Tau at CMS(from tau lepton and tau in SM measurement to tau role in discovery)

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IPM

Brussels, 12/03/2012

Outline

- **Physics Motivation**
- **τ Reco and Id**
  - PFT-10-004
  - TAU-11-001 (JINST)
- **$W \to \tau\nu$ Cross Section Measurement**
  - EWK-11-002 (proceeding of Recontere de Moriond 2011 & arXiv:1108.1089 [hep-ex])
  - EWK-11-019
- **Search for SM Higgs boson in $H \to ZZ \to 2l2\tau$ Final States**
  - HIG-11-013
  - HIG-11-028 (JHEP)
- **Search for SM Higgs boson in $H \to \tau\tau$ Final State associated with Z boson**
  - AN-12-076

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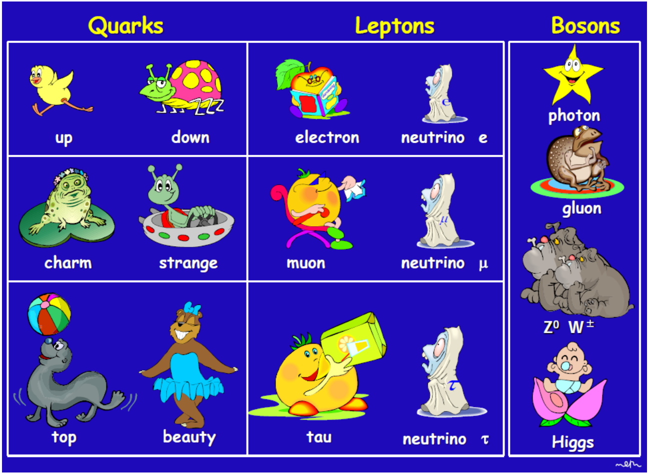
Standard Model of Particle Physics



The only missing part of SM is the Higgs boson

Hope 2012 is the last year for such a statement ;-)

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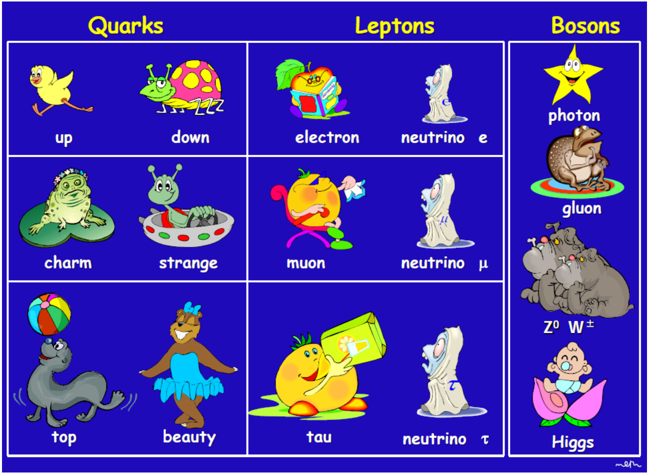

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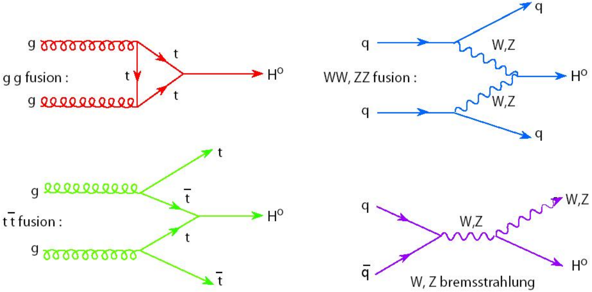
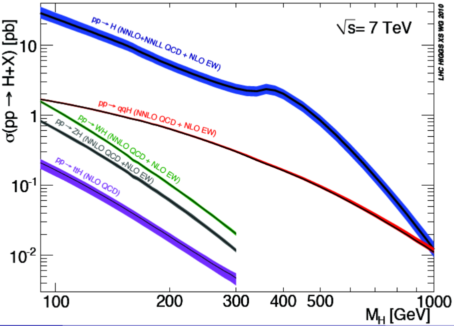
What is the Higgs field?

The Higgs field is a field that fills the universe like a water fills a pool. As particles move through the universe they acquire mass by interacting with the Higgs field. One way to imagine the Higgs field is to imagine trying to walk through a pool:

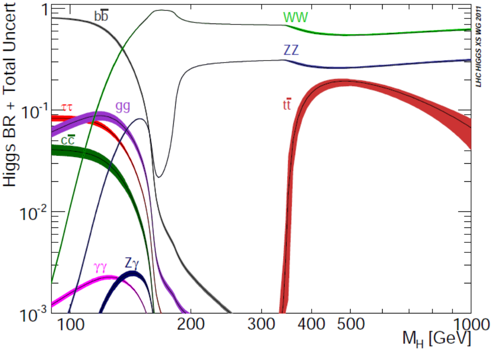
The water pushes against you making you feel heavier, and making it harder for you to move. This effectively generates inertia or mass. Of course, one can climb out of the pool and walk normally. But particles can never escape the Higgs field since it is everywhere, including the vacuum of space.

