Unstable Stau at the LHC

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2012.2.21 @ University of Toyama

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Unstable Stau with Light Gravitino at the LHC

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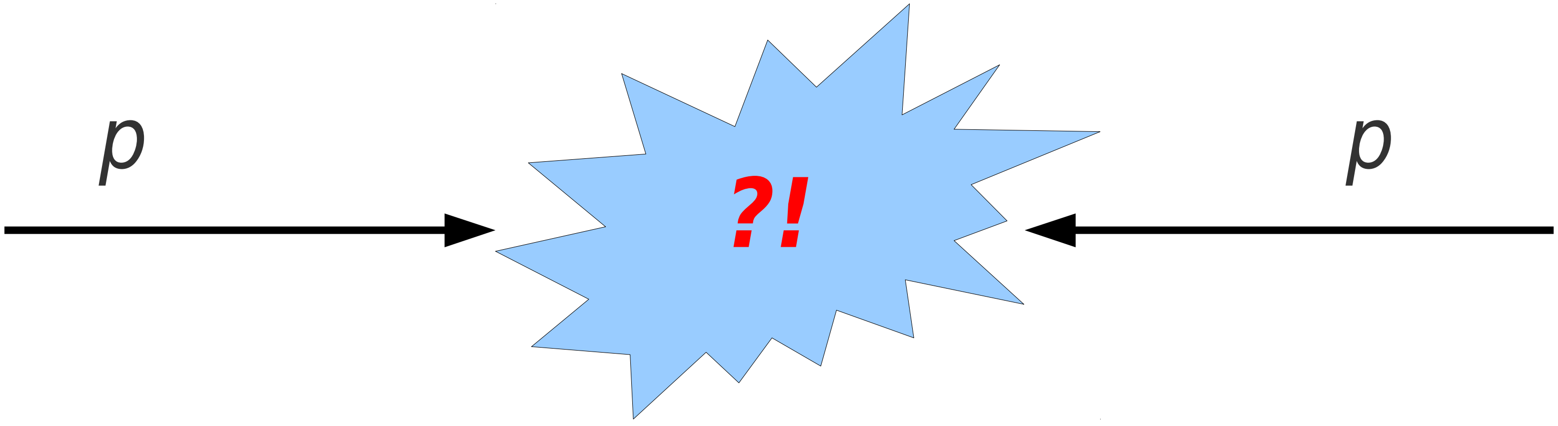
Based on : Asano, Ito, Matsumoto and Moroi, arXiv:1111.3725 [hep-ph] (accepted in JHEP)

Supersymmetry is an attractive candidate of TeV scale new physics.

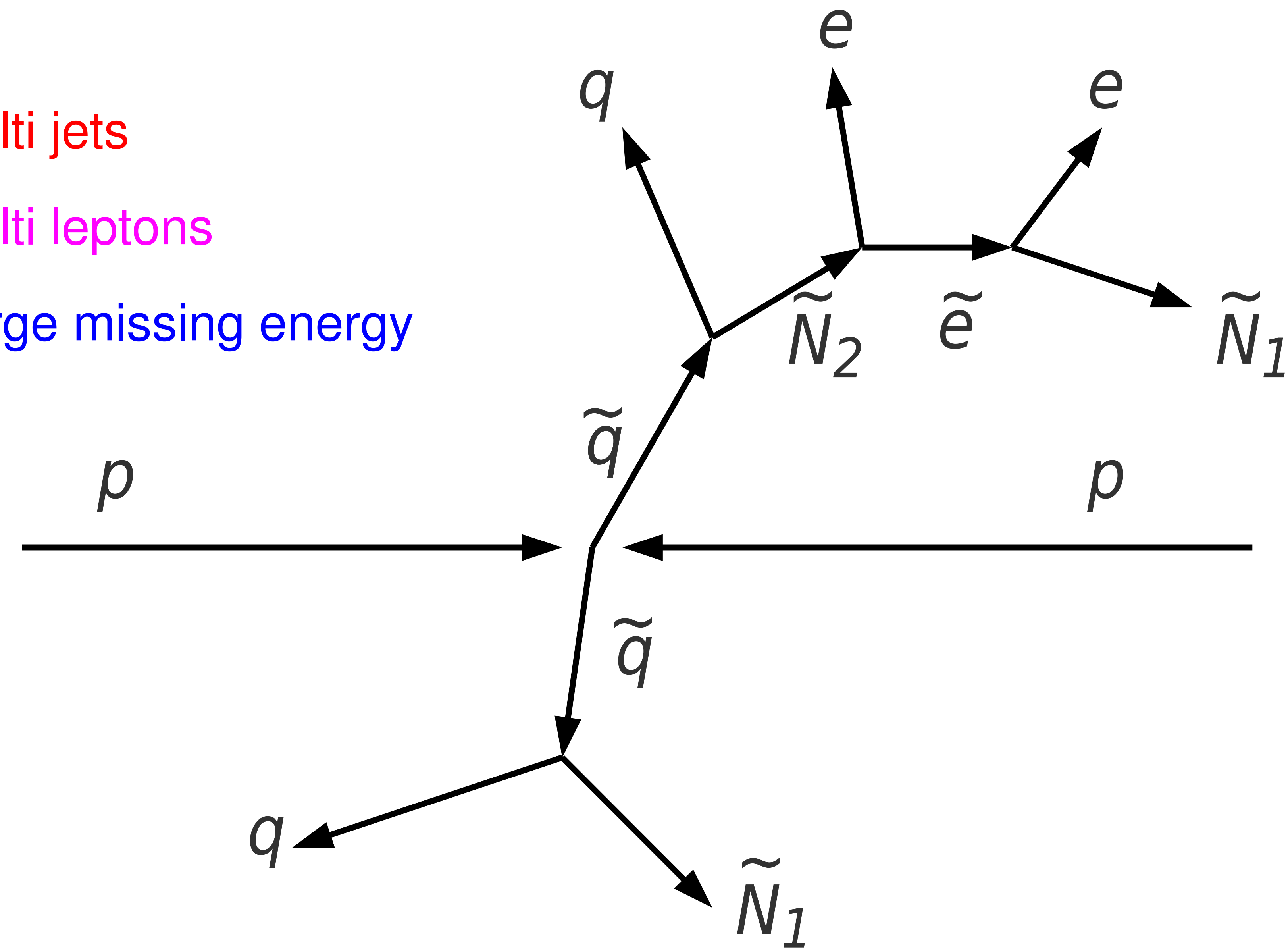
$\rightarrow$ What is the signature of SUSY at the LHC ???



It's important to “optimize” our analysis to study the underlying model deeply.

