Kinematic Tagging and Identification of $e^{\pm}$

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KINEMATIC TAGGING OF μ^- AND μ^+

- *From reconstructed momentum vector determine if the track will reach outer yoke: (i) sample reaching outer yoke; (ii) sample NOT reaching outer yoke.*

- *Veto tracks interacting within STT volume (both μ^- and μ^+ tagging).*

- *Veto protons for μ^+ tagging using NN for proton ID.*

- *For events with ≥ 2 candidate tracks calculate a NN value for each candidate track using two separate NN trainings for the two samples:*
  - *Tracks reaching outer yoke: use training with all events with ≥ 2 candidate tracks, NN$_1$;*
  - *Tracks NOT reaching outer yoke: use training with events with ≥ 2 candidate tracks & $\mu^\mp$ NOT reaching outer yoke (NN$_2$), multiply NN$_2$ values by optimized constant $c = 15.0$.*

- *Select the single negative/positive track in the event with the highest NN output:*

Event sample	Selected track	Tagging efficiency
FHC ν_μ CC	μ^-	**99.1%**
RHC $\bar{\nu}_\mu$ CC	μ^+	**99.3%**

KINEMATIC TAGGING OF e^- AND e^+

- *Lepton universality allows unified kinematic tagging for leading $\mu^\pm$ and $e^\pm$ in CC*

  $\Longrightarrow$ *Same event selection reduces systematics on ν_e/ν_μ and $\bar{\nu}_e/\bar{\nu}_\mu$ ratios*

- *Veto tracks interacting within STT volume (both e^- and e^+ tagging).*

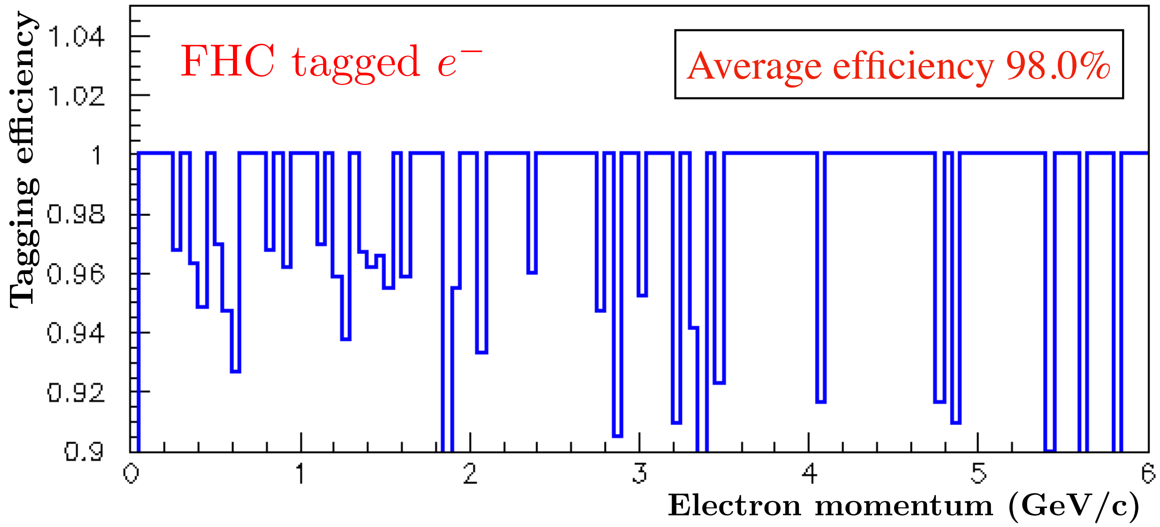
- *Veto protons for e^+ tagging using NN for proton ID (re-trained for e$^+$/p separation).*

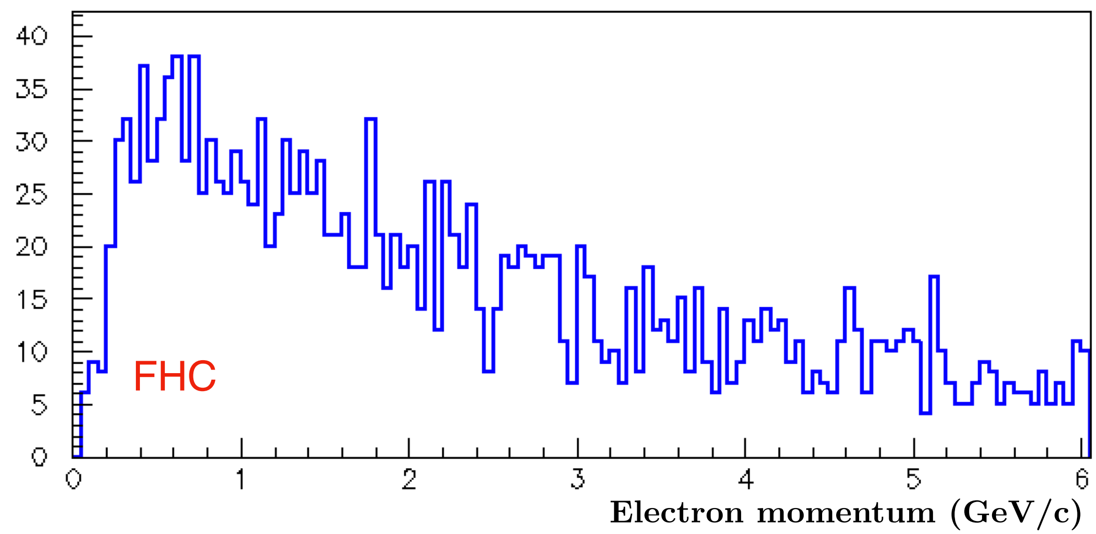
- *For events with ≥ 2 candidate tracks calculate a NN value for each candidate track using the same NN$_1$ training used for $\mu^\pm$ with all events with ≥ 2 candidate track*

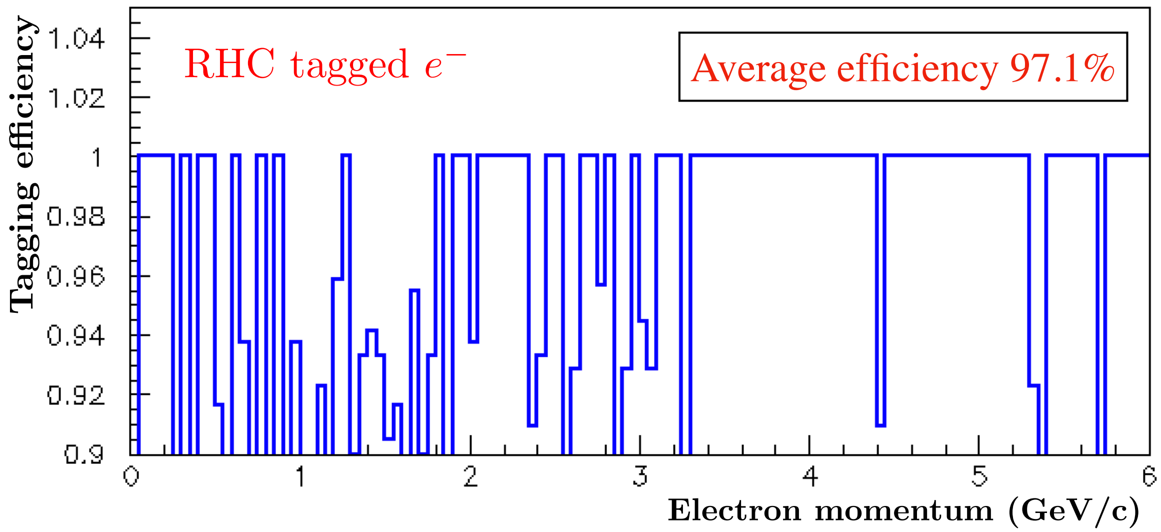
  $\Longrightarrow$ *Single NN$_1$ training since yoke kinematic bias absent for $e^\pm$*

