Observation of Top Quark Production at 7 TeV - CMS

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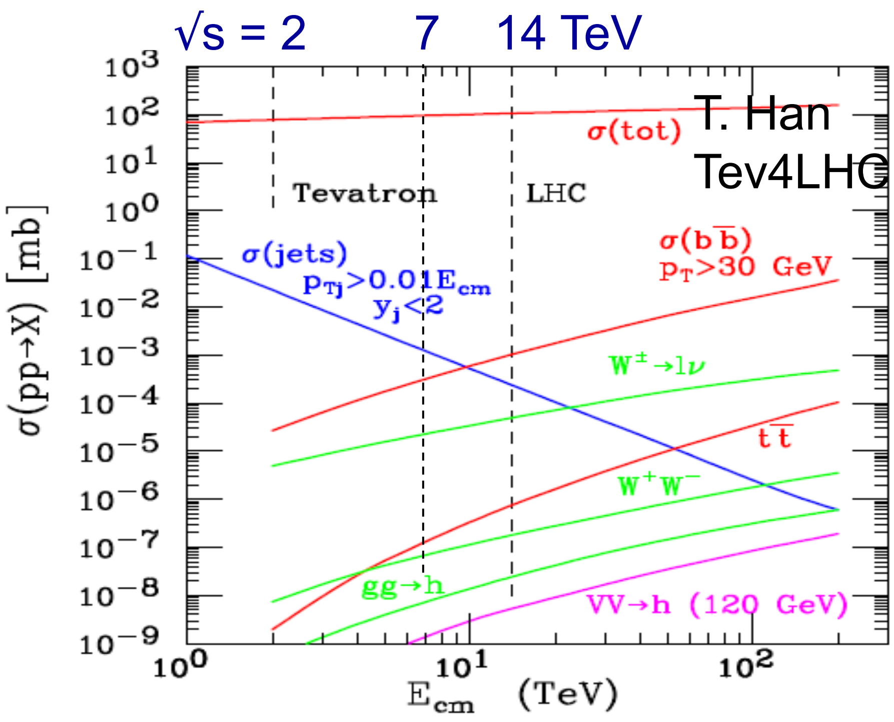
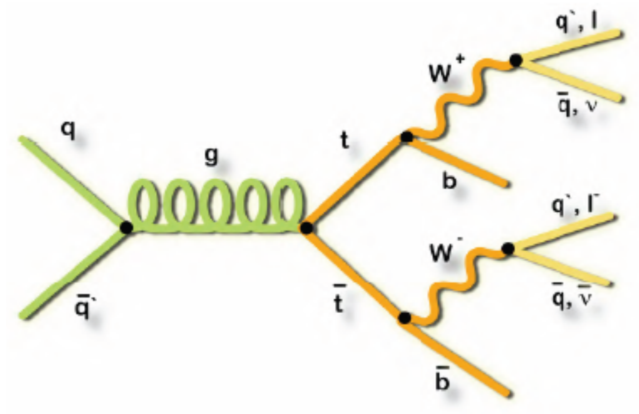
on behalf of the CMS collaboration

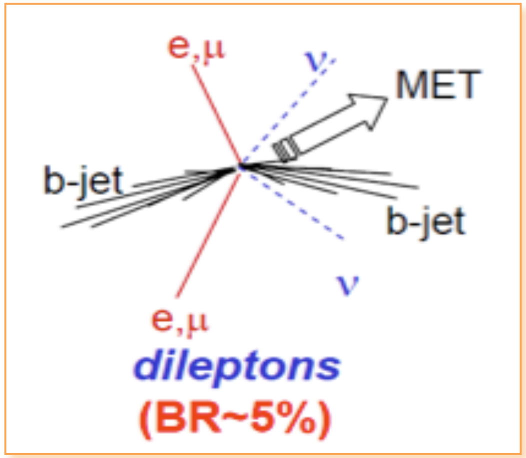
Top Physics at the LHC

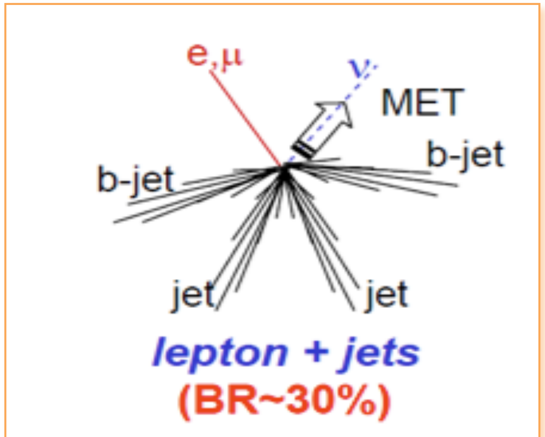
- Precise SM measurements
  - σ, mass, couplings, rare decays
  - Constraints on Higgs mass
  - Study of bare quark production
- A window to new physics
  - New physics might couple preferentially to top
  - New particles may decay to top
  - Non-standard couplings
- Important background to many searches (e.g. SUSY)
- Great tool to calibrate detector
  - Jet energy scale, b tagging eff., MET

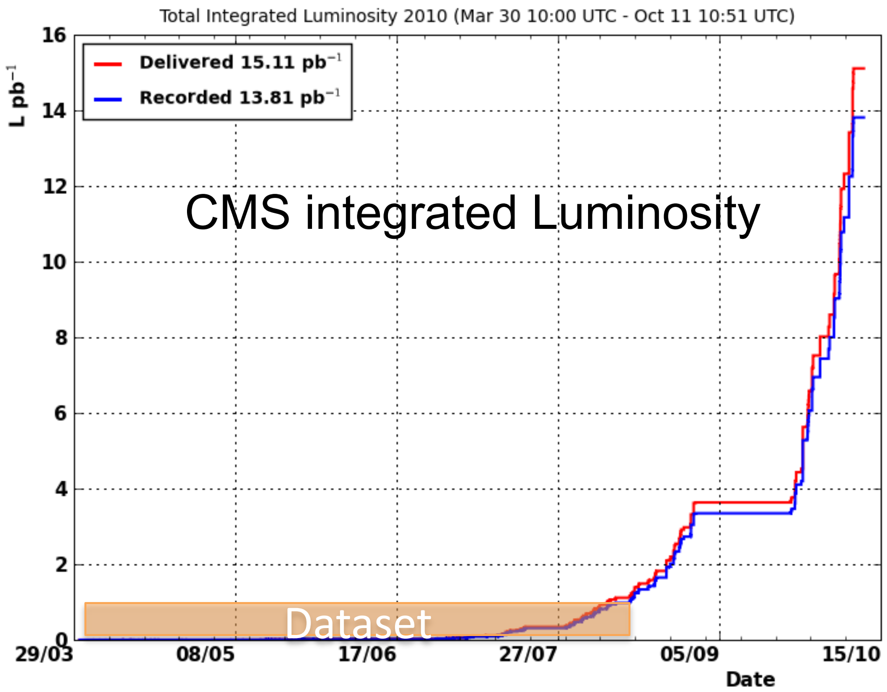




Channels and data samples







Dataset

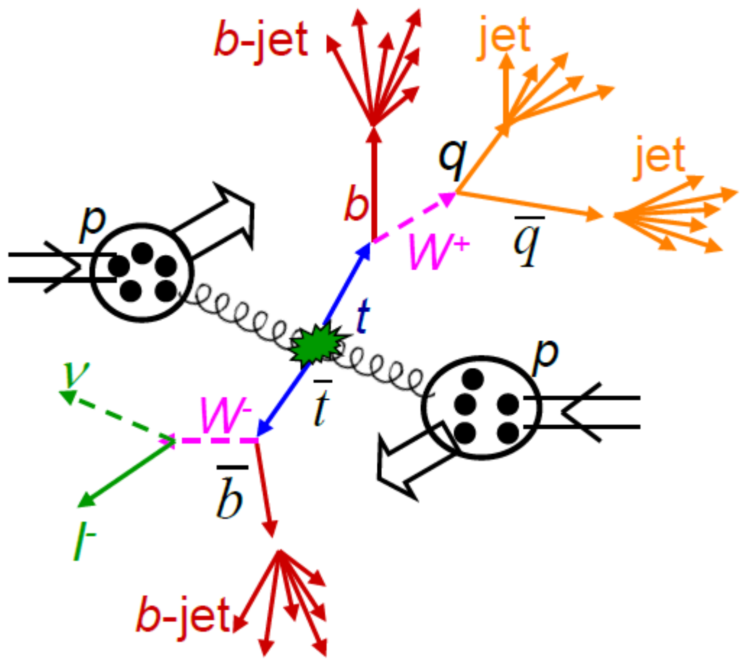
- $L = 0.84\ pb^{-1}$
- Collected up to 11/08

Lepton +jets Event Selection

- Considered modes:
  - e+jets
  - mu+jets
- Single lepton triggers
  - mu+X (Pt>9 GeV), e+X (Pt>15 GeV)
- Exactly one isolated lepton

$$\text{Rel.isol.} = \frac{\sum_{R<0.3} p_T^{\text{track}} + \sum_{R<0.3} p_T^{\text{ECAL}} + \sum_{R<0.3} p_T^{\text{HCAL}}}{p_T(\text{lepton})}$$

