Drell Yan process:
Theory vs. Monte-Carlo

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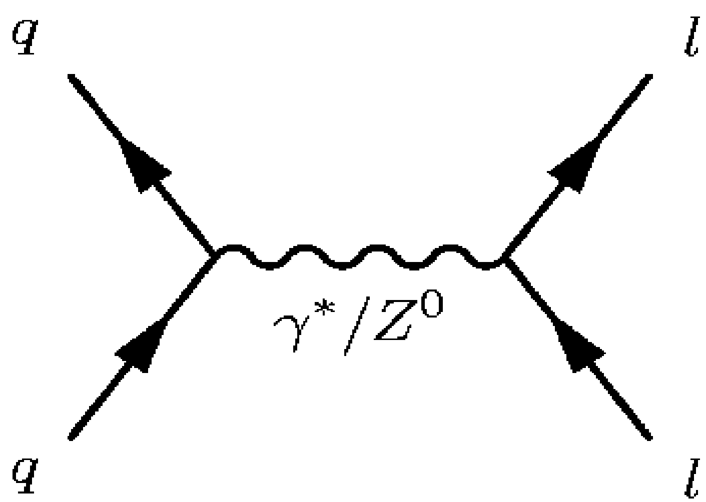
- Introduction to the Drell-Yan process: What it is and why we care about it.
- (Very!) Brief summary of theoretical calculations: What we should be getting (at least in principle).
- Monte Carlo simulation of the process: What we actually get.
- Comparison: Is everything consistent?
- Summary

Introducing the Drell-Yan process

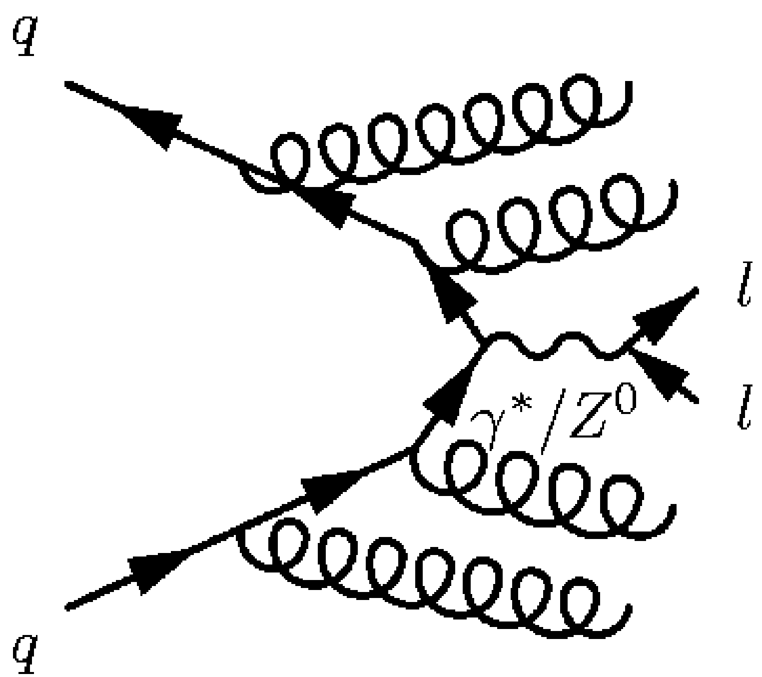
1970 was a very productive year for S.D. Drell and TM. Yan : 7 important papers on Deep Inelastic Scattering! In 'Massive Lepton-Pair Production in Hadron-Hadron Collisions at High Energies' they looked at $q\,\overline{q} \rightarrow l\,\bar{l}$ which became known as the Drell-Yan process when the mediator is a vector boson.



Here we will ignore the photon and focus on the Z boson. When I say 'Drell-Yan', I'll mean the exchange of a virtual Z, not a γ!

Theoretical Predictions

Problem: Gluon emission! If the above diagram was the only one that contributed this would be a simple homework problem. But quarks can radiate gluons before the 'hard' process (i.e. The production of the Z boson).