Higgs Production and Cross Section at LHC





Higgs Decays Modes



2 different regions in Higgs Mass:

- Low Mass (< 140 GeV)
  - $b\bar{b}, \tau\tau, \gamma\gamma$
- High Mass (>140 GeV)
  - WW, ZZ

τ leptons have role both in low masses and high masses Higgs boson search

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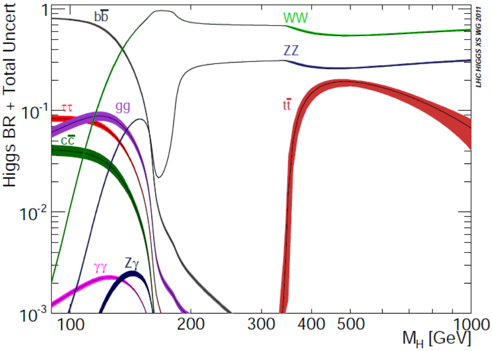

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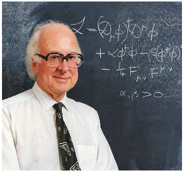
τ leptons have role both in low masses and high masses Higgs boson search

Where do we stand today?

- Indirect search requires the mass of Higgs boson to be less than 180 GeV.
- Results of the direct search from LEP $M_H > 114.4\,GeV$
- Latest results of the direct search from Tevatron excluded Higgs with Mass between $[147 - 179]$ GeV
- No Higgs seen (yet)



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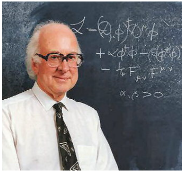

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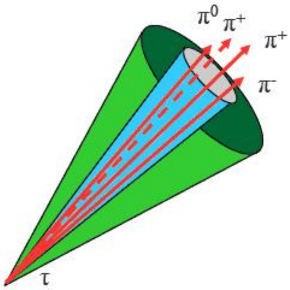
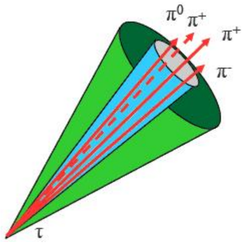
Tau Reconstruction and Identification



Tau lepton properties

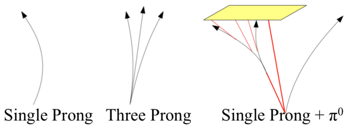
- Tau is the heaviest lepton (1.78 GeV/c^2)
- Lifetime is ~ $3 \times 10^{-13} s$ and decays via weak interaction
- They decay either leptonically to e/μ or hadronically to pions

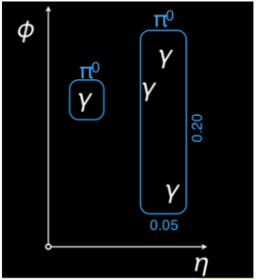


Decay Mode	Resonance	Mass (MeV/c^2)	Branching ratio(%)
$\tau^- \rightarrow h^- \nu_\tau$			11.6 %
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	ρ	770	26.0 %
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a1$	1200	10.8 %
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a1$	1200	9.8 %
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$			4.8 %
Total			63.0%
Other hadronic modes			1.7%

Hadron Plus Strip (HPS) Algorithm

- In the HPS algorithm(based on the decay modes), charged hadrons are combined electromagnetic objects, arranged in strips or single photons.





- 3 Working points are defined as follow:

	no charged hadron P_T [GeV]	no photon E_T[GeV]
Loose	1.0	1.5
medium	0.8	0.8
Tight	0.5	0.5

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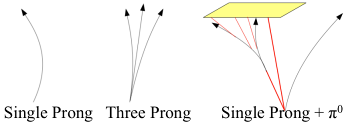

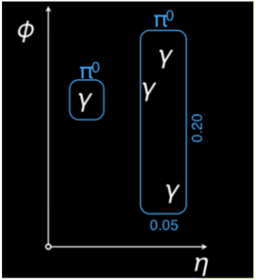

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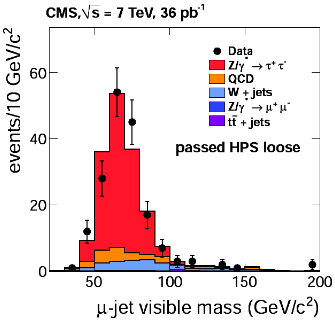
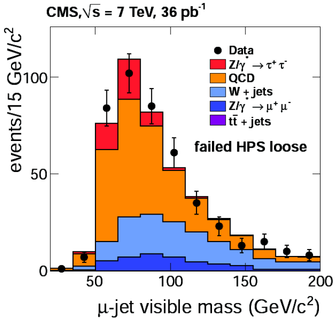
Tau Identification Efficiency using Tag and Probe Method

- events are pre-selected with a good μ, PF Jet, and other kinematics consistent with a $Z \to \tau_\mu \tau_h$ event.





- $N^{pass}_{Z\to\tau\tau}$ = # of PF jet passes Tau ID after background is subtracted.
- $N^{fail}_{Z\to\tau\tau}$ = # of PF jet fails Tau ID after background is subtracted.
- Efficiency is : $\varepsilon = \frac{N^{pass}_{Z\to\tau\tau}}{N^{pass}_{Z\to\tau\tau}+N^{fails}_{Z\to\tau\tau}}$

Algorithm	HPS		
	'loose'	'medium'	'tight'
Efficiency ($pt^{\tau_{had}} > 20$ GeV)	49.9%	36.5%	24.6%

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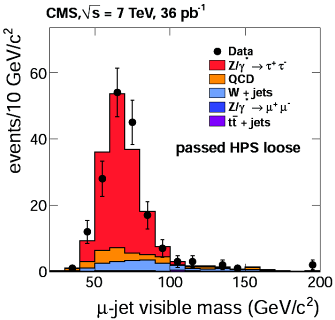

