The BABAR Level 3 Trigger

First Joint Belle-BaBar Workshop on Detector Issues

TRIUMF, Vancouver

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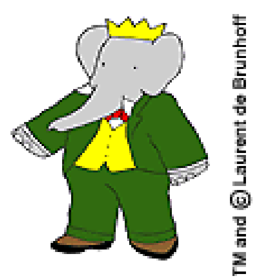
The University of Iowa

Outline

- DAQ System & Level 3 Design
- Tools & Filters
- Monitoring & Diagnostics
- Performance & Upgrade
- Summary & Outlook



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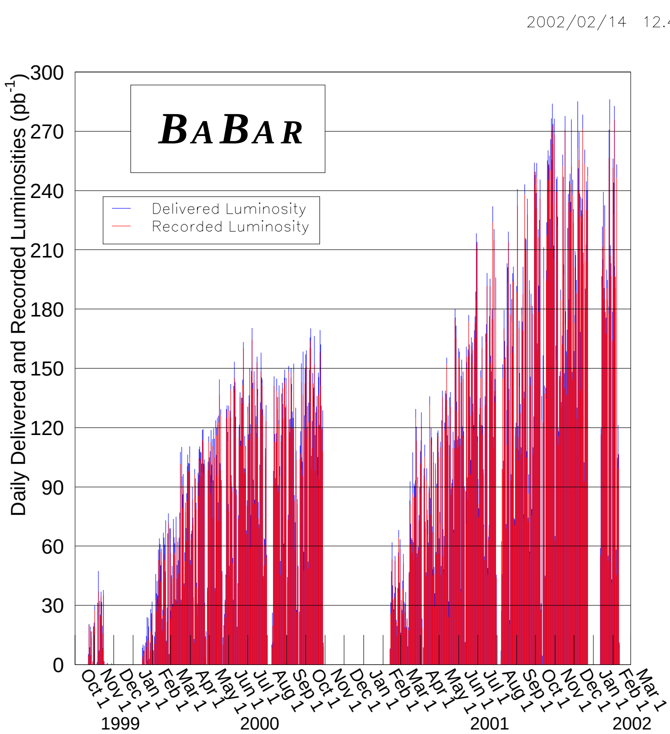
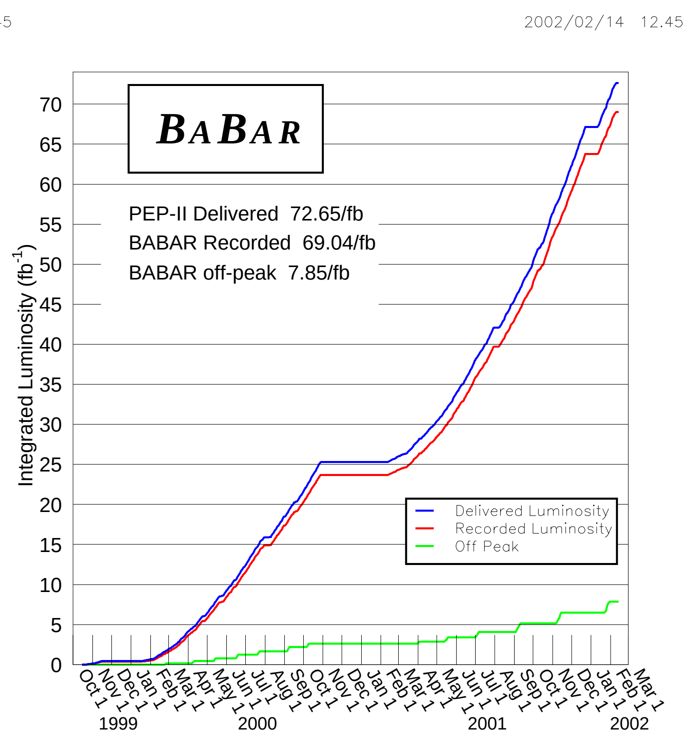
Integrated Luminosity

We have seen our first collision event on May 26, 1999 (4:20am).

Daily Recorded Luminosity

Accumulated Data Set





(luminosity measured by Level 3)

- About 69 fb^{-1} of data recorded as of today
  10-12 % off-resonance
- 95-98 % average data taking efficiency
- Less than 0.5 % deadtime

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B-Factory Event Rates

Physics Cross Sections on the Υ(4S)

$b\bar{b}$	1.05 nb
$c\bar{c}$	1.30 nb
$s\bar{s}$ $u\bar{u}$ $d\bar{d}$	0.35 nb 1.39 nb 0.35 nb
$\tau^+\tau^-$	0.94 nb
$\mu^+\mu^-$	1.16 nb
e^+e^-	~50 nb

Machine Parameters and Data Acquisition Rates

- PEP-II Bunch crossing rate is 238 MHz (4.2 ns bunch spacing)
  => continuous readout, heavily pipelined, 2.7 us cmd spacing
- Beam currents of typically 920 mA (HER) on 1660 mA (LER)
- Current peak luminosity 4.3 x 10^{33} $cm^{-2}s^{-1}$
- L1 accept rate around 1 kHz --> L3 logging rate ~130 Hz

