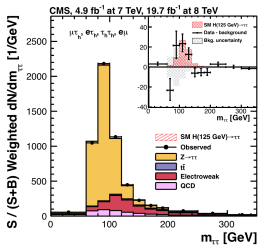
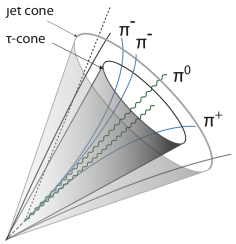
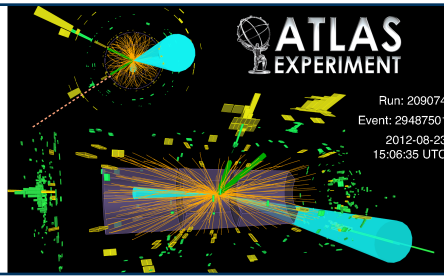
PHYSICS AT THE TERA SCALE

Helmholtz Alliance

ττ WG Report







CMS Compact Muon Solenoid

Jürgen Kroseberg

(Physikalisches Institut der Universität Bonn)

on behalf of the group

Goals of the Group

- original “mission statement”:

> **Development** and verification **of algorithms** related to ττ final states, especially via **exchange of analysis concepts** and experiences **between ATLAS and CMS**, and via **dialogue with theorists**, e.g. about theoretical uncertainties. This **encompasses all physics channels involving ττ mass** distributions, like SM $Z \rightarrow \tau\tau$, SUSY $h/H/A \rightarrow \tau\tau$ or $m_{\tau\tau}$ endpoints in SUSY cascades.

- have been dynamically adjusting scope (see below)

Mode of Operation

- typically **two-day workshops twice per year** (13 so far)
- since 2012 chaired by A. Raspereza (CMS) + J.K. (ATLAS)
- typically **20-30 participants**
- typically 2 **invited speakers from outside Germany,** thus fostering exchange with growing pool of external experts
- **previous workshops** at Dresden, Göttingen (2x), Bonn (2x), KIT, Mainz, Munich, Freiburg, Wuppertal, Würzburg
- **this year:** 2 workshops at DESY

- try not to duplicate other meetings; be pragmatic
- focus on **informal discussions** between ATLAS+CMS (and increasingly between theory+experiment again)

April 2014 Workshop (DESY)

- 24 participants from 10 institutes

Welcome	*RASPEREZA, Alexei*	**CP Properties of Higgs in tautau Channel**	*BERGE, Stefan*
Seminar Room 3, DESY	14:30 - 14:40	*Seminar Room 1b, DESY*	09:30 - 10:10
ATLAS Physics News	*LAI, Stan*	**Simulating Taus and the Higgs CP at CMS**	*NUGENT, Ian*
Seminar Room 3, DESY	14:40 - 15:00	*Seminar Room 1b, DESY*	10:10 - 10:30
CMS Physics News	*RASPEREZA, Alexei*	**TauSpinner studies**	*BANERJEE, Swagato*
Seminar Room 3, DESY	15:00 - 15:20	*Seminar Room 1b, DESY*	10:30 - 10:50
Coffee break		**Discussion**	
Seminar Room 3	15:20 - 15:40	*Seminar Room 1b, DESY*	10:50 - 11:10
Tau Id Developments in CMS	*VEELKEN, Christian*	**Coffee break**	
Seminar Room 3, DESY	15:40 - 16:10	*Seminar Room 1b*	11:10 - 11:30
Tau Id Developments in ATLAS	*YUEN, Stephanie*	**Embedding in CMS**	*BURGMEIER, Armin*
Seminar Room 3, DESY	16:10 - 16:40	*Seminar Room 1b, DESY*	11:30 - 11:50
The di-tau Mass Reconstruction in CMS	*VEELKEN, Christian*	**Embedding in ATLAS**	*LIEBAL, Jessica*
Seminar Room 3, DESY	16:40 - 17:10	*Seminar Room 1b, DESY*	11:50 - 12:10
Discussion		**Discussion**	
Seminar Room 3, DESY	17:10 - 17:30	*Seminar Room 1b, DESY*	12:10 - 12:30

https://indico.desy.de/conferenceDisplay.py?ovw=True&confId=9586

Dec 2014 Workshop (DESY) starting tomorrow

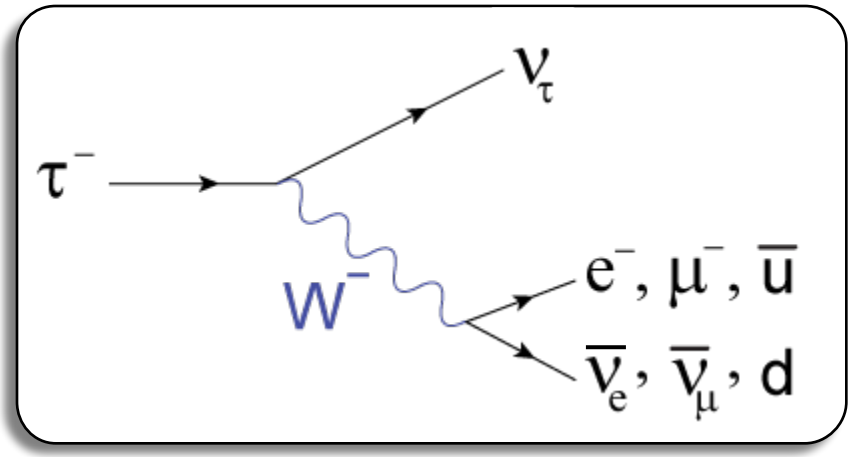
- **28 participants from 11 institutes**

