Ricerche di SUSY in canali leptonici in ATLAS

P. Dondero and M. Reale

On behalf of the SUSY Italia group

X ATLAS Italia Workshop on Physics and Upgrades
Milano, 12-02-2015

Overview

- Introduction
  - Why SUSY? Why stop?
  - SUSY Italia team
- Overview of RUN I results
  - 2014 published analyses
  - Ongoing analyses
- Plans for RUN II
- Conclusion

Why SUSY? Why stop?

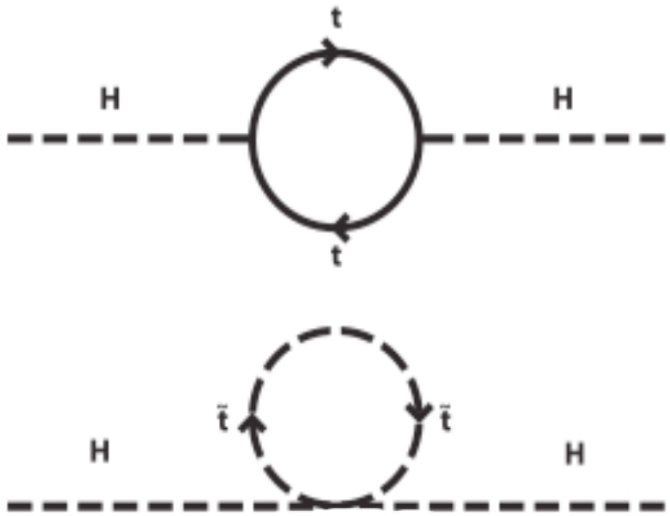
- **SUSY**: one of the **most promising extensions** of the Standard Model

- It can **potentially** solve many physics riddles:

  one of these is the **hierarchy problem for the Higgs boson mass (SM naturalness problem)**

  - **the largest divergent contribution comes from top quark loop**
  - **cancellation** of quark loops with the corresponding squark loops

  a **quite light stop is needed**



- two mass eigenstates, $\tilde{t}_1$ and $\tilde{t}_2$
- $m(\tilde{t}_1) < m(\tilde{t}_2)$ and $\tilde{t}_1$ significantly lighter than the other squarks.
- **charginos** $\tilde{\chi}^{\pm}_{i=1,2}$ and **neutralinos** $\tilde{\chi}^{0}_{i=1,2,3,4}$: mass eigenstates from the combination of the SUSY partners of the Higgs boson and of the electroweak gauge bosons.

The SUSY Italia team during RUN I

- **Lecce**: M. Bianco (now at CERN), E. Gorini, L. Longo, M. Primavera, M. Reale and A. Ventura
- **Milano**: M.I. Besana, A. Favareto, T. Lari, G. Lerner, F. Meloni C. Rizzi and C. Troncon
- **Pavia**: P. Dondero, G. Gaudio and G. Polesello
- **Udine**: S. Brazzale and M.P. Giordani

+ collaboration with S. Darmora (Texas), G.Usai (Texas), S. French (Cambridge) and M. White (Melbourne).

- Different analyses concerning stop research
- Remarkable part of work shared: sample production, cut-flows, code maintenance, estimation of fake leptons...

...and a lot of results achieved!

4 published paper during RUN I:

- Search for supersymmetric particles in events with lepton pairs and large missing transverse momentum in $\sqrt{s}$ = 7 TeV proton-proton collisions with the ATLAS experiment.
  Eur.Phys.J.C 71 (2011) 1682
- Searches for supersymmetry with the ATLAS detector using final states with two leptons and missing transverse momentum in $\sqrt{s}$ = 7 TeV proton-proton collisions.
  Phys. Lett. B709 (2012) 137-157
- Search for a heavy top-quark partner in final states with two leptons with the ATLAS detector at the LHC.
  JHEP 1211 (2012) 094
- Search for direct top-squark pair production in final states with two leptons in pp collisions at $\sqrt{s}$ =8TeV with the ATLAS detector.
  JHEP 06 (2014) 124

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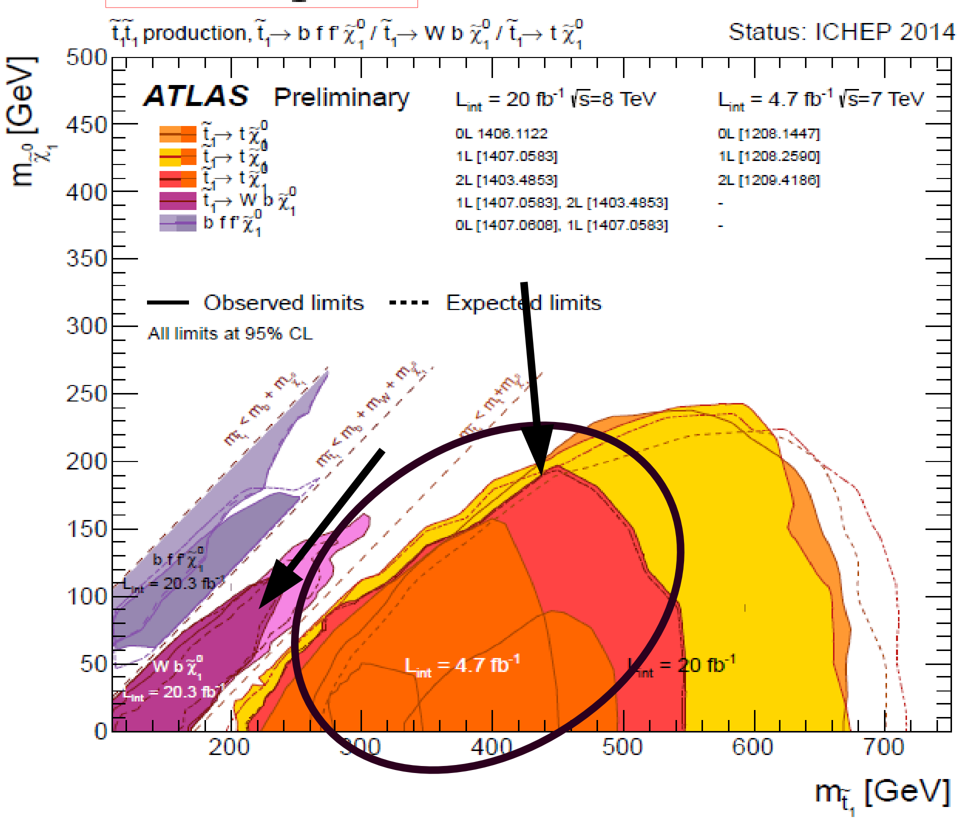
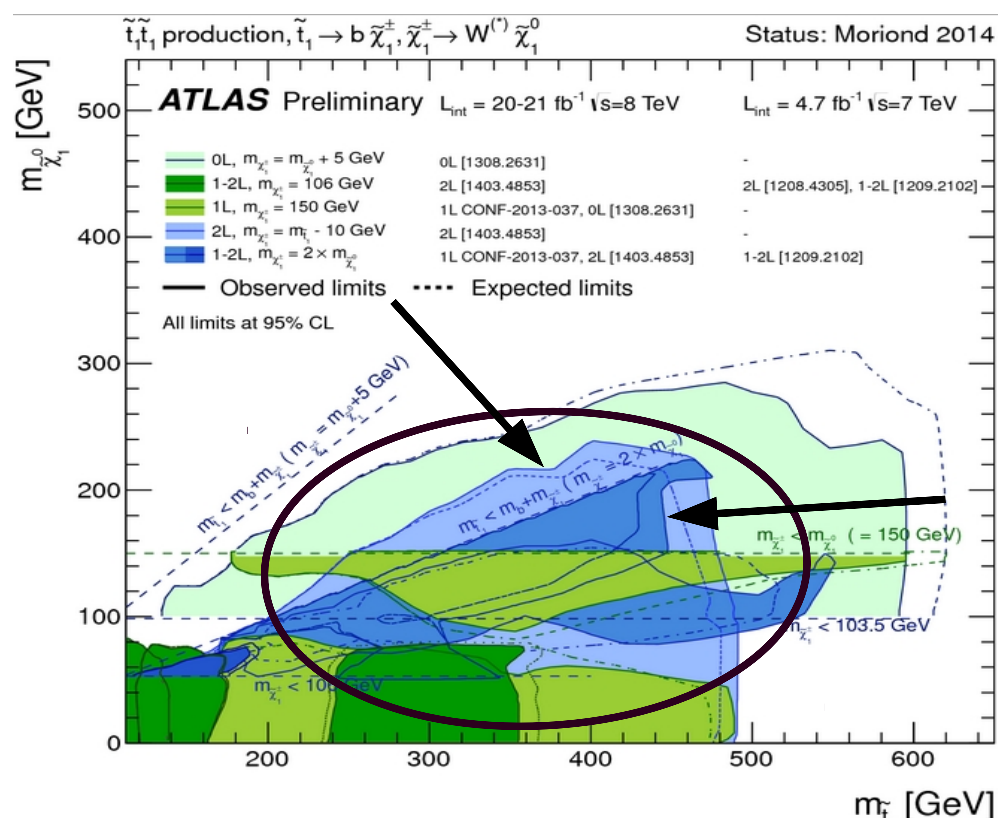
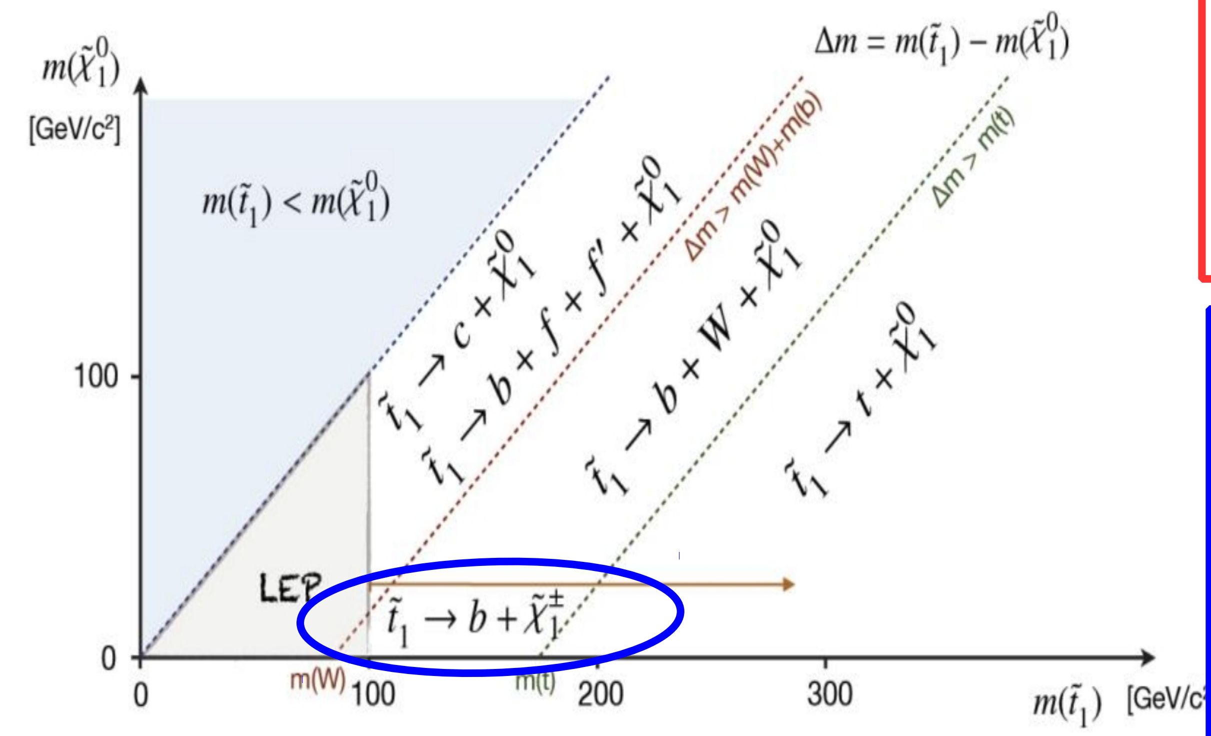


$$\tilde{t}_1 \rightarrow \tilde{\chi}_1^{\pm} + b \qquad \tilde{\chi}_1^{\pm} \rightarrow W^{(*)}\tilde{\chi}_1^0$$



2014 published analyses

Stop in two leptons final states



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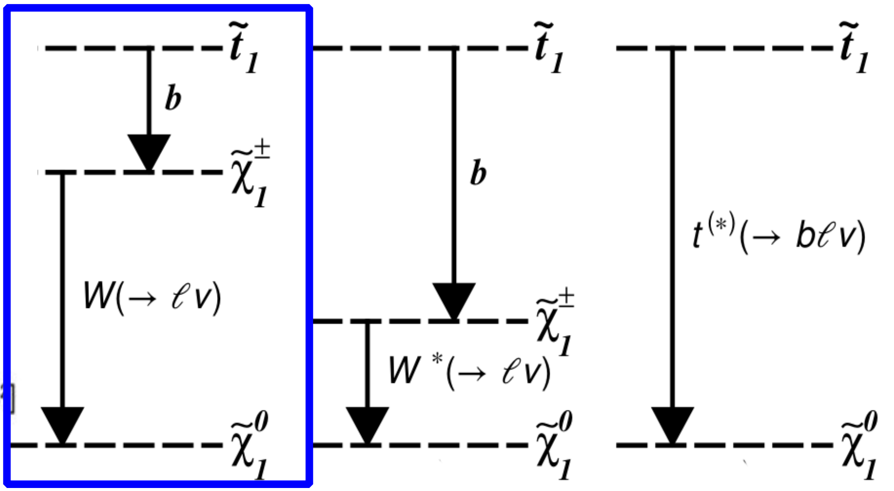


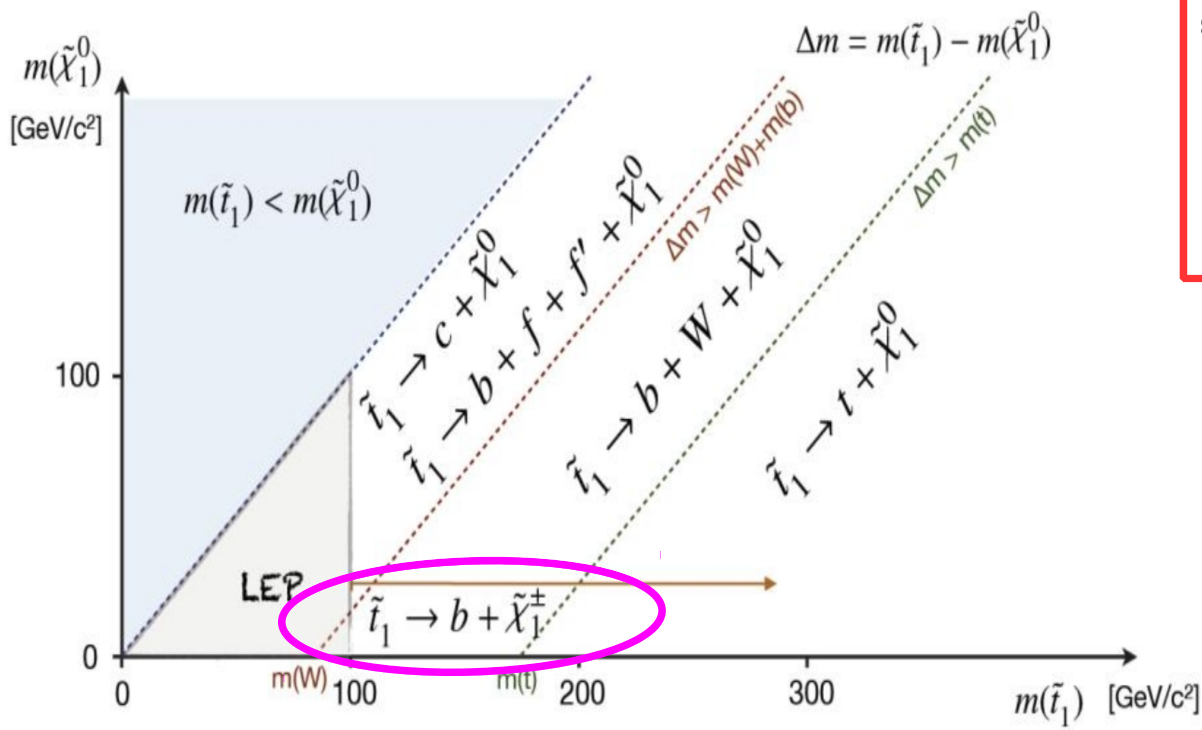
3 different analyses sensitive to different stop decays (depending on **different mass hierarchy):**

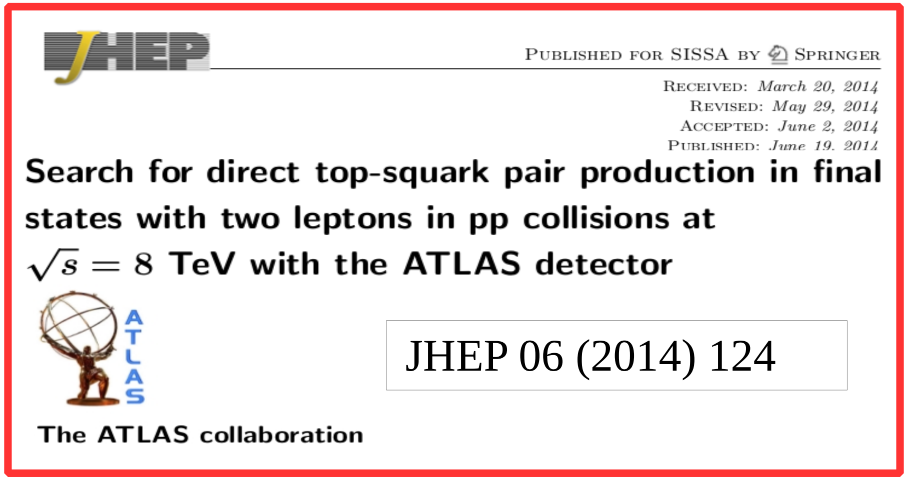
- **leptonic m_{T2}**
- hadronic m_{T2}
- multivariate analysis (MVA)

COMMON FINAL STATE SIGNATURE:

- 2 opposite sign leptons (e, μ)
- 2 b-jets
- E_T^{miss} from ν and $\tilde{\chi}_1^0$

