Search for Gluonic Excitations in Hadrons with GlueX

Hadron 2011

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Outline

Physics Motivation

Can we probe the gluonic field in hadrons directly?

- **hybrid mesons** (i.e. with gluonic excitation)

■ approved

Other physics:

- precision measurement of $\Gamma(\eta \to \gamma\gamma)$ via Primakoff effect
- general light-quark spectroscopy, e.g.
  - excited vector mesons poorly understood
  - strange sector analogs of X, Y, Z mesons
- understand the Ξ spectrum
- inverse DVCS
- production near charm threshold
- hadronization in the nuclear medium

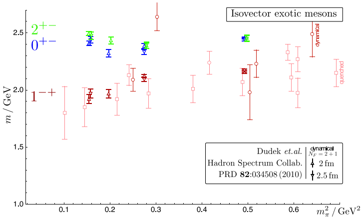

Figure: Lattice QCD mass predictions as a function of pion mass. (J. Dudek et al., 2010)

Meson Quantum Numbers

Consider the $q\bar{q}$ system and its J^{PC} quantum numbers. Since:

- $S = 0, 1$ and $L = 0, 1, 2, \ldots \implies J = L - 1, L, L + 1$
- $P = (-1)^{L+1}$ and $C = (-1)^{L+S}$

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$\therefore$ $q\bar{q}$ quantum numbers:

J	$--$	$++$	$-+$	$+-$
0		0^{++}	0^{-+}	
1	1^{--}	1^{++}		1^{+-}
2	2^{--}	2^{++}	2^{-+}	
3	3^{--}	3^{++}		3^{+-}
4	4^{--}	4^{++}	4^{-+}	
5	5^{--}	5^{++}		5^{+-}

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$\therefore$ $q\bar{q}$ quantum numbers: "exotic" quantum numbers:

J	$--$	$++$	$-+$	$+-$
0	**0^{--}**	0^{++}	0^{-+}	**0^{+-}**
1	1^{--}	1^{++}	**1^{-+}**	1^{+-}
2	2^{--}	2^{++}	2^{-+}	**2^{+-}**
3	3^{--}	3^{++}	**3^{-+}**	3^{+-}
4	4^{--}	4^{++}	4^{-+}	**4^{+-}**
5	5^{--}	5^{++}	**5^{-+}**	5^{+-}

- Exotic states $\implies$ unambiguous signature of new degrees of freedom

Exotic States: Experimental Evidence

The following are some tentative observations of possible exotic states thus far: [1]

State	Mass (GeV)	Width (GeV)	Prod.	Decays	Experiments
$\pi_1(1400)$	1.351 ± 0.03	0.313 ± 0.040	$\pi^- p$, $\bar{p}n$	$\pi^- \eta$,$\pi^0 \eta$	E852, CBAR
$\pi_1(1600)$	1.662 ± 0.015	0.234 ± 0.050	$\pi^- p$, $\bar{p}p$	$\eta' \pi$, $b_1 \pi$, $f_1 \pi$, $\rho\pi$	E852, CBAR, COMPASS, VES
$\pi_1(2015)$	2.01 ± 0.03	0.28 ± 0.05	$\pi^- p$	$b_1\pi$,$f_1\pi$	E852

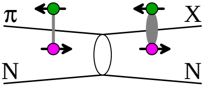
[1] masses and widths from PDG

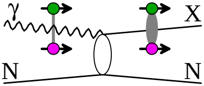
Production Method

Data so far: (mostly) π beam prod. $\Longleftarrow$ exotic hybrid prod. suppressed?

A possible argument: the spin flip needed for exotic q.n. is suppressed.

