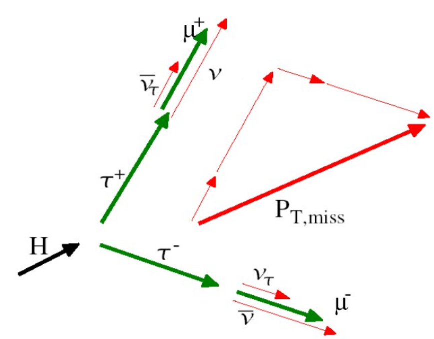
Status and plans of the $m_{\tau\tau}$ working group

http://tautauag.phy.tu-dresden.de

6th Annual Workshop of the Helmholtz Alliance,

Hamburg, 4.12.2012

Kathrin Kormoll



Task of the $m_{\tau\tau}$ group

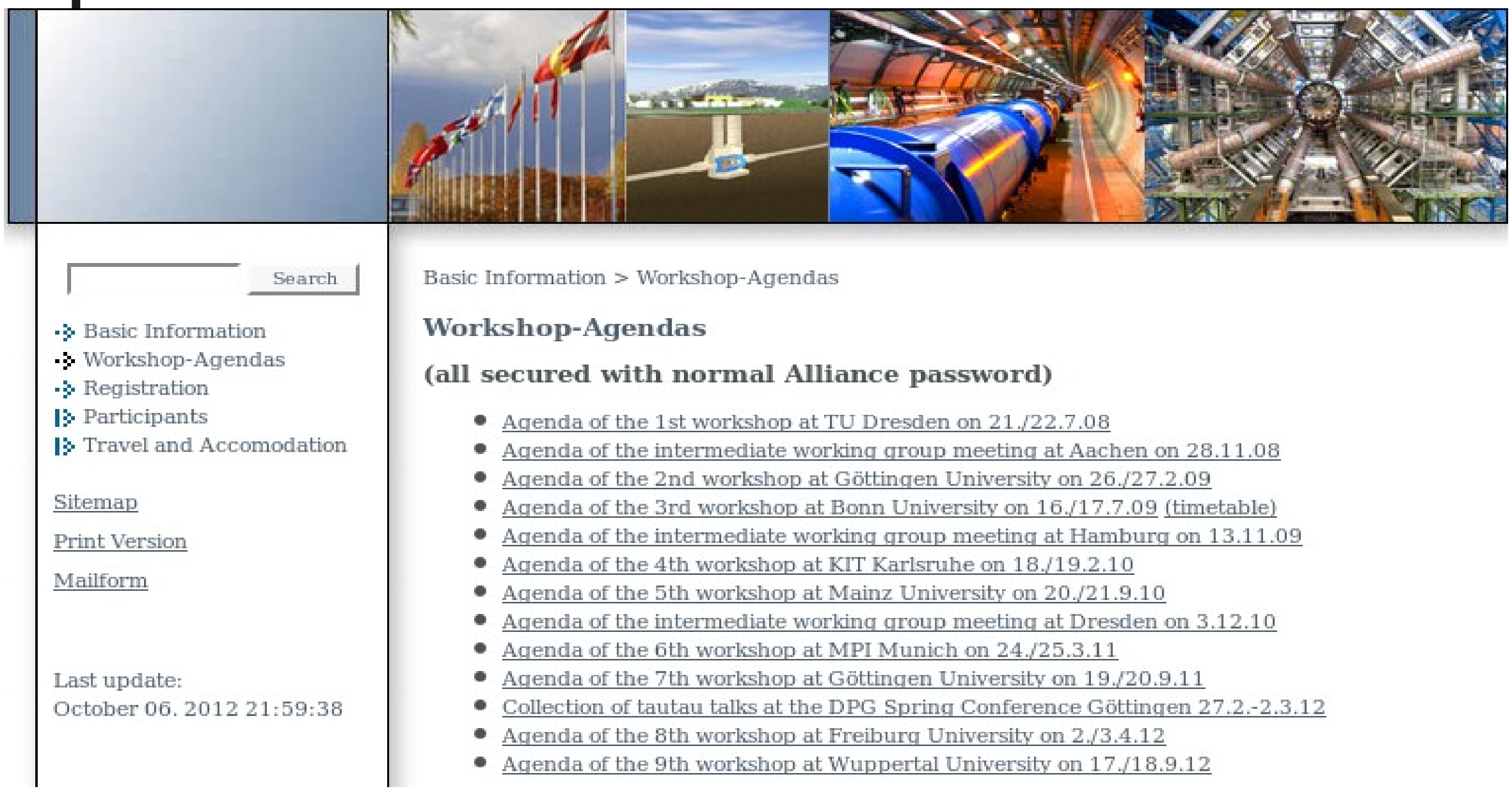
- **Funded by the Helmholtz Alliance since April 2008**
- **Aims**
  - Development and verification of algorithms related to $\tau\tau$ final states (mass definitions and shape extraction from data)
  - Several production channels: Z, h/H/A in VBF and b-quark assoc.
  - All final states: lep-lep, lep-had, had-had
  - Development and verification of methods of background extraction from data (sidebands, OS/SS, cut inversion)
- **Exchange ideas and concepts between ATLAS, CMS and Theory**
  - Focus on discussions, not on latest results to be published

Task of the $m_{\tau\tau}$ group

- **Active members**
  - ATLAS: Bonn, Dresden, Freiburg, Göttingen, München
  - CMS: DESY, Karlsruhe
- **Conveners**
  - **From April 2008 up to September 2012:**
    - Michael Kobel (ATLAS, TU Dresden)
    - Günther Quast (CMS, KIT Karlsruhe)
  - **From October 2012:**
    - Jürgen Kroseberg (ATLAS, Bonn)
    - Alexei Raspereza (CMS, DESY)

Meetings

- **So far nine 2-day workshops (twice a year)**
  - Typically 15-20 participants
- **Short intermediate meetings at annual Helmholtz Alliance workshops**

