Conclusions and Outlook

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Preliminaries

- Thanks to the organizers for inviting me
- If I got something right,it's because the original presentation was clear and interesting
- If I got something wrong, it's my fault
- I tried to consolidate ideas rather than show the same plots even faster; I apologize for anyone or anything I left out

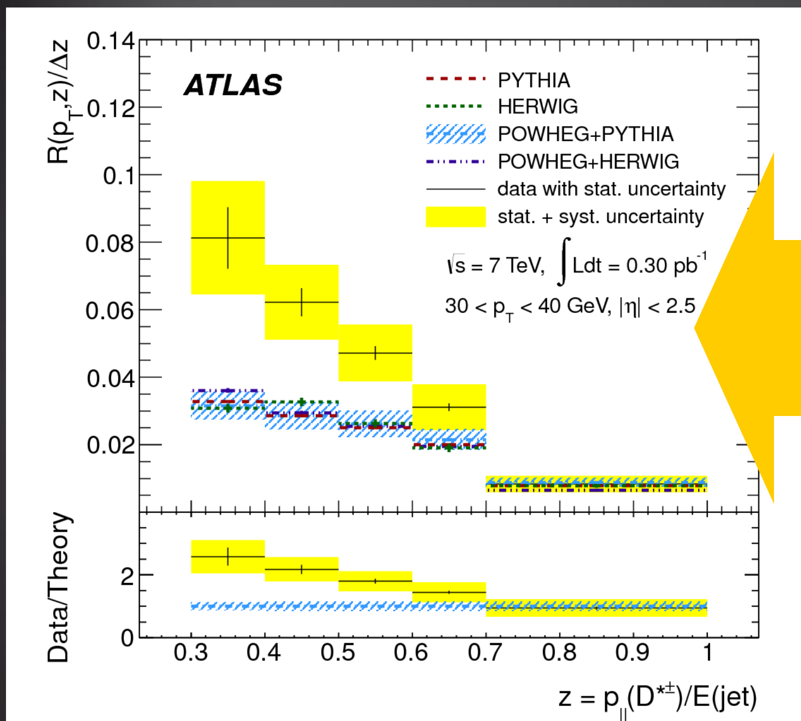
The 2014 Landscape

- *The 125 GeV Higgs mass is telling us there is new physics at the TeV scale*
- *Flavor, particularly FCNCs, is telling us there isn't until 10-15 TeV*
- *It is our responsibility and challenge to sort this out*

More Details

- Consider MSSM as the explanation for the light Higgs
- If squarks are degenerate, experimentally we know that m > 1½ TeV
- However, all that really needs to be light is the stop squark (or Top partner in other theories)
  – But if we do that, we've now introduced a non-trivial flavor sector – one that somehow does not leave its fingerprints on low energy measurements – especially FCNCs
- We heard many ideas on how this might work
  – Which ones are right?

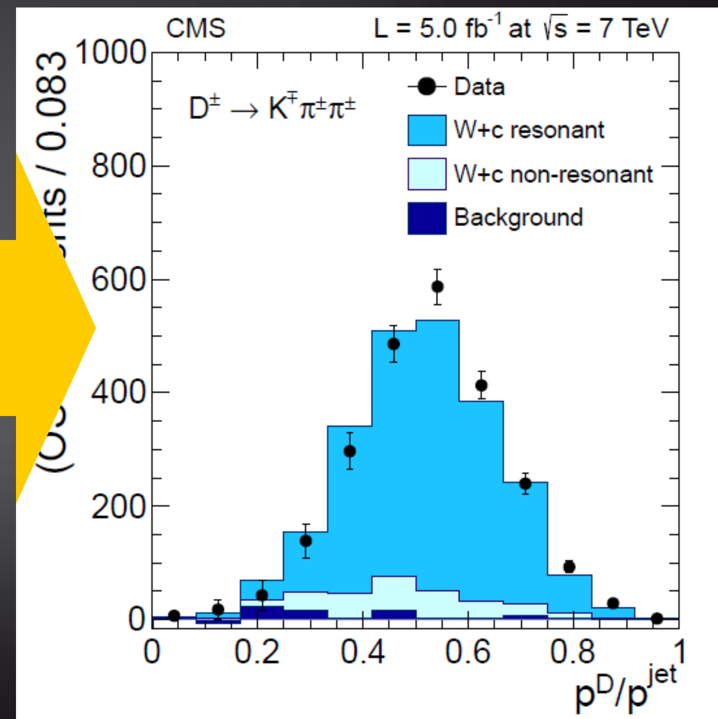
QCD With Charm



This

Looks nothing like

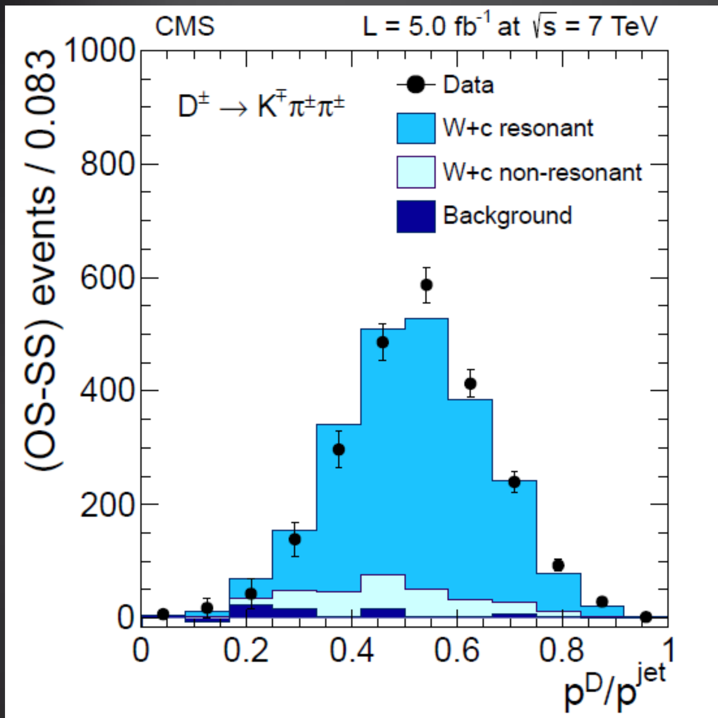
This

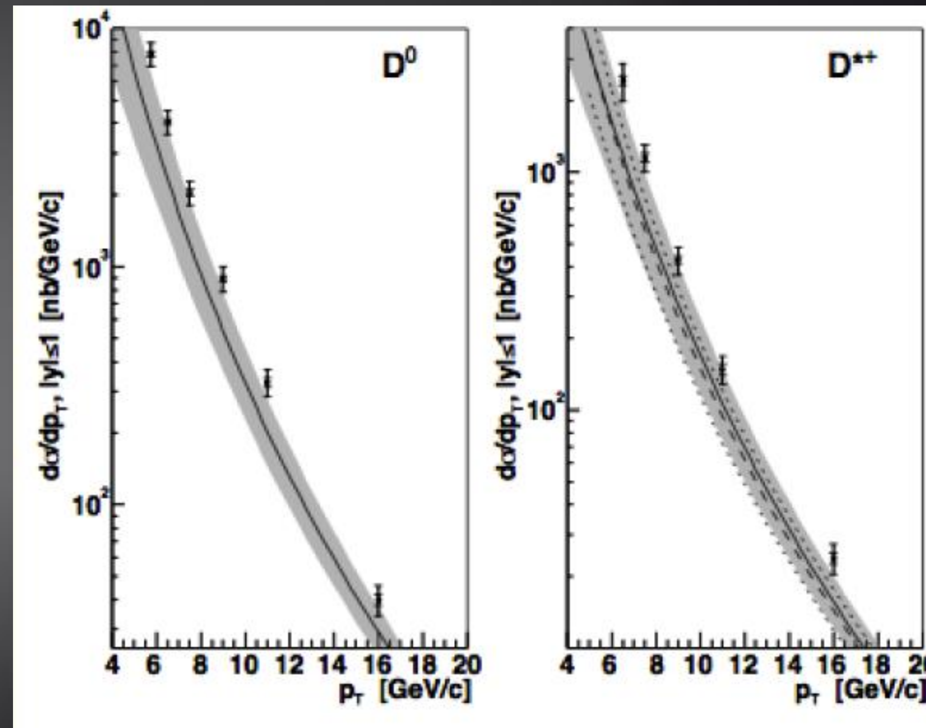


Jets containing charm

Jets initiated by charm

Two Plots from Tuesday





- The left plot suggests that charmed hadrons carry slightly more (~10%) energy than expected.
- If you shift the curve on right plots to the right by ~10%, the discrepancy disappears

QCD w/Charm Summary

- Charm is complicated
  - It's too heavy to be treated as a light quark
  - But not really heavy enough to be a heavy quark
    - This is part of it's…um…charm
- Working with charm requires some clarity on what exactly a c-jet is:
  - Is it a jet initiated by charm
  - Is it a jet containing charm?
- Is it a jet with net charm?

- W+c events not only give us information on the strange sea (and anti-strange sea), give us a pure (statistically) sample of charm-initiated jets

Future QCD Charm program

- We have (statistically) pure samples of charm jets, via W+c
- We have plenty of light-quark jets and gluon jets where we can observe charm in fragmentation
- It's probably time to start repeating the b measurements with c
  - Inclusive production
  - Pair production
  - Angular (and other) correlations

Top FCNCs

- Myth: even in the SM top FNCNs are small
- Fact: in the SM, they are about a million times larger for top than for bottom
  - However, in top the FCNCs are competing with 2 GeV of W+b, and not ~½ meV of other bottom decays
  - This makes the decay searches harder, but opens up the possibility of production searches like g+u → t

Top FCNCs in Production

- The u/c+g → t mode has been used for some time
  - A good fit: the final state is difficult, and the production partonic fluxes are high
- We're starting to see other modes, like associated production: u/c+g → t + Z
  - This explores tZc, in a way that is statistically independent of the search via top decays

Top FCNCs in Decays

- Experiments are setting $t \rightarrow Zc$ limits at the ~5 x 10^{-4} level.
  - There are not many models on the market with a prediction this large (which is not a reason not to look)
- Prospects for Run 2 and Hl-LHC are between 1 and 2 orders of magnitude better
  - These are more interesting with respect to models
  - Caveat: These studies are not as detailed as the analyses of actual data

Top FCNCs with Higgs

- Two general strategies for tcH
  - ATLAS: "Start with the Higgs, and build up from there"
  - CMS: "Start with the final state you want and look for a Higgs in it"
- Present sensitivity is $\Gamma \sim$ 10's of MeV
- Suggestion to use H → b+bbar
  - This looks really tough to me
  - Final state of lvbcbb looks a lot like lvbcsb

Top FCNCs with Photons

- Conspicuous by their absence
- It's not clear why
  - Yes, there is more background, (but tighter kinematics cuts a lot of it away)
  - But the efficiency of a photon is much higher than that of a Z (the branching fraction to leptons is deadly)

Trivia: this was the first public top FCNC

"Precision"

- "High Precision control of thebackgrounds" was an expression used in multiple talks.
- Sometimes the only window into new physics is a counting experiment
- PDF uncertainties can still be the limiting factor
- If something is hiding under or near the top, we may be confused:
  - Example: stop → top + LSP near threshold can pull the top off-shell
  - This will cause it to be differently misreconstructed depending on channel

Charm Tagging

- This is hard
- Real damn hard

- Living in between bottom and light quarks is not a very nice place to be.
  - The average B multiplicity is 5½. For charm it's maybe 2
  - The D^0 lifetime is short
  - B's decay to D's

Charm Tagging Strategies

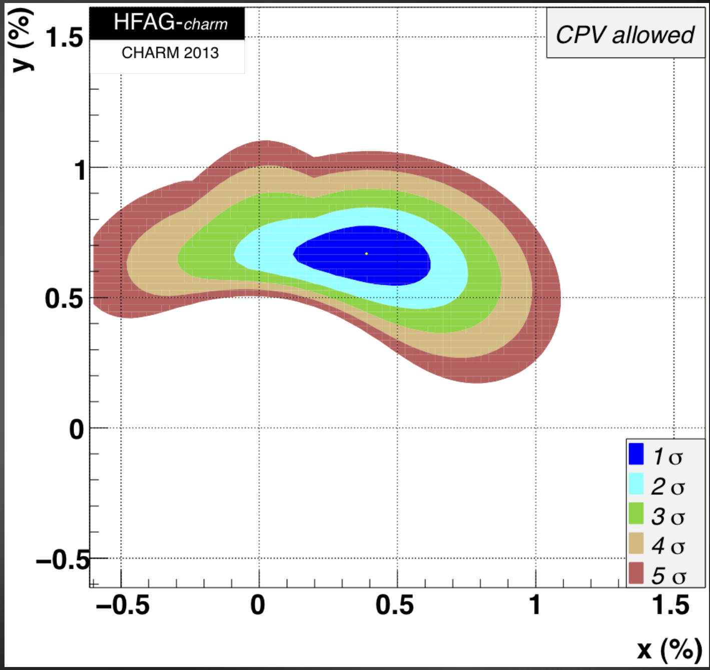
- Look for a D^0 or D^*
  - Pros:you're sure you had a charm
  - Cons: Your are not sure you didn't have a charm from a b-quark decay
  - Branching fractions are not favorable
- Look for a lepton (=muon)
  - Pros: Better branching fraction
  - Cons: Bottom quarks decay this way too
- Lifetime tagging
  - Pros: Well developed techniques from b-tagging, avoids small Branching fractions
  - Cons: Looking for something that looks too much like a light quark to be a b, and too much like a b to be a light quark

Oversimplified numbers

- Everything depends on the operating point
- Efficiencies are in the 10-50% range
- Rejections are in the 10-200 range
  - One can (and does) trade light quark rejection for bottom rejection. What is the best point depends on the exact analysis

Charm CPV and Mixing

- There are hints of CP violation in charm but nothing conclusive
- We can go another order of magnitude before running into the "QCD Muck"*
- It looks like we will get that order of magnitude with LHCb/Belle-II



* Unlike many, I like QCD!

Next Steps

- This tension between EWK and Flavor is THE problem for the next decade :
  - The special role played by the 3rd Family is obviously important
  - Whether or not a special role is also played by the 2nd Family is even more important
- I don't see a shortage of theoretical ideas (but please keep them coming!) – I see a shortage of data that can distinguish between them
  - Fortunately that data is coming soon
- With a few notable exceptions ($t \rightarrow c\,\gamma$), the experiments are not missing analyses. It is time, though, to "dot the I's and cross the T's" before the 14-ish TeV data arrives
  - QCD measurements of charm, using improved Monte Carlos…

Final Thought

- Thanks to the organizers for the invitation
- Thanks to my fellow participants for making this workshop so interesting and worthwhile