Challenges and Opportunities of the Open Physics Trigger of the BaBar Experiment

SLAC Experimental Seminar
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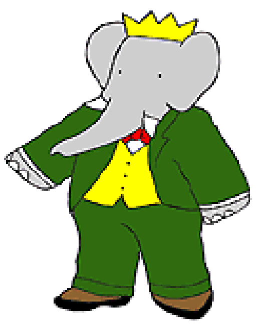
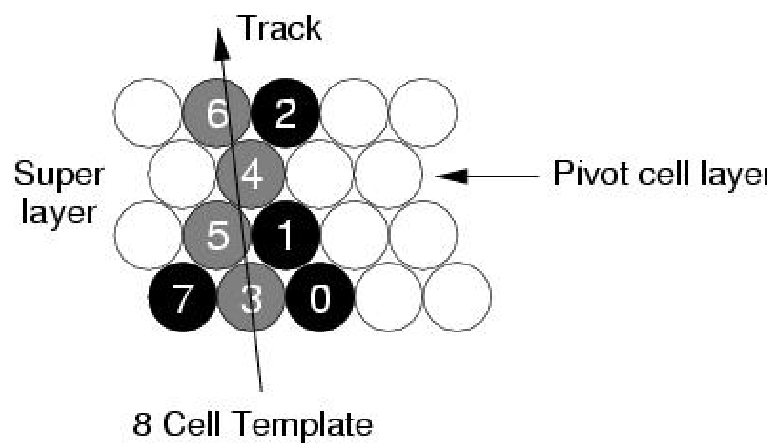


Introduction

- The Trigger is what defines an "event", it initiates the readout of the detector and decides when to log the data
- All HEP experiments use triggers in sequential levels
- BaBar implements just two:
  - A Level 1 hardware trigger that feeds on segment information from the drift chamber (DCH), electromagnetic calorimeter (EMC) and instrumented flux return (IFR)
  - A Level 3 software trigger that processes complete events, does a partial reconstruction of DCH and EMC data and applies a set of algorithms on tracks and clusters

Level 1 Trigger

- The Level 1 Trigger is made of custom−built electronics
  - Track Segment Finders identify hit patterns in 8−wire templates ("pivot groups"), a Binary Link Tracker generates short and long tracks, a PT Discriminator finds tracks whose segments are inside certain momentum envelopes
  - EMT boards sum calorimeter energies in 3 by 8 crystal towers, and towers in theta to phi strips
  - Algorithms are implemented in firmware and configurable via lookup tables



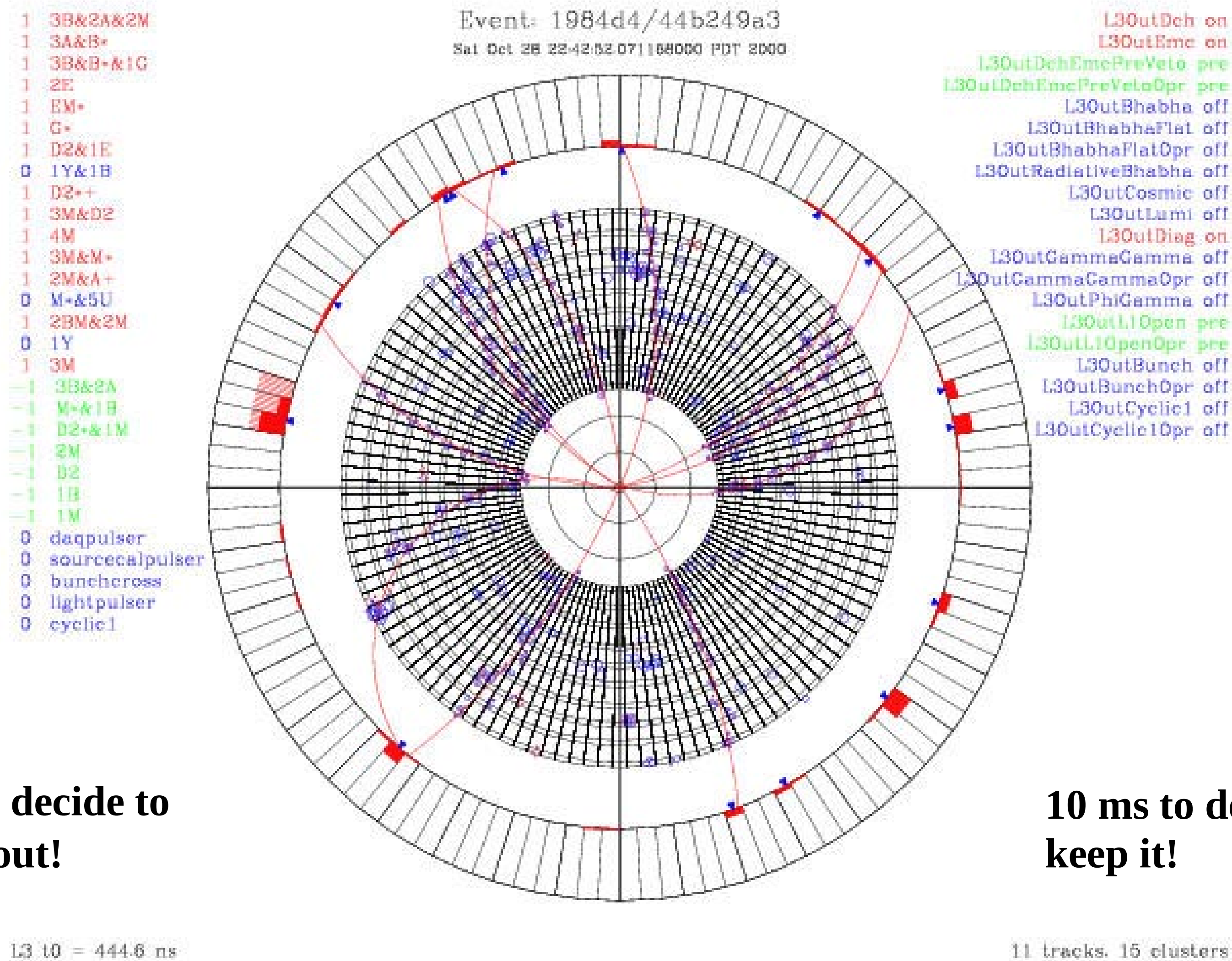
  - L1 Accept decision with a latency of 12 ì s

