Detector Issues at a Linear SuperB Collider

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- Comparison of Circular and Linear Colliders
- Backgrounds at a Linear Collider
- Energy Asymmetry and Beam Energy Spread
- Vertex Detector and Tracking System
- Particle ID
- Calorimetry
- Trigger and DAQ

Comparison of Colliders

Circular Super B parameters from PEP-II Super B design

Linear Super B parameters from John Seeman 2/11/05

Parameter	PEP-II	Circular Super B	Linear SuperB
Luminosity	$1.0 \times 10^{34} cm^{-2} s^{-1}$	$7.0 \times 10^{35} cm^{-2} s^{-1}$	$1.0 \times 10^{36} cm^{-2} s^{-1}$
Bunch spacing	4.2 ns	1.05 ns	1 ns
# Bunches/Repetition	1700	6900	2
Repetition rate	continuous	continuous	136 kHz
Bunch charge	8-12 nC	10-25 nC	24-40 nC
Beam current (detector)	2-3 A	10-20 A	7-11 mA
Bunch length	10 mm	1.7 mm	0.9 mm
Horizontal beamspot	100 μm	40 μm	0.8 μm
Vertical beamspot	5 μm	2 μm	0.8 μm
Beam energies	9.0/3.1 GeV	8.0/3.5 GeV	7.0/4.0 GeV
CM energy spread	2.5 MeV	2.5 MeV	10-15 MeV

Some things are very different at a Linear Super B!

Timing Structure of Bunches

Circular Super B - continuous bunch crossings every **1ns**

Linear Super B - train of 2 crossings in **2ns**
followed by a *repetition gap* of $\mathbf{7}\mu$**s**

- The $\mathbf{7}\mu$**s** gap is useful for trigger and data acquisition
- Single beam backgrounds will be $\times$1000 smaller overall
(but similar within the 2ns of the bunch train?)
- Luminosity related event rates:
  - There will be 1kHz of $B\bar{B}$ events (1/150 bunch trains)
  - There will be 3kHz of continuum events (1/50 bunch trains)
  - There will be $\approx$100kHz of Bhabhas (1/2 bunch trains)

$\Rightarrow$ *Need to separate* $B\bar{B}$ *events from background in bunch train*

$\Rightarrow$ *Radiation damage and readout time should not be problems*

Critical Impact of Timing Structure

In the nominal design nothing happens between a few ns and 7μs

Detectors are **fast enough** if they are < the repetition rate

There is no need to build a really fast detector

This is completely different than for a circular super B

If we change the design to a lower repetition rate and longer bunch trains we get into trouble with multiple events:

- Trains of 25 bunches in 25ns at 10kHz:
  10 Bhabhas per bunch train + 1 hadronic event per 2 trains
  Need to identify and suppress Bhabhas in a few ns

- Trains of 2500 bunches in 2.5μs at 100Hz:
  1000 Bhabhas per bunch train + 10 $B\bar{B}$ and 30 continuum events! Need to separate B vertices and tags in <100ns

Backgrounds at a Linear Super B Collider

- Luminosity related backgrounds from radiative and non-radiative Bhabhas
  radiative Bhabha backgrounds can be suppressed
  by moving the separation of the beams away from the IP
- e^+e^- pairs from converted "beamstrahlung" photons
  mostly low p_t electrons in forward cone which are
  confined to small radius by solenoidal field of detector
- Beam interactions with upstream collimators
- Neutrons from interaction region material
- Hadrons from beam-gas interactions

Naively all single beam backgrounds are suppressed by 1/1000 by the lower beam currents compared to a circular Super B

Beam Energy Asymmetry

Consensus of machine experts: lower asymmetry is better!

Limited by requirements of time dependent CP measurements

Circular Super B design is 3.5 on 8 GeV

$\beta\gamma = 0.43$, $z_b = 205\mu\text{m}$, $\sigma_z \approx 150\mu\text{m}$

Nominal Linear Super B design is 4 on 7 GeV

$\beta\gamma = 0.28$, $z_b = 135\mu\text{m}$

Should we look any lower, e.g. 4.7 on 6 GeV?

$\beta\gamma = 0.12$, $z_b = 60\mu\text{m}$

$\Rightarrow$ *Vertexing is improved by smaller beam spot*

$\Rightarrow$ *Lower backgrounds allow for smaller beam pipe radius*

Beam Energy Spread of ≈10 MeV

Already discussed by David Hitlin and Marica Biagini

Energy spread is broadened by beam-beam interaction
and varies as function of z-position within bunch length (0.8mm)

For the detector design it is critical that we do not lose resolution on B mesons in ΔE as well as in m_{ES}

⇒ *gaseous tracker more accurate than BaBar?*

⇒ *electromagnetic calorimeter more accurate than BaBar?*

Linear Super B Vertex Detector

Requirements:

$\Rightarrow$ Best possible z vertex resolution

$\Rightarrow$ Low p_t tracking over largest possible solid angle

$\Rightarrow$ Reconstruction of $K_s \to \pi^+\pi^-$ decays

Comparison to circular collider:

- Much lower single beam backgrounds
  There are no large backgrounds in horizontal bending plane!
  Are occupancy and radiation damage no longer problems?

