

# New Method for Mass Measurement using Integral Charge Asymmetry at LHC

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4<sup>th</sup> OCEVU General Workshop, CPPM Marseille

May 26, 2015



Talk based upon a revised version of arXiv:1412.6695v2 [hep-ph], to be submitted to JHEP

## 1 Introduction

## 2 A SM Test Bench Process

- Theoretical Prediction of  $A_C(W^\pm \rightarrow \ell^\pm \nu)$
- Experimental Measurement of  $A_C(W^\pm \rightarrow \ell^\pm \nu)$
- Indirect Determination of  $M_{W^\pm}$

## 3 A SUSY Physics Case

- Theoretical Prediction of  $A_C(\tilde{\chi}_1^\pm + \tilde{\chi}_2^0)$
- Experimental Measurement of  $A_C(\tilde{\chi}_1^\pm + \tilde{\chi}_2^0 \rightarrow 3\ell^\pm + \cancel{E}_T)$
- Indirect Determination of  $M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$

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## Introduction

## Working with A Charge Asymmetric Collider

- The LHC is a charge asymmetric machine, unlike most other HE particle colliders
- For charged final states ( $FS^\pm$ ), we define the **integral charge asymmetry (ICA)** as

$$A_c = \frac{N(FS^+) - N(FS^-)}{N(FS^+) + N(FS^-)} \quad (1)$$

- For a given inclusive process produced at the:
  - LHC in  $p + p$  collisions:  $A_c \geq 0$
  - TEVATRON in  $p + \bar{p}$  collisions:  $A_c \approx 0$

## The Simplest Applicable Process

- To illustrate this discussion let's pick the  $W^\pm \rightarrow \ell^\pm \nu + X$  process
- We obviously chose a leptonic decay mode ( $\ell^\pm = e^\pm / \mu^\pm$ ) because:
  - $S/B$  for this process in online and offline event selection
  - the hard isolated lepton enables to measure the sign of the produced  $W^\pm$
- The considered event topology is:  $1\ell^\pm + \cancel{E}_T + X$
- Therefore our actual observable is:

$$A_c = \frac{N(\ell^+) - N(\ell^-)}{N(\ell^+) + N(\ell^-)} \quad (2)$$

## Relation between $A_C(W^\pm \rightarrow \ell^\pm \nu + X)$ and the proton structure

- The ICA originates solely from the production mechanisms
- More quantitatively, let's look at the main flavour contribution to  $A_C$ :

$$A_C \approx \frac{u(x_{1,2}, M_W^2) \bar{d}(x_{2,1}, M_W^2) - \bar{u}(x_{1,2}, M_W^2) d(x_{2,1}, M_W^2)}{u(x_{1,2}, M_W^2) \bar{d}(x_{2,1}, M_W^2) + \bar{u}(x_{1,2}, M_W^2) d(x_{2,1}, M_W^2)} \quad (3)$$

other flavour contributions are CKM suppressed ( $\frac{|V_{cs}|^2}{|V_{ud}|^2}, \frac{|V_{us}|^2}{|V_{ud}|^2}, \frac{|V_{cd}|^2}{|V_{ud}|^2}, \dots$ )

- Producing  $W^\pm$  implies:
  - $Q^2 \approx M_{W^\pm}^2$  and  $x_{1,2} = \frac{M_{W^\pm}}{\sqrt{s}} \cdot e^{\pm y_W}$   
i.e at  $\sqrt{s} = 7\text{TeV}$ :  $|y_W| \leq 4.3 \Rightarrow x \in [1.7 \times 10^{-4}, 1.]$
- And, in this range of  $x$ 's, yields a positive  $A_C(W^\pm \rightarrow \ell^\pm \nu + X)$
- **The key and new (wrt other usage of asymmetries) idea is to correlate  $A_C$  to a mass scale**
- How?
  - by varying  $Q \Rightarrow$  a DGLAP evolution of the PDFs  $\Rightarrow$  an evolution of  $A_C$
  - **a calibrated measurement of  $A_C$  constitutes an indirect measurement of  $M_{W^\pm}$**

