A measurement of Neutralino Mass at the LHC in Light Gravitino Scenarios

Koichi Hamaguchi (Tokyo U. and IPMU)

at LHC focus week, IPMU, June '08

with Eita Nakamura and Satoshi Shirai (Tokyo U.),
arXiv: 0805.2502

Summary:

- We considered SUSY models with

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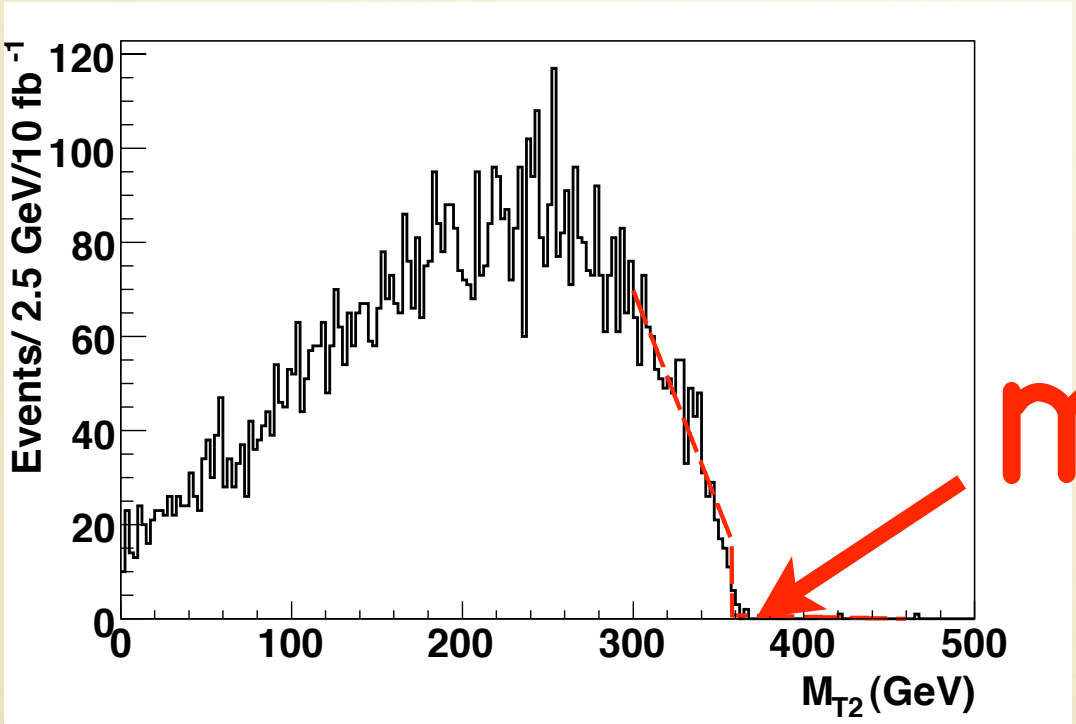

$m_{neutralino}$

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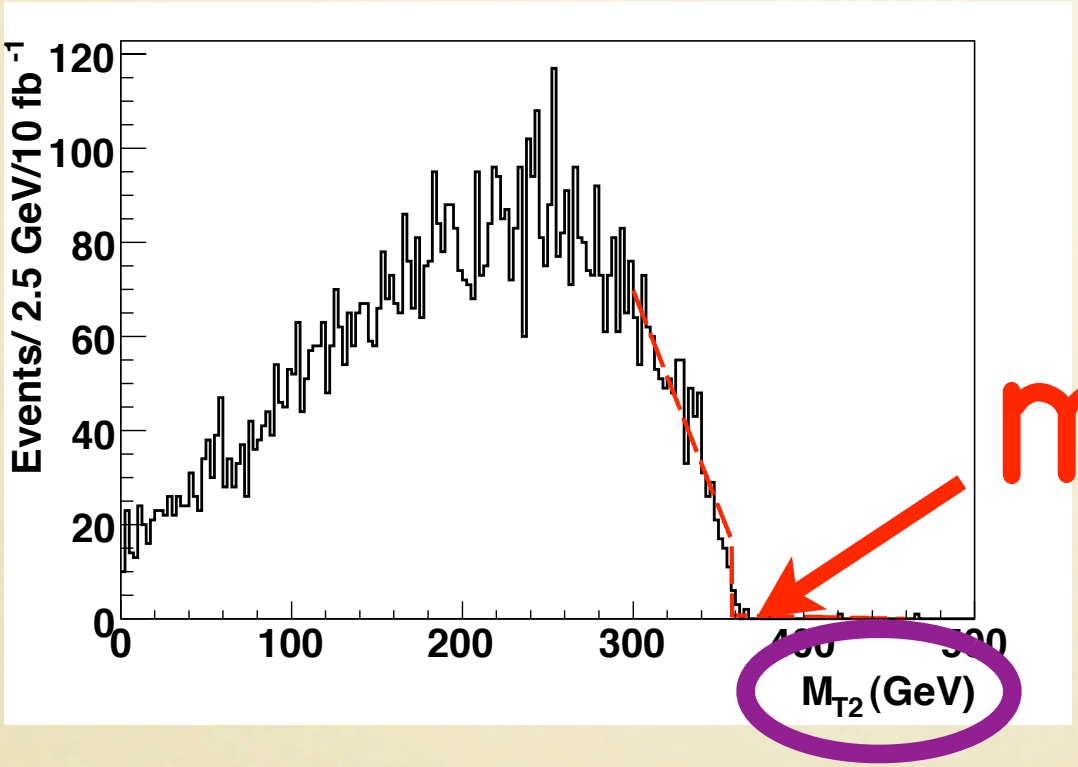

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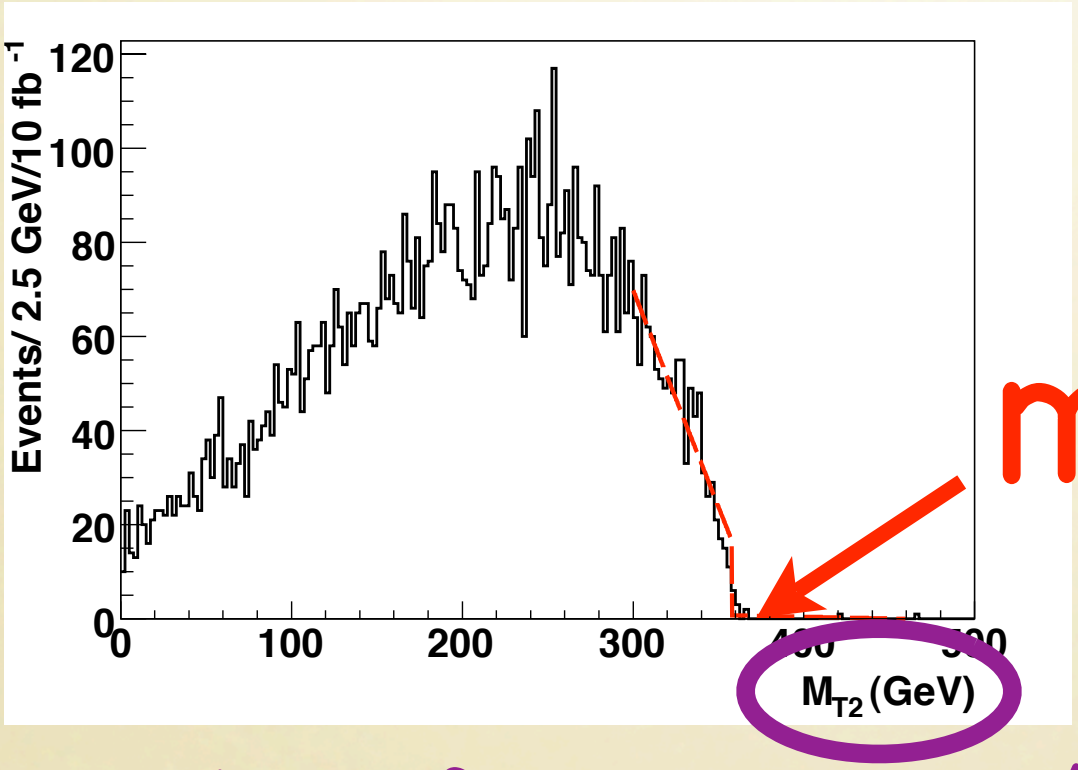

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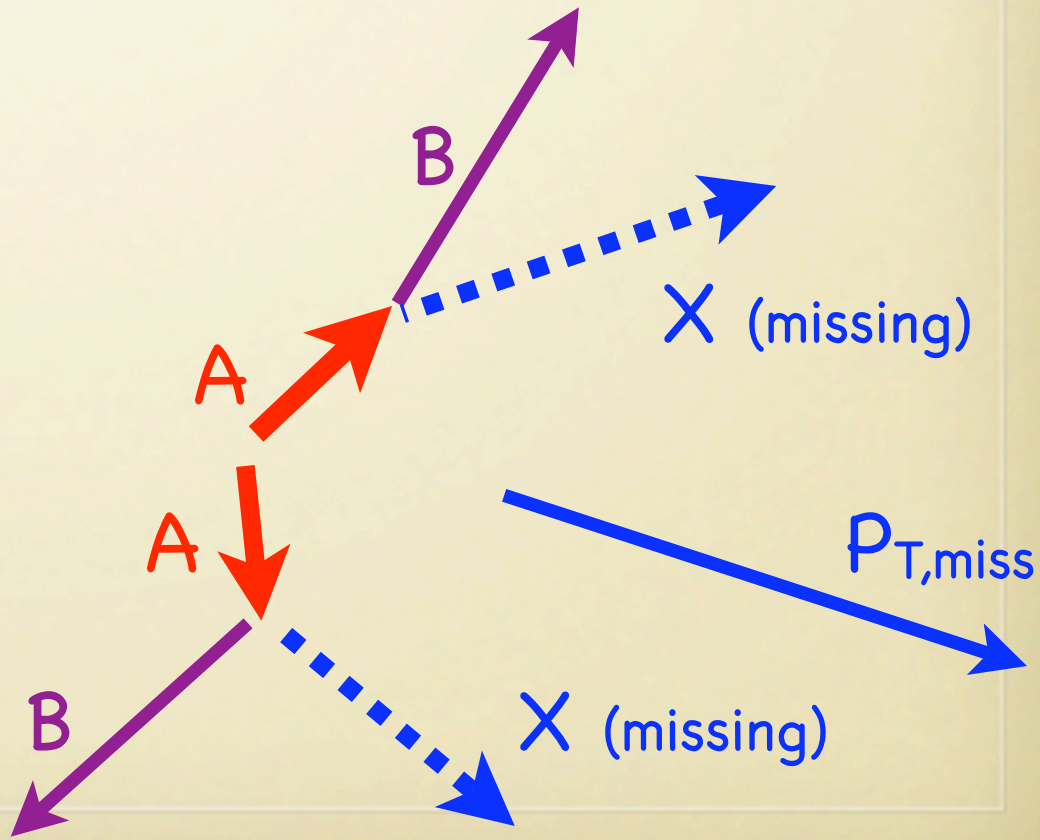
based on M_{T2} method

- independent of other masses / cascade patterns
- complementary to (better than) other methods

M_{T2} method

Lester, Summers,'99
Barr, Lester, Stephens,'03

$m_A = ?$



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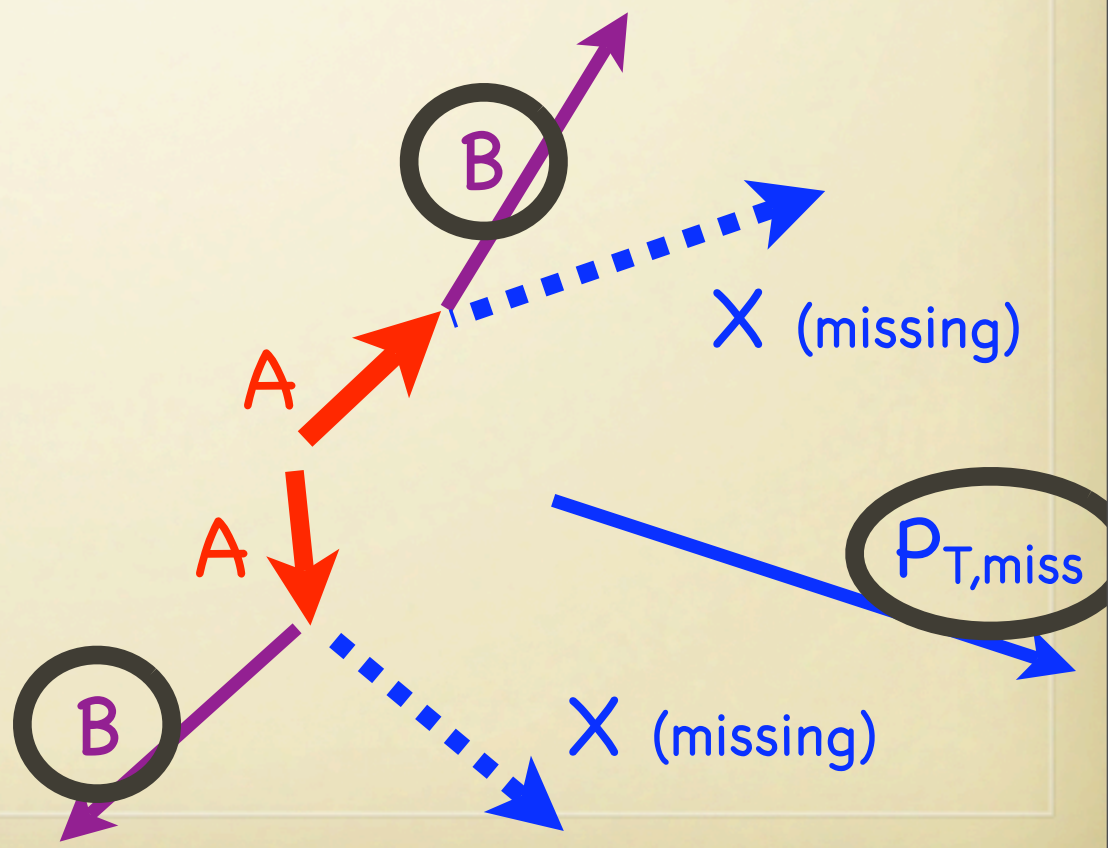

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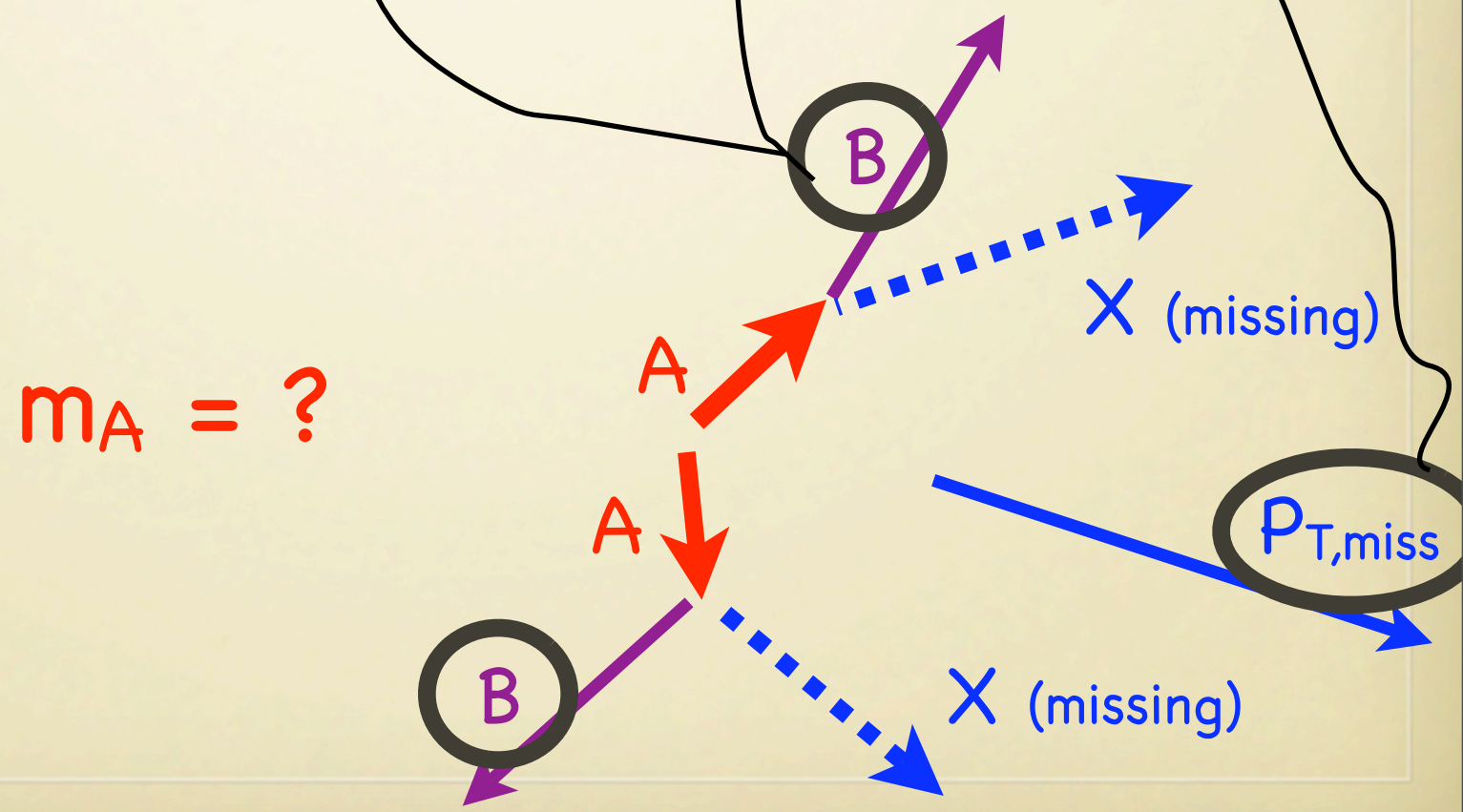

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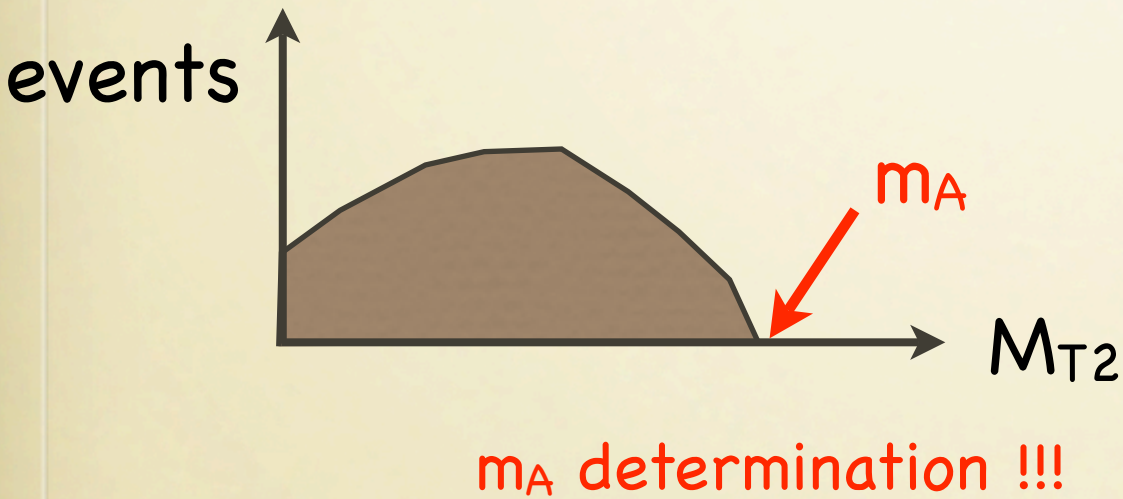

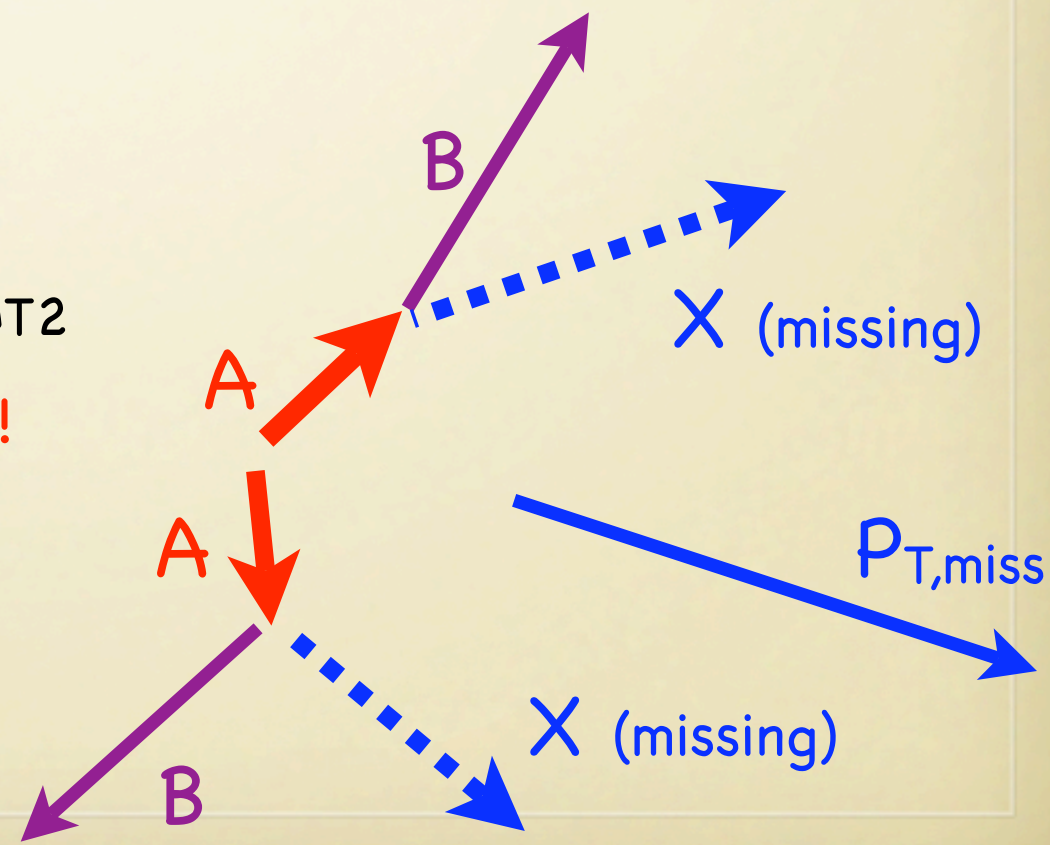

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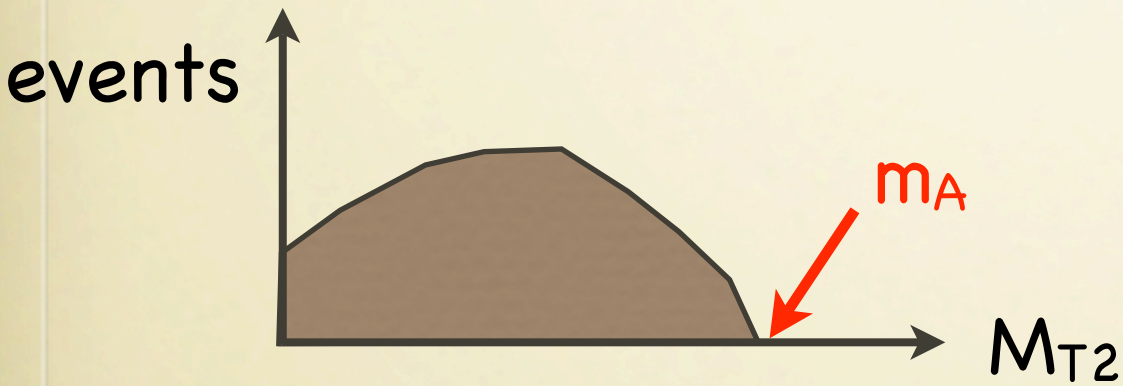

