e/π separation in the NA48 experiment

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Introduction

- 2003 Program for a Precision Measurement of Charged Kaon Decay Parameters
  - Direct CP - violation in $K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\pm}$, $K^{\pm} \rightarrow \pi^{0}\pi^{0}\pi^{\pm}$
  - K_e4 - $K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}e^{\pm}\nu(\bar{\nu})$
  - Scattering lenghts a_0^0 ,a_0^0
  - Radiative decays $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$, $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma\gamma$, $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$

Introduction

K^+ decay modes

Mode	Fraction
$\mu^+\nu_{mu}$	$63 \cdot 51 \times 10^{-2}$
$e^+\nu_e$	$1 \cdot 55 \times 10^{-5}$
$\pi^+\pi^0$	$21 \cdot 16 \times 10^{-2}$
$\pi^+\pi^+\pi^-$	$5 \cdot 59 \times 10^{-2}$
$\pi^+\pi^0\pi^0$	$1 \cdot 73 \times 10^{-2}$
$\pi^0\mu^+\nu_\mu$	$3 \cdot 18 \times 10^{-2}$
$\pi^0 e^+\nu_e$	$4 \cdot 82 \times 10^{-2}$
$\pi^0\pi^0 e^+\nu_e$	$2 \cdot 1 \times 10^{-5}$
$\pi^+\pi^- e^+\nu_e$	$3 \cdot 91 \times 10^{-5}$
$\pi^+\pi^-\mu^+\nu_\mu$	$1 \cdot 4 \times 10^{-5}$

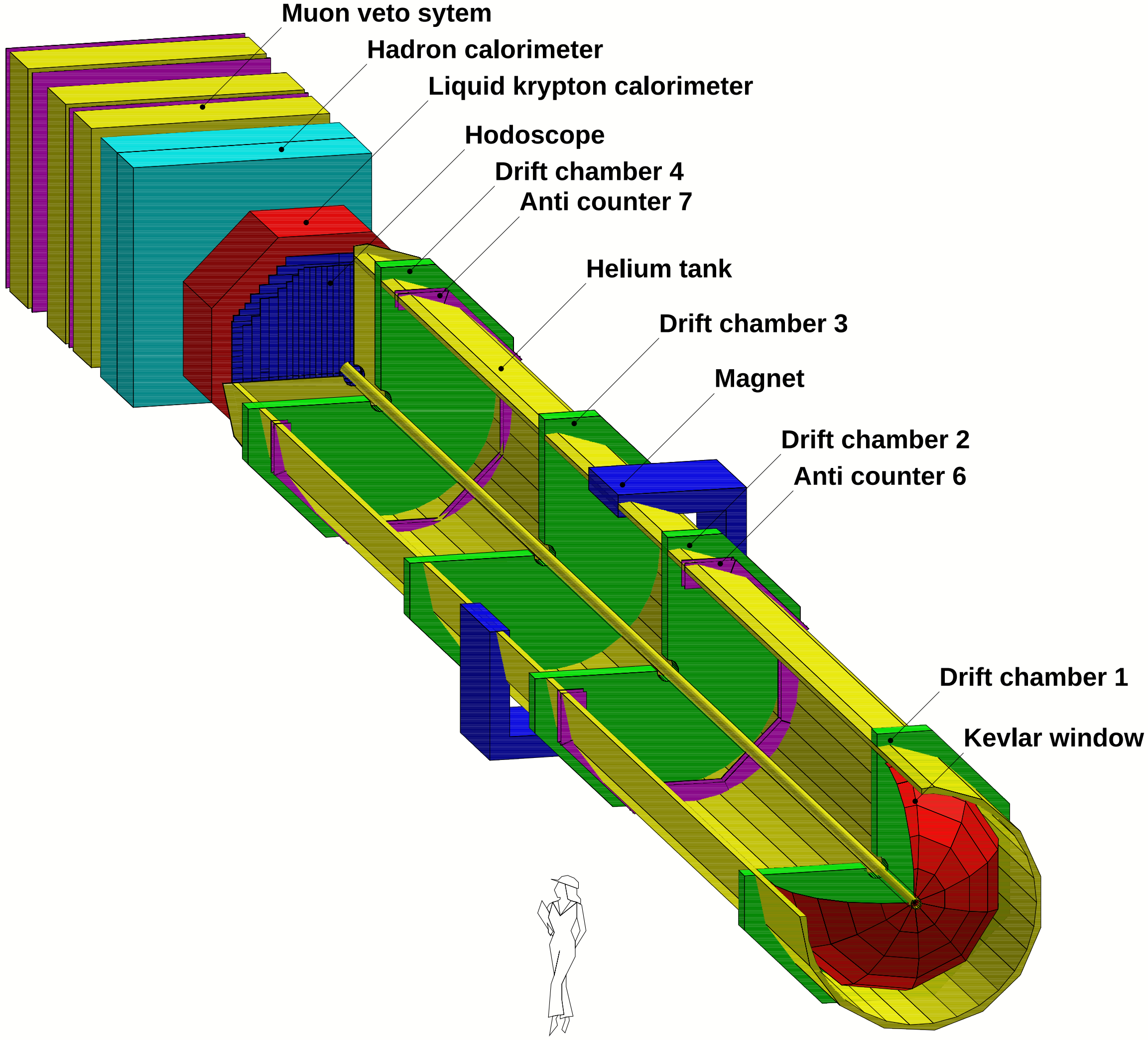
Introduction

- 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}
  - $\epsilon^{\pi\to e} \sim 3 \cdot 10^{-5}$
  - i.e. relatively to E/p < 0.9 cut $\epsilon^{\pi\to e} \sim 2.5 \cdot 10^{-2}$

