Using Integral and Differential Charge Asymmetries for BSM Searches at LHC

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Outline

Talk based upon arXiv:1412.6695v5 [hep-ph] published in JHEP,
and very preliminary new developments

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

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

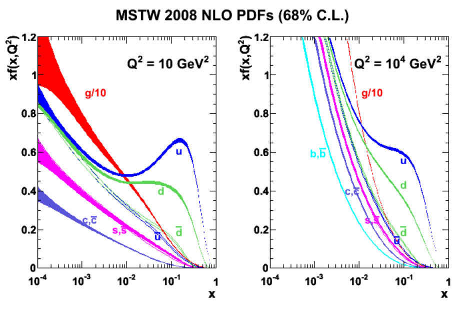
- For a given inclusive process produced at the:
  - LHC in $p+p$ collisions: $A_C \geq 0$
  - TEVATRON in $p+\bar{p}$ collisions: $A_C \approx 0$

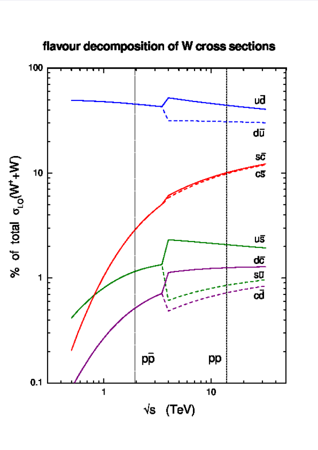
The Simplest Applicable Process

- To illustrate this discussion let's pick the $W^{\pm} \to \ell^{\pm}\nu + X$ 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 toplogy is: $1\ell^{\pm} + \not{E}_T + X$
- Therefore our actual observable is:

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

PDF and W Production at LHC





Relation between $A_C(W^\pm \to \ell^\pm \nu + X)$ 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 $(\frac{|V_{cs}|^2}{|V_{ud}|^2}, \frac{|V_{us}|^2}{|V_{ud}|^2}, \frac{|V_{cd}|^2}{|V_{ud}|^2}, \ldots)$
- Producing $W^\pm$ implies:
  - $Q^2 \approx M_{W^\pm}$ and $x_{1,2} = \frac{M_{W^\pm}}{\sqrt{s}} \cdot e^{\pm y_W}$
    i.e at $\sqrt{s} = 7$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 $A_C(W^\pm \to \ell^\pm \nu + X)$
- 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 $M_{W^\pm}$

Parton Level Setup in MCFM v5.8

- Calculate separately $\sigma^\pm = \sigma(p + p \to W^\pm \to \ell^\pm \nu)$ 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

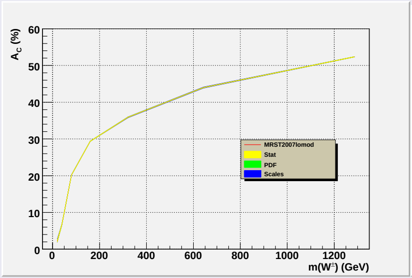
- Statistical: $\delta_{Stat} A_C = \frac{2\sqrt{(\sigma^- \cdot \delta\sigma^+_{Stat})^2 + (\sigma^+ \cdot \delta\sigma^-_{Stat})^2}}{(\sigma^+ + \sigma^-)^2}$
- PDF: $\begin{cases} \delta\sigma^{Up}_{PDF} = \sqrt{\sum_{i=1}^N [Max(\sigma_i^+ - \sigma_0, \sigma_i^- - \sigma_0, 0)]^2} \\ \delta\sigma^{Down}_{PDF}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

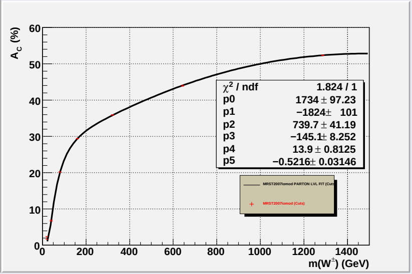
$A_C(W^\pm \to e^\pm \nu_e)$ for MRST2007lomod (1/2)

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

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

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





- Fits functional form: $A_C[M_{W^\pm}] = \sum_{i=0}^{N} A_i \times [Log[Log[M_{W^\pm}]]]^i$, 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