(Will not talk much more about this here)

Level 3 Trigger

- The Level 3 Trigger runs in parallel on a farm of Unix processors
  - Sun Ultra 5, 333 Mhz, 512 MB workstations
  - Initial farm of 32 boxes, extended to 64 last year
  - For 2 kHz of L1, CPU budget is about 10 ms per event

Hadronic Event



12 ì s to decide to read it out!

10 ms to decide to keep it!

Challenges

- Not all events have rich signatures like this one
  - Many events leave only marginal traces in the detector, yet some of them might be good Physics
- Configure a L1 Trigger that is "Open" in terms of minimal signatures, resulting in potentially high rates
- Build a Level 3 process that is able to sustain rates of 2+ kHz
  - Must develop a fast reconstruction and efficient algorithms that can reject unwanted events to a logging rate of 100+ Hz
- Make the system scalable to higher luminosities

Orthogonality

- Having independent inputs from two subdetectors, one of the fundamental concepts of the BaBar Trigger is that of "orthogonality"
  - Events meet independent criteria in drift chamber and calorimeter (*e.g., a Bhabha event passes for both its high momentum tracks and its high energy deposits*)
- Orthogonality is not trivial to realize and maintain, but has decisive benefits:
  - High redundancy in case of temporary failures (*DCH high voltage problem, EMC fiber damage*) −> Stability
  - Measurability of trigger efficiencies from data

How Open is Open?

- The Trigger decision is not composed of a set of individual Physics channels of interest (*such as a B trigger*, *a ô trigger*, *etc*)
- It is built on event topologies, which match all kinds of processes and channels
- Exception: Bhabha events are overwhelming the Physics cross section (~50 nb in the L1 fiducial, vs 1 nb of *bb*)
  - They have to be rejected in Level 3 ("Bhabha veto")

Orthogonality in Level 1 and Level 3

- In the Level 1 Trigger configuration, orthogonality is achieved to a high degree (*e.g.*, *pure two−track or two−cluster triggers*)
  - Some of the criteria had to be backed up by minimal requirements from the other system, to control the rates ("partial orthogonality")
- In Level 3 orthogonality is strict: the final Physics output is passed through two separate lines (L3OutDch, L3OutEmc)
  - The Bhabha veto uses all information, since its logic is reverse and it has to maximize purity
  - Some calibration filters that have more relaxed requirements on stable and measurable efficiencies also use both DCH and EMC for particle identification

A (subjective) Comparison with Belle

		BABAR	***BELLE***
Trigger Rates	L1	1.0 − 1.5 kHz	~ 250 Hz
(logging)	L3	100 − 130 Hz	(~ 120 Hz)
DAQ		pipelined	gated
Minimum intercommand spacing		2.7 ì s	~ 200 ì s
Irreducible deadtime at L1		0.4 %	~ 5 %
DAQ Manpower		3−5 FTE	1−2 FTE

Level 3 Tracking

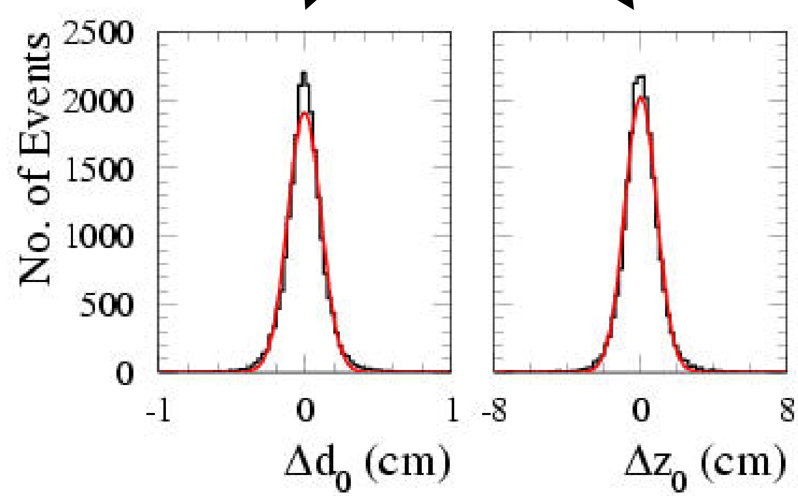
- Track finding seeded on L1 track segments
  - Driven by configurable search tree
  - Reaches down to $p_T \sim 250$ MeV
- Fast t_0 finding to better than 4 ns
- 5−parameter (helix) track fit

