ATLAS WS on Tau Lepton Physics 2009

Conversion Track Tagging and other Track Selection Studies in Tau Reconstruction

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Outline:

1. Photon Conversion Reco & ID
2. Implementation in rel. 15
3. Results with $\approx$ rel. 15
4. Trk Selection & Conv Tagging
5. Summary

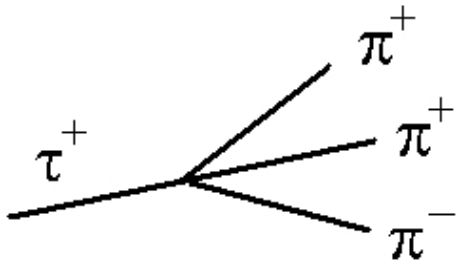
Motivation: τ-Decay and π^0-Decay

- τ-decay:

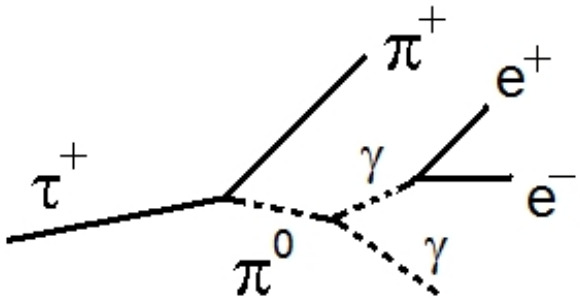
leptonic	**(35.2 %)**
$\tau \rightarrow e + \nu_e + \nu_\tau$	
$\tau \rightarrow \mu + \nu_\mu + \nu_\tau$	
hadronic	
1 Prong	**(46.8 %)**
$\tau \rightarrow \pi^\pm + \nu_\tau$	
$\tau \rightarrow \pi^\pm + n \cdot \pi^0 + \nu_\tau$	
3 Prong	**(13.9 %)**
$\tau \rightarrow \pi^\pm + \pi^\pm + \pi^\pm + \nu_\tau$	
$\tau \rightarrow \pi^\pm + \pi^\pm + \pi^\pm + n \cdot \pi^0 + \nu_\tau$	

- a π^0occurs in 40,58% of all τ-decays
- τ-decay with photon conversion:
  - $\tau^+ \rightarrow \pi^+\pi^0\nu_\tau \rightarrow \pi^+\gamma\gamma\nu_\tau \rightarrow \pi^+\gamma e^+e^-\nu_\tau$
- numerical example:

process: $Z \rightarrow \tau\tau$	100
τ	200
π^0	353
γ-conversions	185



τ decays into three charged π's (3 Prong)



τ decays into one π^+ (1 Prong) and one π^0, which decays into two γ's, one of them makes a e^+e^- pair creation

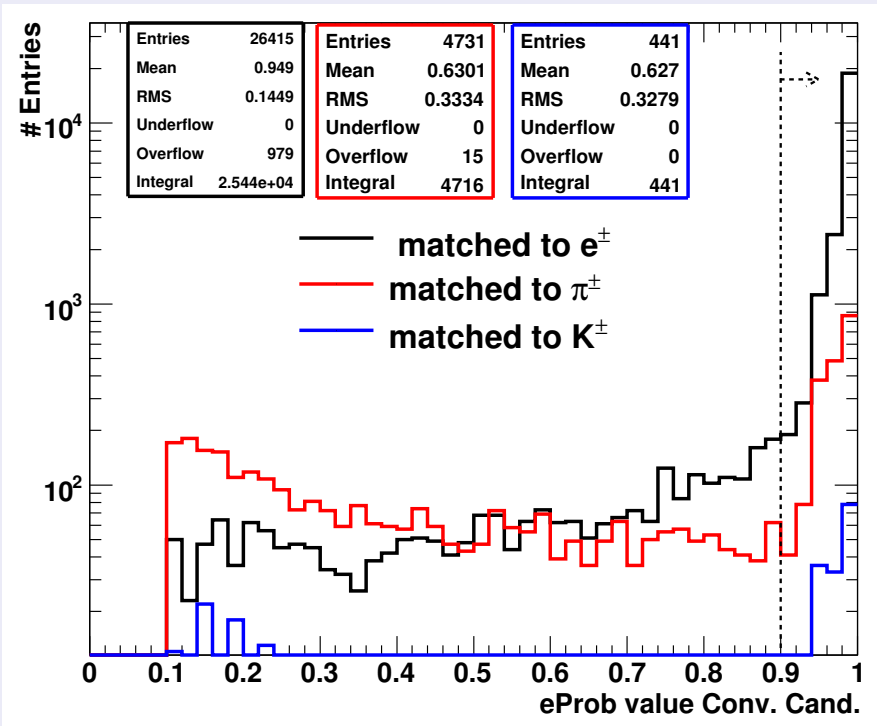
Reconstruction & Identification of Photon Conversions

1. Reconstruction

- investigate all reconstructed tracks
- reject all tracks from IP
- build pos./neg. track pairs
- refit the tracks to a secondary vertex (constraint: inv mass = 0 (m_γ))

2. Identification (modified for τ environment)

- *TRT Electron **P**article **ID**entification Tool* provides:
  - with a Likelihood method
  - based on TRT High Threshold Hits
  - an electron probability for each track
- photon conv. is tagged as identified, if both tracks (eProb $> 90\%$)



Result of τ specific Conversion Identification

1. Reconstruction - Conversion Candidates

$e^{\pm}$	77.8 ± 0.6 %
$\pi^{\pm}$	20.2 ± 0.3 %
$K^{\pm}$	2.0 ± 0.1 %

- already high fraction of electrons
- large number of $\pi^{\pm}$
  - often $\pi^{\pm}$ pairs from 3Prongs
  - identification is needed
  - overwise supressing 'good' τ tracks

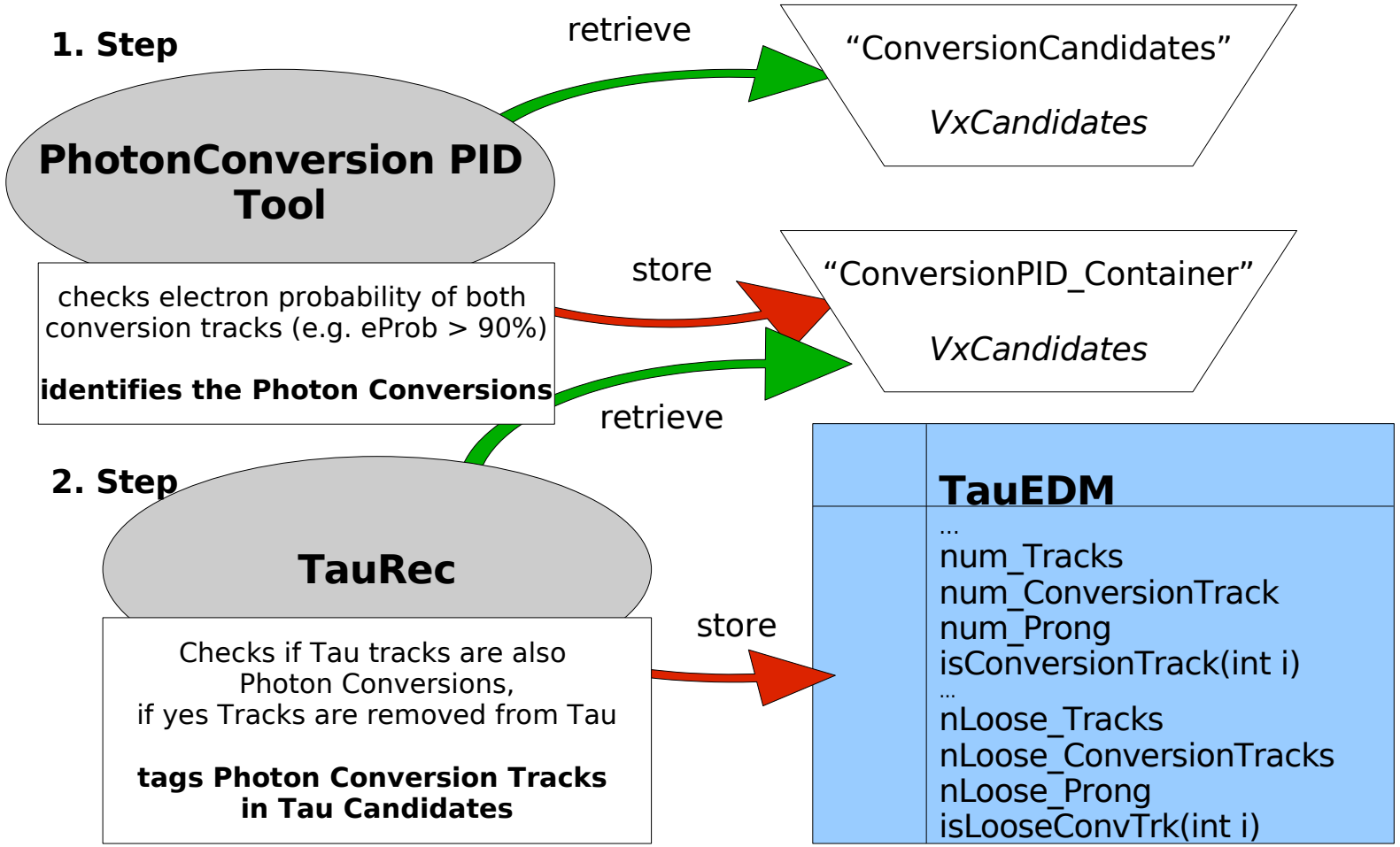
2. Identification - identified Photon Conversions

$e^{\pm}$	92.4 ± 0.9 %
$\pi^{\pm}$	7.0 ± 0.2 %
$K^{\pm}$	0.6 ± 0.1 %

- many $\pi^{\pm}$ could be rejected
- at least an electron purity of 90 % is needed

- Sufficient electron purity to tag photon conversions in τ decays

Implementation in Release 15



- Photon Conversion finding in 2 Steps (impl. in TauRec/run in TauTools)
  1. Identify Photon Conversions from Conversion Candidates
  2. Check if Trk is used to build Conv. and τ Candidate
- new Transient Container with identified Photon Conversions
- Conversion variables in new TauEDM

Testing Setup:

To run recent developements this setup has been used:

- rel. 14.5.1 plus additional tags:
  - RecExCommon-00-10-38
  - tauRec-03-08-16
  - tauEvent-00-04-08
  - TauDiscriminant-00-00-32
  - RecTPCnv-00-05-14-04 (+ cvs update of Tau* to 00-05-20)
  - RecAthenaPool-00-05-02-05
  - TauTools-00-04-02
  - AtlfastConversionTools-00-05-00

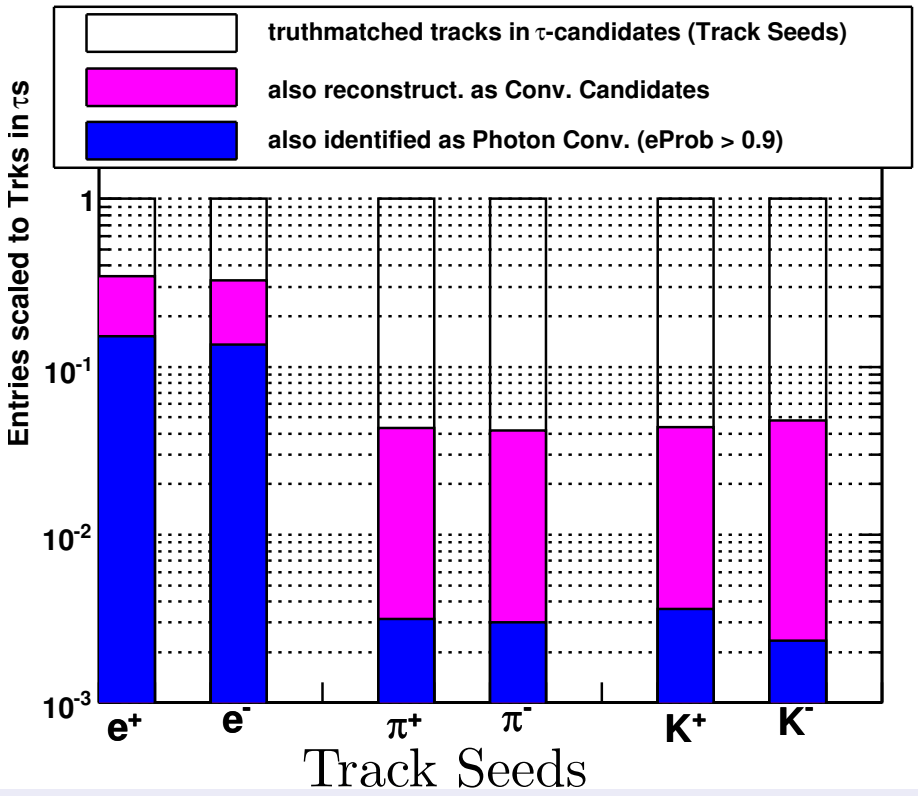
To dump all new variables into D3PD those tags have to be changed:

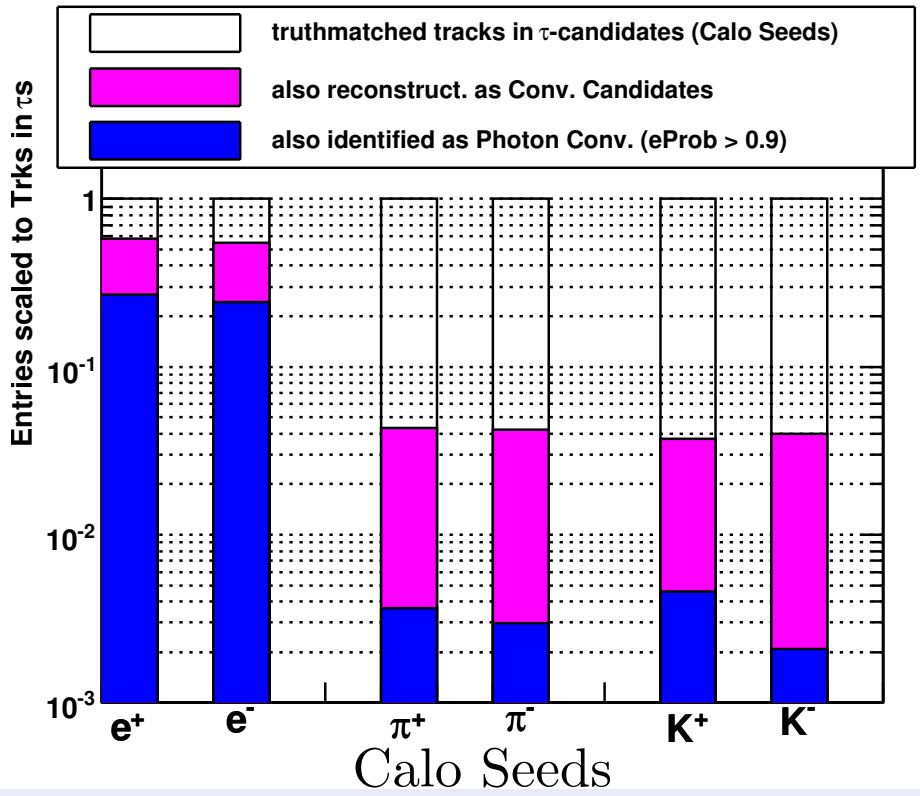
  - EventViewUserData-14-05-00-02
  - TauDPDMaker-00-04-03

- This setup has been used to check rel 15. performance before rel. 15 was built!
  - **Now**: Just use rel 15!