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

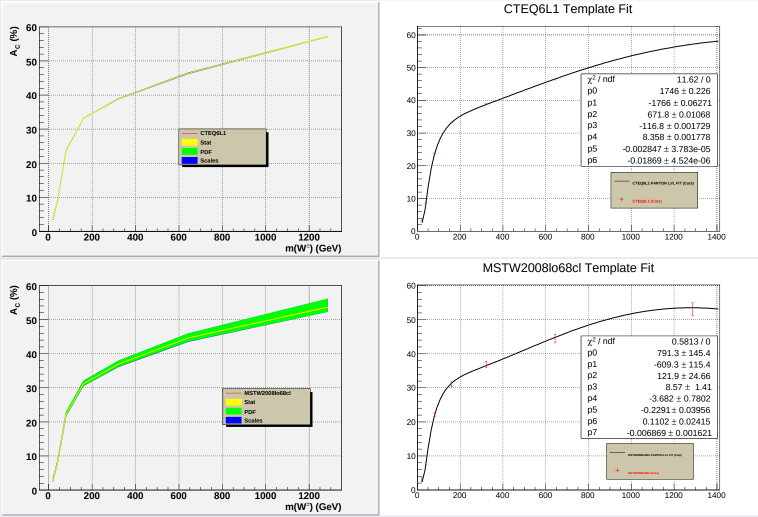


Figure : Theoretical A_C template curves: CTEQ6L1 (upper row) & MSTW2008lo68cl (lower row)

Event Selection: Electron Channel

- Generator: Herwig++ v2.5.0
- Detector Fast Simulation: Delphes v1.9
- Collider Hypotheses:
  - $\sqrt{s} = 7$ TeV
  - L=1 fb^{-1}
- $p_T(e^\pm) > 25$ GeV
- $|\eta(e^\pm)| < 1.37$ or $1.53 < |\eta(e^\pm)| < 2.4$
- Isolation: Tracker & Calorimeter
- $\not{E}_T > 25$ GeV
- $M_T > 40$ GeV

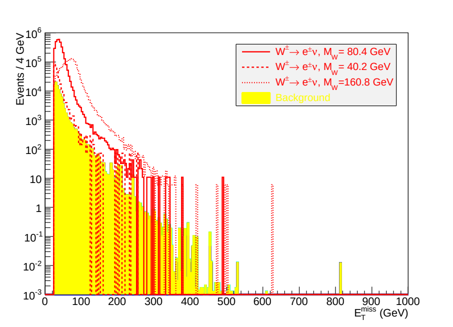


Figure : $\not{E}_T$ distribution for the $W^\pm \to e^\pm \nu_e$ analysis

Event Yields & Expected ICA

Process	ϵ (%)	N_{exp} (k evts)	$A_C \pm \delta A_C^{Stat}$ (%)
Signal: $W^\pm \to e^\pm \nu_e$			
$M(W^\pm) = 40.2$ GeV	0.81 ± 0.01	290.367	9.66 ± 1.57
$M(W^\pm) = 60.3$ GeV	13.69 ± 0.05	2561.508	11.22 ± 0.38
$M(W^\pm) = \underline{80.4}$ GeV	29.59 ± 0.04	3343.195	16.70 ± 0.18
$M(W^\pm) = 100.5$ GeV	39.19 ± 0.07	2926.093	20.77 ± 0.22
$M(W^\pm) = 120.6$ GeV	44.84 ± 0.07	2357.557	23.19 ± 0.21
$M(W^\pm) = 140.7$ GeV	48.66 ± 0.07	1899.820	25.29 ± 0.20
$M(W^\pm) = 160.8$ GeV	51.28 ± 0.07	1527.360	26.87 ± 0.19
$M(W^\pm) = 201.0$ GeV	54.54 ± 0.07	1.032	29.06 ± 0.18
Background	-	91.614 ± 1.706	10.07 ± 0.15
$W^\pm \to \mu^\pm \nu_\mu / \tau^\pm \nu_\tau / q\bar{q}\prime$	0.211 ± 0.003	71.350	12.92 ± 1.25
$t\bar{t}$	5.76 ± 0.02	6.600	1.00 ± 0.37
$t + b,\ t + q(+b)$	3.59 ± 0.01	1.926	28.97 ± 0.35
$W + W,\ W + \gamma^*/Z,\ \gamma^*/Z + \gamma^*/Z$	2.94 ± 0.01	2.331	10.65 ± 0.35
$\gamma + \gamma,\ \gamma + jets,\ \gamma + W^\pm,\ \gamma + Z$	0.201 ± 0.001	0.759	17.25 ± 0.53
γ^*/Z	0.535 ± 0.001	5.746	4.43 ± 0.23
QCD HF	$(0.44 \pm 0.17) \times 10^{-4}$	1.347	14.29 ± 37.41
QCD LF	$(0.87 \pm 0.33) \times 10^{-4}$	1.555	71.43 ± 26.45

$A_C(S)$ after Background Subtraction

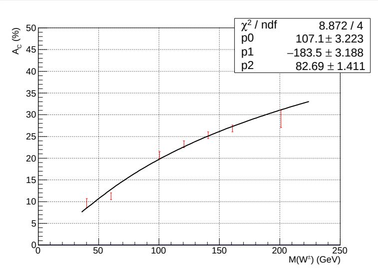
- In presence of B, the measured A_C is that of S+B, not just of S
- $A_C^{Exp}(S+B) = \frac{A_C^{Exp}(S)+\alpha^{Exp}\cdot A_C^{Exp}(B)}{1+\alpha^{Exp}}$, where $\alpha^{Exp} = \frac{N_B^{Exp}}{N_S^{Exp}}$
- Invert the relation to get the *"background subtraction equation"*:

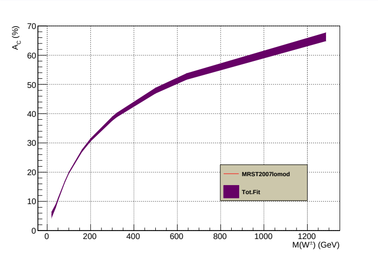
$$A_C^{Exp}(S) = (1+\alpha^{Exp})\cdot A_C^{Exp}(S+B) - \alpha^{Exp}\cdot A_C^{Exp}(B) \quad (4)$$

ICA Experimental Systematic Uncertainties

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





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

- 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:

$$A_C^{Meas.Fit}(S) = (16.70 \pm 0.35)\% \Rightarrow M^{Meas.Fit}(W^\pm \to e^\pm \nu_e) = 81.08^{+2.06}_{-2.01}\ \mathrm{GeV} \quad (6)$$

$$A_C^{Meas.Fit}(S) = (17.52 \pm 0.18)\% \Rightarrow M^{Meas.Fit}(W^\pm \to \mu^\pm \nu_\mu) = 79.67^{+3.56}_{-1.39}\ \mathrm{GeV} \quad (7)$$

- Combine using weighted mean & RMS:

$$M^{Comb.Meas.}(W^\pm) = 80.30 \pm 0.96\ (\mathrm{Exp.Comb.})\ \mathrm{GeV} \quad (8)$$

- Theory uncertainties for this given mass ($^{+0.19}_{-0.21}$ GeV) obtained by looking-up the theoretical template curve
- Sum in quadrature experimental & theory uncertainties

$$M_{W^\pm} = 80.30^{+0.98}_{-0.98}\ (\mathrm{Tot.\ MRST2007lomod})\ \ \mathrm{GeV} \quad (9)$$

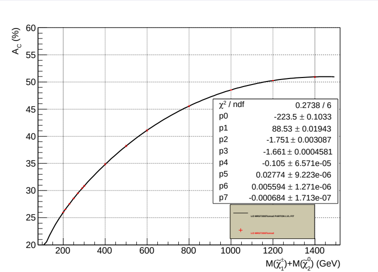
- Repeat the whole procedure for CTEQ6L1 & MSTW2008lo68cl:

$$M_{W^\pm} = 78.95^{+0.62}_{-0.62}\ (\mathrm{Tot.\ CTEQ6L1})\ \ \mathrm{GeV} \quad (10)$$

$$M_{W^\pm} = 81.36^{+1.67}_{-1.51}\ (\mathrm{Tot.\ MSTW2008lo68cl})\ \ \mathrm{GeV} \quad (11)$$

Parton Level Setup using Resummino v1.0.0

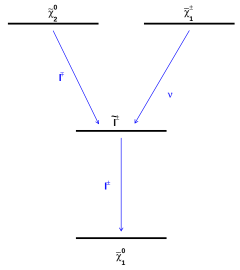
- Calculate separately at $\sqrt{s} = 8$ TeV:
  - $\sigma^+ = \sigma(p + p \to \tilde{\chi}_1^+ + \tilde{\chi}_2^0)$
  - $\sigma^- = \sigma(p + p \to \tilde{\chi}_1^- + \tilde{\chi}_2^0)$
- $A_C^{Theory} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$
- LO MEs & LO PDFs: MRST2007lomod (default), CTEQ6L1, 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



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

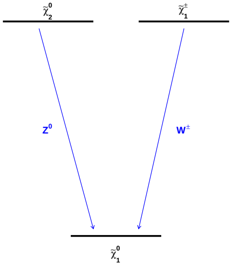
Different SUSY Scenarios (1/2)

- S1 Signal:
  - Lightest SUSY particles: $\tilde{\chi}_1^\pm$, $\tilde{\chi}_{1,2}^0$, $\tilde{\ell}^\pm$
  - $M_{\tilde{\chi}_1^\pm} = M_{\tilde{\chi}_2^0}$
  - $BR(\tilde{\chi}_1^\pm \to \tilde{\ell}^\pm(\to \ell^\pm \tilde{\chi}_1^0) + \nu) = 100\%$
  - $BR(\tilde{\chi}_2^0 \to \tilde{\ell}^\pm(\to \ell^\pm \tilde{\chi}_1^0) + \ell^\mp) = 100\%$
  - Vary: $M_{\tilde{\chi}_2^0} \in [100, 700]$ GeV by steps of100 GeV
  - Set: $M_{\tilde{\chi}_1^0} = M_{\tilde{\chi}_2^0}/2$ and $M_{\tilde{\ell}^\pm} = [M_{\tilde{\chi}_2^0} + M_{\tilde{\chi}_1^\pm}]/2$



