Sho Iwamoto

No. 1

Date . .

$8\times\tilde{q}$, $2\times(\tilde{t},\tilde{b})$
$\tilde{g}$
$6\times\tilde{\ell}$ $3\times\tilde{\nu}$
$\tilde{B}$ $\tilde{W}^0$ $\tilde{H}_u$ $\tilde{H}_d$
$\tilde{W}^\pm$ $\tilde{H}^\pm$

MSSM

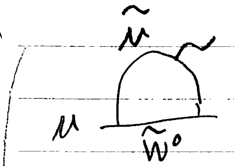
LHC 13TeV 2015 4/fb (2 months)
2016 40 (4.5)
2017 50 (5)
2018 (5) ⌋ 150/fb
2019 } LS2
2020
2021-23 ⌋ 300/fb

SUSY : Solution to
- Fine-tuning problem for 20%-tuning
  - Higgsino mass $|\mu| \lesssim 200$ GeV
  - stop $\lesssim 600$ GeV
  - gluino $\lesssim 900$ GeV [1110.6926]

mostly excluded
→ 1% tuning?
anyway not "good" motivation

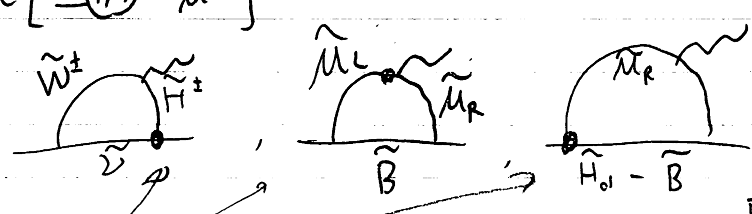
Searches for
⇒ degenerate region

- Gauge-Coupling Unification ✓
- Muon g-2 problem
  SUSY may have extra contrib to solve the anomaly



$$\frac{g_\mu-2}{2} = \mathrm{Re}\left[\mu \text{---} \gamma \text{---} \mu\right]$$

MSSM;



ETC.

- large $\tan\beta$, light electroweakino
  ($\tilde{\mu}$, $\tilde{B}$, $\tilde{H}$, $\tilde{W}$)

light ⟷ heavy
large coupling small coupling
underabund. overabundance
was good motivation for 100GeV SUSY

- DM problem
  - if $\tilde{B}$-DM : $\Omega_{DM}h^2 \gg 0.12$ NotGood
  - $\tilde{H}$-DM : $= 0.12$ ~1 TeV
  - $\tilde{W}$-DM : $= 0.12$ v. 2.7-3.0 TeV (Sommerfeld enh.)

or Modify Nature with the standard cosmology

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- LHC finds
  - 125 GeV Higgs : $m_H^2 = m_Z^2 + \underbrace{\frac{3 g_w^2 m_t^4}{8\pi^2 m_W^2} \ln \frac{m_{\tilde{t}}^2}{m_t^2}}_{\text{SUSY-breaking effect}}$

    $\Rightarrow m_{\tilde{t}} \gtrsim 1\,\mathrm{TeV}$

  - No susy particle
    → extra pages

Trends : SUSY ⊕ LHC
- Abandon SUSY
- Extend MSSM (extra scalar (NMSSM), extra vector-like quark/lepton, extra U(1) …)
- consider MSSM with light - non-colored (< 1 TeV), heavy - colored (> 1 TeV) particles, "split" models
  - how to realize split models ?
  - what we will discover at LHC ?
  - How about SUSY flavor/CP problems?
- Focus on DM
  - history of the Universe
  - Indirect / direct DM detection …) + LHC
  - axion …

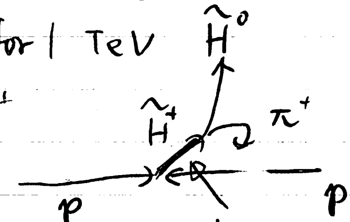
① LHC prospect for SUSY

- DM-motivated
  - $\tilde{W}$-DM : Too heavy → 100 TeV collider
  - $\tilde{H}$-DM :

all xs @ 13 TeV

$pp \to \tilde{H}\tilde{H}$: 30 fb for 500 GeV
1 fb for 1 TeV

but



$c\tau = 1\,\text{cm}$
… very difficult to see

→ Cascade decay from $\tilde{\ell}$ or $\tilde{W}$ → later

IBL = 3.2 cm

- $\tilde{B}$-DM :
  No direct production

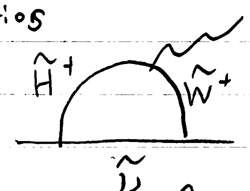
- g-2 -motivated

a_μ depends on $\tan\beta$ and the mass of
$\tilde{B}, \tilde{W}, \tilde{H}, \tilde{\mu}_L, \tilde{\mu}_R$
⇒ general analysis is not easy
(only scatter plots w/o physics)

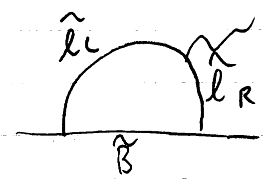
1711 02560
1603.05502
1507.01395
1505.05896
1503.08703

