# 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)

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 $\Xi$ spectrum
- inverse DVCS
- production near charm threshold
- hadronization in the nuclear medium

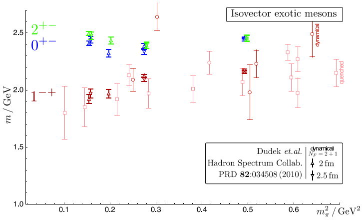


Figure: Lattice QCD mass predictions as a function of pion mass. (J. Dudek et al., 2010)

†approved

# 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 | $\mathbf{0}^{--}$ | $0^{++}$ | $0^{-+}$ | $\mathbf{0}^{+-}$ |
| 1 | $1^{--}$ | $1^{++}$ | $\mathbf{1}^{-+}$ | $1^{+-}$ |
| 2 | $2^{--}$ | $2^{++}$ | $2^{-+}$ | $\mathbf{2}^{+-}$ |
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- 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 |
|---|---|---|---|---|---|
| $\pi_1(1400)$ | $1.351 \pm 0.03$ | $0.313 \pm 0.040$ | $\pi^- p$, $\bar{p}n$ | $\pi^-\eta$, $\pi^0\eta$ | E852, CBAR |
| $\pi_1(1600)$ | $1.662 \pm 0.015$ | $0.234 \pm 0.050$ | $\pi^- p$, $\bar{p}p$ | $\eta'\pi$, $b_1\pi$, $f_1\pi$, $\rho\pi$ | E852, CBAR, COMPASS, VES |
| $\pi_1(2015)$ | $2.01 \pm 0.03$ | $0.28 \pm 0.05$ | $\pi^- p$ | $b_1\pi$, $f_1\pi$ | E852 |

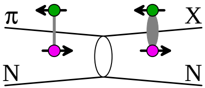
[1] masses and widths from PDG

# Production Method

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

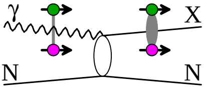
A possible argument: the spin flip needed for exotic q.n. is suppressed.

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




$\pi$ beam ($S = 0$)

| | |
|---|---|
| $0^{--}$ | $0^{++}$ |
| $1^{--}$ | $1^{++}$ |
| $2^{--}$ | $2^{++}$ |




$\gamma$ beam ($S = 1$)

| | |
|---|---|
| $0^{-+}$ | $\mathbf{0^{+-}}$ |
| $\mathbf{1^{-+}}$ | $1^{+-}$ |
| $2^{-+}$ | $\mathbf{2^{+-}}$ |

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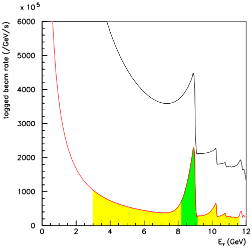
$\gamma$ beam source: Coherent Bremsstrahlung in diamond

- 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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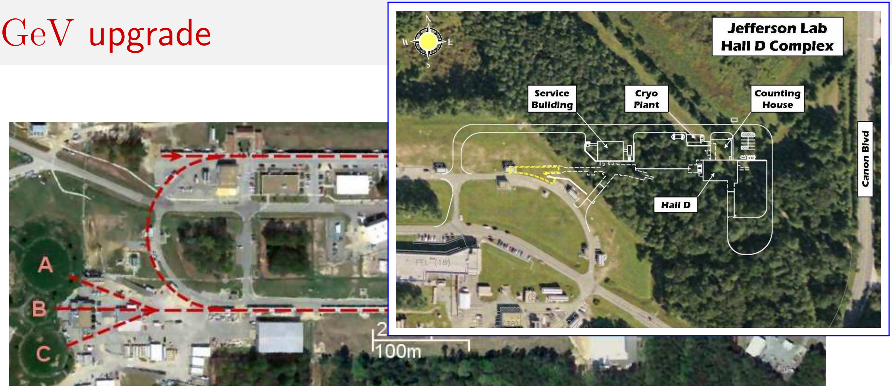

