Overview of Hall D Complex

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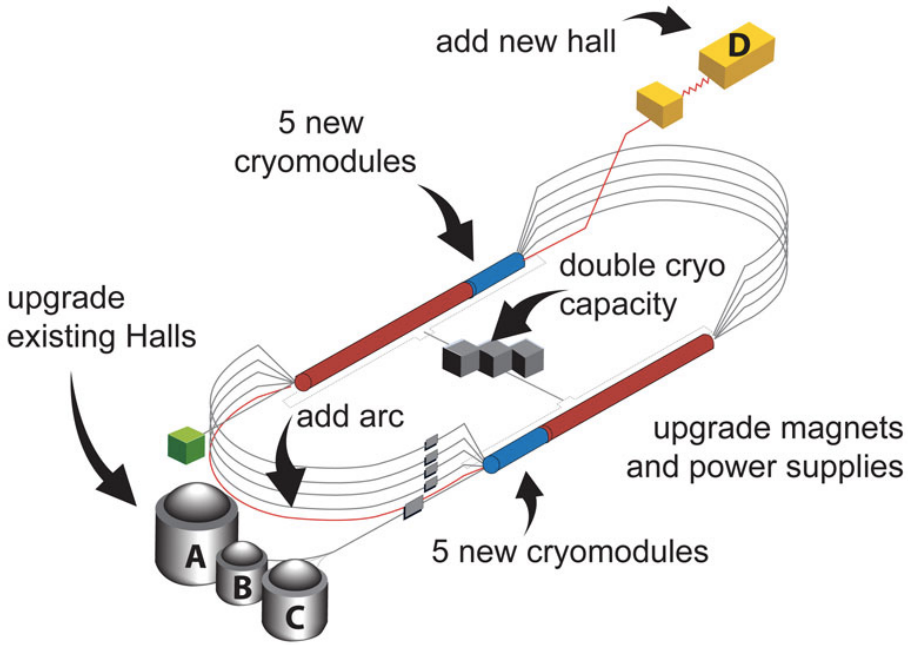
[1]JLab

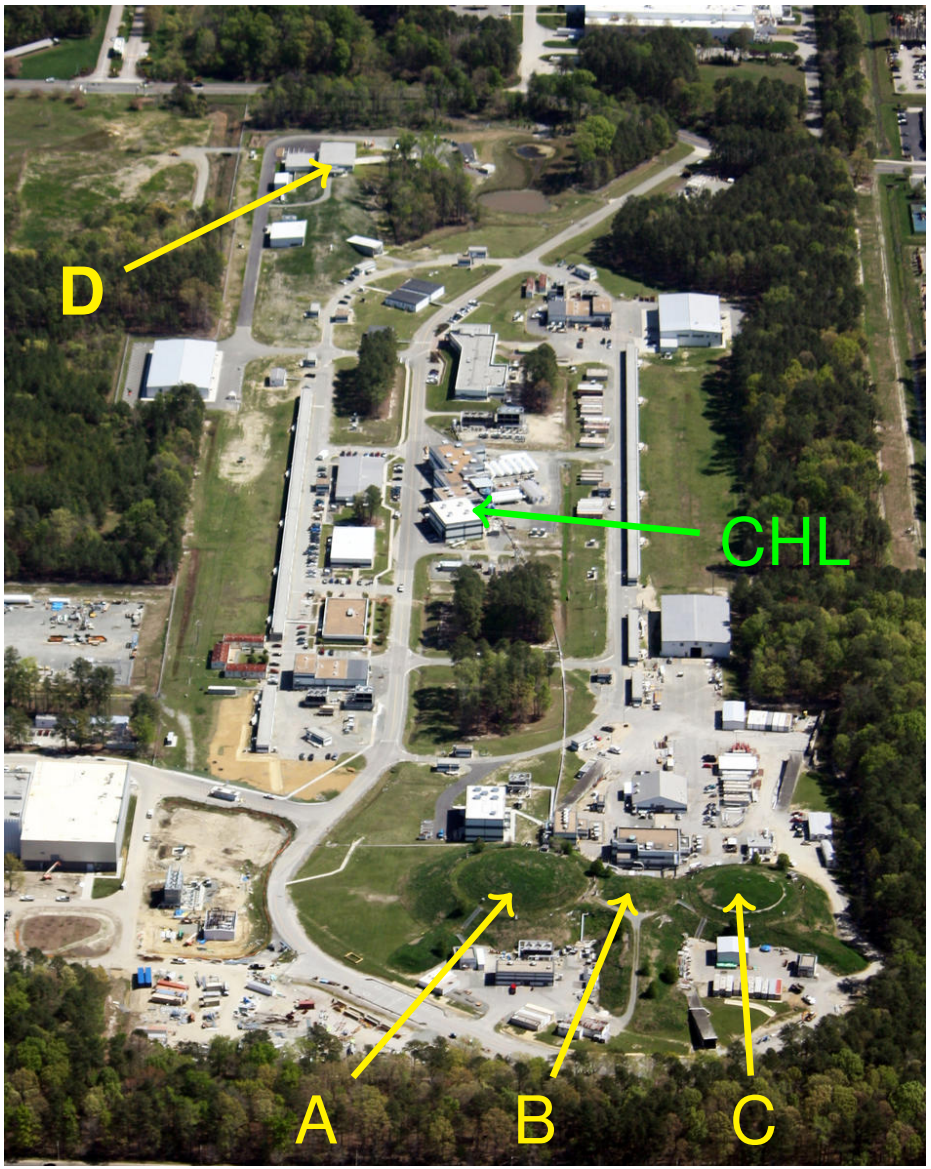
Presented at Workshop
Physics with Neutral Kaon Beam at JLab, KL2016
JLab, 1-3 Feb 2016


Outline

1. JLab at 12 GeV
2. Physics motivation for Hall D: meson spectroscopy
3. Experiment GlueX in Hall D
   - Apparatus
   - Performance during commissioning
4. Experimental program and future plans

CEBAF Upgrade to 12 GeV





Upgrade Goals

- Accelerator: 6 GeV $\Rightarrow$ 12 GeV
- Halls A,B,C: e^- <11 GeV, < 100 μA
- Hall D: e^- 12 GeV $\Rightarrow$ γ-beam

Upgrade Status

- Reached 12 GeV in Dec 2015
- Halls A,D: finished
- Halls B,C: about a year to go

Hall D at Jefferson Lab

- Hall D - a new hall at Jefferson Lab
  - Construction finished in 2015 *(∼$50M project, without the civil part)*
  - Commissioning is in progress
- Physics with high intensity polarized photon beams
  - *Experiment GlueX: search for exotic hybrid mesons*
  - Radiative widths of pseudoscalars, pion polarizability
  - Other topics in preparation: rare decays; nuclear effects
- A new beamline and a new large acceptance detector
  - Coherent Bremsstrahlung $\Rightarrow$ linearly polarized photons
  - Large solenoidal spectrometer $\Rightarrow$ a uniform acceptance
  - Fully pipelined electronics $\Rightarrow$ very high trigger/DAQ rate

Meson spectroscopy

Naive quark model:

- Mesons are $\overline{q}q$, constituent quarks are $S = 1/2$ fermions
- No gluonic degrees of freedom
- Restrictions on the quantum numbers: J^{PC}:
  $P = (-1)^{L+1}$, $C = (-1)^{L+S}$

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

$q\overline{q}$ QN "exotic" QN

Glue and spectroscopy

Gluonic excitations $\Rightarrow$ *hybrid mesons*

- Predicted by models, Lattice QCD
- "Constituent gluon":
  LQCD: 1^{+-}, mass of 1-1.5 GeV
- Exotic QN: an excellent signature
  of a new degree of freedom
  no mixing with the regular $\overline{q}q$ states

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Lattice QCD - the Meson Spectra

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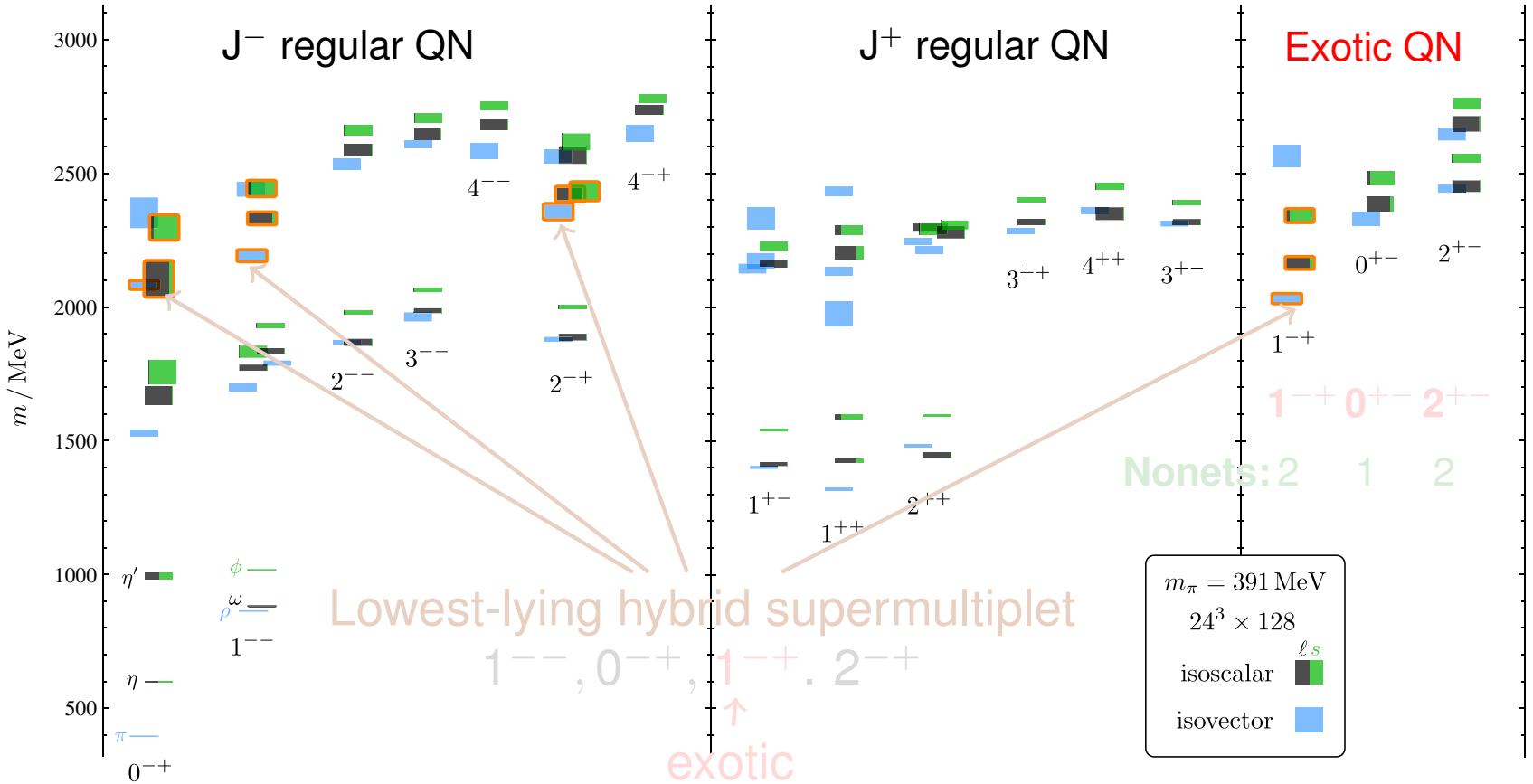
Hybrids identified: States with non-trivial gluonic fields



Calculations for $m_\pi \sim 400 MeV$

Orange frames - lightest hybrids

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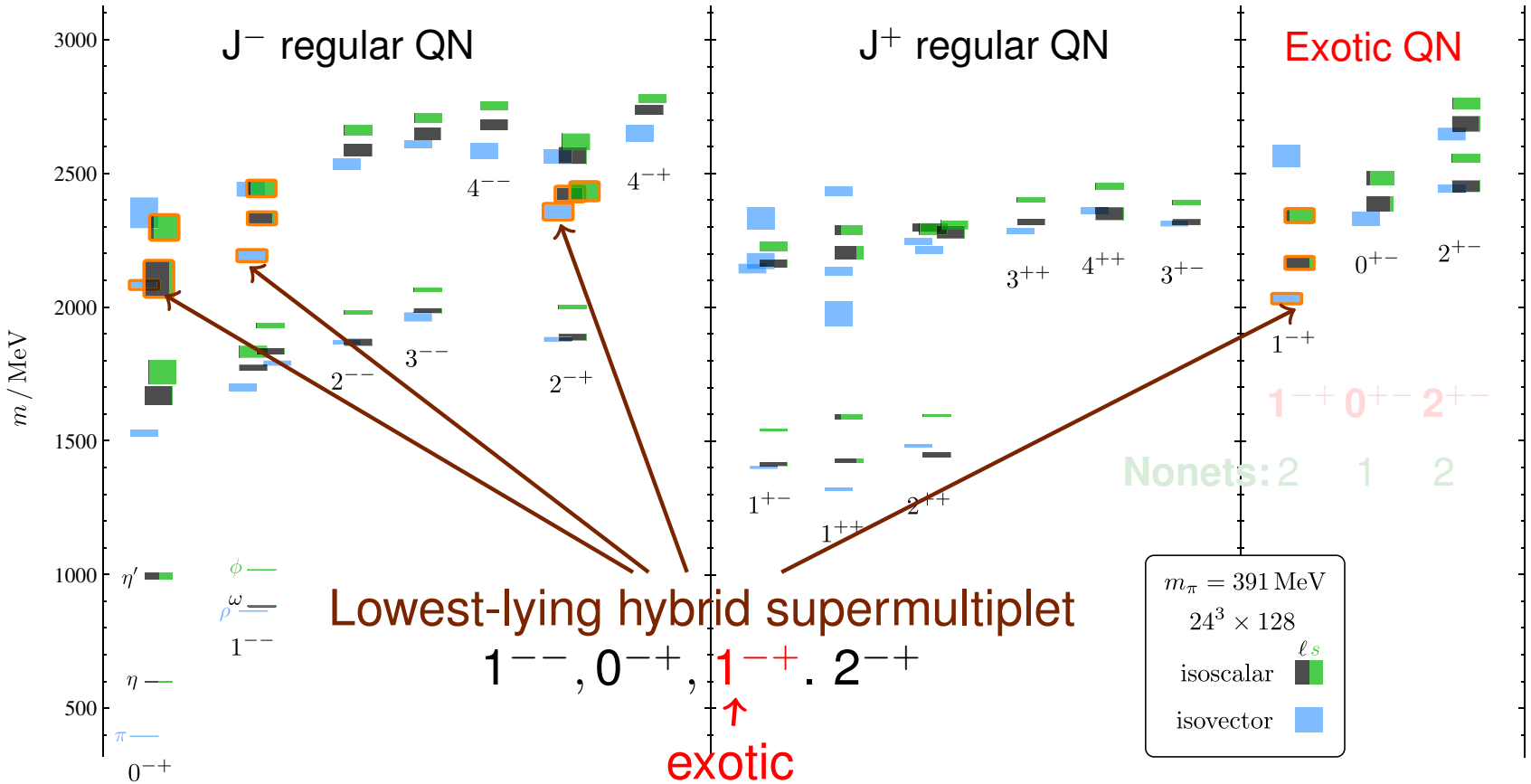

