Two-photon exclusive production of supersymmetric pairs at LHC

Nicolas Schul

Université catholique de Louvain
Center for Particle Physics and Phenomenology (CP3)

Workshop on HE photon interactions, CERN, April 25th, 2008

UCL
Université catholique de Louvain

N. Schul

OUTLINE

1. The physics of γγ → *pair of charged particle*

2. Supersymmetric pairs:

   - SUSY content
   - LM1 benchmark (slepton)
   - LM9 benchmark (chargino)
   - Sweet Spot (NLSP stau)

   --> Detection and mass measurement for sparticles

$\gamma\gamma$ physics

N. Schul

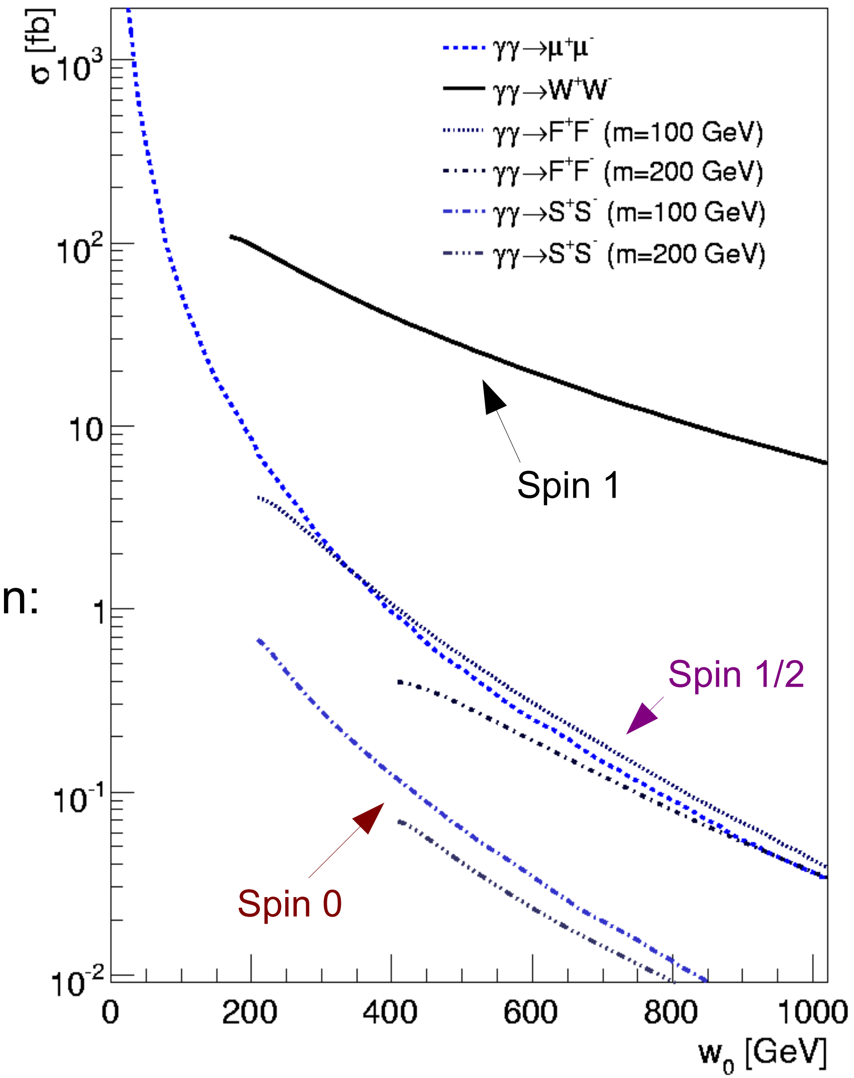
Outline

$\gamma\gamma$ physics

Supersymmetry

$\gamma\gamma$ physics offer an unique and complementary way to study new physics.

Using Madgraph generator with photon spectrum encoded :



Cross sections depend ONLY on:

* mass
* spin
* charge

and can be easily computed

Susy content

Slepton right: $\tilde{e}_R^+$, $\tilde{\mu}_R^+$

Slepton left: $\tilde{e}_L^+$, $\tilde{\mu}_L^+$

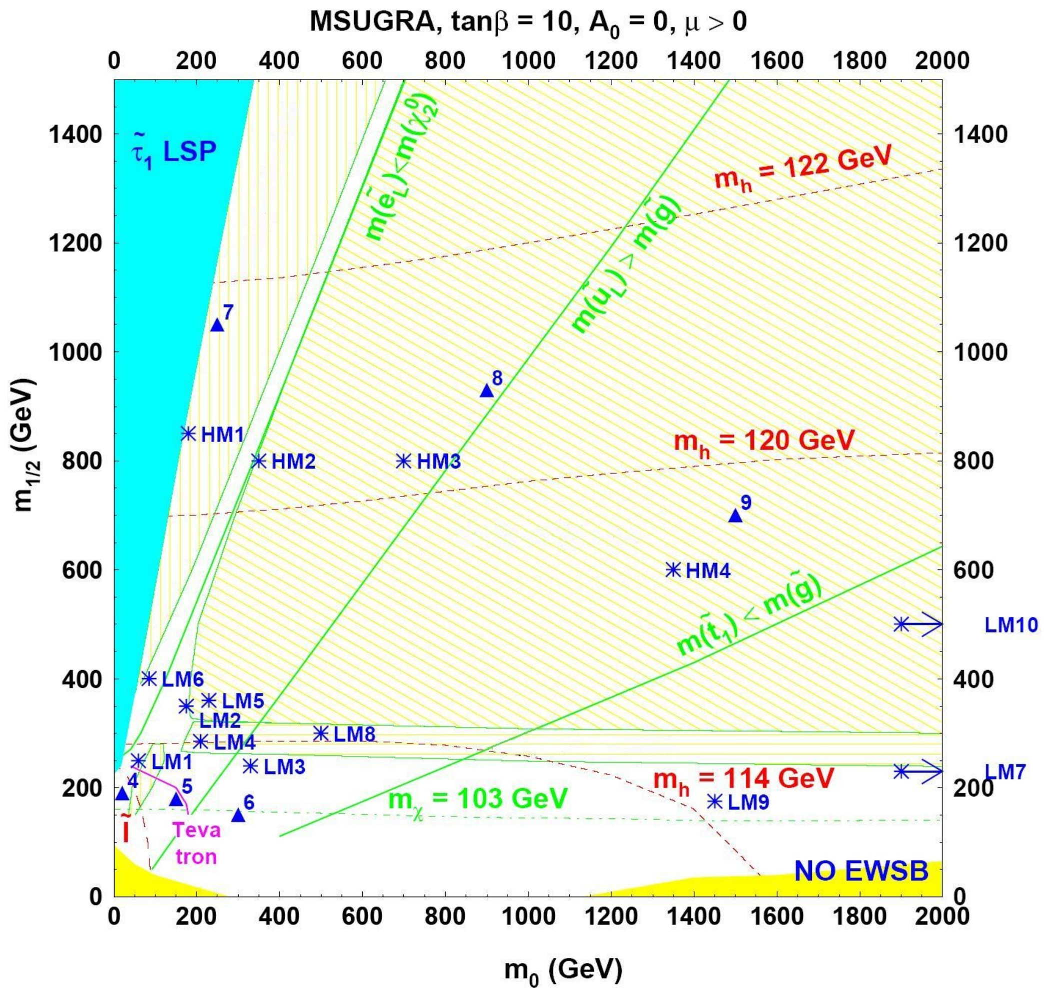
Stau : $\tilde{\tau}_1^+$, $\tilde{\tau}_2^+$

Chargino : $\tilde{\chi}_1^+$, $\tilde{\chi}_2^+$

Higgs : H^+

Neutralino : $\tilde{\chi}^0_{1\to4}$

MSSM plane:



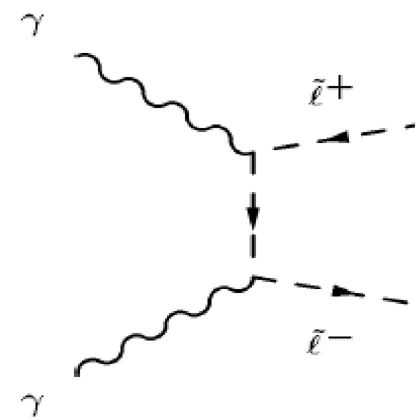
UCL
Université catholique de Louvain

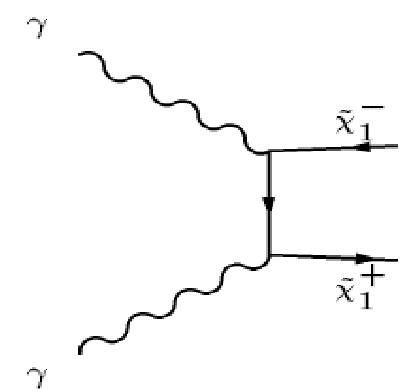
N. Schul

LM1 spectrum

m_0 = 60 GeV, $m_{1/2}$ = 250 GeV, tg(β) = 10, A_0 = 0

Slepton right:	$\sim e_R^+$, $\sim \mu_R^+$	**118 GeV**
Slepton left:	$\sim e_L^+$, $\sim \mu_L^+$	187 GeV
Stau :	$\sim \tau_1^+$, $\sim \tau_2^+$	111 , 190 GeV
Chargino :	$\sim \chi_1^+$, $\sim \chi_2^+$	178 , 360 GeV
Higgs :	H^+	381 GeV
Neutralino :	$\sim \chi^0_{1->4}$	96 -> 369 GeV





