Latest developments in new di-tau mass reconstruction techniques

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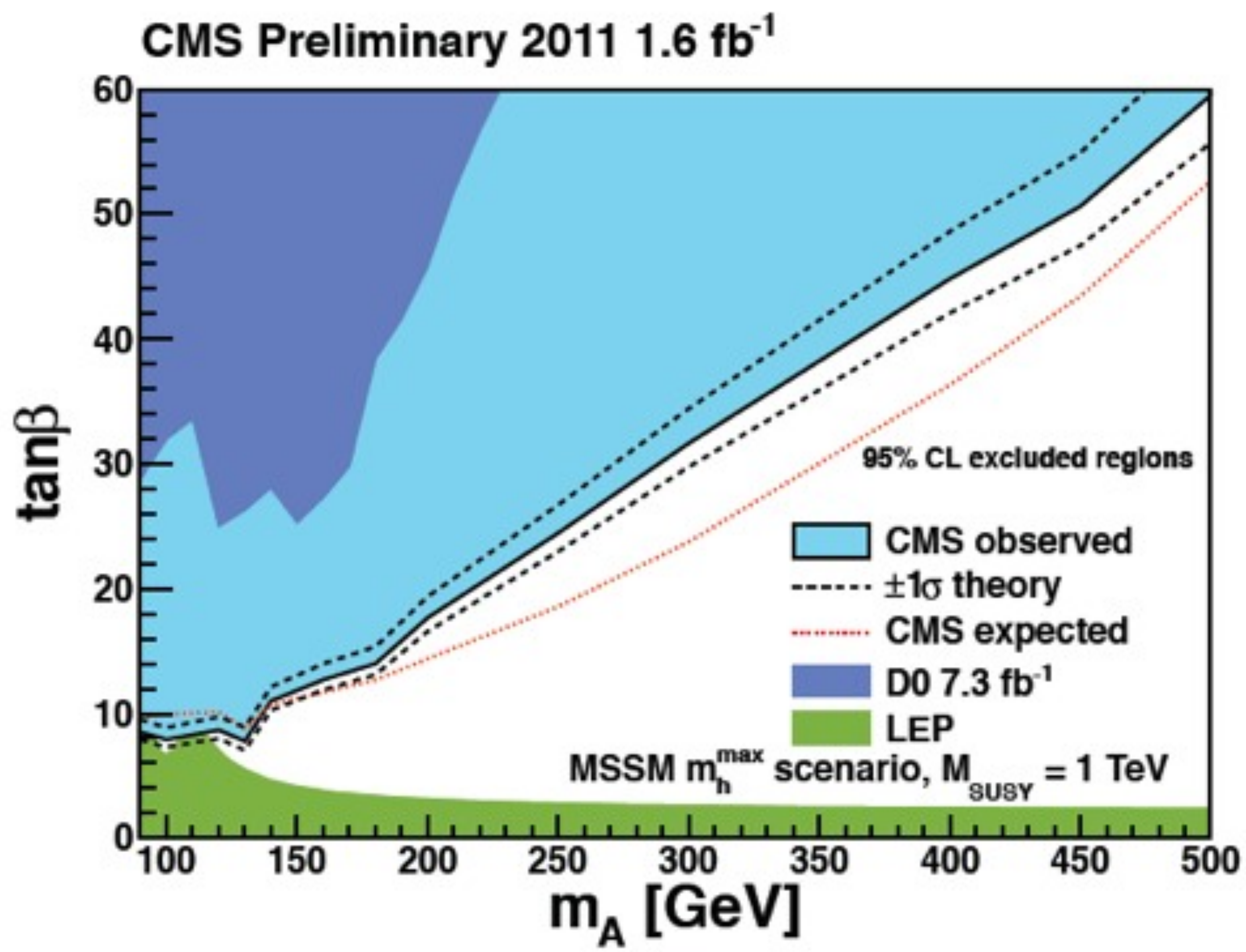
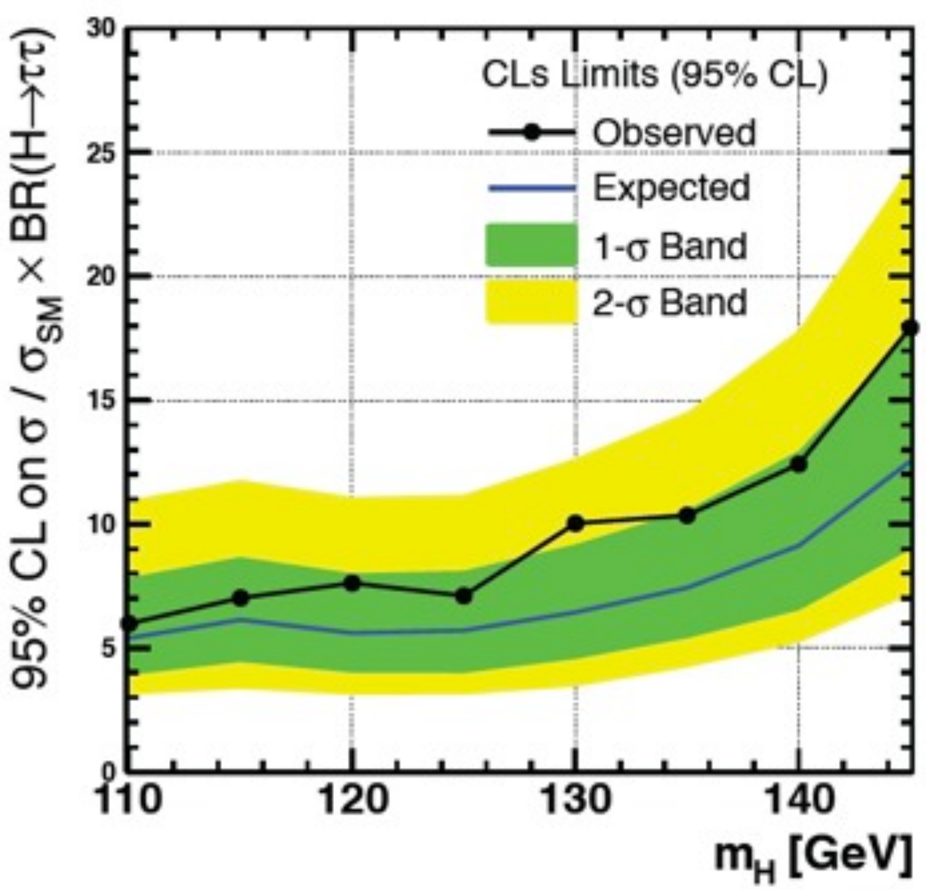
Motivation (I)