Stop in two leptons final states

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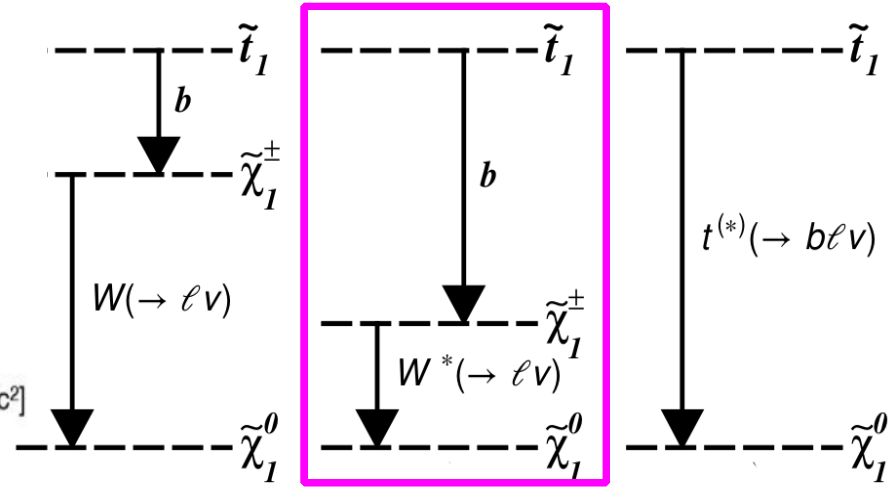


3 different analyses sensitive to different stop decays (depending on **different mass hierarchy):**

- leptonic m_{T2}
- **hadronic m_{T2}**
- multivariate analysis (MVA)

COMMON FINAL STATE SIGNATURE:

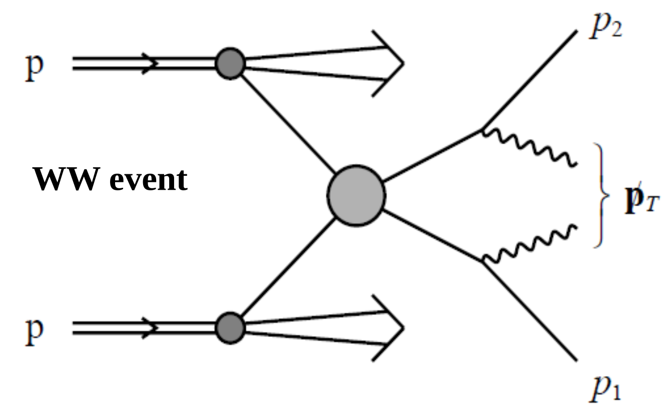
- 2 opposite sign leptons (e, μ)
- 2 b-jets
- E_T^{miss} from ν and $\tilde{\chi}_1^0$

Leptonic and hadronic m_{T2} variables

m_{T2} :generalized transverse mass for systems **with 2 invisible particles.** m_{T2} has an end-point at the true mother mass: m_{T2}<m(mother particle)

$$\boxed{m_{T2}(\vec{p}_T^{(1)},\vec{p}_T^{(2)},\vec{v}_T) = \min_{\vec{q}+\vec{r}=\vec{v}_T}\left\{\max[m_T(\vec{p}_T^{(1)},\vec{q}), m_T(\vec{p}_T^{(2)},\vec{r})]\right\}}$$

take the max of m_T and minimize over all possible 2 missing momenta such that their sum gives the observed missing transverse momentum



LEPTONIC m_{T2}

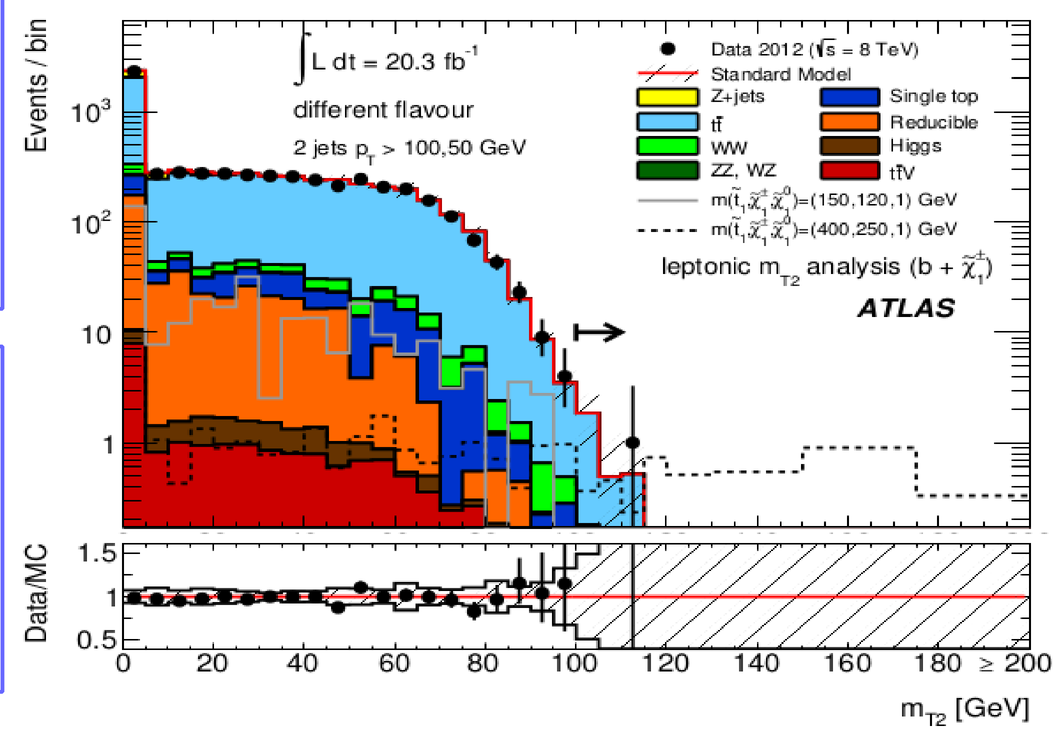
m_{T2} evaluated with 2 leptons $\vec{p}_T$ and $\vec{v}_T=\vec{E}_T^{miss}$

- $t\bar{t}$ or WW events have end-point at the W mass
- SUSY events with higher end-point because of neutralinos' presence

HADRONIC m_{T2}

m_{T2} evaluated with 2 jets $\vec{p}_T$ and $\vec{v}_T=\vec{E}_T^{miss}+\vec{p}_T^{lep1}+\vec{p}_T^{lep2}$

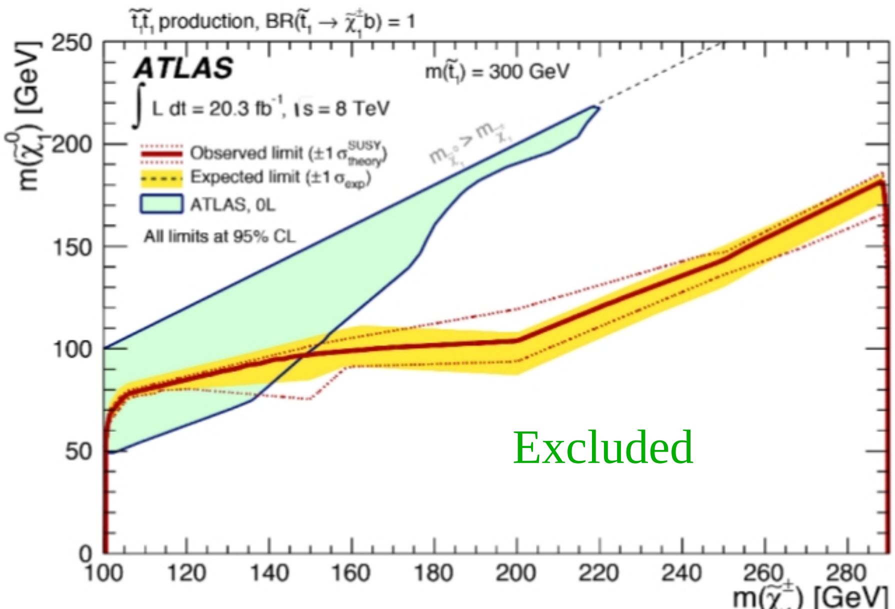
- $t\bar{t}$ events have end-point at the t mass
- For SUSY events $m_{T2}^{b-\text{jet}}$strongly correlated to the stop-chargino mass difference

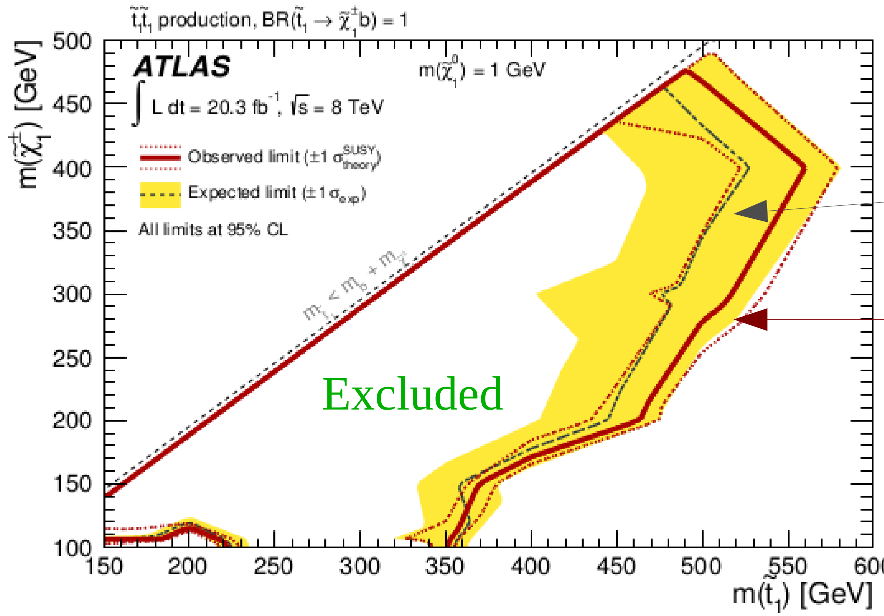


Leptonic and hadronic m_{T2} results combination: **exclusion plots**

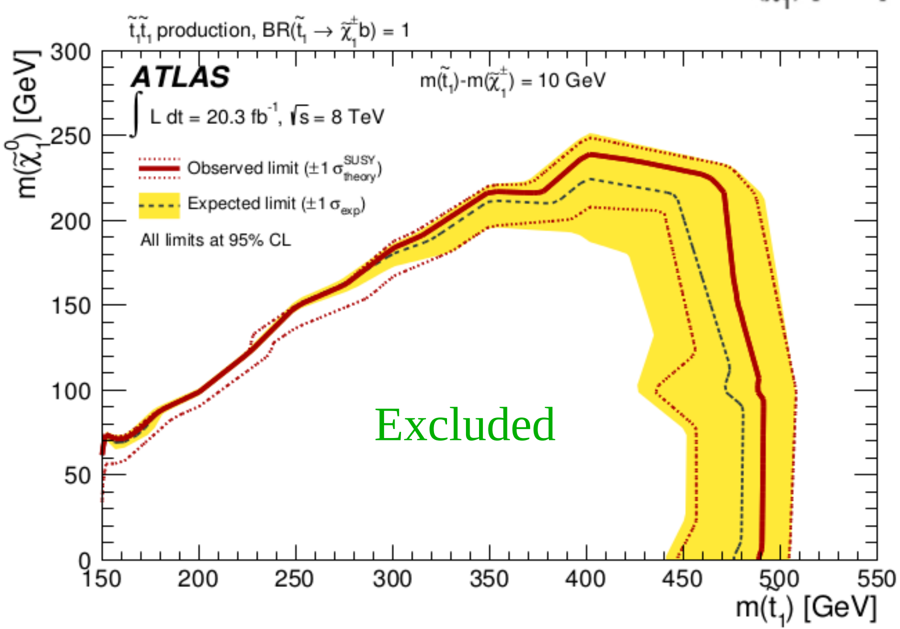
Exclusion in 3-dimensional mass parameter space $\rightarrow$ quantified through various 2-dimensional exclusion contour plots

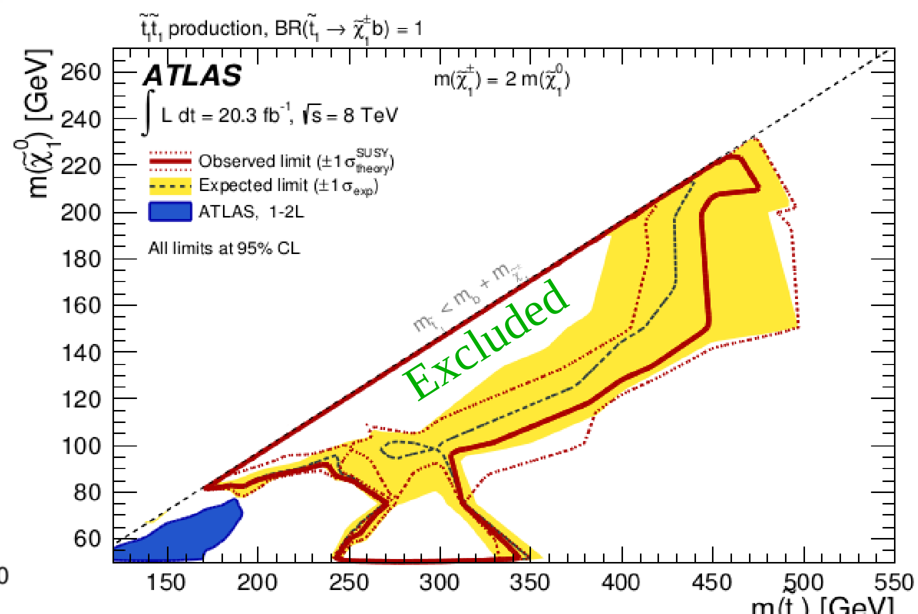
$$m(\tilde{t}_1), m(\tilde{\chi}_1^{\pm}), m(\tilde{\chi}_1^0)$$





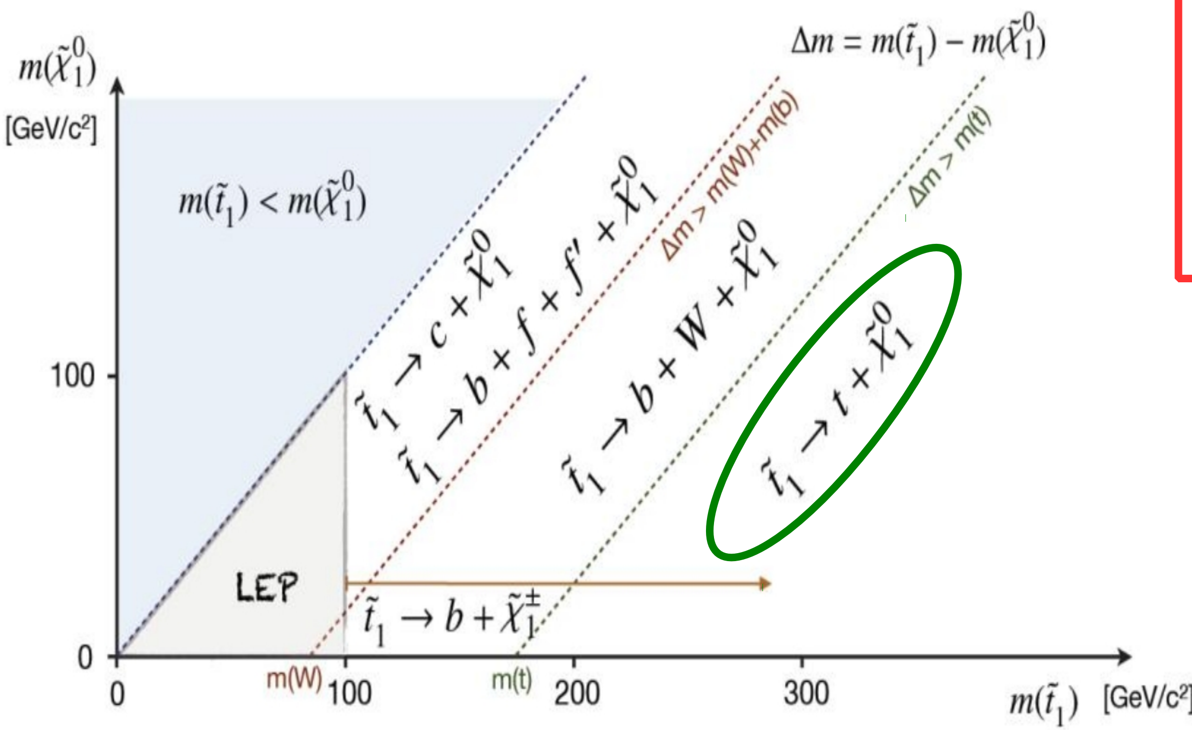
Expected and observed 95% CL limits

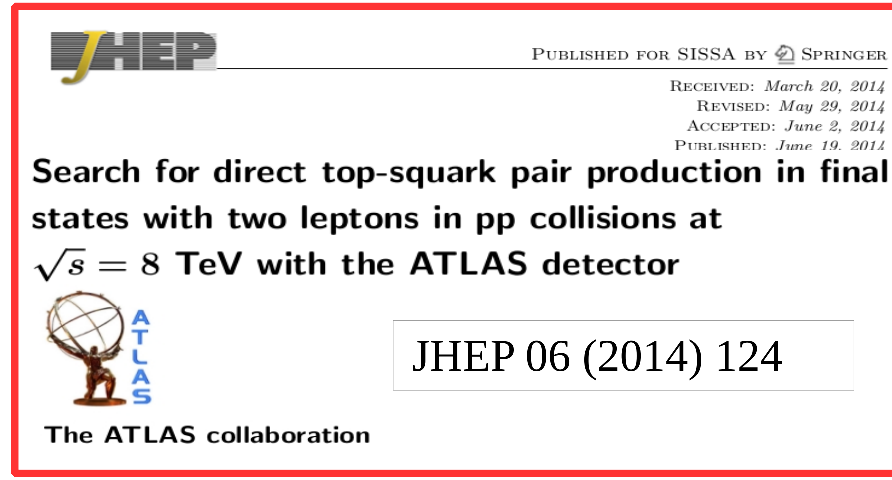




Contribution from **hadr MT2** is provided for $m(\tilde{t}_1)$=300 GeV

Stop in two leptons final states

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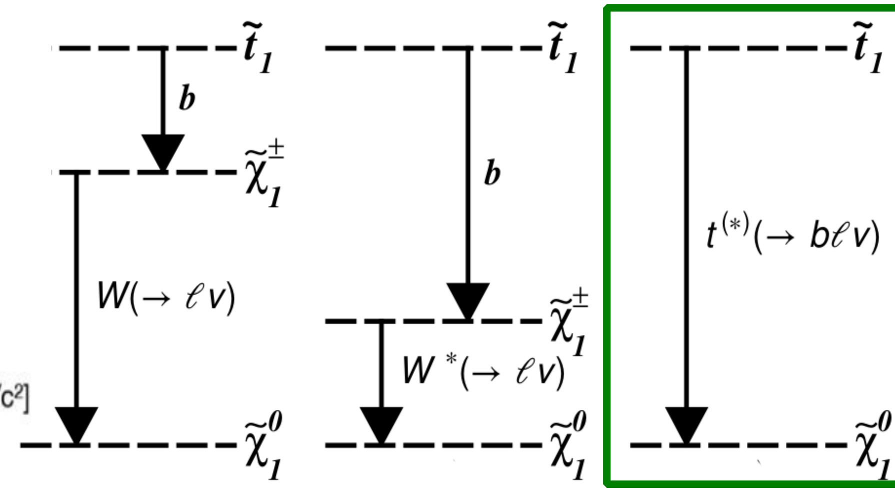


