QCD analyses for MC tuning and interesting observables

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My Charge

We'd like to invite you to speak at the Chicago 2012 workshop on LHC physics, May 2-4, 2012. In particular, we hope you could discuss whether there are low-luminosity QCD analyses that should be updated with the full dataset for a better tuning of MC/other tools. Are there any interesting observables that haven't been investigated?

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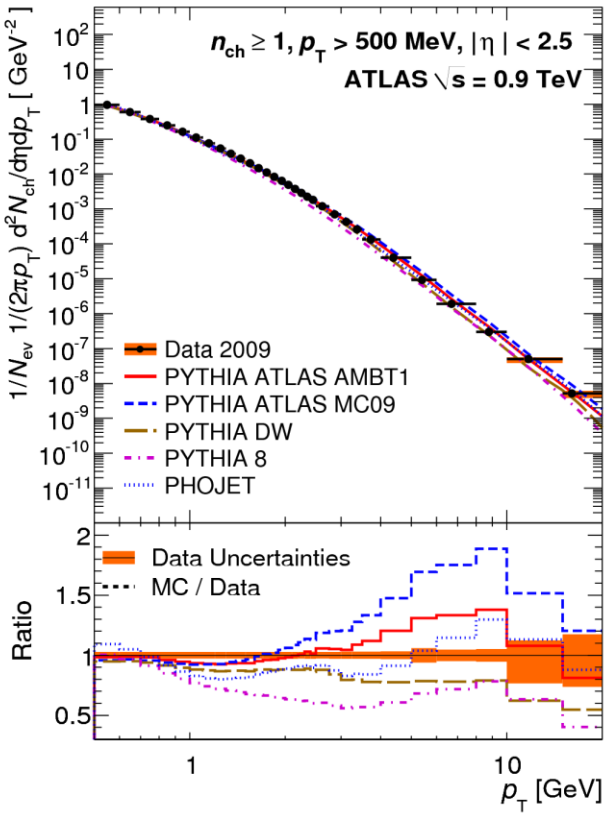
A common reaction when discussing soft QCD

The Charge Is More Exciting Than You Might Think

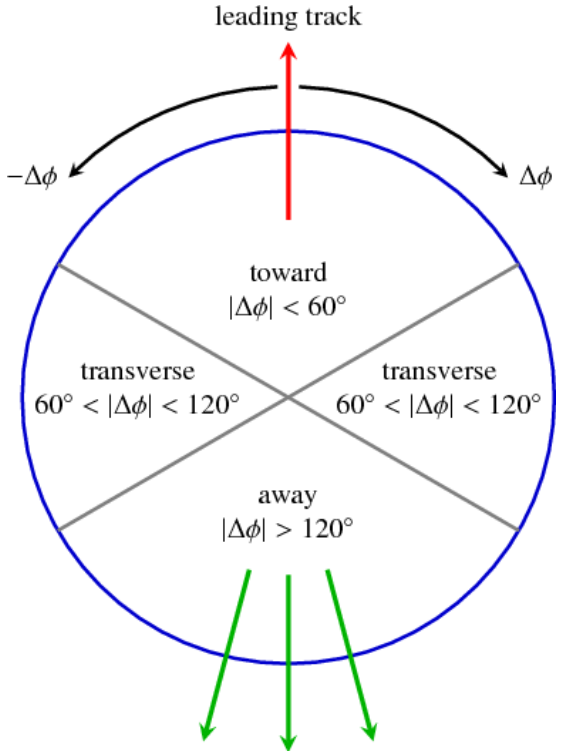
- What do we need to measure better today, in order to have better predictions tomorrow?
- In particular, I'd like to go beyond the measurements that you expect.
- Outline:
  - "The measurements you expect"
  - A word on DPS
  - Heavy flavor production
  - Ws, Zs and PDFs

I have selected mostly ATLAS plots to show, not because I think their measurements are better, but because they usually plot things in a way that best illustrates the point I am trying to make.

The Measurements You Expect

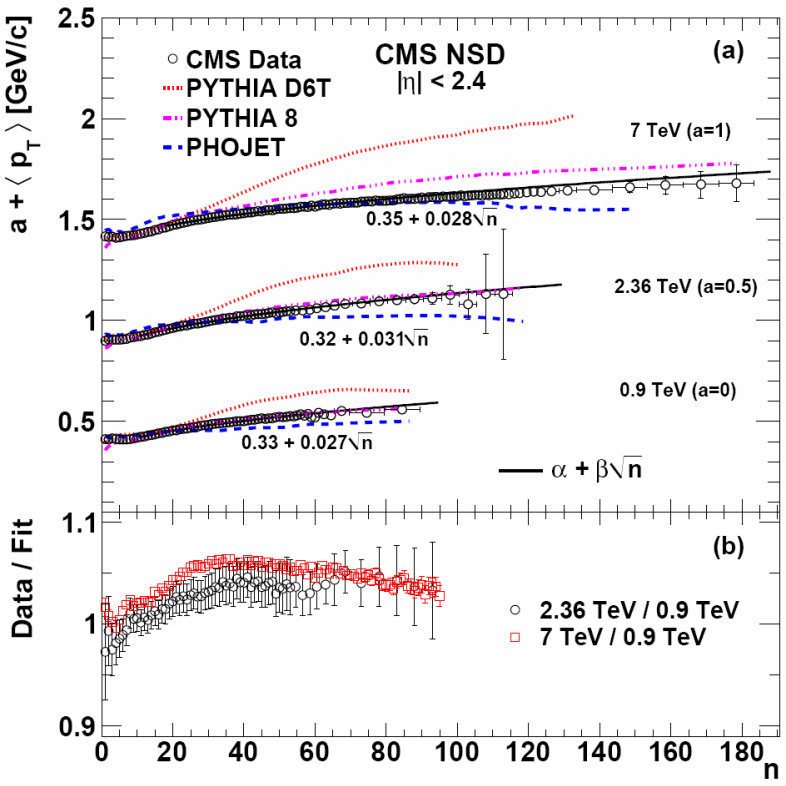


Charged particle production in minimum-bias events.



"Underlying event"

Charged Particles in Minimum Bias Interactions



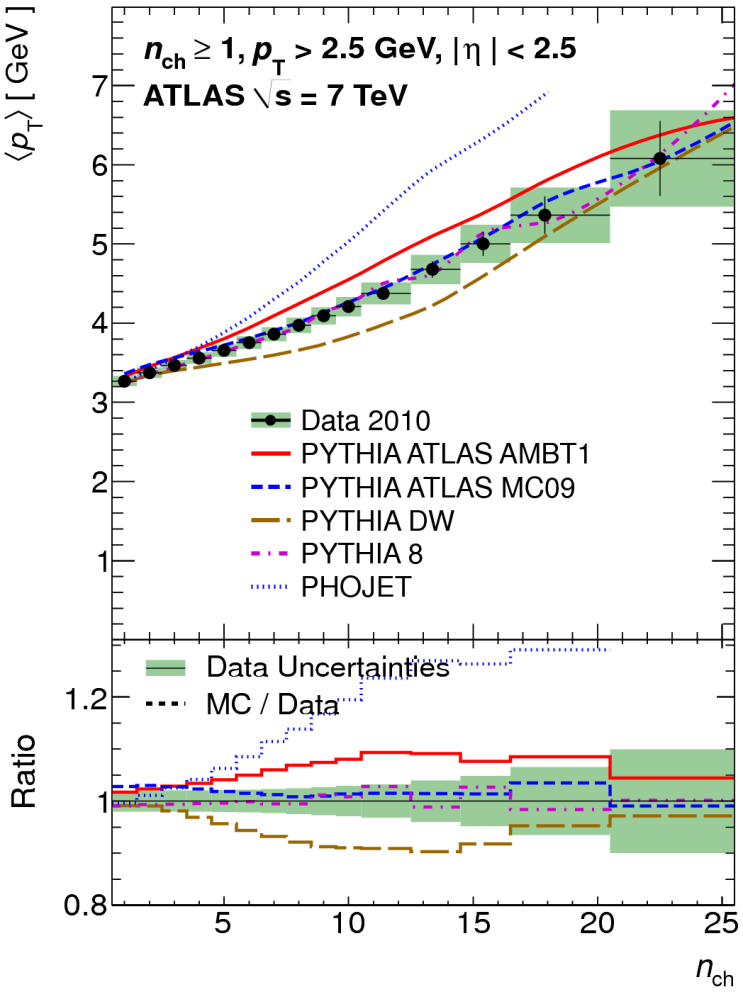
I particularly like the way CMS plots their data here, especially how they chose to flatten it.

- The simplest thing to do is to just count tracks (properly corrected, of course).
- Even these have significant differences (~1.5) between the predictions of various Monte Carlos and Monte Carlo tunes.
- Energy dependence is a factor. Tthe LHC has several energies available:
  - 900 GeV
  - 2.36 TeV
  - 2.76 TeV
  - 3.15 TeV ?
  - 7 TeV
  - 8 TeV

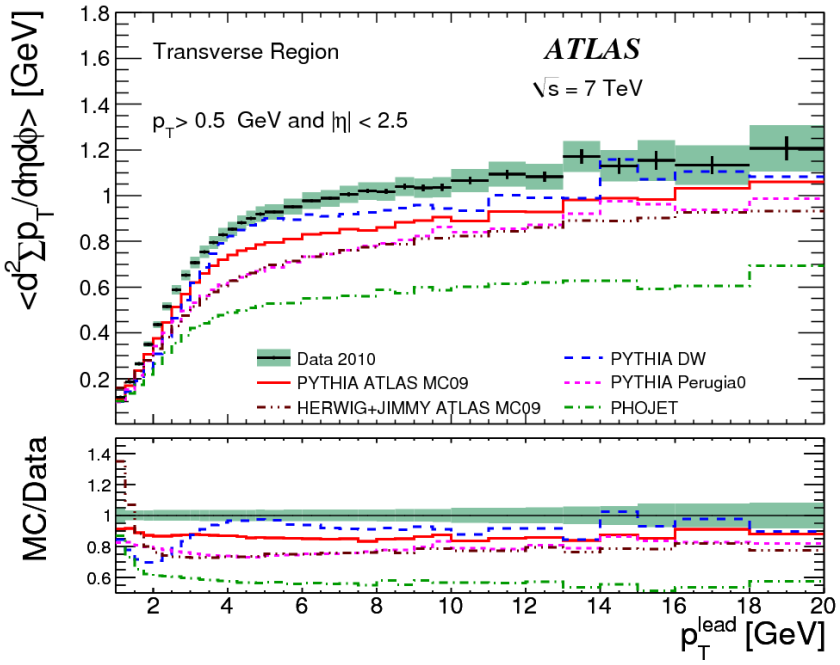
All four experiments participate in these measurements.

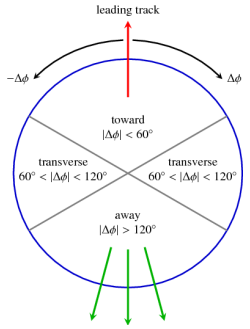
More Complex Measurements

- One can go beyond <n> or $d\sigma/p_T$
- There are several generic questions we expect Monte Carlos and their tunes to answer:
  - Is the energy flow right?
  - Is the energy partitioned correctly as a function of p_T?
  - Is the energy partitioned correctly among the particles?
  - Is the particle composition correct?
    - Baryon/meson ratio
    - Strange/non-strange ratio
- The figure shows the energy partitioning among particles
  - The Monte Carlos have a wide range of predictions
  - Even Monte Carlo tuned on the data doesn't do spectacularly well.



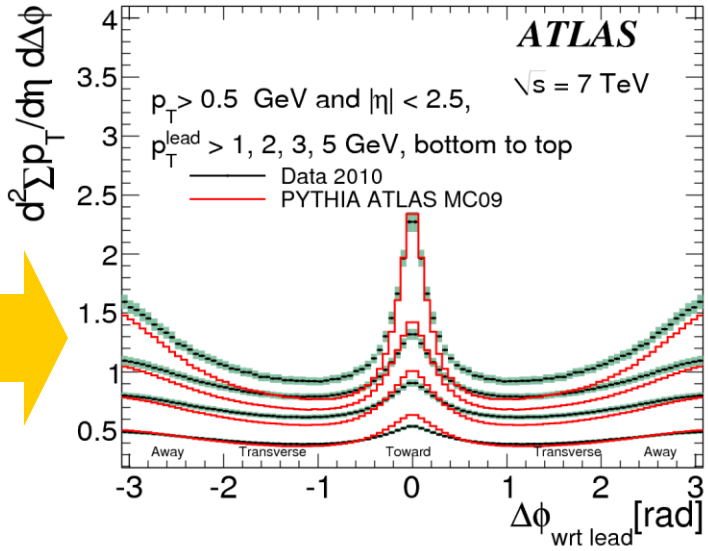
Underlying Event





Particle production in the transverse region is something with a factor ~2 difference in MC predictions. The data is above all of the predictions.

The physics that this covers is the onset of jet production: the gradual change in topology from spherical to back-to-back.

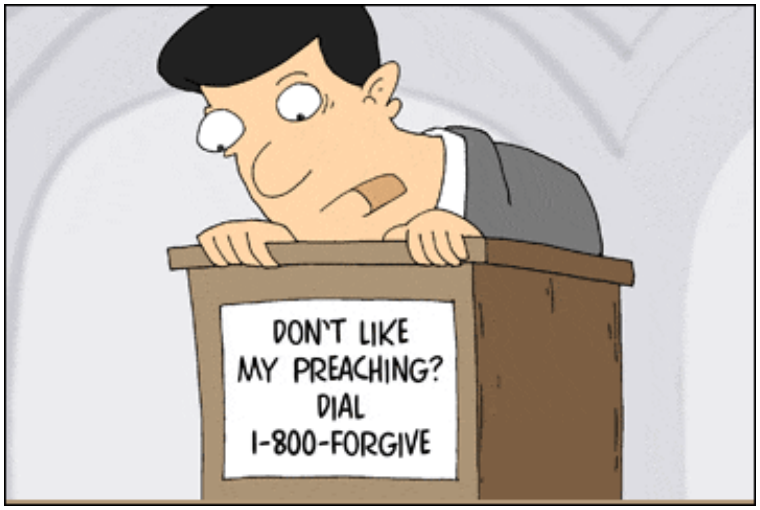


Monte Carlo Tuning

- Typically, one has $O(10^2)$ adjustable parameters
- One has O(10) *types* of measurements – with $O(10^2)$ points each
- One then finds the combination of MC parameters that best fit the data
  - This is usually done in a semi-automated way, using tools like PROFESSOR
  - It usually takes some human intervention
    - For the ATLAS tunes, some CDF data could not be made consistent
- The parameter names may not correspond to the "obvious" measurement (or any measurement, for that matter)
  - Multiple Parton Interactions are primarily constrained by UE multiplicities in the transverse region, not by dedicated MPI measurements.

This is probably the best possible way to incorporate the data we have, but one should not overestimate the predictive power of this technique. One needs to be very careful about drawing physics conclusions from parameter names. (like MPI)

Double Parton Scattering



- Some of you have heard my rant before. I'm afraid you have to hear it again.
- We usually characterize DPS/MPI in terms of a *single number* – the effective cross-section
- We should characterize this as a *function*.
- It must have an energy dependence.
  - At high *x*, momentum conservation shuts off double parton scattering. One cannot have two scatters with $x > 0.5$.
  - At low *x*, geometry enhances double parton scattering.
  - Since we know it cannot be a constant, why express it as one?
- With an energy dependence, we could extrapolate from high p_T, where DPS is measured, to low p_T, where the Monte Carlo tunes want to know it.

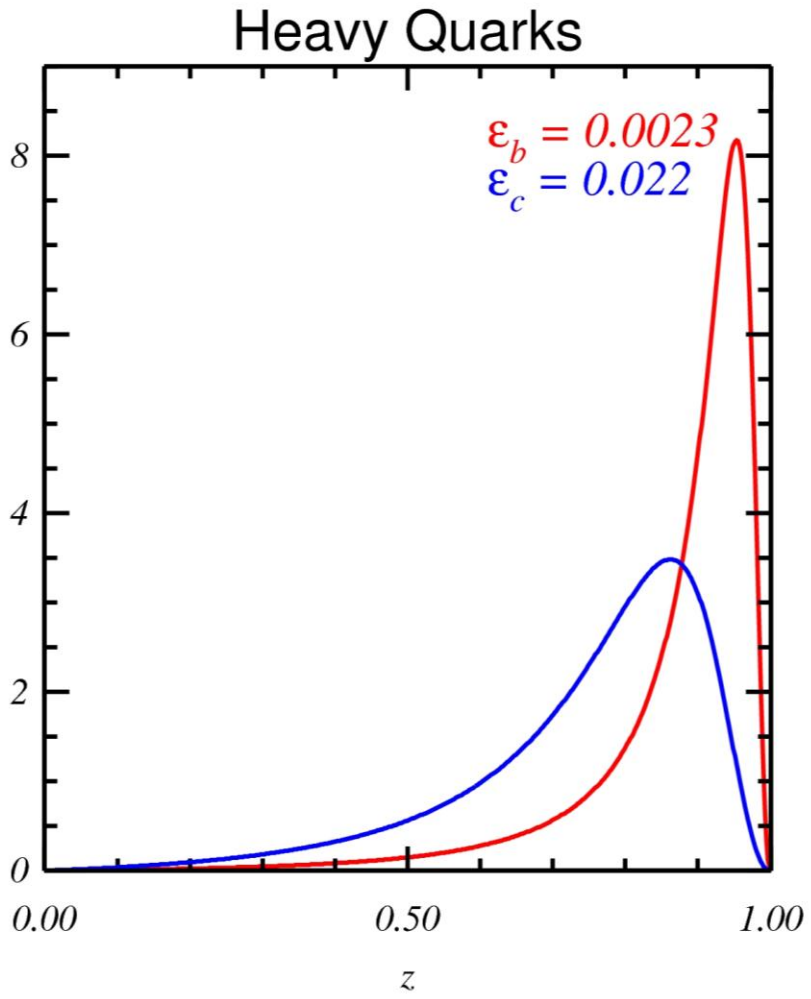
$$\sigma_{AB} = \frac{\sigma_A \sigma_B}{\sigma_{Effective}}$$

$$\sigma_{AB} = A(\hat{s}) \frac{\sigma_A \sigma_B}{\sigma_{Inelastic}}$$

Moving on from multiplicity measurements…

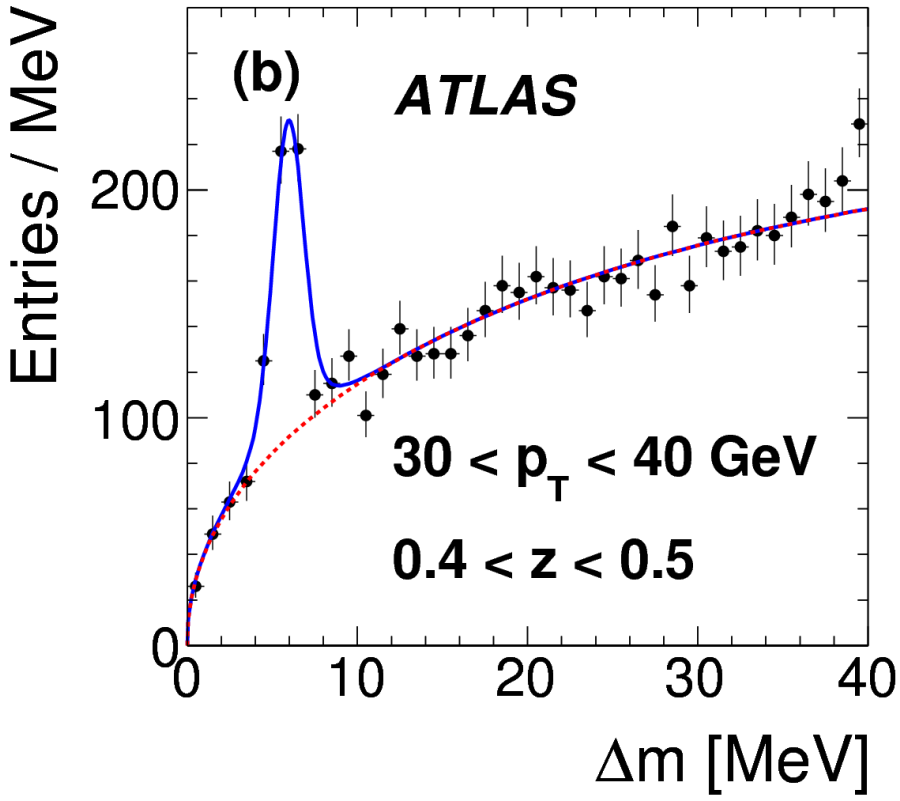
Heavy Flavor Production

- Heavy quarks fragment hard.
  - z = pT(quark)/pT(jet) peaks near 1
  - The heavier the quark, the harder the fragmentation.
- We can see this at, e.g. LEP.
  - Qualitatively it looks like the plot on the right (Peterson)
  - Quantitatively, the agreement is not quite so good – this model is somewhat dated.



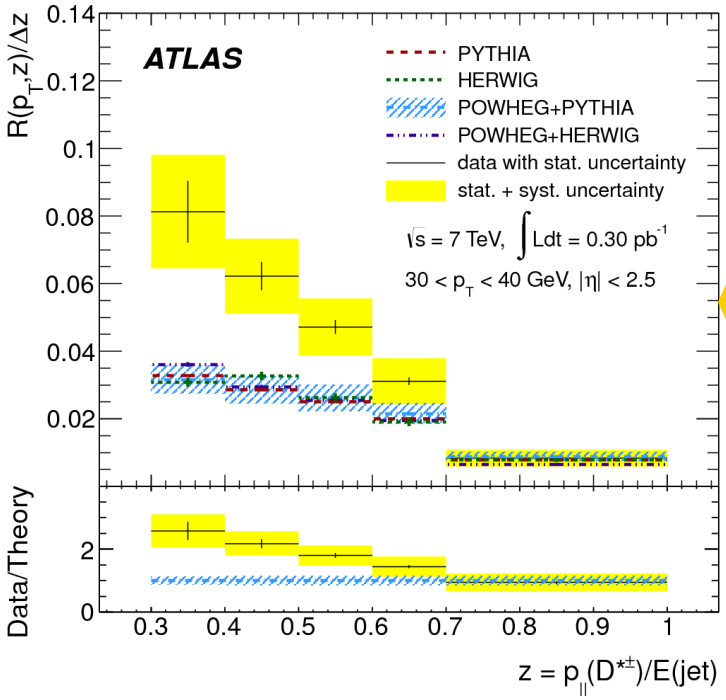
Testing this at the LHC

- ATLAS looks for D* mesons in jets.
  - D* signal is incontrovertable
  - Obviously, this is a charm measurement, not a bottom measurement
- ATLAS then plots something it calls "R" which is essentially dN/dz – the fragmentation function.



$$D^{*+} \rightarrow D^0 \pi^+$$

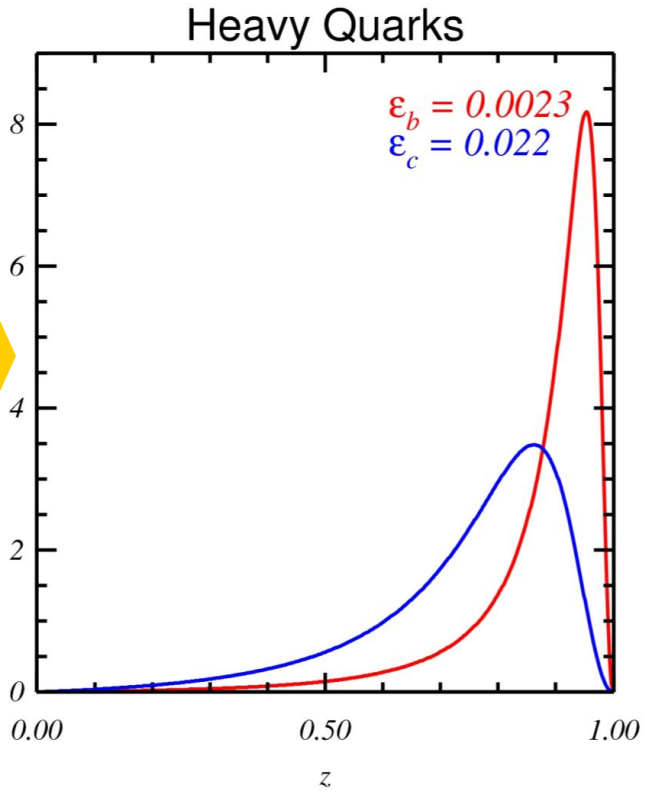
Testing this at the LHC II



This

Looks nothing like

This

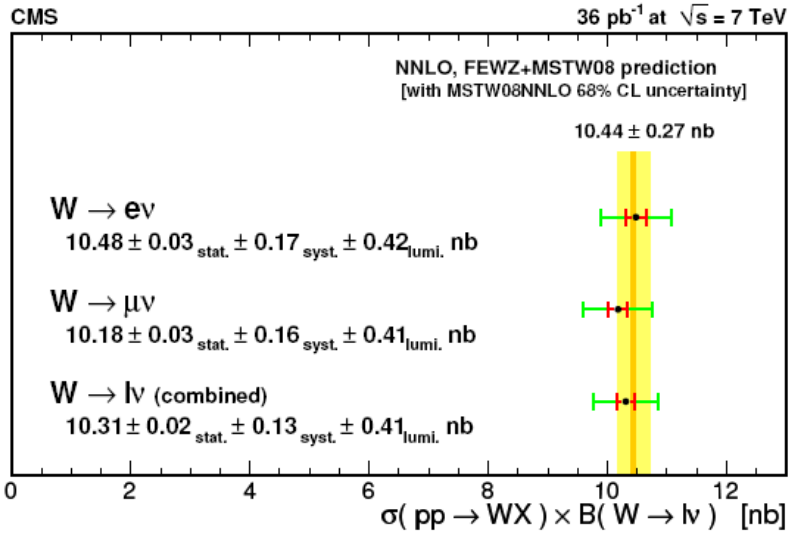


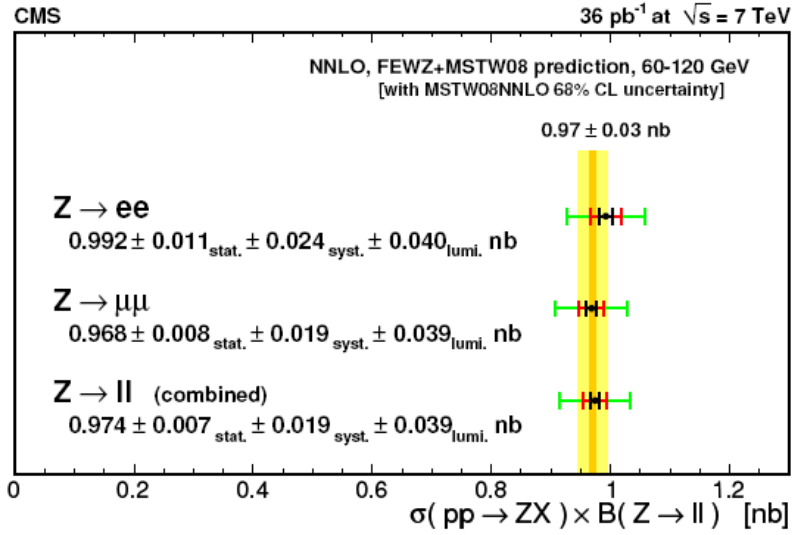
- The data looks nothing like what we expect for charm fragmentation.
- Even the Monte Carlo looks nothing like what we expect from charm fragmentation.
- Just to complete the trifecta, the Monte Carlo looks nothing like the data.

Lessons from Heavy Flavor

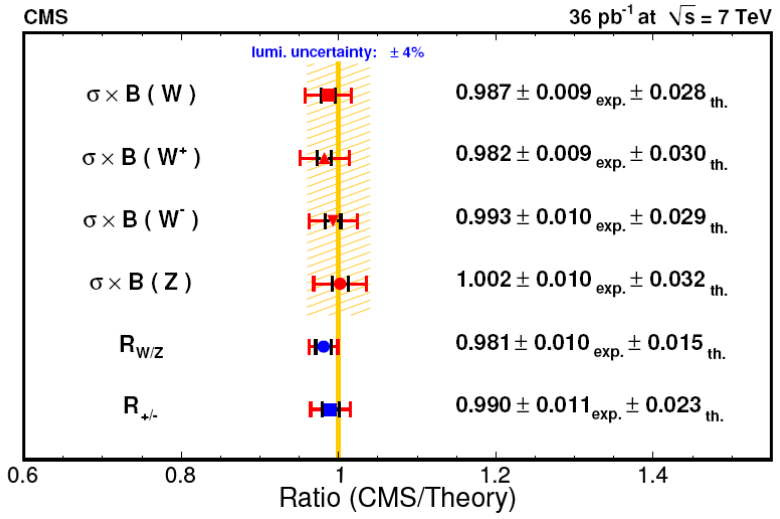
- Monte Carlos show a substantially softer charm spectrum than "conventional wisdom" (i.e. Peterson) suggests
  - Suspicion: we are seeing heavy flavor – at least charm - produced in the shower
  - This implies showering is the dominant production process in charm production at the LHC.
- The Monte Carlos know about showering – but still don't agree very well with data
- For that matter, they don't agree very well with themselves
- I am skeptical that tuning MCs to get the multiplicity distributions correct will get the charm content of a hadronic shower correct.
  - We will need to find a way to fold this into the tuning
- Heavy flavor is an important or dominant background to many searches (SUSY, Higgs). We need to get it right.

W and Z Production



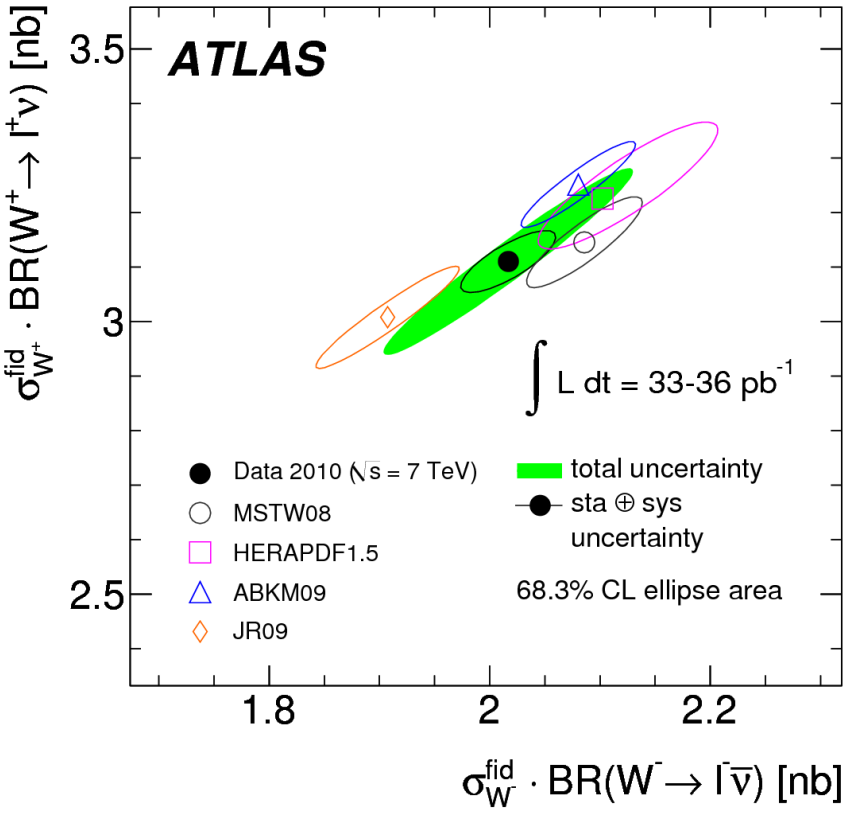


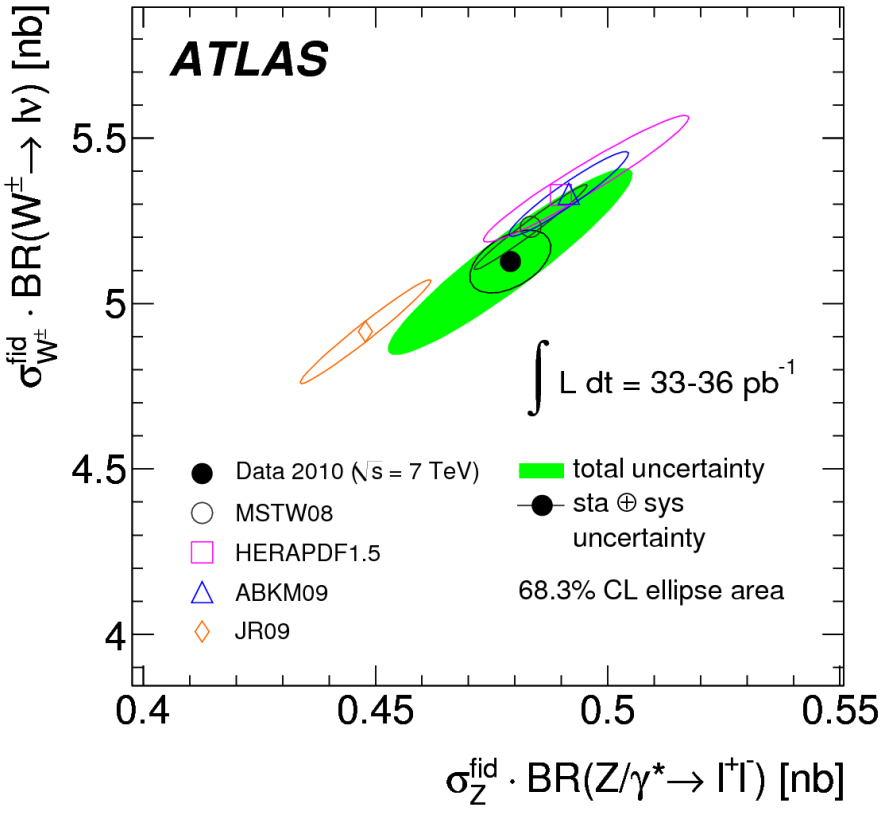
- Conventional wisdom is that since these results are systematically limited, there's no point in going beyond 36 pb^{-1}.
- Both experiments have published 36 pb^{-1} results.



ATLAS results are similar.

There's More Information In These Numbers

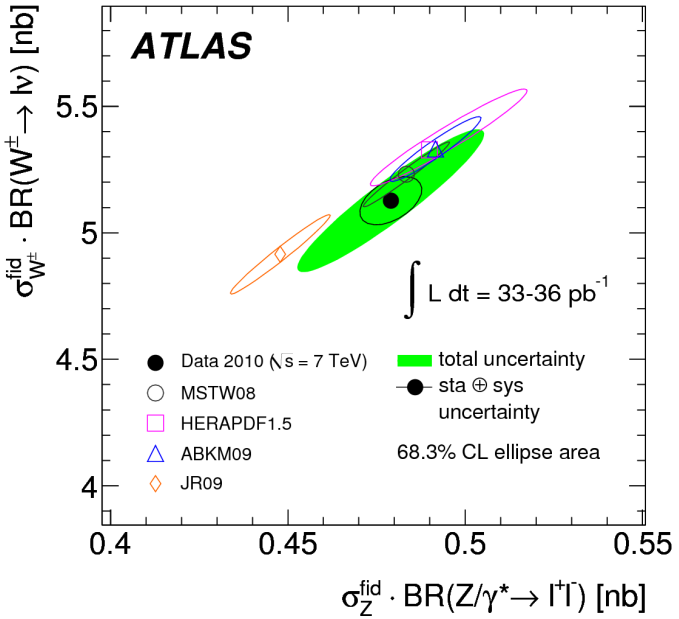




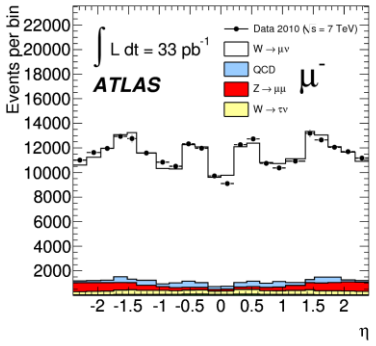
With three numbers [$\sigma(W^+)$, $\sigma(W^-)$ and $\sigma(Z)$] one can make two independent 2-D plots. Theory predictions that overlap in a 1-D plot separate in the 2-D plots.

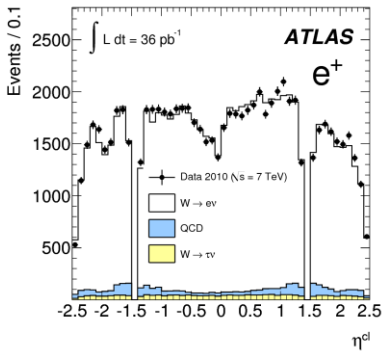
The Future

- The conventional wisdom "systematics means it's not worth going past 36 pb^{-1}" may deserve amending.
- One needs to think of a 5 fb^{-1} data set as being made of ~130 individual 36 pb^{-1} datasets.
- Dividing into rapidity bins is a natural thing to do: y ~ Δx of the partons.
  - This data exists – at least for 36 pb^{-1}.



The key word in this plot is abbreviated, and is "fiducial". In this, ATLAS directly compares what they observe with theoretical predictions for that particular phase space.

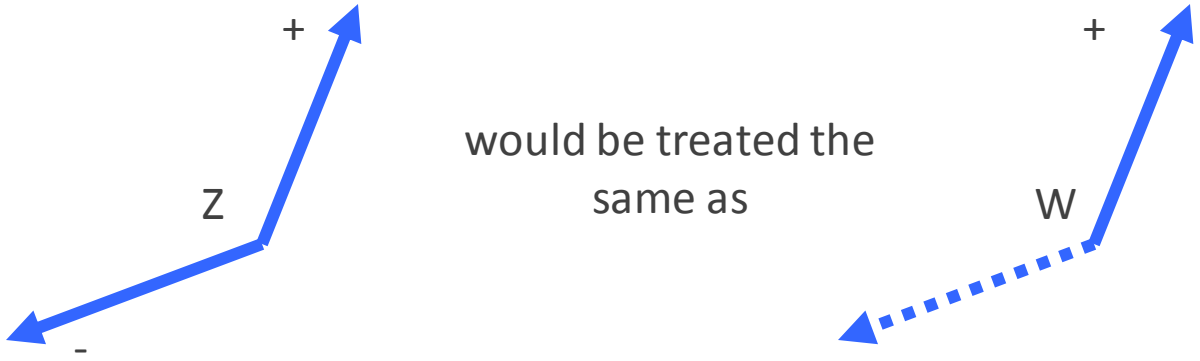




A question I don't know the answer to: what can we learn from comparing, e.g. W^+ production at y = 0.5 with W^- production at y = 0.9?

The Missing Neutrino

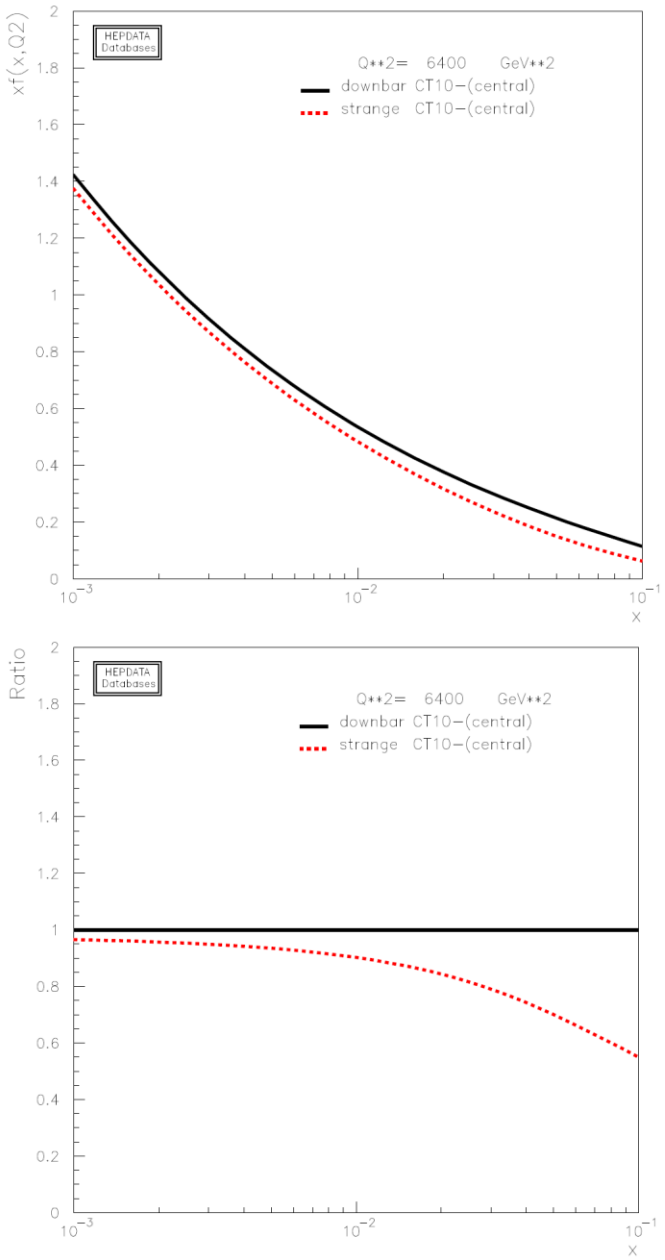
- The W is missing a neutrino. How do we deal with that to get the W rapidity?
  - We know the W mass. We can solve for $p_z(\nu)$, get two solutions:
    - We can simply pick one
    - We can weight the two solutions
  - Alternatively, we can compare the $\eta(l^+)$ and $\eta(l^-)$ distributions for the Ws and Zs.
    - This integrates over the second lepton, irrespective of its charge.



- I have no idea which is better – it's a question of systematics and constraints
  - A nice project for someone

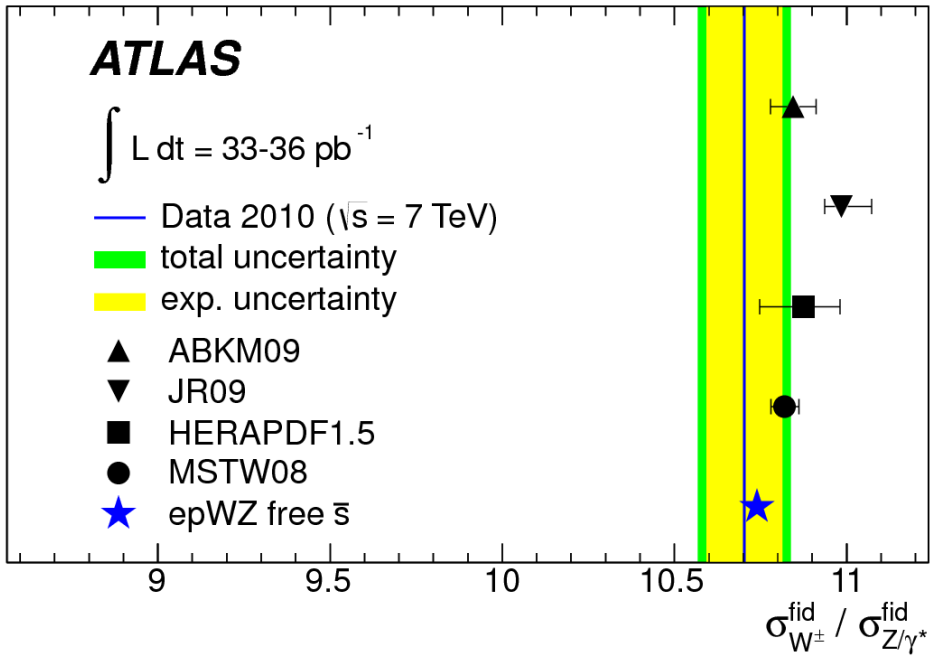
Strangeness PDFs

- The last few slides discussed the momentum content of the proton
  - An interest of mine
- The same measurement also constrains the flavor content of the proton.
  - HEPDATA plots (right) show that production of W's off the strange sea is only Cabibbo suppressed: there is almost as much sbar as dbar in the proton.
  - This varies with x at the 10's of % level
- This is driven by cross-section ratio measurements (as a function of rapidity) which are then added to the PDF global fits.



Strangeness PDFs (II)

- With 36 pb^{-1}, the approximate sensitivity of ATLAS is comparable to the difference between PDF sets.
- However, with 36 pb^{-1} you only get one point. We expect sbar(x)/dbar(x) to vary with x.
- To study this, we need to divide the data into rapidity bins, with comparable numbers of Ws to the 36 pb^{-1} sample. Easy to do with a few fb^{-1}s.



The Final Slide

- Monte Carlo tuning is a complicated business
  - Many parameters, but only a few ***types*** of measurements
  - Today the tuning is driven by multiplicity measurements
    - Even when more direct measurements are available (e.g. DPS)
- Charm production doesn't look right
  - It appears to be dominated by showering
  - Tuning MCs to match multiplicity distributions probably doesn't get HF fragmentation right
  - With more data one could look at bottom…maybe even start to look at top.
- There is still information to extract from the W/Z Cross-sections
  - A multi-femtobarn inclusive measurement is not helpful,
  - But dividing a multi-femtobarn sample into kinematic subsets will be.
    - Probes unconstrained aspects of PDFs, including flavor.
- Thanks to the organizers for inviting me!