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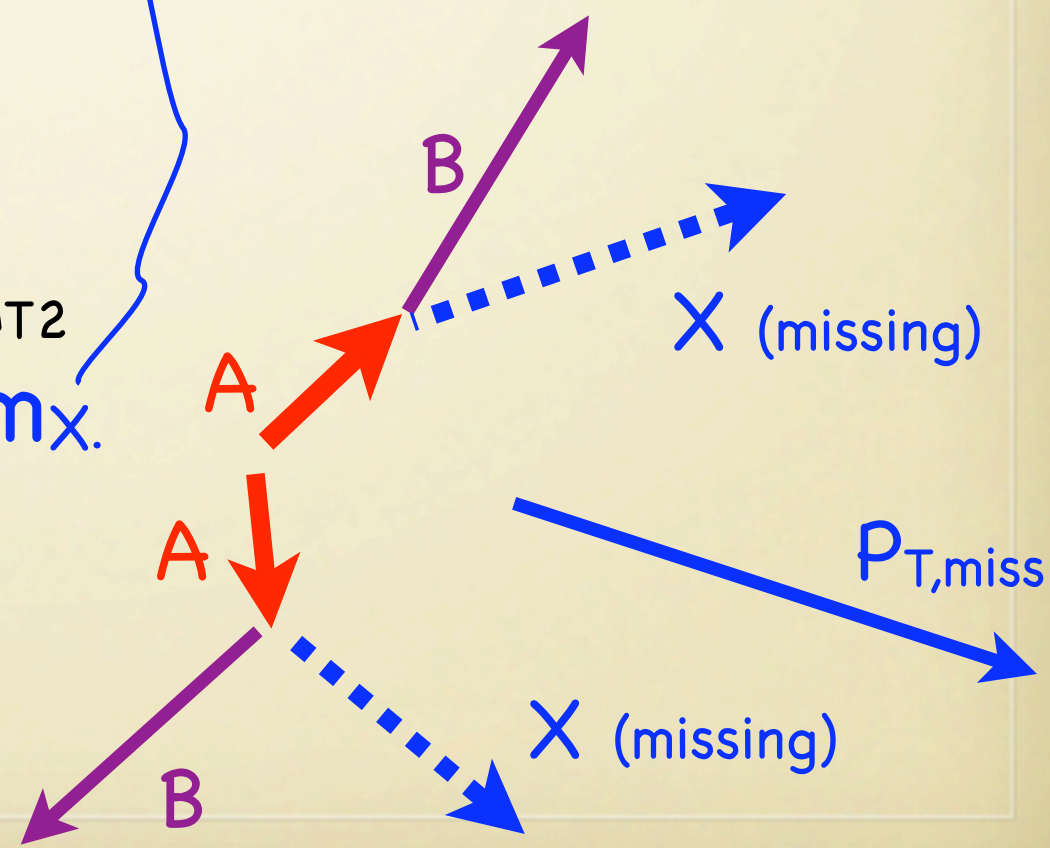

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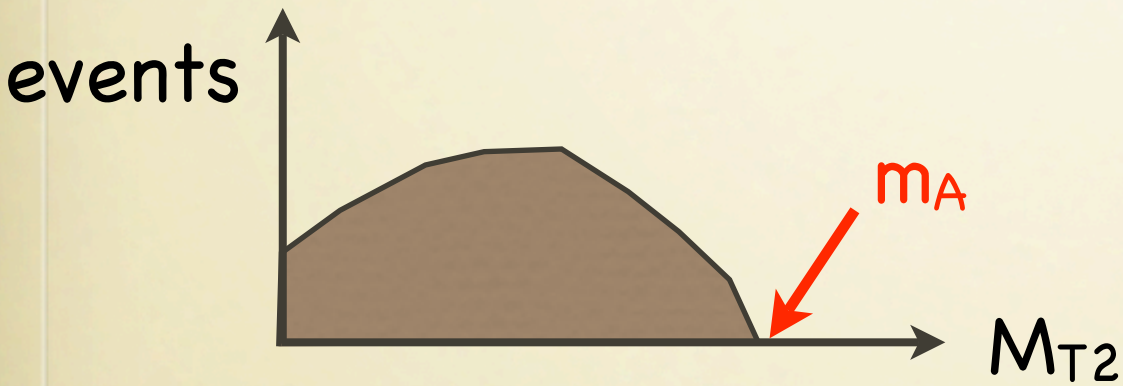

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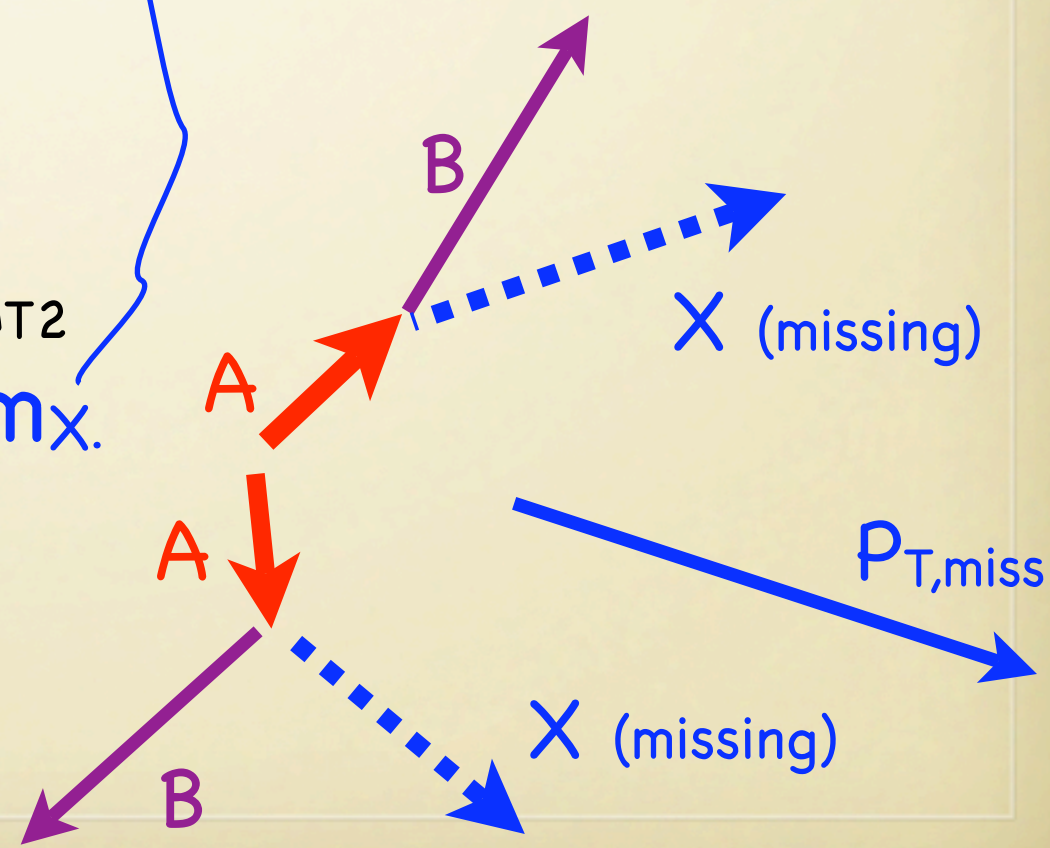
But in general, we don't know m_X.

only a relation $m_A(m_X^{\rm trial})$ obtained.



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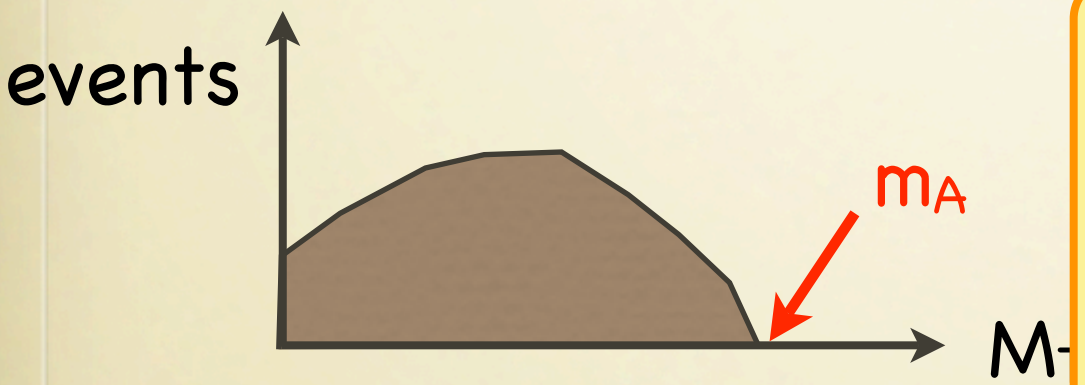

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recent developments:

"kink" in $m_A(m_X^{trial})$ may determine m_A and m_X simultaneously!

(Lester, Barr, 0708;
Cho, Choi, Kim, Park, 0709 + 0711;
Barr, Gripaios, Lester, 0711;
Nojiri, Shimizu, Okada, Kawagoe, 0802;
.....)

☛ See Wednesday Talks by Y.G.Kim, C.Lester, Y.Shimizu.

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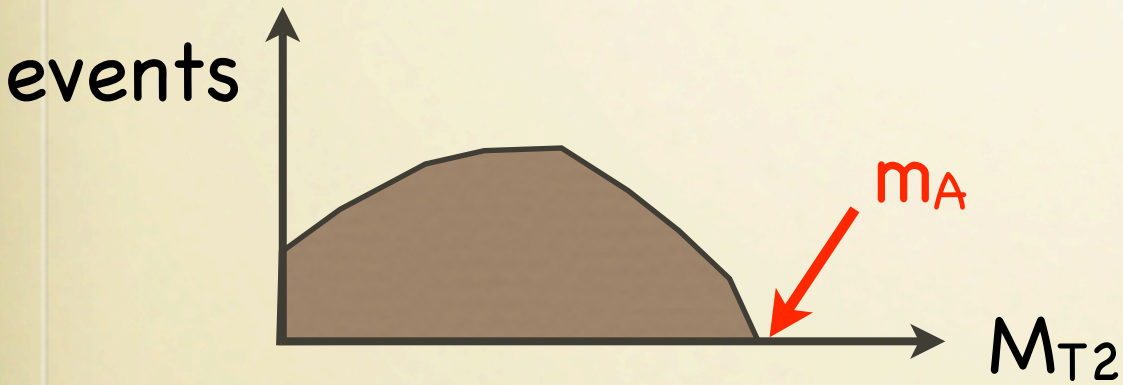

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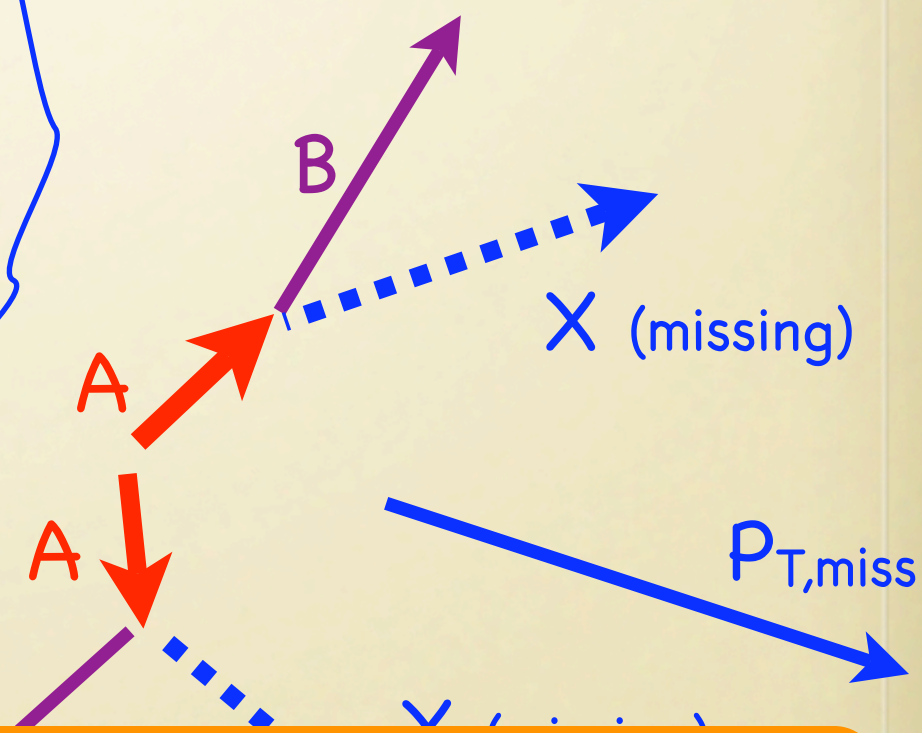

Here, we discuss an interesting case in that we will know $m_X = 0$.

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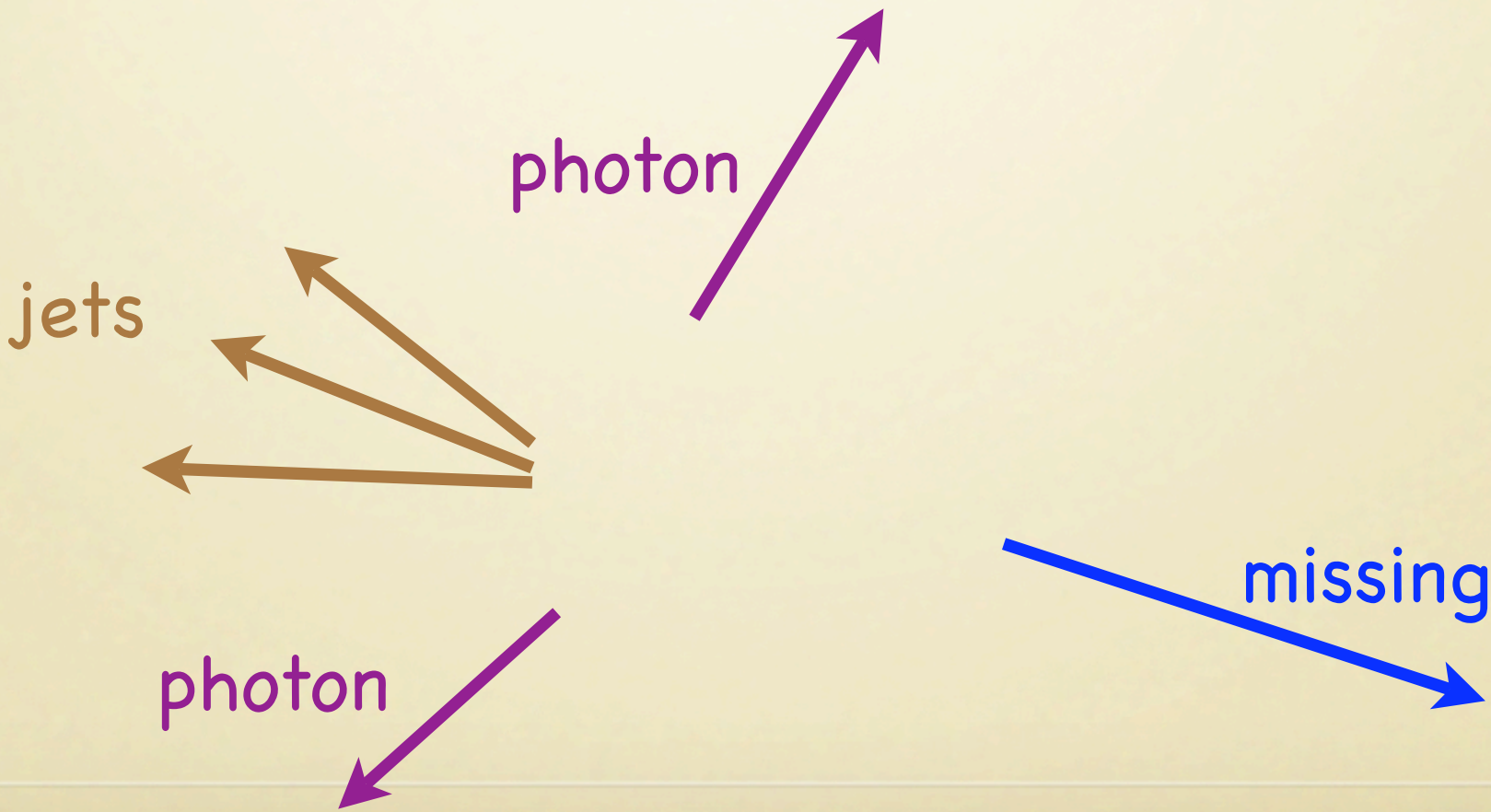

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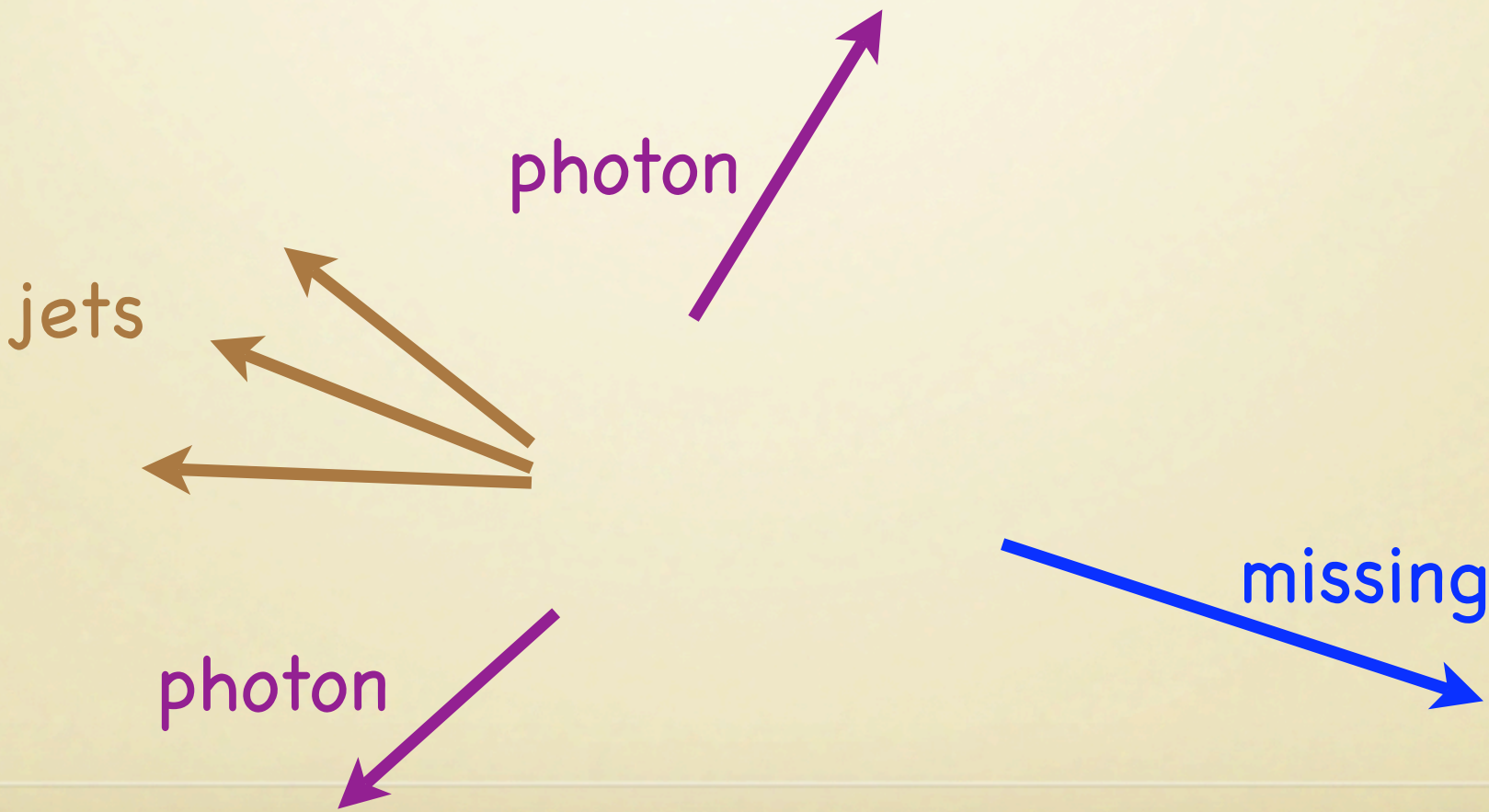
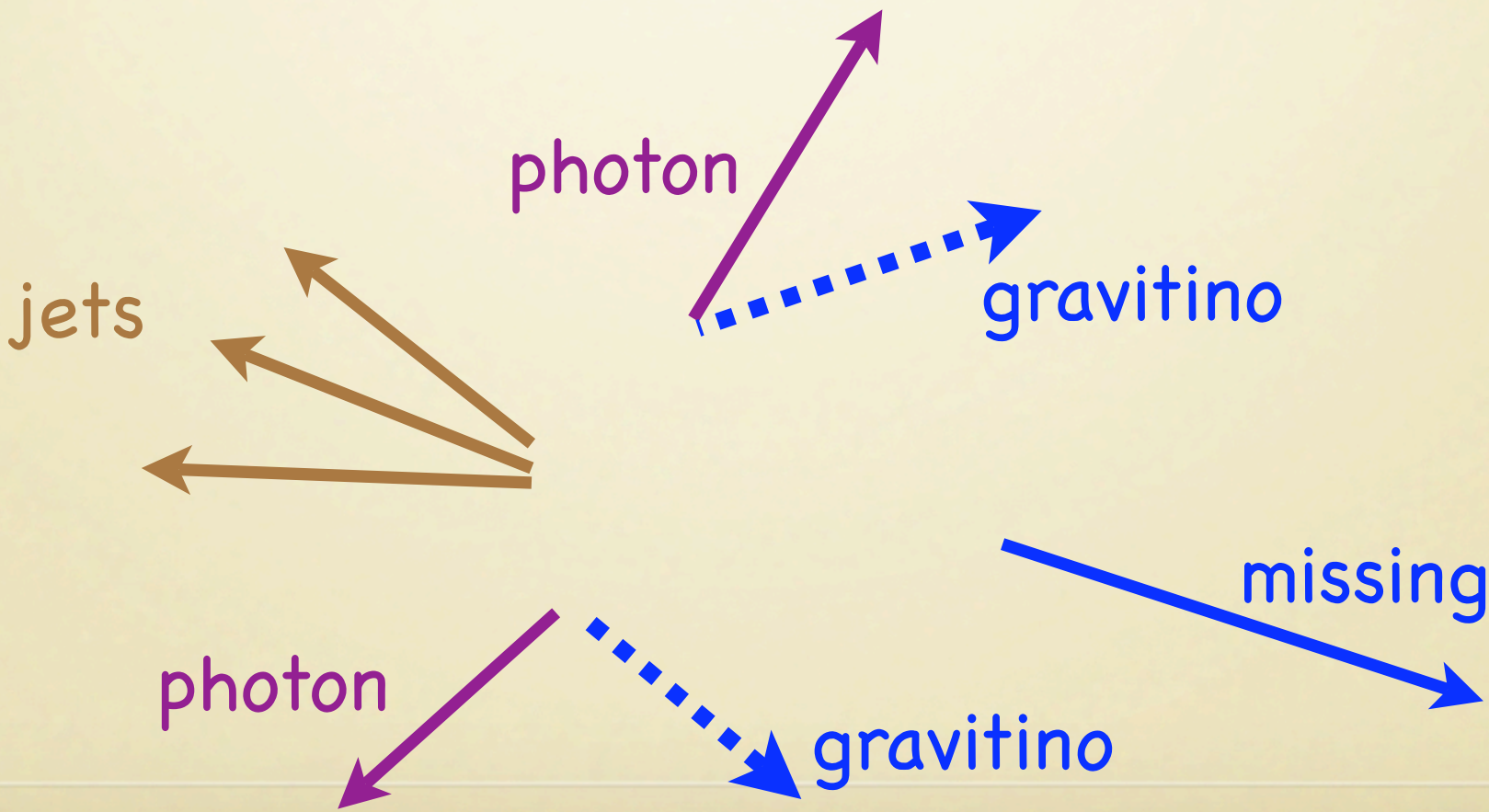


- Suppose that large missing P_T signals at the LHC will be accompanied by two high P_T photons.