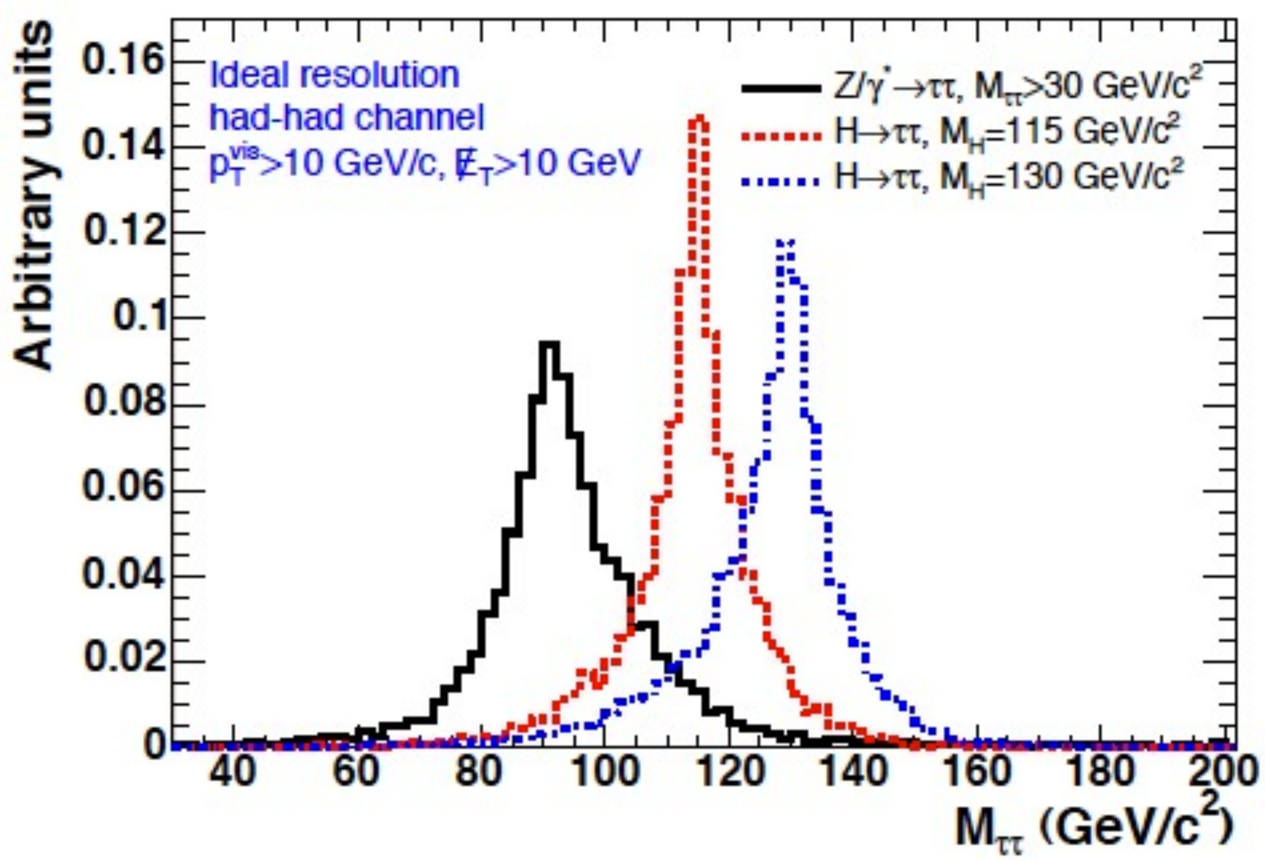
- Looking for H->TauTau signatures
  - golden channel for MSSM Higgs searches
  - Also important for SM Higgs case
    - becoming more and more competitive in the low mass region