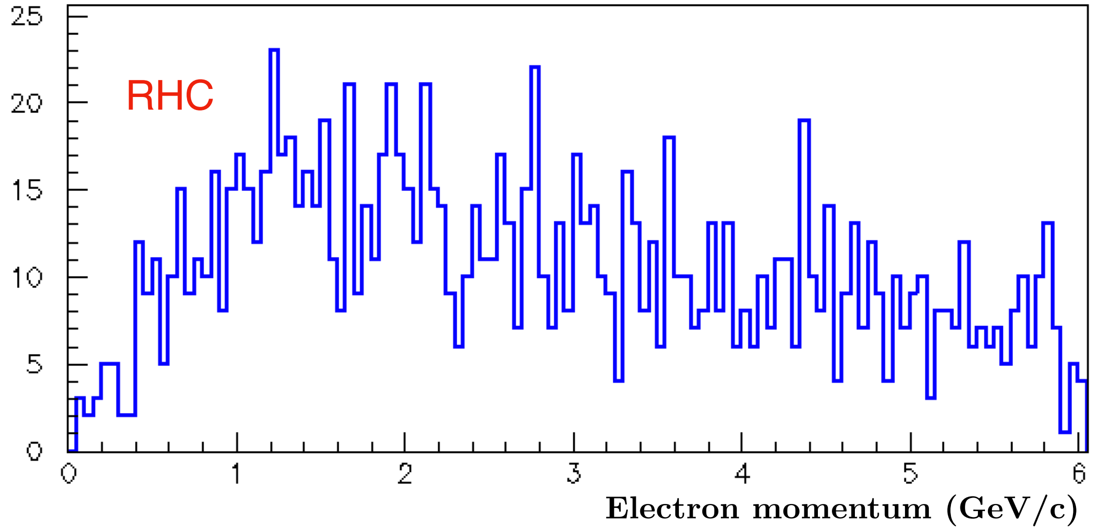
- *Select the single negative/positive track in the event with the highest NN$_1$ output:*

Event sample	*Selected track*	*Tagging efficiency*
FHC ν_e CC	e^-	**98.0%**
RHC $\bar{\nu}_e$ CC	e^+	**97.1%**


FHC tagged e^-
Average efficiency 98.0%
Tagging efficiency
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0
1
2
3
4
5
6
Electron momentum (GeV/c)


FHC
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
Electron momentum (GeV/c)


RHC tagged e^-
Average efficiency 97.1%
Tagging efficiency
Electron momentum (GeV/c)


RHC
Electron momentum (GeV/c)

MUON VETO

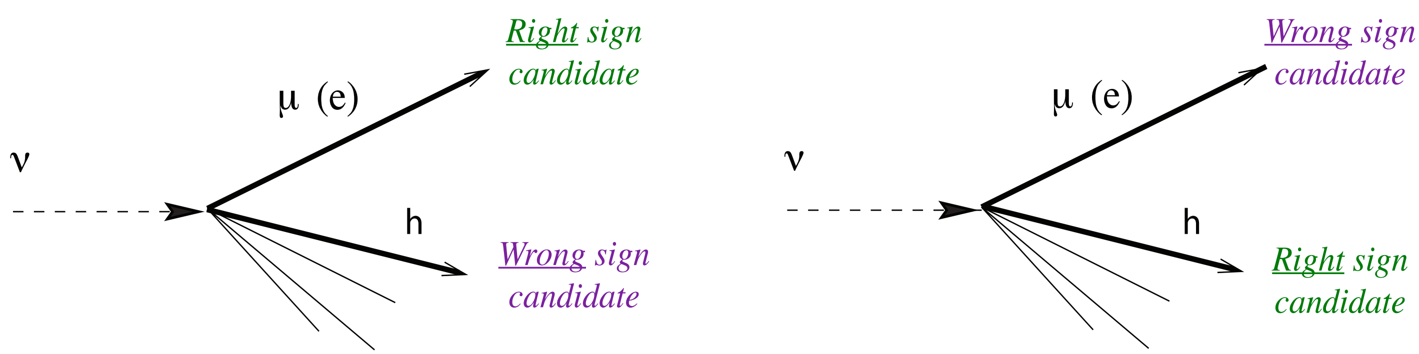
✦ *Double tagging: for each event apply BOTH e^- and e^+ tagging*

$\Longrightarrow$ *Select single e^- candidate and single e^+ candidate within same event*

✦ *For $\nu_\mu(\bar{\nu}_\mu)$ CC the $e^-(e^+)$ candidate is the actual leading $\mu^-(\mu^+)$:*

