Top-Quark Physics at CMS

Chris Neu

University of Virginia

on behalf of

the CMS Collaboration

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leptons quarks gauge bosons

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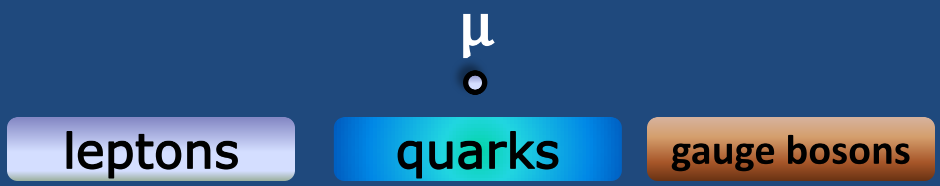

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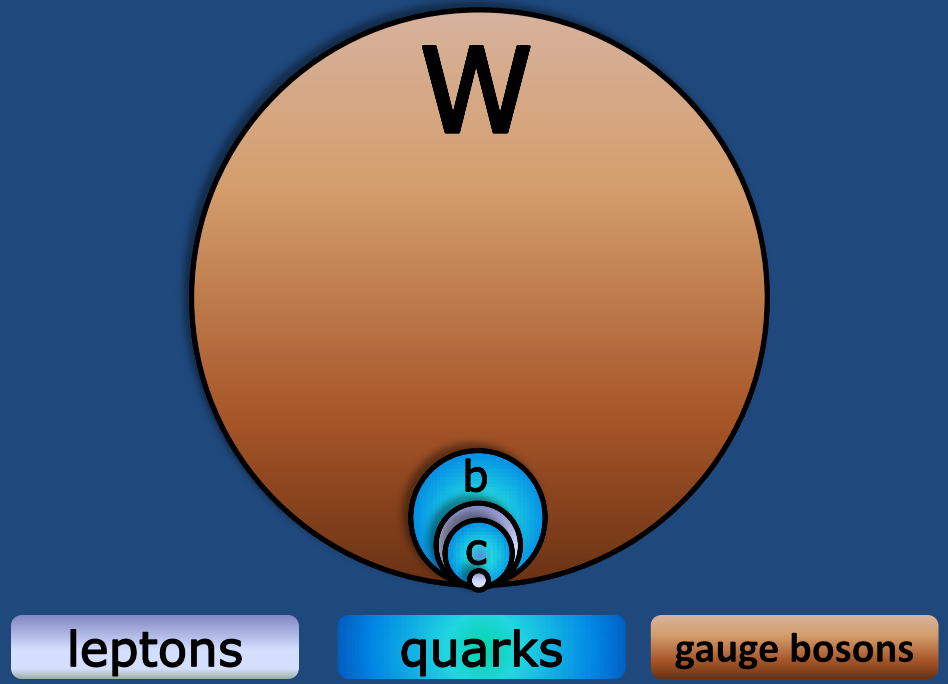

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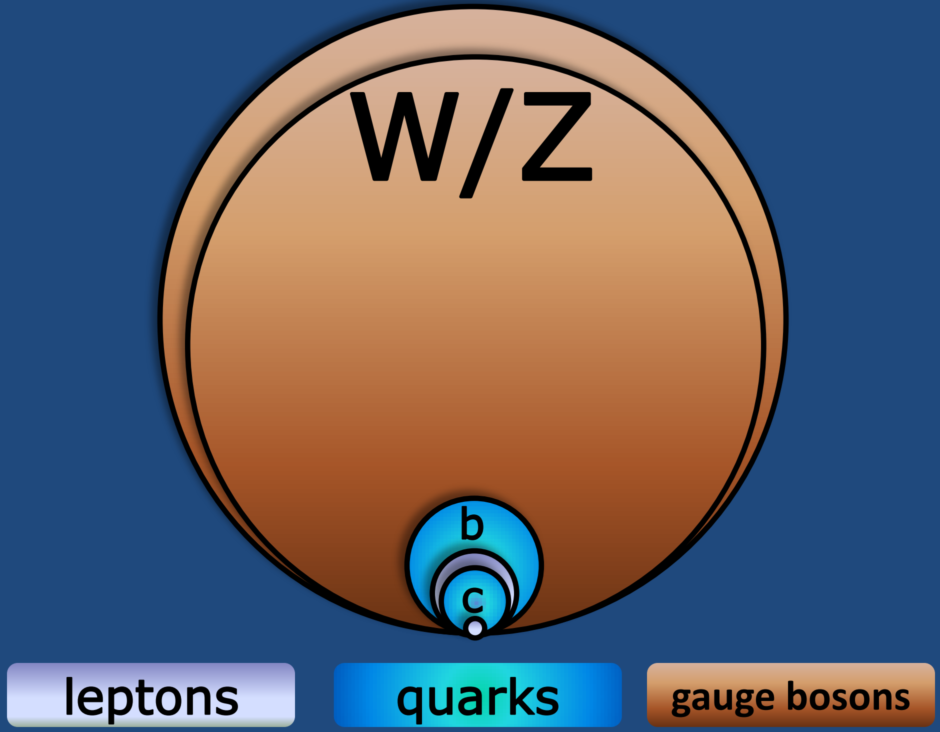

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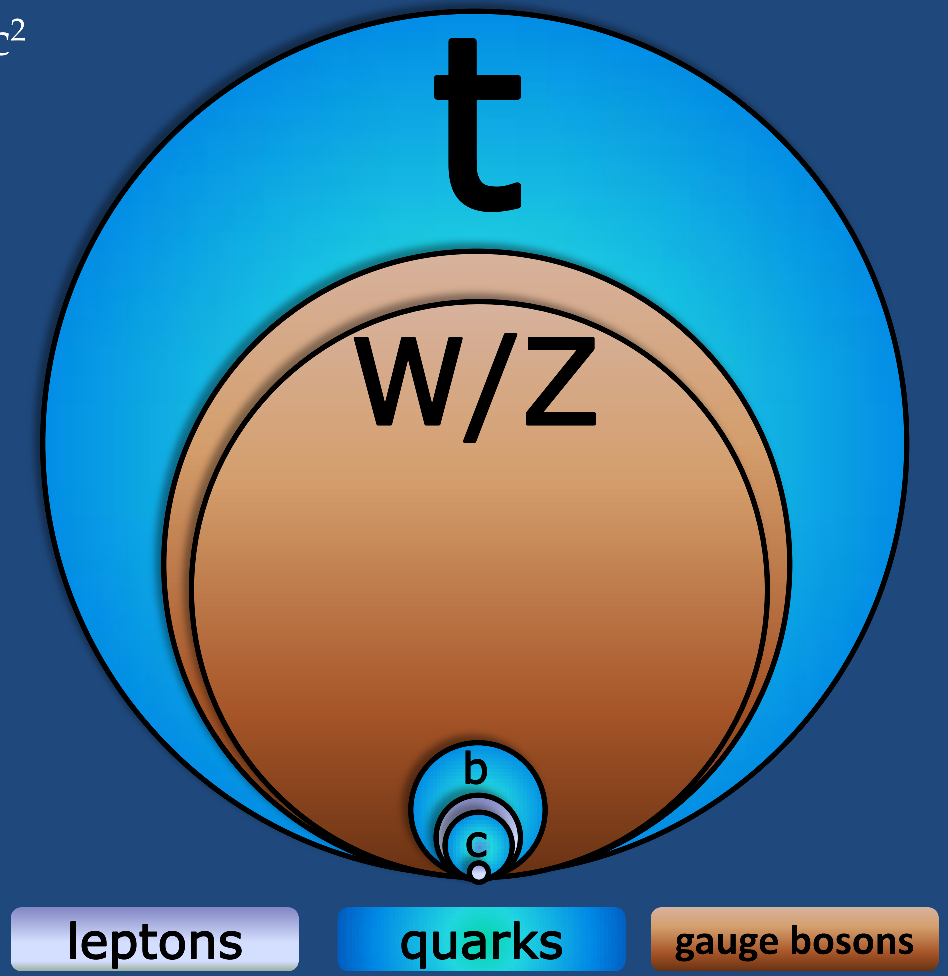

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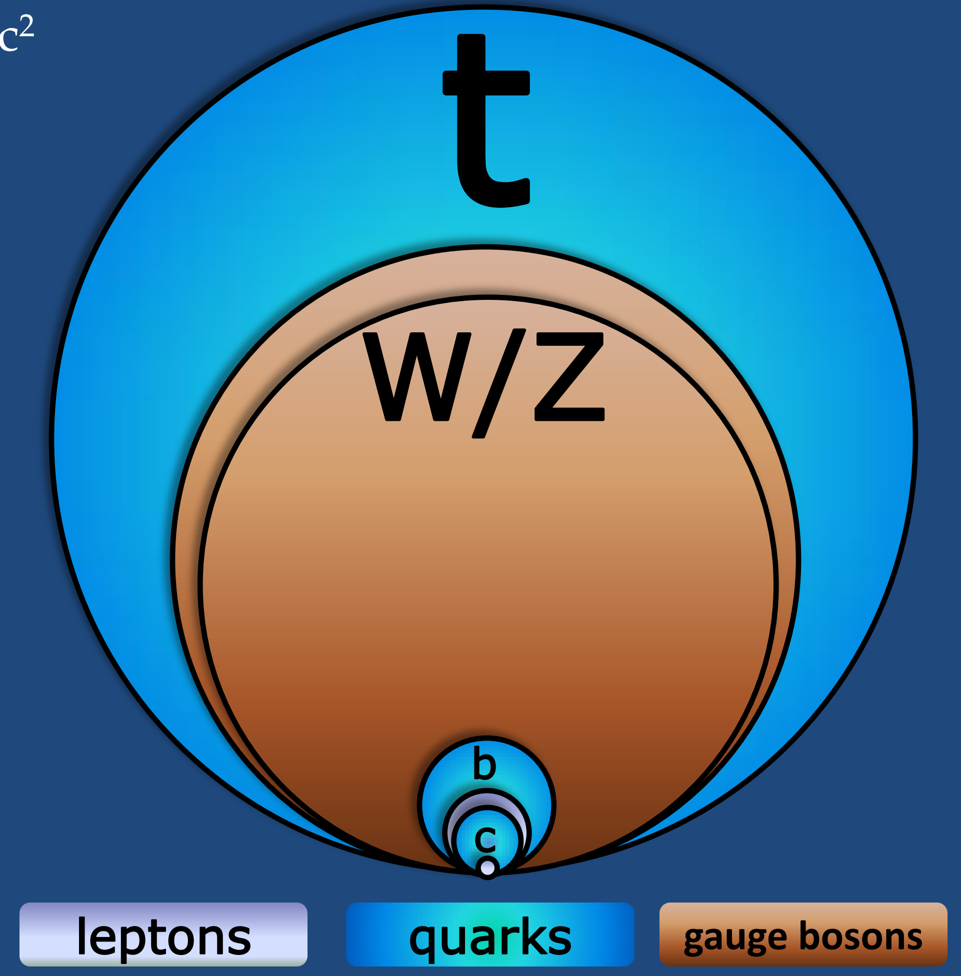
1 atom of Au : mass= ~180 GeV/c^2
^{197}Au = 118 n, 79 p, 79 e^-