Motivations (II)

- The presence of neutrinos deteriorates the invariant mass of tau pairs from resonances
  - Taus are “usually” reconstructed only through their visible decay products
- This results less significant signature compared to resonance decaying in e, mu or gamma
  - Z->TauTau is the dominant background for low mass Higgs searches



This is the goal we want to achieve!

- References:
  - http://www.sciencedirect.com/science/article/pii/S0168900211014112
  - CMS AN-11-165 (only for CMS users)

What WAS on the market

- Visible Mass (Mvis)
  - the invariant mass of only the visible tau decay products
    - The peak is shifted to lower values wrt the real mass.
- Effective Mass (Meff)
  - invariant mass of the visible decay products and MET (considered as particle with Pz = 0)
    - improve the distance between Z and larger mass Higgs boson where larger MET is expected
- Collinear approximation
  - it assumes neutrinos to be collinear with the tau visible decay products
  - Main drawbacks :
    - real solutions do not exists for all the events
    - to recover the efficiency, “fake” solutions are assumed for some events in order not to loose them
      - poor mass resolution with long tails
  - It has been practically abandoned
    - improved methods appeared recently

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What's the problem ?

- In order to reconstruct the neutrinos momenta we need kinematical constraints from the event
  - basically it boils down to solve equations where the components of three-vectors of the neutrinos are the variables to be determined
- the only "measured" constraint is the reco'd MET
  - assumed to be the vector sum of the neutrinos momenta in the transverse plane
    - it is affected by possible mis-measurement due to extra event activity
- We need extra constraints to solve the equations
  - different methods implements different constraints
- We need to take into account possible mis-measurement of the MET

Newest developments

- Recents days have seen the birth of more complex methods
  - based on likelihood maximization to find the proper solution
  - basically one possible solution for each event
- The main algorithms used by ATLAS and CMS are
  - Missing Mass Calculator (MMC)
    - by Elagin et al.
      - http://www.sciencedirect.com/science/article/pii/S0168900211014112
  - Secondary Vertex Fit (SVFIT)
    - by Conway et al.

MMC

- It drops any assumption of the collinearity and tries to resolve the 4 equations in terms of the neutrinos momenta

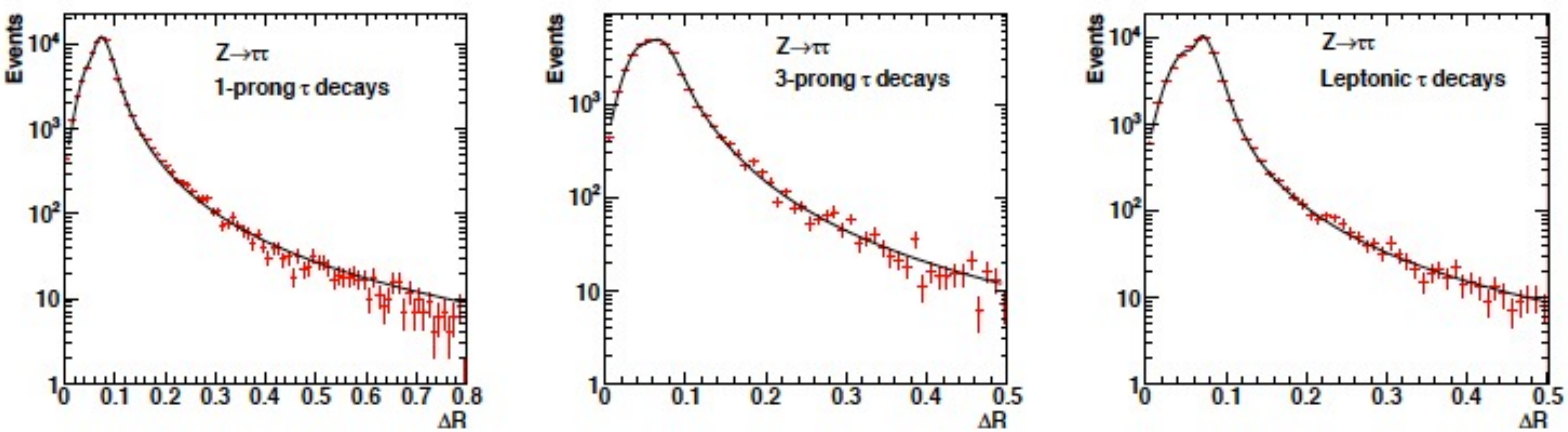
$$\not{E}_{T_x} = p_{\text{mis}_1} \sin\theta_{\text{mis}_1} \cos\phi_{\text{mis}_1} + p_{\text{mis}_2} \sin\theta_{\text{mis}_2} \cos\phi_{\text{mis}_2}$$

