Tau Reconstruction & Decay Mode Classification in ATLAS

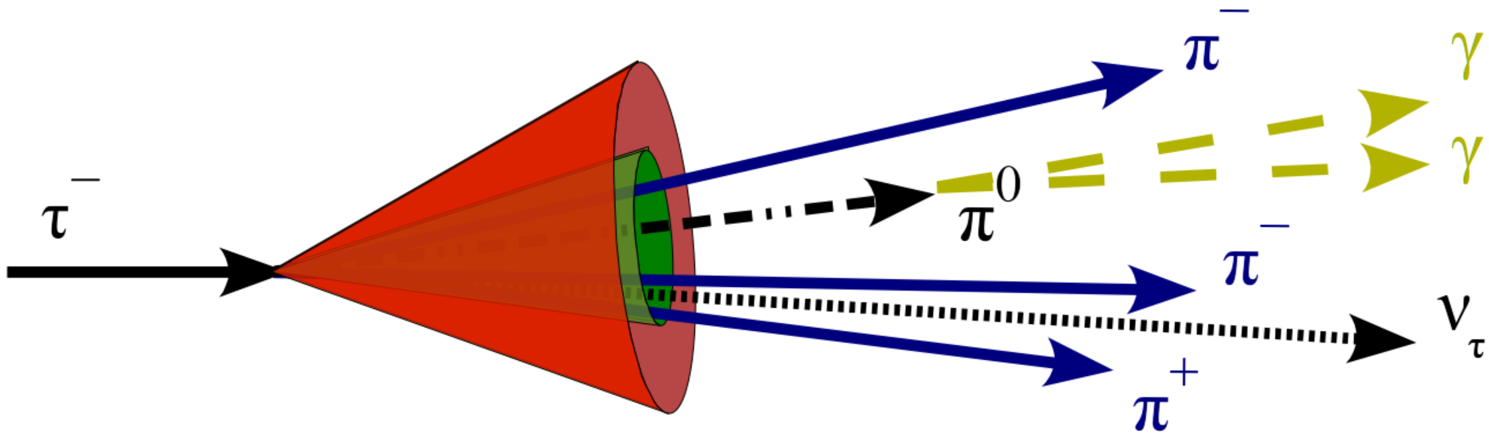
Christian Limbach

Bundesministerium für Bildung und Forschung

universitätbonn

FSP 101 ATLAS

Tau Decay



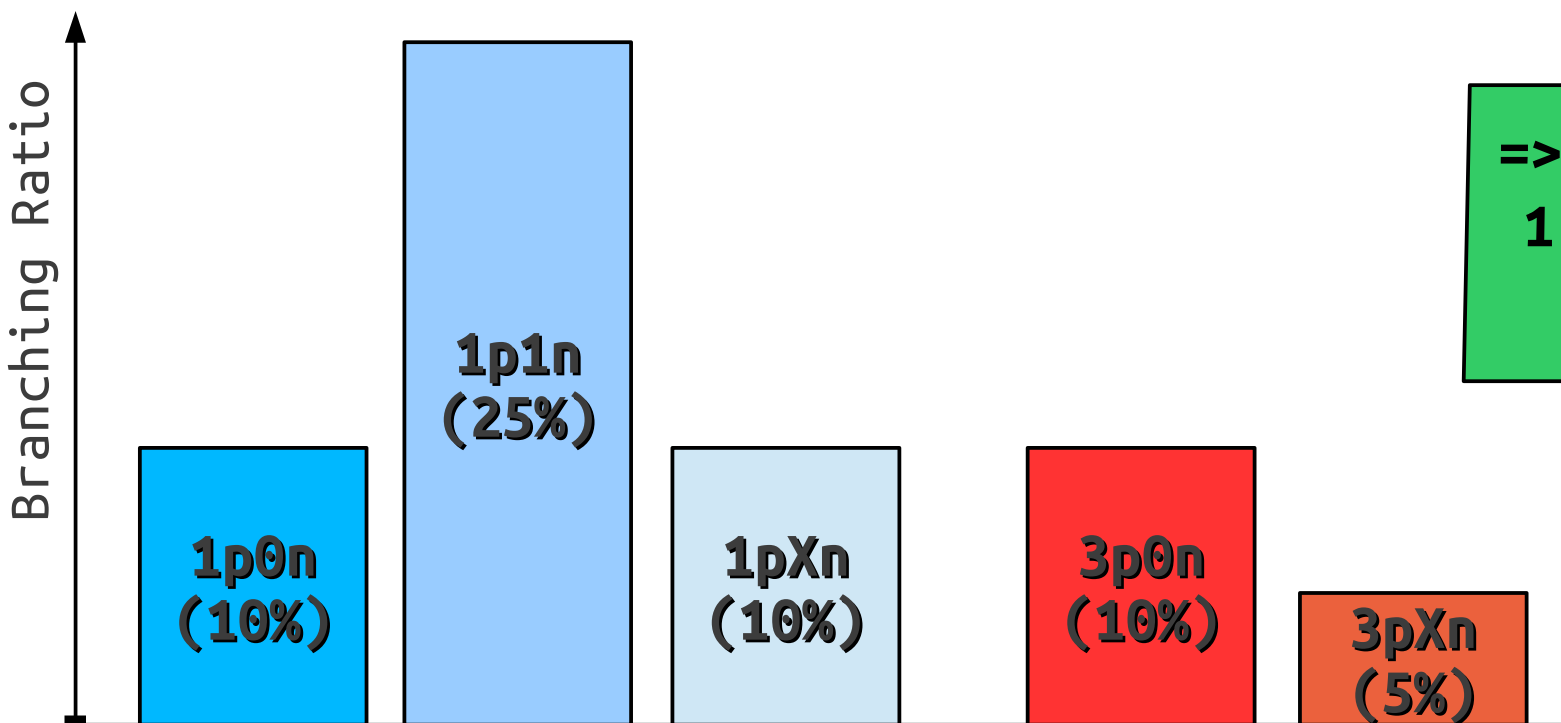
- **Current approach:**
  Based on calorimeter, subsequent determination of decay mode

- **These studies:**
  Particle Flow approach, trying to reconstruct and identify all particles in the tau decay.

- **Motivation / Benefits:**
  - Using different subdetectors for different particles improves energy and directional resolution
  - Tau-Jet discrimination profits from knowing the decay mode
  - Pure samples of 1p0n, 1p1n, 3p0n modes important for polarisation studies

Tau Decay Modes

- Most important modes (rough branching ratios):
  - **„1p0n“ (10%):** $\tau^+ \rightarrow \pi^+ \nu_\tau$
  - **„1p1n“ (25%):** $\tau^+ \rightarrow \pi^+ \pi^0 \nu_\tau$
  - **„1pXn“ (10%):** $\tau^+ \rightarrow \pi^+ \pi^0 \pi^0 \nu_\tau$ (and $\tau^+ \rightarrow \pi^+ x\pi^0 \nu_\tau$ where $x > 2$)
  - **„3p0n“ (10%):** $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu_\tau$
  - **„3pXn“ (5%):** $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \pi^0 \nu_\tau$ (and $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- x\pi^0 \nu_\tau$ with $x > 1$)
- Decays into electrons / muons are not considered
- Rare decays into Kaons possible (but neglected)



=> Signature: 1 or 3 $\pi^{+/-}$, 0-2 π^0

Particle Flow in Taus

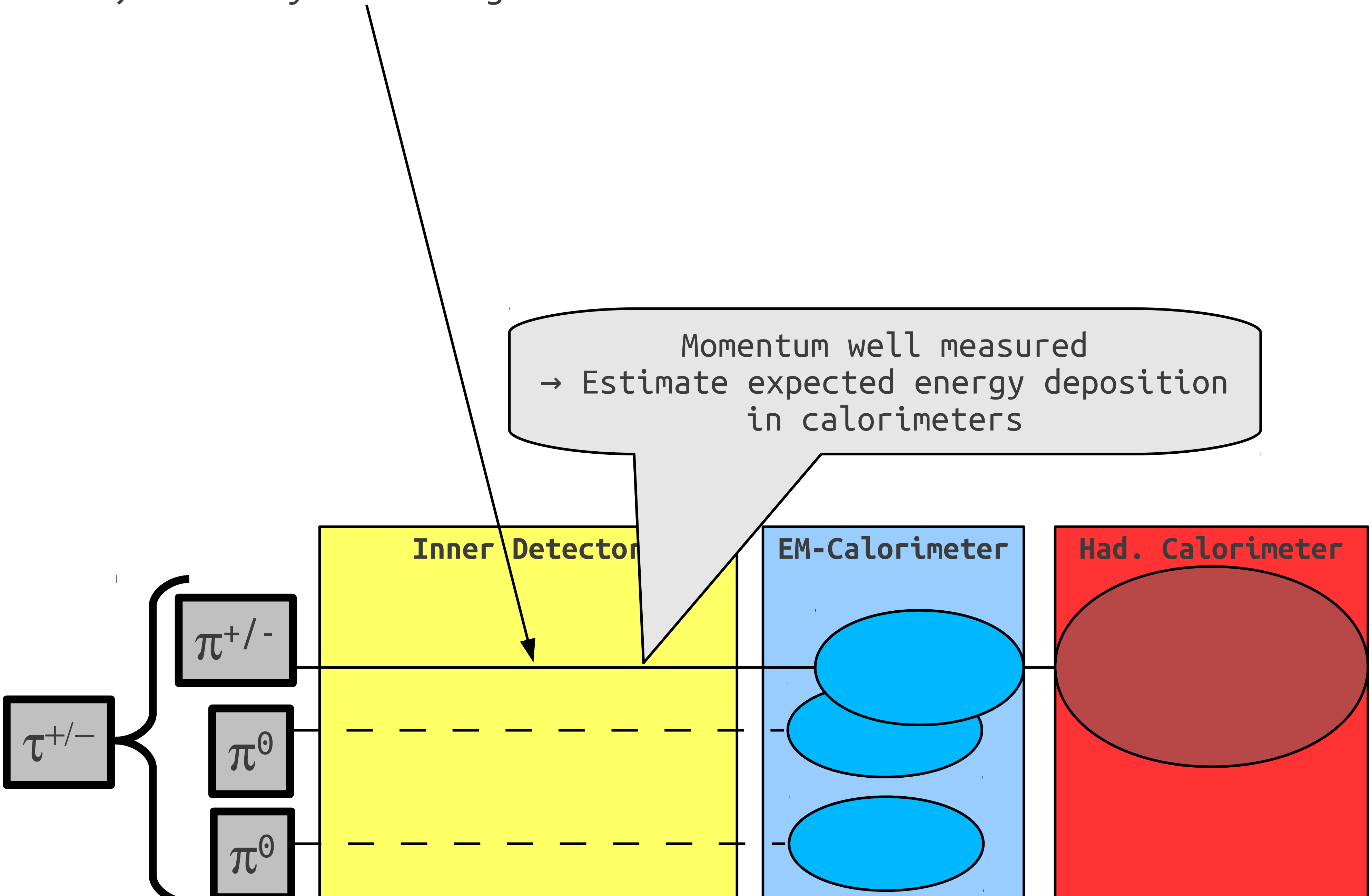
- **Two step process:**

  A) Run a particle flow algorithm.
  - Two algorithms available in ATLAS, „eflowRec“ and „CellBased“.
  - **eflowRec**: Generic particle flow algorithm, not tau-specific.
  - **CellBased**: Specifically developed for taus.
  - Both methods identify neutral pions
  - CellBased uses information from the „Strip Layer“ ('shots')

  B) Apply an additional logic to recover taus which were wrongly classified (**PanTau**), using BDTs.
  - Action based on decay mode given by counting objects
  - Use global tau variables to help in 'hard' cases, like 1p0n -vs- 1p1n.
  - Optimized to maximize total fraction of correctly identified taus