## A SM Test Bench Process

### Parton Level Setup in MCFM v5.8

- Calculate separately  $\sigma^\pm = \sigma(p + p \rightarrow W^\pm \rightarrow \ell^\pm \nu)$  at  $\sqrt{s} = 7$  TeV
- $A_C^{Theory} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$
- LO Matrix Elements (ME):  $W^\pm + 0Lp$  &  $W^\pm + 1Lp$  ( $Lp$ : light partons, i.e. u/d/s/g)
- QCD Scales:  $\mu_R = \mu_F = \mu_0 = \sqrt{M^2(W^\pm) + p_T^2(W^\pm)}$
- LO PDFs: MRST2007lomod (default), CTEQ6L1, and MSTW2008lo68cl
- Vary  $M_{W^\pm}$ : 20.1, 40.2, 80.4, 160.8, 321.6, 643.2, 1286.4 GeV

### Sources of Theoretical Uncertainties

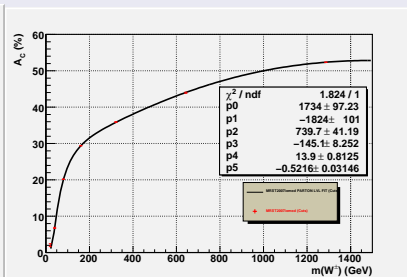
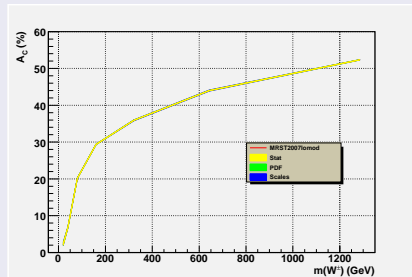
- Statistical:  $\delta_{Stat} A_C = \frac{2\sqrt{(\sigma^- \cdot \delta\sigma_{Stat}^+)^2 + (\sigma^+ \cdot \delta\sigma_{Stat}^-)^2}}{(\sigma^+ + \sigma^-)^2}$
- PDF:  $\begin{cases} \delta\sigma_{PDF}^{Up} = \sqrt{\sum_{i=1}^N [\text{Max}(\sigma_i^+ - \sigma_0, \sigma_i^- - \sigma_0, 0)]^2} \\ \delta\sigma_{PDF}^{Down} = \sqrt{\sum_{i=1}^N [\text{Max}(\sigma_0 - \sigma_i^+, \sigma_0 - \sigma_i^-, 0)]^2} \end{cases}$
- QCD Scales:  $\delta\sigma_{Scale}^{Up} = \sigma(\mu_0/2) - \sigma(\mu_0)$  and  $\delta\sigma_{Scale}^{Down} = \sigma(2\mu_0) - \sigma(\mu_0)$
- Total:  $\delta\sigma_{Total}^{Up/Down} = \sqrt{(\delta\sigma_{PDF}^{Up/Down})^2 + (\delta\sigma_{Scale}^{Up/Down})^2 + (\delta\sigma_{Stat})^2}$

## $A_C(W^\pm \rightarrow e^\pm \nu_e)$ for MRST2007lomod (1/2)

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

**Table :** MRST2007lomod  $A_C$  table with the breakdown of the different sources of theoretical uncertainty.

## $A_C(W^\pm \rightarrow e^\pm \nu_e)$ for MRST2007lomod (2/2)



- Fits functional form:  $A_C[M_{W^\pm}] = \sum_{i=0}^N A_i \times [\text{Log}[\text{Log}[M_{W^\pm}]]]^i$ , inspired by the analytical solution of DGLAP equations
- Fit replaces discrete sampling of  $A_C[M_{W^\pm}]$  and  $\delta A_C[M_{W^\pm}]$  accounts for the correlation between the fit parameters