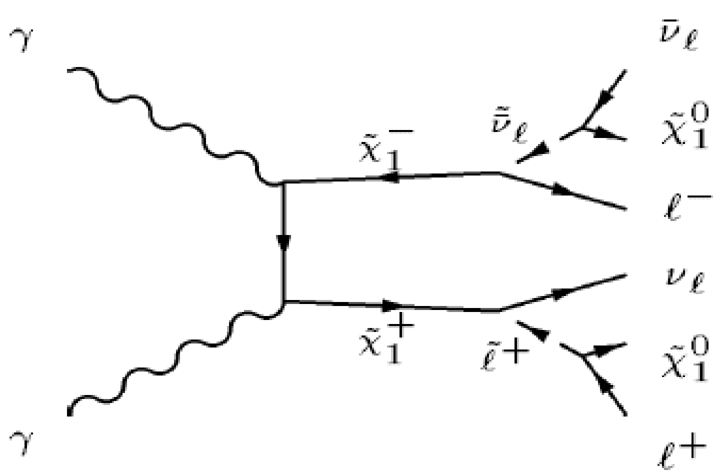
UCL
Université catholique de Louvain

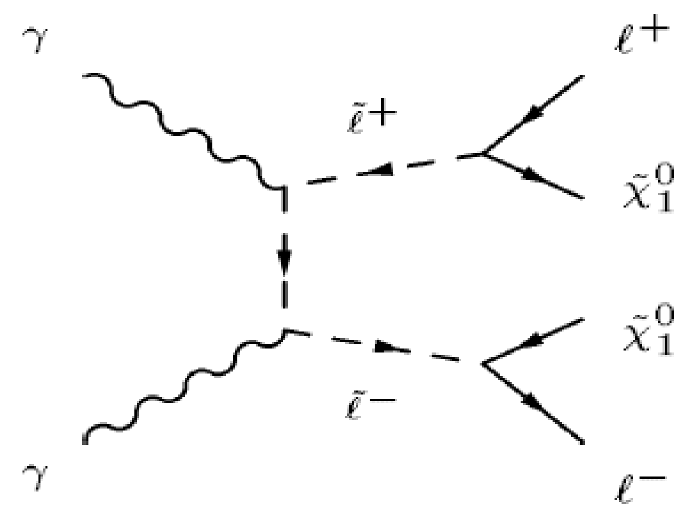
N. Schul

Susy detection

Very clean final state:

2 fwd protons **+** 2 isolated leptons **+** missing energy + ~~acoplanarity~~





Only one irreducible background

$\gamma\gamma \rightarrow W^+ W^- \rightarrow l^+ \nu\, l^- \bar{\nu}$

$\gamma\gamma \rightarrow e^+ e^-$, $\gamma\gamma \rightarrow \mu^+ \mu^-$, $\gamma\gamma \rightarrow \tau^+ \tau^-$

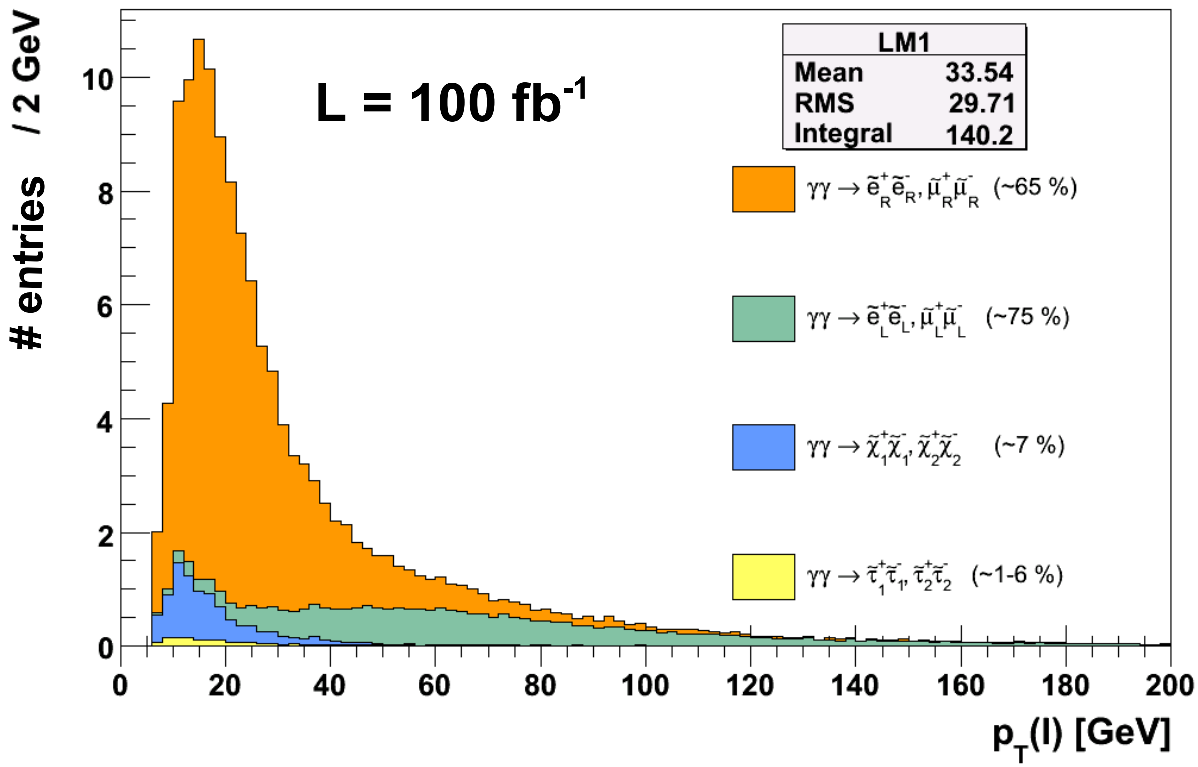
are suppressed because of E_{miss} and acoplanarity

N. Schul

Susy detection

Very clean final state:

2 fwd protons **+** 2 isolated leptons **+** missing energy + ~~acoplanarity~~



Using CalcHEP or MadGraph generator + modified Pythia

<u>Acceptance cuts:</u>

$p_T(e^{+/-}) > 10$ GeV

$p_T(\mu^{+/-}) > 7$ GeV

$|\eta| < 2.5$

σ(LM1 signal) = 2.23 fb --> σ_{acc}(LM1 signal) = 0.707 fb

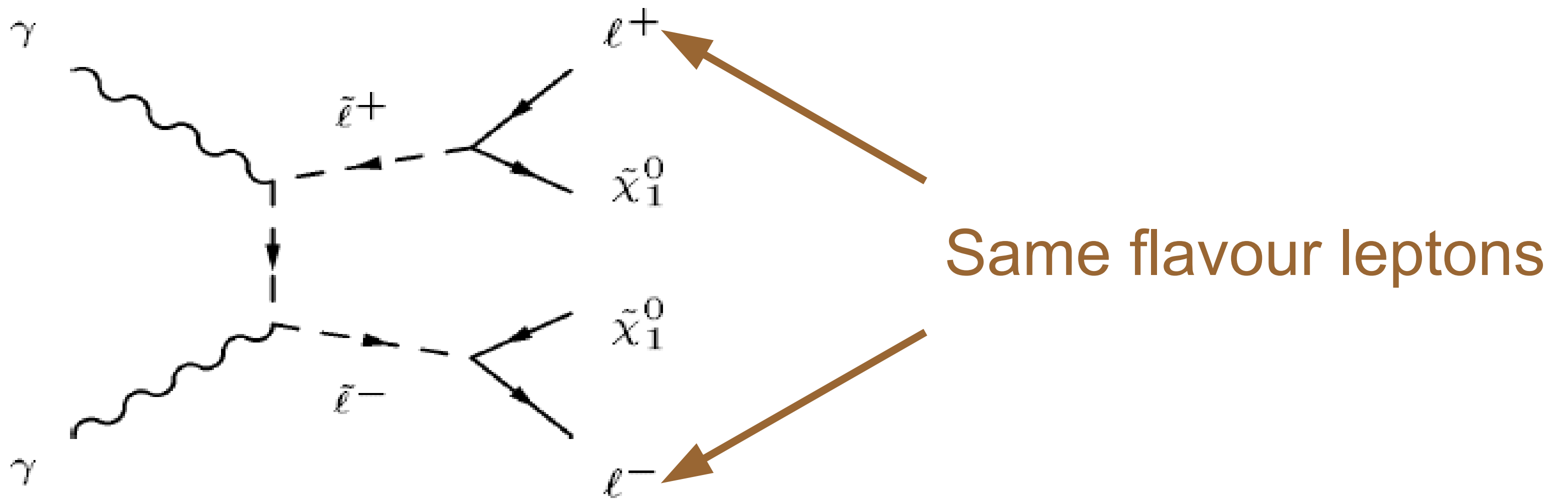
σ(WW bkg) = 108.5 fb --> σ_{acc}(WW bkg) = 3.8 fb

NB: If no tagging, we have to add inelastic contribution --> improved S/B

flavour sharing

N. Schul

Because signal is dominated by $\tilde{e}_R$ and $\tilde{\mu}_R$ contributions:



for LM1, 90% of events are with same flavour leptons

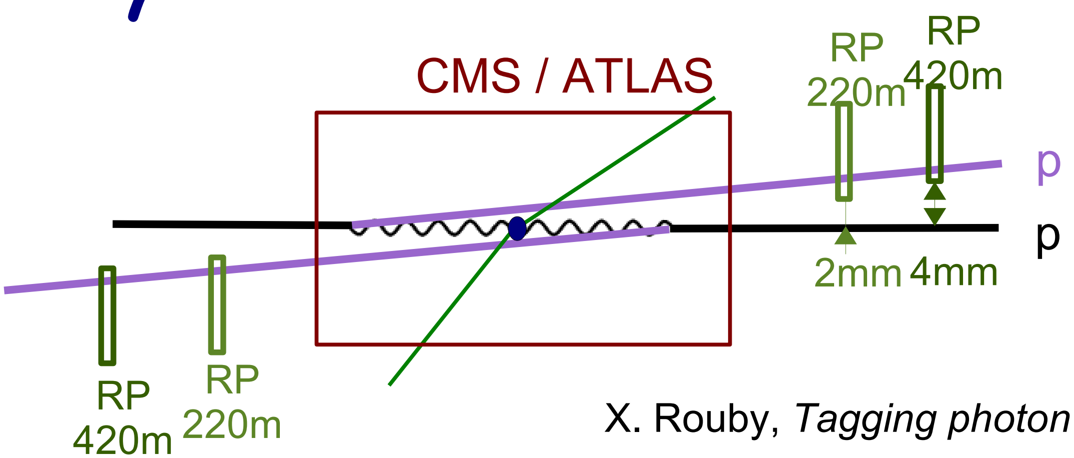
while for WW background:

$W^+W^- \to e^+e^- \nu$'s	25%	$W^+W^- \to e^+\mu^- \nu$'s	25%
$W^+W^- \to \mu^+\mu^- \nu$'s	25%	$W^+W^- \to \mu^+e^- \nu$'s	25%

