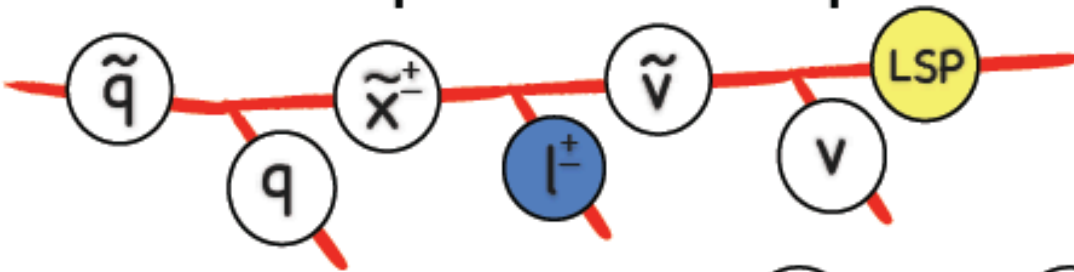
Searches for SUSY with 2 leptons and missing transverse energy with the ATLAS experiment

Joao Firmino da Costa

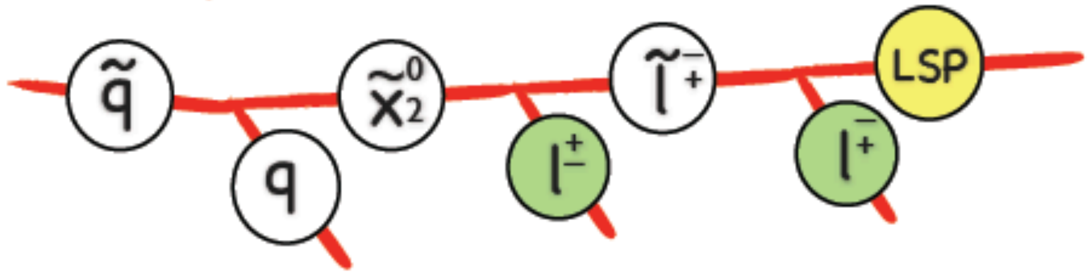
LHC-DESY discussions

Dilepton searches Results from ATLAS

Final state leptons can be produced in different ways...



LSP escapes undetected, giving rise to high missing transverse energy



a) $\tilde{\chi}_i^0 \to l^\pm \nu \tilde{\chi}_j^\mp$

b) $\tilde{\chi}_i^\pm \to l^\pm \nu \tilde{\chi}_j^0$

c) $\tilde{\chi}_i^0 \to l^\pm l^\mp \tilde{\chi}_j^0$

d) $\tilde{\chi}_i^\pm \to l^\pm l^\mp \tilde{\chi}_j^\pm$

(c) and (d) on a single-leg (opposite-sign)
(a) or (b) on both-legs (opposite-sign or same-sign)

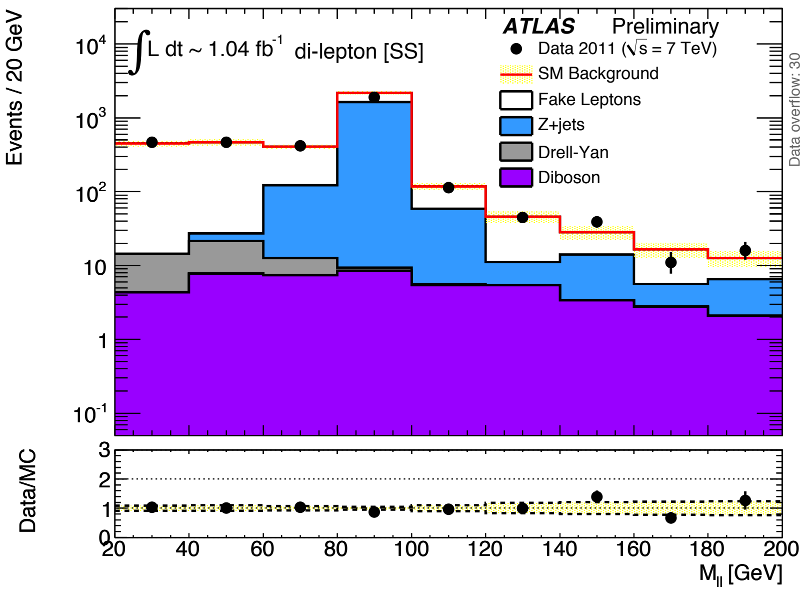
Dilepton final states (opposite sign or same sign)

latest results with 1.04 fb^{-1} (preliminary)
(for 2010 results : EPJC(2011) 1682)