## $A_C(W^\pm \rightarrow e^\pm \nu_e)$ for CTEQ6L1 & MSTW2008lo68cl

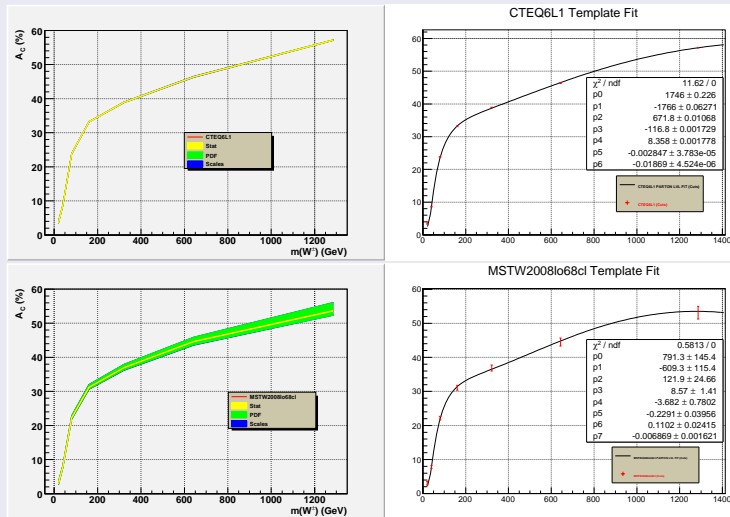


Figure : Theoretical  $A_C$  template curves: CTEQ6L1 (upper row) & MSTW2008lo68cl (lower row)



## Event Selection: Electron Channel

- Generator:  
Herwig++ v2.5.0
- Detector Fast Simulation:  
Delphes v1.9
- Collider Hypotheses:
  - $\sqrt{s} = 7 \text{ TeV}$
  - $L = 1 \text{ fb}^{-1}$
- $p_T(e^\pm) > 25 \text{ GeV}$
- $|\eta(e^\pm)| < 1.37$  or  
 $1.53 < |\eta(e^\pm)| < 2.4$
- Isolation:  
Tracker & Calorimeter
- $\cancel{E}_T > 25 \text{ GeV}$
- $M_T > 40 \text{ GeV}$

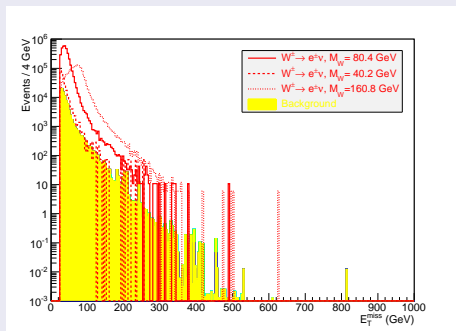


Figure :  $\cancel{E}_T$  distribution for the  $W^\pm \rightarrow e^\pm \nu_e$  analysis

## Event Yields & Expected ICA

Process	$\epsilon$ (%)	$N_{exp}$ (k evts)	$A_C \pm \delta A_C^{Stat}$ (%)
Signal: $W^\pm \rightarrow e^\pm \nu_e$			
$M_{W^\pm} = 40.2$ GeV	$0.81 \pm 0.01$	290.367	$9.66 \pm 1.57$
$M_{W^\pm} = 60.3$ GeV	$13.69 \pm 0.05$	2561.508	$11.2 \pm 0.38$
$M_{W^\pm} = 80.4$ GeV	$29.59 \pm 0.04$	3343.195	$16.70 \pm 0.18$
$M_{W^\pm} = 100.5$ GeV	$39.19 \pm 0.07$	2926.093	$20.77 \pm 0.22$
$M_{W^\pm} = 120.6$ GeV	$44.84 \pm 0.07$	2357.557	$23.1 \pm 0.21$
$M_{W^\pm} = 140.7$ GeV	$48.66 \pm 0.07$	1899.820	$25.29 \pm 0.20$
$M_{W^\pm} = 160.8$ GeV	$51.28 \pm 0.07$	1527.360	$26.8 \pm 0.19$
$M_{W^\pm} = 201.0$ GeV	$54.54 \pm 0.07$	1.032	$29.26 \pm 0.18$
Background	-	$91.614 \pm 1.706$	$10.07 \pm 0.15$
$W^\pm \rightarrow \mu^\pm \nu_\mu / \tau^\pm \nu_\tau / q\bar{q}l$	$0.211 \pm 0.003$	71.350	$12.92 \pm 1.25$
$t\bar{t}$	$5.76 \pm 0.02$	6.600	$1.00 \pm 0.37$
$t + b, t + q(+b)$	$3.59 \pm 0.01$	1.926	$28.97 \pm 0.35$
$W + W, W + \gamma^*/Z, \gamma^*/Z + \gamma^*/Z$	$2.94 \pm 0.01$	2.331	$10.65 \pm 0.35$
$\gamma + \gamma, \gamma + jets, \gamma + W^\pm, \gamma + Z$	$0.201 \pm 0.001$	0.759	$17.25 \pm 0.53$
$\gamma^*/Z$	$0.535 \pm 0.001$	5.746	$4.43 \pm 0.23$
QCD HF	$(0.44 \pm 0.17) \times 10^{-4}$	1.347	$14.29 \pm 37.41$
QCD LF	$(0.87 \pm 0.33) \times 10^{-4}$	1.555	$71.43 \pm 26.45$