UCL
Université catholique de Louvain
N. Schul

Very Forward Detectors

- Principle



X. Rouby, *Tagging photon interactions*

- Two-photon invariant mass :

$$W_{\gamma\gamma} = 2\sqrt{\omega_1 \omega_2}$$

Center of mass energy in γγ system

- Missing energy :

$$E_{miss} = \omega_1 + \omega_2 - E_{\ell_1} - E_{\ell_2}$$

Energy carried away by neutrinos and neutralinos

- Missing invariant mass :

$$W_{miss} = \sqrt{E^2_{miss} - P^2_{miss}}$$

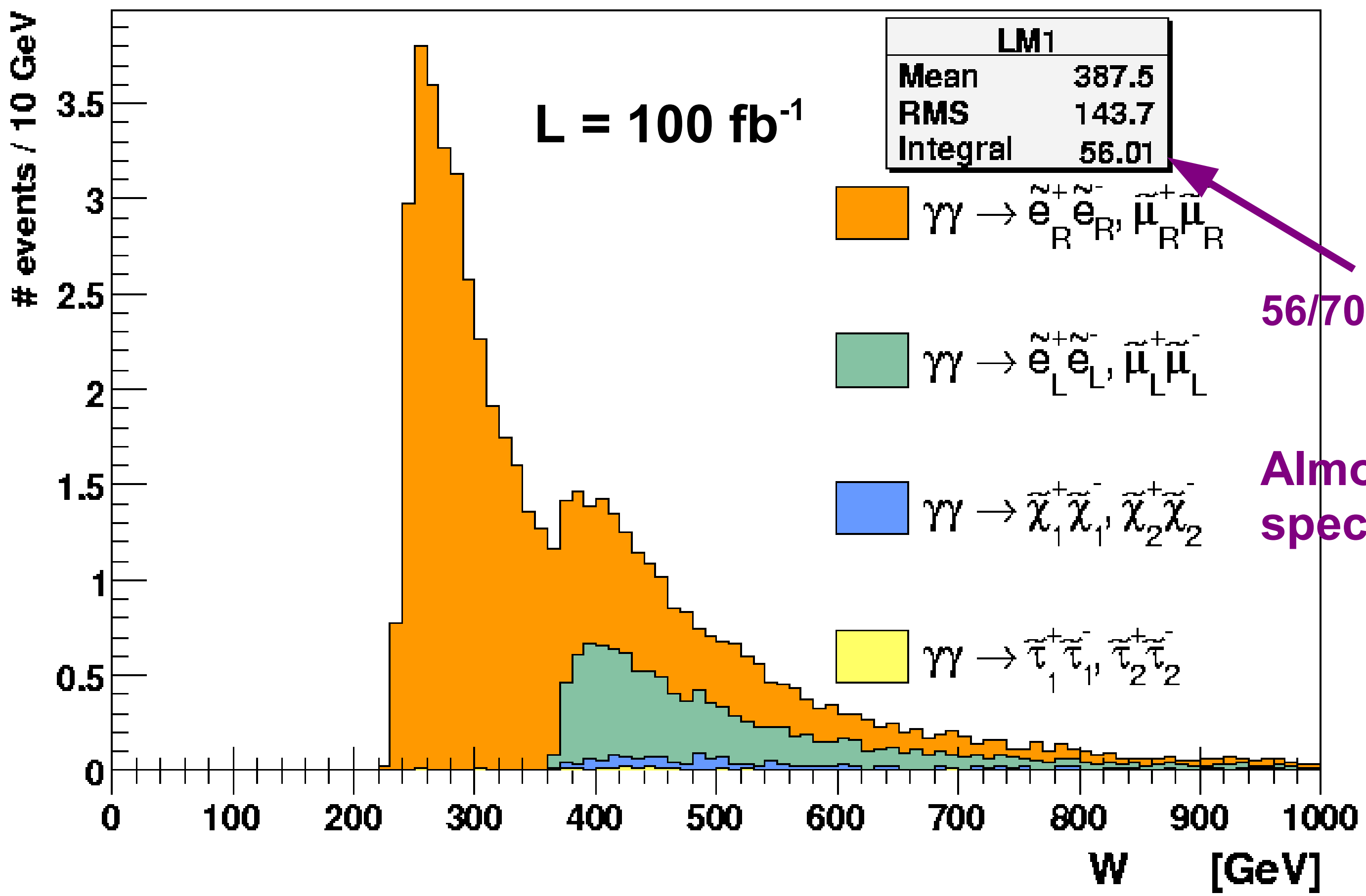
Missing mass
--> better bkg rejection

N. Schul

γγ invariant mass

$$W_{\gamma\gamma} = 2\sqrt{\omega_1\omega_2}$$

Assume **smearing** of proton energy :
Gaussian, max(0.01 E_p, 1.5 GeV)



56/70 = 80%
= double tag ε

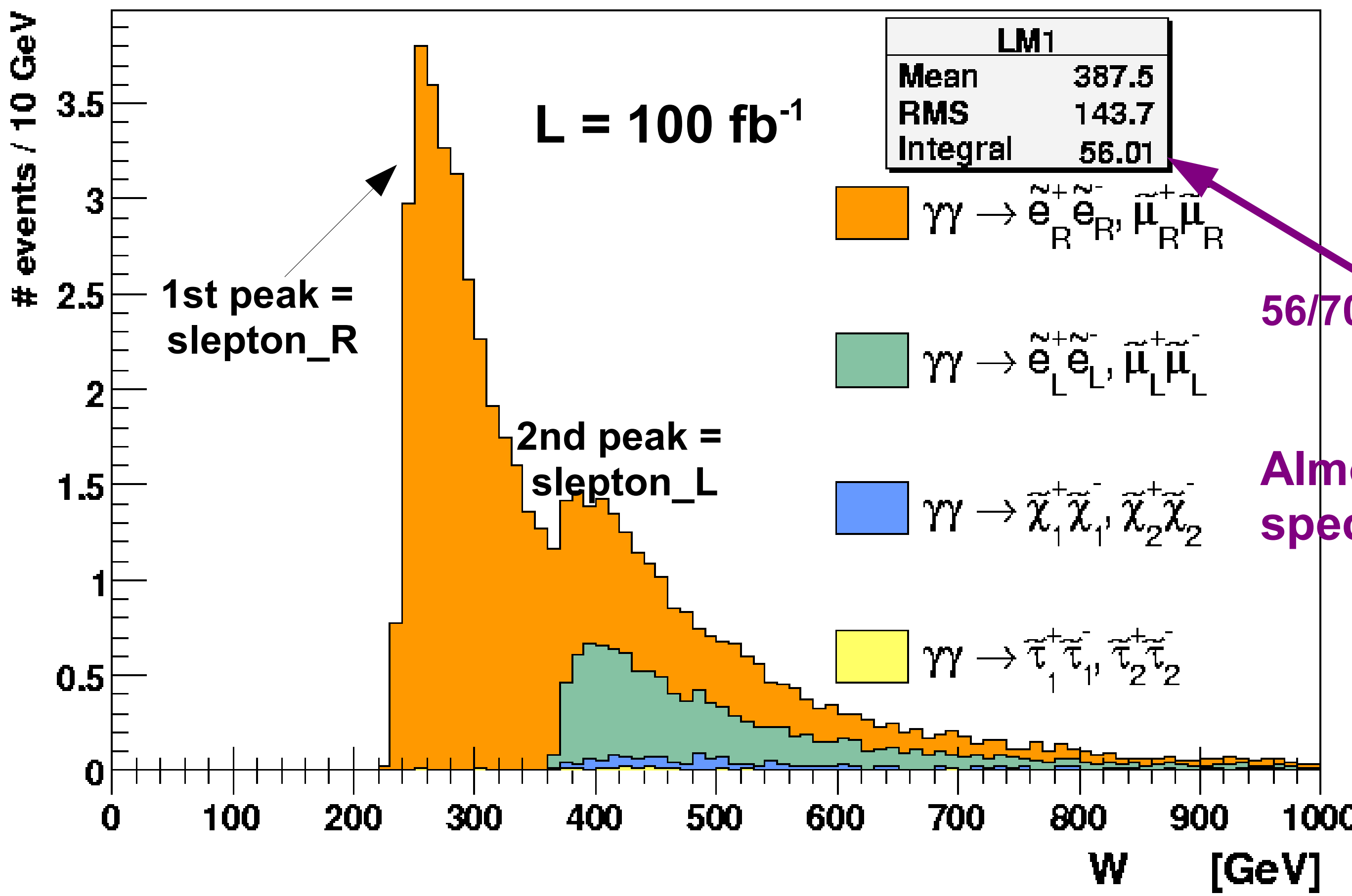
Almost all the photon spectrum is probed

N. Schul

γγ invariant mass

$$W_{\gamma\gamma} = 2\sqrt{\omega_1 \omega_2}$$

Assume **smearing** of proton energy :
Gaussian, max(0.01 E_p, 1.5 GeV)



