e/π Separation in the NA48 Experiment Using Neural Networks

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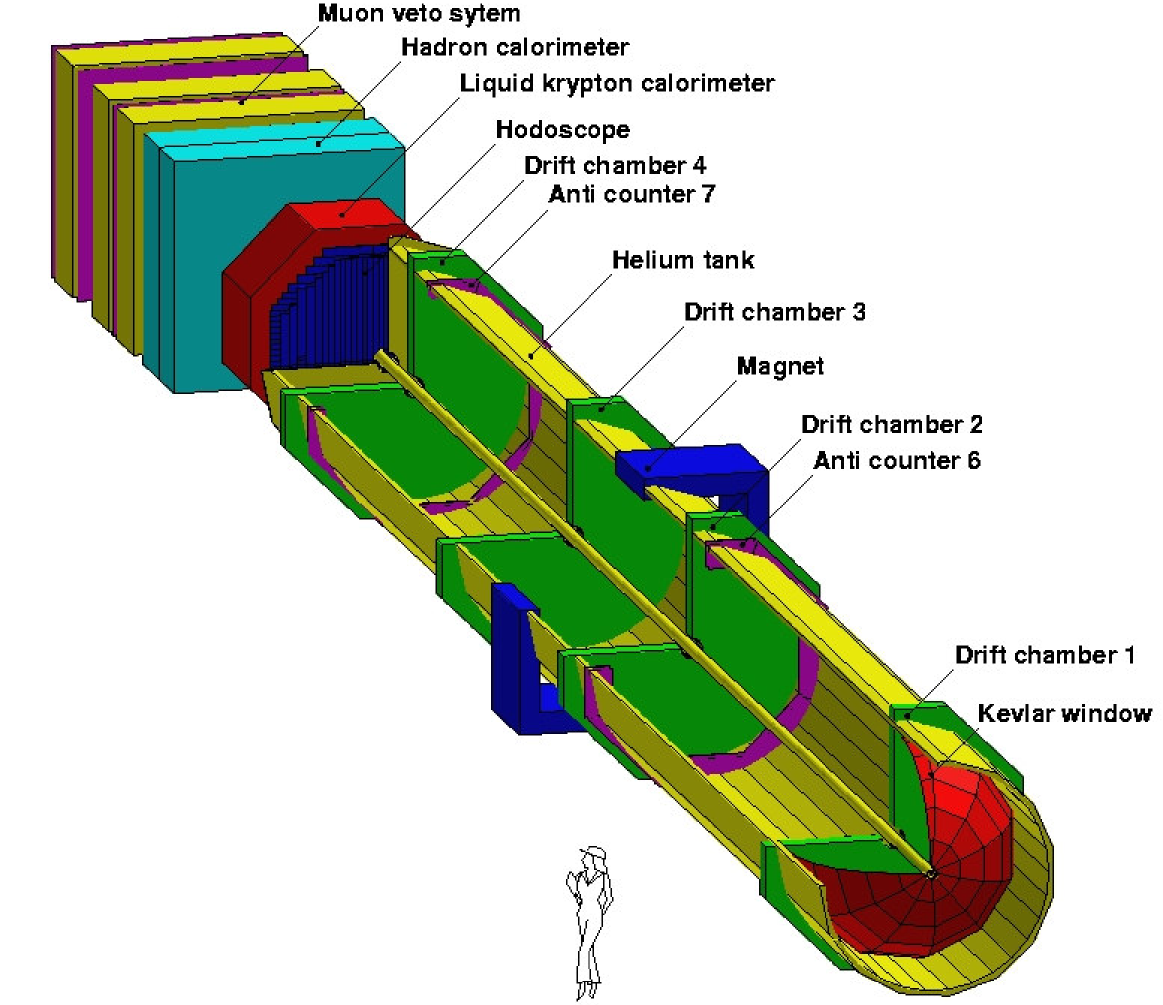
Introduction

❖2003 Program for a precision measurement of Charged Kaon Decays Parameters

- Direct CP – violation in $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$, $K^{\pm} \to \pi^{0}\pi^{0}\pi^{\pm}$
- Ke4 - $K^{\pm} \to \pi^{\pm}\pi^{\mp}e^{\pm}\nu\,(\overline{\nu})$
- Scattering lengths a_0^0, a_0^2
- Radiative decays $K^{\pm} \to \pi^{\pm}\gamma\gamma$, $K^{\pm} \to \pi^{\pm}\gamma\gamma\gamma$, $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$

NA48


Muon veto sytem
Hadron calorimeter
Liquid krypton calorimeter
Hodoscope
Drift chamber 4
Anti counter 7
Helium tank
Drift chamber 3
Magnet
Drift chamber 2
Anti counter 6
Drift chamber 1
Kevlar window

Introduction

- Significant background in K_{e4} comes from $K_{3\pi}$

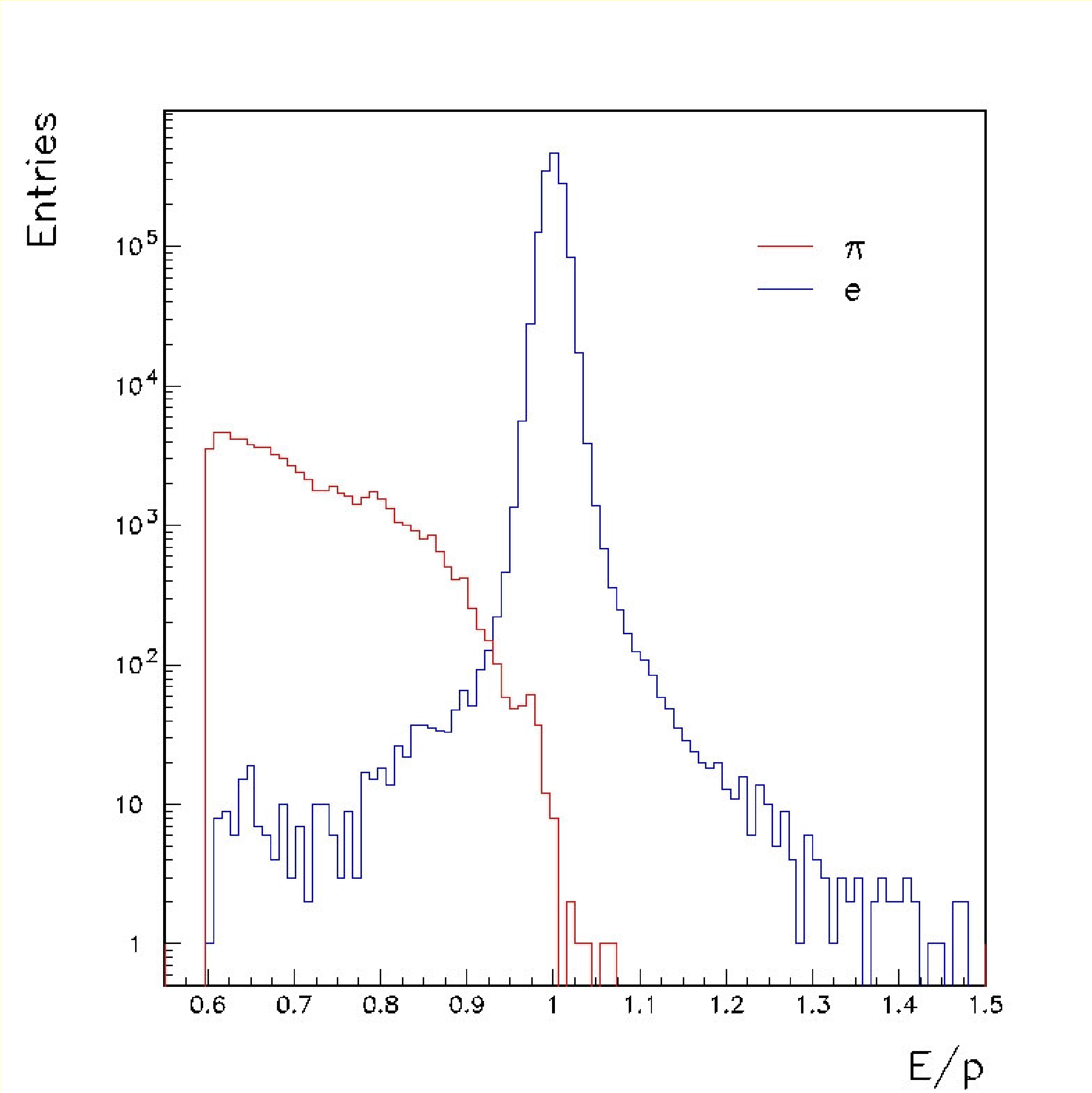
$K^+ \to \pi^+\pi^+\pi^-$ decay	Background in K_{e4}^c
π with $0.9 < E_{cal}/p < 1.1$	4%
$K^+ \to \pi^+\pi^+\pi^- \to \delta ray > eGeV$	$\leq 0.1\%$
$K^+ \to \pi^+\pi^+\pi^- \to e\nu_e(Br = 1.2 \cdot 10^{-4})$	$\leq 0.1\%$
$K^+ \to \pi^+\pi^+\pi^- \to \mu\nu_\mu \to e\nu_e$	$\leq 0.1\%$

- Goal - to reach good enough e/π separation
- $K^+ \to \pi^+\pi^+\pi^- < 0.1$ %
- Definitions:
  - Probability to identify a π as an e : $\epsilon^{\pi \to e}$
  - Probability to identify an e as an e : ϵ^e_{eff}
  - i.e. relatively to E/p < 0.9 cut $\epsilon^{\pi \to e} \sim 2.5 \cdot 10^{-2}$

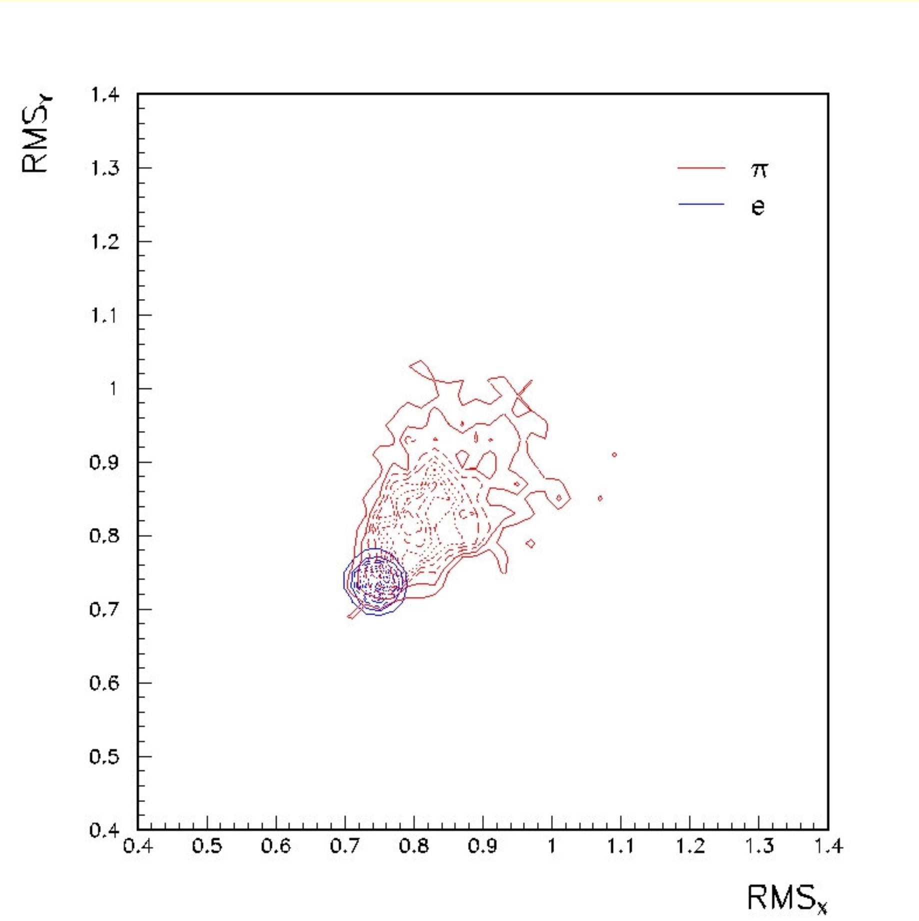
Sensitive Variables

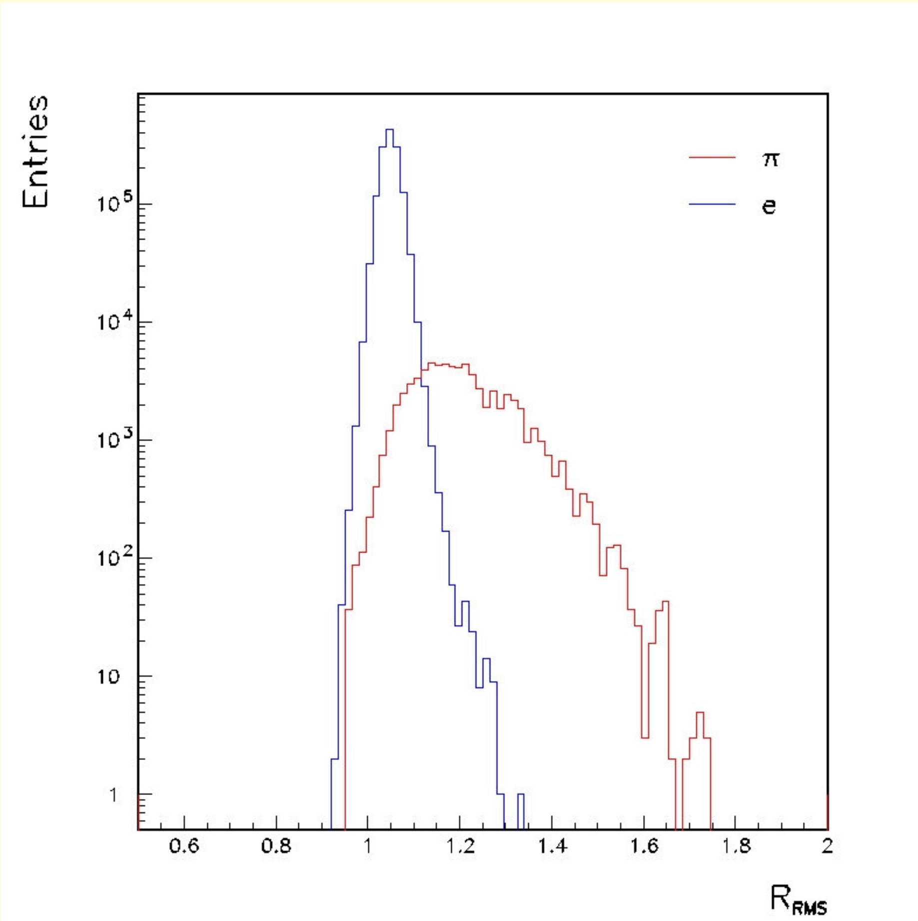
- Difference in development of e.m. and hadron showers
- Lateral development
- LKr gives information for lateral development
- NHODO gives information for longitudinal development
- From LKr
  - E/p
  - E_{max}/E_{all}, RMSX, RMSY
  - Distance between the track entry point and the associated shower
  - Effective radius of the shower