Particle Flow in Taus

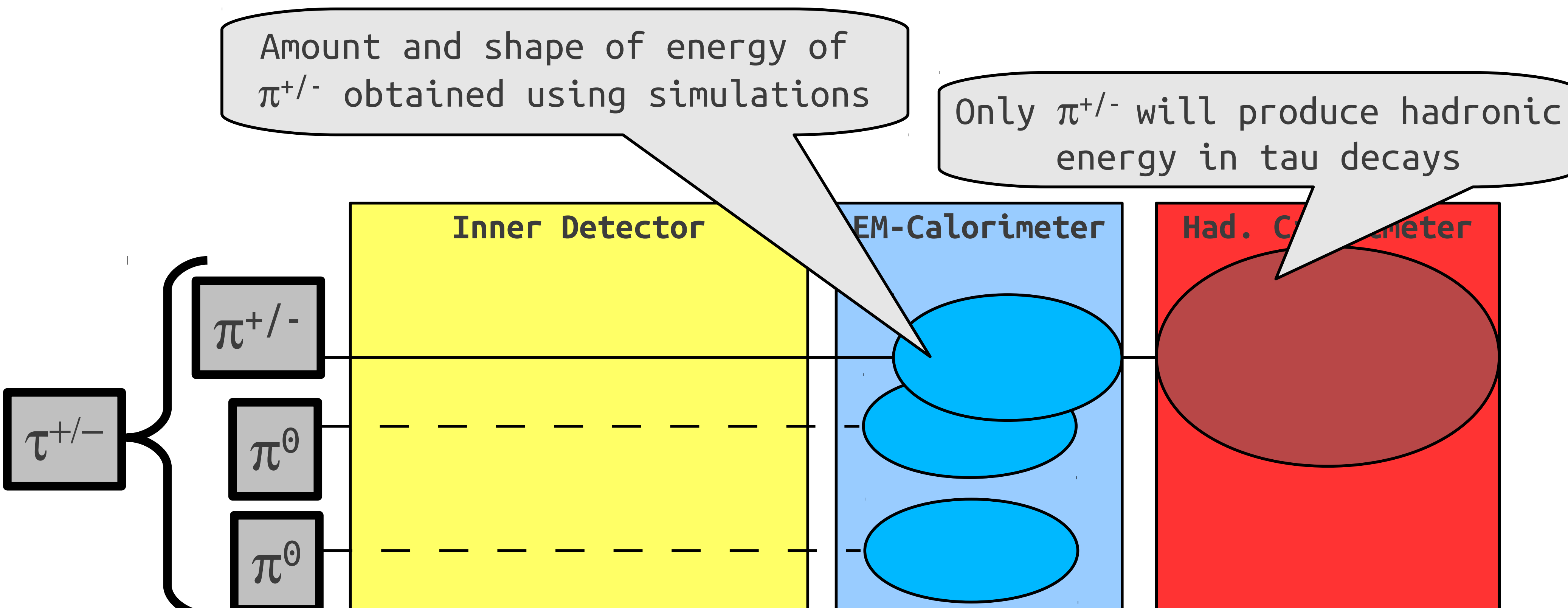
1.) Identify $\pi^{+/-}$ using their tracks



Particle Flow in Taus

1.) Identify $\pi^{+/-}$ using their tracks

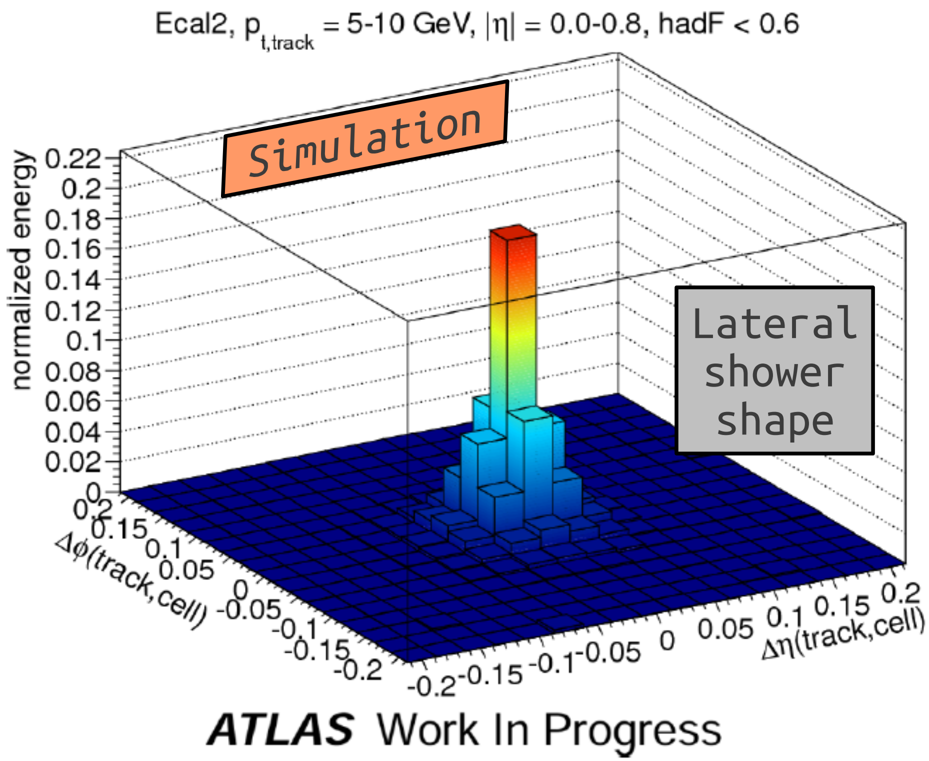
2.) Estimate energy in EM-Calorimeter due to $\pi^{+/-}$

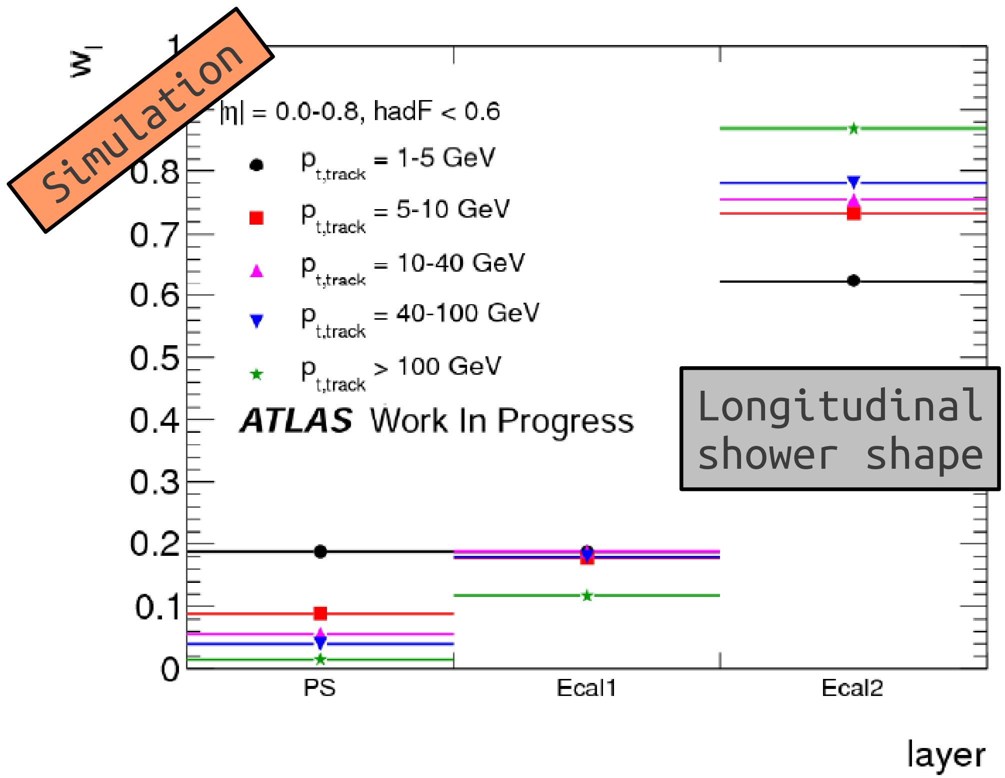


Particle Flow in Taus

1.) Identify $\pi^{+/-}$ using their tracks
2.) Estimate energy in EM-Calorimeter due to $\pi^{+/-}$

Details: Shower Shapes from MC in **CellBased** Algorithm. Use single $\pi^{+/-}$-MC to extract lateral and longitudinal shape





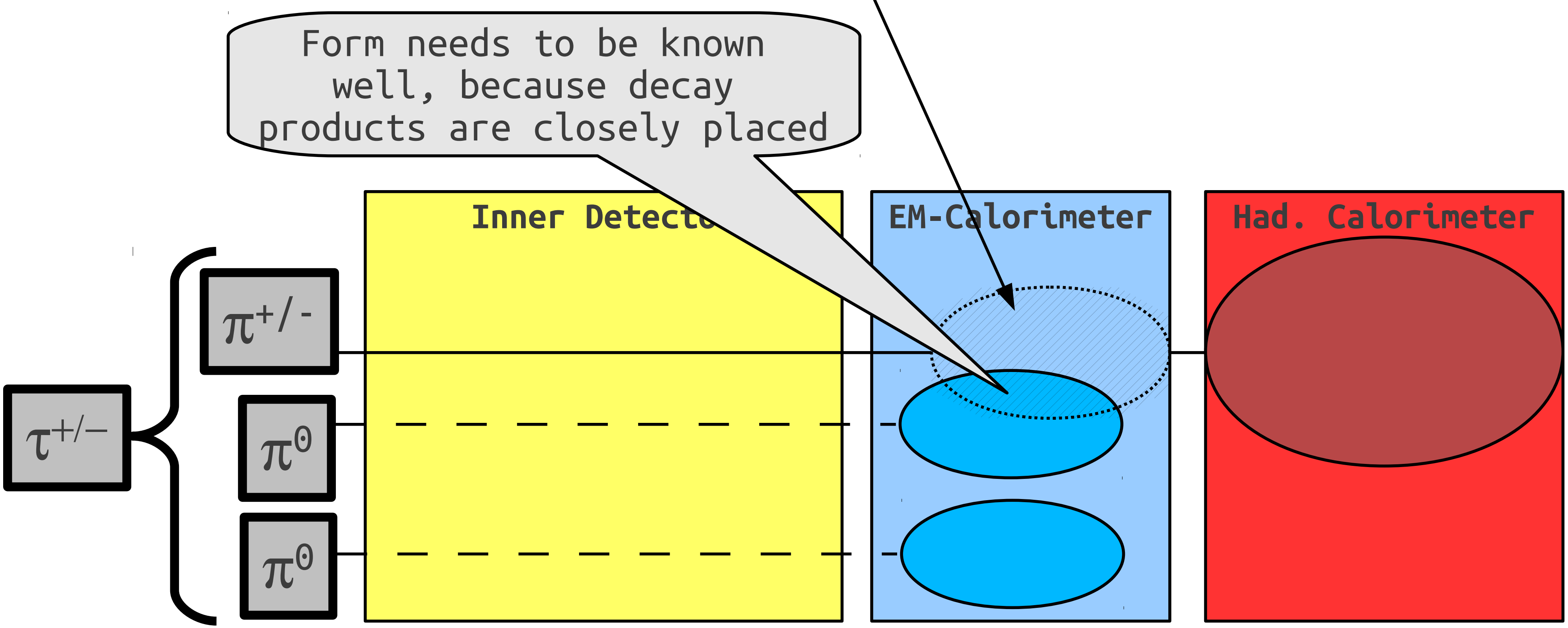
Related studies by Benedict Winter

Particle Flow in Taus

1.) Identify $\pi^{+/-}$ using their tracks

2.) Estimate energy in EM-Calorimeter due to $\pi^{+/-}$

3.) Subtract energy distribution from EM-Calorimeter



Particle Flow in Taus

1.) Identify $\pi^{+/-}$ using their tracks
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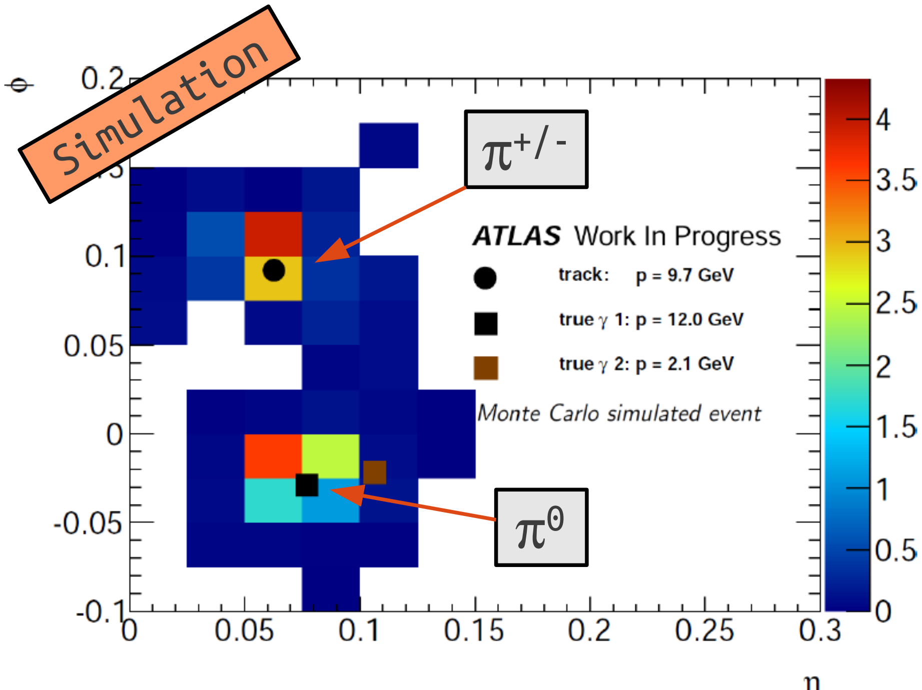
3.) Subtract energy distribution from EM-Calorimeter