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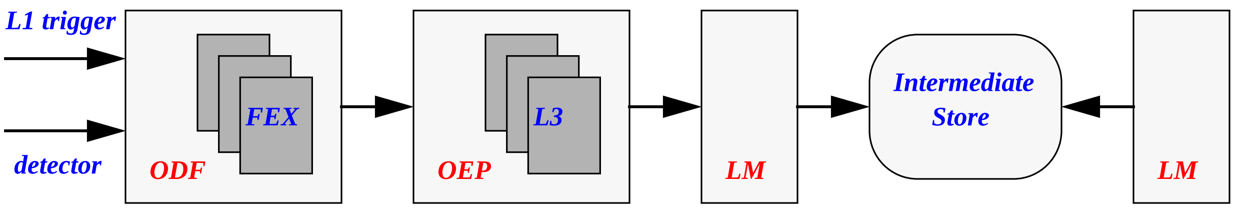
The Event Path



Dataflow (ODF)

- Transports and assembles event data from Front End Elements to the online processing farm
- Provides framework for Feature Extraction (FEX) code
- Fragments vectored to the correct node on the basis of a 56-bit timestamp (no load-balancing to avoid overhead)
- Backpressure implemented through UDP multicasts

Online Event Processing (OEP)

- Receives data from DAQ crates, runs event builder
- Provides framework for Level 3 Trigger (L3) and Fast Monitoring

Logging Manager (LM)

- Collects events from multiple nodes and *writes* files to Intermediate Store
- Ends the deadtime path
- *Reads* from IS and fans out to Prompt Reconstruction farm

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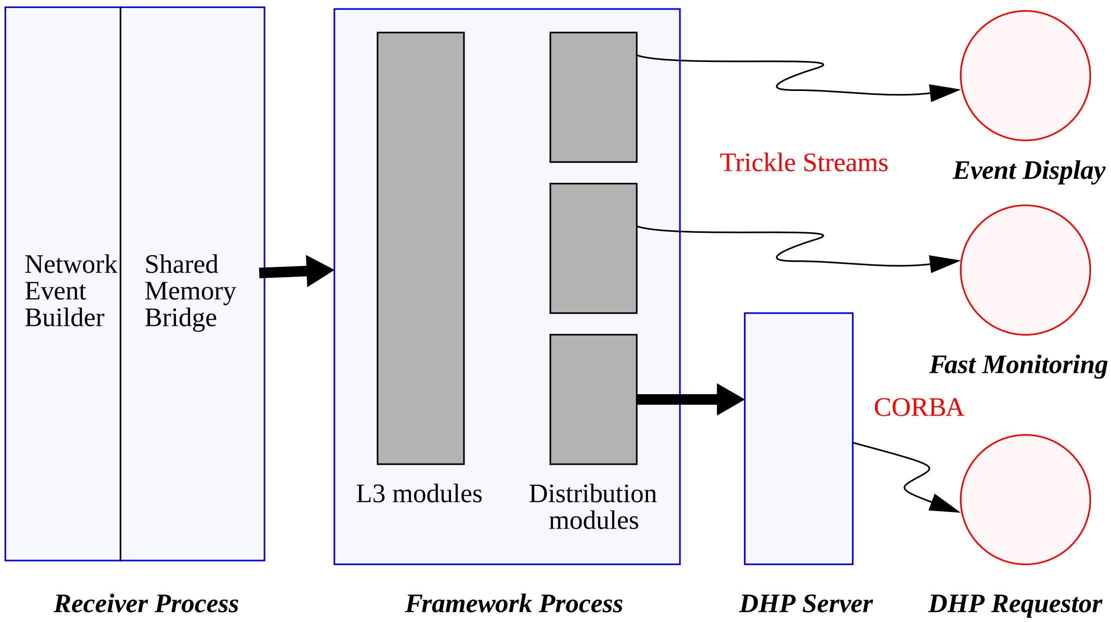
Online Event Processing



Responsibilities

- Supports the Level 3 Trigger (L3)
- Provides for Fast Monitoring and Event Displays
- Provides for Distributed Histogramming Package (DHP)

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Level 3 Trigger

Characteristics

- Makes logging decision
- First part of the DAQ system to see complete events
- Runs on the output rate of the Level 1 (hardware) trigger
- Processes data from:
    - Drift Chamber (DCH) + Drift Chamber Trigger (TSF)
    - Electromagnetic Calorimeter (EMC)
- Adds its own data to the event: reconstructed quantities, filter decisions

Design Requirements

- Reduce the L1 output rate from 2 kHz to 120 Hz
- Provide high efficiency for B physics (> 99%) and other physics processes, *e.g.*, charm, tau and two-photon physics
- Execute fast algorithms: ~10 ms per event (given 70 % CPU on 32 nodes)
- Support online calibration and monitoring

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Level 3 Trigger Design

Framework

- Level 3 runs as part of the Online Event Processing (OEP)
- Implemented using the standard BaBar application framework
- Runs in both online and offline environment (simulation)
- Trigger logic (“execution web”) is fully configurable at startup time

