Gravitino Dark matter

the darkest dark matter

- Coupling / $1/m_{pl}$
- no signal for direct/indirect DM searches
- can not be produced at colliders

New proposal: superWIMP DM

- naturally obtain Ω
- solve BBN ^{7}Li anomaly
- Could be tested at colliders

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Aspen Winter Conference 2005

Outline

- Gravitino
- Gravitino as warm Dark Matter
- Gravitino as cold Dark Matter
  - superWIMP
  - Constraints
    - Late time energy injection and BBN
  - Collider phenomenology
  - Slepton trapping
- Conclusion

Gravitino

- Gravitino: superpartner of graviton
- Obtain mass when SUSY is spontaneously broken $m_{\tilde{G}}$ » F/m_{pl}
- Stable when it is LSP - candidate of Dark Matter

$m_{\tilde{G}}$ ¿ m_{SUSY} » keV warm Dark Matter	$m_{\tilde{G}}$ » m_{SUSY} » GeV - TeV cold Dark Matter

Gravitino: warm dark matter

$m_{\tilde{G}}$ ¿ m_{SUSY} (GMSB)

$$\Omega\ h^2 \text{ » } (m_{\tilde{G}}/\text{keV})\ (100/g_*)$$

- $m_{\tilde{G}}$ » keV : warm Dark Matter
- $m_{\tilde{G}} >$ keV : problematic !

  gravitino dilution necessary

  $\Rightarrow$ stringent bounds on reheating temp.

Moroi, Murayama and Yamaguchi, PLB303, 289 (1993)

Gravitino cold dark matter

$m_{\tilde{G}}$ » m_{SUSY} » GeV - TeV (supergravity)

$\tilde{\chi}, \tilde{l}$ LSP $\tilde{G}$

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superWIMP DM

$\Omega^{thermal}_{LSP} \propto \langle\sigma v\rangle^{-1}$

$\propto$ (weak coupling)$^{-2}$

$\boxed{\text{WIMP}}$

$\tilde{G} \to$ LSP + SM

BBN constraints:

$T_{RH} < 10^5 - 10^8$ GeV

Kawasaki, Kohri and Moroi, asrtro-ph/0402490, astro-ph/0408426

Conflict with thermal leptogenesis:

$T_{RH} > 3$ £ 10^9 GeV

Buchmuller, Bari, Plumacher, NPB665, 445 (2003)

$\Omega^{thermal}_{LSP} \propto \langle\sigma v\rangle^{-1}$

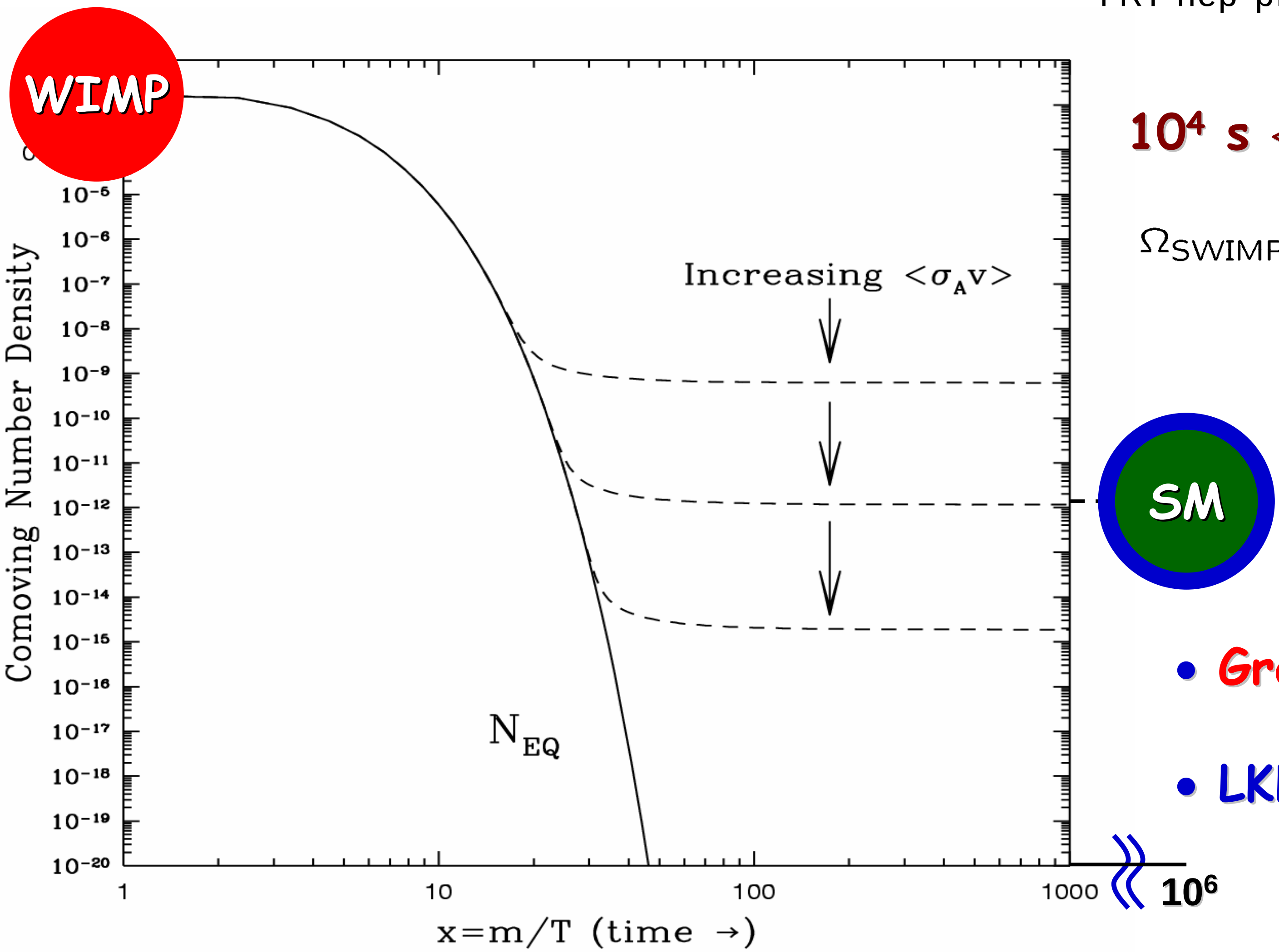
$\propto$ (gravitational coupling)$^{-2}$