56/70 = 80%
= double tag ε

Almost all the photon spectrum is probed

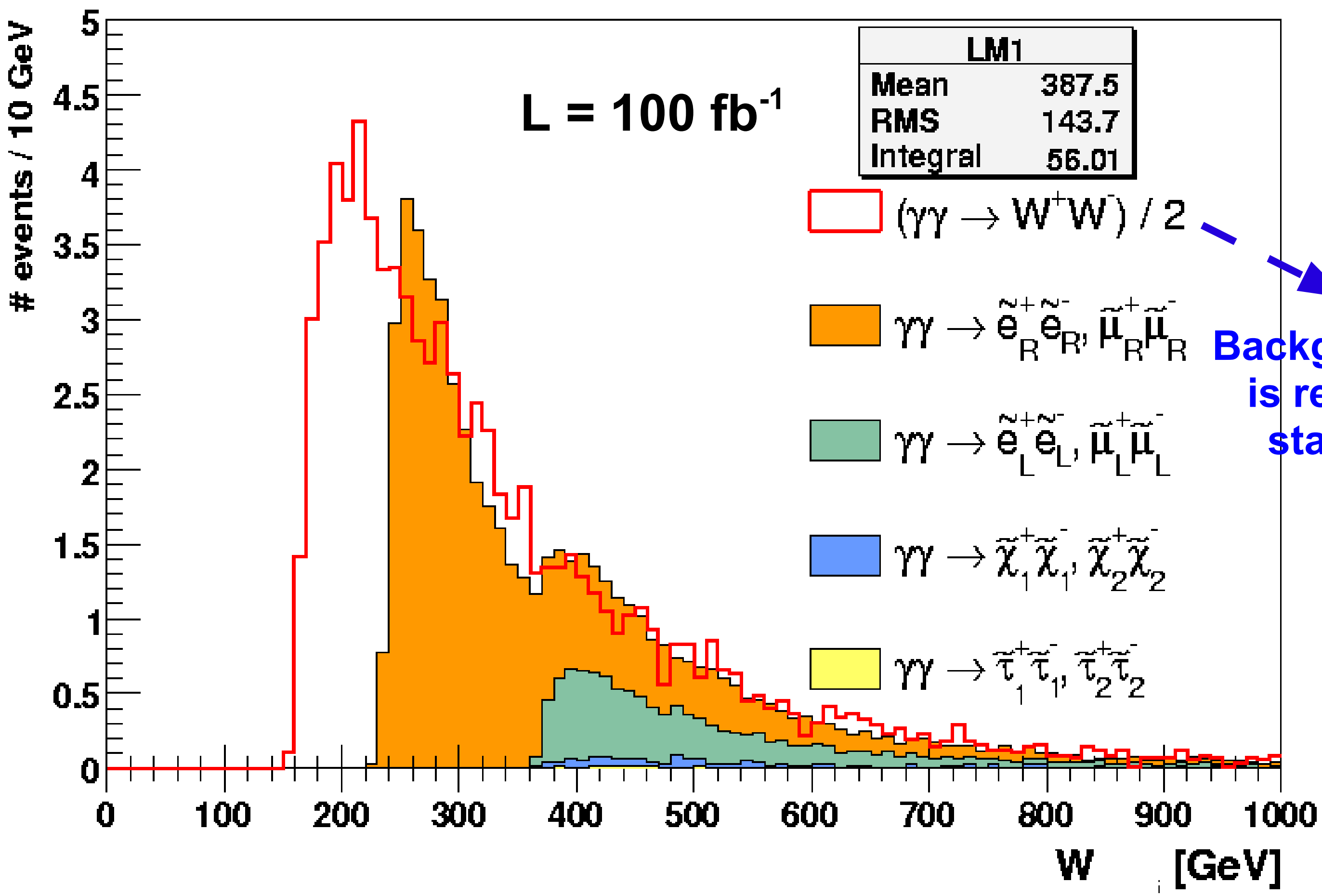
Allow for Right and Left slepton masses determination !

Just have to wait for enough statistic

γγ invariant mass

$$W_{\gamma\gamma} = 2\sqrt{\omega_1\omega_2}$$

Assume **smearing** of proton energy :
Gaussian, max(0.01 E_p, 1.5 GeV)



Background distribution is rescaled to similar statistics as signal

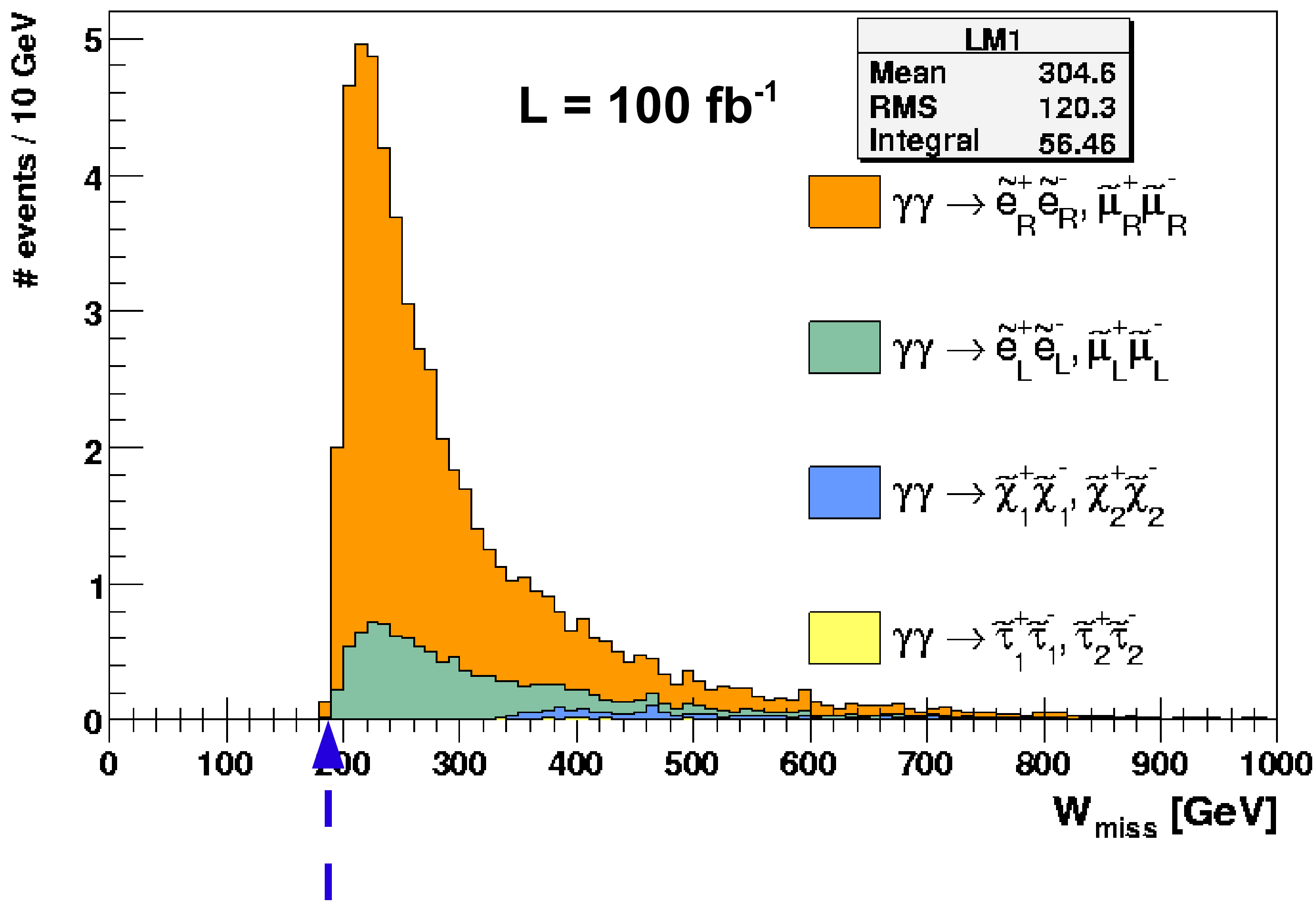
Allow for background rejection !

missing invariant mass

N. Schul

$$E_{miss} = \omega_1 + \omega_2 - E_{\ell_1} - E_{\ell_2}$$

Assume **smearing** of proton energy :
Gaussian, max(0.01 E_p, 1.5 GeV)



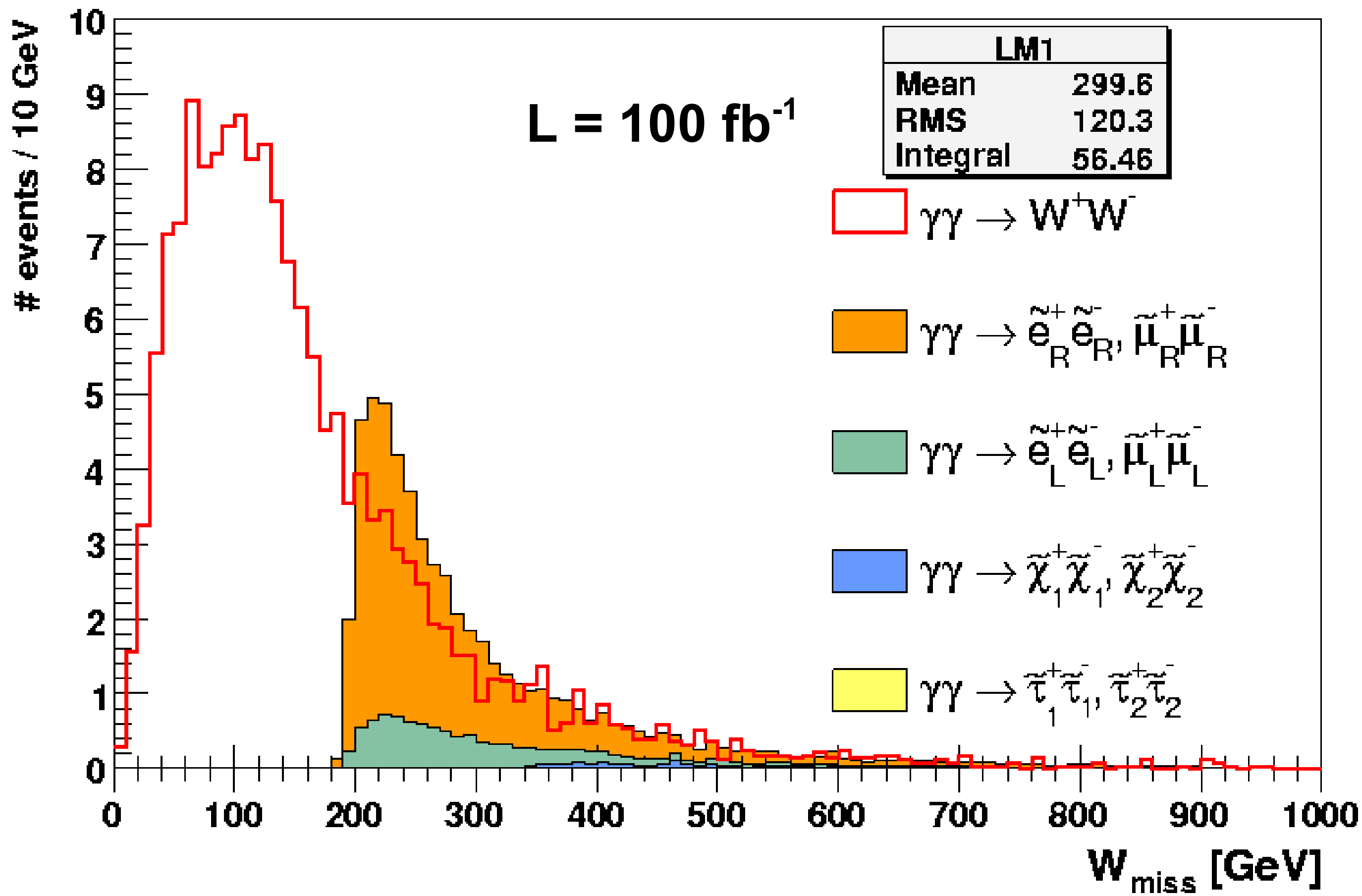
Allow for LSP mass determination !

missing invariant mass

N. Schul

$$E_{miss} = \omega_1 + \omega_2 - E_{\ell_1} - E_{\ell_2}$$

Assume **smearing** of proton energy :
Gaussian, max(0.01 E_p, 1.5 GeV)



Allow for (large) background rejection !

