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

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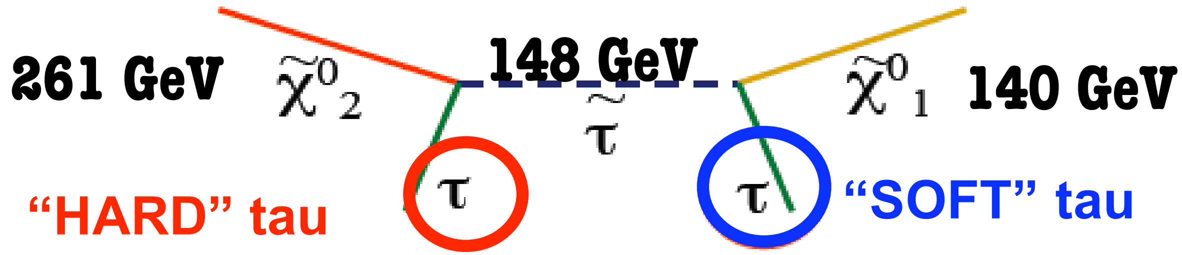
Outline

- Introduction of mSUGRA co-annihilation region and the di-tau decay chain we are studying.
- Tau reconstruction and the poor performance of the current standard ATLAS tau reconstruction algorithm for our analysis.
- A new algorithm for selecting the di-tau event.
- A new likelihood method used to find a very soft tau in the event.
- Performance of the algorithm and likelihood method

Motivation: co-annihilation region di-tau decay chain

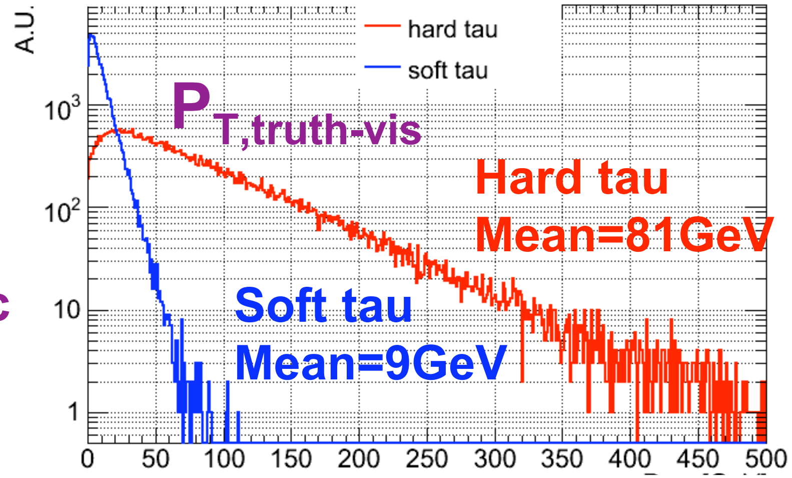


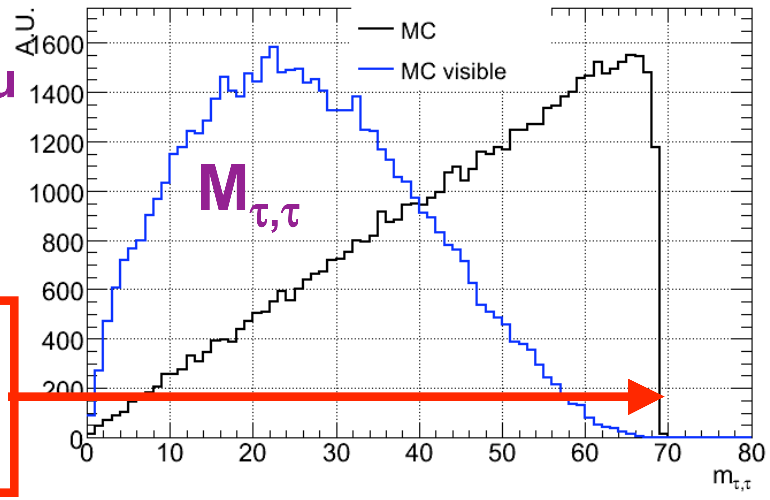
- In the co-annihilation region, the near degeneracy of the lightest stau and chi1 allow for their co-annihilation in the early universe, which makes the chi1 a good candidate for explaining the measured relic DM density.

- Δm(stau, chi1)~8GeV ➔ very soft tau from stau decay

- Ultimately we wish to reconstruct the di-tau invariant mass endpoint which is sensitive to the masses of the particles in the decay chain.

$$M_{ll}^{\max} = M(\tilde{\chi}_2^0)\sqrt{1-\frac{M^2(\tilde{l}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1-\frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{l}_R)}} = 69\text{GeV}$$

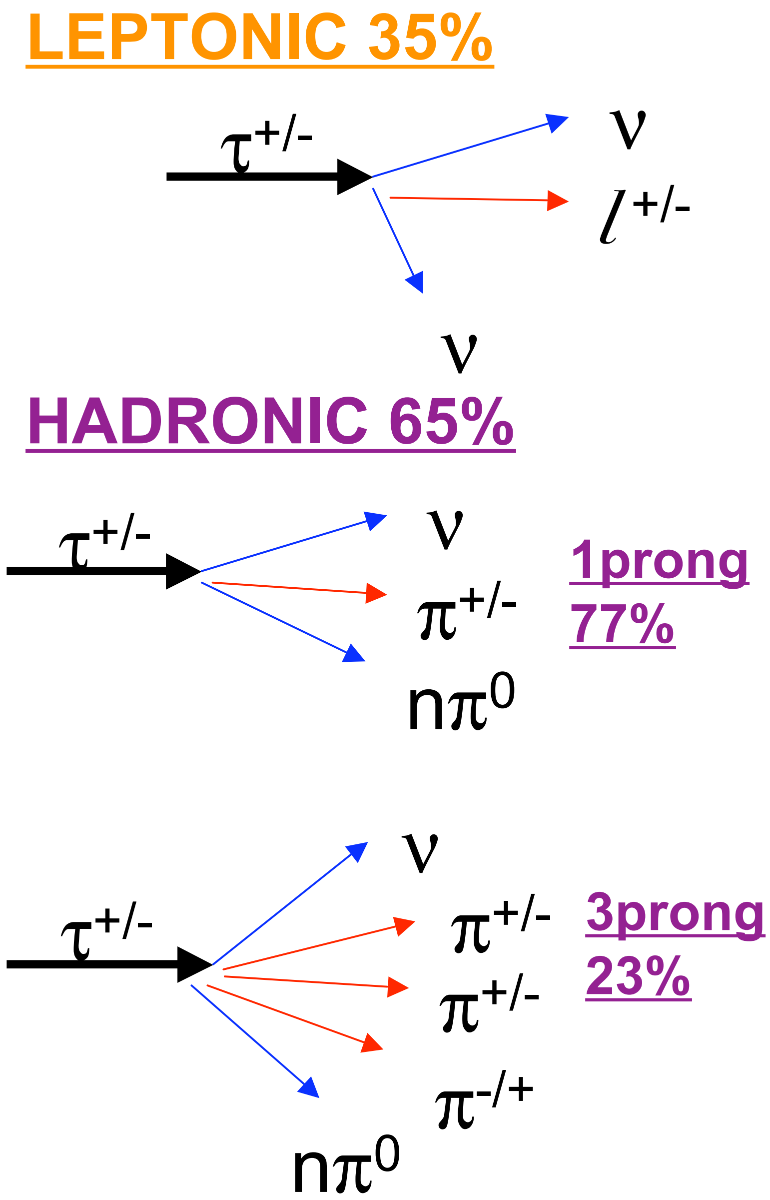




Simulation Parameters

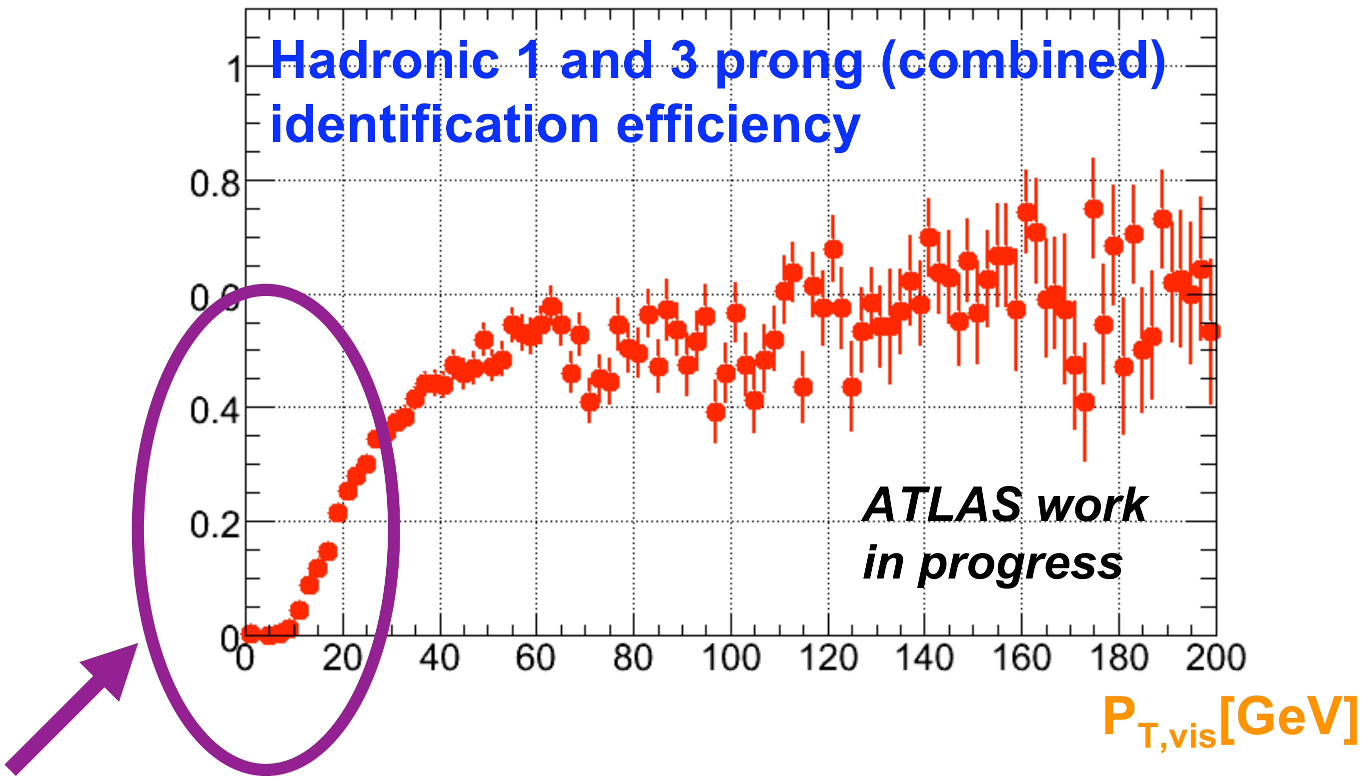
- **Full simulation of events in ATLAS detector based on Geant4 is used with C.O.M energy of 10TeV.**
- **SIGNAL: ATLAS co-annihilation region reference point:**
  - m_0 = 70GeV — Gluino = 829 GeV
  - $m_{1/2}$ = 350GeV — Squark ~ 750 GeV
  - A_0 = 0 — Chi2 = 261 GeV
  - tan(β) = 10 — Stau1 =148 GeV
  - μ > 0 — Chi1 = 140GeV
- **BACKGROUND (for tau reconstruction): QCD samples produced with PYTHIA**

