Hadronic Taus in ATLAS and Higgs Search in $H \to \tau\tau \to hh$ final state

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Tau Leptons

- Discovered not so a long time ago in the '70s by M. L. Perl *et al.* at SLAC
- Tau Leptons are very important in particle physics because they can be used as a benchmark for SM and for the exploration on the physics beyond the SM
- The detection of this particle is difficult becuse it decays immediately in leptons or hadrons ($c\tau \sim 90\ \mu m$)
- This talk will be focused on the most challenging decay mode, that is the *hadronic* one.

OUTLINE:

- Tau Physics: SM and MSSM Higgs
- Tau detection: Branching Ratios and final states
- Hadronic Taus in ATLAS:
  - Tau triggers
  - Tau reconstruction and identification
  - True and fake taus
- Searches in di-tau final state: MSSM Higgs
  - Signal and Background
  - Bkg estimation methods

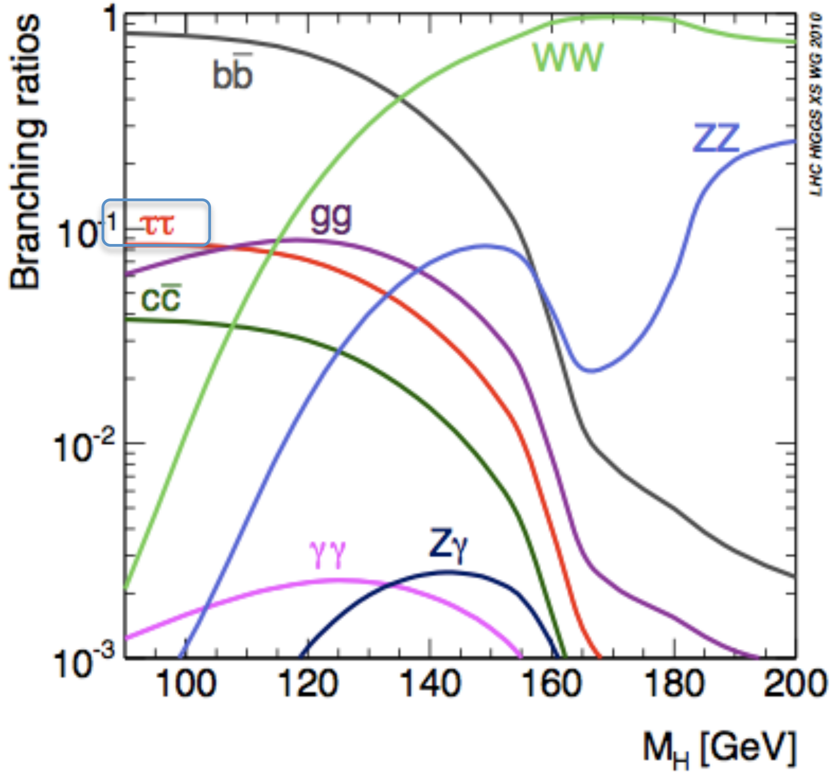
TAU PHYSICS: SM HIGGS

Phenomelogy:

Scalar boson which couples to gauge bosons and fermions:

- HVV couplings ~ m^2
- Hff coupling ~ m

SM Higgs Branching Ratios:

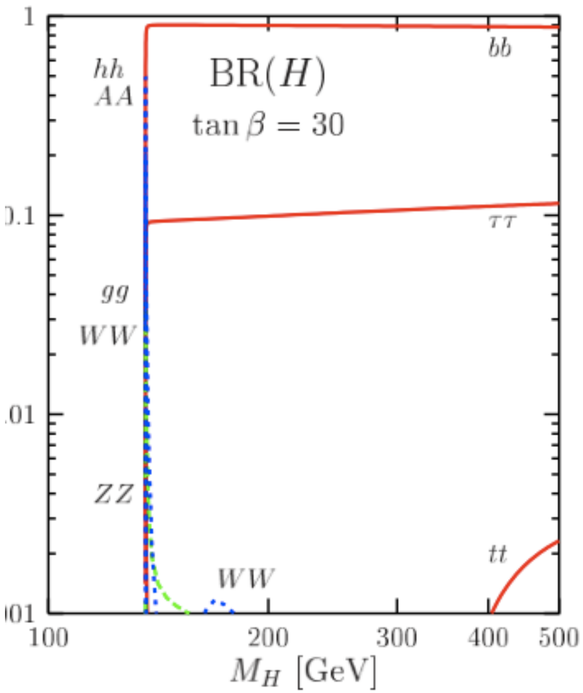


TAU PHYSICS: MSSM HIGGS

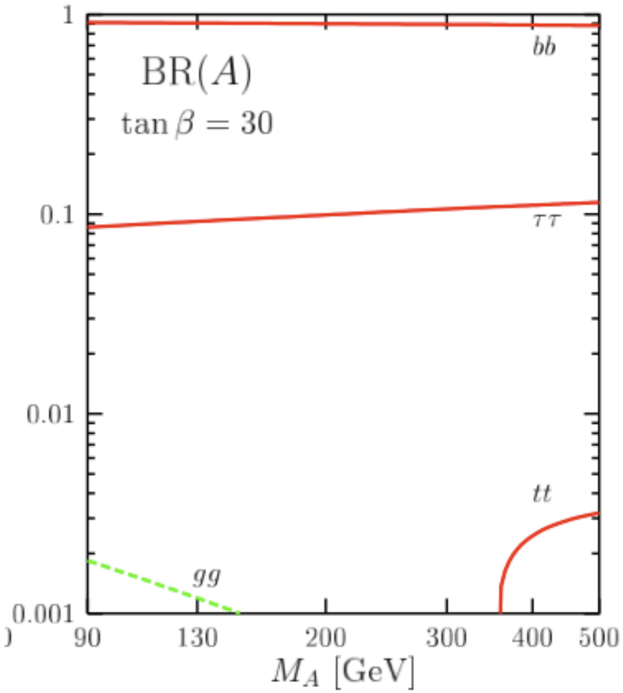
Phenomelogy:

- 5 Higgs bosons: 3 neutral (h,H,A) and 2 charged ($H^{\pm}$)
- coupling to ‘down-type’ fermions enhanced

MSSM Higgs Branching Ratios:



Heaviest CP-even Neutral Higgs



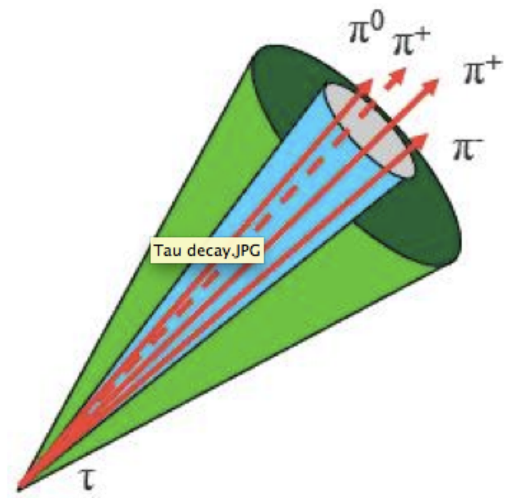
CP-odd Neutral Higgs

TAU PHYSICS: HIGGS SEARCHES

- Both in the SM and the MSSM search, the *bb* final state has the biggest BR but it is almost completely hidden by QCD bkg
- So the di-tau final state is the most promising channel for the SM Higgs around m_H around 120 GeV and the MSSM H/A search
- The probability that both taus decay in hadron is 42%!

Tau detection

- The probability that a tau decays in hadrons is **65%**
- The hadronic decay modes are usually classified by the number of charged tracks in ‘1-prong’ and ‘3-prong’



