GravitinoPack - a tool for calculating gravitino processes

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Framework: general FC MSSM with R_P conservation,
Gravitino mass is a free parameter

Motivation

- Gravitino is NOT the LSP:

Gr lifetime affects primordial Big-Bang Nucleosynthesis (BBN)

(if it decays in that BBN time):

Decays of Gr can change primordial abundance of elements

by electromagnetic/hadronic showers which

destroy or create light nuclear species

Therefore, stringend bounds from BBN

Motivation cont'd

- Gravitino is the LSP:
  - Dark Matter candidate
  - Long-lived NLSP
  - This again might spoil the BBN predictions

- Therefore, precise calculations of decay widths with Gr are necessary

- Calculations can involve many gamma matrices and several Feynman graphs, an automatic tool is very helpful

Gravitino Processes

Two- and three-body decays with gravitino

- **Gravitino decays:**

  "Three-body gravitino decays in the MSSM" – already published,
  H. E., V. C. Spanos, JHEP 1308 (2013) 055.

- **Decays of NLSP into gravitino LSP:**

  Neutralino1 two- and three-body decays
  Stau1 two- and threebody decays
  Stop1 two- and three-body decays

- Fortran program **GravitinoPack1.0** is finished including a MathLink version

- Preparation of the publication discussing decays into gravitino LSP in progress, including the manual for the package "GravitinoPack"

GravitinoPack

For writing the code FeynArts for FormCalc is used with new developed extensions for the computation of all squared Gr decay amplitudes.

- New FeynArts model file derived for Gr interaction with the MSSM, 78 new couplings, new Lorentz structure file written
- FormCalc, extension for auto-generation of Fortran77 code with Gr spin 3/2 many gamma matrices involved – Weyl-van-der Waerden formalism used
- All two-body decay widths are checked with already published analytic formulas [e.g. Ellis et al. 2003, Diaz-Cruz et al. 2007]
- Comparison of all two-body decay widths with FeynRules 2.0.23, agreement
- Code automatically treats possible resonances in three-body decay widths – avoids double counting among two- and three-body decays – good check
- For convenience the libraries SLHALib-2.2 and Cuba-3.3 are added locally
- program supports SLHA input format

Gravitino Interactions with the MSSM

The relevant supergravity Lagrangian reads [Pradler, 07]

$$\mathcal{L}^{(\alpha)}_{\widetilde{G},\,\mathrm{int}} = -\frac{i}{\sqrt{2}M_{\mathrm{P}}}\left[\mathcal{D}^{(\alpha)}_{\mu}\phi^{*i}\overline{\widetilde{G}}_{\nu}\gamma^{\mu}\gamma^{\nu}\chi^{i}_{L} - \mathcal{D}^{(\alpha)}_{\mu}\phi^{i}\overline{\chi}^{i}_{L}\gamma^{\nu}\gamma^{\mu}\widetilde{G}_{\nu}\right] - \frac{i}{8M_{\mathrm{P}}}\overline{\widetilde{G}}_{\mu}[\gamma^{\rho},\gamma^{\sigma}]\gamma^{\mu}\lambda^{(\alpha)\,a}F^{(\alpha)\,a}_{\rho\sigma}\,,$$

with the covariant derivative given by

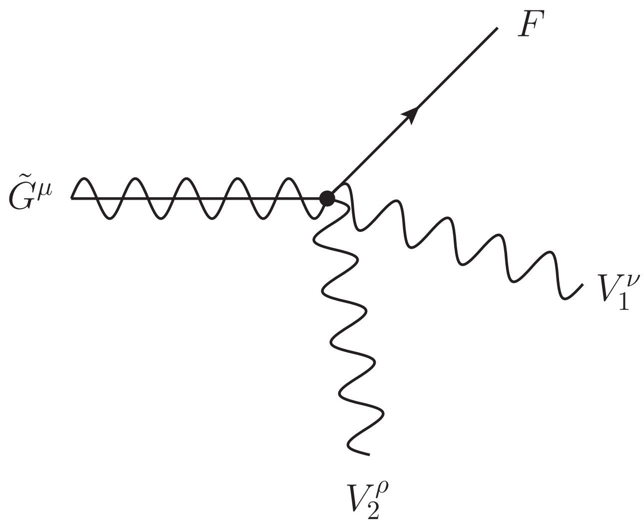
$$\mathcal{D}^{(\alpha)}_{\mu}\phi^{i} = \partial_{\mu}\phi^{i} + ig_{\alpha}A^{(\alpha)\,a}_{\mu}T^{(\alpha)}_{a,\,ij}\,\phi^{j}\,,$$