- $\langle\sigma v\rangle$ too small
- $\Omega^{th}_{\tilde{G}}$ too big
  overclose the Universe
  unless $T_{RH} < 10^{10}$ GeV

Bolz, Brandenburg and Buchmuller, NPB 606, 518 (2001)

WIMP → SWIMP + SM particle

FRT hep-ph/0302215, 0306024



10^4 s < t < 10^8 s

$$\Omega_{\text{SWIMP}} = \frac{m_{\text{SWIMP}}}{m_{\text{WIMP}}} \Omega_{\text{WIMP}}$$

- **Gravitino LSP**
- **LKK graviton**

SuperWIMP and SUSY WIMP

- SUSY case

SWIMP: $\tilde{G}$ (LSP) WIMP: NLSP $m_{\tilde{G}} \gg m_{NLSP}$

Ellis *et. al.*, hep-ph/0312262; Wang and Yang, hep-ph/0405186.

10^4 s < t < 10^8 s

NLSP → $\tilde{G}$ + SM particles

$$\Omega_{\rm SWIMP} = \frac{m_{\tilde{G}}}{m_{\rm NLSP}} \Omega_{\rm NLSP}$$

		neutralino/chargino NLSP	slepton/sneutrino NLSP
BBN	EM	$\chi \to \tilde{G} + \gamma, \chi \to \tilde{G} + Z/W/h$	$\tilde{l} \to \tilde{G} + l \quad \tilde{\nu} \to \tilde{G} + \nu$
	had	$\chi \to \tilde{G} + \gamma^* \to \tilde{G} + q\bar{q}$ $\chi \to \tilde{G} + Z/W \to \tilde{G} + q\bar{q}'$ $Br_{had} > O(0.01)$	$\tilde{l} \to \tilde{G} + Z/W + l'$ $\tilde{l} \to \tilde{G} + q\bar{q}' + l'$ $Br_{had} \le O(10^{-3})$

Constraints

NLSP $\rightarrow \tilde{G}$ + SM particles

① Dark matter density $\Omega_{\tilde{G}}$ · 0.23

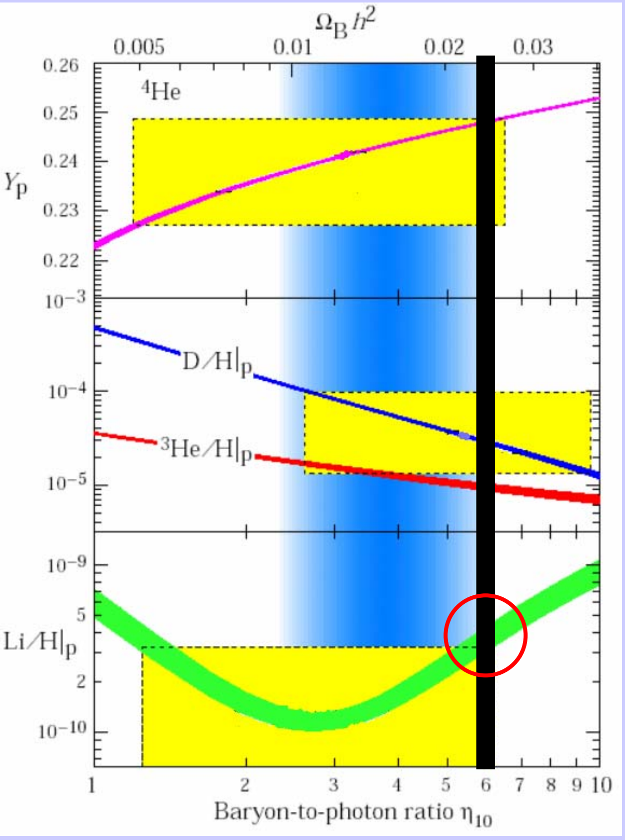
$\Omega_{SWIMP}=(m_{SWIMP}/m_{NLSP})\ \Omega^{th}_{NLSP}$

