LHC Prospects for QCD, Electroweak and Top

101st LHCC Interaction
5 May 2010

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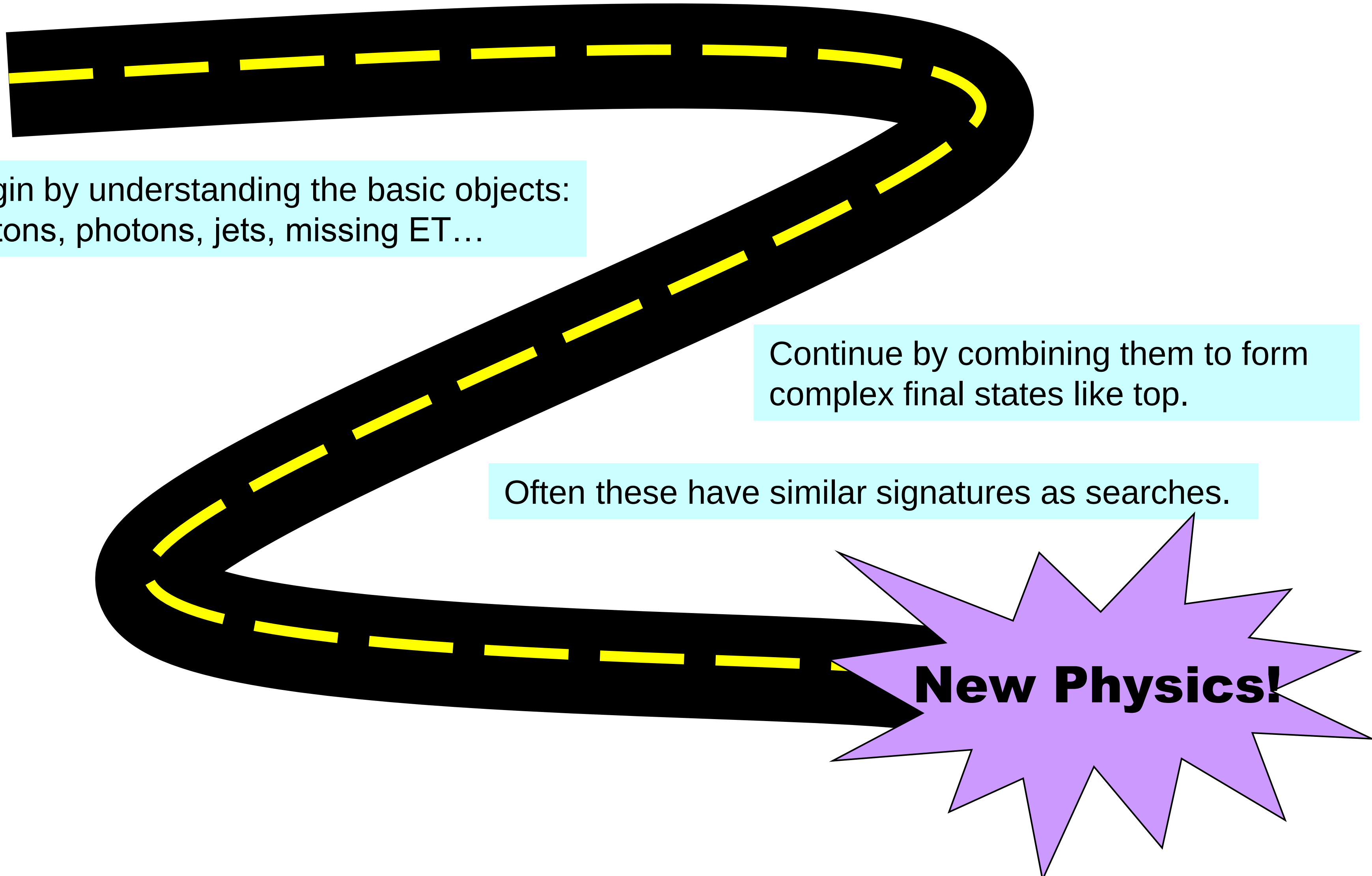
for the ATLAS and CMS Collaborations