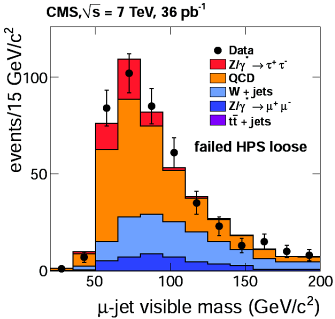

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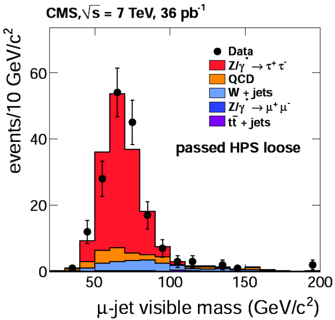

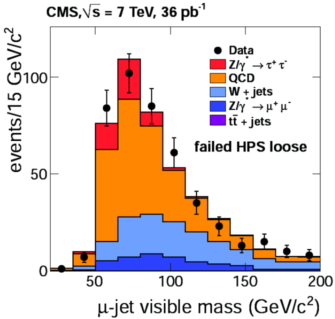

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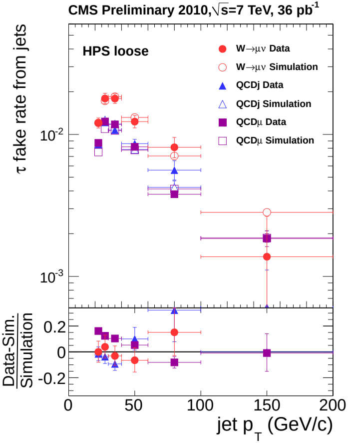
Tau Fake Rate

- Hadronic jets $p_T > 20$ GeV are selected in three types of events:
  - QCD Di-jet events
  - QCD μ enriched ($M_T < 40$ GeV, no μ Iso)
  - W+Jets events ($M_T > 50$ GeV)
- Tau ID is then applied to the jets to measure the fake rate.



Algorithm	QCDj		QCDμ		W + jets	
	MC	DATA/MC	MC	DATA/MC	MC	DATA/MC
HPS "loose"	1.0%	1.00 ± 0.04	1.0%	1.07 ± 0.01	1.5%	0.99 ± 0.04
HPS "medium"	0.4%	1.02 ± 0.06	0.4%	1.05 ± 0.02	0.6%	1.04 ± 0.06
HPS "tight"	0.2%	0.94 ± 0.09	0.2%	1.06 ± 0.02	0.3%	1.08 ± 0.09

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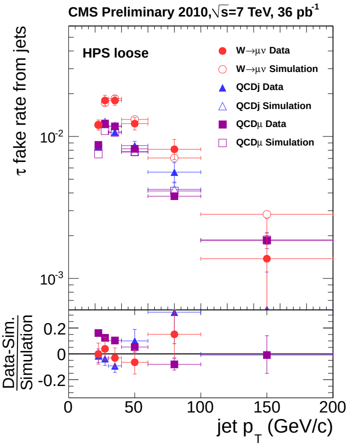

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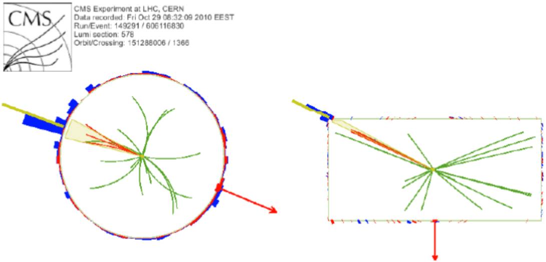
$W \to \tau\nu$ Cross Section Measurement

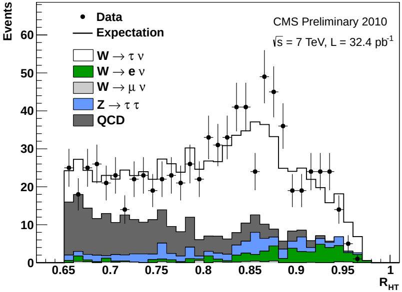


m_{vis} = 0.87 GeV

τ_{had} (3 prong):
p_T = 33 GeV
η = -1.45
p_T(lead. track)– 23 GeV
E_T miss= 43 GeV
$m_T(\tau,\upsilon)$ = 73 GeV

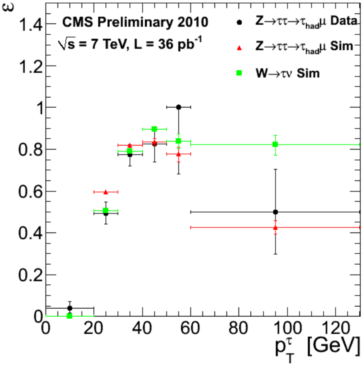
Event Selection

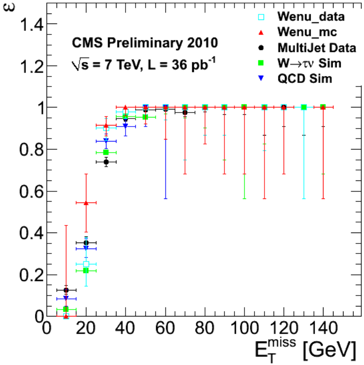
- Tau+Met cross–trigger: HLT_SingleIsoTau20_Trk15_MET20
- τ_{had} candidate selection:
  - tau $p_T > 30$ GeV, Leading track $p_T > 15$ GeV
  - HPS Medium Isolation
- $W \to \mu\nu$ suppression:
  - discrimination against muon
  - veto well identified and isolated muon, $p_T > 15$ GeV
- $W \to e\nu$ suppression:
  - discrimination against electron
  - veto well identified and isolated electron, $p_T > 15$ GeV
- *QCD* suppression:
  - $PFE_T^{miss} > 30$ GeV
  - $TMass_{\tau-MET} > 40$ GeV
  - $R_{HT} > 0.65$ ($R_{HT} = \frac{Pt_\tau}{\sum_{jets} Pt}$)



