"It seems that in any realistic scenario, excluding extreme cases, LHCb would reduce the total uncertainty on the LHC average by 20-40%"

"LHCb has a more ~~[illegible]~~ impact than a second GPD"

→ Table of values to confirm (Table

5) Uncertainties stemming from the p_T^W modelling.

→ source of theoretical uncertainty

→ not discussed in paper, suggestion of further study.

→ Affects templates used to fit data to extract M_W

6) Summary

- "LHCb ~~[illegible]~~ Run II using $W \to \mu\nu$ reduces total uncertainty on the LHC average by 20-40% depending on the assumptions on the experimental uncertainties."
- "It remains to be demonstrated that the p_T^W model uncertainties can be controlled at the necessary level of precision"

Action: Read 2nd Mika Paper, Eur Phys J C 79, 6, 2 2019

→ Detailed analysis of PDFs

(Also revise error calculation w/ correlation)

05/10/20

Error Revision - Tom Hase Book p. Chpt 6 & 7

Standard error in a parameter (a_j) in terms of CURVATURE of the error surface (AKA hyper-surface)

↓

χ^2

$$\alpha_j = \sqrt{\frac{2}{\left(\frac{\partial^2 \chi^2}{\partial a_j^2}\right)}}$$

$$\chi^2 = \Sigma_i \left(\frac{(y_i - y(x_i))^2}{\alpha_i^2} \right)$$

$y(x_i)$ = theoretical model

y_i = data α_i = error bars.

→ Develop matrix methodology for describing the ~~the~~ variation of the χ^2 surface (around minimum value χ^2_{min}) & determining the uncertainties of fit parameters.

"Fit our N data points (x_i, y_i) w/ uncertainties α_i to a nonlinear function w/ a $\mathcal{N}$ parameters $f(x; ~~\alpha_i~~ a_1, a_2, \dots, a_{\mathcal{N}})$"

- The uncertainty of a parameter α_j is defined as the extremum of the $\chi^2_{min}+1$ contour along the a_j-axis.
- When the parameter moves away from its optimal value by $\Delta a = a_j - \bar{a}_j = \alpha_j$, χ^2 evolves to $\chi^2_{min}+1$

$\Rightarrow$ CURVATURE MATRIX $\underline{\underline{A}}$

$\mathcal{N} \times \mathcal{N}$ matrix w/ components $A_{jk} = \frac{1}{2} \frac{\partial \chi^2}{\partial a_j \partial a_k}$

(½ Hessian Matrix, $H_s = H(a_s) = \begin{bmatrix} \frac{\partial^2 \chi^2}{\partial a_1^2} & \cdots & \frac{\partial^2 \chi^2}{\partial a_1 \partial a_{\mathcal{N}}} \\ \vdots & \ddots & \\ \frac{\partial^2 \chi^2}{\partial a_1 \partial a_{\mathcal{N}}} & \cdots & \frac{\partial \chi^2}{\partial a_{\mathcal{N}}^2} \end{bmatrix}$

Off angle terms = degree of correlation of uncertainties in parameters

COVARIANCE or ERROR MATRIX $\underline{\underline{C}}$ $\quad [C] = [A]^{-1}$

$\Rightarrow \alpha_j = \sqrt{C_{jj}}$ if uncorrelated & off diagonal $= 0$ (~~ind~~ independent terms)

C_{jk} = correlation coefficients (can be -ve whilst C_{jj} must be +ve)

Illustration of covariance of 2 variables

- $Z = f(A, B)$, N pairs of measurements (A_i, B_i)

$\rightarrow$ mean $\bar{A}$ & standard deviation σ_A etc

- $Z_i = f(A_i, B_i) \simeq f(\bar{A}, \bar{B}) + (A_i - \bar{A}) \frac{\partial Z}{\partial A} + (B_i - \bar{B}) \frac{\partial Z}{\partial B}$

