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# The Global Charge Asymmetry: « A New Method to Constrain Masses at the LHC »

# Outline

I. Introduction

II. Theoretical Prediction

- Goal: Mass Templates with Theoretical Uncertainties
- Mean: Parton Level Cross Sections

III. Experimental Measurement

- Goal: Mass Templates with Experimental Uncertainties
- Mean: Particle Level Simulation

IV. Indirect Mass Constraint

V. Conclusions

VI. Prospects

# I. Introduction

## - Definition -

- Contrarily to most other high energy colliders, the LHC has an initial state (IS) which charge asymmetric

H.E. Collider	Global Charge of its IS
LEP	0
TEVATRON	0
LHC	2
LC	0

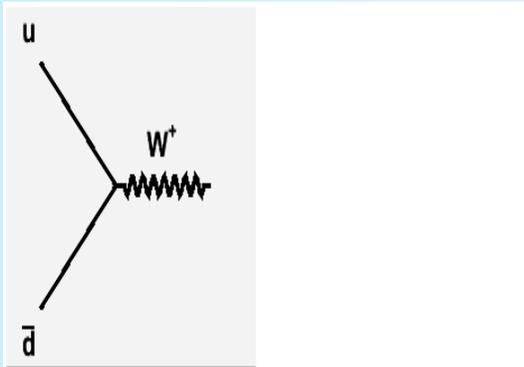
- This is obviously due to the global charge asymmetry (GCA) of the proton valence quarks
- Therefore, and contrarily to the TEVATRON for example, positively charged final states (FS<sup>+</sup>) are more often produced than their negatively charged counterparts (FS<sup>-</sup>)
- The Global Charge Asymmetry (GCA) has a straightforward definition:

$$A_c = \frac{N(\text{FS}^+) - N(\text{FS}^-)}{N(\text{FS}^+) + N(\text{FS}^-)}$$

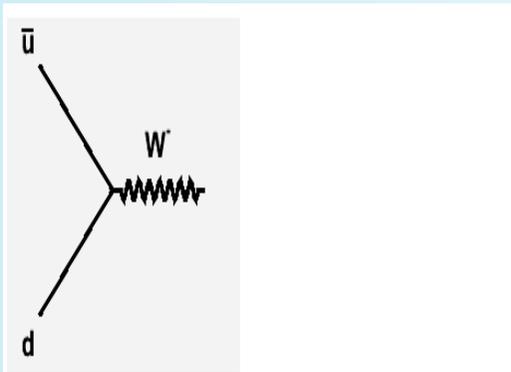
# I. Introduction

## - Example: W Process -

- At the LHC, the most obvious example is the Drell-Yan production of  $W^\pm$
- Qualitatively it immediately appears that:
  - this IS configuration:

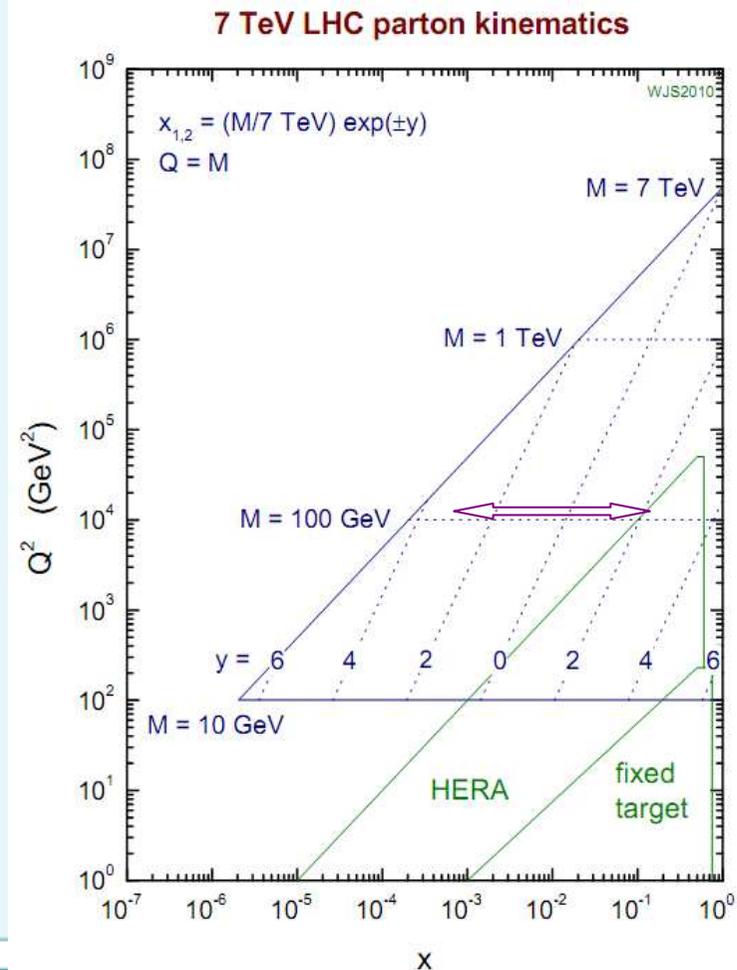


- is more frequent than this one:



- For this simple  $2 \rightarrow 2$  process, one sets  $Q=M_W$ , and the Björken x's span between:

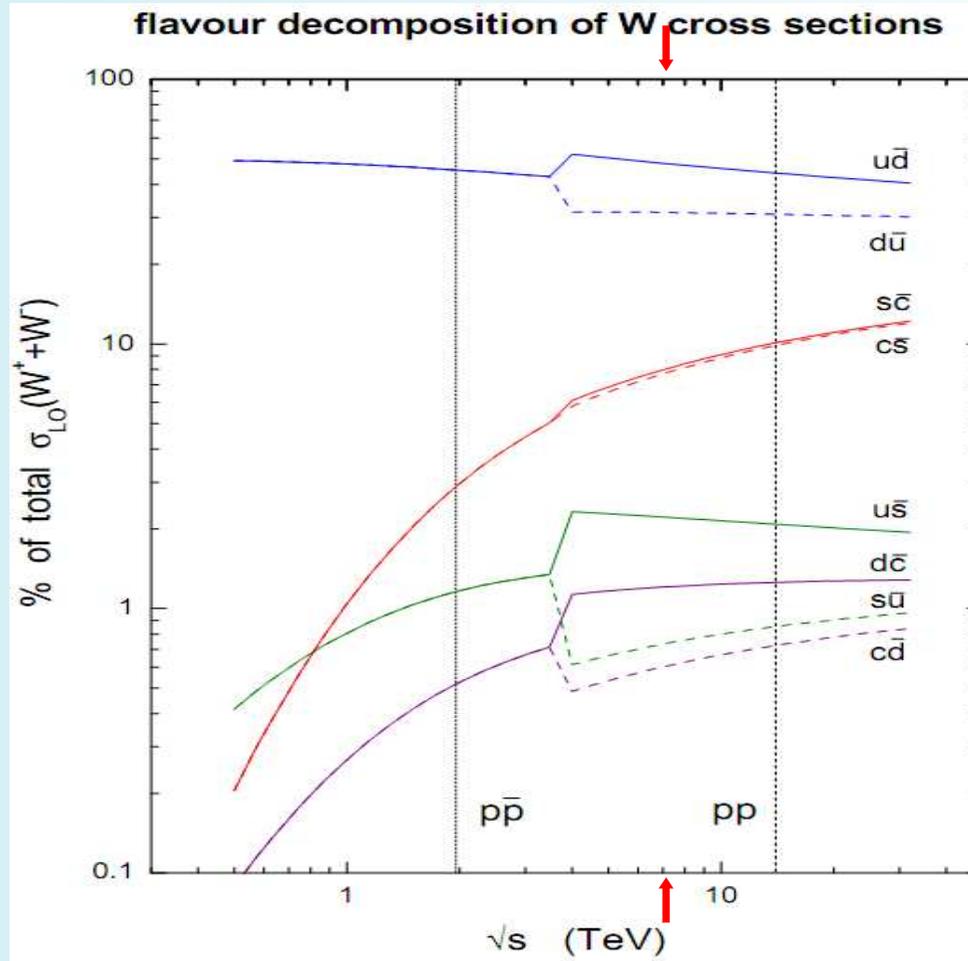
$$x_{\min} = \frac{M_W}{\sqrt{s}} \cdot e^{-y_W} \quad x_{\max} = \frac{M_W}{\sqrt{s}} \cdot e^{+y_W}$$



# I. Introduction

## - $A_C$ vs Proton Structure -

- More quantitatively one can read this process GCA from the plot below:



MSTW2008lo  
J. Stirling

# I. Introduction

## - $A_C$ from Charged Leptons -

- So far, we talked exclusively about the IS
- For the GCA to be a clean and simple observable:
  - we have to tag the sign of the FS using electrons and muons
  - which are easily identifiable particles
  - all that follows also applies to taus, but they are more difficult to identify
- So, we'll actually use a so-called « fiducial » definition of the GCA:

$$A_C = \frac{N(\ell^+) - N(\ell^-)}{N(\ell^+) + N(\ell^-)}$$

- where the leptons:
  - pass the trigger & offline thresholds
  - are within the tracker acceptance
- Experimental Advantages:
  - to have an (indirect) mass measurement that does not require any kinematic reco
  - which is instead a simple counting experiment
  - which has moderate systematic uncertainty since it's a ratio of events count

# I. Introduction

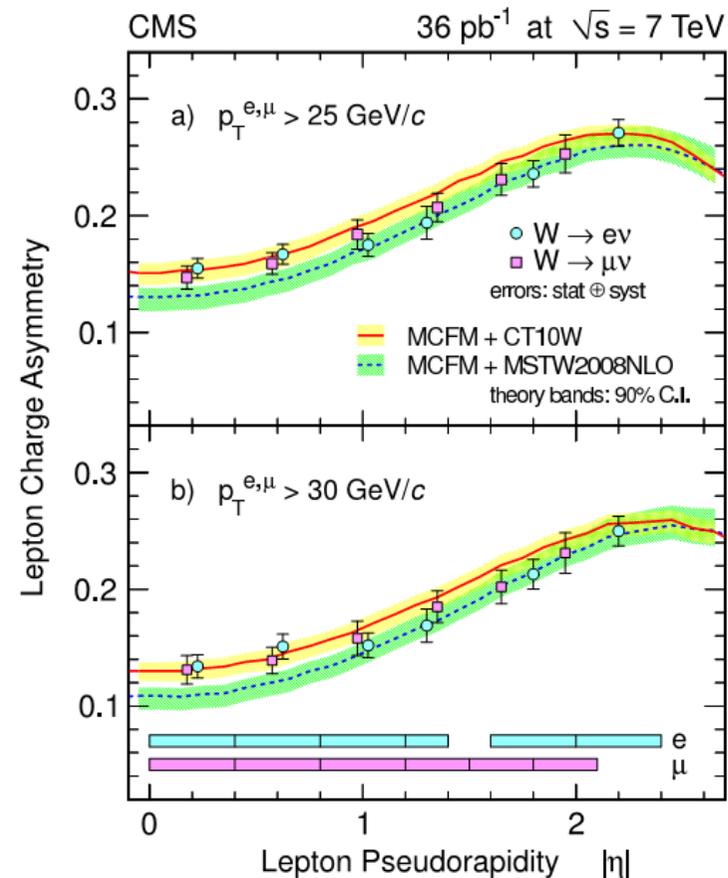
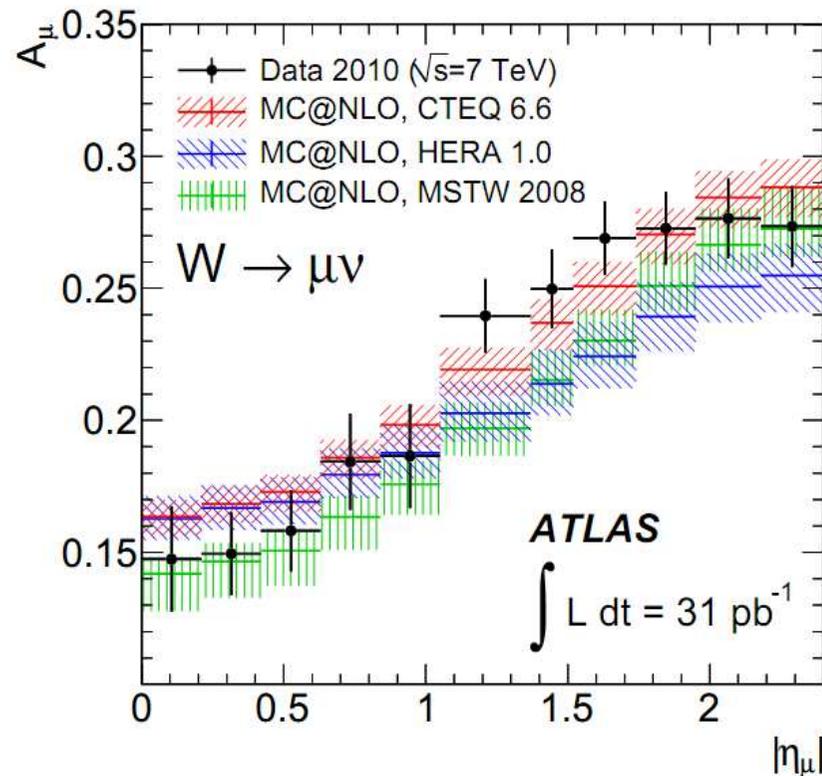
## - LHC Measurements -