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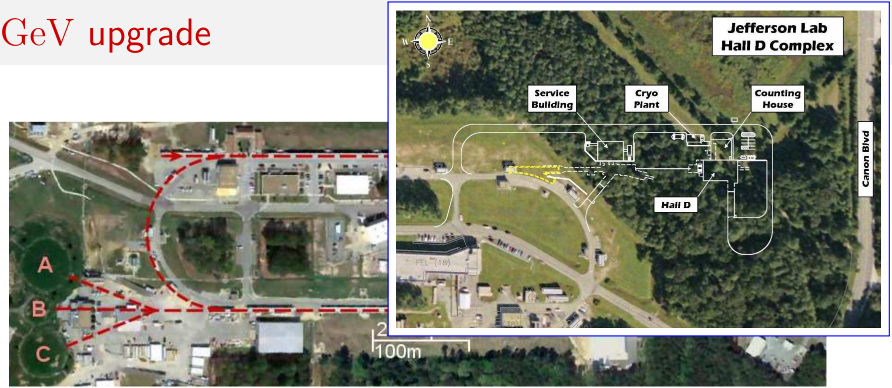
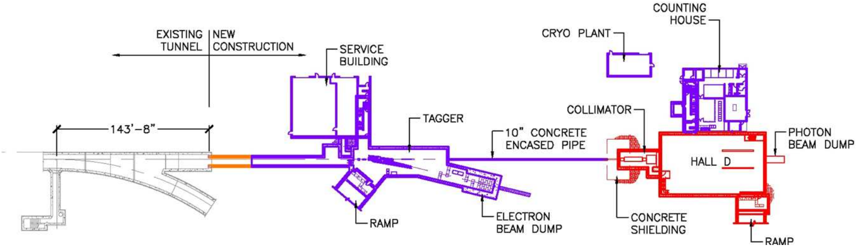
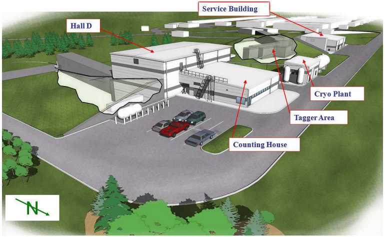


# Hall Construction

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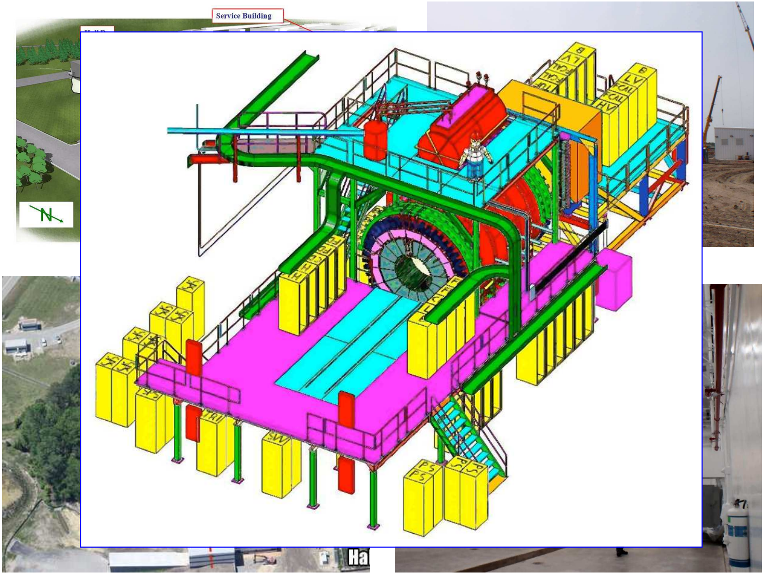
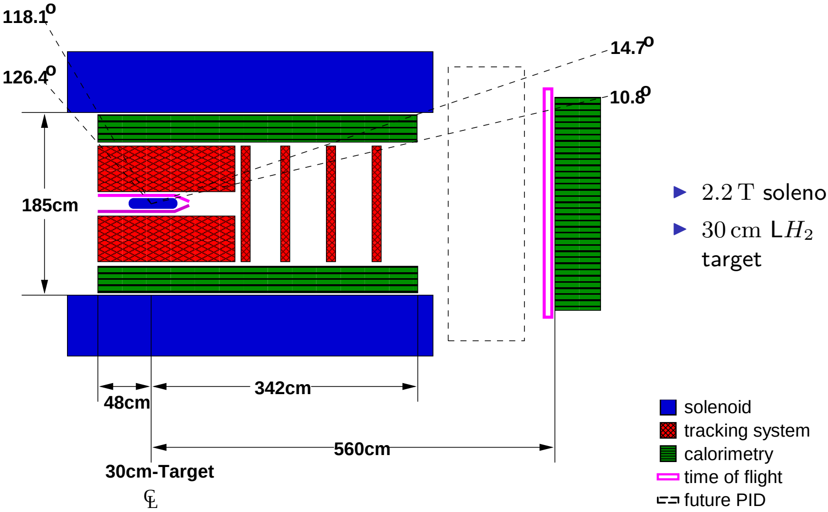
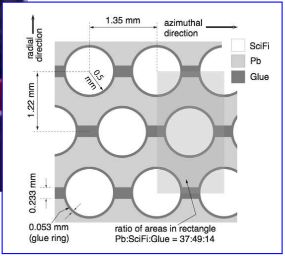


