# Exclusive study of the mSUGRA co-annihilation region using a new soft tau identification method with the ATLAS detector

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# Outline

- Introduction of mSUGRA co-annihilation region
- Phenomenology of this scenario at LHC, and the very soft taus which result from it.
- The standard tau identification algorithm in ATLAS, and the poor performance of it at low Pt.
- Introducing a new method which will increase the soft tau identification.

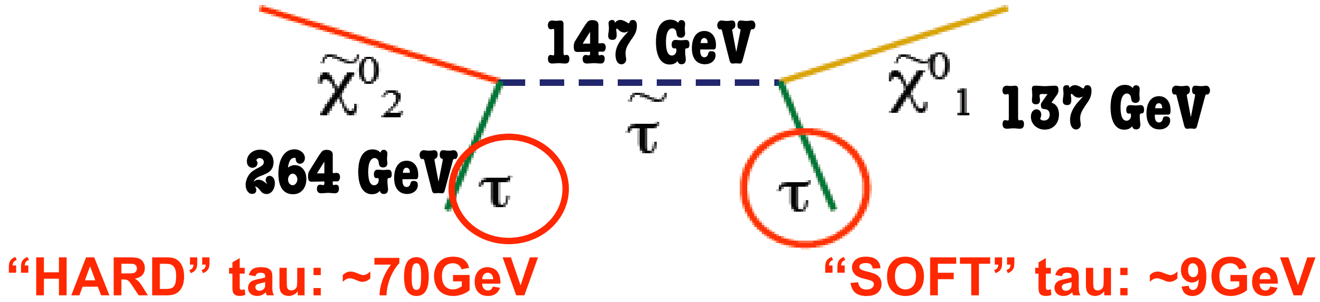
# mSUGRA $\tilde{\chi}_1^0, \tilde{\tau}$ co-annihilation region

- In this region the LSP is $\tilde{\chi}_1^0$ and the NLSP is $\tilde{\tau}$
- The $\tilde{\chi}_1^0$ and $\tilde{\tau}$ are near degenerate in mass ($\Delta$M~ 5-15GeV), which allows for the co-annihilation of them in the early universe.
- This co-annihilation can result in a $\tilde{\chi}_1^0$ density which agrees with the measured DM relic density.
- Once the SUSY mass scale has been determined the $\tilde{\chi}_1^0$ density must be calculated to check its consistency with the measured relic DM density.

# $\tilde{\chi}_2^0$ decay phenomenology

$\tilde{\chi}_2^0 \rightarrow \tilde{\tau} + \tau \rightarrow \tilde{\chi}_1^0 + \tau + \tau$ is the dominant visible decay mode

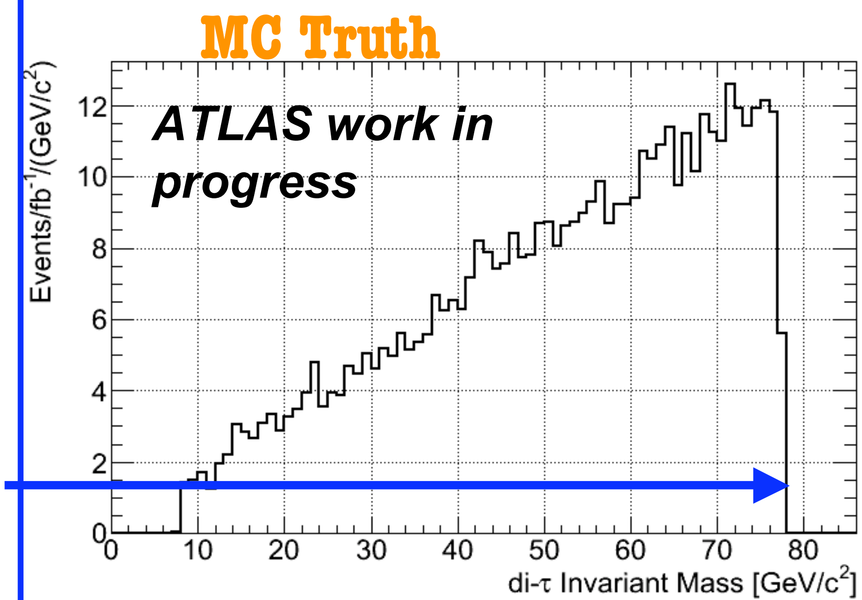
**Δm(Chi1,Stau)~10GeV ➔ very soft taus**




**The endpoint of the $M_{\tau,\tau}$ mass spectrum is sensitive to the masses of the SUSY particles in the chain. We wish to measure this.**

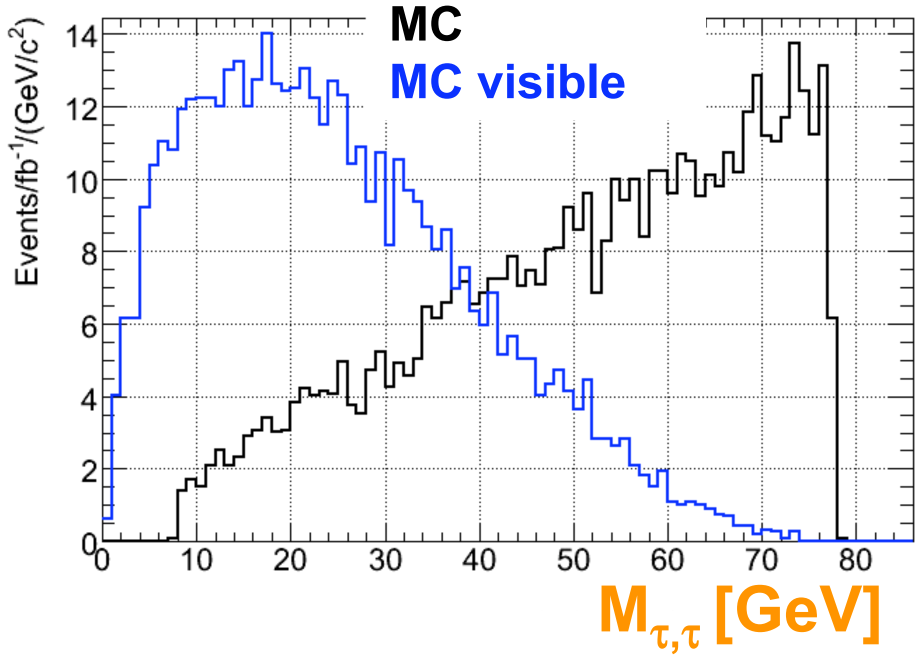
$$M_{ll}^{\max} = M(\tilde{\chi}_2^0)\sqrt{1-\frac{M^2(\tilde{l}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1-\frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{l}_R)}}$$

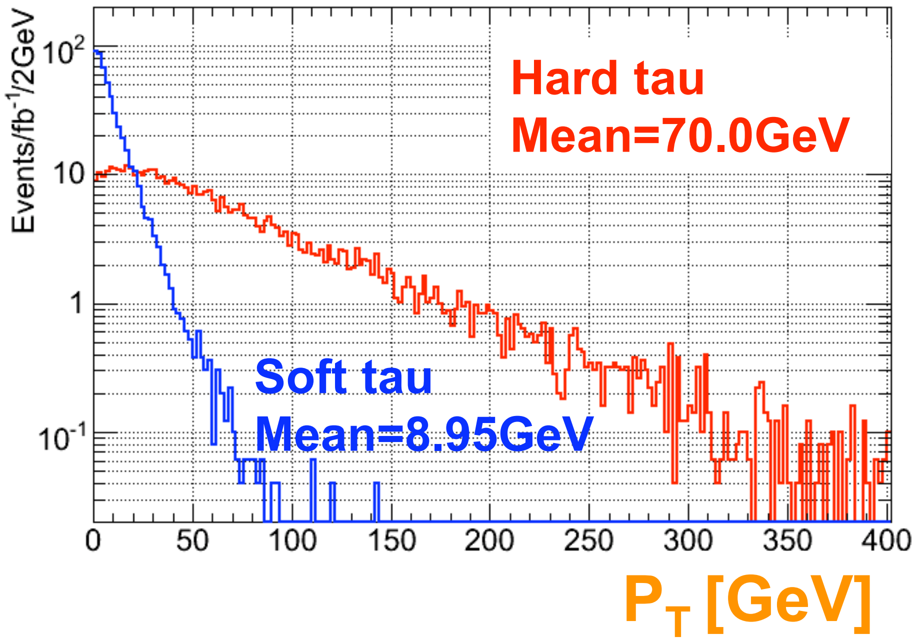
**= 78 GeV for the ATLAS reference point**

