HELAS and MadGraph/ MadEvent with gravitinos

arXiv:1010.4255

Kentarou Mawatari (Vrije Uni. Brussel ← Uni. Heidelberg)

with K. Hagiwara and Y. Takaesu (KEK)

GDR Terascale @ Brussels, 05/11/2010

Outlines

- What is a gravitino?
- What is HELAS and MadGraph/MadEvent?
  - 5-min MG/ME tutorial for non-MG/ME users
- Sample results:
  - Neutralino NLSP
  - Stau NLSP
- Summary and future plans

Gravitinos

- spin-3/2 superpartners of gravitons in local supersymmetric extensions to the SM (Supergravity).
- If SUSY breaks spontaneously, gravitinos absorb massless spin-1/2 goldstinos and become massive by the super-Higgs mechanism.

Mass of the gravitino

- related to the SUSY breaking scale as well as the Planck scale

$$m_{3/2} \sim (M_{\rm SUSY})^2 / M_{\rm Pl}$$

- This implies that the gravitino can take a wide range of mass, depending on the SUSY breaking scale, from eV up to scales beyond TeV, and provide rich phenomenology in particle physics as well as in cosmology.

Gravitinos at colliders

- Although the gravitino can play an important role even in collider signatures when it is the lightest supersymmetric particle (LSP), there is few Monte Carlo event generators which can treat them.

- We added new HELAS subroutines for massive gravitinos and their interactions, and implemented them into MadGraph/MadEvent so that arbitrary amplitudes with external gravitinos can be generated automatically.

- MG/ME v4 supports spin-0, 1/2, 1, and 2.
  [HELAS and MG/ME w/ spin-2 particles by Hagiwara, Kanzaki, Q.Li, KM, EPJC(2008), and extended version by Priscila de Aquino et al.]

Wavefunction of a spin-3/2 particle

- Rarita-Schwinger wavefunction
- expressed by using the vector boson wavefunctions and the spinor wavefunctions:

$$\psi_u^\mu(p,+3/2) = \epsilon^\mu(p,+)\,u(p,+),$$

$$\psi_u^\mu(p,+1/2) = \sqrt{\frac{2}{3}}\,\epsilon^\mu(p,0)\,u(p,+) + \sqrt{\frac{1}{3}}\,\epsilon^\mu(p,+)\,u(p,-)\,e^{i\phi},$$

$$\psi_u^\mu(p,-1/2) = \sqrt{\frac{1}{3}}\,\epsilon^\mu(p,-)\,u(p,+) + \sqrt{\frac{2}{3}}\,\epsilon^\mu(p,0)\,u(p,-)\,e^{i\phi},$$

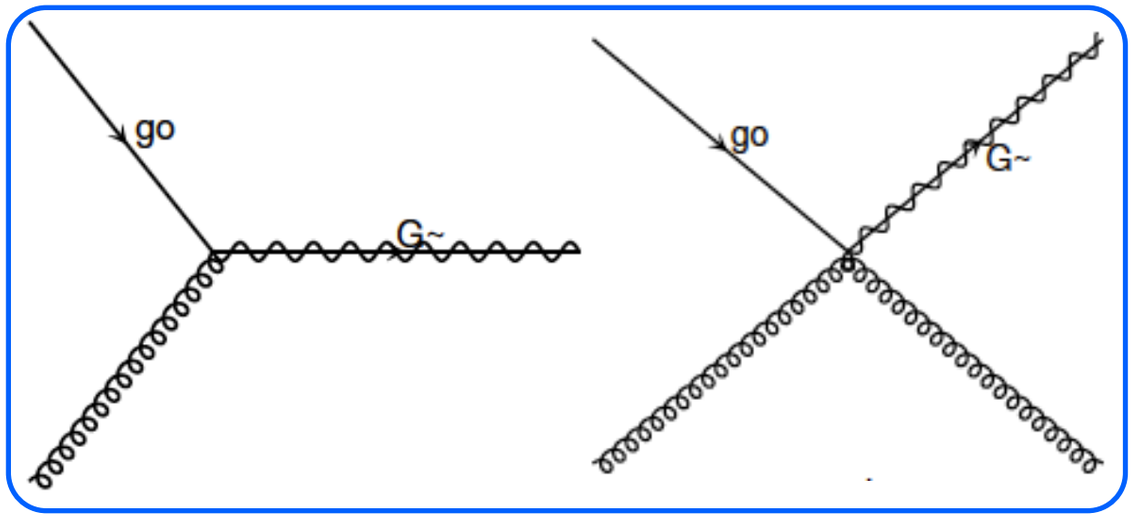
$$\psi_u^\mu(p,-3/2) = \epsilon^\mu(p,-)\,u(p,-)\,e^{i\phi},$$