Sensitive variables - E/p

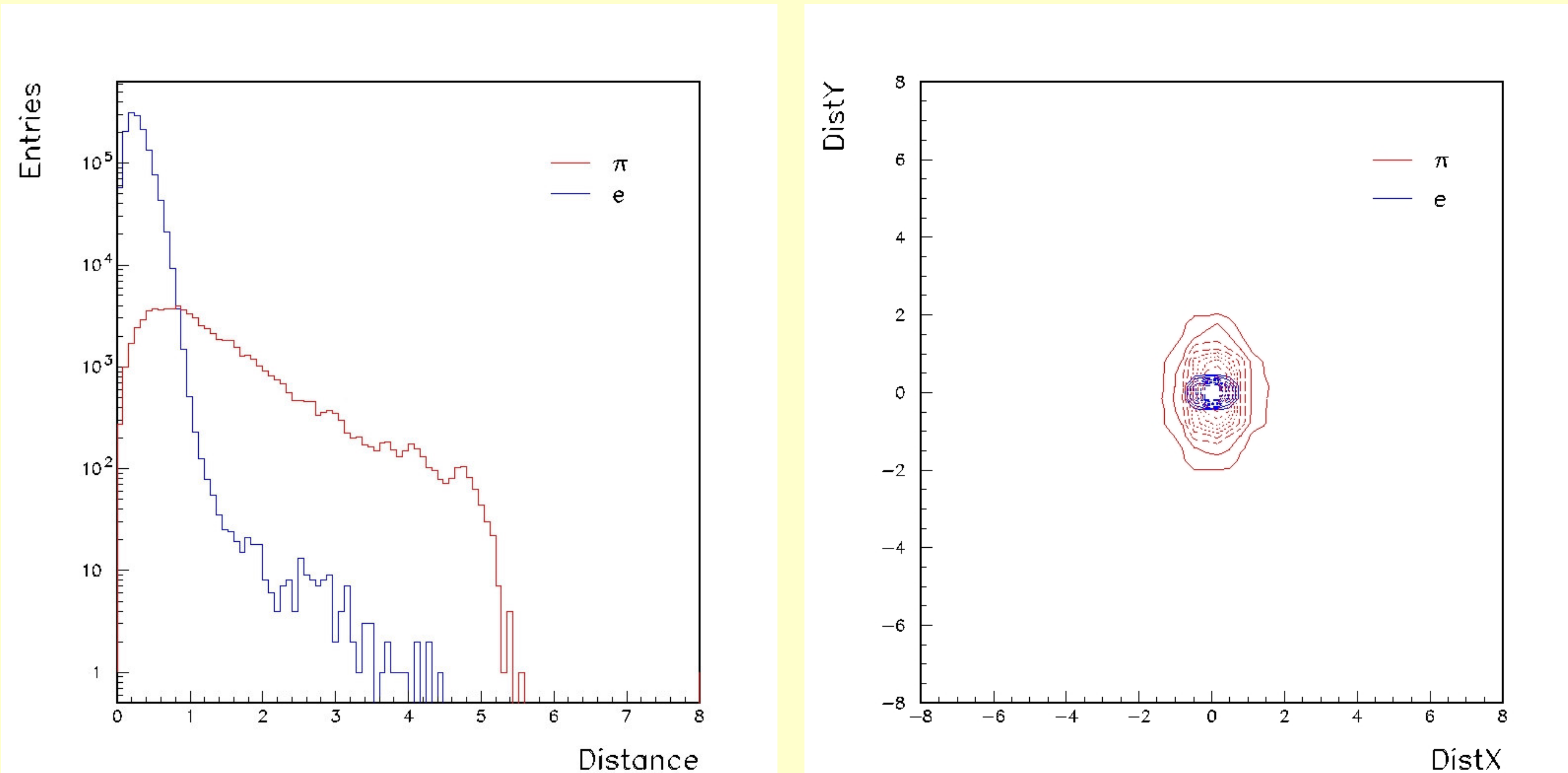


Sensitive variables - RMS

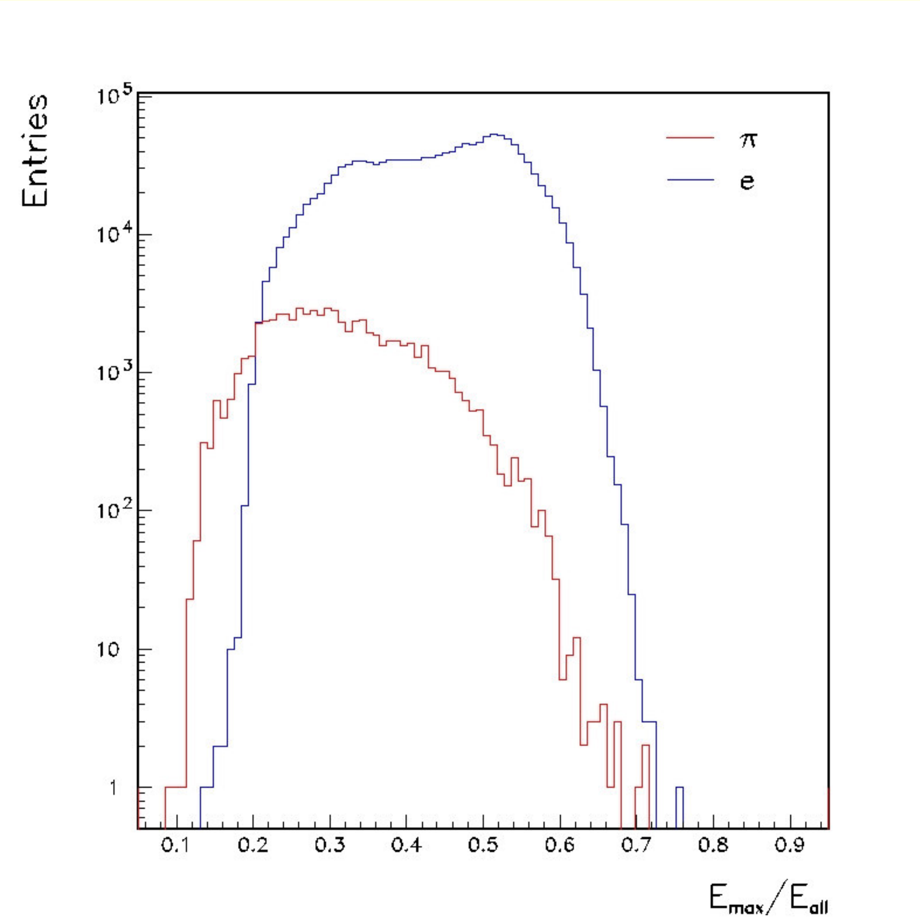


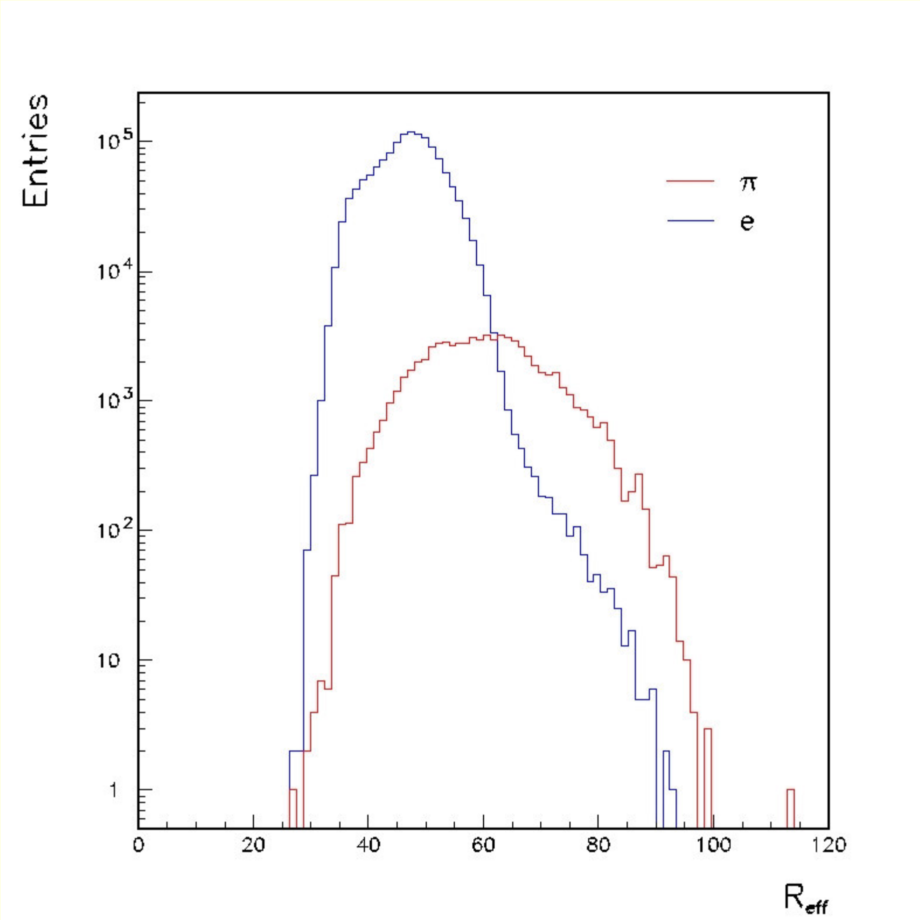


Distance



Sensitive variables - Emax/Eall, Reff





MC

- To test different possibilities we have used:
  - Simulated Ke3 decays – 1.3 M
  - Simulated single e and π – 800 K π and 200 K e
- Using different cuts we have obtained
  - Relatively to E/p < 0.9 cut $\varepsilon_{eff}^{\pi\to e} = 15.7\times10^{-2}$
  - Keeping ε_{eff}^{e} > 95 %
- Using Neural Network it is possible to reach e/π separation:
  - Relatively to E/p < 0.9 cut $\varepsilon_{eff}^{\pi\to e} < 2.0\times10^{-2}$
  - Keeping ε_{eff}^{e} > 98%
- The background from $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$ ~ 0.1%

Neural Network

Powerful tool for:

- ❖Classification of particles and final states
- ❖Track reconstruction
- ❖Particle identification
- ❖Reconstruction of invariant masses
- ❖Energy reconstruction in calorimeters

Basic computing element - Neuron

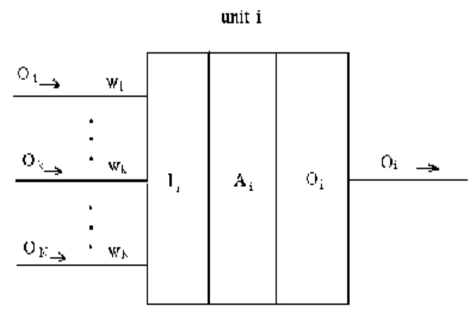


fig 1.NN

neuron performs calculations in three steps

$$I_i = \sum_k w_{ik} O_k, \qquad A_i(I) = \frac{1}{1+e^{-(I_i+b_i)}}, \qquad O_i = \Theta(A_i - A_{0i}), \qquad (1)$$

