Vrije Universiteit Brussel

Mono-X signals in gravitino production

Kentarou Mawatari

(Vrije Universities Brussel and International Solvay Institutes)

Outlines

- A brief review of mono-X searches
- Gravitino phenomenology at colliders
- Monophoton+missing energy at the ILC and LHC

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Review of mono-X searches at colliders

Photon Events with Missing Energy in e^+e^- Collisions at $\sqrt{s} = 130$ to 209 GeV

DELPHI Collaboration

hep-ex/0406019

The production of single- and multi-photon events has been studied in the reaction $e^+e^- \to \gamma(\gamma) + invisible\ particles$. The data collected with the DELPHI detector during the years 1999 and 2000 at centre-of-mass energies between 191 GeV and 209 GeV was combined with earlier data to search for phenomena beyond the Standard Model. The measured number of light neutrino families was consistent with three and the absence of an excess of events beyond that predicted by the Standard Model processes was used to set limits on new physics. Both model-independent searches and searches for new processes predicted by supersymmetric and extra-dimensional models have been made. Limits on new non-standard model interactions between neutrinos and electrons were also determined.

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hep-ex/0205057

Limits on Extra Dimensions and New Particle Production in the Exclusive Photon and Missing Energy Signature in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

The exclusive $\gamma \not{E}_T$ signal has a small standard model cross-section and is thus a good channel in which to look for signs of new physics. This signature is predicted by models with a superlight gravitino or with large extra spatial dimensions. We search for such signals at the CDF detector at the Tevatron, using 87 pb^{-1} of data at $\sqrt{s} = 1.8$ TeV, and extract 95% C.L. limits on these processes. A limit of 221 GeV is set on the scale $|F|^{1/2}$ in supersymmetry models. For 4, 6, and 8 extra dimensions, limits on the fundamental mass scale M_D of 549, 581, and 602 GeV, respectively, are found. We also specify a 'pseudo-model-independent' method of comparing the results to theoretical predictions.

Limits on Gravitino Production and New Processes with Large Missing Transverse Energy in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

hep-ex/0003026

(CDF Collaboration)

Events collected by the Collider Detector at Fermilab (CDF) with an energetic jet plus large missing transverse energy can be used to search for physics beyond the Standard Model. We see no deviations from the expected backgrounds and set upper limits on the production of new processes. We consider in addition the production of light gravitinos within the framework of the Gauge Mediated Supersymmetry Breaking models and set a limit at 95% confidence level on the breaking scale $\sqrt{F} \geq 217$ GeV, which excludes gravitino masses smaller than 1.1×10^{-5} eV/c^2.

ATLAS-CONF-2012-147

Search for New Phenomena in Monojet plus Missing Transverse Momentum Final States using 10 fb^{-1} of pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector at the LHC

Abstract

We report preliminary results on a search for new phenomena in monojet plus large missing transverse momentum final states. The analysis uses 10.5 fb^{-1} of $\sqrt{s} = 8$ TeV data collected in 2012 with the ATLAS detector at the LHC. Good agreement is observed between the number of events in data and the Standard Model predictions. The results are translated into new limits on the production of light grativinos in association with gluinos or scalar quarks in a gauge-mediated supersymmetric model, leading to the best lower bound to date on the gravitino mass. Exclusion limits on models with large extra spatial dimensions and on pair production of weakly interacting dark matter candidates are also presented.

CMS PAS EXO-12-048

Search for dark matter, extra dimensions, and unparticles in monojet events in proton-proton collisions at $\sqrt{s} = 8$ TeV

1408.3583v1 [hep-ex] 15 Aug 2014

The CMS Collaboration*

Abstract

Results are presented from a search for particle dark matter (DM), extra dimensions, and unparticles using events containing a jet and an imbalance in transverse momentum. The data were collected by the CMS detector in proton-proton collisions at the LHC and correspond to an integrated luminosity of 19.7 fb^{-1} at a centre-of-mass energy of 8 TeV. The number of observed events is found to be consistent with the standard model prediction. Limits are placed on the DM-nucleon scattering cross section as a function of the DM particle mass for spin-dependent and spin-independent interactions. Limits are also placed on the scale parameter M_D in the ADD model of large extra dimensions, and on the unparticle model parameter Λ_U. The constraints on ADD models and unparticles are the most stringent limits in this channel and those on the DM-nucleon scattering cross section are an improvement over previous collider results.

CMS PAS EXO-12-047

Search for Dark Matter and Large Extra Dimensions in the $\gamma + \not{E}_T$ final state in pp Collisions at $\sqrt{s} = 8$ TeV

The CMS Collaboration

Abstract

We present a search for ADD, Branon large extra dimensions and dark matter pair-production with a final state of γ + missing transverse energy in pp collisions at $\sqrt{s} = 8$ TeV. We find no deviation from the Standard Model prediction for this final state, and achieve an extension of the current limits on parameter space. This study is done with the data taken by the CMS experiment at the LHC in 2012 corresponding to an integrated luminosity of 19.6 fb^{-1} of data.

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arXiv:1407.7494v1 [hep-ex] 28 Jul

Search for new particles in events with one lepton and missing transverse momentum in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

The ATLAS Collaboration

Abstract

This paper presents a search for new particles in events with one lepton (electron or muon) and missing transverse momentum using 20.3 fb^{-1} of proton–proton collision data at $\sqrt{s} = 8$ TeV recorded by the ATLAS experiment at the Large Hadron Collider. No significant excess beyond Standard Model expectations is observed. A W' with Sequential Standard Model couplings is excluded at the 95% confidence level for masses up to 3.24 TeV. Excited chiral bosons (W^*) with equivalent coupling strengths are excluded for masses up to 3.21 TeV. In the framework of an effective field theory limits are also set on the dark matter–nucleon scattering cross-section as well as the mass scale M_* of the unknown mediating interaction for dark matter pair production in association with a leptonically decaying W.

Review of mono-X searches at colliders

Experiments	Mono-X	BSM models
LEP (OPAL, ALEPH, L3, DELPHI)	photon	LED, SUSY1, SUSY2
Tevatron (D0, CDF)	photon jet	LED LED, SUSY1, DM
ATLAS	photon jet lepton/Z/W	LED, DM SUSY2, LED, DM W'/W*, DM
CMS	photon jet lepton/W/Z	DM, ADD, Branon DM, LED, Unparticle DM

Gravitino phenomenology at colliders

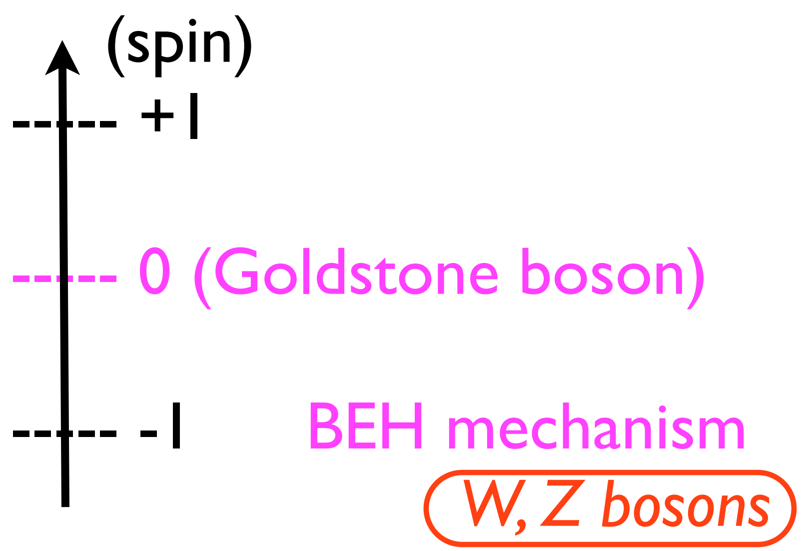
Gravitinos

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

EW to Supergravity

- SU(2)xU(1) gauge symmetry

  ➡ spontaneously broken



  ➡ discovered in 1983

  ➡ established the EW theory

- Local supersymmetry

  ➡ spontaneously broken

  ➡ discover in 201? (??)

  ➡ establish supergravity !!

Kentarou Mawatari (Vrije U. Brussel)

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.

