Search for Low Mass Higgs at CMS

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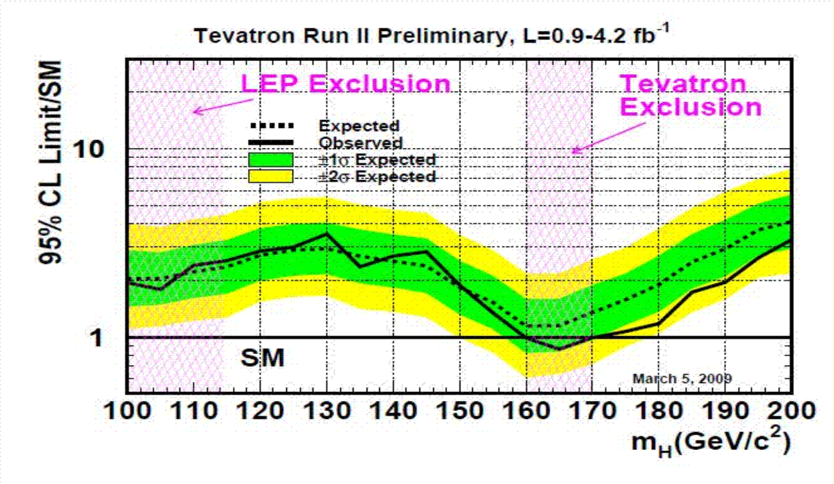
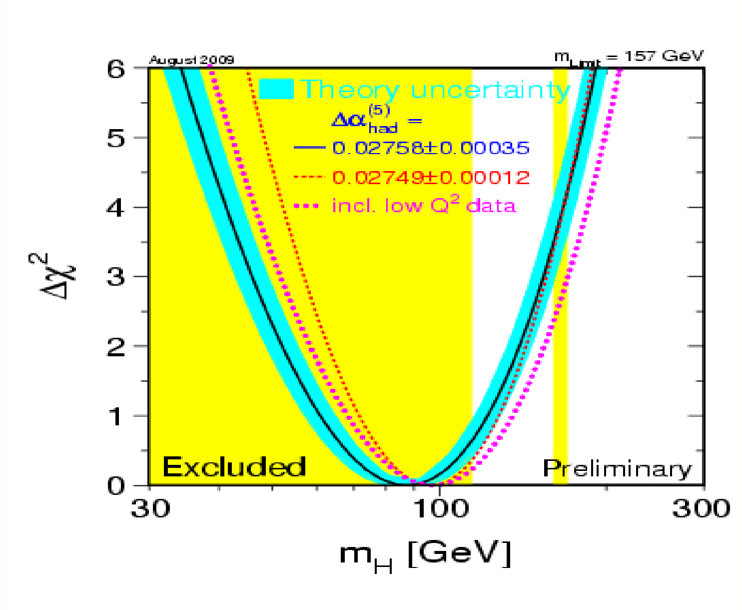
Higgs and LHC

- Minimal scenarios (e.g. SM or MSSM) don't have to be true, but it's hard to get by w/o some sort of a light Higgs
- With no Higgs discovery at the Tevatron, the matter is firmly in the hands of LHC
  - If discovered, next equally important step is figuring out what is it we found
- Phenomenology and LHC reach depend on Higgs mass
  - Without special enhancements (like SUSY), discovery of a "lighter" light higgs (m<120 GeV) will require larger luminosity
  - For benchmarking mostly use SM higgs, which can be easily re-interpreted for more complex models

Current Experimental Landscape

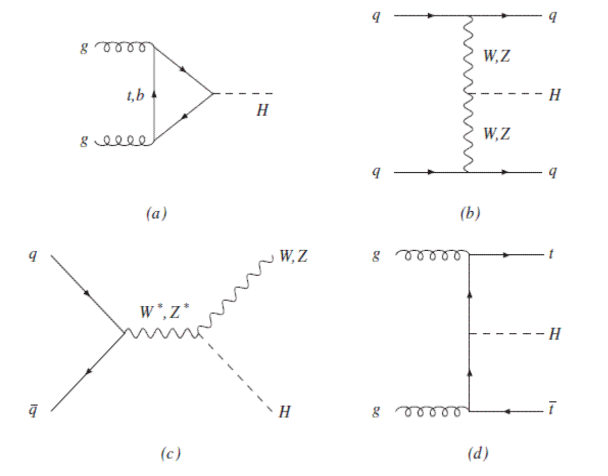
- Direct exclusions:
  - LEP: m>114 GeV
  - Tevatron: 160<m<170 GeV
- Indirect:
  - LEP:
  - Tevatron (W/t mass)
- Most likely range:
  - 114-160 GeV
- *Non-SM scenarios such as NMSSM can weaken both direct and indirect limits*