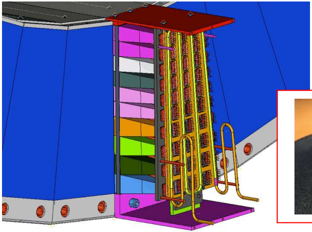
# Detector Overview

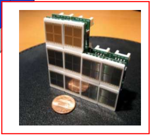



- 2.2 T solenoid
- 30 cm $LH_2$ target

# 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:

- $\gamma$, $\pi^0$, $\eta$ reconstruction
- PID input through: energy, dE/dx, time of flight

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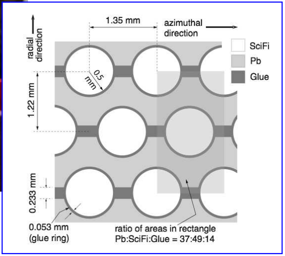


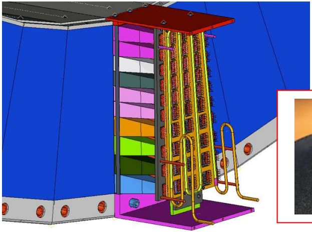

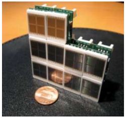

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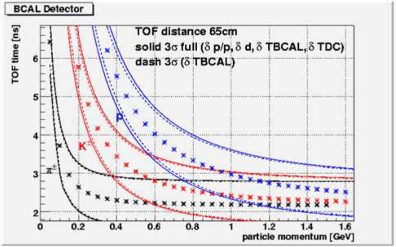
### TOF



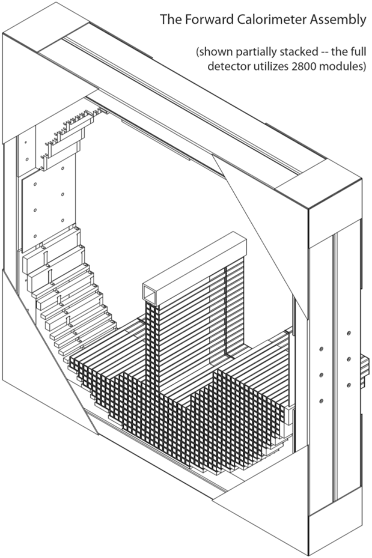

Role:

- $\gamma$, $\pi^0$, $\eta$ reconstruction
- PID input through: energy, dE/dx, time of flight

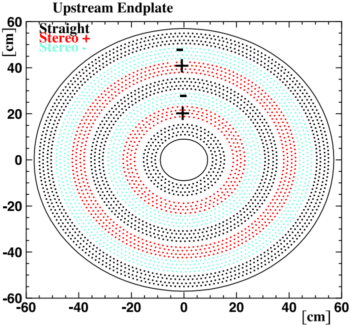
# Forward Calorimeter (FCAL)

## Lead Glass Calorimeter

- $2^\circ < \theta < 11^\circ$ coverage
- 2800 F8-00 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