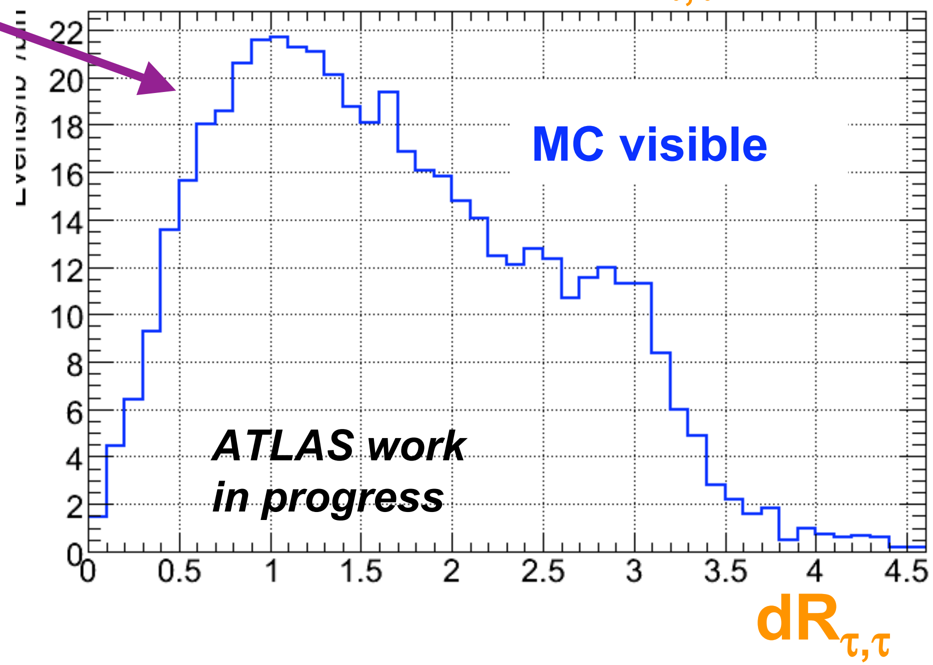


# MC visible information of the signal taus

**Signal "Soft" tau is somewhat confined around "Hard" tau**



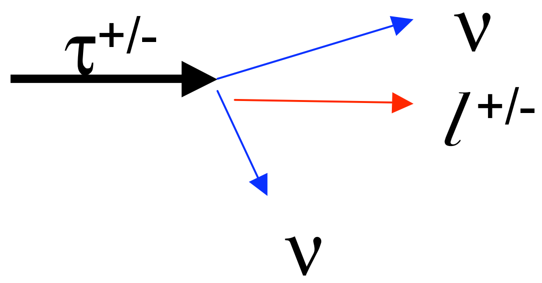





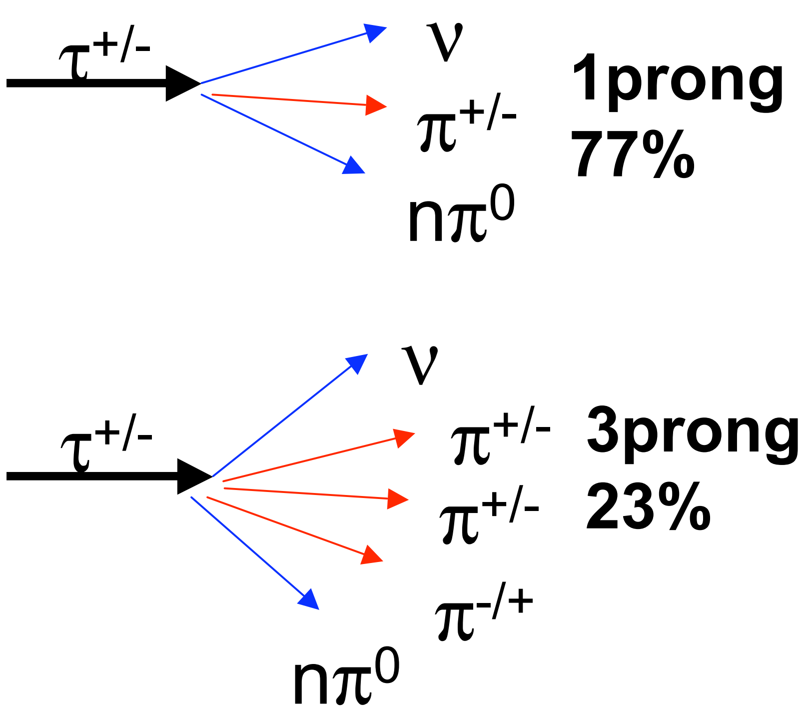

**Full simulation based on Geant4 @ 14TeV**

# Tau identification

**LEPTONIC 35%**

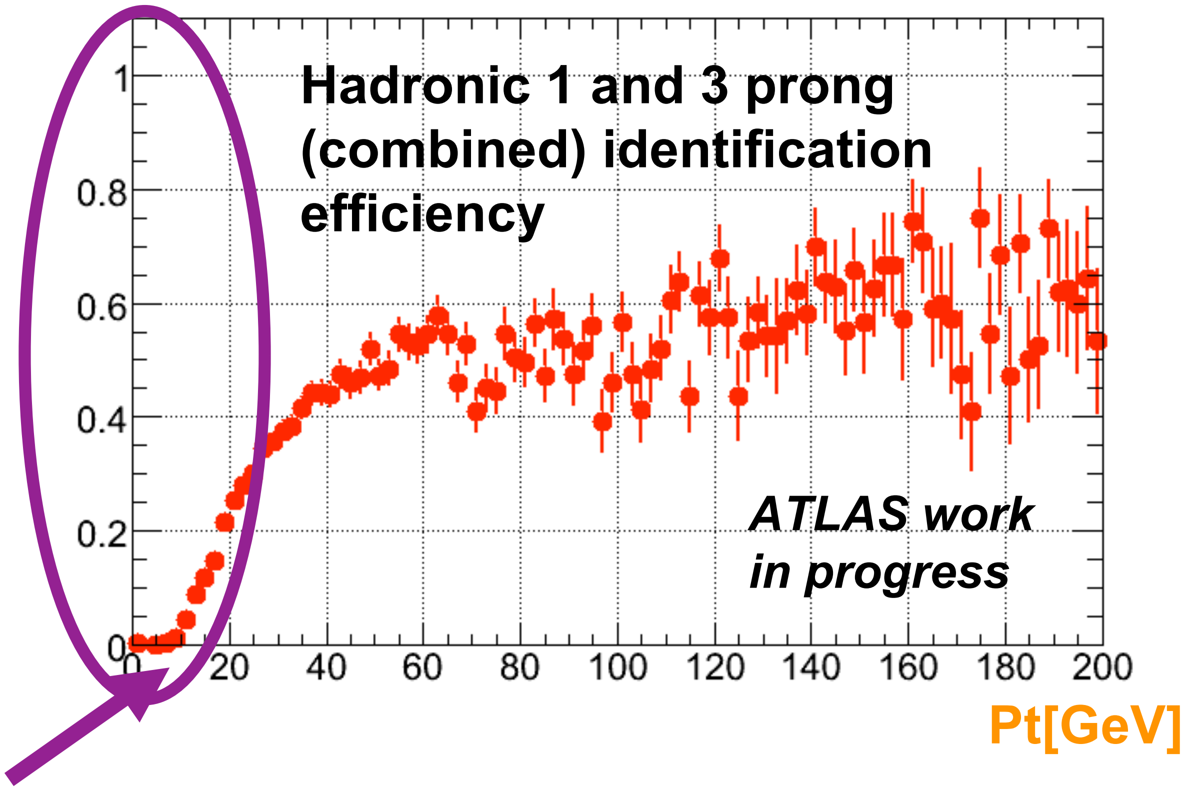



**HADRONIC 65%**




- Reconstruction of taus focuses on their hadronic modes only, since leptonic modes are too difficult to distinguish from primary leptons.
- Hadronic taus need to be disentangled from copious QCD jet background by exploiting narrow jet shapes, track multiplicity etc.
- Especially in busy SUSY environments discrimination against QCD jets is challenging, particularly so for low $P_T$ taus.