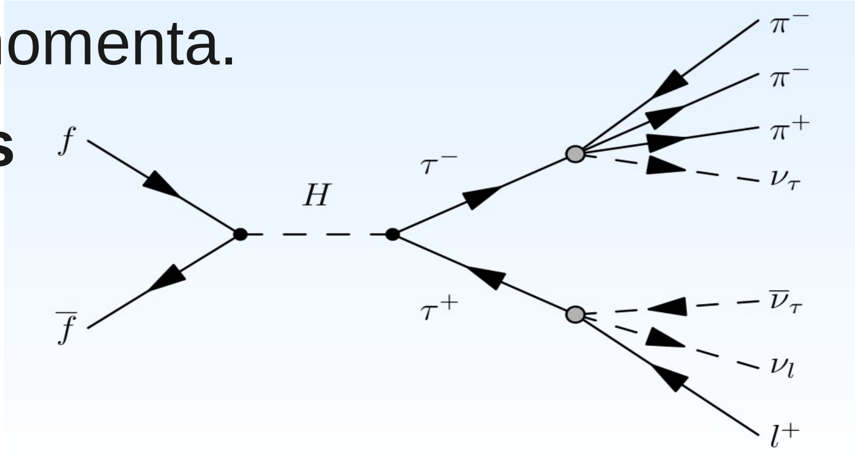


Recent Progress

- **Main Focus on comparison of methods for ττ mass reconstruction**
  - Review from theory side
  - Performance of different mass reconstructions in Monte Carlo simulation and with data
  - New tool for multivariate mass reconstruction
- **Embedding techniques**
  - Trigger studies and update
  - Absolute normalization and comparison between Particle-Level and Hit-Level
- **Analysis methods and background extraction**
  - Focus on Higgs searches at ATLAS and CMS

1) Methods for ττ mass reconstruction

- **Invited theory talk by Teng Jian Khoo (Cambridge University)**
  - From decay 12 constraints on 16 parameters.
  - For each hadronic decay, 1 constraint added.
  - 2-4 free parameters from neutrino momenta.
- **Overview on reconstruction methods**



  - Kinematic constraints
    - Collinear approximation
  - Statistical methods
    - MMC, CMS likelihood - Moves emphasis from reconstruction to modelling, can be computationally intensive, but powerful
  - Mass bound methods
    - Many variables, all connected through transv. Projection T, summation Σ and minimisation principles because of unknowns

1) Methods for ττ mass reconstruction

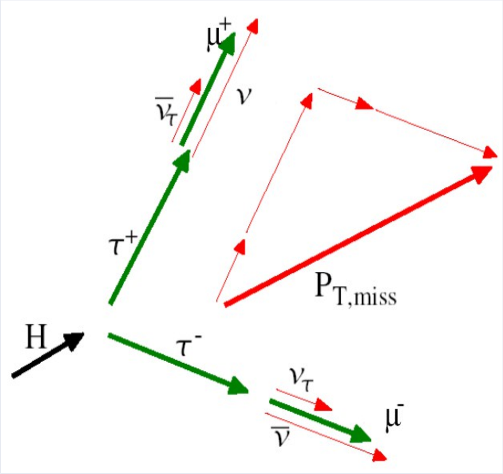
- **Big emphasis on comparison of mass reconstruction methods in fully leptonic and semi-leptonic final state**
- **Visible mass** $m_{\tau\tau}^{vis} = \sqrt{p^{\mu}(vis1)p_{\mu}(vis2)}, \mu = 0,1,2,3$
- **Effective mass**

$$m_{\tau\tau}^{eff} = \sqrt{(p^{vis1} + p^{vis2} + p^{miss})^2}, \text{ where } p^{miss} = (E_T^{miss}, E_x^{miss}, E_y^{miss}, 0)$$

- **Collinear approximation**
  - assumption 1: H/Z boosted $\Rightarrow$ τ decay products produced collinearly to taus $\Rightarrow$ no back-to-back decays are allowed ($|\cos(\delta\phi)| < 0.95$)
  - assumption 2: MET is only coming from ν_τ

$$x_i = \frac{p_T^i}{p_T^i + p_T^{mis}}, \text{i=visible products}$$

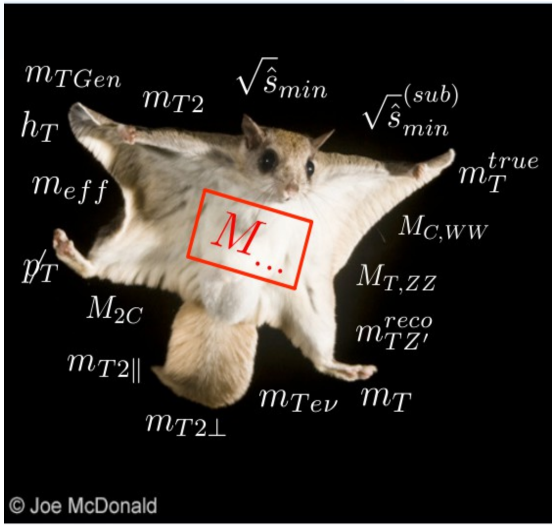
$$m_{\tau\tau} = \frac{m_{vis1vis2}}{\sqrt{x_{vis1} * x_{vis2}}}$$



1) Methods for ττ mass reconstruction

- **Mass bounds** **ArXiv:1105.2977**
  - Early projected transverse mass (T → Σ(4vectors from visible decay products and E_{miss}))
  - Late projected transverse mass (Σ → T)
  - Transverse true mass (transverse mass of visible+invisible decay products, for massless inv. Particles = late proj.tr. mass)
  - Bound mass (summation of 4vectors from vis. decay products and E_{miss})

$$m_{\tau\tau}^{\mathrm{bound}} = \min_{\substack{\vec{q}_T^{\,\tau 1}+\vec{q}_T^{\,\tau 2}=\vec{p}_T^{\,\mathrm{miss}} \\ |q^\mu_{\tau 1,2}+p^\mu_{\tau 1,2}|=m_\tau}} \left|(p^\mu_{\tau 1}+p^\mu_{\tau 2}+q^\mu_{\tau 1}+q^\mu_{\tau 2})\right|$$



1) Methods for ττ mass reconstruction

- **Missing Mass Calculator (ATLAS)** **Arxiv:1012.4686**
  - Scan of the phase space of the free parameters
  - Get a PDF for each point on the grid (from matrix element)
  - $m_{\tau\tau}$ reconstructed is weighted by result from PDF
  - Take most probable $m_{\tau\tau}$ solution as final estimator