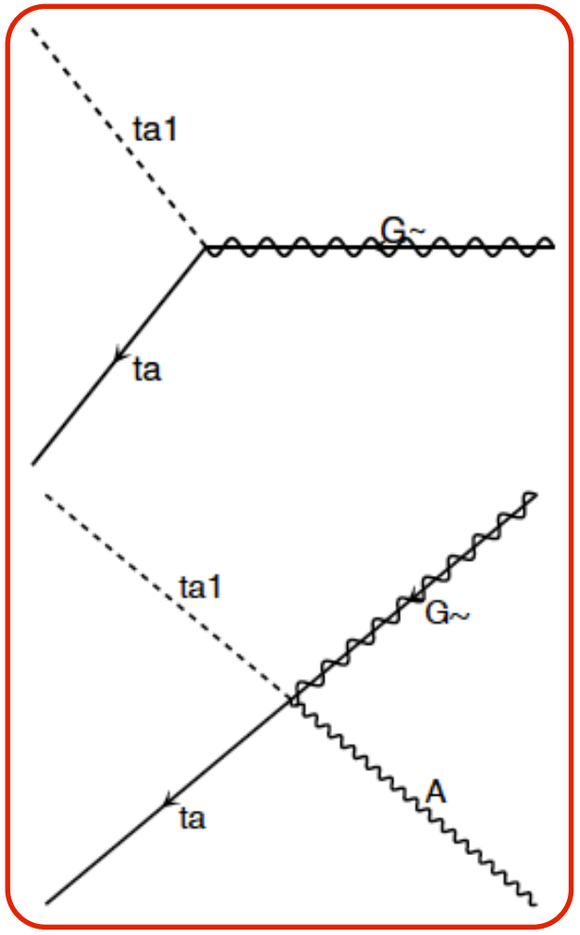
List of the vertices

- The effective interaction Lagrangian:

$$\mathcal{L}_{\rm int} = -\frac{i}{\sqrt{2}\,\overline{M}_{\rm Pl}}\left[\bar{\psi}_\mu \gamma^\nu \gamma^\mu P_{R/L} f^i \left(D_\nu \phi^i_{R/L}\right)^* - \bar{f}^i P_{L/R} \gamma^\mu \gamma^\nu \psi_\mu \left(D_\nu \phi^i_{R/L}\right)\right]$$

$$-\frac{i}{8\overline{M}_{\rm Pl}} \bar{\psi}_\mu [\gamma^\nu, \gamma^\rho] \gamma^\mu \lambda^{(\alpha)a} F^{(\alpha)a}_{\nu\rho} ;$$