② CMB photon energy distribution

③ Big bang nucleosynthesis

Late time EM/had injection could change the BBN prediction of light elements abundances

$\eta/10^{-10}$ = 6.1± 0.4

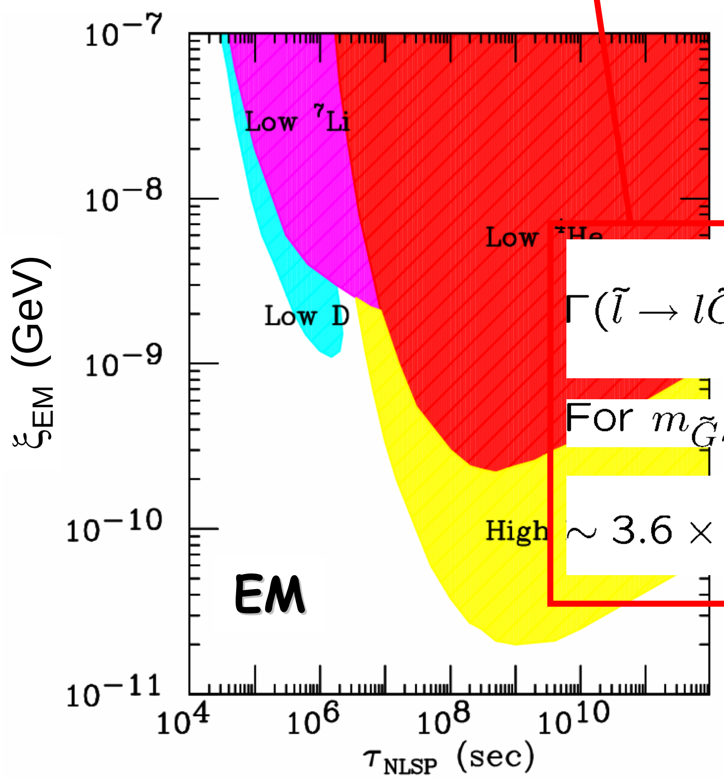


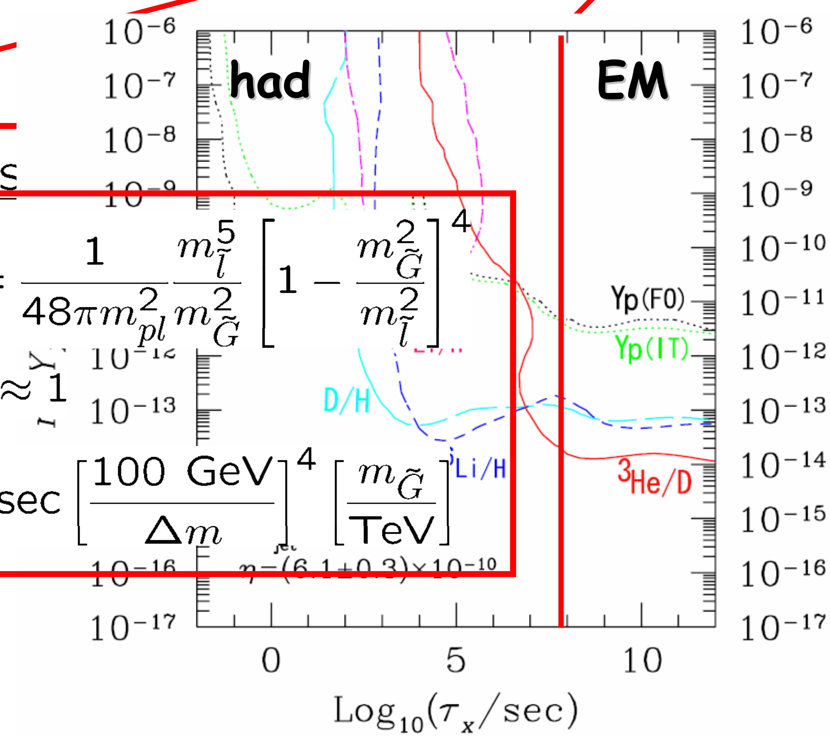
Fields, Sarkar, PDG (2002)

BBN constraints on EM/had injection

- Decay lifetime τ_{NLSP} around a year
- EM/had energy release

$$\xi_{EM,had} = \varepsilon_{EM,had}\, Br_{EM,had}\, Y_{NLSP}$$





$$\Gamma(\tilde{l} \to l\tilde{G}) = \frac{1}{48\pi m_{pl}^2} \frac{m_{\tilde{l}}^5}{m_{\tilde{G}}^2} \left[1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{l}}^2}\right]^4$$