Miss distance measured in Bhabha events:

ó $(d_0) \sim 0.8$ mm

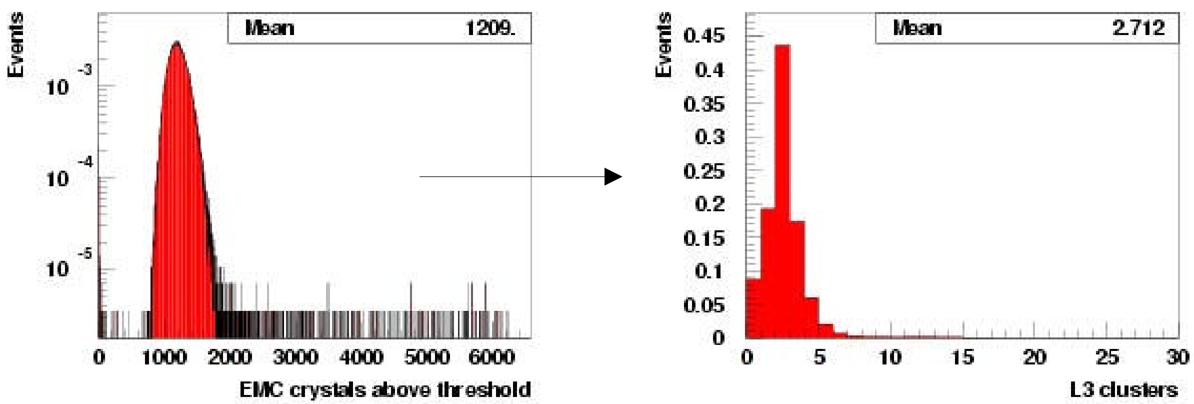
ó $(z_0) \sim 6.1$ mm

$\cdot \frac{1}{\sqrt{2}}$



Level 3 Clustering

- Processes complete EMC readout, ~1200/6580 channels per event
- Fast bootstrap algorithm, forms 2D clusters in a single pass
- Crystal neighboring information configured via lookup table
- Cluster data comprise *energy sum*, *weighted centroid*, *average time*, *cluster shape*



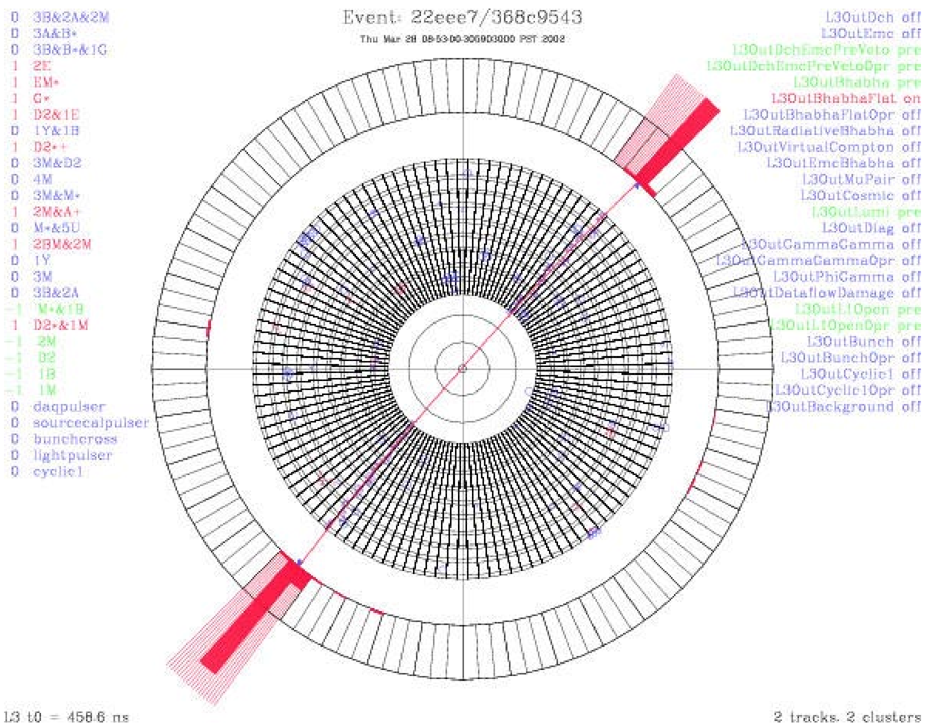
20 Mev noise and time window cut

100 MeV cluster threshold, well below MIP peak (~180 MeV)

Physics Filters

- Drift Chamber Filters (IP track filters)
  - 2 tracks from the IP with:
    $|d_0| < 1.5$ cm, $|z_0| < 10.0$ cm, $p_T > 250$ MeV
  - 1 track from the IP with:
    $|d_0| < 1.0$ cm, $|z_0| < 7.0$ cm, $p_T > 600$ MeV
- Calorimeter Filters (high energy / high multiplicity filters)
  - 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