and the field strength tensor $F^{(\alpha)\,a}_{\mu\nu}$ reads

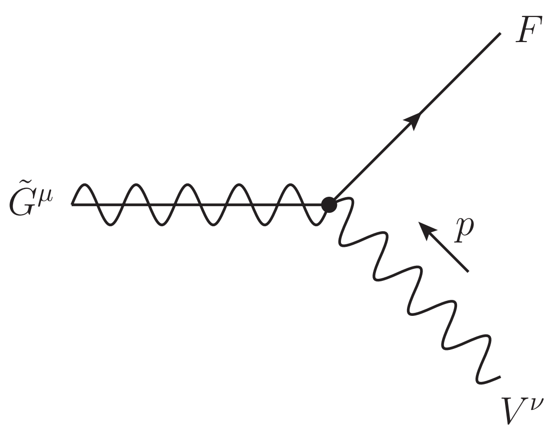
$$F^{(\alpha)\,a}_{\mu\nu} = \partial_{\mu}A^{(\alpha)\,a}_{\nu} - \partial_{\nu}A^{(\alpha)\,a}_{\mu} - g_{\alpha}f^{(\alpha)\,abc}A^{(\alpha)\,b}_{\mu}A^{(\alpha)\,c}_{\nu}\,.$$

The index α corresponds to the three groups $\mathrm{U}(1)_Y$, $\mathrm{SU}(2)_I$, and $\mathrm{SU}(3)_c$ with $a = 1, 3, 8$ and $i = 1, 2, 3$, respectively.

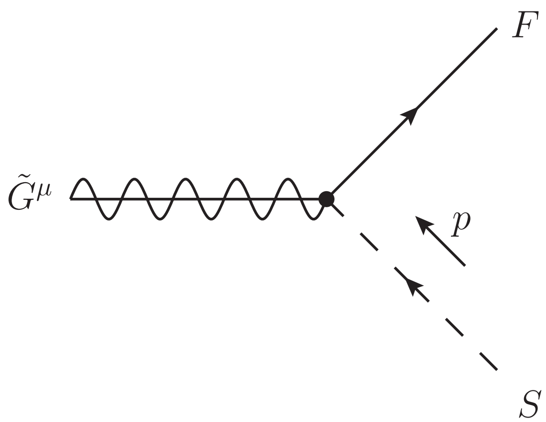
Possible structures of gravitino interactions with MSSM particles:



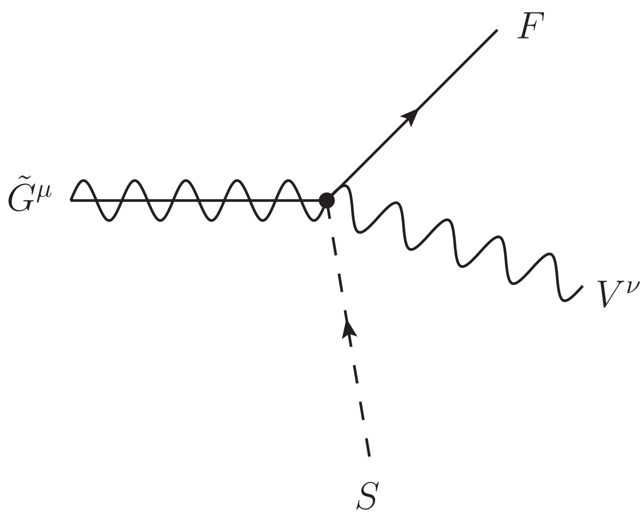
$$\text{struc1}: \begin{pmatrix} \gamma^{\mu}\,[\gamma^{\nu},\,\gamma^{\rho}]\,P_L \\ \gamma^{\mu}\,[\gamma^{\nu},\,\gamma^{\rho}]\,P_R \\ [\gamma^{\nu},\,\gamma^{\rho}]\,\gamma^{\mu}P_L \\ [\gamma^{\nu},\,\gamma^{\rho}]\,\gamma^{\mu}P_R \end{pmatrix} .C[F|\bar{F},\tilde{G}_{\mu},V_{1\nu},V_{2\rho}]$$



$$\text{struc2}: \begin{pmatrix} \gamma^{\mu}\gamma^{\nu}P_L \\ \gamma^{\mu}\gamma^{\nu}P_R \\ \gamma^{\mu}\,[\gamma^{\nu},\,\not{p}]\,P_L \\ \gamma^{\mu}\,[\gamma^{\nu},\,\not{p}]\,P_R \\ \gamma^{\nu}\gamma^{\mu}P_L \\ \gamma^{\nu}\gamma^{\mu}P_R \\ [\gamma^{\nu},\,\not{p}]\,\gamma^{\mu}P_L \\ [\gamma^{\nu},\,\not{p}]\,\gamma^{\mu}P_R \end{pmatrix} .C[F|\bar{F},\tilde{G}_{\mu},V_{\nu}]$$



$$\text{struc3} : \begin{pmatrix} \gamma^\mu \not{p}\, P_L \\ \gamma^\mu \not{p}\, P_R \\ \not{p}\gamma^\mu\, P_L \\ \not{p}\gamma^\mu\, P_R \end{pmatrix} .C[F|\bar{F}, \tilde{G}_\mu, S]$$



$$\text{struc4} : \begin{pmatrix} \gamma^\mu \gamma^\nu P_L \\ \gamma^\mu \gamma^\nu P_R \\ \gamma^\nu \gamma^\mu P_L \\ \gamma^\nu \gamma^\mu P_R \end{pmatrix} .C[F|\bar{F}, \tilde{G}_\mu, V_\nu, S]$$