Typical scenarios

$\mu > 0$ ⇒

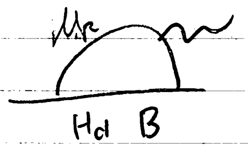


OR



[$\tilde{H}, \tilde{W}^+, \tilde{\ell}_L$ are light $\lesssim 1$ TeV]
[$\tilde{B}, \tilde{\mu}_L, \tilde{\mu}_R$ are light and $\tilde{H} \gg 1$ TeV]

$\mu < 0$ ⇒



[$\tilde{\mu}_R, \tilde{H}_d, \tilde{B}$ are light]

In any case, LHC signals are from

$pp \to \tilde{W}\tilde{W}$	$\tilde{W}^+\tilde{W}^0$	33 fb	1.0
	$\tilde{W}^+\tilde{W}^-$	22	0.62
$pp \to \tilde{H}\tilde{H}$	$\tilde{H}^+\tilde{H}^0$	11	0.3
	$\tilde{H}^+\tilde{H}^-$	6.2	0.18
$pp \to \tilde{\ell}\tilde{\ell}$	$\tilde{\ell}_L\tilde{\ell}_L^*$	0.47	
	$\tilde{\ell}_R\tilde{\ell}_R^*$	0.18	
		500 GeV	1 TeV

$\to$ ×36 to get N_{ev} @ 2015-2016

then what we'll see?

$pp \to \tilde{\ell}\tilde{\ell} \to 2\ell + \not{E}_T$

$pp \to \tilde{\chi}^0\tilde{\chi}^0$: If $\tilde{\chi}^0$ is DM $\to$ disappearing track

$\tilde{H}$: 1cm $\to$ difficult

$c\tau$. $\tilde{W}$: 6cm

CMS: Innermost 4.3 cm $\to$ 700 GeV @ 0.2ns

ATLAS: IBL @ 3.2 cm $\to$ 460 GeV

EXCLUDED below 460 GeV

(much more room for DM or g-2)

CMS EXO-16-044 (Feb 2018)

* ATL 1712.02118

ELSE

$DM < \tilde{\ell} < \tilde{\chi}$: $\tilde{\chi} \to \tilde{\ell}_1 \to DM$, ℓ; $\tilde{\chi} \to \nu, \ell$

$\therefore$ 2ℓ or 3ℓ + $\not{E}_T$

CLEAN

$DM < \tilde{\chi} < \tilde{\ell}$: $\tilde{\chi} \to DM$; $\tilde{\chi} \to W, Z$

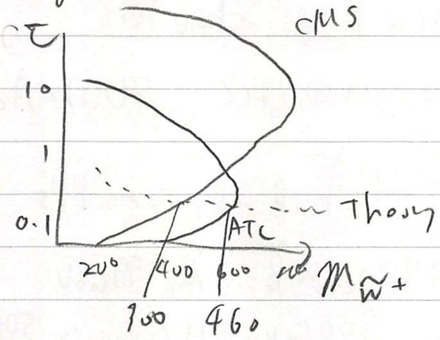
$\therefore$ $WZ + \not{E}_T$

large SM bkg

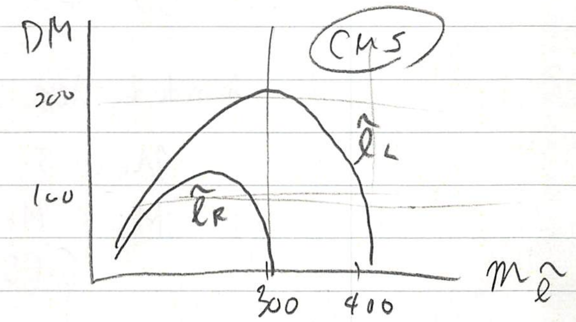
1303.4256
1707.04410
1505.05877
1508.08219

EWKino Bounds (13 TeV 36-38 fb^{-1} : 2016)

