Title: Ultralight Gravitino at the LHC

Date: Jun 03, 2008 02:45 PM

URL: http://pirsa.org/08060136

Abstract: In supersymmetric (SUSY) models with the gravitino being the lightest SUSY particle (LSP), the SUSY breaking scale (i.e., the gravitino mass) could be determined by measuring the lifetime of the next-to-lightest SUSY particle (NLSP). However, for an ultralight gravitino of mass of O(1) eV, which is favored cosmologically, the determination of the SUSY breaking scale, or the gravitino mass, is difficult because the NLSP decay length is too short to be measured directly. We propose a new determination of the gravitino mass by measuring a branching fraction of two decay modes of sleptons, and demonstrate that the gravitino mass may indeed be determined at the LHC with an accuracy of a few 10% for an integrated luminosity 10-100 fb^{-1}. I will also mention dark matter candidates for such a light gravitino LSP.

Ultralight Gravitino at the LHC

Koichi Hamaguchi (Tokyo U.)

with S.Shirai and T.T.Yanagida

arXiv:0705.0219, 0707.2463, **0712.2462**

+ with M.M.Nojiri, A.de Roeck ('06);
with M.M.Nojiri, Y.Kuno, T.Nakaya ('04);
with W.Buchmüller, KH, M.Ratz, T.Yanagida ('04).

@ IPMU, Feb. 2008

Plan

- Ultralight gravitino at the LHC
- discussion: not-so-light gravitino at the LHC

Summary:

Main Message

SUSY models with an ultralight gravitino is interesting!

$(m_{\tilde{G}} \lesssim 10 \text{ eV})$

- No Cosmological Problem! at all!
- LSP (gravitino) ≠ DM, but a natural DM candidate.
- It can be tested at LHC!

(gravitino mass can be determined!)

Gravitino

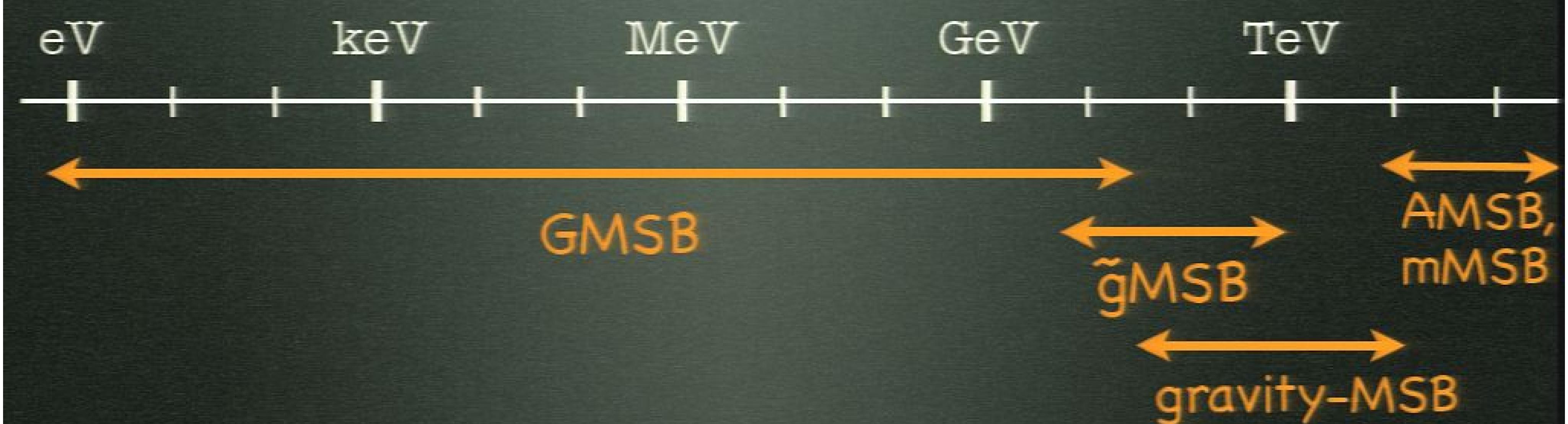
- If SUSY is in nature, it is (probably) a spontaneously broken local symmetry (i.e., not an accidental global symmetry).
- And the gravitino is an inevitable prediction of local SUSY (= SUGRA).

Gravitino

- Gravitino Interaction: extremely weak

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

- Gravitino Mass: model dependent



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ltralight gravitino

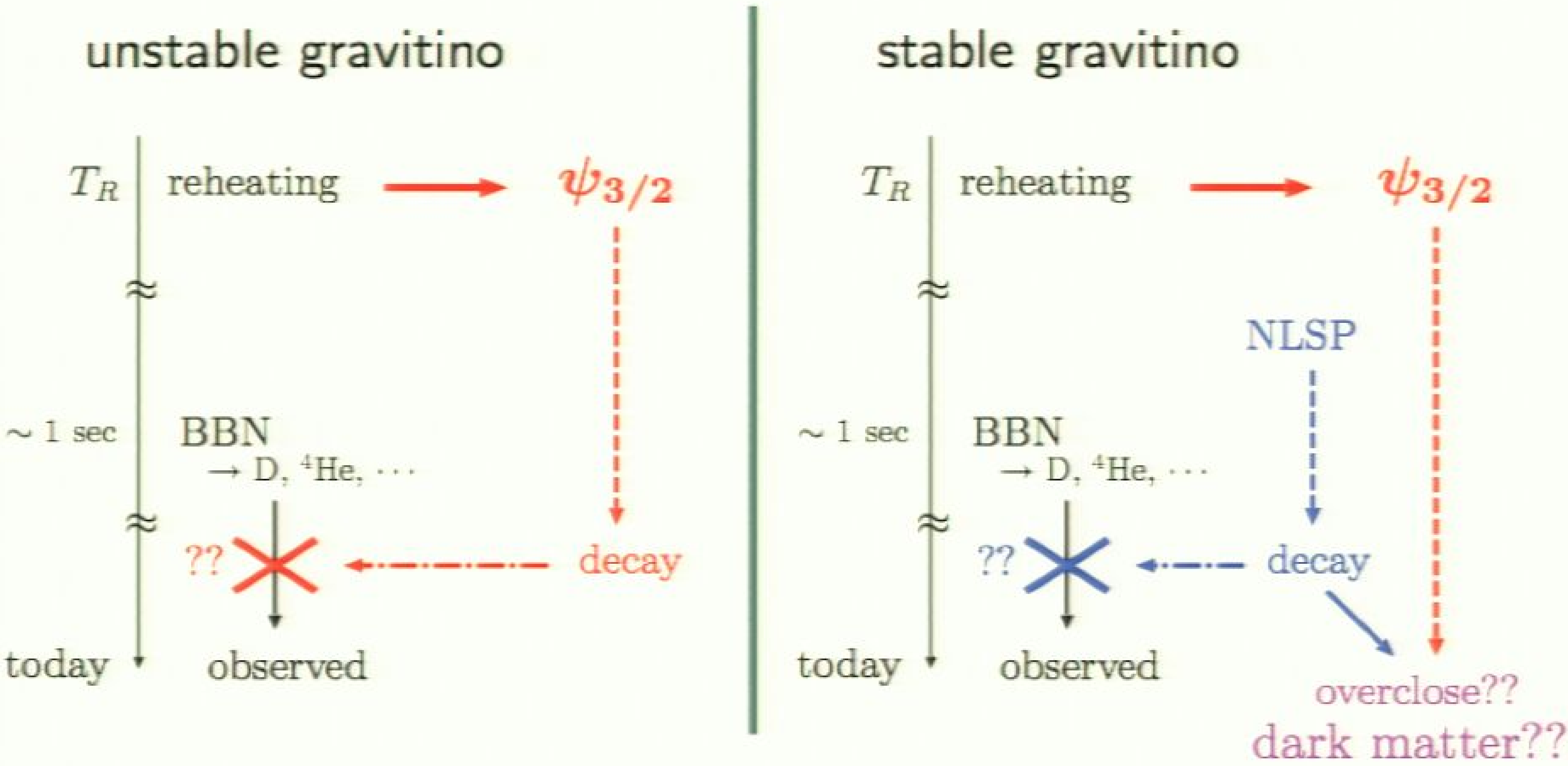
Gravitino Problems

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, $\cdots$
$\approx$		$\downarrow$
14 Gyr	2.7 K	observed

Gravitino Problems

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



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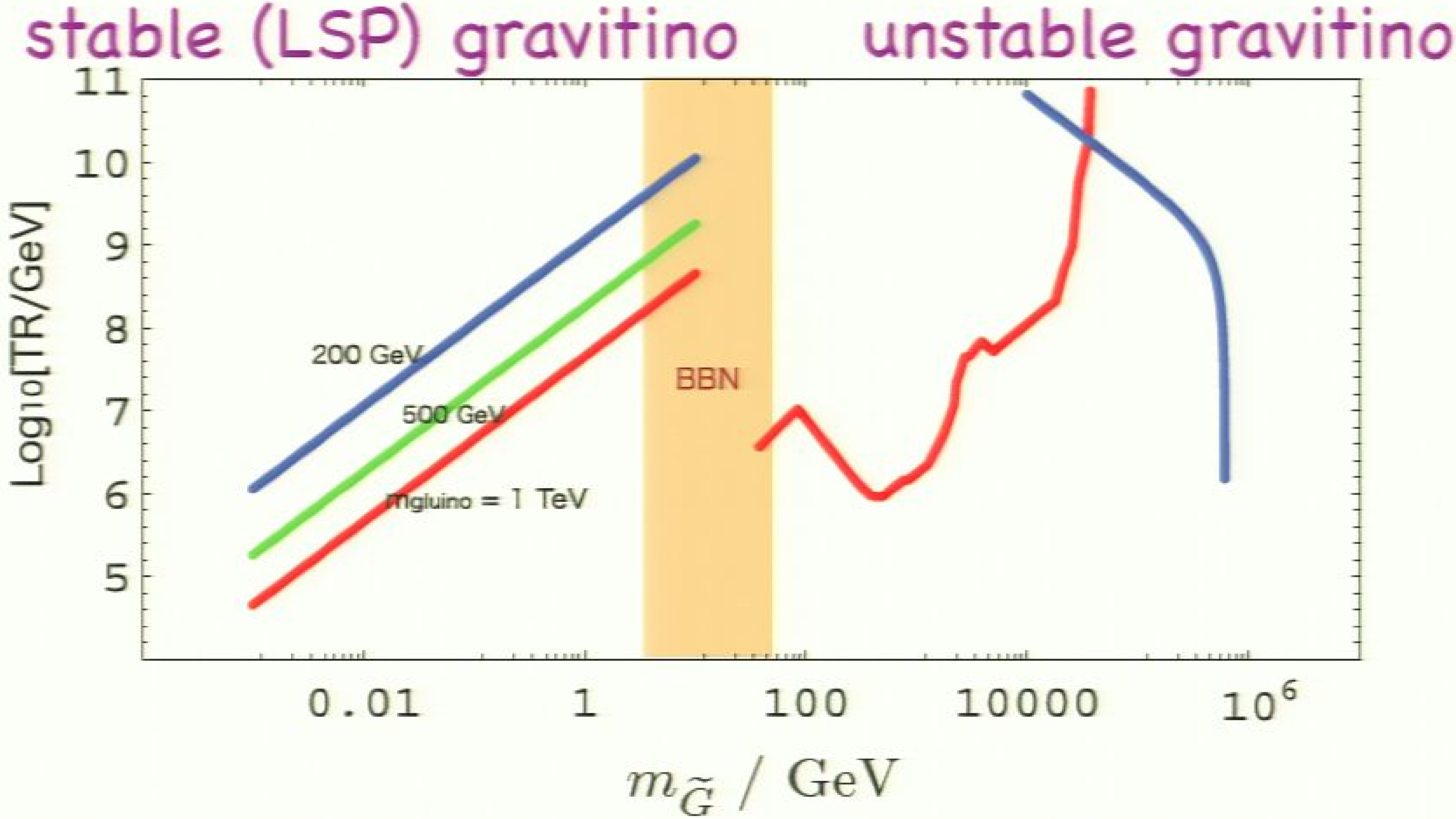

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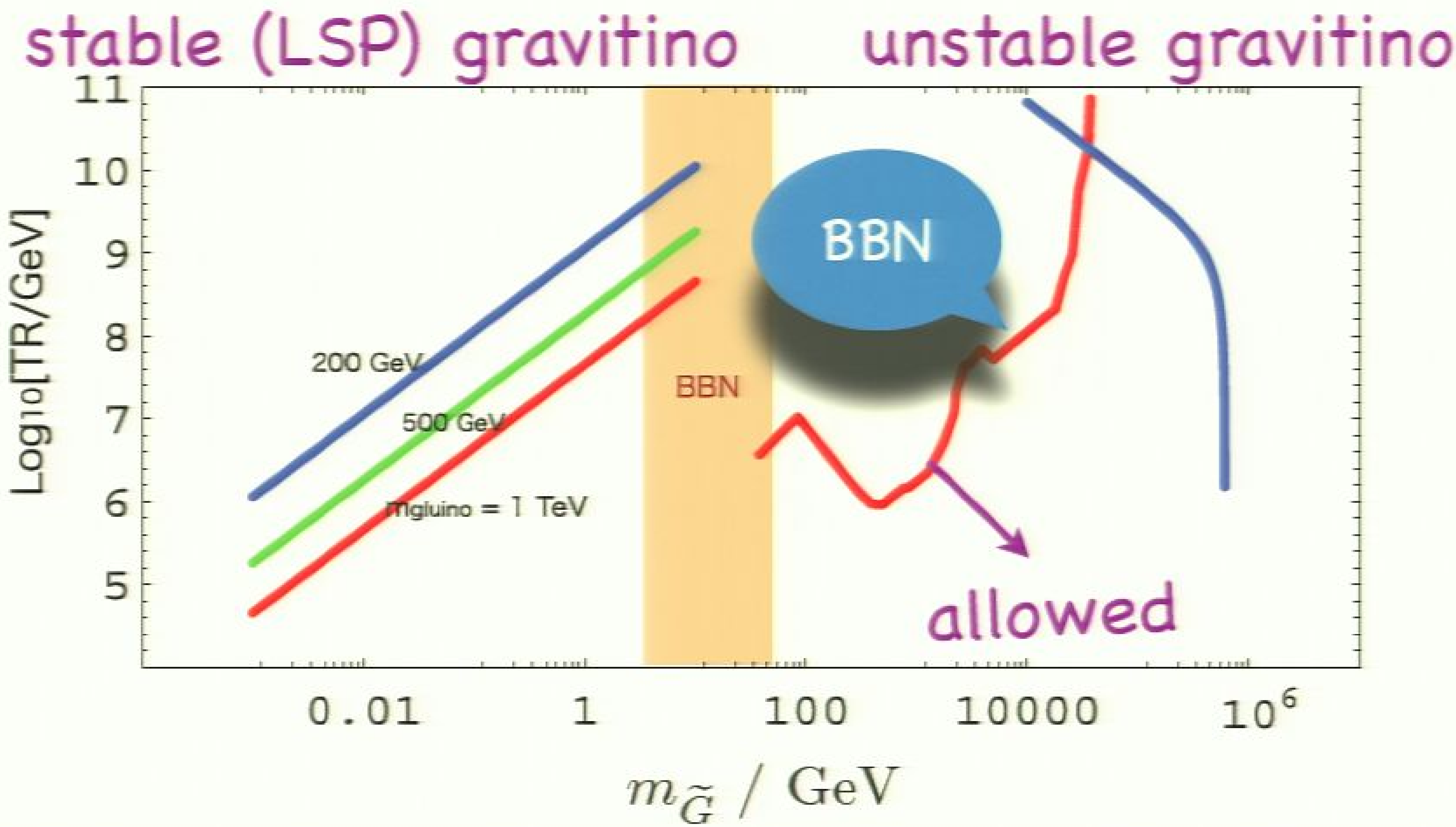