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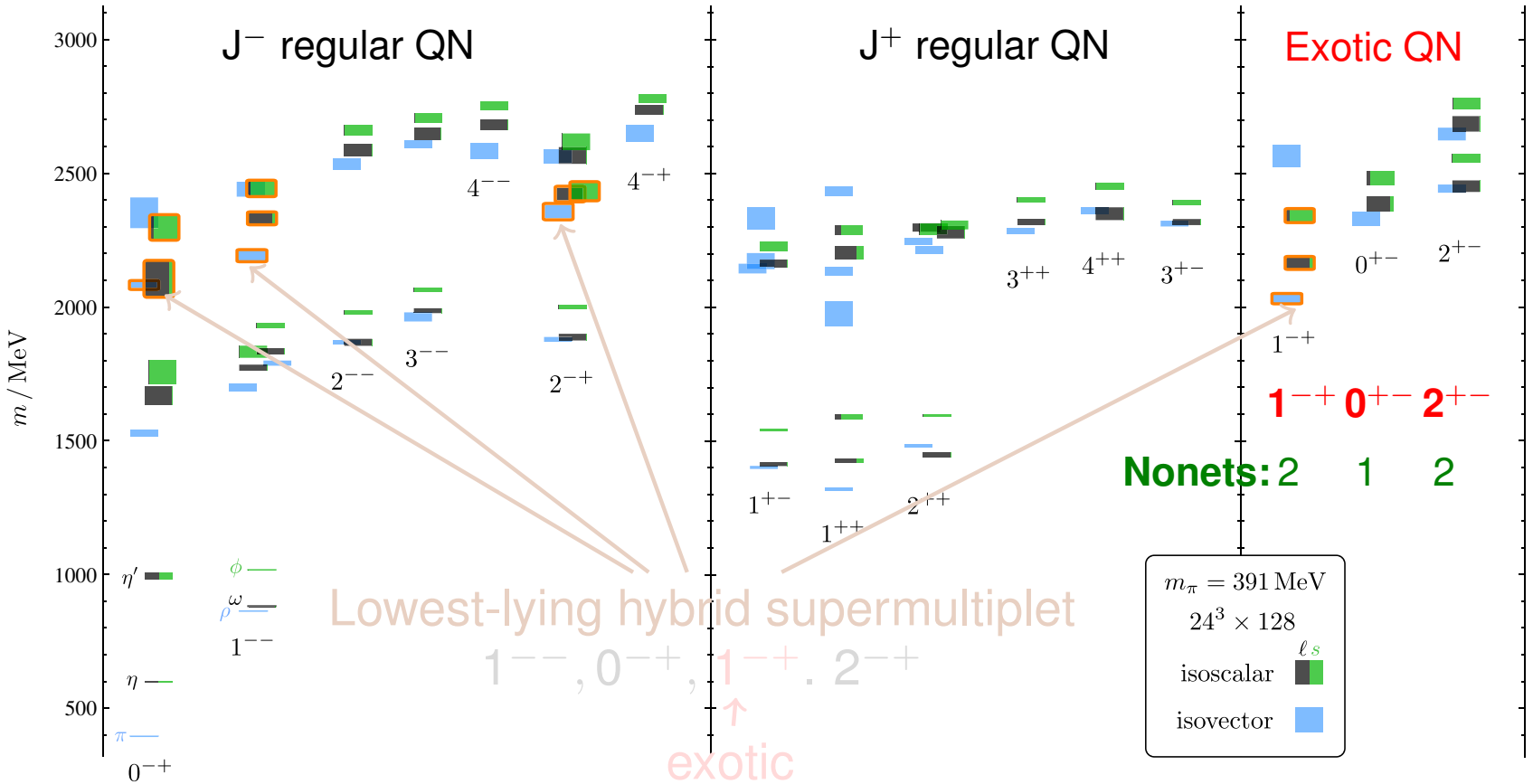

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Hybrids: expected features and ways to detect

Masses

- LQCD: 1^{-+} $\sim$2.0 – 2.4 GeV/c^2
  0^{+-} $\sim$2.3 – 2.5 GeV/c^2
  2^{+-} $\sim$2.4 – 2.6 GeV/c^2

Full Widths

- *Models*: 0.1 – 0.5 GeV/c^2

Decays

- Final states: multiple $\pi^{\pm}$ and γ

No calculations for the decay widths or cross sections so far.

How to detect the hybrids?

- Detect the final states
- Identify the QN using the Partial Wave Analysis (PWA)

GlueX Experiment: Design Goals and Features

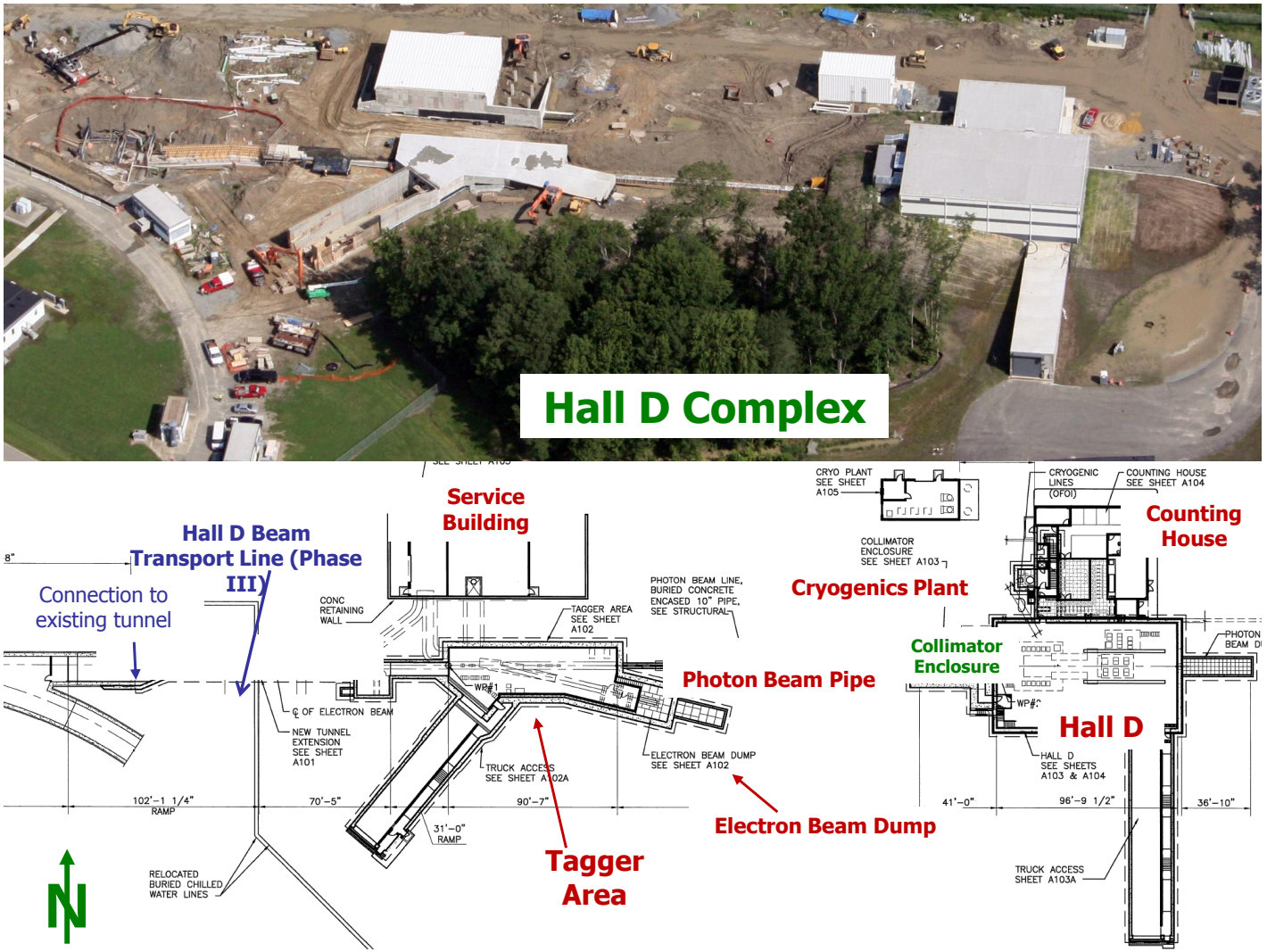
- General requirements:
  - Hermeticity and uniform acceptance for charged particles and photons
  - Good enough resolution to identify exclusive reactions
  - High statistics
- Specific feature: tagged photon beam
  - *Linear polarization helps the QN identification*
  - Beam γ and π^- have different couplings to the hybrid states $\Rightarrow$ complementary to the π^--beam experiments
  - Few photoproduction data exist so far
- Considerable theoretical support for the PWA

The GlueX Collaboration

Arizona State, Athens, Carnegie Mellon, Catholic University, Univ. of Connecticut, Florida International, Florida State, George Washington, Glasgow, GSI, Indiana University, ITEP, Jefferson Lab, U. Mass. Amherst, MIT, MEPhi, Norfolk State, North Carolina A&T, Univ. North Carolina Wilmington, Northwestern, Santa Maria, University of Regina, and Yerevan Physics Institute.

Over 100 collaborators from 23 institutions. Others are planning to join and more are welcome.

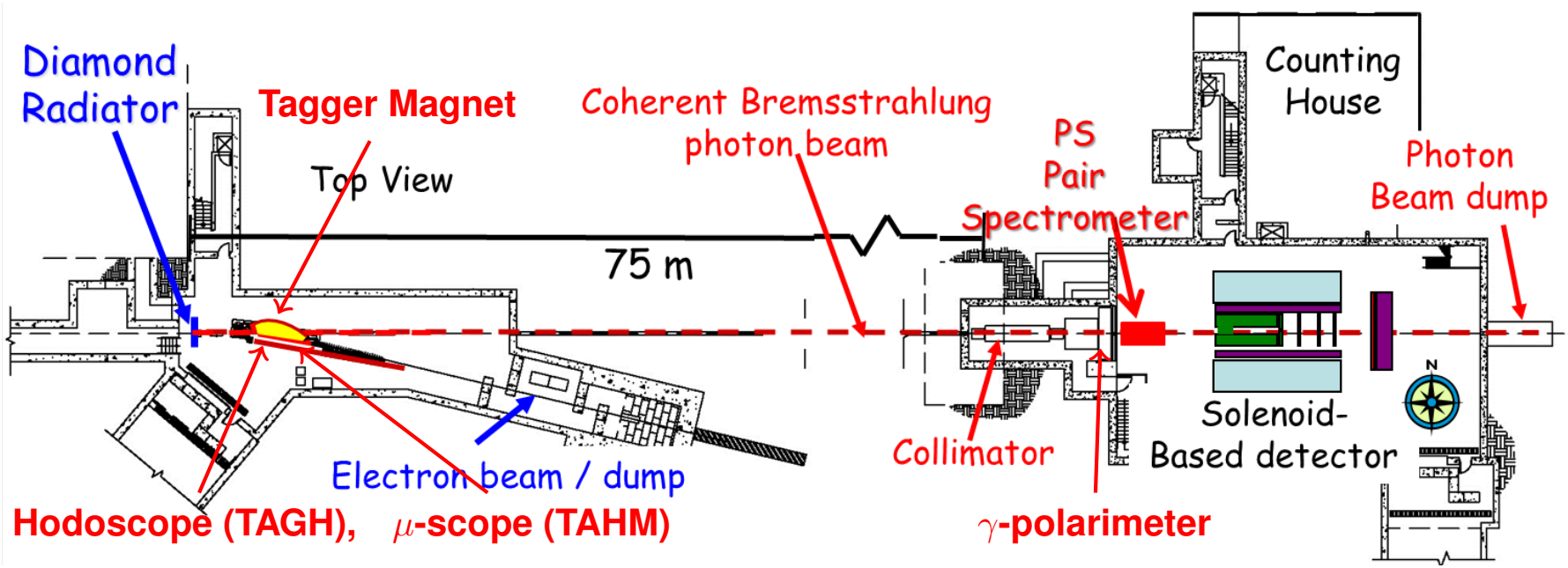
Hall D Complex



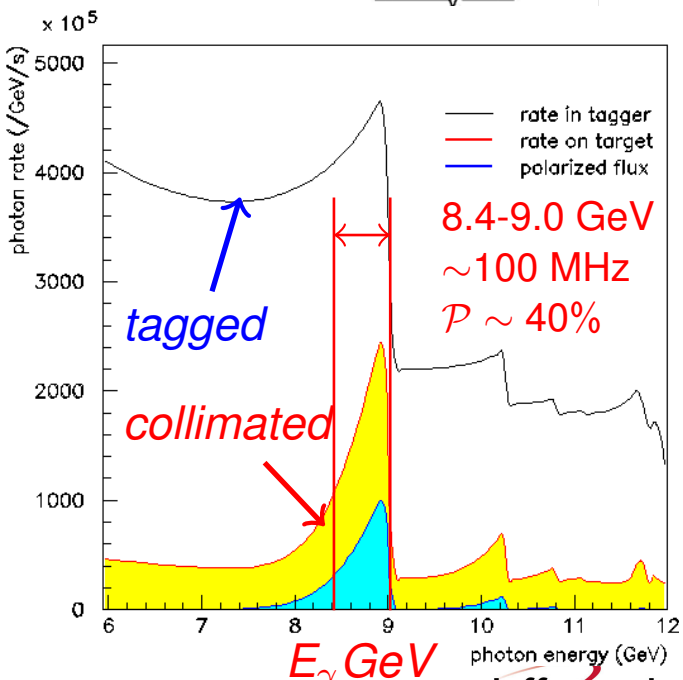
Civil
Photo July 2011
Ready Dec 2011

Beam/detector
Ready Oct 2014

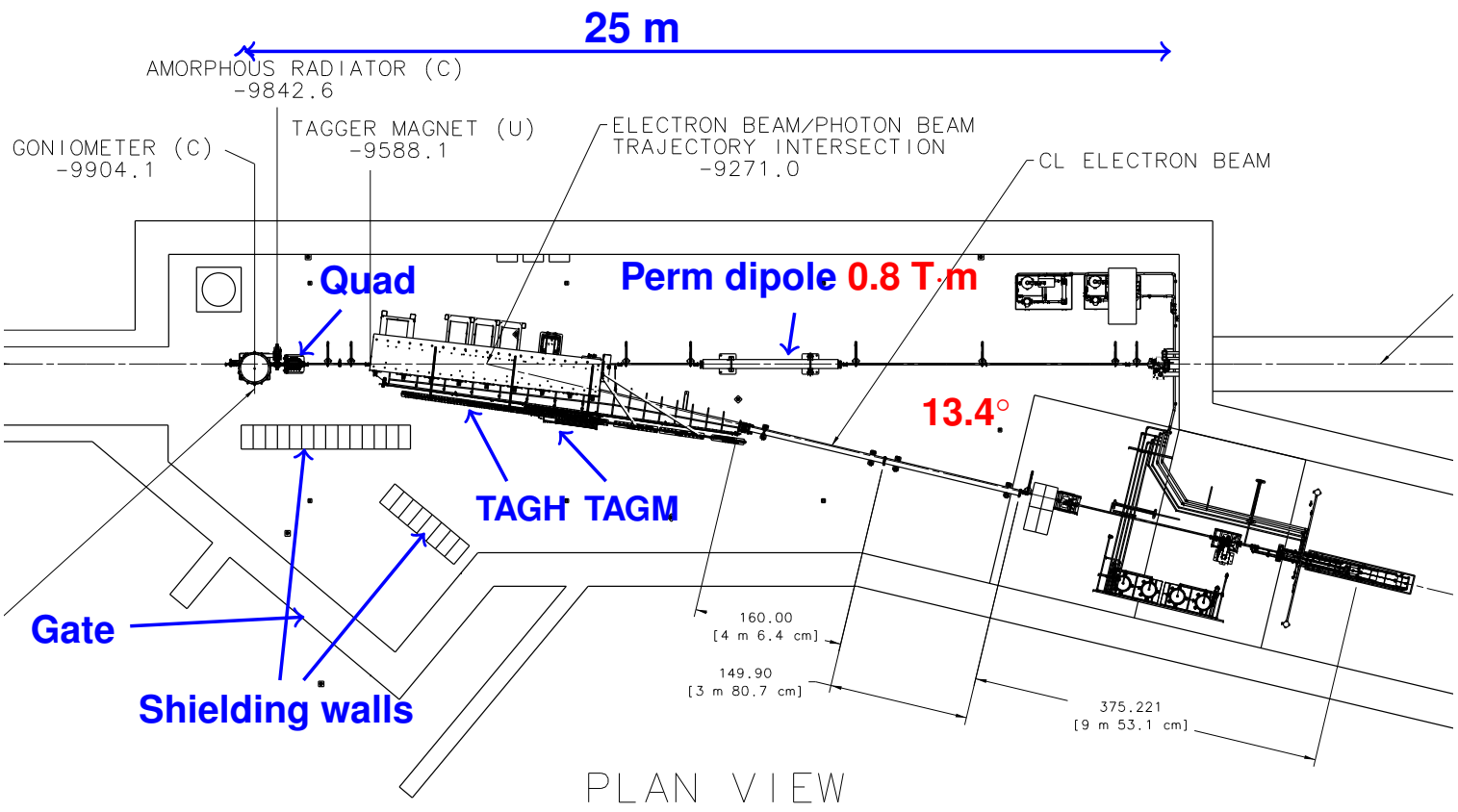
Beamline



- 12 GeV e^- beam $0.01 - 5.0$ μA
- Beam dump $<$60 kW
- 20 μm diamond 0.01% RL: coherent <25 μrad
- Collimation r <1.8 mm at $\sim$ 80 m
- Coherent peak $8.4 - 9.0$ GeV $\quad \mathcal{P} \sim 40\%$
  2.2 μA $\Rightarrow$ 100 MHz γ
- Energy/polarization measured:
  - σ_E/E: Tagger 0.1%; PS 0.5%
  - Pair spectrometer: spectrum $\Rightarrow \sigma_{\mathcal{P}}/\mathcal{P}$ $\sim$5%



Tagger Hall



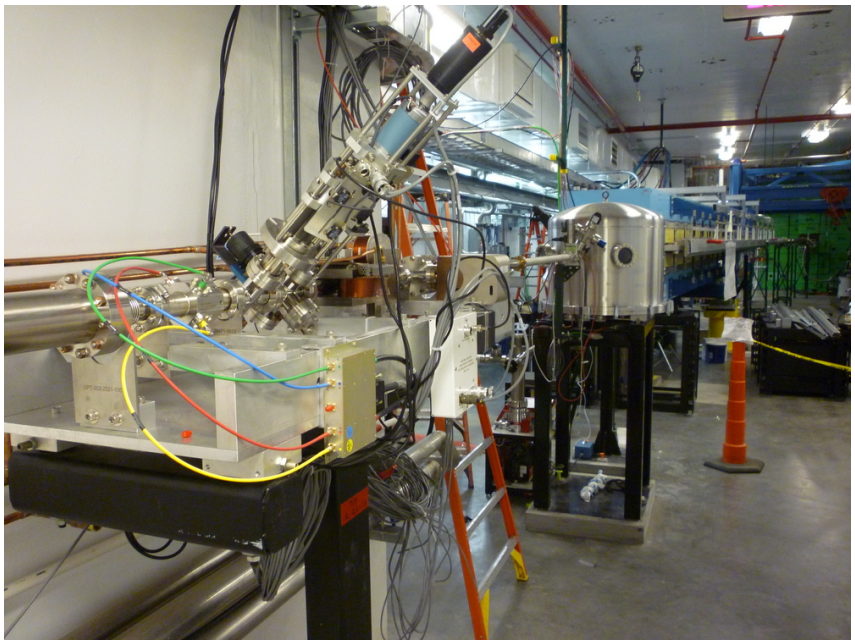
Radiators

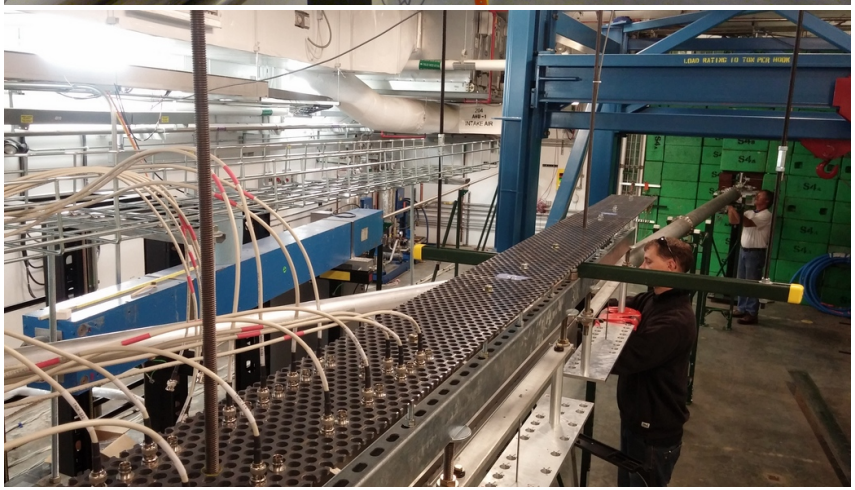
- Diamond (goniometer) 10^{-4} RL
- Amorphous (slide) $0.2 \cdot 10^{-4}, 10^{-4}, 3 \cdot 10^{-4}$ RL

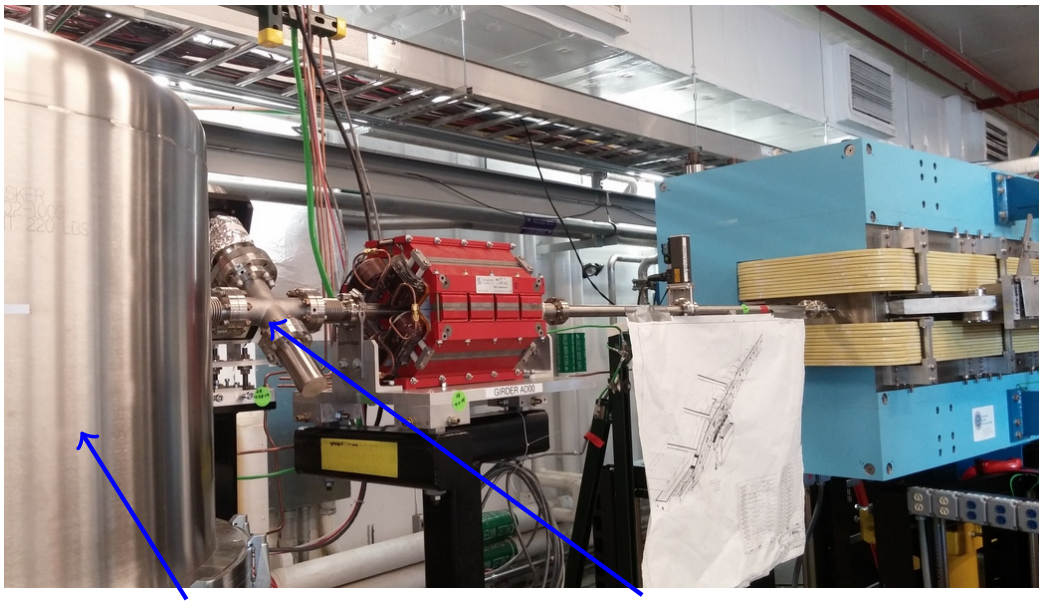
Magnets

- Tagger Dipole 13.4° 1.5 T at 12 GeV
- Quad after radiators (vert. focus)
- Perm dipole 0.8 T·m, e^- down

Tagger Hall Pictures



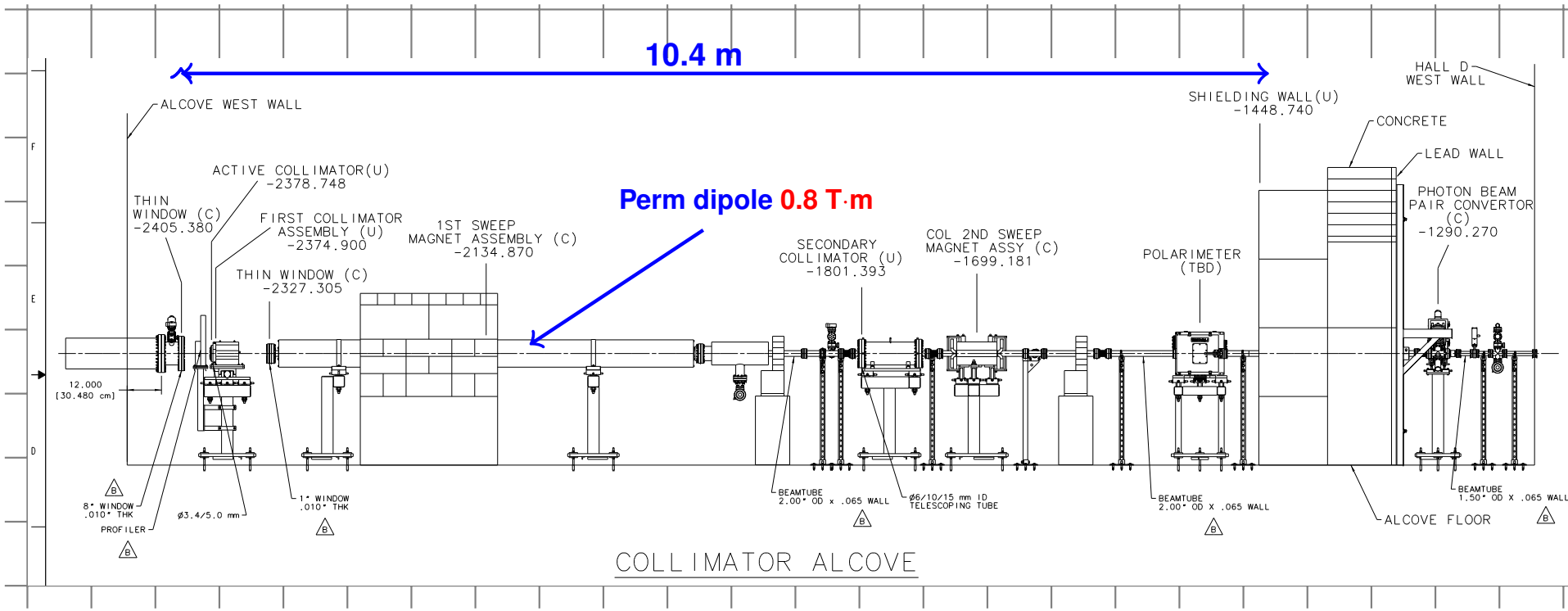


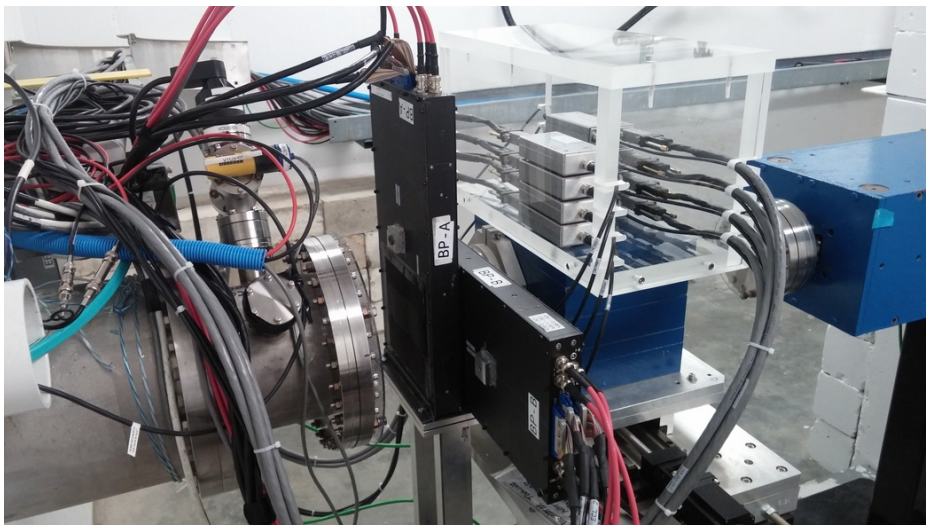


Goniometer Can

Amorph. Rad. Slide

Collimator Alcove





Pair Spectrometer

- Converters 0.03 - 0.5% RL
- High resolution scintillator tile detector
- Coarse scintillator detector