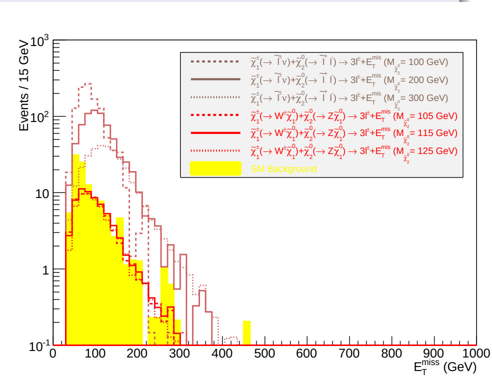
Different SUSY Scenarios (2/2)

- S2 Signal:
  - Lightest SUSY particles: $\tilde{\chi}_1^\pm$, $\tilde{\chi}_{1,2}^0$
  - $M_{\tilde{\chi}_1^\pm} = M_{\tilde{\chi}_2^0}$
  - $BR(\tilde{\chi}_1^\pm \to \tilde{\ell}^\pm(\to \ell^\pm \tilde{\chi}_1^0) + \nu) = 100\%$
  - $BR(\tilde{\chi}_2^0 \to \tilde{\ell}^\pm(\to \ell^\pm \tilde{\chi}_1^0) + \ell^\mp) = 100\%$
  - 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 $M_{\tilde{\chi}_2^0} \in [105, 145]$ 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 $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to 3\ell^\pm + \not{E}_T$ analysis

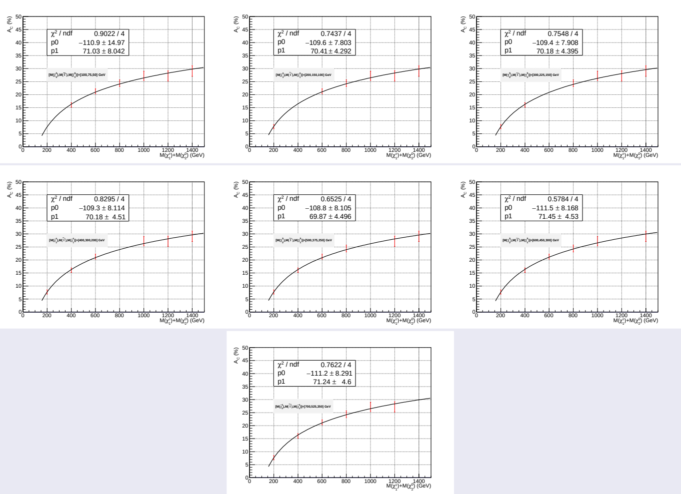
- Generators: Herwig++, Alpgen & Pythia8
- Fast Sim.: Delphes
- Collider Hypotheses:
  - $\sqrt{s} = 8$ TeV, L=20 fb^{-1}
- Electron Candidates:
  $|\eta(e^\pm)| < 1.37$ or
  $1.53 < |\eta(e^\pm)| < 2.47$
  $p_T(e^\pm) > 10$ GeV
- Muon Candidates:
  $|\eta(\mu^\pm)| < 2.4$
  $p_T(\mu^\pm) > 10$ GeV
- $p_T(\ell^\pm_{1,2,3}) > 20, 10, 10$ GeV
- Isolation:
  Tracker & Calorimeter
- $\not{E}_T > 35$ GeV
- $M_{T2} > 75$ GeV



Expected and Measured ICA

Process	$\alpha^{Exp} \pm \delta\alpha^{Stat}$	Z_N (σ)	$A_C^{Meas.}$ (%)	$\delta A_C^{Tot.}$ (%)	$\delta A_C^{Meas.Fit}$ (%)
S1 Signal $[M_{\tilde{\chi}_2^0}, M_{\tilde{\ell}^\pm}, M_{\tilde{\chi}_1^0}]$ GeV					
[100, 75, 50]	$(9.98 \pm 0.26) \times 10^{-2}$	31.70	7.70	0.83	0.74
[200, 150, 100]	$(15.58 \pm 0.36) \times 10^{-2}$	23.86	16.06	0.85	0.44
[300, 225, 150]	$(34.28 \pm 0.79) \times 10^{-2}$	13.79	21.30	0.96	0.48
[400, 300, 200]	$(96.89 \pm 2.22) \times 10^{-2}$	6.04	24.40	1.29	0.58
[500, 375, 250]	$(288.49 \pm 6.61) \times 10^{-2}$	2.25	27.21	1.75	0.69
[600, 450, 300]	$(869.13 \pm 19.89) \times 10^{-2}$	0.74	27.20	1.97	0.77
[700, 525, 350]	$(241.74 \pm 5.55) \times 10^{-1}$	0.23	29.06	2.02	0.85
S2 Signal $[M_{\tilde{\chi}_2^0}, M_{\tilde{\chi}_1^0}]$ GeV					
[100, 50]	$(78.22 \pm 6989.64) \times 10^{1}$	-0.06	7.62	0.88	0.59
[105, 13.8]	$(177.34 \pm 4.21) \times 10^{-2}$	3.55	7.85	1.58	0.56
[115, 13.8]	$(167.29 \pm 3.91) \times 10^{-2}$	3.74	7.73	1.55	0.52
[125, 13.8]	$(190.49 \pm 4.44) \times 10^{-2}$	3.32	9.34	1.60	0.49
[135, 13.8]	$(199.69 \pm 4.61) \times 10^{-2}$	3.18	10.43	1.62	0.46
[145, 13.8]	$(223.26 \pm 5.16) \times 10^{-2}$	2.87	11.50	1.67	0.45
[150, 50]	$(382.23 \pm 8.90) \times 10^{-2}$	1.71	12.06	1.85	0.44
[200, 100]	$(102.35 \pm 2.34) \times 10^{-1}$	0.62	16.66	2.00	0.46
[250, 125]	$(140.58 \pm 3.23) \times 10^{-1}$	0.44	18.28	2.01	0.52
[300, 150]	$(216.42 \pm 4.96) \times 10^{-1}$	0.26	20.98	2.02	0.60
[400, 200]	$(608.39 \pm 13.89) \times 10^{-1}$	0.05	24.11	2.03	0.74
[500, 250]	$(18.88 \pm 0.43) \times 10^{-5}$	-0.03	27.51	2.03	0.86
[600, 300]	$(57.64 \pm 1.32) \times 10^{-5}$	-0.06	27.25	2.03	0.96
[700, 350]	$(182.52 \pm 4.17) \times 10^{-5}$	-0.07	27.91	2.03	1.04

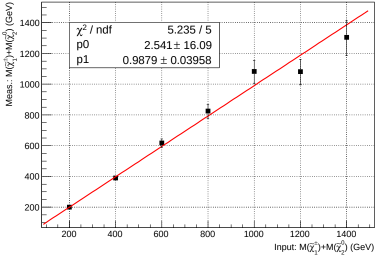
Experimental Template Curves for S1 Signal

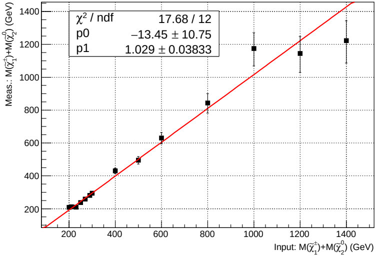


Indirect Determination of $M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$ (Exp. Uncert.)

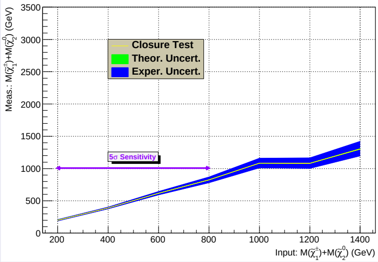
Input $M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$ (GeV)	$A_C^{Meas.Fit} \pm \delta A_C^{Meas.Fit}$ (%)	Meas. $M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_2^0}$ (GeV)
S1 Signal		
200.	7.70 $\pm$ 0.74	$200.37^{+11.51}_{-10.78}$
400.	16.06 $\pm$ 0.44	$390.18^{+14.83}_{-14.21}$
600.	21.30 $\pm$ 0.48	$617.94^{+27.70}_{-26.34}$
800.	24.40 $\pm$ 0.58	$824.61^{+46.98}_{-44.09}$
1000.	27.21 $\pm$ 0.69	$1083.15^{+76.95}_{-71.18}$
1200.	27.20 $\pm$ 0.77	$1082.08^{+86.18}_{-78.99}$
1400.	29.06 $\pm$ 0.85	$1304.01^{+118.38}_{-107.31}$
S2 Signal		
200.	7.62 $\pm$ 0.59	$208.34^{+9.51}_{-9.01}$
210.	7.85 $\pm$ 0.56	$211.99^{+9.20}_{-8.75}$
230.	7.73 $\pm$ 0.52	$210.08^{+8.43}_{-8.05}$
250.	9.34 $\pm$ 0.49	$237.72^{+9.01}_{-8.97}$
270.	10.43 $\pm$ 0.46	$258.55^{+9.52}_{-9.13}$
290.	11.50 $\pm$ 0.45	$281.34^{+10.29}_{-9.86}$
300.	12.06 $\pm$ 0.44	$294.21^{+10.60}_{-10.17}$
400.	16.66 $\pm$ 0.46	$430.69^{+17.35}_{-16.57}$
500.	18.28 $\pm$ 0.52	$495.51^{+23.17}_{-21.97}$
600.	20.98 $\pm$ 0.60	$630.50^{+35.51}_{-33.34}$
800.	24.11 $\pm$ 0.74	$843.48^{+61.79}_{-57.00}$
1000.	27.51 $\pm$ 0.86	$1174.45^{+105.82}_{-95.96}$
1200.	27.25 $\pm$ 0.96	$1144.45^{+115.34}_{-103.44}$

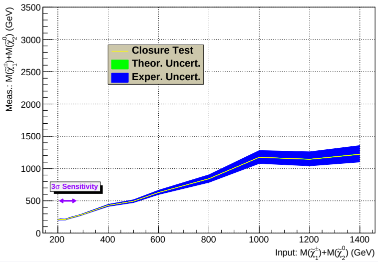
Closure Tests w/ Expt. Uncert.: S1 Signal (LHS), S2 Signals (RHS)





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





Event Selection: Muon Channel

My Selection

- Generators: Herwig++, Alpgen (LO)
- Detector Fast Sim.: Delphes3
- Collider Hypotheses:
  - $\sqrt{s} = 8$ TeV
  - L=20 fb^{-1}
  - PDF: MRST2007lomod
  - No pile-up
- $p_T(\mu^{\pm}) > 45$ GeV
- $|\eta(\mu^{\pm})| < 2.4$
- Tracker Isolation
- $\not{E}_T > 45$ GeV
- $M_T > 800$ GeV

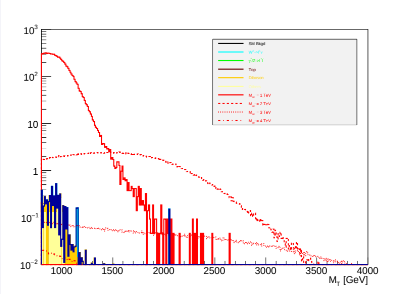
ATLAS Selection (arXiv:1407.7494)

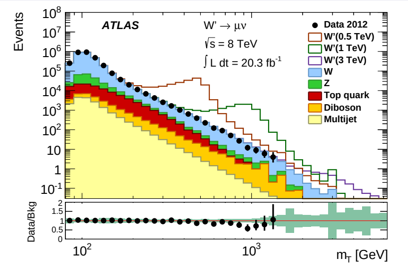
- Generators: Signal: Pythia8 (LO) Main Bkgd: Powheg (NLO)
- Detector Sim.: Geant4
- Collider Parameters:
  - $\sqrt{s} = 8$ TeV
  - L=20.3 fb^{-1}
  - PDF: MSTW2008LO, CT10 (NLO)
  - Pile-up: $< \mu >= 20.7$
- $p_T(\mu^{\pm}) > 45$ GeV
- $|\eta(\mu^{\pm})| < 1.0$ or $1.3 < |\eta(\mu^{\pm})| < 2.0$
- Tracker Isolation
- $\not{E}_T > 45$ GeV
- $M_T > 796, 1500, 1888$ GeV (for $M_{W^{\pm\prime}}$ =1,2,3&4 TeV)

Event Yields & Expected ICA

Process	ϵ (%)	N_{exp} (evts)	$A_C \pm \delta A_C^{Stat}$ (%)
Signal: $W^{\pm\prime} \to \mu^{\pm}\nu_{\mu}$			
$M(W^{\pm\prime}) = 1$ TeV	36.36 ± 0.07	8561.59	48.56 ± 0.94
$M(W^{\pm\prime}) = 2$ TeV	64.04 ± 0.07	317.23	60.61 ± 4.47
$M(W^{\pm\prime}) = 3$ TeV	42.87 ± 0.07	12.53	60.48 ± 22.50
$M(W^{\pm\prime}) = 4$ TeV	21.15 ± 0.06	1.33	57.28 ± 71.04
Background	-	5.91	1.30 ± 41.14
$W^{\pm} \to \mu^{\pm}\nu_{\mu}/\tau^{\pm}\nu_{\tau}/q\bar{q}\prime + LF$	0.00 ± 0.00	0.00	–
$W^{\pm} \to \mu^{\pm}\nu_{\mu}/\tau^{\pm}\nu_{\tau}/q\bar{q}\prime + HF$	$5.28 \times 10^{-4} \pm 1.21 \times 10^{-5}$	1.78	82.51 ± 42.32
$t\bar{t}$	0.00 ± 0.00	0.00	–
$t+b,\ t+q(+b)$	0.00 ± 0.00	0.00	–
VV	$4.09 \times 10^{-4} \pm 1.14 \times 10^{-5}$	1.65	-100.00 ± 0.00
VVV	$5.41 \times 10^{-3} \pm 4.47 \times 10^{-5}$	2.28×10^{-2}	6.85 ± 8.26
$\gamma+\gamma,\ \gamma+jets,\ \gamma+W^{\pm},\ \gamma+Z$	0.00 ± 0.00	0.00	–
$\gamma^*/Z + LF$	$6.97 \times 10^{-2} \pm 3.71 \times 10^{-5}$	2.45	-87.15 ± 46.67
$\gamma^*/Z + HF$	0.00 ± 0.00	0.00	–
QCD HF	0.00 ± 0.00	0.00	–
QCD LF	0.00 ± 0.00	0.00	–

Transverse Mass Plots





- Not a reliable re-casting of ATLAS analysis:
  LO generators, no pile-up, smaller stat., fast simulation
- But, I'll use the experimental systematic uncert. quoted therein

Systematic Uncertainties (1)

- Theoretical:
  - QCD Scales: 0.15%
  - PDF$\oplus\alpha_S$ (next slide)
- Experimental:
  - $\not{E}_T$ scale & resolution: 0.1% (S), 0.5% (B)
  - Lepton energy/momentum scale & resolution: 2.3% (S), 18.1% (B)

Systematic Uncertainties (2)

- Calculated following the latest recom. by PDF4LHC for Run 2 (arXiv:1510.03865)
- Used LHAPDF v6.1.5
- α_S:
  - Reweight full analysis to PDF4LHC15_nlo_mc_pdfas/k with k=101,102
  - $$\delta_{\alpha_S} A_C = \frac{A_C(\alpha_S = 0.1195) - A_C(\alpha_S = 0.1165)}{2} \quad (12)$$
- PDF:
  - Reweight full analysis to PDF4LHC15_nlo_mc_pdfas/k with k=1,N_{mem}=100
  - $$\delta_{PDF} A_C = \sqrt{\frac{1}{N_{mem} - 1} \sum_{k=1}^{N_{mem}} [A_C^{(k)} - < A_C >]^2} \quad (13)$$
- PDF$\oplus\alpha_S$:

$$\delta_{PDF \oplus \alpha_S} A_C = \sqrt{\delta^2_{PDF} A_C + \delta^2_{\alpha_S} A_C} \quad (14)$$

Systematic Uncertainties (3)

Process	$\delta A_C^{Stat} \oplus \delta A_C^{Syst}$ (B)	$\delta A_C^{Stat} \oplus \delta A_C^{Syst}$ (S+B)
$M(W^{\pm\prime}) = 1$ TeV	–	1.74 %
$M(W^{\pm\prime}) = 2$ TeV	–	9.83 %
$M(W^{\pm\prime}) = 3$ TeV	–	161.89 %
$M(W^{\pm\prime}) = 4$ TeV	–	41.31 %
Background	3.88%	–

Statistical Interpretation (1)

- Caveat: these are very preliminary results
- Base the hypothesis test on the Integral Charge Asymmetries
  - H_0: $A_C(B)$
  - H_1: $A_C(S+B)$
- In pratice I start from the fraction of positively charged events:
  - $\mathcal{L}(n|N)$ splitted into $\mathcal{L}(n^{\pm}|N)$, with $n = n^+ + n^-$

Hence:

$$\mathcal{L}(n^+|B) = \frac{\begin{pmatrix} B \\ n^+ \end{pmatrix} \times (\mathcal{P}_B^+)^{n^+} \times (\mathcal{P}_B^-)^{n^-}}{\frac{B^n \times e^{-B}}{B!}} \quad (15)$$

and

$$\mathcal{L}(n^+|S+B) = \frac{\begin{pmatrix} S+B \\ n^+ \end{pmatrix} \times (\mathcal{P}_{S+B}^+)^{n^+} \times (\mathcal{P}_{S+B}^-)^{n^-}}{\frac{(S+B)^n \times e^{-(S+B)}}{(S+B)!}} \quad (16)$$

Note that:

$$\mathcal{P}_H^{\pm} = \frac{1 \pm A_C(H)}{2} \quad (17)$$

Statistical Interpretation (2)

To account for the systematic uncertainties (treated as nuisance parameters), each final likelihood is convoluted with a gaussian:

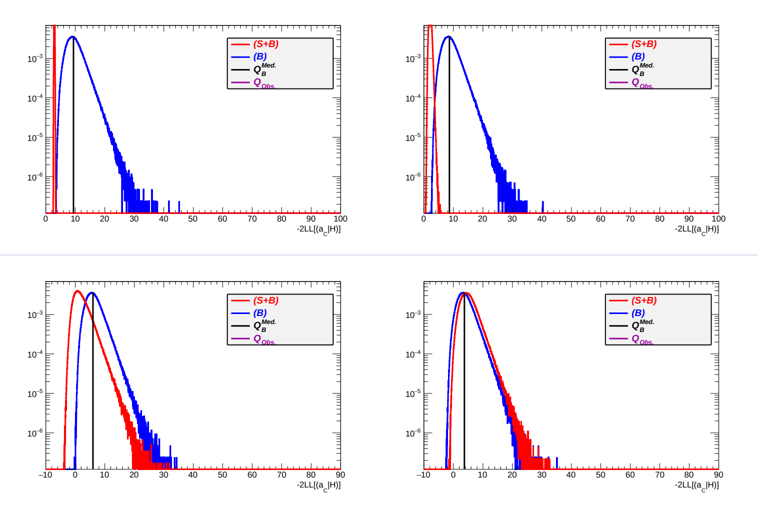
$$\mathcal{L}(a_C|B) = [2\mathcal{L}(n^+|B) - 1] \times \frac{e^{-\left[A_C(B)-A_C^{Exp}(B)\right]^2/2\delta^2[A_C(B)]}}{\sqrt{2\pi\delta^2[A_C(B)]}} \quad (18)$$

Similarly,

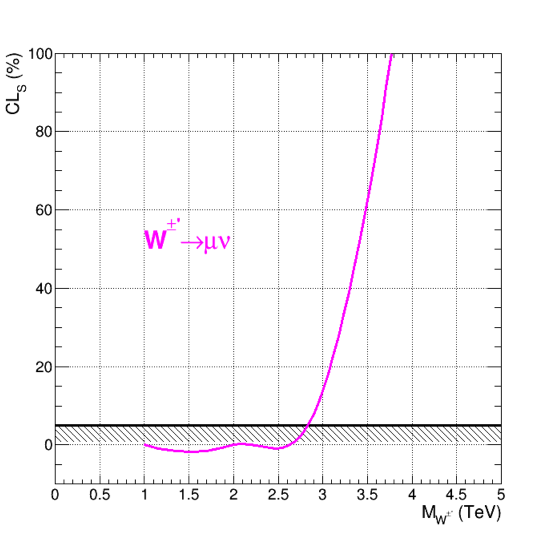
$$\mathcal{L}(a_C|S+B) = [2\mathcal{L}(n^+|S+B) - 1] \times \frac{e^{-\left[A_C(S+B)-A_C^{Exp}(S+B)\right]^2/2\delta^2[A_C(S+B)]}}{\sqrt{2\pi\delta^2[A_C(S+B)]}} \quad (19)$$

Finally the test statistic is defined as: $Q = -2Log[\mathcal{L}(a_C|H)]$, and I calculate the C.L. by integrating its p.d.f.'s distributions for the two hypotheses.
These likelihoods can easily be extended for different search channels and also for binned distributions (differential charge asymmetries).

Test Statistics Distributions



95% C.L. Limits



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

-	$W^{\pm}$	S1 Signal		S2 Signal	
-	M_W =80.4 GeV	5σ: [200-800] GeV	[1.0-1.4] TeV	3σ: [210-270] GeV	[0.29-1.4] TeV
$\frac{\delta M^{Fit}_{FS^{\pm}}}{M^{Fit}_{FS^{\pm}}}$ (%)	**+2.1**	**[+3.8,+5.8]**	**[+7.1,+9.1]**	**[+3.7,+4.4]**	**[+3.6,+11.1]**
$\frac{M^{Fit}_{FS^{\pm}} - M^{True}_{FS^{\pm}}}{M^{True}_{FS^{\pm}}}$ (%)	**+1.2**	**[-2.5,+3.1]**	**[-9.8,+8.3]**	**[-8.7,+1.0]**	**[-12.7,+17.5]**
$\frac{M^{Fit}_{FS^{\pm}} - M^{True}_{FS^{\pm}}}{\delta M^{Fit}_{FS^{\pm}}}$ (σ)	**+0.6**	**[-0.7,+0.7]**	**[-1.4,+1.1]**	**[-2.4,+0.2]**	**[-1.3,+1.8]**

- Note: W results include δ_{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
- Integral or Differential Charge Asymmetries can also be used in searches
  - They have promising sensitivities that deserve further studies
  - Example (95%CL exclusions):

$$\begin{cases} M_{W^{\pm\prime}} > 2.5 - 3.0 \text{ TeV (ICA, muon channel)} \\ M_{W^{\pm\prime}} > 2.97 \text{ TeV } (\mathrm{M_T}, \text{ muon channel}) \end{cases} \quad (20)$$

First Cartoon

- Don't worry about your weight Garfield!

Conclusions (3)

Second Cartoon

- I'm blinded, but just tell me how positive you are
- And I'll tell who you are

Prospects

ICA/DCA for Searches

- Improve the MC Samples
  - Qualitatively: NLO Background
  - Quantitatively: increase the statistics in the high-M_T tail
- Validate of the statistical procedure
- Debug the PDF systematic uncertainty
- Electron channel, plus combination
- Try the DCA
- Combine ICA/DCA with M_T-based selection
- Try other decay modes: $W^{\pm\prime} \to t + \bar{b}$