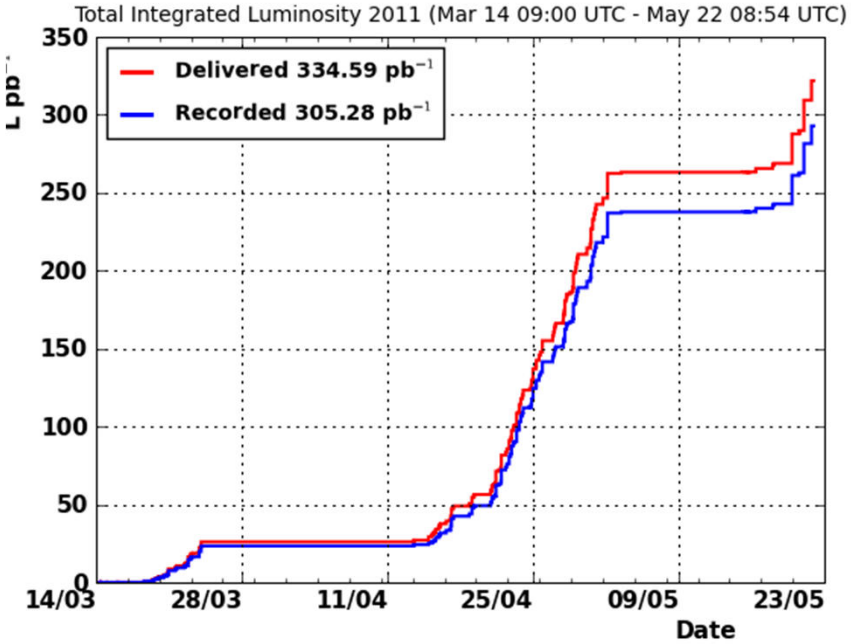
Higgs Searches at CMS

Alexei Raspereza

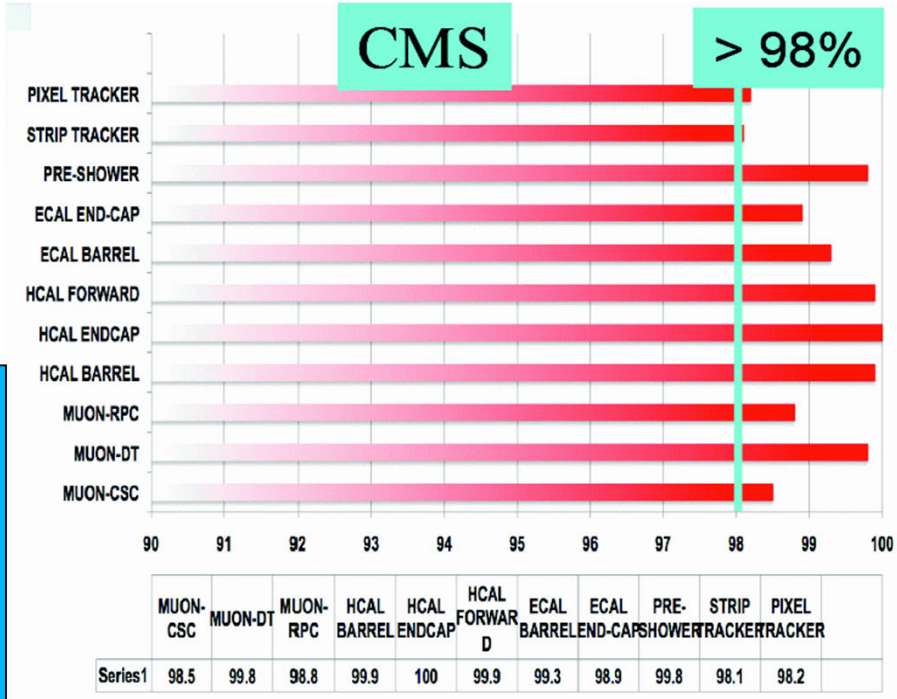
LHC Physics Discussions (Higgs), May 23rd 2011

Status of CMS



data taking efficiency > 91%

190 pb^{-1} of certified good data at disposal of analyzers



	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

≈100M channels
>98% channels operational
⟶ robust event reconstruction

Basic Pillars of Higgs Searches

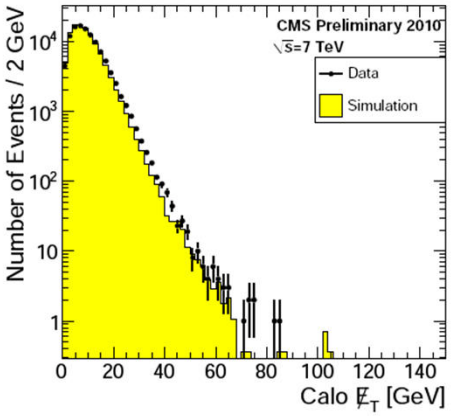
- Efficient Higgs search requires excellent performance from the entire detector in reconstruction of physics objects
- Key objects
  - Photon ($H \to \gamma\gamma$)
  - Electron and Muon ($H \to WW \to 2\ell 2\nu$, $H \to ZZ \to 4\ell$)
  - Tau lepton ($H \to \tau\tau$, $H \to \tau\nu$)
  - B-tagging (boosted Higgs, $HW \to bb\ell\nu$, $HZ \to bb\ell^+\ell^-$)
  - Jets (VBF $WW \to Hqq$)
  - Missing Transverse energy ($H \to WW \to 2\ell 2\nu$, $HW \to bb\ell\nu$, etc)
- Objects commissioning with “standard candles”
- Calibration of searches: measurements of relevant background processes

Commissioning of Physics Objects

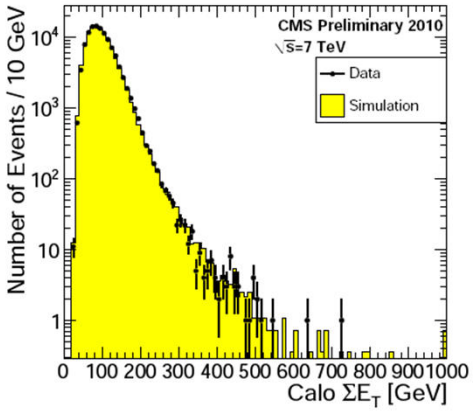
In context of any physics analysis (e.g. Higgs searches) the primary use of first data is to calibrate and commission physics objects relevant for a given physics analyses:

Physics Objects	SM processes used for commissioning
Muons	J/Ψ, Υ(1S,2S,3S), Z → μμ
Electrons	J/Ψ, Υ(1S,2S,3S), Z → ee
Photons	QCD Compton: $gq \to \gamma q$; $\pi^0/\eta \to \gamma\gamma$
Jets	Z+jet, Z→μμ ; QCD dijets
B-tagged jets	jets with muons, ttbar production
MET	Minbias; QCD dijets; W→ℓν
Tau leptons	fake rate with QCD, efficiency from Z→μμ vs Z→ττ comparison assuming lepton universality

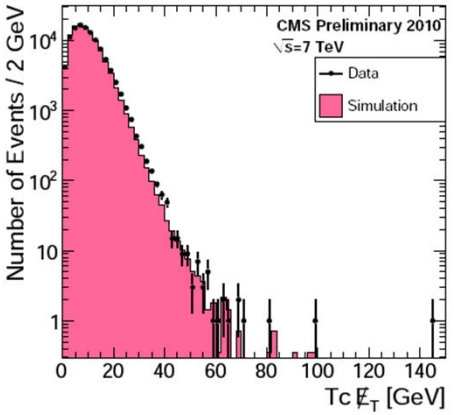
Performance of Physics Object Reconstruction : MET



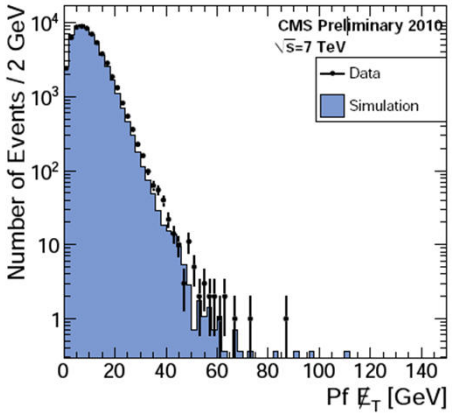
(a) calo$\not\!\!E_T$ distribution



(b) calo$\sum E_T$ distribution



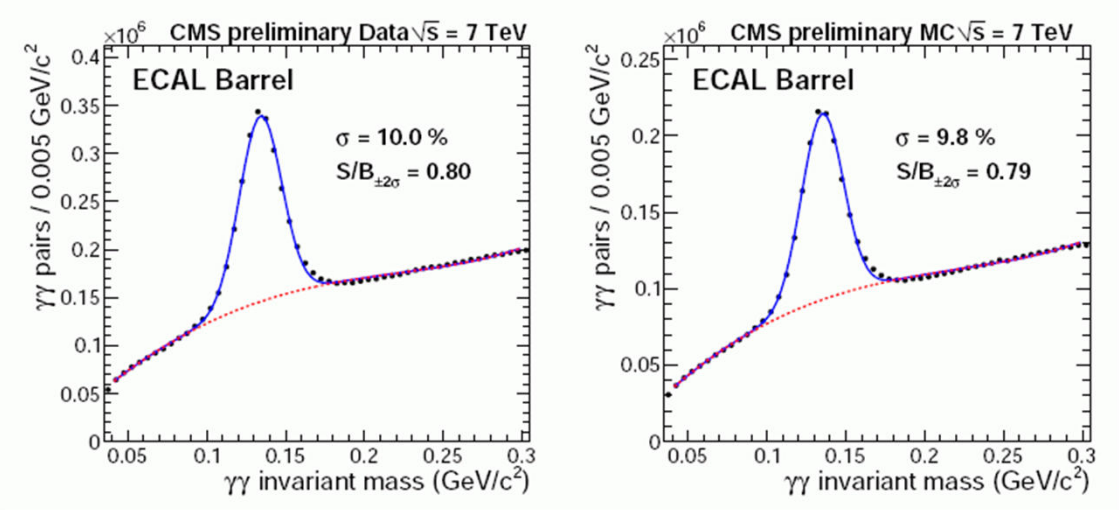
(c) tc$\not\!\!E_T$ distribution



(d) pf$\not\!\!E_T$ distribution

- ***E_T^{miss} in dijet events***
- Good data vs. MC agreement
- New concepts are verified and proved to have high analyzing power
  - Track corrected E_T^{miss}
  - Particle flow concept
- Strategies for PU corrections validated