Trigger Efficiency with Data

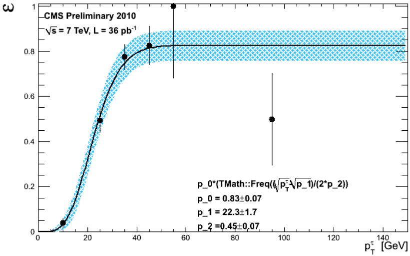
- Decouple the τ and E_T^{miss} leg; Total efficiency is product of two efficiencies.
- τ leg efficiency measured using $Z \to \tau^+\tau^- \to \mu + \tau_{had}$ events in data (triggered by single μ)
- E_T^{miss} leg efficiency measured from QCD/$W \to e\nu$ events in data (triggered by multijet/electron)
- Good agreement between trigger efficiency in data and MC simulation

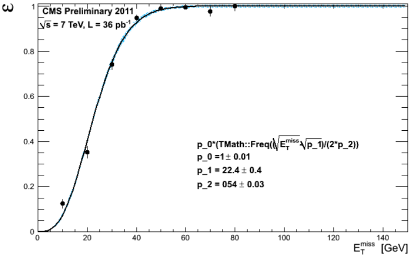




Uncertainty on Trigger efficiency

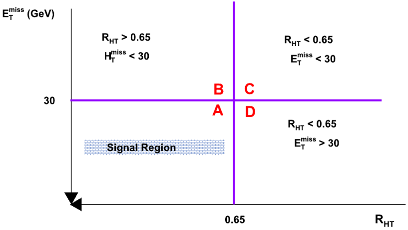
- Trigger efficiency for τ / E_T^{miss} leg measured in data, fitted with Gaussian error function.
- Uncertainty on trigger efficiency measured by varying the fit parameter within their error and 15%(2%) is assigned to the τ (E_T^{miss}) efficiency.
- Uncertainty on trigger efficiency dominated by statistical uncertainty on τ leg.





QCD Estimation using ABCD method

- Classify events passing all analysis cuts except E_T^{miss} and R_{HT}, into 4 regions
- Region A: both cuts are passed [signal dominant]
- Region B,C and D: at least one of the cuts is failed [QCD dominates]



- Provided that E_T^{miss} and R_{HT} are uncorrelated [BU] , yield QCD is:
  - $N_A = \left(\frac{N_B \times N_D}{N_C}\right)$

	Data	$W \to \tau\nu$	$W \to \mu\nu$	$W \to e\nu$	$Z \to \tau\tau$
region A	764	531.3 ±5.7	6.4 ±0.7	41.1 ±1.6	52.7 ±1.3
region B	2248	94.3 ±2.4	0.3 ±0.1	5.4 ±0.6	18.7 ±0.8
region C	35460	181.8 ±3.3	1.3 ±0.3	7.2 ±0.7	74.4 ±1.6
region D	4020	465.2 ±5.3	7.1 ±0.7	27.6 ±1.3	71.4 ±1.5

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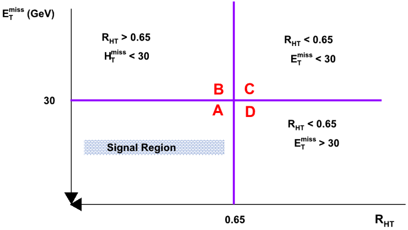

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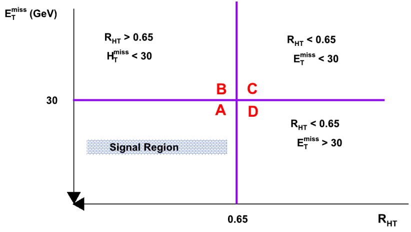

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Template Fitting

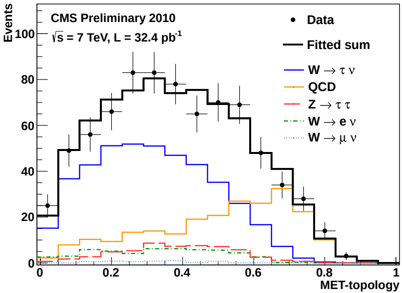
Template Fitting Strategy:

- The idea is to find Signal and BG yield in data via a fit of distributions observed in data with a set of template histograms
- Input of the fit → template histogram of Signal and BG normalized to unit area
- Output of the fit → normalization factors of signal and BG
- A good observable is needed for a fit to converge and lead to a reasonable number for signal and BG with low uncertainty.

MET-topology:

$$\frac{\sum Pt \text{ of particles projected in the } E_T^{miss} \text{ direction}}{\sum Pt \text{ of particles projected opposite to the direction of } E_T^{miss}}$$

- For signal: very little activity in direction of E_T^{miss} → small value of MET-topology
- For QCD multi–jet BG: MET is due to the jet energy mis-measurement → typically higher value w.r.t. Signal



Template Fitting

Template Fitting Strategy:

- The idea is to find Signal and BG yield in data via a fit of distributions observed in data with a set of template histograms
- Input of the fit → template histogram of Signal and BG normalized to unit area
- Output of the fit → normalization factors of signal and BG
- A good observable is needed for a fit to converge and lead to a reasonable number for signal and BG with low uncertainty.