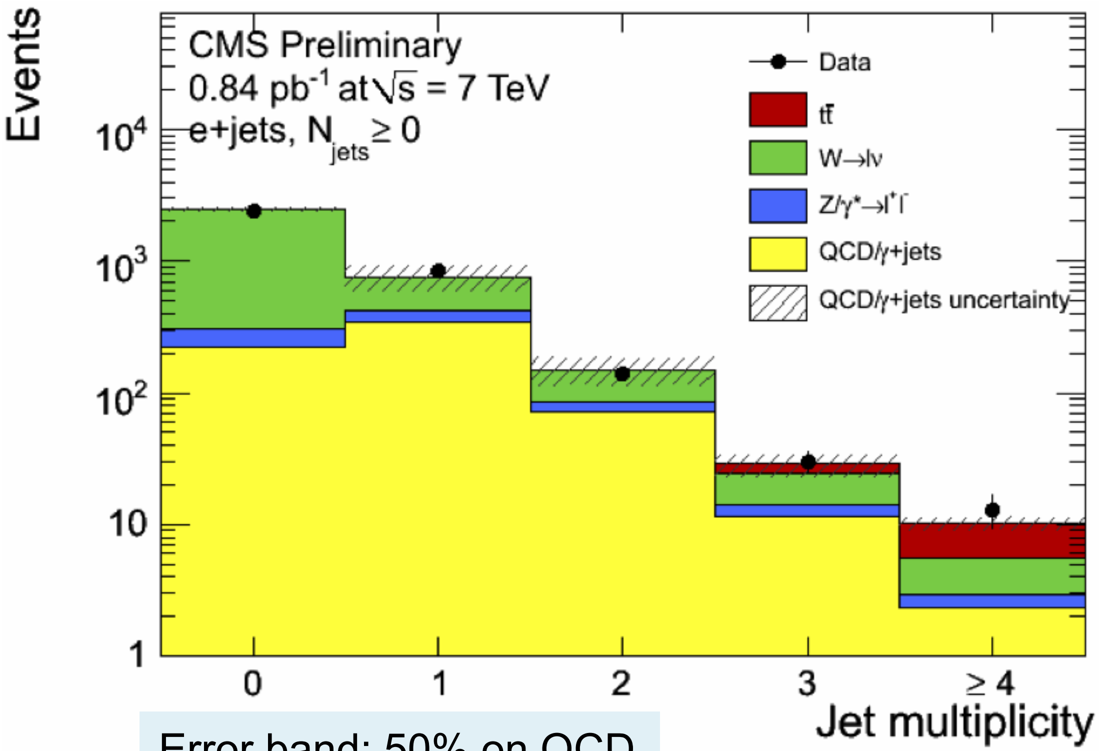
  - Muons: Pt>20 GeV,|eta|<2.1
    - Rel. Isolation < 0.05
  - Electrons: Pt>30 GeV, |eta|<2.4
    - Rel. Isolation < 0.10, conversion veto
- Missing Et (MET)
  - Not used in event selection, but to reconstruct transverse Mass



- Jets
  - Anti-Kt (R=0.5)
  - Pt>30 GeV, |eta|<2.4
  - Expect >=4 jets for ttbar
  - No b-tagging in baseline selection

Electron+jets channel in 0.84 pb^{-1}

Jet multiplicity	ttbar	single top	W+jets	Z+jets	QCD	Sum MC	Data
$N_{jets} \geq 0$	12 ± 2	3.4 ± 0.4	2619 ± 317	180 ± 21	658 ± 73	3472 ± 326	3434
$N_{jets} \geq 1$	12 ± 2	3.1 ± 0.4	419 ± 77	92 ± 11	436 ± 62	962 ± 99	1022
$N_{jets} \geq 2$	11 ± 2	1.9 ± 0.3	74 ± 18	19 ± 5	85 ± 22	191 ± 29	183
$N_{jets} \geq 3$	8.9 ± 1.8	0.70 ± 0.14	13 ± 4	3.3 ± 1.0	14 ± 5	40 ± 7	43
$N_{jets} \geq 4$	4.8 ± 1.2	0.21 ± 0.06	2.6 ± 1.1	0.60 ± 0.23	2.3 ± 1.1	11 ± 2	13



Error band: 50% on QCD

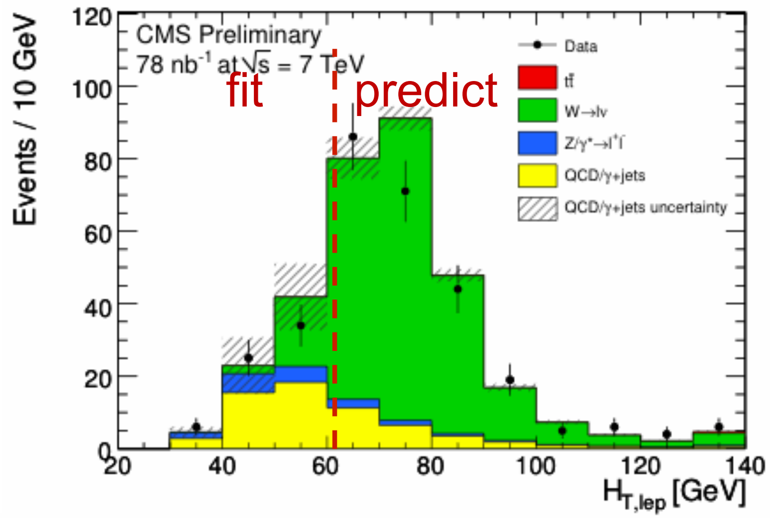
Simulation Uncertainties (table):

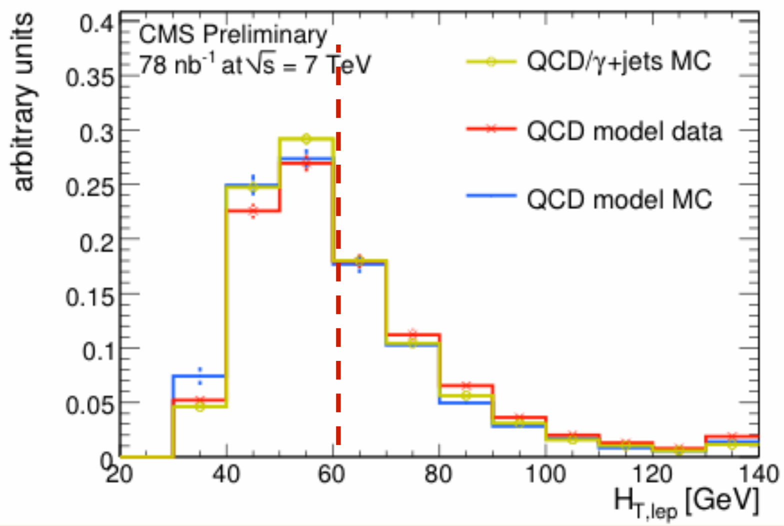
- Jet energy scale (known to 10%)
- Luminosity (known to 11%)
- Cross section unc. (scale, PDF)
- For QCD, the statistical uncertainty of the sample was used

Good agreement observed in all Jet bins!

Data-driven QCD : template fit

- MET and HT(lep) are variables that discriminate between QCD and signal
- Fit templates in QCD dominated region (low MET or HT(lep) region)
  - QCD template from multijet data sample (near-miss electrons or large EMF jets)
  - Signal template from MC simulation
- Predict N(QCD) in signal region





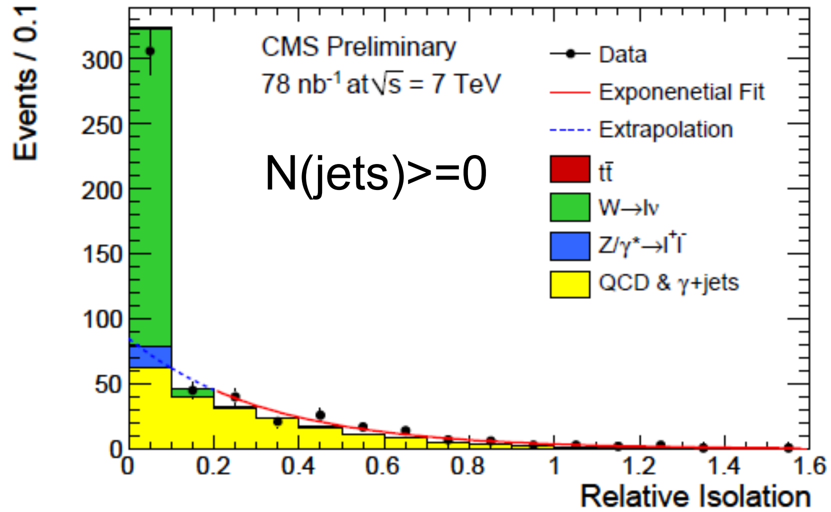
N(jets)>=0	QCD MC	QCD estimate
MET	62.7+/-0.5	60+/-23
HT(lep)	62.7+/-0.5	86+/-24