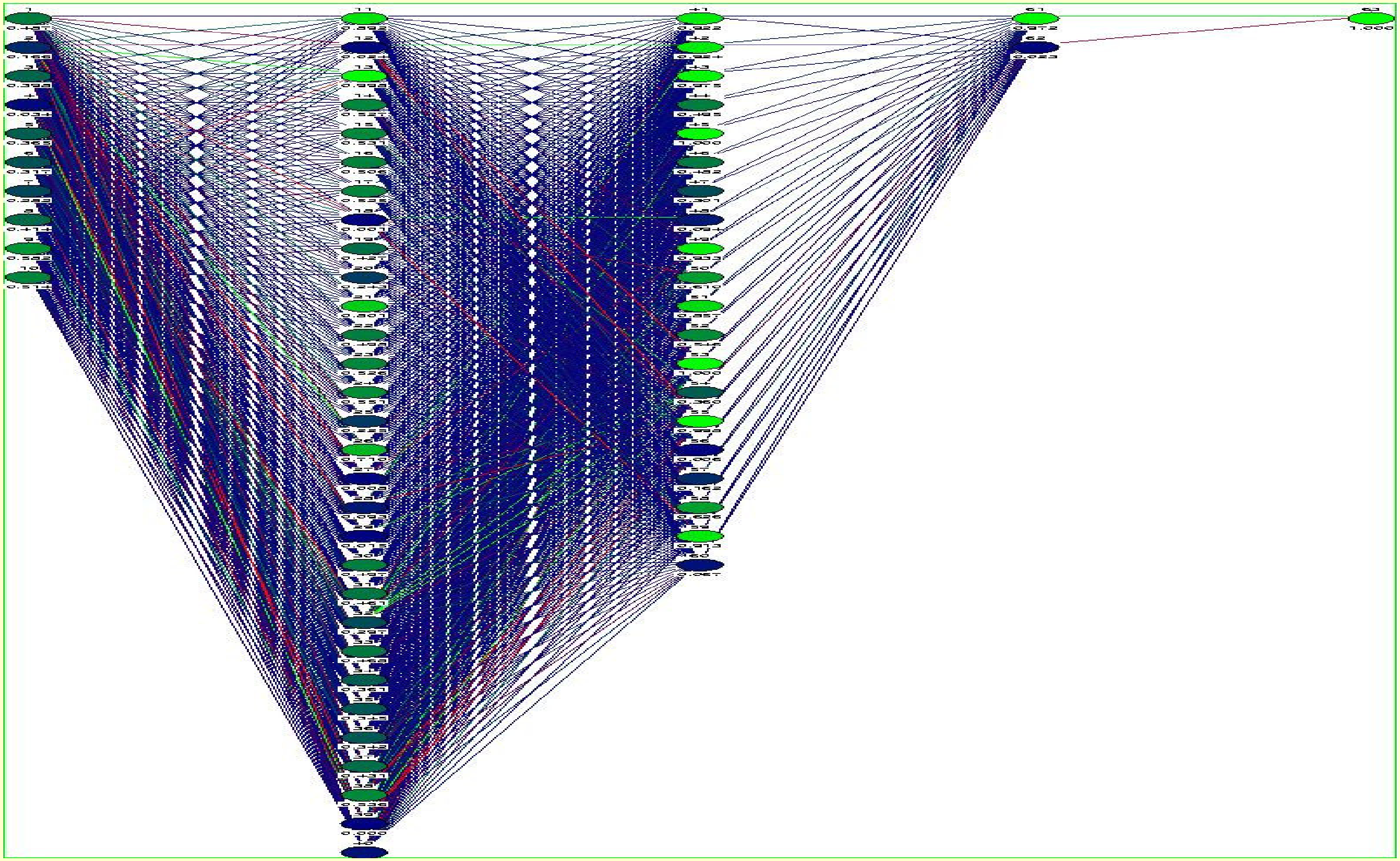
Neural Network

Neural Network

- ❖ Multi-Layer-Feed Forward network consists of:
  - ➢ Set of input neurons
  - ➢ One or more layers of hidden neurons
  - ➢ Set of output neurons
  - ➢ The neurons of each layer are connected to the ones to the subsequent layer
- ❖ Training
  - ➢ Presentation of pattern
  - ➢ Comparison of the desired output with the actual NN output
  - ➢ Backwards calculation of the error and adjustment of the weights
- ❖ Minimization of the error function

$$E = \frac{1}{2} \sum_{j} (t_j - o_j)^2$$

NN 10-30-20-2-1



Neural Network

- Backpropagation learning algorithm

$$\Delta w = -\eta \frac{\partial E}{\partial w}$$

- η - learning rate - varies significantly
- Rprop - uses individual learning rate and Manhattan updating rule

$$\Delta w = -\eta sign[\frac{\partial E}{\partial w}]$$

At every step, η is adjusted as:

$$\eta_{w,t+1} = \gamma^{+}\eta_{w,t} \quad \text{if} \quad \partial E_{t+1}.\partial E_t > 0,$$

$$\eta_{w,t+1} = \gamma^{-}\eta_{w,t} \quad \text{if} \quad \partial E_{t+1}.\partial E_t < 0$$

$$0 < \gamma^{-} < 1 < \gamma^{+}$$

Experimental data

We have used experimental data from three different runs

- Kμ3 special run 99
  - electrons from reconstructed $K^0 e3$
  - pions from $K^0 \to \pi^+ \pi^- \pi^0$
- Charged kaon test run # 1 2001
  - electrons from $K^\pm \to \pi^\pm \pi^0 \to \pi^\pm e^+ e^- \gamma$
  - pions from $K^\pm \to \pi^\pm \pi^\pm \pi^\mp$
- $K^0 e4$ run 2001
  - electrons from $K^0 e3$
  - pions from $K^0 \to \pi^+ \pi^- \pi^0$