3 different analyses sensitive to different stop decays (depending on **different mass hierarchy):**

- leptonic m_{T2}
- hadronic m_{T2}
- **multivariate analysis (MVA)**

COMMON FINAL STATE SIGNATURE:

- 2 opposing sign leptons (e, μ)
- 2 b-jets
- E_T^{miss} from ν and $\tilde{\chi}_1^0$

Multivariate analysis

$$\tilde{t}_1\bar{\tilde{t}}_1 \to t\tilde{\chi}_1^0\ \bar{t}\tilde{\chi}_1^0 \to bW^+\tilde{\chi}_1^0\ \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0\ \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

Multivariate analyses can provide in some cases better signal to background discrimination wrt standard cut based analyses

TRAINING E TESTING

Simulated signal and background samples as input. Divided in:

Training sample:
Used to teach the discriminant method how to distinguish signal from background

Testing sample:
Used to check the method performance

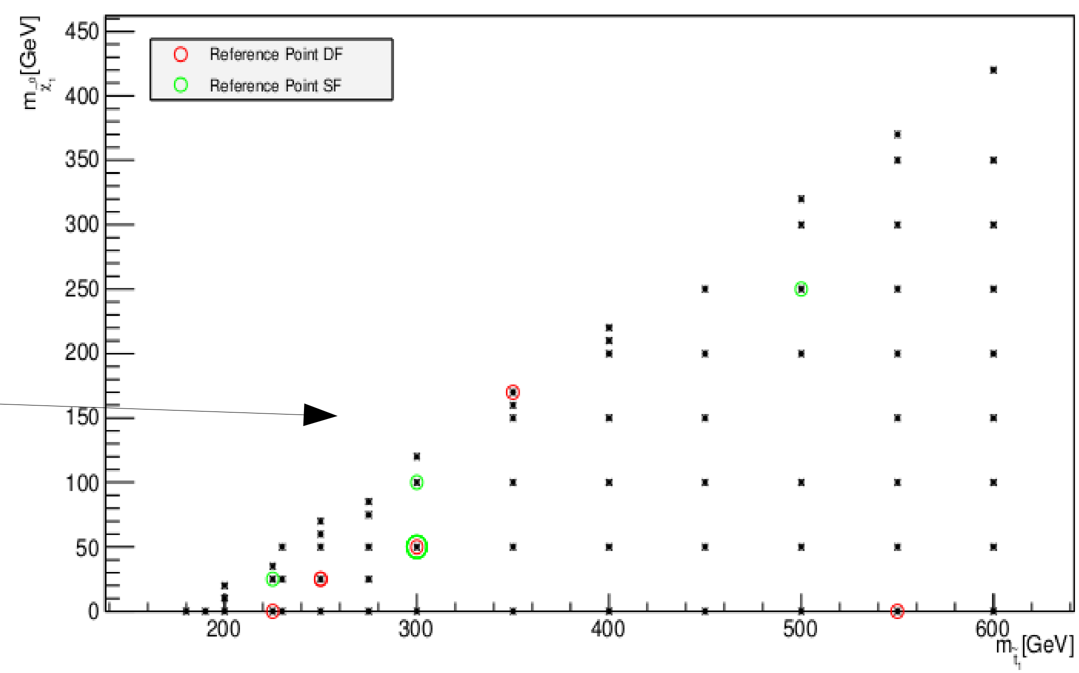
APPLICATION

Assuming that the method has learned the difference between signal and background, it is applied to the analysis sample (which contains a signal-background mixture)

Output: classifier value for each analyzed event

- Discriminant method: Boosted Decision Tree with Gradient Boosting **BDTG**
- **7 input variables (m_{T2} , E_t^{miss} ...)**

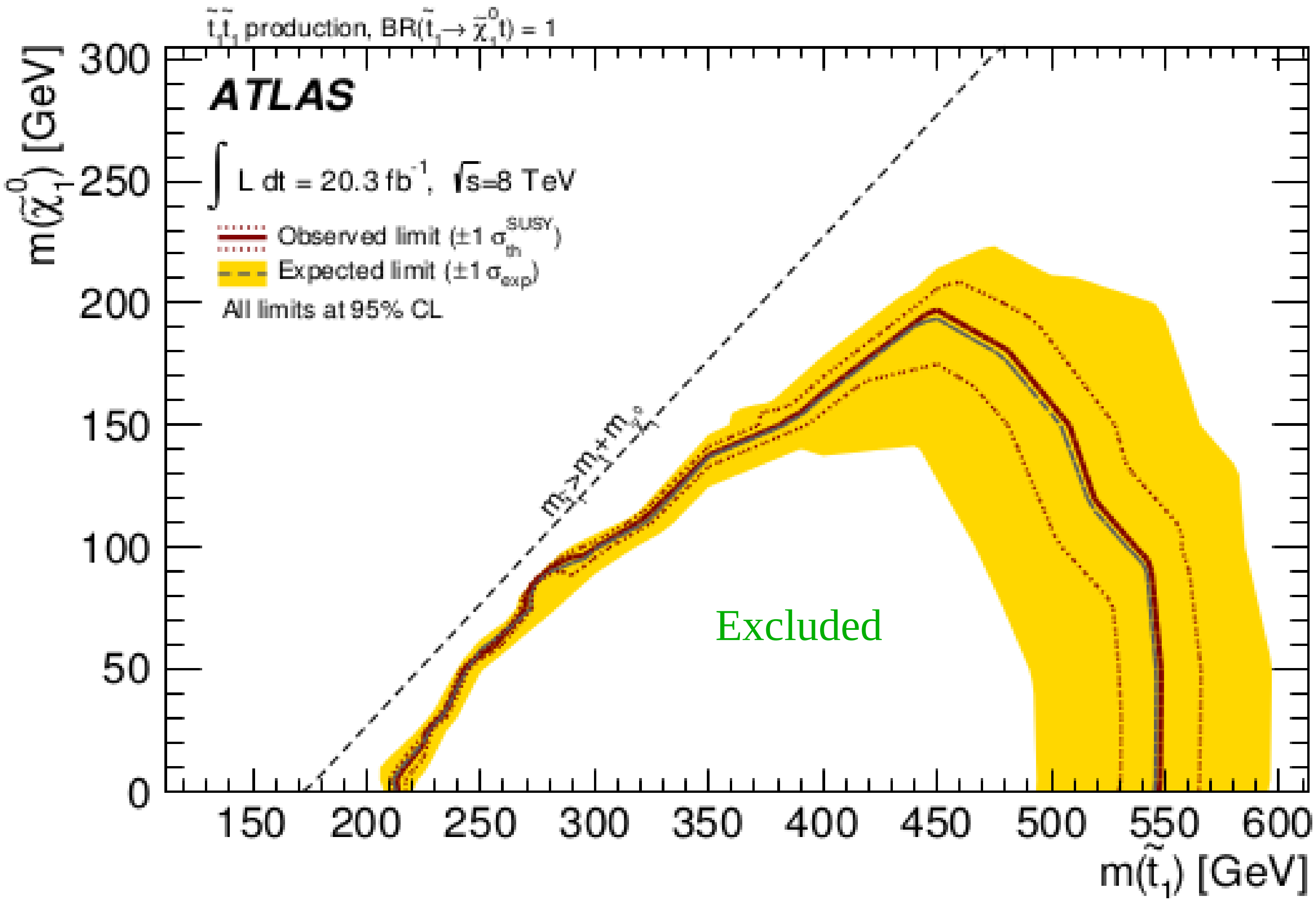
- **Training** procedure optimized to target different regions: selected 8 grid points
- Different **BDTG cuts tuned** to define **different signal regions**



Multivariate analysis

$$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow t\tilde{\chi}_1^0 \ \bar{t}\tilde{\chi}_1^0 \rightarrow bW^+\tilde{\chi}_1^0 \ \bar{b}W^-\tilde{\chi}_1^0 \rightarrow b\nu_l l^+\tilde{\chi}_1^0 \ \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

Exclusion limit at 95% CL



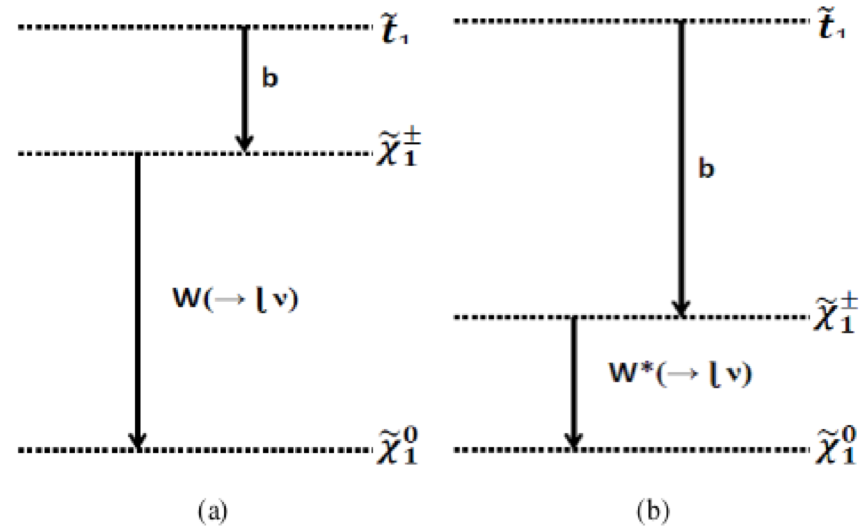
RUN I ongoing analyses

Stop decaying in b+chargino with MVA

$$\tilde{t}_1\bar{\tilde{t}}_1 \to b\tilde{\chi}_1^+ \; \bar{b}\tilde{\chi}_1^- \to bW^+\tilde{\chi}_1^0 \; \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0 \; \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

Final states signature:

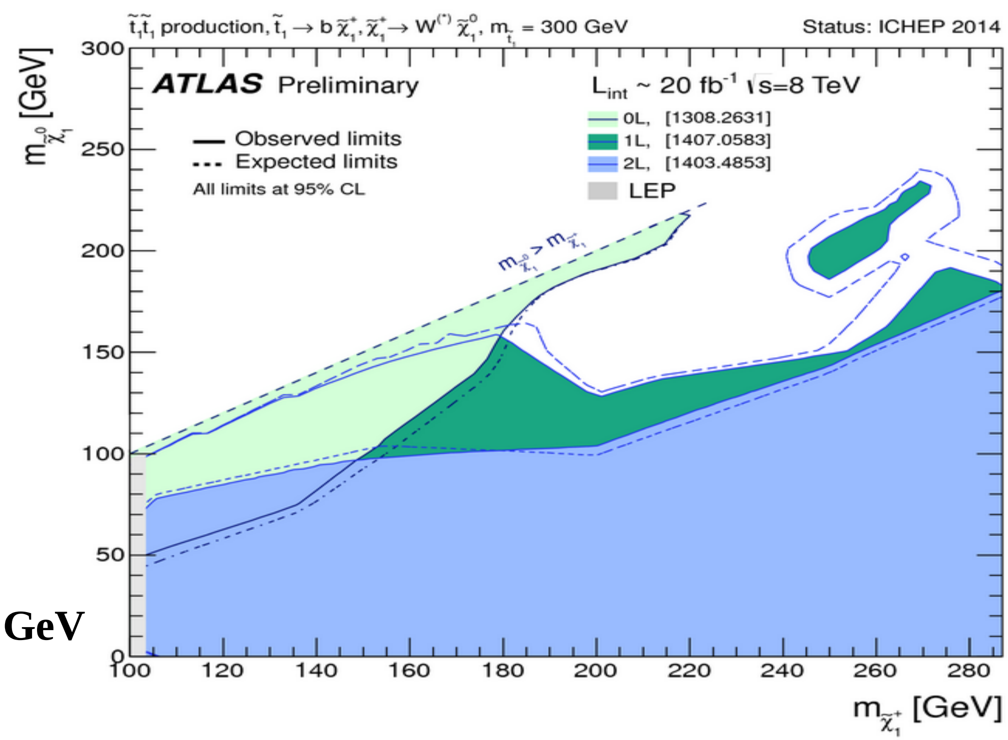
- 2 opposite sign leptons (e, μ)
- 2 b-jets
- E_T^{miss} from ν and $\tilde{\chi}_1^0$



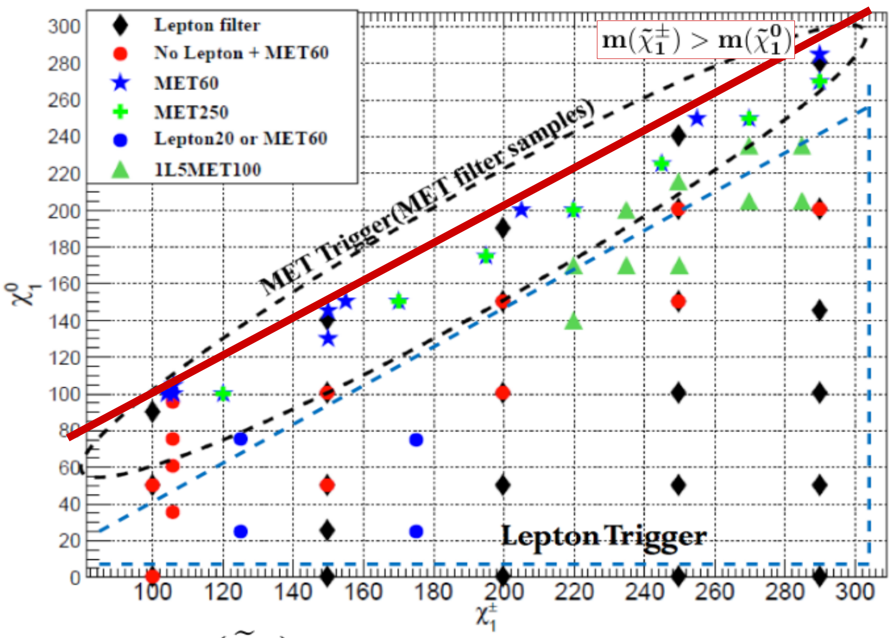
already analyzed physics process **with a standard cut&count approach**

PURPOSE:
apply the **MVA technique** to **improve sensitivity** and thus **cover the still unexcluded regions** in $m(\tilde{t}_1)$, $m(\tilde{\chi}_1^\pm)$ and $m(\tilde{\chi}_1^0)$ parameters space

$m(\tilde{t}_1)$ **set to 300 GeV**



Stop decaying in b+chargino with MVA



$m(\tilde{t}_1)$ **set to 300 GeV**

- Decay kinematics depend upon the mass hierarchy
- **2 complementary strategies** to be sensitive to all the possible mass splittings:

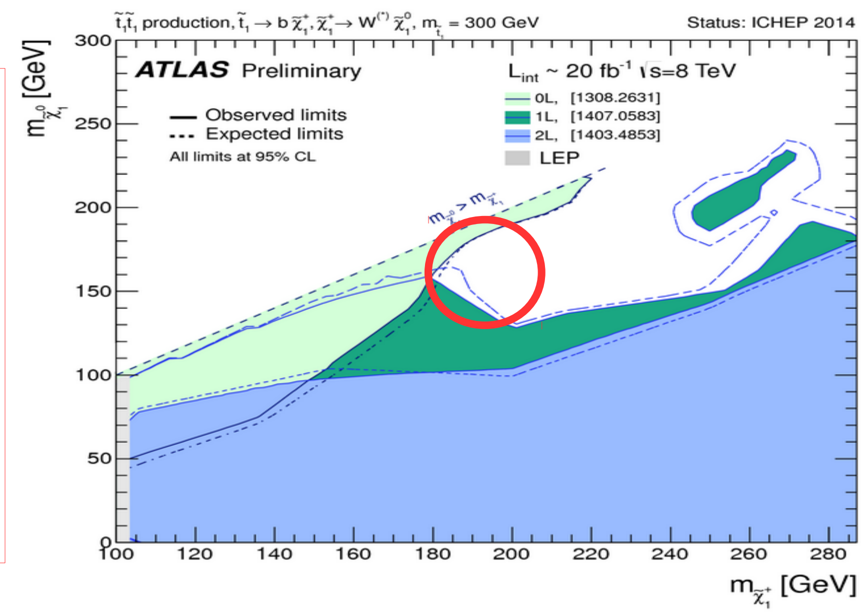
◆ with **LEPTON trigger** **HARD LEPTONS**
(at least 1 lepton with p_T>25 GeV)
→ **target** $m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0) > m(W)$

★ **with MET trigger** **SOFT LEPTONS**
(E_T^{miss} > 120 GeV)
→ **target** $m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0) < m(W)$

MVA TECHNIQUE APPLIED → BDTG

- **11 variables chosen** after several tests
- fake leptons estimation aimed to soft leptons scenario (M. Aliev from Lecce)

PRELIMINARY RESULTS:
the analysis seems to be promising to target the region still uncovered

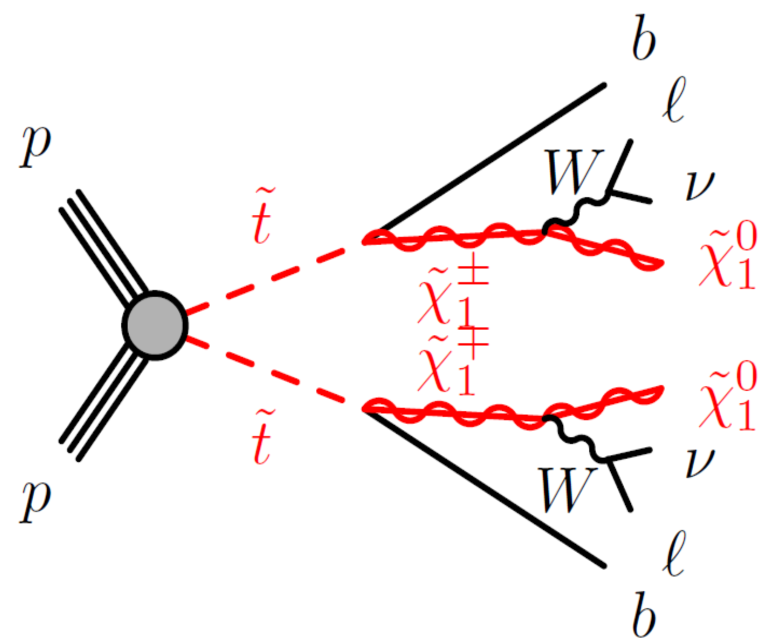


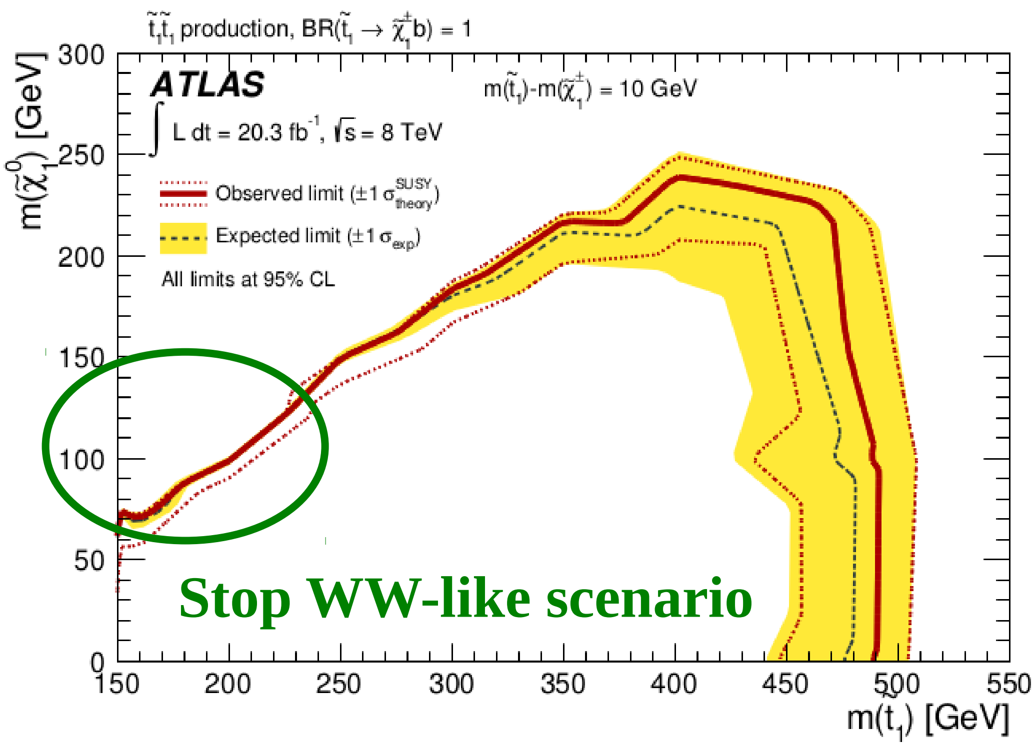
WW-like analysis

Address regions uncovered by previous analysis.