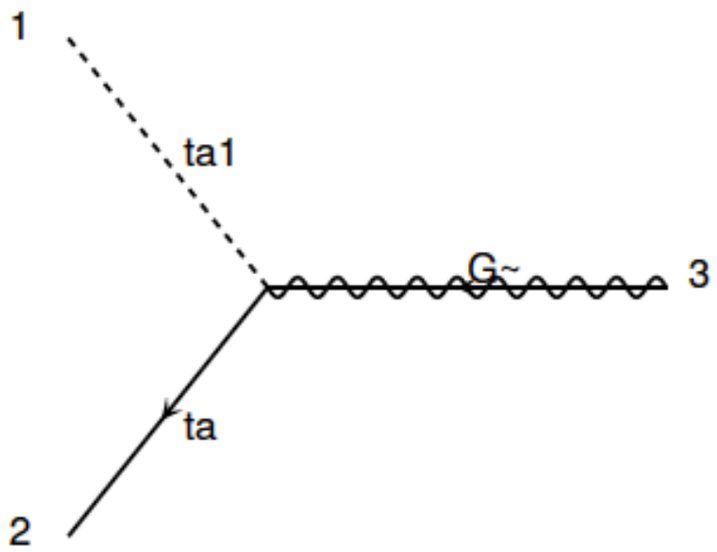




HELAS

- HELicity Amplitude Subroutines (in Fortran77)
  - by H. Murayama, I. Watanabe, K. Hagiwara (1992)
  - he.la.su (減らす) in Japanese = reduce

- e.g., stau l- > tau- + gravitino




```
CALL SXXXXX(P1,          -1,  W1)
CALL OXXXXX(P2, MST1 ,HEL2, +1,  W2)
CALL IRXXXX(P3, MGRO ,HEL3, -1,  W3)

CALL IROSXX(W3, W2, W1, GFRL  ,  AMP)
```

MadGraph/MadEvent

- MG by T. Stelzer and W.F. Long (1994)
- ME by F. Maltoni and T. Stelzer (2003)

- Put your process, e.g., e+e- > n1n1 > a gro a gro
  ./bin/newprocess
- MG automatically draws all possible Feynman diagrams and writes corresponding HELAS codes.
- Set your parameters, e.g., masses, couplings, collider energy, kinematical cuts, ...
  ./bin/generate_events
- ME gives you cross sections and distributions.

Sample results: neutralino NLSP

Ambrosanio, Kane, Kribs, Martin, Mrenna, PRD(1996)

