XIX International Workshop on Deep-Inelastic Scattering and Related Subjects 2011

Physics Results from CMS

Kerstin Hoepfner
RWTH Aachen
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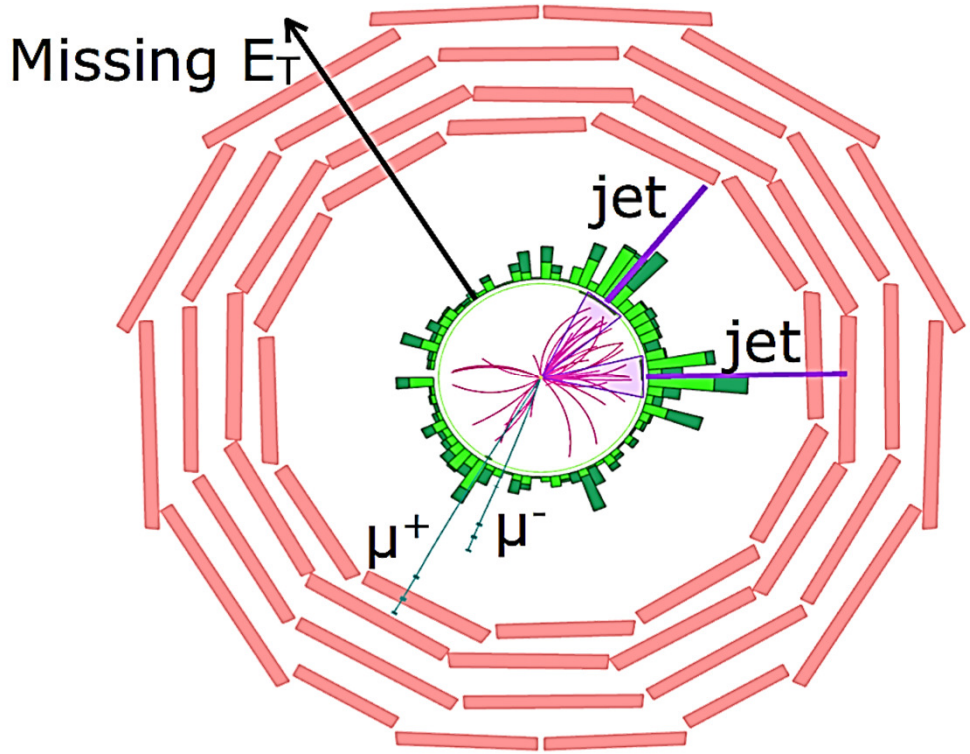
On behalf of the CMS collaboration



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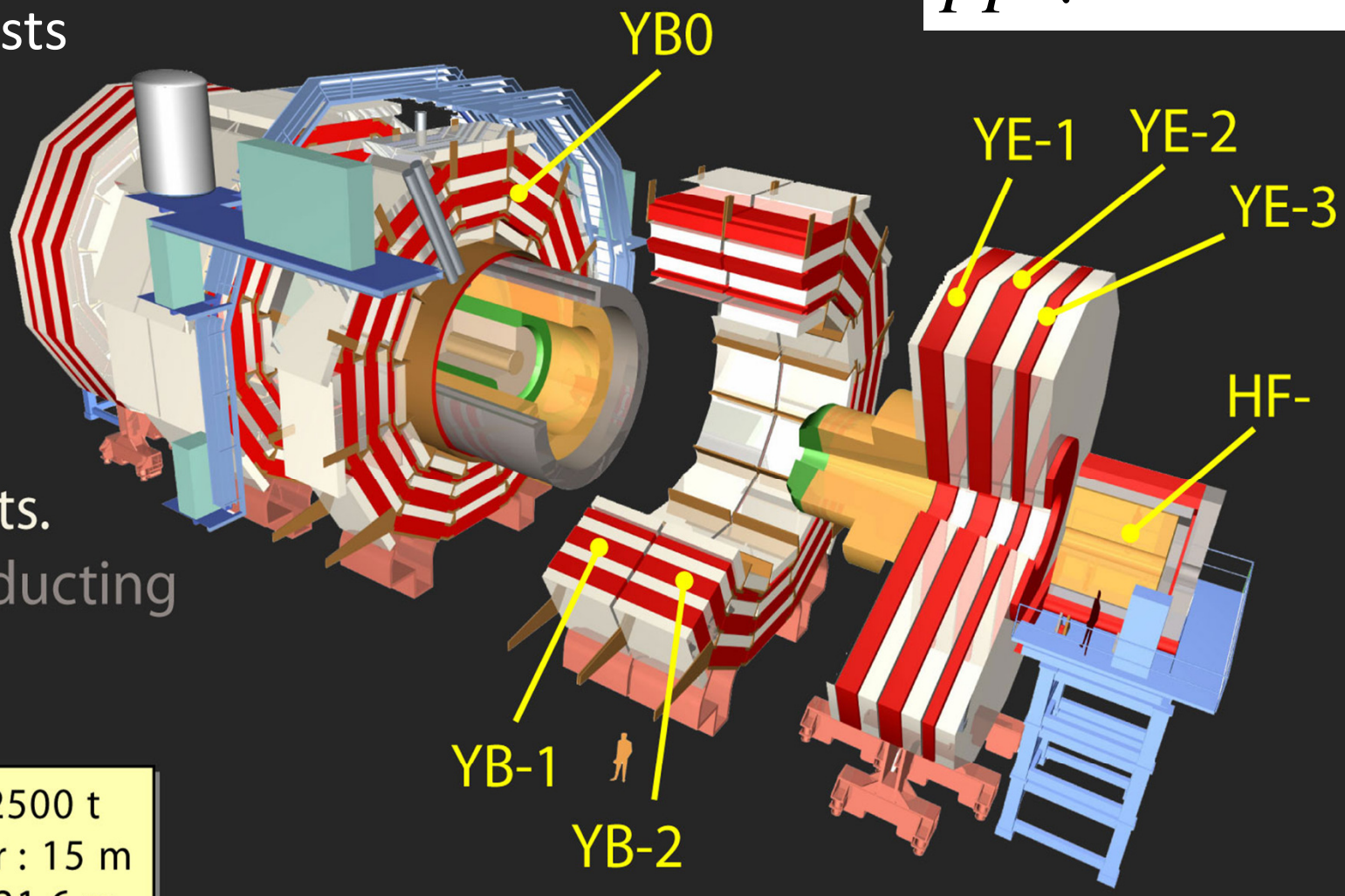
Outline:

1. Overview, CMS, LHC performance
2. Standard Model Physics
3. Prospects for Standard Model Higgs
4. Physics beyond the SM
5. Summary

The Compact Muon Solenoid

$pp\sqrt{s} = 7\,\mathrm{TeV}$

Plus a collaboration of
~3000 physicists



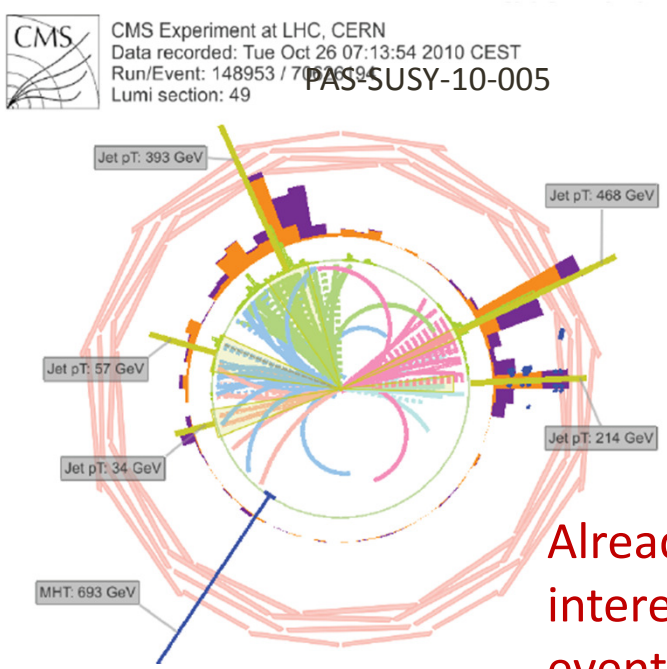
- Pixels
- Tracker
- ECAL
- HCAL
- MUON Dets.
- Superconducting Solenoid

Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

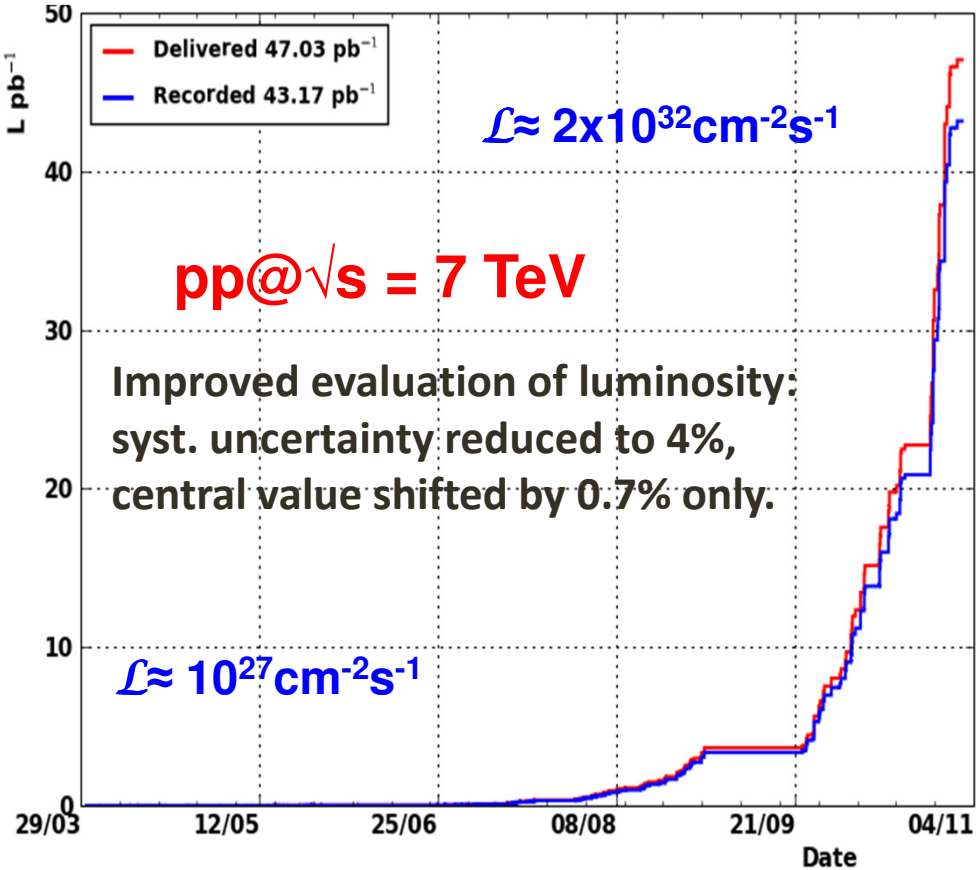
http://cms.cern.ch

LHC and CMS Performance

2010 pp: ~**47pb^{-1}** delivered by LHC and **~43pb^{-1}** collected by CMS.
Overall data taking efficiency **~92%.**



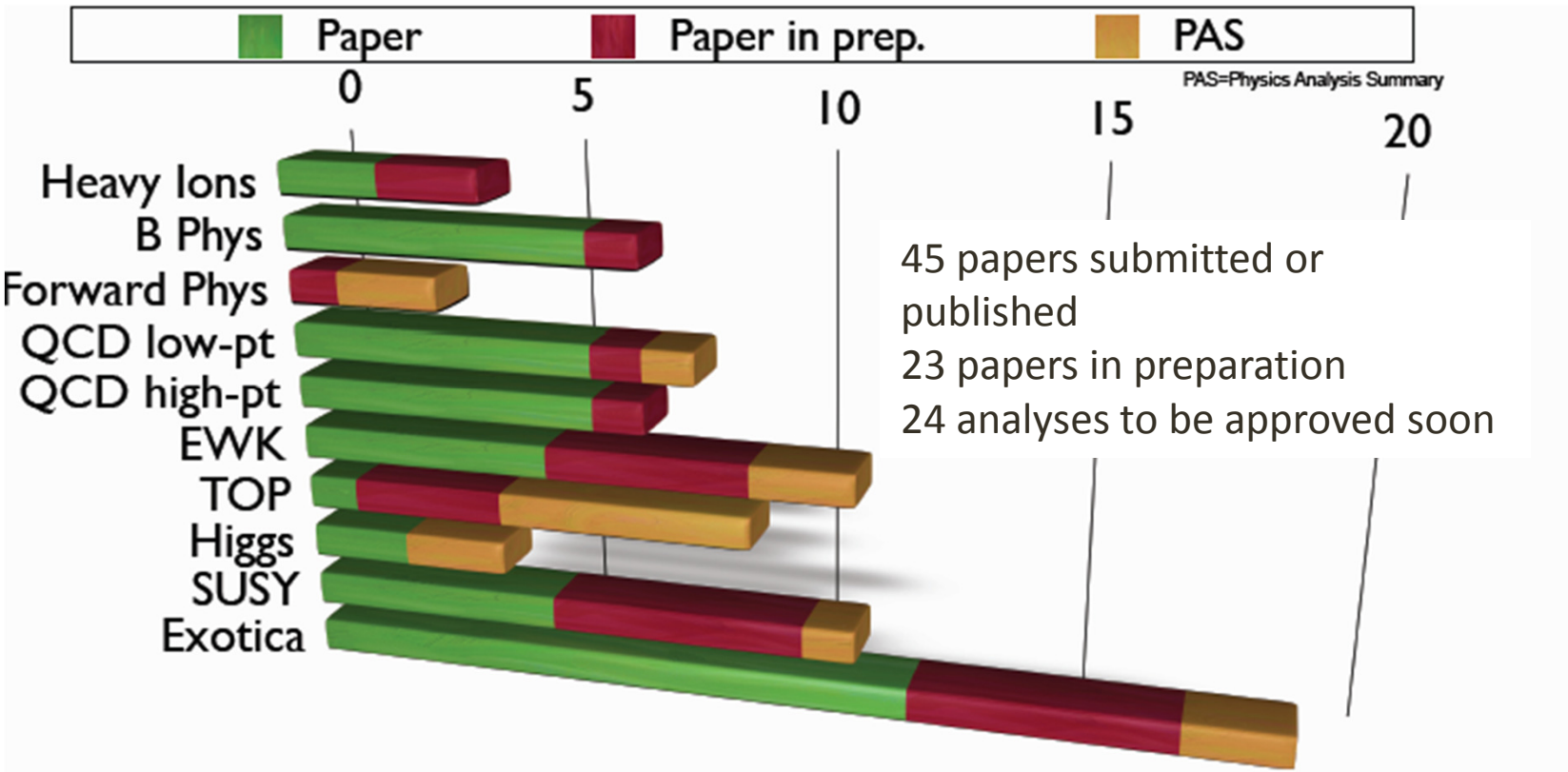
Already some interesting events seen



Average fraction of operational channels per CMS sub-system **>99%.**
Quality of the data for physics (any analysis) **~85%** of recorded data.

Many Physics Results

With 2010 data, 83 physics analyses. Can only show some highlights



For complete information see

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

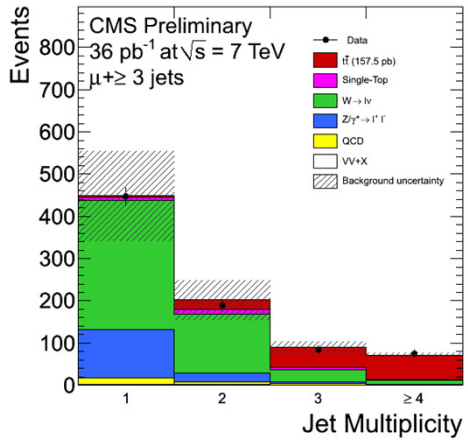
CMS Talks At This Conference I

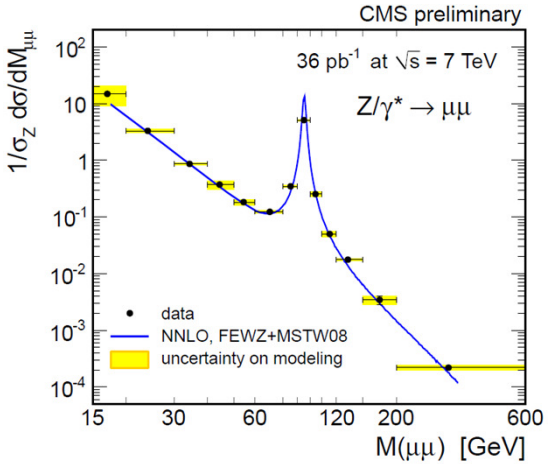
- J/psi differential cross sections in pp collisions at 7 TeV (Paolo Ronchese)
- Jet results from CMS (Cosmin Dragoiu)
- Measurement of top quark pair prod. cross section at 7TeV (Julien Caudron)
- Measurement of the top quark mass at 7TeV (Pedro Vieira De Castro Ferreira Da Silva)
- Measurement of single top quark production at 7 TeV (Dennis Klingenbiel)
- Measurement of the top pair invariant mass distribution at 7 TeV and search for New Physics (Davide Pagano)
- Measurement of the Lepton Charge Asymmetry in Inclusive pp →W + X → (e/μ)nu + X Production at sqrt(s) = 7 TeV (Michele Pioppi)
- Isolated Photon measurements with the CMS Detector at sqrt(s)=7 TeV (Darko Mekterovic)
- Measurement of the Drell-Yan differential cross section at 7 TeV (Norbert Neumeister)
- Measurement of energy flow in a large eta range at the LHC at sqrt{s} = 0.9, 2.36 and 7 TeV (Albert Knutsson)

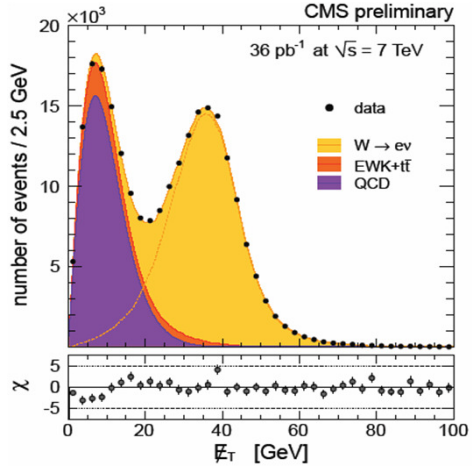
CMS Talks At This Conference II

- Measurement of the polarization of high transverse momentum W bosons at 7 TeV (Markus Stoye)
- Search for new physics with high pT leptons (Federico de Guio)
- Measurement on B-hadron angular correlations with CMS (Andrea Rizzi)
- Exclusive B-hadron production cross sections at 7 TeV with CMS (Alexander Schmidt)
- Measurement of Y(nS) production at 7 TeV with the CMS experiment (Jake Anderson)
- Multijet measurements with the CMS detector at sqrt(s)=7TeV (Joanna Weng)
- Diffraction at CMS (Ann-Karin Sanchez)
- Forward jets and forward-central jets at CMS (Andrea Massironi)
- Exclusive measurements (di-leptons and vector mesons) (Jonathan Hollar)
- Measurement of total visible cross section (Matteo Marone)

