Search for the Higgs Boson decay to Tau Pairs with the CMS detector

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(for the CMS collaboration)

Higgs Workshop at CEA
2nd November 2011

Minimal Super-Symmetric Model (MSSM)

- Two isospin Higgs doublets
- EW symmetry breaking: 5 physical Higgs bosons
  - h, H (scalar, CP-even)
  - A (pseudo-scalar, CP-odd)
  - $H^{\pm}$ (charged)

MSSM Higgs sector @ tree level determined by:
M_A & tanβ
at high tanβ, the pseudo-scalar A degenerate in mass with h & H

Mass hierarchies at tree level: $M_h < M_Z$, $M_A < M_H$ & $M_{W\pm} < M_{H\pm}$

$$M_h \leq \min(M_A, M_Z) \cdot |\cos 2\beta| \leq M_Z$$

Radiative corrections increase upper bound on M_h^{max} ~130 GeV (m_h^{max} scenario studied)

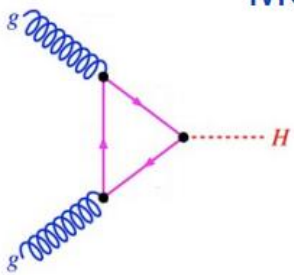
$$\Delta M_h^2 = \frac{3G_\mu}{\sqrt{2}\pi^2} m_t^4 \log\frac{M_S^2}{m_t^2}$$

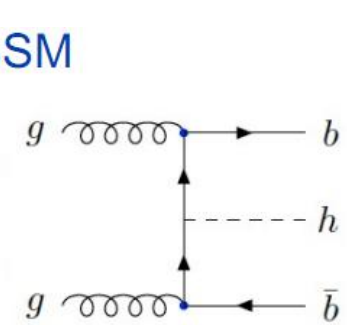
M_h^{max} scenario
maximal M_h<133 GeV

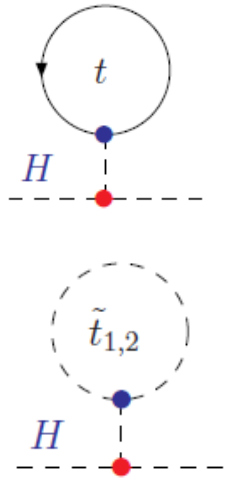
Proposed by Carena et al., Eur. Phys. J. C 26, 601(2003)

- M_{top}= 172.5 GeV
- $m_b(m_b)_{MSbar}$= 4.213 GeV
- $\alpha_S(M_Z)$=0.119

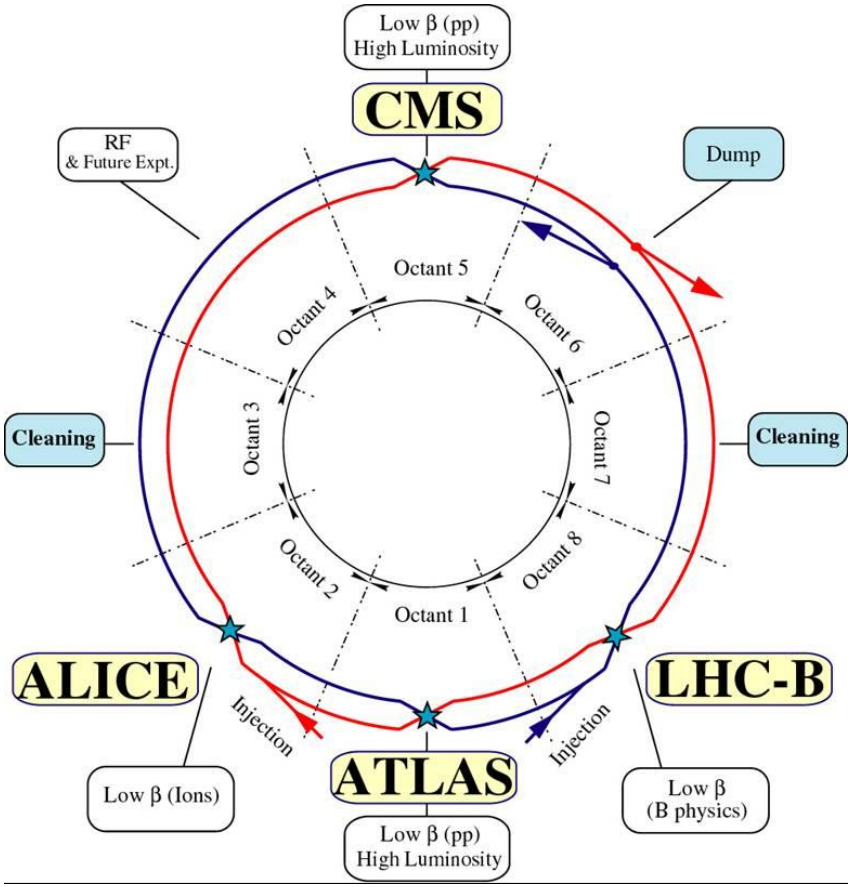
• M_{SUSY} = 1 TeV	soft SUSY-breaking mass
• X_t = 2 TeV	stop mixing parameter
• M_2 = 200 GeV	SU(2) gaugino mass parameter
• m = 200 GeV	Higgs mixing parameter
• M_3 = 800 GeV	gluino mass parameter