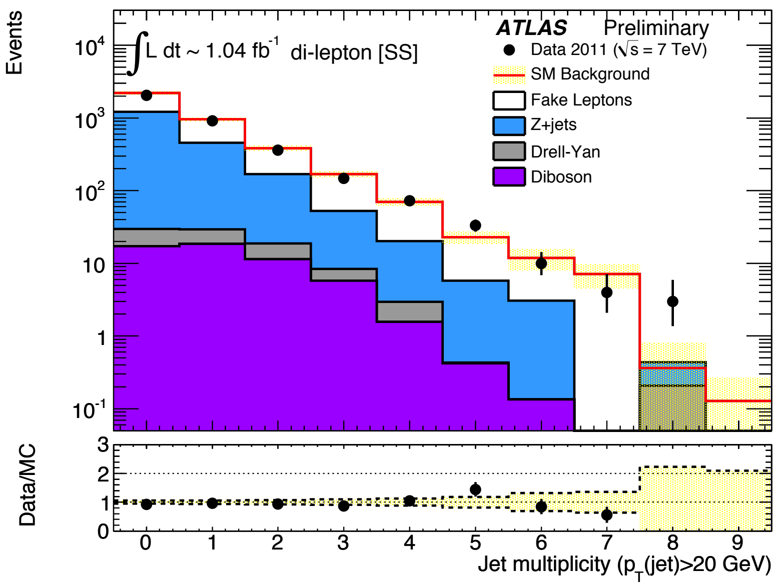
Same-Sign dilepton search

Search for exactly two same-sign leptons and large missing transverse energy

Electron p_T > 20 (25 if leading) GeV
Muon p_T > 10 (20 if leading) GeV
m_{ll} > 12 GeV



Events are triggered using the single electron and single muon triggers.



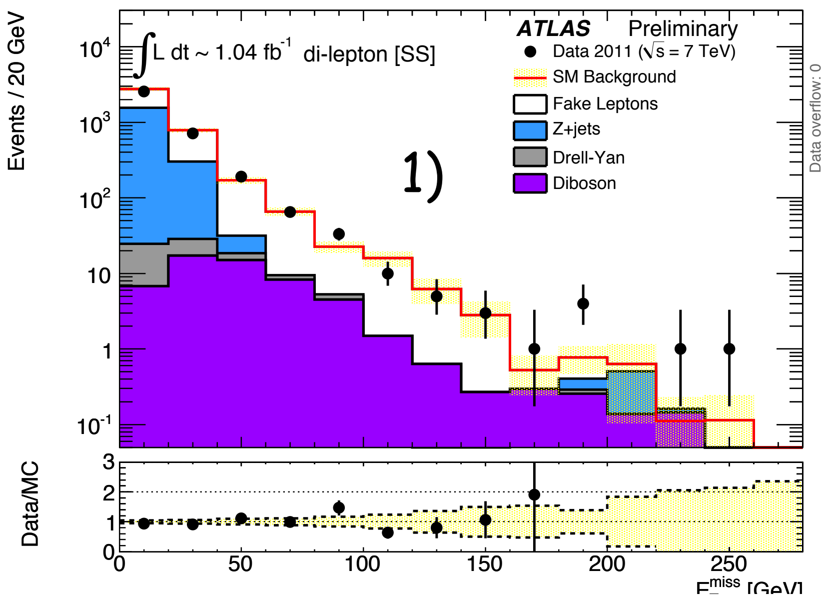
In figures:
All backgrounds MC normalised to luminosity x cross-section.
Except "Fake leptons" component, which is data-derived.

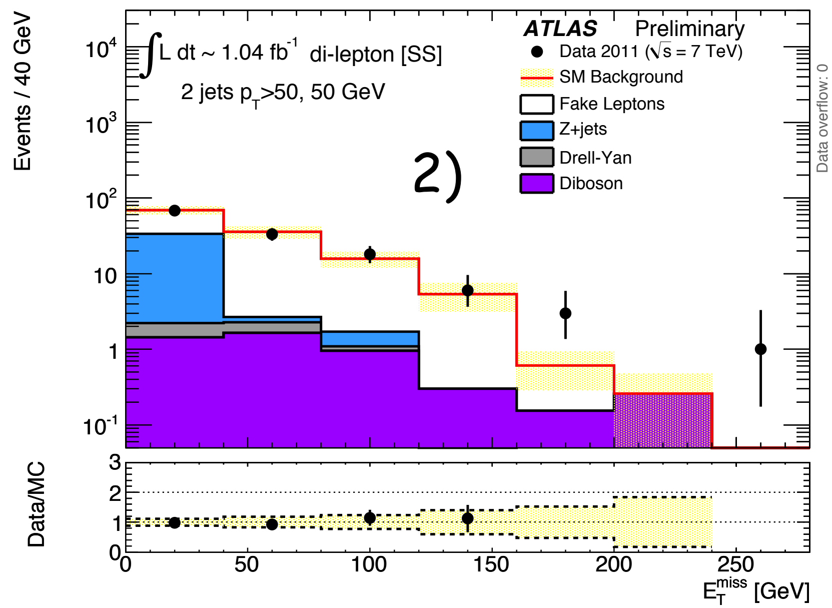
Same-Sign dilepton search – Signal Regions

2 signal regions :

1) Etmiss > 100 GeV
2) Etmiss > 100 GeV & >= 2jets (pT > 50 GeV/c)

good agreement with expectations !