Tau identification



- 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 co-annihilation region



•Standard ATLAS tau reconstruction algorithm is seeded by either a P_T>6GeV track, or a E_T>10GeV calorimeter jet.

•Our “soft” tau is P_T~9GeV ➔ the standard ATLAS algorithm will not reconstruct the $M_{\tau,\tau}$ distribution efficiently.

Thus we are motivated to look for a new way to tag out “soft” tau.

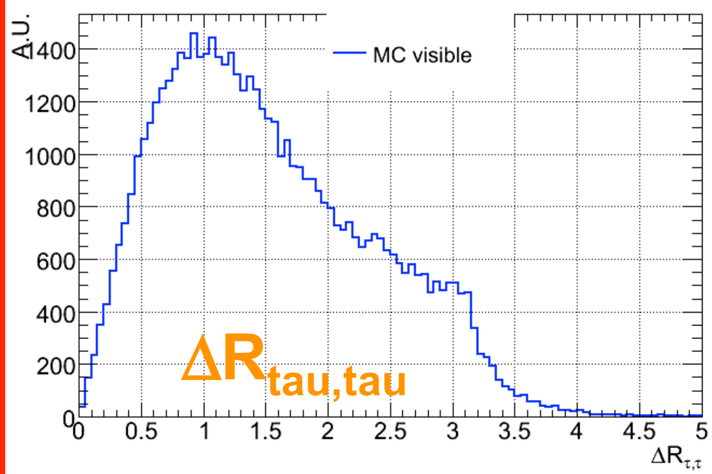
Lowering the threshold for soft tau ID in the co-annihilation region

- <u>TAU INFORMATION</u>
  - We focus on efficiently reconstructing 5GeV < $P_{T,vis}$ < 10GeV "soft" taus
  - We search only for hadronic single prong modes.
  - We use low P_T tracks as seeds.
  - Soft taus → pi0 clusters are identifiable. These can be used to improve discrimination.

Soft tau modes we will study:

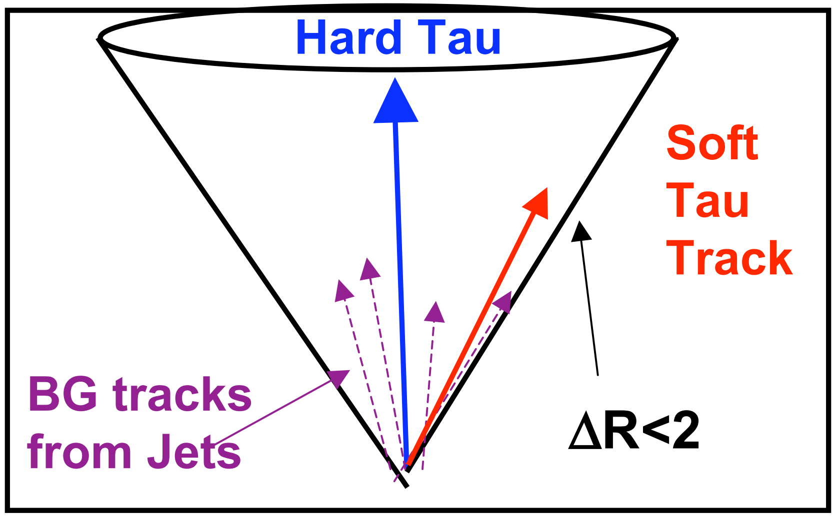
1. $\tau \rightarrow \pi^{+/-} + 0\pi^0$ (10.9%)
2. $\tau \rightarrow \pi^{+/-} + 1\pi^0$ (25.5%)
3. $\tau \rightarrow \pi^{+/-} + 2\pi^0$ (9.3%)

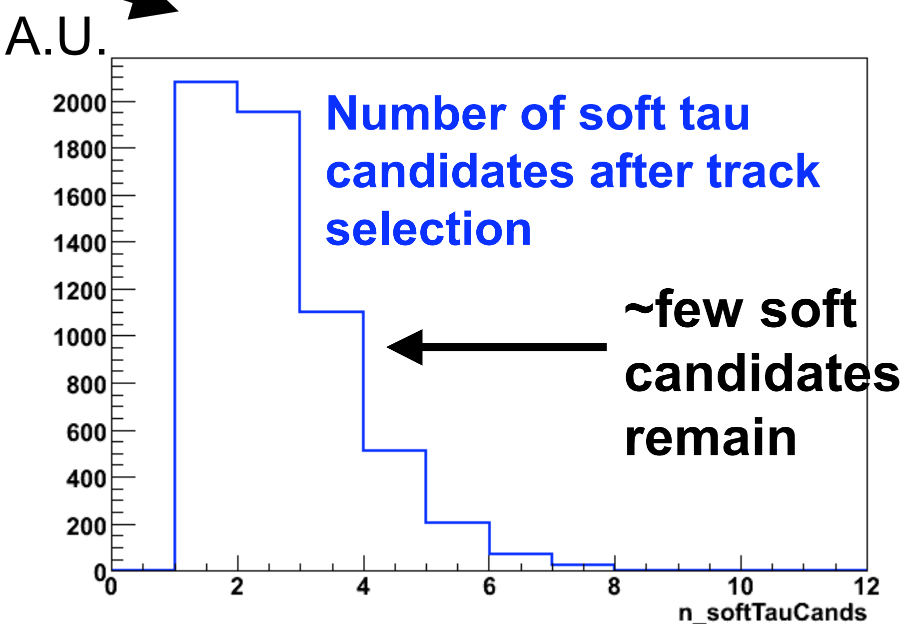
- <u>CO-ANNIHILATION REGION INFORMATION</u>
  - Event contains a hard tau
  - Soft tau is somewhat confined around the hard tau → *we can confine the search area*
  - Finally, the sign of the 2 taus are opposite which we can use to cancel the BG from the $M_{\tau,\tau}$ distribution (OS-SS method)



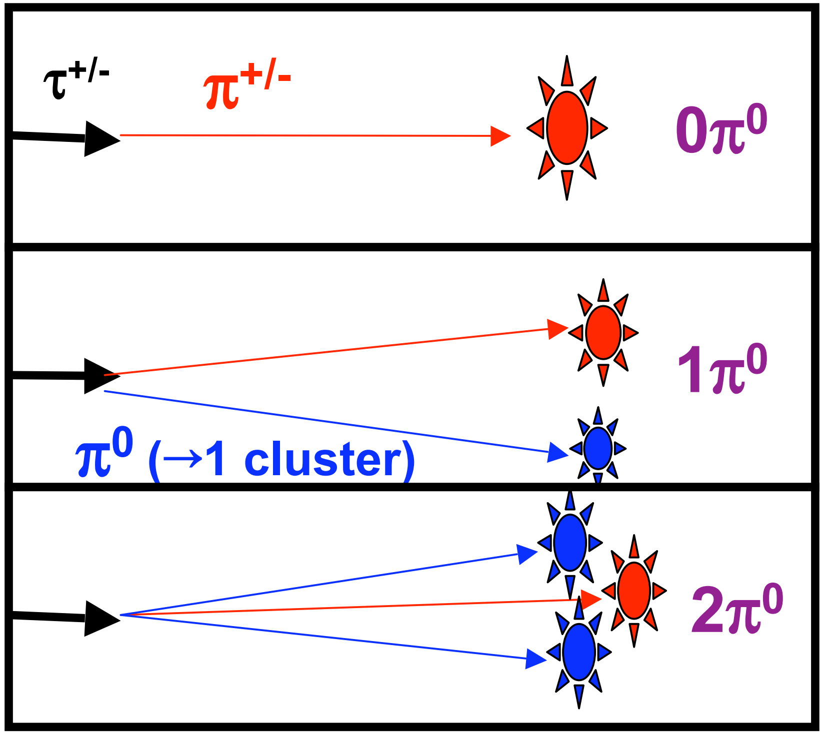
Soft tau candidate search algorithm

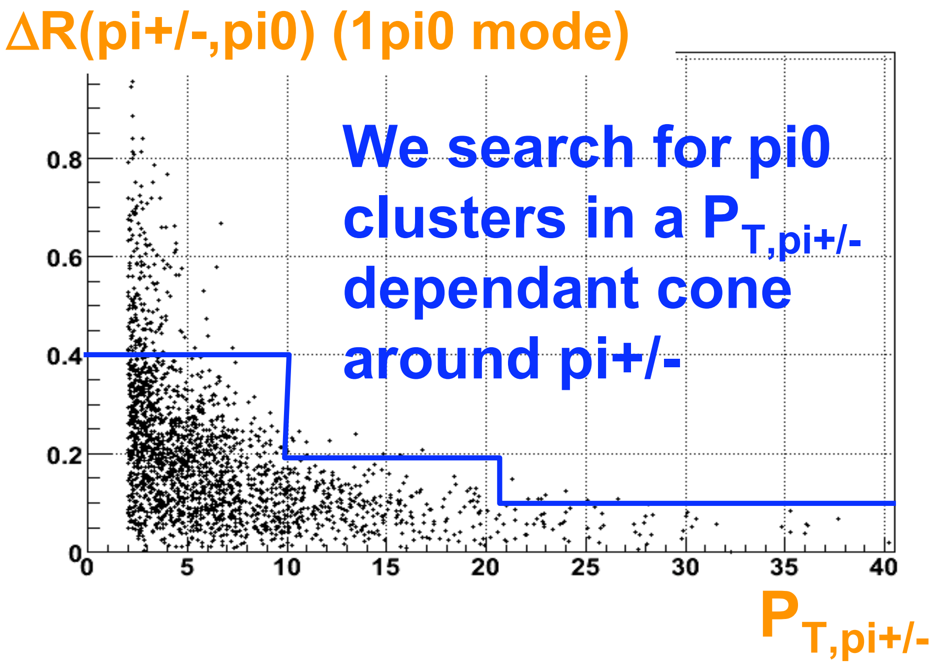
1. Select "hard tau candidates"with P_T>40GeV using standard ATLAS algorithm.
2. Collect all good quality tracks within ΔR<2 of the hard tau candidate (call these "soft tau candidates") .
3. Apply P_T>2GeV and track counting isolation (no tracks in ΔR<0.2) cuts on soft candidates.
4. Search for EM-like clusters around track. Classify candidates according to # EM-like clusters.
5. Apply a likelihood to choose the most tau-like candidate and discrimate against fake candidates.





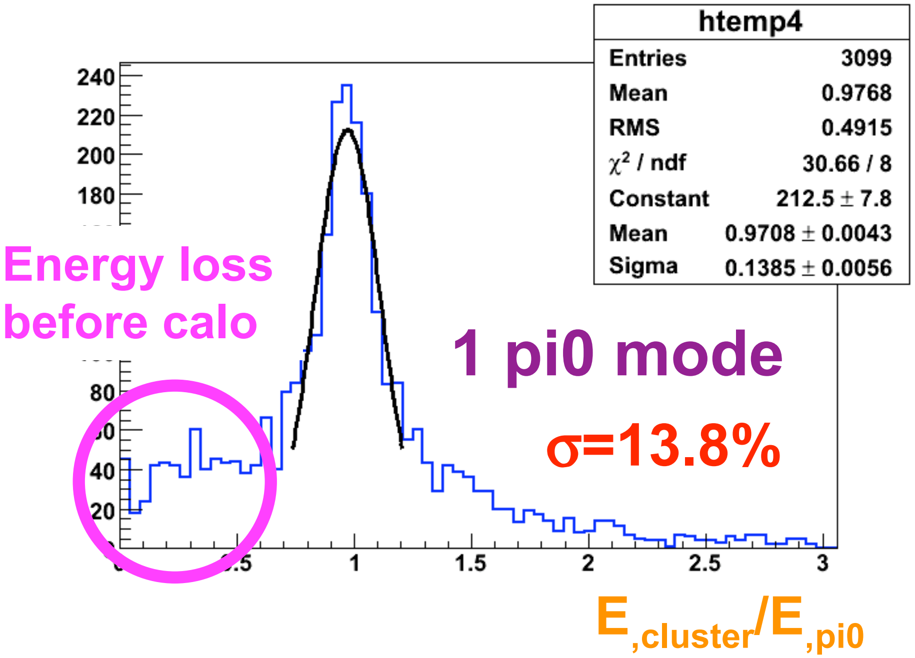
Pi0 Cluster search algorithm

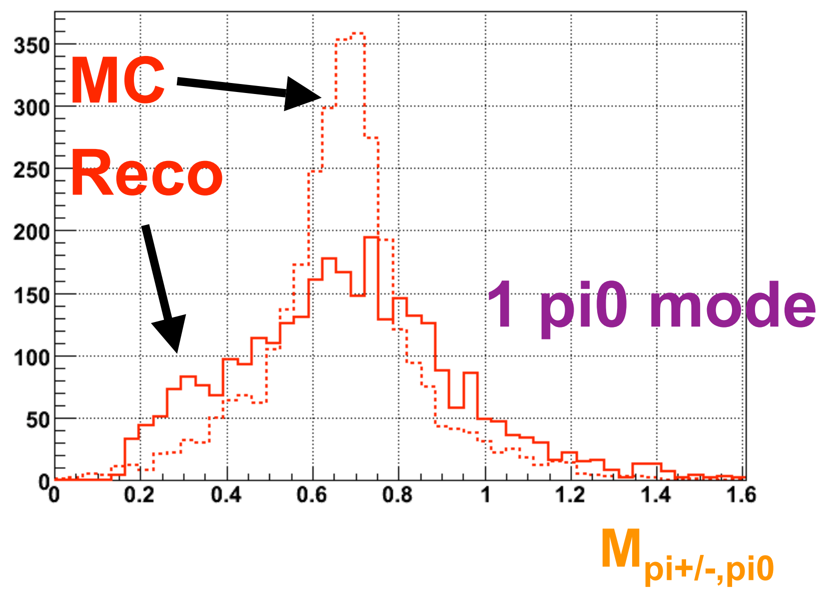




- Standard ATLAS algorithm searches for pi0 clusters within a cone of ΔR<0.2 of pi+/- track after subtracting pi+/- cells from calorimeter.
- For soft taus, the distance of pi0s from pi+/- highly dependant on $P_{T,tau}$, and is often >0.2, so we use a $P_{T,pi+/-}$ dependant search cone around the pi+/-.
- Since pi+/- and pi0 are well separated at low P_T, we do not use cell subtraction, but simply look for "EM-like" clusters around the pi+/- cluster.

Pi0 cluster search algorithm performance

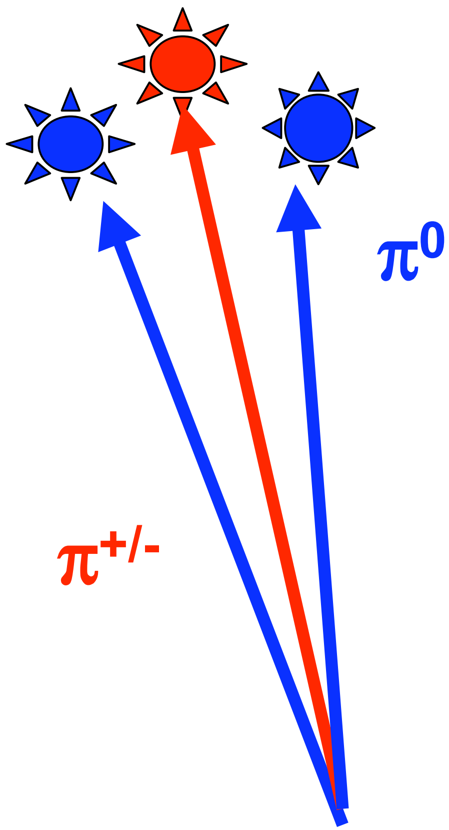




•OUR ALGORITHM (STANDARD ATLAS ALGORITHM) 5GeV<$P_{T,vis}$<10GeV	0 EM clusters	1 EM clusters	2 EM clusters	>2 EM clusters
$\tau \rightarrow \pi^{+/-} + 0\pi^0$	54% (74%)	30% (19%)	10% (2%)	7% (0)
$\tau \rightarrow \pi^{+/-} + 1\pi^0$	32% (33%)	36% (15%)	19% (3%)	13% (1%)
$\tau \rightarrow \pi^{+/-} + 2\pi^0$	19% (14%)	33% (10%)	25% (2%)	23% (1%)
Background (QCD)	41% (13%)	30% (3%)	18% (0)	11% (0)

Standard ATLAS algorithm classifications don't add to 100% because only track seed algorithm has a pi0 search algorithm.

Discriminating against QCD jets



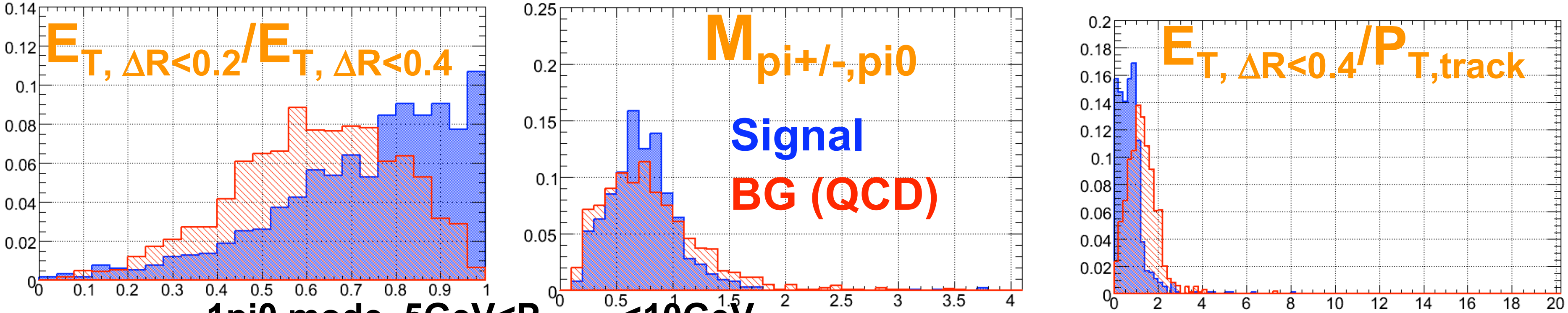
•Single prong tau jets consist of a single pi+/- and 0~2 pi0s.