Collider phenomenology for a gravitino LSP

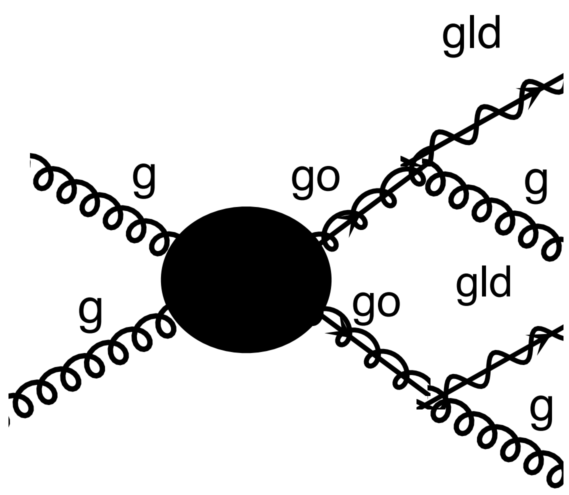
- The low-scale SUSY breaking can naturally happen in gauge-mediated SUSY breaking scenarios, where the gravitino is often the LSP and can play an important role even for collider signatures.
- The phenomenology depends so much on what the NLSP is.
  - In the minimal model of gauge mediation, the lightest neutralino and the lighter stau are often the NLSP.
  - A chargino, sneutrino, gluino, and squark can also be NLSP in, e.g., general gauge mediation models, split SUSY models, ...
  - The different NLSP gives different mono-X signals.

➡ A simulation tool for gravitinos is needed for systematic analyses.

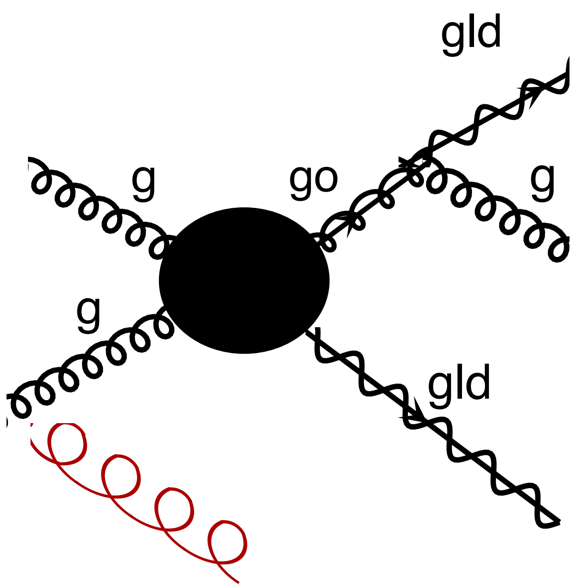
Our gravitino related works (2011-)

- "HELAS and MadGraph with spin-3/2 particles"
  (Hagiwara, KM, Takaesu) EPJC71(2011)1529
- "HELAS and MadGraph with goldstinos"
  (KM, Takaesu) EPJC71(2011)1640
- "Associated production of light gravitinos in e+e- and e-γ collisions"
  (KM, Oexl, Takaesu) EPJC71(2011)1783
- "Collider signatures of a Goldstini model"
  (Argurio, Causmaecker, Ferretti, Mariotti, KM, Takaesu) JHEP1206(2012)096
- "Light gravitino production in association with gluinos at the LHC"
  (Aquino, Maltoni, KM, Oexl) JHEP1210(2012)008
- "Simulating spin-3/2 particles at colliders"
  (Christensen, Aquino, Deutschmann, Duhr, Fuks, Garcia-Cely, Mattelaer, KM, Oexl, Takaesu) EPJC73(2013)2580
- "Multilepton signals of gauge mediated supersymmetry breaking at the LHC"
  (D'Hondt, Causmaecker, Fuks, Mariotti, KM, Petersson, Redigolo) PLB731(2014)7
- "Multiphoton signatures of goldstini at the LHC"
  (Ferretti, Mariotti, KM, Petersson) JHEP04(2014)126
- "Monophoton signals in light gravitino production in e+e- collisions"
  (KM, Oexl) EPJC74(2014)2909
- ...

Production mechanisms of gravitinos at colliders: e.g. gluino NLSP

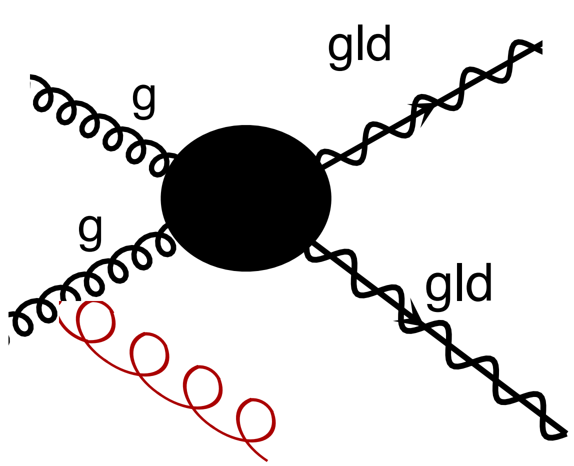


Gluino pair production with the prompt decay of the gluino into a gravitino and a gluon gives dijet plus missing energy signature.



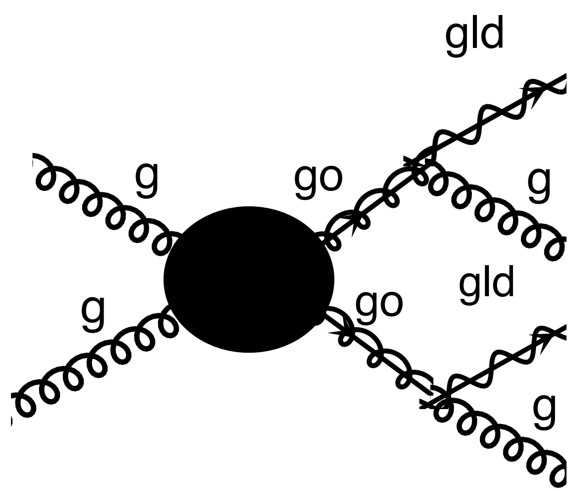
Gluino gravitino associated production with the prompt decay of the gluino gives monojet plus missing energy signature.

Taking into account initial/final state radiation, this process gives also dijet plus missing energy.

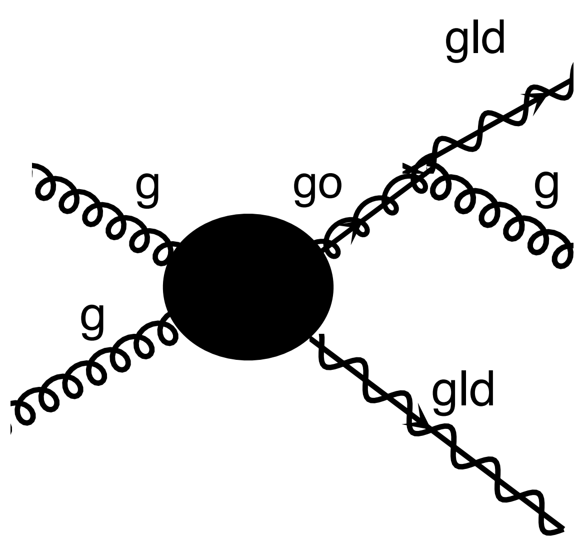


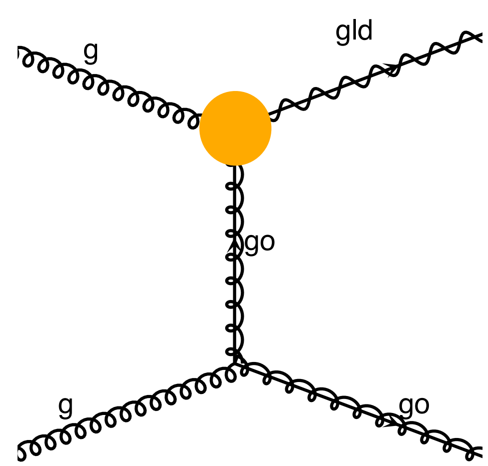
Gravitino pair production with extra radiation gives (mostly soft) monojet plus missing energy signature.

Different scaling with gravitino mass

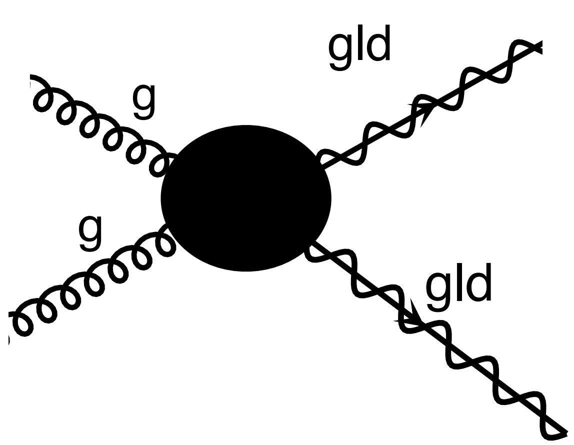


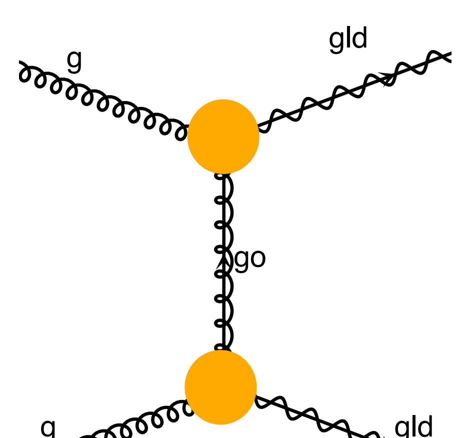
Gluino-pair production cross section is independent of the gravitino mass.