- $\bar{Z} = f(\bar{A}, \bar{B})$

$$\sigma_Z^2 = \frac{1}{N-1} \sum_{i=1}^{N} (Z_i - \bar{Z})^2 = \frac{1}{N-1} \sum_{i=1}^{N} \left(\frac{\partial Z}{\partial A}(A_i - \bar{A}) + \frac{\partial Z}{\partial B}(B_i - \bar{B}) \right)^2$$

$\hookrightarrow$ N-1 due to one fewer degree of freedom, as mean is calculated from the data.

$$\Rightarrow \sigma_Z^2 = \left(\frac{\partial Z}{\partial A}\right)^2 \sigma_A^2 + \left(\frac{\partial Z}{\partial B}\right)^2 \sigma_B^2 + 2\frac{\partial Z}{\partial A}\frac{\partial Z}{\partial B}\sigma_{AB}$$

$$\sigma_{AB} = \frac{1}{N-1}\sum_{i=1}^{N}(A_i - \bar{A})(B_i - \bar{B})$$ COVARIANCE

$= \alpha_{AB}$ uncertainty in correlated variable.

- Variance & covariance do not necessarily have same unit.

CORRELATION MATRIX $(N \times N)$ → dimensionless measure of correlation, diagonal elements $= 1$, off diagonal ρ_{AB}

$$\rho_{AB} = \frac{\sigma_{AB}}{\sigma_A \sigma_B} = \frac{C_{AB}}{\sqrt{C_{AA} C_{BB}}}$$ CORRELATION COEFFICIENT

$-1 \leq \rho_{AB} \leq 1$ 1 = strong +ve, -1 = strong −ve, 0 = uncorrelated

[Look up table TPAHuge pg 95 for correlated $Z = A \pm B$, $A \times B$, A/B]

[Eqns 7.23-25 pg 93 = curvature matrix for straight line fit]

Eur. Phy. J. C (2019) 79:497

Understanding and constraining the PDF uncertainties in a W boson mass measurement with forward muons at the LHC

- M_W predicted with higher precision than measured ⇒ new physics beyond SM
- $M_W = 80354 \pm 7\,\text{MeV}/c^2$
  prediction by gFitter collaboration 2018

- Measurements of M_W @ Hadron colliders made by comparing data to templates of
  - charged lepton transverse momentum
  - missing transverse energy
  - transverse mass

  in $W \to l\nu_l$ decays.

- $p\bar{p}$ collider (Tevatron) ⇒ W from annihilation of valence quarks & anti-q.
- pp collider (LHC) → gluons & sea quarks play a critical role.

⇒ LHC measurements more susceptible to theoretical uncertainties in the modelling of W production, particularly in PDFs

eg. ATLAS $M_W = 80370 \pm 13 \pm \underbrace{14}_{\text{theoretical, PDF dominant.}}$ MeV/c^2

• "LHCb is a single-arm spectrometer w/ full charged particle tracking & identification capabilities over the range $2 < \eta < 5$, which is mostly orthogonal to the acceptance of ATLAS & CMS"

$pp \rightarrow W^+ \rightarrow \mu^+ \nu + X$
$pp \rightarrow W^- \rightarrow \mu^- \bar{\nu} + X$ } decay process to observe

• LHCb Run II → ~ 6 fb^{-1} of pp collisions @ $\sqrt{s} = 13$ TeV
Run I → 3 fb^{-1} @ lower $\sqrt{s}$

• Estimates M_W statistical uncertainty ~10 MeV/c^2

• Papers given for measurement of forward W & Z boson production & future ATLAS measurement prospects

2) Simulation of W production

• 10^8 Monte Carlo events $pp \rightarrow W \rightarrow \mu\nu + X$ $\sqrt{s} = 13$ TeV
• Events ~~mat~~ selected $30 < p_T^{\mu} < 50$ GeV/c → 10% of event sample
$2 < |\eta| < 4.5$

• The invariant mass, m, of W decay products is assumed to follow a relativistic Breit-Wigner distribution:

$$\frac{d\sigma}{dm} \propto \frac{m^2}{(m^2 - M_W^2)^2 + m^4 \Gamma_W^2 / M_W^2}$$

M_W; Γ_W = mass & width of W boson.

3) Fitting Method

4) Understanding the PDF uncertainties

NNPDF3.1

• Figure showing contribution of different partonic subprocesses to the cross-section for W production as a func of rapidity (y).

→ Dominant valence u(d) quarks ($u\bar{d}$ & $d\bar{u}$) (gu, gd)
→ Annihilation of sea quarks & gluons $g q_s$ ~20%

- PDF uncertainty on M_W measurement arises as the p_T^{μ} distribution depends on the W production kinematics, which are characterised by transverse momentum p_T^W, rapidity, & polarisation.
  - → use "distribution of the angle θ^* in the Collins-Soper frame" as a proxy for polarisation"

→ ~~Biases in M_W (from replica sets) that bias~~
W^+: Replicas (from sets) that bias M_W upwards (downwards) tend to predict large (smaller) $\langle y \rangle$ values & smaller (larger) $\langle p_T^W \rangle$.
Opposite for W^-.

→ Replicas that bias M_W upwards (downwards) correspond to a decrease (increase) in predicted cross-section at high p_T^{μ} & high η

Figures 7 & 8 illustrative of how above statement can be used to constrain PDF uncertainty.

5) PDF uncertainty reduction

"Each replica is assigned a weight according to the best-fit χ^2 (χ^2_{min}) for a fit with n degrees of freedom (n):

$$P(\chi^2_{min}) \propto \chi^{2\,(n-1)}_{min}\, e^{-\frac{1}{2}\chi^2_{min}}$$

This has the effect of disregarding replicas that are incompatible with the data"

→ weights reduced widths of χ^2 vs M_W distribution to factor of 3x smaller (W^+) & factor of 2 (W^-))

→ effective # replicas after reweighting $N_{eff} = 113$ (105) W^+ (W^-) where initial $N = 1000$.

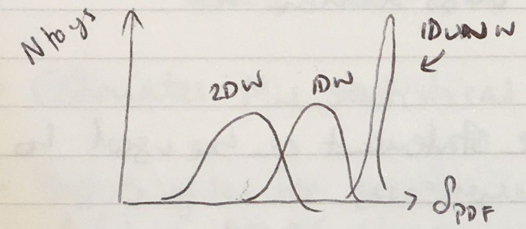
"For a single toy dataset the PDF uncertainty is defined by the RMS of the M_W values for the 1000 replicas"

- 1D weighting case (p_T^μ) reduces PDF uncertainty by an average factor of 10 (20) %
- 2D weighting (p_T^μ, η) reduces PDF uncertainty by a factor of roughly ~2 (1.5)

However ~~data fluct~~ both fits give a large spread under data fluctuations

1D	unweighted	0.04 (0.07) MeV/c^2
1D	weighted	0.8 (1.2) MeV/c^2
2D	weighted	0.9 (1.2) MeV/c^2

→ Since PDF replica weighting outcome depends on the data, PDF uncertainty becomes much more sensitive to the statistical fluctuations of the data themselves.



⇒ use 2D fit in LHCb.

5.1) Simultaneous fit of W^+ and W^- samples
→ partial cancellation of PDF uncertainty when W^+ & W^- data combined.

"2D weighting has a large constraining power of the data"

I've assumed that we want Neff as small as possible but I'm not sure of this → check.

Ensure understand bins, toy data & replicas. Bins.

5.2) Dependence on detector acceptance
→ discussion of the effects of acceptance range of p_T^μ & η on ~~stati~~ uncertainty as range affects statistical uncertainty on M_W
→ although a smaller range may ↓ PDF δ, may ↑ statistical δ

(CONCLUSION) "With large enough data samples, a 2D fit to the p_T^μ vs η distribution, w/PDF replica weighting, would allow the PDF uncertainty to be further restrained." Factor of 2 improvement for W^+ & W^- simultaneous data using LHCb Run 2 statistics.

MIKA MEETING

08/10/20

- Research staff, 1st MPhys group.
  → LHCb 10 years
- Rowan programs outside of the course → probably prefers C++
- Collider – intensive work in C
  – mostly in python → more efficient for fast bits.

- Start on same initial task, then divide later on to different parts of the project.

- GitHub – share code
  – Mika & Rowan can discuss.
  – suggestion to use to for electronic record
  – similar to use for actual research

- Set up GitHub account.

- SCRTP username phukjd

- ssh via putty → ssh -X -Y phukjd@godzilla.csc.warwick.ac.uk
  ↳ method for accessing warwick servers

- Putty for other PC

- Gitgrab

- Github → copy code for git clone
  → ls Mphys Project 2021/
  cd Mphys

emacs -nw is a code editor → one Mika uses.
IDE – powerful but more complicated code editor

(Screen shots of command) → python

Tree data – data has collisional events.

- "DATADIR = " location
  Read in code
  Produces histogram.
- "gs plot.pdf" to view plot
- Sample of collision events with one high momentum muon
  Code plots ~~mom~~ m_T distribution
  Bump = ~~[illegible]~~ W boson → at half of ~~[illegible]~~ M_W
  Rate vs mom in GeV
- ls Makefile to compile C code, screenshot 3.

git clone git@github.com:mvesteri/MPhysProject2021.git

Data access
commands in chat

ls /storage/epp2/phshgg/MPhysProject~~[illegible]~~2021/
~~[illegible]~~ → opens data

- Use Mika GitHub, create own fork

Weekly Meetings

Thursdays 1200

Discuss over GitHub repository
→ no immediate response in evenings or weekend.

- Office work Risk Assessment
- Ask how to get started on Github when all set up.
- Rowan sent message explaining git & ssh.

Px402 Intro Meeting

www.warwick.ac.uk/finalists-briefing
→ sci comp facilities.
→ postgrad & careers.
→ health safety & risk assessment

David Leadley – set of live session timetables on UG handbook
– right of start page
– can access module pages on handbook.
– ONLINE OPEN BOOK EXAMS
– Welcome back :)

SSLC – Aggie Martin, Emily Dekker, Grady Beckett, Shameem Golestaneh

Robin Ball – r.c.ball@warwick.ac.uk

Project Talk

- GET IN TOUCH WITH SUPERVISOR
- Late penalties are 5% per working day.
- Record of work
  - day-by-day working record
  - NOT a beautified document.
  - keep up to date AND DATED.
  - individual record, but fine to cross reference other electronic records
  - BACK UPS
  - suggestion of onenote, but discuss w/ supervisor.
  - ready to share w/ supervisor @ or before meetings.
- Supervisor
  - regular scheduled weekly progress meeting
  - email supervisor for missed work ASAP (flu)
  - expect inspection of work done every 2-3 weeks (min 3/term)
- Rooms available to book on Moodle. for meetings.
- Interim report
  - Intro – aims, lit review & background, objectives
  - T1 achievements 2pg max
  - Realistic T2 work plan 1pg max
  - 10 pgs + references

- If using ionizing radiation, contact Jon Duffy.
- Plagerism example given on powerpoint.
- Contact Robin Ball for mitigation of late work & questions

John Horsle H&S Presentation
- Review of Risk assessment T2 Thurs W2 → 21/01/21
- Need to complete some tabs, given on doc.

SCRTP David Quigley

- warwick.ac.uk/scrtp
- Linux system, shared computing space. ⇒ CentOS7
- Can be used remotely
- Distributed computing infrastructure (the CoW)
- Do not use without EXPLICIT permission from supervisor
- Centrally stored files & settings.

- READ KEY INFO PDF
- ~~Apply for desktop account~~
- ~~Read acceptable use policy~~
- Sign up for scrpt-linux-user email list

- Remote Desktop Protocol, webbrowser, or X2Go software.
- godzilla.csc.warwick.ac.uk
  → DO NOT RUN COMPUTATION
  → editing files, compiling code, plotting simple graphs, submitting computational jobs to the CoW ONLY
- Access example avocado.csc.warwick.ac.uk in web browser (~12min in video)
- Access programs by command line
  module spider ProgramName
  module load

SCRPT USERNAME phukjd

Standard maintenance Wednesday 1300-1700