Prospect for precision measurements of $M_{W^+} - M_{W^-}$ & M_W at the LHC (Shortcuts revisited)

Florent Fayette[(a)],
Witold Krasny[(a)], Wiesław Płaczek[(b),(a)],
Katarzyna Rejzner[(b)] & Andrzej Siódmok[(b),(a)]

[(a)] LPNHE, Universités de Paris VI, Paris VII et IN2P3, Paris,
[(b)] Marian Smoluchowski Institute of Physics, Jagiellonian University, Cracow.

EPS 2009 – Kraków
2009 July 17

1. Introduction

Statu Quo

- Tevatron :
  - CDF II [Aaltonen *et al.*, Phys. Rev. D**77**, 112001 (2008)]

$$\begin{array}{ll} W \to \mu\,\nu_\mu & M_{W^+} - M_{W^-} = 0.286 \pm 0.152\,\text{GeV} \\ W \to e\,\nu_e & M_{W^+} - M_{W^-} = 0.257 \pm 0.117\,\text{GeV} \\ W \to \mu\,\nu_\mu,\, e\,\nu_e & M_W = 80.413 \pm 0.048\,\text{GeV} \end{array}$$

  - Precision on M_W achievable *because* $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,\bar{p}$ collisions

- LHC :
  - Announce $\delta^{(\text{sys.})}_{M_W} \sim 10\,\text{MeV}$,... but forgot $W^+ \overset{CP}{\Longleftrightarrow\!\!\!\!\!\!/\;\;} W^-$ in $p\,p$ collisions

– Our prospect –

Dedicated *systematic-robust* strategies/observables
for $M_{W^+} - M_{W^-}$ & M_W $p_{T,l}$-based measurements

..., but first some basics on W^+ and W^- in Drell–Yan-like at the LHC

Statu Quo

- Tevatron :
  - CDF II [Aaltonen *et al.*, Phys. Rev. D**77**, 112001 (2008)]

$$\begin{array}{lll} W \to \mu\,\nu_\mu & M_{W^+} - M_{W^-} & = 0.286 \pm 0.152\,\text{GeV} \\ W \to e\,\nu_e & M_{W^+} - M_{W^-} & = 0.257 \pm 0.117\,\text{GeV} \\ W \to \mu\,\nu_\mu,\, e\,\nu_e & M_W & = 80.413 \pm 0.048\,\text{GeV} \end{array}$$

  - Precision on M_W achievable *because* $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,\bar{p}$ collisions

- LHC :
  - Announce $\delta^{(\text{sys.})}_{M_W} \sim 10\,\text{MeV}$,... but forgot $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,p$ collisions

– Our prospect –

Dedicated *systematic-robust* strategies/observables
for $M_{W^+} - M_{W^-}$ & M_W $p_{T,l}$-based measurements

..., but first some basics on W^+ and W^- in Drell–Yan-like at the LHC

Statu Quo

- Tevatron :
  - CDF II [Aaltonen *et al.*, Phys. Rev. D**77**, 112001 (2008)]

$$\begin{array}{ll} W \to \mu\,\nu_\mu & M_{W^+} - M_{W^-} = 0.286 \pm 0.152\,\text{GeV} \\ W \to e\,\nu_e & M_{W^+} - M_{W^-} = 0.257 \pm 0.117\,\text{GeV} \\ W \to \mu\,\nu_\mu,\, e\,\nu_e & M_W = 80.413 \pm 0.048\,\text{GeV} \end{array}$$

  - Precision on M_W achievable *because* $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,\bar{p}$ collisions

- LHC :
  - Announce $\delta^{(\text{sys.})}_{M_W} \sim 10\,\text{MeV}$,... but forgot $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,p$ collisions

– Our prospect –

Dedicated *systematic-robust* strategies/observables
for $M_{W^+} - M_{W^-}$ & M_W $p_{T,l}$-based measurements

..., but first some basics on W^+ and W^- in Drell–Yan-like at the LHC

Statu Quo

- Tevatron :
  - CDF II [Aaltonen *et al.*, Phys. Rev. D**77**, 112001 (2008)]

$$\begin{array}{ll} W \to \mu\,\nu_\mu & M_{W^+} - M_{W^-} = 0.286 \pm 0.152\,\text{GeV} \\ W \to e\,\nu_e & M_{W^+} - M_{W^-} = 0.257 \pm 0.117\,\text{GeV} \\ W \to \mu\,\nu_\mu,\, e\,\nu_e & M_W = 80.413 \pm 0.048\,\text{GeV} \end{array}$$

  - Precision on M_W achievable *because* $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,\bar{p}$ collisions

- LHC :
  - Announce $\delta^{(\text{sys.})}_{M_W} \sim 10\,\text{MeV}$,... but forgot $W^+ \overset{CP}{\not\Longleftrightarrow} W^-$ in $p\,p$ collisions

– Our prospect –

Dedicated *systematic-robust* strategies/observables
for $M_{W^+} - M_{W^-}$ & M_W $p_{T,l}$-based measurements

..., but first some basics on W^+ and W^- in Drell–Yan-like at the LHC

Statu Quo

- Tevatron :
  - CDF II [Aaltonen *et al.*, Phys. Rev. D**77**, 112001 (2008)]

$$\begin{array}{ll} W \to \mu\,\nu_\mu & M_{W^+} - M_{W^-} = 0.286 \pm 0.152\,\text{GeV} \\ W \to e\,\nu_e & M_{W^+} - M_{W^-} = 0.257 \pm 0.117\,\text{GeV} \\ W \to \mu\,\nu_\mu,\, e\,\nu_e & M_W = 80.413 \pm 0.048\,\text{GeV} \end{array}$$

  - Precision on M_W achievable *because* $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,\bar{p}$ collisions

- LHC :
  - Announce $\delta^{(\text{sys.})}_{M_W} \sim 10\,\text{MeV}$,... but forgot $W^+ \overset{CP}{\Longleftrightarrow\!\!\!\!\!\!/\;\;} W^-$ in $p\,p$ collisions

– Our prospect –

Dedicated *systematic-robust* strategies/observables
for $M_{W^+} - M_{W^-}$ & M_W $p_{T,l}$-based measurements

..., but first some basics on W^+ and W^- in Drell–Yan-like at the LHC

Statu Quo

- Tevatron :
  - CDF II [Aaltonen *et al.*, Phys. Rev. D**77**, 112001 (2008)]

$$\begin{array}{ll} W \to \mu\,\nu_\mu & M_{W^+} - M_{W^-} = 0.286 \pm 0.152\,\text{GeV} \\ W \to e\,\nu_e & M_{W^+} - M_{W^-} = 0.257 \pm 0.117\,\text{GeV} \\ W \to \mu\,\nu_\mu,\, e\,\nu_e & M_W = 80.413 \pm 0.048\,\text{GeV} \end{array}$$

  - Precision on M_W achievable *because* $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p\,\bar{p}$ collisions

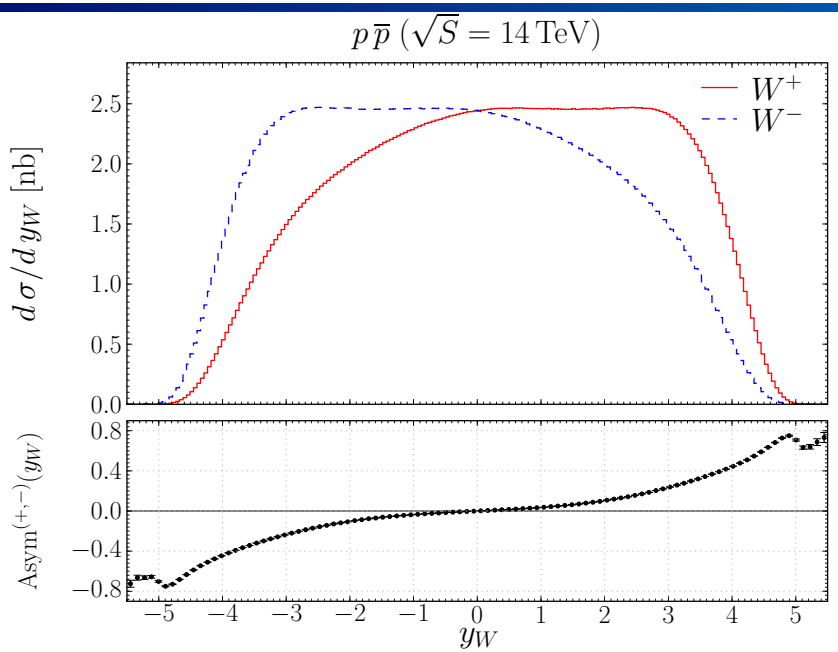
- LHC :
  - Announce $\delta^{(\text{sys.})}_{M_W} \sim 10\,\text{MeV}$,... but forgot $W^+ \overset{CP}{\Longleftrightarrow\!\!\!\!\!\!/\;\;} W^-$ in $p\,p$ collisions