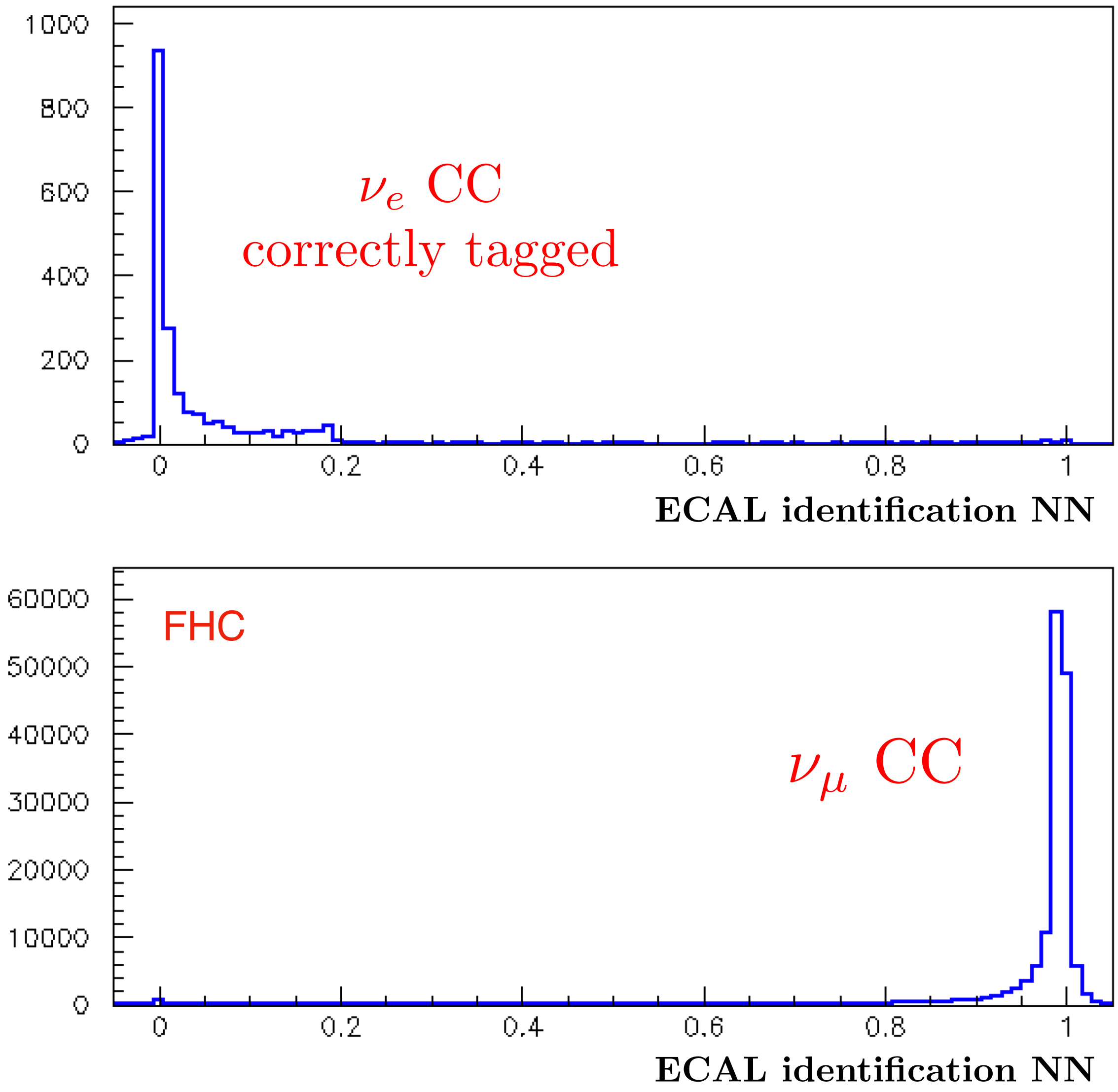
- *Reject events with right sign candidate reaching outer yoke;*
- *Reject events with wrong sign candidate reaching outer yoke;*
- *Reject events with right sign candidate identified as μ in ECAL with NN> 0.95.*

$\Longrightarrow$ *Signal $e^\pm$ and (wrong sign) hadrons rarely reach outer yoke*



Right sign CC

Wrong sign CC



Tagged tracks reaching barrel ECAL (trained with muons/pions)

ELECTRON IDENTIFICATION

✦ *Background and wrong sign candidates selected by kinematic tagging mostly $\mu^{\pm}$ or $h^{\pm}$*

$\Longrightarrow$ *Increased background rejection with electron identification*

✦ *Three criteria available for electron ID:*

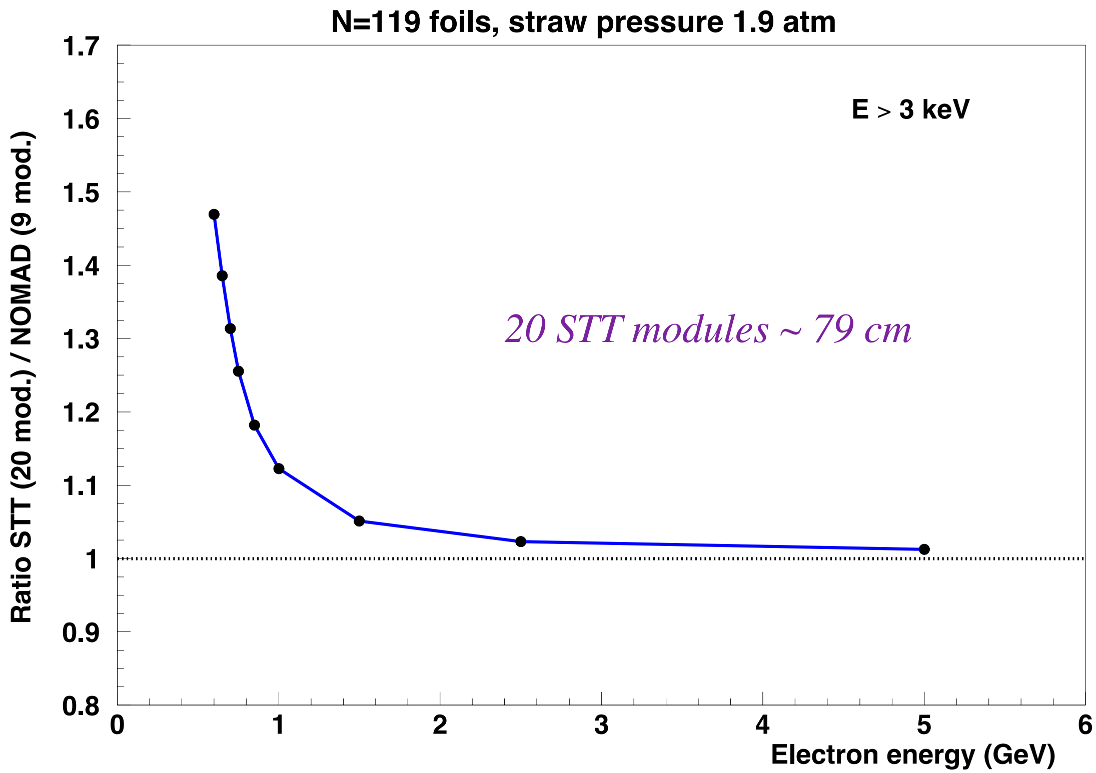
- *Transition Radiation (TR) and dE/dx in STT;*
- *Energy deposition and topology (shower shape) in ECAL;*
- *Consistency between momentum and energy deposited in ECAL.*

$\Longrightarrow$ *Specific cuts applied will depend on the particular physics analysis*