Charged run

$$K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}$$

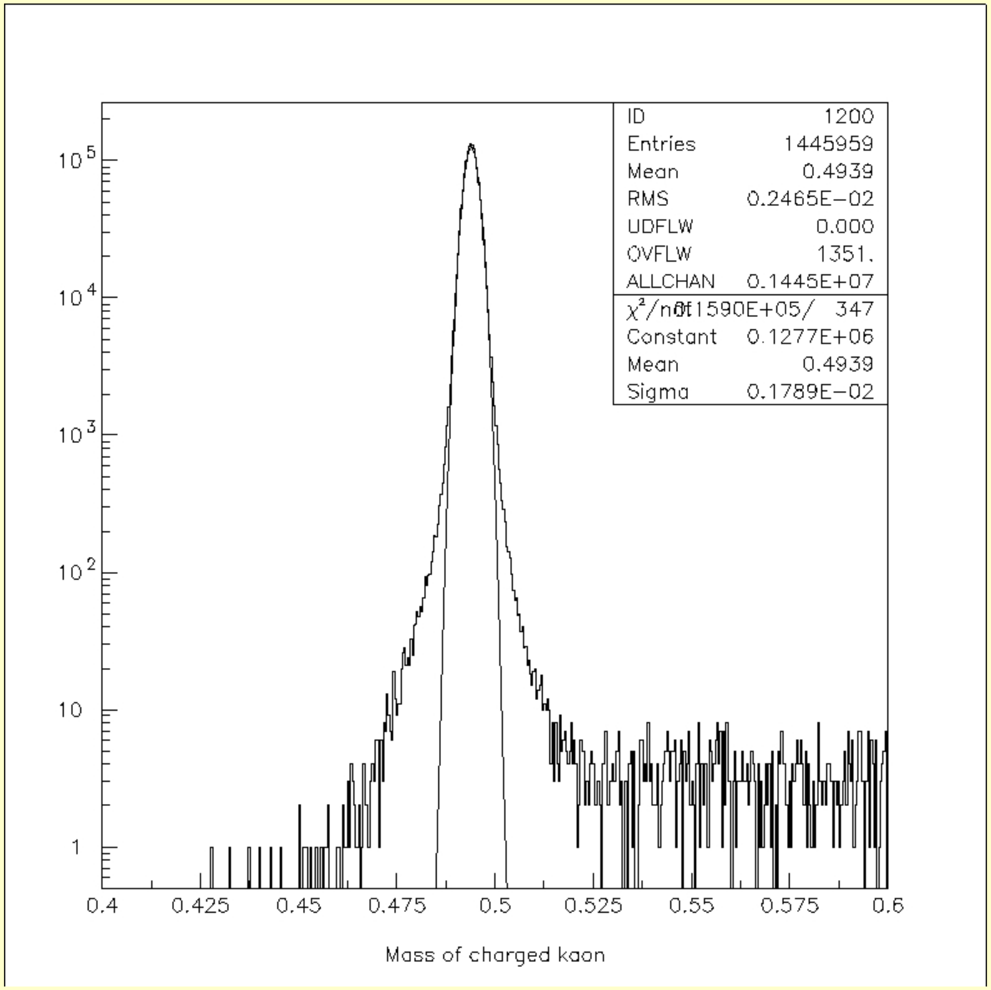
Pions

❖Track momentum . 3 GeV

❖Very tight $K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}$ selection

❖Track is chosen randomly

❖Requirement – E/p < 0.8 for the other two tracks

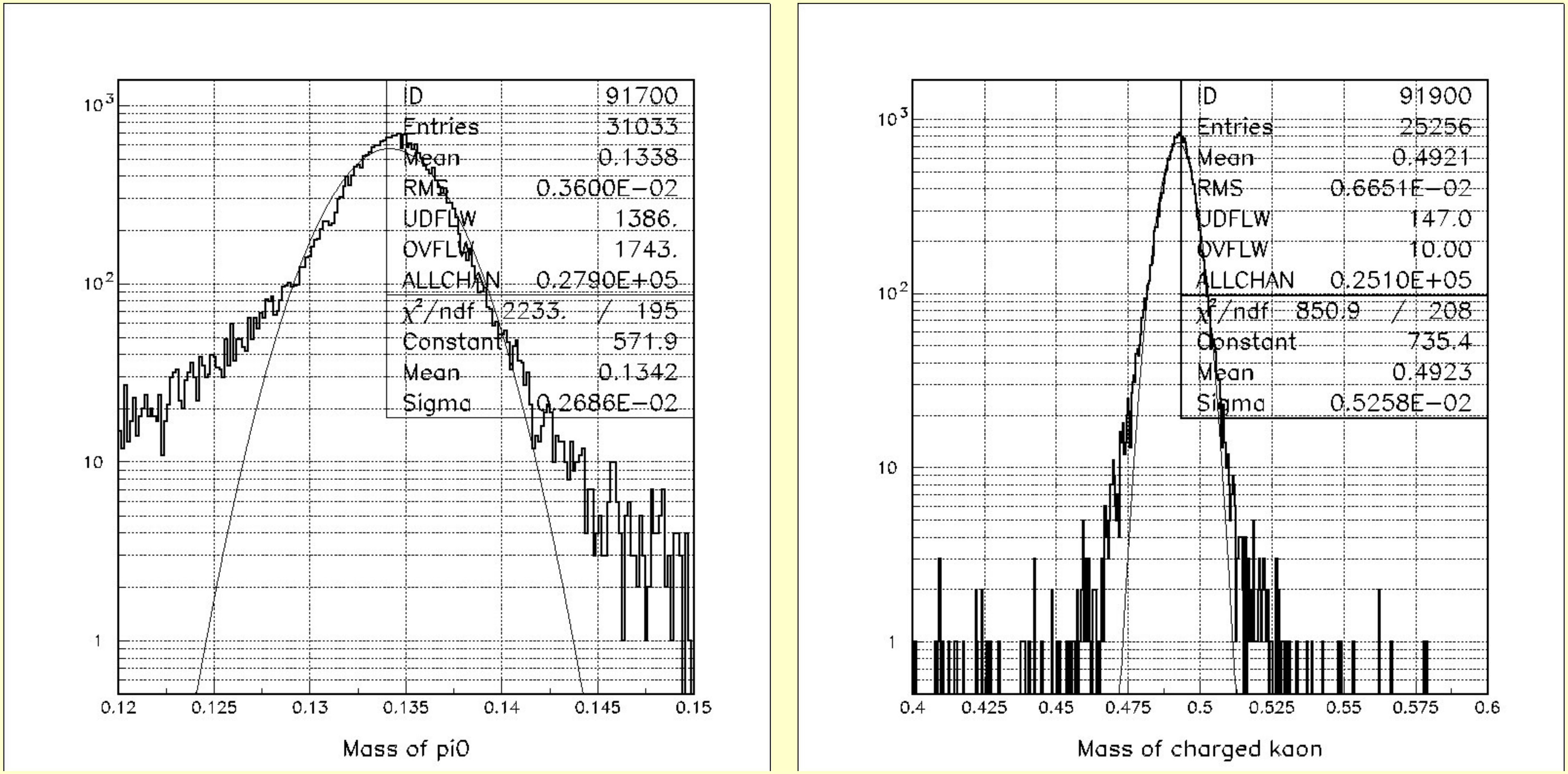


$K^{\pm} \to \pi^{\pm}\pi^{0} \to \pi^{\pm}e^{+}e^{-}\gamma$

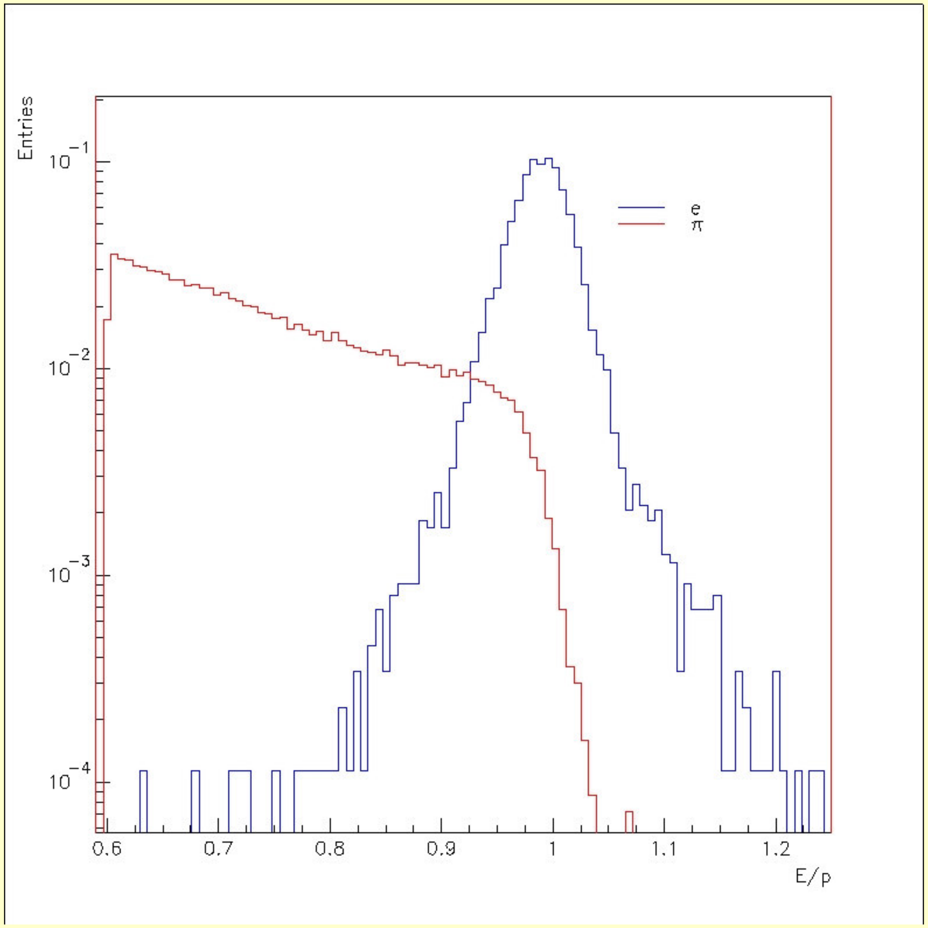
Selection :

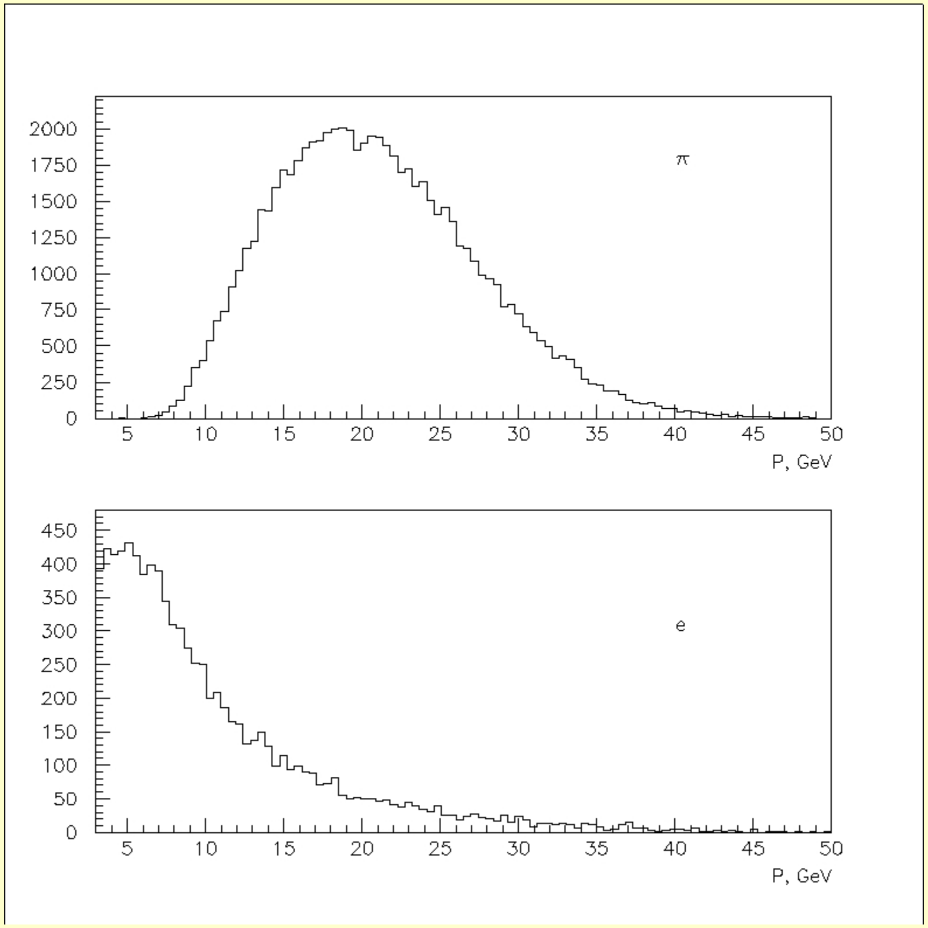
- 3 tracks
- Distance between each two tracks > 25 cm
- All tracks are in HODO and MUV acceptance
- Selecting one of the tracks randomly
- Requirement – two are e (E/p > 0.9) and π (E/p < 0.8)
- The sum of tracks charges is ± 1
- Three-track vertex CDA < 3 cm
- One additional γ in LKr, at least 25 cm away from the tracks
- 0.128 GeV < m_{π^0} < 0.140 Gev
- 0,482 GeV < m_k < 0.505 GeV

$$K^{\pm} \to \pi^{\pm}\pi^{0} \to \pi^{\pm}e^{+}e^{-}\gamma$$

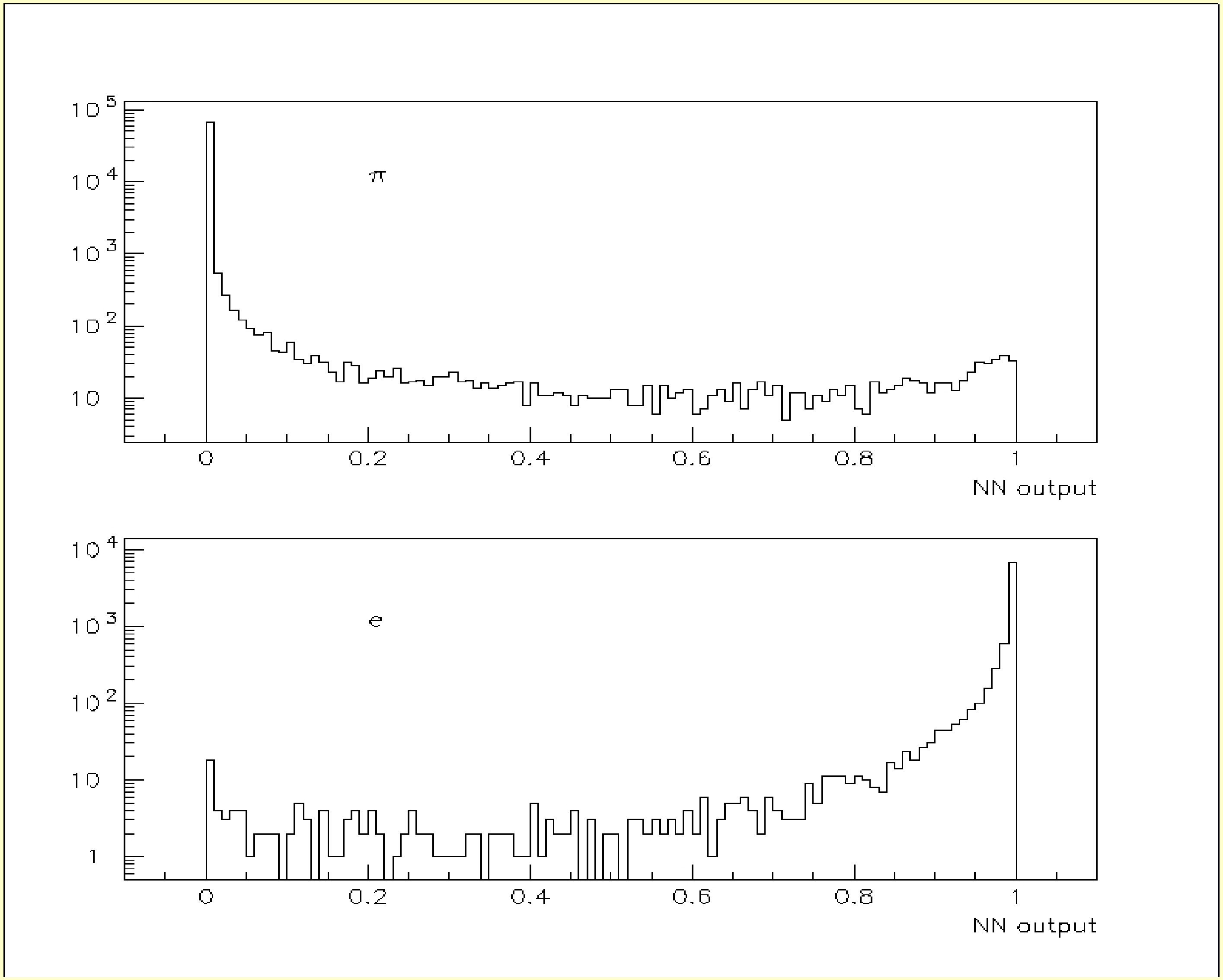


Charged run


Entries
10⁻¹
10⁻²
10⁻³
10⁻⁴
0.6
0.7
0.8
0.9
1
1.1
1.2
E/p
e
π


2000
1750
1500
1250
1000
750
500
250
0
π
5
10
15
20
25
30
35
40
45
50
P, GeV
450
400
350
300
250
200
150
100
50
0
e
P, GeV

Charged run NN output



Charged run NN performance

- Net: 10-30-20-2-1
- Input: E/p, Dist, Rrms, p, RMSx, RMSy, dx/dz, dy/dz, DistX, DistY
- Teaching: 10000 π - $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$, 5000 e - $K^{\pm} \to \pi^{\pm}\pi^{0} \to \pi^{\pm}e^{+}e^{-}\gamma$

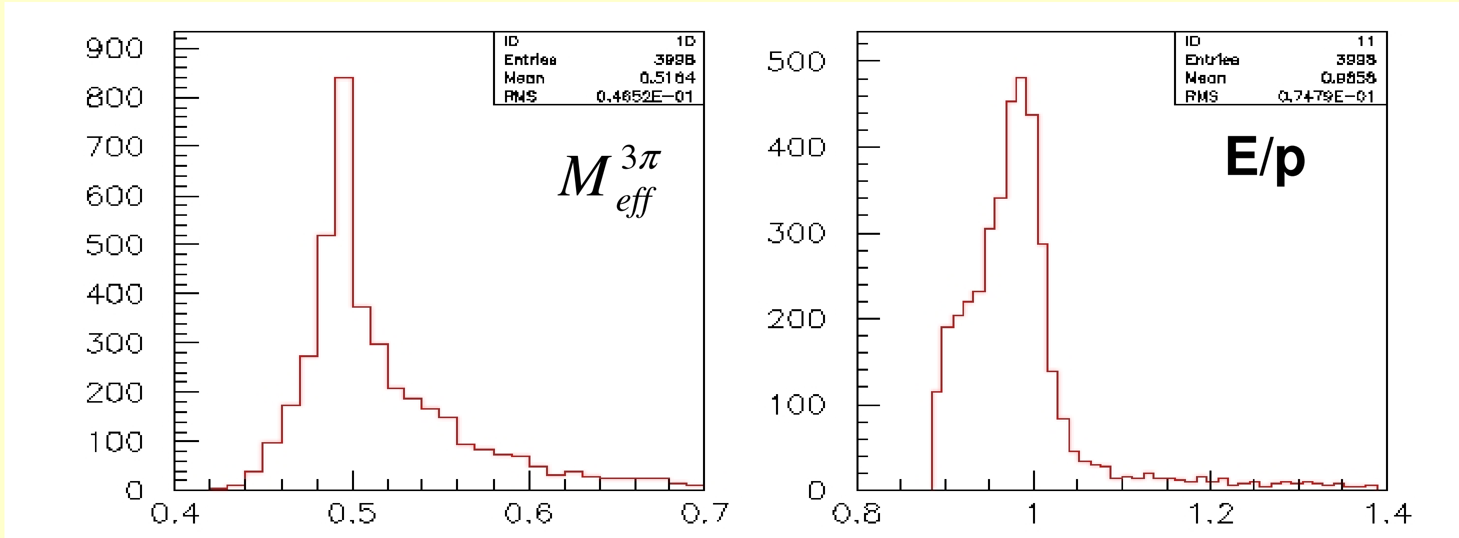
	$e^{\pm}$	$\pi^{\mp}$	ϵ^{e}_{eff},%
ALL	8889	912164	
$E/p > 0.6$	8776	69334	—
$E/p > 0.9$	8662	7533	97.4
out$>$ 0.9	8357	254	94.0
out$>$ 0.95	8070	168	90.8

