Tagger Microscope for Hall D

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Beamline Review
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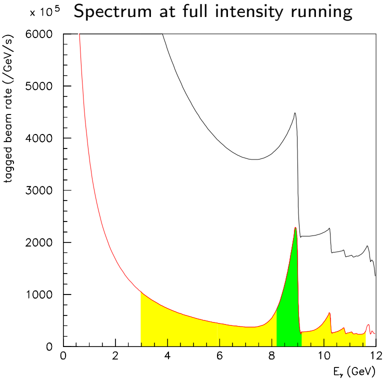
Outline

GlueX Photon Spectrum

Bremsstrahlung in diamond crystal:

- coherent edges
- incoherent background

Beam collimation strongly reduces this background.



— full spectrum
— collimated beam

total coverage by broad-band hodoscope
range of interest to GlueX - instrumented with a tagger "microscope"

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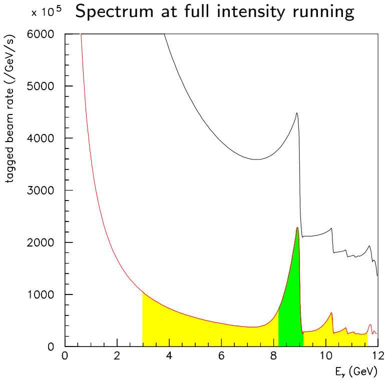


— full spectrum
— collimated beam ⟸ **decreases tagging efficiency**

■ total coverage by broad-band hodoscope
■ range of interest to GlueX - instrumented with a tagger "microscope"

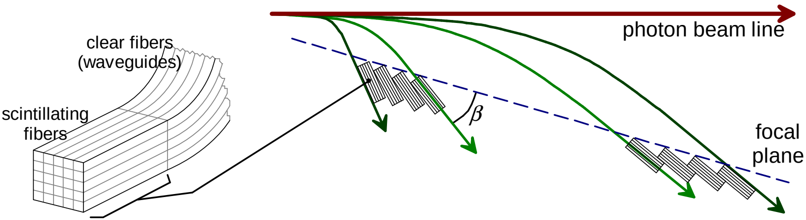
Requirements

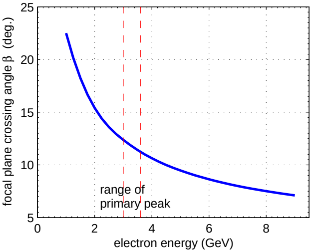
Design requirements of the Hall D tagger:

Category		Requirement source/reason
energy resolution	$60\,\mathrm{MeV}$	GlueX detector capability
time resolution	$200\,\mathrm{ps}$	accurate bunch identification
rate	$2\,\mathrm{MHz}$	collimated spectral peak
tagging efficiency	$50\,\%$	

The rate limitation presents a more stringent requirement for focal plane segmentation.

Focal Plane Geometry

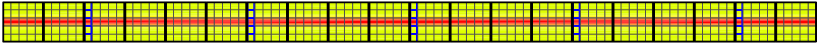




- SciFi detectors $2\,\mathrm{cm}$-long occupy the e^- focal plane aligned along e^- trajectories
- fiber waveguides $\sim 0.5\,\mathrm{m}$-long couple to detectors mounted above
- β varies with energy (steep dependence at the low E_{e^-} limit.)

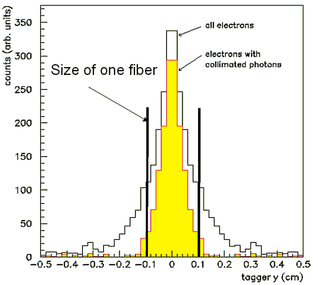
Focal Plane Segmentation

Electron's view of the 100×5 scintillator array



- $2 \times 2\,\mathrm{mm}^2$ cross-section SciFi array
  - small acceptance to mitigate rate
  - resulting $\sim 8\,\mathrm{MeV}$ resolution more than satisfies GlueX requirement
- Tagging efficiency improvement:
  - vertical segmentation +
  - limiting tags to one row
- Economy of readout channels
  - □ vertically summed
  - □ read individually for 2D sensitivity

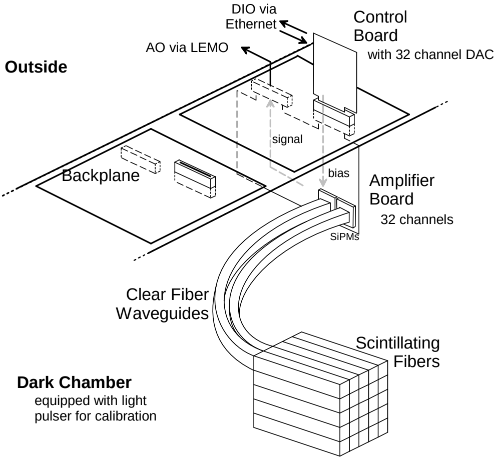
Transverse distribution of electrons.



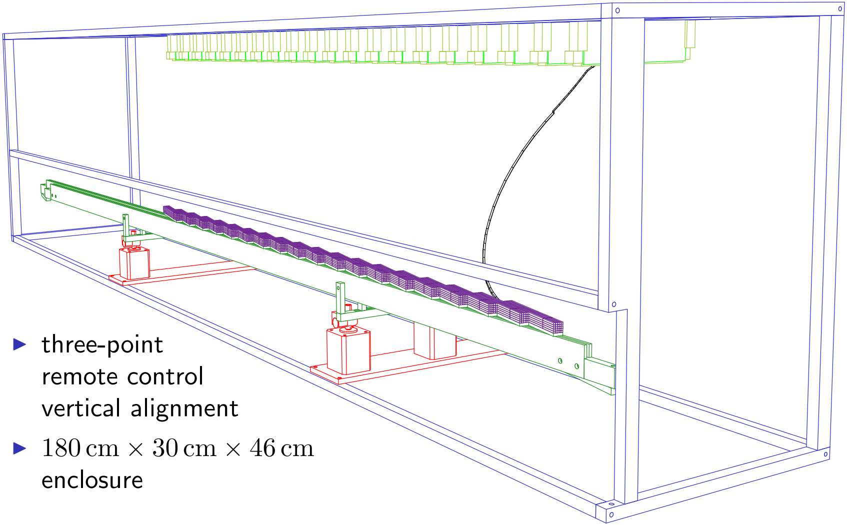
Conceptual Design

Design features:

- electronics out of the e^- plane: SciFi/photo-detector coupling via waveguides
- SiPM-based readout
  - custom amp. board
  - bias voltage control board
- full microscope: 20 board-fiber groups

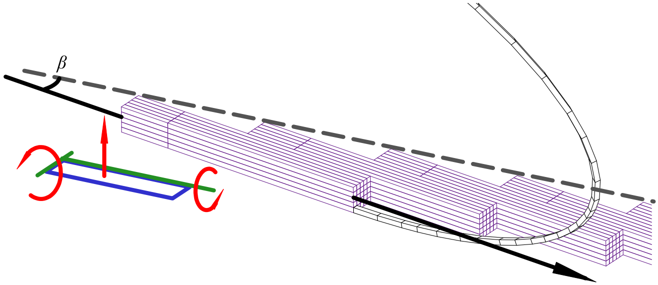


Mechanical Structure



- three-point remote control vertical alignment
- $180\,\mathrm{cm} \times 30\,\mathrm{cm} \times 46\,\mathrm{cm}$ enclosure

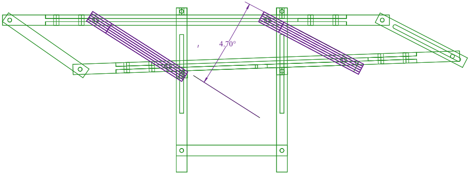
Scintillator Alignment

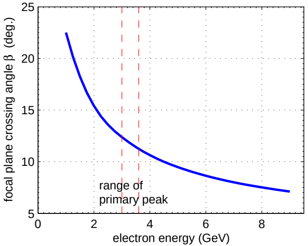


- rotation DOFs: convenient during alignment
- vertical translation: allows selection of scintillator row
- β fixed during assembly

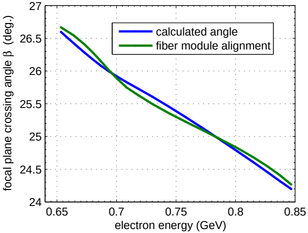
- - focal plane location
— electron trajectory
— available DOFs after assembly

Alignment of Fiber Modules





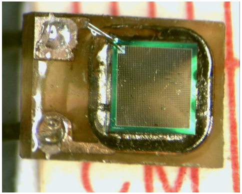
Support frame for fiber modules designed to allow alignment with all crossing angles for the useful energy range.



Choice of Photo-detector

Photo-detector technology chosen:
Silicon Photomultipliers (SiPMs)

- comparable in speed and gain to PMTs
- high voltage not required ($V_{bias} < 100\,\mathrm{V}$)
- size of order $1\,\mathrm{mm}$ - matches fiber cross-section



SSPM-0606BG4

Three SiPM devices were considered:

Firm	Device	Area (mm^2)	
Hamamatsu	050C	1	after-pulsing, inadequate efficiency
Photonique	050701GR	1	inadequate efficiency
Photonique	0606BG4	4.4	*meets requirements*

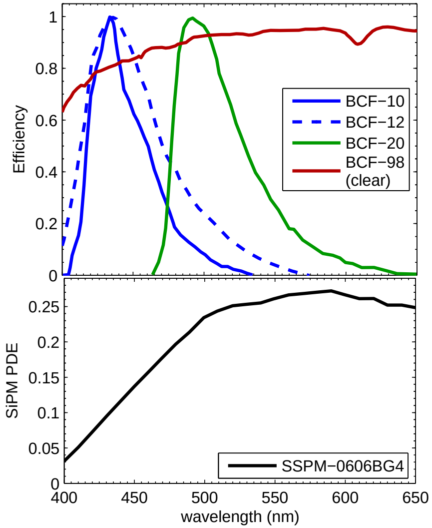
Candidate SiPM

Best unit found: Photonique SSPM-0606BG4

Active window	$(2.1\,\mathrm{mm})^2$	matches $2\,\mathrm{mm}$ square fibers
Pixel number	1700	good dynamic range for $200\,\mathrm{ps}$ resolution (discussed later)
PDE	$\sim 20\%$	sufficient for expected pulses
Gain	$\sim 2 \times 10^5$	
Rise/recovery time	$3\,\mathrm{ns}/25\,\mathrm{ns}$	$\sim 95\,\%$ detection efficiency @ $2\,\mathrm{MHz}$ rate
Dark rate	$10 - 20\,\mathrm{MHz}$	negligible for set discriminator threshold[1]

[1] under the very conservative estimate of 20 MHz dark rate with cross-talk factor of 2, a threshold of 50 $\mathrm{p.e.}$ is crossed at a rate of $1 \times 10^{-43}\,\mathrm{Hz}$

Choice of Scintillating Fiber



Features of BCF-20 scintillator

- close to peak of SiPM sensitivity and BCF-98 transmission
- fast decay time: $2.7\,\mathrm{ns}$
- square, double-clad

Radiation Hardness

- **SiPM**: PDE degradation $< 1\,\%/\mathrm{year}$ based on:
  - radiation damage studies of
    Majos et al. (NIM A 2008) and Bohn et al. (NIM A 2008)
  - JLab Radiation Control Dept. report on Hall D shielding by Abkemeier et al.
    - beam current of $3\,\mu\mathrm{A}$
    - average radiation dose on south wall of tagger hall (*significant overestimate*: includes load of the beam itself)
  - beam duty cycle of $1/3$
- **Scintillator**: expected lifetime $\sim 1\,\mathrm{year}$ based on:
  - Busjan et al. (NIM B 1999) study of the more sensitive BCF-12
  - full beam intensity peak rate of $2\,\mathrm{MHz}$
  - beam duty cycle of $1/3$
  - scintillator rejection threshold: $75\,\%$ output

Time Resolution

Critical Requirement: $200\,\mathrm{ps}$
Scintillator BCF-20 decay time: $2.7\,\mathrm{ns}$ $\implies$ $> 180\,\mathrm{p.e.}$ needed

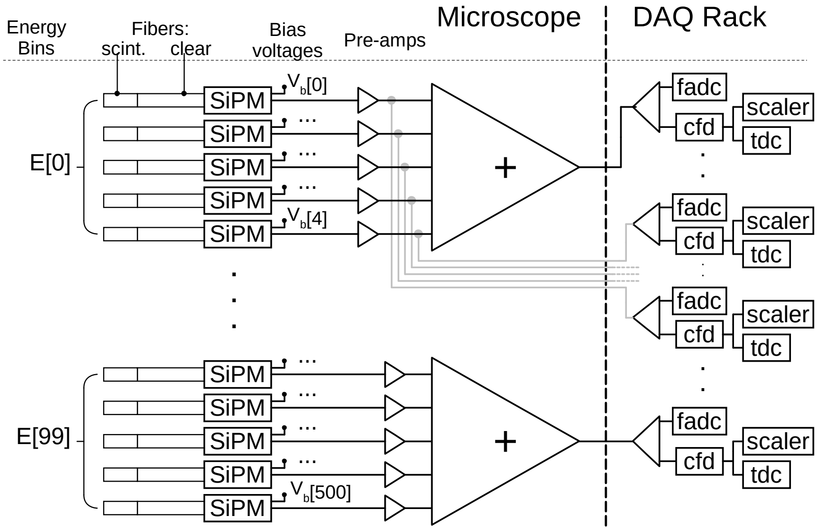
Photo-detector acceptance:

- optical (light capture in fiber, transmission, misalignment): $\sim 4\%$
- SiPM PDE (geometric and quantum efficiencies): $\sim 20\%$

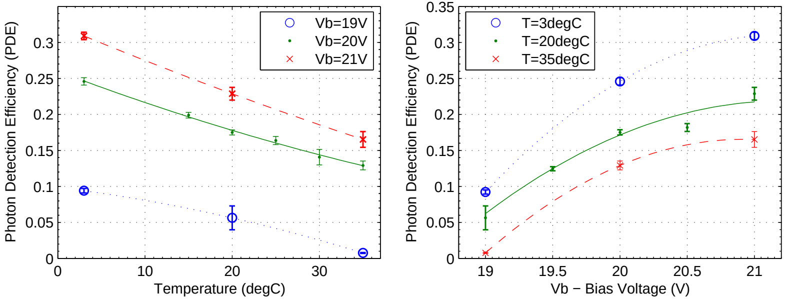
The expected $32 \times 10^3\,\gamma$ in $2\,\mathrm{cm}$ of scintillator yield $\sim 250\,\mathrm{p.e.}$

Reflective scintillator coating on upstream end can nearly double this figure!

Overall Detector Schematic



Case for Individual Bias Control



Sensitivity to ambient temperature (∼2%/°C) and performance variability from one unit to the next demands individual bias voltage control (∼40%/V.) Compensation for shortcomings in optics is also convenient.

Preparing Fibers and Coupling to Sensors

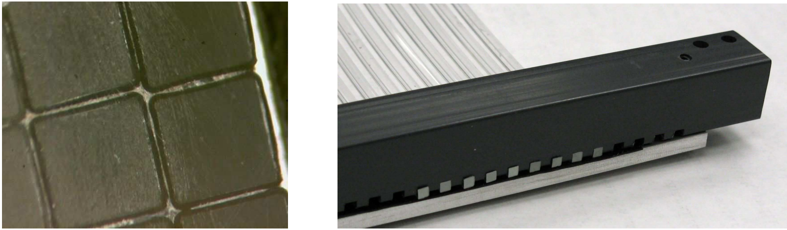


Figure: Fibers cut and polished in bundles (left), glued in arrays (right) and coated to prevent crosstalk. The fixture on the right is also used for coupling fibers to sensor array.

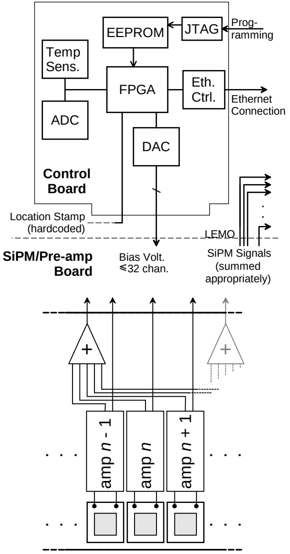
Electronics Overview

Control board:

- FPGA-centered design
- control through ubiquitous, robust, address-aware Ethernet
- V_{bias} via DAC: 32-chan., $14\,\mathrm{bit}$, $\lesssim$ 200 V
- on-board health sensors (Temp., ADC)

Amplifier boards contain:

- array of up to 32 SiPMs
- fast, two-stage transimpedance amplifiers
- summing circuitry
- board temperature sensor ($\pm 0.5°C$)
- precision connectors for alignment with optics



Digital Control Board PCB Layout

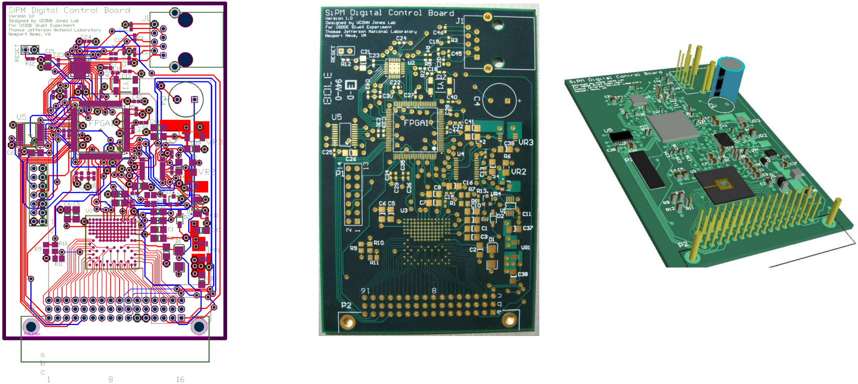
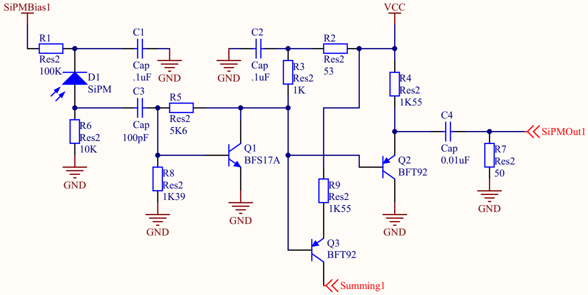


Figure: Layout, PCB and 3D rendering of the eventually populated Digital Control Board.

SiPM Bias and Pre-Amplification



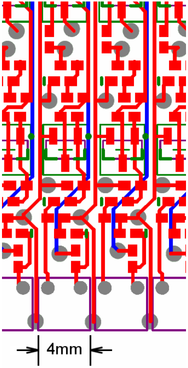
Transimpedance amplifier
- closely modeled after the one provided by the SiPM vendor

- 2-stage device: amplifier and driver
- $\sim 3\mathrm{k}\Omega$ gain @ $V_{cc} = 5\,\mathrm{V}$
- $\sim 25\,\mathrm{ns}$ fall time given C_{SiPM}

Design and Layout of Pre-Amp for Microscope Use

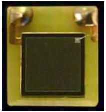
Adaptation of amplifier for operation in microscope

- summing circuit with input drivers added
- pre-amp component values optimized for:
  - expected signals from optics+SiPM
  - operation with an $8\,\mathrm{bit}$ $(0.5 - 2\,\mathrm{V}$ range), $250\,\mathrm{MHz}$ fADC for online testing
  - controllable gain up into single photon counting range (useful for testing with built-in pulser)
  - insensitivity to variation of transistor β
  - short pulses for higher rate capability



Work in progress:

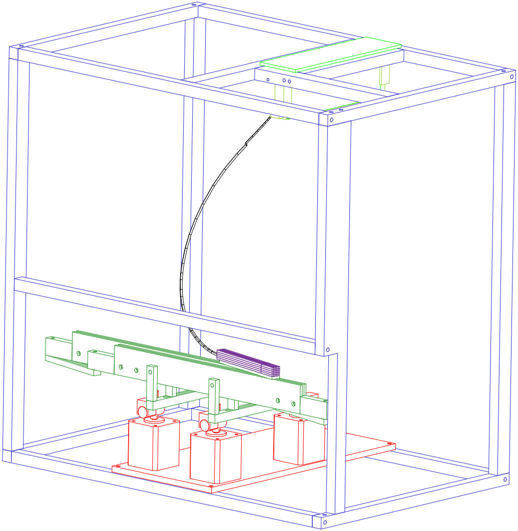
- Amplifier prototyping
- PCB Layout of the full 32-amp board



Microscope Prototype

Realistic test of microscope design:

- all electronic, optical and mechanical components tested
- scaled to 5% of full channel count
- $46\,\mathrm{cm} \times 30\,\mathrm{cm} \times 46\,\mathrm{cm}$ enclosure
- currently being assembled for testing



Summary

The Hall D tagger microscope design presents:

- excellent timing resolution
- high energy resolution ($8\,\mathrm{MeV}$ in range of interest to GlueX)
- exploits vertical focusing of tagger optics
- enhanced tagging efficiency through vertical segmentation to match collimator acceptance
- compact, low-voltage readout design through use of SiPMs
- versatile electronics for amplification and monitoring
- flexible design for use anywhere along the focal plane

Outlook

- Prototype beam test: 2009-2010
- Full microscope construction scheduled for 2011

Distribution of Bremsstrahlung Photons

Distribution of bremsstrahlung γ's in angle and energy

- coherent
- incoherent