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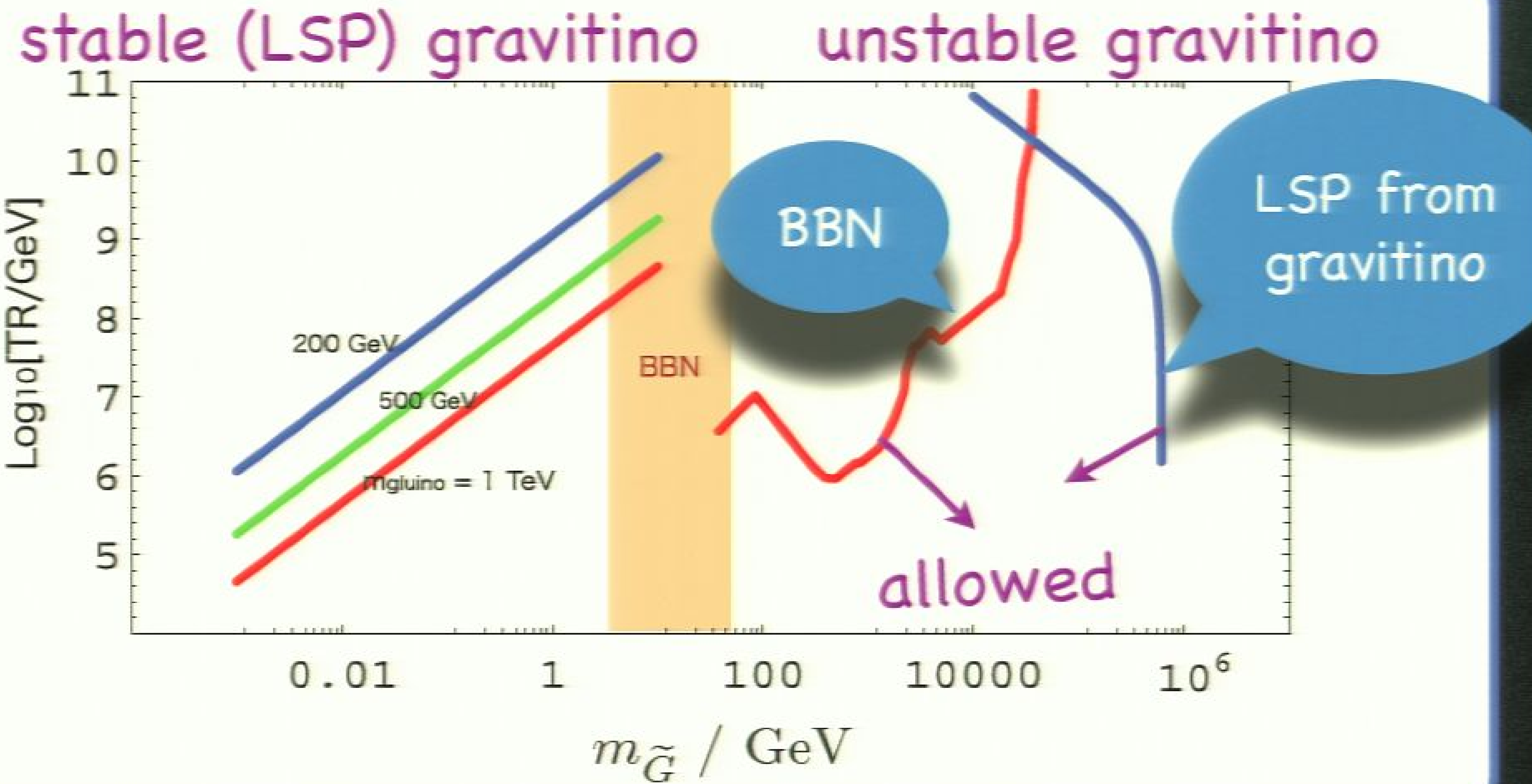

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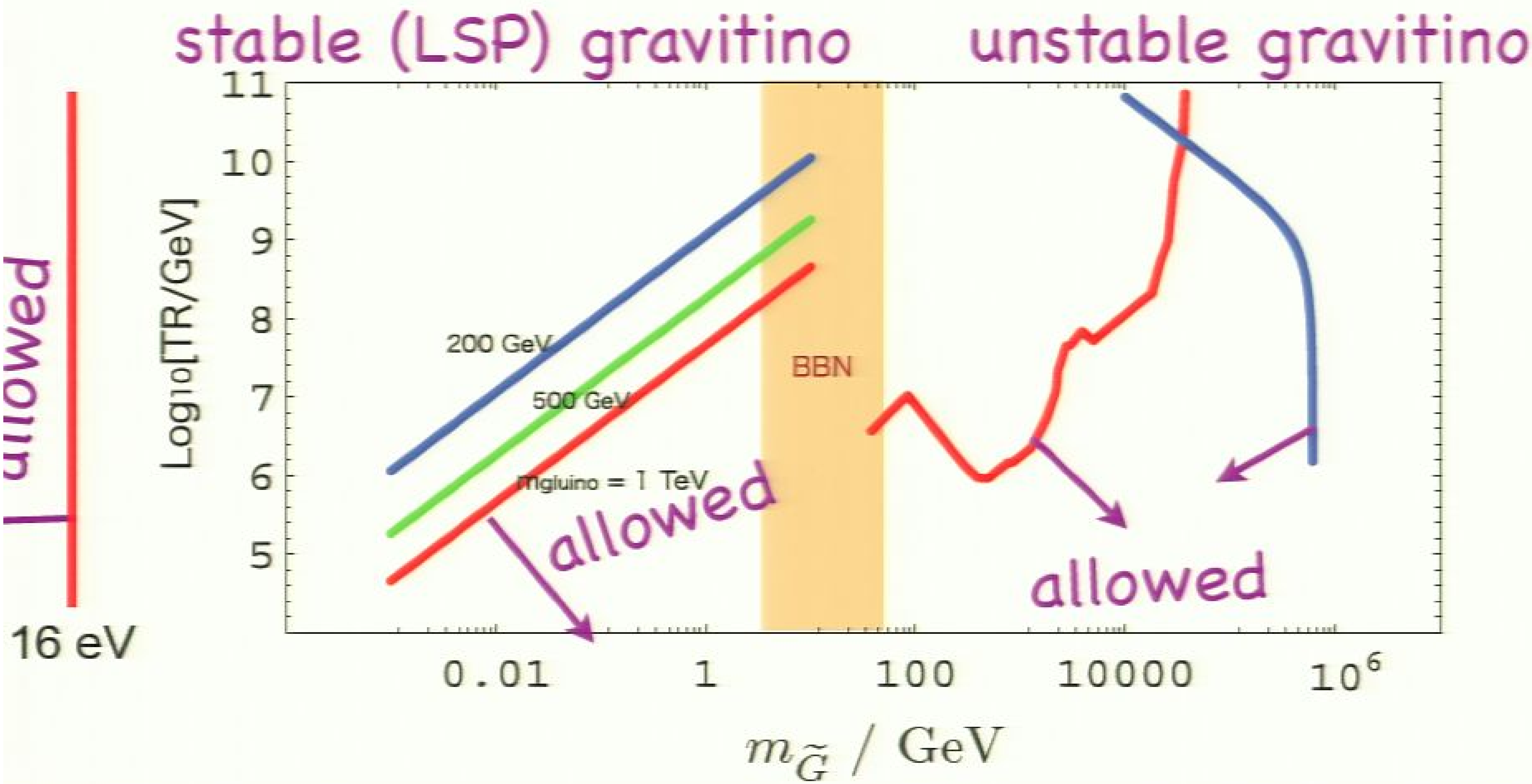

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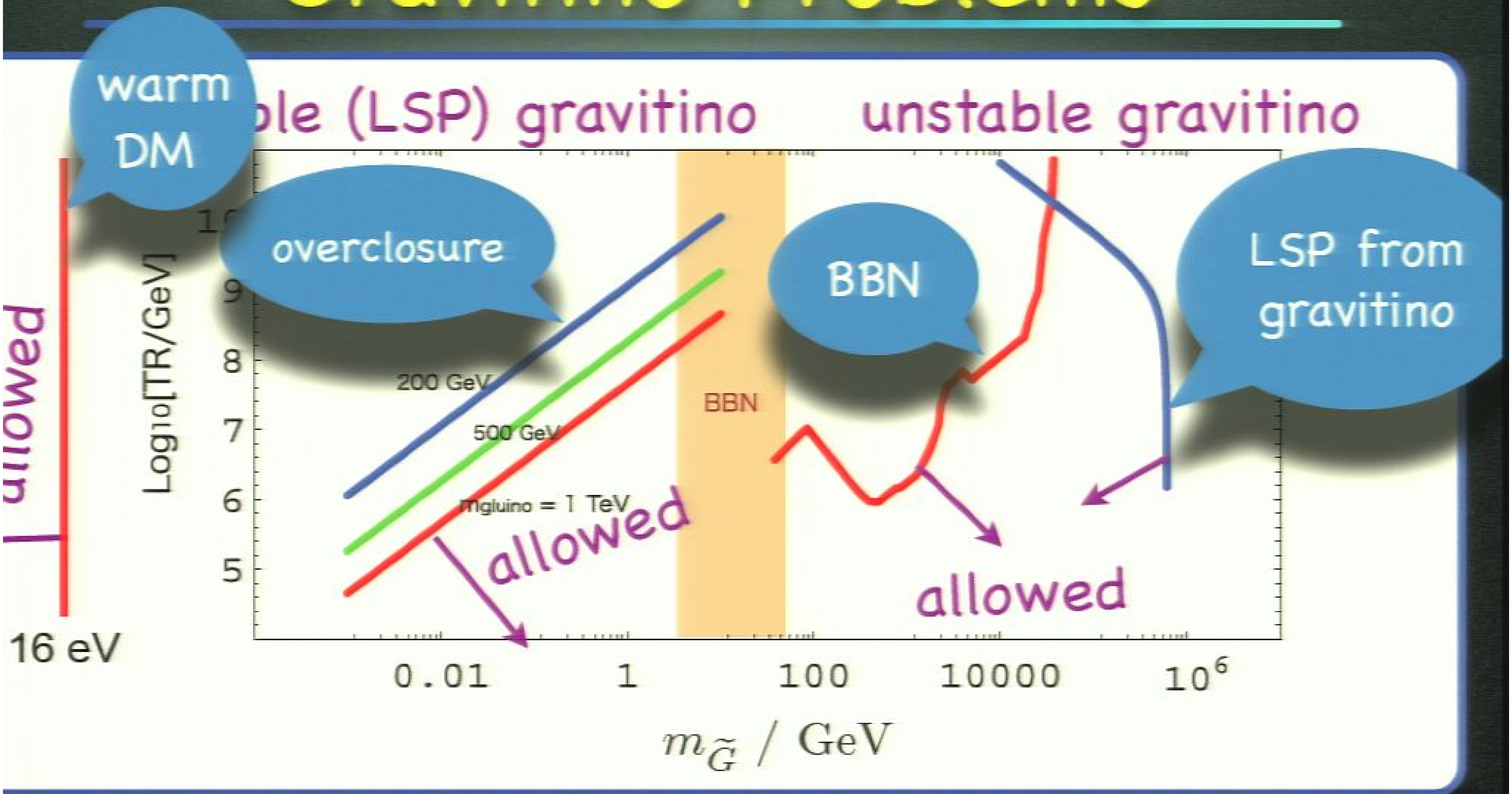

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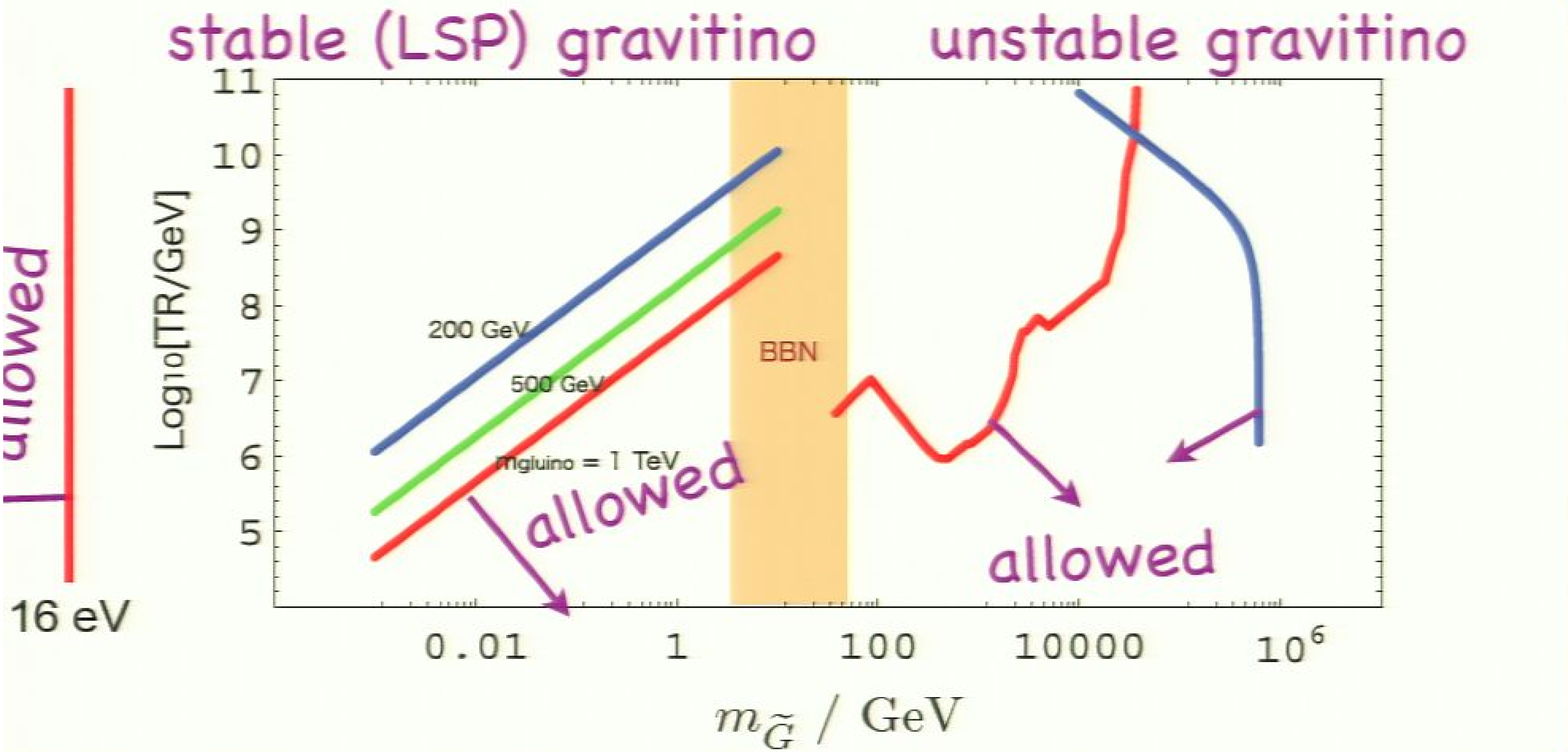