→ a natural candidate for the underlying model is a SUSY model with gravitino LSP



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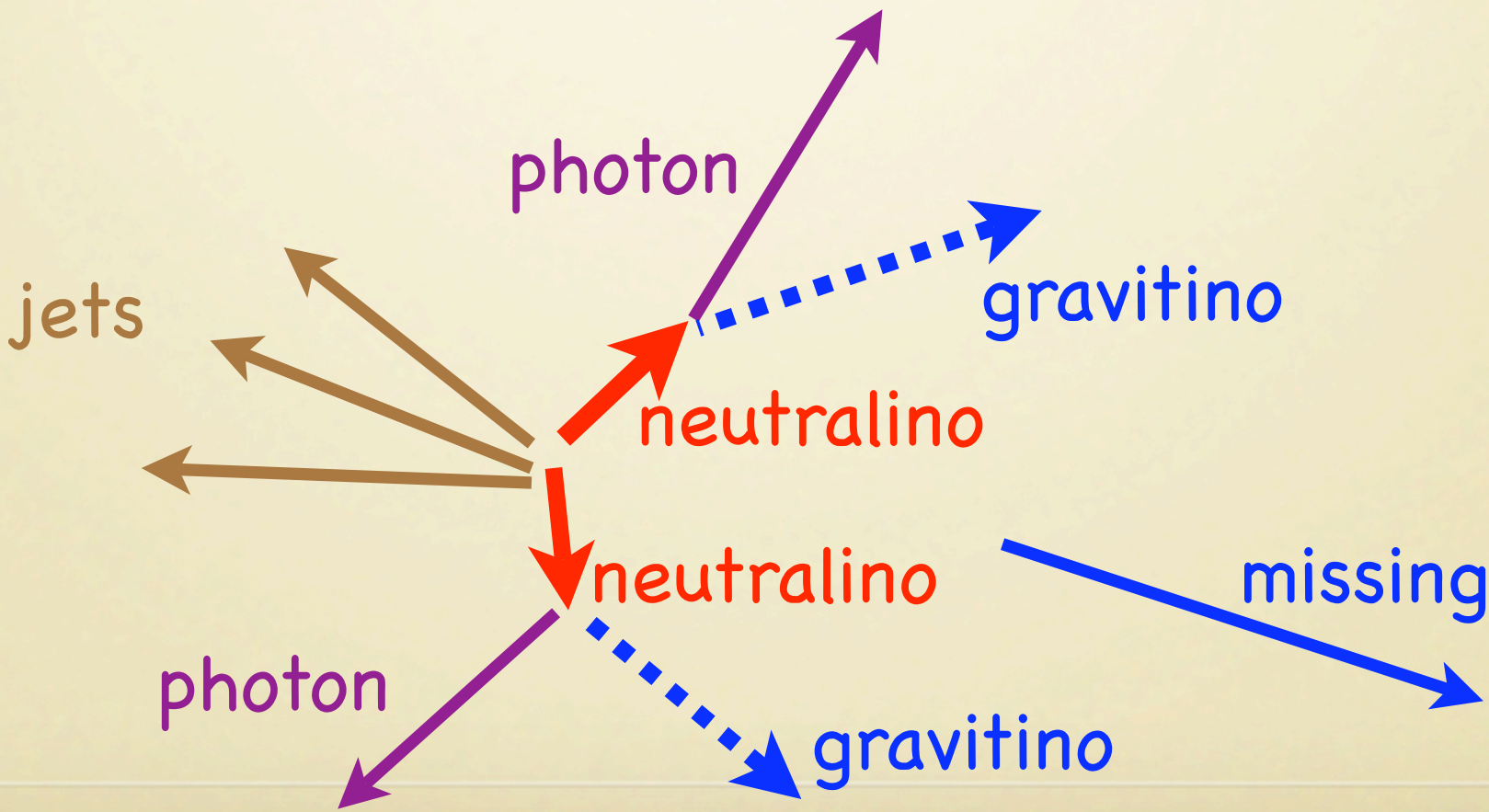
→ a natural candidate for the underlying model is a SUSY model with gravitino LSP + neutralino NLSP.



decay length of NLSP
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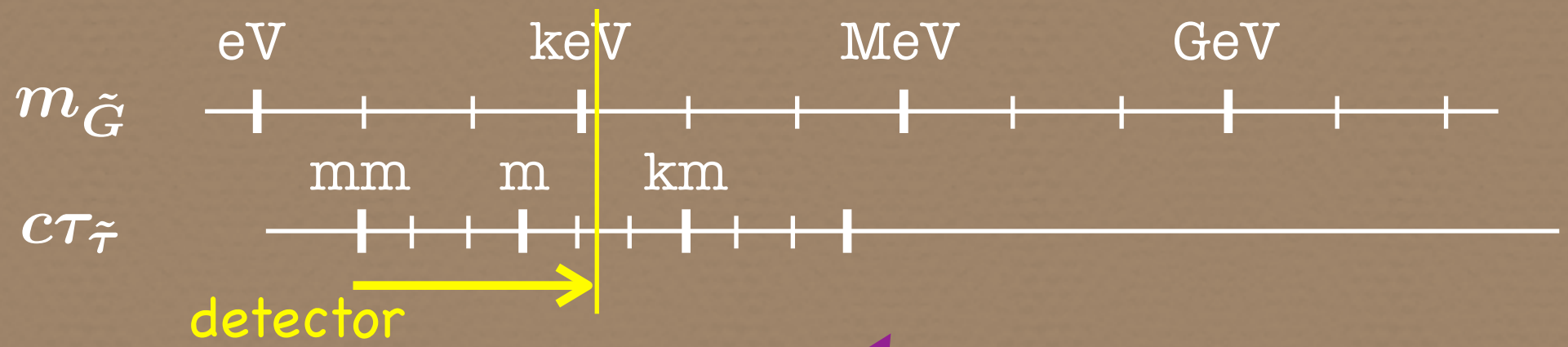
$$c\tau_{\rm NLSP} \sim 20\mu{\rm m}\left(\frac{m_{\tilde{G}}}{1\ {\rm eV}}\right)^2\left(\frac{m_{\rm NLSP}}{100\ {\rm GeV}}\right)^{-5}$$



We can assume

$m_X = m_{\rm Gravitino} \approx 0$

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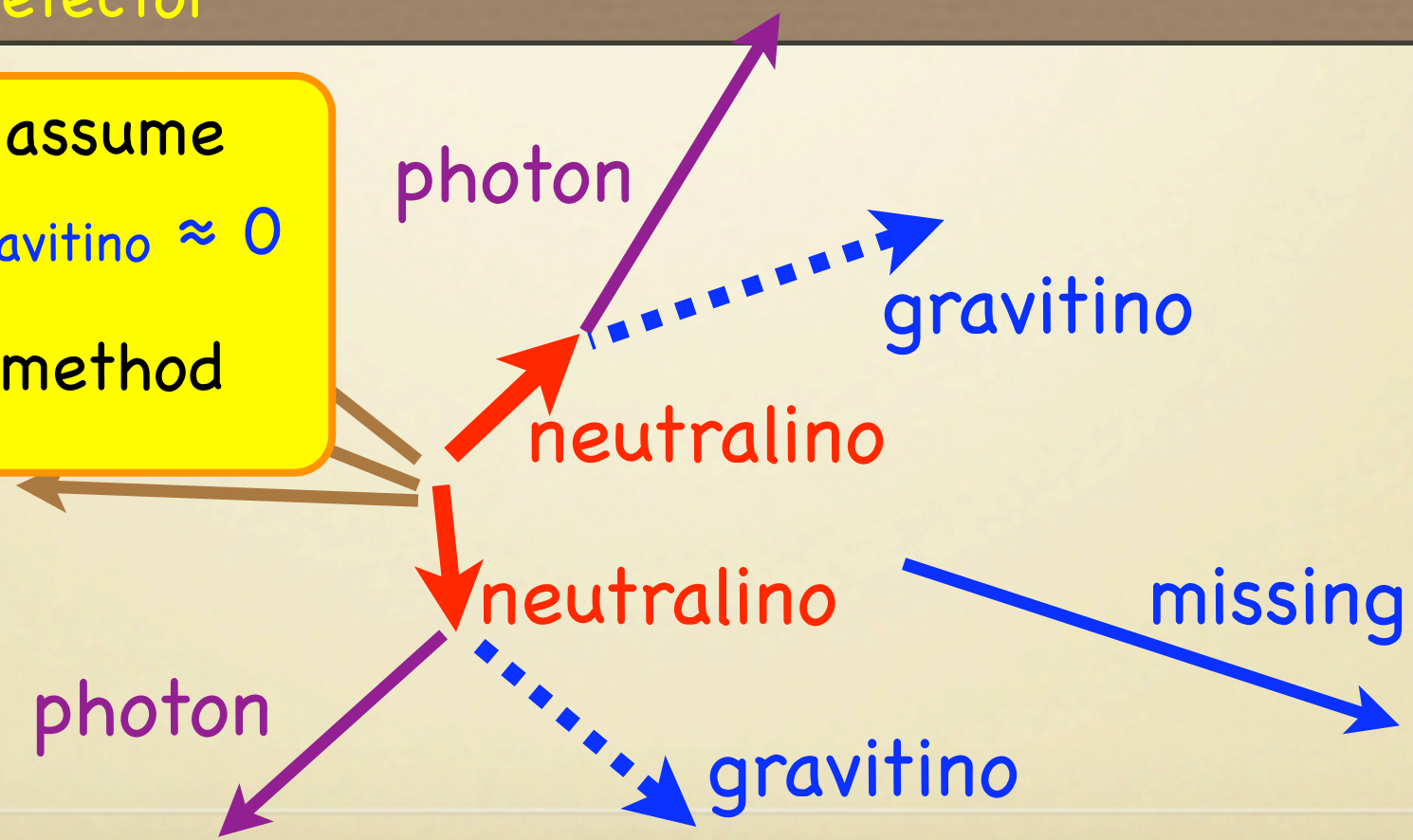

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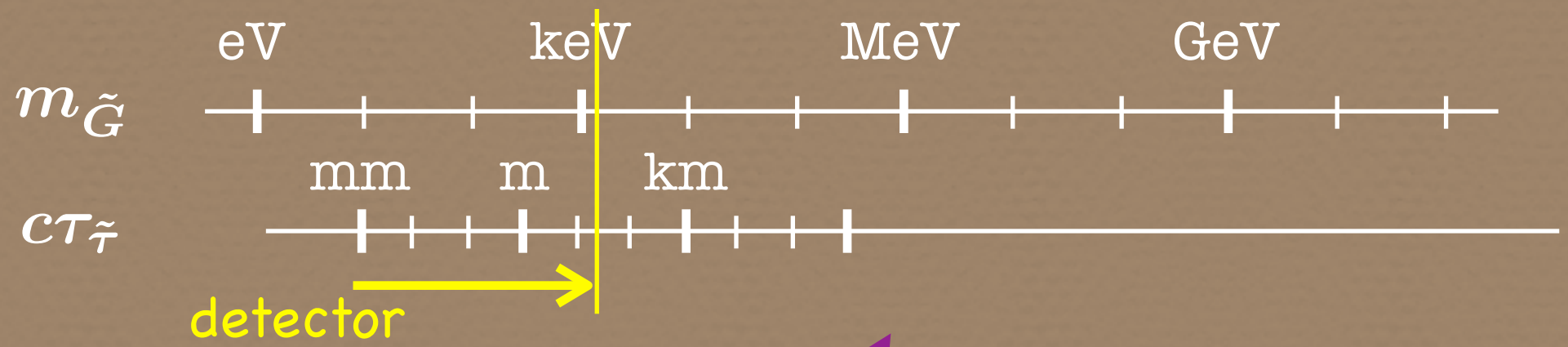

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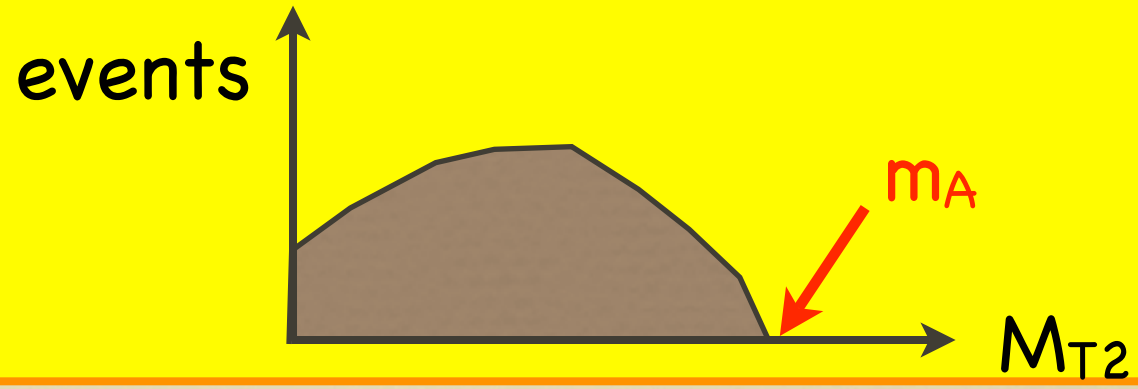
photon

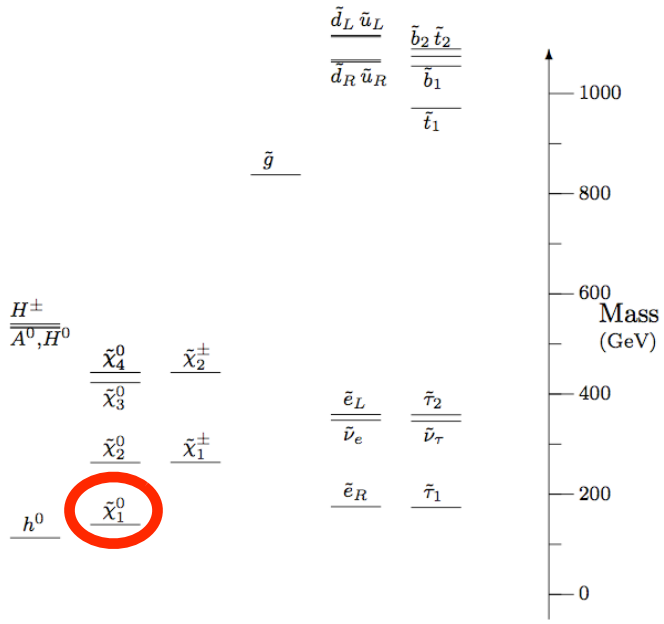
and therefore directly measure

$m_{neutralino}$ by the M_{T2} method.



photon

example 1:
SPS8



- ≥ 4 jets with $p_{\rm T} > 50$ GeV and $p_{\rm T,1,2} > 100$ GeV
- ≥ 2 photons with $p_{\rm T} > 20$ GeV.
- $M_{\rm eff} > 500$ GeV ($M_{\rm eff} = \sum_{\rm jets}^4 p_{{\rm T}j} + p_{\rm T}^{\rm miss}$).
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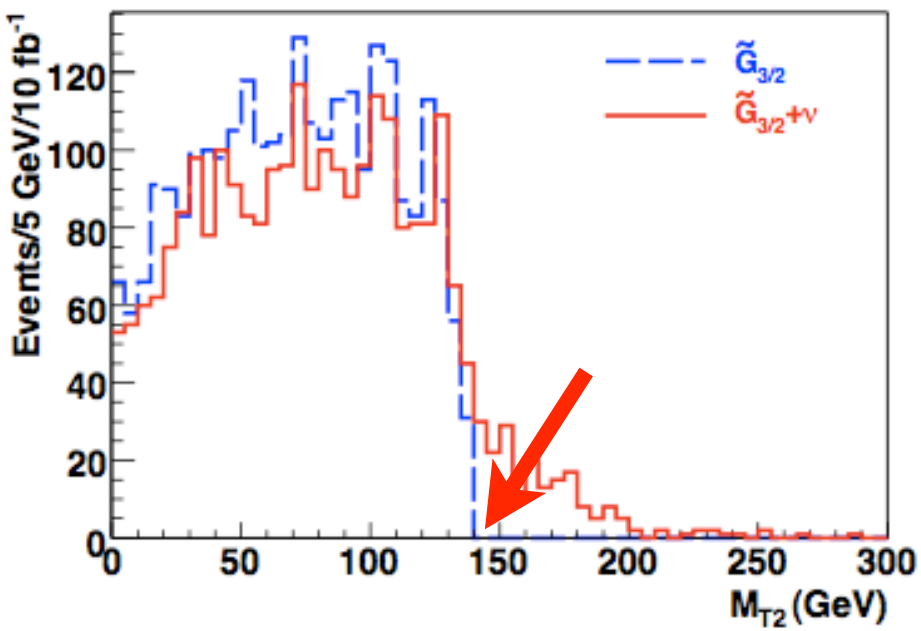
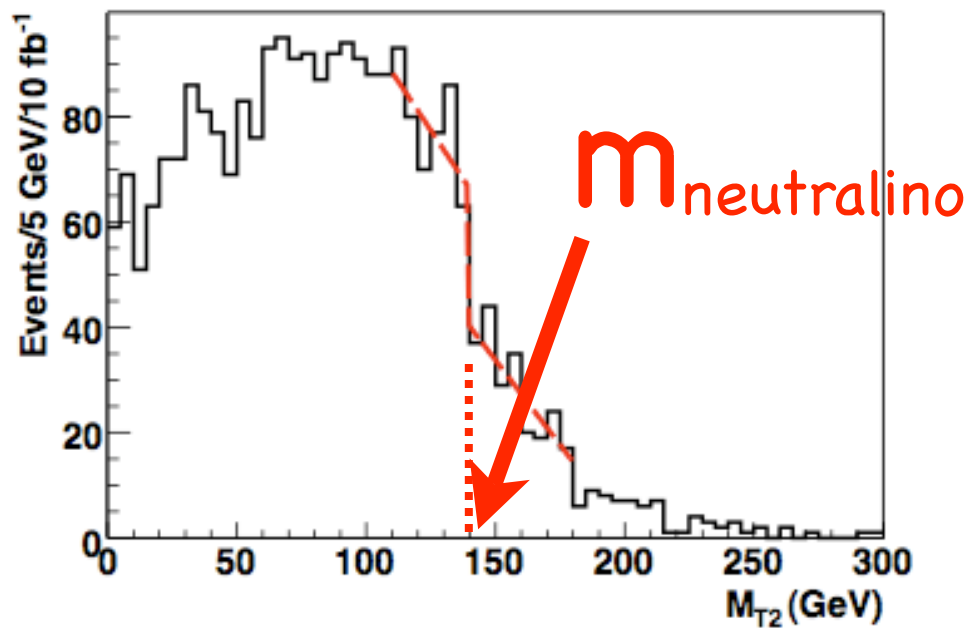
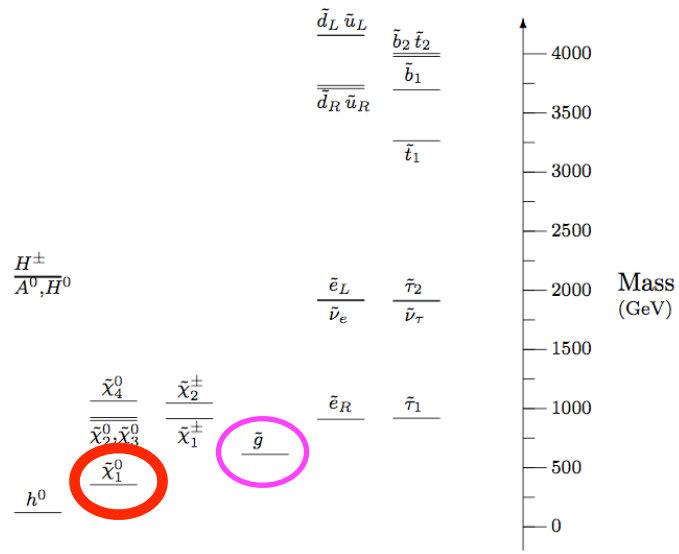