Reconstructed Photon Conversions in τ Decays

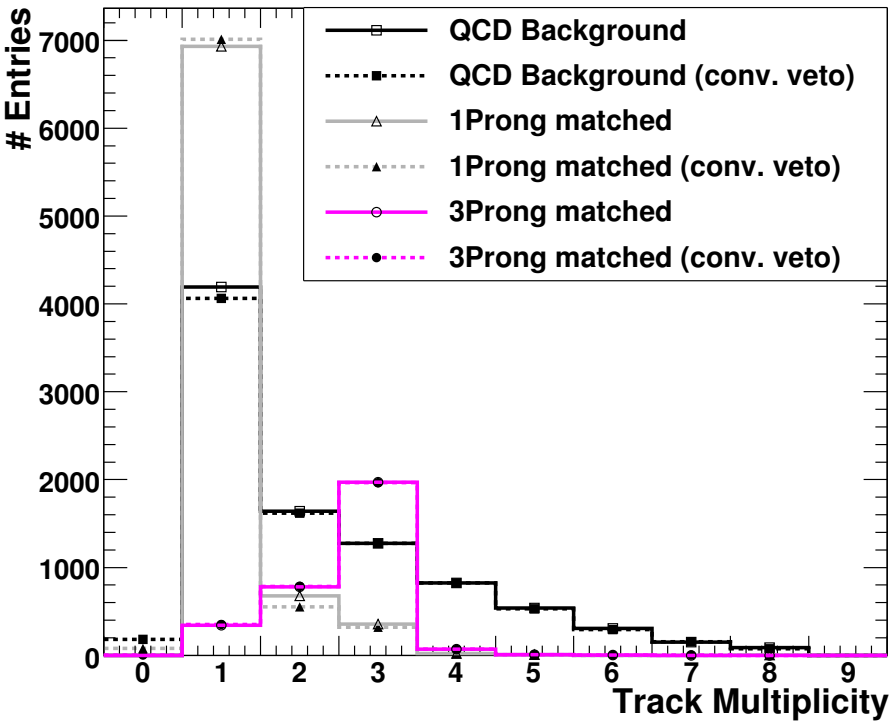
Overlap of τ trks, conv cand trks, and photon conv trks



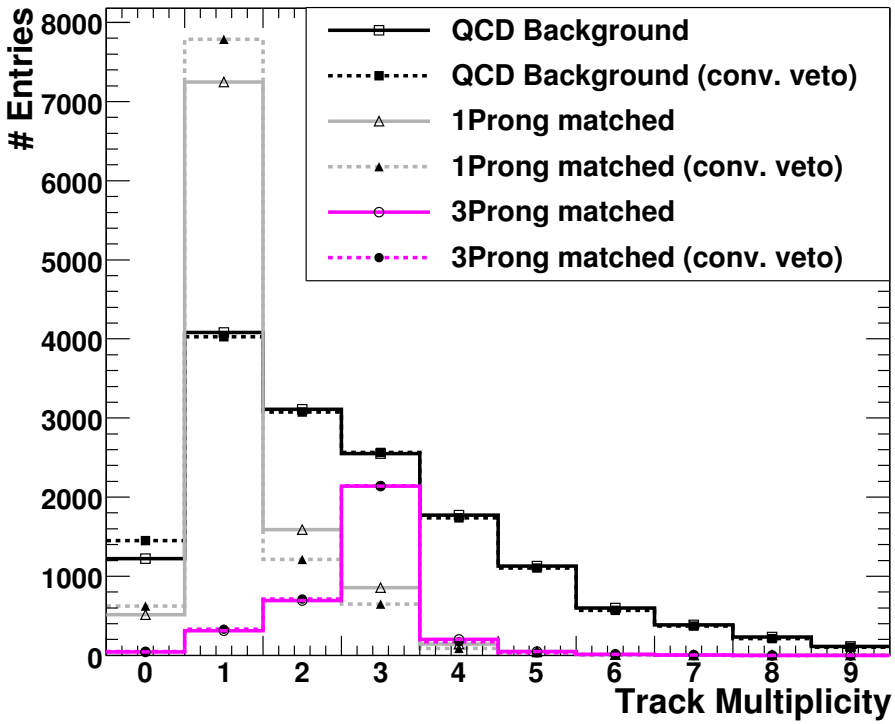


- 29.4 % of $e^{\pm}$ tracks (*Calo Seed*) of τ cand. are tagged as ID conv tracks ($\approx$ 17 % *Track Seed*)
- both Seeds: < 0.45 % of $\pi^{\pm}$ tracks and < 0.35 % of $K^{\pm}$ tracks are tagged wrongly

Corrected Track Multiplicities



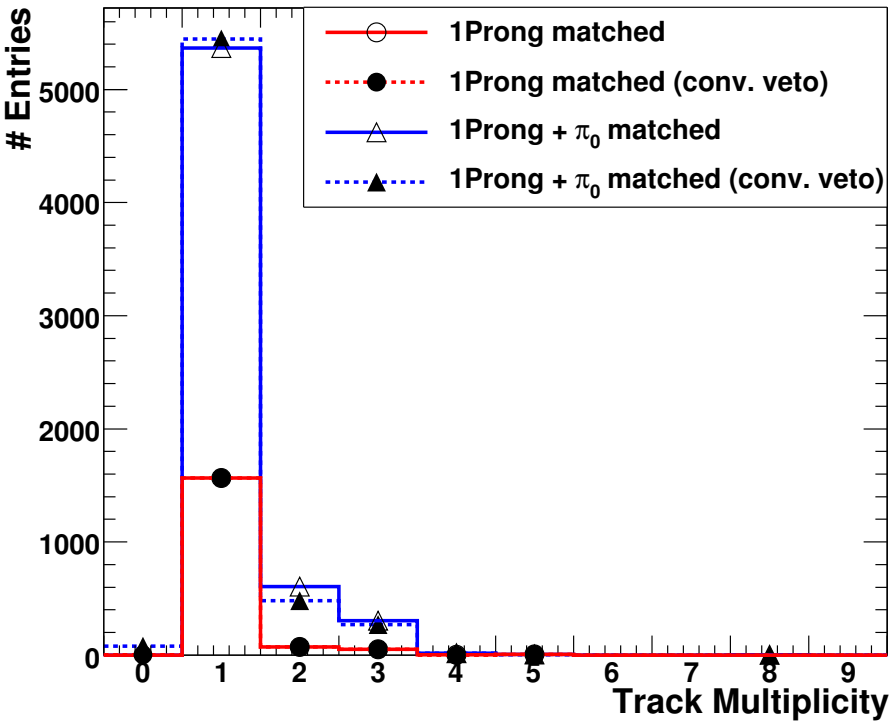
Track Seeds



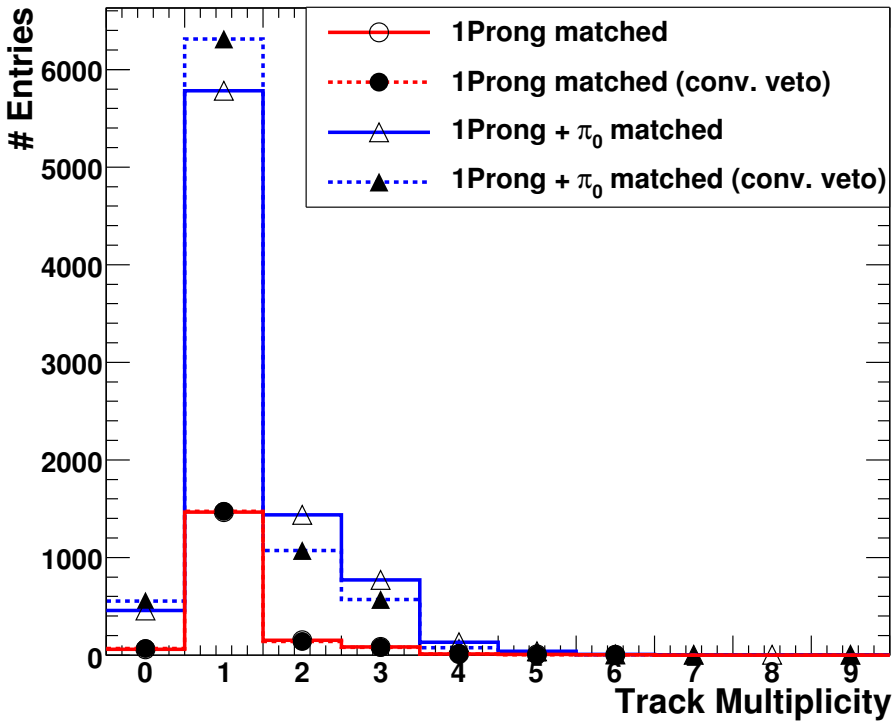
Calo Seeds

- *Track Seed* much lower fraction of QCD background (tighter selection)
- more corrections for matched τs than for QCD background
- much more 1 Prong reconstructed by *Calo Seed* alg.
- conversion tagging much more useful for *Calo Seeds*

1 Prong Track Multiplicities



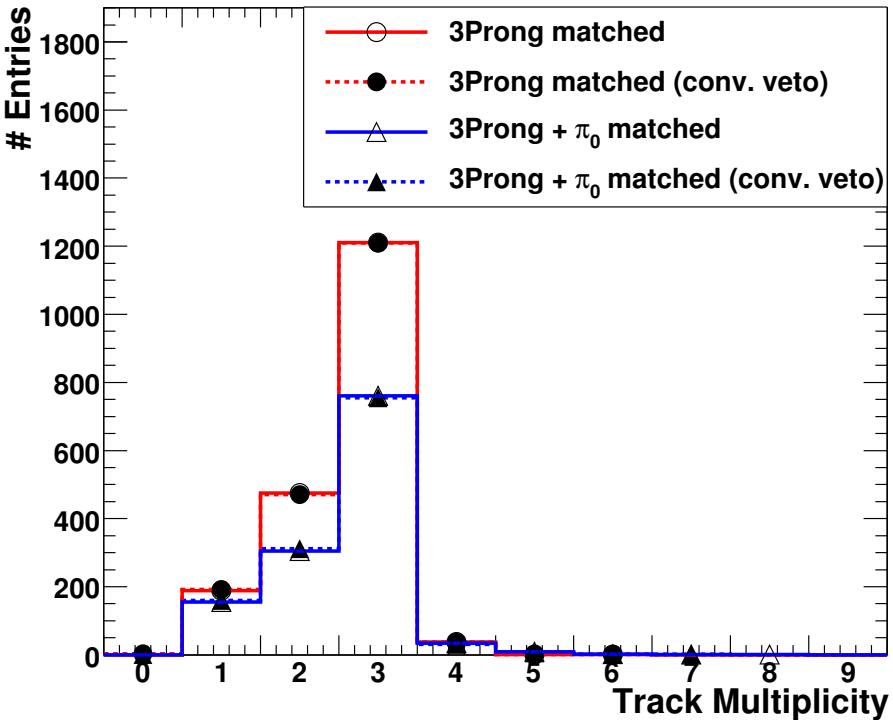
Track Seeds



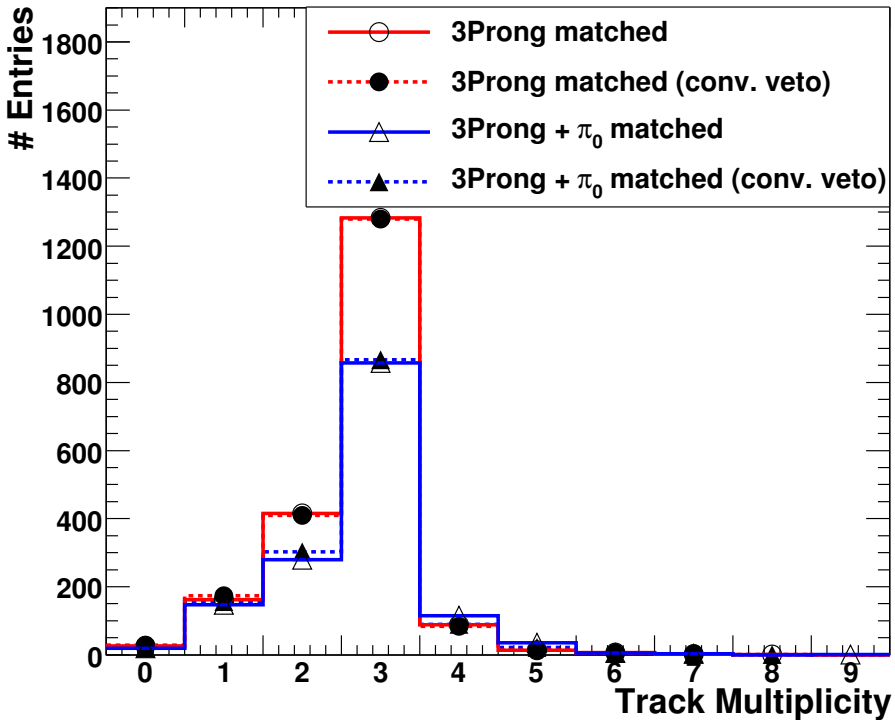
Calo Seeds

- corrections only in τ decays with π^0 (blue)
- good improvement for *Calo Seed* 1 Prong decays

3 Prong Track Multiplicities



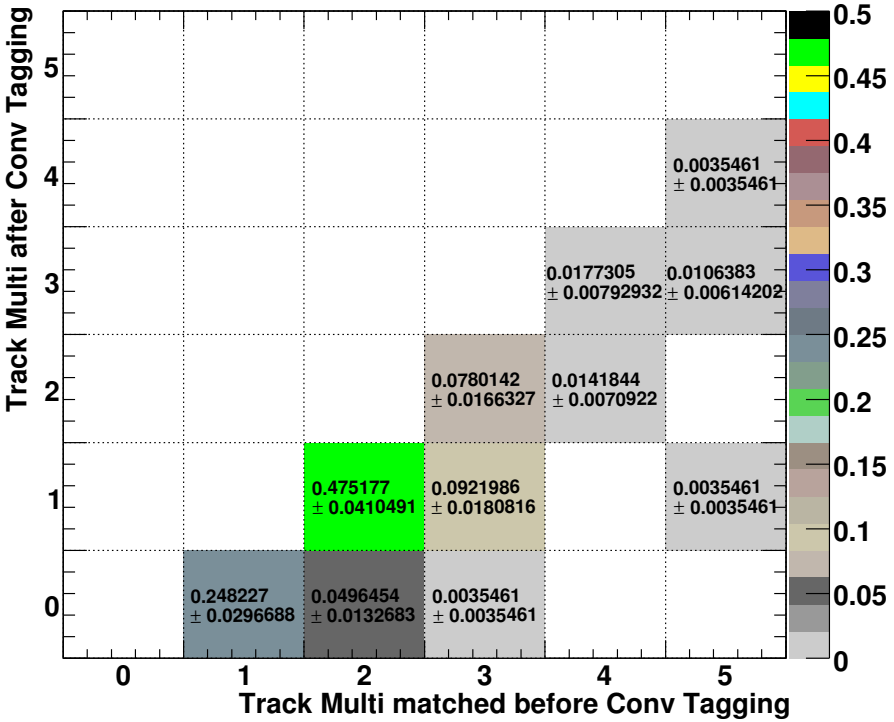
Track Seeds

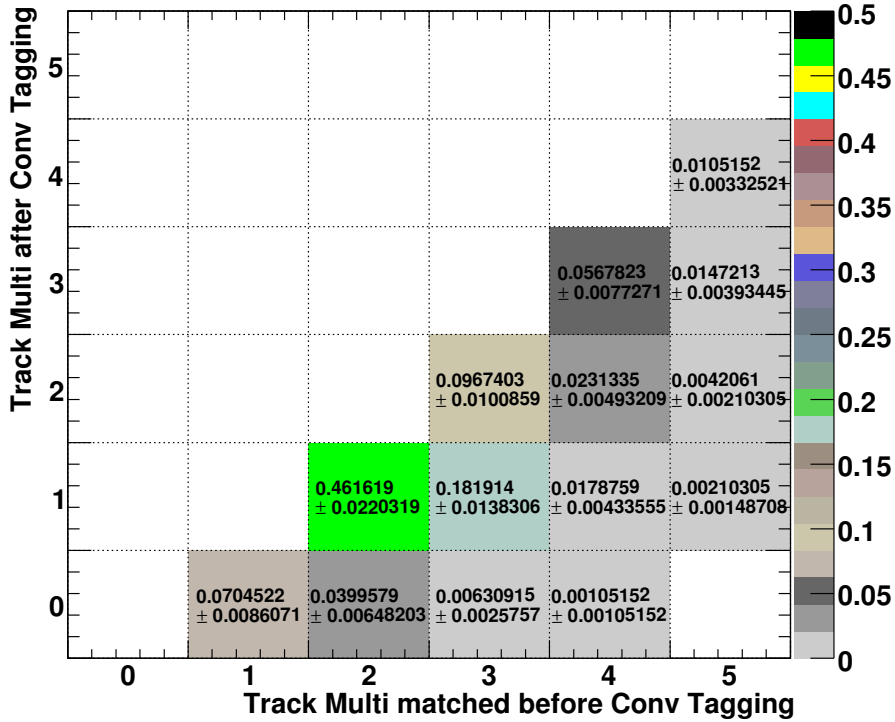


Calo Seeds

- less entries and corrections than in 1 Prong decays
- theoretically understood
  - only in 25.6 % of 3 Prong decays occur π^0 (blue)

Correction Overview





Track Seed:

- 2.0 % of all truthmatched τ candidates are corrected
  - 54.5 % correction $X \rightarrow 1$ Prong (tot.: 1.1 %)
  - 33.1 % miss correction in total $X \rightarrow 0$ Prong (tot.: 0.7 %)

Calo Seed:

- 6.7 % of all truthmatched τ candidates are corrected
  - 67.0 % correction $X \rightarrow 1$ Prong (tot.: 4.5 %)
  - 12.0 % miss correction in total $X \rightarrow 0$ Prong (tot.: 0.8 %)

Summary Table

- Reconstruction efficiency of 1 and 3 Prong τ candidates
- Definition:

$$eff = \frac{\text{reco}\,(1\,\text{Trk})\,\text{matched to true}\,1\,\text{Prong}}{\text{true}\,1\,\text{Prong}}$$

with acceptance cuts $\eta < 2.5$ and $p_{\tau_{\text{Track}}} > 1.0$ Gev on true τs

	Track Seeds		Calo Seeds	
	def.	conv veto	def.	conv veto
1 Prong	52.33	52.95	54.71	58.81
no π^0	66.12	66.16	61.89	62.32
π^0	49.32	50.08	53.15	58.05
3 Prong	48.55	48.38	52.68	52.83
no π^0	51.58	51.53	54.64	54.51
π^0	44.40	44.05	50.00	50.53
Total	51.44	51.88	54.24	57.41

- Improvement for 1 Prong decays (most γ conversions expected)
- Increase reco. efficiency of *Calo Seed* τ candidates by 3.2 % points

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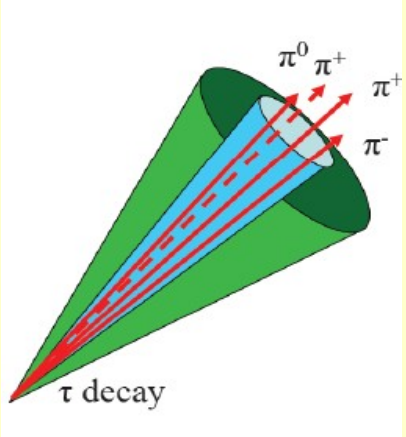
Track Quality Criteria for Taus and Photon Conversion Reconstruction

Motivation: How is the performance of the Track Selection for Taus changed by including the Photon Conversion Tagging Tool?

Track Selection Procedure used in this study

- Select tracks on AOD level (no tau reconstruction)



  - Find true taus ($|\eta|$<2.5 and with true tracks PT>1GeV) and classify them as 1 prong or 3 prongs tau decays (for 'Track Seed' study, require at least one true track PT>6GeV)
  - For 'Calo Seed' taus :
    - count selected tracks within a cone of DR<0.3 around the true tau
  - For 'Track Seed' taus:
    - Find 1st quality track within a cone of DR<0.2 around the true tau
    - Find 2nd quality tracks within a cone of DR<0.2 around the 1st quality track

Default Quality Cuts for Track Selection

Calo Seed:

Cut	Value
pTMin	1000
IPd0Max	1.
IPz0Max	1.5
nHitBLayer	0
nHitPix	0
nHitSct	0
nHitSi	7
nHitTrt	0
$\chi^2 ndf$	99999.

Track Seed:

Cut	Tau1P	Tau3P
pTMin	6000.	1000
IPd0Max	2.	1.
IPz0Max	10.	1.5
nHitBLayer	0	1
nHitPix	0	2
nHitSct	0	0
nHitSi	7	7
nHitTrt	0	0
$\chi^2 ndf$	99999.	99999.

Track Selection Efficiency

Track Selection for 'Calo Seed':

	True 1 Prong tau		True 3 Prong taus		1P + 3P
	w/o conv.	w. conv	w/o conv.	w. conv	
Default	86.8%	64.8%	76.2%	62.9%	73.0 ± 0.4 %
Default + Conv. Tool	87.5%	76.5%	70.2%	62.8%	77.6 ± 0.4 %

significant improvement | but degradation... | total efficiency improves!

Track Selection for 'Track Seed':

	True 1 Prong tau		True 3 Prong taus		1P + 3P
	w/o conv.	w. conv	w/o conv.	w. conv	
Default	90.6%	84.7%	72.0%	66.9%	82.6 ± 0.4 %
Default + Conv. Tool	88.1%	84.1%	67.9%	63.6%	80.5 ± 0.4 %
no Blayer+Conv. Tool	88.1%	81.3%	68.6%	63.6%	79.5 ± 0.4 %

degradation in performance

Track Migration

Track Selection for 'Calo Seed':

	1P→3P		3P→1P	
	w/o conv.	w/ conv.	w/o conv.	w/ conv.
Default	1.4%	8.2 %	1.3%	1.6%
Default + Conv. Tool	0.5%	3.7%	3.7%	5.1%

significant improvement

but degradation...

Track Selection for 'Track Seed':

	1P→3P		3P→1P	
	w/o conv.	w/ conv.	w/o conv.	w/ conv.
Default	0.4%	1.6%	2.5%	2.1%
Default + Conv. Tool	0.3%	1.0%	4.0%	3.2%
No BLayer+Conv. Tool	0.3%	1.6%	3.8%	3.1%

No improvement with conv. tool

Summary

- Method to identify Photon Conv. in τ environment has been worked out
  - Based on TRT Electron PID Tool only
- Improvements in the τ track multiplicity have been shown
- Conversion tagging tool for τ candidates is already implemented in rel. 15
- Study of the impact of tagged conv. trks on the track selection criteria:
  - Calo Seeds:
    - significant improvement in eff. & migration of 1 prongs
    - degrades performance for 3 prongs (which was not seen for reco τs)
  - Track Seeds:
    - No improvement - neither in default setup nor without BLayer cut

Outlook

- Study correlation between reco eff. & effects on TSC eff. in more detail
- Repeat study of conv tagging and TSC with pile-up samples
- Provide likelihood pdf with tagged conversion tracks
  - to study the impact on identified τs
- An internal note about conversion tagging in τ cand. is almost done!
- Study photon conversions in minimum bias events of first data

Back-up Slides

Track Selection Criteria

Track Seeds

Seed building cuts:

ΔR Core Track Cut	0.2
pTLeadTrackCut [GeV]	6.
ΔR OtherTrackCut	0.2
NOther Tracks Cut	7
Reco Other Eta Cut	2.5
ΔR Isol Track Cut	0.4

Tracks selection cuts:

Cut	Tau1P	Tau3P
pTMin	1000	1000
IPd0Max	2.	1.
IPz0Max	10.	1.5
nHitBLayer	0	1
nHitPix	0	2
nHitSct	0	0
nHitSi	7	7
nHitTrt	0	0
$\chi^2 ndf$	99999.	99999.

Calo Seeds

Seed building cuts:

CellEthreshold [GeV]	0.2
StripEthreshold [GeV]	0.2
EMSumThreshold [GeV]	0.5
EMSumRadius	0.2
Track Isol Cone Low	0.1
Track Isol Cone High	0.4

Tracks selection cuts:

Cut	Value
pTMin	1000
IPd0Max	1.
IPz0Max	1.5
nHitBLayer	0
nHitPix	0
nHitSct	0
nHitSi	7
nHitTrt	0
$\chi^2 ndf$	99999.

all cuts are taken from:
/atlas/Reconstruction/tauRec/python/TauMergedGetter.py

Track Selection Efficiency

Track Selection for 'Calo Seed':

Default Track Selection

	1 Prong	1 Prong + Conv.	Total	3 Prongs	3 Prongs + Conv.	Total
≥ 5 Tracks	0.11	0.54	0.38 (0.06)	1.26	6.17	2.54 (0.28)
4 Tracks	0.22	1.42	0.97 (0.10)	4.74	12.45	6.75 (0.45)
3 Tracks	1.35	8.21	5.65 (0.23)	76.21	62.89	72.73 (0.80)
2 Tracks	6.93	20.26	15.28 (0.37)	16.18	16.52	16.27 (0.66)
1 Track	86.83	64.81	73.03 (0.45)	1.26	1.60	1.35 (0.21)
No Tracks	4.56	4.76	4.68 (0.21)	0.35	0.37	0.35 (0.11)

Default Track Selection + Conv. Tool

	1 Prong	1 Prong + Conv.	Total	3 Prongs	3 Prongs + Conv.	Total
≥ 5 Tracks	0.03	0.15	0.10 (0.03)	0.39	2.10	0.84 (0.16)
4 Tracks	0.14	0.54	0.39 (0.06)	2.44	7.77	3.83 (0.34)
3 Tracks	0.50	3.70	2.51 (0.16)	70.25	62.76	68.30 (0.83)
2 Tracks	4.56	11.82	9.11 (0.29)	19.92	20.84	20.16 (0.72)
1 Track	87.49	76.54	80.63 (0.40)	3.74	5.06	4.08 (0.35)
No Tracks	7.29	7.24	7.26 (0.26)	3.26	1.48	2.80 (0.30)

Track Selection Efficiency

Considering only true taus matching to reconstructed TauRec candidates:

Track Selection for 'Calo Seed':

	True 1 Prong tau		True 3 Prong taus		1P + 3P
	w/o conv.	w. conv	w/o conv.	w. conv	
Default	86.8%	64.6%	71.6%	59.8%	71.7 ± 0.4 %
Default + Conv. Tool	87.7%	76.2%	65.6%	58.9%	76.2 ± 0.4 %

Track Selection for 'Track Seed':

	True 1 Prong tau		True 3 Prong taus		1P + 3P
	w/o conv.	w. conv	w/o conv.	w. conv	
Default	79.6%	62.6%	65.4%	56.0%	67.3 ± 0.4 %
Default + Conv. Tool	77.6%	61.8%	61.8%	53.0%	65.6 ± 0.4 %
no Blayer+Conv. Tool	77.6%	59.7%	62.4%	53.0%	64.7 ± 0.4 %

Track Migration

Considering only true taus matching to reconstructed TauRec candidates:

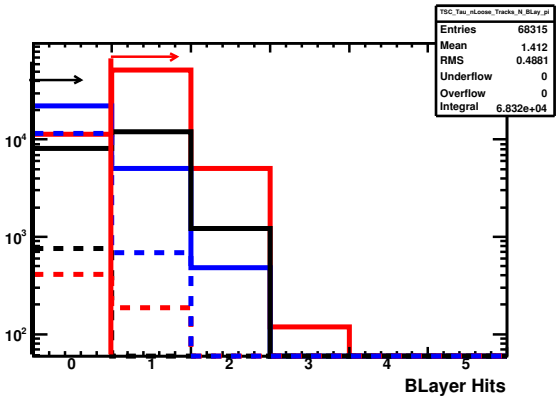
Track Selection for 'Calo Seed':

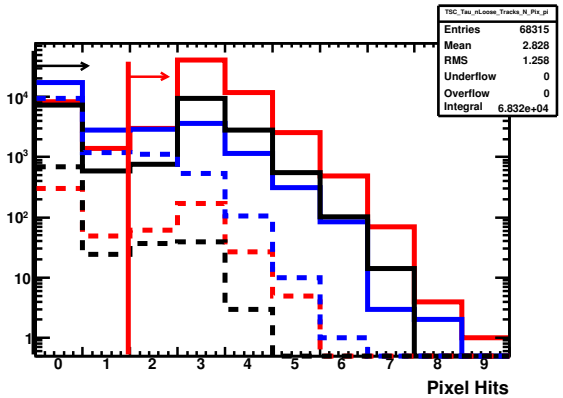
	1P→3P		3P→1P	
	w/o conv.	w/ conv.	w/o conv.	w/ conv.
Default	1.1%	1.30%	2.0%	2.1%
Default + Conv. Tool	0.5%	3.7%	4.5%	5.2%

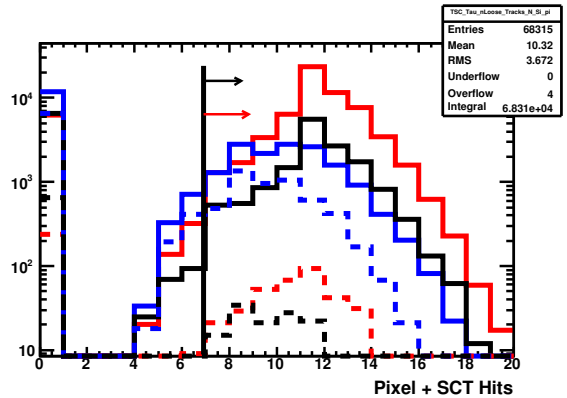
Track Selection for 'Track Seed':

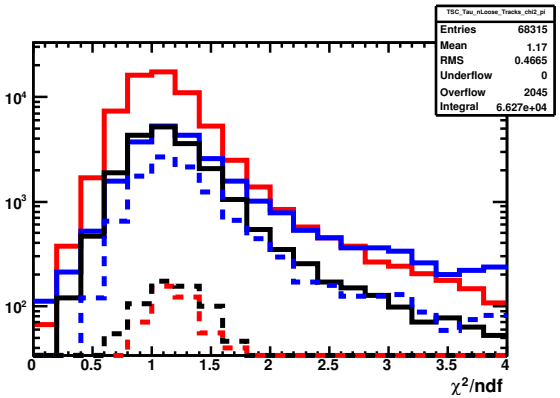
	w/o conv.	w/ conv.	w/o conv.	w/ conv.
Default	0.4%	1.5%	3.4%	2.4%
Default + Conv. Tool	0.2%	0.9%	4.7%	3.5%
No BLayer+Conv. Tool	0.2%	1.6%	4.5%	3.3%

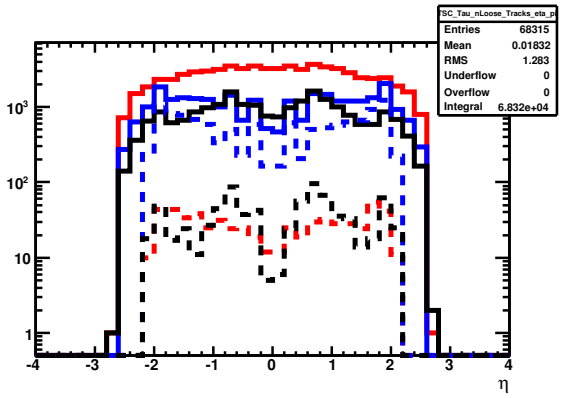
Overview of the Track Selection Criteria Distributions

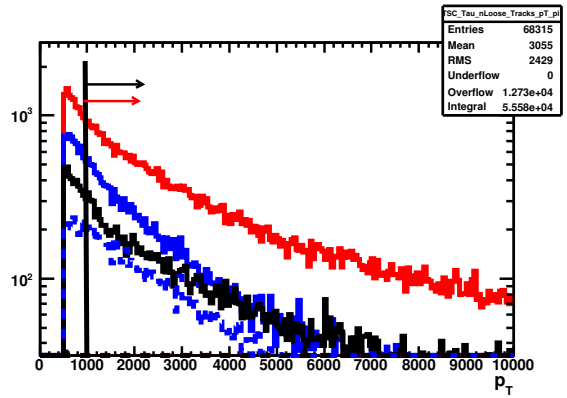


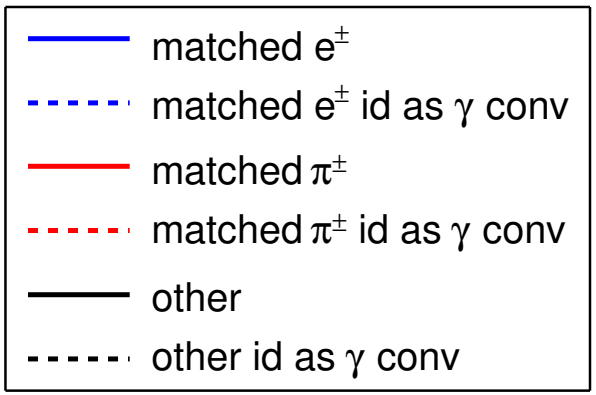






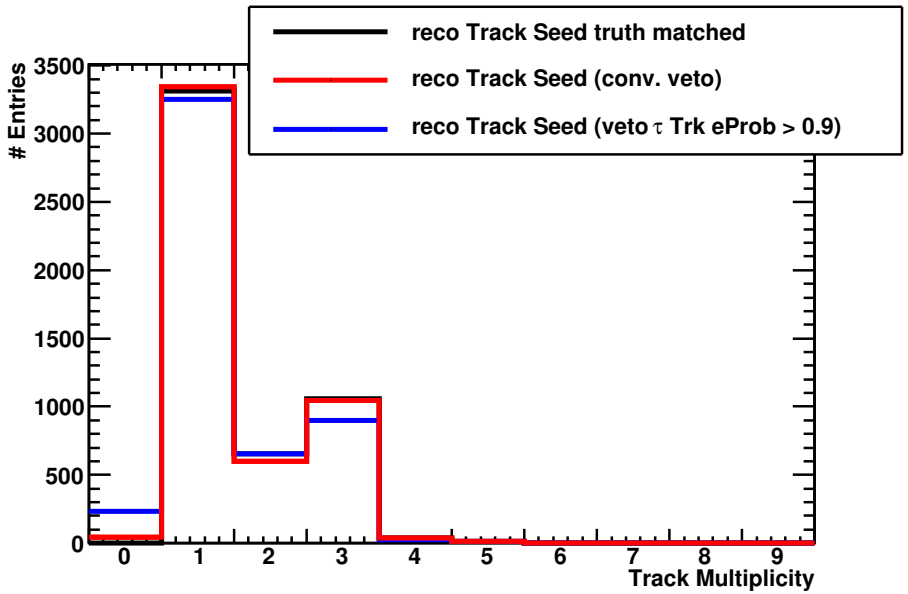


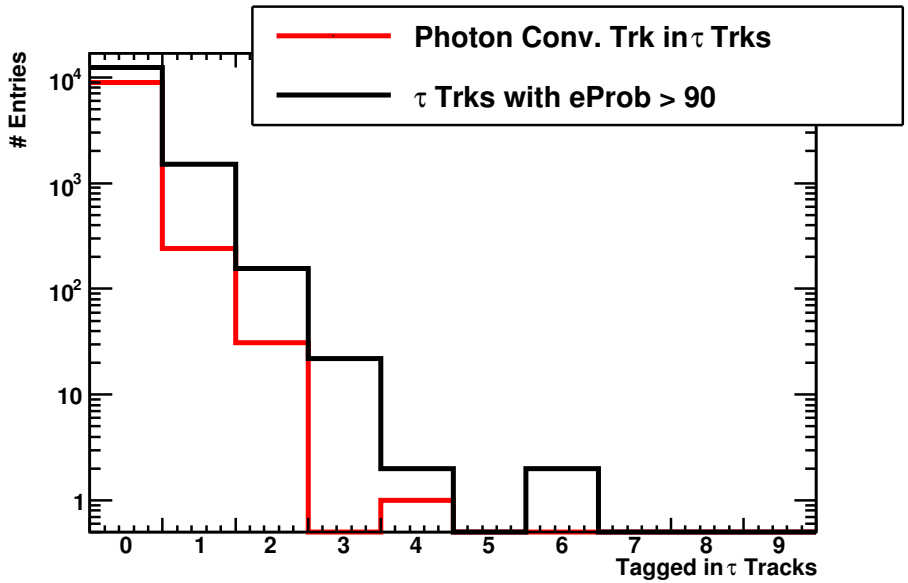


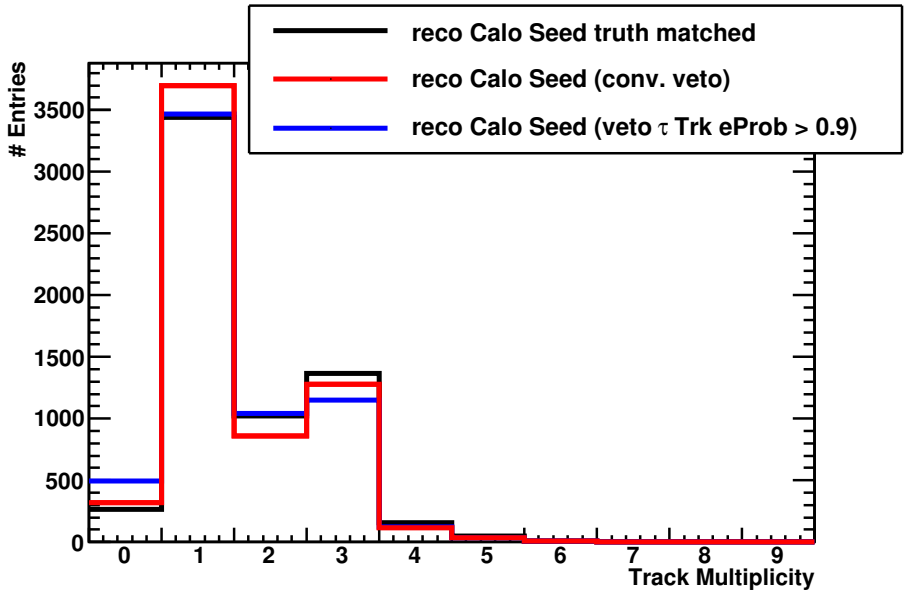


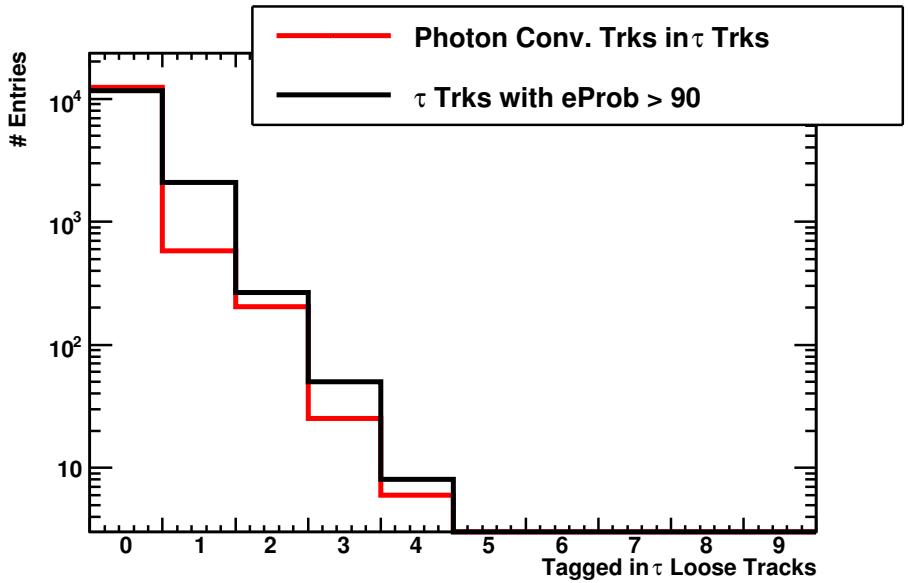
- all trks around *Calo Seed* τ candidates
- cuts: ***Track Seeds*** and ***CaloSeeds***
- cuts are already loosened a lot

Veto with TRT electron PID Tool only









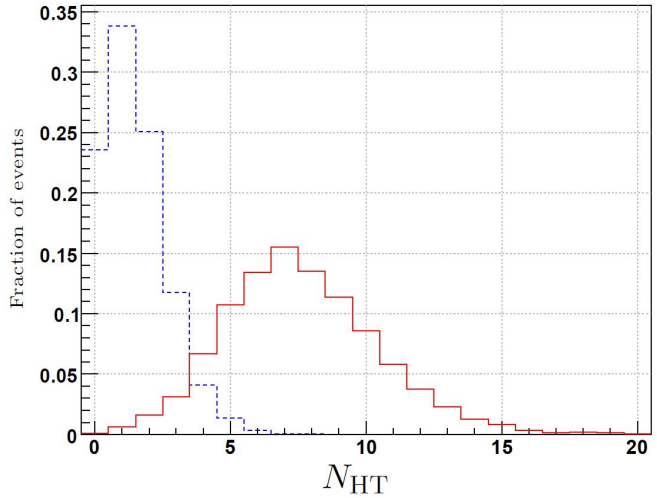
Identification with the TRT PID tool

- probability based (eProb)
- applied informations:
  - High Threshold Hits (HT)
  - Time-Over-Threshold info (ToT)
- probability evaluated from likelihood (each var.):

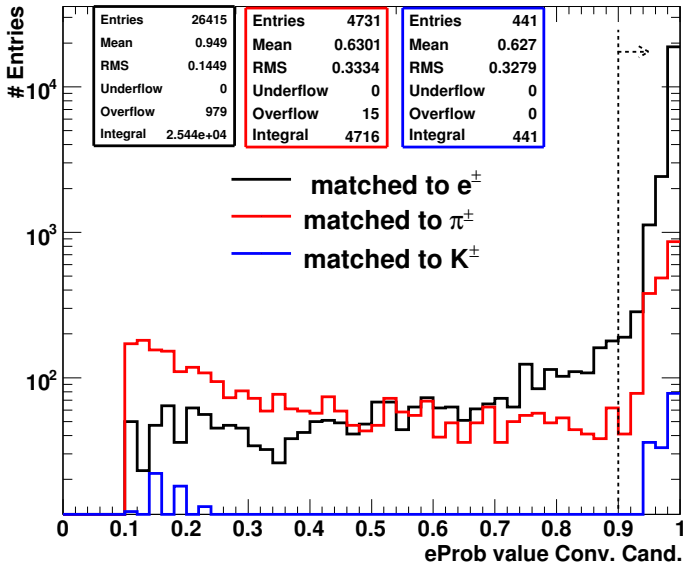
$$p^e_{HT} = \frac{\prod_i p^e_{HT,i}}{\sum_{j=e,\pi} \prod_i p^j_{HT,i}}$$

- combined:

$$eProb = \frac{p^e_{HT} p^e_{ToT}}{\sum_{j=e,\pi} p^j_{HT} p^j_{ToT}}$$

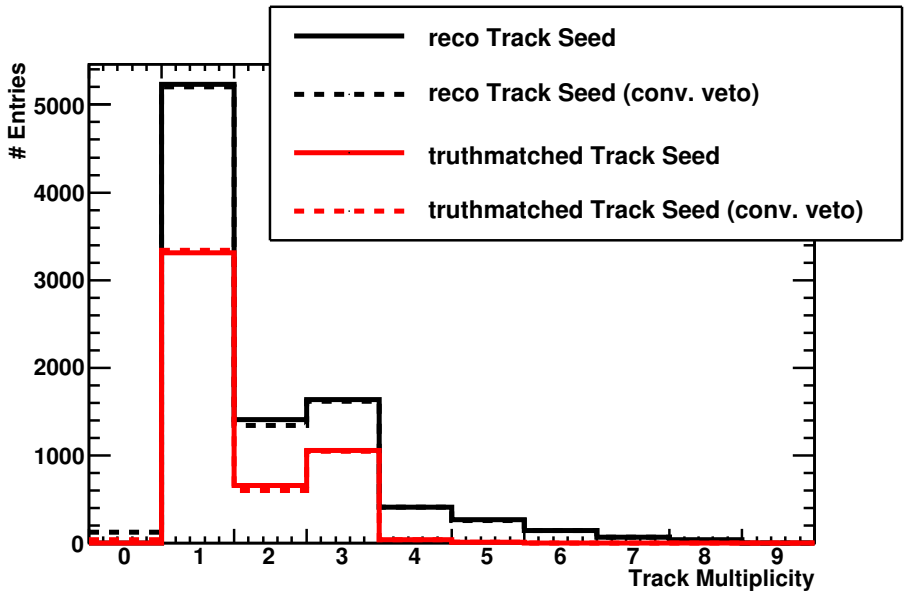


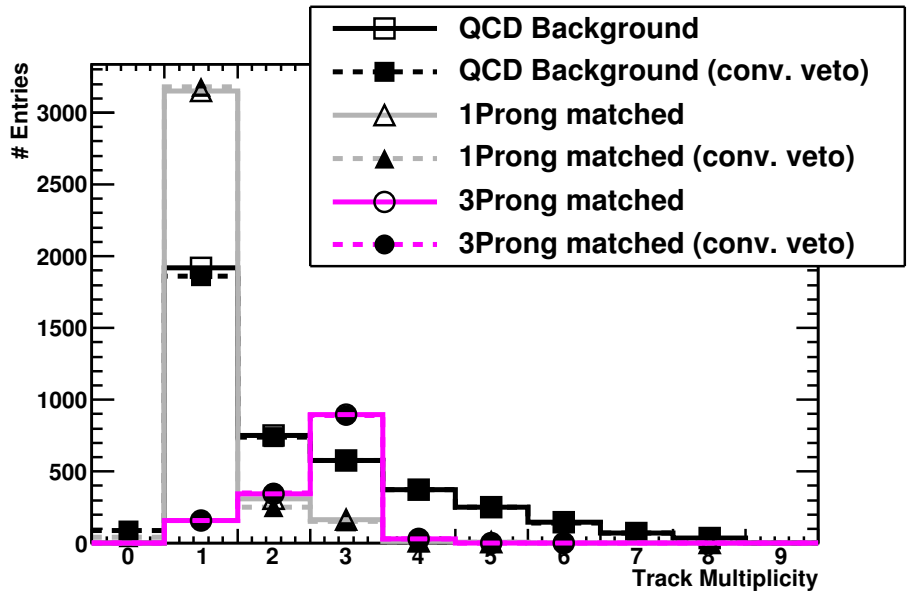
HT hits from e (red) and π (dashed blue)

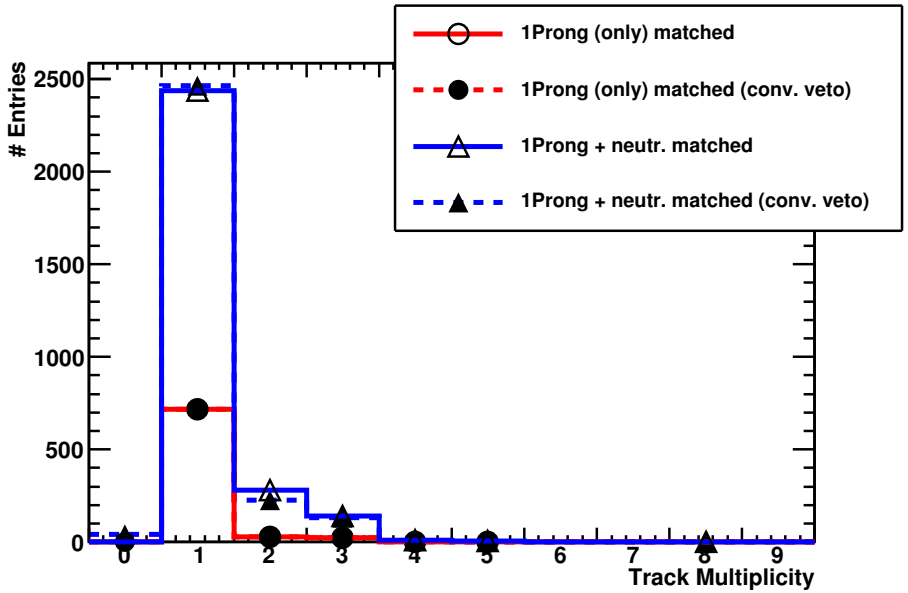


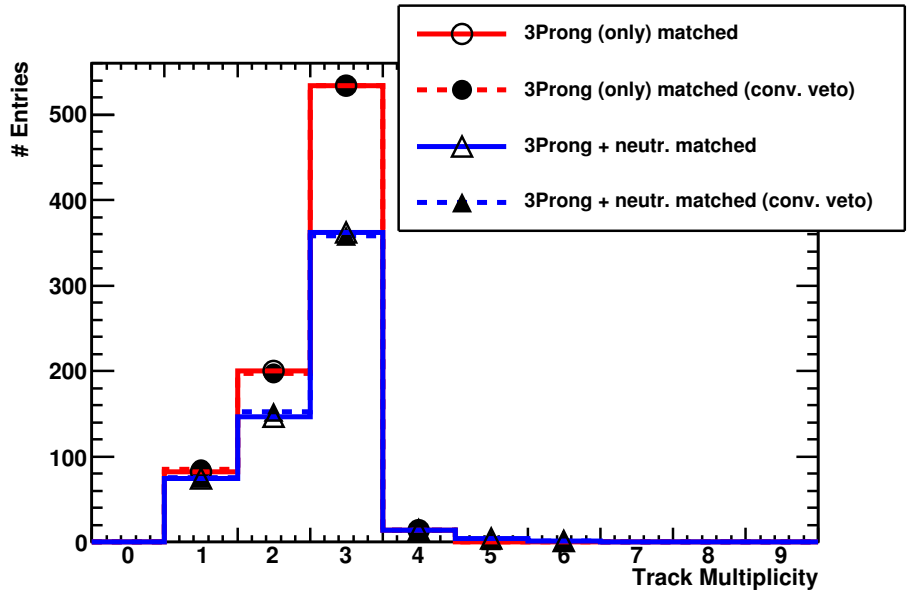
eProb of TRT PID Tool in VxCandidates

Track Seed: Track Multiplicity Preliminary!! (4500 Ev. only!)

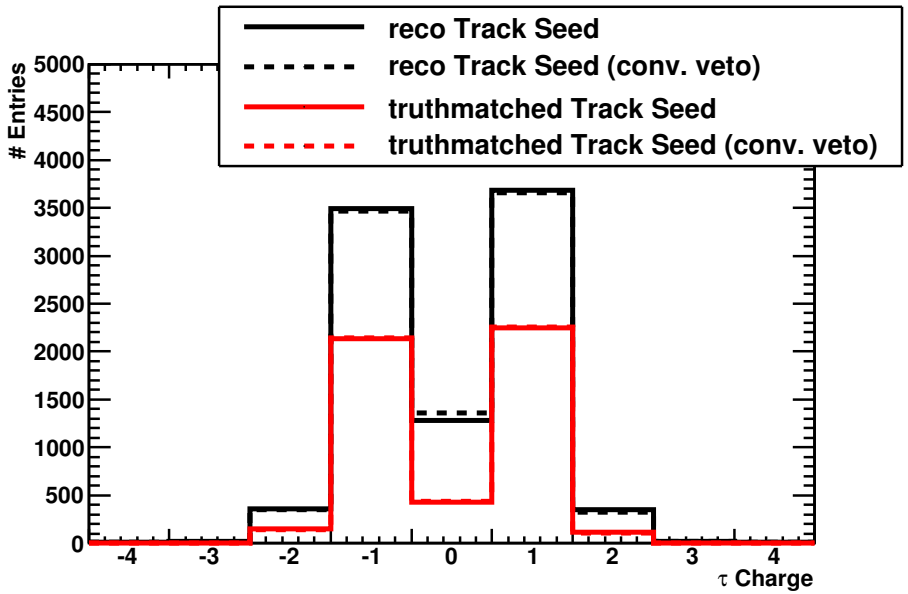


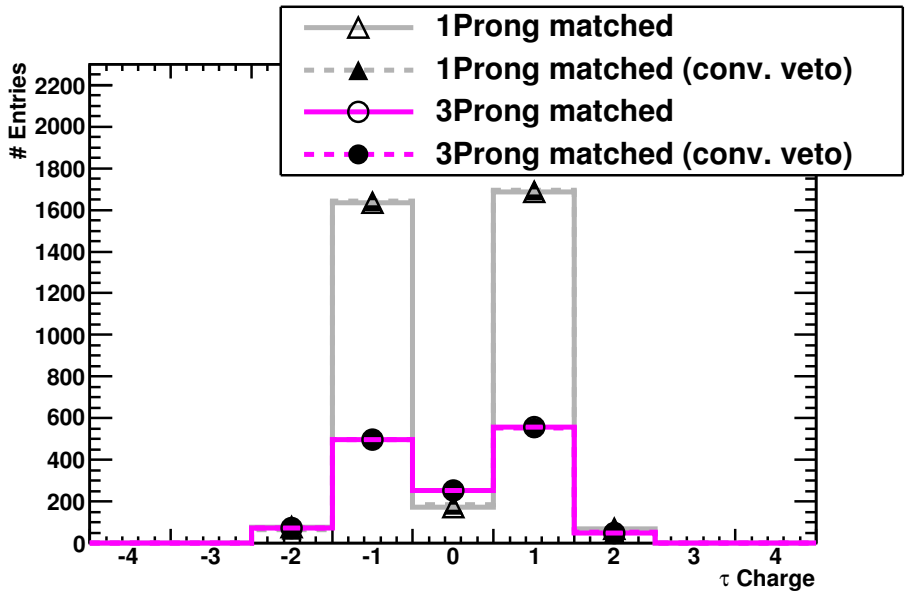


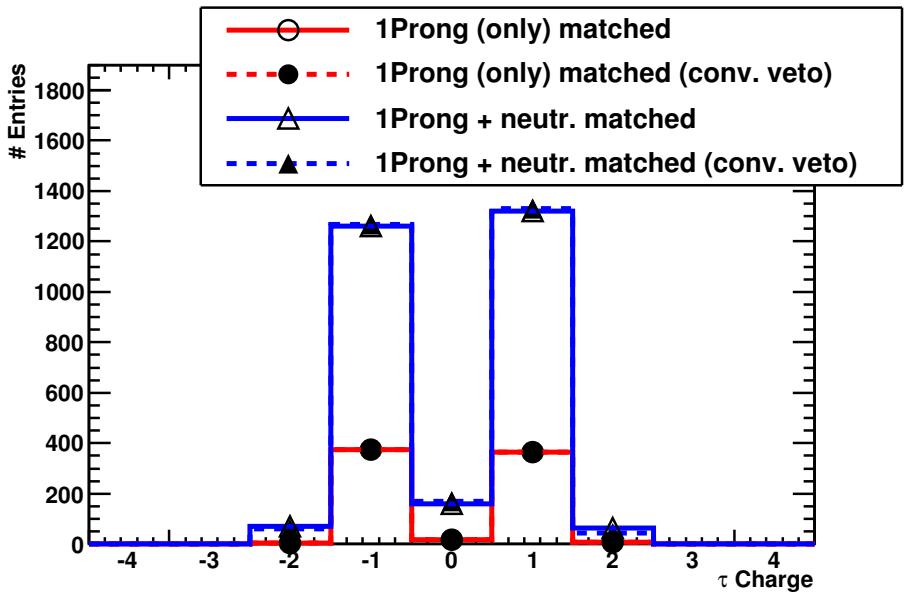


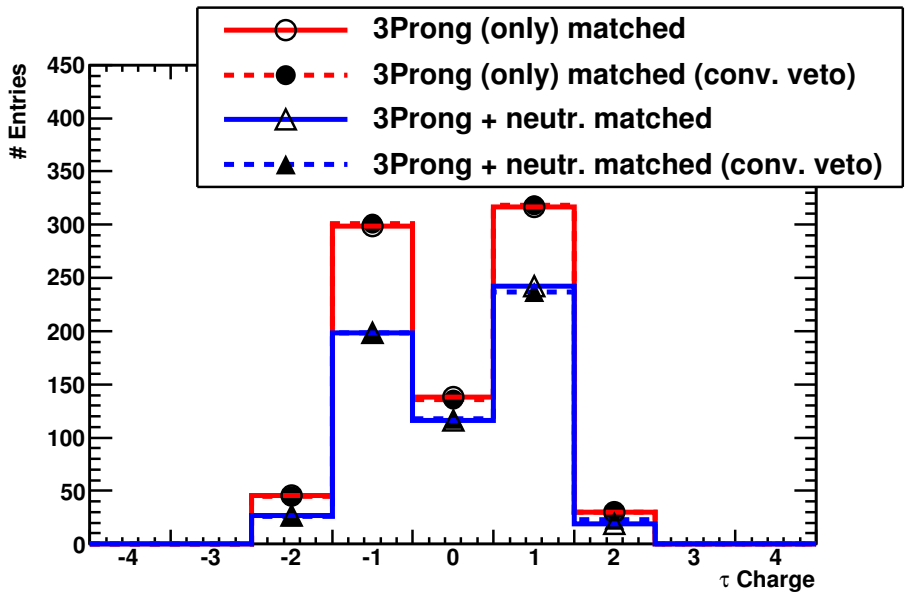


Track Seed: τ Charge Preliminary!! (4500 Ev. only!)

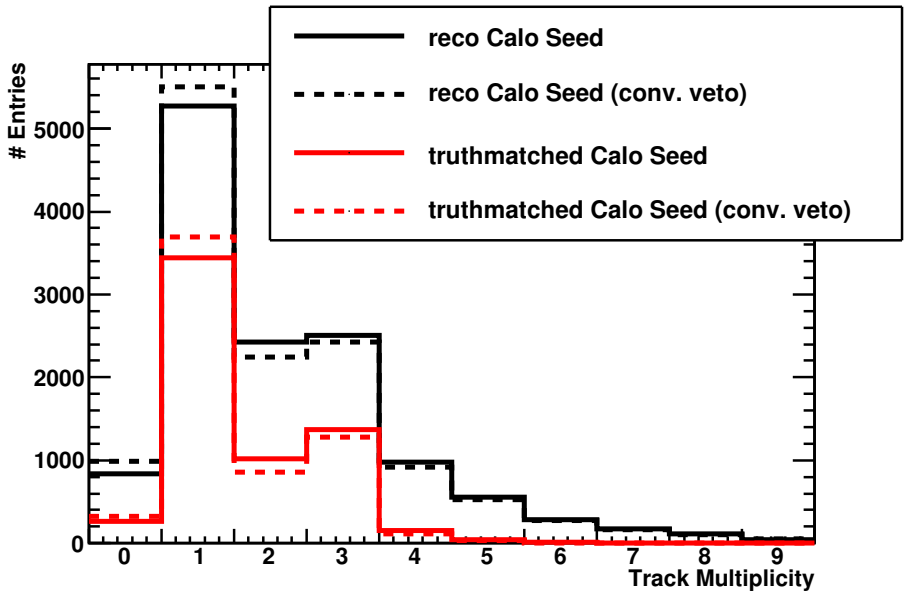


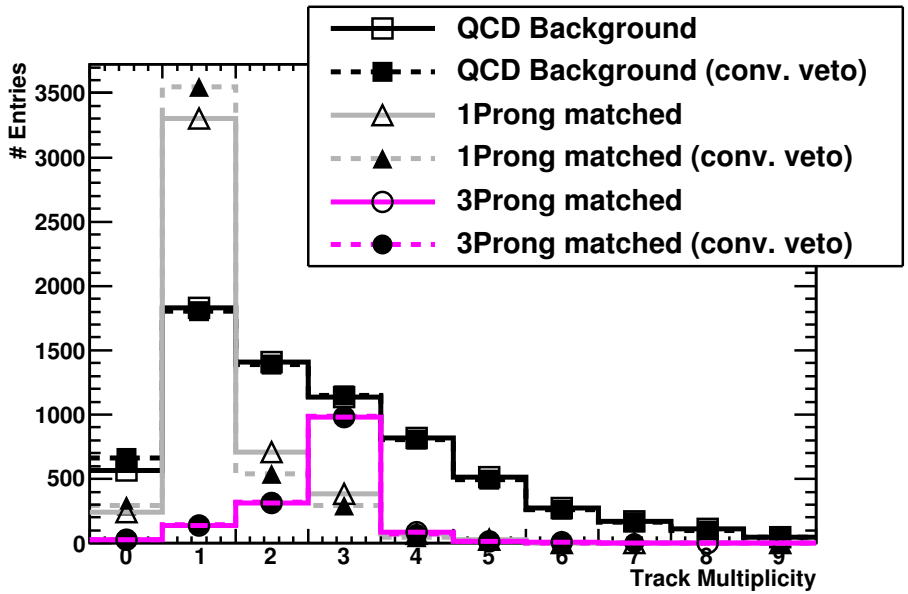


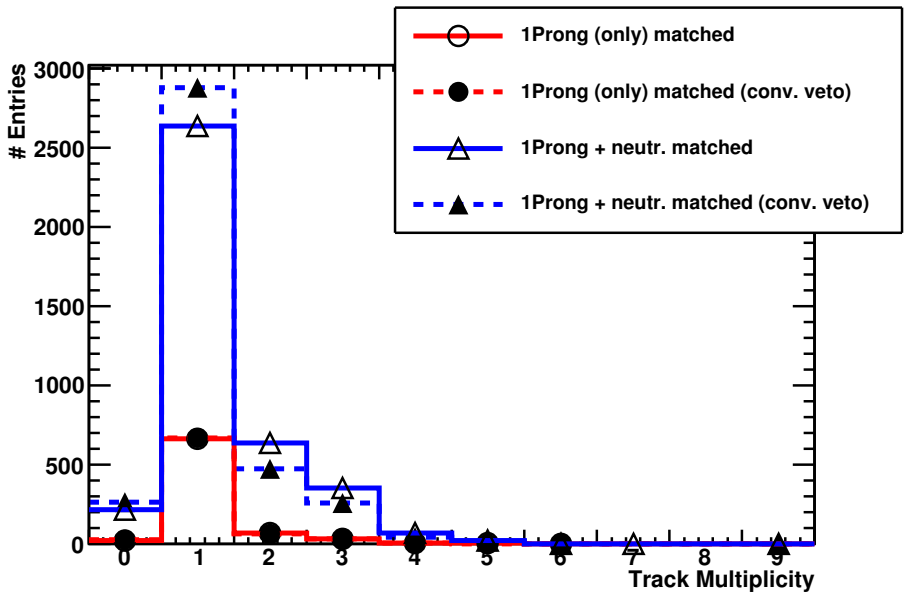


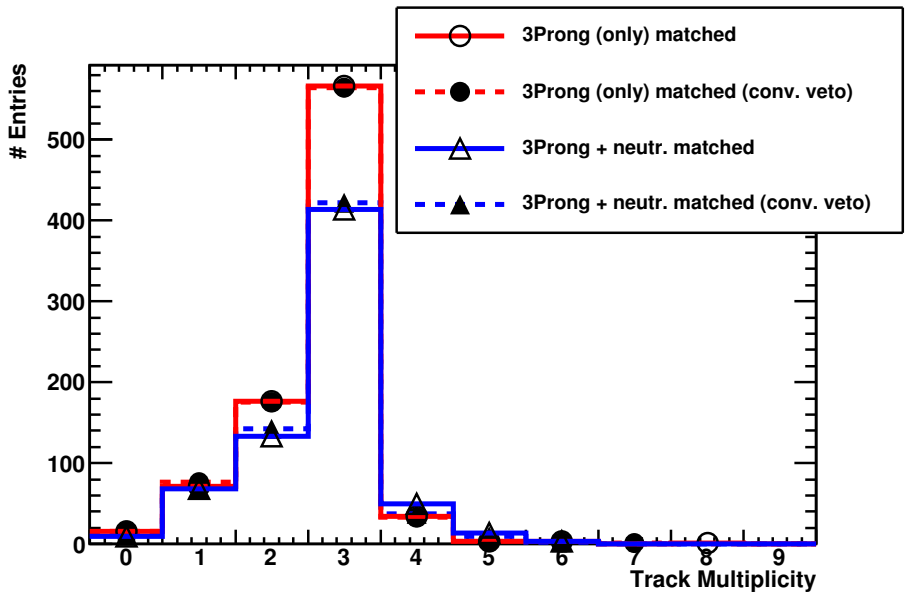


Calo Seed: Track Multiplicity Preliminary!! (4500 Ev. only!)

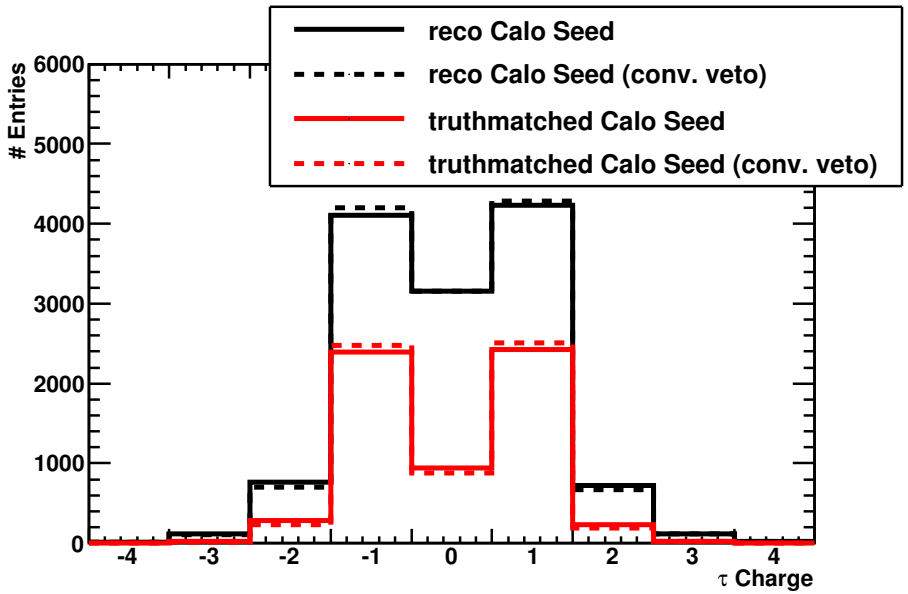


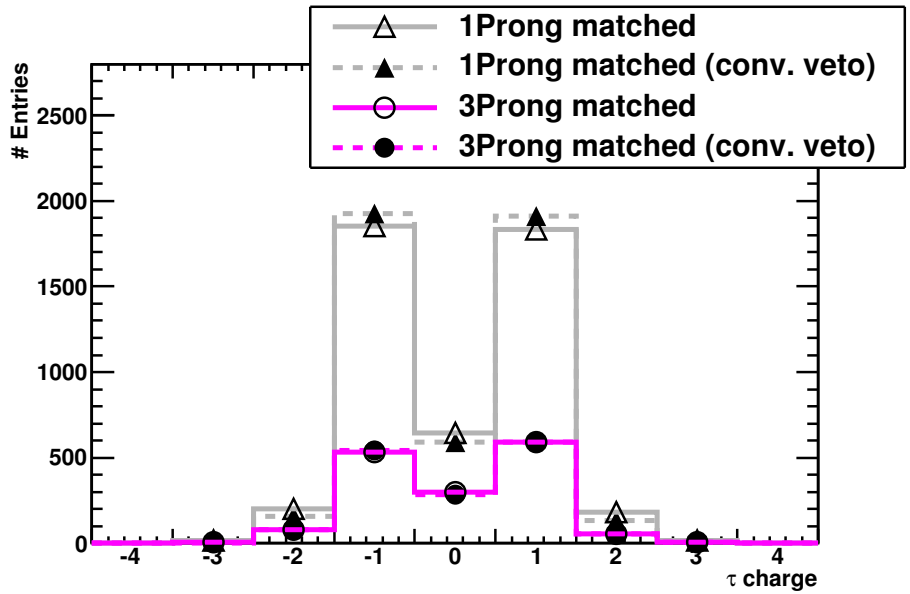


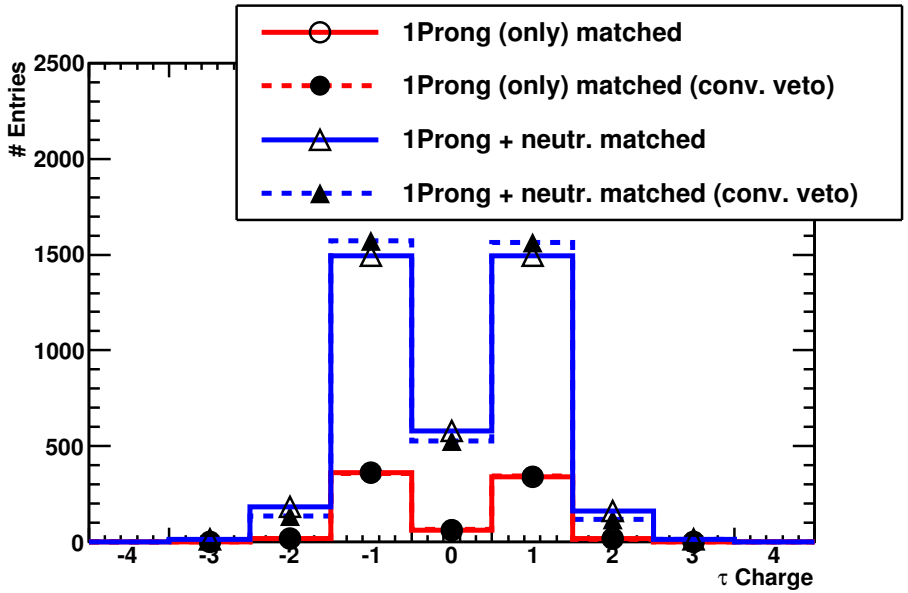


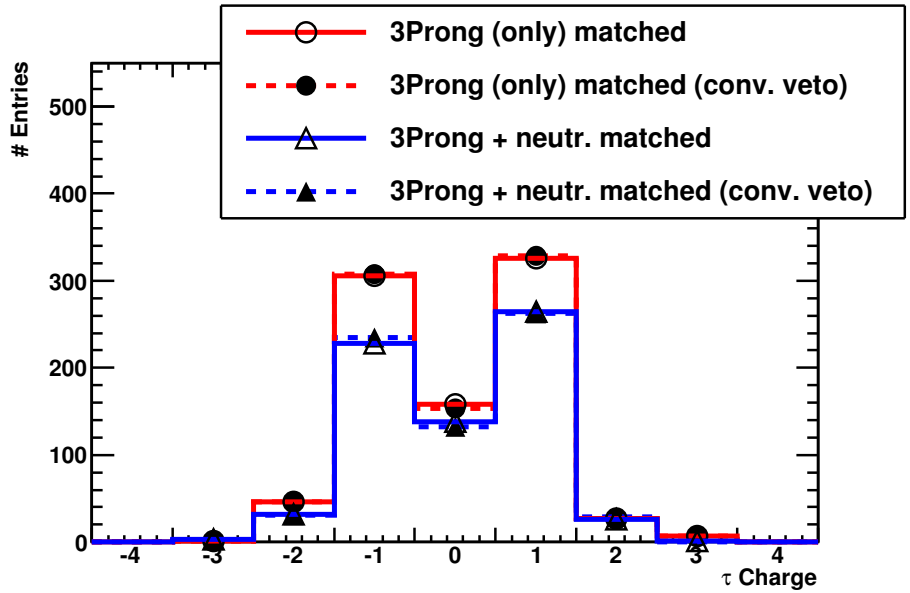


Calo Seed: τ Charge Preliminary!! (4500 Ev. only!)



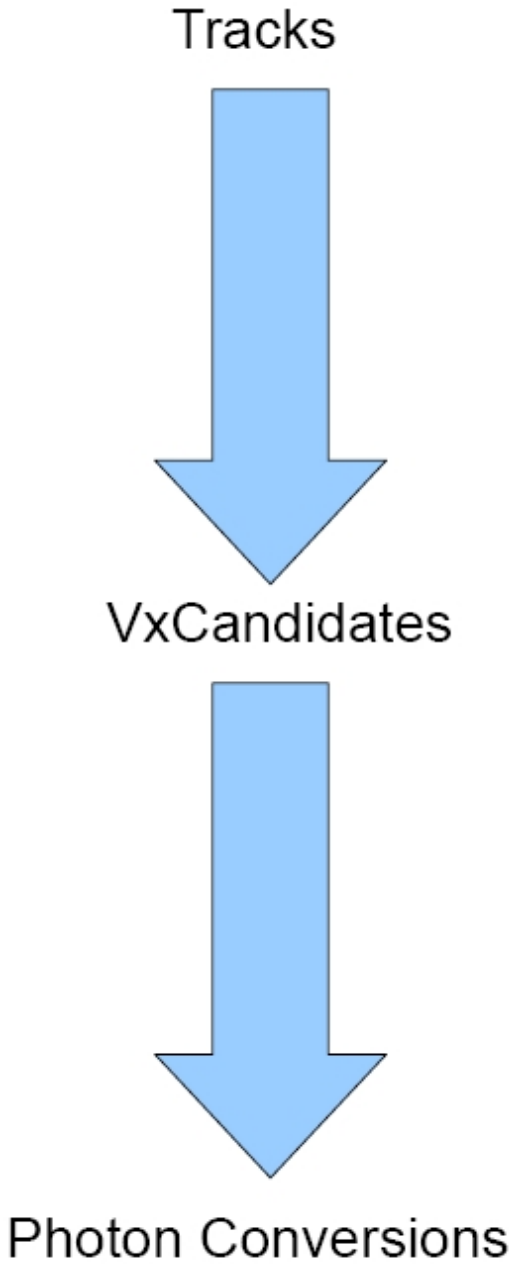






Study in Release 14.2.0

Steps of Photon Conversion Reconstruction



1. Step building VxCandidates *InDetConversionFinder*

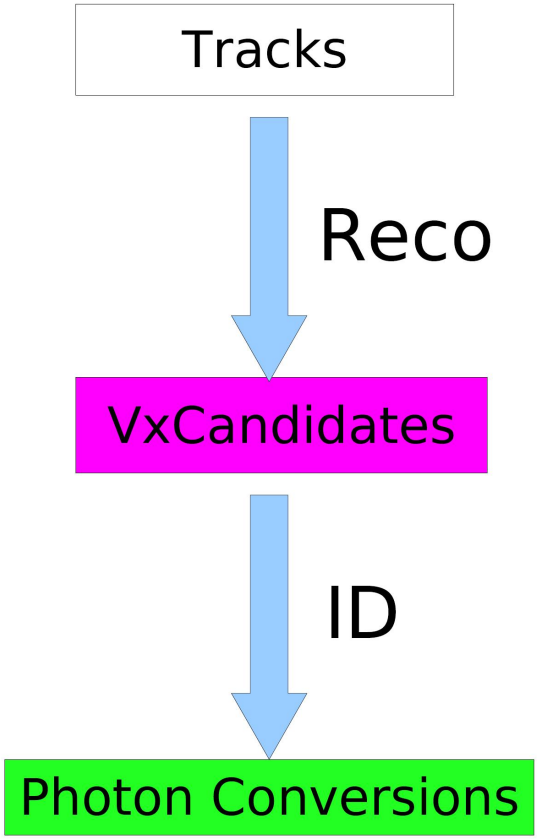
- builds pos/neg trk pairs
- refits secondary vertices
- constraints and cuts like $p_{T,min}$ have to be opened for τ-environment
- This step will be optimzed by M. Donega et al. at University of Pennsylvania

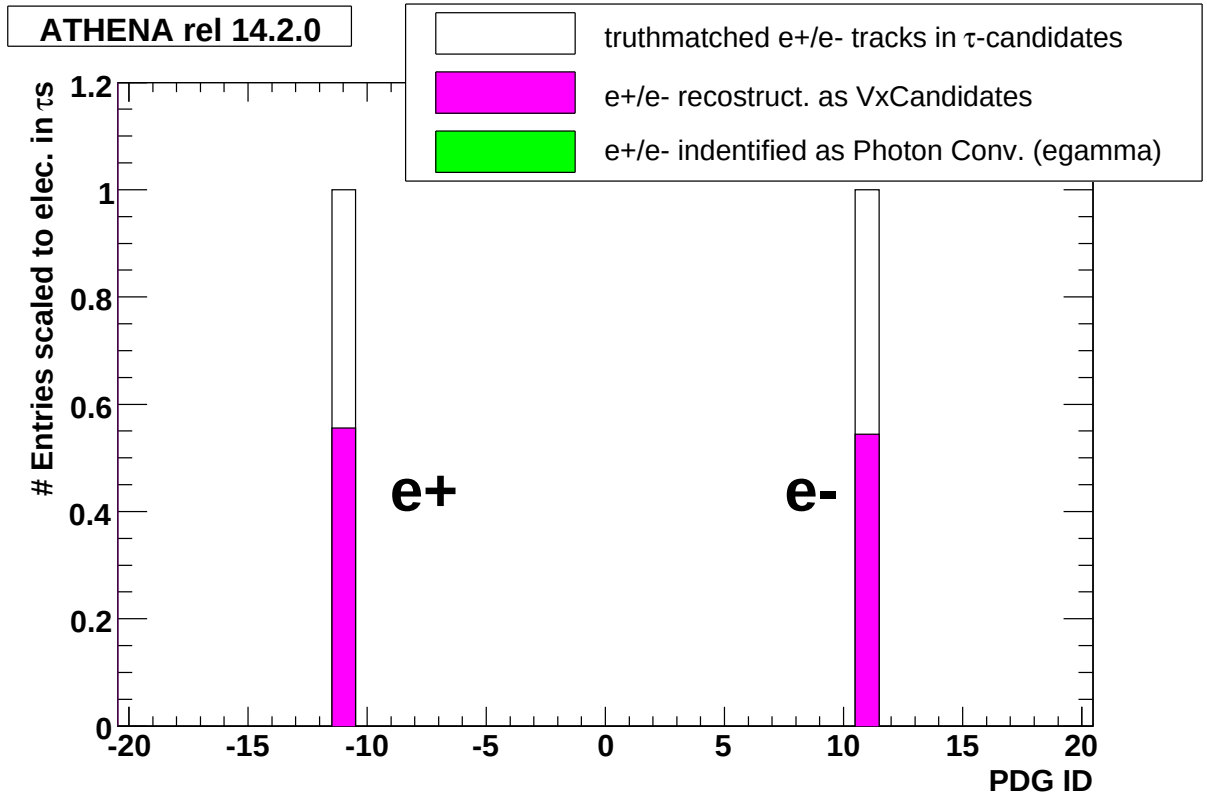
2. Step identify e^+/e^- of photon conversion *EMConversionBuilder*

- extrapolates trks to ECal surface and identify e^+/e^- via CaloCluster informations
- makes add. cuts like $\text{trk}_{minp_T} > 2$ GeV (which is too tight for low p_T conversions from τ)
- A τ specific photon conv. ID has to be implemented (this is what we will present now)

Problems Reconstructing Conversions in τ tracks

- Default Photon Conversion Reconstruction and Identification in τ environment





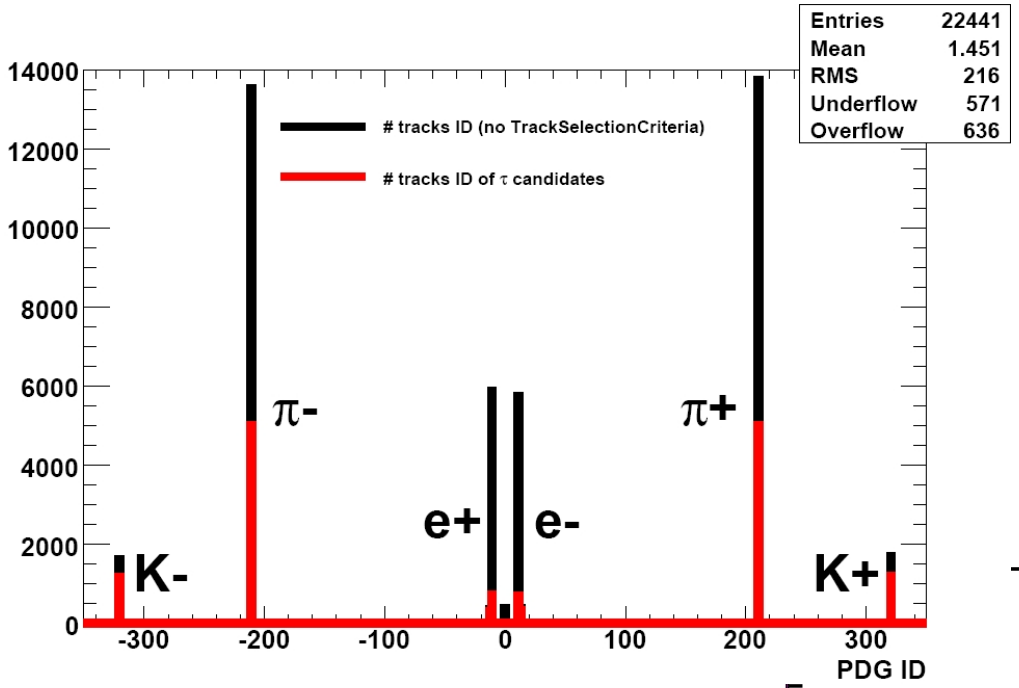
- After ID no Photon Conversion is found within the τ tracks
  - τ specific Conversion ID is needed!

Track ID in τ-Candidates with rel. 13.0.40

- truthmatched track ID of τ-jets

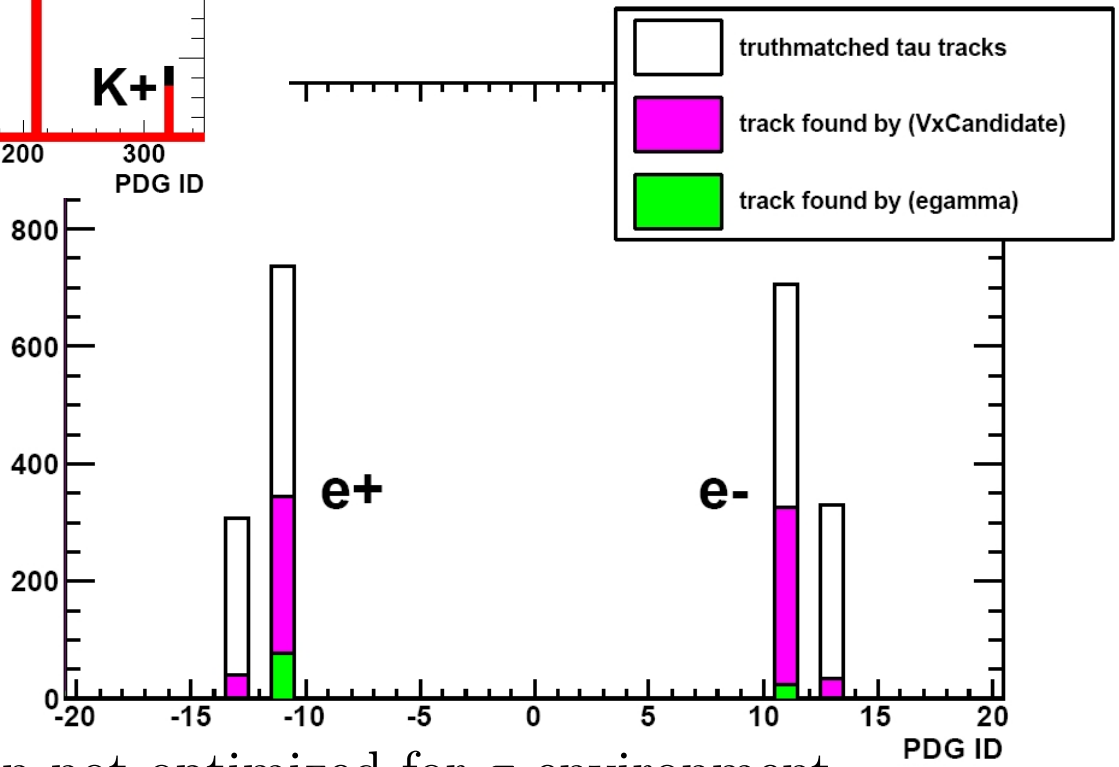
	τ-Cone	τ-Cand
$\pi^+\pi^-$	59.3 %	75.9 %
e^+e^-	25.3 %	6.4 %
K^+K^-	7.8 %	10.5 %
other	7.6 %	7.2%

For



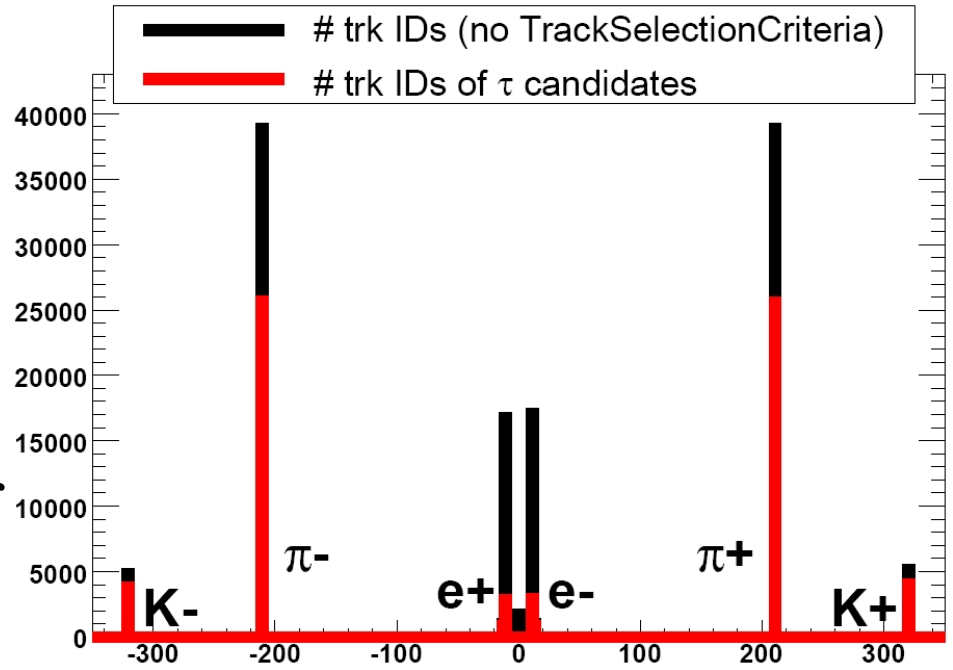
(upper plot in red):

- 46.4 % of e^+e^- in τs have been found by *ConversionFinder*
- 7.1 % are identified as *egamma*-conversion



- *egamma*-conversion definition not optimized for τ-environment

Track ID in τ-Candidates /τ-Cone with rel. 14.2.0

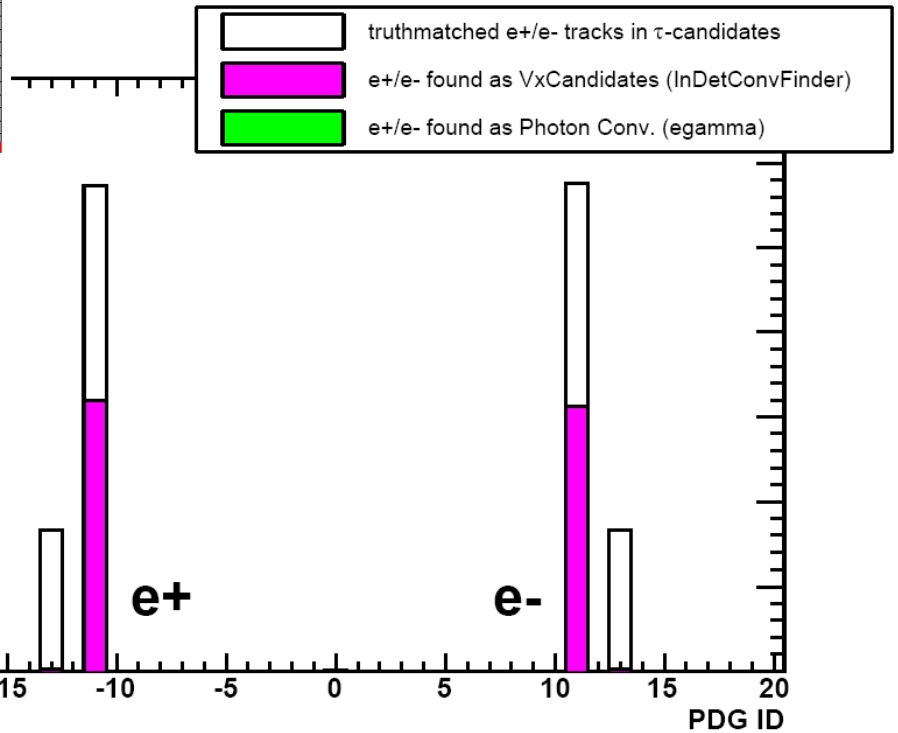


Track Selection Criteria

- $\Delta R < 0.3$
- $p_T > 1.0$ GeV
- $d0 < 1.5$ mm
- $\frac{\chi^2}{ndf} < 3.5$
- # Si Hits (Pixel + SCT) ≥ 6
- # Pixel + B-Layer Hits ≥ 1

For (upper plot in red):

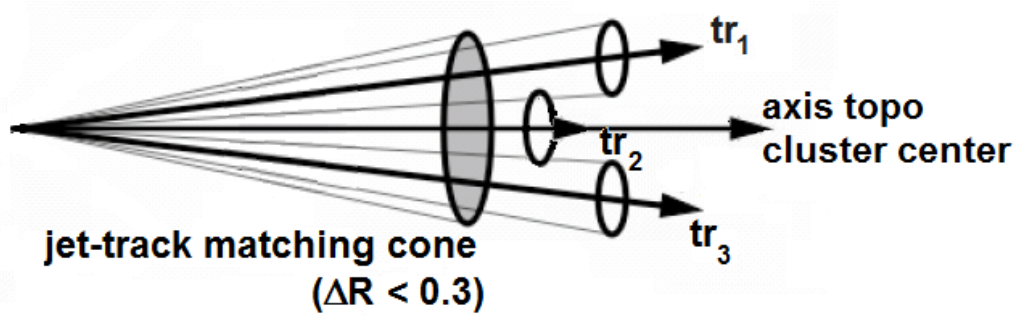
- 55.0 % of e^+e^- in τs have been found by *ConversionFinder*
- after changes in rel. 14.2.x no photon conversions can be identified in τ cone anymore (no green histogram)



Track ID in τ-Candidates /τ-Cone

- truthmatched track ID of τ-jets

	τ-Cone	τ-Cand.(TSC)
$\pi^{\pm}$	58.4 %	74.0 %
$e^{\pm}$	25.4 %	6.8 %
$K^{\pm}$	7.5 %	11.2 %
other	8.7 %	3.6%

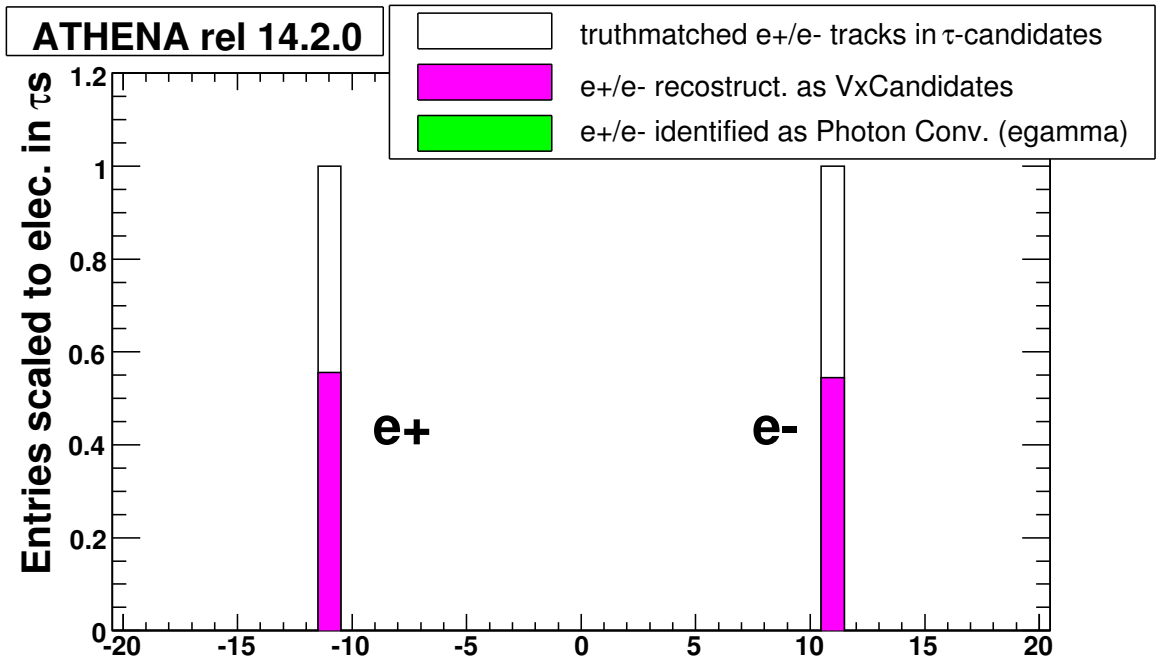


- rel. 14.2.0 def. TauRec **T**rack **S**election **C**riteria (TSC) supress γ conv. (rel 15. TSC are slightly opened)

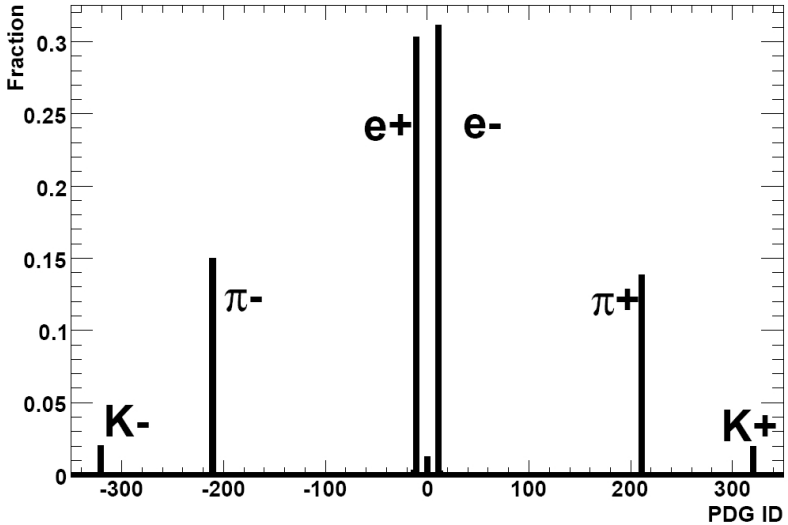
lower part

For τ-Candidates with TSC:

- 55 % of $e^{\pm}$ in τs have been found by *ConversionFinder*
- **since rel. 14**
  0 % are identified as def. *egamma*-conversion
- γ conv. ID method for dense environment has to be developed