- Stop → 2-lep + 2b + E_t^{miss} focusing on the region
  1) m_{stop}-m_{ch} < 30 GeV
  2) m_{ch}-m_{neu} < 100 GeV
  3) m_{stop} < 200 GeV

- Use leptonic m_{T2} to select region in (m_{stop}-m_{neu})



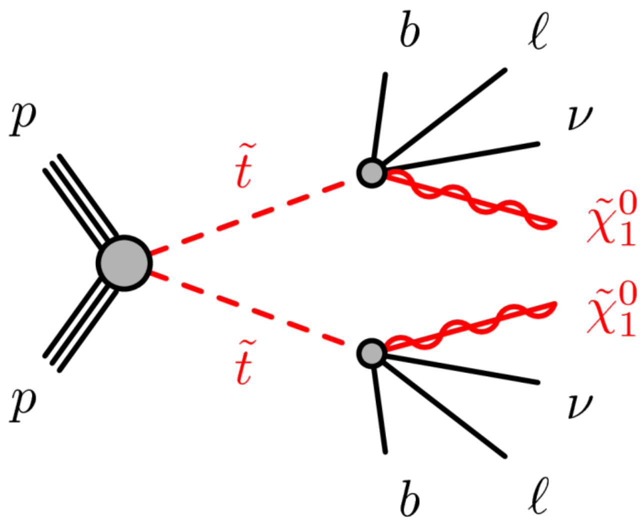


In this region signal is similar to WW production and may be the reason of the WW "excess" observed in the cross section measurement of many analyses.

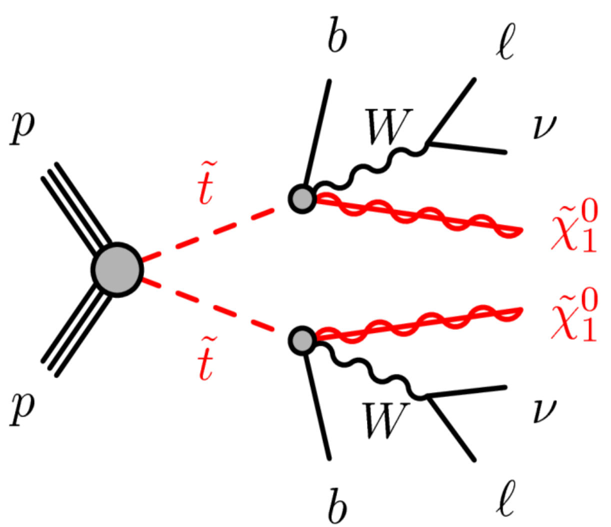
WW-like analysis

Address regions uncovered by previous analysis.

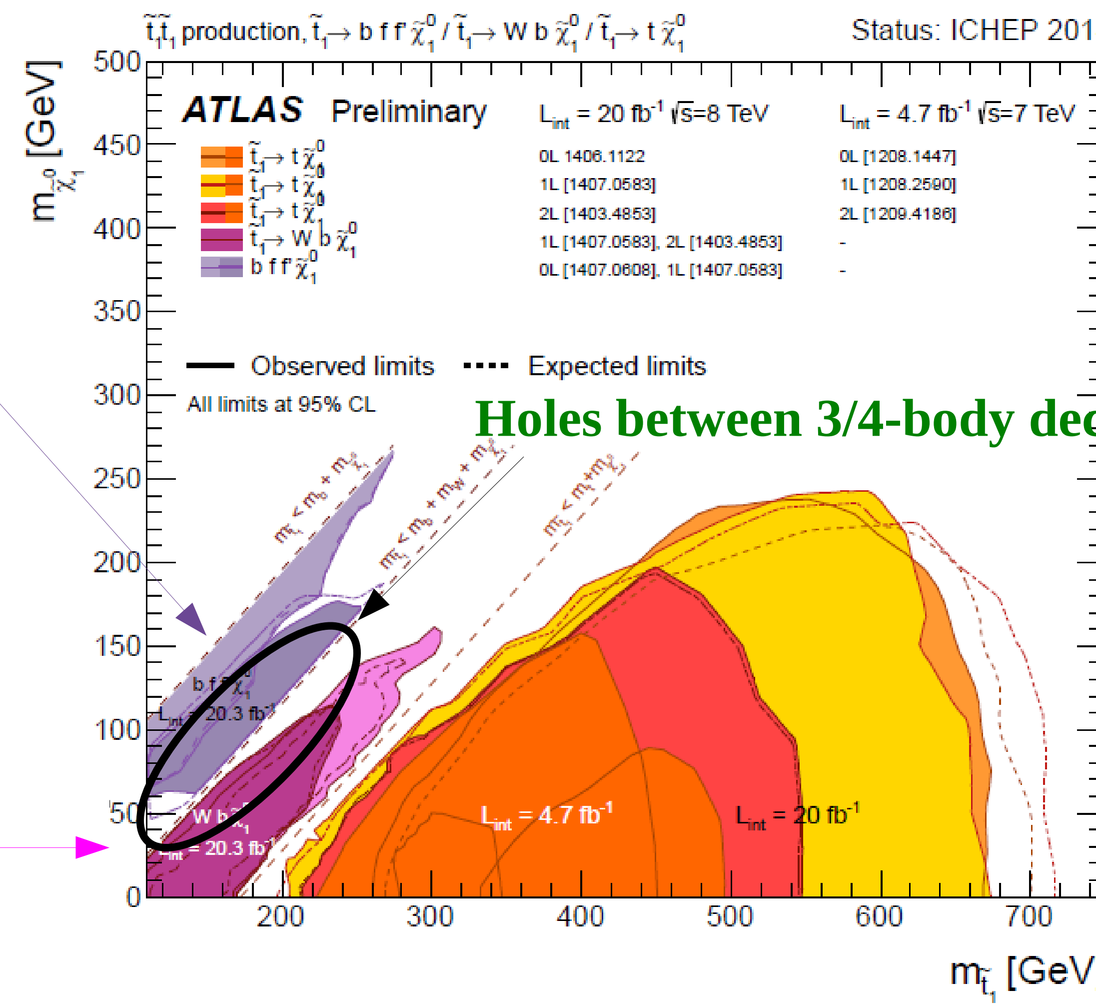
- Also sensitive to the interface region between 3 and 4 body stop decay



4-body decay



3-body decay



Holes between 3/4-body decay

WW-like analysis

Analysis in advanced status: supporting note approved by the SUSY group, will be part of the third generation Summary paper.

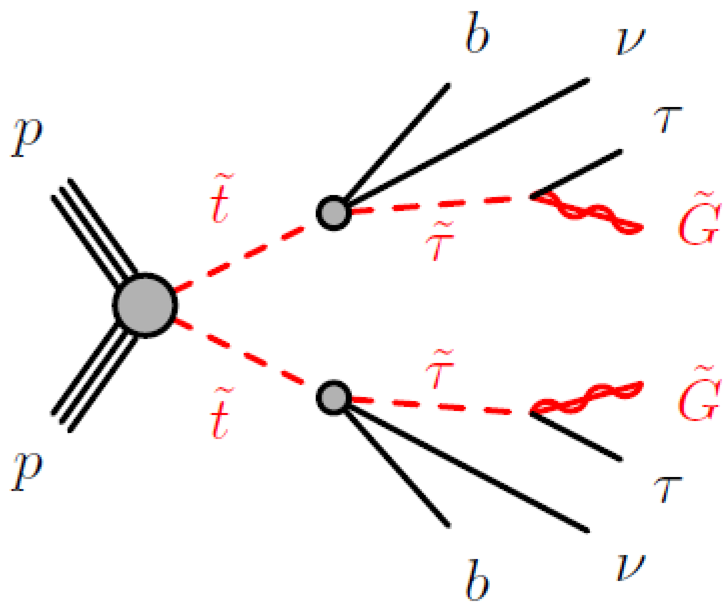
Important preliminary results achieved:

- ✓ Good coverage of the holes between the stop 3-body and 4-body decay
- ✓ WW-like stop decay exclusion preliminary results cover a significant part of the light stop region addressed as a candidate to explain the possible WW excess
- ✓ Contribute to the combined 4-body decay upper limit for the summary paper

ATLAS note: ATL-COM-PHYS-2014-754

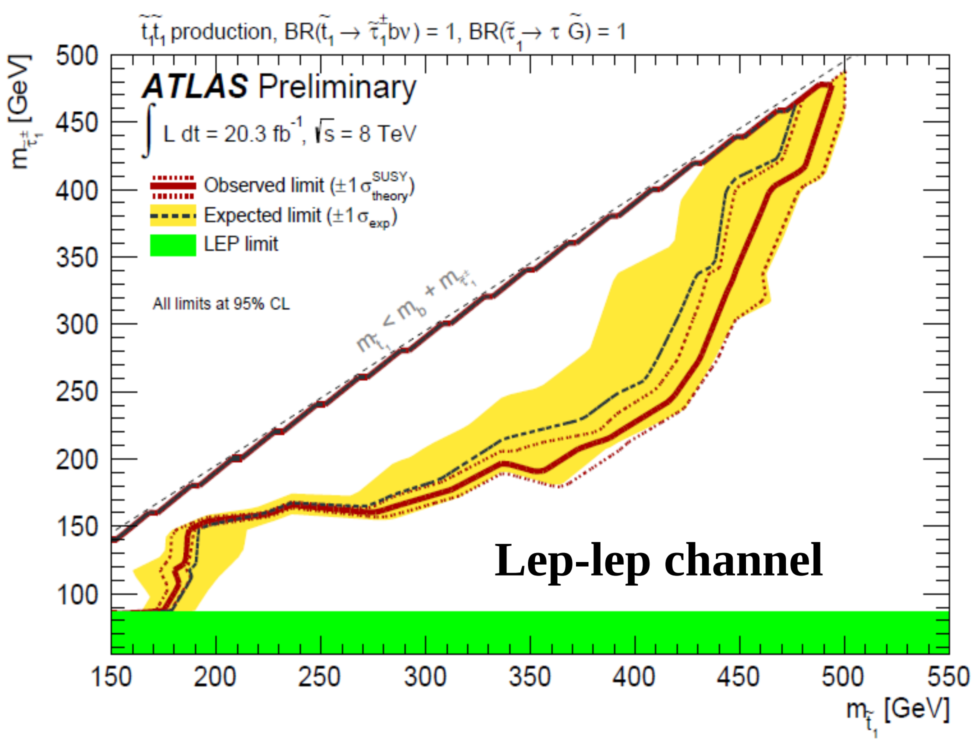
Stop in stau analysis

If sleptons are lighter than stops...



Natural Gauge Mediation theory inspired model with gravitino Lightest SUSY Particle, stau NLSP and stop NNLSP.

Could have escaped current analyses (tau vetoes, top mass cuts...can suppress this kinematics)



- <u>2-lepton channel</u>: ATLAS-CONF-2014-014 (march 2014), concluded
- <u>lepton-hadron channel</u>: ATL-COM-PHYS-2014-890, note in CDS, just unblinded. Collaboration of Milano and other groups, planned paper combination with had-had channel

tb + E_T^{miss}

ATL-COM-PHYS-2014-912

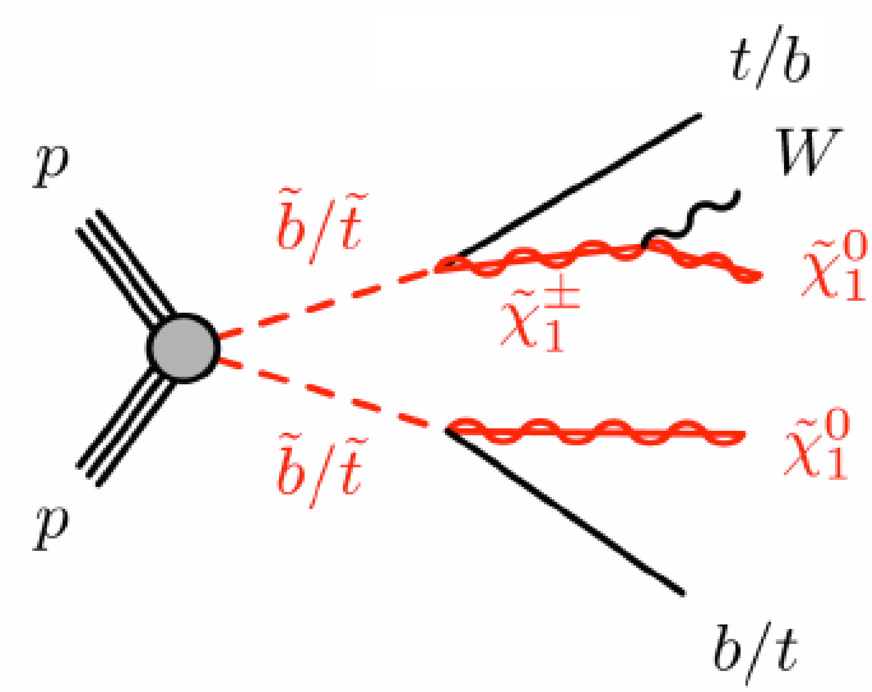
In models where neutralino is higgsino-like

$$m(\tilde{\chi}_1^{\pm}) \approx m(\tilde{\chi}_1^0)$$

$$\tilde{t}_1 \rightarrow \tilde{\chi}_1^{\pm} + b$$

$$\tilde{t}_1 \rightarrow \tilde{\chi}_1^0 + t$$

expected to have **similar BR.**



- Other analyses are optimized for $t\,\bar{t}$ or $b\,\bar{b}$ final states, but not for mixed ones.
- Several pMSSM and simplified models tested.

Collaboration of Milano, Sussex, Sheffield and Liverpool Universities. Will be part of the third generation summary paper. Probably not covered at beginning of RUN II.

RUN II studies

Plans and studies for RUN II

Stop 2-lepton channel team ready for RUN II !!

- **Lecce:** M. Aliev, M. Bianco (now at CERN), E. Gorini, L. Longo, M. Primavera, M. Reale and A. Ventura
- **Milano**: T. Lari and C. Merlassino
- **Pavia**: S. Carrà, P. Dondero, G. Gaudio and G. Polesello

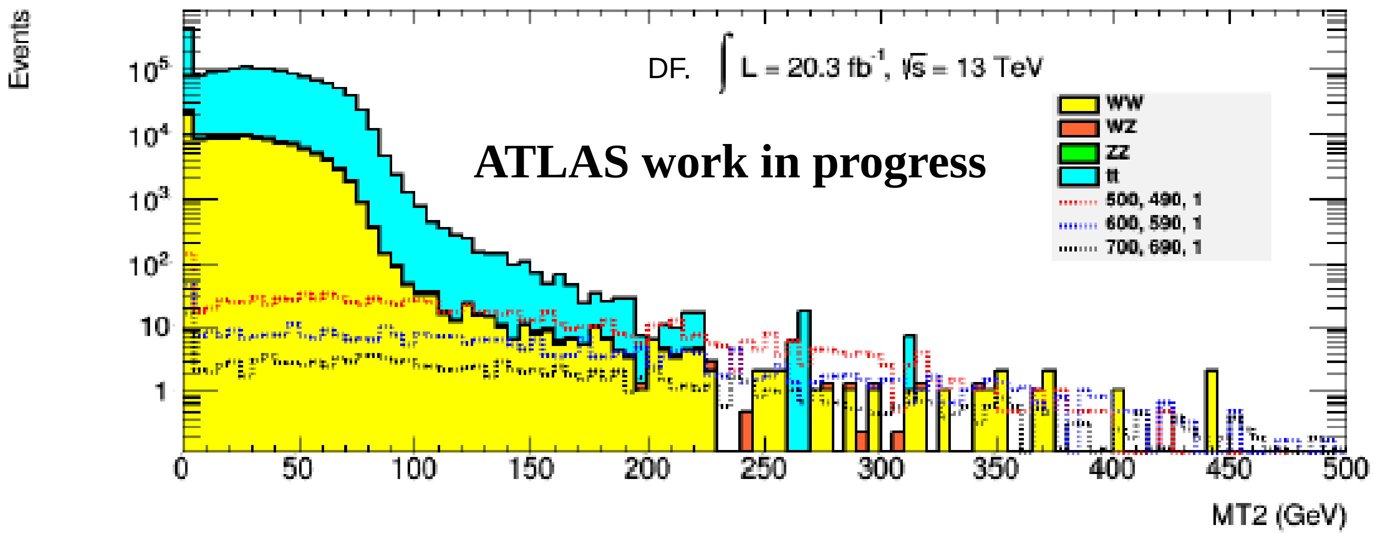
\+ other institutes: **Bern** (A. Cervelli, F. Meloni and M.E. Stramaglia), **Texas** (S. Darmora and G. Usai), **Technion**.