Tools and Filters

- Tools are sequences of framework modules that compute L3 objects, e.g., tracking and clustering
- Filters are modules that implement algorithms based on these objects, providing binary decisions
- Tools and Filters are combined to framework paths called L3 scripts

Event classification

- Level 3 classifies events in terms of track and cluster topologies
- Identification of particular physics processes is provided for monitoring and performance studies
- An exception are Bhabha events, which are identified for vetoing, luminosity measurement and calibration

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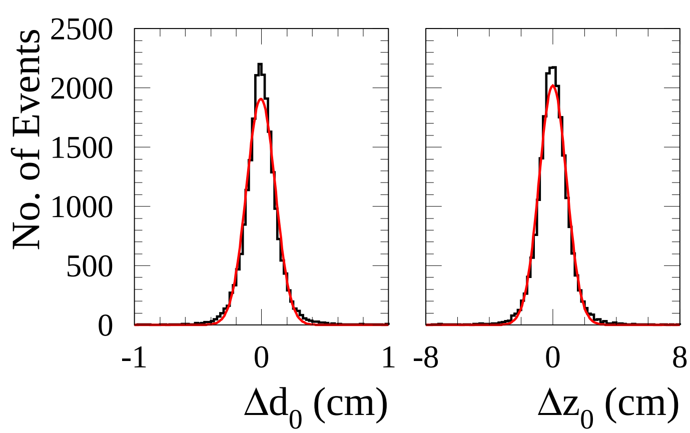
L3 DCH Tracking

Algorithm

- Performs track finding using TSF segments from the L1 drift chamber trigger as seeds (search table driven pattern recognition)
- Finds the event t_0 from drift distances (to better than 4 ns)
- Performs a fast 5 parameter (helix) track fit to associated drift chamber hits (down to $p_T \sim 250$ MeV)

Tracking Resolution

Impact parameter difference from Bhabha events



Impact parameter resolution

- $\sigma(d_0) = 0.8$ mm, $\sigma(z_0) = 6.1$ mm

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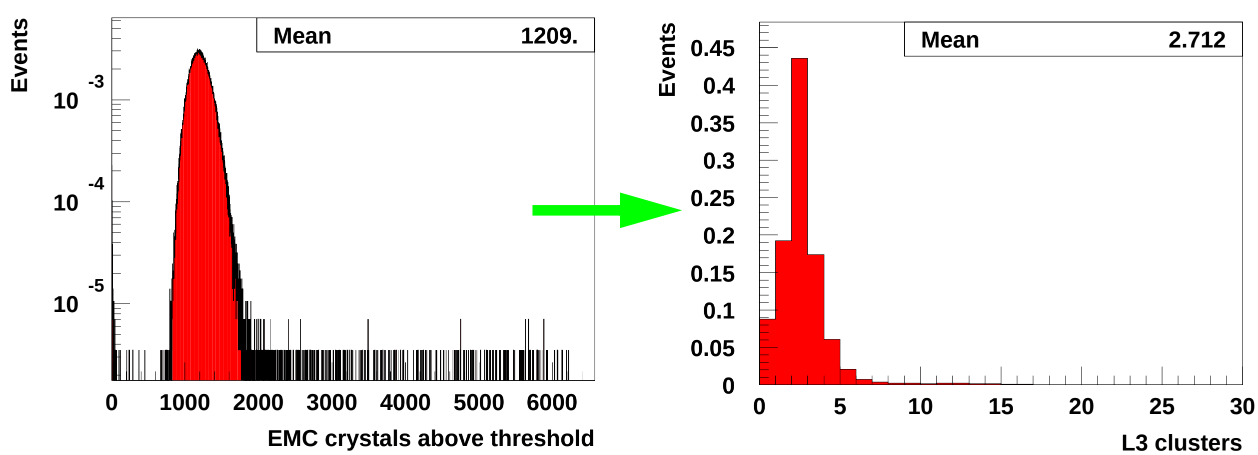
L3 EMC Clustering

Algorithm

- Reads out EMC crystal energies and peak times (above a 20 MeV noise cut)
- Applies a fast 2D clustering algorithm that performs a single iteration over the EMC data
- Neighbor information is configured via a lookup table
- Computes energy sum, centroid, average time and cluster shape variables (cluster moments)
- Clusters are reconstructed down to 100 MeV (well below MIP peak at 180 MeV)



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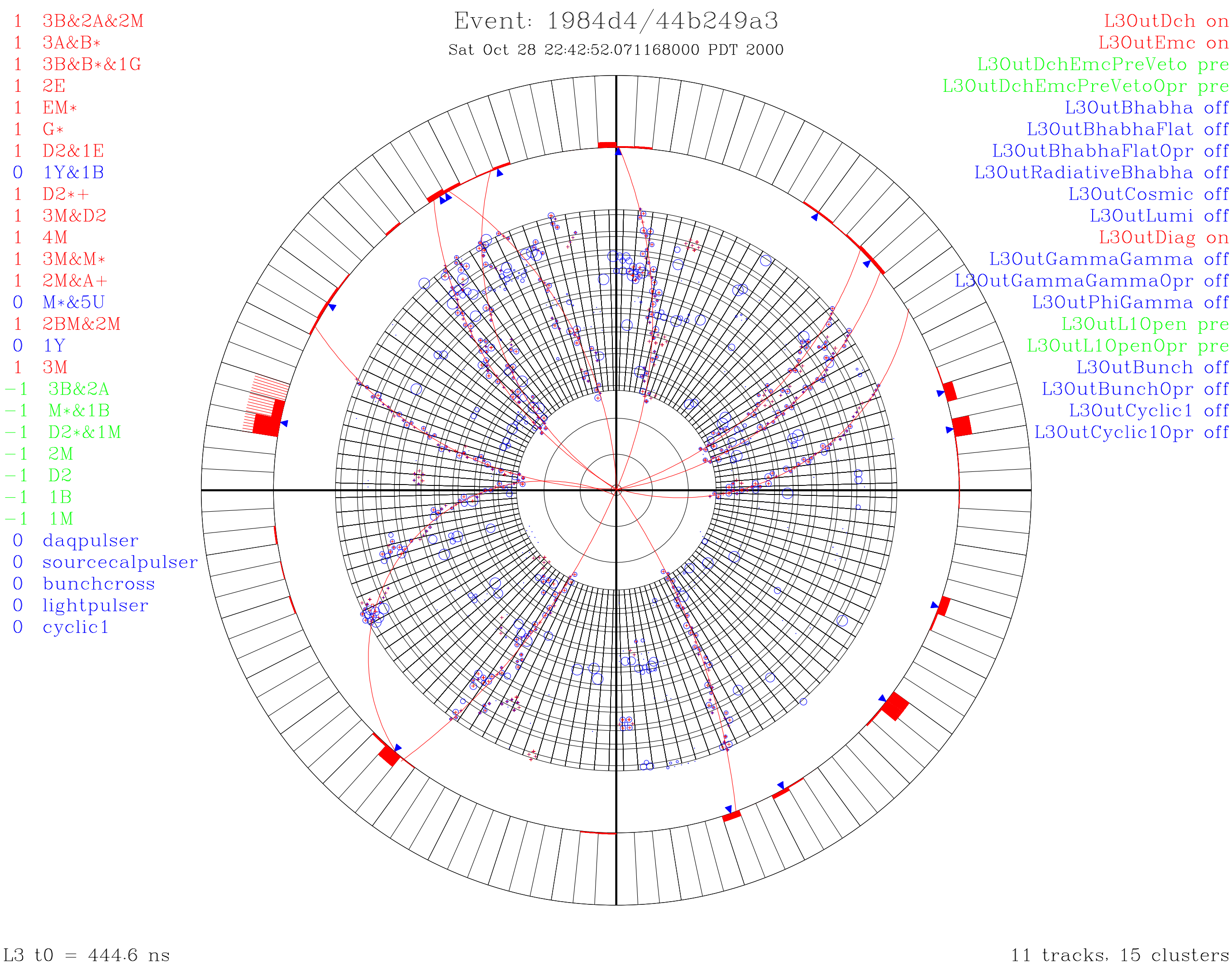
Hadronic Event



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L3 Physics Filters

Two orthogonal sets of filters

Drift Chamber Filters

IP Track Filter (requires tracks close to the interaction point)

- 2 tracks with: $|d_0| < 1.5$ cm, $|z_0| < 10$ cm, $p_T > 250$ MeV
- or 1 track with: $|d_0| < 1.0$ cm, $|z_0| < 7$ cm, $p_T > 600$ MeV

Calorimeter Filters

High Energy Filter and High Multiplicity Filter

- 2 clusters with $E_{lab} > 100$ MeV, $E_{CM} > 350$ MeV, $m_{pseudo} > 1.5$ GeV
- 4 clusters with $E_{lab} > 100$ MeV, $m_{pseudo} > 1.5$ GeV

Bhabha Veto

- Rejects Bhabha events from the above
- 2-prong and 1-prong (degraded Bhabha)
- Extremely pure selection
- Uses tight track-cluster matching, E/p
- Accounts for ISR by exploiting correlation between missing energy and acolinearity

These filters form the physics output line of Level 3

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L3 Calibration and Diagnostics Filters

In addition, there is a variety of filters for calibration samples, offline luminosity measurement etc

Bhabha Accept

- High efficiency, for offline luminosity and calibration

Radiative Bhabha and Virtual Compton Scattering

- Missing p and neutral cluster, for calibration and PID

Online Luminosity

- Lepton-flavor blind selection, track-based, stable, well known efficiency / effective cross section

Hadronic Filters

- 3-prong selection, mass and event shape cuts, two flavors: all hadronic and *B*-enriched