For $m_{\tilde{G}}/m_{\tilde{l}} \approx 1$

$$\sim 3.6 \times 10^8 \mathrm{sec} \left[\frac{100\ \mathrm{GeV}}{\Delta m}\right]^4 \left[\frac{m_{\tilde{G}}}{\mathrm{TeV}}\right]$$

Cyburt, Ellis, Fields and Olive, PRD 67, 103521 (2003)

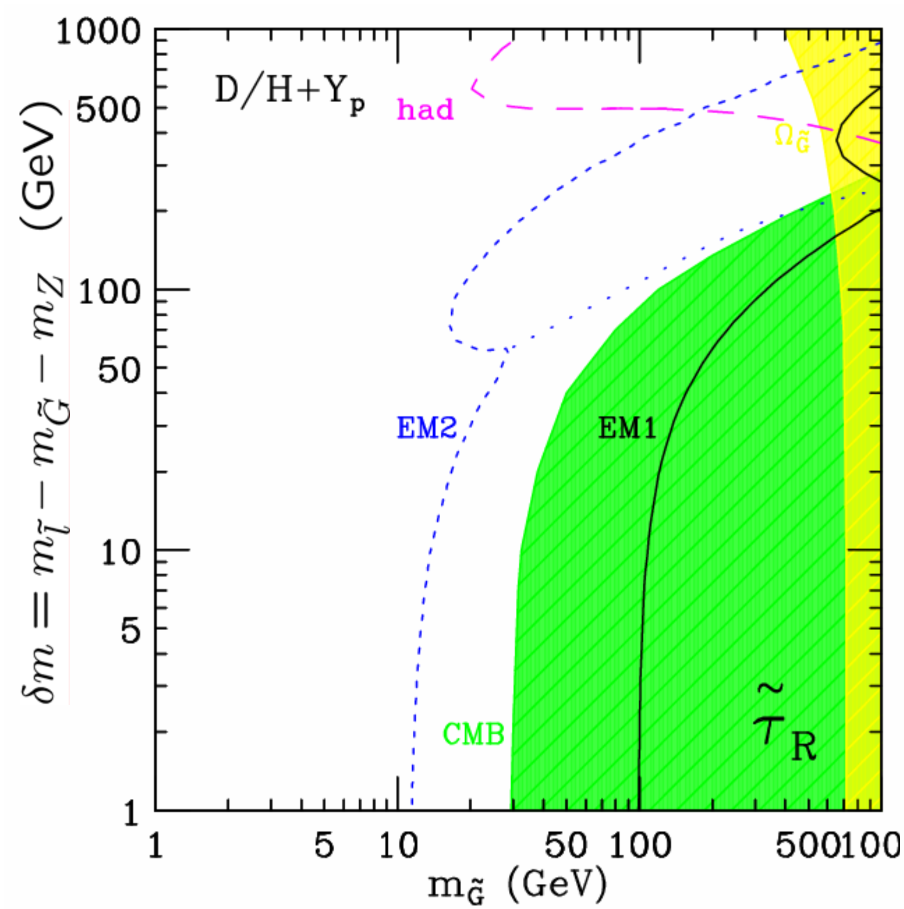
Kawasaki, Kohri and Moroi, astro-ph/0402490

slepton and sneutrino NLSP

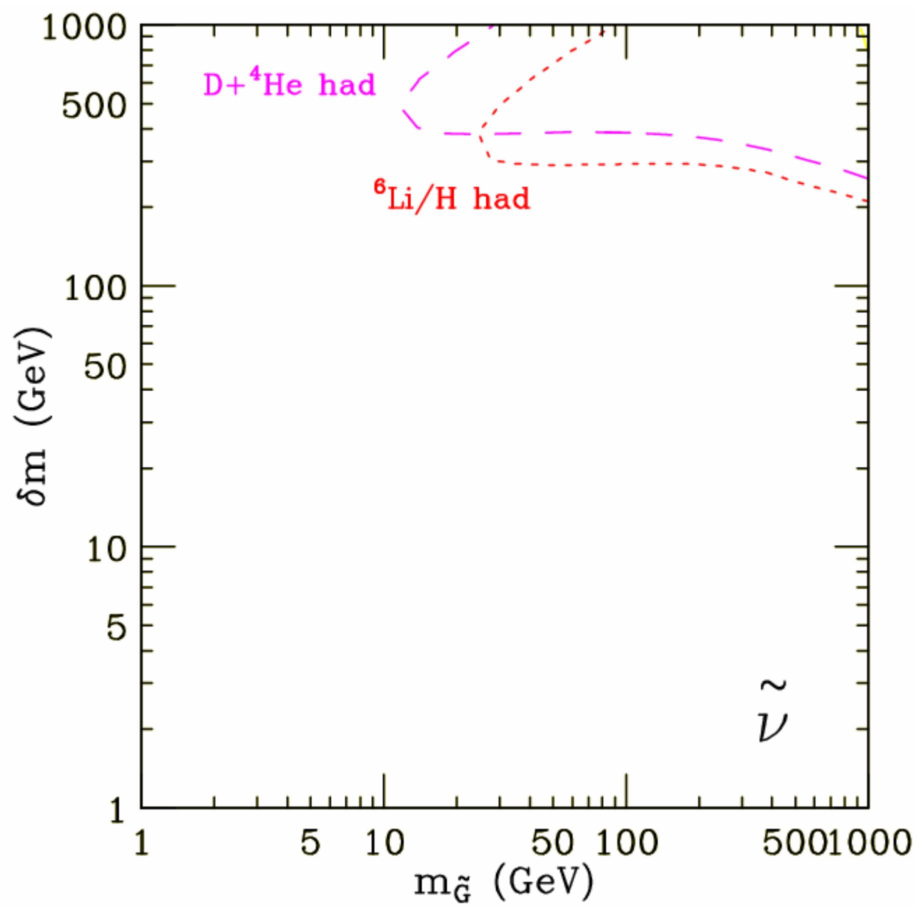
$$\Omega_{\tilde{G}} = (m_{\tilde{G}}/m_{NLSP})\ \Omega^{th}_{NLSP}$$