Details: Subtraction in **CellBased** Algorithm

Lateral energy distribution in Ecal:



Procedure:

Remove $\pi^{\pm}$ shower in Ecal cell by cell.
Use averaged hadronic **shower shapes**

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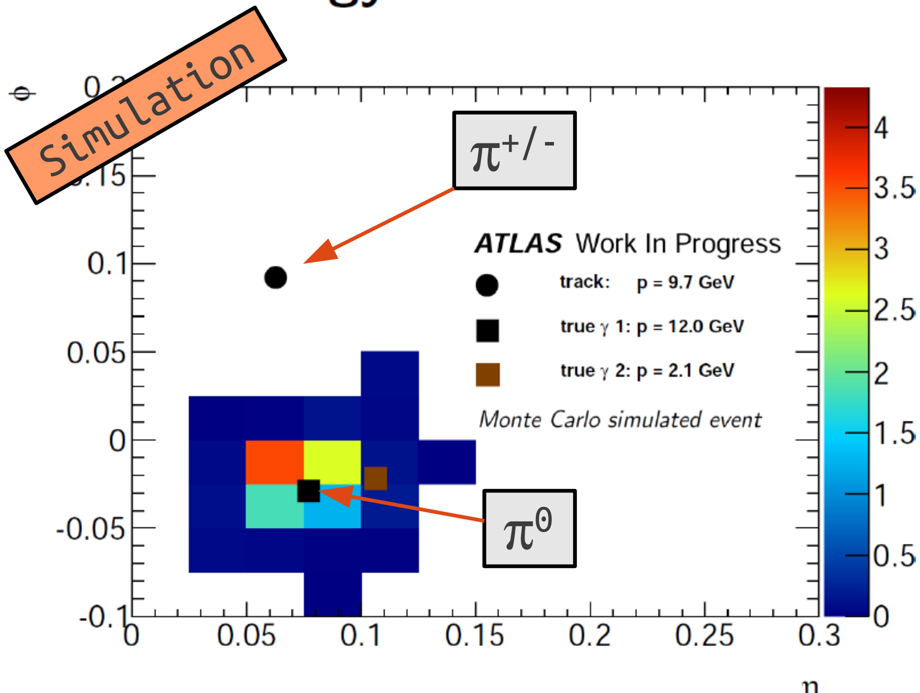

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Remove $\pi^{\pm}$ shower in Ecal cell by cell.
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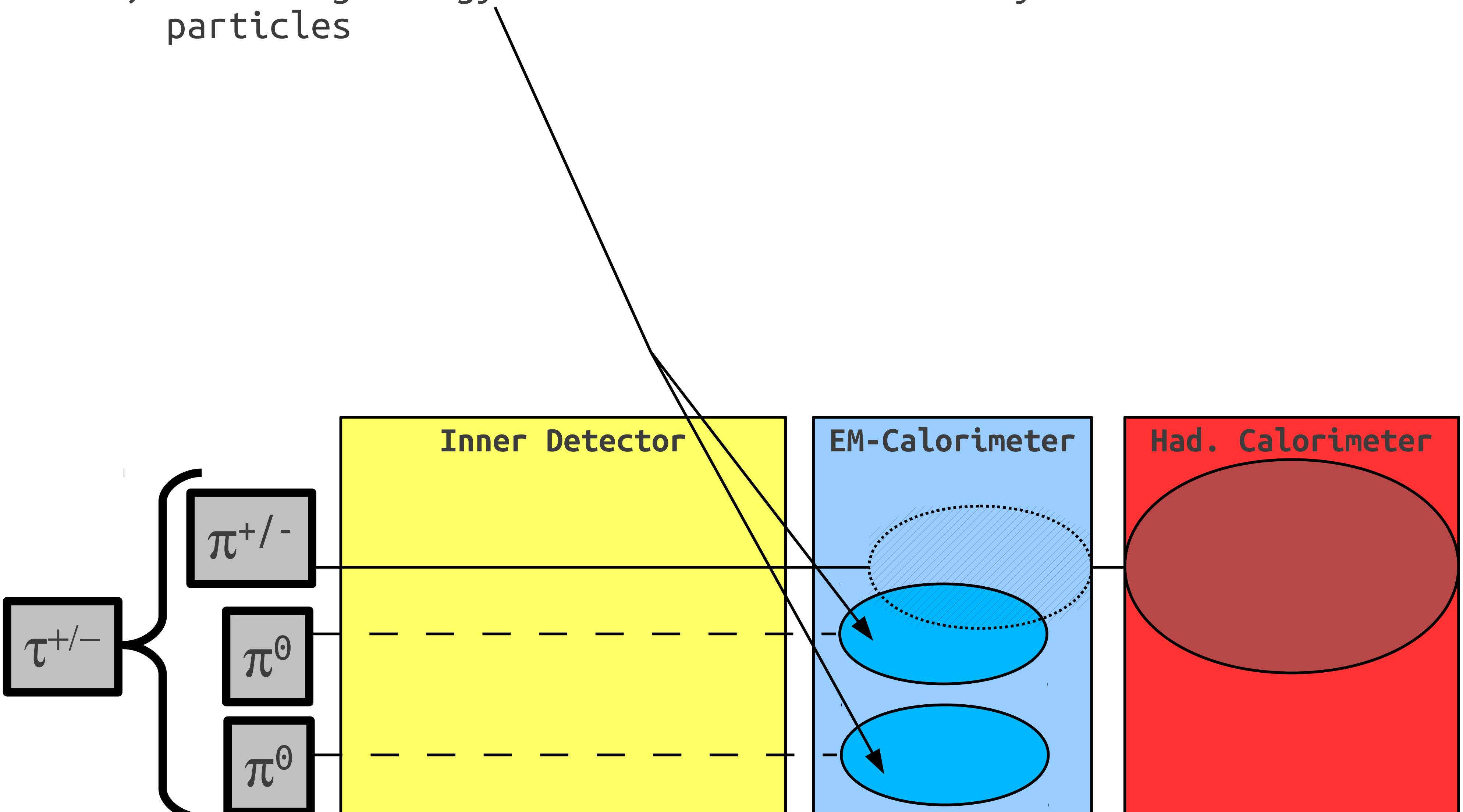
Particle Flow in Taus

1.) Identify $\pi^{+/-}$ using their tracks
2.) Estimate energy in EM-Calorimeter due to $\pi^{+/-}$
3.) Subtract energy distribution from EM-Calorimeter
4.) Remaining energy in EM-Calorimeter is only due to neutral particles



Particle Flow in Taus

1.) Identify $\pi^{+/-}$ using their tracks
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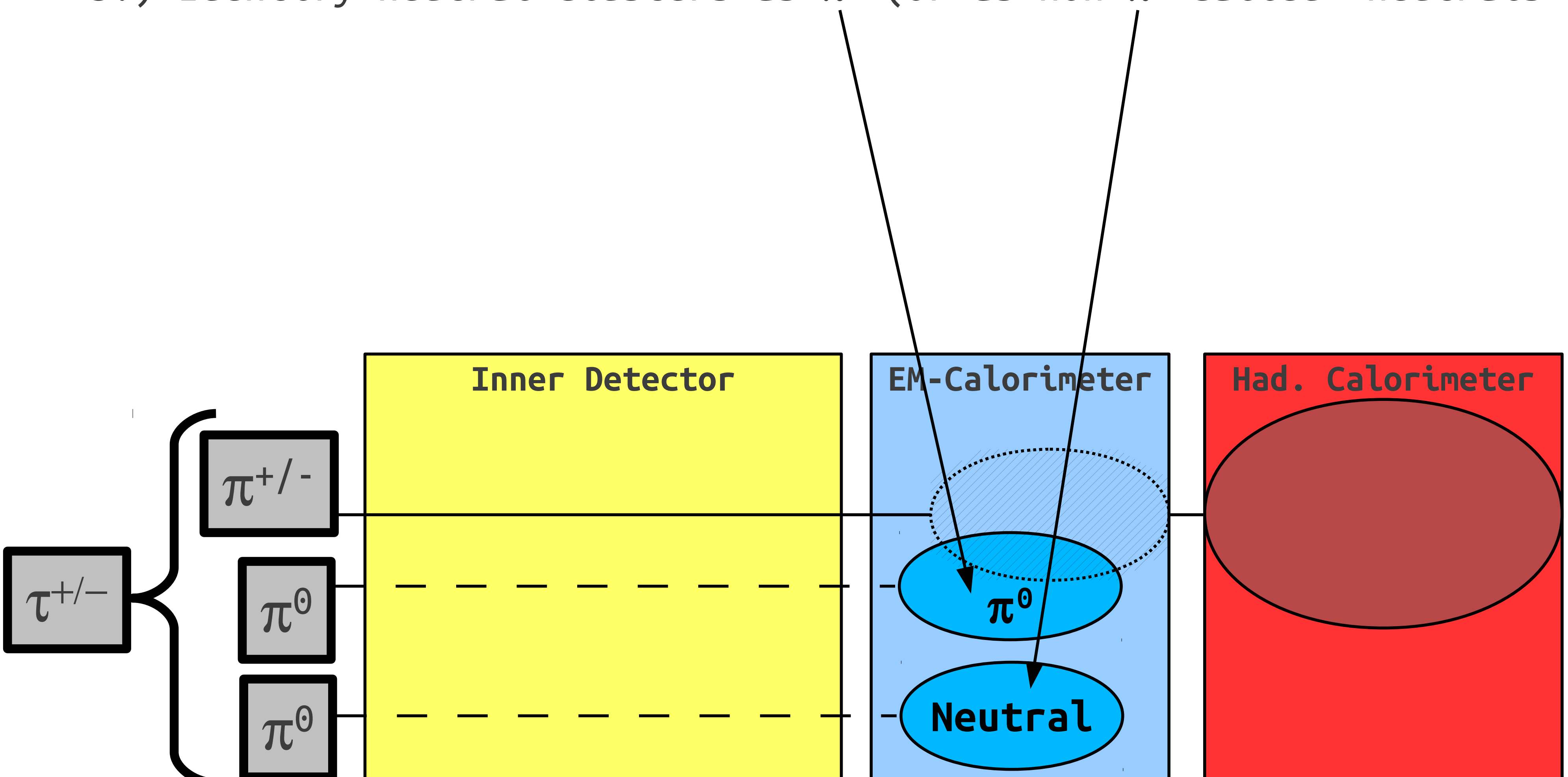
5.) Identify neutral clusters as π^0 (or as non-π^0 called 'neutrals')