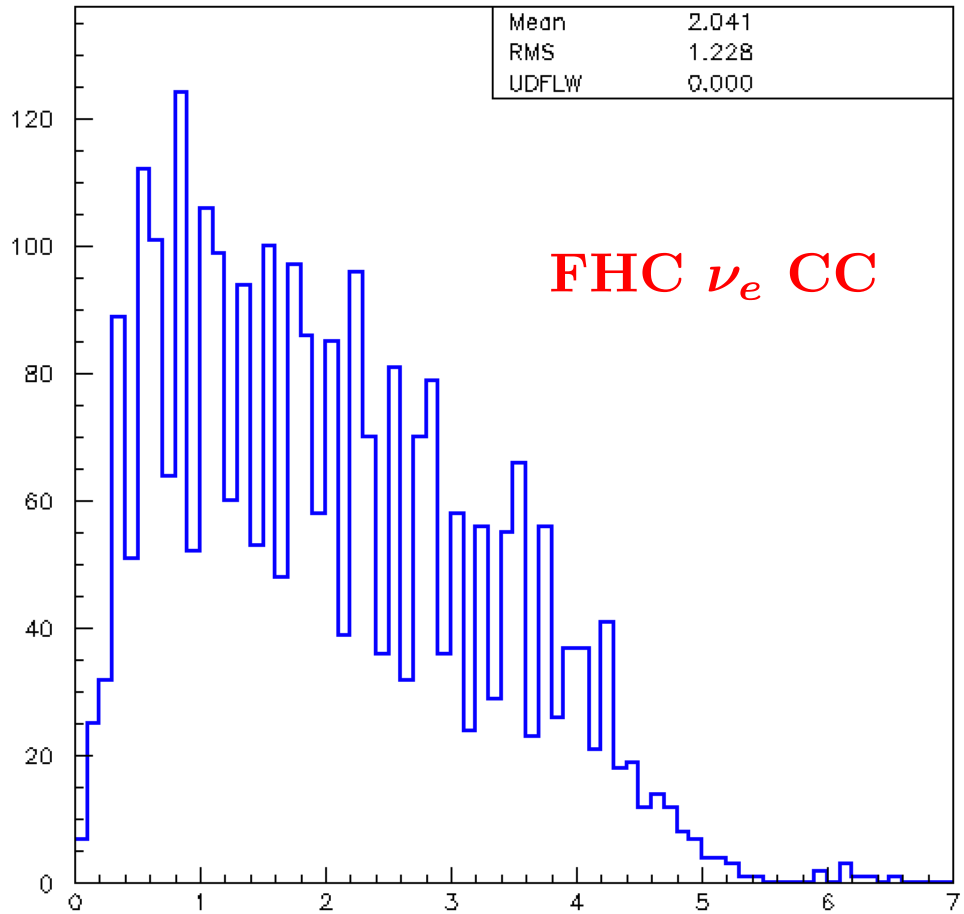
✦ *Preliminary study based only on TR performance in NOMAD:*
pion rejection 10^3 for 90% electron efficiency.

✦ *Electron ID on right sign canddidate efficiently rejects wrong sign interactions*

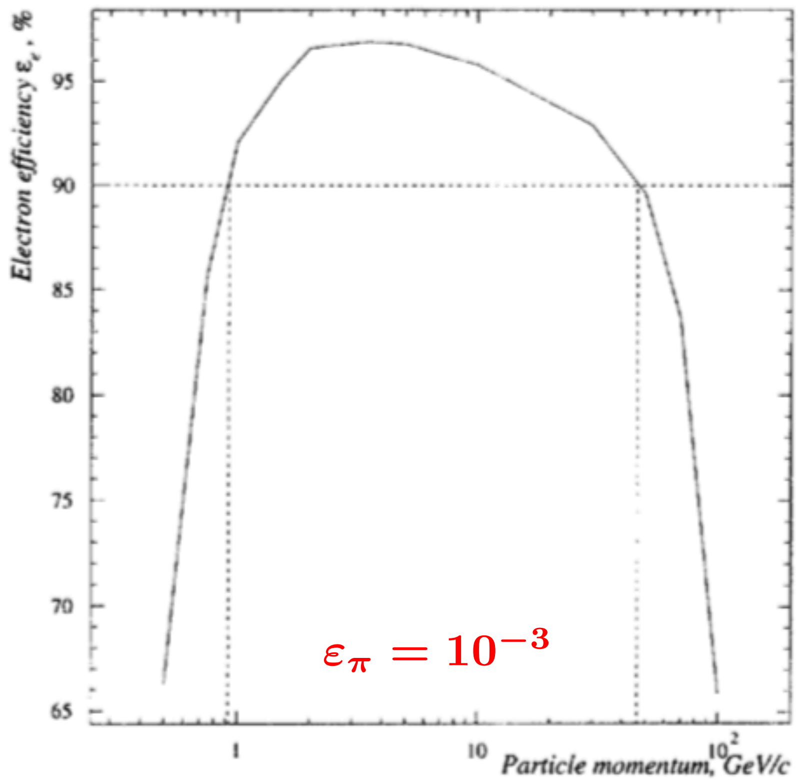
$\Longrightarrow$ *No need to apply electron ID on wrong sign candidate*

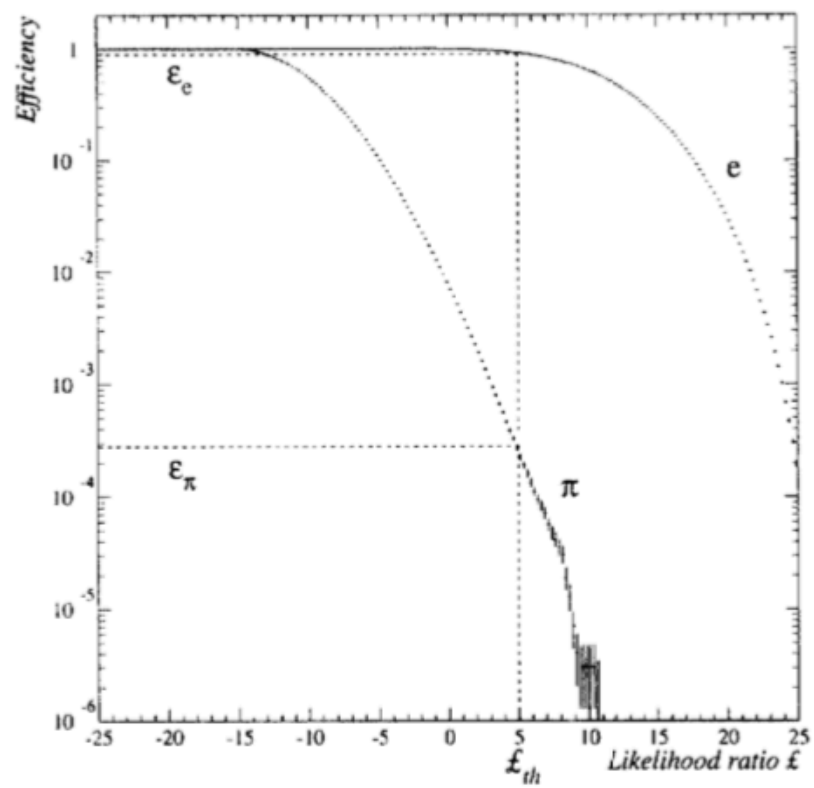


Module #	Electrons E=0.6 GeV > 3.0 keV	> 4.0 keV	> 5.0 keV	Electrons E=1.0 GeV > 3.0 keV	> 4.0 keV	> 5.0 keV	Electrons E=5.0 GeV > 3.0 keV	> 4.0 keV	> 5.0 keV
NOMAD (9 mod.)	7.31	7.05	6.48	15.36	14.74	13.56	20.62	19.77	18.26
STT (20 mod.)	10.74	10.38	9.58	17.24	16.68	15.38	20.88	20.20	18.64
Ratio STT/NOMAD	1.47	1.47	1.48	1.12	1.13	1.13	1.01	1.02	1.02