J. Feng, F. Takayama, S. Su
hep-ph/0404198, 0404231

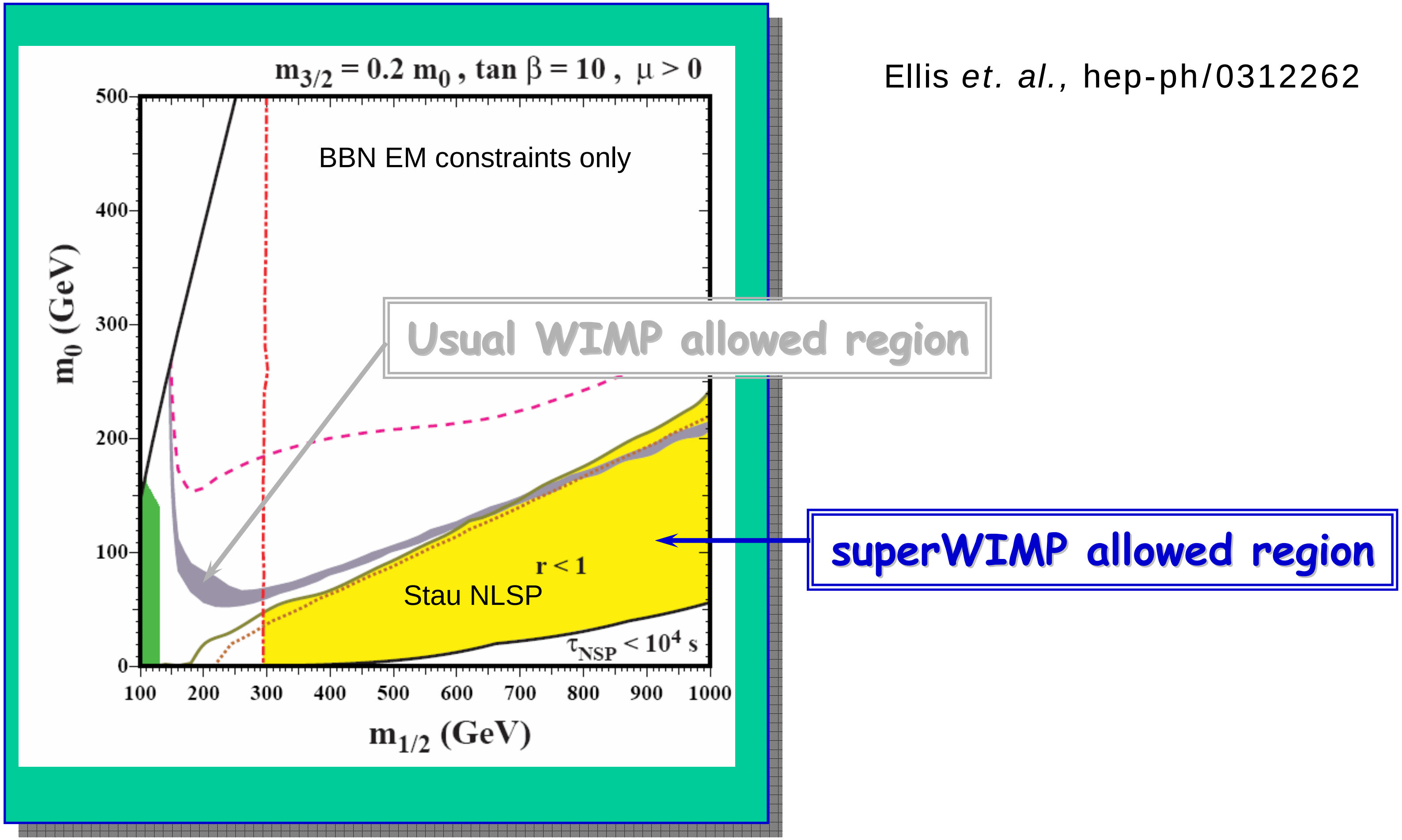
$$\Omega^{th}_{\tilde{l}_R} h^2 \approx 0.2 \left[\frac{m_{\tilde{l}_R}}{\mathrm{TeV}}\right]^2$$



