CMS Physics Results with Taus

Focus on Higgs Sector

Since this is not an official CMS talk, I decided to acknowledge the great contributions (my personal judgement) of graduate students in the CMS tau group explicitly.

TaU STORY

The good

- Single prong: well measured isolated charged hadron
- Three prong: softer well measured and vertexed charged hadrons

The bad

- n π^0s leading to 2n γs -- π^0 not always reconstructed fully
- EM energy clusters spread out in ϕ-strips

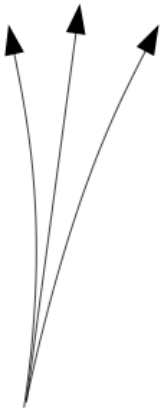
The ugly

- Missing neutrino: fit the missing momentum vector and secondary vertex of visible τ-pair components

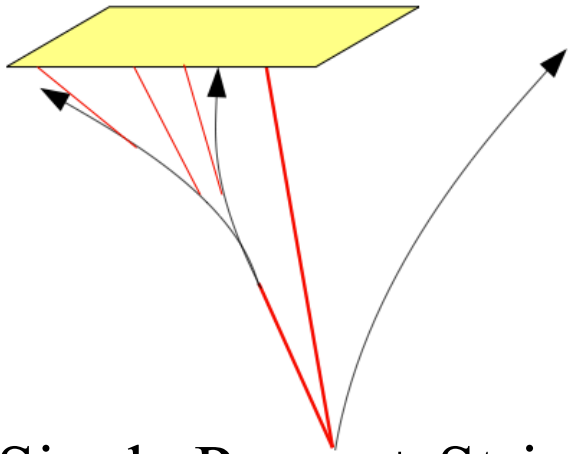
HPS

SVFit

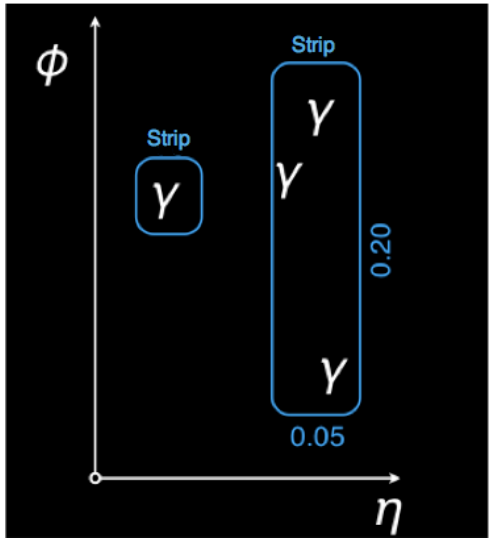
Single Prong



Three Prong



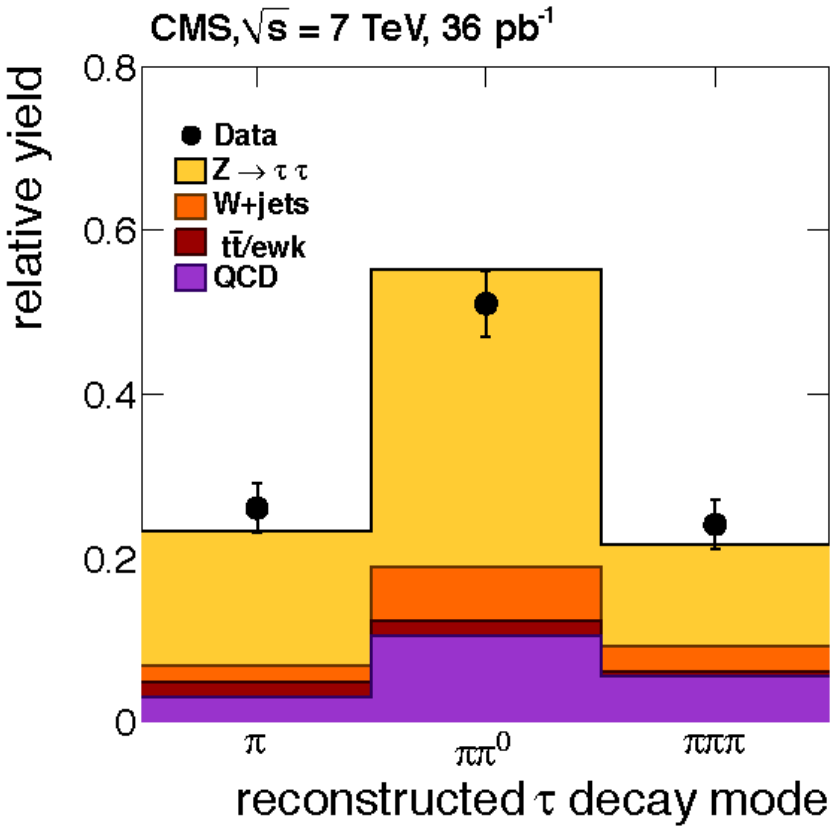
Single Prong + Strip

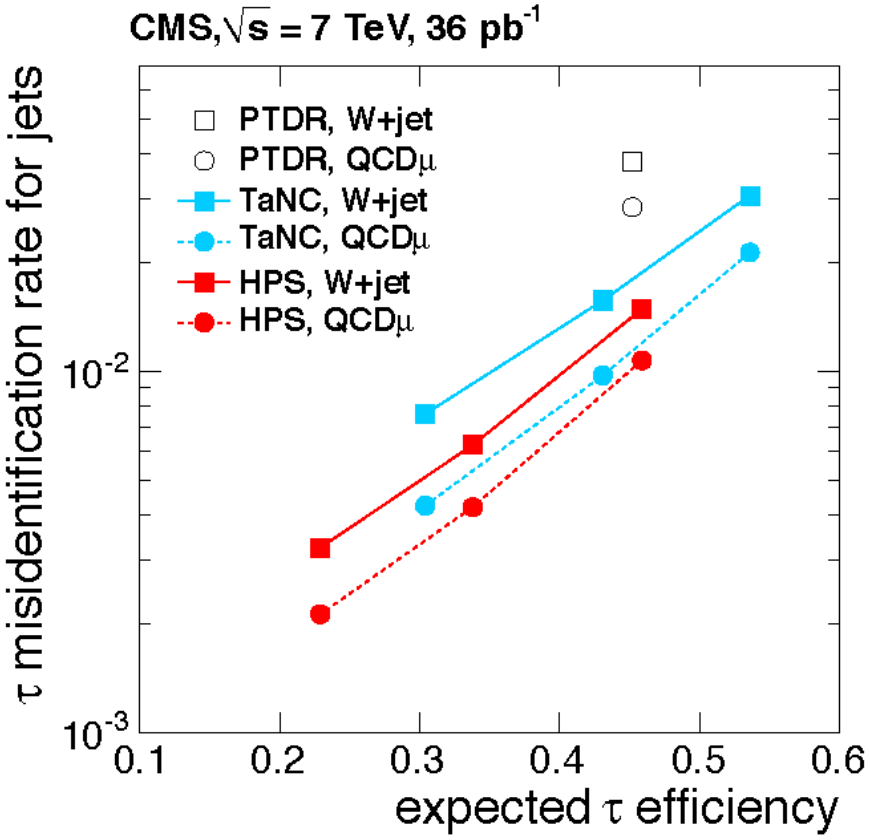


τ lepton reconstruction

JINST 7 (2012) P01001

- Bachtis (Wisconsin), Friis (Davis)
  - Instead of jets of narrow cone, shrinking cone … we truly reconstruct taus
    - In single and three prong modes, adding neutral pizeros
  - Decay mode algorithms HPS and TaNC
  - Established HPS algorithm and analysis techniques for τ physics

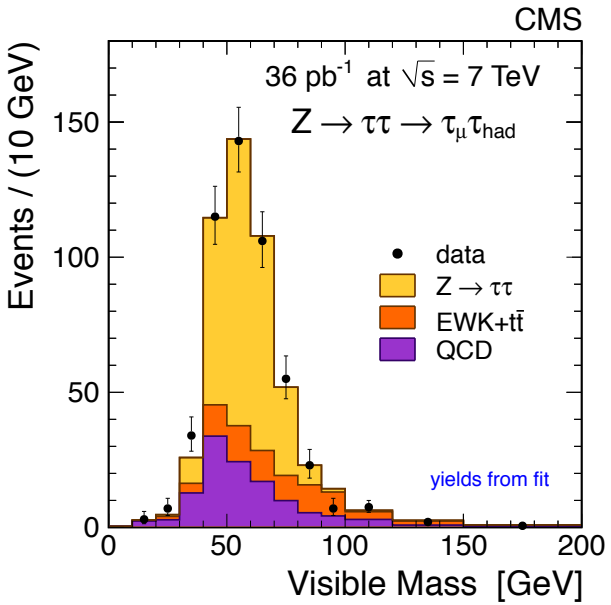


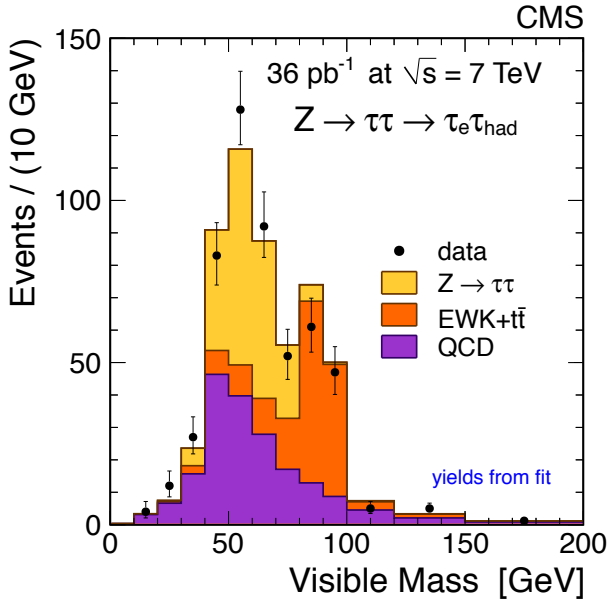


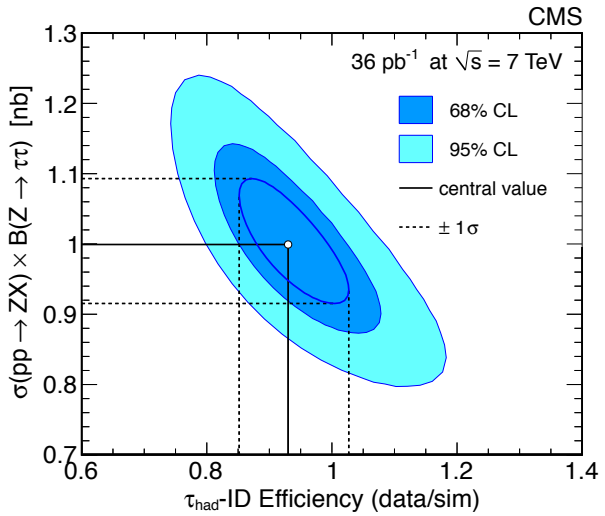
Z to ττ : 2010 Data

J. High Energy Phys. 08 (2011) 117

- Bachtis (Wisconsin), Friis (Davis), Swanson (Wisconsin), Cutajar (Imperial)
  - Measure Z to τ τ cross section and τ identification efficiency
  - Necessary precursor to searches for higgs decays in τ modes

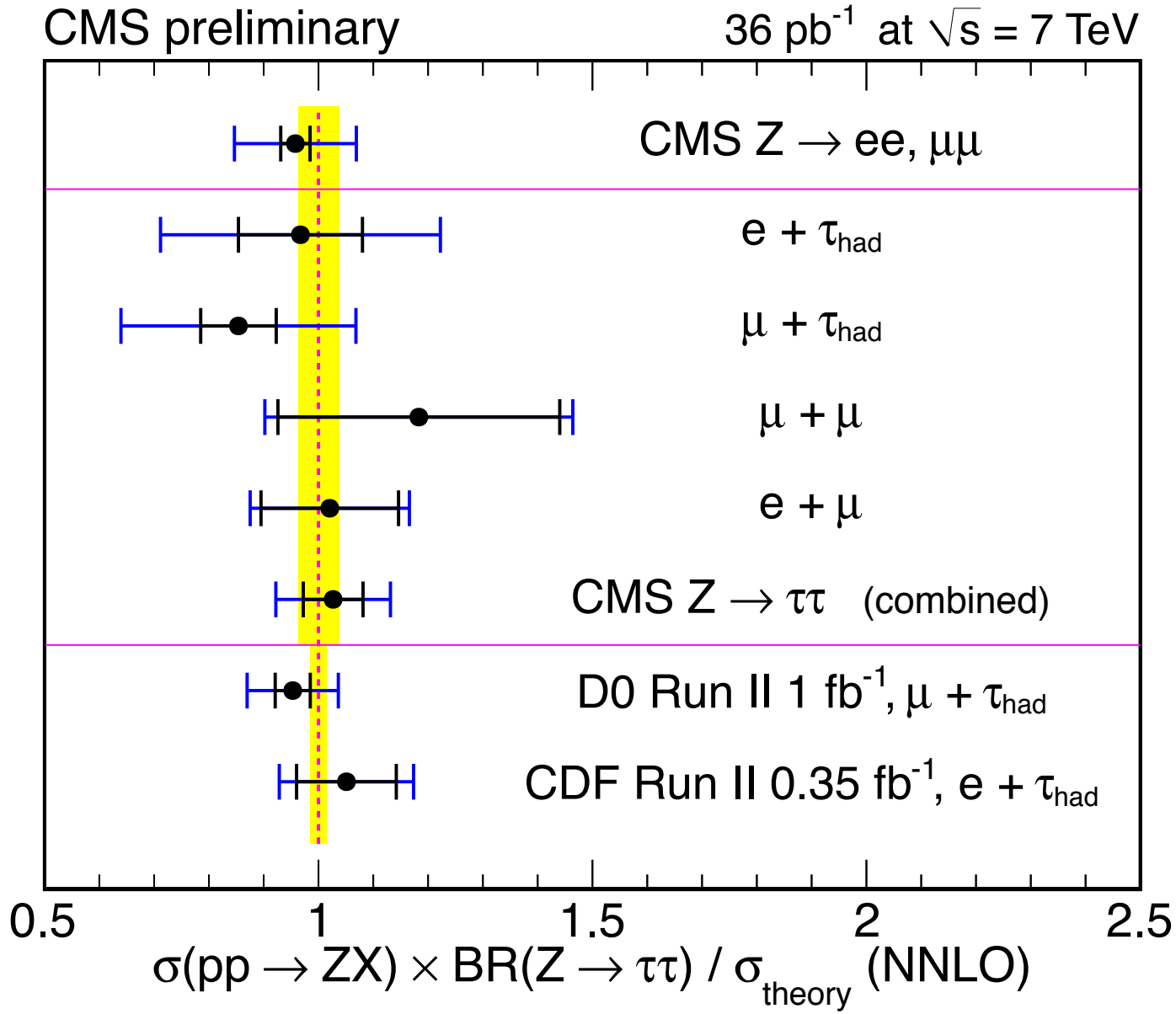






Clean Z signals in τ modes enabled cross section measurement + simultaneously extract τ ID efficiency.