I. Supergravity model … (This has been widely studied !)

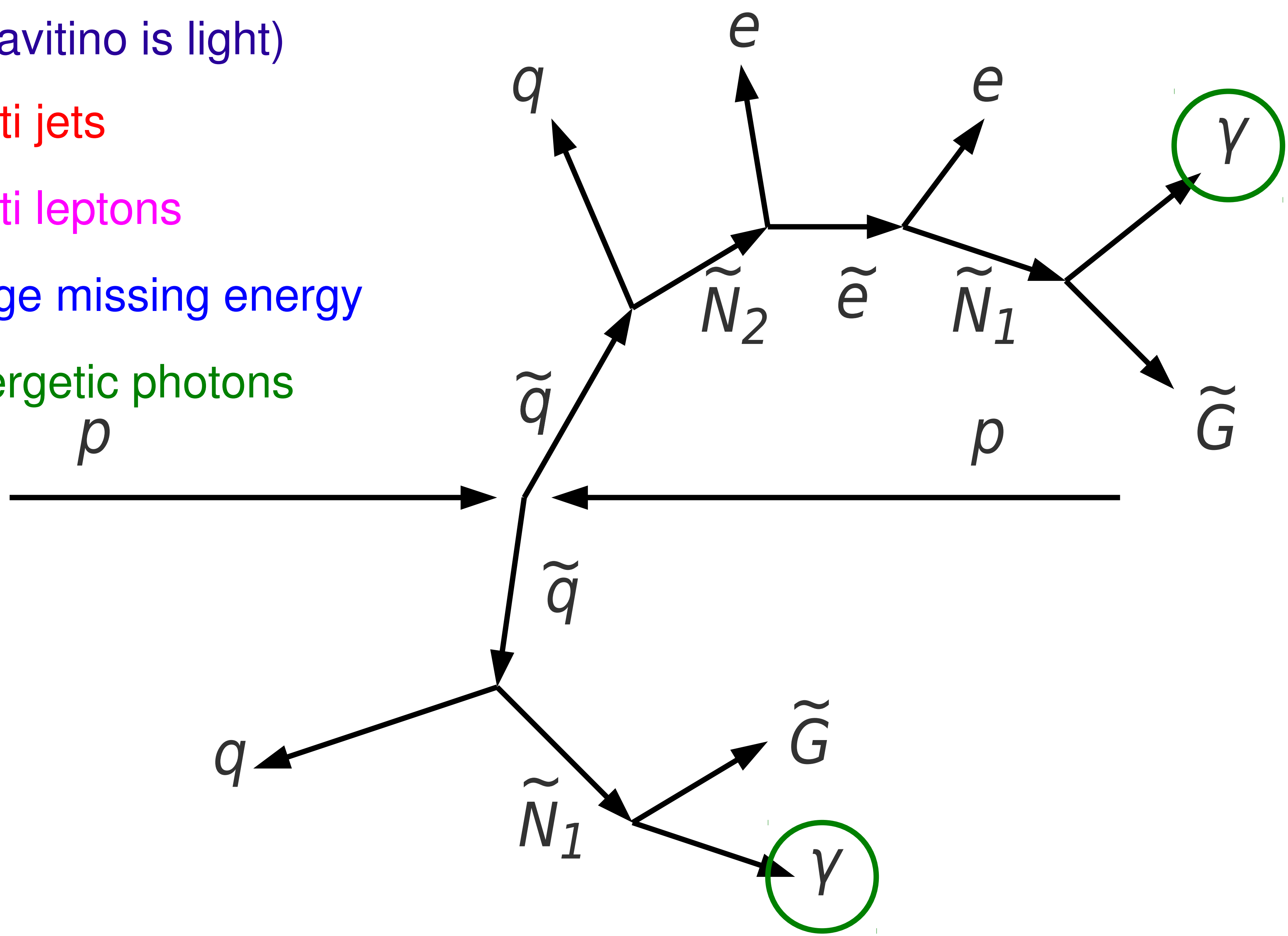
- Multi jets
- Multi leptons
- Large missing energy



IIa. Gauge-mediation model with **neutralino**-NLSP

(If gravitino is light)

- Multi jets
- Multi leptons
- Large missing energy
- Energetic photons



IIa. Gauge-mediation model with **neutralino**-NLSP

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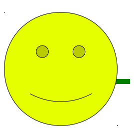
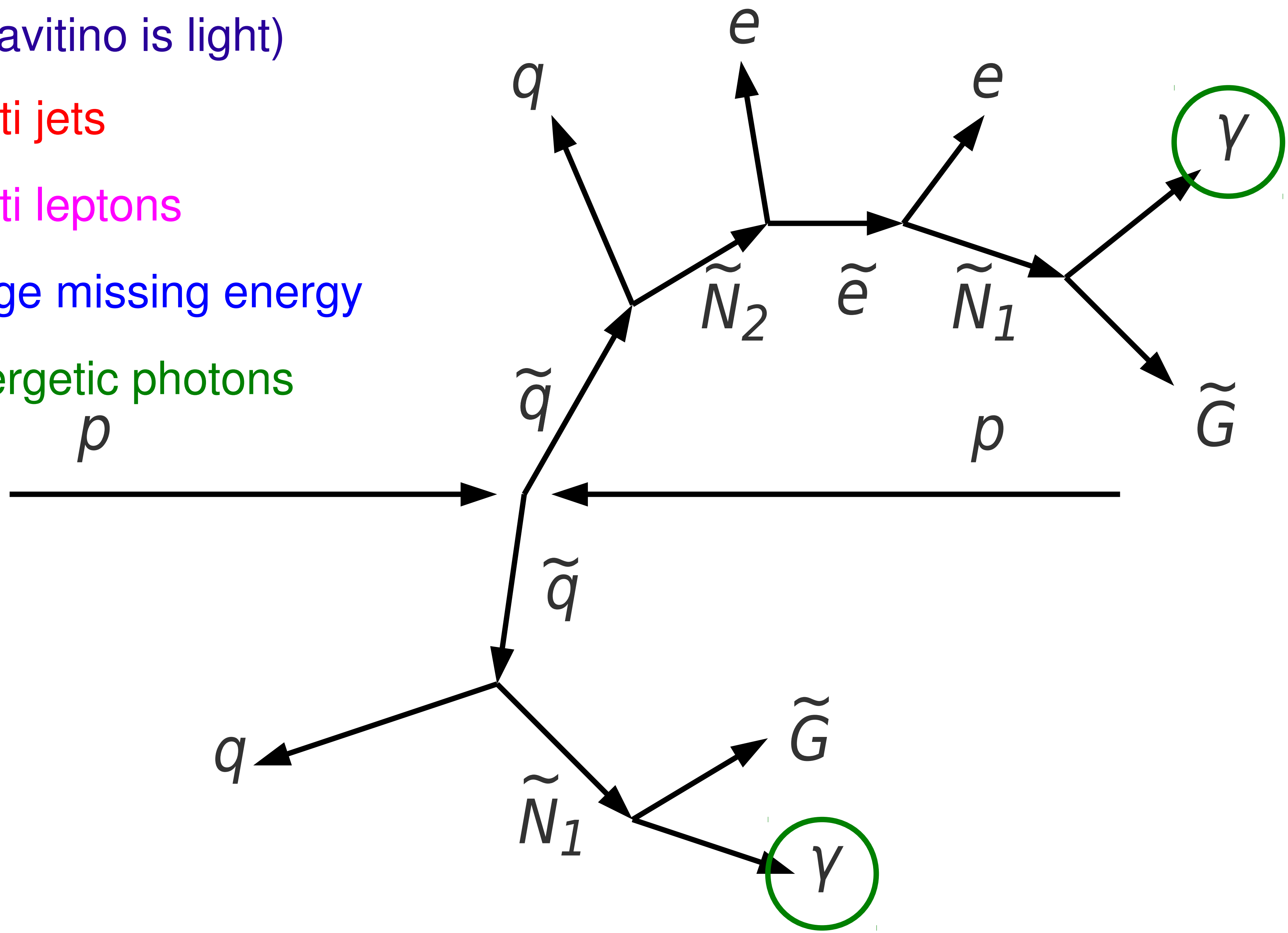


