Using Integral and Differential Charge Asymmetries for BSM Searches at LHC

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Outline

1. Introduction

2. An Exotic Physics Case
   - Search for $W^{\pm\prime} \to \ell^{\pm}\nu$ at LHC

3. Prospects

Introduction

Indirect Mass Measurements based upon Integral Charge Asymmetry

- Preprint: arXiv:1412.6695v5 [hep-ph]
- Publication: JHEP **1604** (2016) 179
- Limiation:
  - Need to have a statistically significant signal to apply this method
  - In BSM: without any new signal from a charged current process, can't do anything
- Questions:
  - Is it possible to use ICA (or DCA) to improve sensitivity to a signal?
  - If yes, how to calculate confidence levels in this case?

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

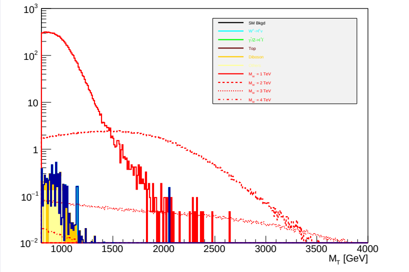
ATLAS Selection (arXiv:1407.7494)

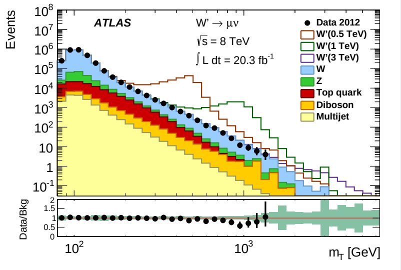
- Generators:
  Signal: Pythia8 (LO)
  Main Bkgd: Powheg (NLO)
- Detector Sim.: Geant4
- Collider Parameters:
  - $\sqrt{s} = 8$ TeV
  - L=20.3 fb^{-1}
  - PDF: MSTW2008LO, CT10 (NLO)
  - Pile-up: $< \mu >= 20.7$
- $p_T(\mu^{\pm}) > 45$ GeV
- $|\eta(\mu^{\pm})| < 1.0$ or $1.3 < |\eta(\mu^{\pm})| < 2.0$
- 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
  - $$\delta_{\alpha_S} A_C = \frac{A_C(\alpha_S = 0.1195) - A_C(\alpha_S = 0.1165)}{2} \quad (1)$$
- PDF:
  - Reweight full analysis to PDF4LHC15_nlo_mc_pdfas/k with k=1,N_{mem}=100
  - $$\delta_{PDF} A_C = \sqrt{\frac{1}{N_{mem}-1} \sum_{k=1}^{N_{mem}} [A_C^{(k)} - < A_C >]^2} \quad (2)$$
- PDF$\oplus\alpha_S$:

$$\delta_{PDF\oplus\alpha_S} A_C = \sqrt{\delta^2_{PDF} A_C + \delta^2_{\alpha_S} A_C} \quad (3)$$

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	41.31%	–

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:

$$\mathcal{L}(n^+|B) = \frac{\begin{pmatrix} B \\ n^+ \end{pmatrix} \times (\mathcal{P}_B^+)^{n^+} \times (\mathcal{P}_B^-)^{n^-}}{\frac{B^n \times e^{-B}}{B!}} \quad (4)$$

and

$$\mathcal{L}(n^+|S+B) = \frac{\begin{pmatrix} S+B \\ n^+ \end{pmatrix} \times (\mathcal{P}_{S+B}^+)^{n^+} \times (\mathcal{P}_{S+B}^-)^{n^-}}{\frac{(S+B)^n \times e^{-(S+B)}}{(S+B)!}} \quad (5)$$

Note that:

$$\mathcal{P}_H^{\pm} = \frac{1 \pm A_C(H)}{2} \quad (6)$$

Statistical Interpretation (2)

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

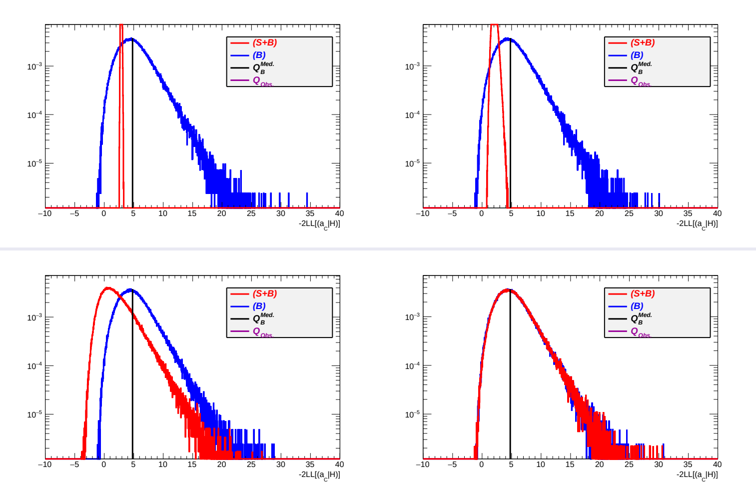
$$\mathcal{L}(a_C|B) = [2\mathcal{L}(n^+|B) - 1] \times \frac{e^{-\left[A_C(B) - A_C^{Exp}(B)\right]^2 / 2\delta^2[A_C(B)]}}{\sqrt{2\pi\delta^2[A_C(B)]}} \quad (7)$$

Similarly,

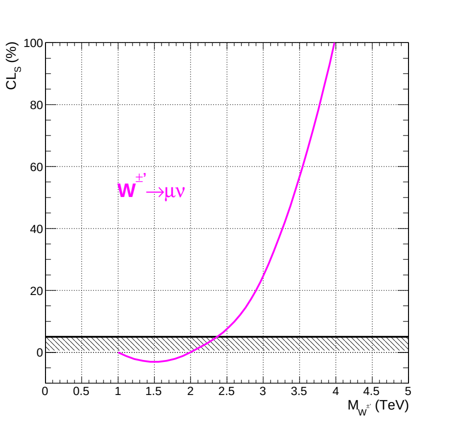
$$\mathcal{L}(a_C|S+B) = [2\mathcal{L}(n^+|S+B) - 1] \times \frac{e^{-\left[A_C(S+B) - A_C^{Exp}(S+B)\right]^2 / 2\delta^2[A_C(S+B)]}}{\sqrt{2\pi\delta^2[A_C(S+B)]}} \quad (8)$$

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


CL_S (%)
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$M_{W^{\pm\prime}}$ (TeV)
$W^{\pm\prime} \to \mu\nu$

Prospects

ICA/DCA for Searches

- Improve the MC Samples
  - Qualitatively: NLO Background (seems much more user-friendly w/ Herwig v7)
  - Quantitatively: increase the statistics in the high-M_T tail
- Improve (LLR) & 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: $W^{\pm\prime} \rightarrow t + \bar{b}$