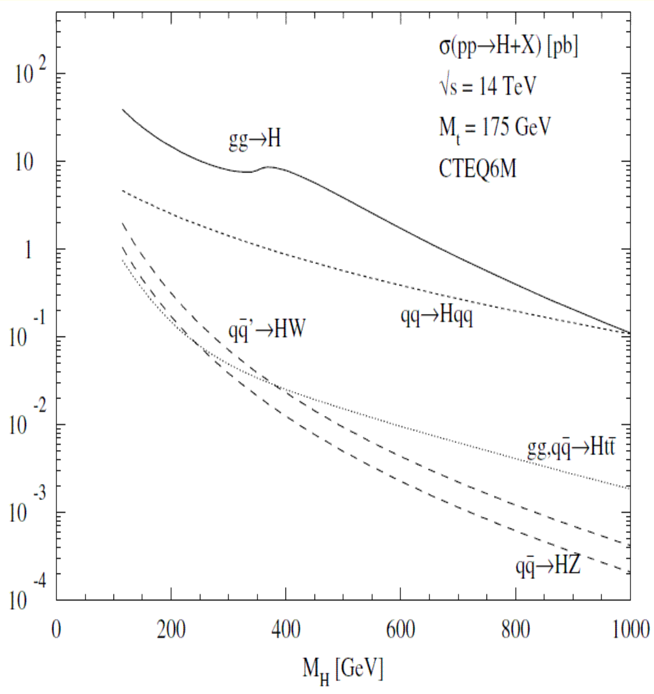




Higgs Production at the LHC

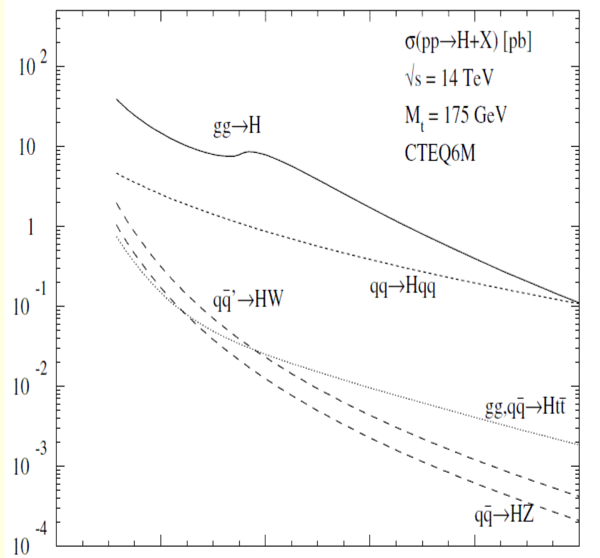
- Dominated by gluon fusion
  - Large decay modes often come with large backgrounds
- Vector Boson Fusion (VBF)
  - While smaller cross section, offers cleaner final states by tagging forward jets
- Associated Production
  - Even smaller cross-section, backgrounds likely a major issue
- Uncovering full Higgs story will require use of all accessible modes and many decay channels
  - Early searches will mainly focus on first two production channels

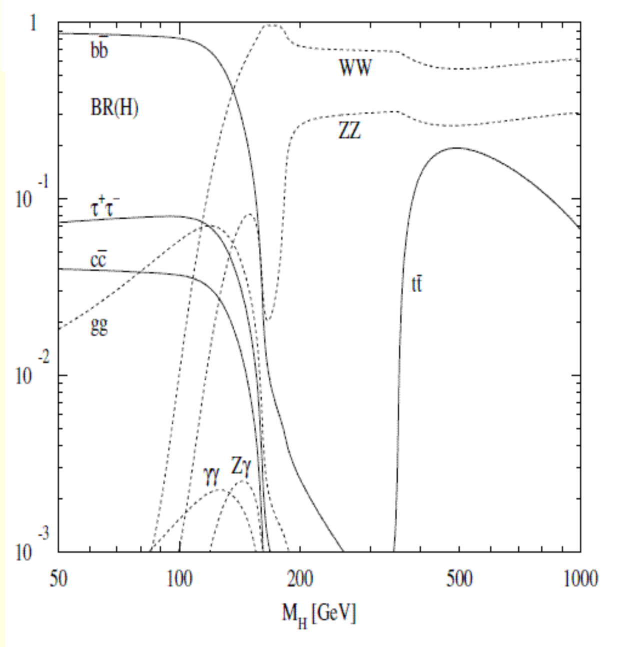




Higgs Search Strategies

- Sensitivity strongly depends on backgrounds for a specific decay channel:
- Range above ~135 GeV:
  - WW/ZZ decay modes
  - Clean final states with leptons, any production mode will do
- Range below ~135 GeV:
  - H→γγ: small BR is the main challenge, need appreciable luminosity
  - H→ττ: large backgrounds, use VBF to improve sensitivity

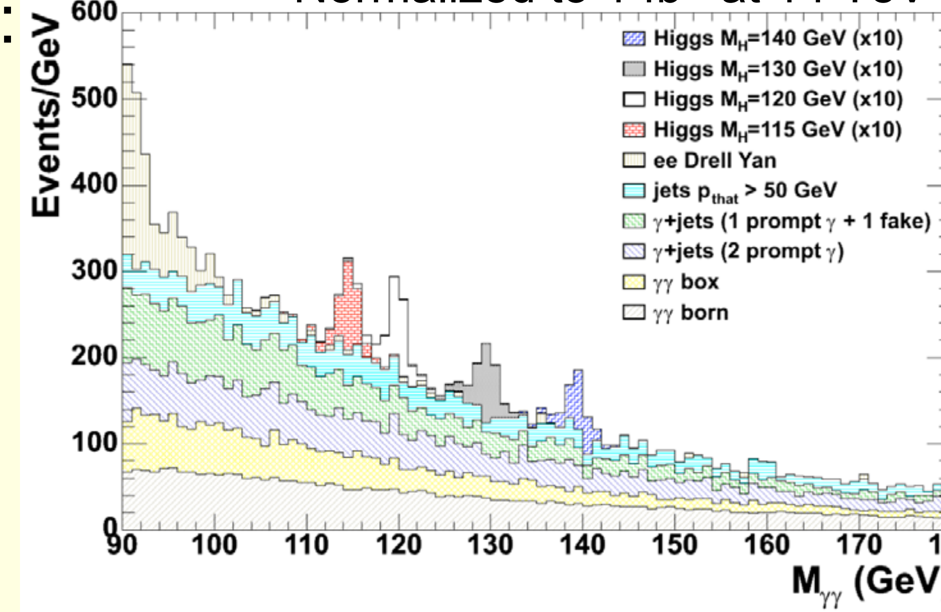




H→γγ: Selections

- Initial Selections:
  - 2 photon candidates in $|\eta|<2.5$
  - $E_T(\gamma_1)>40$, $E_T(\gamma_2)>35$ GeV
  - Isolation: no tracks w/ $p_T>1.5$ GeV in $\Delta R<0.3$
  - Calorimeter Isolation:
  - ECAL clusters:
    - $\Sigma E_T<6(3)$ GeV in $0.06<\Delta R<0.35$ for Central (Endcap)
  - HCAL towers:
    - $\Sigma E_T<6(5)$ GeV in $\Delta R<0.3$ for Central (Endcap)