$$\Omega^{th}_{\tilde{\nu}} h^2 \approx 0.06 \left[\frac{m_{\tilde{\nu}}}{\mathrm{TeV}}\right]^2$$



superWIMP in mSUGRA



Ellis *et. al.*, hep-ph/0312262

Collider Phenomenology

SWIMP Dark Matter

× no signals in direct / indirect dark matter searches

✓ SUSY NLSP: rich collider phenomenology

NLSP in SWIMP: long lifetime ⇒ stable inside the detector

- Charged slepton highly ionizing track, almost background free

Distinguish from stau NLSP and gravitino LSP in GMSB

- GMSB: gravitino m » keV warm not cold DM
- collider searches: other sparticle (mass)
- τ(GMSB) ¿ τ(SWIMP): distinguish experimentally

Feng and Smith, in preparation.

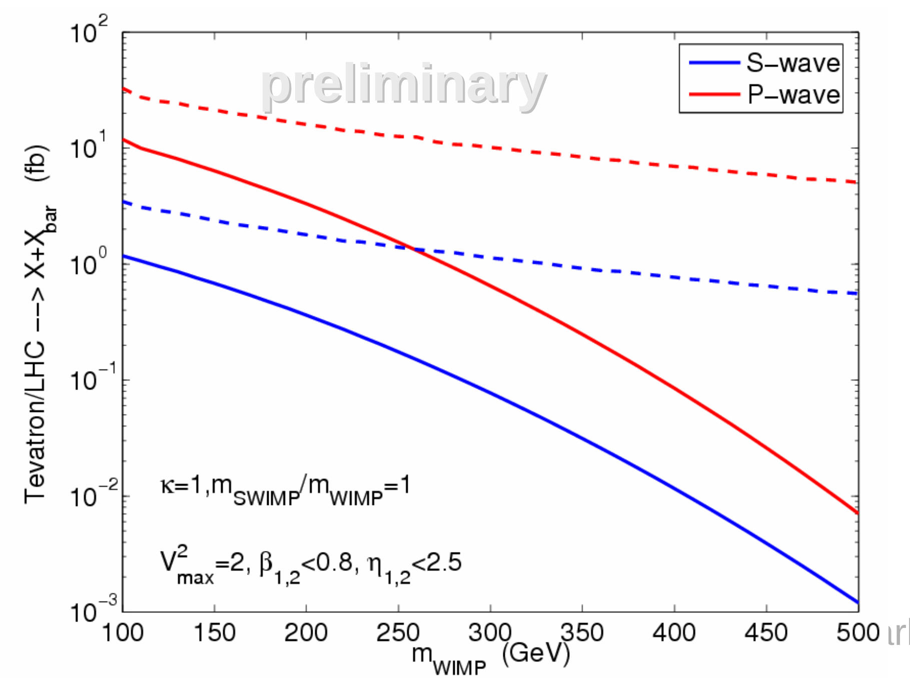
Guaranteed signal at colliders

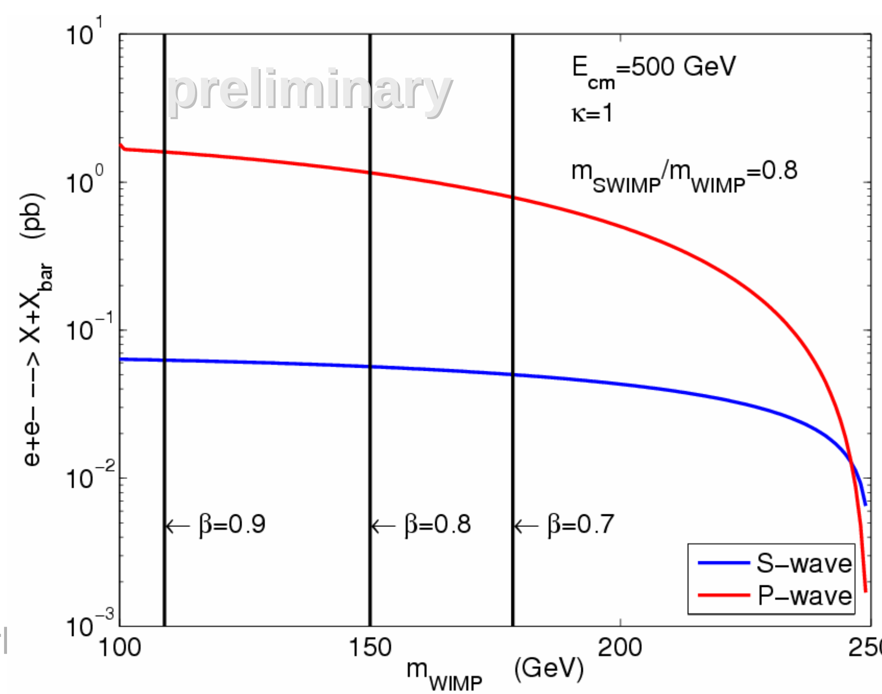
Feng, SS, Takayama, in preparation

Model independent approach: $\Omega_{DM} \Rightarrow \langle\sigma v\rangle_{ann} \Rightarrow \sigma_{production}$

Birkedal, matchev, Perelstein, PRD 70, 077701 (2004).