Welcome	*KROSEBERG, Juergen*	**ATLAS Run 1 Tau Reco/ID Recap**	*JANUS, Michel*
Seminar Room 3, DESY	14:30 - 14:40	*SR 1, DESY*	09:30 - 09:45
CMS tautau Physics News	*GILBERT, Andrew*	**ATLAS Tau Reco/ID for Run2**	*WINTER, Benedict*
SR 1, DESY	14:40 - 15:00	*SR 1, DESY*	09:45 - 10:10
ATLAS tautau Physics News	*SCHILLO, Christian*	**Tau Track Reconstruction with ATLAS**	*DUSCHINGER, Dirk*
SR 1, DESY	15:00 - 15:20	*SR 1, DESY*	10:10 - 10:30
Status of ATLAS H+->tau Searches	*KOPP, Anna*	**CMS Tau Reco/ID for Run2**	*VEELKEN, Christian*
SR 1, DESY	15:20 - 15:40	*SR 1, DESY*	10:30 - 11:00
TAUOLA and TauSpinner Status and Plans	*WAS, Zbigniew*	**Coffee break**	
SR 1, DESY	15:40 - 16:10	*Seminar Room 1b, DESY*	11:00 - 11:20
Coffee break		**TauTau Embedding with ATLAS**	*LIEBAL, Jessica*
Seminar Room 3, DESY	16:10 - 16:30	*SR 1, DESY*	11:20 - 11:40
Z->tautau Polarisation Studies with ATLAS	*WINTER, Benedict*	**Single-Tau Embedding with ATLAS**	*KOPP, Anna*
SR 1, DESY	16:30 - 16:50	*SR 1, DESY*	11:40 - 12:00
Higgs CP Properties from H->tautau	*BERGE, Stefan*	**Search for ttH->tautau with ATLAS**	*STAPF, Birgit*
SR 1, DESY	16:50 - 17:20	*SR 1, DESY*	12:00 - 12:20
Higgs CP Studies with CMS	*NAYAK, Aruna*	**Search for H->taumu with CMS**	*TROENDLE, Daniel*
SR 1, DESY	17:20 - 17:40	*SR 1, DESY*	12:20 - 12:40
Higgs CP Studies with ATLAS	*CALLENBERG, Clara*	**Discussions : Future plans of the group**	
SR 1, DESY	17:40 - 18:00	*SR 1, DESY*	12:40 - 13:00

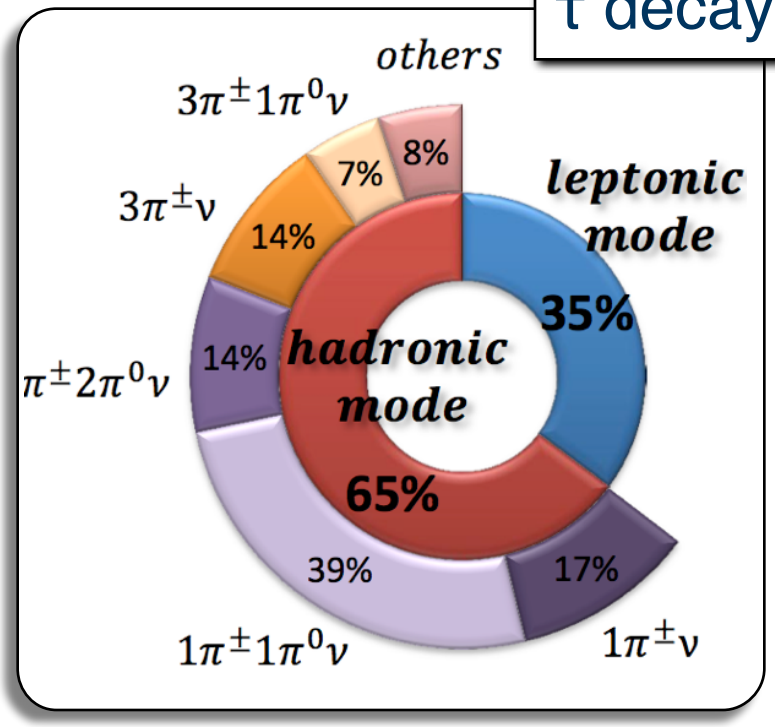
https://indico.desy.de/conferenceTimeTable.py?confId=10937#20141204

Tau(Tau) Decays

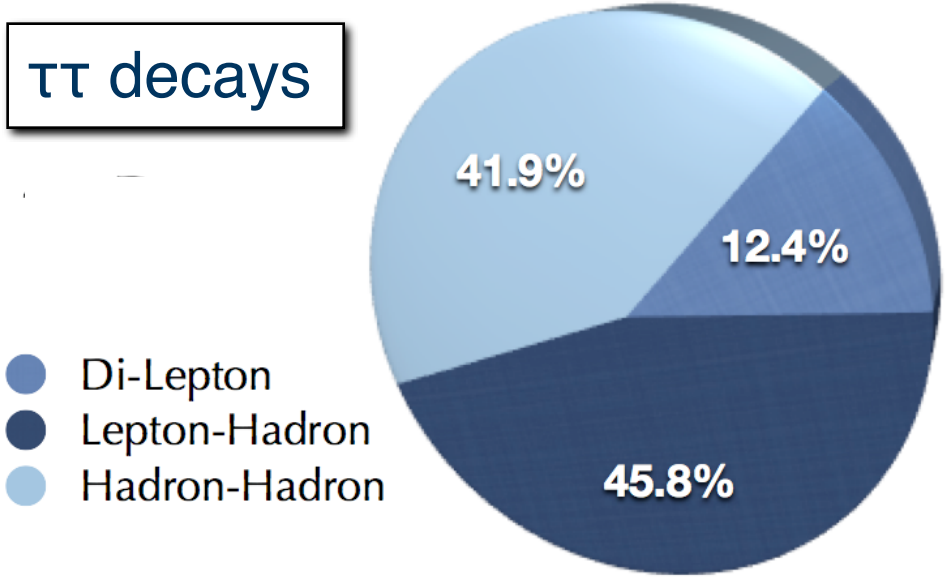
- **Mass**: $m_\tau \approx 1.8$ GeV
- **Lifetime** ≈ 300 fs
- **Decay length** ≈ 87µm