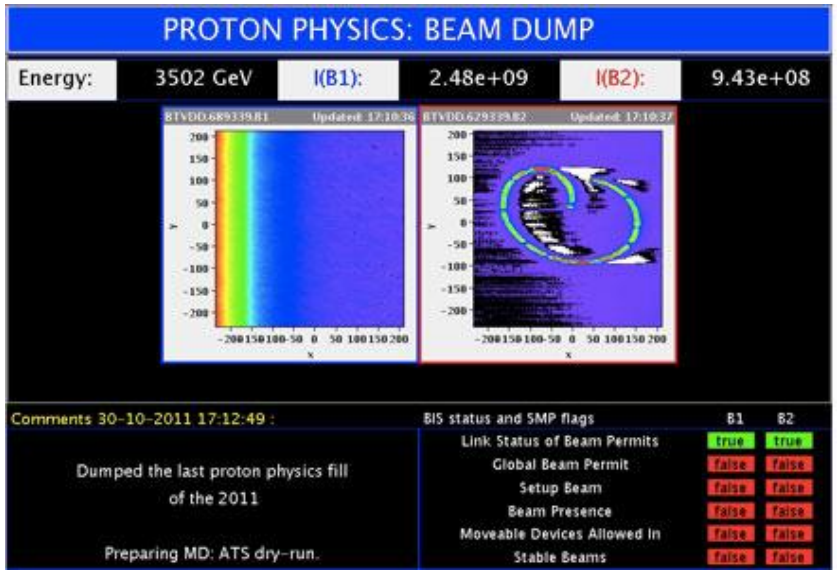


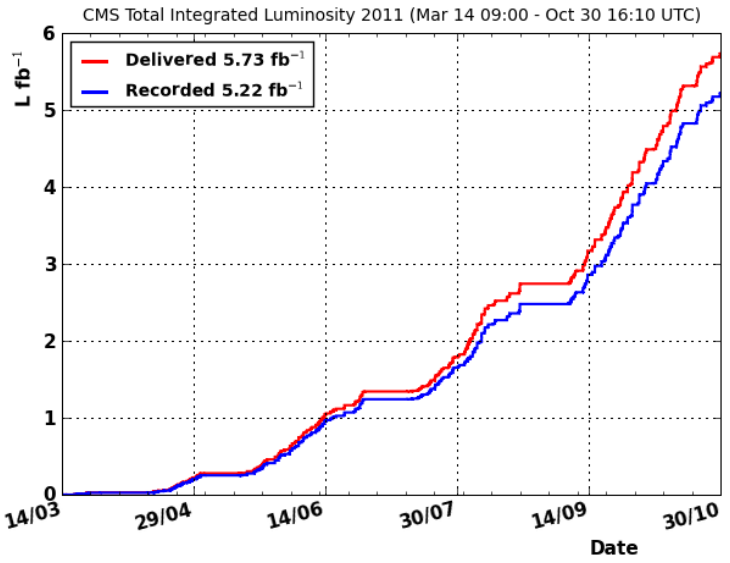




The Large Hadron Collider



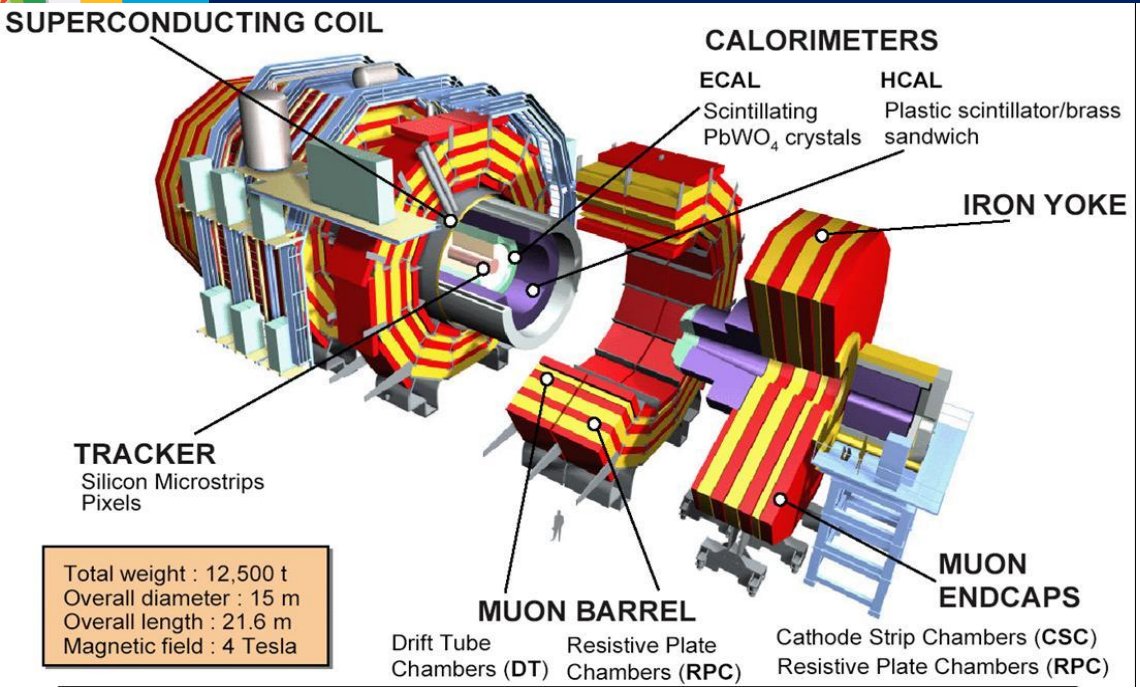




LHC proton run for 2011 reaches successful conclusion

The final data set corresponds to ~ 5 fb^{-1}

The CMS Detector



3.8 T superconducting solenoid :

- **ECAL ($PbWO_4$ crystals)**

Barrel $|\eta| < 1.48$ Endcap $1.48 < |\eta| < 3.0$

- **HCAL (brass/scintillator samplers)**
- **Inner Tracker (silicon pixel and strip detectors) $|\eta| < 2.5$**
- **Muon Chambers – gas ionization detectors embedded in steel return yoke outside the solenoid, $|\eta| < 2.4$ Drift Tubes in Barrel, Cathode Strip Chambers in Endcaps, Resistive Plate Chambers in parts of both Barrel and Endcap**