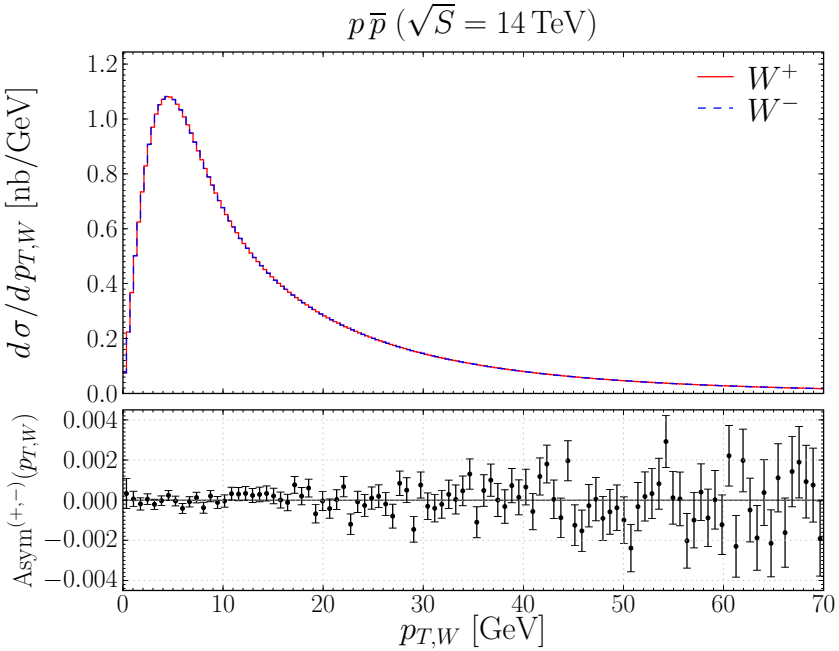
– Our prospect –

Dedicated *systematic-robust* strategies/observables
for $M_{W^+} - M_{W^-}$ & M_W $p_{T,l}$-based measurements

..., but first some basics on W^+ and W^- in Drell–Yan-like at the LHC

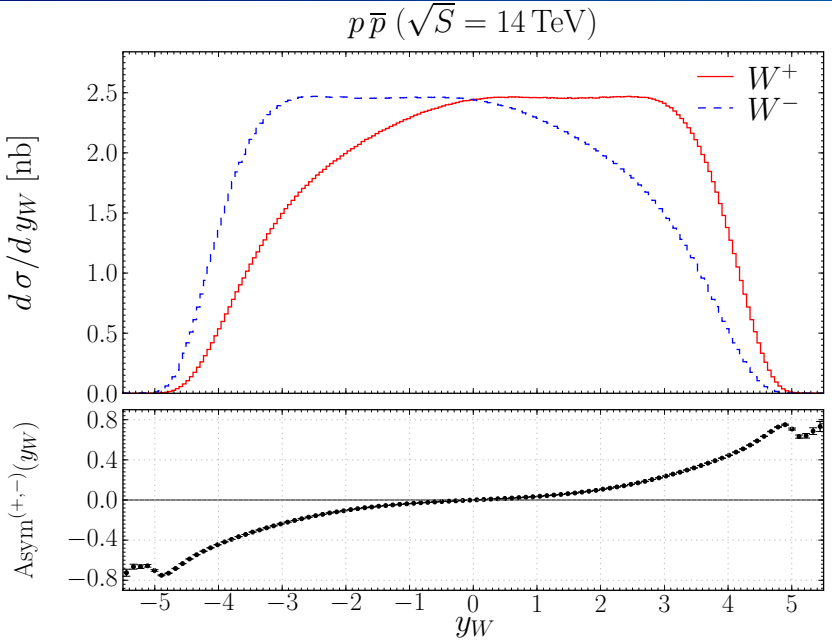
$W^\pm$ production in $p\bar{p}$ & pp collisions

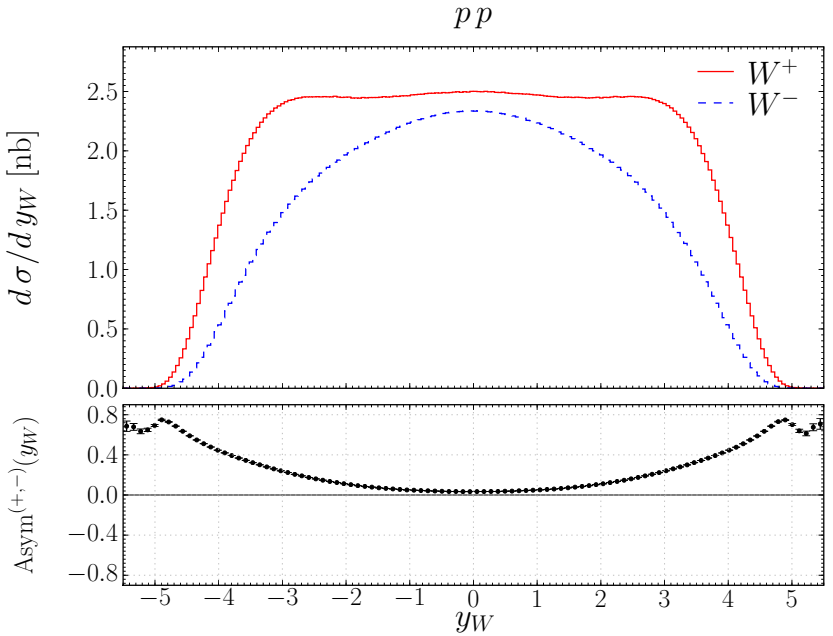


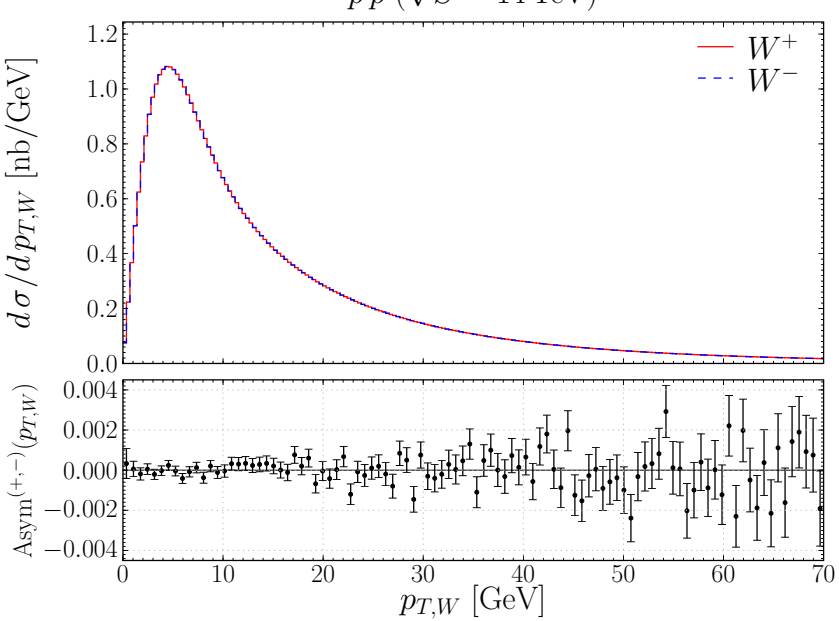


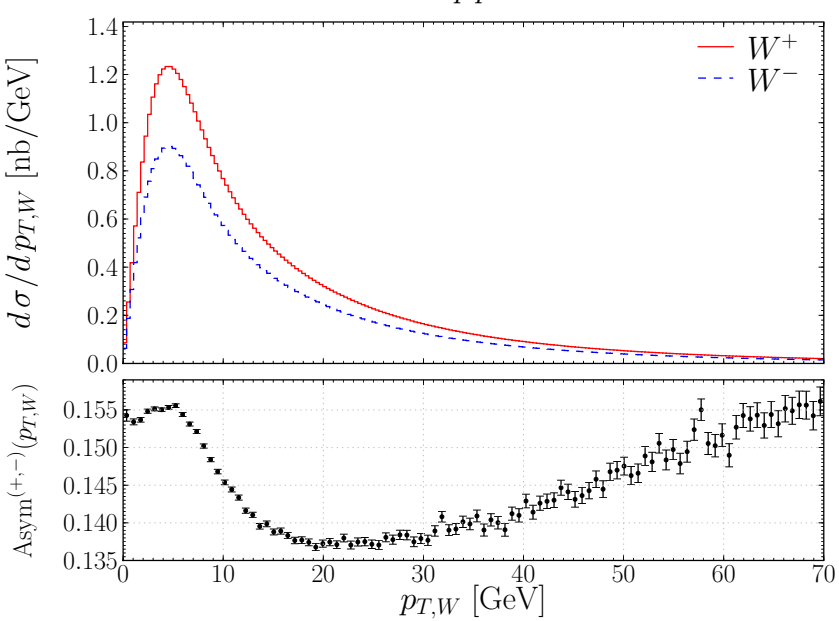
→ $\mathrm{Asym}^{(+,-)}(x) \equiv \frac{d\sigma^+/dx - d\sigma^-/dx}{d\sigma^+/dx + d\sigma^-/dx}$

$W^{\pm}$ production in $p\bar{p}$ & pp collisions

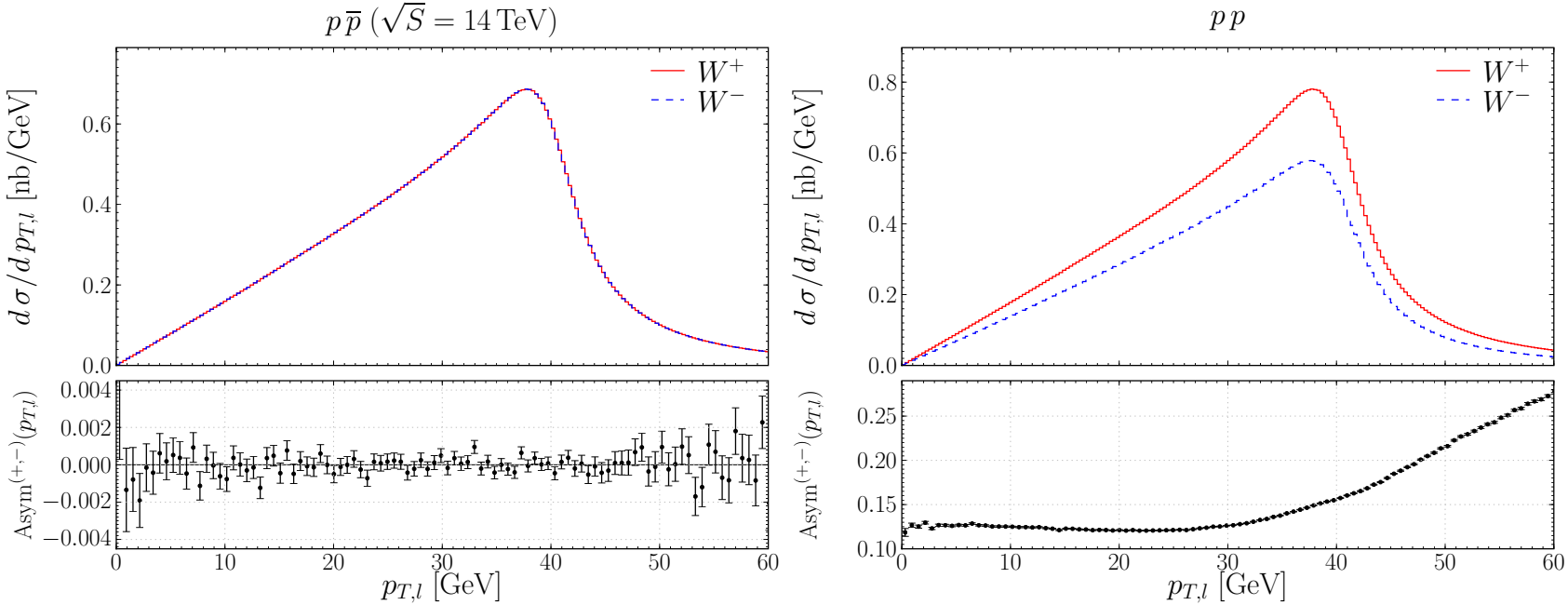








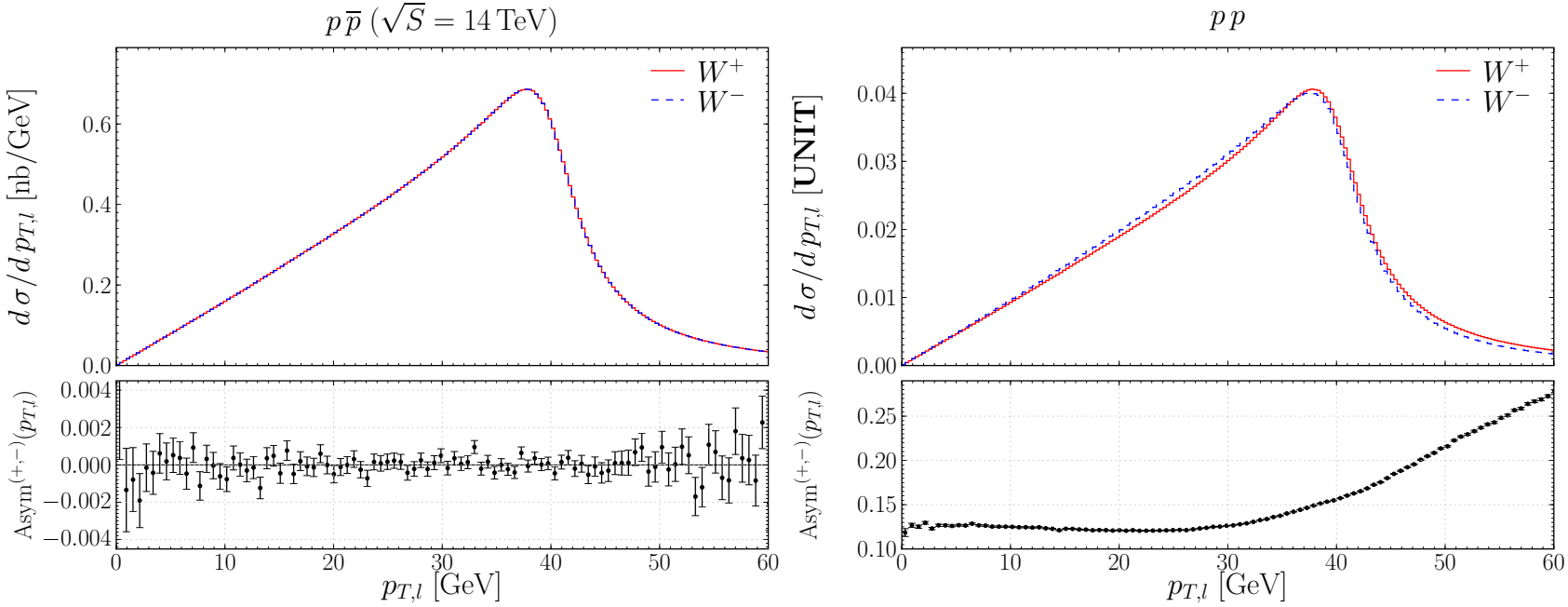
$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

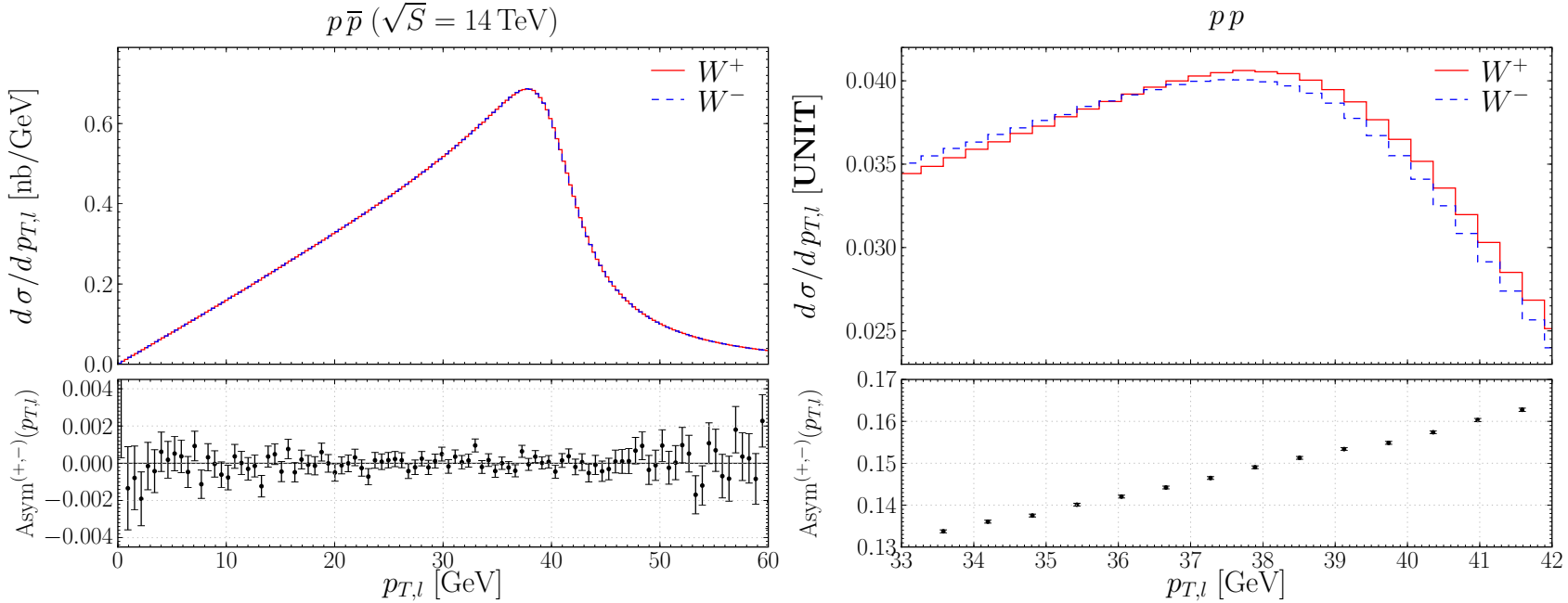
$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

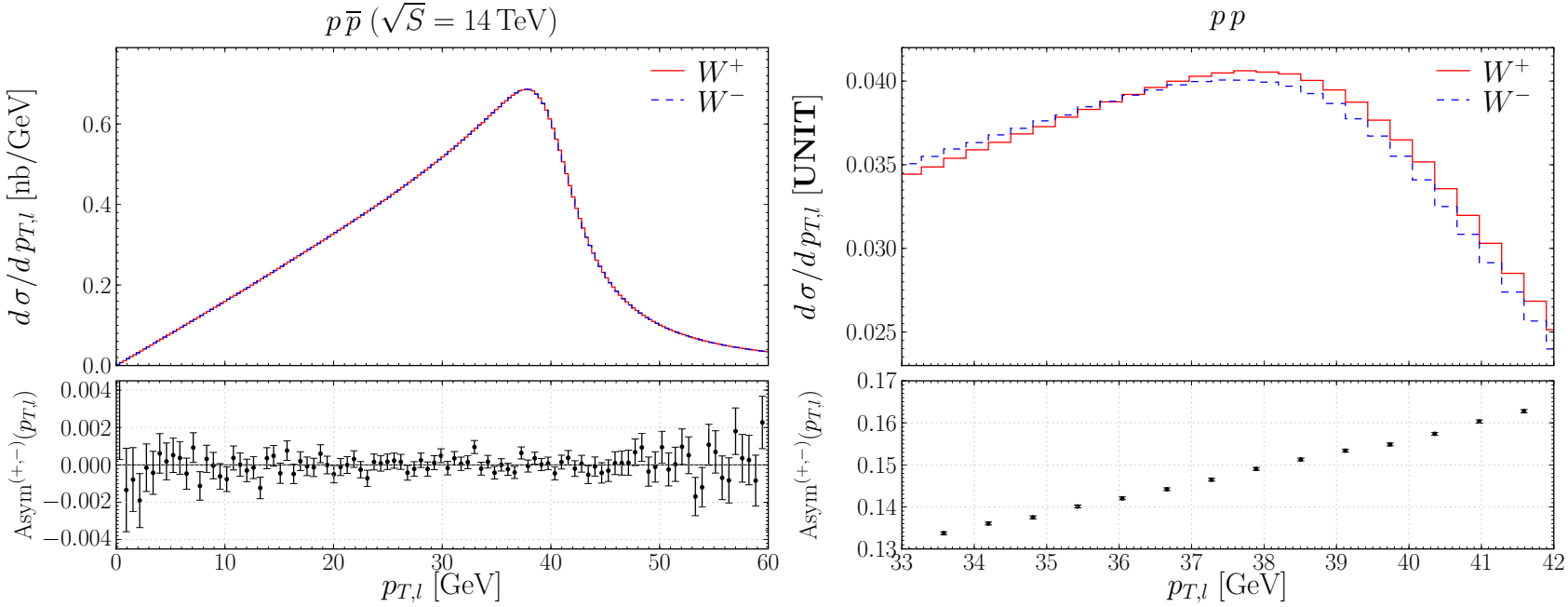
$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

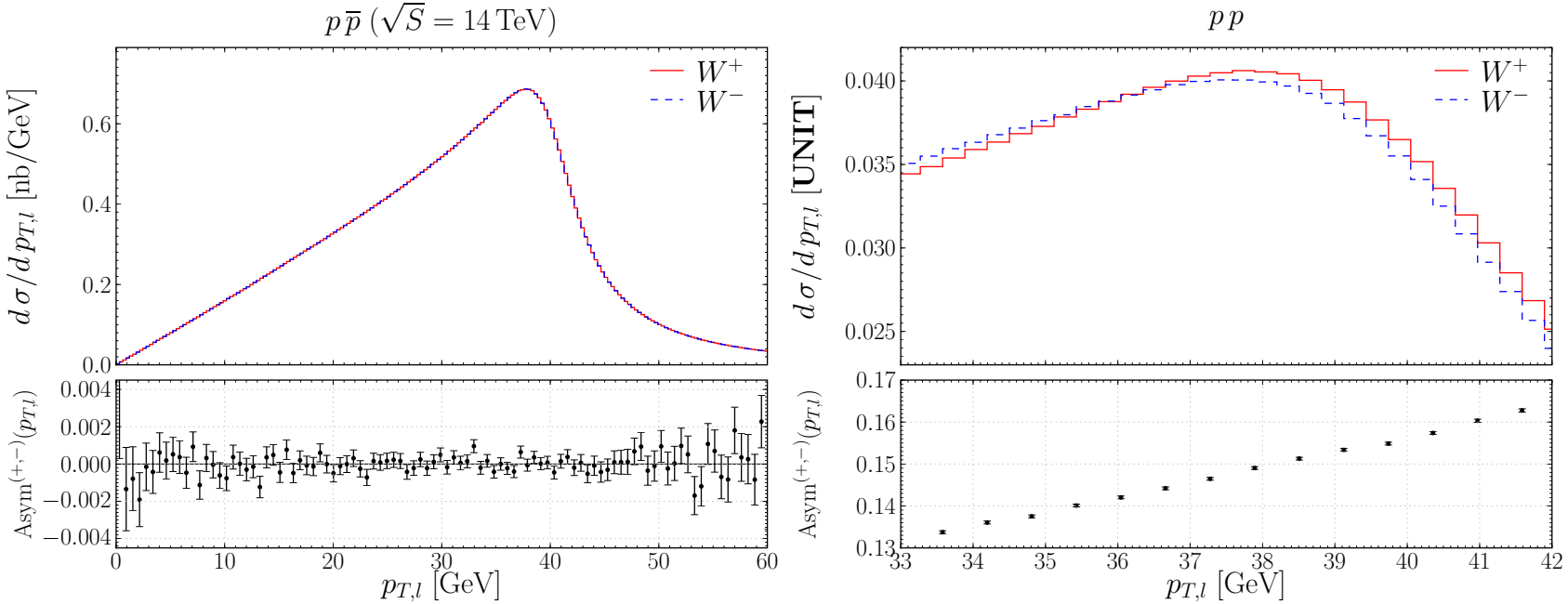
$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

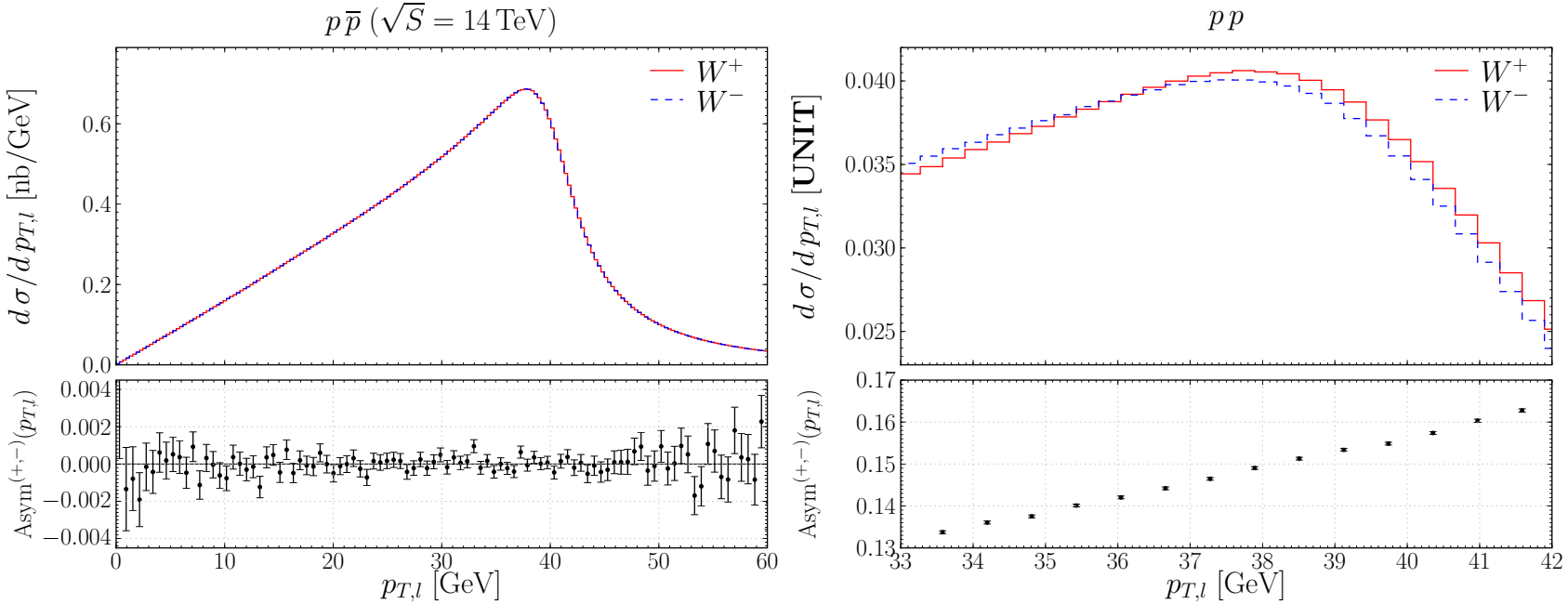
$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

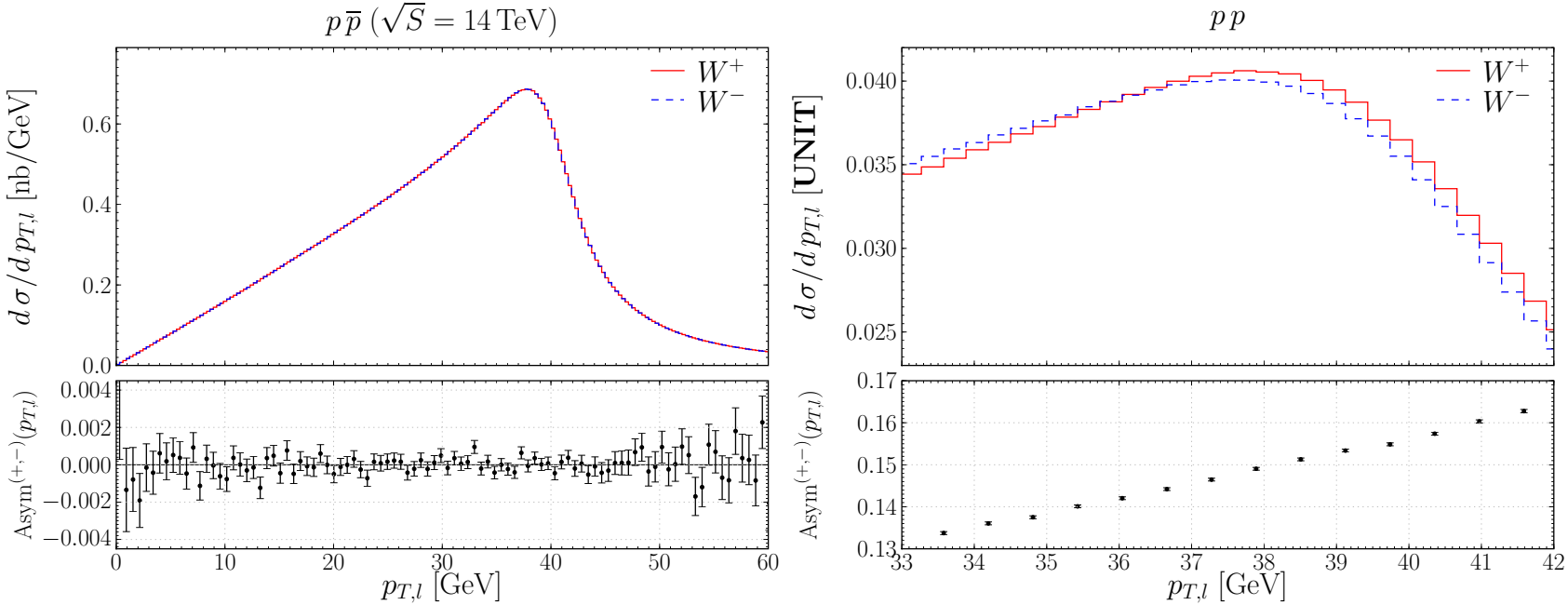
$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

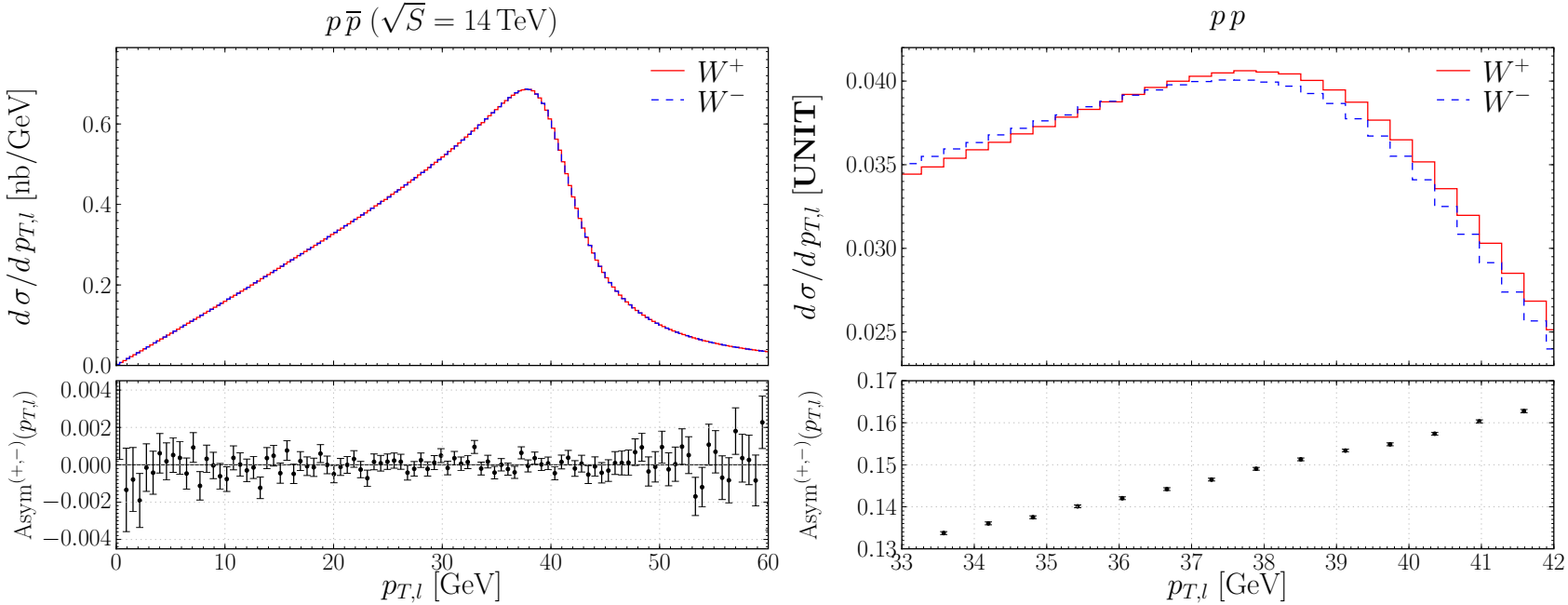
$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

$W^{\pm}$ decay for $p\bar{p}$ & pp collisions



Charge asymmetry at the LHC $= \bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two solutions :
    (1) M_{W+} & M_{W-}
    (2) $(M_{W+} + M_{W-})$ & $(M_{W+} - M_{W-})$

2. $M_{W^+} - M_{W^-}$ & M_W at the LHC

Addressed systematics errors in our studies

- Apparatus :
  - Energy Scale (ES)
    - $(\varepsilon_{l^+} + \varepsilon_{l^-}) \leftarrow J/\Psi,\ \Upsilon,\ Z$
    - $(\varepsilon_{l^+} - \varepsilon_{l^-}) \nleftarrow W^+,\ W^-$ **NEW!**
  - Track parameter reconstruction
- Phenomenology :
  - Quarks $\langle k_T \rangle$
  - PDF (global)
  - $u^{(\mathrm{v})} - d^{(\mathrm{v})}$
  - $s - c$
  - b (M_W)
- Analysis :
  - Monte Carlo : WINHAC[1] $(W \to e\,\nu_e,\ \mu\,\nu_\mu)$, ZINHAC $(Z \to e^+e^-,\ \mu^+\mu^-)$
  - $L = 10\,\mathrm{fb}^{-1}$, ATLAS tracker (*i.e.* $p_{T,l} > 20\,\mathrm{GeV}$ & $|\eta_l| < 2.5$)
  - $M_{W^+} \pm M_{W^-} \to$ Template method (χ^2)

[1] WINHAC : [Płaczek & Jadach, Eur. Phys. J. C**29**:325-339 (2003)]

Addressed systematics errors in our studies

- Apparatus :
  - Energy Scale (ES)
    - $(\varepsilon_{l^+} + \varepsilon_{l^-}) \leftarrow J/\Psi,\ \Upsilon,\ Z$
    - $(\varepsilon_{l^+} - \varepsilon_{l^-}) \nleftarrow W^+,\ W^-$ **NEW!**
  - Track parameter reconstruction

- Phenomenology :
  - Quarks $\langle k_T \rangle$
  - PDF (global)
  - $u^{(v)} - d^{(v)}$
  - $s - c$
  - b (M_W)

- Analysis :
  - Monte Carlo : WINHAC[1] $(W \to e\,\nu_e,\ \mu\,\nu_\mu)$, ZINHAC $(Z \to e^+e^-,\ \mu^+\mu^-)$
  - $L = 10\,\mathrm{fb}^{-1}$, ATLAS tracker (*i.e.* $p_{T,l} > 20\,\mathrm{GeV}$ & $|\eta_l| < 2.5$)
  - $M_{W^+} \pm M_{W^-} \to$ Template method (χ^2)

[1] WINHAC : [Płaczek & Jadach, Eur. Phys. J. C**29**:325-339 (2003)]

Addressed systematics errors in our studies

- Apparatus :
  - Energy Scale (ES)
    - $(\varepsilon_{l^+} + \varepsilon_{l^-}) \leftarrow J/\Psi,\ \Upsilon,\ Z$
    - $(\varepsilon_{l^+} - \varepsilon_{l^-}) \nleftarrow W^+,\ W^-$ **NEW!**
  - Track parameter reconstruction

- Phenomenology :
  - Quarks $\langle k_T \rangle$
  - PDF (global)
  - $u^{(v)} - d^{(v)}$
  - $s - c$
  - b (M_W)

- Analysis :
  - Monte Carlo : WINHAC[1] $(W \to e\,\nu_e,\ \mu\,\nu_\mu)$, ZINHAC $(Z \to e^+e^-,\ \mu^+\mu^-)$
  - $L = 10\,\mathrm{fb}^{-1}$, ATLAS tracker (*i.e.* $p_{T,l} > 20\,\mathrm{GeV}$ & $|\eta_l| < 2.5$)
  - $M_{W^+} \pm M_{W^-} \to$ Template method (χ^2)

[1] WINHAC : [Płaczek & Jadach, Eur. Phys. J. C**29**:325-339 (2003)]

Addressed systematics errors in our studies

- Apparatus :
  - Energy Scale (ES)
    - $(\varepsilon_{l^+} + \varepsilon_{l^-}) \leftarrow J/\Psi,\ \Upsilon,\ Z$
    - $(\varepsilon_{l^+} - \varepsilon_{l^-}) \nleftarrow W^+,\ W^-$ **NEW!**
  - Track parameter reconstruction

- Phenomenology :
  - Quarks $\langle k_T \rangle$
  - PDF (global)
  - $u^{(v)} - d^{(v)}$ **NEW!**
  - $s - c$ **NEW!**
  - b (M_W) **NEW!**

- Analysis :
  - Monte Carlo : WINHAC[1] $(W \to e\,\nu_e,\ \mu\,\nu_\mu)$, ZINHAC $(Z \to e^+e^-,\ \mu^+\mu^-)$
  - $L = 10\,\text{fb}^{-1}$, ATLAS tracker (*i.e.* $p_{T,l} > 20\,\text{GeV}$ & $|\eta_l| < 2.5$)
  - $M_{W^+} \pm M_{W^-} \to$ Template method (χ^2)

[1] WINHAC : [Płaczek & Jadach, Eur. Phys. J. C**29**:325-339 (2003)]

Addressed systematics errors in our studies

- Apparatus :
  - Energy Scale (ES)
    - $(\varepsilon_{l^+} + \varepsilon_{l^-}) \leftarrow J/\Psi,\ \Upsilon,\ Z$
    - $(\varepsilon_{l^+} - \varepsilon_{l^-}) \nleftarrow W^+,\ W^-$ **NEW!**
  - Track parameter reconstruction
- Phenomenology :
  - Quarks $\langle k_T \rangle$
  - PDF (global)
  - $u^{(\mathrm{v})} - d^{(\mathrm{v})}$ **NEW!**
  - $s - c$ **NEW!**
  - b (M_W) **NEW!**
- Analysis :
  - Monte Carlo : WINHAC[1] ($W \to e\,\nu_e,\ \mu\,\nu_\mu$), ZINHAC ($Z \to e^+e^-,\ \mu^+\mu^-$)
  - $L = 10\,\mathrm{fb}^{-1}$, ATLAS tracker (*i.e.* $p_{T,l} > 20\,\mathrm{GeV}$ & $|\eta_l| < 2.5$)
  - $M_{W^+} \pm M_{W^-} \rightarrow$ Template method (χ^2)

[1] WINHAC : [Płaczek & Jadach, Eur. Phys. J. C**29**:325-339 (2003)]

Addressed systematics errors in our studies

- Apparatus :
  - Energy Scale (ES)
    - $(\varepsilon_{l^+} + \varepsilon_{l^-}) \leftarrow J/\Psi,\ \Upsilon,\ Z$
    - $(\varepsilon_{l^+} - \varepsilon_{l^-}) \nleftarrow W^+,\ W^-$ **NEW!**
  - Track parameter reconstruction

- Phenomenology :
  - Quarks $\langle k_T \rangle$
  - PDF (global)
  - $u^{(\mathrm{v})} - d^{(\mathrm{v})}$ **NEW!**
  - $s - c$ **NEW!**
  - b (M_W) **NEW!**

- Analysis :
  - Monte Carlo : WINHAC[1] ($W \to e\,\nu_e,\ \mu\,\nu_\mu$), ZINHAC ($Z \to e^+e^-,\ \mu^+\mu^-$)
  - $L = 10\,\mathrm{fb}^{-1}$, ATLAS tracker (*i.e.* $p_{T,l} > 20\,\mathrm{GeV}$ & $|\eta_l| < 2.5$)
  - $M_{W^+} \pm M_{W^-} \rightarrow$ Template method (χ^2)

[1] WINHAC : [Płaczek & Jadach, Eur. Phys. J. C**29**:325-339 (2003)]

Size of the main and *new* systematic errors

- $M_{W+} - M_{W-}$ $\Rightarrow \chi^2 \left(\text{Asym}^{(+,-)} \left(p_{T,l} \right) \right)$
- $M_W \equiv \frac{1}{2}(M_{W+} + M_{W-})$ $\Rightarrow \chi^2 \left(R_{W/Z} \equiv \frac{W^+ + W^-}{Z} \right)$

Systematic	$\delta^{(\text{sys.})}_{M_{W+}-M_{W-}}$ [MeV]	$\delta^{(\text{sys.})}_{M_W}$ [MeV]
ES		
$u^{(\text{v})} - d^{(\text{v})}$		
$s - c$		

Size of the main and *new* systematic errors

- $M_{W+} - M_{W-} \Rightarrow \chi^2 \left(\mathrm{Asym}^{(+,-)} \left(p_{T,l} \right) \right)$
- $M_W \equiv \frac{1}{2}(M_{W+} + M_{W-}) \Rightarrow \chi^2 \left(R_{W/Z} \equiv \frac{W^+ + W^-}{Z} \right)$

Systematic		$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES	$\varepsilon_{l+} = +\varepsilon_{l-} = 0.5\,\%$		
	$\varepsilon_{l+} = -\varepsilon_{l-} = 0.5\,\%$		
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$			
$s - c$			

Size of the main and *new* systematic errors

- $M_{W+} - M_{W-} \Rightarrow \chi^2 \left(\mathrm{Asym}^{(+,-)} \left(p_{T,l} \right) \right)$
- $M_W \equiv \frac{1}{2}(M_{W+} + M_{W-}) \Rightarrow \chi^2 \left(R_{W/Z} \equiv \frac{W^+ + W^-}{Z} \right)$

Systematic		$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES	$\varepsilon_{l+} = +\varepsilon_{l-} = 0.5\,\%$	7	200
	$\varepsilon_{l+} = -\varepsilon_{l-} = 0.5\,\%$	-550	40

$u^{(\mathrm{v})} - d^{(\mathrm{v})}$

$s - c$

Size of the main and *new* systematic errors

- $M_{W+} - M_{W-} \Rightarrow \chi^2 \left(\mathrm{Asym}^{(+,-)} \left(p_{T,l} \right) \right)$
- $M_W \equiv \frac{1}{2}(M_{W+} + M_{W-}) \Rightarrow \chi^2 \left(R_{W/Z} \equiv \frac{W^+ + W^-}{Z} \right)$

Systematic		$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES	$\varepsilon_{l+} = +\varepsilon_{l-} = 0.5\,\%$	7	200
	$\varepsilon_{l+} = -\varepsilon_{l-} = 0.5\,\%$	-550	40

$u^{(\mathrm{v})} - d^{(\mathrm{v})}$

$u^{(\mathrm{v})}_{\mathrm{max}} = 1.05\, u^{(\mathrm{v})}$

$d^{(\mathrm{v})}_{\mathrm{min}} = d^{(\mathrm{v})} - 0.05\, u^{(\mathrm{v})}$

$s - c$

Size of the main and *new* systematic errors

- $M_{W+} - M_{W-}$ $\Rightarrow \chi^2 \left(\mathrm{Asym}^{(+,-)}\left(p_{T,l}\right) \right)$
- $M_W \equiv \frac{1}{2}(M_{W+} + M_{W-})$ $\Rightarrow \chi^2 \left(R_{W/Z} \equiv \frac{W^+ + W^-}{Z} \right)$

Systematic		$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES	$\varepsilon_{l+} = +\varepsilon_{l-} = 0.5\,\%$	7	200
	$\varepsilon_{l+} = -\varepsilon_{l-} = 0.5\,\%$	-550	40
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$	$u^{(\mathrm{v})}_{\mathrm{max}} = 1.05\, u^{(\mathrm{v})}$ $d^{(\mathrm{v})}_{\mathrm{min}} = d^{(\mathrm{v})} - 0.05\, u^{(\mathrm{v})}$	130	80
$s - c$			

Size of the main and *new* systematic errors

- $M_{W+} - M_{W-} \Rightarrow \chi^2 \left(\mathrm{Asym}^{(+,-)} \left(p_{T,l} \right) \right)$
- $M_W \equiv \frac{1}{2}(M_{W+} + M_{W-}) \Rightarrow \chi^2 \left(R_{W/Z} \equiv \frac{W^+ + W^-}{Z} \right)$

	Systematic	$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES	$\varepsilon_{l+} = +\varepsilon_{l-} = 0.5\,\%$	7	200
	$\varepsilon_{l+} = -\varepsilon_{l-} = 0.5\,\%$	-550	40
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$	$u^{(\mathrm{v})}_{\mathrm{max}} = 1.05\, u^{(\mathrm{v})}$ $d^{(\mathrm{v})}_{\mathrm{min}} = d^{(\mathrm{v})} - 0.05\, u^{(\mathrm{v})}$	130	80
$s - c$	$c_{\mathrm{max}} = 1.1\, c$ $s_{\mathrm{min}} = s - 0.1\, c$		

Size of the main and *new* systematic errors

- $M_{W+} - M_{W-} \Rightarrow \chi^2 \left(\mathrm{Asym}^{(+,-)} \left(p_{T,l} \right) \right)$
- $M_W \equiv \frac{1}{2}(M_{W+} + M_{W-}) \Rightarrow \chi^2 \left(R_{W/Z} \equiv \frac{W^+ + W^-}{Z} \right)$

	Systematic	$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES	$\varepsilon_{l+} = +\varepsilon_{l-} = 0.5\,\%$	7	200
	$\varepsilon_{l+} = -\varepsilon_{l-} = 0.5\,\%$	-550	40
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$	$u^{(\mathrm{v})}_{\mathrm{max}} = 1.05\, u^{(\mathrm{v})}$ $d^{(\mathrm{v})}_{\mathrm{min}} = d^{(\mathrm{v})} - 0.05\, u^{(\mathrm{v})}$	130	80
$s - c$	$c_{\mathrm{max}} = 1.1\, c$ $s_{\mathrm{min}} = s - 0.1\, c$	-15	-100

Prospect for $M_{W+} - M_{W-}$

- Starting $\text{Asym}^{(+,-)}\,(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\text{sys.})}_{M_{W+}-M_{W-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)		
	$u^{(\text{v})} - d^{(\text{v})}$	
	$s - c$	

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \to -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for $M_{W+} - M_{W-}$

- Starting $\text{Asym}^{(+,-)}\,(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\text{sys.})}_{M_{W+}-M_{W-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)		
	$u^{(\text{v})} - d^{(\text{v})}$	
	$s - c$	

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \to -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for $M_{W+} - M_{W-}$

- Starting $\mathrm{Asym}^{(+,-)}(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)	$\mathrm{Asym}^{(+,-)}_{\vec{B}}(p_{T,l}) + \mathrm{Asym}^{(+,-)}_{-\vec{B}}(p_{T,l})$	$-550 \to 5$
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$		
$s - c$		

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \to -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for $M_{W+} - M_{W-}$

- Starting $\text{Asym}^{(+,-)}(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\text{sys.})}_{M_{W+}-M_{W-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)	$\text{Asym}^{(+,-)}_{\vec{B}}(p_{T,l}) + \text{Asym}^{(+,-)}_{-\vec{B}}(p_{T,l})$	$-550 \rightarrow 5$
$u^{(\text{v})} - d^{(\text{v})}$	$\lvert\eta_l\rvert < 0.3$ ($L = 100\,\text{fb}^{-1}$)	$130 \rightarrow 70$
$s - c$		

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \rightarrow -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for $M_{W^+} - M_{W^-}$

- Starting $\mathrm{Asym}^{(+,-)}\,(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_{W^+}-M_{W^-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)	$\mathrm{Asym}^{(+,-)}_{\vec{B}}\,(p_{T,l}) + \mathrm{Asym}^{(+,-)}_{-\vec{B}}\,(p_{T,l})$	$-550 \to 5$
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$	$\lvert\eta_l\rvert < 0.3$ ($L = 100\,\mathrm{fb}^{-1}$)	$130 \to 70$
	$d\,d$ ($\sqrt{S_{nn}} = 7\,\mathrm{TeV}$)	$130 \to 4$
$s - c$		

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \to -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for $M_{W+} - M_{W-}$

- Starting $\text{Asym}^{(+,-)}\,(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\text{sys.})}_{M_{W+}-M_{W-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)	$\text{Asym}^{(+,-)}_{\vec{B}}\,(p_{T,l}) + \text{Asym}^{(+,-)}_{-\vec{B}}\,(p_{T,l})$	$-550 \to 5$
$u^{(\text{v})} - d^{(\text{v})}$	$\lvert\eta_l\rvert < 0.3$ ($L = 100\,\text{fb}^{-1}$)	$130 \to 70$
	$d\,d$ ($\sqrt{S_{nn}} = 7\,\text{TeV}$)	$130 \to 4$
$s - c$	$\lvert y_W\rvert < 0.3$ ($L = 100\,\text{fb}^{-1}$)	$-15 \to -1$

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \to -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for $M_{W+} - M_{W-}$

- Starting $\mathrm{Asym}^{(+,-)}(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)	$\mathrm{Asym}^{(+,-)}_{\vec{B}}(p_{T,l}) + \mathrm{Asym}^{(+,-)}_{-\vec{B}}(p_{T,l})$	$-550 \to 5$
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$	$\lvert\eta_l\rvert < 0.3$ ($L = 100\,\mathrm{fb}^{-1}$)	$130 \to 70$
	$d\,d$ ($\sqrt{S_{nn}} = 7\,\mathrm{TeV}$)	$130 \to 4$
$s - c$	$\lvert y_W\rvert < 0.3$ ($L = 100\,\mathrm{fb}^{-1}$)	$-15 \to -1$

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \to -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for $M_{W+} - M_{W-}$

- Starting $\mathrm{Asym}^{(+,-)}\,(p_{T,l})$ results

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_{W+}-M_{W-}}$ [MeV]
ES ($\varepsilon_{l+} = -\varepsilon_{l-}$)	$\mathrm{Asym}^{(+,-)}_{\vec{B}}\,(p_{T,l}) + \mathrm{Asym}^{(+,-)}_{-\vec{B}}\,(p_{T,l})$	$-550 \to 5$
$u^{(\mathrm{v})} - d^{(\mathrm{v})}$	$\lvert\eta_l\rvert < 0.3$ ($L = 100\,\mathrm{fb}^{-1}$)	$130 \to 70$
	$d\,d$ ($\sqrt{S_{nn}} = 7\,\mathrm{TeV}$)	$130 \to 4$
$s - c$	$\lvert y_W\rvert < 0.3$ ($L = 100\,\mathrm{fb}^{-1}$)	$-15 \to -1$

- Further details : arXiv:0812.2571 [hep-ph], arXiv:0906.4260 [hep-ex]
- $\vec{B} \to -\vec{B}$ & $d\,d$ delicate $\Rightarrow$ alternative methods

Prospect for M_W

- Starting from $R_{W/Z}$, making Z "QCD-identical" to W
  - For W, change $\sqrt{S}$ & $|\vec{B}|$ by a factor $M_W/M_Z \Rightarrow R^{\mathrm{c}}_{W/Z}$

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES ($\varepsilon_{l^+} = +\varepsilon_{l^-}$)	$R^{\mathrm{c}}_{W/Z}$	$200 \rightarrow 5$

- $R^{\mathrm{c}}_{W/Z} \times C_{\mathrm{QCD}}$
  - $\langle k_T \rangle \Rightarrow$ OK
  - PDFs $\Rightarrow$ *no enhancement*

- Further details : Krasny *et al.*, Eur. Phys. J. C**51**:607-617 (2007)

Prospect for M_W

- Starting from $R_{W/Z}$, making Z "QCD-identical" to W
  - For W, change $\sqrt{S}$ & $|\vec{B}|$ by a factor $M_W/M_Z \Rightarrow R^{\mathrm{c}}_{W/Z}$

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES ($\varepsilon_{l^+} = +\varepsilon_{l^-}$)	$R^{\mathrm{c}}_{W/Z}$	$200 \rightarrow 5$

- $R^{\mathrm{c}}_{W/Z} \times C_{\mathrm{QCD}}$
  - $\langle k_T \rangle \Rightarrow$ OK
  - PDFs $\Rightarrow$ *no enhancement*

- Further details : Krasny *et al.*, Eur. Phys. J. C**51**:607-617 (2007)

Prospect for M_W

- Starting from $R_{W/Z}$, making Z "QCD-identical" to W
  - For W, change $\sqrt{S}$ & $|\vec{B}|$ by a factor $M_W/M_Z \Rightarrow R^{\mathrm{c}}_{W/Z}$

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES ($\varepsilon_{l^+} = +\varepsilon_{l^-}$)	$R^{\mathrm{c}}_{W/Z}$	$200 \rightarrow 5$

- $R^{\mathrm{c}}_{W/Z} \times C_{\mathrm{QCD}}$
  - $\langle k_T \rangle \Rightarrow$ OK
  - PDFs $\Rightarrow$ *no enhancement*

- Further details : Krasny *et al.*, Eur. Phys. J. C**51**:607-617 (2007)

Prospect for M_W

- Starting from $R_{W/Z}$, making Z "QCD-identical" to W
  - For W, change $\sqrt{S}$ & $|\vec{B}|$ by a factor $M_W/M_Z \Rightarrow R^{\mathrm{c}}_{W/Z}$

Systematic	Strategies/observables	$\delta^{(\mathrm{sys.})}_{M_W}$ [MeV]
ES ($\varepsilon_{l^+} = +\varepsilon_{l^-}$)	$R^{\mathrm{c}}_{W/Z}$	$200 \rightarrow 5$

- $R^{\mathrm{c}}_{W/Z} \times C_{\mathrm{QCD}}$
  - $\langle k_T \rangle \Rightarrow$ OK
  - PDFs $\Rightarrow$ *no enhancement*

- Further details : Krasny *et al.*, Eur. Phys. J. C**51**:607-617 (2007)

Alternative methods for ES & PDFs sys.

- ES: "Z^+" ($Z \to l^+ l^-$) & "Z^-"($Z \to l^+ l^-$) $\Rightarrow \varepsilon_{l+} - \varepsilon_{l-}$
- PDFs: Dedicated μ DIS experiment (SPS) [LOI, Dydak & Krasny]

Systematic	Expected precision [%]	$\delta^{(\text{sys.})}_{M_{W^+}-M_{W^-}}$ [MeV]
"$\varepsilon_{l+} - \varepsilon_{l-}$"	0.01	10
"$u^{(\text{v})}/d^{(\text{v})}$"	1	25
"$s - c$"	2	< 5

Systematic	Expected precision [%]	$\delta^{(\text{sys.})}_{M_W}$ [MeV]
"$\varepsilon_{l+} - \varepsilon_{l-}$"	0.2	8
"$u^{(\text{v})}/d^{(\text{v})}$"	1	12
"$s - c$"	1	10

Alternative methods for ES & PDFs sys.

- ES: "Z^+" ($Z \to l^+l^-$) & "Z^-"($Z \to l^+l^-$) $\Rightarrow \varepsilon_{l+} - \varepsilon_{l-}$
- PDFs: Dedicated μ DIS experiment (SPS) [LOI, Dydak & Krasny]

Systematic	Expected precision [%]	$\delta^{(\text{sys.})}_{M_{W^+}-M_{W^-}}$ [MeV]
"$\varepsilon_{l+} - \varepsilon_{l-}$"	0.01	10
"$u^{(\text{v})}/d^{(\text{v})}$"	1	25
"$s - c$"	2	< 5

Systematic	Expected precision [%]	$\delta^{(\text{sys.})}_{M_W}$ [MeV]
"$\varepsilon_{l+} - \varepsilon_{l-}$"	0.2	8
"$u^{(\text{v})}/d^{(\text{v})}$"	1	12
"$s - c$"	1	10

Alternative methods for ES & PDFs sys.

- ES: "Z^+" ($Z \to l^+l^-$) & "Z^-"($Z \to l^+l^-$) $\Rightarrow \varepsilon_{l+} - \varepsilon_{l-}$
- PDFs: Dedicated μ DIS experiment (SPS) [LOI, Dydak & Krasny]

Systematic	Expected precision [%]	$\delta^{(\text{sys.})}_{M_{W^+}-M_{W^-}}$ [MeV]
"$\varepsilon_{l+} - \varepsilon_{l-}$"	0.01	10
"$u^{(\text{v})}/d^{(\text{v})}$"	1	25
"$s - c$"	2	< 5

Systematic	Expected precision [%]	$\delta^{(\text{sys.})}_{M_W}$ [MeV]
"$\varepsilon_{l+} - \varepsilon_{l-}$"	0.2	8
"$u^{(\text{v})}/d^{(\text{v})}$"	1	12
"$s - c$"	1	10

4. Conclusion

Summary

- Tevatron : $W^+ \overset{CP}{\Longleftrightarrow} W^-$ $\Rightarrow$ Precision measurement for M_W
- LHC : $W^+ \overset{CP}{\not\Longleftrightarrow} W^-$
  - Loss of symmetry $\Rightarrow$ *New important* sources of $\delta^{(\text{sys.})}$ (*e.g.* PDFs)
- Solutions :
  - ES $(\varepsilon_{l^+} - \varepsilon_{l^-})$:
    (1) "Z^+" & "Z^+", or...
    (2) $\vec{B} \to -\vec{B}$
  - Improve valence sector knowledge :
    (1) Muon DIS (SPS), or...
    (2) $d\,d$ LHC-runs

FINAL WARNING : These problems will have to be considered in other LHC processes (*e.g.* single top)

Summary

- Tevatron : $W^+ \overset{CP}{\Longleftrightarrow} W^-$ $\Rightarrow$ Precision measurement for M_W
- LHC : $W^+ \overset{CP}{\not\Longleftrightarrow} W^-$
  - Loss of symmetry $\Rightarrow$ *New important* sources of $\delta^{(\text{sys.})}$ (*e.g.* PDFs)
- Solutions :
  - ES $(\varepsilon_{l^+} - \varepsilon_{l^-})$:
    (1) "Z^+" & "Z^+", or...
    (2) $\vec{B} \to -\vec{B}$
  - Improve valence sector knowledge :
    (1) Muon DIS (SPS), or...
    (2) $d\,d$ LHC-runs

FINAL WARNING : These problems will have to be considered in other LHC processes (*e.g.* single top)

References

- WINHAC : Płaczek & Jadach, Eur. Phys. J. C**29**:325-339 (2003)

- $M_{W^+} - M_{W^-}$:
  - arXiv:0812.2571 [hep-ph] (submitted to EPJ C)
  - arXiv:0906.4260 [hep-ex] (Ph.D., F.F.)
  - `http://lpnhe-atlas.in2p3.fr/Atlas/Contacts/fayette/talks/`

- M_W :
  - Making Z "QCD identical" to W, Krasny *et al.*, Eur. Phys. J. C**51**:607-617 (2007)
  - M_W paper : to be submitted to EPJ C

- Muon DIS at the SPS : Letter of Intent, F. Dydak & M.W. Krasny (in preparation)