- Both the global and the differential charge asymmetries were measured by ATLAS and CMS

$$A_C \approx (18 \pm [1.5 - 2.0])\%$$

arXiv:1110.0152 [hep-ex]

Phys.Lett. B701 (2011) 31-49  
arXiv:1103.2929 [hep-ex]



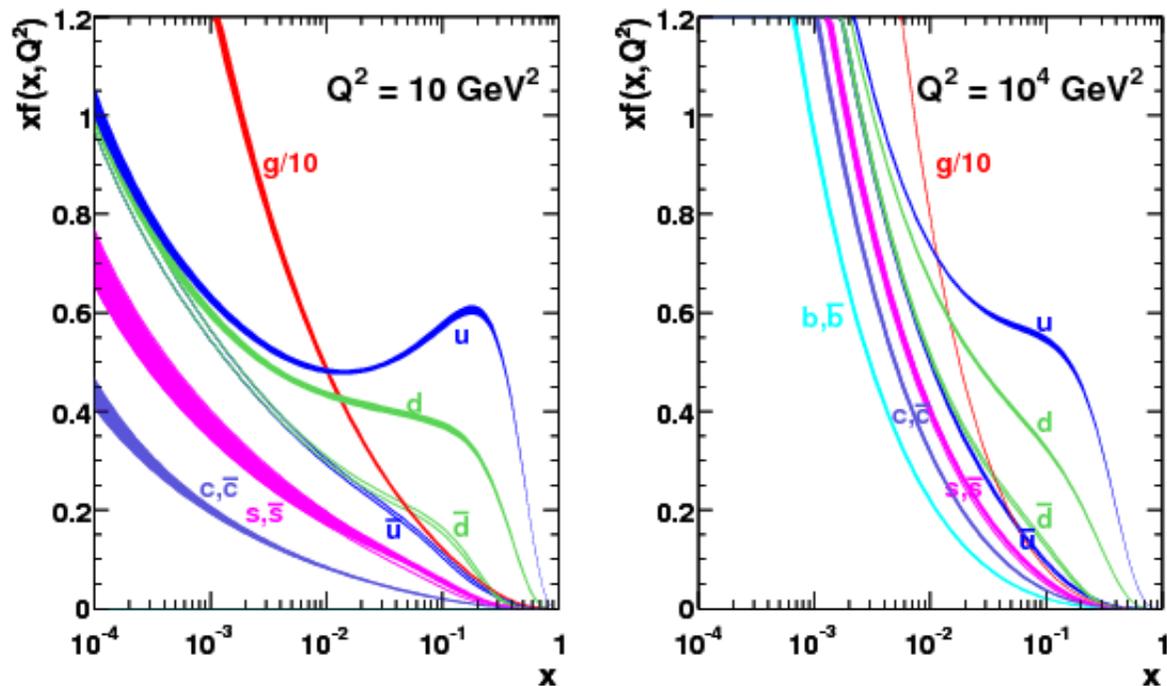
# I. Introduction

-  $A_C = f(M_{FS})$  -

- Considering just the dominant contribution:

$$A_C \approx \frac{u(x_{1/2}, M_W^2) \bar{d}(x_{2/1}, M_W^2) - \bar{u}(x_{1/2}, M_W^2) d(x_{2/1}, M_W^2)}{u(x_{1/2}, M_W^2) \bar{d}(x_{2/1}, M_W^2) + \bar{u}(x_{1/2}, M_W^2) d(x_{2/1}, M_W^2)}$$

MSTW 2008 LO PDFs (68% C.L.)



$M_W^2 \nearrow \Rightarrow A_C \nearrow$

- Could exploit an analytic expression using DGLAP solutions for the u/ubar/d/dbar density functions

# I. Introduction

## - $A_C$ Mass Templates -

- But,
  - there are contributions from other flavor combinations
  - there are higher order contributions (with different IS parton luminosities)
  - and... all of this is obviously process dependent
- Instead of trying to derive an analytic functional form including all these effects, we'll establish numerical mass templates for the GCA by artificially varying  $M(\text{FS}^\pm)$ 
  - Ref: S. Muanza, GDR SUSY Internal Note, May 2000. Unpublished.  
[http://susy.in2p3.fr/GDR-Notes/GDR\\_SUSY\\_PUBLIC/GDR-S-076.ps](http://susy.in2p3.fr/GDR-Notes/GDR_SUSY_PUBLIC/GDR-S-076.ps)

## II. Theoretical Prediction

### - Parton Level Cross Sections -

- In this section, we establish GCA mass templates from parton level calculations of the process cross section:

$$A_c = \frac{\sigma(pp \rightarrow FS^+) - \sigma(pp \rightarrow FS^-)}{\sigma(pp \rightarrow FS^+) + \sigma(pp \rightarrow FS^-)}$$

- **Goal:** establish a look-up table to translate an input GCA into a mass accounting for the theoretical uncertainties
- Hereafter, we just use LO cross sections calculated with MCFM v5.8 with the following settings:

- **Process ME:**

$$\begin{cases} q + \bar{q}' \rightarrow W^\pm \\ q + \bar{q}' \rightarrow W^\pm + g \\ q + g \rightarrow W^\pm + q' \end{cases}$$

- **Collider Energy:**  $\sqrt{s} = 7 \text{ TeV}$

- **PDFs:**

$$\begin{cases} \text{MRST2007lomod (default)} \\ \text{CTEQ6L1} \\ \text{MSTW2008lo68cl} \end{cases}$$

- **Phase Space:**

$$\begin{cases} \text{Pre - Sampling : } 10 \times 20\text{k calls} \\ \text{Actual Sampling : } 10 \times 20\text{k calls} \end{cases}$$

- **QCD Scales:**

$$\mu_R = \mu_F = \mu_0 = \sqrt{M^2(W^\pm) + p_T^2(W^\pm)}$$

- **Decay Mode:**  $W^\pm \rightarrow e^\pm + \nu_e$  (forced)

- **Parton LVL Cuts:**  $\hat{M} > 10 \text{ GeV}$

## II. Theoretical Prediction

### - Theoretical Uncertainties -

• **Statistical Uncertainty:**  $\delta A_C^{\text{Stat}} \longrightarrow \delta A_C^{\text{Stat}} = \frac{2 \cdot \sqrt{(\sigma^-)^2 \cdot (\delta\sigma^+)^2 + (\sigma^+)^2 \cdot (\delta\sigma^-)^2}}{(\sigma^+ + \sigma^-)^2}$

• **Scale Uncertainty:**  $\delta A_C^{\text{Scale}} \longrightarrow \begin{cases} \delta A_C^{\text{Scale}^+} = A_C(\mu_0/2) - A_C(\mu_0) \\ \delta A_C^{\text{Scale}^-} = A_C(2\mu_0) - A_C(\mu_0) \end{cases}$

• **PDF Uncertainty:**  $\delta A_C^{\text{PDF}} \longrightarrow \begin{cases} \delta A_C^{\text{PDF}^+} = \sqrt{\sum_{i=1}^{N_{\text{PDF}}/2} [\text{Max}\{A_{C_i}^+ - A_{C_0}, A_{C_i}^- - A_{C_0}, 0\}]^2} \\ \delta A_C^{\text{PDF}^-} = \sqrt{\sum_{i=1}^{N_{\text{PDF}}/2} [\text{Max}\{A_{C_0} - A_{C_i}^+, A_{C_0} - A_{C_i}^-, 0\}]^2} \end{cases}$

$$\delta A_C^{\text{Total}} = \sqrt{(\delta A_C^{\text{Stat}})^2 + (\delta A_C^{\text{Scale}})^2 + (\delta A_C^{\text{PDF}})^2}$$

## II. Theoretical Prediction

### - Breakdown of Theoretical Uncertainties -

- Scan over  $M_W$ :
  - Factors: 0.25, 0.5, 1.0, 4.0, 6.0, 8.0

MRST2007lomod

$M_{W^\pm}$ (GeV)	$A_C$ (%)	$\delta_{Stat}A_C$ (%)	$\delta_{Scale}A_C$ (%)	$\delta_{PDF}A_C$ (%)	$\delta_{Total}A_C$ (%)
20.1	2.20	$\pm 0.24$	+0.47 +0.10	0.00	+0.52 -0.26
40.2	6.77	$\pm 0.12$	+0.02 -0.11	0.00	+0.12 -0.16
<u>80.4</u>	20.18	$\pm 0.06$	+0.05 -0.03	0.00	+0.08 -0.07
160.8	29.39	$\pm 0.05$	+0.00 +0.03	0.00	+0.05 -0.06
321.6	35.92	$\pm 0.05$	-0.11 +0.10	0.00	+0.11 -0.11
643.2	43.99	$\pm 0.05$	-0.14 +0.13	0.00	+0.15 -0.14
1286.4	52.36	$\pm 0.06$	+0.03 -0.02	0.00	+0.07 -0.07

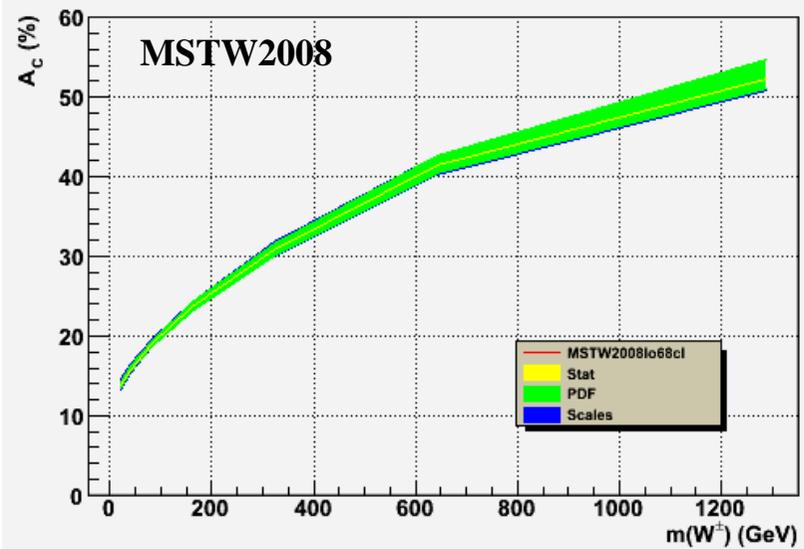
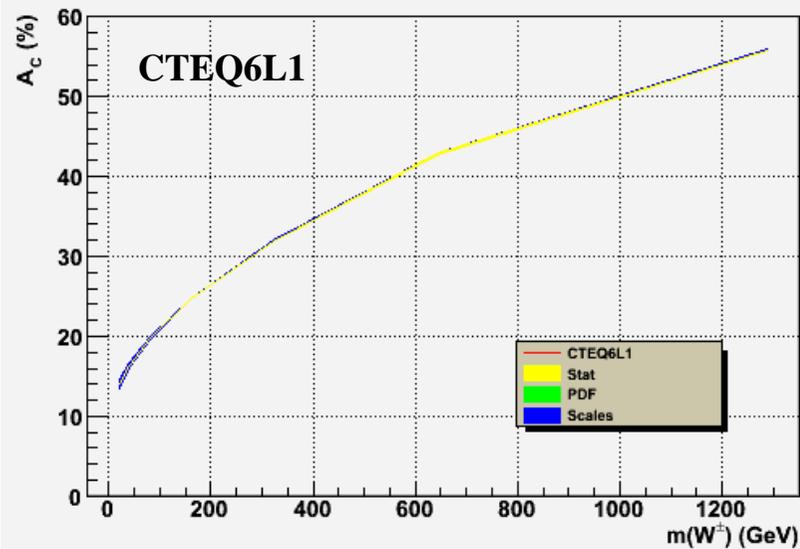
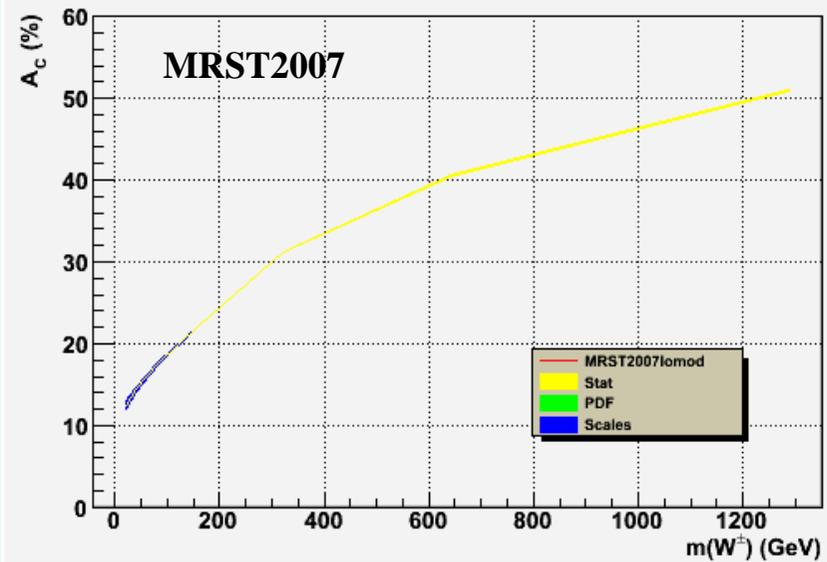
CTEQ6L1