Silicon tracker $|\eta| < 2.5$, B = 3.8T solenoid

$\sigma/p_T \approx 1.5 \cdot 10^{-4} p_T \oplus 0.005$

Calorimetry $|\eta|_{ECAL} < 3$, $|\eta|_{HCAL} < 5$

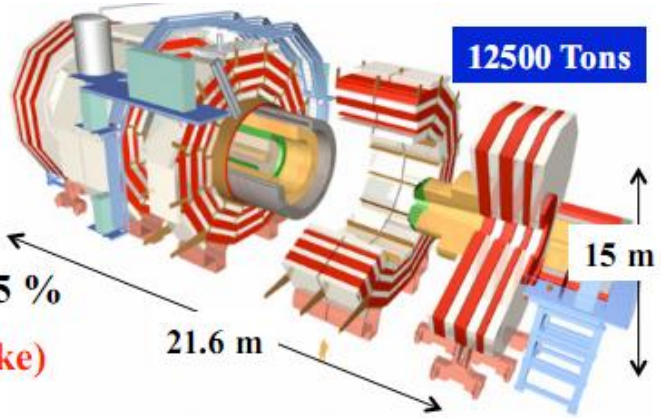
ECAL: PbWO4 crystals, high resolution M(γγ)

$\sigma/E \approx 2.8\%/\sqrt{E} \oplus 12\%/E \oplus 0.3\%$

HCAL: brass+Scintillator $\sigma/E \approx 100\%/\sqrt{E} \oplus 0.05\%$

Muon Spectrometer: B = 2T (solenoid return yoke)

$\sigma/p_T \approx 1\%$ @ 40 GeV $|\eta| < 2.4$



Electron Identification

Combining Gaussian Sum Filter (GSF) Tracks with ECAL super-clusters

Fake electron rate discrimination -

- **Angular difference between track and super-cluster**
- **Ratio of HCAL to ECAL energy deposit associated with super-cluster**
- **ECAL shower shape variable (RMS super-cluster energy)**

Satisfying identification requirements for barrel and endcap

Muon Identification

Reconstructed using both the inner tracker and muon chambers

$N_{hits}(silicon) \geq 10$, $N_{hits}(pixel) \geq 1$
$\chi^2/n_{dof} < 10$
Impact parameter $|d_{xy}| < 0.045$ cm

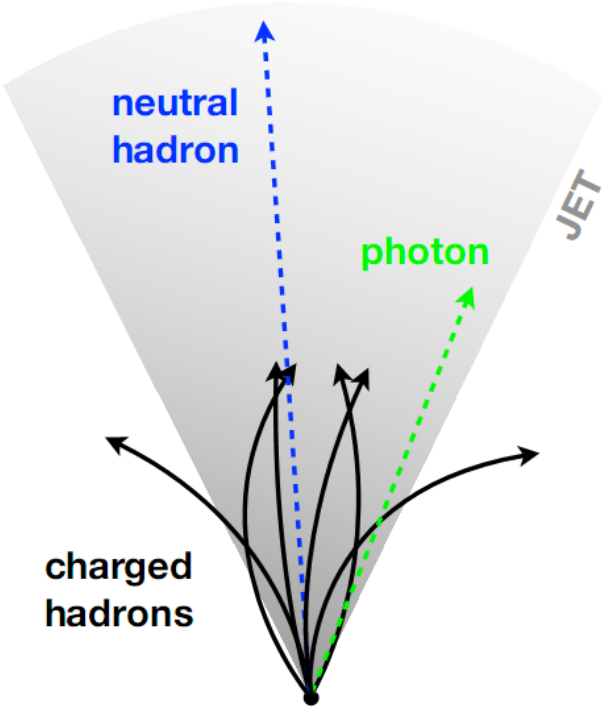
Particle Flow based lepton isolation correcting for pile-up

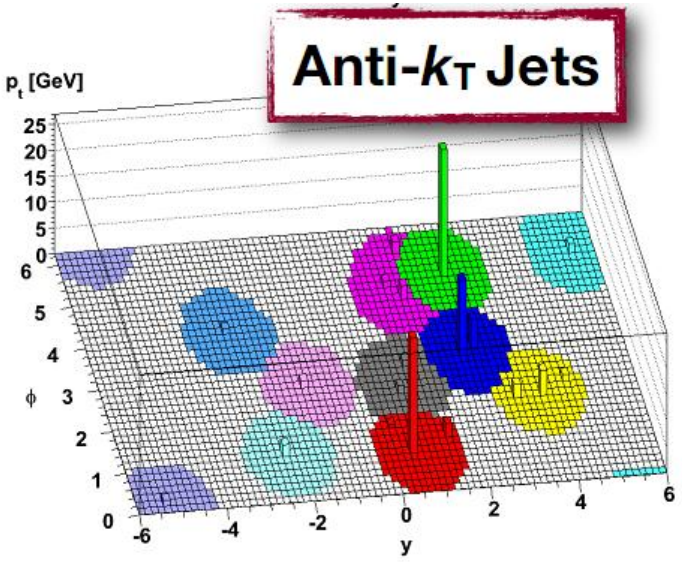
$$I_{rel}^{PF}(\Delta\beta) = \frac{\Sigma\left(P_T^{charged} + max(E_T^{gamma} + E_T^{neutral} - 0.5 \times E_T^{PU}, 0.0)\right)}{P_T^l}$$

Particle F low (PF) Jet Reconstruction:
anti-k_T jet clustering algorithm
Sequential recombination
Infrared / collinear safe
distance parameter R=0.5

Raw Jet × Offset Correction (pile up) × Relative Response (vs. η) × Absolute Response (vs. p_T) = Calibrated Jet

M. Cacciari, G. Salam, G. Soyez :
JHEP 04 (2008) 063





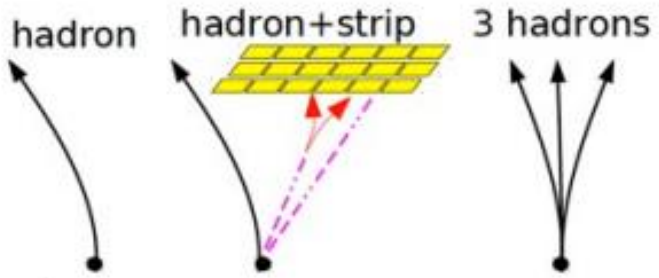
PF jets – best resolution
Data corrected with residual calibration
Jet p_T > 30 GeV , |η| < 5.0

MET – negative vectorial sum of all PF candidates, corrected for muons

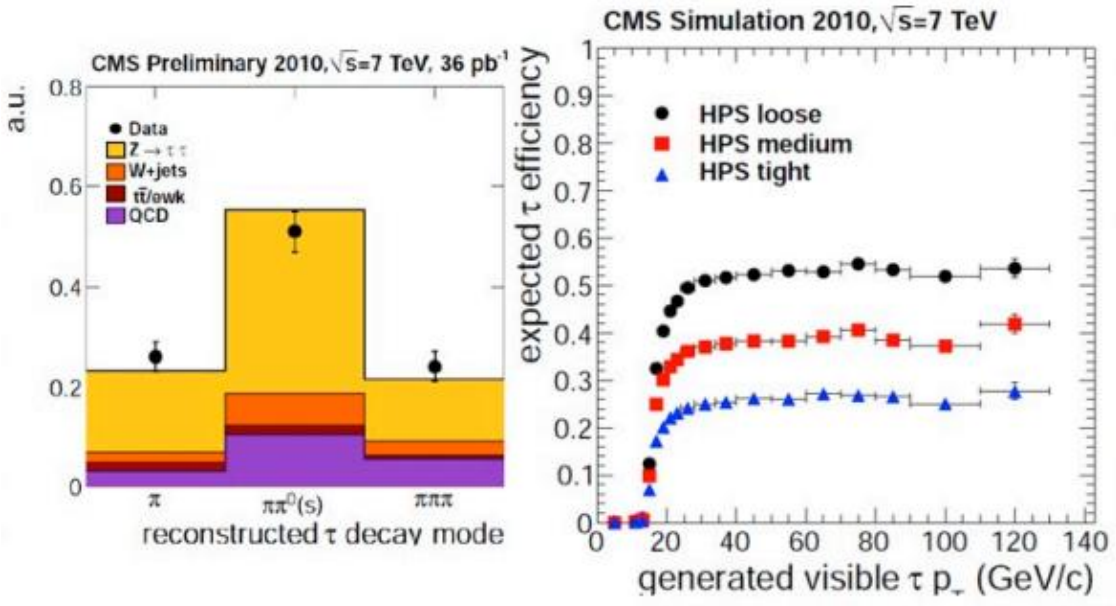
Hadron Plus Strips Algorithm:
Build signal components combinatorially

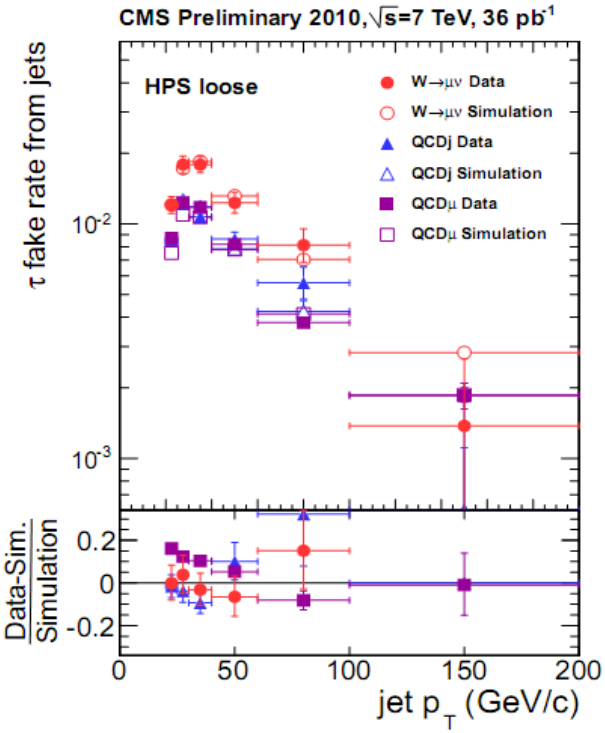
Starts from PF jet and reconstructs possible tau decays inside the jet

1 charged hadron	π^+
Hadron plus 1/2 strips	$\pi^+ \pi^0$
3 charged hadrons	$\pi^+ \pi^+ \pi^-$



Hadron plus Strip mass – compatible with ρ (770) resonance





Trigger & Event Selection

The CMS group at CEA Saclay – involved in analysis in the μ + τ jet channel

Level 1 seeded High Level isolation based Cross Trigger in semi-leptonic and single lepton trigger in fully leptonic

Mu+Tau	Ele+Tau	Mu+Ele
IsoMuon15 and IsoTau15	IsoElectron20 and IsoTau20	Mu8 && Ele17 OR Mu17 && Ele8

At least one primary vertex

$N_{dof} \geq 4$, $|z| \leq 24$ cm , $\rho_0 < 2$ cm

Muon pT > 15 GeV, |eta| < 2.1 and Tau pT >20 GeV, |eta| < 2.3	Ele pT > 20 GeV, |eta| < 2.1 and Tau pT >20 GeV, |eta| < 2.3	Muon pT > 20 (10) GeV, |eta| < 2.1 and Ele pT > 10 (20) GeV, |eta| < 2.5

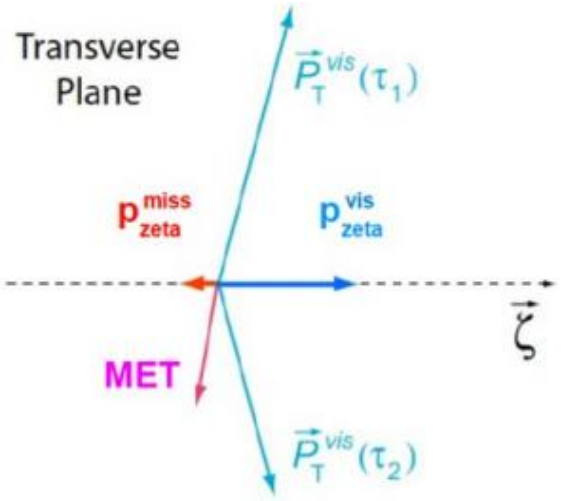
Lepton and Tau Isolation requirements satisfied
Applied Muon and Electron rejection in τ-jet
The lepton and τ-jet must have opposite charge

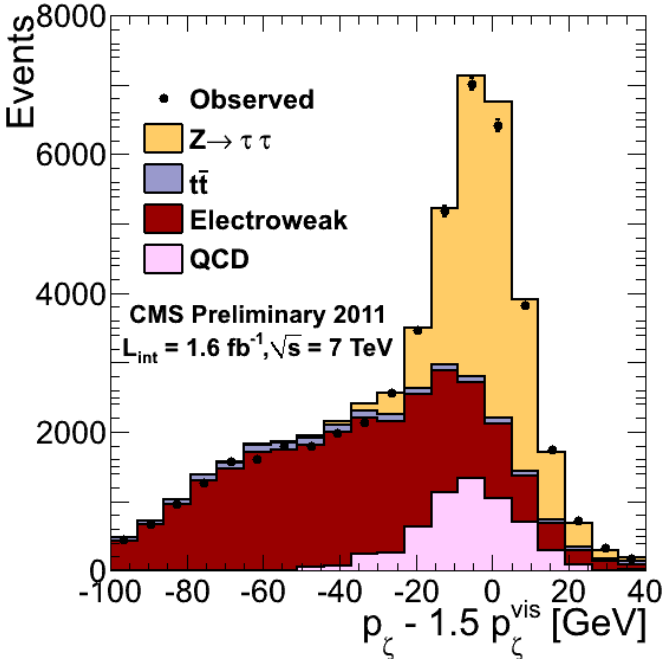
Anti-Z veto:

No 2nd lepton within same detector acceptance and same p_T threshold under a relaxed isolation

P_ζ cut: Evades W + jets background

- $P_\zeta = (p_T^{\tau 1} + p_T^{\tau 2} + \text{MET}) \bullet \zeta$
- $P_\zeta^{vis} = (p_T^{\tau 1} + p_T^{\tau 2}) \bullet \zeta$





$$P_\zeta^{\text{cut},\ell\tau} = P_\zeta - 1.5 P_\zeta^{\text{vis}} \quad \geq \textbf{-20 GeV}$$

$$P_\zeta^{\text{cut},e\mu} = P_\zeta - 1.85 P_\zeta^{\text{vis}} \quad \geq \textbf{-25 GeV}$$

Background Estimation

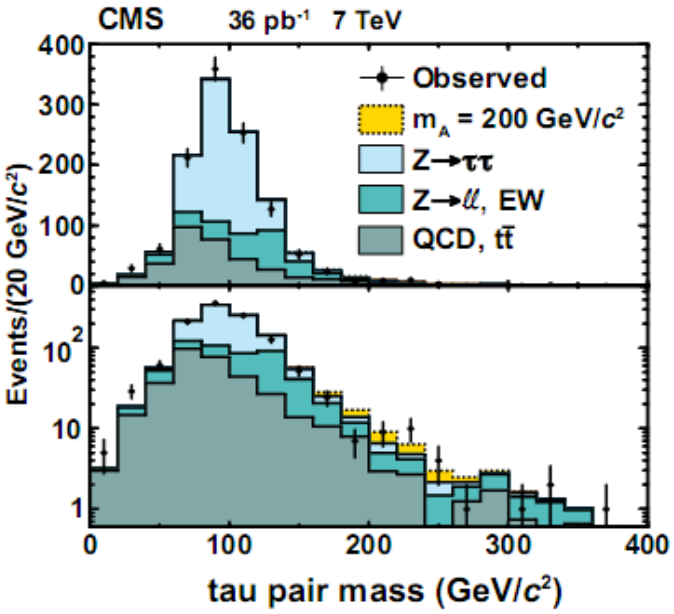
- Z->TauTau
  - MC based shape, with normalization taken from Z->ll CMS measurement (2%)
  - data driven normalization for event categories (using Z->mumu)
- QCD (e+tau and mu+tau)
  - taking SS data and apply correction for OS/SS ratio
    - W+Jets and Z->ll contamination properly subtracted
    - OS/SS ratio measured with single lepton triggers
- W+Jets (e+tau and mu+tau)
  - MC based shape
  - normalization taken from sidebands (reverting the Pzeta cut)
- Fake electrons bkg (for e+mu only)
  - mostly QCD, Z->ll, W+jets. Taken from data using fake rate method
    - uncertainty of 30% used in the fit
- TTbar
  - MC based shape, with normalization taken from CMS measurement
    - 12% uncertainty in the fit
  - data driven normalization for event categories using sidebands
- Di-boson (WW/ZZ/WZ)
  - taken from MC (30% uncertainty in the fit)
- Z->mumu (mu+mu case)
  - bkg normalization and shape taken with sidebands on the Likelihood based variable

Systematic Uncertainties

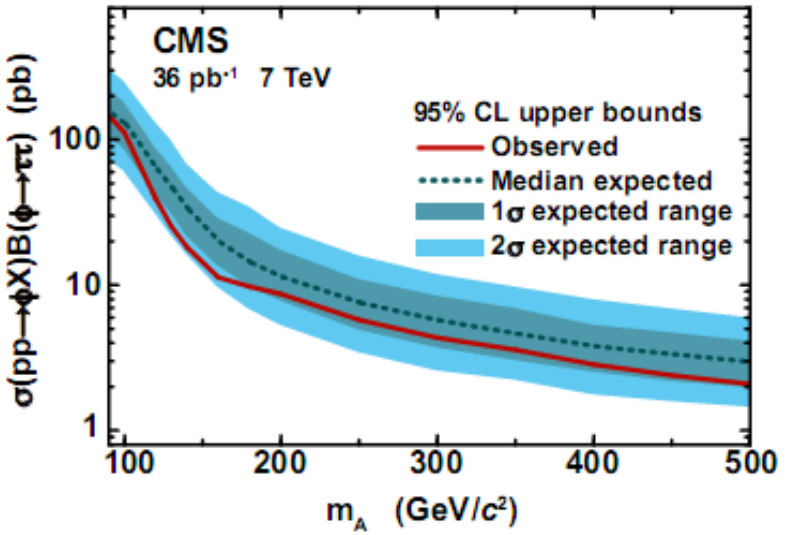
Source	Uncertainty	Final state affected
Normalization Uncertainties		
Tau ID efficiency	6%	$e+\tau_h, \mu+\tau_h$
Luminosity	6%	all
Electron ID & trigger efficiency	2.0 %	$e+\tau_h, e+\mu$
Muon ID & trigger efficiency	2.0 %	$\mu+\tau_h, e+\mu$
b-tagging efficiency	10%	all
Shape Uncertainties		
Muon momentum scale	1%	$\mu+\tau_h, e+\mu$
Electron energy scale	2%	$e+\tau_h, e+\mu$
Tau energy scale	3%	$\mu+\tau_h, e+\tau_h$
Jet energy scale	5%	all

Uncertainty's source	
Muon Momentum Scale	<< 1%
τ-Jet Energy Scale	< 1%
Track Reconstruction	3.9%
Track Momentum Scale	< 1%
Lead. Track P_T Cut	1%
Loose Isolation	2.5%
Jet → τ_{had} Fakes	1.2%
Lead. Track Corr. Factor	1.7%
Loose Iso. Corr. Factor	2.1%
Fit (Statistical Uncertainty)	2.6%
Total uncertainty	6%

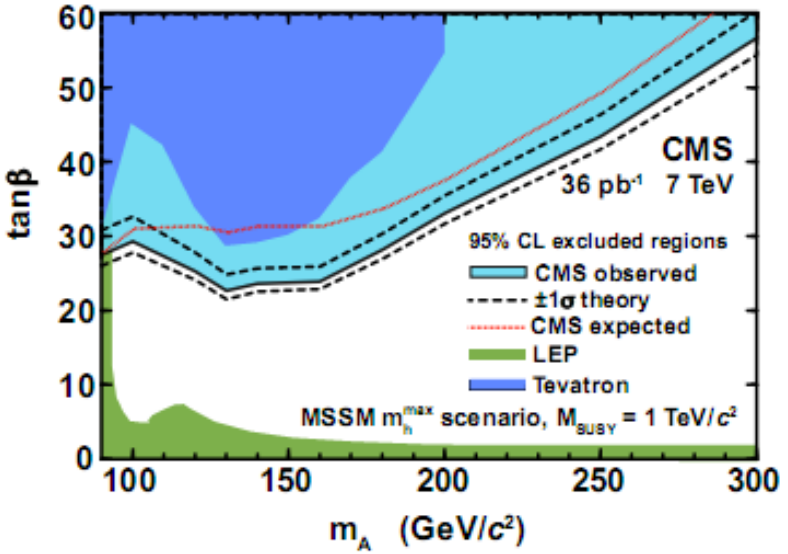
Analysis Results: 2010 data



Physical Review Letters 106, 231801 (2011)

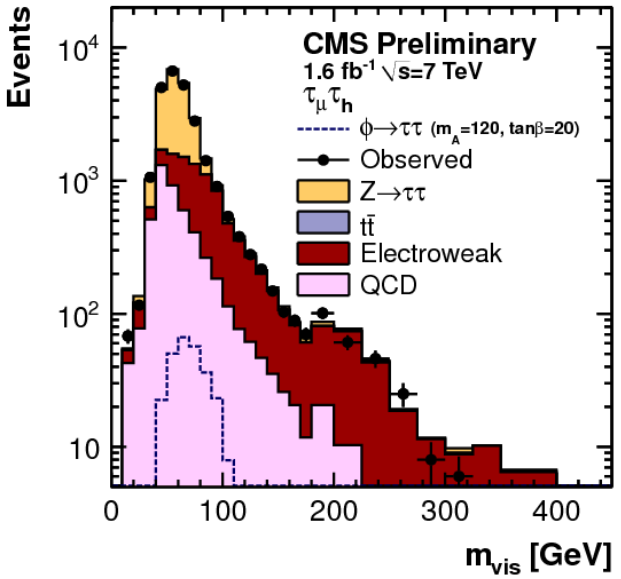


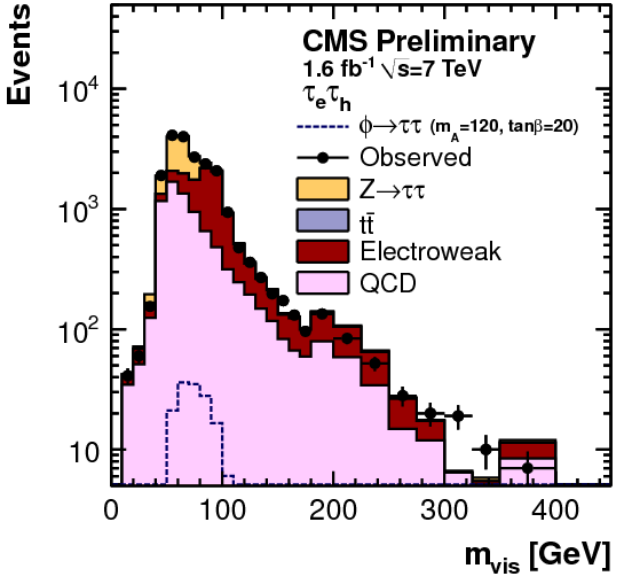
Process	$\mu\tau_h$	$e\tau_h$	$e\mu$
$Z \to \tau\tau$	329 ± 77	190 ± 44	88 ± 5
$t\bar{t}$	6 ± 3	2.6 ± 1.3	7.1 ± 1.3
$Z \to \ell\ell$, jet $\to \tau_h$	6.4 ± 2.4	15 ± 6.2	-
$Z \to \ell\ell$	12.9 ± 3.5	109 ± 28	2.4 ± 0.3
$W \to \ell\nu$	54.9 ± 4.8	30.6 ± 3.1	
$W \to \tau\nu, \tau \to \ell\nu\bar{\nu}$	14.7 ± 1.3	7.0 ± 0.7	1.5 ± 0.5
QCD multijet and γ+jet	132 ± 14	181 ± 23	
WW/WZ/ZZ	1.6 ± 0.8	0.8 ± 0.4	3.0 ± 0.4
Total	557 ± 79	536 ± 57	102 ± 5
Observed	517	540	101
Signal Efficiency	0.0391	0.0245	0.00582

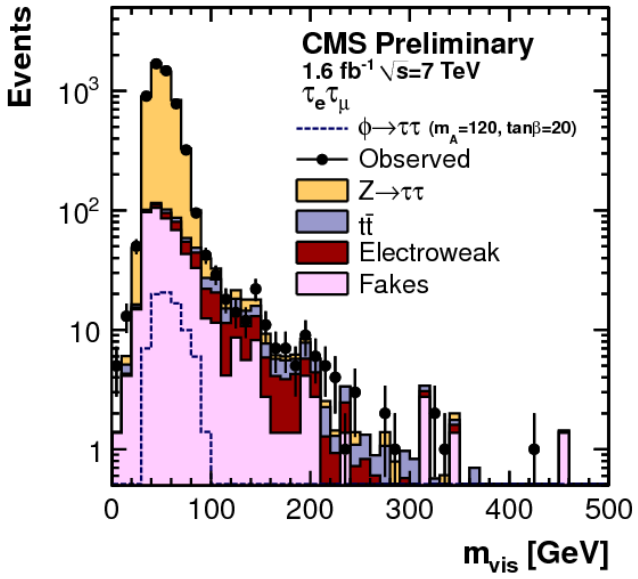


Analysis Results: 2011 data

CMS PAS HIG-11-020







Process	Incl. Sel.
Di-Boson	132 ± 41
$t\bar{t}$	727 ± 86
Z^{l+jet}	488 ± 61
Z^{ll}	220 ± 57
$W + jets$	5544 ± 376
QCD	4868 ± 221
$Z \to \tau\tau$	15853 ± 1129
Total Background	27830 ± 1217
Data	27952

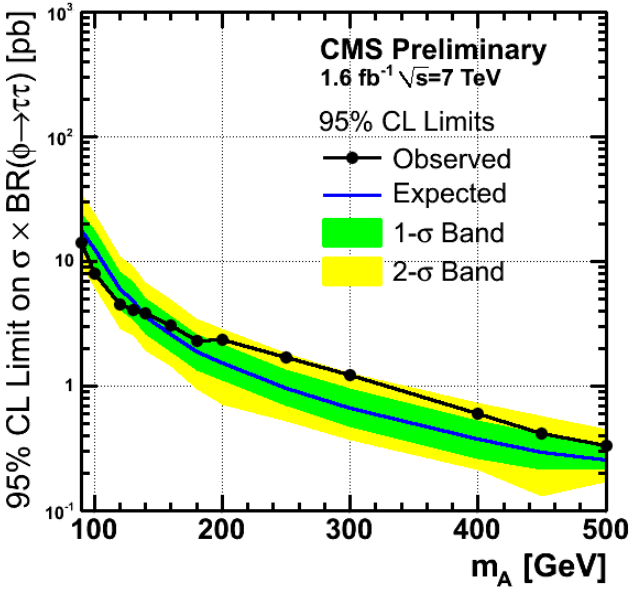
Process	Incl. Sel.
Di-Boson	57 ± 18
$t\bar{t}$	367 ± 44
Z^{l+jet}	805 ± 95
Z^{ll}	2451 ± 208
$W + jets$	3428 ± 237
QCD	8086 ± 418
$Z \to \tau\tau$	6042 ± 433
Total Background	21235 ± 686
Data	22070

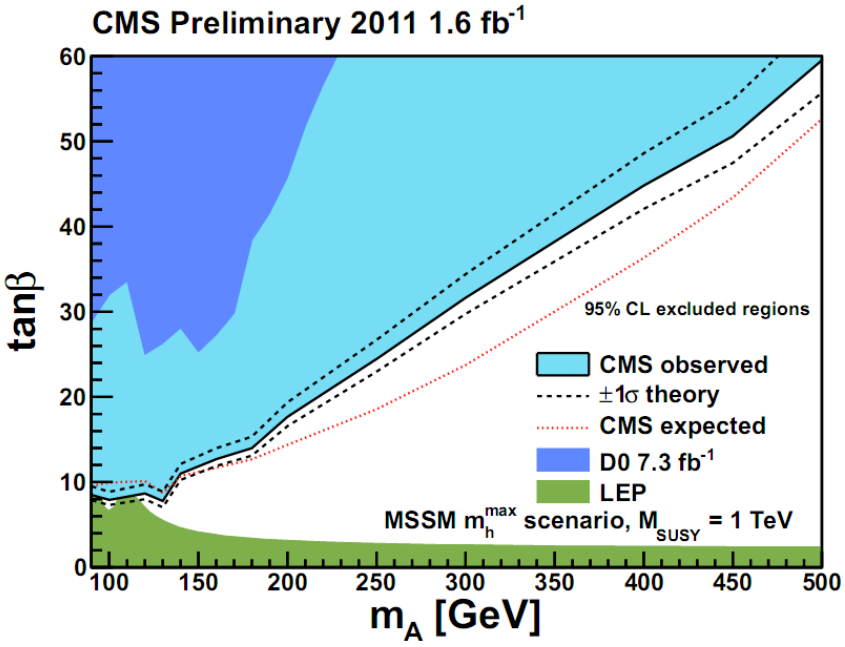
Process	Incl. Sel.
Di-Boson	205 ± 61
$t\bar{t}$	941 ± 94
Fakes	508 ± 152
$Z \to \tau\tau$	5077 ± 152
Total Background	6731 ± 243
Data	6712

Analysis Results: 2011 data

Mass m_A	-95%	-68%	median	+68%	+95%	obs	tan β exp	tan β obs
90	9.2	12.4	17.8	24.9	34.6	14.1	9.6	8.5
100	6.2	8.6	12.6	18.3	24.7	8.0	10.0	7.9
120	2.9	4.1	6.0	8.4	11.2	4.5	10.1	8.7
130	2.6	3.4	4.8	6.9	9.3	4.1	8.8	7.8
140	1.9	2.6	3.7	5.1	6.9	3.8	10.7	11.0
160	1.5	1.9	2.6	3.7	5.0	3.1	11.7	12.7
180	0.94	1.3	1.9	2.6	3.5	2.3	12.7	14.0
200	0.70	1.1	1.5	2.2	2.9	2.4	14.4	17.7
250	0.52	0.70	0.96	1.4	1.8	1.7	18.6	24.5
300	0.37	0.47	0.66	0.96	1.3	1.2	23.8	31.7
400	0.21	0.26	0.38	0.54	0.73	0.60	36.3	44.8
450	0.13	0.21	0.29	0.42	0.58	0.42	43.4	50.6
500	0.17	0.21	0.25	0.33	0.46	0.34	52.7	59.5

Analysis Results: 2011 data





CMS setting world's best limits for MSSM Higgs search
We are almost done with the invasion of the LEP valley

What is the future of the MSSM model? Is it dying?
What is the scenario with supersymmetry search at LHC?
Does a SUSY Higgs really exist? Can we think beyond SUSY?

A non-SUSY scenario

A bound state from a strongly interacting sector – emerges as a pseudo-Goldstone boson from a global symmmetry
Composite Higgs models - Higgs mass generated dynamically through loops of SM fermions and gauge bosons
Prospects - low mass composite Higgs in ττ channel in association with b-jets

Probing the composite nature of Higgs –

- **Anomalous couplings**
  Guidice, Grojean, Pomarol, Rattazzi ’07
- **Strongly scattering**
  Contino, Grojean, Moretti, Piccinini, Rattazzi ’10
- **Identifying discrete symmetries of strong sector**
- **Detecting heavy resonances**

To Higgs or not to Higgs, that is the question
Extra-dimensional Higgsless models, Technicolor models …

Picture taken from Christophe Grojean’s slides of SUSY’11