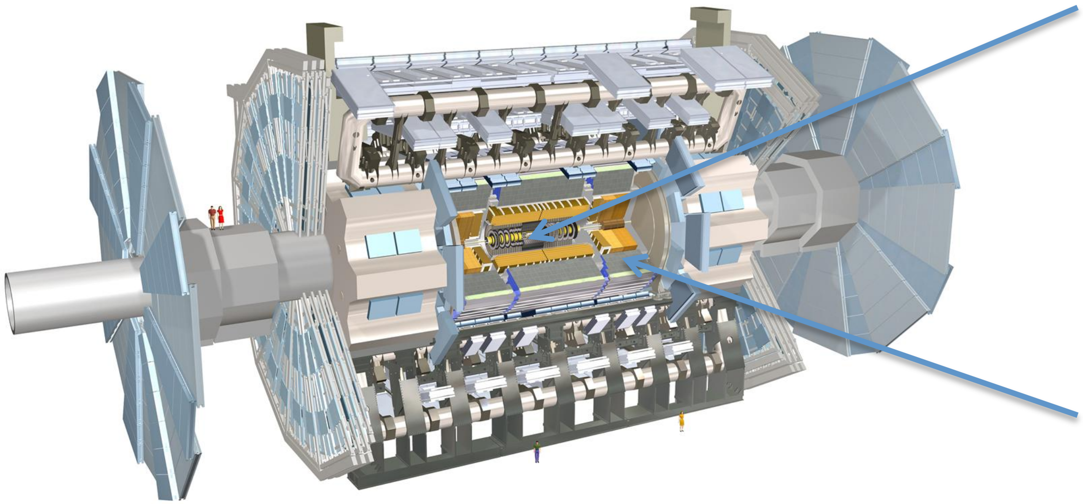
1-prong: $\pi^- + 0,1,2\ \pi^0$

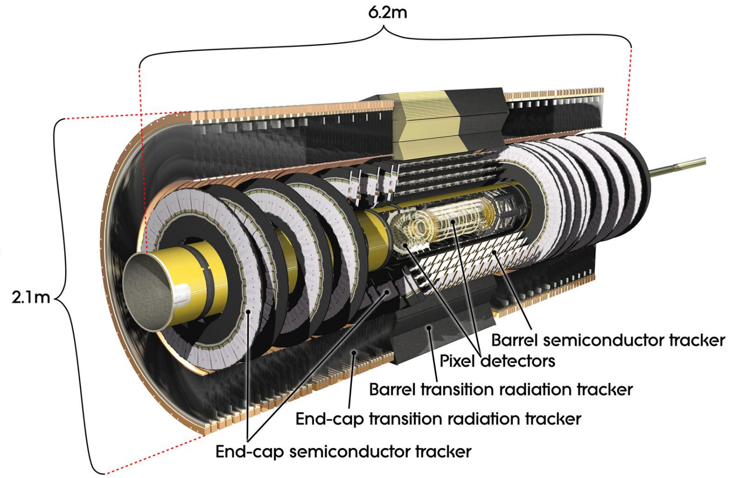
3-prong: $\pi^-\pi^-\pi^+ + 0,1\ \pi^0$

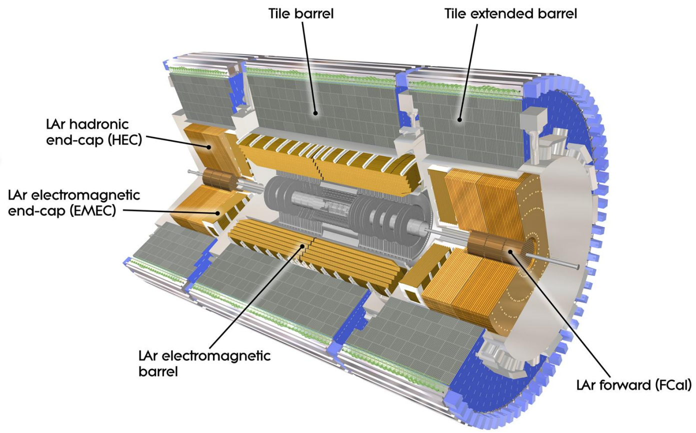
- Collimated and isolated jet with low track multeplicity
- Possible secondary vertex
- Energy deposit both in EM and Hadronic calorimeter