# Standard ATLAS tau reconstruction algorithm performance in mSUGRA co-annihilation region

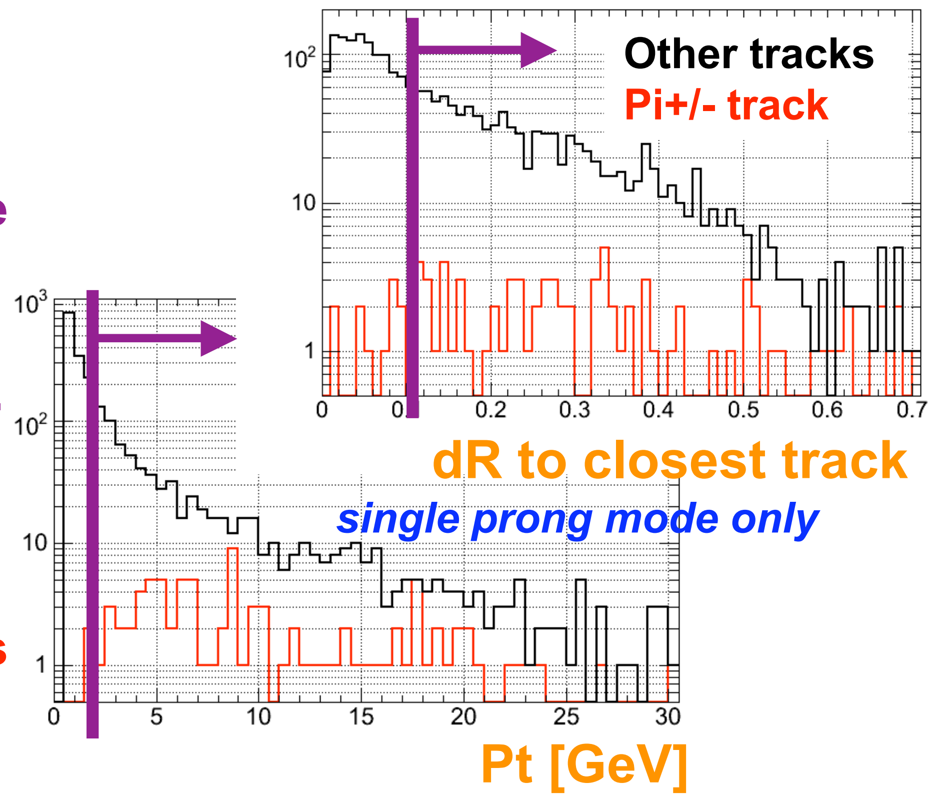


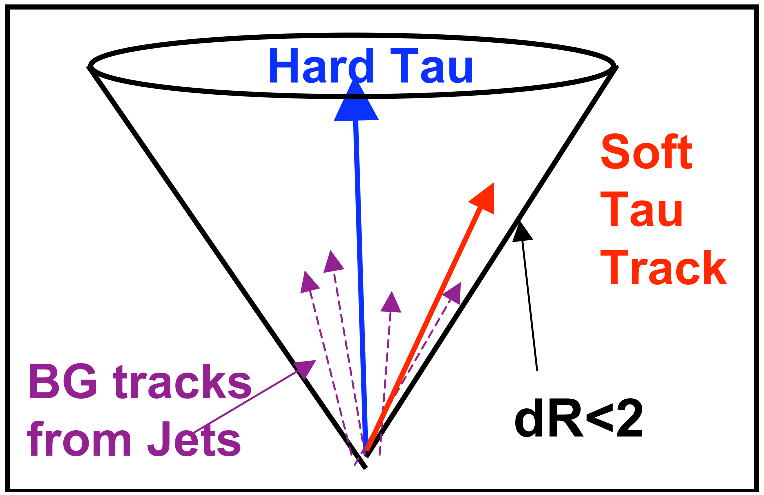

**The present ATLAS algorithm focuses on the Pt>20GeV region, thus the performance for our signal soft taus is very poor (<10% of signal soft taus are identified) .**

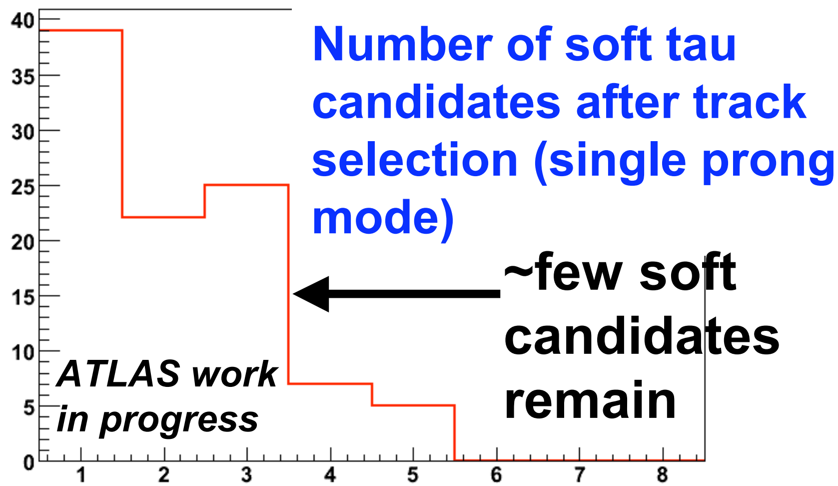
**THUS WE LOOK FOR ANOTHER METHODS FOR DISCRIMINATING THE SIGNAL SOFT TAU.**

# New method : Search for tau-like tracks around the hard tau

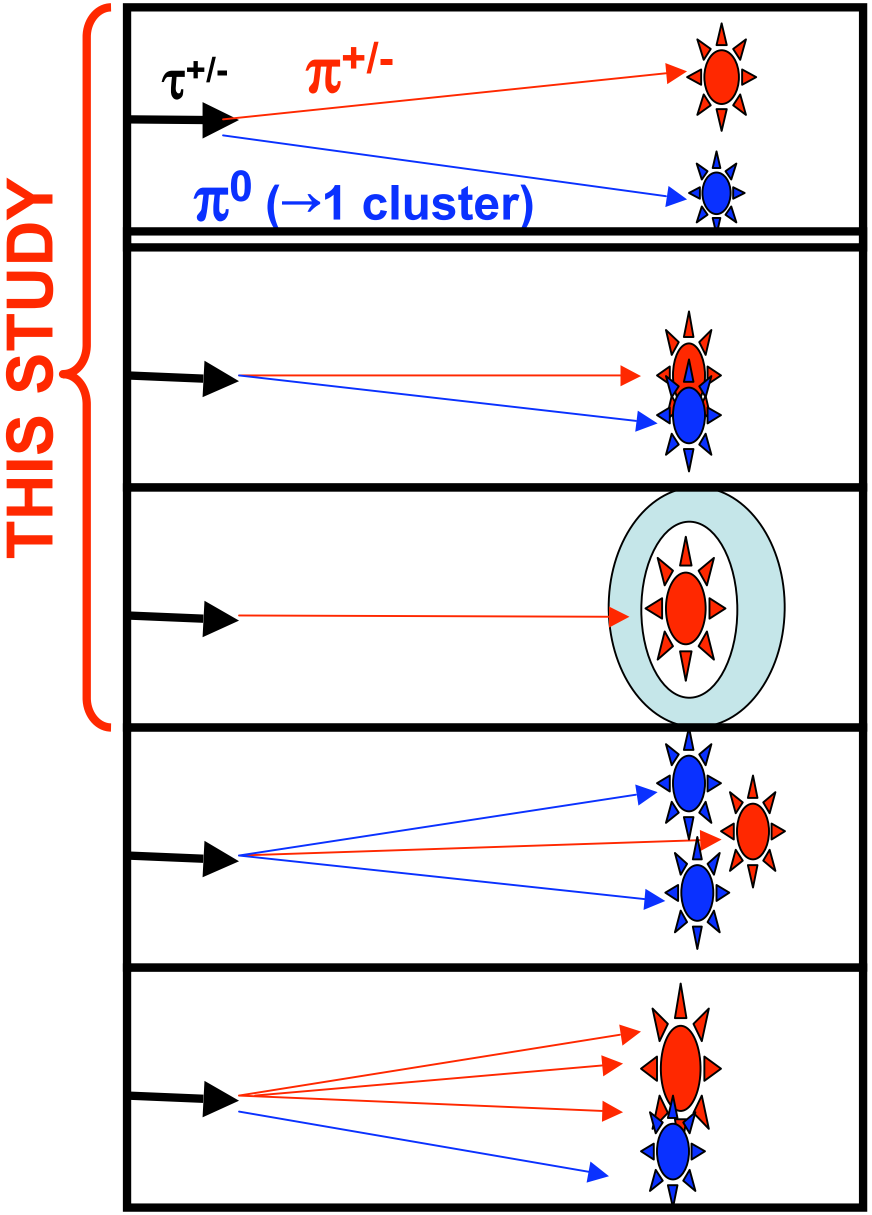
1. Select "hard tau candidates" using existing ATLAS algorithm.
2. Collect all **good quality** tracks within dR<2 of the hard tau candidate (call these "soft tau candidates") .
3. Apply **Pt>2GeV and track isolation (no tracks in dR<0.1)** cuts on soft candidates.
4. If more than one soft candidate: apply **likelihood** (work in progress) to them to select the MOST TAU LIKE candidate
5. Finally we will subtract **same sign pairs from opposite sign pairs** to reduce the uncorrelated background



# Classification of soft tau decay topology for likelihood




**CASE 1.** $\tau \rightarrow \pi^{+/-} + 1\pi^0$ **(B.R=26%). Resolved**

The $\pi^0$ causes an excess above the expected energy and there is an EM cluster in the vicinity of the $\pi^{+/-}$ impact in the calorimeter

**CASE 2.** $\tau \rightarrow \pi^{+/-} + 1\pi^0$**. Unresolved**

The $\pi^0$ causes an excess above the expected energy, but the clusters of the $\pi^{+/-}$ and $\pi^0$ are not resolved.