•We exploit a number of tau characteristics to create a likelihood variable to use for discrimination against QCD:

- •Narrow jet shape (calorimeter isolation, energy spread in calorimeter).
- •Pi0 cluster characteristics ($M_{pi+/-,pi0}$, $\Delta R_{pi+/-,pi0}$)
- •Finite decay length of tau ($c\tau = 87\ \mu m$)
- •Relative large fraction of energy carried by track.

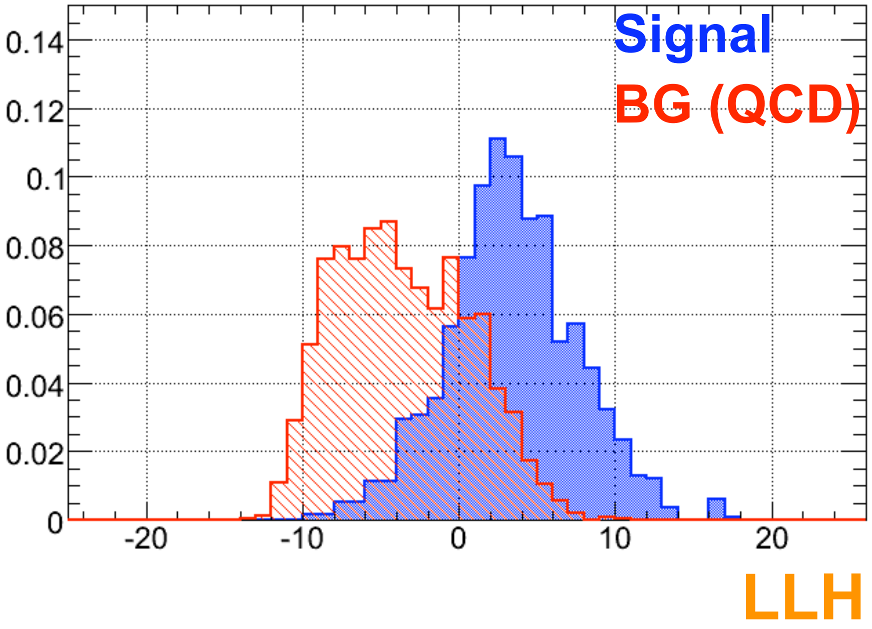
•For calculation of “narrowness” variables, and when comparing the track energy with calorimeter energy, we first subtract the pi0 clusters, thus essentially only looking at the pi+/- energy for these cases.

Creating the likelihood variable



1pi0 mode, 5GeV<$P_{T,track}$<10GeV

+…



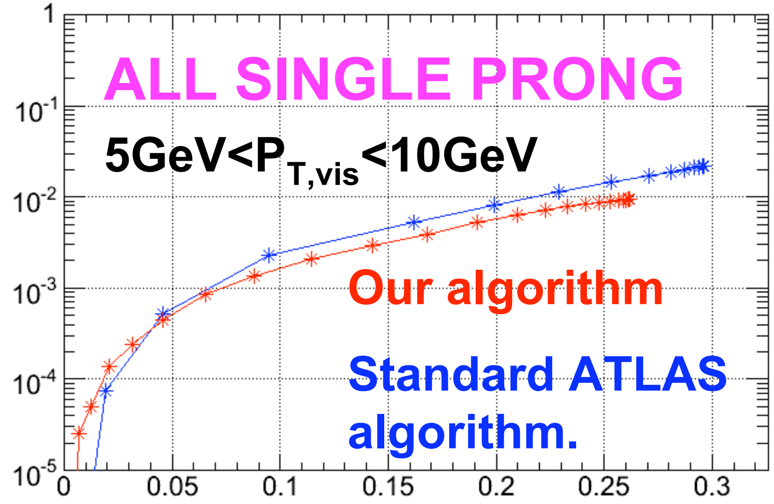
In total we use 9~13 variables to discriminate soft taus from BG (depending on classification). See backup for details.

$$d' = -\ln\left(\frac{1}{d} - 1\right) = \sum_{k=1}^{nVars} \ln \frac{p_k^{S}(x_k)}{p_k^{B}(x_k)}$$

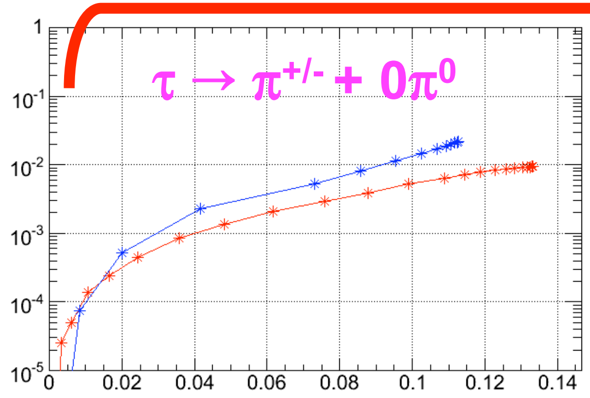
Likelihood performance

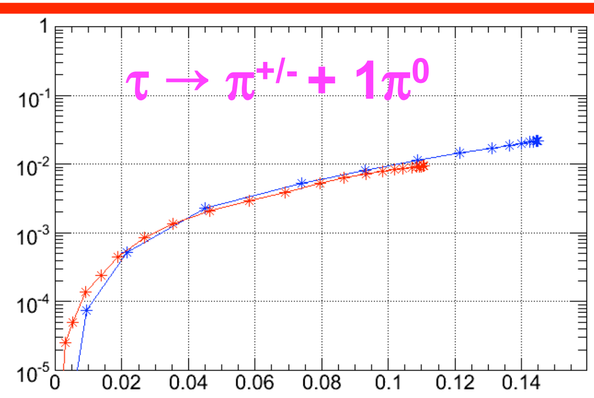
- We compare the performance of our likelihood variable against that of the standard ATLAS algorithm for general soft tau discrimination (no hard tau requirement).
- We achieve about the same efficiency as the standard ATLAS algorithm when we make a track cut of P_T>5GeV, but our fake rate is better.
- We may use a lower P_T cut on the track to increase efficiency, but we need to study the amount of BG this will introduce.

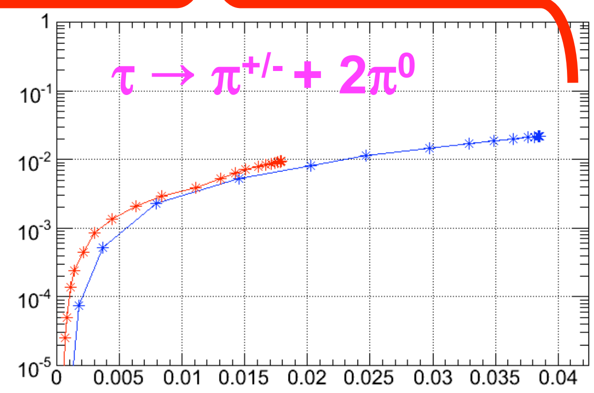
Fake rate (QCD)



Efficiency (/all hadronic taus)

