The BaBar Instrumented Flux Return (IFR) system is used to identify muons and $K_{\text{long}}$’s. Original system based on RPCs. The IFR systems has not lived up to our expectations: Muon Id suffers from lack of absorber material. The IFR RPCs had been losing efficiency at an alarming rate.

After extensive reviews the collaboration decided to built a new IFR detector for the barrel region based on Limited Streamer Tubes (LST) + 6 layers of brass (for a total of 5.3 $\lambda_{\text{int}}$).
The BaBar LST Team
An Italian-US collaboration

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IFR Barrel Performance: Pion fake rate vs $\varepsilon(\mu)$

Simple muon selector -- uses only $\lambda_{int}$ info.
(neural net algorithms improve rejection by factor $\sim 2$)

$p_\mu > 2$ Gev/C
LST Project Overview

- **Barrel RPC’s to be replaced with LSTs**
  - An LST is an 8-cell PVC tube ~ 2 cm x 14 cm x 358 cm, running at 5600 V
  - 2-D readout: wires for \( \phi \), cathode strips for \( z \).
  - LSTs assembled at Pol.Hi.Tech, a company in Italy.

- **A Layer within a sextant consists of 6 to 10 LST Modules**
  - 12 layers of modules
  - Each module consists of 2 or 3 8-cell or 2 7-cell tubes glued together.
  - At Princeton and OSU, the tubes are glued onto a SLAC-produced “phi-plane” to form modules, with gas, HV, and electronics connections ready for installation into BaBar

- **Other key LST systems include:**
  - Z-planes
  - High voltage power supplies
  - Gas
  - Readout Electronics
  - Online and Offline Software
3 different type of modules arranged to minimize the dead space:

- 2 8-cell standard length
- 2-8-cell short length tubes for layer 10
- 3-8 cell standard length

1164 tubes ⇒ 564 modules
What is an LST?
(“Iarroci Tube”)

Relatively robust and inexpensive wire chamber.
made from extruded PVC, inner walls coated with graphite
can cover a large area
radiation resistant
good history of reliability in HEP experiments (ZEUS, SLD….)
commercially available in Italy

Streamers produce “large” signals (~300 pc)
can use inexpensive readout electronics.
very efficient

Measure the phi and Z coordinate.
phi coordinate measured by reading out wire signals
z coordinate measured using signals induced on cathodes

Uses relatively inexpensive and non-explosive gas.
89% Co2:8% isobutene:3% argon
typical voltage operating 5600 V

Our LSTs contain 8 wires/tube, 2 wires ganged together
tubes dimensions: ~ 20 x 154 x 3580 mm
BaBar LSTs

8 cells per tube

full size tube

full scale grad student

Extruded PVC sleeve and profile

Endcap (HV, Gas Inlet)

Wire

Graphite coating

Wire holder

φ ground plane
QC and Module Assembly

We do not want to repeat the experience of the RPCs! 😞

Big effort to insure LSTs work BEFORE installation into BaBar

QUALITY CONTROL

At the factory in Italy for each LST we measure its:

- cell capacitance
- resistance to ground
- singles rate as a function of voltage
- current draw along a wire using a radioactive source
- current draw on cosmic rays over a period of time

LSTs that pass our standards are shipped to the US

Half the LSTs go to OSU, half to Princeton

We then repeat these QC tests at OSU and Princeton!

Tubes that pass the QC tests are made into modules.

Modules that pass the current draw test are shipped to SLAC

Modules are retested at SLAC before installation into BaBar.
Source Scan Table

Poorly made LSTs will draw a lot of current (~μA’s) when exposed to a source.

- Source movement controlled by computer
- Scan uses 7μC Cs\(^{137}\) sources
- I-beam moves \(\perp\) to green unistrut beams
- Sources move along 4m I-beam 10 cm/sec readout 0.1 sec
- Movement controlled by 3 stepper motors
Source Scan Test Results

We read out the current in a wire even when the source is not over the wire. Source induced current 400-500nA

GOOD WIRE
All current measurements below 1 μA.