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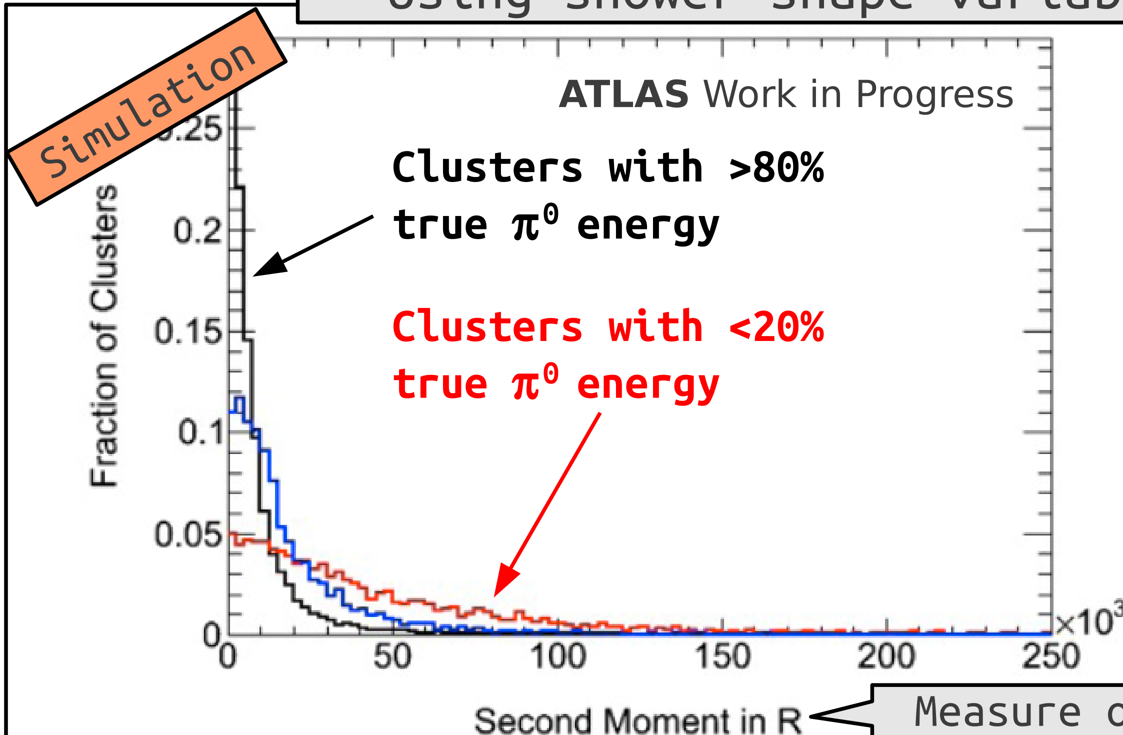
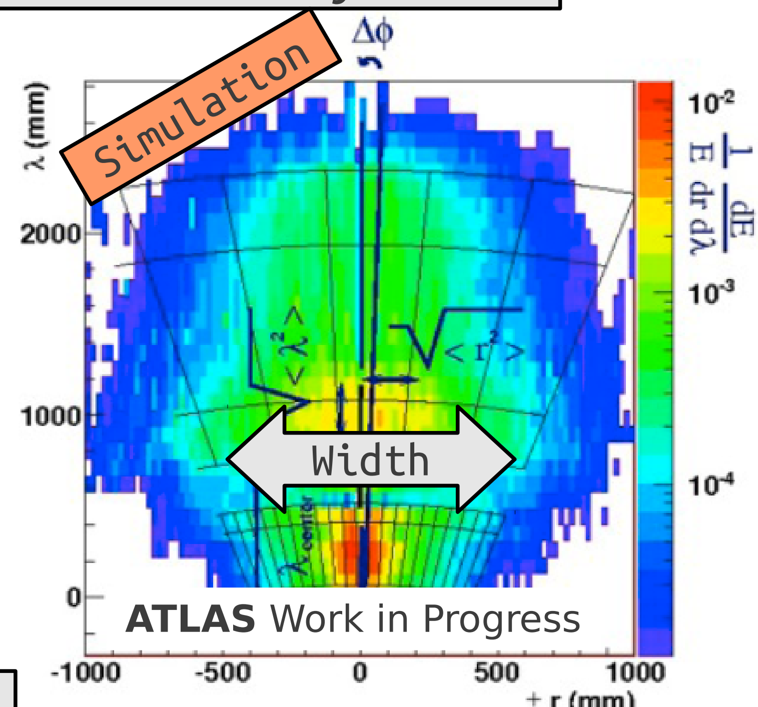
Details: π^0-identification in **eflowRec** Algorithm

Using shower shape variables to identify π^0



Measure of shower width



Related studies by Mark Hodgkinson

Particle Flow in Taus

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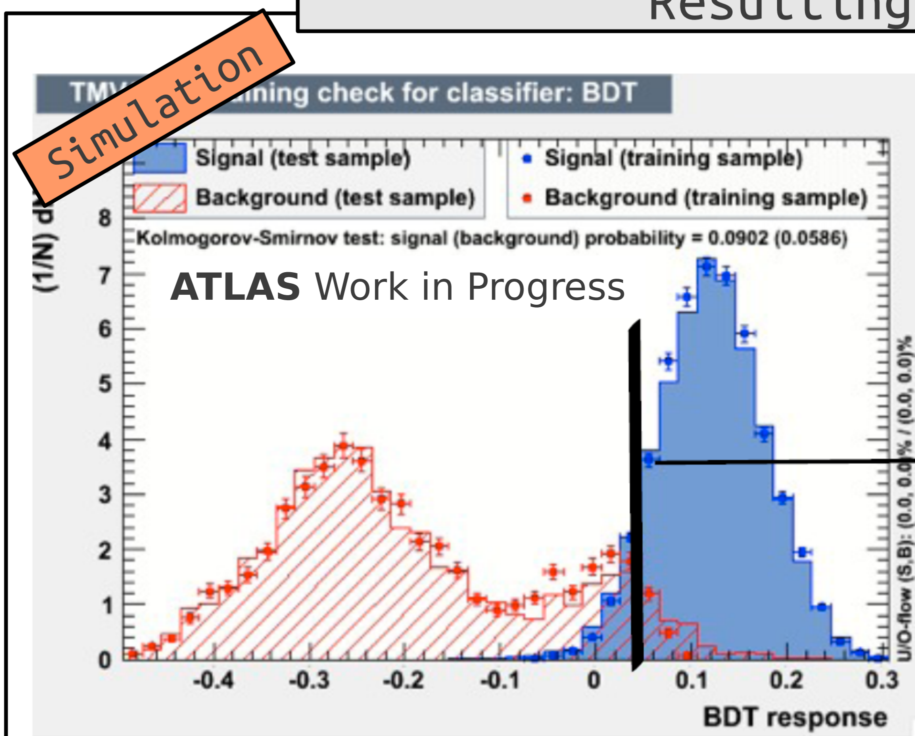
Details: π^0-identification in **eflowRec** Algorithm
Resulting BDT distribution



Neutral EFO is Pi0 tagged when BDT value > 0.05

Note: We moved to using a E_T binned cut on the π^0-BDT

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1.) Identify $\pi^{+/-}$ using their tracks
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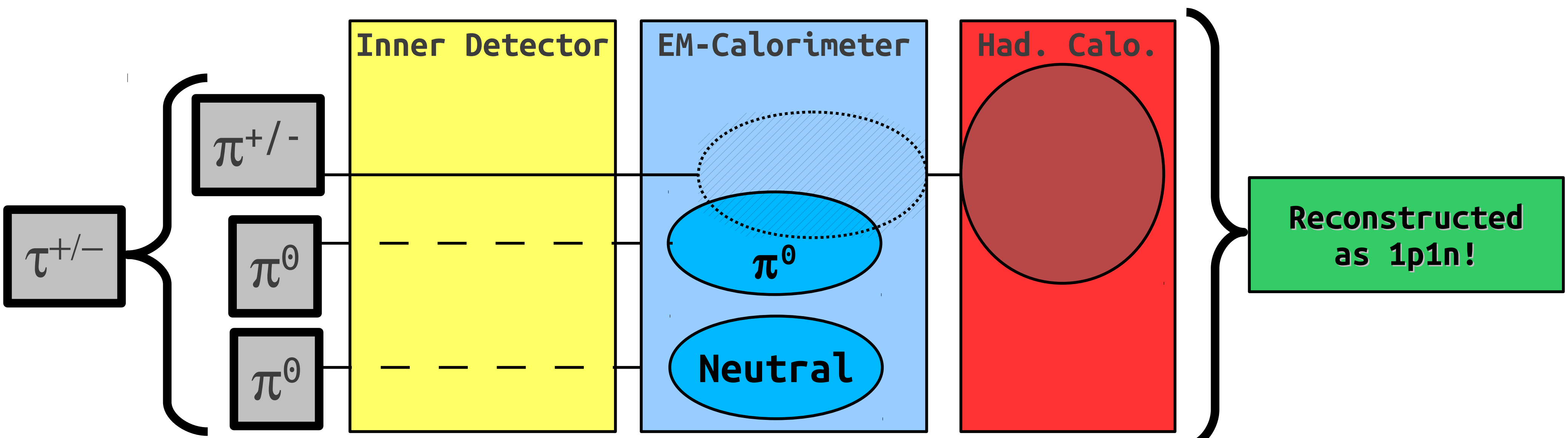
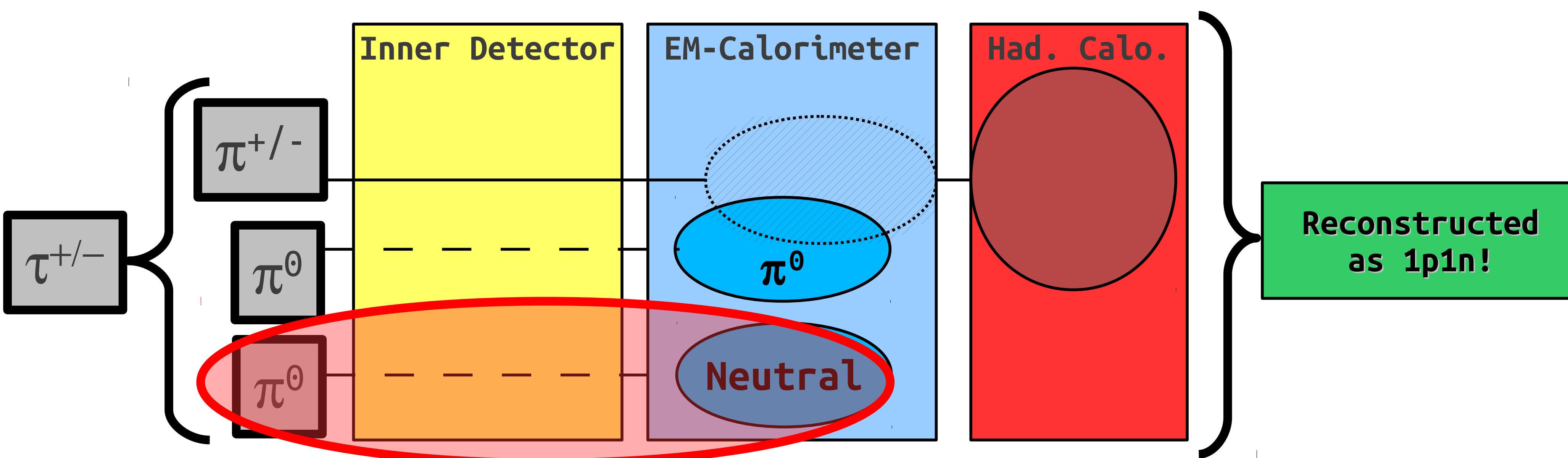
4.) Remaining energy in EM-Calorimeter is only due to neutral particles
5.) Identify neutral clusters as π^0 (or as non-π^0 called 'neutrals')
6.) Tracks in the tracker and clusters in EM-Calo identified as π^0 correspond the $\pi^{+/-}$ and π^0 in the tau decay



Particle Flow in Taus

Problem: Mistagging of π^0 will happen

- A true π^0 was not tagged as such and will not be considered when counting decay products (red eclipse)