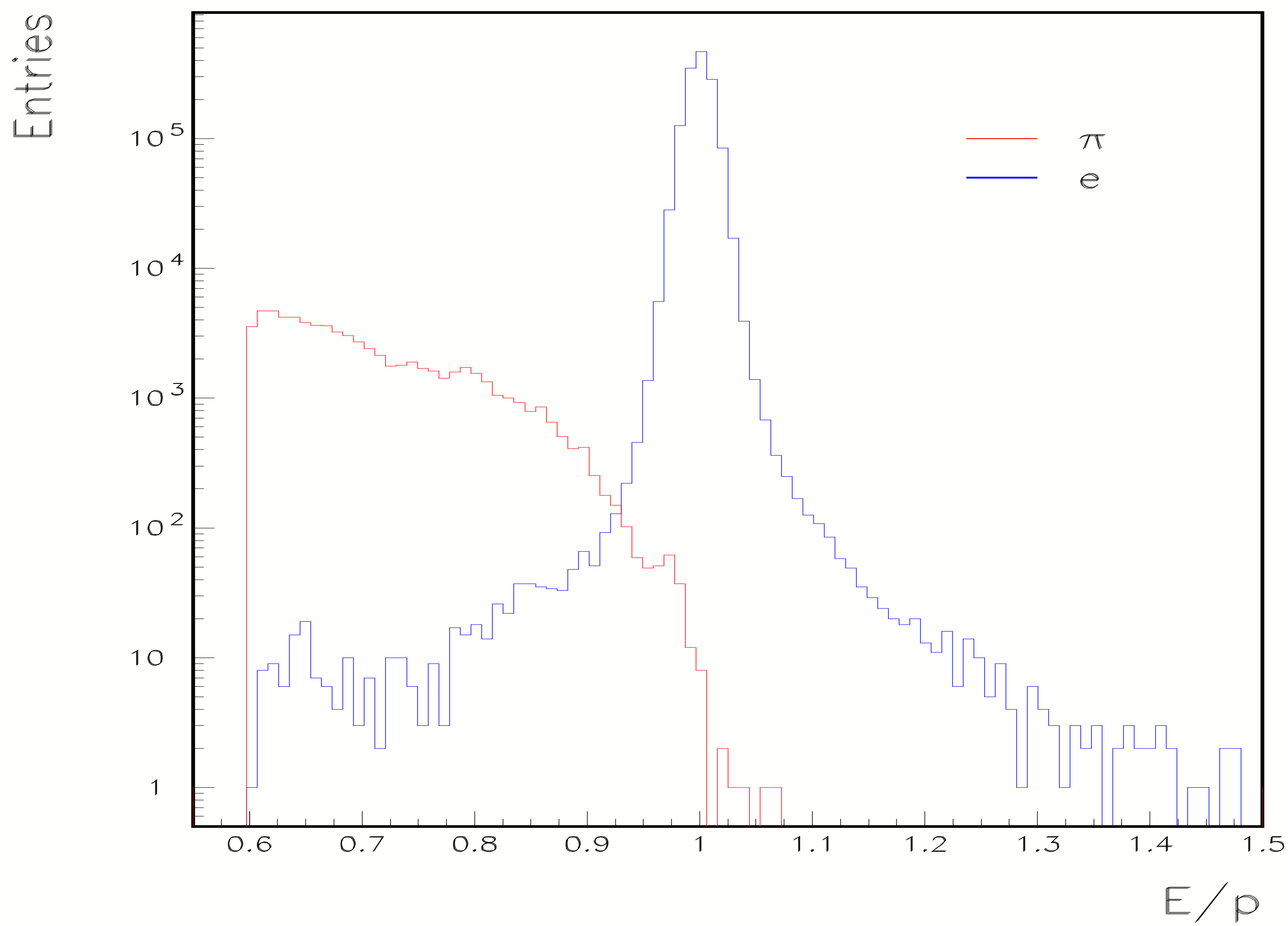
NA48 detector



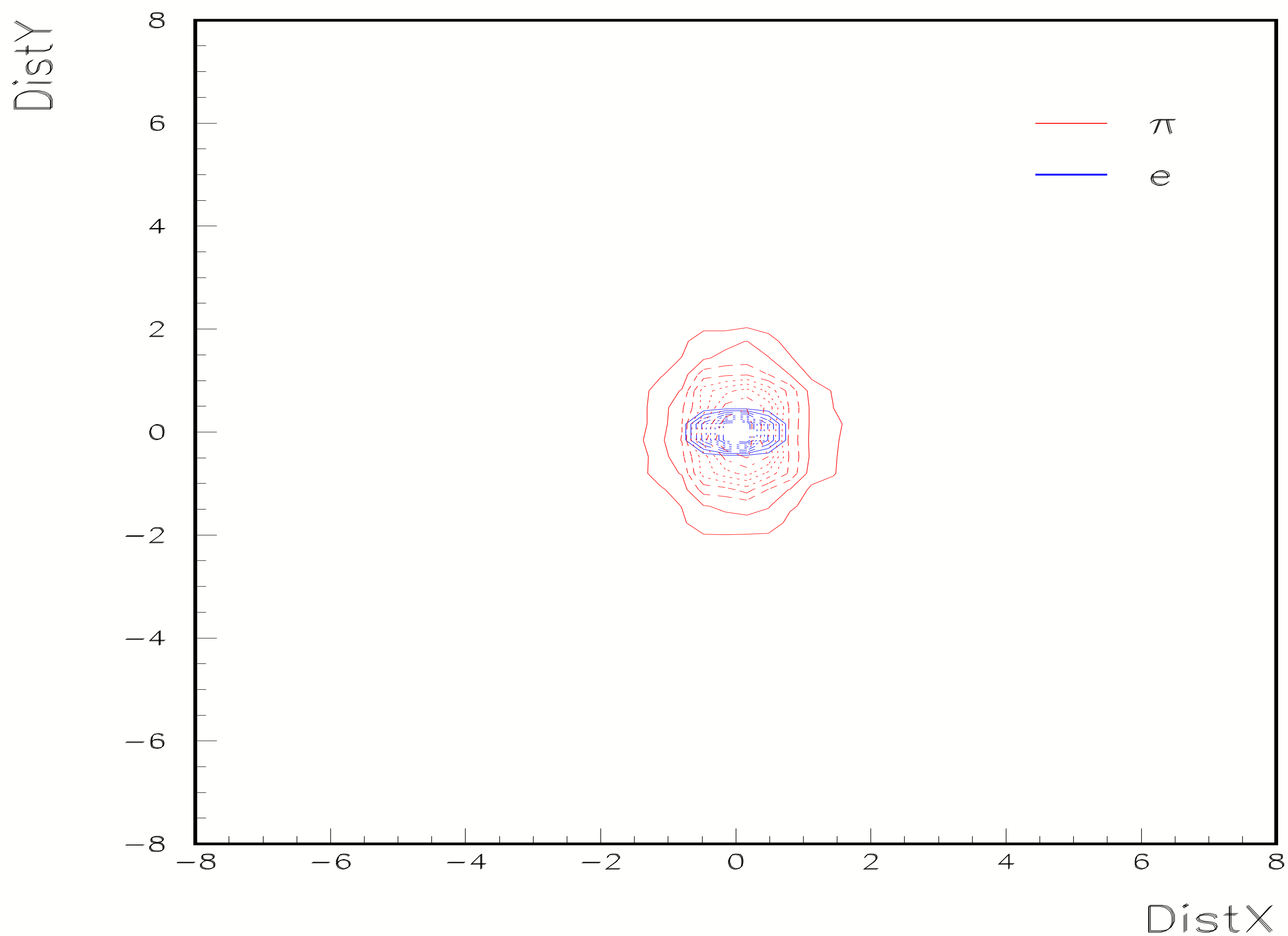
Sensitive variables

- Difference in development of e.m. and hadron showers
- latteral development
- longitudinal development
- LKr gives information for latteral 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
- To test different possibilities we have used:
  - Simulated K_{e3} decays - $1.3 \cdot 10^6$
  - Simulated single e and π - $8 \cdot 10^5$ π and $2 \cdot 10^5$ e