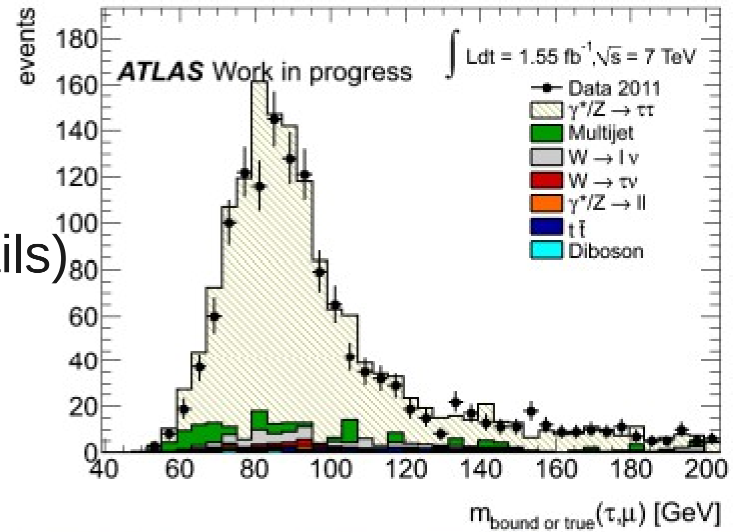
- **Secondary Vertex Fit (SVFit, CMS)** **Arxiv:1202.4083**
  - Maximizes likelihood with respect to τ kinematics and MET

- **Neural Network (CMS)**
  - Direct mass reconstruction
  - Training and testing on Z sample
  - Choose NeuroBayes as neural network
  - 9 input variables (Kinematic variables, Angular variables,Track variables, τ-jet variables)

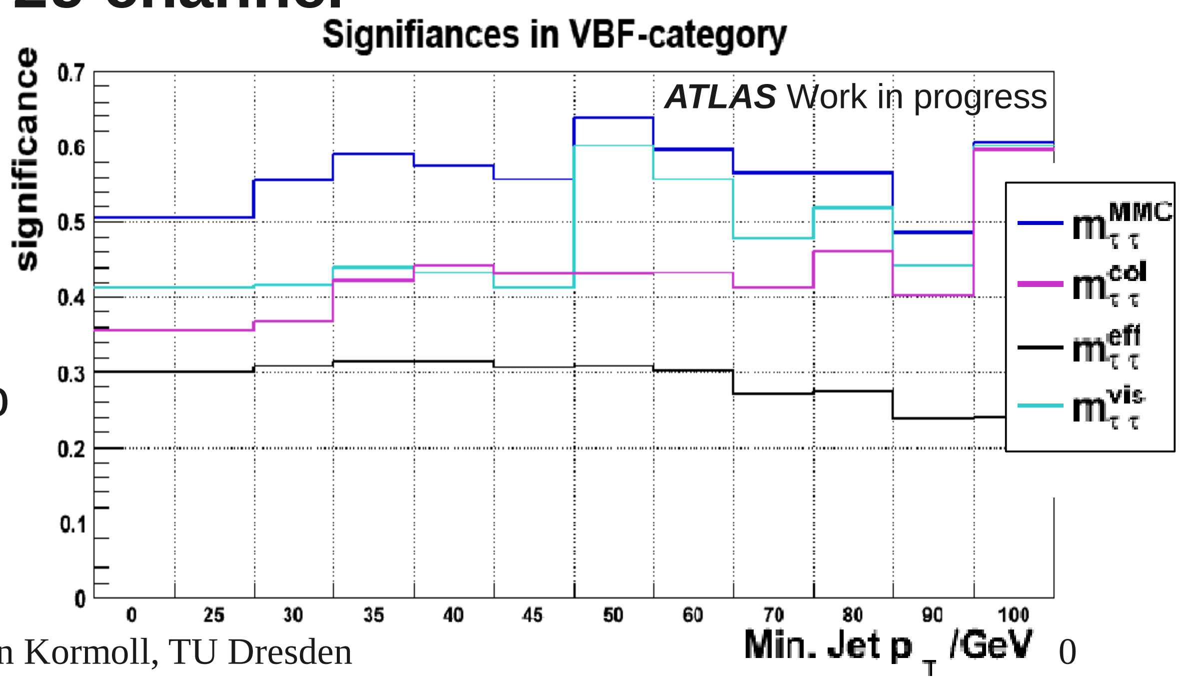
→ Which mass reconstruction yields best performance for specific channel?

1) Methods for ττ mass reconstruction

- **Studies in Z→ττ→e/μ+had+2υ channel by Despoina Evangelakou (Göttingen)**
  - Combination of bound and transv. true mass (utilisation of transv. true mass if bound mass fails)
  - Best performance
  - 100% acceptance, fast, mass peak narrow and close to real Z mass, but tails to higher masses

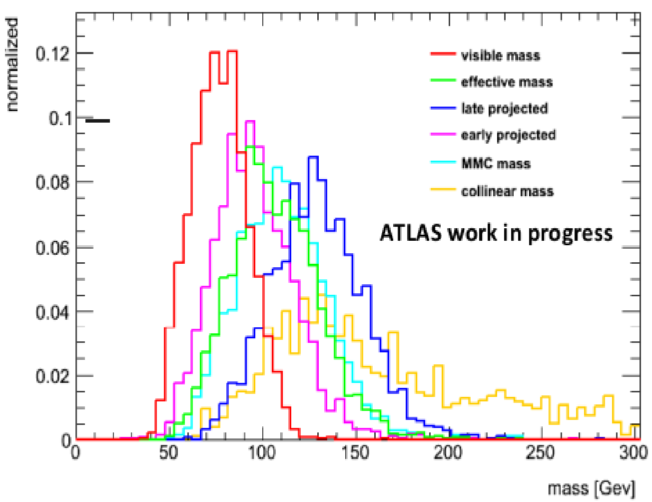


- **Studies in H→ττ→e/μ+had+2υ channel by Birgit Stapf (Bonn)**
  - Separation in VBF category, 1-jets, 2-jets
  - MMC yields best results
  - similar performances
  - Higgs-bound mass: sensitive to resolution of E^{T}_{miss}