Cosmics

- 2 tracks back-to-back in the lab frame

Random / Prescaled Triggers

- Prescaled unbiased *L1 Accept*
- 1 Hz cyclic and bunch crossing signal

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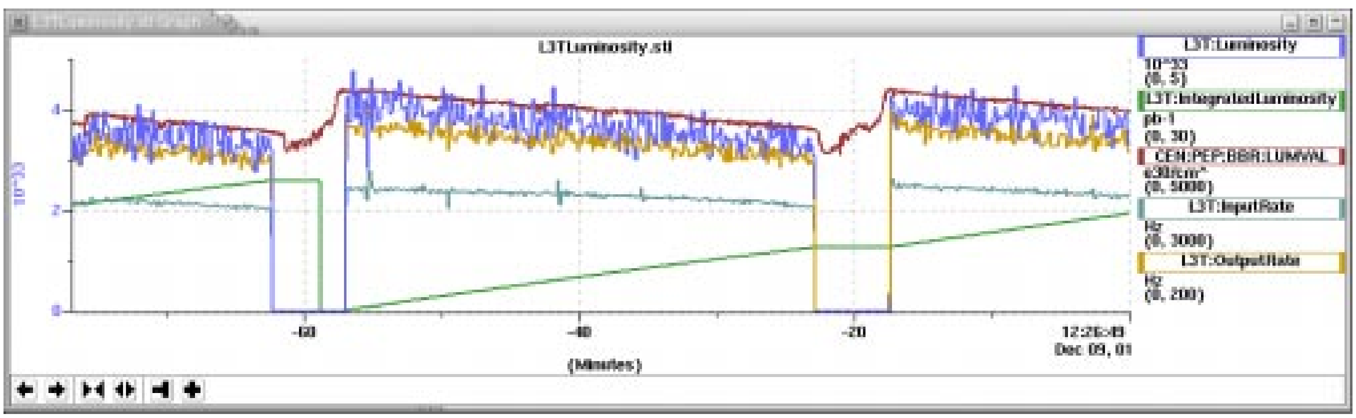
Monitoring Applications

Luminosity and Trigger Rate Strip Chart

- From live L3 data, update rate on the order of 5 s
- Uses bridge from DHP to the EPICS slow control system
- Can be correlated with virtually any Process Variable



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PEP-II Energy Scan

L3 Hadron Ratios

Hadronic selection:

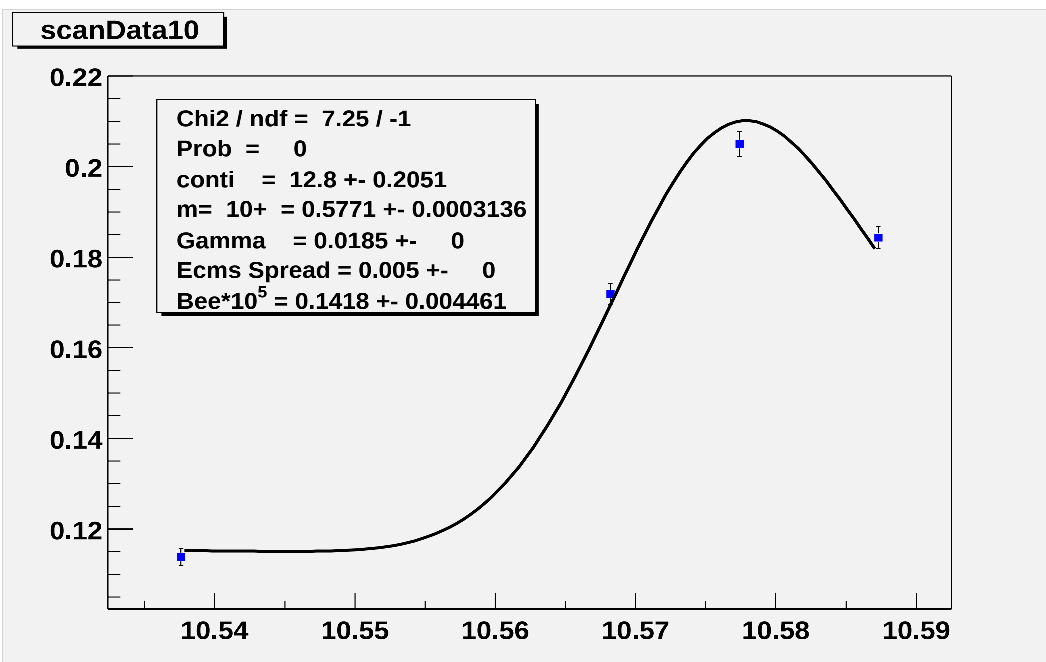
3+ good tracks, $p_T^{max} > 0.5$ GeV, $p^{max} < 4.5$ GeV, $m_{inv}^2 > 5$ GeV^2

R2 < 0.9 (HadA), R2 < 0.4 (HadB) Fox-Wolfram Moment

Luminosity selection:

2 good tracks, $|\cos\theta| < 0.9$, $x_p > 0.8$, $\pi - \theta_1 - \theta_2 > 0.5$

