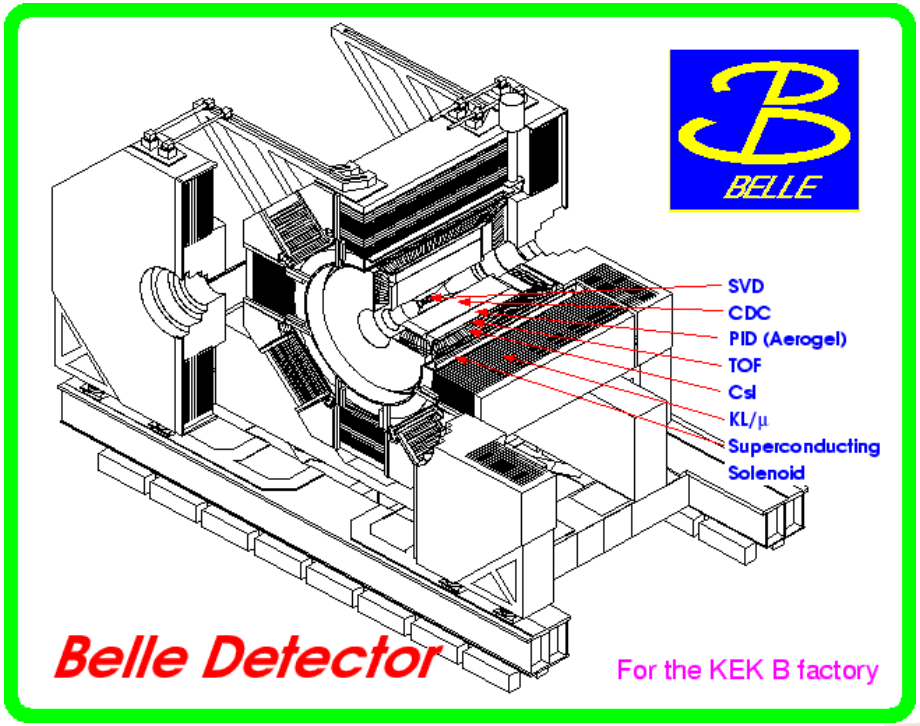
The Belle Experiment

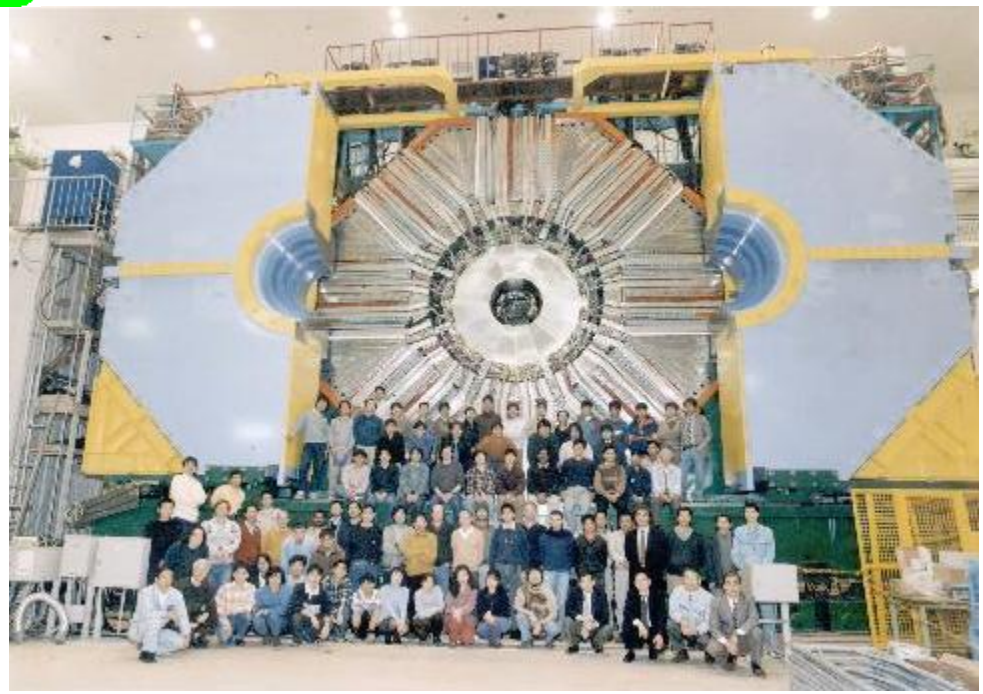
Measurement of the
Matter/antimatter Asymmetry of
Beauty Quarks

Charge Conjugation and Parity
(CP) Violation



Virginia Tech built the KL/muon detectors which consist of 15 layers of Resistive Plate Counters interleaved with iron plates surrounding the solenoidal magnet.

End View of the Detector prior to closing the endcaps and rolling into the beamline.



K_L Muon System

KEK,Osaka City University,Princeton University
Tohoku University, Tokoku–Gakuin University, and
Virginia Polytechnic Institute and State University