MET-topology:

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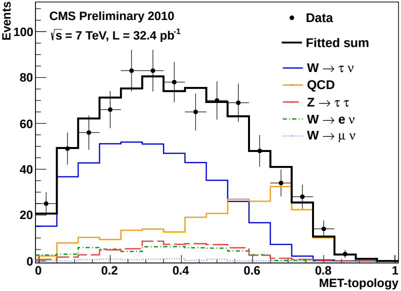


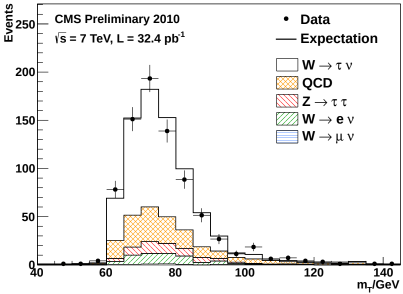
Systematics

Source	Uncertainty
Trigger efficiency	15%
Tau–jet energy scale	${}^{+16.0}_{-14.8}\%$
Jet energy scale	${}^{+10.0}_{-10.1}\%$
ISR + FSR + PDF	2%
tau Id Uncertainty	7%
Luminosity	4%
Background contributions	16.3%

- Uncertainty on background contribution: Estimated QCD from ABCD method and template fit method combined using weighted average.

Results

Data	QCD background	EWK background
793	183 ± 19	109 ± 44



- $\sigma = \frac{N_{Data} - N_{BG}}{\mathscr{L} \cdot A \cdot \varepsilon}$
  - Acceptance: $A/BR = 0.0790 \pm 0.0002(\mathrm{stat.})$ $BR(\tau \to \tau_{had}) = 0.648$
  - Efficiency: $\varepsilon = 0.0334 \pm 0.0006(\mathrm{stat.})$
- $\sigma = 9.08 \pm 0.51(\mathrm{stat.})^{+2.44}_{-2.38}(\mathrm{sys.}) \pm 0.36(\mathrm{lumi.})$ **nb** Theory(NNLO): 10.44 *nb*

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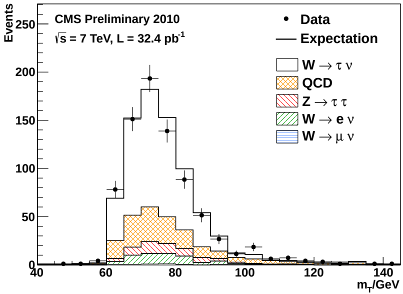

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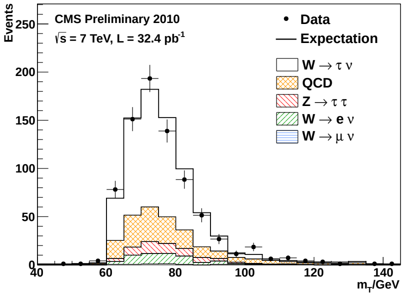

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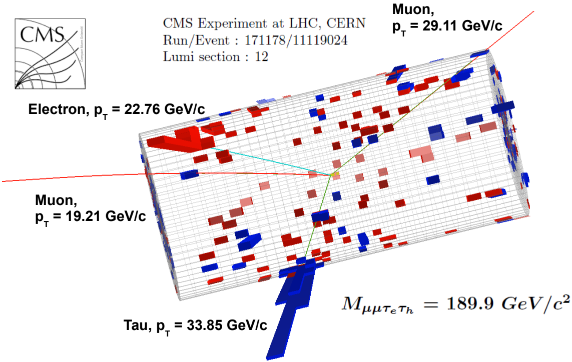
Search for SM Higgs boson in $H \to ZZ \to 2l2\tau$ Final States



Final States of $H \to ZZ \to 2l2\tau$

- **Leading Z decays to pair of e or μ (used for Triggering the events)**
  - $Z \to ee$
  - $Z \to \mu\mu$
- **Sub-Leading Z decays to pair of τ**
  - $Z \to \tau\tau \to \tau_{had}\tau_{had}$
  - $Z \to \tau\tau \to \tau_{had}\tau_{\mu}$
  - $Z \to \tau\tau \to \tau_{had}\tau_{e}$
  - $Z \to \tau\tau \to \tau_{\mu}\tau_{e}$
- There are two main backgrounds:
  - Irreducible: ZZ
  - Reducible: Z+Jets, WZ+Jet, TTbar

In total, 8 final states analyzed with 4.7 fb^{-1}

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In total, 8 final states analyzed with 4.7 fb^{-1}

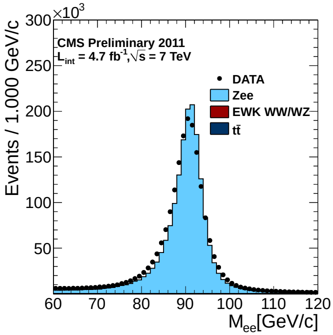
Leading Z Selection

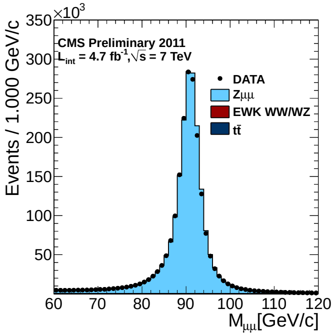
$Z \rightarrow \mu\mu$

- 2 opposite charged identified muons with $p_T > 20, 10\, GeV$
- RelIso < 0.25 and $60 <$Invariant Mass$< 120\, GeV$