Y(4S) Line Shape Fit



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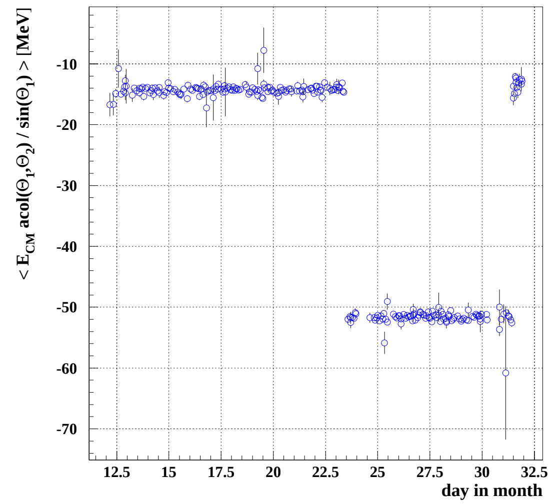
Run-to-Run Monitoring

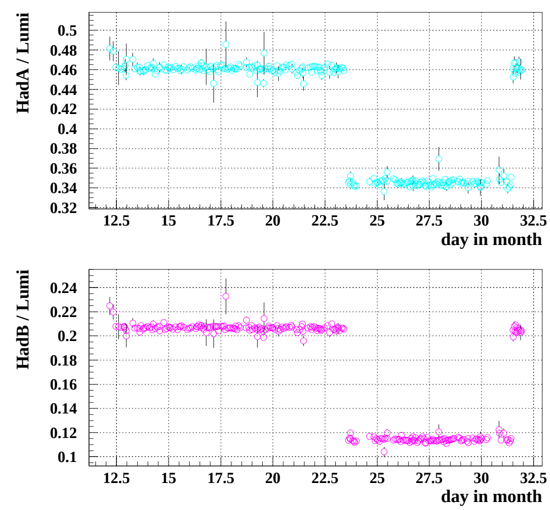
Lorentz Boost Measurement

- Use 2-prong event selection
- Boost back into nominal CM system
- Calculate real boost from net acolinearity
- Very sensitive to single beam energy changes
- Independent monitor for B event yield

L3 Boost Monitor - January 2002



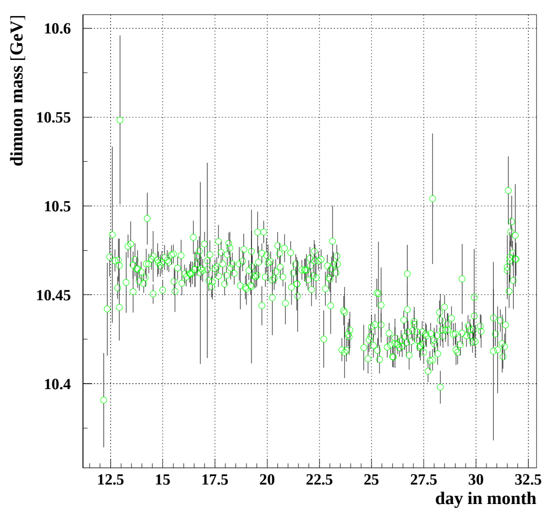
L3 Hadron Ratios - January 2002



Center-of-Mass Energy

- From dimuon filter

L3 CM Energy Monitor - January 2002



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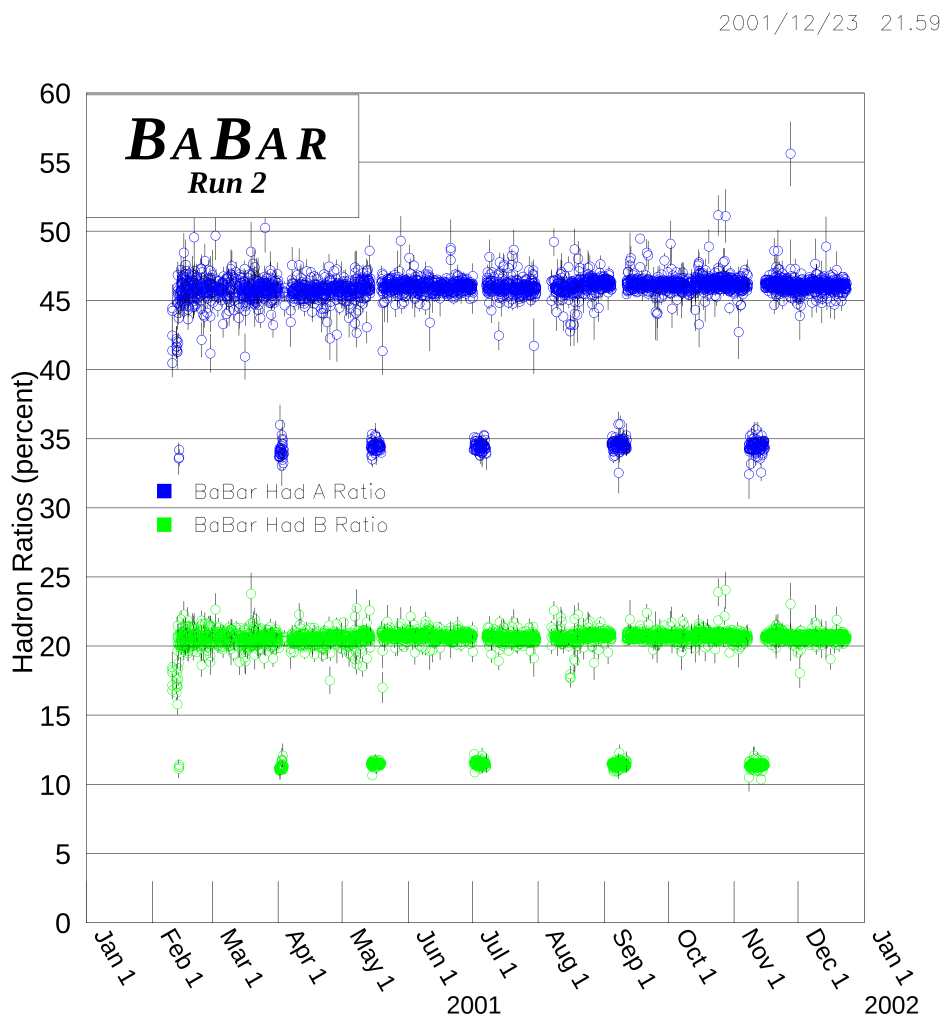
L3 Hadron/Luminosity Ratios