Normalized to 1 fb^{-1} at 14 TeV

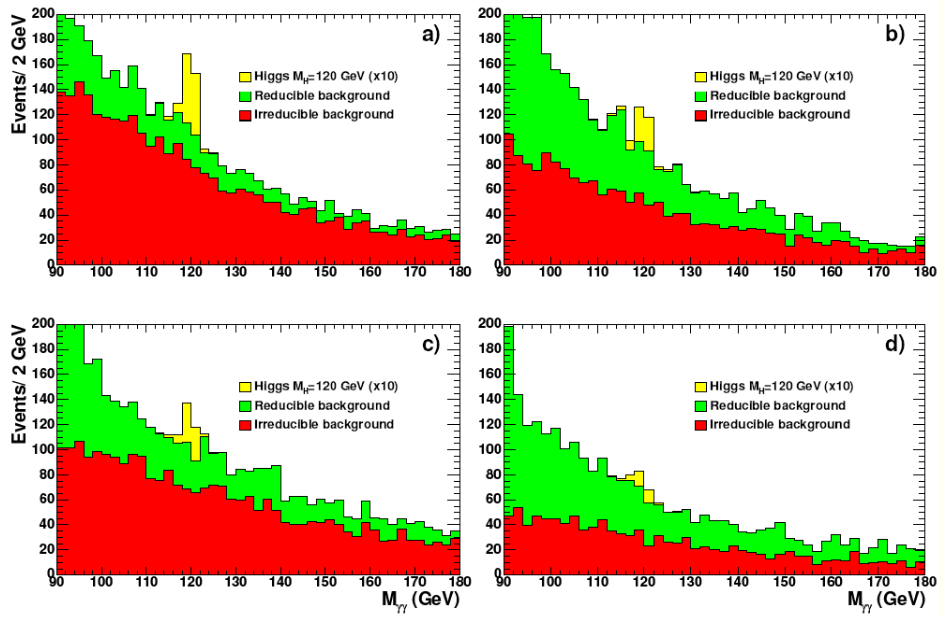


Small bump over large background:

Good mass resolution is critical

$H\rightarrow\gamma\gamma$: Categorization

- To check if there is additional hidden potential, break into categories:
  - 3 bins: $|\eta|$ of the less central photon
  - 4 bins: $R_9=E_T^{3x3}/E_T^{cl}$ of less narrow photon
- Very different S/B and reducible/irreducible background fractions



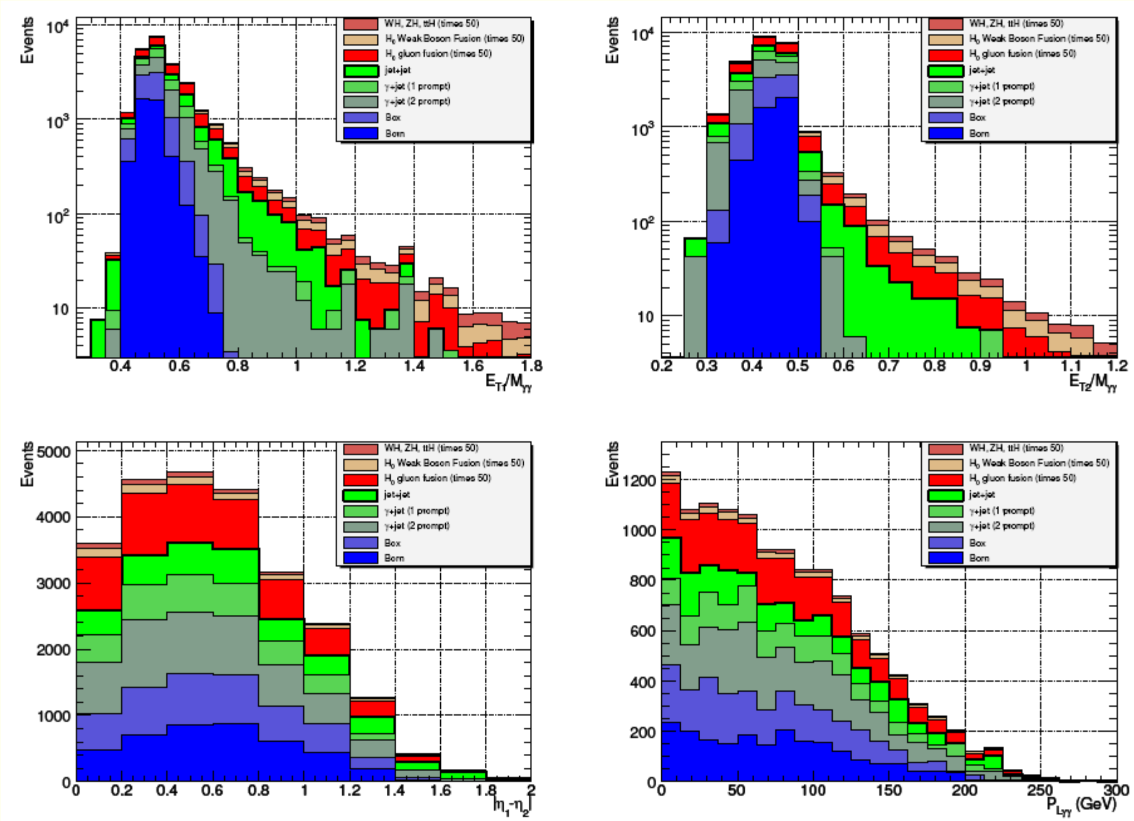
Analysis	5 σ discovery no syst	5 σ discovery syst	3 σ evidence no syst	3 σ evidence syst	95% exclusion no syst	95% exclusion syst
counting exp.	27.4	48.7	10.0	13.2	4.5	6.5
1 category	24.5	39.5	8.9	11.5	4.1	5.8
4 categories	21.3	26.0	7.5	9.1	3.5	4.8
12 categories	19.3	22.8	7.0	8.1	3.2	4.4

