Considerations for Calorimetry at a Super B Factory

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Coniderations for Calorimetry at a Super B Factory

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Session: Introductory

The study of B physics at e^+e^- colliders running in the Υ resgion imposes significant performance requirements on calorimetry. The enviornment of a very high luminosity B factory further restricts calorimetry choices. Calorimeter design is discussed in light of these constraints. A solution using scintillating crystals is explored.

Note:

Considerations for Calorimetry at a Super B Factory

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Introduction, Credits

- B physics requirements on calorimetry
 - Energy resolution, angular resolution
 - (***BABAR*** Technical Design Report)
- Requirements imposed by backgrounds
 - Backgrounds seen currently
 - Extrapolations to higher luminosity
 - Challenge of continuous injection
 - (***BABAR*** Note #533, SLAC-PUB-8970, S.Robertson)
- Scintillating Crystal Calorimeter
 - (***BABAR*** Upgrade Report; SLAC-PUB-8970)

Caveats

- The super B factory work is still in its early stages. The effort continues with significant distractions provided by the wealth of current data provided by the two existing B Factories at KEK and SLAC.
- Detailed exploration of physics opportunities at a super B factory is beyond the scope of this talk.

Performance Requirements

- Goals of a 10^{36} Asymmetric B Factory include:
 - ➡ search for effects of new physics on rare B (and D) decay rates and angular distributions
 - ➡ search for deviations from predictions of CKM parameters in over-constrained tests of the unitarity triangle: $\sin 2\beta \sim 1\%$; $\sin 2\alpha, \gamma \sim \text{several } \%$
 - ◆ this study is done in the ‘clean’ environment of e^+e^- interactions at $\Upsilon(4s)$ and $\Upsilon(5s)$, and is aimed to be complementary to and competitive with hadron machine efforts
- What is needed for competitive B Physics?
 - the calorimeter needs to perform comparably to current B factory calorimeters
 - look at characteristics of photons from generic and specific B decays

Photons from B Decays: Energy Spectra

- Energy Distributions:
 - photons from generic B's
 - photons from $B \rightarrow \pi^0 \pi^0$
 - photons from $B \rightarrow \rho \pi$
- the calorimeter must deal with a broad spectrum efficiently: from low energy photons ($\sim 20\text{MeV}$) from generic & tag B decays to high energy photons from $B \rightarrow \pi^0 \pi^0$ and electrons from bhabhas ($\sim 9\text{GeV}$) and semileptonic decays
- higher energy photons and electrons require a deeper calorimeter: $16\text{-}17.5 X_0$

Photons from B Decays

- Good low energy efficiency is needed for efficient π^0 and B reconstruction efficiency
- B's move relatively slowly in the lab, so energy resolution dominates over angular resolution
- generic B decays contain ~ 5.5 photons: **angular acceptance, segmentation**
- forward direction is more important for acceptance than the backward direction (can leave lab angle not fully covered)

DETECTOR PROTRACTOR - γ 's

Segmentation

- Crystal size: fine segmentation for better photon separation (including background photons), position resolution
- useful crystal transverse size is limited by its properties: Moliere radius (for CsI(Tl) ~3.8cm), readout expense
- longitudinal size driven by energy resolution

$$\frac{\sigma_E}{E} = \frac{1\%}{\sqrt[4]{E(\text{GeV})}} \oplus 1.2\%$$

$$\sigma_\theta = \frac{3\text{mr}}{\sqrt[2]{E(\text{GeV})}} \oplus 2\text{mr}$$

Acceptance, Geometry

- should cover maximum solid angle with minimal interruptions for services, etc.
- ID and OD set by tracking/PID and magnet coil
- material in front of the calorimeter should be minimized

Crystal Performance Issues

- Light yield uniformity and resolution effects
- typical LY $\sim 5.5\text{-}10\text{K pe/MeV}$
- material between crystals
- spec contribute less than 0.5% to σ_E/E up to 5 GeV: issues of readout device and location as well as crystal wrapping contribute here

Material Thickness	σ_E/E (%)	Efficiency (%)
0 μm	1.6	82
500 μm	2.1	79
800 μm	2.3	78

Crystal Performance Issues

- Radiation damage
 - light yield and light yield uniformity effects
 - source system, bhabhas, light pulser
 - design goal 10 yrs, 10krad, less than 20% ly loss

Readout & Electronics

- Spectral response of sensor; B field effects
- electronics noise goals: 150keV (20 MeV criterion)

Backgrounds Issues

- How can calorimeter be affected?
 - Integrated dose and consequent reduction in light yield (and uniformity?)
 - creation of false neutral clusters
 - inclusion of beam background photons during clustering into B decay photon shower
- examples from *BABAR*

Backgrounds Issues II

- *BABAR* 2001

Backgrounds Issues III

- Take special runs to find the sources of backgrounds:
 - HER(e^-) only; LER only; both beams in/out of collision
 - look at occupancy above threshold (1MeV; 0.75MeV with digital filtering): gives handle on rad damage since typical energy is ~ 1 MeV

Backgrounds Issues IV

- Look at clusters: requires 10MeV seed to the multi-crystal shower; shower has energy greater than 20MeV
- use in analysis clusters $>30\text{MeV}$
- typically see one cluster per event due to backgrounds
- these are dominantly produced by HER and ‘luminosity’

Backgrounds Issues V

- Look at effect on π^0 candidate count and resolution: clear indication of extra candidates, but the jury is still out on the resolution

Caveats

- backgrounds are very machine dependent:
 - › note the change with better signal processing and some machine improvements
 - › there is a difference between PEP-II and KEK-B: head-on collisions vs crossing angle, factor ~3-10

Super B Factory

- Parameters based on using the PEP tunnel. A larger tunnel on the SLAC site would save on RF power and supplies, but require civil construction
- particularly note that injection is continuous because of the very short beam lifetime
 - trickle charge (1Hz) appears to broaden π^0 width; suspending readout around injection helps

Parameter	High Energy Ring (HER)	Low Energy Ring (LER)
Beam energy (GeV)	9.0	3.1
Beam particle	e^+	e^-
Center of mass energy (GeV)	10.58	10.58
Circumference (m)	2200	2200
RF Frequency (MHz)	476	476
RF Voltage (MV)	50	30
Synch. Rad. Power (MW)	23	12
Number of bunches	3492	3492
Total beam current (A)	6.6	19.2
$\beta_{y/x}^*$ (cm)	0.32/0.32	0.32/0.32
Emittance (y/x) (nm)	22/22	22/22
Momentum Compaction	0.001	0.0013
Bunch length (mm)	3.5	3.5
Approx. AC power (MW)	50	27
Beam lifetime (min)	5	5
Injection particles per pulse	7.3×10^{10}	5.3×10^{10}
Continuous injection rate (Hz)	20	80
Beam-Beam tune shifts	0.14	0.14
Transverse beam size (μm)	8.4	8.4
Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	10^{36}	10^{36}

Background Extrapolations

- Background sensitivities to each source of lost beam particles will depend on the details of the machine optics and the IR and detector designs: more complete design and simulation is needed for a proper estimate of the backgrounds and dose. In *BABAR* sources are typically vacuum and luminosity sources; the large loss rates to Touschek, beam-beam and dynamic aperture imply these will also contribute

	HER	LER	SuperHER	SuperLER
Beam current (A)	0.7	1.4	5.5	20.5
Beam lifetime τ_b (min)	550	150	4.2	3.2
Beam loss rate I_b/τ_b (A/min)				
Luminosity			0.37	0.35
Vacuum (Brem/Coulomb)			0.06	0.68
Touschek			0.06	2.28
Beam-beam tune shift			0.55	2.05
Dynamic aperture			0.28	1.03
Total	1.3×10^{-3}	9.3×10^{-3}	1.32	6.39

Background Extrapolations II

- Background estimates scaled from measured rates in light of the expected loss rates are suspect due to beam optics differences, aperture limits, and collimation: good to $\sim 10\times$.
- Estimates obtained scaling the beam currents yield lower backgrounds. Touschek is similar to vacuum sources; no estimate for dynamic aperture and beam beam sources.
- Scaled energy deposition yields $\sim 1\text{-}200$ GeV in $1.85\mu\text{s}$, up a factor of 100

Source	<i>BABAR</i> (Rad/year)	Super <i>BABAR</i> (kRad/year)
HER (Vacuum)	≤ 200	2 – 10
HER (Touschek)	-	$\mathcal{O}(10)$
LER (Vacuum)	≤ 200	3 – 15
LER (Touschek)	-	$\mathcal{O}(50)$
<i>Lumi</i>	≤ 200	≤ 100
Injection	(small)	$\mathcal{O}(50)$

(at *BABAR* calorimeter radius)

Strawman Detector

- Compact detector option:
 - eliminate gaseous tracker:
assume that backgrounds from factory operation are too high. Use fast, compact detector, silicon, in a 3T B field.
 - crystal choices (discussed later) are expensive: shrink the volume. Scale *BABAR* by Moliere radius ratio
 - DIRC PID is fine at shrunken radius; R&D forward

Crystal Calorimeter Candidates

- need good light output for energy resolution
- need a rad hard crystal
- need a fast crystal to reduce backgrounds (& need to be clever)

Crystal	CsI(Tl)	CsI	BGO	BaF ₂	PbWO ₄	CeF ₃	YAP	GSO	LSO
τ decay(ns)	680, 3340	16	300	.6, 620	5, 15	10-30	27	56, 600	47
χ_D (cm)	1.86	1.86	1.12	2.03	0.89	1.66	2.63	1.39	1.14
R_{molieres} (cm)	3.8	3.8	2.3	3.4	2.2	2.6	2.8	2.4	2.3
λ_{nuclear} (cm)	37	37	22	30	22	26			
LY (γ /MeV)	56000, 64:36%	2500	8200	1400f, 9950s	100	3500	16200	12500, 1250	27000
λ_{peak} (nm)	550	315	480	220f 310s	420-500	310-340	390	440	420
Rad Hard (Mrad)	.01	.01-.1	.1-1	1	100	1	10	100	100
ρ (g/cm ³)	4.51	4.51	7.13	4.89	8.28	6.16	5.35	6.70	7.40
n_D	1.79	1.95	2.15	1.56	2.20	1.68	1.94	1.85	1.82
Cost (\$ /cc)	3.2	4	4	5	8	3	?	> 15	> 7

Segmented Calorimeter?

- Photosensors must be immune to the high magnetic field and quite compact: PDs for crystals with high light output, APDs?
- Can we reduce cost by longitudinally segmenting the calorimeter: better identification, spatial resolution, ability to reduce backgrounds? Use rad hard compact crystal in front, cheaper, less rad hard crystal in back?

Summary

- Physics requirements for a super B factory calorimeter have been briefly discussed.
- A flavor for the potential beam backgrounds at a super B factory have been extrapolated from PEP-II experience
- A strawman detector and its candidate calorimeter have been discussed.
- R&D needs to proceed to identify the best calorimeter material.

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SuperBABAR

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