**CASE 3.** $\tau \rightarrow \pi^{+/-}$ **(B.R=11%)**

The expected amount of energy is deposited in the calorimeter for the candidate track, and the cluster is ISOLATED

**CASE 4.** $\tau \rightarrow \pi^{+/-} + 2\pi^{0}$ **- (B.R=9%)**

We will look at reconstructing this mode n the future.

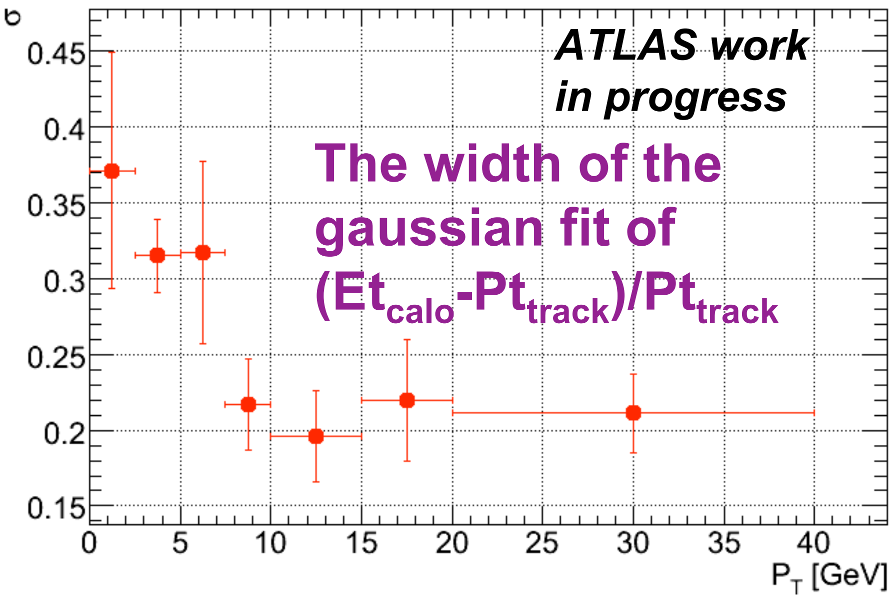
**CASE 5.** $\tau \rightarrow 3\pi^{+/-} + n\pi^{0}$ **- (B.R=14%)**

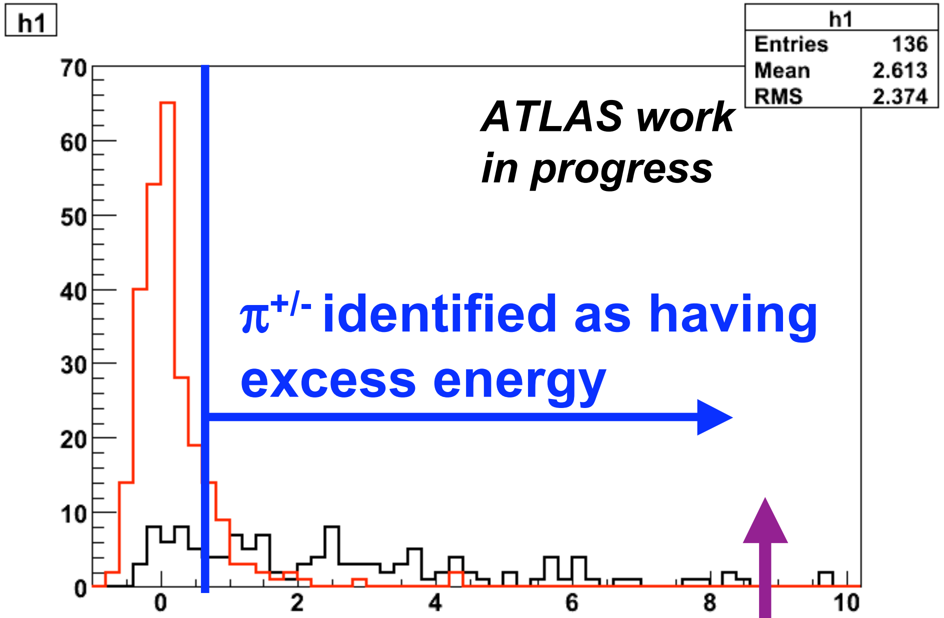
We believe that this mode would be very difficult to discriminate at low Pt so we are not studying it for now.

**For now we focus only on $\tau \rightarrow \pi^{+/-} + \pi^0$(26%) & $\tau \rightarrow \pi^{+/-}$ (11%)**

# Resolution of $\pi^{+/-}$ clusters

**We want to know the resolution of a single $\pi^{+/-}$ in the calorimeter so that we can determine if the energy is greater than that expected from the track. This will separate "with $\pi^0$" soft tau candidates from "without $\pi^0$" soft tau candidates**




**We use the $\tau \rightarrow \pi^{+/}$ mode to determine the calorimeter resolution for $\pi^{+/-}$ as a function of Pt .**

**RED: $(Et_{calo}-Pt_{track})/Pt_{track}$ for $\pi^{+/-}$ from 0 $\pi^0$ mode**

**BLACK: $(Et_{calo}-Pt_{track})/Pt_{track}$ for $\pi^{+/-}$ from 1 $\pi^0$ mode (when the $\pi^0$ is close to the $\pi^{+/-}$)**

# Classifying the soft tau candidate

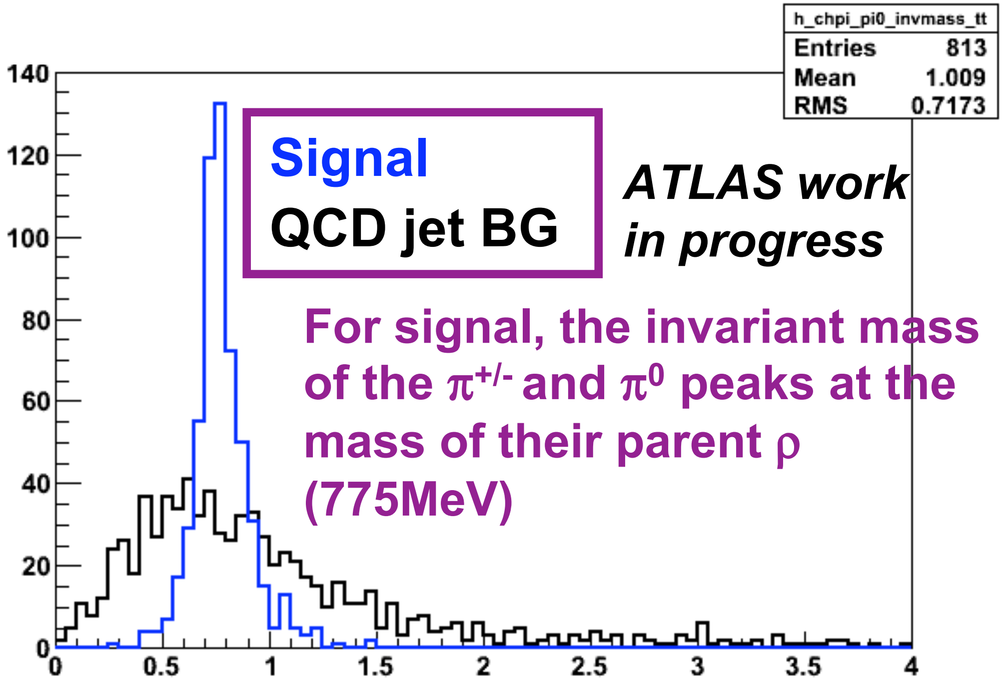
- CASE1: If there is an energy excess around the $\pi^{+/-}$ candidate then look for an EM cluster (the $\pi^0$) in the vicinity of it (dR<0.4).
  - ➔ If there is one, CLASSIFY AS 1-PI0 MODE
- CASE2: If there is an excess of energy around the $\pi^{+/-}$ candidate in the calorimeter, but no EM cluster was found,
  - ➔ ATTEMPT TO RESOLVE $\pi^0$: we are working on a better clustering resolution using fine granularity strip layer of calorimeter
- CASE3: For $\pi^{+/-}$ candidates with no excess, and no $\pi^0$ candidate, require isolation (no hadronic cluster in 0.2<dR<0.4).
  - ➔ If it is isolated CLASSIFY AS $0\pi^0$ MODE
  - ➔ If not isolated classify as jet and discard
- CASE4: If there are n $\pi^0$, CLASSIFY as $n\pi^0$ mode (for now we will not study this case any further).