Categorization improves sensitivity

Makes sense to use more elaborate categorization

H→γγ: Neural Net

- NN to quantify level of isolation for each photon:
  - $Iso_{NN}(\gamma_1)$, $Iso_{NN}(\gamma_2)$
- Other variables:
  - $E_T(\gamma_1)/M_{\gamma\gamma}$
  - $E_T(\gamma_2)/M_{\gamma\gamma}$
  - $|\eta_1-\eta_2|$
  - $P_L(\gamma_1\gamma_2)$
- Categorize by:
  - $R_9=E_T^{3x3}/E_T^{cl}$
  - BB and BE+EE

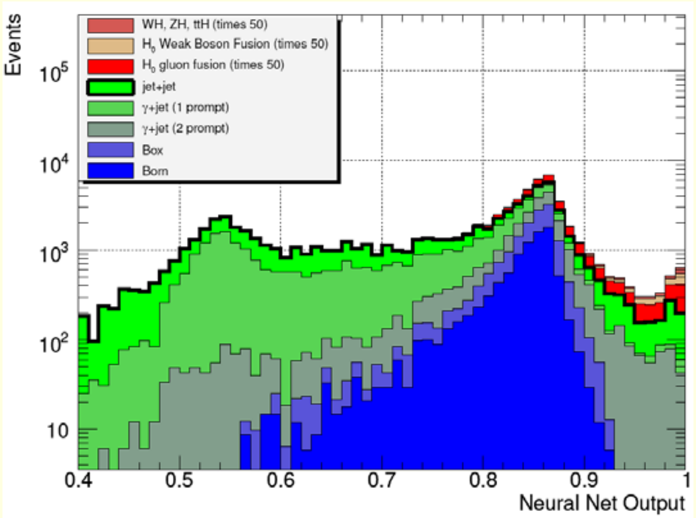


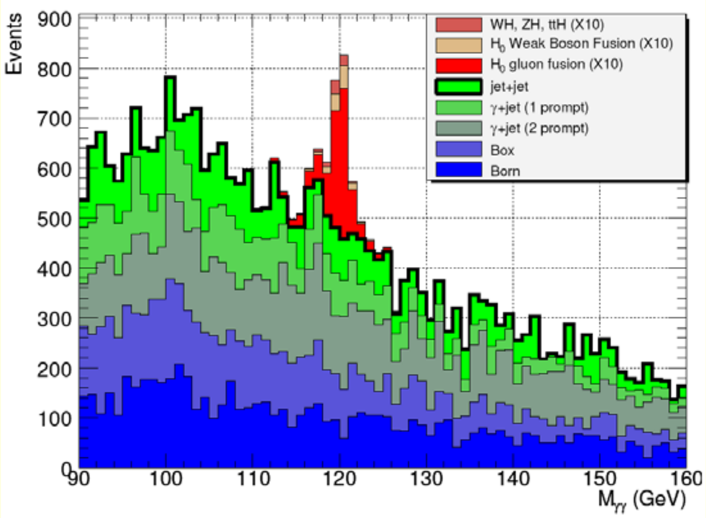
Use sidebands in mass distribution for real data analysis

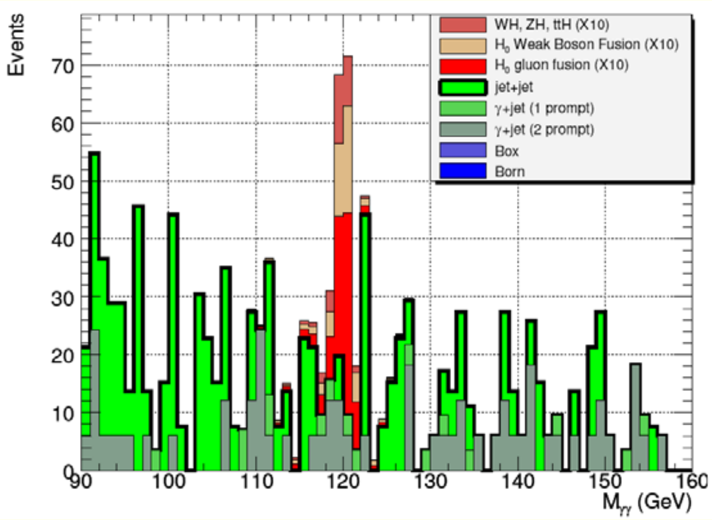
At least something good from having large backgrounds

$H\rightarrow\gamma\gamma$: Neural Net

- Check that NN is doing what it's supposed to do
- Ultimate categorization is to calculate S/B for each event
- Define estimated s/b
  - $(s/b)_{est} = (s/b)_m \times (s/b)_{NN}$