- ✓ Started biweekly informal meetings to work closely together
- ✓ Priority to the leptonic MT2 analysis with a cut and count approach. This analysis probes relatively heavy stops and it is a simple signature, so it is well suited for an early and robust analysis.
- ✓ Evaluation of MVA expected performance for RUN II
- ✓ First studies at 13TeV from Sonia and Giacomo, see next slides(continuing the work by L. Rossini at Milano 3th gen. workshop).

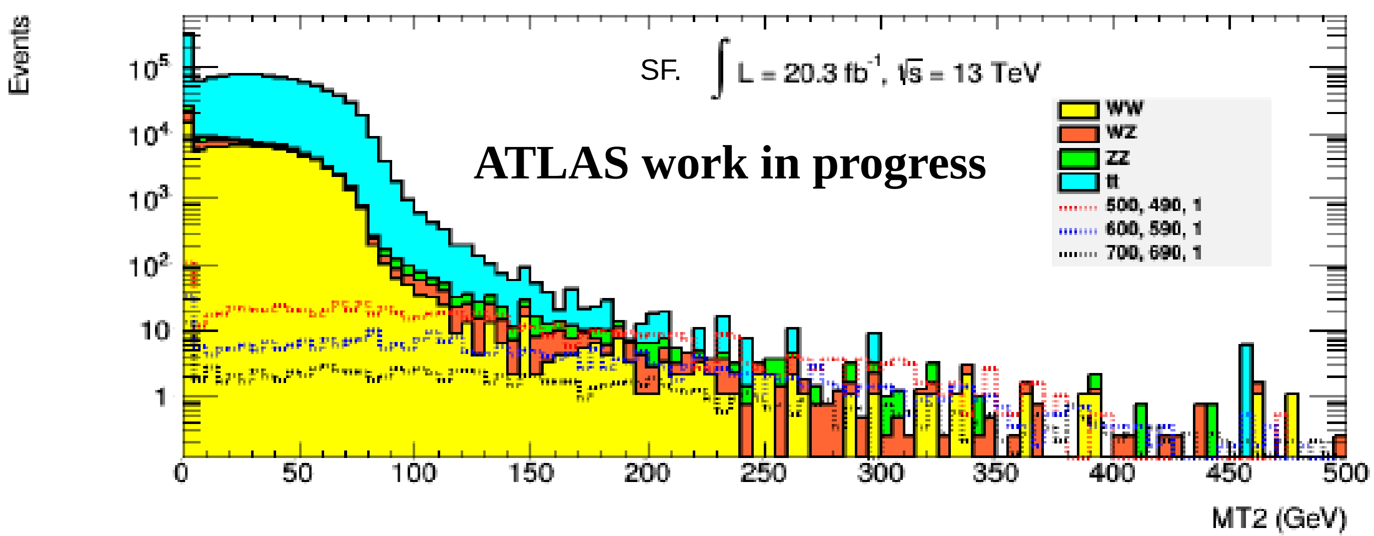
Plans and studies for RUN II

$$\tilde{t} \rightarrow \tilde{\chi}^{\pm} + b \rightarrow \tilde{\chi}^{0} + W^{\pm} + b$$

Stop into 2 lepton channel (from W decay)



Different flavor leptons: main backgrounds are WW and $t\bar{t}$.



Same flavor leptons: also contribution from WZ and ZZ.

M_{T2} distributions at 13TeV

Plans and studies for RUN II

- High stop masses region targeted by the leptonic m_{T2} analysis extended to 13TeV.
- Set of preliminary selections under study.
- Preliminary study of expected sensitivity (to be confirmed with more accurate simulation)
- Possibility to extend current limits just with ~5 fb^{-1} (probably collected by the end of the year)
- With ~20 fb^{-1} expected to cover up to ~800GeV for the stop mass

Conclusion

- Great results achieved during RUN I
- Some analyses still capable to give considerable contributions on RUN I data
- A powerful team that is continuing to work together
- A first plan for RUN II developed and ongoing
- We should be able to extend current limits by the end of the year!

Backup

Fake and non-prompt estimation

Common estimation for italian SUSY teams (different analysis)

Fakes: jet misidentified as leptons (i.e.:semileptonic $t\bar{t}$,W+jets,...)
Non-prompt leptons: heavy-flavour decays or photon conversions

DATA DRIVEN TECHNIQUE

- Two types of lepton isolation criteria are defined for this evaluation: “tight” and “loose”.
- Counts the number of observed events containing loose-loose, loose-tight, tight-loose and tight-tight lepton pairs in a given SR
- The number of events containing a contribution from one or two fake leptons (fake-fake, fake-real, real-fake, real-real) is calculated from these numbers, acting on leptons couples with a 4x4 matrix.
- Each elements of this matrix contain probabilities (f and r) that relate real-real, real-fake, fake-real and fake-fake lepton pair event counts to tight-tight, tight-loose, loose-tight and loose-loose counts
- The probability for real leptons passing the loose selection criteria to also pass the tight selection is measured using a $Z \rightarrow ll$ ($l=e,\mu$) sample. The equivalent probability for fake leptons is measured from multijet enriched control samples.

Background fit

- observed numbers of events in the CRs used to derive SM background estimates in each SR via a profile likelihood fit
- takes into account the correlations across the CRs due to common systematic uncertainties and the cross-contamination in each CR from other SM processes

The fit takes as input, for each SR:

1. The number of events observed in each CR and the corresponding number of events predicted in each by the MC simulation for each (non-fake, prompt) background source.
2. The number of events predicted by the MC simulation for each (non-fake, prompt) background source.
3. The number of fake and non-prompt lepton events in each region (CRs and SR) obtained with the data-driven technique

Each uncertainty source is treated as a nuisance parameter in the fit

Leptonic M_{T2} analysis

m_{T2} is the **key variable** of this **cut-based analysis**

$$\tilde{t}_1\bar{\tilde{t}}_1 \to b\tilde{\chi}_1^+ \; \bar{b}\tilde{\chi}_1^- \to bW^+\tilde{\chi}_1^0 \; \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0 \; \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

$$\tilde{t}_1\bar{\tilde{t}}_1 \to bW^+\tilde{\chi}_1^0 \; \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0 \; \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

4 SRs DEFINED to maximize the discovery potential of the analysis

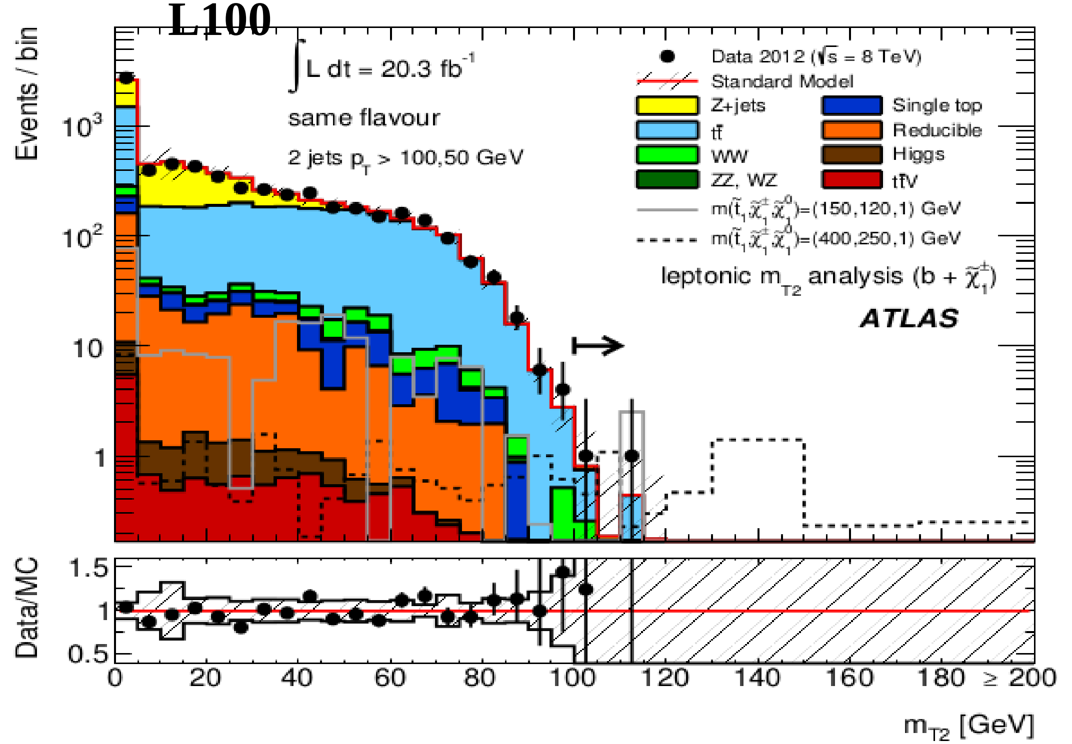
SR	L90	L100	L110	L120
m_{T2} [GeV]	> 90	> 100	> 110	> 120
Leading jet p_T [GeV]	—	> 100	> 20	—
Second jet p_T [GeV]	—	> 50	> 20	—
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^\pm)$	small	large	moderate	small
$\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$	moderate	large	moderate	large

- Cuts on m_{T2} suppress WW and $t\bar{t}$
- Sensitivity to different stop-chargino mass splitting
- m_{T2} selection optimised to target models with **chargino-neutralino mass splitting > m(W)**

ANY EXCESS OF DATA WRT MC
has been observed !!!

Exclusion limits obtained
in combination with hadronic M_{T2} results.

L100



Hadronic M_{T2} analysis

$$\tilde{t}_1\bar{\tilde{t}}_1 \to b\tilde{\chi}_1^+\ \bar{b}\tilde{\chi}_1^- \to bW^+\tilde{\chi}_1^0\ \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0\ \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

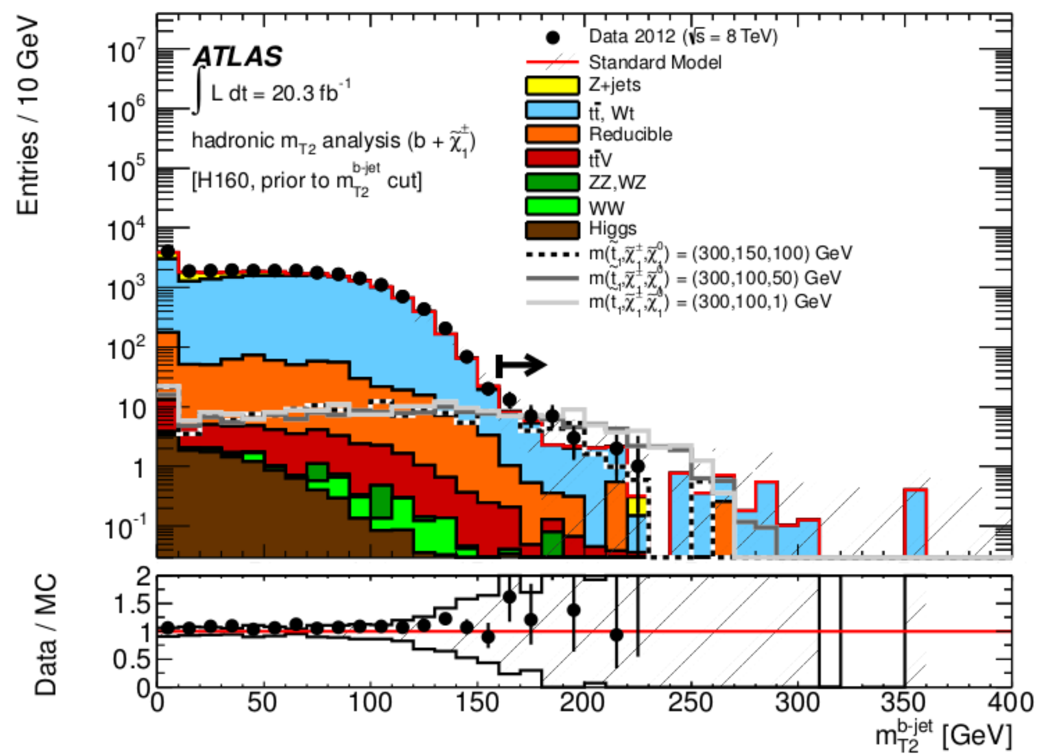
$m_{\mathrm{T2}}^{b-\mathrm{jet}}$ designed to be **sensitive to the models with chargino-neutralino mass splitting < m(W)**

Selects signal over background

Rejects Z/γ^*+jets

Rejects $t\bar{t}$

SR	H160
b-jets	$= 2$
Leading lepton p_{T} [GeV]	< 60
m_{T2} [GeV]	< 90
$m_{\mathrm{T2}}^{b-\mathrm{jet}}$ [GeV]	> 160
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^\pm)$	large
$\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$	small



Exclusion limits presented
in combination with leptonic M_{T2} results.

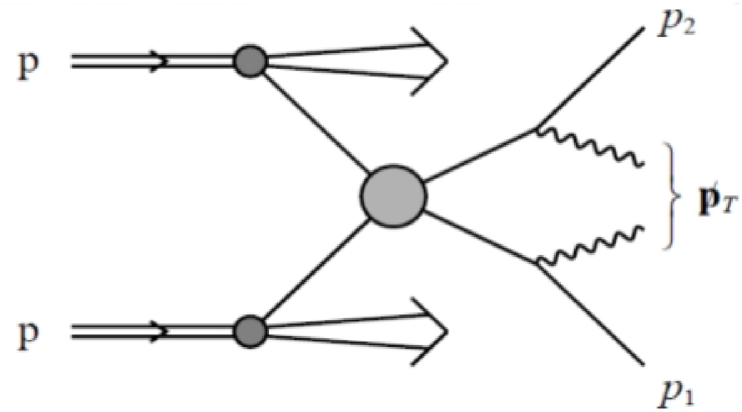
Leptonic m_{T2} variable

Generalized transverse mass
for systems with 2 invisible particles

$$m_T = \sqrt{m_\alpha^2 + m_{\tilde\chi}^2 + 2(E_{\alpha,T}\,\omega_T^{miss} - \vec{p}_{\alpha,T}\cdot\vec{E}_T^{miss})}$$

With m_α and $\vec{p}_{\alpha,T}$ respectively visible particle mass and transverse momentum; $m_{\tilde\chi}$ invisible particle mass;

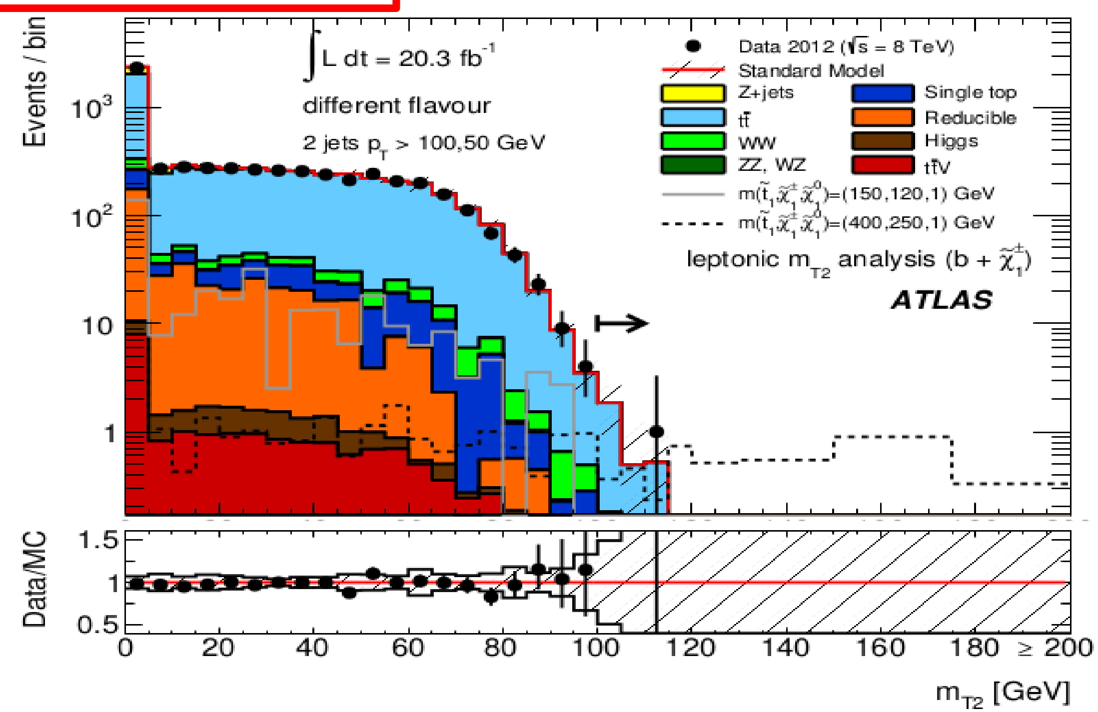
$$\omega_T^{miss} = \sqrt{(E_T^{miss})^2 + m_{\tilde\chi}^2}$$



$$\boxed{m_{T2} = \min_{\vec{q}_T+\vec{r}_T=\vec{E}_T^{miss}}\left\{\max[m_T(\vec{p}_{l_1,T},\vec{q}_T), m_T(\vec{p}_{l_2,T},\vec{r}_T)]\right\}}$$

take the max of m_T and minimize over all possible 2 missing momenta such that their sum gives the observed missing transverse momentum

- for $t\bar{t}$ or WW events m_{T2} is limited to the W mass
- instead for SUSY signal events m_{T2} reaches higher values because of neutralinos presence



MVA method

- A suitable set of **N discriminating variables** $\mathbf{x_i}$ is identified
- **Only one variable** (T) is obtained from the variables set in input to the classifier method. T is like a **map function** and **embodies all the discriminating power** from the input variables set

$\mathbf{T=M(x_i,\omega)}$ **ω=parameters set directly from the classifier algorithm**

Multivariate variable T cut ≠ set of unidimensional cuts but it is better because of the condensed discriminating power

TRAINING E TESTING

Simulated signal and background samples as input.