Z to ττ Cross Section

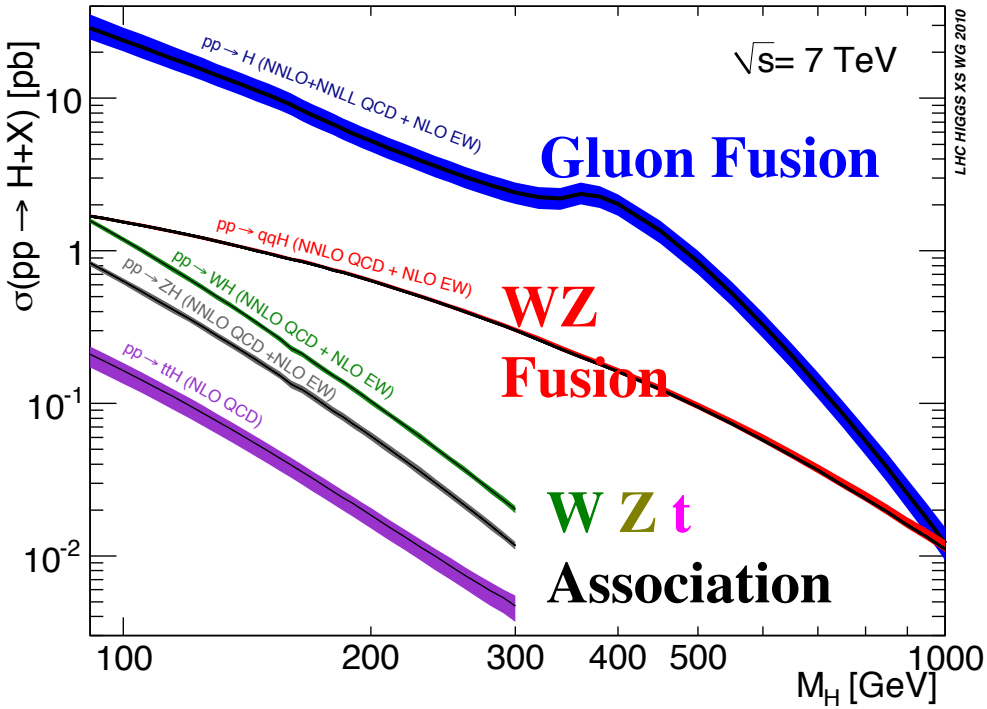


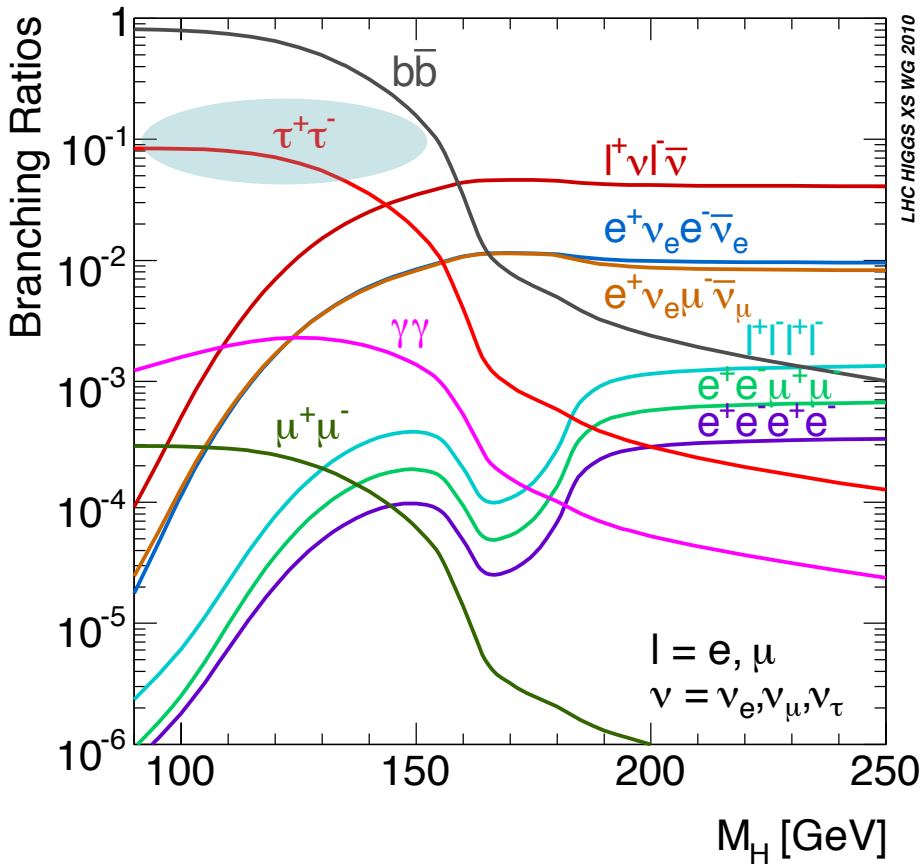
- Taus are legit !

Standard Model Higgs Sector

Generating masses for weak bosons and fermions

- Higgs mechanism provides masses for W and Z
- Yukawa coupling to fermions provides them masses
  - ~10% BR in the low mass region < ~140 GeV

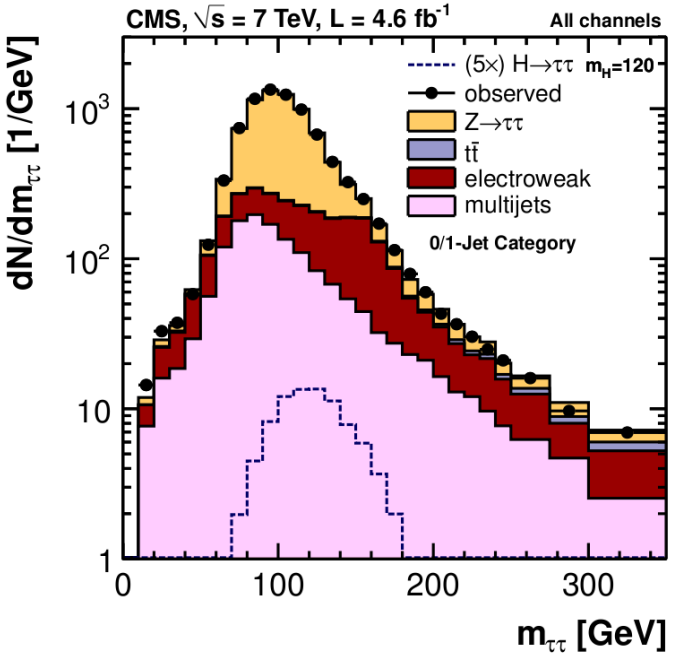




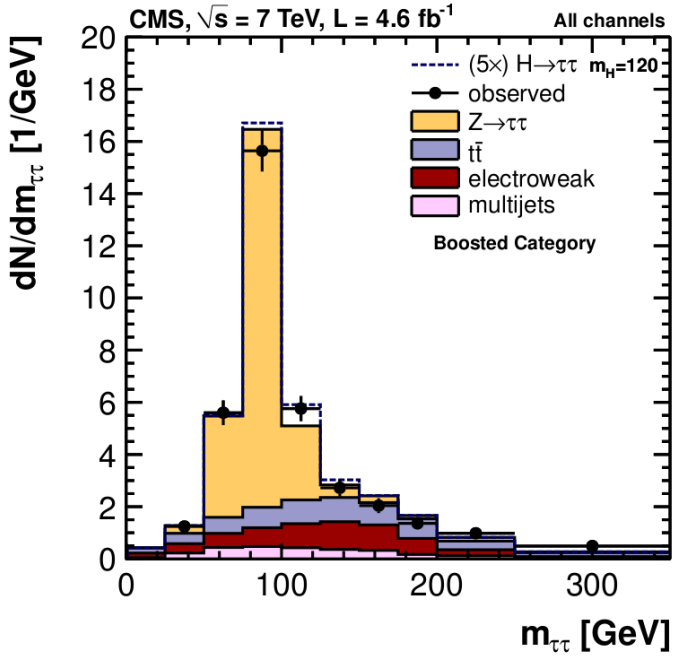
Tau Pair Mass Distributions

arXiv:1202.4083

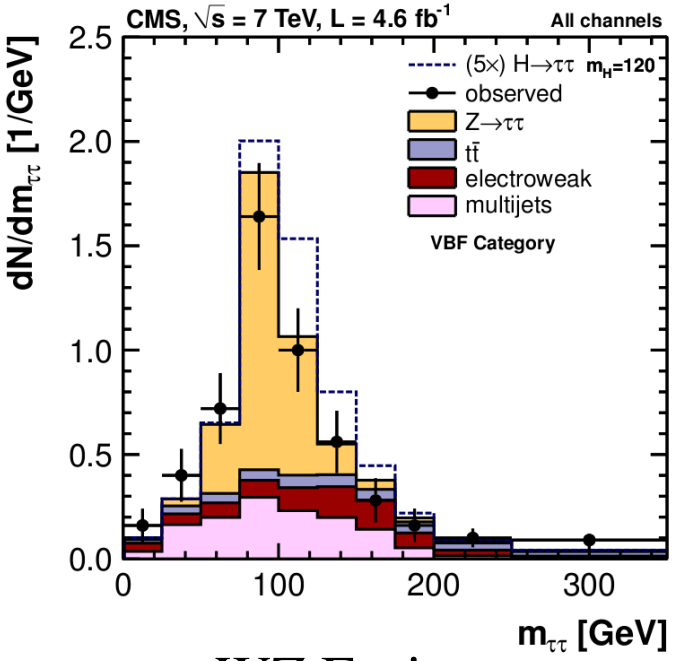
- SVFit: Reconstruct tau-pair invariant mass by taking account of MET magnitude, direction, … better than collinear approximation
- Combine muTau, eTau and eMu mode mass distributions shown
- Three categories to enhance signal to BG; exploit VBF