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Same-Sign dilepton search – Bkg estimation

Sources of backgrounds : "fake" leptons, charge misidentification and dibosons

fake leptons : Estimation using the ABCD matrix method

'N_{FF}' - light or heavy flavour jets

'N_{RF}/N_{FR}' - $t\bar{t} \rightarrow b\ell\nu qq$, W+jets

loosen lepton selection criteria, and call these leptons "loose" (signal leptons are "tight")
measure 'r' (probability of real lepton R passing the "tight" reconstruction criteria)
measure 'f' (probability of a fake lepton F passing the "tight" reconstruction criteria)
count in the signal region the numbers of "loose-loose" (LL), "loose-tight" (LT), "tight-loose" (TL), "tight-tight" (TT) pairs

invert this matrix to find $N_{RF}+N_{FR}+N_{FF}$ ("Fake lepton" background)

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

charge misidentification : Probability from Z MC and apply it to ttbar MC

$$e^{\mp}_{\text{hard}} \rightarrow \gamma_{\text{hard}} e^{\mp}_{\text{soft}} \rightarrow e^{\mp}_{\text{soft}} e^{\mp}_{\text{soft}} e^{\pm}_{\text{hard}}$$

dibosons : Estimation from MC

Same-Sign dilepton search - Results

	Background	Obs.	95% C.L.
SS-SR1	$32.6 \pm 4.4 \pm 4.4$	25	10.2 fb
SS-SR2	$24.9 \pm 4.1 \pm 6.6$	28	20.3 fb

Same Sign [SS-SR1]	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$
Fake	$3.5\pm0.7\pm2.0$	$14.4\pm3.2\pm0.6$	$9.2\pm4.0\pm1.8$
Charge flip	$0.73\pm0.05\pm0.06$	$1.10\pm0.07\pm0.08$	*neg.*
Dibosons	$0.79\pm0.27\pm0.05$	$1.7\pm0.4\pm0.3$	$1.1\pm0.2\pm0.1$
Standard Model	$5.0\pm0.8\pm2.0$	$17.2\pm3.2\pm0.6$	$10.3\pm3.0\pm1.8$
Cosmics	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
Observed	6	14	5

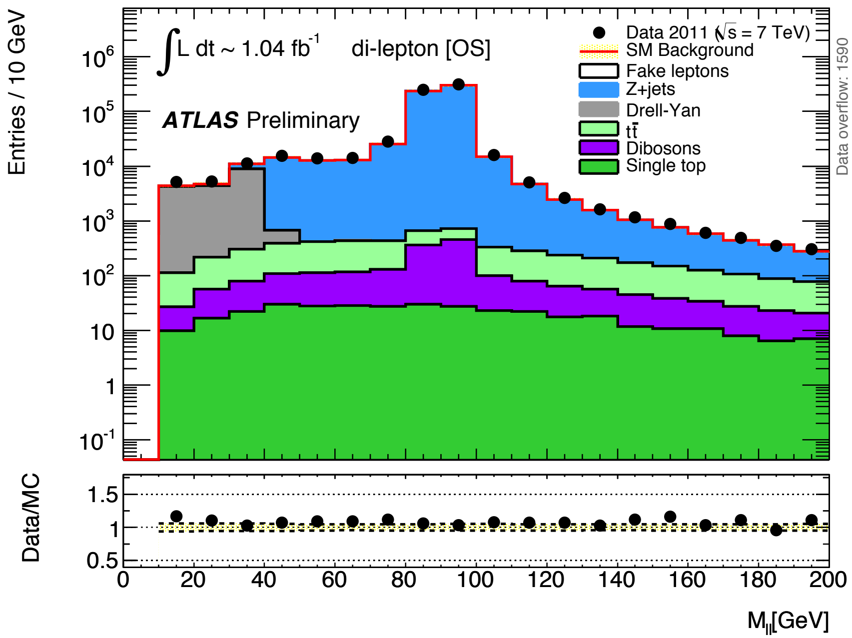
Same Sign [SS-SR2]	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$
Fake	$1.5\pm0.5\pm2.0$	$13.4\pm3.2\pm2.7$	$6.7\pm2.5\pm1.8$
Charge flip	$0.59\pm0.04\pm0.04$	$1.36\pm0.05\pm0.06$	*neg.*
Dibosons	$0.25\pm0.06\pm0.13$	$0.9\pm0.2\pm0.2$	$0.64\pm0.05\pm0.02$
Standard Model	$2.4\pm0.5\pm2.0$	$15.6\pm3.2\pm2.7$	$6.9\pm2.5\pm1.8$
Cosmics	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
Observed	4	14	10

fakes are dominant contribution

Opposite-Sign dilepton search

Search for exactly two opposite-sign leptons and large missing transverse energy

Electron p_T > 20 (25 if leading) GeV
Muon p_T > 10 (20 if leading) GeV
m_{ll} > 12 GeV



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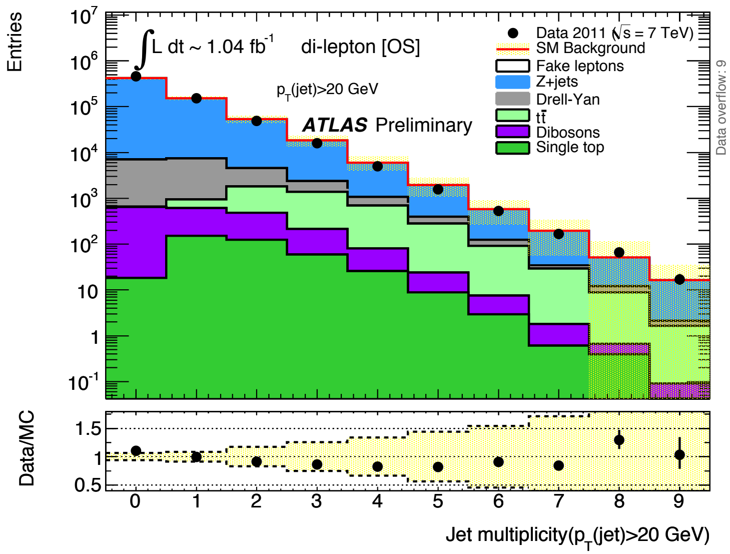