Proposal: use $S = 1$ beam $\rightarrow$ photons! Lowest-lying hybrids (flux-tube model):

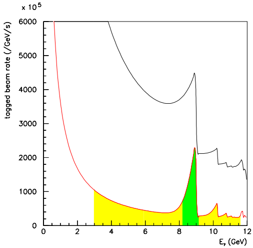




π beam ($S = 0$)		γ beam ($S = 1$)	
$\mathbf{0^{--}}$	0^{++}	0^{-+}	$\mathbf{0^{+-}}$
1^{--}	1^{++}	$\mathbf{1^{-+}}$	1^{+-}
2^{--}	2^{++}	2^{-+}	$\mathbf{2^{+-}}$

γ beam source: Coherent Bremsstrahlung in diamond

- 9 GeV, 40% polarization fraction
- $10^8 \gamma/s$ with $\sim 2\,\mu$A beam current
- collimation 75 m downstream
- 8 MeV/counter tagging with high efficiency



12 GeV upgrade

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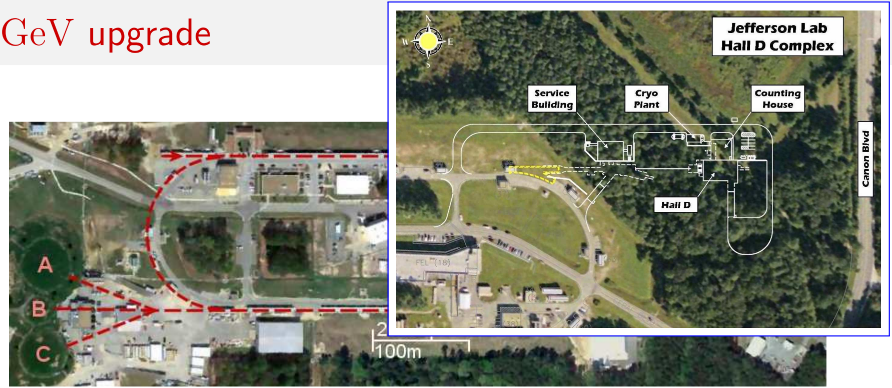

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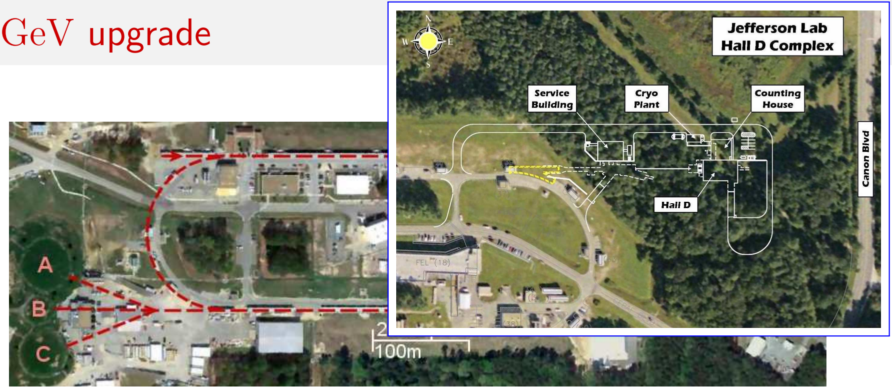
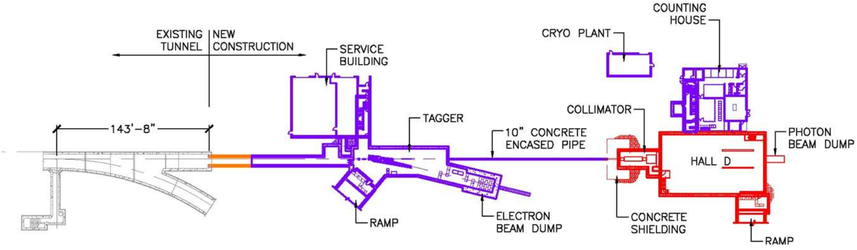
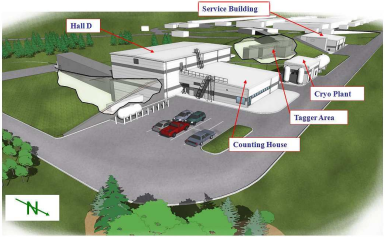