Physics Object Reconstruction : Photons



In-situ calibration

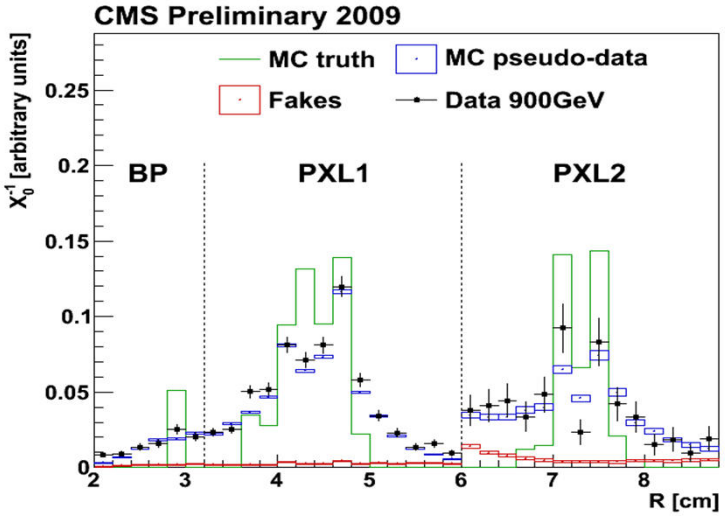
- $\pi^0 \rightarrow \gamma\gamma$
- $\eta \rightarrow \gamma\gamma$

Efficient reconstruction of conversions →

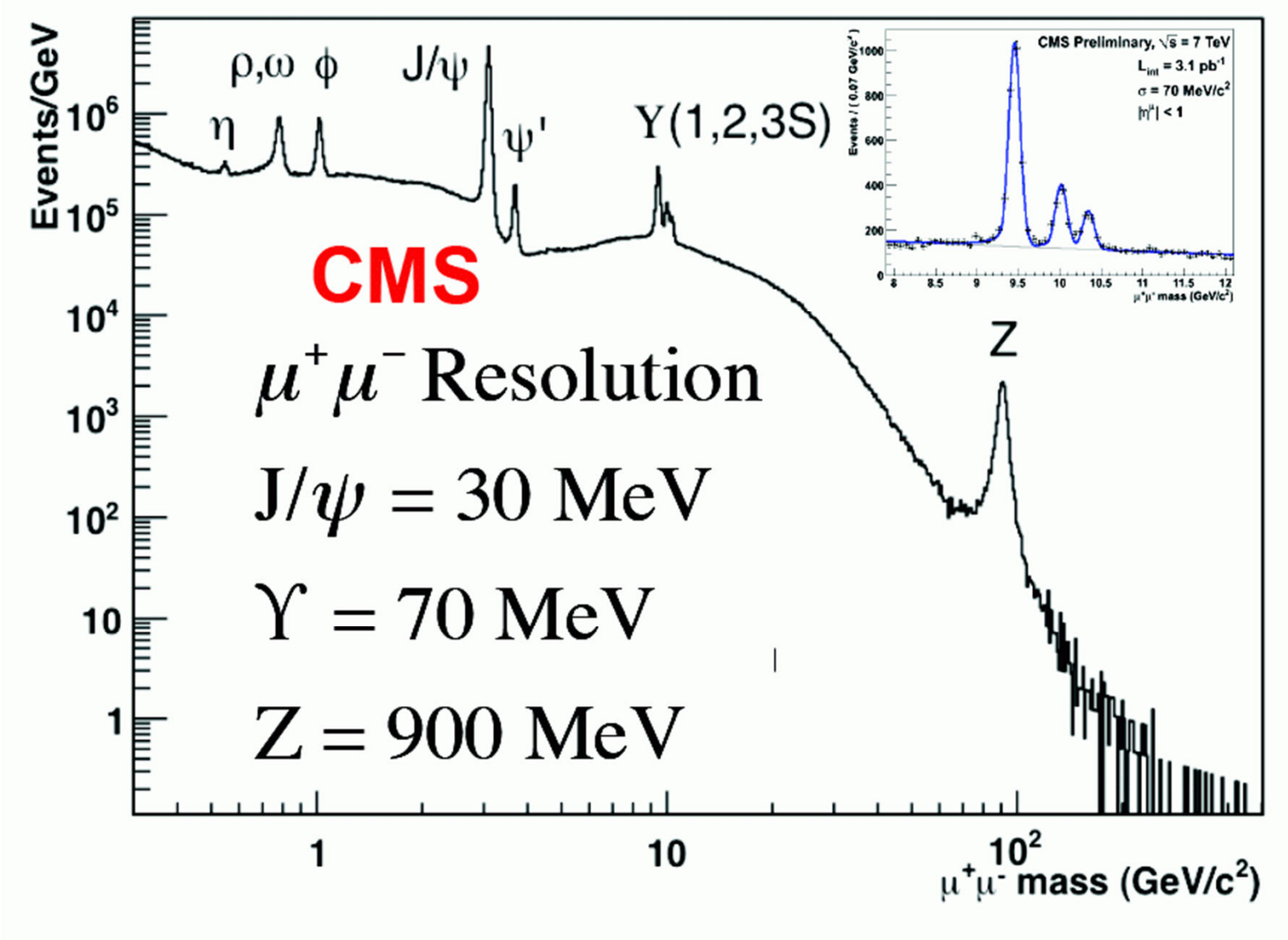
- Radiography of tracker!

- Sophisticated (η-φ) strip clustering of EM objects

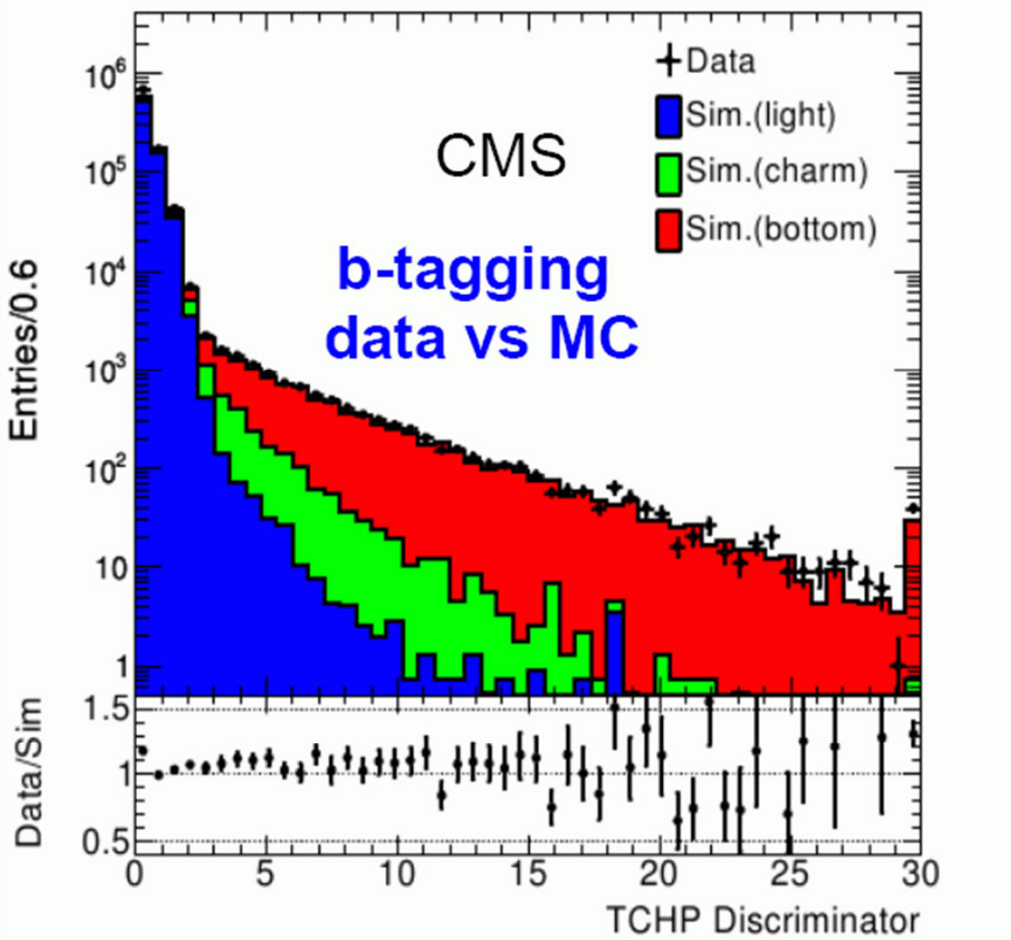
→ recovery for breamsstrahlung in reconstruction of electrons



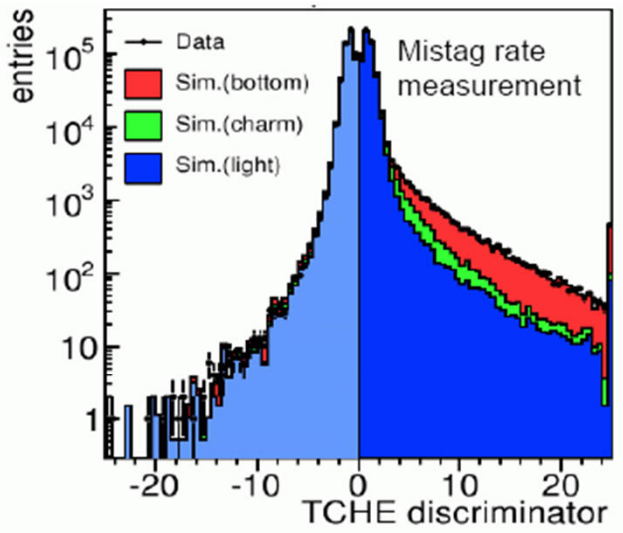
Reconstruction of Physics Objects: Muons