N(jets)>=1	QCD MC	QCD estimate
MET	41.6+/-0.4	37+/-21
HT(lep)	41.6+/-0.4	36+/-14

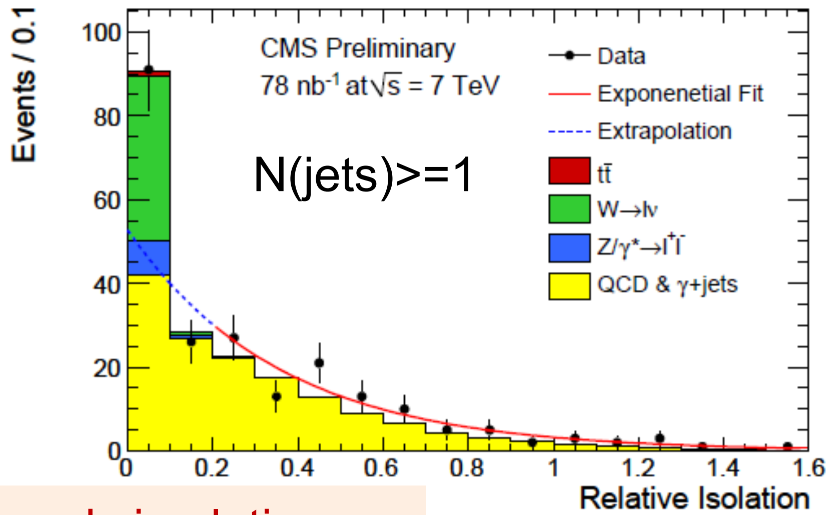
e+jets: DD estimate consistent with MC
For the moment, no cuts on MET or HT

Data-driven QCD : isolation extrapolation

- Fit function to isolation distribution in non-isolated region (QCD dominated)
- Extrapolate to isolated region (W-like)

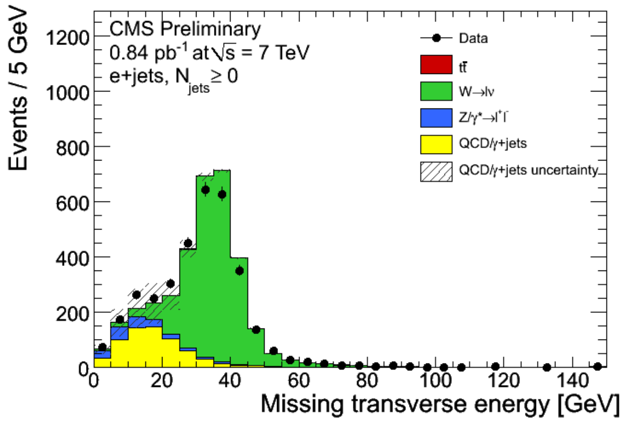


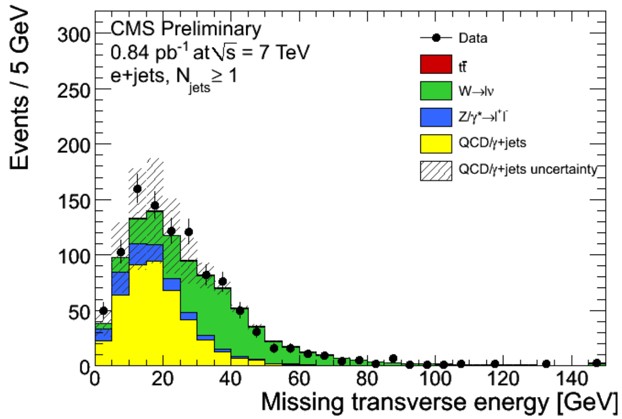
Isolation extrapolation method (e+jets)		
Fit Range	$N^{est.}_{QCD}(\geq 0\text{-jet})$	$N^{est.}_{QCD}(\geq 1\text{-jet})$
0.1–1.6	67 ± 9	40 ± 6
0.2–1.6	73 ± 13	46 ± 9
0.3–1.6	71 ± 17	45 ± 12
Average $N^{est.}_{QCD}$	70 ± 35	44 ± 22
Prediction N^{MC}_{QCD}	63 ± 7	42 ± 6

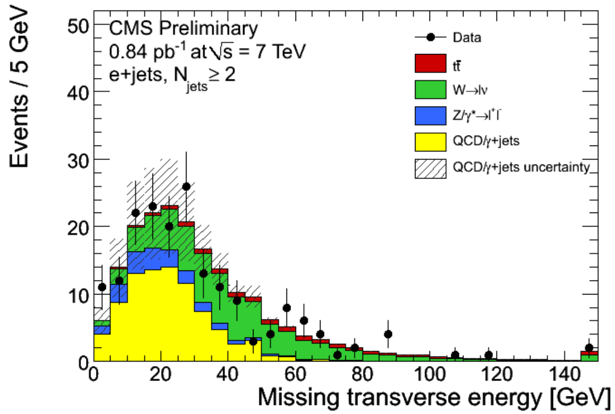


Agreement between data-driven QCD estimate and simulation
Furthermore, isolation extrapolation and template method agree

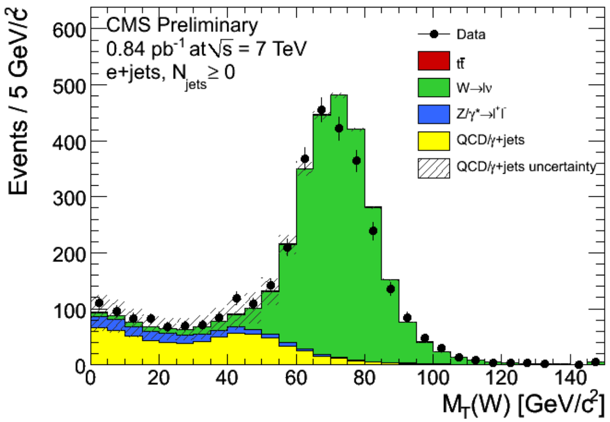
N(jets)>=0 N(jets)>=1 N(jets)>=2

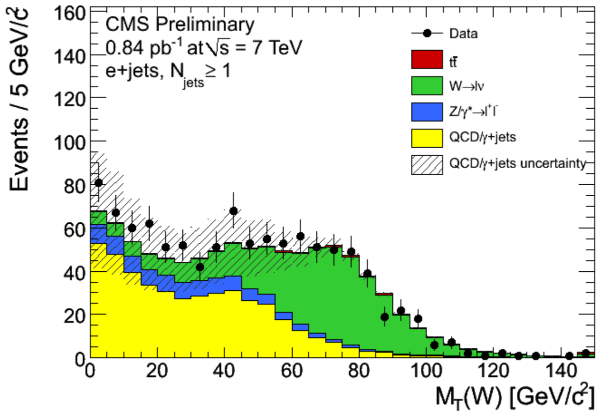


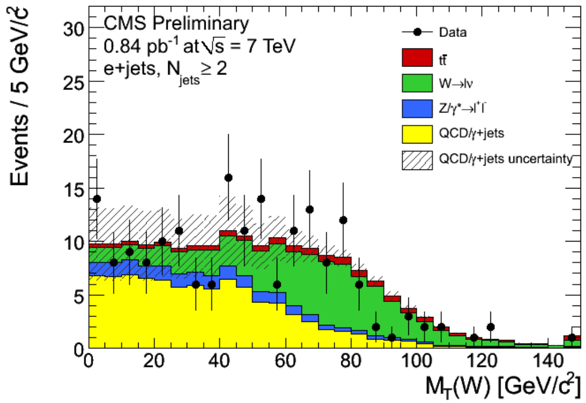




Missing ET (hard to get right, important for any top quark measurement)