Divided in:

Training sample:
Used to teach the classifier method to discriminate signal from background

Testing sample:
Used to check the classifier performance

APPLICATION

Assuming that the classifier has learned the difference between signal and background, the method is applied to the sample (containing unknown signal-background mixture) to be analyzed

Output: T variable value for each analyzed event

Hadronic M_{T2} variable

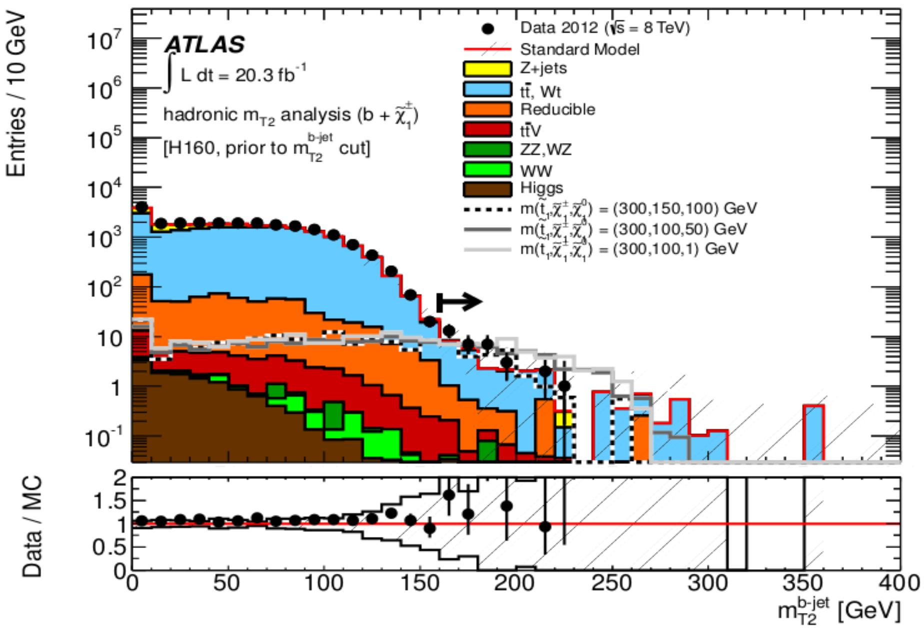
$m_{\mathrm{T2}}^{b-\mathrm{jet}}$ is the **key variable** of this **cut-based analysis**

leptonic M_{T2}

$$\boxed{m_{T2} = \min_{\vec{q}_T + \vec{r}_T = \vec{E}_T^{miss}} \{\max[m_T(\vec{p}_{l_1,T}, \vec{q}_T), m_T(\vec{p}_{l_2,T}, \vec{r}_T)]\}}$$

To obtain $m_{\mathrm{T2}}^{b-\mathrm{jet}}$ definition, replace:

- $\vec{p}_{l_1}$ and $\vec{p}_{l_2}$ with transverse momenta of the two reconstructed b-quarks
- $\vec{E}_T^{miss}$ With the vectorial sum of the lepton transverse momenta and the missing transverse momentum



$m_{\mathrm{T2}}^{b-\mathrm{jet}}$ with **very different kinematic limit**:

Leptonic M_{T2} analysis

$$\tilde{t}_1\bar{\tilde{t}}_1 \to b\tilde{\chi}_1^+ \ \bar{b}\tilde{\chi}_1^- \to bW^+\tilde{\chi}_1^0 \ \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0 \ \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$
$$\tilde{t}_1\bar{\tilde{t}}_1 \to bW^+\tilde{\chi}_1^0 \ \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0 \ \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

PRESELECTION CUTS

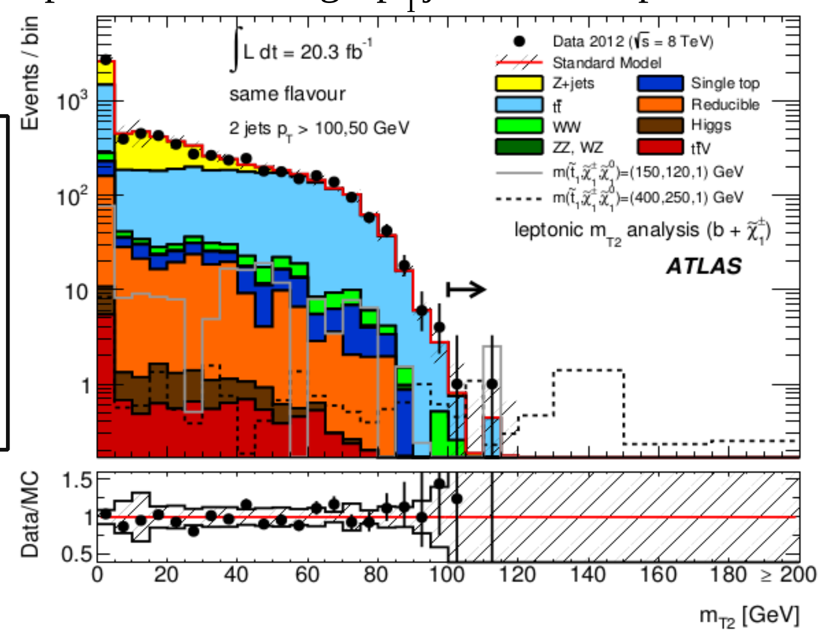
- Exactly 2 opposing sign leptons (e, μ) with same or different flavor (SF or DF)
- leading lepton with p_T>25GeV
- leptons invariant mass m_{ll}>20GeV
- SF events with $m_{ll} \notin$ [71,111]GeV
- $\Delta\phi_b$<1.5 and $\Delta\phi_j$>1

4 INCLUSIVE SRs DEFINED
to maximize the discovery potential of the analysis

SR	L90	L100	L110	L120
m_{T2} [GeV]	>90	>100	>110	>120
Leading jet p_T [GeV]	—	>100	>20	—
Second jet p_T [GeV]	—	>50	>20	—
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^\pm)$	small	large	moderate	small
$\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$	moderate	large	moderate	large

- Cuts on m_{T2} suppress WW and $t\bar{t}$
- Sensitivity to different stop-chargino mass splitting
- m_{T2} selection optimised to target models with **chargino-neutralino mass splitting > m(W)**

Here there is no selection over jets because production of high-p_T jets is not expected



BACKGROUND DETERMINATION

- Main backgrounds: $t\bar{t}$ and diboson (Z/γ*+jets suppressed by m_{T2} cuts)
- Main backgrounds normalised to data in dedicated CRs and extrapolated to the SRs using the MC simulation
- Non-prompt leptons or jets misidentified (fakes) extimated

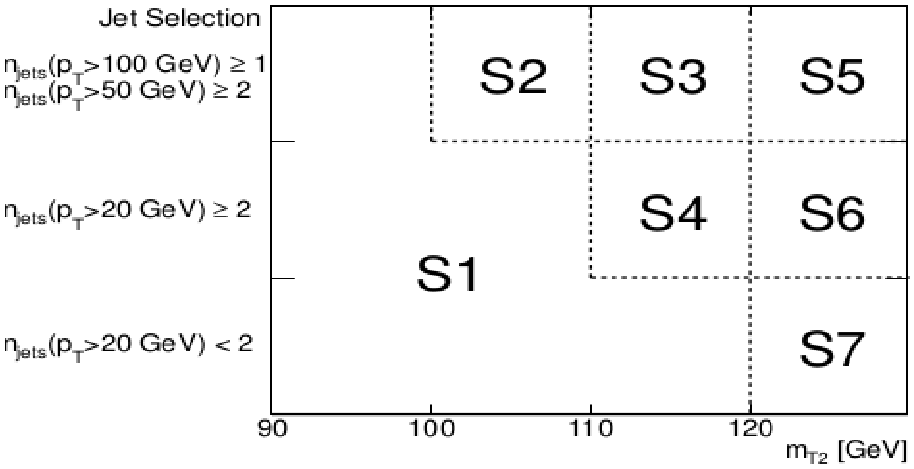
ANY EXCESS OF DATA WRT MC has been observed !!!

- $\Delta\phi_j$: the azimuthal angular distance between $\vec{p}_T^{\,miss}$ and the closest jet
- $\Delta\phi_b$: the azimutal angular distance between $\vec{p}_T^{\,miss}$ and $\mathbf{p}_{Tb}^{\ell\ell}$; $\mathbf{p}_{Tb}^{\ell\ell} = \mathbf{p}_T^{miss} + \mathbf{p}_T^{\ell_1} + \mathbf{p}_T^{\ell_2}$

Leptonic M_{T2} analysis

7 SRs defined
to maximise the exclusion power

statistically independent SRs allow a statistical combination to maximise exclusion potential



derived **limits on the mass of a stop** decaying:

- $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$ 100% BR
- $\tilde{t}_1 \rightarrow bW^{+}\tilde{\chi}_1^{0}$ 100% BR

with **SRs statistical combination**

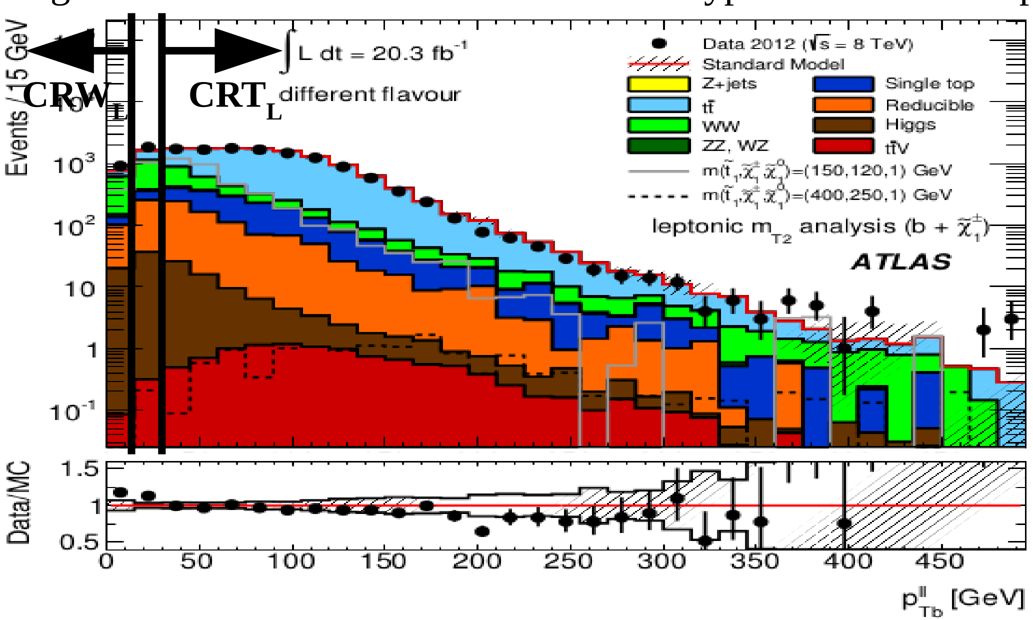
Exclusion limits obtained in combination with hadronic M_{T2} results.

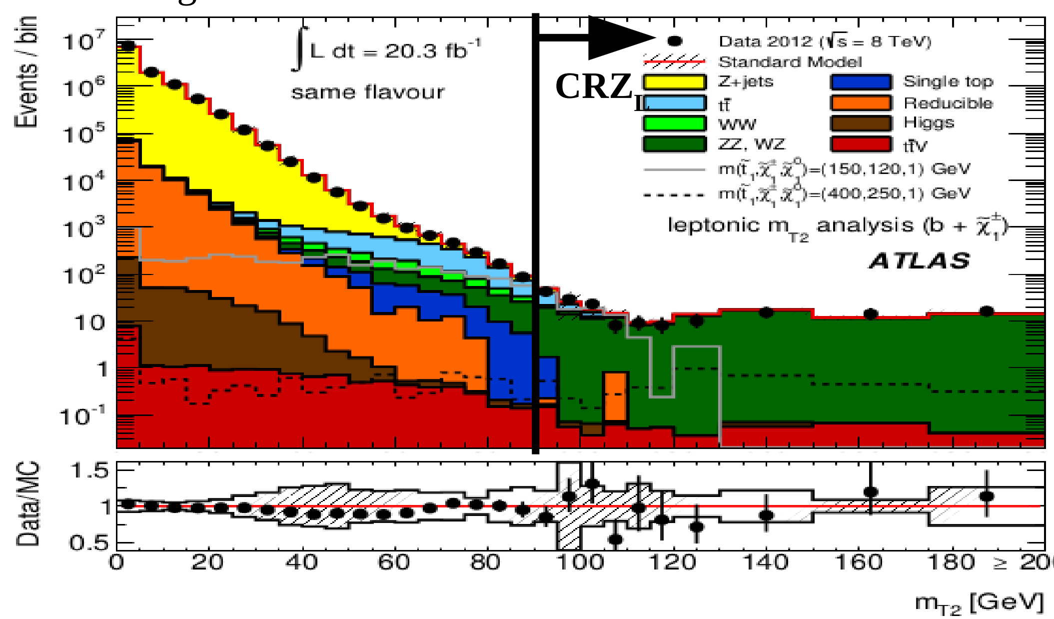
Lept MT2: background estimation

Selection Variable	CRT_L	CRW_L	CRZ_L	VR_L^{DF}	VR_L^{SF}	VR_L^{110}	VR_L^{100}
Flavour	DF	DF	SF	DF	SF	DF	DF
$m_{\ell\ell}$ [GeV]	—	—	71–111	—	< 71 or > 111	—	—
m_{T2} [GeV]	40–80	40–80	> 90	80–90	80–90	40–80	40–80
p_{Tb}^{ll} [GeV]	> 30	< 15	—	—	—	> 30	> 30
$\Delta\phi_j$ [rad]	> 1.0	> 1.0	> 1.0	> 1.0	> 1.0	> 1.0	> 1.0
$\Delta\phi_b$ [rad]	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5
Leading jet p_T [GeV]	—	—	—	—	—	> 20	> 100
Second leading jet p_T [GeV]	—	—	—	—	—	> 20	> 50

- Purity of the CRs improved by exploiting flavour information and selecting either DF or SF pairs.
- The normalisation factors however are applied to all the events in a given process (checks to demonstrate they are not flavour-dependent)

For some models the signal contamination in some CRs can be high (sometimes up to 100%). The same CRs can be kept also for these signal models, despite the high signal contamination, since the expected yields in the SRs would be large enough for these signal models to be excluded even in the hypothesis of null expected background.





The fake and non-prompt lepton background is a small contribution (less than 10% of the total background)

Lept MT2: background estimation

normalisations consistent with one

Channel	$\mathrm{CRT_L}$	$\mathrm{CRW_L}$	$\mathrm{CRZ_L}$
Observed events	12158	913	174
Total (constrained) bkg events	12158 ± 110	913 ± 30	174 ± 13
Fit output, $t\bar{t}$ events	8600 ± 400	136 ± 24	27 ± 6
Fit output, WW events	1600 ± 400	630 ± 50	14 ± 4
Fit output, WZ, ZZ events	64 ± 14	14 ± 5	112 ± 19
Total expected bkg events	12700 ± 700	800 ± 90	190 ± 20
Fit input, expected $t\bar{t}$ events	9500 ± 600	150 ± 25	30 ± 7
Fit input, expected WW events	1260 ± 110	490 ± 80	10.7 ± 2.5
Fit input, expected WZ, ZZ events	76 ± 12	17 ± 4	132 ± 11
Expected $Z/\gamma^* \rightarrow \ell\ell$ events	9^{+11}_{-9}	$1.5^{+2.2}_{-1.5}$	19 ± 8
Expected $t\bar{t}\,V$ events	10.8 ± 3.4	0.08 ± 0.04	0.64 ± 0.21
Expected Wt events	1070 ± 90	35 ± 7	1.6 ± 1.1
Expected Higgs boson events	67 ± 21	20 ± 6	0.08 ± 0.04
Expected events with fake and non-prompt leptons	740 ± 90	81 ± 16	- -

Table 5. Background fit results for the three CRs in the leptonic m_{T2} analysis. The nominal expectations from MC simulation are given for comparison for those backgrounds ($t\bar{t}$, WW, WZ and ZZ) which are normalised to data. Combined statistical and systematic uncertainties are given. Events with fake or non-prompt leptons are estimated with the data-driven technique described in section 6.2. The observed events and the total (constrained) background are the same by construction. Entries marked - - indicate a negligible background contribution. Uncertainties on the predicted background event yields are quoted as symmetric except where the negative error reaches down to zero predicted events, in which case the negative error is truncated.

Lept MT2: background estimation

Channel	L90	L100	L110	L120
Observed events	274	3	8	18
Total bkg events	300 ± 50	5.2 ± 2.2	9.3 ± 3.5	19 ± 9
Fit output, $t\bar{t}$ events	172 ± 33	3.5 ± 2.1	3.4 ± 2.9	1.1 ± 1.1
Fit output, WW events	78 ± 20	1.0 ± 0.5	3.2 ± 1.4	12 ± 7
Fit output, WZ, ZZ events	11.6 ± 2.4	$0.22^{+0.26}_{-0.22}$	0.9 ± 0.5	4.1 ± 2.1
Fit input, expected $t\bar{t}$ events	190 ± 40	3.9 ± 2.4	3.7 ± 3.2	1.2 ± 1.2
Fit input, expected WW events	62 ± 9	0.75 ± 0.38	3 ± 1	9 ± 5
Fit input, expected WZ, ZZ events	13.6 ± 2.4	$0.26^{+0.31}_{-0.26}$	1.1 ± 0.6	4.8 ± 2.5
Expected $Z/\gamma^* \to \ell\ell$ events	2.8 ± 1.4	$0.14^{+0.14}_{-0.14}$	$0.09^{+0.14}_{-0.09}$	$0.07^{+0.09}_{-0.07}$
Expected $t\bar{t}V$ events	1.8 ± 0.6	0.35 ± 0.14	0.62 ± 0.21	0.51 ± 0.18
Expected Wt events	21 ± 7	$0.00^{+0.19}_{-0.00}$	- -	$0.35^{+0.39}_{-0.35}$
Expected Higgs boson events	0.65 ± 0.22	$0.02^{+0.02}_{-0.02}$	0.03 ± 0.03	0.31 ± 0.12
Expected events with fake and non-prompt leptons	13.0 ± 3.5	- -	1.0 ± 0.6	1.1 ± 0.8

Table 18. Number of events and composition in the leptonic m_{T2} SRs for an integrated luminosity of 20.3 fb^{-1}. The nominal expectations from MC simulation are given for comparison for those backgrounds that are normalised to data. Combined statistical and systematic uncertainties are given. Events with fake or non-prompt leptons are estimated with the data-driven technique described in section 6.2. Entries marked - - indicate a negligible background contribution. Uncertainties on the predicted background event yields are quoted as symmetric except where the negative error reaches down to zero predicted events, in which case the negative error is truncated.