- 352 Superlayer Modules with Glass Electrode Resistive Plate Counters

  Largest module 2.7 m x 2.2 m

  ~2200 m^2 total area

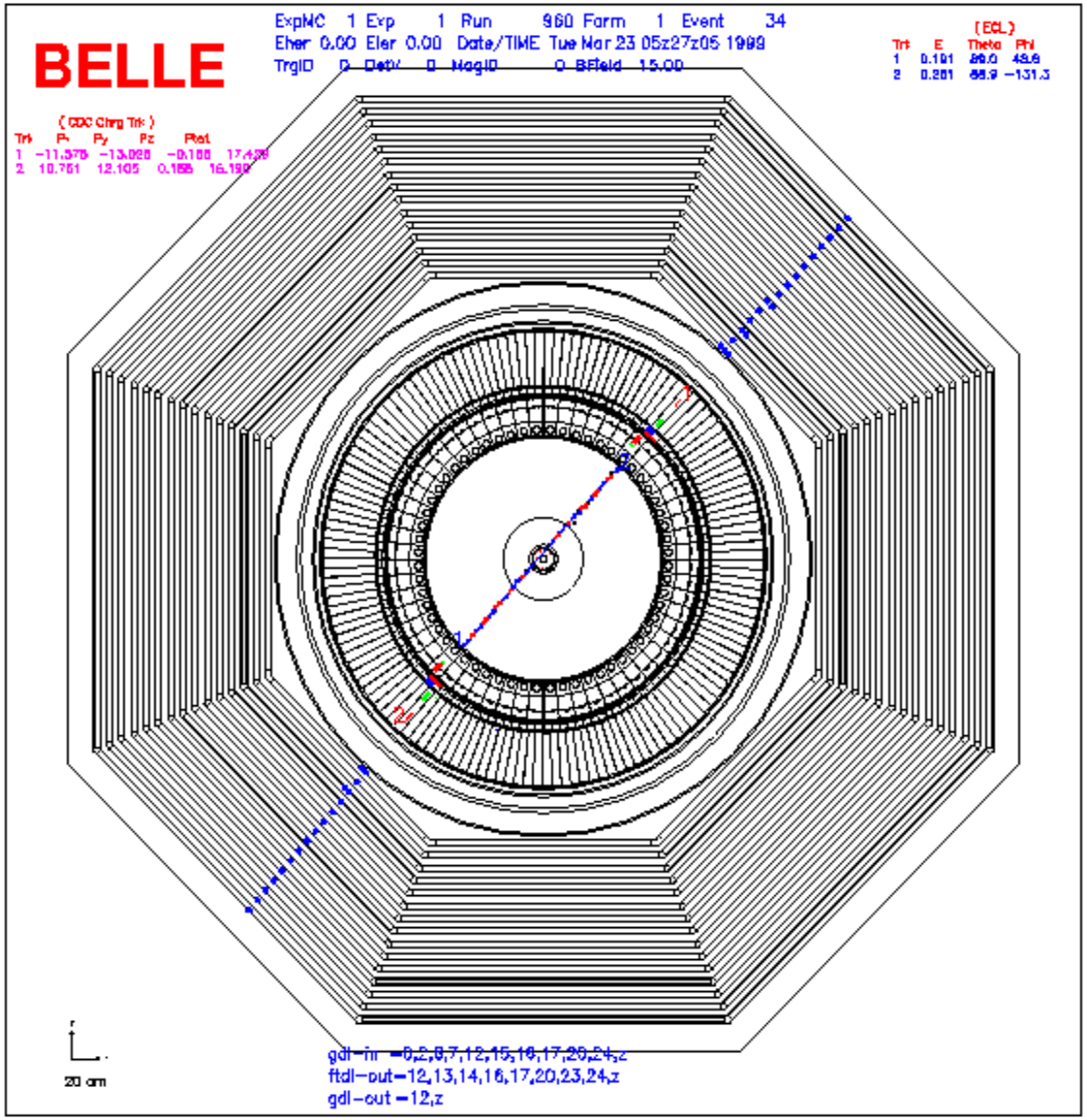
  62% R134a 30% argon 8% isobutane gas mixture

- 38016 signal readout strips

  30 mV Threshold

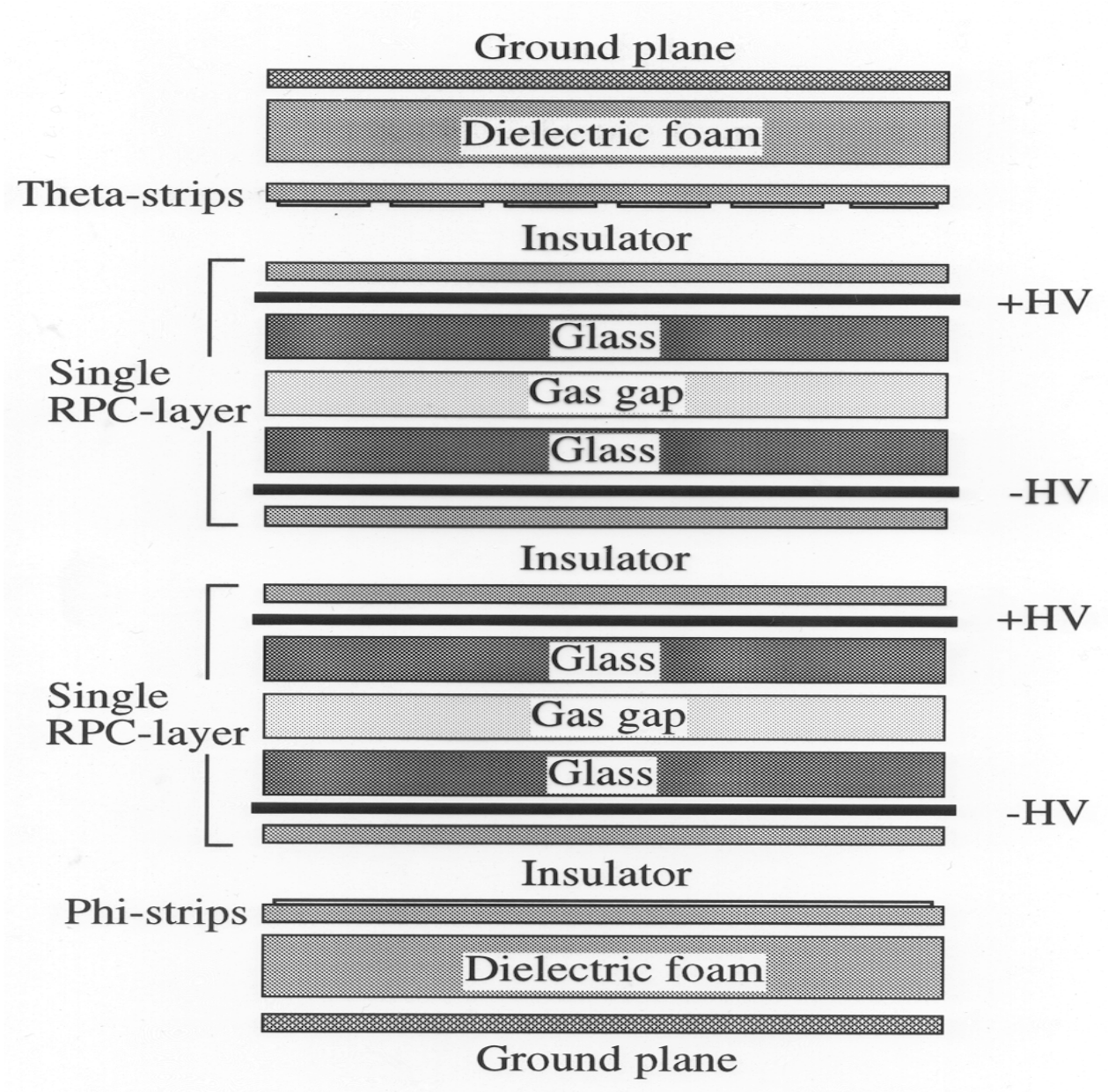
  12x Time multiplexing to 3168 TDC channels

  Spatial Resolution of ~1.5 cm


BELLE
ExpMC 1 Exp 1 Run 960 Form 1 Event 34
Eher 0.00 Eler 0.00 Date/TIME Tue Mar 23 05z27z05 1999
TrgID 0 DetV 0 MagID 0 BField 15.00
(ECL)
Trk E Theta Phi
1 0.191 89.0 49.8
2 0.261 88.9 -131.3
(CDC Chrg Trk)
Trk Px Py Pz Ptot
1 -11.575 -13.026 -0.166 17.429
2 10.751 12.105 0.155 16.199
20 cm
gdl-in =0,2,6,7,12,15,16,17,20,24,z
ftdl-out=12,13,14,16,17,20,23,24,z
gdl-out =12,z

Resistive Plate Counters

Glass electrodes are used to apply an electric field of ~4kV/mm across a 2mm gap. The gap has a mixture of argon,isobutane and HFC134a gas. An ionizing particle initiates a discharge which capacitively induces a signal on external pickup strips.