- Usual WIMP: missing energy + jet or photon
  irreducible SM background
- superWIMP: promising event rates at LHC/LC.





Sneutrino and neutralino NLSP

- sneutrino and neutralino NLSP missing energy

  signal: energetic jets/leptons + missing energy

① Is the lightest SM superpartner sneutrino or neutralino?

– angular distribution of events (LC)

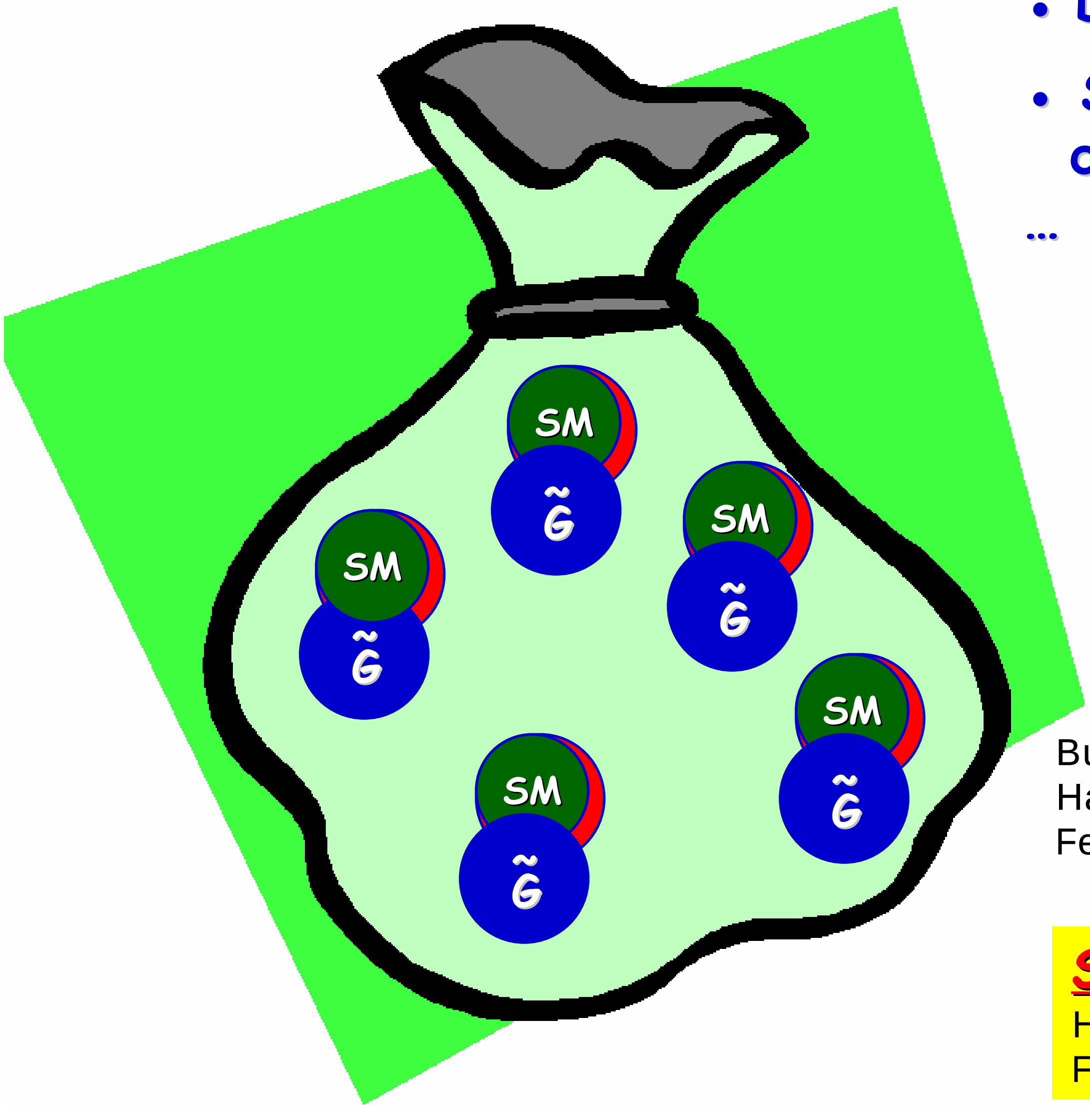
$e^+e^- \to \tilde{l}\tilde{l} \to l\nu\tilde{\nu}q\bar{q}'\tilde{\nu}$ vs. $e^+e^- \to \tilde{\chi}^+\tilde{\chi}^- \to l\nu\tilde{\chi}^0 q\bar{q}'\tilde{\chi}^0$

② Does it decay into gravitino or not?