## $A_C(S)$ after Background Subtraction

- In presence of B, the measured  $A_C$  is that of S+B, not just of S

- $A_C^{Exp}(S+B) = \frac{A_C^{Exp}(S) + \alpha^{Exp} \cdot A_C^{Exp}(B)}{1 + \alpha^{Exp}}$ , where  $\alpha^{Exp} = \frac{N_B^{Exp}}{N_S^{Exp}}$

- Invert the relation to get the "*background subtraction equation*":

$$A_C^{Exp}(S) = (1 + \alpha^{Exp}) \cdot A_C^{Exp}(S+B) - \alpha^{Exp} \cdot A_C^{Exp}(B) \quad (4)$$

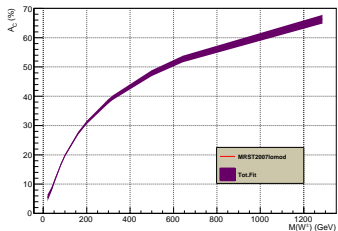
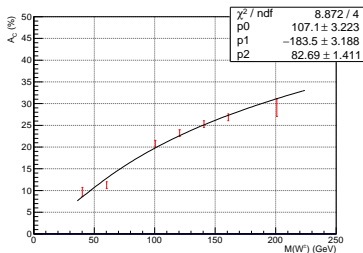
## ICA Experimental Systematic Uncertainties

- Strategy:

- instead of trying to derive unreliable systematics using Delphes,
- we use systematics quoted in analyses of real data
- $\delta_{Syst} A_C(W^\pm \rightarrow e^\pm \nu_e / \mu^\pm \nu_\mu) = 1.0 / 0.4\%$  [arXiv:1206.2598 / arXiv:1312.6283 [hep-ex]]
- $\delta_{Syst} \frac{\sigma(pp \rightarrow W^\pm \rightarrow \ell^\pm \nu_\ell)}{\sigma(pp \rightarrow \gamma^* / Z \rightarrow \ell^\pm \ell^\mp)} = 1.0\%$  [arXiv:1107.4789 [hep-ex]]

- Gaussian smearings of  $N_S^\pm$  and  $N_B^\pm$  propagated into the subtraction equation
- Enable to calculate both  $A_C^{Meas}(S)$  and  $\delta A_C^{Meas}(S)$  account for the correlations between  $A_C(S+B)$ ,  $A_C(B)$ , and  $\alpha$
- Build reconstructed  $A_C^{Meas}(S) \pm \delta A_C^{Meas}(S)$  mass templates
- Fit these templates with polynomials of Log(Log) and include the correlations between the fit parameters into  $\delta A_C^{Meas.Fit}(S)$

## Experimental Template Curve for the Electron Channel



$$A_C^{Meas}(W^\pm \rightarrow e^\pm + \nu_e) = -107.1 - 183.5 \times \text{Log}(\text{Log}(M_{W^\pm})) + 82.69 \times \text{Log}(\text{Log}(M_{W^\pm}))^2 \quad (5)$$

- This template curve encodes the 2 types of experimental biases:
  - the event selection
  - the remaining background

## Extracting $M_{W^\pm}$ in the Electron and Muon Channels

- Analogous analysis performed to the muon channel
- Measured ICA of both channels are translated into indirect  $M_{W^\pm}$  measurements:

$$A_C^{Meas}(S) = (16.70 \pm 0.35)\% \Rightarrow M^{Meas}(W^\pm \rightarrow e^\pm \nu_e) = 81.08_{-2.02}^{+2.06} \text{ GeV} \quad (6)$$

$$A_C^{Meas}(S) = (17.52 \pm 0.18)\% \Rightarrow M^{Meas}(W^\pm \rightarrow \mu^\pm \nu_\mu) = 80.83_{-0.82}^{+0.82} \text{ GeV} \quad (7)$$

- Combine using weighted mean & RMS:

$$M^{Comb.Meas.}(W^\pm) = 80.86 \pm 0.54 \text{ (Exp.Comb.) GeV} \quad (8)$$

- Theory uncertainties for this given mass ( $\pm 0.24$  GeV) obtained by looking-up the theoretical template curve
- Sum in quadrature experimental & theory uncertainties

$$M_{W^\pm} = 80.86_{-0.59}^{+0.59} \text{ (Tot. MRST2007lomod) GeV} \quad (9)$$

- Repeat the whole procedure for CTEQ6L1 & MSTW2008lo68cl:

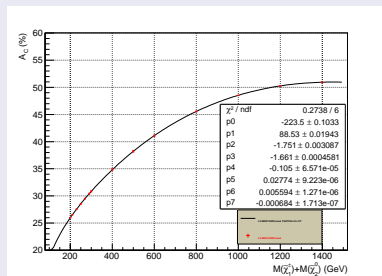
$$M_{W^\pm} = 80.14_{-0.60}^{+0.60} \text{ (Tot. CTEQ6L1) GeV} \quad (10)$$

$$M_{W^\pm} = 81.36_{-1.44}^{+1.48} \text{ (Tot. MSTW2008lo68cl) GeV} \quad (11)$$

## A SUSY Physics Case

### Parton Level Setup using Resummino v1.0.0

- Calculate separately at  $\sqrt{s} = 8$  TeV:
  - $\sigma^+ = \sigma(p + p \rightarrow \tilde{\chi}_1^+ + \tilde{\chi}_2^0)$
  - $\sigma^- = \sigma(p + p \rightarrow \tilde{\chi}_1^- + \tilde{\chi}_2^0)$
- $A_C^{Theory} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$
- LO MEs & LO PDFs:  
 MRST2007lomod (default),  
 CTEQ6L1, and MSTW2008lo68cl
- QCD Scales:  
 $\mu_R = \mu_F = \mu_0 = M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$
- Vary:  $M_{\tilde{\chi}_1^\pm} = M_{\tilde{\chi}_2^0} =$   
 100, 105, 115, 125, 135, 145, 150, 200, 250,  
 300, 400, 500, 600, 700 GeV

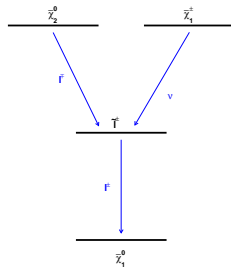


$$A_C[M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}] = \sum_{i=0}^N A_i \times [\text{Log}[\text{Log}[M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}]]]$$

## Different SUSY Scenarios (1/2)

- S1 Signal:

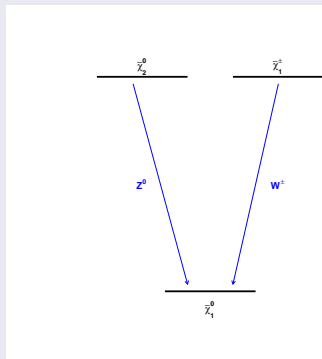
- Lightest SUSY particles:  $\tilde{\chi}_1^\pm, \tilde{\chi}_{1,2}^0, \tilde{\ell}^\pm$
- $M_{\tilde{\chi}_1^\pm} = M_{\tilde{\chi}_2^0}$
- $BR(\tilde{\chi}_1^\pm \rightarrow \tilde{\ell}^\pm (\rightarrow \ell^\pm \tilde{\chi}_1^0) + \nu) = 100\%$
- $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}^\pm (\rightarrow \ell^\pm \tilde{\chi}_1^0) + \ell^\mp) = 100\%$
- Vary:  $M_{\tilde{\chi}_2^0} \in [100, 700]$  GeV by steps of 100 GeV
- Set:  $M_{\tilde{\chi}_1^0} = M_{\tilde{\chi}_2^0}/2$  and  $M_{\tilde{\ell}^\pm} = [M_{\tilde{\chi}_2^0} + M_{\tilde{\chi}_1^\pm}]/2$