Inclusive – WZF - Boost



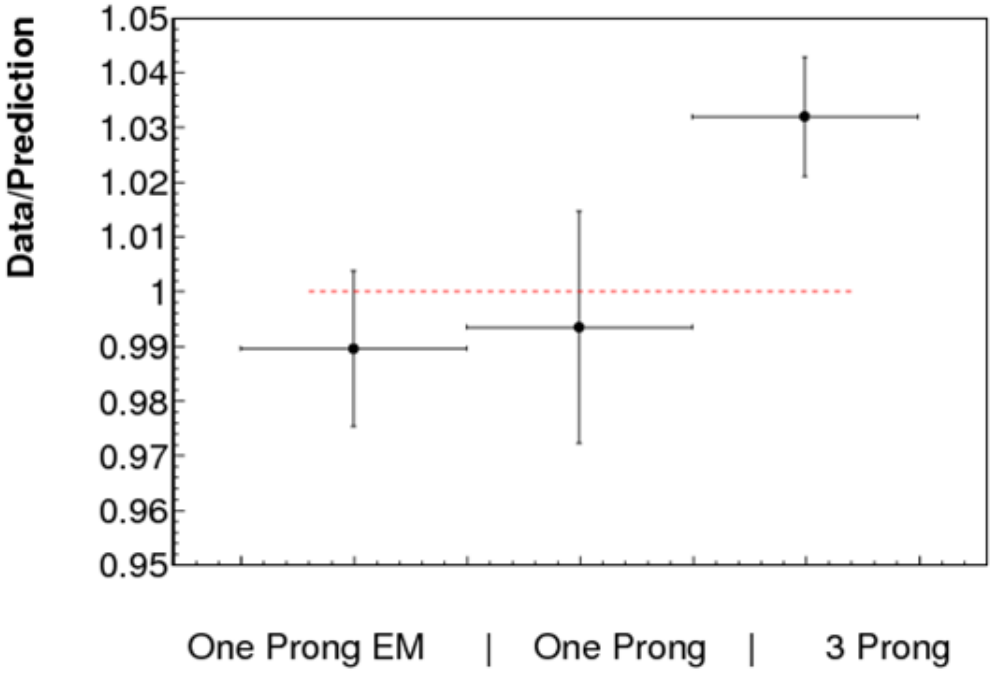
Boosted 1-Jet
$P_T > 150$ GeV

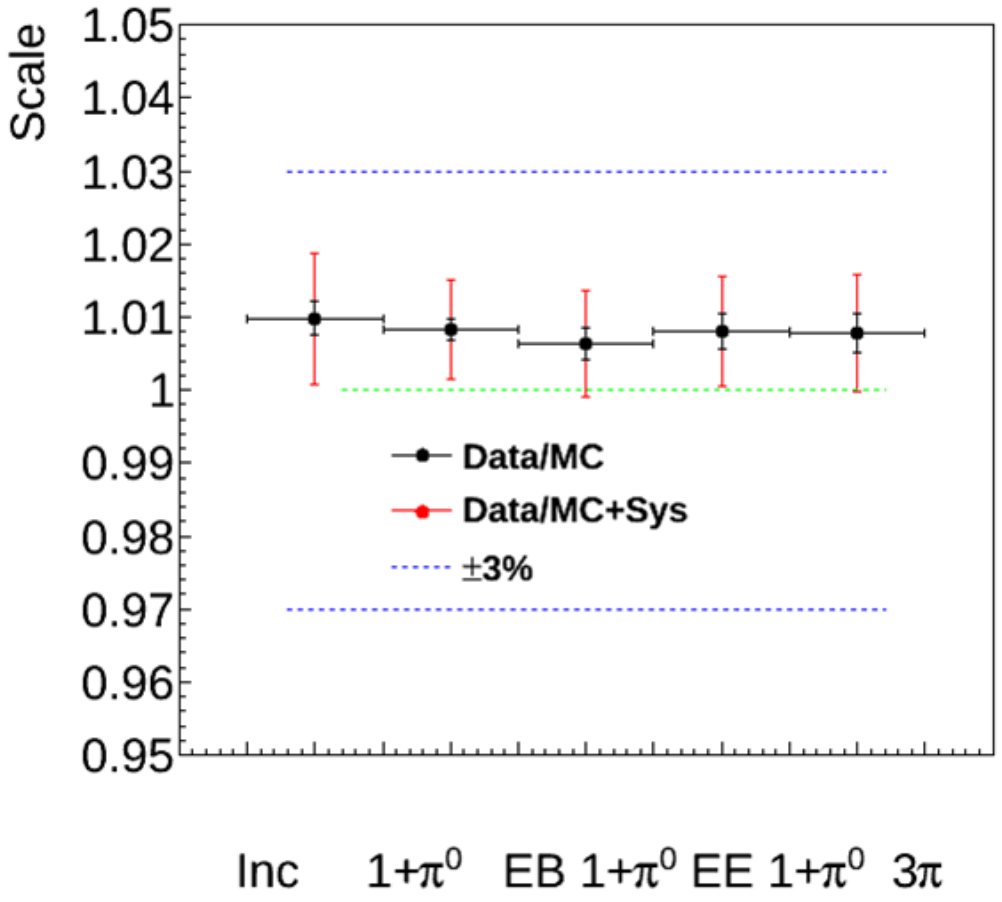


WZ Fusion
2-jets, $\Delta\eta>4$, $\eta_1.\eta_2<0$,
$M_{jj}>400$ GeV
Third jet $P_T < 30$ GeV

Tau Decay Modes & Energy Scale

- Tau reconstruction yields and energy scale are well understood!
- Tau efficiency, especially at high masses is self-calibrated in the fit. 6% uncertainty estimated from tag & probe is only relevant in Z region





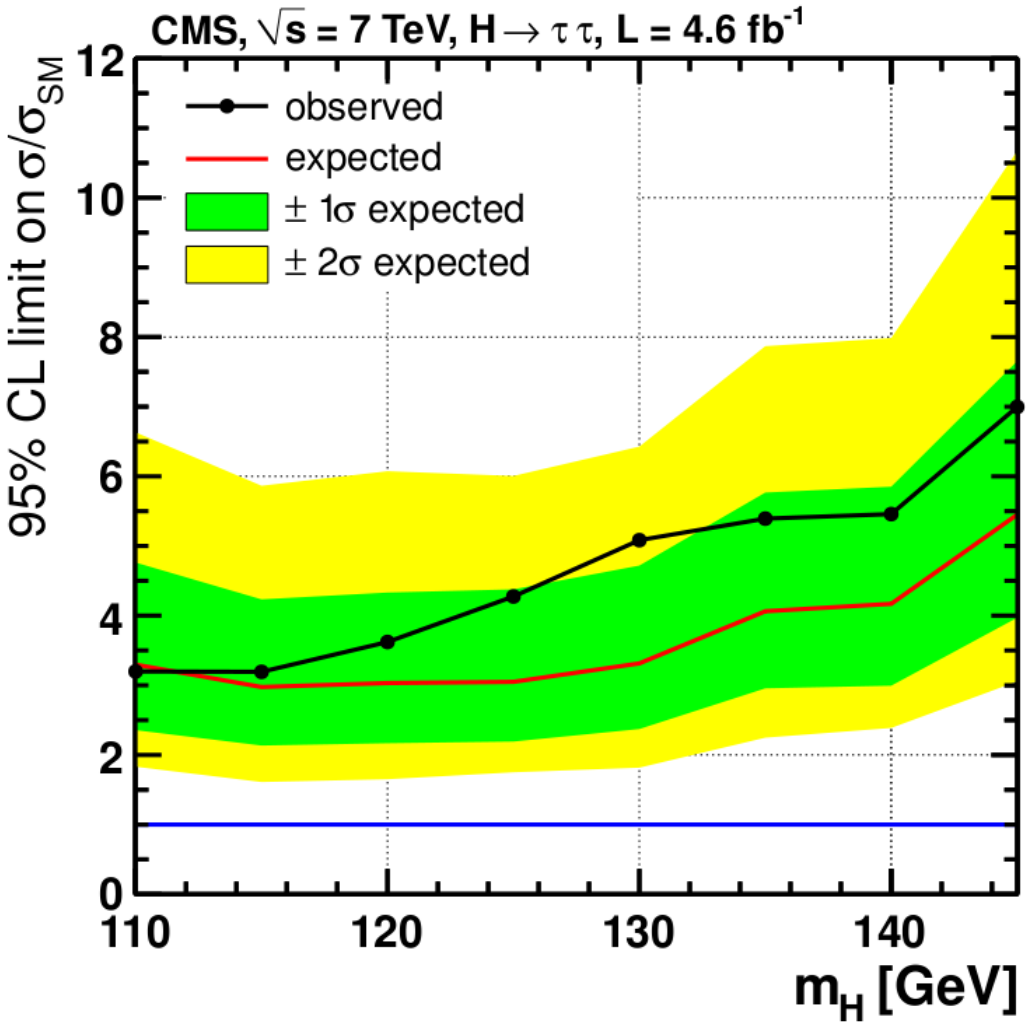
Relative yields of each hadronic tau decay mode resulting from a fit to the inclusive tau mass spectrum floating separately the yields of the individual decay modes.

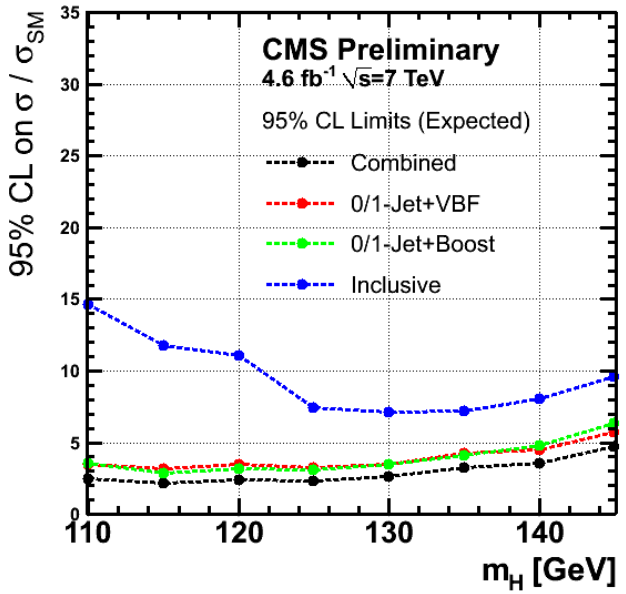
SM Higgs Limit

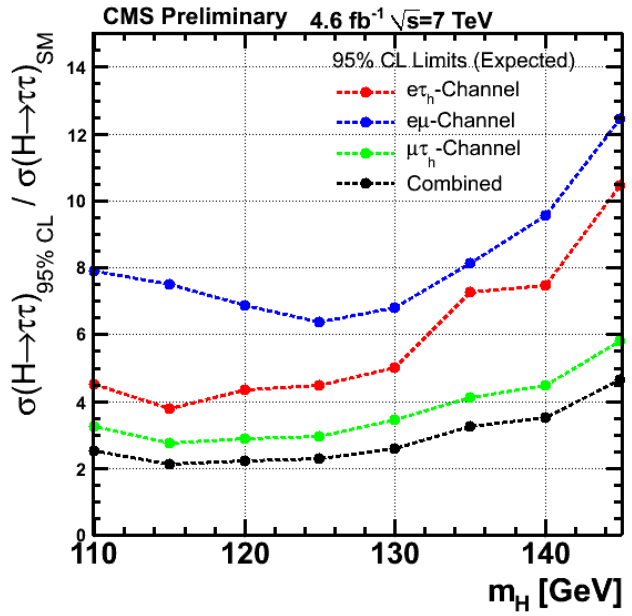
arXiv:1202.4083

Bachtis (Wisconsin), Bianchi (LLR), Dutta (MIT)

- Not yet sensitive at SM level, but setting limits on cross section ratio



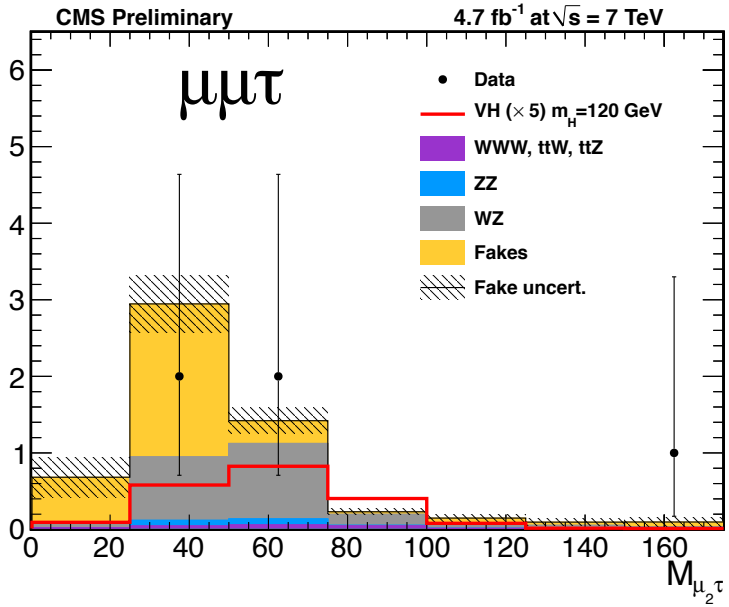


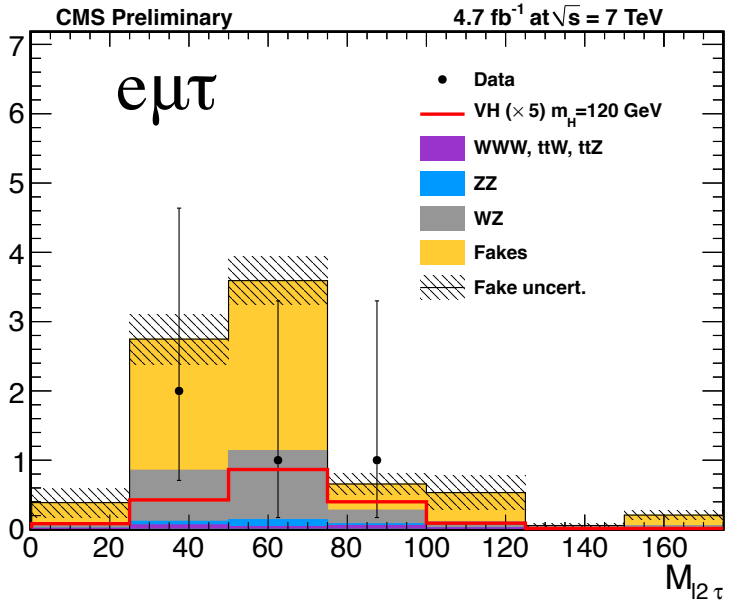


WH to μμτ & eμτ

- W associated production has low BG, reduced by requiring unlike charges of light leptons, estimated using measured τ-fake probabilities
- Contribution from H to ττ at low, and WW at higher mass
- Clean but low yields