In figures:
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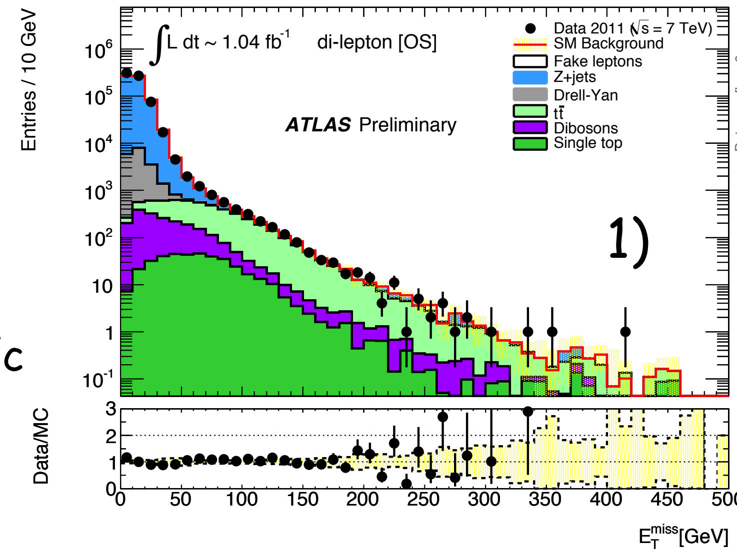
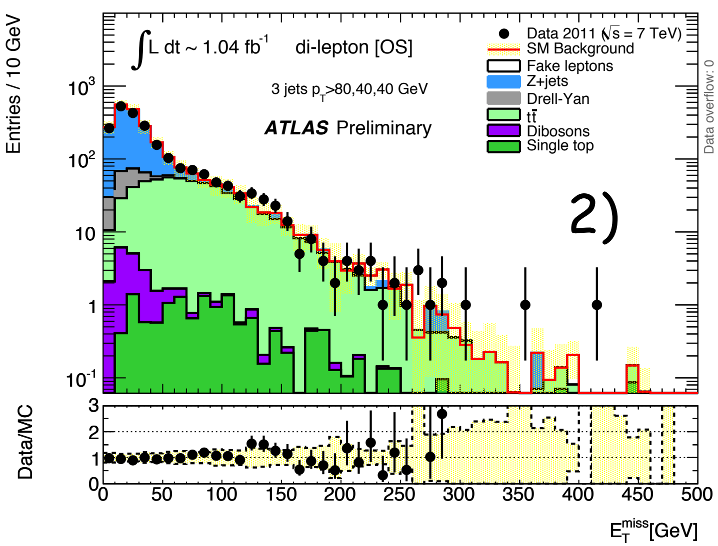
Except "Fake leptons" component, which is data-derived.

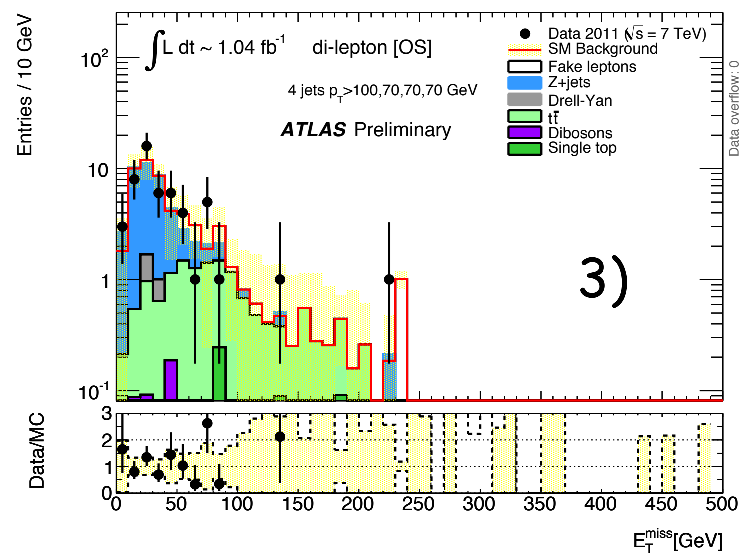
Opposite-Sign dilepton search – Signal Regions

3 signal regions :

1) Etmiss > 250 GeV
2) Etmiss > 220 GeV, jets pT > 80,40,40 GeV/c
3) Etmiss > 100 GeV, jets pT > 100,70,70,70 GeV/c







Opposite-Sign dilepton search – Bkg estimations

Sources of backgrounds : fully leptonic ttbar, Wt, "fake" leptons, Z+jets and dibosons

- exploit top dilepton decay kinematics to tag $t\bar{t}$ like events in intermediate E_T^{MISS} region
- define CRs that are similar to corresponding SR (to reduce systematic uncertainties)
- extrapolate from CR to SR
- The number of $t\bar{t}$ events in the signal region $(N_{tt})_{SR}$ is given by:

$$(N_{tt})_{SR} = \left((N^{tag}_{data})_{CR} - (N^{tag}_{non-tt,MC})_{CR}\right) f_{CR\to SR}$$