τ decays

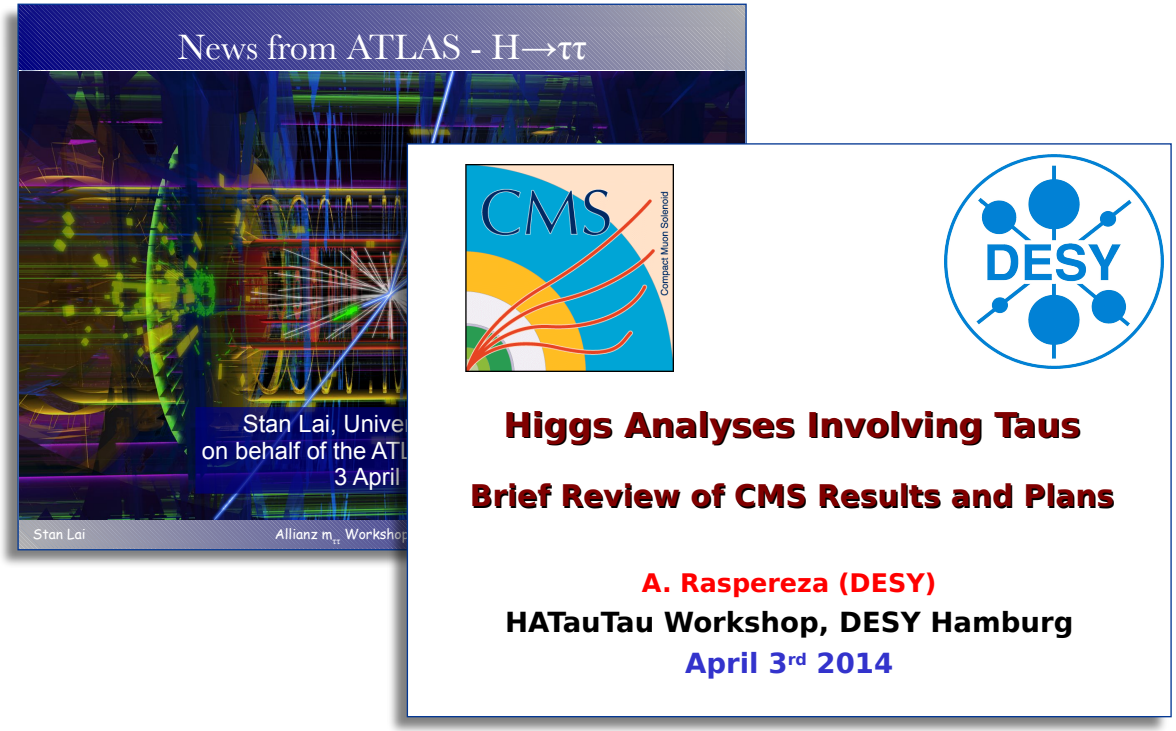


ττ decays



Review of Physics Results

- **not the focus** of the group
- **still**, reviewing and discussing recent conference results and papers **has become a regular and productive ingredient**



- similar function as “collider cross talks” at CERN in (even) more informal setting

- Evidence for SM H→ττ
- Final run1 MSSM Higgs→ττ limits
- Z’→ττ limits
- Search for LFV Higgs decays
- $H^+ \rightarrow \tau\nu$ limits
- …

Run 2 ττ Physics Program

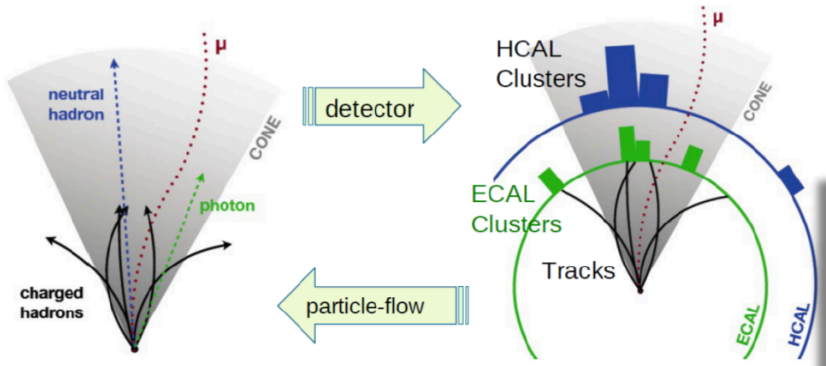
- establish inclusive **5σ signal**
- optimise for maximal impact in combined **coupling analysis**
- establish signals for **individual production mechanisms** ([VBF], VH, ttH)
- fiducial/**differential measurements**
- **Polarisation**/Spin/**CP**
- (re-)connect to **BSM** aspect (Higgs portal etc)
- …
- also **single-tau program**, e.g. $H^+ \rightarrow \tau\nu$

Reco/ID of Hadronic Tau Decays

Particle Flow Algorithm

Consistent Interpretation of all detector Signal in terms of individual Particles:

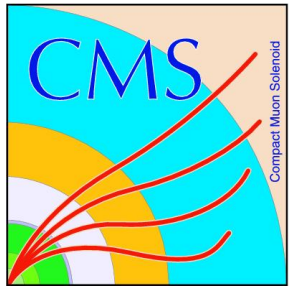
- e, μ, photons, charged Hadrons, neutral Hadrons



Higher level Objects are reconstructed using individual Particles as Input:

- τ_h, Jets (incl. b-tagging), E_T^{miss}
- Particle Isolation

Christian Veelken Tau ID in CMS

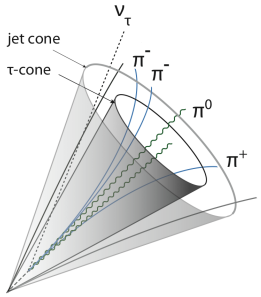


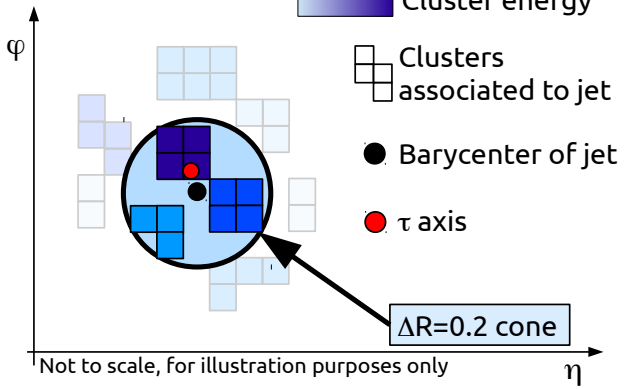
Reconstruction of τ leptons in ATLAS

(7)