# Algorithm applied to signal and QCD jet BG

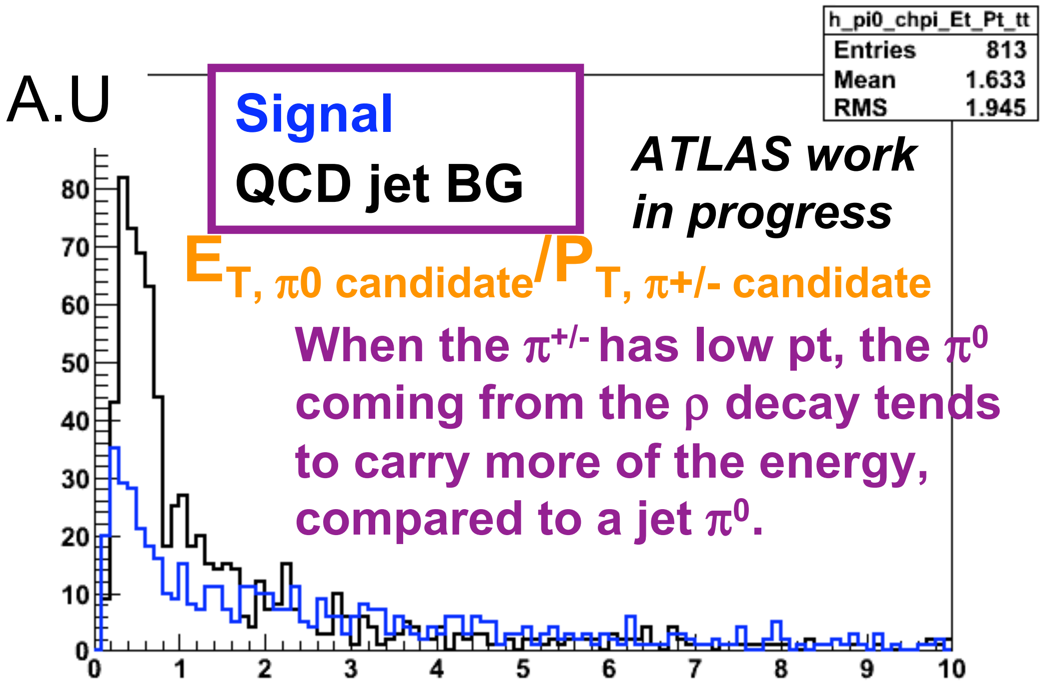
| | $\tau \rightarrow \pi^{+/-} + 1\pi^0$ [/16fb$^{-1}$] | $\tau \rightarrow \pi^{+/-} + 0\pi^0$ [/16fb$^{-1}$] | QCD Jets |
|---|---|---|---|
| Passes hard tau selection cuts | 1447 | | |
| BRANCHING FRACTION | 357 | 194 | |
| $\pi^{+/-}$ track reconstructed within dR<2.0 of hard tau | 226 | 141 | |
| Track quality, pt, isolation cuts | 89 | 87 | |
| CASE1: Classified as 1 $\pi^0$mode | 29(33%) | 5 (6%) | 30% |
| CASE2: Excess but no EM cluster | 14 (16%) | 3 (3%) | 21% |
| CASE3: | | | |
| Isolation → Classified as 0 $\pi^0$ mode | 29 (33%) | 70 (80%) | 13% |
| no isolation → Classified as jet | 9 (10%) | 7 (8%) | 16% |
| CASE4: more than 1 EM cluster | 8 (9%) | 2 (2%) | 21% |

Many $\pi^0$ clusters lost due to being too close/far from $\pi^{+/-}$ or being classified as hadronic

# Work in progress: Using $\pi^0$ to discriminate against jets




For signal, the invariant mass of the $\pi^{+/-}$ and $\pi^0$ peaks at the mass of their parent ρ (775MeV)




When the $\pi^{+/-}$ has low pt, the $\pi^0$ coming from the ρ decay tends to carry more of the energy, compared to a jet $\pi^0$.

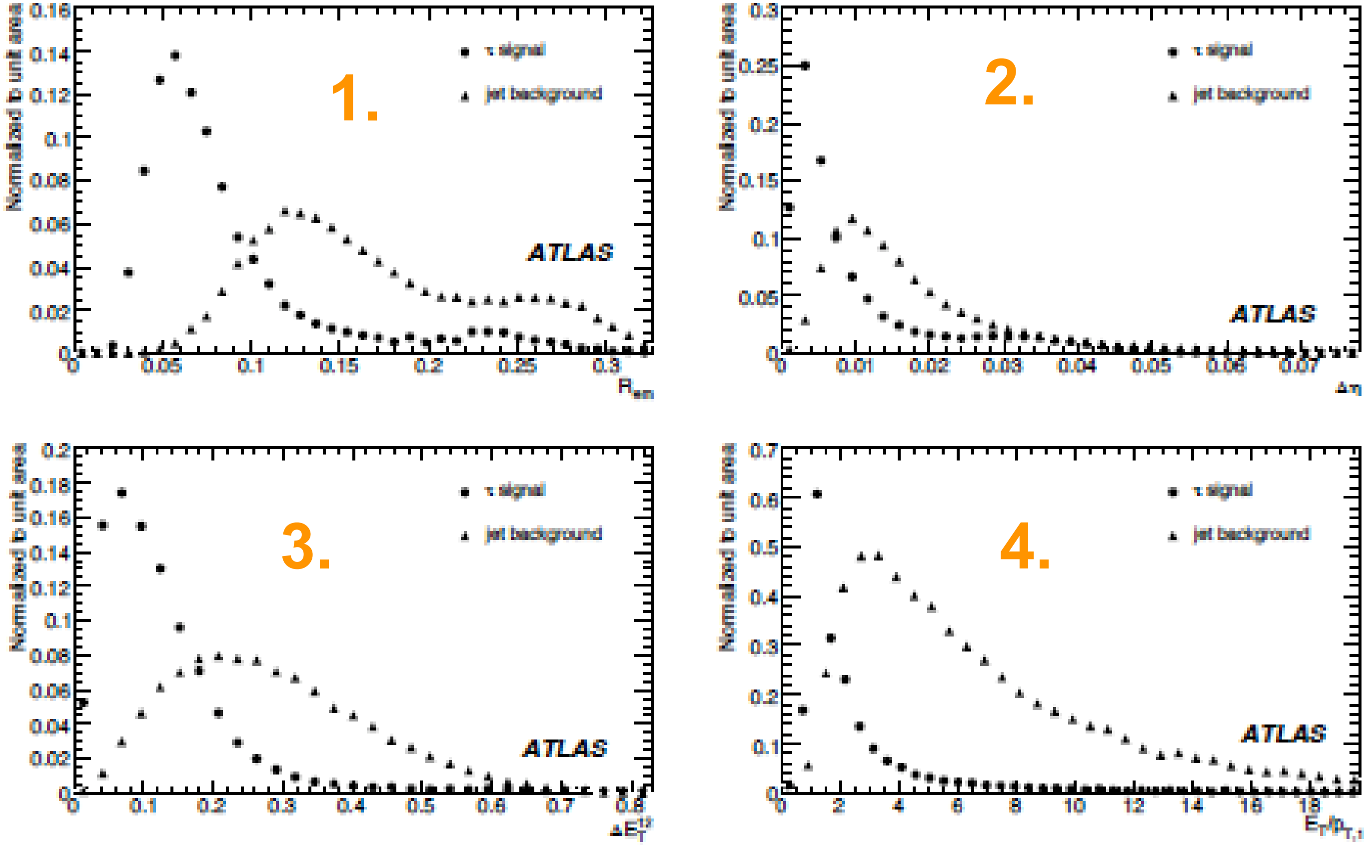
**We are presently building a likelihood to choose the most tau like candidate**

# Conclusion

- The mSUGRA co-annihilation region is a good new physics candidate and would explain the observed dark matter density.
- The existing ATLAS tau identification algorithm performs poorly for the low Pt taus that result from this scenario.
- A new method is proposed that will boost the soft tau identification efficiency.
  - We have investigated the resolution of $\pi^0$ from the $\tau \rightarrow \pi^{+/-} + 1\pi^0$ mode and have reconstructed it 33% of the time. The parent $\rho$ mass has been reconstructed.
  - We are currently working on a likelihood method to select the soft tau from the soft tau candidates.
- This soft tau reconstruction could be useful for other studies including VBF H->tau,tau.