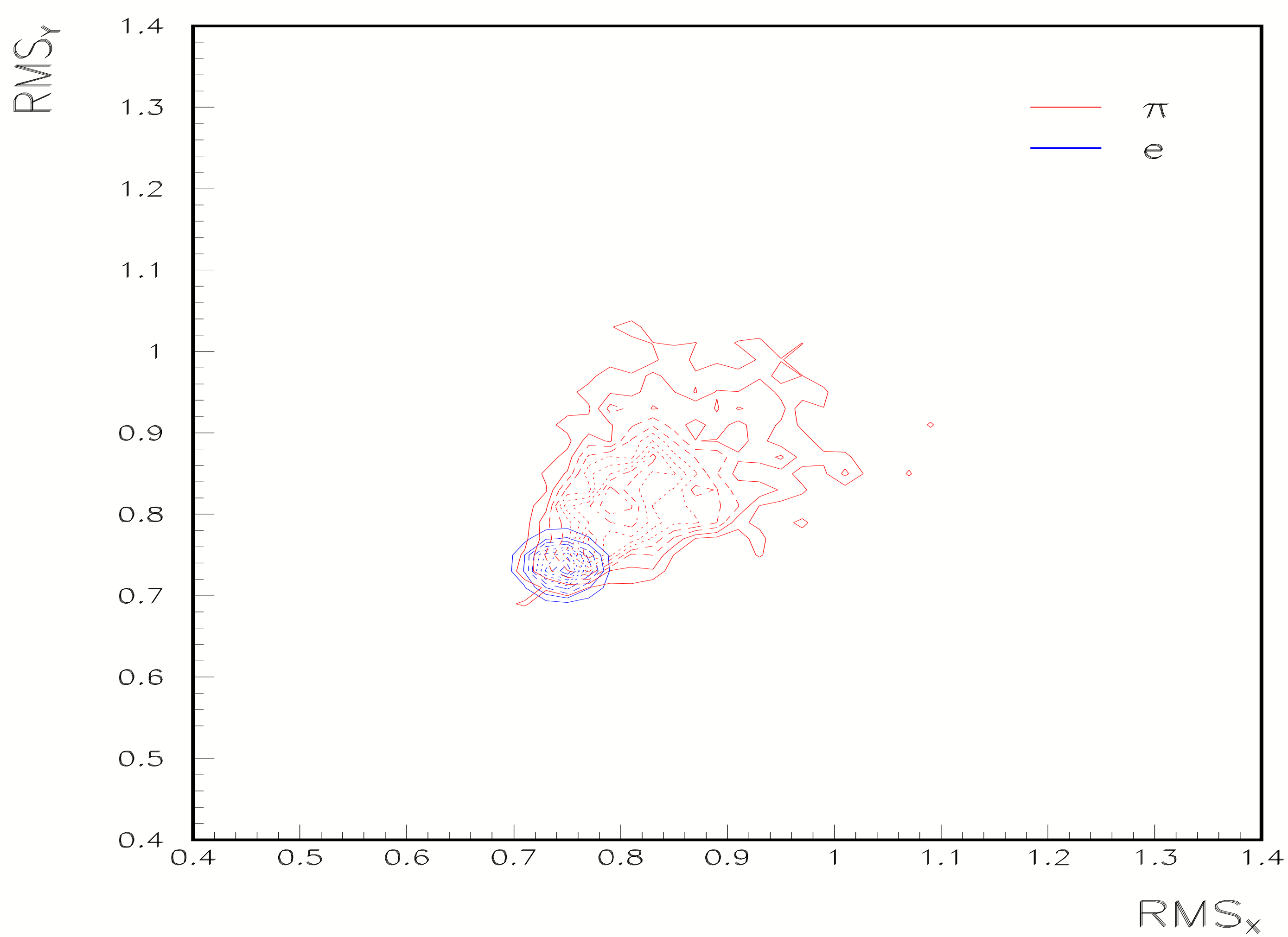
E/p



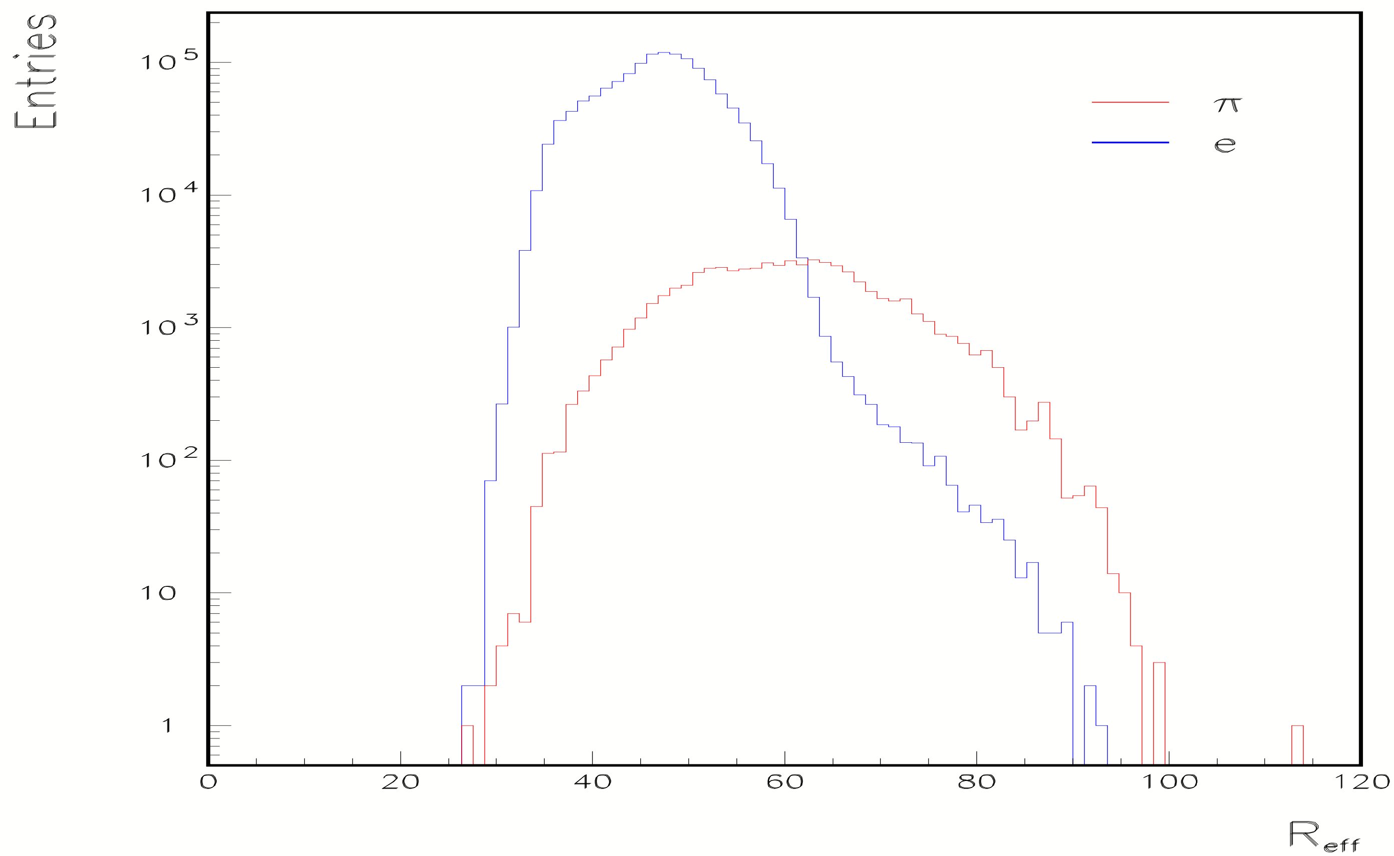
DistXY



RMSX/RMSY


RMS$_Y$
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
RMS$_X$
π
e

R_{eff}



$$R_{eff} = \left[\frac{\sum E_{ij}x^2 + \sum E_{ij}y^2}{\sum E_{ij}} - \frac{(\sum E_{ij}x)^2 + (\sum E_{ij}y)^2}{(\sum E_{ij})^2}\right]^{1/2}$$

$Ke3$ *events*

- MC using nasim031
- Zero Suppression Threshold : 0.2 GeV
- Kaon momentum spectrum $\in$ (60,180) GeV
- standart selection criteria
  - 2 tracks and 1 vertex
  - rejecting overflows
  - Z vertex $\in (600, 3400)cm$
  - CDA $>$ 3 cm
  - Tracks in the DCH, Lkr and MUVeto acceptance
  - No in time MUV hit
  - distance to closest dead cell $>$ 2cm
  - momentum track $>$ 10 GeV
  - space difference between 2 tracks in LKR $>$ 25 cm
  - $M_{\pi^+\pi^-}$ 3σ away from M_K
  - $\pi^+\pi^-\pi^0$ rejection ($P_0'^2 < -0.004$)

Single e and π

- MC using nasim031
- Zero Suppression Threshold : 0.2 GeV
- Momentum spectrum $\in$ (1,50) GeV
- uniform distribution on Z, momentum and angles
- good track in acceptance and associated cluster

GMM

- $E/p > 0.6$
- $E/p > 0.9$
- Dist - distance between the track and the associate cluster (XY projection at Lkr) as a function of P
- Rrms of the cluster - $Rrms^2 = RMSX^2 + RMSY^2$

	$e^{\pm}$	$\pi^{\mp}$
ALL	1213880	1213880
$E/p > 0.6$	1213741	87557
$E/p > 0.9$	1213287	1272
Dist cut	1193383	241
Rrms cut	1166042	200

	$\epsilon^{\pi \to e}$	ϵ^{e}_{eff}
ALL	$16.5 \cdot 10^{-5}$	96.06%
$E/p > 0.9$	$15.7 \cdot 10^{-2}$	96.11%