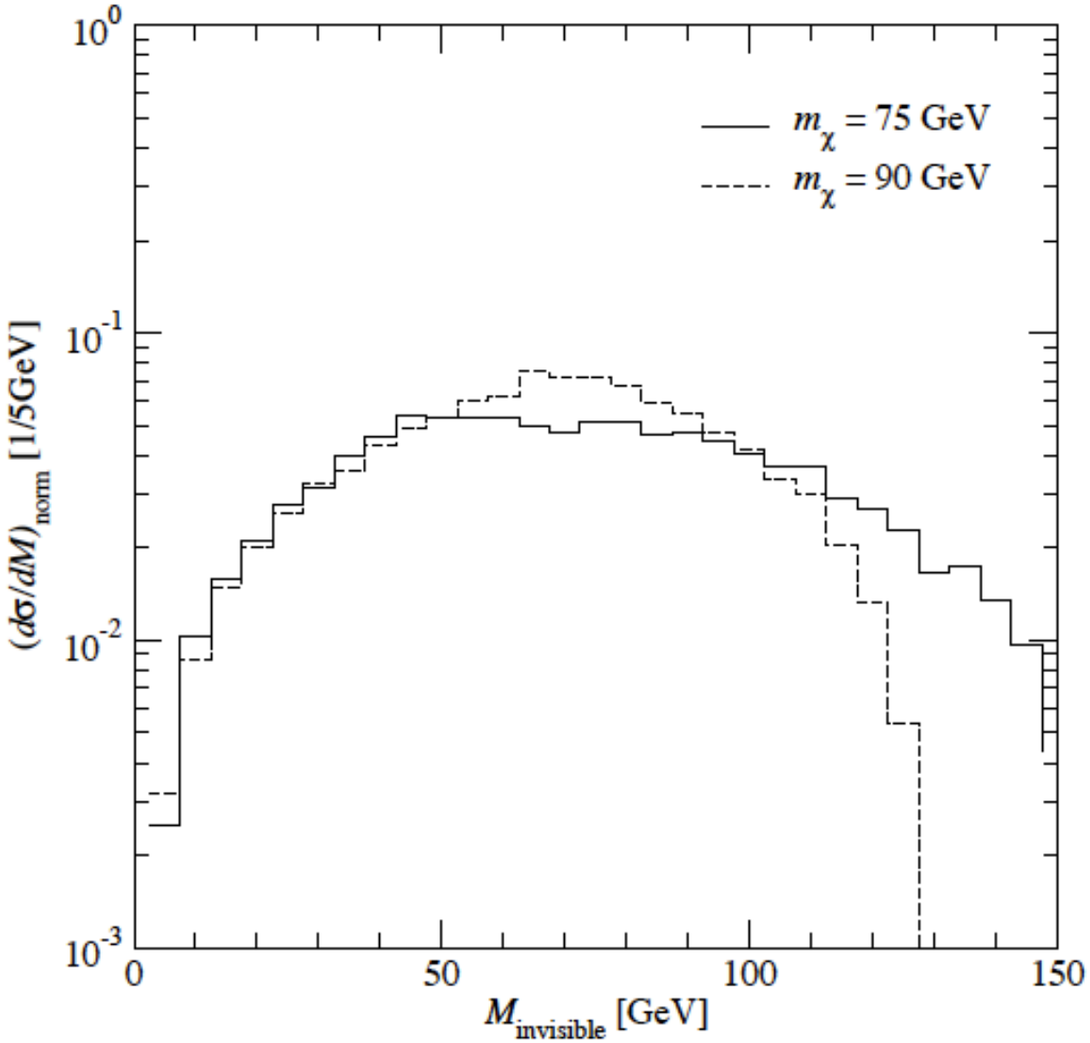


Fig. 4. Missing invariant mass distributions for $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \gamma\gamma\tilde{G}\tilde{G}$ at $\sqrt{s} = 190$ GeV. The cases for the neutralino mass $m_\chi = 75$ and 90 GeV are shown as a solid and dashed line, respectively, with the normalized cross section after kinematical cuts of (121).