$M_{W^\pm}$ (GeV)	$A_C$ (%)	$\delta_{Stat}A_C$ (%)	$\delta_{Scale}A_C$ (%)	$\delta_{PDF}A_C$ (%)	$\delta_{Total}A_C$ (%)
20.1	3.70	$\pm 0.24$	-0.27 -0.11	0.00	+0.36 -0.26
40.2	8.65	$\pm 0.12$	-0.02 -0.00	0.00	+0.12 -0.12
<u>80.4</u>	19.69	$\pm 0.03$	+0.14 -0.05	0.00	+0.14 -0.06
160.8	24.67	$\pm 0.03$	+0.00 -0.01	0.00	+0.03 -0.03
321.6	31.97	$\pm 0.04$	-0.12 -0.06	0.00	+0.12 -0.07
643.2	42.84	$\pm 0.05$	-0.17 -0.08	0.00	+0.18 -0.09
1286.4	55.84	$\pm 0.06$	-0.07 -0.04	0.00	+0.10 -0.07

MSTW2008lo68cl

$M_{W^\pm}$ (GeV)	$A_C$ (%)	$\delta_{Stat}A_C$ (%)	$\delta_{Scale}A_C$ (%)	$\delta_{PDF}A_C$ (%)	$\delta_{Total}A_C$ (%)
20.1	3.07	$\pm 0.24$	-0.21 +0.14	+0.46 -0.40	+0.56 -0.49
40.2	7.85	$\pm 0.12$	+0.10 +0.07	+0.43 -0.33	+0.46 -0.36
<u>80.4</u>	22.24	$\pm 0.06$	+0.15 +0.13	+0.64 -0.42	+0.66 -0.44
160.8	31.19	$\pm 0.05$	+0.21 +0.19	+0.78 -0.53	+0.81 -0.57
321.6	36.96	$\pm 0.05$	+0.16 +0.33	+0.96 -0.70	+0.97 -0.77
643.2	44.63	$\pm 0.06$	+0.17 +0.41	+1.28 -0.96	+1.29 -1.05
1286.4	53.66	$\pm 0.07$	+0.31 +0.33	+2.39 -1.28	+2.42 -1.32

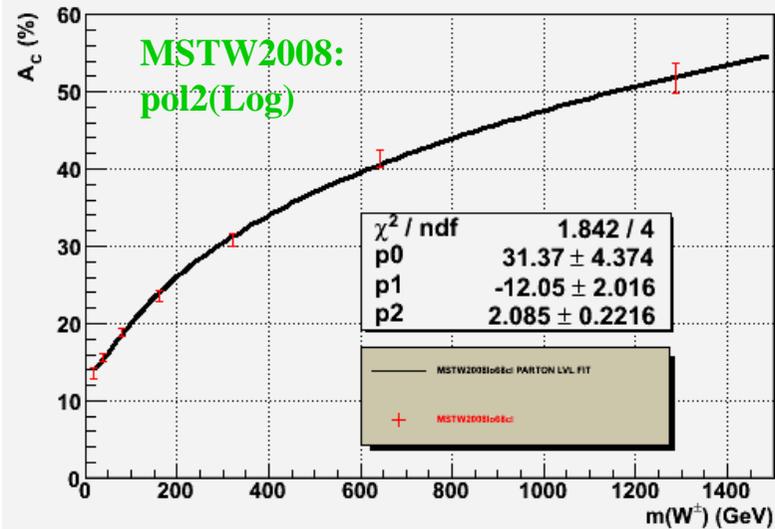
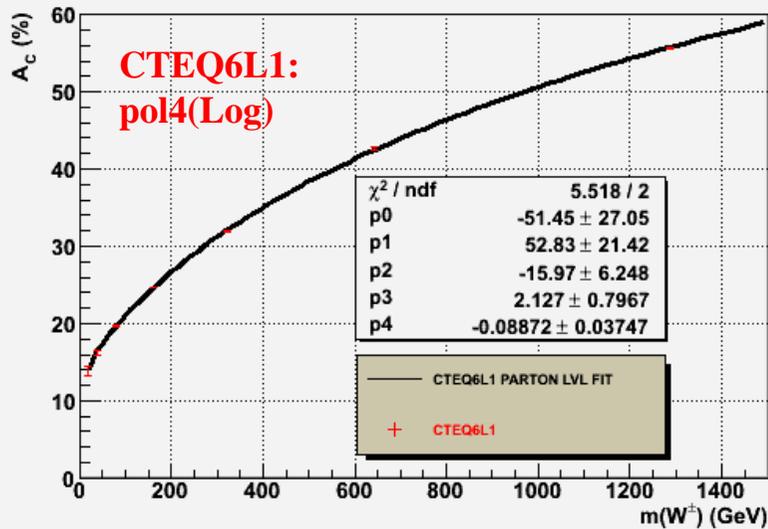
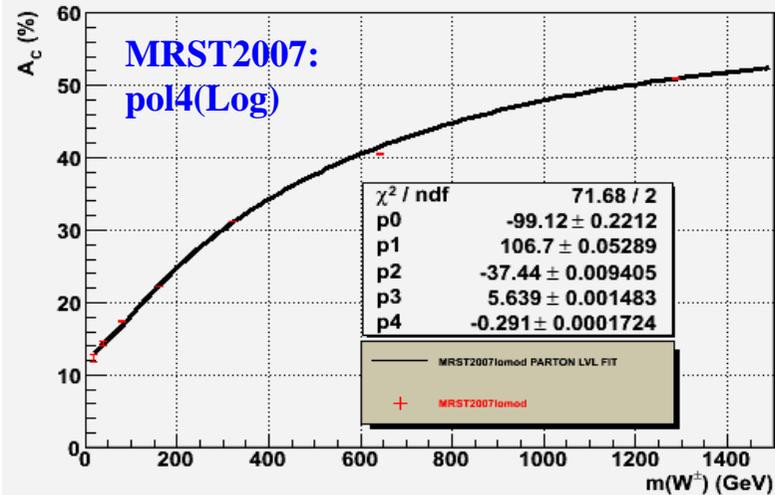
## II. Theoretical Prediction - GCA Mass Templates -



## II. Theoretical Prediction - GCA Central Values Fit -

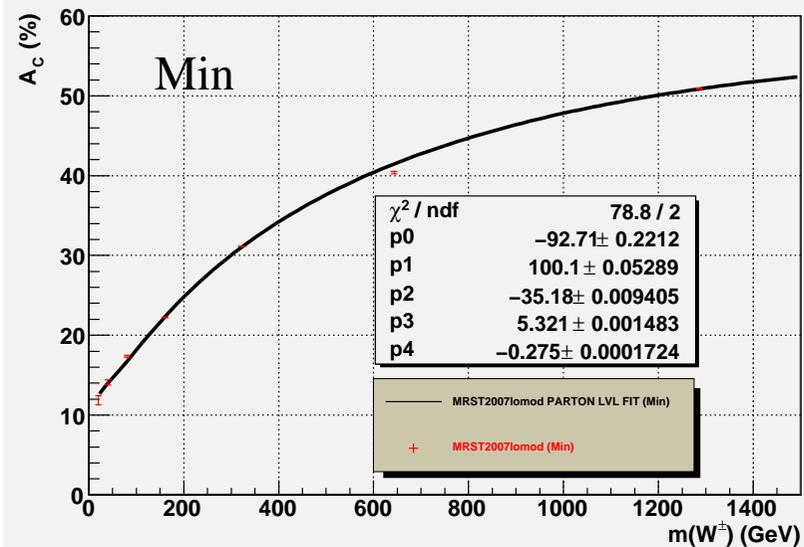
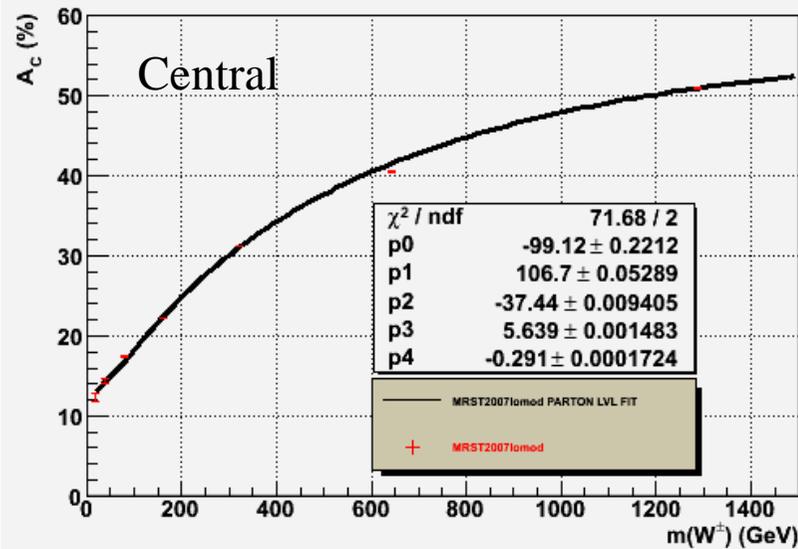
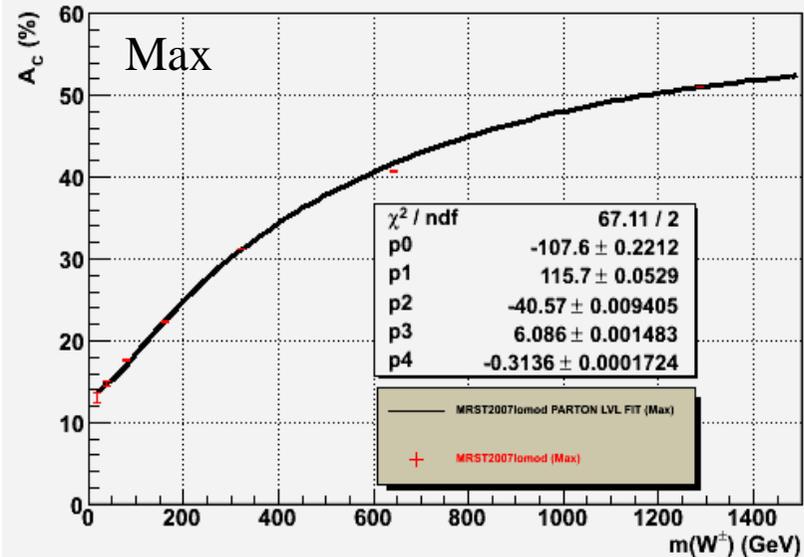
$$A_C = a_0 + a_1 \times \text{Log}(M_W) + a_2 \times \text{Log}^2(M_W) + a_3 \times \text{Log}^3(M_W) + a_4 \times \text{Log}^4(M_W)$$

Fit range: [15,1500] GeV, for all fits



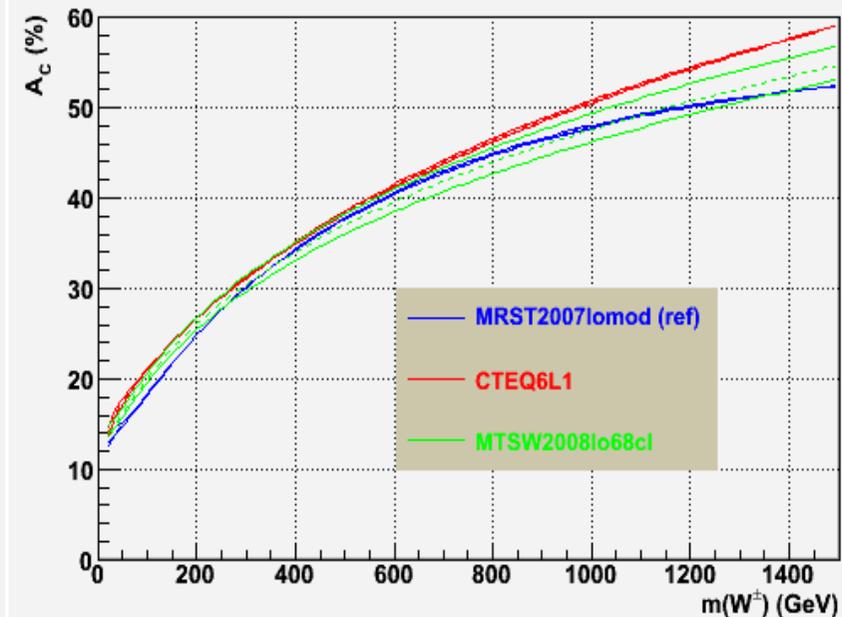
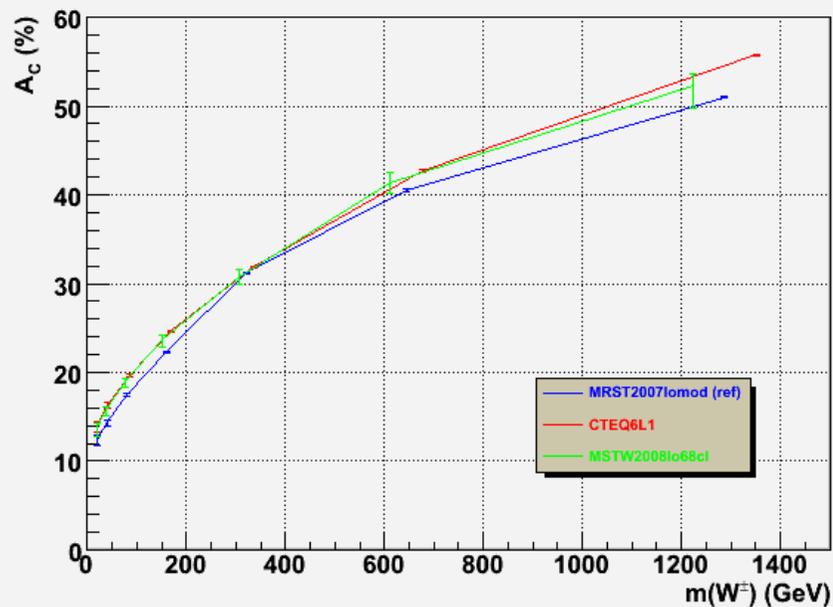
## II. Theoretical Prediction - GCA Enveloppes Fits -