CMS-HIG-12-006



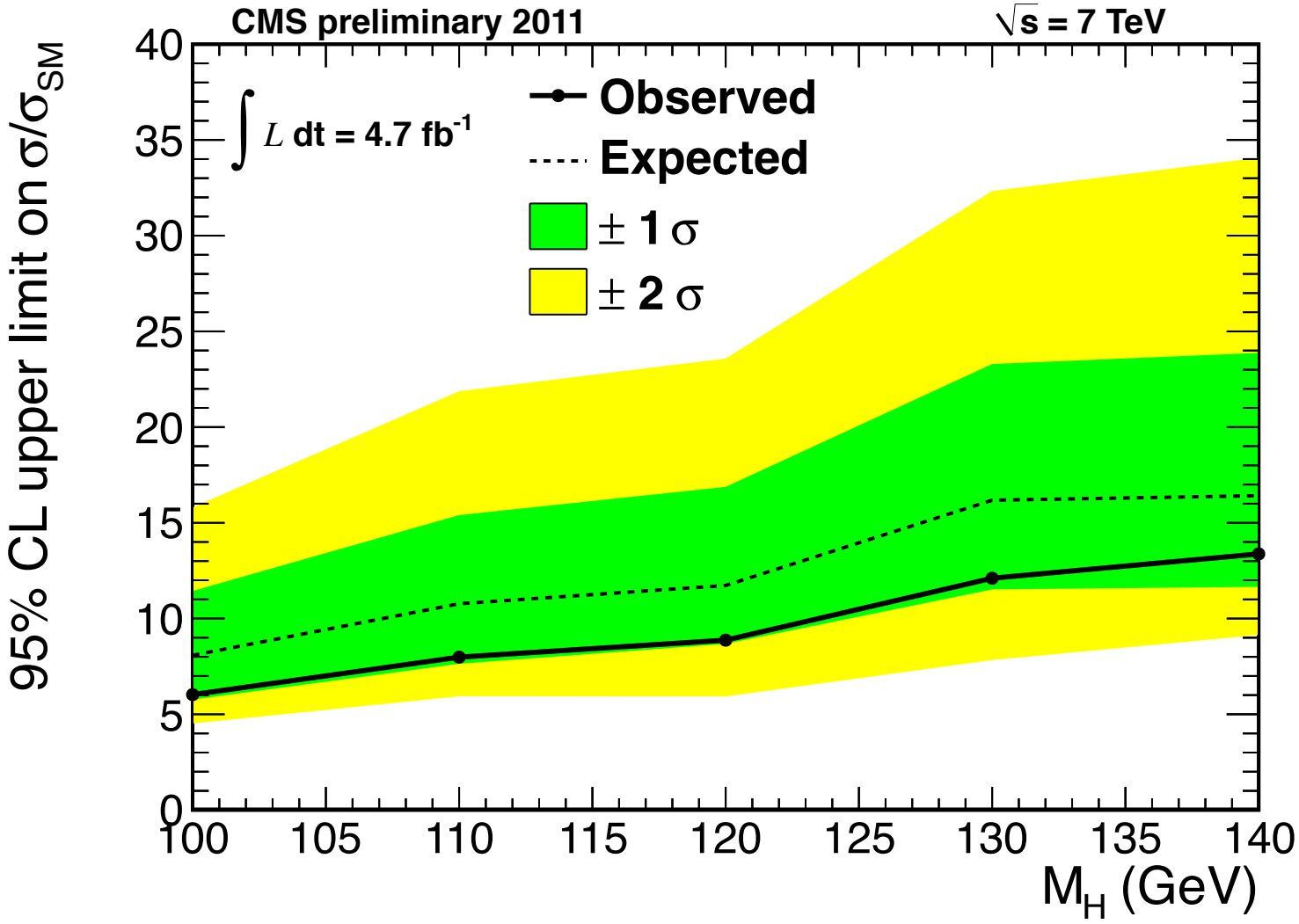


Invariant mass of sub-leading lepton and hadronic tau
Leading lepton primarily comes from W decay

SM WH Limit

CMS-HIG-12-006

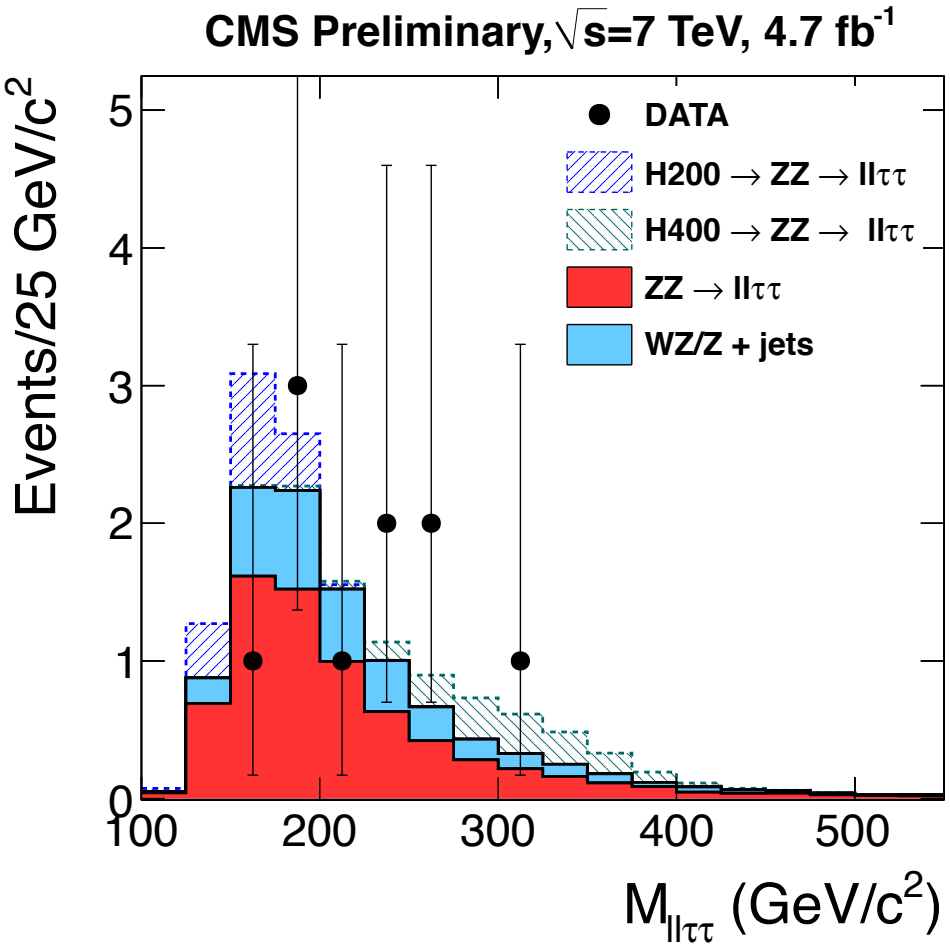
- Not yet sensitive at SM level even here, but set limits on cross section ratio

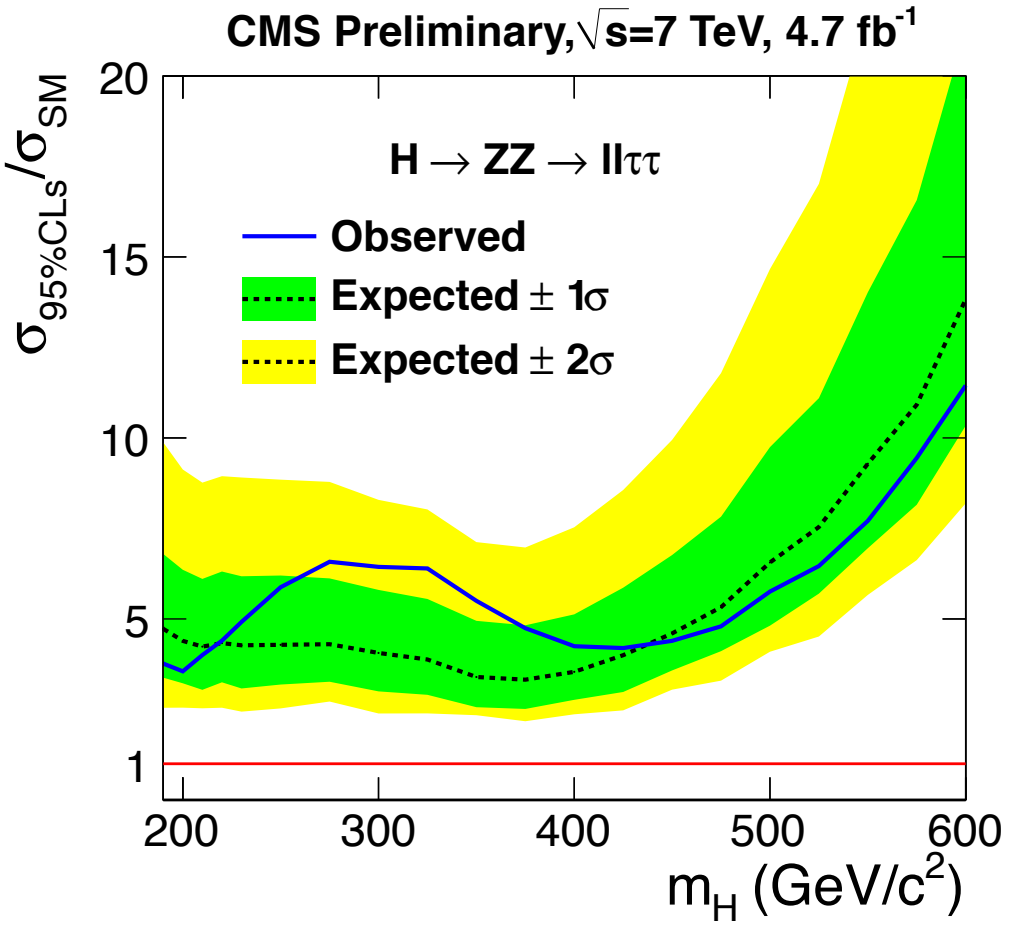


Contribution to High Mass H

- Ross, Swanson (Wisconsin), Mohammadi (Tehran), Singh (INFN)
  - Search for H in ZZ modes in 2l2τ final state
  - BG estimated using measured τ-fake probabilities

arXiv:1202.3617v1





Beyond the Standard Model

There are many possibilites that change the precise predictions of the minimal higgs sector of the Standard Model

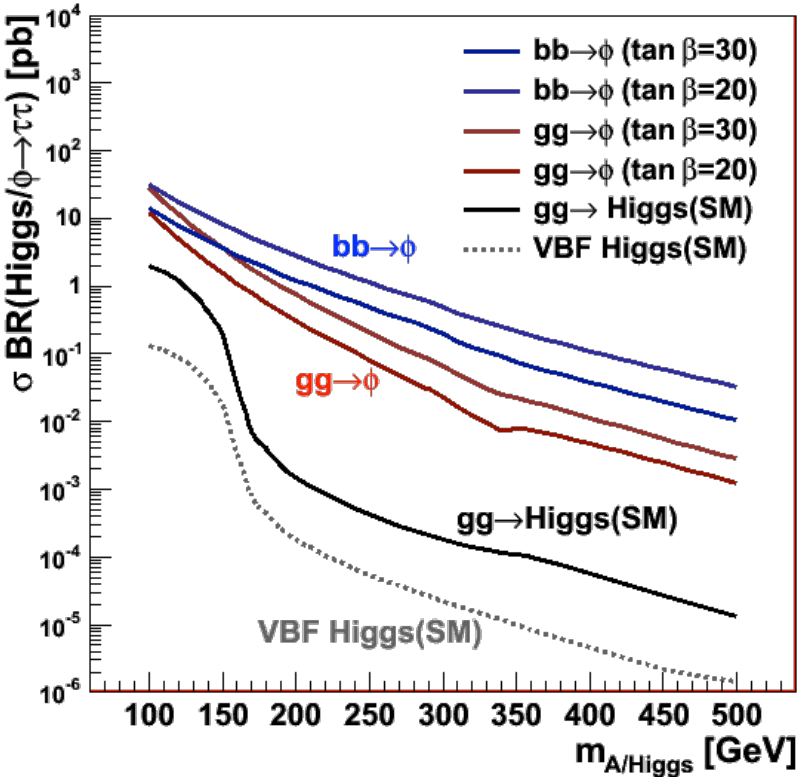
- **Fourth (heavy) generation of fermions modify H couplings**
  - **Enhances SM4 higgs cross section over SM**
- **Fermiophobic higgs – perhaps, fermion mass matrices have a different origin from the higgs mechanism**
  - **Changes low mass higgs production & decays dramatically**
- **Beyond minimal higgs doublet field**
  - **Two higgs doublet model (2HDM)**
    - **Multiple higgs bosons: 3 neutral and 2 charged**
    - **Minimal Supersymmetric Model (MSSM) requires 2HDM**
  - **NMSSM, triplets … have even more higgses**
    - **Very light pseudoscalar higgs, Doubly charged …**
- **This talk focuses on these non-standard higgs bosons**