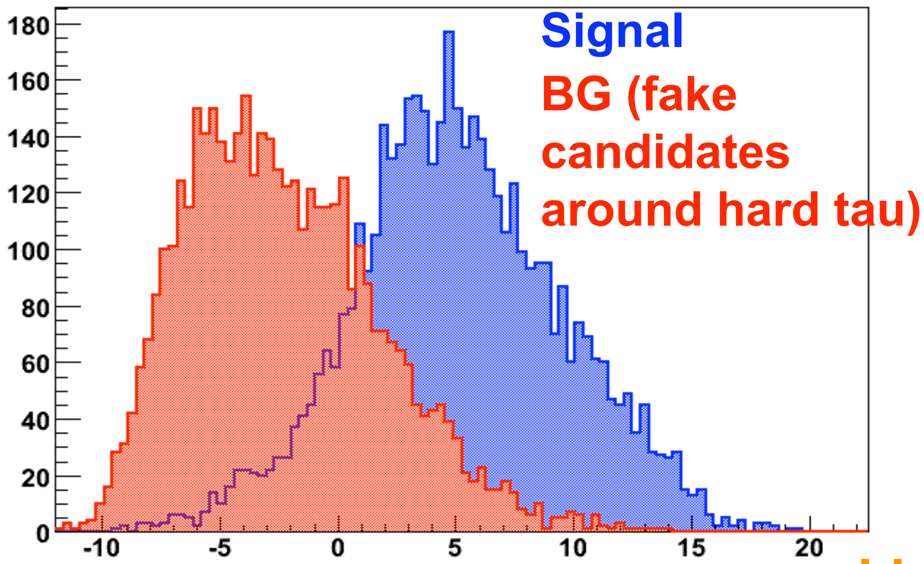






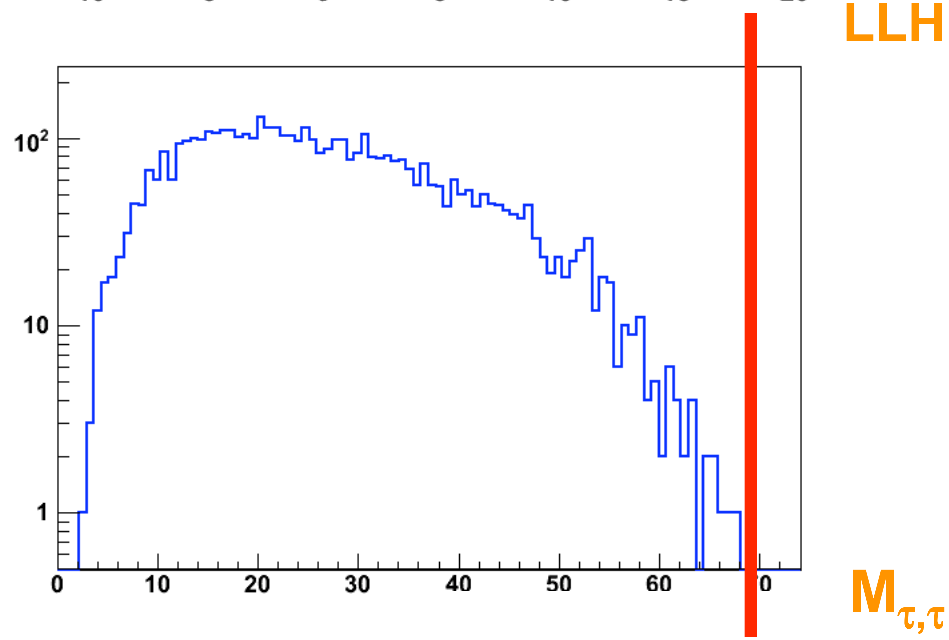
Applying the likelihood to the soft tau search algorithm

- **After applying the soft tau search algorithm (with 2GeV track cut) the signal soft tau is the most tau-like candidate around the hard tau 78% of the time.**



- **Finally, we construct the $M_{\tau,\tau}$ distribution from the reconstructed hard tau and the signal soft tau track.**

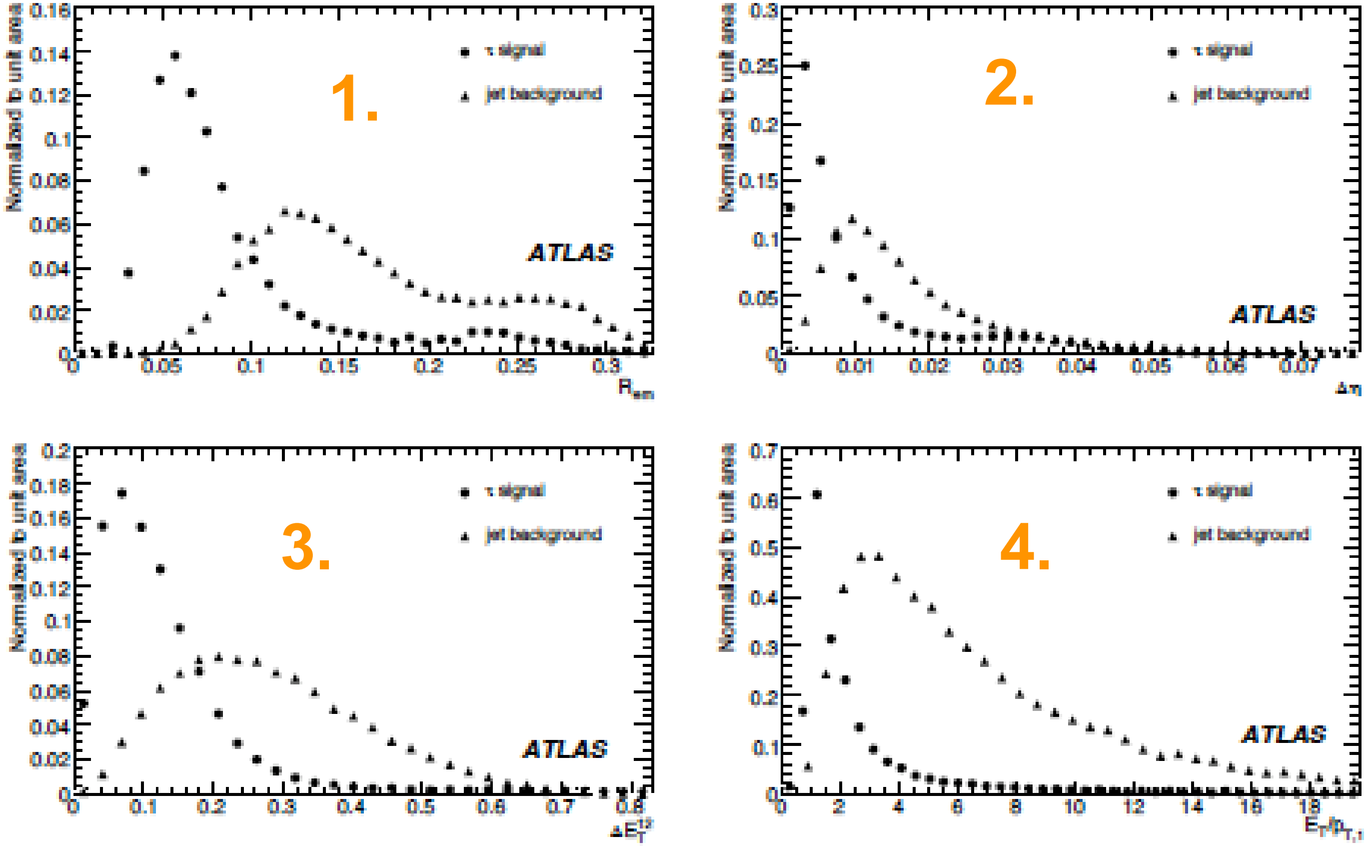
- **We are currently working on correctly reconstructing the energy of the soft tau which will improve the endpoint of the $M_{\tau,\tau}$ distribution.**



Summary

- We are studying a particular di-tau decay chain in the mSUGRA co-annihilation region. This region provides a very good dark matter candidate particle (chi1).
- The mass difference between the LSP and the NLSP in this region is very small which results in one of the taus in the chain being very soft (~9GeV).
- The present ATLAS tau reconstruction algorithm performs poorly for P_T<10GeV and so we are motivated to find a new method for tagging this soft tau.
- We have developed a new algorithm for selecting the di-tau event, and a new likelihood for discriminating this very soft tau. The soft tau is correctly selected from around the hard tau 78% of the time.
- We expect that this type of analysis will be useful for other physics with di-tau chains, e.g. VBF H->tau,tau

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

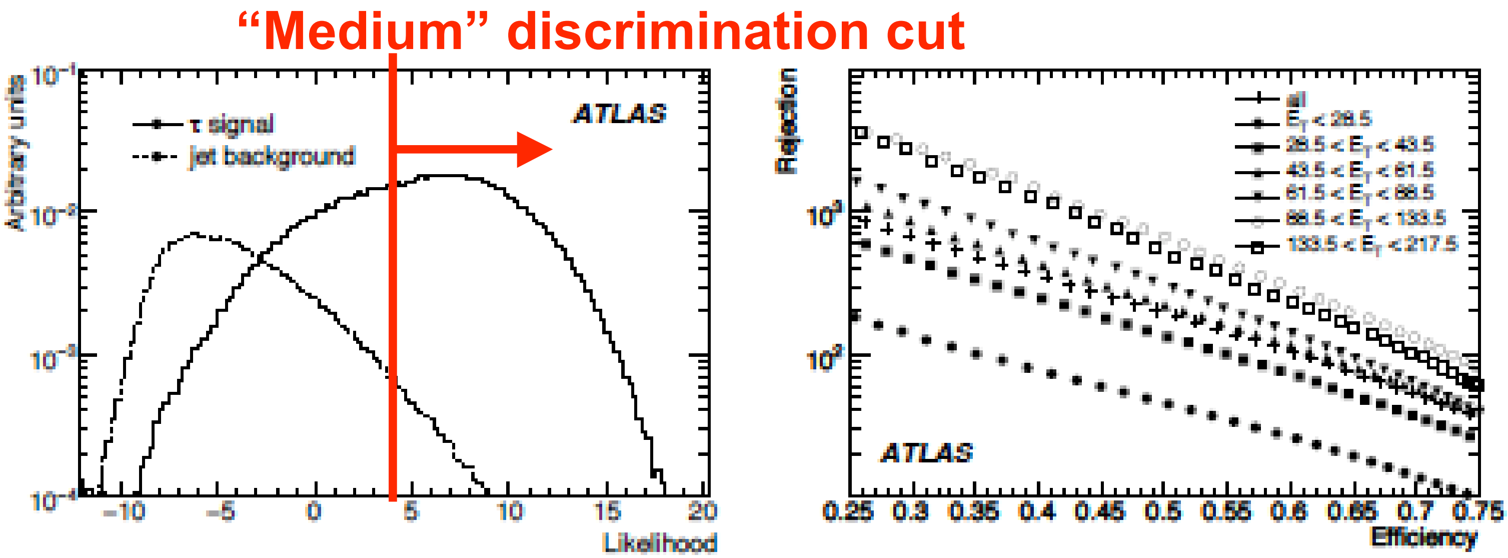
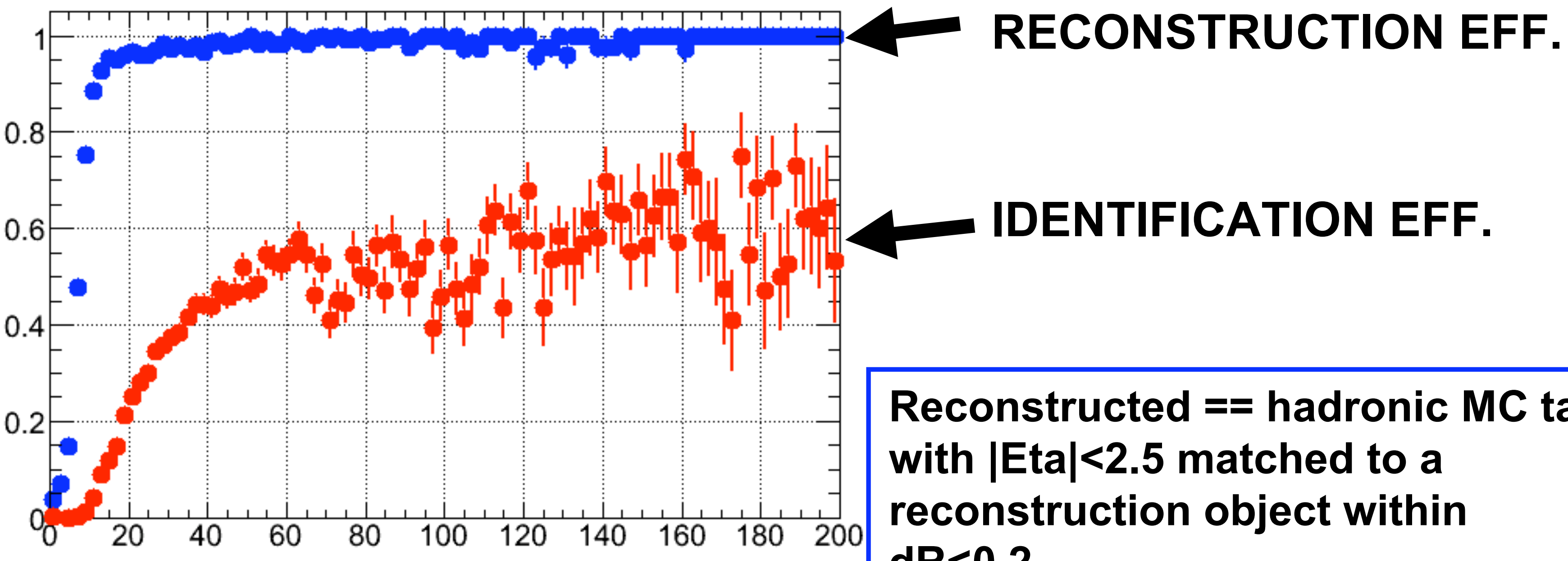