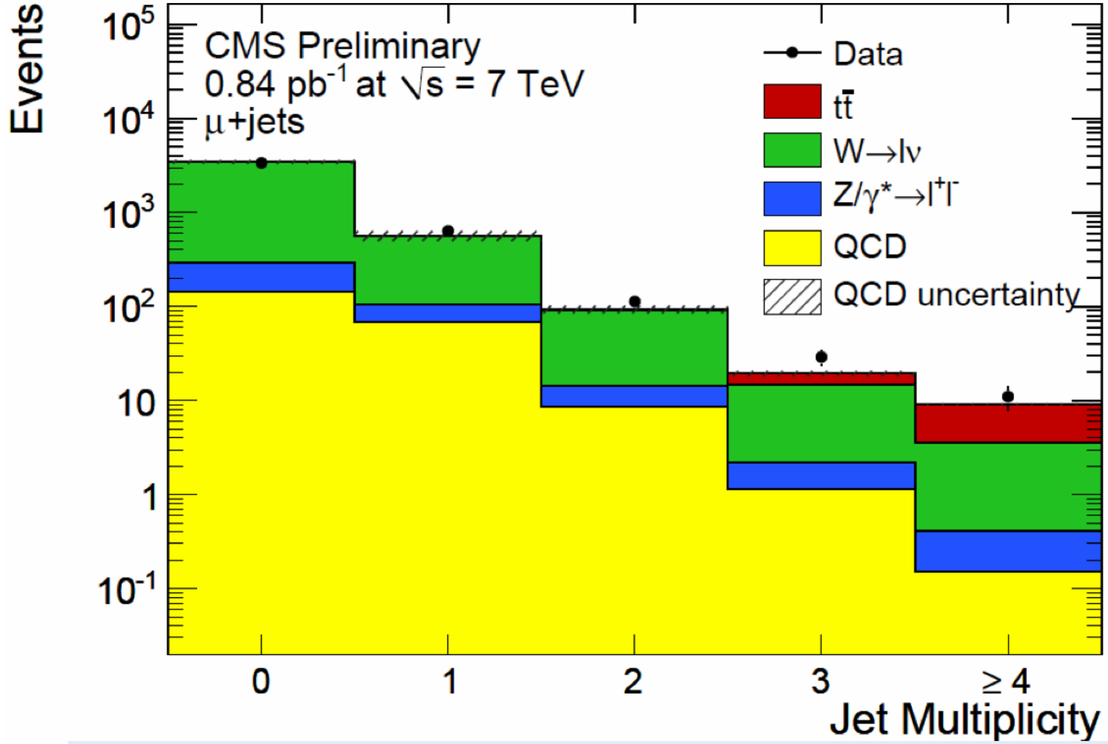


M_T(W): transverse W mass (calculated from lepton+MET)

Good agreement Data-Simulation! QCD background important in e+jets!

Muon+jets channel in $0.84\ pb^{-1}$

Jet multiplicity	ttbar	single top	W+jets	Z+jets	QCD	Sum MC	Data
$N_{jets} \geq 0$	13 ± 3	4.2 ± 0.4	3708 ± 448	192 ± 29	223 ± 25	4140 ± 450	4142
$N_{jets} \geq 1$	13 ± 3	3.9 ± 0.4	552 ± 106	42 ± 12	79 ± 17	690 ± 108	789
$N_{jets} \geq 2$	13 ± 2	2.3 ± 0.3	92 ± 24	7.1 ± 4.4	10 ± 3	124 ± 25	153
$N_{jets} \geq 3$	10 ± 2	0.82 ± 0.15	16 ± 5	1.3 ± 0.9	1.3 ± 0.5	29 ± 5	40
$N_{jets} \geq 4$	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



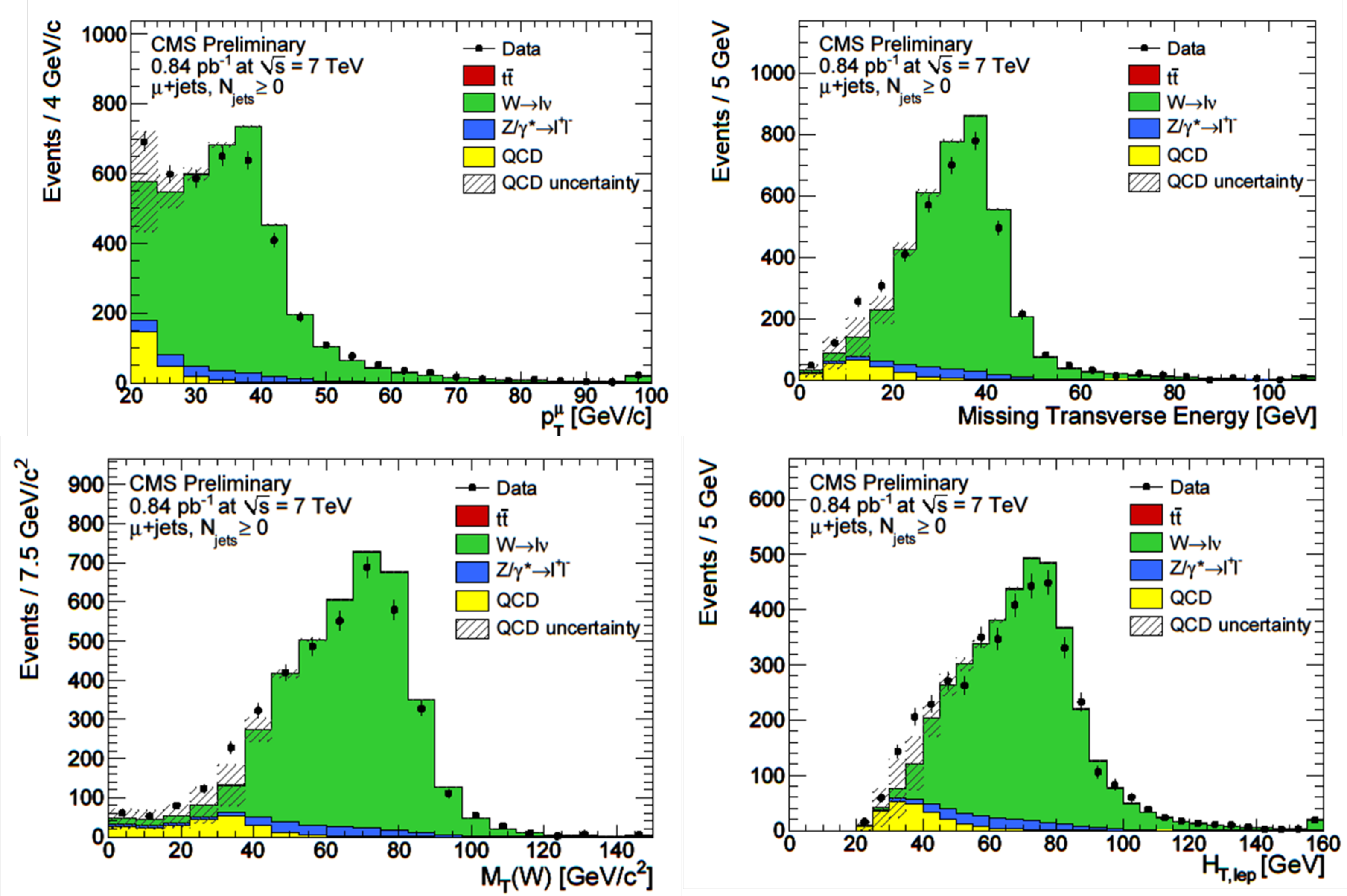
Error band: 100% on QCD (from data-driven methods)

MC Uncertainties (table):
- Jet energy scale (known to 10%)
- Luminosity (known to 11%)
- Cross section unc. (scale, PDF)

- For QCD, the statistical uncertainty of the sample was used

Good agreement observed in all Jet bins!