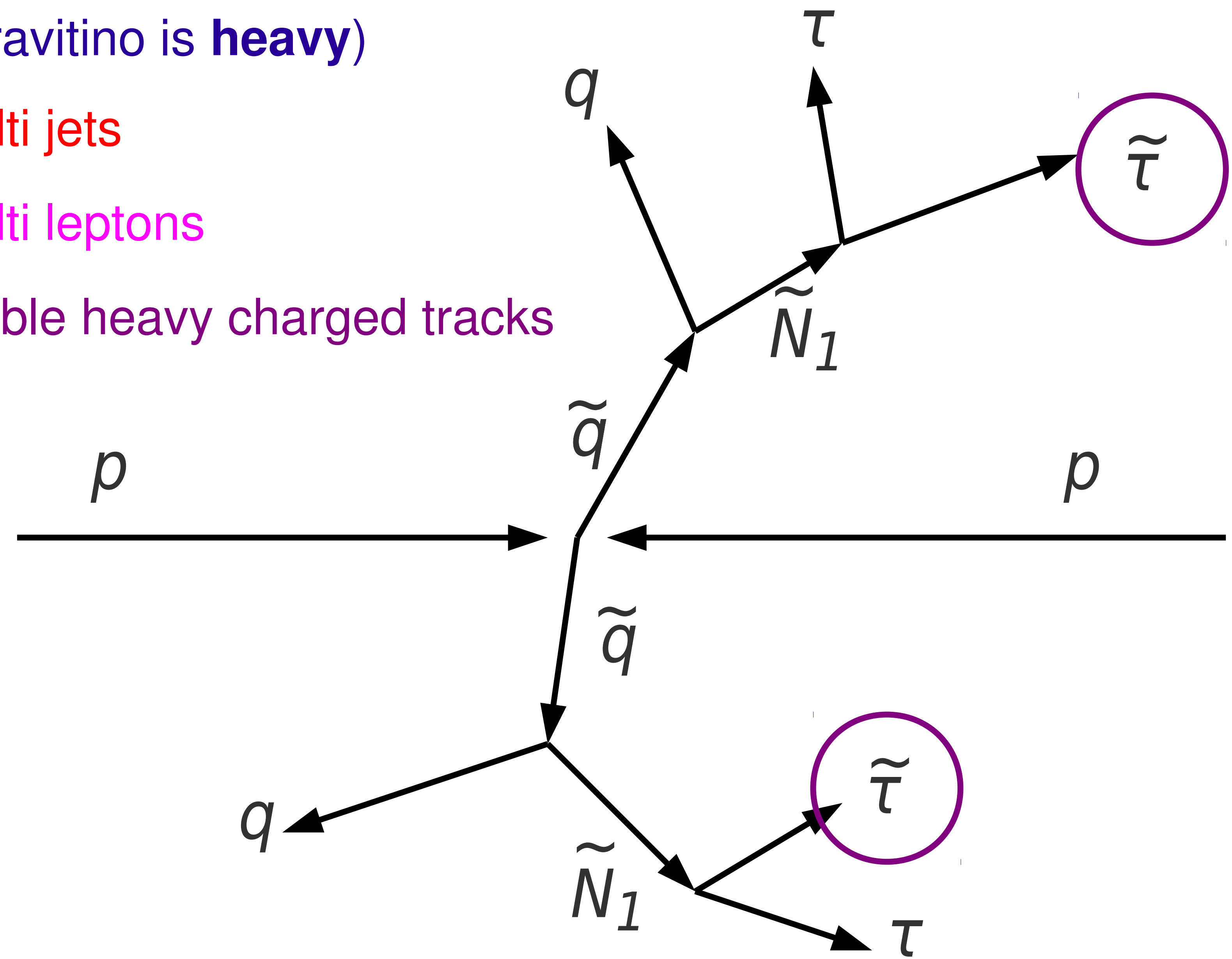
OK !



IIb. Gauge-mediation model with **stau**-NLSP

(If gravitino is **heavy**)

- Multi jets
- Multi leptons
- Stable heavy charged tracks

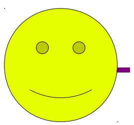


IIb. Gauge-mediation model with **stau**-NLSP

(If gravitino is **heavy**)