$Z \rightarrow ee$

- 2 opposite charged identified electrons with $p_T > 20, 10\, GeV$
- RelIso < 0.25 and $60 <$Invariant Mass$< 120\, GeV$





Second Z selection

- $Z \to \mu + \tau_{had}$
  - muon with $p_T > 10\,GeV$,and rel Iso < 0.15
  - Loose Isolated HPS τ with $p_T > 20\,GeV$, e/μ rejection
  - $Q_\tau + Q_\mu = 0$ and 30 <visibleMass($\mu\tau$) $< 80\,GeV$
- $Z \to e + \tau_{had}$
  - electron with $p_T > 10\,GeV$, and rel Iso < 0.10
  - Loose Isolated HPS τ with $p_T > 20\,GeV$, e/μ rejection
  - $Q_\tau + Q_\mu = 0$ and 30 <visibleMass($e\tau$) $< 80\,GeV$
- $Z \to \tau_{had} + \tau_{had}$
  - 2 opposite charged, Medium Isolated HPS τs with $p_T > 20\,GeV$, e/μ rejection
  - 30 <visibleMass($\tau\tau$) $< 80\,GeV$
- $Z \to \mu + e$
  - Muon with $p_T > 10\,GeV$ and rel Iso < 0.25
  - Electron with $p_T > 10\,GeV$ and rel Iso < 0.25
  - $Q_e + Q_\mu = 0$ and visibleMass(μe) $< 90\,GeV$

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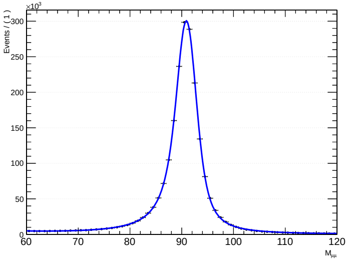
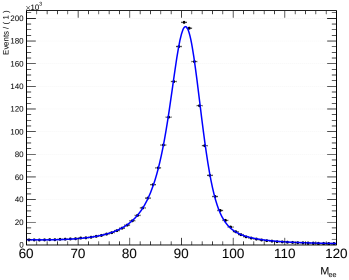
Irreducible ZZ Estimation

- ZZ estimation based on comparison to inclusive Z production
- Z yield extracted via fit (Voigtian convolved with CB for signal and exponential for BG)

$$N_{ZZ}^{\text{estimated}} = N_{Z}^{\text{obs}} \cdot \frac{\sigma_{ZZ}^{\text{SM}} \cdot A_{ZZ}}{\sigma_{Z}^{\text{SM}} \cdot A_{Z}}$$

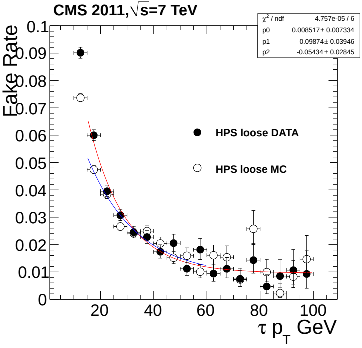
	Data	Simulation
$Z \to \mu\mu$	1973040	1873130
$Z \to ee$	1668740	1596940

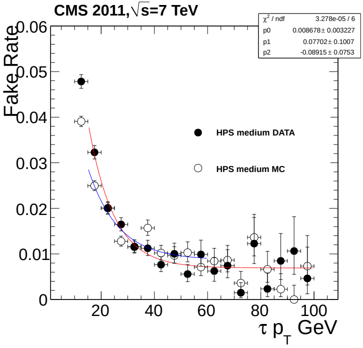




Reducible BG Estimation(fake rate estimation)

- Select events with one Z and two non-isolated SS tau(BG dominant regions)
- fake rate: probability of a jet to pass τ isolation.
- Fit it with exponential function $F(p_T(\tau)) = C_0 + C_1 e^{C_2 p_T(\tau)}$
- Consider e/μ fake rate pt-independent
- For Z+jet use $Est = \frac{Nf_1 f_2}{1-f_1 f_2}$ and for WZ+jet use $Est = \frac{Nf}{1-f}$





Systematic Uncertainty

Systematic uncertainties common to all channels.	
Source	Uncertainty
Luminosity measurement	4.5%
Higgs cross section	17 - 20%
PP background estimate	10%
Reducible background estimate	30%
Trigger efficiency	1%

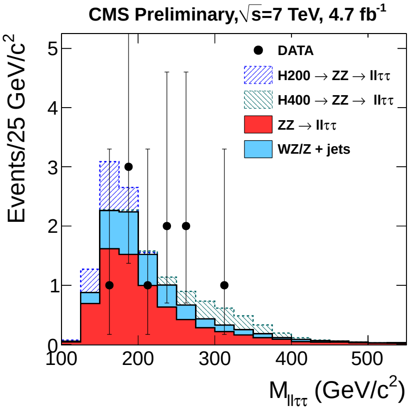
Channel specific systematic uncertainties.				
Channel	μ ID/Iso/ES	e ID/Iso/ES	τ ID/Iso	τ ES
$\mu\mu\tau\tau$	1.4%	-	10%	4%
$\mu\mu\mu\tau$	1.7%	-	6%	3%
$\mu\mu e\tau$	1.4%	1%	6%	3%
$\mu\mu e\mu$	1.7%	1%	-	-
$ee\tau\tau$	-	1.4%	10%	4%
$ee\tau\mu$	1%	1.4%	6%	3%
$ee\tau e$	-	1.7%	6%	3%
$ee\mu e$	1%	1.7%	-	-