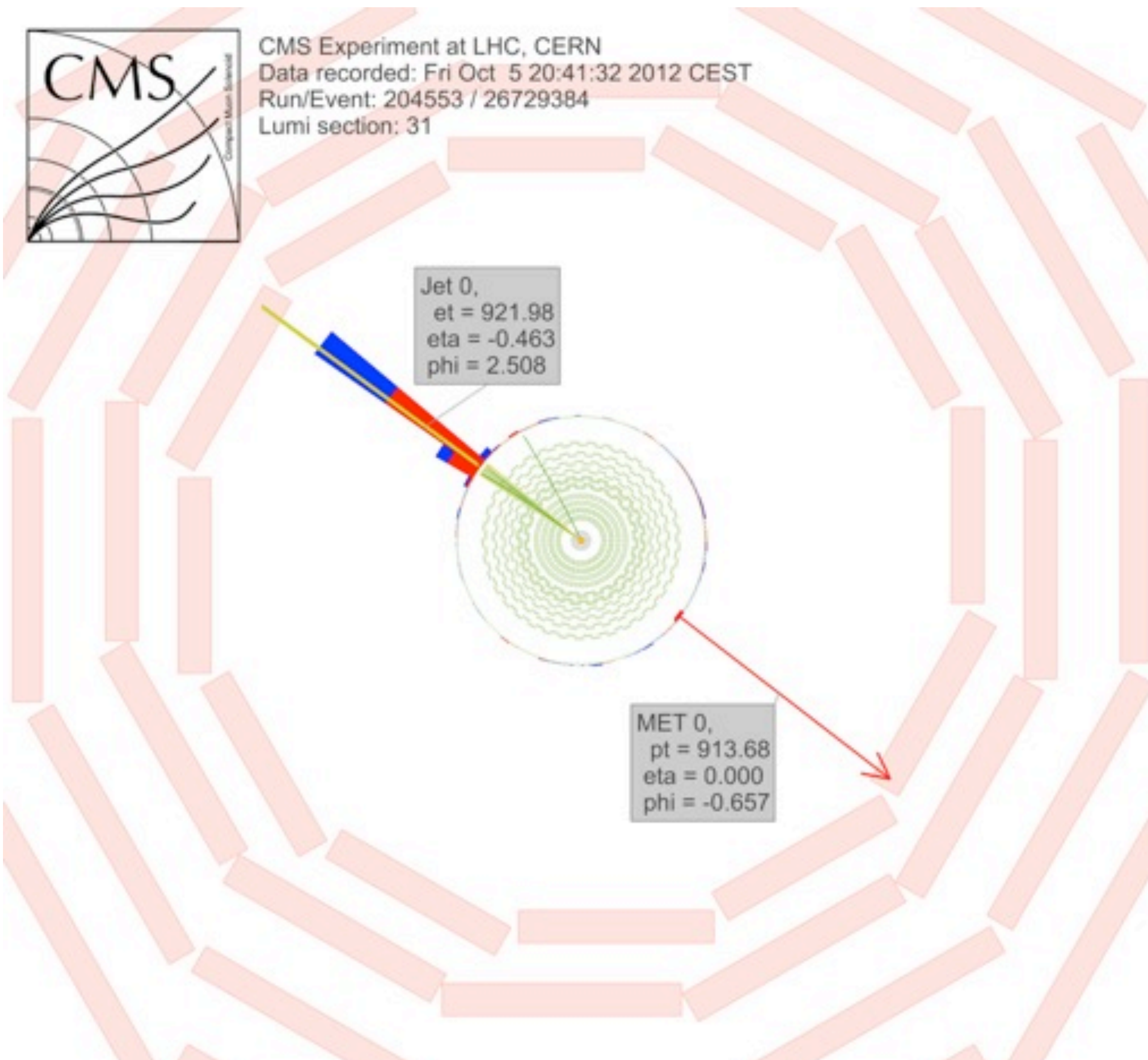
$$\sigma(\tilde{G}\tilde{g}) \sim \frac{1}{F^2} \sim \frac{1}{m_{3/2}^2}$$





$$\sigma(\tilde{G}\tilde{G}) \sim \frac{1}{F^4} \sim \frac{1}{m_{3/2}^4}$$

Jet plus missing energy

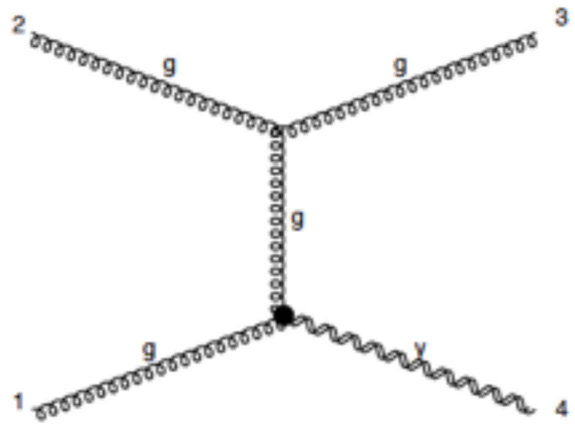
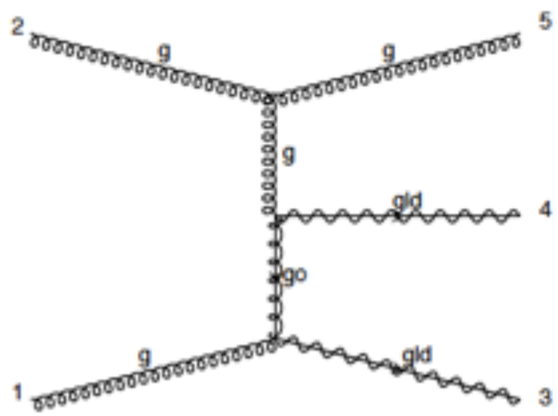
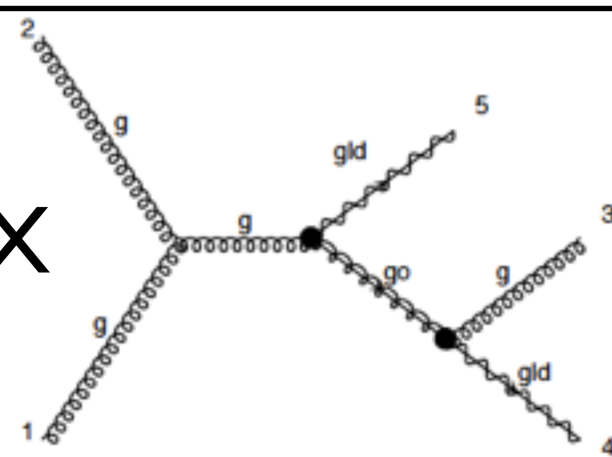