$$\not{E}_{T_y} = p_{\text{mis}_1} \sin\theta_{\text{mis}_1} \sin\phi_{\text{mis}_1} + p_{\text{mis}_2} \sin\theta_{\text{mis}_2} \sin\phi_{\text{mis}_2}$$

$$M_{\tau_1}^2 = m_{\text{mis}_1}^2 + m_{\text{vis}_1}^2 + 2\sqrt{p_{\text{vis}_1}^2 + m_{\text{vis}_1}^2}\sqrt{p_{\text{mis}_1}^2 + m_{\text{mis}_1}^2} - 2p_{\text{vis}_1} p_{\text{mis}_1} \cos\Delta\theta_{vm_1}$$

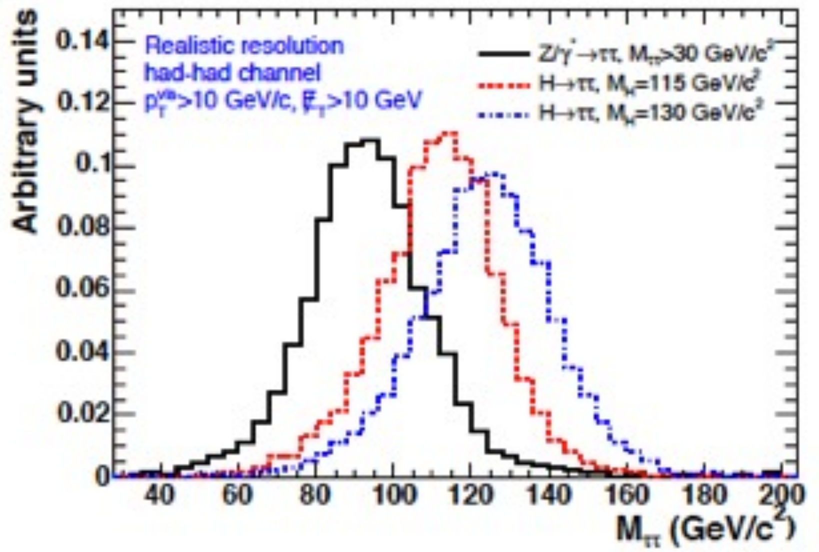
$$M_{\tau_2}^2 = m_{\text{mis}_2}^2 + m_{\text{vis}_2}^2 + 2\sqrt{p_{\text{vis}_2}^2 + m_{\text{vis}_2}^2}\sqrt{p_{\text{mis}_2}^2 + m_{\text{mis}_2}^2} - 2p_{\text{vis}_2} p_{\text{mis}_2} \cos\Delta\theta_{vm_2}$$

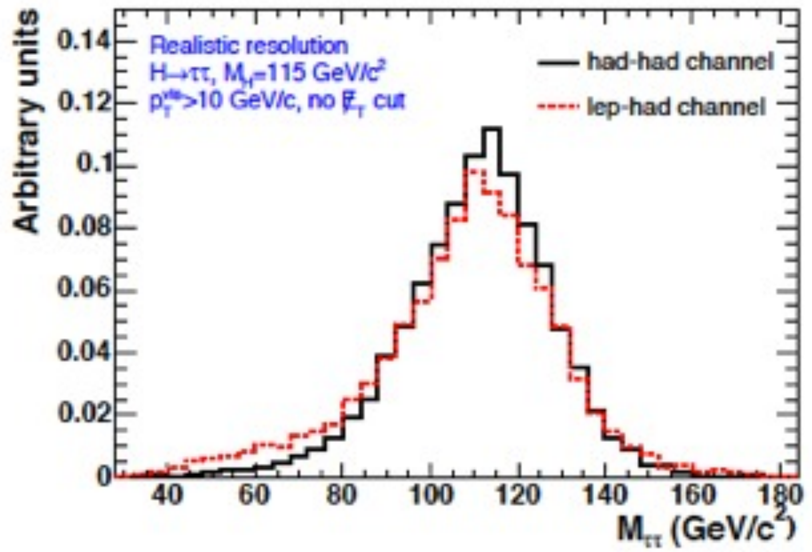
- per each possible solution a reconstructed mass is created weighted by the output of a Likelihood function
  - DeltaR distribution between visible taus and the assumed neutrino direction

