Sensitivity Analysis To The Strong Interaction Using Monte Carlo Simulations

Samuel Hansen

Tufts UNIVERSITY

INTRODUCTION

Of great importance within the realm of particle physics is the Quantum Chromo Dynamics Theory which describes the strong nuclear interaction responsible for holding the atomic nucleus together.

This force is mediated by particles called gluons which act on particles called quarks which are the fundamental constituents of the nucleus.

Collisions at particle accelerators involve quarks and gluons colliding but we can not a priori know energy or momentum, we can only extract it from experiment.

Parton Distribution Functions are phenomenological models fit to this experimental data.

But…

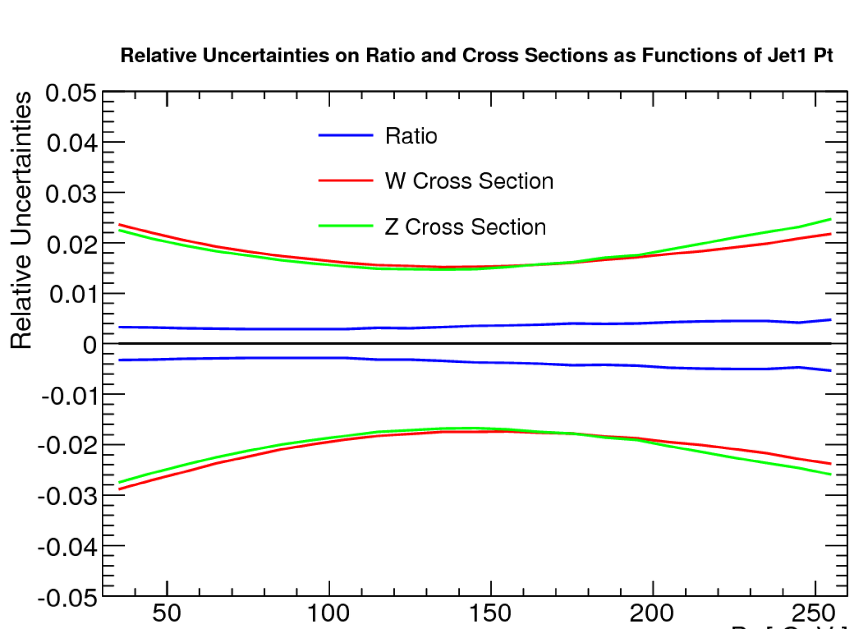
- There are 25 parameters and the system is under-constrained
- Physicists have to make assumptions about different parameters to constrain the system and have different approaches
- Yields a variety of PDF sets

PDF's can be among the largest sources of uncertainty in new physics searches or on precision measurements at the Large Hadron Collider.

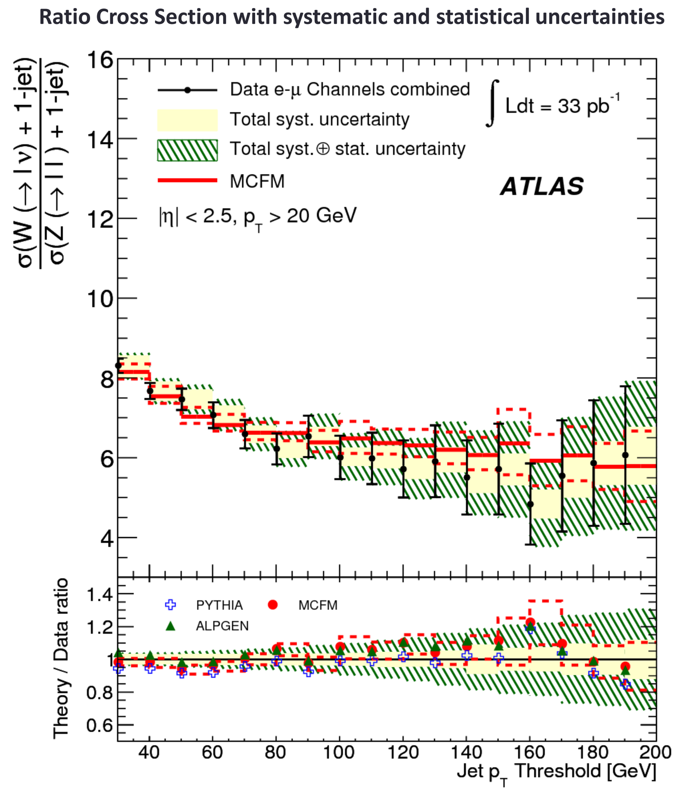
EXPERIMENTAL CONTEXT

PDF uncertainty is not the only source affecting measurements, in fact some of the highest uncertainty comes from hard emissions (collisions with high energy)

The ratio W+jet/Z+jet differential cross section was designed to study this hard emission at very high precision. To that end the dominant source of systematic uncertainty cancels in the ratio. Additionally, nonpertabative QCD effects and PDF uncertainties are expected to cancel in the ratio.