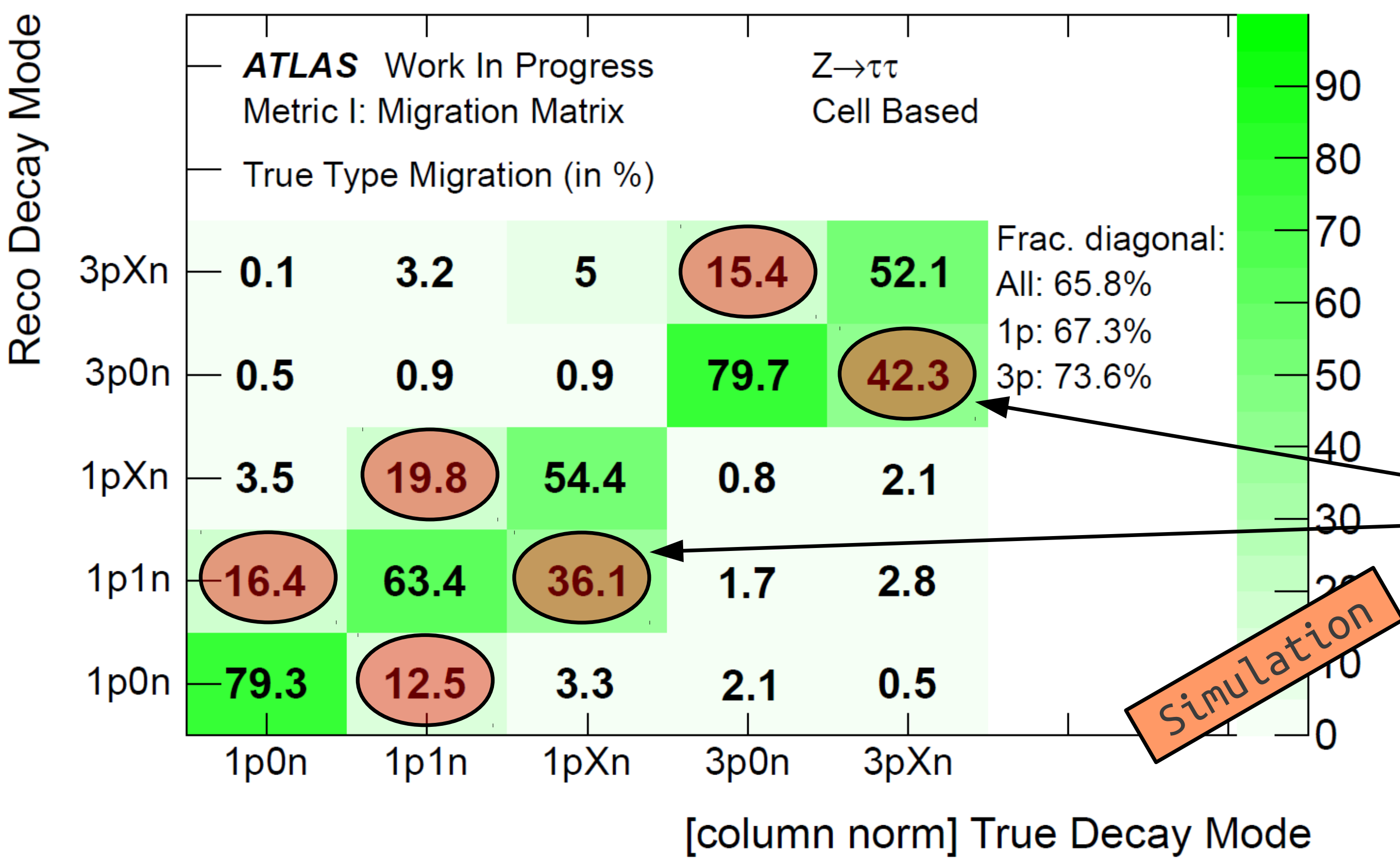


Particle Flow in Taus

Problem: Mistagging of π^0 will happen

- Oversubtraction or merging of clusters can lead to too few π^0
- Pile up or cluster splitting can lead to too many π^0

Classification Performance of **CellBased**



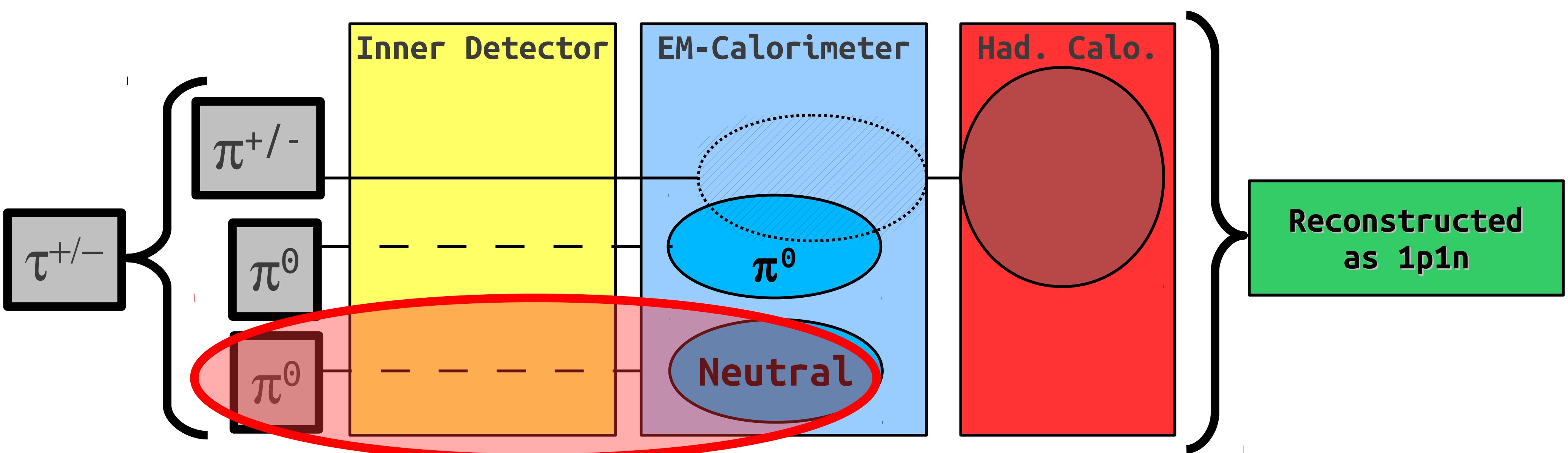
„Efficiency Matrix“
Entries in percent.
Each column adds to 100%.

Next-to-diagonal elements cause most trouble.
Otherwise counting works reasonably well.

Particle Flow in Taus

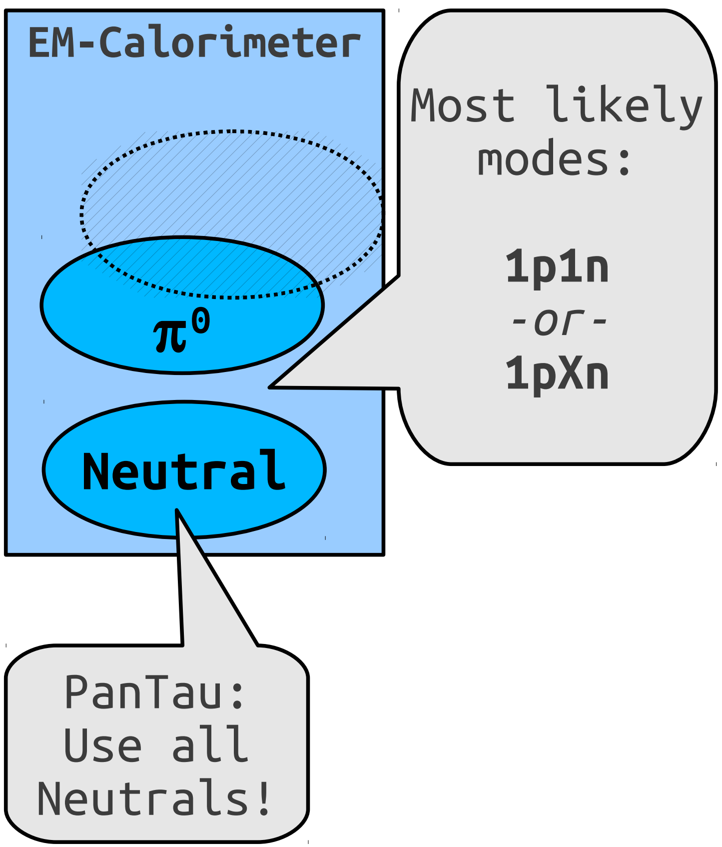
- **Problem: Mistagging of π^0 will happen**
- For example, the second π^0 was not identified (red eclipse)
- Indeed, this is the main cause for misclassification (prev. slide)

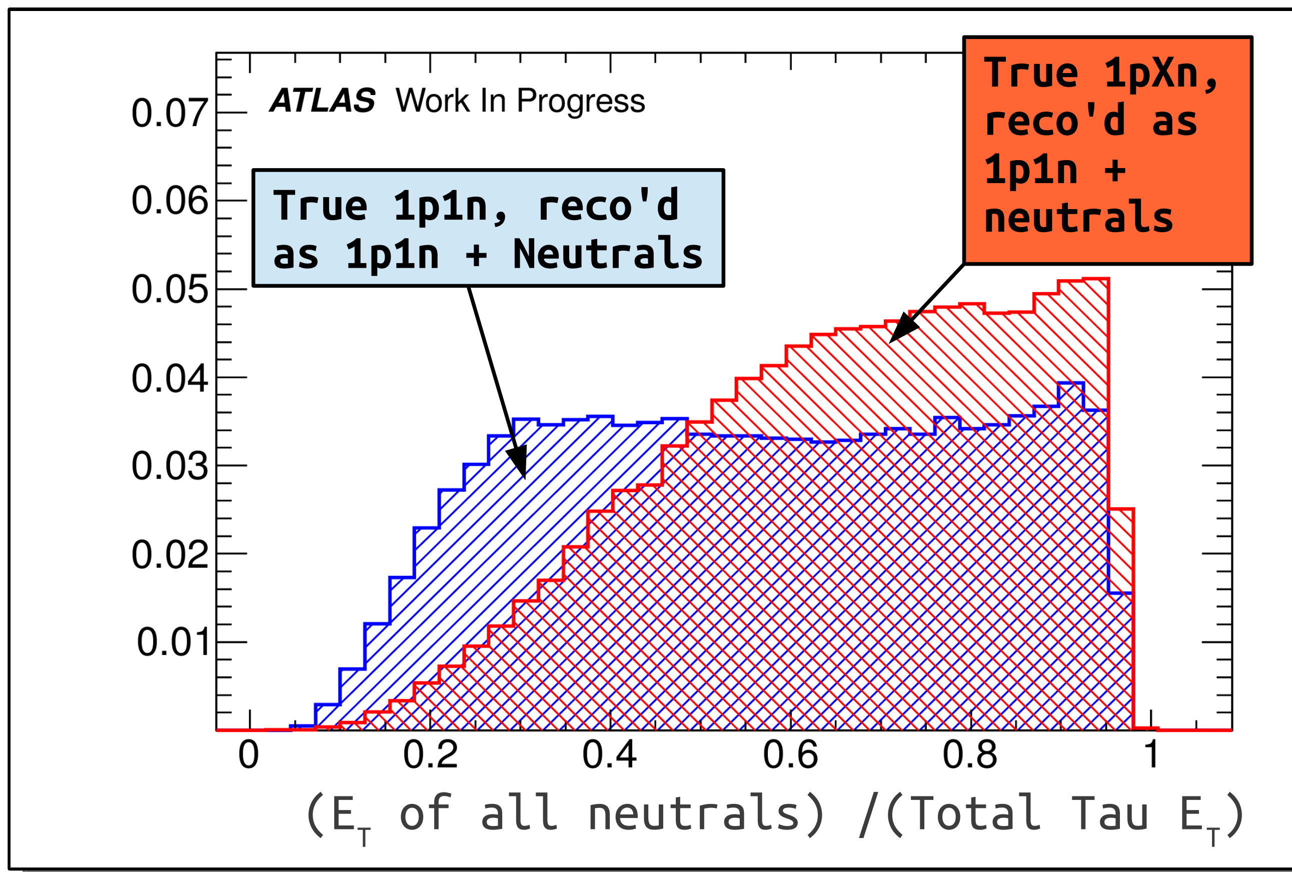
- **Solution:**
  - The tau contains more information than the number of its decay products
  - Apply additional algorithm to use all neutral particles and to calculate kinematic variables using the complete tau
  - With this information, revisit decay mode classification and alter the decay mode, if necessary
    → **PanTau**



PanTau ansatz

- Consider all reconstructed decay products:
  - Use both: neutrals and π^0.
  - Also use the $\pi^{+/-}$.
- Calculate variables that make use of more than one particle:
  - Example: Ratio of E_T in all neutrals and E_T of all particles
- Compare variables for the two most likely modes



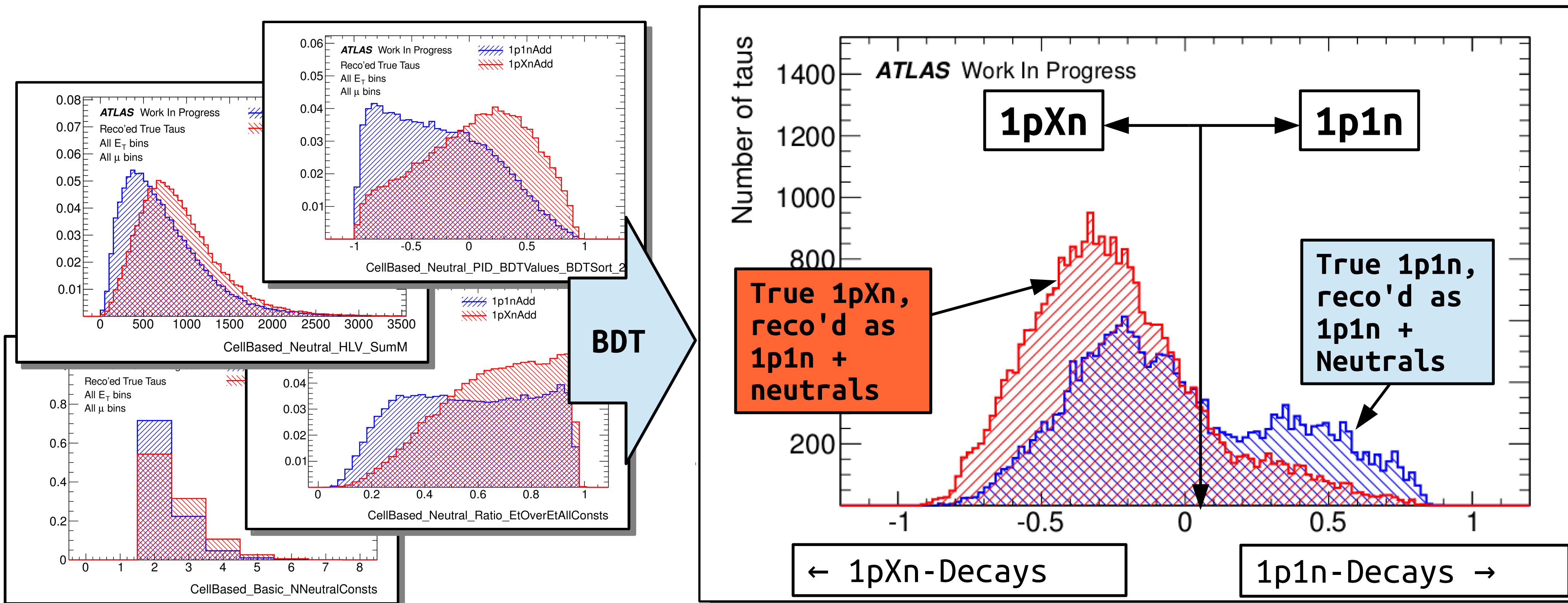


Combination of variables

- Many such variables are calculated, several show residual separation in addition to particle flow based counting.
- Variables are combined using BDTs