1) Methods for ττ mass reconstruction

- **Studies in H → ττ → e/μ+had+2υ by Felix Friedrich (TU Dresden)**
  - MC study for b-quark assoc. Higgs production
  - Mass mean is dependent in kinematic quant. (higgs-pt, τ-pt, jet-pt)
  - Elimination of dependency
  - Elimination does not improve separation w.r.t. Z → ττ, ttbar bkg., but leads to better resolution



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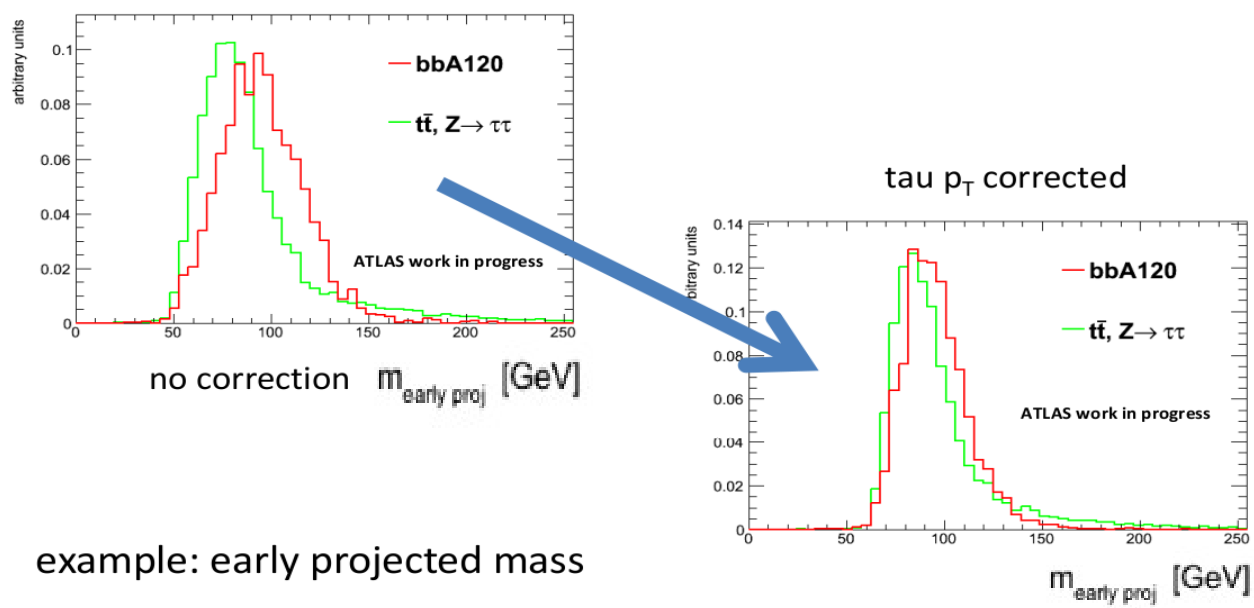


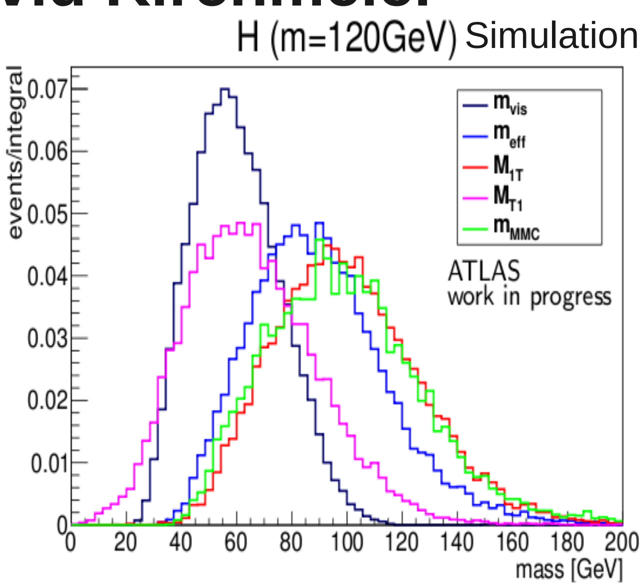
example: early projected mass

1) Methods for ττ mass reconstruction

- **Studies in H→ττ→eμ+4υ VBF channel by Julian Maluck** (Freiburg)
  - collinear approximation and MMC reach higher significances than invariant mass and effective mass
  - Mass algorithms sensitive to E^{T}_{miss} input
  - Investigation of coll. Mass with E^{T}_{miss} input from MMC scan
  - MMC not significantly better than collinear approximation with E^{t}_{miss} correction for VBF

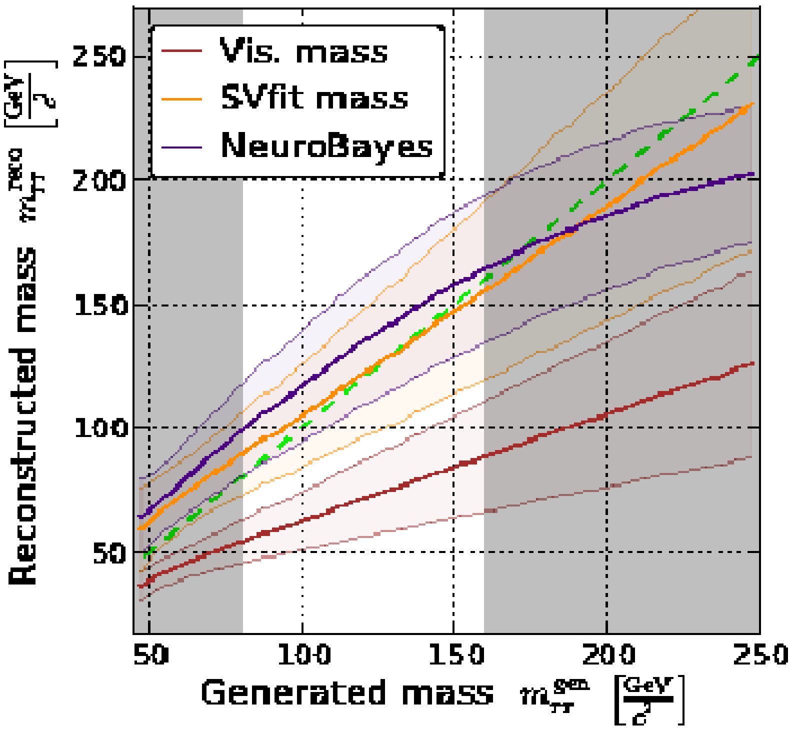
	mean	σ
collinear approximation	125,5 GeV	19,5 GeV
MMC Peak	130,0 GeV	17,8 GeV
coll $\vec{E}_T$-MMC	129,8 GeV	17,7 GeV