(a) parton level



(b) detector level

example 2:
SIGM



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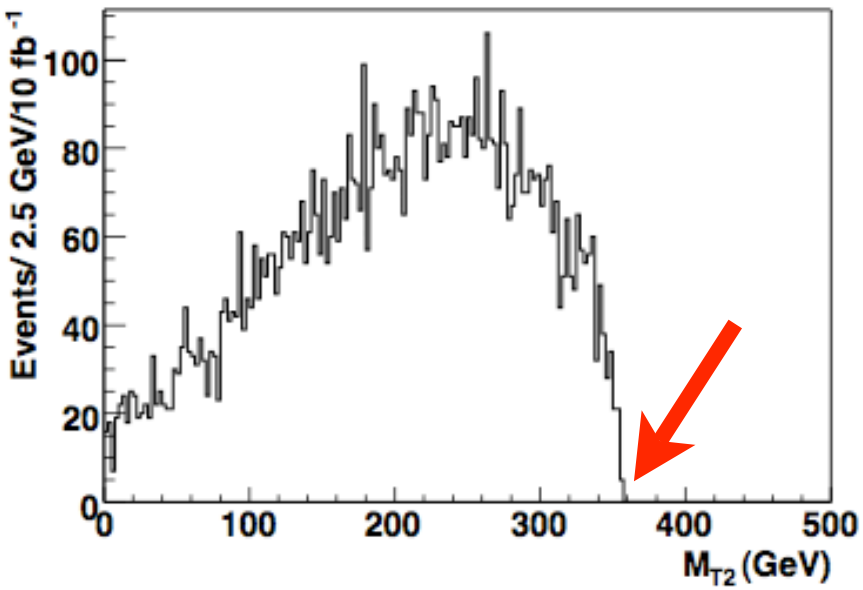
model from
KH, Shirai, Nakamura, Yanagida,'08



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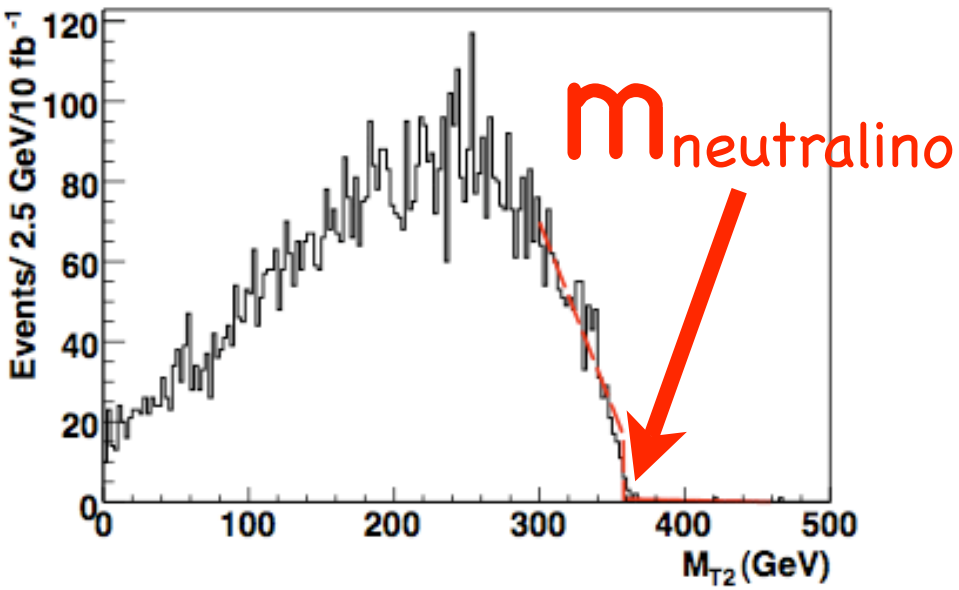

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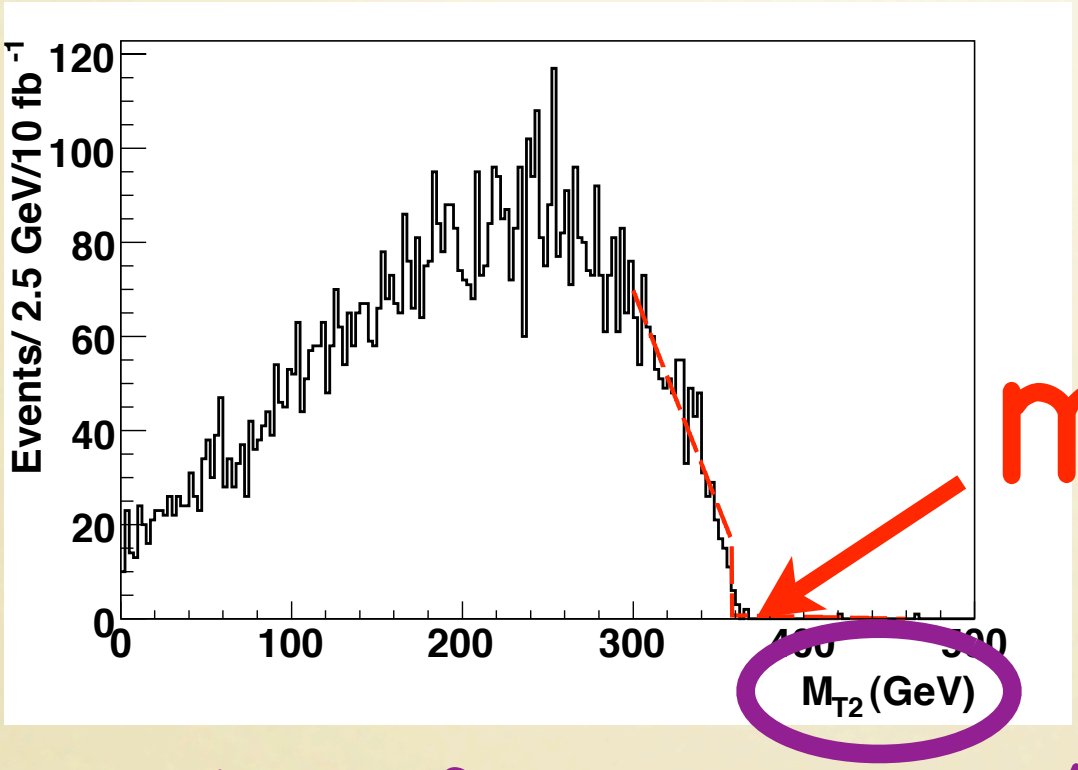

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based on M_{T2} method

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Motivation:

Why gravitino LSP ??

Why such a light gravitino ??

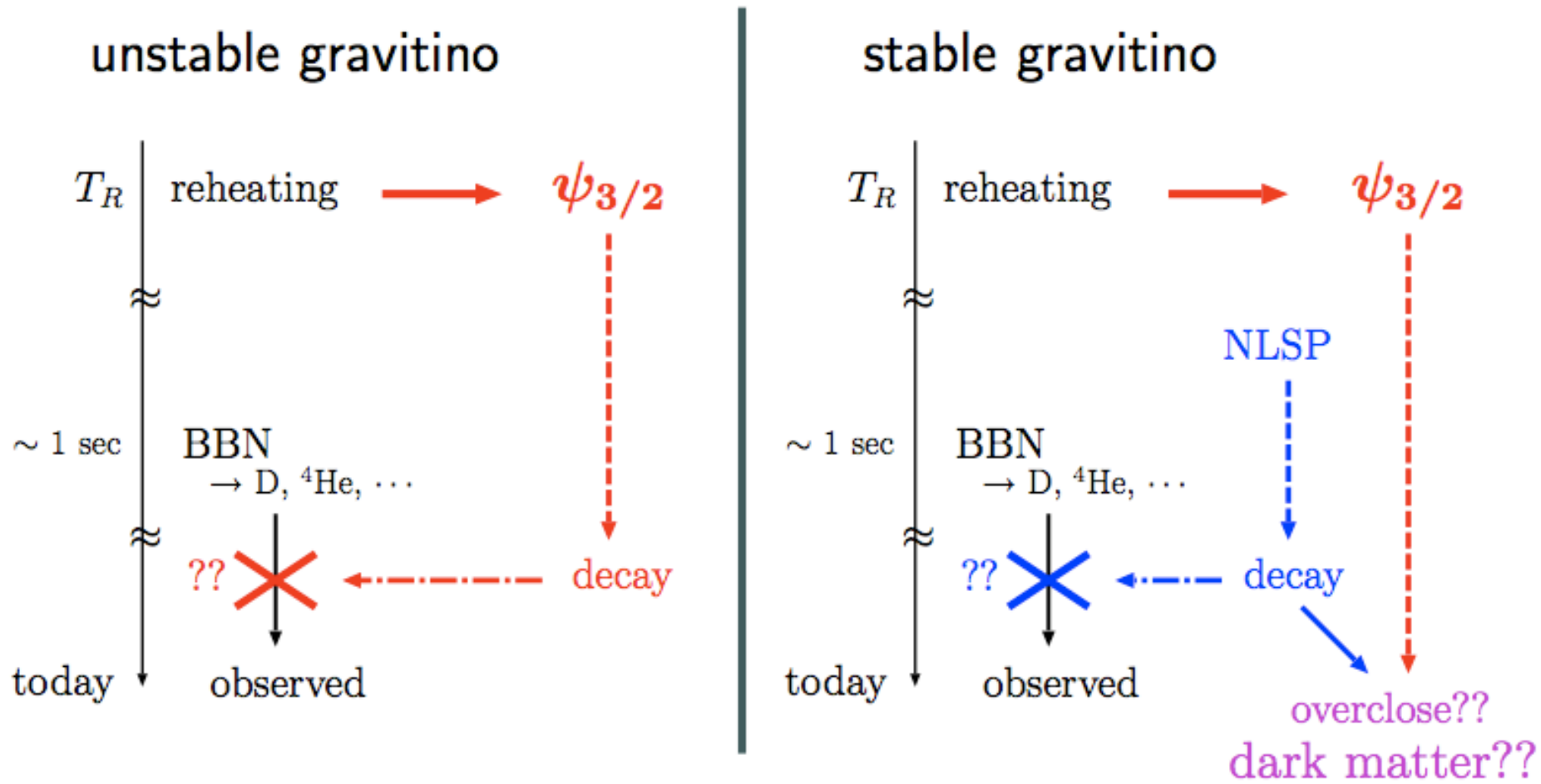
Gravitino Problems

thermal history

time	temperature	
??	~ 0	inflation
??	T_R	reheating
	$\approx$	baryogenesis $\rightarrow n_B/s \simeq 10^{-10}$
~ 1 sec	~ 1 MeV	Big Bang Nucleosynthesis $\rightarrow$ D, ^{4}He, $\cdots$
	$\approx$	
14 Gyr	2.7 K	observed

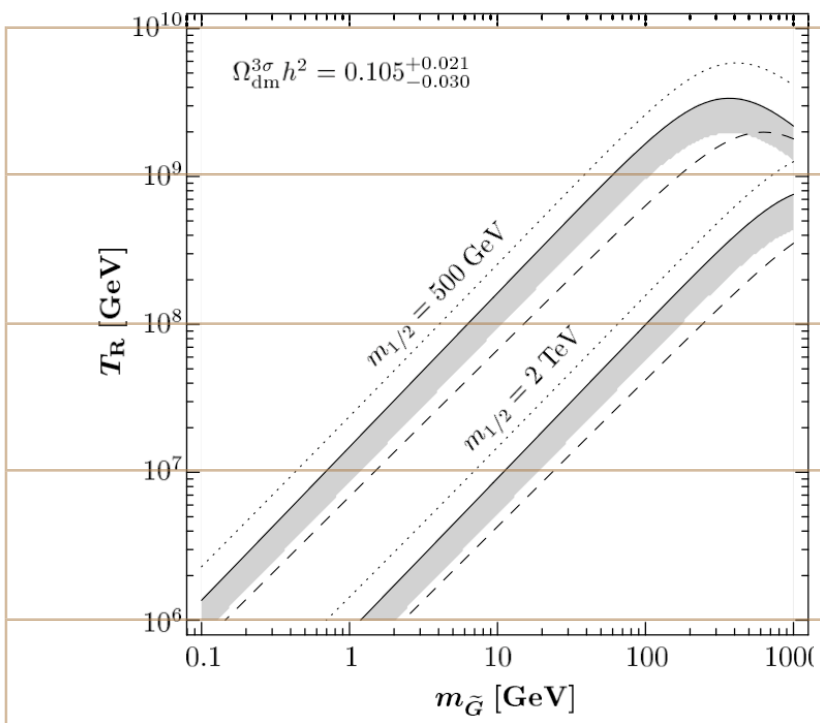
Gravitino Problems

thermal history with gravitino $\psi_{3/2}$



Gravitino Problems

stable (LSP) gravitino



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Bolz, Brandenburg, Buchmuller,'00
Fig. from Steffen and Pradler,'06

Pagels and Primack,'82,
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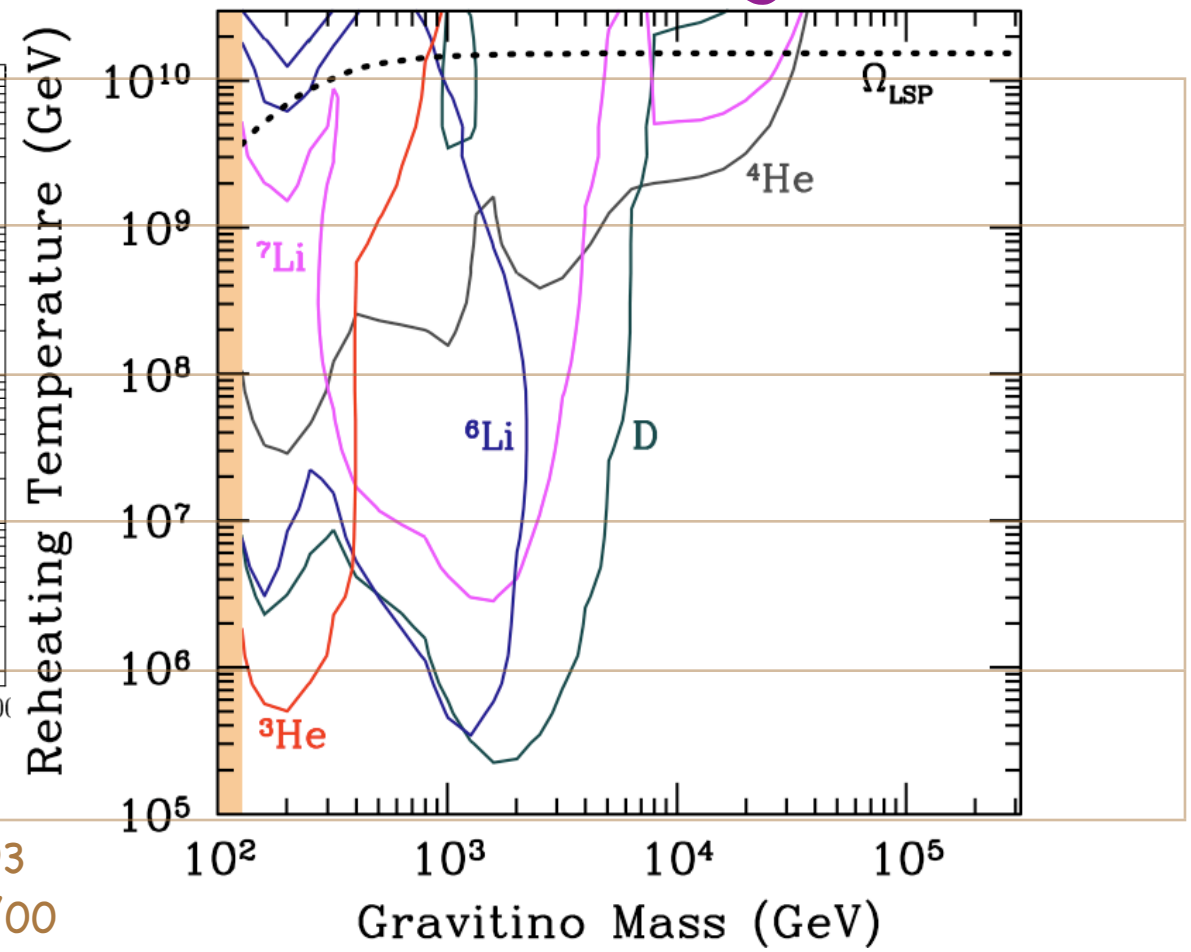
unstable gravitino



Weinberg,'82 + many others
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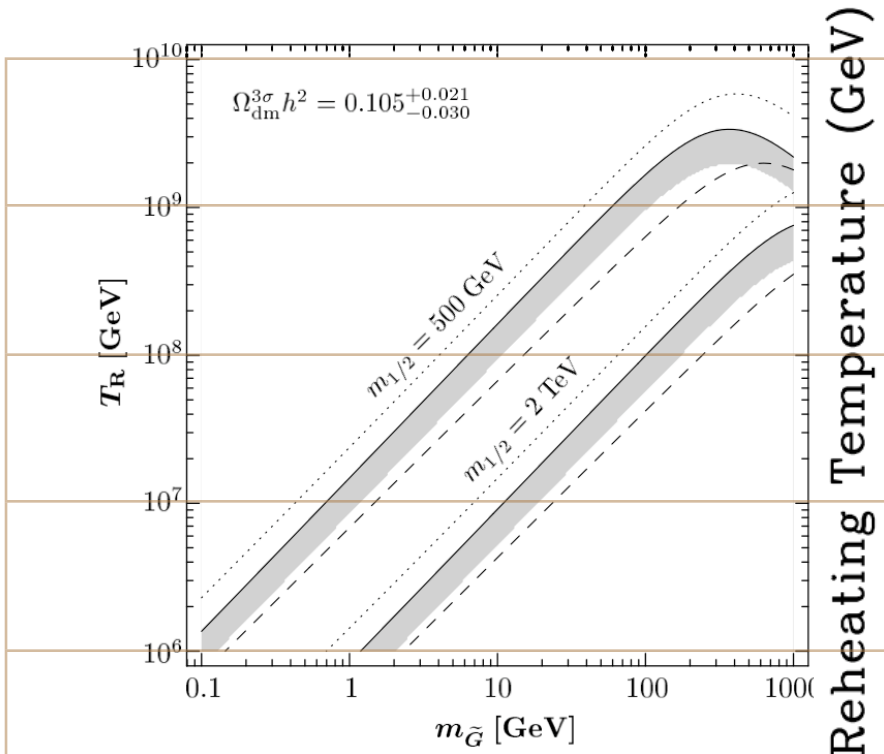

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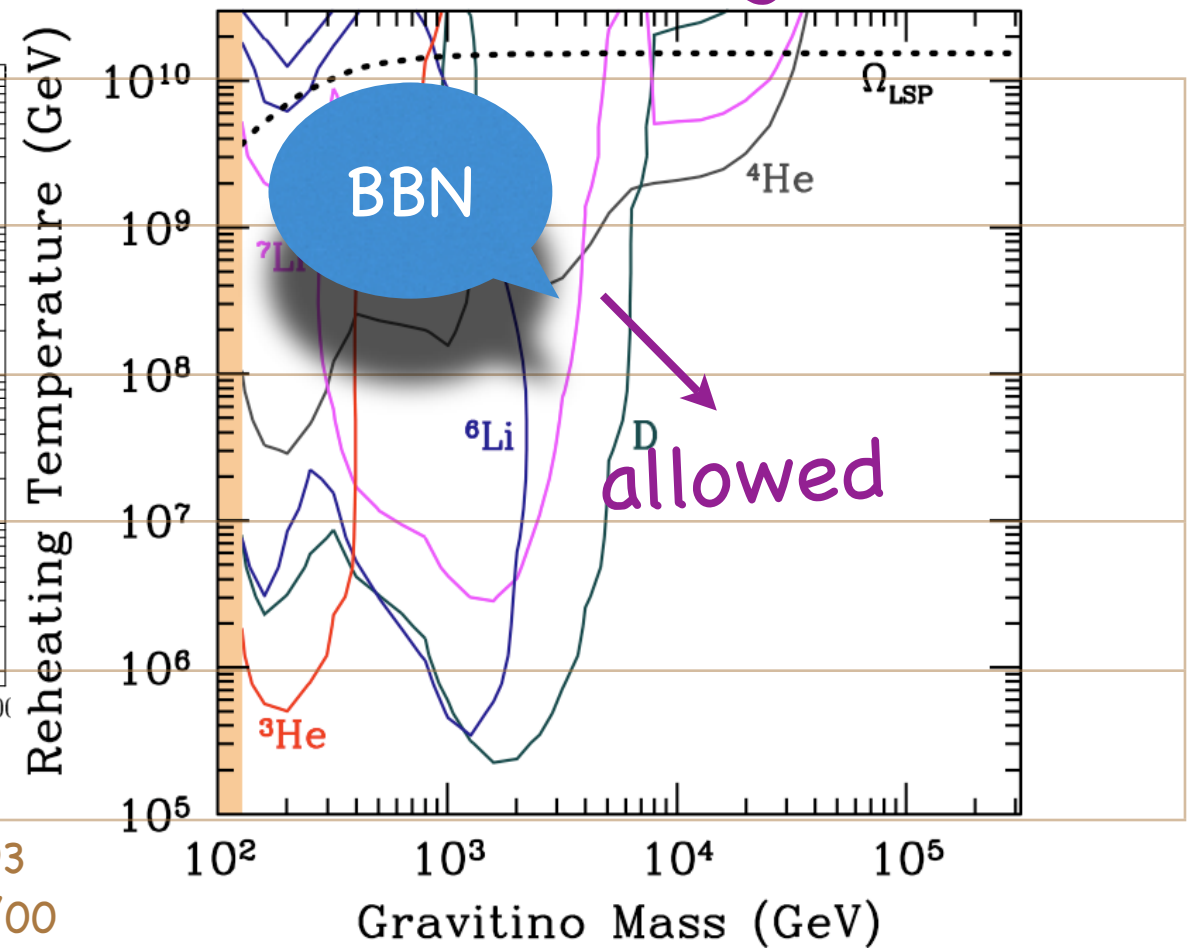

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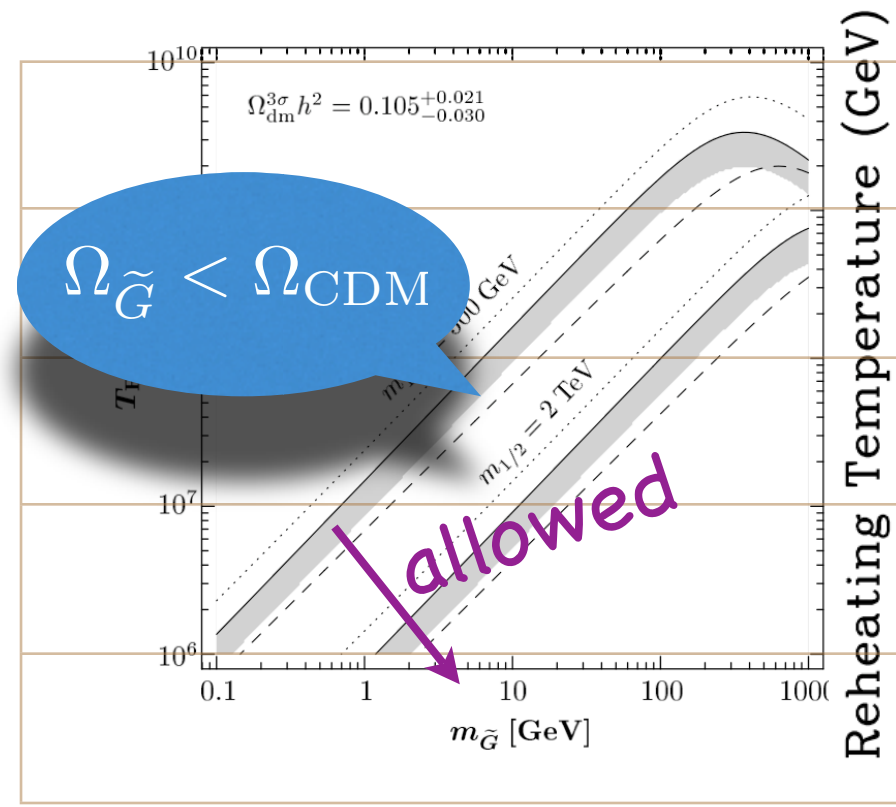