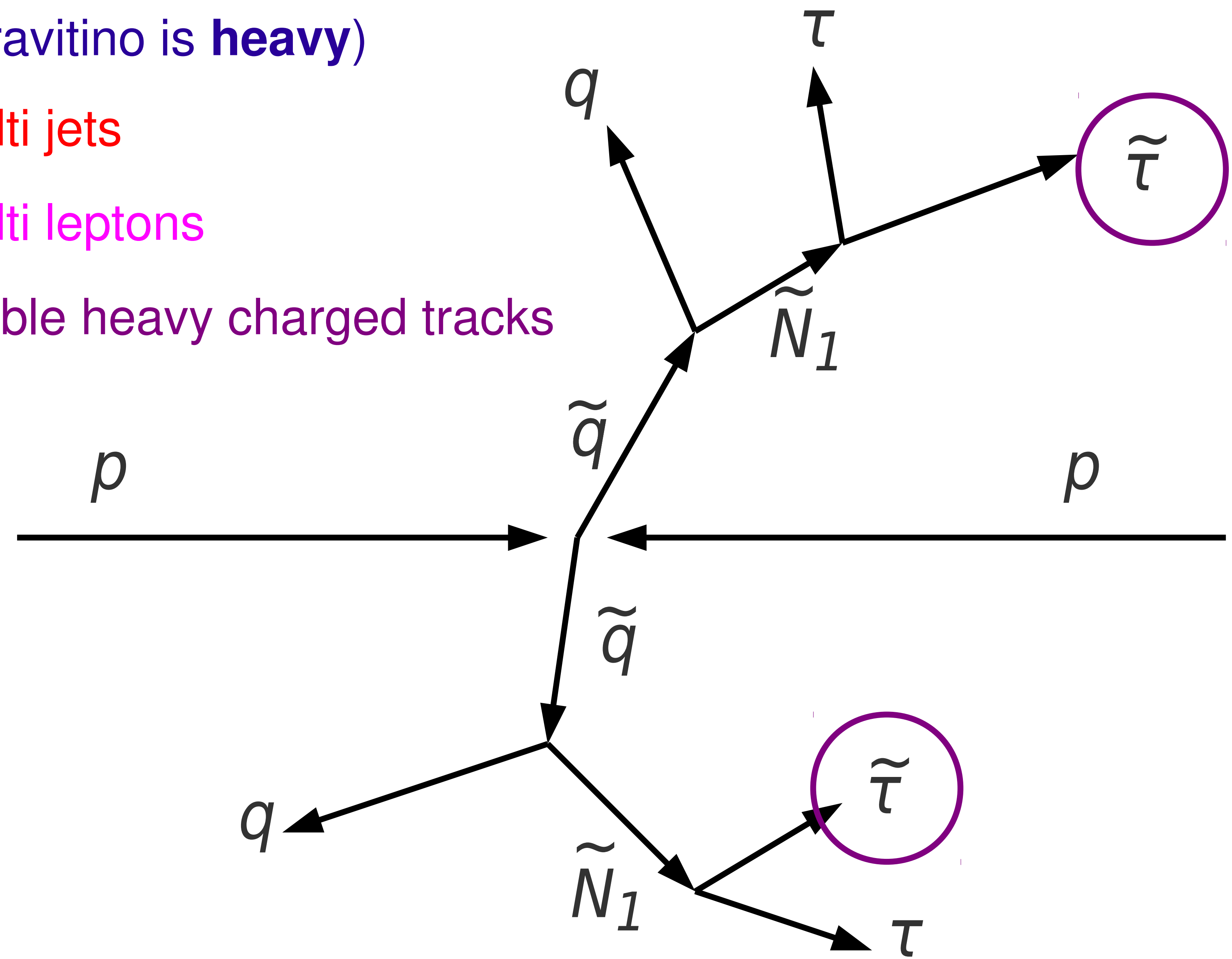
- Multi jets

- Multi leptons



- Stable heavy charged tracks

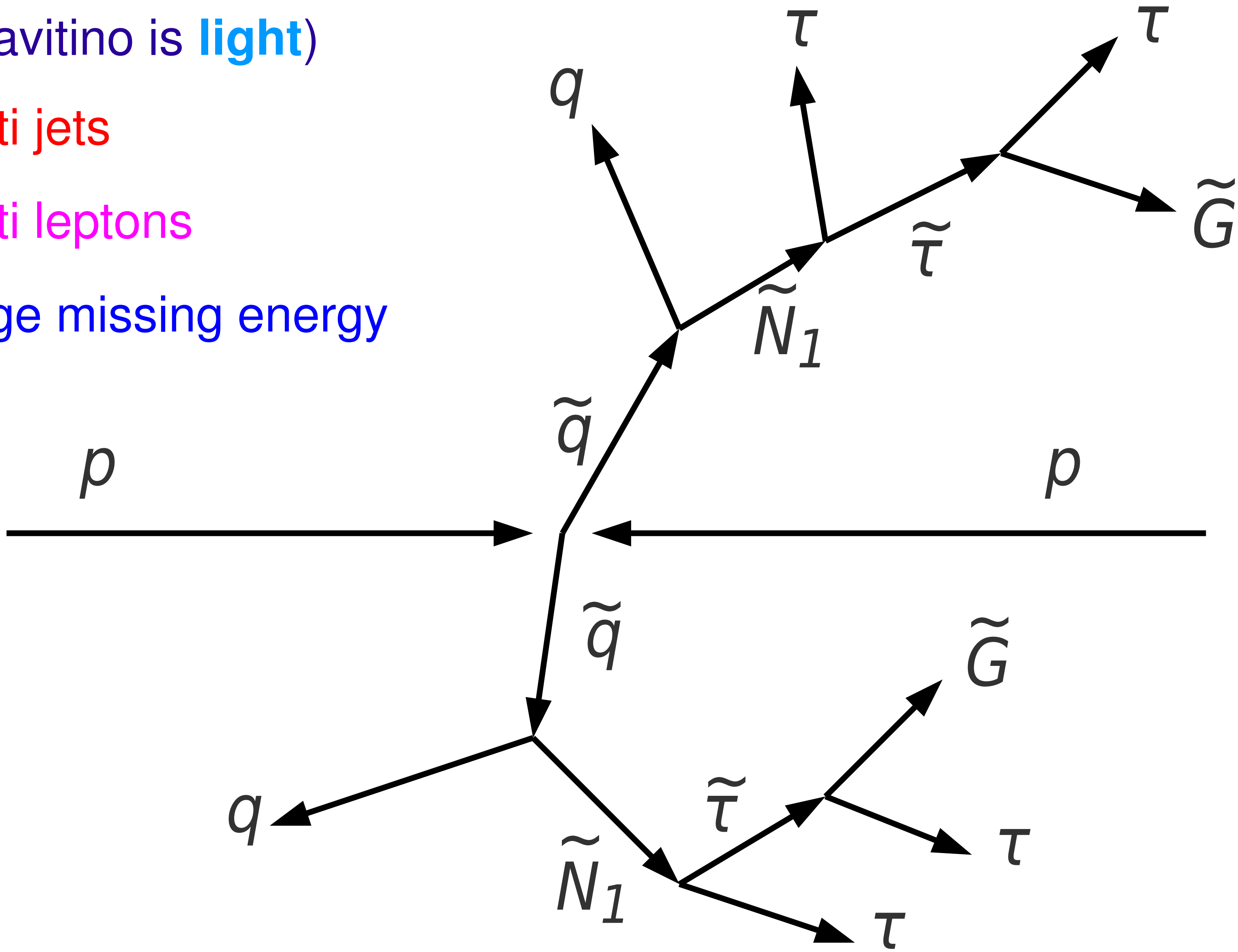
OK !



IIc. Gauge-mediation model with **stau**-NLSP

(If gravitino is **light**)

- Multi jets
- Multi leptons
- Large missing energy



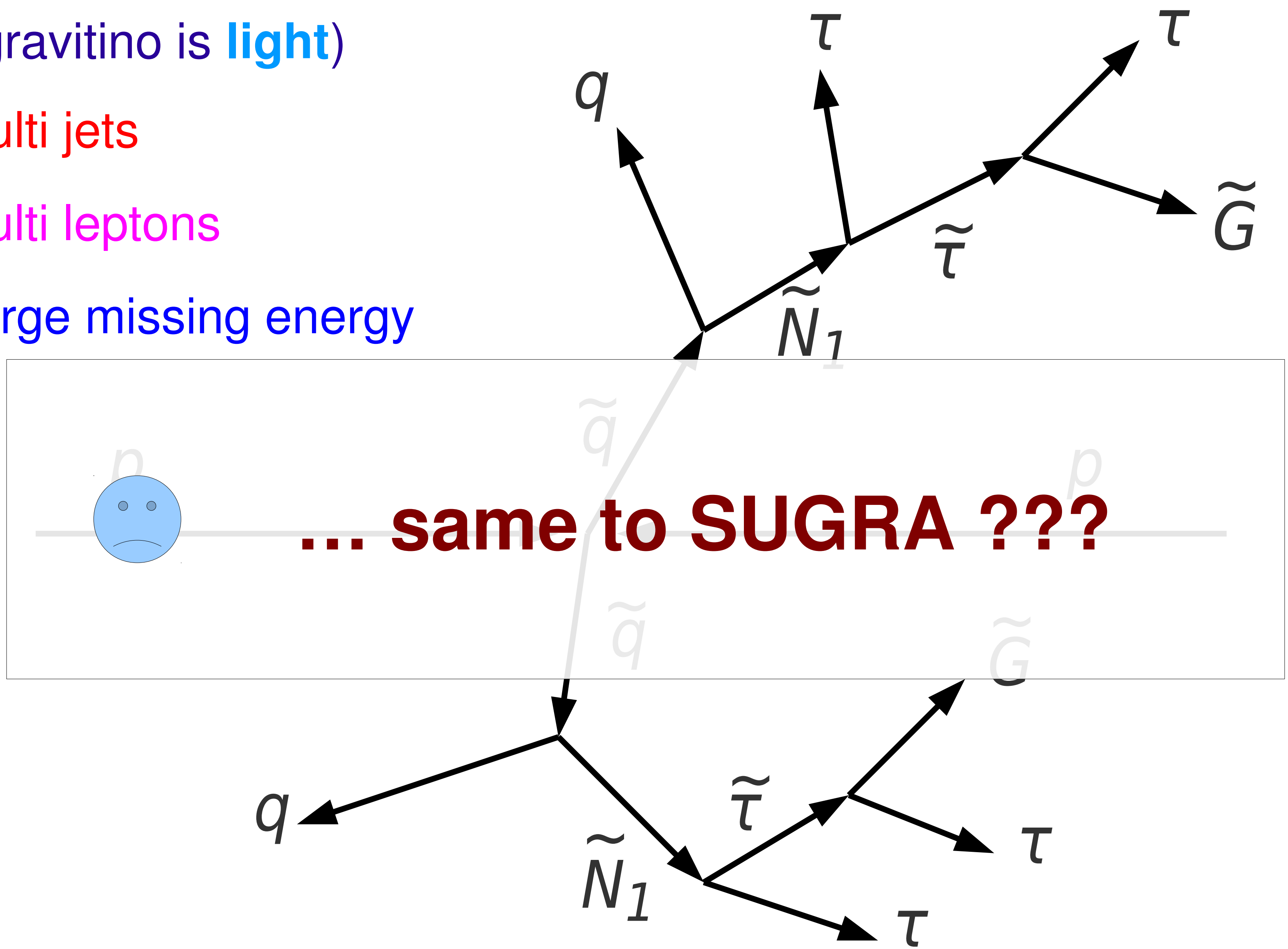
IIc. Gauge-mediation model with **stau**-NLSP

(If gravitino is **light**)

- Multi jets

- Multi leptons

- Large missing energy



SUSY model with gravitino mass of O(10) eV

- The most interesting case among the light gravitino scenarios, because the model is cosmologically favored.

  * BBN   Kawasaki, Kohri, Moroi, Yotsuyanagi (2008)

  * large structure formation in the Universe   Viel, Lesgourgues, Haehnelt, Matarrese, Riotto (2005)

Gravitino mass of O(10) eV

$\rightarrow c\tau_{\mathrm{stau}} = O(100)\ \mu\mathrm{m}$

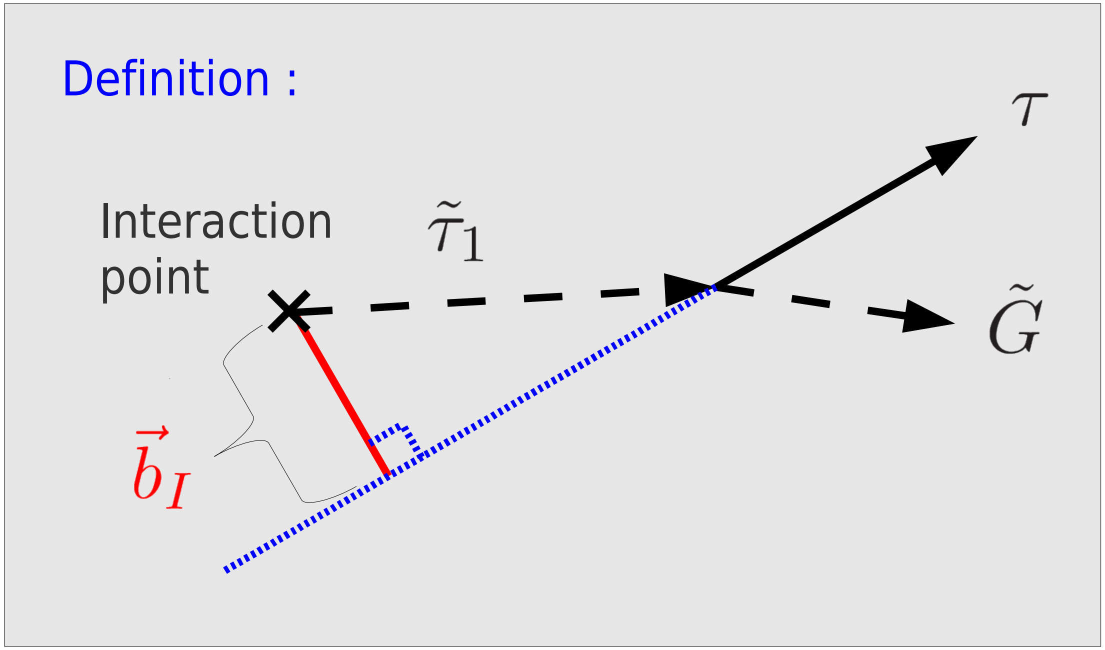
$\tilde{\tau} \rightarrow \tau + \tilde{G}$

$$\tau_{\tilde{\tau}} = 48\pi M_{\mathrm{pl}}^2 \left(\frac{m_{3/2}^2}{m_{\tilde{\tau}}^5} \right)$$

Stau decay before hitting the inner detector. Hence, similar to SUGRA cases...