- Example: Tau with $1\pi^{+/-}$, $1\pi^0$, 1 neutral is tested to be 1p1n or 1pXn
- Depending on BDT score (say -0.2), the decay mode is changed (fixed)

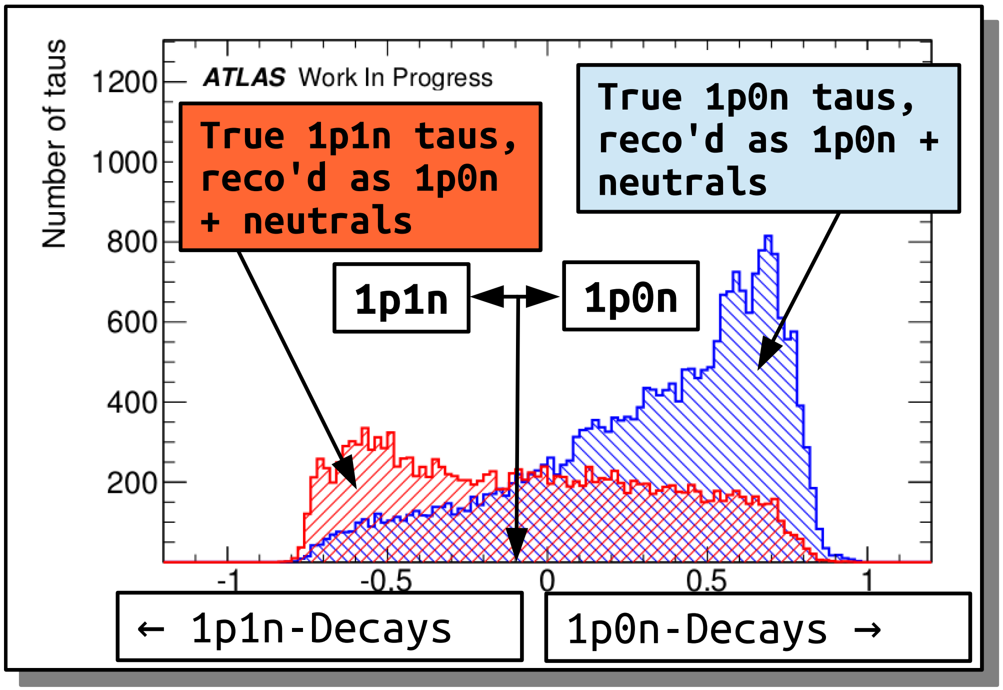
→ **Net gain in number of correctly classified taus**

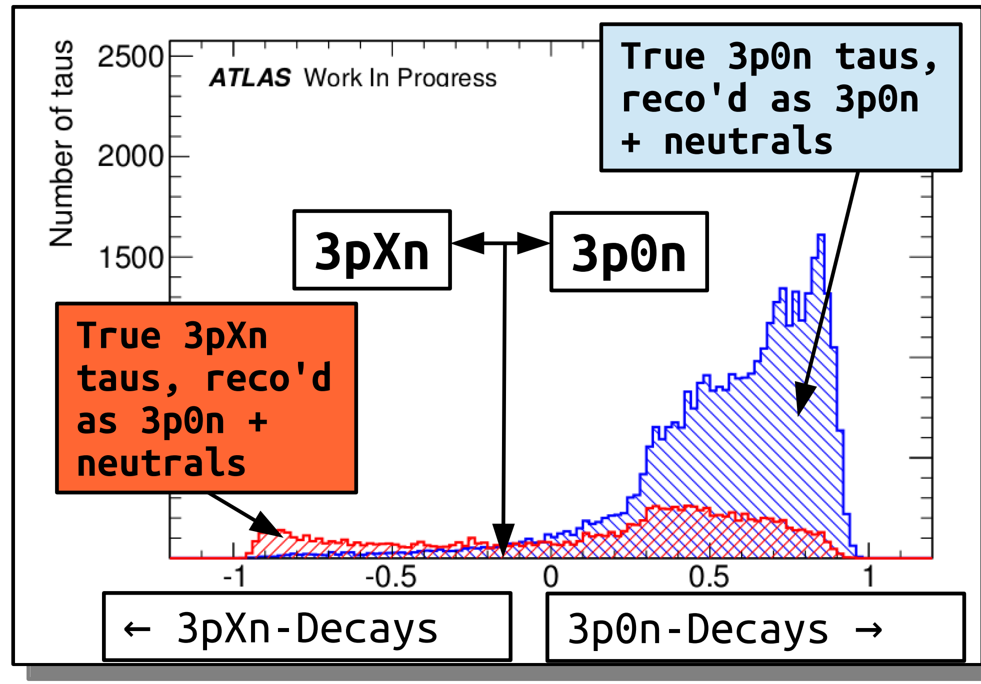


Additional BDTs (1p0n and 3p0n)

Similar tests are performed in case of a reco tau with...

- 1 $\pi^{+/-}$, 0 π^0, 1 neutral → Test 1p0n -vs- 1p1n
- 3 $\pi^{+/-}$, 0 π^0, 1 neutral → Test 3p0n -vs- 3pXn
- Analog tests in case every neutral is a π^0





Quick summary:

Using kinematic variables, PanTau checks if...

a) … a π^0 actually is a π^0

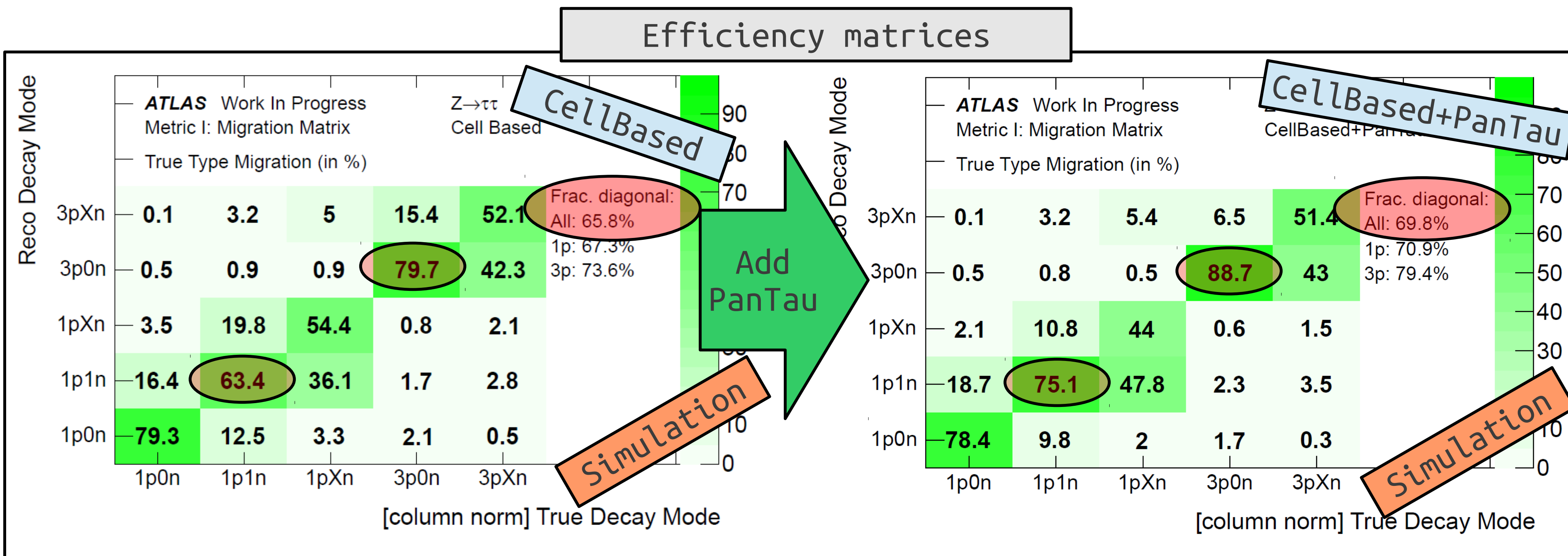
b) … a neutral may have been a π^0.

The decay mode is changed accordingly.

Results: Mode efficiencies

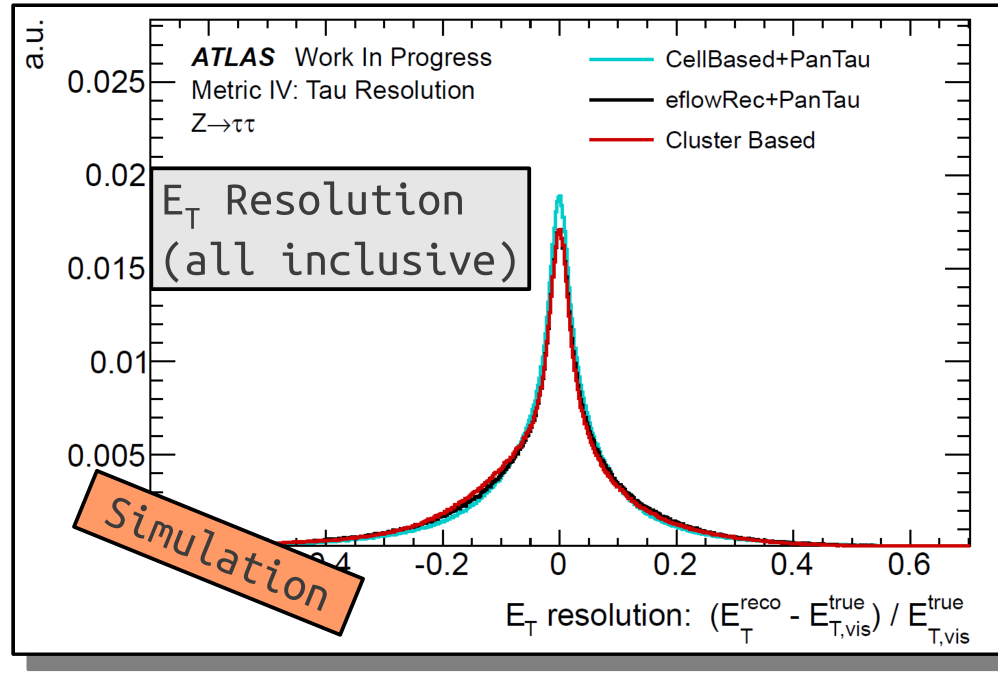
- „Figure of Merit“, FoM: Fraction of correctly classified taus
  - Note: FoM is roughly 55% when just setting 1-track taus to 1p1n and 3-track taus to 3p0n (because of branching ratios)
- CellBased (similar for eflowRec) improves FoM by ~10%
- PanTau improves FoM by an additional 4%