Ratio Cross Section with systematic and statistical uncertainties



The cancelling of systematic uncertainties motivates the project as a whole. In order achieve a greater understanding and sensitivity of QCD effects the PDF dependence on the ratio must be studied further.

OBJECTIVES

Given the proof of principle shown in the experimental context the following must be accomplished in order to establish a significant conclusion about the ratio:

- Show that the cancelling of uncertainties is still true in higher kinematic regions
- Examine whether this phenomena also occurs for other observables and several different PDF sets
- Check whether the ratio just cancels systematic errors or if it cancels differences in the central values

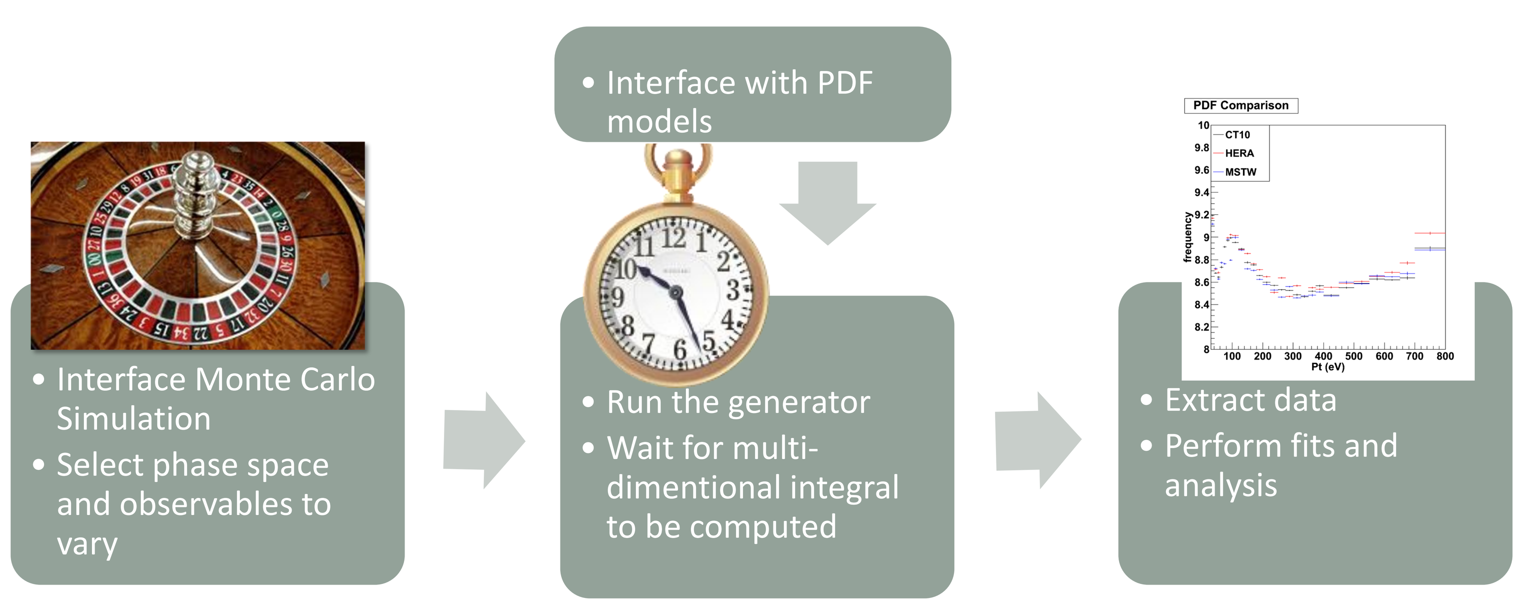
METHODOLOGY

The general format is to use MCFM calculations (the most sophisticated Monte Carlo simulation available) to achieve the objectives .

To that end, running MCFM gives us a number called the *cross-section*, the probability for the process of interest to occur in a *pp* collision.