BAD WIRE
Self Sustaining Discharge

We do not use a tube if it fails the scan test twice.
~1/15 fail source test first time
~1/50 fail source test twice
All info goes into data base
Singles Rate Plateau Curves

A good tube should have a singles rate plateau >300V in all 4 of its cells. Measure the number of pulses/sec with amplitude >30mV in 3µs window.
Module Assembly at Ohio State & Princeton

Two tubes+phi plane glued together to form a module

We will finish module production in ~ 1 month
Module assembly

LSTs have been assembled in modules to improve the mechanical rigidity of the structure and to make easier the cabling.

Three type of modules have been designed to minimize the dead space inside the gap:

- 2x8 cells
- 2x7 cells
- 3x8 cells

A ground plane is glued on top of the module. Mechanical supports have been installed to hold cables and connectors and for the grounding.
Long Term Module Testing
at Princeton and OSU

After modules are assembled they are put back on gas and HV for 4 weeks. The current per tube is monitored. Very low failure rate: ~1%. Modules are shipped to SLAC.
LSTs at SLAC

So far two shipments of modules sent to SLAC. Enough modules for 1st two sextants.

QC on modules performed at CEH.
Installation into BaBar

August 15-October 10: Two sextants of modules installed in BaBar
Recent LST Results

Lots of ongoing work in IR2

- **Data taking with cosmic rays**
- **Mapping and mis-mapping**
- **Occupancy plots**
  - noisy channels
  - dead channels
- **Detector optimization**
  - single rates
  - threshold scan
  - efficiency plots
- **Reconstruction software**
  making progress
Studies with Cosmic Rays

- In addition to the conventional BaBar cosmic triggers, we use a standalone data taking mode triggering on each singular hit in the wires of the LSTs.
- This way we trigger on the noise too.
- The standalone mode has been used to measure the performances and to optimize the detector:
  - alignment of modules & z-planes
  - single rates
  - threshold scan
  - search for dead/hot channels
  - cabling errors

![Graph showing residuals from layer 2 φ-plane]
Single rate measurements

All cells in all tubes have good plateaus
Efficiency measurement

Average layer efficiency is
~92.5%
No efficiency variations as function of the threshold
LST Summary

• Two sextants installed this summer
  ♦ installation completed ahead of schedule.

• Cosmic runs have been and are very useful for detector optimization and performances monitoring.
  ♦ Looking forward to colliding beams!

• The installed detectors perform according to expectations.
  ♦ 288 tubes installed ⇔ 1152 R/O channels, all working properly !!!
  ♦ 1612 z-strips installed and tested, only 5 bad channels !!!
  ♦ Average layer efficiency is 92.5%.
  ♦ Noise from electronics is negligible.

• Reconstruction software in good shape
  ♦ 1D cluster reconstruction using new geometry is ready.
  ♦ 3D software in progress

• Will complete production of all components soon.
  ♦ modules, HV power supplies, FECs, cables,…..

• Will be ready for installation of next 4 sextants whenever the shutdown occurs.
Back up slides
Automated Singles Rate Plateau Curve Measurement

The operator just pushes a button, the computer does the rest…..
Hitmaps at the FEC level

view 0 (φ wires)

view 1 (z strips)
...mis-mapping

When one strip is hit in a layer, plot location of hit strips in adjacent layers

correctly mapped layer

wrongly mapped layer
Threshold scan

For wire signals

Counts vs. Threshold (mV)

Channel 1
Channel 2
Channel 3
Channel 4
This noisy channel is due to an hot spot in one of the tube. The channel is recovering (blue plot) being under HV.

The 2 hot channels were due to noisy FECs which have been replaced. The hole is a dead z channel (the strips got disconnected).
Mapping and…

wire n. vs FEC channel – layer 5  
sxt 1  

strip n. vs FEC channel – layer 8  
sxt 1
1D Cluster Reconstruction

Average multiplicity ~1.13

wire multiplicity

Average multiplicity ~1.82

strip multiplicity
1D Cluster Map (LST Geometry)

Reconstructed 1D cluster positions using new geometry packages in release 15.7.0