SUPERGRAVITY AT COLLIDERS

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(DESY)

@ YITP workshop '04

based on .....

W. Buchmüller, KH, M. Ratz, T. Yanagida
hep-ph/0402179, 0403203.

0402179 → (PLB 588, 90)

0403203 → (Contribution to the LHC/LC Study Group Report)

PLAN

- Introduction
- gravitino at colliders
- goldstino at colliders.

same as the talk @ susy'04

MOTIVATION:

Can we prove the existence of supergravity in nature?

CONCLUSION:

Can we prove the existence of supergravity in nature?

Yes!!

if....

• What would prove the supergravity ?

Standard Model

$\parallel$

spontaneously broken local (gauge) symmetry

$\Downarrow$ Higgs mechanism

massive gauge (spin-1) bosons

Z & $W^{\pm}$

..... discovered in 1983.

• What would prove the supergravity ?

Standard Model	Supergravity
=	=
spontaneously broken local symmetry.	spontaneously broken local supersymmetry
⇓ Higgs mechanism	⇓ super-Higgs mechanism
massive gauge (spin-1) bosons	massive spin-3/2 fermion
Z & $W^{\pm}$	**gravitino** $\psi_{3/2}$
..... discovered in 1983	..... needs to be discovered!

We consider a scenario where .....

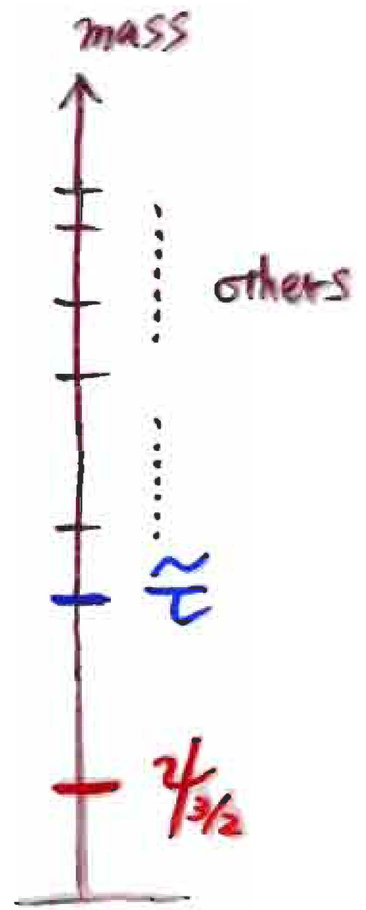
- **LSP** (lightest SUSY particle) = gravitino $\psi_{3/2}$

  $\longrightarrow$ stable

- **NSP** (next-to-lightest SUSY particle) = charged slepton $\tilde{\tau}$

  $\longrightarrow$ long-lived

$$\left(\Gamma(\tilde{\tau} \to \tau + \psi_{3/2})^{-1} \simeq 9 \text{ days} \left(\frac{m_{3/2}}{10 \text{ GeV}}\right)^2 \left(\frac{150 \text{ GeV}}{m_{\tilde{\tau}}}\right)^5 \right)$$



- **LSP = gravitino $\psi_{3/2}$** $\longrightarrow$ stable

..... naturally realized in many models:

gauge mediation ($m_{3/2} \ll 100$ GeV)
gaugino mediation ($m_{3/2} \lesssim 100$ GeV)
gravity mediation ($m_{3/2} \neq m_0, M_{1/2}$)

..... can be Dark Matter !!

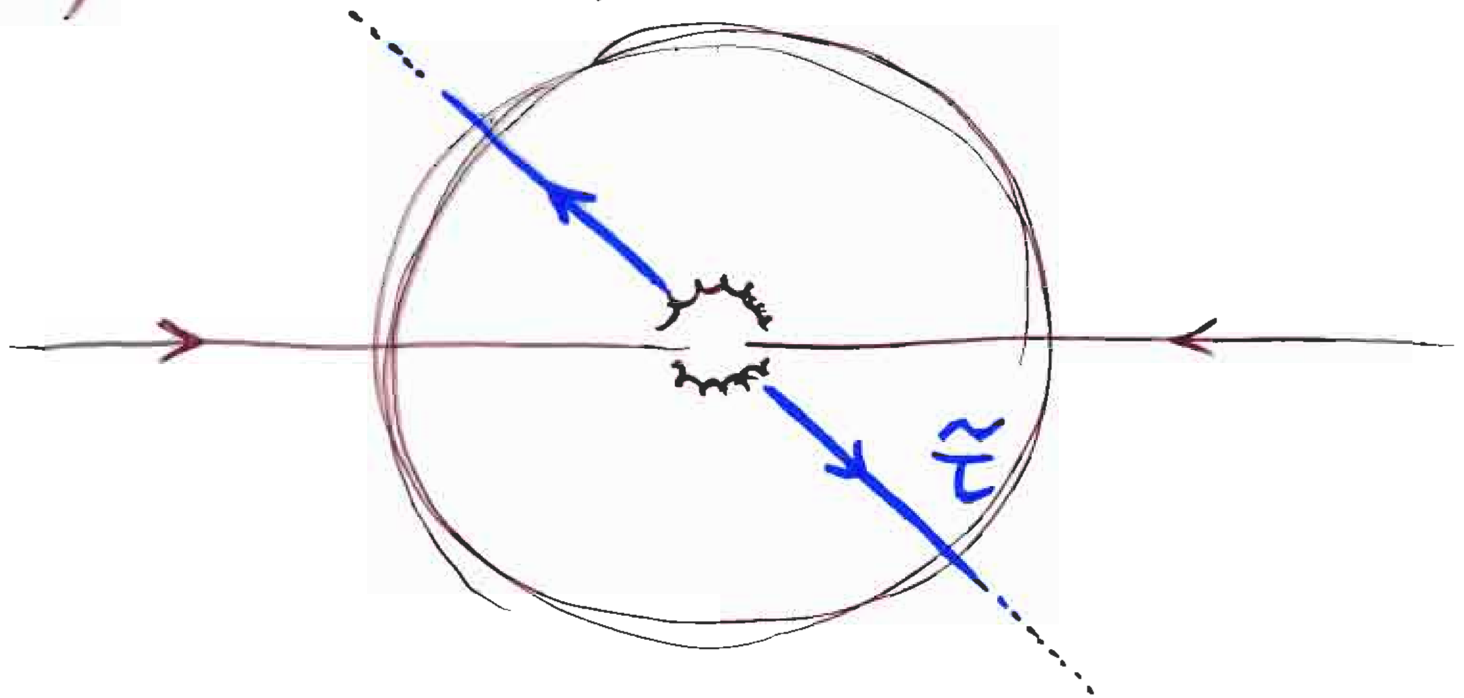
- **NSP = charged slepton $\tilde{\tau}$** $\longrightarrow$ long-lived

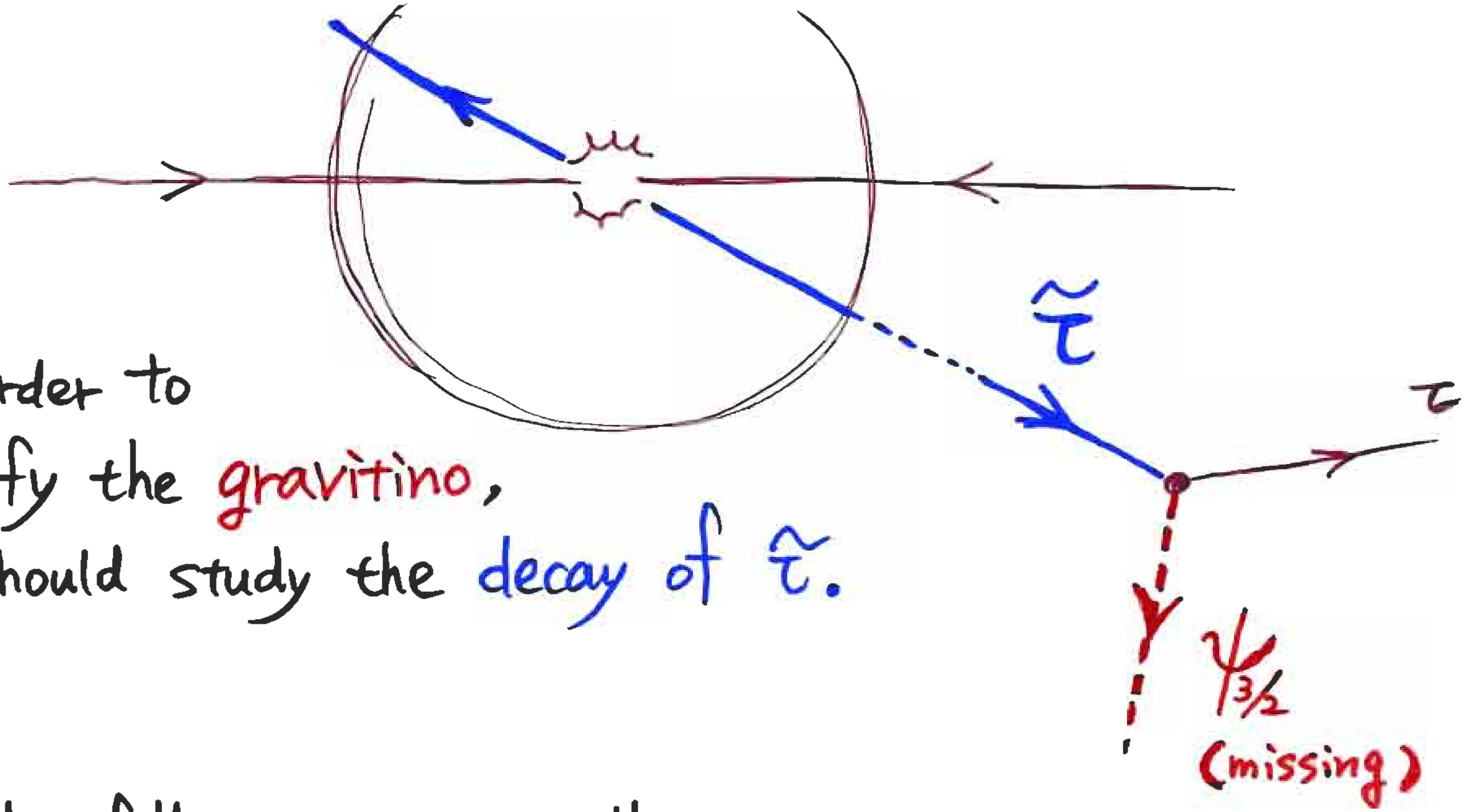
..... from the viewpoint of RG running,
NSP = naturally $\tilde{\tau}$ or $\tilde{\chi}^0$.

..... $\tilde{\tau}$ is better than $\tilde{\chi}^0$ for BBN constraint.
(hadronic branching is small.)

At colliders, many (up to $10^5 \sim 10^6$) $\tilde{\tau}$s will be produced, and they look completely stable. (unless $m_{3/2} \ll 10$ keV)

(Tevatron
LHC
LC
⋮)





In order to identify the gravitino, one should study the decay of $\tilde{\tau}$.

In the following, we will ....

— assume that many $\tilde{\tau}$s are produced and somehow collected,

— and study the decay of $\tilde{\tau}$.

Method ①

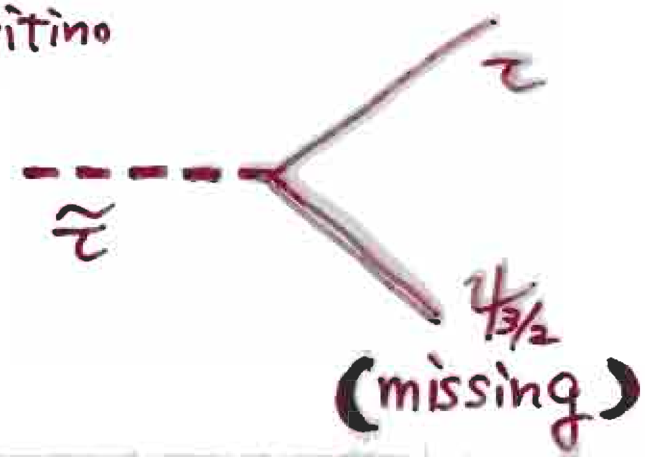
Measurement of the Planck scale M_P.

microscopic

(W. Buchmüller, KH, M. Ratz, T. Yanagida
hep-ph/0402179 (PLB 588))

$$\mathcal{L}_{\text{supergravity}} \supset \frac{-1}{\sqrt{2} M_P} \partial_\nu \tilde{\tau}_R^* \bar{\psi}^\mu \gamma^\nu \gamma_\mu P_R \tau + \text{h.c.} + \cdots$$

slepton: $\tilde{\tau}_R^*$; gravitino: $\bar{\psi}^\mu$; lepton: τ



$$\Gamma_{\tilde{\tau}} = \Gamma_{\tilde{\tau}}(\tilde{\tau} \to \tau + \psi_{3/2}) = \frac{m_{\tilde{\tau}}^5}{48\pi m_{3/2}^2 M_P^2}\left(1 - \frac{m_{3/2}^2}{m_{\tilde{\tau}}^2}\right)^4$$

prediction of supergravity

$$\Longleftrightarrow \quad M_P^2(\text{supergravity}) = \frac{1}{48\pi}\frac{1}{\Gamma_{\tilde{\tau}}}\frac{m_{\tilde{\tau}}^5}{m_{3/2}^2}\left(1 - \frac{m_{3/2}^2}{m_{\tilde{\tau}}^2}\right)^4$$

will be measured ($\Gamma_{\tilde{\tau}}$, $m_{\tilde{\tau}}$)

can be "measured" by kinematics ($m_{3/2}$)

$$\left(m_{3/2}^2 = m_{\tilde{\tau}}^2 - m_\tau^2 - 2m_{\tilde{\tau}}E_\tau \right)$$

$\tau \longleftarrow \tilde{\tau} \dashrightarrow \psi_{3/2}$

consistency check !!

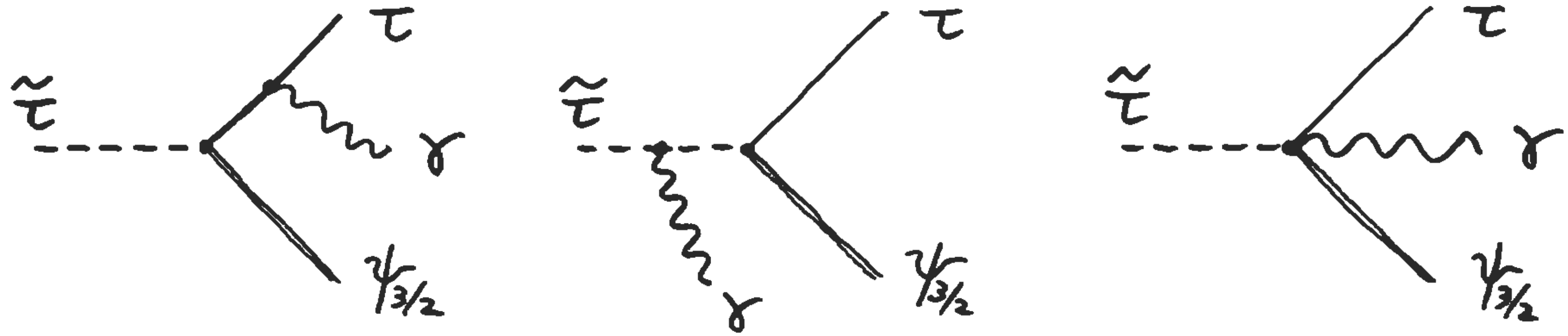
$$M_P^2(\text{gravity}) = (8\pi G_N)^{-1} = (2.44 \times 10^{18}\,\text{GeV})^2$$

G_N: Newton const

Method ②

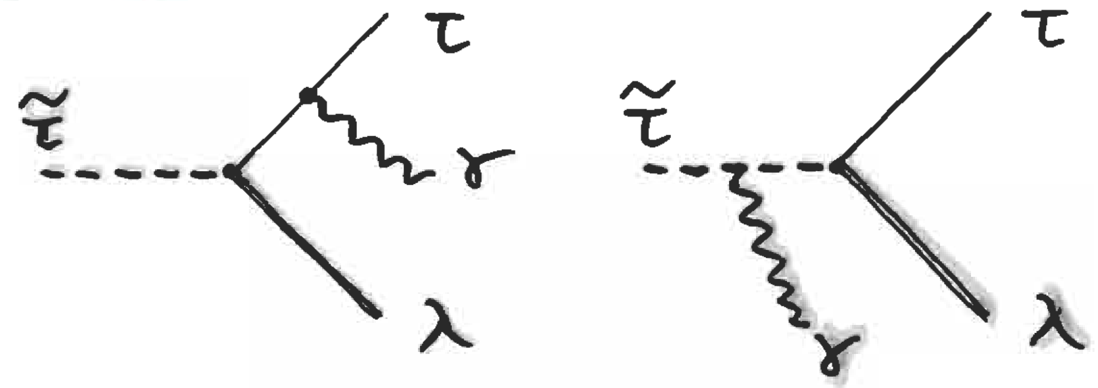
Test of particular gravitino couplings by 3-body decay

$$\mathcal{L} = \frac{-1}{\sqrt{2} M_P} (\partial_\nu + ieA_\nu) \tilde{\tau}_R^* \bar{\Psi}^\mu \gamma^\nu \gamma_\mu P_R \tau + \cdots$$

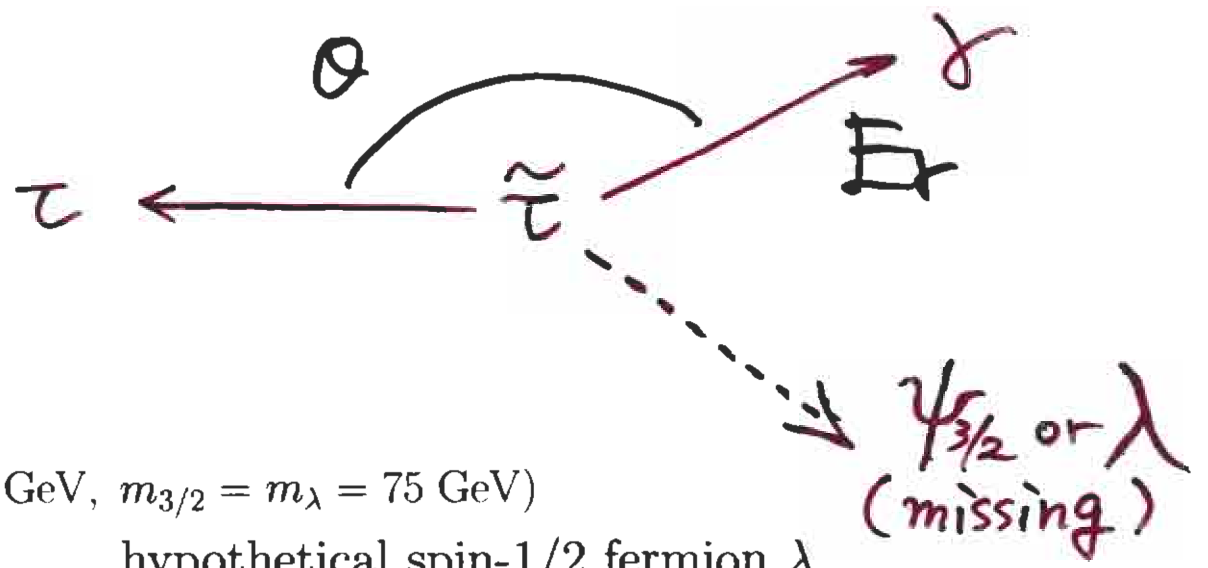


Compare with hypothetical spin-½ fermion λ.

$$\mathcal{L} = y(\tilde{\tau}_R^* \bar{\lambda} P_R \tau + \tilde{\tau}_L^* \bar{\lambda} P_L \tau) + h.c. \qquad y \ll 1$$



angular and energy distributions of τ and γ



Results (for right-handed $\tilde{\tau}_R$, $m_{\tilde{\tau}} = 150$ GeV, $m_{3/2} = m_\lambda = 75$ GeV)

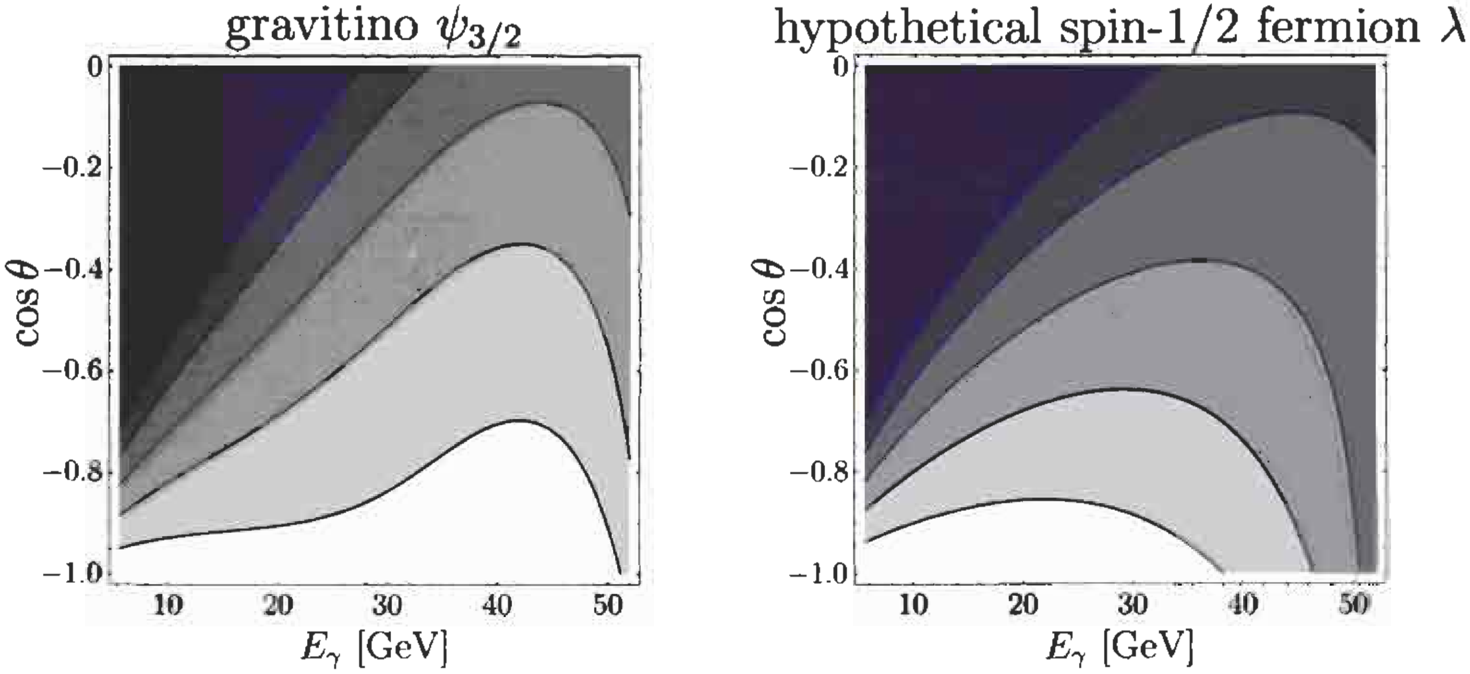
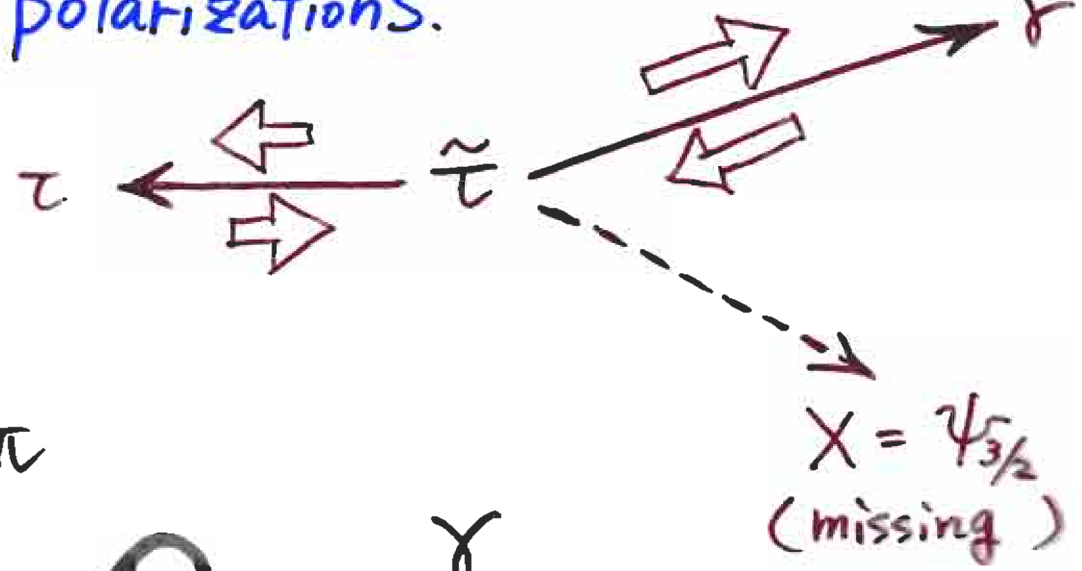


Figure: Contour plots of $\frac{d^2 B_r}{dE_\gamma d\cos\theta} = \frac{1}{\Gamma_{\tilde{\tau}}}\frac{d^2\Gamma_{\tilde{\tau}}(\tilde{\tau} \to \tau + \gamma + X)}{dE_\gamma d\cos\theta}$ for $X = \psi_{3/2}$ and λ.

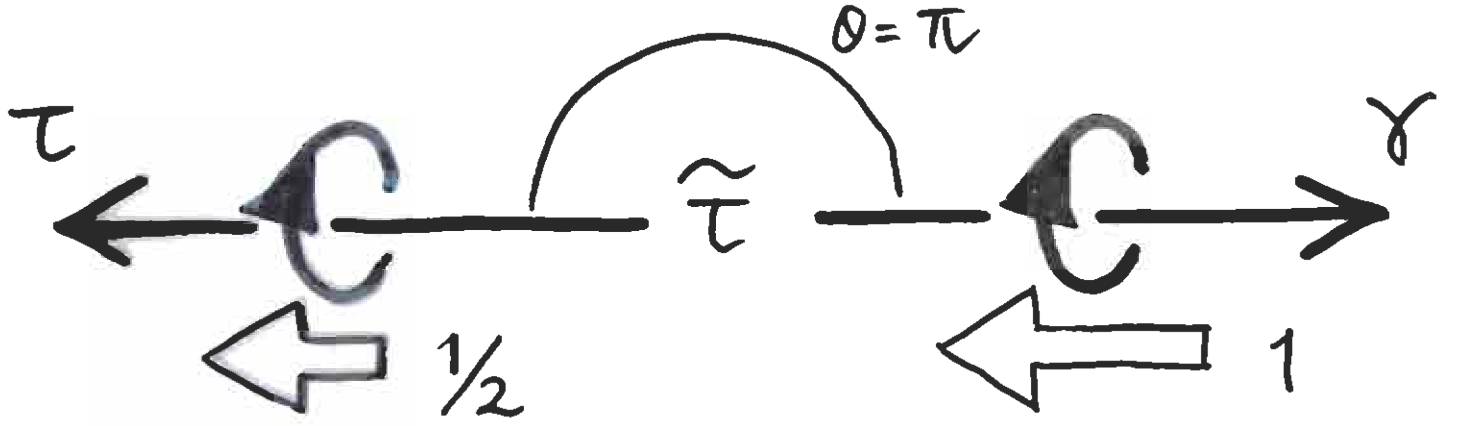
Darker shading = larger rate. (Boundaries are [1, 2, 3, 4, and 5] $\times 10^{-3}\alpha$ [GeV^{-1}].)

Method ③

Measurement of the gravitino spin ($= 3/2$)
by 3-body decay + polarizations.

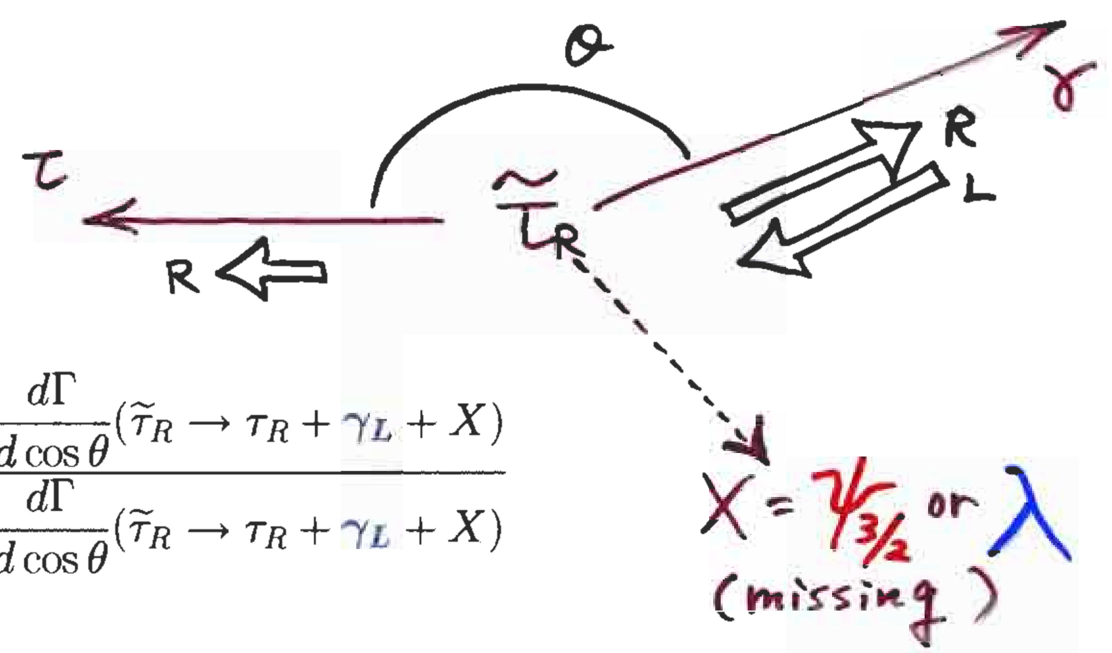


In particular, ...



$\tilde{\tau} \to \tau_R + \gamma_L + X$ at $\theta = \pi$ is possible
only if the missing particle X has spin $3/2$.

angular distribution and polarizations of τ & γ



$$A_{RL}(\cos\theta) = \frac{\frac{d\Gamma}{d\cos\theta}(\tilde{\tau}_R \to \tau_R + \gamma_R + X) - \frac{d\Gamma}{d\cos\theta}(\tilde{\tau}_R \to \tau_R + \gamma_L + X)}{\frac{d\Gamma}{d\cos\theta}(\tilde{\tau}_R \to \tau_R + \gamma_R + X) + \frac{d\Gamma}{d\cos\theta}(\tilde{\tau}_R \to \tau_R + \gamma_L + X)}$$

Results (for right-handed $\tilde{\tau}_R$, $m_{\tilde{\tau}} = 150$ GeV)

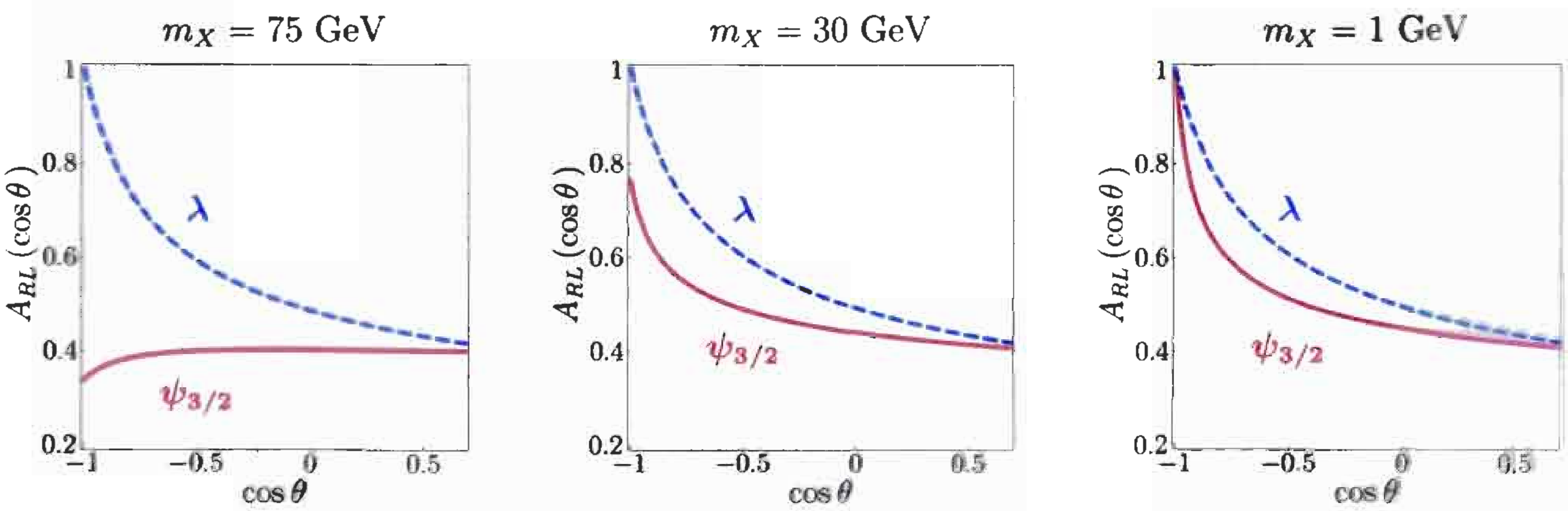


Figure: $A_{RL}(\cos\theta)$.

We cut the soft photon (energy below 10% of maximal photon energy, $E_\gamma^{\max} = (m_{\tilde{\tau}}^2 - m_{3/2}^2)/2m_{\tilde{\tau}}$).

CONCLUSION: ([redacted])

Can we prove the existence of supergravity ?

Yes !!

If LSP = gravitino, and if we can collect NSPs at future colliders, we can .....

- measure the Planck scale M_P, ← 2-body
- test the gravitino couplings, ← 3-body
- measure the gravitino spin ← 3-body

by studying the NSP decays.

Comment.

Very light gravitino ($m_{3/2} \ll m_{\tilde{\tau}}$) $\simeq$ goldstino (spin 1/2 fermion)

2-body decay

→ measurement of M_P is difficult.

($m_{3/2}^2 = m_{\tilde{\tau}}^2 + m_\tau^2 - 2m_{\tilde{\tau}}E_\tau \simeq 0$) ← $E_\tau \simeq \frac{1}{2}m_{\tilde{\tau}}$

3-body decay

→ measurement of gravitino spin is difficult.

→ But we can still see the peculiar coupling. → See Fig.s

NOTE:

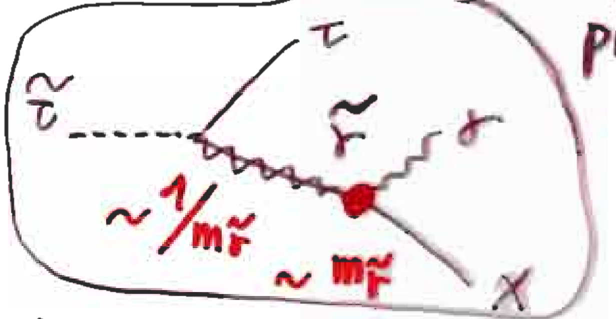
If $m_{3/2} \ll 10$ keV, $\tilde{\tau}$ can decay inside the detector!

(for comparison) define "pseudo-goldstino" χ, which has ....

<u>goldstino interactions</u>

$$\mathcal{L}_{goldstino} = \left(\frac{m_{\tilde{\tau}}^2}{\sqrt{3}\, m_{3/2} M_P}\right)\left(\tilde{\tau}_R^* \bar{\chi} P_R \tau + h.c\right) - \frac{m_{\tilde{\gamma}}}{4\sqrt{6}\, m_{3/2} M_P} \bar{\chi} [\gamma^\mu, \gamma^\nu] \tilde{\gamma} F_{\mu\nu}$$

photino



+

<u>a mass</u>

$m_\chi \longrightarrow$ explicit breaking of global SUSY gravitino $\psi_{3/2}$ vs. (pseudo) goldstino χ vs. hypothetical spin-1/2 fermion λ

$$A_{RL}(\cos\theta) = \frac{\frac{d\Gamma}{d\cos\theta}(\widetilde{\tau}_R \to \tau_R + \gamma_R + X) - \frac{d\Gamma}{d\cos\theta}(\widetilde{\tau}_R \to \tau_R + \gamma_L + X)}{\frac{d\Gamma}{d\cos\theta}(\widetilde{\tau}_R \to \tau_R + \gamma_R + X) + \frac{d\Gamma}{d\cos\theta}(\widetilde{\tau}_R \to \tau_R + \gamma_L + X)}$$

$X = \psi_{3/2}, \chi$ or λ

Results (for right-handed $\widetilde{\tau}_R$, $m_{\widetilde{\tau}} = 150$ GeV)

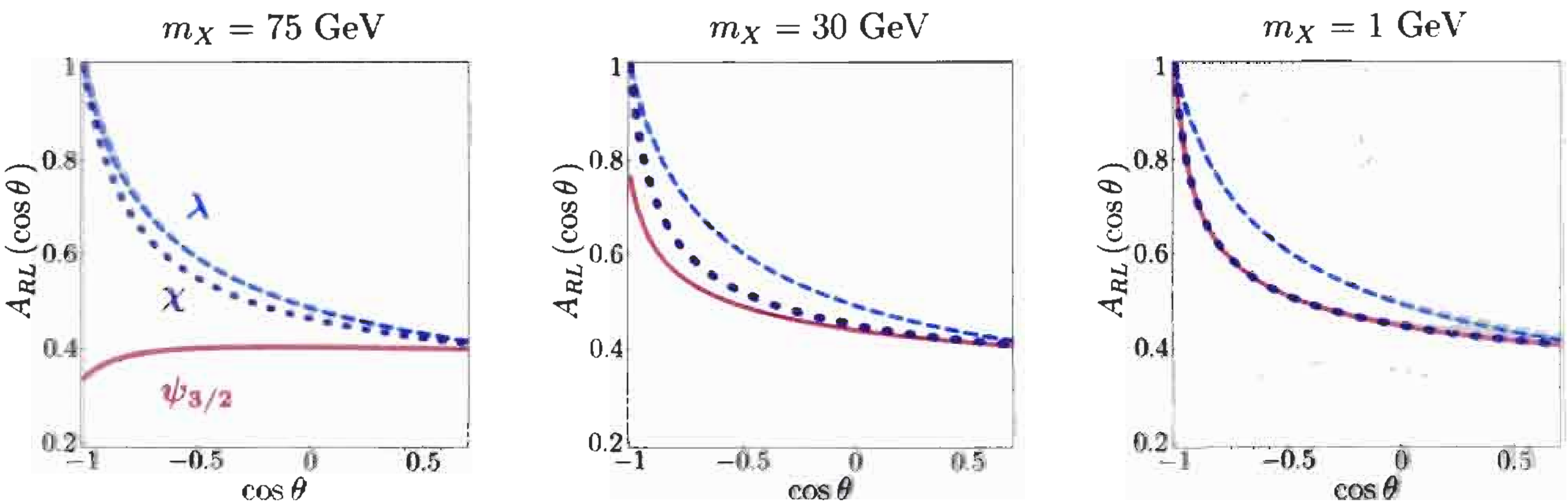
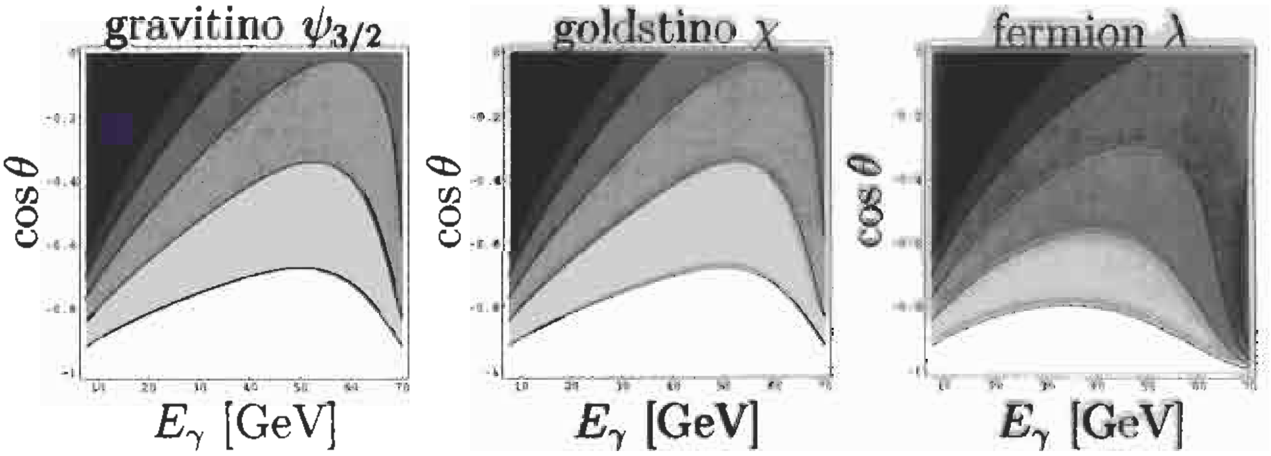
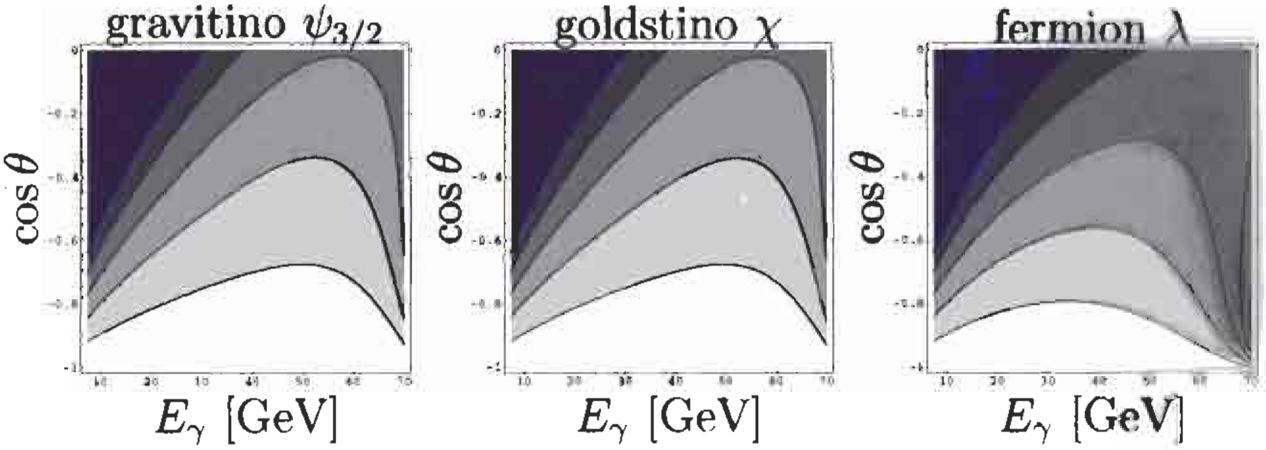


Figure: $A_{RL}(\cos\theta)$.

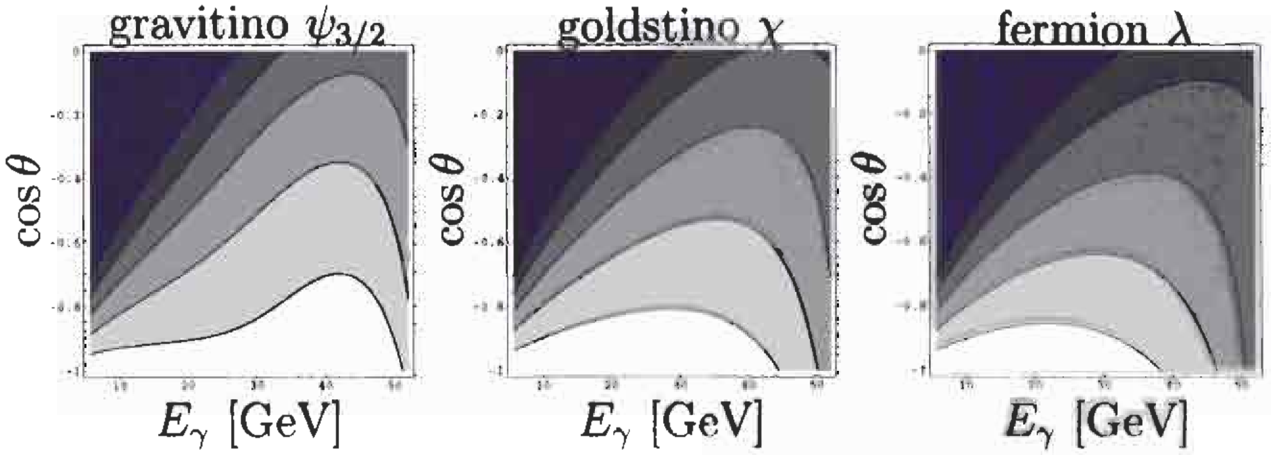
We cut the soft photon (energy below 10% of maximal photon energy, $E_\gamma^{max} = (m_{\widetilde{\tau}}^2 - m_{3/2}^2)/2m_{\widetilde{\tau}}$).



$m_{\tilde{\tau}} = 150$ GeV, $m_X = 0.1$ GeV.



$m_{\tilde{\tau}} = 150$ GeV, $m_X = 10$ GeV.



$m_{\tilde{\tau}} = 150$ GeV, $m_X = 75$ GeV.

CONCLUSION: ([redacted])

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