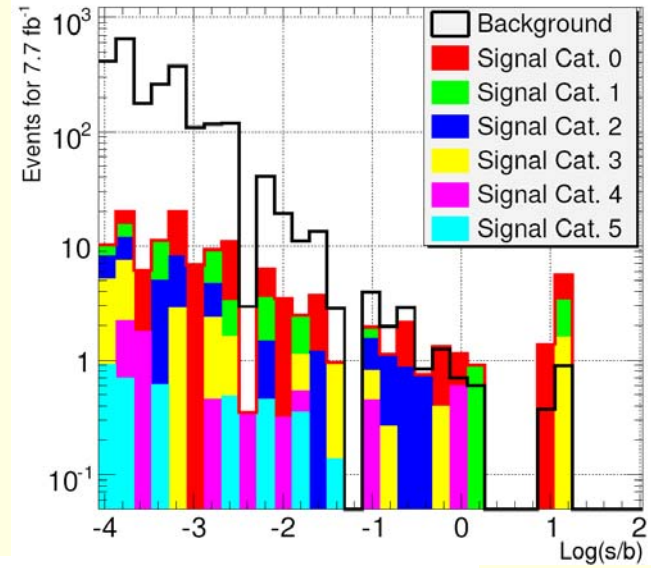


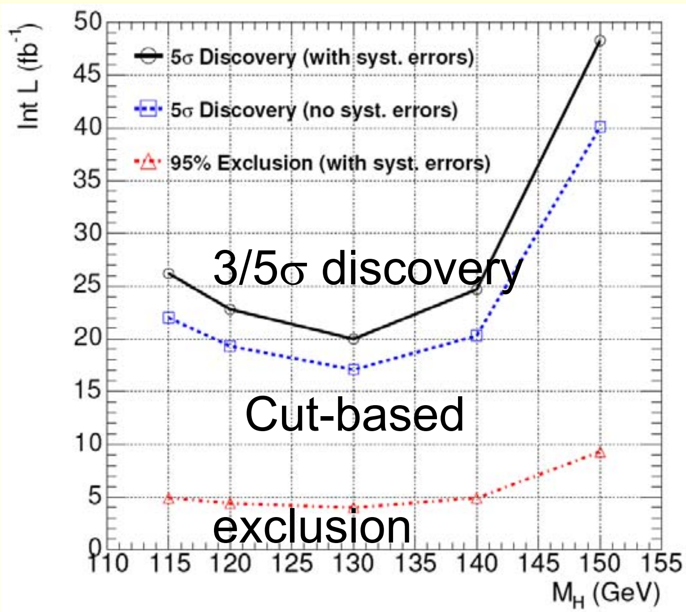


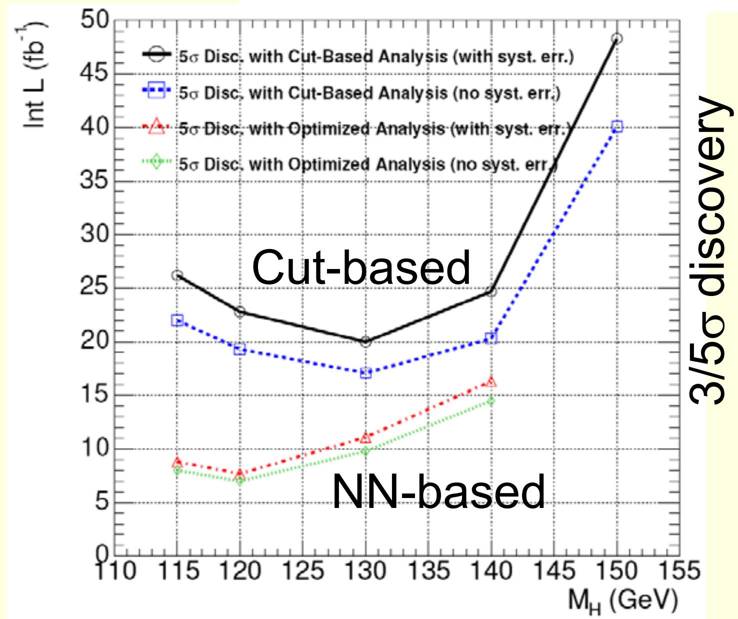


H→γγ: Neural Net

- Plot *Log(s/b)* for all events
  - At this time it is ok to combine different categories
- Use it to calculate exclusion and discovery levels vs Lumi
  - Trial factors weaken reach







$H \rightarrow \tau\tau$ Analysis

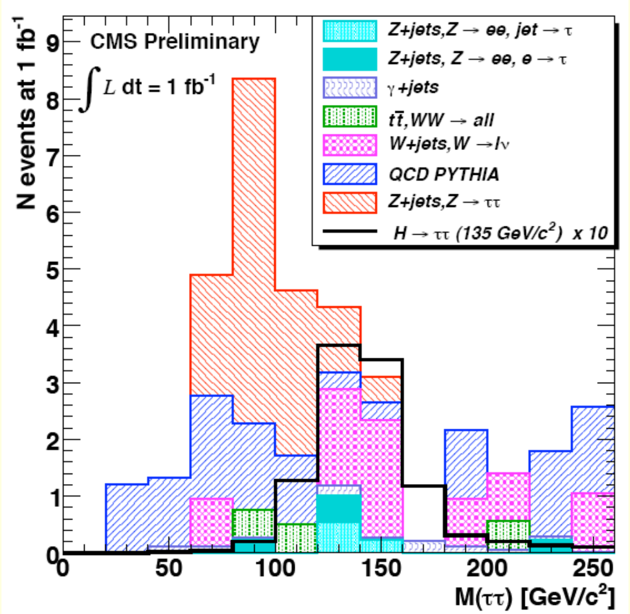
- An important confirmation (if seen in $h \rightarrow \gamma\gamma$) or a discovery channel (e.g. some SUSY scenarios)
- Critical verification of Yukawa nature of *Hff* coupling requires two channels
- Main challenges:
  - Relatively soft spectrum of visible tau decay products due to escaping neutrinos
  - Large backgrounds
    - Hadronic taus look too much like QCD jets, fully leptonic modes have low branching fractions
      - $B(\tau \rightarrow \tau_{had}) \approx 64\%$, $B(\tau \rightarrow \mu\nu\nu) \approx B(\tau \rightarrow e\nu\nu) \approx 18\%$
  - Wide shape of the signal distribution (neutrinos)
    - Difficult to distinguish from irreducible $Z \rightarrow \tau\tau$
      - Collinear approximation suffers a lot from MET resolution effects