These carry away momentum therefore broaden the distribution of the boson.

time for annihilation ~ 1/Q so the larger Q is, the broader the distribution in Q_T is

Theoretical Predictions

Let Q be the transfer of 4-momentum and Q_T its transverse component. In theory the process can be neatly described in the two limiting cases :

1. Q ~ Q_T : We can use pertubation theory and depending on our patience compute the result to any desired order.
2. Q >> Q_T : Things become harder. Alpha_s becomes large and, horror of horrors, standard pertubation theory doesn't work!

Theorists are clever people. 3 particularly clever people (J.C. Collins, E. Soper, G. Sterman, 1985) managed to use a technique known as 'resummation' to formulate a prediction for the low Q_T region.

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Theoretical Predictions

Their result is:

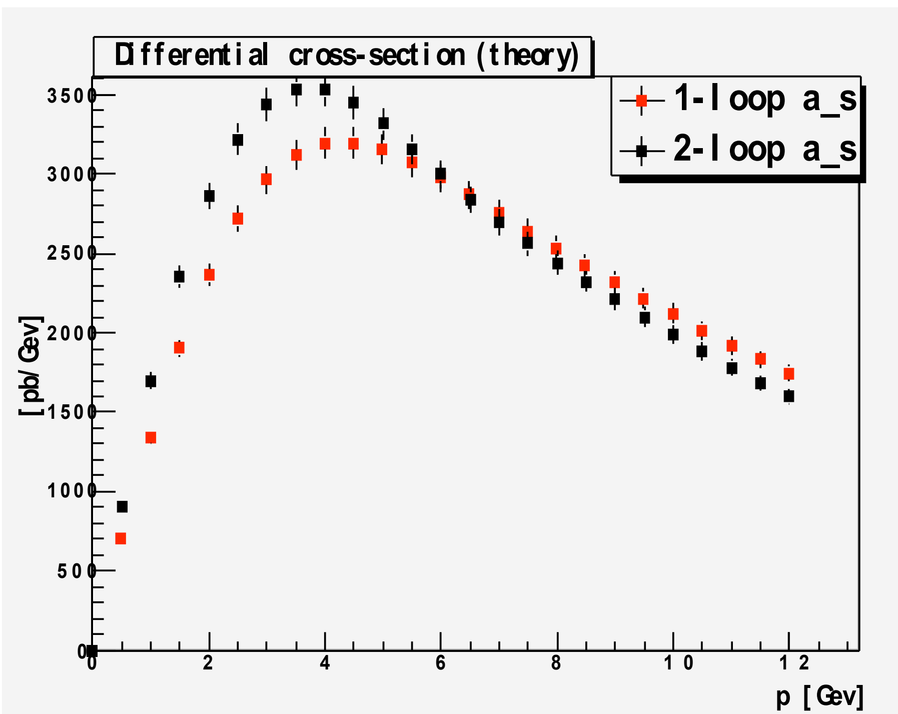
$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}Q_T^2\mathrm{d}y} = \frac{1}{(2\pi)^2}\frac{4\pi^3 a_{fs}}{3s}\int \mathrm{d}^2\boldsymbol{b}\, e^{i\boldsymbol{p}\cdot\boldsymbol{b}}$$
$$\times \exp\left\{ -C_F \int_{C^2/b^2}^{M_z^2} \frac{\mathrm{d}k^2}{k^2}\frac{\alpha_s(k^2)}{\pi}\left[\ln\frac{{M_z}^2}{k^2} - 1.5\right]\right\}$$
$$\times \sum_a H^0_{a,a} f_a\left(x_A, C^2/b^2\right) f_a\left(x_B, C^2/b^2\right).$$

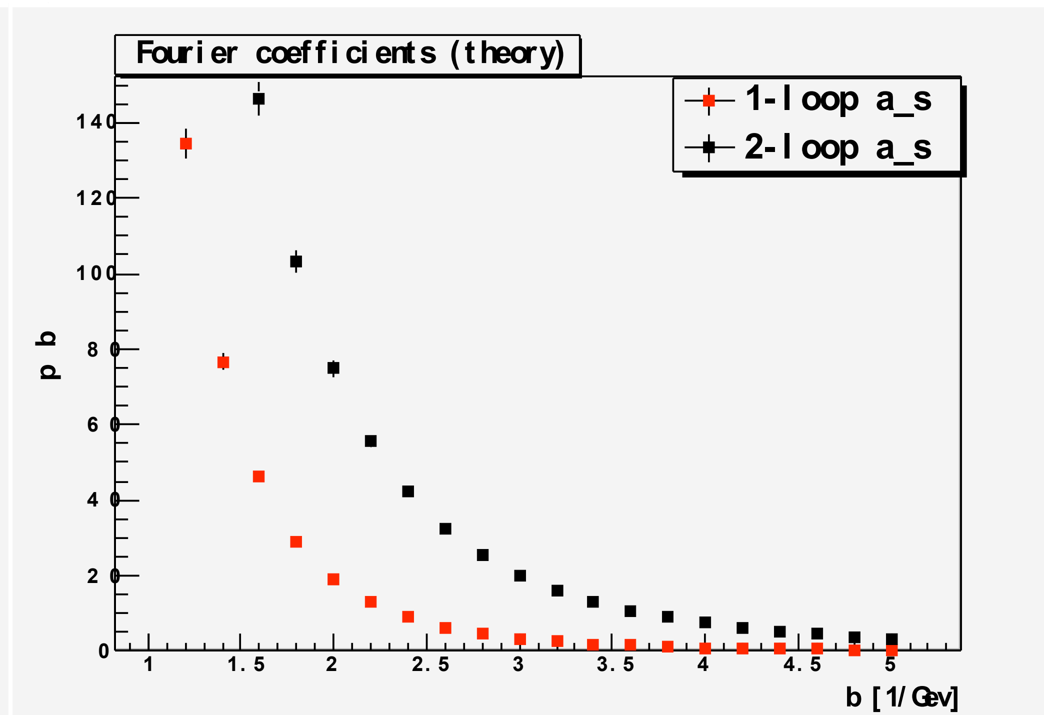
Problem: a_s diverges! This is the so called 'Landau pole'. We get round it by freezing a_s. This shouldn't really change our results.

Keep in mind that this described a highly idealised situation!

Calculating the theoretical prediction

Evaluating the formula on the previous slide is computationally intensive.
(thankfully integral in exponential can be done analytically!)

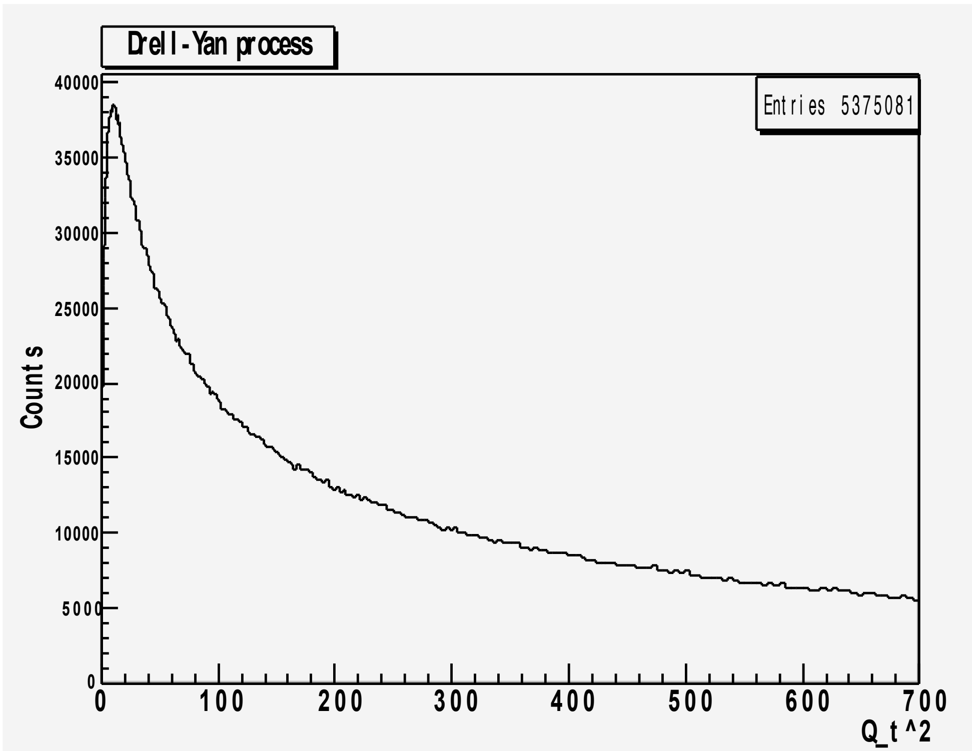


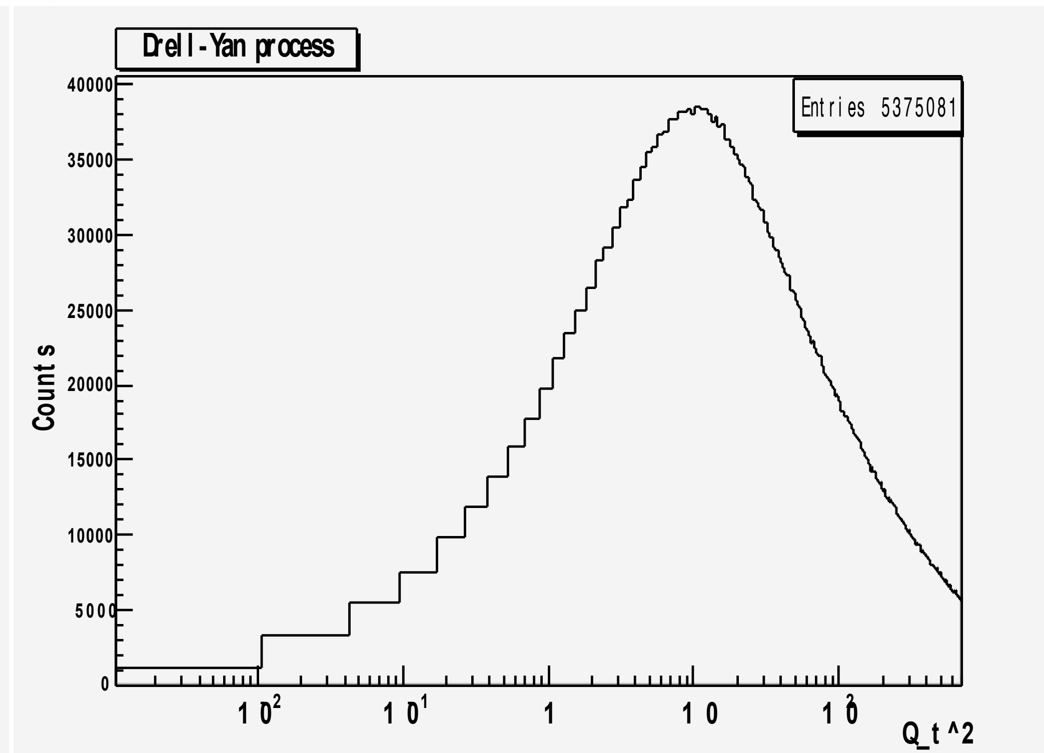


Interesting discrepancy in the 2nd graph: I don't know why!

Monte Carlo results

PYTHIA6 results (s=14TeV)

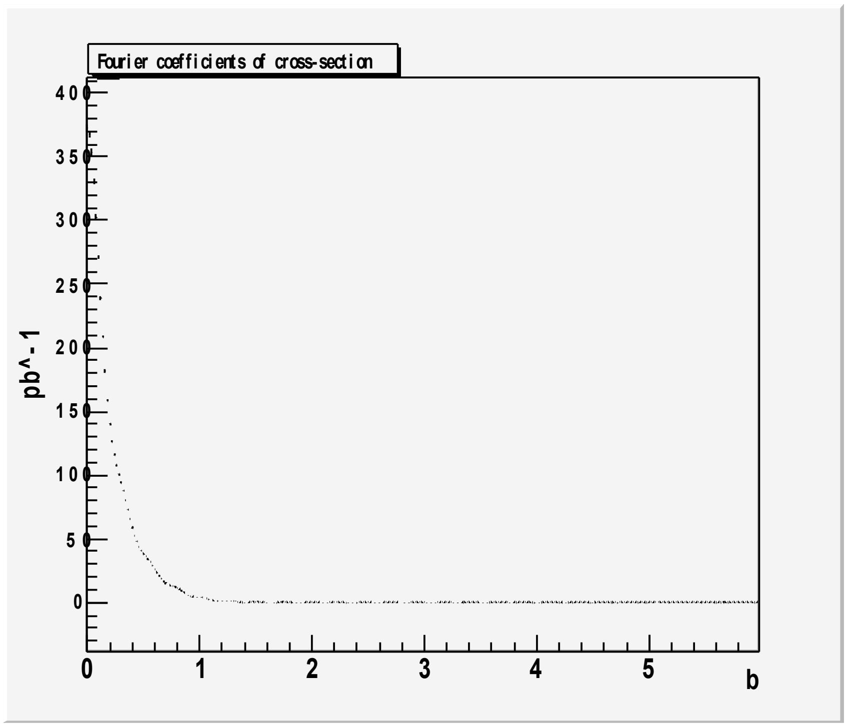


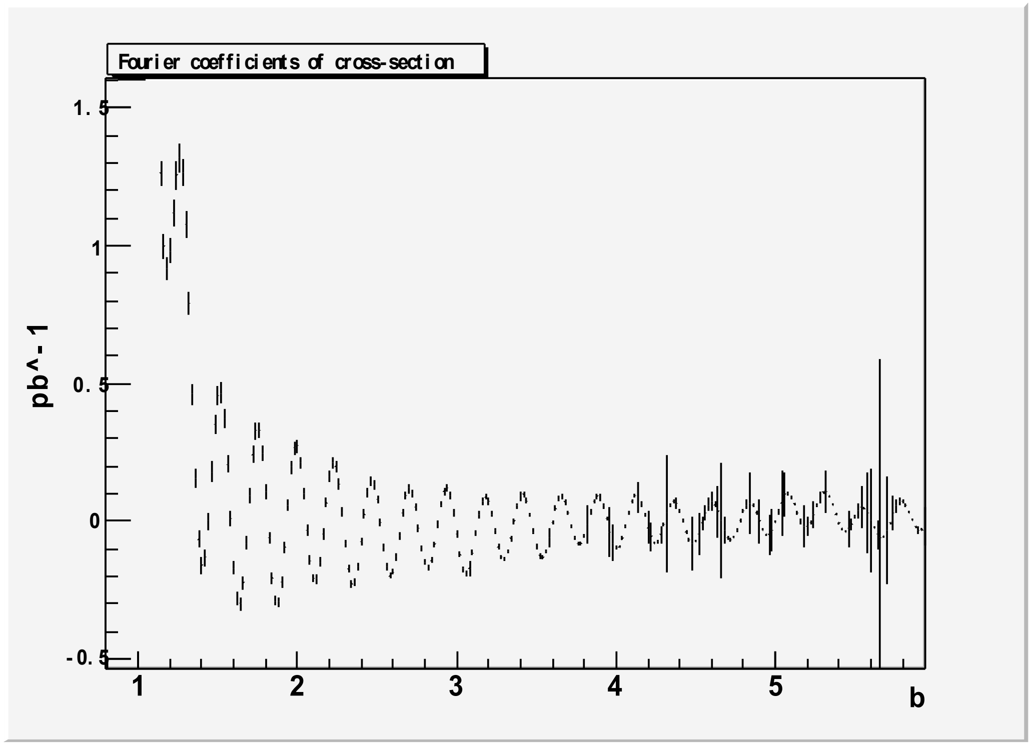


Things to note:
- Cross-section -> 0 as Q_T->0
- Very sharp drop after the maximum
- Long tail (variable binning to help us out)

Monte Carlo results

Treat histogram as a normal function -> Fourier coefficients

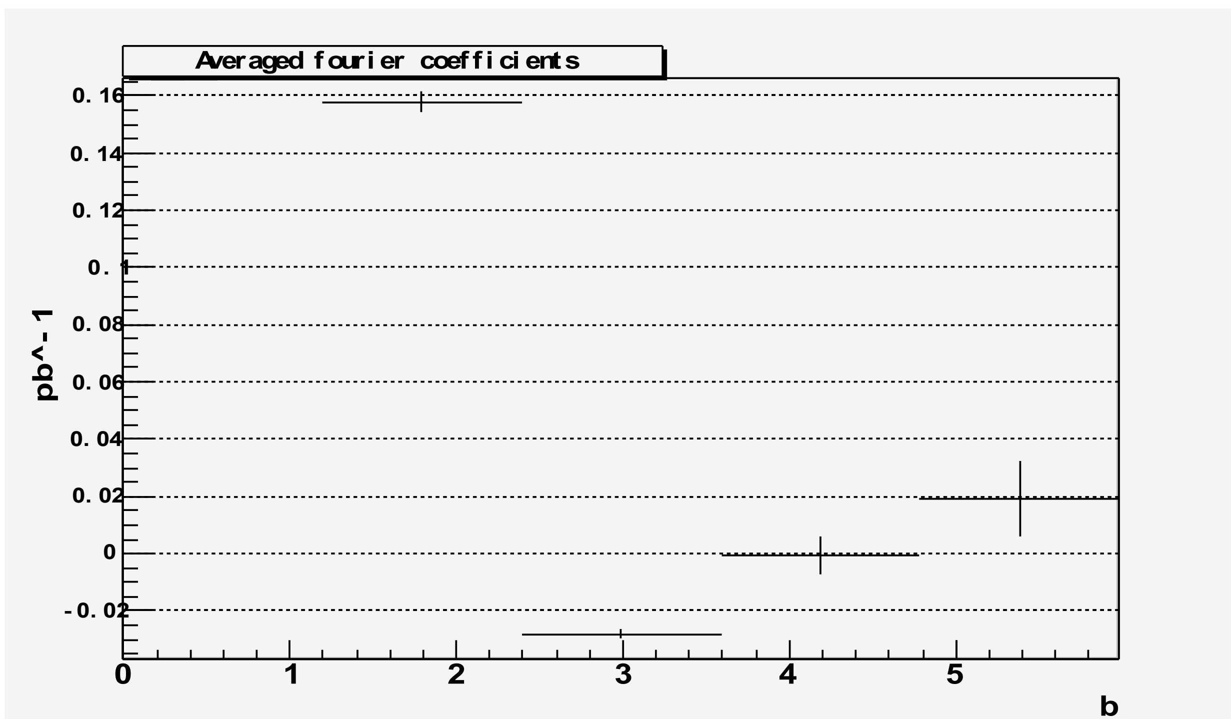




These oscillations are not supposed to be there! I'm not sure what auses them (any ideas?). Could be discontinuities in histogram?

Monte Carlo results

Maybe an averaging procedure will help? Try to create a histogram out of the graph.



Bummer! 2^{nd} bin is negative! Still though we probably can arrange for it to become positive ------> histogram is a dishonest solution.

Comparing the cross-section

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Summary & Thoughts

- Drell-Yan important for LHC – need to know whether Monte-Carlo event generators faithfully reproduce QCD predictions

- My results are 'Inconclusive'
  - Need to understand the origin of the oscillations in the Fourier coefficients and how to get rid of them (I don't think histograms are the way to go)
  - Theory is almost certainly correct (has been tested against experimental data). Look for problem in my code / Monte Carlo simulation.
  - Use the theoretical predictions of the theory for high pt to resolve discrepancy in cross-section