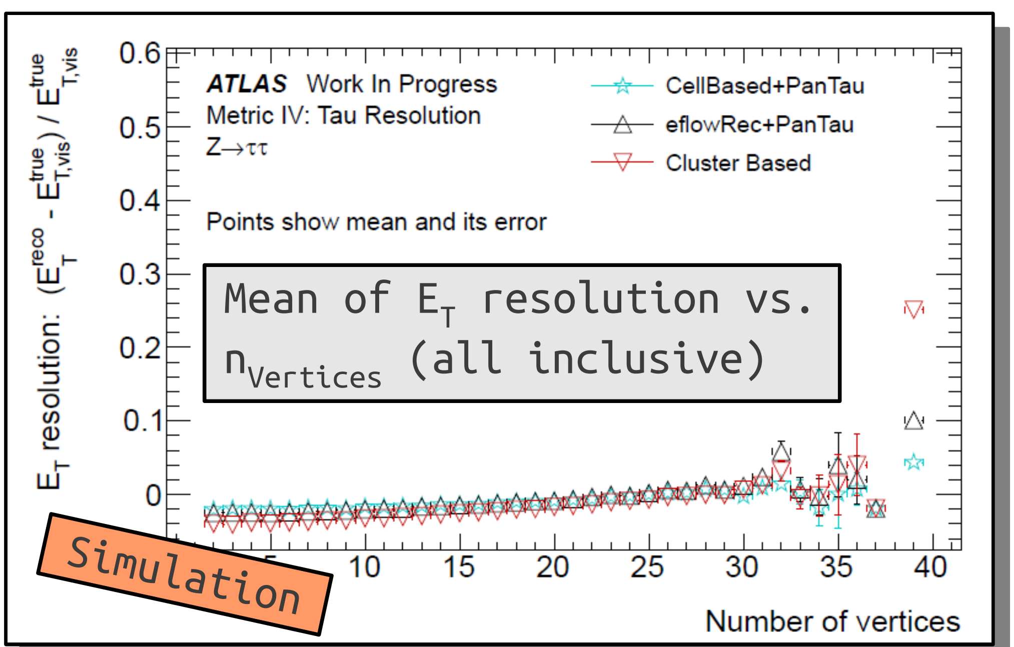
- Biggest improvement in 1p1n efficiency, which compensates the 1pXn → 1p1n migration in terms of purity
- The same is true for 3p0n

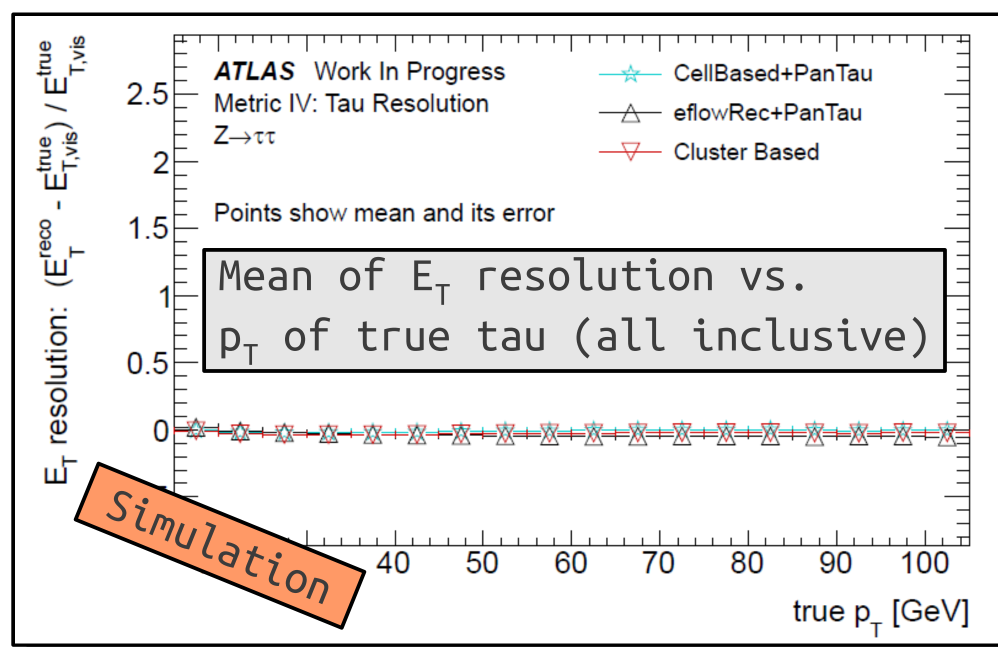


Results: Energy resolution

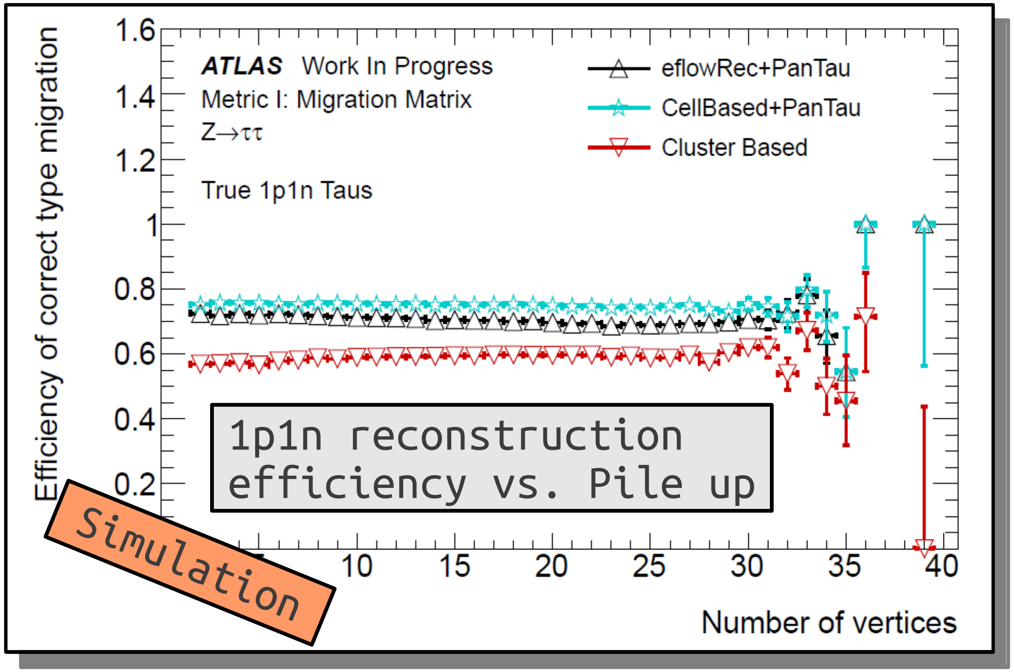
- Energy resolution ~< 10%
- No dependence on tau p_T
- Few percent increase of mean E_T over 35 vertices:
  - No dedicated pile up correction implemented yet
  - Pile up suppressed by E_T cut on tau decay products