Figure 12: Left: The log likelihood (LLH) distribution for τ leptons (solid) and jets from QCD production (dashed). The likelihood is applied after a preselection on the number of associated tracks, i.e. requiring $1 \leq N_{tr} \leq 3$. (Candidates with LLH < -10 had variables outside the boundaries 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.

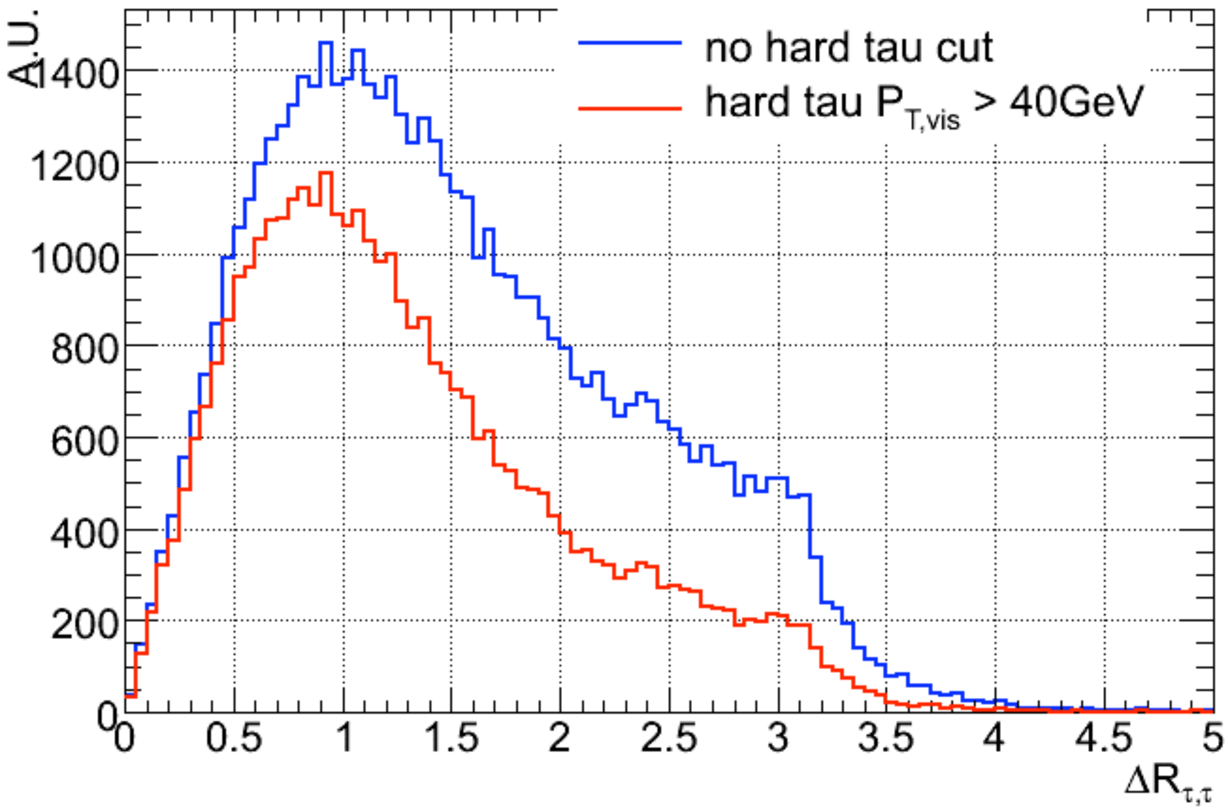
Standard ATLAS tau reconstruction algorithm applied to mSUGRA co-annihilation events



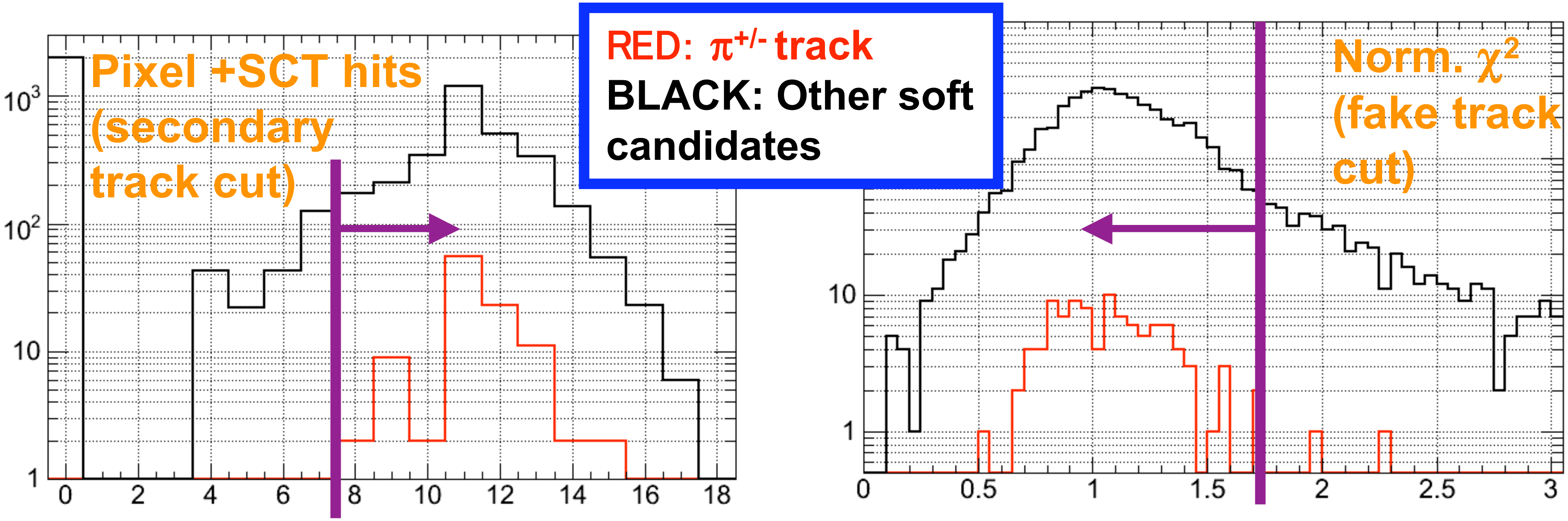
Reconstructed == hadronic MC tau with |Eta|<2.5 matched to a reconstruction object within dR<0.2

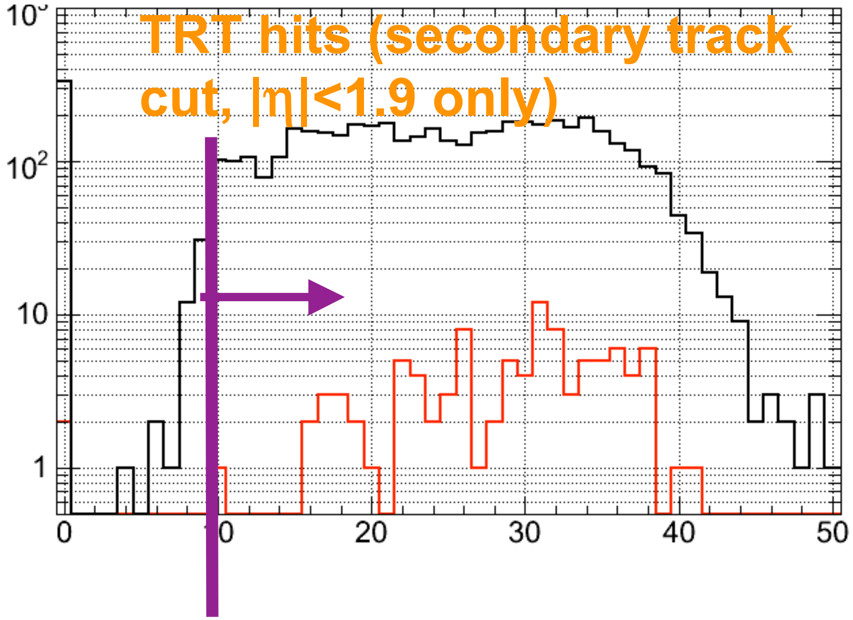
Identified == Reconstructed + passes discrimination cut