	$\epsilon^{\pi\to e}$	ϵ^{e}_{eff},%
out$>$ 0.9/ALL	$2.8 \cdot 10^{-4}$	94.
out$>$ $0.9/E/p > 0.9$	$3.4 \cdot 10^{-2}$	96.5
out$>$ 0.95/ALL	$1.8 \cdot 10^{-4}$	90.8
out$>$ $0.95/E/p > 0.9$	$2.2 \cdot 10^{-2}$	93.2

$K^{\pm} \to \pi^{\pm}\pi^{\mp}e^{\pm}\nu(\bar{\nu})$

E/p > 0.9

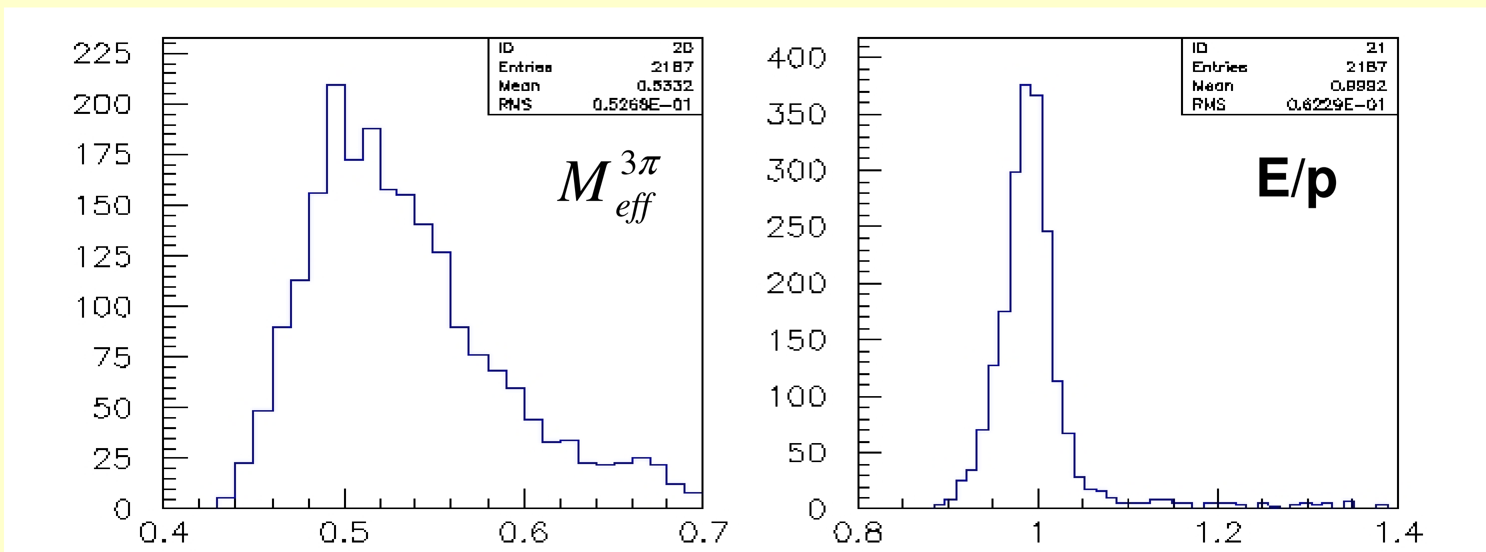
Non symmetric E/p distribution



E/p > 0.9

outNN > 0.9

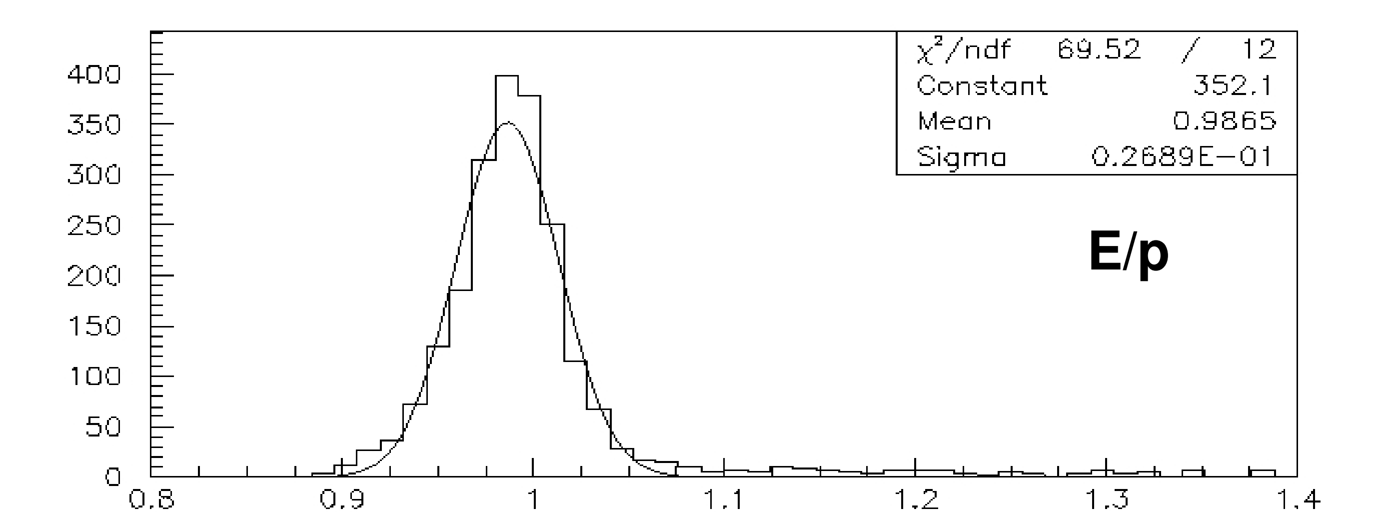
Symmetric E/p distribution



$K^{\pm} \to \pi^{\pm}\pi^{\mp}e^{\pm}\nu(\bar{\nu})$

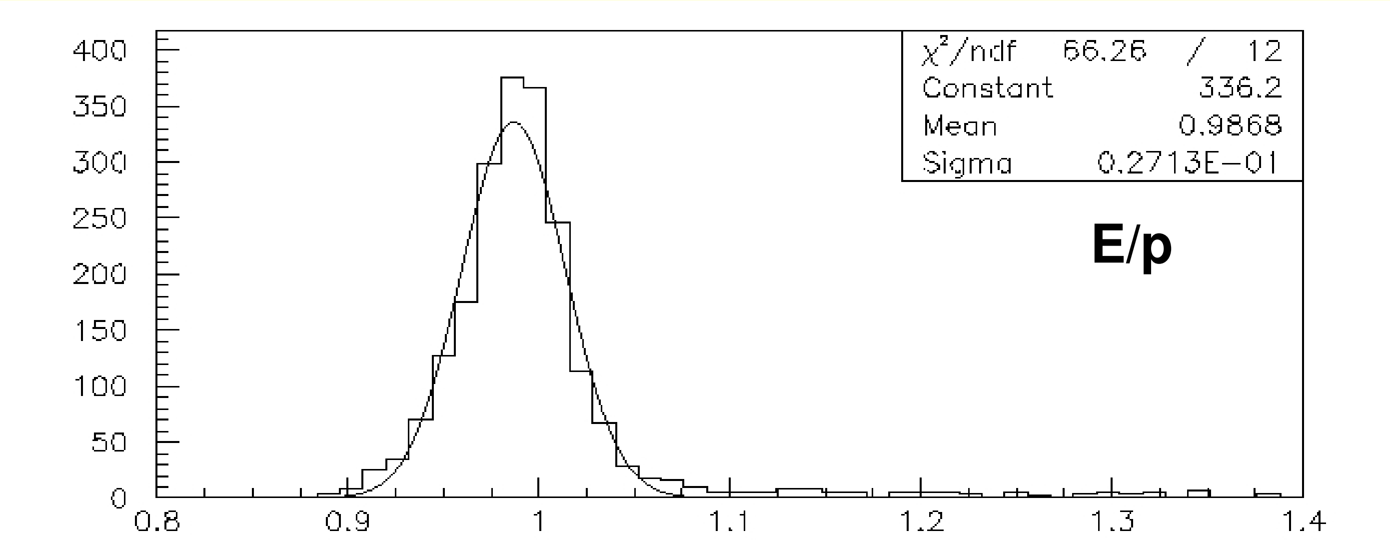
E/p Distribution

outNN > 0.9

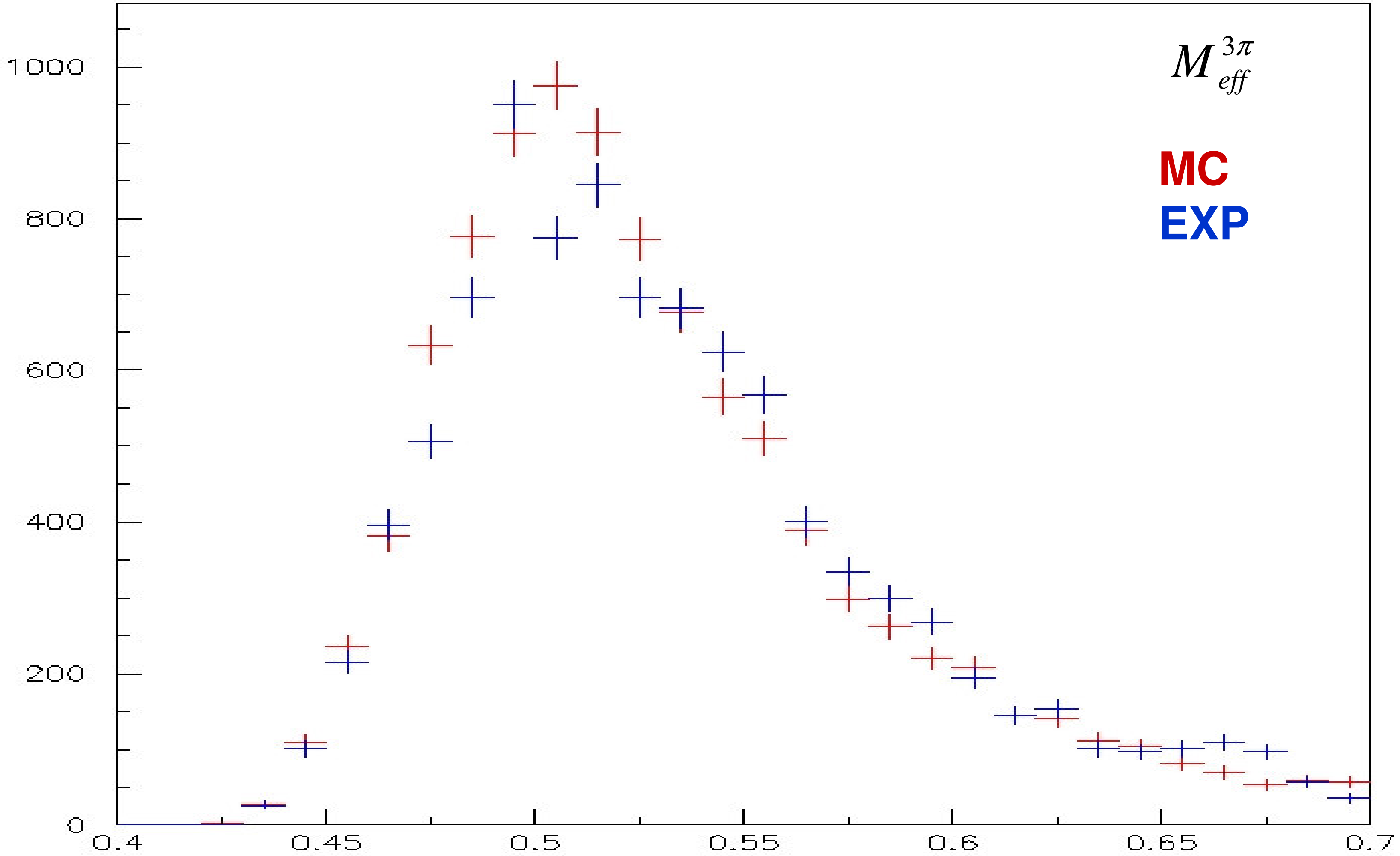


E/p Distribution

outNN > 0.8



$K^{\pm} \rightarrow \pi^{\pm}\pi^{\mp}e^{\pm}\nu(\bar{\nu})$



There is a good agreement between MC and Experimental distributions

Kμ3 run

Electrons: $K^0 \to \pi^\pm e^\mp \nu$

❖Standard Ke3 selection

❖Except E/p cuts

❖Track momentum > 10 GeV

❖Requirement – 0.15 < E/p < 0.6 and selecting the other one

Pions from $K^0 \to \pi^+ \pi^- \pi^0$

❖2 tracks and one vertex

❖Two or more gammas

❖ M_{eff} of the two γ within 3σ of m_{π^0}

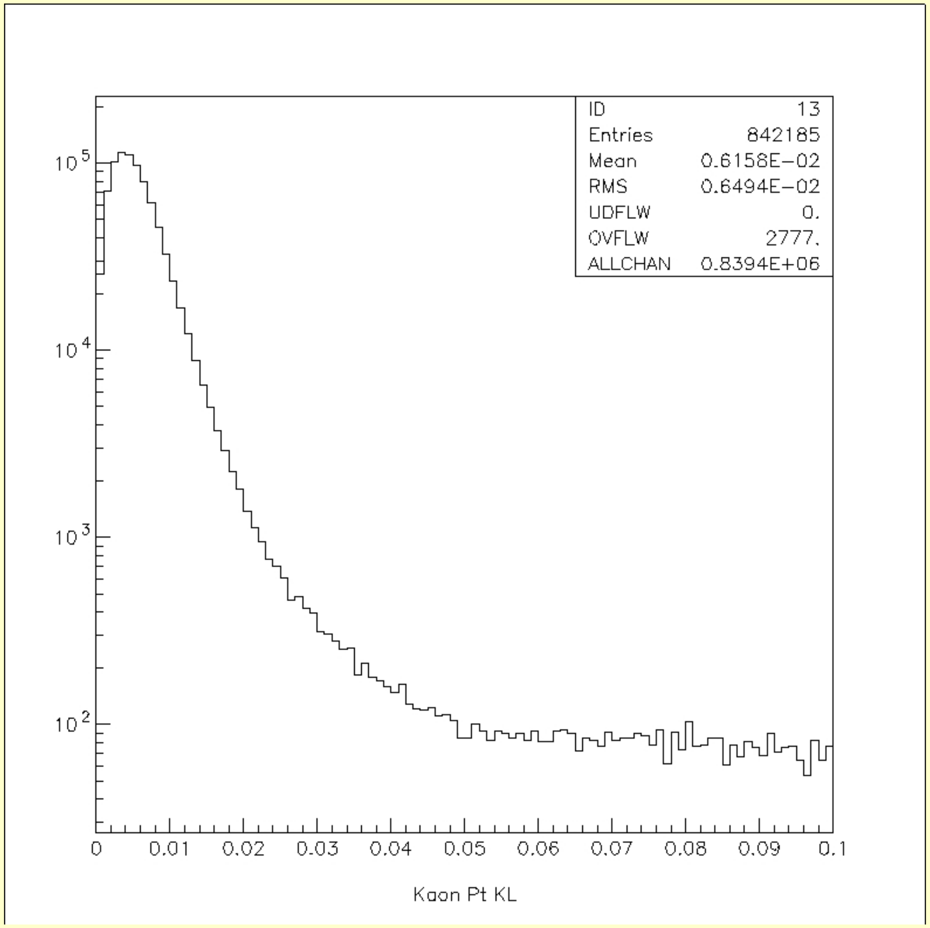
❖Background rejection ($P_0'^2$ > -0.005)

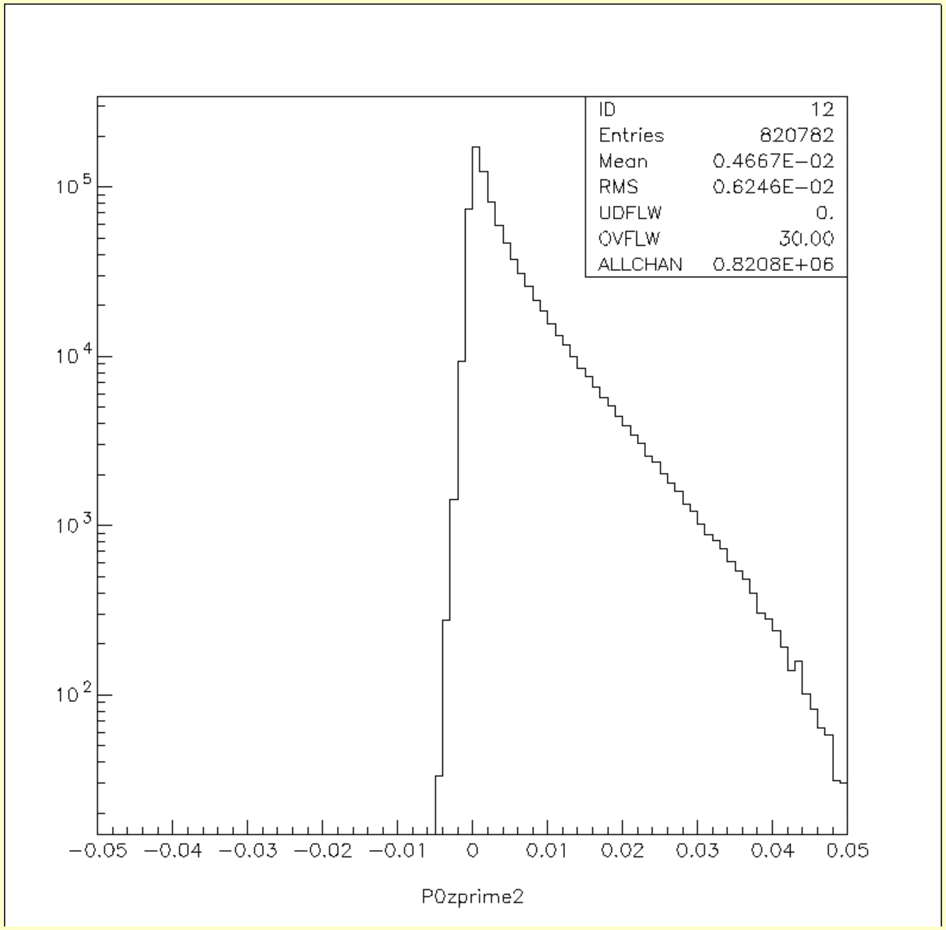
❖Transversal momentum of the K < 0.012 GeV

❖ $M_{eff}^{3\pi}$ within 3σ of M_K

Kμ3 run

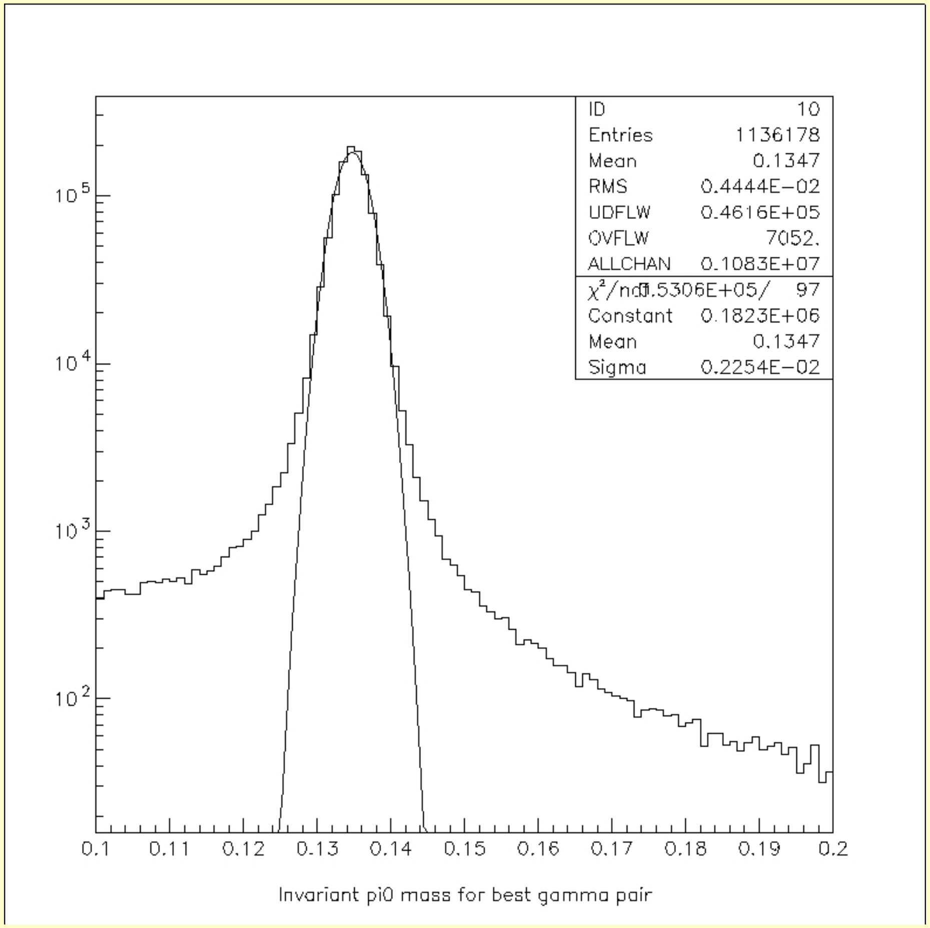
$$K^0 \rightarrow \pi^+ \pi^- \pi^0$$

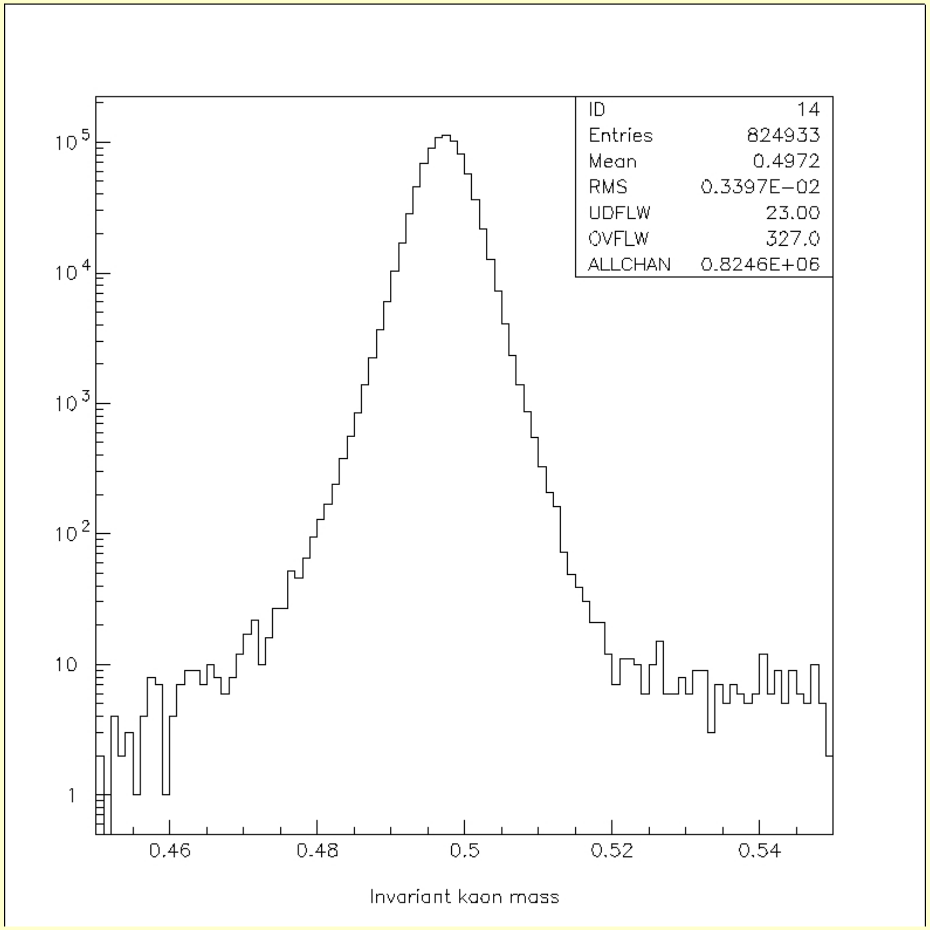




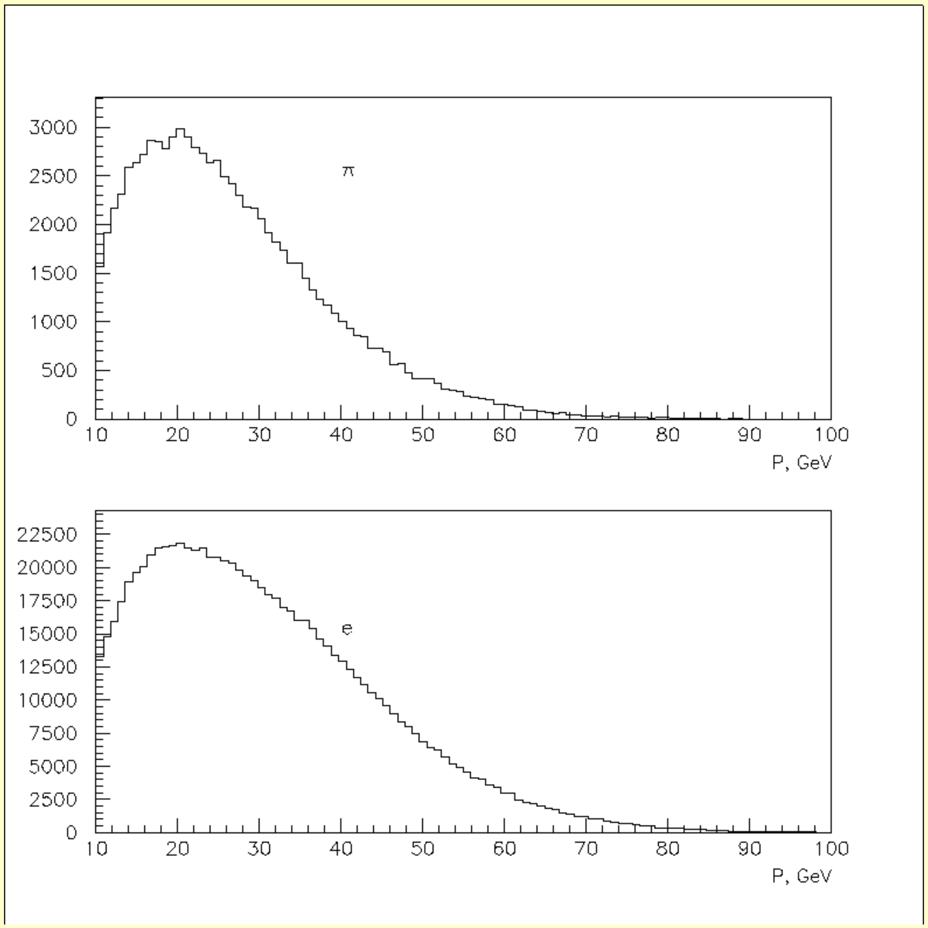
Kμ3 run

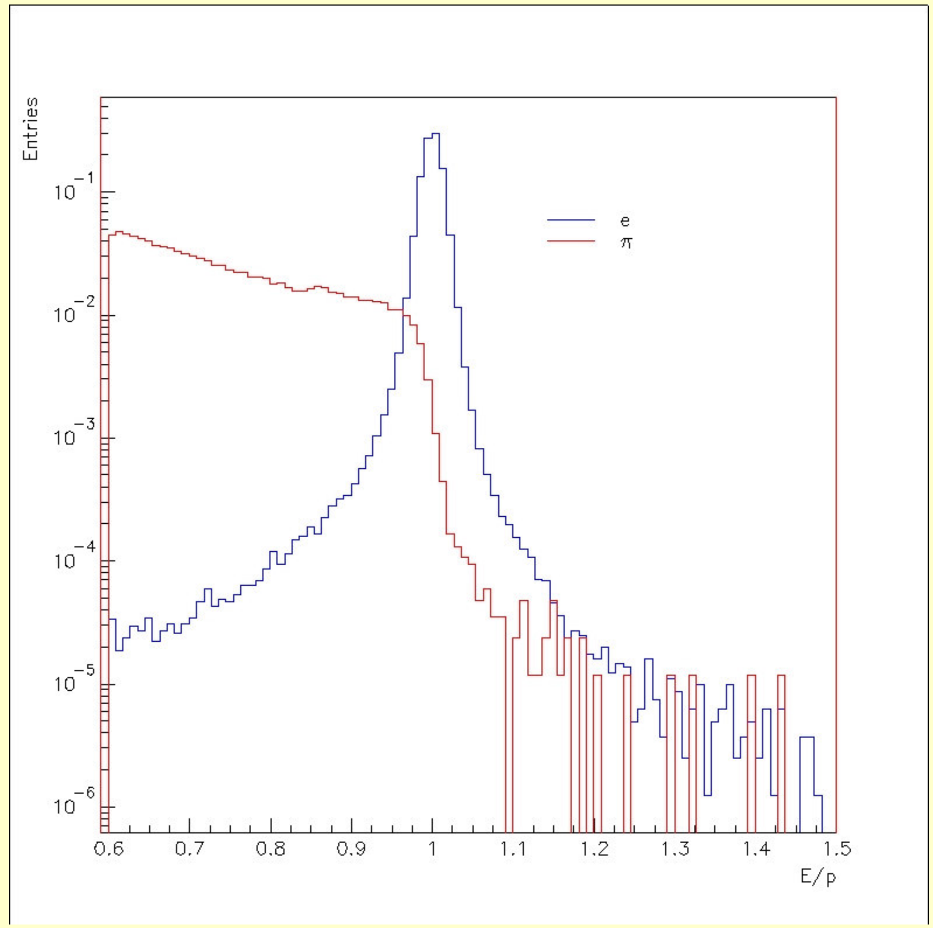
$$K^0 \rightarrow \pi^+ \pi^- \pi^0$$



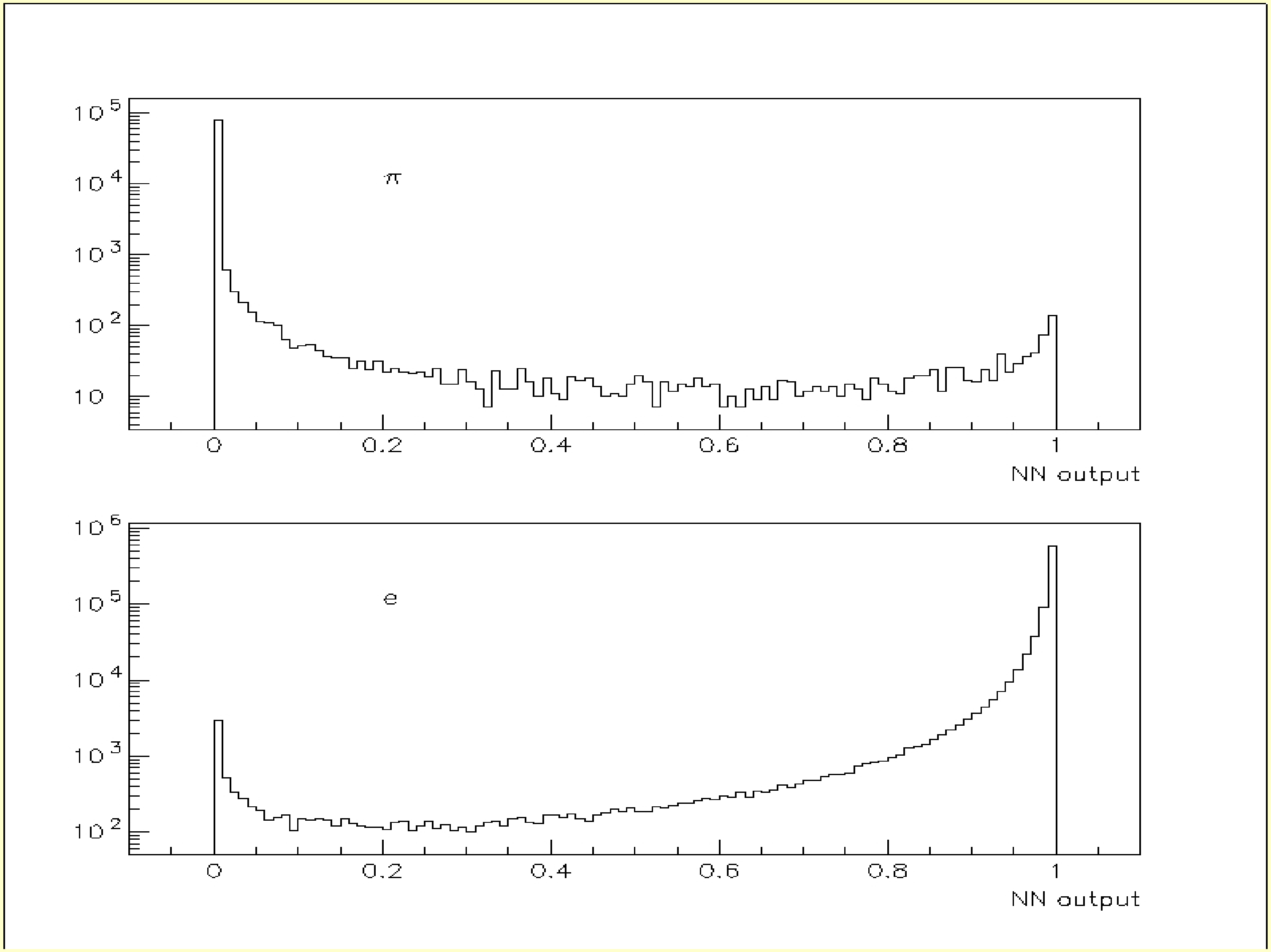


Kμ3 run





Kμ3 run – NN output



Kμ3 run NN performance

- Net: 10-30-20-2-1
- Input: E/p, Dist, Rrms, p, RMSx, RMSy, dx/dz, dy/dz, DistX, DistY
- Teaching: 10000 π - $K^0 \to \pi^+\pi^-\pi^0$, 5000 e - $K^0 \to \pi^{\pm} e^{\mp} \nu$

	$e^{\pm}$	$\pi^{\mp}$	ϵ^e_{eff},%
ALL	808657	970337	
$E/p > 0.6$	808656	84578	—
$E/p > 0.9$	806163	9934	99.7