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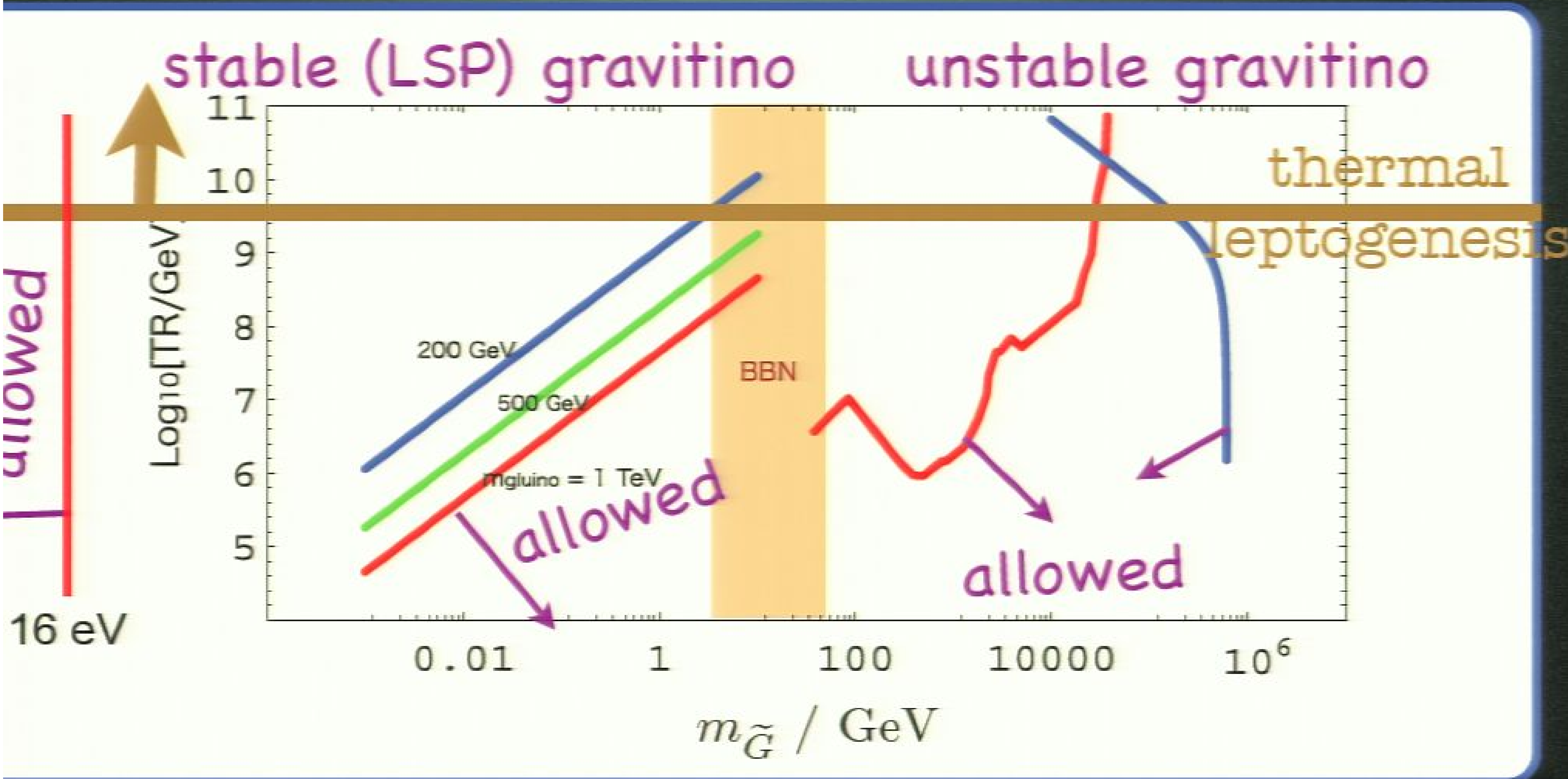

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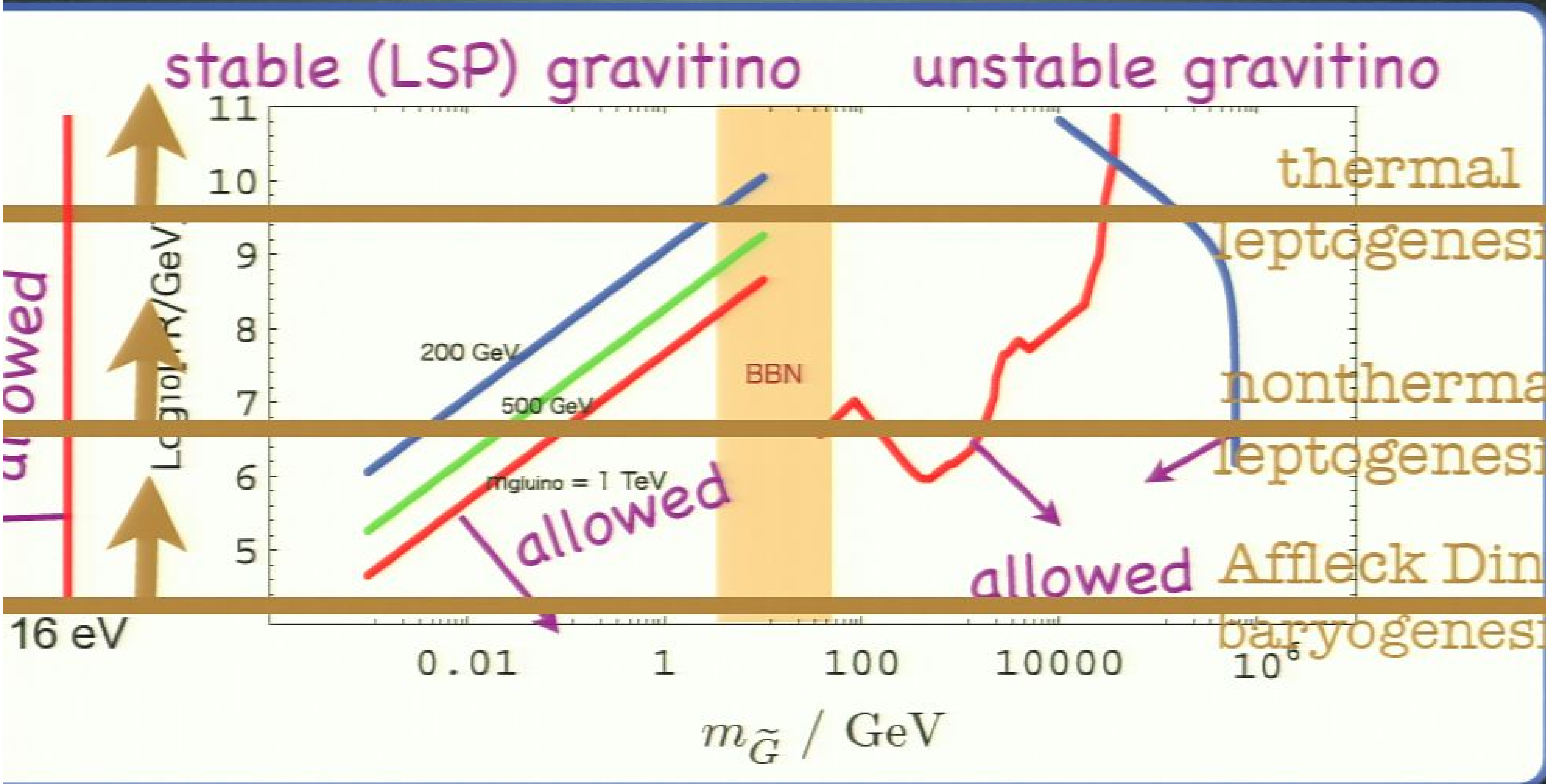

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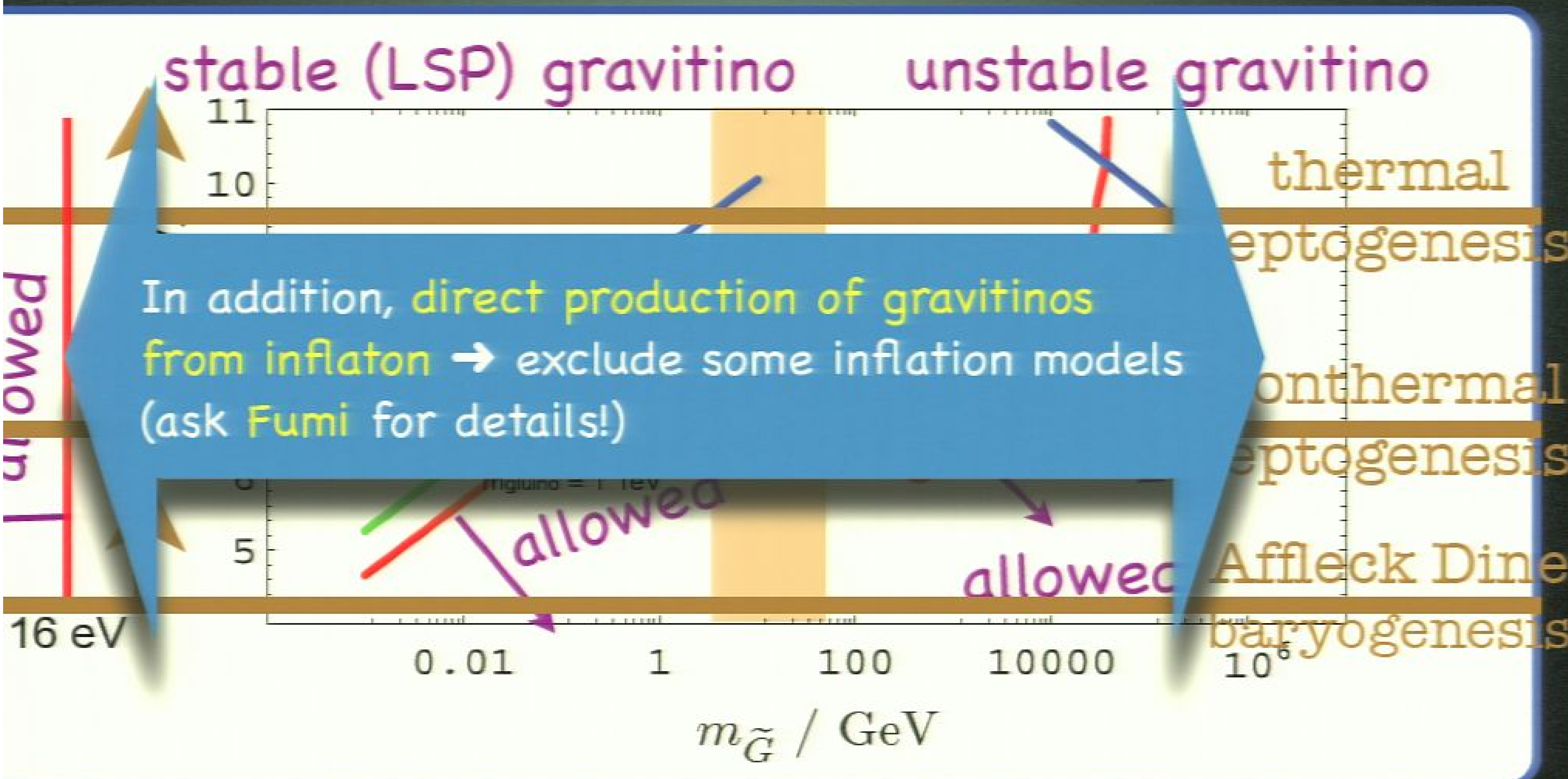

In addition, direct production of gravitinos from inflaton ➔ exclude some inflation models (ask Fumi for details!)

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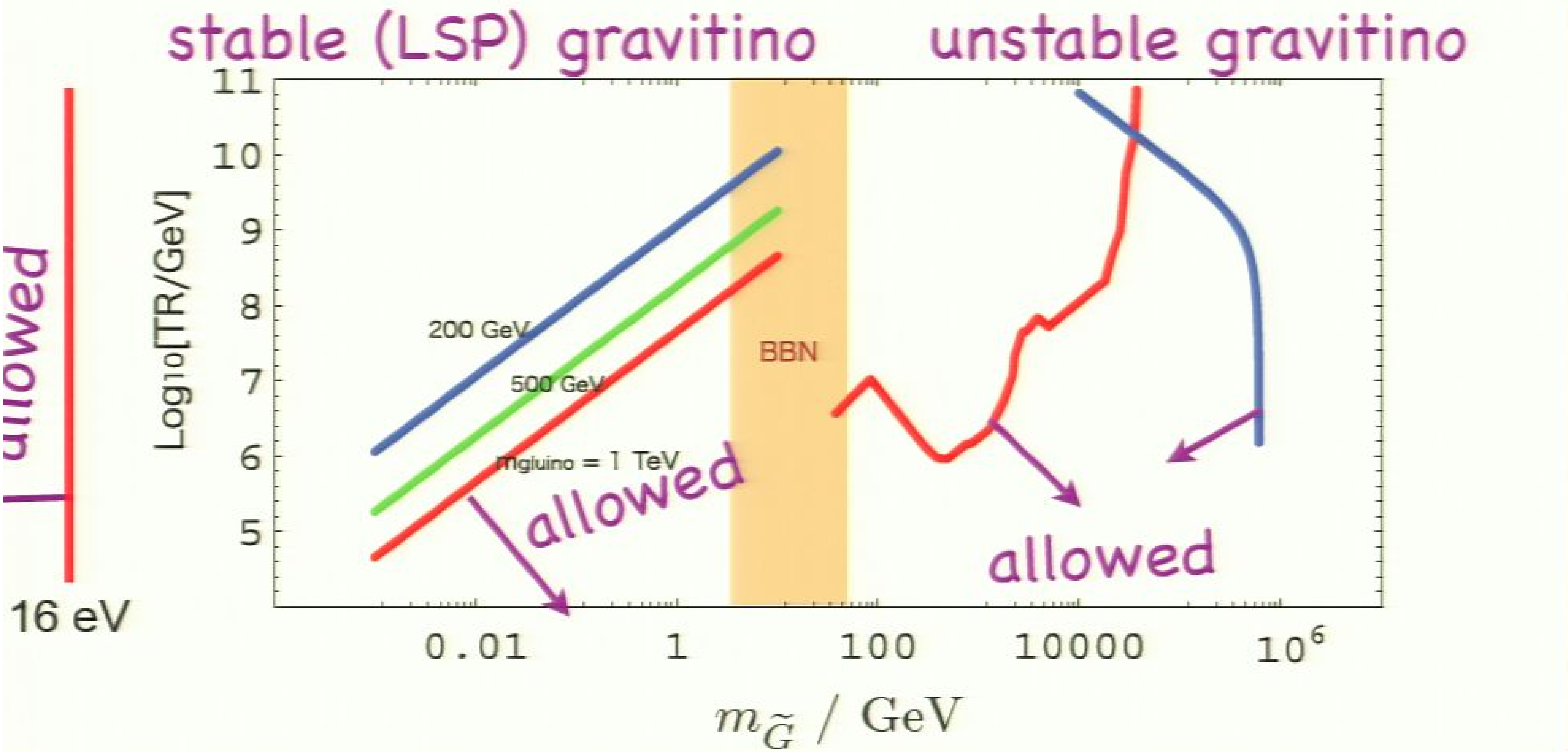
Gravitino Problems