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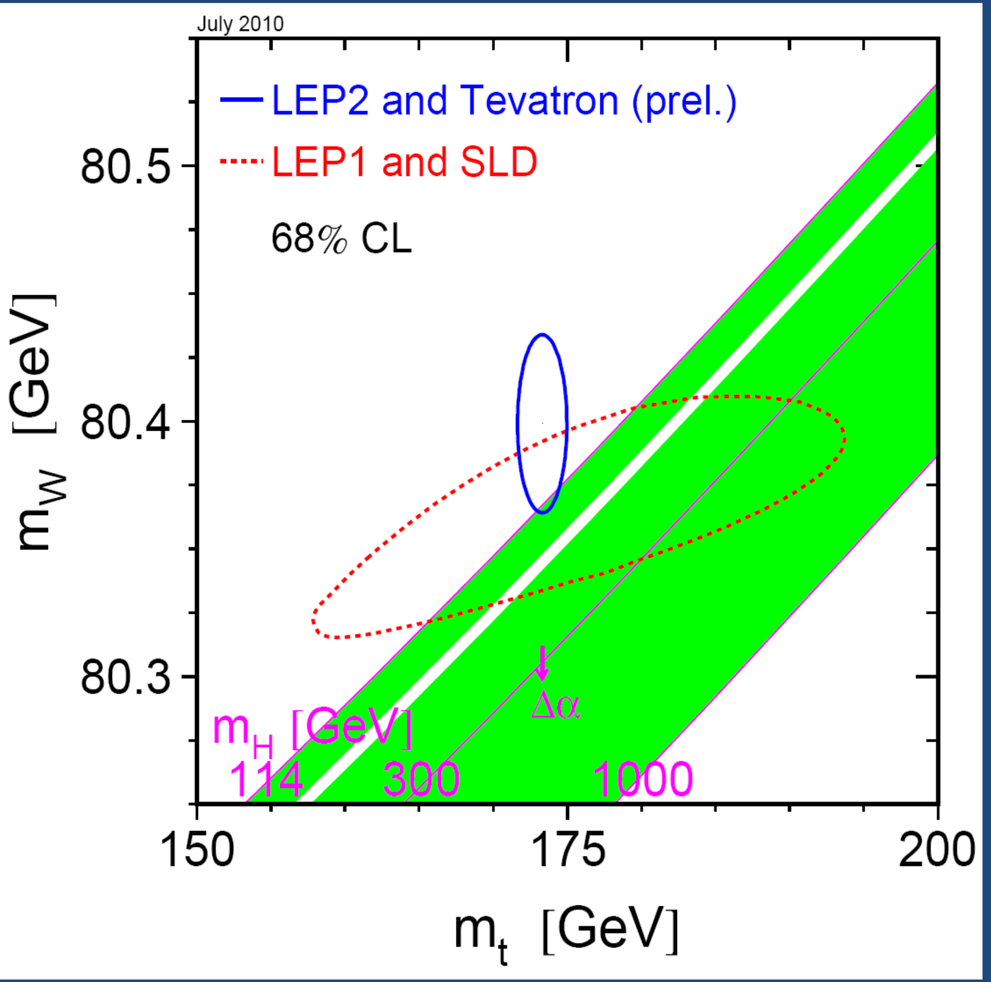

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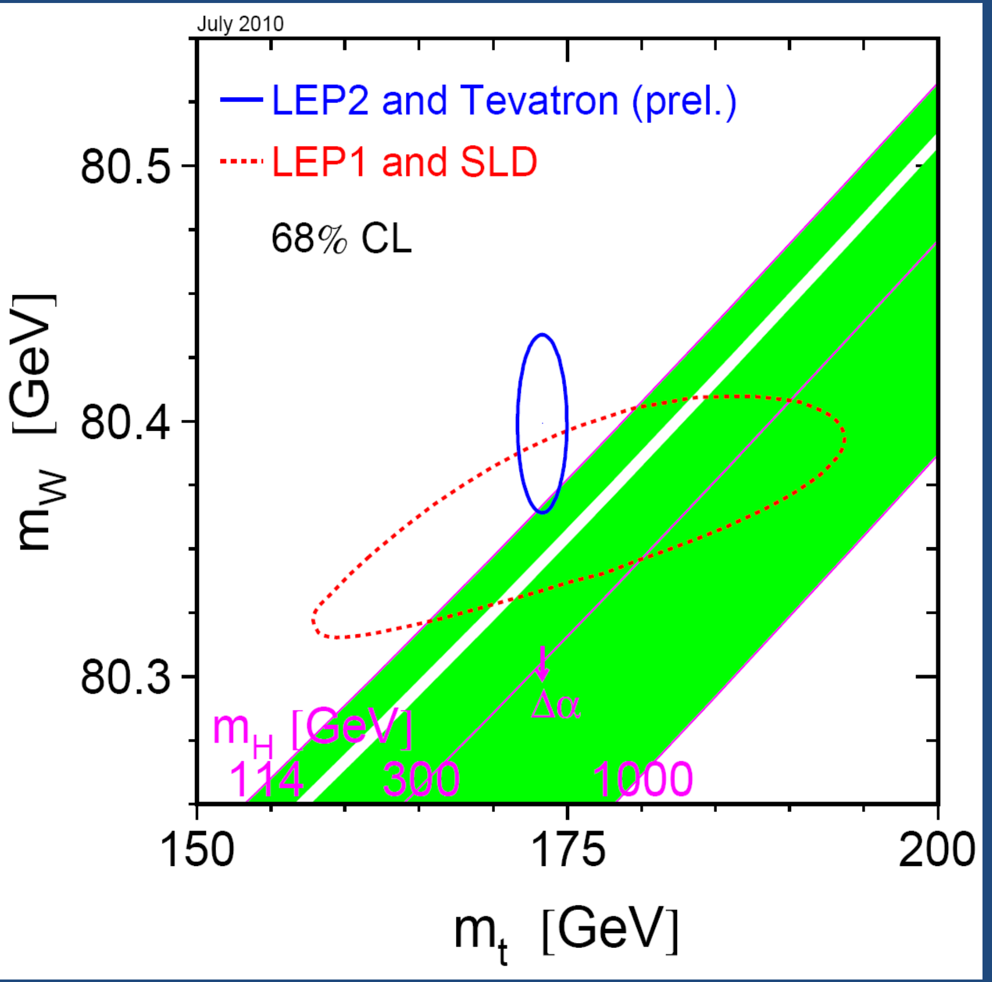
  - large mass could indicate special role in EWSB



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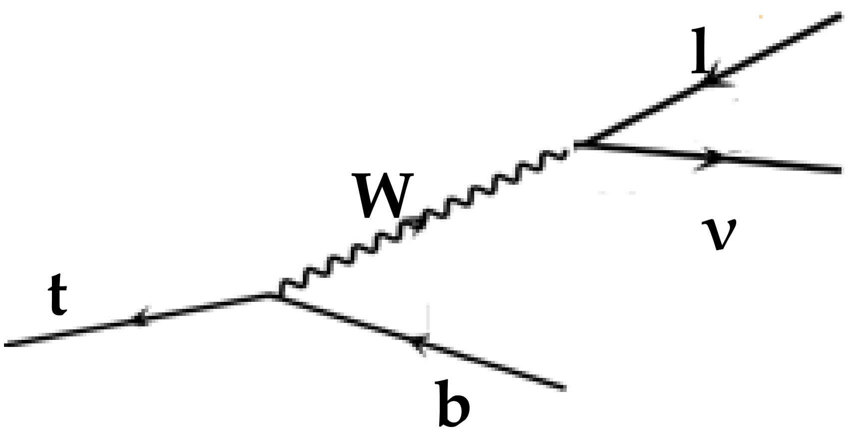
  - decays very rapidly – glimpse of free quark



Allows for measurements of:
- mass
- spin
- electric charge
- etc

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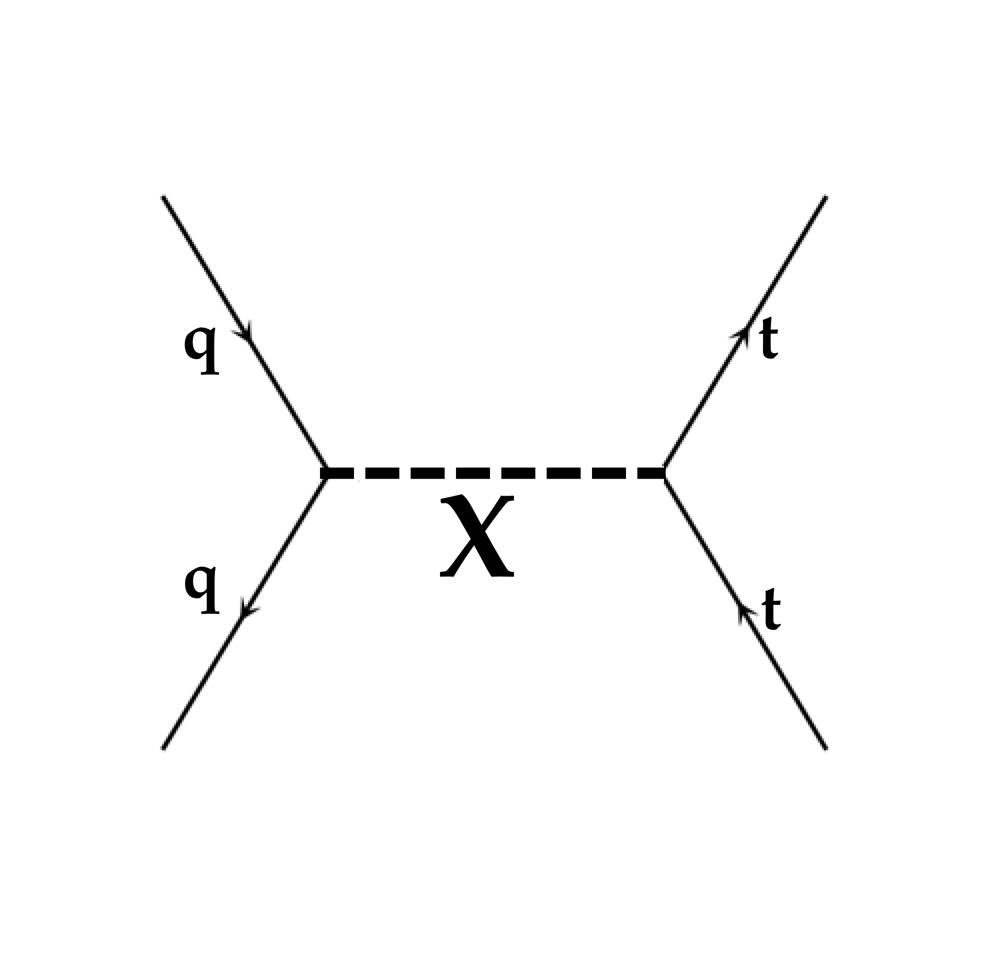
  - many signatures of NP share the same signature or contain tops themselves