However, we show that impact parameter of tau is useful in this case !

Impact parameter



(3-dimensional) impact parameter

$$b_I \equiv \left| \vec{b}_I \right|$$

$$\delta\left(b_I\right) \simeq 100\ \mu\mathrm{m}$$

Transverse impact parameter

$$d_I \equiv \left| \left(\vec{b}_I \right)_T \right|$$

$$\delta\left(d_I\right) \simeq 10\ \mu\mathrm{m}$$

Better resolution. (c.f., arXiv:0901.0512[hep-ex])

Hence, we use d_I in the following.

τ-decay product with large impact parameter is

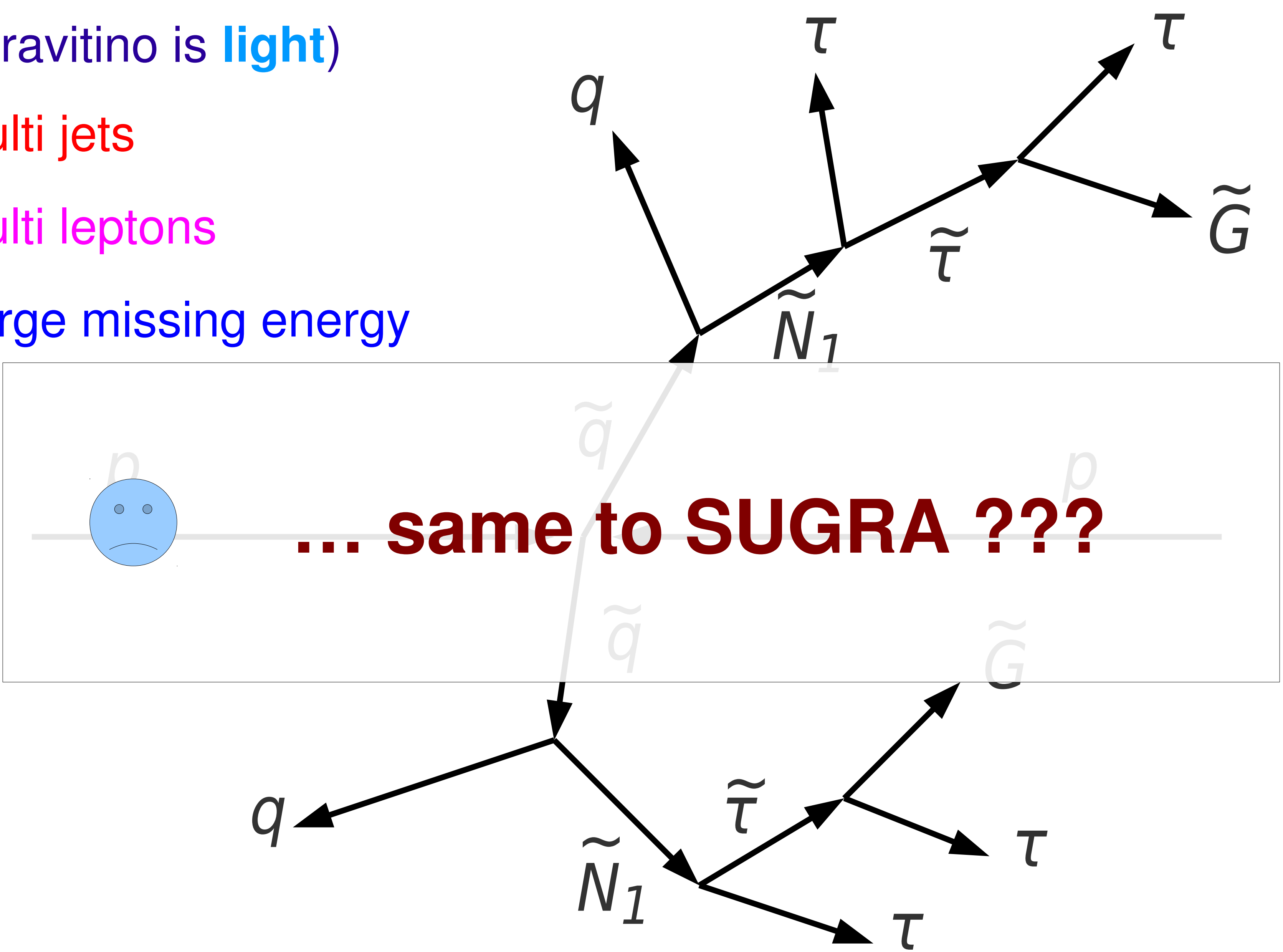
a characteristic signature of the model.

* Notice that typically, $d_I \sim c\tau$

IIc. Gauge-mediation model with **stau**-NLSP

(If gravitino is **light**)

- Multi jets
- Multi leptons
- Large missing energy



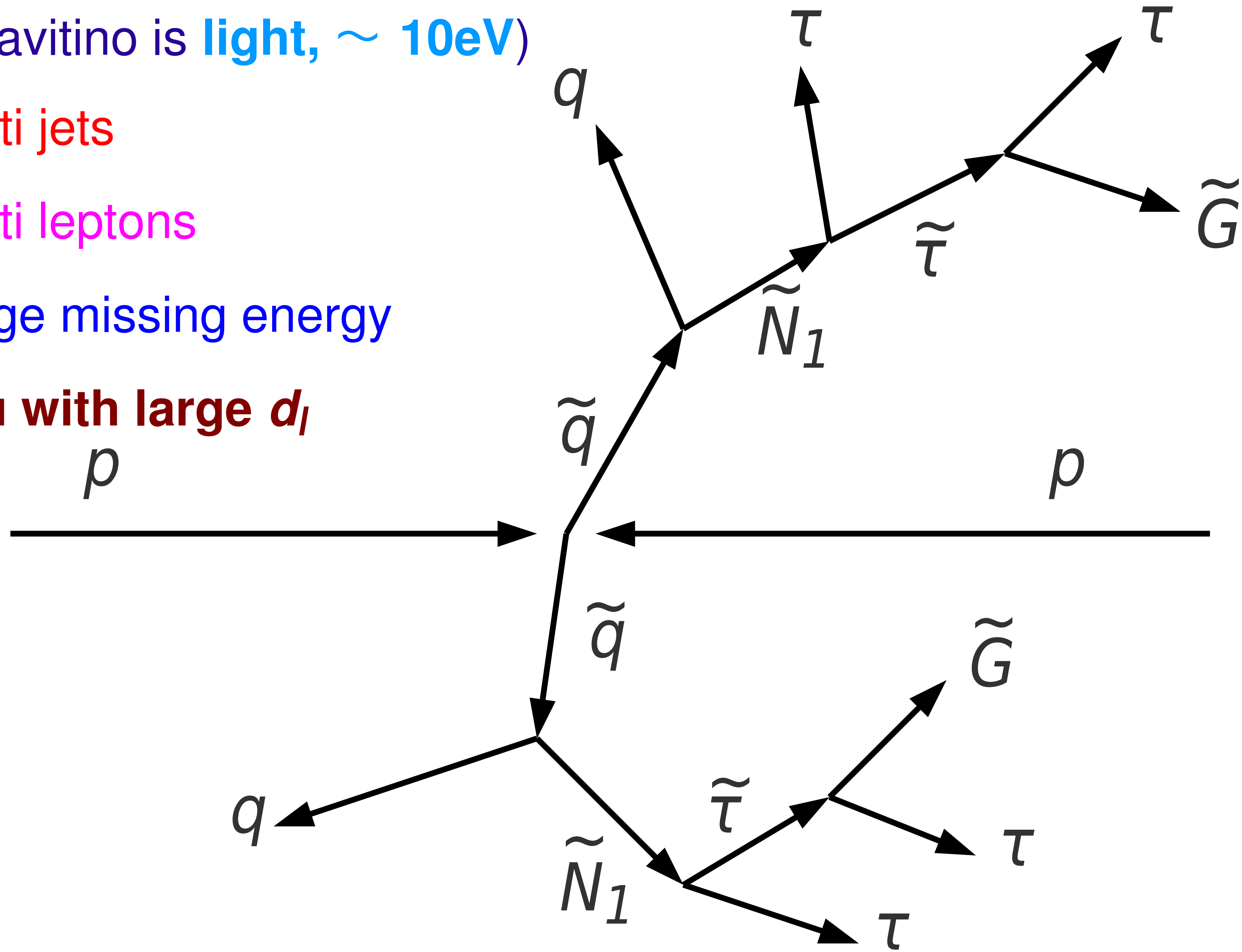
… same to SUGRA ???