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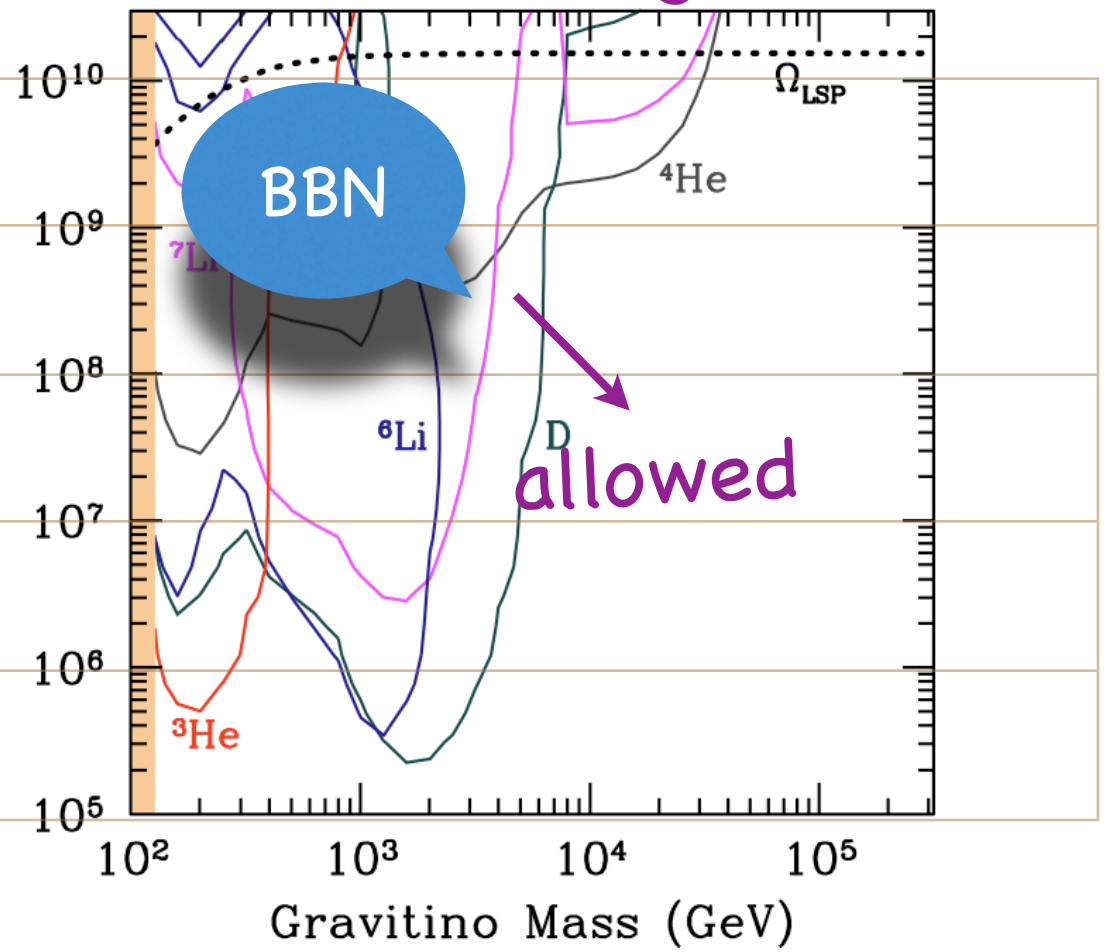

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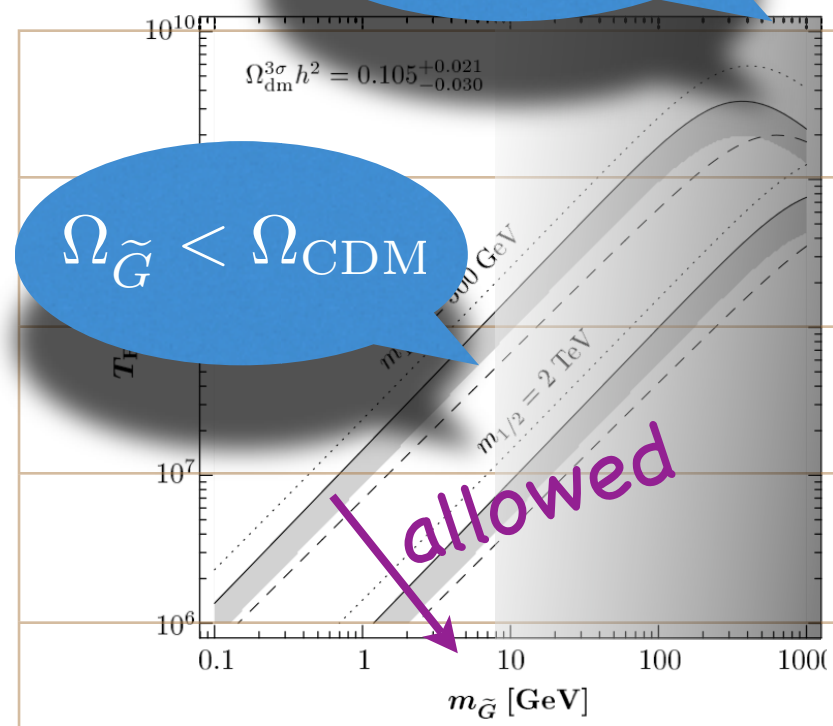
stable ino

BBN (NLSP)



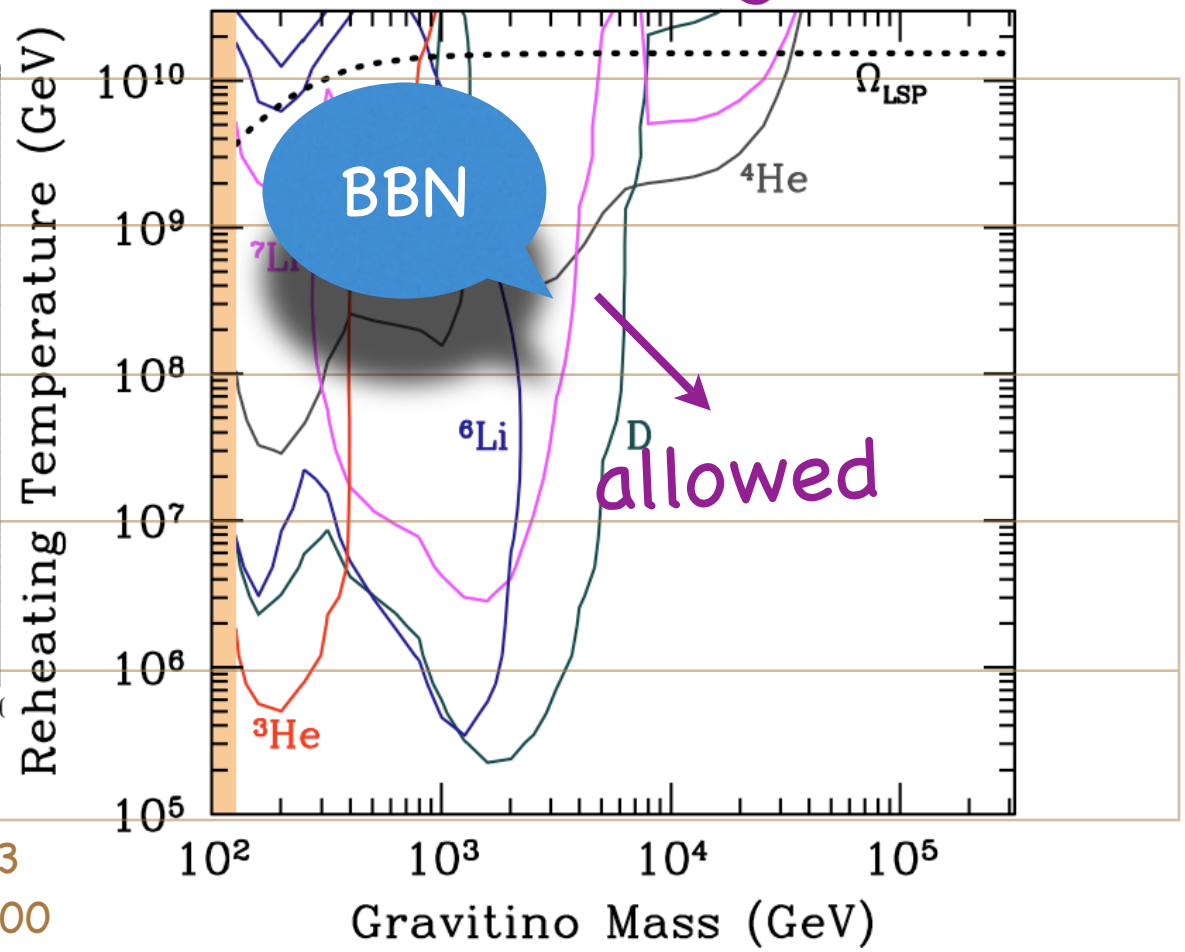
$\Omega_{\tilde{G}} < \Omega_{\rm CDM}$

allowed

Moroi, Murayama, Yamaguchi,'93
Bolz, Brandenburg, Buchmuller,'00
Fig. from Steffen and Pradler,'06

Pagels and Primack,'82,
Viel, Lesgourgues, Haehnelt, Matarrese, Riotto,'05

unstable gravitino



BBN

allowed

Weinberg,'82 + many others
Fig. from Kawasaki, Kohri, Moroi, Yotsuyanagi,'08

Gravitino Problems

stable gravitino

BBN (NLSP)

hot DM

$\Omega_{\tilde{G}} < \Omega_{\rm CDM}$

allowed

allowed

$= 0.105^{+0.021}_{-0.030}$

$m_{1/2} = 2$ TeV

10^7

10^6

0.1 1 10 100 1000

$m_{\tilde{G}}$ [GeV]

16 eV

Moroi, Murayama, Yamaguchi,'93

Bolz, Brandenburg, Buchmuller,'00

Fig. from Steffen and Pradler,'06

Pagels and Primack,'82,

Viel, Lesgourgues, Haehnelt, Matarrese, Riotto,'05

unstable gravitino

BBN

allowed

Reheating Temperature (GeV)

10^{10} 10^9 10^8 10^7 10^6 10^5

$\Omega_{\rm LSP}$

^{4}He

^{7}Li

^{6}Li

D

^{3}He

10^2 10^3 10^4 10^5

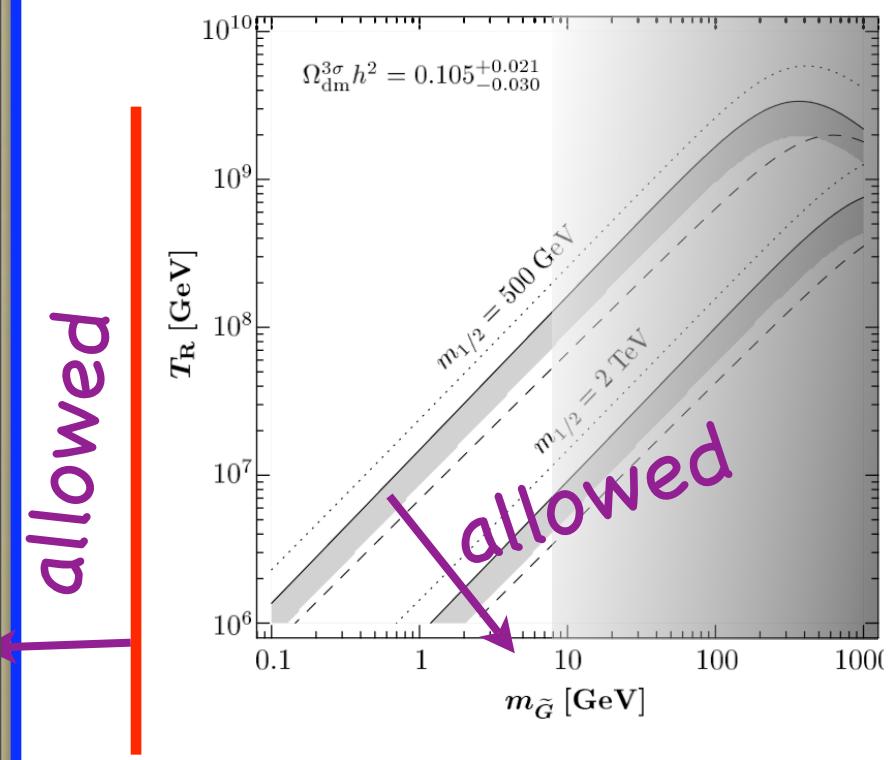
Gravitino Mass (GeV)