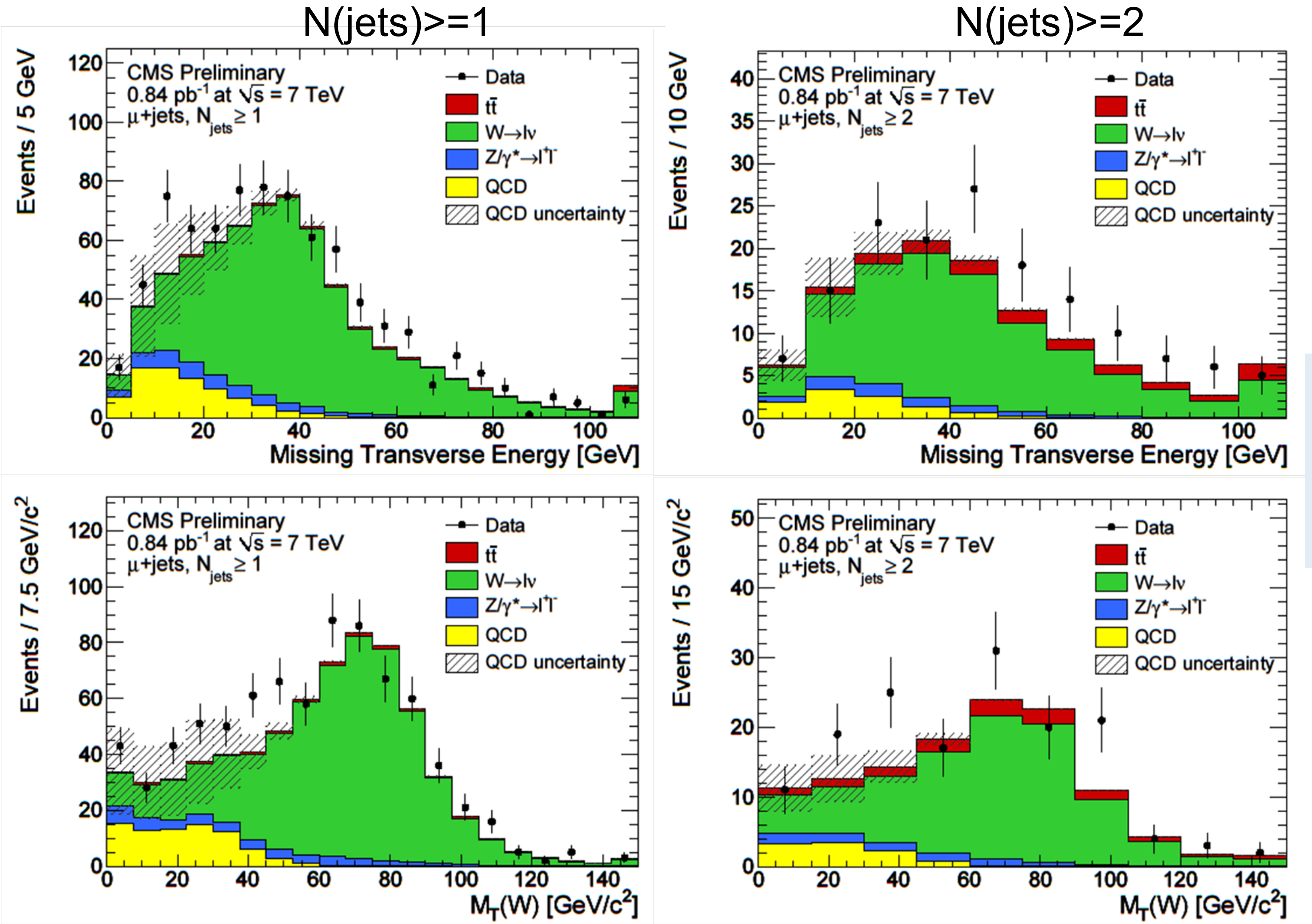
Muon+jets in N(jets) >=0



Excess observed in data at low Pt(mu), MET, MT and HT
Consistent with QCD MC being factor ~2 too low

Error band: 100% on QCD
(from data-driven methods)

Muon+jets in N(jets)>=1,2



Consistent with QCD too low by factor ~2, indep. of N(jets)

Data slightly above simulation also where QCD less important

Note: expect significant JES & theory uncertainties (not incl. in error bars!)

Bottom jets in lepton+jets

- Jets from b-quarks are a signature of top quark decays

•Using secondary vertex b-tagger (~1% fake rate)

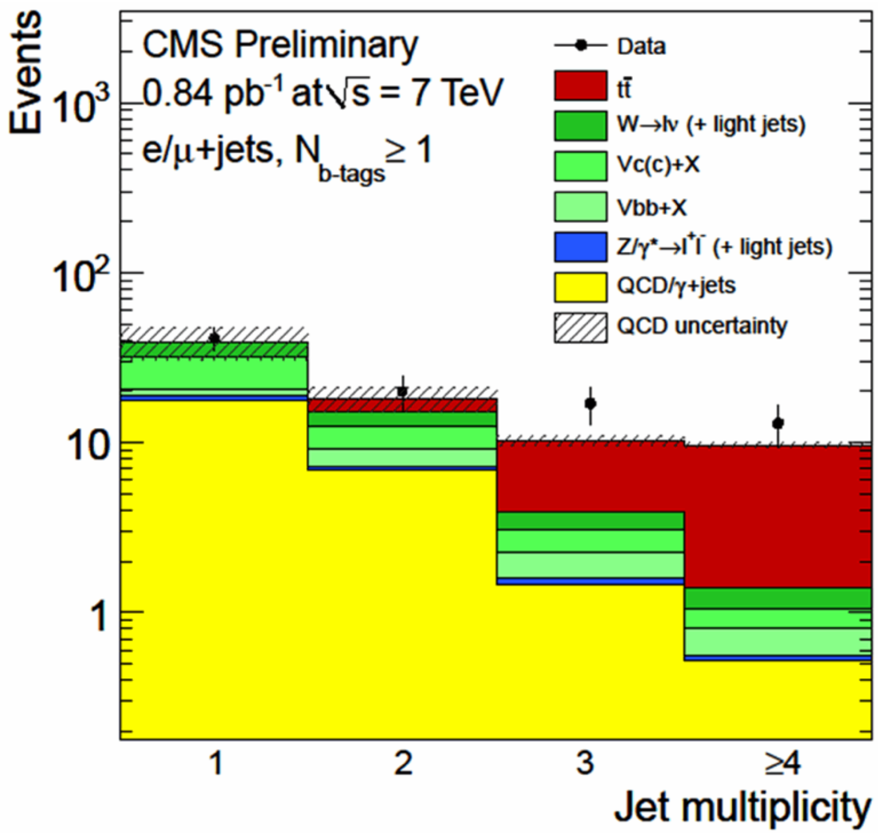
• Jet multiplicity for events with at least one b-jet

For N(jets)>=3:

Observed data=30

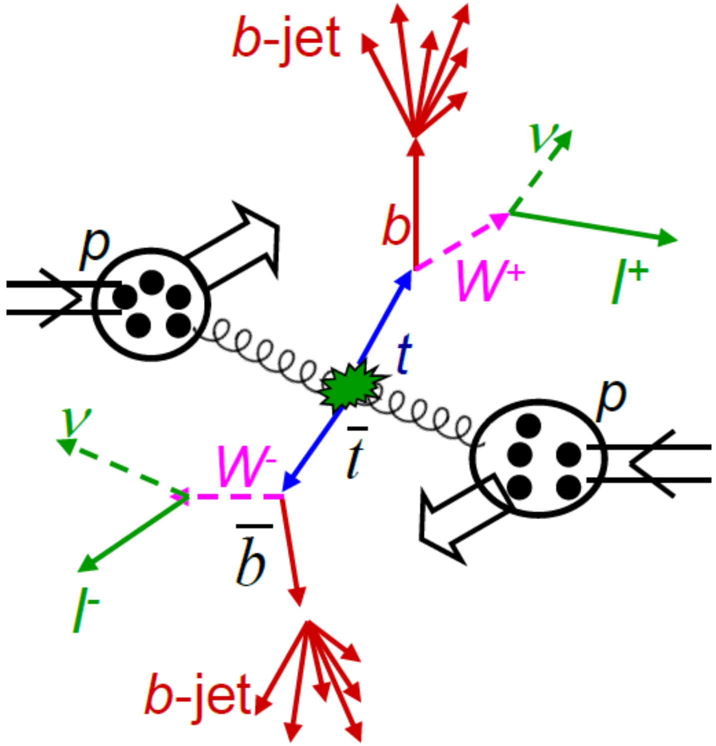
Prediced background =5.3

Predicted signal =15



Seeing ttbar events at a rate roughly consistent with NLO cross section, considering experimental (JES,b-tagging) and theoretical (scale, PDF, HF modelling, …) uncertainties

