

# Alma 9 Validation

## Dark Photon Samples

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# Introduction

- Validate ALMA9 version of Calypso for the track variables
- Sinead already looked at single muon samples
- Ansh looked at the  $A'$  analysis cutflow
- We want to look at the “two track reconstruction” as a function of separation between them

# Data Description

- We will look at Dark-Photon decays to electron pairs
- Data samples used are
  - /eos/experiment/faser/data0/sim/mc24/foresee/1100{33,38,51}/
    - 110033 : Mass = 10 MeV, epsilon = 1E-5
    - 110038 : Mass = 100 MeV, epsilon = 1E-5
    - 110051 : Mass = 10 MeV, epsilon = 1E-4
- ALMA 9 samples : ./phy/s0008-dev/
- CENTOS 7 samples: ./phy/s0008-r0019/
- Chaining them together for better statistics [total 60k events]
- Can separate based on mass/couplings if interested

# Overview of Validation

**Objective: To quantify the Efficiency of two track reconstruction as a function of separation between tracks**

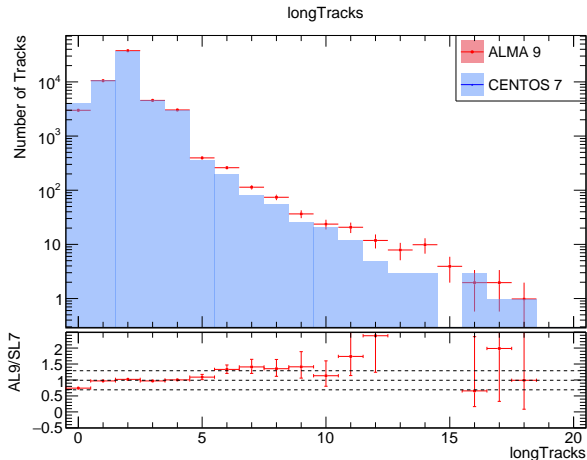
- Perform an initial assessment of the Track Parameters
- Quantify the separation between tracks
- Evaluate generic track reconstruction performance
- Define a metric for “Reconstruction Efficiency”

# Distribution of Track Parameters

## Basic Plot Parameters to assess

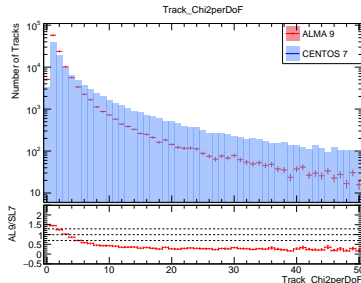
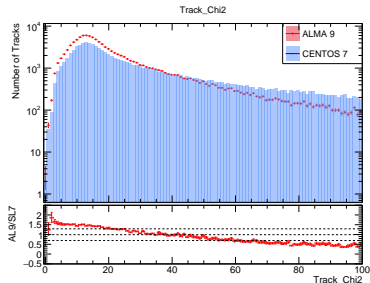
- longTracks
- Track Chi2
- Track Chi2perDoF
- Track nDoF
- Track charge
- Track nLayers

# Distribution of longTracks



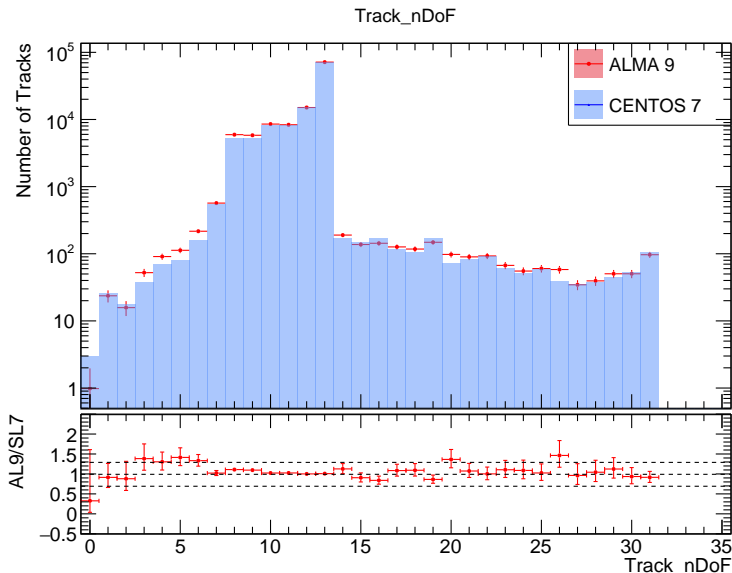
- ALMA9 has fewer 0-track events;
- Also reconstructs more events with more than 5 tracks.
- Total number of longTracks: CENTOS7: 115,206, AL9: 118,491
- A 2.8% increase in longTracks in AL9.