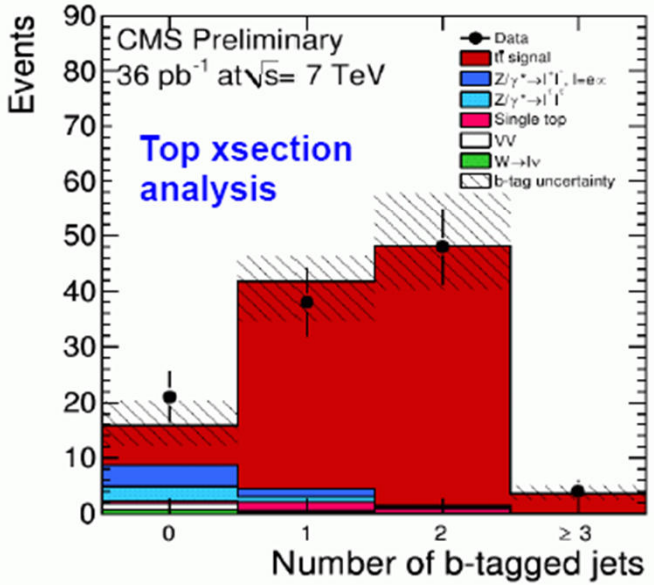


Reconstruction of Physics Objects: B-Jets



Efficiency and mis-tag rate evaluated from data.
Agreement with MC simulation within few %

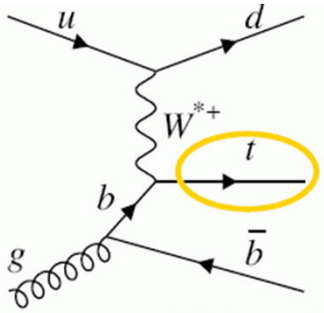




And putting all pieces together…

… we can detect very tiny signals… and convince ourselves that if Higgs is there it won't escape our net…

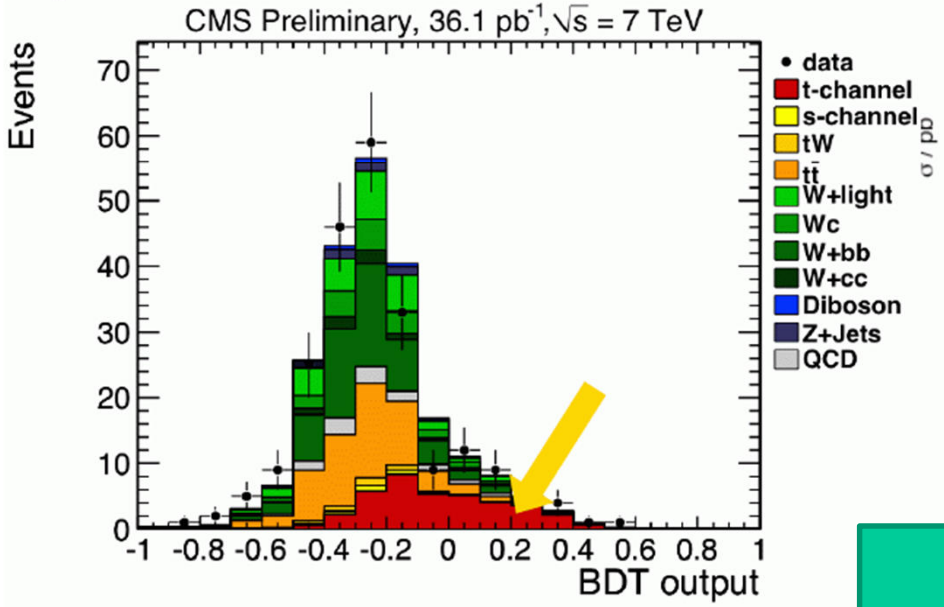
Detection of tiny signals with leptons, b-tag , MET and jets →

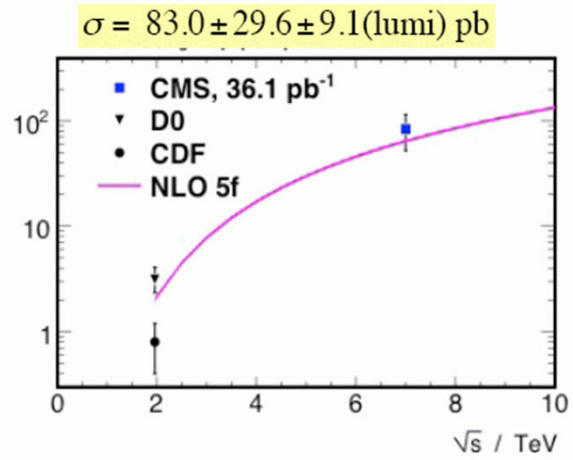


t channel
(σ ≈ 62 pb @ 7 TeV)

Two methods employed:

- Cut based using angular info
- MVA with 37 kinematic observables





gives us confidence!

CMS Public Results on Higgs Searches

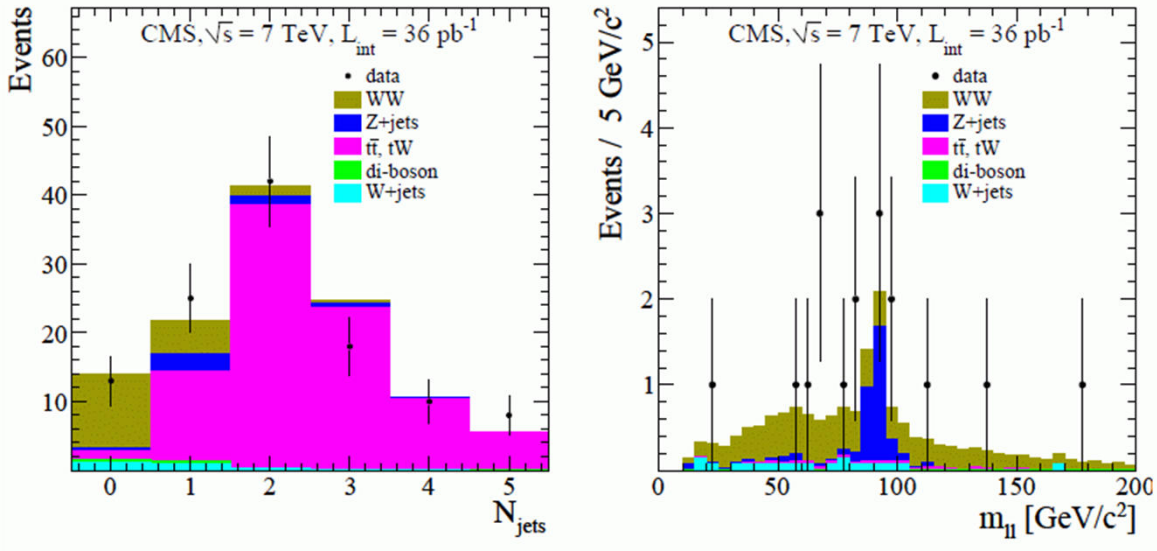
- Public results with 2010 data (L=36 pb^{-1})
  - Measurement of W^+W^- Production and Search for the Higgs Boson in pp Collisions at sqrt(s) = 7 TeV
    Phys.Lett. B695 (2011) 25-47
  - Search for Neutral MSSM Higgs Bosons Decaying to Tau Pairs in pp Collisions at sqrt(s) = 7 TeV
    arXiv: 1104.1619v1 [hep-ex], submitted to Phys.Rev.Lett.
  - Inclusive Search for Φ^{++} in leptonic final states at sqrt(s) = 7 TeV
    CMS Physics Analysis Summary HIG-11-001
  - Search for the Charged Higgs Boson in the $e\tau$ and $\mu\tau$ Dilepton Channels of Top Quark Pair Decays
    CMS Physics Analysis Summary HIG-11-002

$H \rightarrow WW \rightarrow 2\ell 2\nu$. Key Channel for $130 < m_H < 200$

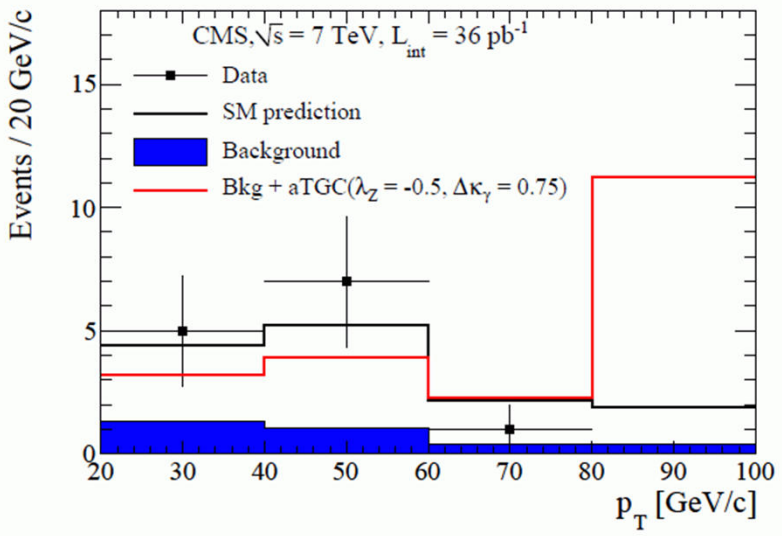
- WW Production
  - Distinguished by:

    $\Delta\varphi_{ll}$, m_{ll},

    N_{jets}, E_T^{miss}

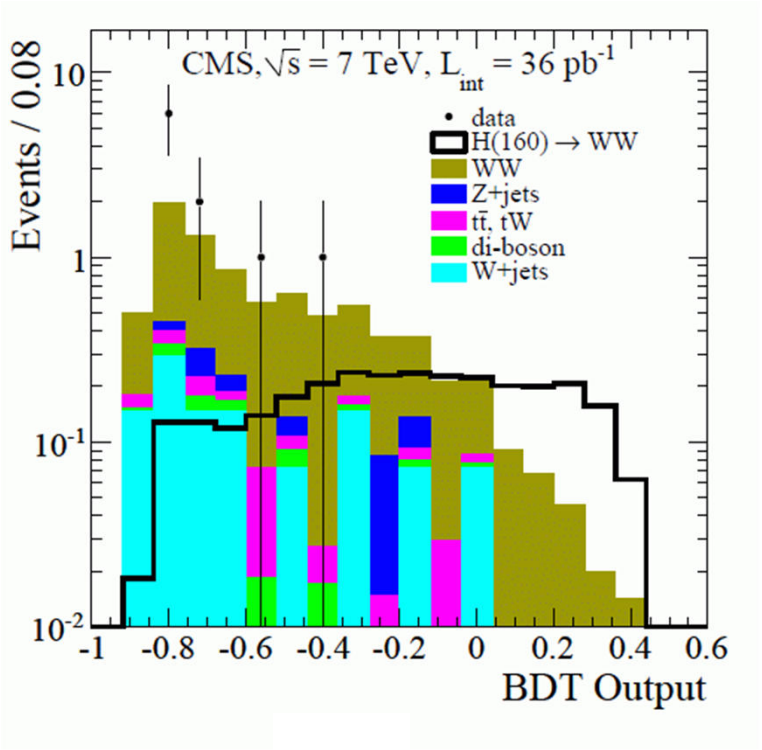


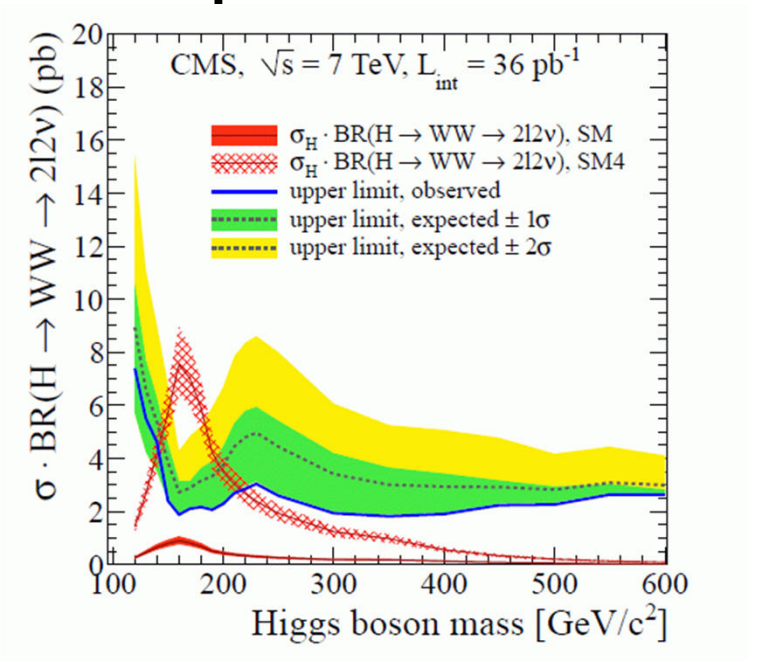
- CMS search for $H \rightarrow WW$ was preceded by studies of the non-resonant WW production
  - first di-boson measurement at LHC
  - Understanding of the main background for $H \rightarrow WW$ search
  - Probes of anomalous WW TGC couplings

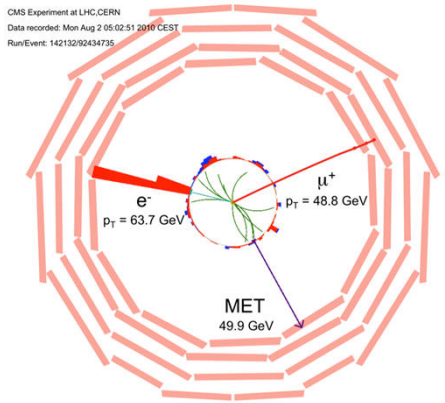


H→WW→2ℓ2ν Search Results

- **Count excess above a cut on MVA output**





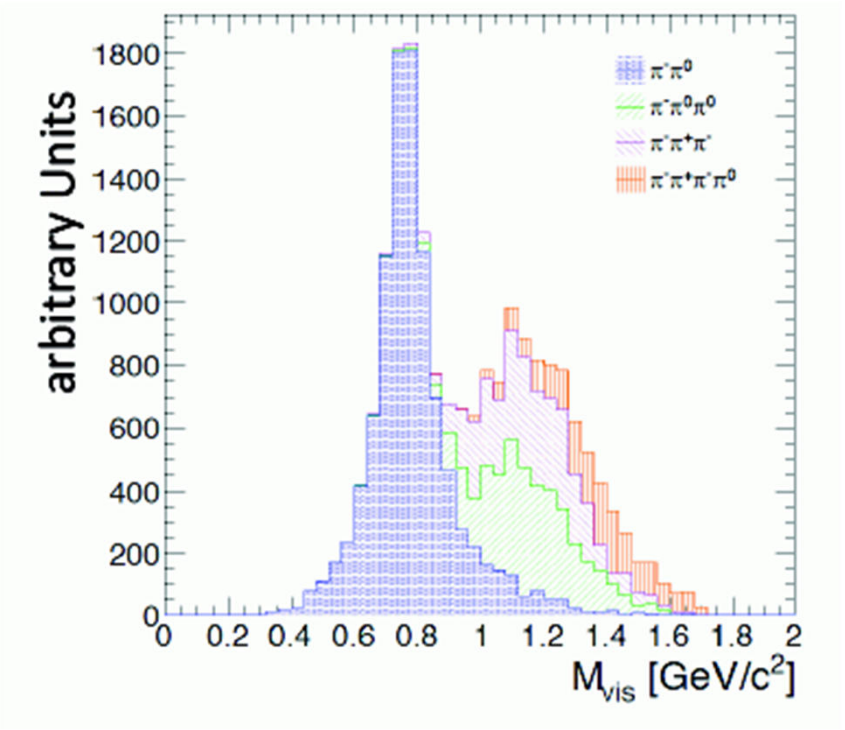


- **Backgrounds are assessed using data-driven techniques**
  - **measured non-resonant WW background**

σ(pp→WW) = 41.1±15.3(stat)±5.8(syst)±4.5(lumi)

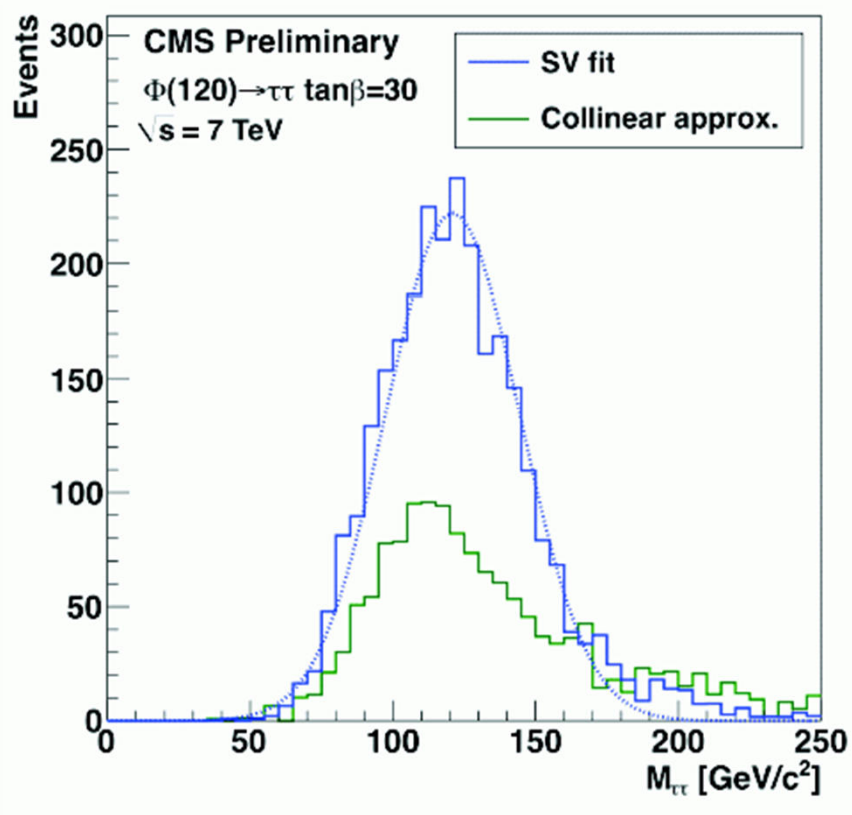
Higgs with Tau Leptons (Commissioning of Taus)

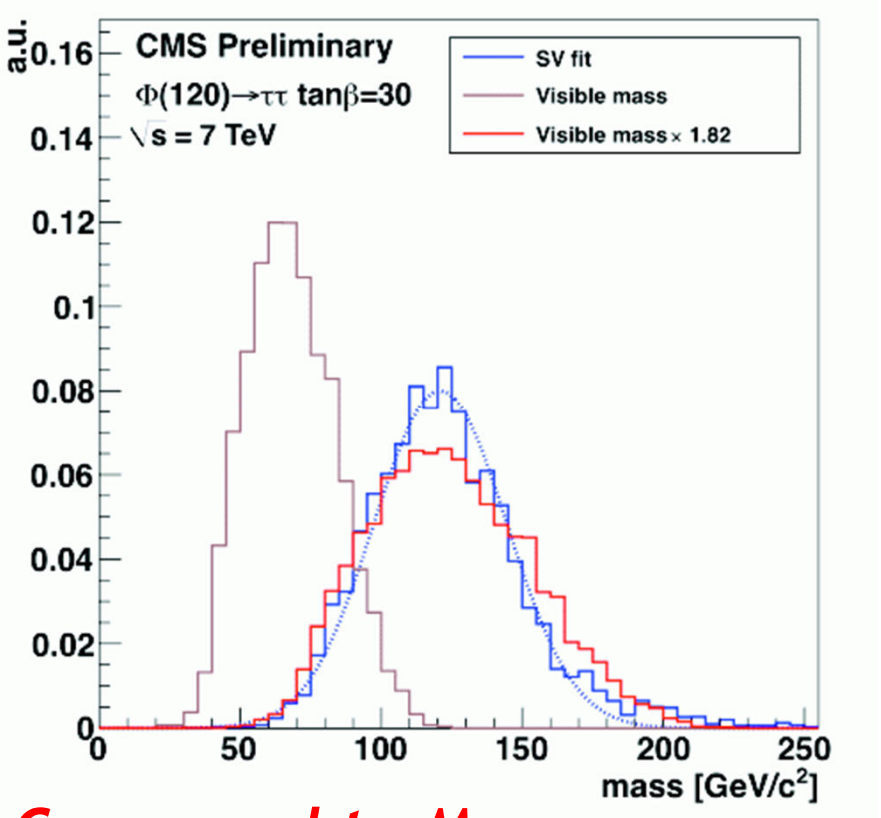
- Area where DESY Higgs group is actively working
- Reach and sophisticated toolkit for Tau reconstruction developed at CMS
  - Algorithms attempts to reconstruct tau decay mode, exploiting mass information
  - Full reconstruction of tau lepton pair kinematics via probabilistic approach [likelihood]
  - Identification of Tau decay vertex in 3-prong decays
  - improved ditau mass reconstruction
  - Tools for Tau ID efficiency measurements from data
  - etc..