- Removes Bhabha events from the Physics lines
- Extremely pure selection
- 2−prong and 1−prong (degraded Bhabha)
- Uses acolinearity, track−cluster matching, E/p
- Accounts for initial and final state radiation

Physics Efficiencies

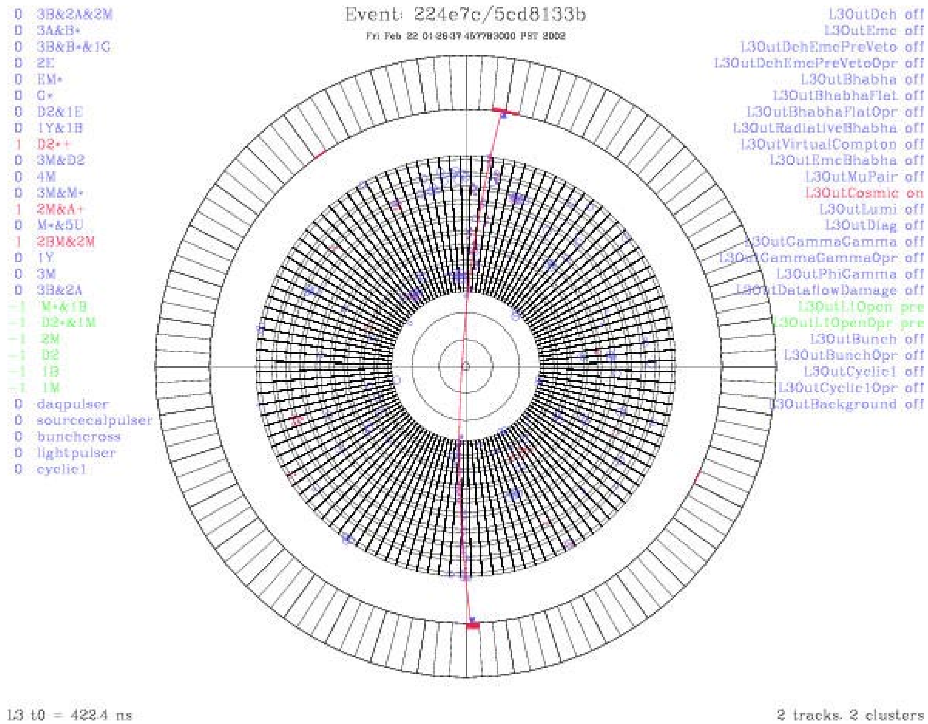
	BB	***B* → ð^{0}ð^0**	***B* → ô í $_{ô}$**	**ô ô**
1 track filter	89.9	69.9	86.5	94.1
2 track filter	98.9	84.1	94.5	87.6
Comb. Drift chamber	99.4	89.1	96.6	95.5
2 cluster filter	25.8	91.2	14.2	34.3
4 cluster filter	93.5	95.2	62.3	37.8
Comb. Calorimeter	93.5	95.7	62.3	46.3
Comb. L3	> 99.9	99.3	98.1	97.3
Comb. L1+L3	> 99.9	99.1	97.8	92

Calibration Samples

- In addition to the Physics output from DCH and EMC, our trigger provides a whole variety of "output lines" for events that can be used for offline calibrations
- Initially we added cosmics and Bhabhas (that bypass the physics veto), but soon spawned off a real industry
  - Radiative Bhabhas, ãã (final state), Virtual Compton Scattering
  - Some of these use either tracks or clusters, some only part of the signatures, to provide unbiased selections for PID etc
- This was only possible because we were able to program filter algorithms in a very efficient way

Cosmics

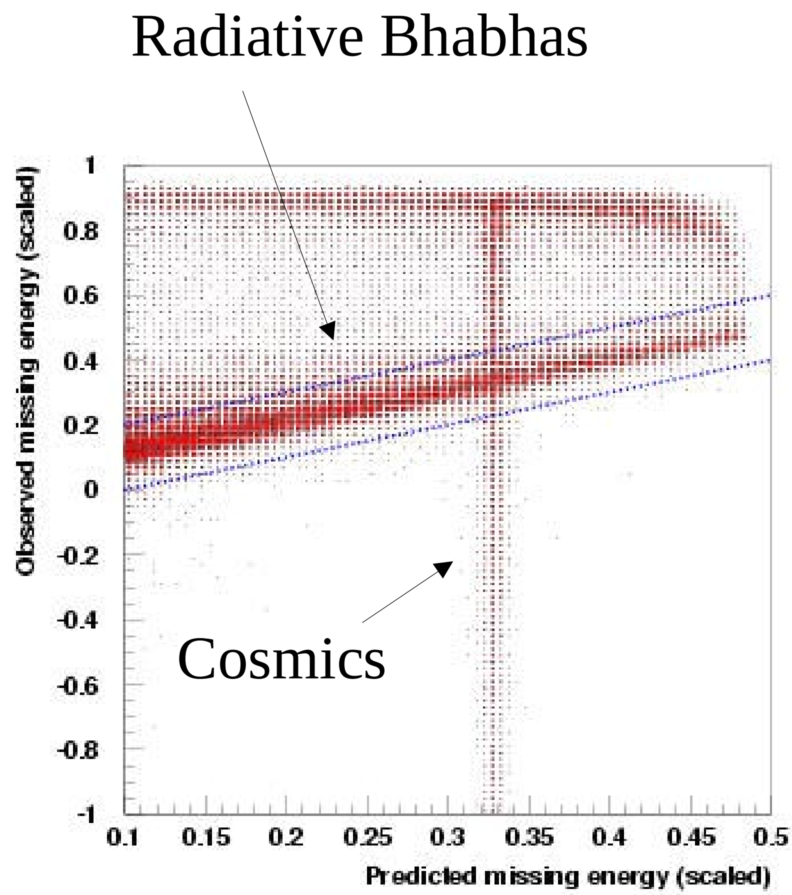
- Track−based selection (gives unbiased MIP clusters)
- 2 tracks, back−to−back in the lab, balanced in p_T
- Small miss distance
- Extended vertex cuts $|d_0| < 1.5$ cm, $|z_0| < 30$ cm (covers most of the SVT)