Hall Construction



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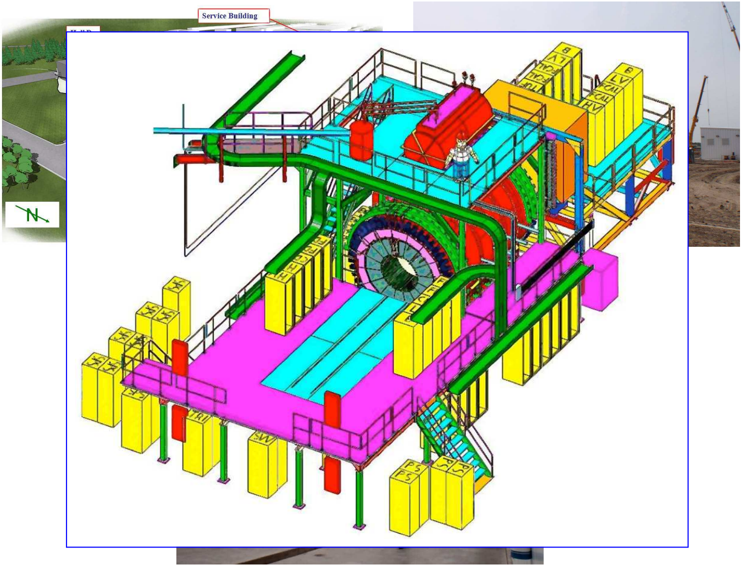
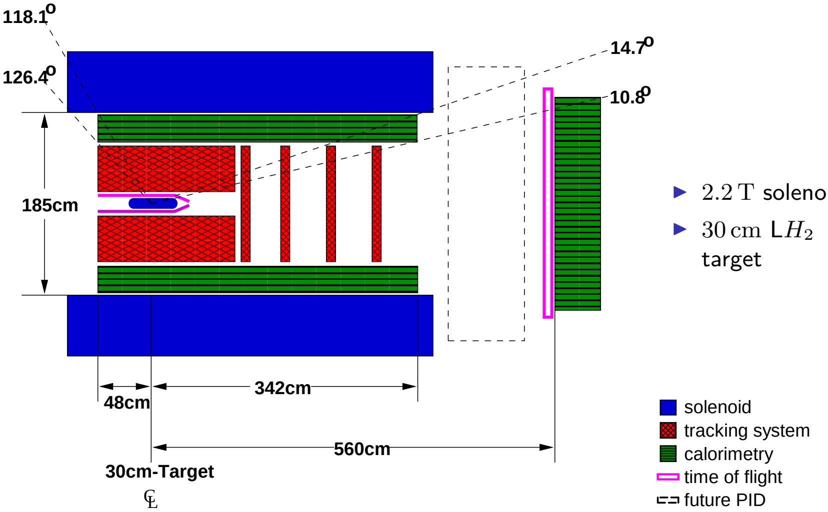
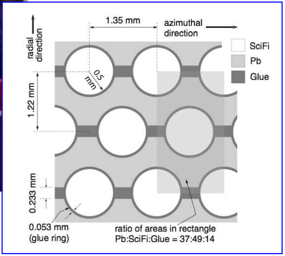


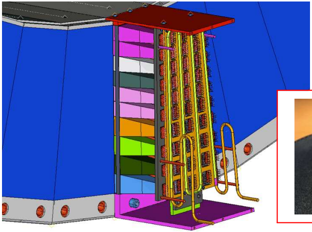
Detector Overview

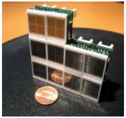


- 2.2 T solenoid
- 30 cm LH_2 target

Barrel Calorimeter (BCAL)