VxCandidates have to be cleaned



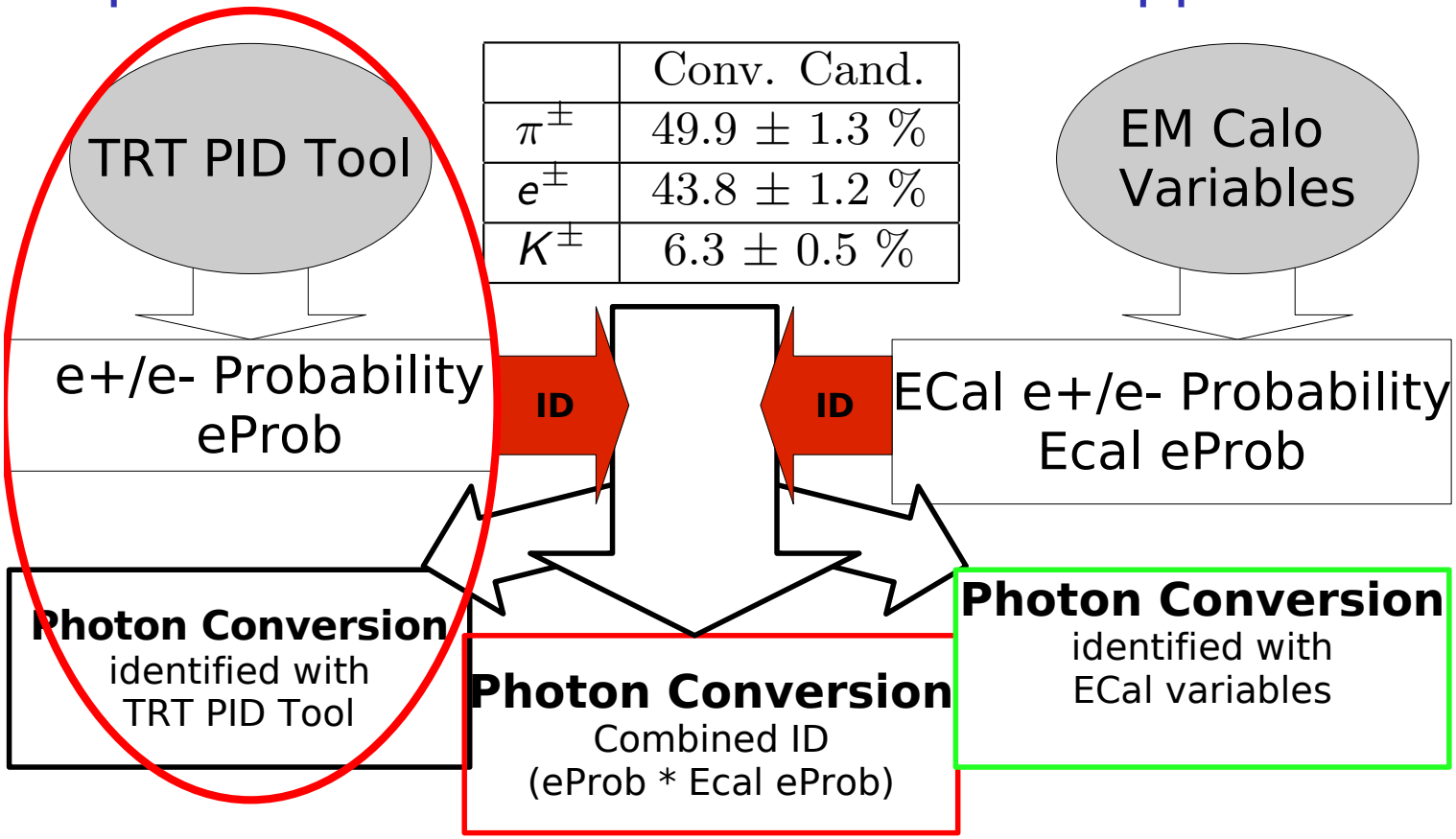
- 30 % of the VxCand. trks are from $\pi^{\pm}$
- $\Rightarrow \pi^{\pm}$ will be rejected in the τ's !
- is the $e^{\pm}$ purity good enough, VxCand. can be used to supress photon conv. in the τ-candidates

How to clean VxCandidates from pions determine electron probabilities with two methodes:

- *TrackSummaryTool* calculates via inner detector variables (e.g. TRT high threshold hits) an electron probability (**eProb**)
- additionally we decided to define a electron probability calculated out of ECal informations
  1. extrapolate trk to ECal surface (similar to *EMConversionBuilder*)
  2. via TMVA a BDT value out of ECal infos has been calculated (compare track momentum with ECal cluster)

combine the 2 probabilities to cut on

Two Independent Photon Conversion ID Approaches



	Conv. Cand.
$\pi^{\pm}$	49.9 ± 1.3 %
$e^{\pm}$	43.8 ± 1.2 %
$K^{\pm}$	6.3 ± 0.5 %

- TRT Electron PID Tool (by Troels Peterson)
  - electron prob. for each Trk
  - Likelihood based on TRT HT Hits
  - to distinguish $e^{\pm}$ from $\pi^{\pm}$
  - cut: eProb. > 90 % (both Trk)
- Based on ECal var. ONLY
  - lin. uncorrelated from ID var.
  - add. information
    $\rightarrow$ add. seperation power?

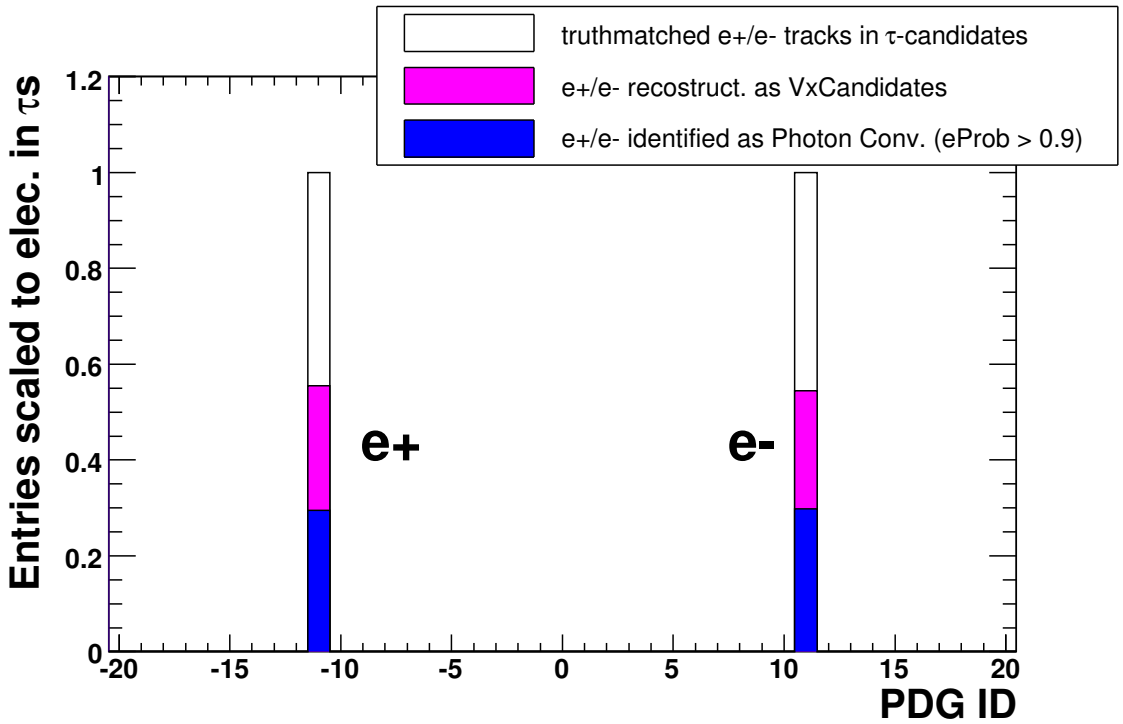
Results Using TRT PID Tool to ID Photon Conversions

- Conversion Candidates before identification:

	Conversions Candidates
$\pi^{\pm}$	49.9 ± 1.3 %
$e^{\pm}$	43.8 ± 1.2 %
$K^{\pm}$	6.3 ± 0.5 %

- Identified with the TRT PID Tool (cut: eProb $> 90\%$)

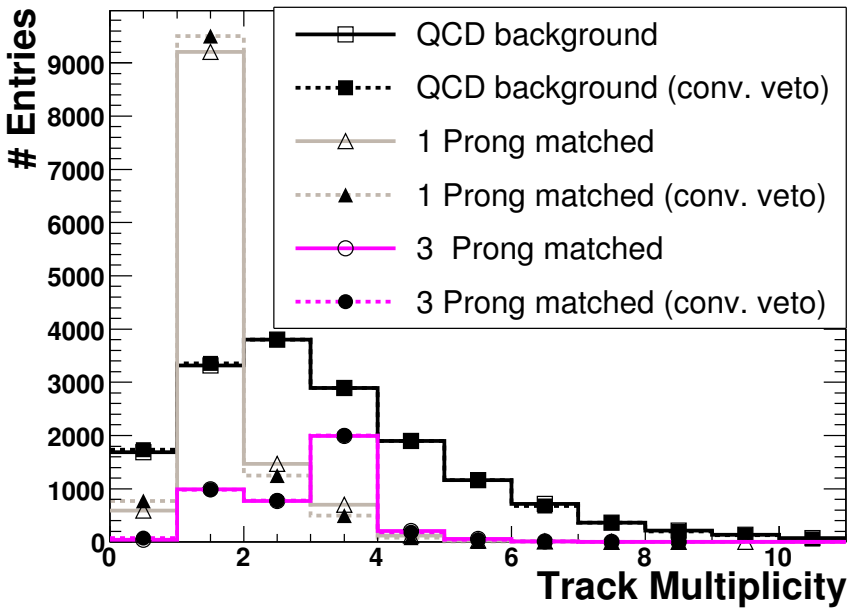
	Photon Conversions
$\pi^{\pm}$	9.1 ± 1.0 %
$e^{\pm}$	89.5 ± 3.1 %
$K^{\pm}$	0.9 ± 0.3 %

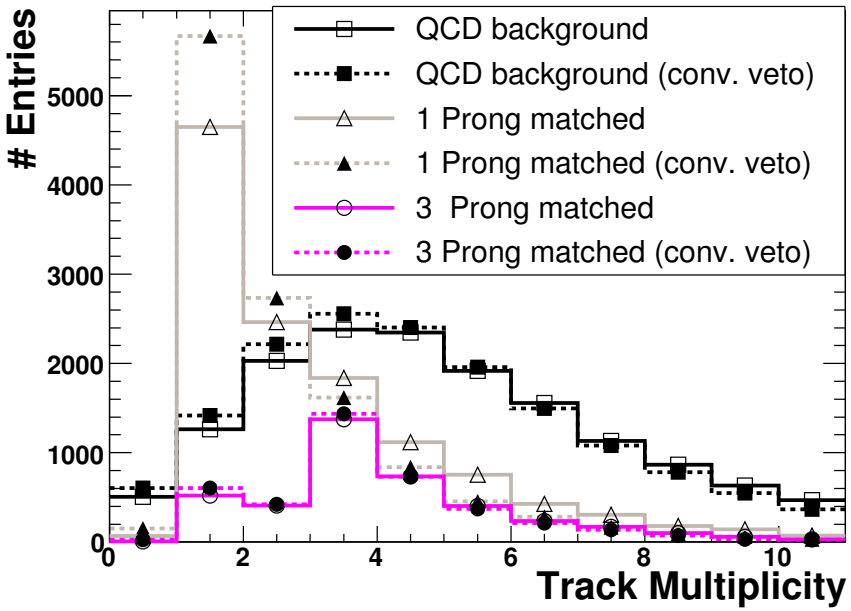


- Identification of Conversion Candidates with TRT PID Tool
  - 29.7 % of $e^{\pm}$ of τ candidate tracks are tagged as Photon Conversions

Corrected τ Track Multiplicity

def. *TauRec* Track Selection Criteria: all Trks with dR < 0.3 around τ-axis:



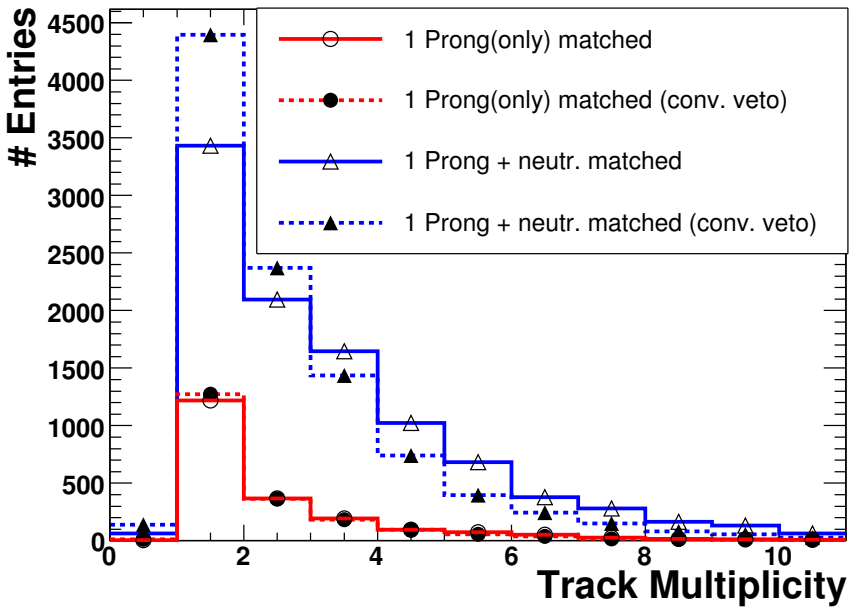


- Even if the TSC are applied a slight improvement can be observed
- Rel. 15 some of the TSC are loosened
  $\rightarrow$ we expect something between the two plots

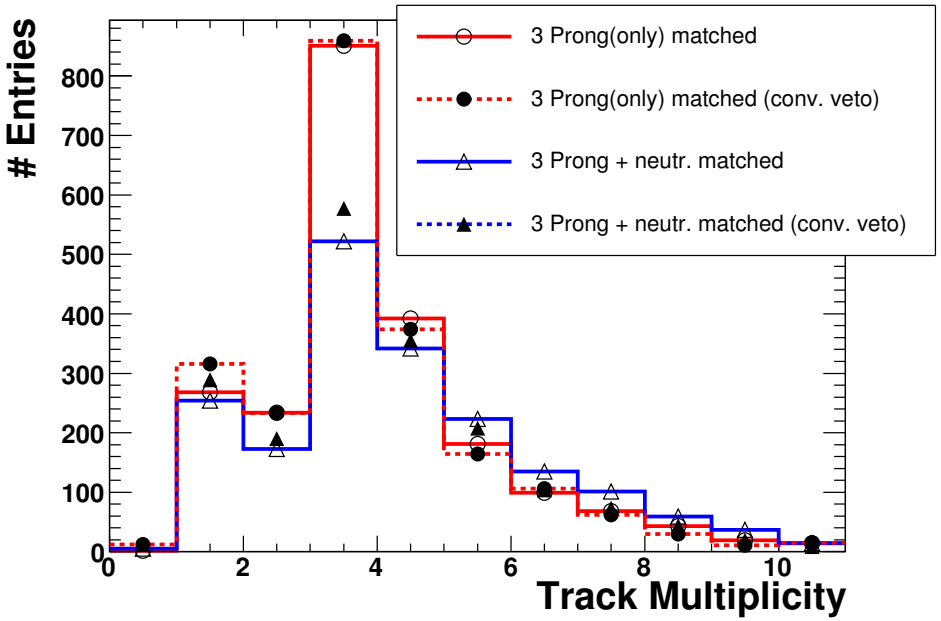
Corrected τ Track Multiplicity

With opened Tracks Selection Criteria (all Trks with dR < 0.3 around τ-axis), Track Multiplicities are matched to truth hadronic...

... 1-Prong decays:



... 3-Prong decays:



- (in blue) photon conversions are only expected in decays with neutral π_0s
  - mainly in these decays corrections due to conversion track veto can be seen
- less entries / corrections for 3 Prong decays
  - only 25.6 % of 3 Prong decays are with neutral π_0s

Summary of the Study

- Def. photon conversion ID method does not work in τ environment
- τ specific conversion ID has been worked out
- Photon conversions are identfied with an $e^{\pm}$ purity of $\approx 90\%$
- Corrections in τ track multiplicity have been shown
- Corrections mainly in decay modes with π_0
  (where corrections are expected)