Fitting p_T^W and m_W at LHCb

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with thanks to W. Barter, S. Farry, R. Hunter and M. Pili for interesting discussions

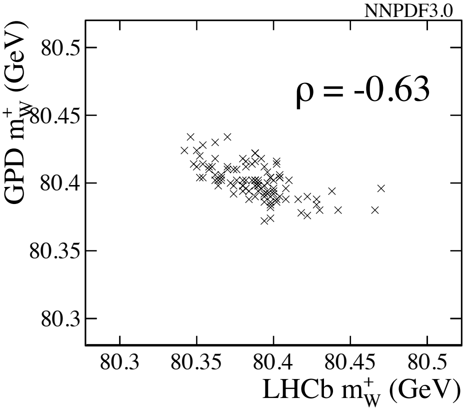
1 July 2019

Introduction

- First: very brief recap of LHCb plans for m_{W}.
- Then: summary of a toy study showing techniques planned for m_{W} @ LHCb.[1]

[1] Writeup on arXiv soon, ∼ready for a while but held up by other commitments.

- LHCb plans[1] presented several times in these meetings, *e.g.* [link] [link] [link] [link].
- In brief, Run 1 + 2 is enough for $\mathcal{O}(10\,\text{MeV}/c^2)$ stat. error and our acceptance is highly complementary to ATLAS and CMS.
- This may allow us to exploit PDF uncertainty anticorrelations in the LHC average. $\longrightarrow$
- Plans for in-situ constraints of PDF uncertainties described in recent paper.[2]



[1] G. Bozzi, L. Citelli, M. Vesterinen, and A. Vicini, "Prospects for improving the LHC W boson mass measurement with forward muons", Eur. Phys. J. **C75**, 601 (2015), arXiv:1508.06954

[2] S. Farry, O. Lupton, M. Pili, and M. Vesterinen, "Understanding and constraining the PDF uncertainties in a W boson mass measurement with forward muons at the LHC", Eur. Phys. J. **C79**, 497 (2019), arXiv:1902.04323

Nuisance parameter study – motivation

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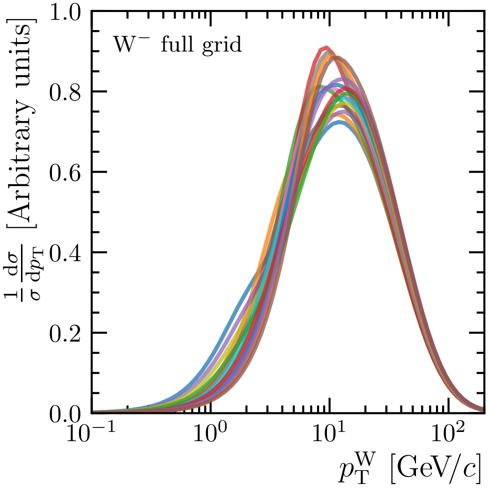
- Describing p_T^W is a major part of a m_W measurement, especially with p_T^μ.
- The p_T^Z distribution, within experimental acceptance, is well-known from data.
- If predictions of p_T^V were known up to a set of process-independent and process-dependent nuisance parameters[1], could we determine the process-dependent parameters from the p_T^μ distribution simultaneously with m_W?

[1] As suggested by F. Tackmann, for example [link] at this meeting last November.