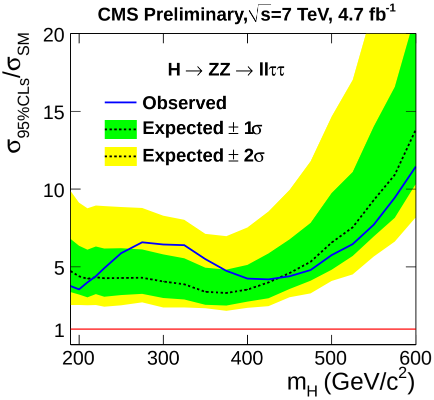
Results with 4.7 fb^{-1}

channel	N_{ZZ}^{est}	Reducible background	Observed
$\mu\mu\tau\tau$	$0.79 \pm 0.02(stat.) \pm 0.08(sys.)$	$0.74 \pm 0.05(stat.) \pm 0.22(sys.)$	0
$ee\tau\tau$	$0.75 \pm 0.02(stat.) \pm 0.08(sys.)$	$0.71 \pm 0.05(stat.) \pm 0.21(sys.)$	1
$ee\tau_e\tau$	$1.12 \pm 0.03(stat.) \pm 0.11(sys.)$	$0.80 \pm 0.16(stat.) \pm 0.24(sys.)$	3
$\mu\mu\tau_e\tau$	$1.20 \pm 0.03(stat.) \pm 0.12(sys.)$	$0.31 \pm 0.10(stat.) \pm 0.09(sys.)$	3
$\mu\mu\tau_\mu\tau$	$1.08 \pm 0.02(stat.) \pm 0.11(sys.)$	$0.20 \pm 0.08(stat.) \pm 0.06(sys.)$	2
$ee\tau_\mu\tau$	$0.94 \pm 0.02(stat.) \pm 0.09(sys.)$	$0.20 \pm 0.07(stat.) \pm 0.06(sys.)$	0
$ee\tau_e\tau_\mu$	$0.51 \pm 0.02(stat.) \pm 0.05(sys.)$	$0.14 \pm 0.04(stat.) \pm 0.04(sys.)$	0
$\mu\mu\tau_e\tau_\mu$	$0.58 \pm 0.02(stat.) \pm 0.06(sys.)$	$0.16 \pm 0.04(stat.) \pm 0.05(sys.)$	1
Total	$6.97 \pm 0.08(stat.) \pm 0.26(sys.)$	$3.25 \pm 0.23(stat.) \pm 0.41(sys.)$	10

- Higgs Expected yield: H(250) = 1.49

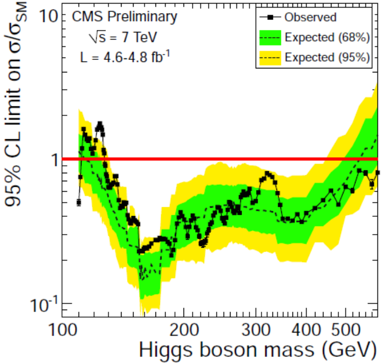
Higgs Mass and Limit

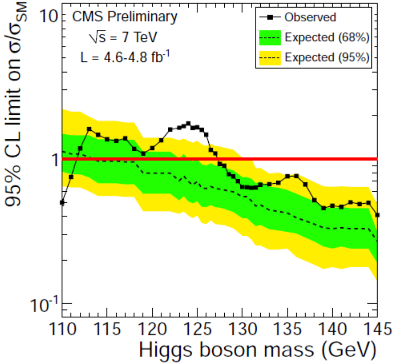




- No Evidence for a significant deviation from Standard Model expectation
- Exclude cross-section of about 4 to 7 times expected values in the range 190 $< m_H < 500\ GeV/c^2$.

Higgs Combination





- If Higgs boson exists, its mass should be low (< 130 GeV)

Search for SM Higgs boson in $H \to \tau\tau$ Final State associated with Z boson

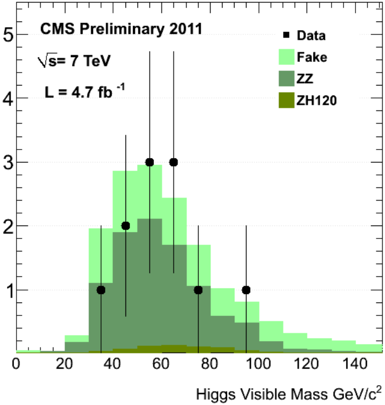
Analysis in 4.7 fb^{-1}

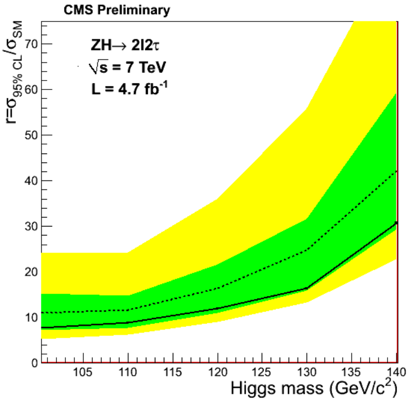
- Preliminary studies shows that extending the $H \to ZZ \to 2l2\tau$ to low mass is hopeless (due to low Higgs BR and trigger)
- This analysis has the same signature as $H \to ZZ \to 2l2\tau$
  - very few cuts in difference
  - Shape of the Higgs boson differs in two analyses