## Different SUSY Scenarios (2/2)

### • S2 Signal:

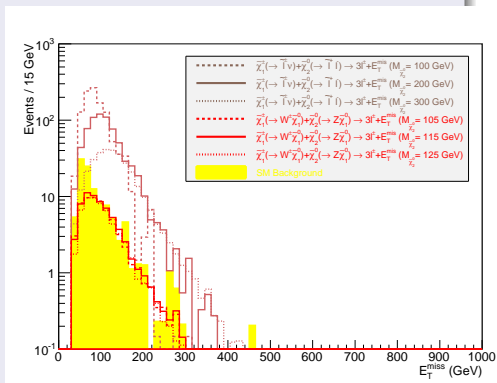
- Lightest SUSY particles:  $\tilde{\chi}_1^\pm, \tilde{\chi}_1^0$
- $M_{\tilde{\chi}_1^\pm} = M_{\tilde{\chi}_2^0}$
- $BR(\tilde{\chi}_1^\pm \rightarrow \tilde{\ell}^\pm (\rightarrow \ell^\pm \tilde{\chi}_1^0) + \nu) = 100\%$
- $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}^\pm (\rightarrow \ell^\pm \tilde{\chi}_1^0) + \ell^\mp) = 100\%$
- Set:  $M_{\tilde{\chi}_1^0} = M_{\tilde{\chi}_2^0}/2$
- Case S2a:  $W$  and  $Z$  decay off-shell,  
 $M_{\tilde{\chi}_2^0} = 100$  GeV and  $M_{\tilde{\chi}_1^0} = 50$  GeV
- Case S2b:  $W$  and  $Z$  decay on-shell,  
 $M_{\tilde{\chi}_2^0} \in [200, 700]$  GeV by steps of 100 GeV, also  
 $M_{\tilde{\chi}_1^0} \in [105, 145]$  GeV by steps of 10 GeV with  $M_{\tilde{\chi}_1^0} = 13.8$  GeV, plus  
 $[M_{\tilde{\chi}_2^0}, M_{\tilde{\chi}_1^0}] = [150, 50]$  GeV and  
 $[250, 125]$  GeV





## Event Selection for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell^\pm + \cancel{E}_T$ analysis

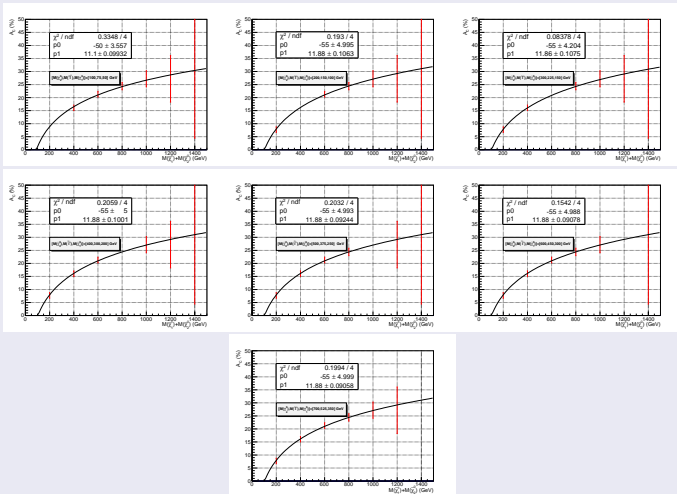
- Generators: Herwig++,  
Alpgen & Pythia8
- Fast Sim.: Delphes
- Collider Hypotheses:
  - $\sqrt{s} = 8 \text{ TeV}, L=20 \text{ fb}^{-1}$
- Electron Candidates:
  - $|\eta(e^\pm)| < 1.37$  or
  - $1.53 < |\eta(e^\pm)| < 2.47$
  - $p_T(e^\pm) > 10 \text{ GeV}$
- Muon Candidates:
  - $|\eta(\mu^\pm)| < 2.4$
  - $p_T(\mu^\pm) > 10 \text{ GeV}$
- $p_T(\ell_{1,2,3}^\pm) > 20, 10, 10 \text{ GeV}$
- Isolation:  
Tracker & Calorimeter
- $\cancel{E}_T > 35 \text{ GeV}$
- $M_{T2} > 75 \text{ GeV}$