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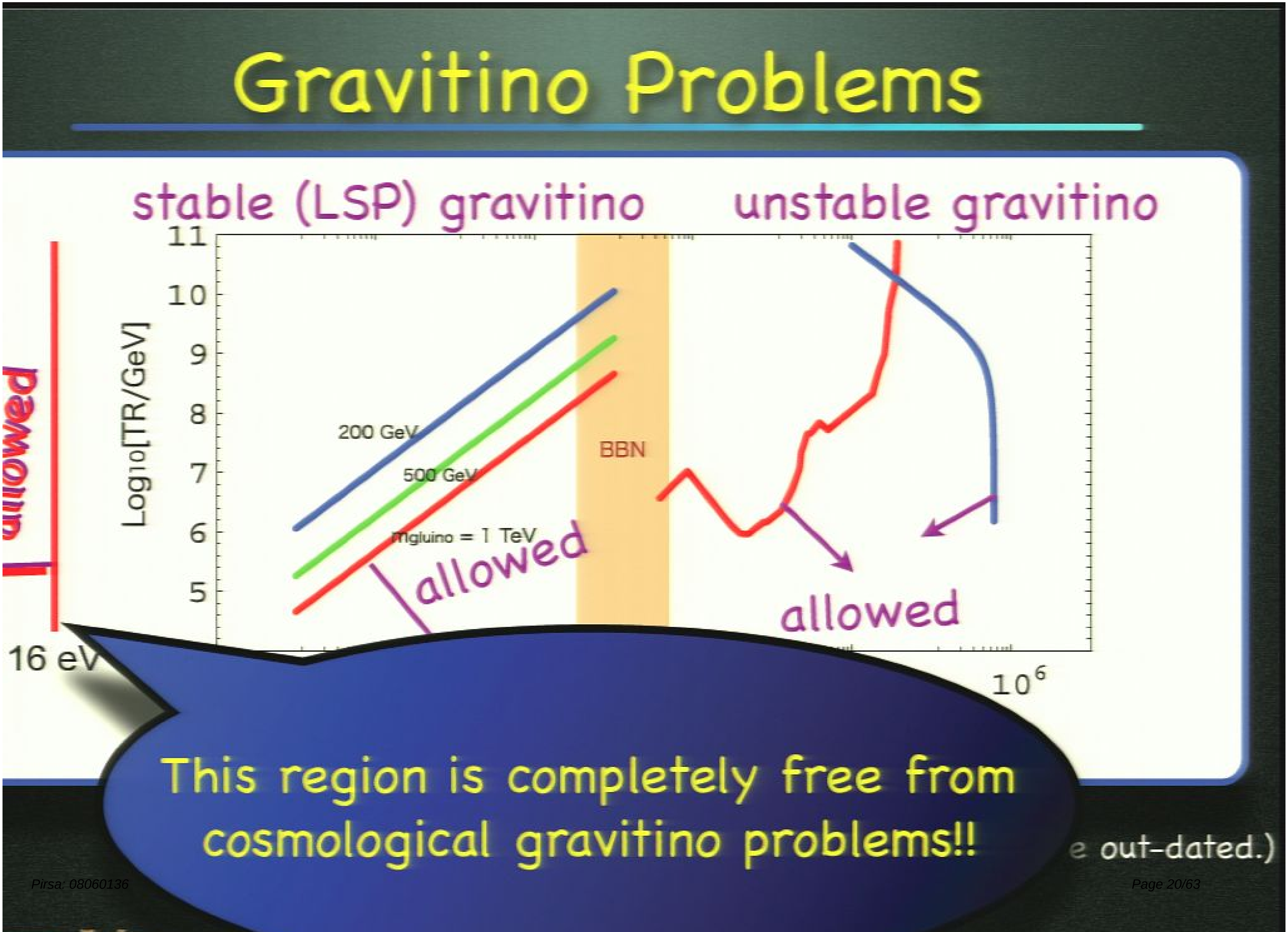

Gravitino Problems
stable (LSP) gravitino
unstable gravitino
Log10[TR/GeV]
200 GeV
500 GeV
mgluino = 1 TeV
BBN
allowed
allowed
allowed
16 eV
10^6
This region is completely free from
cosmological gravitino problems!!
e out-dated.)

Main Message

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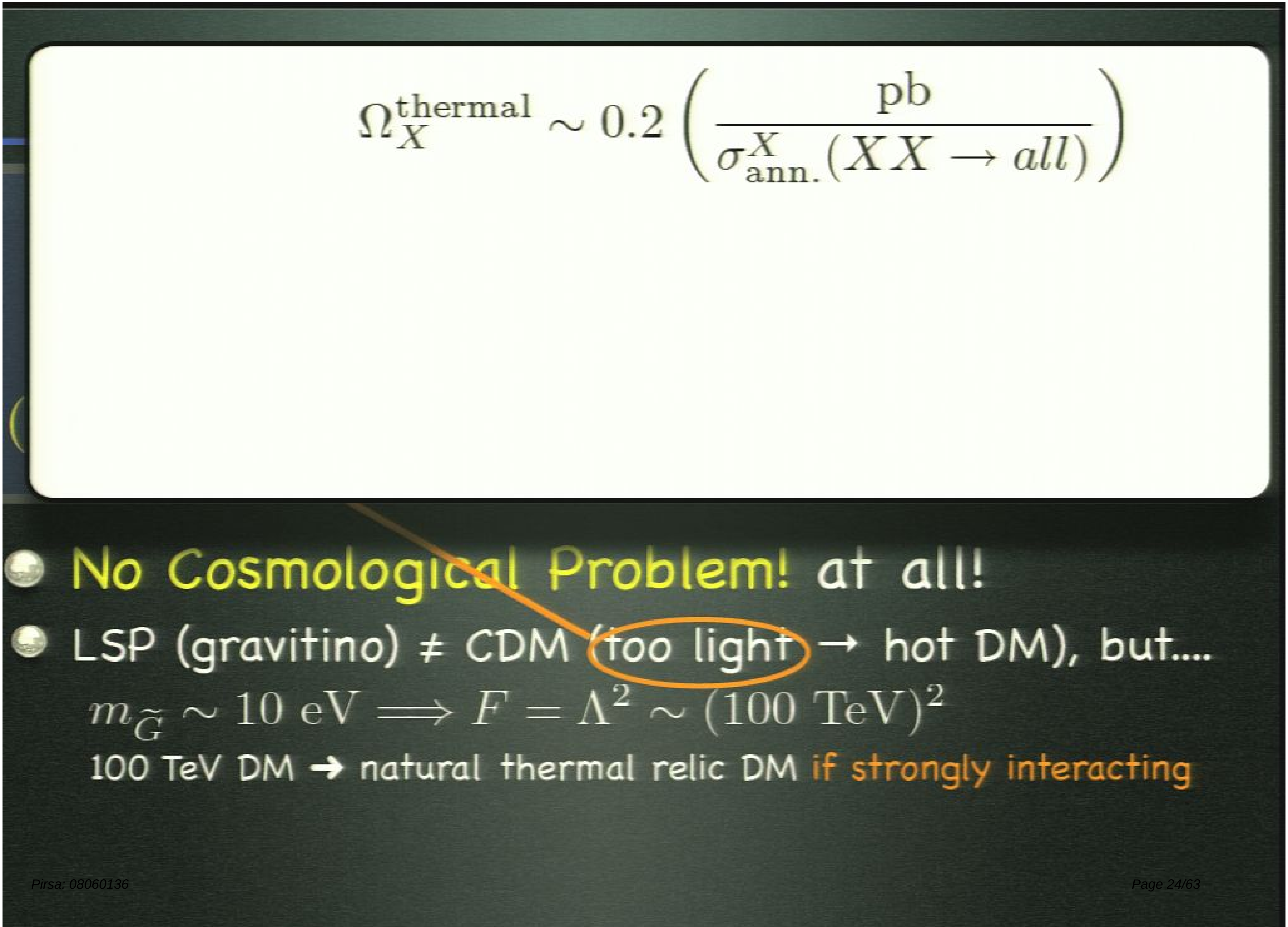
  $m_{\tilde{G}} \sim 10\ \mathrm{eV} \Longrightarrow F = \Lambda^2 \sim (100\ \mathrm{TeV})^2$

  100 TeV DM ➔ natural thermal relic DM if strongly interacting


$$\Omega_X^{\rm thermal} \sim 0.2 \left(\frac{\rm pb}{\sigma^X_{\rm ann.}(XX \to all)} \right)$$
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100 TeV DM → natural thermal relic DM if strongly interacting

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$$\sigma_{\rm ann.}^X \simeq \frac{\mathcal{O}(\alpha)}{m^2} \longrightarrow m \sim \mathcal{O}(0.1-1)\ \mathrm{TeV}$$ WIMP

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$$\sigma^X_{\rm ann.} \simeq \frac{\mathcal{O}(4\pi)}{m^2} \longrightarrow m \sim \mathcal{O}(10 - 100)\ \text{TeV}$$

strongly self-interacting

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100 TeV DM → natural thermal relic DM if strongly interacting

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

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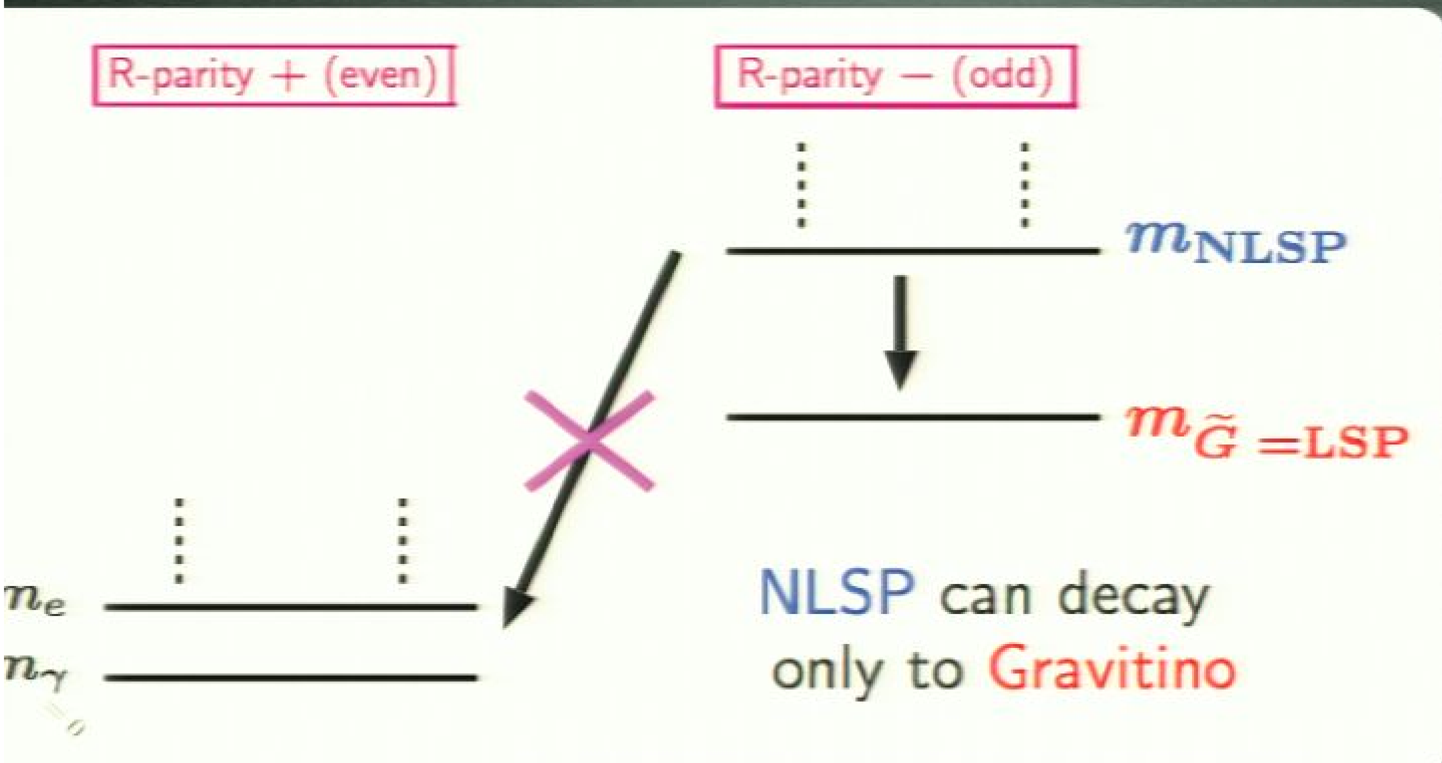
Can it be tested at LHC?

(Can the gravitino mass = SUSY breaking scale

e determined?)

NLSP (Next-to-Lightest SUSY Particle)

In Gravitino LSP scenario, the NLSP decay always include the gravitino.



Interaction

$$\sim \frac{1}{F} \sim \frac{1}{M_{\rm P} m_{\tilde{G}}}$$

NLSP (Next-to-Lightest SUSY Particle)

In Gravitino LSP scenario, the NLSP decay always include the gravitino.