# Distribution of TrackChi2



- Displays the greatest improvement in ALMA9.
- Overall Tracks have lower Chi2/DoF in ALMA9.

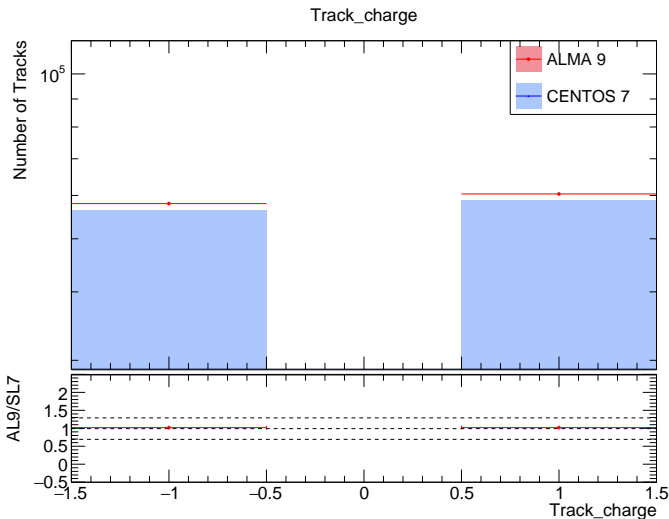
# Distribution of TrackNDoF



- Generally strong agreement, except for bins 3-5.

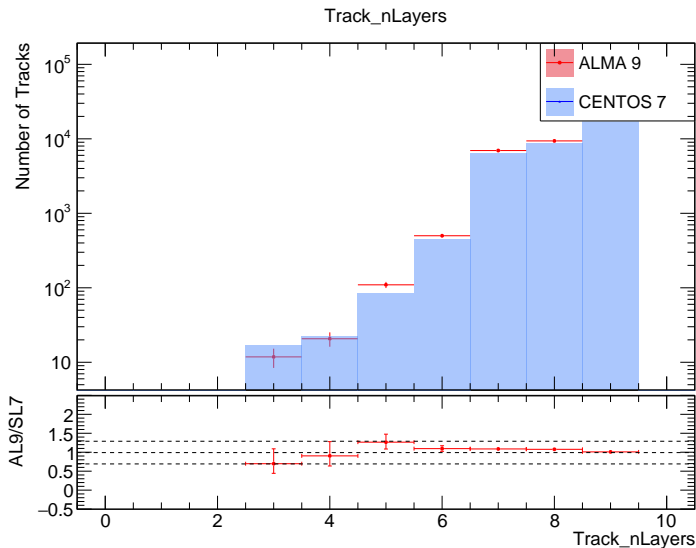


# Distribution of Track Charge



- The ratio is 1.028 [same factor of increase seen in longTracks]
- Ratio of positive to negative tracks is 1.04 in both. ChargeMISID?

# Distribution of Track nLayers



- Similar agreement within statistical uncertainties.

# Quantifying Separation

## Possible Track Separation Variables

- $\Delta R_{0,1}$  : Separation between the electron and positron at the first/last tracking station in the x-y plane
- $\theta_{0,1}$  : Angle between the line connection decay vertex to the two tracks at the first/last tracking station
- $\Delta X_{0,1}$  : Same as above but only in x direction
- $\Delta Y_{0,1}$  : Same as above but only in y direction
- $\Delta R_P = \sqrt{\Delta \eta^2 + \Delta \phi^2}$  : Momentum space separation between electron and positron

## Notes:

- Particle predominantly separated in the y-direction due to magnetic field
- DeltaX looks symmetric but separation here is much lower. [ $\Delta R \approx \Delta R$ ]
- DeltaRP has a relatively “flat” distribution and is not a good separation to quantify reconstruction
- We shall use DeltaR and Theta as the primary separation variables

# Track Separation Calculations

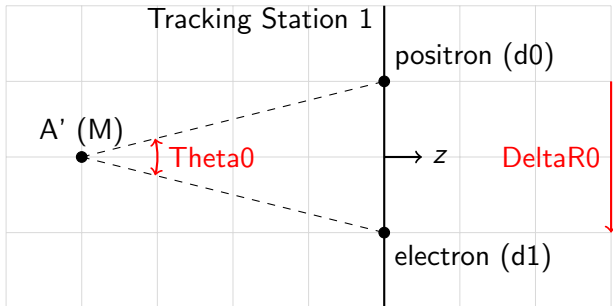


Figure: Angle and separation between the particles defined

## Calculation of Separation Variables

- Separation variables are calculated using MC-truth data.
- This ensures consistency across both ALMA9 and CENTOS7.
- The separation variables used are :
  - $truthd0\_x$ ,  $truthd0\_y$ ,  $truthd1\_x$ ,  $truthd1\_y$ ,  $truthd0\_z$ ,  $truthd1\_z$
  - They are vectors containing the “truth positions” of d0 ( $e^+$ ) and d1 ( $e^-$ ):
  - at the vertex, the first, second, and third tracking stations.

# Distribution of DeltaR

Distribution of DeltaR0 [Truth Level]

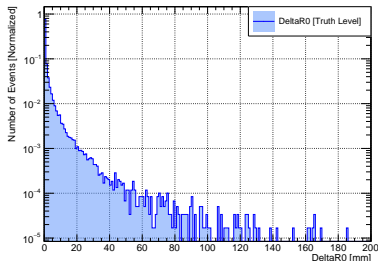


Figure: Distribution of DeltaR0 [DeltaR at Station 1]

Distribution of DeltaR1 [Truth Level]

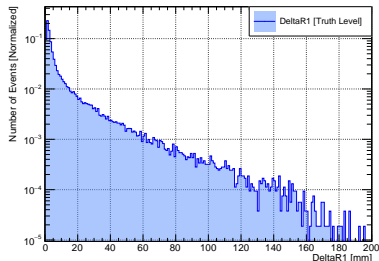
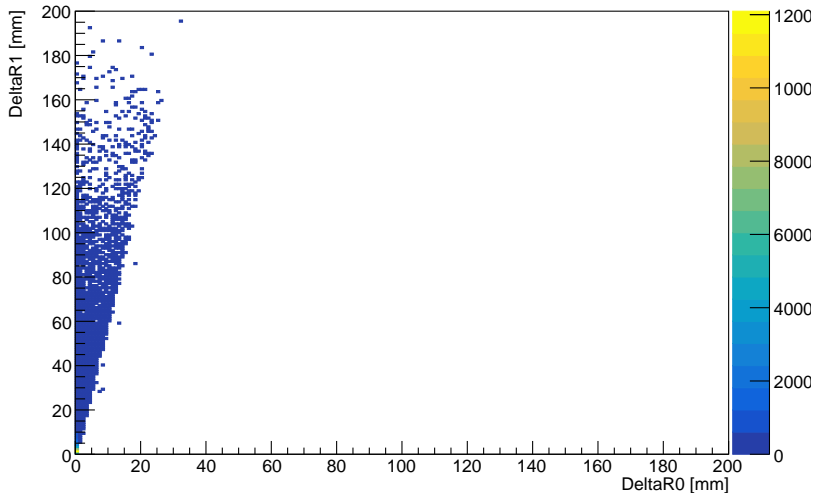


Figure: Distribution of DeltaR1 [DeltaR at Station 3]

- NEvents decay with increasing separation as expected
- Separations increase at the last tracking station due to the magnetic field
- Large separations at Station1 [ $>30$  mm] aren't reconstructed at Station3

# Transfer Plot between DeltaR0 and DeltaR1

DeltaR0 vs DeltaR1



# Distribution of Theta

Distribution of Theta0 [Truth Level]

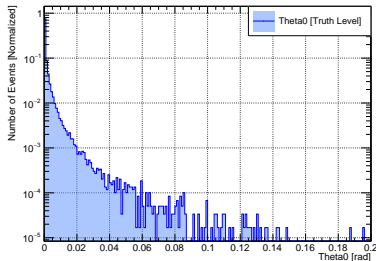


Figure: Distribution of Theta0 [Theta at Station 1]

Distribution of Theta1 [Truth Level]