Hall D/GlueX Spectrometer and DAQ

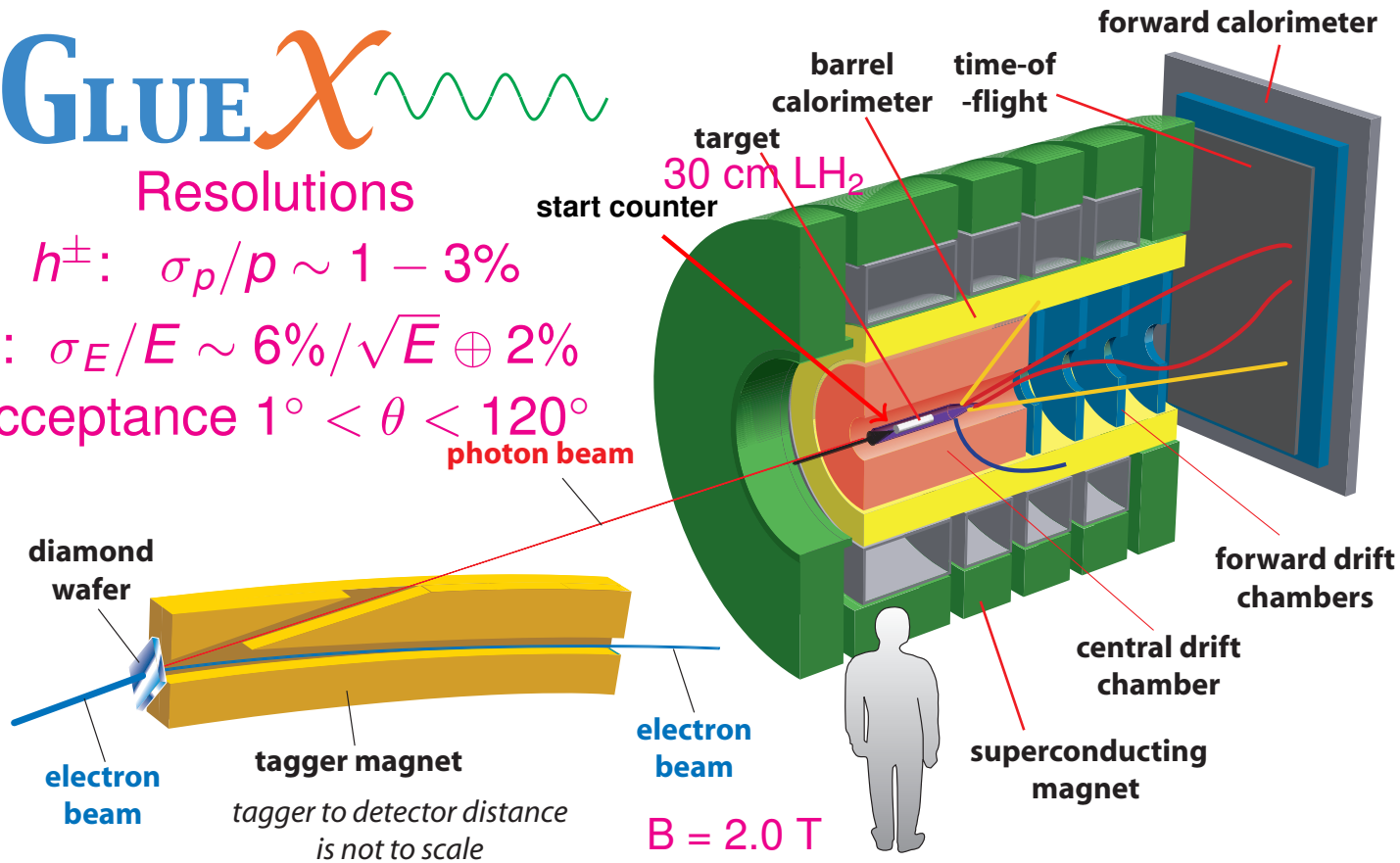
GLUEX

Resolutions

$h^{\pm}$: $\sigma_p/p \sim 1-3\%$

γ: $\sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$

Acceptance $1^\circ < \theta < 120^\circ$



Detectors

- CDC, FDC
- BCAL, FCAL
- TOF, ST

Plans to add

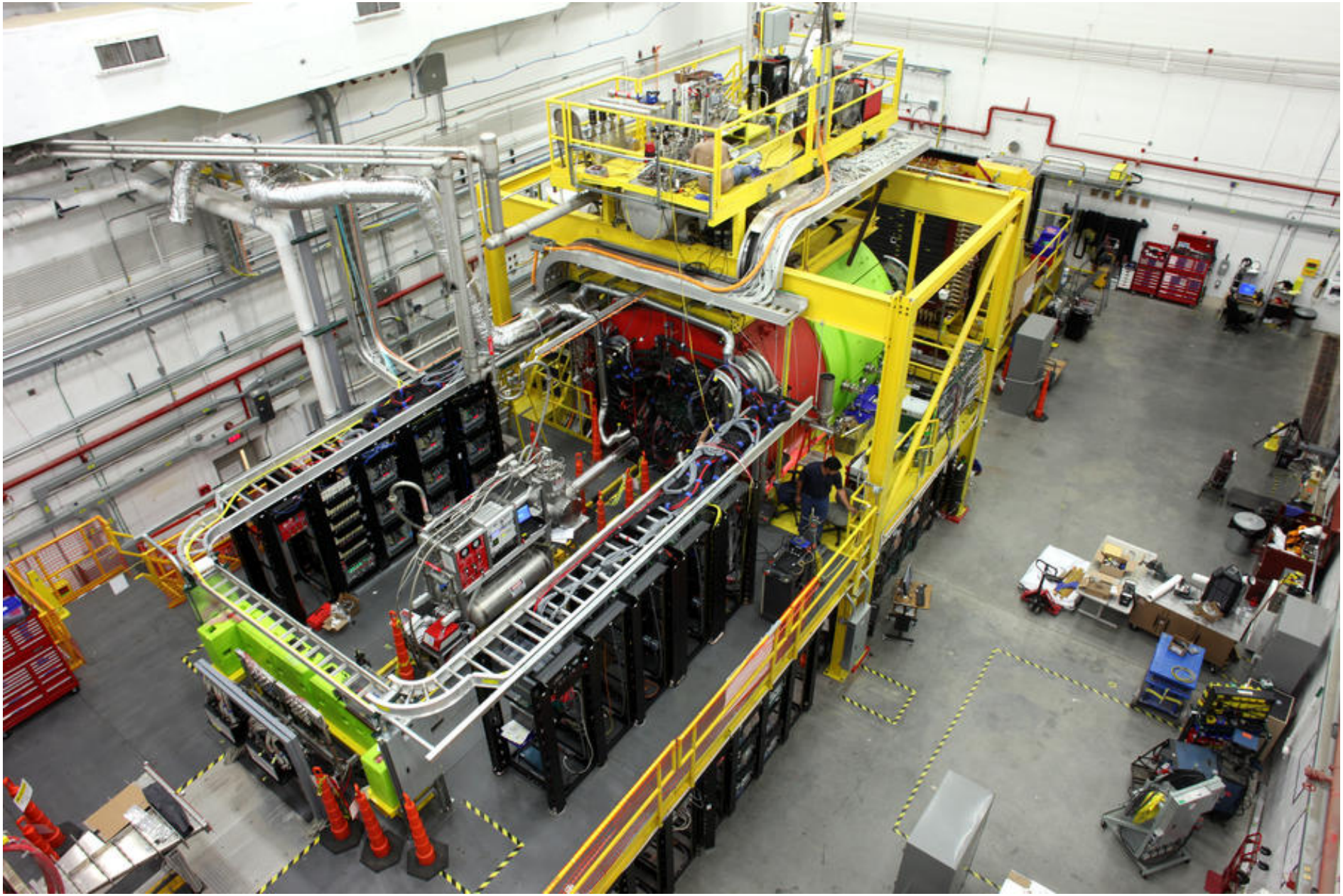
- 2017 L3
- 2018 Cherenkov

Photoproduction γp 15 kHz for a 100 MHz beam

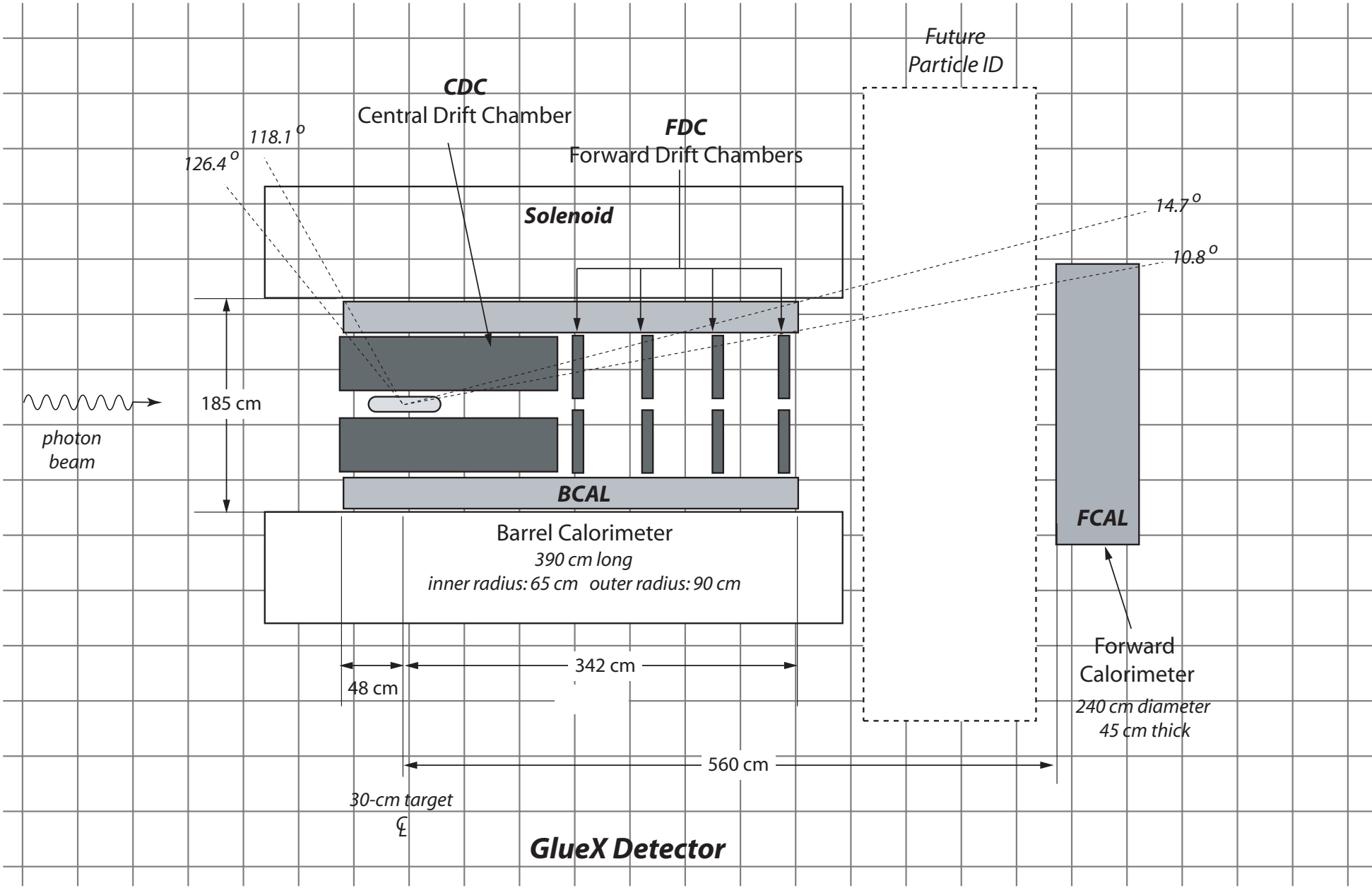
Beam 10 MHz/GeV: inclusive trigger 20 kHz $\Rightarrow$ DAQ $\Rightarrow$ tape

Beam 100 MHz/GeV: inclusive trigger 200 kHz $\Rightarrow$ DAQ $\Rightarrow$ L3 farm $\Rightarrow$ tape

Hall D



Spectrometer, Detectors and Dimensions



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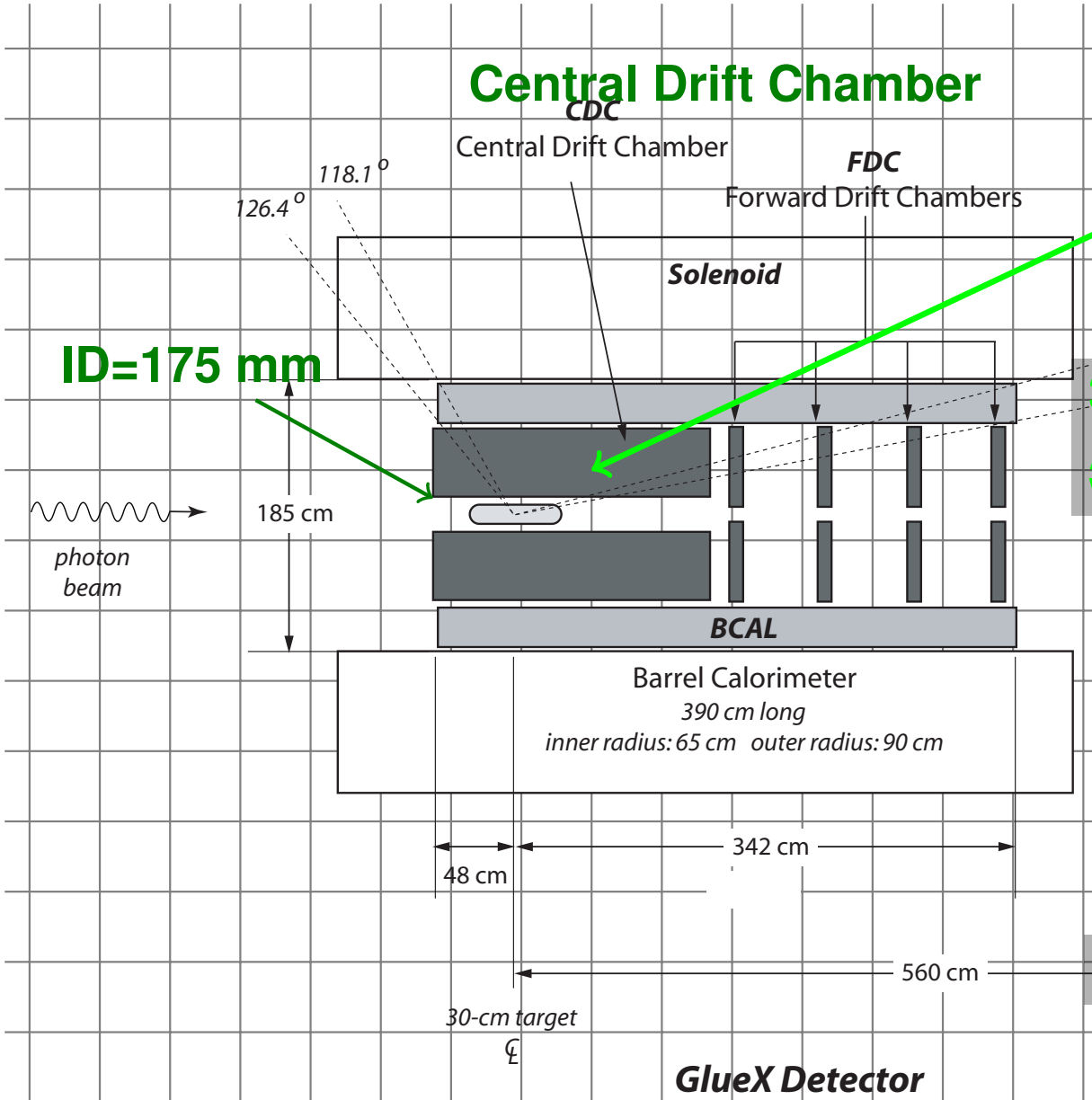
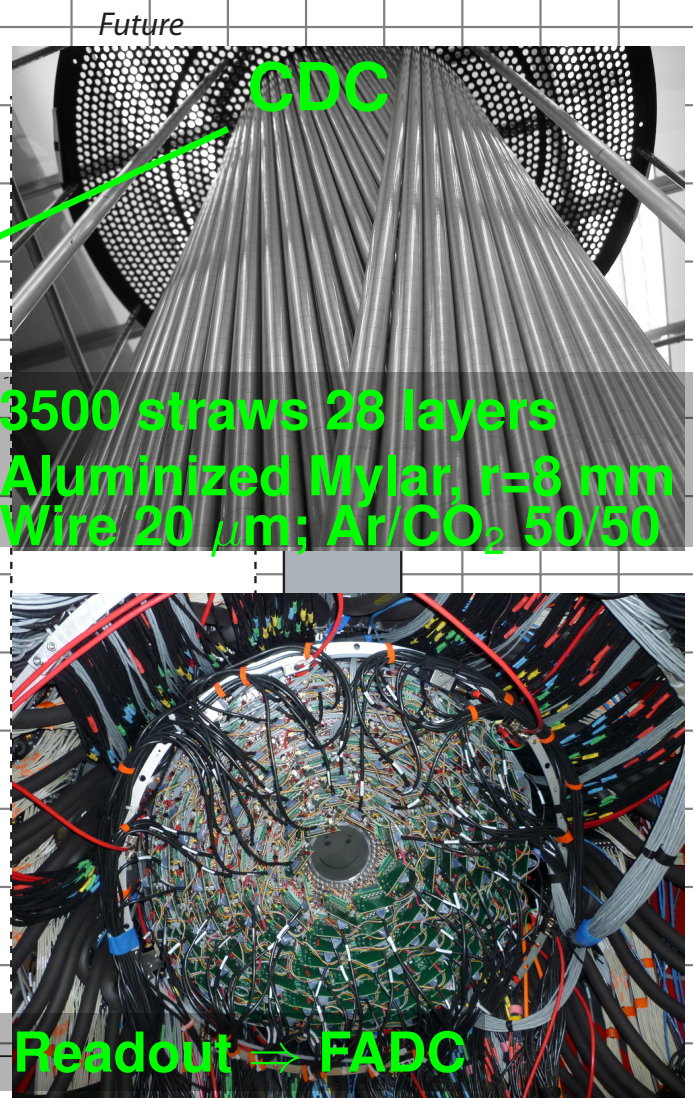
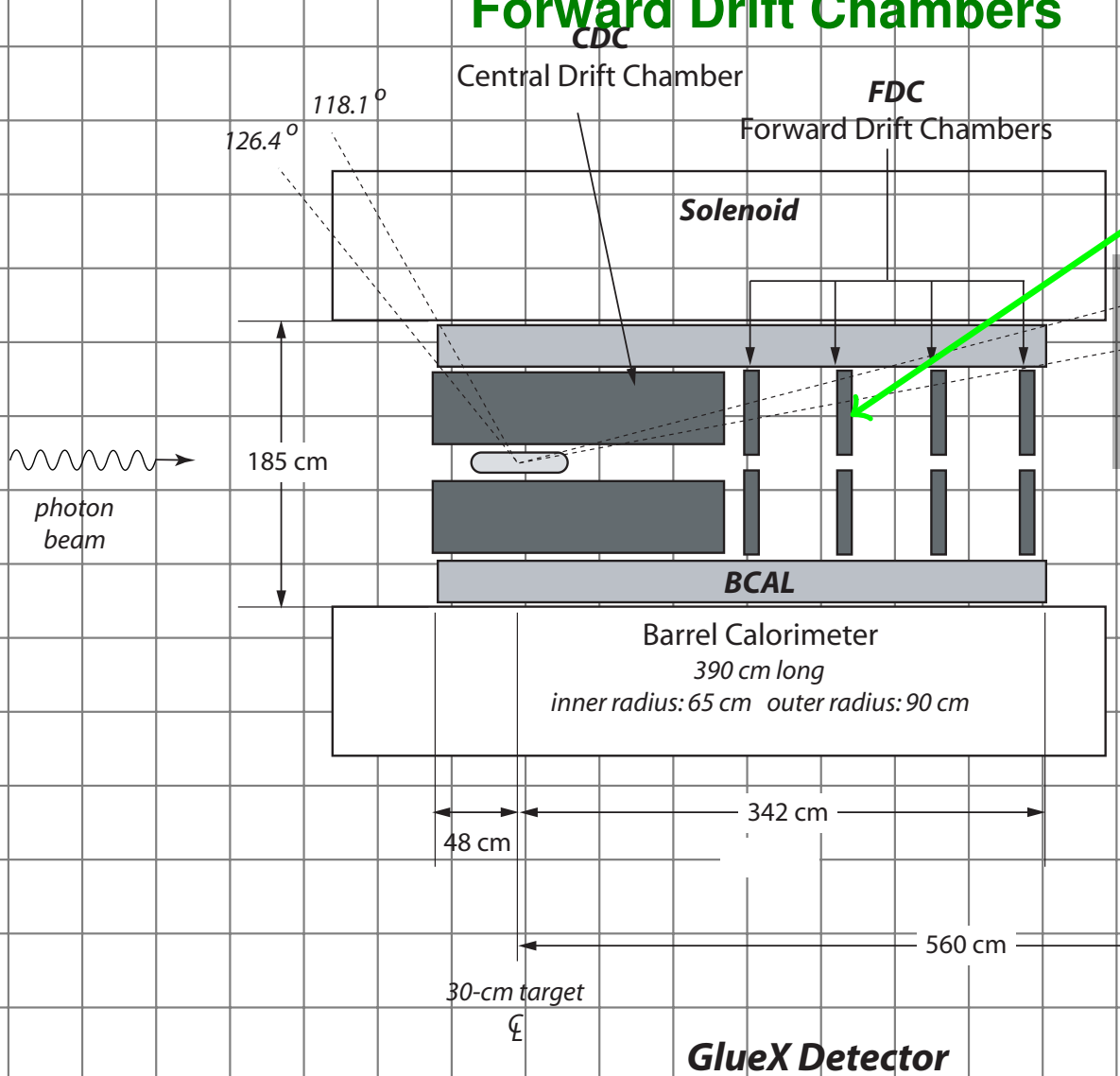