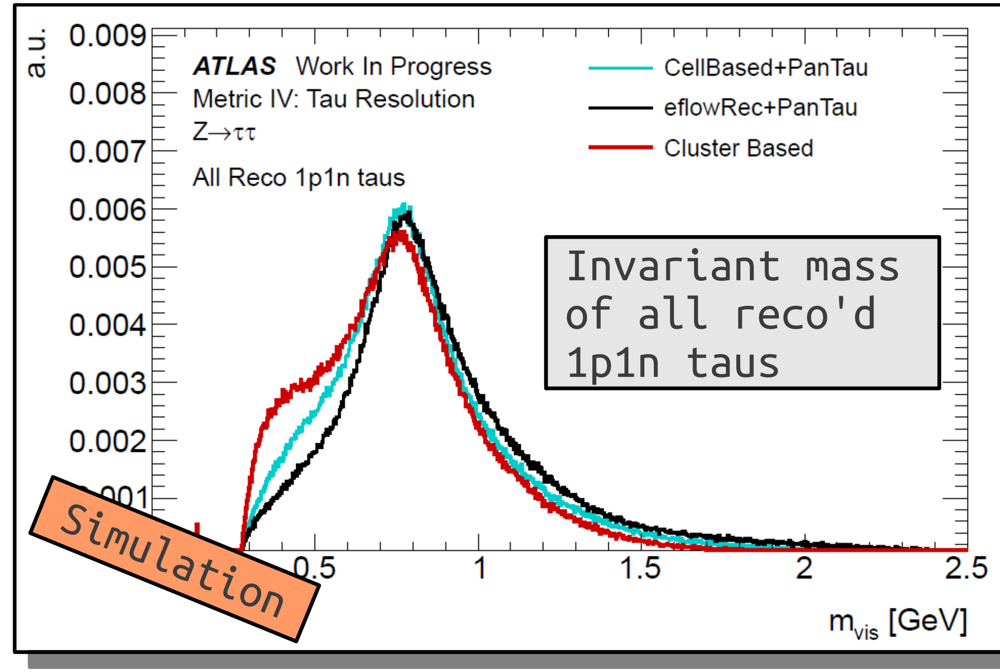


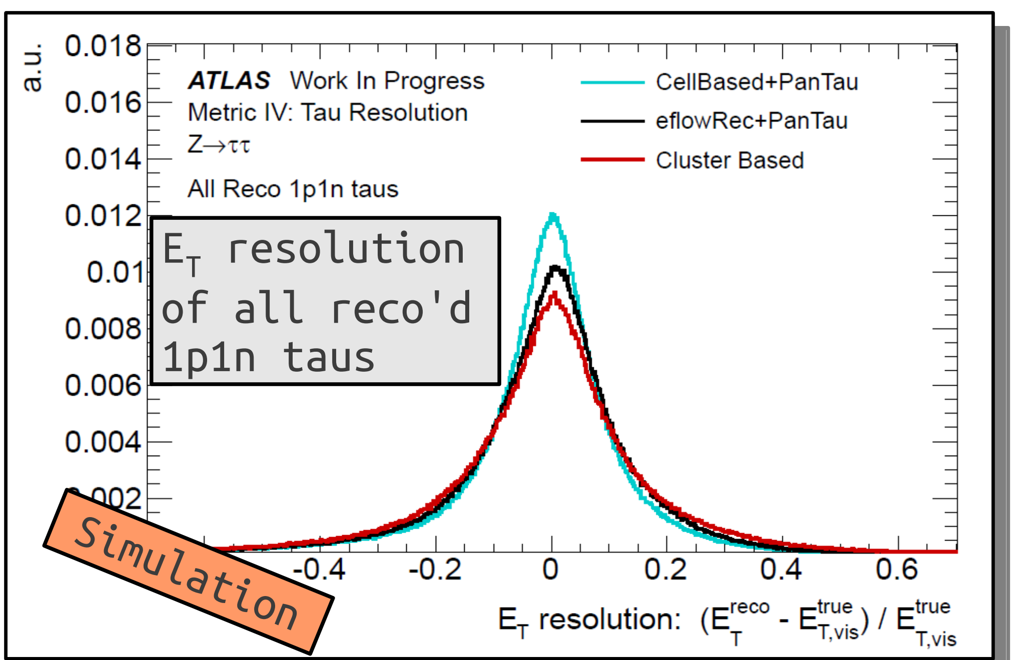


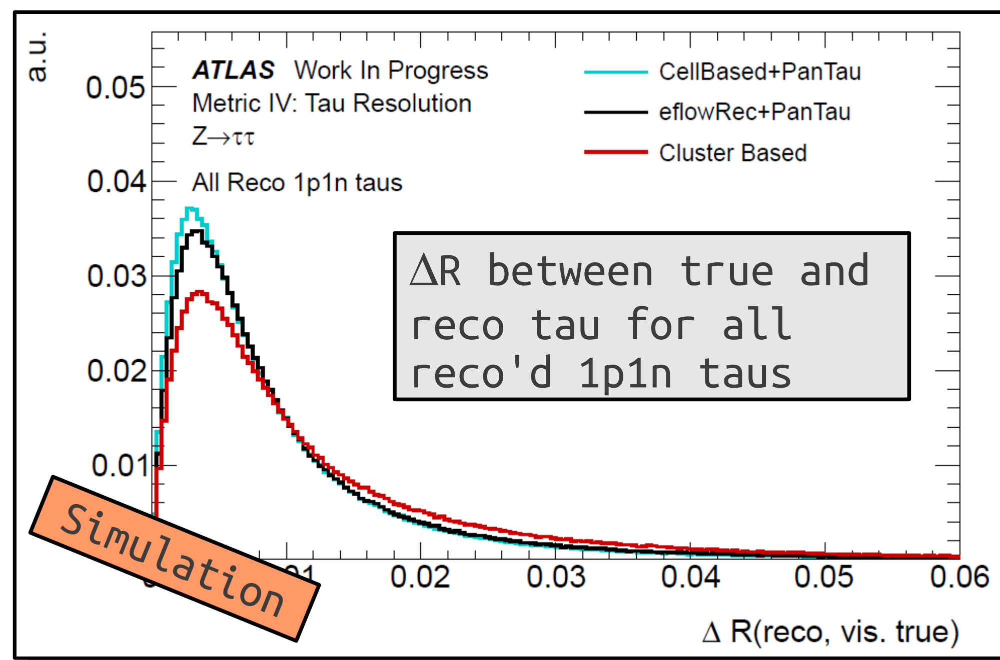


Results: 1p1n Taus



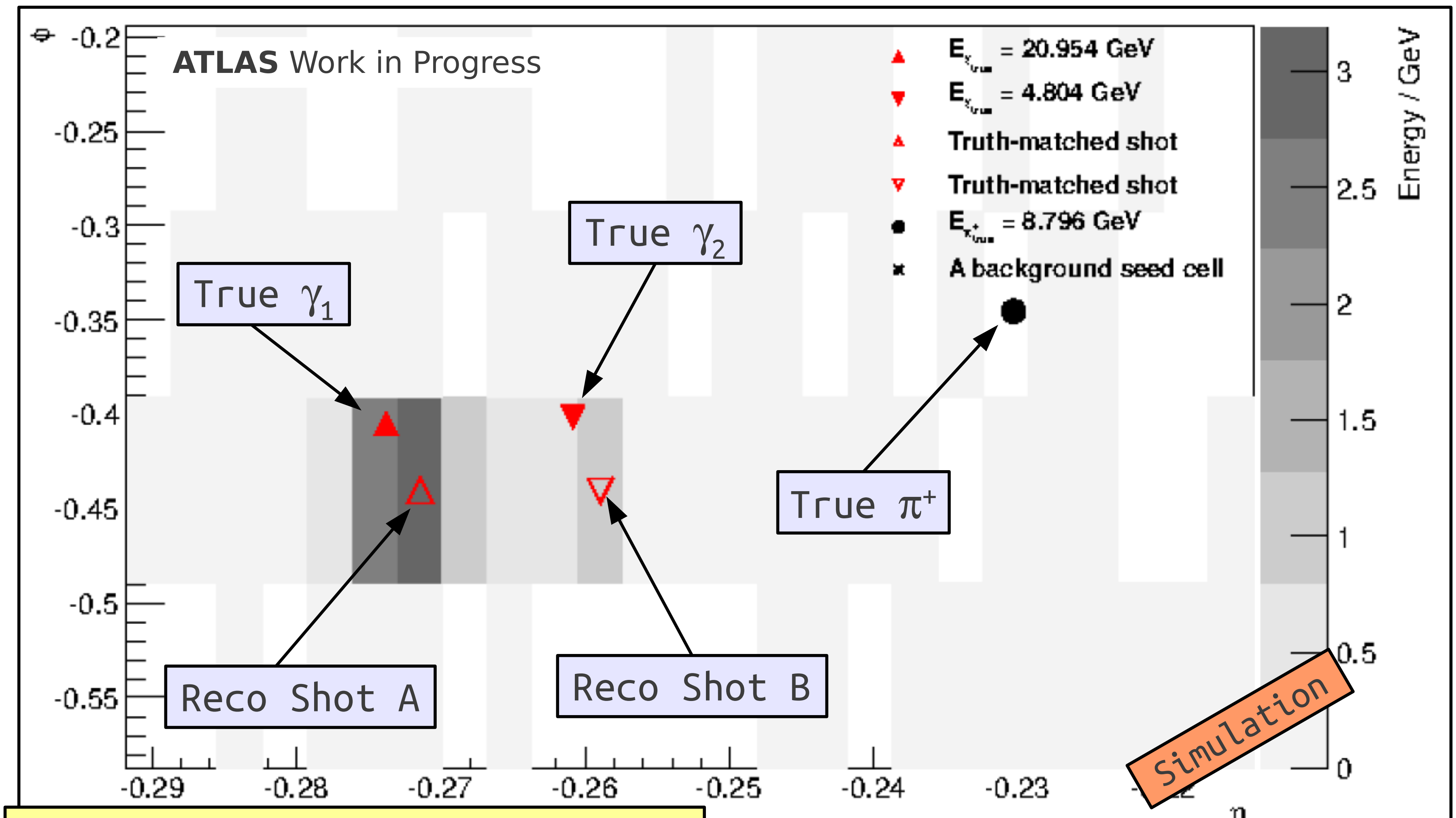






Additional studies: „Shots“

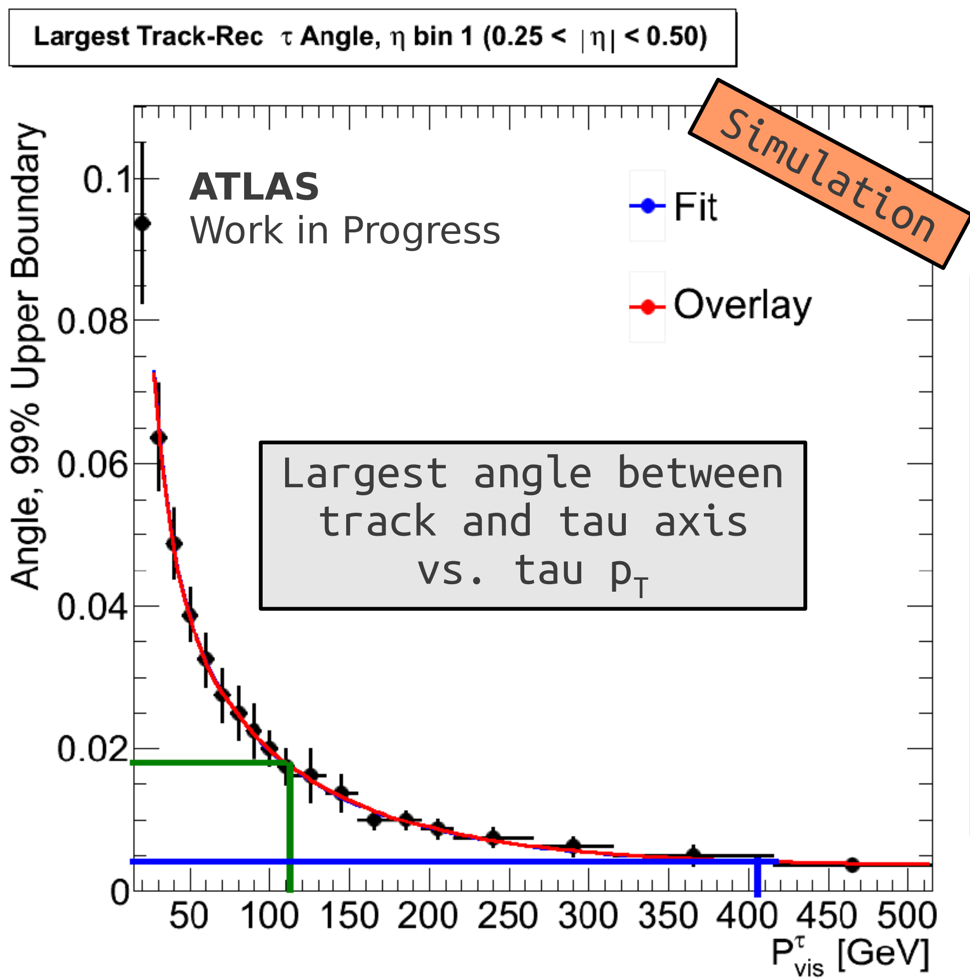
- Exploit high granularity in ECAL1 (Strip Layer) to count single photons from π^0 decay
- Helps to identify π^0 clusters (require at least 2 photons) and may also be used for high p_T (better (worse) Calo (tracking) resolution)



Related studies by Stephanie Yuen

Additional studies: Shrinking Cone

- With increasing energy, decay products are more and more colimated
- Adapt cone size used to select decay products around axis to suppress contributions from pile up



Two cones are calculated:
A) Cone for tracks
B) Cone for neutral clusters

Only objects in cones are used for mode classification.

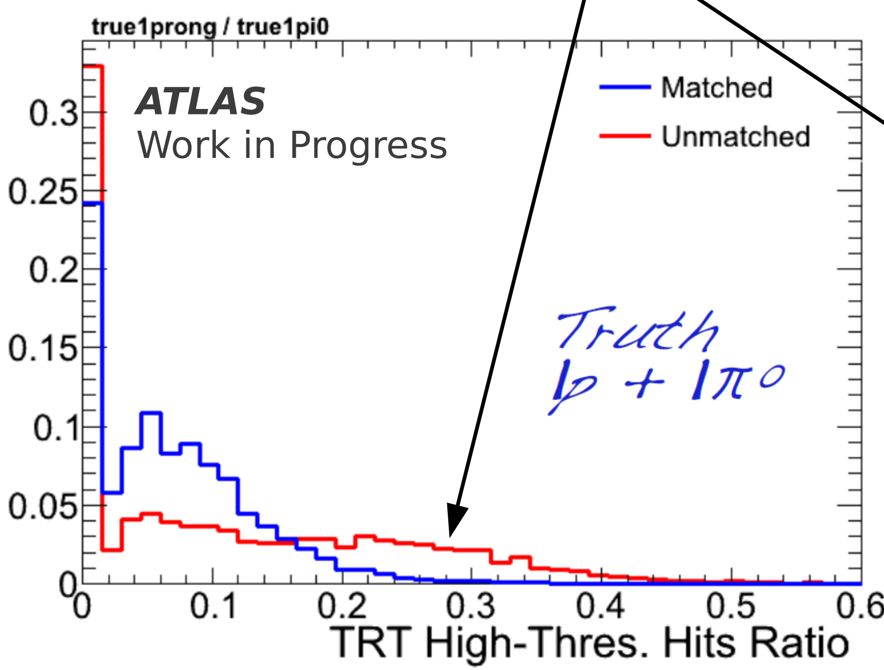
Objects outside of shrinking cone (but in starting cone) are kept for jet rejection.

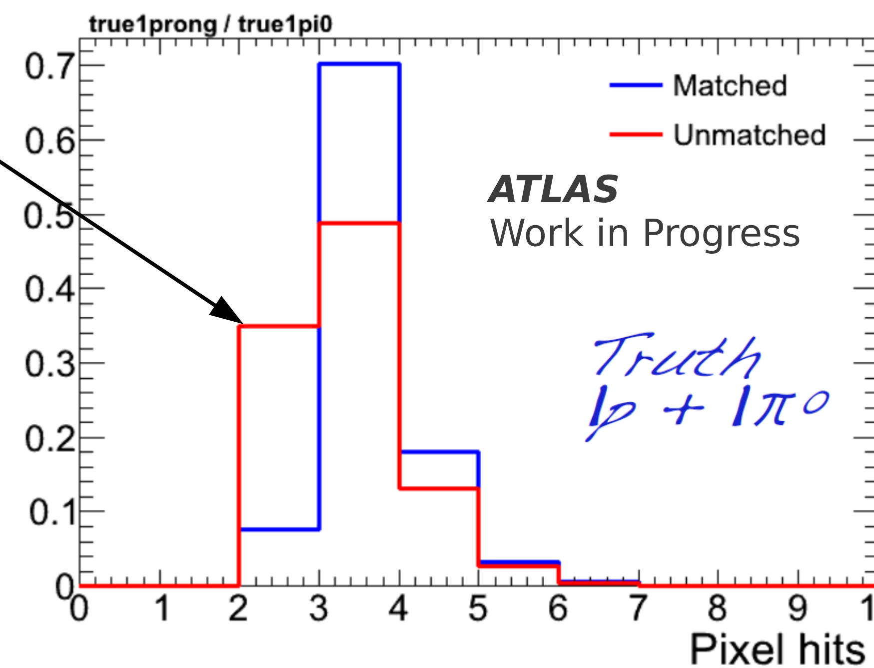
Related studies by Robert Clarke

Additional studies: Conversions

- The π^0 decays into two photons which can convert into a e^+-e^-pair
  → may cause 1p → 2p (or even 1p → 3p) and 3p → 4p migration
- Studies ongoing to identify tracks from conversions

Tracks from conversions tend to have
A) more high threshold hits in the TRT
(electrons emit more transition radiation)
B) less hits in the inner detector
(conversion may happen anywhere)





Related studies by Dimitris Varouchas

Summary & Outlook

Summary

- Tau reconstruction studies in ATLAS follow a 2-step approach
  A) Reconstruct the individual particles using particle flow
  B) Use kinematic variables to improve the mode classification
- Extensive performance studies of the algorithms have been performed, a few results were shown as examples:
  - Correct classification in ~70% of all cases
  - Classification is pile up robust
  - Energy resolution stable wrt. PT and pile up
  - Reasonable mass resolution in reconstructed 1p1n decays

Outlook

- Improvements are expected in several areas:
  Strip layer...: Full potential not exploited yet
  Shrinking Cone: Should further increase pile up stability
  Conversions...: Recovery of 2-track taus