RPC and Muon Detection at Belle

Kazuo Abe
KEK

Belle-BaBar Workshop
Vancouver, February 2002

Contents

Belle RPC system

- 15 (14) superlayers in Barrel (Endcap). Total 240 (112) Superlayers in Barrel (Endcap).

- Two RPC layers per superlayer with independent HV and gas supplies. One (ϕ, z) measurements (r, ϕ for Endcap) per superlayer.

- Operate at 8,000V (7,850V) for Barrel (Endcap). Monitor dark current of 704 individual layers with negative supply channels (fixed at -3.5kV). Ramp down by $\sim$1000V during beam injection.

- 2 independent gas supply lines for both Barrel and Endcap. Use $Ar/butane/HFC134a$ (30/8/62) gas mixture. Flow rates $\sim$ one RPC volume replacement per day. HV is interlocked with mixing fraction variation.

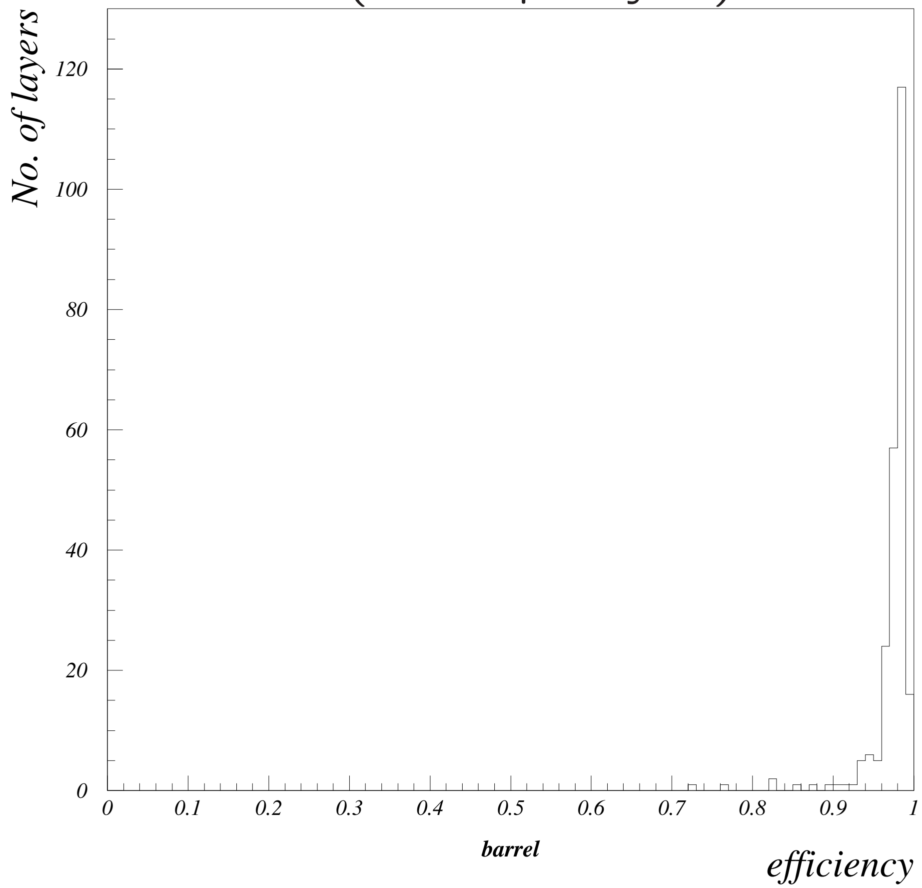
- $\sim$38,000 readout strips. Discriminator threshold 30mV$\sim$50mV. 12channels are fast-ORed and time-multiplexed and sent to a 32μsec range TDC channel.

- Superlayer efficiencies are routinely measured off-line using dimuon events.

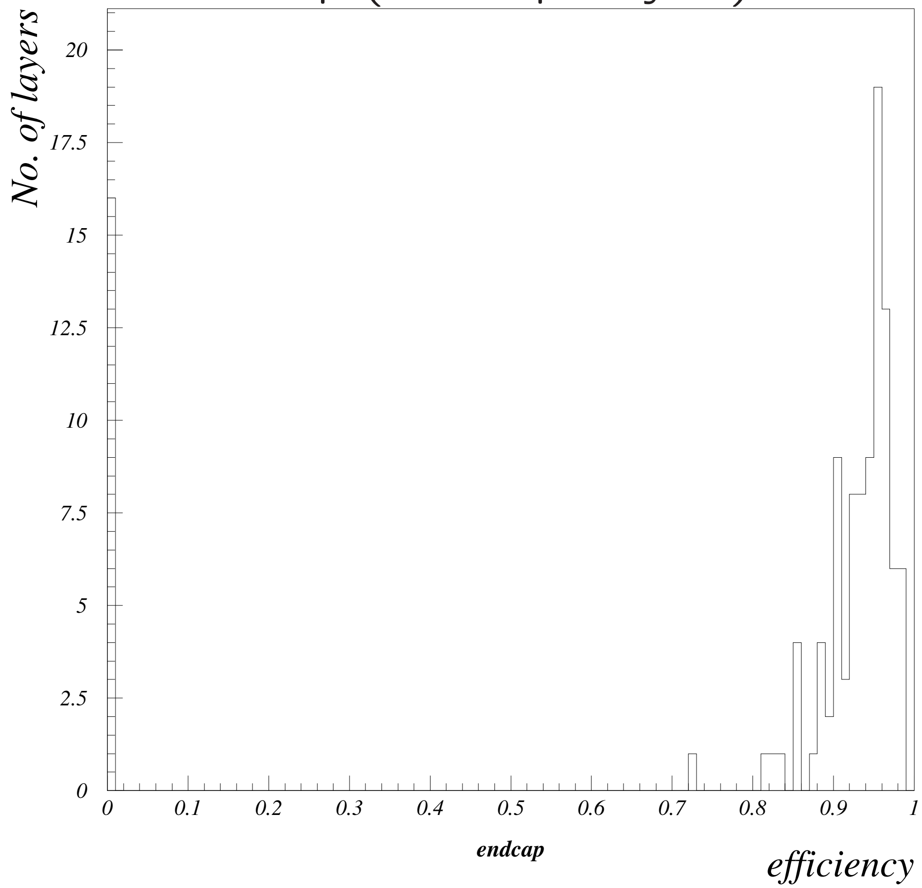
Superlayer Efficiencies

(determined using dimuon events during 2001 fall runs (1200mA/800mA))

Barrel (240 superlayers)