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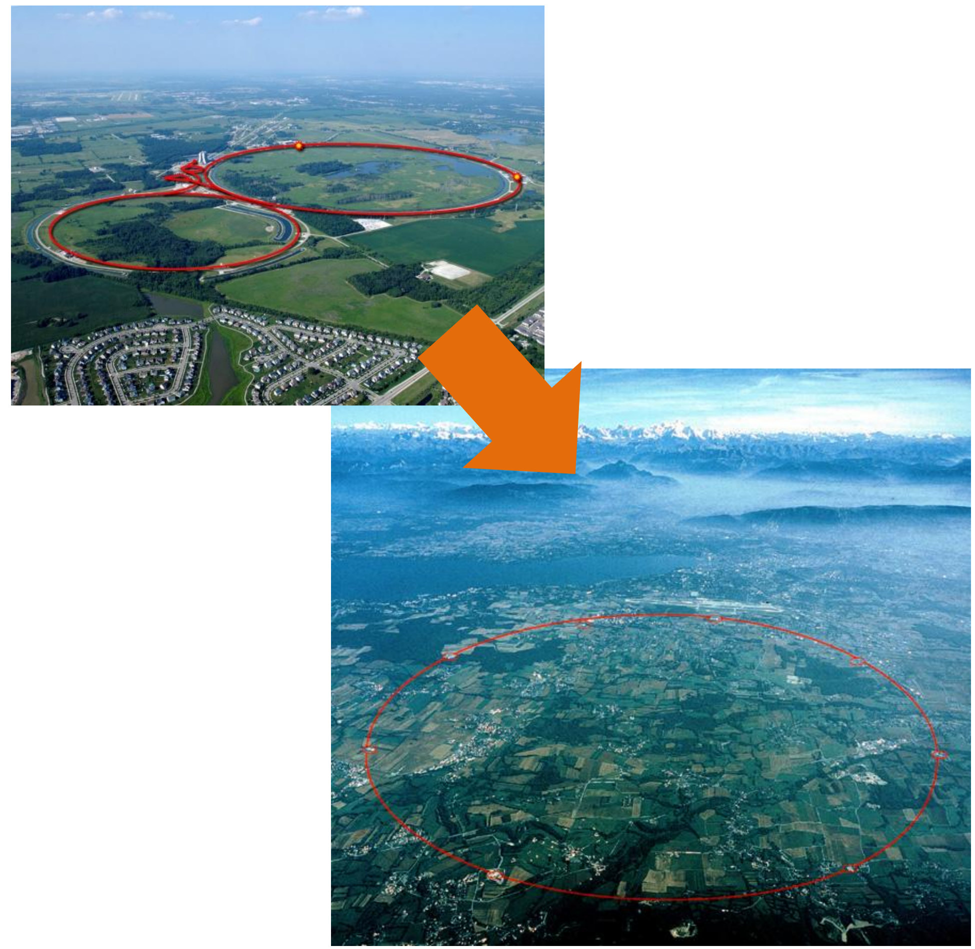
  - large coupling to the Higgs
  - large mass could indicate special role in EWSB
  - decays very rapidly – glimpse of free quark
  - many signatures of NP share the same signature or contain tops themselves
  - only observed at one facility by just two experiments -- significant opportunity for new physics

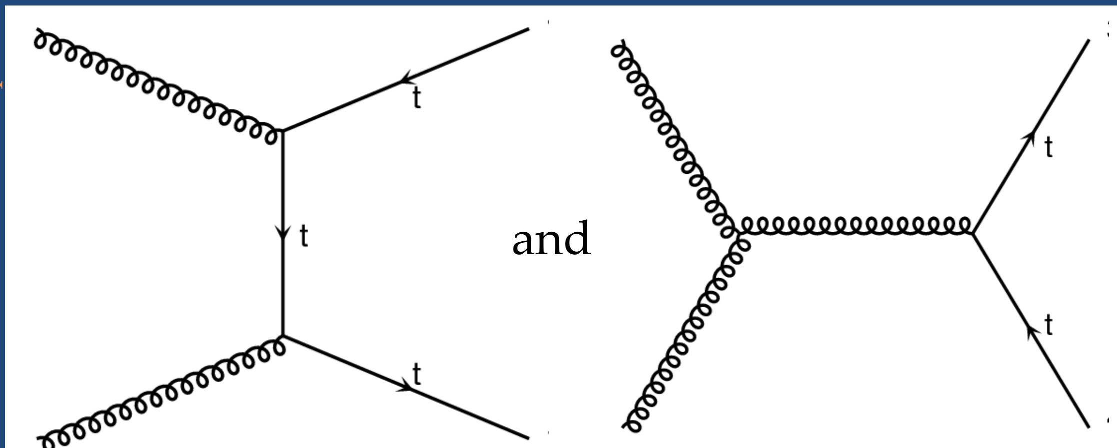


Top Quark Production

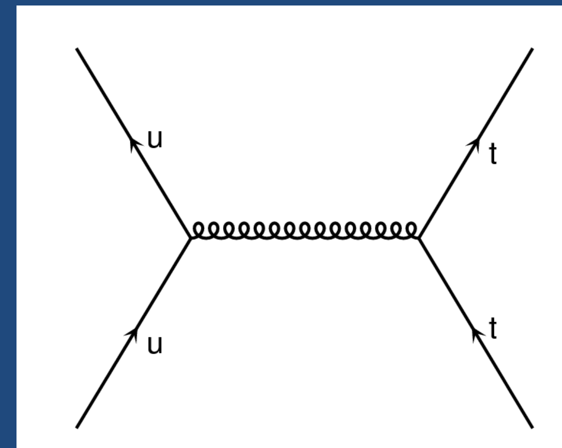
- Top quarks at the LHC are produced mainly in top-antitop pairs:
  σ = 158 ± 23 pb @ NLO (MCFM)

Focus of this talk

Made with MadGraph

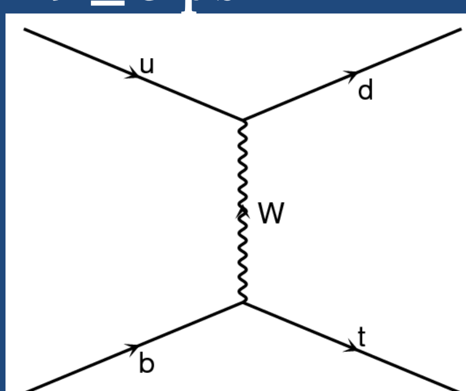


gluon-gluon fusion ~85%

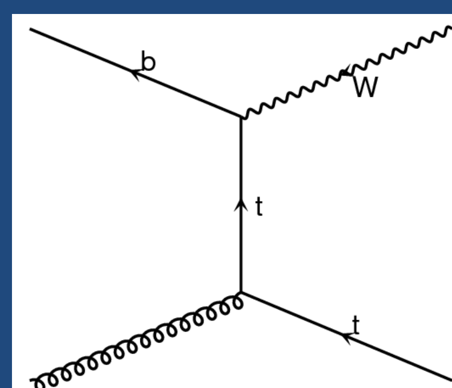


q-qbar annihilation ~15%

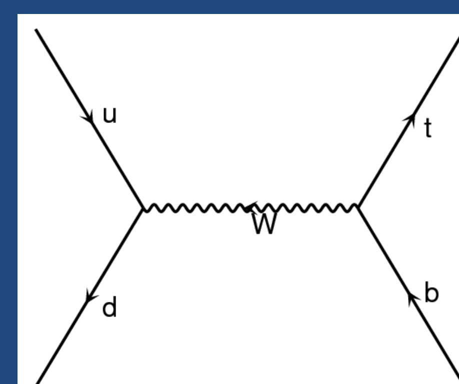
- EWK production of single top quarks is also possible:
  σ = 79 ± 3 pb



t-channel



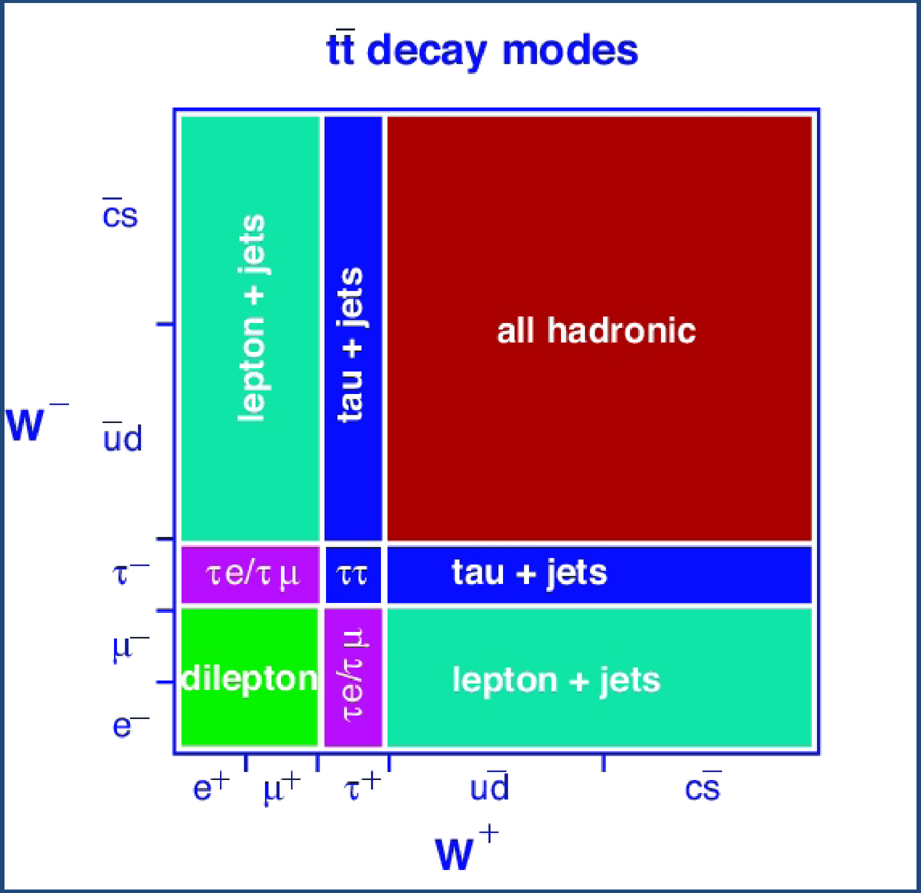
Associated tW

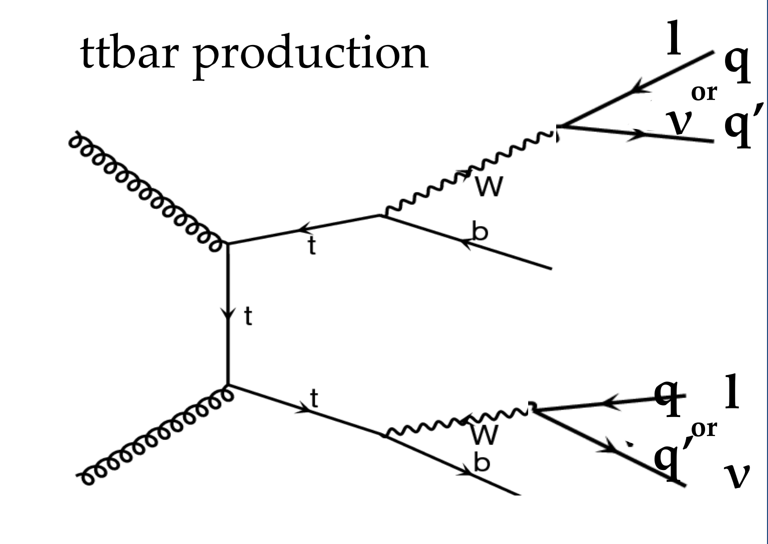


s-channel

Top Quark Decay

- The top quark is predicted to decay nearly 100% of the time to a W and a b
- Top-quark pair events are categorized by decays of two W's