Weinberg,'82 + many others

Fig. from Kawasaki, Kohri, Moroi, Yotsuyanagi,'08

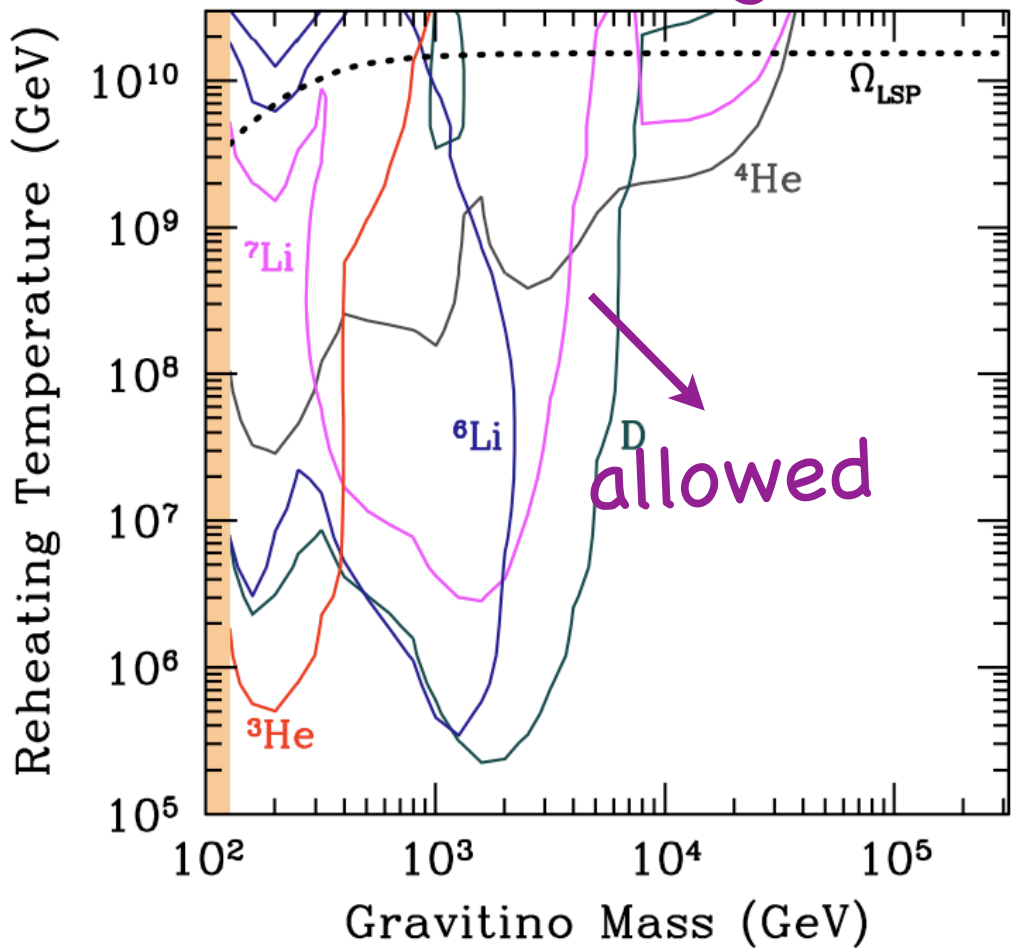
Gravitino Problems

stable (LSP) gravitino



16 eV

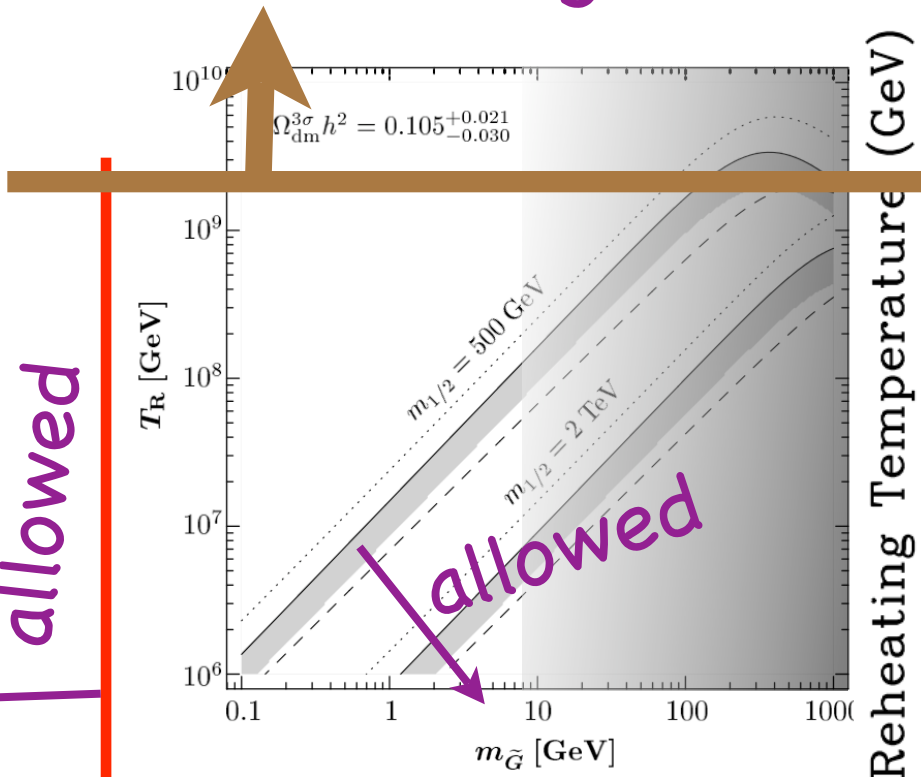
unstable gravitino



Gravitino Problems

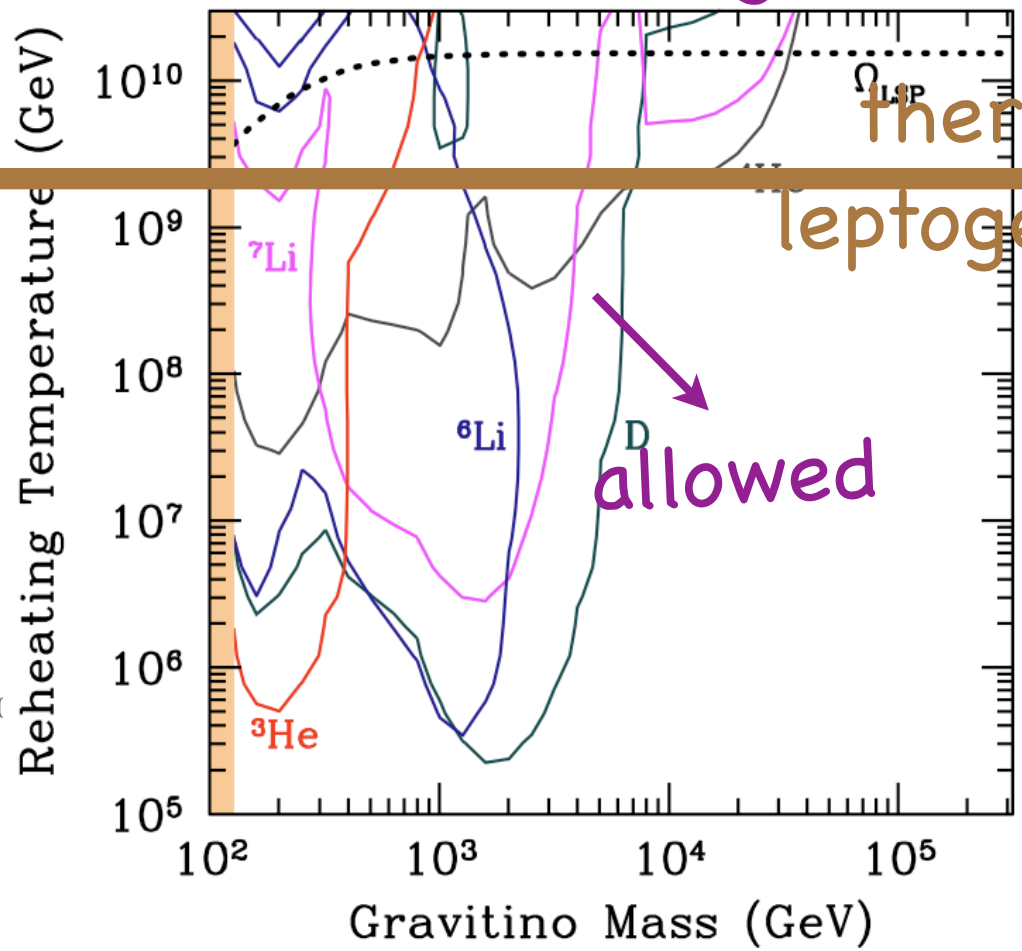
stable (LSP) gravitino

unstable gravitino



allowed

16 eV



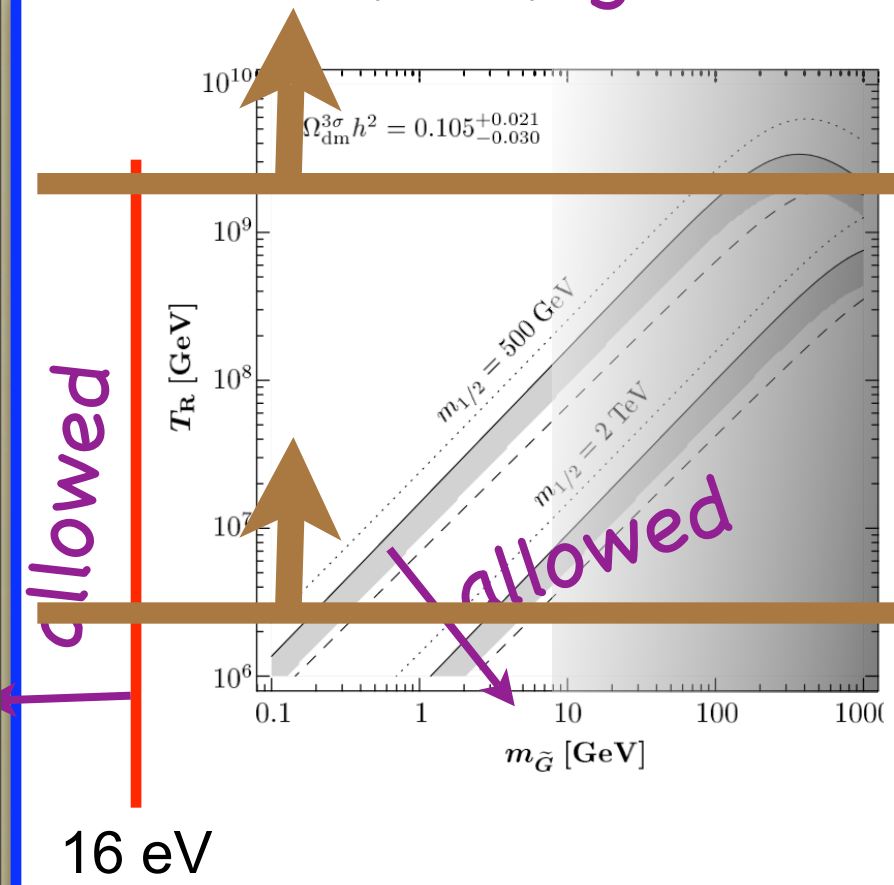
thermal

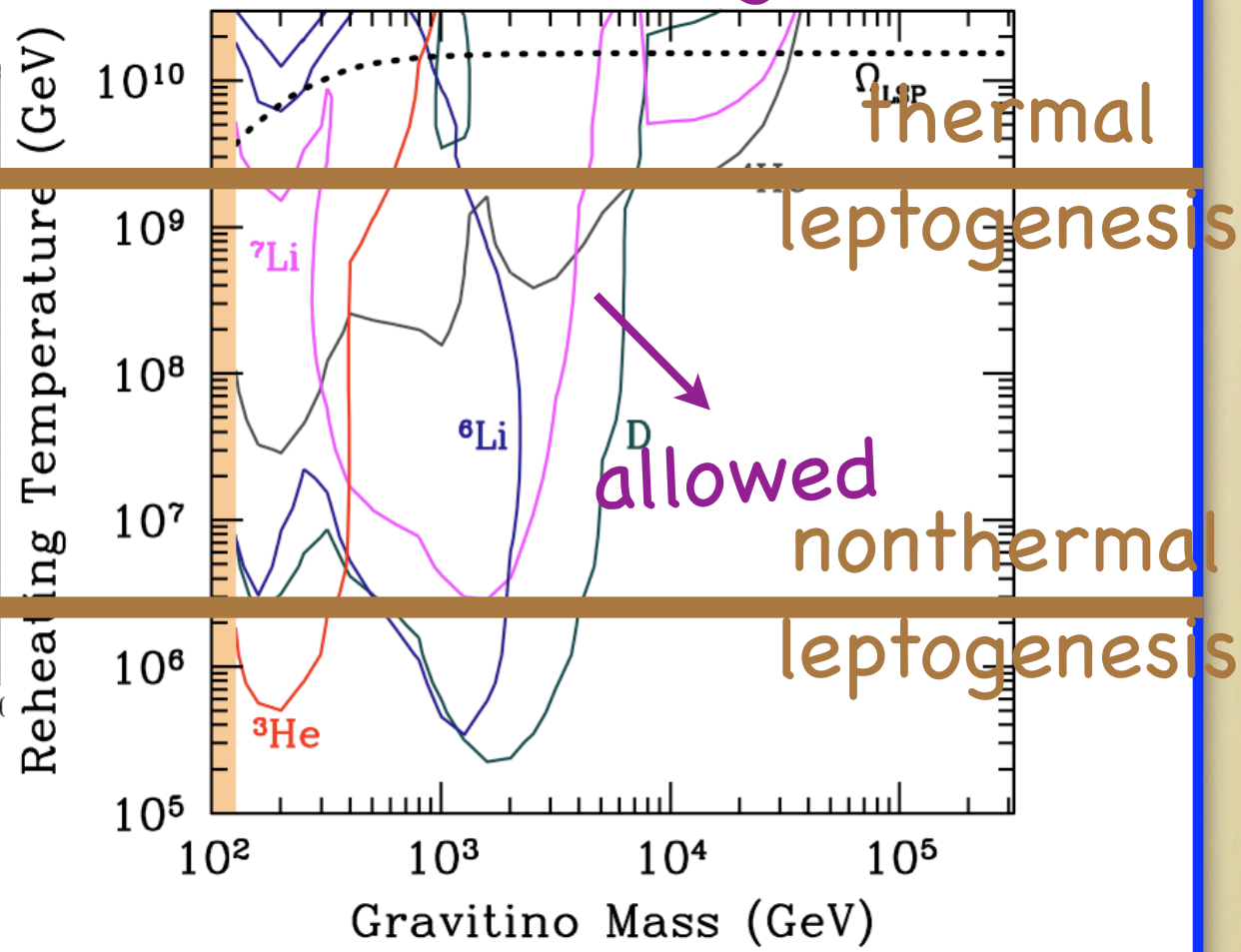
leptogenesis

Gravitino Problems

stable (LSP) gravitino

unstable gravitino

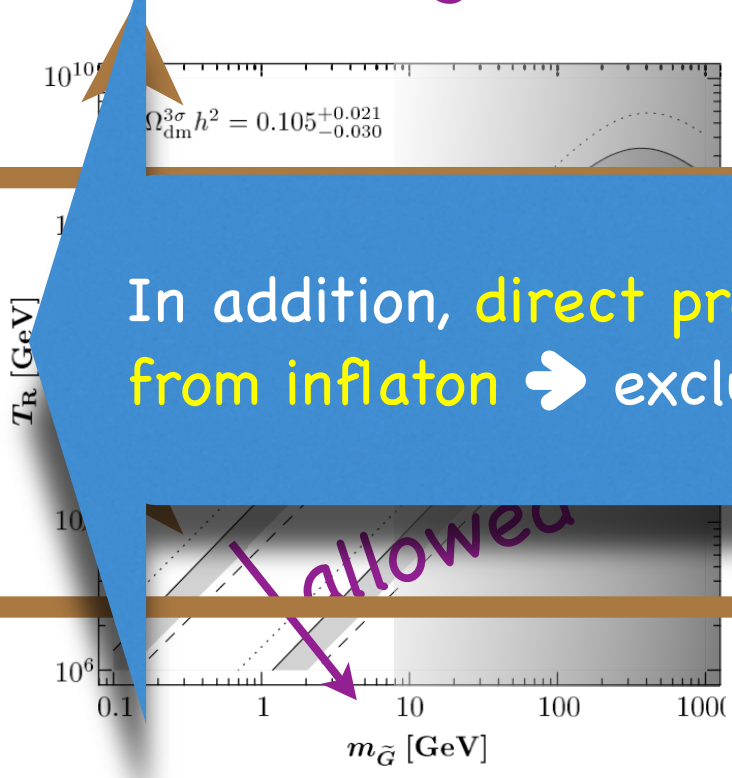


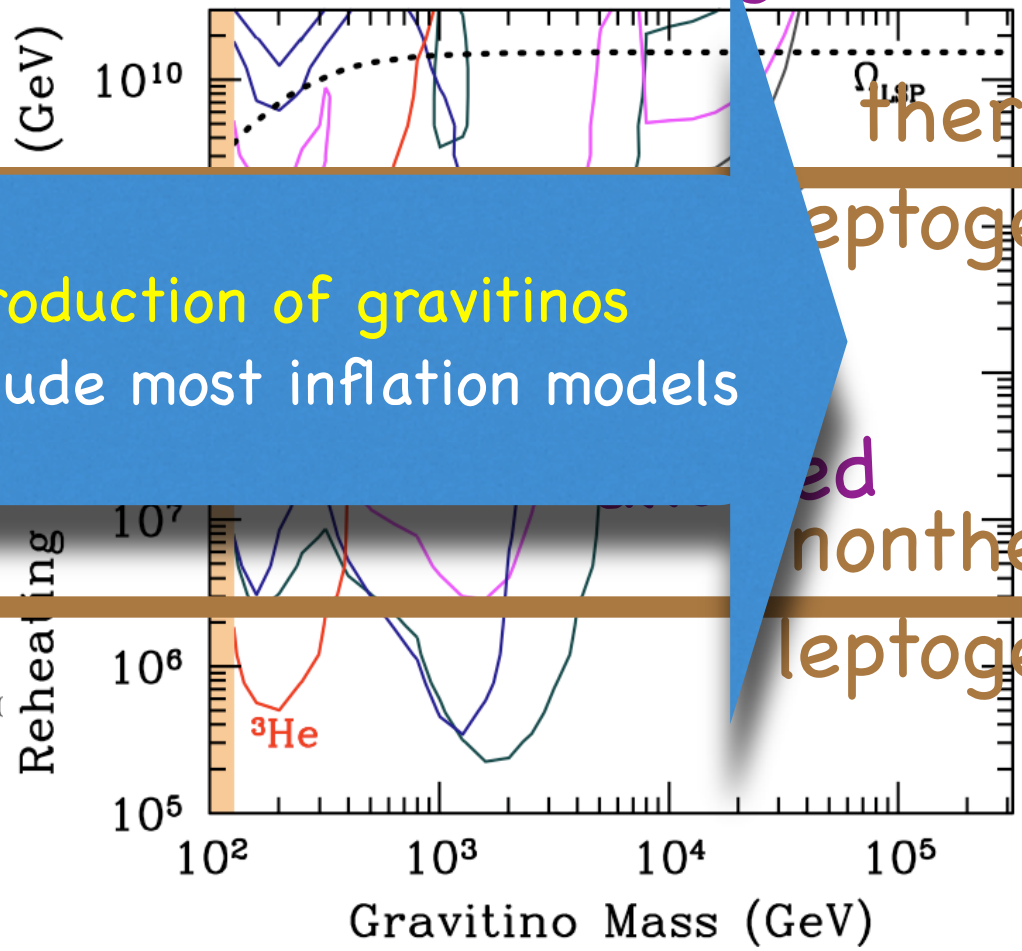


Gravitino Problems

stable (LSP) gravitino

unstable gravitino





In addition, direct production of gravitinos from inflaton → exclude most inflation models

thermal leptogenesis

nonthermal leptogenesis

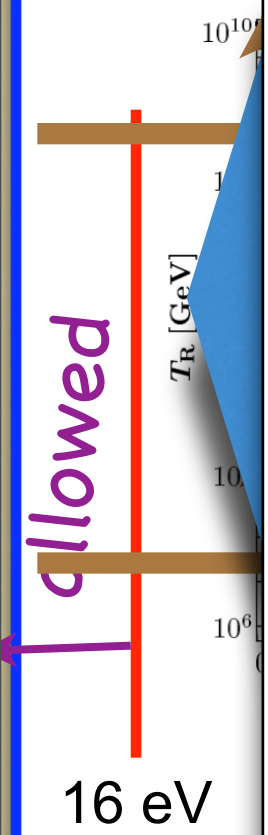
allowed

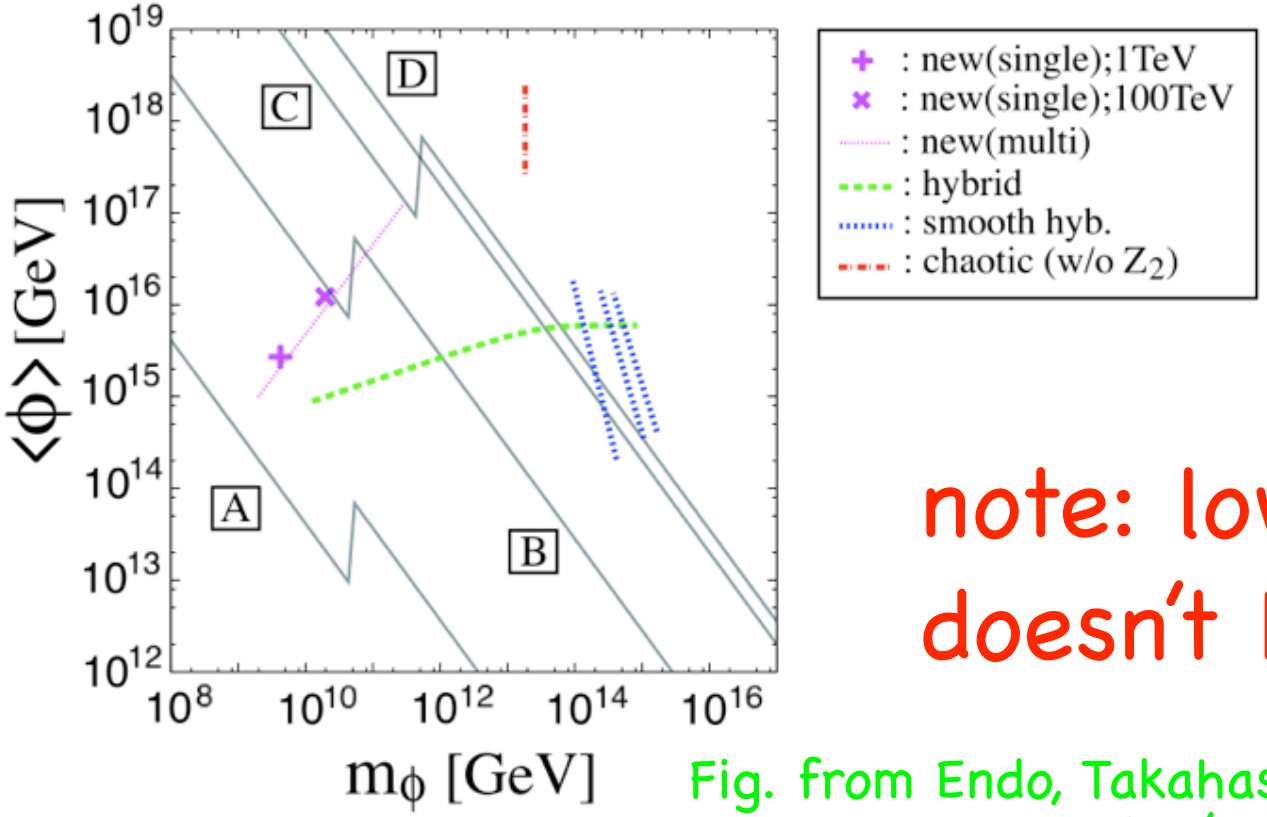
16 eV

Gravitino Problems

stable (LSP) gravitino

unstable gravitino





note: low TR doesn't help.

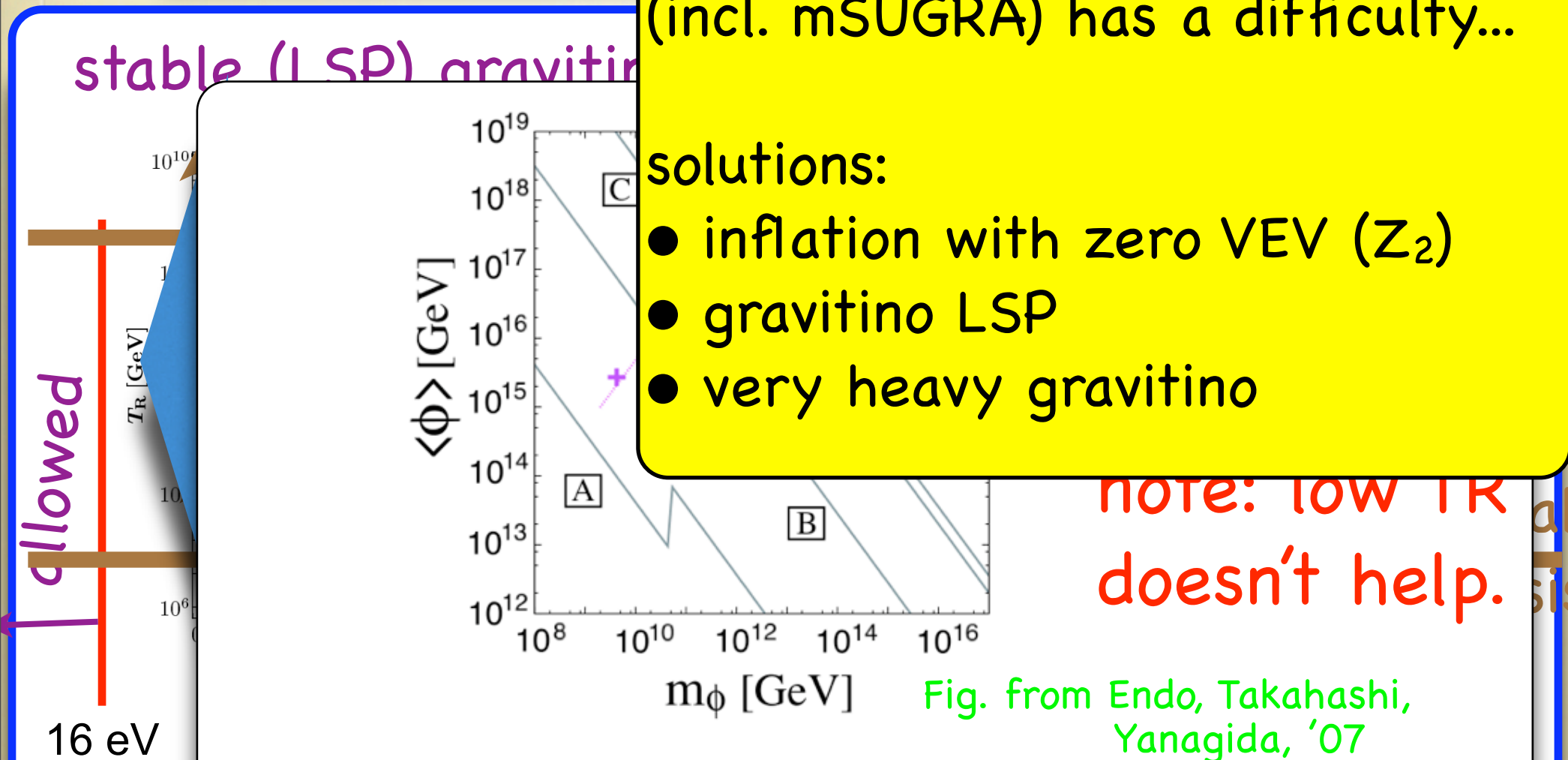
Fig. from Endo, Takahashi, Yanagida, '07

FIG. 3: Constraints from the gravitino production by the inflaton decay, for $m_{3/2} = 1\,\mathrm{TeV}$ with $B_h = 1$ (case A), $m_{3/2} = 1\,\mathrm{TeV}$ with $B_h = 10^{-3}$ (case B), $m_{3/2} = 100\,\mathrm{TeV}$ (case C), and $m_{3/2} = 1\,\mathrm{GeV}$ (case D). The region above the solid (gray) line is excluded for each case. For

in particular, gravity-mediation (incl. mSUGRA) has a difficulty...

solutions:

- inflation with zero VEV (Z_2)
- gravitino LSP
- very heavy gravitino



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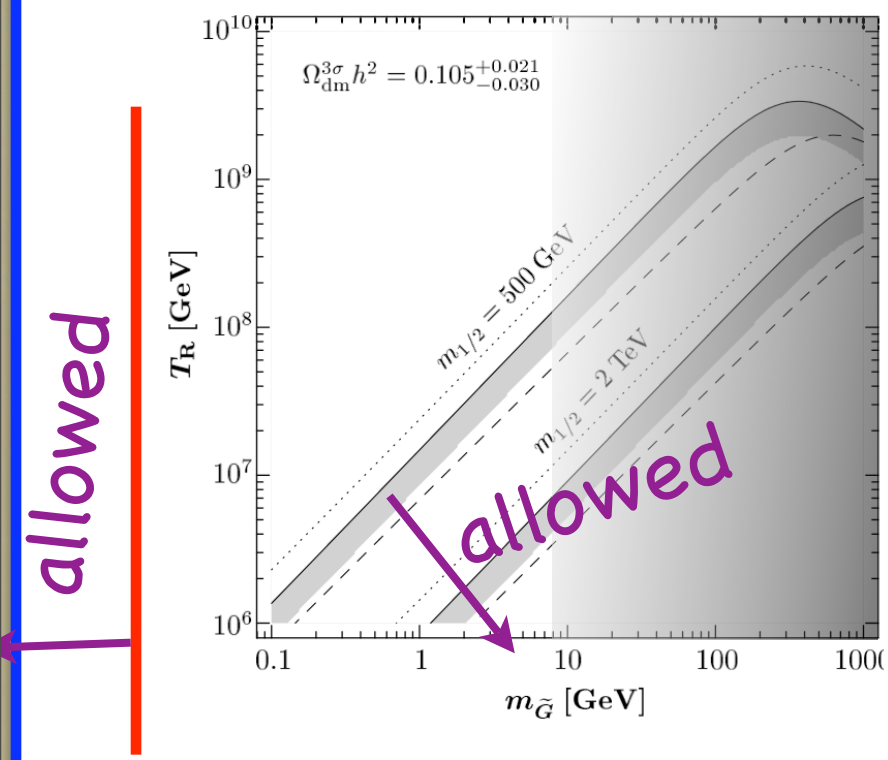
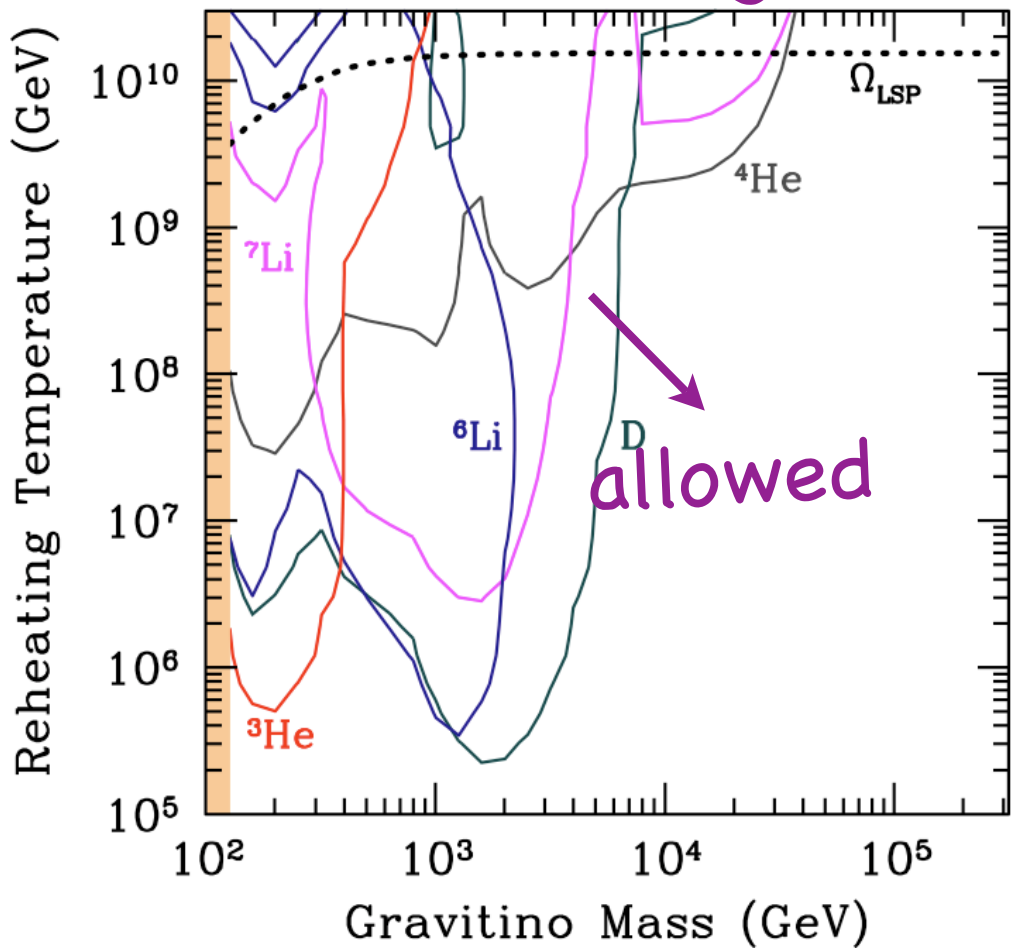
Gravitino Problems