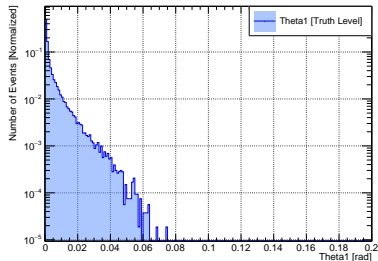
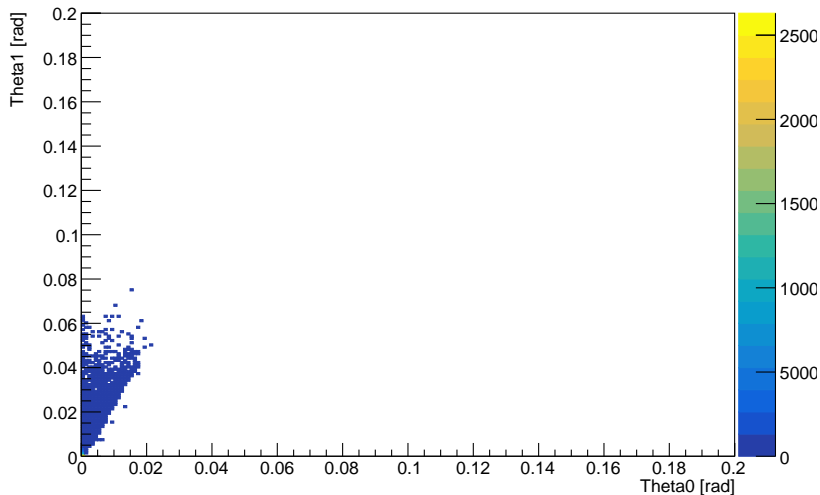


Figure: Distribution of Theta1 [Theta at Station 3]

- As previously seen, separations increases at the last tracking station.
- Large separations at Station1 [ $>0.03$  rad] aren't reconstructed at Station3
- Minimum angle for which a track can still go through the tracking spectrometer  $0.083$  rad [ $\arctan \frac{0.2m}{2.4m}$ , without accounting for the magnetic field]

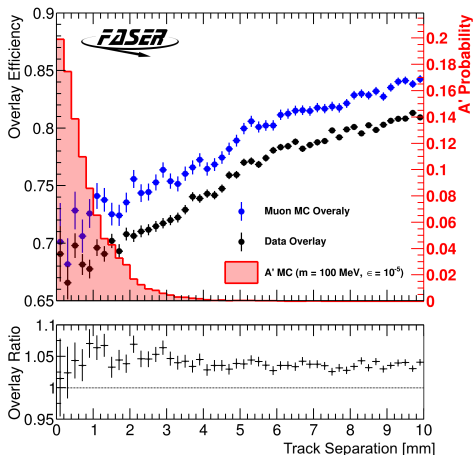
# Transfer Plot between Theta0 and Theta1

Theta0 vs Theta1





# Previous Efficiency Studies : Overlay



**Figure:** Overlay plot from Search for dark photons with the FASER detector at the LHC  
The separation variable used is the "distance between the two tracks at their first measurements"

# Previous Efficiency Studies : A' Tracking CutFlow

Selection	ALMA9				CENTOS7				$\Delta\text{Eff.}$
	Pass	All	Eff.	Cum. Eff.	Pass	All	Eff.	Cum. Eff.	
$\geq 1$ LongTracks	56989	60000	94.98	94.98	56002	60000	93.34	93.34	1.64
$\geq 2$ LongTracks	46416	56989	81.45	77.36	45210	56002	80.73	75.35	0.72
$= 2$ LongTracks	37807	46416	81.45	63.01	36746	45210	81.28	61.24	0.17
<b>Opposite Charge</b>	32427	37807	85.77	54.04	30375	36746	82.66	50.62	<b>3.11</b>
MaxRadius < 100	31489	32427	97.11	52.48	29520	30375	97.19	49.20	-0.08
goodTrack Cuts									
$\geq 7$ Layers	31435	31489	99.83	52.39	29472	29520	99.84	49.12	-0.01
$\chi^2/\text{DoF} < 25$	31121	31435	99.00	51.87	27710	29472	94.02	46.18	<b>4.98</b>
$\geq 7$ DoF	31115	31121	99.98	51.86	27706	27710	99.99	46.18	-0.01

**Table:** Comparison of efficiency and cumulative efficiency for ALMA9 and CENTOS7.

Note: The Cutflow is at an Event Level (not track level), thus the conditions have to met by all tracks in the event.

- Highest improvement in goodTrack Cut of  $\chi^2/\text{DoF} < 25$
- Better ChargeID in ALMA9?
- We want to take a look at it differentially

# Definition of Fiducial

Before we define the efficiency we must account for the detector acceptance by ensuring the particle to be Fiducial.

## Fiducial Criteria Based on Truth-Level Data

- $\text{truthd0\_r} [\{1,2,3\}] < 100$
- $\text{truthd1\_r} [\{1,2,3\}] < 100$
- $\text{truthd0\_pz} > 20 \text{ GeV}$
- $\text{truthd1\_pz} > 20 \text{ GeV}$

A truth-level prescription is preferred because the reconstruction-based approach depends on reconstruction performance, whereas “fiducial” should ideally be a function of the detector alone.

**Note:**  $\text{truthd0\_r} = \sqrt{\text{truthd0\_x}^2 + \text{truthd0\_y}^2}$ , and similarly for d1.

# Fiducial CutFlow

Selection Criteria	Pass	All	Eff (%)	Cum. Eff (%)
truthd_st1_r < 100	59228	60000	98.71	98.71
truthd_st2_r < 100	56549	59228	95.48	94.25
truthd_st3_r < 100	52640	56549	93.09	87.73
truthd_pz > 20 GeV	50444	52640	95.83	84.07

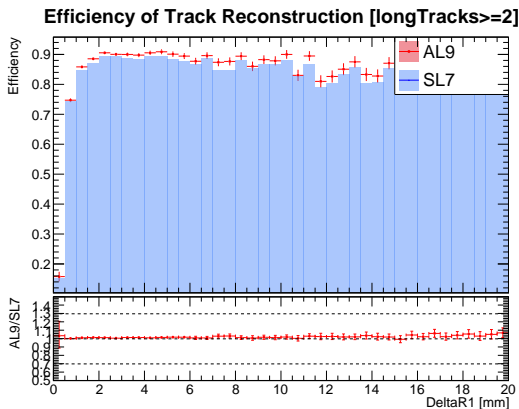
**Table:** Efficiencies and cumulative efficiencies for truth-level selection steps. [same for ALMA9/CENTOS7]

# Track Reconstruction Efficiency Defined

- Remove acceptance based on fiducial cuts at truth level
- Define Efficiency as the fraction of events with  $\geq 2$  reconstructed longTracks divided by the total number of events which is same as  $\geq 0$  longTracks. [Given both are fiducial]

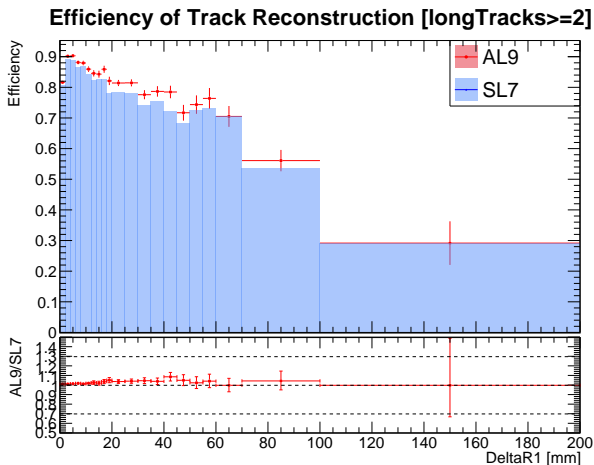
$$\text{Efficiency} = \frac{N_{\text{Events}}(\geq 2 \text{ longTracks} \mid \text{fiducial})}{N_{\text{Events}}(\geq 0 \text{ longTracks} \mid \text{fiducial})}$$

# $\geq 2$ Track Efficiency as a function of DeltaR1



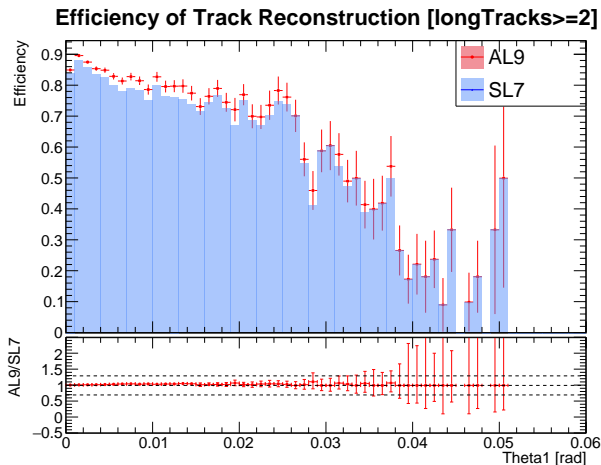
- There is generally agreement between ALMA9 and CENTOS7
- Although characteristics is different from the overlay study
  - Overlay shows a more gradual growth to 90% efficiency

# $\geq 2$ Track Efficiency as a function of DeltaR1



- The Efficiency seem to decay at higher separation!

# $\geq 2$ Track Efficiency as a function of Theta1

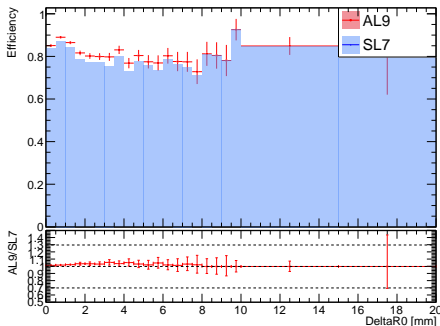


- The decay of efficiency at large separation is existent here as well.

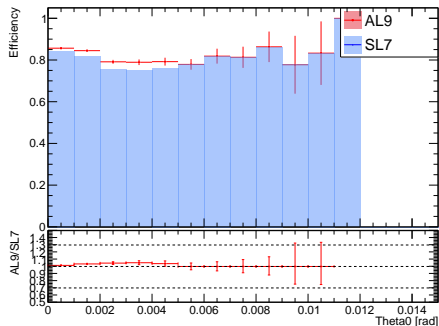


# Efficiencies as a Function of Separation @ Station 1

Efficiency of Track Reconstruction [longTracks>=2]



Efficiency of Track Reconstruction [longTracks>=2]



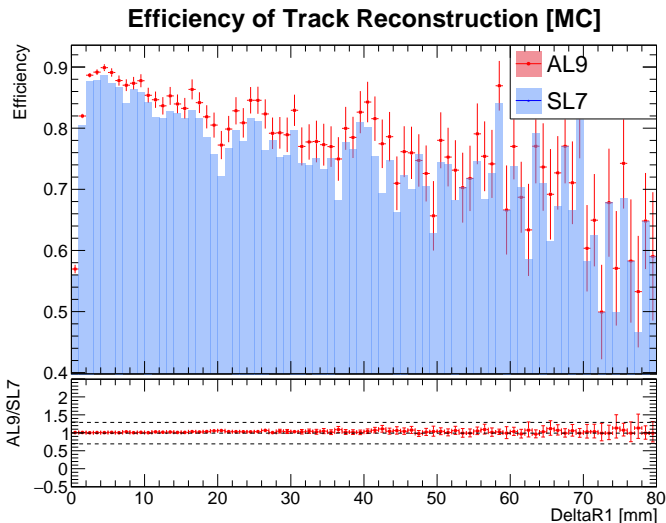
- The efficiencies at Station 1 seem constant throughout!
- No decrease in efficiency at low separations!

# Efficiency Metric based on Reconstructed Truth

We are interested only in the two primary tracks from  $e^+e^-$ . Thus we can use the reconstructed truth variables to check if the underlying truth particles are reconstructed.

- For acceptance: Truth Position of  $e^+e^- < 100$
- **Identify the two primary tracks**
  - $t\_barcode = 2,3 \implies$  primary tracks
  - Also require  $t\_barcode\_parent = 1 \implies$  from DarkPhoton
- TLDR; Ran the analysis with the above definition, but the results are the exact same as  $\geq 2$  case
- So if event reconstructed has more than 2 longTracks, the two primary tracks are reconstructed, according to above definition.

# Efficiency Metric based on Reconstructed Truth



**Figure:** Efficiency defined using reconstructed truth variables is same as the  $\geq 2$  longTracks definition

# Conclusions

- The “efficiencies” generally agrees between ALMA9 and CENTOS7
- Lack of agreement with the overlay study
- Interpretation of efficiency decay at Station 3 is unclear
- The resolution of track reconstruction (Track  $\chi^2$ ) has improved.
  - Can try to quantify the above in “efficiency”