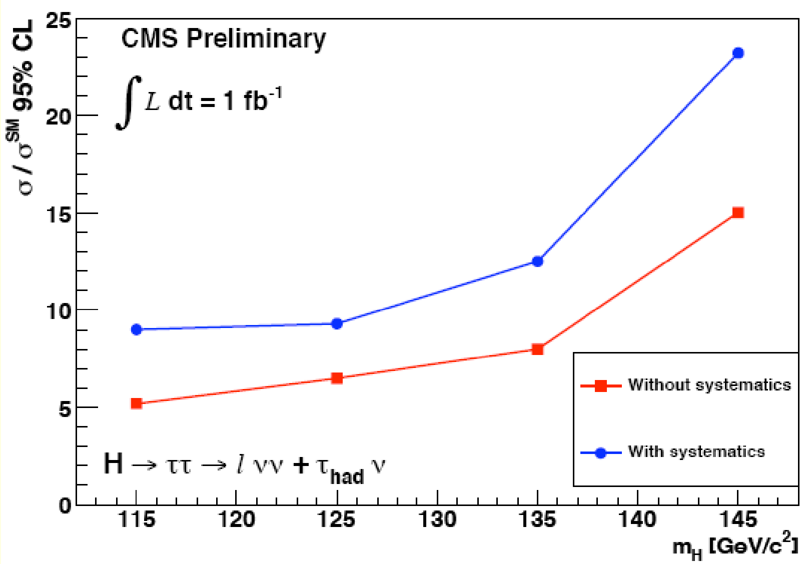
$H \to \tau\tau$ Analysis Selections

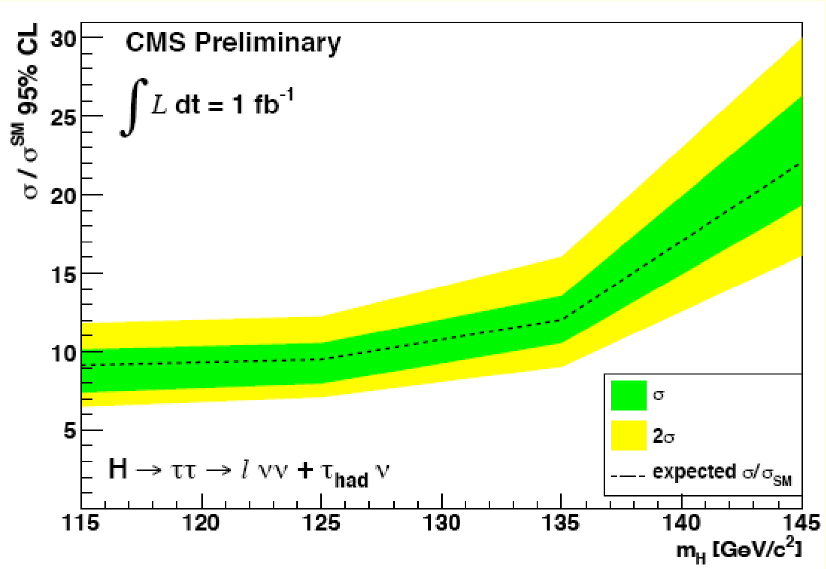
- Rely on VBF production and tag forward jets to reduce backgrounds:
  - 2 jets E_T>30 GeV in $|\eta|<4.5$
  - $\eta_1 x \eta_2 < 0$, M_{jj}>400 GeV
- Use $\tau\tau \to e/\mu + \tau_{had}\nu\nu\nu$ decay mode:
  - Electron: E_T>15 GeV, $|\eta|<2.4$, fiduciality, tight isolation
  - Muon: p_T>15 GeV, $|\eta|<2.1$, isolation
  - Hadronic Tau: E_T>30, $|\eta|<2.4$, tight track isolation (essentially only 1-prongs selected)
    - Electron/muon rejection and quality selections
    - Tau ε=36% for E_T>40 GeV, jet mis-ID rate≈3%

H→ττ Mass Spectrum

- Use collinear approximation
  - Better sensitivity than simple l+τ_h mass
  - Background control is the main challenge
    - Dominated by Z+jets events, control not trivial even for Z's (e.g. VBF cut efficiency)
- Likelihood fit of the distribution
  - LLR to calculate 95% CL limits