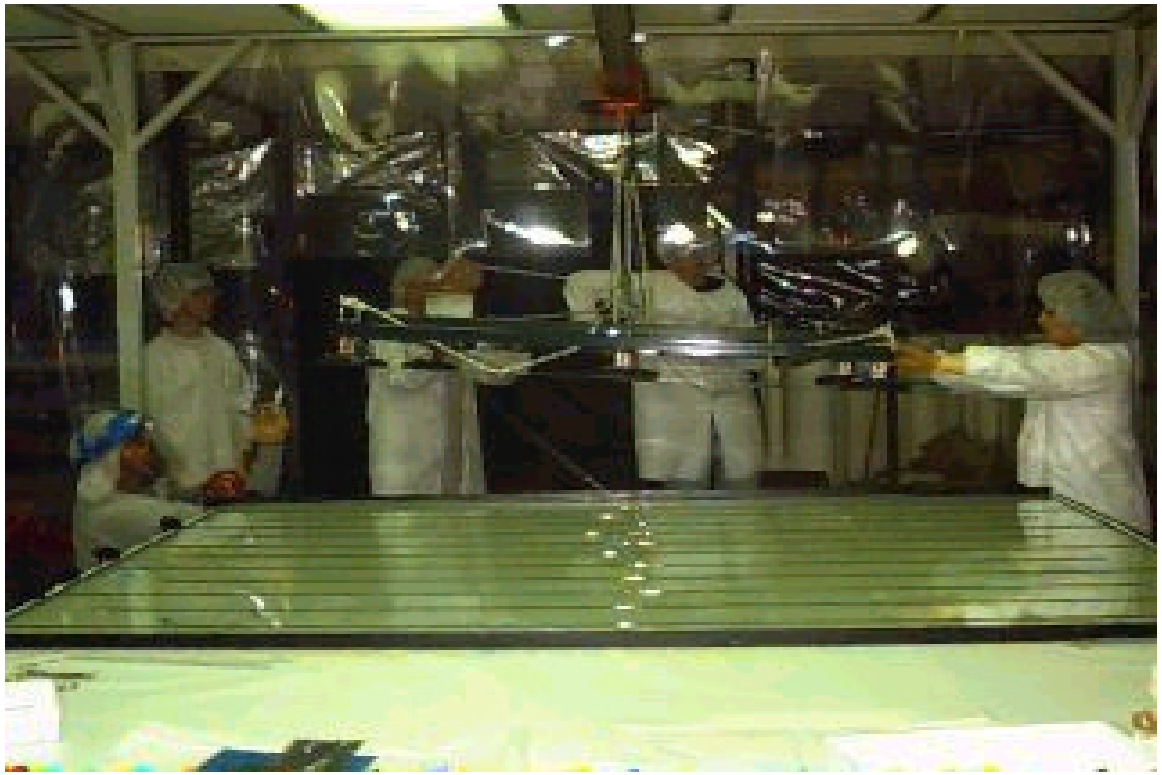


Resistive Plate Counter Construction at Virginia Tech

Two sheets of glass are separated by 1.9mm Noryl spacers epoxied in place

Laying spacers on the glass

Lowering the top sheet of glass



Applying weights

The epoxy cured
overnight
with pressure applied
by weights

Applying the conducting ink

Conducting ink is applied to the outer surfaces of the glass to distribute the electrical potential.

Sealing with Mylar

The high voltage electrodes are sealed with two layers of mylar.

Signal Pickup Strips

Signals are picked up on 3cm wide conducting strips on either side of the RPCs

Superlayer Modules

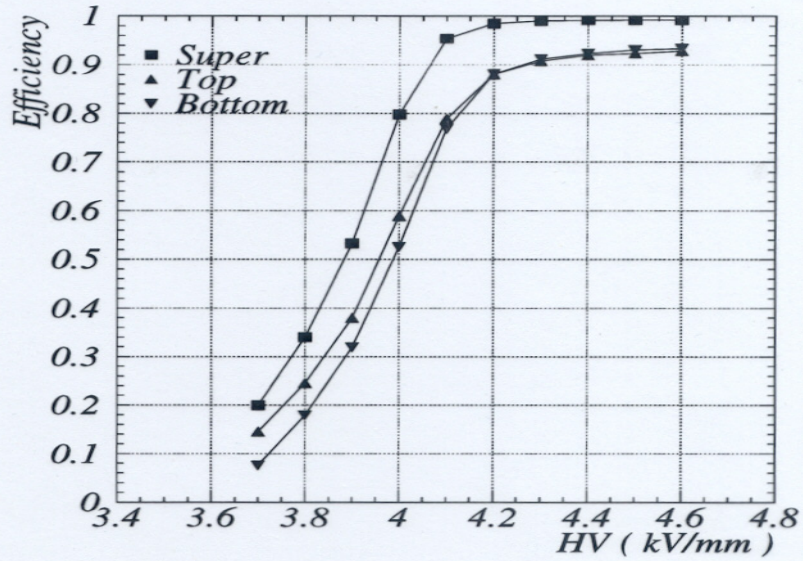
Signals,gas lines and HV are accessed on one end.

This shows signal cables prior to completion of the aluminum superlayer box

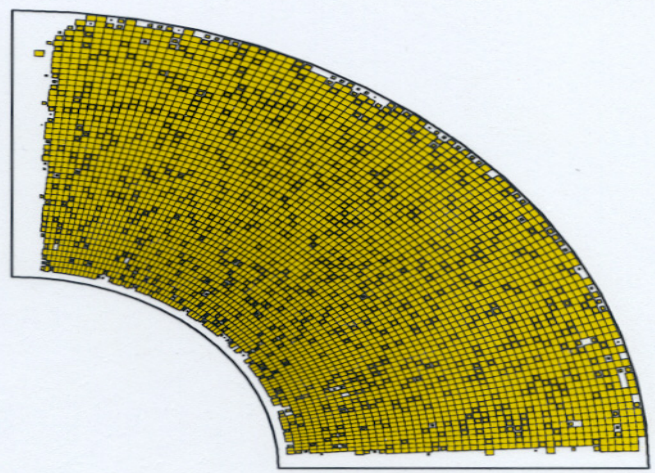
240 modules of 15 different sizes covering ~1200 m^2 were shipped to Japan