	ZZ	Reducible	Total BG	Observed
$\mu\mu\tau\tau$	1.04 $\pm$ 0.10	0.98 $\pm$ 0.13	2.02 $\pm$ 0.15	0
$\mu\mu e\tau$	1.11 $\pm$ 0.11	0.67 $\pm$ 0.27	1.78 $\pm$ 0.30	3
$\mu\mu\mu\tau$	1.50 $\pm$ 0.15	0.83 $\pm$ 0.14	2.33 $\pm$ 0.17	2
$\mu\mu\mu e$	0.80 $\pm$ 0.08	0.49 $\pm$ 0.38	1.29 $\pm$ 0.40	2
$ee\tau\tau$	1.00 $\pm$ 0.10	0.63 $\pm$ 0.11	1.63 $\pm$ 0.13	1
$ee\mu\tau$	1.34 $\pm$ 0.13	0.48 $\pm$ 0.11	1.82 $\pm$ 0.14	0
$eee\tau$	1.09 $\pm$ 0.11	1.37 $\pm$ 0.33	1.46 $\pm$ 0.36	3
$eee\mu$	0.49 $\pm$ 0.05	0.53 $\pm$ 0.38	1.02 $\pm$ 0.40	0
Total	8.38 $\pm$ 0.30	5.98 $\pm$ 0.73	14.3 $\pm$0.8	11

- Higgs Expected yield: ZH(120) = 0.64 & ZH(130) = 0.43

Higgs Mass and Limit



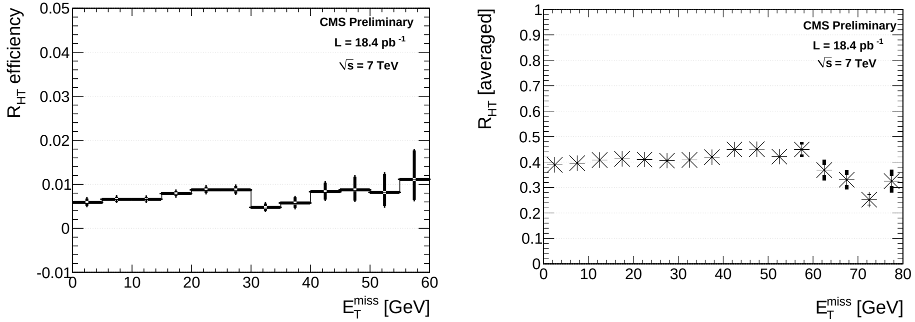


- The limits is performed using the shape analysis with Bayesian approach
- Exclude cross-section of about 8 to 15 times expected values in the range $100 < m_H < 130\ GeV/c^2$.
- This is an on-going analysis

Thank You

BackUp

Correlation between R_{HT} and MET



- Plots shows that R_{HT} and E_T^{miss} are indeed uncorrelated

Reducible BG Estimation(fake rate application)

After the Z is fixed, two more objects (μ,e, τ) are required.
for applying the fake rates there are 3 different categories.

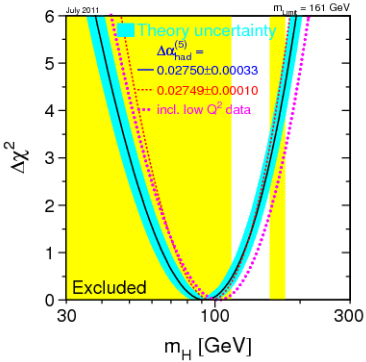
- category 0: both objects are anti-isolated [Zjets + ttbar BG]
  - $Est_0 = \frac{N_0 f_1 f_2}{1-f_1 f_2}$
- category1,2 : one of the object is isolated while the other is anti-isolated [WZ + (Z+jet and ttbar where one jet faked object)]
  - $Est_1 = \frac{N_1 f_1}{1-f_1}$ $\qquad Est_2 = \frac{N_2 f_2}{1-f_2}$

BG estimation would be the sum of estimation in all three categories (by taking into account the contamination of category 0 into 1 and 2)

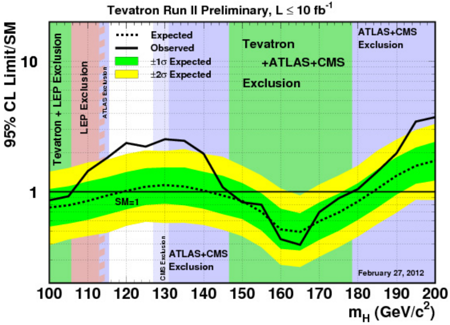
$$Est_{tot} = N_0.f_1.f_2 + (N_1\text{-}N_0.f_2).f_1 + (N_2\text{-}N_0.f_1).f_2 = N_1.f_1 + N_2.f_2 - N_0.f_1.f_2$$

Indirect Search for Higgs Boson

- The mass of the top quark and the W boson have been measured with a good precision
- It is possible to perform a χ^2 fit involving these measurements to constrain the Higgs boson mass
- black line indicates the central value and the blue band indicates the total systematic uncertainty.
- The most probable Mass for Higgs is around 100 GeV and Masses below 180 GeV is excluded.



Latest Tevatron Results for Higgs Search



Tevatron (by combining the CDF and D0 experiment) excluded the Higgs mass between 147 and 179 GeV