Improved Ditau Mass Reconstruction

$$H \rightarrow \tau\tau \rightarrow \mu + \tau_{had}, \quad m_H = 120\,GeV/c^2$$



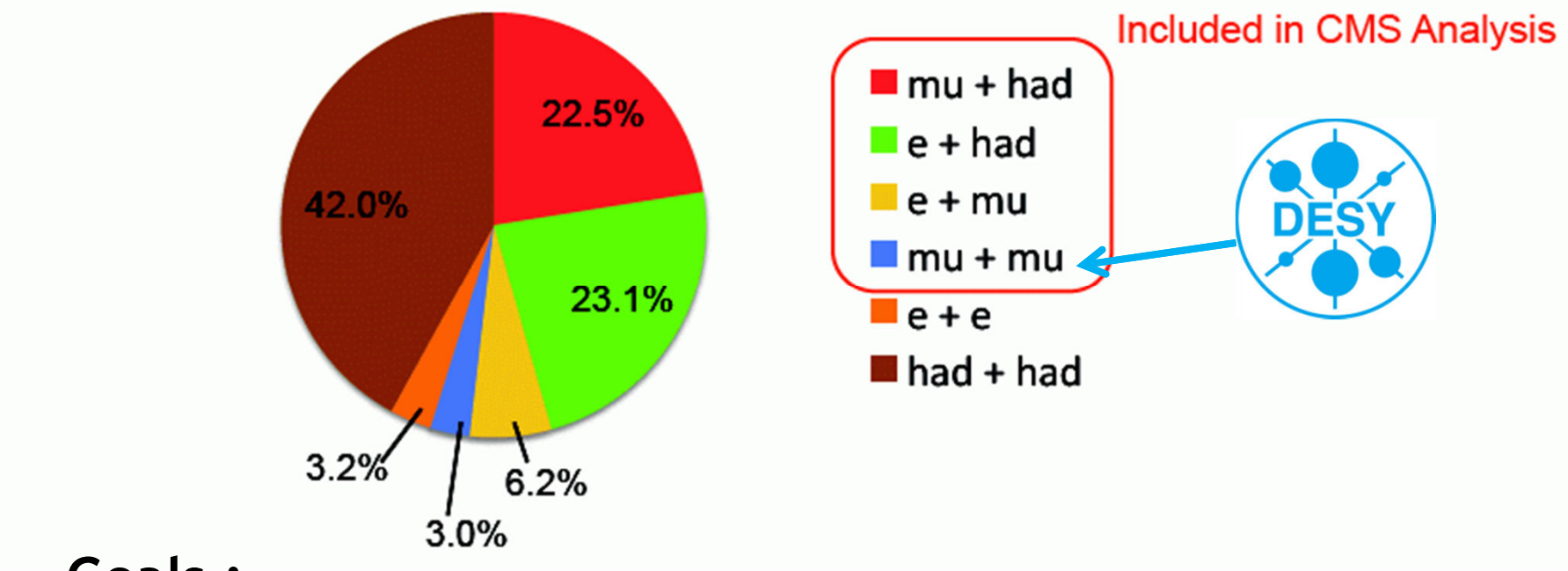


Compared to CA :
- provides better resolution
- increases statistics by factor 2

Compared to M_{vis} :
improves $\Delta M(\tau\tau)/M(\tau\tau)$;
establishes linear correlation between $M_{\tau\tau}$(reco) & $M_{\tau\tau}$(true)

Commissioning of H→ττ with Z→ττ "Standard Candle"

- Data sample : 36 pb^{-1} , $\sqrt{s}$ = 7 TeV

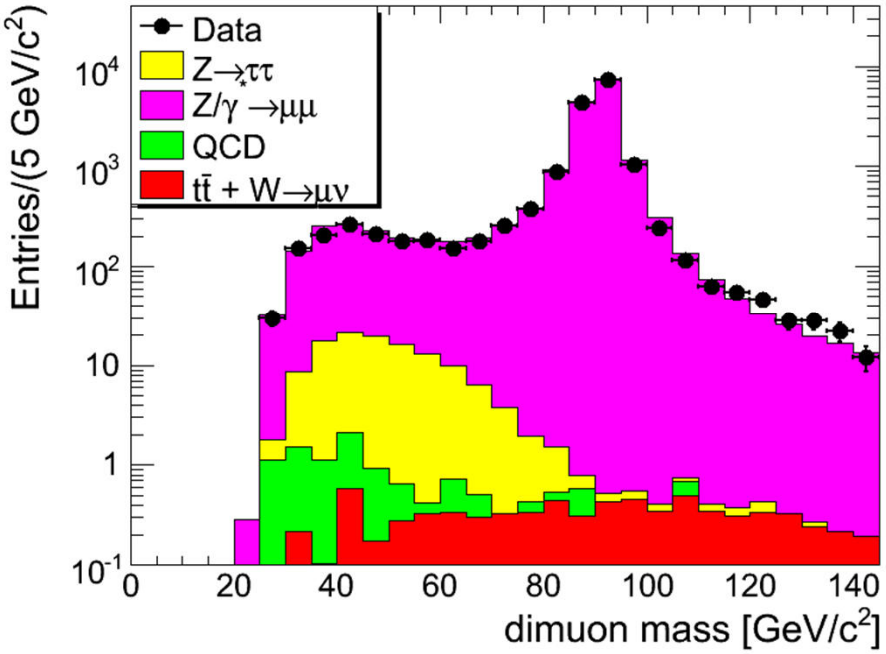


- Goals :
  - Measurements of σ(pp→Z)·Br(Z→ττ)
    → test of NNLO calculations
  - Evaluation of Z→ττ background for MSSM Higgs → ττ searches
  - Commissioning of analyses searching for MSSM Higgs → ττ
  - Study τ-id performance

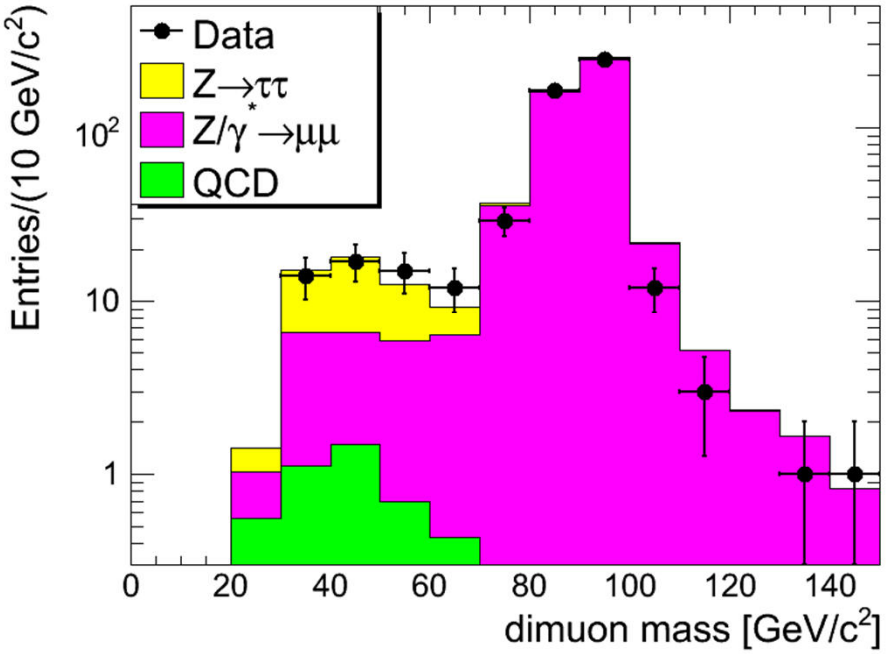
H/Z→ττ→μμ Channel

- A novel analysis develped by DESY group
- Challenges
  - Large direct Drell-Yan background
  - Relatively small topological branching *B(ττ→2μ4ν)≈3%*

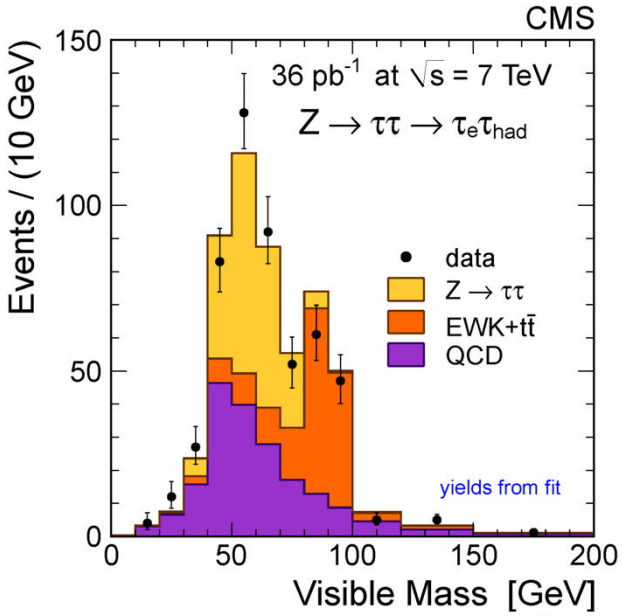
Conventional dimuon selection → S/√B=0.5