Endcap Efficiency (Superlayer)

Plateau curve
@ $V_{\mathrm{th}} = 50\,\mathrm{mV}$

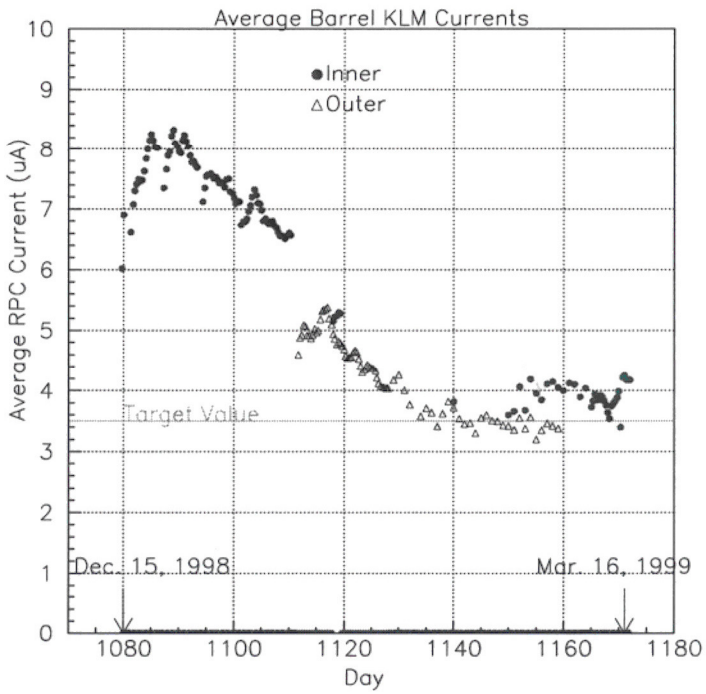


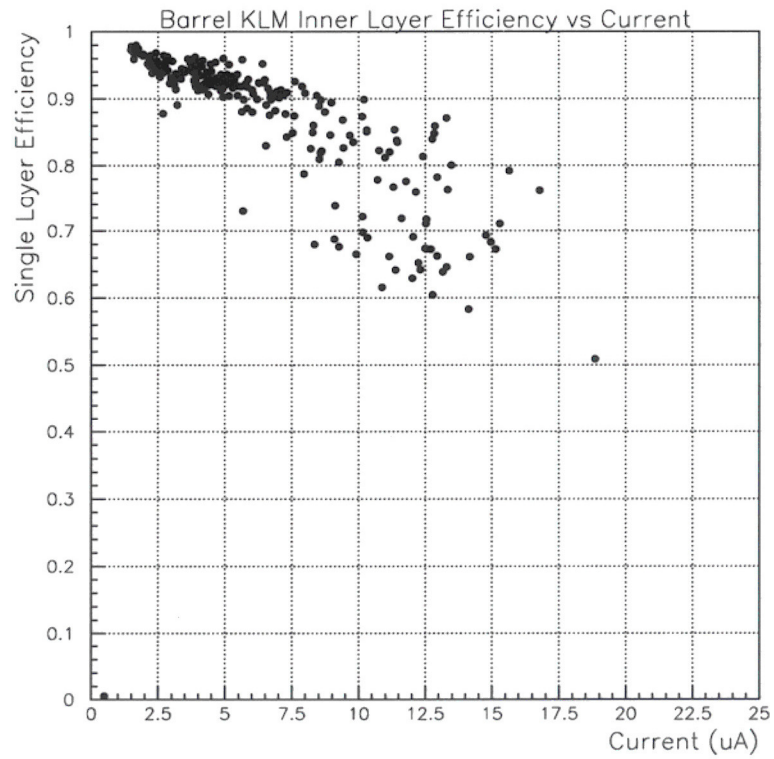
Efficiency vs θ–ϕ
(on plateau)



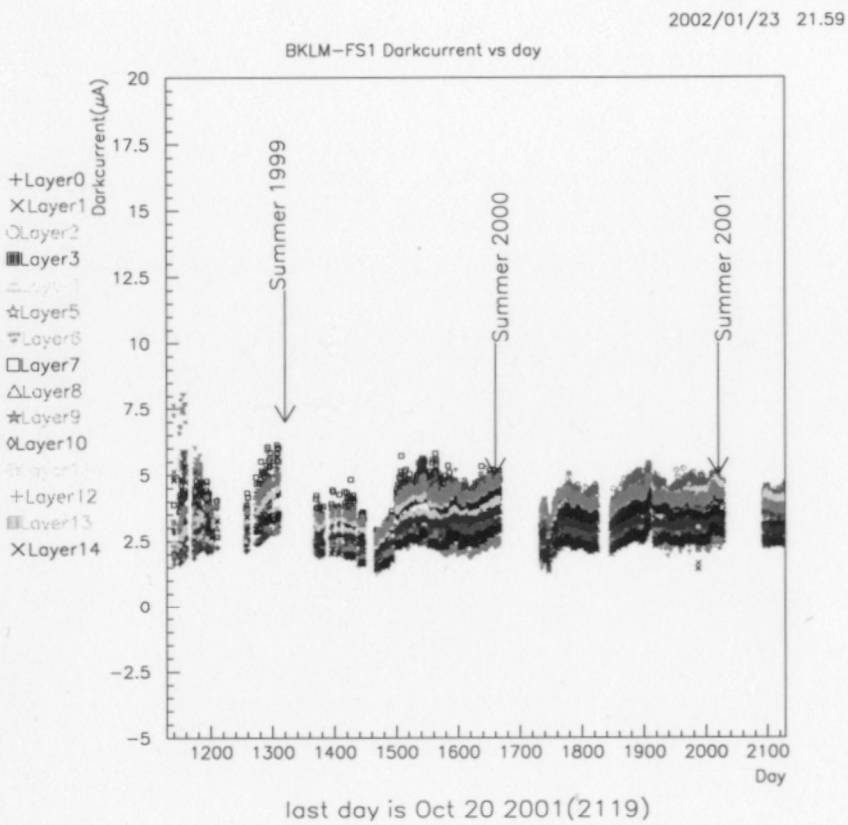
Efficiency vs Dark Current

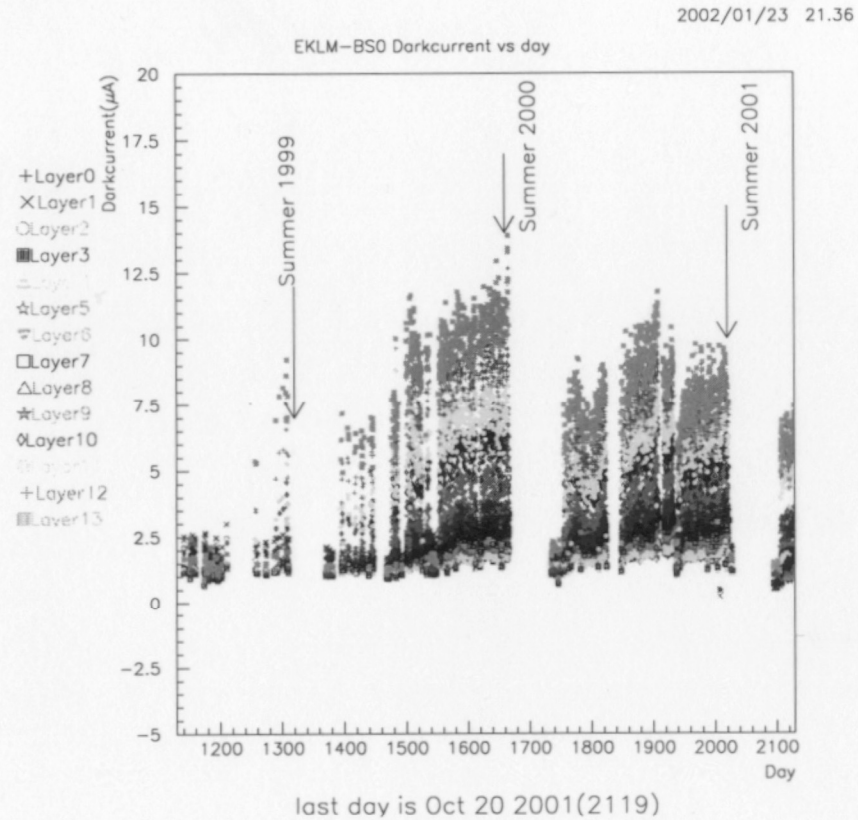
In 1998 summer we contaminated RPCs with water vapor which caused dark current to increase. During this period, we could measure efficiency vs dark current relations for single layers.(during data runs, we can only measure the superlayer efficiencies)





Long Term Variation of Dark Current

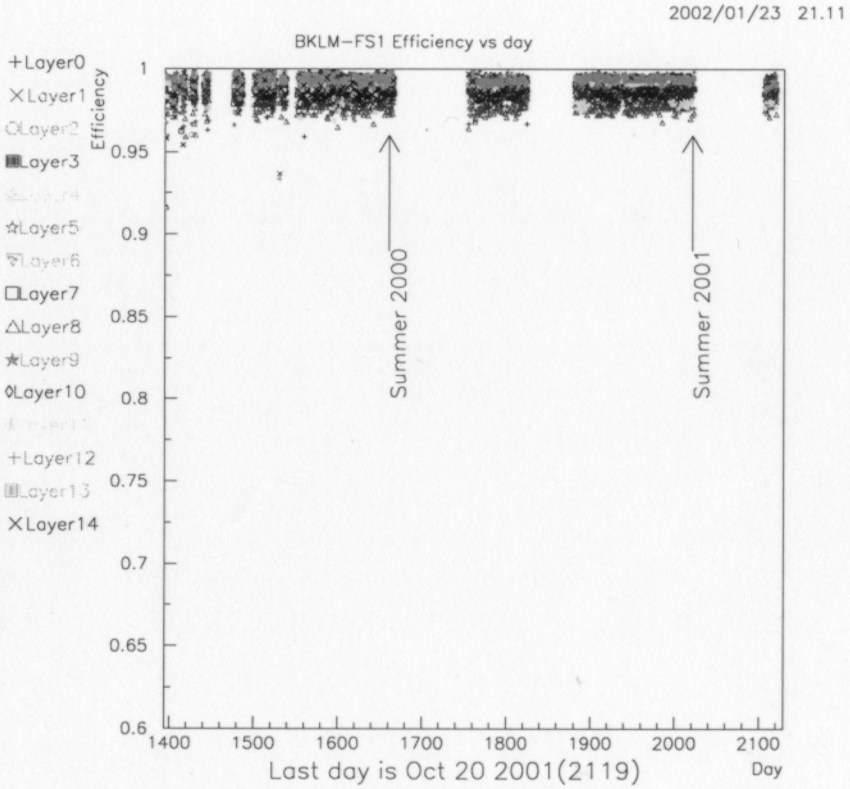


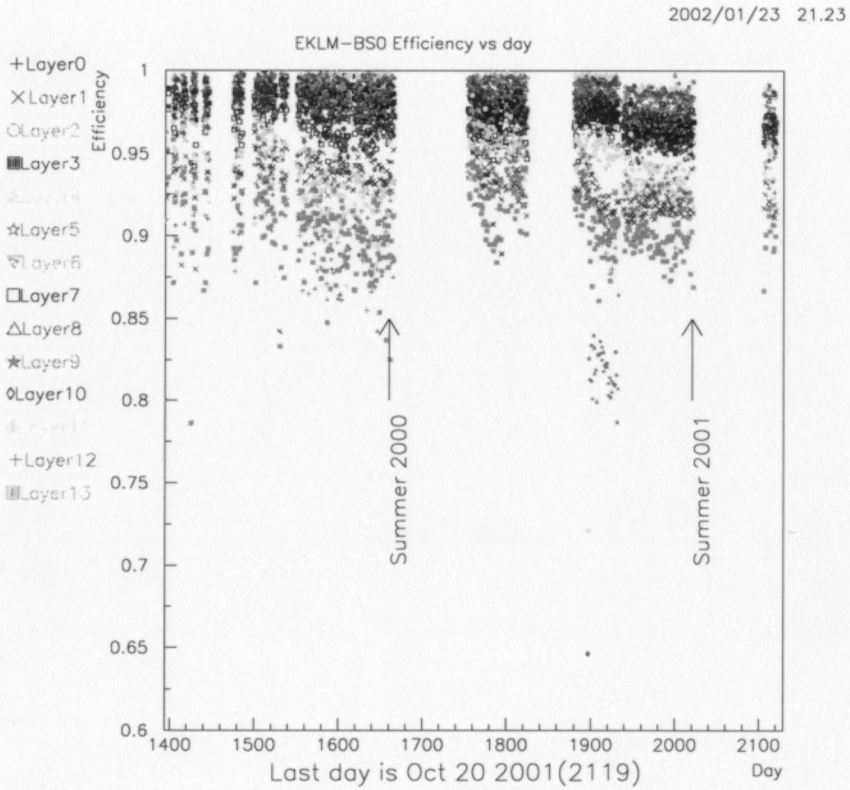


Endcap outer-layers suffer from the beam background. Added 10cm Pb shield in summer 2000. Reduced Endcap HV and threshold after spring 2001 (8000→7850V, 70→40mV).

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

Long Term Variation of Efficiency

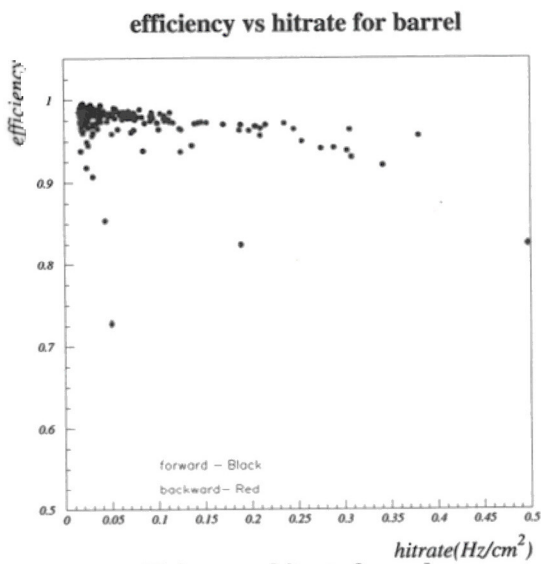


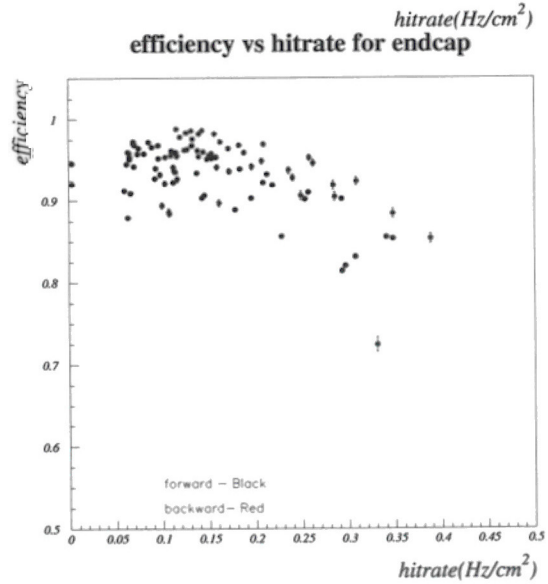


No change for the barrel. Endcap outer layers suffer from the beam background.

Superlayer Efficiency vs Hit Rate

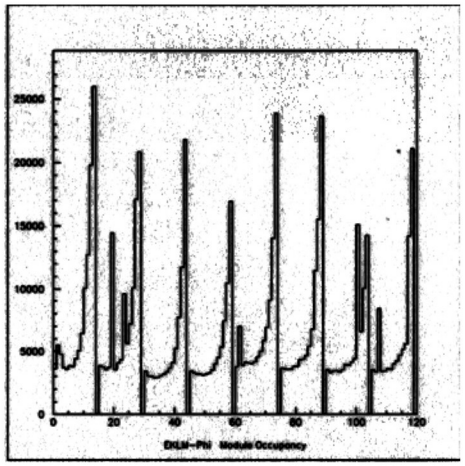
(2001 fall runs(1200mA/800mA))



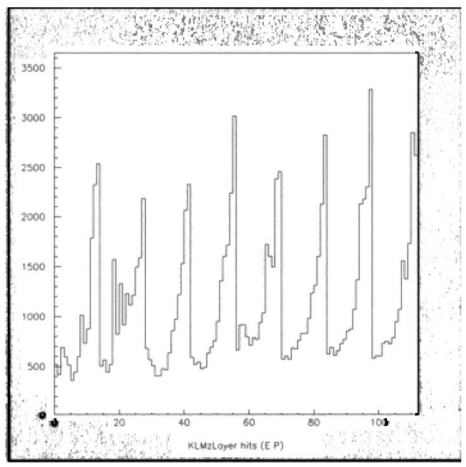


- Hit rate at 1200mA/800mA
  - **Barrel:** $\sim 0.02 Hz/cm^2$ (~same as no beam case)
  - **Endcap:** $\sim 0.1 Hz/cm^2$
- **Extrapolation to ×10 beam current (assuming linear)**
  - Barrel: at most $\sim 0.2 Hz/cm^2$ **at most a few** % efficiency drop, no problem
  - Endcap: $\sim 1 Hz/cm^2$ significant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

Occupancy vs Superlayer Number in Endcap



1999 fall (560mA/320mA)



2001 fall (1200mA/800mA)

- Outer layers suffer from beam background.

  This pattern 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.

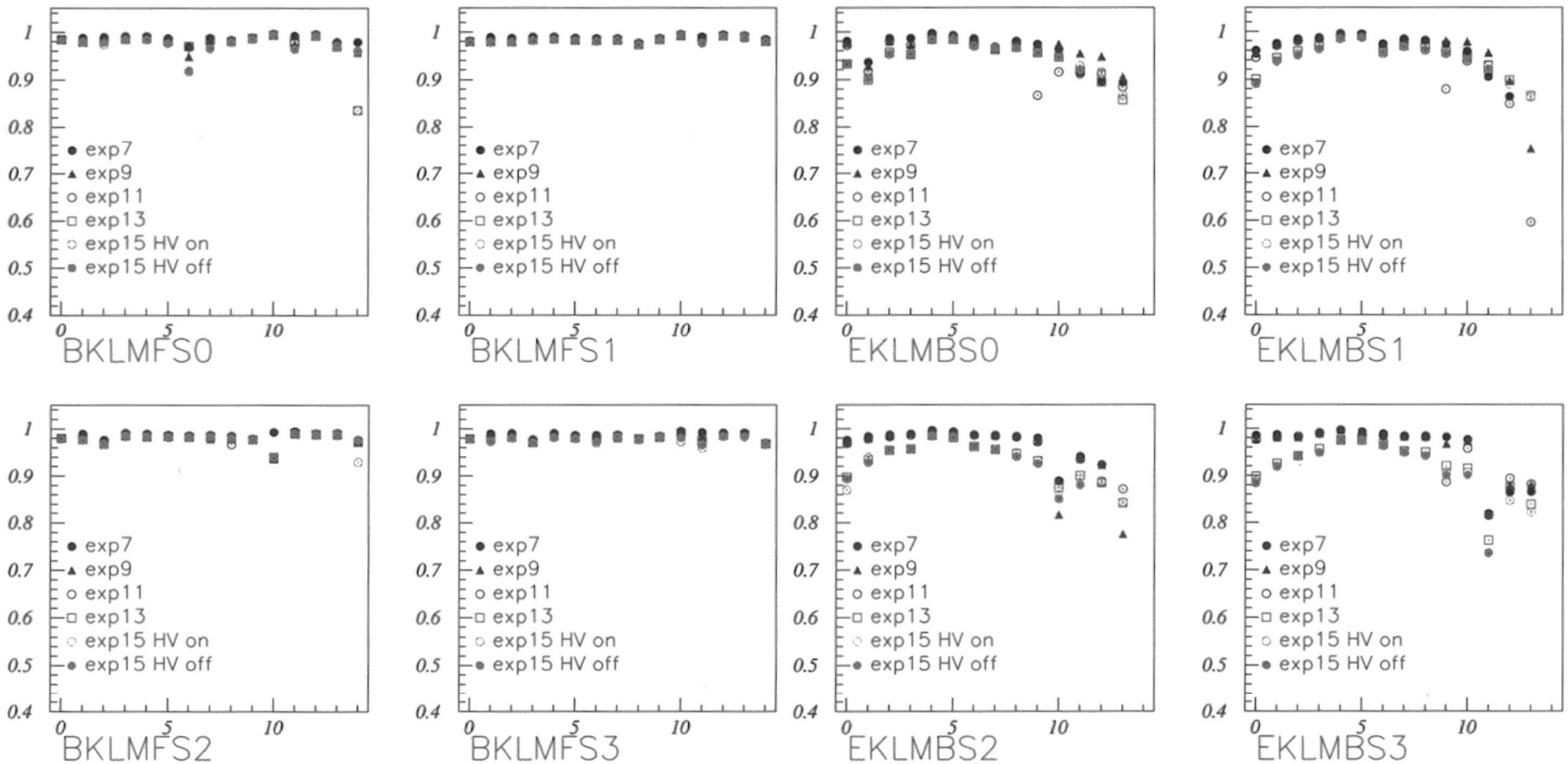
- If a few MeV photons were dominating, the 10cm thick lead should have reduced the effect to negligible level.