- Interpolate the  $1\sigma$  uncertainty curves
- Same  $\delta A_C^{\text{Total}}$
- Fit 2 curves with:  $A_C^{\text{Central}} \pm \delta A_C^{\text{Total}}$



## II. Theoretical Prediction - Comparing the PDFs -

- GCA from MRST2007lomod, MSTW2008lo68cl and CTEQ6L1 compatible within uncertainties

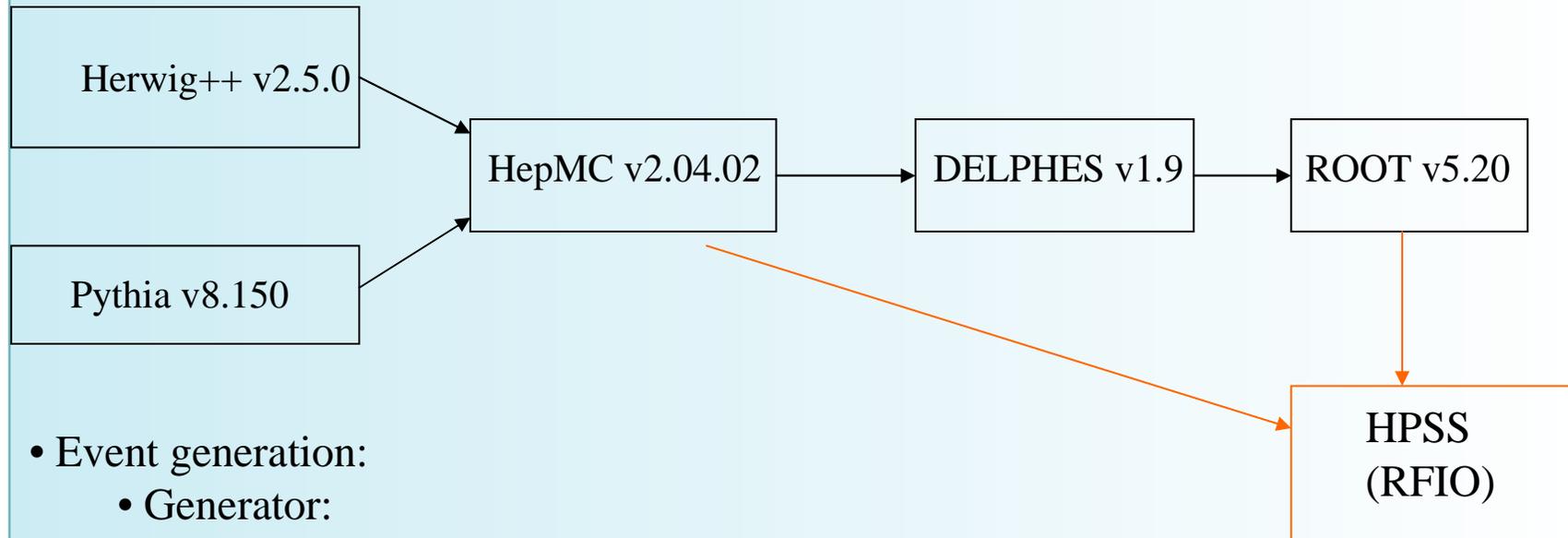


## III. Experimental Measurement

### - Goals -

- Extract the GCA of a given signal in a « realistic » environment
- Study the experimental biases affecting  $A_C$ :
  - Event selection (Trigger & Offline)
  - Background contamination
- Account for experimental systematic uncertainties

### III. Experimental Measurement - MC Production Tools -



- Event generation:
  - Generator:
    - Herwig++ v2.5.0
      - For all SM processes (except...)
    - Pythia v8.150
      - For Single Top

# III. Experimental Measurement - MC Production Setup -

- PDF: MRST2007lomod
- H++ UE Tune:
  - Name: « LHC-UE7-2 »
  - Ref: ATLAS\_2010\_S8894728
- Py8 UE Tune:
  - Name: « 2M »
  - Ref: arXiv:1003.2384 [hep-ph]
- ME: LO
- Normalization: LO xsect
  - No K-factors: QCD (LF), cc, bb,  $\gamma$ +jets,  $\gamma\gamma$  (very low  $\epsilon$ )
  - NLO K-Factors: tt, t+X, VV,  $\gamma$ +V (V=W or  $\gamma^*/Z$ )
  - NNLO K-Factors: V
- Statistics: 85.0 M evts, just the root-tuples take 2.65 Tb
- Full details about:
  - MC Production: in appendix 1
  - Fast Detector Simulation: in appendix 2

$$\sqrt{s} = 7 \text{ TeV}$$

$$\int \mathcal{L} dt = 1 \text{ fb}^{-1}$$

$$\begin{cases} M_t = 172.0 \text{ GeV (pole)} \\ M_b = 4.20 \text{ GeV } (\overline{MS}) \\ M_c = 1.27 \text{ GeV } (\overline{MS}) \end{cases}$$

# III. Experimental Measurement - Trigger & Event Skimming -

## Trigger Emulation

- Isolated Leptons:
  - 1e ( $p_T > 25$  GeV)
  - 1 $\mu$  ( $p_T > 20$  GeV)
  - 2e ( $p_T > \ll 2 \times 15 \gg$  GeV)
  - 2 $\mu$  ( $p_T > \ll 2 \times 10 \gg$  GeV)
- Isolated Photons:
  - 1 $\gamma$  ( $p_T > 60$  GeV)
  - 2 $\gamma$  ( $p_T > \ll 2 \times 20 \gg$  GeV)
- Tau plus missing  $E_T$ :
  - $\tau + mE_T$  ( $p_T > 35$  &  $mE_T > 45$  GeV)
- Jet plus missing  $E_T$ :
  - Jet +  $mE_T$  ( $p_T > 70$  &  $mE_T > 70$  GeV)
- Inclusive Jets:
  - 1j ( $p_T > 400$  GeV)
  - 3j ( $p_T > \ll 3 \times 165 \gg$  GeV)
  - 4j ( $p_T > \ll 4 \times 110 \gg$  GeV)

## Event Skimming

- Goal:
  - Reduce specific data subsets to manageable size (that can be staged)
  - Event filtering: based on trigger bits
- 1e: 163.7 Gb (6.2%)
- 1 $\mu$ : 205.1 Gb (7.7%)
- $\ll$  lep+jets  $\gg$ :
  - single lepton (lep=e/ $\mu$ ) OR Jet +  $mE_T$
  - 487.4 Gb (18.3 %)
- $\ll$  tau +  $mE_T$   $\gg$ : 23.9 Gb (0.9 %)
- $\ll$  3lep  $\gg$ :
  - single lepton OR di-lepton
  - 418.1 Gb (15.8 %)

# III. Experimental Measurement

## - Event Selection -

- Here I describe the event selection of the  $W \rightarrow \mu\nu$  channel

### Preselection (1)

- Cuts:

- $p_T(\mu_0) > 20 \text{ GeV}$
- $|\eta(\mu_0)| < 2.4$
- Muon Isolation:
  - Tracker: IsolFlag = 1
  - Calo: ETRatio < 0.25
- $mE_T > 25 \text{ GeV}$

No add'l tracks w/  $p_T > 2 \text{ GeV}$   
in a cone of  $\Delta R=0.5$  around  $\mu_0$

$$ETRatio = \frac{\sum_{\Delta R < 0.5} E_T (3 \times 3 \text{ Towers})}{p_T(\mu_0)}$$

- Caveat:

- muon reco threshold:  $p_T(\mu) > 10 \text{ GeV}$
- $mE_T$  corrected for reco'd  $\mu$  only (not for those below threshold)

### III. Experimental Measurement - Event Selection -

- Event Yield:

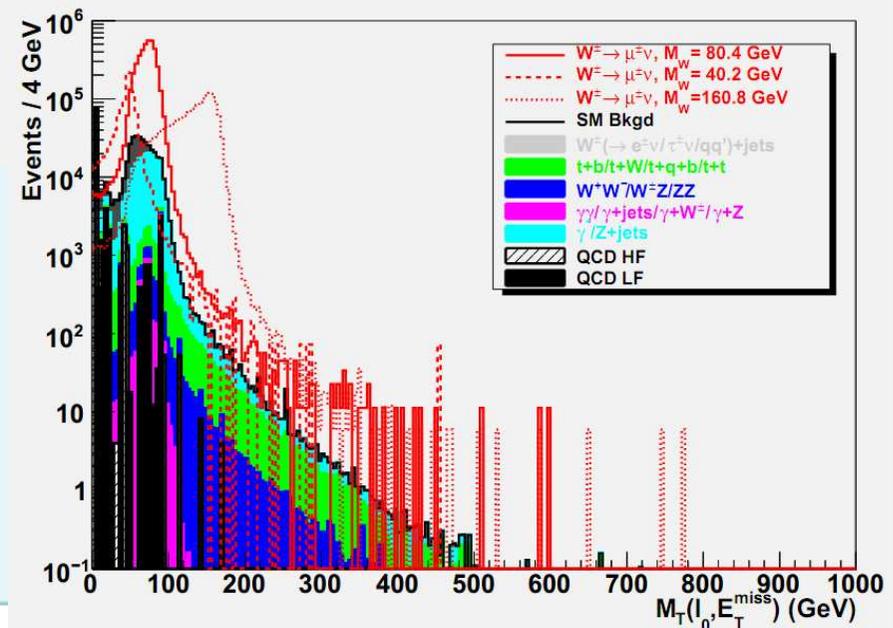
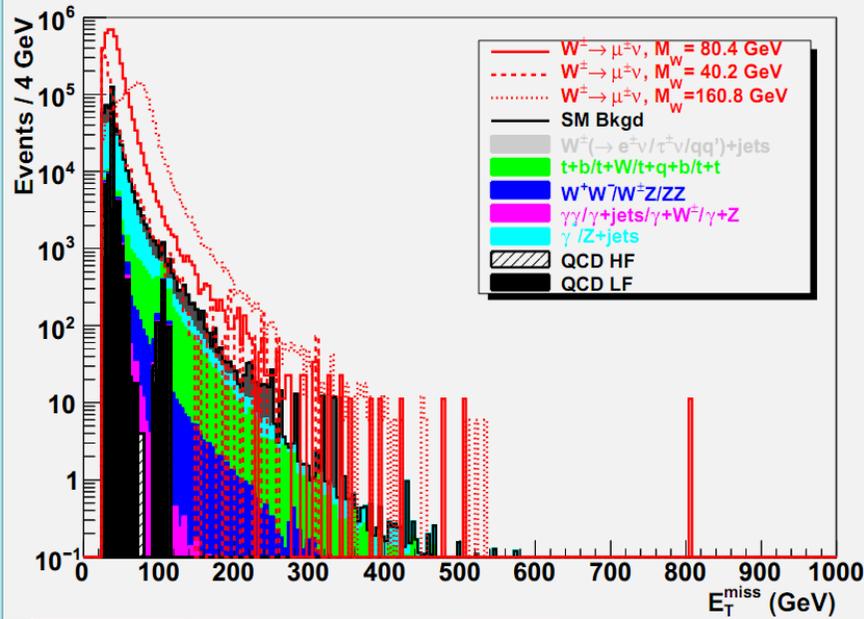
#### Preselection (2)