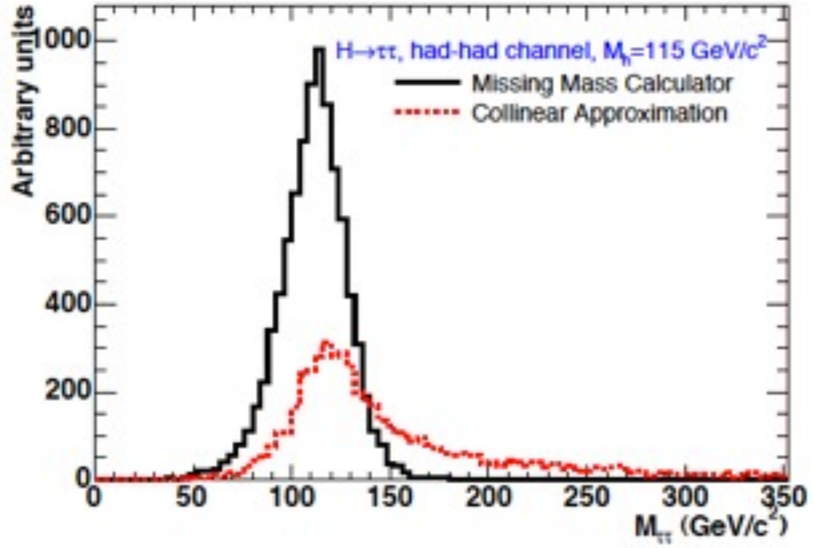


MMC cont'd

- MET mis-measurement is taken into account by the use of an extra term in the Likelihood
  - basically parametrizing the MET uncertainty
- The hadronic tau decays are the simplest ones to reconstruct
  - only two neutrinos, hence 6 missing variables
- For the leptonic decays things are getting more complicated
  - the number of possible solutions is larger and hence the probability of taking the wrong reconstructed mass increases.







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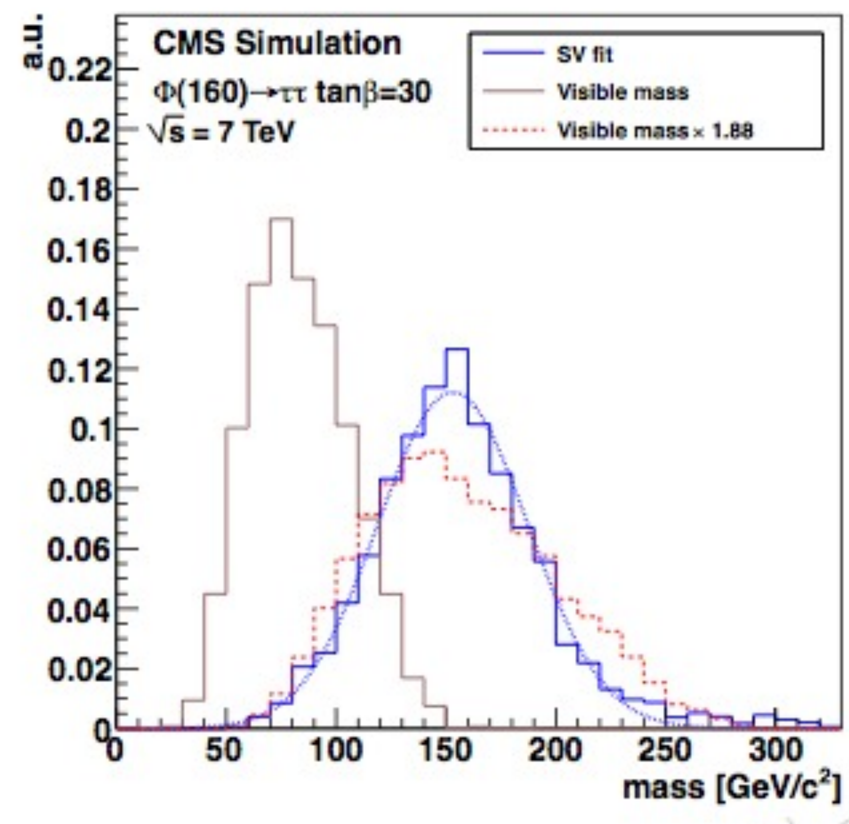
(N)SVFIT