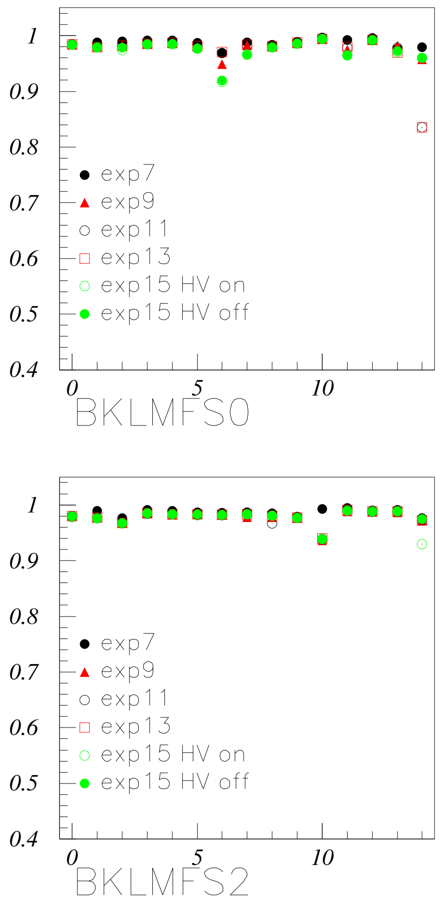
Endcap (112 superlayers)



Efficiency vs Superlayer Number

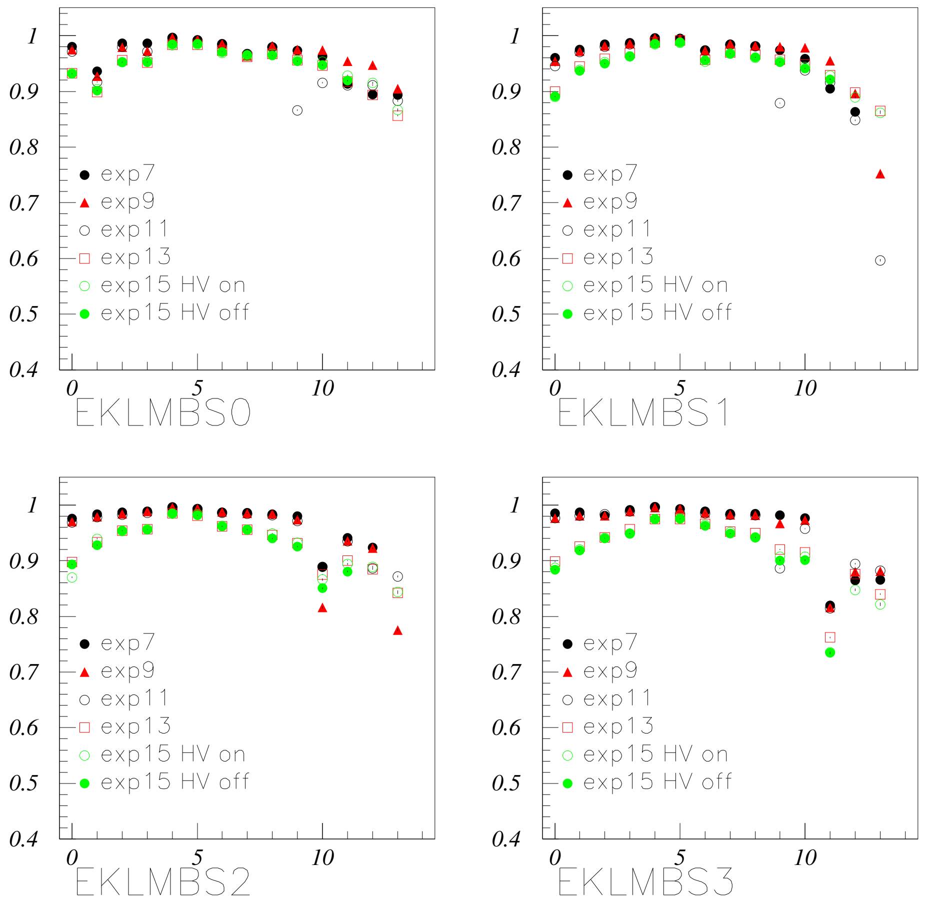
Barrel Modules (4 out of 16 shown)

Layer Efficiency



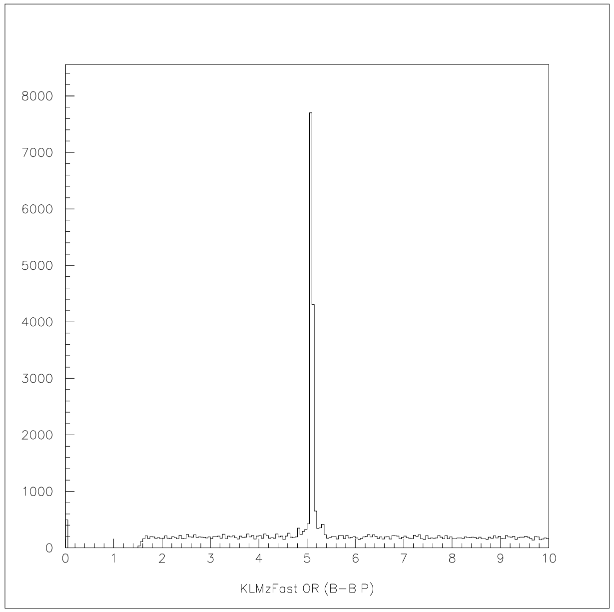
Endcap Modules (4 out of 8 shown)

Layer Efficiency

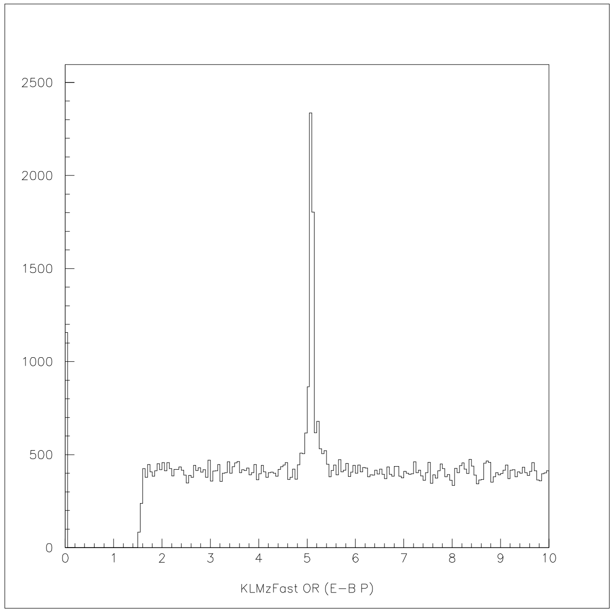


Time Resolution of RPC

(from Fast OR Signals)



