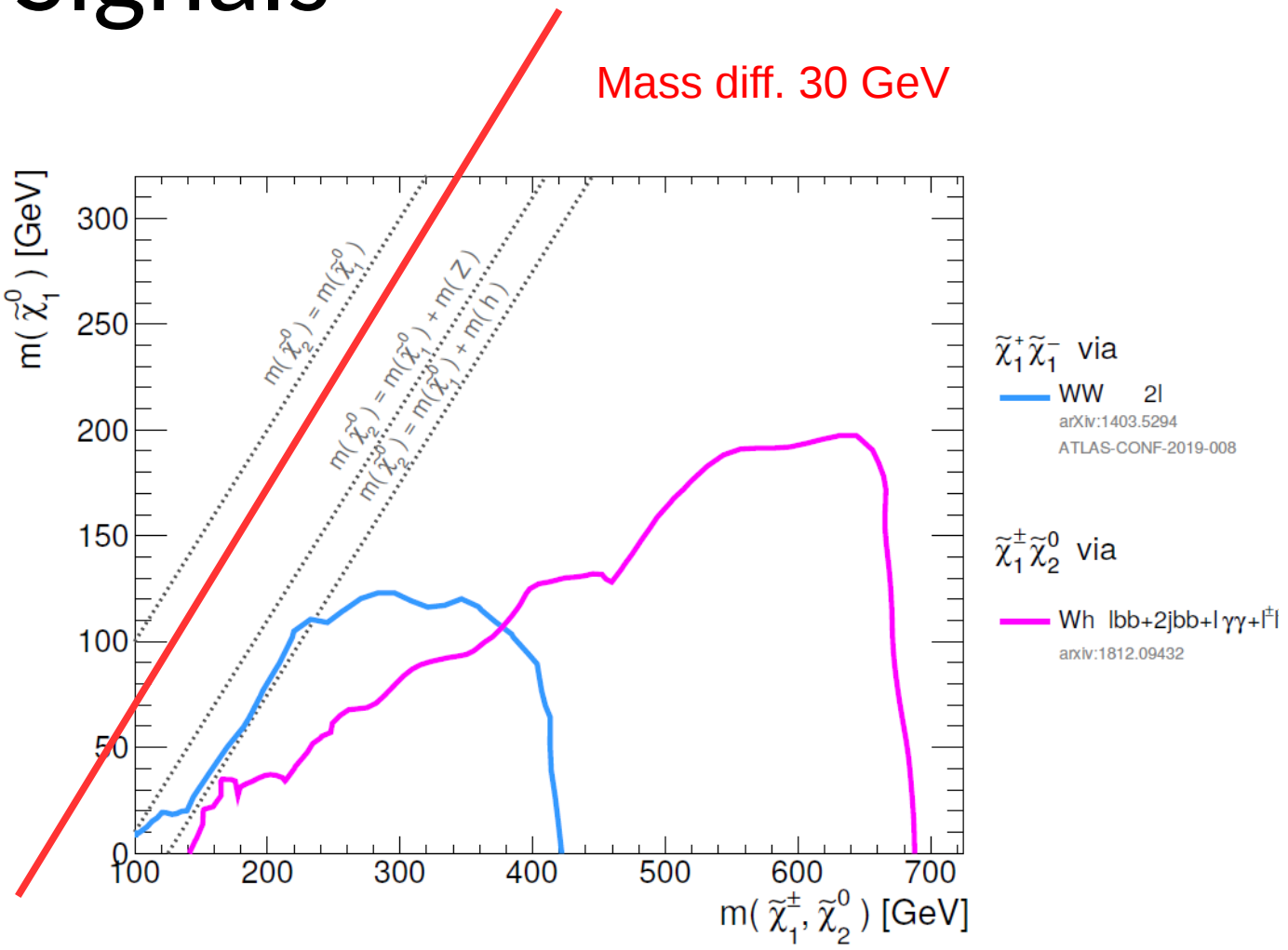
Bino-Wino Coannihilation

Bino-Wino Coannihilation

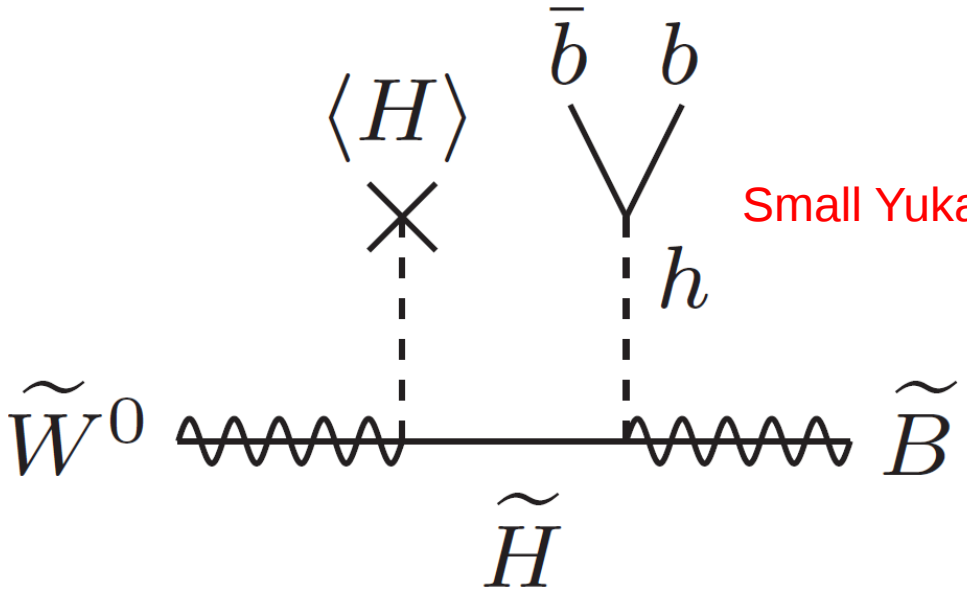


A few tens of GeV mass diff.

LHC Signals


Mass diff. 30 GeV
m($\tilde{\chi}_1^0$) [GeV]
m($\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$) [GeV]
m($\tilde{\chi}_2^0$) = m($\tilde{\chi}_1^0$)
m($\tilde{\chi}_2^0$) = m($\tilde{\chi}_1^0$) + m(Z)
m($\tilde{\chi}_2^0$) = m($\tilde{\chi}_1^0$) + m(h)
$\tilde{\chi}_1^+\tilde{\chi}_1^-$ via
WW 2l
arXiv:1403.5294
ATLAS-CONF-2019-008
$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via
Wh lbb+2jbb+l γγ+l$^\pm$l
arxiv:1812.09432

Wino Decay (tree)

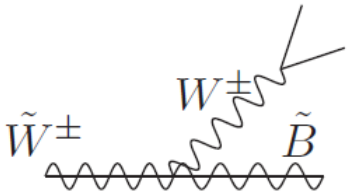


Small Yukawa

Long-lived neutral wino

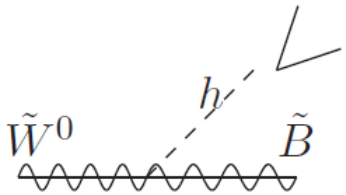
Suppressed by Higgsino mass

Wino Decay

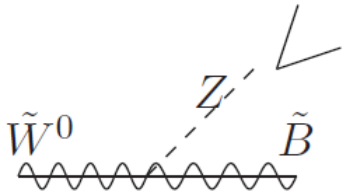


$\propto \mu^{-1}$

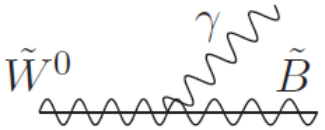
Prompt charged Wino decay



$\propto \mu^{-1}$



$\propto \mu^{-2}$

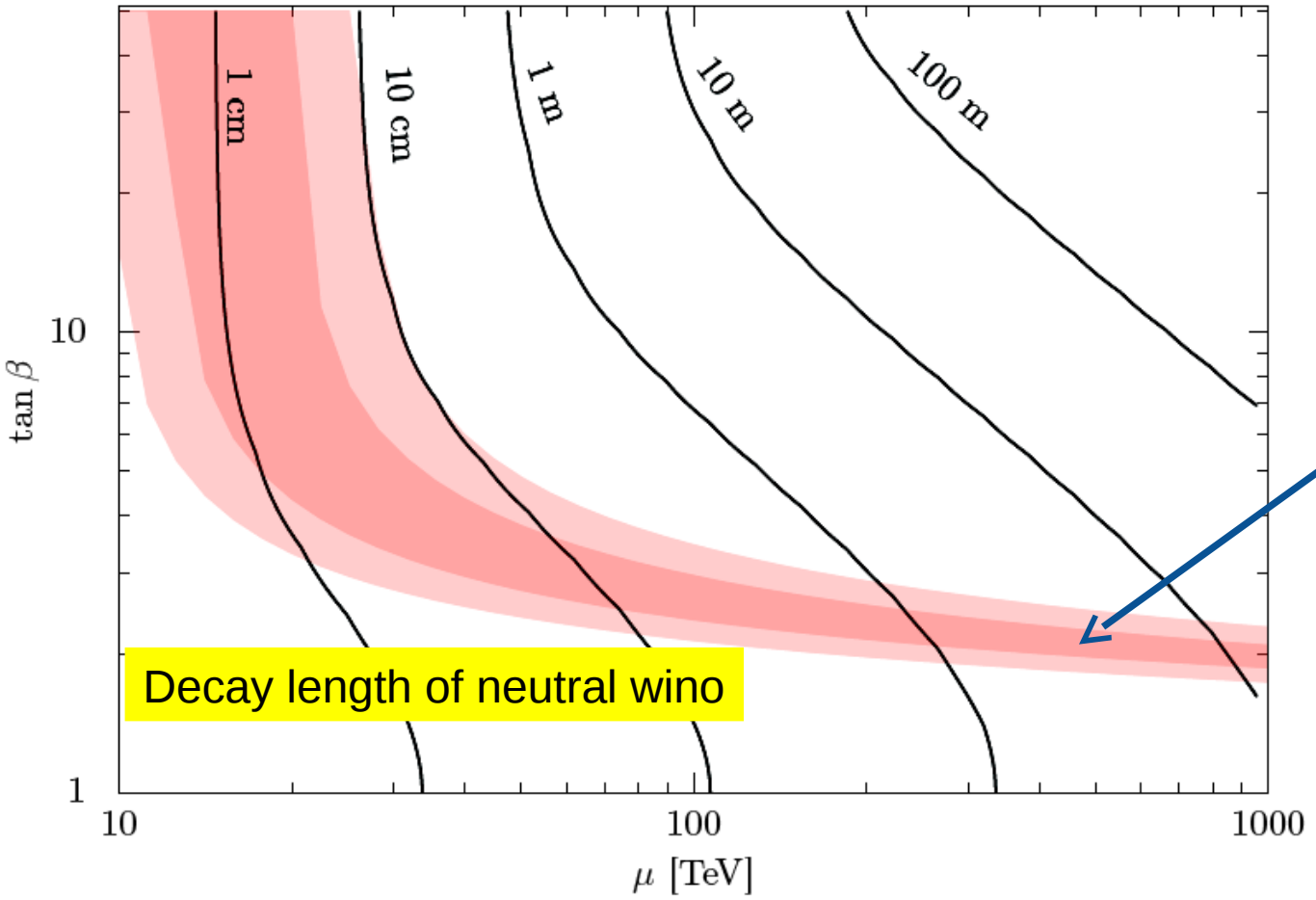


$\propto \frac{\alpha}{4\pi}\mu^{-2}, \left(\frac{\alpha}{4\pi}\right)^2 \mu^{-1}$