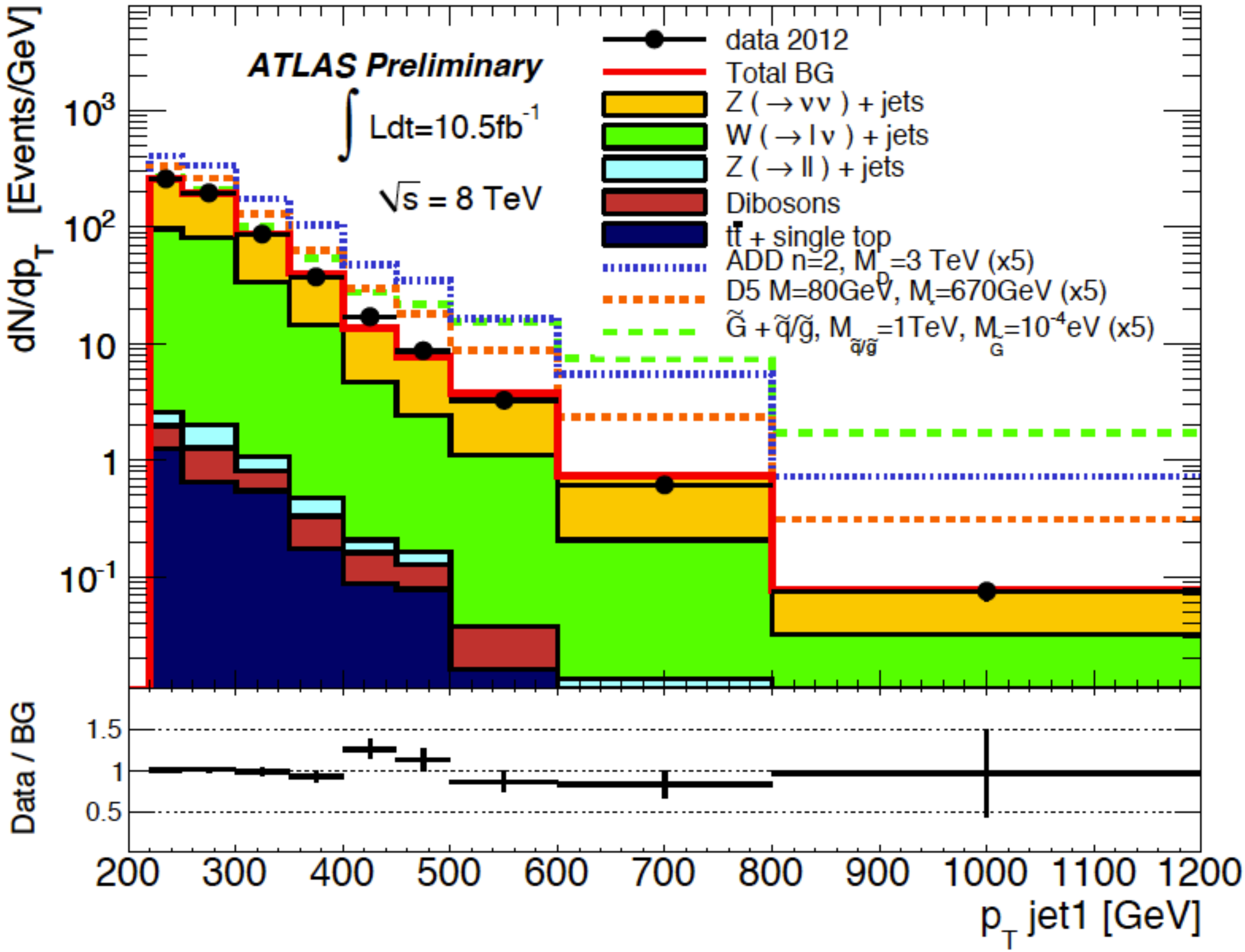
The signal could be standard model background

$$pp \to jZ \to j\nu\tilde{\nu}$$

or new physics signal:

massive gravitons,
neutralino,
gravitino,
...

Topology		Models	p_{Tj}
p p → j X		LED (X=ADD graviton) Unparticle (X=unparticle)	soft
p p → j X X		SUSY1 (X=gravitino) DM (X=WIMP)	soft
p p → (Y→jX) X		SUSY2 (X=gravitino, Y=gluino/squarks)	hard



ATLAS Preliminary
$\int$ Ldt=10.5fb^{-1}
$\sqrt{s}$ = 8 TeV
data 2012
Total BG
Z (→ νν) + jets
W (→ l ν) + jets
Z (→ ll) + jets
Dibosons
$t\bar{t}$ + single top
ADD n=2, M_D=3 TeV (x5)
D5 M=80GeV, M_*=670GeV (x5)
$\tilde{G}+\tilde{q}/\tilde{g}$, $M_{\tilde{q}/\tilde{g}}$=1TeV, $M_{\tilde{G}}$=10^{-4}eV (x5)
dN/dp_T [Events/GeV]
Data / BG
p_T jet1 [GeV]