In more specific terms the process consists of:

- First interfacing the calculation to different PDF estimates
- Select the phase space over which the calculation are to be integrated
- Run the numerical integrator to get the final cross section in the region of interest
  - Numerical integration uses Monte Carlo technique
- Look at various bins of Pt and eta to reconstruct the differential cross section over a large kinematic region
- Analyze the calculation results computing uncertainties using dedicated HEP software



RESULTS

OBJECTIVE 1

The data show cancellation in the extensive kinematic region for various PDF's

- Using CT10 demonstrated proof of principal that the systematic PDF uncertainties for the scan over the transverse momentum are smaller than the statistical uncertainties

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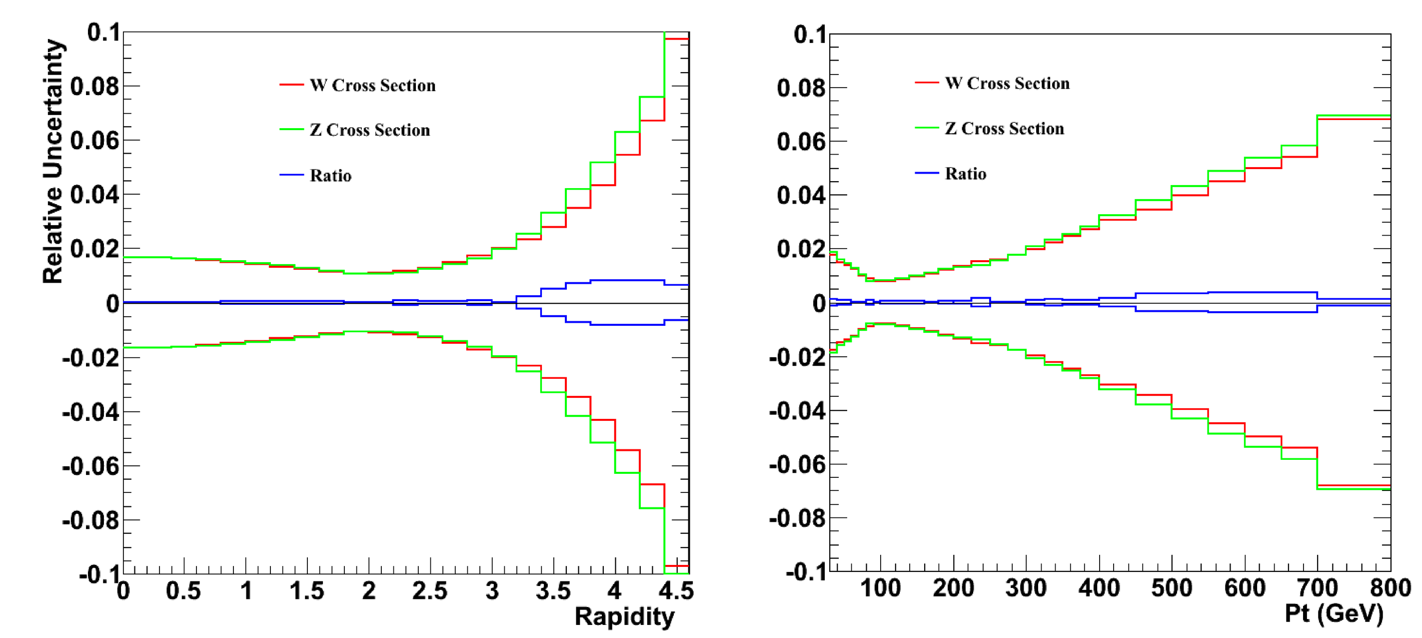
A measurement of the ratio of the W and Z cross sections with exactly one associated jet in pp collisions

OBJECTIVE 2

Similarly demonstrate that PDF uncertainties for different observable, rapidity, are greatly reduced in the ratio. We note however that some small residual deviation in the high rapidity region might be due to the conservative approach adapted.