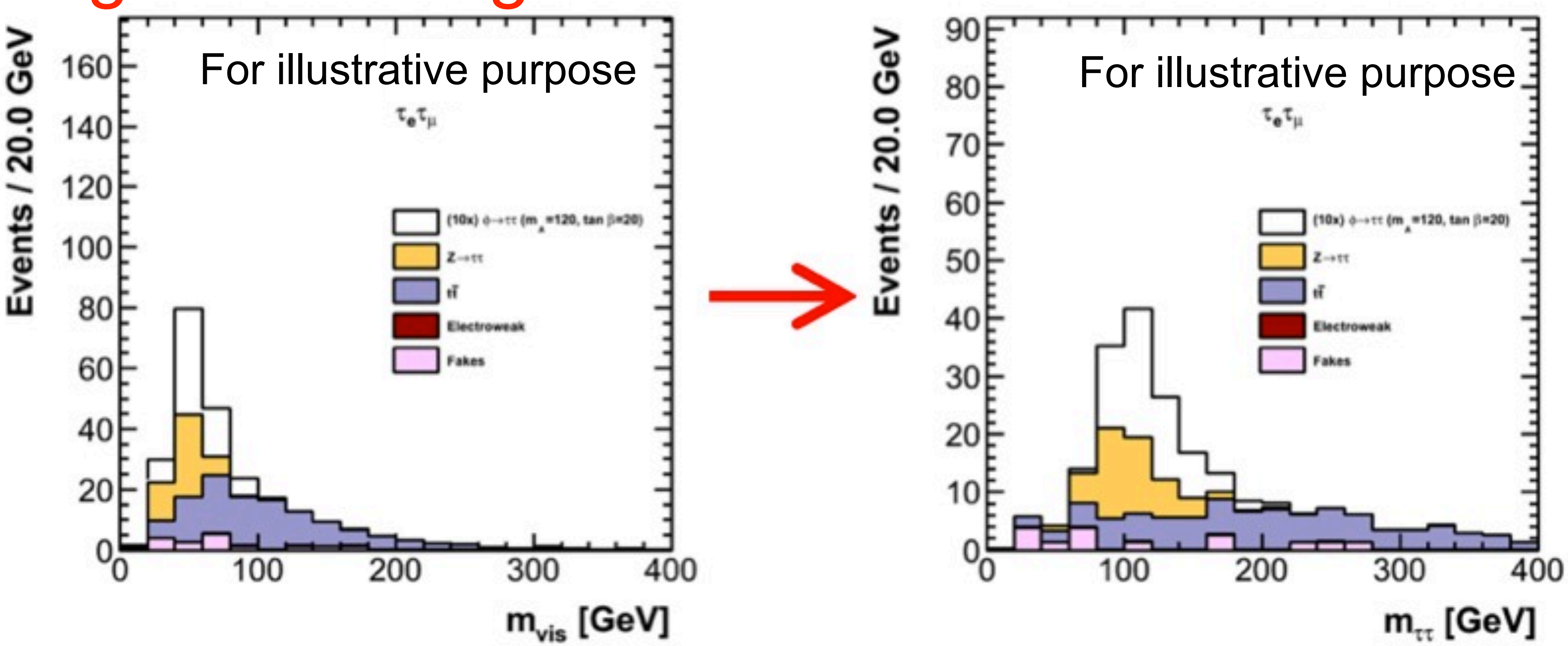
- Method similar to the MMC
  - a bit more elaborated
    - there was the initial intention of using also the Secondary Vertices in the fit
- Different variables used for spanning the solutions
- Added a $\ln(M_{inv})$ to the likelihood to favour low mass solutions
  - hence reducing the tails



Reconstructed mass from simulation

Pro’s

- Invariant mass resolution improves
- the peak value is nearer to the generated one
  - hence better discrimination between Higgs and Z->TauTau
- Not resonant bkg are flattened improving further the signal to background ratio