Hadronic M_{T2} analysis

$$\tilde{t}_1\bar{\tilde{t}}_1 \to b\tilde{\chi}_1^+ \; \bar{b}\tilde{\chi}_1^- \to bW^+\tilde{\chi}_1^0 \; \bar{b}W^-\tilde{\chi}_1^0 \to b\nu_l l^+\tilde{\chi}_1^0 \; \bar{b}\bar{\nu}_l l^-\tilde{\chi}_1^0$$

$m_{\mathrm{T2}}^{b-\mathrm{jet}}$ designed to be **sensitive to the models with chargino-neutralino mass splitting < m(W)**

PRESELECTION CUTS
- Exactly 2 opposing sign leptons (e, μ) with same or different flavor (SF or DF)
- leading lepton with p_T>25GeV
- leptons invariant mass m_{ll}>20GeV

SR	H160
b-jets	$= 2$
Leading lepton p_{T} [GeV]	< 60
m_{T2} [GeV]	< 90
$m_{\mathrm{T2}}^{b-\mathrm{jet}}$ [GeV]	> 160
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^{\pm})$	large
$\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$	small

Selects signal over background

Rejects Z/γ*+jets

Rejects $t\bar{t}$

BACKGROUND DETERMINATION
- Main backgrounds: $t\bar{t}$,Wt
- Main backgrounds and Z/γ*+jets normalised to data in dedicated CR and extrapolated to the SR using the MC simulation
- Non-prompt leptons or jets misidentified (fakes) extimated

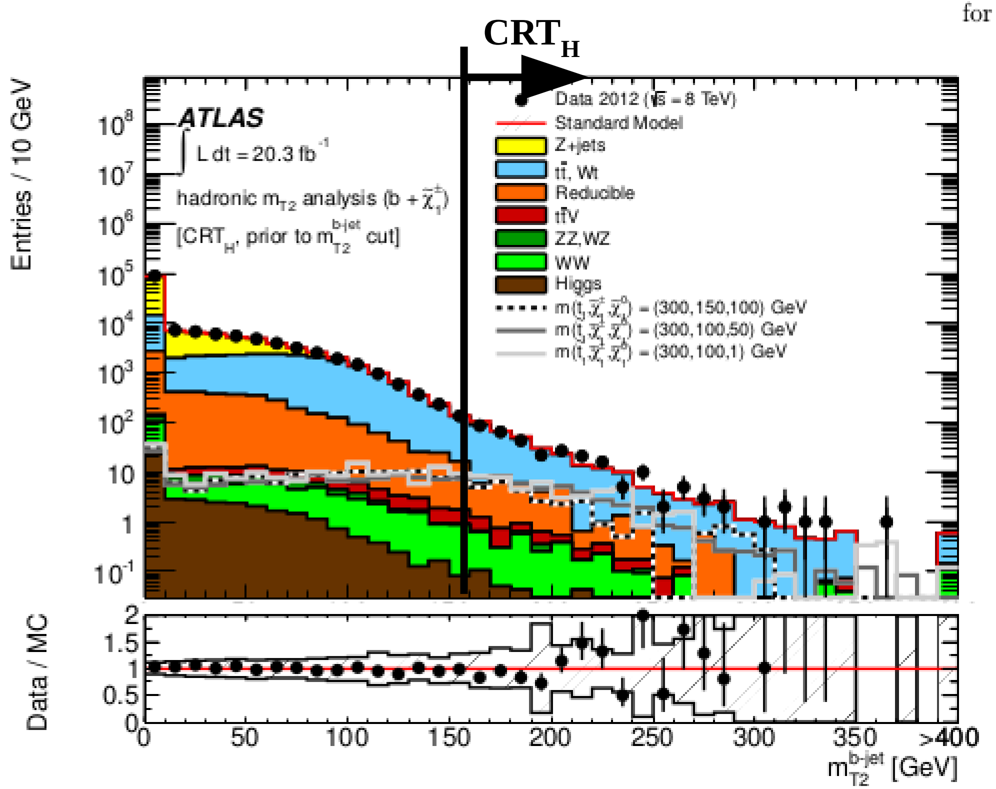
derived **limits on the mass of a stop** decaying:
- $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$ 100% BR

Exclusion limits presented in combination with leptonic M_{T2} results.

Hadr MT2: background estimation

Selection Variable	$\mathrm{CRT_H}$	$\mathrm{CRZ_H}$	$\mathrm{VRT_H}$
Flavour	any	SF	any
b-jets	$= 1$	$= 2$	$= 2$
leading lepton p_{T} [GeV]	< 60	> 60	> 60
$m_{\ell\ell}$ (SF events only) [GeV]	—	81–101	< 81 or > 101
m_{T2} [GeV]	< 90	< 90	< 90
$m_{\mathrm{T2}}^{b-\mathrm{jet}}$ [GeV]	> 160	> 160	> 160

Table 7. Definitions of the CRs and VR in the hadronic m_{T2} analysis: $\mathrm{CRT_H}$ (used to constrain $t\bar{t}$ and Wt), $\mathrm{CRZ_H}$ (used to constrain Z/γ^*+jets decays to ee and $\mu\mu$) and $\mathrm{VRT_H}$ (validation region for $t\bar{t}$ and Wt).



Hadr MT2: background estimation

Channel	$\mathrm{CRT_H}$	$\mathrm{CRZ_H}$	$\mathrm{VRT_H}$
Observed events	315	156	112
Total (constrained) bkg events	315 ± 18	156 ± 13	110 ± 50
Fit output, $t\bar{t}, Wt$ events	256 ± 27	4 ± 4	70 ± 40
Fit output, $Z/\gamma^* \to ee, \mu\mu$+jets events	$0.9^{+1.1}_{-0.9}$	147 ± 13	20 ± 8
Total expected bkg events	335 ± 90	110 ± 36	110 ± 60
Fit input, expected $t\bar{t}, Wt$ events	280 ± 90	5 ± 5	80 ± 60
Fit input, expected $Z/\gamma^* \to ee, \mu\mu$+jets events	$0.6^{+0.7}_{-0.6}$	100 ± 34	13.8 ± 2.4
Expected WW events	3^{+4}_{-3}	$0.07^{+0.14}_{-0.07}$	1^{+3}_{-1}
Expected $t\bar{t}V$ events	2.3 ± 0.8	1.5 ± 0.5	2.3 ± 0.7
Expected WZ, ZZ events	0.40 ± 0.16	$0.06^{+0.32}_{-0.06}$	$0.10^{+0.15}_{-0.10}$
Expected $Z/\gamma^* \to \tau\tau$+jets events	23 ± 17	0.14 ± 0.09	2.15 ± 0.28
Expected events with fake and non-prompt leptons	29.4 ± 1.7	0.36 ± 0.24	12.8 ± 1.2
Expected Higgs boson events	0.35 ± 0.05	2.06 ± 0.30	0.50 ± 0.06

Table 8. Background fit results for the two CRs and VR region in the hadronic m_{T2} analysis. The nominal expectations from MC simulation are given for comparison for those backgrounds ($t\bar{t}$, Wt and $Z/\gamma^*(\to ee, \mu^+\mu^-)$+jets production) which are normalised to data. Combined statistical and systematic uncertainties are given. Events with fake or non-prompt leptons are estimated with the data-driven technique described in section 6.2. The observed events and the total (constrained) background are the same in the CRs by construction; this is not the case for the VR, where the consistency between these event yields is the test of the background model. Uncertainties on the predicted background event yields are quoted as symmetric except where the negative error reaches down to zero predicted events, in which case the negative error is truncated.

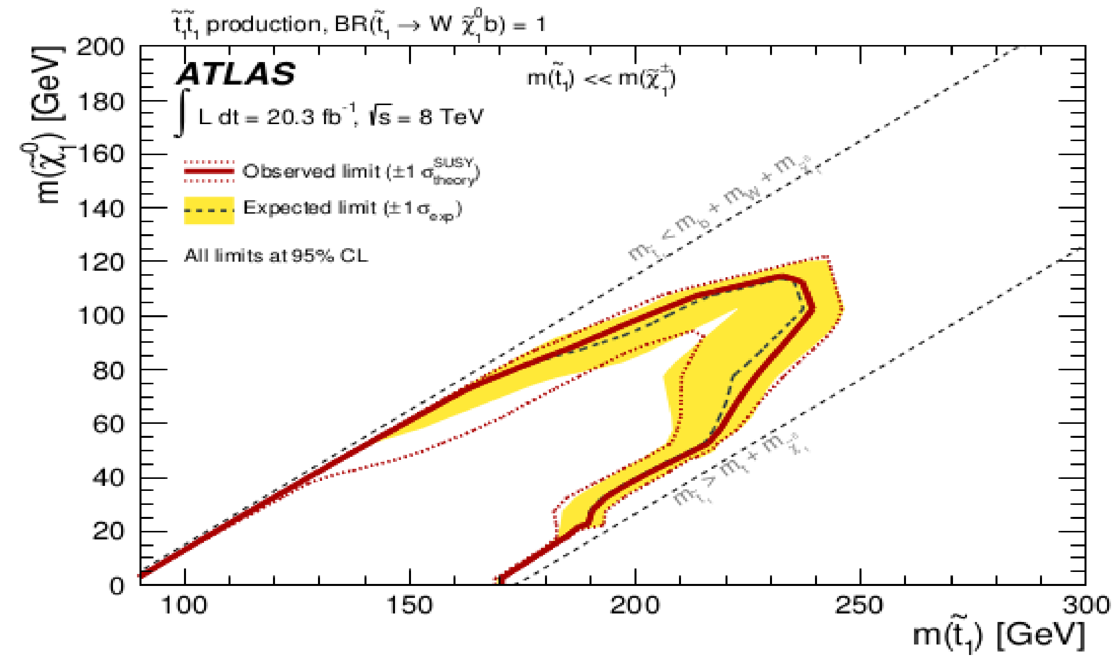
Normalizations consistent with one

Hadr MT2: background estimation

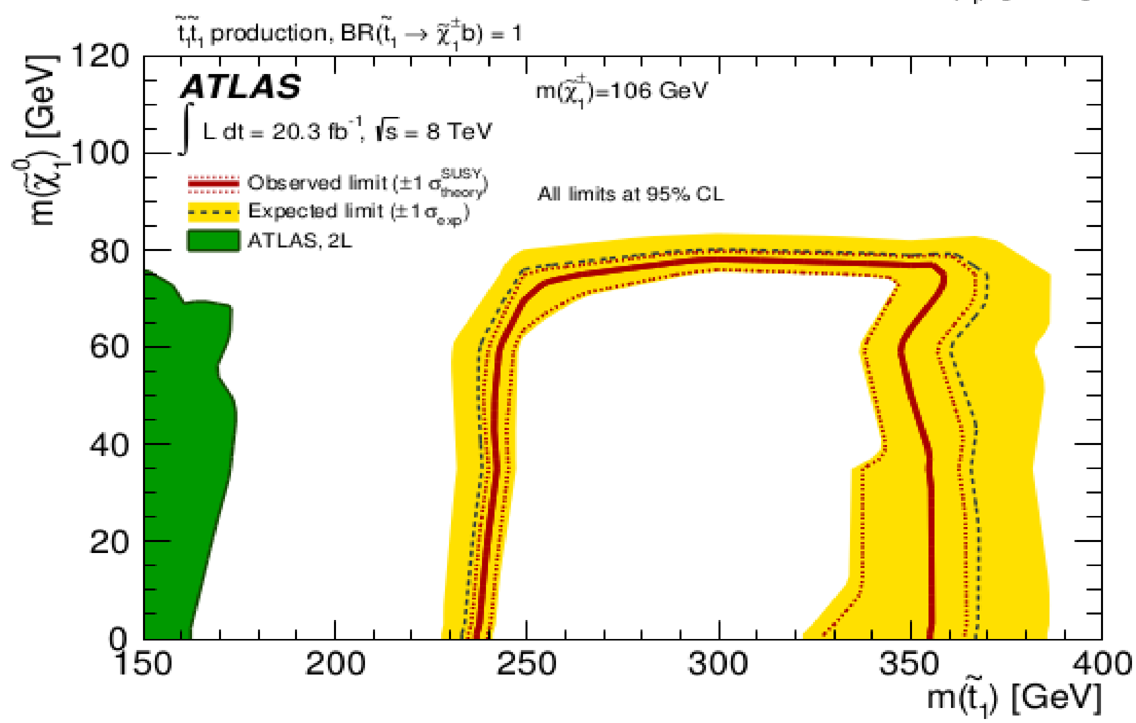
Channel	H160
Observed events	33
Total bkg events	26 ± 6
Fit output, $t\bar{t}, Wt$ events	22 ± 5
Fit output, $Z/\gamma^* \to ee, \mu\mu$+jets events	$0.2^{+1.8}_{-0.2}$
Fit input, expected $t\bar{t}, Wt$ events	24 ± 7
Fit input, expected $Z/\gamma^* \to ee, \mu\mu$+jets events	$0.2^{+1.2}_{-0.2}$
Expected WW events	$0.00^{+0.35}_{-0.00}$
Expected $t\bar{t}V$ events	0.47 ± 0.16
Expected WZ, ZZ events	0.11 ± 0.11
Expected $Z/\gamma^* \to \tau\tau$+jets events	0.86 ± 0.15
Expected events with fake and non-prompt leptons	2.5 ± 0.4
Expected Higgs boson events	0.08 ± 0.02

Lept and hadr m_{T2} results: **exclusion plots**

leptonic m_{T2} analysis results
used to derive limits on the stop mass decaying $\tilde{t}_1 \rightarrow bW^+\tilde{\chi}_1^0$ 100% BR



hadronic m_{T2} analysis results
used to derive limits on $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$
for fixed 106 GeV chargino mass



MVA method

cut&count method

- A suitable set of **N discriminating variables $\mathbf{x}_i$** is identified
- Comparing MC signal and background variables distribution **a set of cut values is defined**

↓

Like a sequence of univariate analyses

multivariate analysis

- A suitable set of **N discriminating variables $\mathbf{x}_i$** is identified
- **Only one variable** (T) is obtained from the variables set in input to the classifier method. T is like a **map function** and **embodies all the discriminating power** from the input variables set

↓

$\mathbf{T=M(x_i,\omega)}$

ω = parameters set directly from the classifier algorithm

- **Multivariate variable T cut ≠ set of unidimensional cuts** because of the condensed discriminating power
- Multivariate method particularly useful for problems with great variables quantity →
  - Variables correlation taken in account
  - dimensionality of the problem is potentially reduces

TRAINING E TESTING

Simulated signal and background samples as input.

Divided in:

Training sample:
Used to teach the classifier method to discriminate signal from background

Testing sample:
Used to check the classifier performance

APPLICATION

Assuming that the classifier has learnt the difference between signal and background, the method is applied to the sample (containing unknown signal-background mixture) to be analyzed

↓

Output: T variable value for each analyzed event

TMVA: background estimation

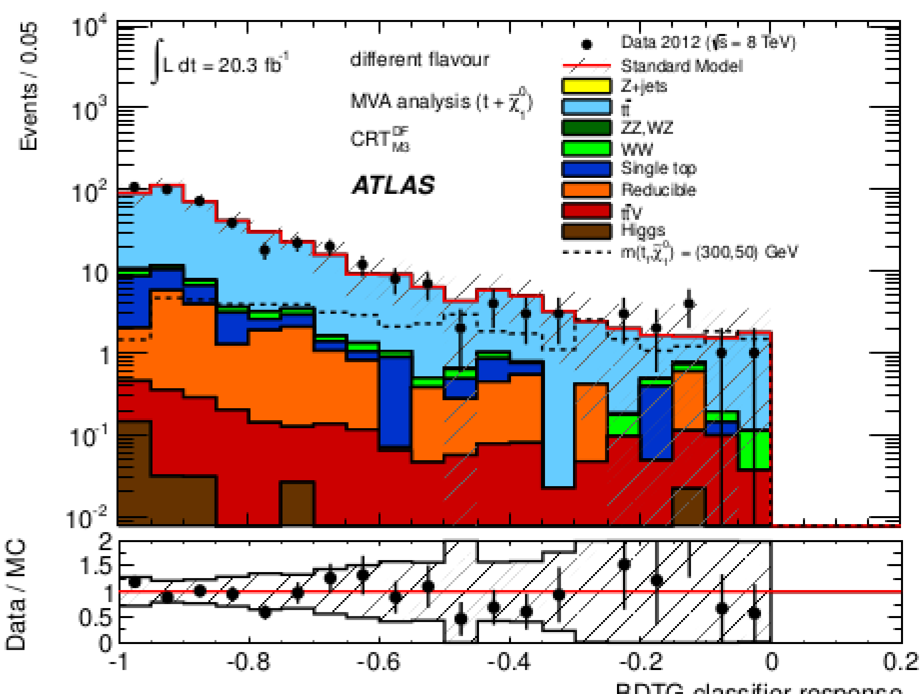
Defined a CR for each SR, statistically independent

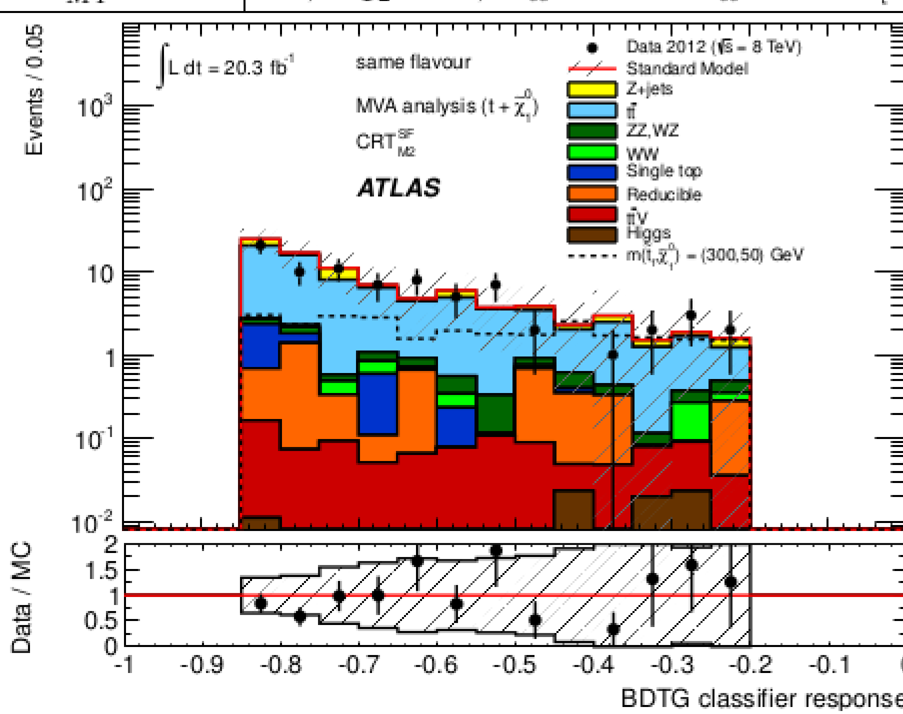
PRESELECTION CUTS

- Exactly 2 opposing sign leptons (e, μ) with same or different flavor (SF or DF)
- leading lepton with p_T>25GeV
- leptons invariant mass m_{ll}>20GeV
- At least 2 jets
- Leading jet with p_T>50GeV
- meff>300GeV

meff= somma scalare della met, dei momenti trasversi dei due leptoni e dei momenti trasversi dei primi due jet più energetici

Control Region	Event Variable Selection [GeV]	BDTG range
$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M1}}$	C1, $m_{\mathrm{T2}} > 90$	$[-1.00, -0.20]$
$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M2}}$	C1, $m_{\mathrm{T2}} > 90$	$[-1.00, -0.30]$
$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M3}}$	C1, $m_{\mathrm{T2}} > 90$	$[-1.00, 0.00]$
$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M4}}$	C2, $m_{\mathrm{T2}} > 90$	$[-1.00, -0.70]$
$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M5}}$	C4, $m_{\mathrm{T2}} > 90$	$[-1.00, -0.50]$
$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M1}}$	C1, $m_{\mathrm{T2}} > 90$, $m_{\ell\ell} < 61$ or $m_{\ell\ell} > 121$	$[-0.85, -0.75]$
$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M2}}$	C1, $m_{\mathrm{T2}} > 90$, $m_{\ell\ell} < 61$ or $m_{\ell\ell} > 121$	$[-0.85, -0.20]$
$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M3}}$	C1, $m_{\mathrm{T2}} > 90$, $m_{\ell\ell} < 61$ or $m_{\ell\ell} > 121$	$[-0.95, -0.80]$
$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M4}}$	C3, $m_{\mathrm{T2}} > 90$, $m_{\ell\ell} < 61$ or $m_{\ell\ell} > 121$	$[-0.98, -0.78]$





TMVA: background estimation

Usually low signal contamination.