FeynArts Model file `MSSMGrav.mod`, 78 couplings:

`struc1:`
`[FGrVV]` Chargino – Gravitino – 2 Gauge Bosons
`[FGrVV]` Neutralino – Gravitino – 2 Gauge Bosons
`[FGrVV]` Gluino – Gravitino – 2 Gluons

`struc2:`
`[FGrV]` Chargino – Gravitino – Gauge Boson
`[FGrV]` Neutralino – Gravitino – Gauge Boson
`[FGrV]` Gluino – Gravitino – Gluon

`struc3:`
`[FGrS]` Chargino – Gravitino – Higgs
`[FGrS]` Neutralino – Gravitino – Higgs
`[FGrS]` Lepton – Gravitino – Slepton
`[FGrS]` Quark – Gravitino – Squark

`struc4:`
`[FGrVS]` Chargino – Gravitino – Higgs – Gauge Boson
`[FGrVS]` Neutralino – Gravitino – Higgs – Gauge Boson
`[FGrVS]` Lepton – Gravitino – Slepton – Gauge Boson
`[FGrVS]` Quark – Gravitino – Squark – Gauge Boson
`[FGrVS]` Quark – Gravitino – Squark – Gluon

Gravitino field representation

The four polarisation states of the gravitino field in the momentum space in terms of spin-1 and spin-1/2 components:

$$
\begin{aligned}
\psi_\mu(\mathbf{k}, \tfrac{3}{2}) &= u(\mathbf{k}, \tfrac{1}{2})\, \epsilon_\mu(\mathbf{k}, 1)\,, \\
\psi_\mu(\mathbf{k}, \tfrac{1}{2}) &= \sqrt{\tfrac{1}{3}}\, u(\mathbf{k}, -\tfrac{1}{2})\, \epsilon_\mu(\mathbf{k}, 1) + \sqrt{\tfrac{2}{3}}\, u(\mathbf{k}, \tfrac{1}{2})\, \epsilon_\mu(\mathbf{k}, 0) \\
\psi_\mu(\mathbf{k}, -\tfrac{1}{2}) &= \sqrt{\tfrac{1}{3}}\, u(\mathbf{k}, \tfrac{1}{2})\, \epsilon_\mu(\mathbf{k}, -1) + \sqrt{\tfrac{2}{3}}\, u(\mathbf{k}, -\tfrac{1}{2})\, \epsilon_\mu(\mathbf{k}, 0) \\
\psi_\mu(\mathbf{k}, -\tfrac{3}{2}) &= u(\mathbf{k}, -\tfrac{1}{2})\, \epsilon_\mu(\mathbf{k}, -1)\,,
\end{aligned}
$$

[1941]

From the field equation for the spin-3/2 particle, the so called Rarita-Schwinger equation, we get three equations in momentum space, which we have to fulfill by the right choice of the spin-1 and spin-1/2 component representations

$$
\begin{aligned}
\gamma^\mu \psi_\mu(\mathbf{k}, \lambda) &= 0 \\
k^\mu \psi_\mu(\mathbf{k}, \lambda) &= 0 \\
(\not{k} - m_{\tilde{G}})\psi_\mu(\mathbf{k}, \lambda) &= 0
\end{aligned}
$$

Our implementation of ψ_μ in the numerical code indeed fulfills these three equations.

Gravitino decays:

Two-body decays

$$\tilde{G} \to FS\,,$$
$$\to f\tilde{f}_i^*,\ \tilde{\chi}_j^0(h^0, H^0, A^0),\ \tilde{\chi}_k^+ H^-$$
$$\tilde{G} \to FV\,,$$
$$\to \tilde{g}g,\ \tilde{\chi}_j^0(Z^0, \gamma),\ \tilde{\chi}_k^+ W^-$$

Three-body decays to neutralino + SM pair

$$\widetilde{G} \to \tilde{\chi}_i^0\,\bar{f}f\,,$$
$$\widetilde{G} \to \tilde{\chi}_i^0\,VV\,, \quad VV = Z^0Z^0\,, Z^0\gamma\,, W^+W^-$$
$$\widetilde{G} \to \tilde{\chi}_i^0\,VS\,, \quad VS = (Z^0, \gamma)(h^0, H^0, A^0), W^+H^-, W^-H^+$$
$$\widetilde{G} \to \tilde{\chi}_i^0\,SS\,, \quad SS = (h^0, H^0, A^0)(h^0, H^0, A^0), H^+H^-$$