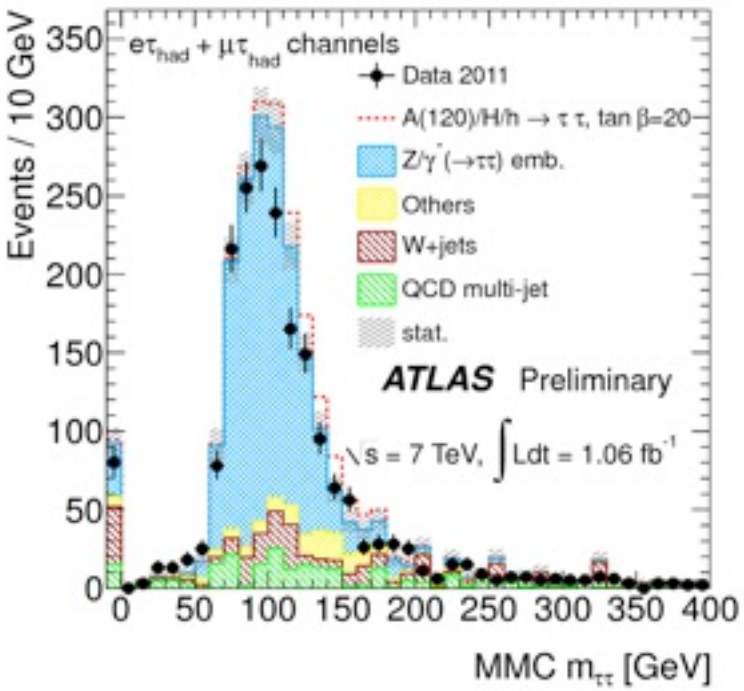


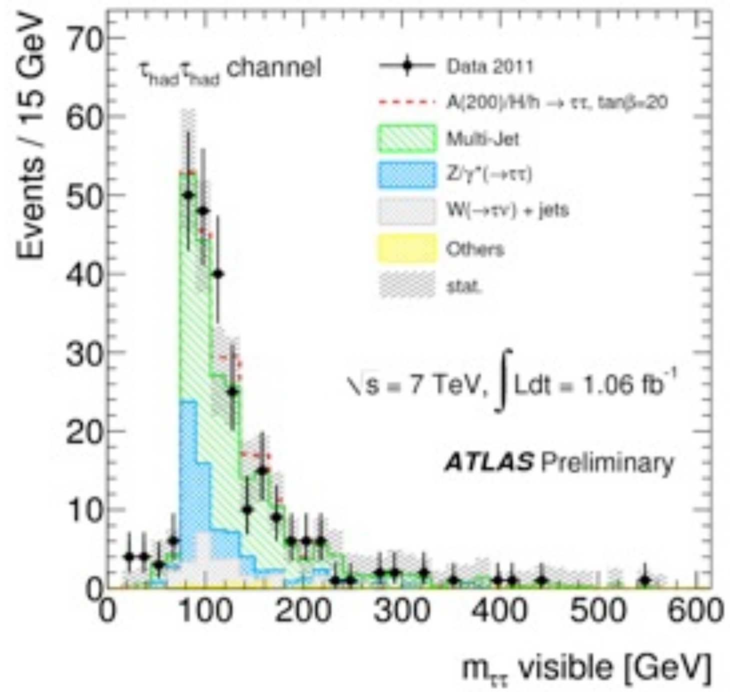
Weak points

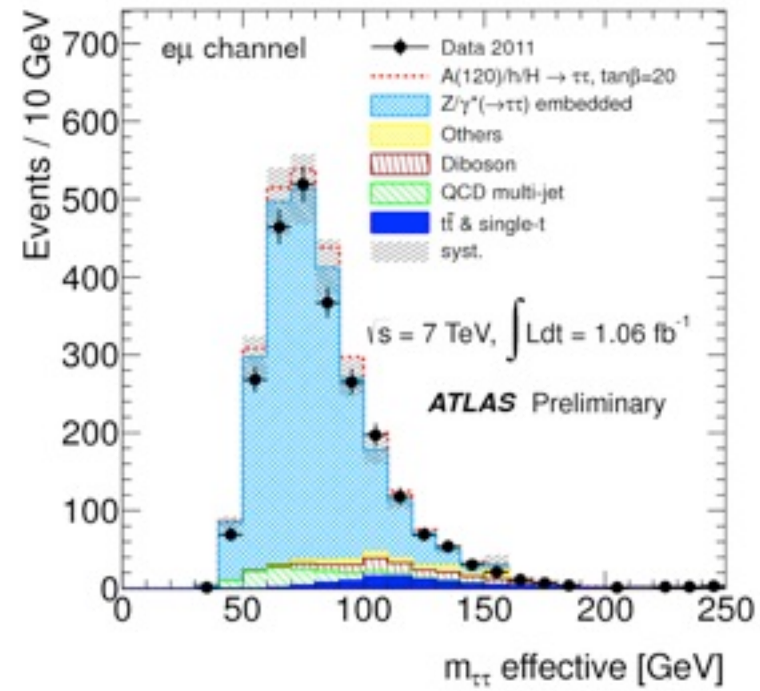
- The algorithms work under the assumption that neutrinos are the only source of MET
  - In real events MET can be affected by energy mis-measurements
  - If not taken properly into account a 5% resolution of the MET would result in a 30-40% inefficiency and a degradation of the reconstructed mass
- Even if MET resolution is taken into account through extra likelihood functions
  - MET resolution depends on the event topology
    - in general on the total SumET of the event
  - A not-so-perfect simulation of the MET resolution may results in large disagreement between data and MC
    - Tails of the invariant mass distribution can be mostly affected
- The fitting and the integration methods take too much time
  - ~ 1 minute per events
  - difficult to run on large MC samples