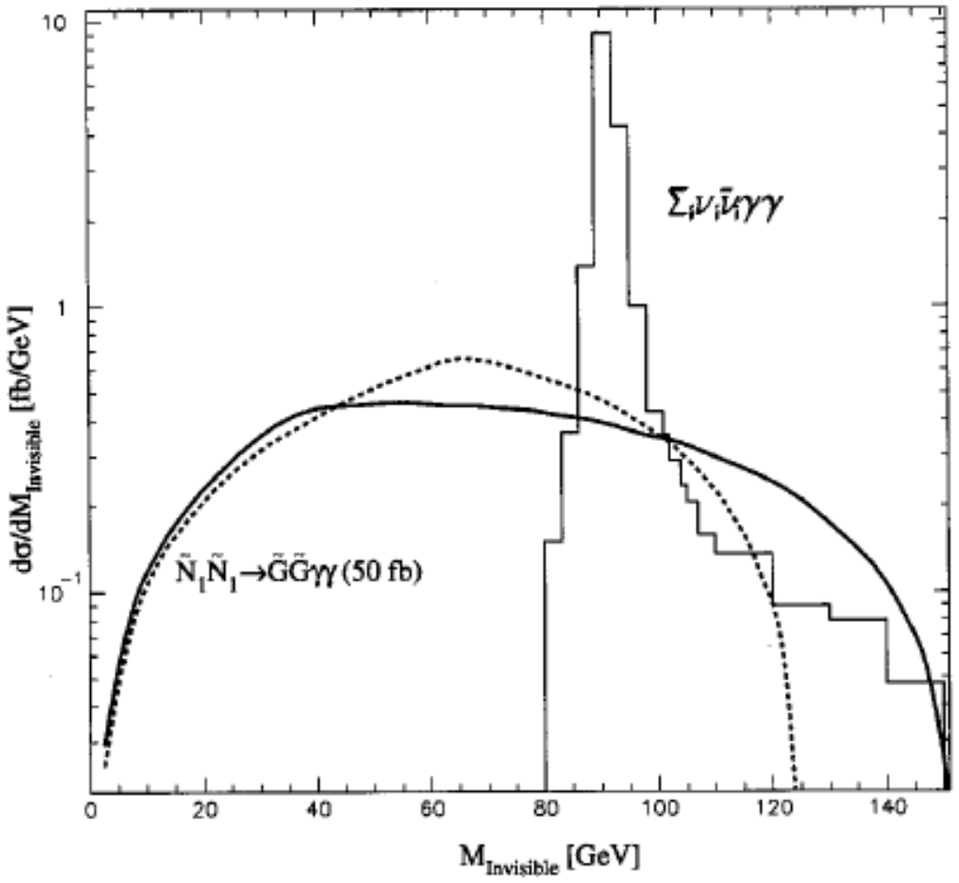


FIG. 16. Distribution of the missing invariant mass in $\gamma\gamma\not{E}$ events at LEP with $\sqrt{s} = 190$ GeV. Angular and photon energy cuts have been applied as described in the text. The lighter solid line is the remaining total background (56 fb) for all three neutrino species. The signals for $m_{\tilde{N}_1} = 75$ and 90 GeV are the solid and dashed