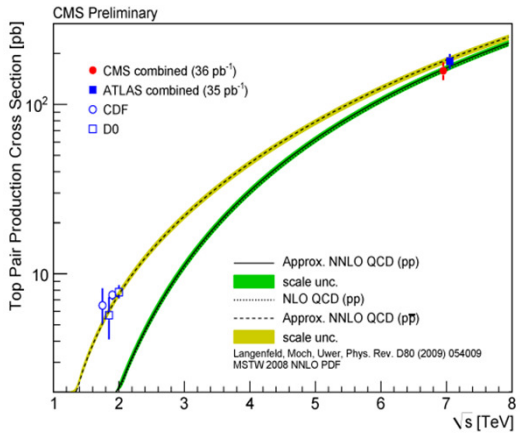
Much more information in these dedicated talks in the parallel sessions

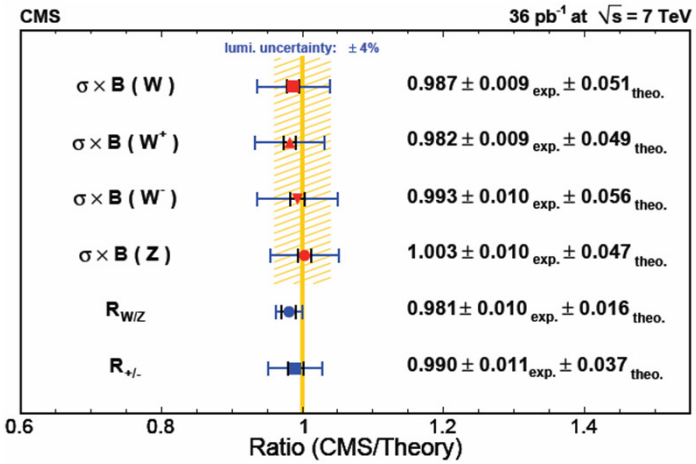


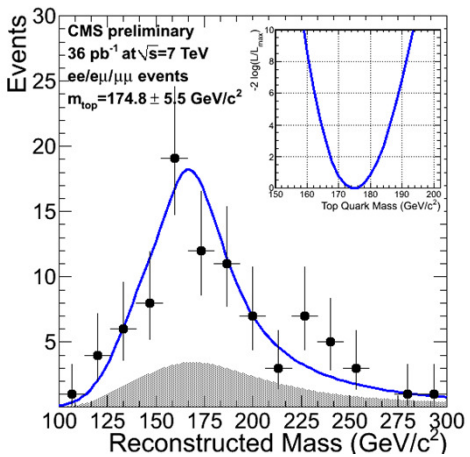




STANDARD MODEL PHYSICS



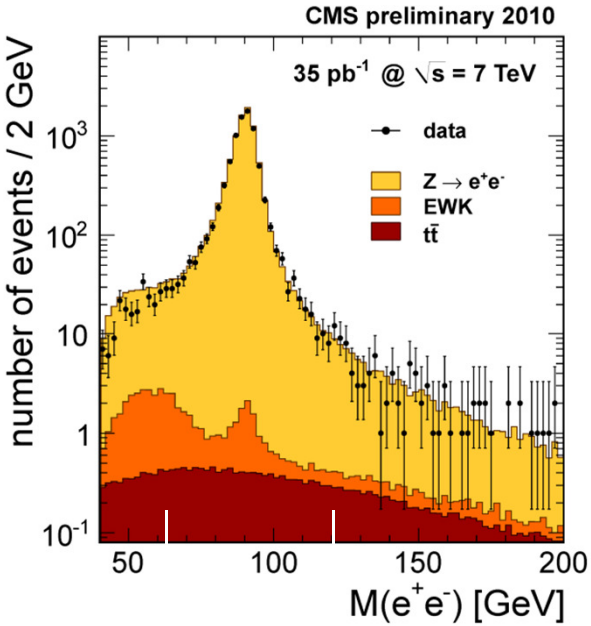


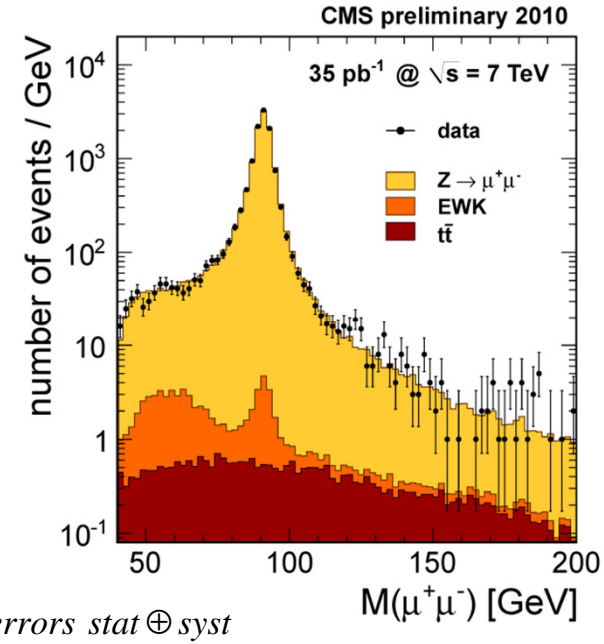


Re-discovering the Standard Model

With 2.9/pb JHEP01(2011) 080, Latest result with 35/pb PAS-EWK-10-005

Z Boson



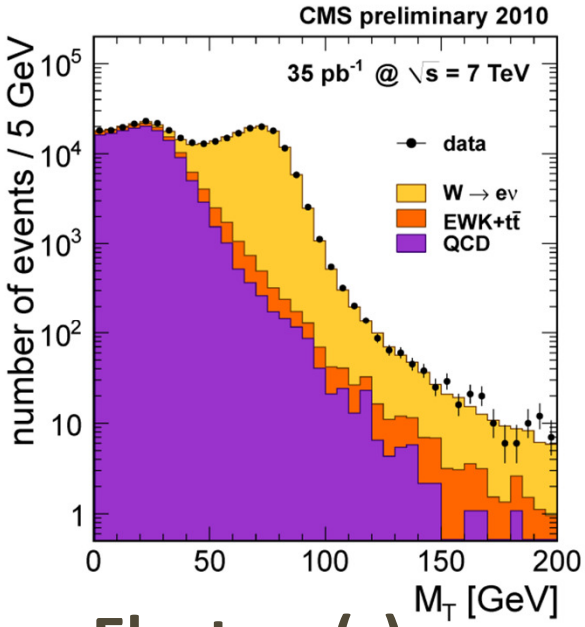


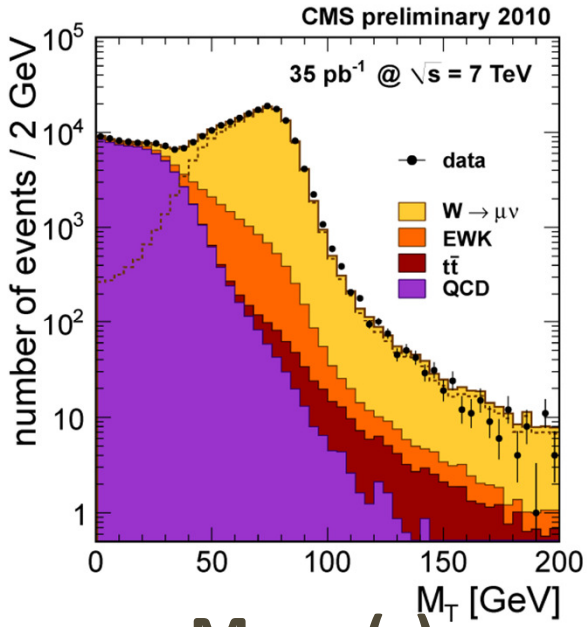
errors stat ⊕ syst

In general excellent data-MC agreement

Z events are important tool: data-driven methods for controlling lepton efficiency, scale, resolution and E_T^{miss} (hadronic recoil)

W Boson





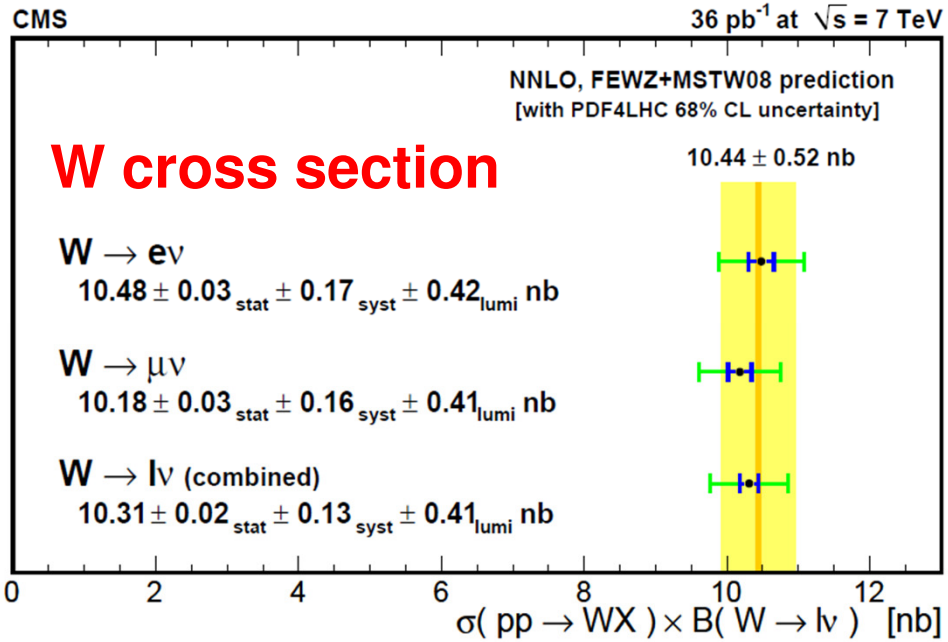
$\sigma(pp \to WX) \times BF(W \to ln)$ = 10.31 +/- 0.02(stat.) +/- 0.09(syst.) +/- 0.10(th.) +/- 0.41(lumi.) nb

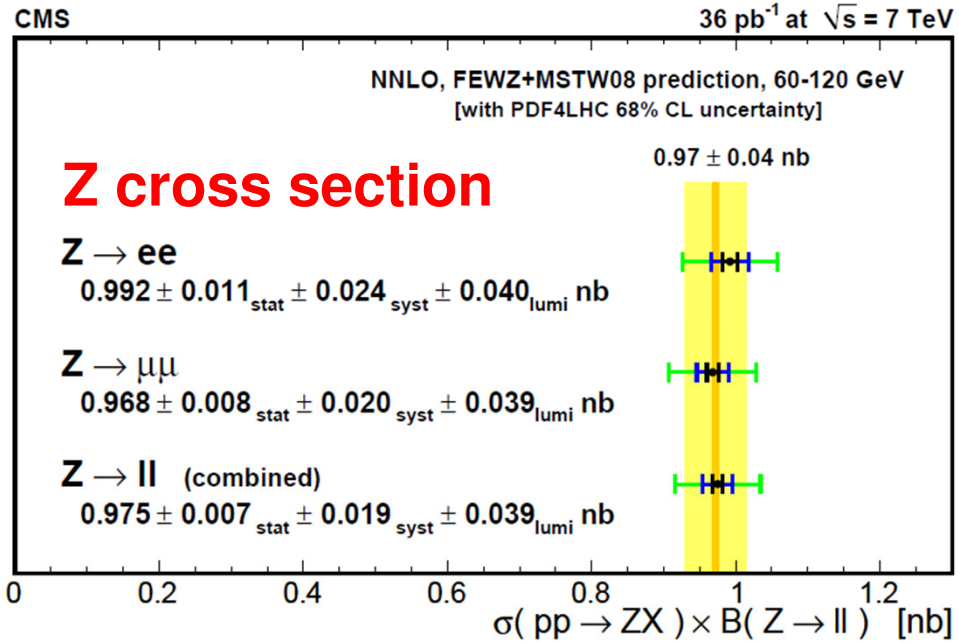
$\sigma(pp \to ZX) \times BF(Z \to l+ l-)$ = 0.975 +/- 0.007(stat.) +/- 0.007(syst.) +/- 0.018(th.) +/- 0.039(lumi.) nb

Electron(s) **Muon(s)**

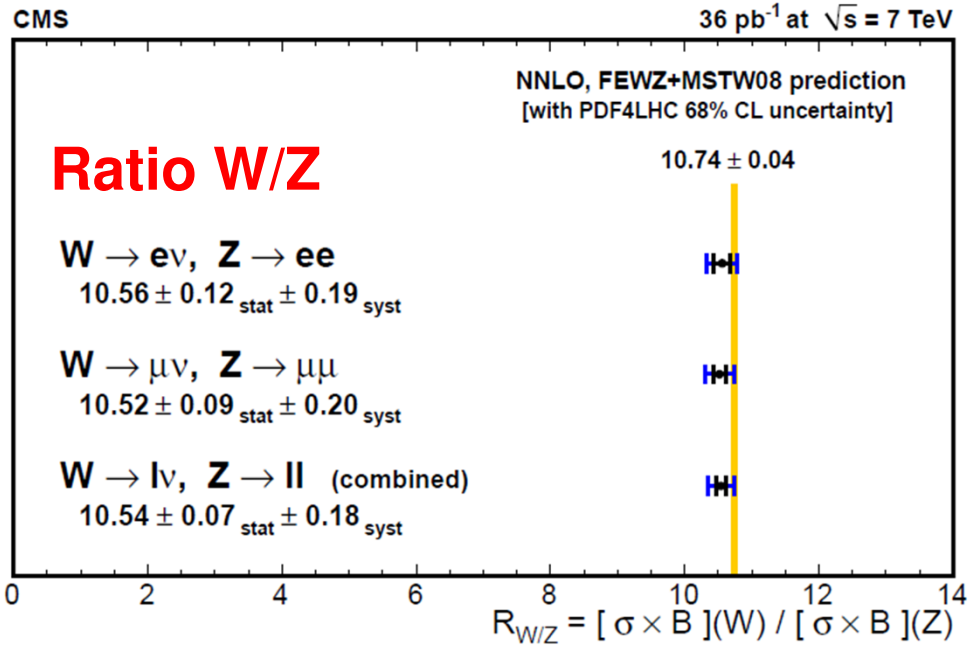
Precise Set of EWK Measurements

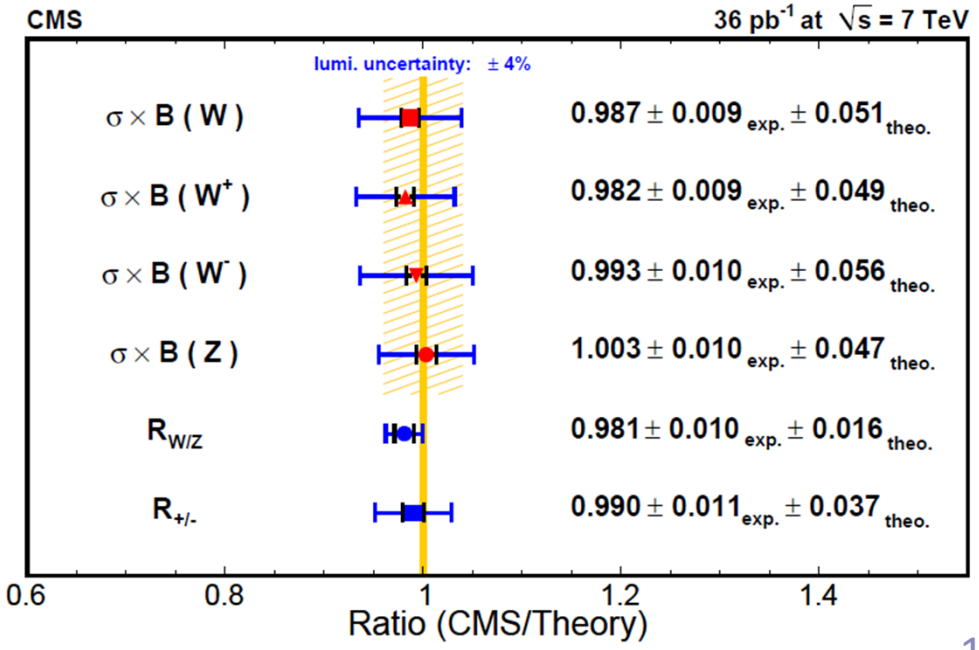
Amazing precision reached, ~1% experimental !





All plots PAS-EWK-10-005





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Measure W Boson Properties

Precision of xsec measurement ~1% experimental. Start to put constraints on theory (NNLO, PDFs)

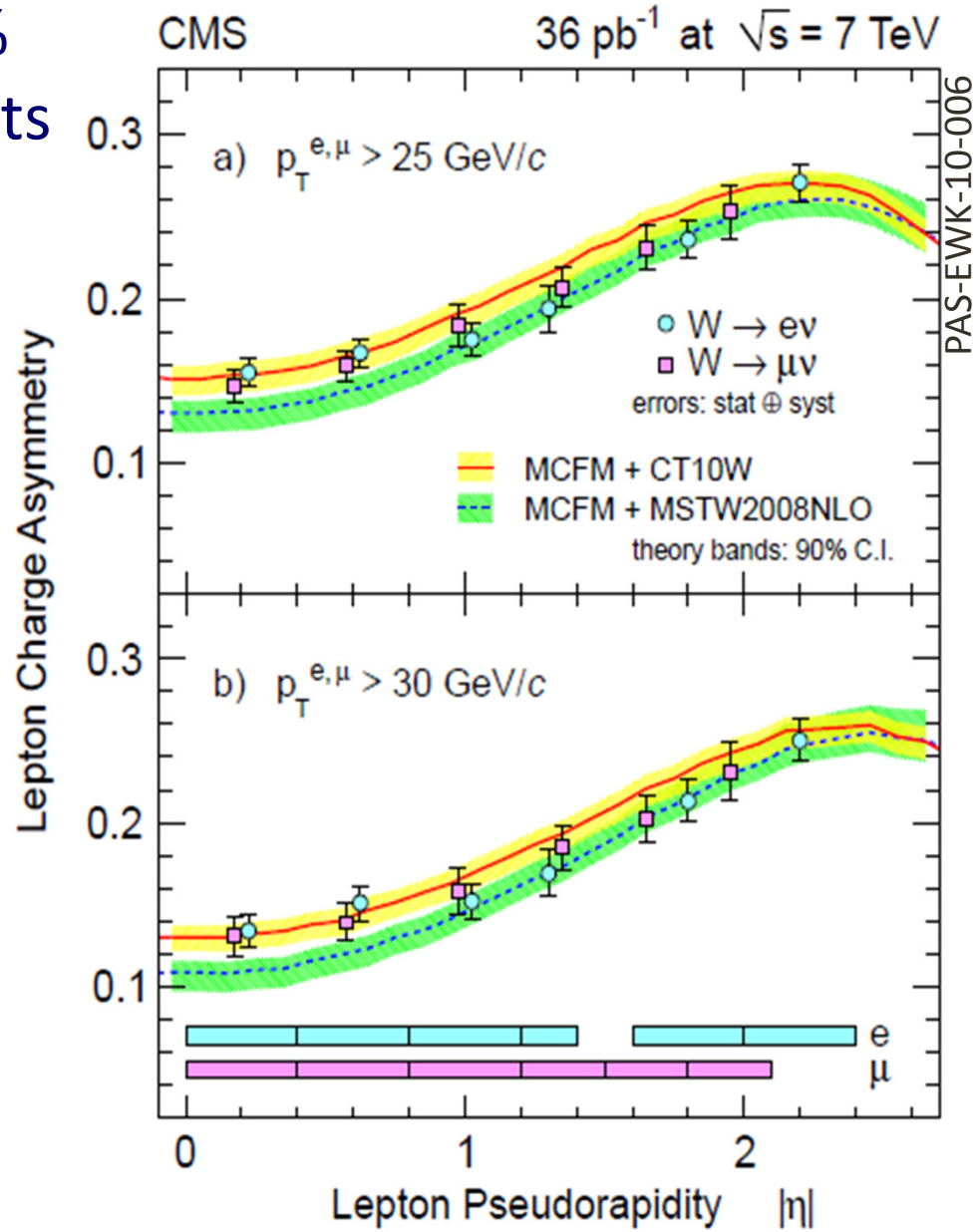
W charge asymmetry

$$u\bar{d} \rightarrow W^+ \;\; and \;\; d\bar{u} \rightarrow W^-$$

$$\frac{\sigma(W^+)}{\sigma(W^-)} = 1.43 \pm 0.05$$

Experimental quantity :