HADRONIC TAUS IN ATLAS

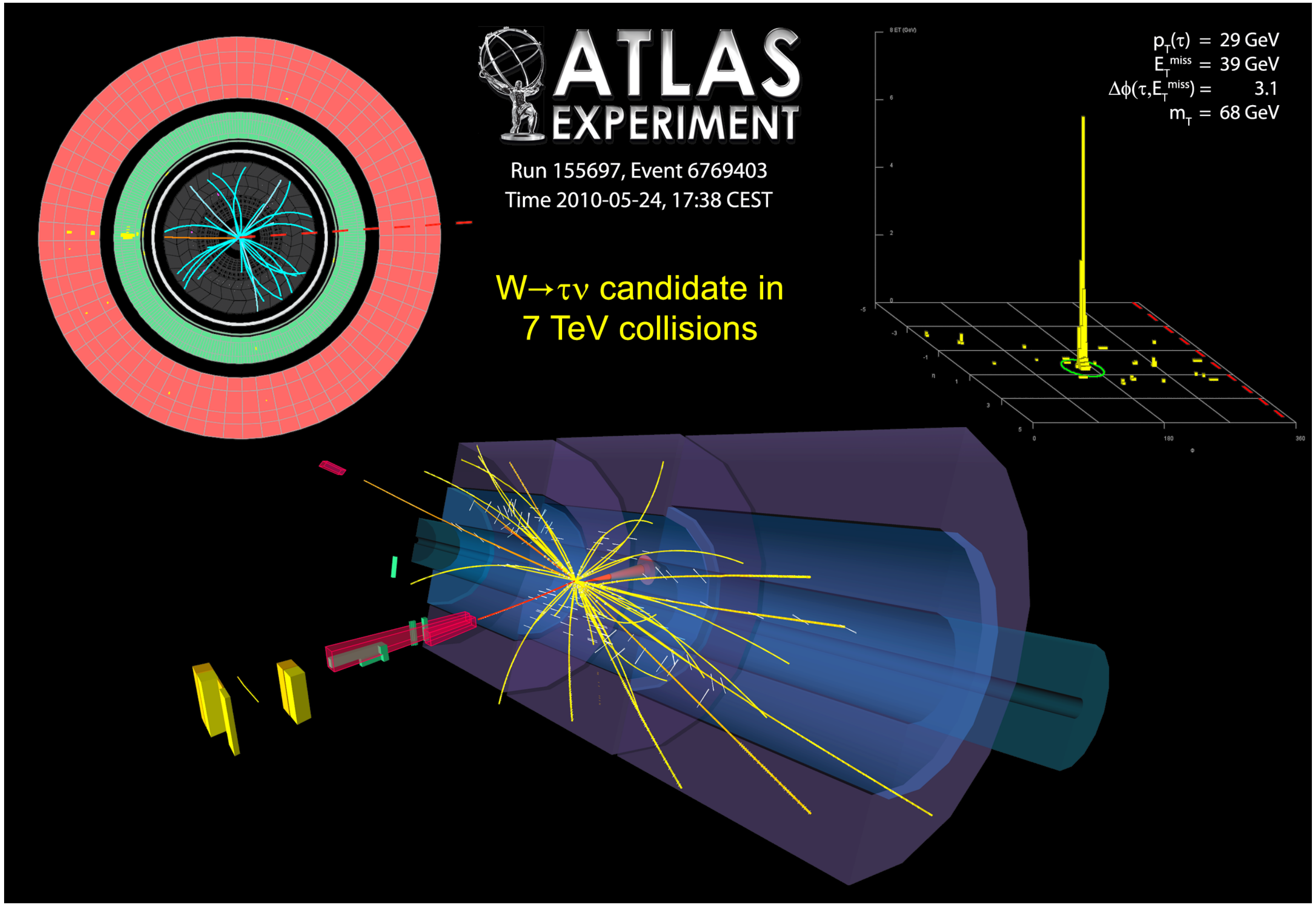
- The detection of this particle requires a detector with very good performances since we need to rely both on the *tracking* and the *calorimetric* systems!







HADRONIC TAUS: $W \rightarrow \tau\ \nu$



TAU DETECTION: TRIGGER

- It is impossible to store on tape all the events, so we need to implement an *online* event selection, 'triggers'
- *double-hadronic-tau triggers* are extremely chalenging: must provide enough rejection against QCD jets with limited information in order to keep the rate low and not loose di-tau events

ATLAS has 3 level of triggers:

- *Level 1*, 4000Hz: finds region of activity in the calorimeters and applys basic cuts. Latency ~2μs!
- *Level 2*, 60 Hz: combines the information from calorimeters and tracking system. Selection on #tracks, isolation, energy deposit shape. Latency ~40ms
- *Level 3 (HLT)*, 8 Hz: algorithm close to offline tau reconstruction

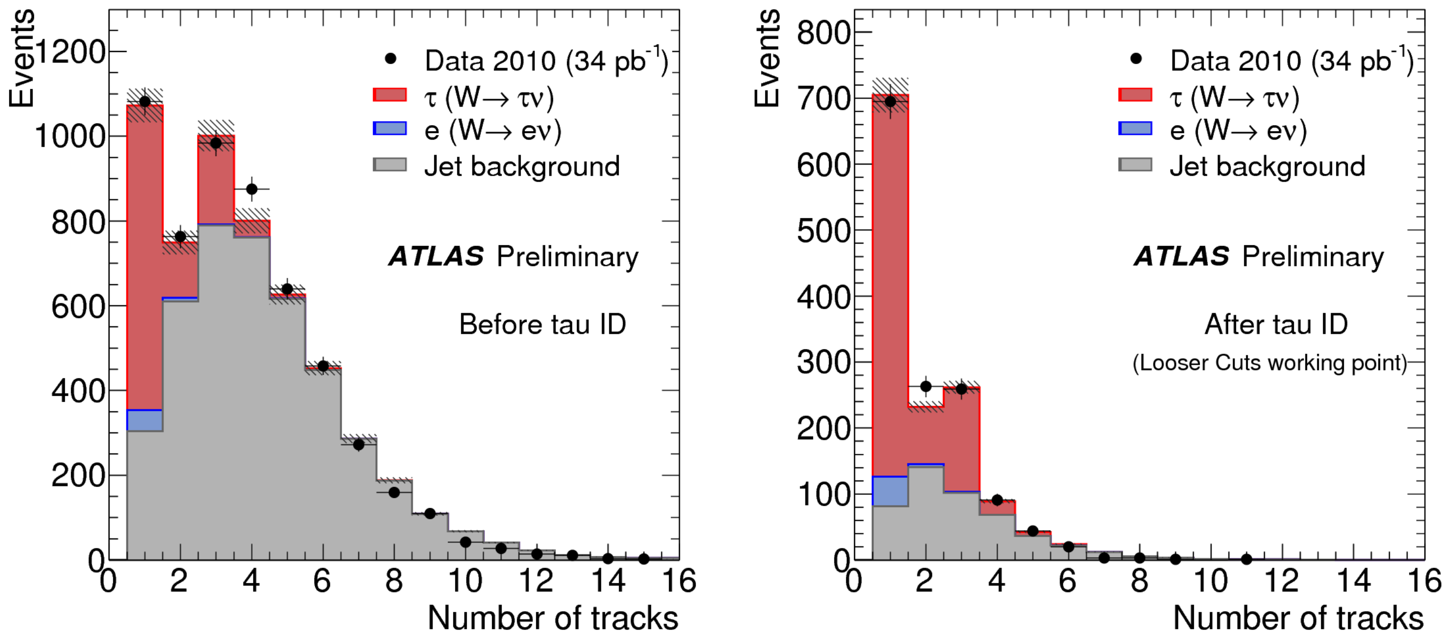
Rates only for one double hadronic tau trigger!

TAU DETECTION: OFFLINE

- The tau offline reconstruction is 'seeded' by *good quality tracks* in the tracking system and/or *energy deposit* in the calorimeters
- Such reconstruction provides a very bad rejection against QCD jets, so **IDentification** methods are strongly needed
- Three methods are used in ATLAS and they are based on simple cuts, BDT and likelihood
- Example of variable used:
  - *masses*: cluster mass, track mass
  - *radii*: track radius, EM radius
  - leading *track* momentum fraction
  - *cluster shape*: core energy fraction, EM energy fraction

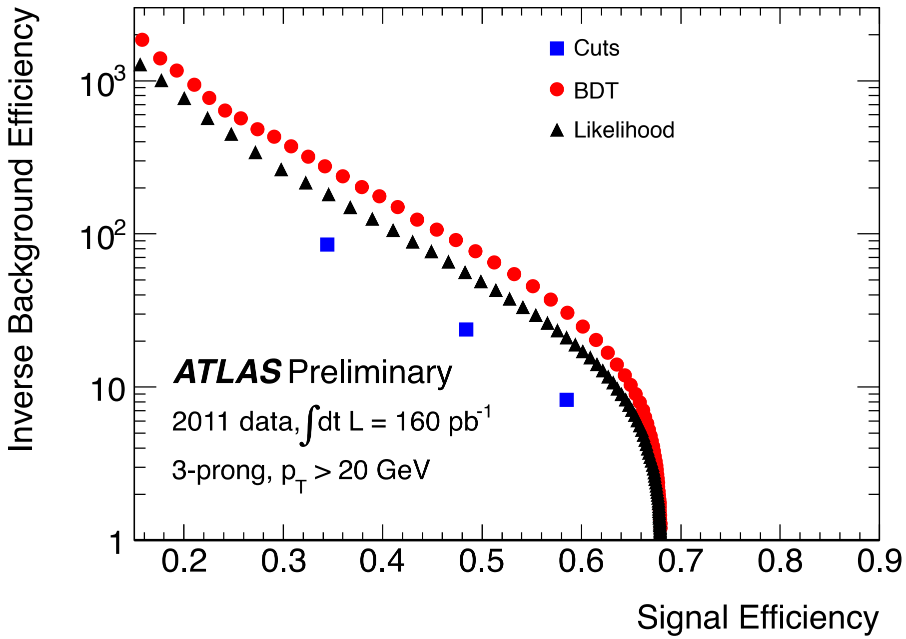
TAU DETECTION: ID EFF

- The performances of these ID methods have to be well understood and estimated not only using simulation, but also real data
- It is possible to do that using, for instance, $W \rightarrow \tau\ \nu$ events:



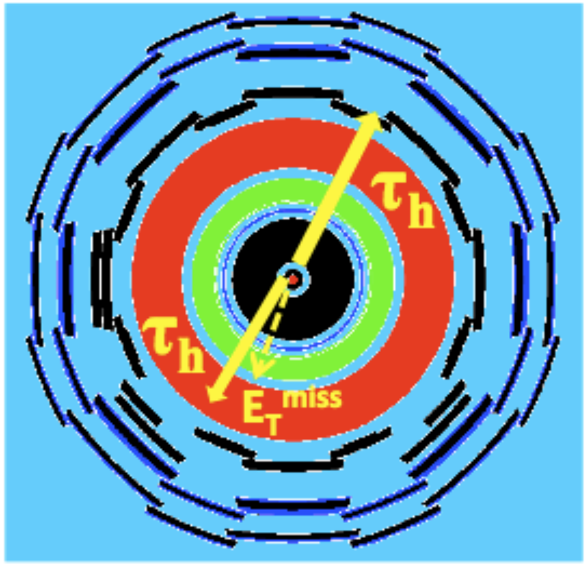
TAU DETECTION: FAKE RATE

- The other crucial point is the rejection of QCD jets reconstructed as taus, aka fake taus
- This can be estimated using di-jet or $W \rightarrow \mu \nu$ events in real data:



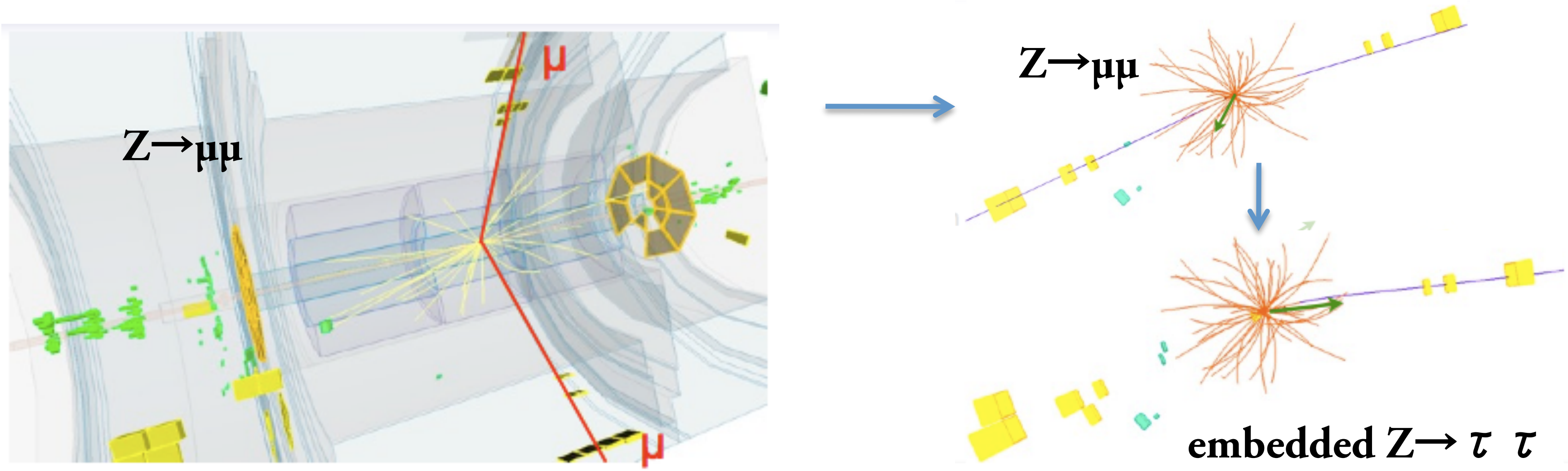
MSSM Higgs Search in di-tau-jets events

- The first paper in this channel is being reviewed, so results are not public yet!
- Since this is the first time that we perform such analysis we need to be very convincing that we have all the issues related to this search well understood
- What we have described so far is the 'hidden' work needed to identify correctly hadronic taus
- Now we need to find a way to distinguish H decaying in taus from other SM processes like:
  - *QCD jets*: two fake taus
  - *W+jets*: one real tau fron the W decay and one jet
  - *Z+jets*: two real taus coming from the Z boson



EW BKG ESTIMATION: EMBEDDING

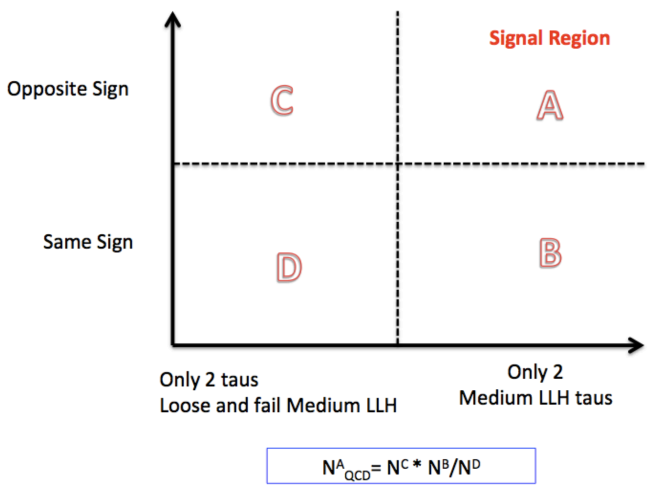
- This method is based on the selection of W→μ ν and Z→μμ events in data
- These events are *signal free* and all the important features like **Undelying Event** (like ISR) and **pile-up** (additional proton collisions) are 'trustable' since these are data!
- So the trick is to remove all the tracks and the energy deposits associated to the muon and simulate the decay of the vector boson in hadronic taus



QCD Bkg estimations: ABDC

- The QCD Bkg cannot be model properly by simulation. It is necessary to use a data-driven estimation
- The ABCD method allows to estimate the normalization and the shape of the QCD Bkg in the signal region

ABCD



The idea is:

- find two UNCORRELATED variables
- define 4 regions in the 2D plot, one of them QCD enhanced
- then the ratio of $N^{A}_{QCD}/N^{C}_{QCD} = N^{B}_{QCD}/N^{D}_{QCD}$
- take the shape of QCD Bkg from a region signal free (in our case ‘C’)

SUMMARY

- At the moment the Higgs search is under review, so results are not public
- However, I described all the stages needed to perform such analysis and in which I'm currently involved:
  - *Online Trigger*: selection and storaging of double hadronic tau events
  - *Offline Reco and tauID*: reconstraction of the 4-momentum of taus from the energy deposits in the detector
  - *Bkg estimation*: evaluation of events with true and fake taus that can look like an Higgs decay
- We hope to have nice results very soon!!