Channel	$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M1}}$	$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M2}}$	$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M3}}$	$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M4}}$	$\mathrm{CRT}^{\mathrm{DF}}_{\mathrm{M5}}$
Observed events	419	410	428	368	251
Total (constrained) bkg events	419 ± 20	410 ± 20	428 ± 21	368 ± 19	251 ± 16
Fit output, $t\bar{t}$ events	369 ± 23	363 ± 23	379 ± 24	325 ± 22	214 ± 19
Total expected bkg events	430 ± 70	420 ± 60	440 ± 70	380 ± 60	260 ± 50
Fit input, expected $t\bar{t}$	380 ± 60	375 ± 60	390 ± 70	340 ± 50	220 ± 40
Expected $t\bar{t}V$ events	2.7 ± 0.8	2.2 ± 0.7	2.4 ± 0.7	2.7 ± 0.8	1.9 ± 0.6
Expected Wt events	20 ± 5	19 ± 5	20 ± 5	16 ± 5	15 ± 4
Expected WW events	8^{+9}_{-8}	7^{+8}_{-7}	7^{+9}_{-7}	6^{+8}_{-6}	6^{+7}_{-6}
Expected ZW, ZZ events	1.0 ± 1.0	$0.9^{+1.0}_{-0.9}$	1.0 ± 1.0	$0.5^{+0.8}_{-0.5}$	1.0 ± 0.8
Expected $Z/\gamma^* \to \ell\ell$+jets events	$0.3^{+0.4}_{-0.3}$	$0.31^{+0.35}_{-0.31}$	$0.31^{+0.35}_{-0.31}$	$0.3^{+0.4}_{-0.3}$	$0.3^{+0.4}_{-0.3}$
Expected Higgs boson events	0.26 ± 0.10	0.24 ± 0.10	0.26 ± 0.10	0.12 ± 0.05	0.19 ± 0.10
Expected events with fake and non-prompt leptons	18 ± 4	18 ± 4	19 ± 4	17 ± 4	12.5 ± 3.2

Table 10. Background fit results for the DF CRs in the MVA analysis. The nominal expectations from MC simulation are given for comparison for $t\bar{t}$, which is normalised to data by the fit. Combined statistical and systematic uncertainties are given. Events with fake or non-prompt leptons are estimated with the data-driven technique described in section 6.2. The observed events and the total (constrained) background are the same in the CRs by construction. Uncertainties on the predicted background event yields are quoted as symmetric except where the negative error reaches down to zero predicted events, in which case the negative error is truncated.

Normalisation factors are **consistent within one standard deviation (1σ)** of the normalisation factor derived for $t\bar{t}$ in the leptonic mT2 analysis

TMVA: background estimation

Channel	$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M1}}$	$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M2}}$	$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M3}}$	$\mathrm{CRT}^{\mathrm{SF}}_{\mathrm{M4}}$
Observed events	99	79	133	27
Total (constrained) bkg events	99 ± 10	79 ± 9	133 ± 12	27 ± 5
Fit output, $t\bar{t}$ events	82 ± 12	55 ± 14	101 ± 16	14 ± 8
Total expected bkg events	94 ± 16	88 ± 16	129 ± 23	32 ± 10
Fit input, expected $t\bar{t}$	77 ± 13	65 ± 9	95 ± 20	19 ± 7
Expected $t\bar{t}V$ events	0.98 ± 0.31	0.95 ± 0.31	1.4 ± 0.4	0.70 ± 0.23
Expected Wt events	1.6 ± 1.5	2.8 ± 1.6	4.0 ± 1.6	$0.20^{+0.33}_{-0.20}$
Expected WW events	$1.3^{+1.7}_{-1.3}$	$1.4^{+1.5}_{-1.4}$	$1.7^{+1.8}_{-1.7}$	$0.7^{+1.0}_{-0.7}$
Expected ZW, ZZ events	1.3 ± 0.8	2.1 ± 0.7	2.1 ± 1.3	1.4 ± 0.5
Expected $Z/\gamma^* \to \ell\ell$+jets events	7 ± 7	12 ± 11	14 ± 9	7 ± 6
Expected Higgs boson events	0.06 ± 0.06	0.08 ± 0.05	0.12 ± 0.05	0.04 ± 0.04
Expected events with fake and non-prompt leptons	3.7 ± 1.7	3.7 ± 1.7	6.9 ± 2.3	2.8 ± 1.2

Table 11. Background fit results for the SF CRs in the MVA analysis. The nominal expectations from MC simulation are given for comparison for $t\bar{t}$, which is normalised to data by the fit. Combined statistical and systematic uncertainties are given. Events with fake or non-prompt leptons are estimated with the data-driven technique described in section 6.2. The observed events and the total (constrained) background are the same in the CRs by construction. Uncertainties on the predicted background event yields are quoted as symmetric except where the negative error reaches down to zero predicted events, in which case the negative error is truncated.

Normalisation factors are **consistent within one standard deviation (1σ)** of the normalisation factor derived for $t\bar{t}$ in the leptonic mT2 analysis

TMVA: background estimation

Channel	$\mathrm{M1}^{\mathrm{DF}}$	$\mathrm{M2}^{\mathrm{DF}}$	$\mathrm{M3}^{\mathrm{DF}}$	$\mathrm{M4}^{\mathrm{DF}}$	$\mathrm{M5}^{\mathrm{DF}}$
Observed events	9	11	5	3	1
Total bkg events	5.8 ± 1.9	13 ± 4	5.1 ± 2.0	1.3 ± 1.0	1.0 ± 0.5
Fit output, $t\bar{t}$ events	5.0 ± 1.9	11 ± 4	3.1 ± 1.7	$0.6^{+0.8}_{-0.6}$	$0.29^{+0.35}_{-0.29}$
Fit input, expected $t\bar{t}$	5.2 ± 2.6	11 ± 5	3.2 ± 2.1	$0.6^{+0.8}_{-0.6}$	$0.3^{+0.4}_{-0.3}$
Expected $t\bar{t}V$ events	0.43 ± 0.15	0.83 ± 0.27	0.73 ± 0.24	0.38 ± 0.13	0.23 ± 0.09
Expected Wt events	$0.00^{+0.09}_{-0.00}$	0.9 ± 0.7	0.4 ± 0.4	- -	- -
Expected WW events	$0.3^{+0.5}_{-0.3}$	$0.7^{+1.1}_{-0.7}$	$0.8^{+0.9}_{-0.8}$	$0.3^{+0.5}_{-0.3}$	0.49 ± 0.19
Expected ZW, ZZ events	$0.05^{+0.06}_{-0.05}$	0.11 ± 0.10	$0.10^{+0.12}_{-0.10}$	$0.05^{+0.07}_{-0.05}$	0.03 ± 0.03
Expected events with fake and non-prompt leptons	$0.00^{+0.29}_{-0.00}$	$0.00^{+0.33}_{-0.00}$	$0.00^{+0.30}_{-0.00}$	$0.00^{+0.27}_{-0.00}$	$0.00^{+0.35}_{-0.00}$

Table 20. Number of events and composition of the DF signal regions for an integrated luminosity of 20.3 fb^{-1} in the MVA analysis. Nominal MC simulation expectation is given for comparison for the background ($t\bar{t}$) that is normalised to data. Combined statistical and systematic uncertainties are given. Events with fake or non-prompt leptons are estimated with the data-driven technique described in section 6.3. Entries marked - - indicate a negligible background contribution. Backgrounds which contribute negligibly to all SRs are not listed. Uncertainties on the predicted background event yields are quoted as symmetric except where the negative error reaches down to zero predicted events, in which case the negative error is truncated.

TMVA: background estimation

Channel	$\mathrm{M1^{SF}}$	$\mathrm{M2^{SF}}$	$\mathrm{M3^{SF}}$	$\mathrm{M4^{SF}}$
Observed events	6	9	0	5
Total bkg events	7.6 ± 2.2	9.5 ± 2.1	1.1 ± 0.7	2.5 ± 1.0
Fit output, $t\bar{t}$ events	7.1 ± 2.2	3.8 ± 1.6	0.7 ± 0.7	0.6 ± 0.5
Fit input, expected $t\bar{t}$	6.6 ± 2.2	4.4 ± 1.8	0.7 ± 0.7	0.7 ± 0.6
Expected $t\bar{t}V$ events	0.07 ± 0.03	0.50 ± 0.17	0.06 ± 0.04	0.17 ± 0.10
Expected Wt events	$0.02^{+0.08}_{-0.02}$	$0.02^{+0.20}_{-0.02}$	- -	- -
Expected WW events	$0.08^{+0.14}_{-0.08}$	$0.18^{+0.30}_{-0.18}$	$0.00^{+0.04}_{-0.00}$	$0.06^{+0.07}_{-0.06}$
Expected ZW, ZZ events	$0.03^{+0.05}_{-0.03}$	2.3 ± 0.5	$0.08^{+0.15}_{-0.08}$	1.2 ± 0.9
Expected $Z/\gamma^* \to \ell\ell$+jets events	$0.02^{+0.03}_{-0.02}$	$1.4^{+1.6}_{-1.4}$	- -	$0.5^{+0.6}_{-0.5}$
Expected events with fake and non-prompt leptons	$0.3^{+0.4}_{-0.3}$	1.1 ± 0.8	$0.25^{+0.26}_{-0.25}$	$0.00^{+0.06}_{-0.00}$

Table 21. Number of events and composition of the SF signal regions for an integrated luminosity of 20.3 fb^{-1} in the MVA analysis. Nominal MC simulation expectation is given for comparison for the background ($t\bar{t}$) that is normalised to data. Combined statistical and systematic uncertainties are given. Events with fake or non-prompt leptons are estimated with the data-driven technique described in section 6.3. Entries marked - - indicate a negligible background contribution. Backgrounds which contribute negligibly to all SRs are not listed. Uncertainties on the predicted background event yields are quoted as symmetric except where the negative error reaches down to zero predicted events, in which case the negative error is truncated.

Statistical uncenterties

EXPERIMENTAL:

- **JES** (Jet Energy Scale)
- **JER** (Jet Energy Resolution)
- **SCALEST** (CellOut energy scale)
- **RESOST** (CellOut energy resolution)
- **PileUp** (incertezza legata alla sovrapposizione di più interazioni per bunch-crossing)
- **Luminosity** (set to 2.8%)
- **JVF** (Jet Vertex Fraction)
- **Trigger** (related to the leptonic trigger simulation efficiency; set to 3%)

THEORETICAL (only for backgrounds):

- **Cross-section**
- **MC generator**
- **Parton Shower**
- **ISR-FSR** (Initial e Final State Radiation)

$$\frac{\Delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}}=10\% \qquad \frac{\Delta\sigma_{t\bar{t}V}}{\sigma_{t\bar{t}V}}=30\%$$

$$\frac{\Delta\sigma_{Wt}}{\sigma_{Wt}}=6.7\% \qquad \frac{\Delta\sigma_{Z}}{\sigma_{Z}}=15\%$$

$$\frac{\Delta\sigma_{WW}}{\sigma_{WW}}=6\% \qquad \frac{\Delta\sigma_{WZ(ZZ)}}{\sigma_{WZ(ZZ)}}=7\%$$

$$\frac{\Delta\sigma_{Zt}}{\sigma_{Zt}}=100\%$$

Stop decaying in b+chargino with MVA

Considered background

$t\bar{t}$
Wt
Zt
WW
$ZZ(\rightarrow 4l)$
$ZZ(\rightarrow 2l2\nu)$
WZ
Z+jets ($m_{ll} > 40$ GeV)
Drell-Yan (8 GeV< $m_{ll} < 40$ GeV)
$t\bar{t} + W$
$t\bar{t} + Z$
$t\bar{t} + WW$
$ggH \rightarrow ZZll\nu\nu$
$ggH \rightarrow WW2l$
$WH \rightarrow WWl\nu$
$WH \rightarrow b\bar{b}l\nu$
$ZH \rightarrow WW2l$
$ZH \rightarrow b\bar{b}2l$

PRESELECTION CUTS

- Exactly 2 opposing sign leptons (e, μ) with same or different flavor (SF or DF)
- For MET TRIGGER: met>120GeV
- For LEPTON TRIGGER: pT_lep1>25GeV
- At least 2 jets with pT>20GeV, but no b-tagging

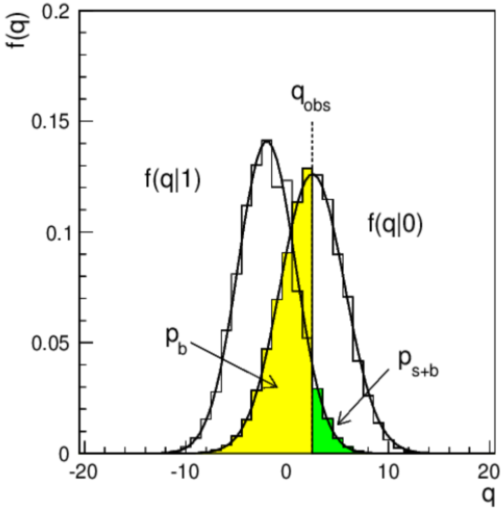
- **(MET Trigger: MC1)** $m_{ll} > 8\ GeV$;
- **(Lepton trigger: LC1)** $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV, $m_{ll} > 20\ GeV$ and $m_{eff} > 200$ GeV;
- **(Lepton trigger: LC2)** $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV, $m_{ll} > 20\ GeV$ and $m_{eff} > 300$ GeV;

$$E_T^{miss},\ M_{T2},\ M_{T2}^{b-jet},\ \Delta\phi(l_1,l_2),\ \Delta\eta(l_1,l_2),\ \Delta\phi(E_T^{miss},l_1),\ \Delta\phi(j_1,l_1),\ \Delta\phi(E_T^{miss},\ p_{Tb}^{ll}),\ \sum_{i=1,2} p_T^{l_i},\ \frac{\sum_{i=1,2} p_T^{j_i}}{\sum_{i=1,2} p_T^{l_i}},\ \frac{E_T^{miss}}{\sum_{i=1,2} p_T^{l_i}}$$

METODO DEL CL_S

OBIETTIVO: arrivare ai plot con i limiti di esclusione sul piano $(m(\tilde{t}_1), m(\tilde{\chi}_1^0))$

Come si esclude un punto sulla griglia? ➔ apposito **test di ipotesi**



- Si considera **variabile di prova** q
- Si confrontano le distribuzioni degli eventi di fondo e di fondo+segnale
- Si fissa **ipotesi nulla** (da verificare) = ipotesi di fondo+segnale
- Dato il valore della variabile $\mathbf{q_{obs}}$, calcolata cioè sui dati osservati sperimentalmente, si calcola il **p-value** associato ad esso, cioè la probabilità di ottenere un risultato pari o più estremo di quello ottenuto.
- Si fissa α **livello di significatività** (di solito pari a 0.05)
- Si esclude un punto della griglia se per quel modello p-value < α **RIGETTO DELL'IPOTESI NULLA al 95% di livello di confidenza** (viceversa si ha l'accettazione)

➔ in questa ipotesi **p-value ≡ $\mathbf{CL_{S+B}}$**

Allo stesso modo nell'ipotesi di solo fondo **p-value ≡ $\mathbf{CL_B}$**

Se le distribuzioni di segnale+fondo e di solo fondo siano molto simili fra loro ($N_S << N_B$)

➔ Si potrebbe avere un'**esclusione** del modello per effetto di una **sottofluttuazione di $\mathbf{N_{obs}}$ rispetto a $\mathbf{N_{S+B}}$**

➔ esclusione di un modello a cui l'analisi non è sensibile

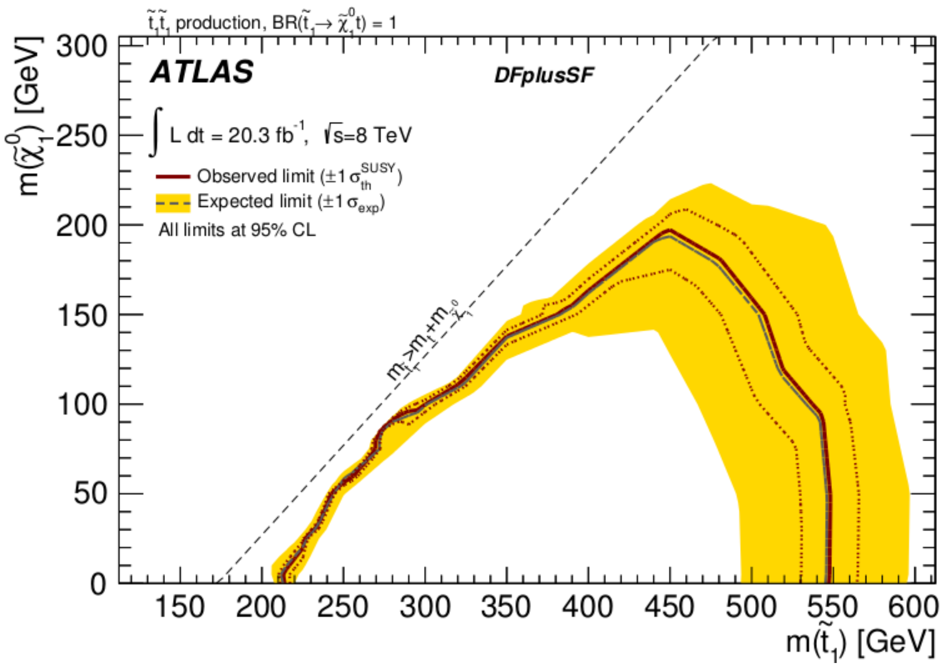
➔ si definisce $\boxed{CL_S = \dfrac{CL_{S+B}}{1 - CL_B}}$

- per distribuzioni ben separate $\mathbf{CL_S \approx CL_{S+B}}$
- per distribuzioni molto simili $\mathbf{CL_S \to 1}$

$\boxed{\textbf{ESCLUSIONE} \quad \mathbf{CL_S < 0.05}}$

LIMITI DI ESCLUSIONE

- derivati attraverso *HistFitter*
- basati sulla valutazione del $\mathbf{CL_s^{exp}}$ e $\mathbf{CL_s^{obs}}$ per ogni punto



Valutazione delle **bande di errore**

- Sul limite osservato → variando di **1σ di incertezza teorica** la sezione d'urto dei segnali

- Sul limite atteso → considerando gli estremi dell'intervallo centrato attorno al q_{exp} associato al **68% della distribuzione**