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) - d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) + d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}.$$



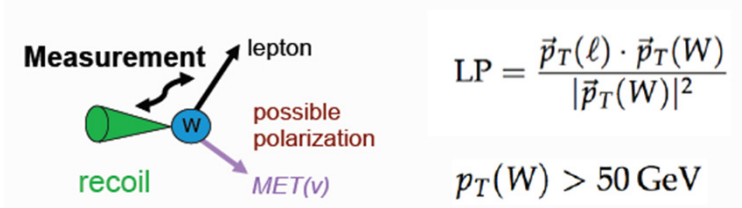
Measure W Boson Properties

Precision of xsec measurement ~1% experimental. Start to put constraints on theory (NNLO, PDFs)

Results from combined (e+mu) fits (EWK-10-014)

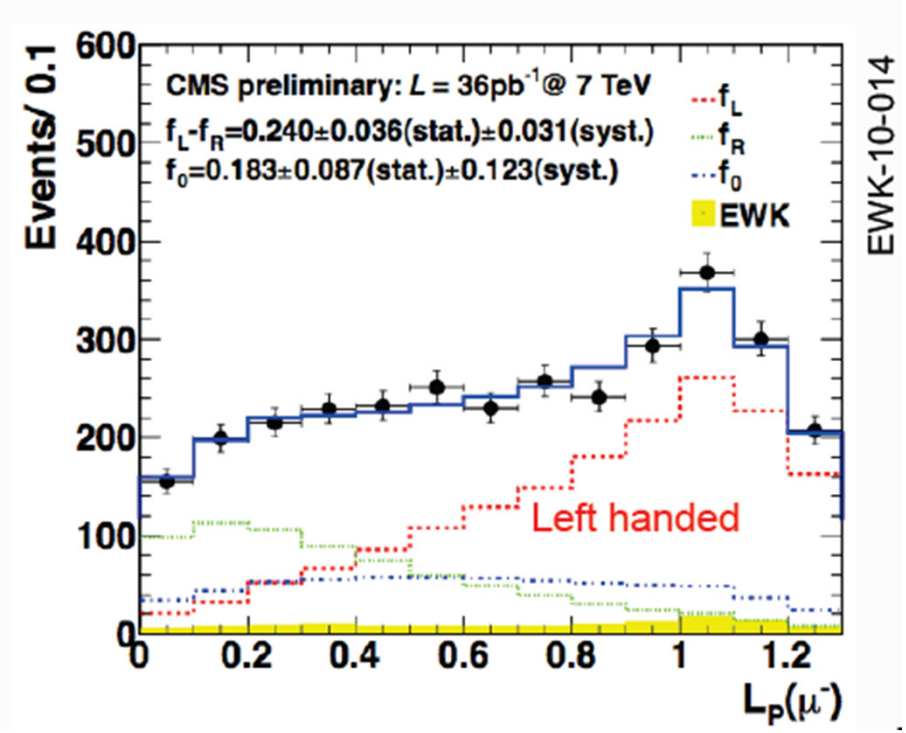
Combined: $(f_L - f_R)^-$	0.226 ± 0.031 (stat.) ± 0.050 (syst.)
Combined: f_0^-	0.162 ± 0.078 (stat.) ± 0.136 (syst.)
Correlation	0.304 (stat.), -0.326 (stat. + syst.)
Combined: $(f_L - f_R)^+$	0.300 ± 0.031 (stat.) ± 0.034 (syst.)
Combined: f_0^+	0.192 ± 0.075 (stat.) ± 0.089 (syst.)
Correlation	-0.660 (stat.), -0.121 (stat. + syst.)

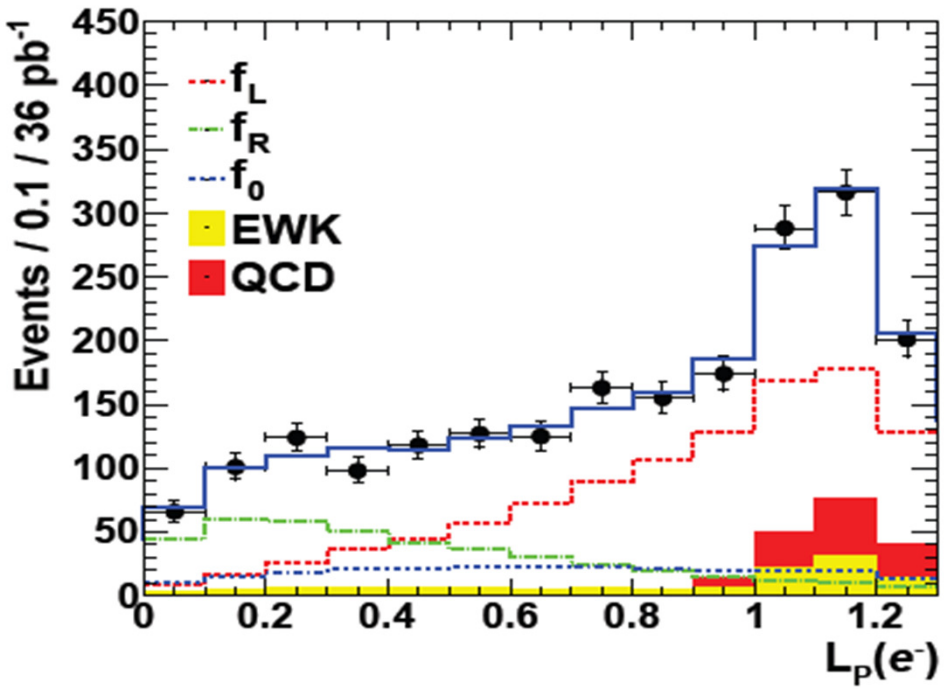
First measurement of W polarisation: both W^+ and W^- preferred left-handed as predicted by SM



$$LP = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

$$p_T(W) > 50\ \text{GeV}$$





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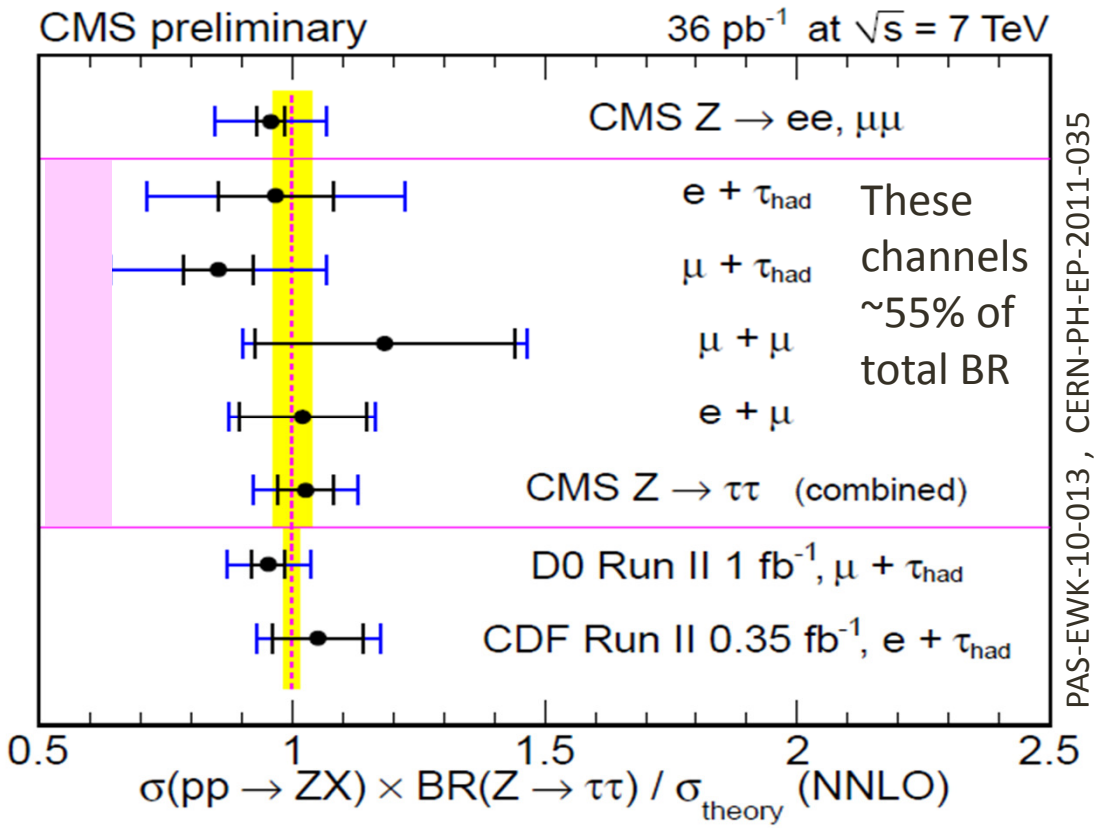
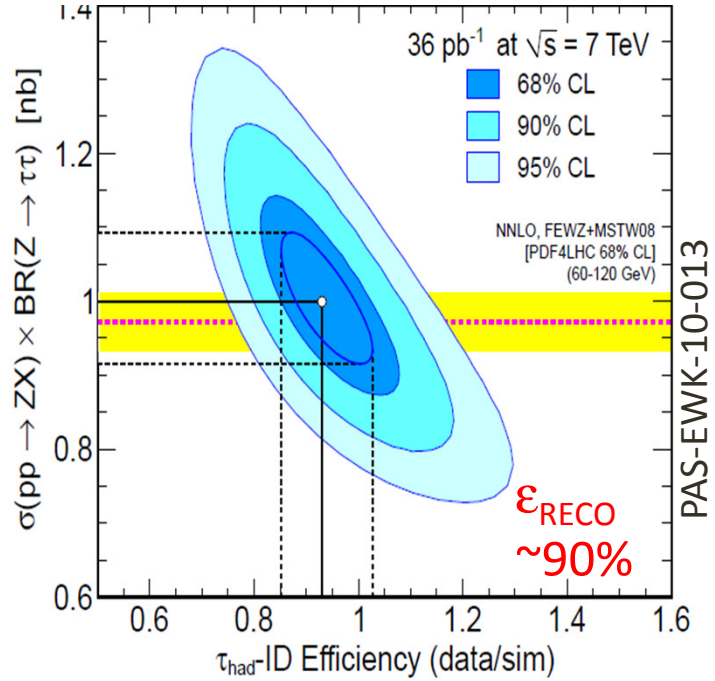
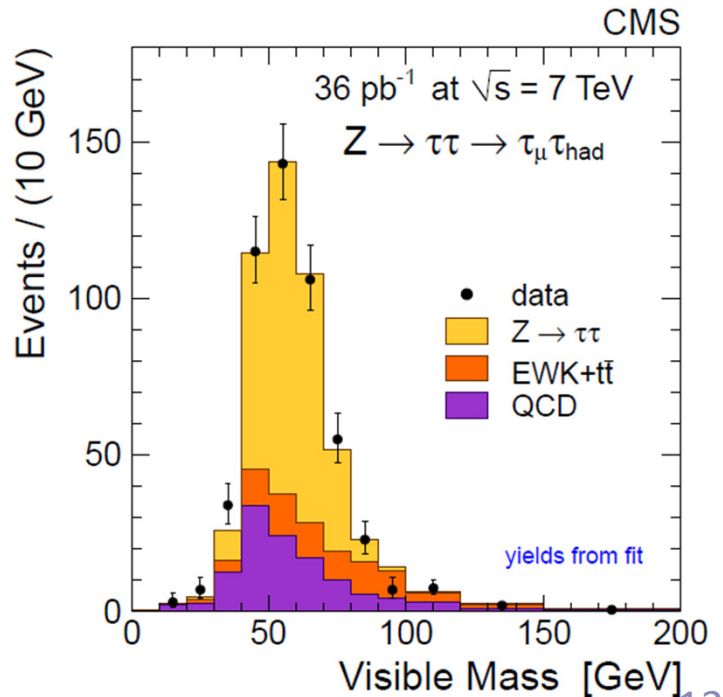
Tau Performance

- Reconstruction of individual decay modes of tau leptons based on particle flow
- Inclusive measurement of $Z \rightarrow \tau\tau$. Also $W \rightarrow \tau\nu$



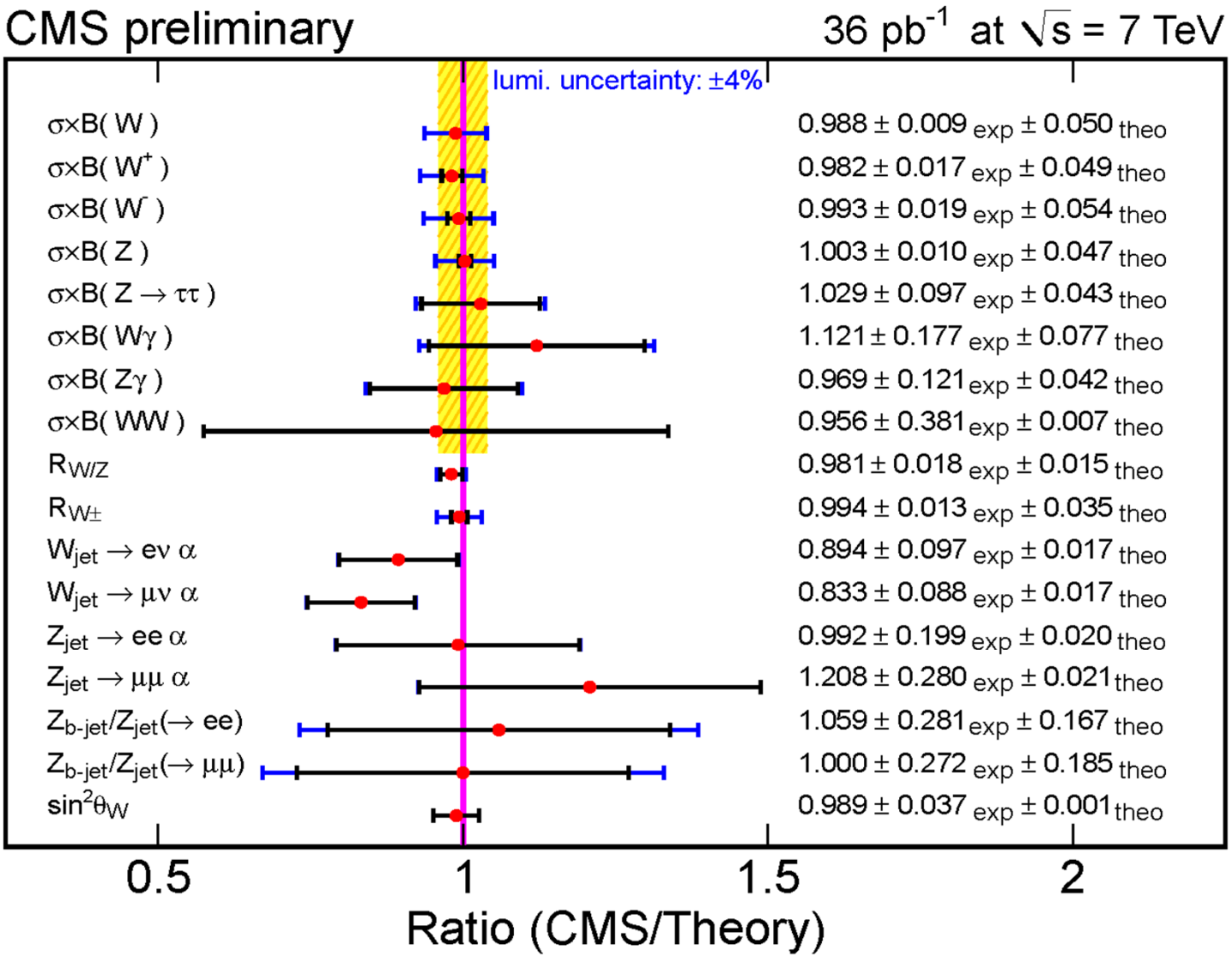
Combined results in the σ×B versus τ-ID-efficiency plane





- Established tau as an important tool for many analyses, **in particular Higgs**

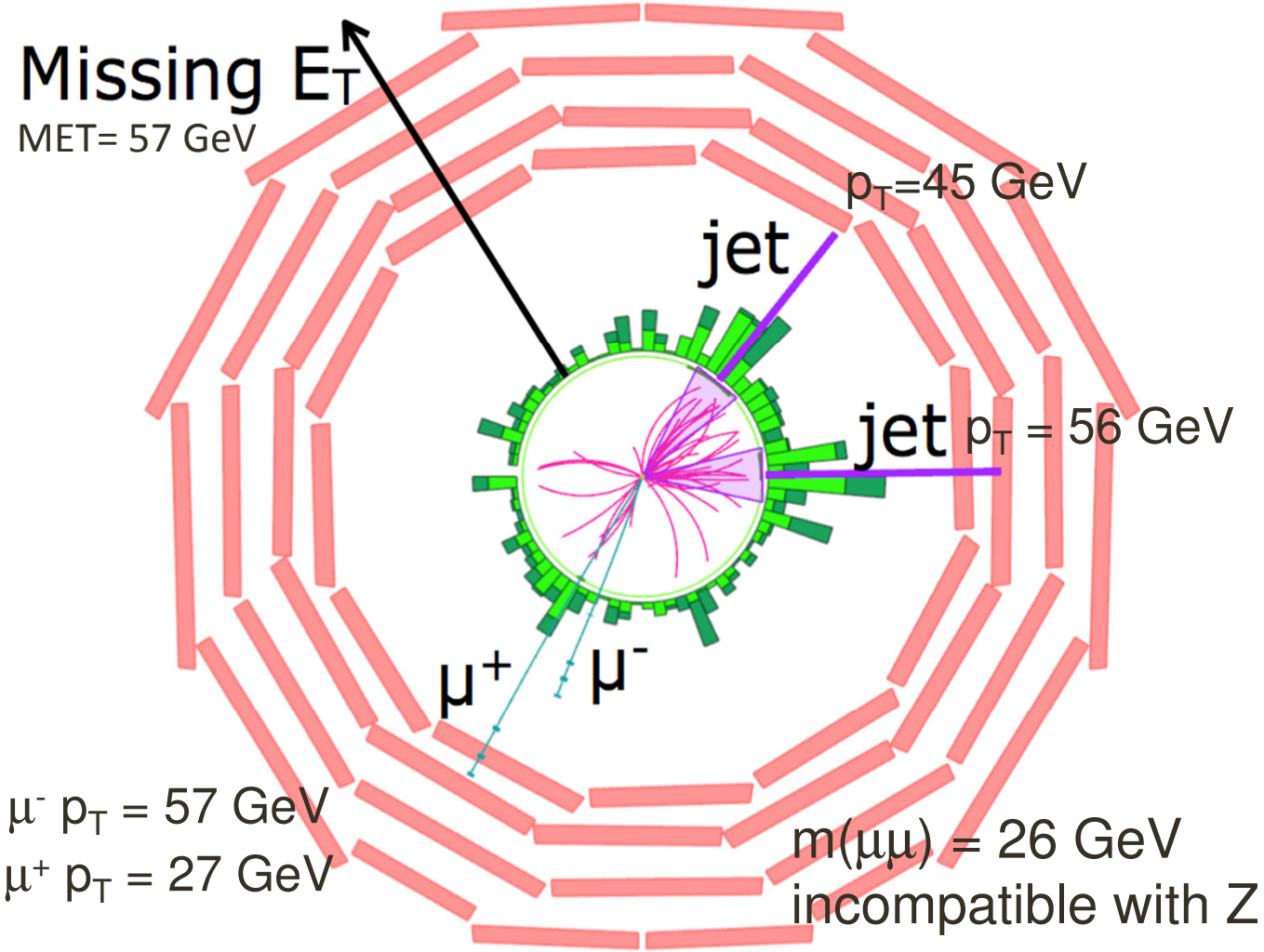
Summary of SM Measurements



Standard Model at 7 TeV

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEWK

Observation of Top Quark Candidates



Top Di-Muon Candidate Event

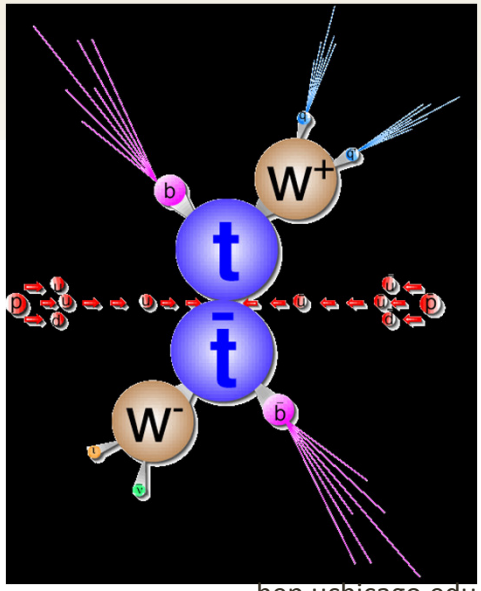
This example: 2 opposite sign muons + jets + large MET