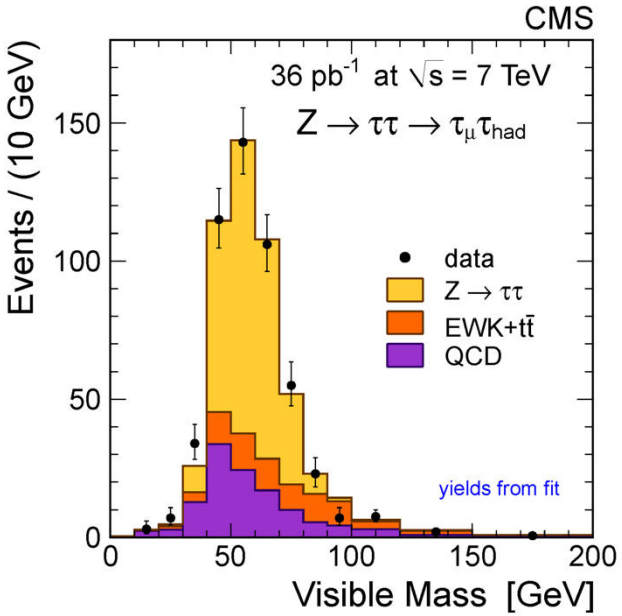


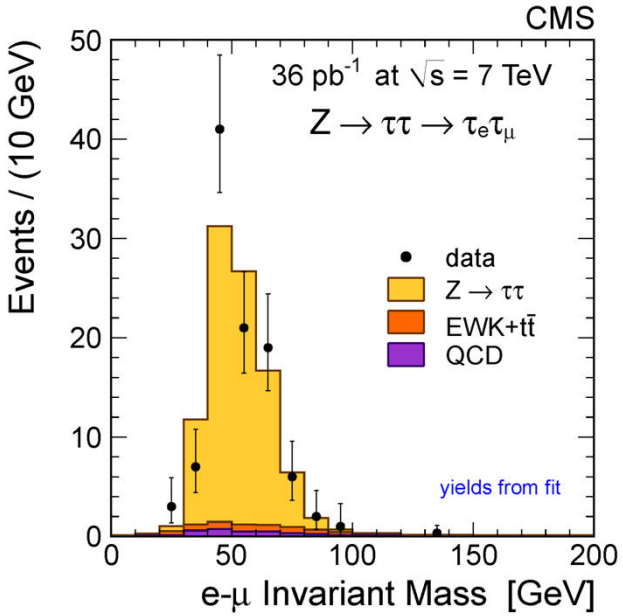
Dedicated MVA Z→ττ→μμ selection → S/√B=6

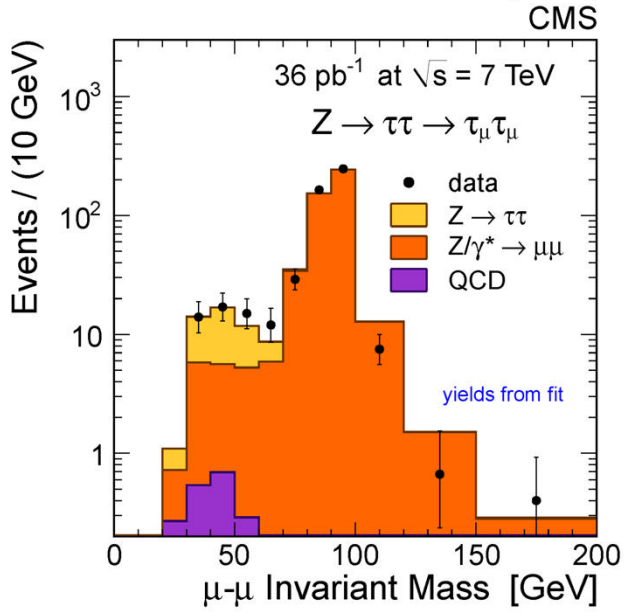


Study of the Z→ττ "Standard Candle"

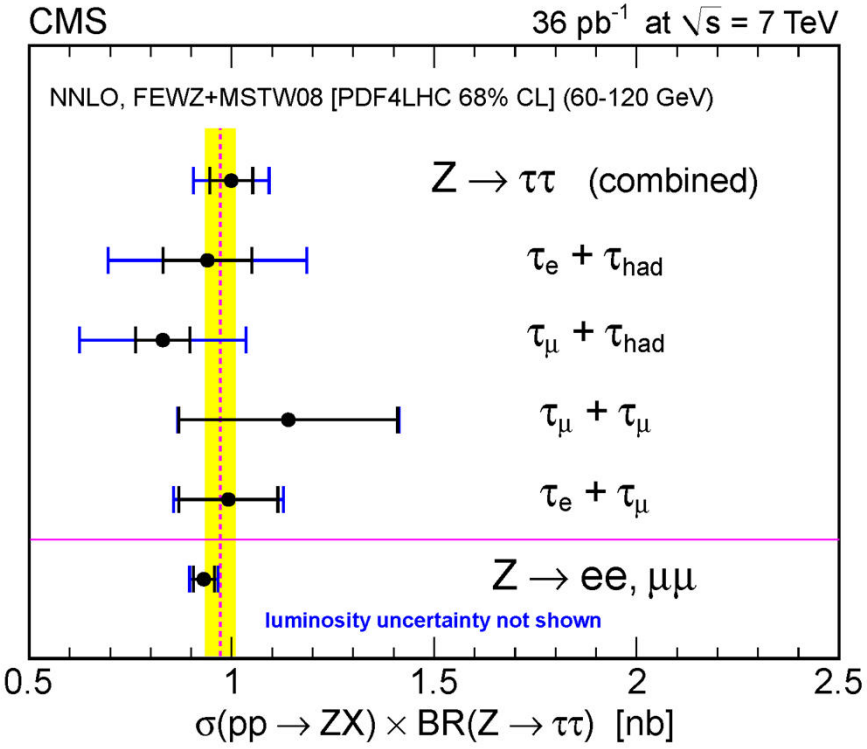


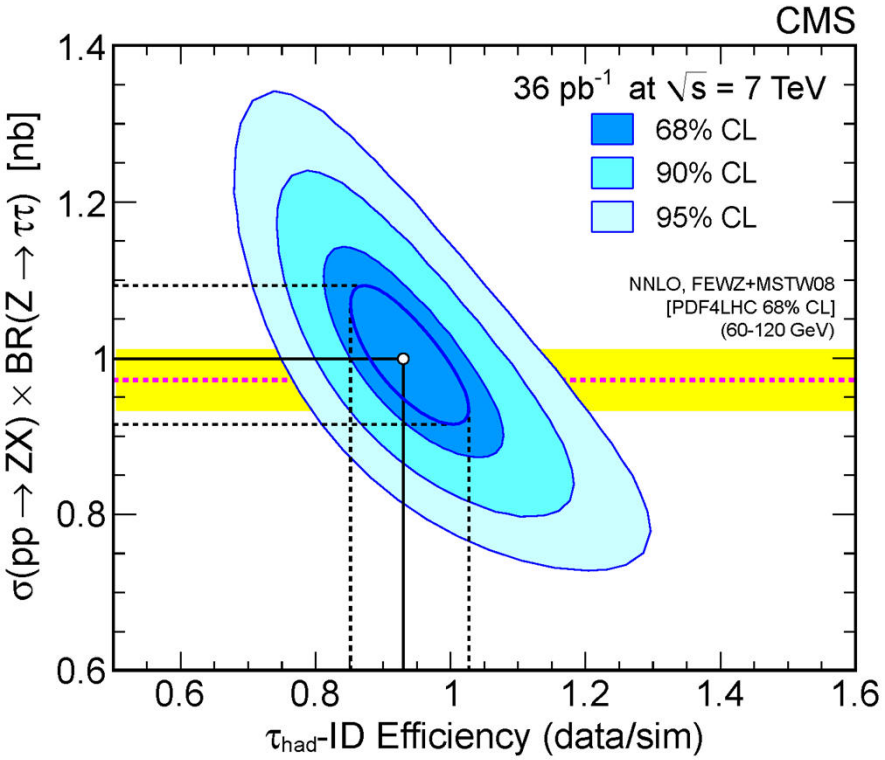






Z→ττ Cross Section Measurement





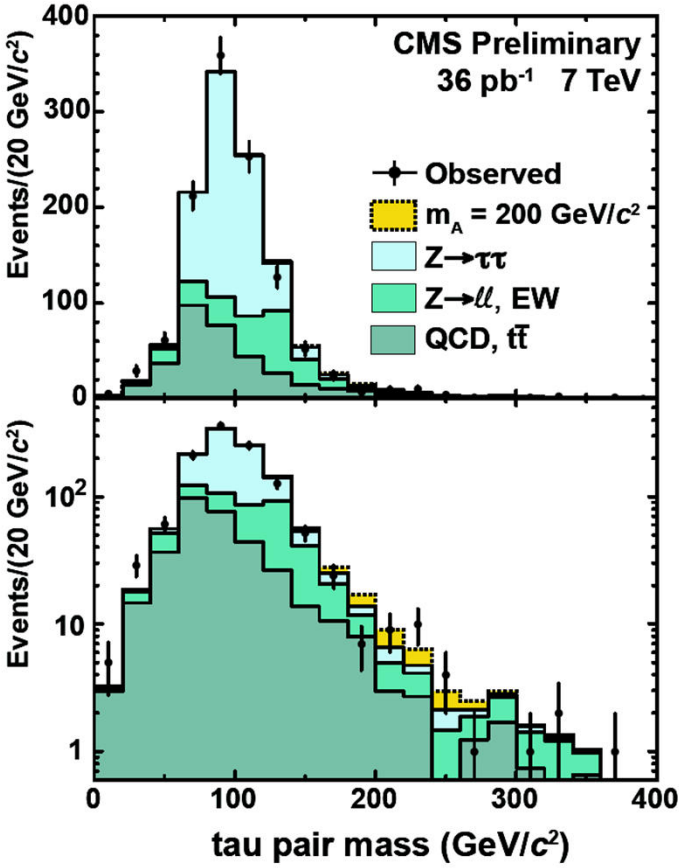
- **Tau ID efficiency from fits**
  - **Combined M_{vis} fit in Z→ττ channels : Data/MC = 0.94 ± 0.09**
  - **Fits with σ(pp→Z) fixed to measurements in Z→ee,μμ channels : Data/MC = 0.96 ± 0.07**