Sampling (10%) SpaCal

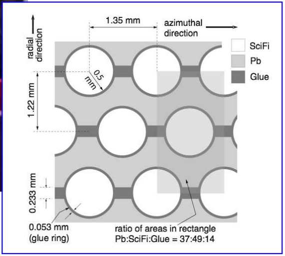
Design based on KLOE Emcal:

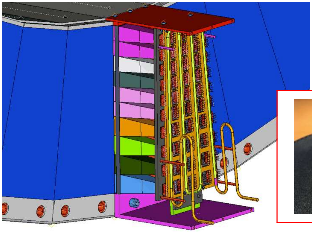
- $40\,\mathrm{MeV} - 3.5\,\mathrm{GeV}$ range
- $11^\circ < \theta < 120^\circ$ coverage
- 191 Sci/Pb layers $\rightarrow$ $15.5\,\mathrm{X}_0$
- $\sigma_E/E = 5.54/\sqrt{E} \oplus 1.6\%$
- $\sigma_z = 5\,\mathrm{mm}$
- $\sigma_{\Delta t/2} = 70\,\mathrm{ps}/\sqrt{E}$
- $+5\,^\circ\mathrm{C}$-stabilized Hamamatsu SiPM readout

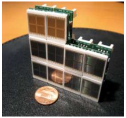
Role:

- γ, π^0, η reconstruction
- PID input through: energy, dE/dx, time of flight

Barrel Calorimeter (BCAL)







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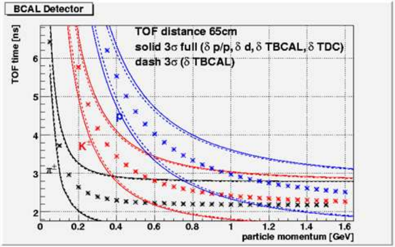
TOF



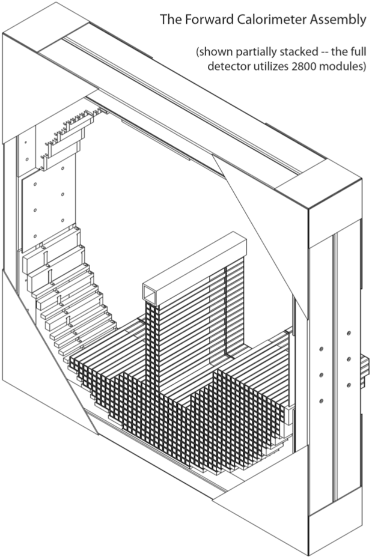
Role:

- γ, π^0, η reconstruction
- PID input through: energy, dE/dx, time of flight

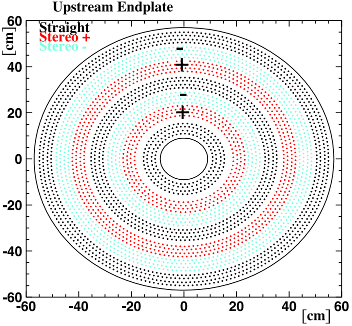
Forward Calorimeter (FCAL)

Lead Glass Calorimeter

- $2^\circ < \theta < 11^\circ$ coverage
- 2800 F8-00 and F108 Pb-glass blocks: $4 \times 4 \times 45\,\mathrm{cm}$
- FEU 84-3 PMT readout
- $\sigma_E/E = 5.7/\sqrt{E} \oplus 1.6\%$
- $\sigma_r = 5 - 6\,\mathrm{mm}$
- $\sigma_t < 150\,\mathrm{ps}$ using algorithms on FPGA

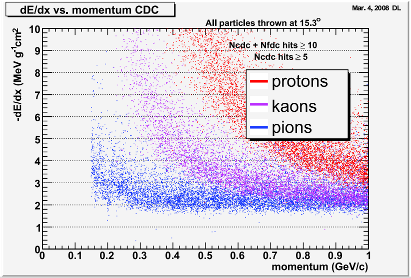


Central Drift Chamber (CDC)