- 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.

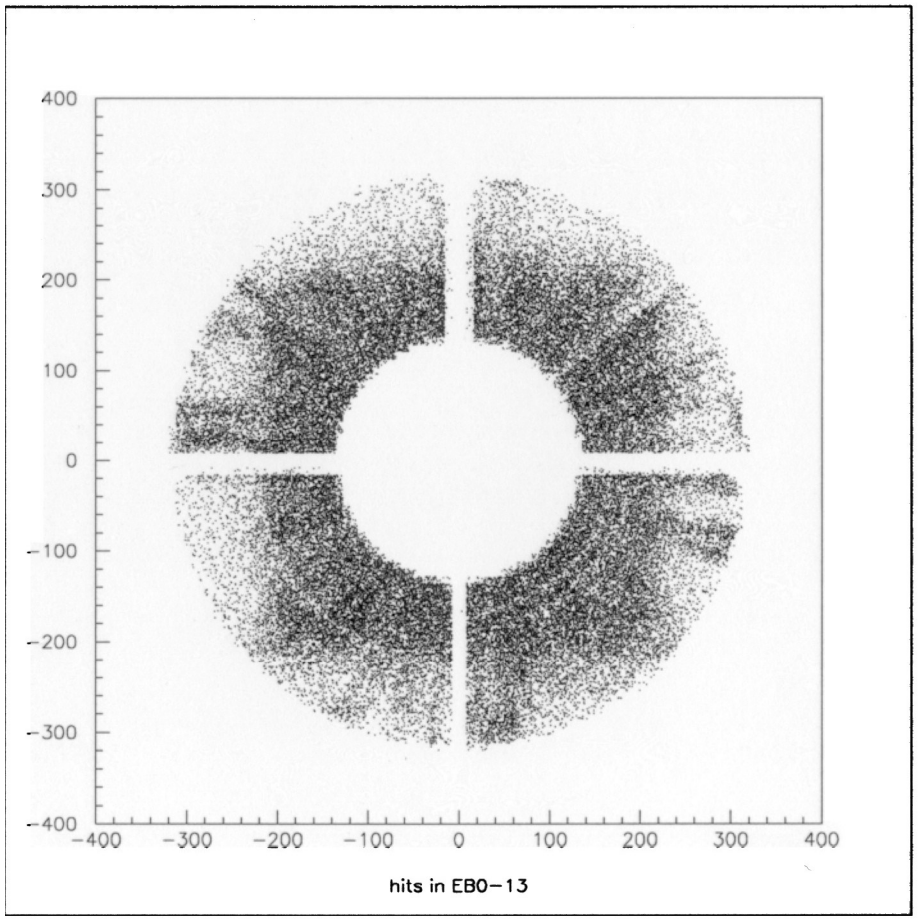
Efficiency vs Superlayer Number

Barrel Modules (4 out of 16 shown)
Layer Efficiency

Endcap Modules (4 out of 8 shown)
Layer Efficiency



Beam Background in Endcap

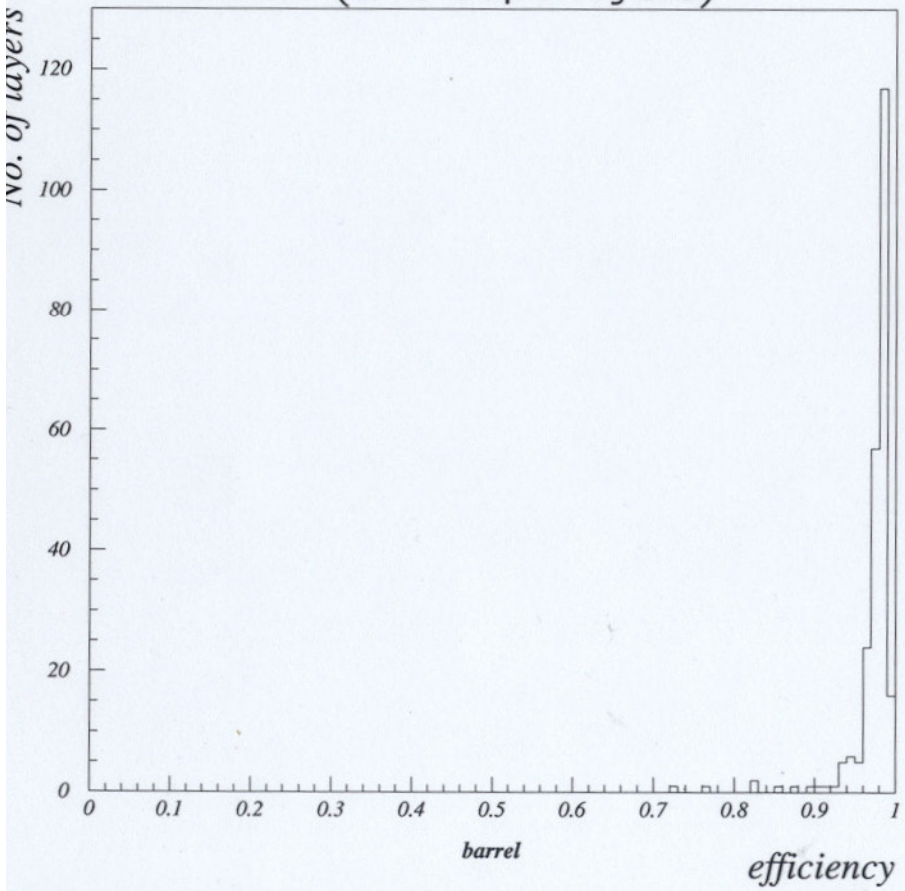


- Two dimensional hit distribution of outer-most layer in the Backward Endcap during fall 2001 runs.
- Square-shaped area which is directly exposed to the machine tunnel is clearly visible.