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

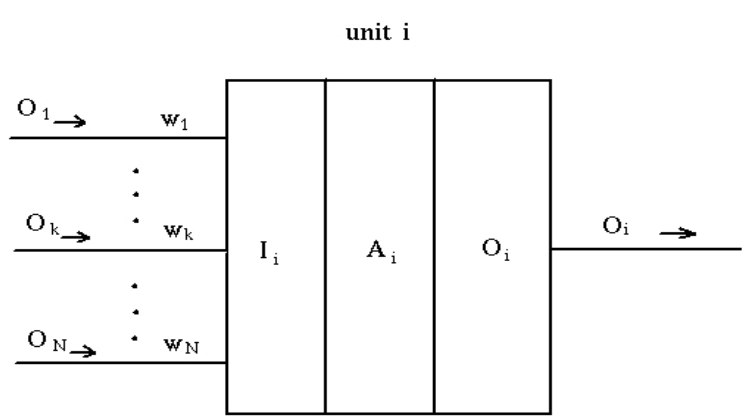


fig 1.NN

Neural Network

neuron performs calculations in three steps

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

- Multi-Layer-Feed Forward network consists of:
  - set of input neurons
  - one or more layers of hiden neurons
  - set of output neurons
  - the neurons of each layer are connected to the ones to the subsiquent layer
- Training
  - presentation of patern
  - 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

$$E = \frac{1}{2} \sum_j (t_j - o_j)^2, \qquad (2)$$

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:

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

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

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

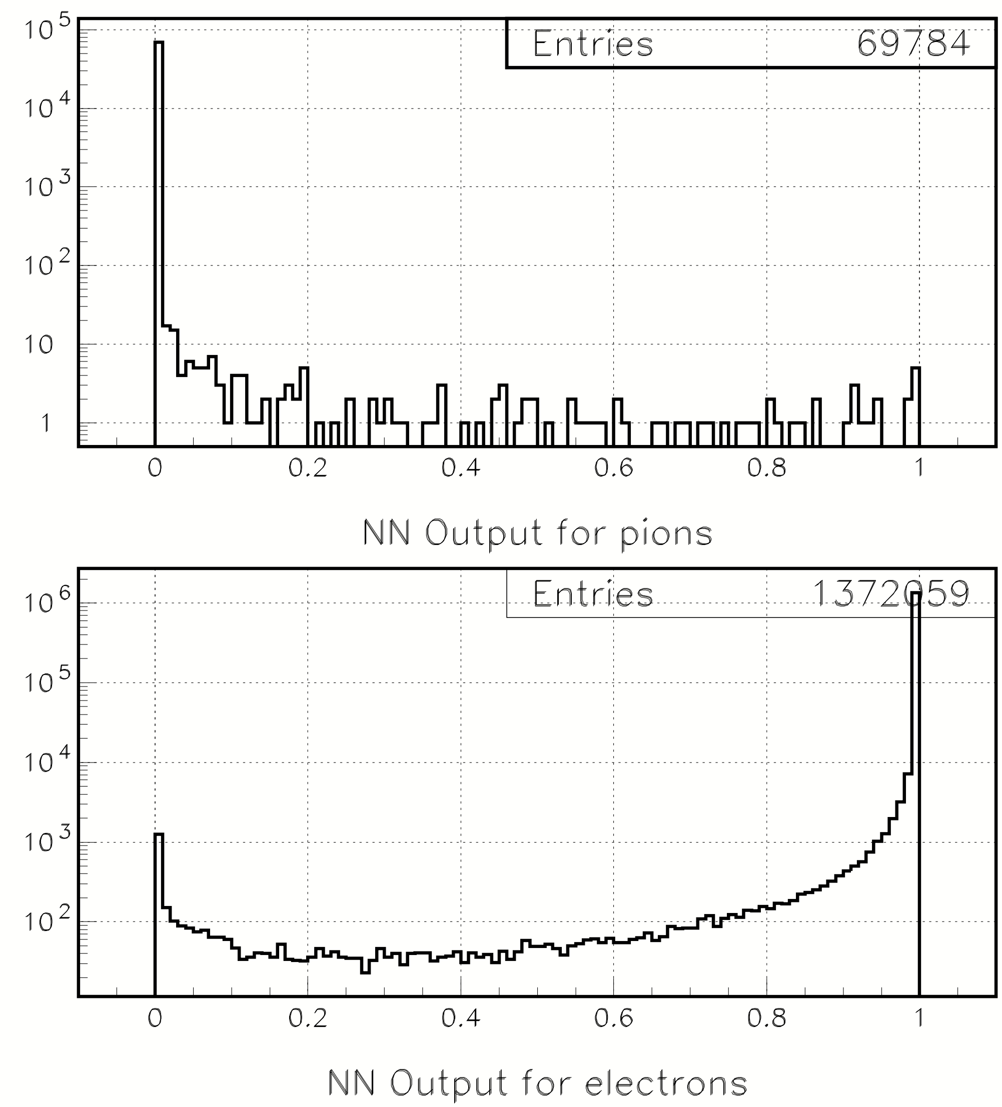
NET2

- Net: 10-30-20-2-1
- Input: E/p, Dist, RMSX, RMSY, Rrms, E_m/E_{all},, p, R_{eff},dx/dz,dy/dz
- Teaching: 15000π, $5000e$ - $Ke3$
- Test: $Ke3$

	$e^{\pm}$	$\pi^{\mp}$	e loss	ϵ^{e}_{eff},%
ALL	1372216	1095673		
$E/p > 0.6$	1372059	69784	157	99.99
$E/p > 0.9$	1371519	967	697	99.95
out> 0.9	1363768	15	8448	99.38
out> 0.95	1360484	7	11732	99.15

	$\epsilon^{\pi\to e}$	ϵ^{e}_{eff},%
out> 0.9/ALL	$1.4 \cdot 10^{-5}$	99.38
out$> 0.9/E/p > 0.9$	$1.6 \cdot 10^{-2}$	99.43
out> 0.95/ALL	$6.4 \cdot 10^{-6}$	99.15
out$> 0.95/E/p > 0.9$	$0.7 \cdot 10^{-2}$	99.20

NET2


10^5
10^4
10^3
10^2
10
1
Entries 69784
0
0.2
0.4
0.6
0.8
1
NN Output for pions
10^6
10^5
10^4
10^3
10^2
Entries 1372059
0
0.2
0.4
0.6
0.8
1
NN Output for electrons