## Expected and Measured ICA

Process	$\alpha^{Exp} \pm \delta\alpha^{Stat}$	$Z_N$ ( $\sigma$ )	$A_C^{Exp} \pm \delta A_C^{Stat}$ (%)	$A_C^{Meas.} \pm \delta A_C^{Meas.}$ (%)
<b>S1 Signal</b>				
$[M_{\tilde{\chi}_2^0}, M_{\tilde{\ell}^\pm}, M_{\tilde{\chi}_1^0}]$ GeV				
[100, 75, 50]	$(9.98 \pm 0.26) \times 10^{-2}$	31.70	$7.70 \pm 0.27$	$7.70 \pm 0.83$
[200, 150, 100]	$(15.58 \pm 0.36) \times 10^{-2}$	23.86	$16.06 \pm 0.20$	$16.06 \pm 0.85$
[300, 225, 150]	$(34.28 \pm 0.79) \times 10^{-2}$	13.79	$21.30 \pm 0.17$	$21.30 \pm 0.96$
[400, 300, 200]	$(96.89 \pm 2.22) \times 10^{-2}$	6.04	$24.40 \pm 0.18$	$24.40 \pm 1.29$
[500, 375, 250]	$(288.49 \pm 6.61) \times 10^{-2}$	2.25	$27.21 \pm 0.16$	$27.21 \pm 1.75$
[600, 450, 300]	$(869.13 \pm 19.89) \times 10^{-2}$	0.74	$27.20 \pm 0.14$	$27.20 \pm 1.97$
[700, 525, 350]	$(2417.44 \pm 55.45) \times 10^{-2}$	0.23	$29.06 \pm 0.15$	$29.06 \pm 2.02$
<b>S2 Signal</b>				
$[M_{\tilde{\chi}_2^0}, M_{\tilde{\chi}_1^0}]$ GeV				
[100, 50]	$(78.221 \pm 6989.644) \times 10^1$	-0.06	$7.62 \pm 0.38$	$7.62 \pm 0.88$
[105, 13.8]	$(177.34 \pm 4.21) \times 10^{-2}$	3.55	$7.84 \pm 0.23$	$7.85 \pm 1.58$
[115, 13.8]	$(167.29 \pm 3.91) \times 10^{-2}$	3.74	$7.73 \pm 0.21$	$7.73 \pm 1.55$
[125, 13.8]	$(190.49 \pm 4.44) \times 10^{-2}$	3.32	$9.34 \pm 0.21$	$9.34 \pm 1.60$
[135, 13.8]	$(199.69 \pm 4.61) \times 10^{-2}$	3.18	$10.43 \pm 0.17$	$10.43 \pm 1.62$
[145, 13.8]	$(223.26 \pm 5.16) \times 10^{-2}$	2.87	$11.50 \pm 0.19$	$11.50 \pm 1.67$
[150, 50]	$(382.23 \pm 8.90) \times 10^{-2}$	1.71	$12.06 \pm 0.19$	$12.06 \pm 1.85$
[200, 100]	$(1023.46 \pm 23.44) \times 10^{-2}$	0.62	$16.66 \pm 0.20$	$16.66 \pm 2.00$
[250, 125]	$(1405.78 \pm 32.29) \times 10^{-2}$	0.44	$18.28 \pm 0.18$	$18.28 \pm 2.01$
[300, 150]	$(2164.23 \pm 49.59) \times 10^{-2}$	0.26	$20.98 \pm 0.18$	$20.98 \pm 2.02$
[400, 200]	$(6083.89 \pm 138.89) \times 10^{-2}$	0.05	$24.11 \pm 0.17$	$24.11 \pm 2.03$
[500, 250]	$(18.881 \pm 0.431) \times 10^{-5}$	-0.03	$27.51 \pm 0.16$	$27.51 \pm 2.03$
[600, 300]	$(57.637 \pm 1.316) \times 10^{-5}$	-0.06	$27.25 \pm 0.18$	$27.25 \pm 2.03$
[700, 350]	$(182.517 \pm 4.167) \times 10^{-5}$	-0.07	$27.91 \pm 0.17$	$27.91 \pm 2.03$

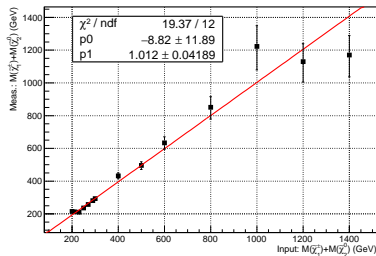
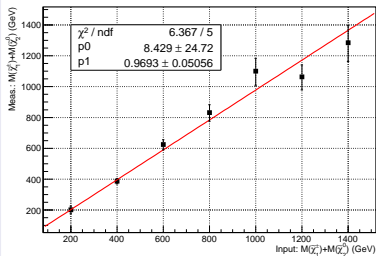
## Experimental Template Curves for S1 Signal



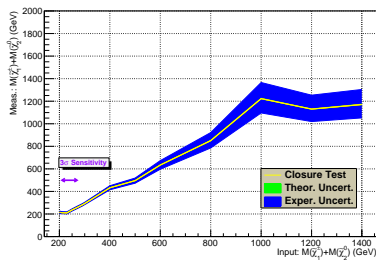
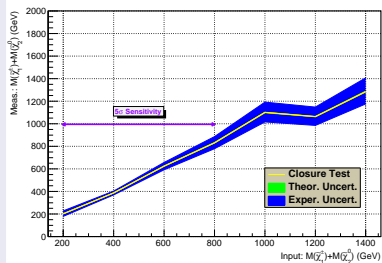
## Indirect Determination of $M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$ (Exp. Uncert.)