lines, respectively, with an arbitrary choice of 50 fb for the signal before cuts in each case.

Sample results: stau NLSP

Buchmuller, Hamaguchi, Ratz, Yanagida, PLB(2004)

- Radiative stau decays to study the spin-3/2 nature of the gravitino

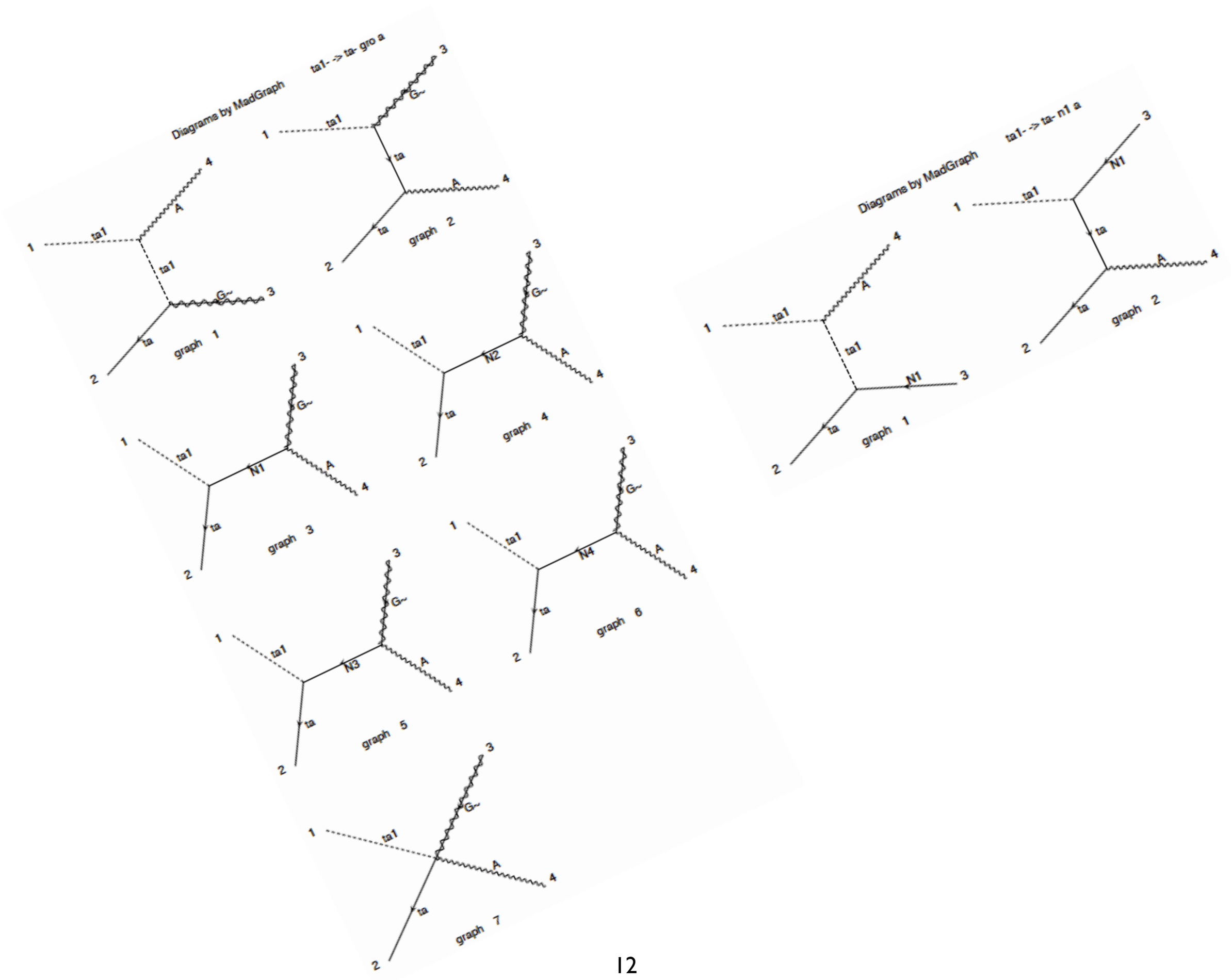
$$\tilde{\tau}_R^- \to \tau^- \tilde{G}\,\gamma \quad \text{vs.} \quad \tilde{\tau}_R^- \to \tau^- \tilde{\chi}_1^0\,\gamma$$