long-lived Wino



$pp \to \tilde{\ell}\tilde{\ell}^* \to 2\ell + \not{E}_T$

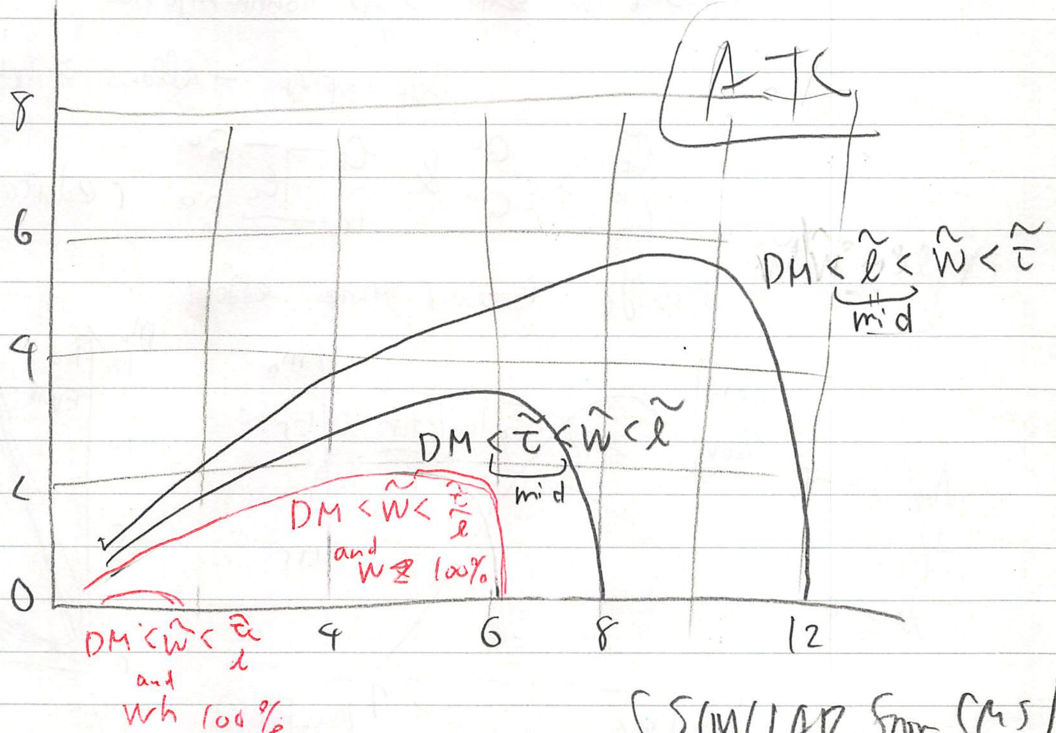


$pp \to \tilde{\tau}\tilde{\tau}^* \to 2\tilde{\tau} + \not{E}_T$: NO EXCLUSION YET

CMS: 1 σ excess (Dec 2017)

ATLAS: 1 σ excess (Jun 2017)

$pp \to \tilde{\chi}\tilde{\chi}$



(SIMILAR from CMS)

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A few examples of recent works

- 1801.00514 Belyaev King Schaefers

A model for g-2 ⊕ DM ⊕ LHC : $SU(5) \times A_4$ → Scatter Plot

$m_0(1,3) \gg m_0(2)$
$M_1 < M_2 \ll M_3$
gives some BPs

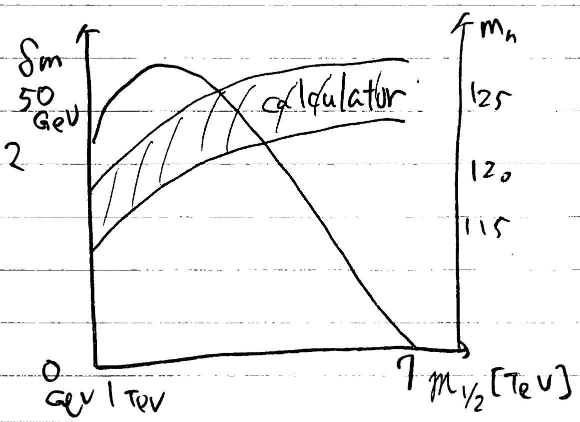
LSP $\tilde{\chi}_1^0$: 90 GeV ~ $\tilde{B}$, $\tilde{\mu}_R$: 99 GeV
Wino ~ 300 GeV Higgsino ~ 500 GeV
BHR g-2, DM = coannihilation

- 1801.09855 : Ellis Evans Luo Olive Zheng

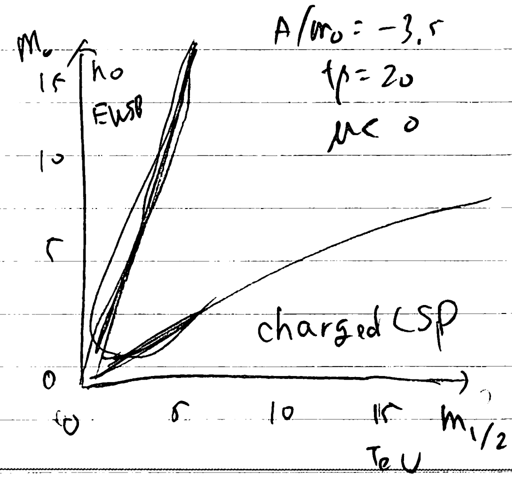
CMSSM w. ~~Stau~~- Stop coannihilation
large coupling → allows > TeV LSP

$\tilde{t}_R \tilde{t}_R^* \to G^0 G^0$ & $\tilde{t}_R \tilde{t}_R \to G^0 G^0$ (t_L exchange) reduces $\tilde{B}$-dM.

large m_t + bound-state effect



$A_0/M_0 = -4.2$
$\tan\beta = 20$
$\mu > 0$



analysis of Sub-Gut models
($M_{\text{unif.}} \neq M_{\text{GUT}}$)

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DM spin-independent

$$\mathcal{L} \ni \frac{1}{2} \lambda_h h \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

$$\lambda_h = g_1 \left[\frac{\mu \sin 2\beta + M_1}{\mu^2 - M_1^2} m_Z S_W + O\left(\frac{m_Z S_W}{\mu}\right)^2 \right]$$

$$\sin 2\beta = \frac{2t}{1+t^2}$$

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