<i>Process</i>	$\epsilon$ (%)	$N_{exp}$ (M evts)
Signal: $W^\pm \rightarrow \mu^\pm \nu_\mu$		
$M(W^\pm) = 40.2 GeV$	$3.13 \pm 0.02$	1.13
$M(W^\pm) = 60.3 GeV$	$21.12 \pm 0.06$	3.95
$M(W^\pm) = 80.4 GeV$	$36.59 \pm 0.05$	4.13
$M(W^\pm) = 100.5 GeV$	$45.80 \pm 0.07$	3.42
$M(W^\pm) = 120.6 GeV$	$51.74 \pm 0.07$	2.72
$M(W^\pm) = 140.7 GeV$	$55.68 \pm 0.07$	2.17
$M(W^\pm) = 160.7 GeV$	$58.54 \pm 0.07$	1.74
$M(W^\pm) = 201.0 GeV$	$62.44 \pm 0.07$	$1.18 \times 10^{-3}$
Background	-	0.48
$W^\pm \rightarrow e^\pm \nu_e / \tau^\pm \nu_\tau / q\bar{q}'$	$0.44 \pm 0.004$	0.15
$t\bar{t}$	$10.03 \pm 0.03$	0.012
$t + b, t + q(+b)$	$5.34 \pm 0.016$	$2.89 \times 10^{-3}$
$W + W, W + \gamma^*/Z, \gamma^*/Z + \gamma^*/Z$	$5.42 \pm 0.014$	$3.84 \times 10^{-3}$
$\gamma + \gamma, \gamma + jets, \gamma + W^\pm, \gamma + Z$	$0.303 \pm 0.001$	$1.11 \times 10^{-3}$
$\gamma^*/Z$	$5.789 \pm 0.004$	0.21
QCD HF	$(2.88 \pm 0.43) \times 10^{-4}$	$9.93 \times 10^{-3}$
QCD LF	$(2.00 \pm 0.50) \times 10^{-4}$	0.093

# III. Experimental Measurement

## - Event Selection -

### Preselection (3)



# III. Experimental Measurement

## - Event Selection -

### Final Selection (1)

- Cuts:
  - $M_T(\mu_0, mE_T) > 40 \text{ GeV}$
  - Add'l Isolated Muons:
    - Reject evts w/  $\text{IsolFlag}(\mu_1) = 1$
    - For  $\mu_1$  below threshold:
      - If  $\text{SIGN}(\text{track}_1) = -\text{SIGN}(\mu_0)$ :
        - Reject evts w/  $M(\mu_0, \text{track}_1) > 50 \text{ GeV}$
  - Add'l Isolated Electron:
    - Reject evts w/  $\text{IsolFlag}(e_0) = 1$

## III. Experimental Measurement

### - Event Selection -

- Event Yield:

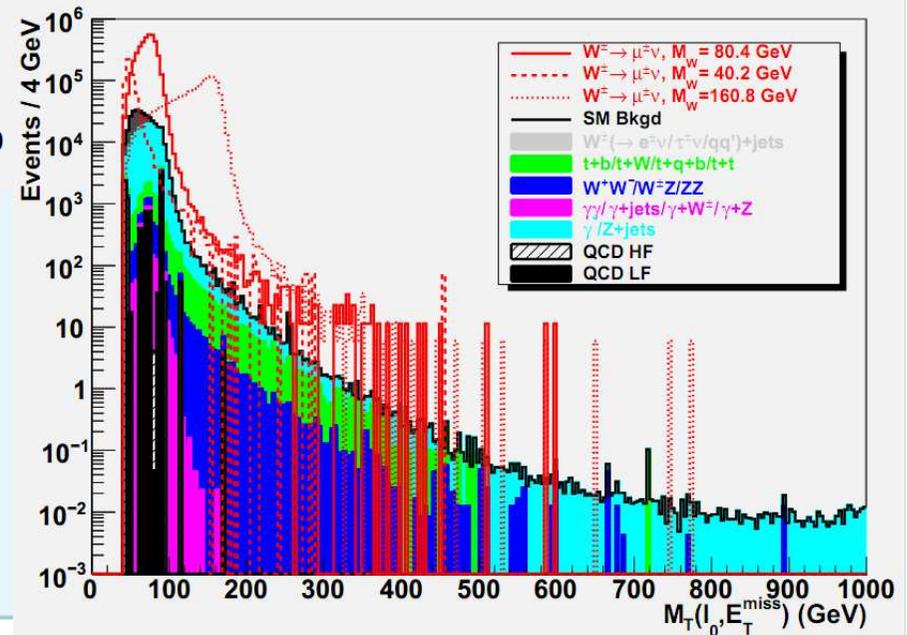
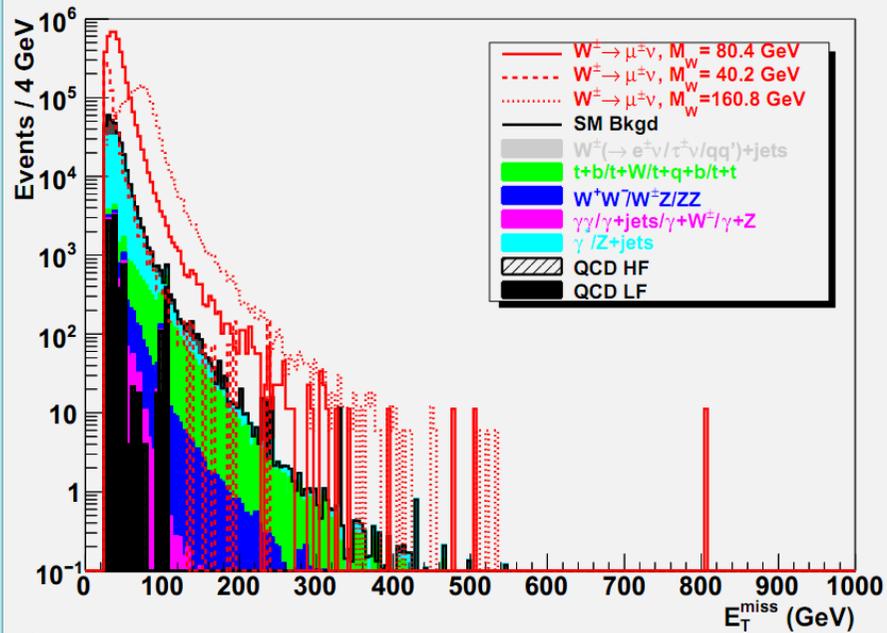
#### Final Selection (2)

<i>Process</i>	$\epsilon$ (%)	$N_{exp}$ (k evts)	$A_C \pm \delta A_C^{Stat}$ (%)
Signal: $W^\pm \rightarrow \mu^\pm \nu_\mu$			
$M(W^\pm) = 40.2 GeV$	$2.26 \pm 0.02$	816.08	$8.50 \pm 0.94$
$M(W^\pm) = 60.3 GeV$	$20.21 \pm 0.06$	3780.59	$12.35 \pm 0.31$
$M(W^\pm) = \underline{80.4 GeV}$	$35.52 \pm 0.05$	4013.88	$17.52 \pm 0.17$
$M(W^\pm) = 100.5 GeV$	$44.57 \pm 0.07$	3328.06	$21.33 \pm 0.21$
$M(W^\pm) = 120.6 GeV$	$50.34 \pm 0.07$	2647.01	$24.36 \pm 0.19$
$M(W^\pm) = 140.7 GeV$	$54.09 \pm 0.07$	2111.98	$25.93 \pm 0.19$
$M(W^\pm) = 160.8 GeV$	$56.77 \pm 0.07$	1690.84	$27.47 \pm 0.18$
$M(W^\pm) = 201.0 GeV$	$60.29 \pm 0.07$	1.14	$30.05 \pm 0.17$
Background	-	328.27	$5.87 \pm 0.08$
$W^\pm \rightarrow e^\pm \nu_e / \tau^\pm \nu_\tau / q\bar{q}'$	$0.347 \pm 0.003$	116.88	$16.17 \pm 0.97$
$t\bar{t}$	$6.75 \pm 0.02$	7.73	$0.41 \pm 0.34$
$t + b, t + q(+b)$	$4.447 \pm 0.045$	2.41	$28.84 \pm 0.32$
$W + W, W + \gamma^*/Z, \gamma^*/Z + \gamma^*/Z$	$3.98 \pm 0.01$	2.93	$10.53 \pm 0.30$
$\gamma + \gamma, \gamma + jets, \gamma + W^\pm, \gamma + Z$	$0.2765 \pm 0.001$	1.02	$17.02 \pm 0.45$
$\gamma^*/Z$	$3.715 \pm 0.003$	188.02	$3.84 \pm 0.09$
QCD HF	$(6.269 \pm 1.983) \times 10^{-5}$	3.73	$-20.0 \pm 30.98$
QCD LF	$(6.304 \pm 1.901) \times 10^{-5}$	5.55	$27.3 \pm 29.01$

# III. Experimental Measurement

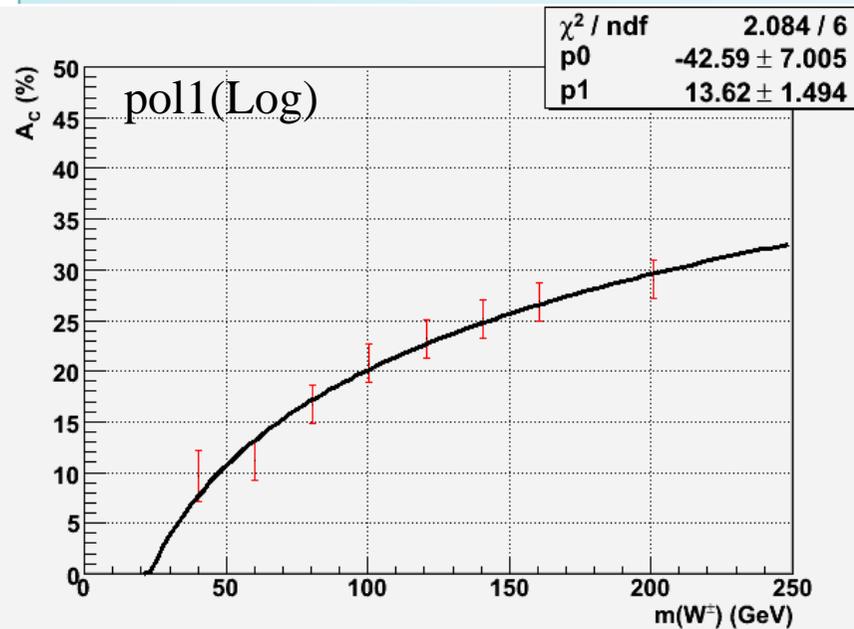
## - Event Selection -

### Final Selection (3)

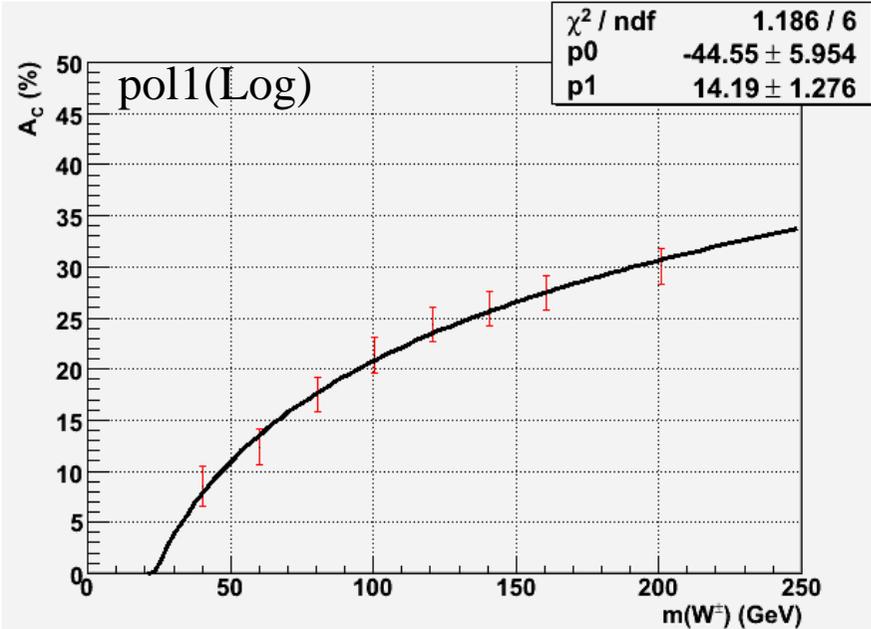


### III. Experimental Measurement - Experimental Mass Templates -

$$W^{\pm} \rightarrow e^{\pm} \nu_e$$



$$W^{\pm} \rightarrow \mu^{\pm} \nu_{\mu}$$



## III. Experimental Measurement - Experimental Uncertainties -

- Hereafter, I'll illustrate the method to extract of the signal GCA on the  $W \rightarrow \mu\nu$  channel
  - It accounts for:
    - the background contamination
    - the experimental systematic uncertainties
- Experimental systematic uncertainties:
  - Not derived by any DELPHES study
  - Take more realistic values from real data analyses
  - Very conservative examples ( $L < 35 \text{ pb}^{-1}$ ):
    - Asymmetries:
      - in muon channel: 1.0% (ref: [arXiv:1103.2929v1 \[hep-ex\]](#))
      - in electron channel: 1.5% (ref: ATLAS-CONF-2010-051)
    - S/B ratio:
      - in muon channel: 2.32% (ref: ATLAS-CONF-2011-041 )
      - in electron channel: 2.80% (ref: ATLAS-CONF-2011-041 )
  - We used 1.0% for GCA and 1.2% for S/B