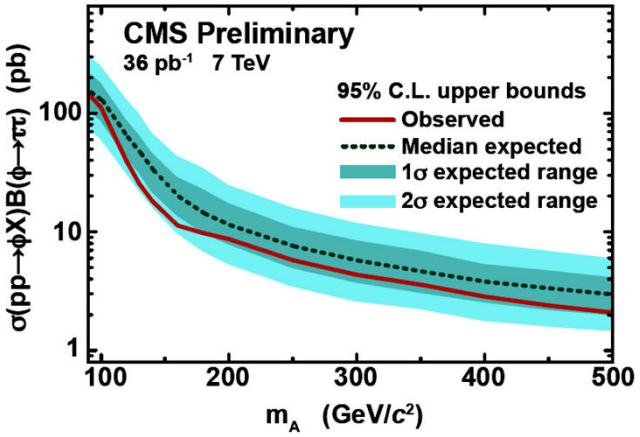
Development of H→ττ→μμ Analysis by DESY Group

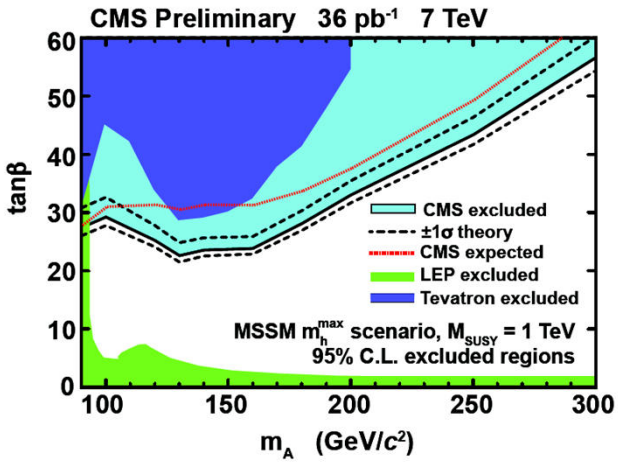
- DESY group develops a novel analysis in the H→ττ→μμ channel
  - Striking success, despite challenges…
- Very promising first results
  - Analysis is competitive in sensitivity with other channels
  - at the moment search is inclusive
  - improvements with b-tagging are anticipated
  - extended analysis for the VBF production of the SM Higgs
- …no public results with 2011 data yet
- …but channel has good prospects and will be included in the CMS-wide combination of Higgs searches
- by-product : MVA of the H→ττ→e+μ channel
  - competes with the reference analysis
  - has common systematics with the H→ττ→μμ model

Results of MSSM H→ττ Searches with 2010 Data

- Channels considered: $\mu+\tau_{had}$ $e+\tau_{had}$ $e+\mu$ without our channel yet…





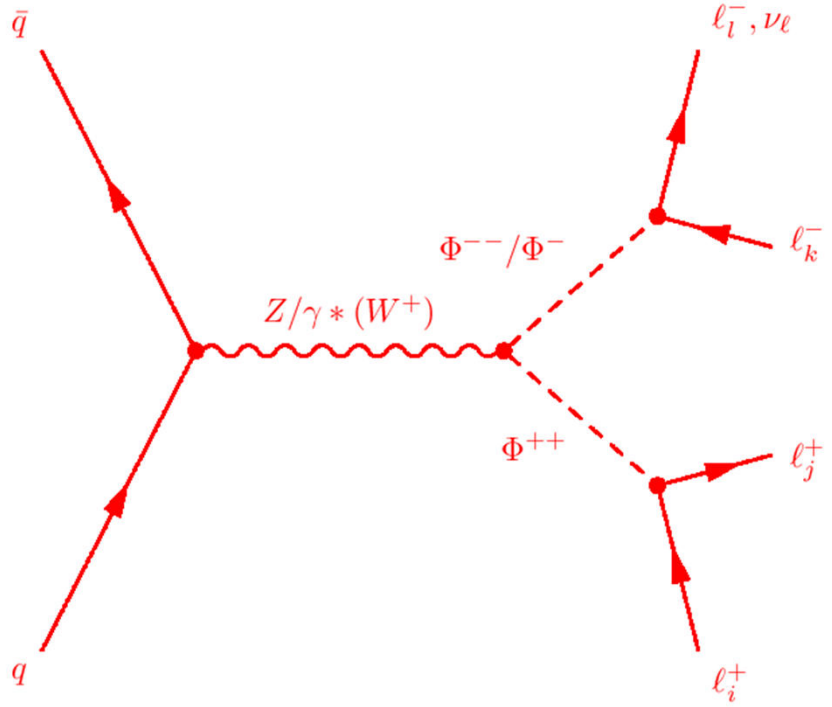


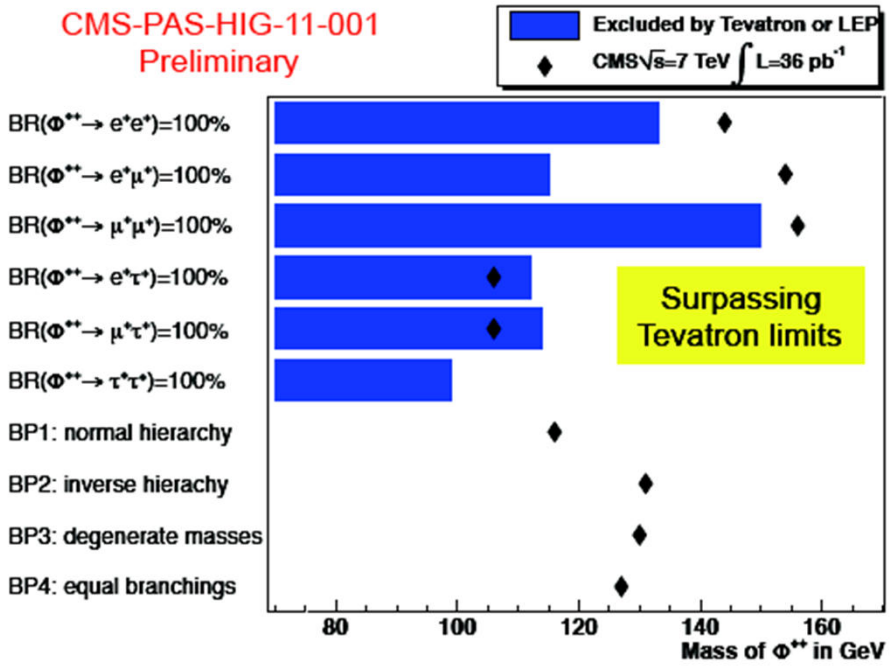
- We had to prove that the dimuon channel worthwhile invested efforts → channel will be include in the next round of CMS combination of H→ττ searches

Exotic Higgs Searches

$\Phi^{++} \rightarrow \ell^+ \ell^+$

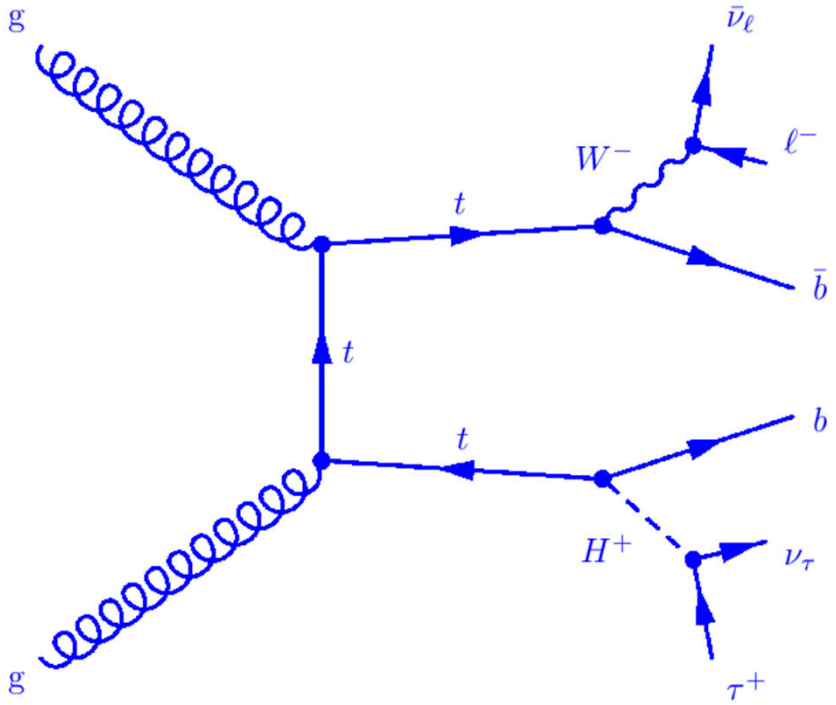
- Arises in models with Higgs triplets
- Triplet responsible for small neutrino mass
- Broad search (branchings unknown)
- Below $M \approx 2M_W$ only leptonic decays
- 4- and 3-lepton search