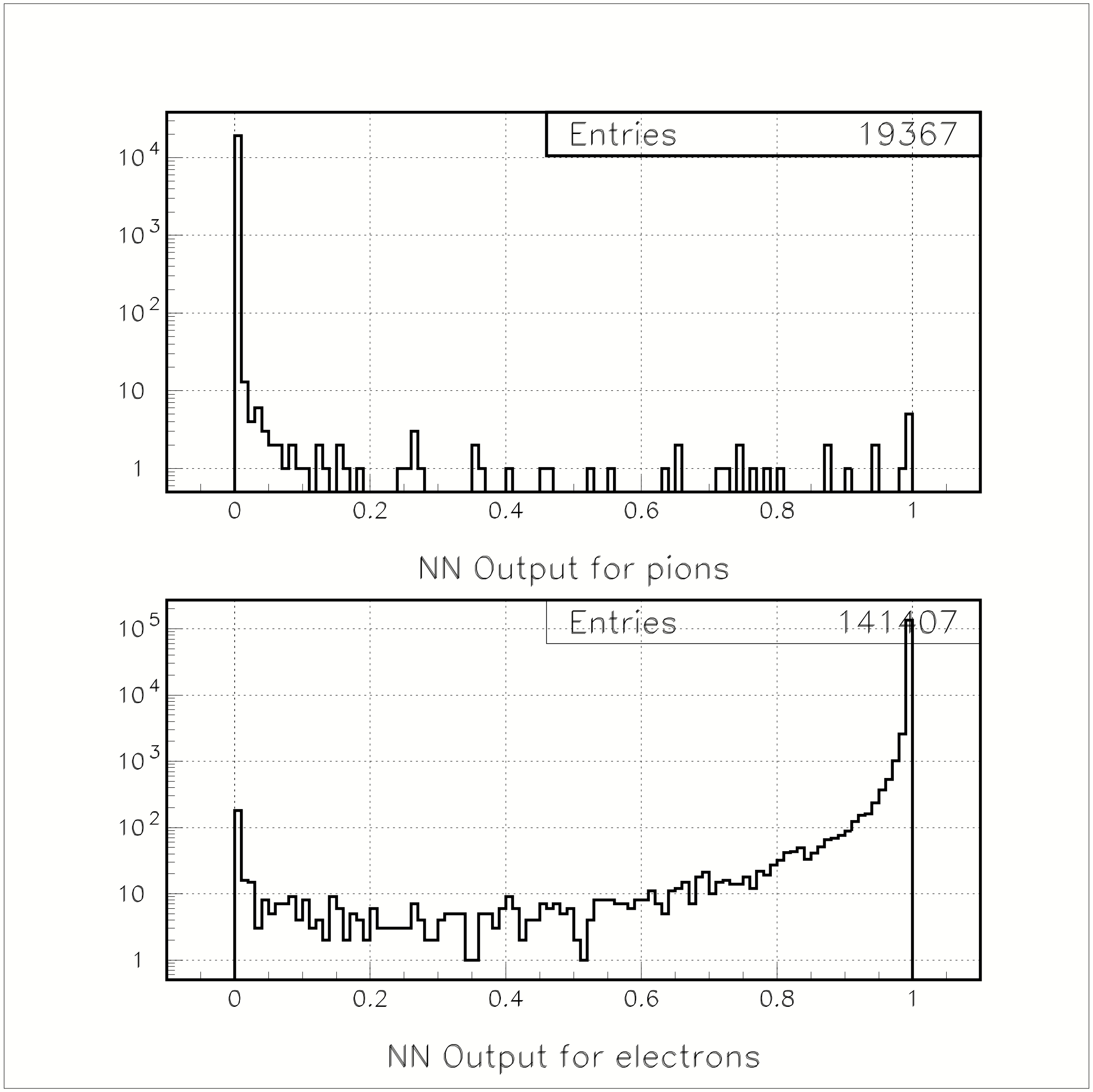
NET3

- Net: 10-30-20-2-1
- Input: E/p, Dist, RMSX, RMSY, Rrms, E_m/E_{all},, p, R_{eff},dx/dz,dy/dz
- Teaching: 15000π, $5000e$ - single π and e
- Test sample: single π and e

	$e^\pm$	$\pi^\mp$	e loss	ϵ^e_{eff},%
ALL	142843	293451		
$E/p > 0.6$	141407	19367	1436	99.0
$E/p > 0.9$	141200	345	1643	98.9
out> 0.9	140132	9	2017	98.1
out> 0.95	139368	8	3475	97.6

	$\epsilon^{\pi\to e}$	ϵ^e_{eff},%
out> 0.9/ALL	$3 \cdot 10^{-5}$	98.1
out$> 0.9/E/p > 0.9$	$1.9 \cdot 10^{-2}$	99.24
out> 0.95/ALL	$2.7 \cdot 10^{-5}$	97.6
out$> 0.95/E/p > 0.9$	$1.7 \cdot 10^{-2}$	98.7

NET3



Entries 19367
10^4
10^3
10^2
10
1
0
0.2
0.4
0.6
0.8
1
NN Output for pions
Entries 141407
10^5
10^4
10^3
10^2
10
1
0
0.2
0.4
0.6
0.8
1
NN Output for electrons