Staw Tube Drift Chamber

- 3522 aluminized mylar straw tubes, $1.6\,\mathrm{cm}$ dia.
- 12 axial, 16 (6°) stereo layers
- dE/dx for π,K, $p < 450\,\mathrm{MeV/c}$
- $\sigma_r = 150\,\mu\mathrm{m}$, $\sigma_z = 1.5\,\mathrm{mm}$
- $\sigma_p/p = 1.5 - 3\%$
- $6^\circ < \theta < 165^\circ$ coverage



Forward Drift Chamber

Cathode Strip Design:

- 4 packages × 6 planes/package × 96 wires/plane = 2304 wires
- 4 packages × 12 planes/package × 216 strips/plane= 10368 strips

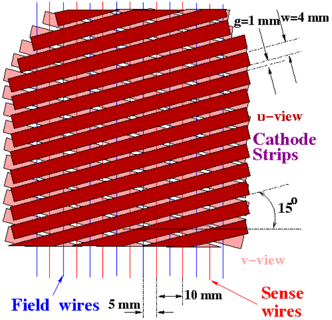
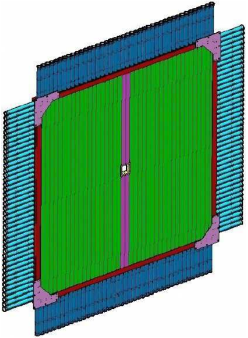


Figure: Cathode readout, redundancy and angular shifts to reduce ghosting. Next layer offset by 60°

- $1\,\mathrm{cm}$ sense wire pitch
- $0.5\,\mathrm{cm}$ cathode plane pitch
- $\sigma_{x,y} = 200\,\mu\mathrm{m}$
- $1^\circ < \theta < 30^\circ$ coverage

Time of Flight Wall and Start Counter

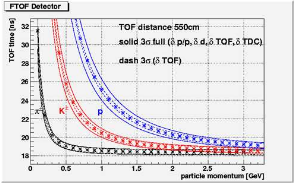


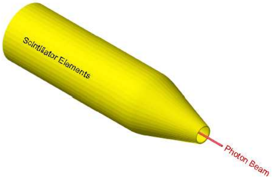
Time of Flight Wall

- cross-hatched scintillator paddles
- $2.5\,\mathrm{cm}$ thick, $6\,\mathrm{cm}$ wide
- double-sided readout
- goal: $100\,\mathrm{ps} = (\sigma_0 = 80\,\mathrm{ps}) \oplus (\sigma_{TDC} = 60\,\mathrm{ps})$
  Demonstrated so far: $110\,\mathrm{ps}$

Start Counter: beam bunch ID

- 40 scintillators with cooled SiPM readout
- σ_t optimization in progress: material/resolution trade-off





Electronics & Software

Fully pipelined front-end electronics

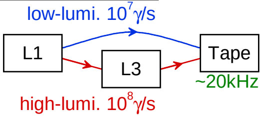
- VMEx64/VXS startards
- fADC: 12 bit, $8\,\mu\mathrm{s}$ buffer with FPGA-based algorithms. Version:
  - 250 MHz, 16 channel
  - 125 MHz, 72 channel
- F1TDC: $3.9\,\mu\mathrm{s}$ buffer ($3\,\mu\mathrm{s}$ trigger latency expected)
  - 60 ps resolution, 32 channel
  - 120 ps resolution, 64 channel
- $\sim 3\,\mathrm{GB/s}$ DAQ rate, $\sim 300\,\mathrm{MB/s}$ to tape $\rightarrow$ L3 computer farm essential

Software: significant efforts in parallelization

1. vectorized operations on CPU (SIMD etc.)
2. GPU for PWA fits, tracking?
3. fully-multithreaded reconstruction/analysis code, on-demand reconstruction
4. integration of beowulf clusters and collaboration with Open Science Grid (OSG)