▼ **GravitinoPack`**

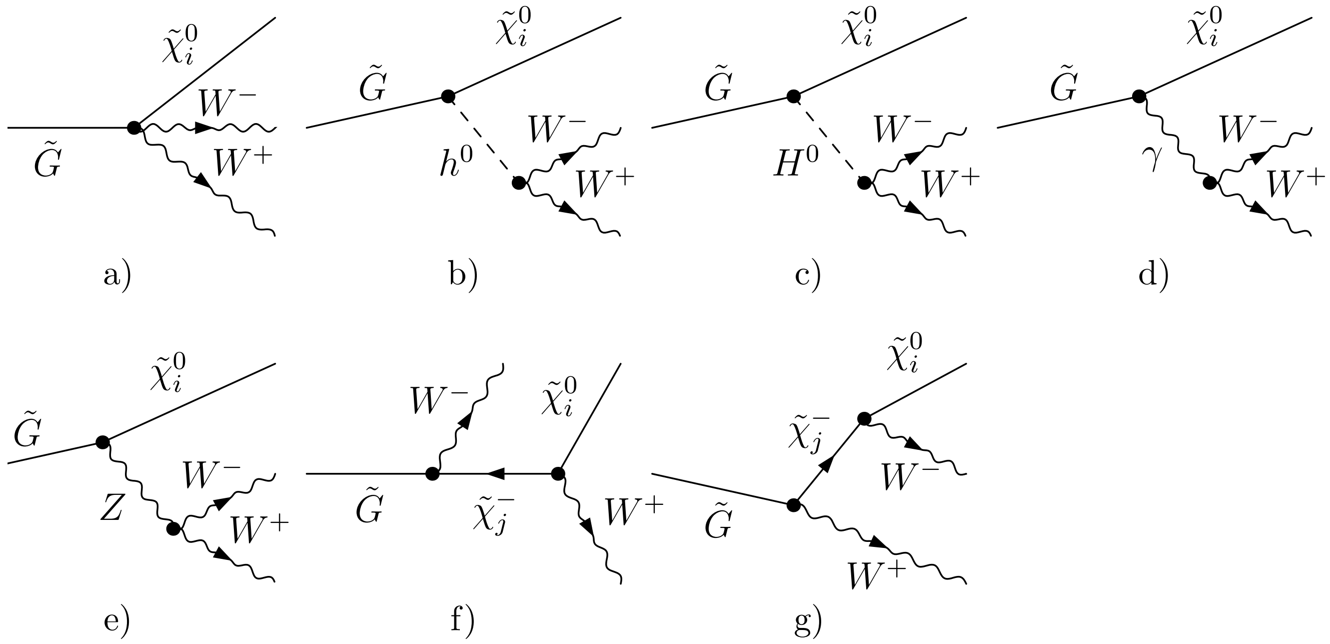
GravTotalWidth	GravWidth2body	GravWidth3body

All possible three-body decays of Gravitino into neutralino

process $\widetilde{G} \to \tilde{\chi}_i^0 XY$	number of graphs	first decay $\widetilde{G} \to \tilde{X}Y$	possible resonances
$\tilde{\chi}_i^0 f \bar{f}$	7	$\tilde{\chi}_i^0(h^0, H^0, A^0, \gamma, Z^0), f\tilde{f}_l^*, \tilde{f}_l\bar{f}$	$h^0, H^0, A^0, Z^0, \tilde{f}_l$
$\tilde{\chi}_i^0 Z^0 Z^0$	4	$\tilde{\chi}_i^0(h^0, H^0), Z^0\tilde{\chi}_k^0, \tilde{\chi}_k^0 Z^0$	$H^0, \tilde{\chi}_k^0$
$\tilde{\chi}_i^0 Z^0 \gamma$	1	$\tilde{\chi}_k^0\gamma$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 W^+ W^-$	$6 + 4pt$	$\tilde{\chi}_i^0(h^0, H^0, \gamma, Z^0), W^+\tilde{\chi}_j^-, \tilde{\chi}_j^+ W^-$	$H^0, \tilde{\chi}_j^\pm$
$\tilde{\chi}_i^0 Z^0 h^0$	$4 + 4pt$	$\tilde{\chi}_i^0(A^0, Z^0), Z^0\tilde{\chi}_k^0, \tilde{\chi}_k^0 h^0$	$A^0, \tilde{\chi}_k^0$
$\tilde{\chi}_i^0 Z^0 H^0$	$4 + 4pt$	$\tilde{\chi}_i^0(A^0, Z^0), Z^0\tilde{\chi}_k^0, \tilde{\chi}_k^0 H^0$	$A^0, \tilde{\chi}_k^0$
$\tilde{\chi}_i^0 Z^0 A^0$	$4 + 4pt$	$\tilde{\chi}_i^0(h^0, H^0), \tilde{\chi}_k^0 Z^0, A^0\tilde{\chi}_k^0$	$H^0, \tilde{\chi}_k^0$
$\tilde{\chi}_i^0 \gamma h^0$	1	$\tilde{\chi}_k^0\gamma$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 \gamma H^0$	1	$\tilde{\chi}_k^0\gamma$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 \gamma A^0$	1	$\tilde{\chi}_k^0\gamma$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 W^+ H^-$	$5 + 4pt$	$\tilde{\chi}_i^0(h^0, H^0, A^0), W^+\tilde{\chi}_j^-, \tilde{\chi}_j^+ H^-$	$H^0, A^0, \tilde{\chi}_j^\pm$
$\tilde{\chi}_i^0 W^- H^+$	$5 + 4pt$	$\tilde{\chi}_i^0(h^0, H^0, A^0), W^-\tilde{\chi}_j^+, \tilde{\chi}_j^- H^+$	$H^0, A^0, \tilde{\chi}_j^\pm$
$\tilde{\chi}_i^0 h^0 h^0$	4	$\tilde{\chi}_i^0(h^0, H^0), h^0\tilde{\chi}_k^0, \tilde{\chi}_k^0 h^0$	$H^0, \tilde{\chi}_k^0$
$\tilde{\chi}_i^0 H^0 H^0$	4	$\tilde{\chi}_i^0(h^0, H^0), H^0\tilde{\chi}_k^0, \tilde{\chi}_k^0 H^0$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 h^0 H^0$	4	$\tilde{\chi}_i^0(h^0, H^0), h^0\tilde{\chi}_k^0, \tilde{\chi}_k^0 H^0$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 A^0 A^0$	4	$\tilde{\chi}_i^0(h^0, H^0), A^0\tilde{\chi}_k^0, \tilde{\chi}_k^0 A^0$	$H^0, \tilde{\chi}_k^0$
$\tilde{\chi}_i^0 h^0 A^0$	3	$\tilde{\chi}_i^0(A^0, Z^0), h^0\tilde{\chi}_k^0$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 H^0 A^0$	3	$\tilde{\chi}_i^0(A^0, Z^0), H^0\tilde{\chi}_k^0$	$\tilde{\chi}_k^0$
$\tilde{\chi}_i^0 H^+ H^-$	6	$\tilde{\chi}_i^0(h^0, H^0, \gamma, Z^0), H^+\tilde{\chi}_j^-, \tilde{\chi}_j^+ H^-$	$H^0, \tilde{\chi}_j^\pm$