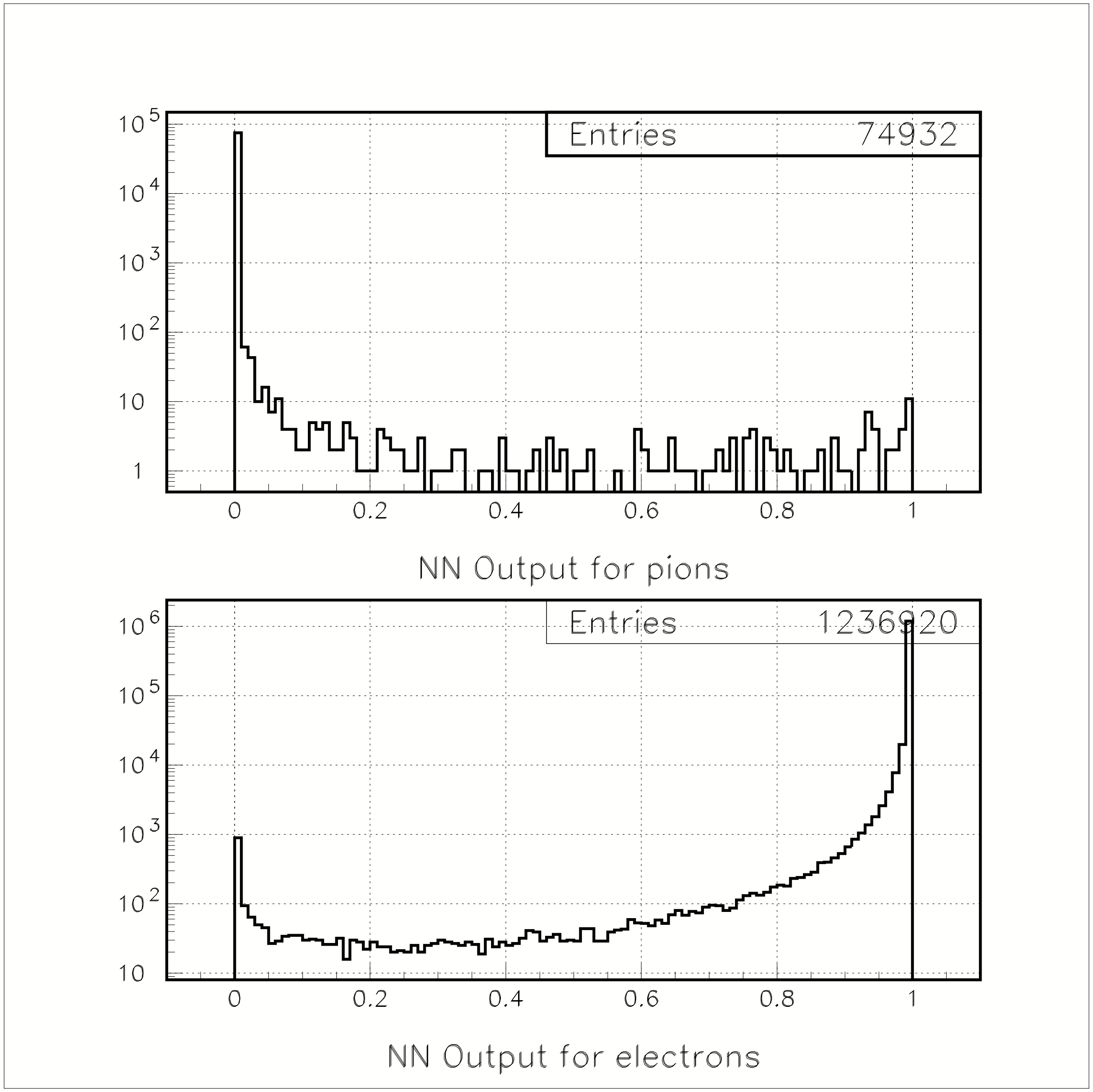
NET4

- Net: 10-30-20-2-1
- Input: E/p, Dist, RMSX, RMSY, Rrms, E_m/E_{all},, p, R_{eff},dx/dz,dy/dz
- Teaching: 15000π, $5000e$ - single π and e
- Test sample: $Ke3$

	$e^{\pm}$	$\pi^{\mp}$	e loss	ϵ^{e}_{eff},%
ALL	1237061	995417		
$E/p > 0.6$	1236920	74932	141	99.99
$E/p > 0.9$	1236000	1334	1061	99.91
out> 0.9	1229211	33	7850	99.40
out> 0.95	1223501	19	13560	98.90

	$\epsilon^{\pi \to e}$	ϵ^{e}_{eff},%
out> 0.9/ALL	$3.3 \cdot 10^{-5}$	99.40
out$> 0.9/E/p > 0.9$	$2.5 \cdot 10^{-2}$	99.45
out> 0.95/ALL	$1.9 \cdot 10^{-5}$	98.90
out$> 0.95/E/p > 0.9$	$1.4 \cdot 10^{-2}$	98.99

NET4


Entries 74932
10^5
10^4
10^3
10^2
10
1
0 0.2 0.4 0.6 0.8 1
NN Output for pions
Entries 1236920
10^6
10^5
10^4
10^3
10^2
10
0 0.2 0.4 0.6 0.8 1
NN Output for electrons

Summary table

	$\epsilon^{\pi\to e}$ NET1	$\epsilon^{\pi\to e}$ NET2	$\epsilon^{\pi\to e}$ NET3	$\epsilon^{\pi\to e}$ NET4
out> 0.9/ALL	$2.3 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$	$3 \cdot 10^{-5}$	$3.3 \cdot 10^{-5}$
out$> 0.9/E/p > 0.9$	$2.2 \cdot 10^{-2}$	$1.6 \cdot 10^{-2}$	$1.9 \cdot 10^{-2}$	$2.5 \cdot 10^{-2}$
out> 0.95/ALL	$1.2 \cdot 10^{-5}$	$6.4 \cdot 10^{-6}$	$2.7 \cdot 10^{-5}$	$1.9 \cdot 10^{-5}$
out$> 0.95/E/p > 0.9$	$1.1 \cdot 10^{-2}$	$0.7 \cdot 10^{-2}$	$1.7 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$

$\epsilon^{e}_{eff} > 99\%$ in all cases

Assuming the NN works with the same efficiency in the case of $K_{3\pi}$

$K^+ \to \pi^+\pi^+\pi^-$ decay	Background in K^c_{e4}
π with $0.9 < E_{cal}/p < 1.1$	4%
NET1	$\sim 0.05\%$
NET2	$\sim 0.03\%$
NET3	$\sim 0.07\%$
NET4	$\sim 0.06\%$

Selection of e and π from experimental data

Electrons:

- stronger Ke3 selection
- track momentum $> 10GeV$
- asking $0.25 < E/p < 0.6$ for one of the tracks and selecting the other one