– sneutrino case: most likely gravitino is LSP

– neutralino case: most likely neutralino LSP

- direct/indirect dark matter search
  positive detection $\Rightarrow$ disfavor gravitino LSP
- precision determination of SUSY parameter: $\Omega^{th}_{\tilde{\chi},\tilde{\nu}}$
  $\Omega_{\tilde{\chi},\tilde{\nu}} > 0.23 \Rightarrow$ favor gravitino LSP



- **Decay life time**
- **SM particle energy/angular distribution**

...

$\Rightarrow m_{\tilde{G}}$

$\Rightarrow m_{pl}$

$\Rightarrow$ LFV

...

Buchmuller et. al., hep-ph/0402179
Hamaguchi and Ibarra, hep-ph/0412229
Feng et. al., Hep-ph/0405248

Slepton trapping:
Hamaguchi et. al. hep-ph/0409248
Feng and Smith, hep-ph/0409278

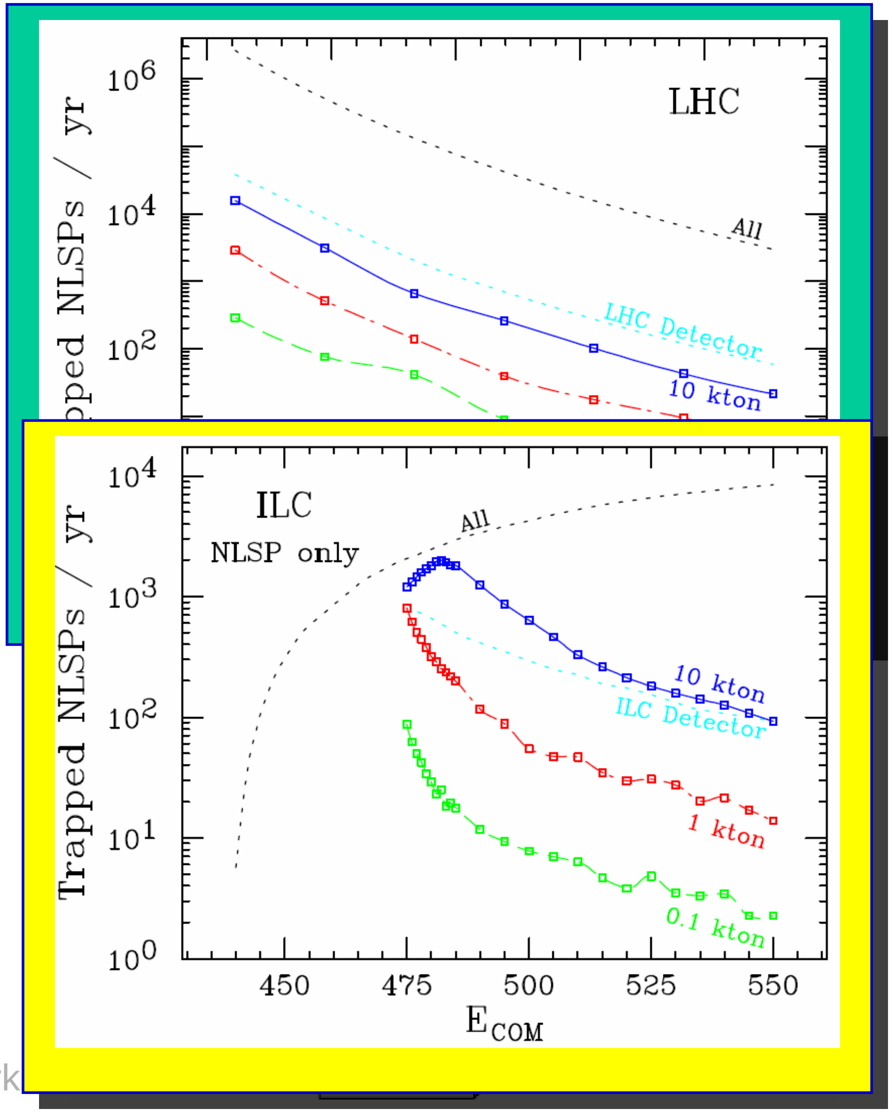
Slepton trapping

Feng and Smith, hep-ph/0409278

- Slepton could live for a year, so can be trapped then moved to a quiet environment to observe decays

- LHC: 10^6 slepton/yr possible, but most are fast. By optimizing trap location and shape, can catch » 100/yr in 1000m^3 water

- LC: tune beam energy to produce slow sleptons, can catch 1000/yr in 1000m^3 water



Courtesy of J. Feng

Conclusions

- Gravitino could be warm DM: m » keV
- Gravitino could be cold DM: m » few hundred GeV
  - thermal production: $T_{RH} < 10^{10}$ GeV
  - Non-thermal production: superWIMP

WIMP → superWIMP + SM particle

SuperWIMP: gravitino LSP WIMP: slepton/sneutrino/neutralino

- Constraints from BBN: EM injection and <u>hadronic</u> injection viable parameter space
- Rich collider phenomenology (no direct/indirect DM signal)
  - charged slepton: highly ionizing track
  - sneutrino/neutralino: missing energy
- Slepton trapping