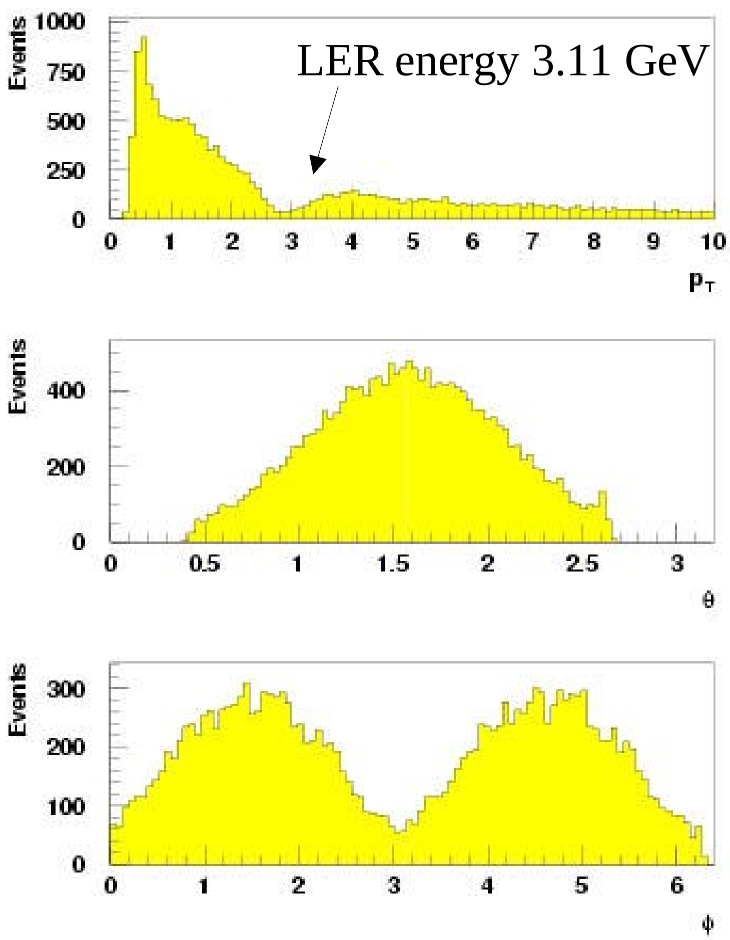
Cosmics (purified)

- Hard ISR Bhabha events can fake the back−to−back topology in the lab
- Predict missing energy from polar angles, compare to observed missing energy
- Reject if consistent with photon of momentum k

$$\frac{k}{W} = \frac{\left|\sin(\vartheta_1+\vartheta_2)\right|}{\left|\sin(\vartheta_1+\vartheta_2)\right|+\sin(\vartheta_1)+\sin(\vartheta_2)}$$