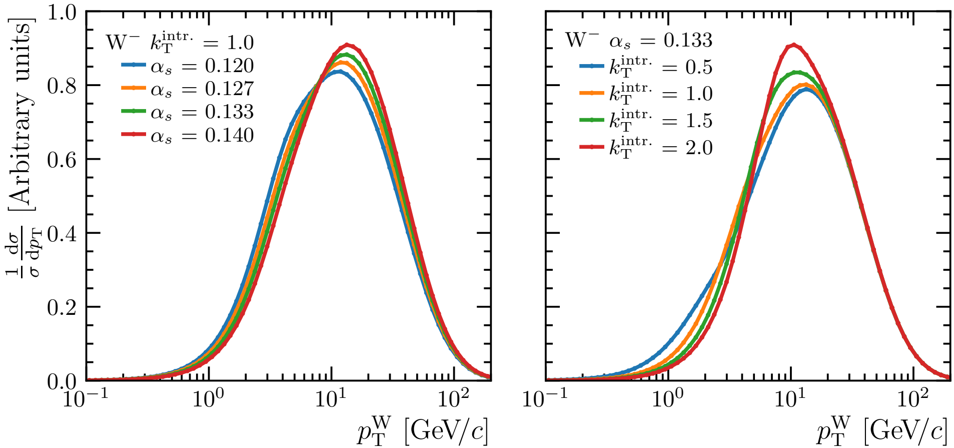
Nuisance parameter study – overview

- PYTHIA-based: choose α_s and $k_T^{\text{intr.}}$ as QCD nuisance parameters that shape p_T^W.
  - Better think of this α_s as a PYTHIA tuning knob, not the strong coupling constant.
- Can we disentangle the effect of these parameters on p_T^μ from that of m_W?
- Set up fits where m_W, α_s and $k_T^{\text{intr.}}$ are all free parameters in MINUIT to see.

(Spoiler: yes, it works nicely.)

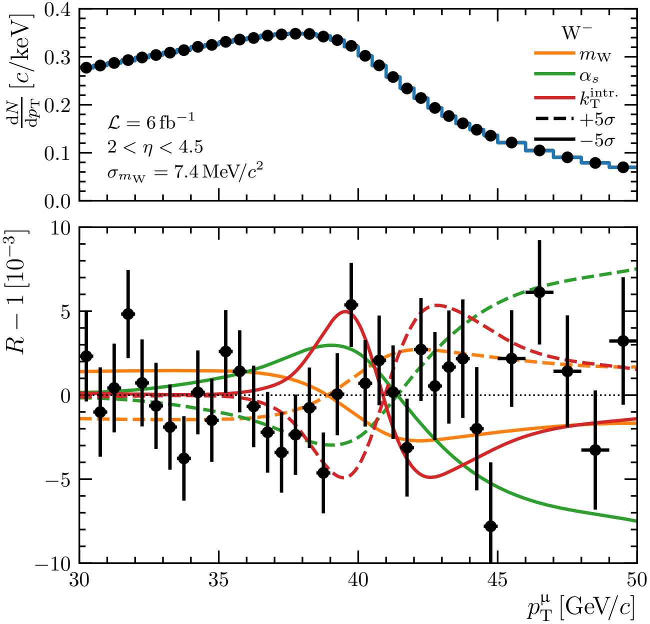


What sort of variations in p_T^W are we playing with?



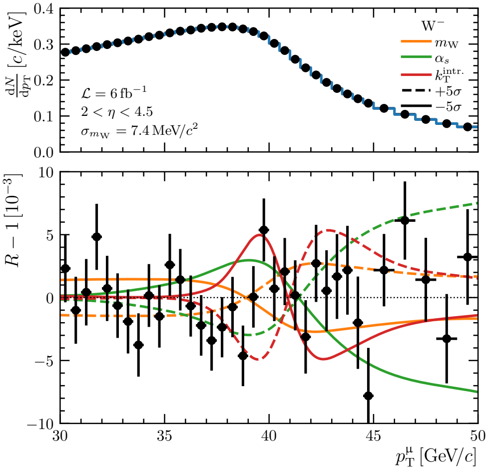
- The effect of varying α_s (left) and $k_T^{intr.}$ (right) separately is what you might expect.

So, what do the fits look like?



And what do the fits look like?

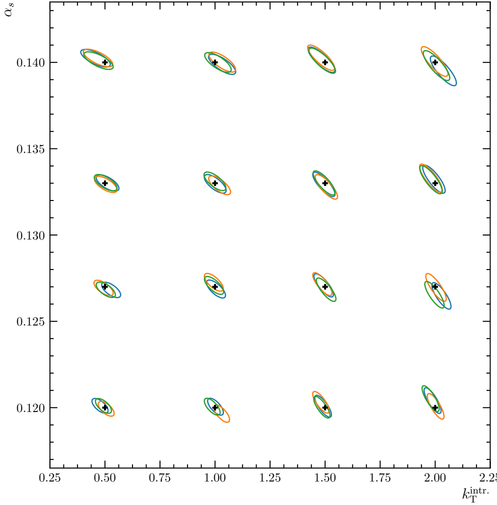
- Study uses a set of Pythia samples using α_s and $k_T^{\text{intr.}}$ values taken from a 4×4 grid.
- Template fits to p_T^{μ}, "data" are Pythia events from one $(\alpha_s, k_T^{\text{intr.}})$, templates are reweighted from some other $(\alpha_s, k_T^{\text{intr.}})$.
- Coloured curves illustrate the effect on p_T^{μ} of $\pm 5\sigma$ variations in m_W, α_s and $k_T^{\text{intr.}}$.
- This fit assumes the statistics and fiducial region used in our PDF study.[1]
- $(N_{\text{data}} \sim 10^7,\ N_{\text{template}} \sim 6 \times 10^7)$
- (Here W^+/W^- are fit together, with shared α_s and $k_T^{\text{intr.}}$, but it doesn't matter much.)



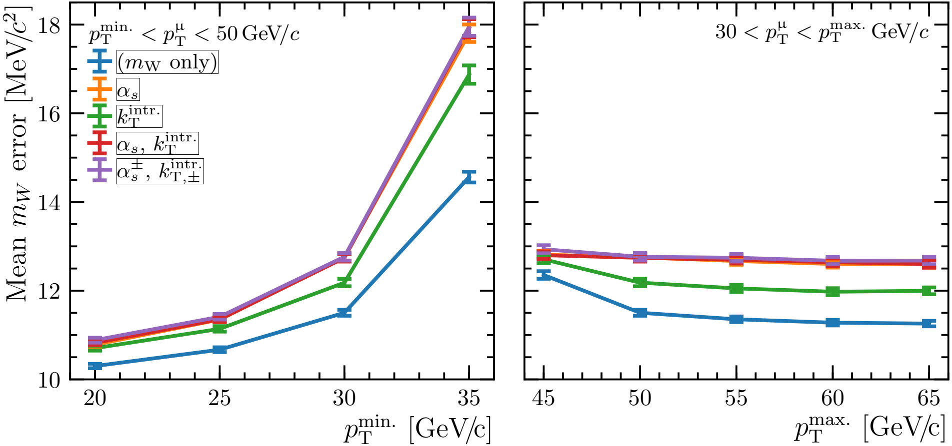
[1] S. Farry, O. Lupton, M. Pili, and M. Vesterinen, "Understanding and constraining the PDF uncertainties in a W boson mass measurement with forward muons at the LHC", Eur. Phys. J. C79, 497 (2019), arXiv:1902.04323

Is everything well-behaved?

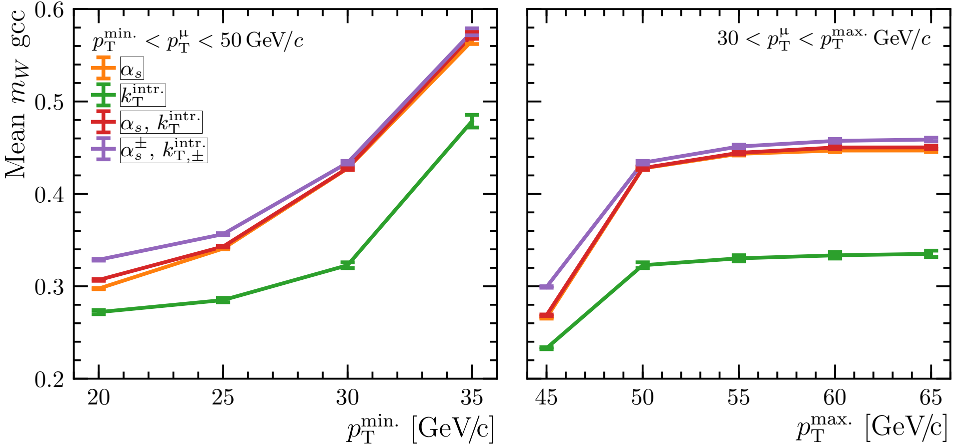
- In brief, yes. Pseudoexperiments[1] show unbiased results and correct coverage.
- The plots illustrating that aren't much fun.
- Lots of info from MINUIT, *e.g.* we see that α_s and $k_{\mathrm{T}}^{\mathrm{intr.}}$ are anticorrelated in the p_{T}^{μ} fits.
- Also shows the 4×4 grid. Reweighting happily transports template events from one grid point to another despite separation $\gg$ uncertainties shown by the $(\mathbf{3}\boldsymbol{\sigma})$ ellipses.



[1] With slightly reduced statistics.



- Dilution of the statistical precision on m_W "blue *vs.* red" $\mathcal{O}(10\,\%)$.



- Unsurprisingly, m_W less correlated to the nuisance parameters with wider p_T^{μ} range.

Conclusions

"If predictions of $p_{\mathrm{T}}^{\mathrm{V}}$ were known up to a set of process-independent and process-dependent nuisance parameters, could we determine the process-dependent parameters from the p_{T}^{μ} distribution simultaneously with m_{W}?"

- This study suggests "yes". Obviously, the α_s and $k_{\mathrm{T}}^{\mathrm{intr.}}$ used here are imperfect proxies for theoretically-robust nuisance parameters from more accurate tools than Pythia.
- Clearly the real measurement is more complex: backgrounds, PDF uncertainties, *etc.*

Backup

PYTHIA tuning parameters

The quantity α_s used throughout this talk refers to the PYTHIA configuration options `TimeShower:alphaSvalue` and `SpaceShower:alphaSvalue`, while the quantity $k_{\mathrm{T}}^{\mathrm{intr.}}$ is a scale factor applied to the configuration options

$$\begin{aligned}\texttt{BeamRemnants:halfScaleForKT} &= 1.5 \times k_{\mathrm{T}}^{\mathrm{intr.}},\\ \texttt{BeamRemnants:primordialKTsoft} &= 0.9 \times k_{\mathrm{T}}^{\mathrm{intr.}},\\ \texttt{BeamRemnants:primordialKThard} &= 1.8 \times k_{\mathrm{T}}^{\mathrm{intr.}}.\end{aligned}$$

The 4×4 grid consists of $\alpha_s \in \{0.120, 0.127, 0.133, 0.140\}$ and $k_{\mathrm{T}}^{\mathrm{intr.}} \in \{0.5, 1.0, 1.5, 2.0\}$. With the exception of these parameters, the default tuning of PYTHIA 8.235 is used.

Fit technology

- Custom template fit using the Beeston-Barlow-lite method and MINUIT

1. Template events ($W^{\pm}$ $p_T/y/m$, p_T^{μ} bin number) are reweighted on-the-fly to the current values of (m_W, α_s, $k_T^{intr.}$). m_W reweighting is parametric with RBW functor
2. (α_s, $k_T^{intr.}$) reweighting based on $\sim$ 2D histograms of $W^{\pm}$ p_T and y, one from each point on the 4×4 grid of PYTHIA samples
3. Template events looked up in these $\frac{1}{\sigma}\frac{d^2\sigma}{dp_T y}$ histograms, giving 16 values
4. These values are interpolated with an ($n = 2$)-dimensional cubic spline to the current working point in (α_s, $k_T^{intr.}$), weights simple to derive from this
5. Template histogram reconstructed, BB-lite metric recalculated *etc.*

- Straightforward to extend to other tools; coincidental that in this study PYTHIA is both generating the events and providing the cross-section histograms
- Similarly, straightforward to include PDF variations via the lookup histograms