For a slepton NLSP,.....

$$\Gamma(\tilde{\tau} \to \tilde{G}\tau) \simeq \frac{m_{\tilde{\tau}}^5}{48\pi m_{\tilde{G}}^2 M_{\rm pl}^2} \left(1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^2}\right)^4$$

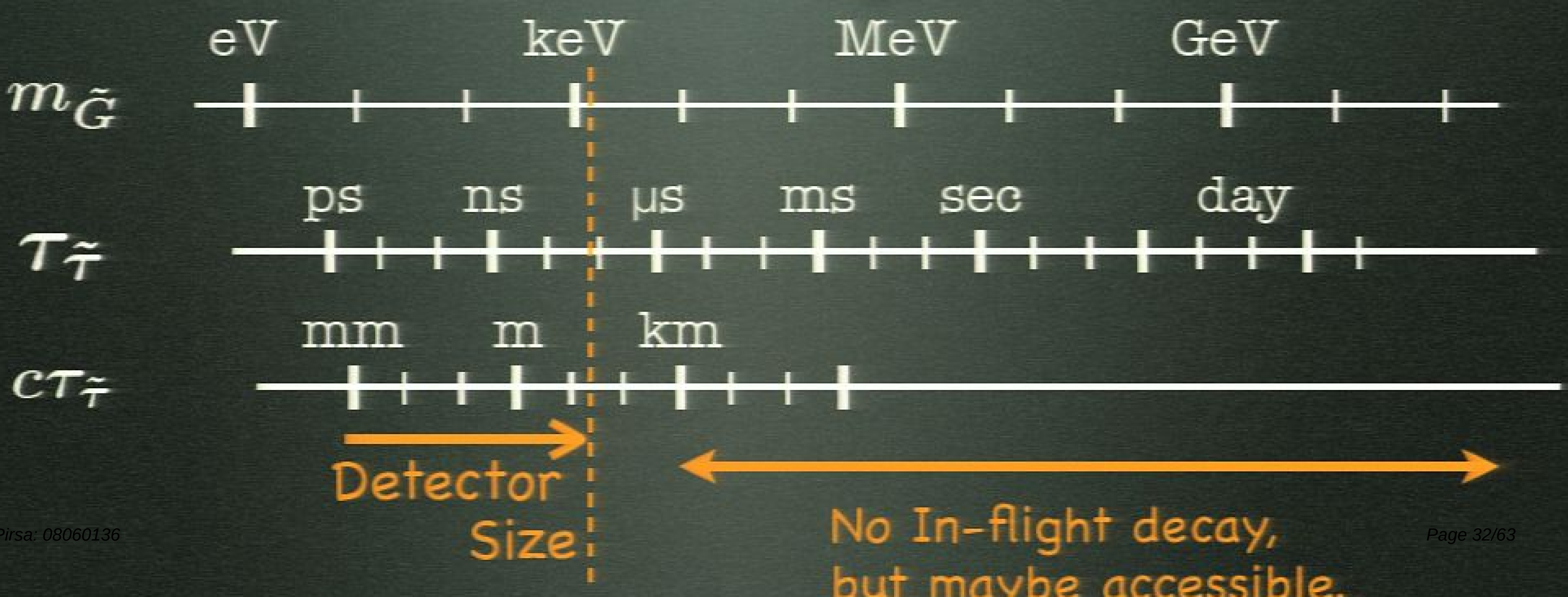
The gravitino mass may be determined by measuring the NLSP decay rate! However,.....

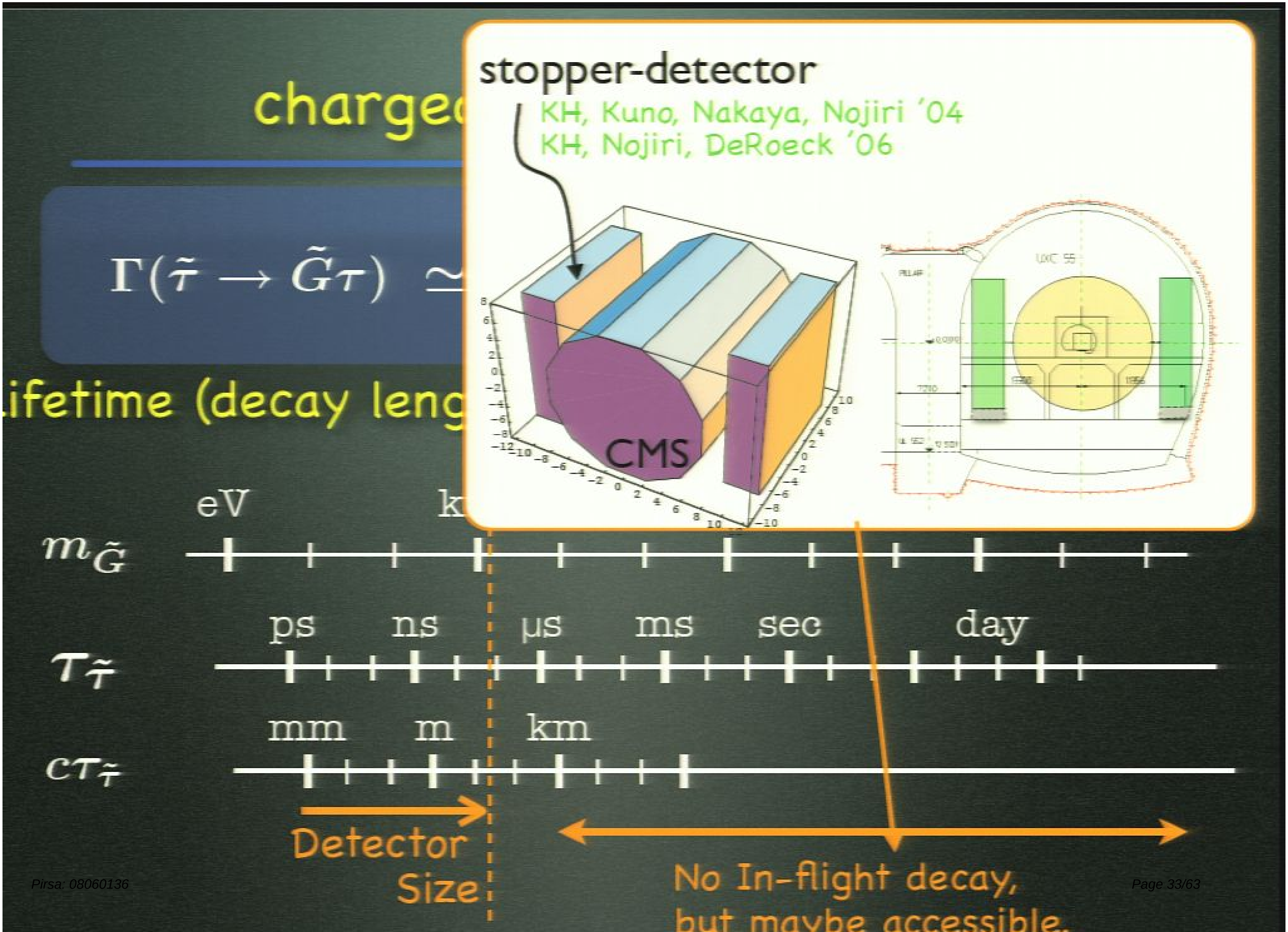
charged sleptons @ LHC

$$\Gamma(\tilde{\tau} \to \tilde{G}\tau) \simeq \frac{m_{\tilde{\tau}}^5}{48\pi m_{\tilde{G}}^2 M_{\rm pl}^2} \left(1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^2}\right)^4$$

Lifetime (decay length) of NLSP stau

e.g., for $m_{\tilde{\tau}} = 100\ \mathrm{GeV}$,




stopper-detector
KH, Kuno, Nakaya, Nojiri '04
KH, Nojiri, DeRoeck '06
CMS
$\Gamma(\tilde{\tau} \to \tilde{G}\tau) \simeq$
eV
$m_{\tilde{G}}$
ps
ns
μs
ms
sec
day
$\tau_{\tilde{\tau}}$
mm
m
km
$c\tau_{\tilde{\tau}}$
Detector Size
No In-flight decay,

charged sleptons @ LHC

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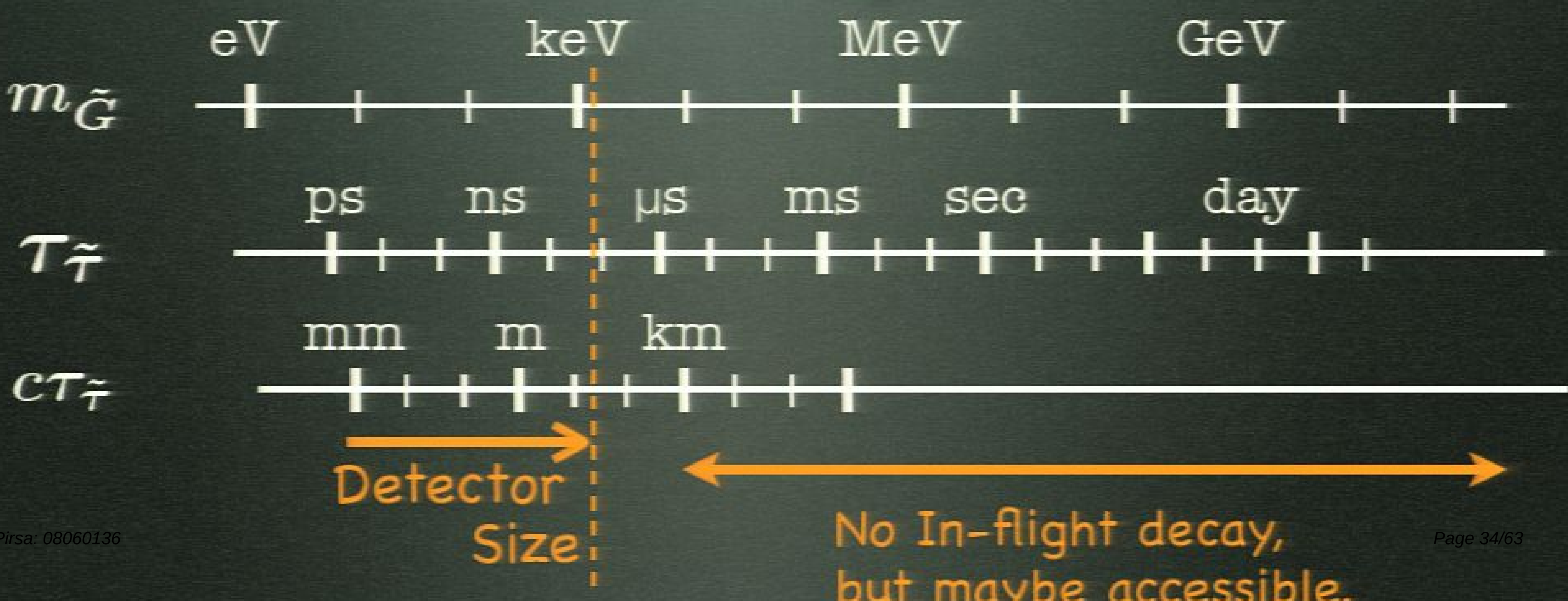

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for $m_{\tilde{\tau}} = 100\ \mathrm{GeV}$,

Idea: Look at NNLSP sleptons

KH, Shirai, Yanagida '07

two decay modes

$$\tilde{\mu} \to \mu \tau \tilde{\tau} : \ \Gamma_{3\mathrm{body}}$$

$$\tilde{\mu} \to \mu \tilde{G} : \ \Gamma_{2\mathrm{body}}$$

$$m^2_{\widetilde{G}} \propto \frac{1}{\Gamma_{2\mathrm{body}}}$$

difficult to measure

o short decay length)

charged sleptons @ LHC

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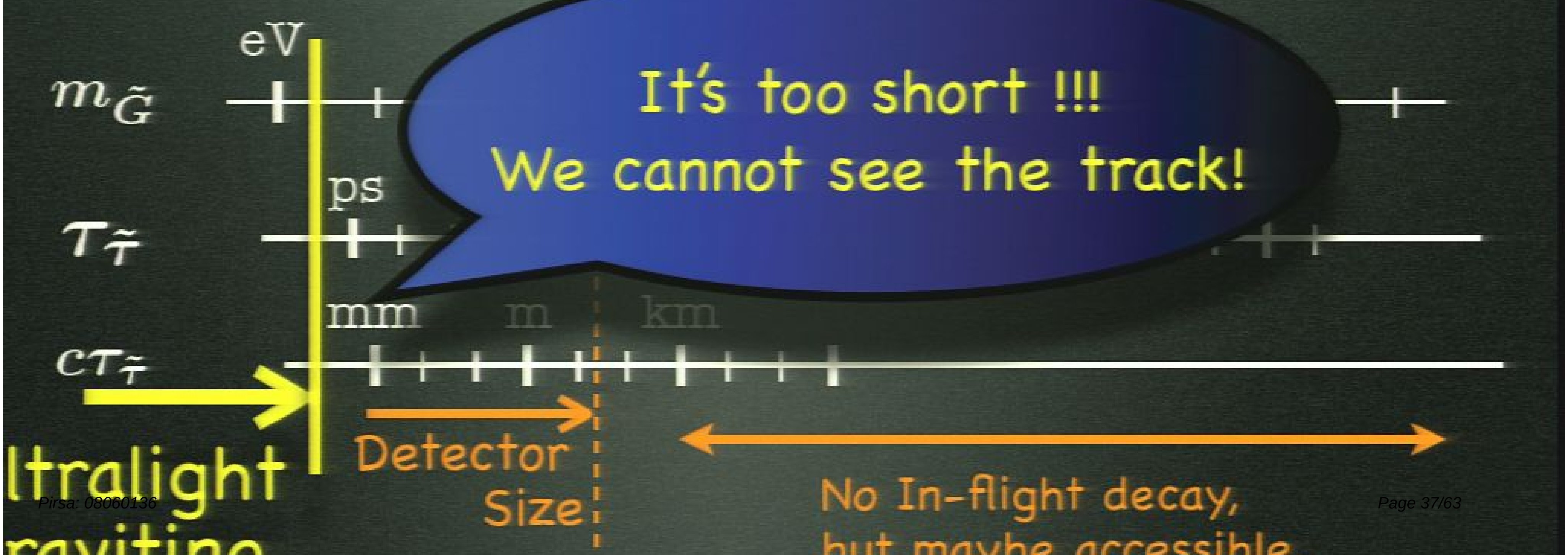
$= 100\ \mathrm{GeV}$,



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$$\tilde{\mu} \to \mu\tau\tilde{\tau} : \ \Gamma_{\text{3body}}$$

$$\tilde{\mu} \to \mu\tilde{G} : \ \Gamma_{\text{2body}}$$

$$m_{\widetilde{G}}^2 \propto \frac{1}{\Gamma_{\text{2body}}}$$

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dea

$$m^2_{\tilde{G}} \propto \frac{1}{\Gamma_{2\text{body}}} = \frac{1}{\Gamma_{3\text{body}}}\left(\frac{\Gamma_{3\text{body}}}{\Gamma_{2\text{body}}}\right)$$

lifficult to measure
o short decay length)

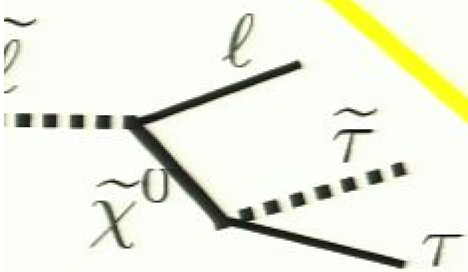
calculable if other
SUSY masses are known

measurable!