$$f = \nu_e, \nu_\mu, \nu_\tau, e, \mu, \tau, u, c, t, d, s, b$$

19 individuel decay channels



Feynman graphs for the decay $\widetilde{G} \to \tilde{\chi}_i^0 W^- W^+$

Neutralino1 decays into gravitino:

Two-body decays

$$\tilde{\chi}_1^0 \rightarrow \tilde{G}\,(Z^0\,,\gamma)$$
$$\tilde{\chi}_1^0 \rightarrow \tilde{G}\,(h^0, H^0, A^0)$$

Three-body decays to Gr + SM pair

$$\tilde{\chi}_1^0 \rightarrow \tilde{G}\,\bar{f}\,f$$
$$\tilde{\chi}_1^0 \rightarrow \tilde{G}\,V\,V\,, \quad VV = Z^0 Z^0\,, Z^0\gamma\,, W^+W^-$$
$$\tilde{\chi}_1^0 \rightarrow \tilde{G}\,V\,S\,, \quad VS = (Z^0,\gamma)(h^0, H^0, A^0), W^+H^-, W^-H^+$$
$$\tilde{\chi}_1^0 \rightarrow \tilde{G}\,S\,S\,, \quad SS = (h^0, H^0, A^0)(h^0, H^0, A^0), H^+H^-$$