The effect of P_T>40GeV cut on $\Delta R_{tau,tau}$



Track quality cuts for soft tau search

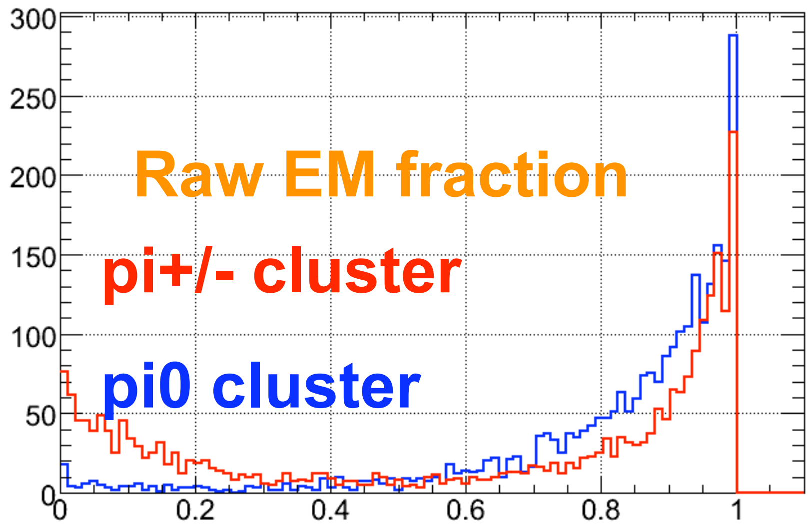


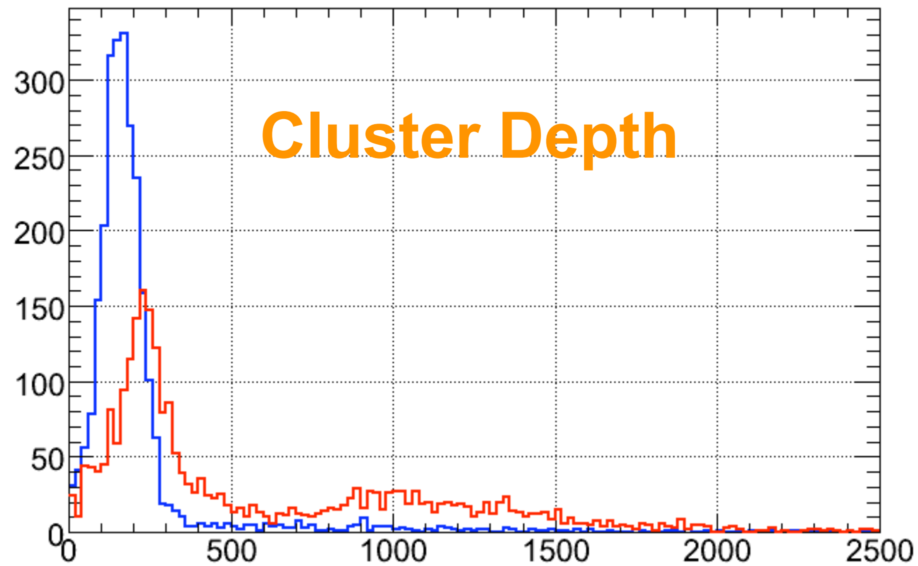


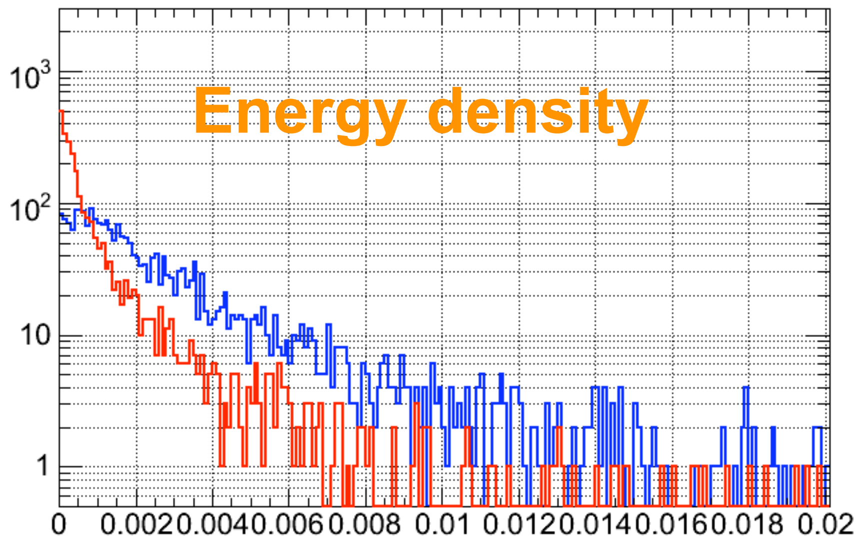
Also require that d0<1mm

ATLAS work in progress

Some variables used for determining whether a cluster is “EM-like”



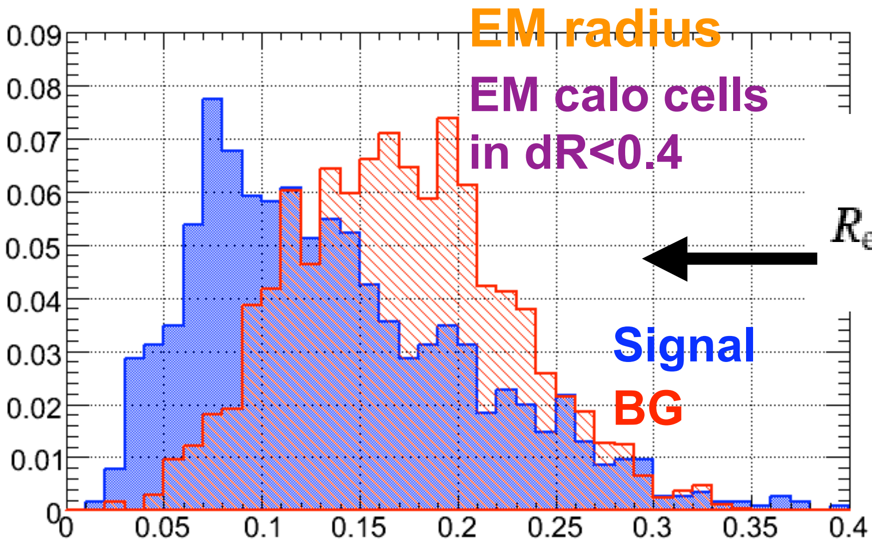




Official ATLAS cluster classification algorithm combines such variables with tracker energy loss corrections and out of cluster energy loss corrections to create a variable on which a cut is applied to determine “EM-like”ness.

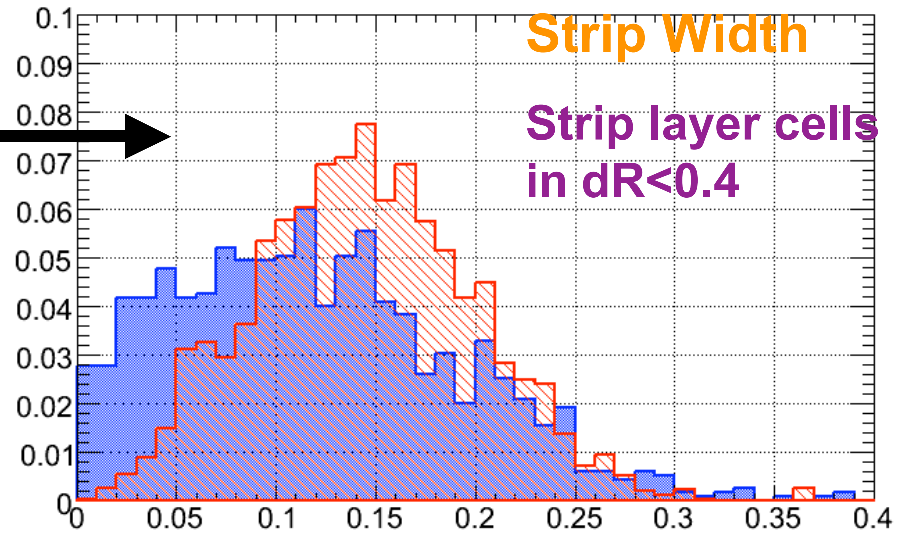
LLH variables for 1pi0 mode when 5GeV$<P_{T,track}<$10GeV

