Search for a diphoton and E_T^{miss} final state in pp collision at the LHC using the ATLAS detector

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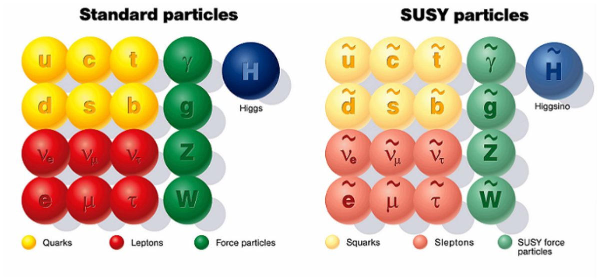
Supersimmetry



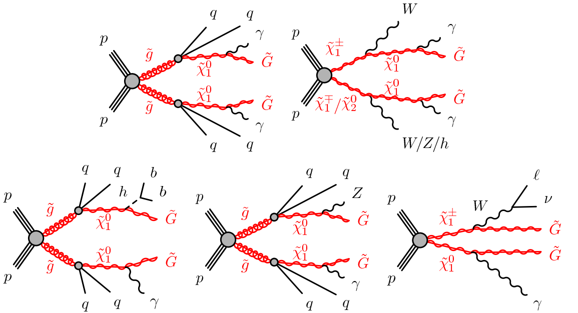
- Supersimmetry:
  - new bosonic field to each SM fermion
  - new fermionic field to each SM gauge boson

$\rightarrow$ Solve the Higgs/hierarchy problem

$\rightarrow$ In Susy the unification of the coupling costants is far more precise

$\rightarrow$ Dark matter: LSP SUSY particle (with R-parity conservation)

- Search for a signal from General Gauge Mediated models
  - LSP Gravitino
  - NLSP Neutralino



GGM Model	Experimental Signature	Produced State(s)	Compositio n of NLSP	Free Parameters
Gluino-bino	diphoton	gluino	bino	$M_{\tilde{g}}$,$M_{\tilde{\chi}_1^0}$
Wino-bino	diphoton	wino	bino	$M_{\tilde{W}}$,$M_{\tilde{\chi}_1^0}$
Higgsino-bino ($\mu < 0$)	photon+b	gluino, higgsino	higgsino/ bino	$M_{\tilde{g}}$,$f_-(M_1,\mu)$
Higgsino-bino ($\mu > 0$)	photon+j	gluino, higgsino	higgsino/ bino	$M_{\tilde{g}}$,$f_+(M_1,\mu)$
Wino NLSP	photon+ℓ	wino	wino	$M_{\tilde{W}}$

- Prompt decay $\tilde{\chi}_1^0 \to \tilde{G}\gamma$ ($c\tau < 0.1$ mm)

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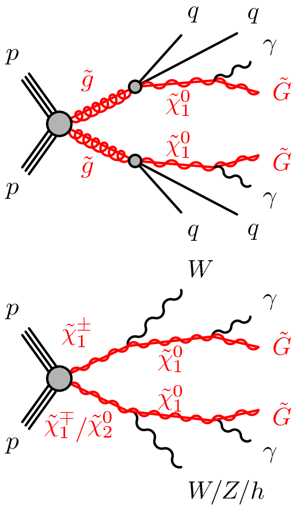
- Search for a signal from GGM models
  - Lightest Stable Particle Gravitino
  - Next to LSP Neutralino
- Two processes identified with $\gamma\gamma + E_T^{miss}$ final state:
  - Strong production
    - gluinos→Neutralinos (bino-like)+jets→photons+Gravitinos+jets
  - Electroweak production
    - wino triplet→neutralinos+gauge-bosons→photons+Gravitinos
- The mass of the neutralino is treated as a free parameter $m_{\tilde{\chi}_1^0} \in (0GeV, m_{\tilde{g}}/m_{(\tilde{\chi}_1^{\pm 1}, \tilde{\chi}_2^0)})$
- Prompt decay $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ ($c\tau < 0.1$ mm)