▼ **GravitinoPack`**

Neu1toGrTotalWidth	Neu1toGrWidth2body	Neu1toGrWidth3body

All possible three-body decays of neutralino1 into gravitino

process $\tilde{\chi}_1^0 \to \tilde{G}XY$	number of graphs	first decay $\tilde{\chi}_1^0 \to \tilde{X}Y$	possible resonances
$\tilde{G} f \bar{f}$	7	$\tilde{G}(h^0, H^0, A^0, \gamma, Z^0), f \tilde{f}_l^*, \tilde{f}_l \bar{f}$	h^0, H^0, A^0, Z^0
$\tilde{G} Z^0 Z^0$	4	$\tilde{G}(h^0, H^0), Z^0 \tilde{\chi}_k^0, \tilde{\chi}_k^0 Z^0$	H^0
$\tilde{G} Z^0 \gamma$	1	$\tilde{\chi}_k^0 Z^0$	–
$\tilde{G} W^+ W^-$	$6 + 4pt$	$\tilde{G}(h^0, H^0, \gamma, Z^0), W^+ \tilde{\chi}_j^-, \tilde{\chi}_j^+ W^-$	H^0
$\tilde{G} Z^0 h^0$	$4 + 4pt$	$\tilde{G}(A^0, Z^0), Z^0 \tilde{\chi}_k^0, \tilde{\chi}_k^0 h^0$	A^0
$\tilde{G} Z^0 H^0$	$4 + 4pt$	$\tilde{G}(A^0, Z^0), Z^0 \tilde{\chi}_k^0, \tilde{\chi}_k^0 H^0$	A^0
$\tilde{G} Z^0 A^0$	$4 + 4pt$	$\tilde{G}(h^0, H^0), \tilde{\chi}_k^0 Z^0, A^0 \tilde{\chi}_k^0$	H^0
$\tilde{G} \gamma h^0$	1	$\tilde{\chi}_k^0 h^0$	–
$\tilde{G} \gamma H^0$	1	$\tilde{\chi}_k^0 H^0$	–
$\tilde{G} \gamma A^0$	1	$\tilde{\chi}_k^0 A^0$	–
$\tilde{G} W^+ H^-$	$5 + 4pt$	$\tilde{G}(h^0, H^0, A^0), W^+ \tilde{\chi}_j^-, \tilde{\chi}_j^+ H^-$	H^0, A^0
$\tilde{G} W^- H^+$	$5 + 4pt$	$\tilde{G}(h^0, H^0, A^0), W^- \tilde{\chi}_j^+, \tilde{\chi}_j^- H^+$	H^0, A^0
$\tilde{G} h^0 h^0$	4	$\tilde{G}(h^0, H^0), h^0 \tilde{\chi}_k^0, \tilde{\chi}_k^0 h^0$	H^0
$\tilde{G} H^0 H^0$	4	$\tilde{G}(h^0, H^0), H^0 \tilde{\chi}_k^0, \tilde{\chi}_k^0 H^0$	–
$\tilde{G} h^0 H^0$	4	$\tilde{G}(h^0, H^0), h^0 \tilde{\chi}_k^0, \tilde{\chi}_k^0 H^0$	–
$\tilde{G} A^0 A^0$	4	$\tilde{G}(h^0, H^0), A^0 \tilde{\chi}_k^0, \tilde{\chi}_k^0 A^0$	H^0
$\tilde{G} h^0 A^0$	3	$\tilde{G}(A^0, Z^0), h^0 \tilde{\chi}_k^0$	–
$\tilde{G} H^0 A^0$	3	$\tilde{G}(A^0, Z^0), H^0 \tilde{\chi}_k^0$	–
$\tilde{G} H^+ H^-$	6	$\tilde{G}(h^0, H^0, \gamma, Z^0), H^+ \tilde{\chi}_j^-, \tilde{\chi}_j^+ H^-$	H^0

$$f \;=\; \nu_e,\, \nu_\mu,\, \nu_\tau,\, e,\, \mu,\, \tau,\; u,\, c,\, t,\, d,\, s,\, b$$

19 individuel decay channels

Stau1 decays into gravitino:

Two-body decays

$$\widetilde{\tau}_1^- \;\rightarrow\; \tilde{G}\,\tau^-$$

Three-body decays to Gr + SM pair

$$\begin{aligned}
\widetilde{\tau}_1^- &\rightarrow \tilde{G}\,Z\,\tau^- \\
\widetilde{\tau}_1^- &\rightarrow \tilde{G}\,W^-\,\nu_\tau \\
\widetilde{\tau}_1^- &\rightarrow \tilde{G}\,(h^0, H^0, A^0)\,\tau^- \\
\widetilde{\tau}_1^- &\rightarrow \tilde{G}\,H^-\,\nu_\tau
\end{aligned}$$

no resonances possible

▼ GravitinoPack`

Stau1toGrTauWidth	Stau1toGrTotalWidth	Stau1toGrWidth3body

Stop1 decays into gravitino:

If stop1 is NLSP only t can become resonant

Two-body decays

$$\tilde{t}_1 \rightarrow \tilde{G}\, t$$

Three-body decays to Gr + SM pair

$$\tilde{t}_1 \rightarrow \tilde{G}\, Z^0\, t$$
$$\tilde{t}_1 \rightarrow \tilde{G}\, W^+\, b$$
$$\tilde{t}_1 \rightarrow \tilde{G}\, (h^0, H^0, A^0)\, t$$
$$\tilde{t}_1 \rightarrow \tilde{G}\, H^+\, b$$

process $\tilde{t}_1 \to \tilde{G}XY$	number of graphs	first decay $\tilde{t}_1 \to \tilde{X}Y$	possible resonances
$\tilde{G}Z^0t$	$3+4pt$	$\tilde{G}t,\ \tilde{t}_iZ^0,\ \tilde{\chi}^0_kt$	$\tilde{\chi}^0_k$
$\tilde{G}W^+b$	$3+4pt$	$\tilde{G}t,\ \tilde{b}_iW^+,\ \tilde{\chi}^+_jb$	$t, \tilde{b}_i, \tilde{\chi}^+_j$
$\tilde{G}h^0t$	3	$\tilde{G}t,\ \tilde{t}_ih^0,\ \tilde{\chi}^0_kt$	$\tilde{\chi}^0_k$
$\tilde{G}H^0t$	3	$\tilde{G}t,\ \tilde{t}_iH^0,\ \tilde{\chi}^0_kt$	$\tilde{\chi}^0_k$
$\tilde{G}A^0t$	3	$\tilde{G}t,\ \tilde{t}_iA^0,\ \tilde{\chi}^0_kt$	$\tilde{\chi}^0_k$
$\tilde{G}H^+b$	3	$\tilde{G}t,\ \tilde{b}_iH^+,\ \tilde{\chi}^+_jb$	$t, \tilde{b}_i, \tilde{\chi}^+_j$

▼ GravitinoPack`

Stop1toGrTopWidth	Stop1toGrTotalWidth	Stop1toGrWidth3body

GravitinoPack MathLink functions

There exist also analogous Fortran77 functions, the usage is shown in some example*.F files.