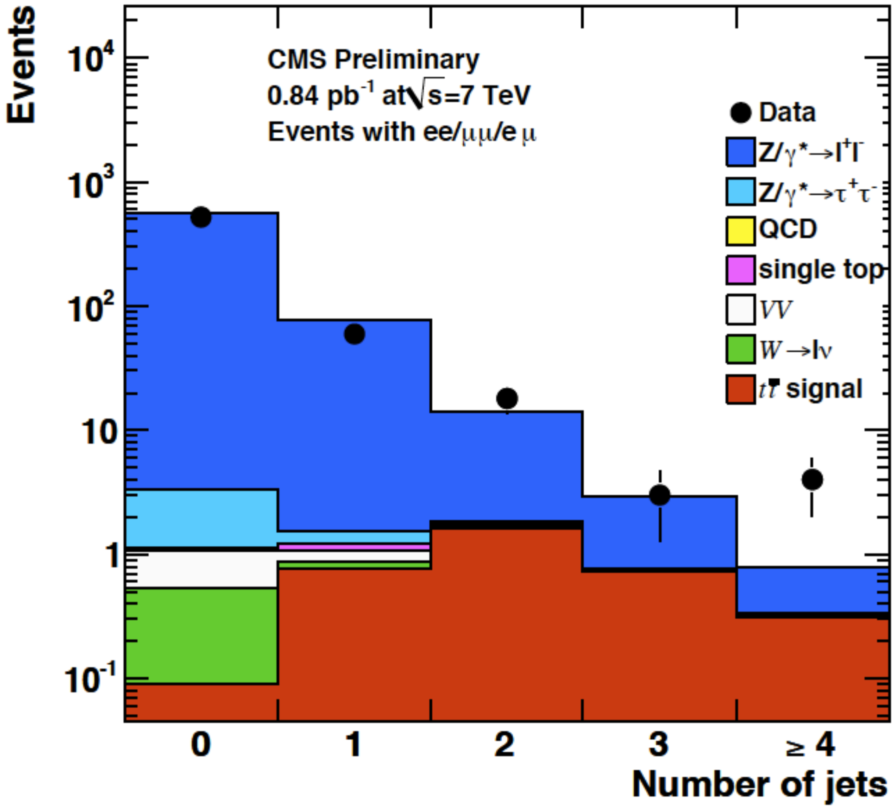
Dilepton event selection

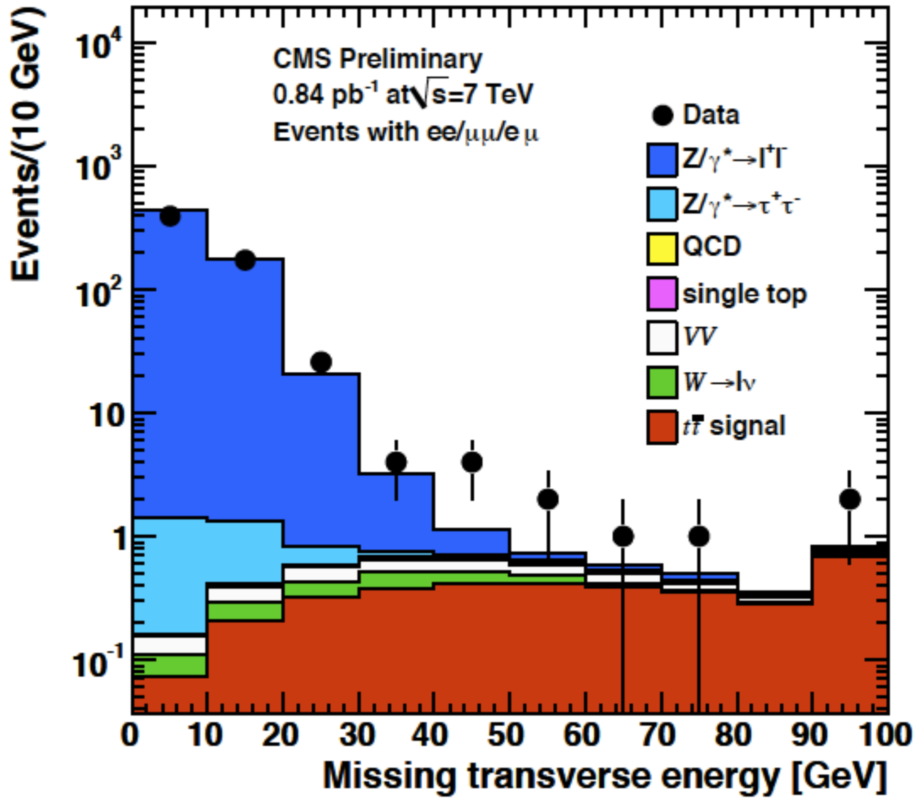


- Single lepton triggers
  - mu+X (Pt>9 GeV),e+X (Pt>15 GeV)
- Two isolated, opposite charge leptons (ee,mumu,emu)
  - Pt>20 GeV, |eta|<2.5
  - Rel. isolation < 0.15
- Z-boson veto (ee,mumu)
  - |M(ll)-M(Z)|>15 GeV
- Missing Et (MET)
  - Using calorimeter & tracking
  - MET>30(20) GeV in ee,mumu (emu)
- Jets
  - Anti-Kt (R=0.5)
  - Using calorimeter & tracking
  - Pt>30 GeV, |eta|<2.4
  - Expect >=2 jets for ttbar

Data: relaxed event selection

- No Z-veto, no MET, no N(jets) requirements

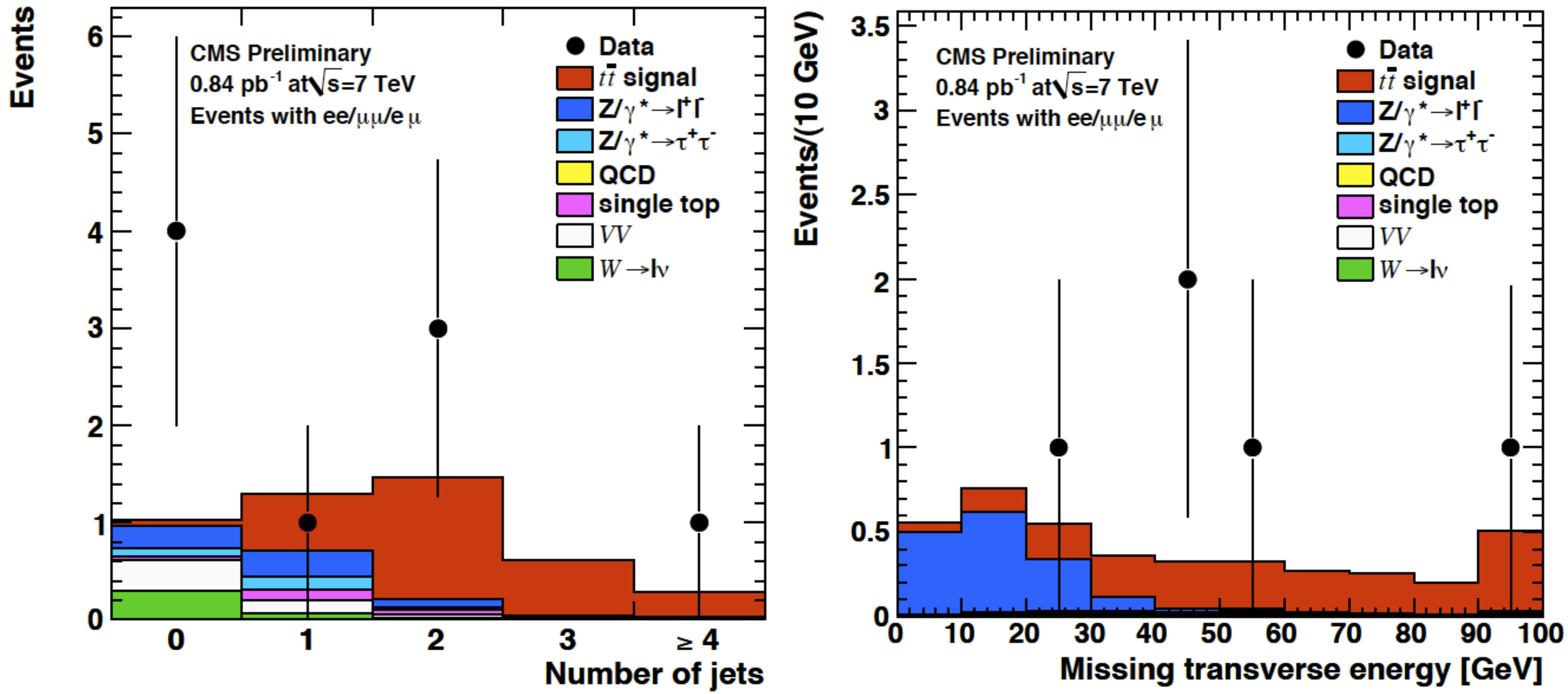




Drell-Yan is dominant at this stage of event selection
Fair agreement between data and simulation

- Excess of events with large MET is consistent with more events from DY with jets
    - ➢ Additional justification to estimate the DY background from data

- **Full Event selection, except MET requirement**



Signal contribution is significant after full selection

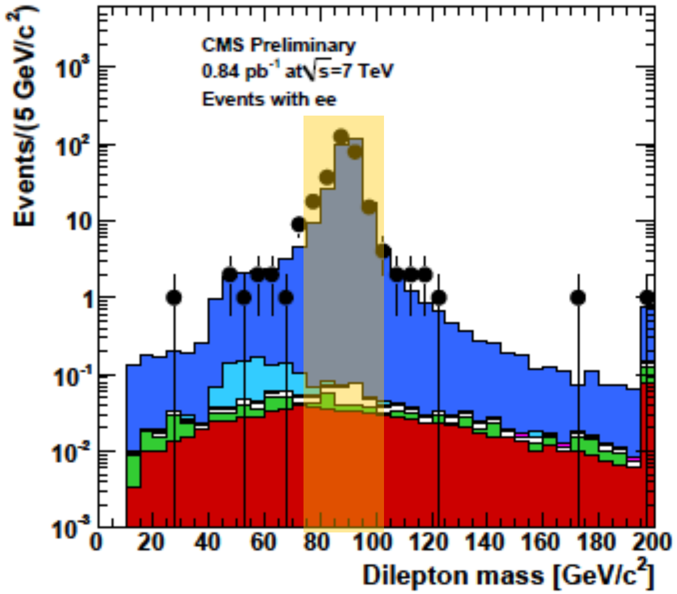
Data-driven Drell-Yan background

Estimate Drell-Yan background outside Z-veto region from events inside:

ratio outside/inside from *DY* simulation

$$N_{\mathrm{out}}^{ee,\mathrm{data}} = \overbrace{R_{\mathrm{out/in}}^{ee}}\left(N_{\mathrm{in}}^{ee,\mathrm{data}} \underbrace{- 0.5 N_{\mathrm{in}}^{e\mu,\mathrm{data}} k_{ee}}\right)$$

correction for non-DY contribution in *Z*-veto region from eμ sample



Sample	ID, ISO, Z-veto	with $N_{\mathrm{jet}} \geq 1$	with $N_{\mathrm{jet}} \geq 2$ and $\not{E}_T > 30$ GeV
ee			
DY in simulation	26 ± 6	4.2 ± 1.1	0.04 ± 0.01
DY estimate in data	$26 \pm 1.6 \pm 13$	$3.6 \pm 0.6 \pm 1.8$	$0.4 \pm 0.2 \pm 0.2$
$\mu\mu$			
DY in simulation	31 ± 8	5.0 ± 1.2	0.07 ± 0.02
DY estimate in data	$27 \pm 1.6 \pm 13$	$4.3 \pm 0.7 \pm 2.1$	$0.21\,^{+0.23}_{-0.21} \pm 0.11$