- Jet (anti-Kt, R=0.4) with $p_{T,Calibrated} > 10$ GeV → use as τ candidate
- Use barycenter of clusters (cluster = set of calorimeter cells)
- Collect clusters within ΔR=0.2 cone
- Recalculate cluster position wrt. Tau vertex
- "TJVA" → backup

→ Tau axis





18th September, Tau 2014, Aachen, Germany C. Limbach: Tau Reconstruction in ATLAS

ATLAS Tau Reco/ID Run1 vs. Run2

Run 1

1-prong / 3-prong

Calorimeter 4-momentum

ID with basic substructure (no substr. online)

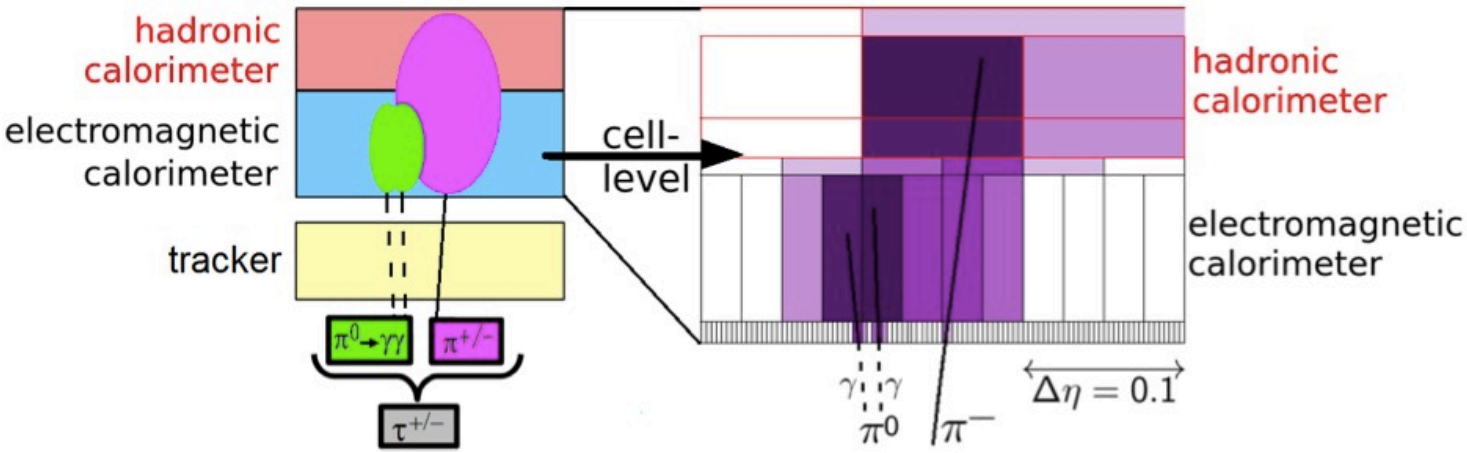
Run 2

1p0n / 1p1n / 1pXn / 3p0n / 3pXn

Calo / p-flow 4-momentum

ID with approx. substr. (on/offline harmony)

Access to pions



Tau Reco/ID Requirements

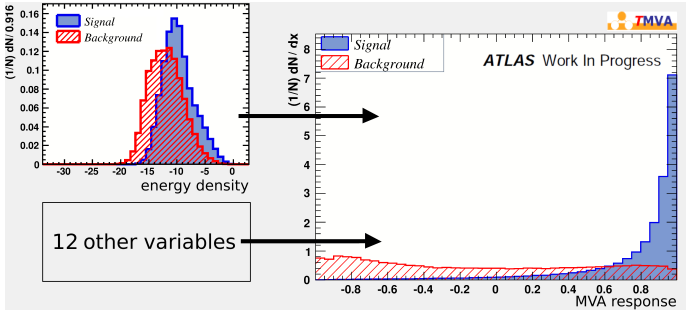
- also under **run2 conditions**
- also for **new features**: substructure information decay mode classification, continuous tau ID
- also for additional/ **specific applications**
- also for **complex environments**

- **efficient** reconstruction & ID
- good **separation** from QCD jets, electrons (and muons)
- **precise** measurement of direction and energy (and thus of mass)
- good **control** of associated systematic uncertainties
- also other **related tools**: MMC, TauSpinner, tau embedding, simulation, …

Tau Reco/ID for Run2

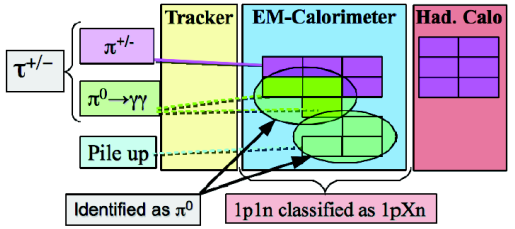
- e.g. ATLAS

Neutral pion identification



- Determine quality (π^0-likeness) of each neutral PFO by using a BDT. Exploit shape of neutral PFOs (=clusters), only. Preliminary π^0-taggi
- Cluster shapes not altered by charged pion energy removal. This is a difference wi
  - Disadva of remov
  - Advanta subtract
  - Advanta

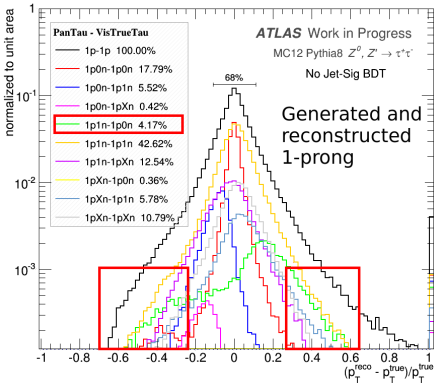
MVA-based identification of decay mode



- Combine info calculated upstream for final identification of mode
  - 4-momenta of charged PFOs
  - neutral PFOs quality and 4-momenta
  - number of reconstructed photons
- One BDT each to distinguish

Mode	Nomenclature
$\tau^\pm \to \pi^\pm \nu_\tau$	1p0n
$\tau^\pm \to \pi^\pm \pi^0 \nu_\tau$	1p1n
$\tau^\pm \to \pi^\pm > 1\pi^0 \nu_\tau$	1pXn