Pions:

- charged kaon test run #1
- very tight $K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}$ selection
- track momentum $> 10GeV$
- asking $0.2 < E/p < 0.8$ for two of the tracks and selecting the third one

Test of NN on experimental data

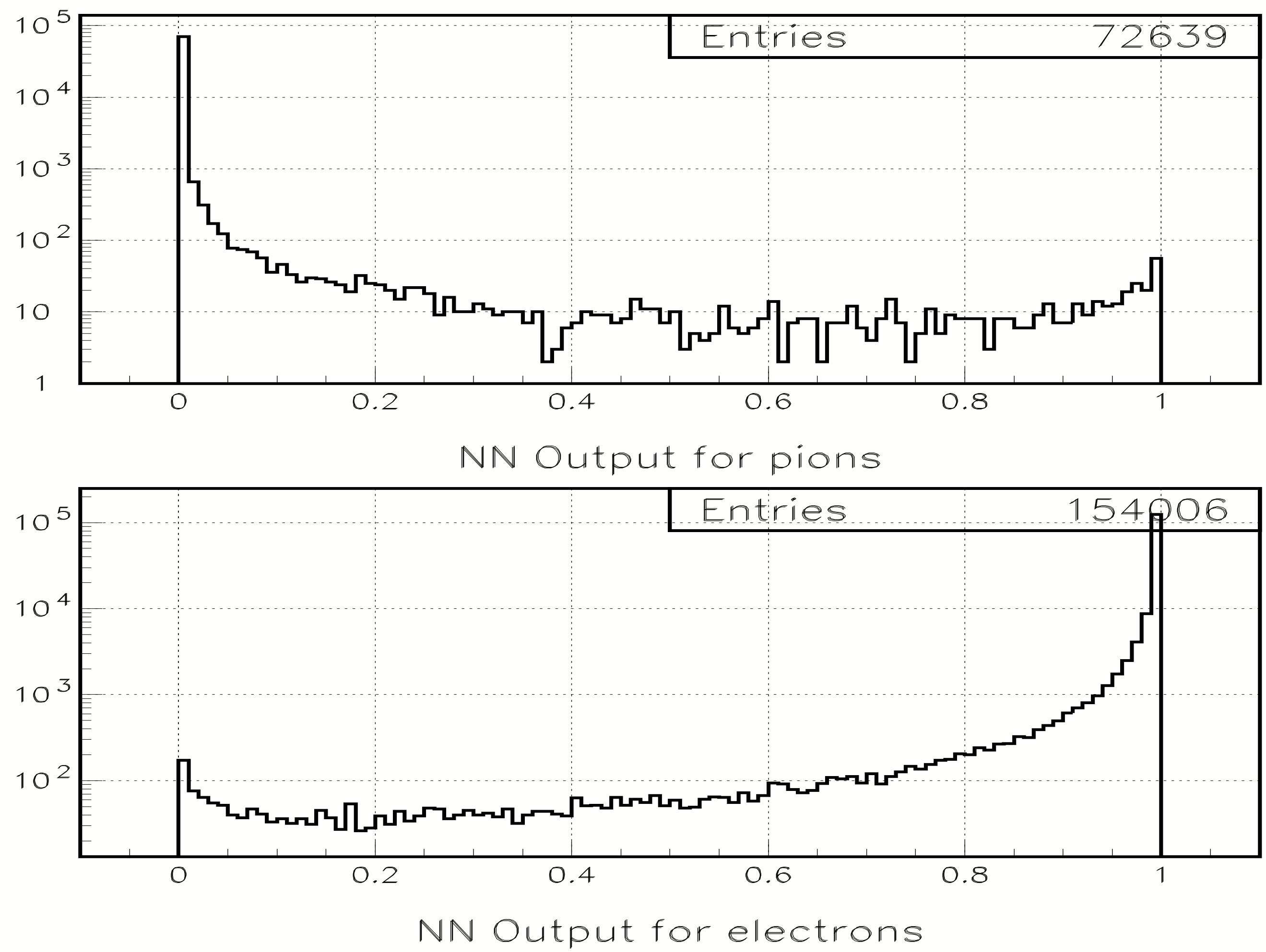
Preliminary data

- Net: 10-30-20-2-1
- Input: E/p, Dist, Rrms, p, RMSX, RMSY, dx/dz, dy/dz, DistX, DistY
- Teaching: 15000π from $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$, $5000e$ - K^0e3
- Test: π from $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$ and e from K^0e3

	$e^{\pm}$	$\pi^{\mp}$	e loss	ϵ^e_{eff},%
ALL	154006	943625		
$E/p > 0.6$	154006	72639	–	–
$E/p > 0.9$	153739	7775	267	99.83
out> 0.9	145254	188	8485	94.32
out> 0.95	140906	133	12833	91.49

	$\epsilon^{\pi \to e}$	ϵ^e_{eff},%
out> 0.9/ALL	$2.0 \cdot 10^{-4}$	94.32
out$> 0.9/E/p > 0.9$	$2.4 \cdot 10^{-2}$	94.48
out> 0.95/ALL	$1.4 \cdot 10^{-4}$	91.49
out$> 0.95/E/p > 0.9$	$1.7 \cdot 10^{-2}$	91.65

Test of NN on experimental data



Conclusions

- Using Neural Networks it is possible to reach e/π separation:
- $\epsilon^{\pi\to e} \sim 0.7 \cdot 10^{-5}$ - $1.9 \cdot 10^{-5}$
- i.e. relatively to E/p < 0.9 cut $\epsilon^{\pi\to e} \sim 0.7 \cdot 10^{-2}$ - $1.4 \cdot 10^{-2}$
- keeping $\epsilon^{e}_{eff} > 99\%$
- The background from $K^+ \to \pi^+\pi^+\pi^-$ < 0.1 %
- We have safety factor $\sim$ 2
- to be done
  - test on experimetal data
  - simulate $K^+ \to \pi^+\pi^+\pi^-$ and to processe them applying K_{e4} selection + NN

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