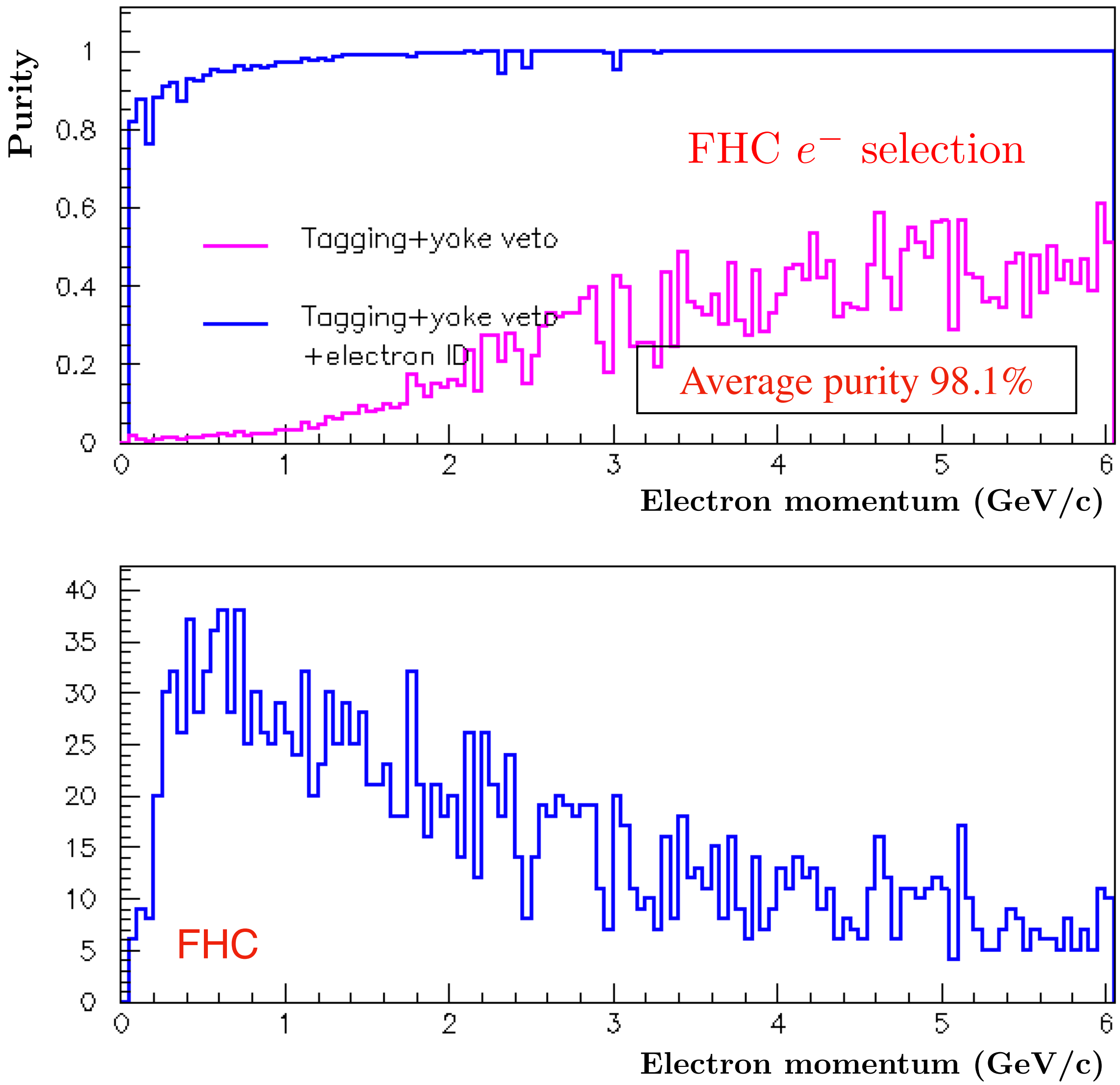


Ratio of average number of TR photons detected STT/NOMAD:
for 76% of leading CC electrons TR in STT higher than TR in NOMAD