Influence of missing a π^0 or having a fake

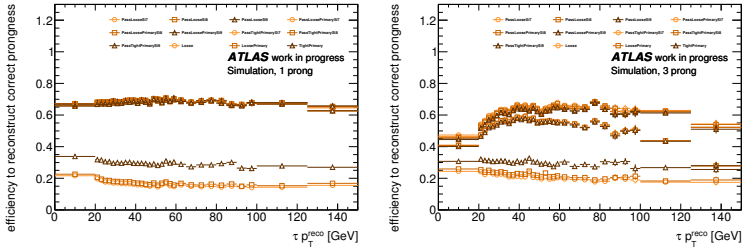


- Strong contribution from generated 1p0n taus, which are reconstructed as 1p1n
- Call generated $\tau^\pm \to \pi^\pm K^0 \nu_\tau$ decays 1p0n in this plot

17

Variation of silicon hits requirement

- tested track association performance for varied silicon hits requirement
- not counted conversion tracks to observe, what best effect a dedicated conversion tagger could be achieved
- requirements on # silicon hits greater than 7, 8, 9 has shown to give best performances



- similar performance as applying run 1 selection on top of recommended working points

Dirk Duschinger (dirk.duschinger@cern.ch) | Tau Track Reconstruction | 9 / 23

B. Winter et al

D. Duschinger

Reco/ID of Boosted Tau Decays

Boosted Taus

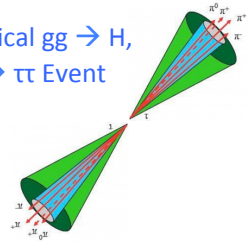
Isolation of τ_h is main handle to suppress large background arising from Jet → τ_h fakes

➔ All CMS analyses with τ_h in the final state use isolation, either via the cut-based or the MVA Tau ID

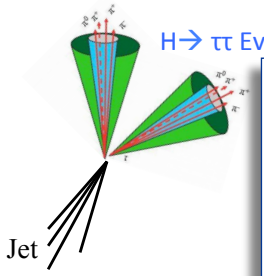
➔ Crucial to maintain good τ_h isolation performance for all final state topologies

Angular Separation between Leptons is typically larger than size of isolation cones (currently 0.5 for τ_h, soon to be reduced to 0.4 to reduce PU effects)

Typical gg → H, H → ττ Event



H→ ττ Event with H of high P_T

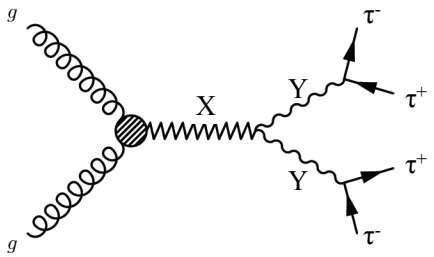


Are there cases when angular Separation < size of Isolat

- e.g. CMS

Boosted Taus (cont'd)

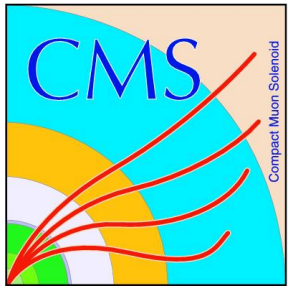
Yes: Cascade Decays of high Mass Resonances (M_X >> M_Y)



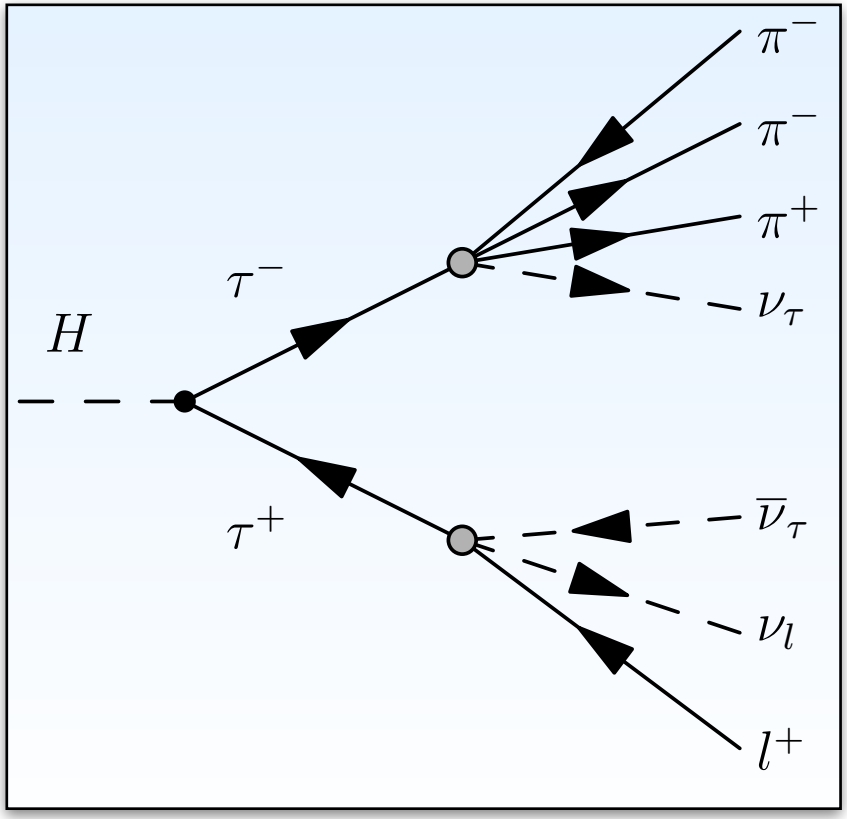
- Angular separation between Electrons, Muons and Taus from Y Decay approximately $\Delta R = \frac{2.0 \cdot M_Y}{P_T^Y}$, $P_T^Y \approx \frac{M_X}{2}$

➔ Efficiency of "standard" Lepton Isolation decreases significantly when $P_T^Y > 5.0 \bullet M_Y$ or equivalently $M_X > 10 \bullet M_Y$