- **Studies in H→ττ→eμ+4υ channel by David Kirchmeier** (TU Dresden)
  - MMC performance is not convincing in comparison to other reconstructions
  - early projected mass well suited
  - high bias, but can be calibrated
  - acceptable dependencies on event variables
  - good performance in $t\bar{t}$ separation



1) Methods for ττ mass reconstruction

- **Studies in H → ττ → μ+had+ 2υ channel by Thomas Müller** (KIT Karlsruhe)
  - Presentation of Neural Network results for mass reconstruction
  - Precision as good as best current method (Svfit) in the entire mass range
  - Resolution up to 5% better for 100-150 GeV true mass
  - Very fast calculation with trained network

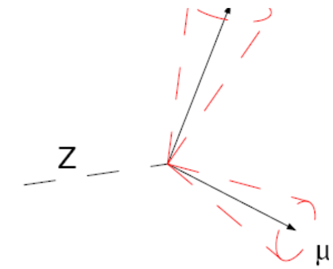


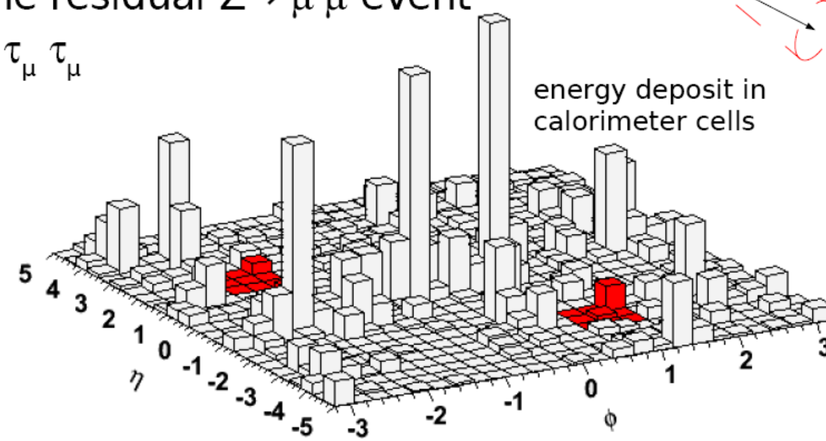
2) Embedding Techniques

- **Was established within the $m_{\tau\tau}$ working group and became standard tool in both ATLAS and CMS.**
- **Employed successfully for the Higgs boson searches.**

Procedure (“embedding technique”)

- take a real $\gamma^*/Z \rightarrow \mu\,\mu$ event and remove the muons from event
- simulate two taus with the kinematics of the muons
- overlay the result of the tau reco with the residual $Z \rightarrow \mu\,\mu$ event
- re-reconstruct to get an artificial $\gamma^*/Z \rightarrow \tau_\mu\,\tau_\mu$

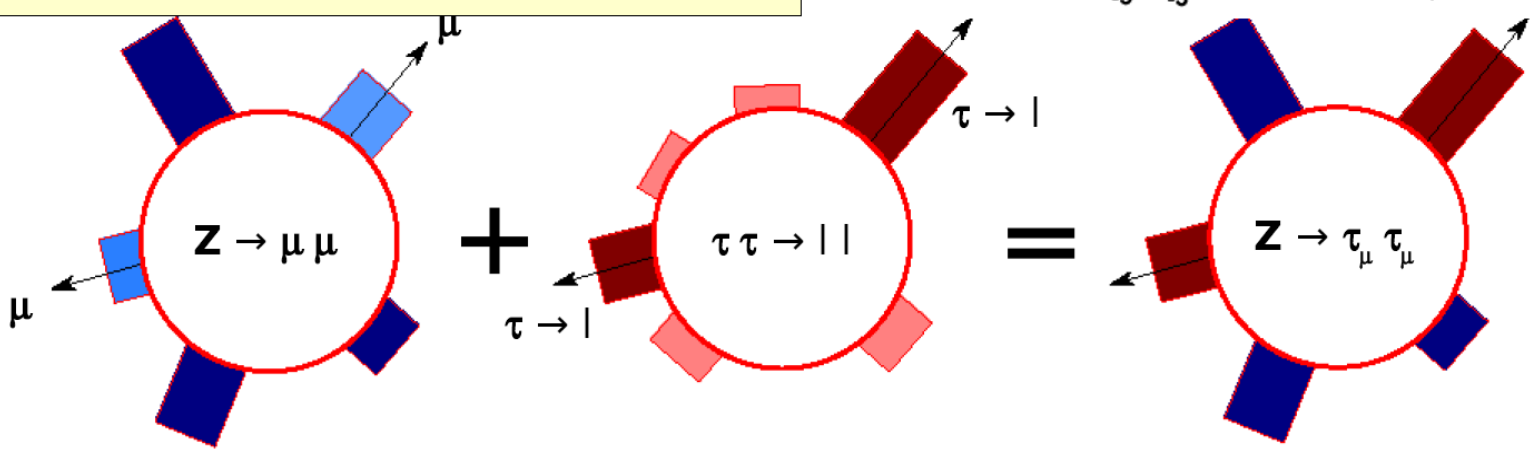




Overlay

a) replace all hits in the tracker and in the calorimeter associated to the muons and the tau decay products

b) replace only the deposited energy in the calorimeter cells in a cone around the muon direction

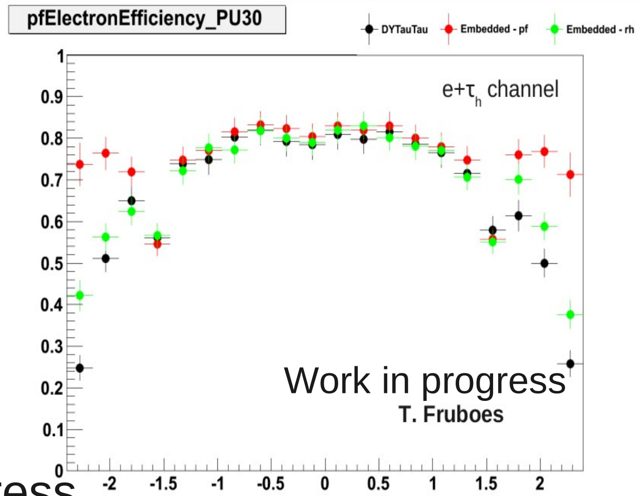


taken from:

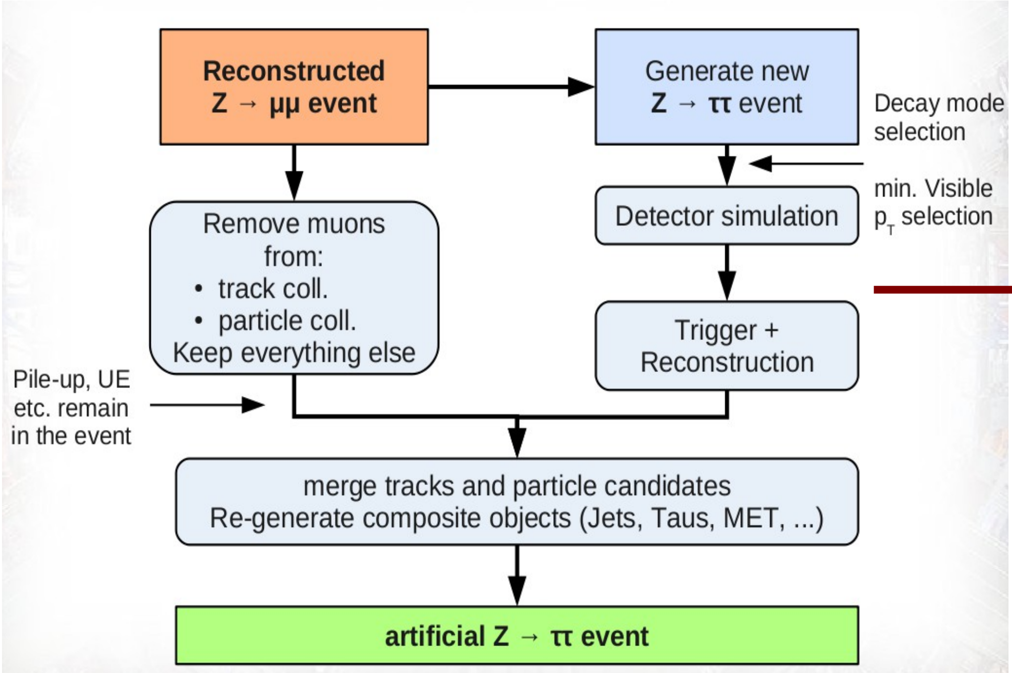
Manuel Zeise (CMS)

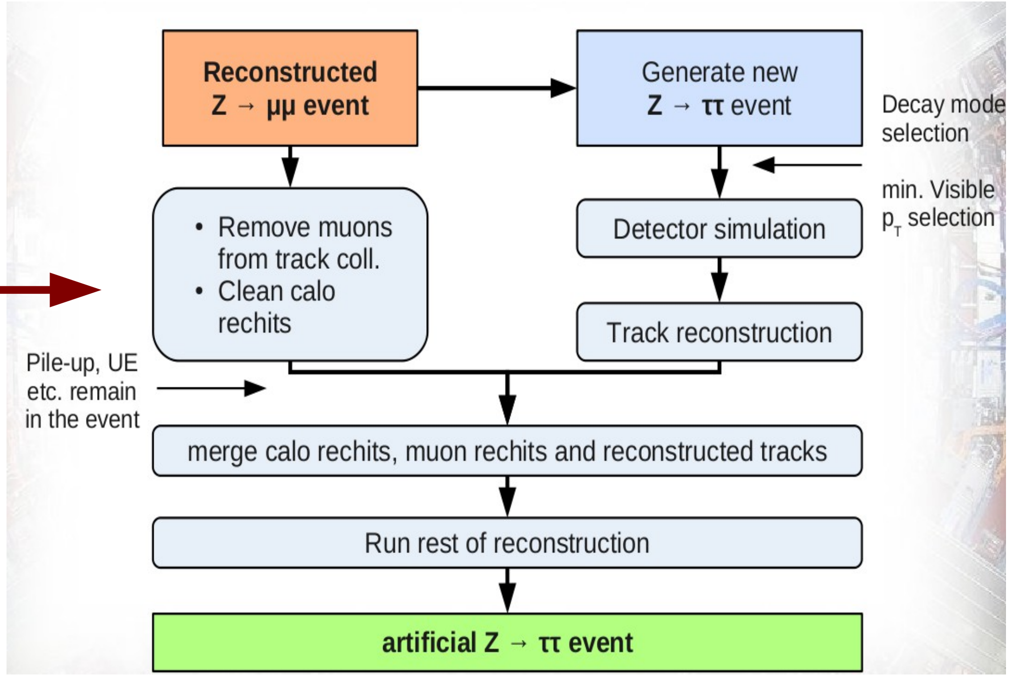
2) Embedding Techniques

- **Armin Burgmeier**
  (KIT Karlsruhe)
  - Absolute normalisation with 2011 data with selection, isolation efficiencies, di-m backgrounds, phase space acceptance
  - New Technique: move from particle-level to hit-level