IIc. Gauge-mediation model with **stau**-NLSP

(If gravitino is **light, $\sim$ 10eV**)

- Multi jets
- Multi leptons
- Large missing energy
- **Tau with large d_l**

OK !



Monte Carlo study

* Sample spectrum (GMSB)

gluino ... 1096 GeV

squark_R ... 920 GeV

neutralino_1 ... 197 GeV

stau_1 ... 126 GeV

gravitino ... $\sim$ 0 GeV

* Total SUSY cross section : 2.7 pb

* Event generation : HERWIG6.510
* Detector simulation : PGS4

* Resolution of d_I :

$$\delta\left(d_I\right) = 10\ \mu\text{m}$$

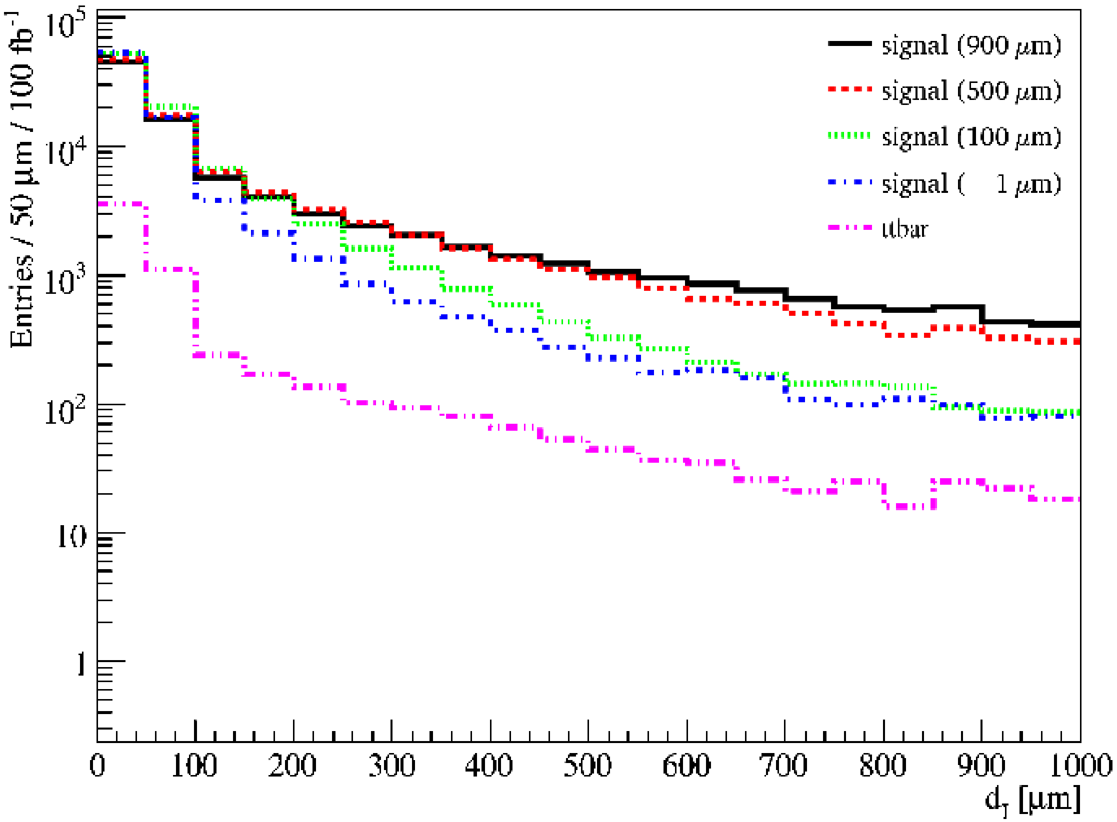
Basic cut	SUSY	$t\bar{t}$
(Integrated luminosity of 100 fb^{-1})	273,600	49,610,000
$\not{p}_T > 150$ GeV	190,504	1,644,160
The number of lepton-like objects ≥ 4	70,641	55,537
The number of b-jets $= 0$	56,228	41,673
The first jet with $p_T > 200$ GeV	49,819	5,915
The second jet with $p_T > 100$ GeV	41,007	1,984

After cut

Distribution of the transverse impact parameter, d_I

* Backgrounds (here, ttbar) are reduced sufficiently by the kinematical cuts.

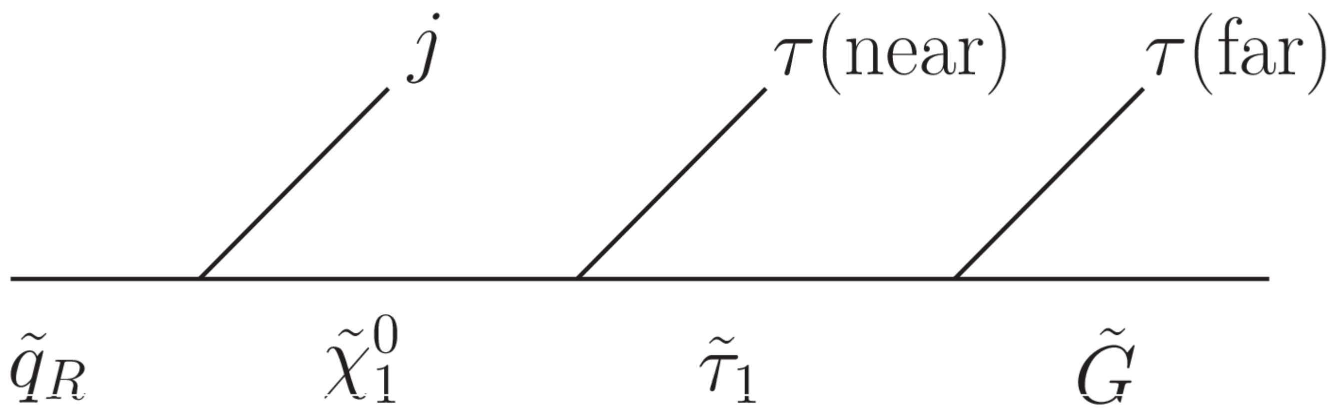
* The distribution depends on the stau lifetime.



- First, we show that impact parameter information is useful to measure the SUSY masses in this scenario.
- Then, we discuss the determination of the stau-NLSP lifetime.