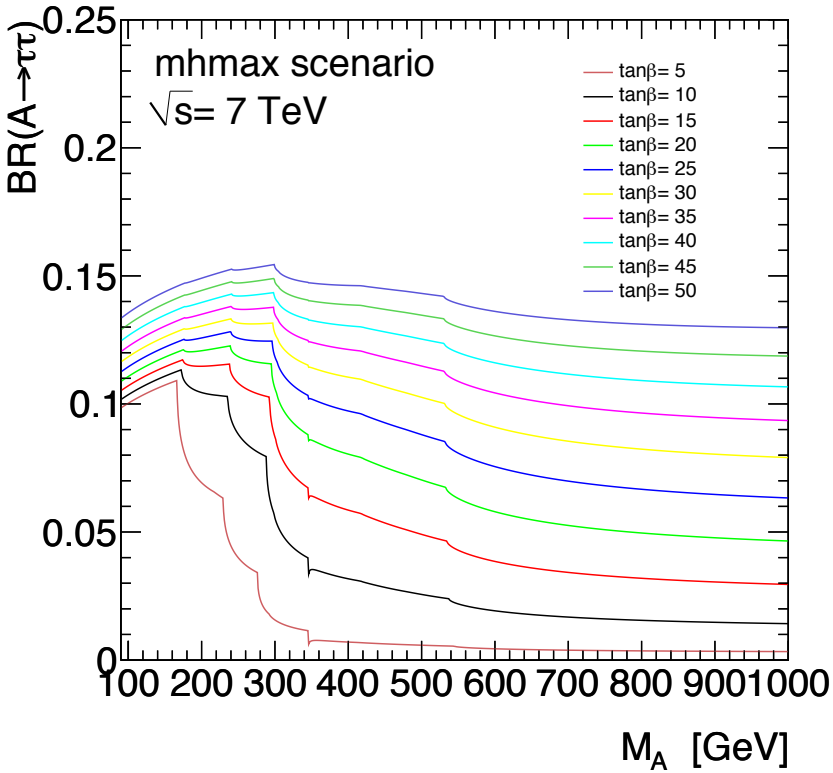
MSSM Higgs

- Higgs sector in SUSY theory is more complicated
  - Need 2 higgs doublets each with 4 degrees of freedom
    - Results in the Standard Model like Higgs (h^0)
    - Plus, two neutral higgs (A^0, H^0) and charged ($H^{\pm}$)
    - However, only 2 parameters (M_A, tanβ – ratio of the two doublets)
    - Masses of higgs and Z related
    - Search in (M_A, tanβ) plane
- Neutral Higgs
  - Look for ϕ=(h^0, A^0, H^0) in decays to tau-leptons
- Charged Higgs
  - Look for $H^{\pm}$ in top decays

MSSM ϕ(h, H, A)

- Enhanced coupling to b-quarks and τ-leptons
  - Production rate enhanced × $\tan^2\beta$
    - Gluon fusion with b,t loops + associated b quark production
  - Decays to b-quark and τ-lepton pairs enhanced at all masses

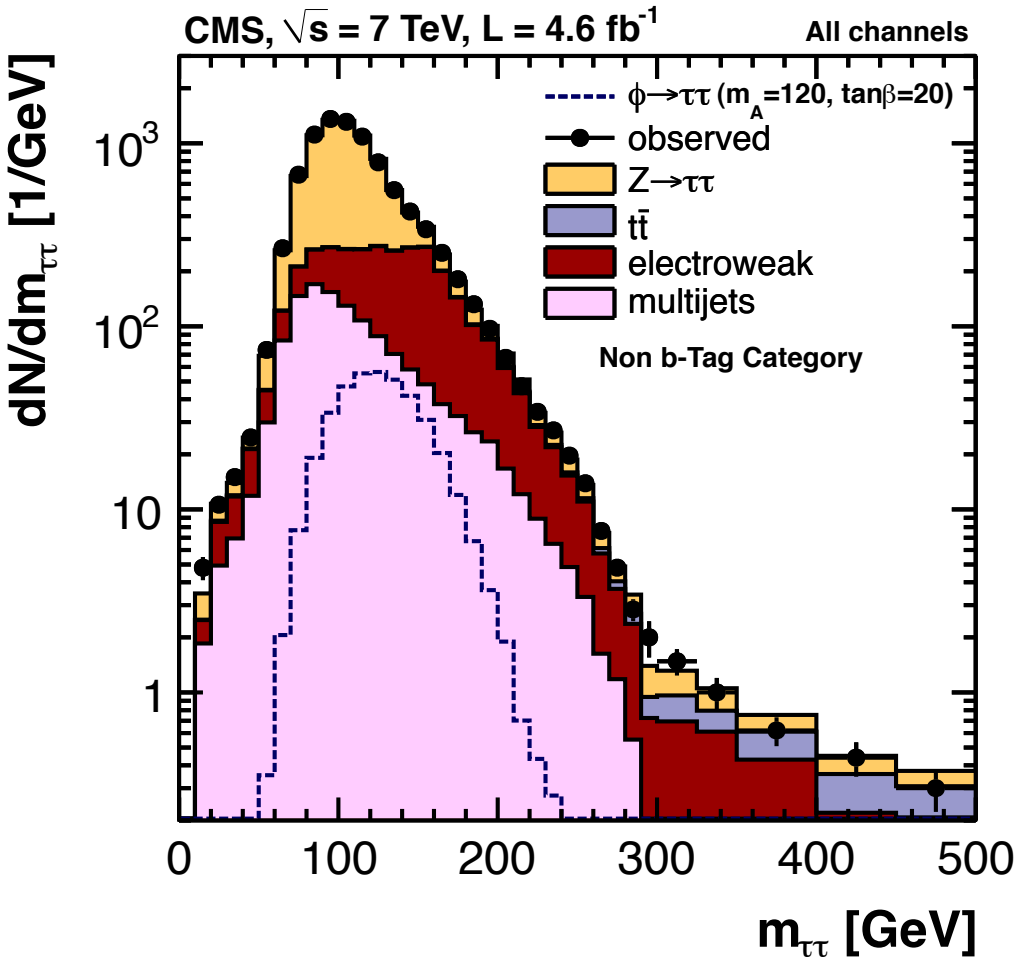


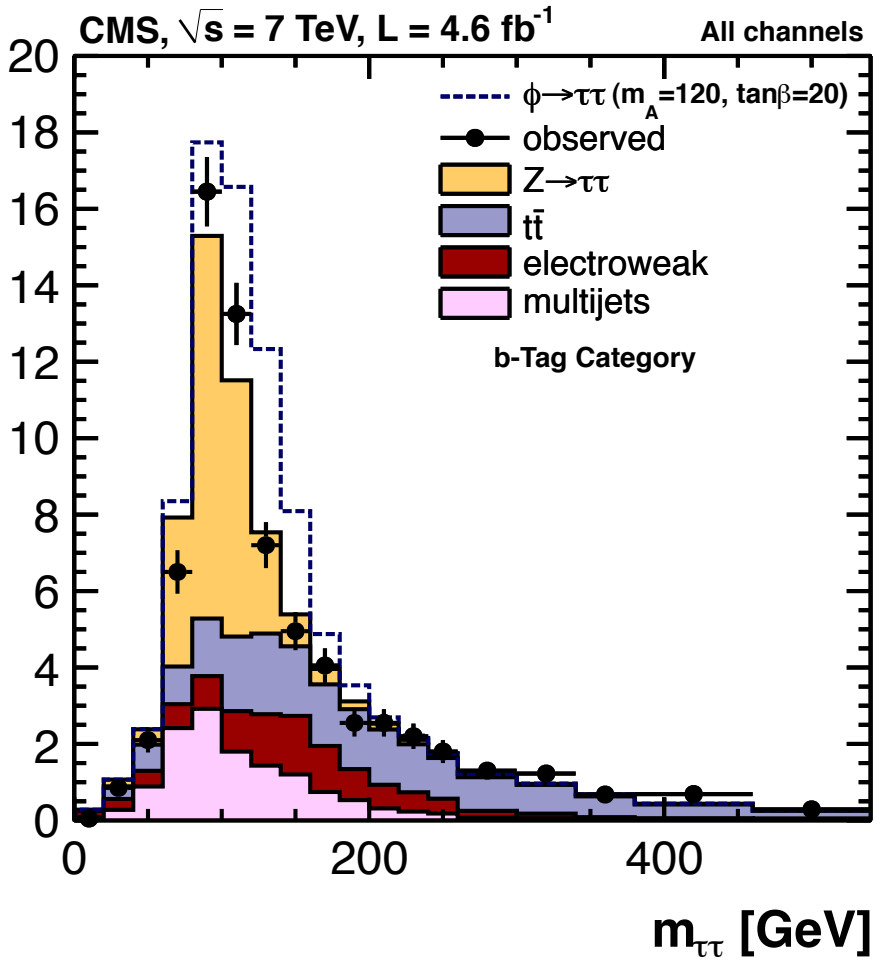


Mass of ττ : 2011 Data

arXiv:1202.4083

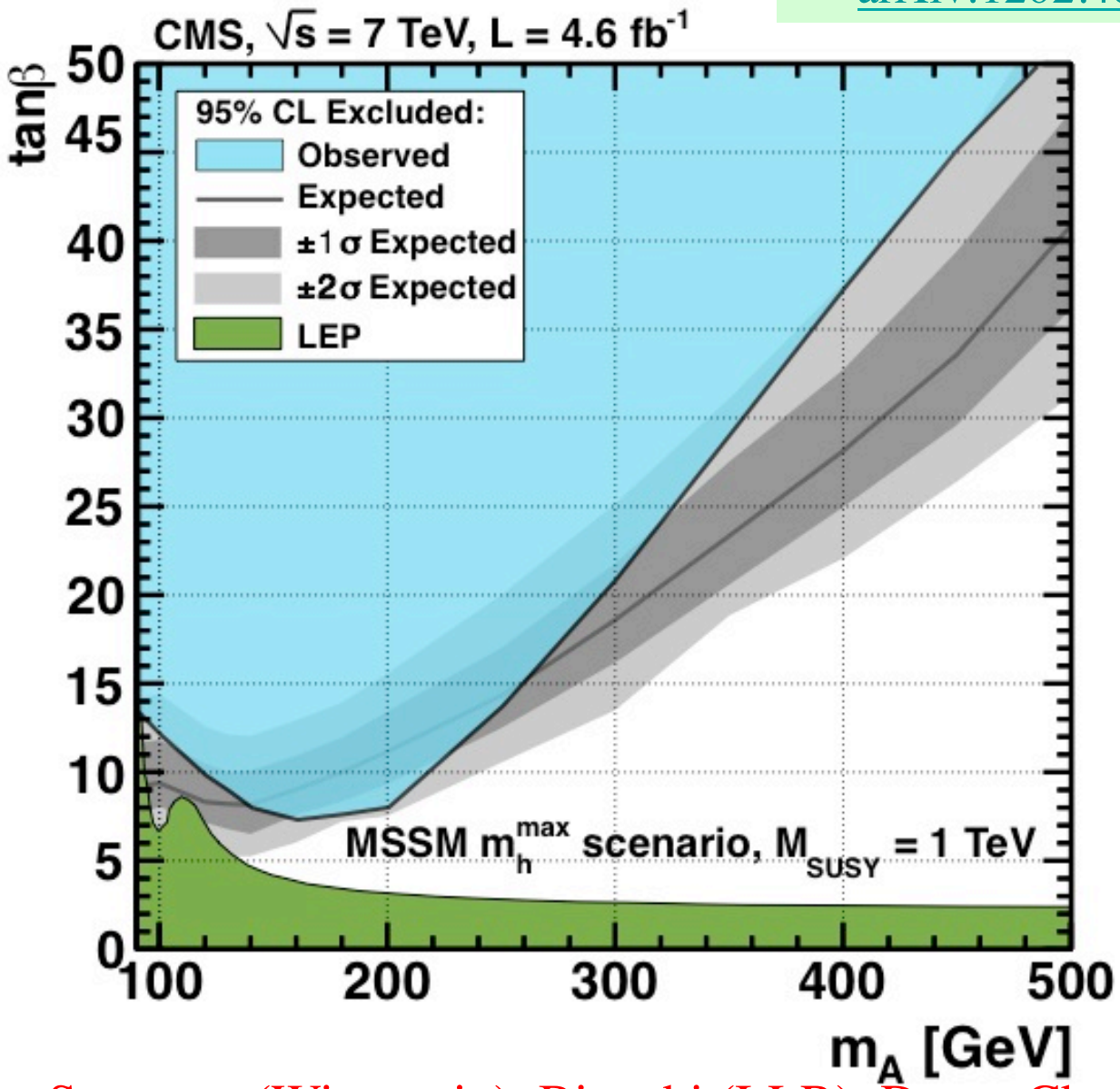
Tau pairs reconstructed in decays to leptons (e or μ) + hadrons (1 or 3 prong) or two leptons (eμ)
Kinematic fit to obtain tau pair mass – used to search for H to ττ contribution
Two categories: non-b-tagged and b-tagged to enhance bbϕ





