Calcolo della sezione d'urto di produzione di bosoni W ad LHC, da scattering singolo e doppio

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MPI workshop, 24/3/16

♡ ♡ Bruxelles ♡ ♡

Outlook

- W production in hadronic collisions : theory, briefly
- Benchmarks of the code for single W production vs other codes
  - How well does it work the LO approx vs data
  - How predictions based on Hadronic Model pdfs compare with MSTW08 ones
- First estimate of same-sign W's production cross section
- Perspectives and other channels

Decay kinematics in W rest frame

- $pp \to W^{\pm}(\to l^{\pm} \overset{(-)}{\nu})X$
- W rest frame $\equiv$ partonic centre of mass $(x_a = x_b = 1)$
- D-type = d,s,b; U-type = u,c,t
- θ^*_{lD} is the angle between the charged lepton and D-type quark
- partonic subprocesses : $U\bar{D} \to l^+\nu$ and $D\bar{U} \to l^-\bar{\nu}$

$$\frac{1}{\sigma_{U\bar{D}}}\frac{d\sigma_{U\bar{D}}}{d\cos\theta^*_{lD}} = \frac{1}{\sigma_{D\bar{U}}}\frac{d\sigma_{D\bar{U}}}{d\cos\theta^*_{lD}} = \frac{3}{8}(1+\cos\theta^*_{lD})^2$$

- helicity conservation:
  l^+ follows the direct $\bar{D}$ direction, l^- follows the direct D direction

$$E^*_T = E^* \sin\theta^*_{lD} = \frac{M_W}{2}\sin\theta^*_{lD}, \qquad E^{max}_T = \frac{M_W}{2}$$

- E_T invariant for longitudinal boost: $E_T = E^*_T$

kinematics detail

- W rapidity $y_W = \frac{1}{2} \ln \frac{x_a}{x_b}$
- neutrino unobserved $\rightarrow$ W rapidity under-determined
- $A = M_W/(2E_T)$, $B = \sqrt{1 - 1/A^2}$

$$\eta_l = y_W + \frac{1}{2} \ln \frac{1 \pm B}{1 \mp B}$$

- twofold ambiguity in the determination of W rapidity and hence in x_a and x_b
- Motivation : for a given E_T and η, 2 possible y_W's

$$x_a = e^{\eta} \frac{M_W}{\sqrt{s}} (A \pm \sqrt{A^2 - 1}) \qquad x_b = e^{-\eta} \frac{M_W}{\sqrt{s}} (A \mp \sqrt{A^2 - 1})$$

- Lorentz invariants u, t read in terms of η and E_T

$$t = (p_a - p_l)^2 = -x_a \sqrt{s} E_T e^{-\eta}, u = (p_b - p_l)^2 = -x_b \sqrt{s} E_T e^{\eta}$$

Cross sections

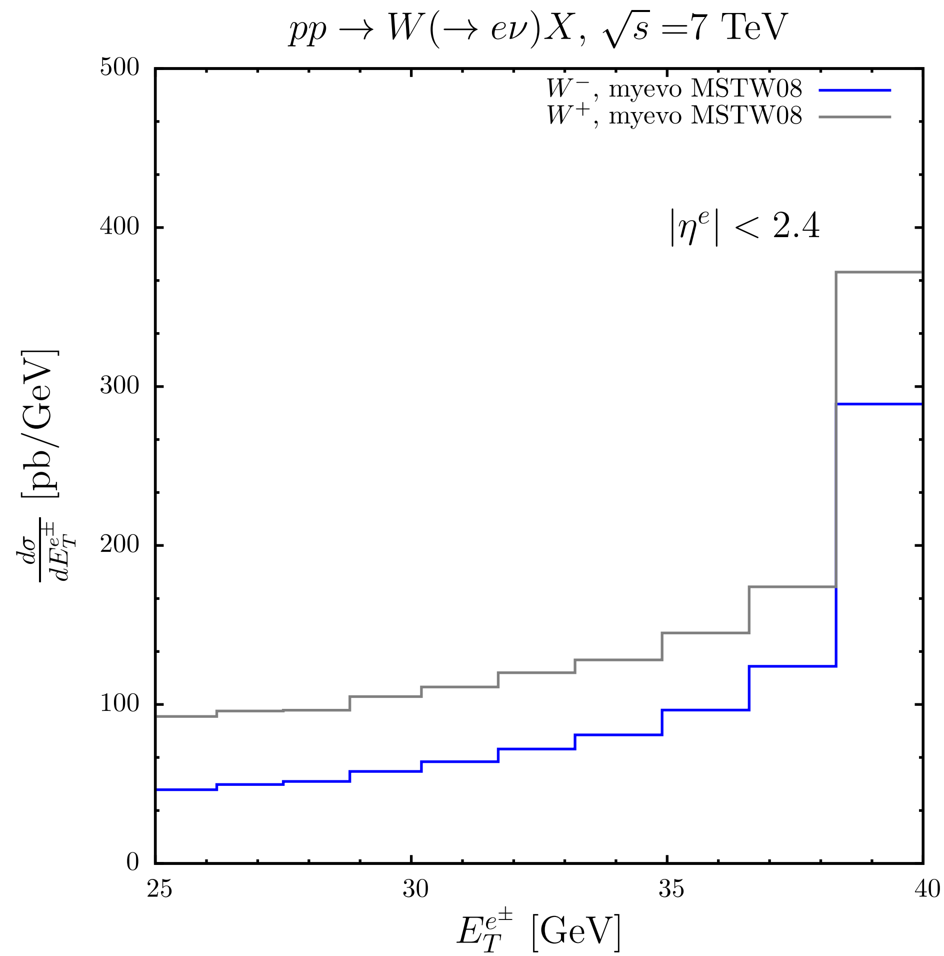
- Neglect here Cabibbo suppressed contributions
- narrow width approx (NWA): $\hat{s} = M_W$
- $A = M_W/(2E_T)$
- D = d,s,b; U=u,c,t
- EW currents: partonic subprocesses not P invariant, but hadronic initial state (pp) is $\rightarrow$ final distribution (summed over partonic channels) is symmetric in rapidity
- σ differential in lepton rapidity and transverse momentum (neutrino unobserved)

$$\frac{d^2\sigma^{pp\rightarrow W^-(\rightarrow l^-\bar{\nu})X}}{d\eta dE_T} = \frac{G_F^2}{6s\Gamma_W}\frac{1}{\sqrt{A^2-1}}V_{D\bar{U}}^2\left[f_D(x_a)f_{\bar{U}}(x_b)u^2 + f_{\bar{U}}(x_a)f_D(x_b)t^2\right]$$

$$\frac{d^2\sigma^{pp\rightarrow W^+(\rightarrow l^+\nu)X}}{d\eta dE_T} = \frac{G_F^2}{6s\Gamma_W}\frac{1}{\sqrt{A^2-1}}V_{U\bar{D}}^2\left[f_U(x_a)f_{\bar{D}}(x_b)t^2 + f_{\bar{D}}(x_a)f_U(x_b)u^2\right]$$

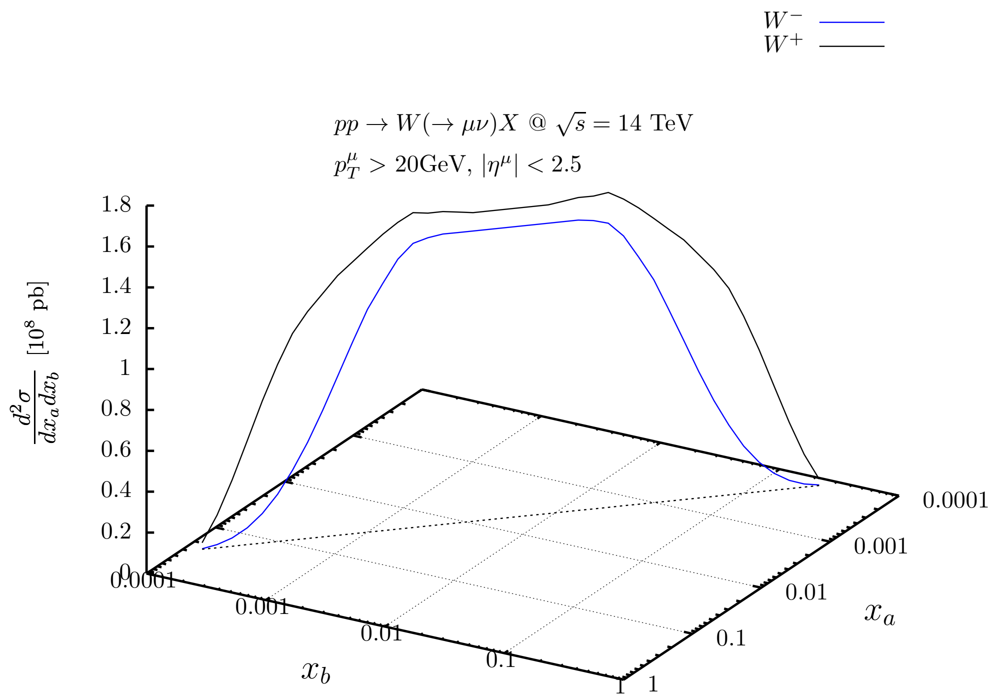
E_T distribution, jacobian peak

- change from $(x_a, x_b) \to (\eta, E_T)$
- $A = M_W/(2E_T)$
- $E_T^{max} = M_W/2$
- $d\sigma \propto \frac{1}{\sqrt{A^2-1}}$



(x_a, x_b) coverage

- Useful input for x-grids for double parton distributions
- NWA $\rightarrow \hat{s} = M_W^2 \rightarrow x_a x_b = M_W^2/s$



Benchmark with DYNNLO

- DYNNLO code (Catani & al.) vs mycode for SPS $pp \to W(\to l\nu)X$ production
- Basic settings and cuts:
  - $\sqrt{s} = 7$ TeV, $E_T^l > 25$ GeV, $|\eta^l| < 2.4$
  - $\mu_F = M_W$, LO, NWA, MSTW08LO PDFs, $n_f = 5$ active flavours
  - No lepton isolation cut, No $\not{E}_T$ cut (both redundant at LO)
  - EW parameters from PDG'12 (as in DYNNLO).

cross section (fiducial)	DYNNLO [pb]	Mycode [pb]
$\sigma^{W^+(\to l^+\nu)}$	2536.9 $\pm$ 0.3	2524
$\sigma^{W^-(\to l^-\bar{\nu})}$	1668.8 $\pm$ 0.2	1658

- Agreement at the level of 1% top

Accuracy and grids

- Study η (linear) and E_T (power) grids size
- $\sigma(W^+)$ cross section as case study

nET / neta	10	10^2	10^3	10^4	10^5
10	2404	2498	2526	2535	2538
10^2	2402	2495	2524	2532	*
10^3	2402	2495	2524	*	*

- η dependence flat (c.f.r. distributions)
- $\sigma(10 \times 10^4)$ in agreement with DYNNLO at 0.1%

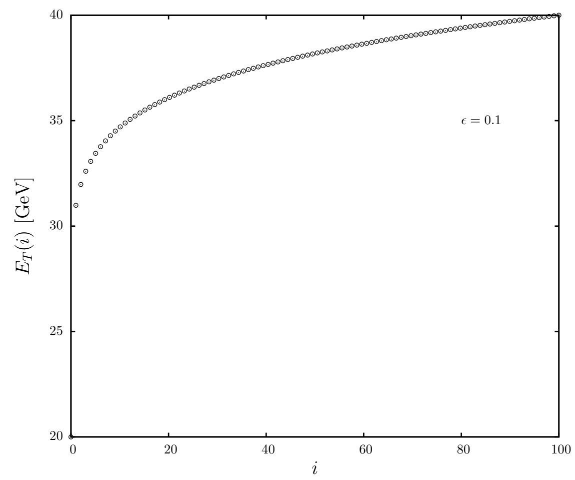
E_T-integration grid optimisation

- set : neta=10, nET=10^3, $\sigma^{W^+}(\epsilon = 0.33) = 2526$ [pb]

$$E_T(i) = E_T^{min} \left[\frac{E_T^{max}}{E_T^{min}} \right]^{(i/nET)^{\epsilon}}$$

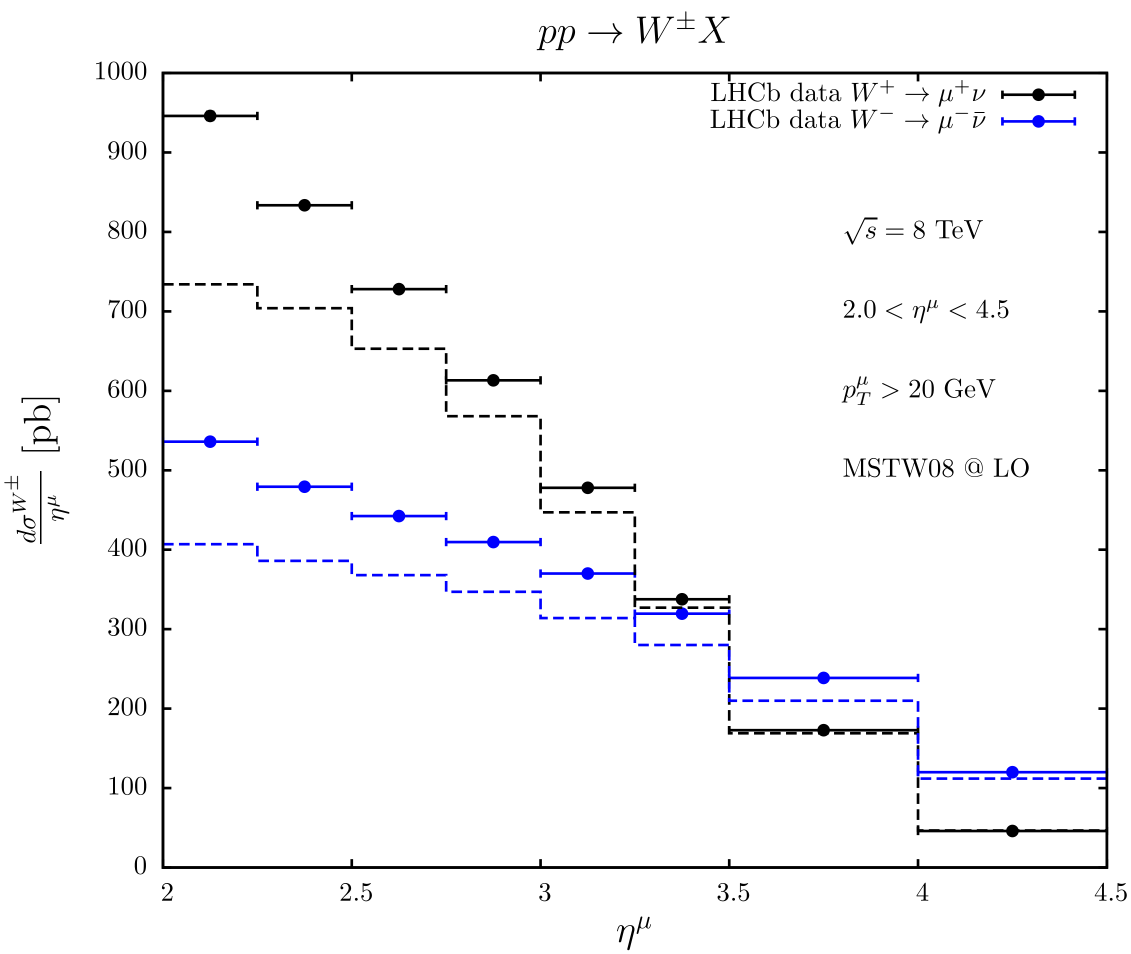
- $\epsilon < 1 \rightarrow$ more points around E_T^{max} (Jaco peak)

ϵ	σ^{W^+} [pb]
1.00	2516
0.50	2523
0.33	2526
0.25	2528
0.10	2530
0.05	2517



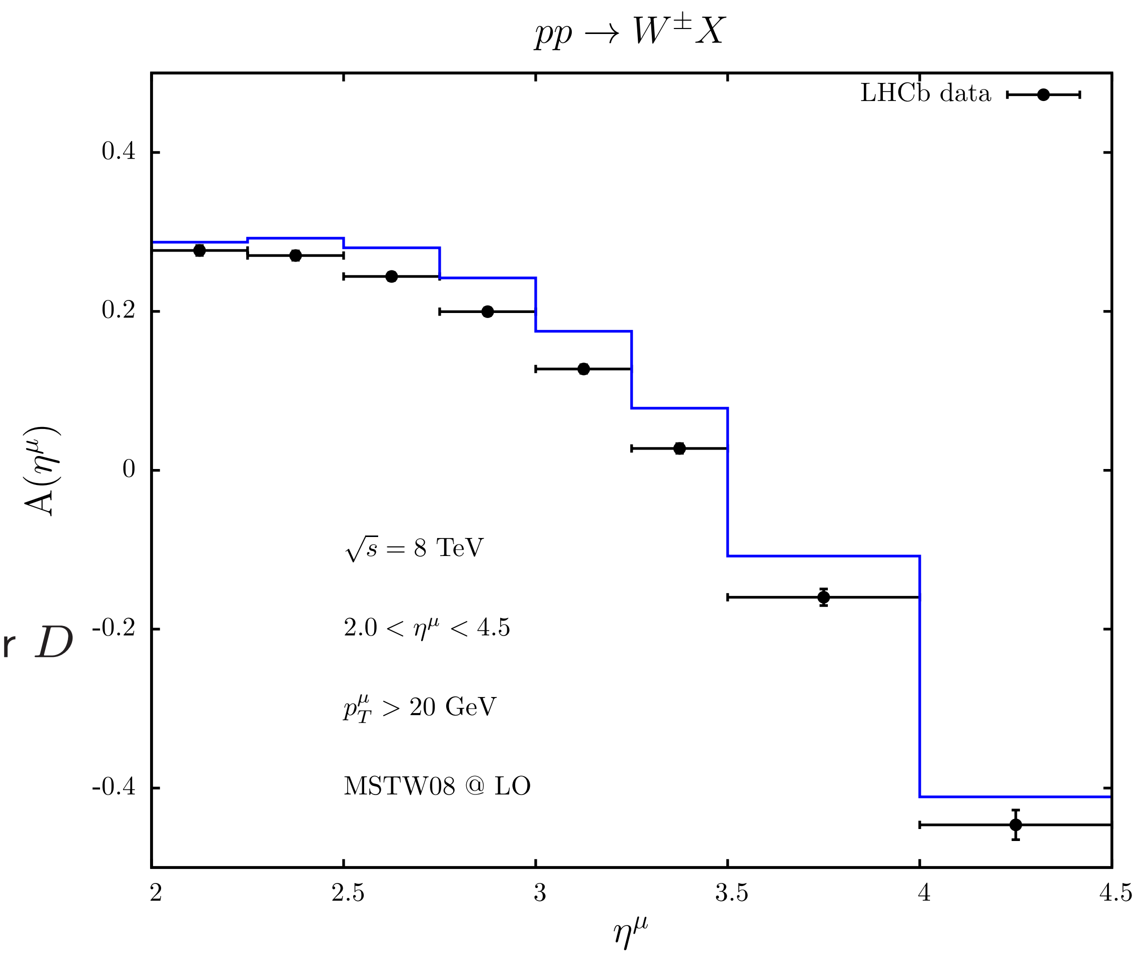
Charged lepton distributions, LHCb

- LHCb, JHEP01 (2016) 155
- Missing strenght
  at mid-rapidity
- 25% in the first bin



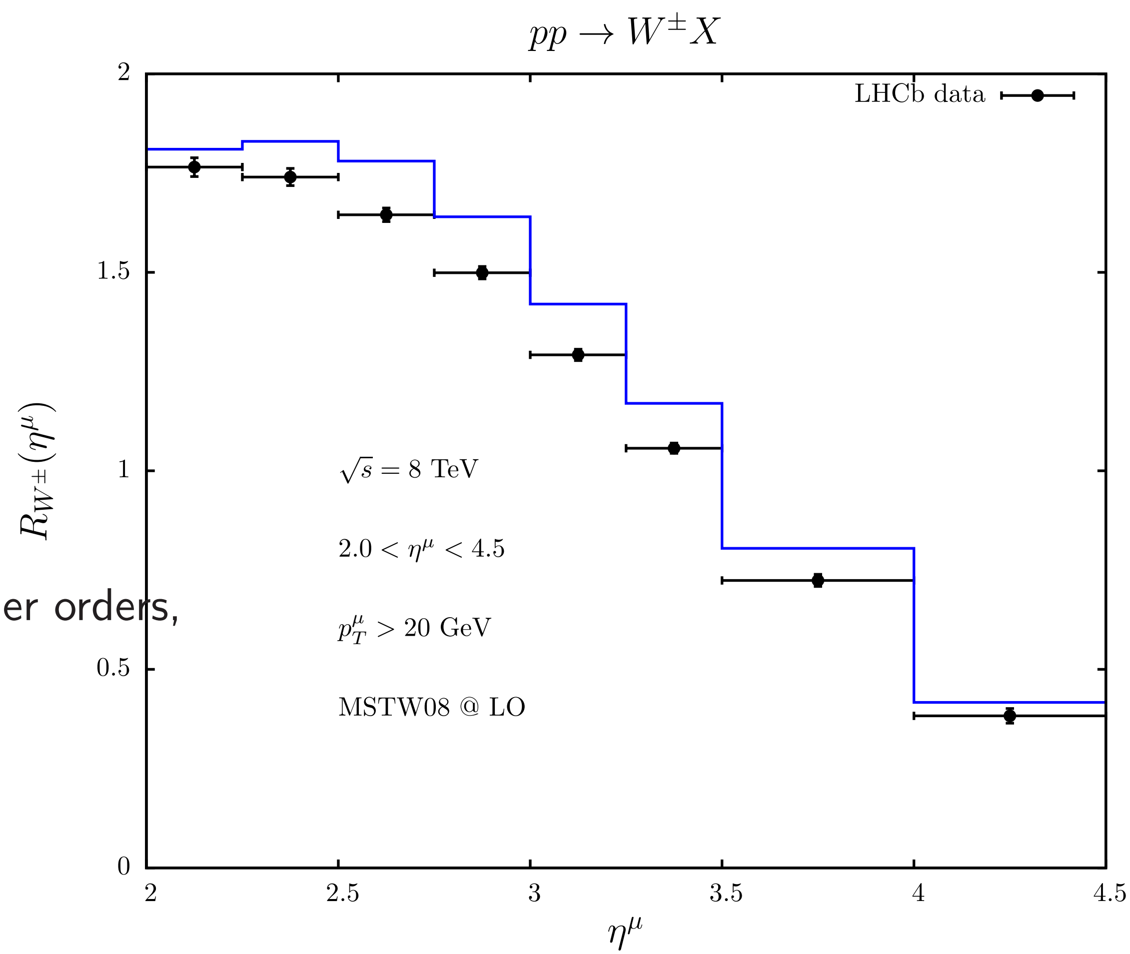
Charged lepton asymmetry, LHCb

- LHCb, JHEP01 (2016) 155
- $A(\eta^l) = \dfrac{\frac{d\sigma^{l^+}}{d\eta^l} - \frac{d\sigma^{l^-}}{d\eta^l}}{\frac{d\sigma^{l^+}}{d\eta^l} + \frac{d\sigma^{l^-}}{d\eta^l}}$
- Signifincant xcess of U over D



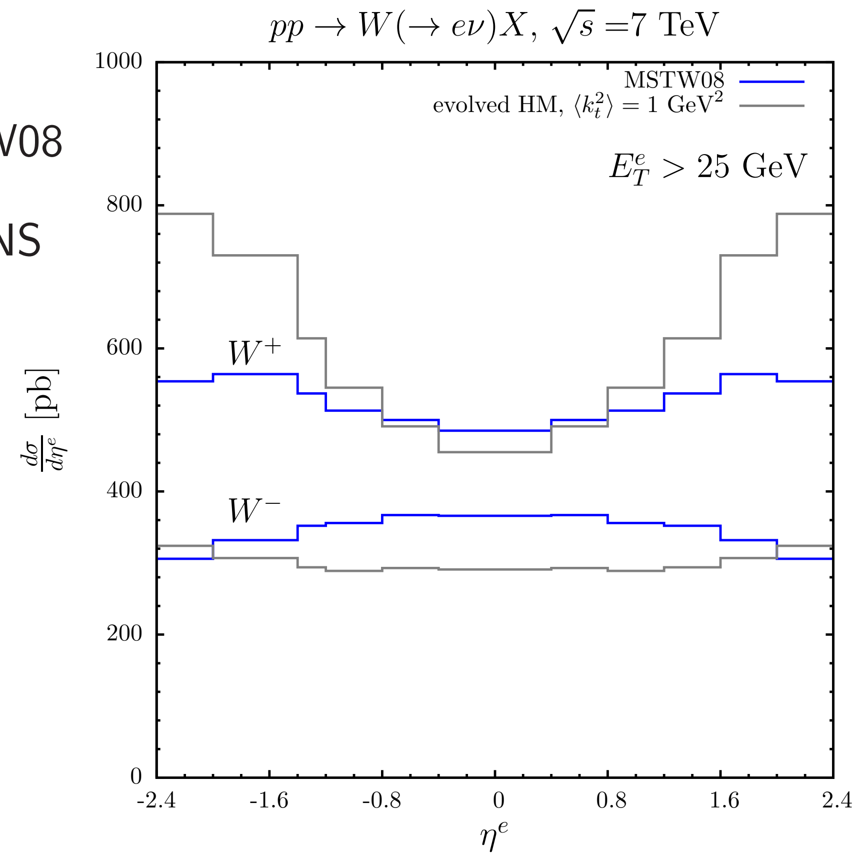
W^+/W^- ratio, LHCb

- LHCb, JHEP01 (2016) 155
- $R_W(\eta^l) = \dfrac{\frac{d\sigma^{l^+}}{d\eta^l}}{\frac{d\sigma^{l^-}}{d\eta^l}}$
- Despite we are missing higher orders, the agreement is fair



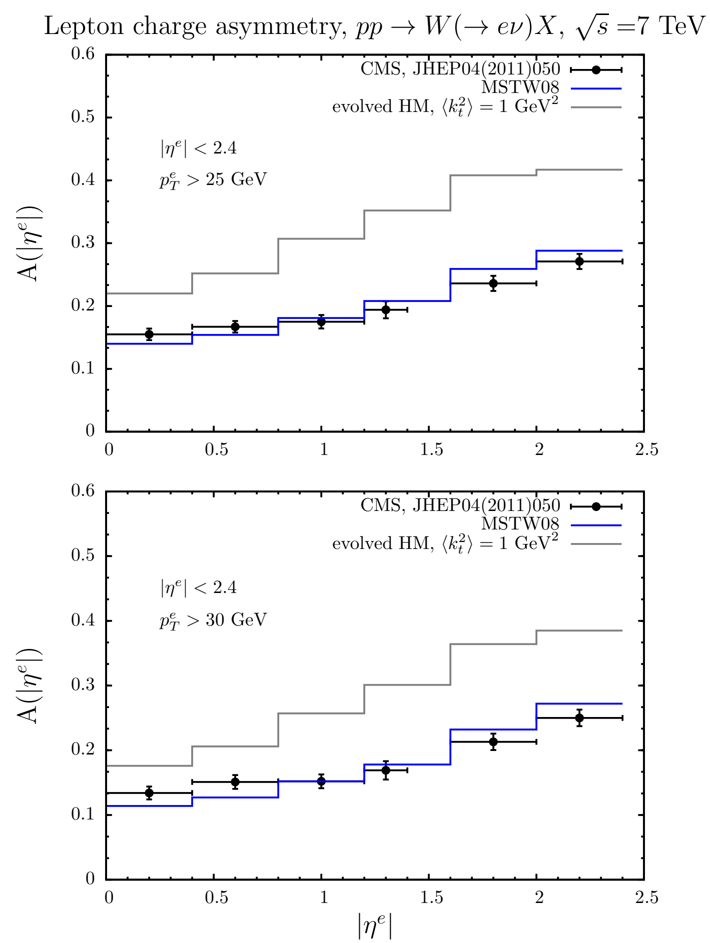
Charged lepton distributions: eHM vs MSTW08

- Evolved Hadronic Model (eHM) vs MSTW08
- private evo code, $\alpha_s(M_Z) = 0.139$, VFNS
- $m_c = 1.4$, $m_b = 4.76$ GeV
- infrared sensitivity : $\alpha_s(Q^2 + \langle k_t^2 \rangle)$
- $\langle k_t^2 \rangle = 1$ GeV^2
- $\mu_0^2 < Q^2 < M_W^2$, $\mu_0^2 = 0.08$ GeV^2
- Normalisation almost ok, shape different



Lepton charge asymmentry, CMS

- Observable : $A(\eta^l) = \dfrac{\frac{d\sigma^{l^+}}{d\eta^l} - \frac{d\sigma^{l^-}}{d\eta^l}}{\frac{d\sigma^{l^+}}{d\eta^l} + \frac{d\sigma^{l^-}}{d\eta^l}}$
- Observable is pdf-shape sensitive
- Hadronic model (HM) evolved to $Q = M_W$
- infrared sensitivity : $\alpha_s(Q^2 + \langle k_t^2 \rangle)$
- $\langle k_t^2 \rangle = 1$ GeV^2
- MSTW08 : shape ok
- HM : higher than observed asymmetry
  $\rightarrow u(x) = 2\, d(x)$ not supported by data



$\sigma(WW)$ with GS09 double PDFs

- Compare with results presented in the paper of Gaunt & al., EPJ C69 (2010) 53
- Basic settings and cuts:
  - $\sqrt{s} = 14$ TeV, $E_T^l > 20$ GeV, $|\eta^l| < 2.5$, no inv. mass cut
  - $\mu_F = M_W$, LO, NWA, GS09 double PDFs, $n_f = 5$
  - $\sigma_{eff} = 14.5$ mb
  - $\sigma(W^\pm W^\pm) = 1/2[\sigma(W^\pm)]^2$ (NB: at differential level)
  - neta=10, nET=100, $\epsilon = 0.1$, run time: 5 hours (locally)

σ fiducial	EPJ C69 (2010) 53 [fb]	`Mycode` [fb]
$\sigma^{W^-W^-}$	0.46	0.58
$\sigma^{W^+W^+}$	0.82	1.05

- $\sim 20\%$ disagreement, $\sigma_{LO} > \sigma_{NLL}$, under study
- however σ's calculated under different approximations

Muons invariant mass cut

- CMS : $20 < M_{ll} < 70$ GeV, $M_{ll} > 105$ GeV
  the cut suppresses WZ and ZZ backgrounds
- $l_i^\mu = E_{T,i}(\cosh\eta_i, \sin\phi_i, \cos\phi_i, \sinh\eta_i) \quad i = 1, 2$
- $M_{ll}^2 = 2E_{T,1}E_{T,2}(\cosh\Delta\eta - \cos\Delta\phi) \qquad \Delta\eta = \eta_2 - \eta_1, \quad \Delta\phi = \phi_2 - \phi_1$
- ME does not depend upon ϕ_i's, unfold the integrals

$$\frac{d^4\sigma^{pp\to WWX}}{d\eta_1 dE_{T,1} d\eta_2 dE_{T,2}} = \frac{1}{2\sigma_{eff}} D_{ij}(x_1, x_2, M_W) D_{kl}(x_3, x_4, M_W) \frac{d^2\sigma_{ik}^{pp\to WX}}{d\eta_1 dE_{T,1}} \frac{d^2\sigma_{jl}^{pp\to WX}}{d\eta_2 dE_{T,2}} \mathcal{I}$$

- The function $\mathcal{I}$ provides the necessary reweighting

$$\mathcal{I}(\eta_i, E_{T,i}) = (2\pi)^{-1} \int_0^{2\pi} d\Delta\phi \prod_n \Theta_n(M_{ll}(E_{T,i}, \Delta\eta, \Delta\phi), M_n^{cut})$$

Factorised dPDFs and impact of mass cut

- Preliminar simulations ($n_f = 4$, neta=10, nET=10, $\epsilon = 0.33$, run time: few minutes)
  - $\sqrt{s} = 13$ TeV, $E_T^l > 25$ GeV, $|\eta^l| < 2.4$
  - Mass cut: $20 < M_{\mu\mu} < 70$ GeV, $M_{\mu\mu} > 105$ GeV
  - $\sigma_{eff} = 14.5$ mb
  - $f_{ij}(x_a, x_b, M_W) = f_i(x_a, M_W) f_j(x_b, M_W)(1 - x_a - x_b)^n$

Mass cut on	$n = 0$ [fb]	$n = 1$ [fb]	$n = 2$ [fb]
$\sigma^{W^-W^-}$	0.41	0.39	0.37
$\sigma^{W^+W^+}$	0.75	0.69	0.64
Mass cut off	$n = 0$ [fb]	$n = 1$ [fb]	$n = 2$ [fb]
$\sigma^{W^-W^-}$	0.61	0.57	0.54
$\sigma^{W^+W^+}$	1.08	1.00	0.93

- Mass cut impact 30-33%, n-impact (large x) 10-15 %

Next step

- use evolved our own double PDFs
- no need to plug σ_{eff}

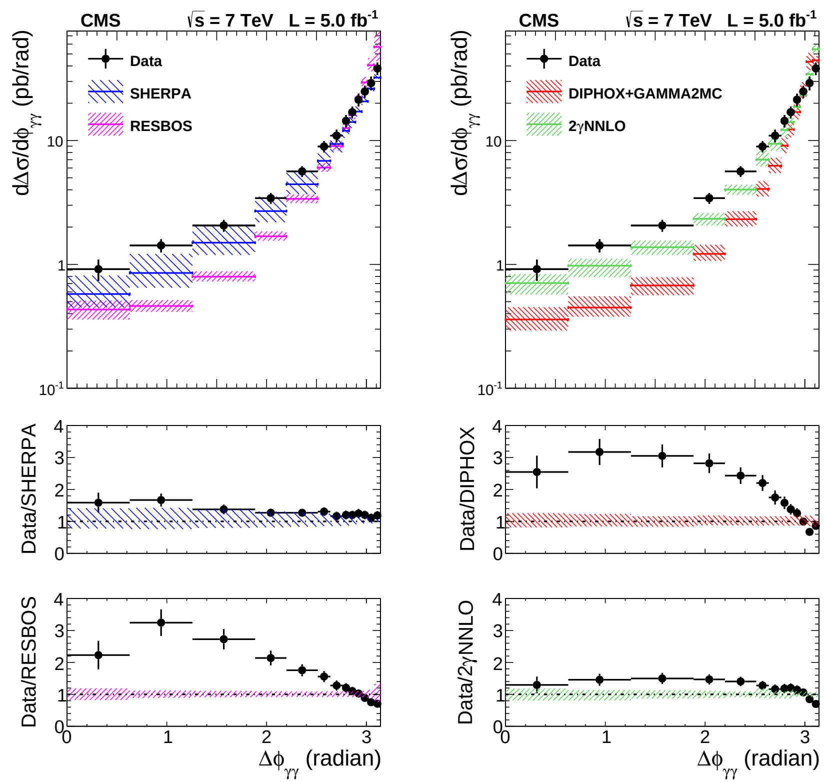
$$\frac{d^4\sigma^{pp\to WWX}}{d\eta_1 dE_{T,1} d\eta_2 dE_{T,2}} = \sum_{i,k,j,l} \frac{1}{2} \int d^2\boldsymbol{b} D_{ij}(x_1, x_2, \boldsymbol{b}, M_W) D_{kl}(x_3, x_4, \boldsymbol{b}, M_W) \cdot$$

$$\cdot \frac{d^2\sigma_{ik}^{pp\to WX}}{d\eta_1 dE_{T,1}} \frac{d^2\sigma_{jl}^{pp\to WX}}{d\eta_2 dE_{T,2}} \mathcal{I}(\eta_i, E_{T,i})$$

- we should
  - tackle computational issue related to additional $\boldsymbol{b}$ integration
  - handle large-index matrices (x_i's, flavours, etc.)

Diphoton channel

- Consider $pp \to \gamma\gamma X$
- Higgs, 750 GeV canditate etc.
- cross sections known at NNLO + resummations.
- CMS measurement: EPJ C74 (2014) 3129
- $\sqrt{s} = 7$ TeV, $|\eta^\gamma| < 2.5$, $E_T^\gamma > 25, 40$ GeV, $\Delta R(\gamma_1, \gamma_2) > 0.45$, $\sigma \sim 17$ pb
- theory low at low $\Delta\Phi_{\gamma\gamma}$: possible DPS contribution?



Diphoton channel: data-driven DPS estimate

- Consider $pp \to \gamma X$, CMS measurament: PRD84 (2011) 052011
- $\sqrt{s} = 7$ TeV, $|\eta^{\gamma}| < 2.5$
- from published $d^2\sigma/dE_T d|\eta|$:
  $\sigma(E_T^{\gamma} > 25$ GeV$) \sim 28$ nb, $\sigma(E_T^{\gamma} > 40$ GeV$) \sim 4$ nb
- Assume $\sigma_{eff} = 14.5$ mb
- $\sigma^{DPS} = \sigma(ij \to \gamma_1 X) \otimes \sigma(lk \to \gamma_2 X)/\sigma_{eff}$
  $\sigma^{DPS}(E_{T,1} > 25\text{GeV}, E_{T,2} > 40\text{GeV}) = 8$ fb
- $\sigma^{SPS}(exp) \simeq 17$ pb, but for $0 < \Delta\Phi_{\gamma\gamma} < \pi/5 \to \sigma^{SPS}(exp) \simeq 0.57$ pb
- Assuming flat behaviour of DPS vs $\Delta\Phi_{\gamma\gamma}$:
  - $\sigma^{DPS}(E_{T,1} > 25\text{GeV}, E_{T,2} > 40\text{GeV}, 0 < \Delta\Phi_{\gamma\gamma} < \pi/5) = 8/5$ fb
  - Assume integrated lumi 10 fb^{-1} $\to S/\sqrt{B} \sim 0.2$
- DPS alone is too small to fill the gap since (theory-exp) $\sim$ 0.3 pb

Conclusions

- First benchmarks with other codes: OK
- LO reasonable, as a first crude approx
- Code optimisation underway
- Almost ready to implement our own double PDFs:
  model dependent but σ_{eff}-free estimate of same sign Ws cross section
- Looking for DPS in other channels :
  - $\gamma\gamma$ (not feasible for now)
  - $Wb\bar{b}$ (within reach given tools at our disposal)
  - UE in DY (one hard/one soft), connection DPS vs UE
  - photoproduction of 4 jets in pA and eP to pin down the $3 \to 4$ contribution