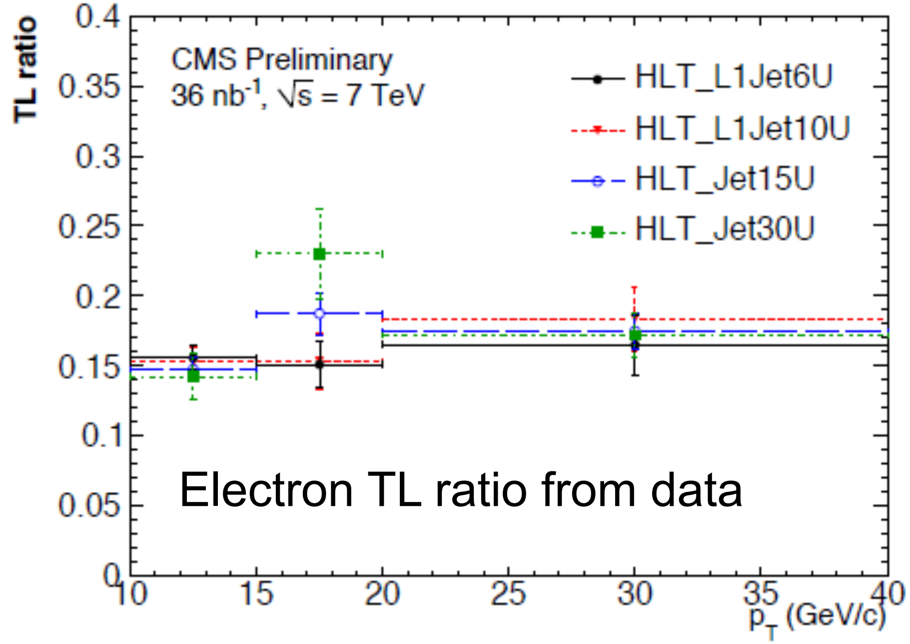
Agreement between simulation and data-driven estimate

Data-driven QCD, W+jets background

- "Fake" lepton backgrounds:
  - W+jets : one fake lepton
  - QCD: two fake leptons
- Determine a 'tight-to-lose ratio' (TL) in jet-triggered sample
- Apply to events where one (both) leptons pass loose, but fail tight lepton selection
- Weighed sum yields background estimate
- 50% systematics per "fake" lepton

$$N_{nn}^{QCD} = \sum_{i,j} \frac{TL_i TL_j}{(1-TL_i)(1-TL_j)} N_{\bar{n}\bar{n}}^{ij}$$

$$N_{nn}^{WJets} = \sum_{i,j} \frac{TL_i}{(1-TL_i)} N_{\bar{n}n}^{ij}$$



Dilepton channel in 0.84 pb^{-1}

- Event yield for selection with Z-veto and N(jets)>=1

Sample	ee	$\mu\mu$	$e\mu$
Dilepton $t\bar{t}$	$0.63 \pm 0.09 \pm 0.12$	$0.70 \pm 0.11 \pm 0.13$	$1.70 \pm 0.26 \pm 0.32$
VV	0.05 ± 0.03	0.05 ± 0.03	0.12 ± 0.06
Single top - tW	0.04 ± 0.02	0.05 ± 0.03	0.12 ± 0.06
Drell-Yan $\tau\tau$	0.08 ± 0.04	0.13 ± 0.07	0.19 ± 0.09
Drell-Yan ee, $\mu\mu$	4.2 ± 1.1	5.0 ± 1.2	0.04 ± 0.02
Non-dilepton $t\bar{t}$	0.02 ± 0.01	0.003 ± 0.002	0.03 ± 0.02
W+jets	0.06 ± 0.03	$0.000\,^{+0.002}_{-0.000}$	0.07 ± 0.04
QCD multijets	$0\,^{+10}_{-0}$	$0\,^{+10}_{-0}$	$0\,^{+10}_{-0}$
Total simulated	5.1 ± 1.1	5.9 ± 1.2	2.3 ± 0.4
QCD data-driven	$0.0\,^{+0.1}_{-0.0}\,^{+0.1}_{-0.0}$	$0.0\,^{+0.2}_{-0.0}\,^{+0.2}_{-0.0}$	$0.0\,^{+0.1}_{-0.0}\,^{+0.1}_{-0.0}$
W+jets data-driven	$0.2\,^{+0.2}_{-0.0}\,^{+0.1}_{-0.0}$	$0.0\,^{+0.4}_{-0.0}\,^{+0.2}_{-0.0}$	$0.0\,^{+0.4}_{-0.0}\,^{+0.2}_{-0.0}$
Drell-Yan data-driven	$3.6 \pm 0.6 \pm 1.8$	$4.3 \pm 0.7 \pm 2.1$	N/A
Data	6	6	2

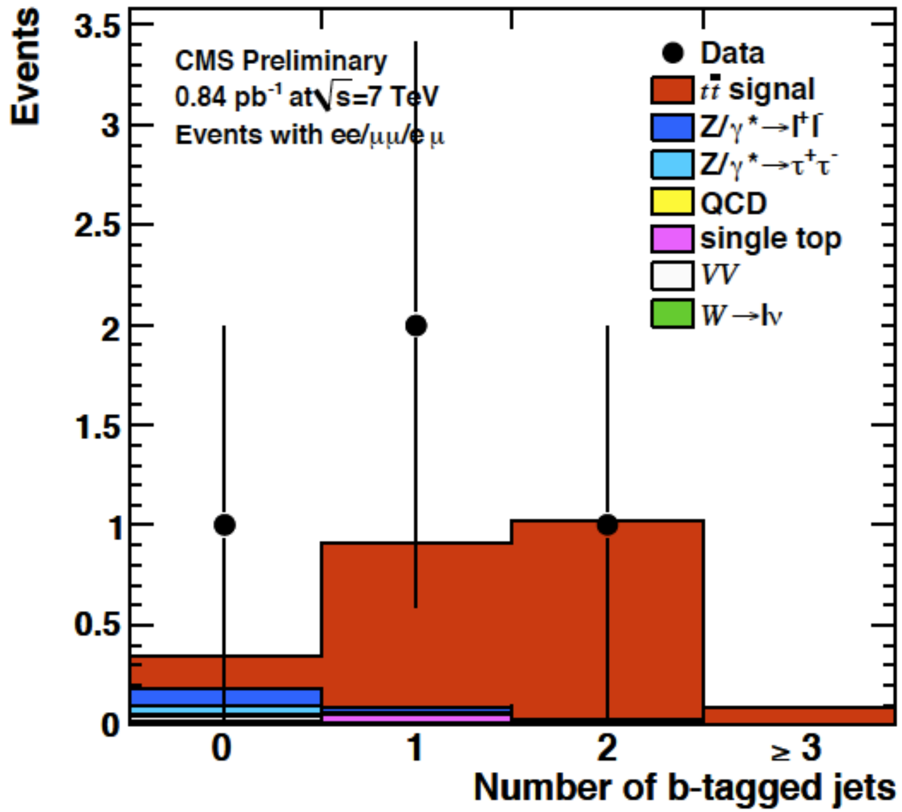
Systematics:
- Signal : 16%
- DY prediction from simulation : 15%
- Other backgrounds from simulation : 50%
- Data-driven backgrounds : 50 % for W+Jets, 50% for DY, 100% for QCD
- Luminosity : 11%

Good agreement between data and simulation for all channels

Bottom-jet identification

- Jets from b-quarks are a signature of top quark decays
  - b-tagging not yet applied in the selection, but we start to analyze the heavy flavour content of the sample