C. Veelken et al



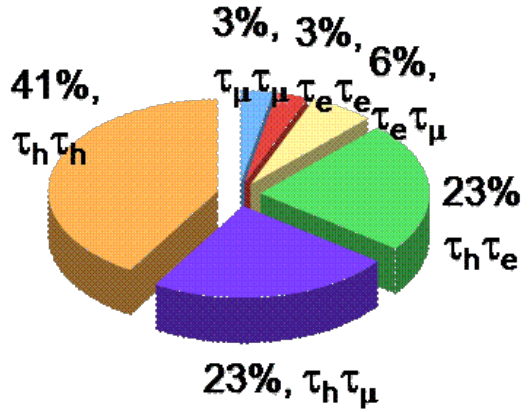
TauTau Mass Reconstruction



- reconstruct resonance over large BG from **under-constrained system**, mainly based on events with additional jets

(could) use

- visible momenta
- missing momentum
- secondary vertex information
- tau mass constraints
- other features of decay kinematics, spin correlations, …



TauTau Mass Reconstruction

SVfit Algorithm

$M_{\tau\tau}$ Solutions obtained by finding Maximum of Probability density:

$$\frac{dL(M_{\tau\tau})}{dM_{\tau\tau}} = \int_{\Omega} \frac{df(\mathbf{x}_u|\mathbf{x}_m)}{d\mathbf{x}_u} \delta(M_{\tau\tau} - M_{\tau\tau}(\mathbf{x}_u, \mathbf{x}_m)) d\mathbf{x}_u$$

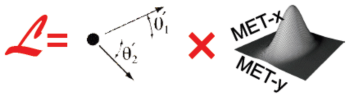
Histogram

x_u: unknown Variables θ*, ϕ*, m_{vv}

x_m: measured Observables E_x^{miss}, E_y^{miss}; Momenta of visible τ Decay products

Likelihood function f incorporates our Knowledge about:

- τ Decay Kinematics
- Experimental Resolution on E_x^{miss}, E_y^{miss}

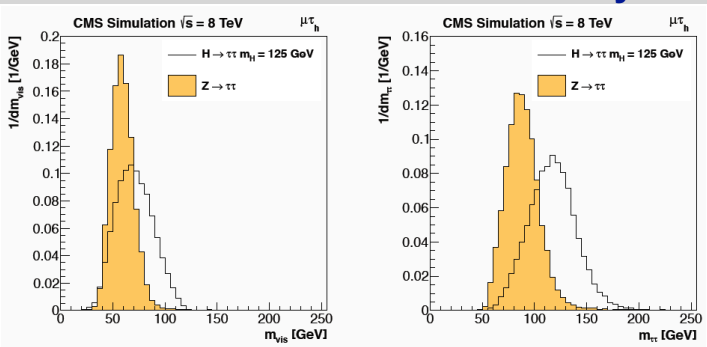


Integral over Likelihood function is computed numerically.

2 Methods implemented in SVFit:

- Adaptive Integration (VEGAS, part of GNU Scientific Library)
- Markov Chain (custom Implementation in SVfit)

Performance in CMS H → ττ Analysis



- SVfit improves Separation between H → ττ Signal and irreducible Z → ττ Background
- Reducible Backgrounds W+Jets, QCD, tt approximately flat

  → Effective Background Contribution decreases if Higgs Signal concentrated in narrow Mass window

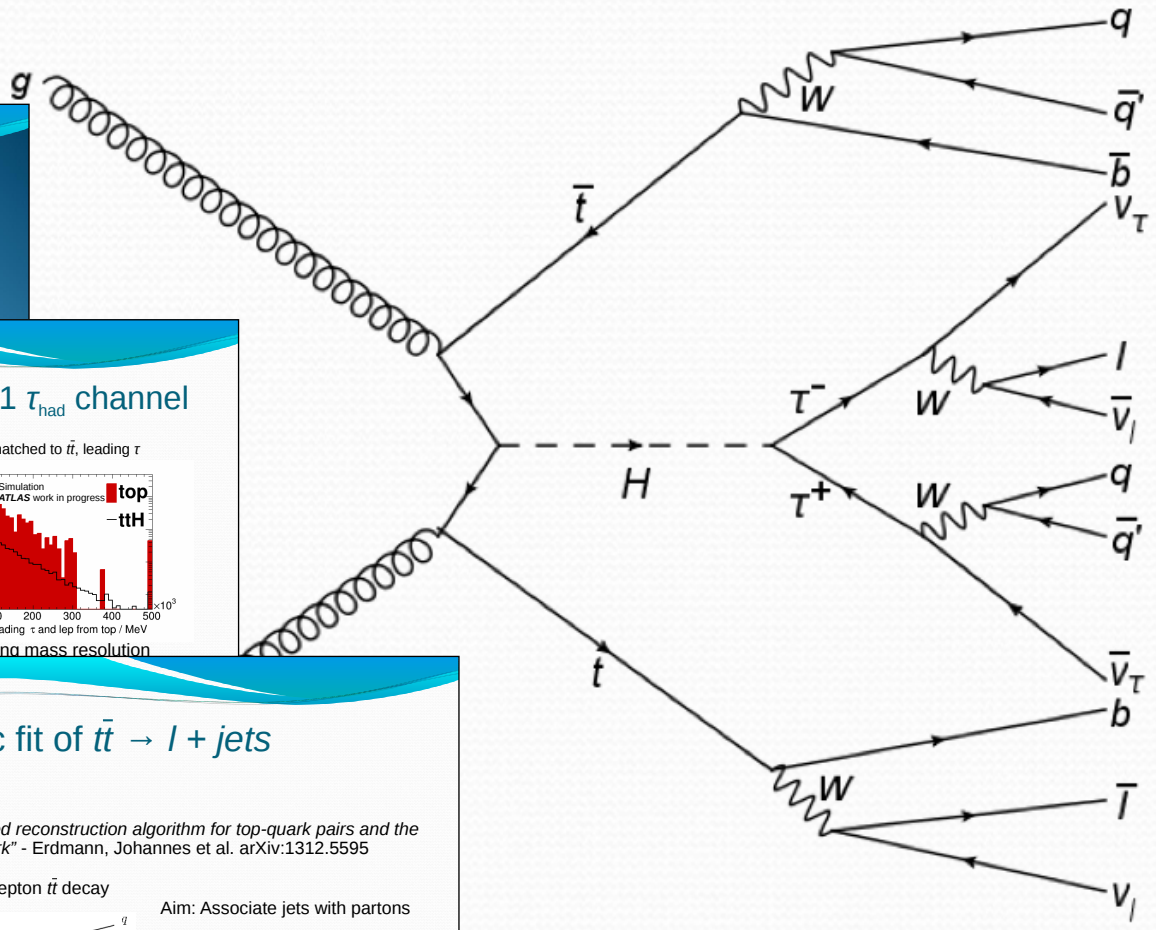
- ATLAS: missing mass calculator (**MMC**)
- CMS: **SVfit**

future:

- reconsider / **tune** algorithms **for specific uses**
- tune for broader **use beyond mass reconstruction**
- neutrino reconstruction?
- use in polarisation-related analyses
- use of **substructure** decay classification?