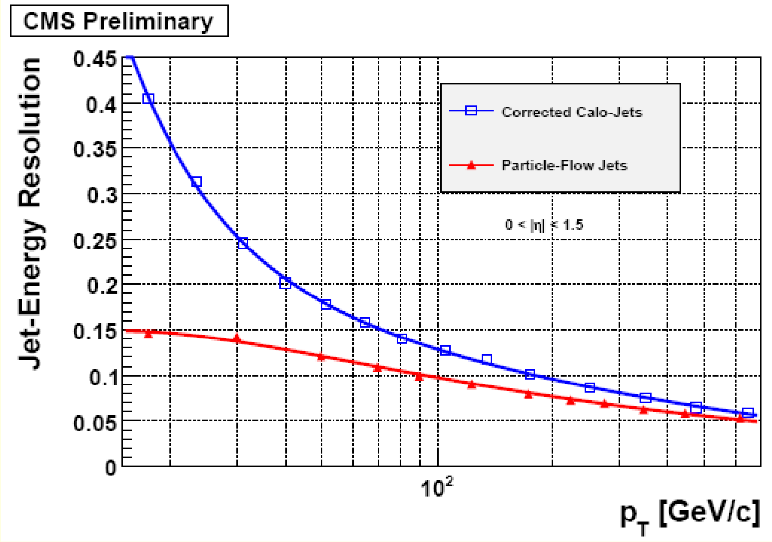


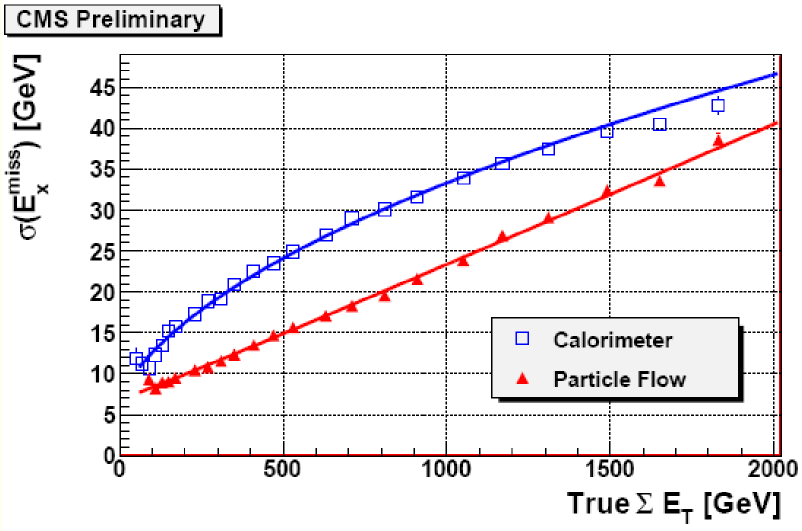




H→ττ: Tackling Challenges

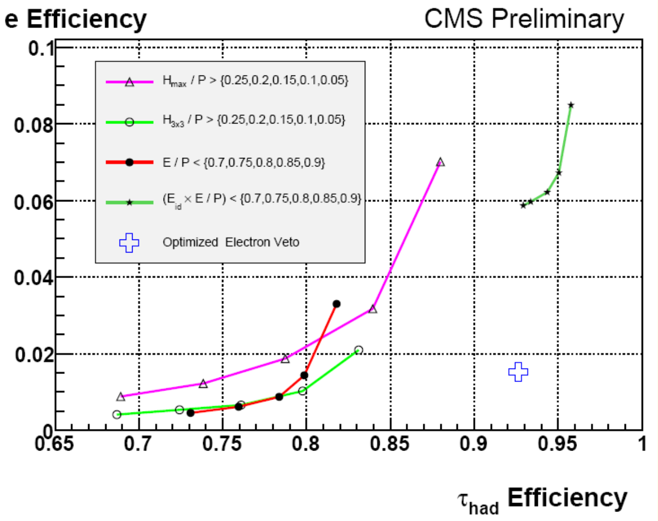
- One important challenge is poor H-Z separation in the mass plot
  - Improvements can come from a better use of kinematics differences (MVA?)
  - Or better MET resolution to sharpen the two peaks
    - Particle Flow algorithm developed at CMS can help there
      - see illustrations

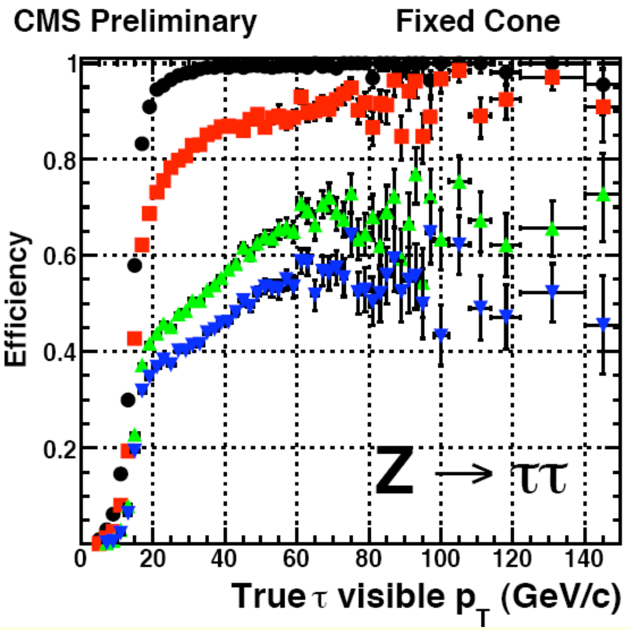


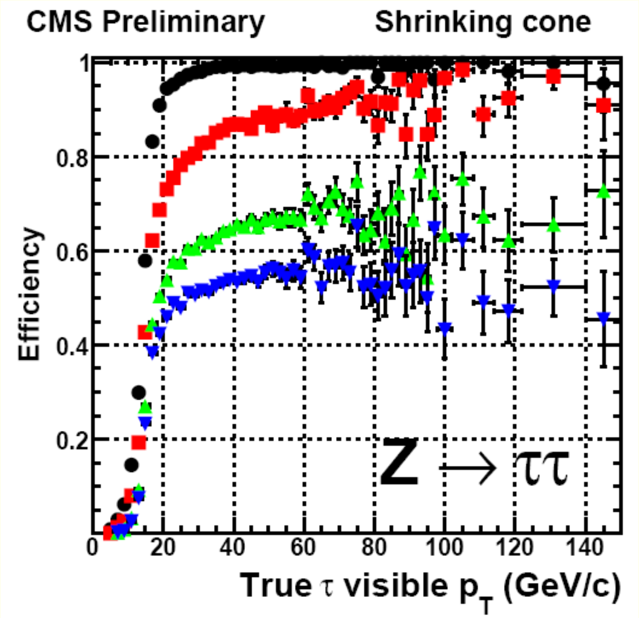


$H \to \tau\tau$: Tackling Challenges

- Another important challenge is low tau ID efficiency:
  - One example – improved electron rejection
- Lower E_T suffers the most:
  - Recent developments in tau ID improve eff in E_T=20-40 GeV







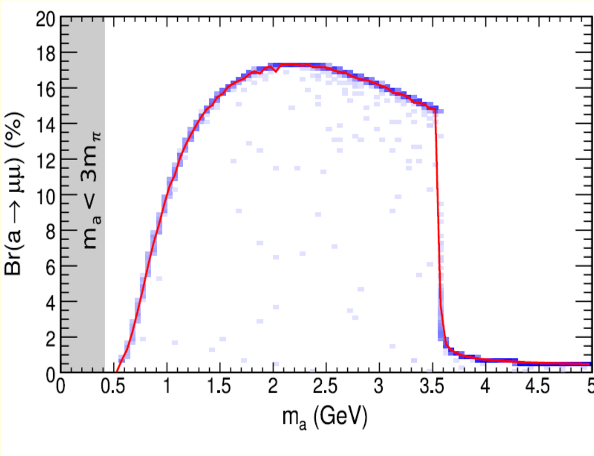
While no silver bullet, factor of 2-3 in sensitivity seems possible