- with the extrapolation factor given by

$$f_{CR\to SR} = \frac{(N_{top,MC})_{SR}}{(N^{tag}_{top,MC})_{CR}}$$

m_{CT} variable : explores kinematics of *ttbar->b bbar l l 2nu*

Z CR : Z peak, low mll, extrapolate back to SR using MC

fake leptons : ABCD matrix method

Wt and dibosons : MC estimations

Opposite-Sign dilepton search - Results

	Background	Obs.	95% C.L.
OS-SR1	$15.5 \pm 1.2 \pm 4.4$	13	9.5 fb
OS-SR2	$13.0 \pm 1.8 \pm 4.1$	17	15.2 fb
OS-SR3	$5.7 \pm 1.1 \pm 3.5$	2	5.0 fb

Opposite Sign [OS-SR1]	$e^{\pm}e^{\mp}$	$e^{\pm}\mu^{\mp}$	$\mu^{\pm}\mu^{\mp}$
$t\bar{t}$	1.84±0.07±0.49	5.09±0.19±1.35	3.34±0.13±0.88
Z/γ^*+jets	0.013±0.008±0.67	1.03±0.42±0.02	0.81±0.26±0.06
Fakes	0.17±0.19±0.36	0.92±0.96±1.15	-0.08±0.03±0.003
Dibosons	0.54±0.29±0.07	0.04±0.03±0.03	0.67±0.25±0.31
Single-top	0.11±0.11±0.05	0.47±0.16±0.16	0.48±0.17±0.09
Standard Model	2.67±0.37±1.29	7.55±1.07±2.13	5.30±0.42±1.29
Cosmics	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
Observed	2	8	3

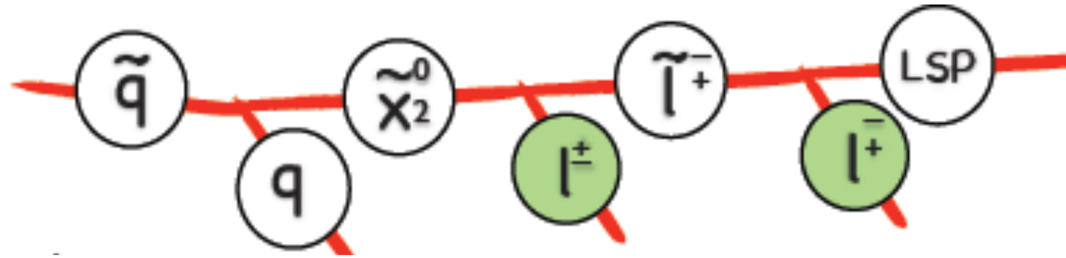
Opposite Sign [OS-SR2]	$e^{\pm}e^{\mp}$	$e^{\pm}\mu^{\mp}$	$\mu^{\pm}\mu^{\mp}$
$t\bar{t}$	1.41±0.11±0.33	3.90±0.30±0.95	2.56±0.20±0.62
Z/γ^*+jets	0.45±0.23±0.44	0.84±0.59±0.32	0.27±0.14±0.27
Fakes	0.01±0.14±0.19	2.77±1.64±2.11	-0.13±0.04±0.01
Dibosons	*neg.*	0.03±0.03±0.03	0.24±0.21±0.02
Single-top	0.05±0.10±0.02	0.39±0.16±0.25	0.09±0.15±0.08
Standard Model	1.92±0.31±0.77	7.93±1.77±1.41	3.16±0.36±0.94
Cosmics	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
Observed	3	9	5

Opposite Sign [OS-SR3]	$e^{\pm}e^{\mp}$	$e^{\pm}\mu^{\mp}$	$\mu^{\pm}\mu^{\mp}$
$t\bar{t}$	0.77±0.14±0.51	2.14±0.38±1.41	1.40±0.25±0.92
Z/γ^*+jets	0.01±0.01±0.17	*neg.*	0.27±0.20±0.47
Fakes	0.13±0.13±0.03	0.91±0.94±0.04	-0.03±0.02±0.001
Single-top	*neg.*	0.0±0.0±0.02	0.10±0.10±0.05
Standard Model	0.91±0.19±0.67	3.05±1.01±1.43	1.77±0.34±1.41
Cosmics	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
Observed	0	1	1

ttbar is dominant contribution

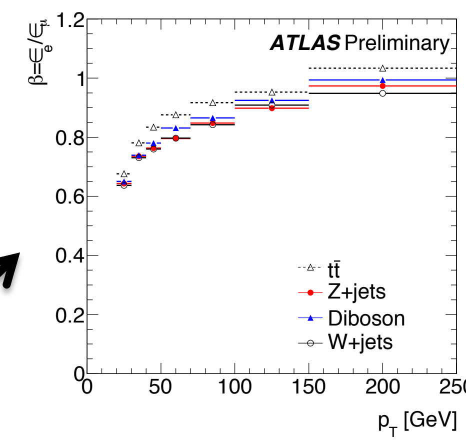
Opposite-Sign Flavour subtraction search

Use the selected opposite-sign di-leptons and search for excess of same-flavour events over opposite-flavour



Offers a great to measure SUSY mass parameters
Via the measurement of <u>mass edges</u>

Most important bkgs (ttbar) are combinatorics so they cancel with the <u>Flavour Subtraction</u>