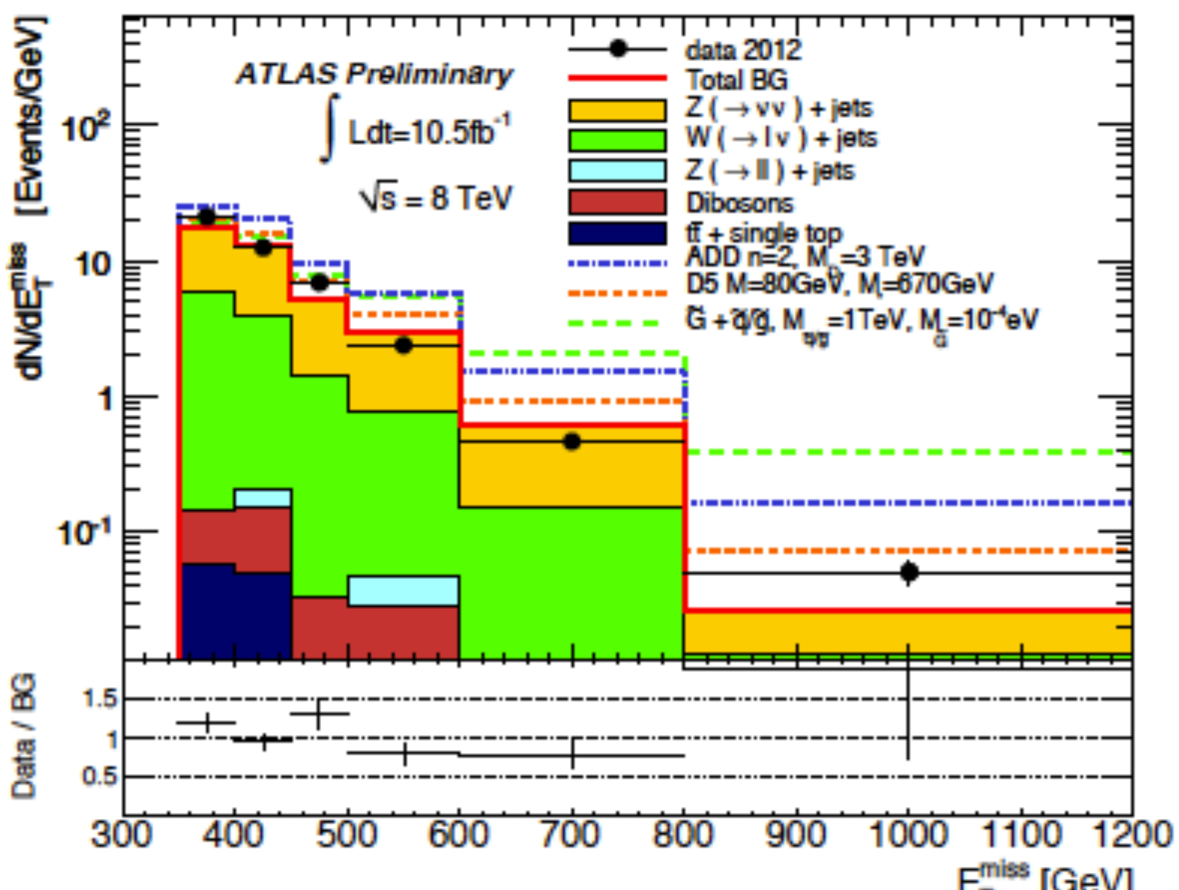
ATLAS-CONF-2012-147

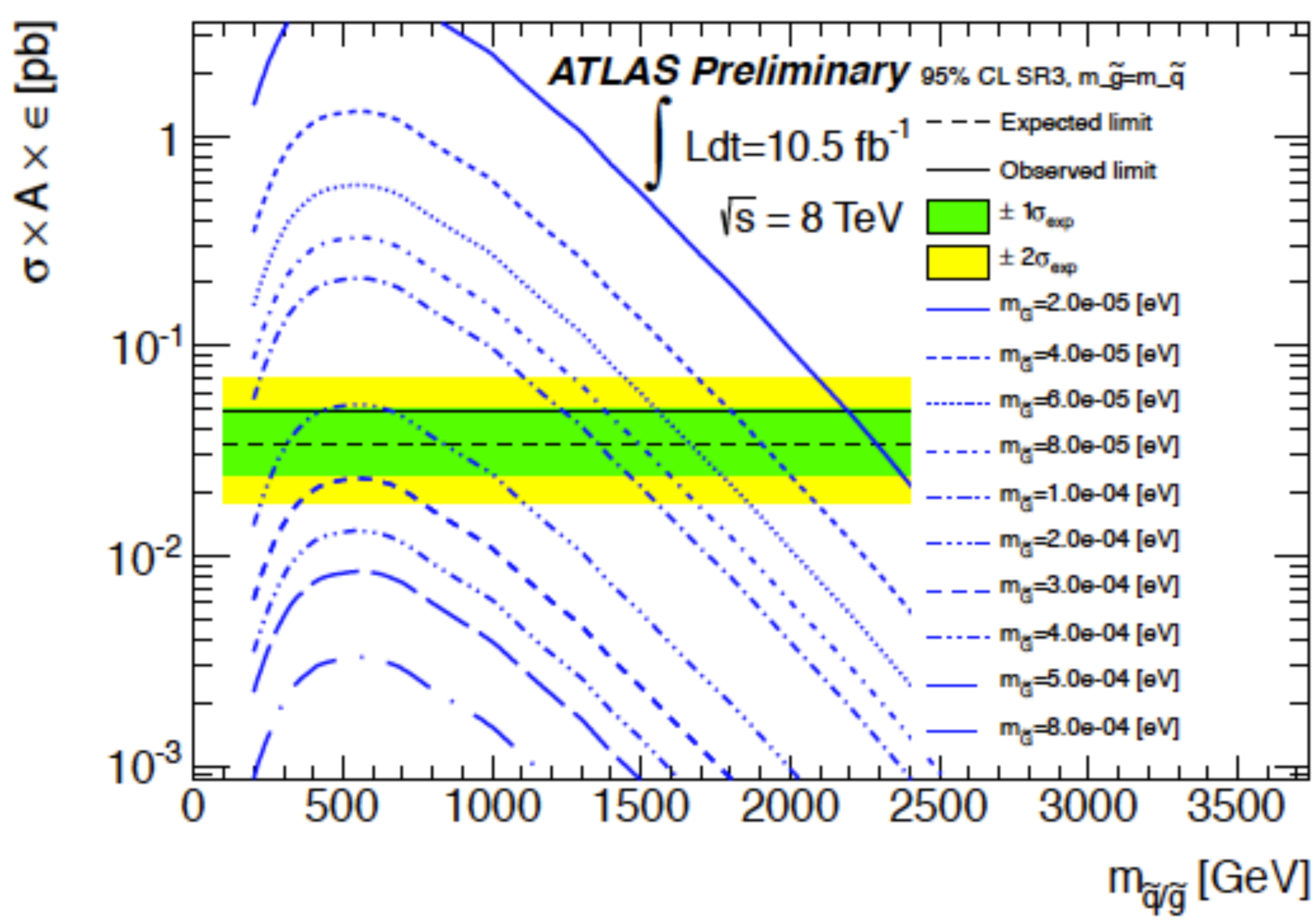
Search for New Phenomena in Monojet plus Missing Transverse Momentum Final States using 10 fb^{-1} of pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector at the LHC

Finally, MC simulated samples for gravitino production in association witn a gluino or a squark in the final state, $p\bar{p} \to \tilde{G}\tilde{g} + X$ and $p\bar{p} \to \tilde{G}\tilde{q} + X$, are generated using LO matrix elements in MADGRAPH [50] interfaced with PYTHIA and using CTEQ6L1 PDFs. The narrow width approximation (NWA) for the

[50] K. Mawatari and Y. Takaesu, *HELAS and MadGraph with goldstinos*, Eur.Phys.J. **C71** (2011) 1640, arXiv:1101.1289 [hep-ph].

$$\sigma(pp \to \tilde{g}\tilde{G}) \propto 1/(M_{\rm Pl}\, m_{3/2})^2$$





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[50] K. Mawatari and Y. Takaesu, *HELAS and MadGraph with goldstinos*, Eur.Phys.J. **C71** (2011) 1640, arXiv:1101.1289 [hep-ph].

models. Gravitino masses below $1\cdot10^{-4}$ eV ($4\cdot10^{-5}$ eV) are excluded at 95% CL for squark/gluino masses of 500 GeV (1.7 TeV). These results significantly improve previous results at LEP and the Tevatron and constitute the best bounds on the gravitino mass to date. For very high squark/gluino masses the NWA

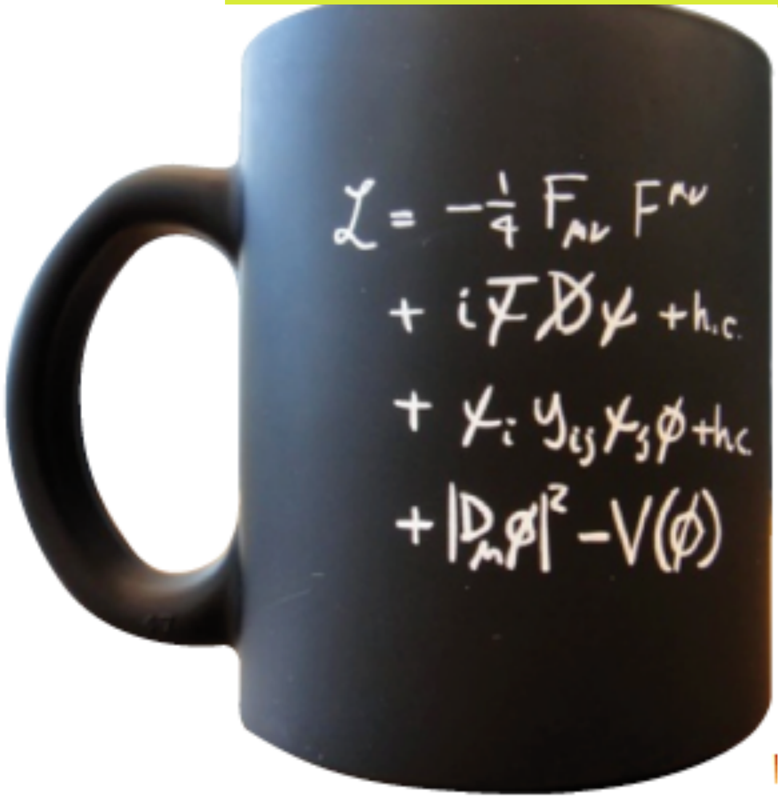
LIGHT $\tilde{G}$ (Gravitino) MASS LIMITS FROM COLLIDER EXPERIMENTS

The following are bounds on light ($\ll$ 1 eV) gravitino indirectly inferred from its coupling to matter suppressed by the gravitino decay constant.

Unless otherwise stated, all limits assume that other supersymmetric particles besides the gravitino are too heavy to be produced. The gravitino is assumed to be undetected and to give rise to a missing energy ($\not{E}$) signature.

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$> 1.09 \times 10^{-5}$	95	[1] ABDALLAH	05B	DLPH	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 1.35 \times 10^{-5}$	95	[2] ACHARD	04E	L3	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 1.3 \times 10^{-5}$		[3] HEISTER	03C	ALEP	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 11.7 \times 10^{-6}$	95	[4] ACOSTA	02H	CDF	$p\bar{p} \to \tilde{G}\tilde{G}\gamma$
$> 8.7 \times 10^{-6}$	95	[5] ABBIENDI,G	00D	OPAL	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 10.0 \times 10^{-6}$	95	[6] ABREU	00Z	DLPH	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 11 \times 10^{-6}$	95	[7] AFFOLDER	00J	CDF	$p\bar{p} \to \tilde{G}\tilde{G}$ +jet

Lagrangian (TH) ⇔ Data (EXP)



FeynRules

UFO model file

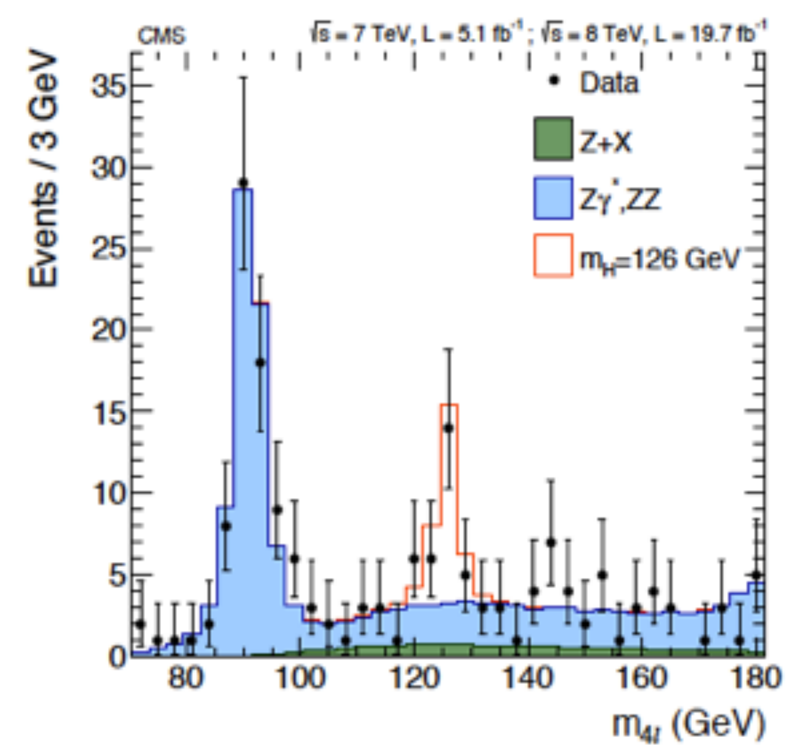
MadGraph5_aMC@NLO
(Herwig, Pythia)