Cosmics Uses

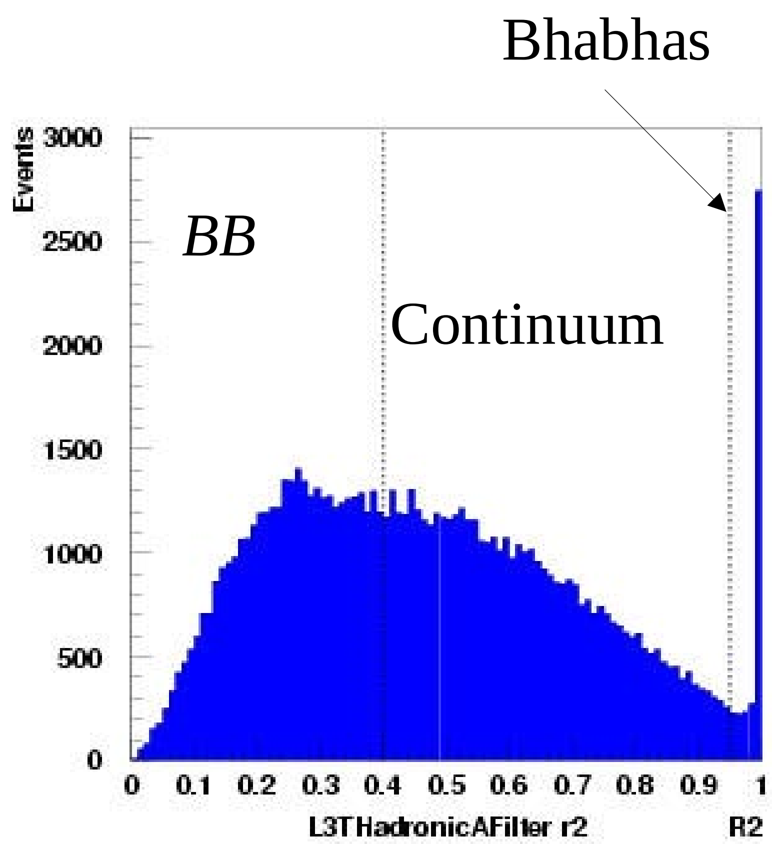


- Cosmics events present valuable samples for
  - Tracking efficiency studies
  - Calorimeter MIP cluster selection (unbiased)
  - SVT local alignment
- They are a part of normal data taking
  - It took a long time until BaBar discovered they are useful
  - Gap at p_T = 3 GeV to be closed

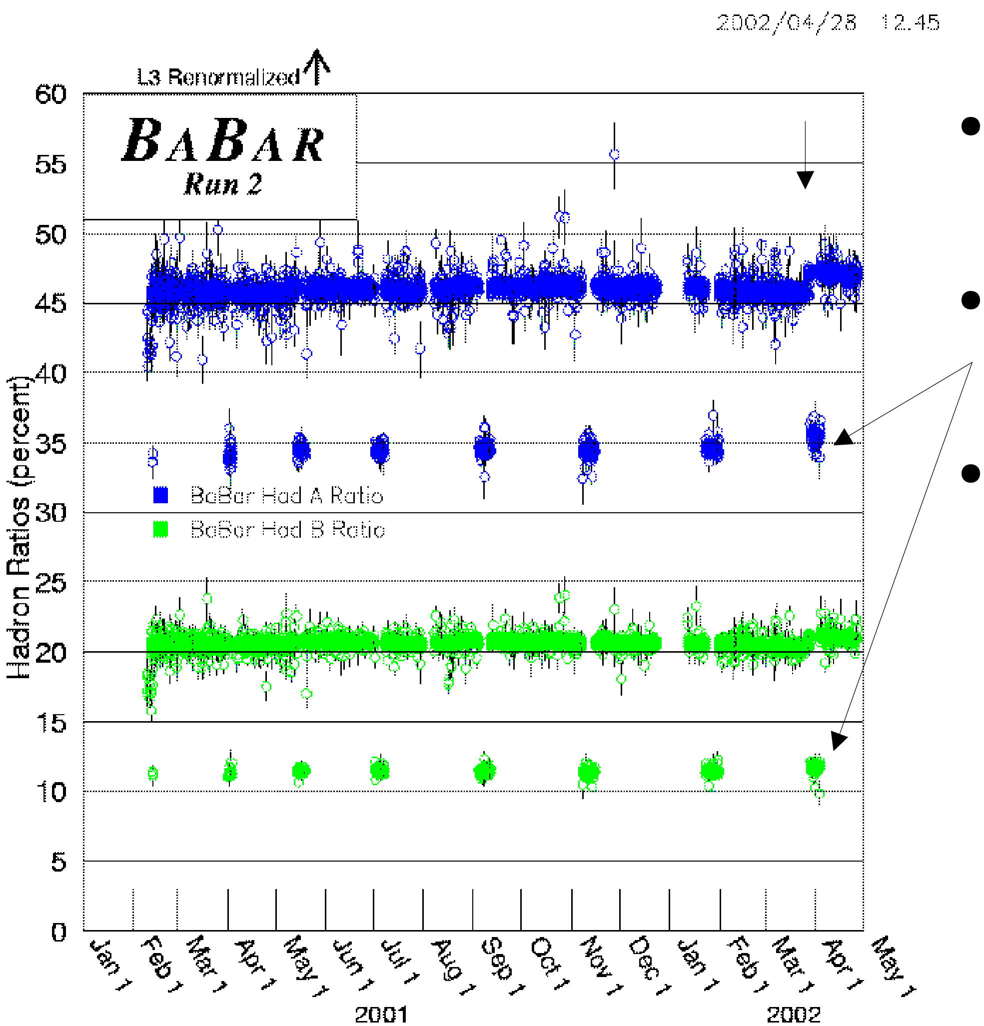
Hadronic Monitors

- Select events w/ 3 good tracks
  - max pT > 0.5 GeV
  - max p < 4.5 GeV (c.m.)
  - (invariant mass)^2 > 5 GeV^2
- Cut on Fox−Wolfram moment R2 = H2/H0
  - R2 < 0.95 ("HadA")
  - R2 < 0.40 ("HadB")