Analysis of complex final states

- e.g. ttH→ττ



Kinematically constraining $t\bar{t}H(\tau\tau)$ events

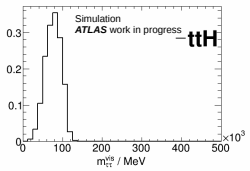
2 *l*, 1 τ_{had} cha

$m_{\tau\tau}$ workshop

December 04, 2014

Mass of ττ-system in 2 *l*, 1 τ_{had} channel

l and τ truth matched to Higgs



l truth matched to $t\bar{t}$, leading τ

Ideal identification of the systems → promising mass resolution and shape separation

Leading p_T τ *is* from *H*

Identifying lepton not

"Simple" criteria (e.g.

jet) found not to work

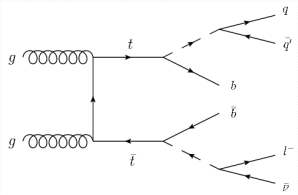
05.12.2014

Kinematic fit of $t\bar{t}$ → *l* + *jets*

KLFitter:

"A likelihood-based reconstruction algorithm for top-quark pairs and the KLFitter framework" - Erdmann, Johannes et al. arXiv:1312.5595

Example: Single lepton $t\bar{t}$ decay



Aim: Associate jets with partons

→ Fit exactly 4 jets:
4! = 24 permutations

Not sensitive to commutation of 2 jets from hadronic *W*:

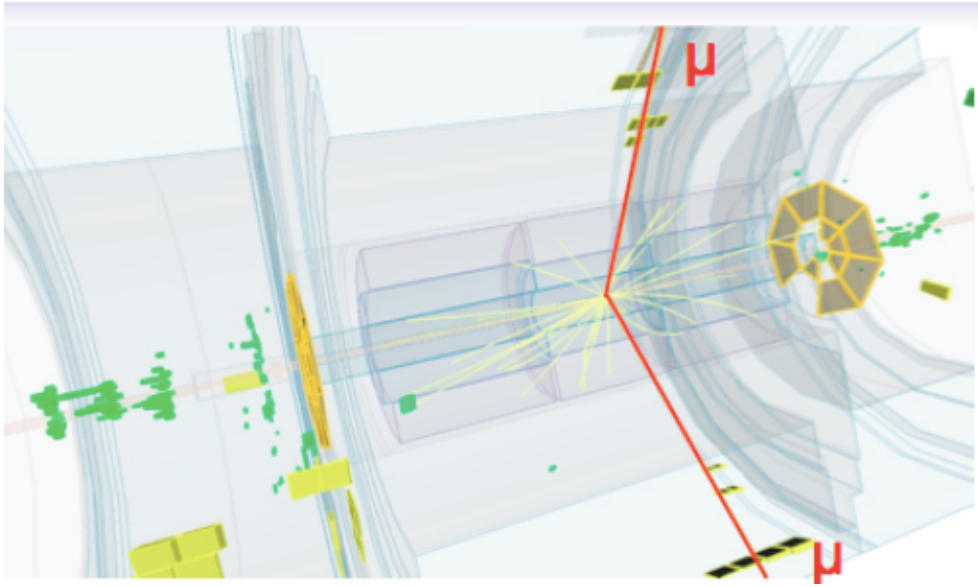
→ 12 permutations !
(6 if one *b*-tag, 2 if both)

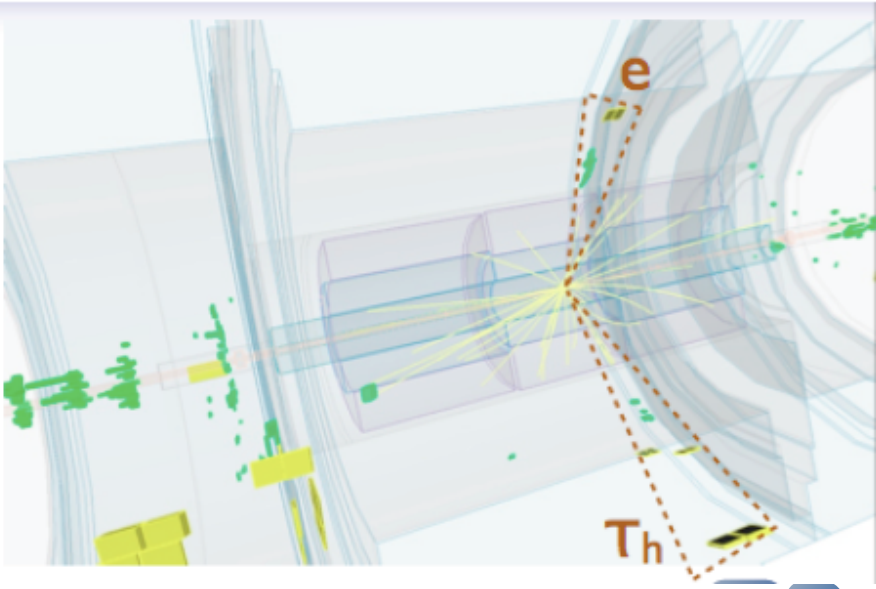
05.12.2014 10

B. Stapf

Tau "Embedding"

- **start from (real-data) Z→μμ** events: very similar to Z→ττ (except for Z decay leptons) and can be selected very purely and signal-free (b/c Higgs→μμ BR is small)
- **replace data muons with simulated tau leptons**, so that Z decay kinematics is preserved (correcting for tau/ muon mass difference)