### III. Experimental Measurement - Extracting Signal GCA -

- Now we need to extract the signal GCA:
  - without bias from the remaining background

Ideal case

$$A_C^{Exp}(S) = \frac{N_S^+ - N_S^-}{N_S^+ + N_S^-}$$

$$A_C^{Exp}(B) = \frac{N_B^+ - N_B^-}{N_B^+ + N_B^-}$$



More realistic case

$$A_C^{Exp}(S+B) = \frac{N_S^+ + N_B^+ - N_S^- - N_B^-}{N_S^+ + N_B^+ + N_S^- + N_B^-}$$

$$\alpha = \frac{N_B}{N_S}$$

$$\Rightarrow A_C^{Exp}(S+B) = \frac{A_C^{Exp}(S) + \alpha \cdot A_C^{Exp}(B)}{1 + \alpha}$$

$$\Rightarrow A_C^{Exp}(S) = (1 + \alpha) \cdot A_C^{Exp}(S+B) - \alpha \cdot A_C^{Exp}(B)$$

- Note: only ratios appear in extracted signal GCA (low systematics)

### III. Experimental Measurement - Extracting Signal GCA Cont'd -

- Now we need to account for all signal and background statistical and systematic uncertainties
- We propagate those numerically into the previous formula. This enables to account simultaneously for all the uncertainties and their correlations.

$$A_C^{Exp}(S) = (1 + \alpha) \cdot A_C^{Exp}(S + B) - \alpha \cdot A_C^{Exp}(B)$$

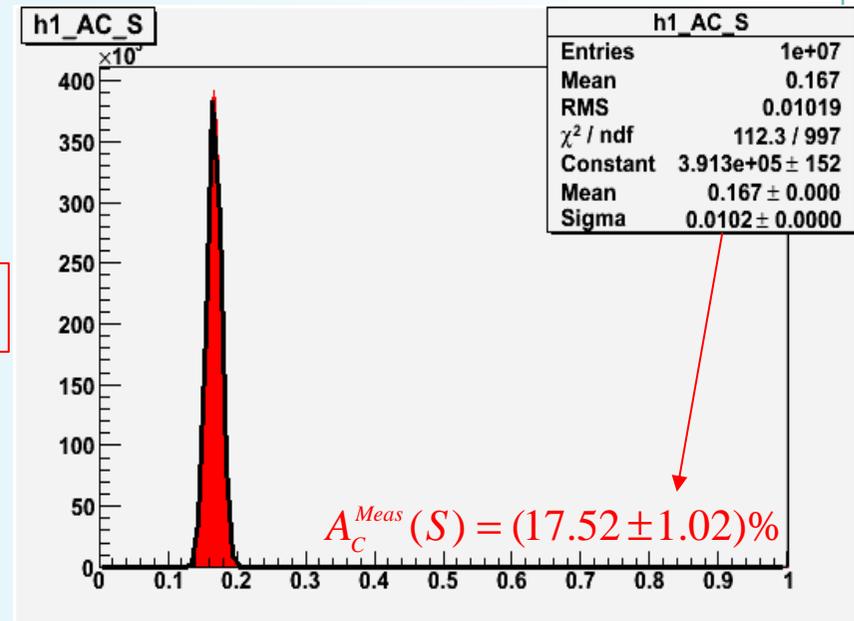


$$A_C^{Meas}(S) = (1 + \tilde{\alpha}) \cdot \tilde{A}_C^{Exp}(S + B) - \tilde{\alpha} \cdot \tilde{A}_C^{Exp}(B)$$

$$\left\{ \begin{array}{l} \alpha \rightarrow \tilde{\alpha} \\ A_C^{Exp}(S + B) \rightarrow \tilde{A}_C^{Exp}(S + B) \\ A_C^{Exp}(B) \rightarrow \tilde{A}_C^{Exp}(B) \end{array} \right.$$

3 gaussian smearings,  $RMS = \sqrt{stat_i^2 + syst_i^2}$

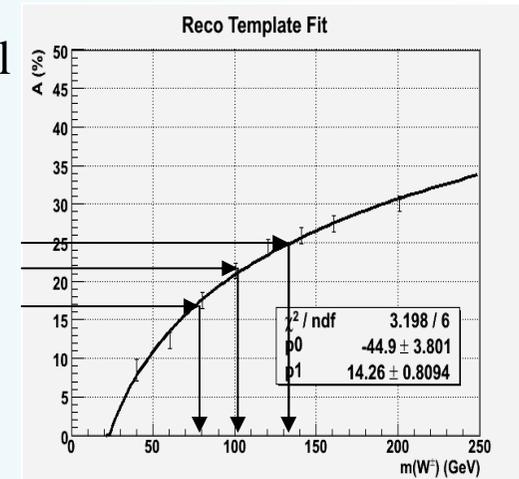
10 M trials



### III. Experimental Measurement - Combined Mass Constraints -

- By inserting the extracted signal GCA into the experimental mass templates we can derive our first mass constraints:

$$A_C^{Meas}(S) \pm \delta A_C^{Meas}(S)$$



$$M_W^{Reco} \pm \delta M_W^{Reco}$$



$$A_C^{Meas}(S) = (16.70 \pm 1.02)\%$$

$$M_W^{Meas} = \left\{ \begin{array}{l} 78.66 + 6.22 \\ 78.66 - 5.84 \end{array} \right\} \text{ GeV}$$



$$A_C^{Meas}(S) = (17.52 \pm 1.02)\%$$

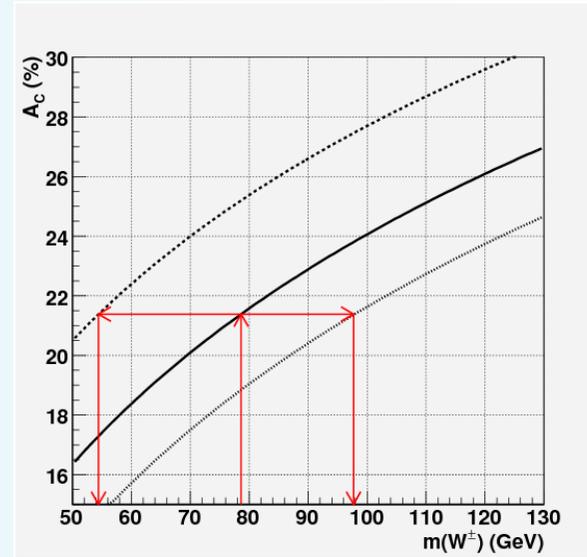
$$M_W^{Meas} = \left\{ \begin{array}{l} 78.86 + 5.82 \\ 78.86 - 5.45 \end{array} \right\} \text{ GeV}$$

- Combined using the mean average formula (w/ largest uncertainty for each channel)

$$\langle M_W^{Meas} \rangle = \{ 78.78 \pm 4.25(\text{Ex}) \} \text{ GeV}$$

## IV. Indirect Mass Constraint

- We then look-up the theoretical mass templates to figure the size of the theory uncertainties:



PDF	W Mass Estimate	
MRST2007	$M_W^{\text{Final}} = \left\{ 78.78 \pm 4.25(\text{Ex}) \begin{matrix} +1.82 \\ -2.72 \end{matrix} (\text{Th}) \right\} \text{ GeV}$	$M_W^{\text{Final}} = \left\{ 78.78 \begin{matrix} +4.62 \\ -5.04 \end{matrix} \right\} \text{ GeV}$
CTEQ6L1 (Caveat)	$M_W^{\text{Final}} = \left\{ 78.78 \pm 4.25(\text{Ex}) \begin{matrix} +1.51 \\ -2.27 \end{matrix} (\text{Th}) \right\} \text{ GeV}$	$M_W^{\text{Final}} = \left\{ 78.78 \begin{matrix} +4.51 \\ -4.81 \end{matrix} \right\} \text{ GeV}$
MSTW2008 (Caveat)	$M_W^{\text{Final}} = \left\{ 78.78 \pm 4.25(\text{Ex}) \begin{matrix} +6.19 \\ -7.68 \end{matrix} (\text{Th}) \right\} \text{ GeV}$	$M_W^{\text{Final}} = \left\{ 78.78 \begin{matrix} +7.51 \\ -8.77 \end{matrix} \right\} \text{ GeV}$

## IV. Indirect Mass Constraint - PDF RW in DELPHES -

- The experimental mass templates are based on the MRST2007lomod PDF
- To correctly interpret our results for any other PDF, either:
  - we redo the full MC production using that PDF
  - or
  - we apply a PDF reweighting to the MRST samples:

$$\text{RW - Factor} = \frac{f_{new}^{flav1}(x_1, Q^2) \cdot f_{new}^{flav2}(x_2, Q^2)}{f_{old}^{flav1}(x_1, Q^2) \cdot f_{old}^{flav2}(x_2, Q^2)}$$

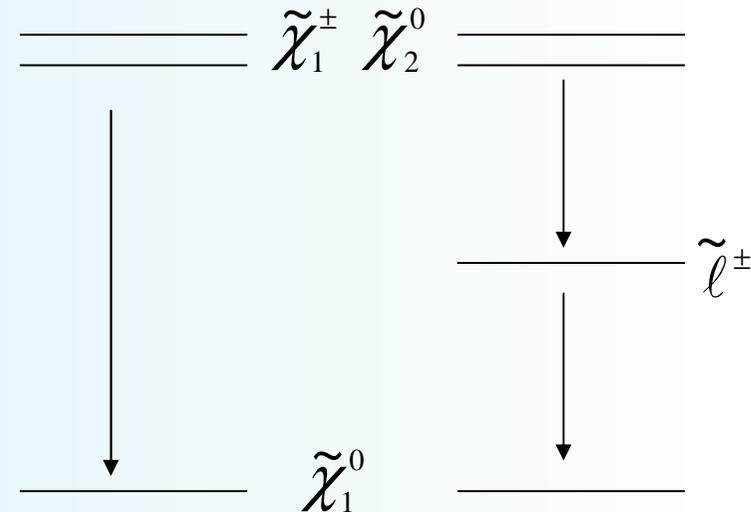
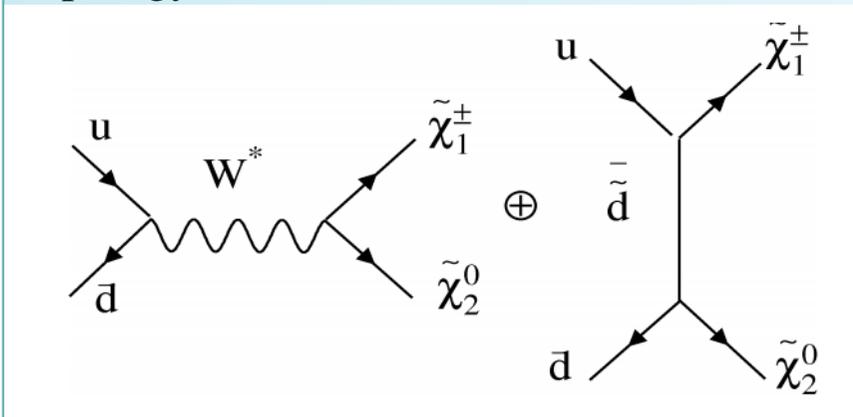
- Oops! I forgot to check whether the PDF variables ( $x_1, x_2, flav_1, flav_2, Q^2$ ) were stored in the DELPHES MC truth informations
- Good news #1: they are stored by default in HepMC
- Bad news: DELPHES ignore these infos!
- ...
- Good news #2: I fixed this problem by:
  - retrieving the HepMC::PdfInfo object from the HepMC input file
  - stored the PDF variables into the « GEN » tree of DELPHES
  - you can find my fix at <https://server06.fynu.ucl.ac.be/projects/delphes/ticket/44>

## V. Conclusions

- We introduced a new method exploiting the GCA at the LHC to constrain the mass of charged final states
- We managed to reconstruct the  $W$  mass indirectly:
  - Acceptable central values
  - Very bad resolution (as expected)
- To be applied on real data, this method requires a very good MC modeling of the data

## VI. Prospects - Physics Case-

- The new method we propose applies to any charged final state at the LHC (ie: W')
- It worthwhile only if:
  - the standard kinematic reconstruction has a very poor resolution
  - too many final state particles are invisible
- My main focus is to apply it to the following SUSY process in the trilepton+mET topology:



$$M_{\ell^\pm \bar{\ell}^\mp}^{Max} = M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0} \quad M_{\ell^\pm \bar{\ell}^\mp}^{Max} = \sqrt{\left(\frac{M_{\tilde{\chi}_2^0}^2}{M_{\tilde{\chi}_1^\pm}^2} - 1\right) \left(1 - \frac{M_{\tilde{\chi}_1^0}^2}{M_{\tilde{\chi}_1^\pm}^2}\right)}$$

- GCA could provide additional handle:  $A_C(pp \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow 3\ell^\pm) = f(M_{\tilde{\chi}_2^0} + M_{\tilde{\chi}_1^\pm})$