# BACKUP

# Standard ATLAS tau reconstruction algorithm discrimination 1




**1.** $$R_{\rm em} = \frac{\sum_{i=1}^{n} E_{T,i}\sqrt{(\eta_i - \eta_{\rm cluster})^2 + (\phi_i - \phi_{\rm cluster})^2}}{\sum_{i=1}^{n} E_{T,i}},$$

**2.** $$\Delta\eta = \sqrt{\frac{\sum_{i=1}^{n} E_{Ti}^{\rm strip}\,(\eta_i - \eta_{\rm cluster})\,2}{\sum_{i=1}^{n} E_{Ti}^{\rm strip}}}.$$

**3.** $$\Delta E_{\rm T}^{12} = \frac{\sum_i E_{T,i}}{\sum_j E_{T,j}},$$

**4.** $E_T$ over $p_T$ of the leading track:

# Standard ATLAS tau reconstruction algorithm discrimination 2

**Discrimination variables are combined to form a likelihood**

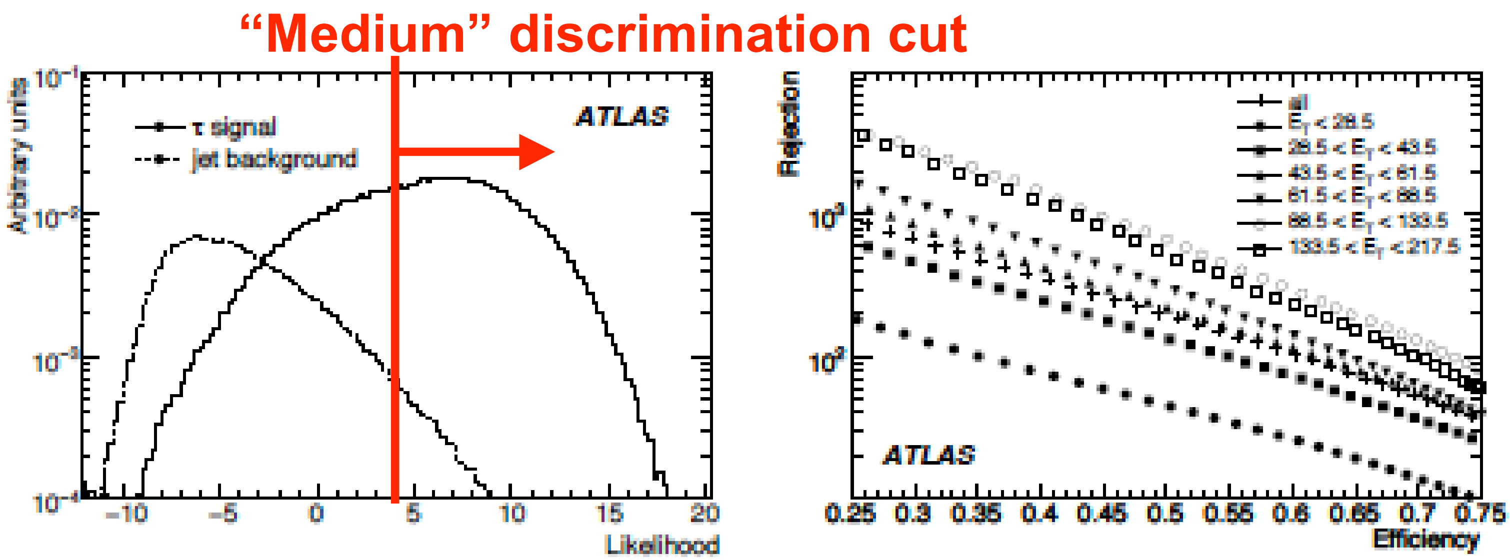
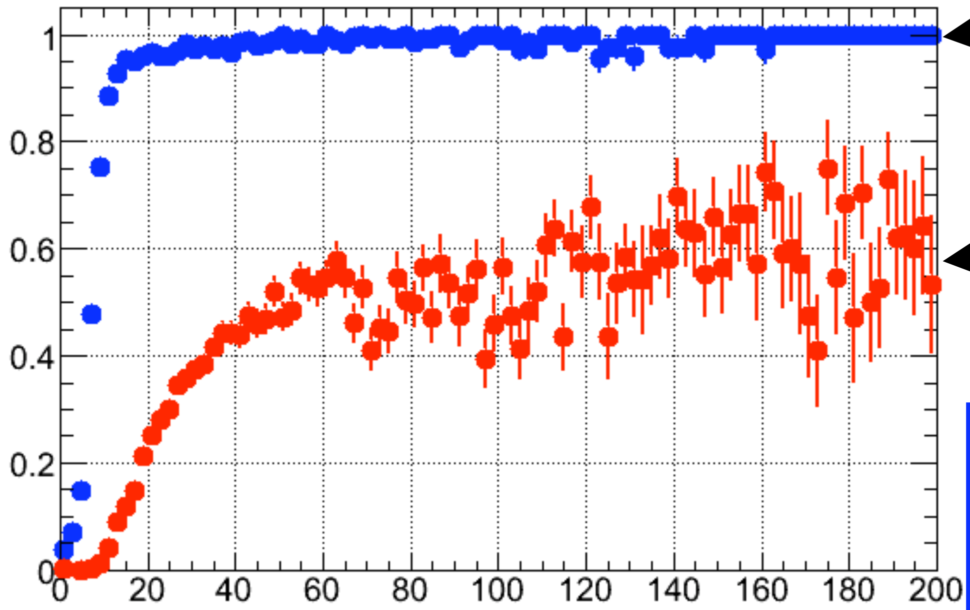



Figure 12: Left: The log likelihood (LLH) distribution for τ leptons (solid) and jets from QCD production (dashed). The likelihood is applied after a preselection on the number of associated tracks, i.e. requiring $1 \leq N_{tr} \leq 3$. (Candidates with LLH $< -10$ had variables outside the boundaries of histograms used when obtaining the PDFs for the likelihood calculation). Right: Efficiency for τ leptons and rejection against jets for different $E_T$ ranges, achieved with the likelihood selection.