Idea: Look at NNLSP sleptons

$$\Gamma(\tilde{\ell} \to \ell + \tilde{\tau} + \tau) \approx \frac{2}{15\pi}\left(\frac{\alpha_{\rm EM}}{\cos^2\theta_W}\right)^2 m_{\tilde{\ell}} \frac{(1+r^2_{\tilde{\chi}^0_1})}{(r^2_{\tilde{\chi}^0_1}-1)^2}\left(\frac{\Delta m}{m_{\tilde{\ell}}}\right)^5$$

$$= 4.4\ {\rm eV}\left(\frac{m_{\tilde{\ell}}}{100\ {\rm GeV}}\right)^{-4}\left(\frac{\Delta m}{10\ {\rm GeV}}\right)^5 \frac{1+r^2_{\tilde{\chi}^0_1}}{(r^2_{\tilde{\chi}^0_1}-1)^2}$$



$r_{\tilde{\chi}^0_1} = m_{\tilde{\chi}^0_1}/m_{\tilde{\ell}}$. assumed $\Delta m = m_{\tilde{\ell}} - m_{\tilde{\tau}} \gg m_\tau$

dea

$$m^2_{\widetilde{G}} \propto \frac{1}{\Gamma_{2\rm body}} = \frac{1}{\Gamma_{3\rm body}}\left(\frac{\Gamma_{3\rm body}}{\Gamma_{2\rm body}}\right)$$

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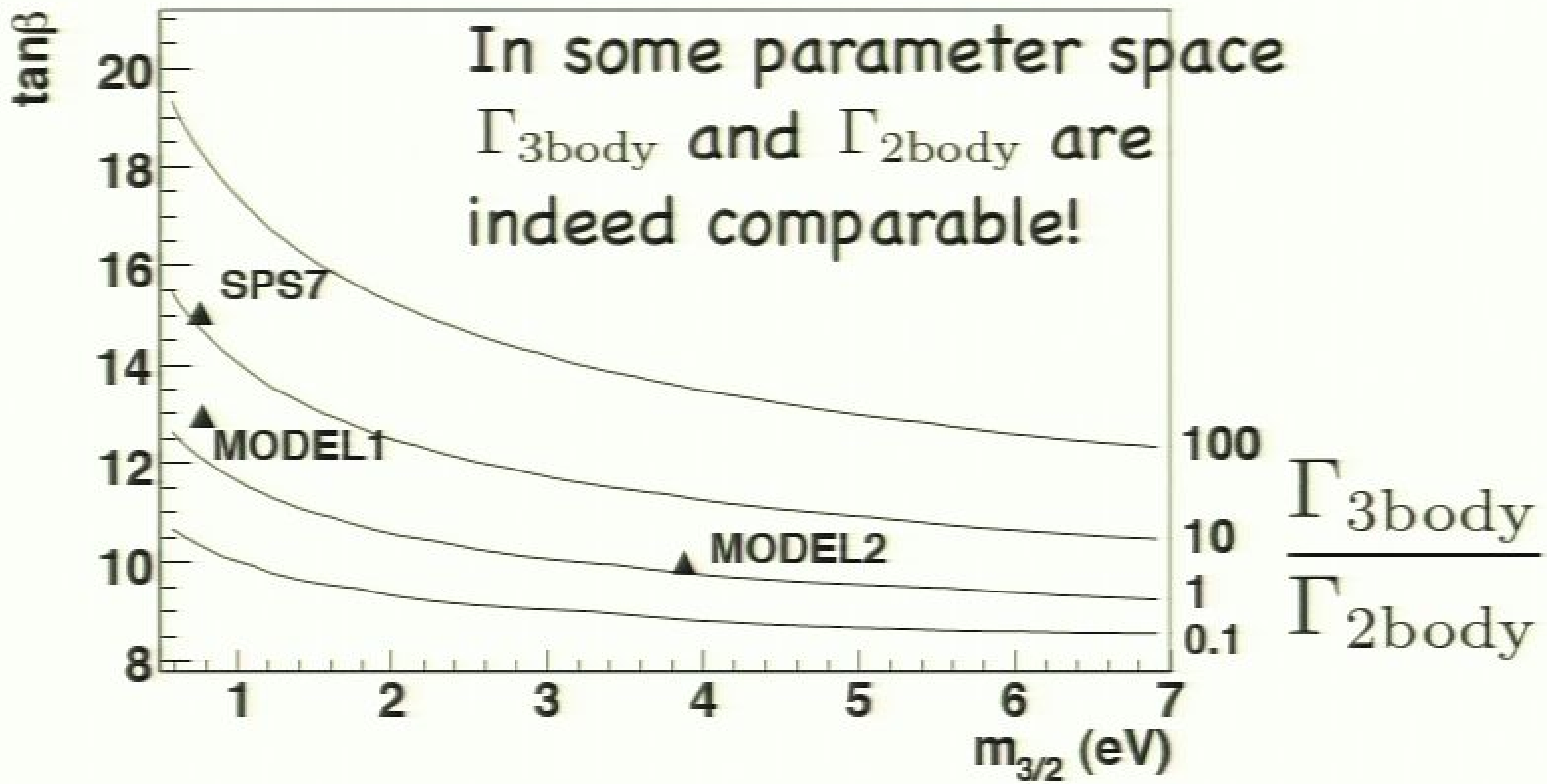
Idea:

$\tilde{\mu}$

$\tilde{\tau}$

$\tilde{G}$



dea

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How can we measure the $\Gamma_{3\text{body}}/\Gamma_{2\text{body}}$?

- look at the dilepton invariant mass $m_{\ell\ell} = (p_{\ell,1} + p_{\ell,2})^2$

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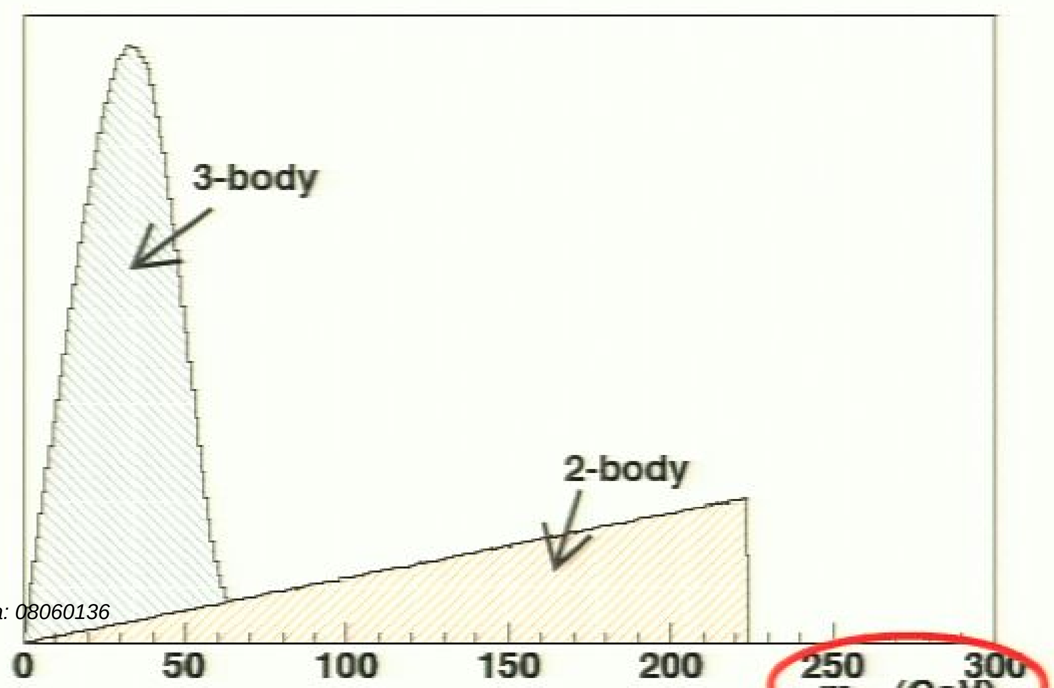

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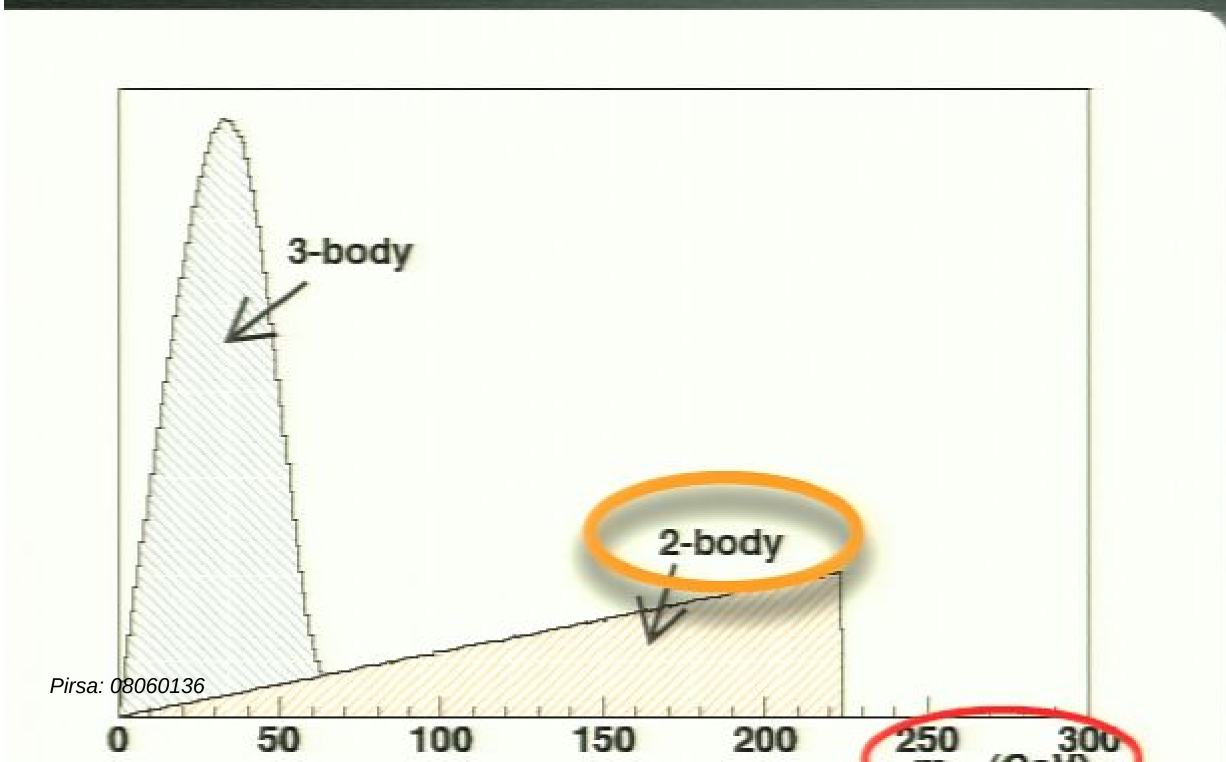

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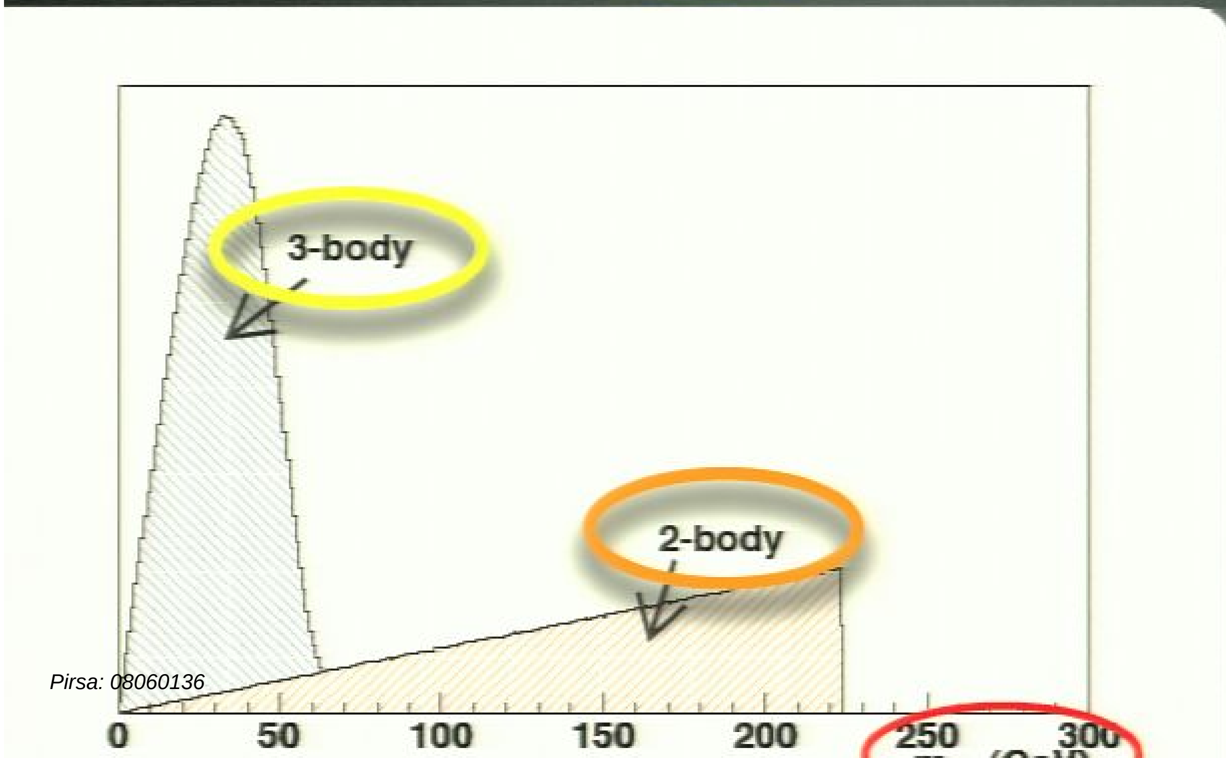

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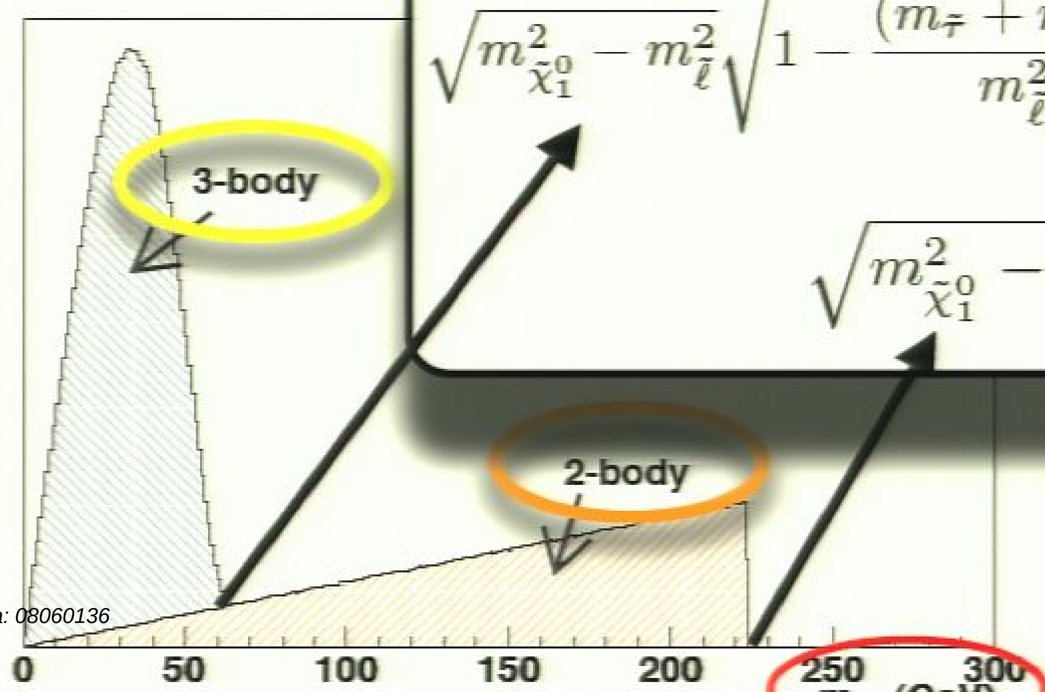

$$\sqrt{m_{\tilde{\chi}_1^0}^2 - m_{\tilde{\ell}}^2}\sqrt{1 - \frac{(m_{\tilde{\tau}} + m_\tau)^2}{m_{\tilde{\ell}}^2}} \to \Gamma_{3\mathrm{body}}$$

$$m_{\tilde{\ell}} \to \Gamma_{3\mathrm{body}}$$

$$\sqrt{m_{\tilde{\chi}_1^0}^2 - m_{\tilde{\ell}}^2} \to \Gamma_{3\mathrm{body}}$$