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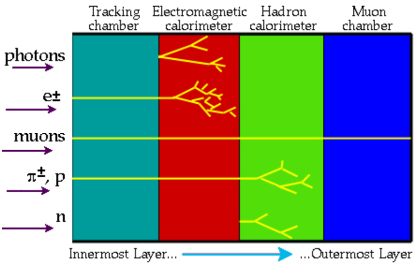
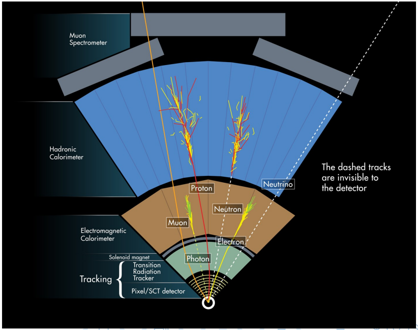
Photon Identification and reconstruction

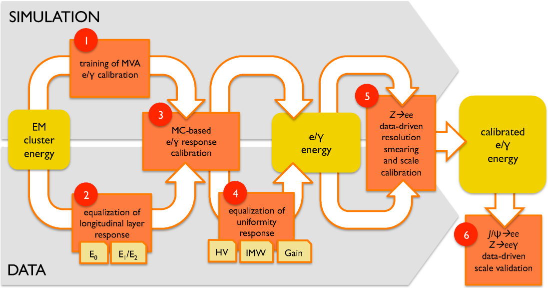
- Photon Reconstruction:
  - Energy deposit in the electromagnetic calorimeter
  - Tracks to determine if the candidate is an electron or converted/unconverted photon
- Photon Identification:
  - Energy leakage in the hadronic calorimeter
  - Shower shapes in the three longitudinal layer of EM calorimeter
- Isolation: further discrimination between jets and photons: Isolation
  - energy around the candidate in a cone $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$

  → jets faking a photons have lots of other particles around it



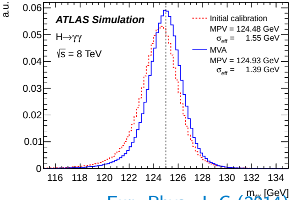


- Goal: $E_{reco} \to E_{true}$



- My qualification task: training the MVA calibration (1)
  - Monte Carlo based
  - advantages:
    - easiness to derive a new set of correction
    - take into account the correlation between the inputs
- Non completely related to my analysis:

  → much important for resonance search



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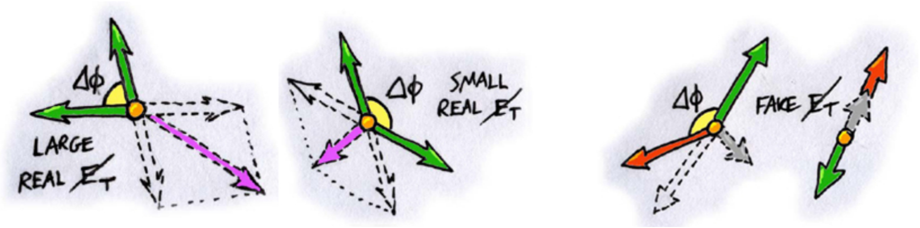
Missing Transverse Energy

- E_T^{miss} = Missing Transverse Momentum
  - Negative vector sum of the transverse momenta of all detected particles
  - Global quantity of the event
  - The handle for the invisible part of the event



- Real E_T^{miss}:
  - New particles
  - Neutrinos

- Fake E_T^{miss}:
  - Mis-calibrations
  - Mis-measurements
  - Limited detector acceptance
  - Detector Noise

Missing Transverse Energy

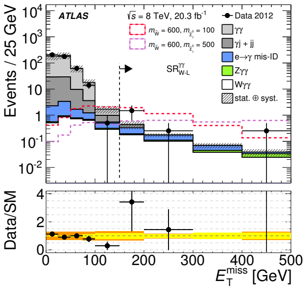
$$E_{x(y)}^{miss} = E_{x(y)}^{miss,e} + E_{x(y)}^{miss,\gamma} + E_{x(y)}^{miss,\tau} + E_{x(y)}^{miss,jets} + E_{x(y)}^{miss,\mu} + E_{x(y)}^{miss,Soft}$$

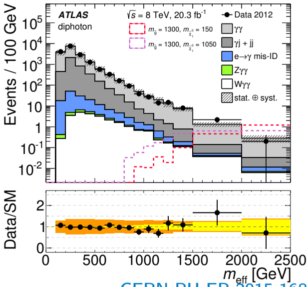
$$E_{x(y)}^{miss,k} = -\sum_{k} p_T^k$$

- Hard Terms
  - Reconstructed and calibrated physics objects:
    - electrons, photons, taus, muons (identified objects)
    - Hadronics jets: $p_T > 20$ GeV
- Soft Terms
  - Unmatched tracks and clusters
  - soft jets with 7 GeV$< p_T <$20 GeV

Backgrounds

- QCD background (instrumental E_T^{miss} + 1 or 2 real photons):
  - SM $\gamma\gamma$, γ+jet
- Eelctroweak background (genuine E_T^{miss} + 1 real photon)
  - W+γ (W$\to$eν), Z+γ (Z$\to \tau^+\tau^-$), $t\bar{t}$+γ ($t \to$beν)
- Irreducible background (genuine E_T^{miss} + 2 real photons):
  - Finale state identical to the searched signal
  - Z+$\gamma\gamma$ (Z$\to \nu\nu$)
  - W+$\gamma\gamma$ (W$\to e\nu$)
- Discriminant variables:
  - p_T^{γ}
  - E_T^{miss}
  - $\Delta\phi(jet, E_T^{miss})$ (to reduce fake E_T^{miss} contribution)
  - $\Delta\phi(\gamma, E_T^{miss})$, (signal γ and E_T^{miss} are expected to be back to back
  - H_T (=total transverse energy of all visible objects)
  - m_{eff} (scalar sum of H_T and E_T^{miss})





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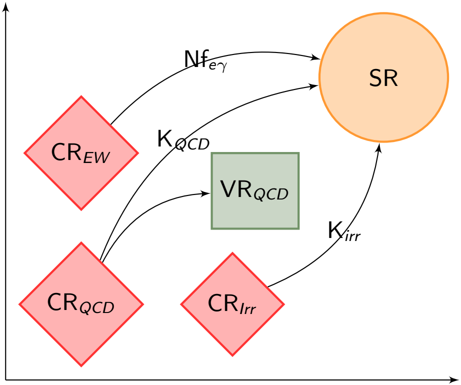
- RUN1 data: $\sqrt{s} = 8$ TeV and $L = 20.3$ fb^{-1}
- Cut and count analysis:
  - Signal Region optimisation
  - Background evaluation:
    - SM contribution
    - Evaluation in Control Region (orthogonal to SR) with data-driven/MC methods
    - Validation Region
  - Statistical comparison of Expected (bkg) events vs. Observed



Event selection and Signal Regions

- Event selection:
  - Two passing identification (shower shapes) and isolated photons
  - Event Cleaning (jet cleaning, cosmic muon cleaning)

→ Inclusive signature: no explicit requests on jets, leptons

- Four Signal Regions optimised:
  - Two for strong production (SH, SL)
    - m($\tilde{g}, \tilde{\chi}^0_1$)(1300, 1050) GeV and (1300, 150) GeV
  - Two for ew production (WH, WL)
    - m($\tilde{\chi}^{\pm 1}_1 / \tilde{\chi}^0_2, \tilde{\chi}^0_1$) (600, 500) GeV and (600, 100) GeV.
  - Using variables:
    - p_T^{γ}
    - E_T^{miss}, $\Delta\phi(\gamma, E_T^{miss})$, $\Delta\phi(jet, E_T^{miss})$
    - H_T (=total transverse energy of all visible objects)
    - m_{eff} (scalar sum of H_T and E_T^{miss})

Signal Region BWH	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-L}}$	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-H}}$	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-L}}$	
No. photons (E_T [GeV])	> 1 (> 75)	> 1 (> 75)	> 1 (> 75)	> 1 (> 75)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 250	> 150	> 200
H_{T} [GeV]	–	–	> 600	> 400
m_{eff} [GeV]	> 1800	> 1500	–	–
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$ (No. leading jets)	> 0.5 (2)	> 0.5 (2)	> 0.5 (2)	> 0.5 (2)
$\Delta\phi_{\mathrm{min}}(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$	–	> 0.5	–	> 0.5

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QCD Background

- QCD background:
  - Instrumental E_T^{miss}
  - SM $\gamma\gamma$, γ+jet
- QCD sample:
  - $\gamma\gamma$: di-photon MC sample $\rightarrow$ 75%
  - γ+jet: pseudo-photon control sample $\rightarrow$ 25%
    - use control region in which one photon fails some of the shower shape requirements and pass looser isolation criteria
    - leptons veto $\rightarrow$ avoid W events
- Control Region: scale factor in region $0<E_T^{miss}<60$ GeV tight-tight photon and H_T,m_{eff}, $\Delta\phi(\gamma, E_T^{Miss})$, $\Delta\phi(jet, E_T^{Miss})$ request
- Validation Region: side-bands $100<E_T^{miss}<150$ GeV in bins of 300 GeV in H_T
- Systematic uncertainties:
  - varying the relative contribution $\gamma\gamma$-QCD control sample

Signal Regions	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$	$SR^{\gamma\gamma}_{W-L}$	$SR^{\gamma\gamma}_{W-H}$
QCD	$0.00^{+0.24}_{-0.00}$	$0.00^{+0.24}_{-0.00}$	$0.32^{+0.45}_{-0.32}$	$0.22^{+0.33}_{-0.22}$

EW Background

- EW background
  - Genuine E_T^{miss}
  - W+γ (W$\rightarrow$eν), Z+γ (Z$\rightarrow \tau^+\tau^-$), $t\bar{t}$+γ ($t \rightarrow$beν)
- electron faking photon:
  - tag-and-probe method using $Z \rightarrow ee$
  - request tag electron (25<p$_T$<50 GeV and Tight++) and search for an electron/photon (p$_T$>50 GeV)
  - evaluate scale factor $f = \frac{N_{e\gamma}}{N_{ee}}$
    - scale factor depends on the amount of material in front of the calorimeter
    - $\rightarrow$ for five η bins $(-2.47, -1.52], (-1.37, -0.6], (-0.6, 0.6), [0.6, 1.37), [1.52, 2.47)$
- Control Region: electron-photon control sample with the request of a tight photon and a tight electron with $p_T > 75$ GeV
- Systematic uncertainties:
  - varying the fitting window of Z peak
  - varying the p$_T$ request for the probe

Signal Regions	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$	$SR^{\gamma\gamma}_{W-L}$	$SR^{\gamma\gamma}_{W-H}$
EW	0.02 ± 0.02	0.0 ± 0.0	0.64 ± 0.27	0.13 ± 0.08

Irreducible Background

- Z+$\gamma\gamma$ (Z$\rightarrow \nu\nu$)
  - Sherpa cross section (10.1 fb) rescaled to MadGraph at NLO (2.8 LO, K-factor 2)
- W+$\gamma\gamma$ (W$\rightarrow e\nu$)
  - Sherpa distribution (after full detector simulation) normalised to data in Control Region:
    - 50<E_T^{miss}<150 GeV
    - photon wiht p_T>50 GeV
    - $p_T^{\gamma\gamma\ell}$>100 GeV

Signal Regions	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$	$SR^{\gamma\gamma}_{W-L}$	$SR^{\gamma\gamma}_{W-H}$
$(W \rightarrow \ell\nu)\gamma\gamma$	0.04 ± 0.02	0.05 ± 0.04	1.01 ± 0.62	0.53 ± 0.34
$(Z \rightarrow \nu\nu)\gamma\gamma$	0.00 ± 0.00	0.01 ± 0.01	0.07 ± 0.04	0.13 ± 0.07

- Z+$\gamma\gamma$ (Z$\rightarrow \nu\nu$)
  - Sherpa cross section (10.1 fb) rescaled to MadGraph at NLO (2.8 LO, K-factor 2)
- W+$\gamma\gamma$ (W$\rightarrow e\nu$)
  - Sherpa distribution (after full detector simulation) normalised to data in Control Region:
    - 50<E_T^{miss}<150 GeV
    - photon wiht p_T>50 GeV
    - $p_T^{\gamma\gamma\ell}$>100 GeV

Signal Regions	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-L}}$	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-H}}$	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-L}}$	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-H}}$
Expected background events	$0.06^{+0.24}_{-0.03}$	$0.06^{+0.24}_{-0.04}$	$2.04^{+0.82}_{-0.75}$	$1.01\ ^{+0.48}_{-0.42}$
QCD	$0.00^{+0.24}_{-0.00}$	$0.00^{+0.24}_{-0.00}$	$0.32^{+0.45}_{-0.32}$	$0.22^{+0.33}_{-0.22}$
EW	0.02 ± 0.02	0.0 ± 0.0	0.64 ± 0.27	0.13 ± 0.08
$(W \rightarrow \ell\nu)\gamma\gamma$	0.04 ± 0.02	0.05 ± 0.04	1.01 ± 0.62	0.53 ± 0.34
$(Z \rightarrow \nu\nu)\gamma\gamma$	0.00 ± 0.00	0.01 ± 0.01	0.07 ± 0.04	0.13 ± 0.07

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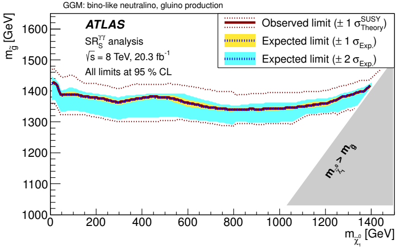
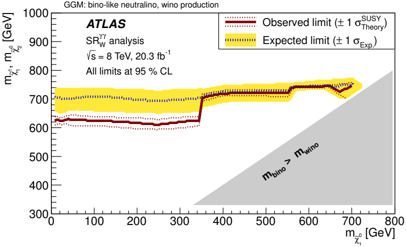
Signal region	$N_{\rm obs}$	$N^{\rm SM}_{\rm exp}$	$S^{95}_{\rm obs}$	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-L}}$	0	$0.06^{+0.24}_{-0.03}$	3.0	0.15
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-H}}$	0	$0.06^{+0.24}_{-0.04}$	3.0	0.15
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-L}}$	5	$2.04^{+0.82}_{-0.75}$	8.2	0.41
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-H}}$	1	$1.01^{+0.48}_{-0.42}$	3.7	0.18

- No statistically significant deviation from the SM is observed
- For each signal region 95% CL upper limit is set on the visible cross section:
  - SL (SH) 0.15 (0.15) fb
  - WL (WH) 0.25 (0.18) fb
- 95% CL lower limits are set on
  - $m_{\tilde{g}}$ at 1290 GeV (at $-1\sigma^{SUSY}_{Theory}$)
  - $m_{(\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_2)}$ at 590 GeV (at $-1\sigma^{SUSY}_{Theory}$)





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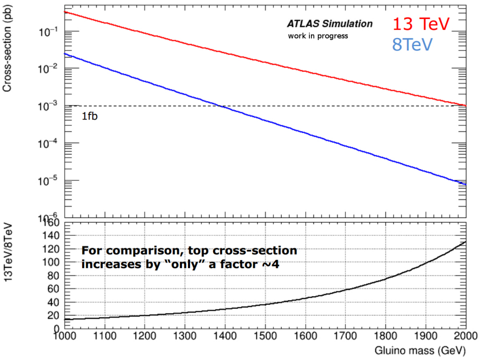
Run2 ($\sqrt{s} = 13$ TeV) Prospect



- Considering a single signal point, gluino with mass 1400 GeV, just above the 8 TeV exclusion limit:
  - Signal: $\sigma(13\,TeV)/\sigma(8\,TeV) \sim 30$
  - Background: $\sigma(13\,TeV)/\sigma(8\,TeV) \sim 2-3$
  - $S/\sqrt{B} \sim 20$ times bigger than at 8 TeV (at the same L)
- The sensitivity of the 8 TeV analysis will be reached with L=1-2 fb^{-1} at 13 TeV

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Conclusion

- The results of the di-photon + E_T^{miss} analysis at $\sqrt{s} = 8$ TeV are presented
  - $m_{\tilde{g}}$ excluded up to 1290 GeV
  - $m_{(\tilde{\chi}_1^{\pm 1}, \tilde{\chi}_2^0)}$ excluded up to 590 GeV
- Run 2 at $\sqrt{s} = 13$ TeV analysis ongoing:
  - Signal region optimization
  - Data-driven background evaluation
  - Statistical framework


Stay tuned!