Mass Measurement of M$_{\text{squark}}$, M$_{\text{bino}}$ and M$_{\text{stau}}$

SUSY cascade decay chain :



$M_{\tau\tau}$

$M_{j\tau(\text{near})}$

$M_{j\tau(\text{far})}$

$M_{j\tau\tau}$

$M_{T2}(\tilde{q})$

$\vdots$

* $\tau^{(\text{near})}$ and $\tau^{(\text{far})}$ can be distinguished by

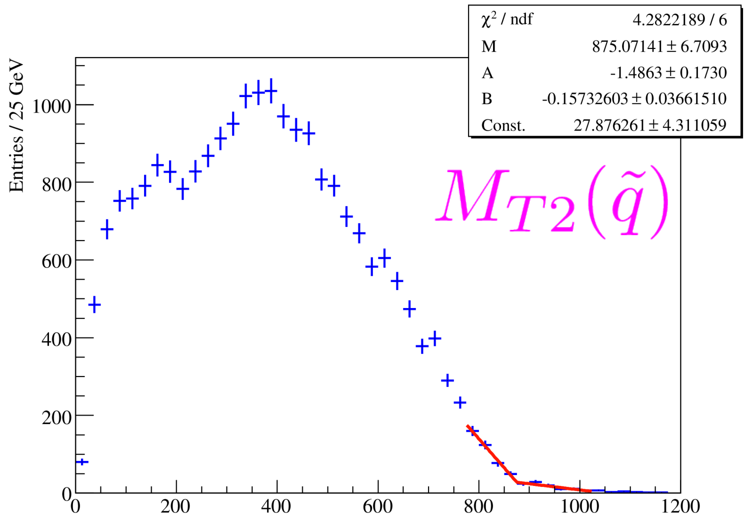
$$d_l\,(\tau^{(\text{near})}) \quad < \quad d_l\,(\tau^{(\text{far})}).$$

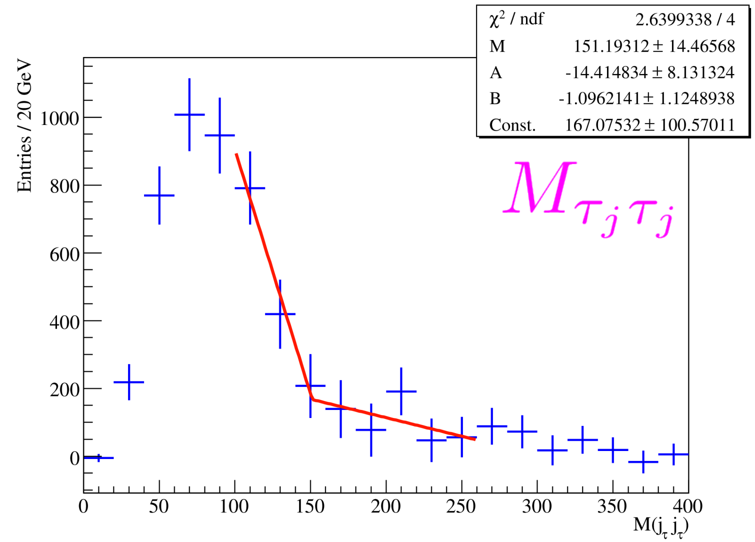
Then, we can study $M_{j\tau(\text{near})}$ (or $M_{j\tau(\text{far})}$)

$$M_{T2}(\tilde{q}) = \min_{\mathbf{k}_T + \mathbf{k}'_T = \not{\mathbf{p}}_T^{\text{eff}}} \left[\max\left\{M_T(\mathbf{p}_T, \mathbf{k}_T), M_T(\mathbf{p}'_T, \mathbf{k}'_T)\right\}\right]$$

* We regards all particles as “missing particle”, except for leading 2-jets.

RESULT : Mass Measurement



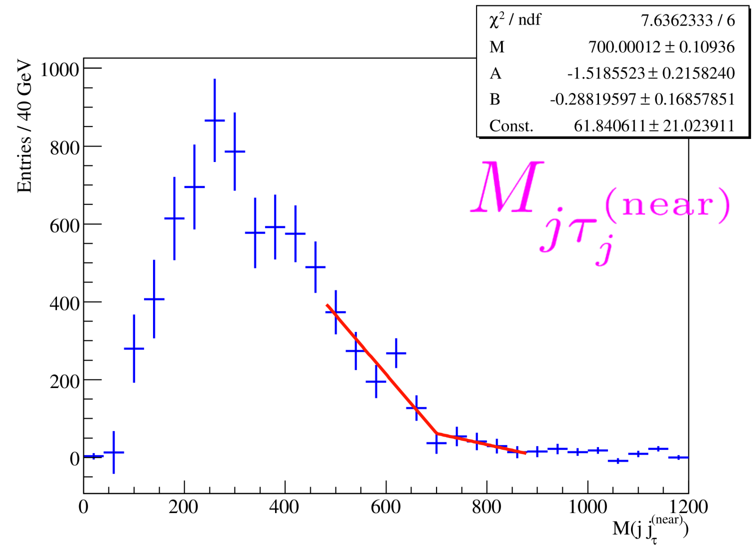


Assuming $m_{3/2}$ = 0, we obtain

$$M_{\tilde{q}} = 916 \pm 6 \text{ GeV}$$
$$(m_{\tilde{q}} = 922 \text{ GeV})$$

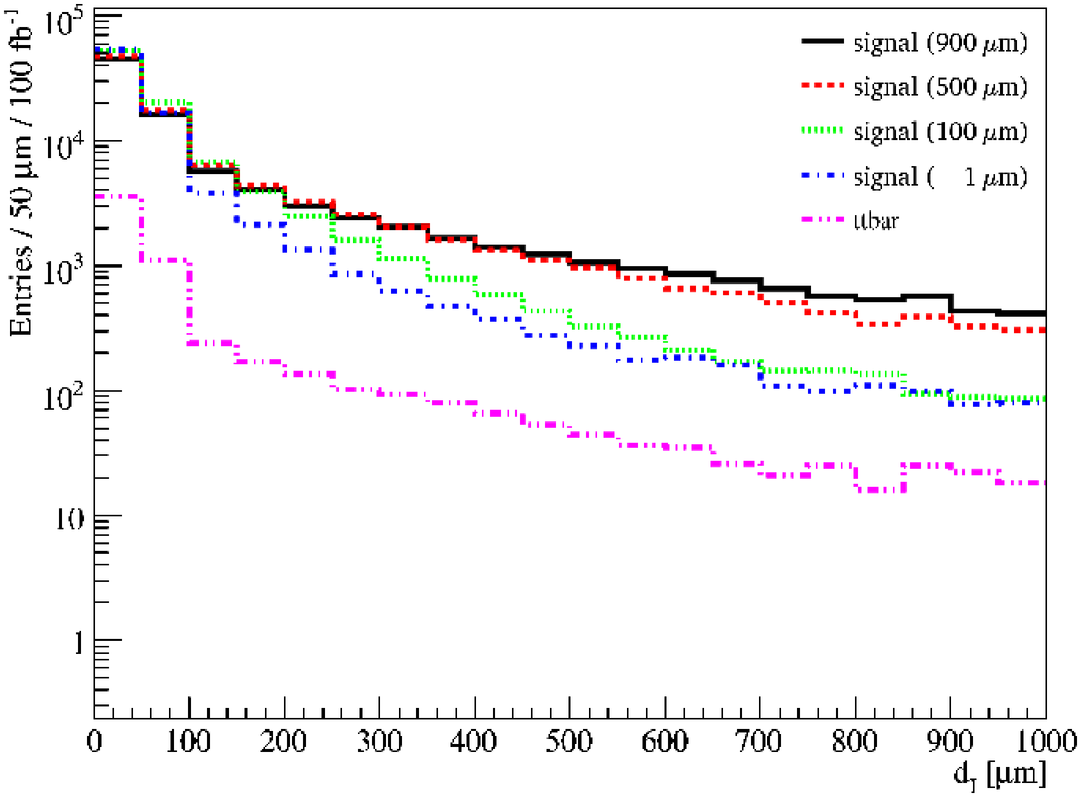
$$M_{\tilde{B}} = 193 \pm 20 \text{ GeV}$$
$$(m_{\tilde{B}} = 197 \text{ GeV})$$

$$M_{\tilde{\tau}} = 121 \pm 18 \text{ GeV}$$
$$(m_{\tilde{\tau}} = 126 \text{ GeV})$$



Stau Lifetime Determination

- d_l distribution reflects the NLSP lifetime.
- Inner bins are dominated by mainly (QCD-) fake taus.
- Outer bins do not dump; fakes from heavy mesons
- The shape of d_l distribution is NOT simple exponential function. (more complex one)



Stau Lifetime Determination

We use templates of the simulated stau decay events.