StdHep event file

Delphes

LHCO event file

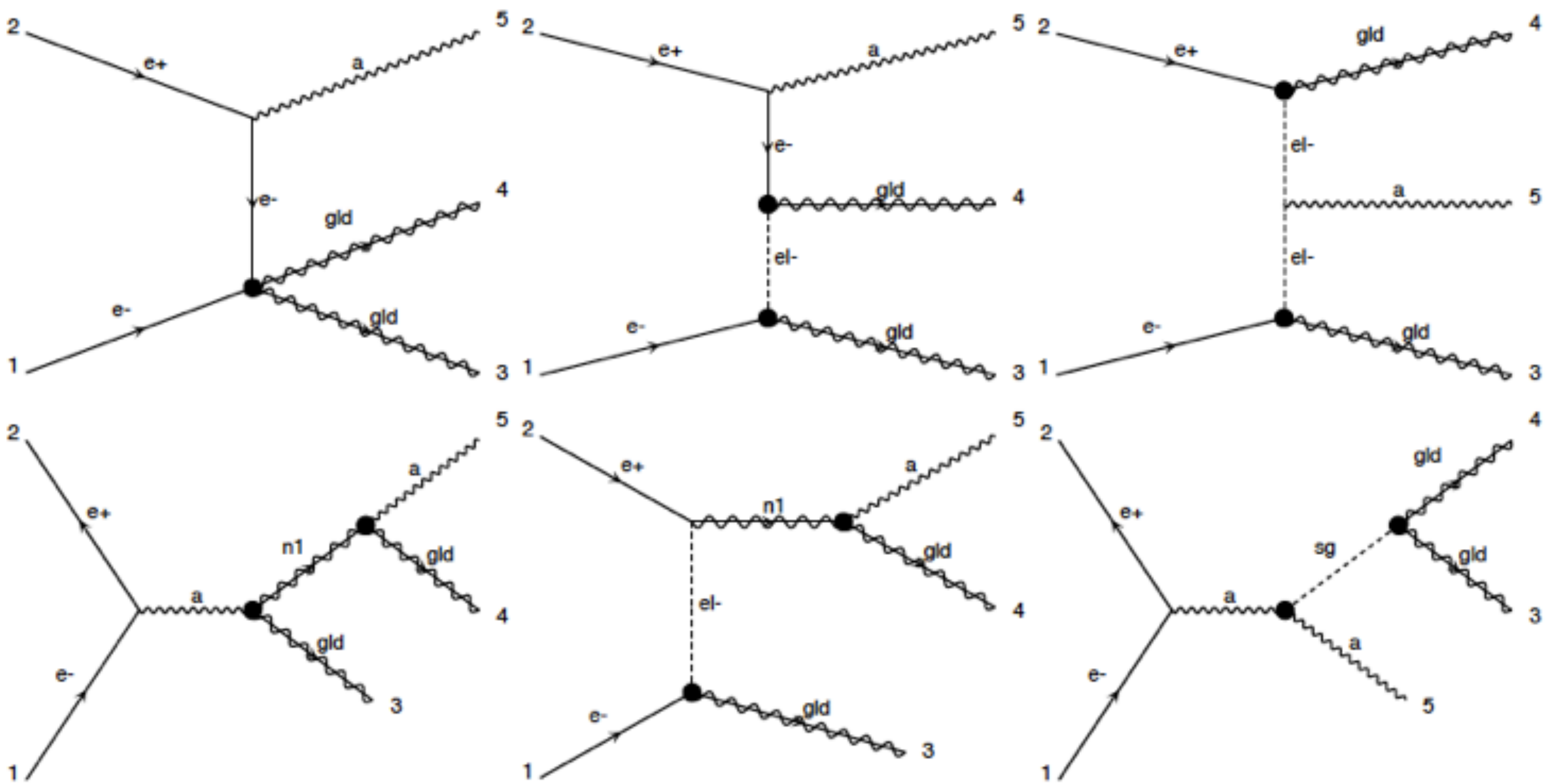
MadAnalysis5



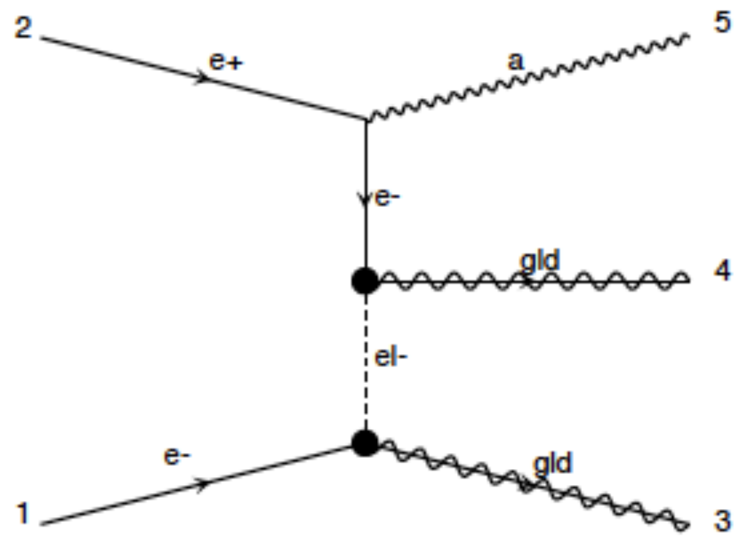
1-min MadGraph5_aMC@NLO tutorial

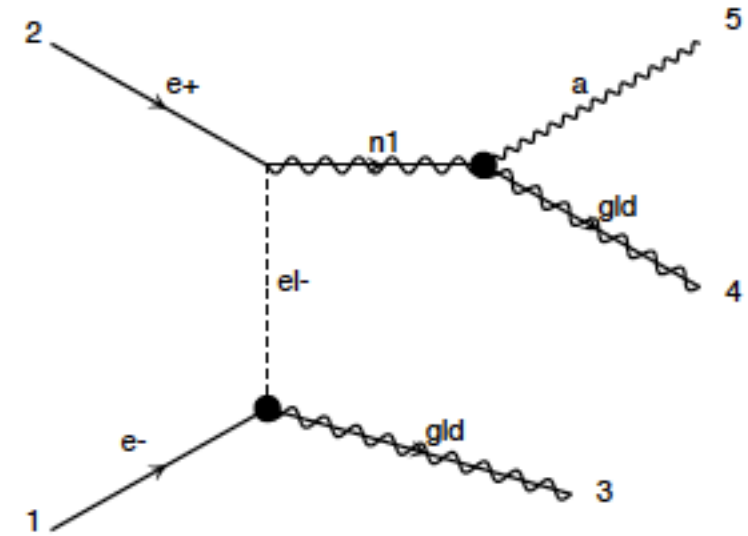
```
./bin/mg5_aMC
>import model mssm-sgld
>generate e+ e- > gld gld a
>output
>launch
```

- Start the MG5_aMC shell
- Import the model
- Generate the process
- Write the code
- Generate the LO/NLO events