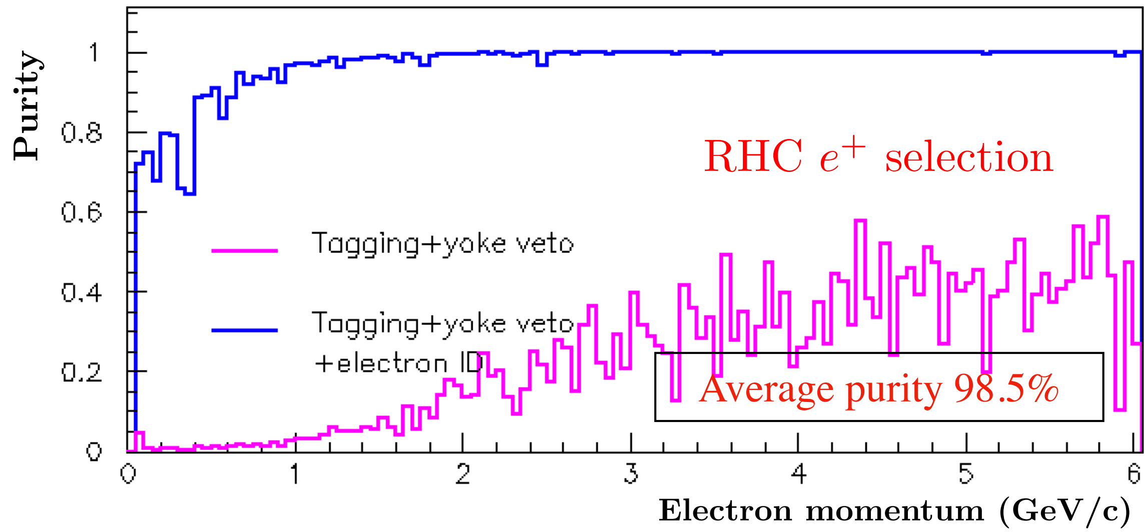


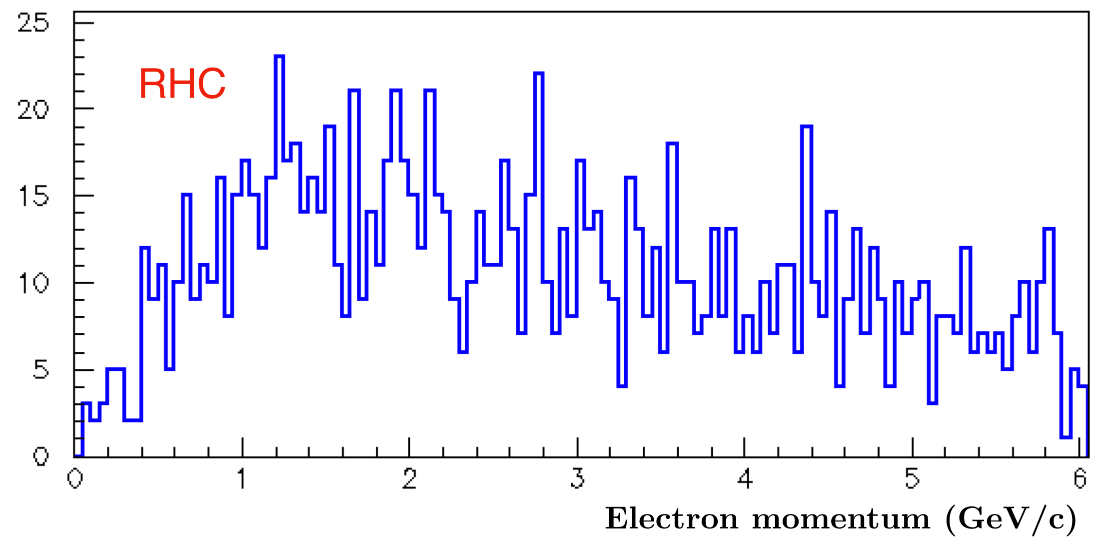


Performance of electron/pion separation with TR in NOMAD

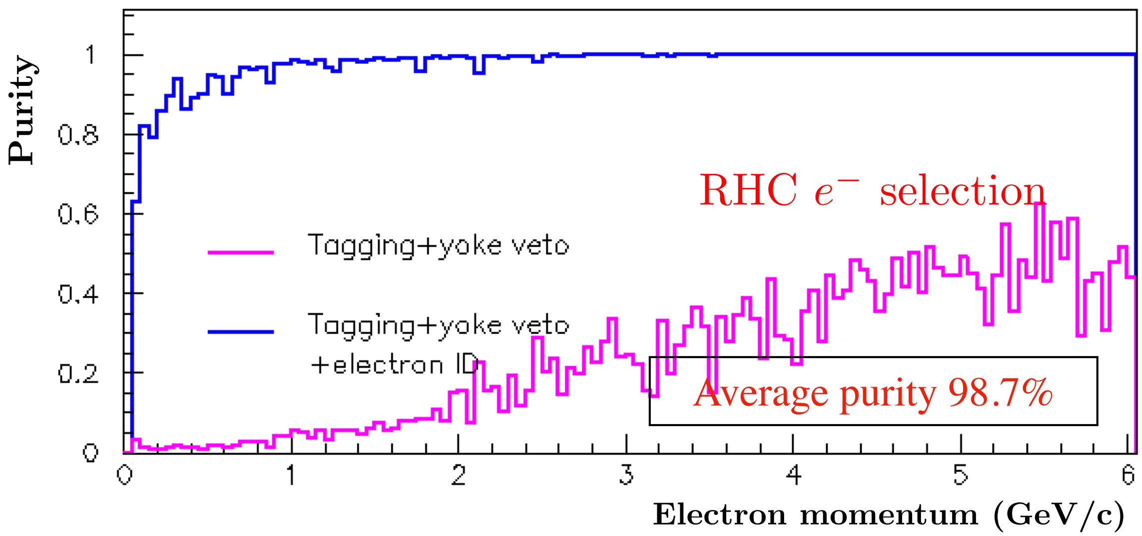


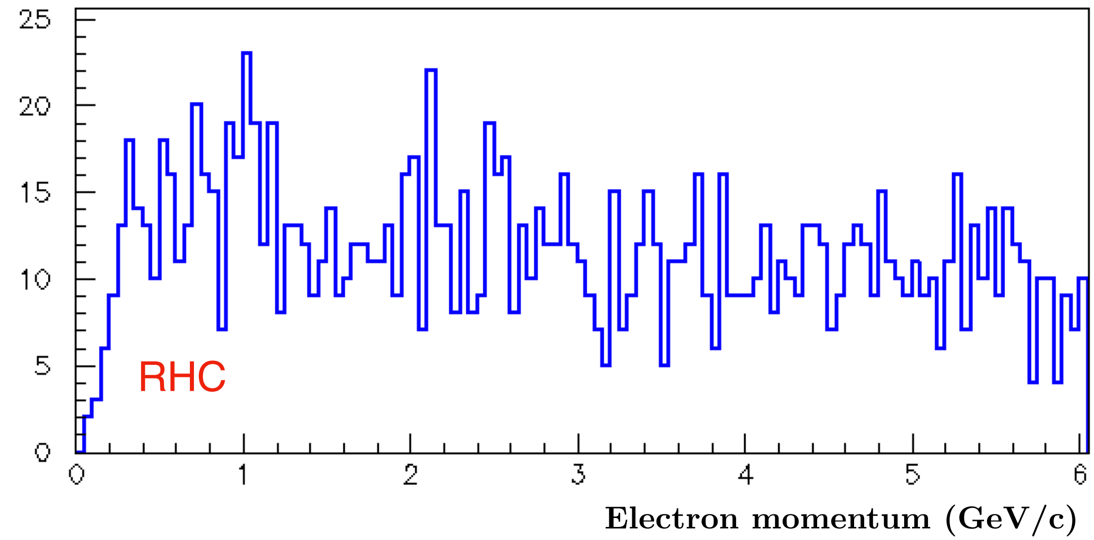
$\nu_\mu CC + \bar{\nu}_\mu CC + \nu_e CC + \bar{\nu}_e CC + NC$: *efficiency 86.4%*