Limit in m_A-tanβ Plane

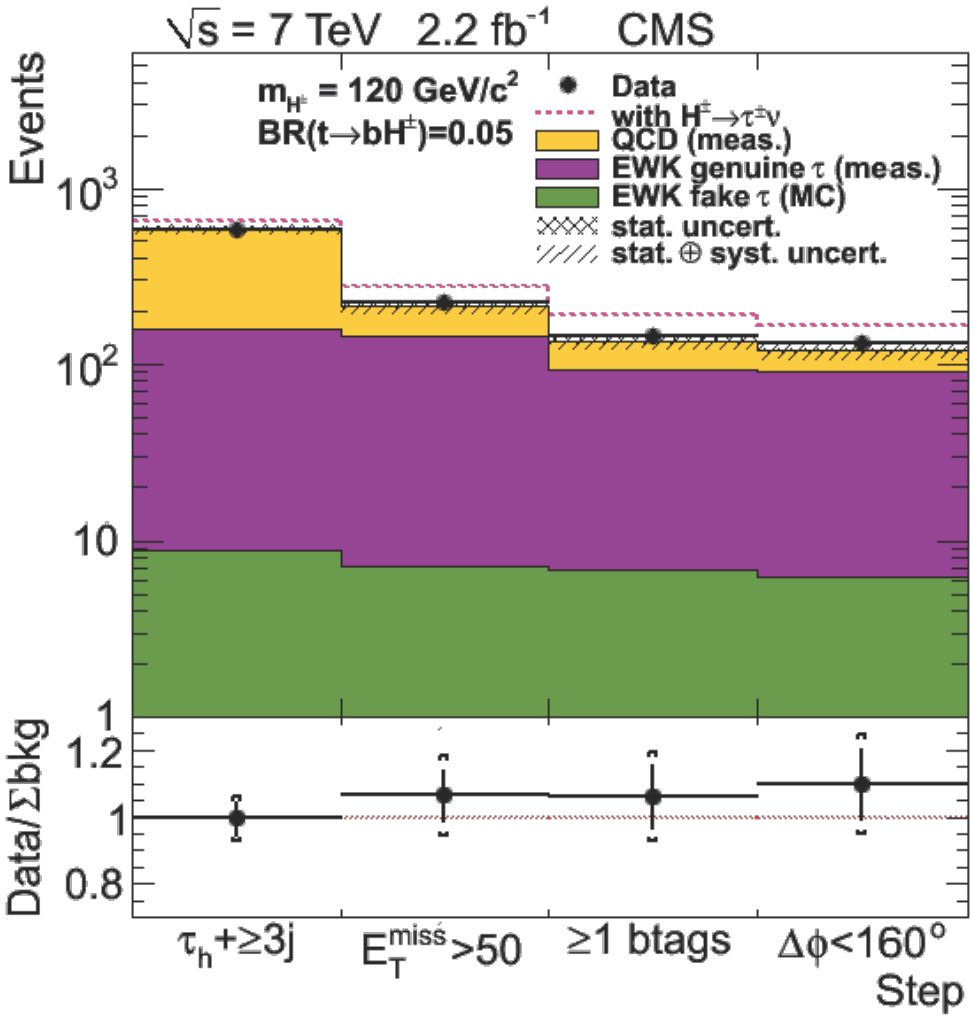
arXiv:1202.4083



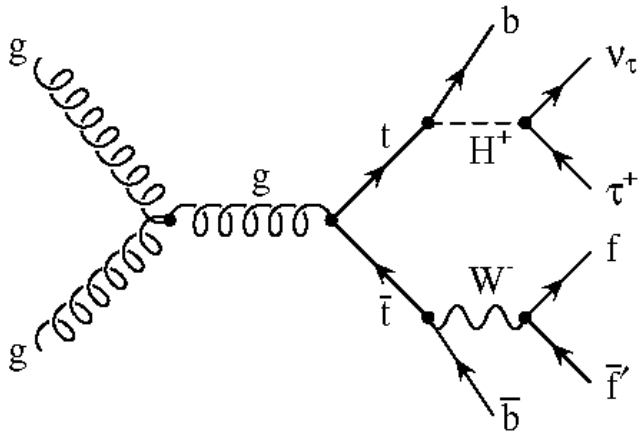
Bachtis, Swanson (Wisconsin), Bianchi (LLR), Dutta, Chan (MIT)

Charged Higgs Selection

Look for $H^{\pm}$ in top decays: τ+jets, eτ, μτ and eμ modes considered



CMS PAS HIG-11-019

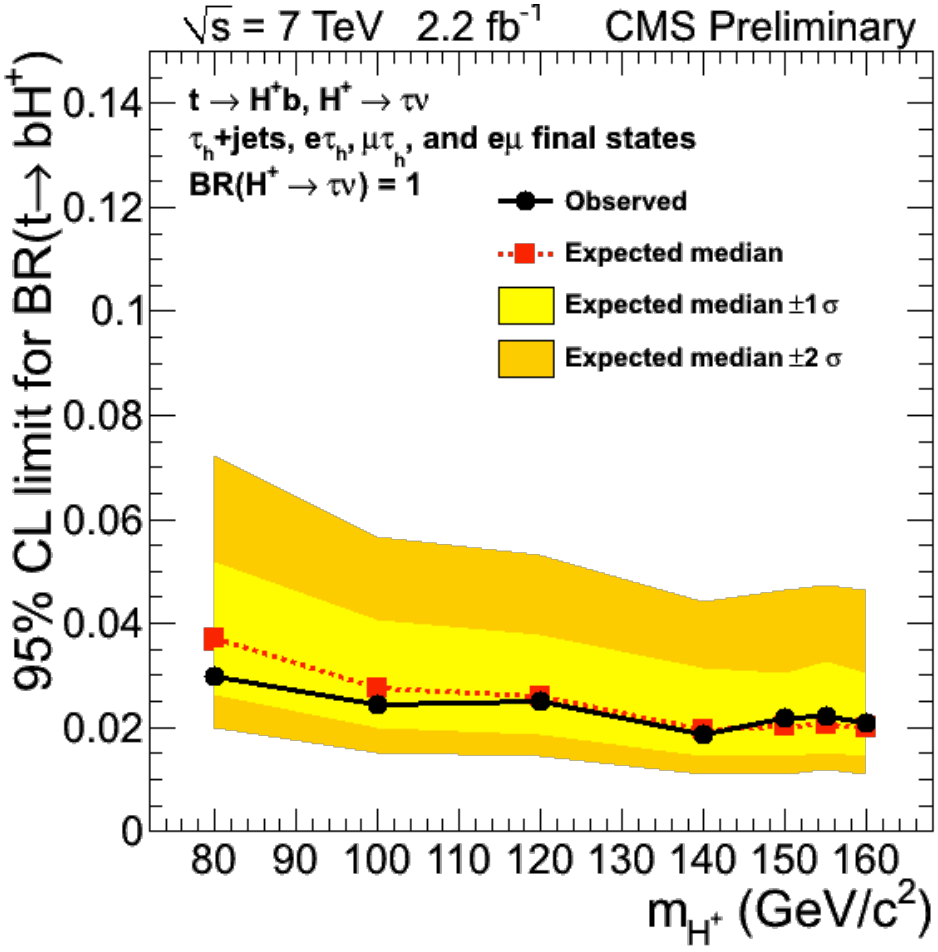


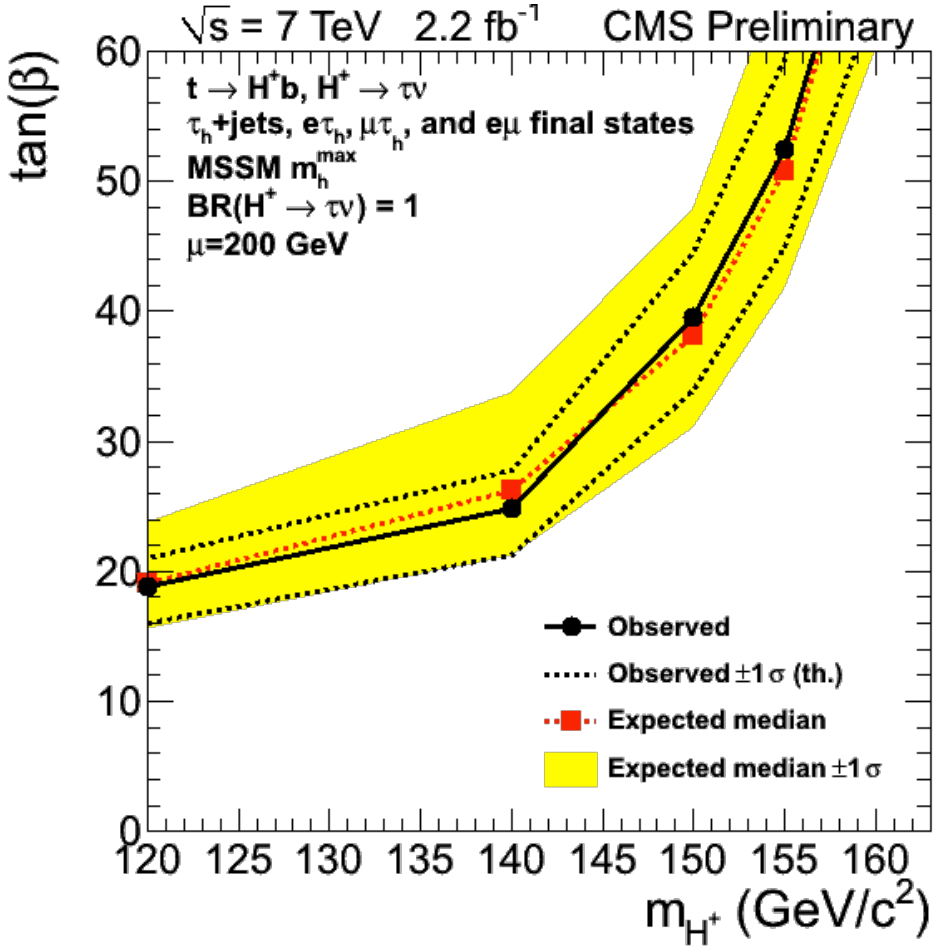
Event with
τ + MET from $H^{\pm}$
2 b-jets,
2 jets from W or
e/μ + MET from W