Several final states used for top cross section and mass measurement:

- Dilepton
- Lepton + Jets
- Lepton + Jets + b-Tag

Needs good understanding of **all physics objects**

Measuring Top Events



hep.uchicago.edu

Top quark topologies use most physics objects

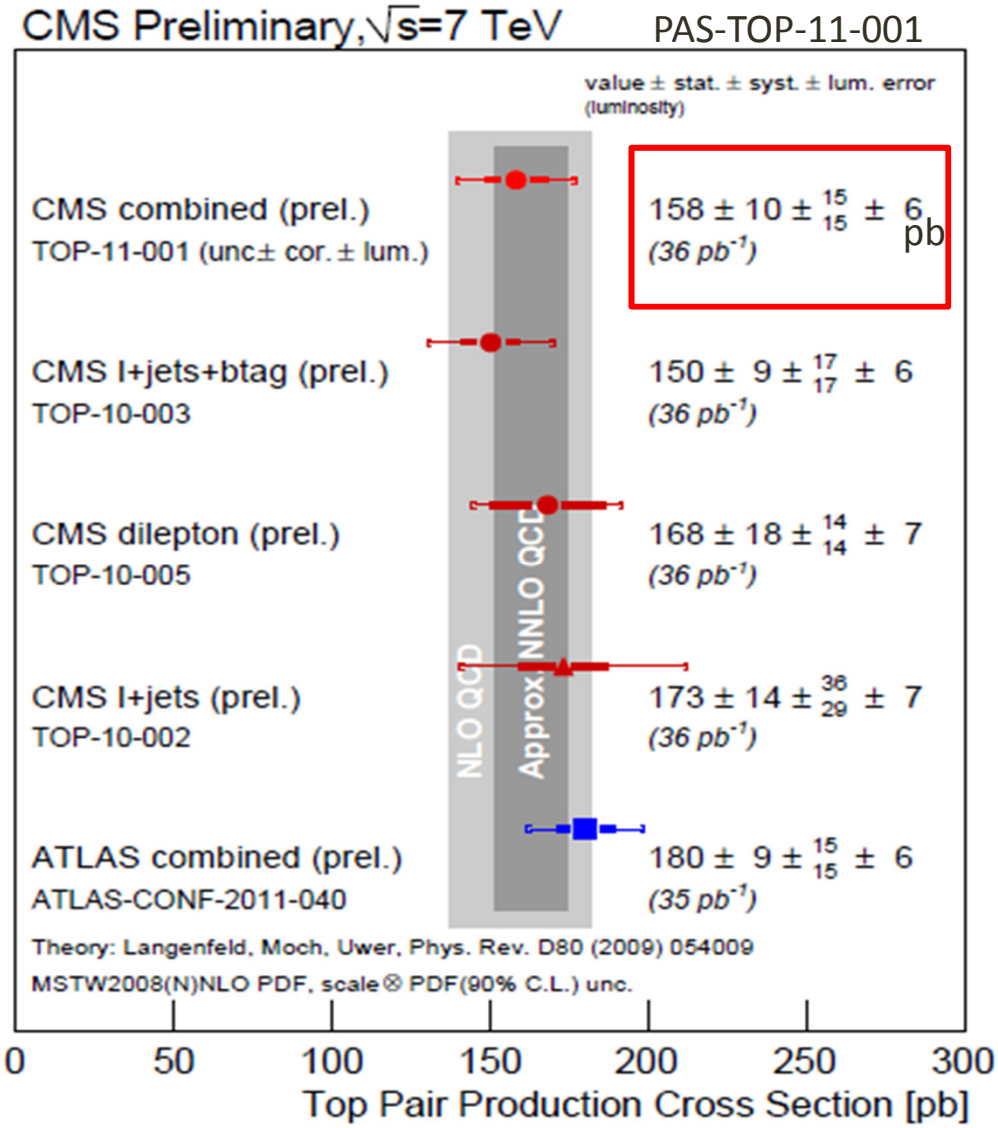
- **Leptons**
  - Excellent momentum measurement for e, μ
  - Isolation (to reject QCD), conversion rejection for e
  - Tau Leptons: good efficiency & low fake rate
- **Jets and Missing ET**
  - Multi-jet topologies (up to 6 in hadronic channel)
  - Precise event kinematics
  - MET resolution for QCD rejection and top mass reconstruction
- **Reconstruction of primary and secondary vertices (b-tagging)**
  - Efficient identification of the 2 b-jets
  - Pile-up

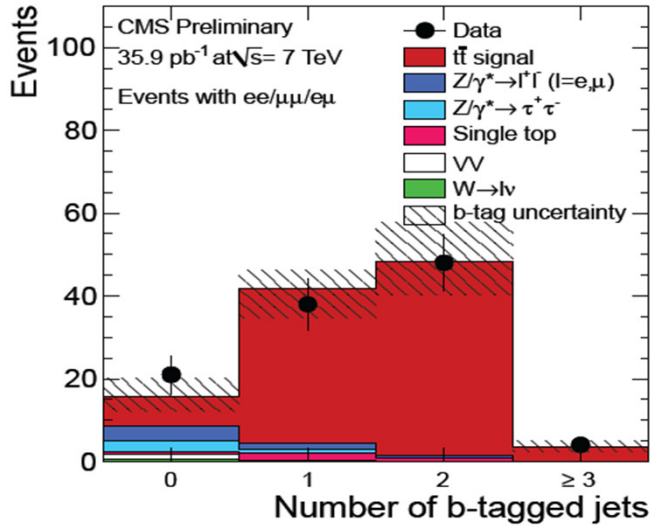
Systematic uncertainties usually dominated by

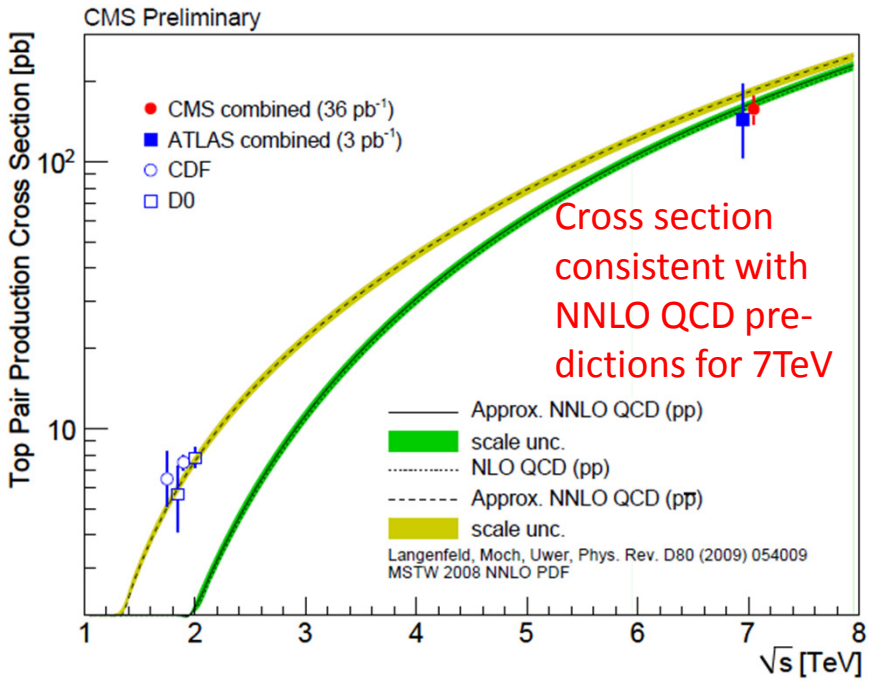
- Jet /MET energy scale, b-tagging efficiency, W+jets Q^2-scale
- Most relevant gain of Particle Flow (PF) for analysis: jets & MET

Measured Top-Pair Cross Section

Divide sample into distinct categories: # jets, # b-tags, electrons, muons







Syst. uncertainty (in total 11%) dominated by JES (3.1 GeV) and b-JES (2.5 GeV)

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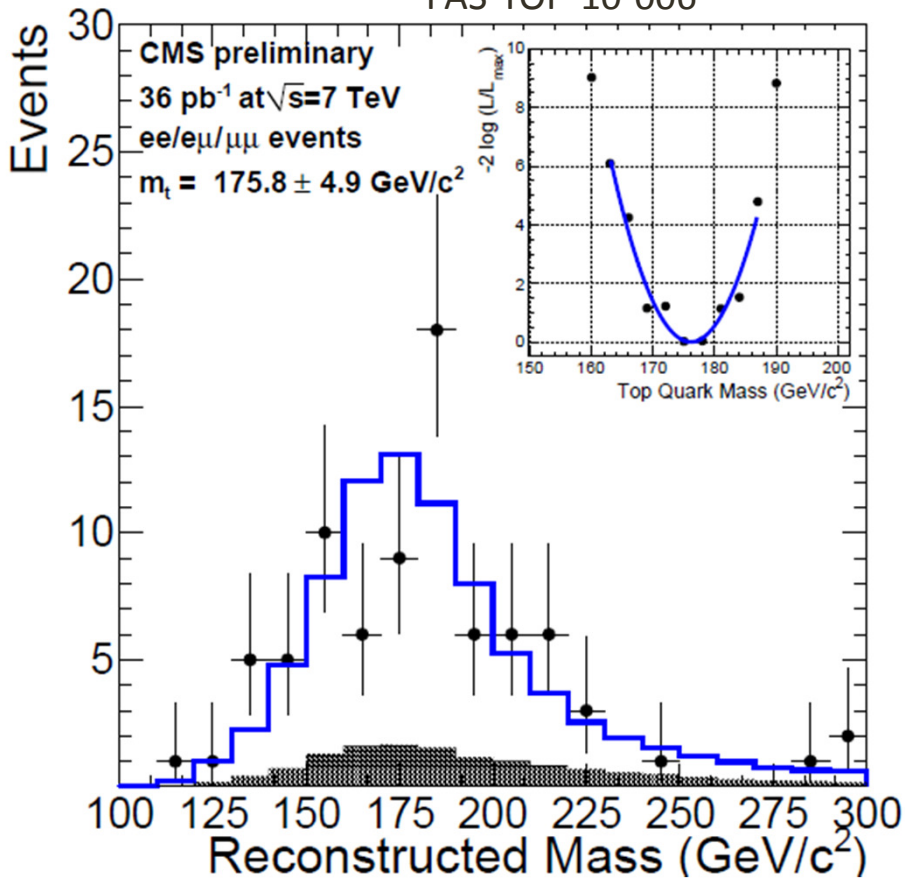
Measured Top Mass

In dilepton ttbar events and single top analysis

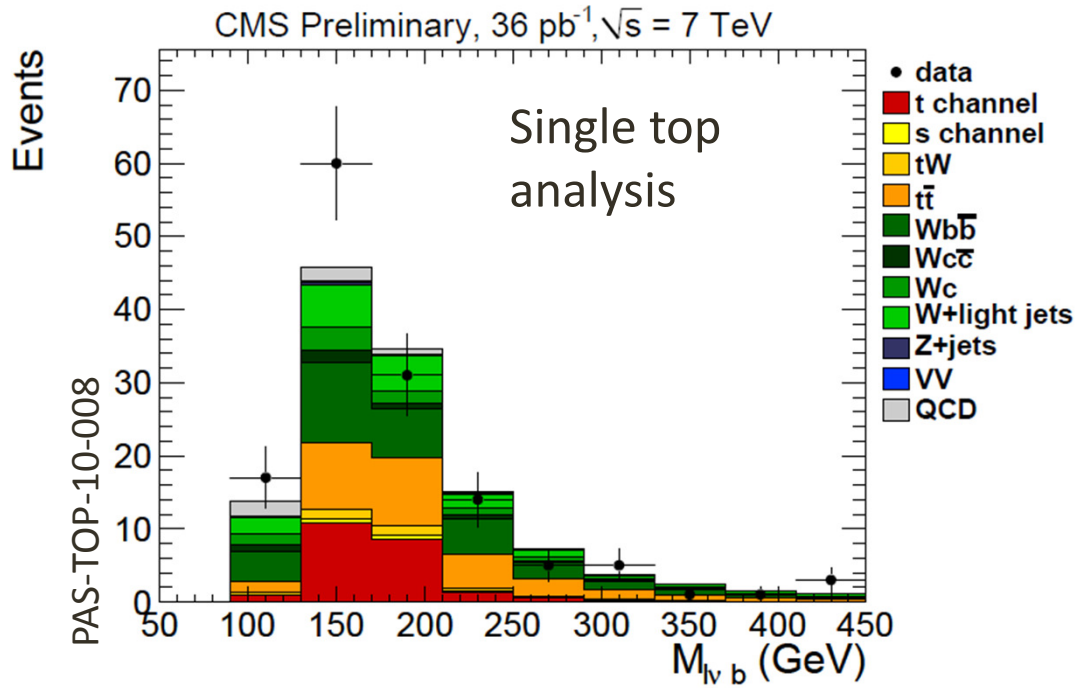
PAS-TOP-10-006



Reconstructed mass in dilepton decay channel

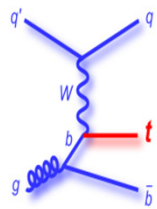
Two methods in dilepton ttbar analysis:

- Full kinematical analysis
- Matrix element weighting technique



Reconstructed top mass mu channel single top

Single Top

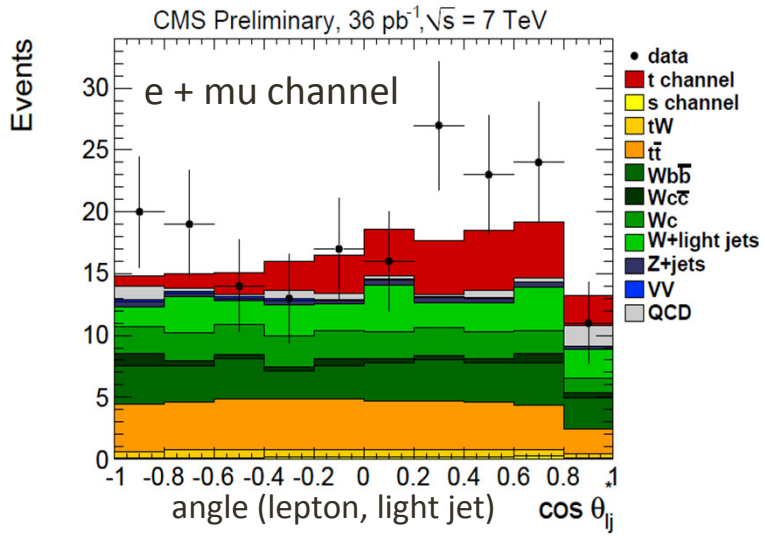


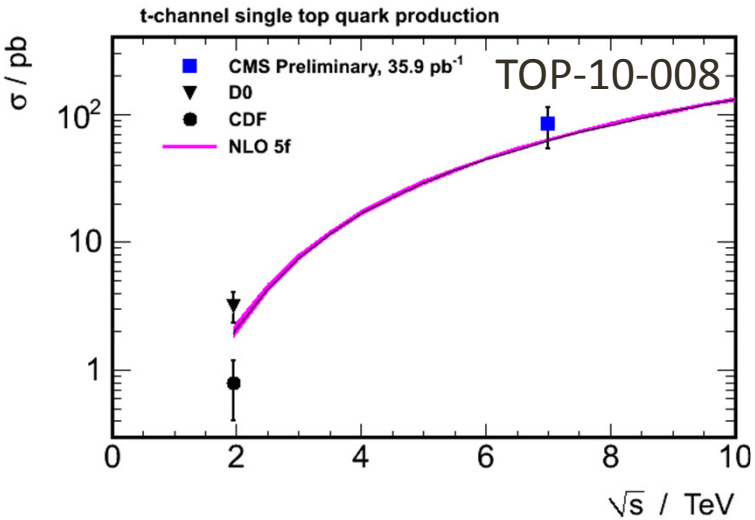
First observation of single top at the LHC

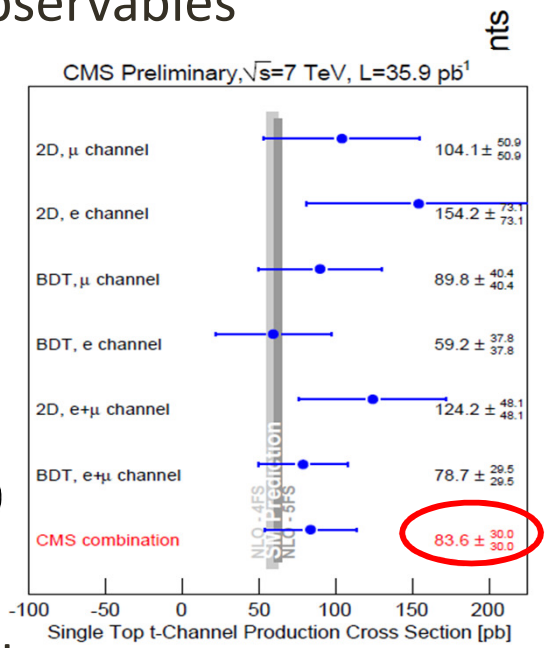
- about 20x higher than at the Tevatron.