▼ GravitinoPack`

Geti2body	GravWidth2body	PrintWidths	SetSMparameters
Geti3body	GravWidth3body	Seti2body	SLHAfile
GetiCMS	IsGrtheLSP	Seti3body	Stau1toGrTauWidth
GetiGrHel	IsNeu1theNLSP	SetiCMS	Stau1toGrTotalWidth
Getionlygamma	IsStau1theNLSP	SetiGrHel	Stau1toGrWidth3body
GetMSSMmasses	IsStop1theNLSP	Setionlygamma	Stop1toGrTopWidth
GetSLHAParameters	Neu1toGrTotalWidth	SetMSSMOSmasses	Stop1toGrTotalWidth
GetSMparameters	Neu1toGrWidth2body	SetMSSMOSparamet-ers	Stop1toGrWidth3body
GravTotalWidth	Neu1toGrWidth3body	SetMSSMparameters	

❖ First a scenario has to be fixed – locally or by SLHA2 file format

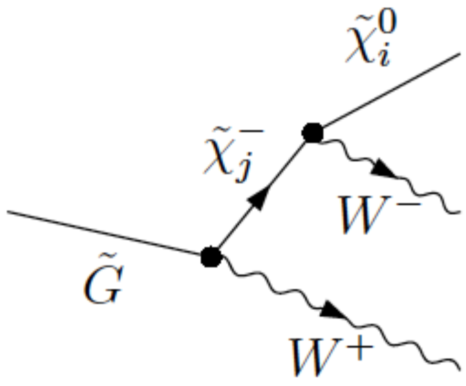
❖ Then widths and branching ratios can be calculated

Three-body decays: assuming that the dominant two-body channel is kinematically possible, $m_{\tilde{G}} > m_{\tilde{X}} + m_Y$, the gravitino decays to the LSP $\tilde{\chi}_1^0$ as

$$\widetilde{G} \xrightarrow{grav} \widetilde{X}\, Y \xrightarrow{EW} \tilde{\chi}_1^0\, X\, Y$$