Trigger

Goal: high-multiplicity, minimum-bias events $E_\gamma > 8.4\,\mathrm{GeV}$



1. commissioning, warm-up at $10^7\,\gamma/\mathrm{s}$
2. full hardonic rate: $10^8\,\gamma/\mathrm{s}$
   $\therefore$ photo-production: $360\,\mathrm{kHz}$

Alogorithm: require:

1. track multiplicity
2. energy minimum:
   $E_{BCAL} = A + B \cdot E_{FCAL}$

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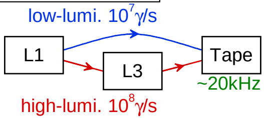

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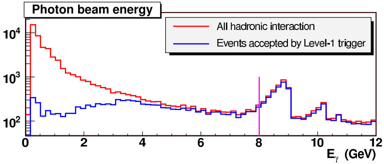

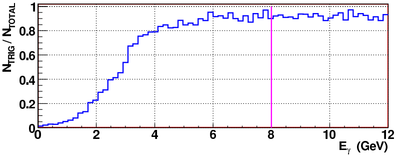

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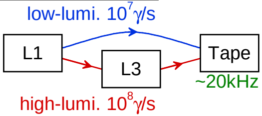

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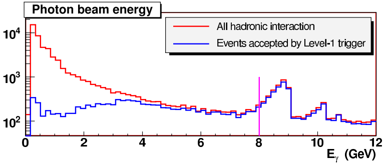
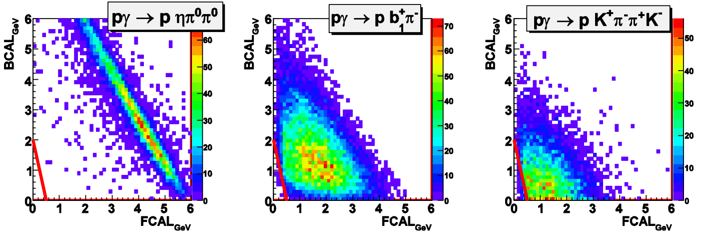




Acceptance relative to E852

Goal set forth: high and uniform acceptance

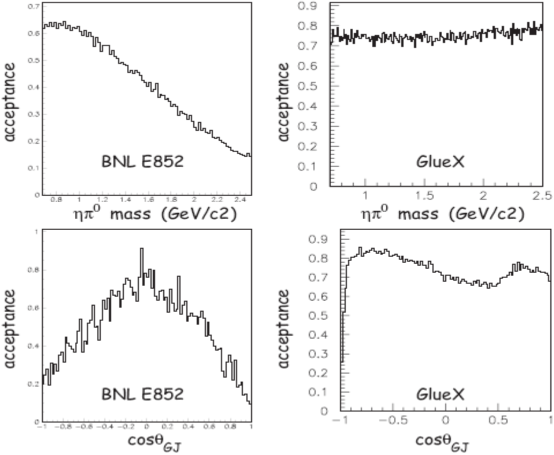


Figure: Comparative acceptance plots in a sample channel: high and uniform acceptance in invariant mass and Gottfried-Jackson frame angles.

Summary

GlueX: an imperative new search

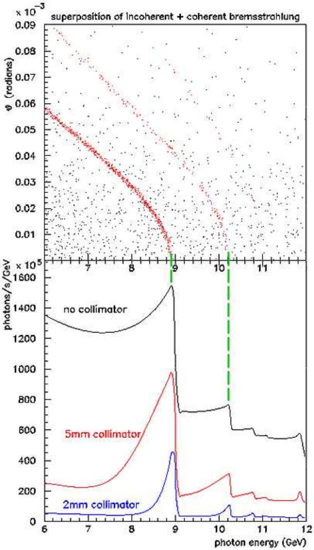
- mesons with excited gluonic degrees of freedom
  - an important test of QCD
  - understanding confinement
- vast new source of photo-production data

Fitness for its mission:

- linearly polarized photon beam
- high statistics with minimum-bias trigger
- hermetic detector $\rightarrow$ proper PWA
- construction on schedule, transition to installation
- beam in 2014
- ...but plenty to do and with many openings for collaborators!