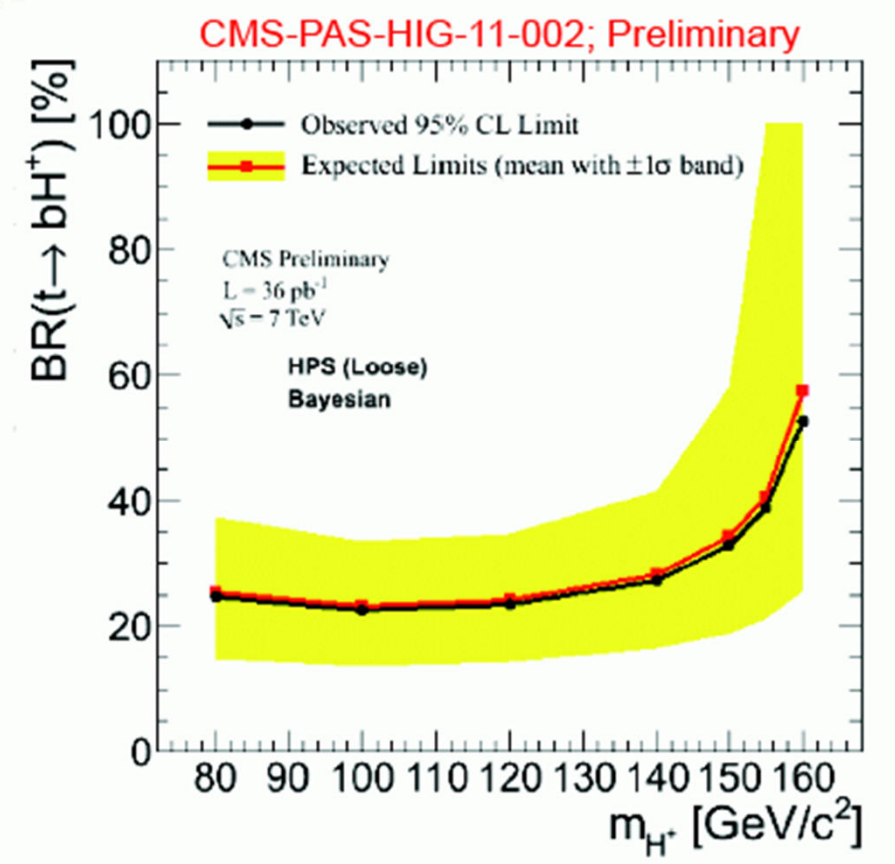




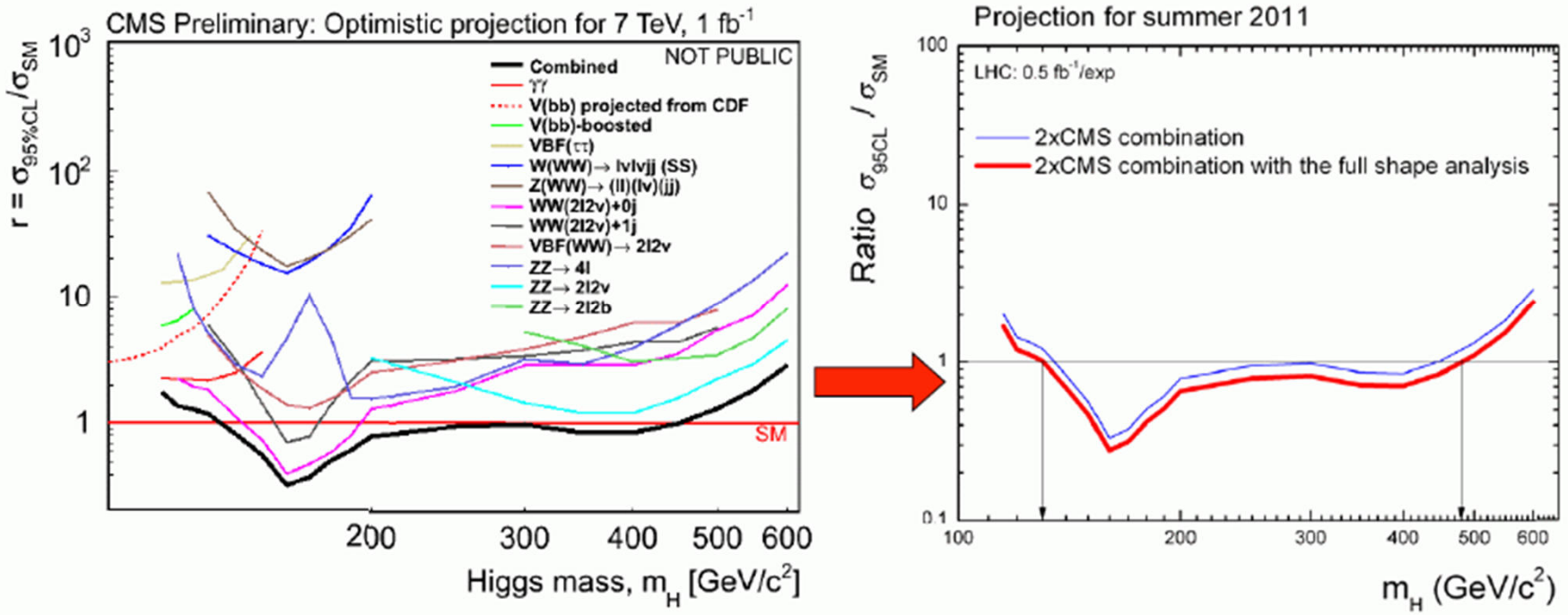
H^+ in Top Decays

- Top pair production followed by top decays:
  - $gg \rightarrow tt \rightarrow W^+bH^-b$
- H^+ is searched for via decay $H^+ \rightarrow \tau^+\nu$
- Hadronic tau decays exploited
- Tagging leptonic decay of W





SM Higgs Searches at CMS: Optimistic Forecast



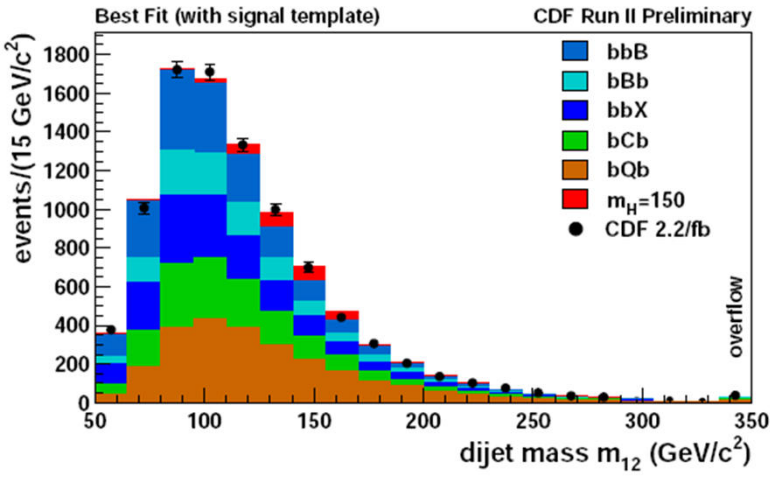
CMS should be able to exclude $130 < M_H < 480$ GeV

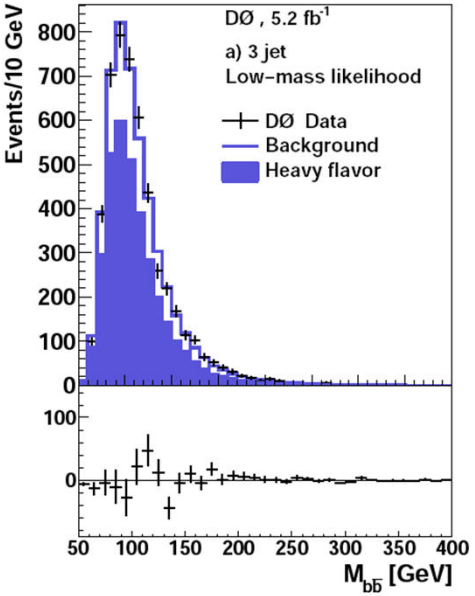
Picture should improve when more modes come into play

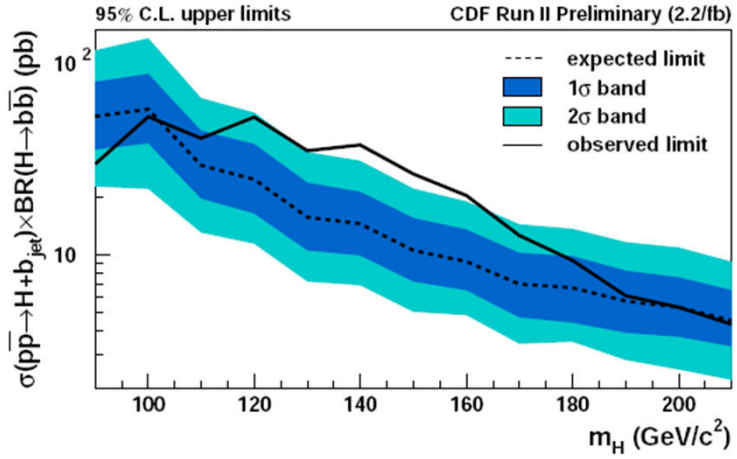
This includes improved sensitivity using MVA methods

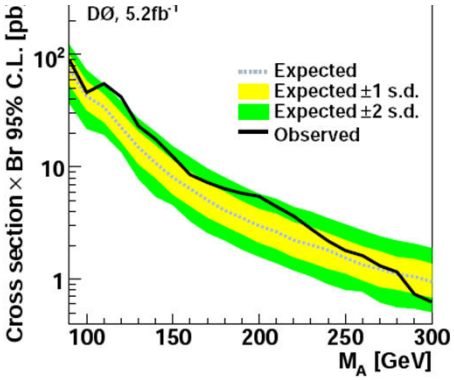
MSSM bbΦ→4b Channel. Revived Interest

- MSSM bbΦ→4b channel experiencing explosion of interest thanks to recent observations at Tevatron









- D0 and CDF observe excess in 3(4)b search in adjacent mass regions

MSSM bbΦ→4b Venture at CMS

- Extremely difficult channel to observe (huge QCD background)
- CMS DESY group is one of only three groups which took a challenge to tackle this channel
- … and we are already making substantial contributions to the bbΦ→4b enterprise at CMS
  - Dedicated fully hadronic trigger (3-jets/2-btags) developed and deployed in CMS trigger menu
  - with quickly increasing luminosity and constantly changing machine conditions, lifetime of triggers (at least in their un-prescaled incarnations) is extremely short
    - Need to keep up pace with quick developments & maintain permanent and coherent evolution of triggers
- no related public CMS results with 2011 data yet
- …but plans are ambitious
  - QCD background studies, commissioning with Z→bb "standard candle", b-tag calibration, improving m_{bb} reco…

Summary

- Physics objects successfully commissioned with early LHC data
- CMS Higgs analyses are steamed up and ready for discoveries ☺
- Considerable improvement of sensitivity in many analyses:
  - application of MVA techniques
  - addition of new previously neglected channels
- First impressive results in some of channels already with 2010 data ($L = 36\ pb^{-1}$)
- DESY group is getting involved in CMS Higgs activities and has already something to offer to the CMS Higgs PAG
  - a novel analysis : MSSM Higgs search in the $\Phi \rightarrow \tau\tau \rightarrow 2\mu$ channel
- Nice physics results as outcome of MSSM Higgs analysis commissioning
  - $\sigma(pp \rightarrow Z \rightarrow \tau\tau)$ measurement in the $Z \rightarrow \tau\tau \rightarrow 2\mu$ channel
- DESY CMS Higgs group is taking new challenges : MSSM $bb\Phi \rightarrow 4b$ analysis
  - Dedicated fully hadronic trigger is developed and kept evolved
  - Started looking at b-enriched multi-jet sample