stable (LSP) gravitino



16 eV

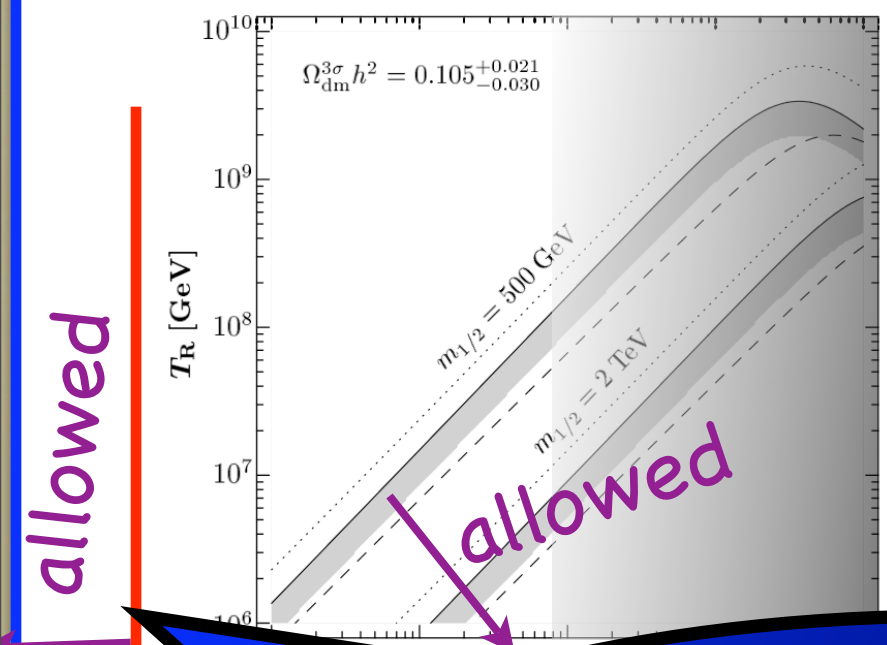
unstable gravitino

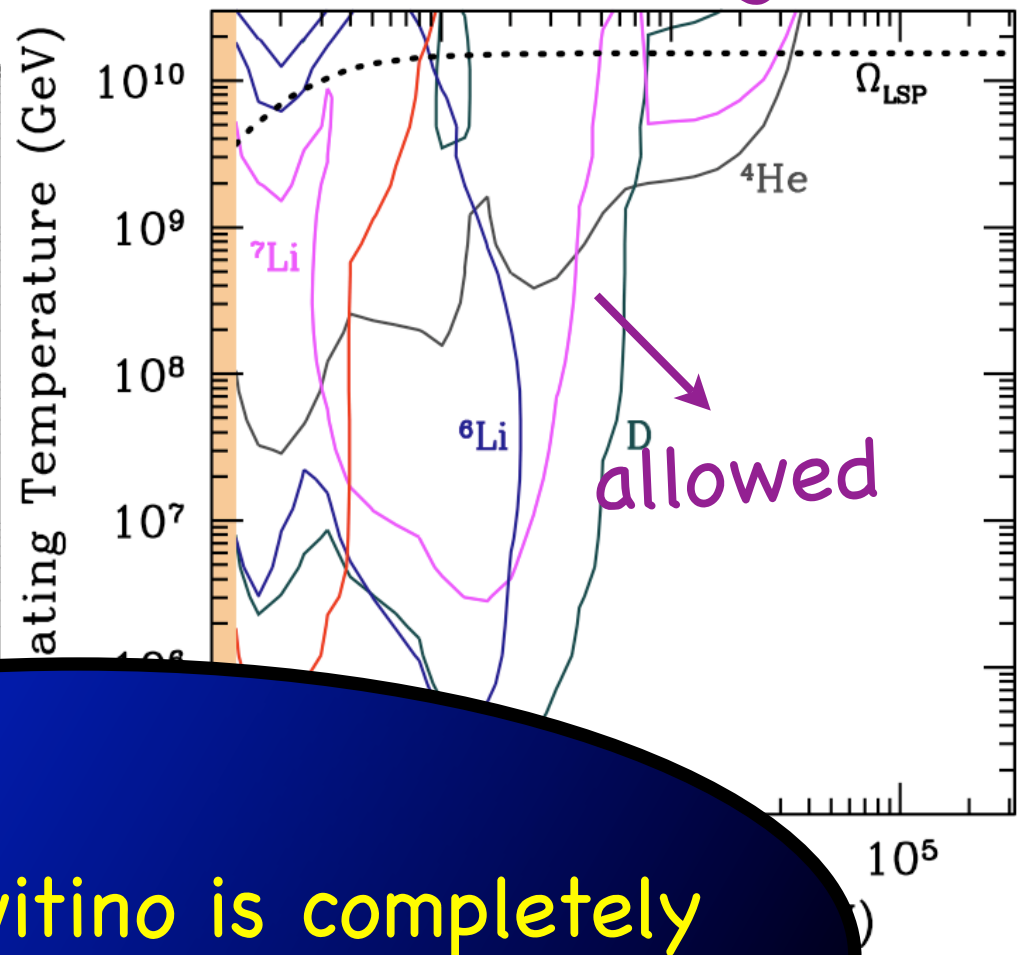


Gravitino Problems

stable (LSP) gravitino

unstable gravitino

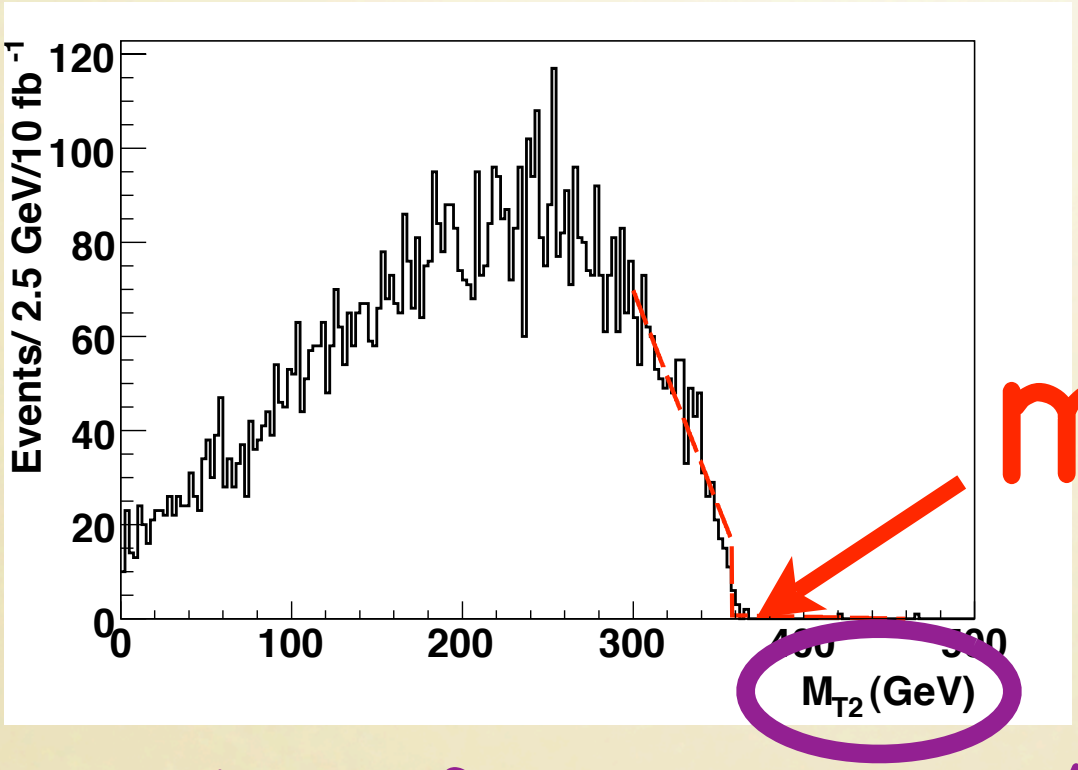




Ultralight gravitino is completely free from cosmological problems!!

Summary:

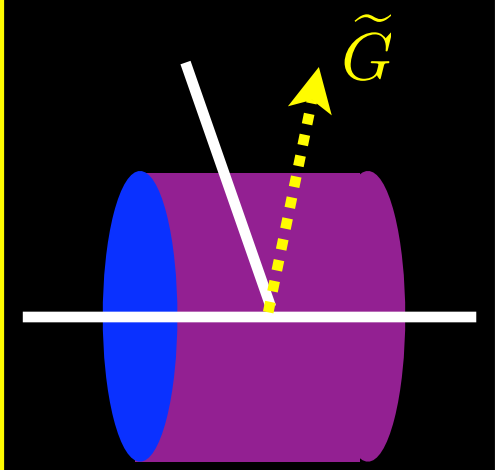
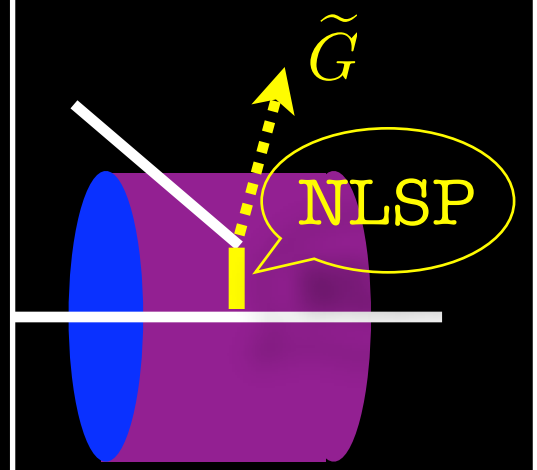
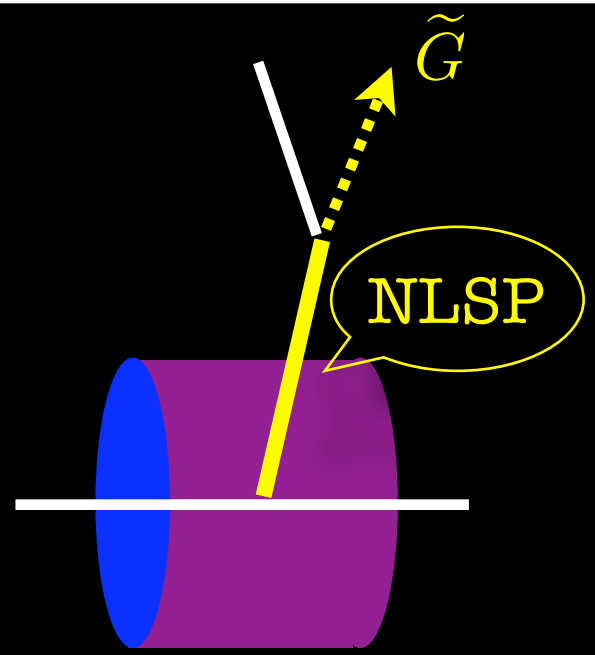
- We considered SUSY models with
  a very light gravitino LSP
  and a neutralino NLSP
- and presented a neutralino mass measurement

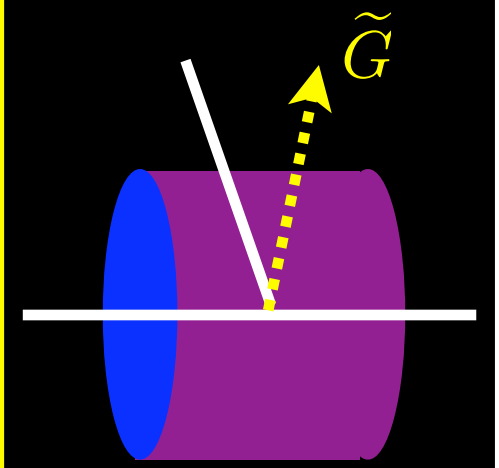
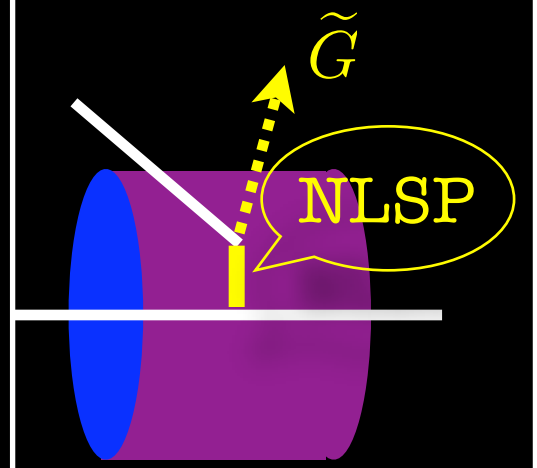
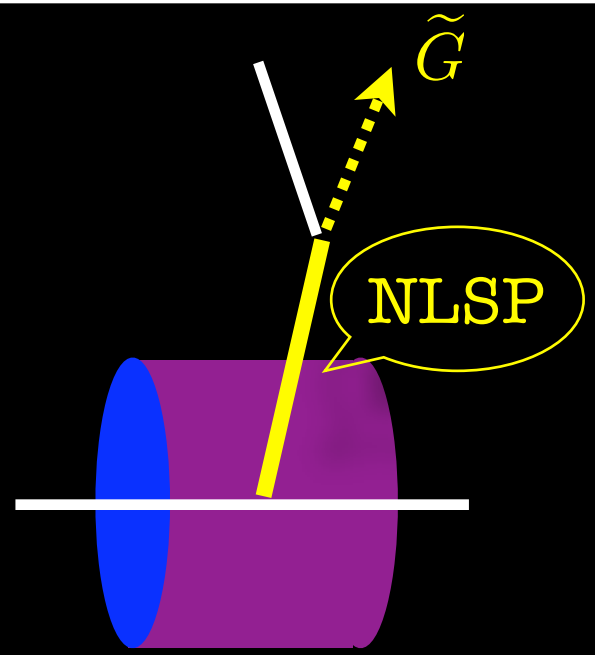


$m_{neutralino}$

based on M_{T2} method

- independent of other masses / cascade patterns
- complementary to other methods

Gravitino and NLSP at the LHC	ultralight gravitino 		
$\widetilde{\tau}$ NLSP		"kink" in charged track	charged track
$\widetilde{\chi}^0$ NLSP	$2\gamma + E_{\mathrm{T,miss}}$ This work	non-pointing photon	the same as $\widetilde{\chi}^0$ LSP signal....

Gravitino and NLSP at the LHC	ultralight gravitino 		
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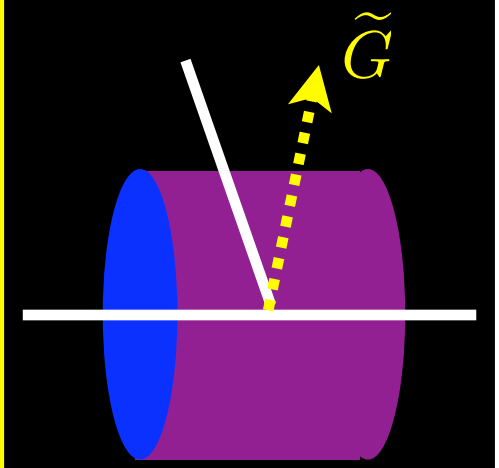
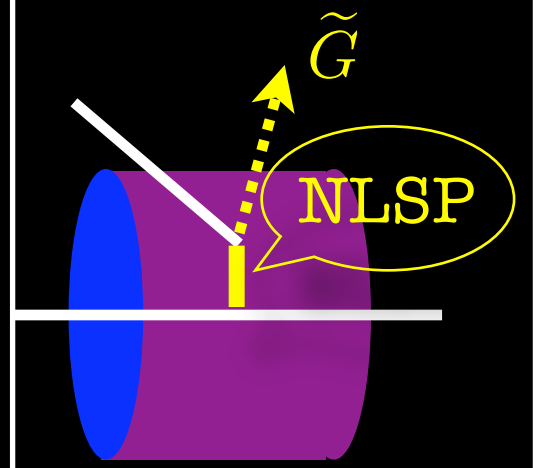
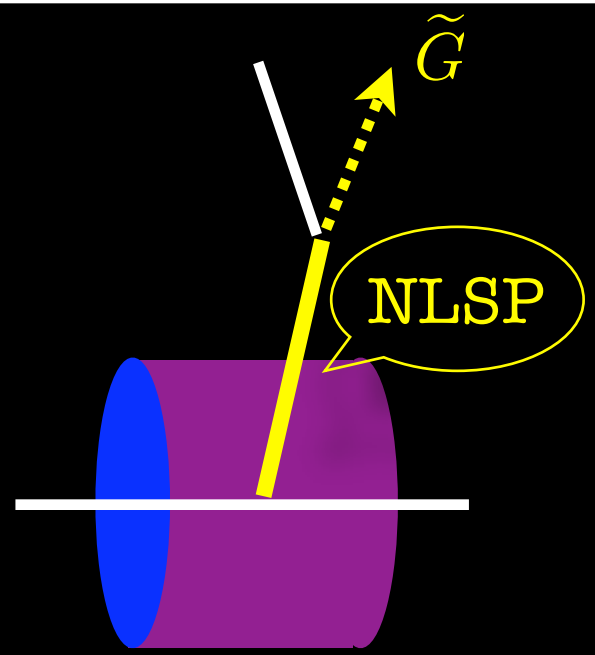
Gravitino and NLSP at the LHC	ultralight gravitino 		
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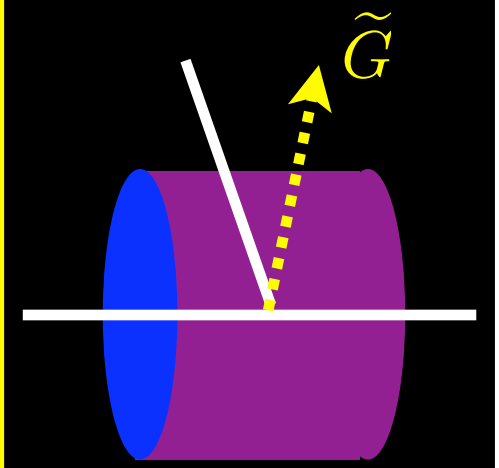
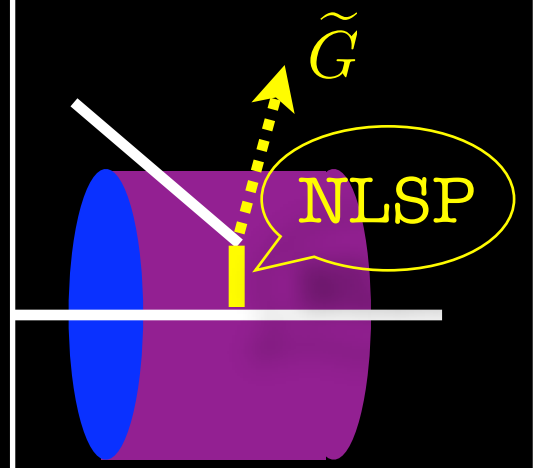
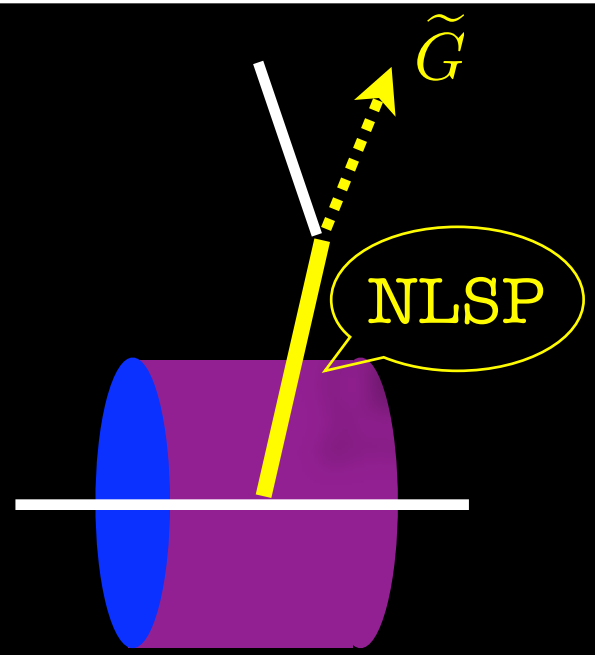
Gravitino and NLSP at the LHC	ultralight gravitino 		
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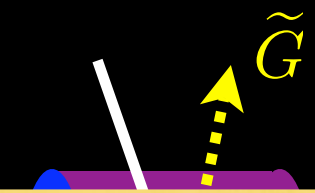
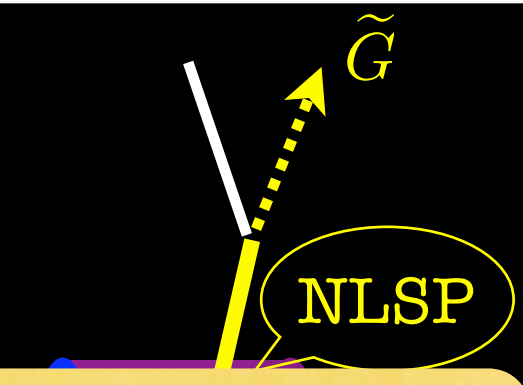
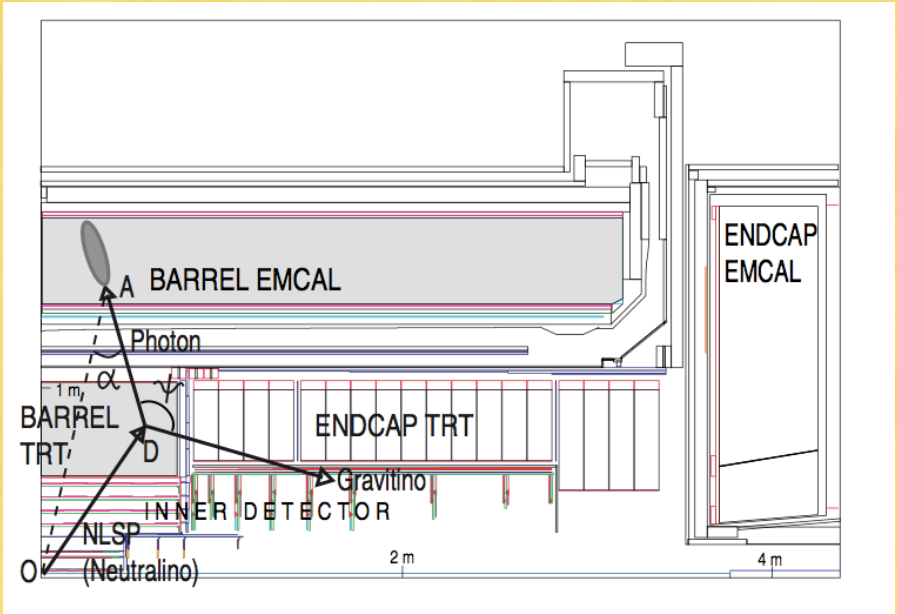
Gravitino

ultralight gravitino







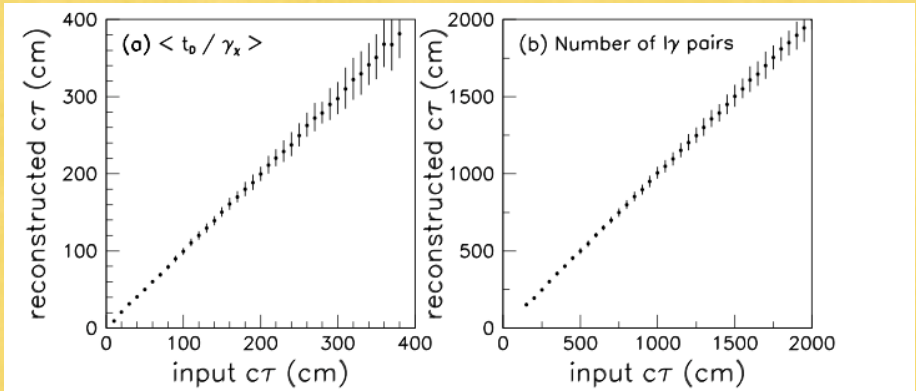


FIG. 7: Estimated resolution of the lifetime $c\tau$ for an integrated luminosity of 13.9 fb^{-1} from (a) the average t_D/γ_χ and (b) the number of $\ell\gamma$ pairs $N_{\ell\gamma}$. The input $m_{\tilde{\ell}}$ and $m_{\tilde{\chi}}$ are used for the reconstruction and their errors are ignored.