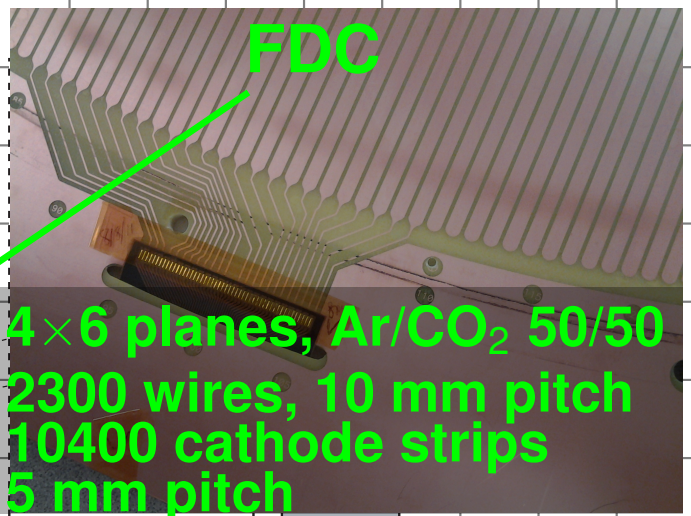


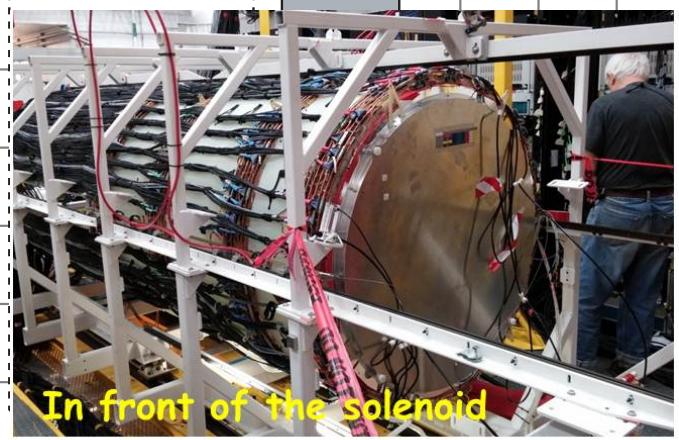
Spectrometer, Detectors and Dimensions

Forward Drift Chambers



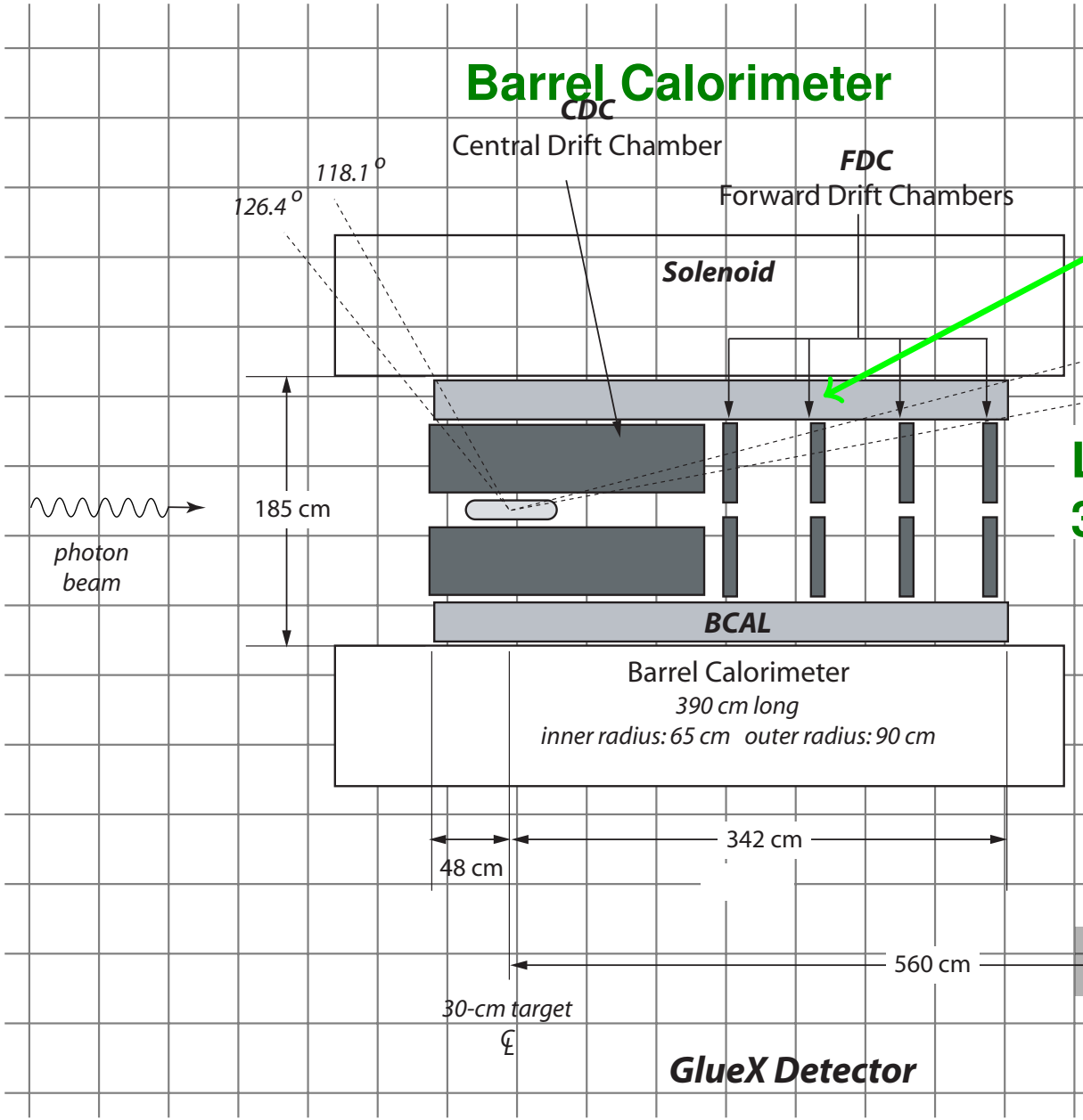
Future





Readout: strips ⇒ FADC
Readout: wires ⇒ TDC

Spectrometer, Detectors and Dimensions



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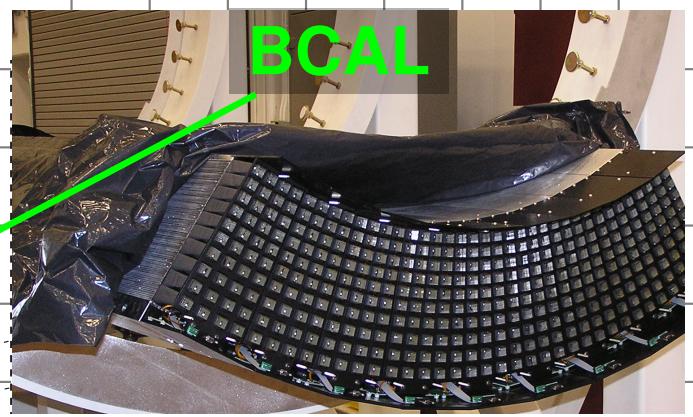

Lead-scintill.fibers
3840 light guides ⇒ SiPMs

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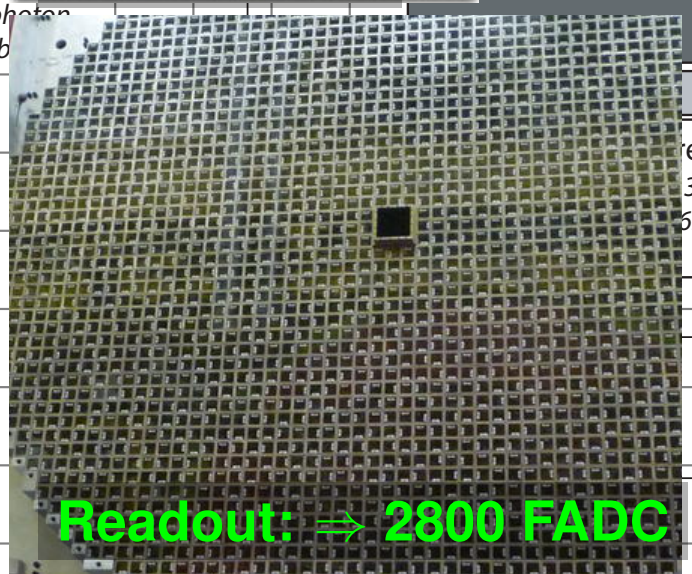


Forward Calorimeter

Future
Particle ID

CDC
ntral Drift Chamber

FDC
Forward Drift Chambers

Solenoid

14.7°

10.8°

BCAL

el Calorimeter
390 cm long
65 cm outer radius: 90 cm

342 cm

FCAL

Forward
Calorimeter
240 cm diameter
45 cm thick

560 cm

GlueX Detector

Commissioning Status

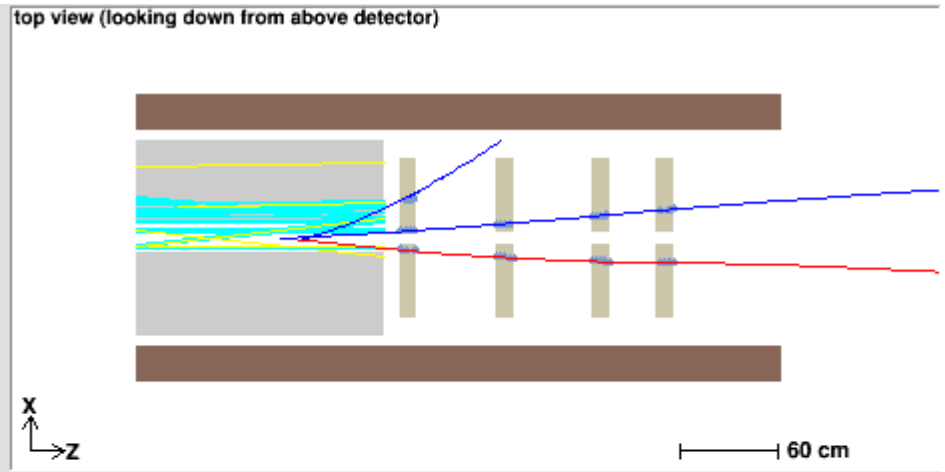
Runs with beam:

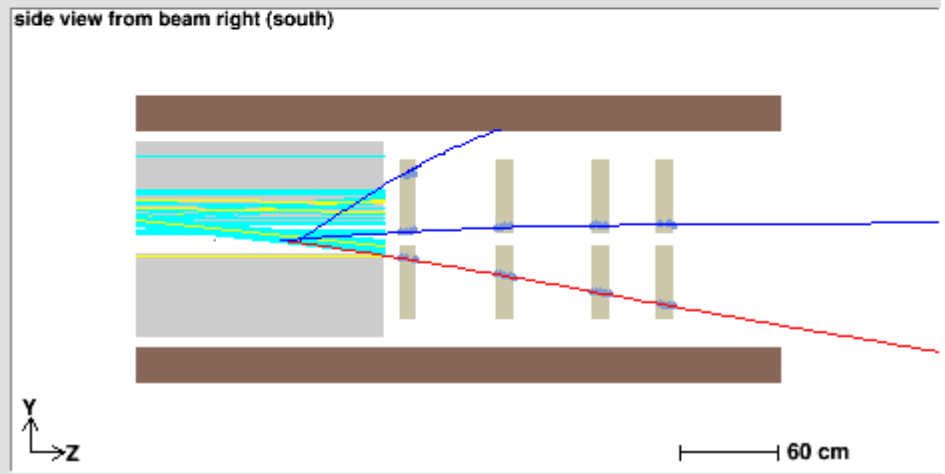
- Fall 2014 10.0 GeV beam: beam commissioning and detector checkout
- Spring 2015 5.5 GeV beam: 1 week of beam - commissioning
- Fall 2015 12 GeV beam (accelerator priority) $\sim$ 2 days of beam
- Spring 2016 (plans): 12 GeV beam - completing the commissioning
  - Data for early physics results

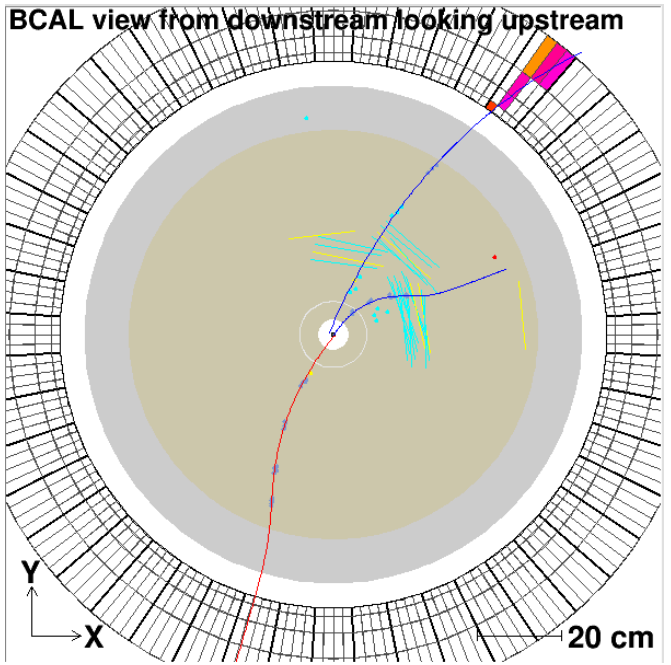
All the equipment for GlueX-I has been commissioned at some level!

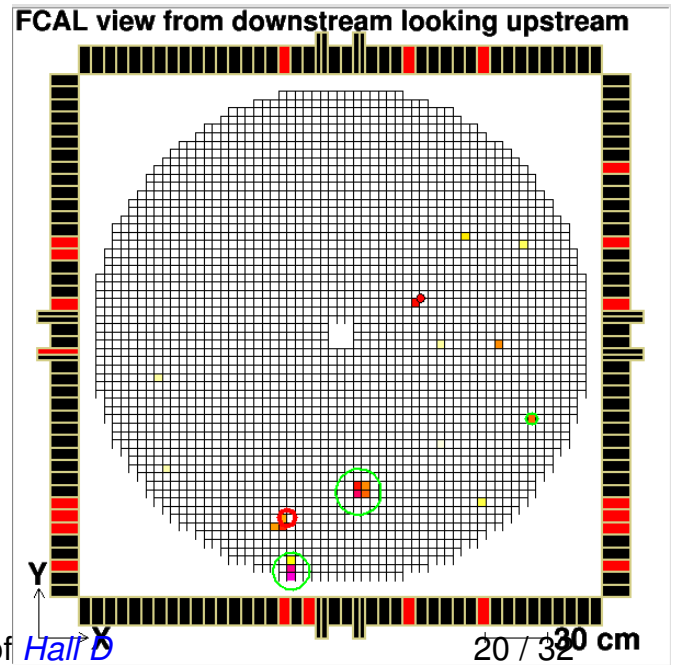
All the detector systems are within 30% of the design specs, some have reached the specs.

Event Display



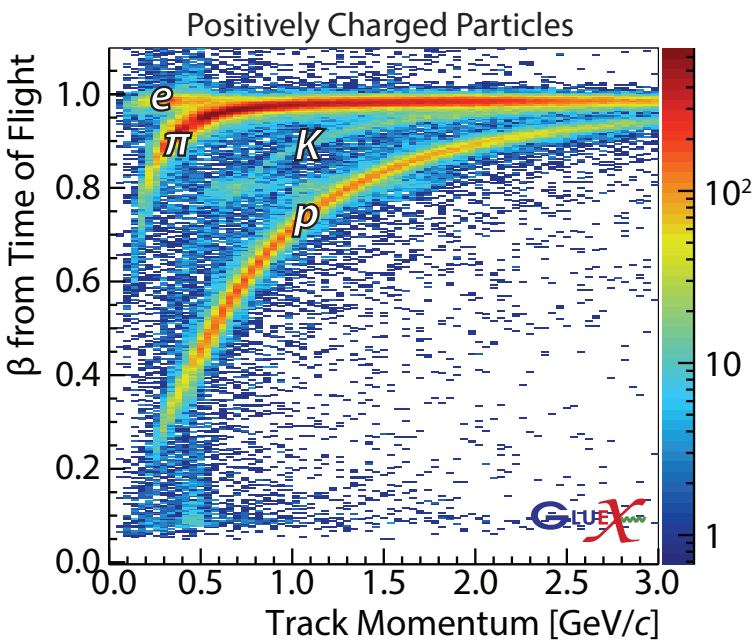


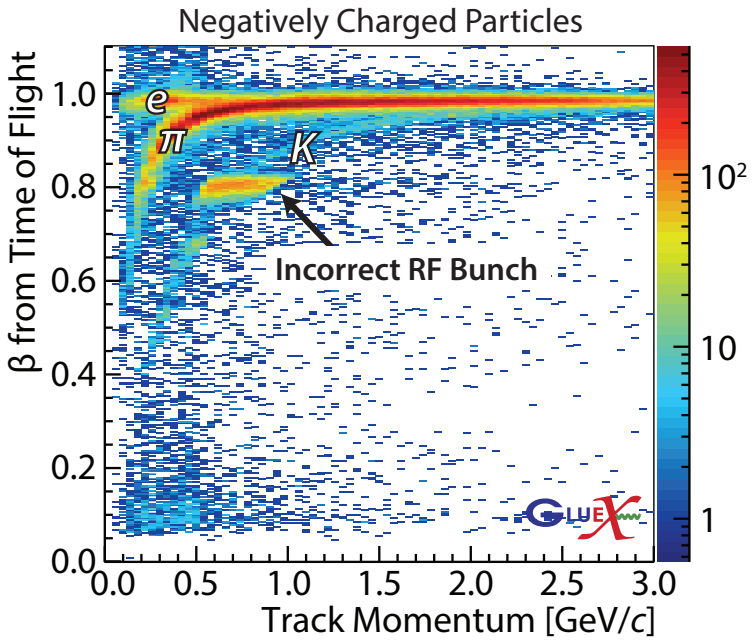


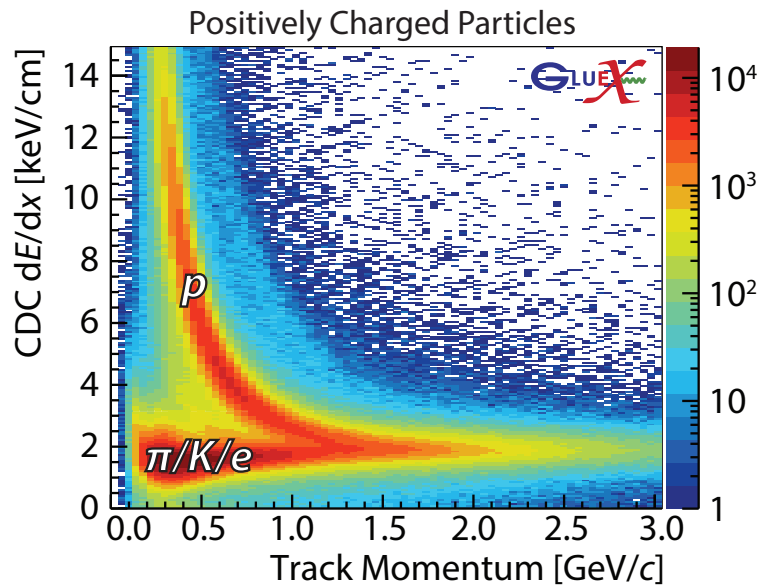


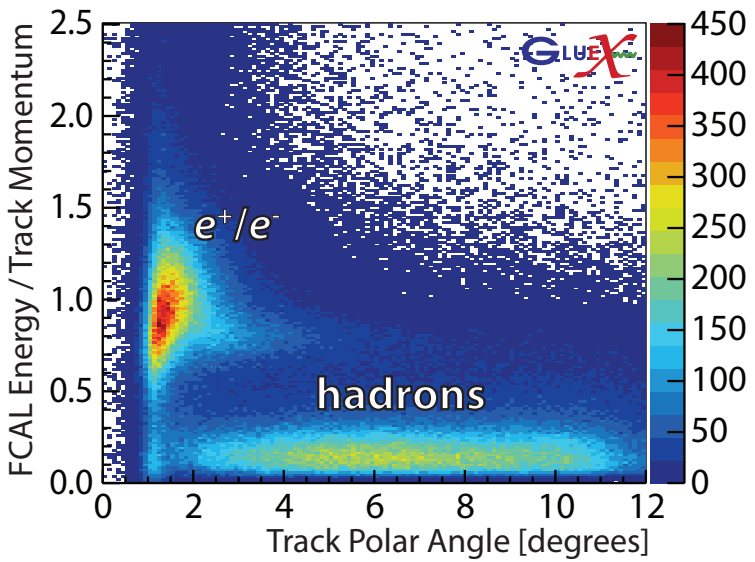
- 2 positive tracks
- 1 negative track
- Hits in FDC, CDC, BCAL, FCAL. TOF

PID

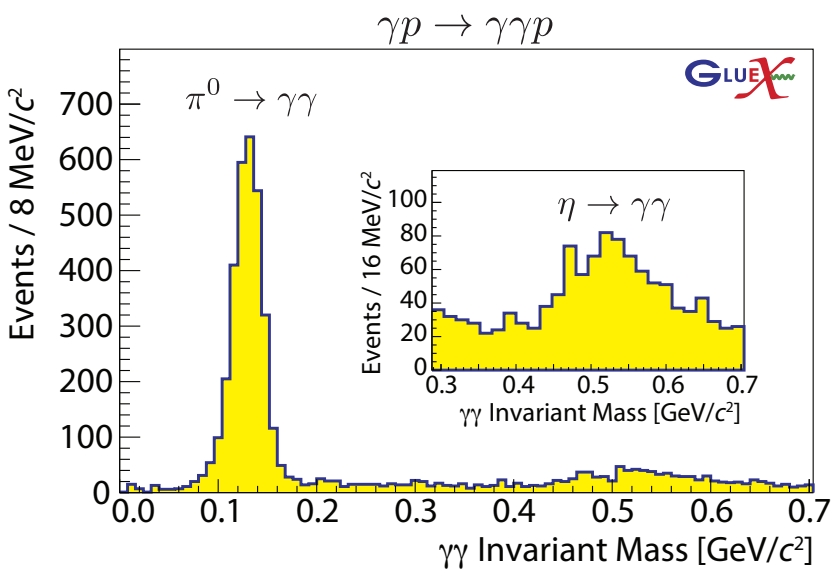

Positively Charged Particles
β from Time of Flight
Track Momentum [GeV/c]
e
π
K
p
GLUEX

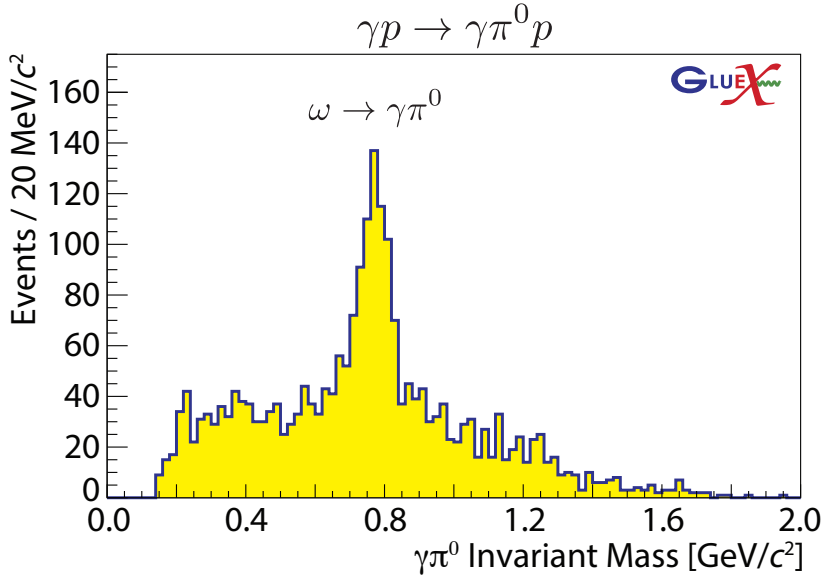

Negatively Charged Particles
β from Time of Flight
Track Momentum [GeV/c]
e
π
K
Incorrect RF Bunch
GLUEX

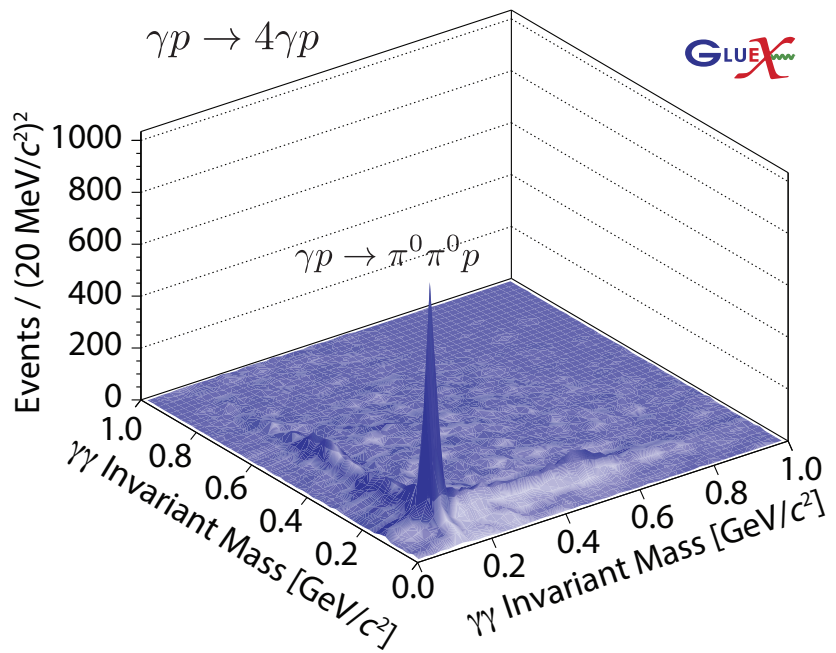

Positively Charged Particles
CDC dE/dx [keV/cm]
Track Momentum [GeV/c]
p
π/K/e
GLUEX

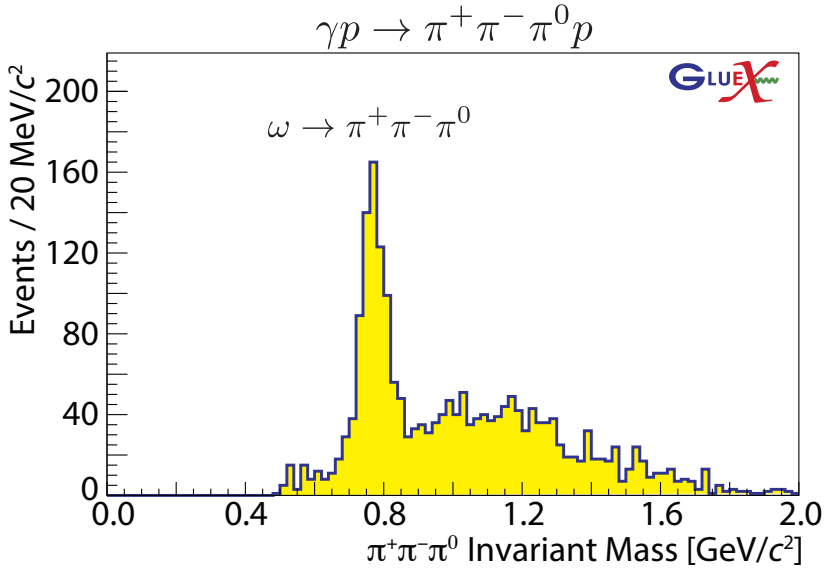

FCAL Energy / Track Momentum
Track Polar Angle [degrees]
e⁺/e⁻
hadrons
GLUEX

Event Reconstruction and Signals Observed

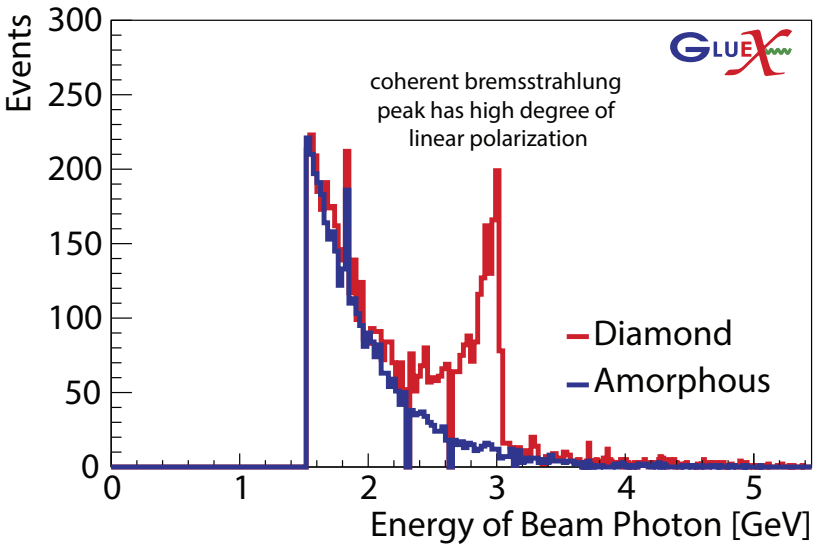


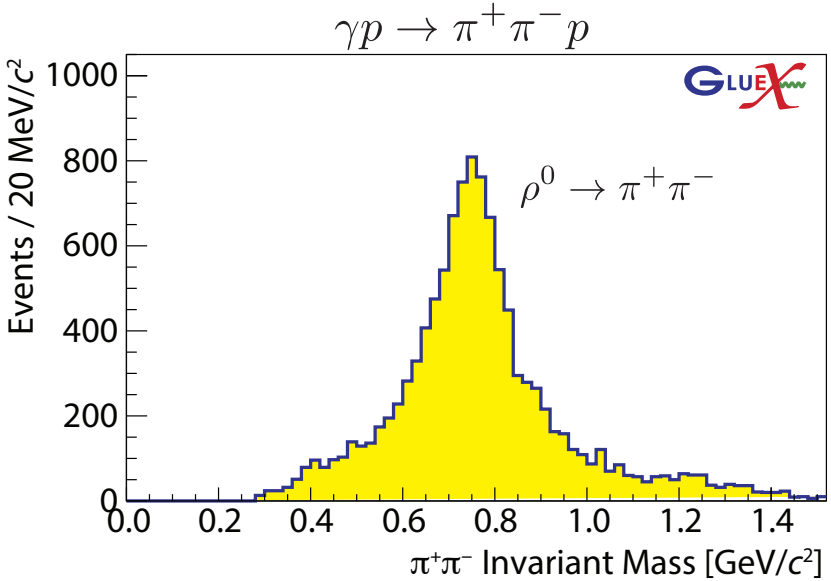


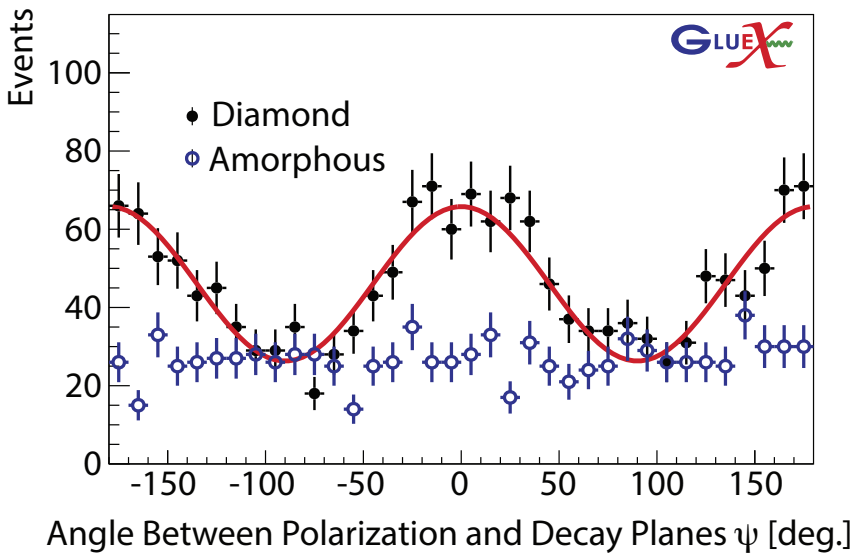


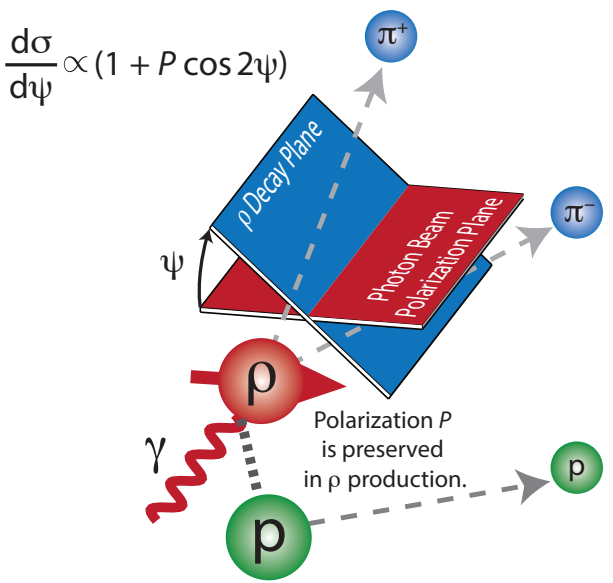


Physics With Linearly Polarized Beam









Plans for “Early Physics”

Expected in 2016:

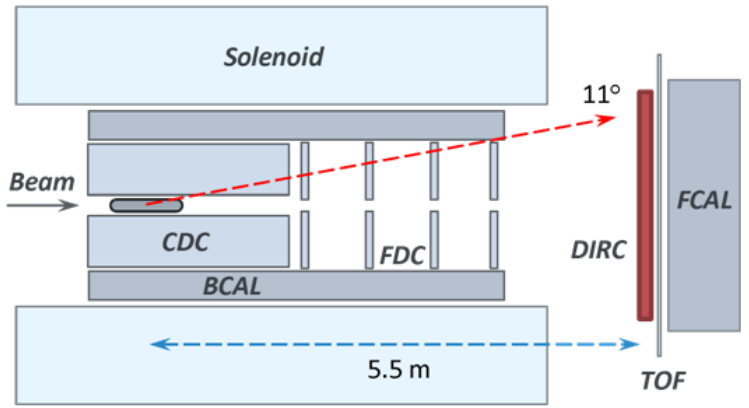
- Polarization transfer and beam asymmetry measurements $\gamma p \to (\rho, \omega, \phi)p$, $\gamma p \to (\pi^\circ, \eta, \eta')p$,
- Cross section measurements
- Identify known mesons in PWA

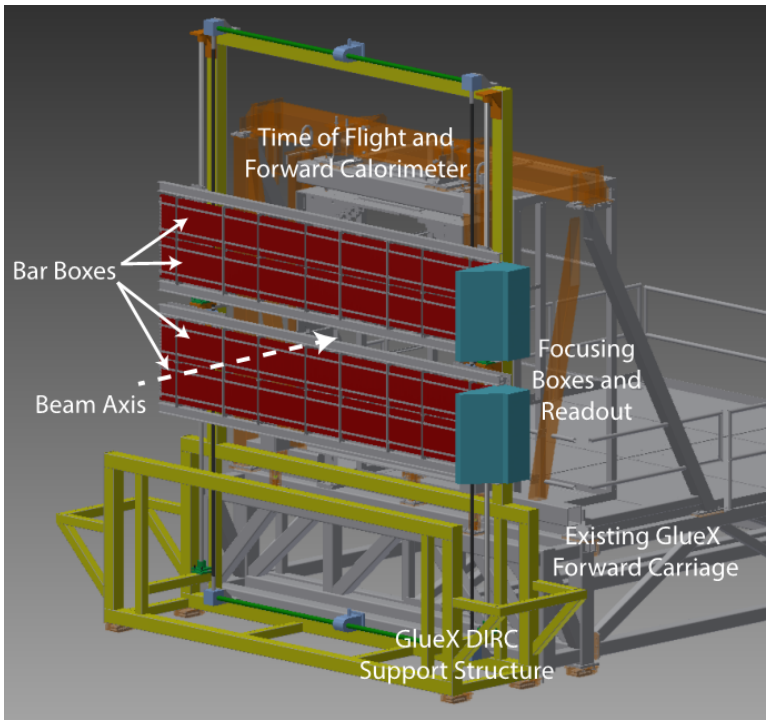
Future: Forward Kaon Identification

Present PID: TOF, dE/dx, Kinematics

Upgrade

- 4 of the BaBar DIRC bar boxes
- New readout system
- Allows to study:
  - Strangeonium and hybrids
  - Hyperons
- Installation planned for 2018





Physics Program

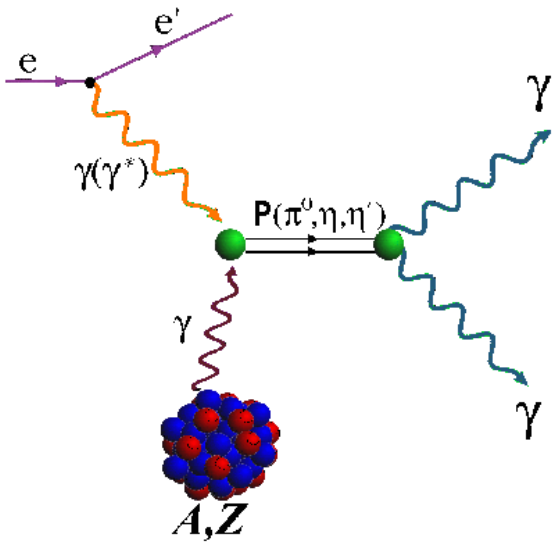
Proposal/ experiment	Sta- tus	Title	Beam days	PAC #
E12-06-102	A	Mapping the Spectrum of Light Quark Mesons and Gluonic Excitations with Linearly Polarized Photons	120	30
E12-10-011	A-	A Precision Measurement of the η Radiative Decay Width via the Primakoff Effect	79	35
E12-13-003	A	An initial study of hadron decays to strange final states with GlueX in Hall D	200	40
E12-13-008	A-	Measuring the Charged Pion Polarizability in the $\gamma\gamma \to \pi^+\pi^-$ Reaction	25	40
E12-12-002	A	A study of meson and baryon decays to strange final states with GlueX in Hall D	220	42
C12-14-004	C2	Eta Decays with Emphasis on Rare Neutral Modes: The JLab Eta Factory Experiment (JEF) *partly concurrent with GlueX* ($\eta \to 3\pi$)	(130)	42
LOI12-15-001		Physics with secondary K_L° beam		43
LOI12-15-006		ω-production on nuclei		43

Summary

- Hall D complex: construction and installation are finished, operations started
- Experiment GlueX is well into commissioning. All the detector systems are performing close to the specifications. More commissioning time is needed for full calibration
- GlueX is planning to finish commissioning in Spring 2016 and to use the data for studying relatively simple reactions
- By the Fall 2016 GlueX is planning to be ready to start the main program - the search for exotic mesons
- Planned upgrade: Cherenkov detector for kaon identification to be installed in 2018
- A scientific program beyond the search for exotic hybrid is in place and growing

APPENDIX

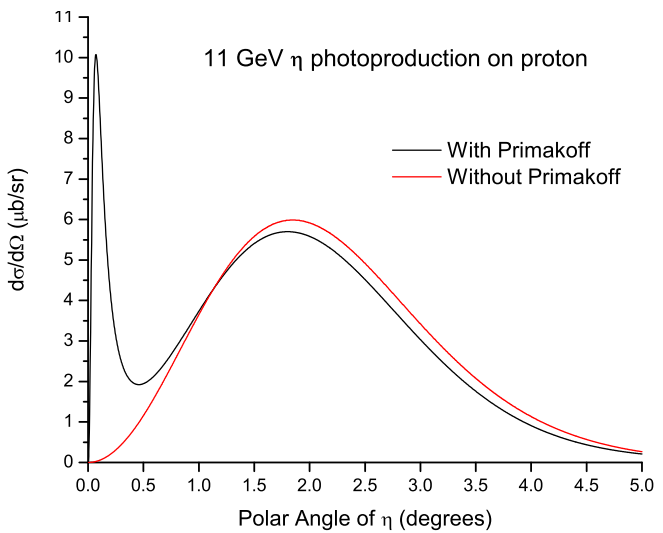
$\pi^\circ, \eta, \eta' \to \gamma\gamma$ coupling in Primakoff reaction



- $\Gamma(\pi^\circ \to \gamma\gamma)$
  test of Chiral symmetry/anomalies
  6 GeV E-02-103 in Hall B
- $\Gamma(\eta \to \gamma\gamma)$
  light quark mass ratio,
  $\eta - \eta'$ mixing angle
  12 GeV PR12-10-011 in Hall D

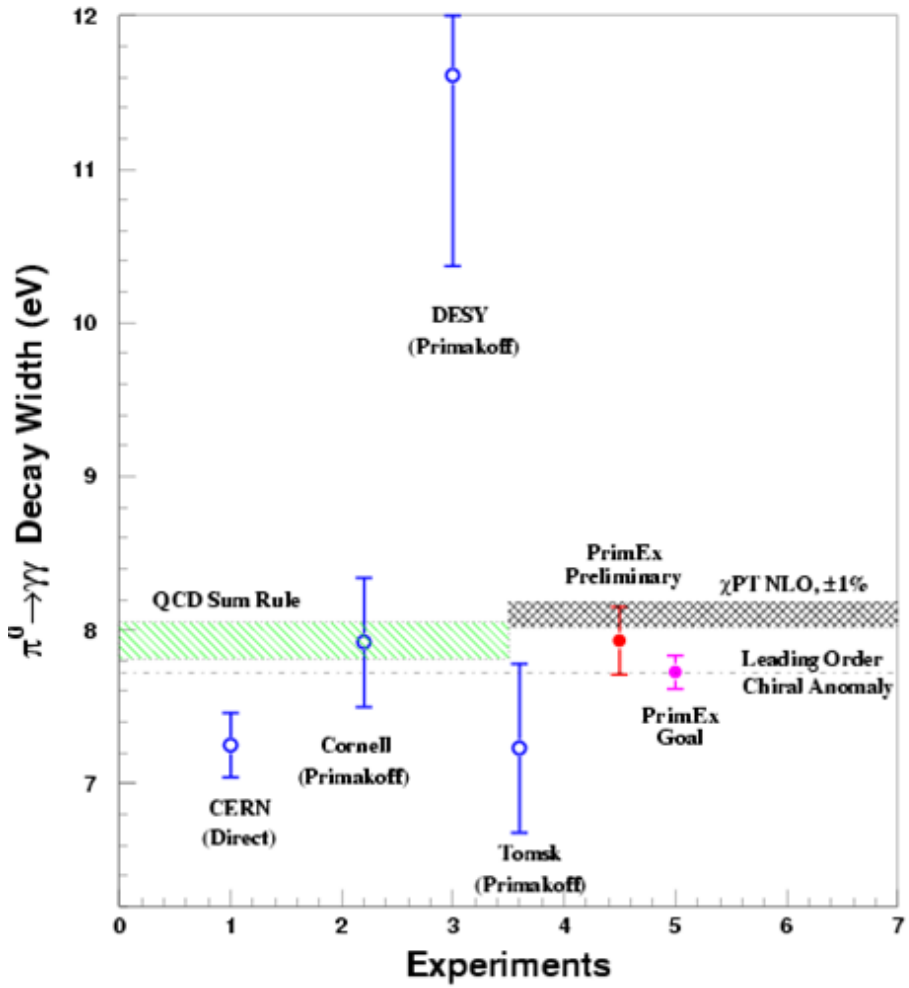
$$\frac{d\sigma}{d\Omega} = \Gamma_{\gamma\gamma} \frac{8\alpha Z^2 \beta^3 E^4}{m^3 Q^4} |F_{e.m.}(Q)|^2 \cdot \sin^2\theta$$

- Primakoff $\theta < 0.5^\circ$
- Primakoff-Nuclear interference
  $\Rightarrow \theta < 5^\circ$
- Fit to $\frac{d\sigma}{d\Omega}(\theta)$

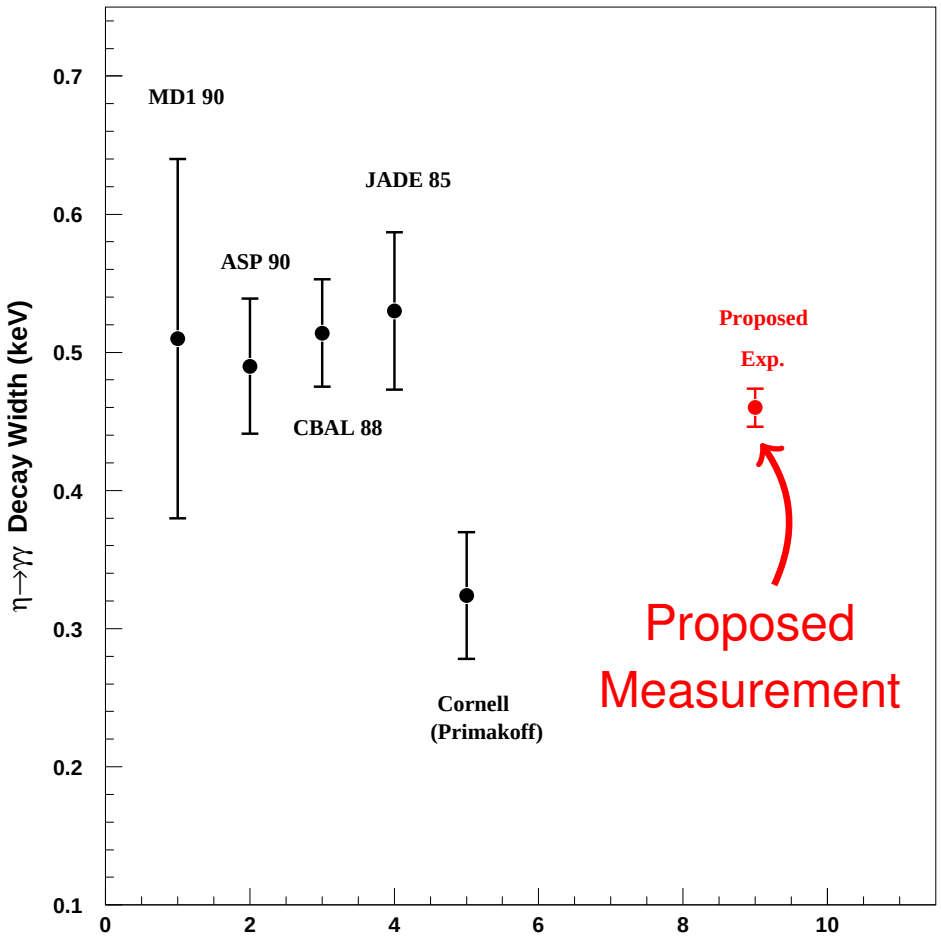


PRIMEX Projected Results

$\Gamma(\pi^\circ \to \gamma\gamma)$ *Hall B*



$\Gamma(\eta \to \gamma\gamma)$ *Hall D projection*

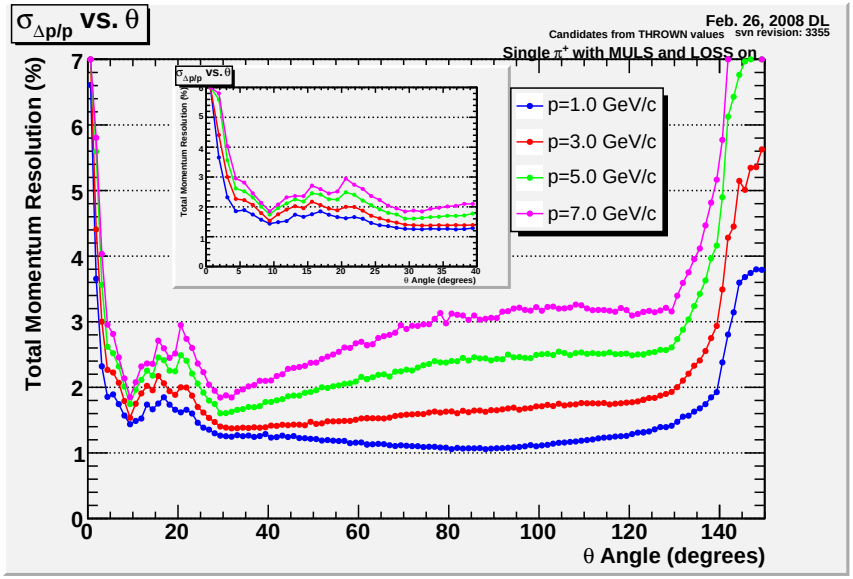


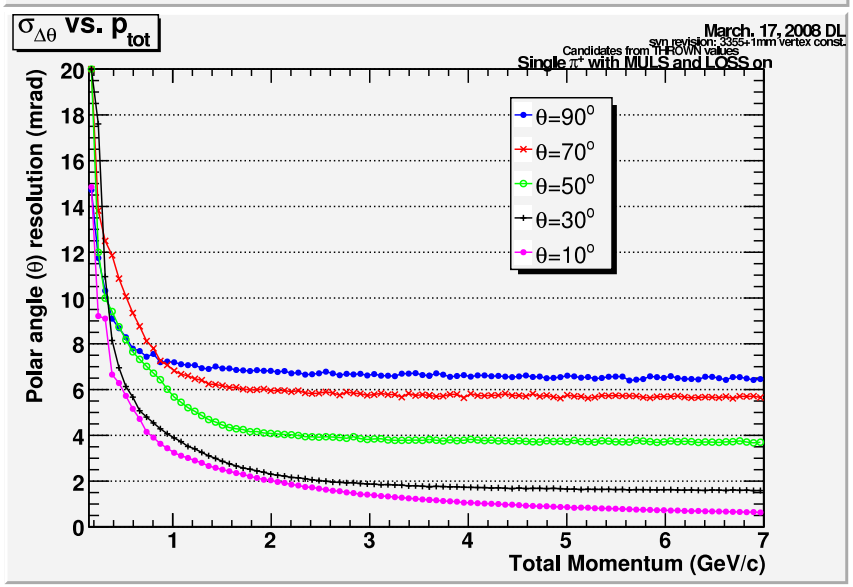
Calculations of the backgrounds

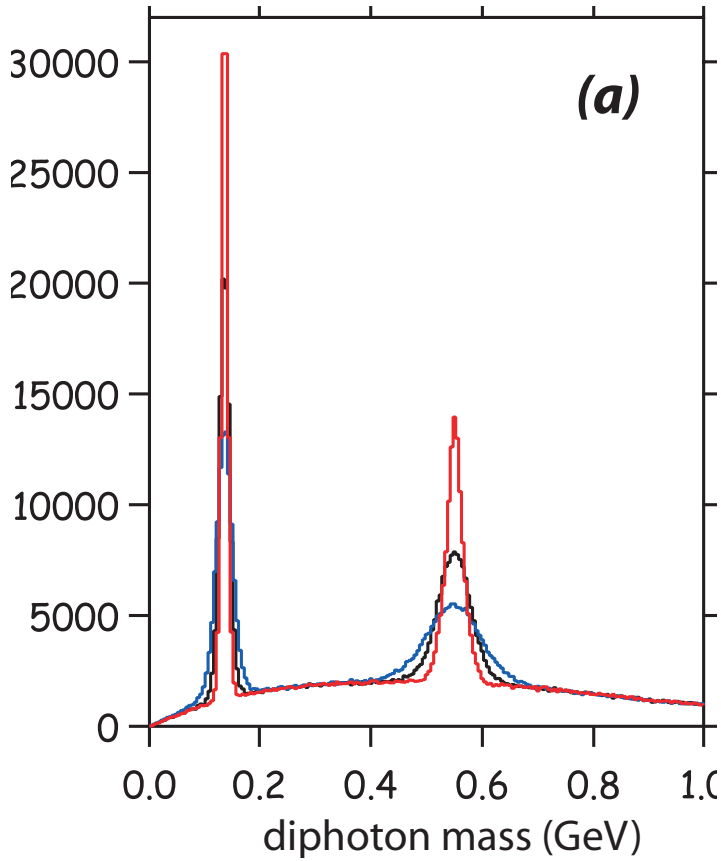
Design Parameters

Capability	*Quantity*	*Range*
Charged particles	**Coverage**	$1^o < \theta < 160^o$
	Momentum Resolution (5^o-140^o)	$\sigma_p/p = 1 - 3\%$
	Position resolution	$\sigma \sim 150\text{-}200\ \mu m$
	dE/dx measurements	$20 < \theta < 160^o$
	Time-of-flight measurements	$\sigma_{ToF} \sim 60$ ps; $\sigma_{BCal} \sim 200$ps
	Barrel time resolution	$\sigma_t^{\gamma} < (74/\sqrt{E} \oplus 33)$ ps
Photon detection	**Energy measurements**	$2^o < \theta < 120^o$
	LGD energy resolution (E > 60 MeV)	$\sigma_E/E = (5.7/\sqrt{E} \oplus 2.0)\%$
	Barrel energy resolution (E > 60 MeV)	$\sigma_E/E = (5.54/\sqrt{E} \oplus 1.6)\%$
	LGD position resolution	$\sigma_{x,y,} \sim 0.64\ cm/\sqrt{E}$
	Barrel position resolution	$\sigma_z \sim 0.5cm/\sqrt{E}$
DAQ/trigger	**Level 1**	**< 200 kHz**
	Level 3 event rate to tape	**~ 15 kHz**
	Data rate	**300 MB/s**
Electronics	**Fully pipelined**	**250 / 125 MHz fADCs, TDCs**
Photon Flux	**Initial: 10^7 γ/s**	**Final: 10^8 γ/s**

Resolutions



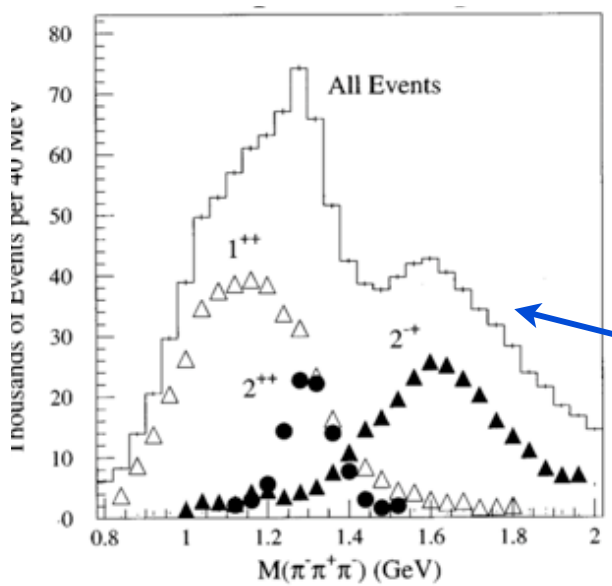




Resolution: 8.5 MeV for π°
30 MeV for η

How to Measure J^{PC}?

Example from pion production: $\pi^- p \rightarrow \pi^-\pi^-\pi^+ p$ at 18 GeV/c



Partial Wave Analysis Method:

In every bin of 3π mass, fit for the (complex) sizes of different J^{PC} amplitudes using all available event kinematics.

Dominant resonances are remarkably stable.

$$I(\Omega) = \sum_{\alpha} \left| \sum_{\beta} V_{\alpha,\beta} A_{\alpha,\beta}(\Omega) \right|^2$$

A(Ω) = Resonance Angles × Isobar Angles × Isobar Breit Wigner

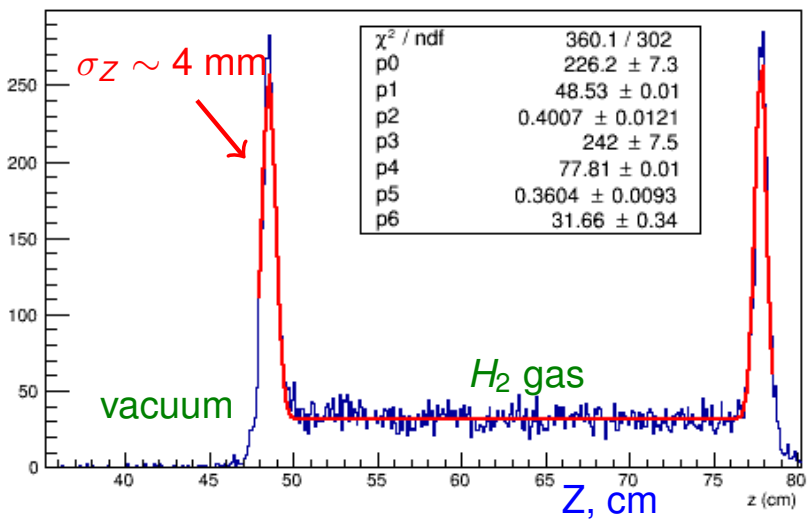
Track Reconstruction in Drift Chambers

Alignment, calibration: in progress

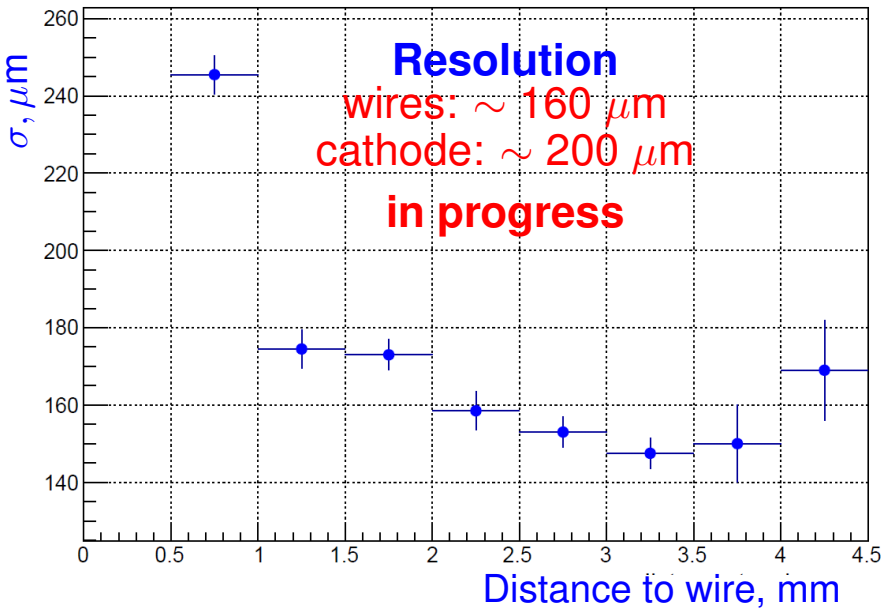
Field-off alignment

- FDC - tracks from the target
- CDC - cosmics

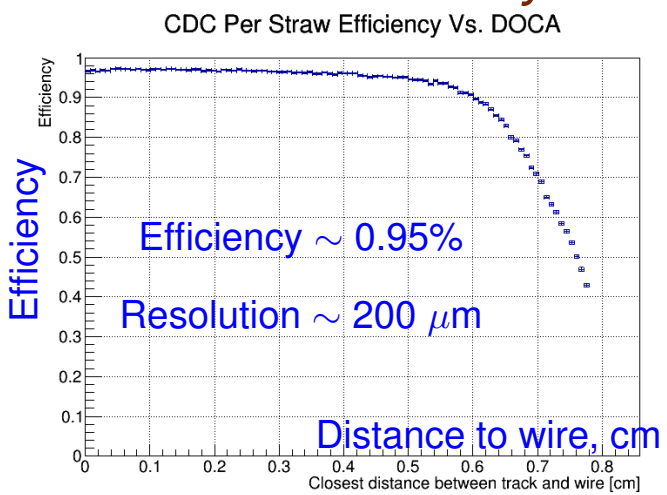
Empty LH_2 Target: thin windows



FDC: Resolution

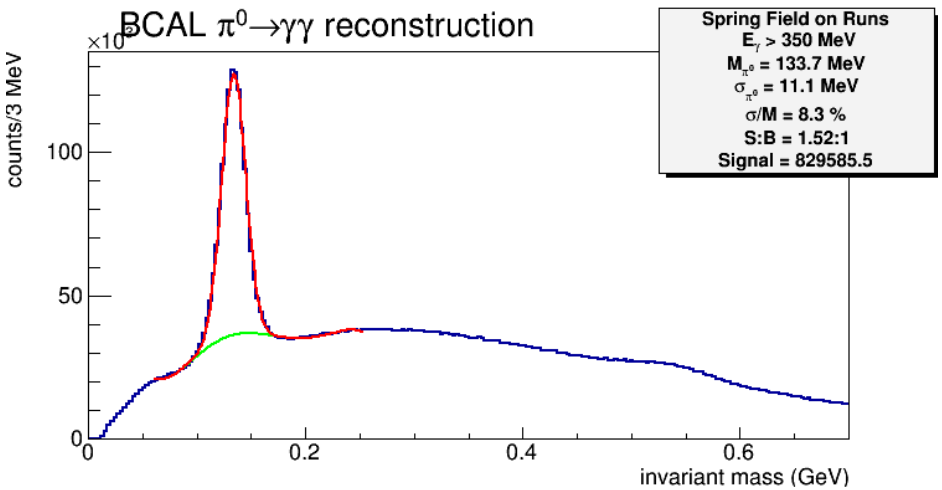


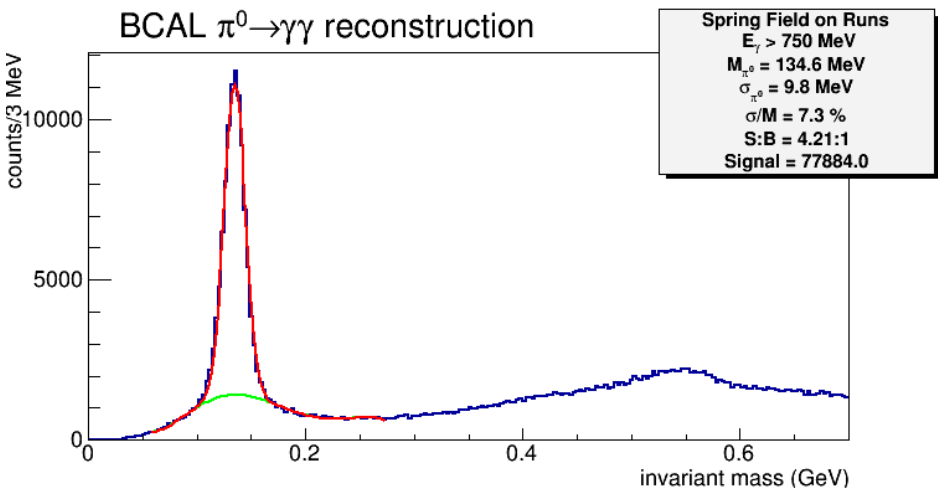
CDC efficiency



EM calorimetry: Calibration using π° mass

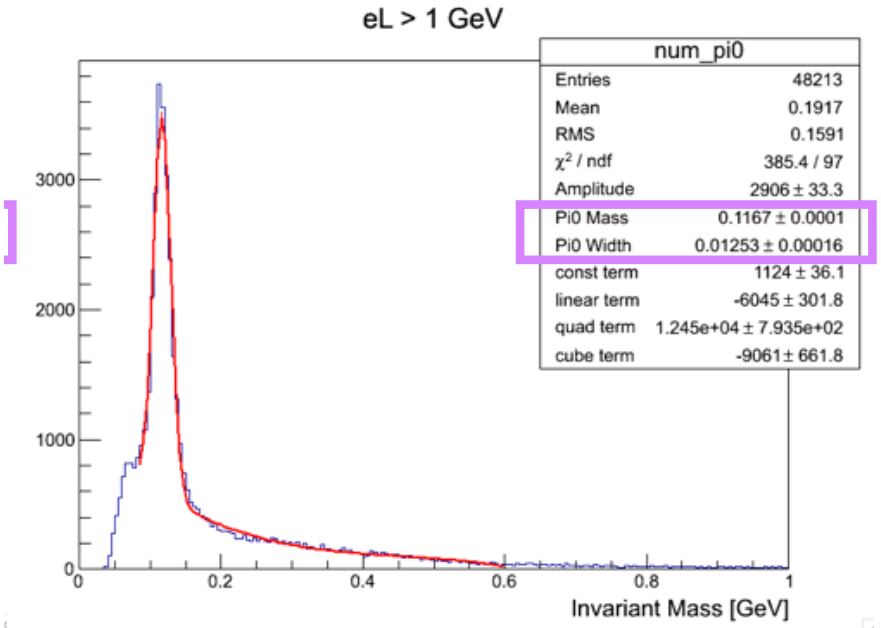
BCAL





Calibration with π° well advanced;
π° width is $\sim$ $\times 1.15$ of the specs

FCAL



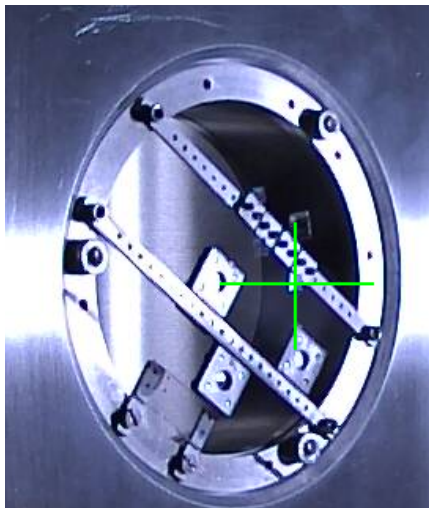
$\approx$ 18,000 π^0

$\times 10$ more statistics needed
π° width is $\sim$ $\times 1.3$ of the specs

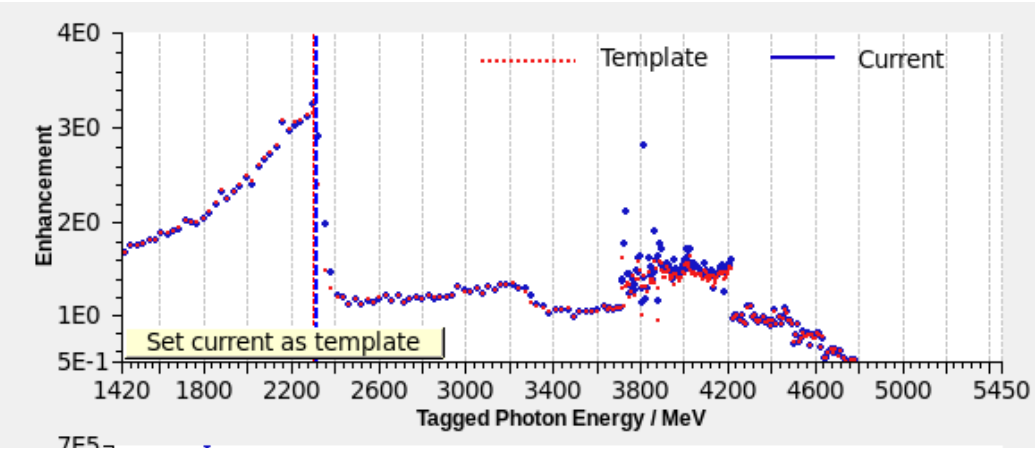
Coherent Bremsstrahlung

- 50 μm thick diamond radiator
- Precision alignment using a goniometer

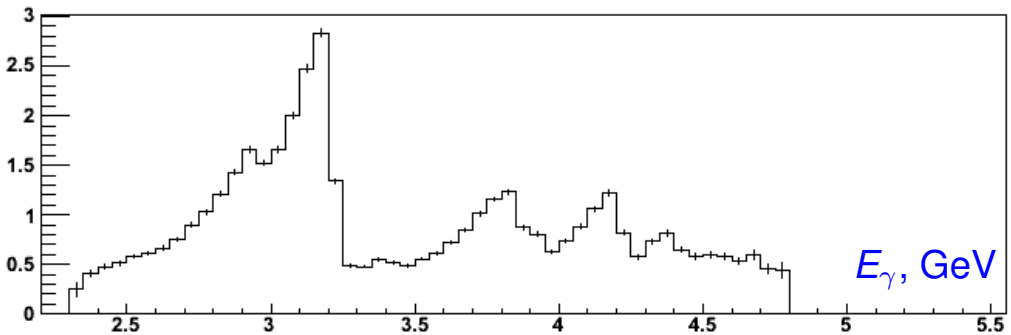
Goniometer - radiator mounting



Tagger, normalized to incoherent spectra



Pair Spectrometer



Calculated Linear Polarization