Quantify the excess of Same Flavour (SF) through the usage of the variable S :

$$S = \underbrace{\frac{N(e^{\pm}e^{\mp})}{\beta(1-(1-\tau_e)^2)}}_{\text{SF}} - \underbrace{\frac{N(e^{\pm}\mu^{\mp})}{1-(1-\tau_e)(1-\tau_\mu)}}_{\text{DF}} + \underbrace{\frac{\beta N(\mu^{\pm}\mu^{\mp})}{(1-(1-\tau_\mu)^2)}}_{\text{SF}}$$

measured with in Z CR and variation due to process from MC

DESY work : J. F.C., M. Boehler, W. Ehrenfeld, P. Bechtle, M. Zvolsky

Opposite-Sign Flavour subtraction search – Signal Regions

3 signal regions :

1) Etmiss > 80 GeV and Z peak veto (80-100)
2) Etmiss > 80 GeV, jets pT > 20, 20 GeV/c
3) Etmiss > 250 GeV

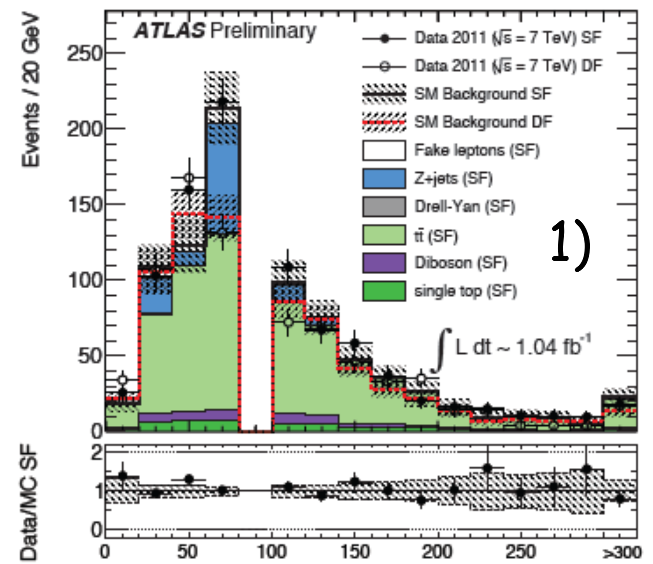
Same sources of backgrounds as OS analysis:

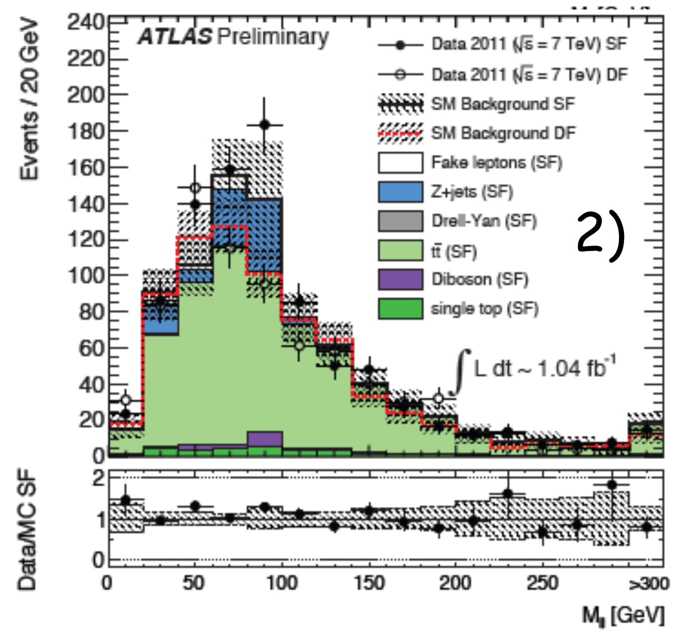
ttbar estimation from m_{CT} (for SR3) or from MC (SR1, SR2)

Z CR : Z peak, low mll, extrapolate back to SR using MC

fake leptons : ABCD matrix method

Wt and dibosons : MC estimations



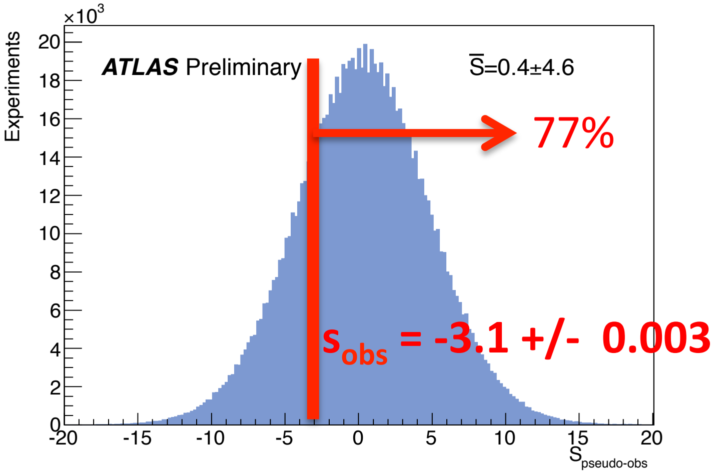


Opposite-Sign Flavour subtraction search - Results

- Determine $\mathcal{S}$ ($\mathcal{S}_b$) done with MC toy experiments:
  - toy experiment for each SM process in each channel
  - based on data driven expectations nominal values and uncertainties
- observed $\mathcal{S}_b$ in agreement with SM pred. within 1 σ (FS-SR2 within 1.5 σ)