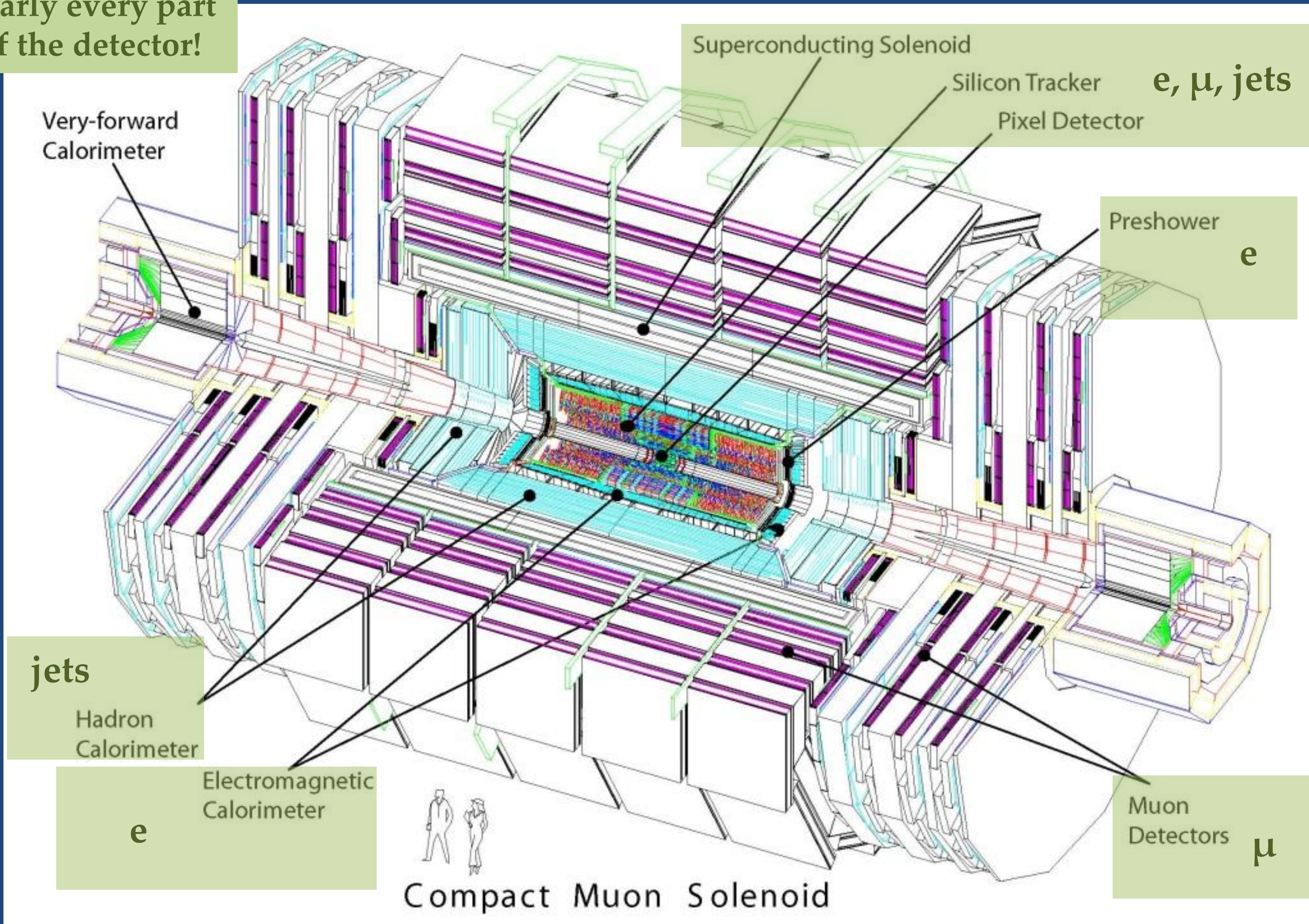




- **Dilepton channel:**
  - two isolated charged leptons (e or μ)
  - MET
  - two b-quark jets
- **Lepton + jets channel:**
  - one isolated e/μ, MET
  - four jets, two from b's
- All-hadronic
- Tau channels

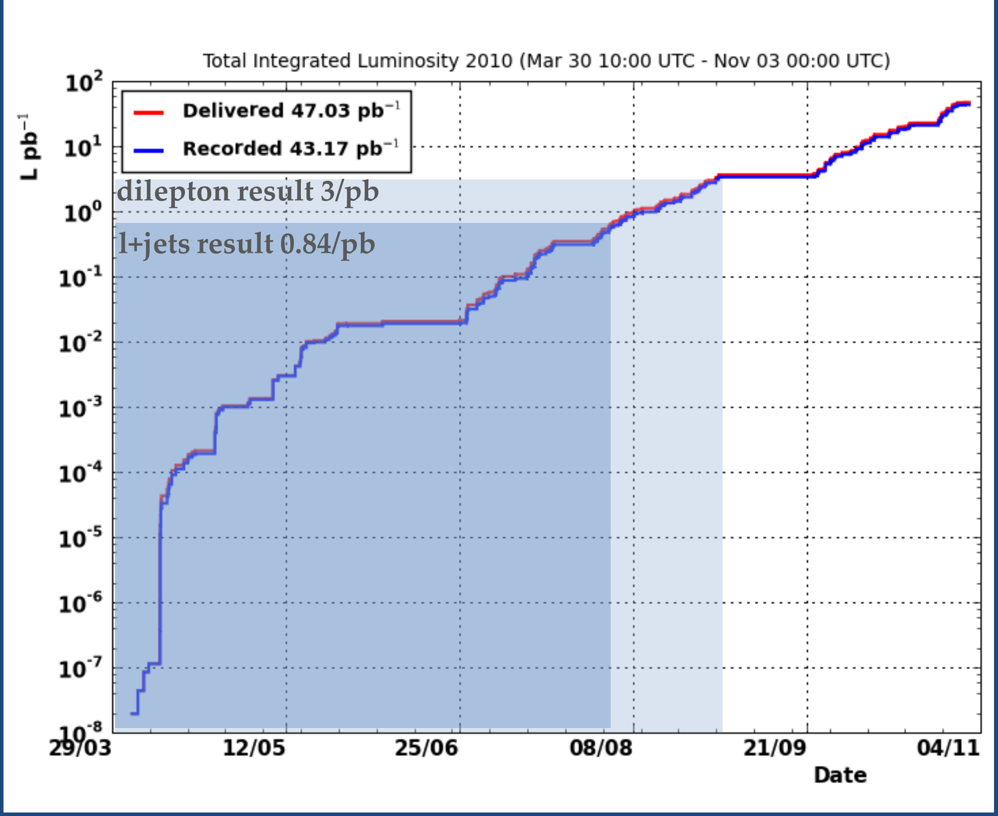
The CMS Experiment

Top-quark physics touches nearly every part of the detector!



The CMS Top-Quark Physics Program

- **Early focus:**
  - top-pair cross sections
  - dilepton and l+jets channels
- Once established include **other measureables:**
  - differential cross sections
  - top mass
  - single top production
  - tau and all-had channels
  - charge, spin, BR, etc
- Goal: Know the signature very well – **use it for searches:**
  - X→ttbar, X→tb
  - t′ searches , t′ → W b
  - charged Higgs searches, t → H^+ b
  - ttH production
  - Rare decays, FCNCs



Disclaimer:
Many new measurements in the approval process at CMS were not available in time for Aspen.
Today I will talk about our earliest dilepton and l+jets cross section analyses.

Cross Section Measurement in the Dilepton Channel

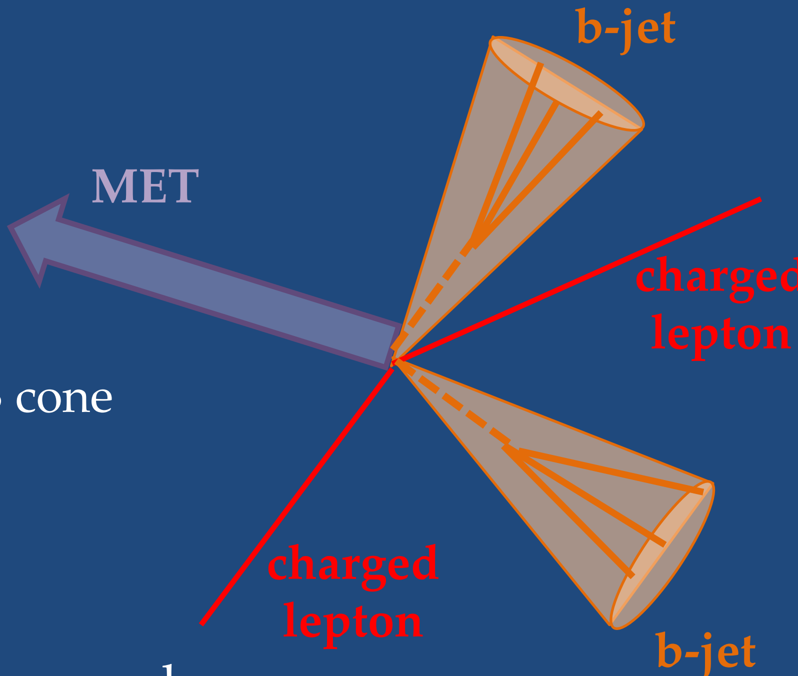
L_{int} = 3/pb

Top-Pair Cross Section: Dilepton Channel

- Three modes: ee, μμ, eμ

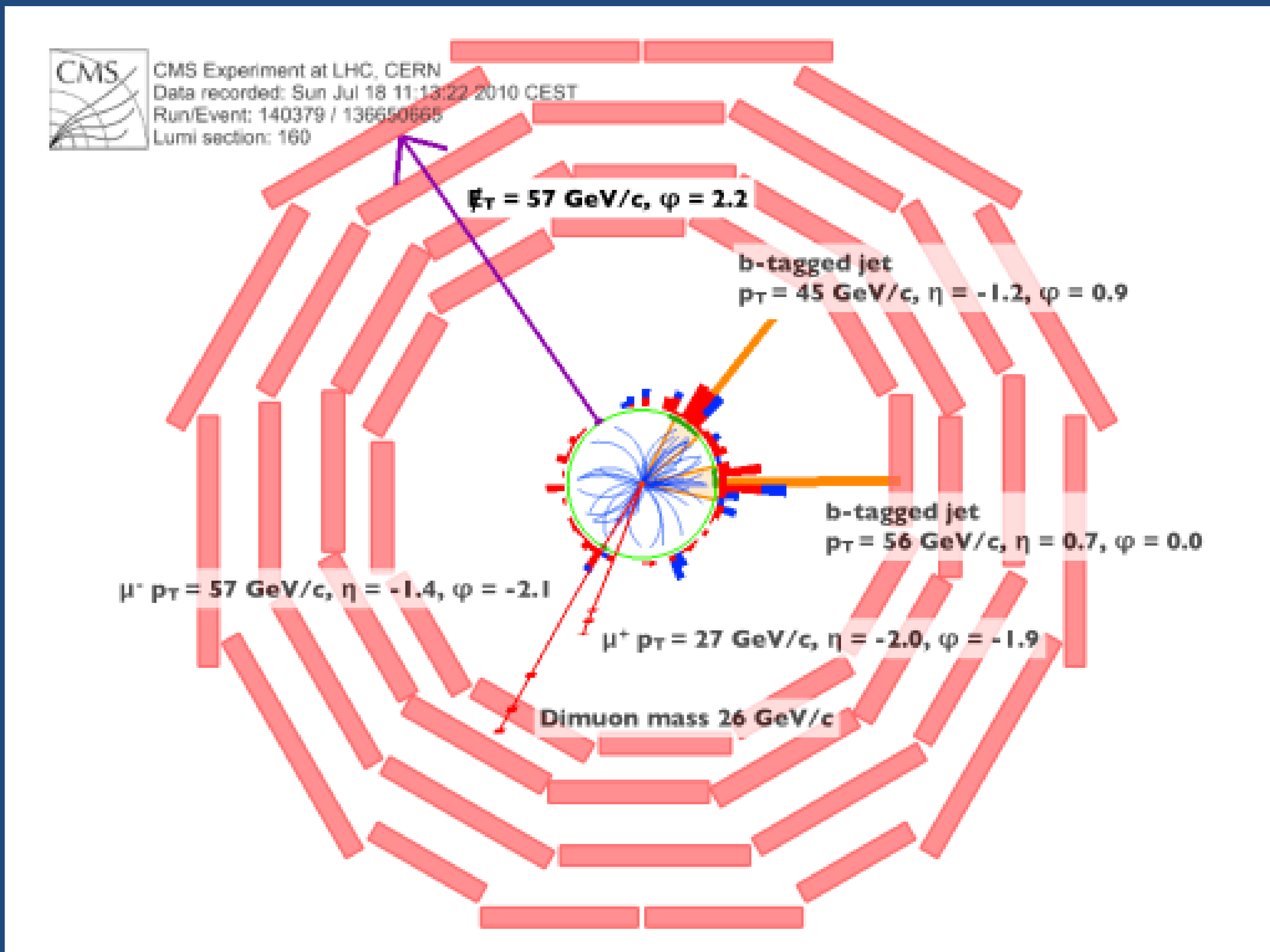
Published in Physics Letters B, Volume 695, Issue 5.