Displaced neutral Wino decay

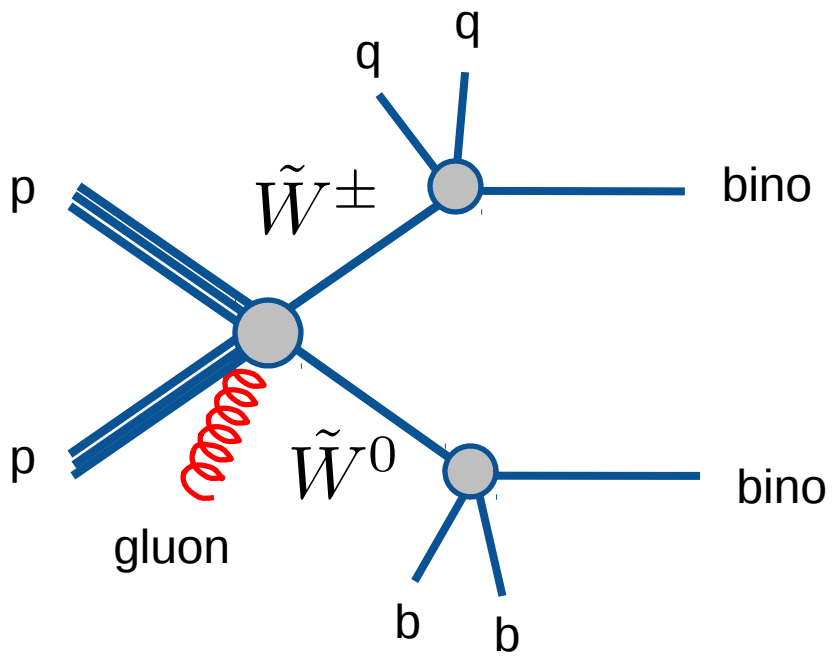
Wino Decay

Bino = 400 GeV
Wino = 430 GeV



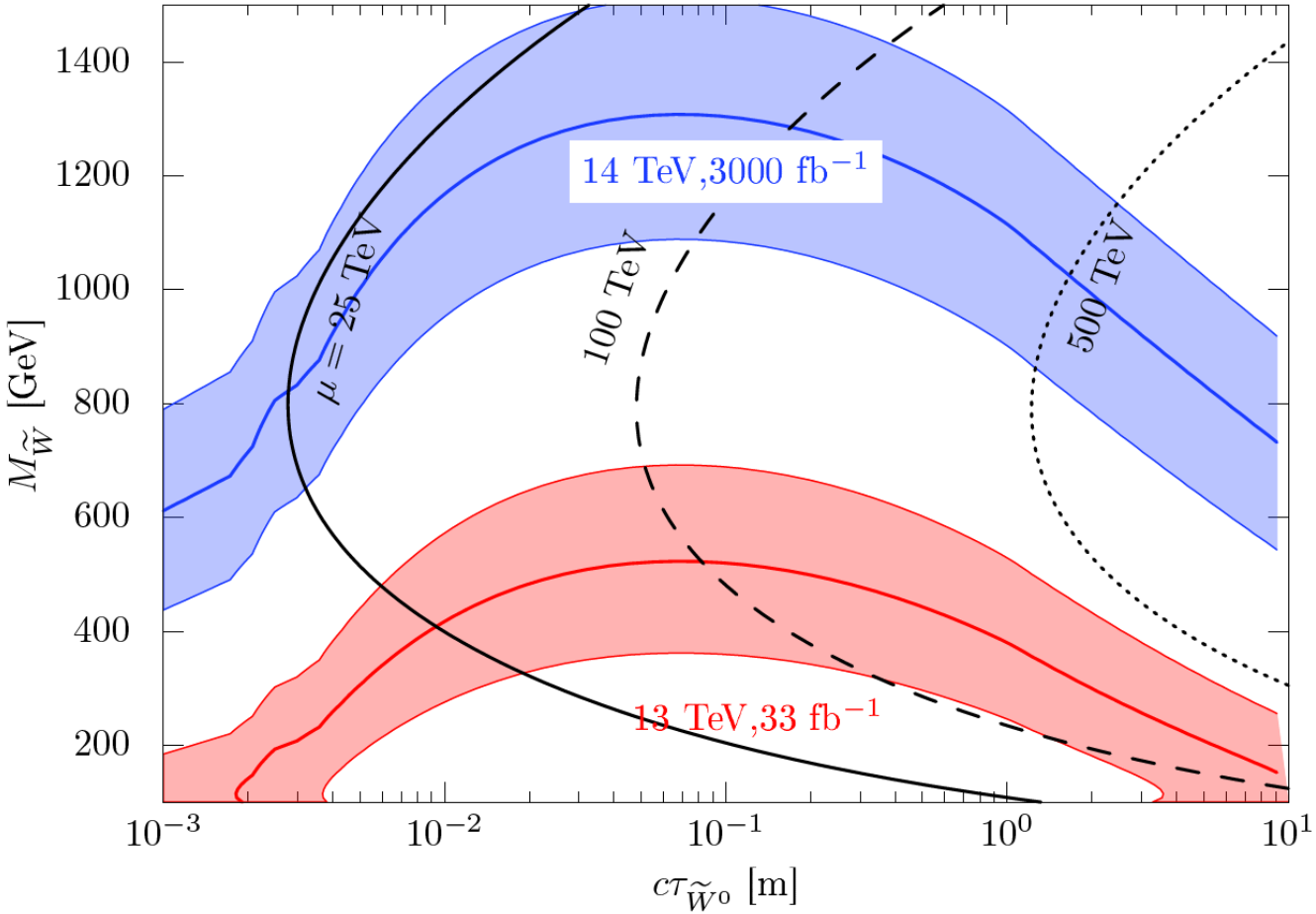
Higgs mass OK

LHC Signals



Low mass ~ 10 GeV DV
+
MET

LHC Prospects



Summary

- Mini-split is simplest SUSY model with 125 GeV Higgs
- DM in mini-split likely provide meta-stable particles
  - Wino DM: disappering track
  - Gluino-bino DM: long-lived R-hadron
  - Wino-bino DM: long-lived neutral wino
- Improvement of LLP detection