Outlook

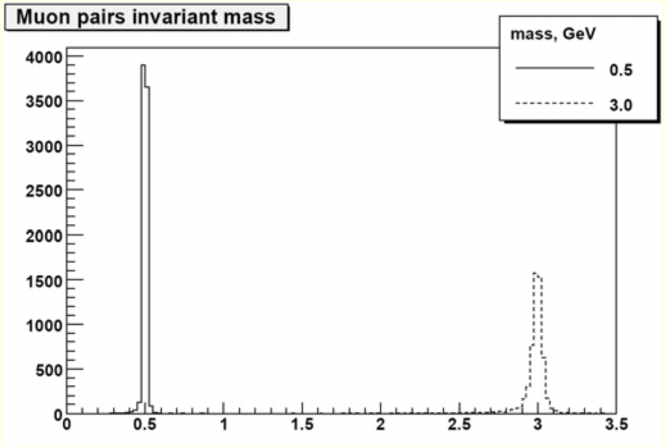
- It is fairly clear that the low Higgs mass range will remain a challenge until
  - either LHC accumulates a few fb^{-1} of data
  - … or if Nature enhanced Higgs production cross-section (MSSM w/ $\tan\beta=\infty$? :)
  - … or offered a new clean channel, e.g. NMSSM with light a_1 decaying to muons and a large $B(h_1 \rightarrow a_1 a_1)$
    - An illustration to follow if time permits
- In the meantime we should continue diligently working on understanding our detector and improving analysis techniques to be ready for discovery when the time comes

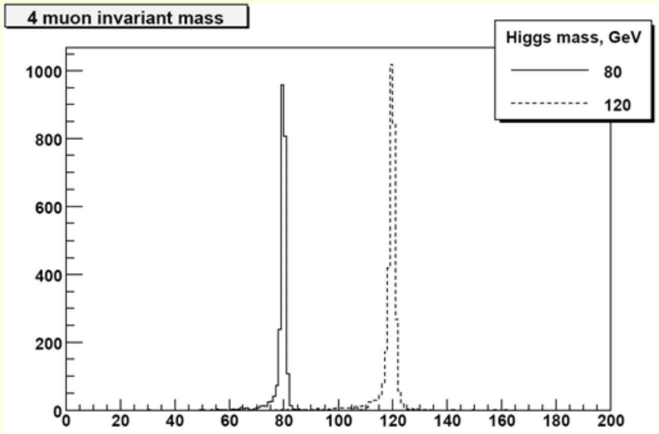
NMSSM with Light CP-odd Higgs

- Extended Higgs sector in NMSSM contains a light (possibly below 2τ threshold) CP-odd a_1
  - Such a_1 would often decay to $\mu\mu$
- For large $B(h_1 \rightarrow a_1 a_1)$, a new important channel $h_1 \rightarrow a_1 a_1 \rightarrow \mu\mu\mu\mu$
  - Near zero backgrounds and multiple built-in constraints:
    - Masses $m(\mu_1,\mu_2)=m(\mu_3,\mu_4)=m_a$, $m(\mu_1,\mu_2,\mu_3,\mu_4)=m_h$



Belyaev, Pivarski, AS, Senkin

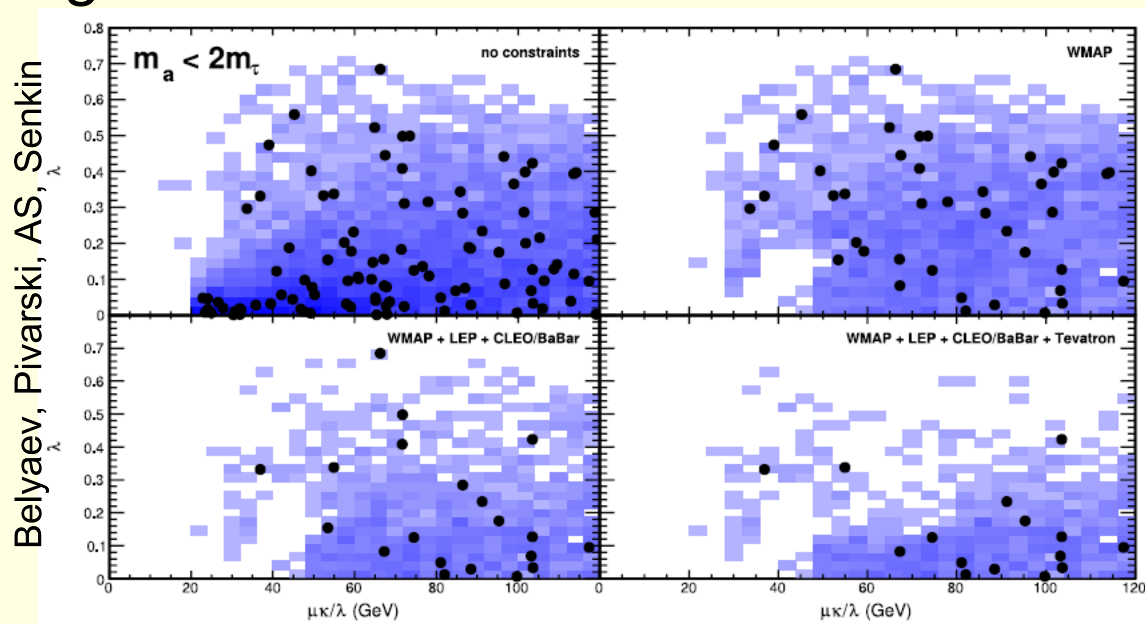




* Not a CMS analysis yet, only a pheno study

Constraints from Current Data

- Strong constraints from WMAP and LEP (m_h below 90 GeV excluded)
- Additional constraints from recent Tevatron data (D0) using $h \to aa \to \mu\mu\mu\mu$ signature
- Large fraction of parameter space remains unconstrained
  - Tevatron will need a huge increase in data to dig into it



- Should be accessible by LHC with an order of ~100 pb^{-1} of data

NMSSM with Light a_1 at LHC

- At 14 TeV, already 100 pb^{-1} of LHC data will significantly expand the Tevatron reach
  - Statement softens but remains true for lower LHC energies
- If we are lucky, new physics can reveal itself very soon

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Belyaev, Pivarski, AS, Senkin