out> 0.9	775522	530	95.7
out> 0.95	759423	416	93.9

	$\epsilon^{\pi \to e}$	ϵ^e_{eff},%
out> 0.9/ALL	$5.5 \cdot 10^{-4}$	95.9
out> $0.9/E/p > 0.9$	$5.3 \cdot 10^{-2}$	96.2
out> 0.95/ALL	$4.3 \cdot 10^{-4}$	93.9
out> $0.95/E/p > 0.9$	$4.2 \cdot 10^{-2}$	94.2

Ke4 run

Decay $K^0 \rightarrow \pi^{\pm} e^{\mp} \pi^0 \nu$

- ❖Significant background comes from $K^0 \rightarrow \pi^+ \pi^- \pi^0$
- ❖when one π is misidentified as an e

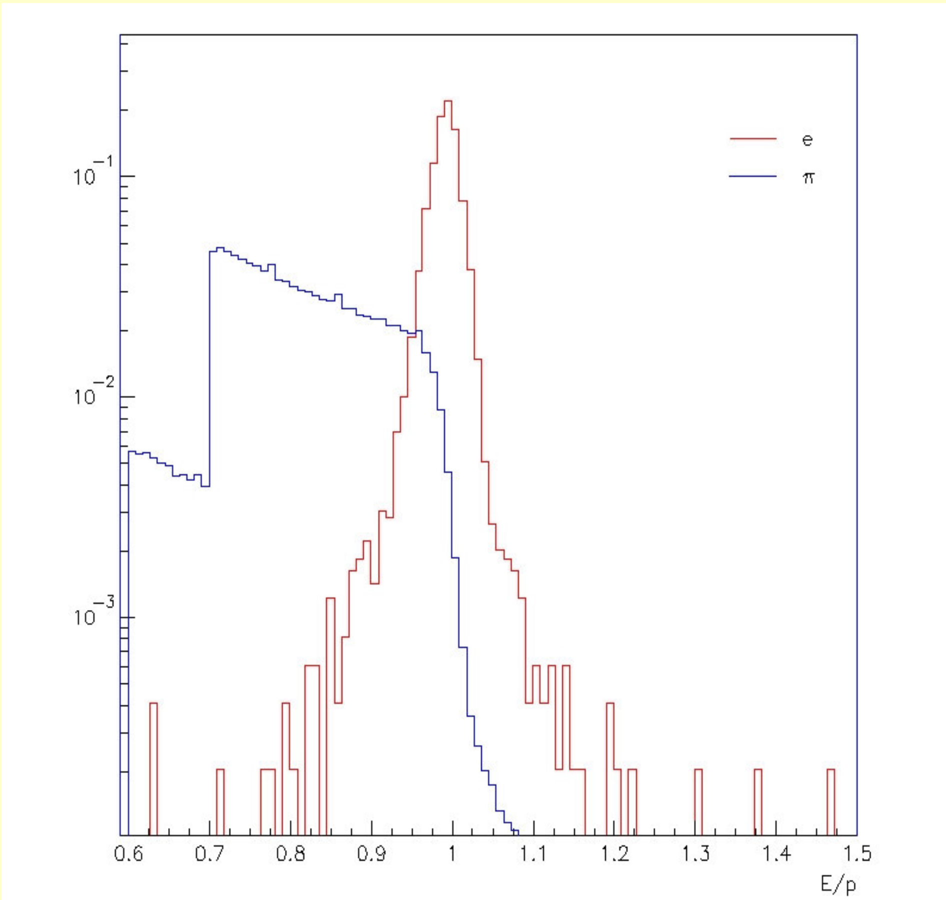
❖Teaching sample:

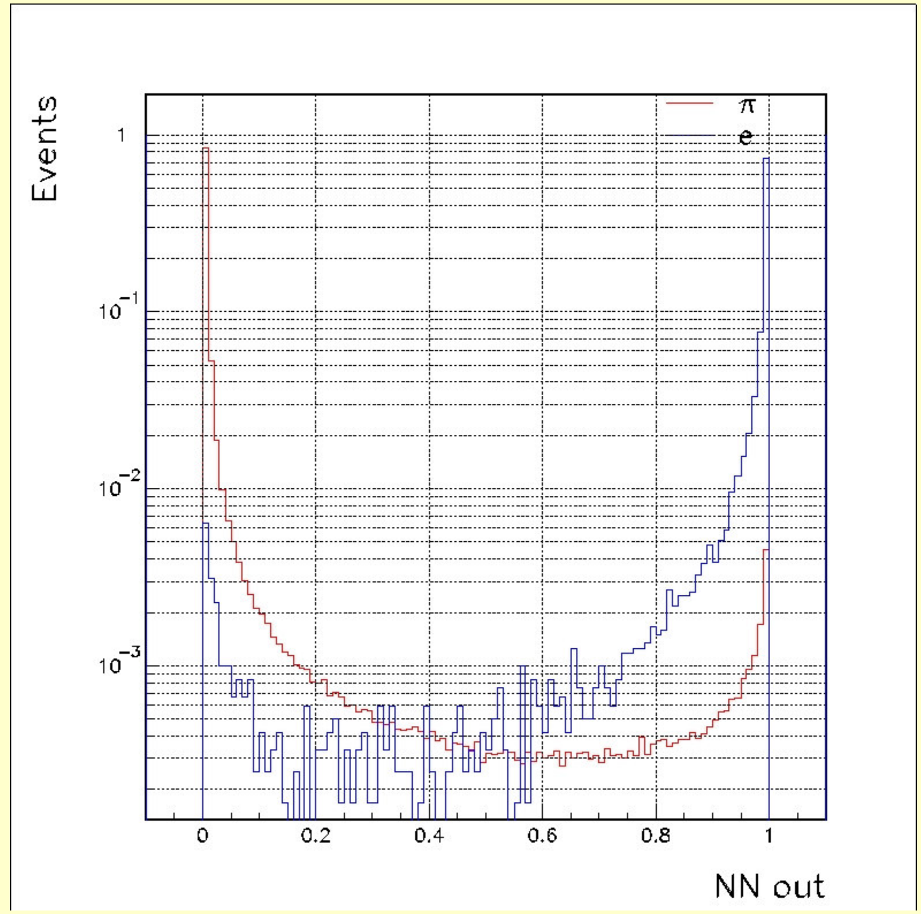
- ➢Pions - from $K^0 \rightarrow \pi^+ \pi^- \pi^0$, 800 K events
- ➢Electrons - from $K^0 \rightarrow \pi^{\pm} e^{\mp} \nu$, 22 K events