# Standard ATLAS tau reconstruction algorithm applied to mSUGRA co-annihilation events



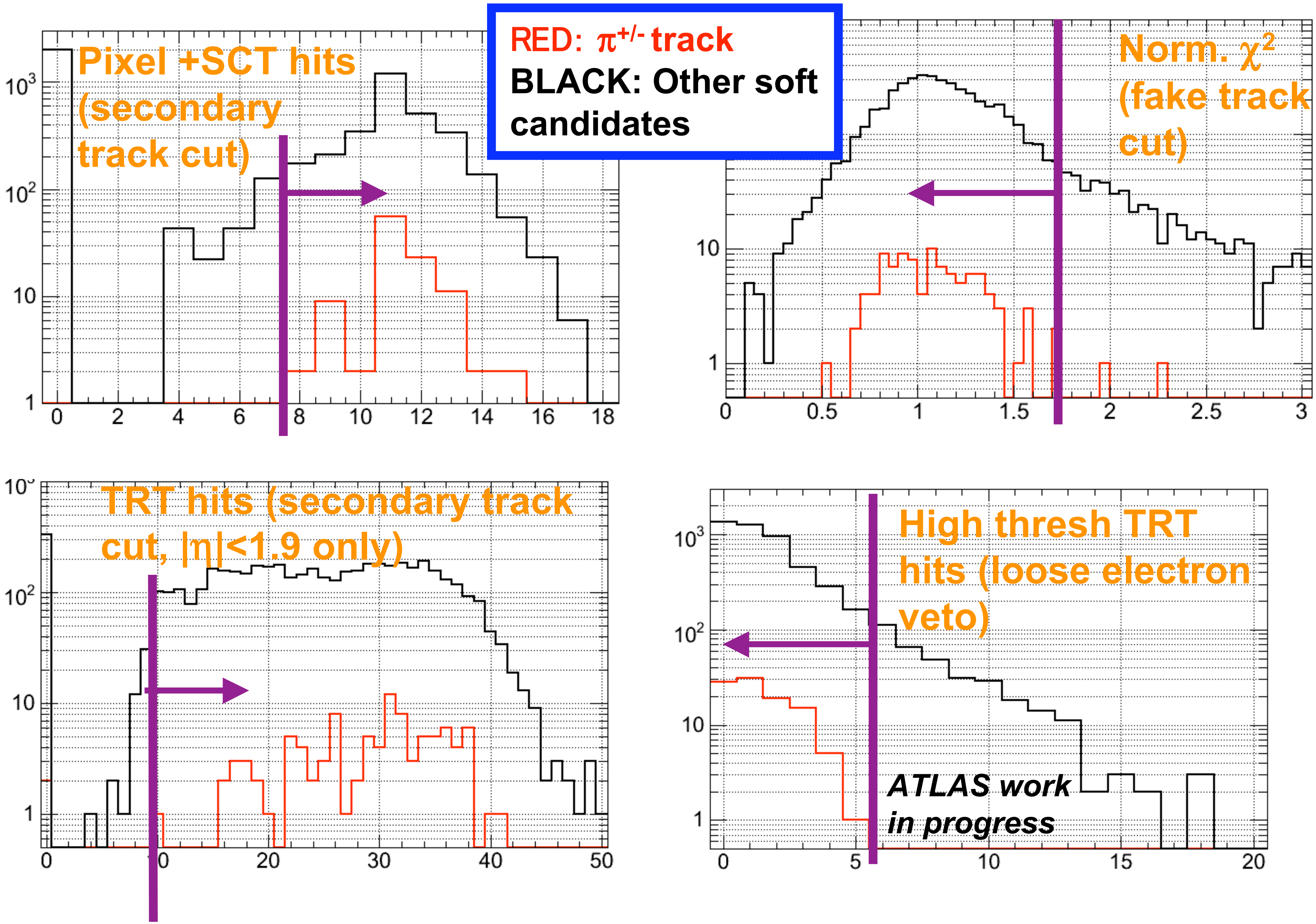

**RECONSTRUCTION EFF.**

**IDENTIFICATION EFF.**

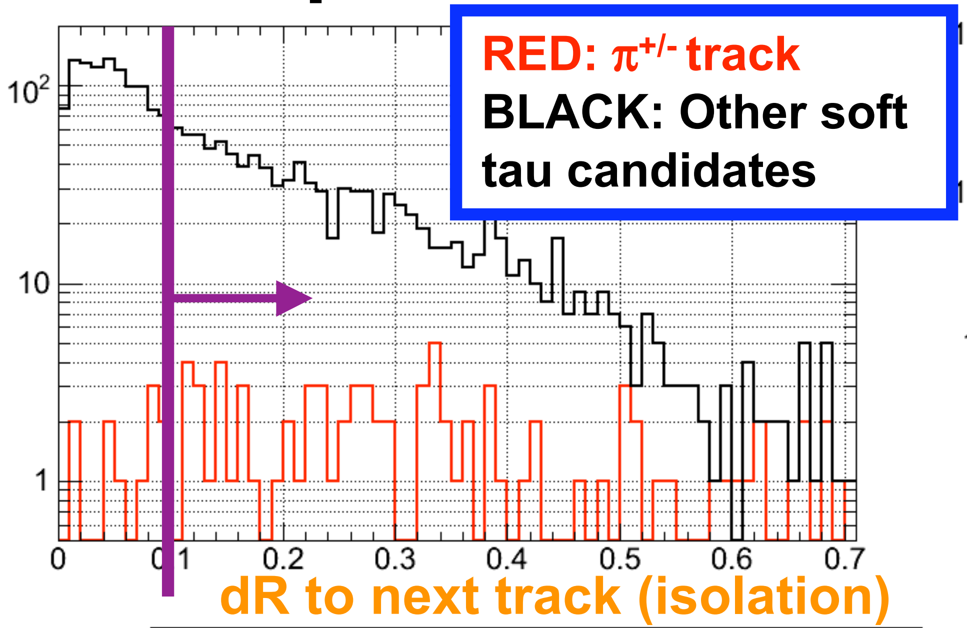
**Reconstructed == hadronic MC tau with |Eta|<2.5 matched to a reconstruction object within dR<0.2**

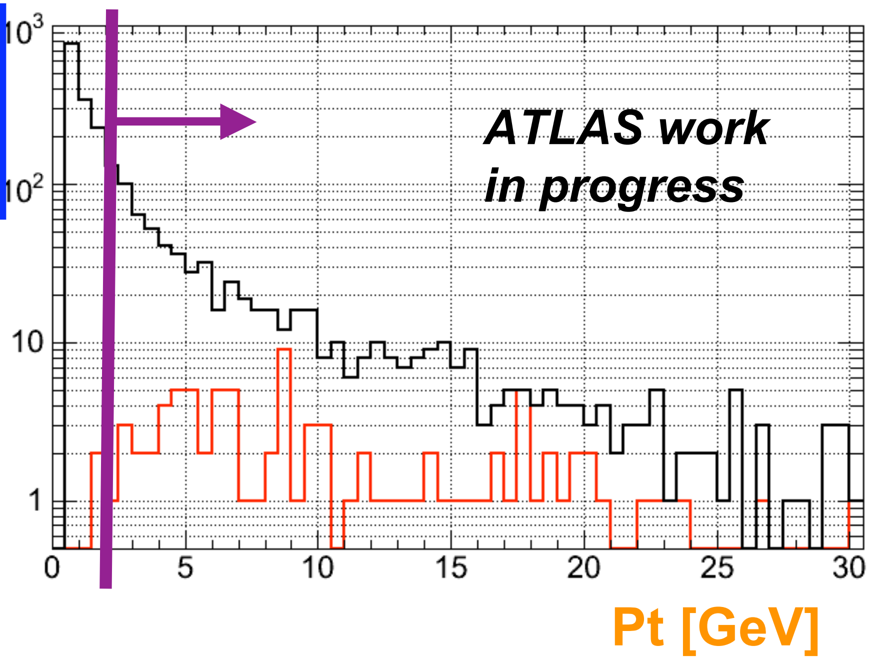
**Identified == Reconstructed + passes discrimination cut**

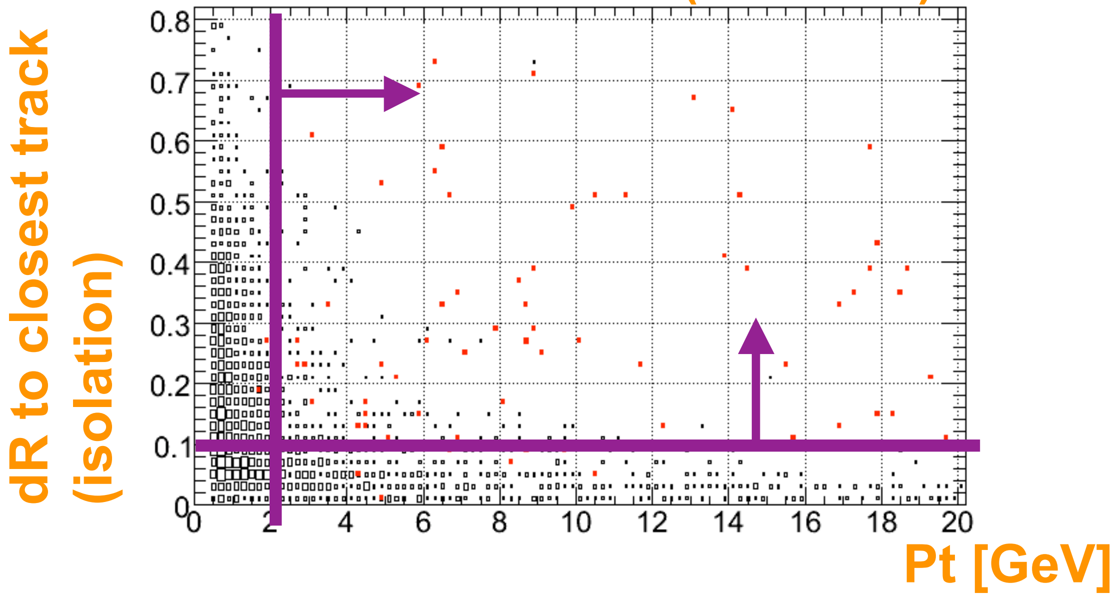
# Track quality cuts for soft tau search