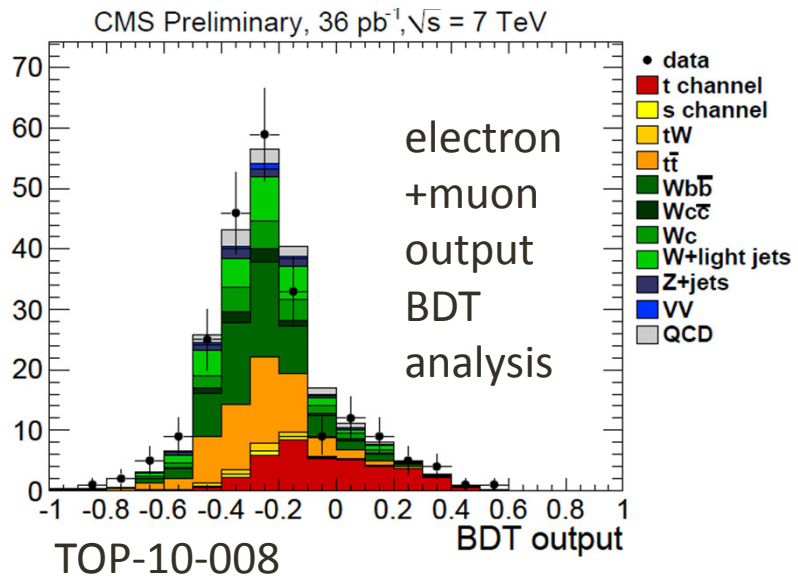
Using leptonic channels and two methods

- Cut based analysis, shape fit for angle (lepton, light jet) in top restframe and eta(lightjet)
- BDT, based on kinematic observables









xsec t-channel: ~63pb,
s-channel: ~ 5pb, tW: ~11-15pb

Example of finding a tiny signal. Showing the readiness for challenging searches such as low mass Higgs

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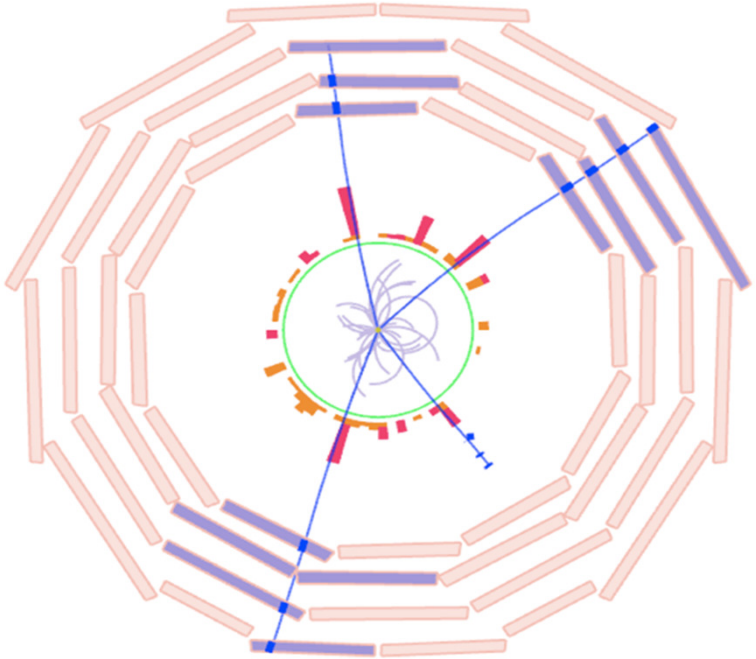
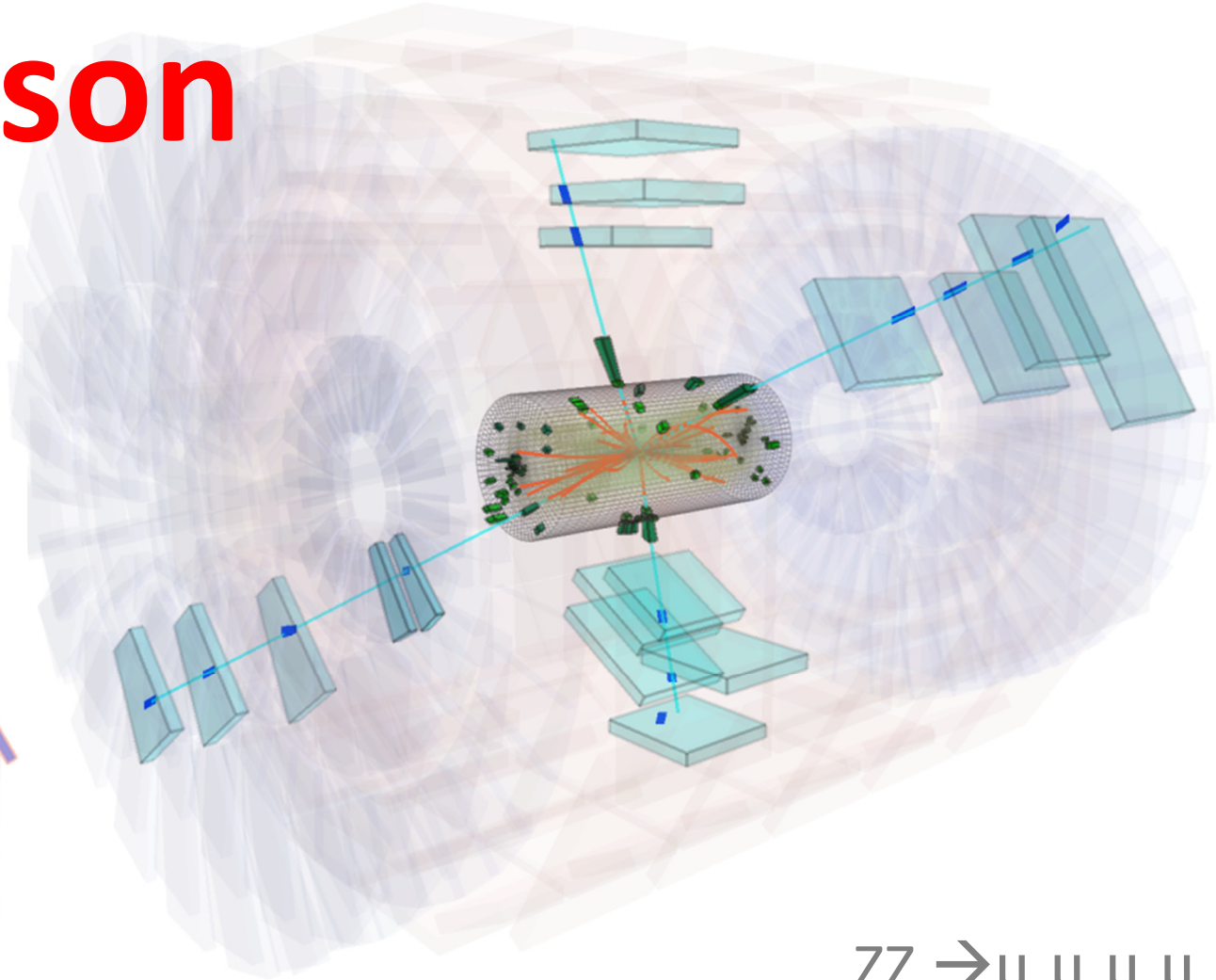
Prospects for the SM Higgs Boson

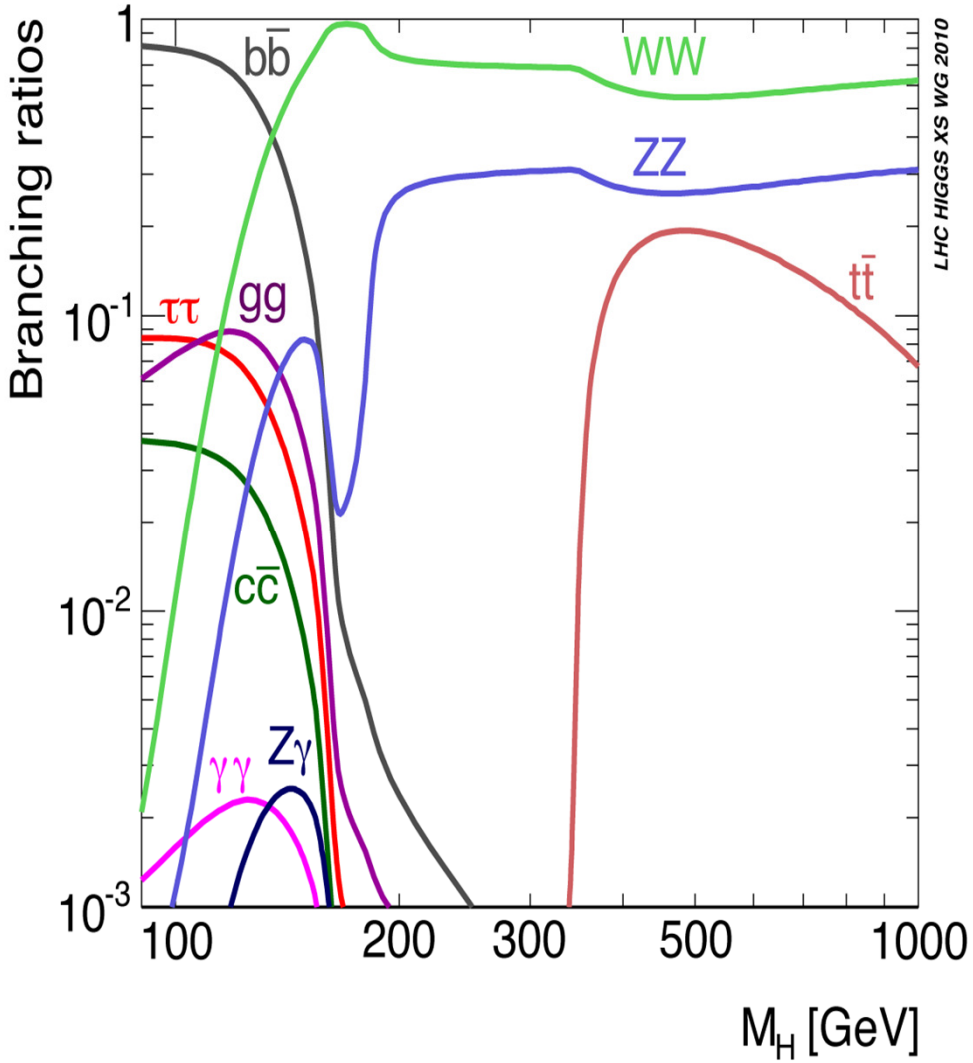




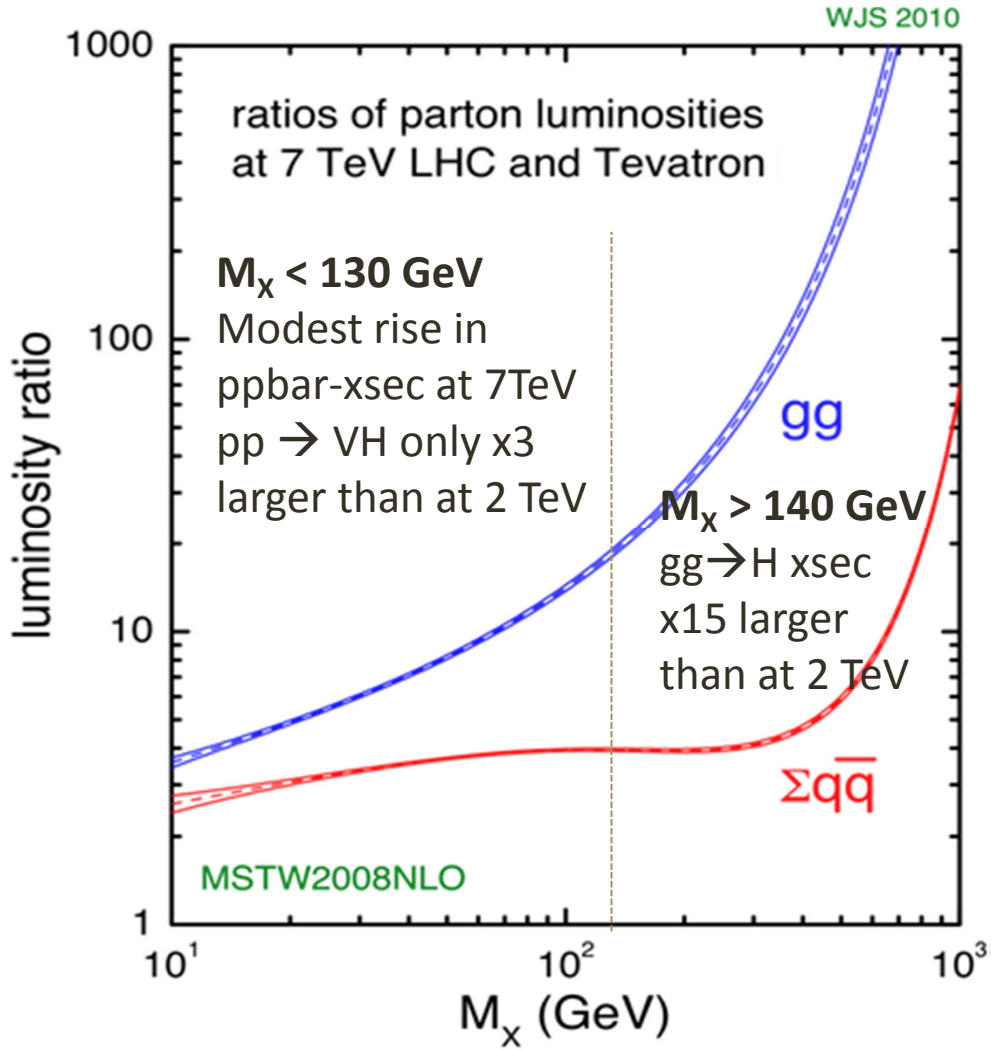
$ZZ \rightarrow \mu\,\mu\,\mu\,\mu$

Prospects for the Higgs Boson at LHC

Suitable decay channels depend on Higgs mass



Gain in production cross section at pp collider with 4x higher CM



Search Strategy for SM Higgs: Combination of Channels

Efficient Higgs search requires many physics objects: photons, electron and muons, taus, b-tagging, jets, MET (already working for single top)

Channels included	≈ Mass range (GeV)	Status, Comments
H→ γγ	**115-150**	Challenging.
VBF H→ ττ	**115-145**	Results with 2010 data. Breaking new ground
VH, H→bb (highly boosted)	**115-125**	
VH, H→WW→lνjj	**130-200**	Results with 2010 data. Work horse for 120-200 GeV, large yield
H→WW→2l2ν + 0/1 jets	**120-600**	
VBF H→WW→2l2ν	**130-500**	
H→ZZ→4l	**120-600**	The golden channel. Low bkgr but low yield
H→ZZ→2l2ν	**200-600**	Major bkgr is diboson and top. Profits from jet, MET reco and good b-tagging
H→ZZ→2l2b	**300-600**	

A First Look for the Higgs

Results with 36/pb for $H \rightarrow WW$, $H \rightarrow \tau\tau$, $H^+ \rightarrow \tau^+\nu$, $H^{++} \rightarrow \ell^+\ell^-$

Background studies for xsec of $pp \rightarrow WW$, $pp \rightarrow Z \rightarrow \tau\tau$ and $\gamma\gamma$ rate

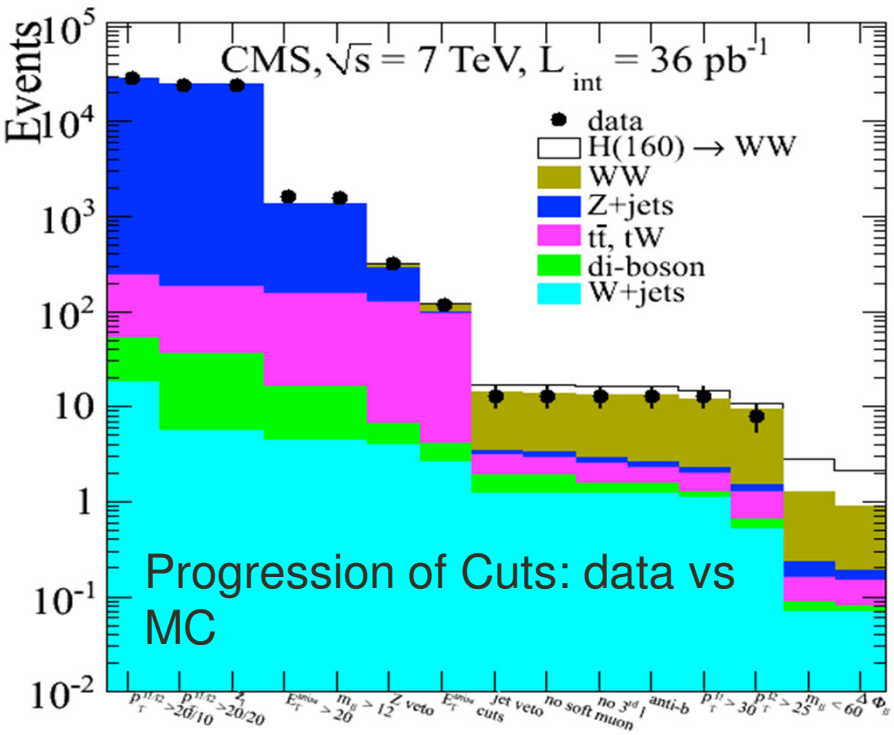
$H \rightarrow WW$ http://arxiv.org/abs/1102.5429

Higgs search used 2 counting methods:

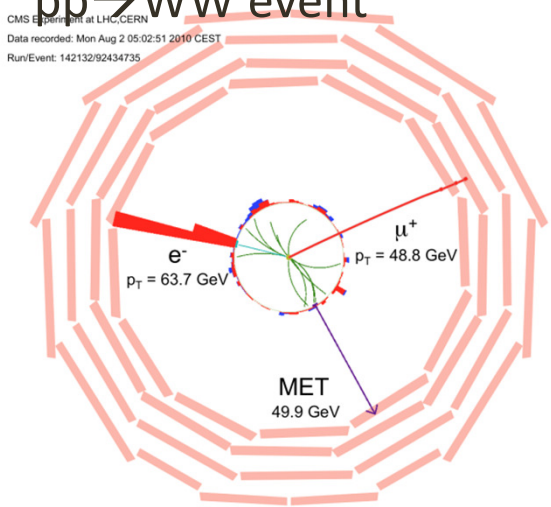
- Cut on kinematic observables
- Cut on a BDT output & count
  - 15% higher eff for same bkgnd

From 13 observed events passing $pp \rightarrow WW$ cut-based selection, measure:

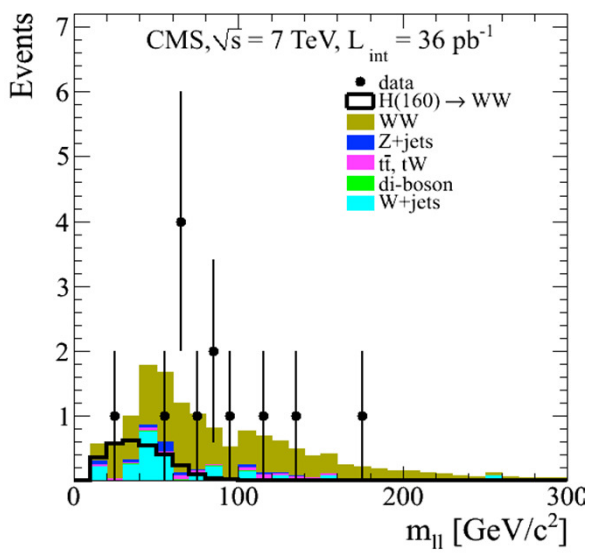
$$\sigma(pp \rightarrow WW) = (41.1 \pm 15.3 \pm 5.8 \pm 4.5(lumi))\ \text{pb}$$



pp→WW event

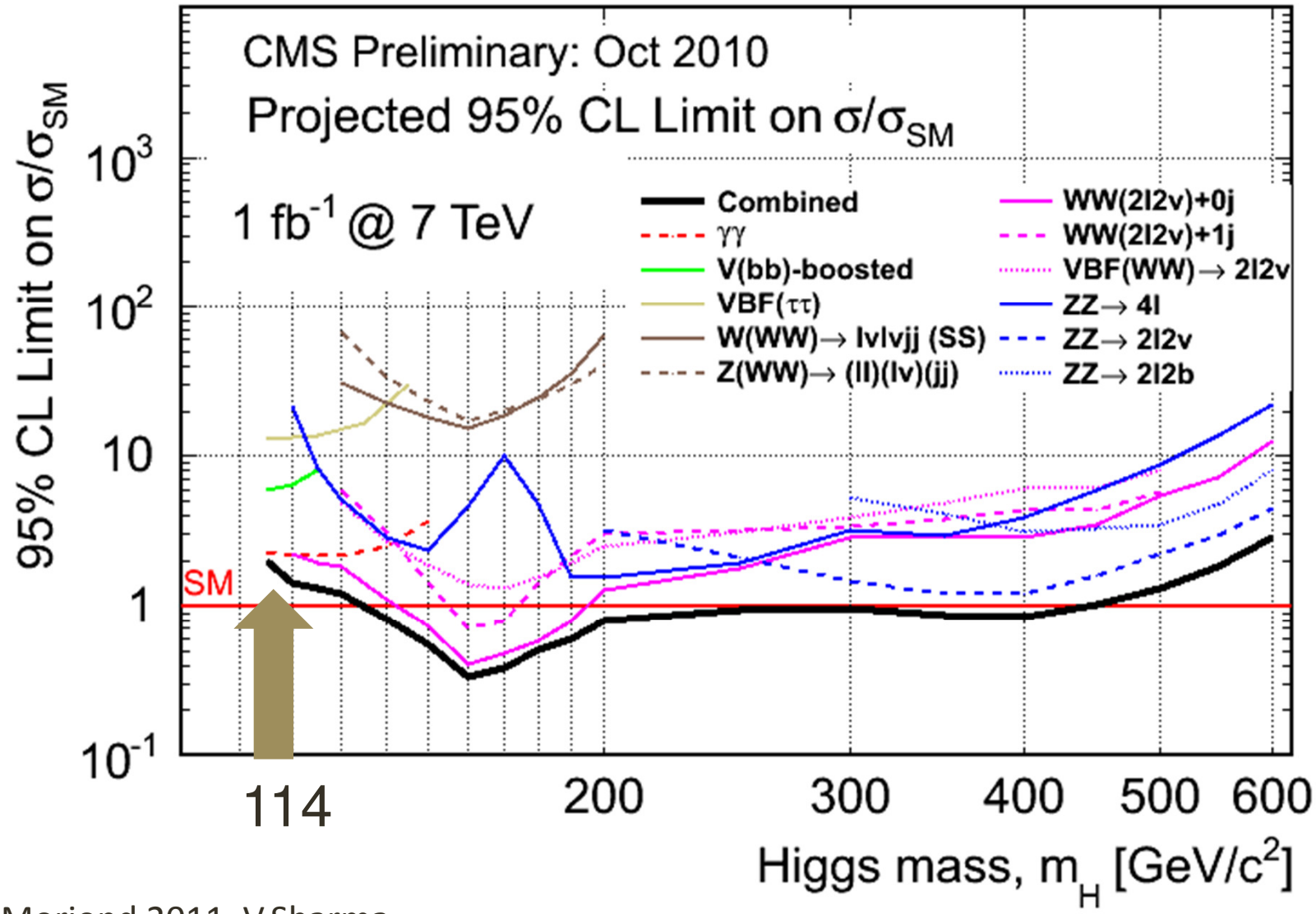


Dilepton inv. mass



Projected Exclusions with 1fb^{-1}@7 TeV

LEP M_H>114 GeV Tevatron 158 < M_H<173 GeV



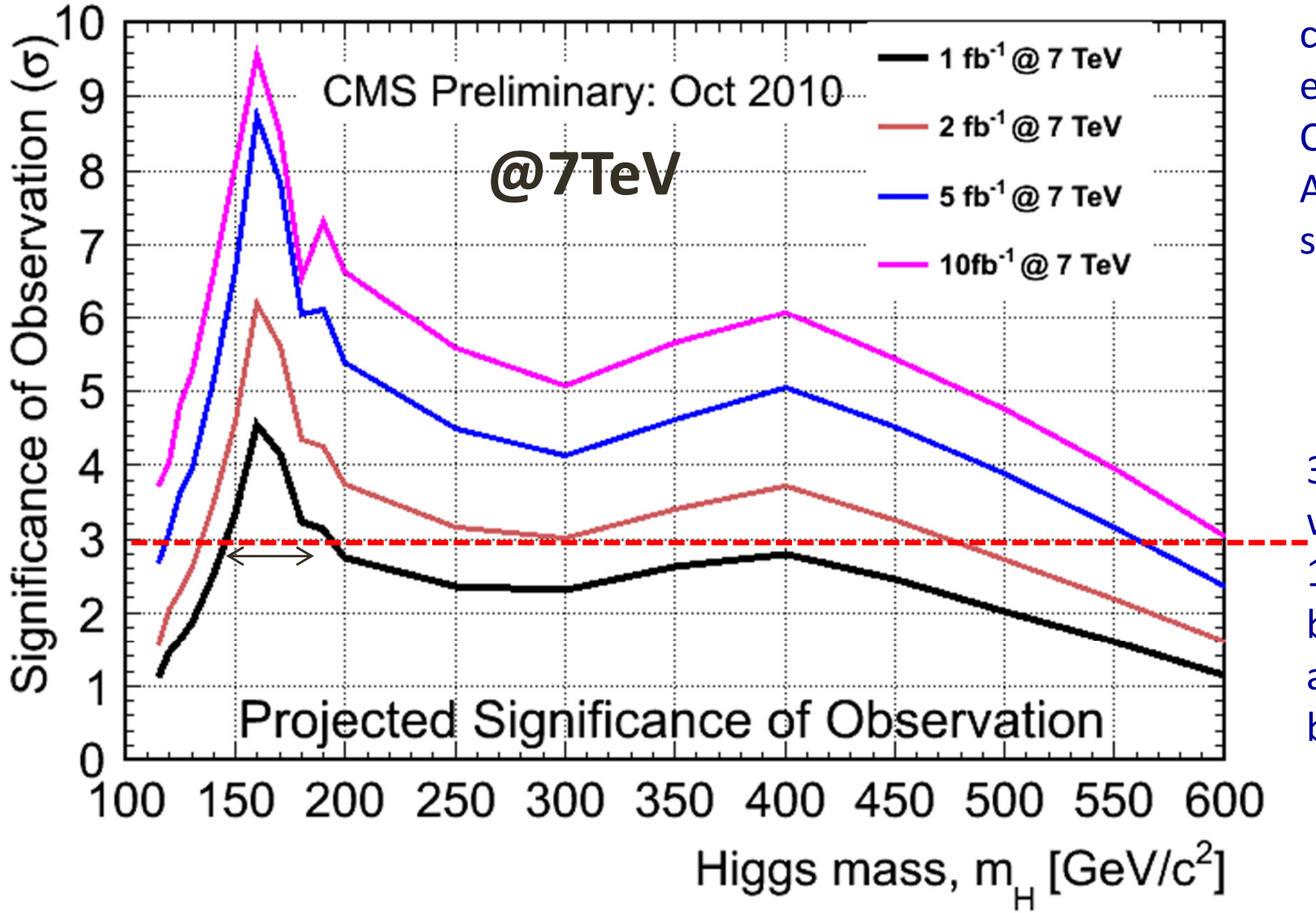
Combination of many channels would just allow to exclude a wide mass range 130<M_H<450GeV

Below 130GeV extremely challenging. Needs H→γγ

Moriond 2011, V.Sharma

Projected Observation Significance

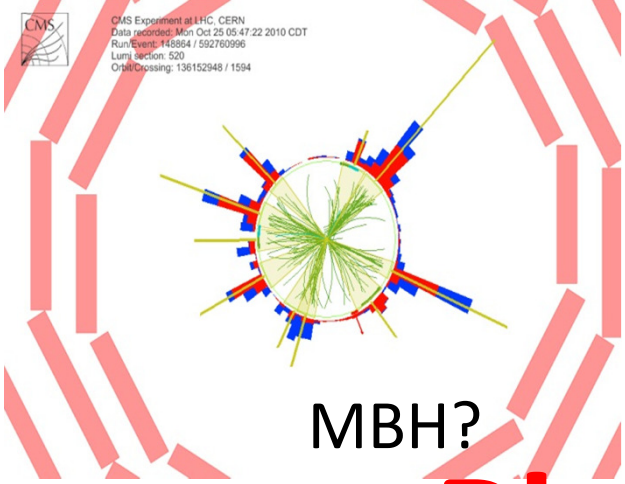
LEP M_H>114 GeV Tevatron 158 < M_H<173 GeV



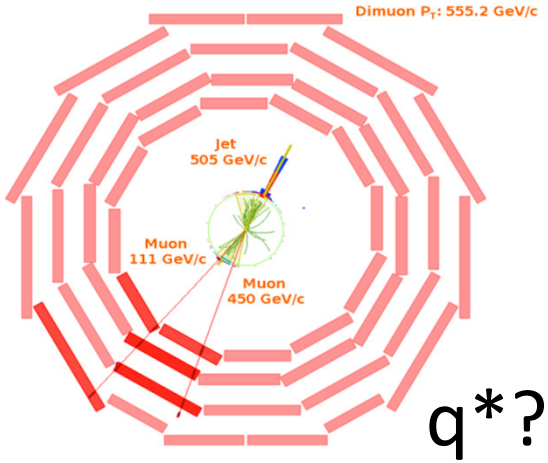
Observation very challenging for one experiment. Combination effort ATLAS + CMS has started

3σ can be reached with 2/fb for 150<M_H<470GeV but partially already excluded by Tevatron

Moriond 2011, V.Sharma

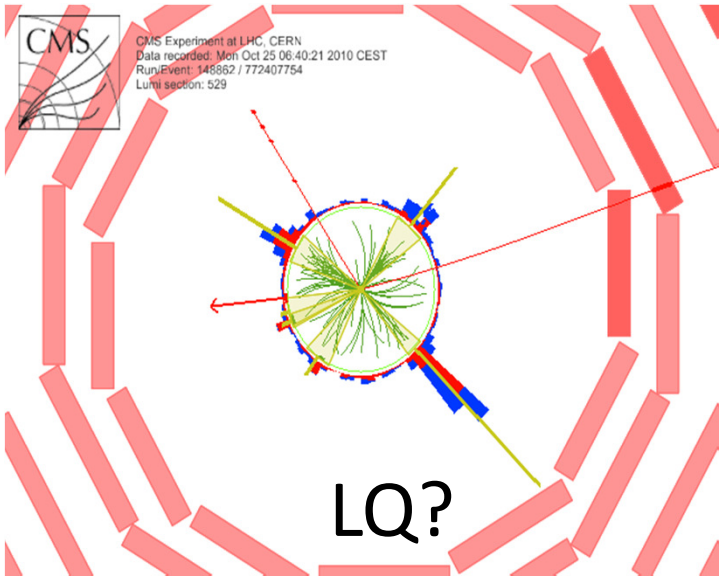


MBH?

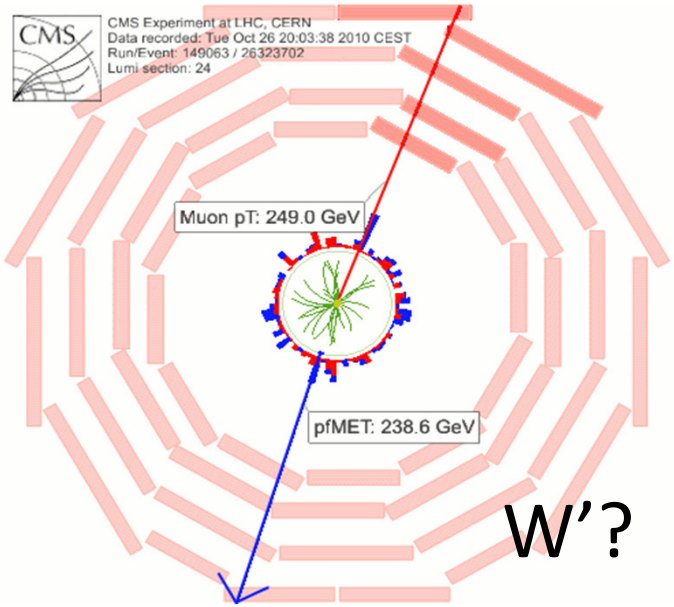


q*?

Physics Beyond the Standard Model



LQ?



W'?

About 30 searches, see:

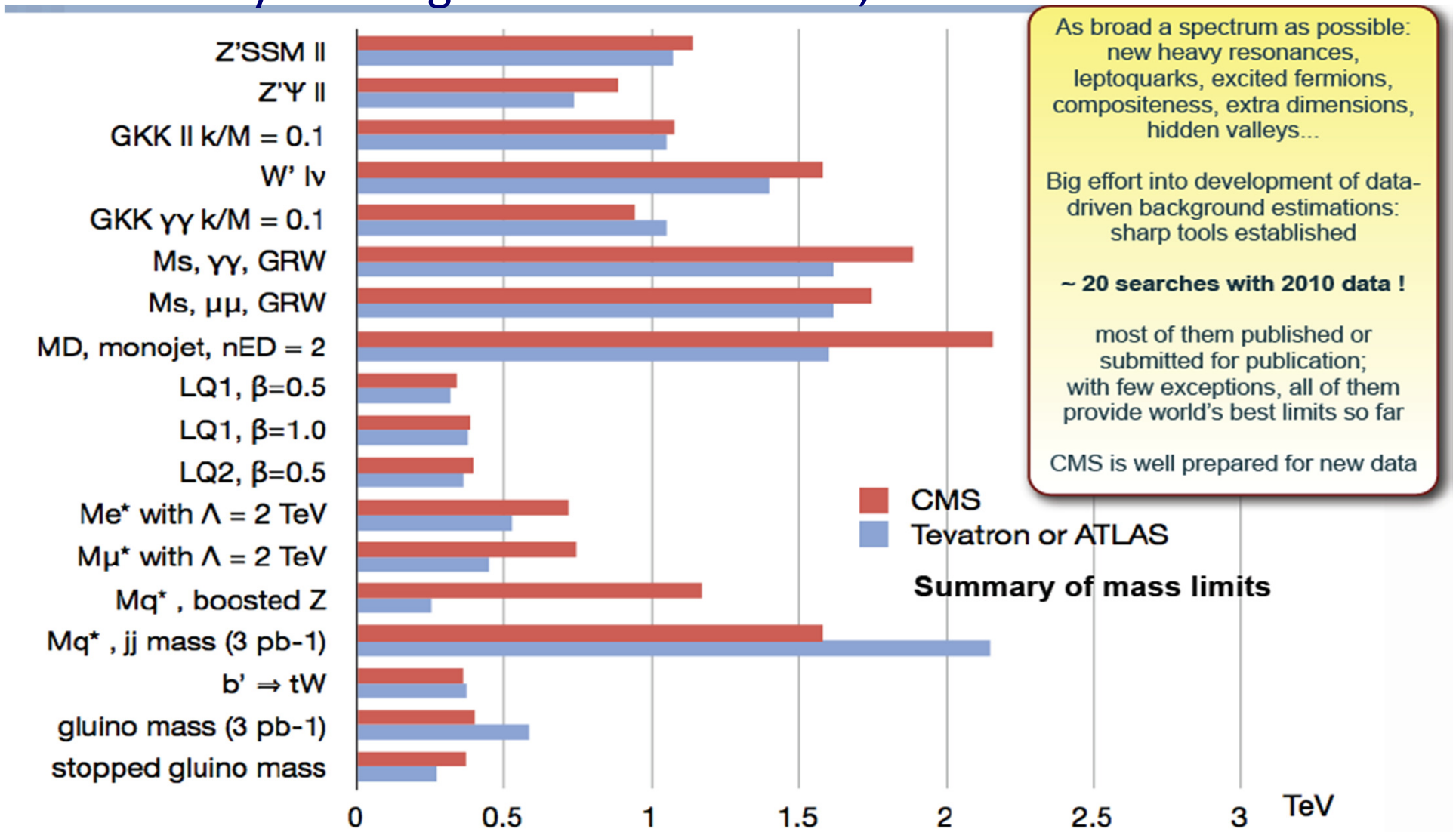
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

New Particle Searches in Full Swing

LHC is a discovery machine!

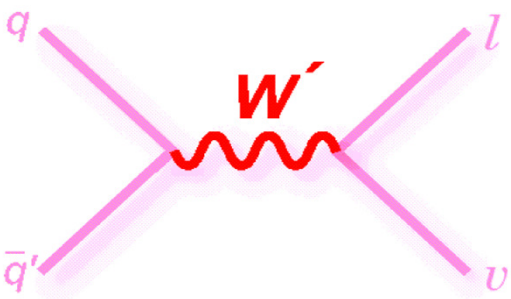
With 2010 data set CMS performed ~20 searches for new particles.
Unfortunately nothing found ☹ Set limits, most of them worlds best.