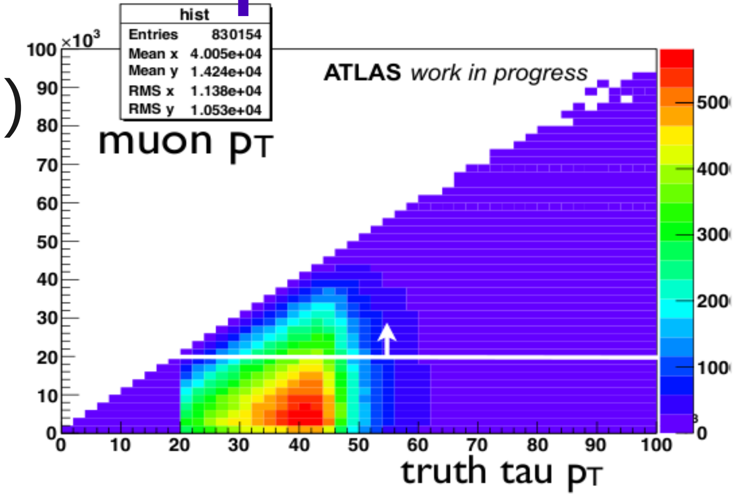


Work in progress

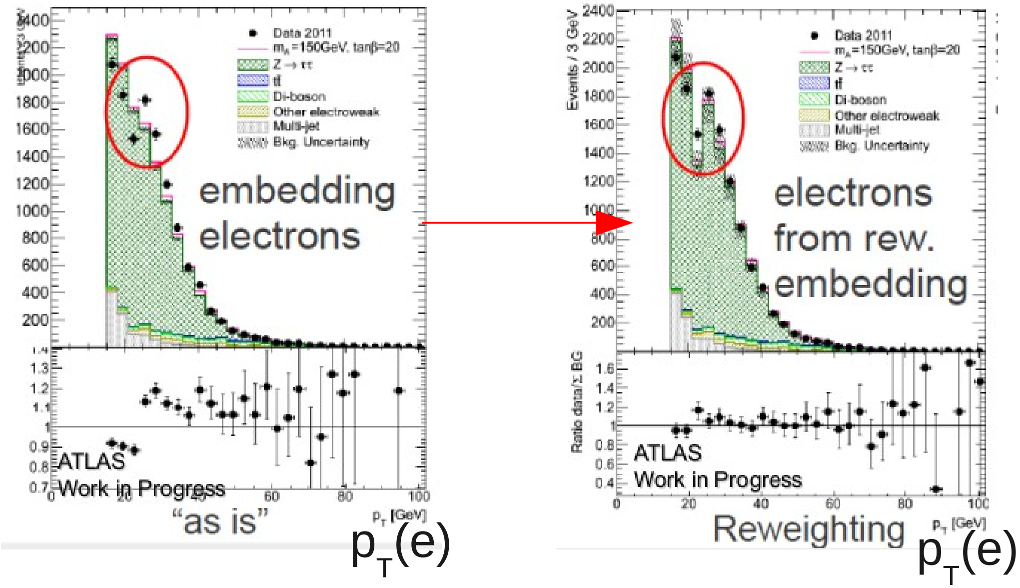




2) Embedding Techniques



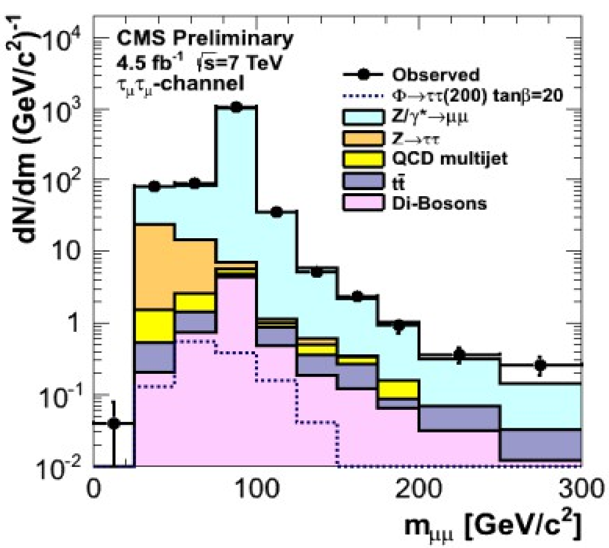
- **Thomas Schwindt, Jessica Liebal** (Bonn)
  - Kinematic studies on embedded τ-decays
  - Filter on generator niveau to adress kinematic cuts in studies on embedded samples
  - Gain in statistics of order ~3, depending on decay channel
- **Holger von Radziewski, Michel Janus** (Freiburg)
  - Trigger-parametrisation from data
  - To modell trigger bias on p_T shape for combination of several triggers:
    - Reweight embedding with trigger efficiency from data
    - Emulate trigger decisions using random numbers and efficiency from data

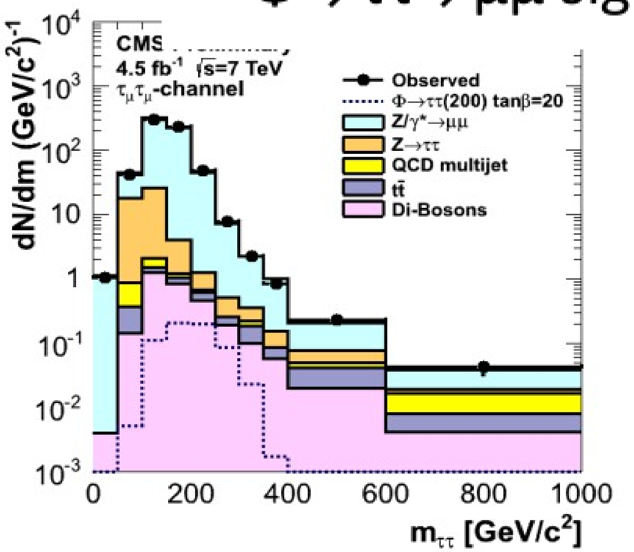


3) Analysis methods and background extraction

- **Analysis of H→ττ→μμ+4υ by Agni Bethani** (DESY/ KIT)
  - 5 Event categories:
    - SM (VBF, boosted Higgs, gluon fusion), MSSM (b-tag, no b-tag)
  - Building likelihood method with 3 event classes (j)
    - $Prob(j) = \prod_{i=1}^{m} f(j, x_i)$
    - $L(j) = \frac{Prob(j)}{\sum_{k=1}^{3} Prob(k)}$
    - $Z/\gamma^* \rightarrow \mu\mu$
    - $Z \rightarrow \tau\tau \rightarrow \mu\mu$
    - $\Phi \rightarrow \tau\tau \rightarrow \mu\mu$ signal

MSSM No b-tag Cat.