The Road Ahead

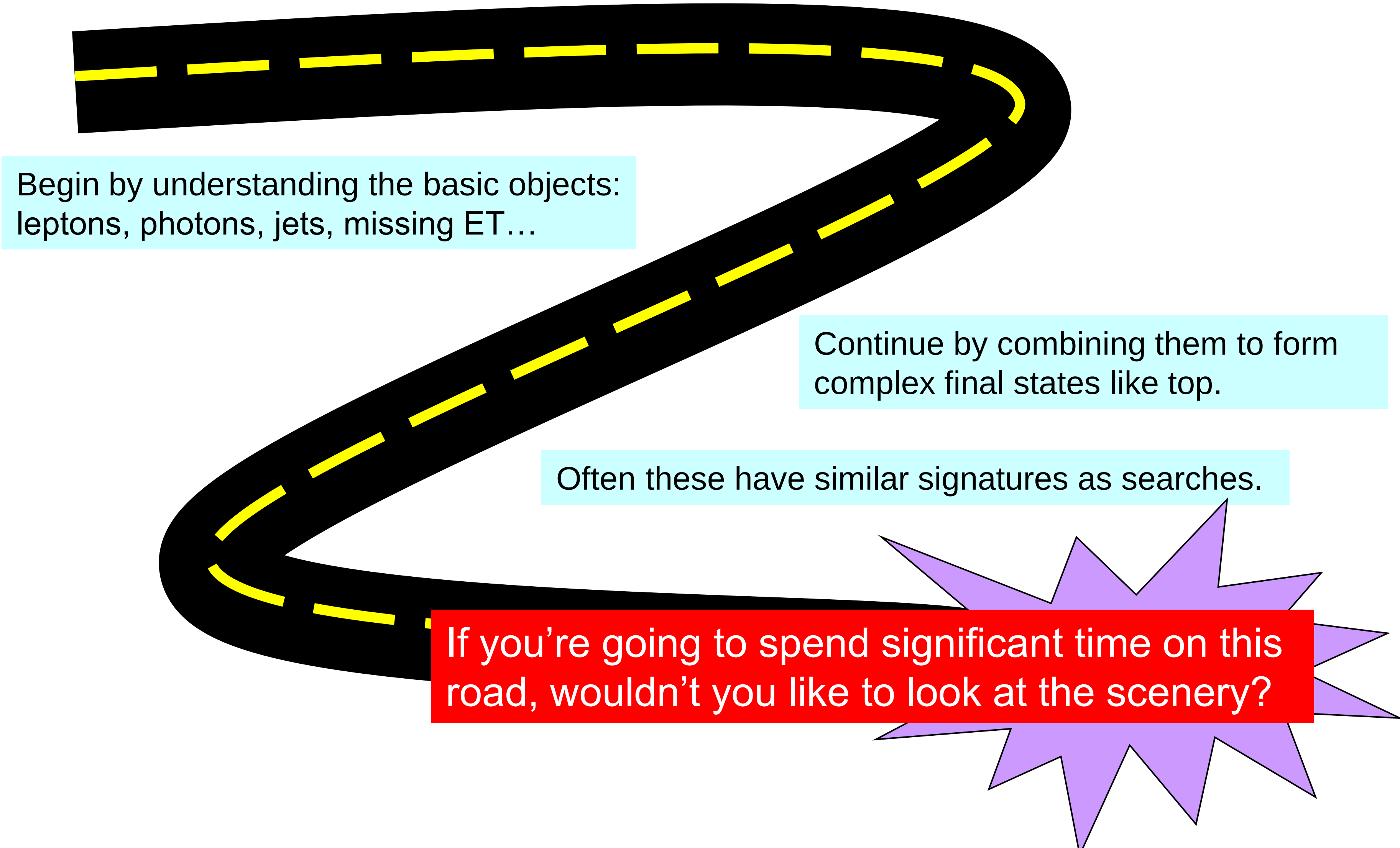


Begin by understanding the basic objects: leptons, photons, jets, missing ET…

Continue by combining them to form complex final states like top.

Often these have similar signatures as searches.

The Road Ahead



Outline

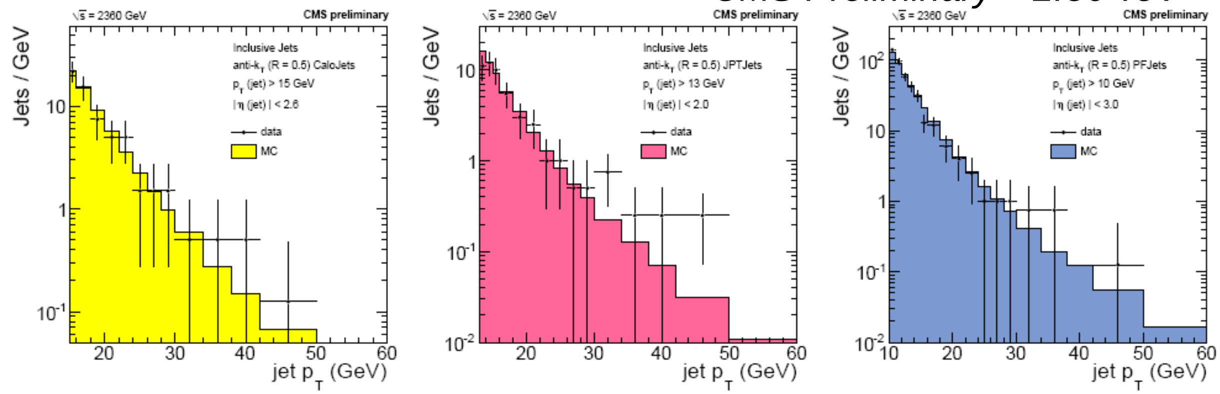
- I will discuss some of the interesting attractions on this road, concentrating on milestones of 100-200 pb^{-1} and 1 fb^{-1}.
  - Hard QCD
  - W's, Z's
  - Top

- This talk is intended to be mostly illustrative and qualitative.
  - By it's nature, it will be somewhat episodic
  - There will be a lot of scaling and extrapolations
  - I am afraid I will omit far more than I can include

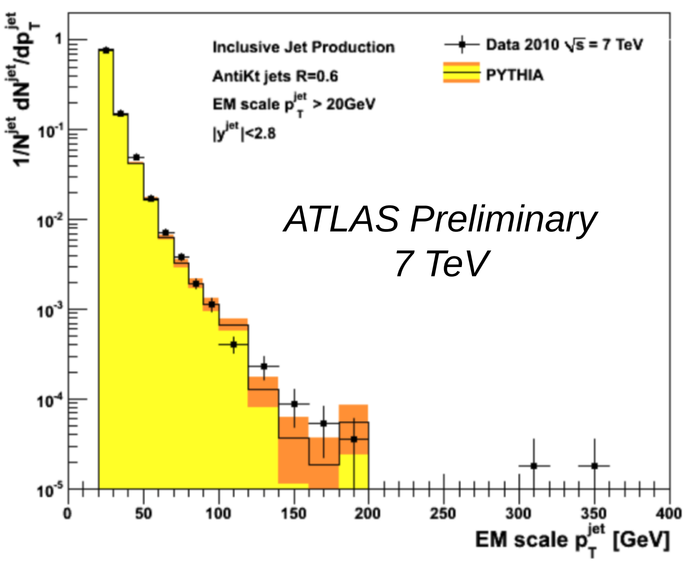
Jets Today

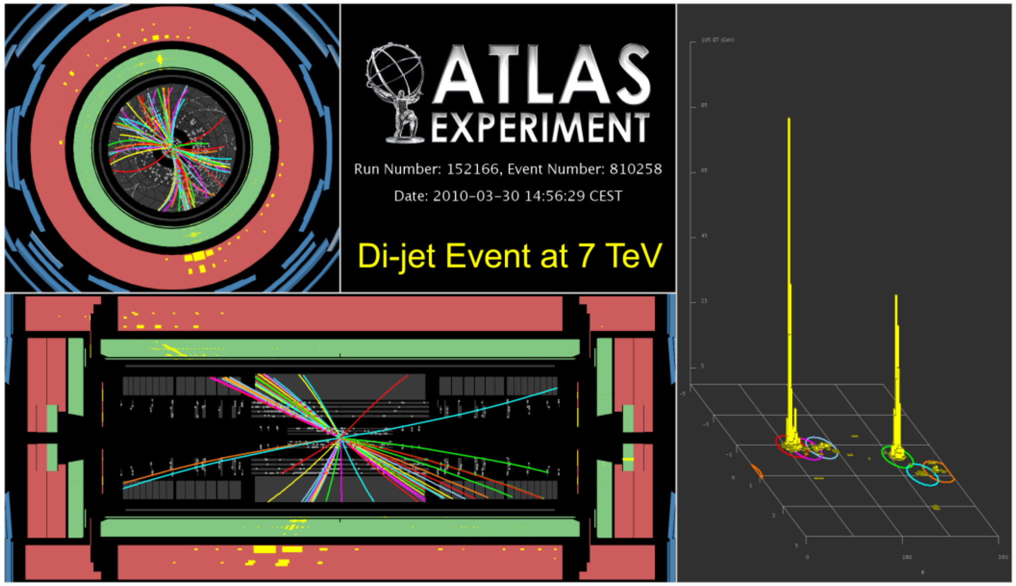
Both experiments see jets, and are busy producing a jet energy scale for the summer conferences.

CMS Preliminary – 2.36 TeV

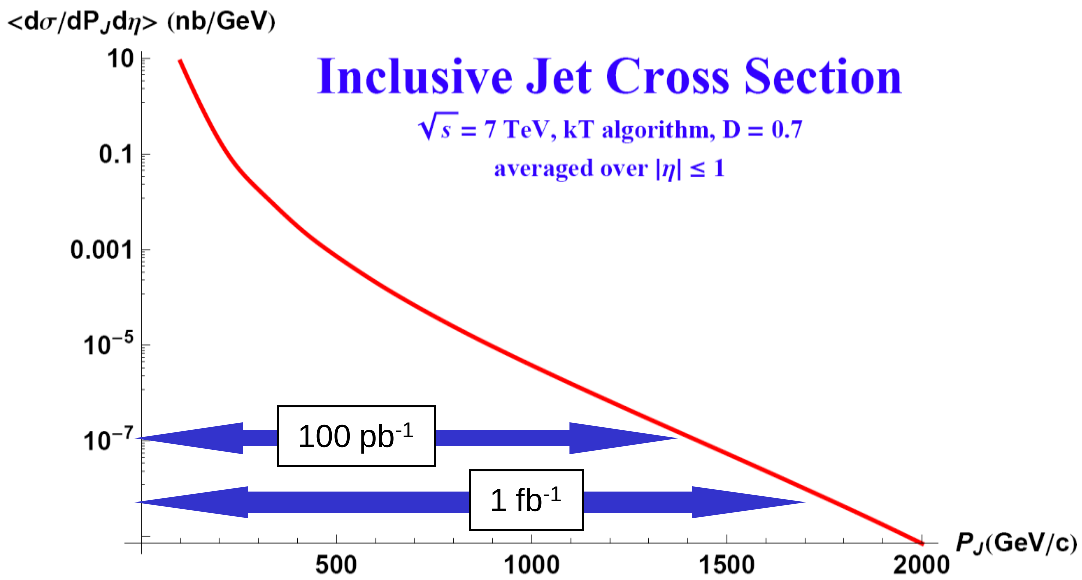


Calorimeter jets | Calorimeter jets + Track jets | Particle-flow jets





Jets: After The First Inverse Nanobarn



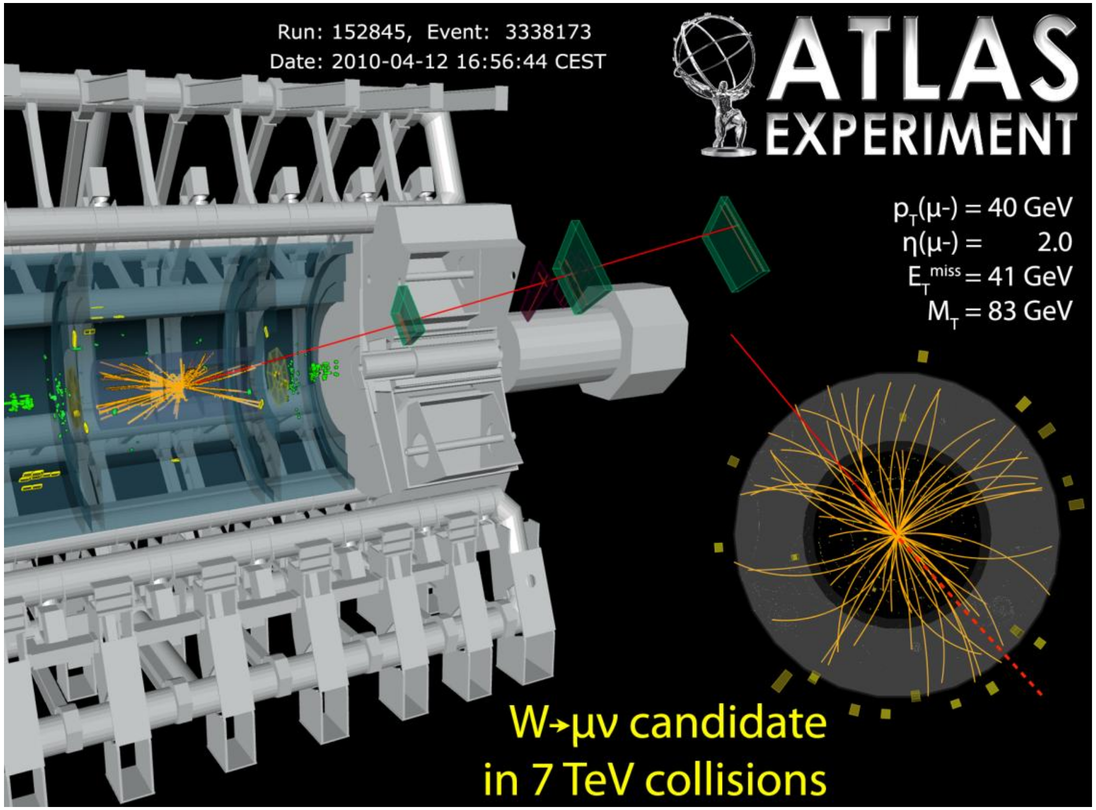
- NLO QCD jet spectrum – no detector effects included
- Thanks to Steve Ellis for making this
  - Aside: shows the value in having a strong theory group (including visitors) nearby.

- We expect to reach jets with E_T's of around 1.4 TeV after the first 100 pb^{-1}
- Also, jets with E_T's of around 1.7 TeV after the first fb^{-1}
- Reminder: as a rule of thumb, the sensitivity to a contact interaction Λ is roughly 4x the E_T of the most energetic jet.
  - **We expect to have world-class limits very soon.**

W’s and Z’s

The LHC is producing W’s and the experiments are reconstructing them.

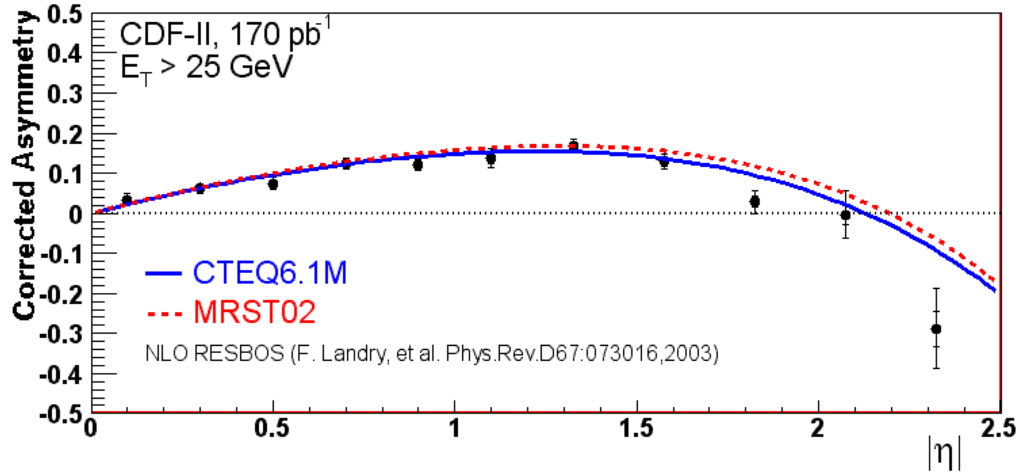
Kevin showed this event this morning, but I am showing it again because I like it.



- Each experiment expects ~25,000 Z’s and ~250,000 W’s (for each flavor) every 100 pb^{-1}.
  - In the past, we have discussed the utility of these events for calibration, etc.
  - I’d like to highlight a few physics measurements possible – beyond the obvious cross-sections and p_T spectra.

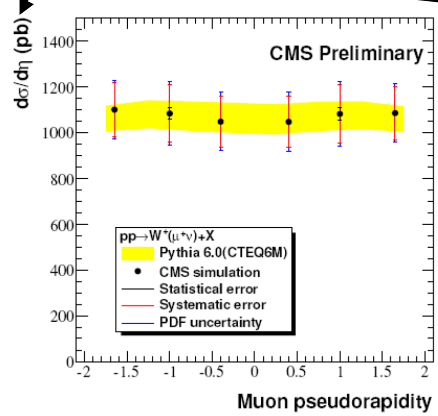
"W Asymmetry"

- At the Tevatron, there is an η-dependence to the W lepton spectrum
  - Due to two factors:
    - The quark PDFs
    - The W decay distribution (known)
  - Because it's proton-antiproton, this is an odd function of η.
- At the LHC, the same thing happens.
  - It depends more on sea quark PDFs (no valence antiquarks)
  - Because it's proton-proton, this is an even function of η. ("Asymmetry" is not the best word, but the terminology stuck.)



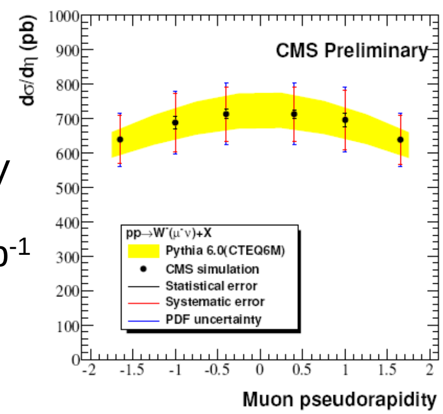
Note scales

CMS-PAS-EWK-09-003



10 TeV

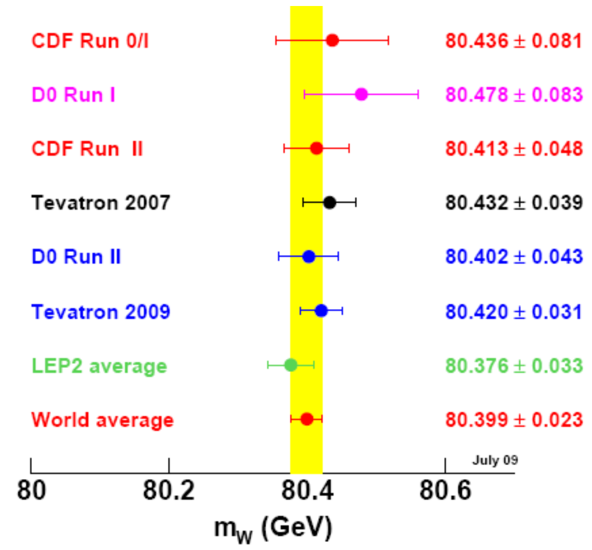
100 pb^{-1}

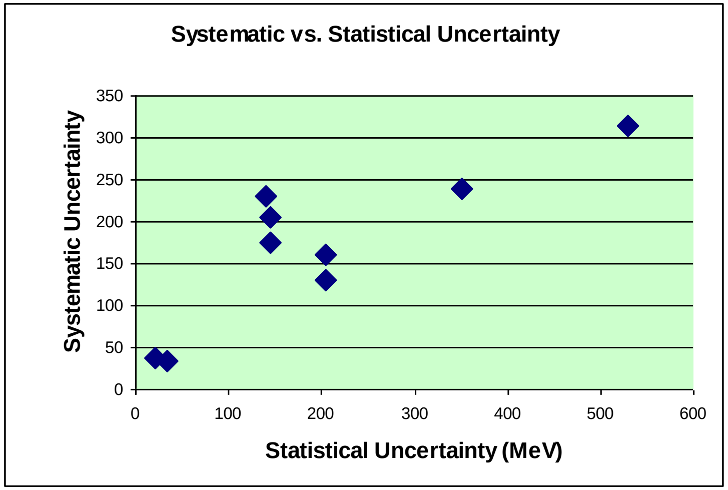


At 7 TeV, we get the same W yield at ~150 pb^{-1}. However, the asymmetry is expected to be larger at lower energy.

W Mass

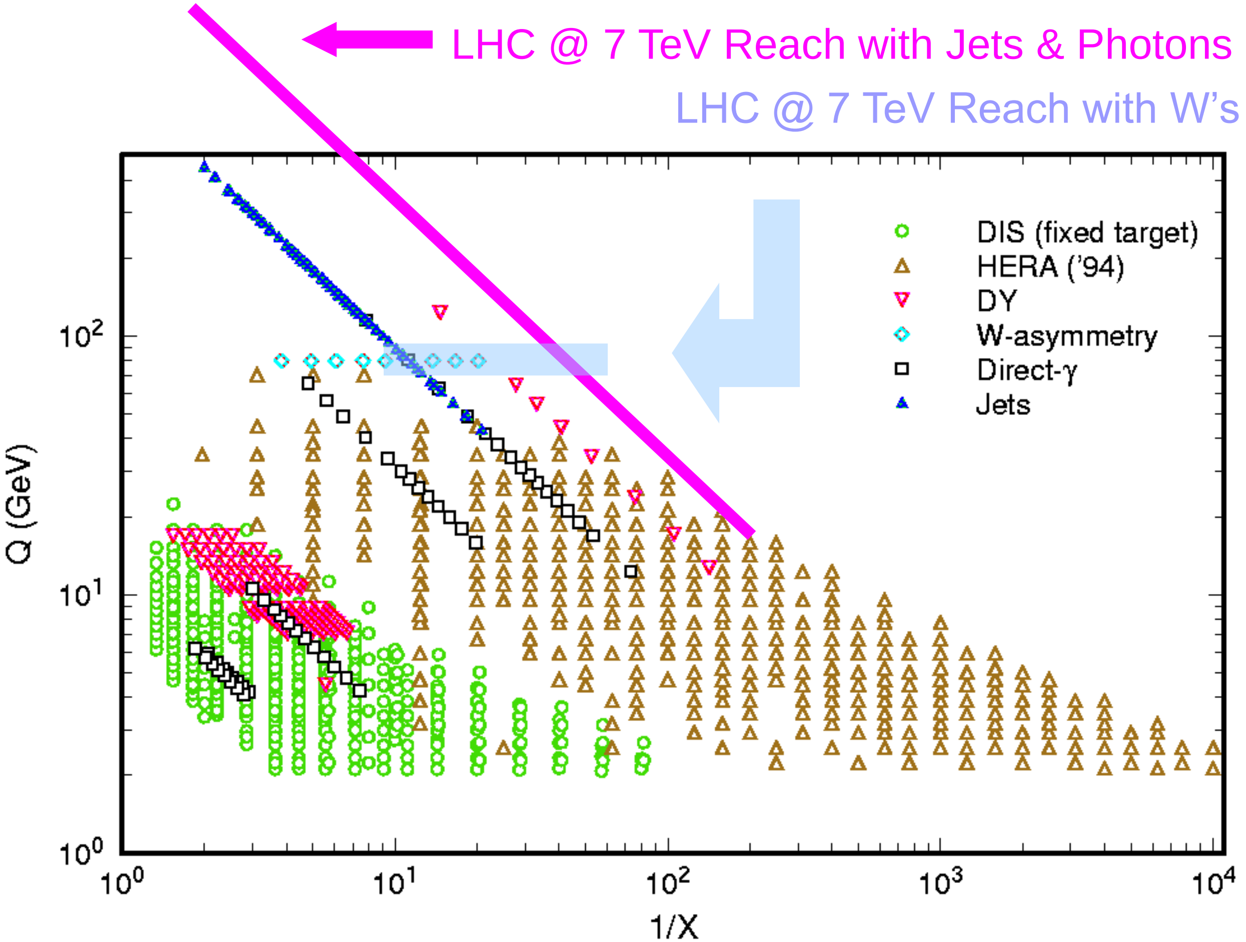
- A <u>very</u> challenging measurement
  - Limited by systematic uncertainties
- Today's measurement with the most events is D0's, based on 500K W's.
  - Each experiment will collect a comparable amount of data after ~200 pb^{-1}
  - A large data set is a necessary, but not sufficient condition to do this measurement.
- Historically, systematic uncertainties track statistical uncertainties
  - More events let you better understand and control these systematics, in particular the lepton energy scale.
- While not a fast measurement, it is an important measurement
  - One important difference at 7 TeV vs. 14 TeV: the QCD corrections are smaller





Tevatron measurements

Kinematic Reach of a 7 TeV LHC



In the 2010-11 Run, the LHC will substantially increase the kinematic range available for study.

In particular, W production allows probing low x, high Q^2 quarks and antiquarks.

The 7 TeV data "fills the gap" between the Tevatron and a 14 TeV LHC.

From CTEQ: these are the inputs to CTEQ5

Top Quark "Rediscovery" – Dileptons

- Signature is 2 leptons, 2 jets + missing E_T.
- With ~10 pb^{-1}, we expect a convincing signal
  - Each experiment will have ~30 events with an expected background of 5 or 6.
- Even with 5 pb^{-1}, many will find the signal plausible:
  - Each experiment will have ~15 events over a background of around 3.
- At 1 pb^{-1}, interesting event displays will start to appear at conferences
  - "Here's an event with many features one would expect from top pair production."

Expected 10 pb^{-1} sensitivity (per experiment)

Channel	N(Signal)	N(background)
e - μ	14	2.5
$e - e$	4.3	1.1
$\mu - \mu$	6.6	1.9
Total	**25**	**5.5**

ATL-PHYS-PUB-2009-086 + scaling to 10 pb^{-1} @ 7 TeV.

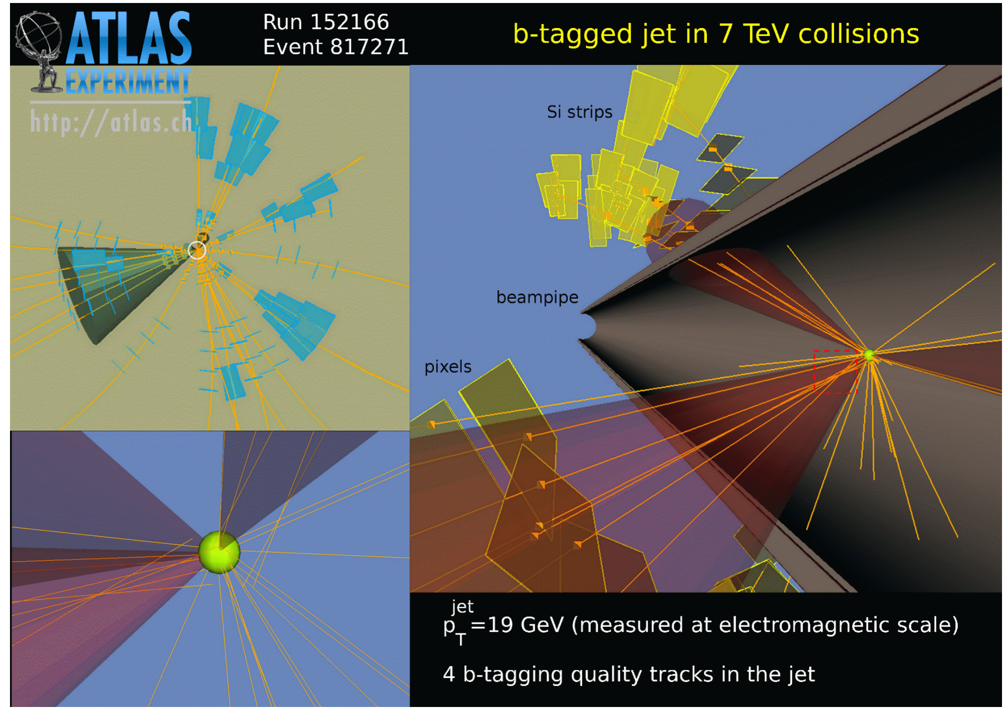
This, however, is not the whole story: these aren't just jets – they are *b*-jets. The above table does not make use of this - additional confirmation can be obtained via flavour tagging.

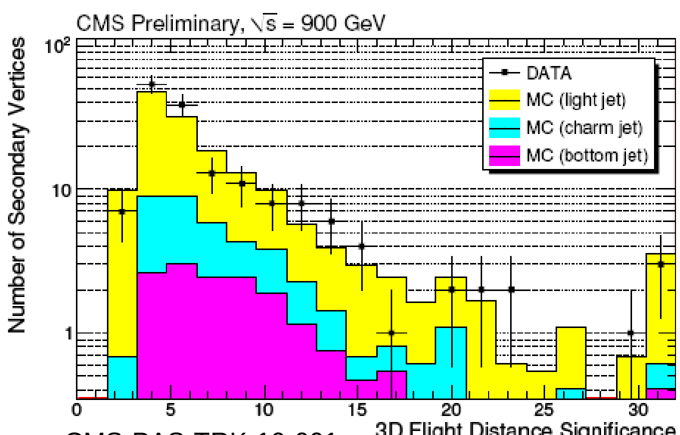
Cross-section scaling used: $\sigma(t\bar{t})_7 \cong 40\%\ \sigma(t\bar{t})_{10}$

$$\sigma(W + \text{jets})_7 \cong 45\%\ \sigma(W + \text{jets})_{10}$$

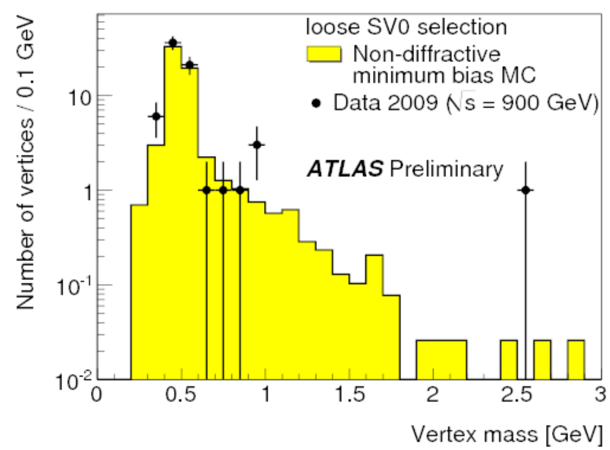
Flavour Tagging Today

- Both experiments are studying flavour tagging with the data in hand.
  - Many tagged jets have been found, sometimes correlated with nearby leptons or second tags in the event
- The emphasis is on "early taggers"
  - Not necessarily the ultimate performance, but can be understood quickly.



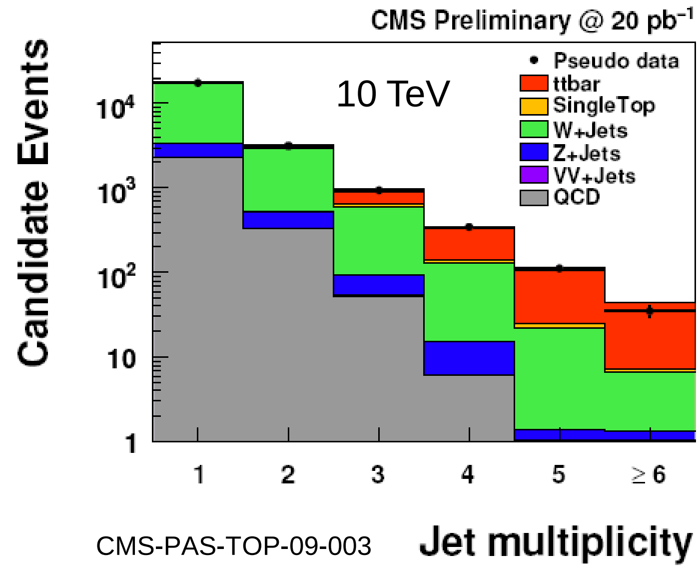


CMS-PAS-TRK-10-001

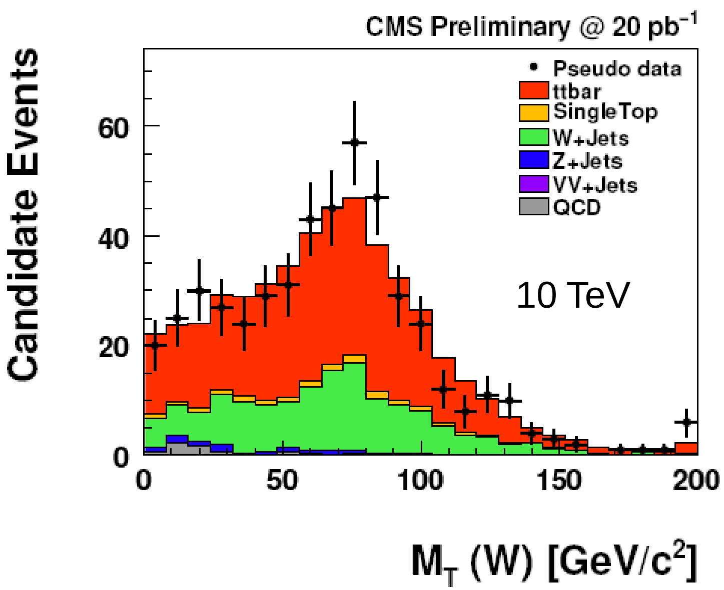


Top Quark "Rediscovery" – Lepton+Jets

- Here too, a few pb^{-1} gets us to an interesting region
  - This N_{jets} plot is for 20 pb^{-1} at 10 TeV; so it looks similar to what we would expect for ~50 pb^{-1} at 7 TeV.
  - At 7 TeV and 10 pb^{-1}, we expect ~60 top events per lepton flavour per experiment over a background of ~40 in the 4 jet, 5 jet and 6+ jet bins.



CMS-PAS-TOP-09-003



The dijet mass is expected to show a peak near the W: additional confirmation.

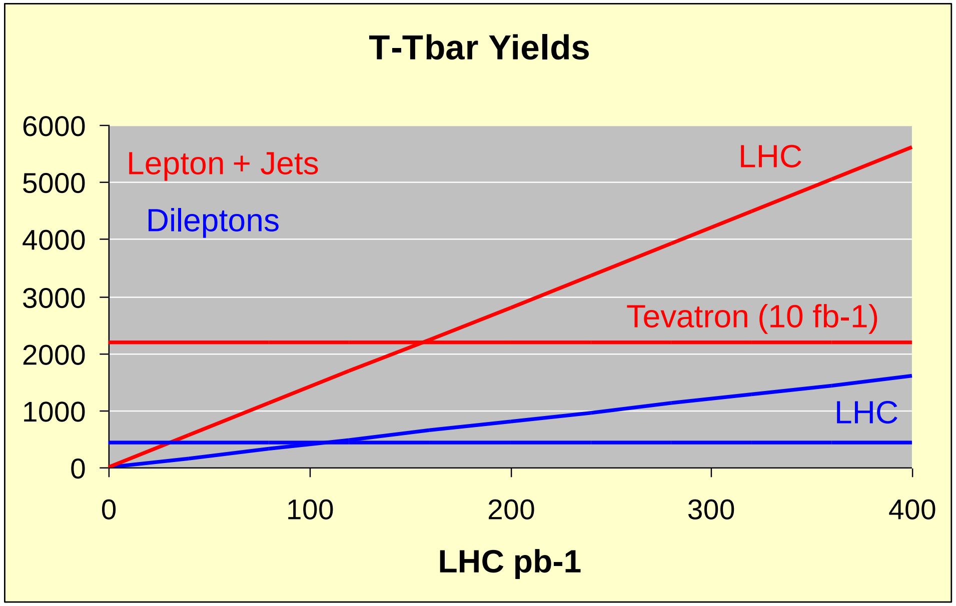
Again, this is done without flavour tagging, which can be used to confirm the top content of the W+multijet sample.

Cross-section scaling used: $\sigma(t\bar{t})_7 \cong 40\%\ \sigma(t\bar{t})_{10}$

$$\sigma(W + \text{jets})_7 \cong 45\%\ \sigma(W + \text{jets})_{10}$$

The Next Few Hundred pb^{-1}

- Each experiment expects top yields of
  - Dilepton: ~400 per 100 pb^{-1}
  - Lepton (e & μ) + Jets: ~1400 per 100 pb^{-1} (with large variations depending on selection requirements)
- By the end of 2010, the LHC will have samples comparable to the Tevatron's.

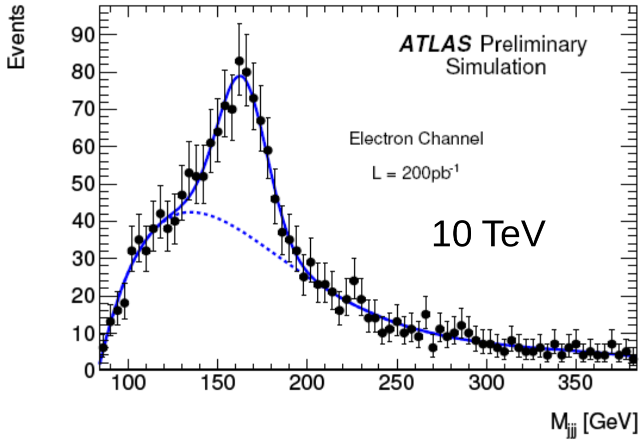


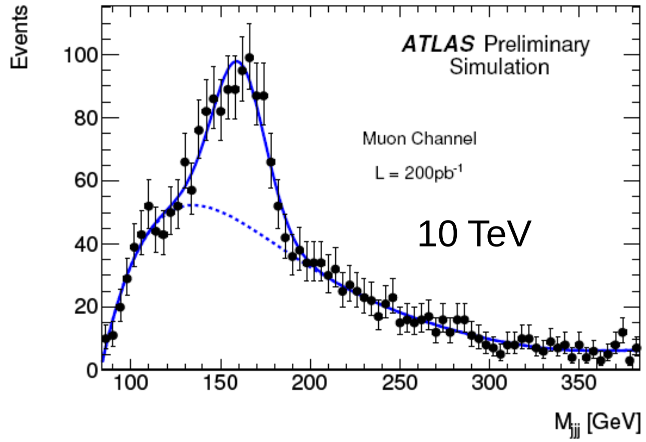
- By the end of 2011, the top samples will be substantially larger
- The physics program with a few hundred pb^{-1} will look very familiar
  - Top cross-section (at a new energy)
  - Top mass (at the end of the year you will see averages over 4 experiments, not 2)
  - Single Top
  - Rare decays

Top Production with More Data

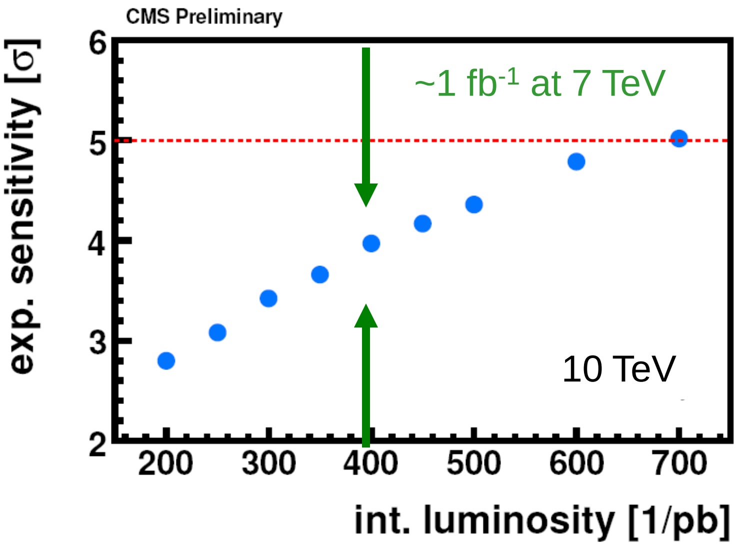
Top pair production in the lepton+jets mode with ~500 pb^{-1} at 7 TeV. This analysis has an m(jj) = m(W) requirement.

The background has a large component from misassignment: b-tagging will help.





- Single top production is quite challenging
  - The top pair background is enormous
  - The uncertainty on the backgrounds is larger than the expected signal: makes a pure counting experiment impossible

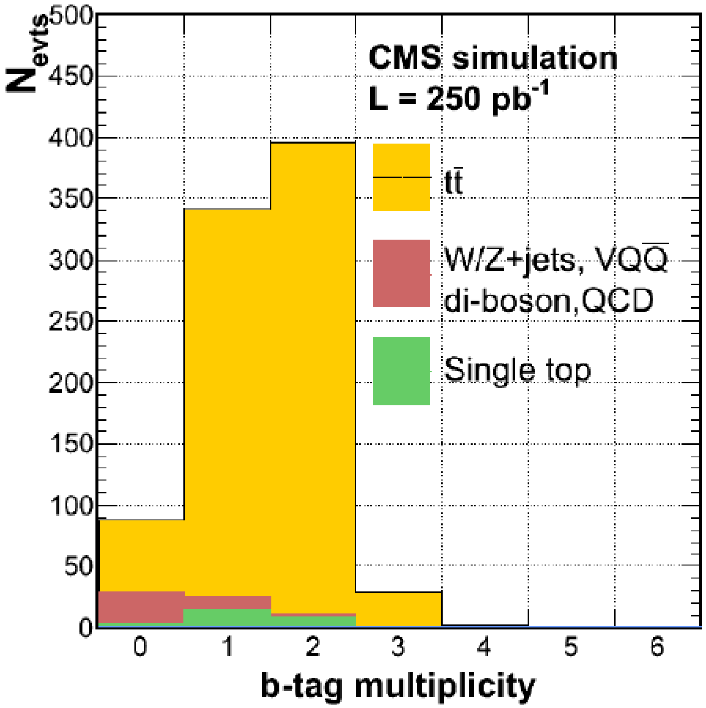


Rare Top Decays (I)

- The limits on the FCNC decays $t \rightarrow qZ$ and $t \rightarrow q\gamma$ are driven by the top quark pair yield: more tops implies a better limit
- The measurement of $BF(t \rightarrow Wb)/B(t \rightarrow Wq)$ (=R) is driven by the knowledge of the *b*-tagging efficiency.
  - CMS has developed a technique to do this in a data-driven manner:

CMS-PAS-TOP-09-001

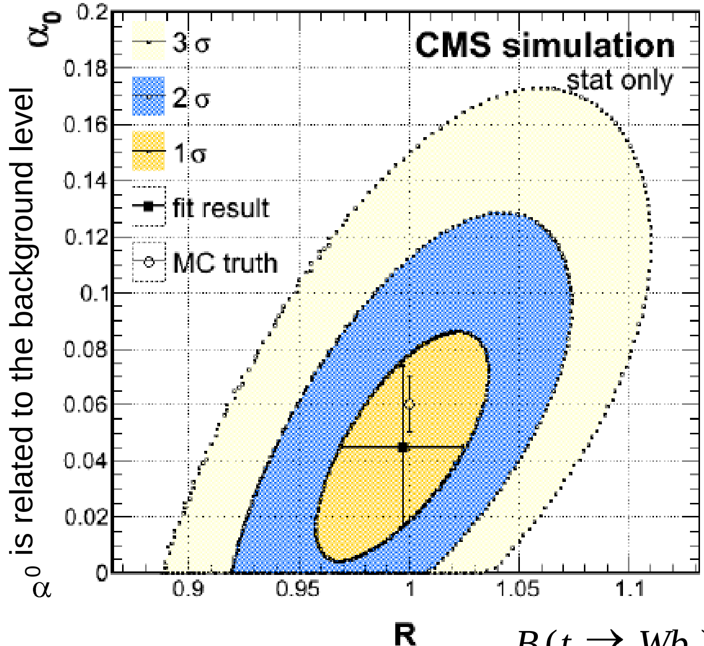
- Start with top dilepton (e-μ) events
  - The purest sample we have
  - We would like to know R, ε_b and the non-top contamination in the sample
- Measure the number of events with 0, 1 and 2 tags.
  - The ratios N_2/N_1 and N_1/N_0 depend **differently** on R and ε_b (i.e. not only on their product)
- Correct for misassignment
  - I won't describe the two techniques here.



Rare Top Decays (II)

- With 250 pb^{-1} of 10 TeV data, CMS expects a ±9% measurement of R.
  - This is the present PDG uncertainty
  - The systematic uncertainties are uncorrelated between this measurement and the Tevatron's.
- This corresponds to ~600 pb-1 of 7 TeV data: mid-2011 in the present schedule

CMS-PAS-TOP-09-001



$$R \equiv \frac{B(t \to Wb)}{B(t \to Wq)}$$

- The volume of the LHC top dataset allows us to do measurements in different ways than the Tevatron:
  - For example, restricting ourselves to the cleanest e-μ channel.
- This makes combination easier, but more importantly, adds robustness
  - Independent systematic uncertainties

Summary

- The LHC is not *about to start* an interesting physics program
- The LHC is *in the midst* of an interesting physics program!
  - Involving 900 GeV, 2.36 TeV and 7 TeV data

- This program will
  - Permit measurements in new regions:
    - The new region in the x-Q^2 plane – including TeV-scale jets
    - The new region of top physics opened up by having many thousands of events
  - Provide many thesis opportunities for our graduate students
  - Will build the foundation for our searches for new physics – **see Oliver's talk (next).**

Tom LeCompte, ANL