Cut progression includes
MET, bTags

Charged Higgs Limits

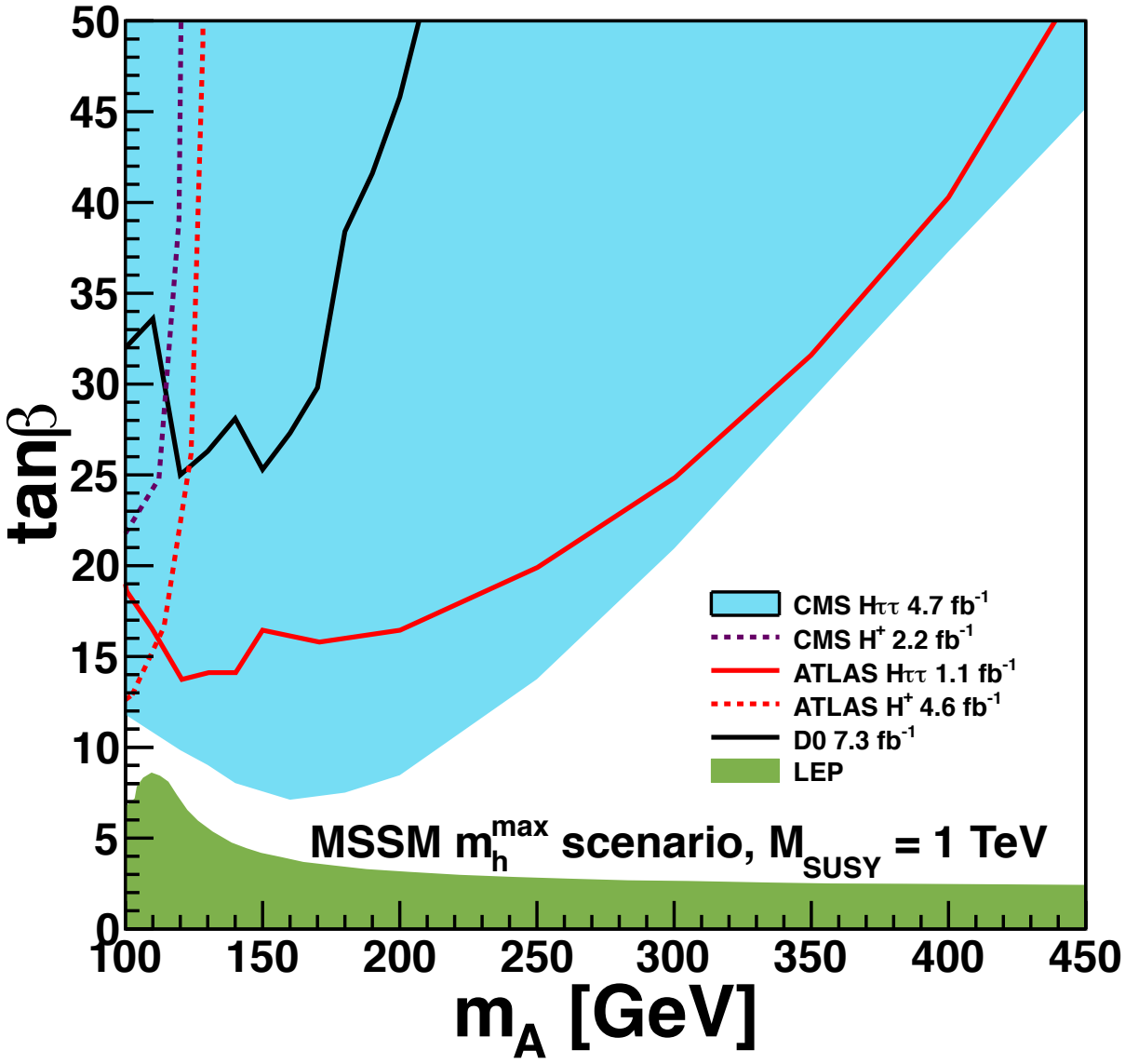
CMS PAS HIG-11-019





τj, eτ, μτ, eμ
2.2 fb^{-1}

MSSM Higgs Summary



arXiv:1202.4083

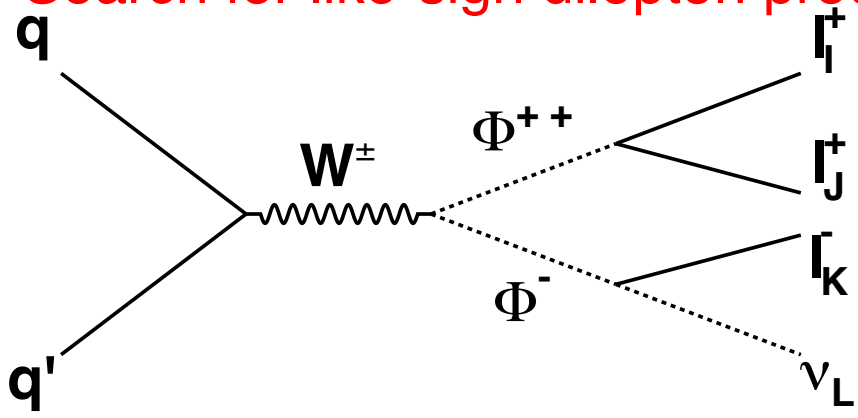
ATLAS CONF 2012-11

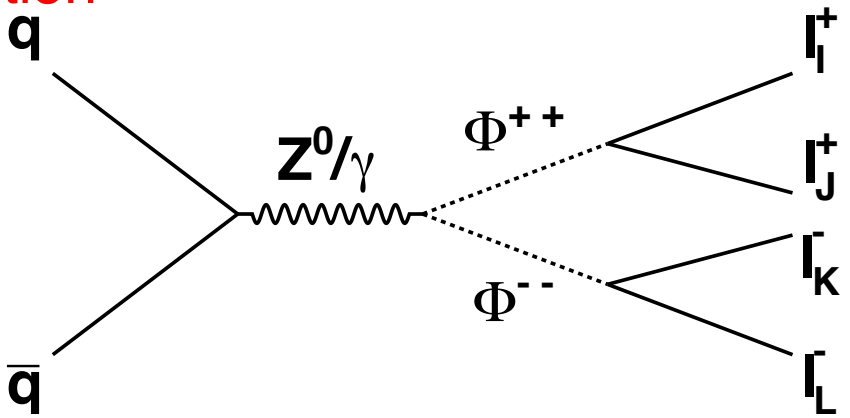
CMS PAS HIG-11-019

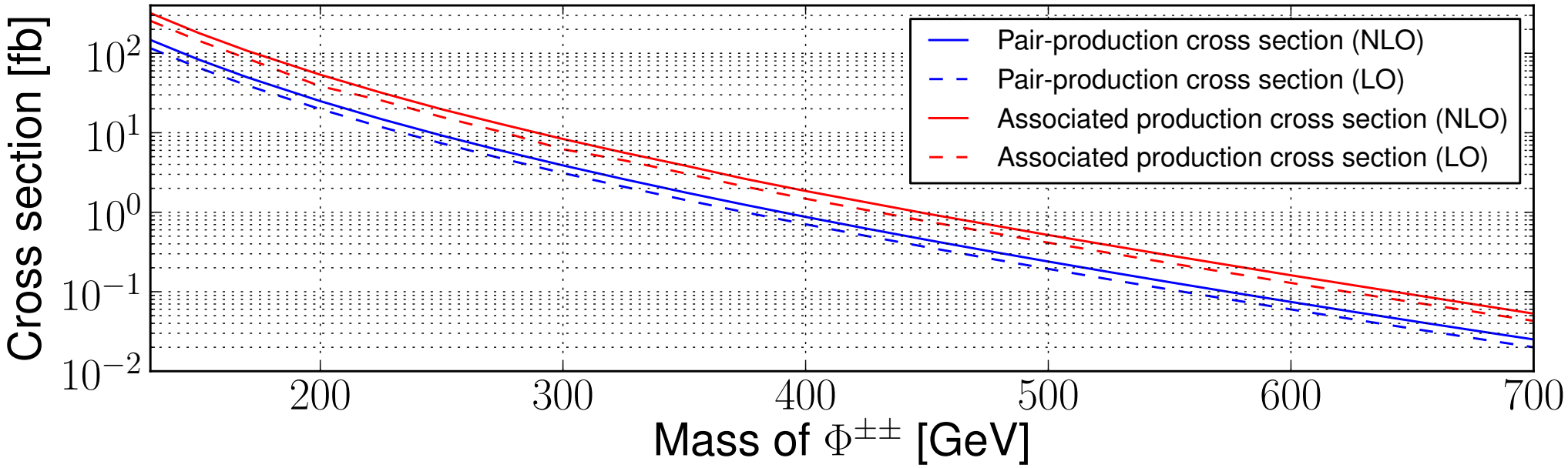
Doubly Charged $\Phi^{\pm\pm} \rightarrow l^{\pm} l^{\pm}$

CMS PAS HIG-12-005

- Models with triplet of higgs fields, predict doubly charged bosons
  - Interestingly triplet models can include fermiophobic neutral higgs
- Search for like-sign dilepton production