Otherwise we have directly

$$\widetilde{G} \xrightarrow{grav} \tilde{\chi}_1^0\, X\, Y$$

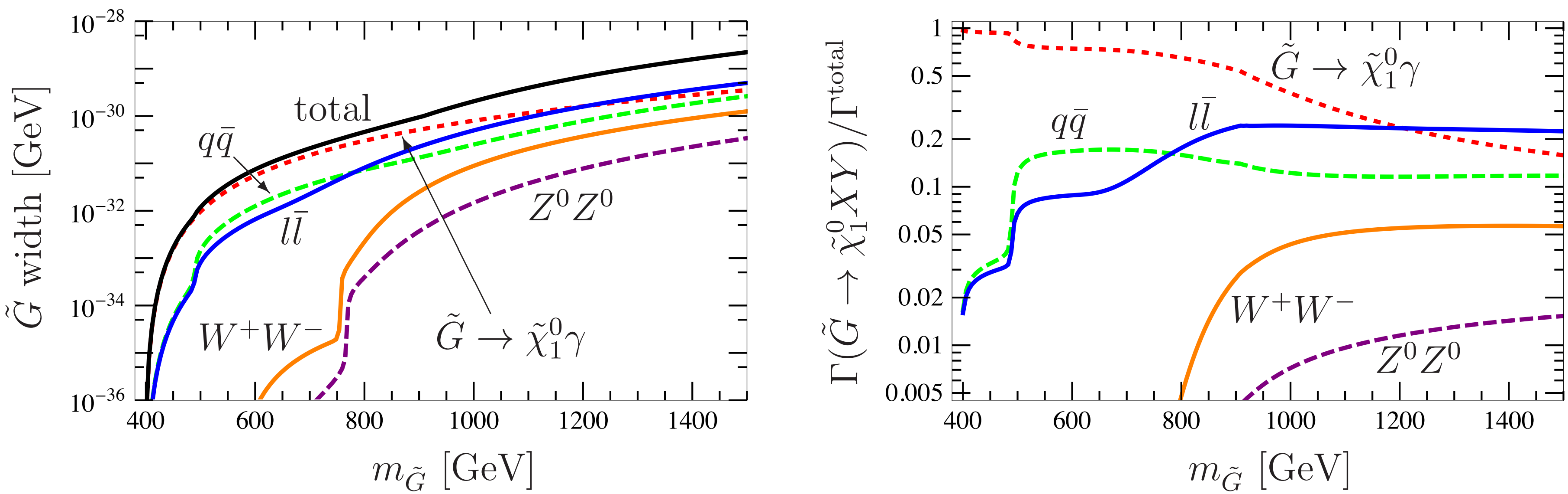


? Seti3body

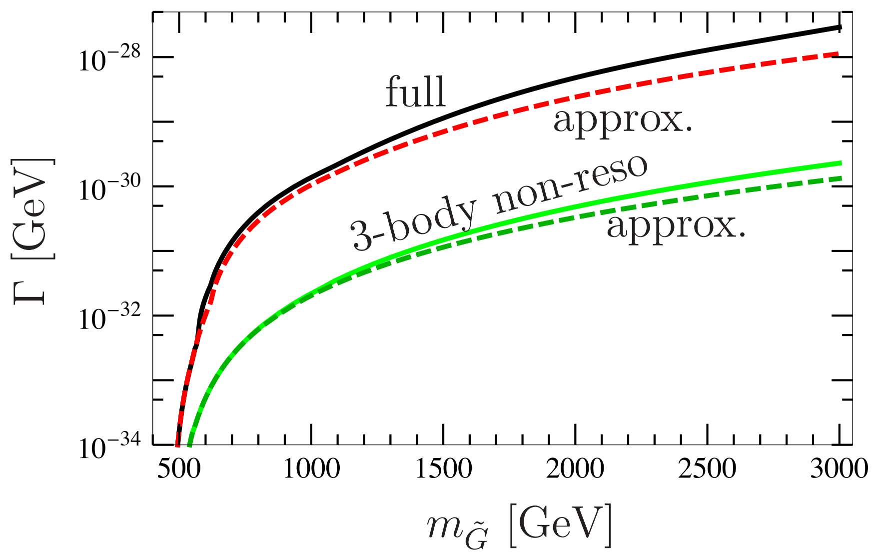
Seti3body[i] sets the common block variable ithreebody = i,
ithreebody = 0 == full calculation, also in case of resonances,
ithreebody = 1 == NWA for resonances + non–resonant part,
ithreebody = 2 == narrow width approx. for resonances only,
ithreebody = 3 == non–resonant part only.

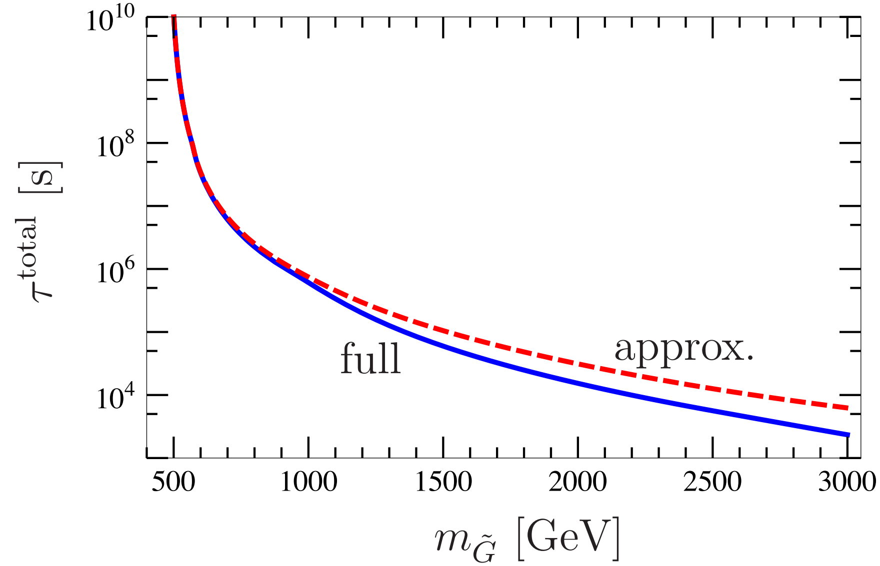
? Geti3body

Geti3body[] returns common block variable ithreebody,
details see the description to Seti3body[]



The three-body decay widths of the gravitino decaying into $\tilde{\chi}_1^0$ and $q\bar{q}$,$l\bar{l}$, W-pairs, and Z-pairs at the A^0-funnel point; "total" denotes $\Gamma^{\rm total}$ which is the full two-body width plus the sum of the non-resonant part of three-body decay widths with $\tilde{\chi}_1^0$; $q\bar{q}$ stands for the sum over all six quark flavors and $l\bar{l}$ for the sum over the three charged lepton and three neutrino flavors. The red dotted lines denote the two-body decay $\widetilde{G} \to \tilde{\chi}_1^0\gamma$. In the right figure we display the corresponding branching ratios for the decay channels plotted in the left figure.





Comparison of our results with a commonly used approximation for a NUHM point (right) and a CMSSM point (left)

Conclusions

- New calculations of decay widths with gravitino presented
- Program package GravitinoPack presented,
  works at Fortran77 level and with MathLink, public available soon,
  includes
- All two-body decays and three-body decays to neu1 + SM pair of Gr
- All two- and three-body decays of NLSP neu1, stop1, stau1 to Gr + SM pair
- Possible resonances in three-body decays treated automatically by using narrow width approximation – avoids double-counting
- Knowledge of complete three-body decay width important below and also above thresholds of possible resonant propagators

Outlook

- Numerical study of NLSP to Gr LSP
- 4body decays of stau1 and stop1

Thank you!