Hadron Ratios are monitored as part of the daily operations



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Event Prescaling

Simple Prescalers

Counter-based, run separately on each L3 node, preserve input count

Example: unbiased L1 Accepts

- Save every *n-th* L1 trigger for efficiency studies (-> 0.5%)

Binned Prescalers

Array of prescale factors, depend on the value of an observable

Example: theta-flattened Bhabhas

- Offline luminosity measurement can undo prescaling w/o loss of statistical precision (30nb -> 10nb)

Weighted Prescalers

Select events on one trigger line based on the rate of another line

Example: background mixing

- Seed on luminosity trigger, ‘scan forward’ to find the next random trigger event (1:40 of B-events)
- Used to provide continuous, luminosity-weighted background sample, overlayed on top of simulated events at the pulse/waveform level

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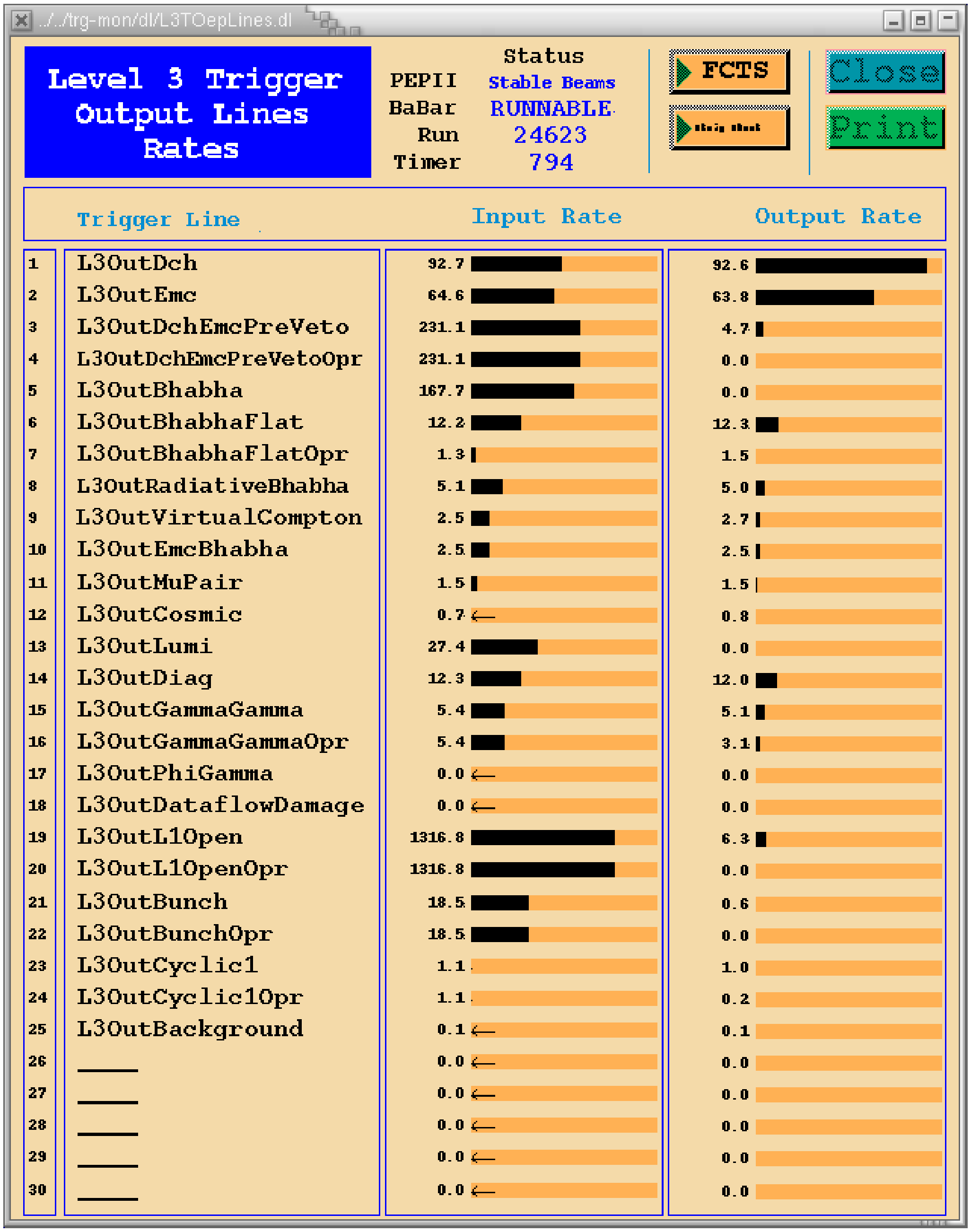
Rate Monitoring