Barrel Backward

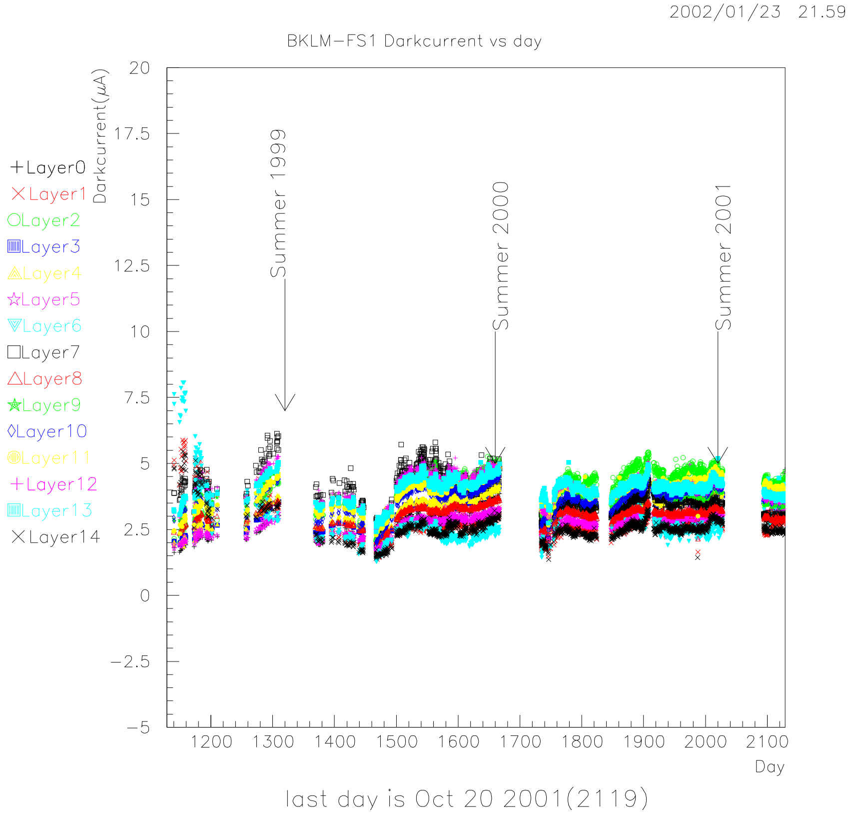


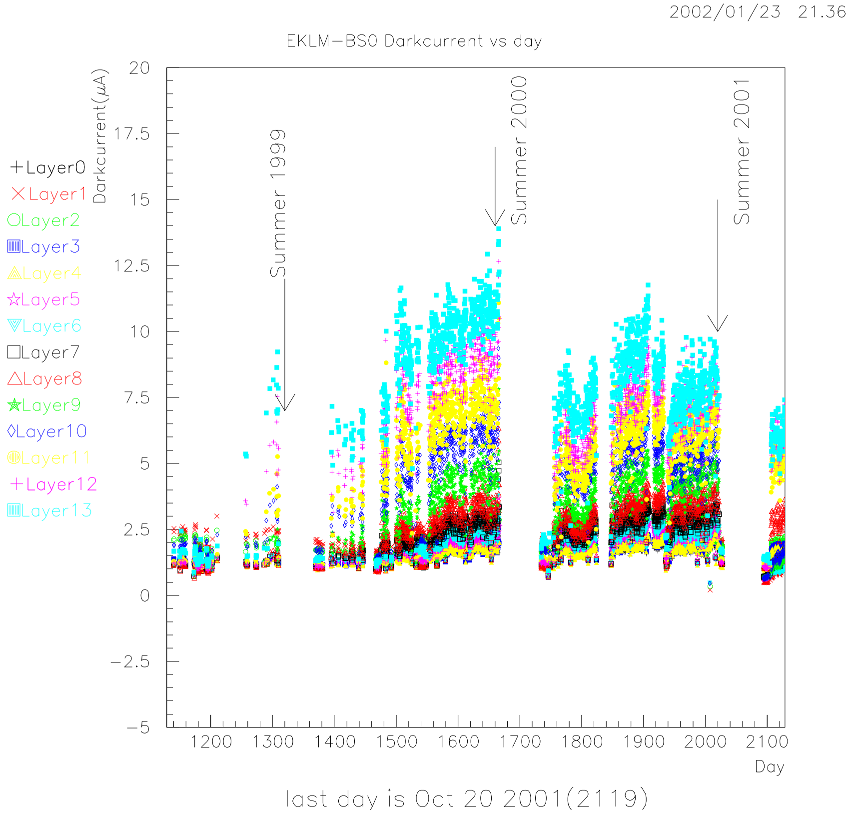
Endcap Backward

- RPC time resolution of present readout scheme is $\sim$ 150ns (intrinsic resolution of RPC is $\sim$5ns, but worsened by time-jitter inside Xilinx chips, differences for strip lengths and cable lengths).

- Present data analysis uses 1μsec time window.

Long Term Variation of Dark Current

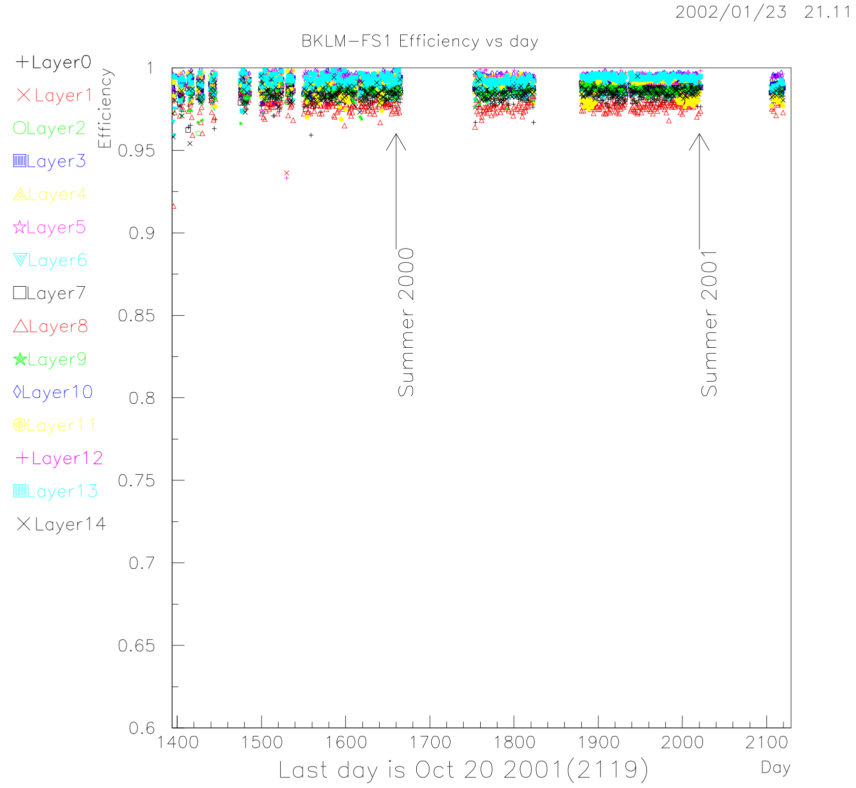


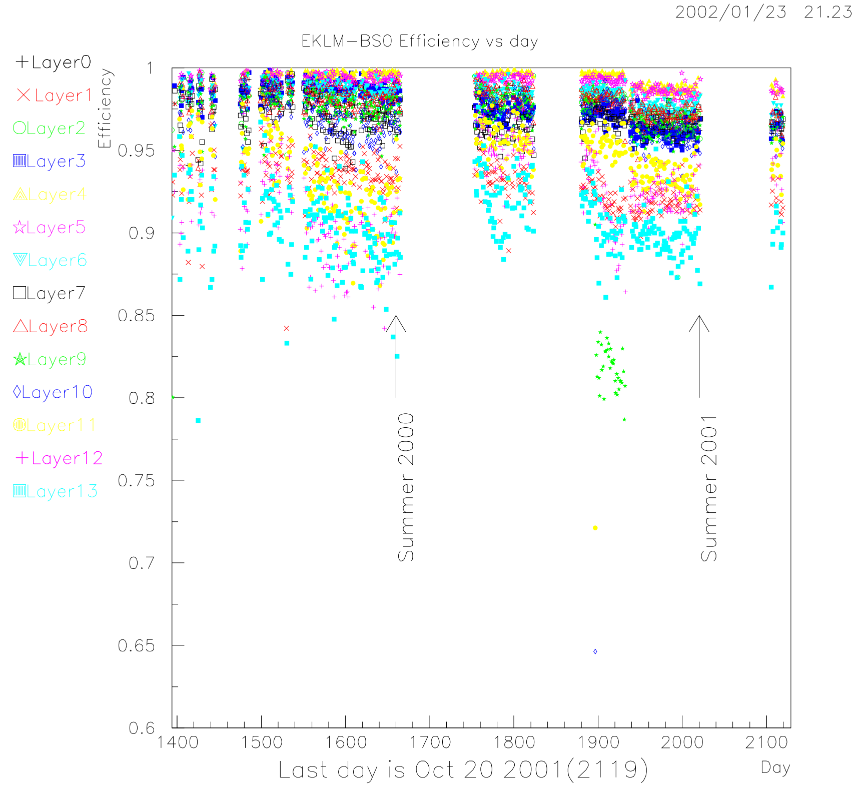


Endcap outer-layers suffer from the beam background. Added 10cm Pb shield in summer 2000. Reduced Endcap HV and threshold after spring 2001 (8000→7850V, 70→40mV).

When no beam, dark current has no change in barrel, reduces to $\sim 1\mu$A for endcap.

Long Term Variation of Efficiency

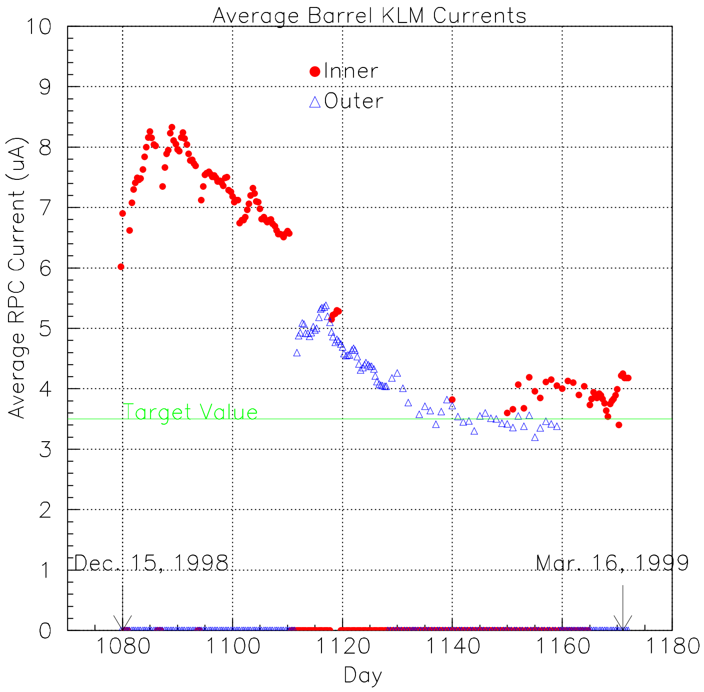


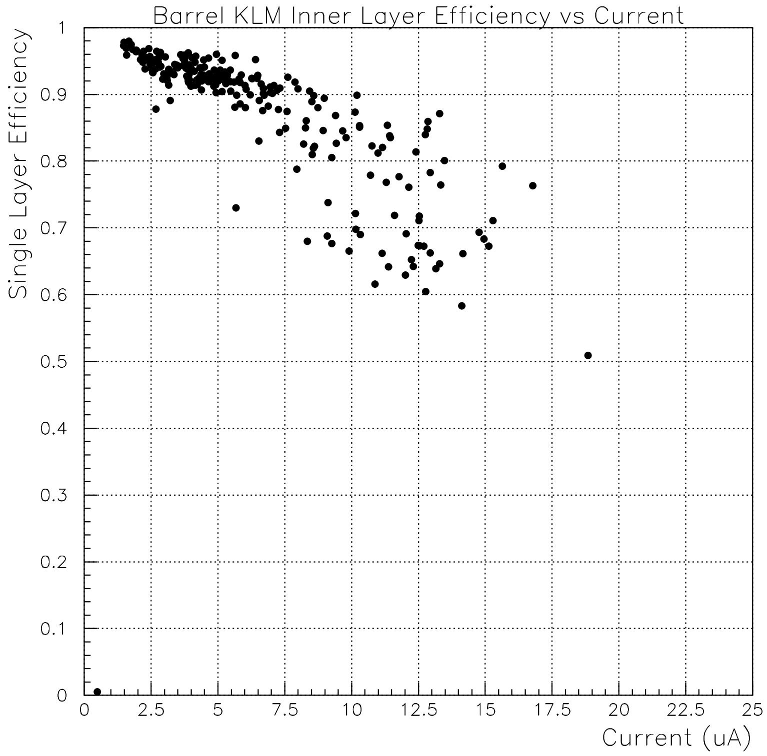


No change for the barrel. Endcap outer layers suffer from the beam background.