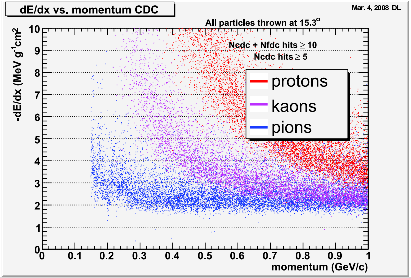


# Central Drift Chamber (CDC)




Staw Tube Drift Chamber

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

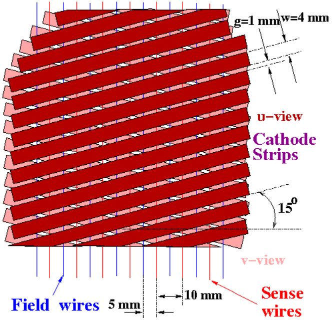
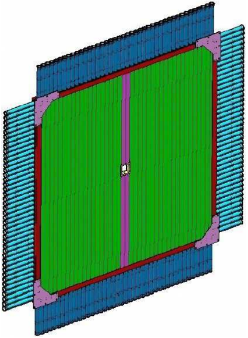



Figure: Cathode readout, redundancy and angular shifts to reduce ghosting. Next layer offset by $60^\circ$

- $1\,\mathrm{cm}$ 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

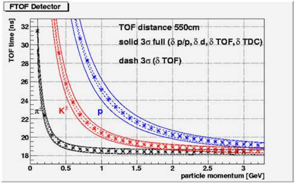


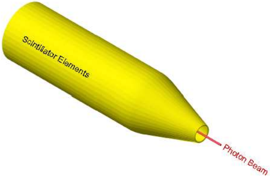
## Time of Flight Wall

- 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
- $\sigma_t$ optimization in progress: material/resolution trade-off



# Electronics & Software

## Fully pipelined front-end electronics

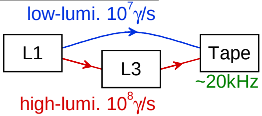
- VMEx64/VXS startards
- fADC: 12 bit, $8\,\mu s$ buffer with FPGA-based algorithms. Version:
  - 250 MHz, 16 channel
  - 125 MHz, 72 channel
- F1TDC: $3.9\,\mu s$ buffer ($3\,\mu s$ trigger latency expected)
  - 60 ps resolution, 32 channel
  - 120 ps resolution, 64 channel
- $\sim 3\,\mathrm{GB/s}$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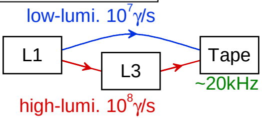


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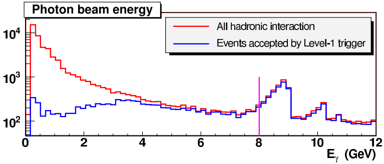


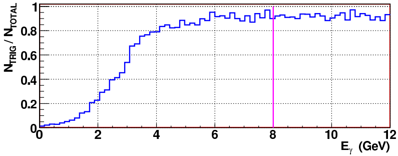

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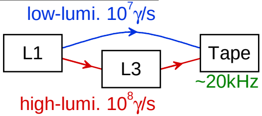


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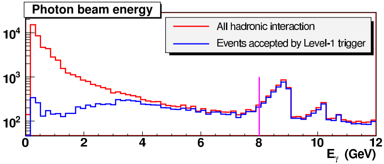
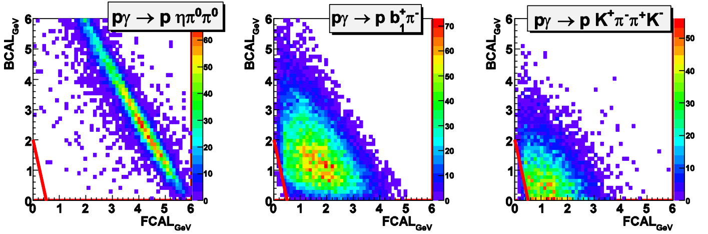


# Acceptance relative to E852

Goal set forth: high and uniform acceptance

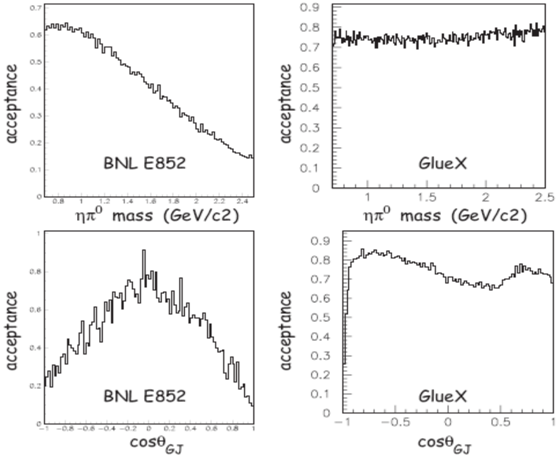



Figure: Comparative acceptance plots in a sample channel: high and uniform acceptance in invariant mass and Gottfried-Jackson frame angles.

# Summary

## GlueX: an imperative new search

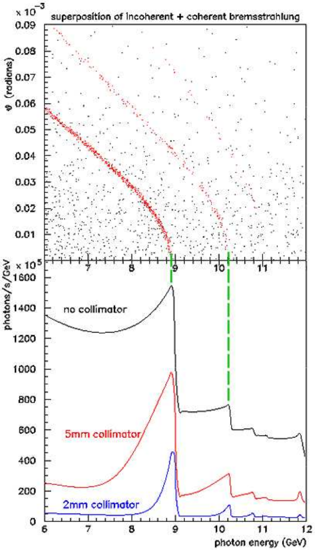
- mesons with excited gluonic degrees of freedom
  - an important test of QCD
  - understanding confinement
- vast new source of photo-production data

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 $\gamma$ peaks

Issues: smearing from $e^-$ multiple scattering

Experimental Implementation:

diamond thinned to $20\,\mu\mathrm{m}$ to reduce multiple scattering

- 40% pol. frac. under 9 $\mathrm{GeV}$ 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

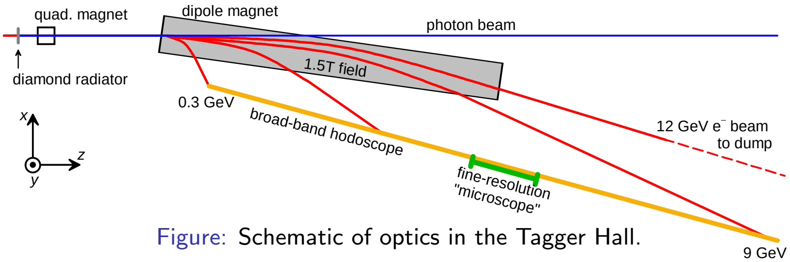
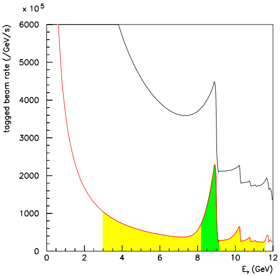



Figure: Schematic of optics in the Tagger Hall.

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



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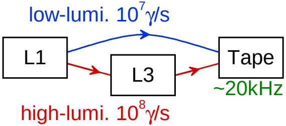



**Track multiplicity + energy requirement:** $E_{BCAL} = A + B\dot{E}_{FCAL}$

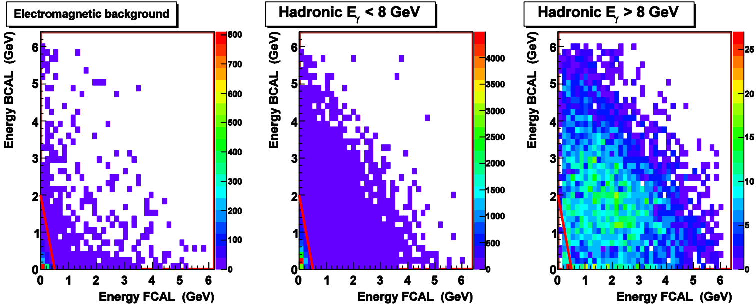
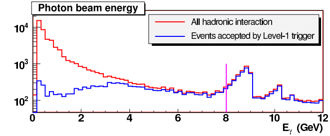


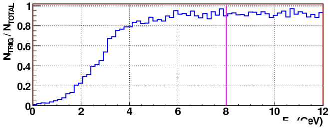

Figure: a distinct, low-end peak in energy distributions $\Longrightarrow$ clear cut!

# 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: