Goldstini

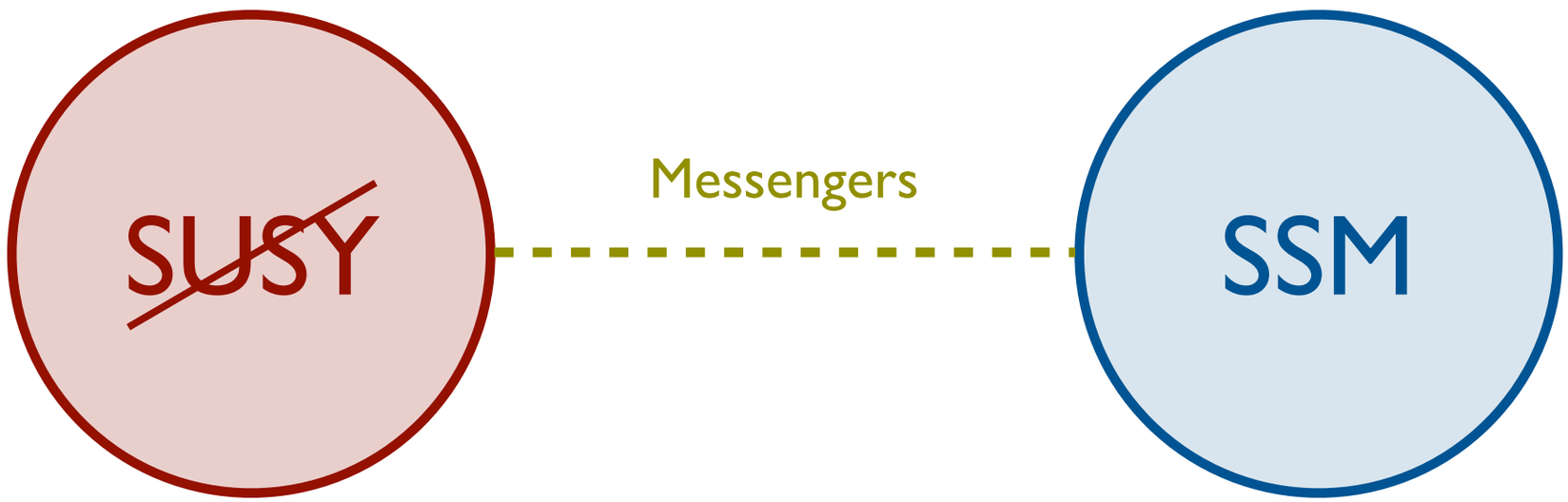
Jesse Thaler

with Cliff Cheung, Jeremy Mardon, and Yasunori Nomura
Recent work with Francesco D'Eramo and Zachary Thomas

SUSY 2011 — August 28, 2011

How many times is SUSY broken?

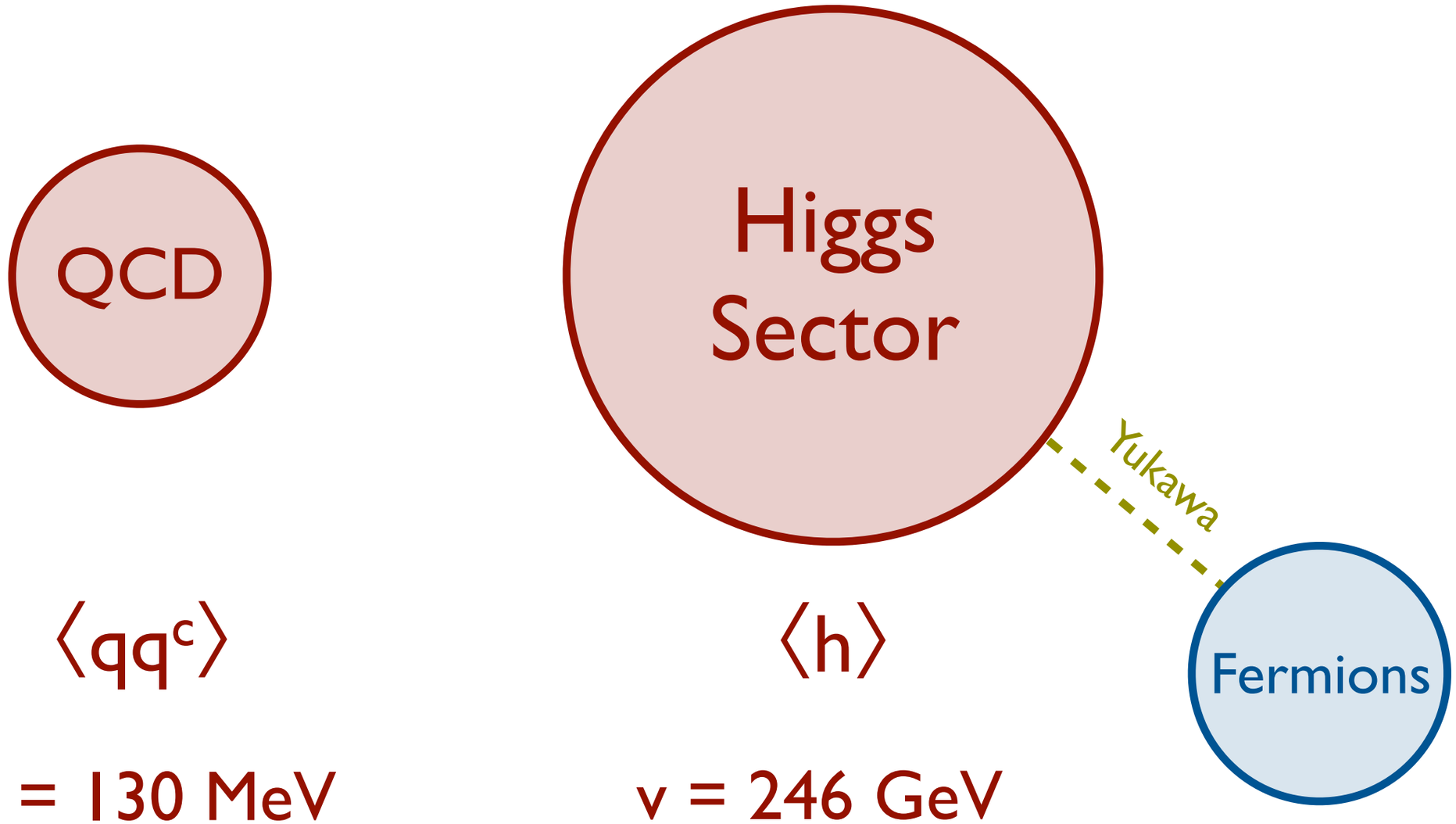
The SUSY Canon



"There is only one SUSY and it is broken exactly once."

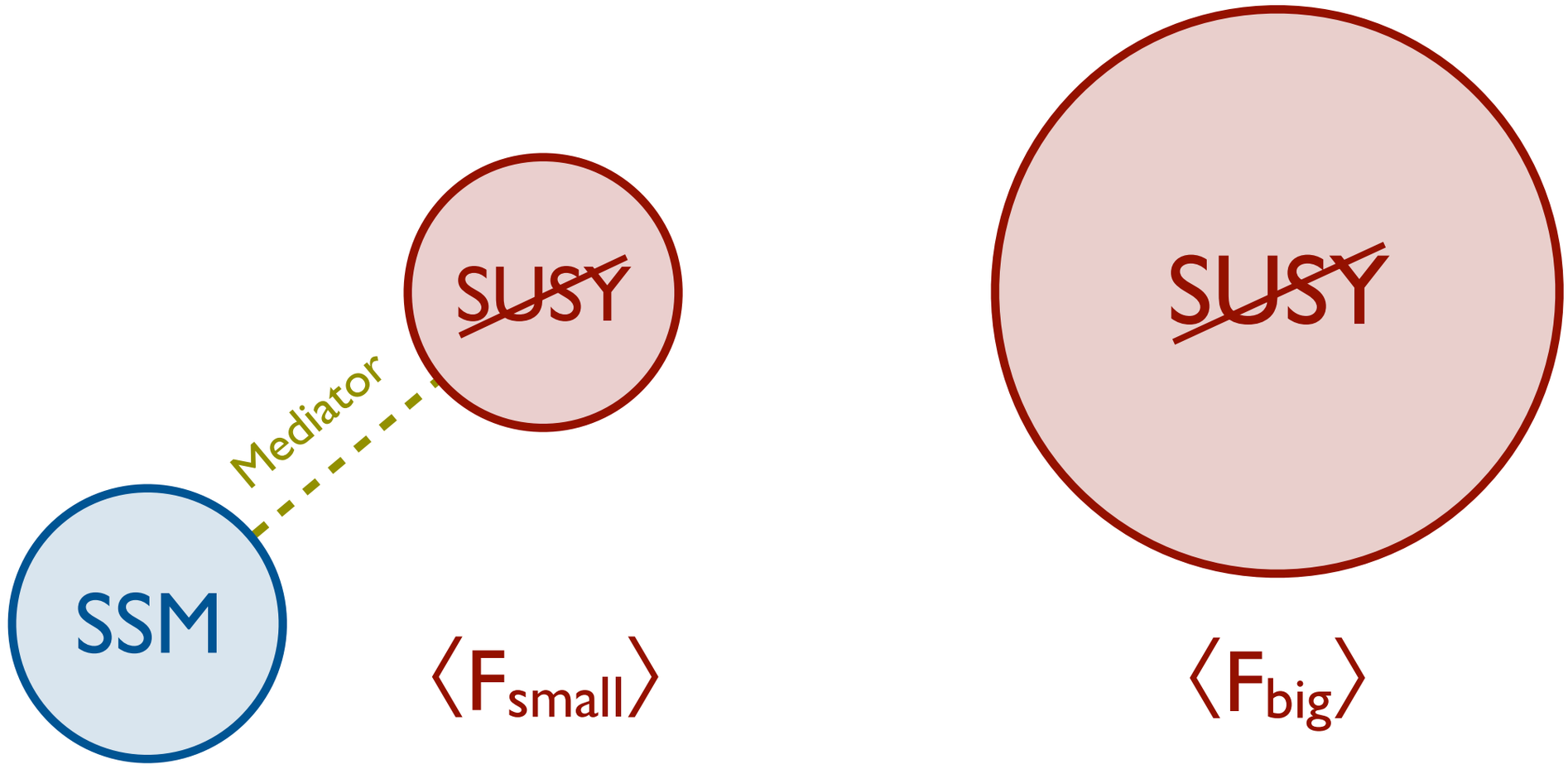
How many times is $SU(2)_L \times U(1)_Y$ broken?

(At Least) Twice!



$\langle qq^c \rangle$	$\langle h \rangle$
f_π = 130 MeV	v = 246 GeV
Pions!	Longitudinal W/Z
$m_{\pi 0}$ = 135 MeV	m_Z = 91 GeV

Multiple Supersymmetry Breaking



$\langle F_{small} \rangle$

$\langle F_{big} \rangle$

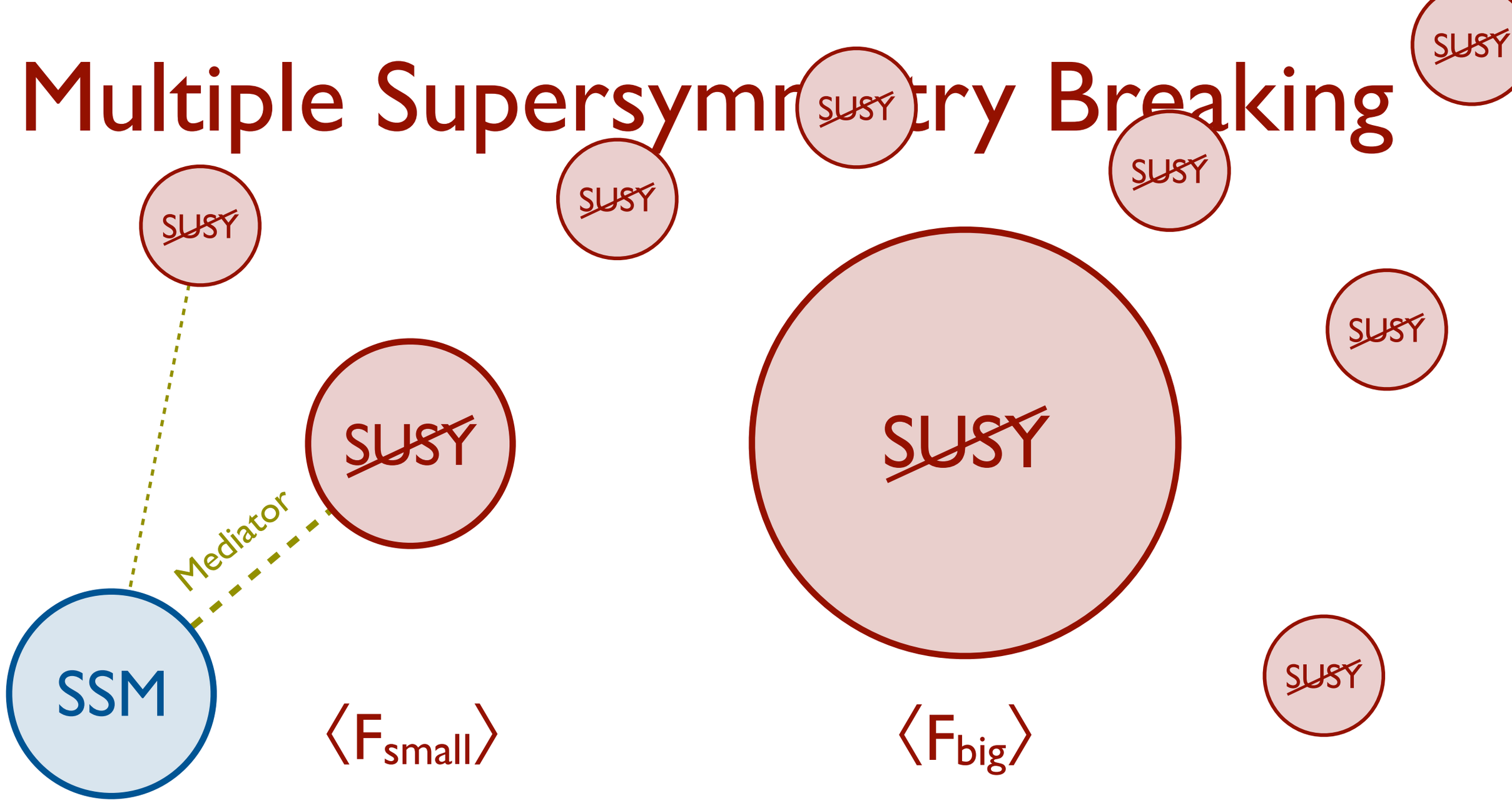
Uneaten Goldstini!

Longitudinal Gravitino

$m_\zeta = 2m_{3/2}$

$m_{3/2} \approx F/M_{Pl}$

Multiple Supersymmetry Breaking



$\langle F_{small} \rangle$

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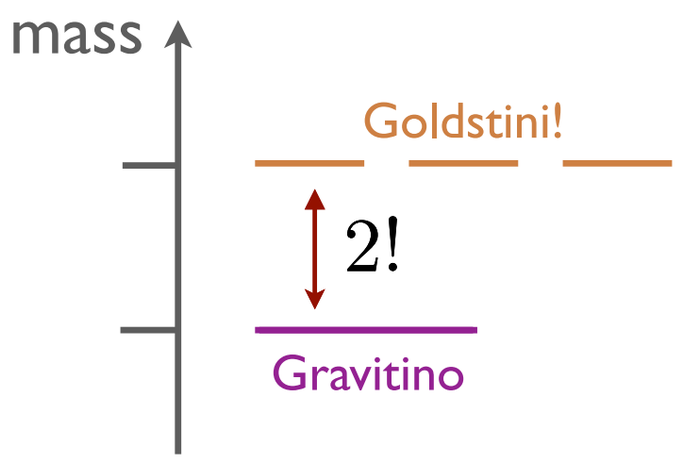
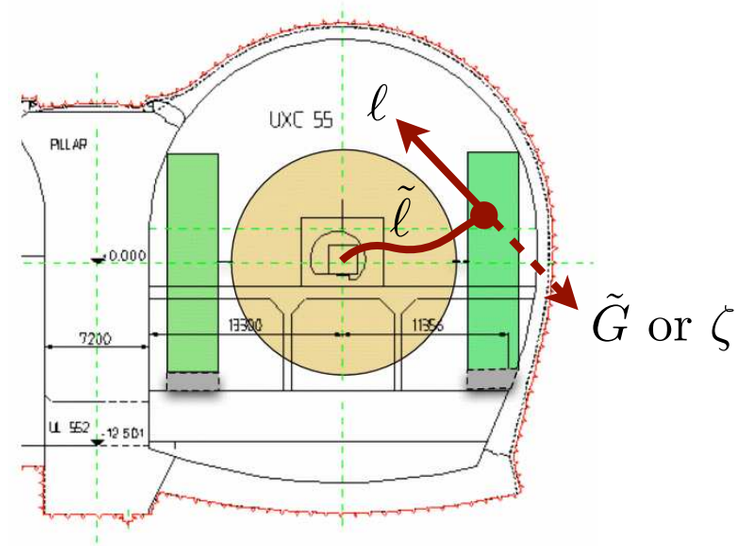
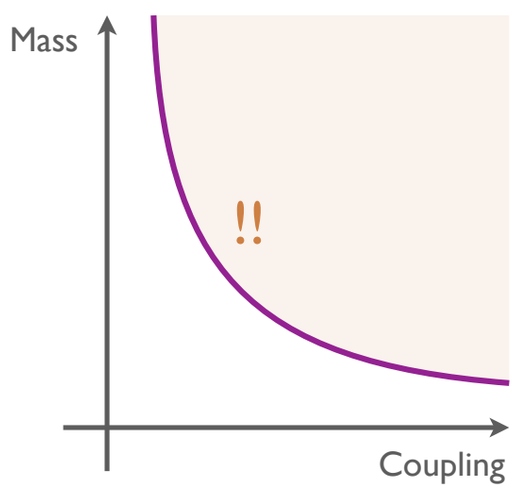
Goldstini



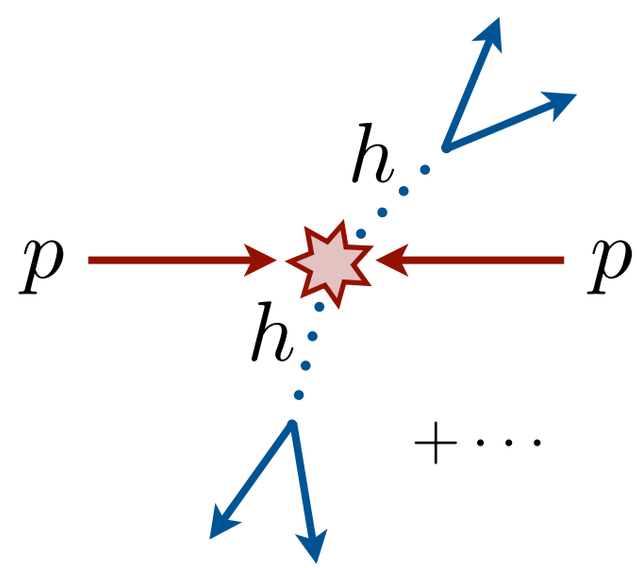
A Curious Factor of Two



The Smoking Gun at the LHC



Modified Mass/Coupling Relation



(Giving the Higgs a Boost)

References

Original Goldstini Papers

Cheung, Nomura, JDT, 1002.1967
Cheung, Mardon, Nomura, JDT, 1004.4637
(Benakli and Moura, 0706.3127)

Variations in Spectrum

Craig, March-Russell, McCullough, 1007.1239
Argurio, Komargodski, Mariotti, 1102.2386
Cheung, D'Eramo, JDT, 1104.2600

Models of Dark Matter

Cheng, Huang, Low, Menon,1012.5300

Collider Surprises

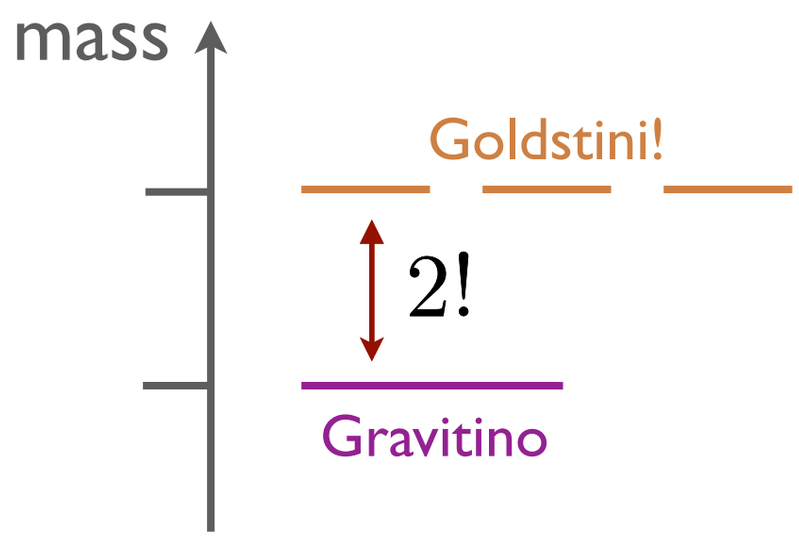
JDT, Zachary Thomas, 1103.1631

Model Building Implications

McCullough, 1010.3203
Izawa, Nakai, Shimomura,1101.4633
Bertolini, Rehermann, JDT, in progress

New SUGRA Techniques

Cheung, D'Eramo, JDT, 1104.2598
[See Francesco's Talk at 3:50pm]

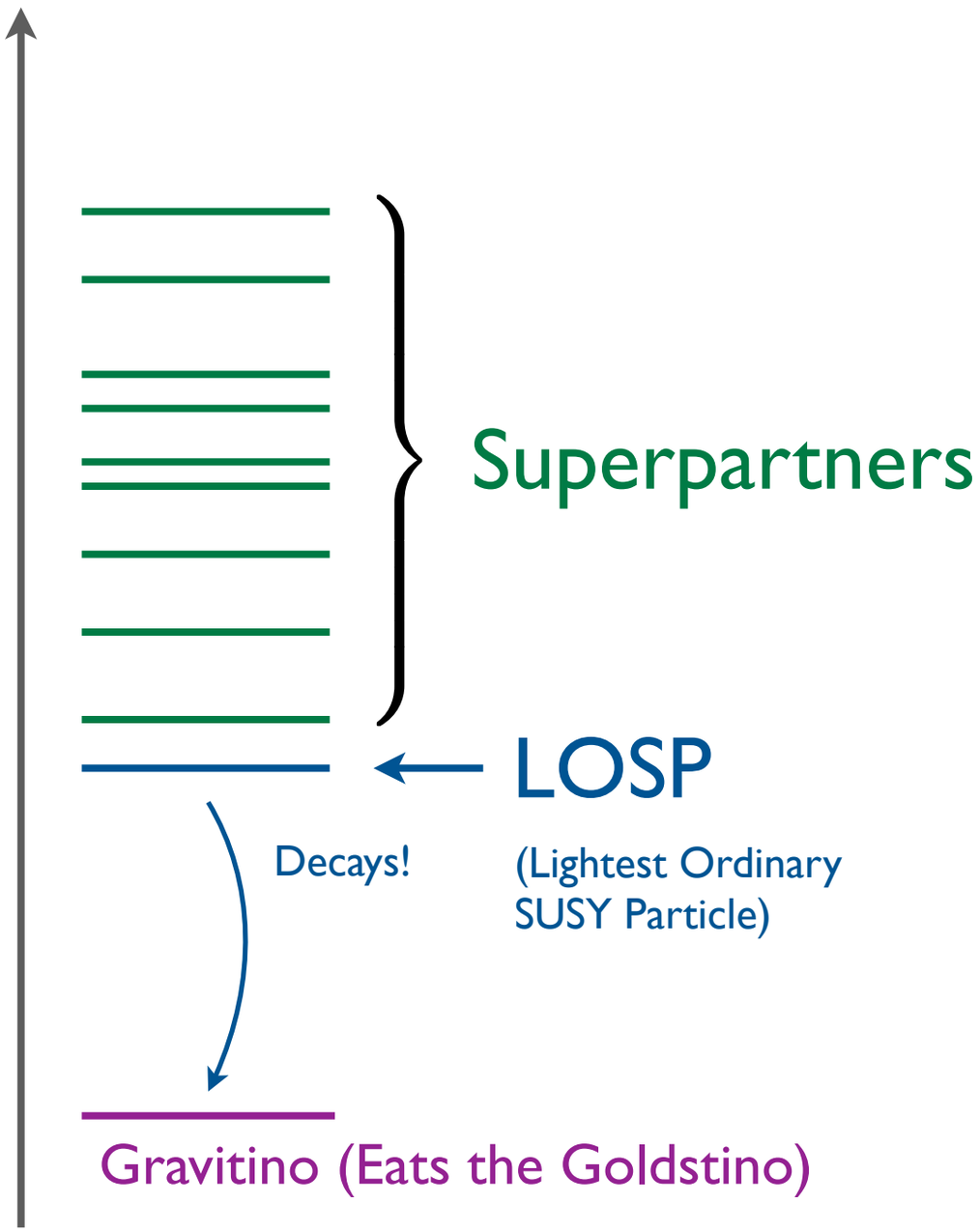


A Curious Factor of Two

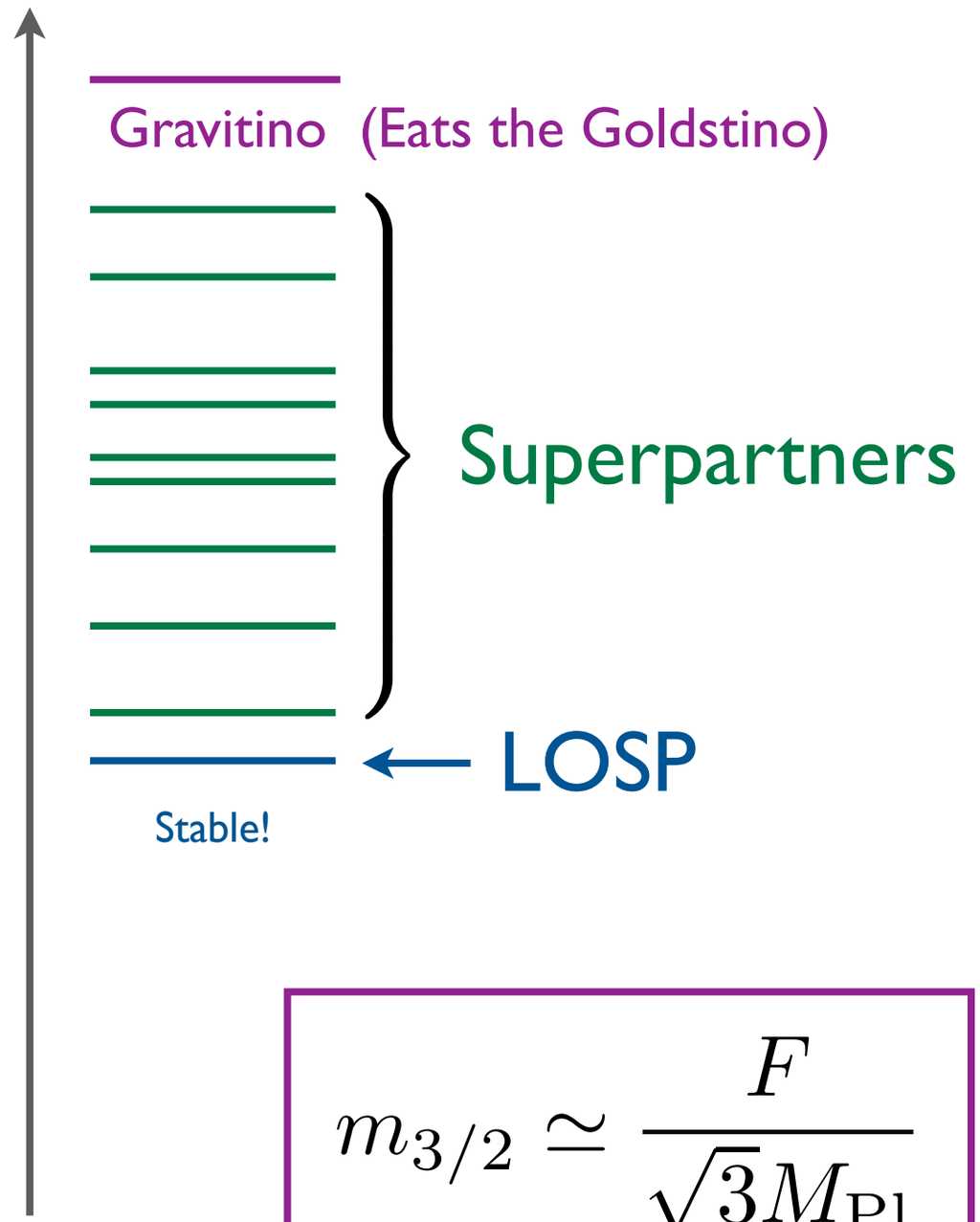
Cheung, Nomura, JDT, 1002.1967
Cheung, D'Eramo, JDT, 1104.2598 & 1104.2600

Two Options for SUSY

"Gauge Mediation-like"



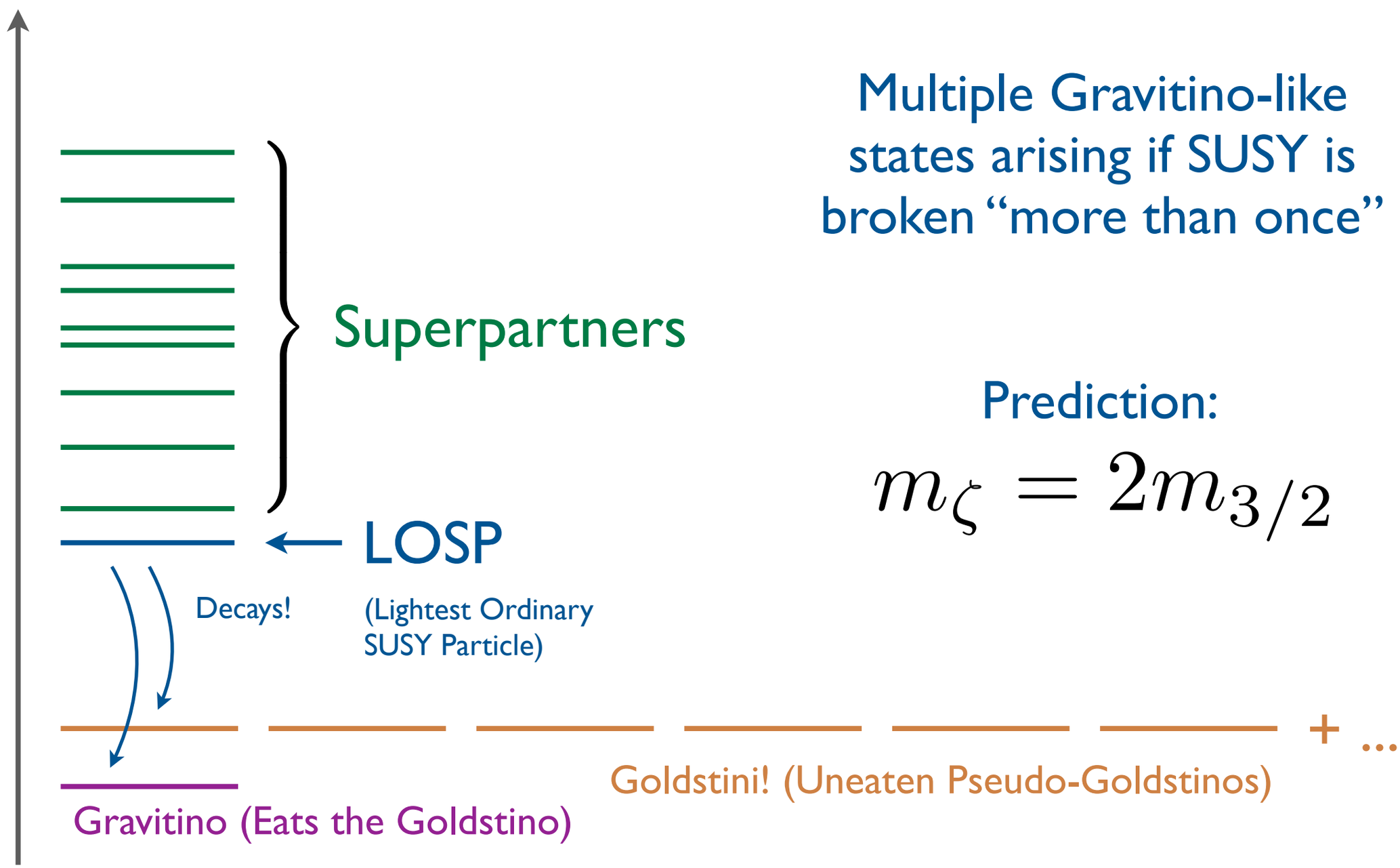
"Gravity Mediation-like"



$$m_{3/2} \simeq \frac{F}{\sqrt{3} M_{\rm Pl}}$$

A New Possibility

"Goldstini!"

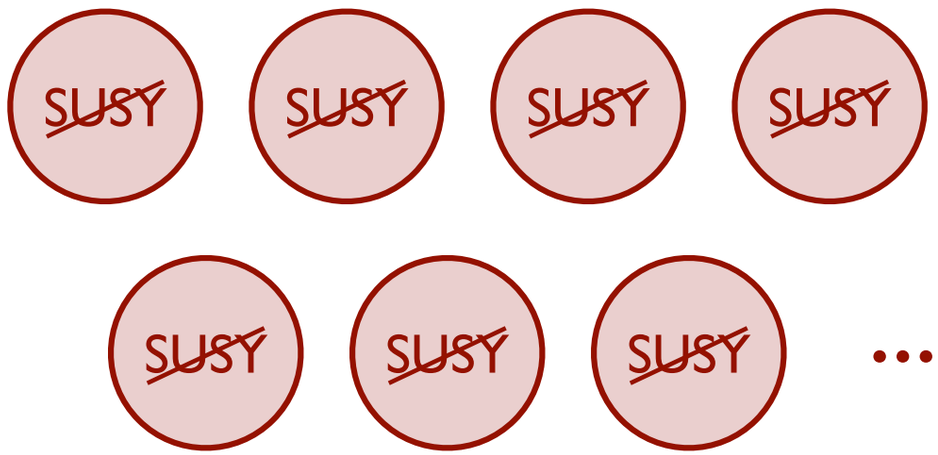


Multiple Gravitino-like states arising if SUSY is broken "more than once"

Prediction:

$$m_\zeta = 2m_{3/2}$$

Multiple SUSY Breaking



N Sectors:

Break SUSY Independently
(Quasi-)Sequestered
SUSY persists for $M_{Pl} \to \infty$
No Light Sgoldstino
Fine-Tune CC to Zero

$$W = W_1 + W_2 + \cdots$$
$$-3e^{-K/3} = \Omega_1 + \Omega_2 + \cdots$$

SUGRA Fermion Masses

$$m_{ij} = e^{G/2}(\nabla_i G_j + G_i G_j)$$

$$\text{Recall}: G \equiv K + \log W + \log W^*$$

Tree-Level Spectrum

(By Explicit Calculation)

1 Eaten Goldstino

$$m_{3/2} = e^{G/2}$$

N–1 Uneaten Goldstini

$$m_\zeta = 2m_{3/2}$$

(! but ?)

Focus on One Sector

~~SUSY~~

$$\mathcal{L}^A = \int d^4\theta\, \mathbf{\Phi}^\dagger \mathbf{\Phi}\, \mathbf{\Omega}^A(\boldsymbol{X}^i, \boldsymbol{X}^{j\dagger}) + \int d^2\theta\, \mathbf{\Phi}^3\, \boldsymbol{W}^A(\boldsymbol{X}^i) + \cdots$$

graviton/gravitino terms

Conformal Compensator

$$\begin{aligned} \mathbf{\Phi} &= e^{\boldsymbol{Z}/3}(1 + \theta^2 F_\Phi) \\ \boldsymbol{Z} &= \langle K/2 - i\mathrm{Arg}\, W\rangle + \langle K_i\rangle \boldsymbol{X}^i \end{aligned}$$

[See Francesco's Talk]

With Our Assumptions

$$\Rightarrow \quad \mathbf{\Phi} = 1 + \theta^2 m_{3/2}$$

Non-linear Parametrization of Goldstino

$$\boldsymbol{X}^i = \tilde{\theta}^2 F^i \qquad \tilde{\theta} = \theta + \frac{\eta^A}{\sqrt{2}F^A} \qquad F^A = \sqrt{g_{ij}F^iF^j}$$

field in sector A

sector A goldstino

SUSY breaking in sector A

Focus on One Sector

~~SUSY~~

$$\mathcal{L}^A = \int d^4\theta\, \mathbf{\Phi}^\dagger \mathbf{\Phi}\, \mathbf{\Omega}^A(\boldsymbol{X}^i, \boldsymbol{X}^{j\dagger}) + \int d^2\theta\, \mathbf{\Phi}^3\, \boldsymbol{W}^A(\boldsymbol{X}^i) + \cdots$$

graviton/gravitino terms

Use shifted theta coordinate and expand!

$$\mathbf{\Phi} = 1 + \left(\tilde{\theta} - \frac{\eta^A}{\sqrt{2}F^A}\right)^2 m_{3/2}$$

$$\mathcal{L}_1 \supset \frac{1}{2} m_{3/2} \left(\frac{m_{3/2}\mathbf{\Omega}^A|_{\bar{\theta}^2}}{(F^A)^2} + \frac{\mathbf{\Omega}^A|_{\theta^4}}{(F^A)^2} + \frac{3\boldsymbol{W}^A|_{\theta^2}}{(F^A)^2} \right) \eta^A \eta^A$$

$$\underbrace{\quad 0 \quad}_{\text{(by assumption)}} + \underbrace{\quad 1 \quad} + \underbrace{\quad -3 \quad} = \boxed{-2}$$

Every sector has a goldstino with mass $2m_{3/2}$!

(diagonalize to find true goldstino, eaten by gravitino to *lose* mass)

Goldstini Variations

Arbitrary F- and D-terms?

$$m_\zeta = 2m_{3/2}$$

[Cheung, D'Eramo, JDT]

No-Scale SUSY Breaking?

$$m_\zeta = 0$$

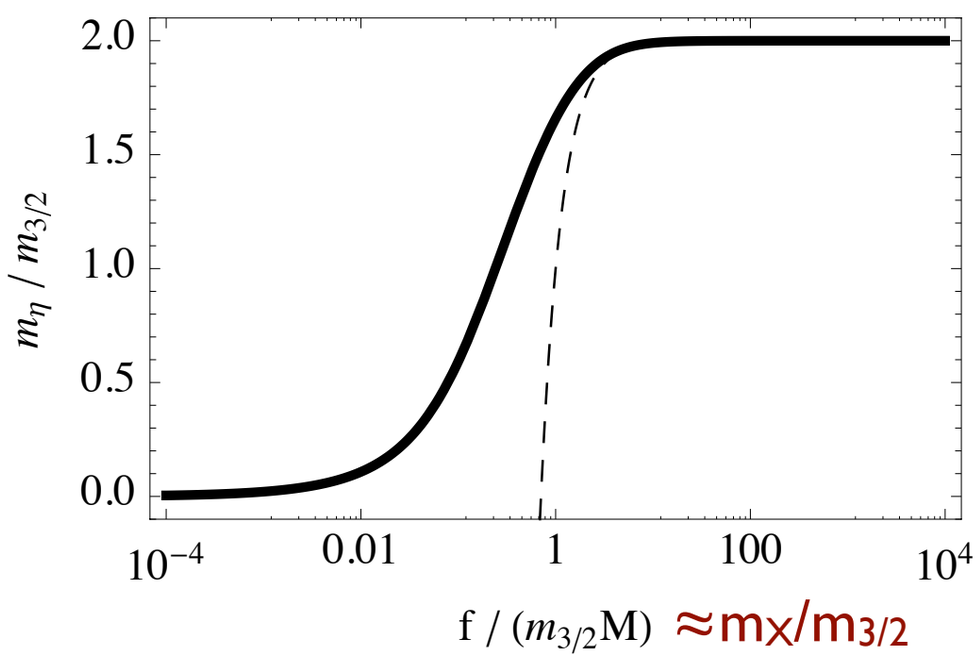
[See Francesco's Talk]

Conformal Sequestering?

$$m_\zeta = (2-\gamma)\tilde{F}_\Phi$$

[Craig, March-Russell, McCullough]

Light Sgoldstino?



[Cheung, D'Eramo, JDT]

[Craig, March-Russell, McCullough]

Non-sequestered SSM Loops?

$$m_\zeta = \left(\frac{1}{16\pi^2}\right)^n m_{\rm soft}$$

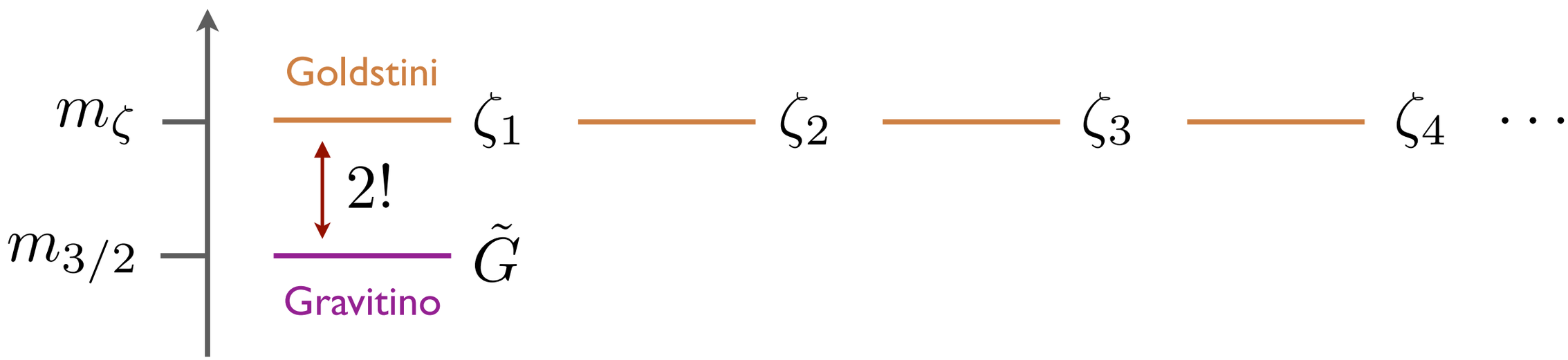
[Cheung, Nomura, JDT]

Multiple Gauge Mediation?

Above with $n = 2$

[Argurio, Komargodski, Mariotti]

Pure SUGRA: $m_\zeta = 2m_{3/2}$



Heuristic for Factor of 2

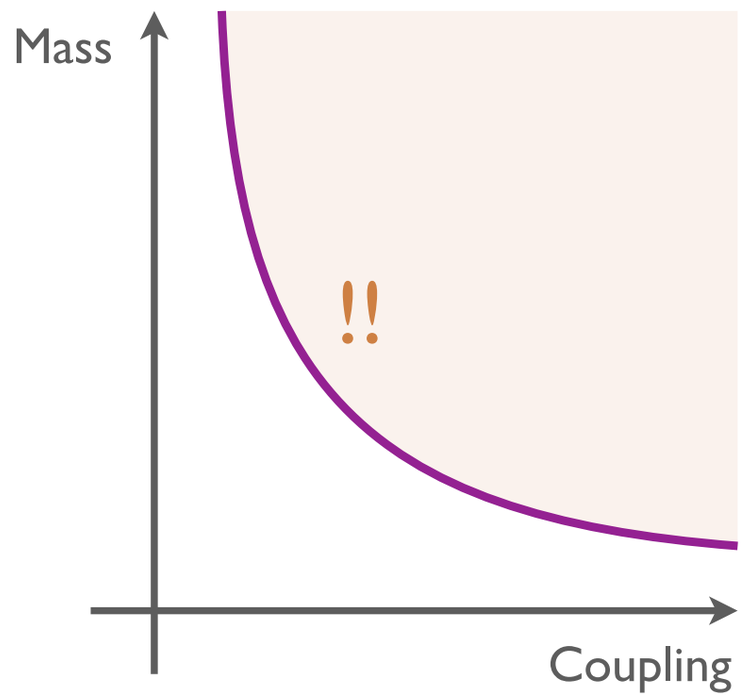
SUGRA ⇒ Gravity ⇒ Mass ⇒ Conformal Compensator

+

~~SUSY~~ ⇒ F/D term ⇒ Mass Dimension 2

Goldstini Mass = $2F_\Phi$

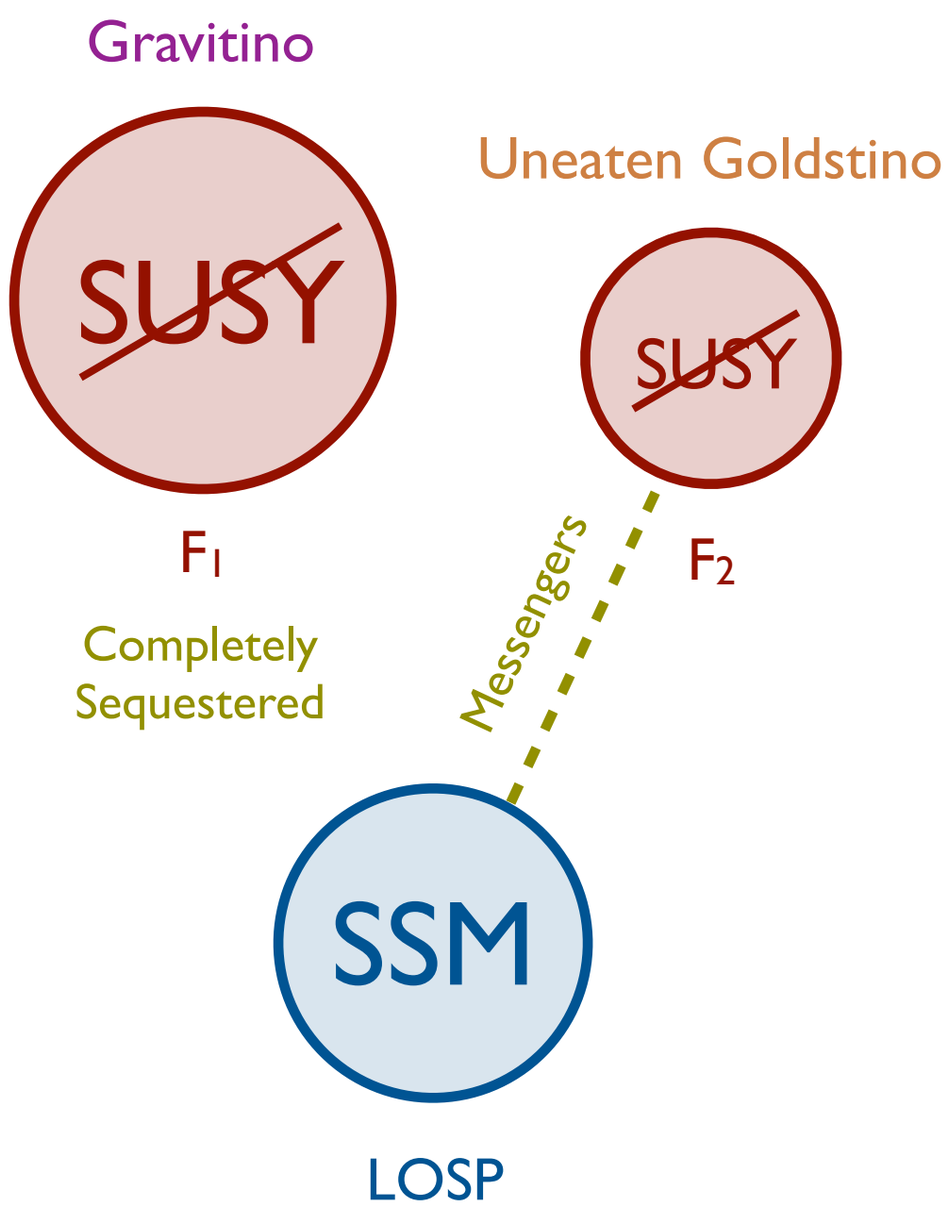
(Analogous to μ/B_μ problem in AMSB: $B_\mu = \mu F_\Phi$)

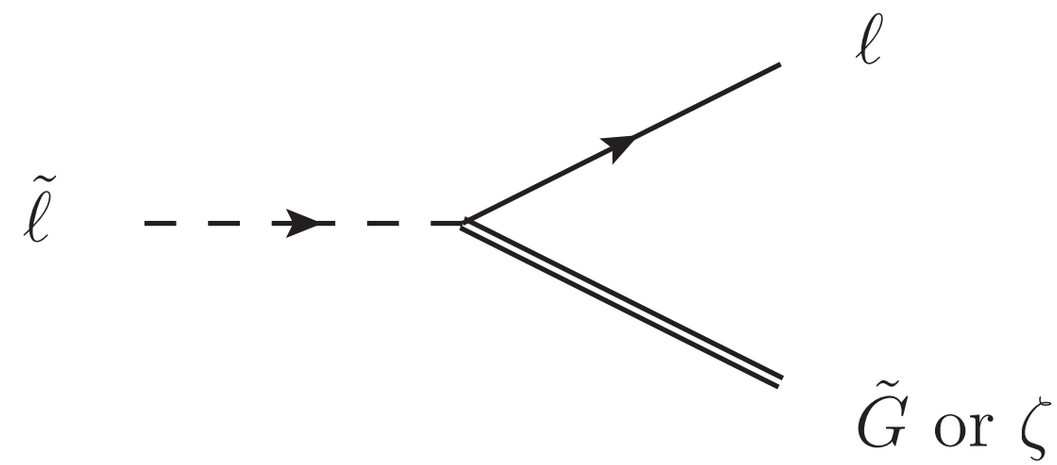


Modified Mass/Coupling Relation

Cheung, Nomura, JDT, 1002.1967

Minimal Goldstini Scenario





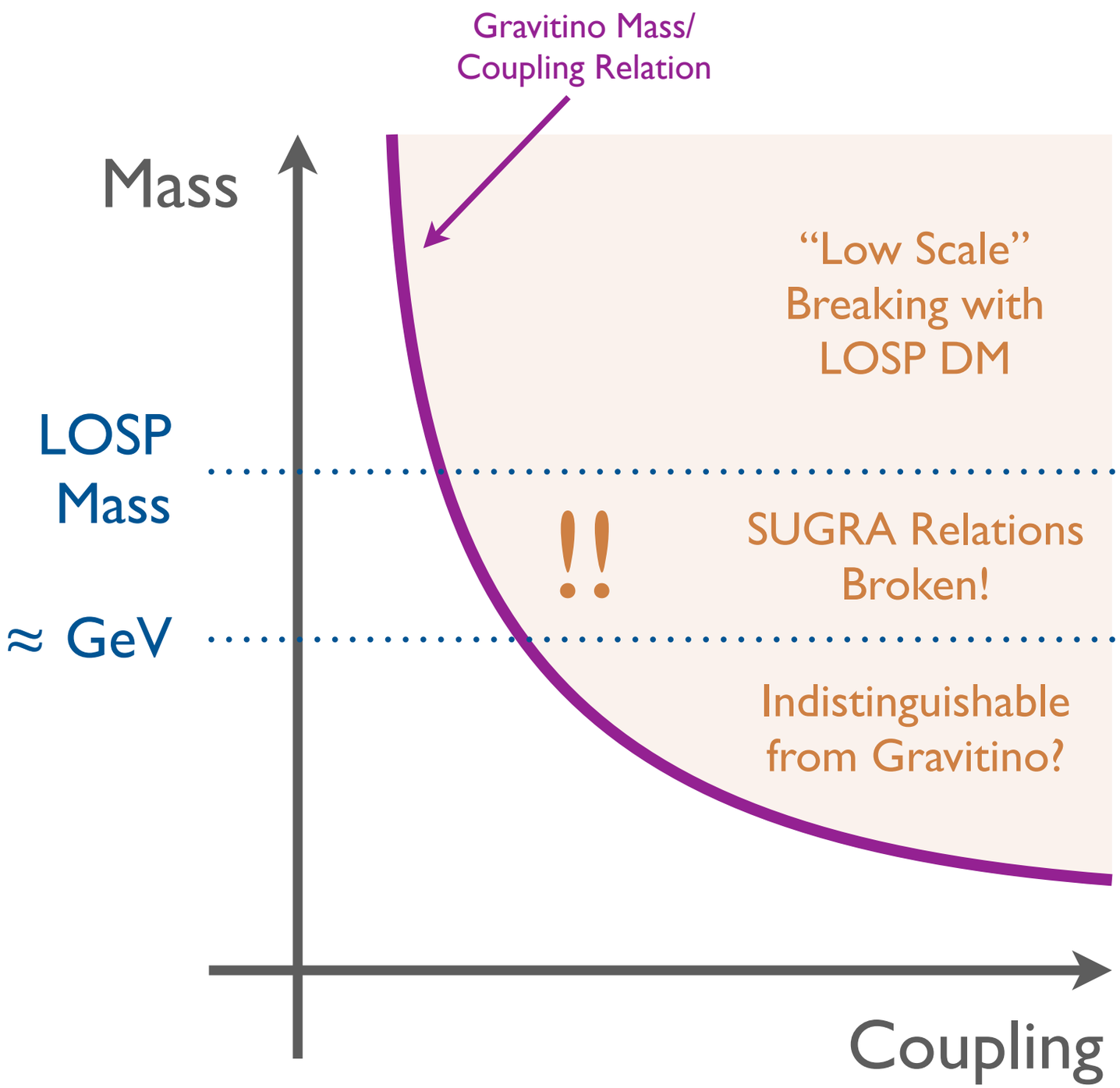
$$\mathcal{L}_{\rm int} \simeq \left(\frac{\tilde{m}^2}{F_{\rm eff}} \tilde{G} + \frac{\tilde{m}^2}{F_2} \zeta \right) \ell \tilde{\ell}^\dagger$$

Supercurrent — New Coupling!

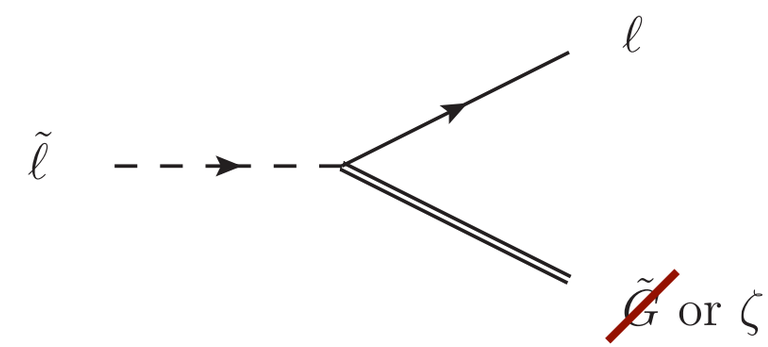
Goldstino Mass: $2m_{3/2} \simeq \dfrac{2F_{\rm eff}}{M_{\rm Pl}}$

Goldstino Coupling: $\dfrac{1}{F_2} \gg \dfrac{1}{m_{3/2} M_{\rm Pl}}$

Mass/Coupling Relation



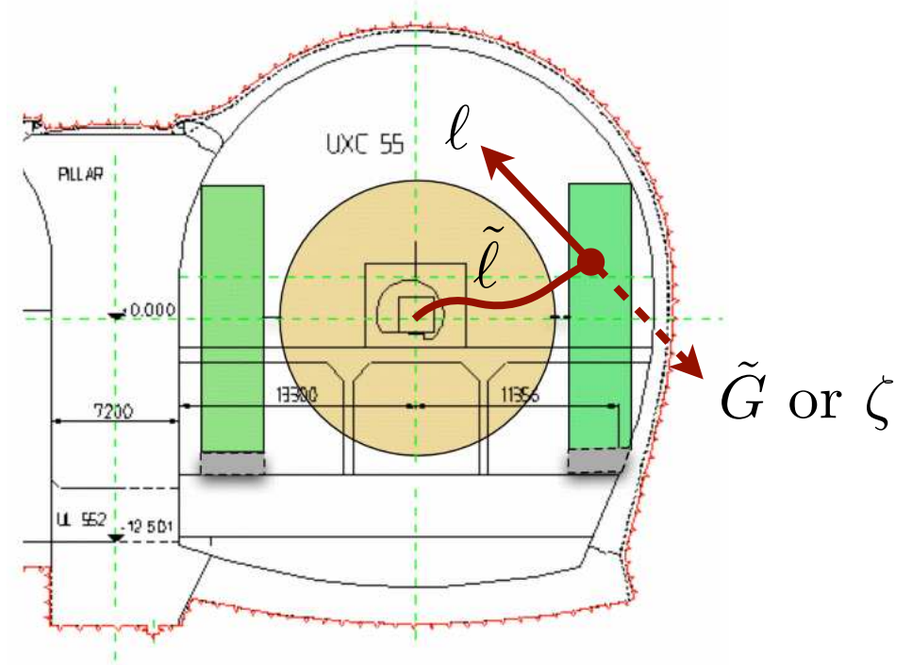
Gravitino Prediction:



$$M_{\rm Pl}^2 \simeq \frac{m_{\tilde{\ell}}^5}{48\pi\Gamma_{\tilde{\ell}\to\ell\tilde{G}} m_{3/2}^2}$$

[Buchmüller, Hamaguchi, Ratz, Yanagida]

Broken if LOSP decays to Goldstino instead!

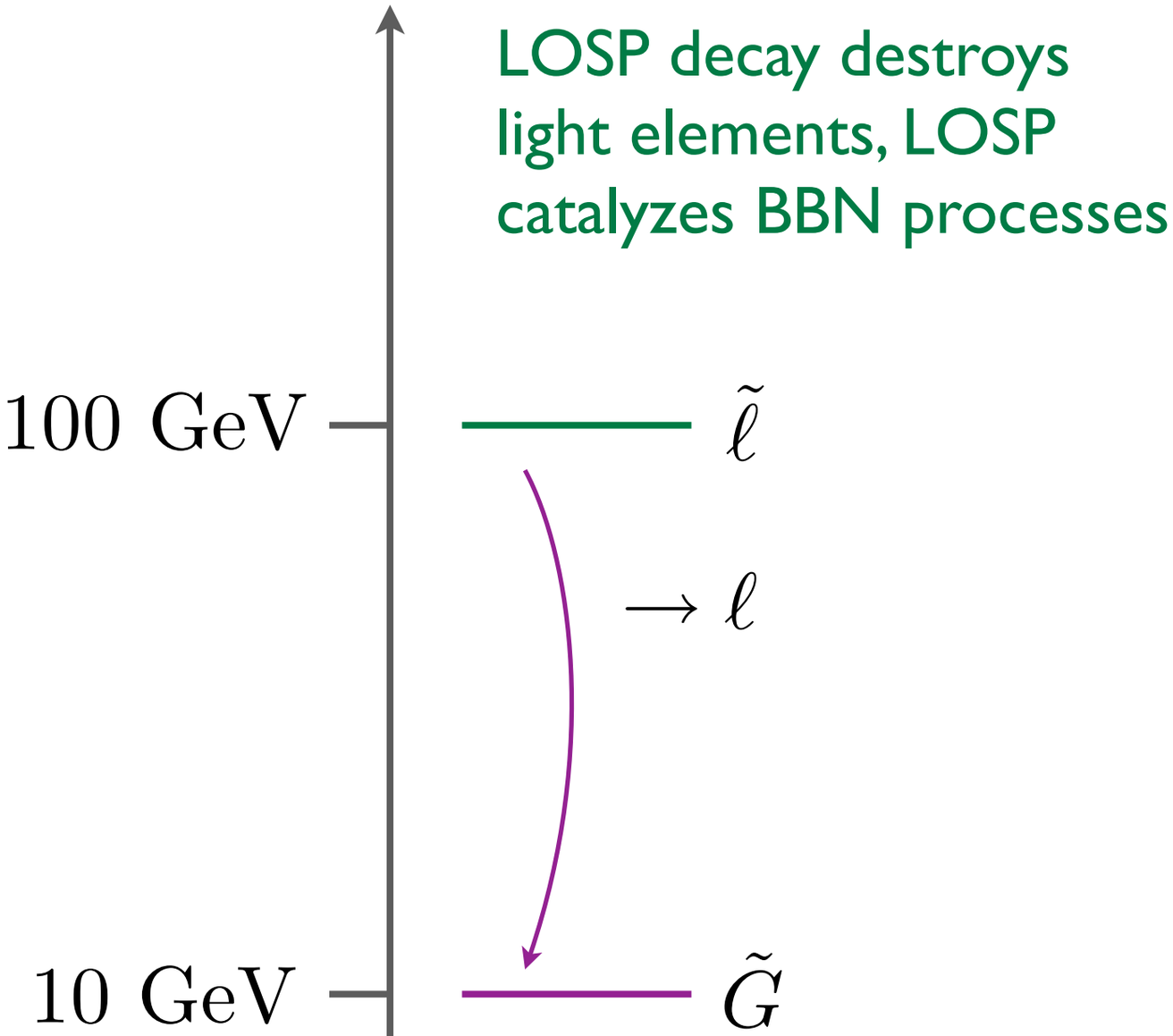


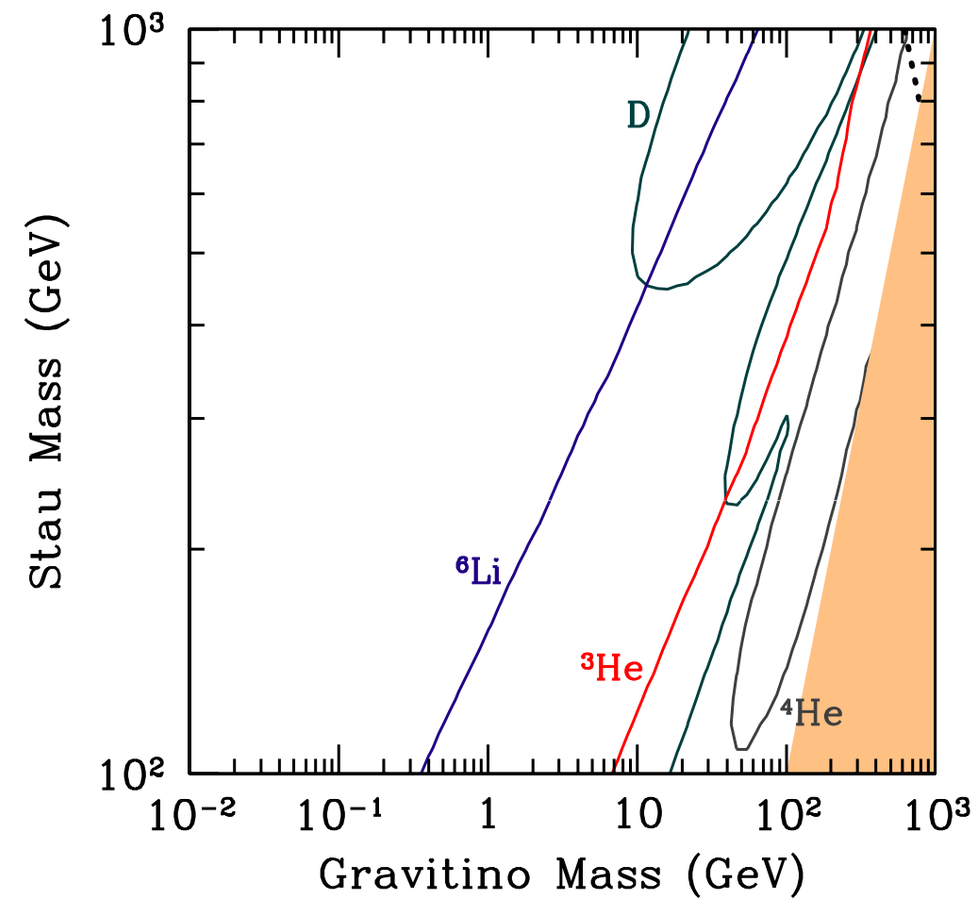
The Smoking Gun at the LHC

Cheung, Mardon, Nomura, JDT, 1004.4637

Gravitino at LHC vs. BBN?

LOSP decay destroys light elements, LOSP catalyzes BBN processes



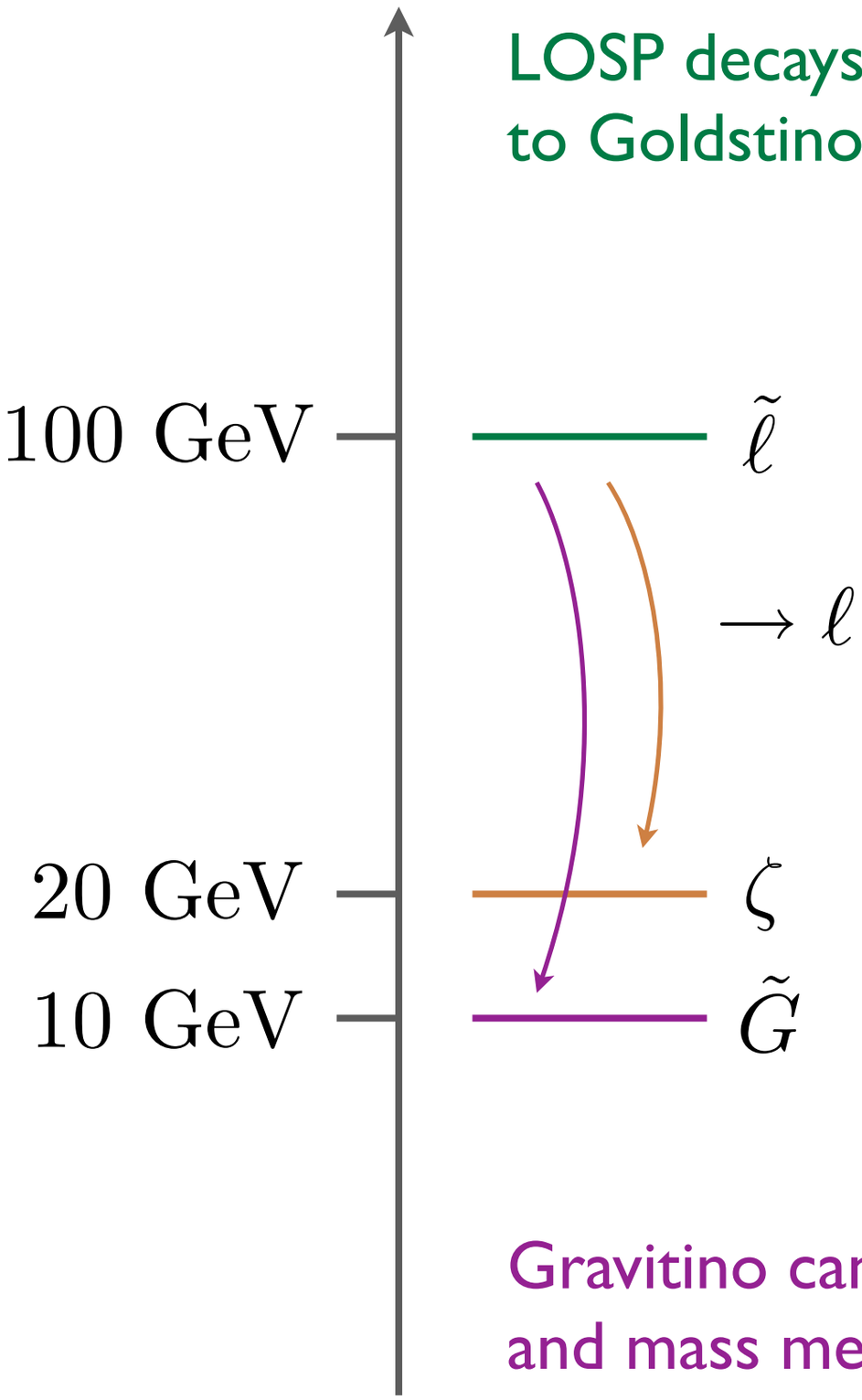


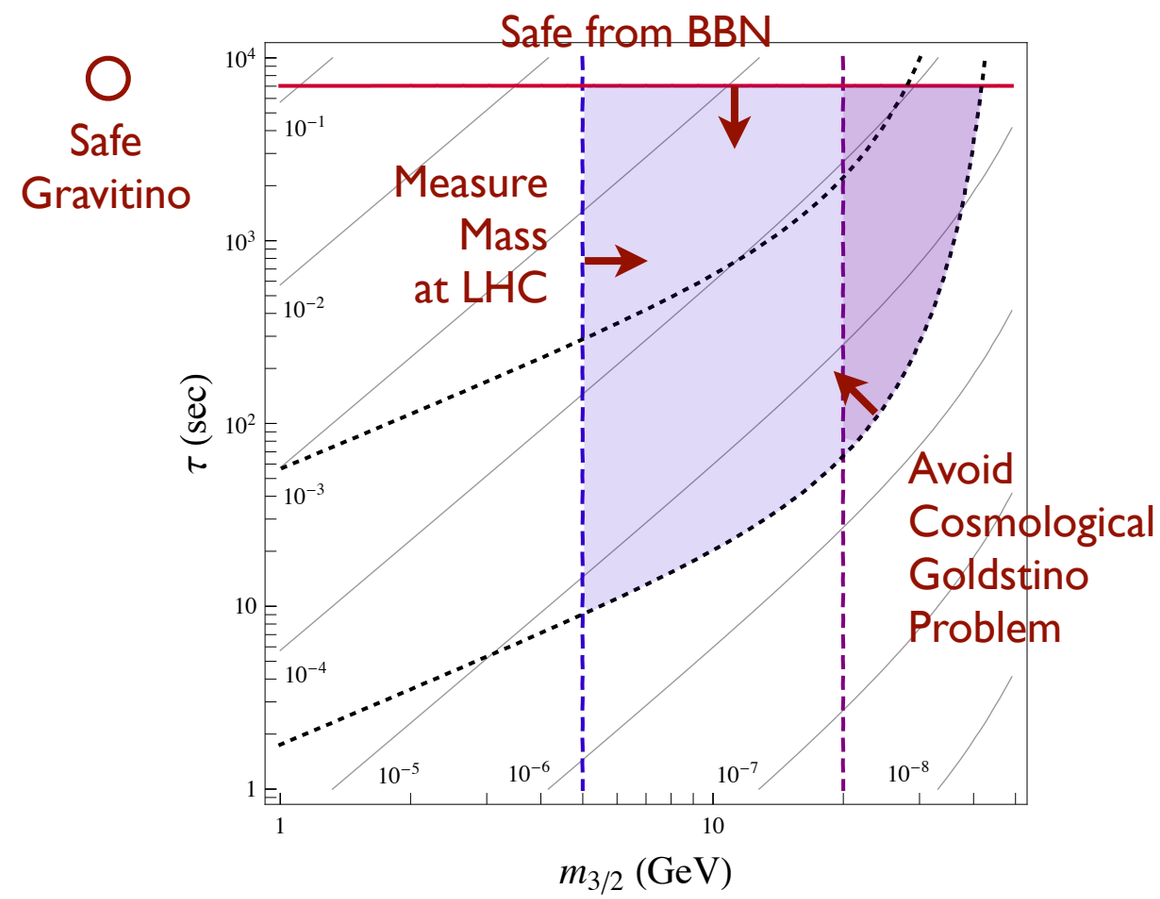
[Kawasaki, Kohri, Moroi, Yotsuyanagi]

$m_{3/2}$ < 1–10 GeV to not mess up BBN

$m_{3/2}$ > 1–10 GeV to measure gravitino mass at LHC

Goldstini Rescue BBN/LHC!



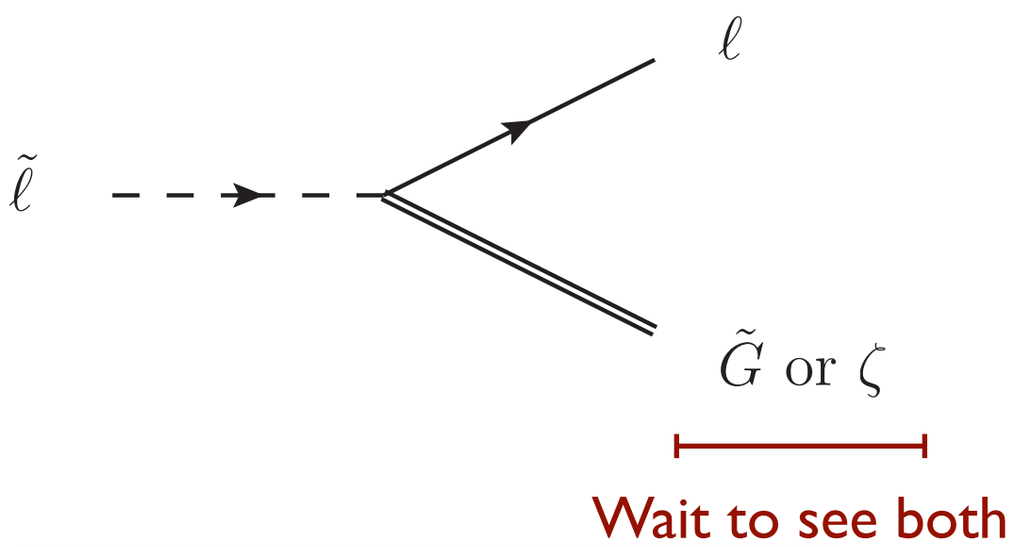


[Cheung, Mardon, Nomura, JDT]

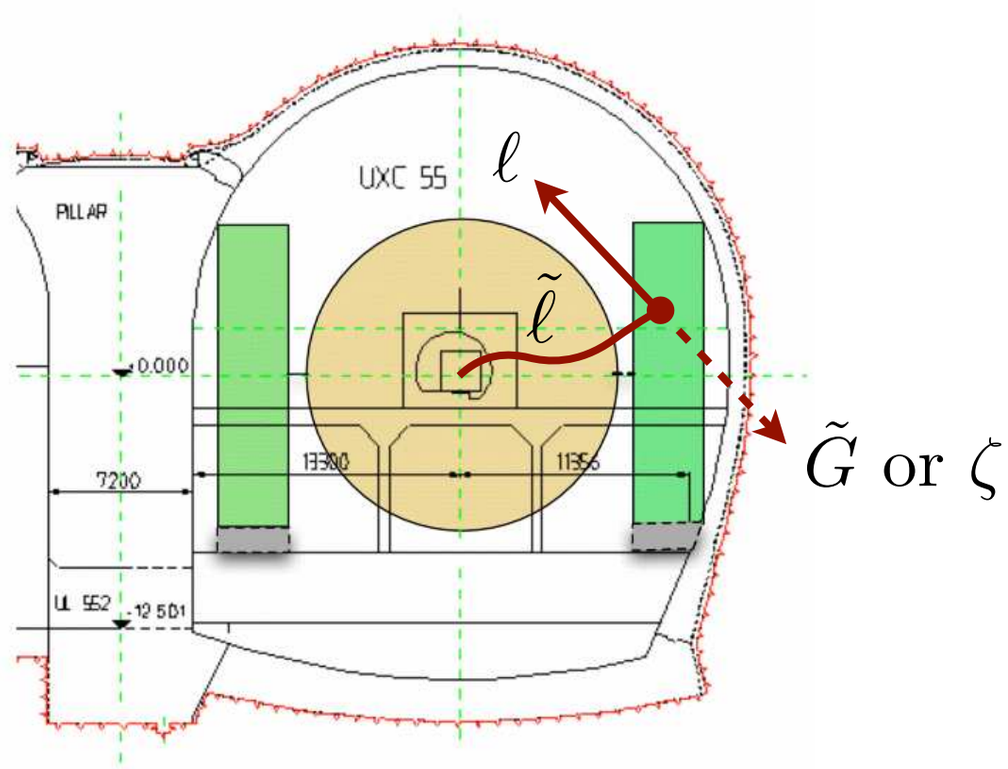
Gravitino can be 1-100 GeV,
and mass measured at LHC!

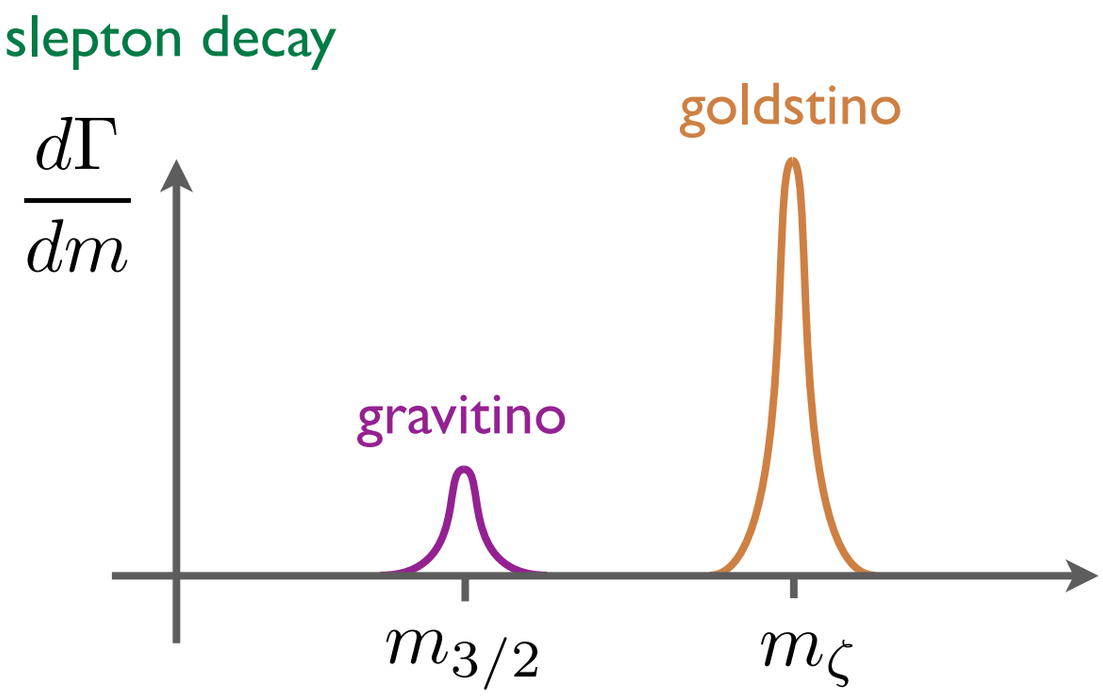
($\approx 10^2$ second lifetime)

The Smoking Gun



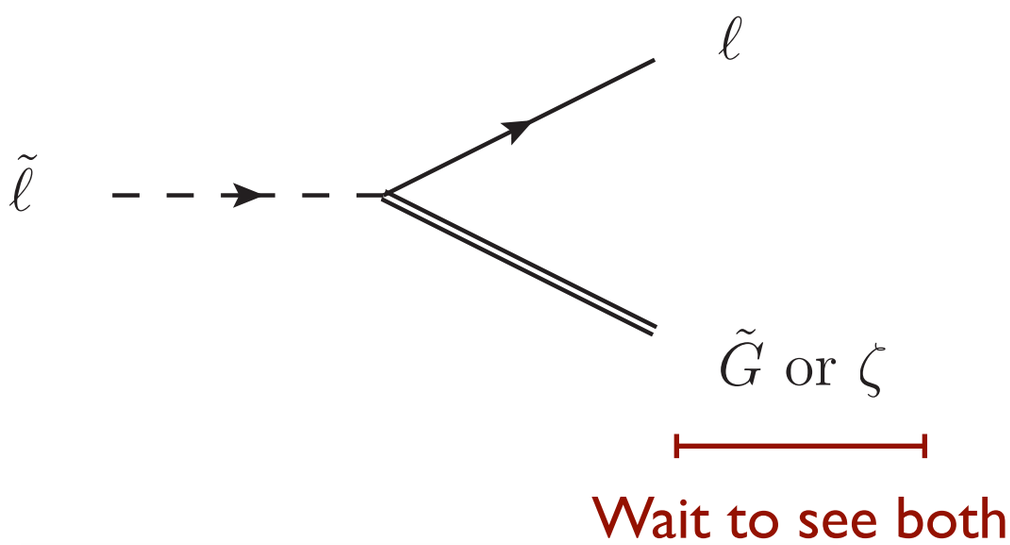
Stable charged tracks stopping in calorimeter, eventually decaying to *bichromatic* leptons





[See also: Hamaguchi, Kuno, Nakaya Nojiri; Feng, Smith; Hamaguchi, Nojiri, de Roeck; ...]

The Smoking Gun



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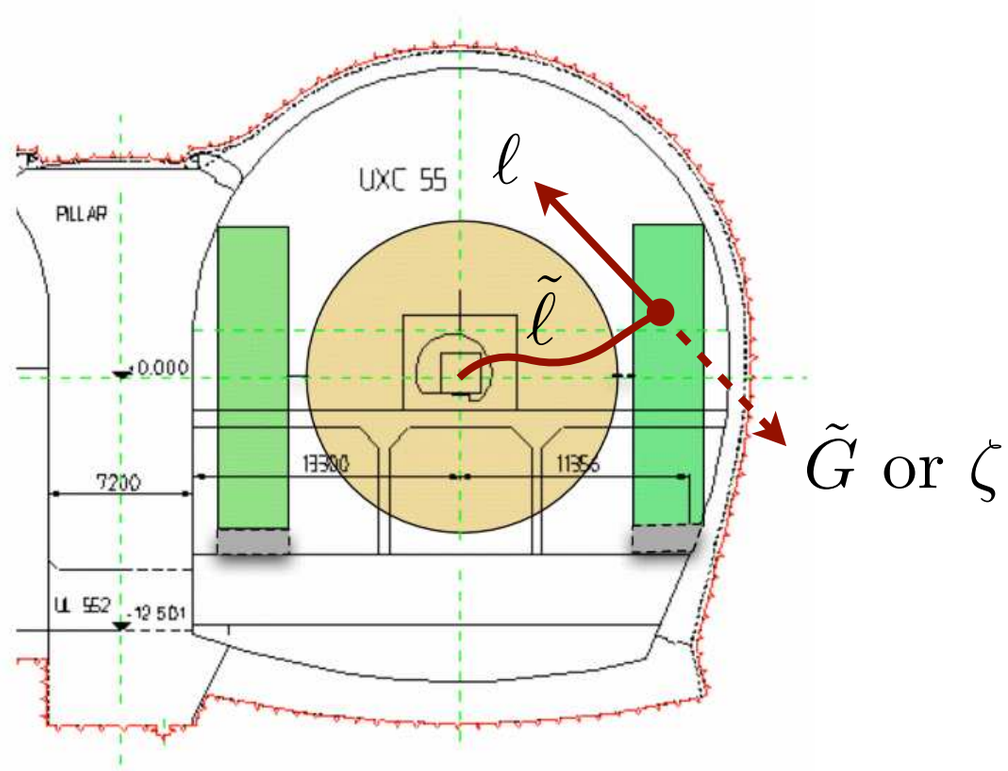
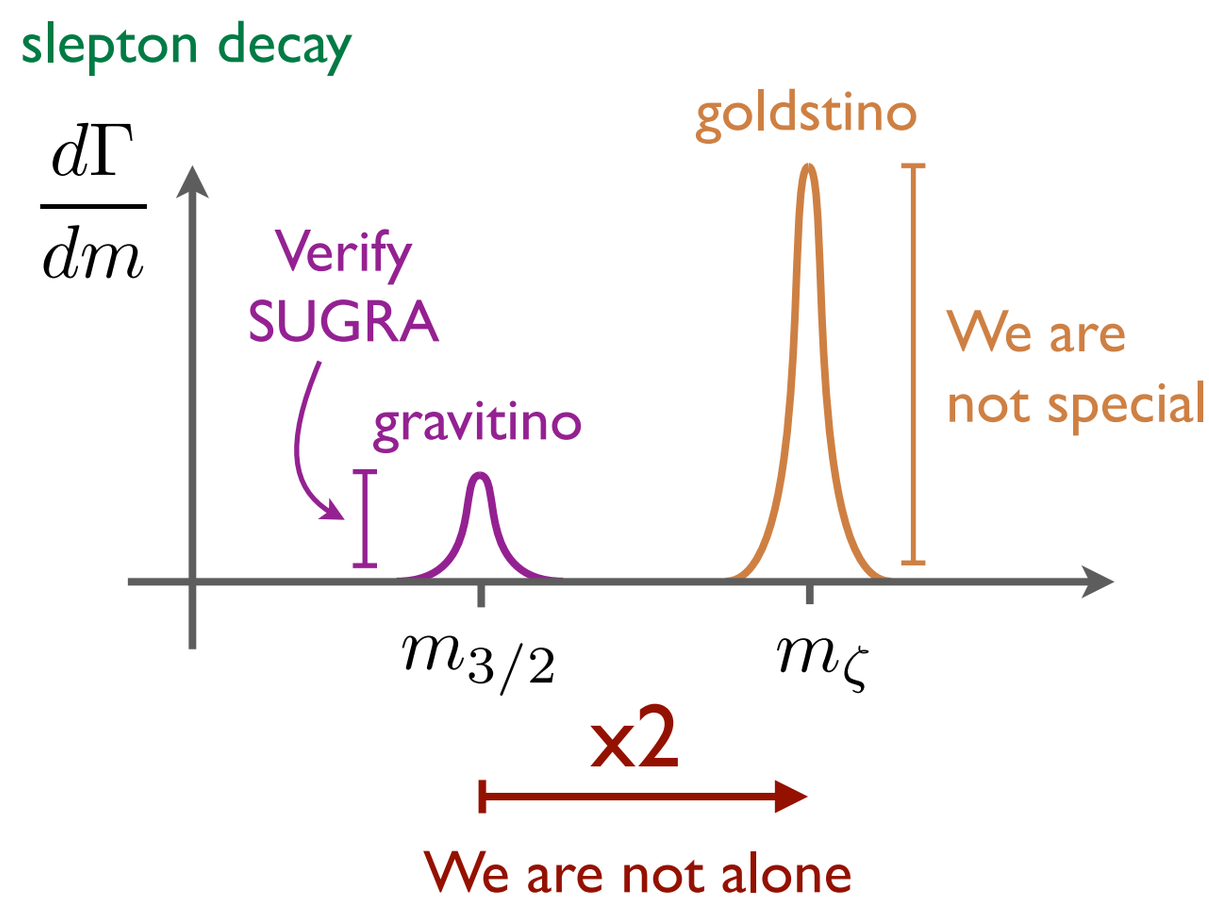
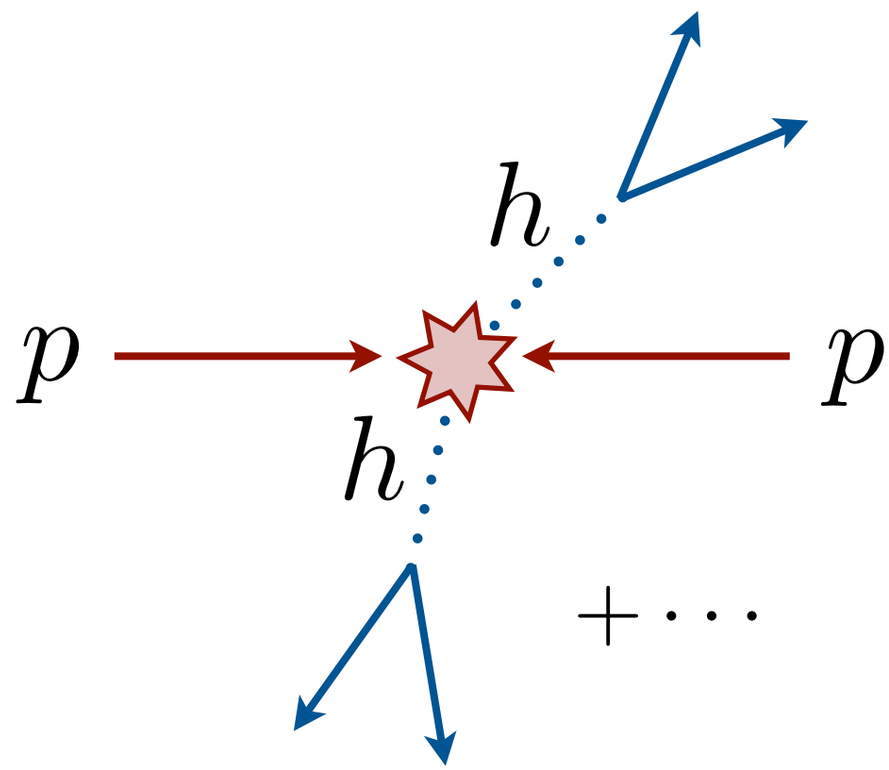




[See also: Hamaguchi, Kuno, Nakaya Nojiri; Feng, Smith; Hamaguchi, Nojiri, de Roeck; ...]

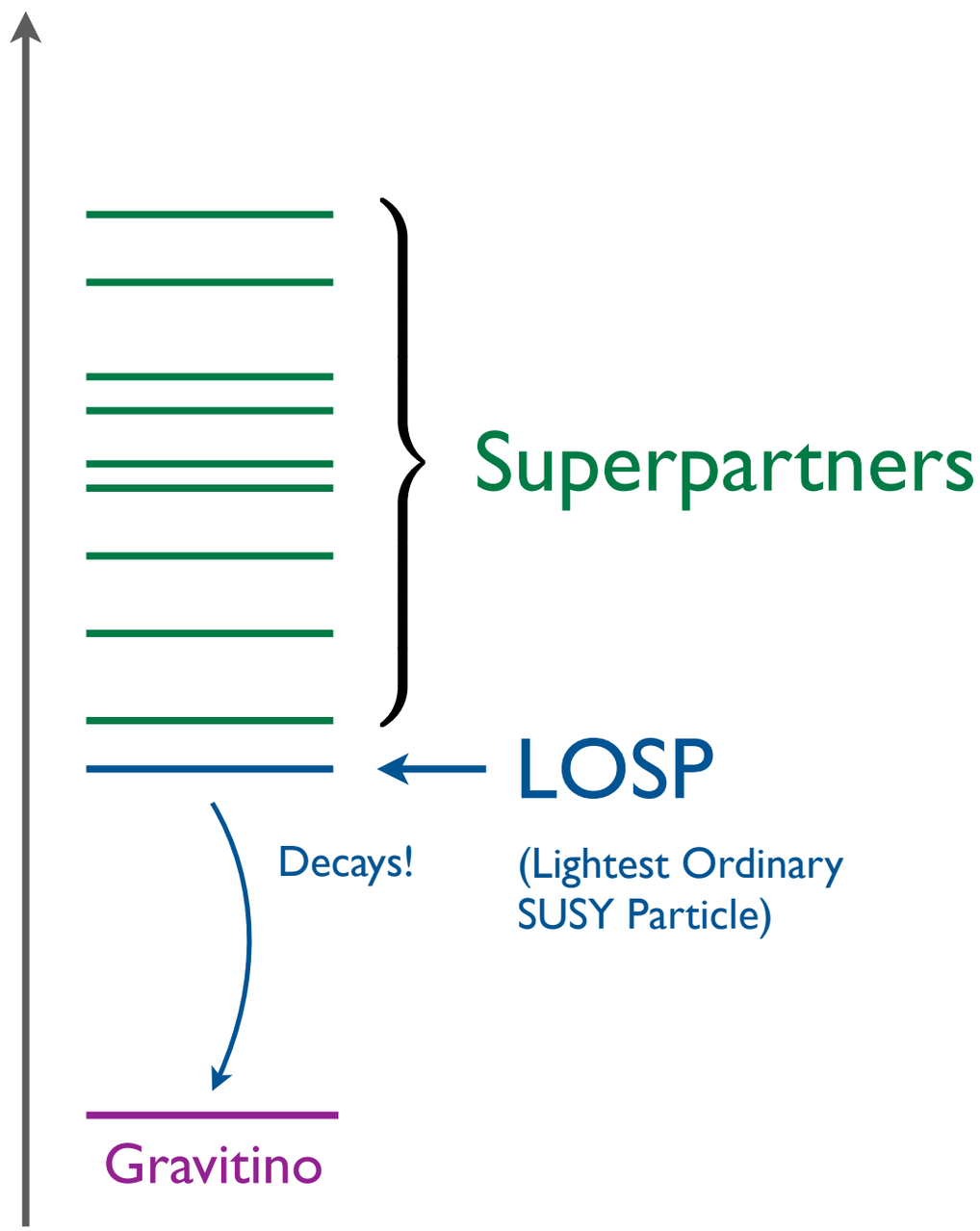


Giving the Higgs a Boost

JDT, Zachary Thomas, 1103.1631

LOSP Possibilities

"Gauge Mediation-like"



LOSP Type Determines Dominant Collider Signature

Bino LOSP → γ/Z + Gravitino

Classic 2γ + E_T Signature

Higgsino LOSP → h_0/Z_L + Gravitino

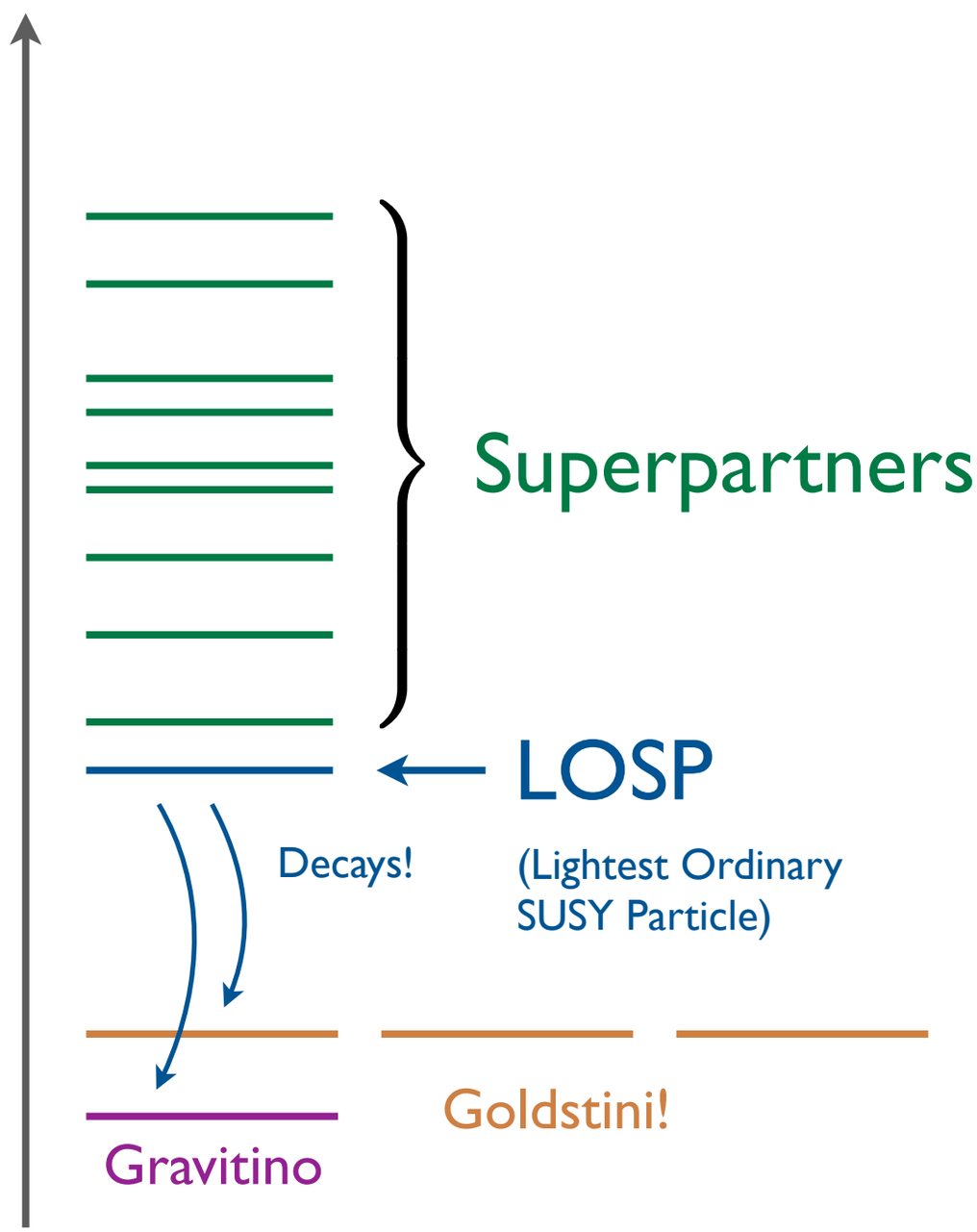
Stau LOSP → τ + Gravitino

Gluino LOSP → g + Gravitino

...

LOSP Identity Crisis

"Goldstini!"



Counterintuitive LOSP Decays Possible!

Gravitino

$$\tilde{\tau}_R \to \tau_R + \widetilde{G}$$

Enforced by Supercurrent

Uneaten Goldstino

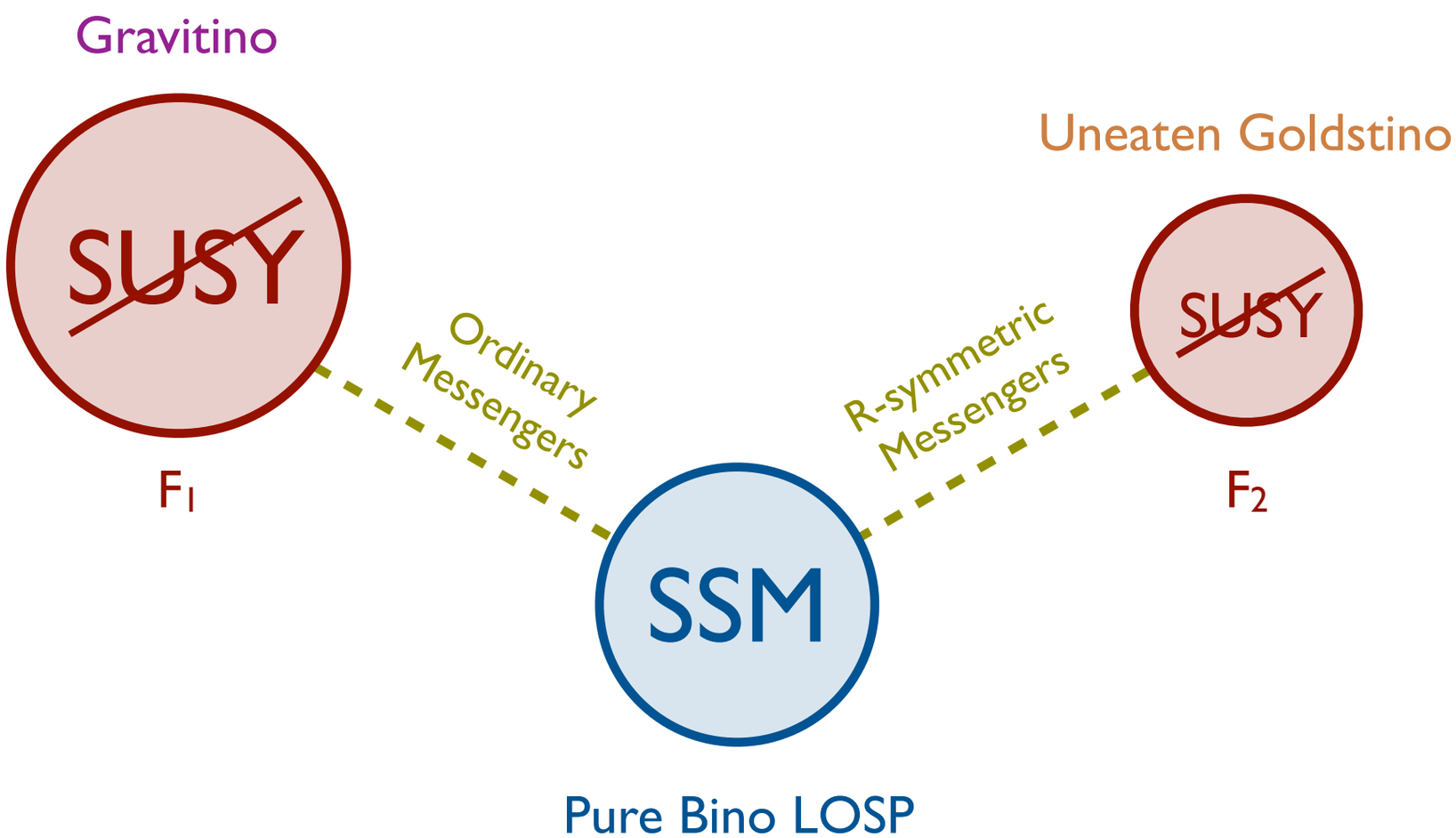
$$\tilde{\tau}_R \to \tau_L + \eta$$

Unconstrained!

(Not easy to measure this one...)

Counterintuitive LOSP decays dominate if larger coupling to goldstino

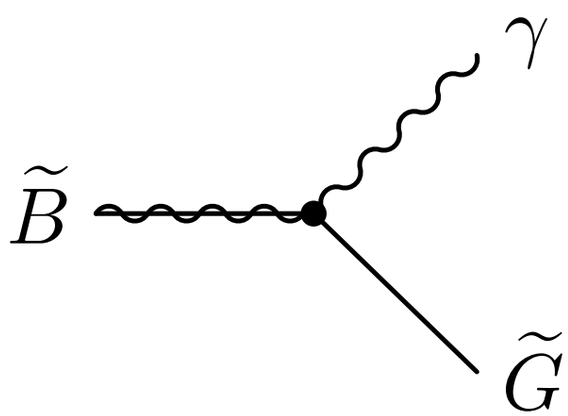
Goldstini with an R-symmetry



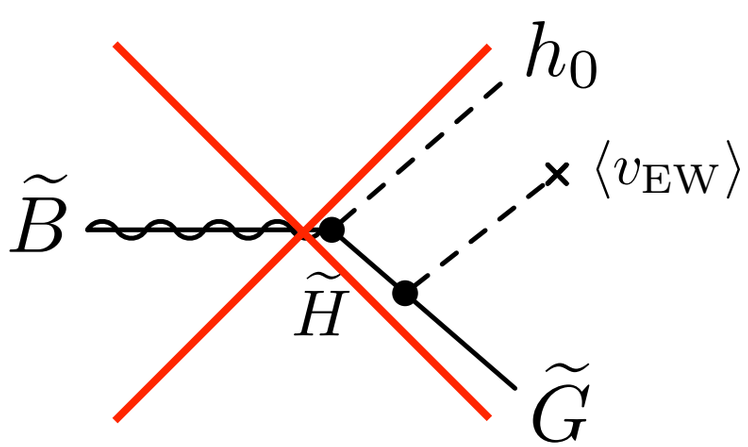
Goldstino couplings determined by R-symmetry,
"standard" decays forbidden

Pure Bino LOSP

Gravitino

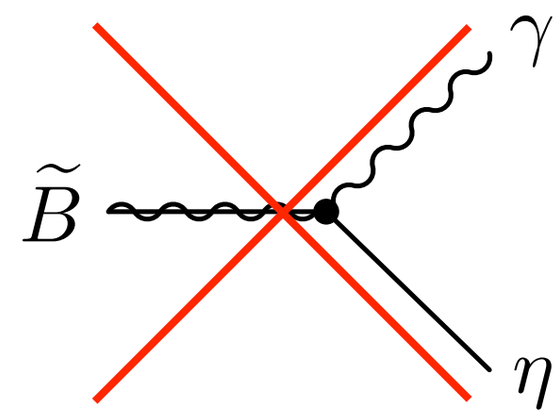


Usual Supercurrent Coupling

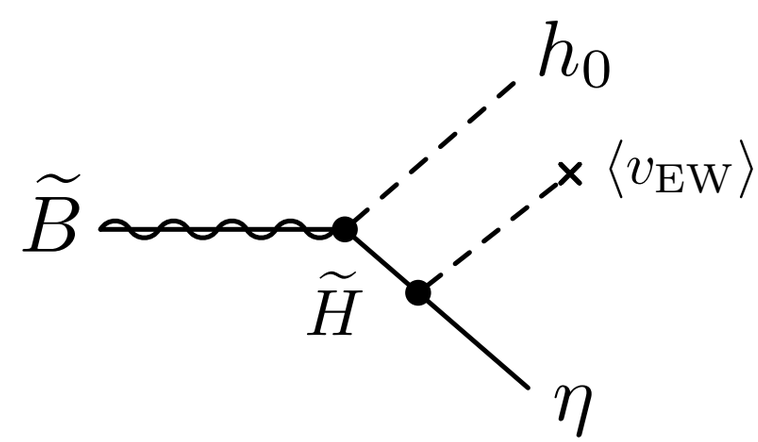


No Higgsino Mixing for Large μ

R-Symmetric Goldstino

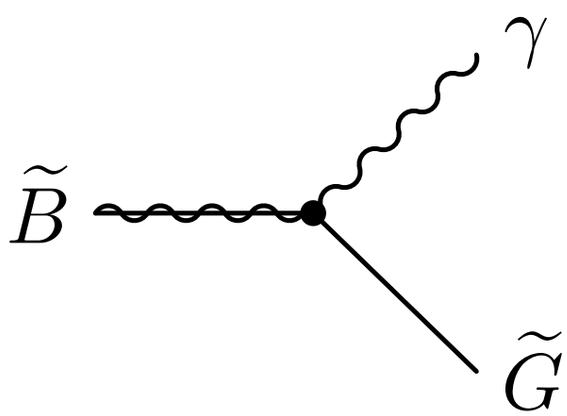


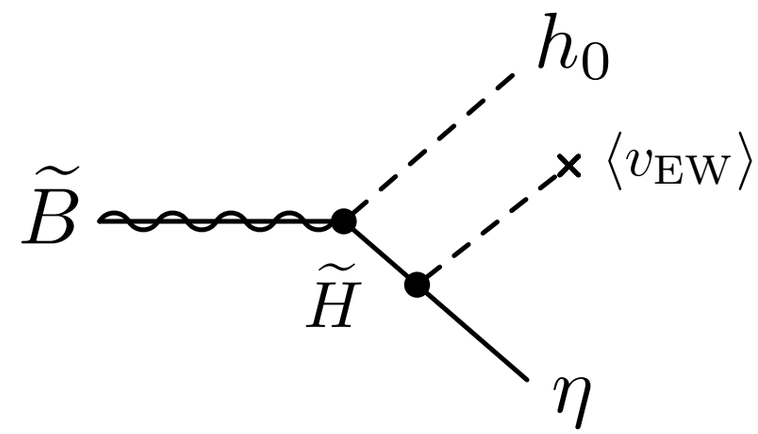
Suppressed by R-symmetry!



Leading Operator
Preserved by R-symmetry!

Gravitino vs. Goldstini Couplings





Gravitino

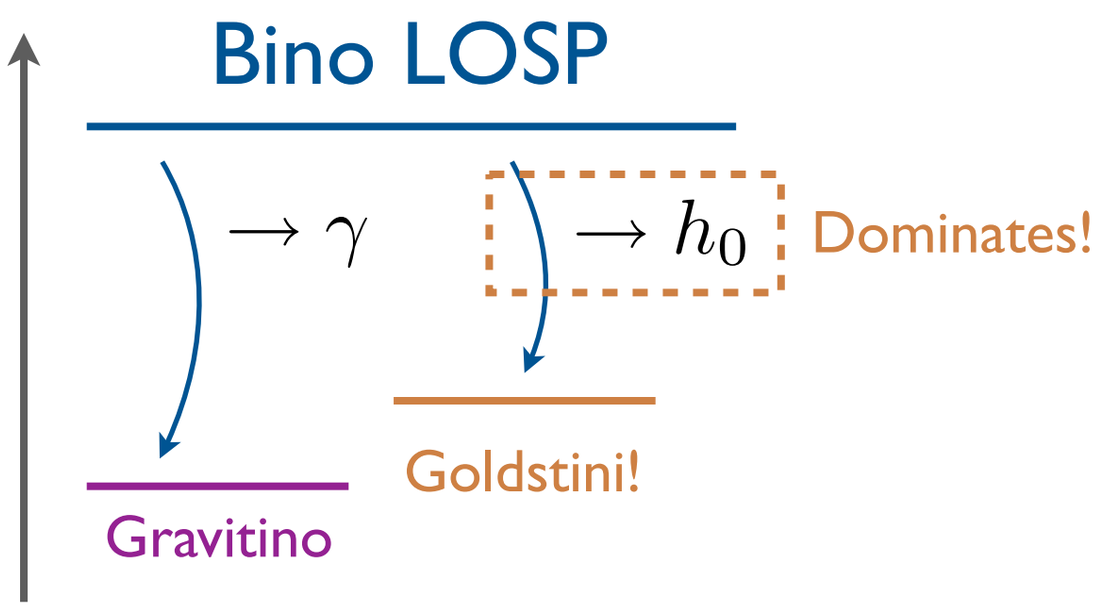
$$\frac{1}{F_1}\chi\sigma^{\mu\nu}\tilde{G}F_{\mu\nu}$$

$\ll$

Typically

Uneaten Goldstino

$$\frac{\mu}{F_2}(\chi\eta)(h_u h_d)^\dagger$$

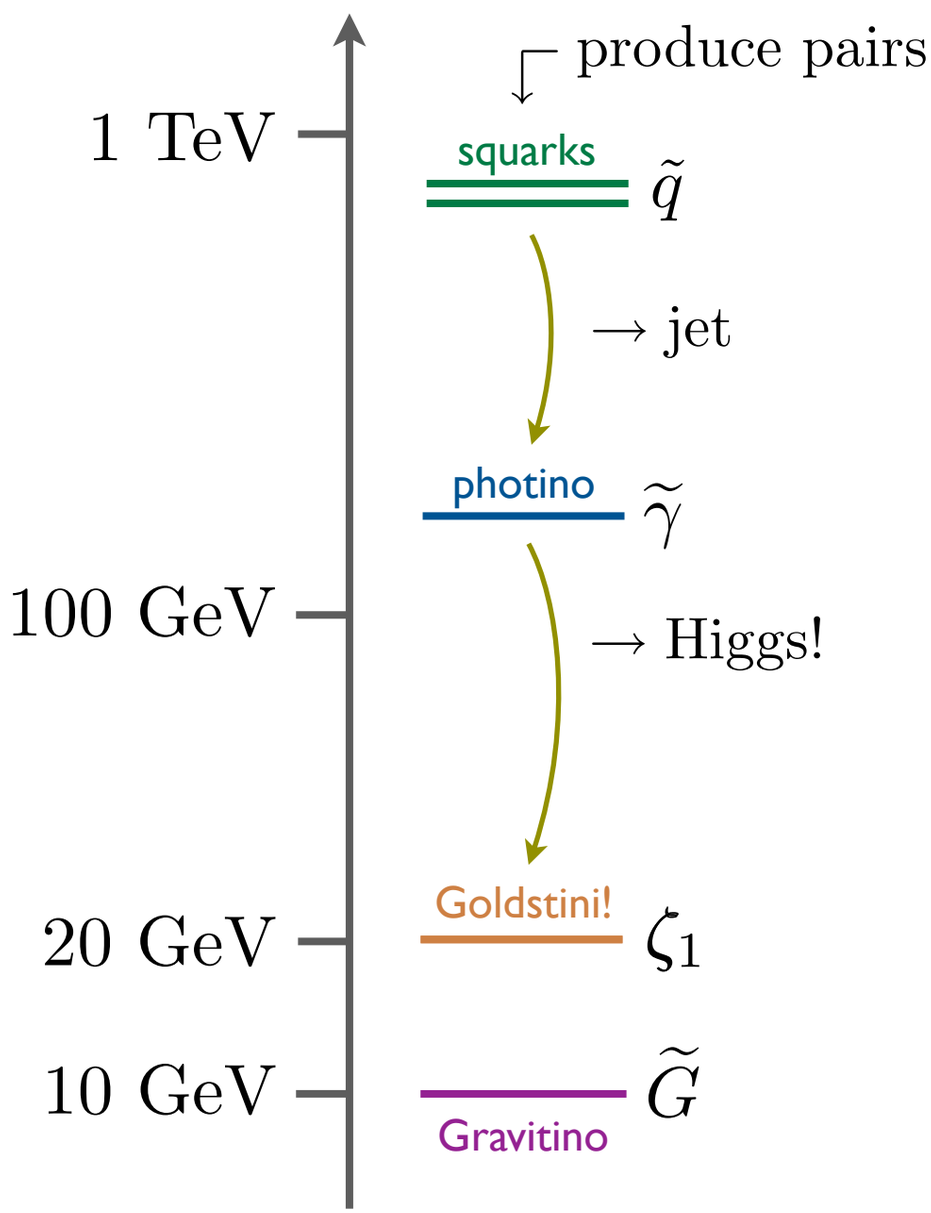


Every SUSY Cascade has Two Physical Higgses!

(Compare to Higgsino LOSP, typically 50% Higgs, 50% Z)

Goldstini Give the Higgs a Boost

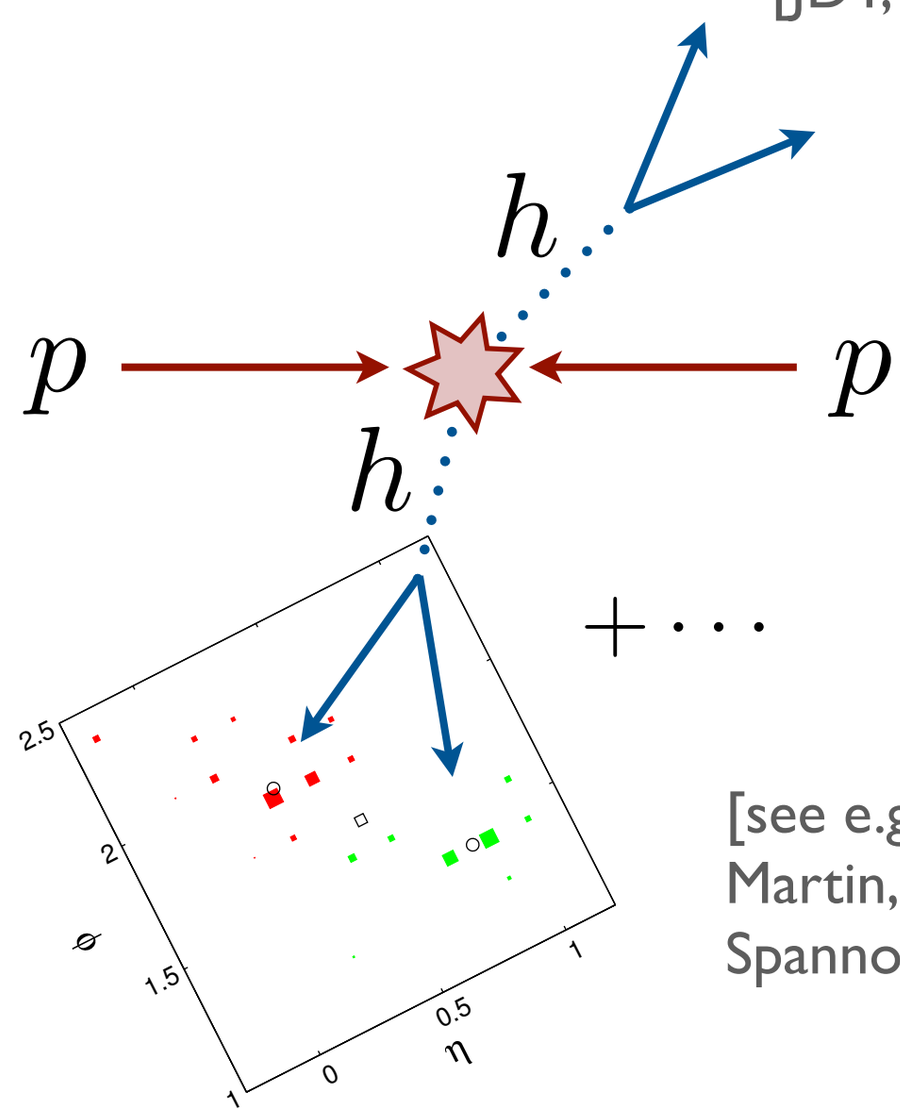
Boost in Cross Section...



Unique* to Goldstini!

...Boost in Kinematics

[JDT, Thomas]

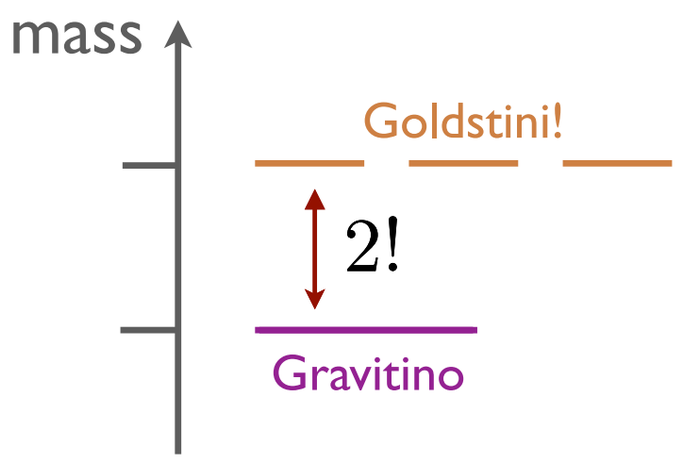


[see e.g. Kribs, Martin, Roy, Spannowsky]

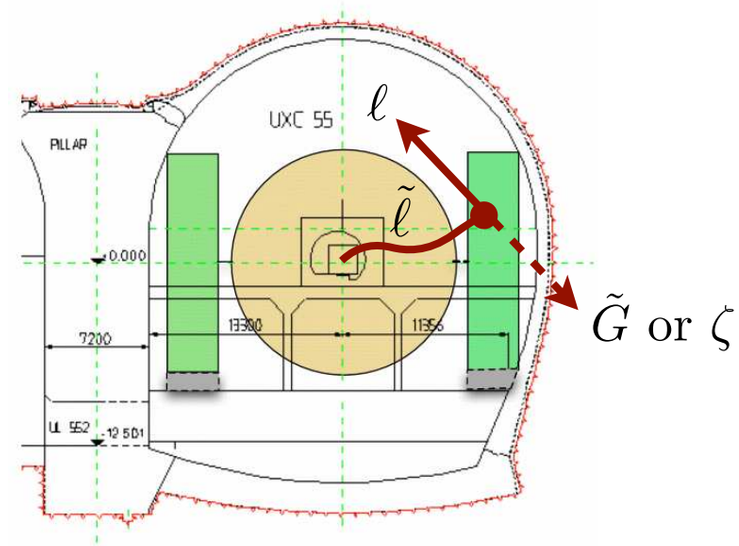
Ask me about "*N*-subjettiness"

[JDT, Van Tilburg]

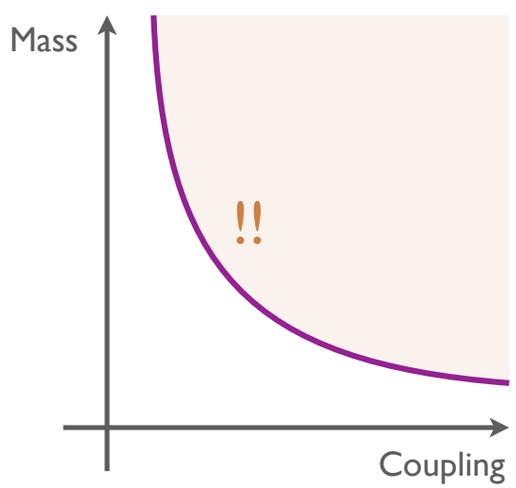
Goldstini



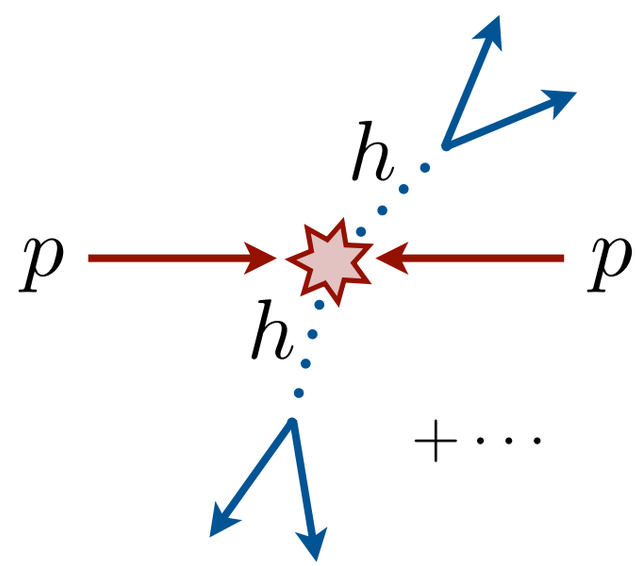
A Curious Factor of Two



The Smoking Gun at the LHC



Modified Mass/Coupling Relation



(Giving the Higgs a Boost)