Efficiency vs Dark Current

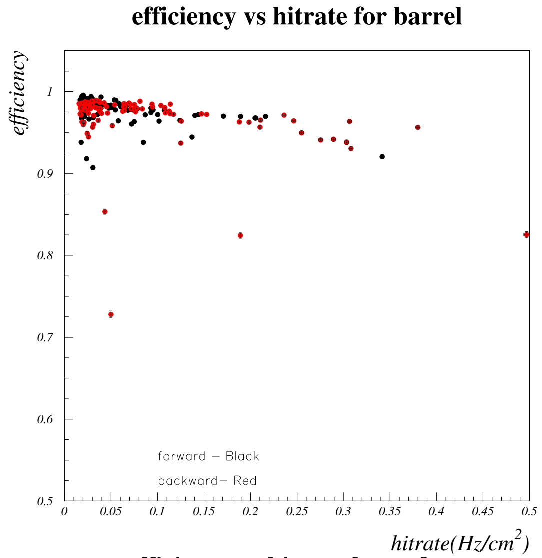
In 1998 summer, we contaminated RPCs with water vapor which caused dark current to increase. During this period, we could measure efficiency vs dark current relations for single layers.(during data runs, we can only measure the superlayer efficiencies)

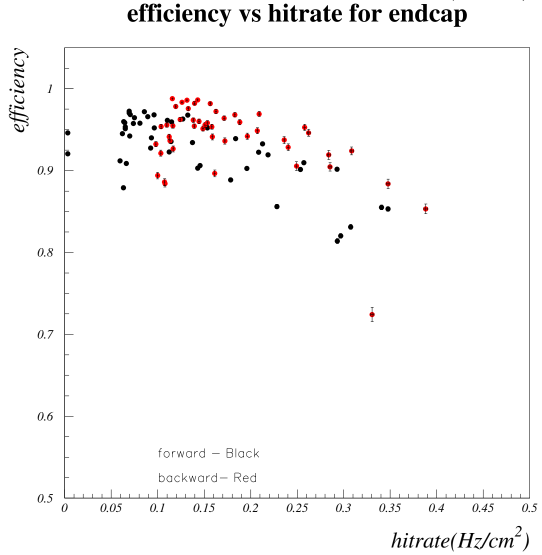




Superlayer Efficiency vs Hit Rate

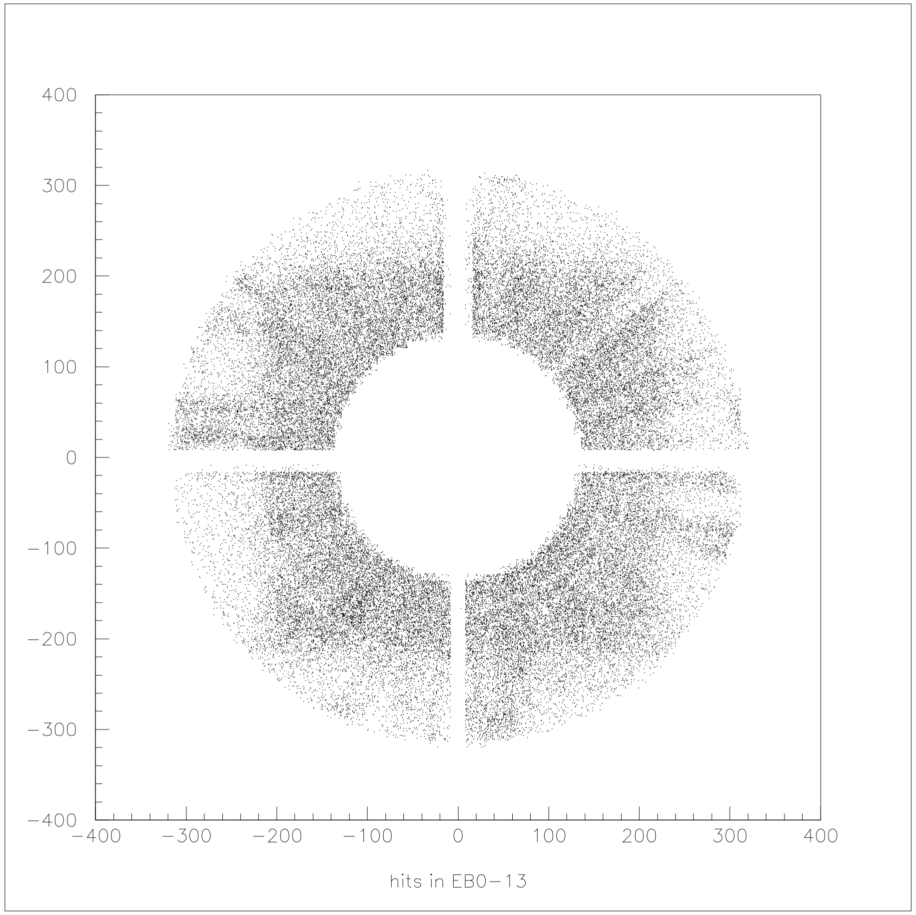
(2001 fall runs(1200mA/800mA))





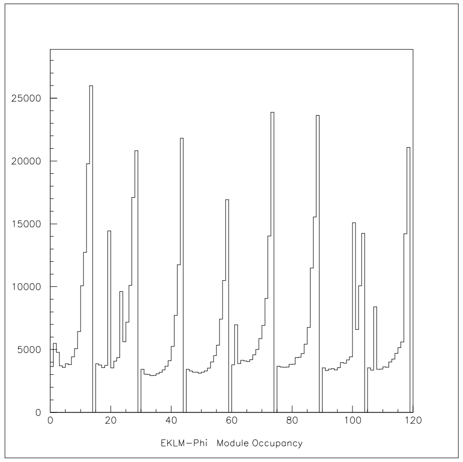
- Hit rate at 1200mA/800mA
  - Barrel: $\sim 0.02 Hz/cm^2$ (∼same as no beam case)
  - Endcap: $\sim 0.1 Hz/cm^2$
- Extrapolation to $\times 10$ beam current (assuming linear)
  - Barrel: at most $\sim 0.2 Hz/cm^2$ at most a few % efficiency drop, no problem
  - Endcap: $\sim 1 Hz/cm^2$ significant efficiency drop, something must be done

Beam Background in Endcap

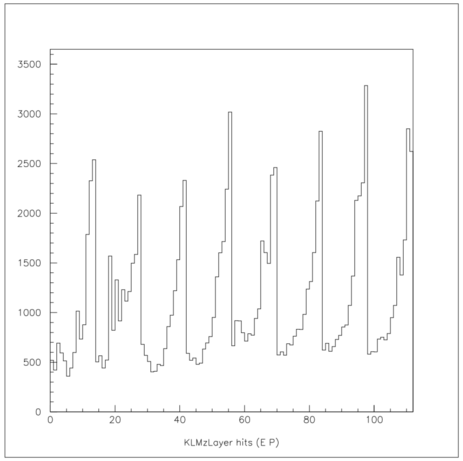


- Two dimensional hit distribution of outer-most layer in the Backward Endcap during fall 2001 runs.
- Square-shaped area which is directly exposed to the machine tunnel is clearly visible.

Occupancy vs Superlayer Number in Endcap



1999 fall (560mA/320mA)



2001 fall (1200mA/800mA)

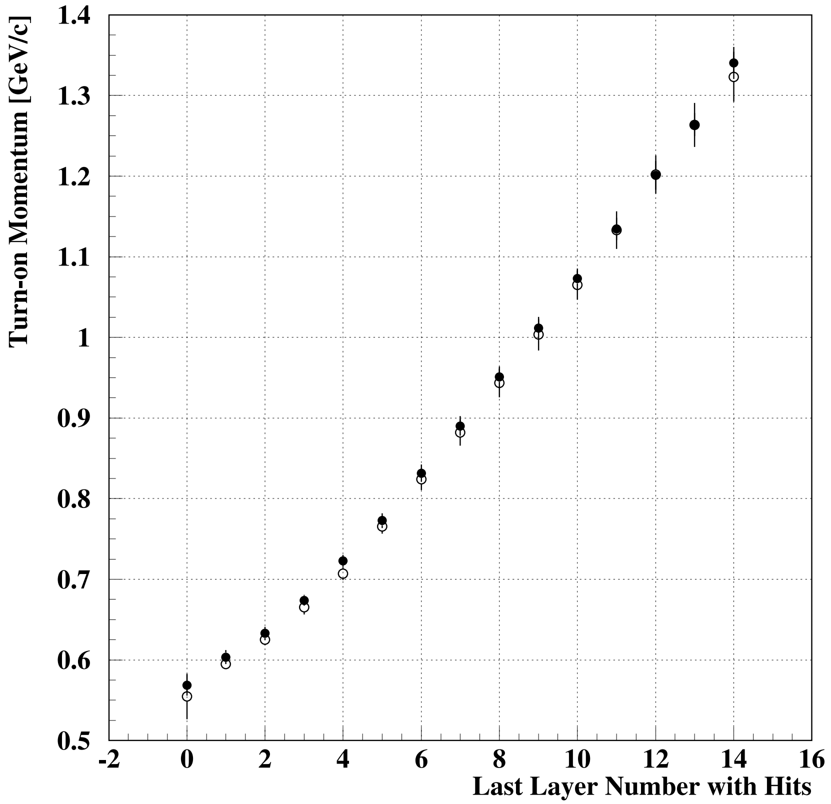
- Outer layers suffer from beam background.
  - This patter started to show after 210mA/90mA(July 99).
  - 10cm thick lead were added to the square-shaped regions during summer 2000. We could not turn on the outer-most layers before this shielding. Some improvement but not much.
- If a few MeV photons were dominating, the 10cm thick lead should have reduced the effect to negligible level.
- Neutron contribution must be dominating now. Large probability (Giant Dipole Resonance) for $\sim$ 10MeV photons to generate a few MeV neutrons inside the iron and lead.

Alternatives to Freon (HFC 134a)

Freon (HFC 134a) has a high global warming power. We must be prepared for a ban in future. We tested three possible alternative gas mixtures.

	Ar/butane/CO_2/O_2 (10/4/76/10)	Ar/butane (50/50)	Ar/butane/SF_6 (90/9/1)	Ar/butane/HFC134a (30/8/62)
Plateau (kV/cm)	3.6	3.7	2.2	4.0
Efficiency (%)	90	92	92	95
Dark current (μA/m^2)	0.77	0.43	0.45	0.25
Single Rate (Hz/cm^2)	0.052	0.042	0.045	0.04
Mean Charge (pC)	280	230	55	81
Fraction of 1st peak (%)	26	80	45	81
Time Resolution (ns)	1.7	2.6	2.9	2.6
Cluster size (mm)	6.0	6.4	5.7	4.9
		flammable		standard gas

”Turn-on Momentum”



- Minimum detectable momentum for muons at each layers

  close circles (cosmic muons), open circles (MC)

- Good agreement within the accuracy of this method (∼10 MeV/c).

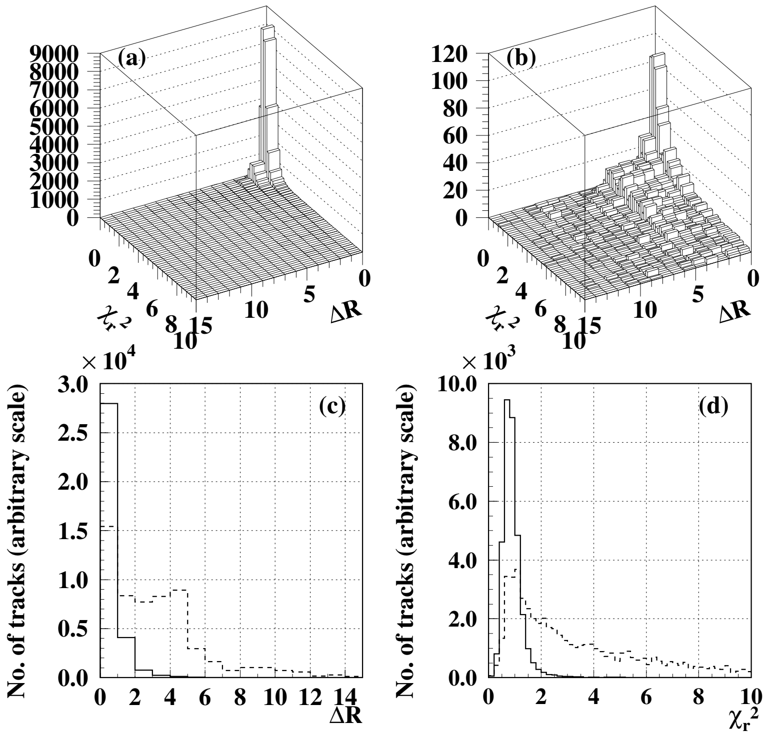
Method of Muon Detection

- Extrapolate CDC tracks to KLM.
- Measure R (range) and χ_r^2 (transverse deviation of hits)
- Calculate ΔR for μ, π, K hypotheses.
- Using MC-generated PDF (barrel and endcap separately), calculate probabilities for being μ, π, K:

$$p_i(\Delta R, \chi_r^2) = p_i(\Delta R) \cdot p_i(\chi_r^2)$$

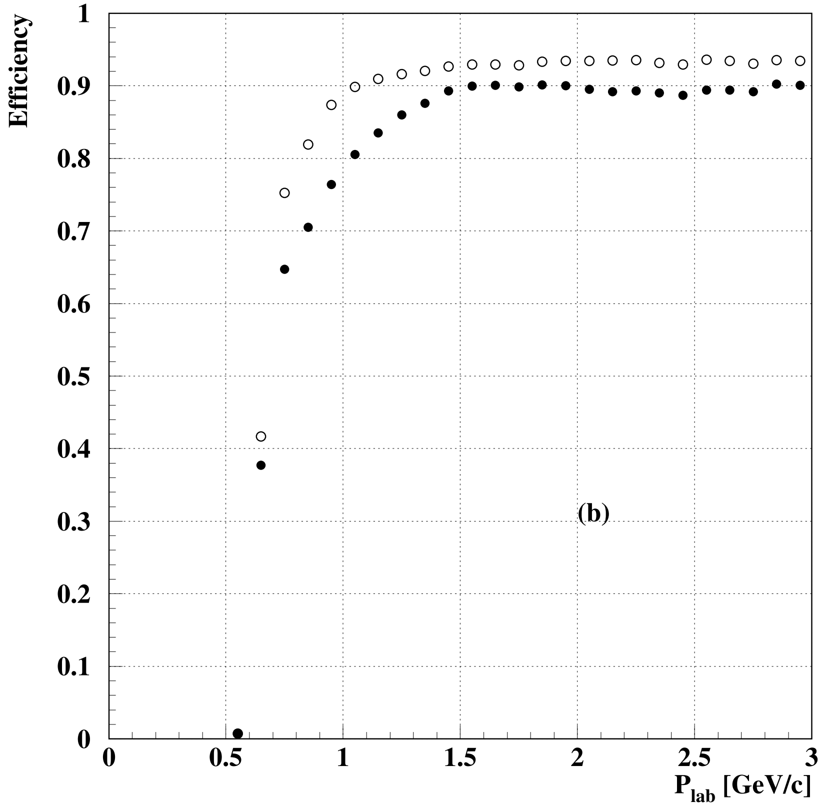
- Calculate muon likelihood:

$$L_\mu = p_\mu / (p_\mu + p_\pi + p_K)$$



Muon Detection Efficiency

(determined from $e^+e^- \to e^+e^-\mu^+\mu^-$ events)



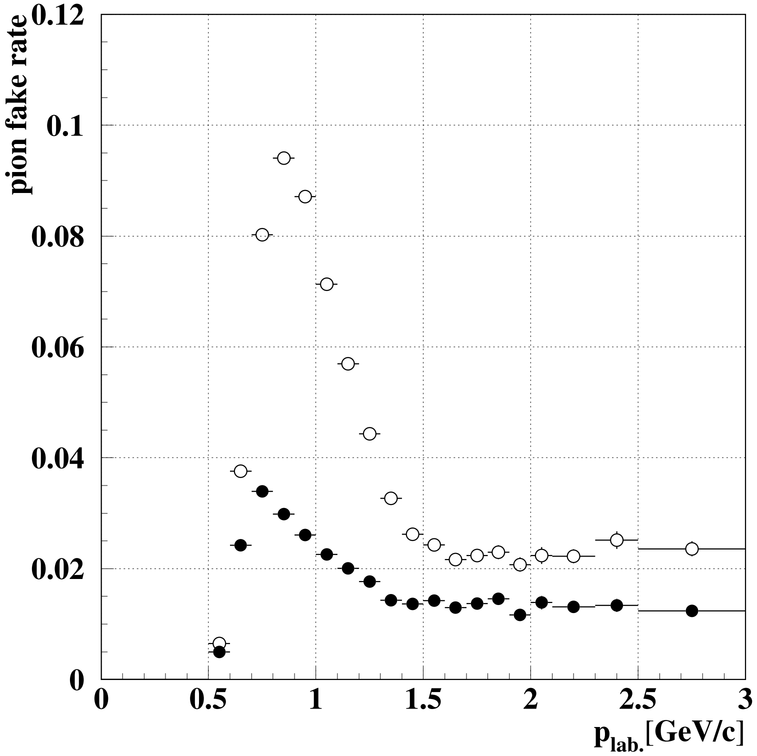
$L_\mu > 0.1$(open), $L_\mu > 0.9$(closed)

Uncertainly of muon detection efficiency is 2% based on differences among different methods.

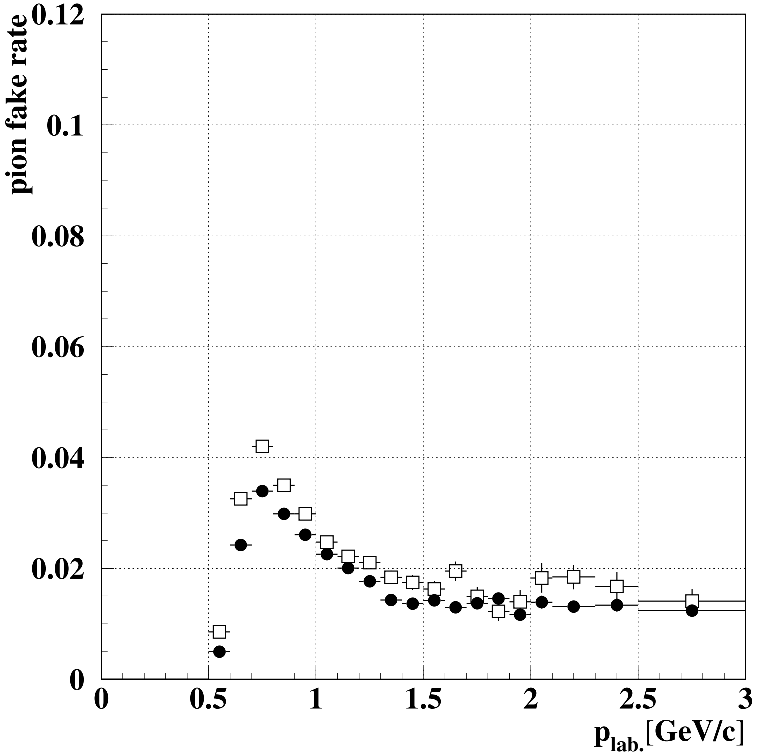
Pion Fake Rate

($K_S \to \pi^+\pi^-$ events)

$L_\mu > 0.1$(open), > 0.9(closed)



MC(open) vs data(closed) at $L_\mu > 0.9$

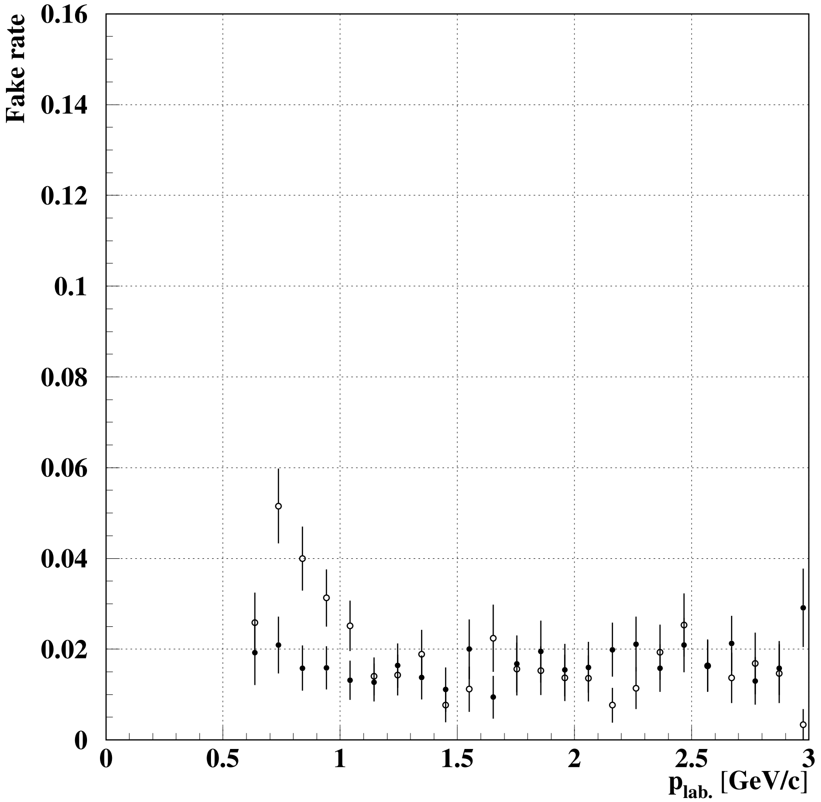


MC (GEANT3-Fluka) over-estimates the fake rate by $\sim$10%.

Kaon Fake Rate

($D \to K\pi$ events)

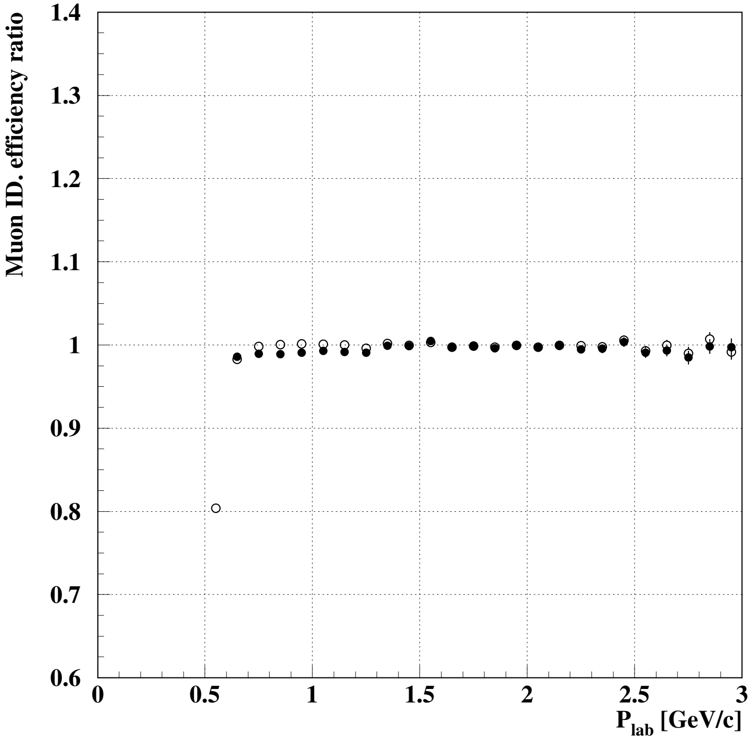
Kaon(cloded), pion(open) for $L_\mu > 0.9$



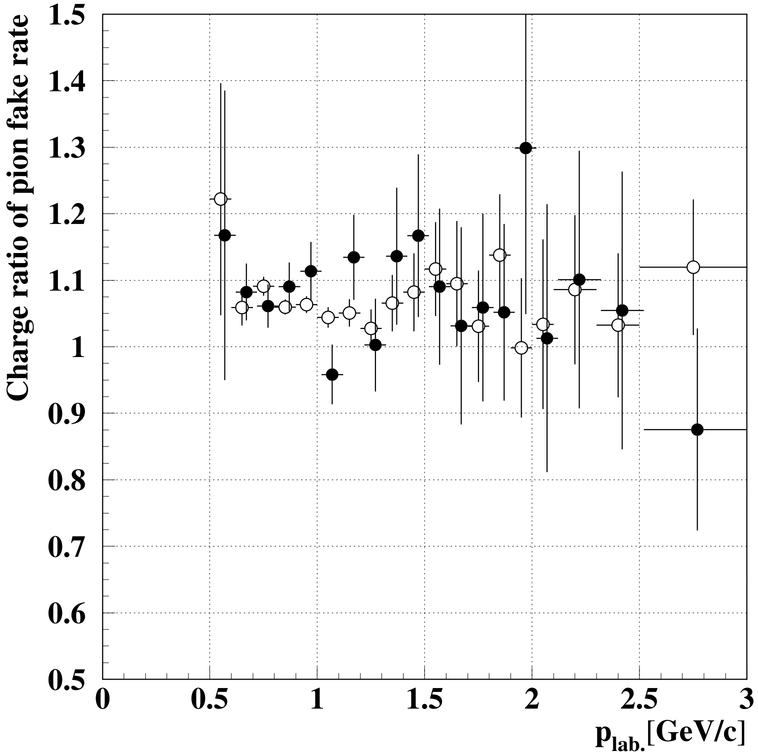
Charge Dependence

(positive to negative ratio)

Muon efficiency for $L_\mu > 0.9$(open), $L_\mu > 0.1$(closed)



Pion fake rate for $L_\mu > 0.9$(open), $L_\mu > 0.1$(closed)



Efficiency ratio is unity. Negative pions have a higher cross section for nuclear capture and less likely to punch-through.

Conclusion

- Superlayer efficiencies for most of the barrel and inner endcap stay better than 95%.
- Endcap outer-layer efficiencies suffer from beam background. Getting worse as the beam current increases.

  (Two outer-most layers had to be turned off from 2001 fall run)
- No long term effect is seen except the beam background problem.
- The beam background probably is dominated by a few MeV neutrons generated by $\sim$10 MeV photons through Giant Dipole Resonance in the lead shield and KLM iron.
- $\times$10 beam current should have no effect on Barrel. Endcap efficiencies will deteriolate significantly unless properly shielded.
- Muon detection performs as expected. Monte Carlo over-estimates the hadron fake rate by $\sim$10%.