Input $M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$ (GeV)	$A_C^{Meas.Fit} \pm \delta A_C^{Meas.Fit}$ (%)	Meas. $M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$ (GeV)
S1 Signal		
200.	$7.70 \pm 1.62$	$201.79^{+26.30}_{-22.78}$
400.	$16.06 \pm 0.52$	$386.63^{+17.42}_{-16.56}$
600.	$21.30 \pm 0.56$	$624.12^{+33.36}_{-31.43}$
800.	$24.40 \pm 0.67$	$831.24^{+55.66}_{-51.70}$
1000.	$27.21 \pm 0.80$	$1100.14^{+91.85}_{-83.85}$
1200.	$27.20 \pm 0.78$	$1063.52^{+84.32}_{-77.32}$
1400.	$29.06 \pm 0.89$	$1285.12^{+121.49}_{-109.70}$
S2 Signal		
200.	$7.62 \pm 0.74$	$214.89^{+12.08}_{-11.33}$
210.	$7.85 \pm 0.60$	$212.28^{+9.83}_{-9.32}$
230.	$7.73 \pm 0.60$	$210.37^{+9.81}_{-9.30}$
250.	$9.34 \pm 0.53$	$236.25^{+10.02}_{-9.54}$
270.	$10.43 \pm 0.50$	$257.54^{+10.34}_{-9.85}$
290.	$11.50 \pm 0.47$	$280.68^{+10.83}_{-10.34}$
300.	$12.06 \pm 0.46$	$293.53^{+11.19}_{-10.71}$
400.	$16.66 \pm 0.49$	$432.55^{+18.63}_{-17.73}$
500.	$18.28 \pm 0.54$	$495.50^{+24.10}_{-22.79}$
600.	$20.98 \pm 0.66$	$633.64^{+39.45}_{-36.79}$
800.	$24.11 \pm 0.83$	$850.74^{+71.20}_{-64.95}$
1000.	$27.51 \pm 1.07$	$1222.74^{+143.06}_{-126.20}$

## Closure Tests w/ Expt. Uncert.: S1 Signal (LHS), S2 Signals (RHS)



## Final Plots w/ Full Uncert.: S1 Signal (LHS), S2 Signal (RHS)



## Conclusions (1/2)

### New Method

- Designed for charged-current production processes at LHC
- Independent of the final state kinematics
- Model Independent
  - Does not depend on BSM couplings
  - Only depends on proton PDF
- Especially well-suited when many final state particles escape detection

### Accuracy of Indirect Measurements

	$W^\pm$ $M_{W^\pm} = 80.4 \text{ GeV}$	S1 Signal		S2 Signal	
		$5\sigma$ : [200-800] GeV	[1.0-1.4] TeV	$3\sigma$ : [210-270] GeV	[0.29-1.4] TeV
$\frac{\delta M_{FS^\pm}^{Fit}}{M_{FS^\pm}^{Fit}}$ (%)	1.8	1.3-6.7	8-9	4.0-4.6	4-12
$\frac{ M_{FS^\pm}^{Fit} - M_{FS^\pm}^{True} }{M_{FS^\pm}^{True}}$ (%)	1.8	0.9-3.9	8.2-11.4	0.2-0.9	3.2-16.4
$\frac{ M_{FS^\pm}^{Fit} - M_{FS^\pm}^{True} }{\delta M_{FS^\pm}^{Fit}}$ ( $\sigma$ )	1.0	0.1-0.6	0.9-1.6	0.2-1.2	0.6-1.7

- Note: W results include  $\delta_{PDF}$ , SUSY results don't

## Conclusions (2/2)

### Linearity & Bias

- This indirect mass measurement technique
  - does not need any linearity corrections
  - does not need any offset corrections

### Thanks for your attention



- Don't be sorry Garfield!
- Remember, you have to stay positive for me to measure your mass at LHC