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event selection

- at least four jets with $P_\mathrm{T} \geq 25$ GeV, where τ-jets are excluded.
- missing transverse momentum $P_{\mathrm{T,miss}} \geq 100$ GeV.
- $M_\mathrm{eff} \geq 500$ GeV, where

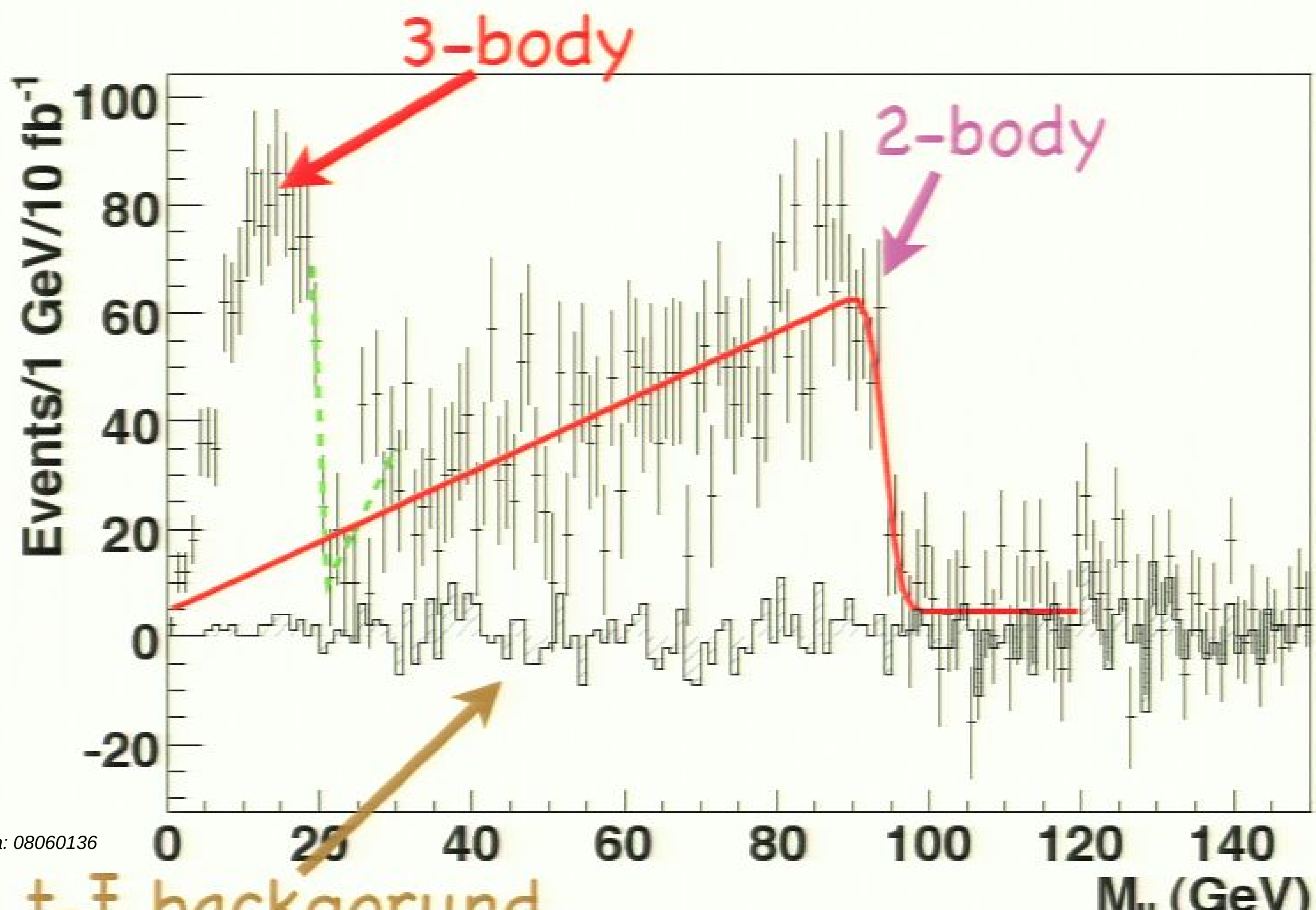
$$M_\mathrm{eff} = \sum_{\mathrm{jets}(\neq\tau)}^{4} P_{\mathrm{T_j}} + P_{\mathrm{T,miss}} .$$

- two leptons with $P_\mathrm{T} \geq 20$ GeV and $|\eta| < 2.5$.
- the dilepton mass is formed only if one of the two leptons has $P_\mathrm{T} \geq 20$ GeV, $|\eta| < 2.5$ and the other has $P_\mathrm{T} \geq 6$ GeV, $|\eta| < 2.5$.
- $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$

event selection

An example (Model 1): 10 fb^-1

(We used ISAJET(mass spectrum) + HERWIG + AcerDET)



2.5

event selection

An example (Model 1): 10 fb^-1

(We used ISAJET(mass spectrum) + HERWIG + AcerDET)

- from the # of events,

$$\frac{\Gamma_{3\text{body}}}{\Gamma_{2\text{body}}} = \frac{N_3/R_3}{N_2/R_2} = (1.50 \pm 0.15)\left(\frac{R_2/R_3}{4.5}\right)$$

$R_2, R_3 \cdots$ correction factor due to P_T cut

In this case, $R_2/R_3 \simeq 4.5 \pm 1.1$

- from the endpoints of $M_{\ell\ell}, M_{\ell j}, M_{\ell\ell j}$

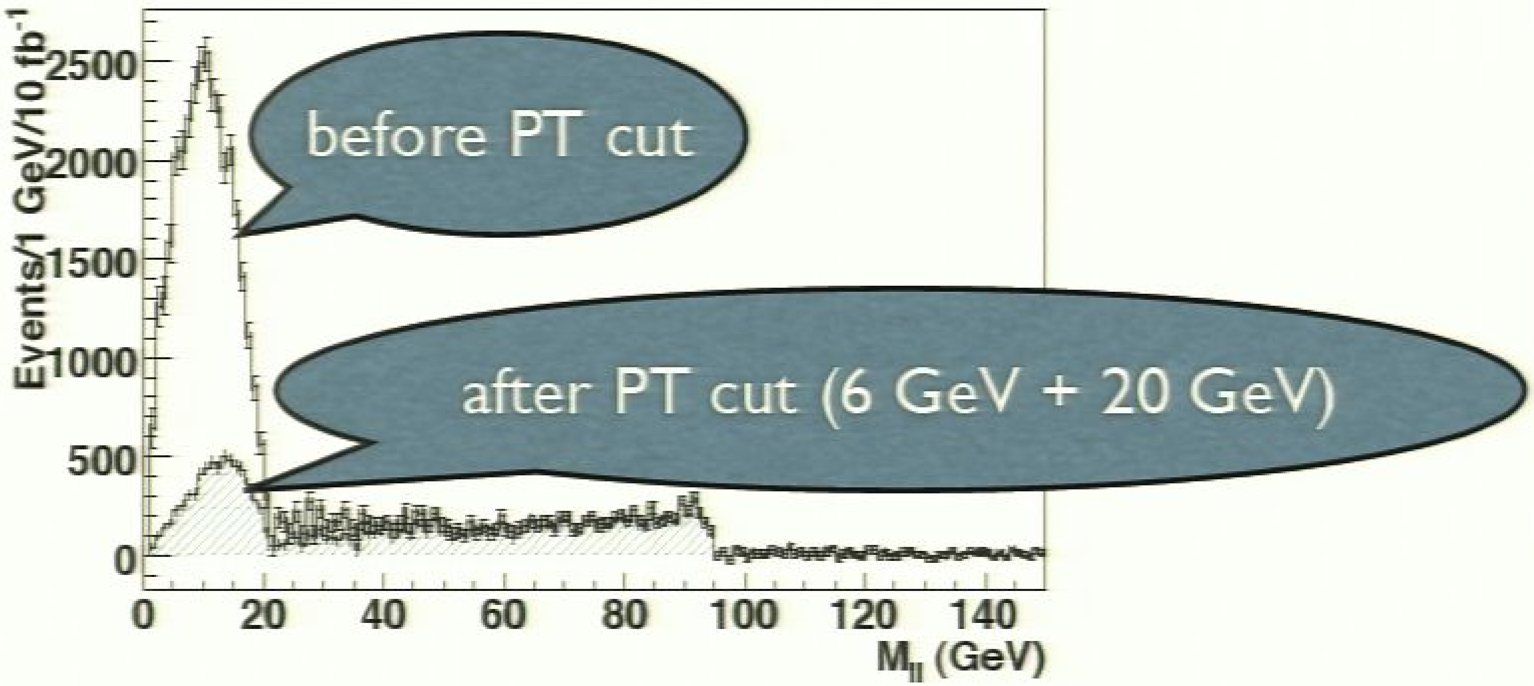
$$\Gamma_{3\text{body}} = 0.21^{+0.09}_{-0.07}\ \text{eV}$$

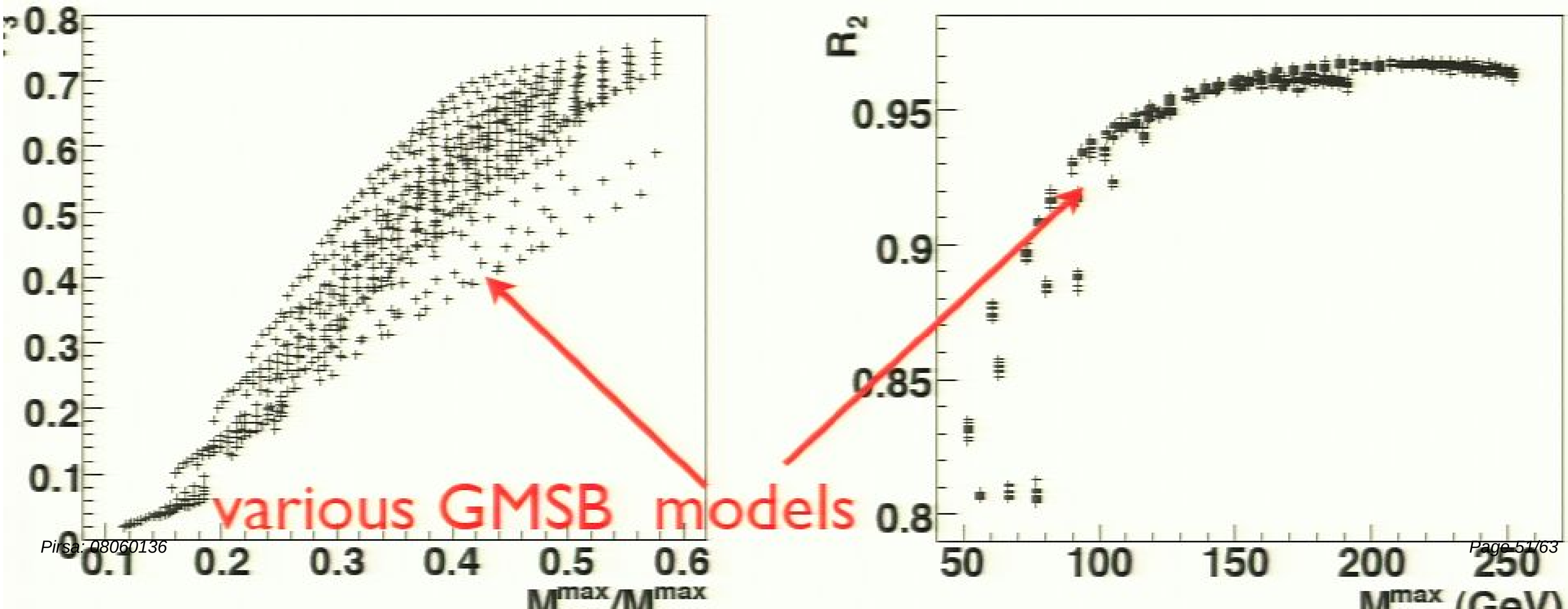
- We then obtain the gravitino mass!!

$$m_{\tilde{G}} = (0.53^{+0.11}_{-0.10})\left(\frac{R_2/R_3}{4.5}\right)^{1/2}\ \text{eV}$$

$$(\text{true value} : m_{\tilde{G}} = 0.77\ \text{eV})$$

eduction
actor R





Summary: Main Message

SUSY models with an ultralight gravitino is interesting!

$(m_{\tilde{G}} \lesssim 10 \text{ eV})$

- No Cosmological Problem! at all!
- LSP (gravitino) ≠ DM, but a natural DM candidate.
- It can be tested at LHC!