## VI. Prospects - To Do List -

- Finalize the W analysis:
  - Analyse the PDF reweighted samples for CTEQ6L1 and MSTW2008
  - Derive the corresponding W mass constraints
- Produce theoretical mass templates for chargino+neutralino process:
  - sub-project: write a nice interface between LHAPDF and PROSPINO v2
- I already produced the SM process at 8 TeV
- Analyze the SUSY trilepton samples
- Constrain (chargino+neutralino) mass
- ...
- Try all that on ATLAS data

# BACK-UP

# Appendix 1 -MC Production-

No K-Factors

<i>Sub - Process</i>	$N_{gen}$ (M evts)	$\sigma_{LO}$ (pb)
<b>QCD</b>		
10 < $\hat{m}$ < 75 GeV	1.05	$1.58 \times 10^8$
75 < $\hat{m}$ < 125 GeV	1.00	$8.81 \times 10^7$
125 < $\hat{m}$ < 250 GeV	1.00	$5.06 \times 10^7$
250 < $\hat{m}$ < 500 GeV	1.00	$1.46 \times 10^7$
500 < $\hat{m}$ < 1000 GeV	0.95	$3.06 \times 10^6$
1000 < $\hat{m}$ < 2000 GeV	1.00	$3.80 \times 10^5$
2000 < $\hat{m}$ < 4000 GeV	1.00	$1.76 \times 10^4$
4000 < $\hat{m}$ < 7000 GeV	1.00	$4.73 \times 10^1$
<b><math>c + \bar{c}</math></b>		
10 < $\hat{m}$ < 75 GeV	1.00	$6.79 \times 10^7$
75 < $\hat{m}$ < 125 GeV	1.00	$3.77 \times 10^6$
125 < $\hat{m}$ < 250 GeV	1.00	$2.10 \times 10^6$
250 < $\hat{m}$ < 500 GeV	1.00	$5.54 \times 10^5$
500 < $\hat{m}$ < 1000 GeV	1.00	$9.69 \times 10^4$
1000 < $\hat{m}$ < 2000 GeV	1.00	$8.26 \times 10^3$
2000 < $\hat{m}$ < 4000 GeV	1.00	$1.52 \times 10^2$
4000 < $\hat{m}$ < 7000 GeV	1.00	$2.75 \times 10^{-2}$
<b><math>b + \bar{b}</math></b>		
10 < $\hat{m}$ < 75 GeV	1.00	$4.32 \times 10^6$
75 < $\hat{m}$ < 125 GeV	1.00	$2.37 \times 10^6$
125 < $\hat{m}$ < 250 GeV	1.00	$1.23 \times 10^6$
250 < $\hat{m}$ < 500 GeV	1.00	$3.06 \times 10^5$
500 < $\hat{m}$ < 1000 GeV	0.95	$5.00 \times 10^4$
1000 < $\hat{m}$ < 2000 GeV	1.00	$4.00 \times 10^3$
2000 < $\hat{m}$ < 4000 GeV	1.00	$7.15 \times 10^1$
4000 < $\hat{m}$ < 7000 GeV	1.00	$1.58 \times 10^{-2}$
<b><math>\gamma + jets</math></b>		
10 < $\hat{m}$ < 75 GeV	0.90	$3.78 \times 10^4$
75 < $\hat{m}$ < 125 GeV	1.00	$1.04 \times 10^4$
125 < $\hat{m}$ < 250 GeV	0.95	$2.62 \times 10^3$
250 < $\hat{m}$ < 500 GeV	1.00	$2.45 \times 10^2$
500 < $\hat{m}$ < 1000 GeV	1.00	$1.59 \times 10^1$
1000 < $\hat{m}$ < 2000 GeV	1.00	$5.40 \times 10^{-1}$
2000 < $\hat{m}$ < 4000 GeV	1.00	$5.12 \times 10^{-3}$
4000 < $\hat{m}$ < 7000 GeV	0.95	$8.31 \times 10^{-7}$

<i>Sub - Process</i>	$N_{gen}$ (evts)	$\sigma_{LO}$ (pb)	NLO K-Factor
<b><math>\gamma + \gamma</math></b>			
10 < $\hat{m}$ < 75 GeV	1.00	$3.34 \times 10^1$	-
75 < $\hat{m}$ < 125 GeV	1.00	$9.44 \times 10^0$	-
125 < $\hat{m}$ < 250 GeV	1.00	$2.66 \times 10^0$	-
250 < $\hat{m}$ < 500 GeV	1.00	$3.32 \times 10^{-1}$	-
500 < $\hat{m}$ < 1000 GeV	1.05	$3.07 \times 10^{-2}$	-
1000 < $\hat{m}$ < 2000 GeV	1.00	$1.63 \times 10^{-3}$	-
2000 < $\hat{m}$ < 4000 GeV	1.00	$2.75 \times 10^{-5}$	-
4000 < $\hat{m}$ < 7000 GeV	0.25	$6.12 \times 10^{-9}$	-
$\gamma + W^\pm$	1.05	17.40	1.354
$\gamma + Z$	1.05	15.35	1.038
$W^\pm + W^\mp$	0.75	24.70	1.350
$W^\pm + \gamma^*/Z$	1.00	8.71	1.418
$\gamma^*/Z + \gamma^*/Z$	1.00	3.43	1.233

<i>Sub - Process</i>	$N_{gen}$ (M evts)	$\sigma_{LO}$ (pb)	NLO K-Factor
$t + b$	1.04	3.54	1.527
$t + q(+\bar{b})$	1.02	59.58	0.775
$t + t$	1.25	$1.02 \times 10^{-2}$	1.127

• K-Factors:

• MCFM v5.8:

• Same setting as in p10,

• Except:

• QCD Scales:  $\mu_R = \mu_F = \sqrt{\hat{s}}$

• LO PDF: MSTW2008lo68cl

• NLO PDF: MSTW2008nlo68cl

$$K = \frac{\sigma_{NLO}}{\sigma_{LO}}$$

# Appendix 1

## -MC Production-

<i>Sub - Process</i>	$N_{gen}$ (M evts)	$\sigma_{LO}$ (pb)	NNLO K-Factor
$\gamma^*/Z(\rightarrow e^\pm e^\mp) + jets$			
10 < $\hat{m}$ < 75 GeV	1.35	$4.71 \times 10^2$	1.148
75 < $\hat{m}$ < 125 GeV	0.90	$6.41 \times 10^2$	1.139
125 < $\hat{m}$ < 250 GeV	1.10	$1.20 \times 10^2$	1.150
250 < $\hat{m}$ < 500 GeV	1.35	$1.56 \times 10^1$	1.139
500 < $\hat{m}$ < 1000 GeV	2.00	$1.17 \times 10^0$	1.103
1000 < $\hat{m}$ < 2000 GeV	0.75	$4.47 \times 10^{-2}$	0.955
2000 < $\hat{m}$ < 4000 GeV	1.55	$4.67 \times 10^{-4}$	0.637
4000 < $\hat{m}$ < 7000 GeV	0.45	$9.62 \times 10^{-8}$	0.100
$\gamma^*/Z(\rightarrow \mu^\pm \mu^\mp) + jets$			
10 < $\hat{m}$ < 75 GeV	1.00	$4.70 \times 10^{+2}$	1.148
75 < $\hat{m}$ < 125 GeV	1.00	$6.40 \times 10^{+2}$	1.139
125 < $\hat{m}$ < 250 GeV	1.00	$1.19 \times 10^{+2}$	1.150
250 < $\hat{m}$ < 500 GeV	1.00	$1.57 \times 10^{+1}$	1.139
500 < $\hat{m}$ < 1000 GeV	2.05	$1.17 \times 10^0$	1.103
1000 < $\hat{m}$ < 2000 GeV	1.05	$44.8 \times 10^{-2}$	0.955
2000 < $\hat{m}$ < 4000 GeV	1.00	$4.65 \times 10^{-4}$	0.637
4000 < $\hat{m}$ < 7000 GeV	2.20	$9.68 \times 10^{-8}$	0.100
$\gamma^*/Z(\rightarrow \tau^\pm \tau^\mp) + jets$			
10 < $\hat{m}$ < 75 GeV	1.05	$4.68 \times 10^{+2}$	1.148
75 < $\hat{m}$ < 125 GeV	1.00	$6.40 \times 10^{+2}$	1.139
125 < $\hat{m}$ < 250 GeV	1.00	$1.19 \times 10^{+2}$	1.150
250 < $\hat{m}$ < 500 GeV	1.00	$1.57 \times 10^{+1}$	1.139
500 < $\hat{m}$ < 1000 GeV	1.00	$1.17 \times 10^0$	1.103
1000 < $\hat{m}$ < 2000 GeV	1.00	$44.6 \times 10^{-2}$	0.955
2000 < $\hat{m}$ < 4000 GeV	1.00	$4.65 \times 10^{-4}$	0.637
4000 < $\hat{m}$ < 7000 GeV	1.05	$9.58 \times 10^{-8}$	0.100
$Z \rightarrow \nu \bar{\nu}$	1.00	$4.63 \times 10^{+3}$	1.136
$\gamma^*/Z \rightarrow q \bar{q}$			
10 < $\hat{m}$ < 75 GeV	1.00	$2.51 \times 10^{+2}$	1.148
75 < $\hat{m}$ < 125 GeV	1.00	$1.07 \times 10^{+4}$	1.139
125 < $\hat{m}$ < 250 GeV	1.00	$1.62 \times 10^{+3}$	1.150
250 < $\hat{m}$ < 500 GeV	1.00	$1.93 \times 10^{+2}$	1.139
500 < $\hat{m}$ < 1000 GeV	1.05	$1.50 \times 10^{+1}$	1.103
1000 < $\hat{m}$ < 2000 GeV	1.00	$5.91 \times 10^{-1}$	0.955
2000 < $\hat{m}$ < 4000 GeV	0.95	$6.15 \times 10^{-3}$	0.637
4000 < $\hat{m}$ < 7000 GeV	0.90	$1.33 \times 10^{-6}$	0.100

<i>Sub - Process</i>	$N_{gen}$ (M evts)	$\sigma_{LO}$ (pb)	NNLO K-Factor
$W^\pm(\rightarrow e^\pm \nu_e) + jets$			
$M_{W^\pm} = 40.2$ GeV	0.50	$2.53 \times 10^{+4}$	1.425
$M_{W^\pm} = 60.3$ GeV	0.50	$1.31 \times 10^{+4}$	1.425
$M_{W^\pm} = 80.4$ GeV	1.00	$7.94 \times 10^{+3}$	1.425
$M_{W^\pm} = 100.5$ GeV	0.50	$5.24 \times 10^{+3}$	1.425
$M_{W^\pm} = 120.6$ GeV	0.50	$3.71 \times 10^{+3}$	1.425
$M_{W^\pm} = 140.7$ GeV	0.50	$2.74 \times 10^{+3}$	1.425
$M_{W^\pm} = 160.8$ GeV	0.50	$2.09 \times 10^{+3}$	1.425
$M_{W^\pm} = 201.0$ GeV	0.50	$1.32 \times 10^0$	1.425
$W^\pm(\rightarrow \mu^\pm \nu_\mu) + jets$			
$M_{W^\pm} = 40.2$ GeV	0.50	$2.53 \times 10^{+4}$	1.425
$M_{W^\pm} = 60.3$ GeV	0.50	$1.31 \times 10^{+4}$	1.425
$M_{W^\pm} = 80.4$ GeV	1.00	$7.93 \times 10^{+3}$	1.425
$M_{W^\pm} = 100.5$ GeV	0.50	$5.24 \times 10^{+3}$	1.425
$M_{W^\pm} = 120.6$ GeV	0.50	$3.69 \times 10^{+3}$	1.425
$M_{W^\pm} = 140.7$ GeV	0.50	$2.74 \times 10^{+3}$	1.425
$M_{W^\pm} = 160.8$ GeV	0.50	$2.09 \times 10^{+3}$	1.425
$M_{W^\pm} = 201.0$ GeV	0.50	$1.33 \times 10^0$	1.425
$W^\pm(\rightarrow \tau^\pm \nu_\tau) + jets$	1.00	$7.91 \times 10^{+3}$	1.425
$W^\pm(\rightarrow q \bar{q}') + jets$	1.00	$3.60 \times 10^{+4}$	1.425

• K-Factors:

• PHOZR:

• Same setting as in p10,

• Except:

• QCD Scales:  $\mu_R = \mu_F = M_{ff}$

• LO PDF: MRST2007lomod

• NLO PDF: MSTW2008nlo68cl

$$K = \frac{\sigma_{NNLO}}{\sigma_{LO}}$$

## Appendix 2

### -Fast Detector Simulation-

DELPHES v1.9

- Detector datacard: ATLAS

#### Sub-Detectors Acceptance

- Inner Tracker:  $|\eta| < 2.5$
- Central Calorimeter:  $|\eta| < 1.7$
- End-Cap Calorimeter:  $|\eta| < 3.2$
- Forward Calorimeter:  $|\eta| < 4.9$
- Muon Spectrometer:  $|\eta| < 2.7$