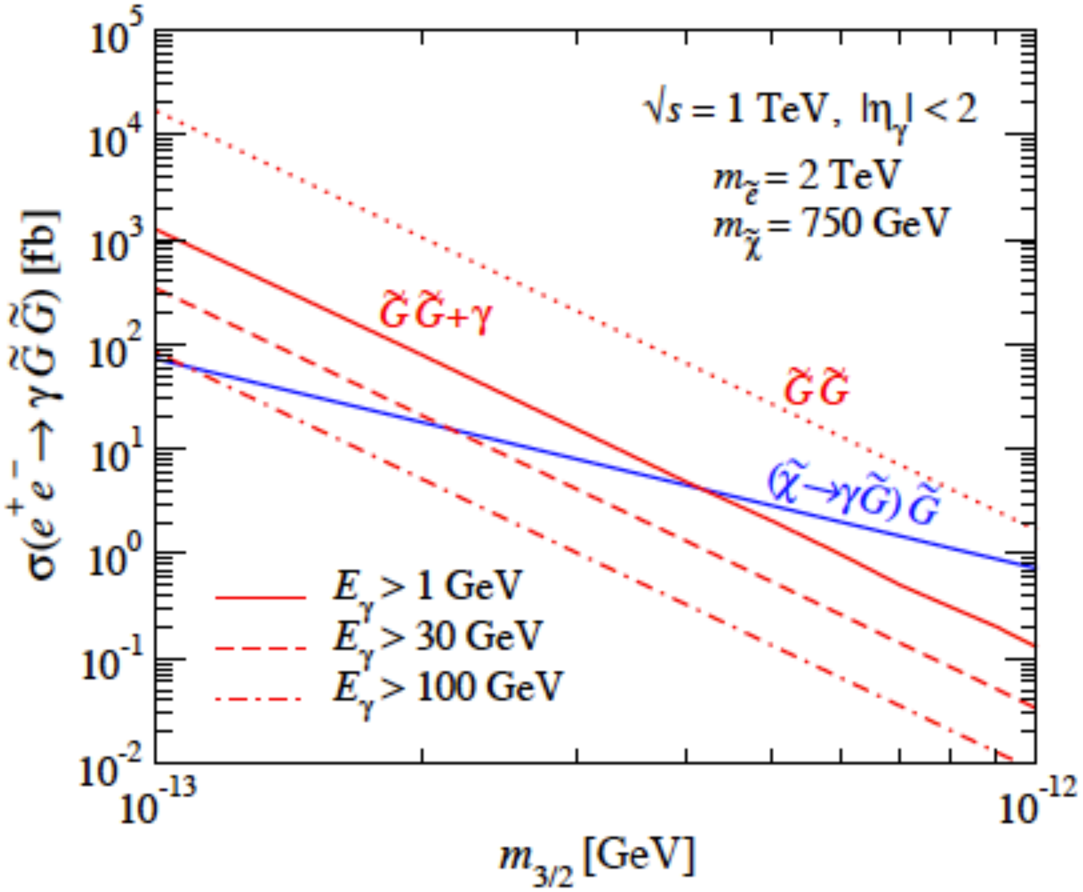


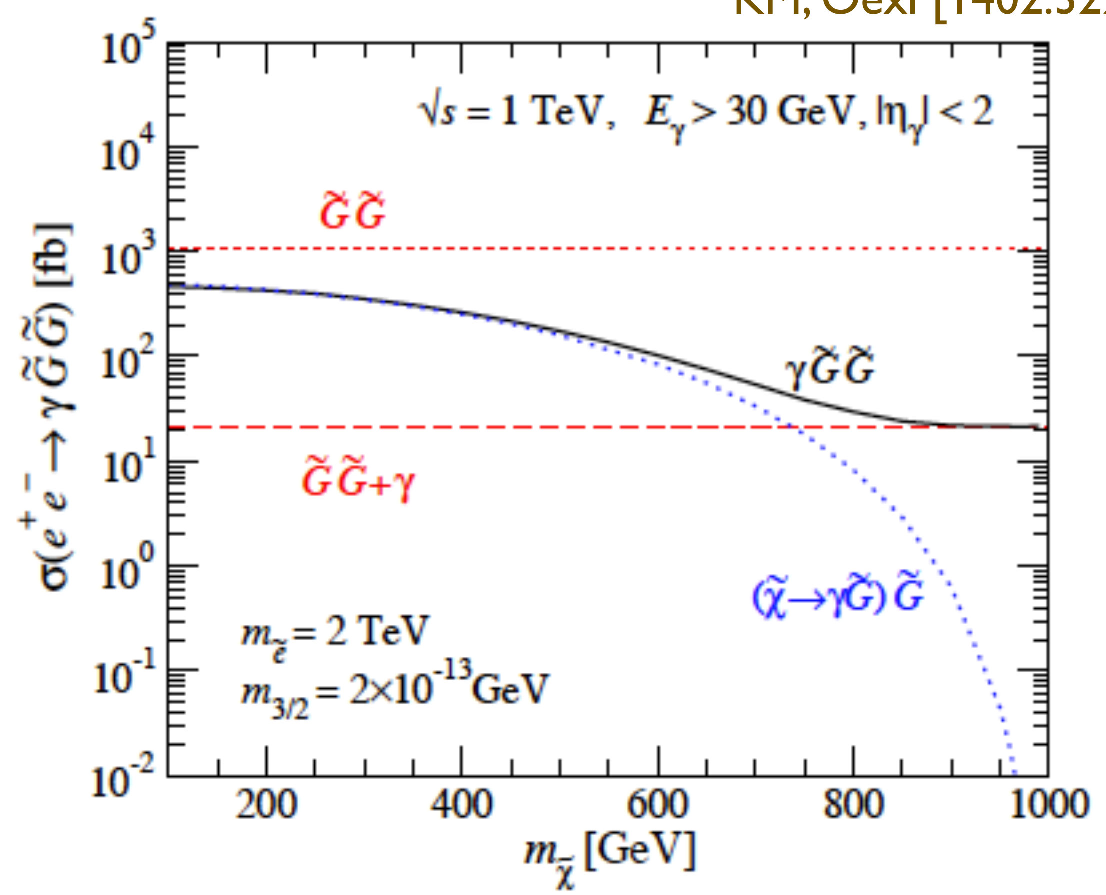
Monophoton+missing energy at the ILC





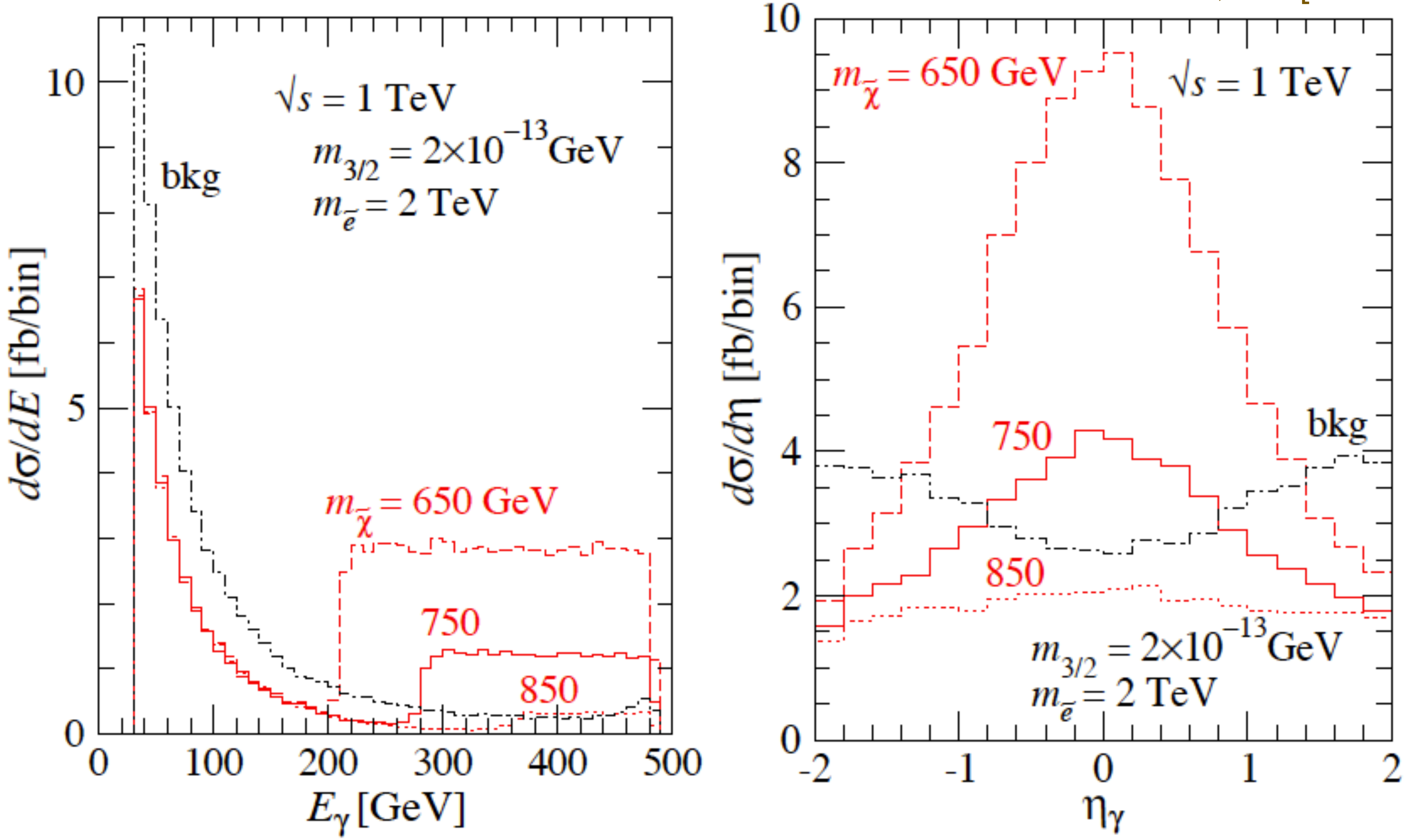
KM, Oexl [1402.3223]