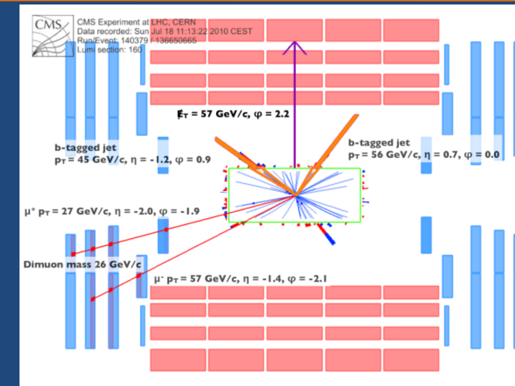
- Event Selection:
  - **Trigger:** single electron (muon) with $p_T > 15$ (9) GeV/c
  - **Electron and muon selection:**
    - $p_T > 20$ GeV/c and $|\eta| < 2.5$
    - Relative Isolation: RelIso < 0.15 in R=0.3 cone
    - Two required, opposite charge
  - **Z veto for ee, μμ modes:**
    - If $|M_{ll} - M_Z| < 15$ GeV, veto event
  - **Neutrinos:** missing energy in the transverse plane
    - Major bkgs Drell-Yan and QCD multijets have no natural source of MET
    - MET > 30 GeV for ee, μμ modes, MET > 20 GeV for eμ
    - Calculated from calorimeter; corrected for muon, per-track response
  - **Jets:** Anti-k_T clustering with R = 0.5
    - At least two, with $p_T > 30$ GeV/c and $|\eta| < 2.5$
    - Corrected for uniformity in η, absolute response in p_T

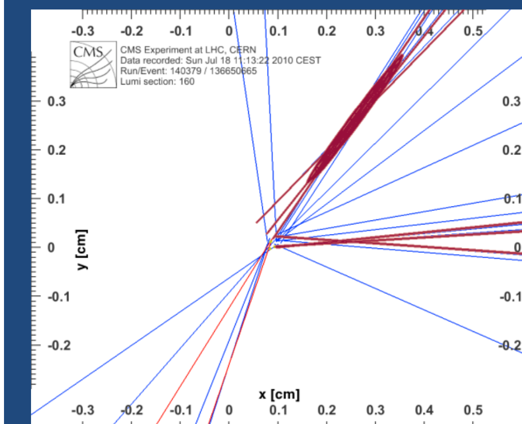


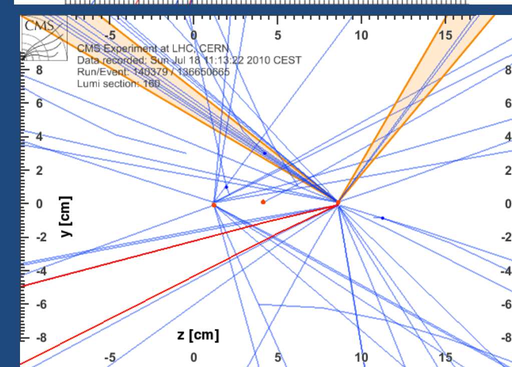
No b-tagging required for initial measurement.

Dilepton Channel: Example Event







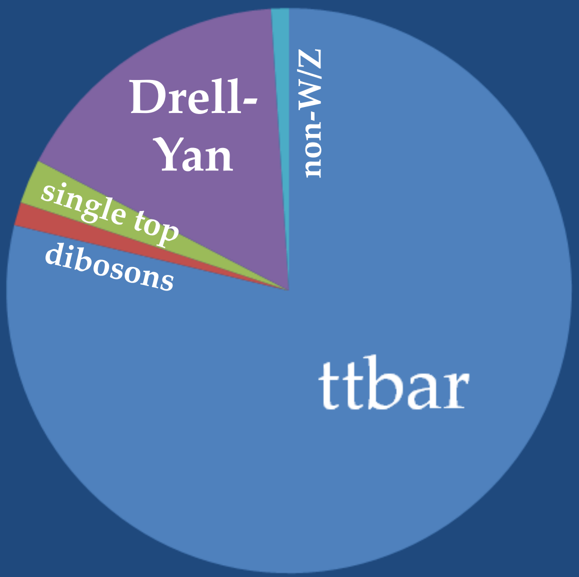


Note the pileup vertices

Dilepton Channel: Selected Sample

$L_{int} = 3/pb$

Source	Number of events
Expected $t\bar{t}$ **(σ= 158 pb)**	7.7 ± 1.5
Dibosons (VV)	0.13 ± 0.07
Single top (tW)	0.25 ± 0.13
Drell-Yan $Z/\gamma^* \to \tau^+\tau^-$	0.18 ± 0.09
Drell-Yan $Z/\gamma^* \to e^+e^-, \mu^+\mu^-$	$1.4 \pm 0.5 \pm 0.5$
Events with non-W/Z leptons	$0.1 \pm 0.5 \pm 0.3$
Total backgrounds	2.1 ± 1.0
Expected total, including $t\bar{t}$	9.8 ± 1.8
Data	11

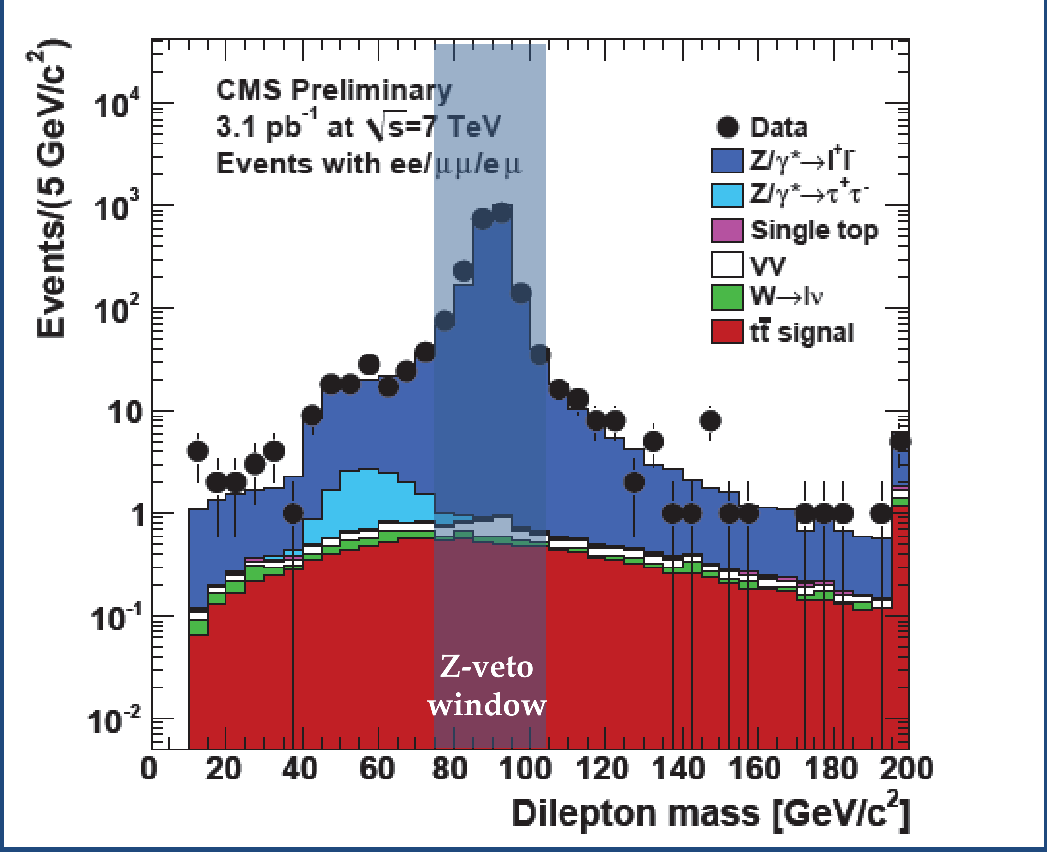


- **Signal estimate:** 7.7 events = 1.5 ee +1.7 μμ + 4.5 eμ
  - MadGraph + Pythia showering + GEANT detector simulation
  - NLO cross section from MCFM assumed: **σ = 158 ± 23 pb** (scale and PDFs)
- **Backgrounds:**
  - MC estimates used for dibosons, single top, DY $Z/\gamma^* \to \tau\tau$
  - Data-driven estimates for DY $Z/\gamma^* \to ee, \mu\mu$ and non-W/Z
- Predicted purity of selected sample is very high: **~79%**

Dilepton Channel: Drell-Yan Background

- Hard to model accurately
- Use the rejected data events from the Z-veto window
  - Subtract out the non-DY contribution in vetoed events
  - Use simulated DY events to determine ratio off-peak to near-peak
  - Scale DY component of Z-vetoed events by this ratio
  - **Result:** estimate of residual DY contribution surviving in selected sample

M_{ll} dist before any MET, jet multiplicity requirements

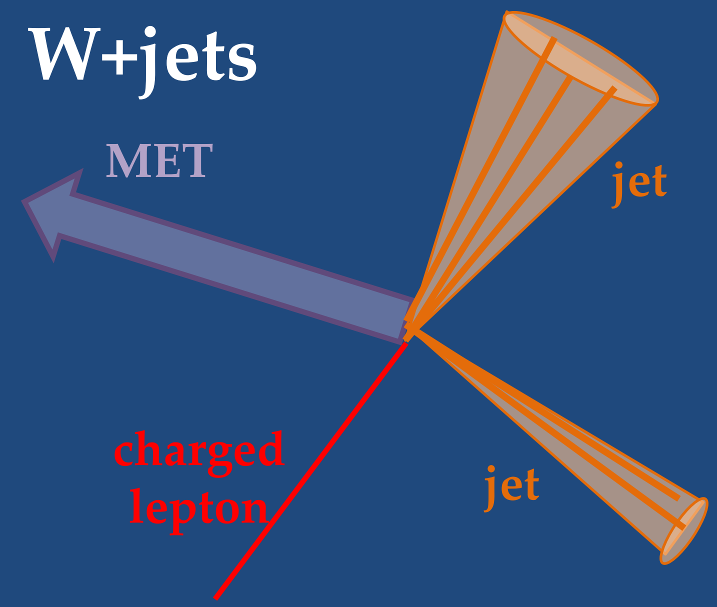


Relative systematic uncertainty:
- 50% in each mode
- dominated by changes in yield for different selection criteria in jet multiplicity, MET

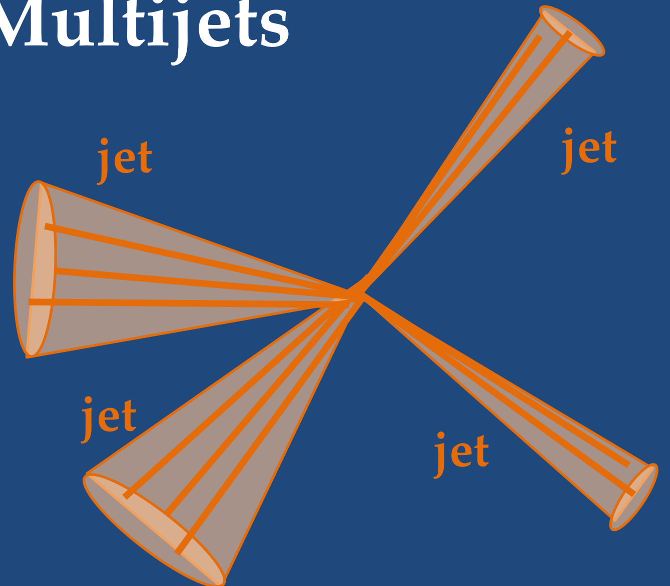
Dilepton Channel: Non-W/Z Background

- Spurious dilepton event candidates can come from
  - **W+jets:**
    - leptonically decaying W with one jet faking the charged lepton
  - **Multijets:**
    - two jets fake the charged lepton ID, jet mismeasurement provides spurious MET

W+jets



Multijets



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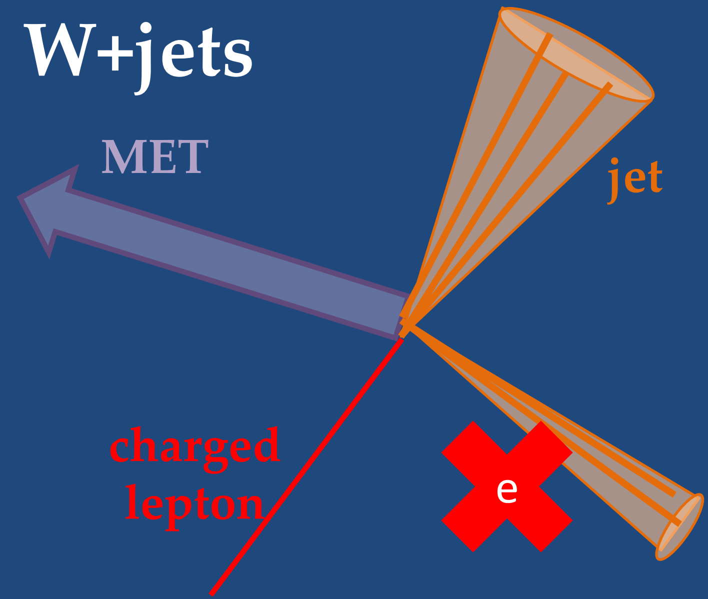

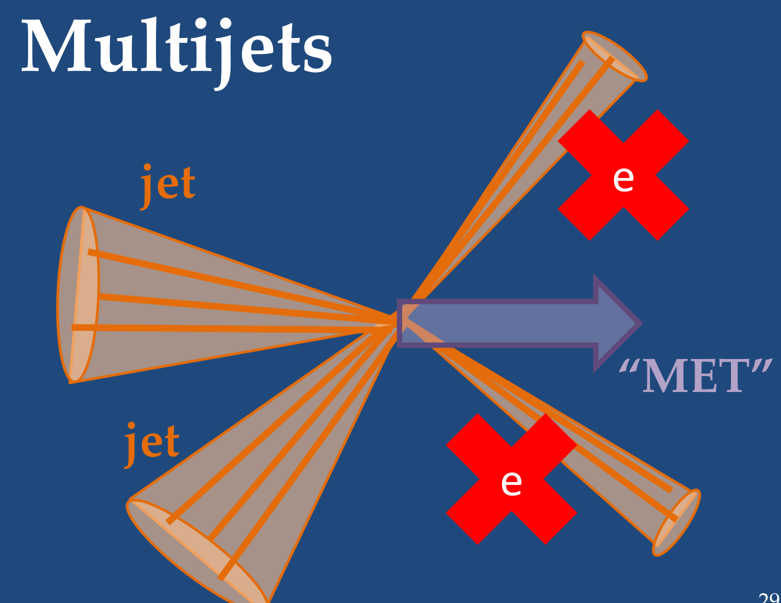

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  - **W+jets:**
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  - **Multijets:**
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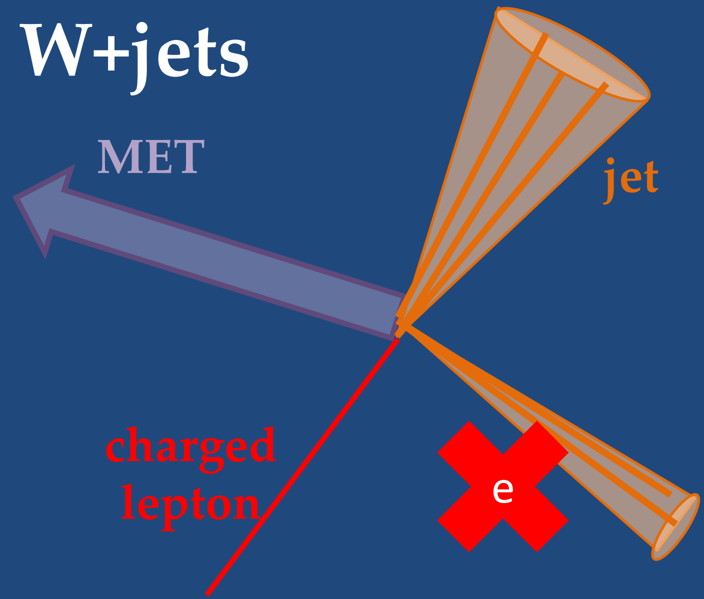
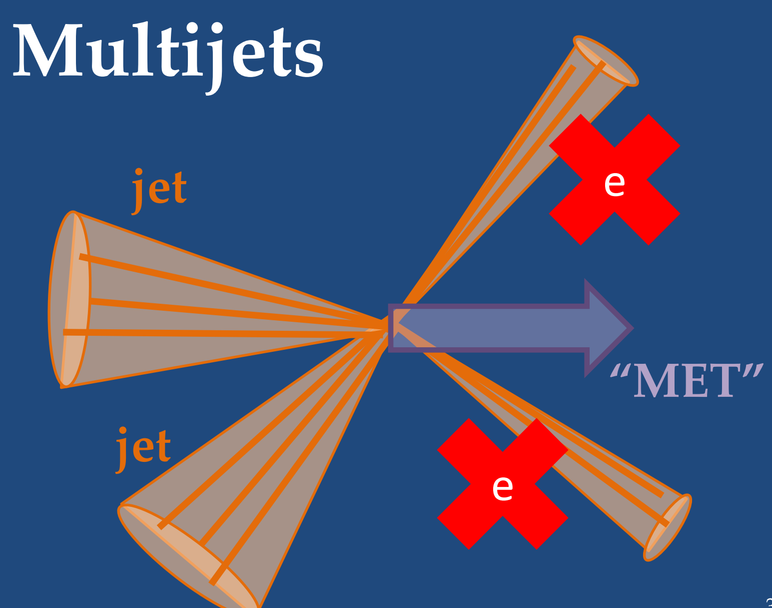
- Hard to model accurately
- Create superset of dilepton candidates in data – loosen lepton ID on both
- Use a multijet dominated data calibration sample, require one such loose lepton
- Determine tight-to-loose ratio, fnc of pT, η
- Apply to superset of dilepton candidates
  - W+jets: one lepton fails tight criteria
  - Multijets: both leptons fail tight criteria





Dilepton Channel: Cross Section Results

- Simple cut-and-count analysis

Source	Number of events
Expected $t\bar{t}$	7.7 ± 1.5
Dibosons (VV)	0.13 ± 0.07
Single top (tW)	0.25 ± 0.13
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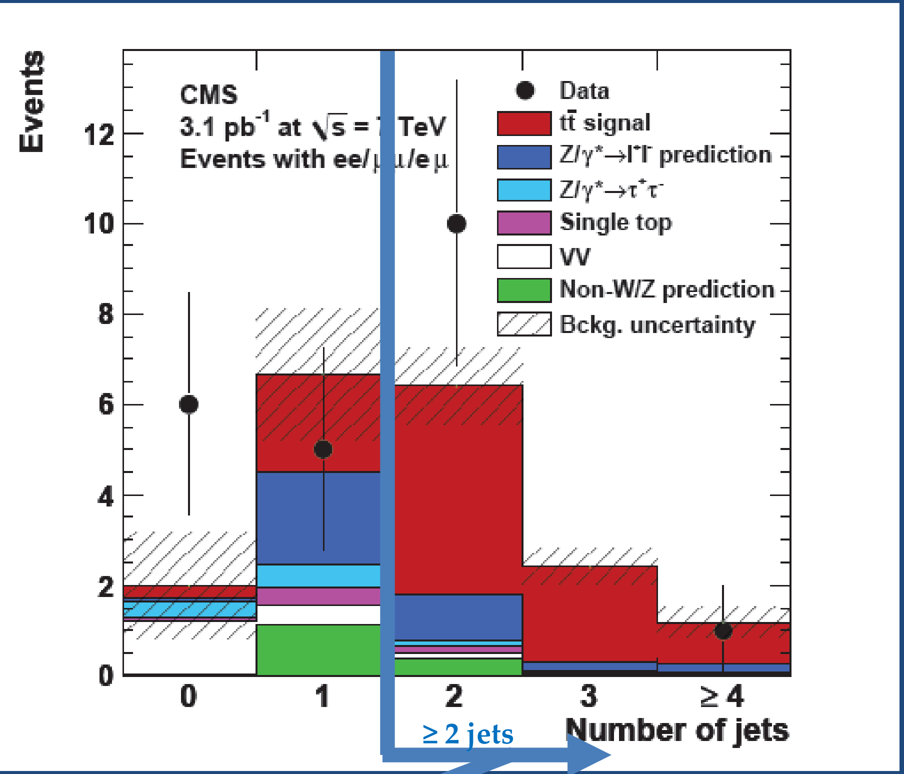
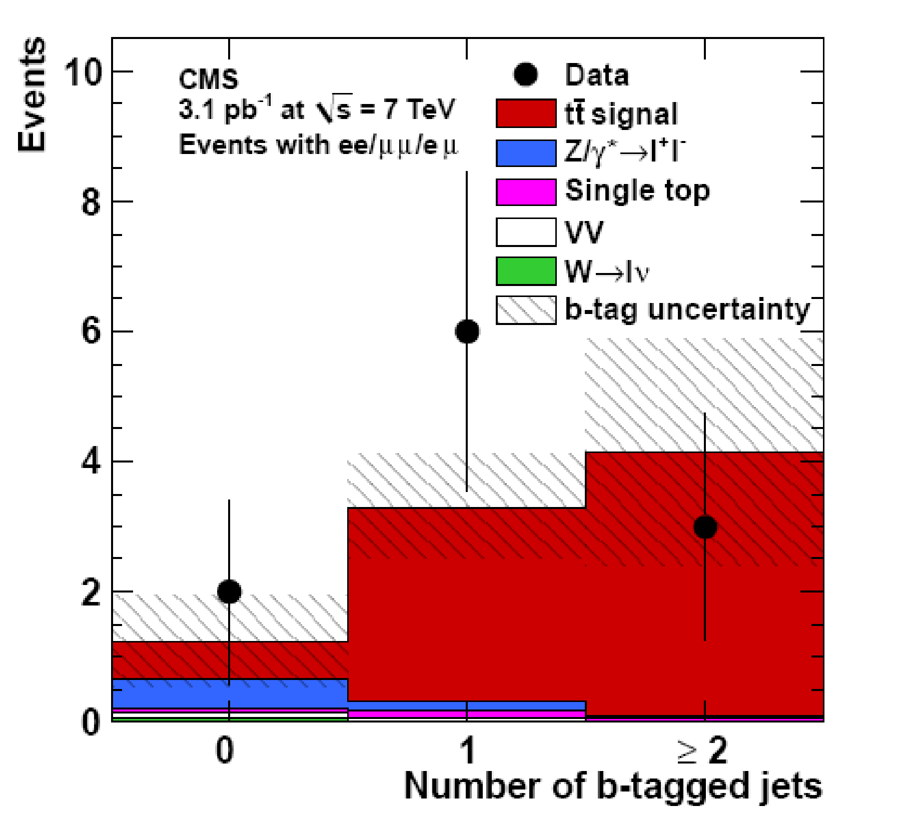


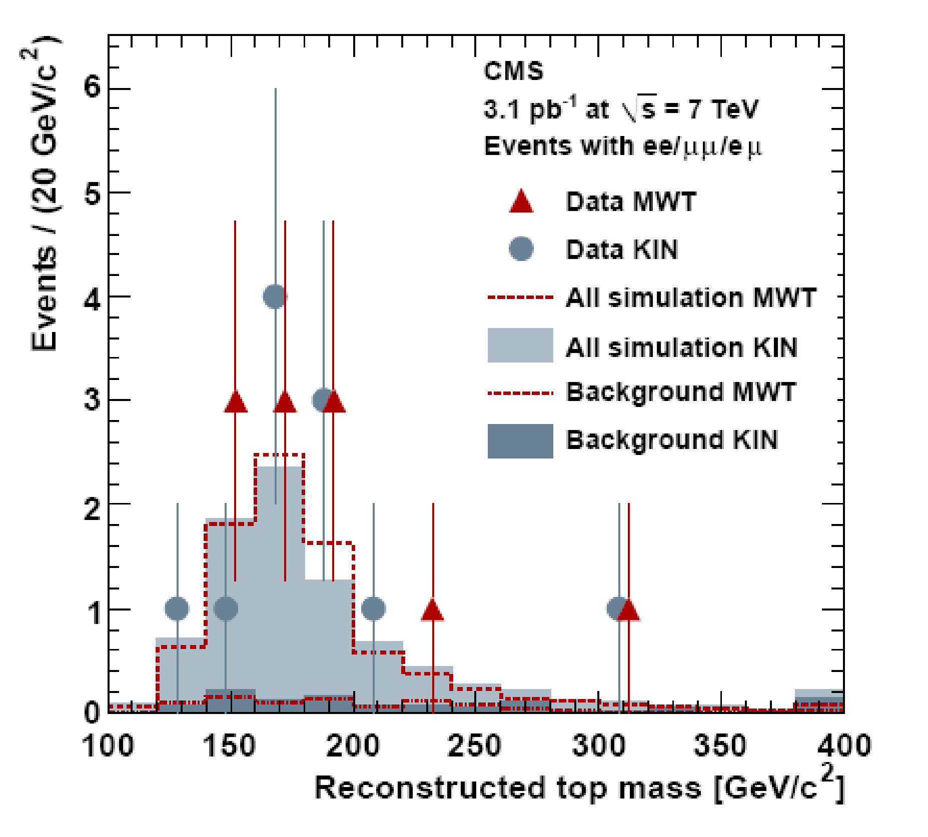
- Systematics:

Source	all
Lepton selection	4.4%
Energy scale	3.7%
ISR/FSR	1%
Decay model	2%
Branching fraction	1.7%
Subtotal (no backgrounds, no luminosity)	6.4%
Backgrounds	11%
Total without luminosity	12%
Integrated luminosity	11%

Result:
$\sigma(\text{ttbar}) = 194 \pm 72(\text{stat}) \pm 24(\text{syst}) \pm 21(\text{lumi})$ pb

Dilepton Channel: Cross Checks





- **In selected events, are the jets consistent with b-quark jets?**
- Use track-counting algorithm
  - 80% efficient at 10% false-positive rate
- Good evidence for b-jets in sample

- **Are selected events consistent with top-quark production?**
- Two top mass techniques, one value returned per event
- Good evidence for top-quarks in these events

Top Quark Production in the Lepton+Jets Channel

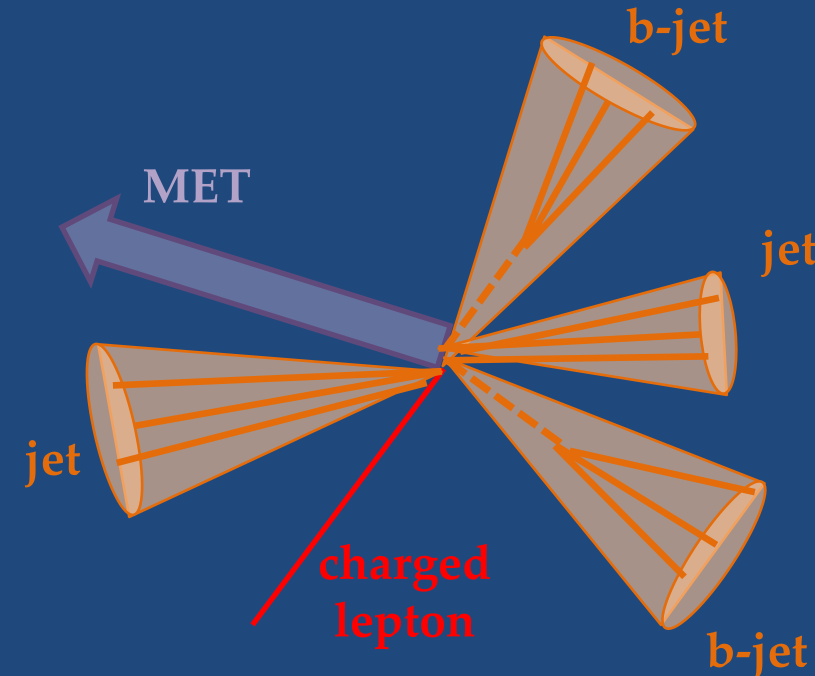
L_{int} = 0.84/pb

Top-Quark Pairs: Lepton+Jets Channel

Not published – see TOP-10-004 in CDS.

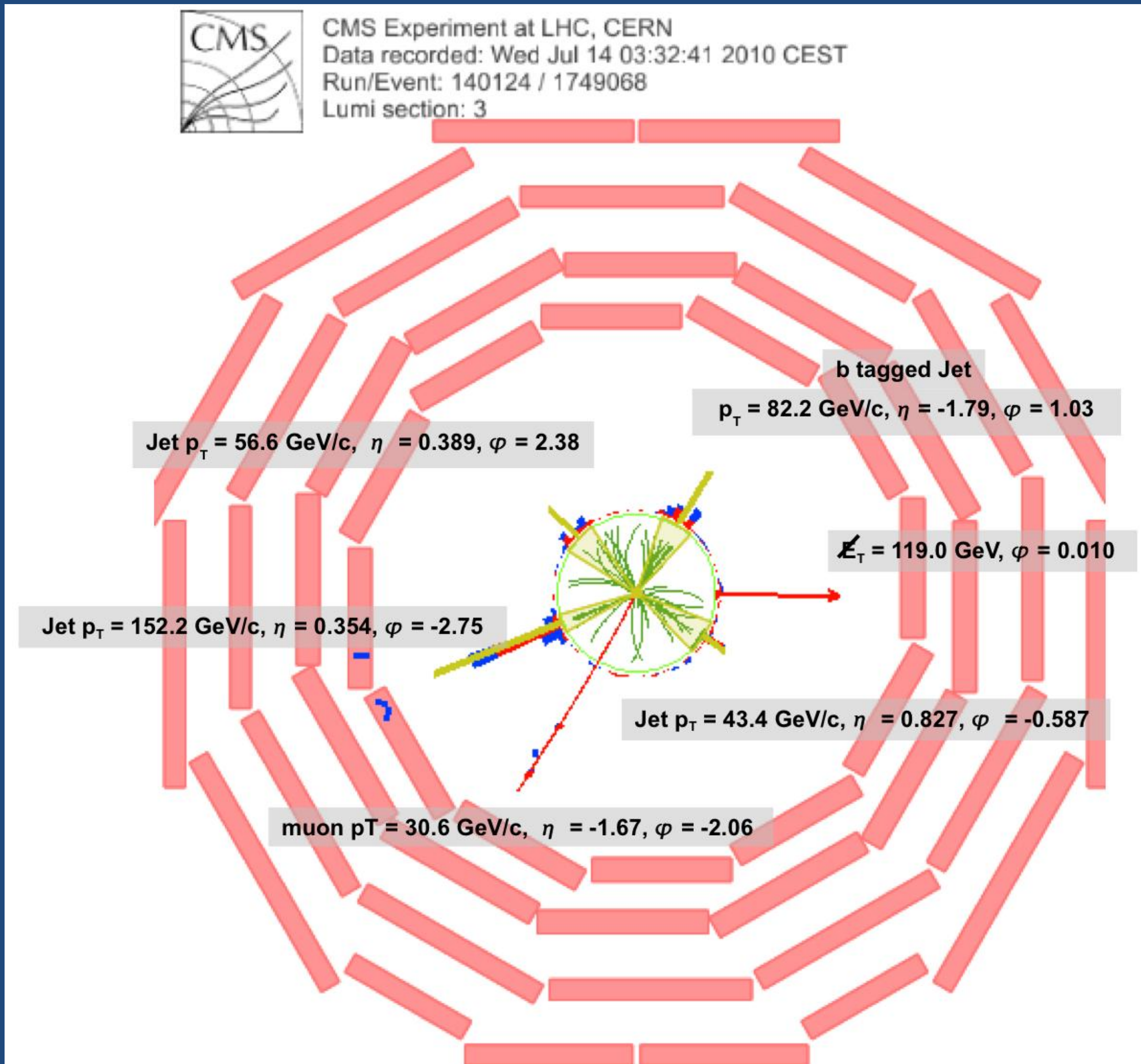
- Two modes: mu+jets and e+jets
- Event selection:
  - **Trigger:** single electron (muon) with $p_T > 15$ (9) GeV/c
  - **Muon selection:**
    - $p_T > 20$ GeV/c and $|\eta| < 2.1$
    - RelIso < 0.05 in R=0.3 cone
  - **Electron selection:**
    - $p_T > 30$ GeV/c and $|\eta| < 2.4$
    - RelIso < 0.10
  - **Neutrinos:**
    - No cut on MET
    - Prefer to reserve MET as a handle for estimating bkgds
  - **Jets:** Anti-k_T clustering with R = 0.5
    - Four expected, with $p_T > 30$ GeV/c and $|\eta| < 2.5$
    - Corrected for uniformity in η, absolute response in p_T

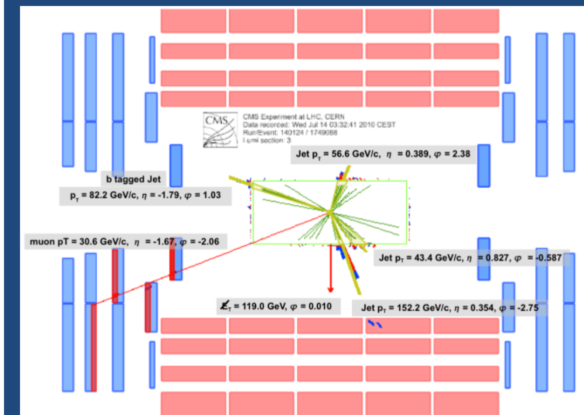
Tighter wrt Dileptons

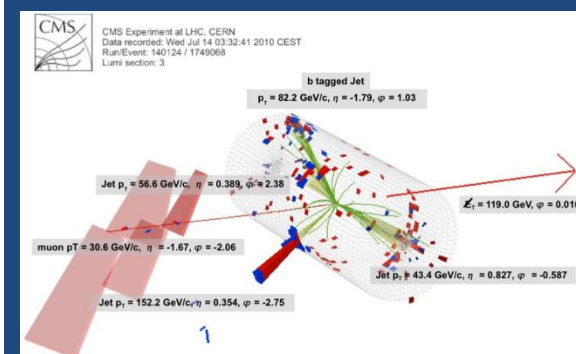


No b-tagging required for initial studies.

Lepton+Jets Channel: Example Event







Lepton+Jets Channel: Selected Sample

L_{int} = 0.84/pb

μ + jets

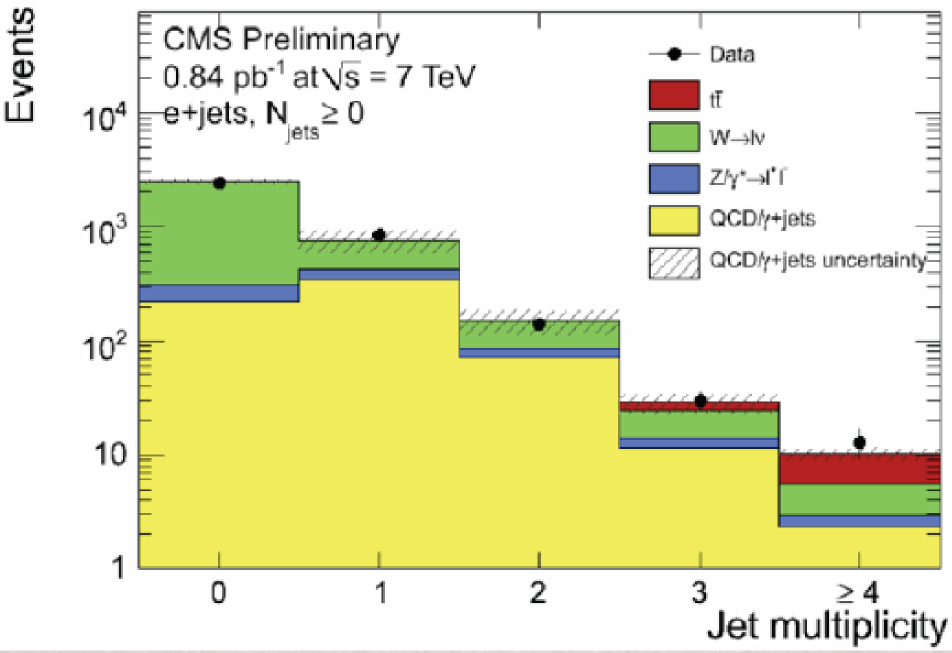
Jet multiplicity	$t\bar{t}$	Single top	W+jets	Z+jets	QCD	∑MC	Data
$N_{jets}\geq2$	13 2	2.3 0.3	92 24	7.1 4.4	10 3	124 25	**153**
$N_{jets}\geq3$	10 2	0.82 0.15	16 5	1.3 0.9	1.3 0.5	29 5	**40**
$N_{jets}\geq4$	5.6 1.4	0.24 0.06	3.1 1.2	0.25 0.18	0.15 0.07	9.3 1.9	**11**

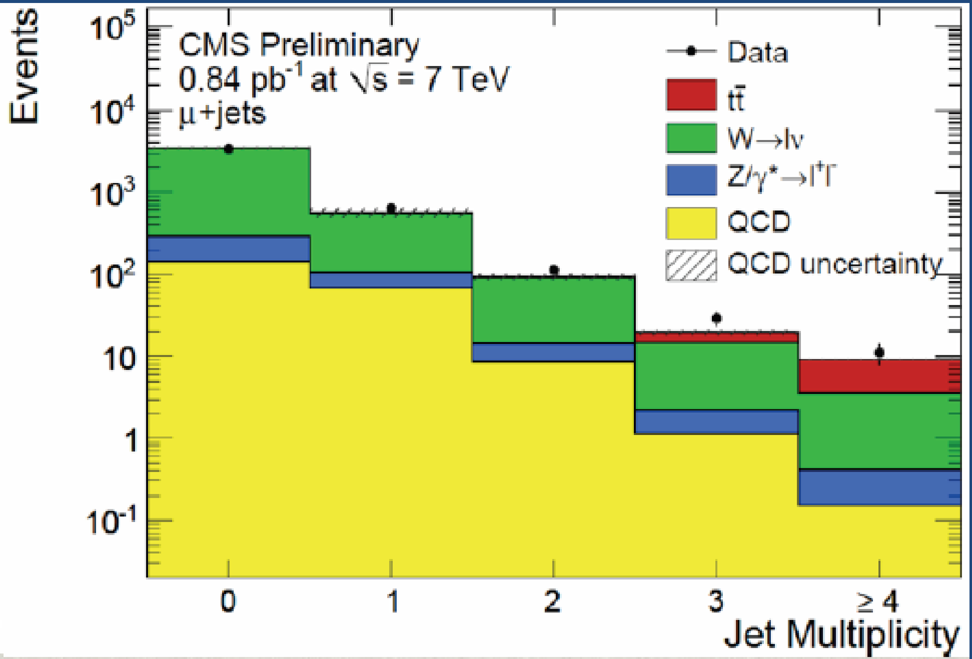
e + jets

Jet multiplicity	$t\bar{t}$	Single top	W+jets	Z+jets	QCD	∑MC	Data
$N_{jets}\geq2$	11 2	1.9 0.3	74 18	19 5	85 22	191 29	**183**
$N_{jets}\geq3$	8.9 1.8	0.70 0.14	13 4	3.3 1.0	14 5	40 7	**43**
$N_{jets}\geq4$	4.8 1.2	0.21 0.06	2.6 1.1	0.60 0.23	2.3 1.1	11 2	**13**

- MC-only predictions:
  - MadGraph+Pythia (ttbar, W/Z+jets) and Pythia (QCD w/ k = 2.0 and 50% error)
- Although 4 jets are expected…
  - 3-jet bin has not-insignificant amount of signal
  - 3-jet bin is valuable for pinning down W+jets and QCD backgrounds
- Data-driven estimate for QCD multijets is preferred – and is implemented in the soon-to-be approved results
- Predicted purity in ≥ 4 jet bin is ~50%, clearly less than that of dileptons

Lepton+Jets Channel: Yields

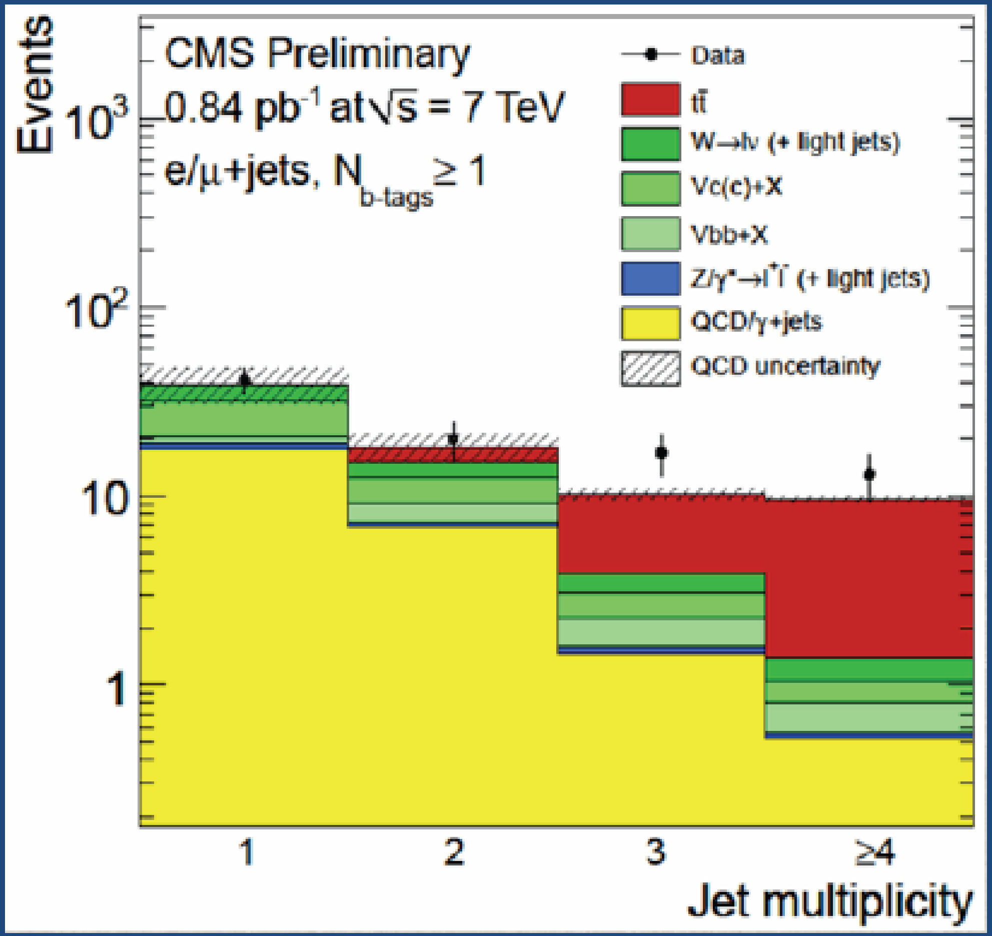




- Data-to-MC comparison – impressive consistency for these early studies
- Small backgrounds not included
- Error band reflects just the 50% error on the QCD normalization, completely MC-driven – temporary for these early studies

- No fit or other signal extraction technique, so ttbar content exactly reflects the input cross section we used (158 pb, NLO)

Lepton+Jets Channel: With Tagging



Simple Secondary Vertex Algorithm
~55% efficiency with ~1% false positive rate

- Can examine the b-tagged jet content of this selected sample
- Flavor discrimination = need for more extensive V+HF samples
- Plotted here, the total jet multiplicity for events with 1 or more b-tagged jets
  - ttbar will favor the 3,≥4-jet bins
  - QCD, W+jets the 1,2-jet bins
- Combined e/μ+jets sample
- Necessarily ≥1 jet in all such events
- Good agreement once again

Summary and Outlook

- The CMS top-quark physics program got off to a great start in 2010
  - ICHEP: Establishment of presence of top quarks in our data sample
  - First measurement of the ttbar cross section at the LHC, using dileptons
  - Early studies of the lepton + jets channel encouraging as well

- This is only the beginning
  - A rich suite of measurements and searches is envisioned
  - Several new measurements using entire 2010 data sample will be available in the coming weeks
    - updated dilepton cross section
    - cross sections in the e/μ+jets modes, both with and without tagging
    - first official top-quark mass measurements
    - measurement of single top production cross section
    - searches for new physics exploiting the m_{ttbar} distribution
  - And then the abundant top samples expected in the 2011-12 run and beyond

Additional Material

Top Mass Measurement Techniques

- Two top mass measurement techniques
  - Consider ensemble of possible values of jet energies and MET near measured values, given their resolutions
  - Solutions for the kinematic equations describing dilepton ttbar events are solved for the ensemble of input values
  - Neutrinos ⇒ underconstrained system
    - Kinematic (KIN) method:
      - apply constraint on the longitudinal momentum of the tt system
      - assumption on longitudinal momentum has little impact on measured top mass
      - many possible top mass values produced in a given event – most probable one is returned as the per-event top mass estimator
    - Matrix Weighting Technique (MWT):
      - Kinematic system is solved for a spectrum of possible top mass values
      - Weights are assigned based on the likelihood of each solution
      - The mass for which the sum of the weights of all solutions is maximized is used as the per-event mass estimator