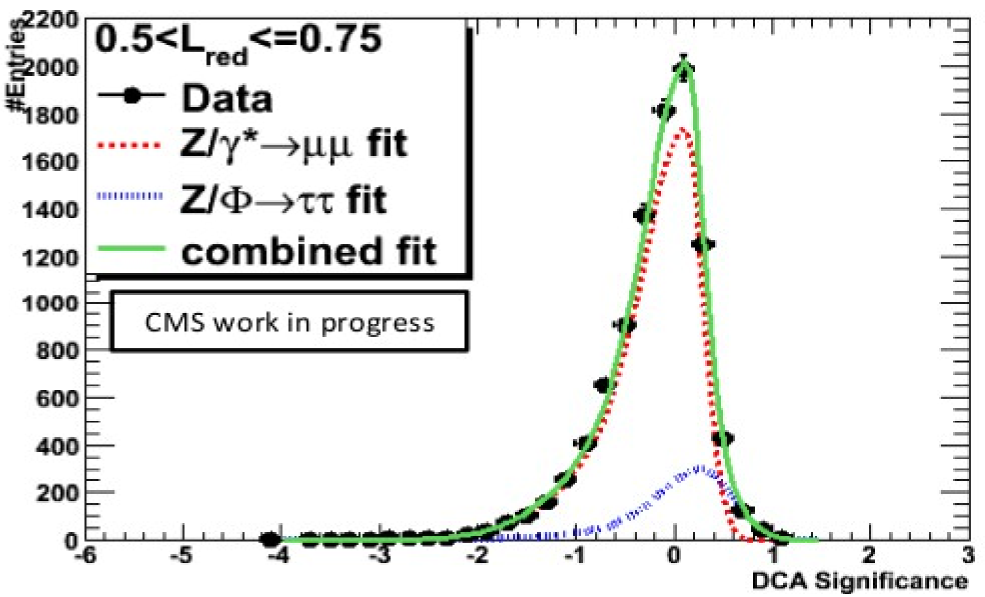
3) Background extraction: $Z/\gamma^* \to \mu\mu$

- By exploiting the difference in the shapes of the intermuon DCA significance between:
  - $Z/\gamma^* \to \mu\mu$
  - $Z \to \tau\tau$ and $\Phi \to \tau\tau \to \mu\mu$ signal
- The DY background is estimated in 5 dimuon mass regions

DCA – distance of closest approach of both muon tracks

The method:

- New “reduced” likelihood (L_{red}) from same variables except the DCA significance
- DCA significance distributions are fitted in bins of L_{red} for every dimuon mass region.
  - templates for $Z/\gamma^* \to \mu\mu$ and $Z/\Phi \to \tau\tau \to \mu\mu$
- Then the data are fitted as a superposition of the 2 templates



3) Background extraction

- **Top quark pair normalisation by Holger von Radziewski** (Freiburg)
  - Ratio K= SR/CR and shapes of distributions from simulated events

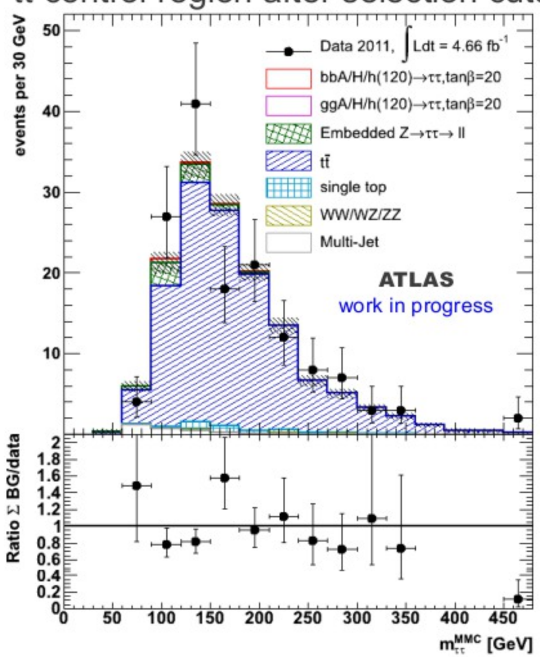
$H_T = \Sigma\, p_T(\text{jets})$

Control Region (CR)
2 b-jets, no H_T cut

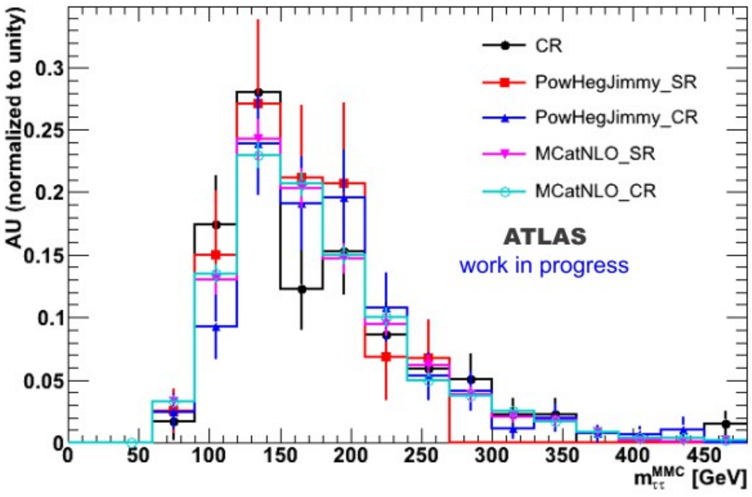
$*K$ →

Signal Region (SR)
1 b-jet, H_T < 100 GeV

$t\bar{t}$ control region after selection cuts



Shape of MC prediction describes data in control region. Normalization adjusted by 13%.



Shape of reconstructed mass agrees between CR and SR within statistical uncertainty. Use shape from MC in SR.

Issues and plans

- Continue with new conveners Jürgen Kroseberg (ATLAS, Bonn) and Alexei Raspereza (CMS, DESY) after 2012
- Keep focus on experimental methods
- Widen the scope to X(126 GeV) property analyses (spin, angular distributions), MSSM/ high-mass searches.
- In that aspect involve input from theorists.
- Identify topics where CMS and ATLAS (so far) took somewhat different/complementary experimental approaches
- adjust format when useful for work within updated scope
- try to remain complementary and get connected to other existing LHC groups

Issues and plans

- New members are welcome to join!
- Information can be found here:
  - Homepage http://tautauag.phy.tu-dresden.de
  - Wiki https://wiki-mtautau.terascale.de/index.php
  - Meeting dates and agendas

    http://www.terascale.de/calendar/ → Alliance Indico → Research Topics → Physics Analysis → Working Groups
  - Subscription to mailing list

    https://lists.desy.de/sympa/subscribe/hgfa-mtautauag

    has to be done actively by each member.

THANK YOU!