Determination of the Mass of an Ultralight Gravitino at LHC

Koichi Hamaguchi (Tokyo U.)

with S.Shirai and T.T.Yanagida

today!

arXiv:0705.0219, 0707.2463, **0712.2462**

@ “IPMU focus week: Facing LHC data”, Dec. 2007

Summary: (beer is waiting for us.....)

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

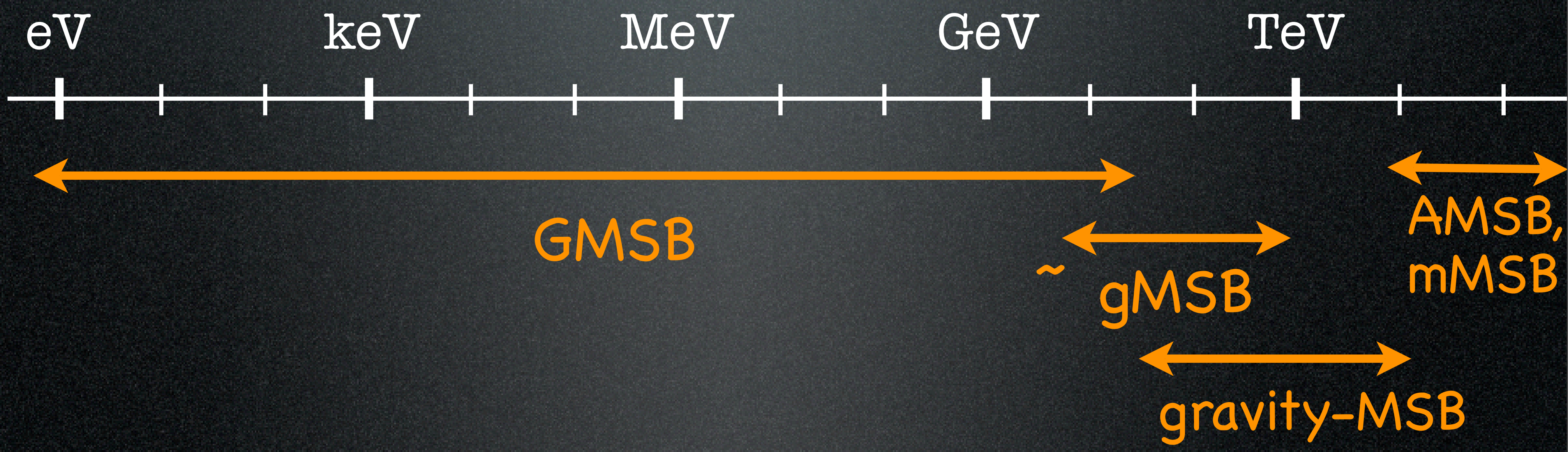
- If SUSY is in nature, it is (probably) a spontaneously broken local symmetry (i.e., not an accidental global symmetry).
- And the gravitino is an inevitable prediction of local SUSY (= SUGRA).

Gravitino

- Gravitino Interaction: extremely weak

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

- Gravitino Mass: model dependent



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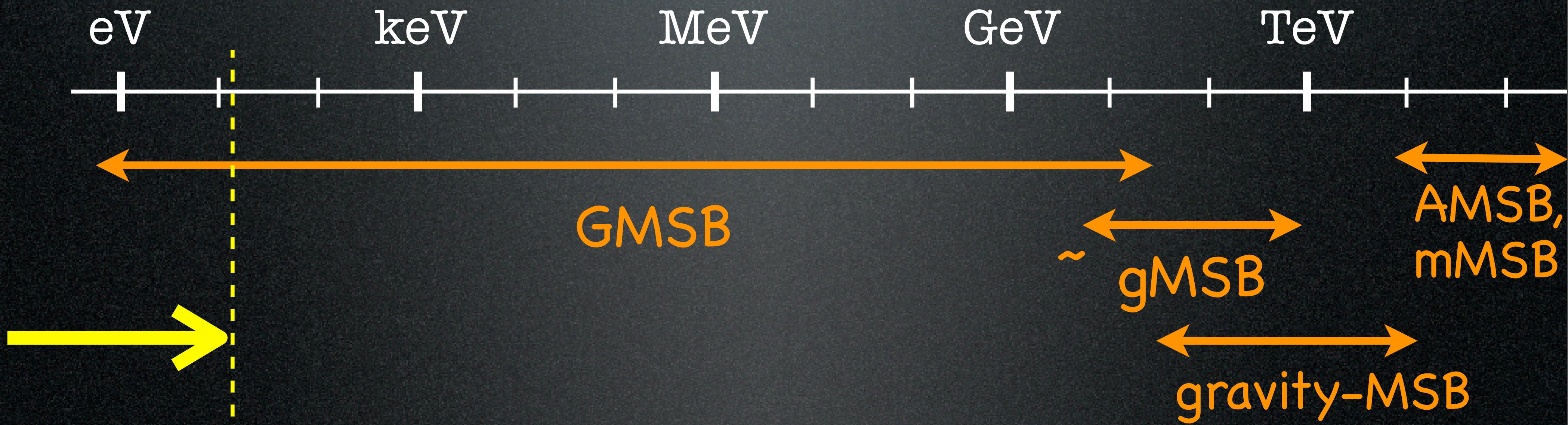
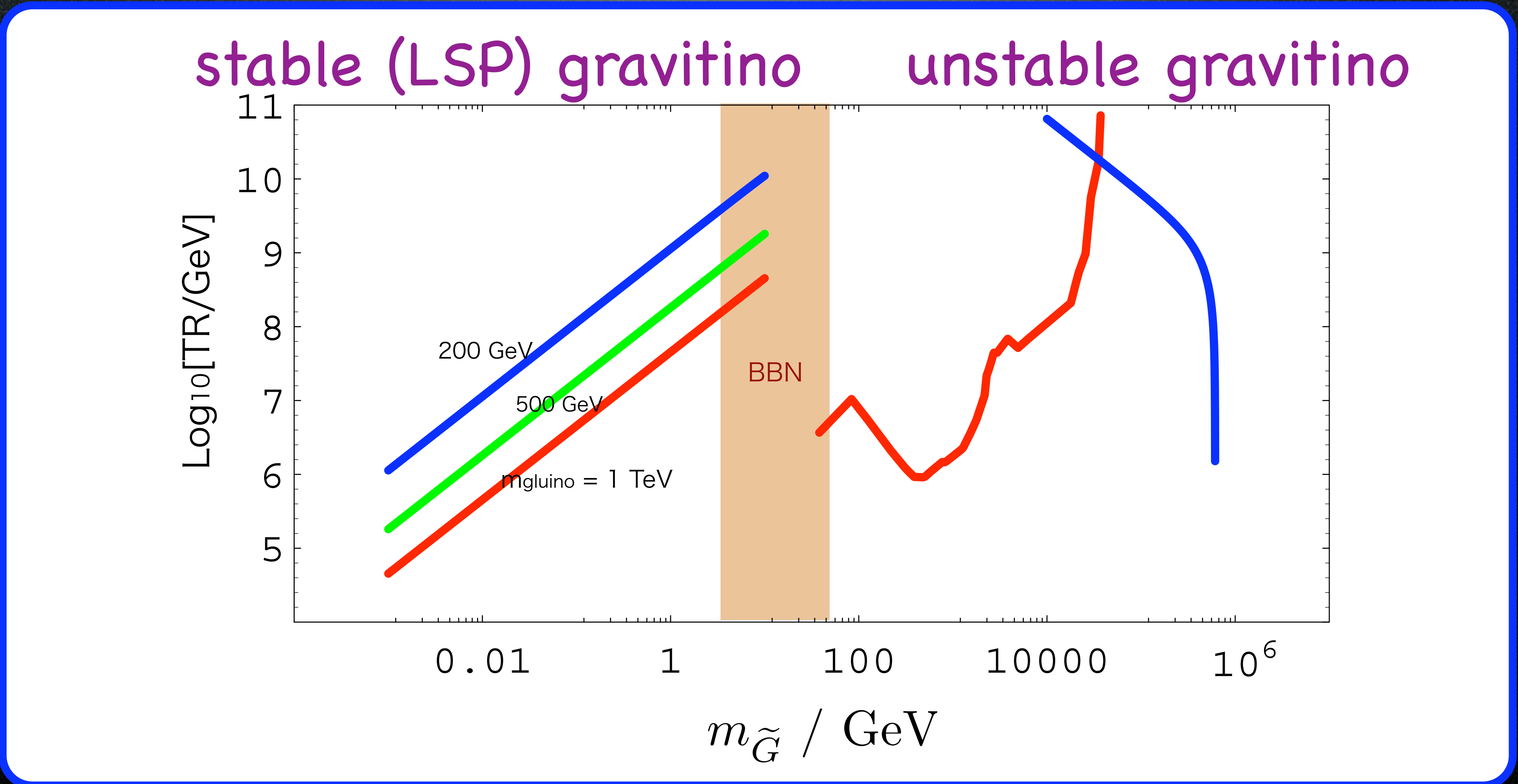


ultralight gravitino

Gravitino Problems



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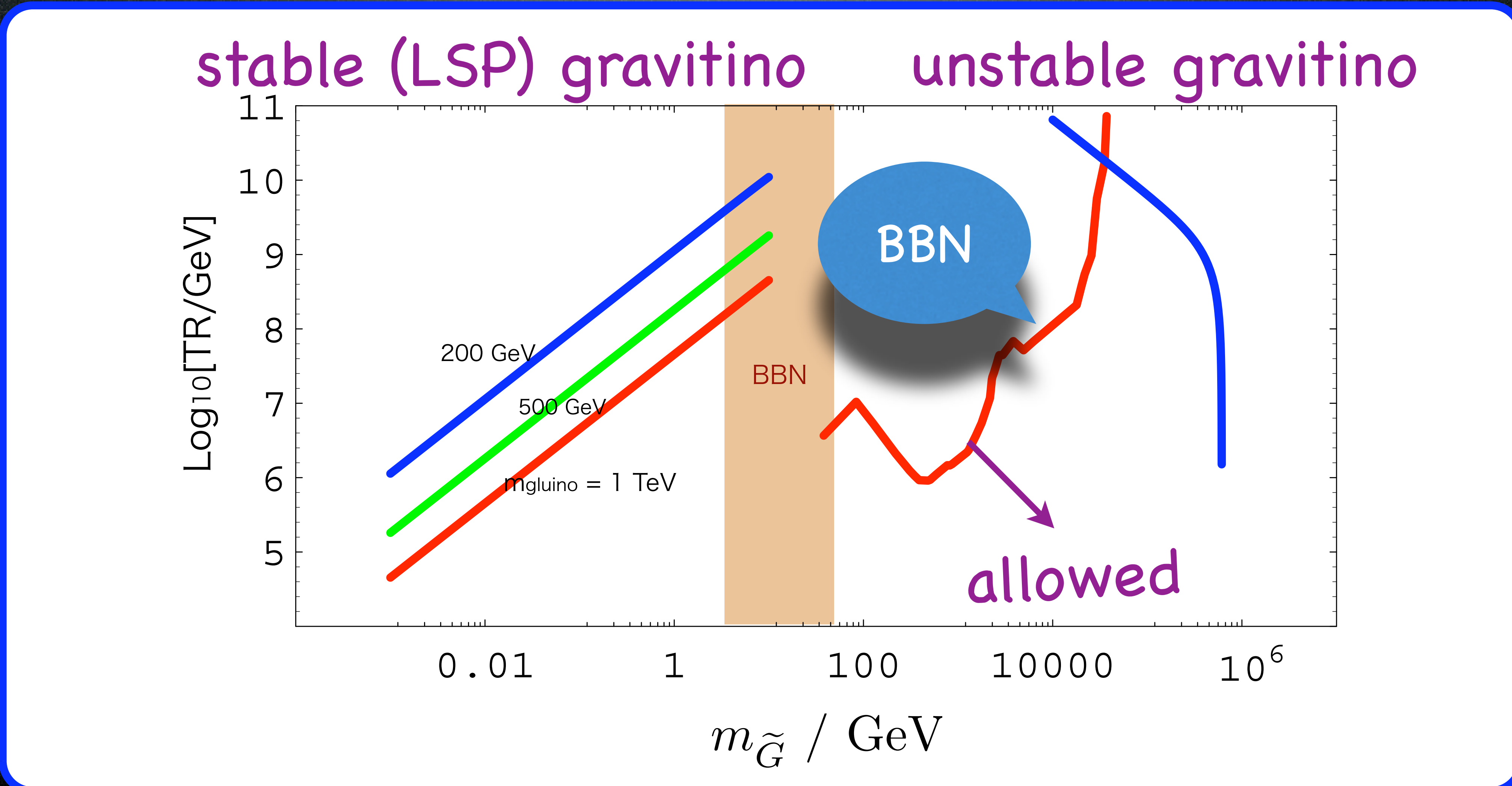

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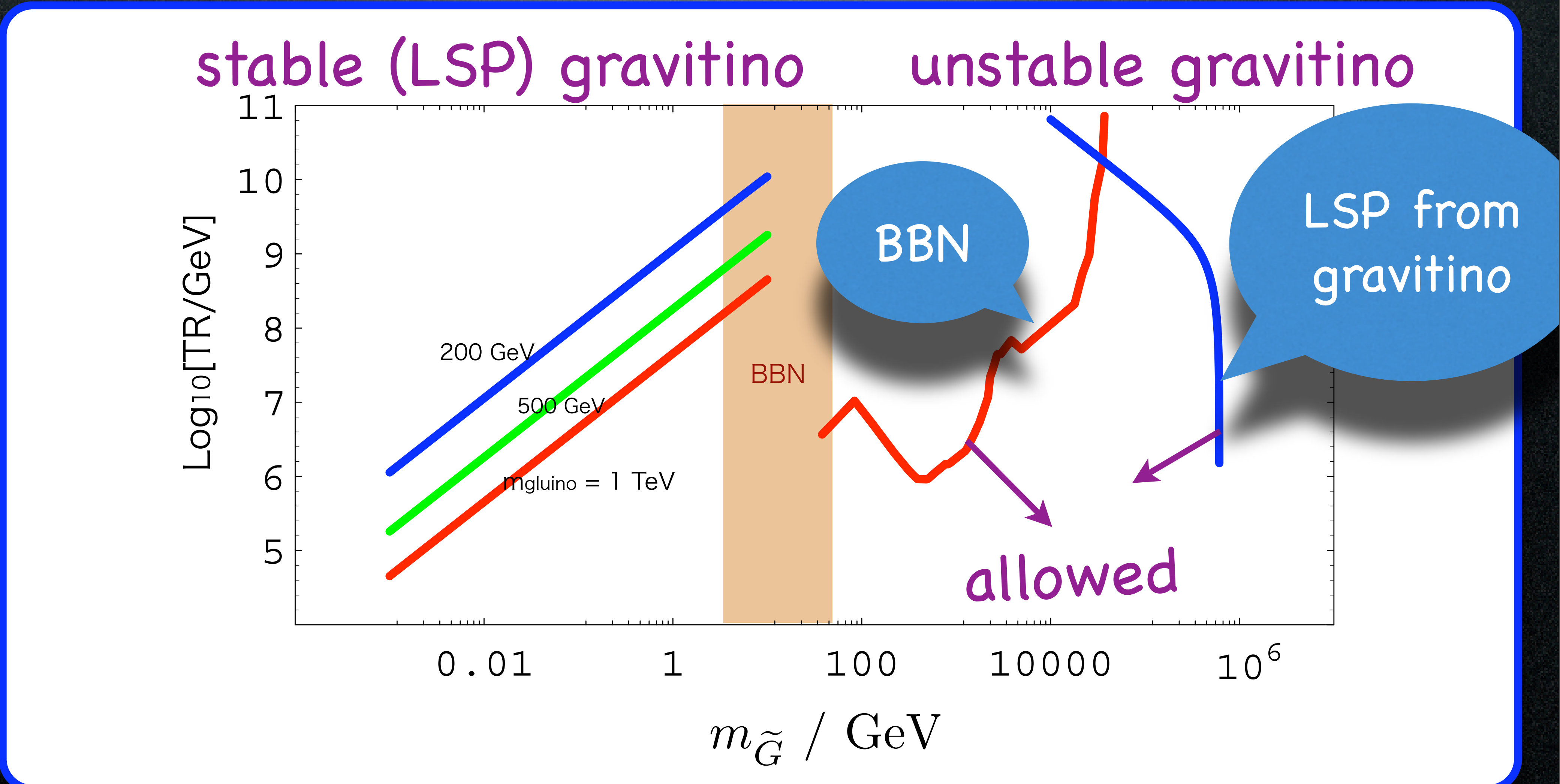

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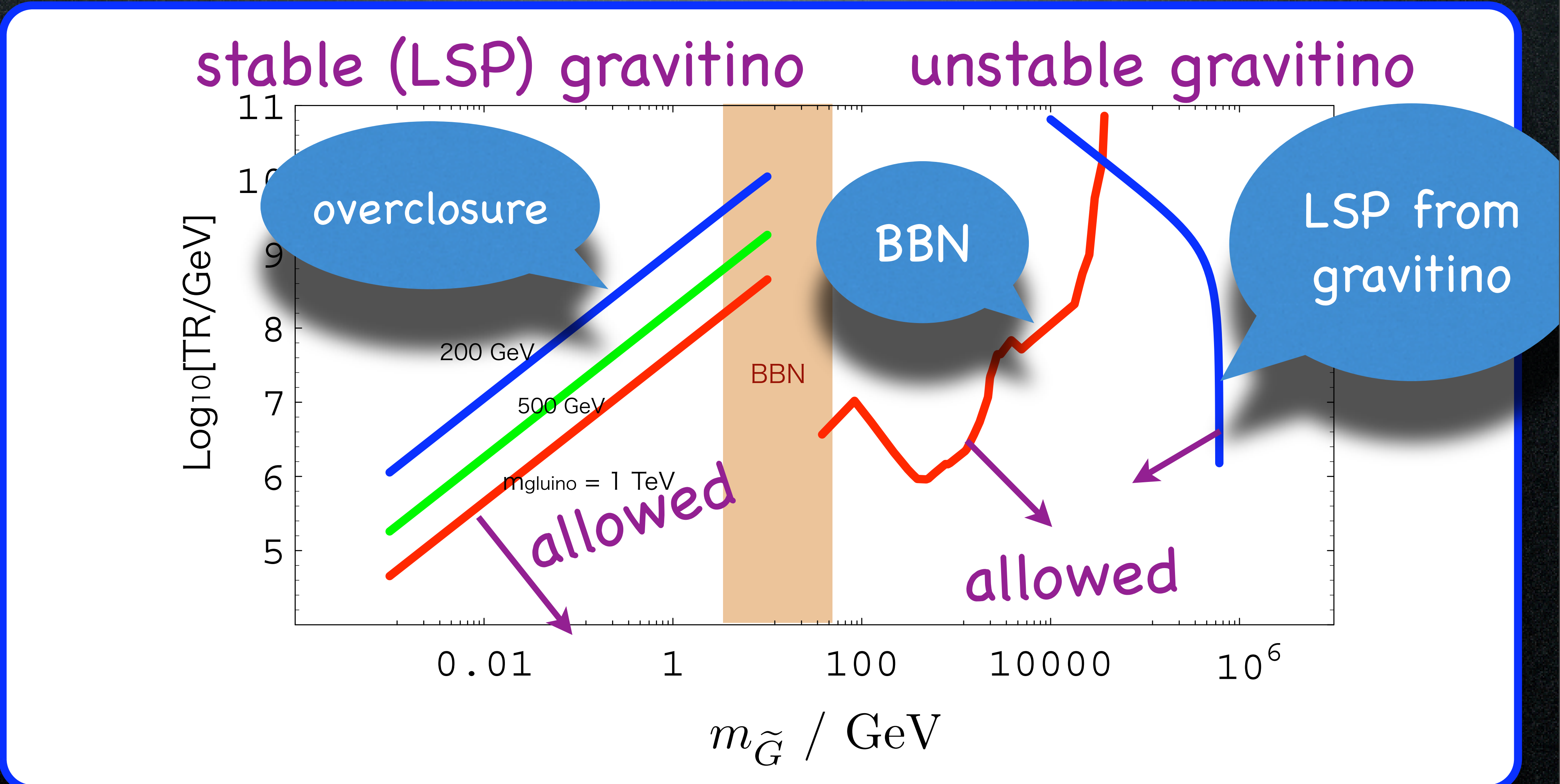

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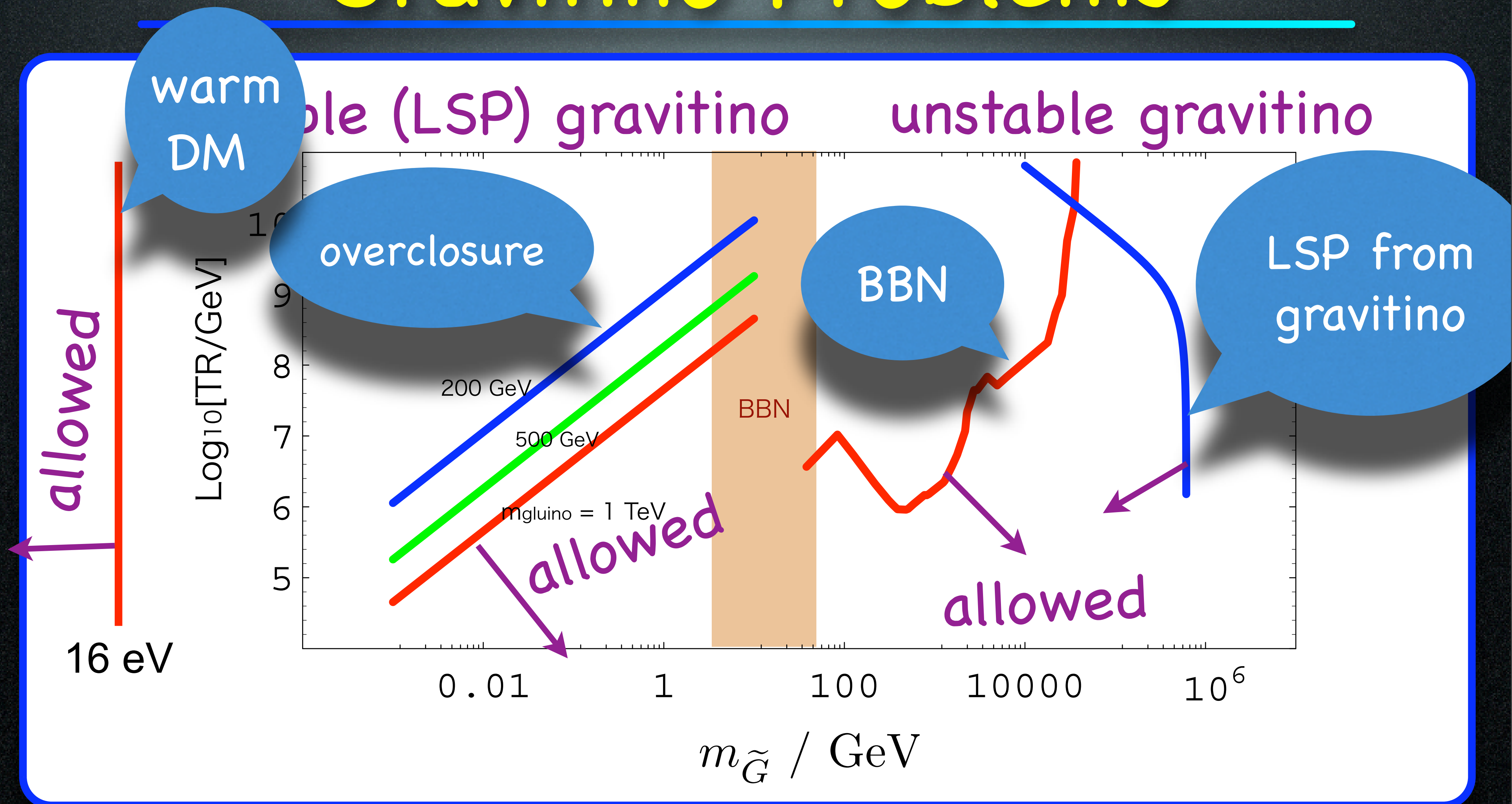

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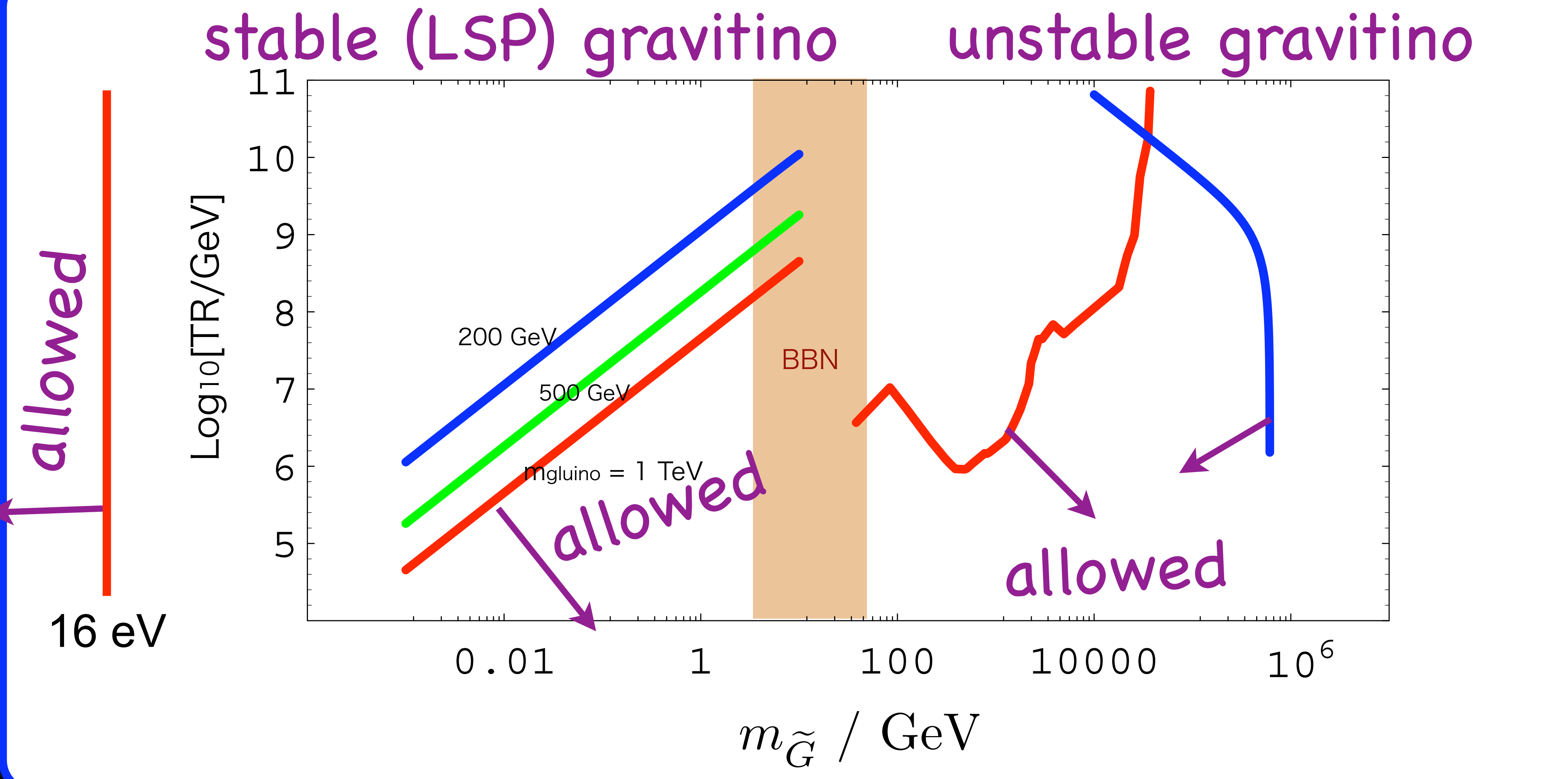

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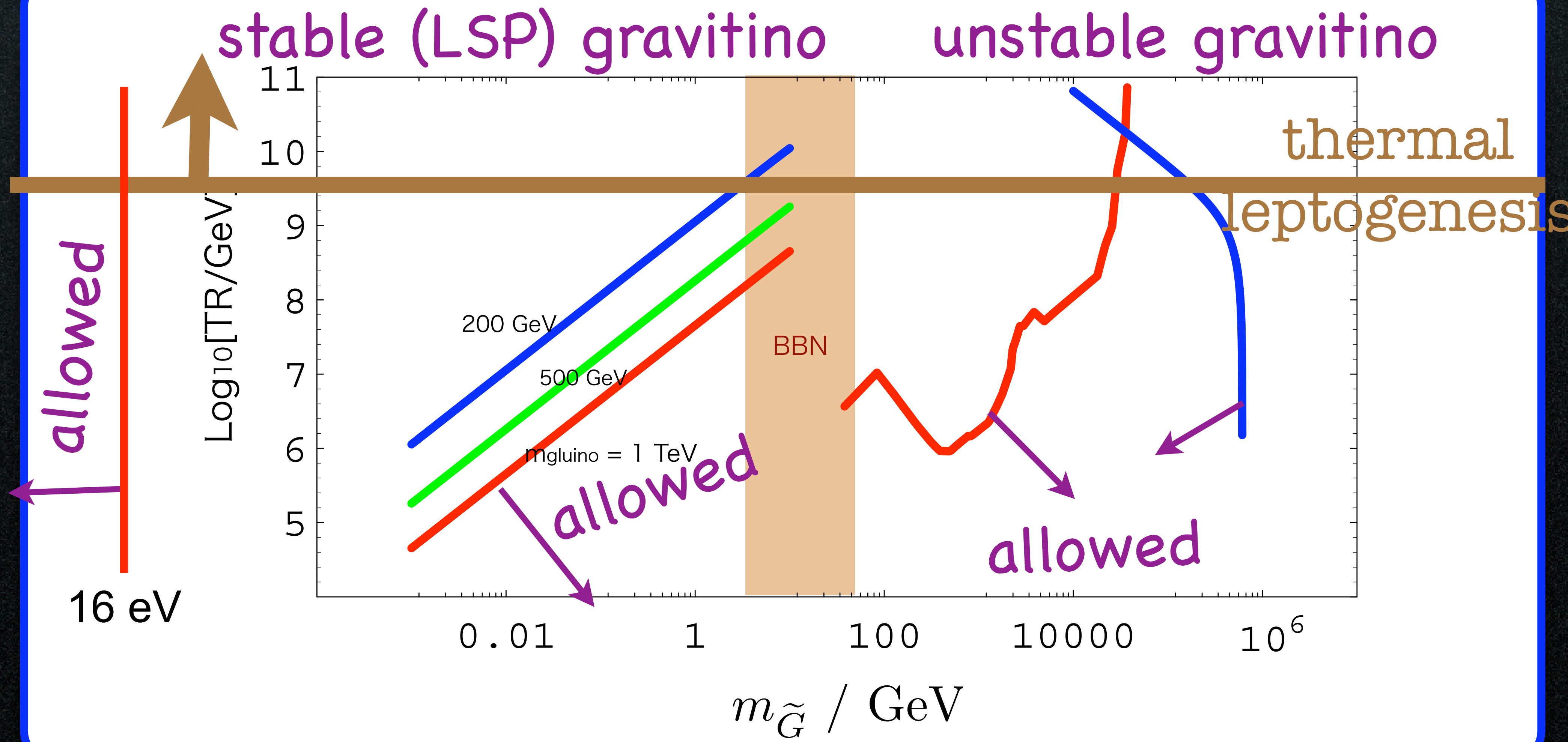

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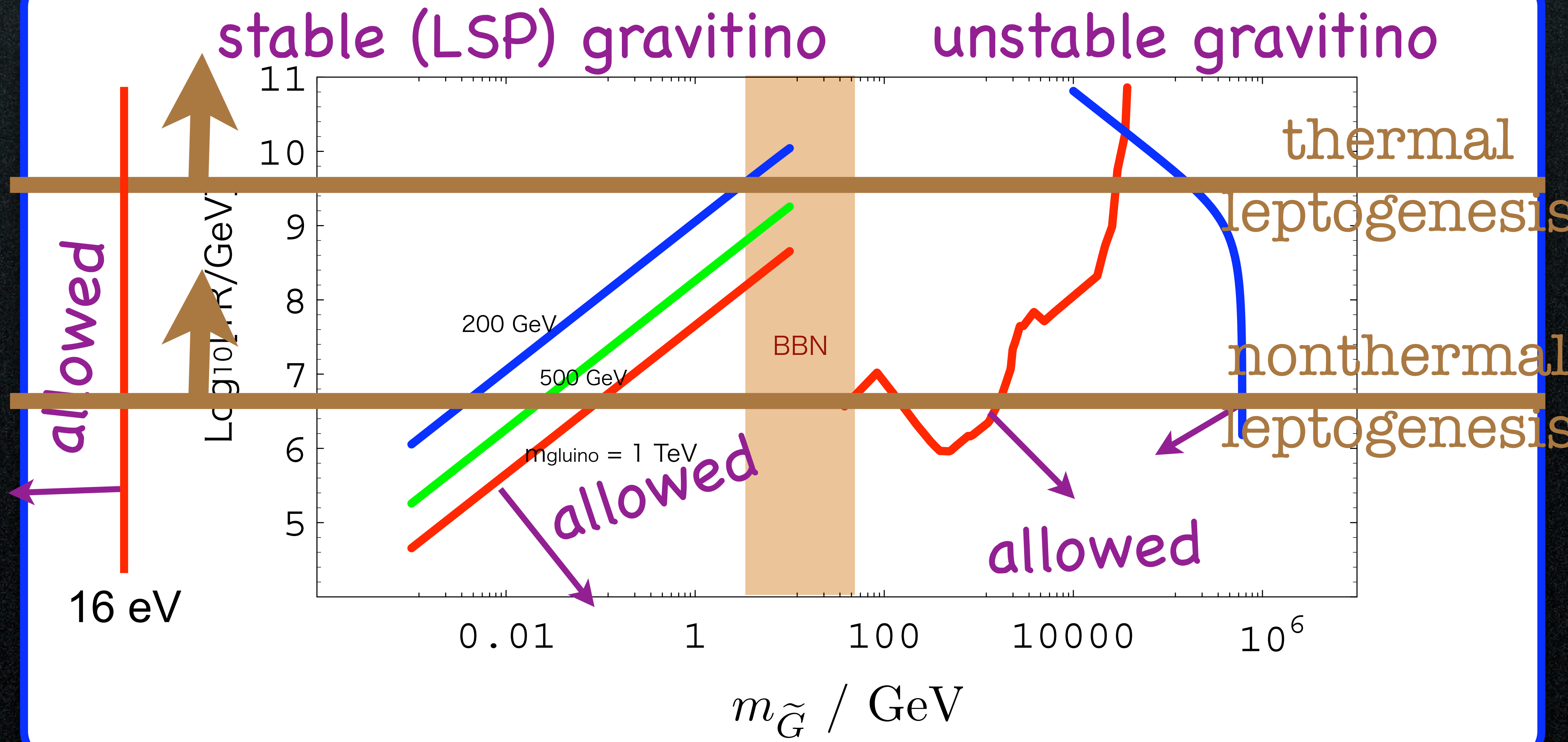

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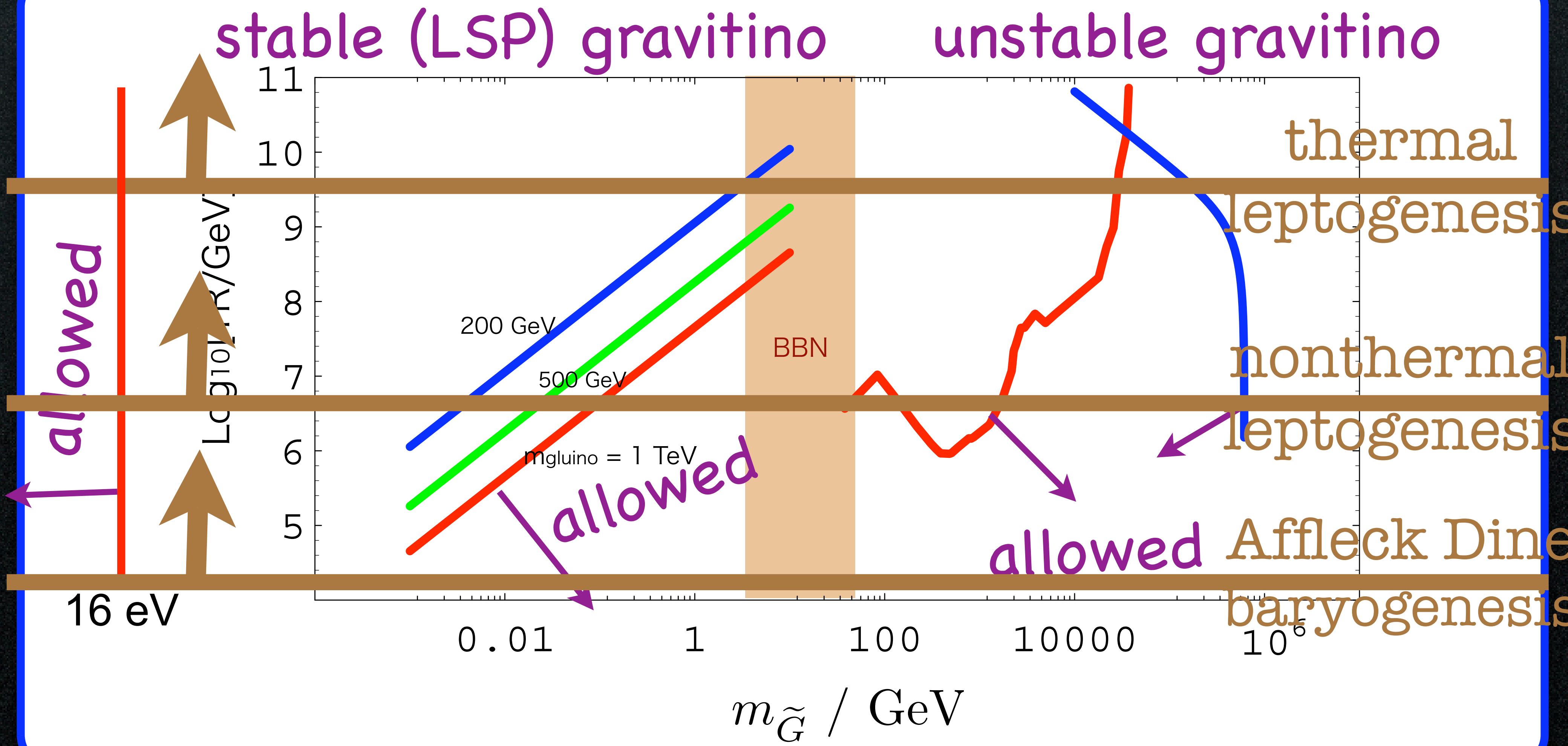

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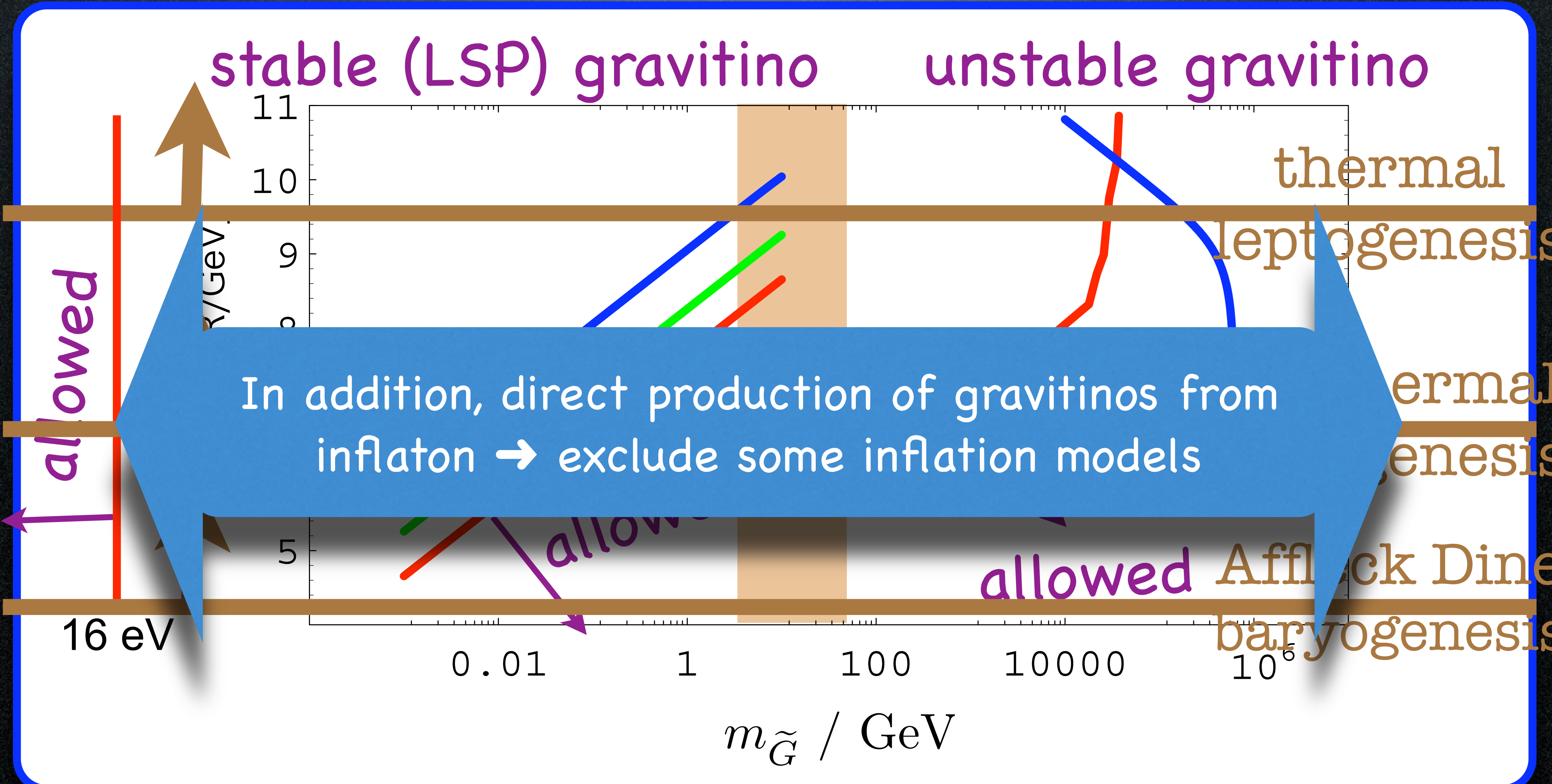

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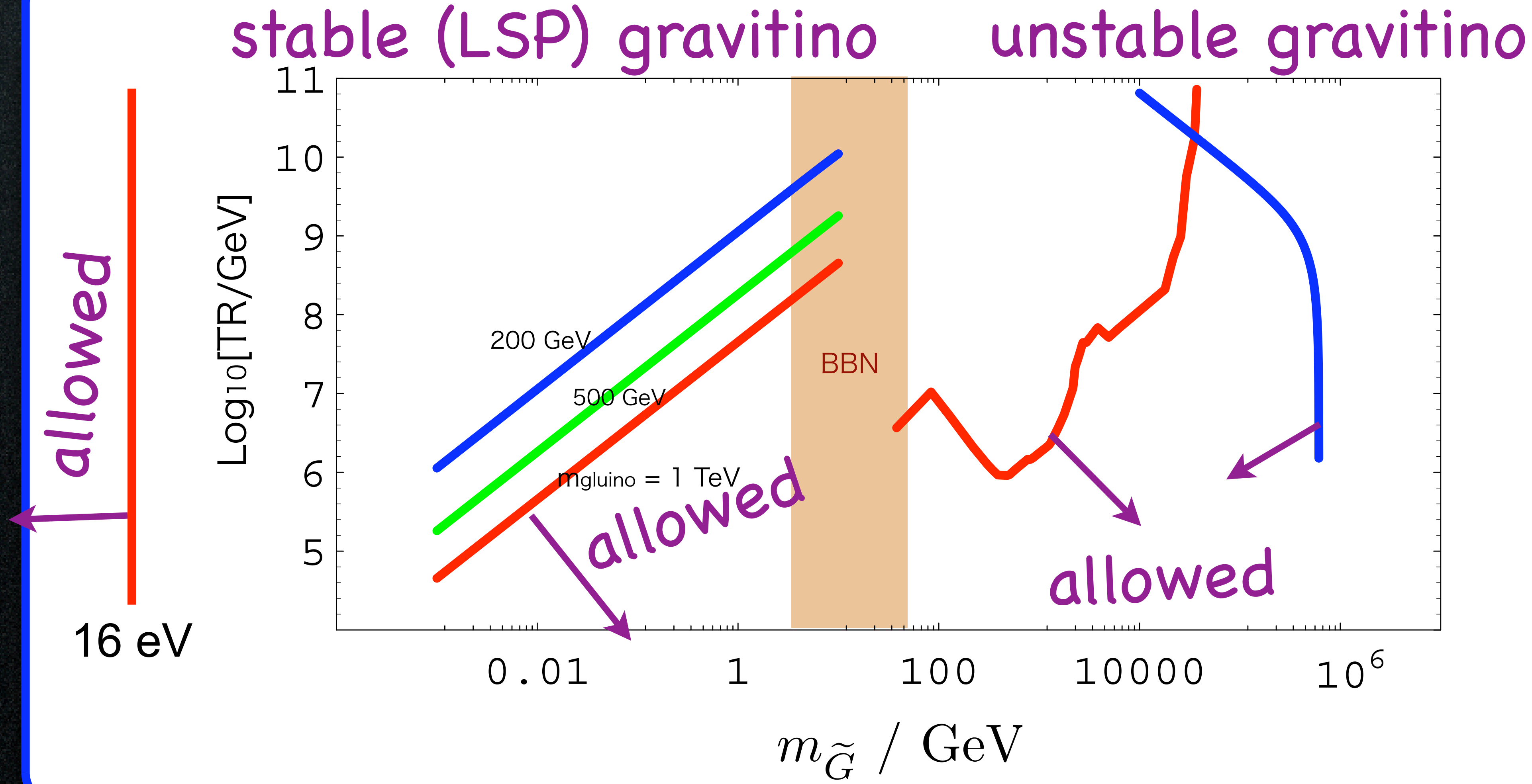

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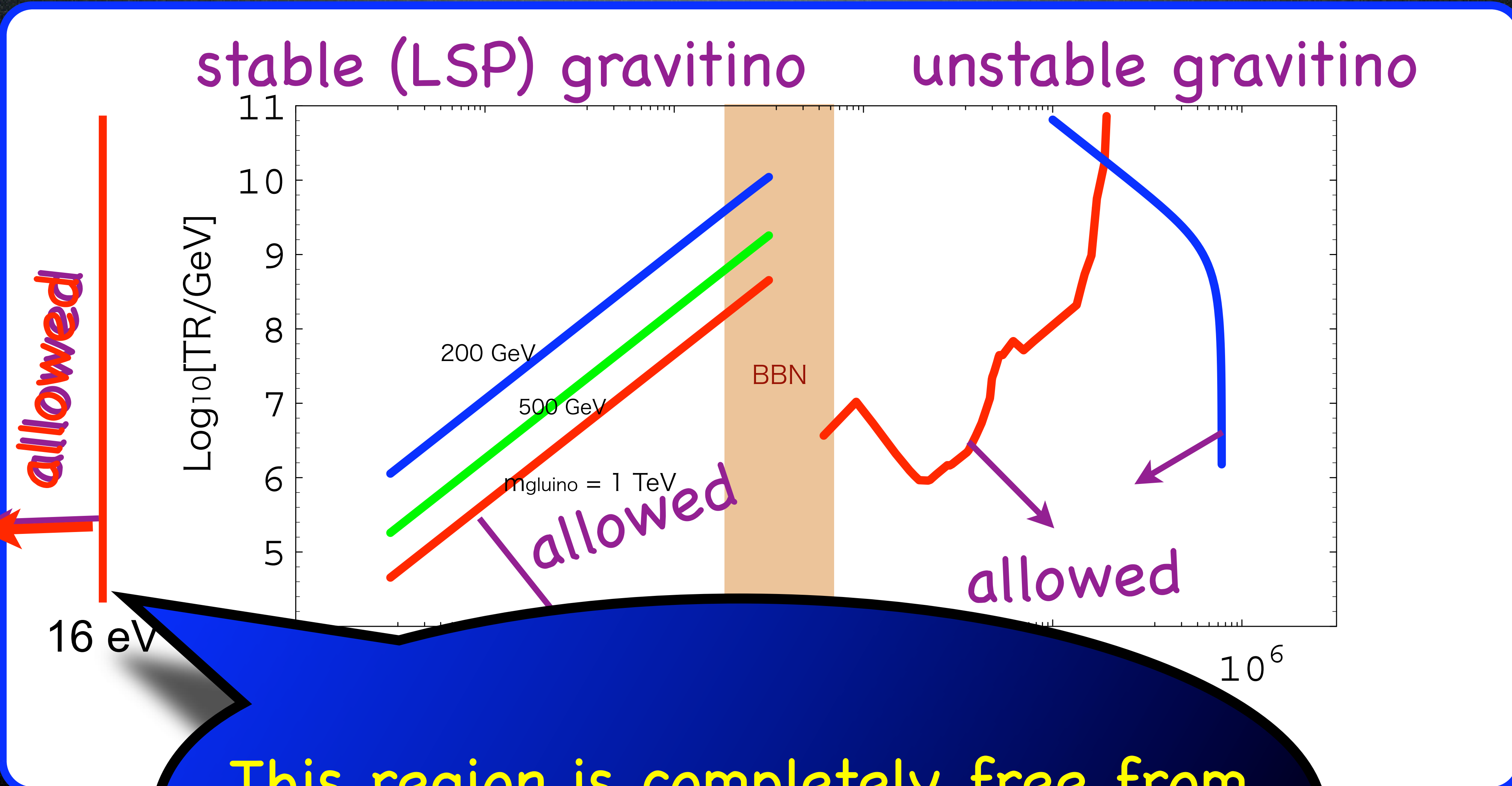

This region is completely free from cosmological gravitino problems!!

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

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

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

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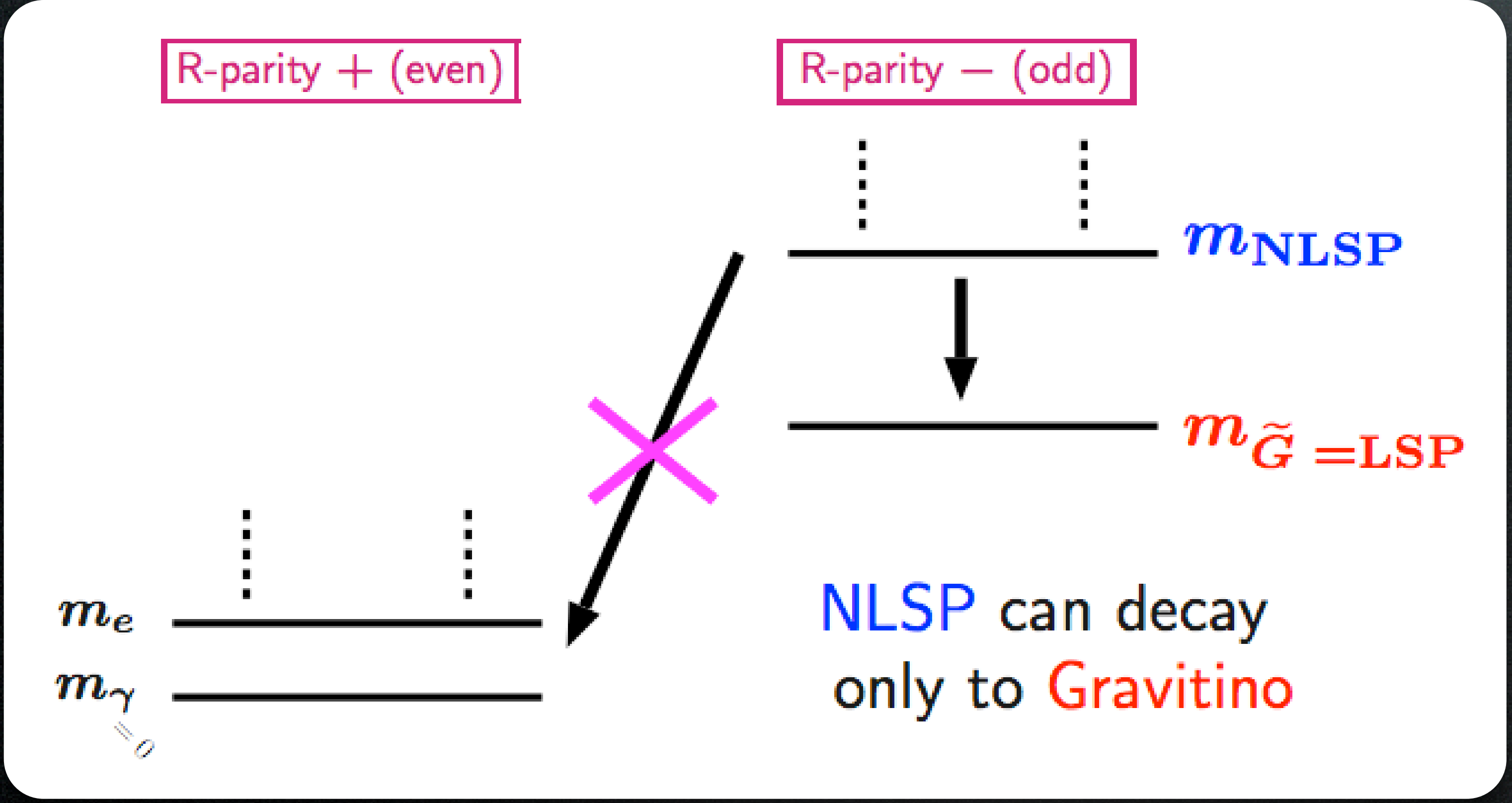
Can it be tested at LHC?

(Can the gravitino mass = SUSY breaking scale be 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)

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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

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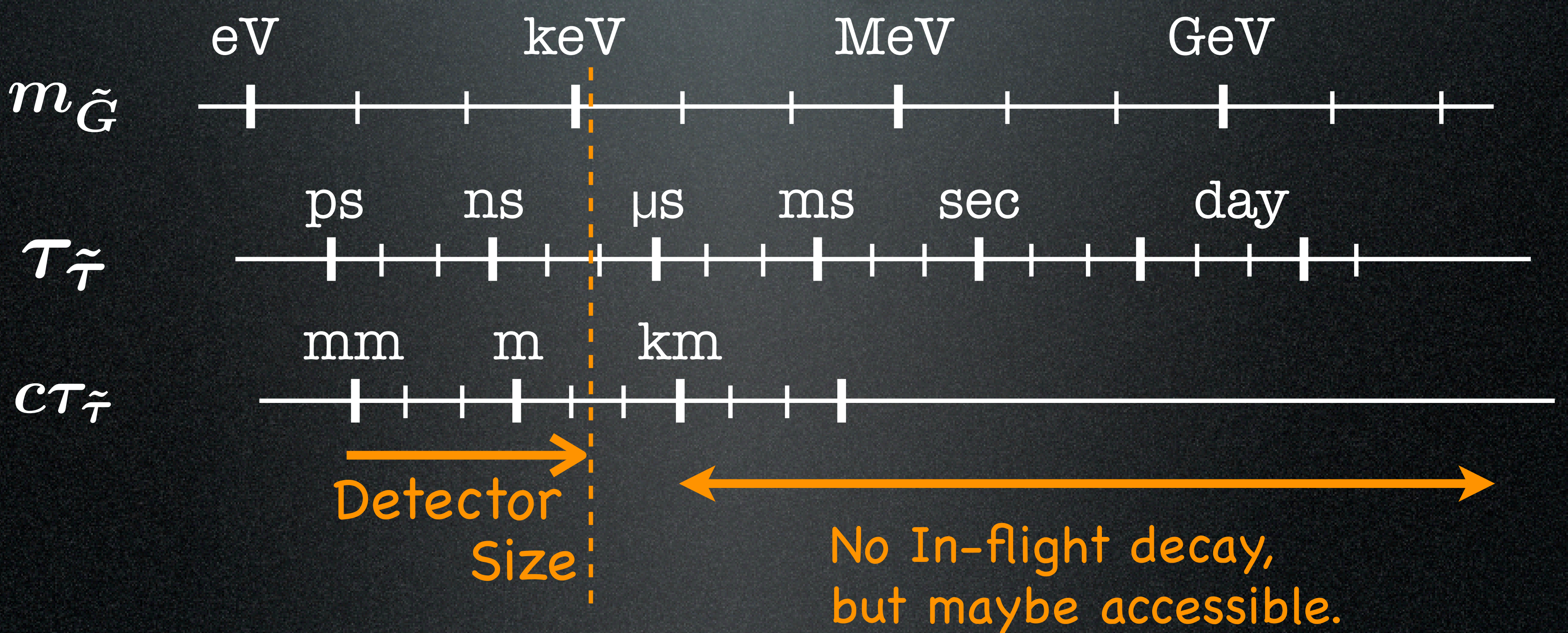
Lifetime (decay length) of NLSP stau

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



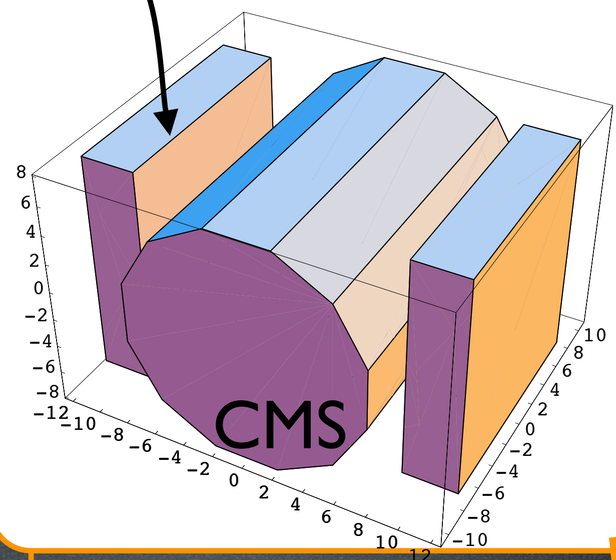
charge[...]

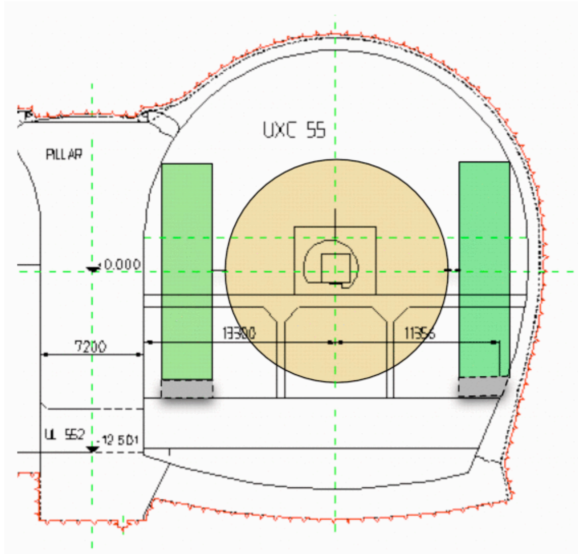
$$\Gamma(\tilde{\tau} \rightarrow \tilde{G}\tau) \simeq$$

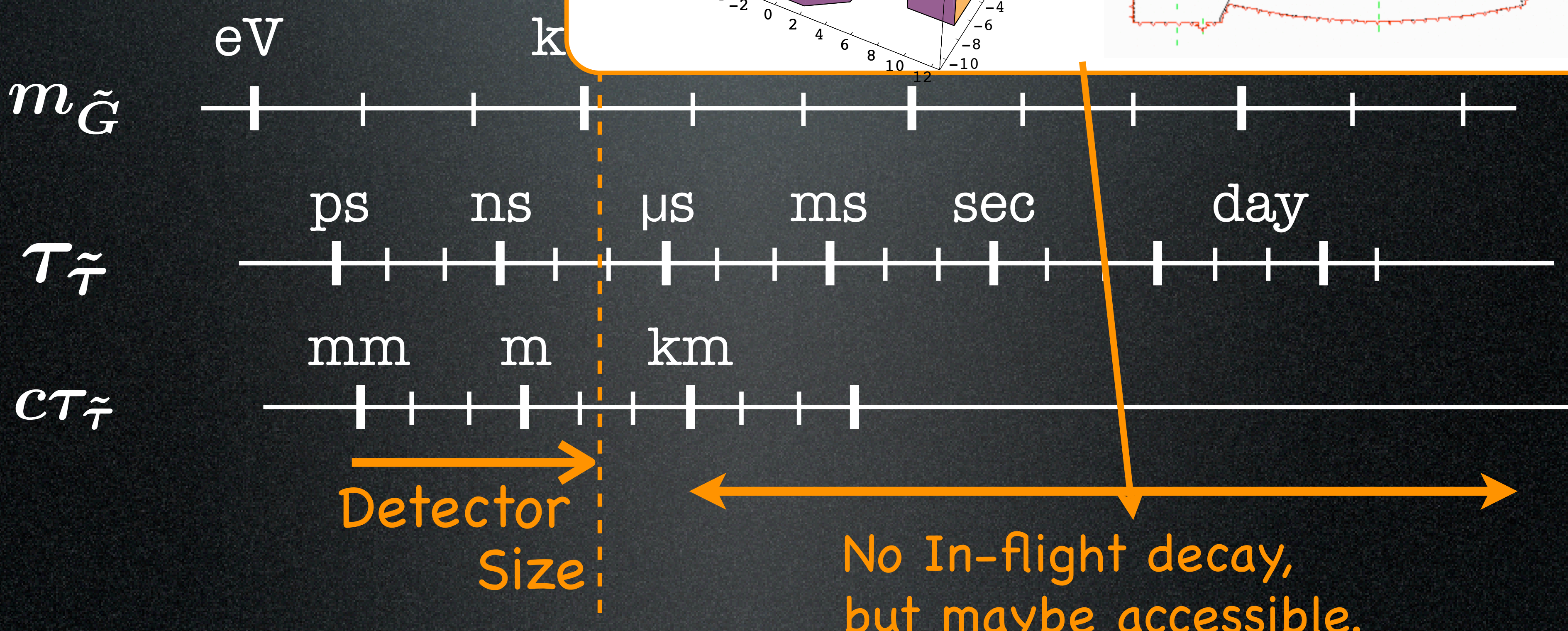
Lifetime (decay leng[...]

stopper-detector

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







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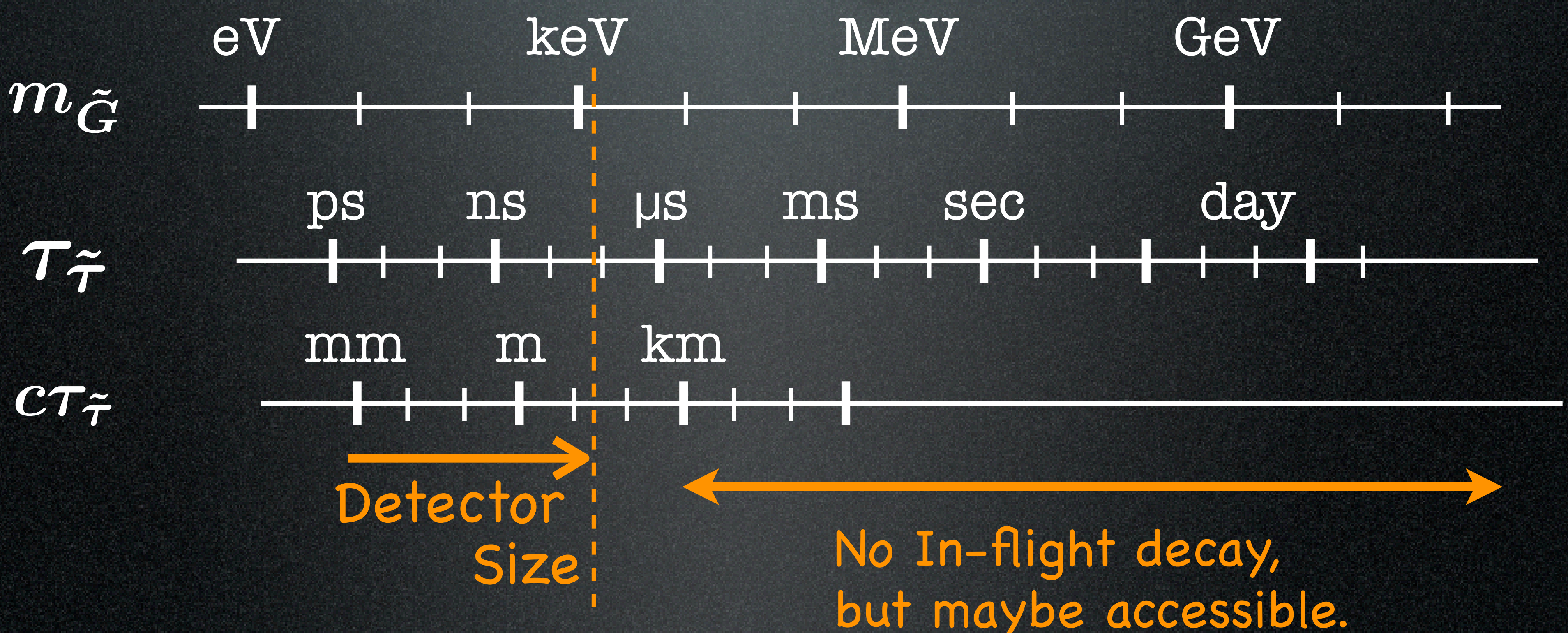

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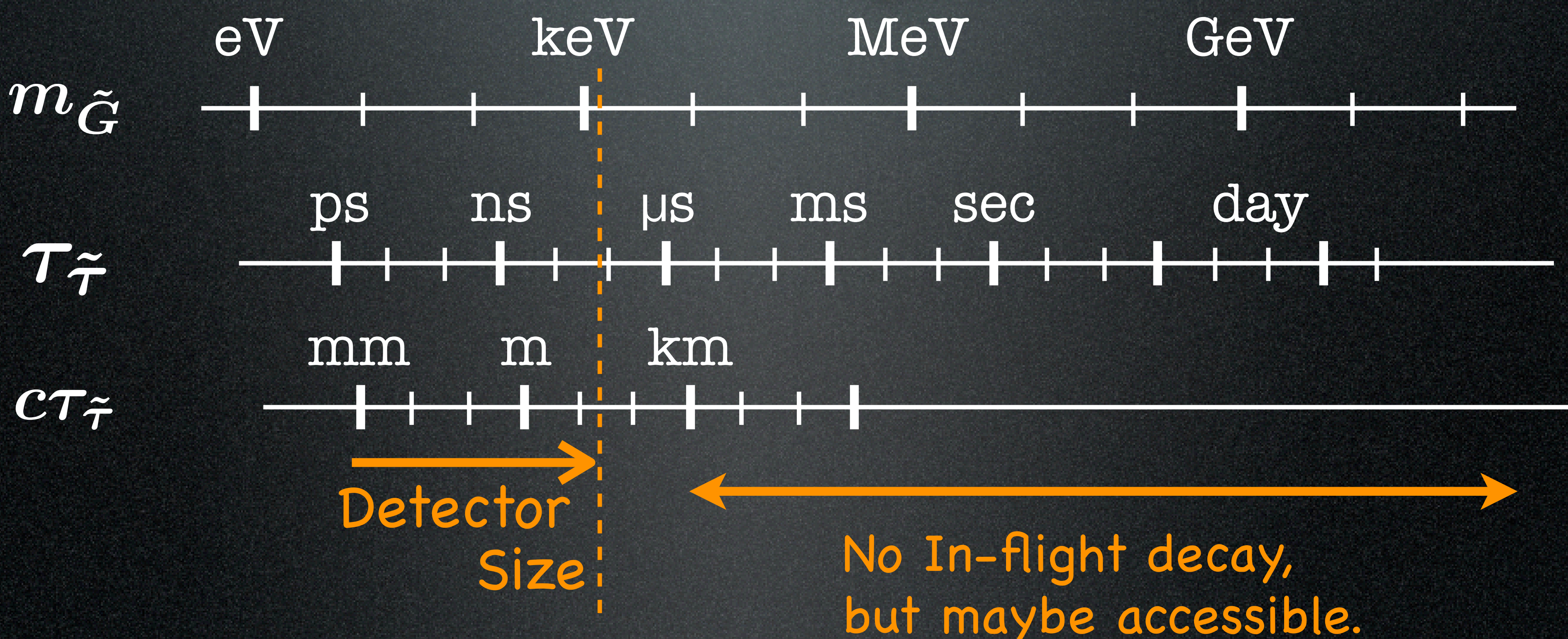

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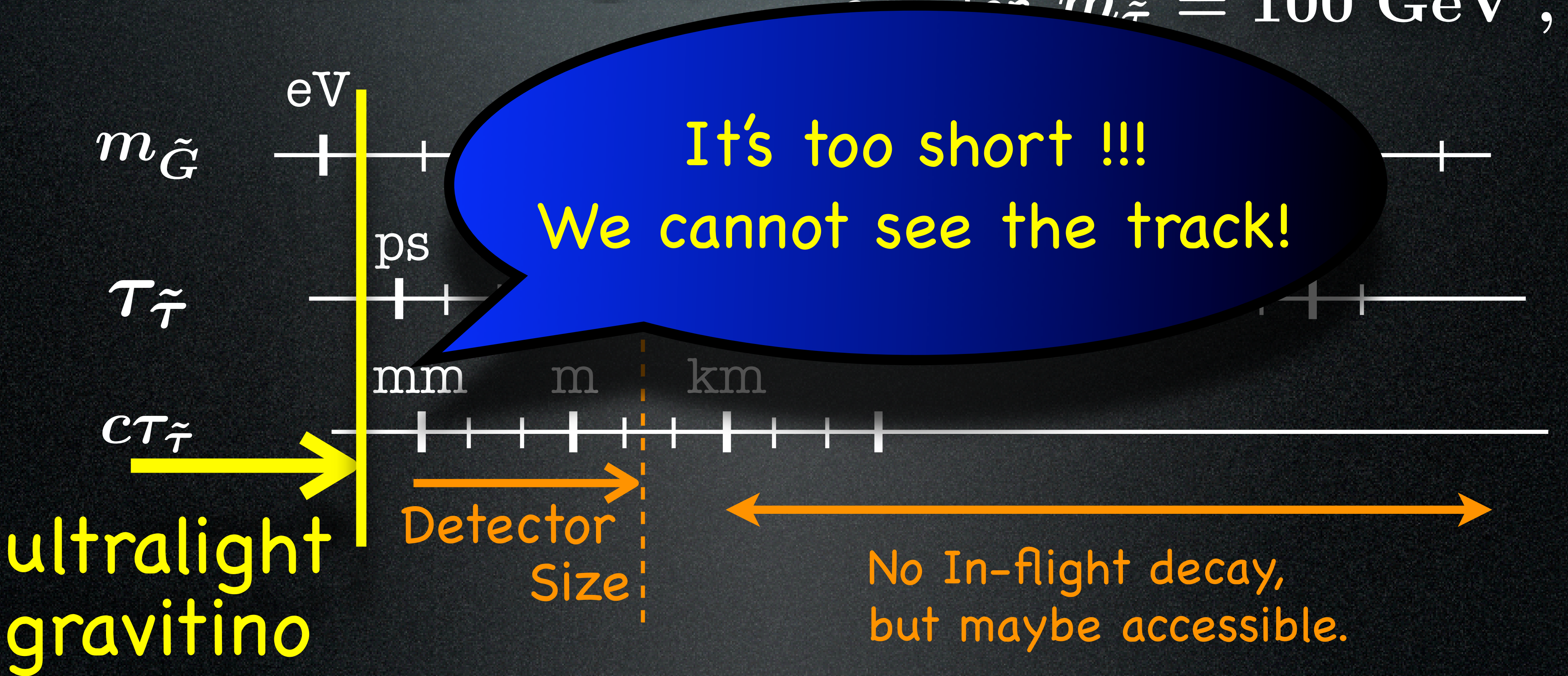
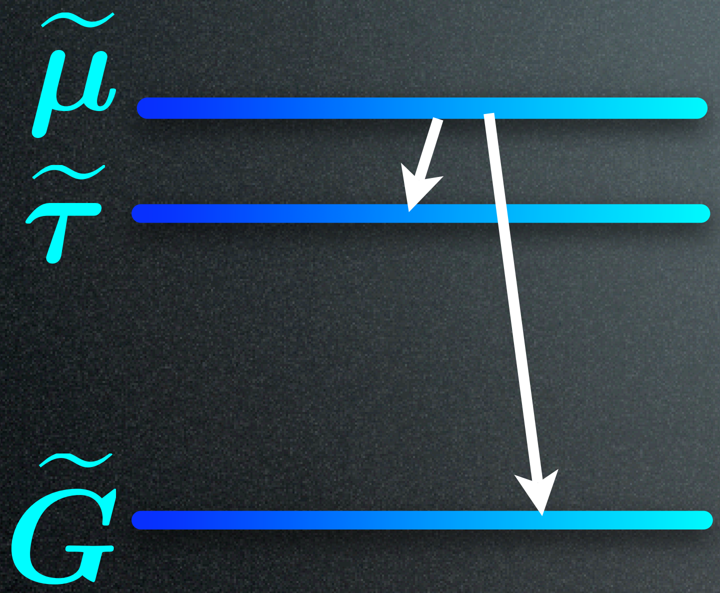


Idea: Look at NNLSP sleptons



two decay modes

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

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

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

difficult to measure
(too short decay length)

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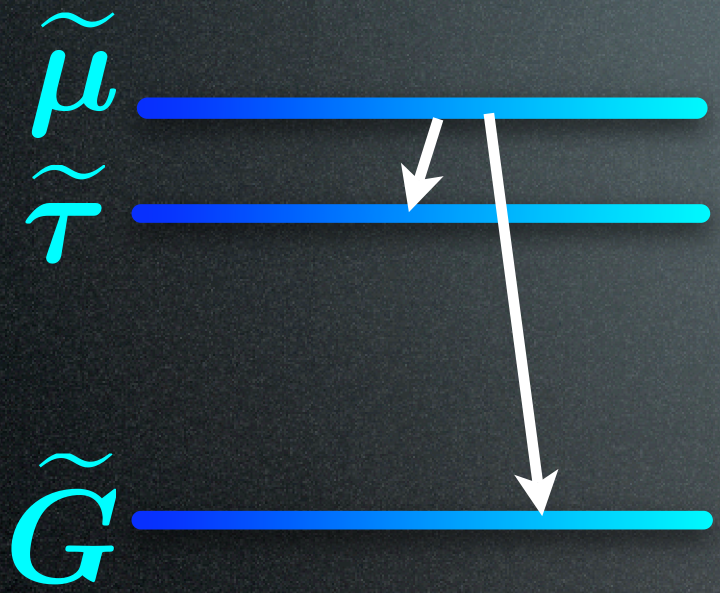

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calculable if other
SUSY masses are known

measurable!

Idea: Look at NNLSP sleptons

$\widetilde{\mu}$

$\widetilde{\tau}$

$\widetilde{G}$

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

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

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

idea

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

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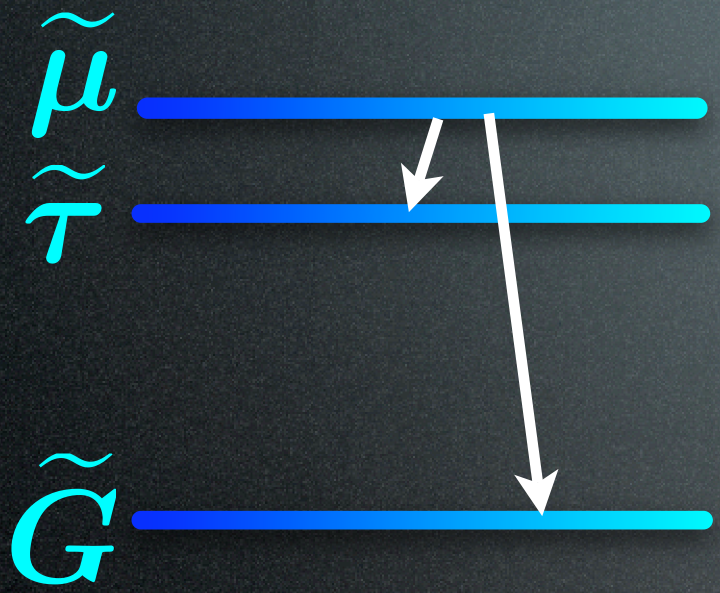

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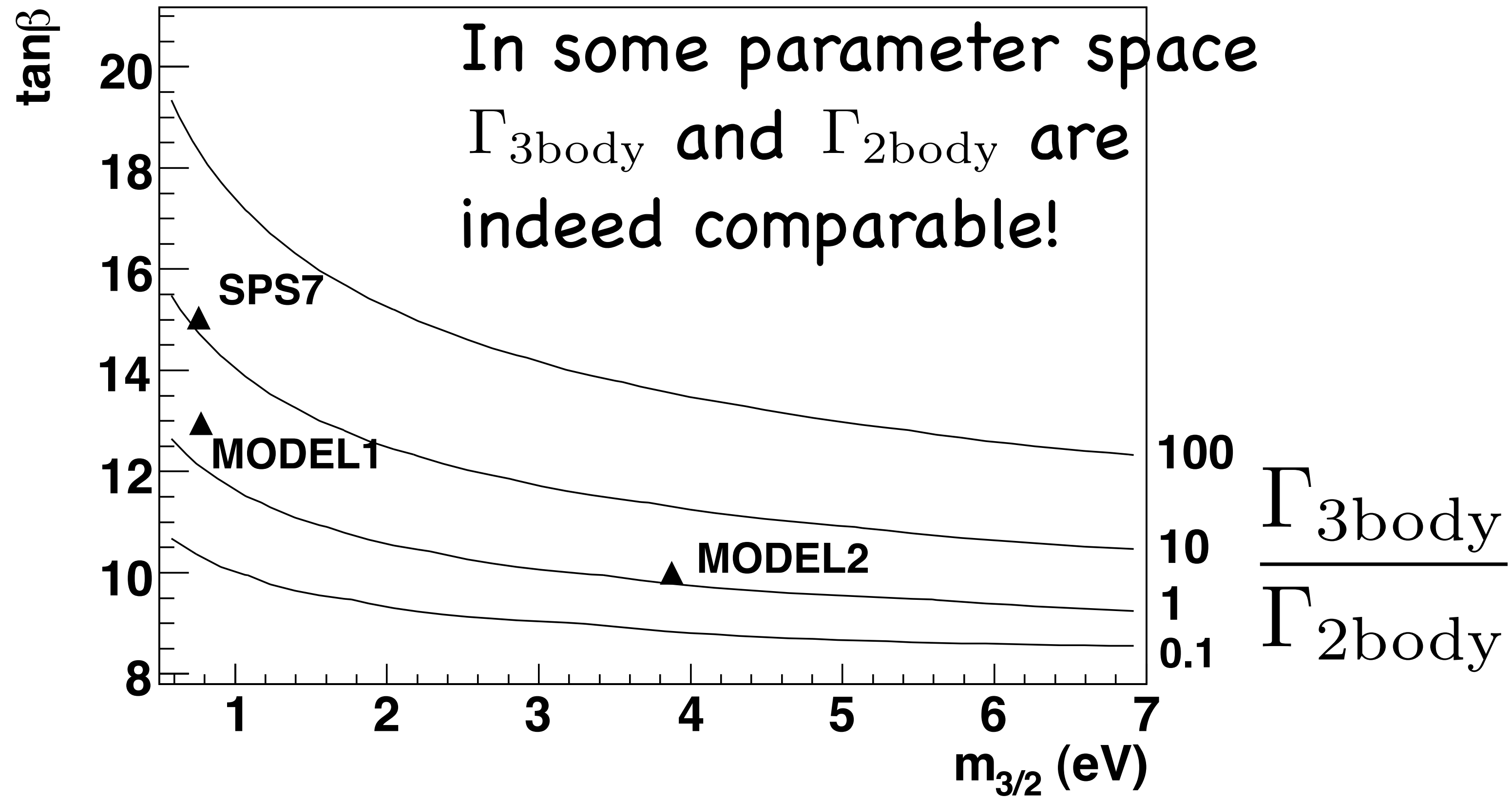

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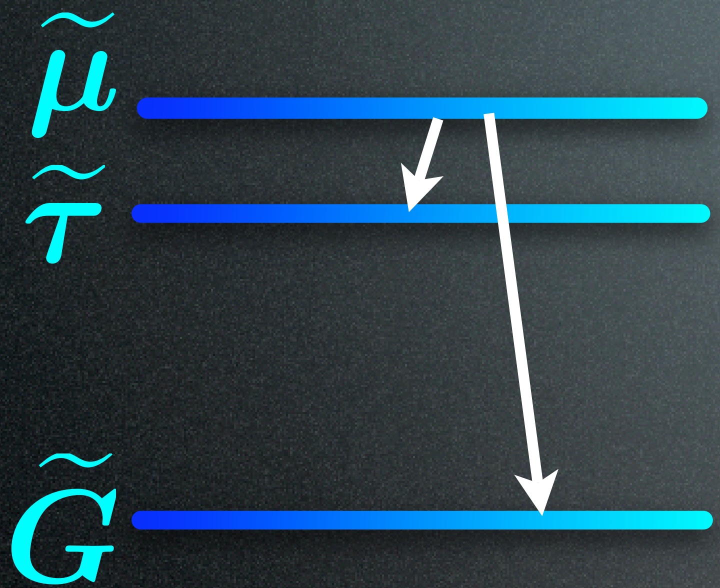

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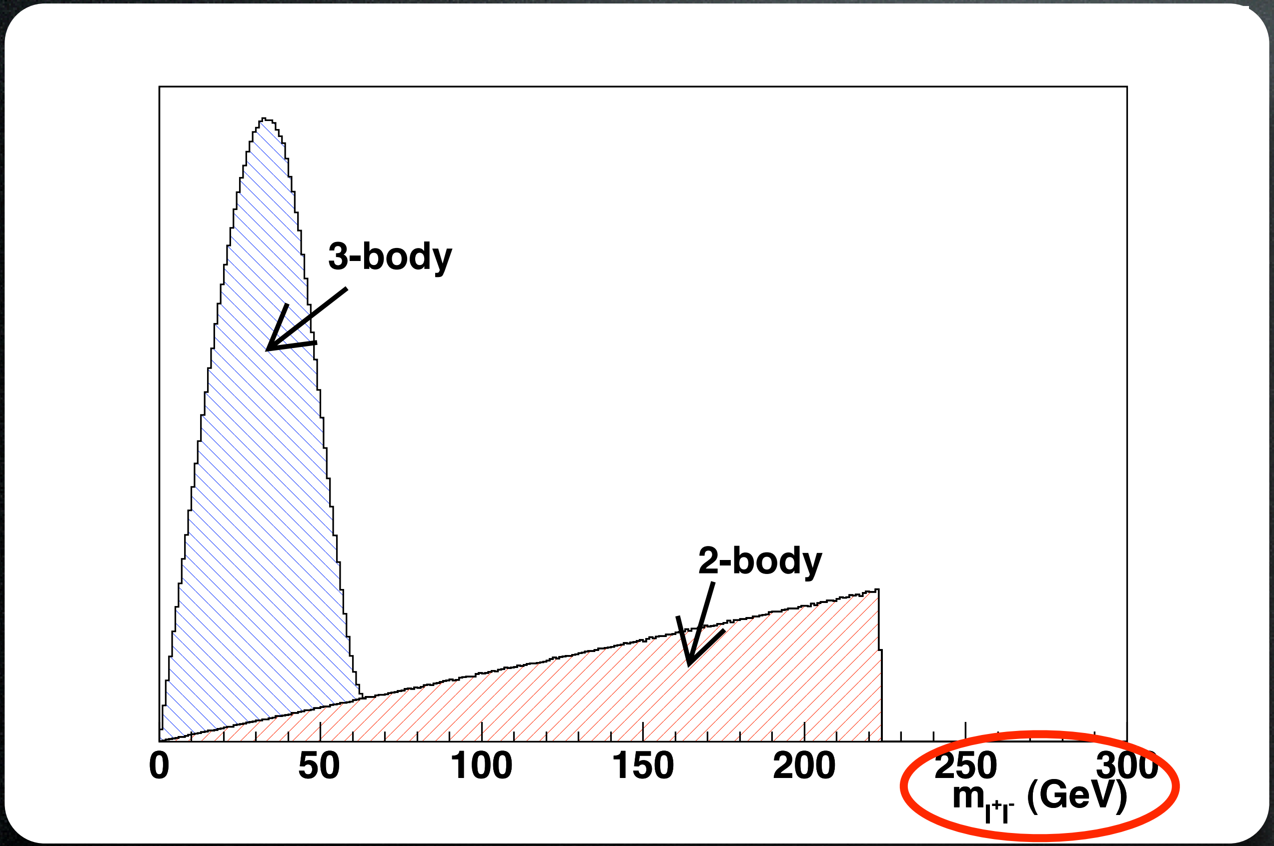
How can we measure the $\Gamma_{3\text{body}}/\Gamma_{2\text{body}}$?

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

$$\widetilde{\chi}_1^0 \to \ell + \widetilde{\ell} \qquad \begin{array}{ll} \widetilde{\ell} \to \ell + \widetilde{G} & \text{(2 body)} \\ \widetilde{\ell} \to \ell + \widetilde{\tau} + \tau & \text{(3 body)} \end{array}$$



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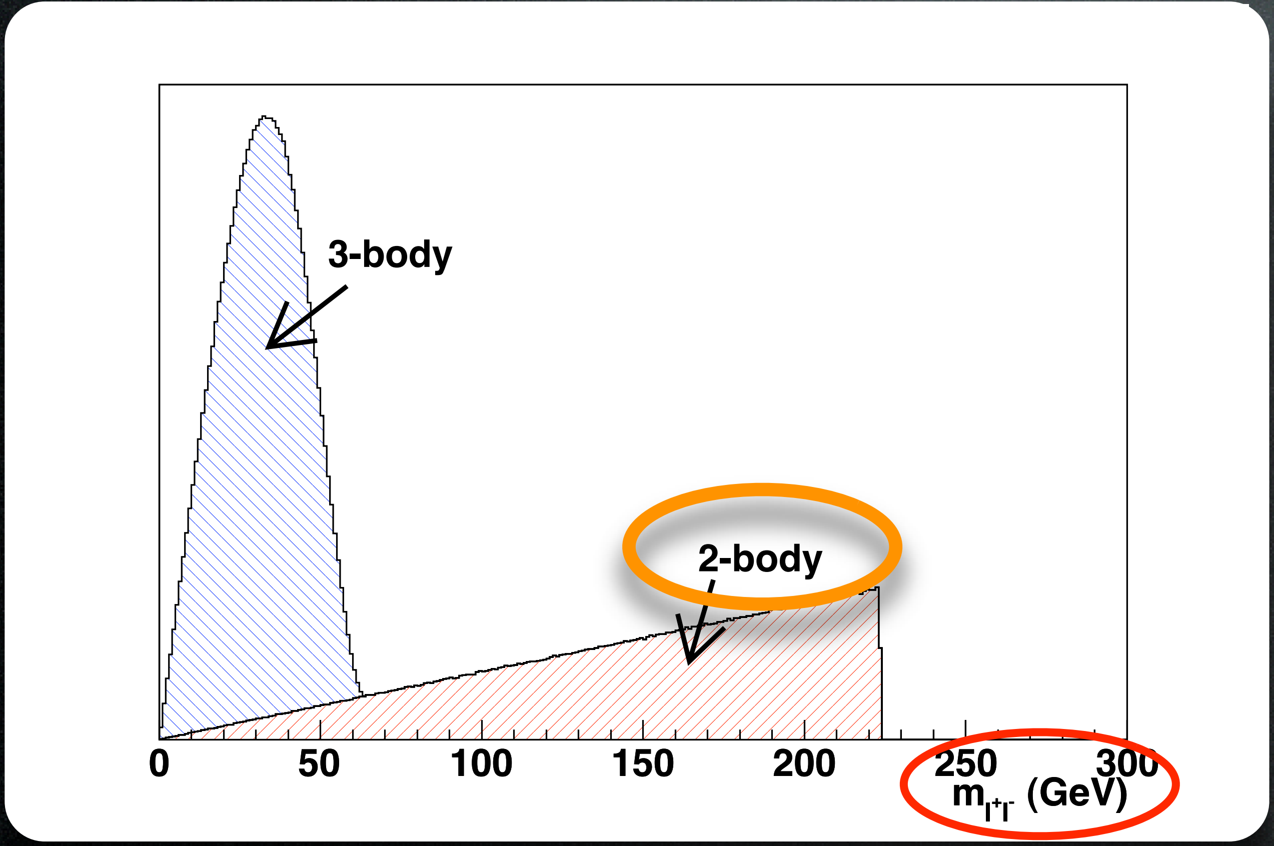

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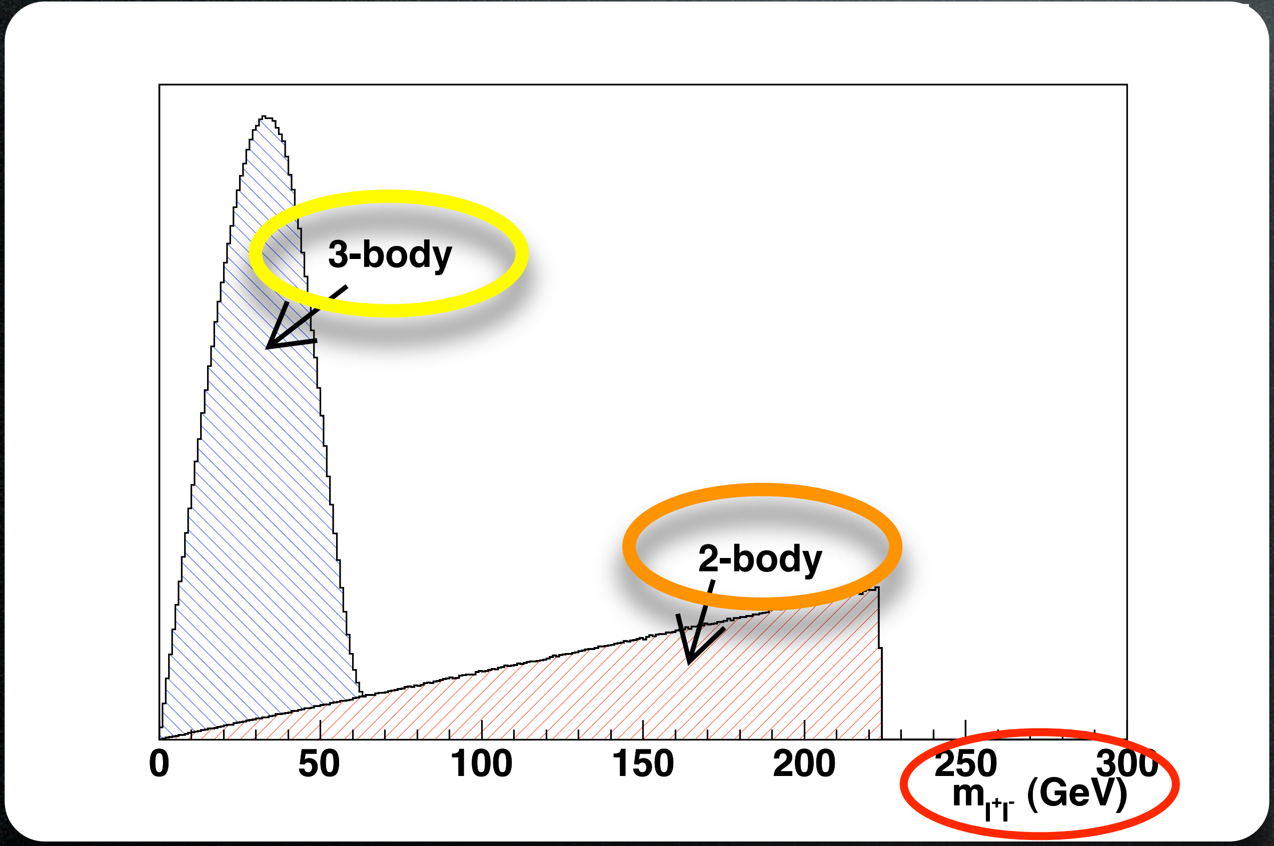

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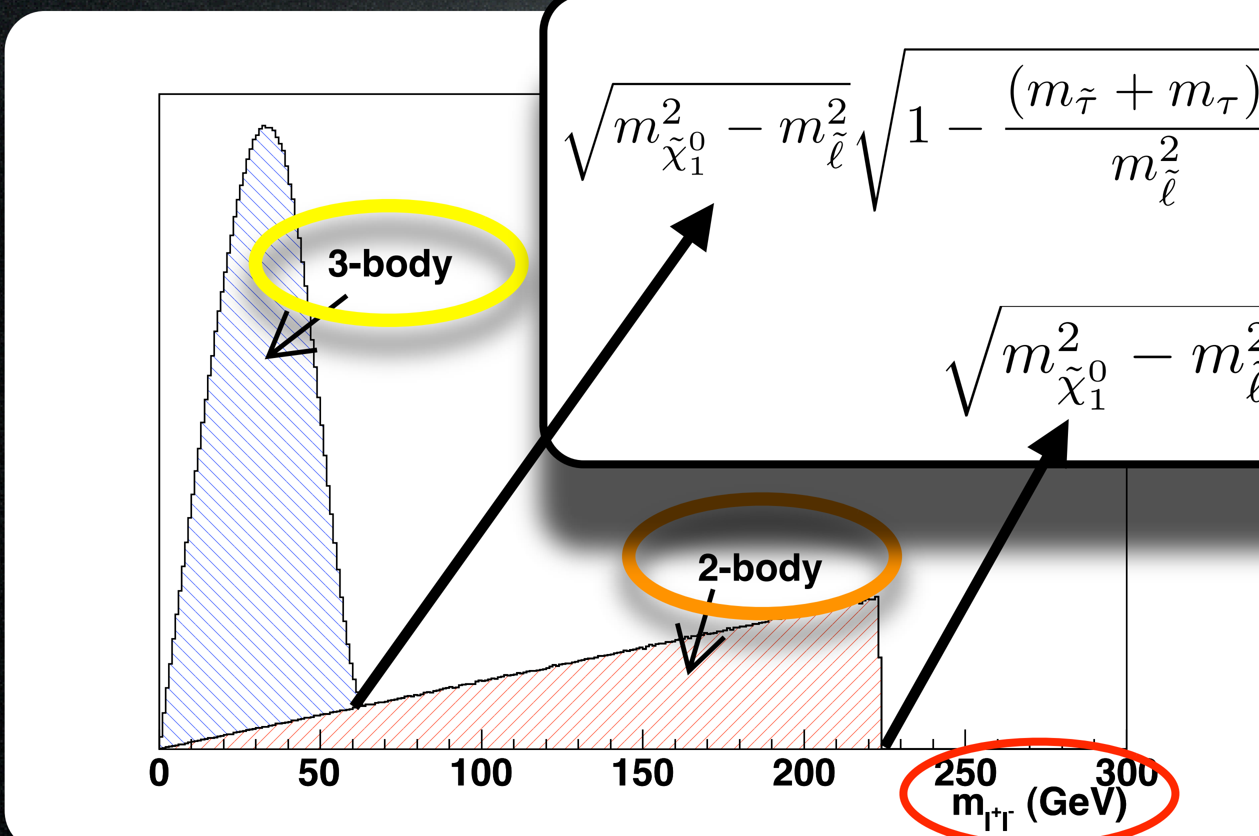

$$\sqrt{m^2_{\tilde{\chi}^0_1} - m^2_{\tilde{\ell}}}\sqrt{1 - \frac{(m_{\tilde{\tau}} + m_\tau)^2}{m^2_{\tilde{\ell}}}}$$

$$m_{\tilde{\ell}}$$

$$\sqrt{m^2_{\tilde{\chi}^0_1} - m^2_{\tilde{\ell}}}$$

$$\to \Gamma_{3\text{body}}$$

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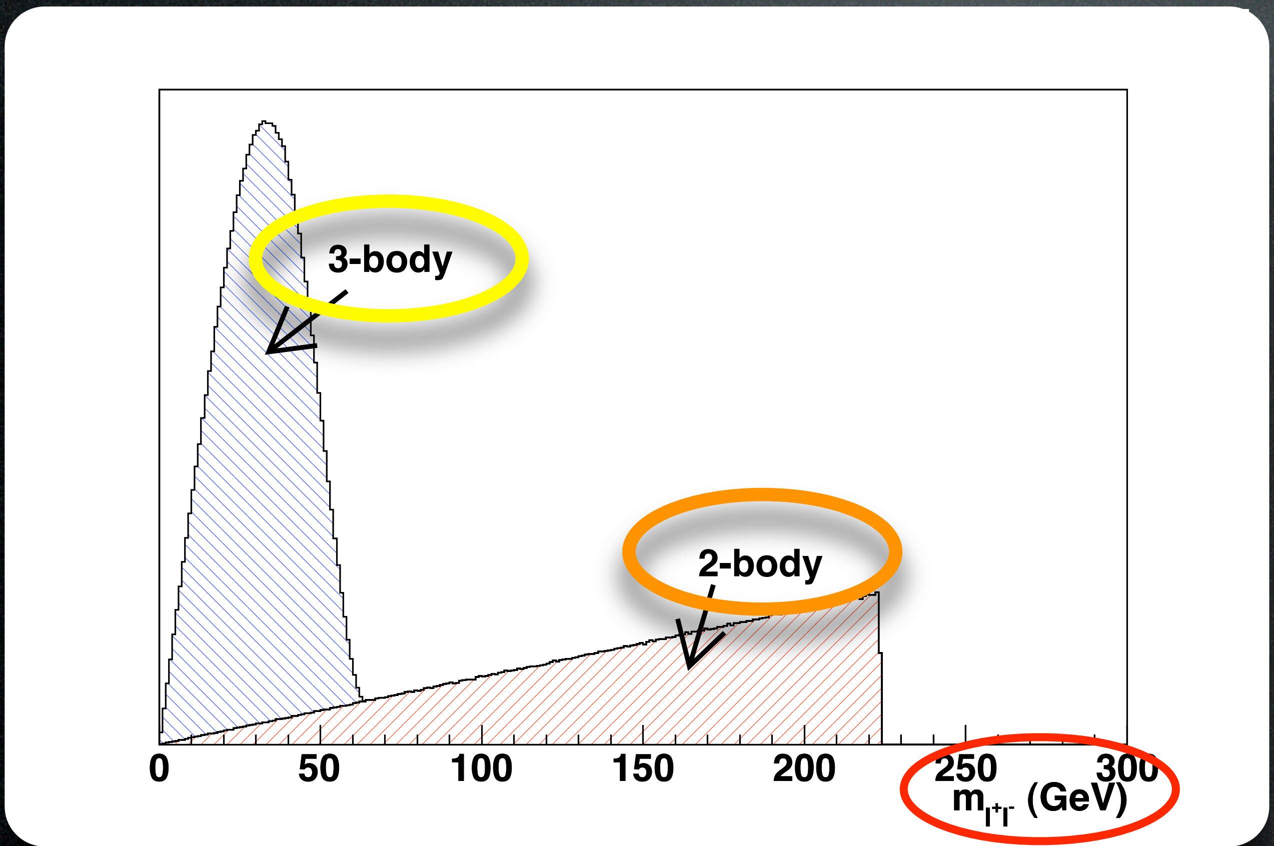

$$\frac{\Gamma_{3body}}{\Gamma_{2body}} = \frac{N_{3body}}{N_{2body}}$$

event selection

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

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

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

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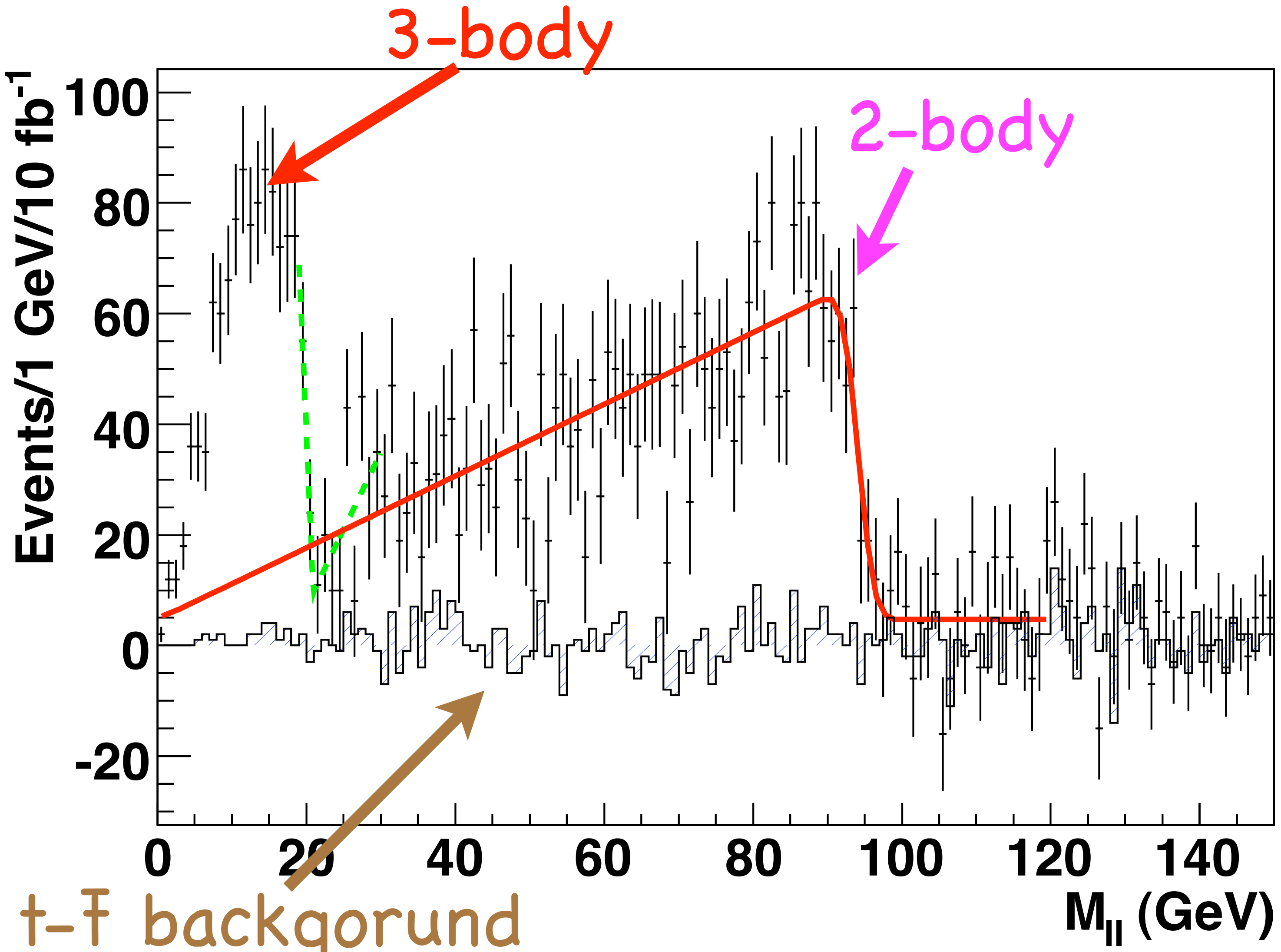
We have checked that our method works even if a harder cut $P_T > 10$ GeV is taken.

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

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



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- from the # of events,

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

$R_2, R_3 \cdots$ correction factor due to P_{T} cut

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

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

$$\Gamma_{3\mathrm{body}} = 0.21^{+0.09}_{-0.07}\ \mathrm{e}V$$

- We then obtain the gravitino mass!!

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

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

Events/1 GeV/10 fb^{-1}

t-t̄ background

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!)

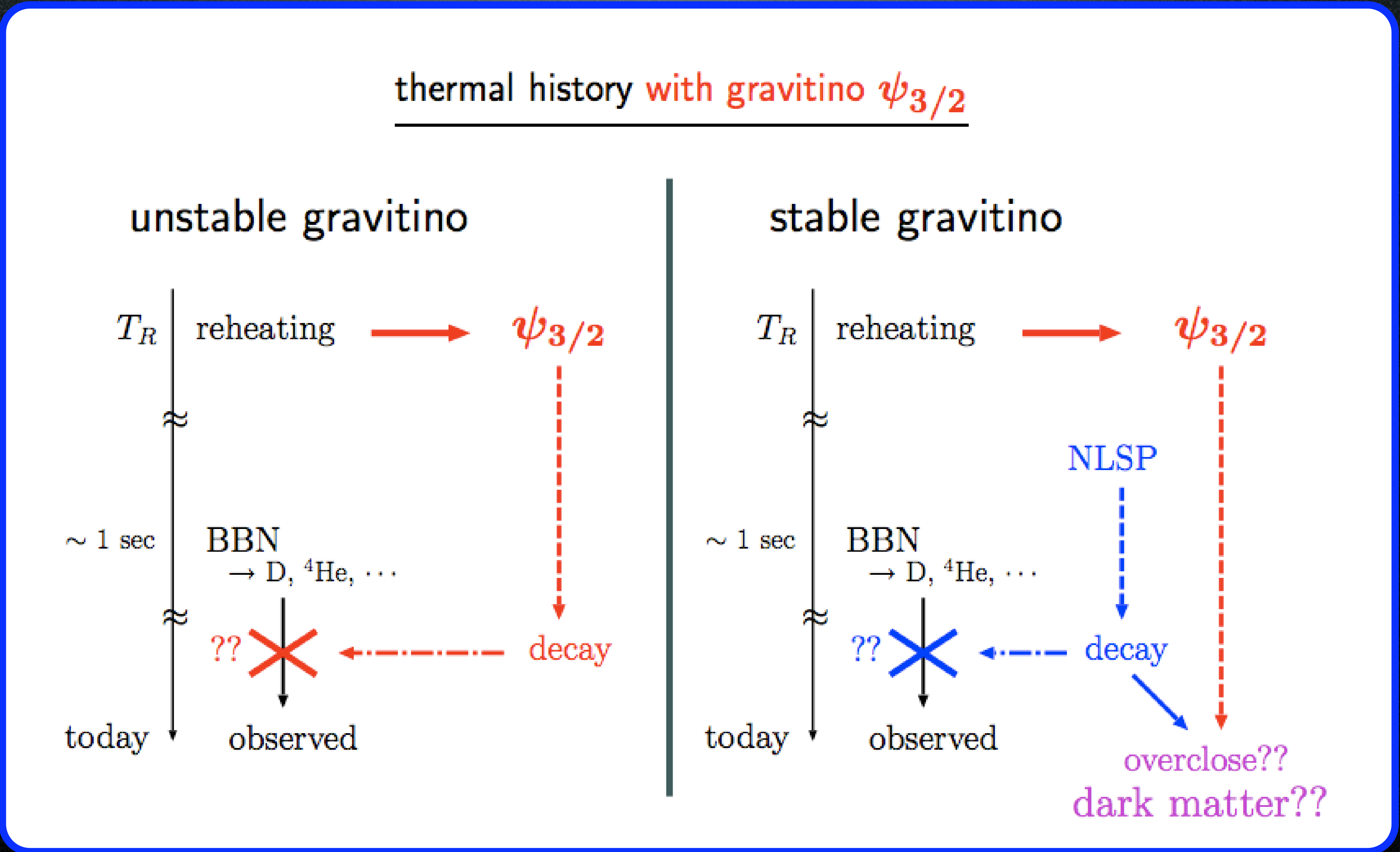
Backup Slides

Gravitino Problems

thermal history

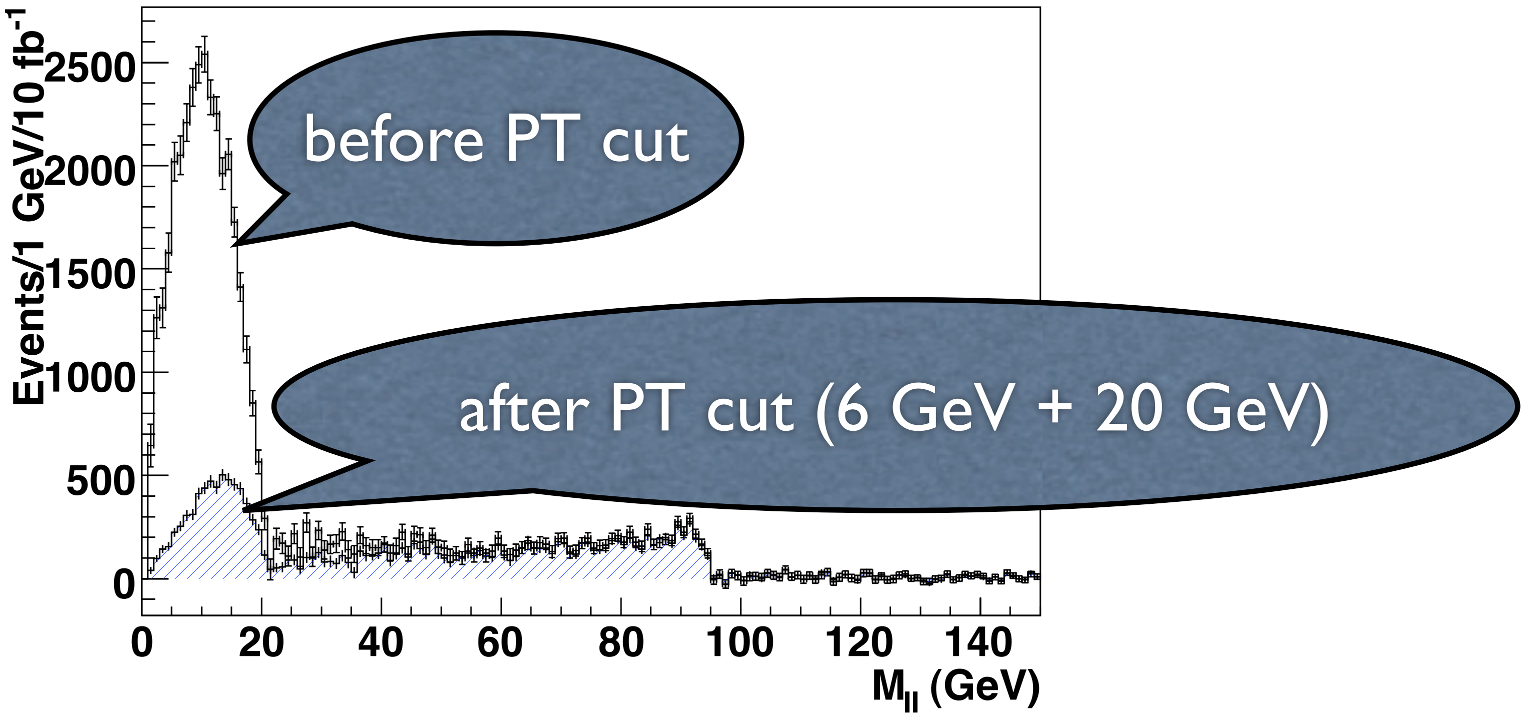
time	temperature	
??	~ 0	inflation
??	T_R	reheating
$\approx$		baryogenesis $\rightarrow n_B/s \simeq 10^{-10}$
~ 1 sec	~ 1 MeV	Big Bang Nucleosynthesis $\rightarrow$ D, ^{4}He, $\cdots$
$\approx$		↓
14 Gyr	2.7 K	observed

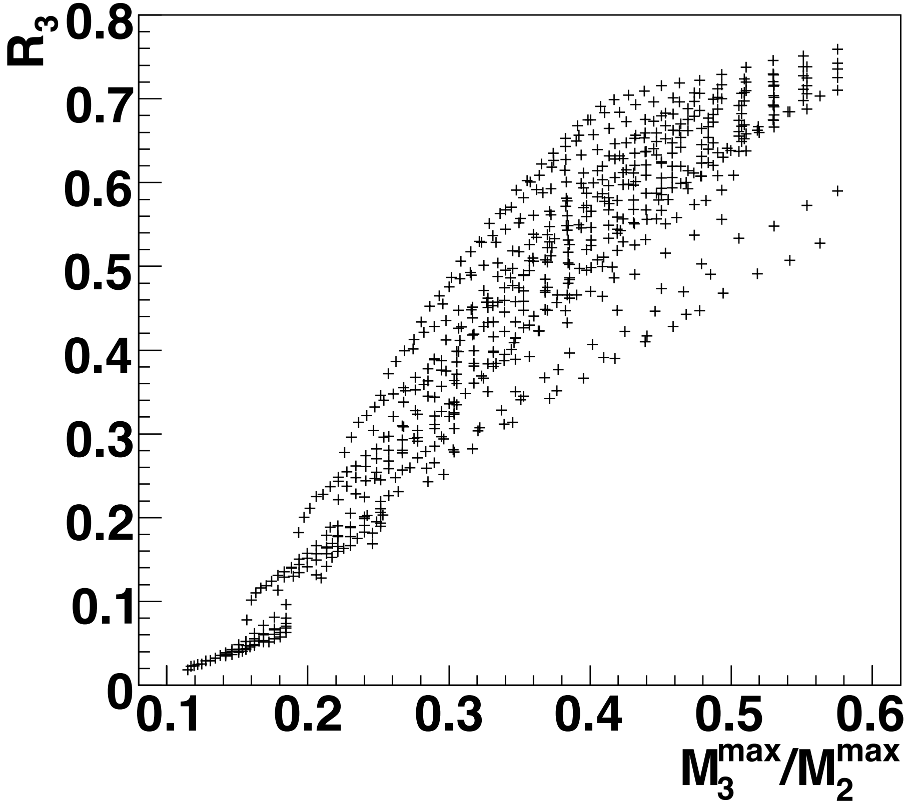
Gravitino Problems

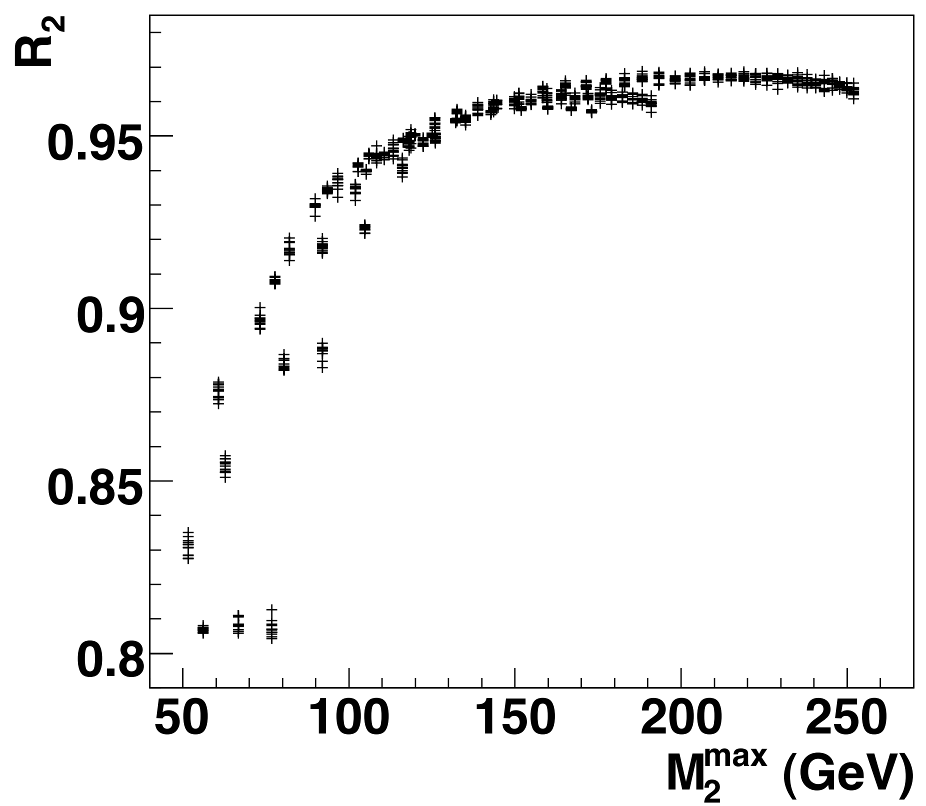


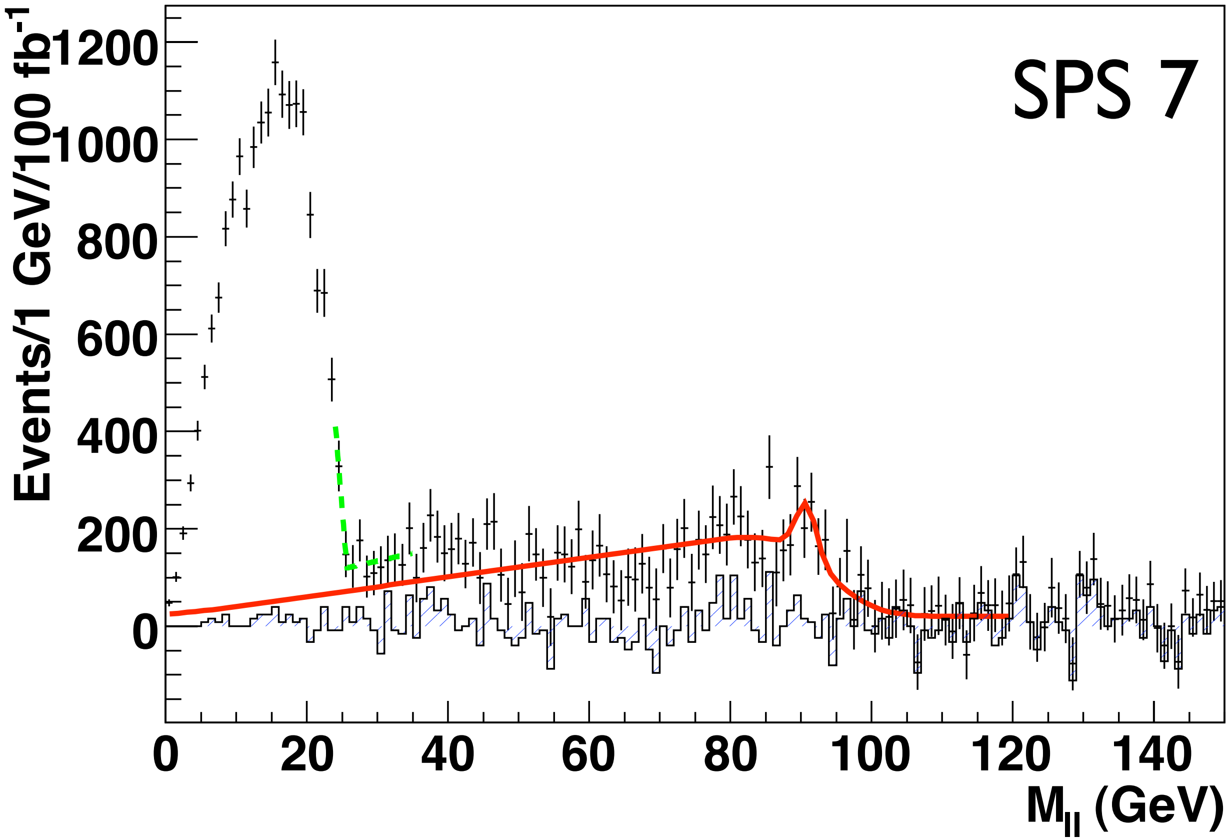
Sorry, I drop references.

Reduction factor R









$$\frac{\Gamma_{3-\mathrm{body}}}{\Gamma_{2-\mathrm{body}}} = \frac{N_3 R_2}{N_2 R_3} = (5.01 \pm 0.84)\left(\frac{R_2}{0.90}\right)\left(\frac{R_3}{0.35}\right)^{-1}$$

Assuming that we know $m_{\tilde{\ell}_R} = 129.1 \pm 0.5$ GeV, we estimate

$$\Gamma_{3-\mathrm{body}} = 1.16^{+1.28}_{-0.59}\mathrm{eV} \text{ (the true value is } \Gamma_{3-\mathrm{body}} = 1.11 \text{ eV}),$$

which leads to

$$m_{3/2} = (0.41^{+0.17}_{-0.12})\left(\frac{R_2}{0.90}\right)^{\frac{1}{2}}\left(\frac{R_3}{0.35}\right)^{-\frac{1}{2}} \text{ eV}.$$

The expected value is $m_{3/2} = 0.77$ eV.

- from the # of events,

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

$R_2, R_3 \cdots$ correction factor due to $P_{\rm T}$ cut

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

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

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

- from the # of events,

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

$R_2, R_3 \cdots$ correction factor due to $P_{\rm T}$ cut

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

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