Calorimeter LLH Variables I

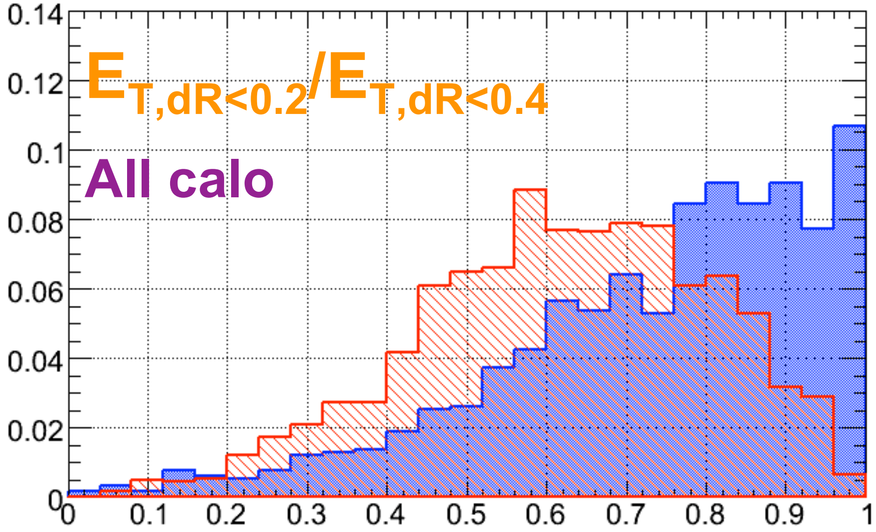


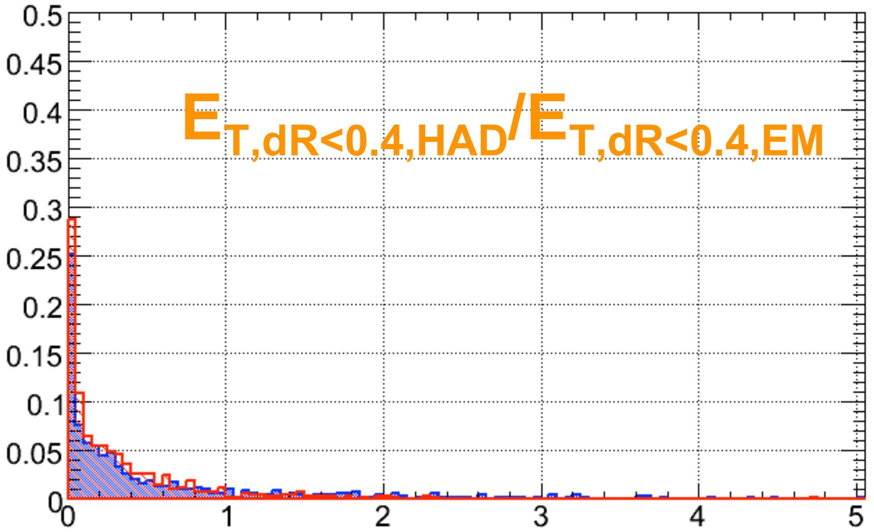
$$R_{\mathrm{em}} = \frac{\sum_{i=1}^{n} E_{T,i}\sqrt{(\eta_i - \eta_{\mathrm{Pi+/-}})^2 + (\phi_i - \phi_{\mathrm{Pi+/-}})^2}}{\sum_{i=1}^{n} E_{T,i}},$$

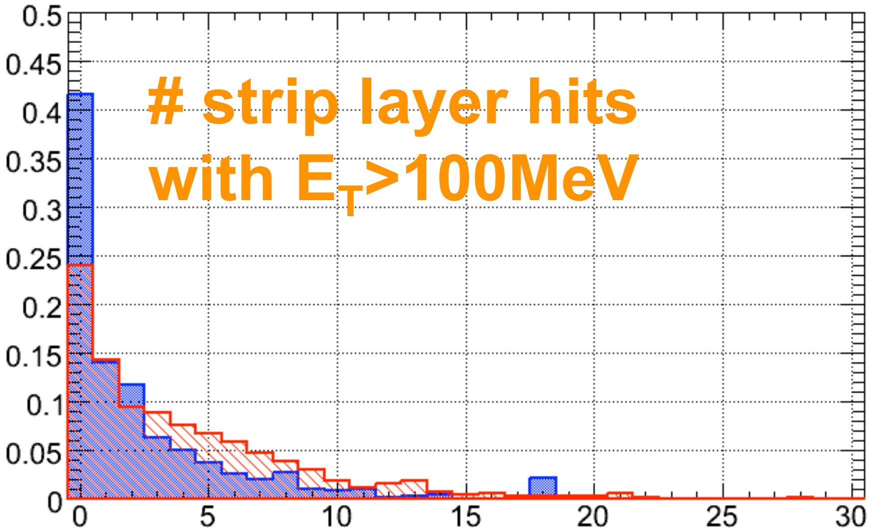
$$\Delta\eta = \sqrt{\frac{\sum_{i=1}^{n} E_{Ti}^{\mathrm{strip}}\,(\eta_i - \eta_{\mathrm{Pi+/-}})2}{\sum_{i=1}^{n} E_{Ti}^{\mathrm{strip}}}}.$$



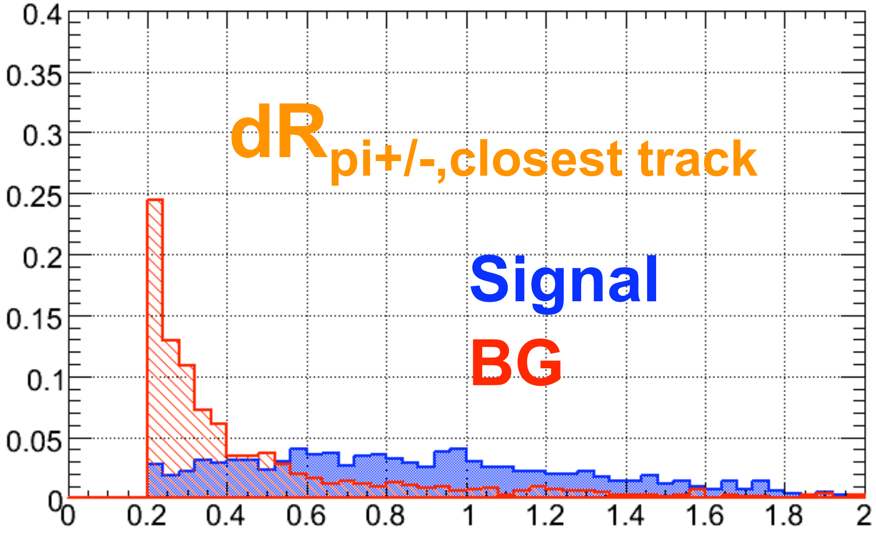
Calorimeter LLH Variables II

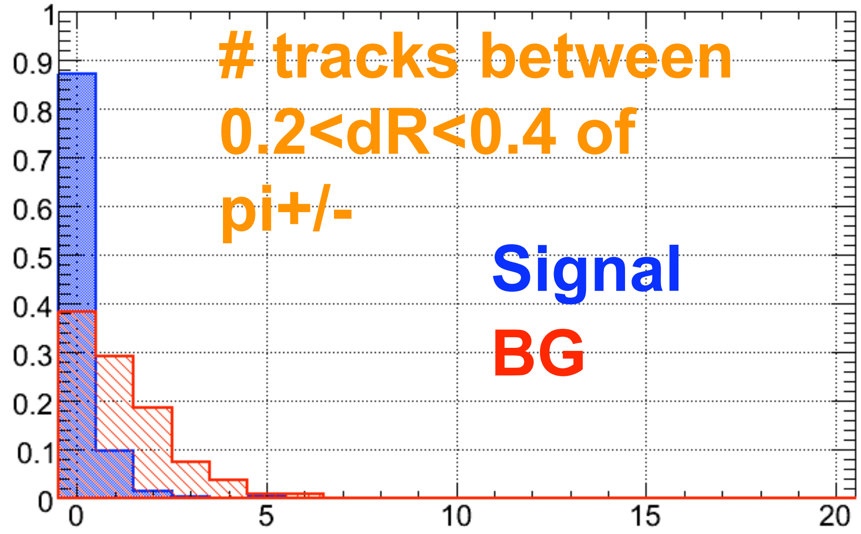


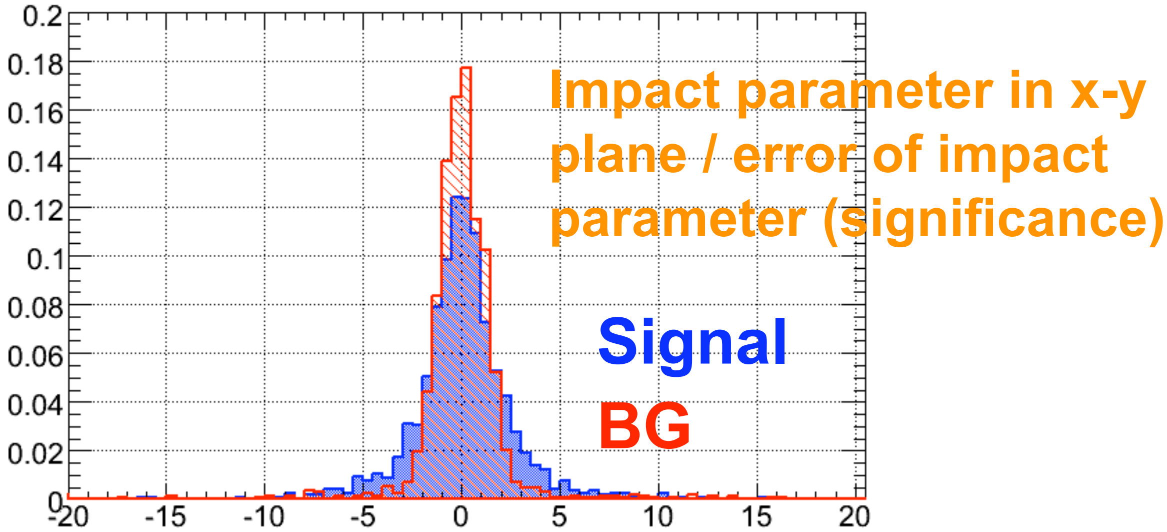




Track LLH Variables







Calorimeter + track LLH variables