$$H_l = \sum_{(i \neq j)} \frac{|p_i||p_j|}{s} P_l(\cos\vartheta_{ij})$$



Hadron Ratios for 2001/2002

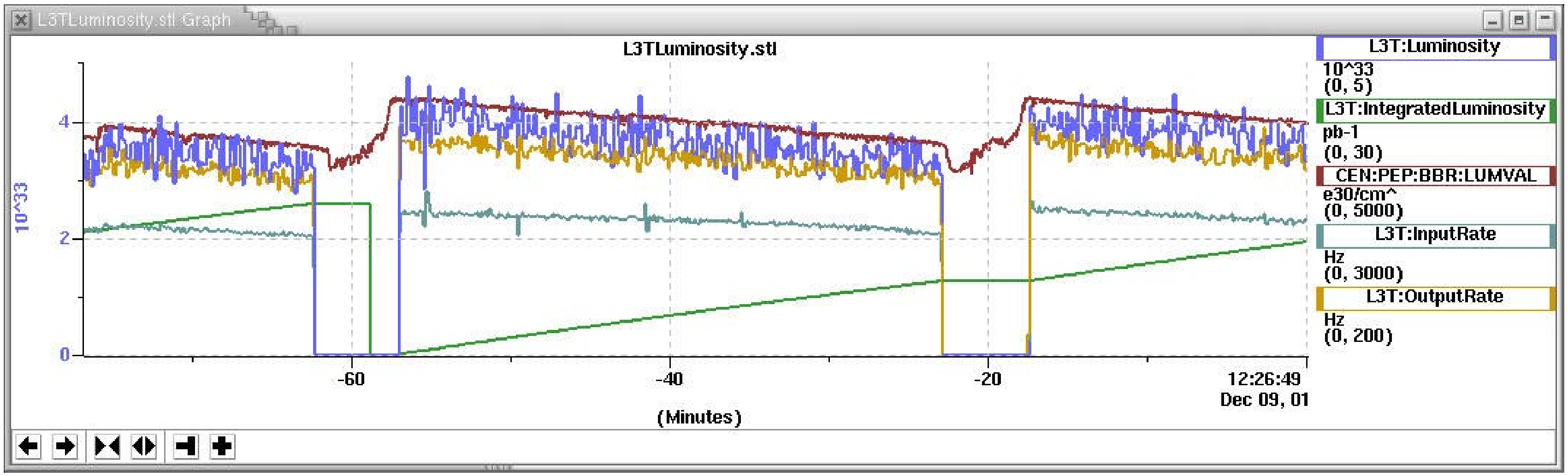


- Very stable over periods of many months
- Low values represent off−peak data taking
- Recent jump from installation of improved Level 3 tracking

EPICS Rate Monitoring

- Left column: filter output before prescaling
  - Dominated by Bhabha rate and unprescaled L1 accept
- Right column: logging rate
  - Dominated by Physics lines

Luminosity Strip Chart

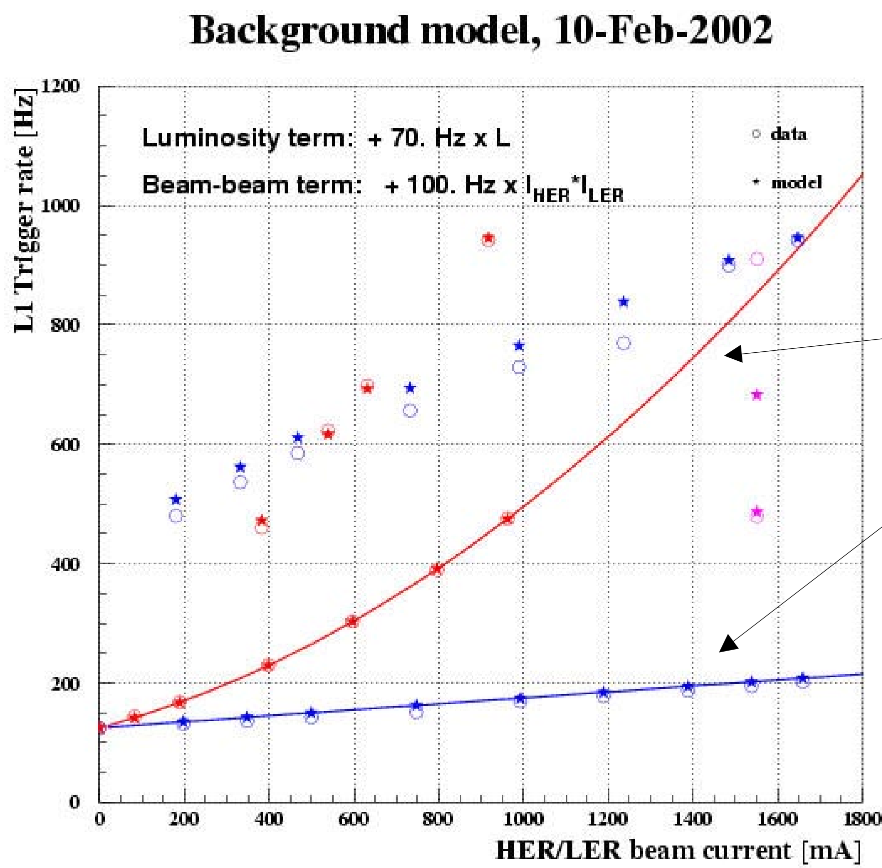


- Records Trigger rates, instantaneous & integrated Luminosity
- Update rate ~5 s or multiple
- Can be correlated with any other EPICS record

PEP−II Machine Background Studies

- Recent program to measure Trigger rates as a function of the beam currents
  - Varied HER over 0...950 mA, LER over 0...1650 mA
  - Set up single beam, colliding beams, and two beams out−of−collision
- Data are most valuable for rate projections and upgrade planning

Background Model



- New data show clear quadratic dependence on HER current
- LER contribution lower than in summer 2000
- Collision data seem to suggest beam−beam contribution