Templates of the d_I distribution

- Take some lifetime, $c\tau^{(\mathrm{test})}_{\mathrm{NLSP}}$ (= 10, 20, 30, …, 1100 μm).
- Lorentz boost factor of the stau is fixed, β (= β_{ave}).
- Stau's production direction is assumed to be isotropic.

  (Notice : our simulation is "simplified")

$\rightarrow$ d_I distribution of the "signal" is tested with the templates.

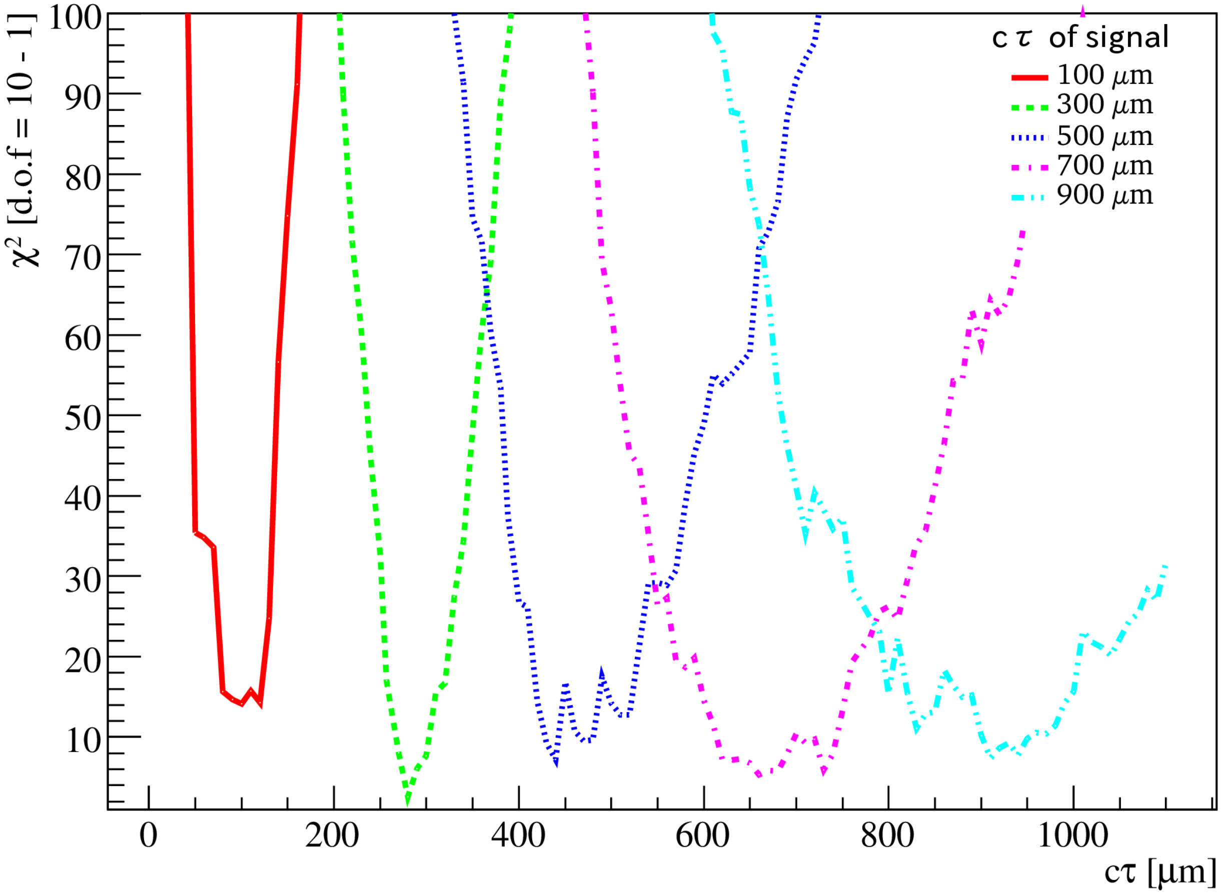
- We use events with $0.5\times c\tau^{(\mathrm{test})} < d_I < 2\times c\tau^{(\mathrm{test})}$,

  in order to overcome backgrounds (i.e., fake-taus).

RESULT : Lifetime Determination

* “Signal” MC (all SUSY events)
  ctau (stau) = 100, 300,
  500, 700, 900 μm

* Even though our study is very simplified, the lifetime of the stau can be well estimated.



The stau lifetime is estimated with the accuracy of O(10) %.
Also, the gravitino mass can be calculated from the results.
$\delta(m_{3/2})$ = O(10) %; we can confirm that $m_{3/2}$ = O(10) eV.

Summary

The model that NLSP is stau and LSP is light gravitino is studied.

* Important event signature is tau with large impact parameter.

$\rightarrow$ We have proposed analyses utilizing d_l of tau.

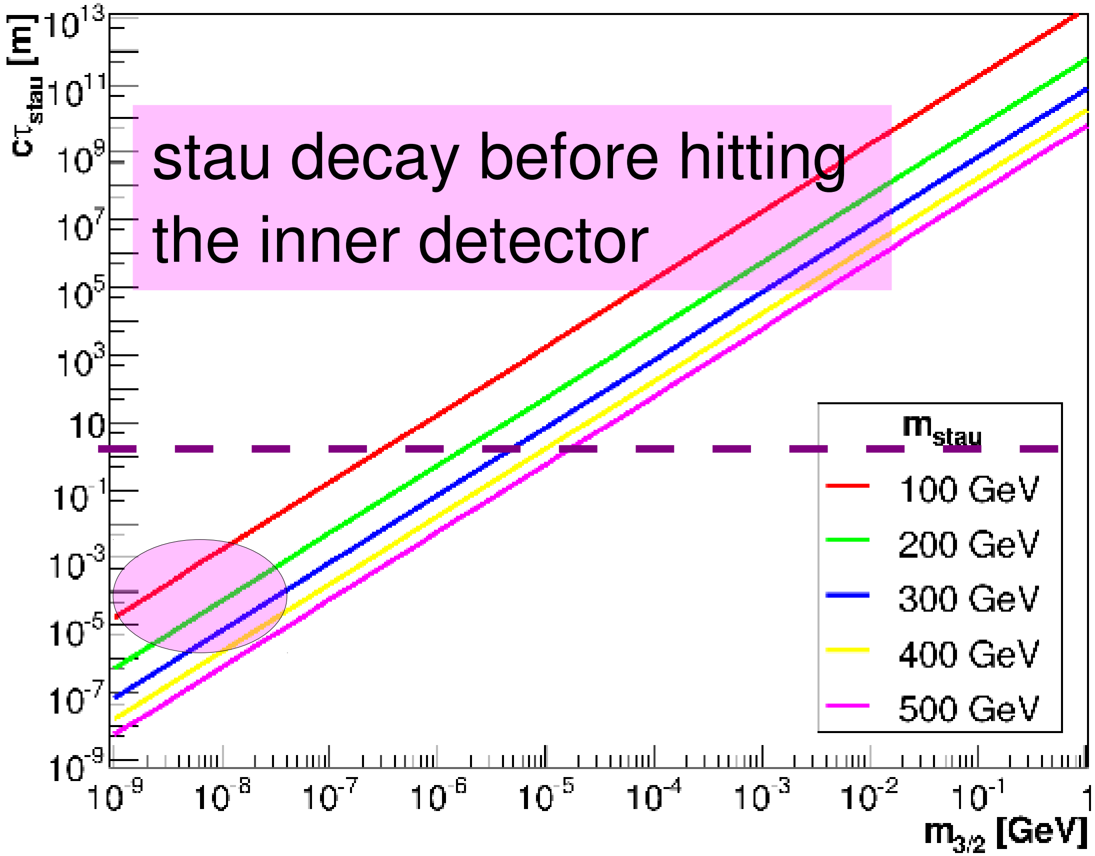
- Mass measurement (squark, neutralino, stau)
- Stau lifetime determination
- Gravitino mass determination

Remark :

d_l information may improve a discovery/exclusion reach of this kind of models.

backup

SUSY model with gravitino mass of O(10) eV



Gravitino mass of O(10) eV $\rightarrow c\tau_{stau} = O(100)\ \mu m$