❖Two splits – here the results obtained using the old one are represented

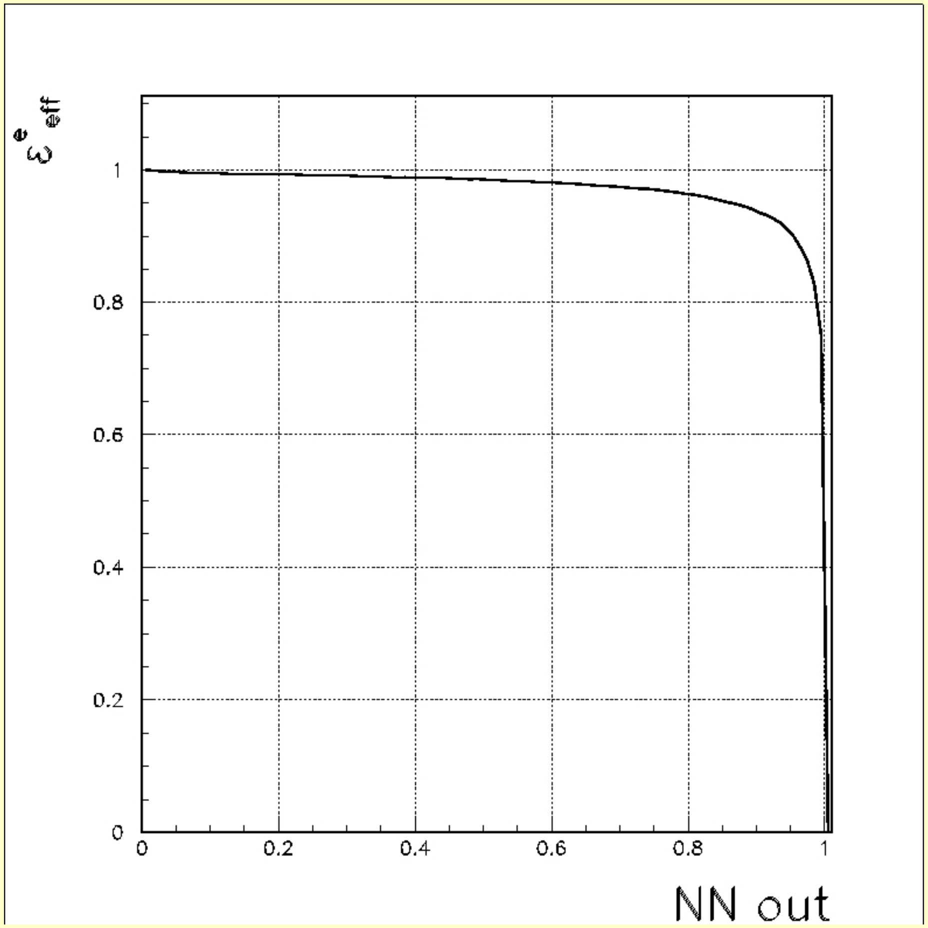
Thanks to Laurenz

Ke4 run

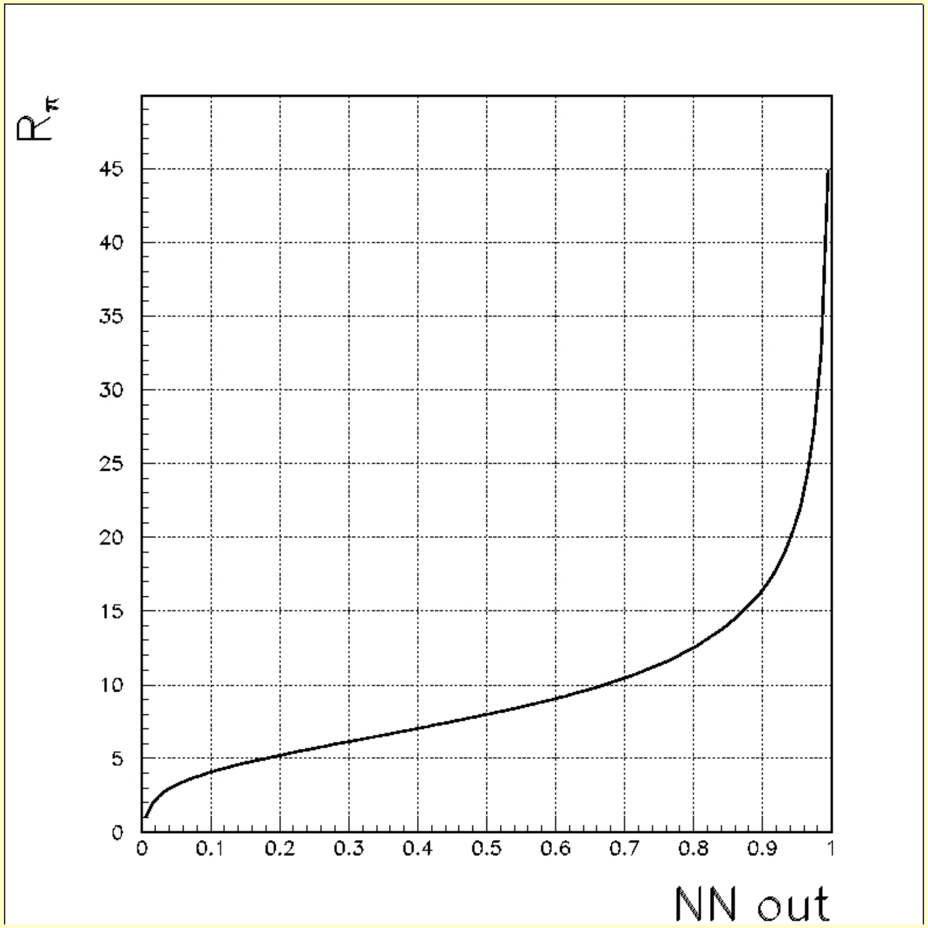




Ke4 run



ε^e_{eff}
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
NN out



R_π
45
40
35
30
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
NN out

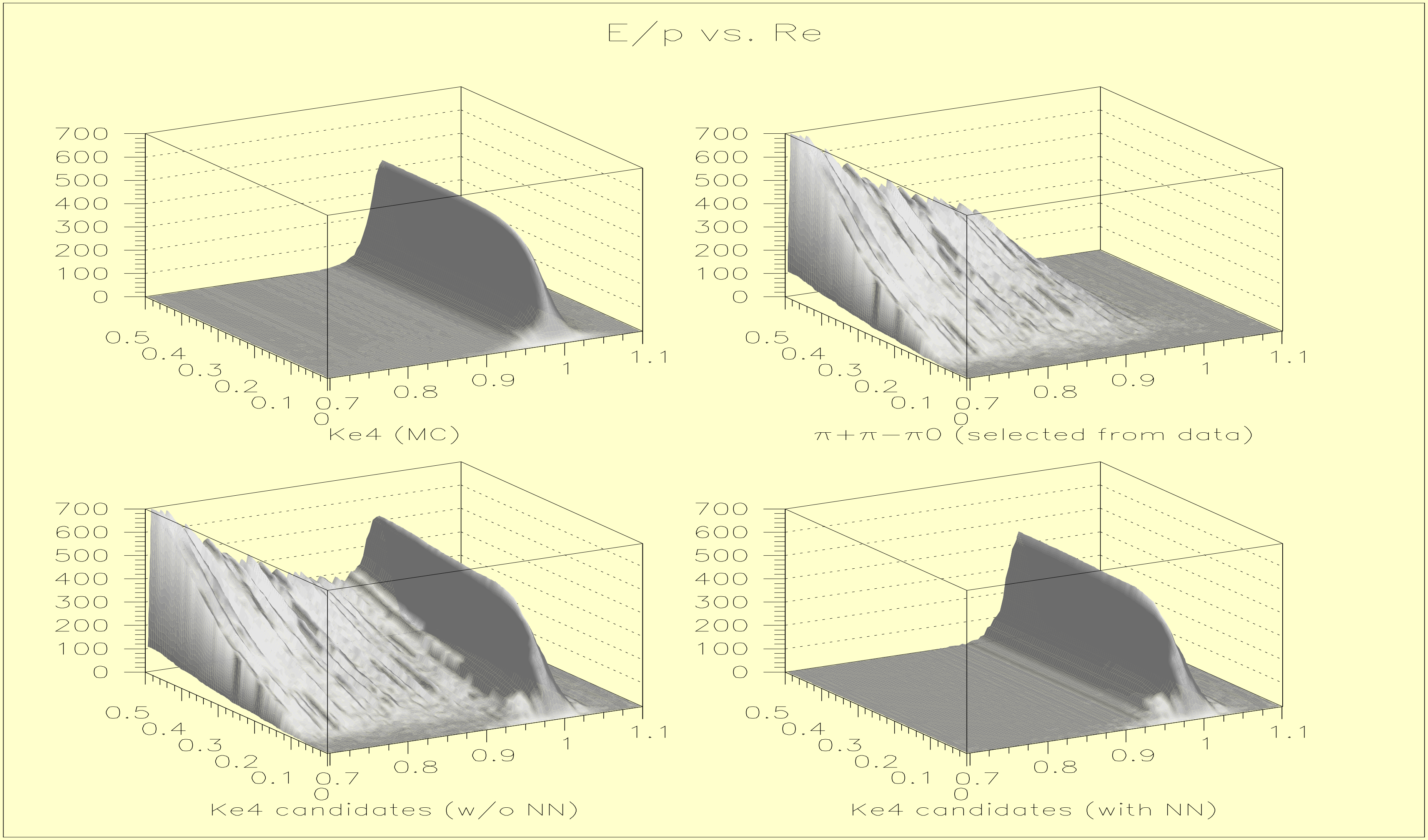
Ke4 run NN performance

- Net: 10-30-20-2-1
- Input: E/p, Dist, Rrms, p, RMSx, RMSy, dx/dz, dy/dz, DistX, DistY
- Teaching: 10000 π - $K^0 \to \pi^+\pi^-\pi^0$, 5000 e - $K^0 \to \pi^{\pm} e^{\mp} \nu$

	$e^{\pm}$	$\pi^{\mp}$	ϵ^e_{eff},%
ALL	4940	616705	
$E/p > 0.6$	4915	461856	—
$E/p > 0.9$	4857	89605	98.3
out> 0.85	4667	4630	94.5
out> 0.9	4386	3729	88.8

	$\epsilon^{\pi \to e}$	ϵ^e_{eff},%
out> 0.85/ALL	$7.5 \cdot 10^{-3}$	94.5
out> 0.85/$E/p > 0.9$	$5.1 \cdot 10^{-2}$	95.0
out> 0.9/ALL	$6.0 \cdot 10^{-3}$	92.7
out> 0.95/$E/p > 0.9$	$3.2 \cdot 10^{-2}$	89.2

$K^0 \to \pi^{\pm} e^{\mp} \pi^0 \nu$



Conclusions

❖e/π separation with NN has been tested on experimental data

❖For charged K run we have:

➢Relatively to E/p < 0.9 cut $\varepsilon_{eff}^{\pi \to e} \sim 3.4 \times 10^{-2}$

➢At ε_{eff} ~ 96%

❖For Kμ3 run we have:

➢Relatively to E/p < 0.9 cut $\varepsilon_{eff}^{\pi \to e} < 4.2 \times 10^{-2}$

➢At ε_{eff} ~ 94%

❖For Ke4 run we have:

➢Relatively to E/p < 0.9 cut $\varepsilon_{eff}^{\pi \to e} \sim 5.1 \times 10^{-2}$

➢At ε_{eff} ~ 95%

Conclusions

❖NN for e/π separation is implemented in the NA48 off-line analysis software

❖Using NN it is possible to reduce significantly the background in the Ke4 decays coming from $K \to 3\pi$

❖It is possible to improve NN performance using cell by cell information from row data

❖ This work was done in close collaboration with C. Cheshkov, G. Marel, S. Stoynev and Laurenz Widhalm