Kawagoe, Kobayashi, Nojiri, Ochi, '03

$\tilde{\chi}^0$ NLSP

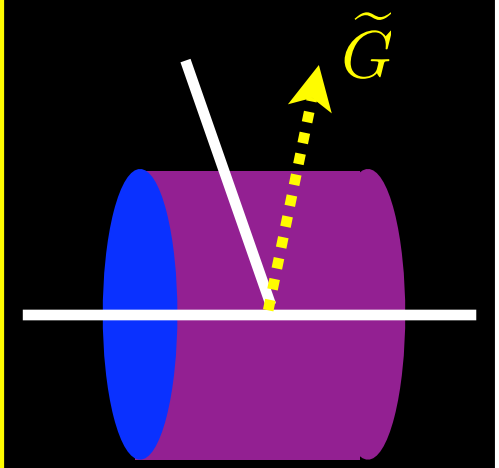
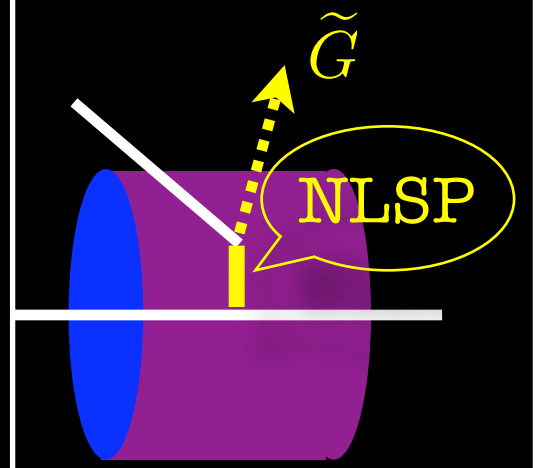
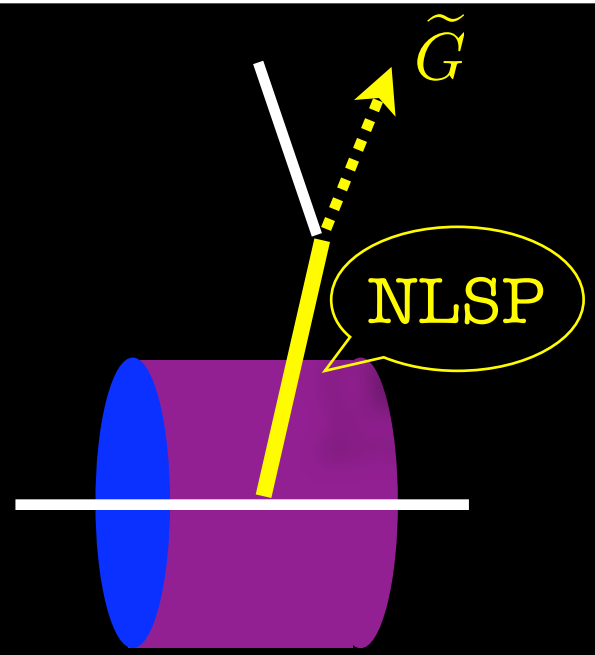
$2\gamma + E_{\mathrm{T,miss}}$

This work

non-pointing photon

F determination

$\tilde{\chi}^0$ the same as LSP signal....

Gravitino and NLSP at the LHC	ultralight gravitino 		
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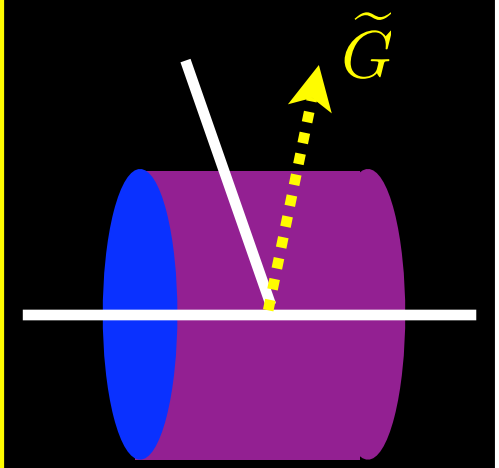
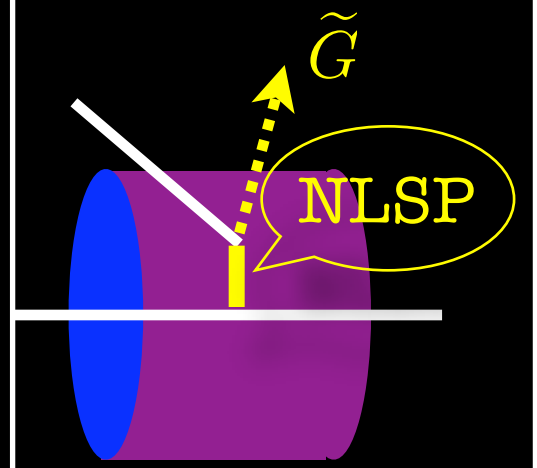
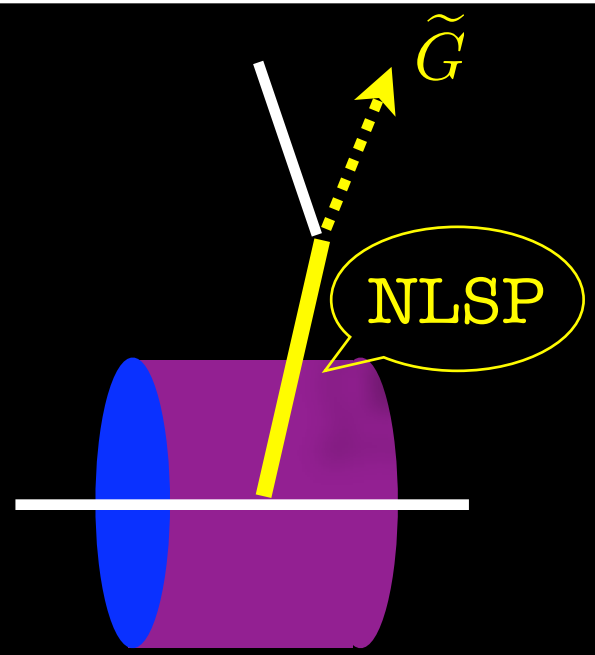
Gravitino and NLSP at the LHC	ultralight gravitino 		
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ultralight gravitino

$\tilde{G}$

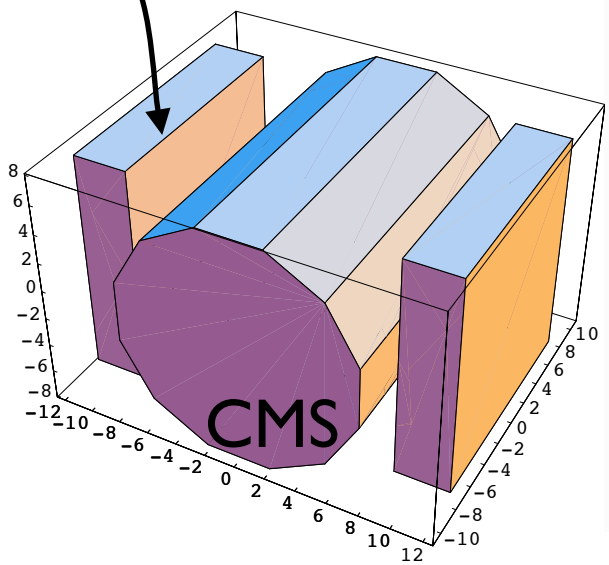
$\tilde{G}$

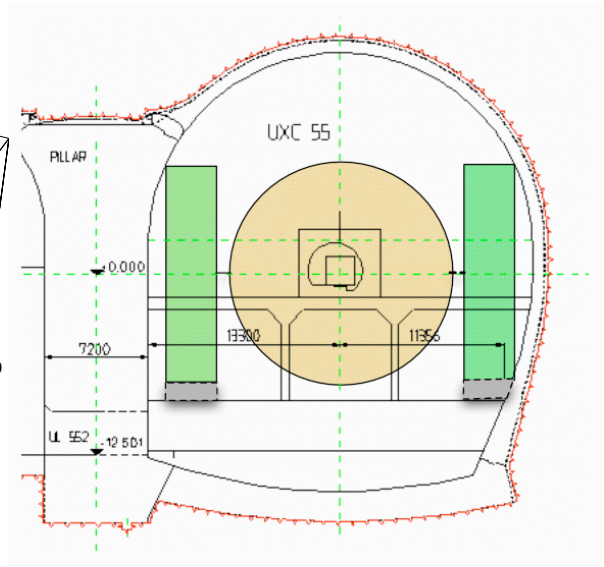
$\tilde{G}$

NLSP

stopper-detector

KH, Kuno, Nakaya, Nojiri '04
KH, Nojiri, DeRoeck '06





SUGRA test?! (Buchmuller ,KH, Ratz, Yanagida,'04)

charged track

☛ talk by R.Kitano on Thursday!

$\tilde{\chi}^0$ NLSP

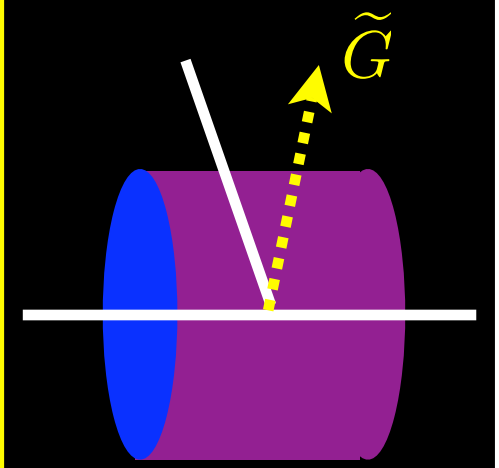
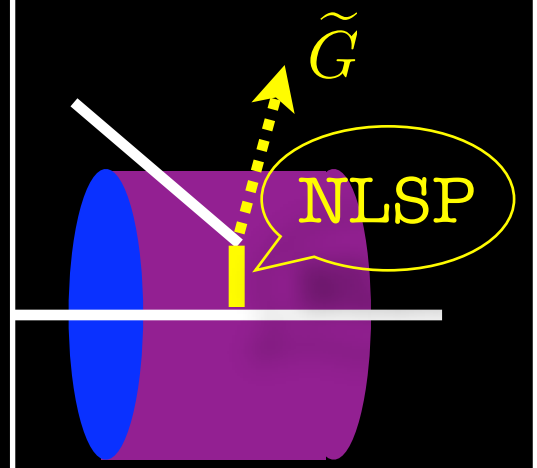
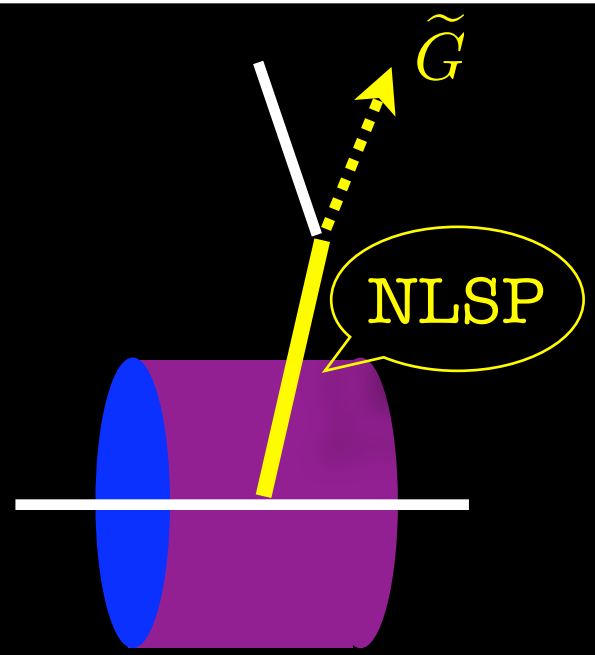
$2\gamma + E_{\mathrm{T,miss}}$

This work

non-pointing photon

F determination

the same as $\tilde{\chi}^0$ LSP signal....

Gravitino and NLSP at the LHC	ultralight gravitino 		
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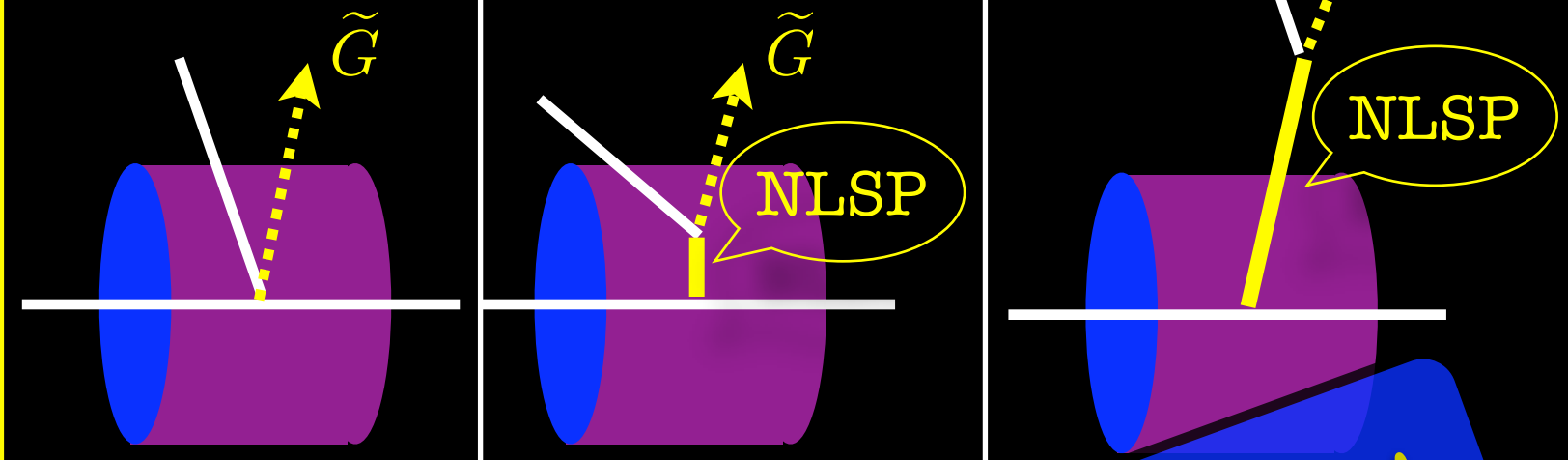
Gravitino and NLSP at the LHC

ultralight gravitino



$\widetilde{\tau}$ NLSP

K.H, Shirai, Yanagida,'07
cf. talk at previous focus week (Dec.'07)

F determination

"kink" in charged track

F determination

charged track

☛ talk by R.Kitano on Thursday!

$\widetilde{\chi}^0$ NLSP

$2\gamma + E_{\mathrm{T,miss}}$

This work

non-pointing photon

F determination

the same as $\widetilde{\chi}^0$ LSP signal....

Let's see what the LHC will find.....!

backup slides

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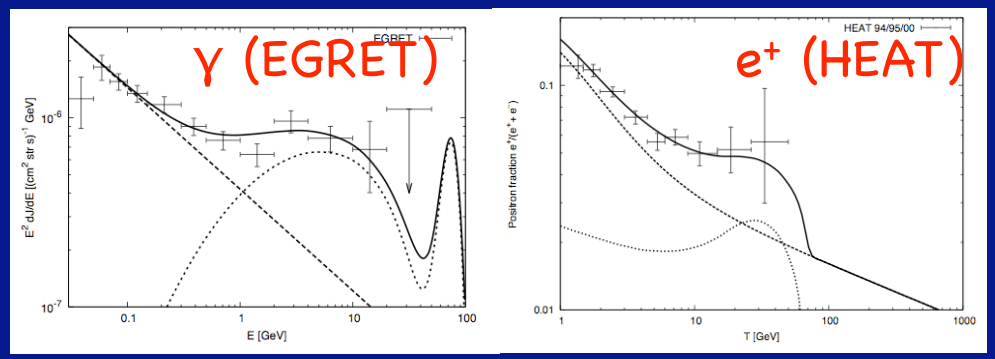
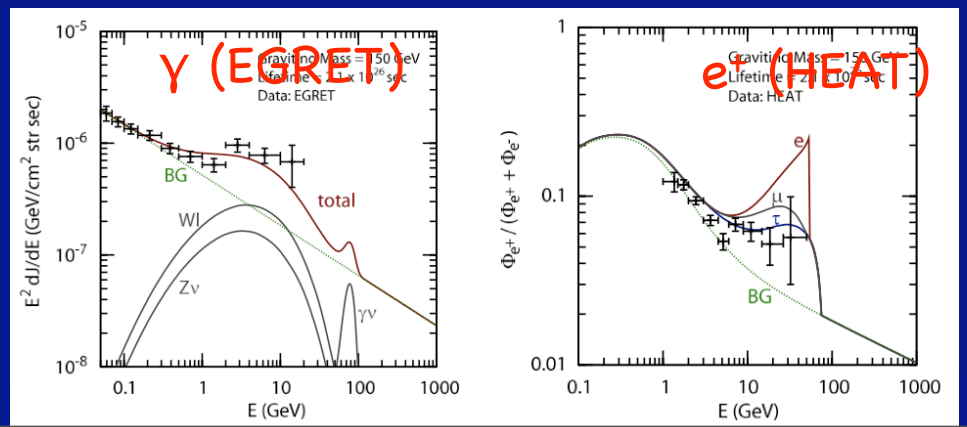
And the gravitino DM decay can be (or has already been?!) seen by CRs !!!

Ibarra, Tran,'08 →



Ishikawa, Matsumoto, Moroi,'08 →

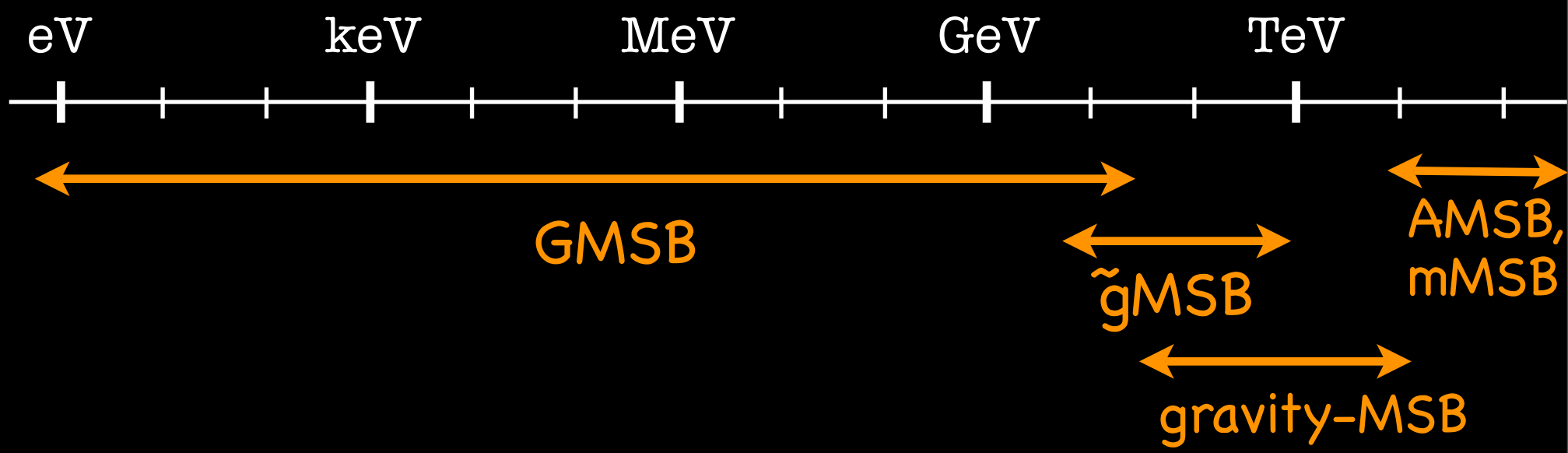


Gravitino

- Gravitino Interaction: extremely weak

  suppressed by $\sim \frac{1}{M_{\rm P}}$ (or $\sim \frac{1}{F} \sim \frac{1}{M_{\rm P} m_{\tilde{G}}}$)

- Gravitino Mass: model dependent



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DM may be 100 TeV composite "baryon" made from strongly self-interacting hidden-sector/messenger particles

Dimopoulos, Giudice, Pomarol '96 / KH, Shirai, Yanagida '07