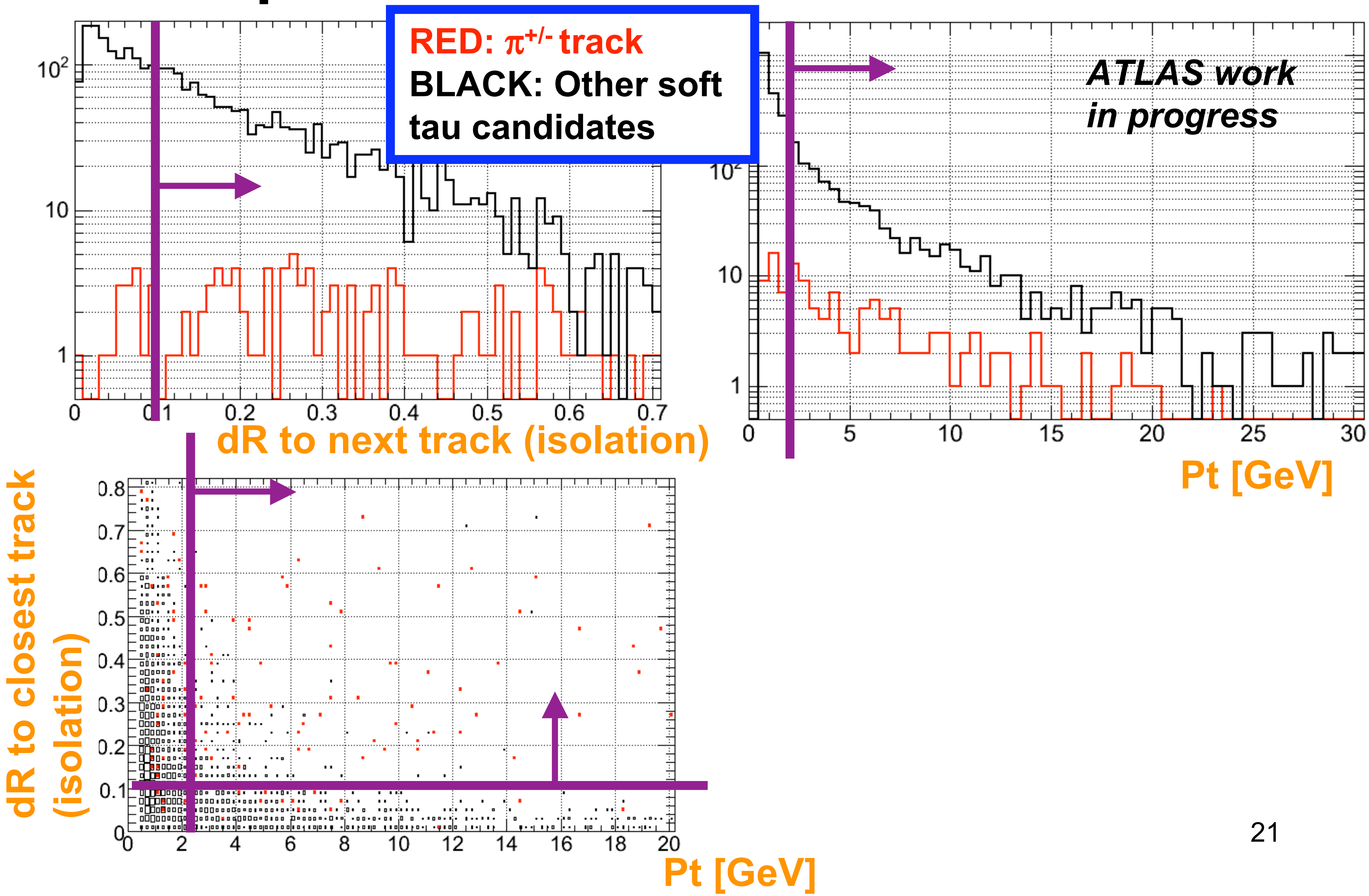
# Isolation and $P_T$ of $\pi^{+/-}$ from $\tau \rightarrow \pi^{+/-} + 0\pi^0$ compared to other soft tau candidates



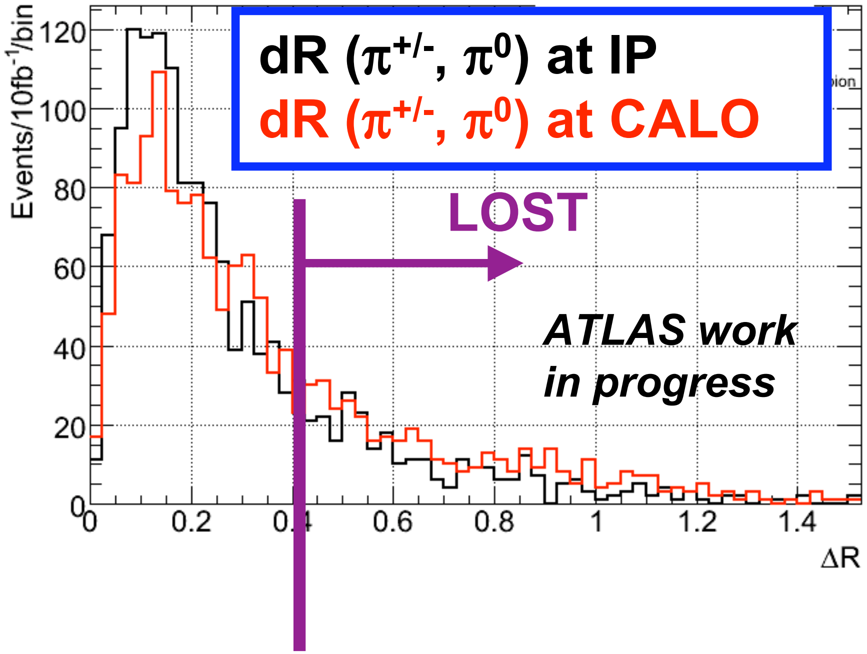



# Isolation and $P_T$ of $\pi^{+/-}$ from $\tau \rightarrow \pi^{+/-} + 1\pi^0$ compared to other soft tau candidates

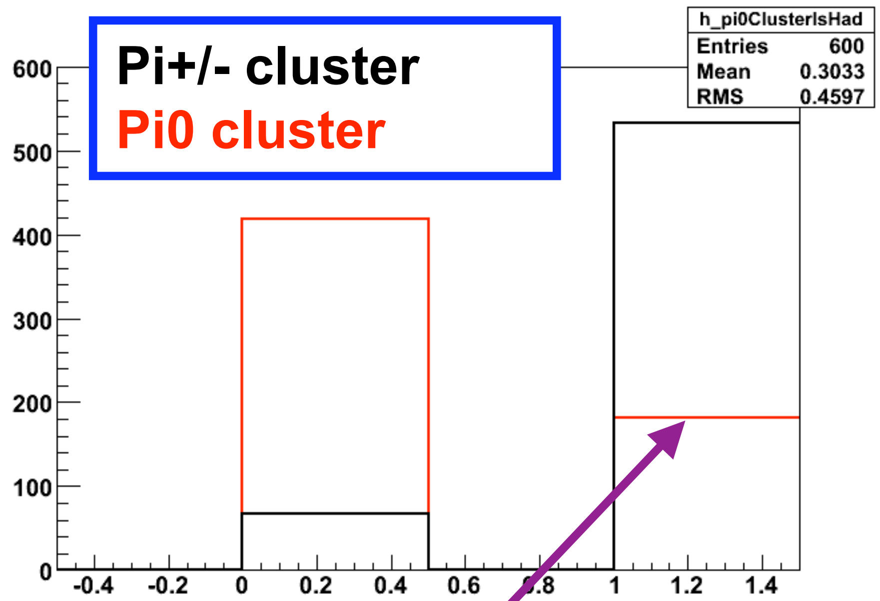


# $\tau \rightarrow \pi^{+/-} + 1\pi^0$ mode: loss of $\pi^0$ cluster in algorithm

The ATLAS topological clustering algorithm uses clusters shape to classify clusters as either EM or hadronic




$\pi^0$ too far from $\pi^{+/-}$ get lost by algorithm




Classified as EM

Classified as hadronic

30% of $\pi^0$ clusters are classified as hadronic

# Source of taus in mSUGRA co-annihilation region (MC Truth)

| | | No Pt cut | Pt>40 |
|---|---|---|---|
| 1 | W1SS->tau | 30% | 16.3% |
| 2 | W1SS->Stau1->tau | 24% | 2.0% |
| 3 | W1SS->Stau2->tau | 1.2% | 4.4% |
| 4 | W1SS->W->tau | 1.1% | 2.5% |
| 5 | Chi^0_2->tau ****SIGNAL**** | 12% | 40% |
| 6 | +Stau1->tau | 12% | 1.1% |
| 7 | Chi^0_2->tau | 1.0% | 3.6% |
| 8 | +Stau2->tau | 1.0% | 0 |
| 9 | W->tau (other than 4) | 6.5% | 13% |
| 10 | Z->tau | 0.4% | 1.0% |
| 11 | B->tau | 6.1% | 3.5% |
| 0 | Other sources | 4.7% | 10.7% |

# Effect of Pt cut on $dR_{tau,tau}$ and $M_{tau,tau}$