Backup Slides

Coherent Bremsstrahlung



Coherent scattering of e^- on a crystal lattice.

or

quasi-Compton scattering from virtual photons in the crystal reciprocal lattice

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Result: bremsstrahlung spectrum enhancement with polarized γ peaks
Issues: smearing from e^- multiple scattering

Experimental Implementation:
diamond thinned to $20\,\mu m$ to reduce multiple scattering

- 40% pol. frac. under 9 GeV peak
- $10^8\gamma/s$ with $\sim 2\,\mu\mathrm{A}$ beam current
- collimation with long lever arm ($75\,\mathrm{m}$ downstream) to filter out widely distributed incoherent photons.

Beamline

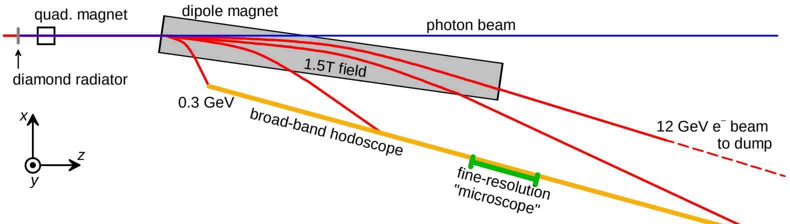
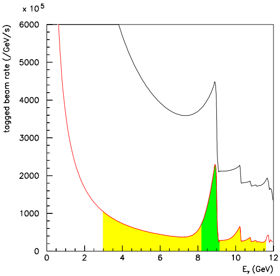


Figure: Schematic of optics in the Tagger Hall.

- Broad-band hodoscope
  - γ-spectrum measured $3 - 11.7\,\mathrm{GeV}$
  - tagging $9 - 11.7\,\mathrm{GeV}$
  - $30\,\mathrm{MeV}/\mathrm{counter}$
- Fine-resolution hodoscope ("microscope")
  - tagging $8.3 - 9.1\,\mathrm{GeV}$
  - $8\,\mathrm{MeV}/\mathrm{counter}$
  - vertical collimation for tagging efficiency improvement



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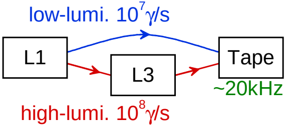


Track multiplicity + energy requirement: $E_{BCAL} = A + B\dot{E}_{FCAL}$

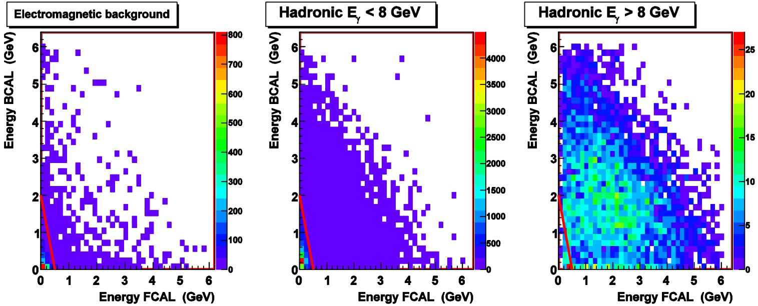
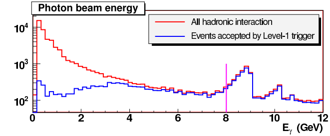


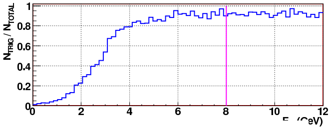
Figure: a distinct, low-end peak in energy distributions $\Longrightarrow$ clear cut!

Trigger Cut Effects

Result:

- low-energy hadronic rate cut with good yield in area of interest
- rate after L1 @ $10^8\,\gamma/\mathrm{s}$: $\sim 150\,\mathrm{kHz} < 200\,\mathrm{kHz}$ limit





Checking some signal channels: