BTeV Ring Imaging Cherenkov Detector

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Introduction

Requirements

- Physics requirements
  - At least $4\sigma$ separation for $K$, $\pi$, $p$ in the momentum range 3-70 GeV/c $\Rightarrow$ average Cherenkov angle resolution per track better than 0.12 mrad.

- Geometrical Requirements:
  - full BTeV solid angle coverage (10-300 mrad).
  - Thickness $\leq 20\%$ of a radiation length

Key features

- Excellent hadron identification in the the momentum range 3-70 GeV/c
- Lepton identification in the solid angle between 200 and 300 mrad (not covered by electron and muon ID systems)
The BTeV RICH Components

Mirror Focused Gas Radiator RICH

- Mirror Array
- Gas Radiator $\text{C}_4\text{F}_8\text{O}$
- $3m$ length

Proximity Focused Liquid Radiator RICH

- Liquid Radiator $\text{C}_5\text{F}_{12}$
- 4948 PMTs (1 cm thick)
- 9016 MaPMTs (944 HPDs)

$\gamma$s
Gas Radiator Photon Detectors

- Baseline solution: 16 channel Hamamatsu R8900-00-M16 MaPMTs (9016 devices for 2 arrays)
- Main features:
  - Predicted $\sigma_{\text{track}} \sim 0.115$ mr
  - Predicted $N_{\gamma} \sim 52$ detected
  - $\text{QE} \times \text{CE}$ 13-15%
  - Active area: 85%
  - 6x6 mm pixel size well suited for BTeV
  - Gain $[1-4 \times 10^6]$
  - HV 600-900 V (negative)
  - Standing current in voltage divider 340 $\mu$A
- Alternative solution 163 pixel HPD from DEP
MAPMT vs HPD

**MAPMT:** Hamamatsu R8900-M16

**HPD:** DEP PP0380AT
Development of MAPMT (Hamamatsu)

- First used in RICH detector by HERA-b (since 1998)
  - 1488 R5900-M16 + 752 R5900-M4
  - Active area: 36%
  - Double-lens focusing system
- Improved version with increased segmentation tested by LHC-b
  - R7600-M64
  - Active area: 48%
  - Single convex-plano lens system increases geometrical efficiency to 74%
- Redesigned focusing scheme on the first dynode
  - R8900-M16
  - Active area: 85%
  - No lens system needed!
  - 6x6 mm pixel size well suited for BTeV
  - R8900-M25 developed for EUSO telescope
Photon detector electronics

- **FRONT END ASIC must feature:**
  - Noise consistent with the minimum threshold giving us full counting efficiency [1/10 of average MaPMT gain]
  - On chip sparsification
  - High Dynamic range
  - Parallel digital readout to allow event synchronization

- **PROTOTYPING STEPS implemented:**
  - VA_BTeV1 [for HPD readout: low noise (500e- ENC), discriminator not optimized for high counting rates] & Va+BTeV1.1 [improved discriminator and 1 analog test channel]
  - VA_MaPMT [for MAPMT, improved discriminator, 1 analog test channel]
  - In progress: optimization of dynamic range for MaPMT applications and of noise versus $C_{in}$ for PMT applications
• Two large mirrors, each one has 200cm (width) and 400cm (height). They can be broken down to any number of mirrors of any shape, so that cost and performance are optimized.
• A half circle hole in the side for the beam pipe (∼3 cm radius).
• Mean radius of curvature is fixed to 697cm.
• 1-2% radiation length
• CMA approach: each mirror made up of 8 square tiles
Mirror aberrations

- We have performed extensive simulations of possible mirror distortions and their effects on both Cherenkov angle resolution and simple mirror quality test:

Spot size measurement:

Simulations:

Surface deviations from the ideal spherical mirror parameterized in cylindrical coordinates of the mirror tile: \( W(\rho, \theta) \)
Two prototype mirrors obtained from IMMA Compas, Turnov, Czech Republic (R~660 cm)

- 6 mm glass (4.7% of $X_0$)
  - $D_{95}=3.0 \text{ mm}$
  - For the central part only: $D_{95}=4.1 \text{ mm}$

- 2.2 mm glass + Carbon Fiber + foam (2.2% of $X_0$)

Examples of spot size measurements
Mirror quality tests

- In addition to the spot size measurement we plan to perform Ronchi test
  - Gives qualitative information on type of mirror distortions
  - Look for deviation of the interference fringes from straight uniformly distributed lines:

Glass mirror

- Polishing imperfections

CF+glass mirror

- Bad distortions at the edges
CMA mirrors

- CMA has developed a proprietary process which incorporates a very thin layer of pure resin at the surface. The resin layer imparts a super-smooth (RMS~7 angstroms) optical surface totally free from carbon fiber print-through.
- Unlike in traditional glass working, there is little or no distortion of the optical figure due to stress release at corners and edges. Can produce mirrors of non-traditional shape.
- Produces lightweight mirrors for space program telescopes.
CMA has made 11" x 11" mirror prototype for us with radius of curvature R=3.5m.
Structure of the CMA mirror prototype

- Average radiation thickness 1.2% $X_0$ (+mounts 0.1% $X_0$)
Compatibility with $\text{C}_4\text{F}_8\text{O}$

- CMA covers CF surfaces with protective glue layer
- Test compatibility of the CMA mirror prototype with $\text{C}_4\text{F}_8\text{O}$ at Syracuse

CMA CF mirror inside transparent box with $\text{C}_4\text{F}_8\text{O}$.

Monitor mirror optical properties.

No change in mirror spot size and mean radius over more than 2 months
Gas RICH Test Beam Studies

Details can be found in physics/0505110
In M-TEST area

Glass mirror

Gas tank: air and \( \text{C}_4\text{F}_8\text{O} \)

MAPMTs

Beam (120 GeV p)

June 2004, Jan. 2005 (including set-up)
What are we testing?

- First test beam of MAPMTs with large active area:
  - R5900 used in HERA-b RICH: active area: 36%
  - R7600 tested by LHC-b: active area: 48%
  - R8900 developed for BTeV and EUSO: active area: 85%

- First test beam of C₄F₈O gas radiator:
  - Production of C₄F₁₀ discontinued (largest refractive index among RTP gases; used in many RICH detectors)
  - Optical measurements of $n$ suggest that C₄F₈O is a good replacement

- Advanced prototype of FE readout board based on VA_BTEV MAPMT ASIC developed with IDE AS

- Prototype of MAPMT base(board)

- Prototype of mechanical support

- Validity of many components of RICH simulations used to design the detector and to predict its physics performance

- Step in system integration
Data vs MC

BTeV RICH Beamtest
(01/10/05-01/31/05)
Run 01112 Nevent 012757

Ring intensity pattern well reproduced in MC

MC after minimazation
HV SCAN

- HV1, 2, 3 = the three groups of gain-equalized MAPMTs
- Operating point: 800/750/700 for most of data-taking

![Graph b) Number of Clusters vs. High Voltage]

![Graph c) Cluster Size vs. High Voltage]
Parameter Determination

**BTeV RICH Beamtest**
(01/10/05-01/31/05)
Run 1112  Nevent 016900

Fit these 3 parameters by minimizing:

$$\chi^2 \equiv \sum_{i \text{(pixels)}} (I_i^{\text{data}} - I_i^{\text{MC}})^2$$

- Angles check alignment
- Index of refraction compared with optical measurements
Index of refraction data

Measurements with Michelson-Morley interferometer

Average n-1 from the fit

1389±24

(averaged with the $1/\lambda^2$ weight within the gas RICH bandwidth 280-600 nm)
This is a single run with nominal setting.

Cross talk contributes to the resolution in real data.
Track Cherenkov Angle Resolution

Single track peak
\[ \langle N \rangle_{\text{Data}} = 43.1 \]
\[ \langle N \rangle_{\text{MC}} = 40.5 \]
The difference is about 5%, which is the same as cross talk effect.

\[ \sigma_{\text{Data}} = 0.1164 \text{ mrad} \]
\[ \sigma_{\text{MC}} = 0.112 \text{ mrad} \]
Conclusions

- BTeV gas RICH detector performance was validated by extensive test beam studies:
  - R8900 MAPMTs + Front End deliver anticipated Cherenkov photon yield
  - $C_4F_8O$ proved suitable Cherenkov radiator
  - Biasing scheme for the R8900 worked well
- New iteration of electronics is being studied that should eliminate residual cross talk problem
- BTeV terminated in the president’s budget 2006: we hope that some of this technology will be transferred to other applications