Full event selection , including MET and N(jets)>=2



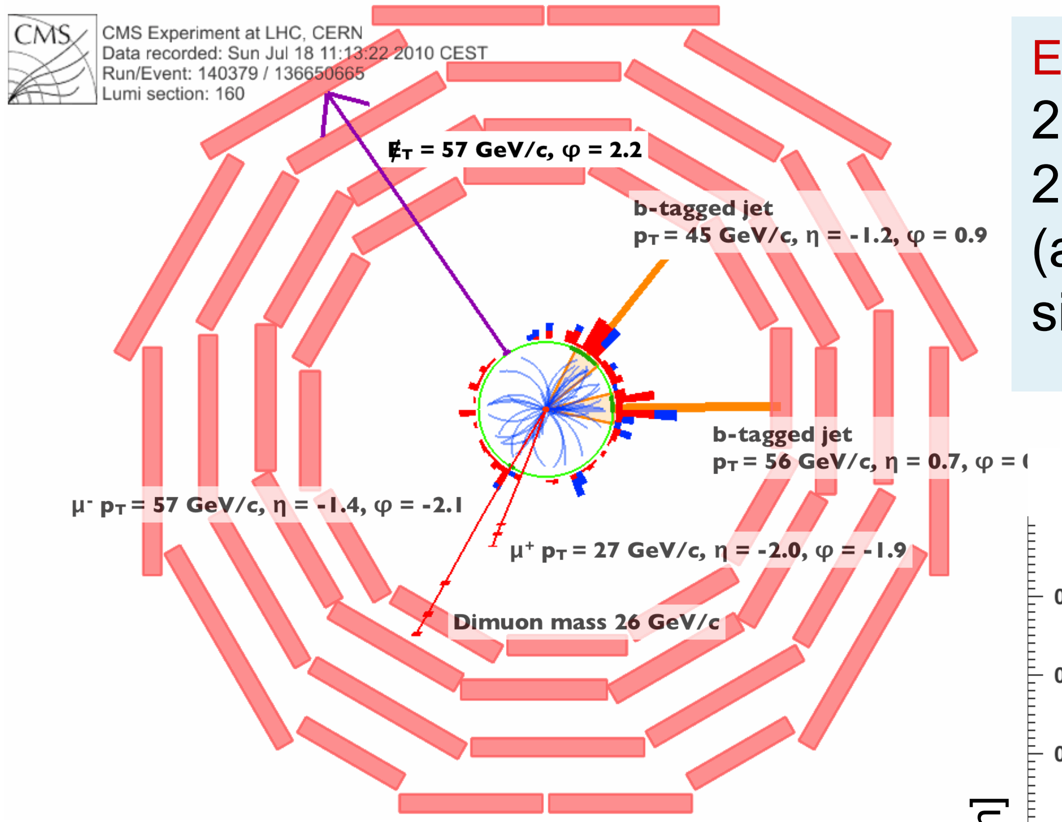
Example:
B-tagging algorithm using the significance of the impact parameter (IPsig) of the tracks associated to the jet

IPsig of track with 2nd highest IPsig > 1.7
81 % efficiency for tagging b-jets
10 % false positive rate

4 candidate events

Evidence of ttbar production in selected data

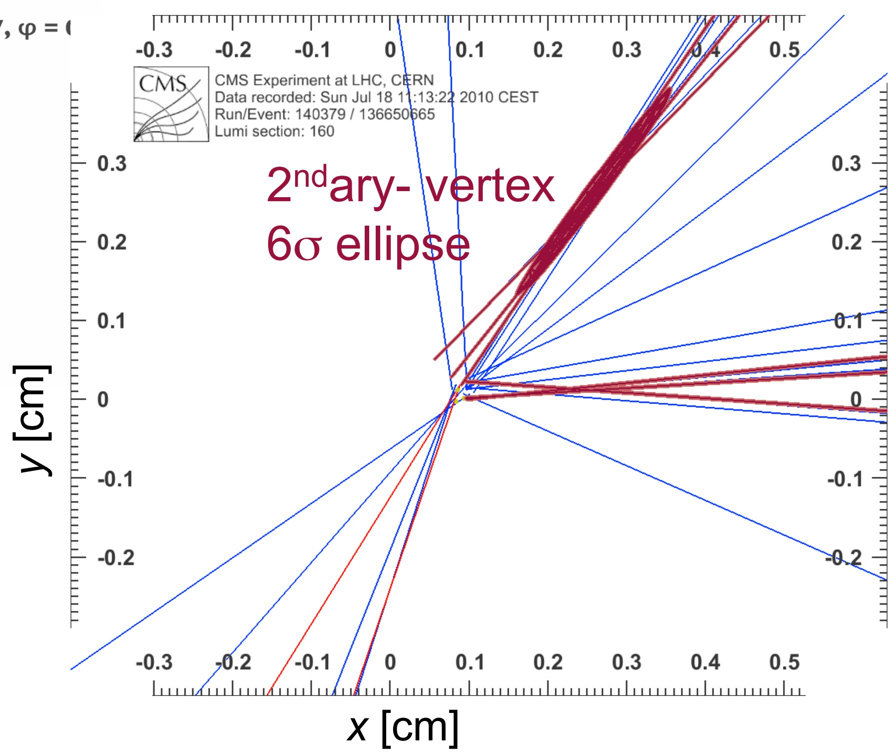
A dimuon event with two b-tags



Event passes full selection:

- 2 muons with opposite charge
- 2 jets, both w/ good/clear *b*-tags
- (and secondary vertices!)
- significant MET (>50 GeV)

Preliminarily reconstr. mass in the range 160–220 GeV/c^2



Conclusions

- Analyzed 0.84 pb-1 of 7 TeV Data
    - Events yields consistent with simulation, within uncertainties
    - Successfully tested data-driven background estimation
- In lepton+jets seeing ttbar events at rate consistent with expectation
- Observed 4 events in dilepton channel passing full selection
- Further evidence of ttbar production provided by analysis of heavy flavour content
- Strong evidence for excellent performance of CMS detector (jets, MET, leptons, b-tagging)!
- Next step: measurement of top-quark pair production cross section

Acknowledgments

Frank-Peter Schilling (HCP 2010 talk)
HQL 2010 organizing committee
LHC and CMS collaboration

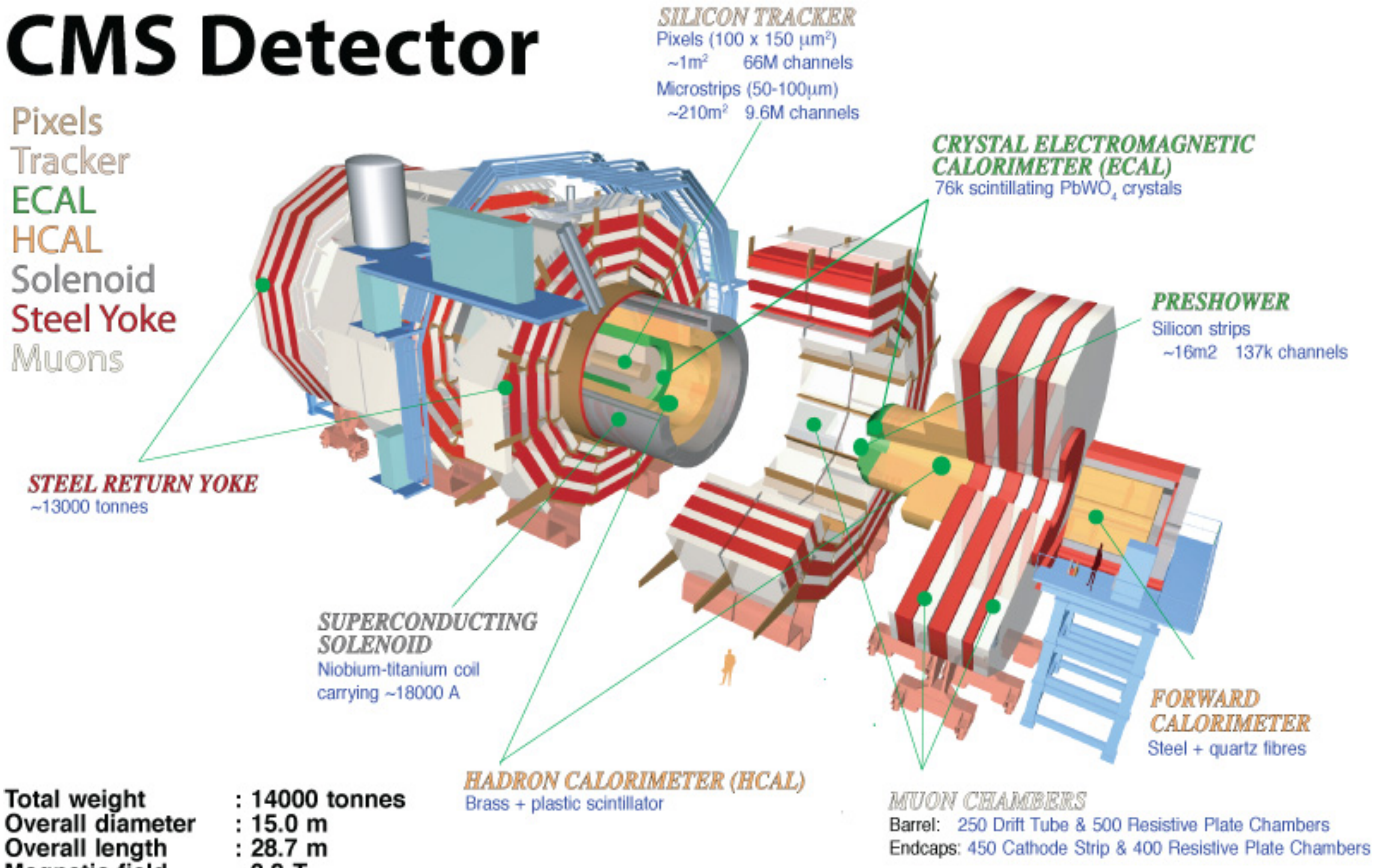
References

"Selection of Top-Like Events in the Dilepton and Lepton-plus-Jets channels in Early 7 TeV data", CMS Physics Analysis Summary,
CMS-PAS-TOP-10-004 (2010)

CMS twiki page with results for Top Physics
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Backup

CMS Detector



Total weight	: 14000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T