Significance

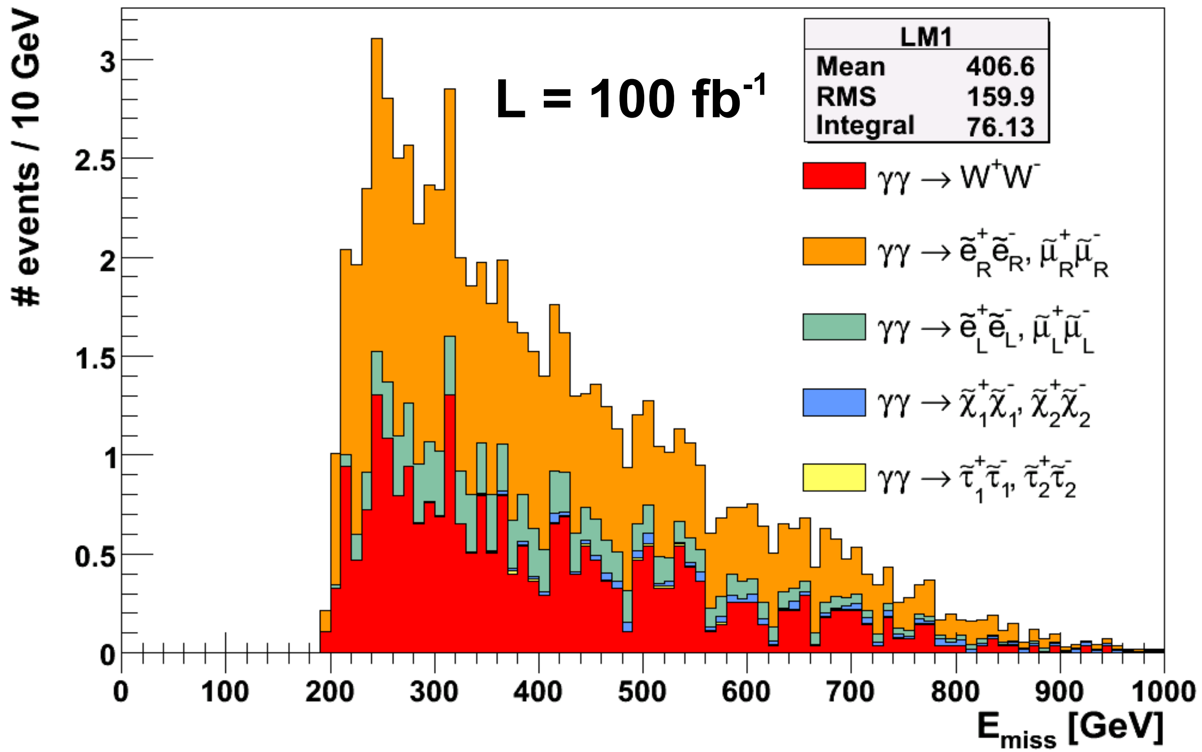
N. Schul

Outline
γγ physics
Supersymmetry
LM1
detection
VFD
significance
mass
LM9
Sweet Spot

$W_{\gamma\gamma}$ + W_{miss} + kinematic cuts on Δη, ΔR + flavour :

σ(LM1 signal) = 2.23 fb --> $\sigma_{acc+cut}$(LM1 signal) = 0.508 fb

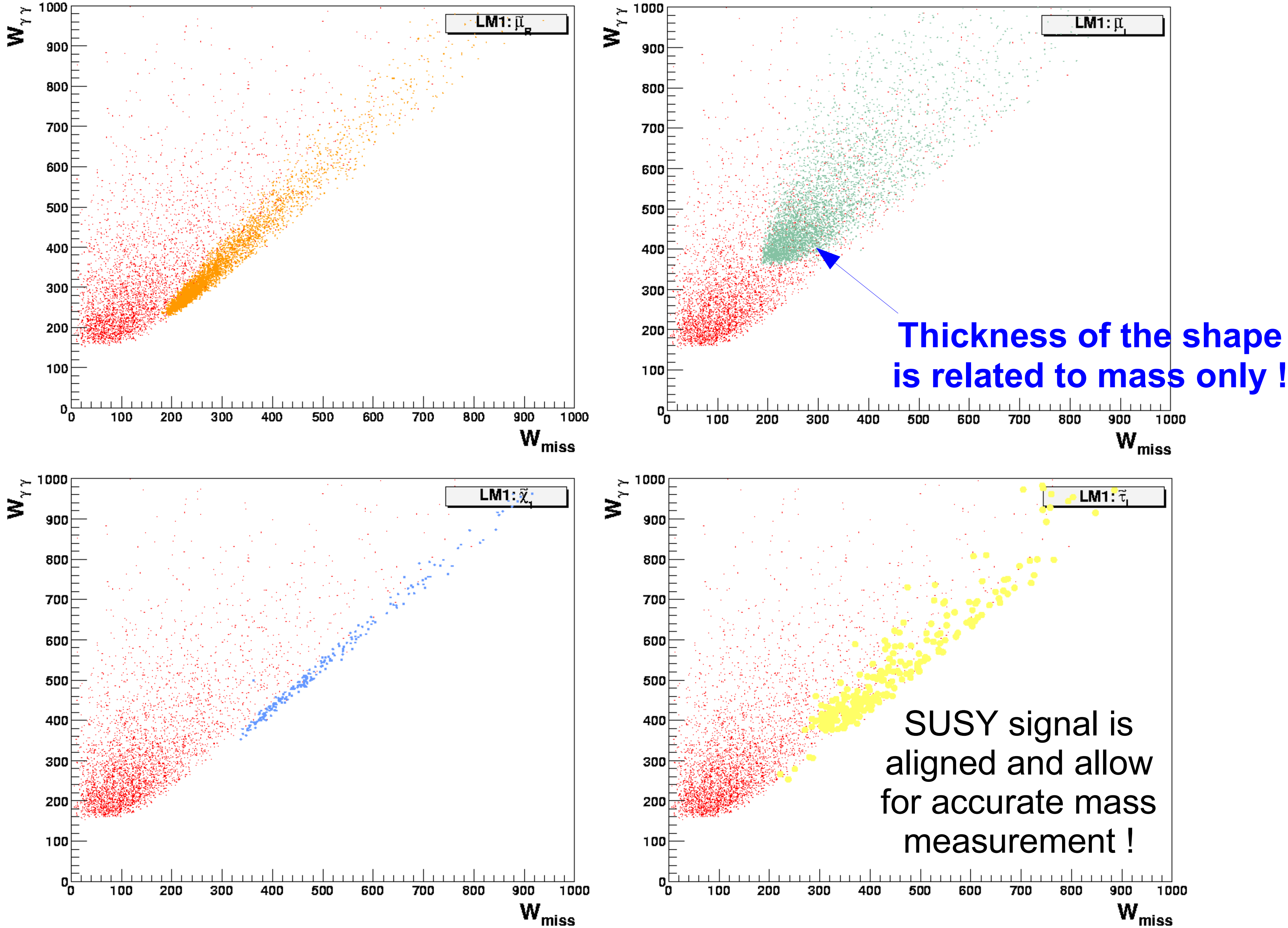
σ(WW bkg) = 108.5 fb --> $\sigma_{acc+cut}$(WW bkg) = 0.255 fb



==> 5 σ detection after L = 25 fb^{-1}

N. Schul

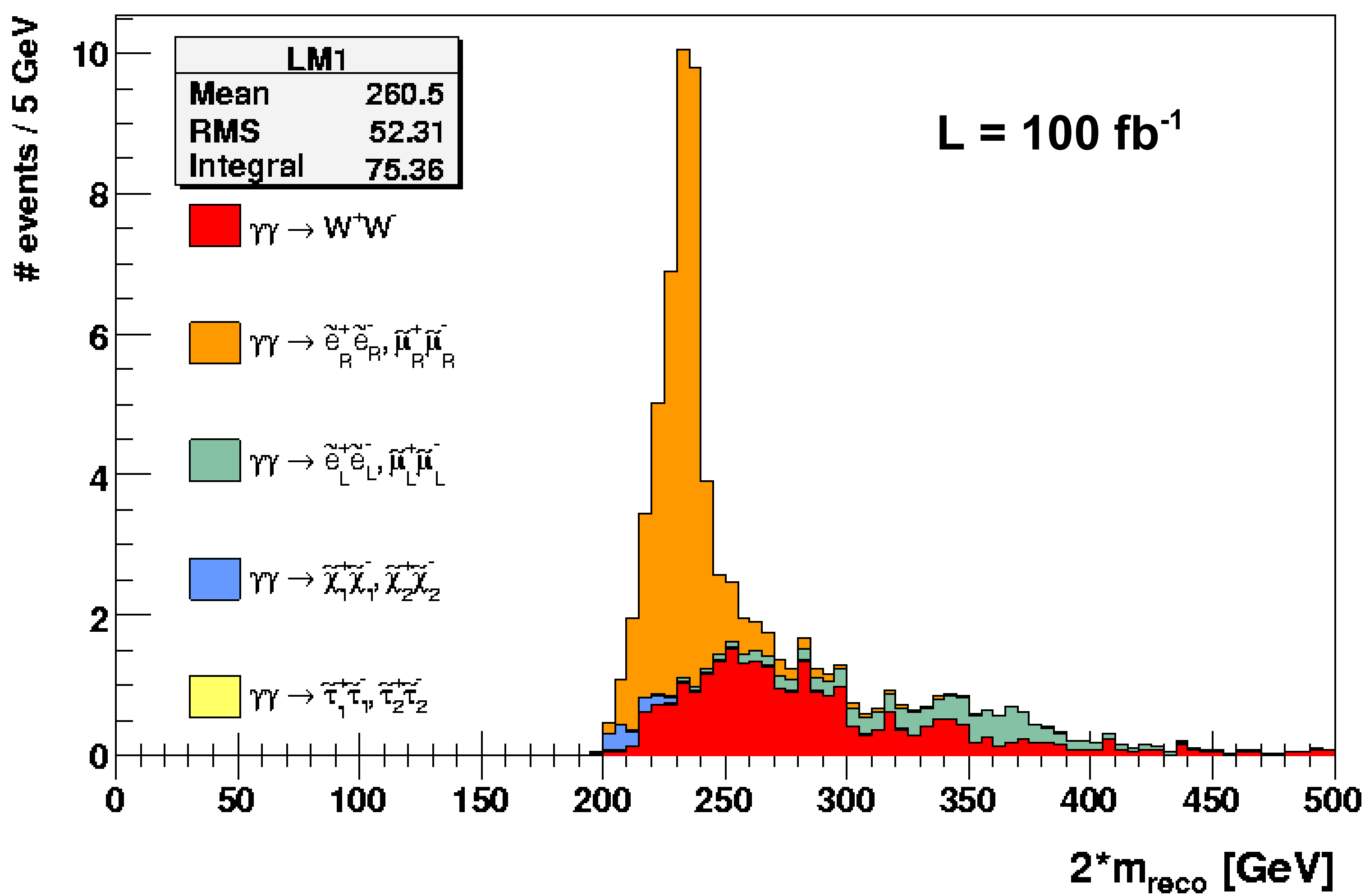
Mass measurement



N. Schul

Mass measurement

$$(2m)^2 = W_{\gamma\gamma}^2 - \left([W_{miss}^2 - 4m_{\tilde{\chi}_1^0}^2]^{1/2} + [W_{lep}^2 - 4m_{lep}^2]^{1/2}\right)^2$$



==> mass determination with few GeV resolution

UCL
Université catholique de Louvain

N. Schul

LM1 benchmark

- Light supersymmetry (right slepton ~120 GeV)
- Very clean final state, easy to detect with high resolution
- Significant cross section after acceptance cuts $\sigma \sim 1$ fb
- High background rejection possibilities (Wγγ, W_{miss}, kinematics, ...)
- Detection of LM1 sleptons after 25 fb^{-1} integrated luminosity
- Two-photon physics give a possibility to specify SUSY scheme
- VFD needed for precise mass measurement (LSP and charged sparticles)
- Same analysis can be done for similar points (LM2, LM4, LM6)

LM9 spectrum

m_0 = 1450 GeV, $m_{1/2}$ = 175 GeV, tg(β) = 50, A_0 = 0

Slepton right:	$\sim e_R^+$, $\sim\mu_R^+$	1450 GeV
Slepton left:	$\sim e_L^+$, $\sim\mu_L^+$	1450 GeV
Stau :	$\sim\tau_1^+$, $\sim\tau_2^+$	1054 , 1267 GeV
Chargino :	$\sim\chi_1^+$, $\sim\chi_2^+$	107 , 223 GeV
Higgs :	H^+	495 GeV
Neutralino :	$\sim\chi^0_{1->4}$	65 -> 224 GeV

} no contribution (Slepton right, Slepton left, Stau)

N. Schul

N. Schul

Outline

γγ physics

Supersymmetry

LM1

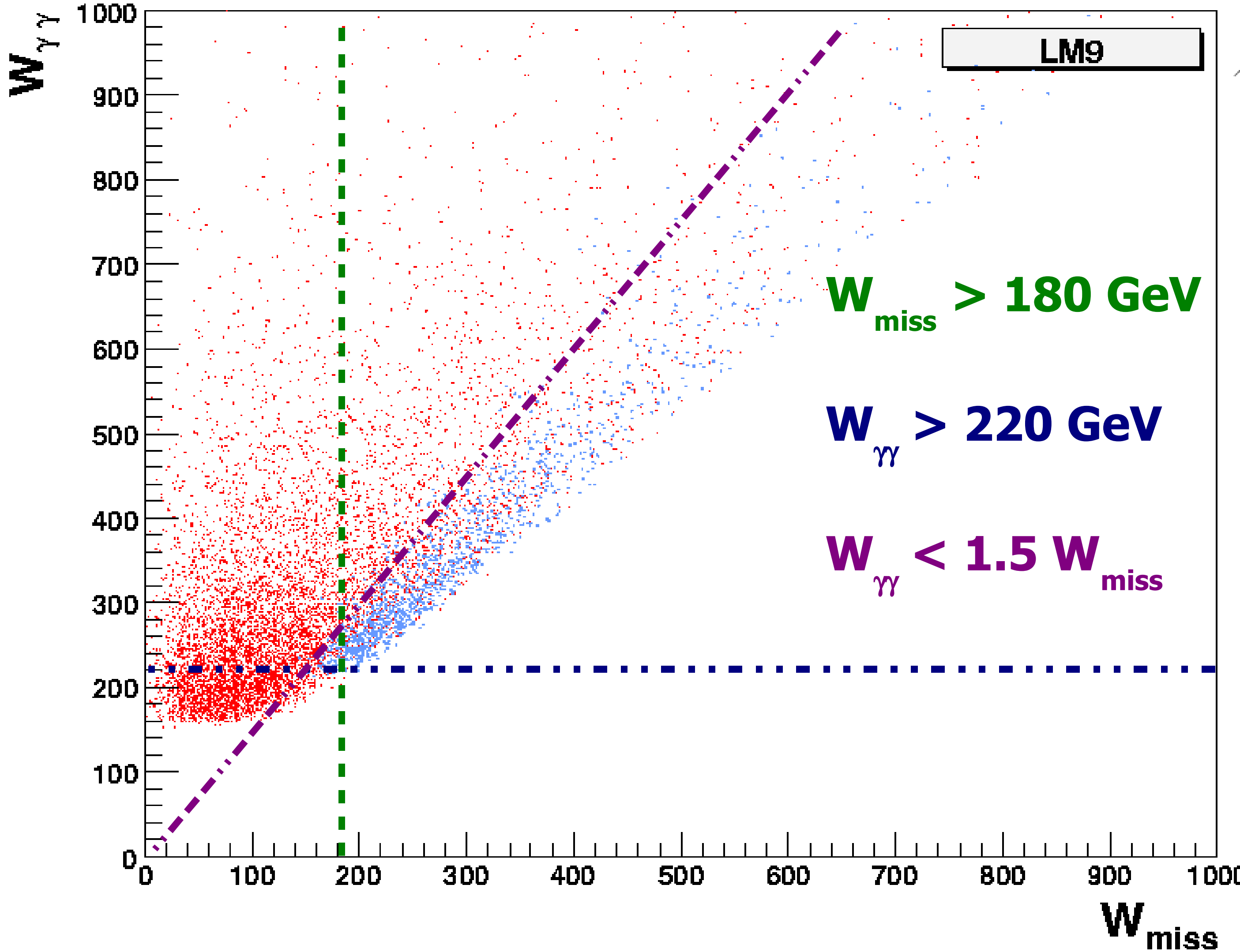
LM9

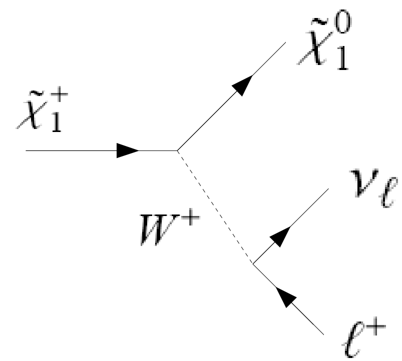
VFD

results

Sweet Spot

$W_{\gamma\gamma}$ and W_{miss}





Acceptance cuts:

$p_T(e^{+/-})$ > 10 GeV

$p_T(\mu^{+/-})$ > 7 GeV

$|\eta|$ < 2.5

Results

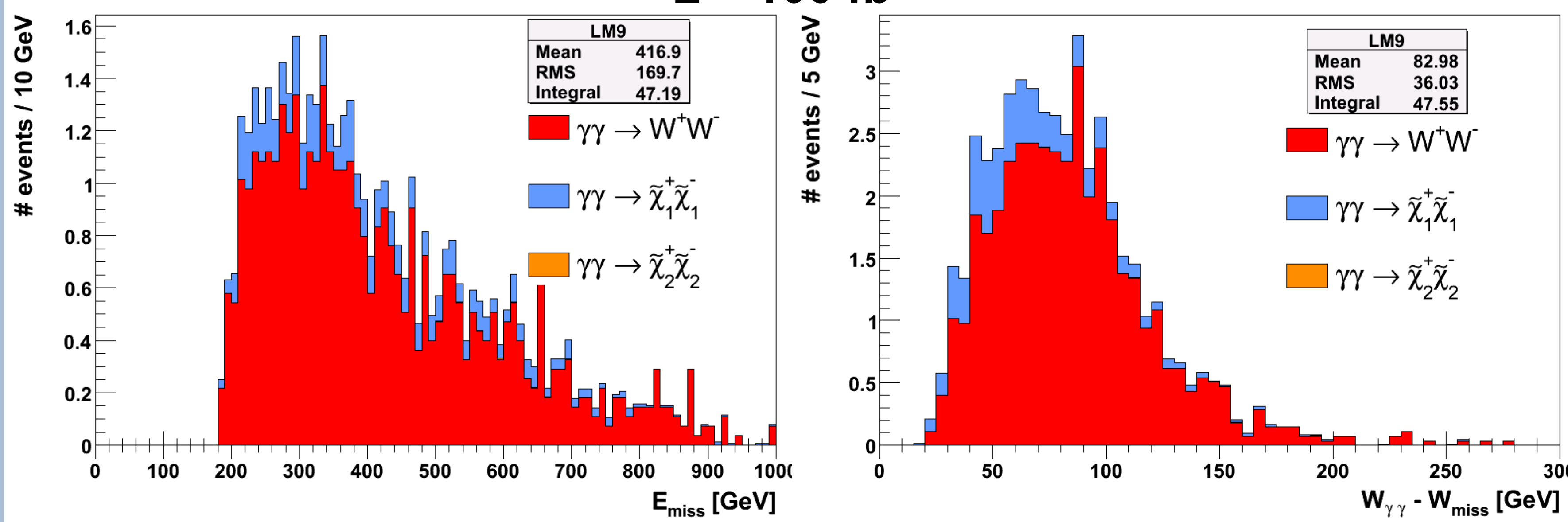
N. Schul

$W_{\gamma\gamma}$ + W_{miss} + kinematic cuts on $\Delta\eta$, ΔR (no flavour sharing here):