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L3 Trigger Efficiencies

From simulation of benchmark processes:

	$B\overline{B}$	$B\text{->}\pi^0\pi^0$	$B\text{->}\tau\nu$	$\tau\tau$
1 track filter	89.9	69.9	86.5	94.1
2 track filter	98.9	84.1	94.5	87.6
Comb. DCH	99.4	89.1	96.6	95.5
2 cluster filter	25.8	91.2	14.2	34.3
4 cluster filter	93.5	95.2	62.3	37.8
Comb. EMC	93.5	95.7	62.3	46.3
Comb. L3	>99.9	99.3	98.1	97.3
Comb. L1 + L3	>99.9	99.1	97.8	92.0

- The concept of the orthogonal DCH/EMC triggers enables us to maintain a high, well measurable, generic $B\overline{B}$ efficiency

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Level 3 Performance

Current Hardware

- 333 MHz *Sun Ultra-5*, 512 MB memory, 2 MB L2 cache, running *Solaris 5.8*
- 78 installed, currently 60 nodes used for Level 3

Performance Figures

- L3 process saturates at about 72 % CPU (rest spent in Event Builder and *Solaris* kernel)
- L3 takes ~10 ms per event, 70 Hz per node, ~4200 Hz limit

Design Upgrade Options

- Original pool was 32 nodes (with 2 kHz limit)
- Can add capacity in two ways, install more nodes, or replace with faster CPUs
- Explored node axis first
- Need to address scaling issues (serialization points, e.g. configuration database)
- Helped to pass the 3 x 10^{33} design limit, but cost in operations overhead

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L3 Rate Extrapolation

Without any improvements:

	L3 Output Rate (Hz)		
	Now	1 x 10^{34}	3 x 10^{34}
Hadronic + μ + τ	24	60	180
Calibration	40	45	50
Sum wanted events	64	105	230
Bhabha "leakage"	21	53	160
QED/two-photon	30	75	225
Beam-wall	13	27	33
Total	128	260	648 ←

New Challenges

- Beam-wall background will become much less important
- "Leakage" of Bhabha veto will become a major contamination
- Open trigger will be flooded by a variety of higher order QED and (low-mass) two-photon events
- With at least two thirds of these events coming form the IP, geometry will help less, one needs to exploit the kinematics

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Level 3 Upgrade

Luminosity Increase

- Will need to sustain higher L1 Accept rates
- Will need to tighten the L3 output rate (*i.e.* what goes to Prompt Reconstruction)

New Level 3 Filter Strategies

A Tighter "Open" Trigger

- Phase out the 1-prong track trigger
- Form an open DCH trigger using a low-p_t 2-track filter
- Introduce effective mass cuts against low-mass two-photon events: eeee, ee$\mu\mu$, eef_2
- Improve Bhabha veto efficiency further (no more 1-prong veto)

Will Need More Powerful Computational Tools

- Need to improve L3 reconstruction to achieve this
- Tracking has to reach down in p_T from 250 MeV to ~150 MeV
- Clustering be extended below the 20 MeV threshold

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Summary

Looking Back

- PEP-II has achieved peak luminosities up to 4.3 x $10^{33} cm^{-2} s^{-1}$
- The Trigger and DAQ System have met the challenge of recording up to 300 pb^{-1} of data a day, with negligible deadtime (< 0.5%)
- We have so far accumulated a total of 69 fb^{-1} of data
- Both L1 and L3 have exceeded the design specs, providing > 99.9 % efficiency for $B\overline{B}$ events at less than 120 Hz logging rate
- Many applications of Level 3, that weren't part of the original design, proved useful for the experiment: online luminosity, hadron ratios, background skimming etc

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Outlook

Toward 10^{34} cm^{-2} s^{-1} and beyond

- A challenge for all detector components that have to respond to higher rates, higher occupancies, higher radiation doses etc
- High luminosity running will shift the focus of the Trigger from rejecting machine backgrounds to rejecting unwanted collision events
- The planned DCT z-trigger upgrade will help early to absorb L1 rate (and push L3 further in that direction)

  --> *see Su Dong's talk*
- L3 upgrade will add the necessary capacity for keeping up with higher input rates and for tightening the physics output rate
- Geometrical criteria will help less, one needs to exploit the kinematics of the events
- Improved L3 tracking/clustering and new filter strategies are being developed to manage the increased (collision) event rates

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