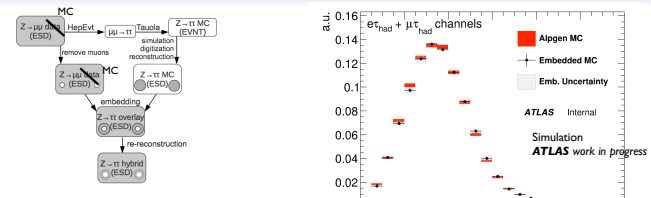


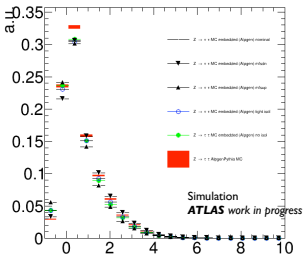
Tau Embedding

- nicely illustrates spirit and scope of this group:
  - genuine **German** key **contribution** to very high-profile analysis
  - productive **CMS-ATLAS collaboration** (even outside workshops) **since the beginning** of the group until now
  - **focus on** experimental **concepts**; simple idea, complex details
  - good balance of **common ideas and** implementation **differences**
  - highly **relevant beyond mass** reconstruction

Tau Embedding

MC closure check

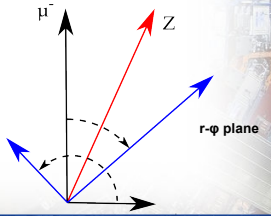




- Use Z→μμ MC instead of data as input
  - Apple to apple comparisons between MC embedding/Pythia MC
    - Provided same simulation conditions
- Check if MC embedding matches with Z→ττ MC within systematic uncertainties

4-Vector Transformation (2)

- Instead: Mirror the four vector in the proton-Z plane
  - Corresponds to the transformation φ → -φ
  - The Z decay seems to be invariant under this transformation
- Has a simple interpretation in the laboratory frame:
  - Swap "sides" of muons wrt. Z boson momentum in r-φ
  - Changes only phi coordinate
  - p_T and η remain invariant
  - Geometric acceptance stays the same!



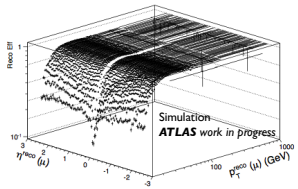
Apr 04, 2014

External embedding corrections

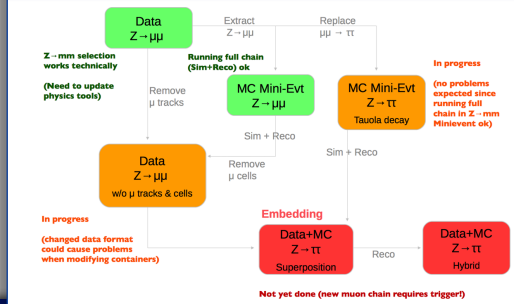
- **Reco Eff of original muons**
- **Trigger Eff of original muons**
- Exp B-Layer flag correction
- Analysis trigger emulation
- TauSpinner weight

Embedded samples biased due to Z→μμ selection on data
- Muon trigger efficiency
- Muon offline reconstruction efficiency

→ Efficiency correction needed



Preperation for run2



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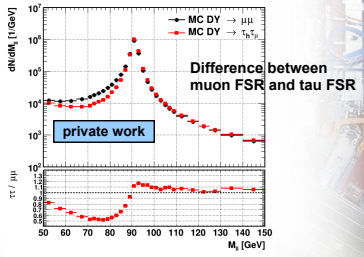
Final State Radiation

- Muon FSR introduces two effects:
  - The radiated energy is lost for the replacement taus
  - Radiated photons contribute to the isolation around the embedded objects
- Tau FSR is much smaller than Muon FSR
- For the simulated leptons in embedding:
  - Radiation enabled for μμ → ττ embedding



Apr 04, 2014 A. Burgmeier, DESY: Z → ττ Embedding Studies in CMS 16

J. Liebal et al

A. Burgmeier

Determination of the Higgs CP mixing angle
in the tau decay channels:
Z-boson background processes

Stefan Berge, RWTH Aachen

in collaboration with W. Bernreuther and S. Kirchner

TauSpinner Studies

Swagato Banerjee

rkshop of the tautau Analysis Working Group
DESY, 3-4 April 2014

RWTH AACHEN UNIVERSITY

Simulating τ and the Higgs CP at CMS

ττ analysis Working Group
04.04.2014

Ian M. Nugent

III. Physikalisches Institut B
RWTH Aachen University

Outline

Introduction – Higgs CP

Simulating $\tau \rightarrow \pi\pi\pi\nu$

Simulating the τ Spin Correlatons

Obtaining the τ 4-Vector

Prospects for Measuring the Higgs and its CP

Summary & Outlook

Spin / CP Analyses

- **hot** topic and **long-term** effort
- study **experimental challenges**
- **theory tools** up to the task?

Tomorrow afternoon:

TAUOLA and TauSpinner Status and Plans	*WAS, Zbigniew*
SR 1, DESY	15:40 - 16:10
Coffee break	
Seminar Room 3, DESY	16:10 - 16:30
Z->tautau Polarisation Studies with ATLAS	*WINTER, Benedict*
SR 1, DESY	16:30 - 16:50
Higgs CP Properties from H->tautau	*BERGE, Stefan*
SR 1, DESY	16:50 - 17:20
Higgs CP Studies with CMS	*NAYAK, Aruna*
SR 1, DESY	17:20 - 17:40
Higgs CP Studies with ATLAS	*CALLENBERG, Clara*
SR 1, DESY	17:40 - 18:00

excellent topic for this working group!

Impact of Alliance Funding

- we are grateful for the **continuing financial support**; it doesn't take large amounts to make a difference
- somewhat **lowers the threshold to join workshops**, especially for younger group members
- **adds some flexibility** to the workshop organisation
- most importantly makes it possible to **invite outside experts**
  - complements the program, **broadens the expertise**
  - **strengthens network** outside the German community
  - **carries** discussions and **results back into** the LHC **collaborations** (and possibly theory communities)

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Thanks!