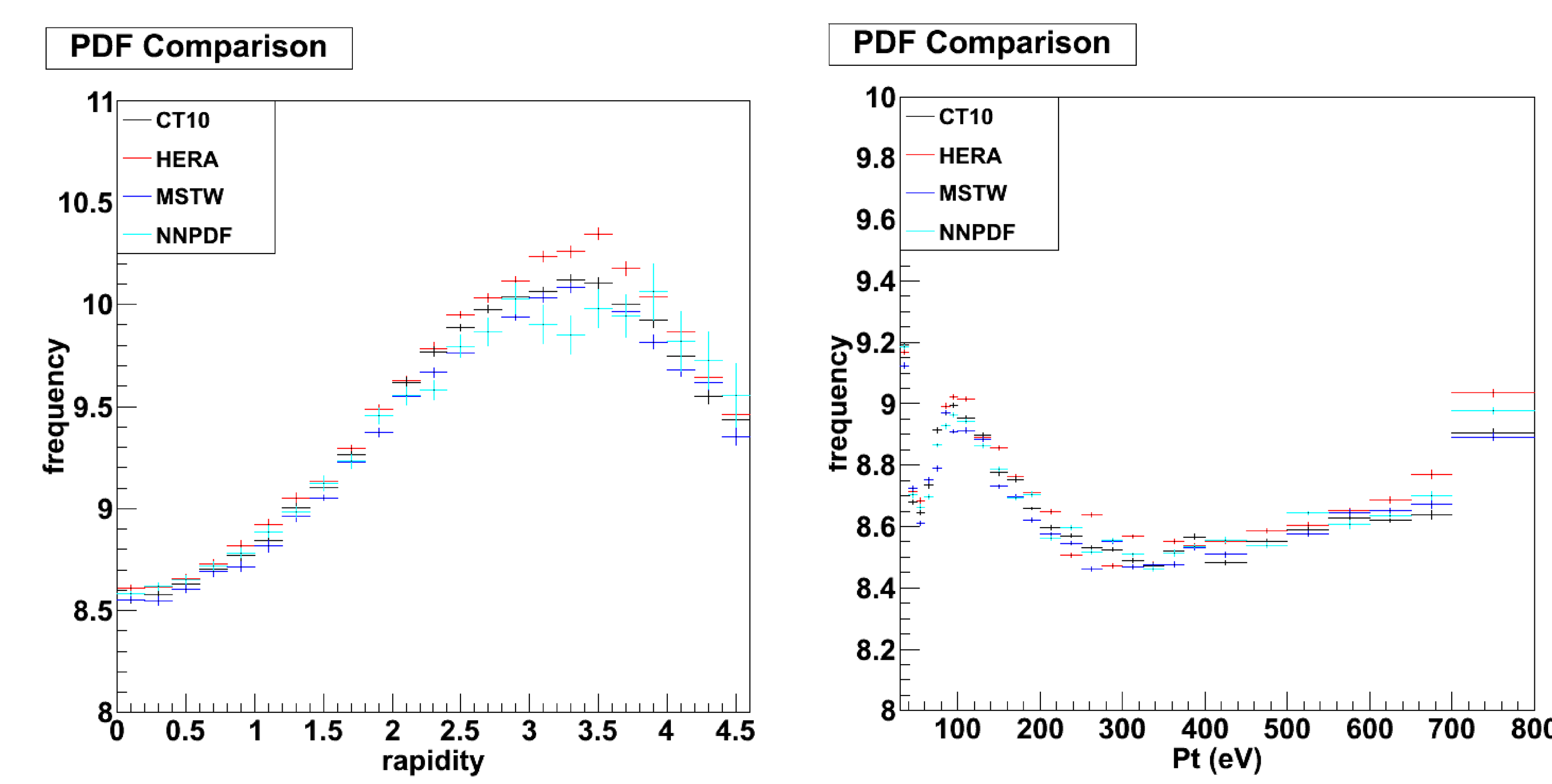
Relative Uncertainty for Cross Section and Ratio in extended kinematic region



Results in extended Kinematic region demonstrate a decreased relative uncertainty for both rapidity and transverse momentum W+jet/Z+jet ratios

OBJECTIVE 3

Results of comparison between various PDF calculations demonstrate that there exist differences that are significantly larger than experimental systematic uncertainties. This effect, testable empirically, may improve overall PDF knowledge.



Comparison of W+jet/Z+jet ratio calculated by PDF sets CT10, HERA, MSTW, and NNPDF in scan over the rapidity (left) and transverse momenta (right)

CONCLUSIONS

- Significant cancellation of systematic uncertainty occurs in wide kinematic region for Pt observable
- Similar cancellation occurs for rapidity and deviations are negligible across the full rapidity range available to the detector .

Furthermore demonstrate the cancellations effect occurs using several other PDF sets

- Sensitivity to various PDF calculations yielded a difference in the ratios that are significantly larger than experimental systematic uncertainty. To that end the effect is testable empirically and may allow for a greater understanding of PDF effects.