Monophoton+missing energy at the ILC

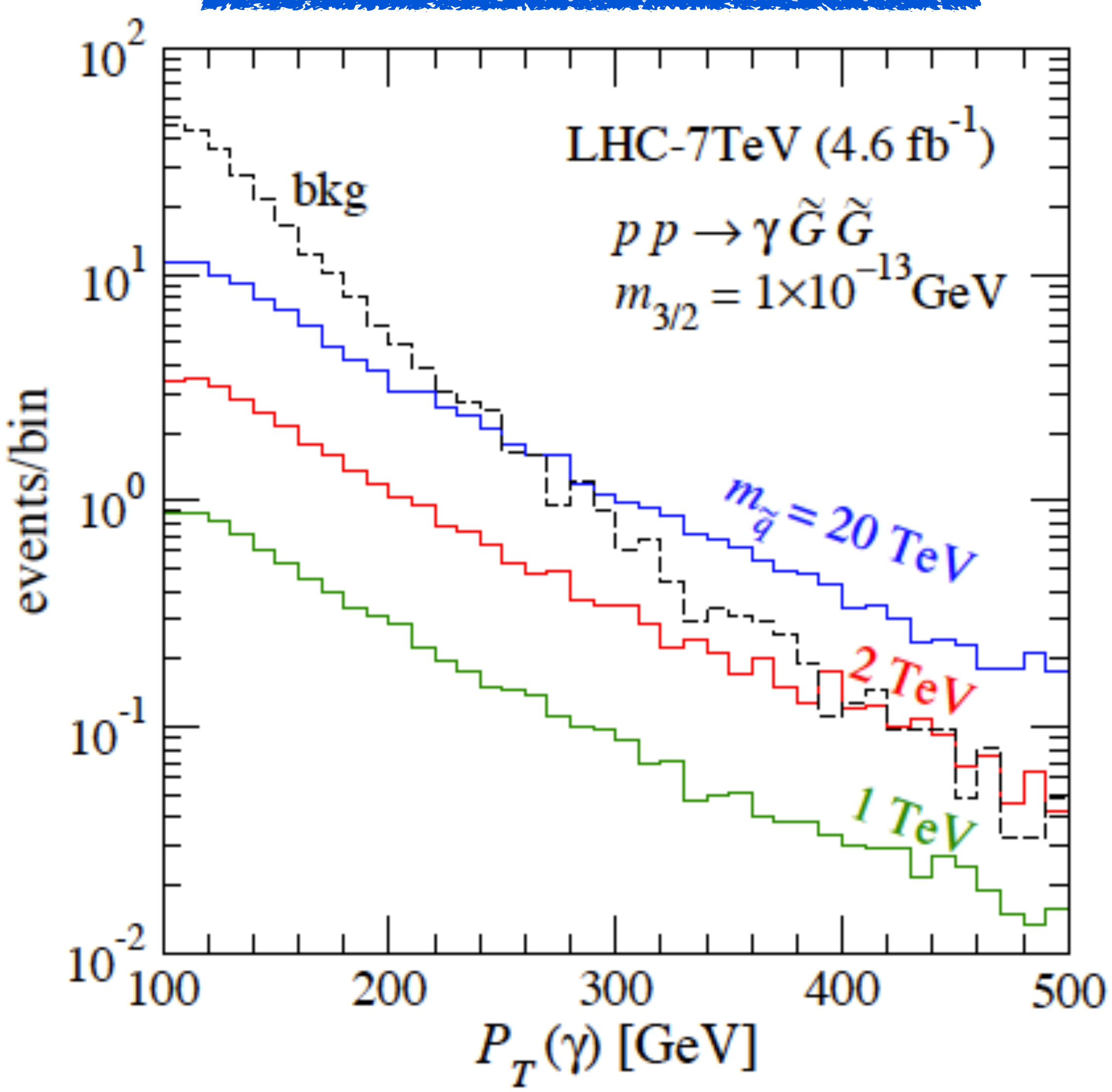
KM, Oexl [1402.3223]

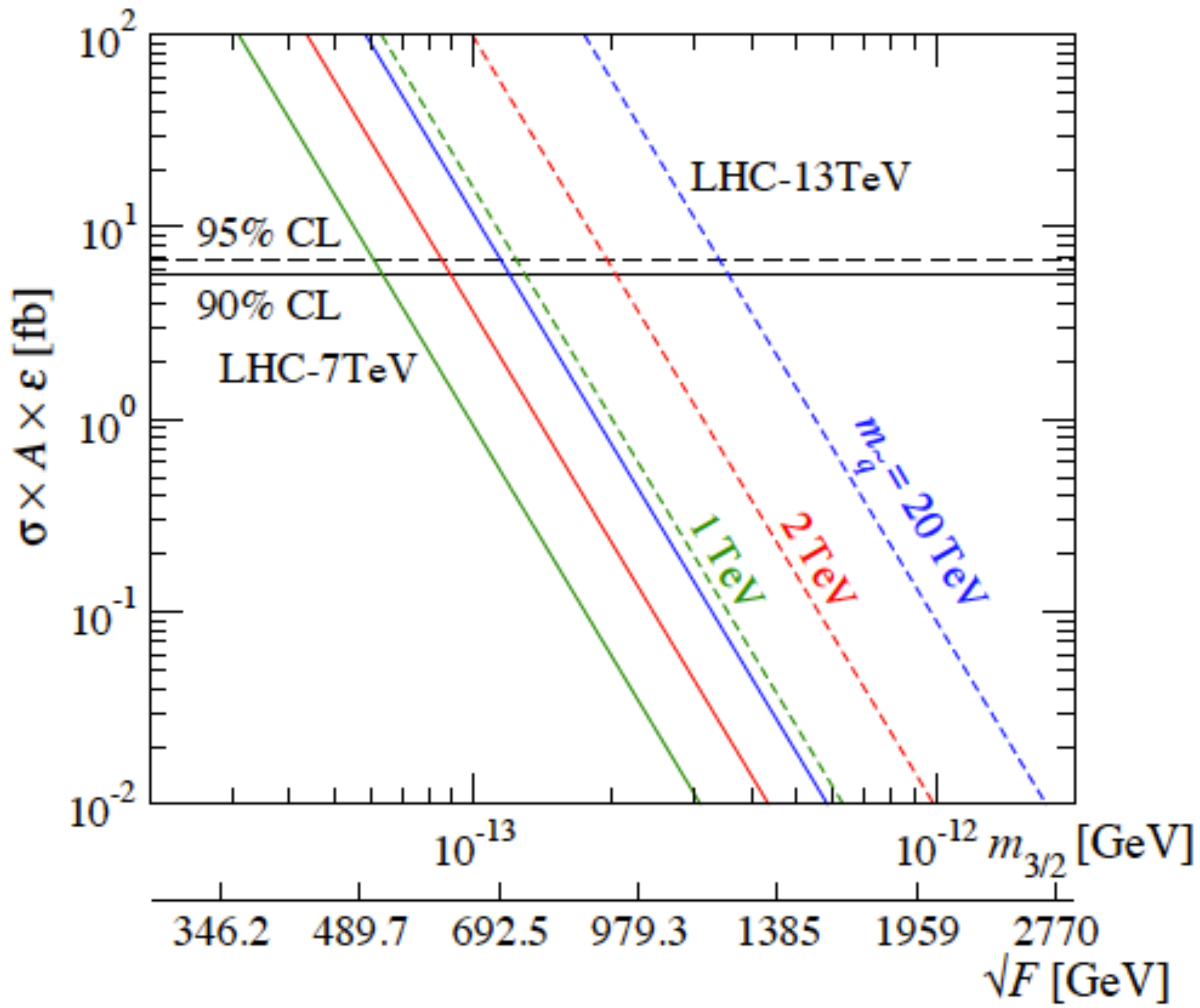


Monophoton+missing energy at the LHC

```
./bin/mg5_aMC
>import model mssm-sgld
>generate p p > gld gld a
>output
>launch
```

Maltoni, Martini, KM, Oexl [in progress]





Summary

- Gravitinos can provide rich phenomenology in particle physics as well as in cosmology, and especially play an important role in collider signatures, especially mono-X signals, when it is the LSP. The phenomenology depends on what the NLSP is.

- The gravitino-related tools have been intensively developed for the last few years, and are ready for gravitino pheno!