Choices made by the ATLAS and CMS

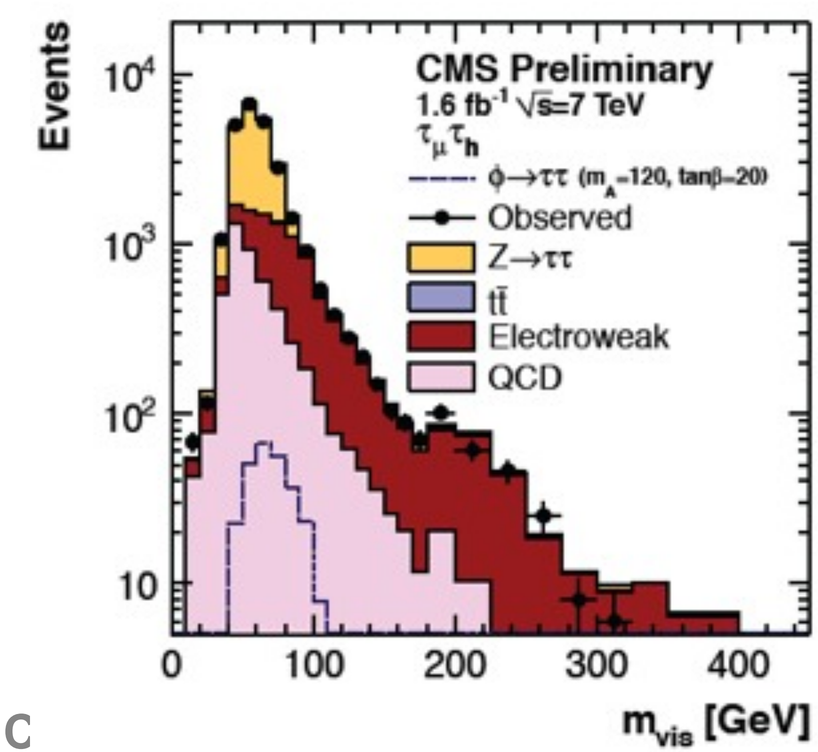
- ATLAS uses MMC, visible mass and the effective mass

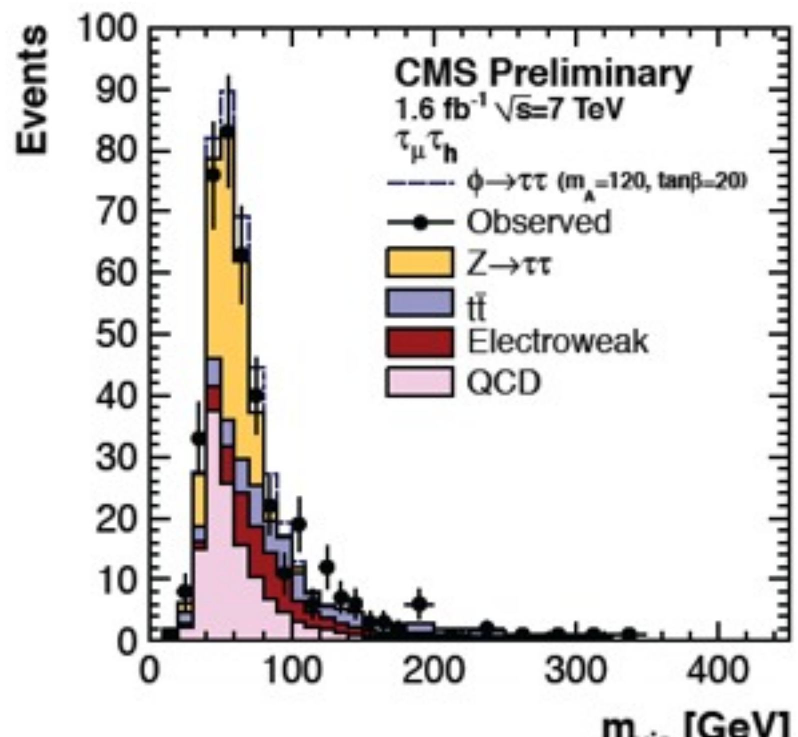






- CMS has used the SVFIT in 2010 but came back to the visible mass





What's needed

- deep scrutiny on both techniques
  - understanding of the influence of the MET resolution in the tails
  - detailed data/MC comparisons
- quantifying the improvements in terms of limit setting per each channel
  - improvements may depend on the bkg composition
- improvements in the timing

Conclusions

- New di-Tau mass reconstruction techniques are available
  - improved signal to background ratio is granted
- Most advanced ones:
  - MMC and NSVFIT
    - only MMC used in current analyses
  - As far as SVFIT is concerned:
    - Few caveats are remaining hopefully will be understood in the next analysis iteration