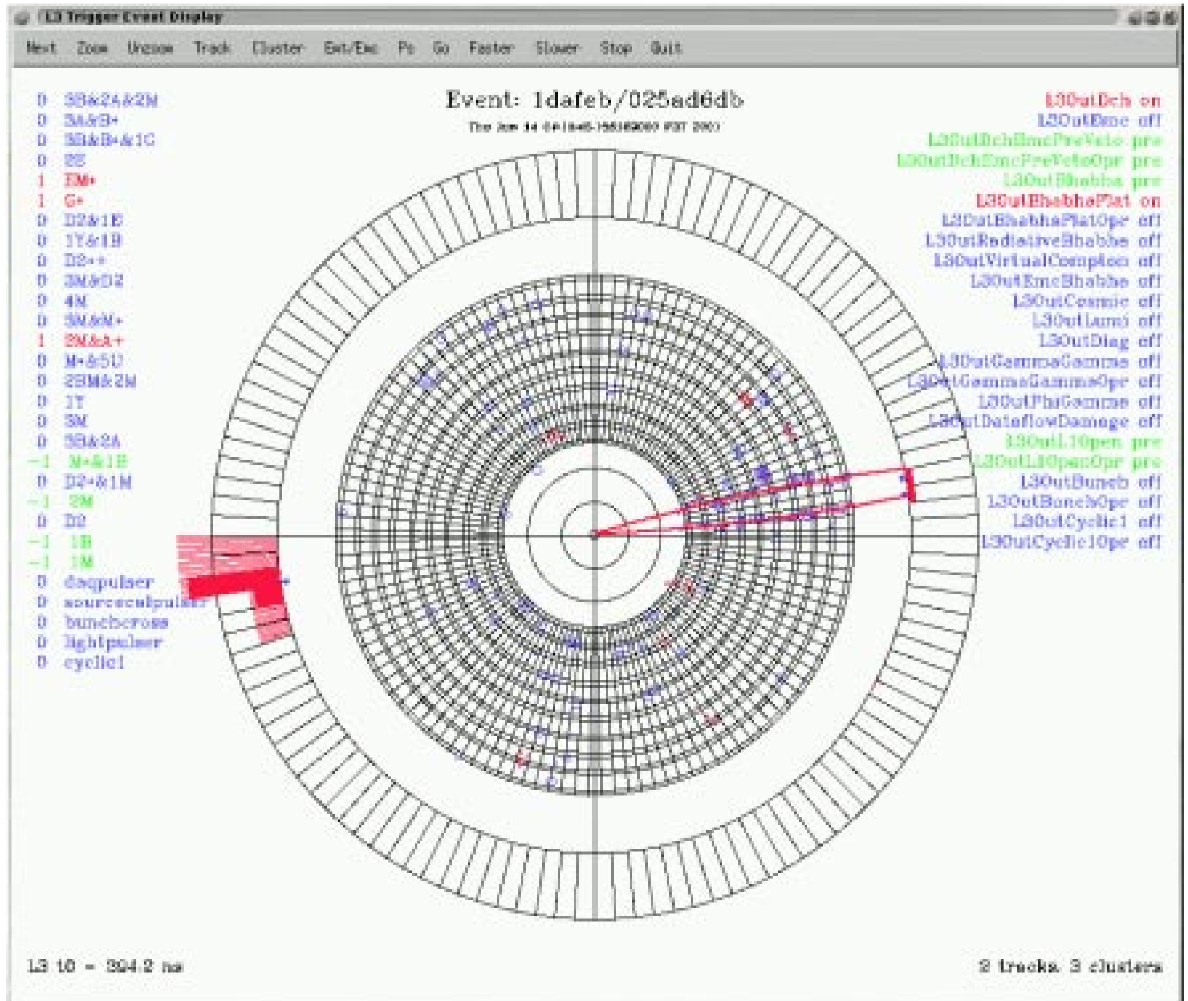
$$L1[Hz]=125+50\,x\,I_{LER}[A]+190\,x\,I_{HER}[A]+180\,x\,(I_{HER}[A])^2+110\,x\,L[nb^{-1}s^{-1}]$$

Summary (1)

- The rate capability of the deeply buffered BaBar DAQ system enables us to construct an Open Trigger
  - We achieve very high efficiencies for generic *BB* events, and high efficiencies for rare modes such as $B \to$ ð^{0}ð^0 and $B \to$ ôí$_{\text{ô}}$
  - Orthogonality ensures to make these efficiencies
    - ✔ High
    - ✔ Stable
    - ✔ Well−measurable

ISR

- Caught with nearly 100 % efficiency in both L1 and L3
- This is not an "accident" but a consequence of the design
- Belle’s L1 kills those
- We are going to analyse them



Summary (2)

- Significant rate reduction can be performed on the event filter farm (Level 3)
  - The ability to process a high rate of "minimum signature" events has opened many possibilities in
    - Logging a variety of calibration events continuously, (*e.g.*, *cosmics, ì −pairs, (radiative) Bhabhas, VCS, ãã, Ö Ks*)
    - Monitoring all sorts of observables in real time, (*e.g.*, *luminosity, hadron ratios, CM energy, boost, beam spot*)
- Despite the many improvements and extensions, constant code optimization let us stayed within the CPU budget all the time (*because we had to*)