K.Hoepfner, CMS coll., DIS conference 2011

Search for Heavy Vectorbosons W'

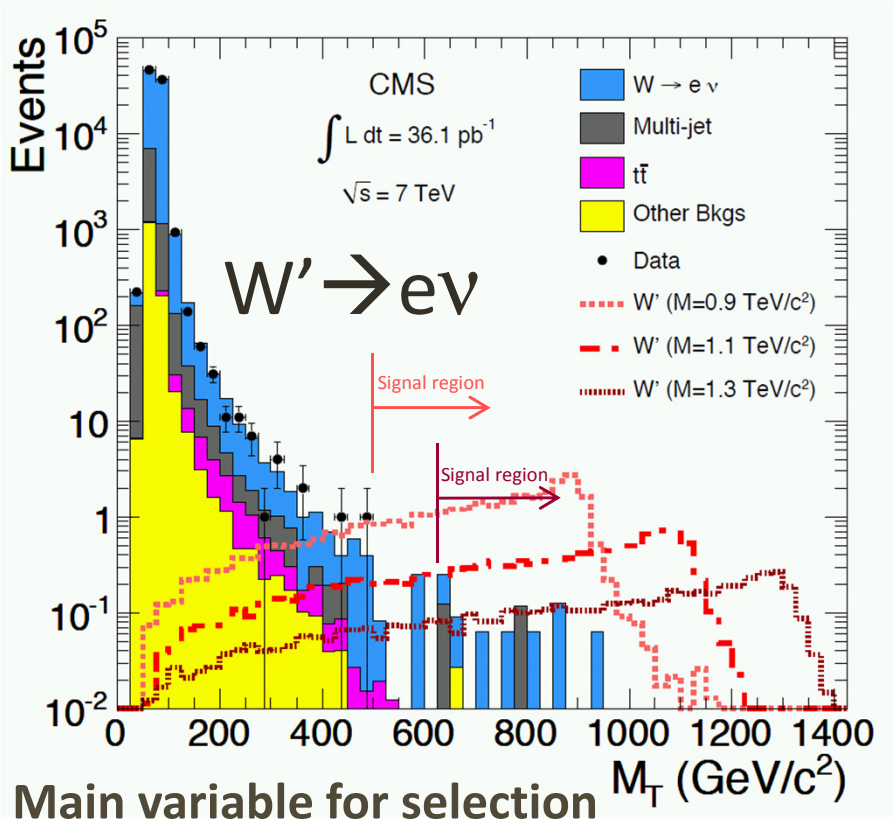
arXiv:1103.0030 (hep-ex) arXiv:1012.4945 (hep-ex)



Reference model

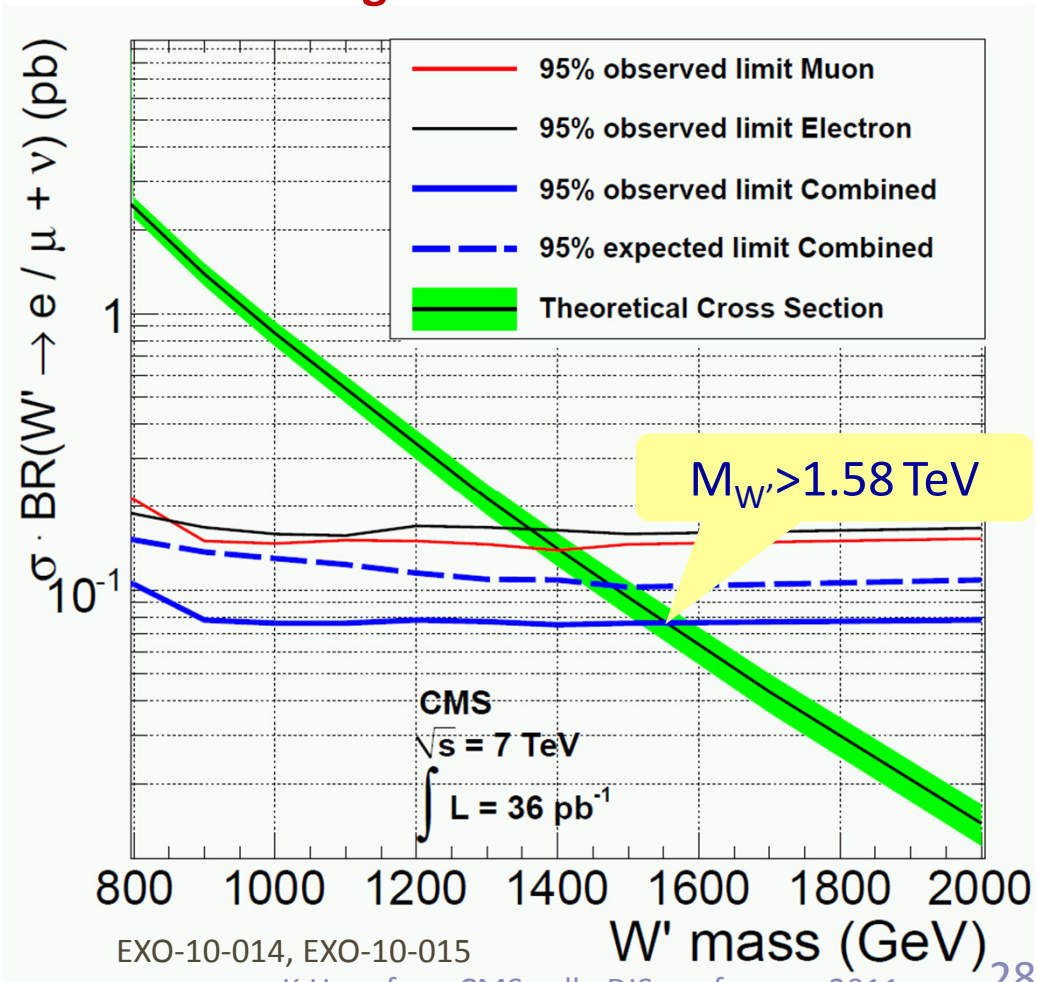
- W' has W-like fermionic couplings
- W' does not couple to other gauge bosons

Experimental limit before LHC = 1.1 TeV (FNAL, W'→e ν)



Main variable for selection = transverse mass M_T

World's best exclusion limit when combining electron + muon channels



EXO-10-014, EXO-10-015

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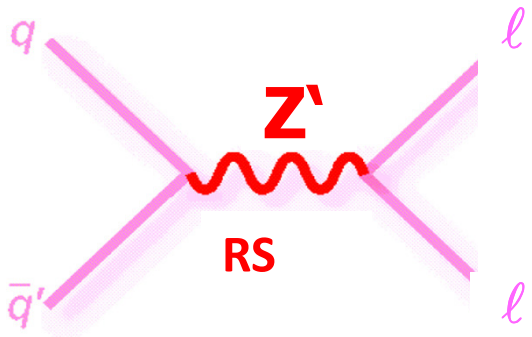
New Di-lepton Resonances

arXiv:1103.0981 (hep-ex)

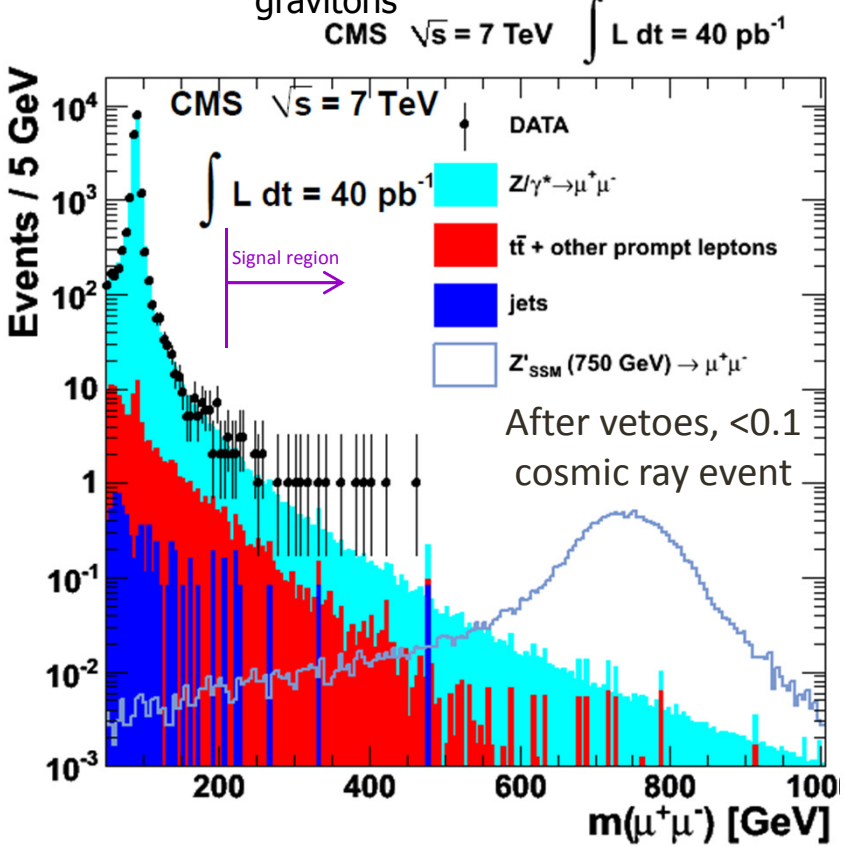


Experimental signature: Two isolated electrons, or two isolated, opposite sign, muons

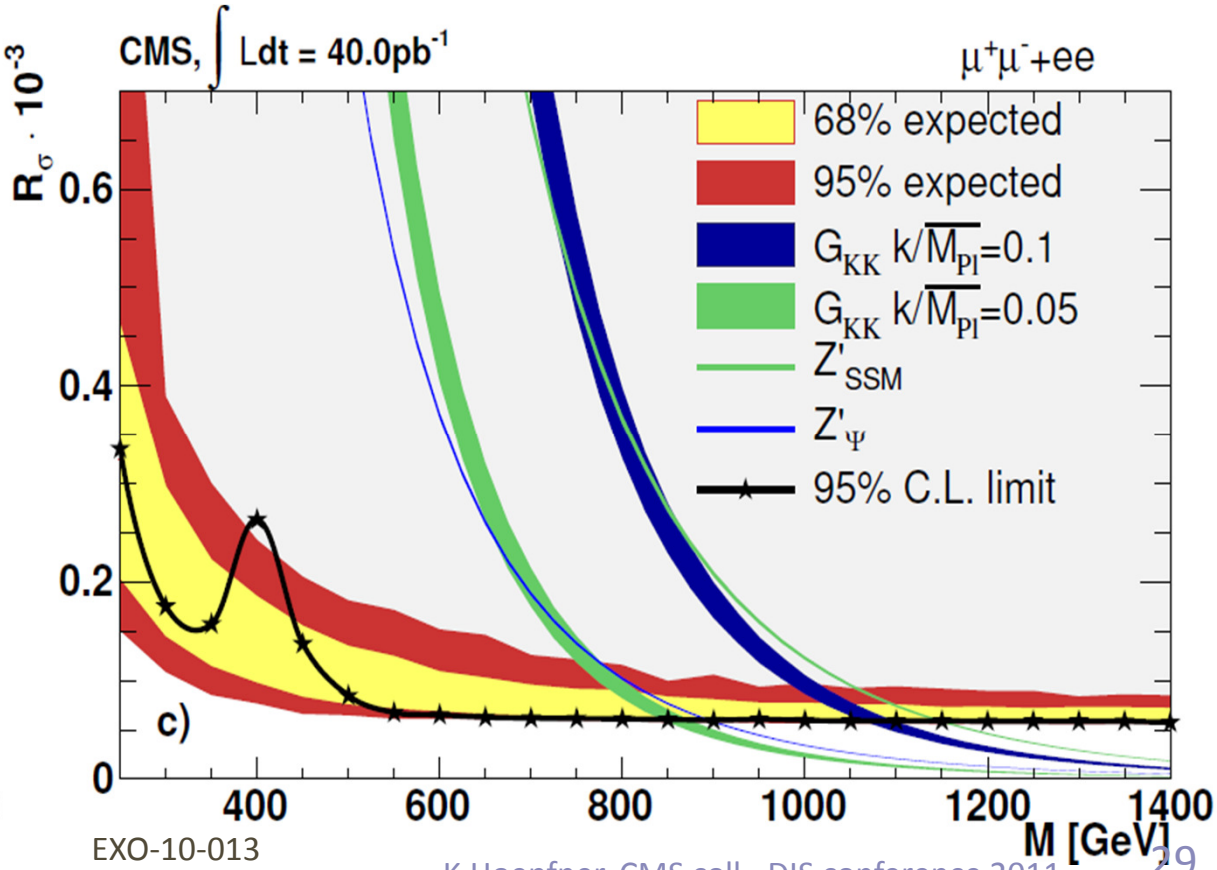
Extrapolation systematics: NNLO k-factor and PDFs

Details of statistical inference have little effect since M> 465GeV, no events & little background expected

Exp. Z` limit = 700-100 GeV depending on model (FNAL), 900 GeV for RS gravitons



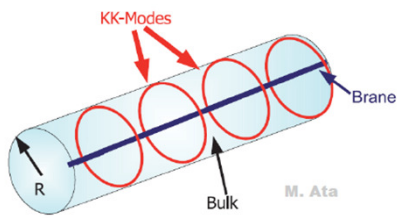
After vetoes, <0.1 cosmic ray event



EXO-10-013

Searches for Large Extra Dimensions

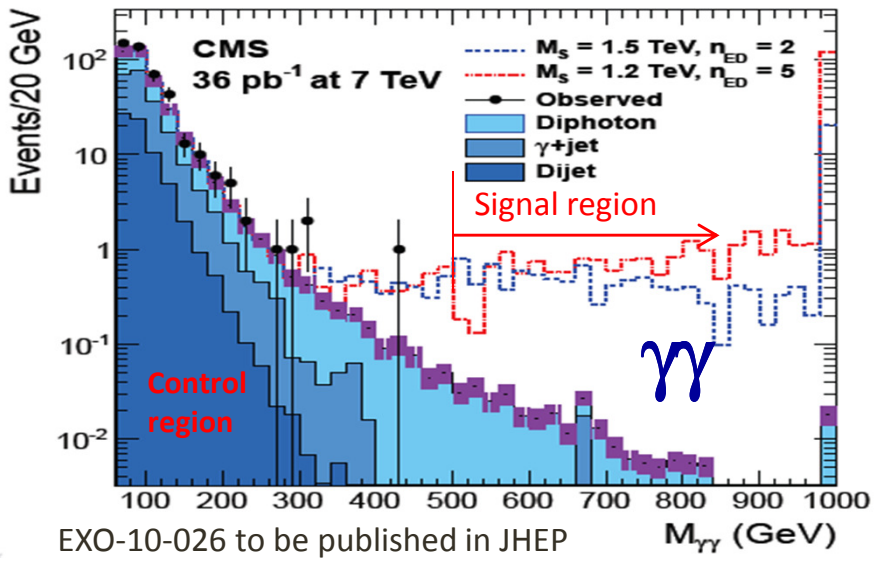
Large Extra Dimensions, ADD (Arkani-Hamed, Dimopoulos, Dvali) [*Phys. Lett. B 429 (1998) 263*], results in an effective field theory



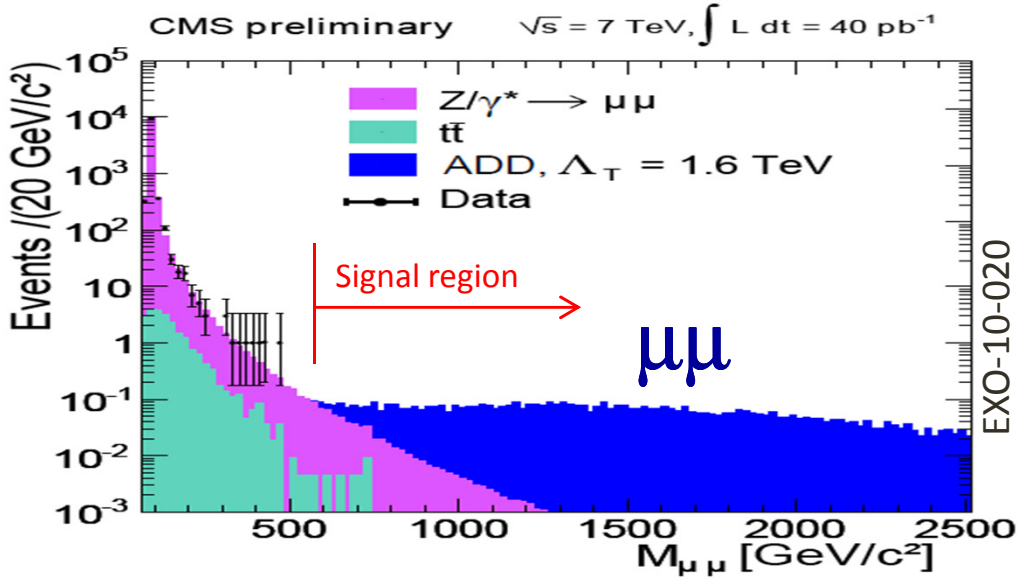
- SM is constrained in 3+1 dimensions
- Gravity propagates through entire multidimensional space and its strength is diluted -> fundamental Planck scale is observed

Experimental searches:

- Channels studied in CMS: diphotons, dielectrons, dimuons, monophoton+MET
- Signal is a broad excess in dilepton or diphoton final states
- Main background = SM Drell-Yan. Need to understand tails



EXO-10-026 to be published in JHEP



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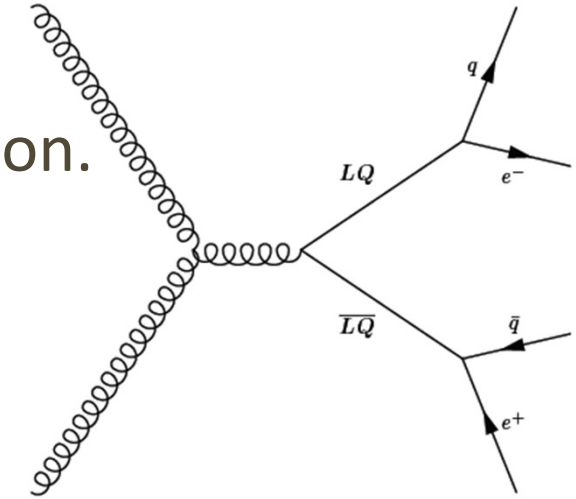
Leptoquarks → Leptons + Jets

Particles that carry both color and lepton flavour, allow transitions $\ell \leftrightarrow q$ within the given SM generation.

LQ produced in pairs

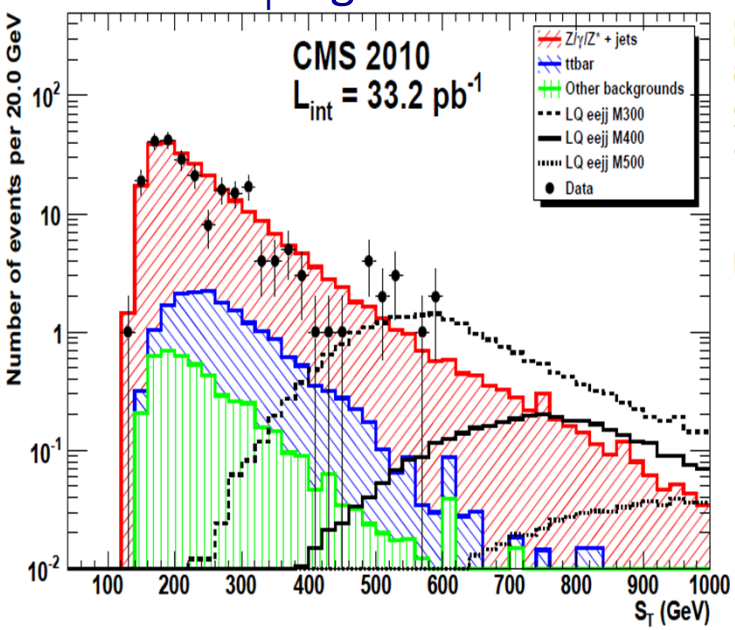


- 1. generation: electrons + jets, e ν + jets

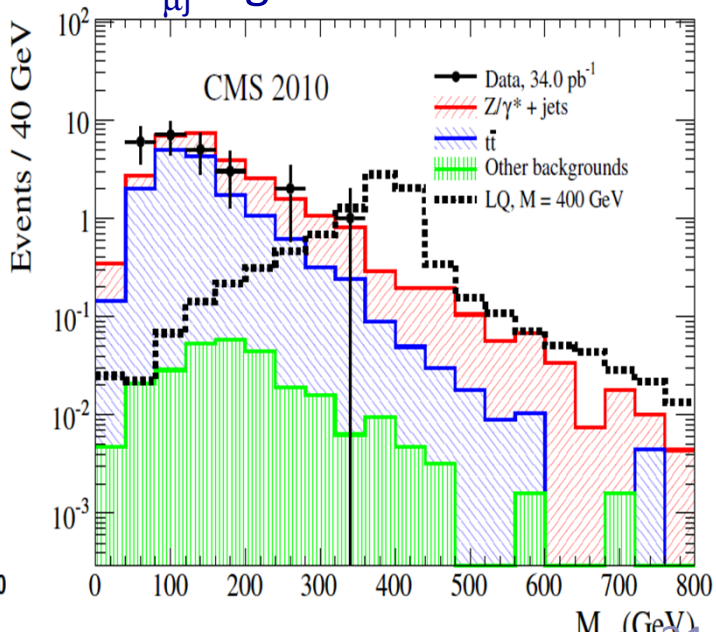
  2. generation: muons + jets, μ ν + jets
- Striking signature with isolated
  - 2 high p_T leptons and
  - 2 high p_T jets

Scalar sum S_T of the p_T of the 2 leading leptons and 2 leading jets (developed by D0), $S_T > f(M_{LQ})$ Also used in other analyses →