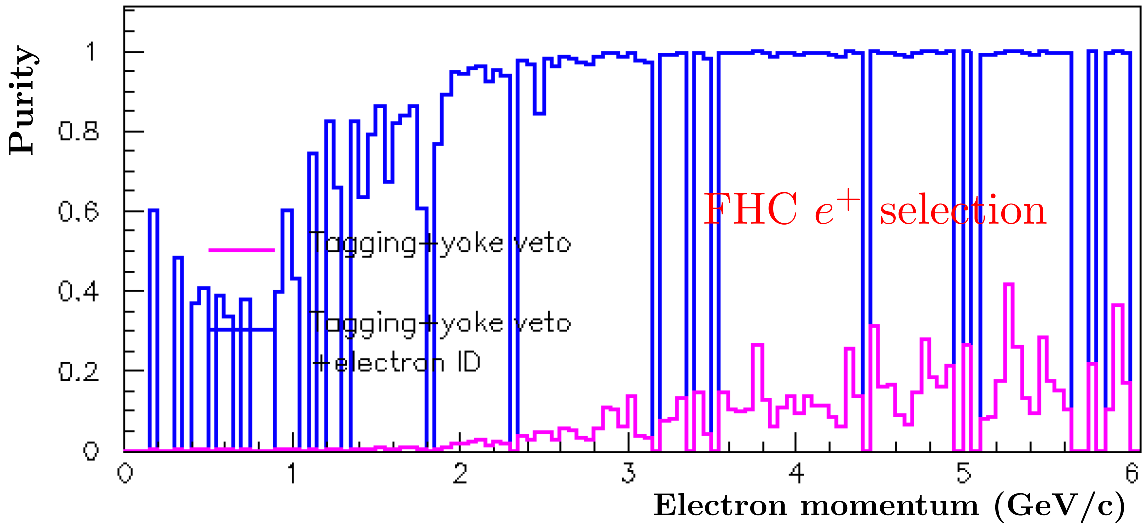


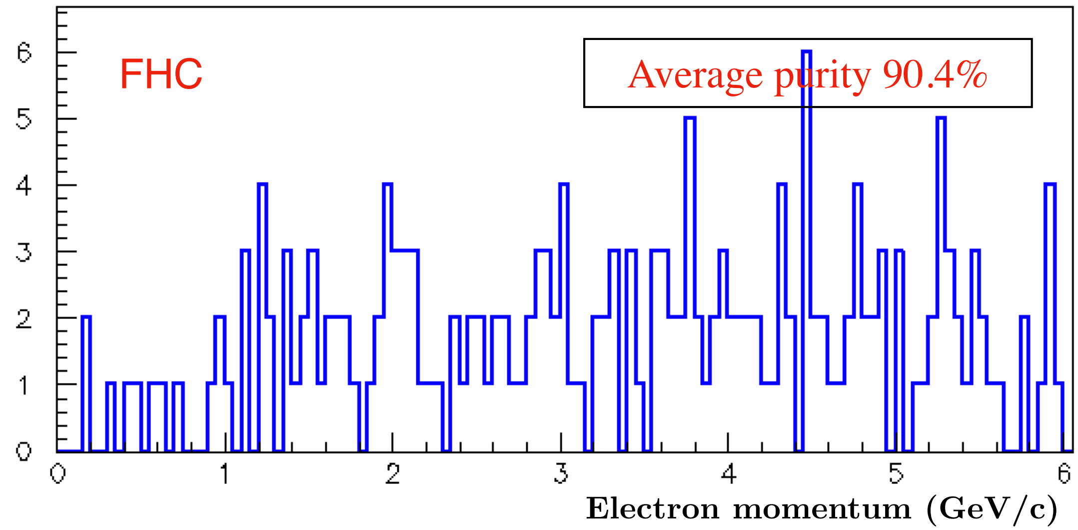
$\nu_\mu CC + \bar{\nu}_\mu CC + \nu_e CC + \bar{\nu}_e CC + NC$: efficiency 86.1%





$\nu_\mu CC + \bar{\nu}_\mu CC + \nu_e CC + \bar{\nu}_e CC + NC$: efficiency 86.0%





$\nu_\mu CC+\bar{\nu}_\mu CC+\nu_e CC+\bar{\nu}_e CC+NC$: efficiency 87.7%

SUMMARY OF ν_e & $\bar{\nu}_e$ CC SELECTION

Event type	*Efficiency*	*Purity* $\nu_\mu CC+\bar{\nu}_\mu CC+\nu_e CC+\bar{\nu}_e CC+NC$
Tagging + muon veto:		
FHC ν_e *CC with tagged* e^-	96.0 %	5.2 %
RHC $\bar{\nu}_e$ *CC with tagged* e^+	95.8 %	6.3 %
RHC ν_e *CC with tagged* e^-	95.6 %	7.8 %
FHC $\bar{\nu}_e$ *CC with tagged* e^+	97.4 %	0.9 %
Tagging + muon veto + $e^\pm$ **ID:**		
FHC ν_e *CC with tagged* e^-	86.4 %	98.1 %
RHC $\bar{\nu}_e$ *CC with tagged* e^+	86.1 %	98.5 %
RHC ν_e *CC with tagged* e^-	86.0 %	98.7 %
FHC $\bar{\nu}_e$ *CC with tagged* e^+	87.7 %	90.4 %

- *Generic CC selections: purities can be further increased with tighter cuts (+ kinematics)*
- *The selection of specific processes/topologies results in additional background rejection.*
- *Similar selection of* $e^\pm$ *and* $\mu^\pm$ *reduces systematics on the* ν_e/ν_μ *and* $\bar{\nu}_e/\bar{\nu}_\mu$ *ratios.*

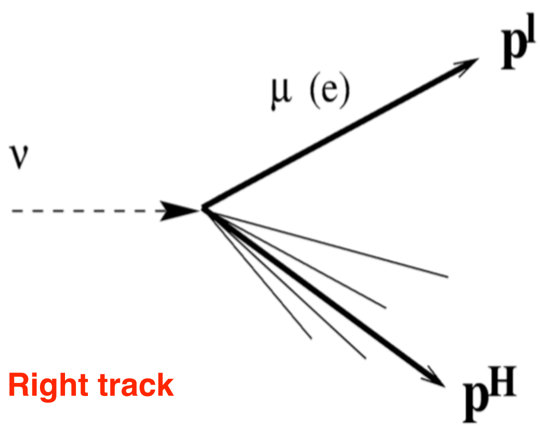
Backup slides

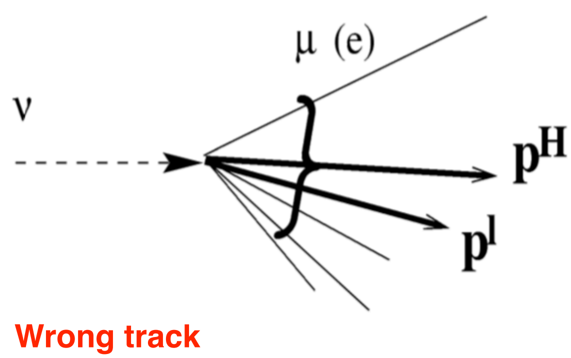
KINEMATIC VARIABLES

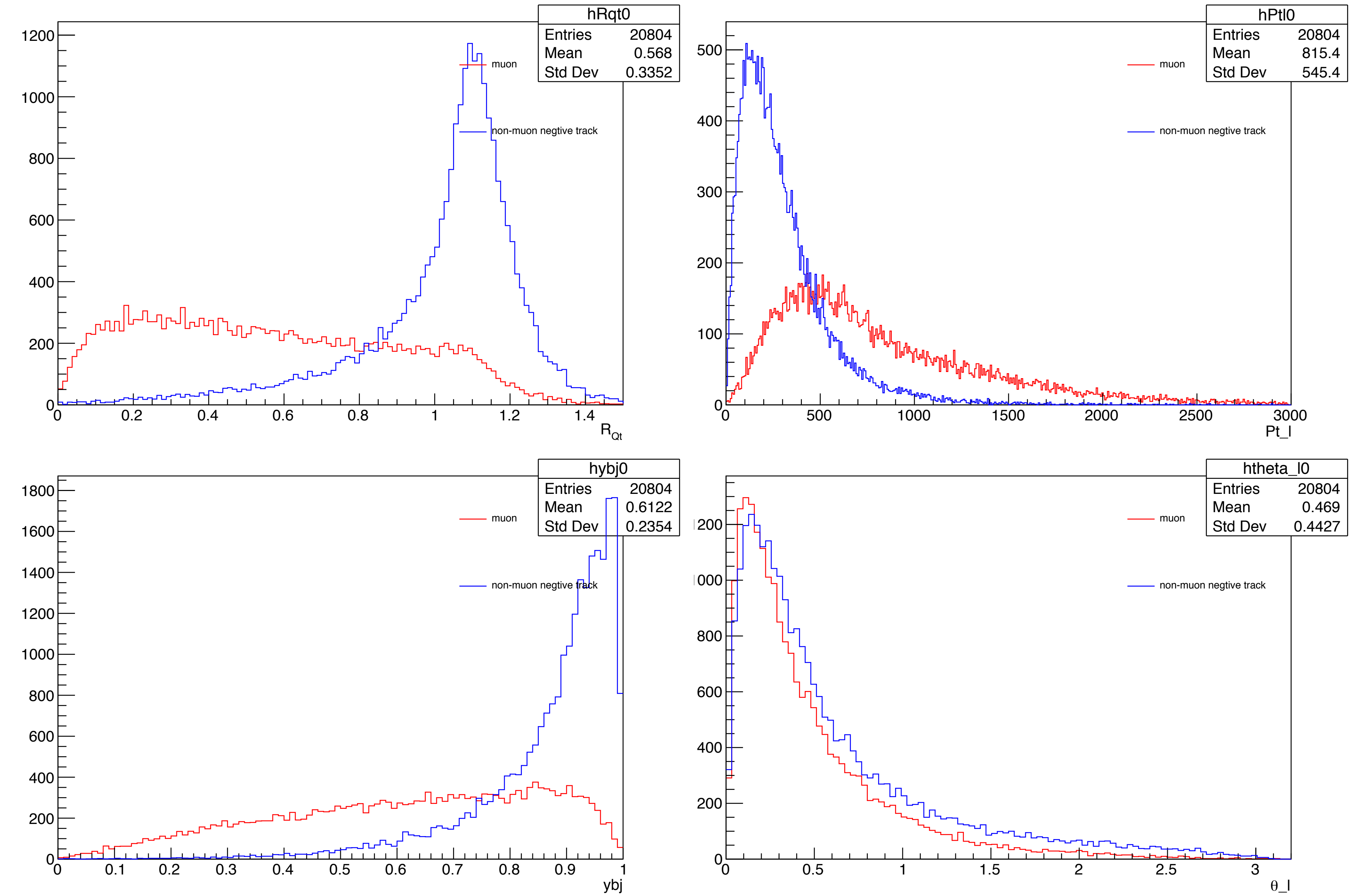
✦ *Kinematic tagging must discriminate between the true $\mu^{\pm}$ track and wrong $h^{\pm}$ track inside the SAME CC event: total visible momentum is constant (3 constraints).*