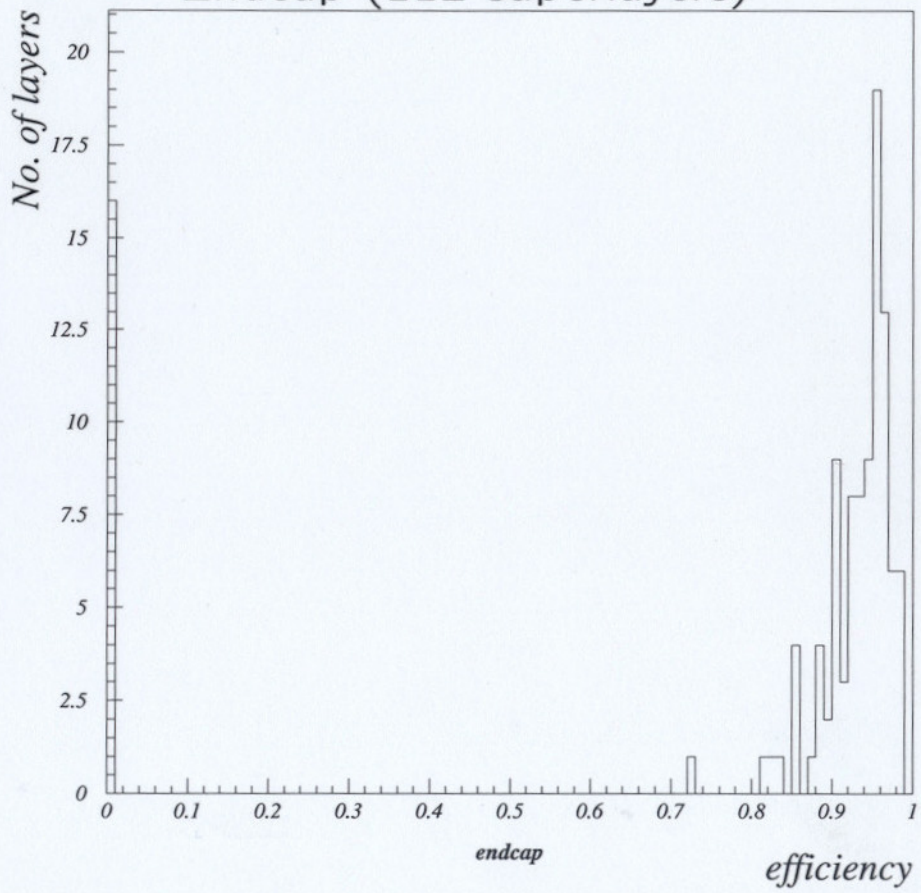
Superlayer Efficiencies

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

Barrel (240 superlayers)

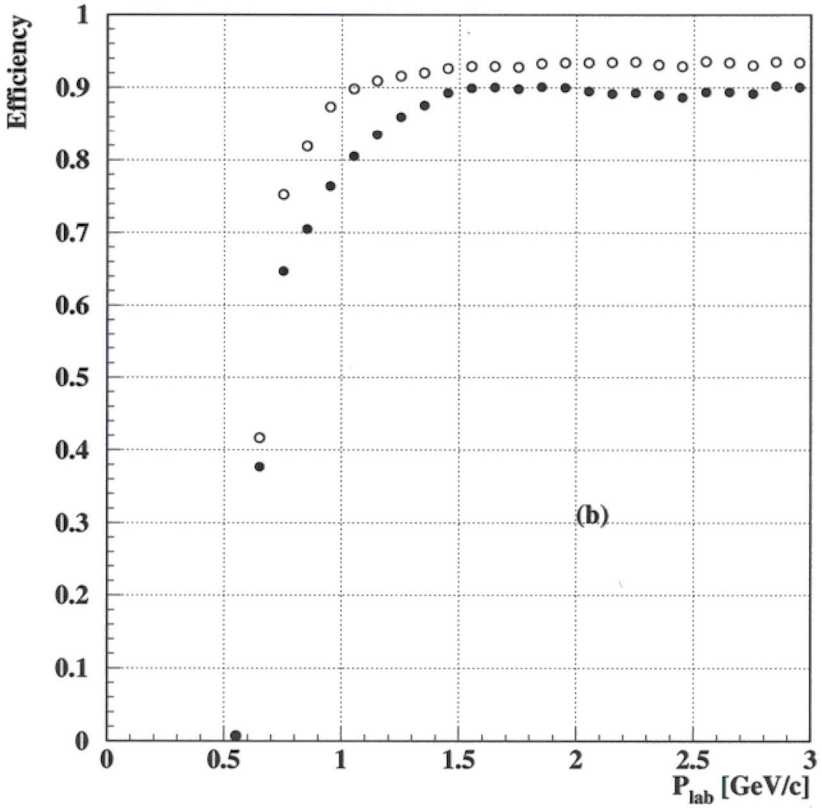


Endcap (112 superlayers)



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.

Cost of BELLE RPCs built at Virginia Tech

- *Material cost* - $420k or ~$140/m^2
  includes everything – tools,dollies,tables,kimwipes,alcohol,…
- *Labor* - $126k or ~$40/m^2
  technicians and students
- *Shipping to Japan* - $96k or ~$30/m^2

Does not include high voltage or electronics or the gas system.

Things to Consider

- Gas system – no plastic tubing (clean and dry with pressure control)
- Recirculation vs. cost of gas with one volume change per day?
- Assembly location – on site if possible. Avoids storage,shipping, and duplicate test facilities.

  (shipping cost can be significant)
- Readout system - large continuous area gives opportunity for long transmission line pickup strips and therefore fewer channels/m^2

References

- "The Klong/muon detector for Belle…"NIM A449 (2000) 112-124
- http://belle.kek.jp/
- http://www.awa.tohoku.ac.jp/html/BELLE/HTML/
- http://www.hep.princeton.edu/~marlow/ - Dan Marlow
- http://www.phys.vt.edu/~nmorgan/ -Norman Morgan
- E-mail: nmorgan@vt.edu
- E-mail: chagner@eta.phys.vt.edu - Caren Hagner