- Photon polarization by means of Stokes parameters

$$\frac{d\rho_{\lambda\lambda'}}{dE_\gamma\, d\cos\theta} = \frac{1}{2}\left(1 + \sum_{i=1}^{3} P_i \sigma_i\right)_{\lambda\lambda'} \cdot \frac{d\Gamma_{\text{sum}}}{dE_\gamma\, d\cos\theta}$$

- The photon density matrix

$$d\rho_{\lambda\lambda'} = \frac{1}{2m_{\tilde{\tau}}} \sum \mathcal{M}_\lambda \mathcal{M}^*_{\lambda'}\, d\Phi_3$$


Diagrams by MadGraph
ta1- -> ta- gro a
graph 1
graph 2
graph 3
graph 4
graph 5
graph 6
graph 7
ta1
ta
G~
A
N1
N2
N3
N4

Diagrams by MadGraph
ta1- -> ta- n1 a
graph 1
graph 2
ta1
ta
N1
A

spin-3/2 vs. spin-1/2

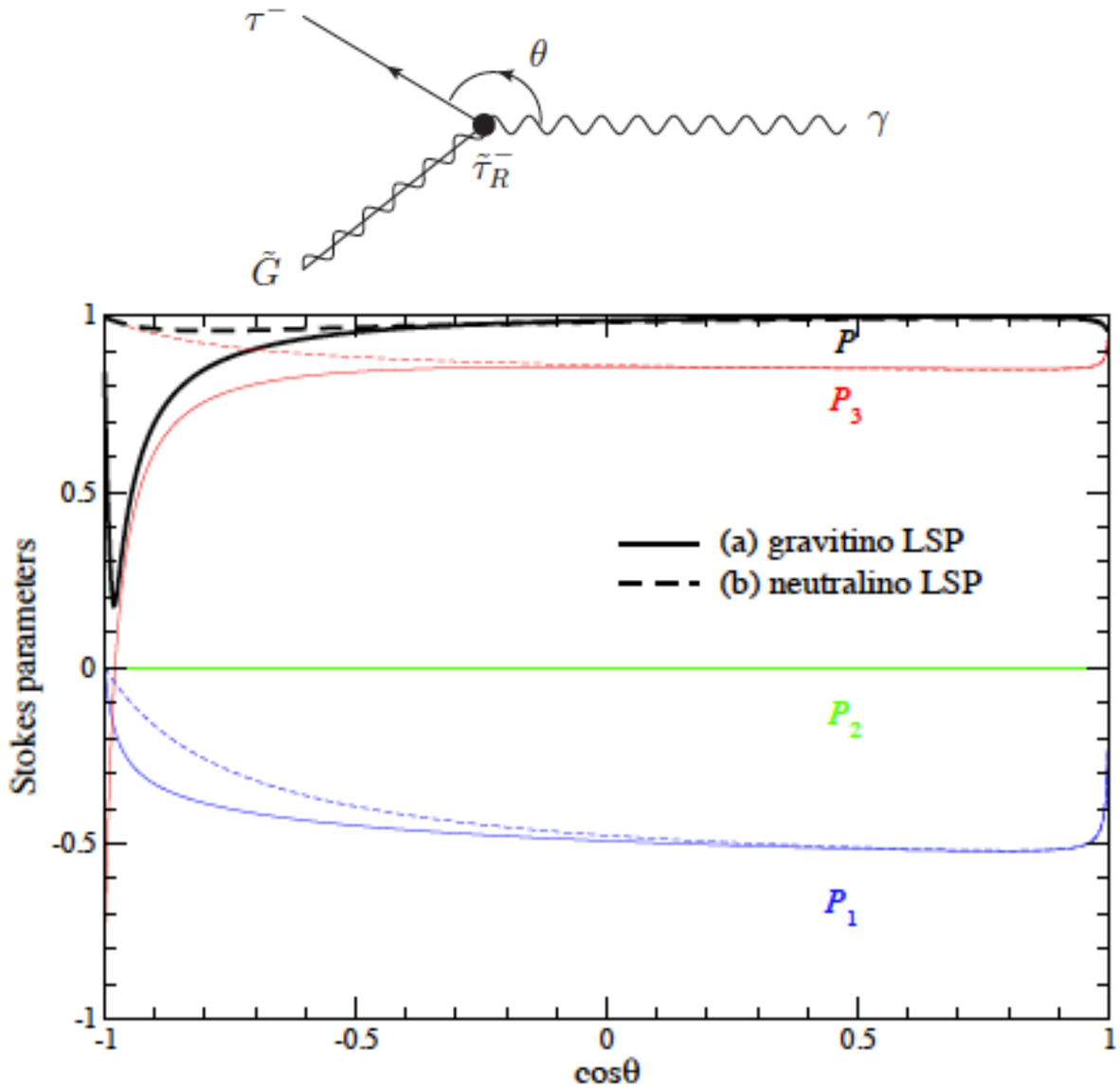


Fig. 3. Angular dependence of the Stokes parameters of the radiated photon for the $\tilde{\tau}$ decay process, $\tilde{\tau}_R \to \tau\tilde{G}\gamma$ (a) and $\tilde{\tau}_R \to \tau\tilde{\chi}_1^0\gamma$ (b), where θ is the decay angle between the photon and the tau-lepton. We set $m_{\tilde{\tau}} = 150$ GeV, $m_{\rm LSP} = 75$ GeV and $E_\gamma = 40$ GeV.

- P_3 shows the right-left asymmetry of circular polarizations;
  P_3=1: right-handed
  P_3=-1: left-handed

- cosθ>0: the photon bremsstrahlung is dominant, and only 1/2 helicities of the gravitino are allowed.

- cosθ~-1: The left-handed photon is only allowed for spin-3/2 LSP, i.e. gravitino.

Summary

- added new HELAS subroutines to calculate helicity amplitudes with massive gravitinos.
- coded them in such a way that arbitrary amplitudes with external gravitinos can be generated automatically by MadGraph.
- tested carefully by making use of the gauge invariance of the helicity amplitudes.
- presented sample numerical results for the neutralino NLSP and the stau NLSP scenarios.

Future plans

- add new HELAS subroutines for goldstinos.
- test the goldstino equivalence of the gravitino in the high energy limit.
- enjoy the gravitino phenomenology for the LHC !

The code is available at
http://madgraph.kek.jp/KEK/

New pheno group at the VUB

- A 5-year project on "Supersymmetric Models and their Signatures at the LHC"
  - B. Craps, A. Sevrin, A. Mariotti (theory) -9th floor
  - C. De Clercq (IceCube), J. D'Hondt (CMS) -0th floor
  - F. Maltoni (pheno) -CP3/UCL
- New members since this fall
  - Kentarou Mawatari (from Uni. Heidelberg since Oct/1) -Project leader
  - Phillip Grajek (from KEK since Nov/??) -PD
  - Bettina Oexl (from Uni. Tuebingen since Nov/3) -PhD
  - ...
- Contact to
  - http://we.vub.ac.be/dntk/onderzoek/GOAindex.htm
  - pheno@vub.ac.be