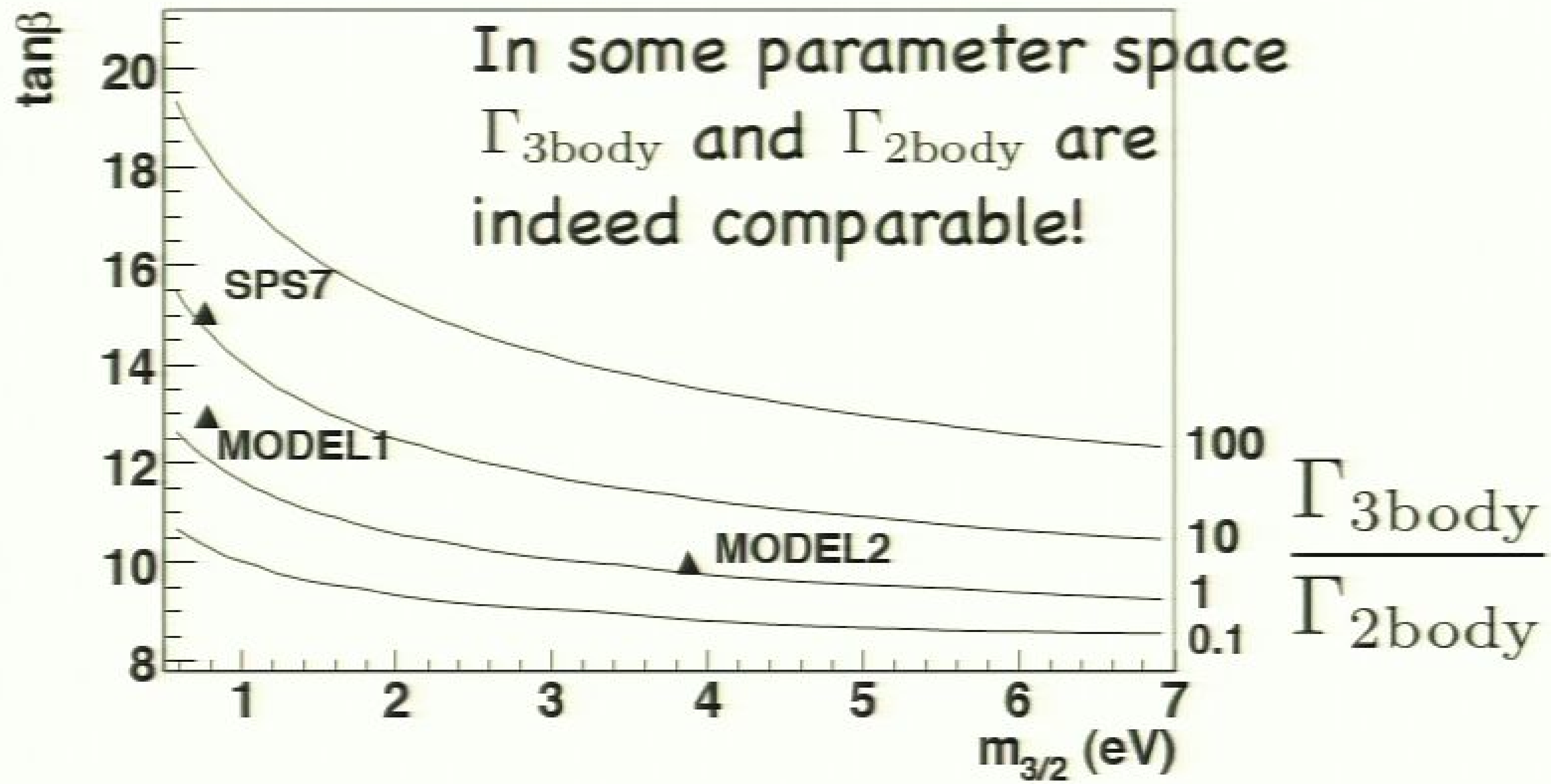
(gravitino mass = SUSY breaking scale can be determined!)

Idea:

$\tilde{\mu}$

$\tilde{\tau}$

$\tilde{G}$



dea

$$m_{\tilde{G}}^2 \propto \frac{1}{\Gamma_{2\mathrm{body}}} = \frac{1}{\Gamma_{3\mathrm{body}}}\left(\frac{\Gamma_{3\mathrm{body}}}{\Gamma_{2\mathrm{body}}}\right)$$

lifficult to measure
o short decay length)

calculable if other
SUSY masses are known

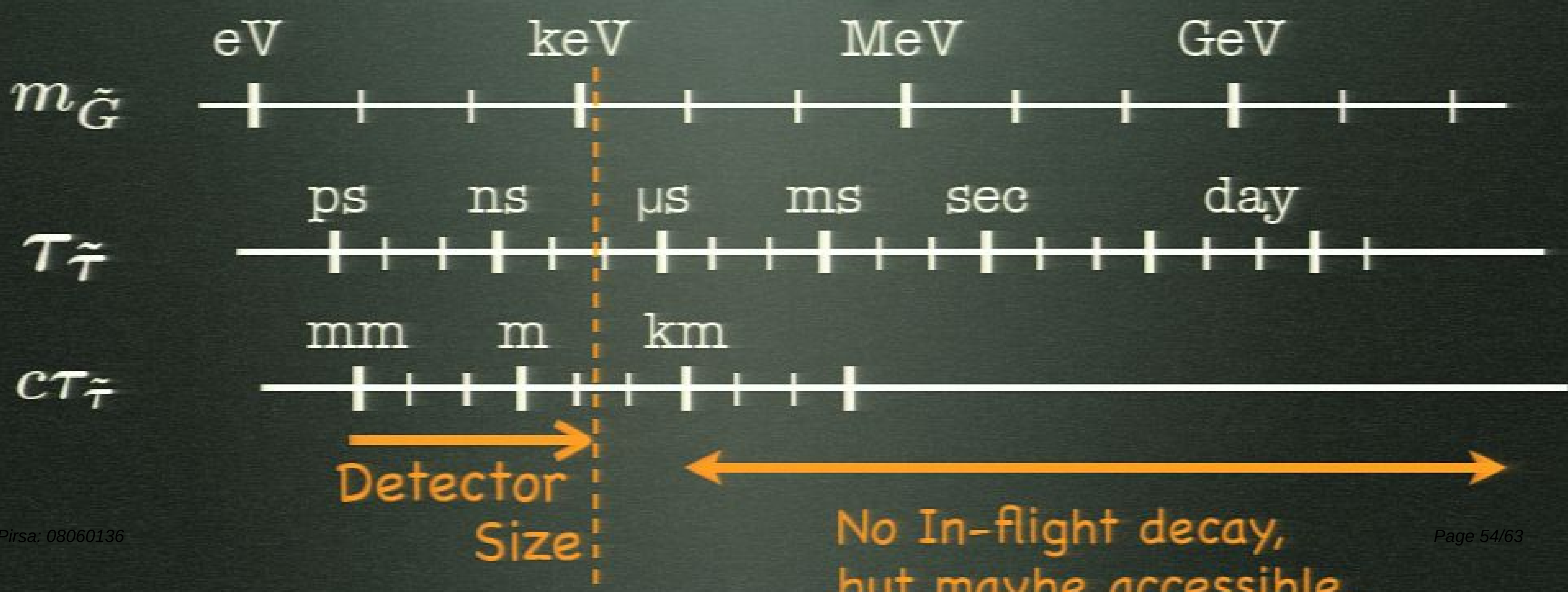
measurable!

charged sleptons @ LHC

$$\Gamma(\tilde{\tau} \to \tilde{G}\tau) \simeq \frac{m_{\tilde{\tau}}^5}{48\pi m_{\tilde{G}}^2 M_{\rm pl}^2} \left(1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^2}\right)^4$$

Lifetime (decay length) of NLSP stau

e.g., for $m_{\tilde{\tau}} = 100$ GeV ,



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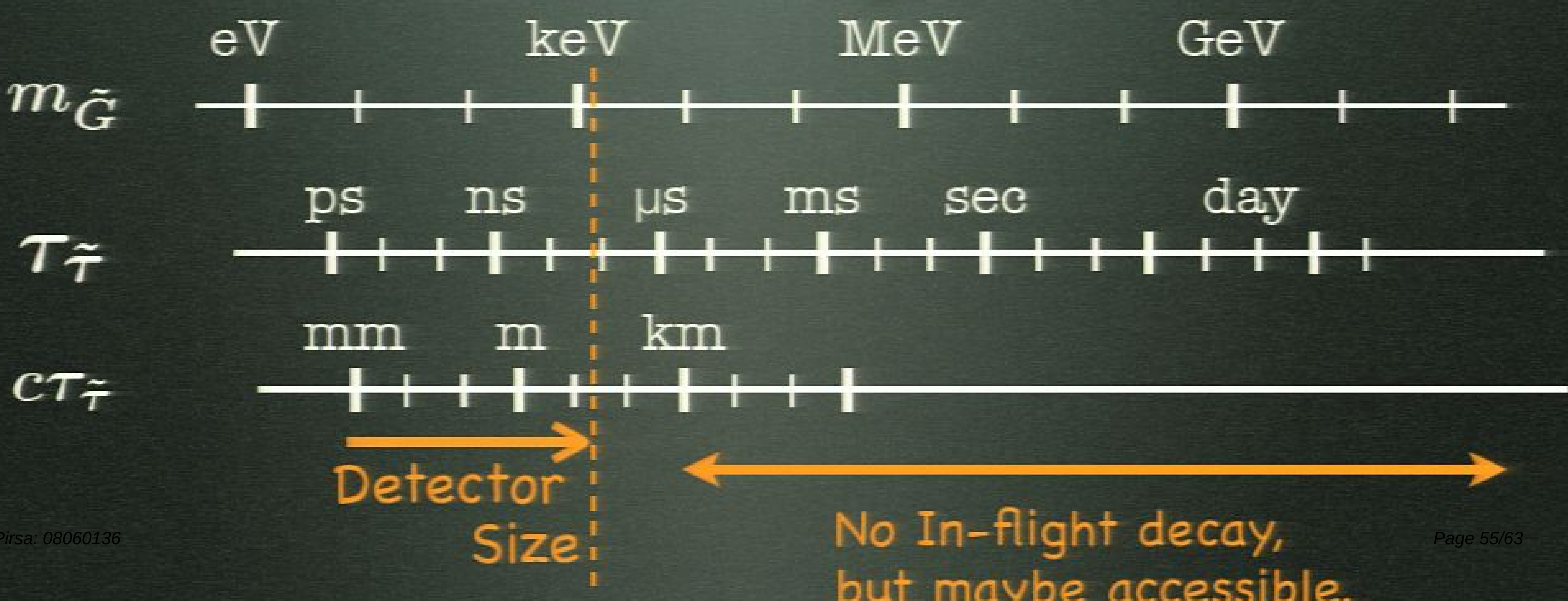

NLSP (Next-to-Lightest SUSY Particle)

In Gravitino LSP scenario, the NLSP decay always include the gravitino.

For a slepton NLSP,.....

$$\Gamma(\tilde{\tau} \to \tilde{G}\tau) \simeq \frac{m_{\tilde{\tau}}^5}{48\pi m_{\tilde{G}}^2 M_{\rm pl}^2} \left(1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^2}\right)^4$$

The gravitino mass may be determined by measuring the NLSP decay rate! However,.....

Main Message

SUSY models with an ultralight gravitino is interesting!

$(m_{\tilde{G}} \lesssim 10 \text{ eV})$

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- LSP (gravitino) ≠ DM, but a natural DM candidate exist.

Can it be tested at LHC?

(Can the gravitino mass = SUSY breaking scale
e determined?)

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$$\Omega_X^{\rm thermal} \sim 0.2 \left(\frac{\rm pb}{\sigma^X_{\rm ann.}(XX \to all)} \right)$$

$$\sigma^X_{\rm ann.} \simeq \frac{\mathcal{O}(\alpha)}{m^2} \longrightarrow m \sim \mathcal{O}(0.1-1)\ {\rm TeV}$$ WIMP

$$\sigma^X_{\rm ann.} \simeq \frac{\mathcal{O}(4\pi)}{m^2} \longrightarrow m \sim \mathcal{O}(10-100)\ {\rm TeV}$$

strongly self-interacting

- No Cosmological Problem! at all!
- LSP (gravitino) ≠ CDM (too light → hot DM), but....

$$m_{\widetilde{G}} \sim 10\ {\rm eV} \Longrightarrow F = \Lambda^2 \sim (100\ {\rm TeV})^2$$

100 TeV DM ➔ natural thermal relic DM if strongly interacting

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

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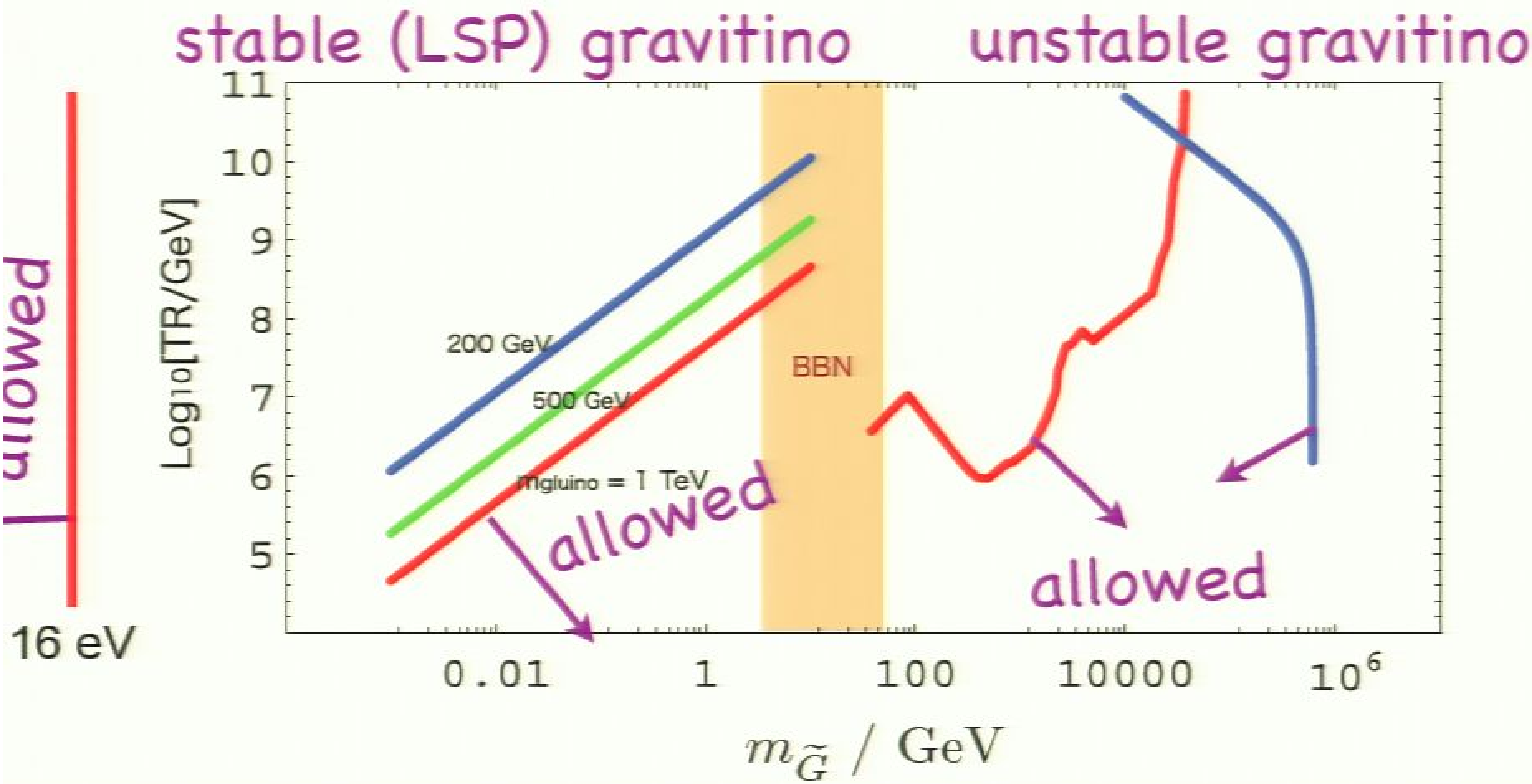
Gravitino Problems



(NOTE: precise line positions in this figure may be out-dated.)