- Timing resolution $\approx$ 100ns is $<<$ repetition rate

- Readout is only required for bunch trains producing hadronic events (a few kHz after L1 trigger decision)

- Inner radius can be reduced to 1.0-1.5cm

Reminder of Some Vertexing Options

1. Silicon strips should work fine
   Don't need to go to striplets!
2. Monolithic Active Pixels (MAPs)
   Not required to reduce occupancy
   Is material thickness too large?
3. Charge-Coupled Devices (CCDs)
   as used by SLD and being considered for ILC
   Can they be read out between bunch trains (multiplexing)?
   How radiation tolerant are CCDs (worry about neutrons)?

⇒ How thin should we make the innermost layer?

Tracking System Requirements

Only needs to be **fast enough** ... maximum drift time $< 7\mu$s

Can we use this extra time to improve tracking resolution?

Yes - with appropriate choice of gas and geometry

Low diffusion, uniform time-distance relation

Get rid of most of the wires

The other choice to make is between:

- Large radius, moderate B field
- Small radius, large B field

This choice is probably driven by the calorimeter design

Tracking Options

1. Minicell drift chamber with slow gas
   He:DME (70:30) or He:CO_2:iC_4H_{10} (80:10:10)
   Drift distance up to 2cm, drift velocity 0.5-2cm/μs
   Spatial resolution $<$100μm achieved in test chambers

2. Jet chamber with He:iC_4H_{10} (80:20) or He:CO_2:iC_4H_{10}
   Drift distance up to 10cm, drift velocity $\approx$2cm/μs
   Minimizes regions of poor resolution at edges of cells

3. Time Projection Chamber (TPC) as considered for ILC
   GEM or MicroMega detectors coupling to readout pads
   r/ϕ resolution $\approx$100μm, z resolution a few 100μm (diffusion)
   Maximum drift distance $\approx$1m means drift time $> 7\mu$s
   but can determine t_0 from apparent z vertex position of tracks

Particle Identification

We only need a “not-so-fast” RICH or DIRC

Can the available time of 7μs be used to improve the precision of the Cherenkov angle measurement?

Where do we put the DIRC/RICH readout?

The lower energy asymmetry means there will need to be a backward calorimeter

I assume there are no significant issues with muon detection

Calorimetry Requirements

The 7μs time window is a very good match to CsI(Tl) crystals

BaBar and Belle have a large supply of these - save money!

Should we try and do better on energy resolution?

There is a large rate of Bhabhas in the forward/backward direction

- What is the maximum solid angle coverage of the calorimetry?
- Is radiation damage an issue in these regions?
- Do we need fine granularity and/or a small Moliere radius to separate showers?

LSO and LYSO Crystals

Lutetium (+ Yttrium) Oxyorthosilicate crystals are used in medical imaging:

- Fast light output in 40ns (*only needed at circular Super B!*)
- Small radiation length of 1.15cm (CsI 1.86cm)
- Small Moliere radius of 2.3cm (CsI 3.8cm)
- Very radiation hard (100 MRad)
- Light output is 60% of CsI(Tl) peaked at 420nm (CsI 550nm)
  Need APDs to read out at this wavelength
- Cost is $20-50/cc

Liquid Xenon

Can use fine-grained sampling along shower depth to give good spatial resolution and shower separation.

- Fast light output in 20ns (*only needed at circular Super B!*)
- Radiation length of 2.9cm (CsI 1.86cm)
- Moliere radius of 5.7cm (CsI 3.8cm)
- Light output similar to CsI(Tl) but peaked at 175nm
  Need wavelength shifters and APDs to read out
- Mechanical design is complicated - needs a cryostat
- Cost is \$2.5/cc

Trigger and DAQ

The 7μs time window is a very good match to a L1 trigger

Use calorimeter and/or tracking information to decide if there was a hadronic event in that bunch train

L1 output rate of 5-10kHz?

Need to remove Bhabhas in the forward/backward direction

Then read out detector and pass to online farm for selection of interesting hadronic events and prompt reconstruction.

Summary

- The existing BaBar detector would work quite well at a Linear Super B collider (*not true for a circular Super B collider*)
  Conclusion depends on timing structure
- Single beam backgrounds are much lower
- Vertexing needs improvement because of the lower asymmetry and beam energy spread
- The time structure may allow better tracking resolution
- The forward/backward regions may need modifying to deal with the rate of Bhabhas