#### Objects Reconstruction

- Calorimeter Granularity:
  - $|\eta| < 2.6$ :  $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
  - $|\eta| > 2.6$ :  $\Delta\eta \times \Delta\phi = 0.1 \times 0.2$
- Hadrons deposit in EM and HAD, separately smeared with EM and HAD resolutions
- No Shower Simulation or Library!
- Missing  $E_T$ :

$$\cancel{E}_T = \sqrt{\left(-\sum_{i=1}^{N_{\text{towers}}} p_x^i\right)^2 + \left(-\sum_{i=1}^{N_{\text{towers}}} p_y^i\right)^2}$$

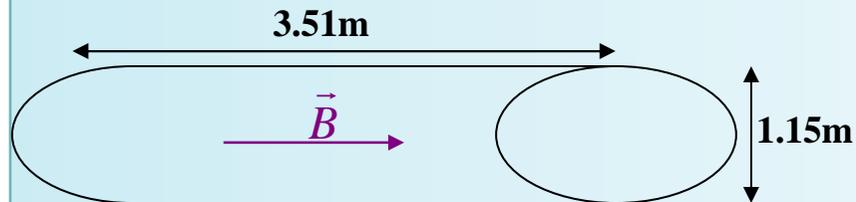
## Appendix 2

### -Fast Detector Simulation-

DELPHES v1.9

#### Objects Reconstruction

- Jet Finder: FastJet v?
  - Algo: « Anti- $k_T$  »
  - Cone radius:  $\Delta R=0.4$
  - Seed:  $p_T > 1 \text{ GeV}$



- Solenoidal Magnetic Field:
  - $B=2 \text{ T}$
  - Applied on all stable charged particles
- No simulation of toroidal magnetic field
- Overall tracking efficiency:  $\varepsilon = 90\%$

#### Objects Reconstruction Thresholds

- Tracks:  $p_T > 0.9 \text{ GeV}$
- Electrons:  $p_T > 10 \text{ GeV}$
- Photons:  $p_T > 10 \text{ GeV}$
- Jets:  $p_T > 20 \text{ GeV}$
- Muons:  $p_T > 10 \text{ GeV}$
- Taus:  $p_T > 10 \text{ GeV}$

## Appendix 2

### -Fast Detector Simulation-

DELPHES v1.9

• Objects Resolution:

• Calorimeters:

$$\frac{\sigma_E}{E} = \frac{S}{\sqrt{E}} \oplus \frac{N}{E} \oplus C$$

Part of the Calorimeters		
CC	EC	FWD
$\left\{ \begin{array}{l} S_{EM} = 10.1\% \\ N_{EM} = 0.0\% \\ C_{EM} = 0.17\% \end{array} \right.$	$\left\{ \begin{array}{l} S_{EM} = 10.1\% \\ N_{EM} = 0.0\% \\ C_{EM} = 0.17\% \end{array} \right.$	$\left\{ \begin{array}{l} S_{EM} = 28.5\% \\ N_{EM} = 0.0\% \\ C_{EM} = 3.5\% \end{array} \right.$
$\left\{ \begin{array}{l} S_{HAD} = 52.05\% \\ N_{HAD} = 1.59\% \\ C_{HAD} = 3.02\% \end{array} \right.$	$\left\{ \begin{array}{l} S_{HAD} = 70.60\% \\ N_{HAD} = 0.0\% \\ C_{HAD} = 5.0\% \end{array} \right.$	$\left\{ \begin{array}{l} S_{HAD} = 94.20\% \\ N_{HAD} = 0.0\% \\ C_{HAD} = 0.075\% \end{array} \right.$

## Appendix 2

### -Fast Detector Simulation-

DELPHES v1.9

- Output informations are stored into 3 different ROOT trees
  - « GEN »: MC truth (particles, ID, status, 4-p, charge, parenthood links,...)
  - « Analysis »: Reconstructed Objects (type, number, 4-p,...)
  - « Trigger »:
    - Pass or Fail for a list of trigger conditions
    - Based on a TCloneArray of the Analysis tree
    - No real separate trigger simulation:
      - Same calorimeter granularity
      - Same objects resolutions

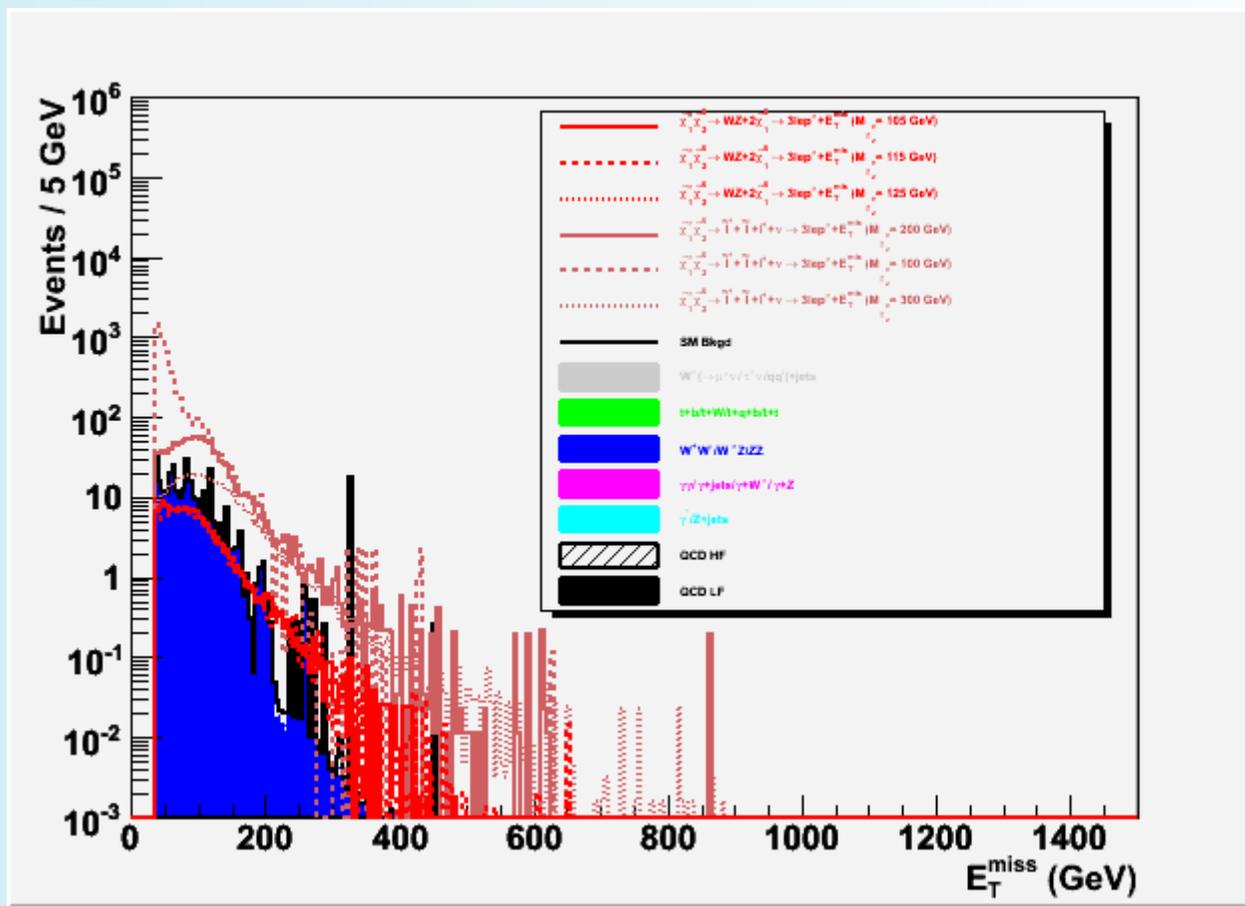
- Understanding the bias caused by each event selection cut at particle LVL:

Cuts	$A_C(W \rightarrow \mu\nu)$
No Cuts	20.65%
$N(\mu) > 0$	20.68%
$ \eta(\mu_0)  < 2.4$	20.53%
$p_T(\mu_0) > 20 \text{ GeV}$	18.29%
$mE_T > 25 \text{ GeV}$	18.37%
$\text{Isol\_Trk}(\mu_0) = 1$	18.42%
$\text{Isol\_Calo}(\mu_0) < 0.25$	17.67%
$mT(\mu_0, mE_T) > 40 \text{ GeV}$	17.52%
Reject evts w/ $\text{Iso\_Trk}(\mu_1) = 1$	17.52%
Reject evts w/ $\text{Iso\_Trk}(e_0) = 1$	17.52%
Reject evts w/ $3 < p_T(\text{trk}_1) < 10 \text{ GeV}$ & $\text{SIGN}(\mu_0) = -\text{SIGN}(\text{trk}_1)$ & $M(\mu_0, \text{trk}_1) > 50 \text{ GeV}$	17.52%

# Very Preliminary Results on a SUSY Use Case

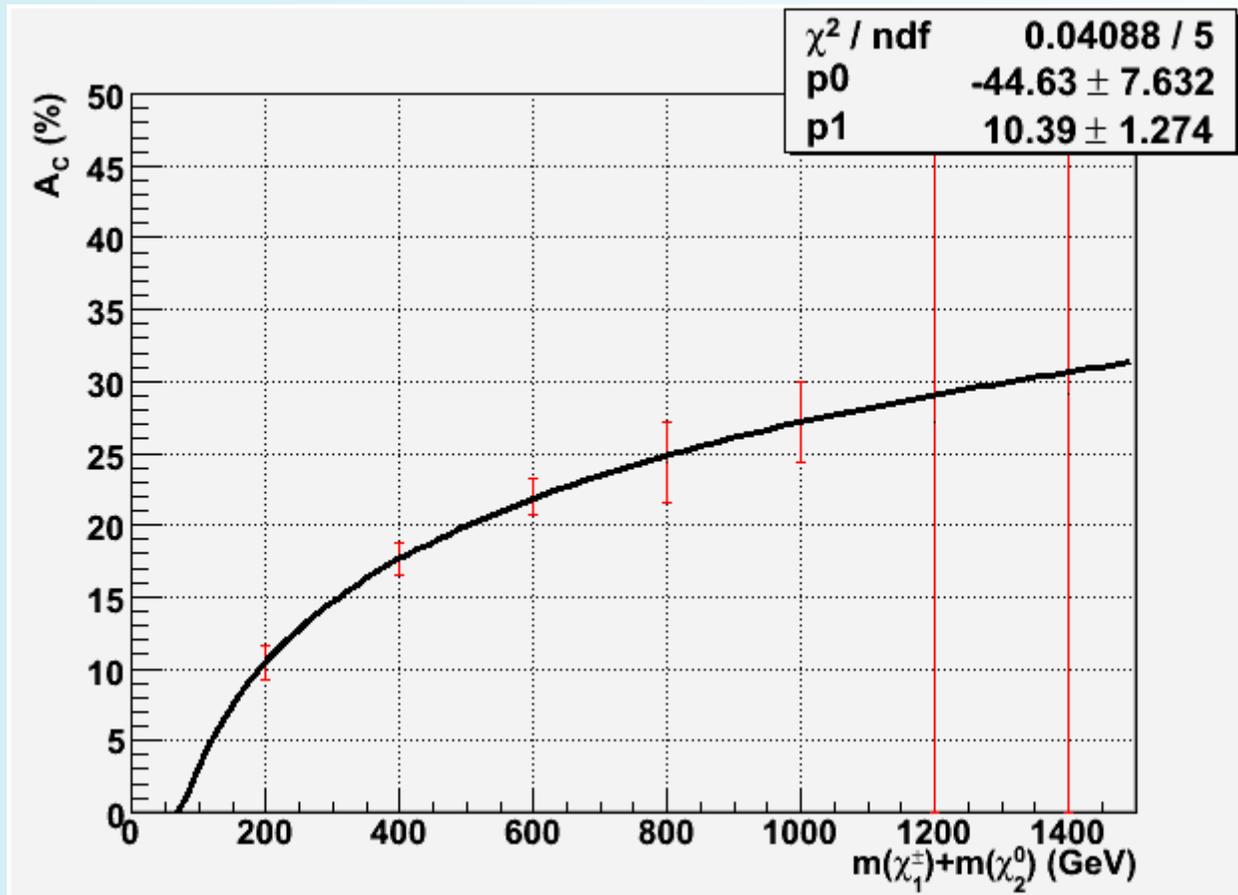
## MC Production

- SM background processes at 8 TeV for L=25/fb
- SUSY chargino1+neutralino2  $\rightarrow$  trilpton+mET (intermediate sleptons)



# Very Preliminary Results on a SUSY Use Case

## Reconstructed Mass Template



# Very Preliminary Results on a SUSY Use Case

- 100\_75\_50:

$$A_C^{Meas}(S) = (10.42 \pm 1.093)\%$$

$$M_{(\tilde{\chi}_1^+ + \tilde{\chi}_2^0)}^{Meas} = \left\{ \begin{array}{l} 199.60 + 22.11 \\ -20.96 \end{array} \right\} \text{ GeV}$$

To be compared to 200 GeV