	$\mathcal{S}_{obs}$	$\bar{\mathcal{S}}_b$	RMS
FS-SR1	131.6±0.6(sys)	126.5±23.5±17.2	49.9
FS-SR2	142.2±0.6(sys)	70.0±23.2±16.8	49.1
FS-SR3	-3.1±0.0(03)(sys)	0.4±1.2±1.2	4.6

errors on $\bar{\mathcal{S}}_b$ are stat. and syst. errors



Limits:

- Probability of observing a value $\mathcal{S} > \mathcal{S}_{obs}$ evaluated
- Limit set on mean contribution of potential signal ($\bar{\mathcal{S}}_s$)

- assumptions for signal events which are added to the toys as signal:
  - same BR for ee and $\mu\mu$ in SUSY events and NO contribution of $e\mu$

	$\mathcal{S} > \mathcal{S}_{obs}$ (%)	Limit $\bar{\mathcal{S}}_s$ (95% C.L.)
FS-SR1	46	88
FS-SR2	7	156
FS-SR3	77	4.9

Summary

- Analysed first 1.04 fb^{-1} of ATLAS data from 2011 runs
- Presented 3 different 2-lepton + E_T^{MISS} analyses:
  - Opposite Sign(OS)
  - Same Sign(SS)
  - Flavour Subtraction (FS)

- All SM backgrounds are evaluated
- Most relevant backgrounds are estimated from data or with semi-data driven techniques
  - Fake leptons, $t\bar{t}$, Z+jets

- OS and SS: no excess observed $\rightarrow$ Limits set on $A \times \epsilon \times \sigma$

- FS: no FS excess observed $\rightarrow$ Limits set on $\bar{\mathcal{S}}_s$

- no new physics found so far...

Discussions

Discussion – Experiment vs Theory

CMS provides also limits on the excess of same flavor events dependent on the mass edge position

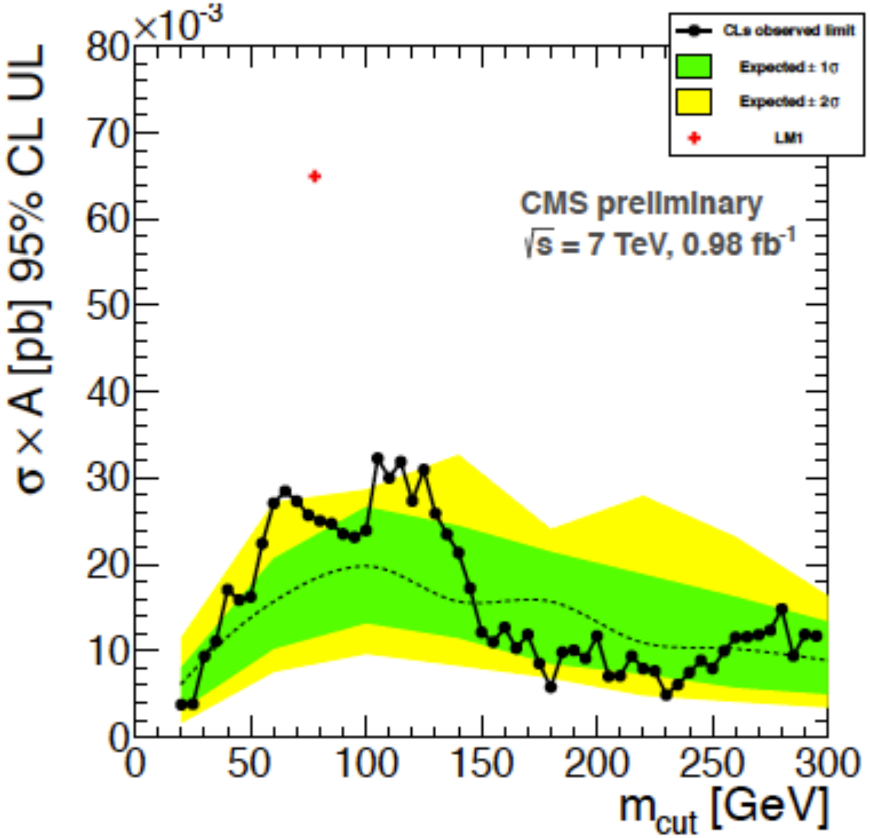


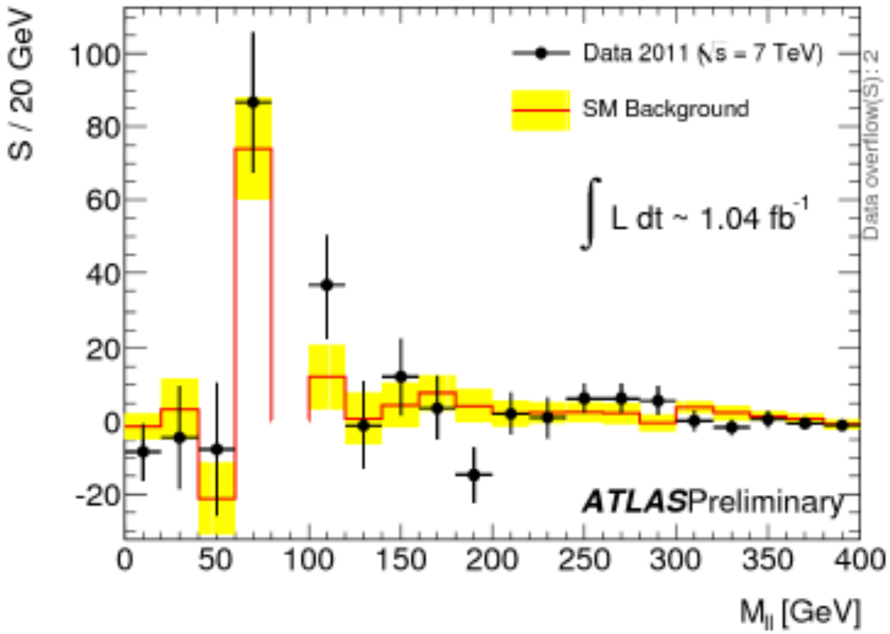
Figure 6: CL_S 95% confidence level upper limit on cross-section times acceptance as a function of the endpoint in the invariant mass spectrum assuming a triangular shaped signal.