S_T 1.generation



$M_{\mu j}$ 2.generation



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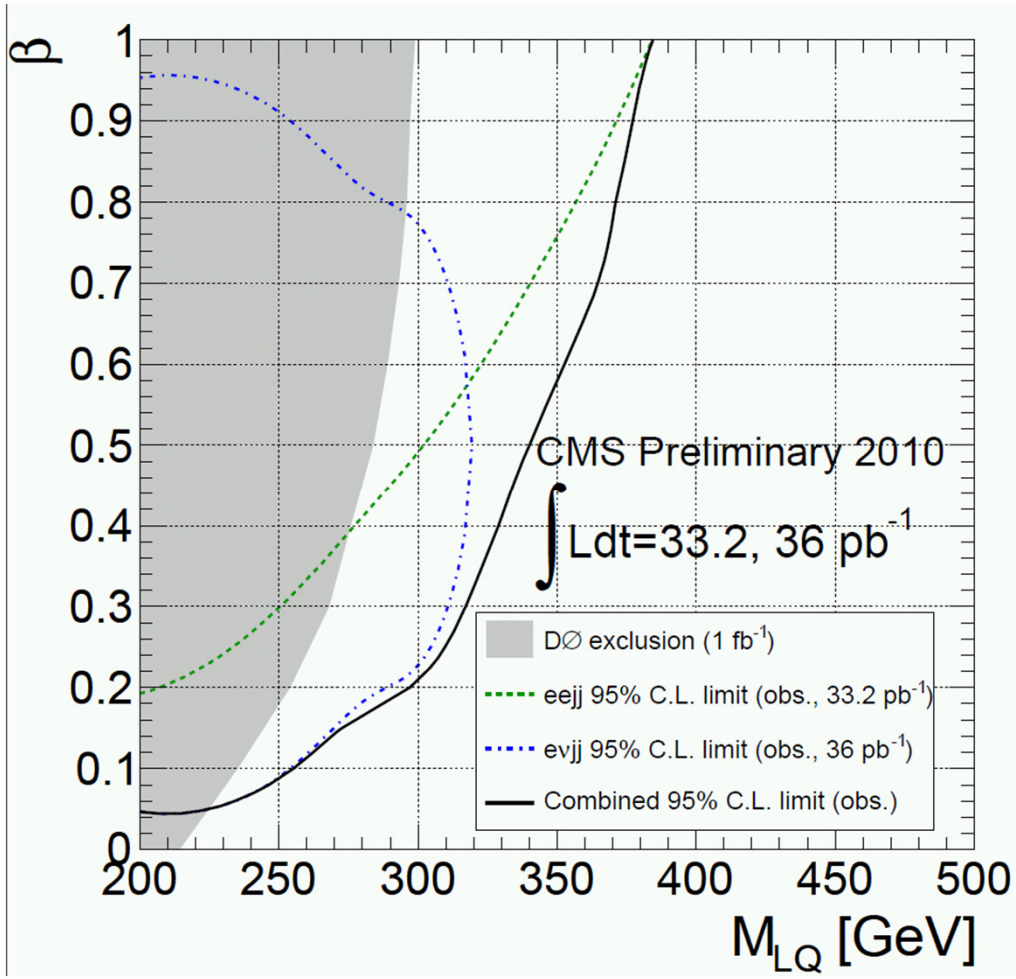
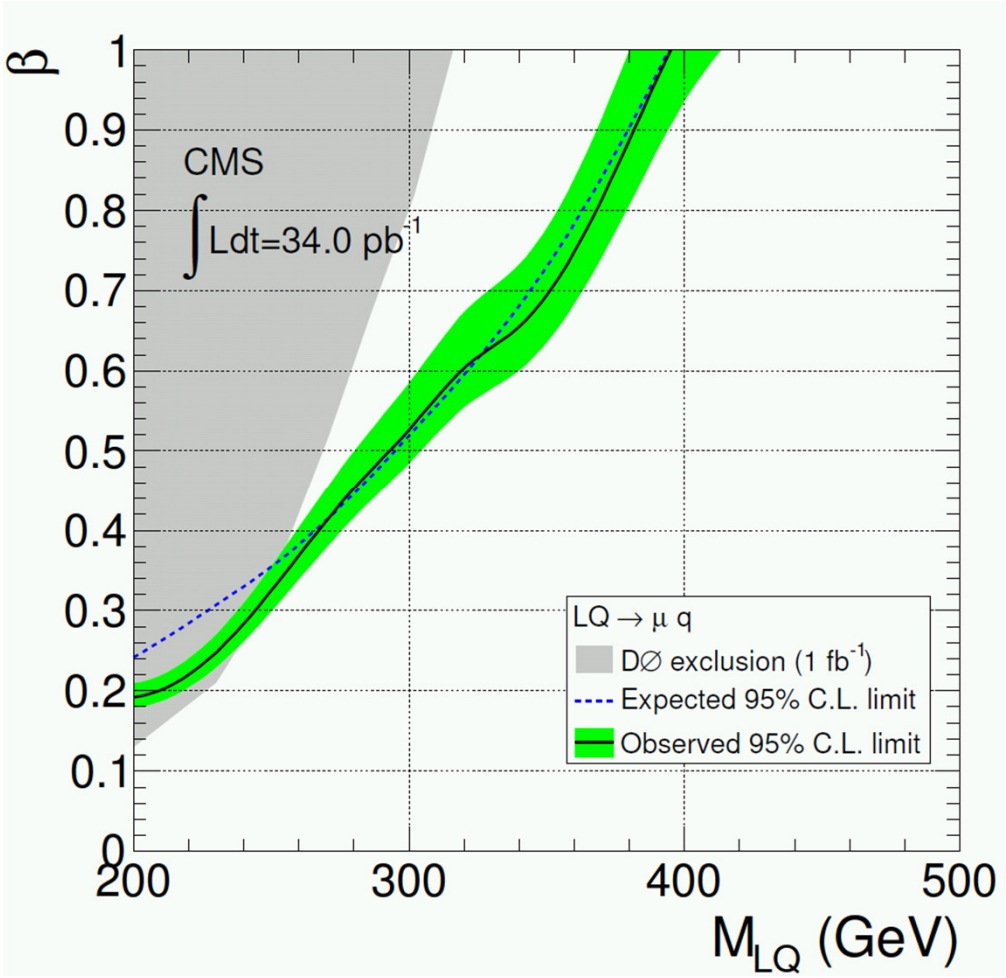
Leptoquark Limits

Exceed Tevatron limits (except at very low β)

1st generation



2nd generation



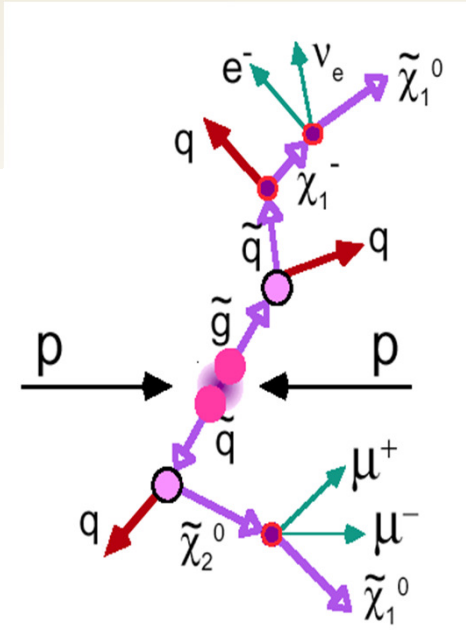
eejj - arXiv:1012.4031 Accepted by PRL

eνjj – EXO-10-006

Very similar to the 1st generation channels

μμjj - arXiv:1012.4033 Accepted by PRL

Seeking "SUSY"



- SUSY offers large variety of final states
- Long decay chains, often low-energy particles
- 2 LSP (conserving R parity) → causes MET

Strategy: divide by signatures. As much inclusive as possible

0 Leptons
- jets + MET
- b-jets

1 Lepton
- electron
- muon

2 Leptons
- opposite-sign
- same-sign

≥ 3 Leptons

... + Jets + MET

1 Photon + 1 Lepton + MET

2 Photons + Jets + MET

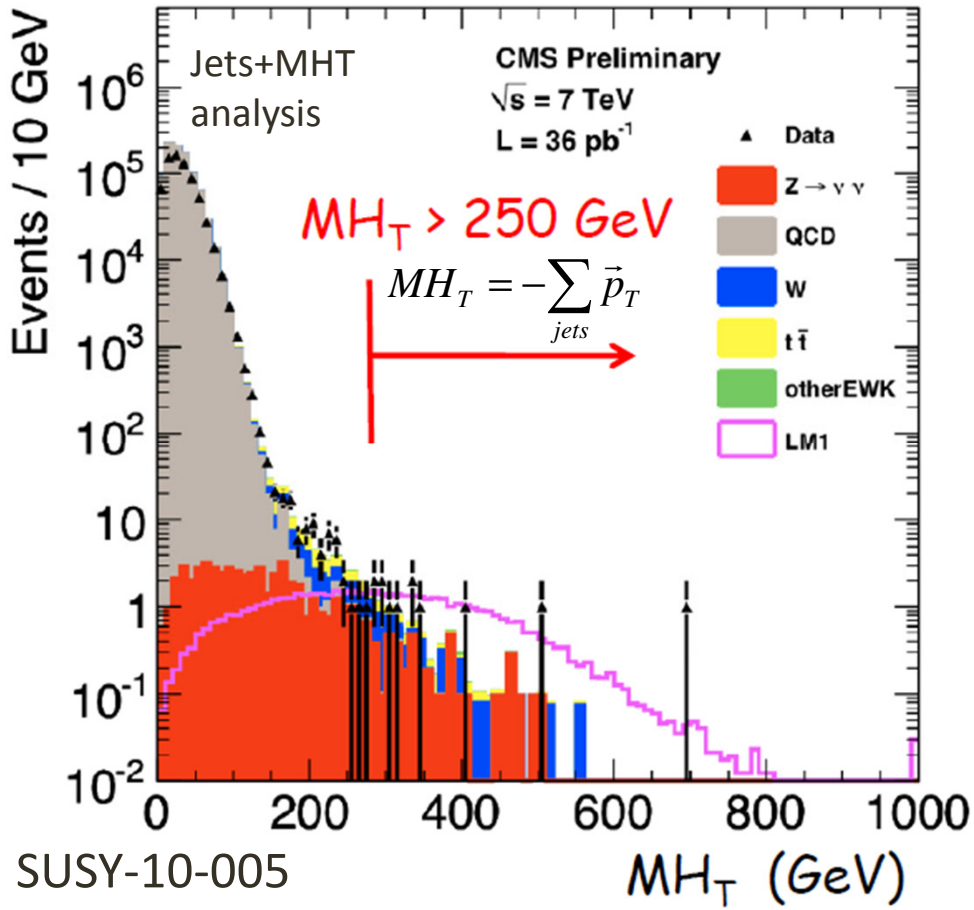
- Complementary approaches for most subjects
- Sensitivity determined by detector understanding (MET tails, jet performance, lepton ID, energy scale)

SUSY: Jets + MH_T Analysis

Hadronic final state with 3 or more jets (E_T>50 GeV, anti-kT algorithm).
Veto on isolated electrons or muons

Best sensitivity at present

MH_T > 250 GeV
Observed: 15
Expected 18.8 +- 3.5
Good data-MC agreement



SUSY-10-005

Add b-tagging

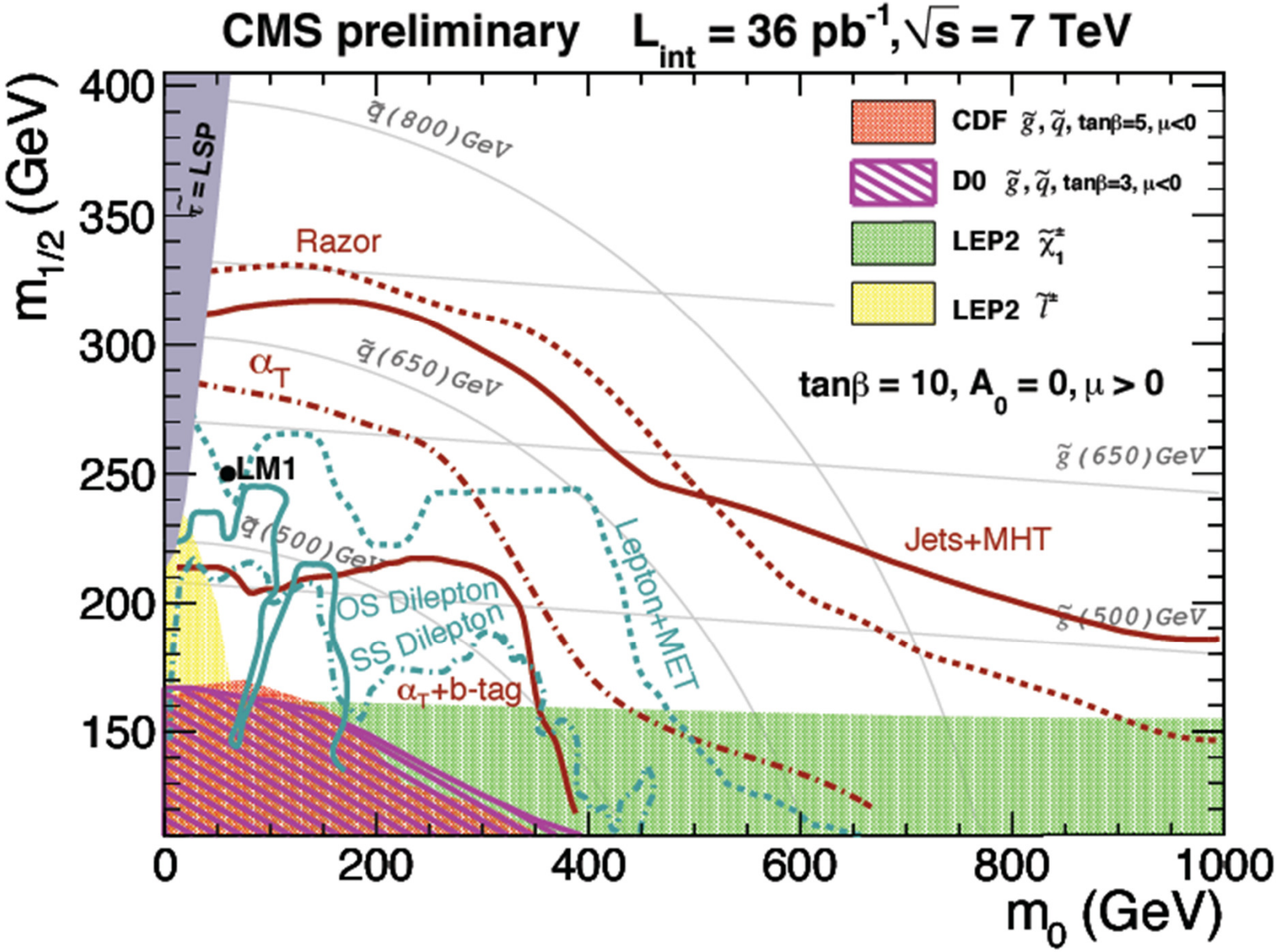
- to gain sensitivity to models with enhanced production of third generation squarks
- Reduce non-top backgrounds

Dilepton analyses

- Small cross section but clean signature

SUSY: Combined Exclusion Plot

Limits extend Tevatron



K.Hoepfner, CMS coll., DIS conference 2011

Summary

- With the 2010 data taking CMS has performed a comprehensive set of Standard Model measurements at 7 TeV for W, Z, top and QCD. First precision measurements.

- Many searches for new physics are performed. Unfortunately nothing found yet. New limits have been set, in many areas, exceeding the current best limits available from the Tevatron Collider.

- Prospects for Susy and Higgs search in 2011-12 appear to be very promising.

Awaiting eagerly more data in 2011

Stay tuned

SPARES

Systematic Uncertainties W,Z

Table 1: Systematic uncertainties in percent for all inclusive W and Z cross sections. "n/a" means the source does not apply. A common luminosity uncertainty of 4% applies to all channels.

Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	1.3	0.9	1.8	n/a
Trigger pre-firing	n/a	0.5	n/a	0.5
Momentum scale & resolution	0.5	0.22	0.12	0.35
$\not{E}_T$ scale & resolution	0.3	0.2	n/a	n/a
Background subtraction / modeling	0.35	0.4	0.14	0.28
Total experimental	1.5	1.1	1.8	0.7
PDF uncertainty for acceptance	0.6	0.7	0.9	1.2
Other theoretical uncertainties	0.7	0.8	1.4	1.6
Total theoretical	0.9	1.1	1.7	2.0
Total	1.7	1.6	2.5	2.1

Z→tau tau

Table 1: Number of expected background events and total number of data events passing all offline selections.

	$\tau_\mu \tau_{had}$	$\tau_e \tau_{had}$	$\tau_e \tau_\mu$	$\tau_\mu \tau_\mu$ ($M_{\mu\mu} < 70$ GeV)
$Z \to \ell^+\ell^-$, jet misidentified as τ	6.4 ± 2.4	15.0 ± 6.2	-	
$Z \to \ell^+\ell^-$, lepton misidentified as τ	12.9 ± 3.5	109 ± 28	2.4 ± 0.3	20.1 ± 1.3
$t\bar{t}$	6.0 ± 3.0	2.6 ± 1.3	7.1 ± 1.3	0.15 ± 0.03
$W \to \ell\nu$	54.9 ± 4.8	30.6 ± 3.1	1.5 ± 0.5	2.5 ± 2.5
$W \to \tau\nu$	14.7 ± 1.3	7.0 ± 0.7		
QCD multijet	132 ± 14	181 ± 23		
WW/WZ/ZZ	1.6 ± 0.8	0.8 ± 0.4	3.0 ± 0.4	-
Total background	228 ± 16	346 ± 37	14.0 ± 1.8	22.8 ± 2.8
Total data	517	540	101	58

EWK-10-013

Table 2: Summary of the sources of systematic uncertainties and the estimated effect on the measured cross section.

Source	$\tau_\mu \tau_{had}$	$\tau_e \tau_{had}$	$\tau_e \tau_\mu$	$\tau_\mu \tau_\mu$
Trigger	0.2 %	3 %	0.2 %	0.3 %
Lepton identification and isolation	1.0 %	1.1 %	1 %	1 %
τ_{had} identification	23 %		-	
Efficiency of M_T selection	2 %		-	
Likelihood selection efficiency	-			2 %
Acceptance due to τ_{had} energy scale, 3 %	3.5 %		-	
Acceptance due to e energy scale, 2 %	-	1.6 %	1.6 %	-
Acceptance due to μ momentum scale, 1 %	1 %	-	1 %	2 %
Luminosity	4 %			
Parton distribution functions	2 %			

List of Top Results

- **Top pair cross section**
  - in l+jets using kinematic properties TOP-10-002 (goes to paper)
  - in l+jets using b-tagging TOP-10-003 (goes to paper)
  - in dileptons TOP-10-005 (goes to paper with TOP-10-006)

- **Top mass in dileptons TOP-10-006**

- **M(ttbar) and search for new physics**
  - TOP-10-007 (stays as PAS)
- **Single top cross section**
  - TOP-10-008 (goes to letter)
- **Top pair charge asymmetry**
  - TOP-10-010 (stays as PAS)

Generators

- W Powheg + CT10 PDF
- QCD Pythia + CTAEQ6L PDF
- ttbar MG or Pythia + MC@NLO
- Dibosons Pythia NLO
- Other backgrounds Pythia with k-factor for NLO (except QCD)
- Tau decay with tauola