✦ *Consider 4 kinematic variables for muon tagging:*

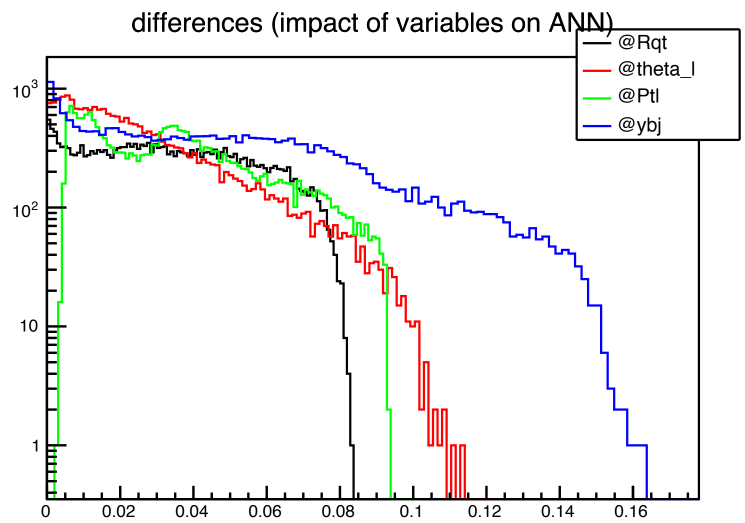
- p_T^l: *transverse momentum of the track candidate;*
- $\theta_{\nu l}$: *angle of the track candidate with respect to beam direction;*
- y_{Bj}: *ratio between the energy of the "hadron system" (visible energy minus track energy) and the total visible energy;*
- R_{Q_T}: *ratio between the transverse size of the of the "hadron system" $\langle Q_T^2 \rangle_H$ and that of the full event $\langle Q_T^2 \rangle$, where Q_T component of the track momentum perpendicular to the total visible momentum.*

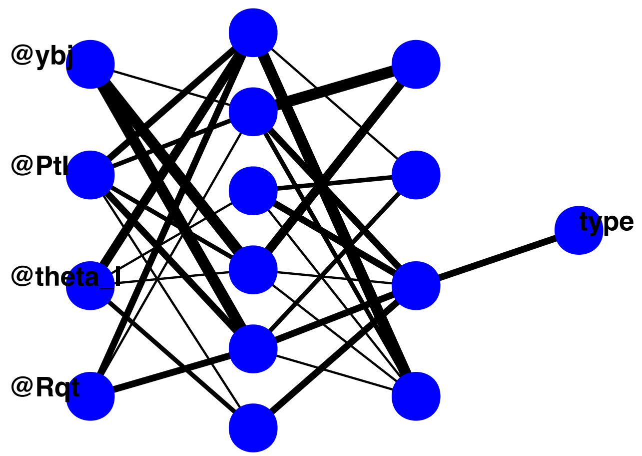


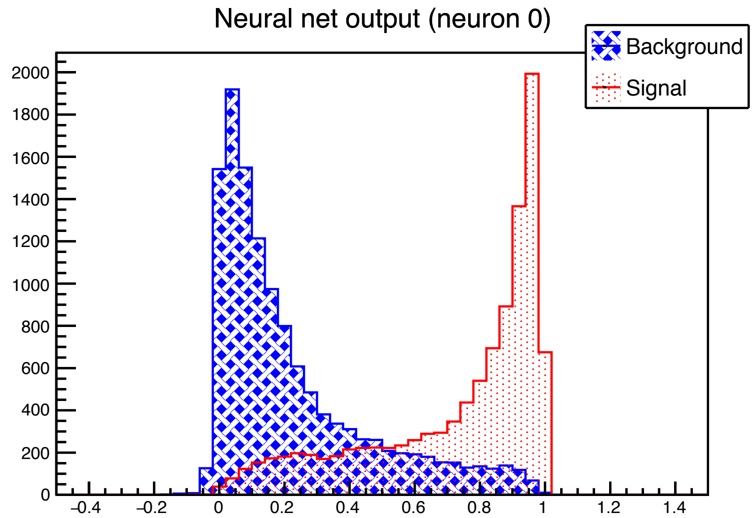


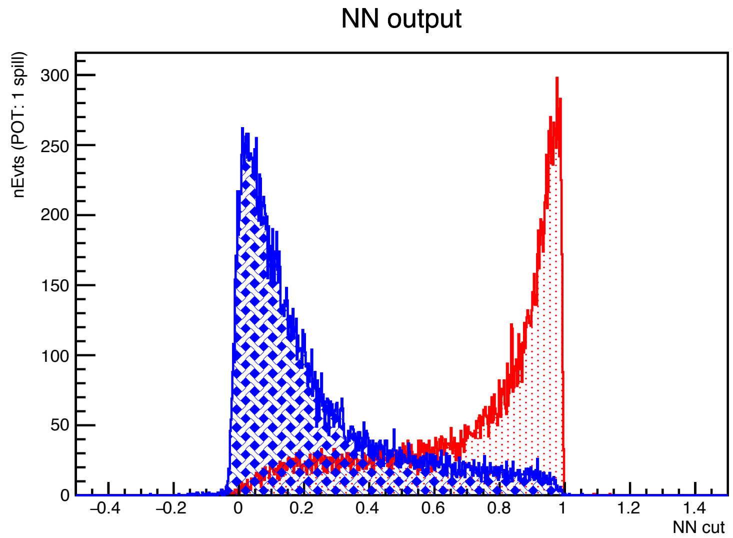


CC events with more than one negative track: <u>all tracks</u>









CC events with more than one negative track: all tracks