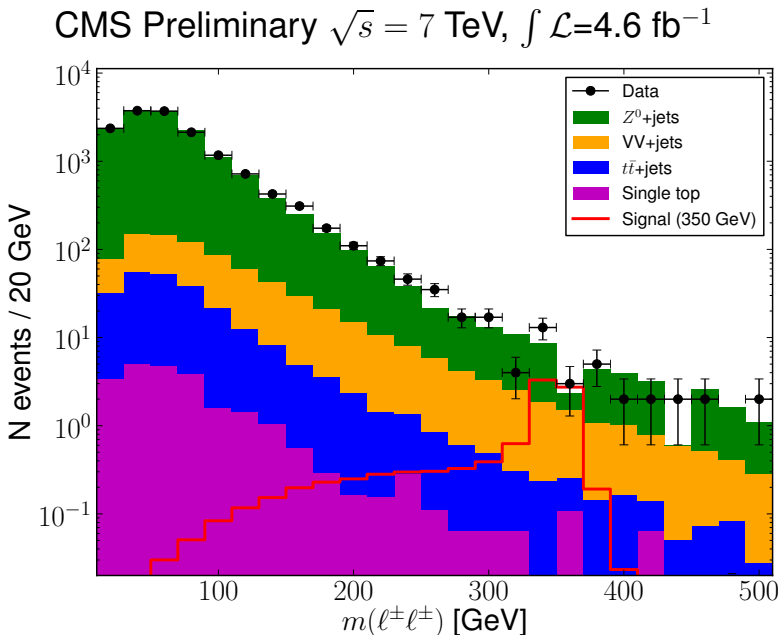


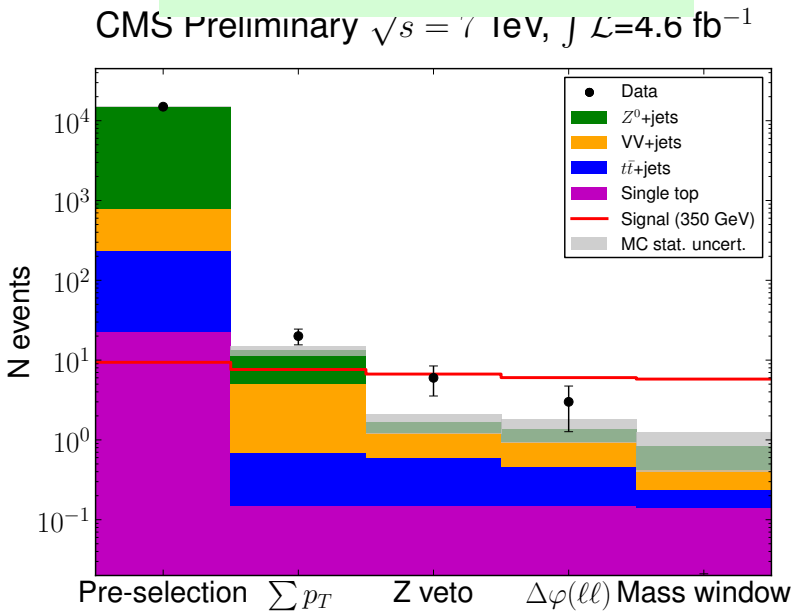


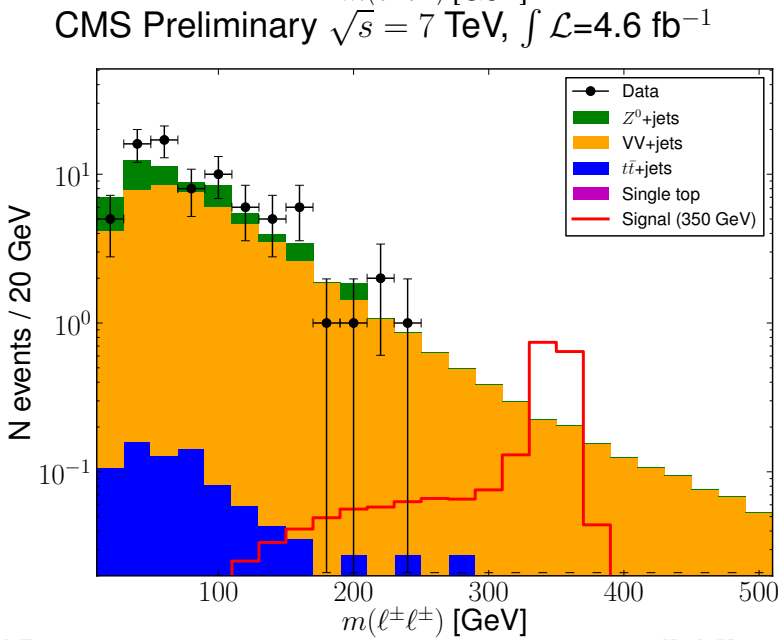


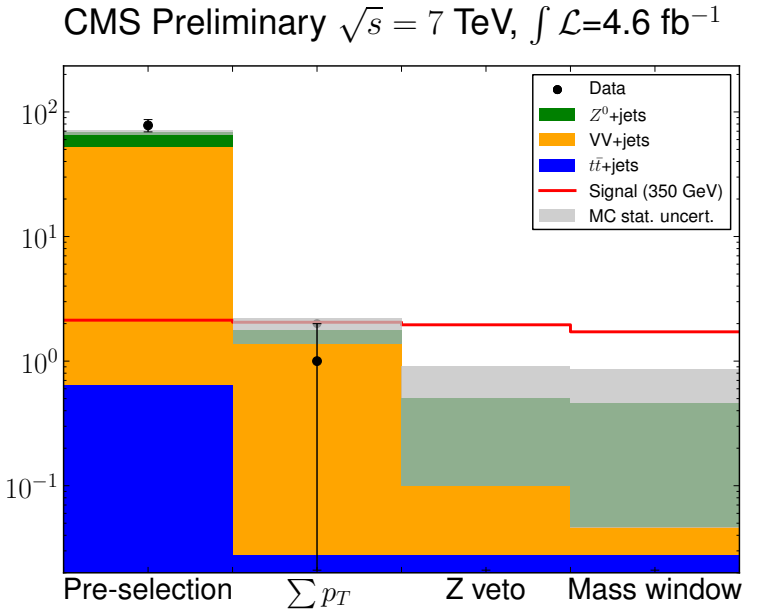
Trilepton & Quadlepton Modes

CMS PAS HIG-12-005



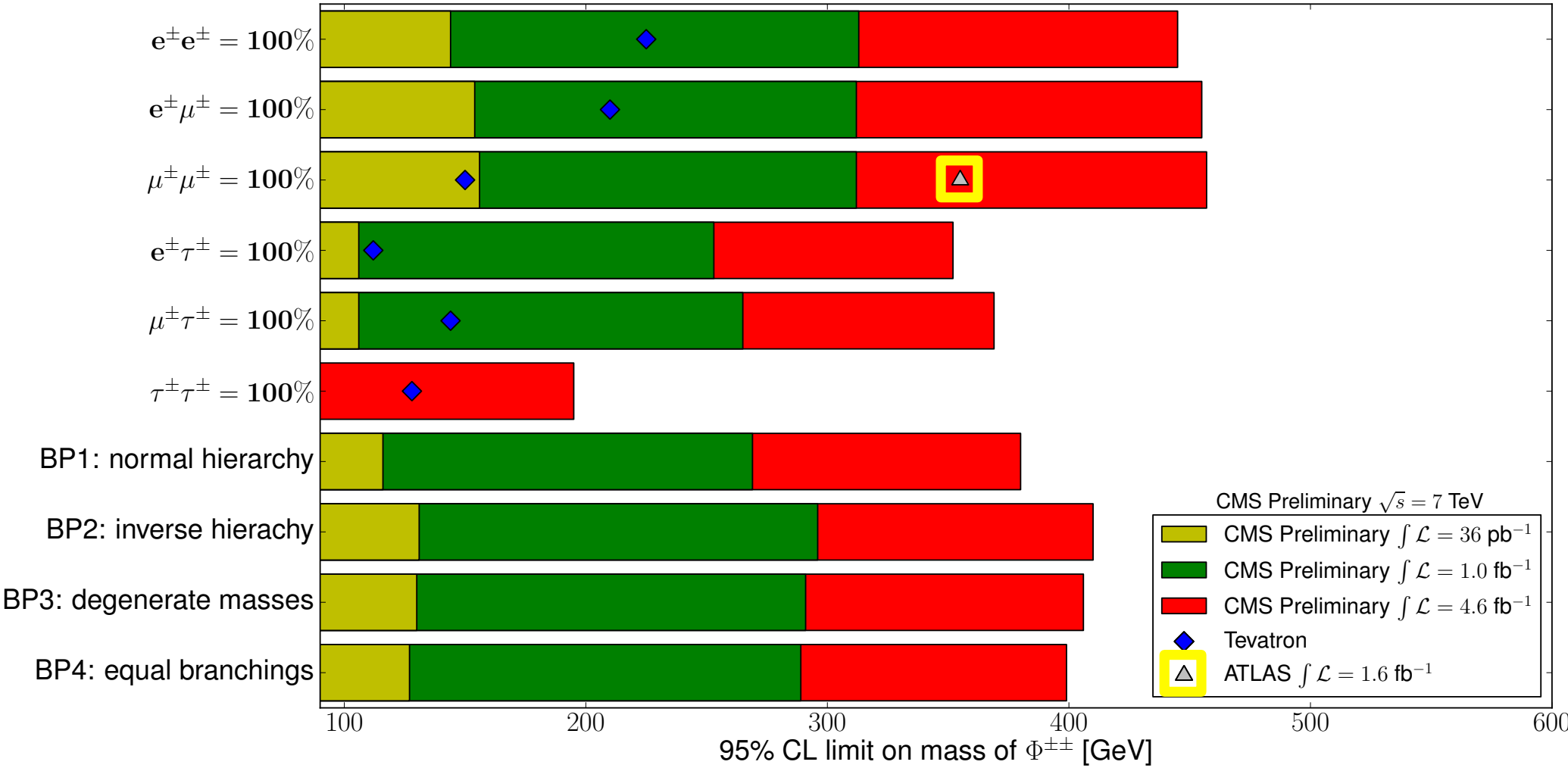






Doubly Charged $\Phi^{\pm\pm} \to l^{\pm} l^{\pm}$ Limits

CMS PAS HIG-12-005

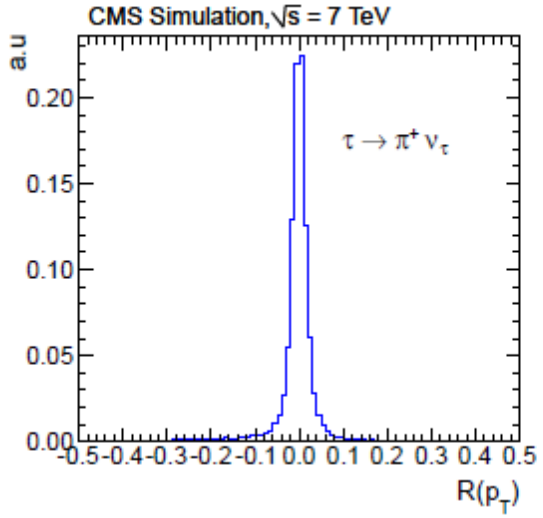


Summary

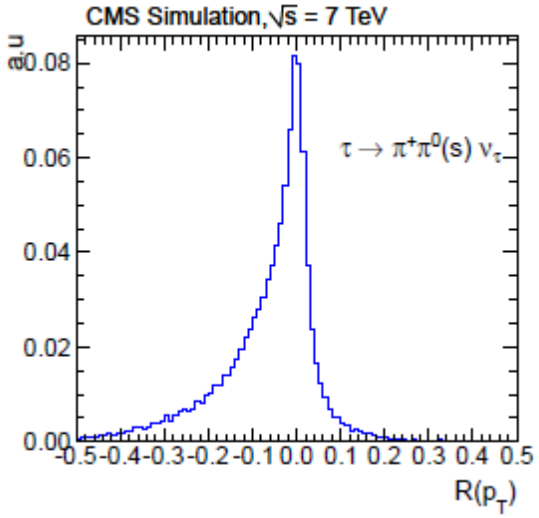
- CMS invented some of the best tau-identification methods at hadron colliders
  - Tau algorithms were validated with measurement of Z production in di-tau mode
- CMS made searches sensitive to the minimal higgs of the Standard Model and Beyond
  - No evidence for SM-like nor BSM higgs is found in several models
    - SM: Gluon Fusion, WZ Fusion and W Associated production
    - MSSM: $gg\phi$ and $bb\phi$ production
    - MSSM higgs parameter space is being constrained using modes with τ-leptons
- With the expected 15+ fb^{-1} sample at 8 TeV, tau-mode measurements are likely to participate prominently in resolving the higgs sector situation at the end of 2012

Tranvserse momentum resolution

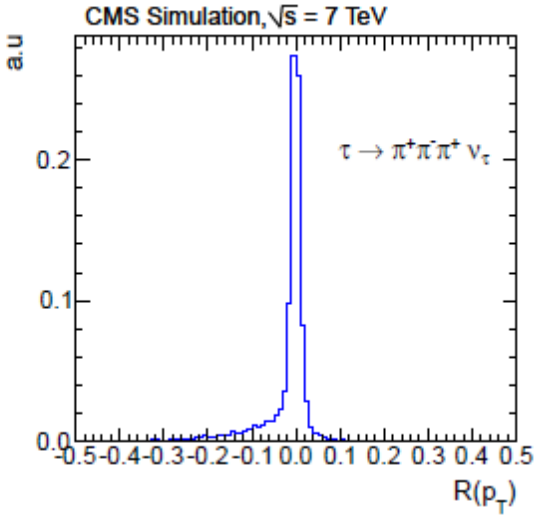
hadron



hadron+strip



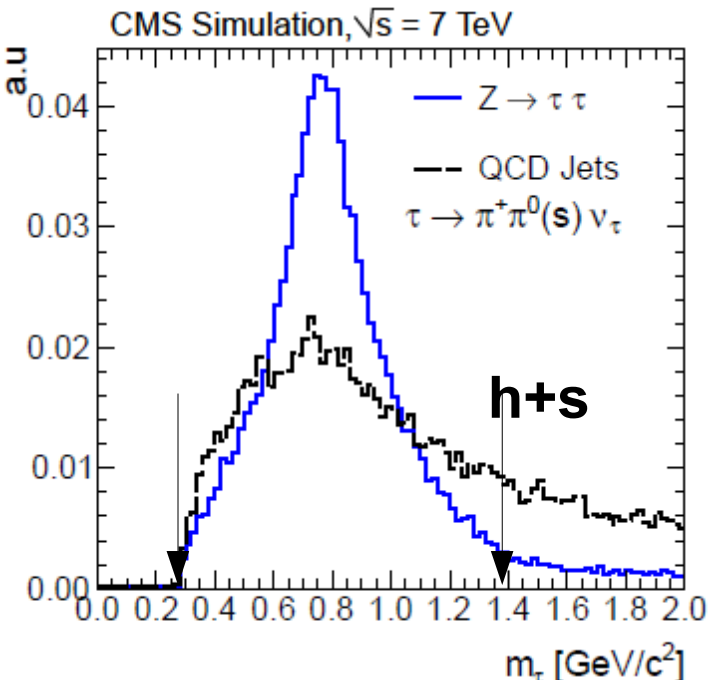
3 hadrons

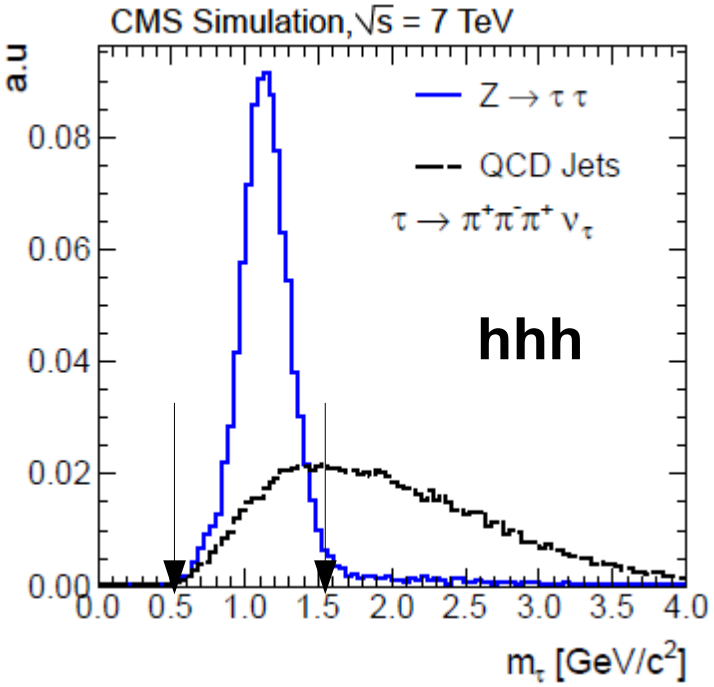


- One and three prong ecay modes dominated by the tracker
  - Excellent resolution
- Hadron+strip decay mode dominated by energy loss
  - Material effects , mis-identification of neutral pions

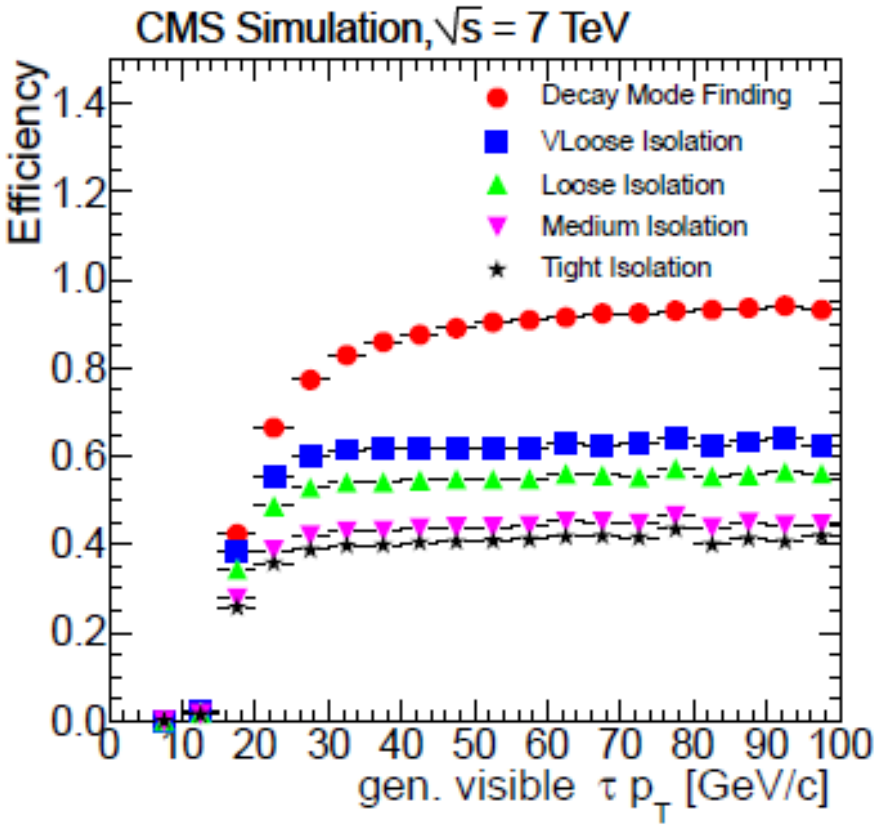
The Hadrons+Strips (HPS) Algorithm

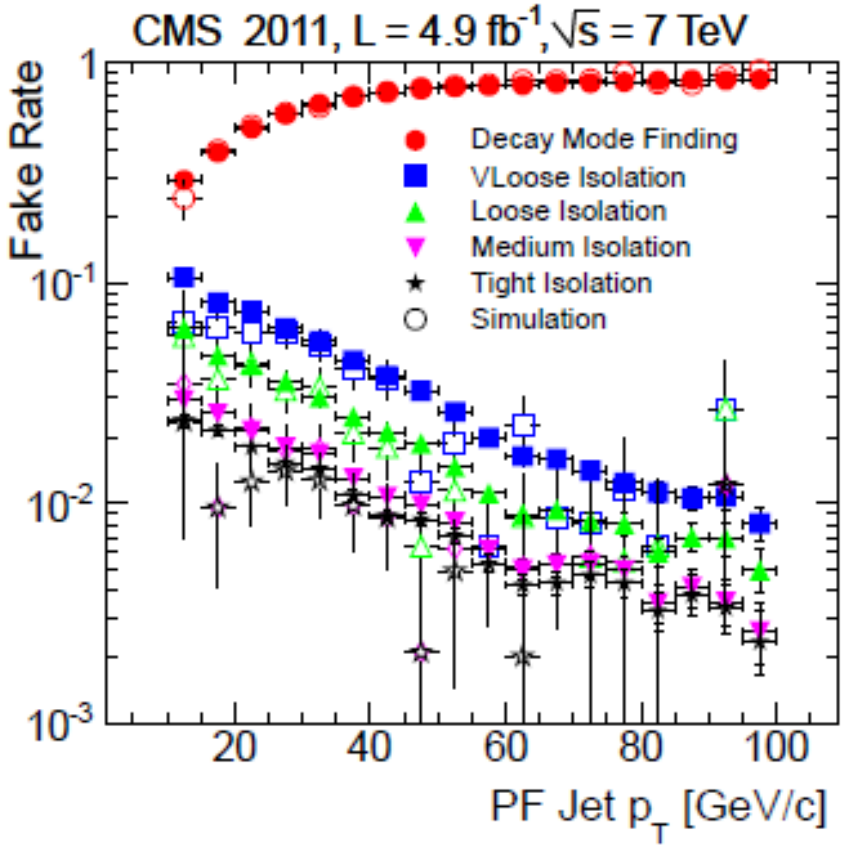
- Start from a jet
- Build combinatorially tau decay modes using PF candidates
  - One charged hadron
  - Three charged hadrons
  - One hadron+ strip
    - Strip is introduced to account for material effects
      - As in electrons
- Apply mass requirements on the decay mode
- Apply isolation on a solid cone of 0.5
  - After subtracting tau constituents





HPS Efficiency and fake rate





- Efficiency calculated on simulation
- Fake rate calculated on data
  - +compared to simulation
- HPS Algorithm achieves an efficiency of 50-60% for a fake rate <= 1%