σ(LM9 signal) = 3.55 fb --> $\sigma_{acc+cut}$(LM9 signal) = 0.0672 fb

σ(WW bkg) = 108.5 fb --> $\sigma_{acc+cut}$(WW bkg) = 0.408 fb

L = 100 fb^{-1}



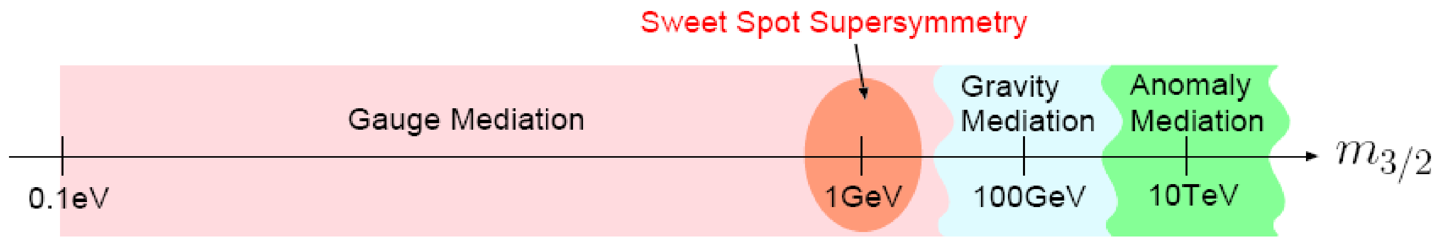
Could be further improved considering semi-leptonic final states (S↑), or other constraints like spin measurements (B↓)

Université catholique de Louvain

N. Schul

Sweet spot susy

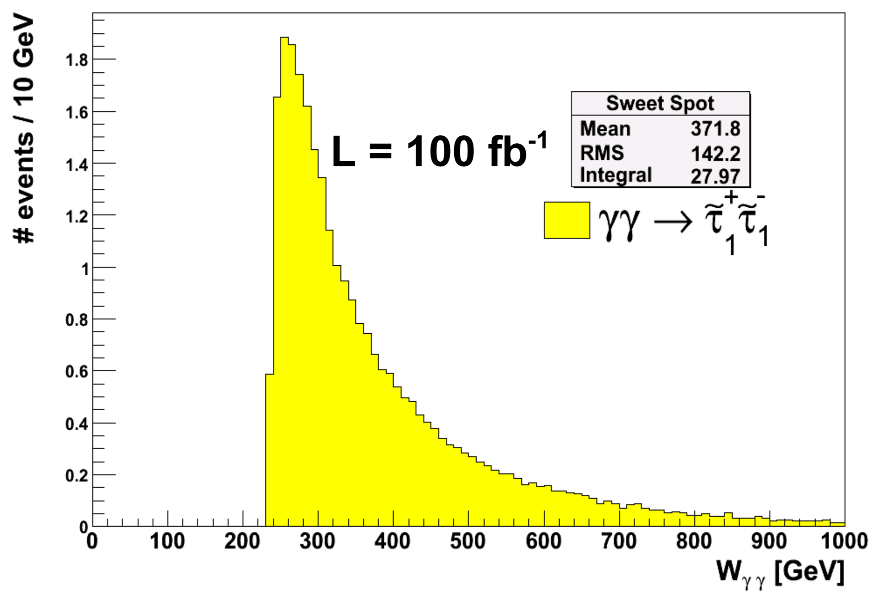
Example of two-photon exclusive production of heavy stable particles



M. Ibe and R. Kitano, JHEP08(2007)016

Stau_1 $\tilde{\tau}_1^+$ - is the NLSP

- is quasi-stable, O(3000s)



m_{stau1} = 116 GeV

↓

σ = 0.43 fb

--> detection via dE/dx method

2 ~Heavy Stable Charged Particles + 2 forward protons

UCL
Université catholique de Louvain

N. Schul

Summary

Two-photon physics offer a complementary way to study new physics

--> Detection of sleptons (with L = 25 fb^{-1})

--> Constraint the MSSM plane (for low mass scenario)

--> Measure mass of the LSP

--> Measure mass of light SUSY charged particles (resolution of few GeV)

--> ...

since the detection of scattered protons give us lot of information about the event kinematics.

N. Schul

Backup slides

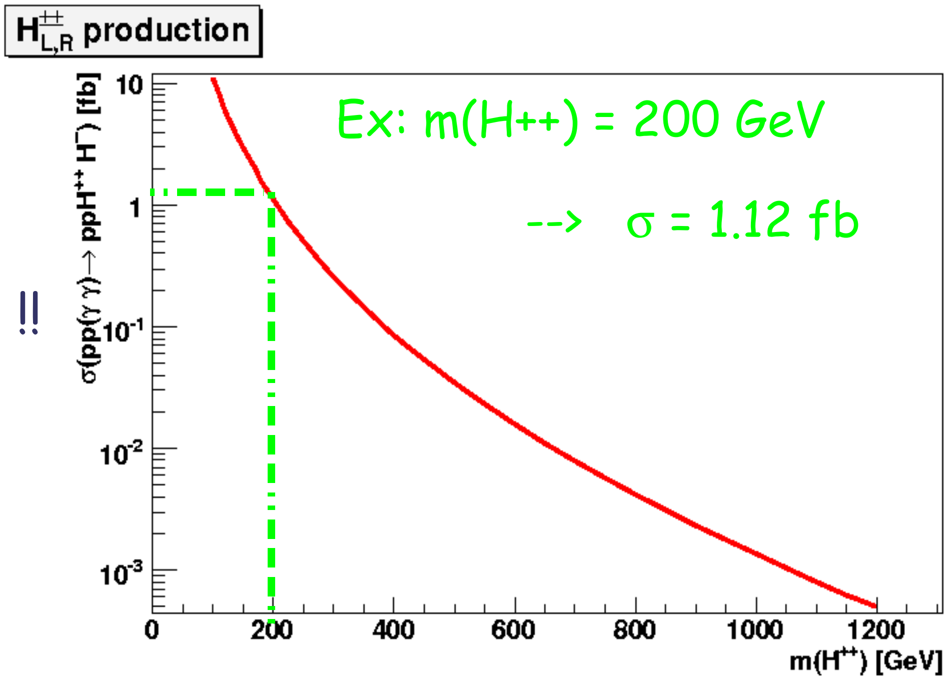
Left-Right symmetry

N. Schul

Doubly charged higgs bosons exist in some models with Left-Right symmetry.
Ex: $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

==> predict H_R^{++} and H_L^{++} particles

Production cross section (computed with an implemented LR-CalcHEP) is model independent:



σ(H++H--) = 16 σ(H+H-) !!

UCL
Université catholique de Louvain

N. Schul

H++ decay

- DCH decays into 2 lepton, violating the *lepton number conservation*

- Very exotic 4-leptons final state is than possible:

$$pp \to pp(\gamma\gamma) \to pp\, H^{++}H^{--} \to pp\, e^+e^+\mu^-\mu^-$$

$$\to pp\, e^-e^-\mu^+\mu^+$$

- Only two backgrounds: $\gamma\gamma \to \tau^+\tau^+\tau^-\tau^-$ σ = 1.8 fb

  $\gamma\gamma \to W^+ W^+ W^- W^-$ σ = 0.14 fb

We assume no SM contribution at the LHC

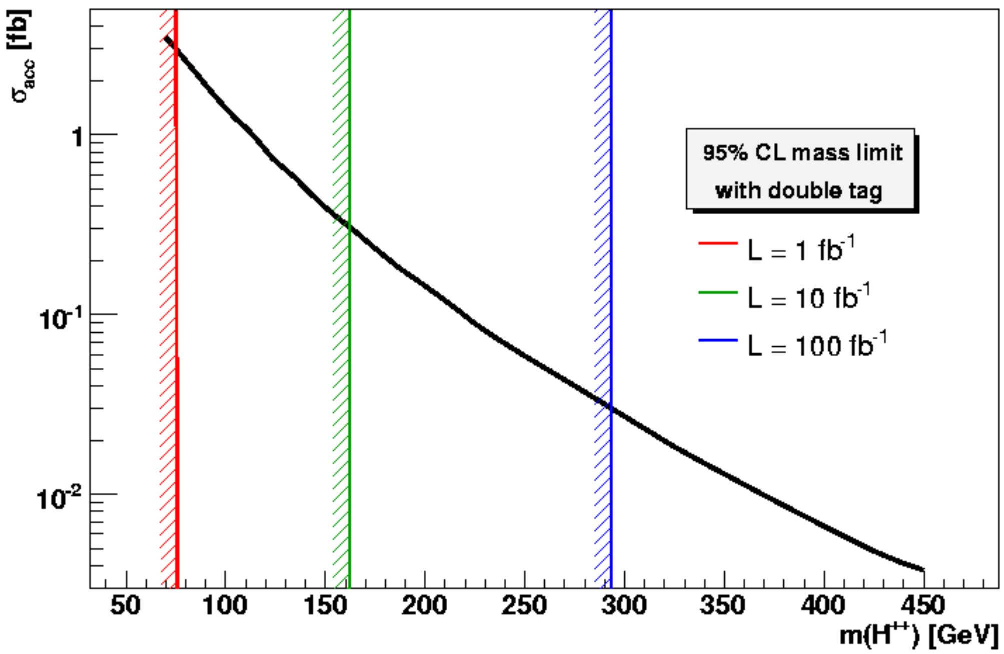
N. Schul

H++ decay

- DCH decays into 2 lepton, violating the *lepton number conservation*
- Very exotic 4-leptons final state is than possible:

$$pp \to pp(\gamma\gamma) \to pp\ H^{++}H^{--} \to pp\ e^+e^+\mu^-\mu^-$$

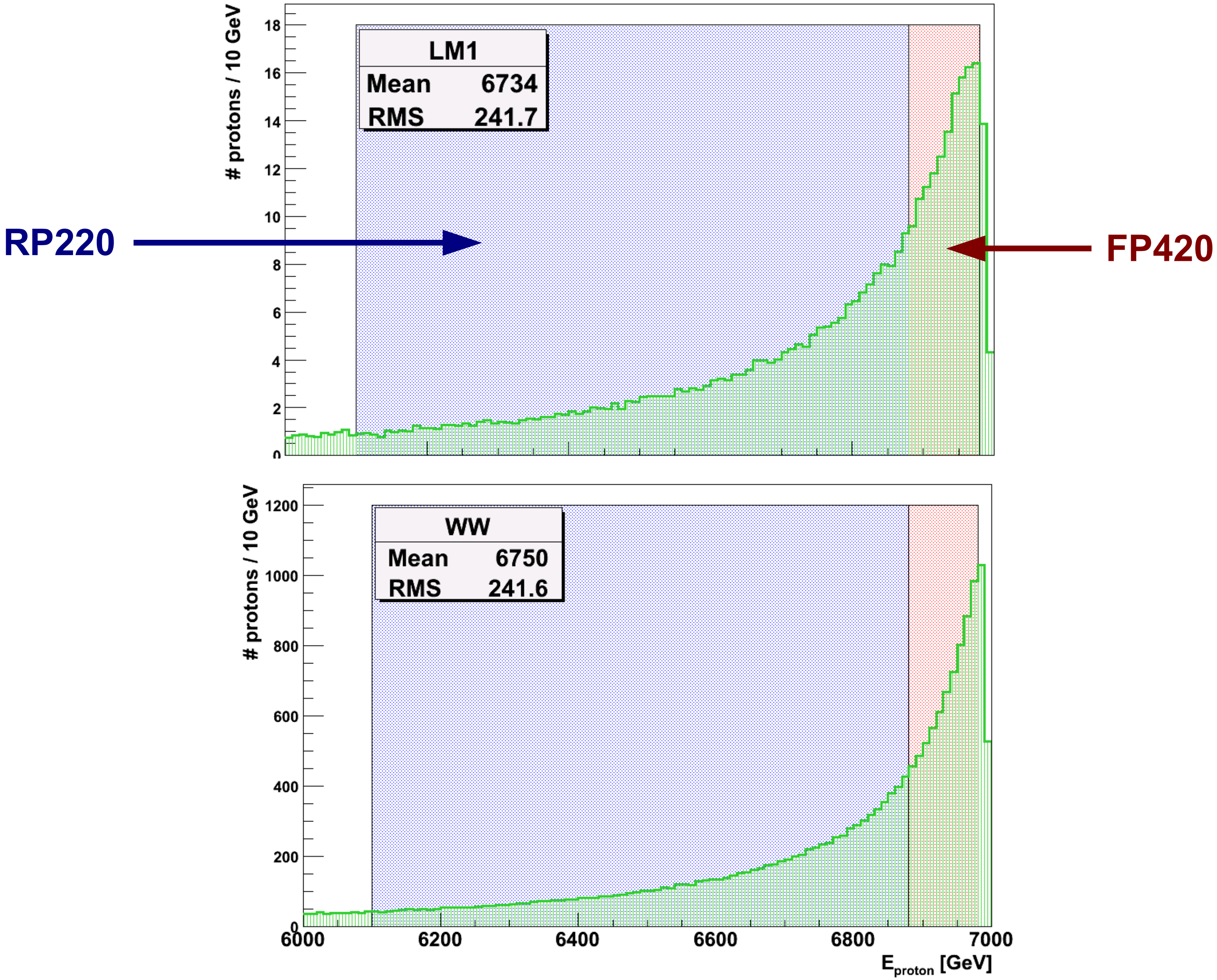
$$\to pp\ e^-e^-\mu^+\mu^+$$



after	L = 1fb^{-1}	m(H++) >	75 GeV
	L = 10 fb^{-1}		163 GeV
	L = 100 fb^{-1}		295 GeV

Photon spectrum

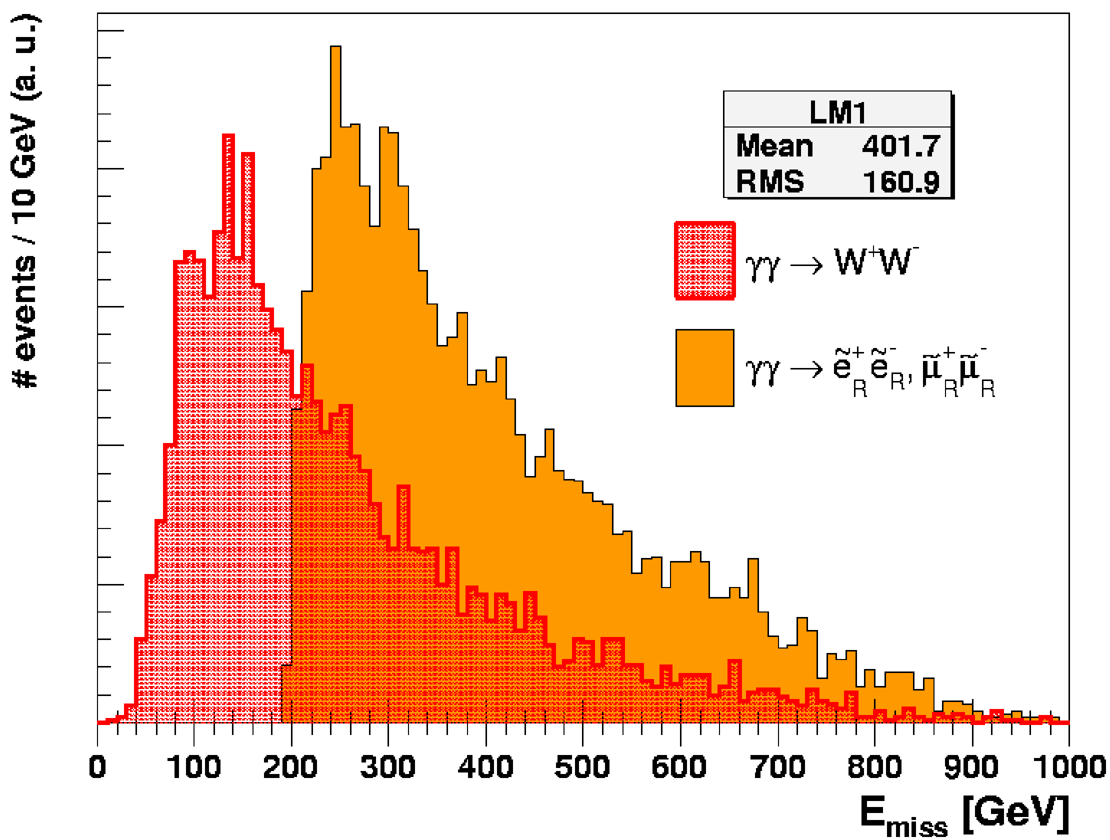
N. Schul

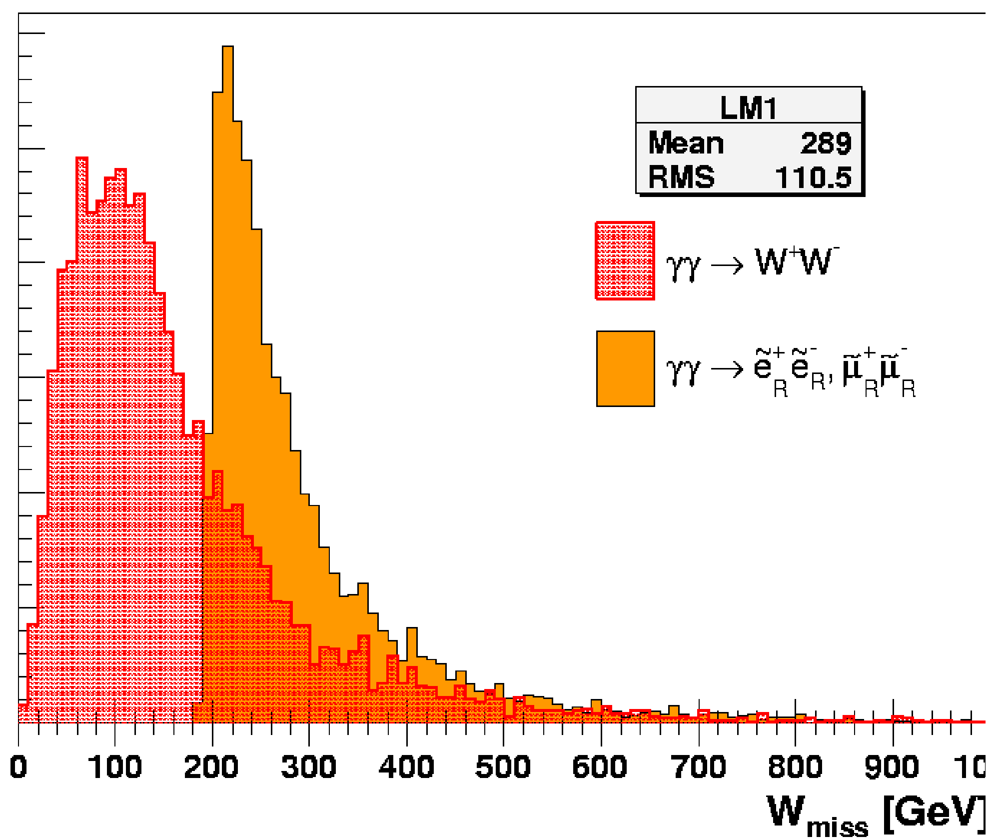


E_{miss} vs. W_{miss}

N. Schul

$$E_{miss} = \omega_1 + \omega_2 - E_{\ell_1} - E_{\ell_2} \qquad W_{miss} = \sqrt{E^2_{miss} - P^2_{miss}}$$





N. Schul

Mass measurement

$$(2m)^2 = W_{\gamma\gamma}^2 - \left([W_{miss}^2 - 4m_{\tilde{\chi}_1^0}^2]^{1/2} + [W_{lep}^2 - 4m_{lep}^2]^{1/2} \right)^2$$