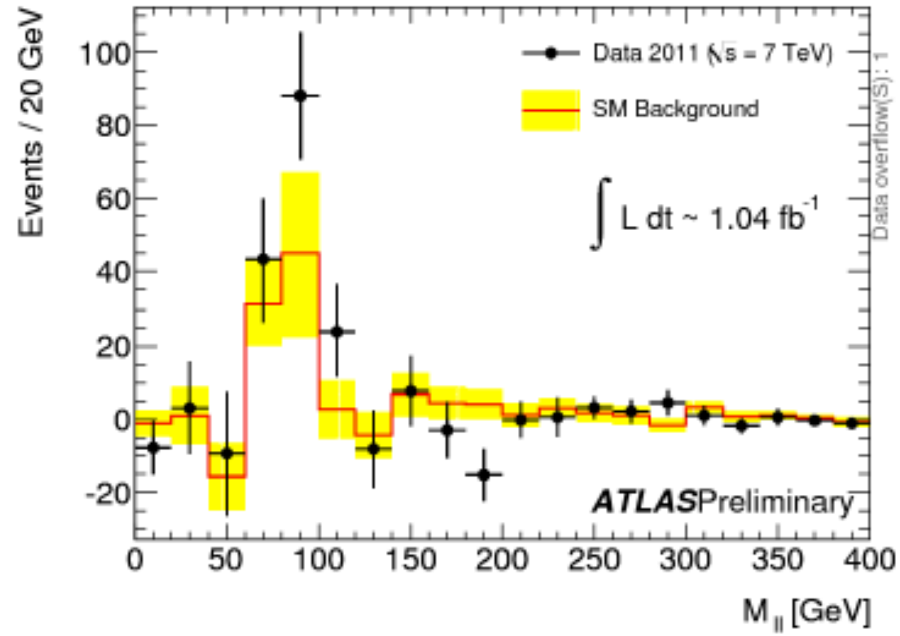
How useful can these nice results be to theorists ?
Ideas for providing the most useful experimental results are welcome !

Discussion – Experiment vs Theory

2 signal regions :

1) Etmiss > 80 GeV and Z peak veto (80-100)
2) Etmiss > 80 GeV, jets pT > 20, 20 GeV/c

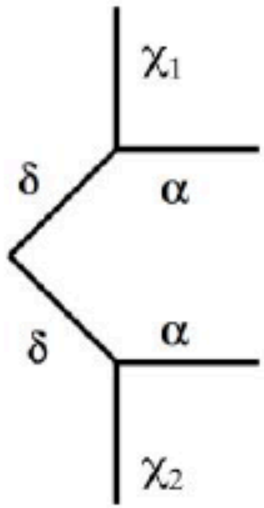




Is it useful to provide limits per bin in mass ?

Back-up

$t\bar{t}$ Background (OS): Contransverse Mass Tagger



- In the decay of a two pair-produced heavy states δ which decay via $\delta \to \alpha\chi_i$:
$$m^2_{CT}(\chi_1, \chi_2) = [E_T(\chi_1) + E_T(\chi_2)]^2 - [\mathbf{p_T}(\chi_1) - \mathbf{p_T}(\chi_2)]^2$$
- m_{CT} distributions have endpoints defined by $m(\delta)$, $m(\alpha)$ and the vector sum of transverse momenta of the visible particles upstream of the system for which the contransverse mass is calculated (p_b)
- For the $t\bar{t}$ system $m_{CT}(\ell\ell)$, $m_{CT}(jj)$, $m_{CT}(j\ell, j\ell)$ can be constructed

Contransverse mass tagger

1. Event with least 2 jets with $p_T > 20$ GeV
2. Consider all 2 jet permutations j_1, j_2, such that the two jets have $p_T > 20$ GeV and $p_T(j_1) + p_T(j_2) + p_T(\ell_1) + p_T(\ell_2) > 100$ GeV
3. $m_{CT}(\ell_1, \ell_2)$ in the allowed area of the $(m_{CT}(\ell_1, \ell_2), p_b(\ell\ell))$ plane
4. Build all pairs $((j_i\ell_1)(j_j\ell)_2)$ such that $m(j_i\ell_1) < 155$ GeV and $m(j_j\ell_2) < 155$ GeV
5. One combination with $m_{CT}(jj)$ in the allowed area of the $m_{CT}(jj)$, $p_b(jj)$ plane
6. $m_{CT}(j\ell, j\ell)$ should be compatible with $t\bar{t}$

- m_{CT} tagger has an efficiency of 85% in signal region
- Control region for $t\bar{t}$ estimation:
  - m_{CT}-tagged events
  - $60 < E_T^{miss} < 80$ GeV