Standard Model Physics at the Large Hadron Collider

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on behalf of the ATLAS and CMS collaborations

Preliminaries

There are two pieces to the Standard Model – QCD and Electroweak Theory. Usually when I give a talk like this, I split this about 60-40 in favor of QCD.

In light of “recent developments”, there’s a strong argument to spend a little more time on the electroweak side.

Choice of Material

- There are dozens of published results and more than a hundred preliminary results on SM physics.
  - 15 seconds per topic seemed not the right way to organize things
- Instead, I will concentrate on:
  - Analyses that will provide some background on results that you will be seeing over the next year or two
  - Analyses that change the way we do things or think about things
  - ~~Analyses that I think are kind of neat~~ No time!
  - Analyses that ***you*** might want to work on
- I will not in any way be complete
- In particular, if I show a result from one experiment, it does not mean that the other one didn't do it.


= something I wish someone would have explained to me when I was earlier in my career

Before We Take Off

STOP ME if I go too fast or you have questions!!

I know I talk too fast, so please interrupt me – my goal is not to cover as much material as possible: it's to *uncover* as much material as possible

The Twin Pillars of the Standard Model

- Quantum Chromodynamics
  - Quarks carry a charge called “color” carried by gluons which themselves also carry color charge.
  - A strong force (in fact, THE strong force)
  - Confines quarks into hadrons

- Electroweak Unification
  - The electric force, the magnetic force and the weak interaction that mediates β-decay are all aspects of the same “electroweak” force.
  - Only three constants enter into it: e.g. α, G_F and $\sin^2(\theta_W)$.
  - A chiral theory: it treats particles with left-handed spin differently than particles with right-handed spin.

A beautiful theory.

Beautiful does not mean perfect.

Why Study The Standard Model?

Why Study The Standard Model?

- Understanding it is a necessary precondition for discovering anything beyond the Standard Model
  - Whatever physics you intend to do in 2011, you'll be studying SM physics in 2008
    - *Rate is also an issue*
- It's interesting in and of itself
  - It's predictive power remains extraordinary (e.g. g-2 for the electron)
- We know it's incomplete
  - It's a low energy effective theory: can we see what lies beyond it?

- We've lived with the SM for ~25 years
  - Long enough so that features we used to find endearing are starting to become annoying
- Think of the LHC as "marriage counseling" for the SM

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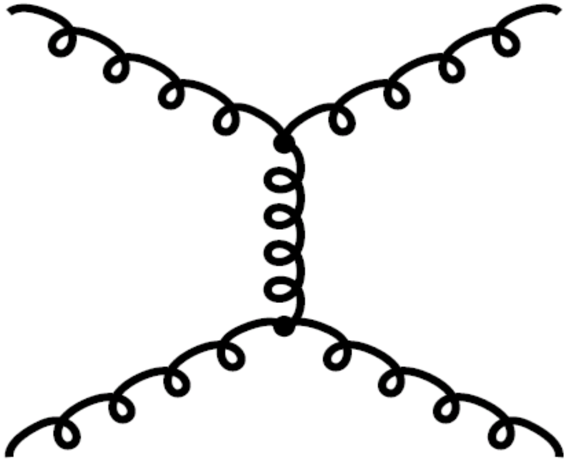
A slide from four years ago.

The Issue with QCD

Calculations can be extraordinarily difficult – many quantities we would like to calculate (e.g. the structure of the proton) need to be measured.

Portrait of a Simple QCD Calculation

One part: the
calculation of the
“hard scatter”

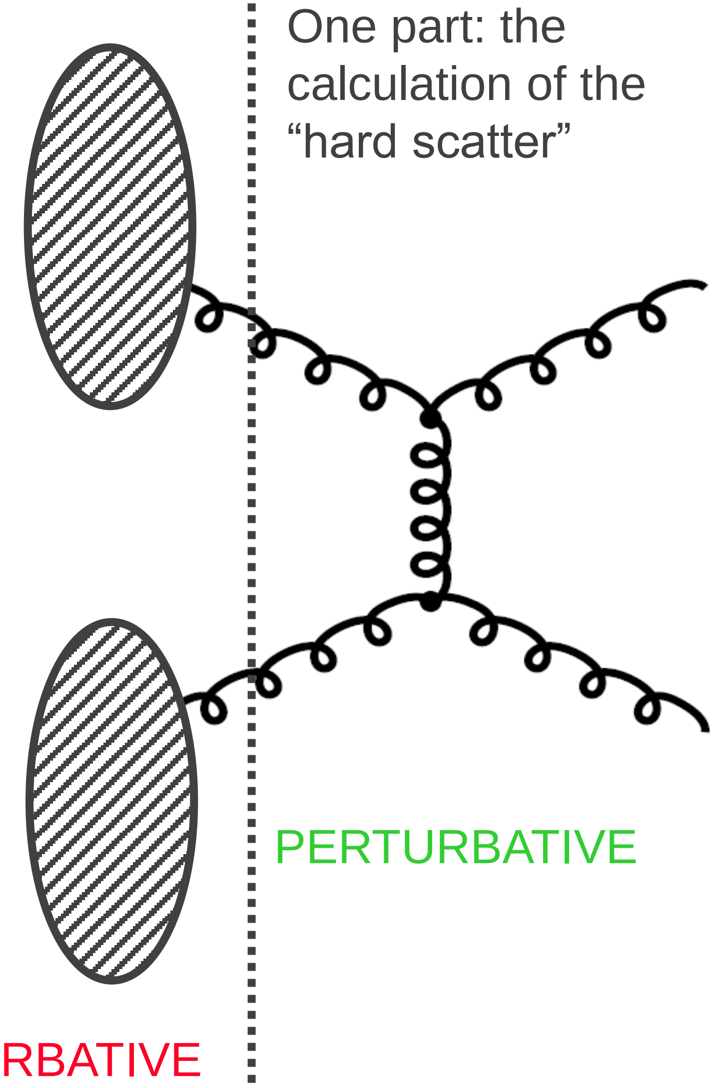


PERTURBATIVE

Portrait of a Simple QCD Calculation

One part: the calculation of the "hard scatter"

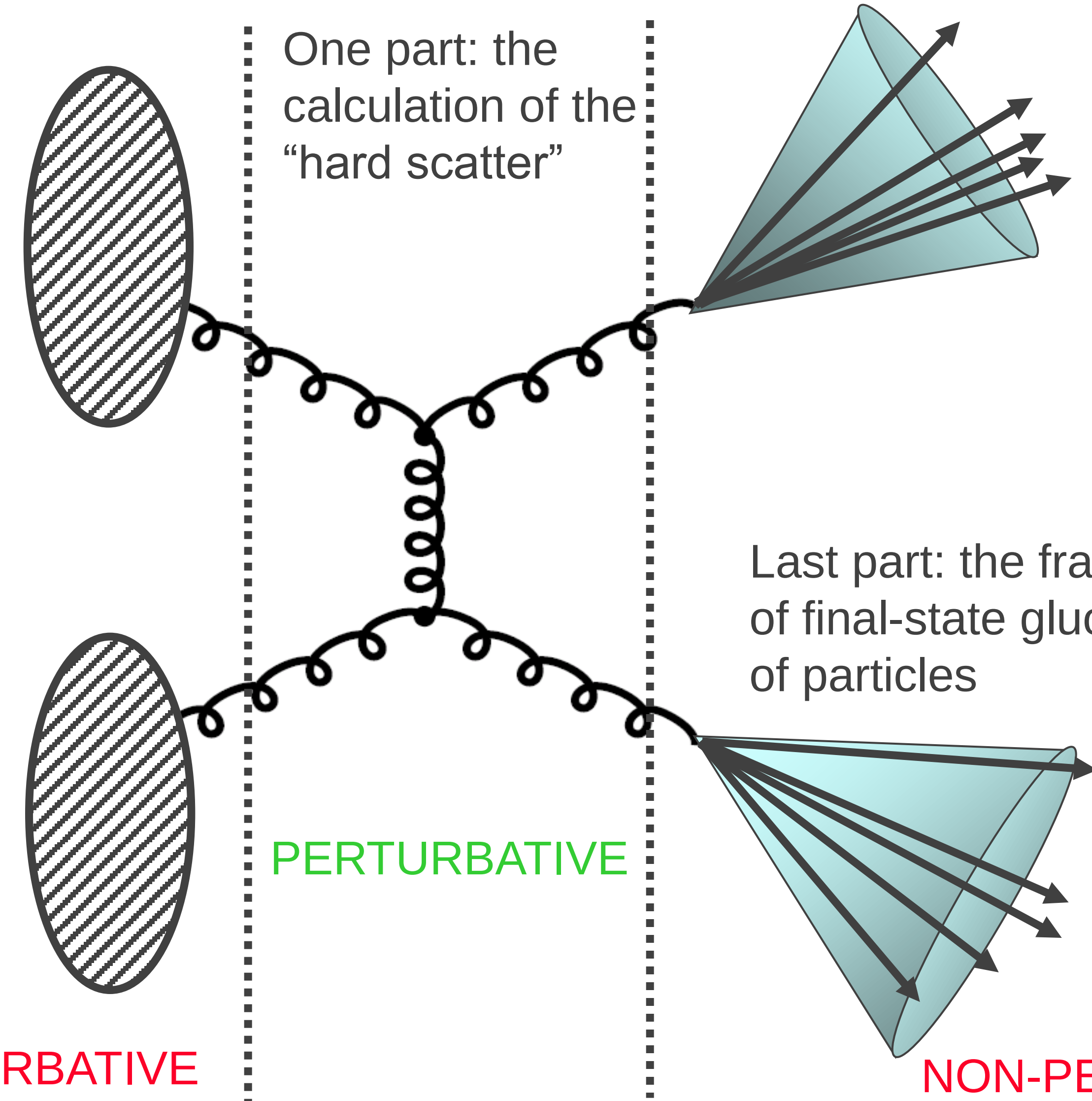
Another part: connecting the calculation (which involves gluons) to protons (which contain gluons)



PERTURBATIVE

NON-PERTURBATIVE

Portrait of a Simple QCD Calculation



One part: the calculation of the "hard scatter"

Another part: connecting the calculation (which involves gluons) to protons (which contain gluons)

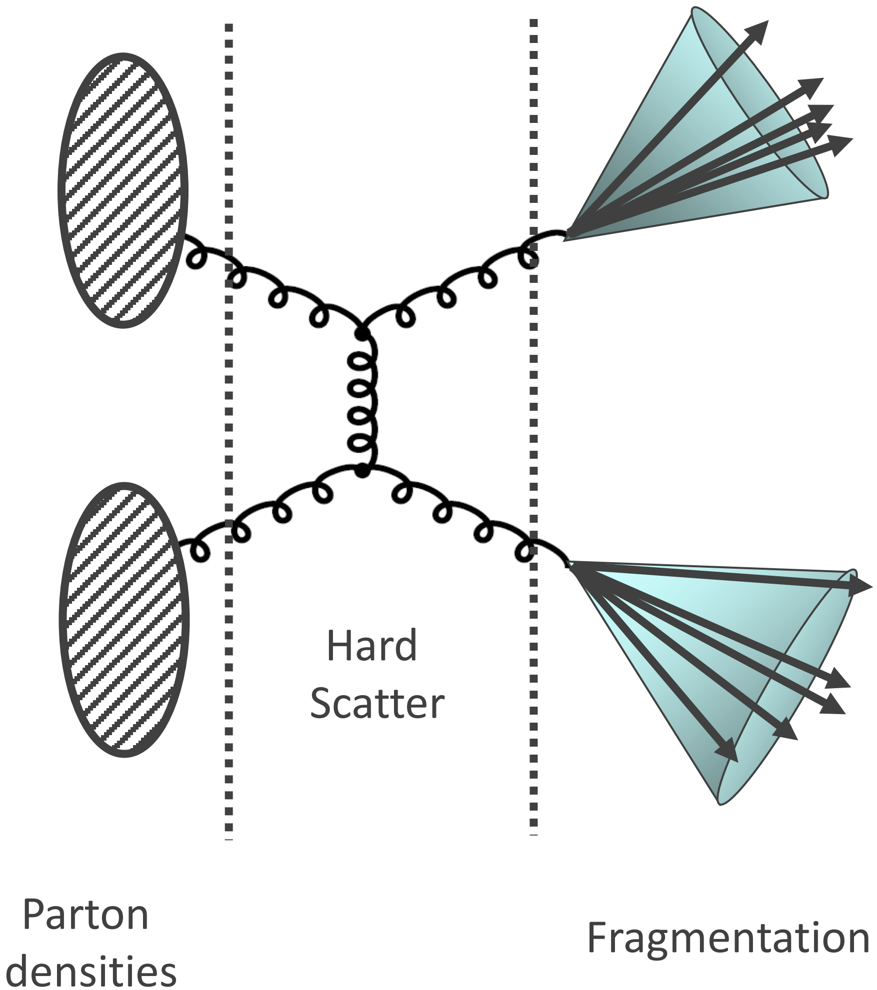
Last part: the fragmentation of final-state gluons into jets of particles

PERTURBATIVE

NON-PERTURBATIVE

NON-PERTURBATIVE

Comparison with Experiment



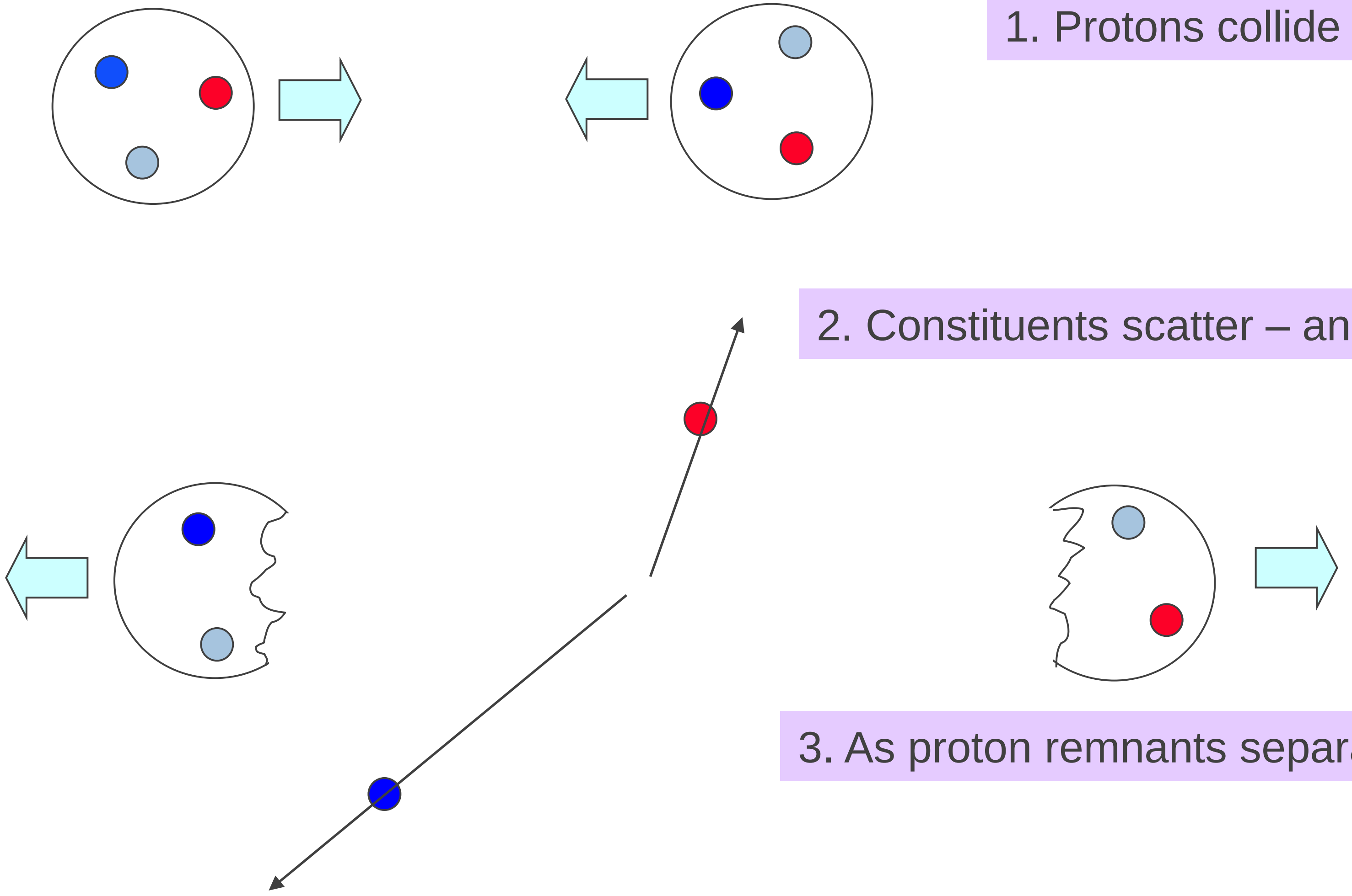
- Our experience has been that progress is made when we already know 2 of the 3 parts.
  - Experiment then constrains the third.
- It is possible to gain information when this is not true, but the situation is much more confusing.

Proton Collisions: The Ideal World

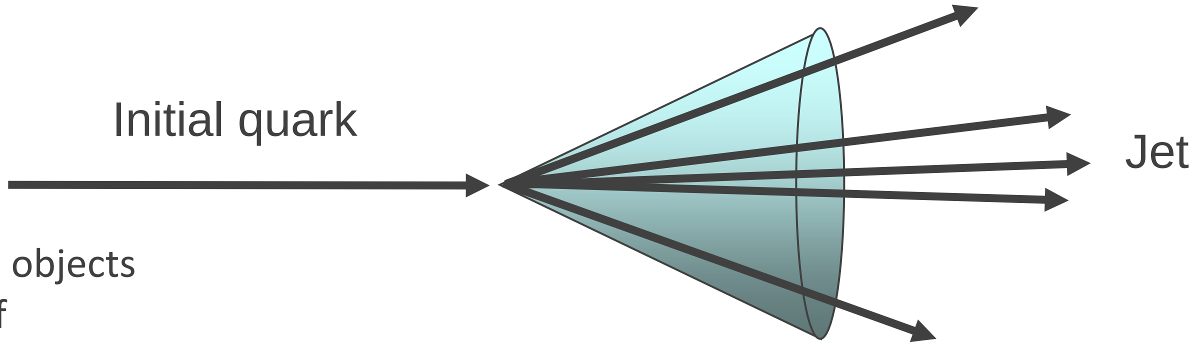
1. Protons collide

2. Constituents scatter – and form jets

3. As proton remnants separate



Jets

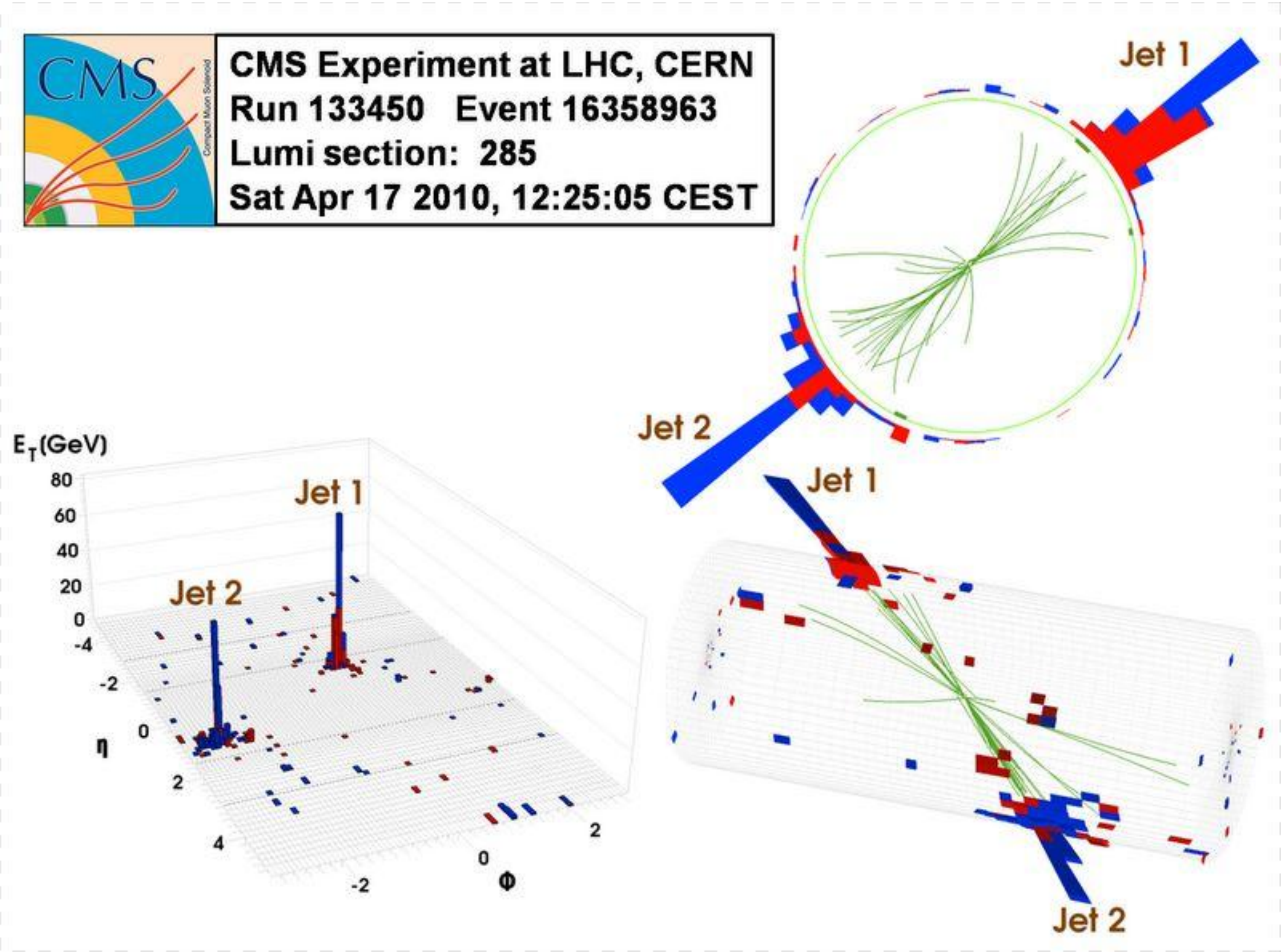


- The force between two colored objects (e.g. quarks) is ~independent of distance
  - Therefore the potential energy grows (~linearly) with distance
  - When it gets big enough, it pops a quark-antiquark pair out of the vacuum
  - These quarks and antiquarks ultimately end up as a collection of hadrons
- We can't calculate how often a jet's final state is, e.g. ten π's, three K's and a Λ.

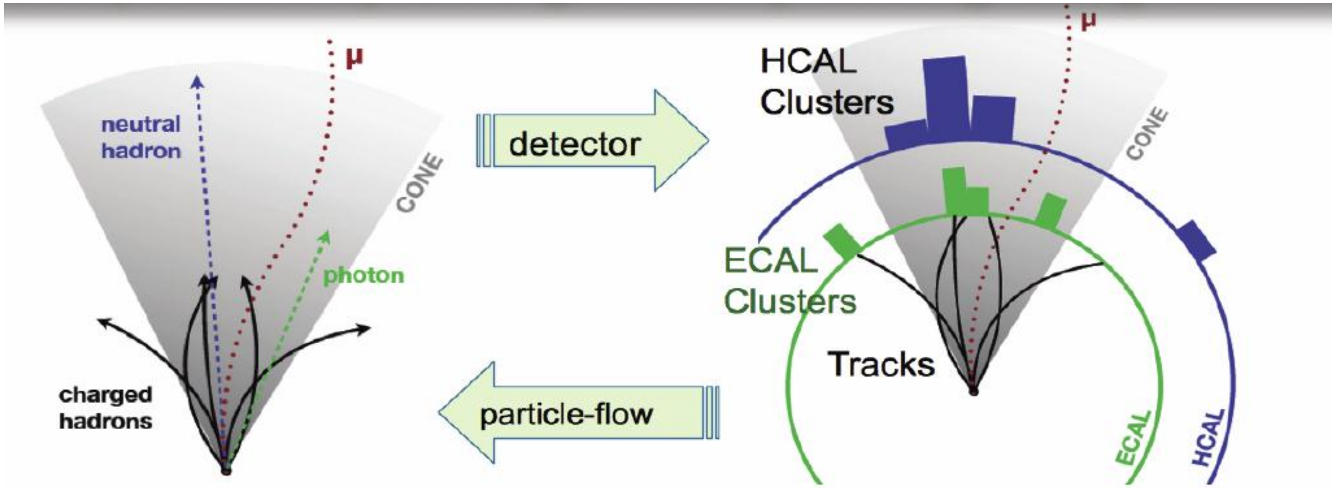
- Fortunately, **it doesn't matter**.
  - We're interested in the quark or gluon that produced the jet.
  - Summing over all the details of the jet's composition and evolution is A Good Thing.
    - Two jets of the same energy can look quite different; this lets us treat them the same

What makes the measurement possible & useful is the conservation of energy & momentum.

Jets in Real Life



CMS, Particle Flow and ATLAS



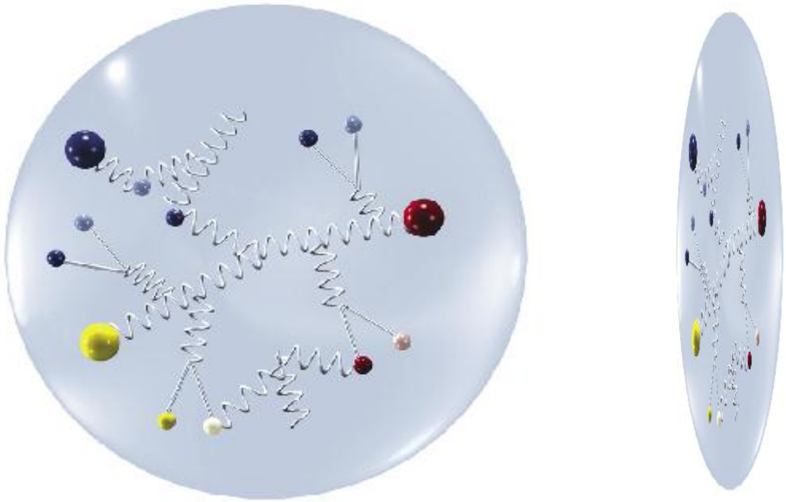
With Particle Flow, energy deposits in the calorimeters are replaced by the momenta of tracks that point at them.

Only ~11% of the energy is contained in neutral hadrons.

- If this is such a good idea, why does ATLAS use calorimetric jets?
- The benefits to ATLAS are smaller than they are to CMS
  - This is due to the design choices of the experiment
  - CMS put more emphasis on tracking; ATLAS put more emphasis on hadron calorimetry
  - ATLAS needs it less, and it helps ATLAS less

The Structure of the Proton

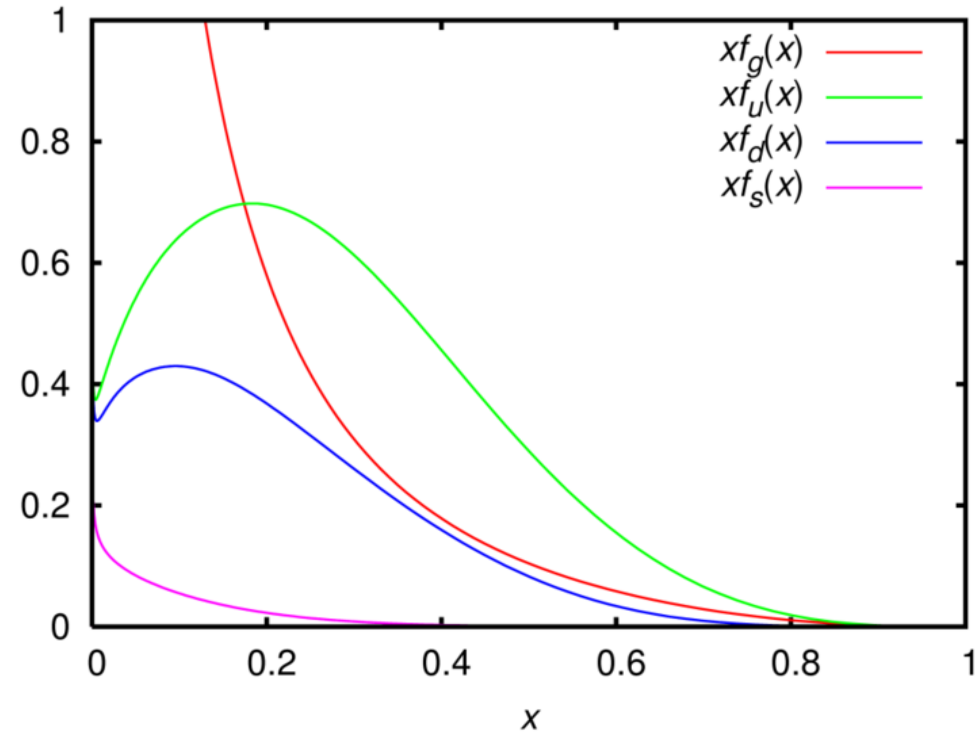
These kinds of measurements can be used to probe the structure of the proton.



Because the proton is traveling so close to the speed of light, it’s internal clocks are slowed down by a factor of 4000 (in the lab frame) – essentially freezing it.   We look at what is essentially a 2-d snapshot of the proton.

Parton Densities

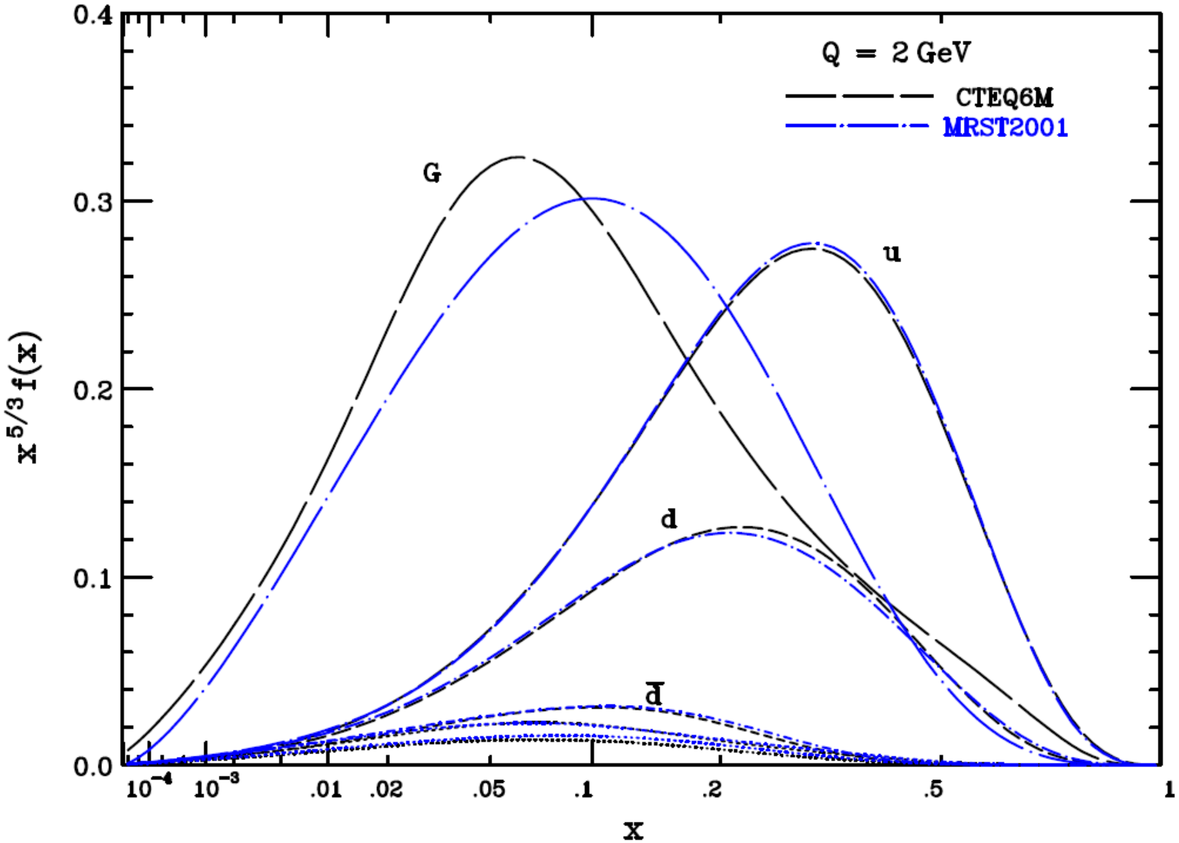
- What looks to be an inelastic collision of protons is actually an elastic collision of partons: quarks and gluons.
- In an elastic collision, measuring the momenta of the final state particles completely specifies the momenta of the initial state particles.
- Different final states probe different combinations of initial partons.
  - This allows us to separate out the contributions of gluons and quarks.
  - Different experiments also probe different combinations.



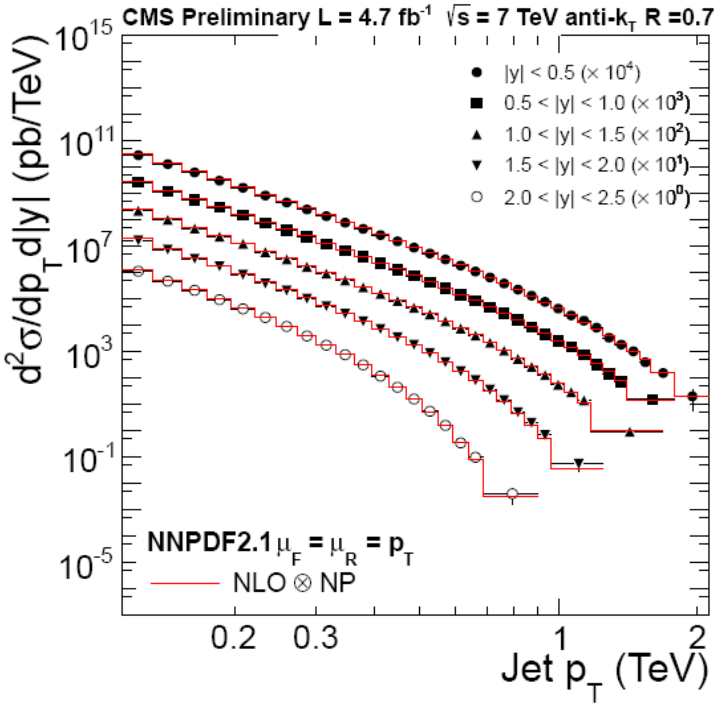
- It's useful to notate this in terms of x:
  - $x = p(\text{parton})/p(\text{proton})$
  - The fraction of the proton's momentum that this parton carries
- This is actually the Fourier transform of the position distributions.
  - Calculationally, leaving it this way is best.

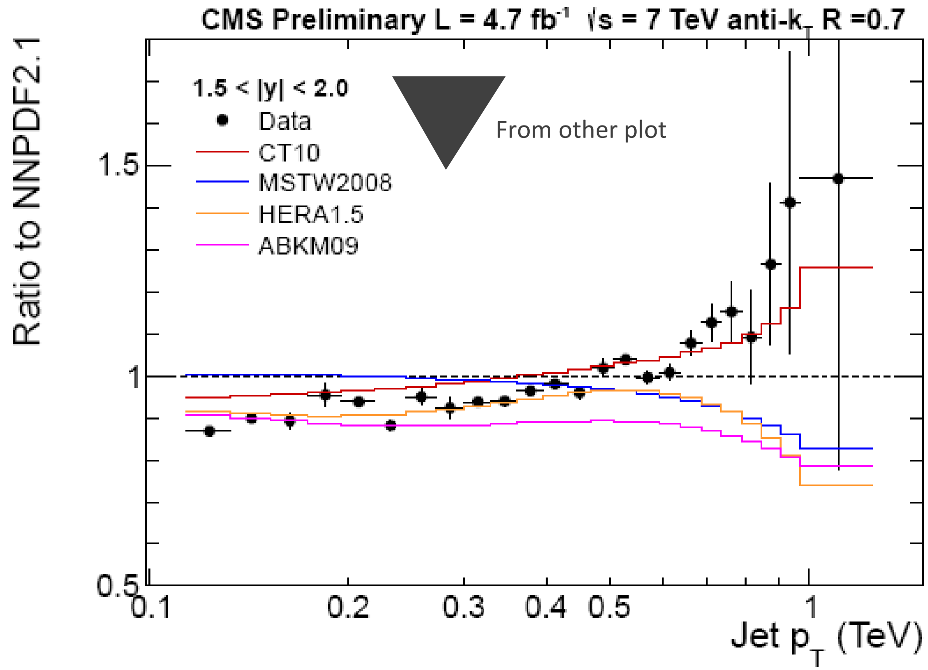
Parton Density Functions in More Detail

- One fit from CTEQ and one from MRS is shown
  - These are global fits from all the data
- Despite differences in procedure, the conclusions are remarkably similar
  - Lends confidence to the process
  - The biggest uncertainty is in the gluon – more on that later
- The gluon distribution is enormous:
  - The proton is mostly glue, not mostly quarks



CMS Jet Results

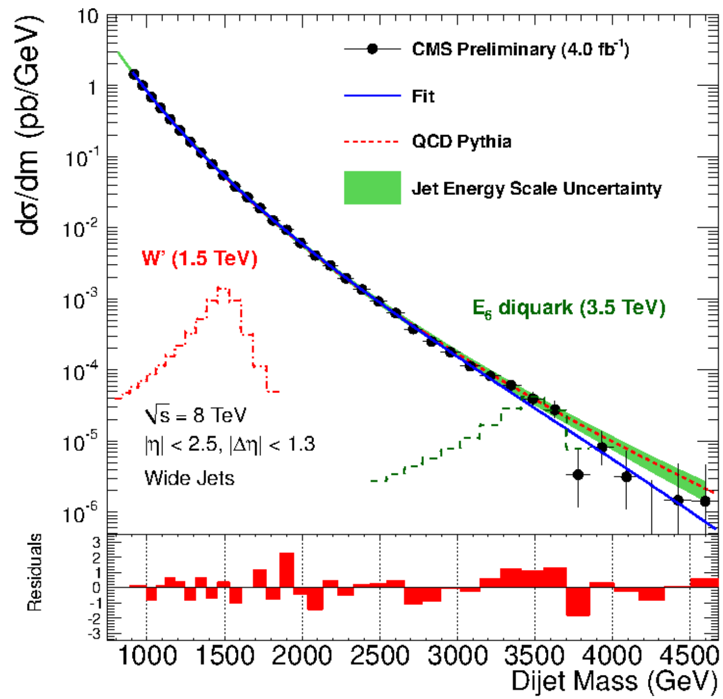




- At the LHC, jets above 1 TeV are relatively common
- At low-to-mid p_T, different PDF sets predict cross-section changes of ~10% or so
  - Bigger in some kinematic regions, smaller in others
  - "You can't tell anything from a log plot"
- The data is now of high enough quality to start constraining these PDFs.

Searches With Jets

- A question you might have – "How come both ATLAS and CMS are showing search results from 8 TeV data, but jet cross-sections from 7 TeV data?"
- This is the evil dark side of the 10% differences in predictions
  - If I want 10% precision on the cross-section, I need about 2% precision on the jet energy scale. This is about the state of the art today.
  - In contrast, there is no requirement for an absolute background prediction in the searches: the only requirement is that the background be smooth.

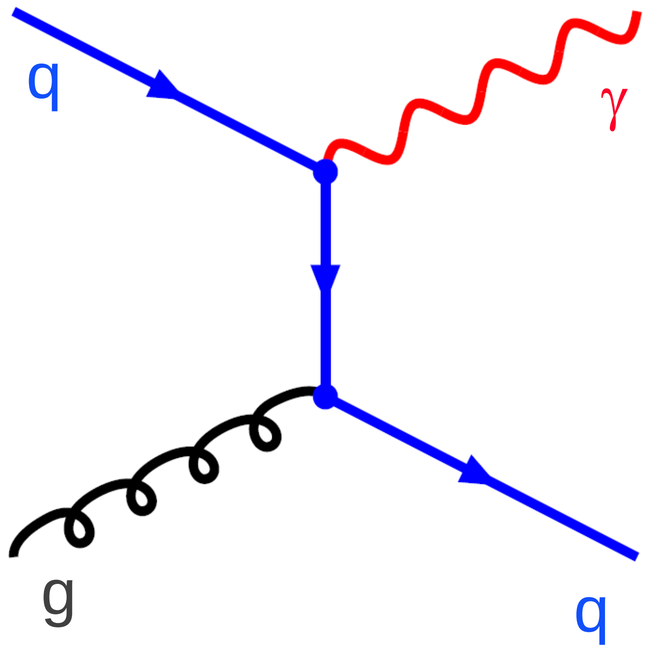


Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.0, 4.69]	[1.0,4.64]
Excited Quark (Q*)	qg	[1.0, 3.19]	[1.0,3.43]
E_6 Diquark (D)	qq	[1.0, 4.28]	[1.0,4.12]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.0, 3.28]	[1.0,3.55]
s8 Resonance (s8)	gg	[1.0, 2.66]	[1.0,2.53]
W′ Boson (W′)	$q\bar{q}$	[1.0, 1.74] [1.97, 2.12]	[1.0,1.92]
Z′ Boson (Z′)	$q\bar{q}$	[1.0, 1.60]	[1.0,1.50]
RS Graviton (RSG)	$q\bar{q}$+gg	[1.0, 1.36]	[1.0,1.20]

- Standard Model measurements simply take longer.

Direct Photons and the Gluon PDF

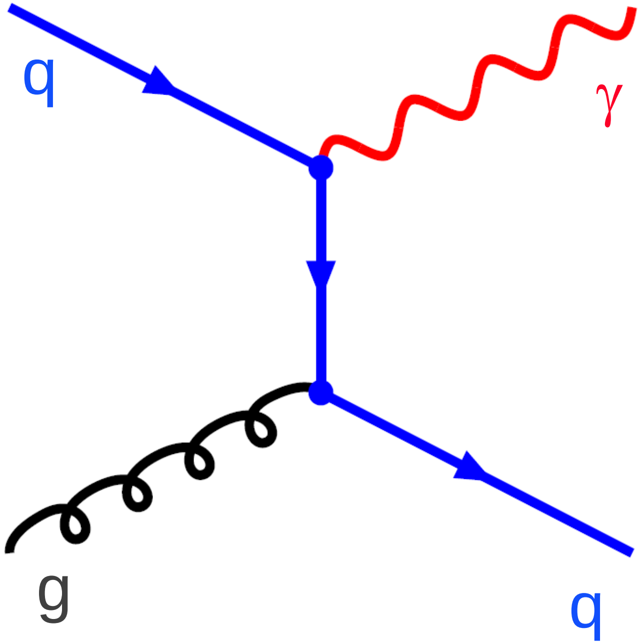
- DIS and Drell-Yan are sensitive to the quark PDFs.
- Gluon sensitivity is indirect
  - The fraction of momentum not carried by the quarks must be carried by the gluon.
- It would be useful to have a direct measurement of the gluon PDFs
  - Even if it were less sensitive than the indirect measurements, it would lend confidence to the picture that is developing
  - It also has the potential to probe higher Q^2 than the indirect methods.
  - This process depends on the (largely known) quark distributions and the (less known) gluon distribution



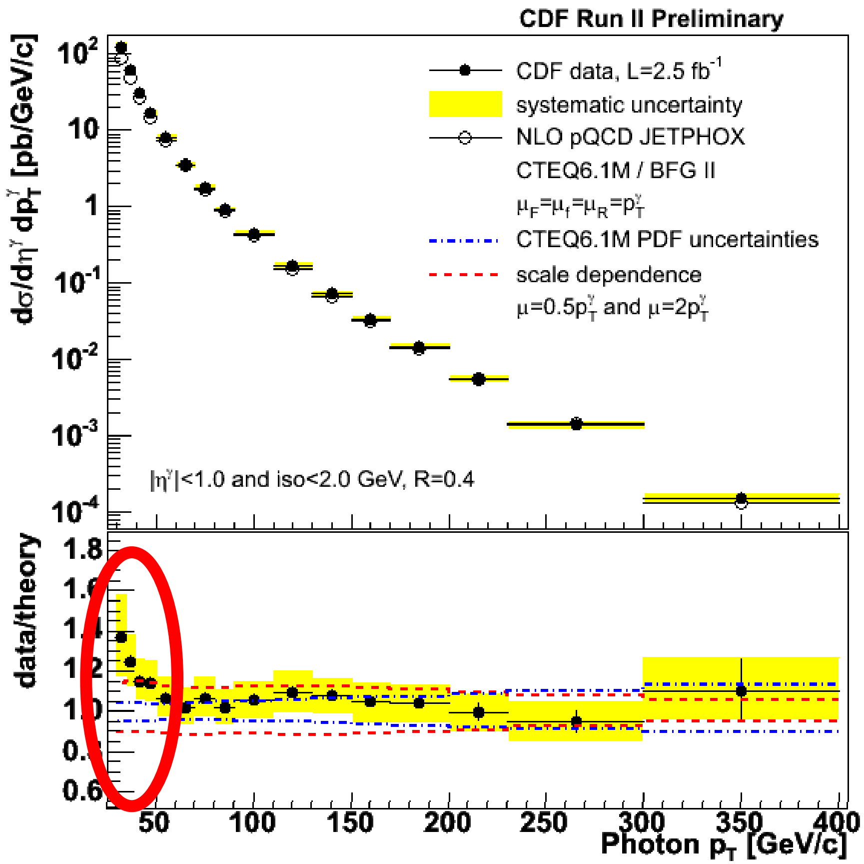
Direct photon “Compton” process.

If this is such a good idea, how come this process is unpopular with the global fits?

The Problem with Direct Photons

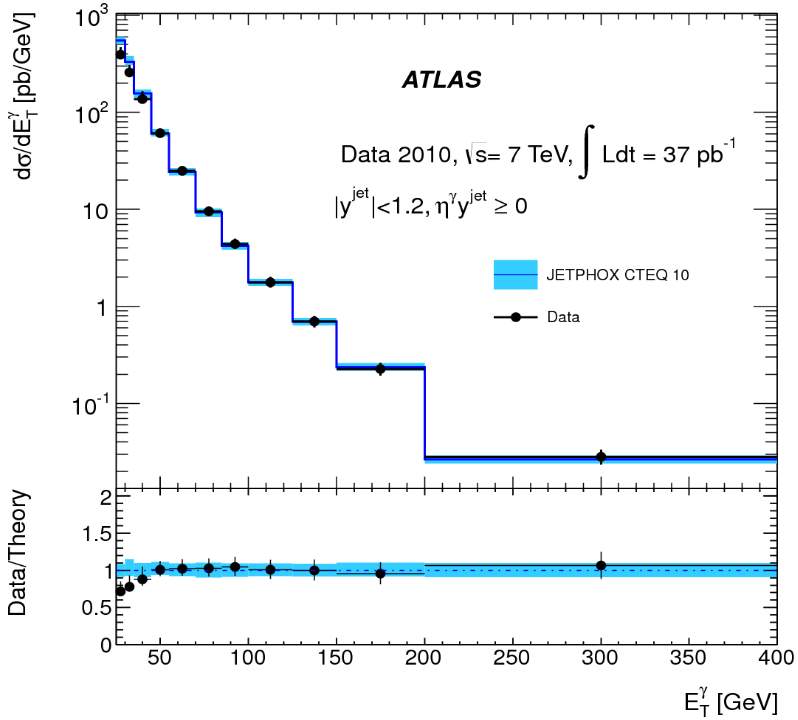


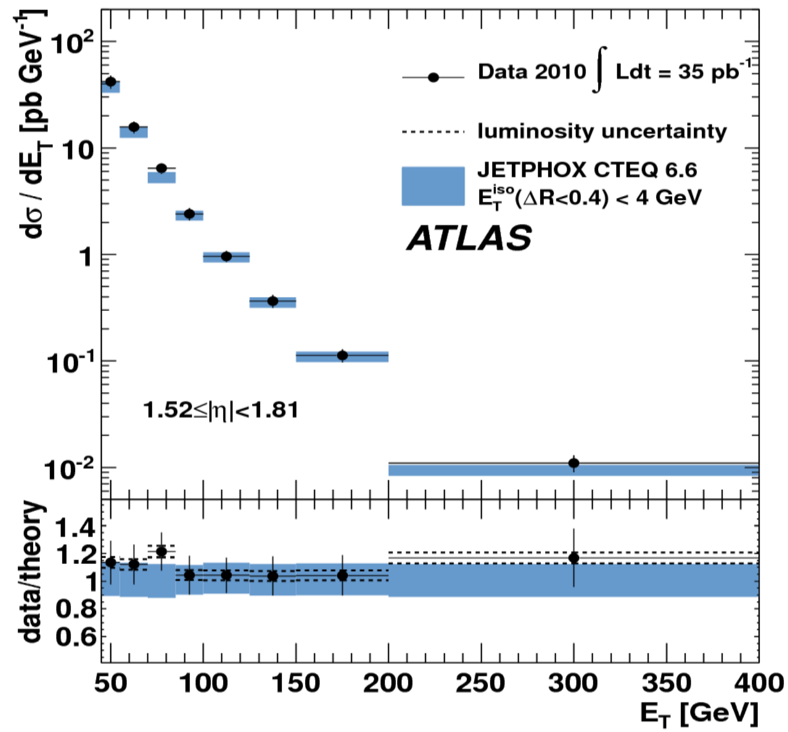
Direct photon "Compton" process.



- There is a discrepancy at low p_T, seen at the Tevatron experiments
- There are theoretical ideas on how to resolve this, but the cross-section calculation and the PDF measurements have become intertwined.
  - No longer a clean PDF measurement.

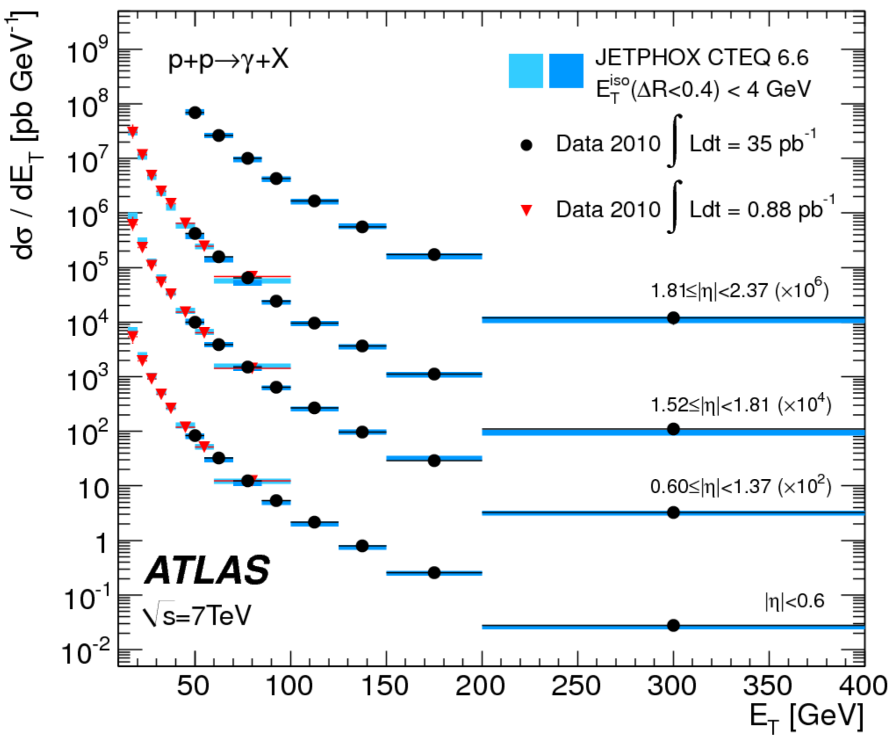
Direct Photons at the LHC

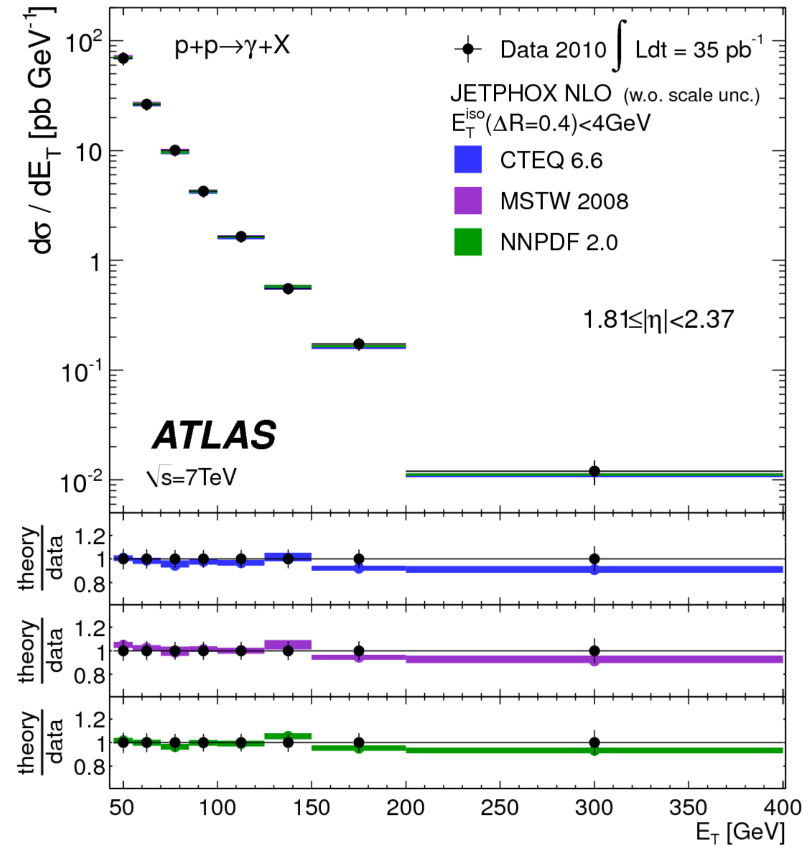




- There is still something not entirely understood going on below 50 GeV
  - But we know now that this is a function of E_T, not of x_T. **We can now separate PDF effects from the calculational issues**.
- The additional kinematic reach of the LHC is apparent
  - For the same x_T, the LHC goes out 3.5x or 4x farther in E_T.
  - With only 1% of the data, the kinematic reach is the same as the Tevatron's
  - The troublesome region below 50 GeV becomes only a tiny piece of what will be studied

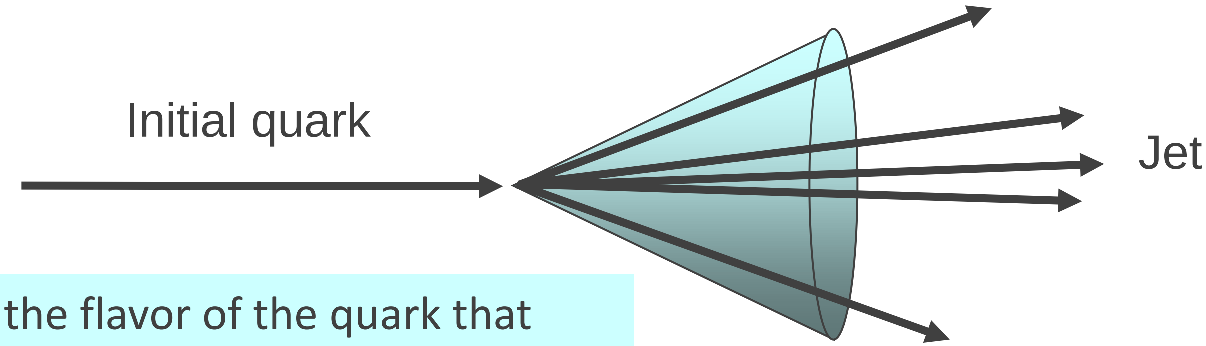
Binning In Rapidity



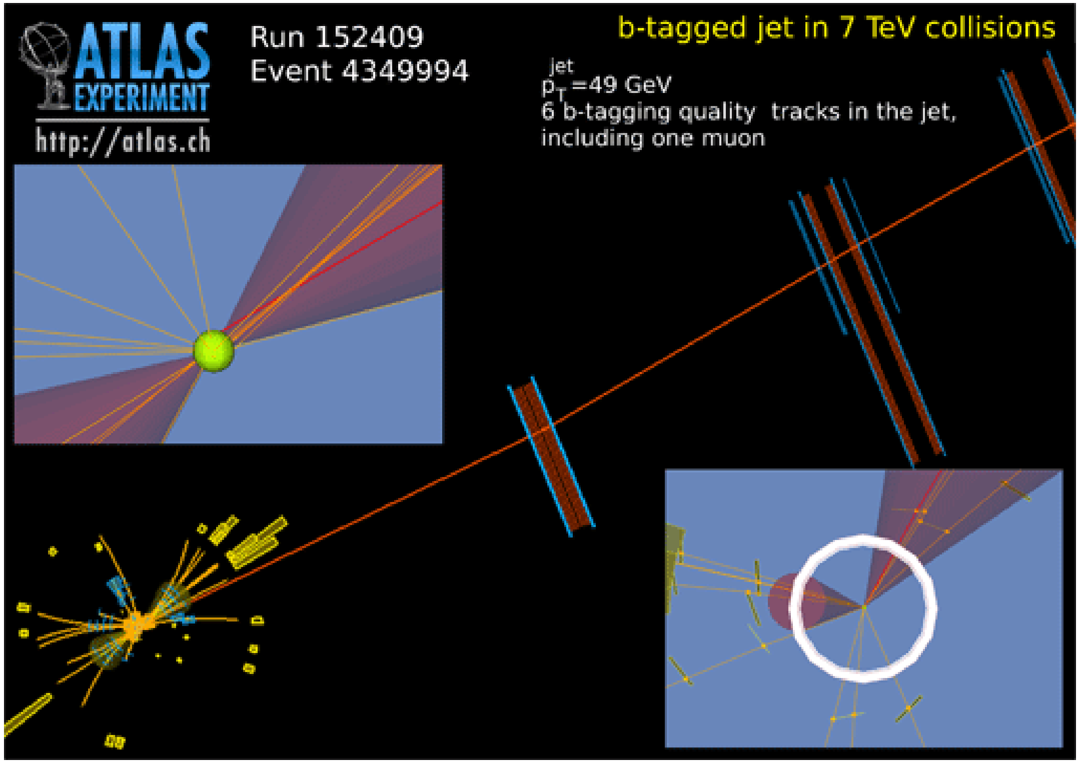


ATLAS and CMS have collected enough data to bin in y as well as E_T. The narrower the binning in y (which is essentially x_1-x_2), the more constraining the measurement. The full 2011 dataset should let us measure out to E_T's of about 1 TeV.

Jets With Flavor



A natural question: what was the flavor of the quark that initiated that jet?

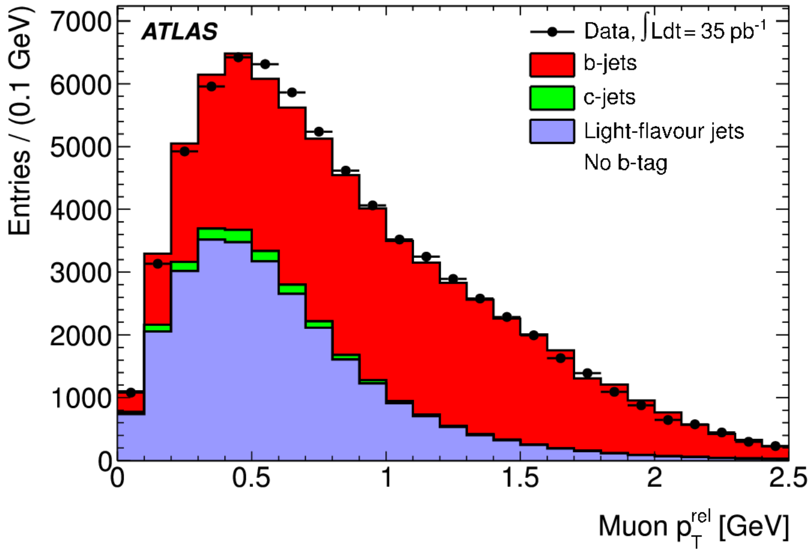


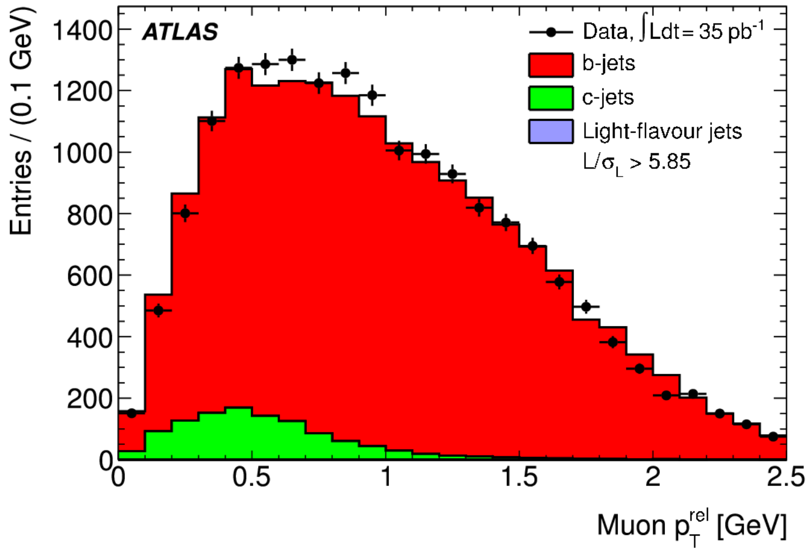
Identifying heavy flavor in jets is commonplace (today – I am old enough to remember when it wasn't).

The two most used techniques are looking for either a displaced vertex or a nearby muon.

This is useful in identifying decays like t → Wb.

Separating Flavors



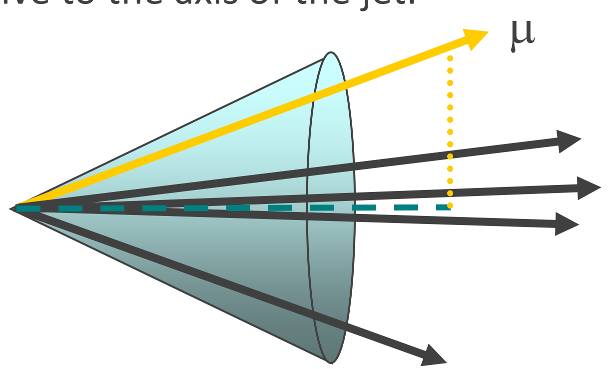


Here ATLAS is looking at jets with nearby muons, with and without a secondary vertex tag.

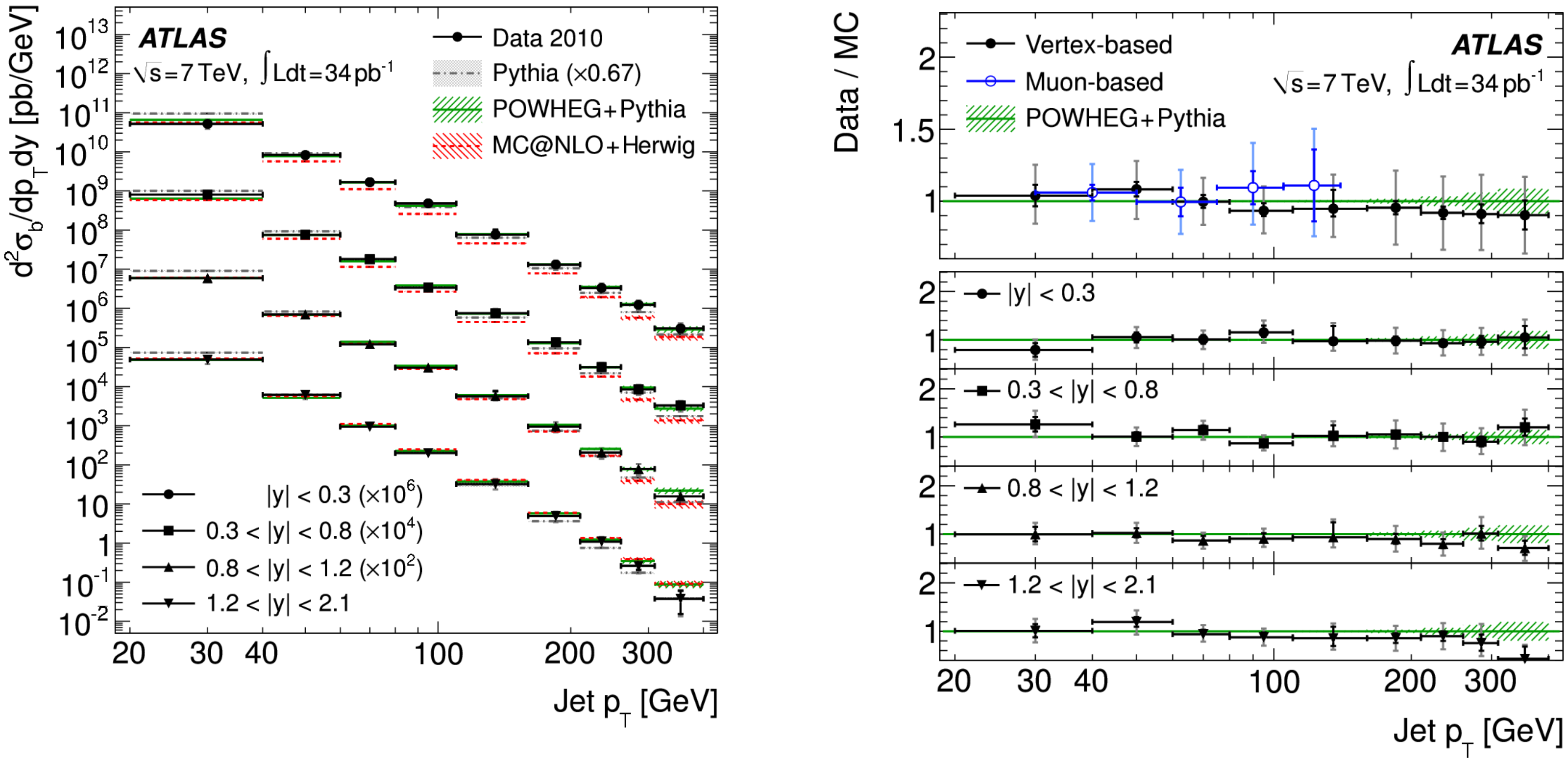
The three components can be statistically separated.

Very pure samples of b-jets can be obtained.

p_T(rel) is the pT of the muon relative to the axis of the jet.



Results

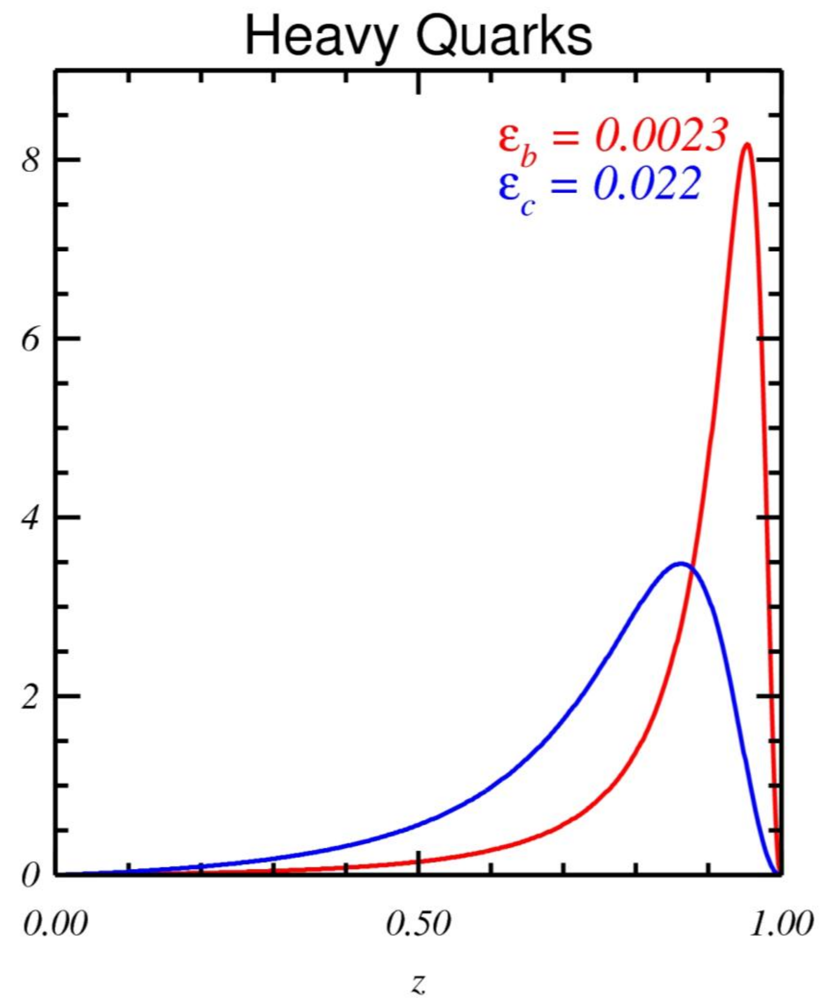


Here ATLAS uses the two methods separately (so one can check consistency) to measure the cross-section of b-jets.

Note that the uncertainties are somewhat larger than for inclusive jets.

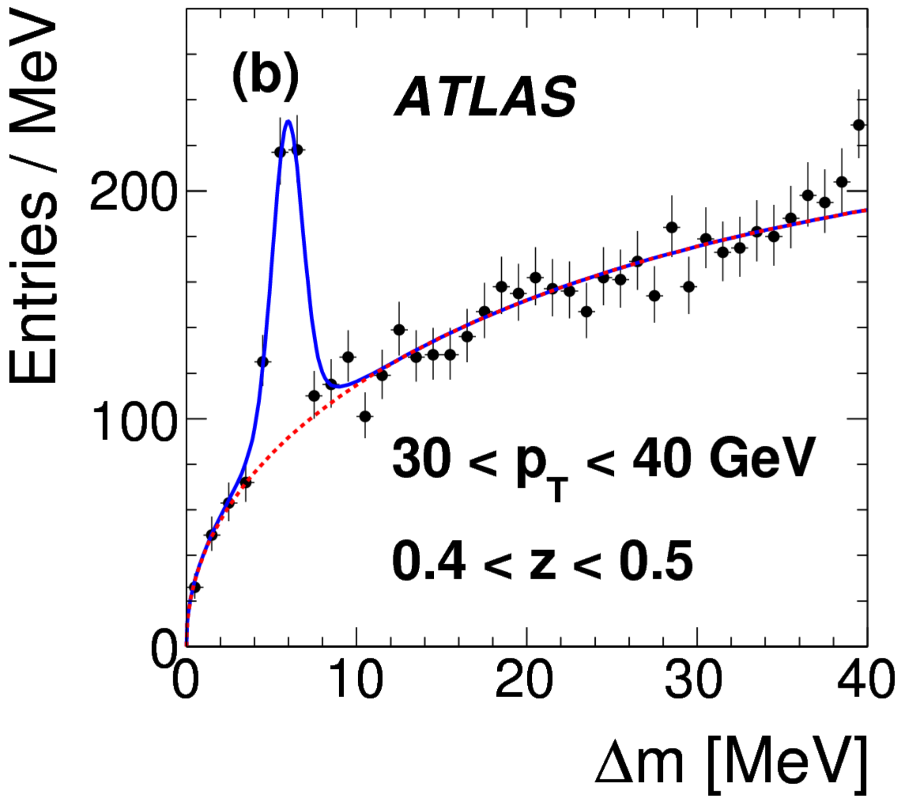
Heavy Flavor Production – A Closer Look

- 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.



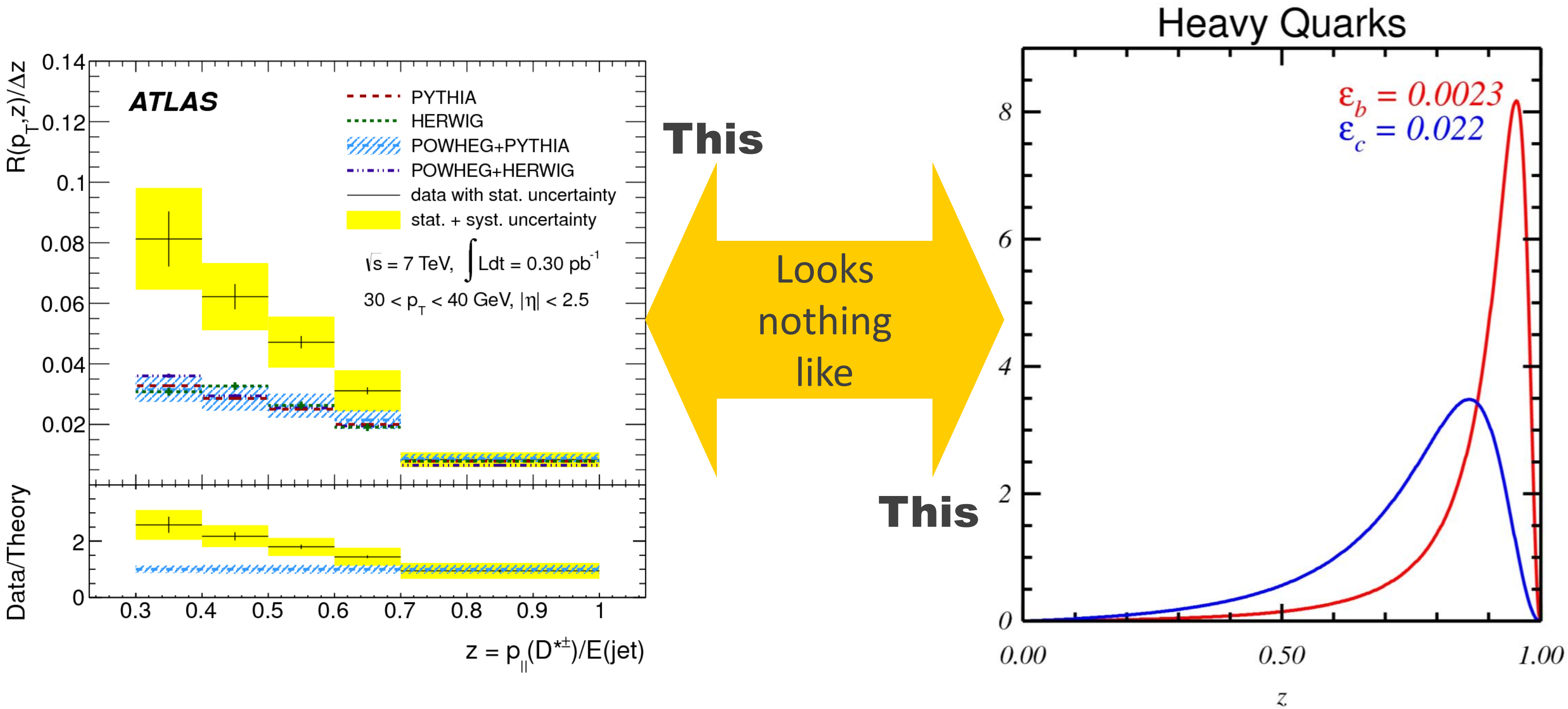
Testing this at the LHC

- 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.



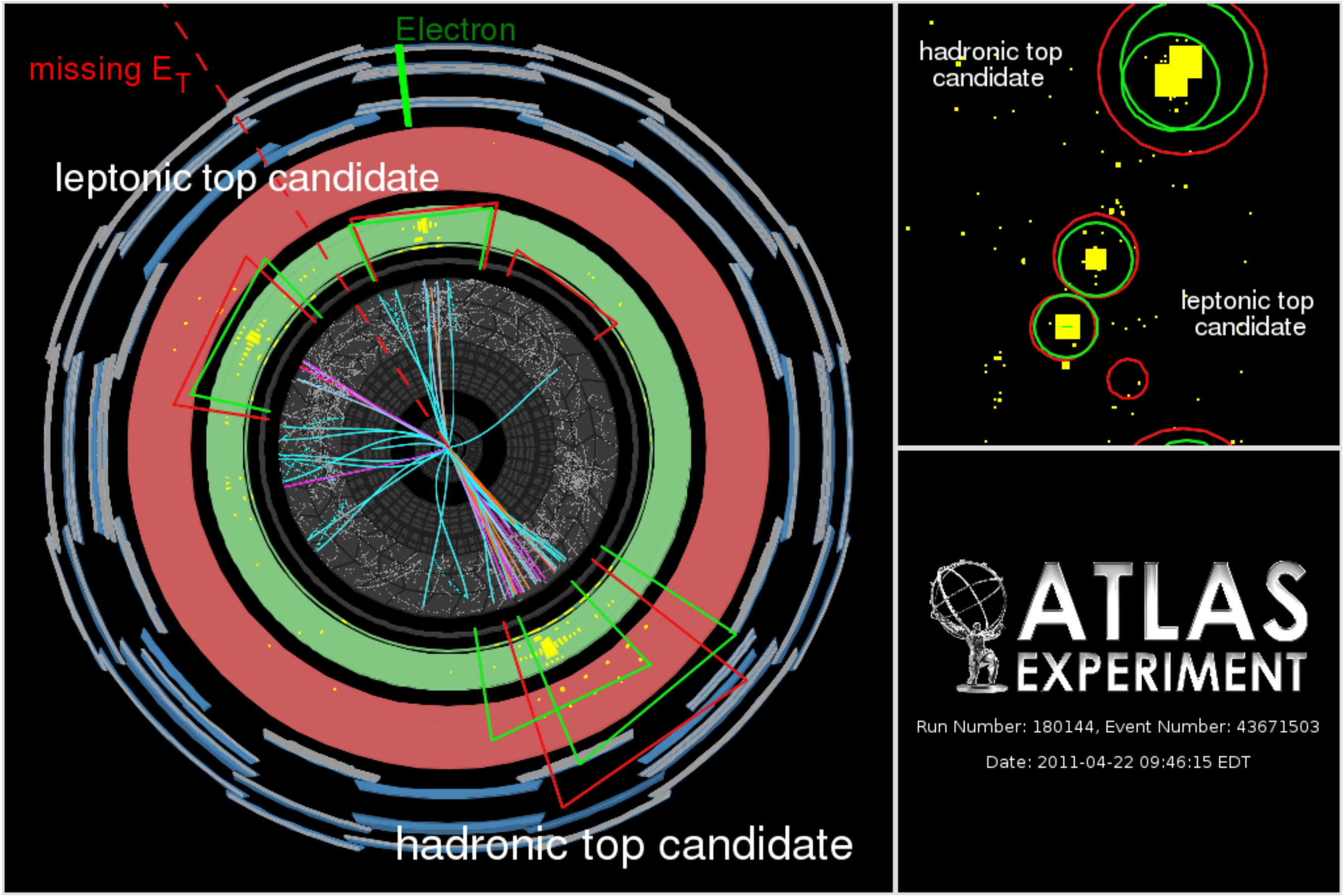
$$D^{*+} \to D^0 \pi^+$$

Testing this at the LHC II



- What's gone wrong?
- In the past, we have used "a jet initiated by a heavy quark" and "a jet containing a heavy quark" as synonyms.
  - At the LHC, they are not. Qualitatively, the Monte Carlos "know" this.
- What it means to say "this is a b-jet" is an area of active study.

And Jets Containing Tops



AT LHC energies, we are able to make top quarks (and W's, Z's and Higgs bosons) with sufficient p_T that their daughters merge into a single jet. These jets are called "boosted objects" and this is another field of active study.

Mid-Talk Summary

- The structure of the proton cannot be calculated perturbatively in QCD: it must be measured.
  - We work in momentum space and call these “parton density (or distribution) functions.”
- LHC measurements are becoming precise enough to constrain them
  - The additional kinematic range allows us to avoid troublesome regions for direct photon measurements; I hope to see them constraining the gluon once more.

- The flavor content of jets can be measured, and the story that emerges is not simple:
  - A jet can be initiated by a heavy flavor quark
  - A jet can contain a heavy flavor quark produced in the shower
  - A jet’s origin and its contents do not have a 1:1 map to each other

- Extreme boosts cause heavy objects (W/Z, t and H) to merge into a single jet.
  - Studying these “boosted objects”

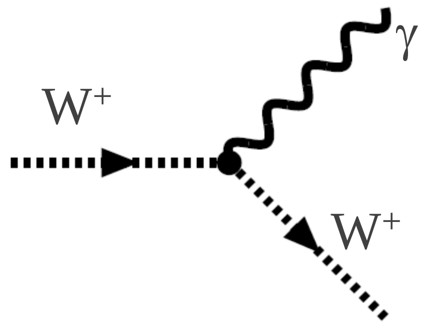
The Problem with Electroweak Theory

Pre July 4th: Here we have the opposite problem than QCD – here calculations are easier, but there is a fundamental flaw in the underlying theory.

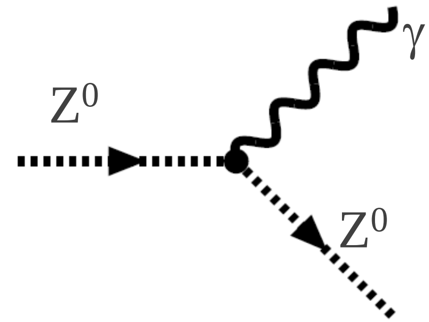
Post July 4th: We think we have found the fix to this problem – the Higgs boson – but need to check that it does in fact fix what it is supposed to.

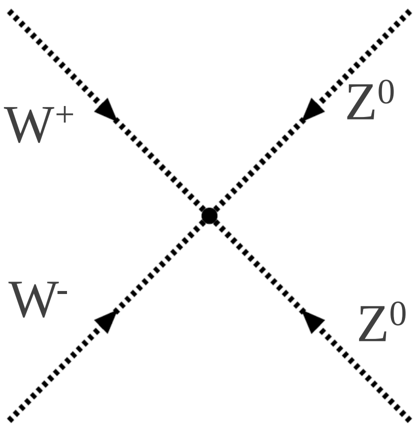
What is the Standard Model?

The (Electroweak) Standard Model is the theory that has interactions like:



but not





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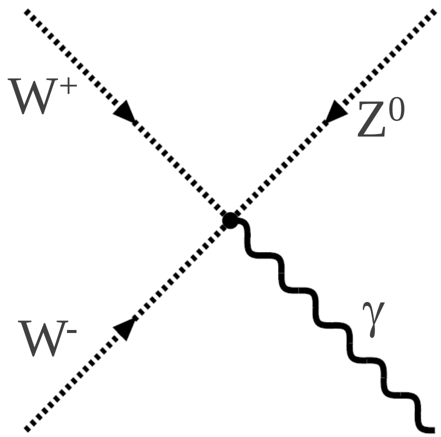

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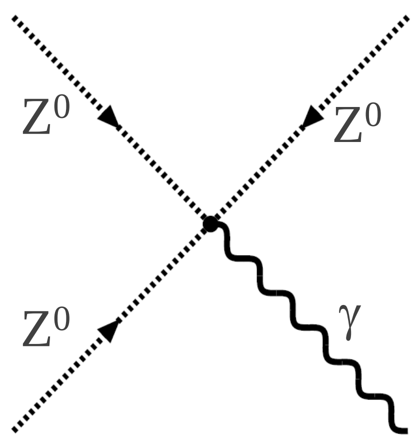

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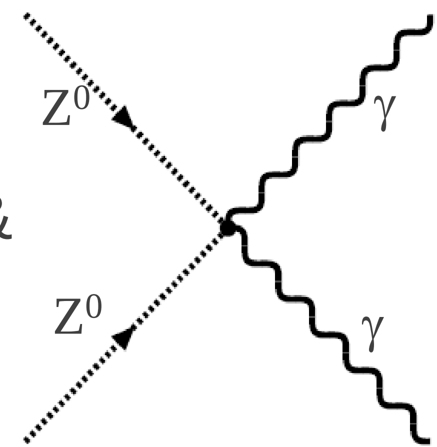
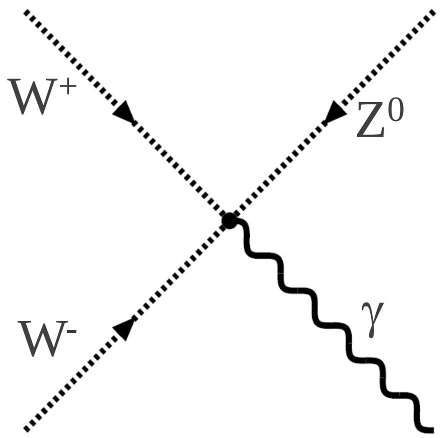


Only three parameters - G_F, α and $\sin^2(\theta_W)$ - determine all couplings.

Homework

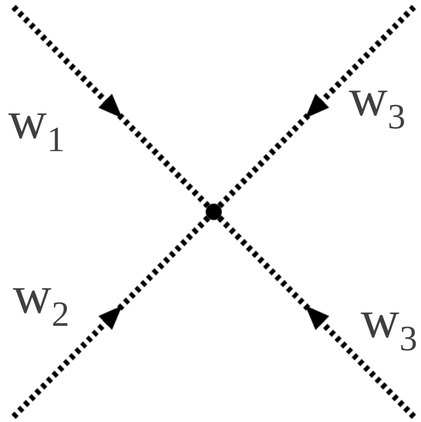
Couplings like this:



For theorists: prove that for an SU(2)xU(1) theory, there are no all-neutral couplings (trilinear or quartic).

Hint: What is the branching fraction $\rho^0 \rightarrow \pi^0\ \pi^0$?

Are remnants of the unbroken SU(2) symmetry:



For experimenters: find a theorist who has done this proof correctly.

Portrait of a Troublemaker

- This diagram (and its friends on the next page) is where the SM gets into trouble – and this is what the
- It's vital that we measure this coupling, whether or not we see a Higgs.

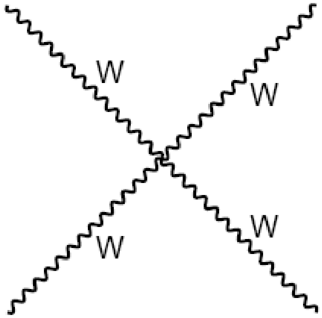
Yields are not all that great

M_{Higgs} (GeV)	200	400	600	800
$W^+W^-W^-$	68	28	25	25
$W^+W^+W^-$	112	49	44	44
W^+W^-Z	32	17	15	15
W^-ZZ	1.0	0.51	0.46	0.45
W^+ZZ	1.7	0.88	0.79	0.79
ZZZ	0.62	0.18	0.13	0.12

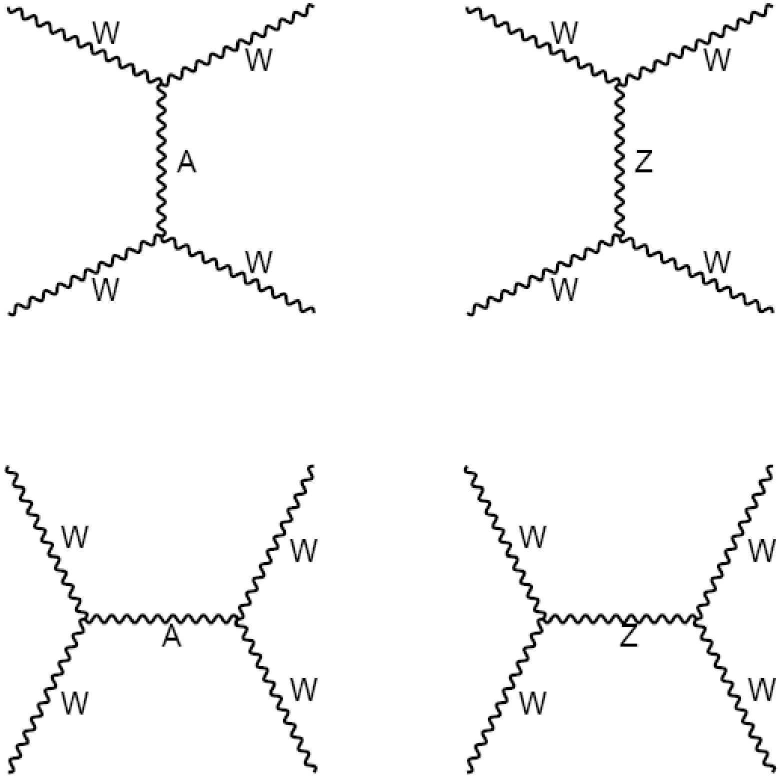
From Azuelos et al. hep-ph/0003275

100 fb-1, all leptonic modes inside detector acceptance

A Complication



If we want to understand the quartic coupling…

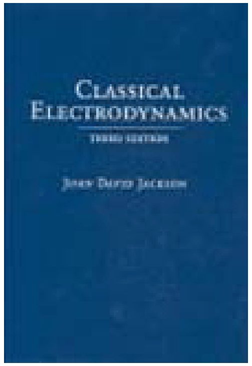


…first we need to measure the trilinear couplings

We need a TGC program that looks at all final states: WW, WZ, Wγ (present in SM) + ZZ, Zγ (absent in SM)

The Semiclassical W

- Semiclassically, the interaction between the W and the electromagnetic field can be completely determined by three numbers:
  - The W's electric charge
    - Effect on the E-field goes like $1/r^2$
  - The W's magnetic dipole moment
    - Effect on the H-field goes like $1/r^3$
  - The W's electric quadrupole moment
    - Effect on the E-field goes like $1/r^4$



- Measuring the Triple Gauge Couplings is equivalent to measuring the 2nd and 3rd numbers
  - Because of the higher powers of $1/r$, these effects are largest at small distances
  - Small distance = short wavelength = high energy

Triple Gauge Couplings

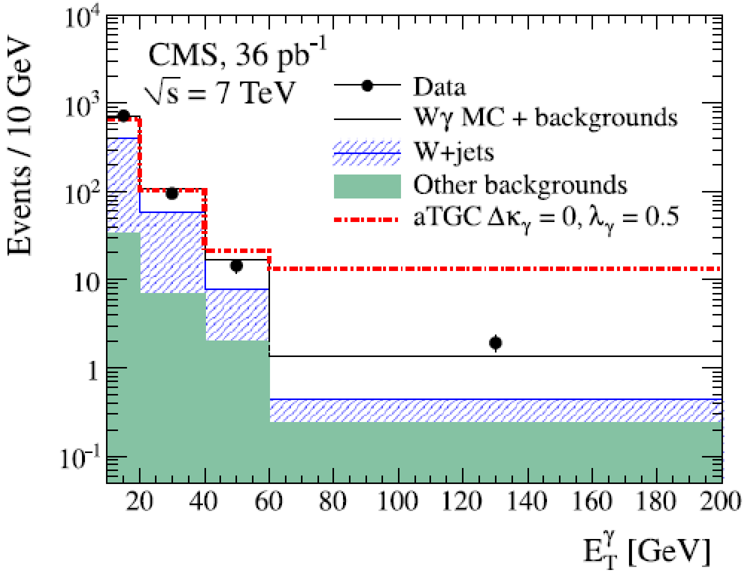
- There are 14 possible $WW\gamma$ and WWZ couplings
- To simplify, one usually talks about 5 independent, CP conserving, EM gauge invariance preserving couplings: g_1^Z, κ_γ, κ_Z, λ_γ, λ_Z
  - In the SM, $g_1^Z = \kappa_\gamma = \kappa_Z = 1$ and $\lambda_\gamma = \lambda_Z = 0$
    - *Often useful to talk about Δg, $\Delta\kappa$ and $\Delta\lambda$ instead.*
    - *Convention on quoting sensitivity is to hold the other 4 couplings at their SM values.*
  - Magnetic dipole moment of the W = $e(1 + \kappa_\gamma + \lambda_\gamma)/2M_W$
  - Electric quadrupole moment = $-e(\kappa_\gamma - \lambda_\gamma)/2M_W^2$
  - Dimension 4 operators alter Δg_1^Z,$\Delta\kappa_\gamma$ and $\Delta\kappa_Z$: grow as $s^{½}$
  - Dimension 6 operators alter λ_γ and λ_Z and grow as s
- These can change either because of loop effects (think e or μ magnetic moment) or because the couplings themselves are non-SM

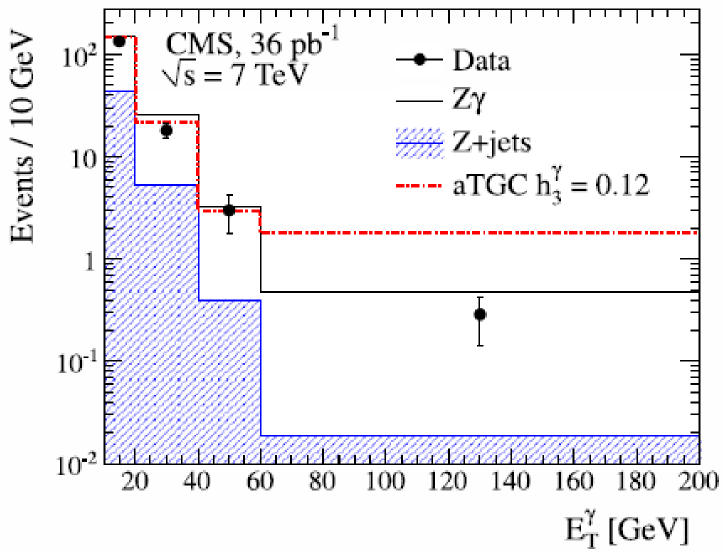
See Degrande et al. http://arxiv.org/abs/arXiv:1205.4231 for a better convention – one I hope the field adopts.

Why Center-Of-Mass Energy Is Good For You

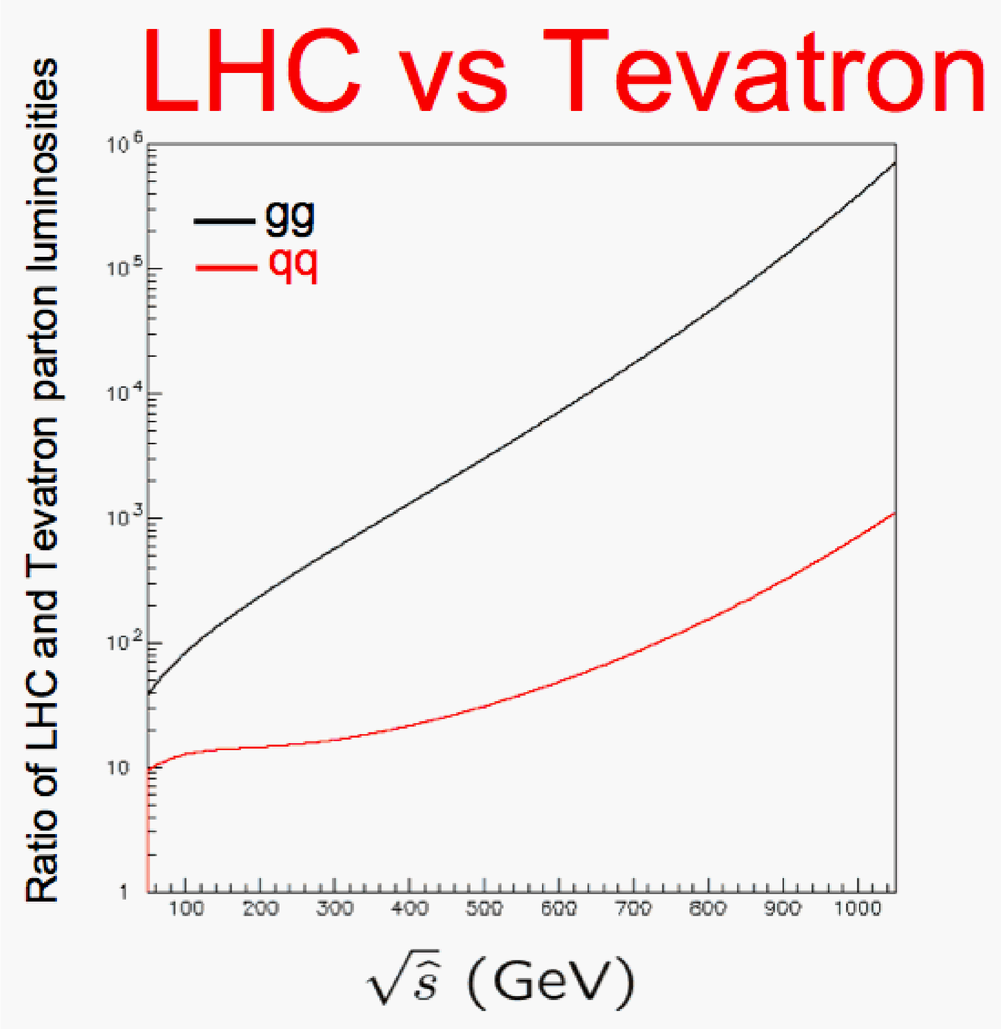
- The red dashed line is the expectation for $\lambda_\gamma = 0.5$
  - This is already excluded from the data, but qualitatively this shows that the excess occurs at large masses. (Or other correlated varaibles)

- This is a universal feature for all of the anomalous couplings.
  - This plot shows what happens when setting one of the $Z\gamma$ couplings to a non-zero value.





Not All W's Are Created Equal

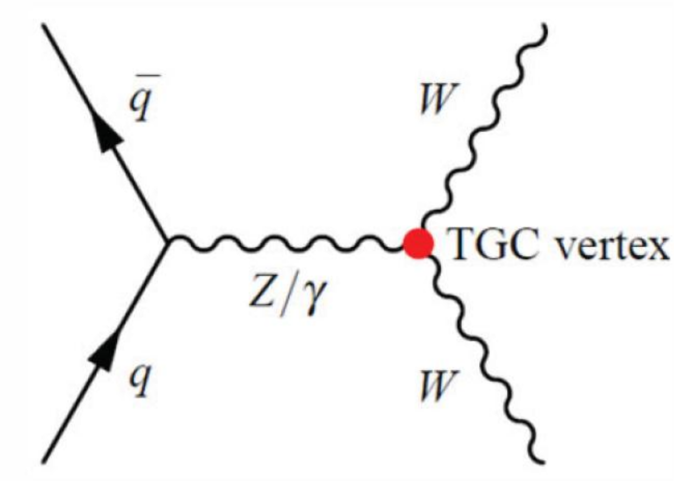


From Claudio Campagnari/CMS – for 14 TeV

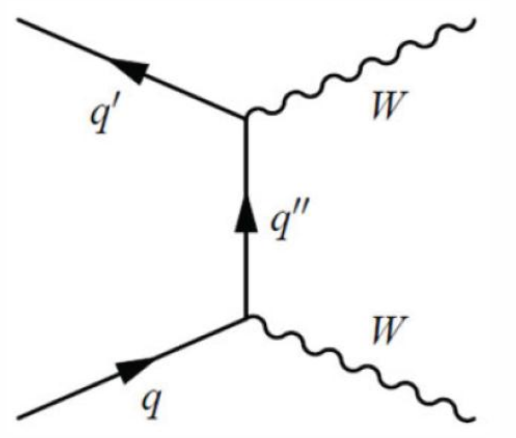
- The reason the inclusive W and Z cross-sections are 10x higher at the LHC (14 TeV) is that the corresponding partonic luminosities are 10x higher
  - No surprise there
- Where you want sensitivity to anomalous couplings, the partonic luminosities can be hundreds of times larger.
- The strength of the LHC is not just that it makes millions of W's. It's that it makes them in the right kinematic region to explore the boson sector couplings.

One More Argument for High p_T

WW shown; the argument holds for VV in general.



This process has…



…this as a background.

- In QM amplitudes add. Experiments measure rates. These are intertwined.
- However, if the TGC's have non SM values, this shows up at at large p_T (short distances)
  - This is a region where the background from the right diagram is small

Confession Is Good For The Soul

- There is a built-in swindle to this formalism

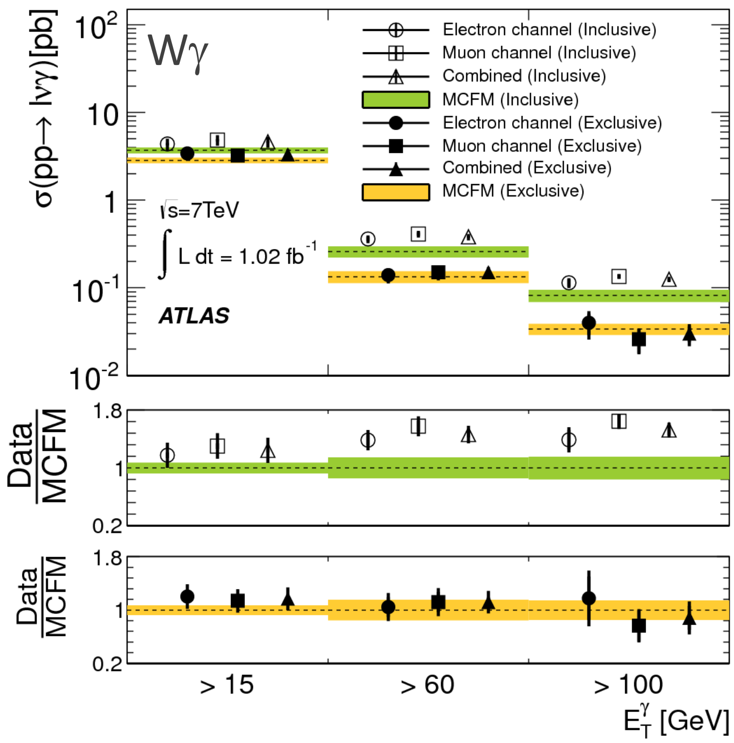
- Effects that grow as $s^{1/2}$ or s are easy to see at large m(VV)
  - As m(VV) grows, these effects eventually violate unitarity
    - Of course those are easy to see! They're impossible to miss!

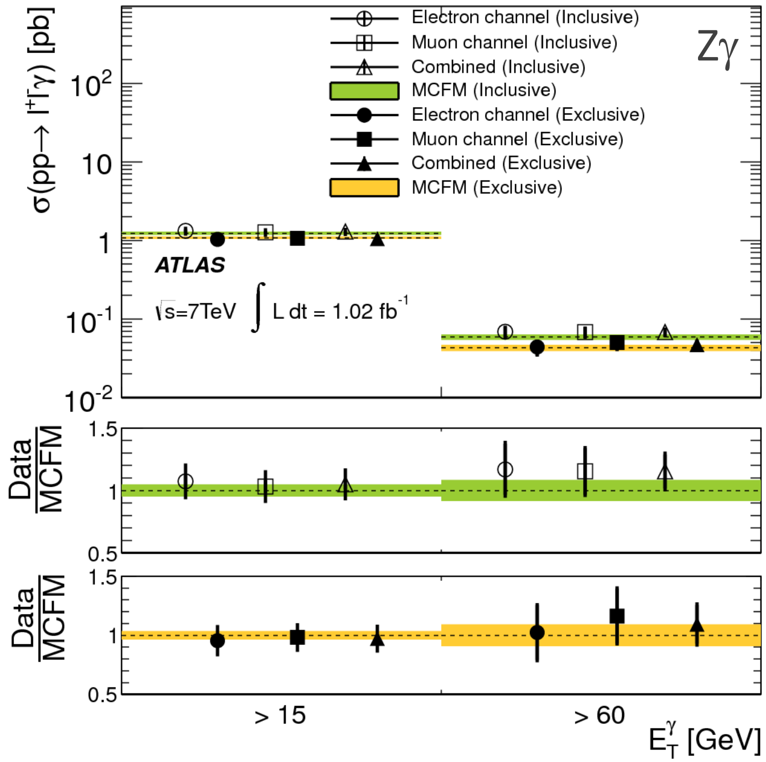
- It may be useful to think about turning this around
  - If there is new physics at high Q^2/short distances, it can manifest itself at lower Q^2/longer distances as changes in the couplings: g_1^Z, κ_γ, κ_Z, λ_γ and λ_Z
  - While the effects will be largest at high Q^2, they might not look like exactly like these predictions – it all depends on what this new physics is.

- NLO effects tend to increase the VV cross-section at high Q^2 – this reduces sensitivity somewhat.

"That's not confessin' – that's advertisin!" – Cole Porter

Some Results

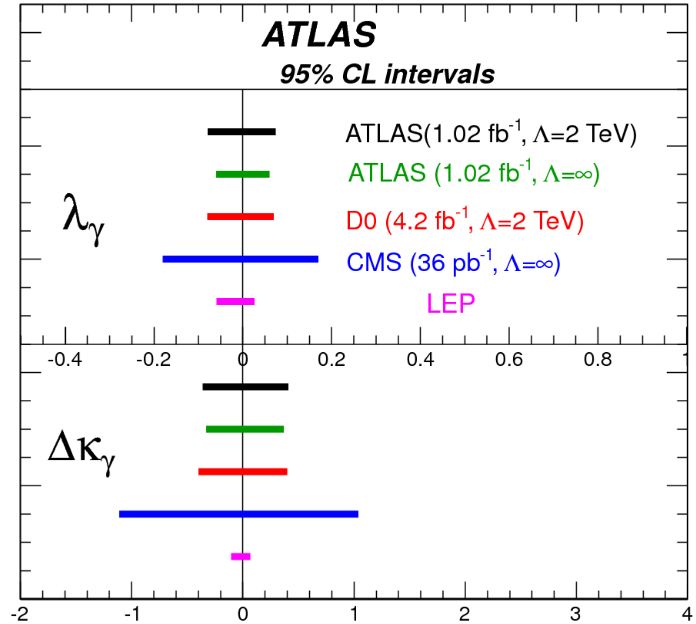




- Key ideas:
  - Split into p_T bins: the high p_T bin is where the TGC sensitivity is.
  - Split into Njet=0 and Njet>1 bins: different backgrounds and different calculations
  - In the SM, there is no TGC component to the right plot.

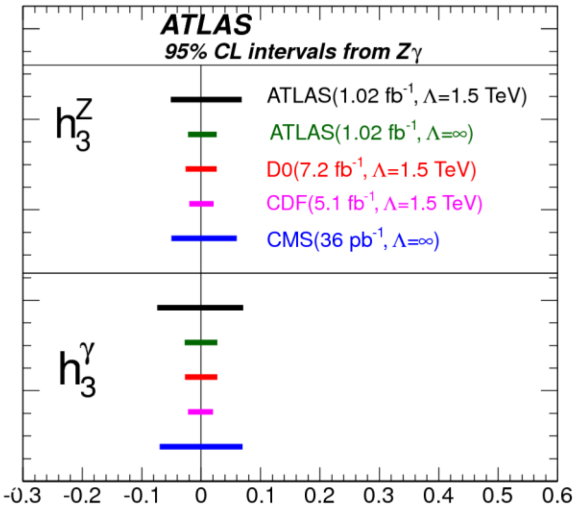
$W\gamma$ TGC's - the bottom line

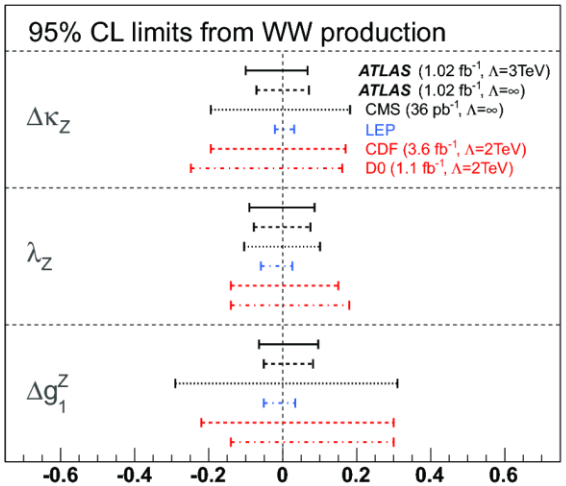
Coupling	Present Value	LHC Sensitivity at 14 TeV (95% CL, 30 fb-1 one experiment)
Δg_1^Z	$-0.016^{+0.022}_{-0.019}$	0.005-0.011
$\Delta\kappa_\gamma$	$-0.027^{+0.044}_{-0.045}$	0.03-0.076
$\Delta\kappa_Z$	$-0.076^{+0.061}_{-0.064}$	0.06-0.12
λ_γ	$-0.028^{+0.020}_{-0.021}$	0.0023-0.0035
λ_Z	$-0.088^{+0.063}_{-0.061}$	0.0055-0.0073

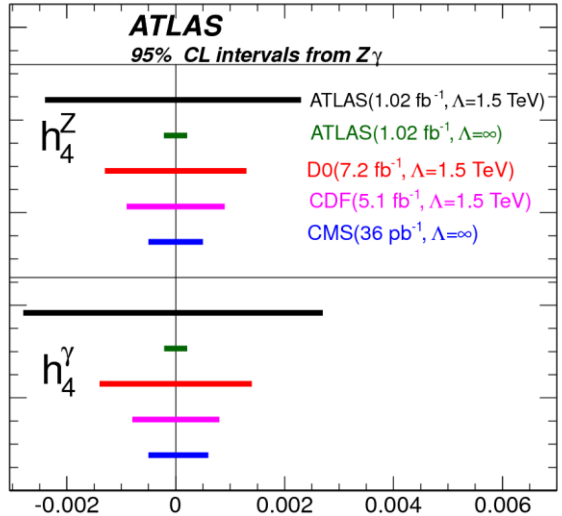


- Not surprisingly, the LHC does best with the Dimension-6 parameters
- Sensitivities are ranges of predictions given for either experiment
- The measurements are not yet competitive – low luminosity and low energy both hurt.

TGCs for Zγ and WW signatures



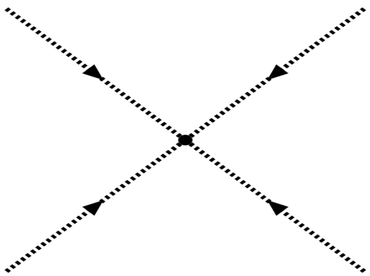




This is done the same way as for Wγ, with a different final state. The couplings are different (and all zero) for the Zγ case.

Note the greater sensitivity for h_4 vs. h_3. This is because h_4 is associated with a Dimension-8 operator, and h_3 is Dimension-6. (Same reason we have more sensitivity in λ than κ)

Coming Soon (?): Quartic Couplings



(this is how we motivated the last few slides)

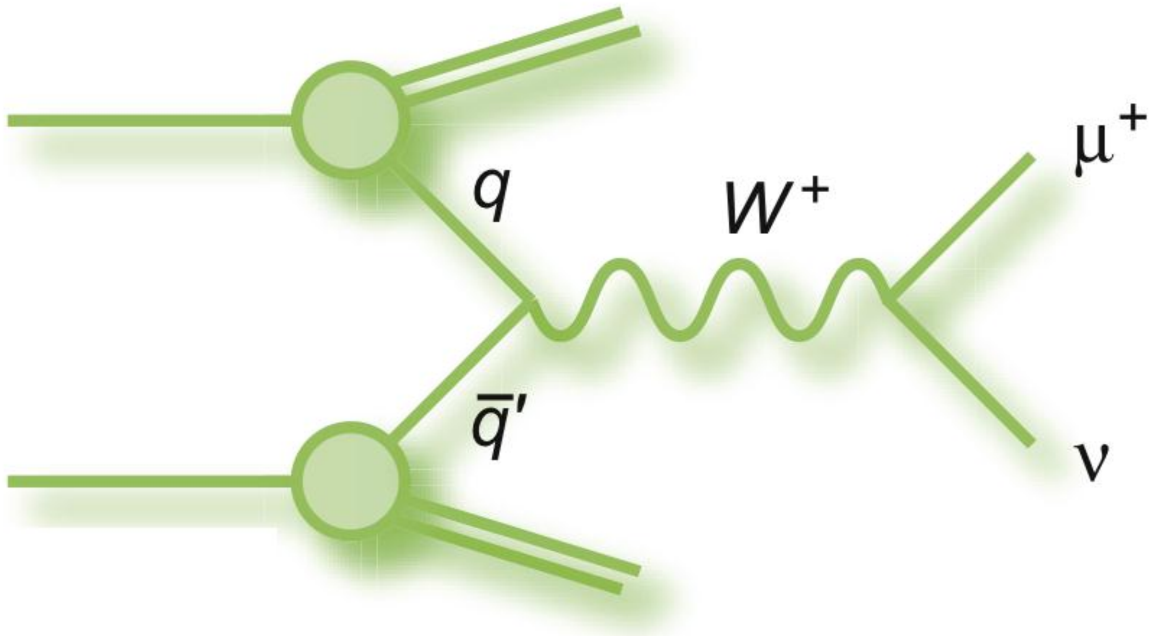
- $W\gamma\gamma$ production: this is the process with the largest cross-section – perhaps a dozen events per experiment by the end of the run.

- WWW production
  - This has a fierce background from WH production followed by H → WW*
    - After less than a month, the Higgs has become “a troublesome background”
- The community will have to retool for very high mass WWW triplets
  - The rate is lower, but that’s where the AQGC couplings produce events
  - To compensate for the lower rate, perhaps one could allow for one W to decay hadronically
    - The ttbar background is large, but the tt background is small
    - Only the two same sign W’s need to decay leptonically

- WW → WW via vector boson fusion
  - People are looking at its cousin, WW → H → WW in Higgs searches, although the data set is not exactly large.
  - One feature that will have to be addressed is that this probes a mix of couplings: WW → WW, ZZ → WW, and $\gamma\gamma$ → WW.

- Z’s in the final state are hard: one is fighting the small branching fractions to charged leptons.

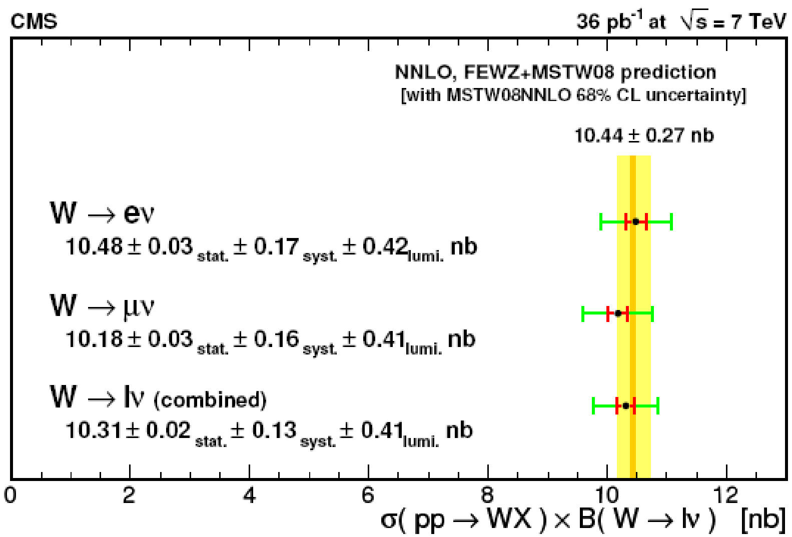
QCD with Electroweak Bosons

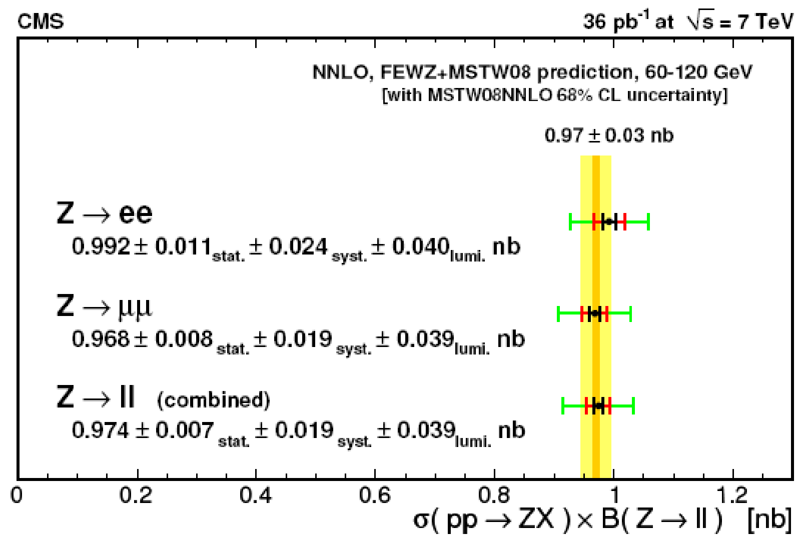


Like jets and photons, production of W's and Z's can tell you something about the parton densities in the proton. Like photons and unlike jets, fragmentation/showering is not a complication.

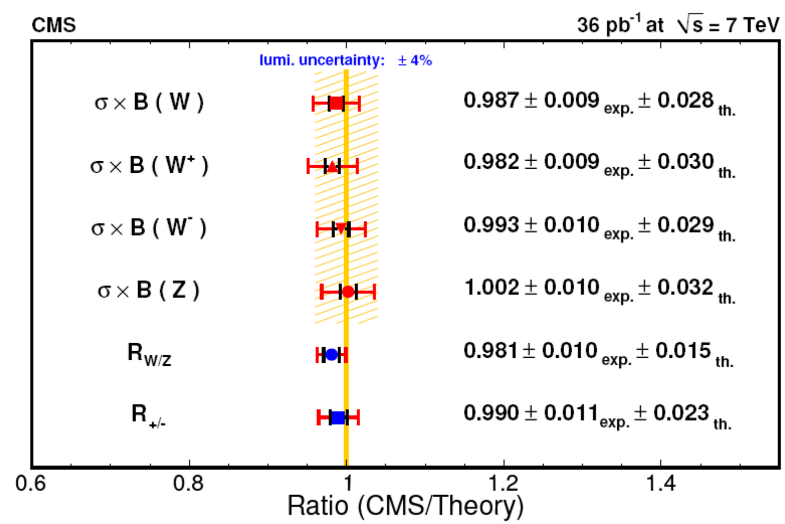
We usually think of "q" being "u" or "d". At LHC energies, production off strange and even charm (for W's) is non-trivial.

W and Z Production



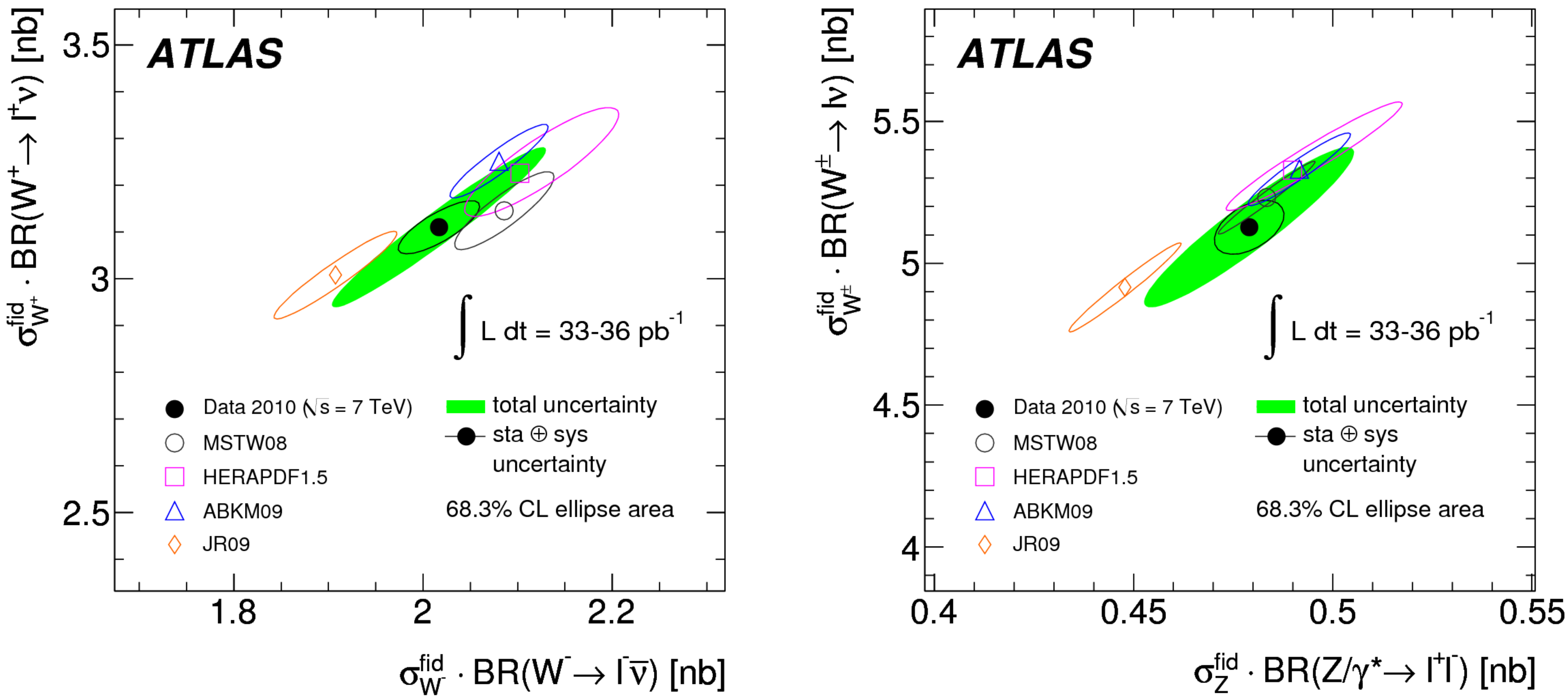


- Conventional wisdom is that since these results are systematically limited, there's no point in going beyond 36 pb^{-1}.
- Both experiments have published 36 pb^{-1} results at 7 TeV.



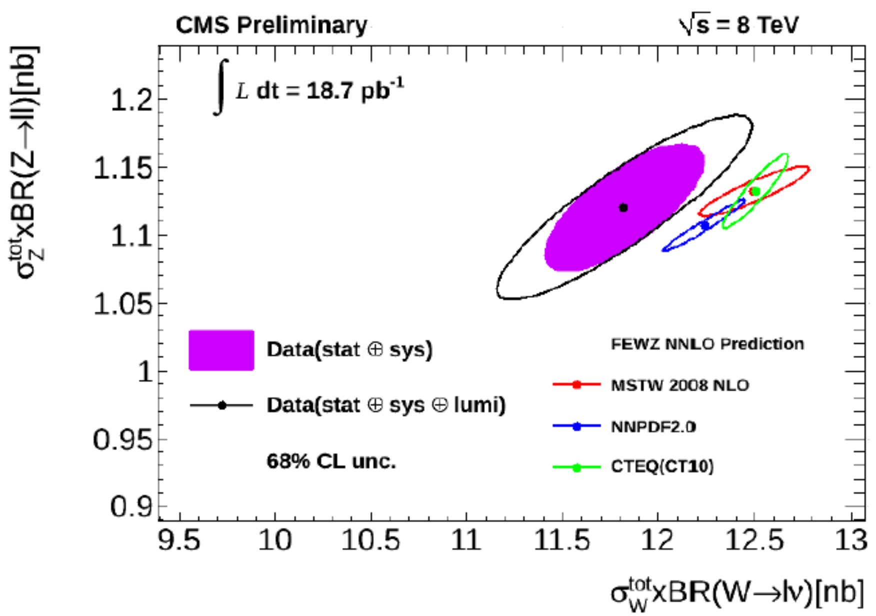
ATLAS results are similar.

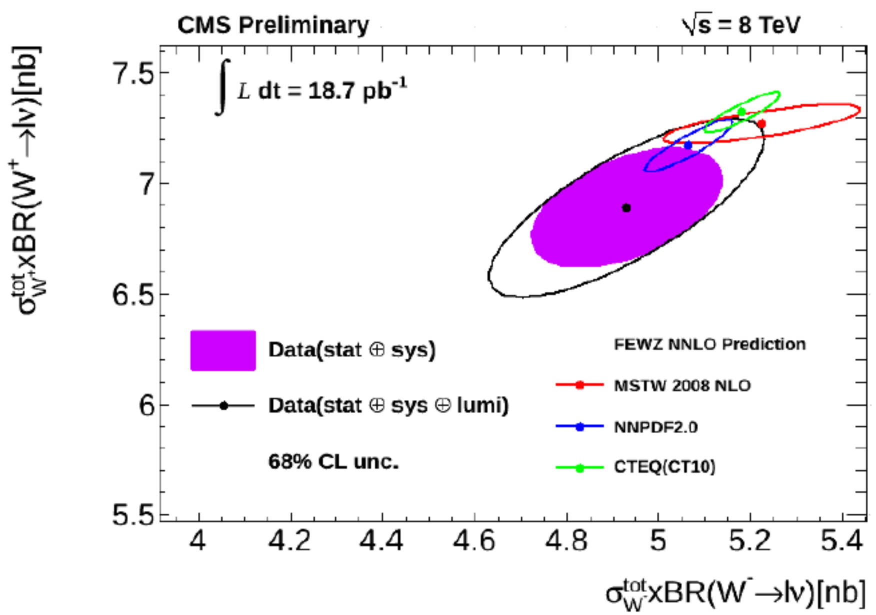
There’s More Information In These Numbers



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.

And at 8 TeV



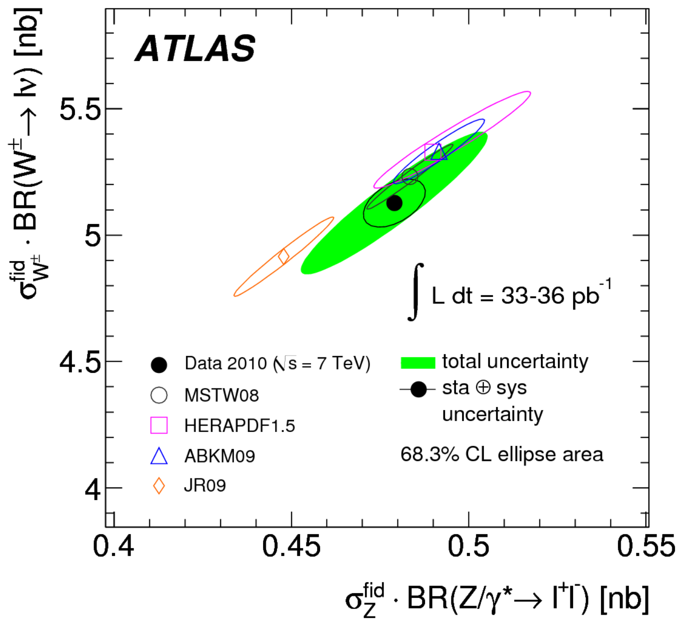


8 TeV vs. 7 TeV seems to make a substantial difference in the quality of the agreement.

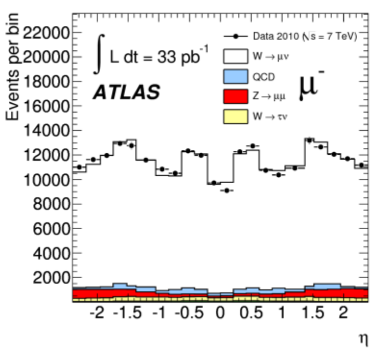
Note that this is a small part of the data – 19 pb^{-1} – because again this measurement becomes systematics limited quickly.

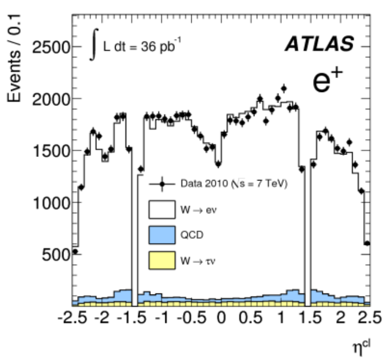
The Future

- 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.

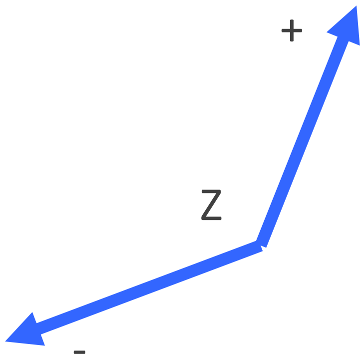




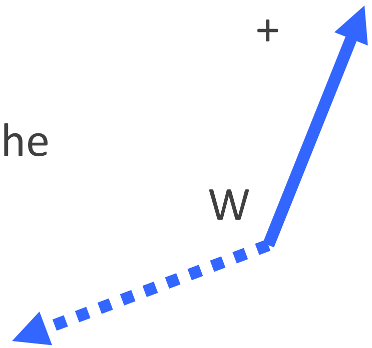
A question I don't know the answer to: what can we learn from comparing, e.g. W^+ production at y = 0.5 with W^- production at y = 0.9?

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.



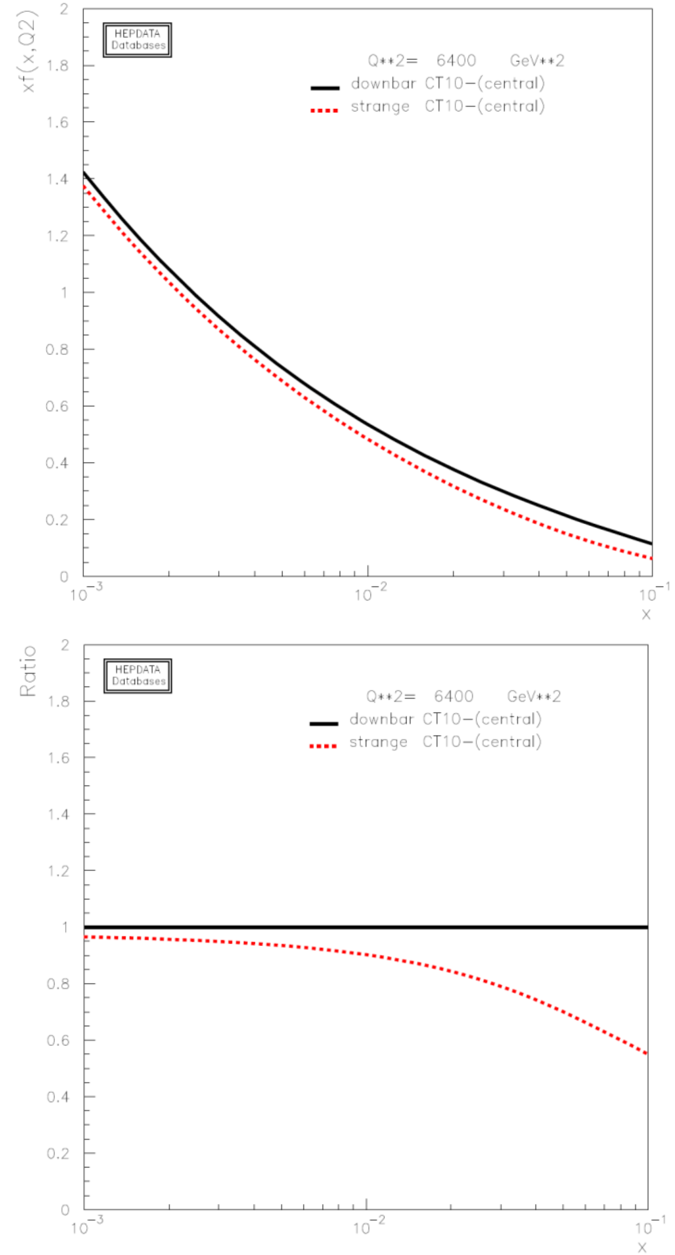
would be treated the same as



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

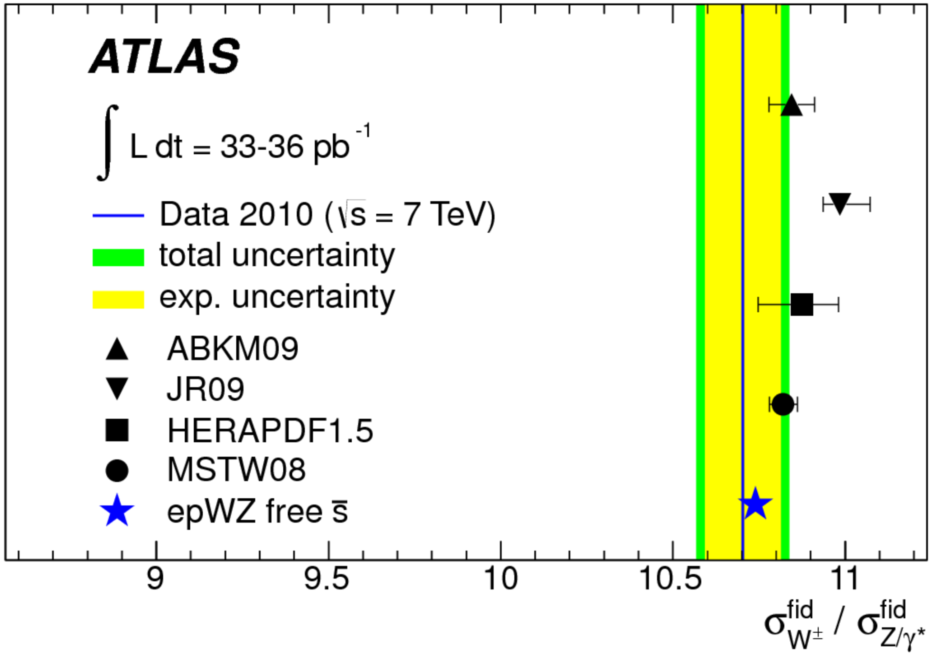
Strangeness PDFs

- 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)

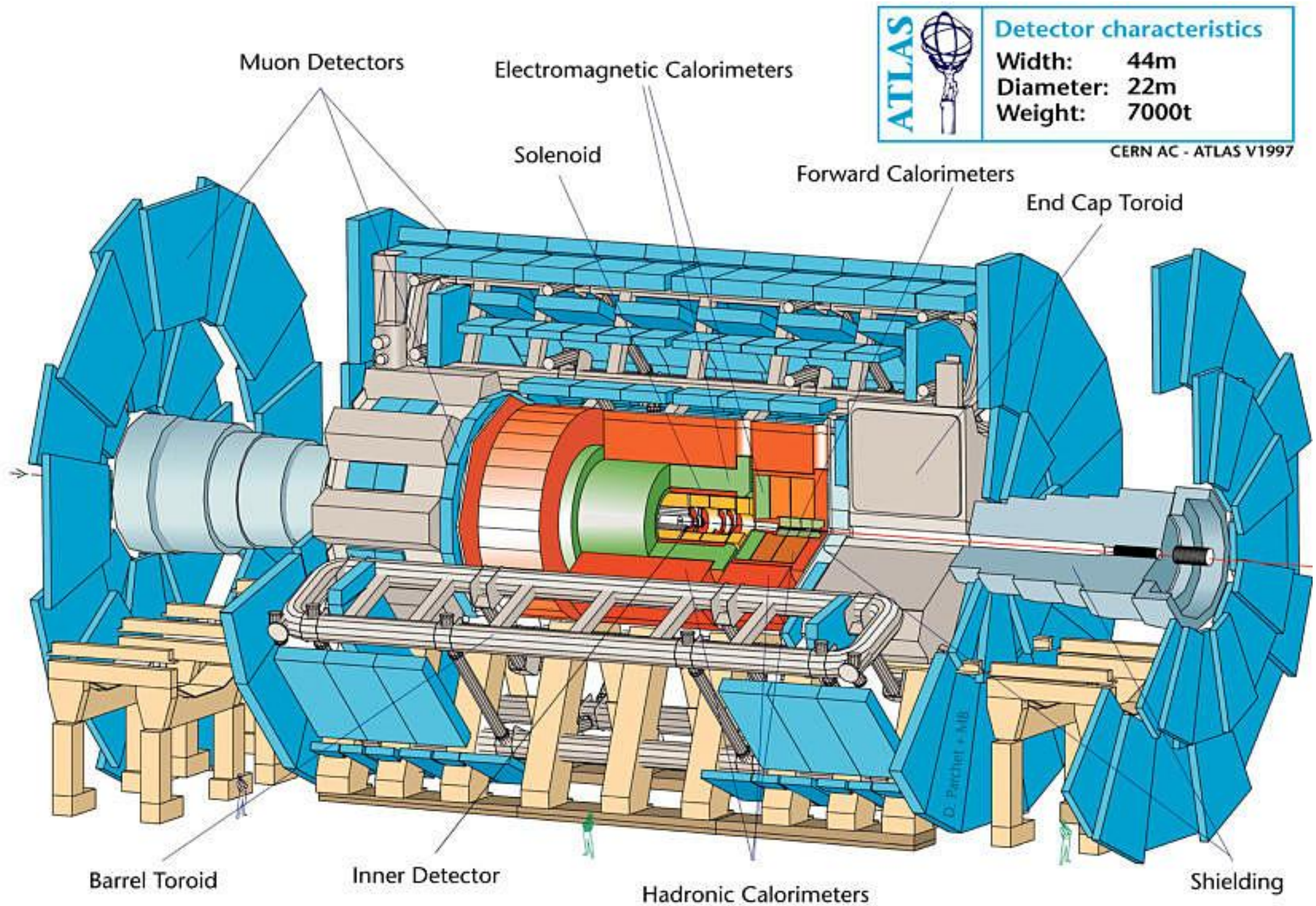
- With 36 pb^{-1}, the approximate sensitivity of ATLAS is comparable to the difference between PDF sets.
- However, with 36 pb^{-1} you only get one point. We expect sbar(x)/dbar(x) to vary with x.
- To study this, we need to divide the data into rapidity bins, with comparable numbers of Ws to the 36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



Second Half Summary

- Now that we have a “Higgs-like Boson” in hand, we need to see if it not only looks like a Higgs, but does the job of the Higgs.
  - One part of its job is to moderate the quartic gauge couplings
  - Studying this is a long-term project, starting with measuring the TGC’s
  - It may be time to incorporate some of things things we have learned in the last 20 years into our parameterizations
- Electroweak bosons provide a window into the structure of the proton
  - We will need to learn how to use the 99.8 or 99.9% of the data that we presently ignore.
- Thanks to the organizers for inviting me, and to my ATLAS and CMS colleagues for providing this material.

ATLAS Detector



CMS Detector