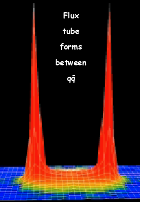
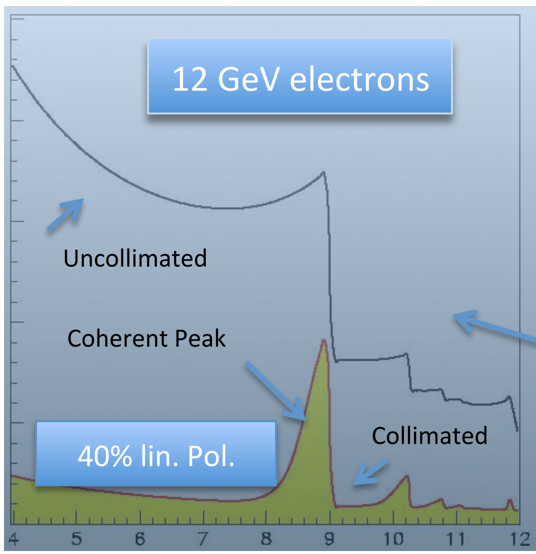
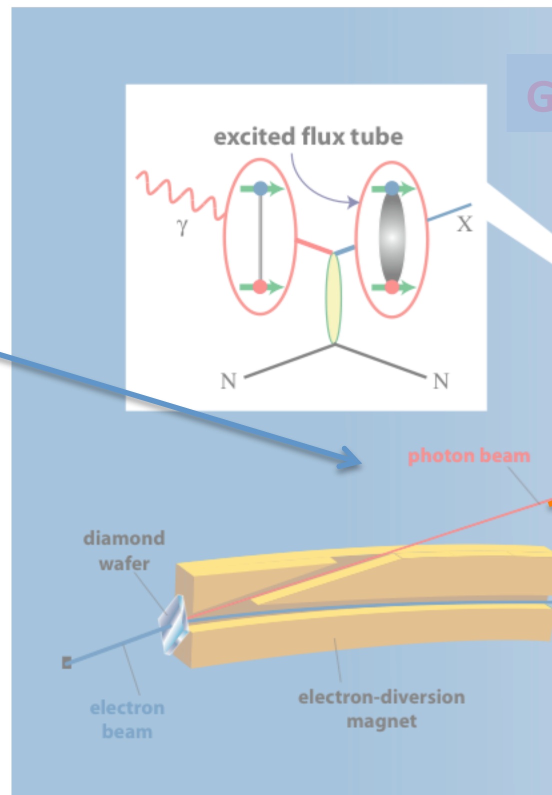


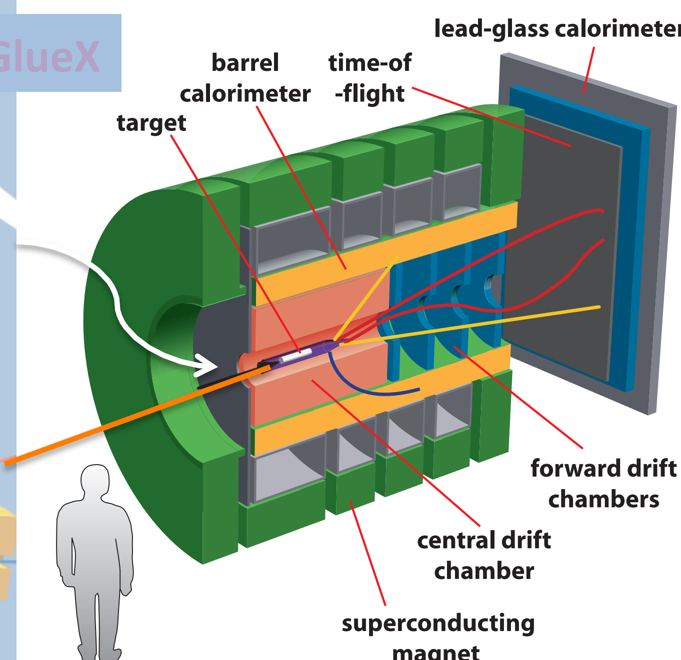
An initial study of mesons and baryons containing strange quarks with GlueX

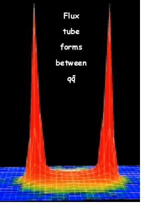
A Proposal to Jefferson Lab PAC 40

The GlueX Collaboration
Curtis A. Meyer, GlueX Spokesperson



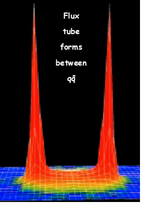






Outline

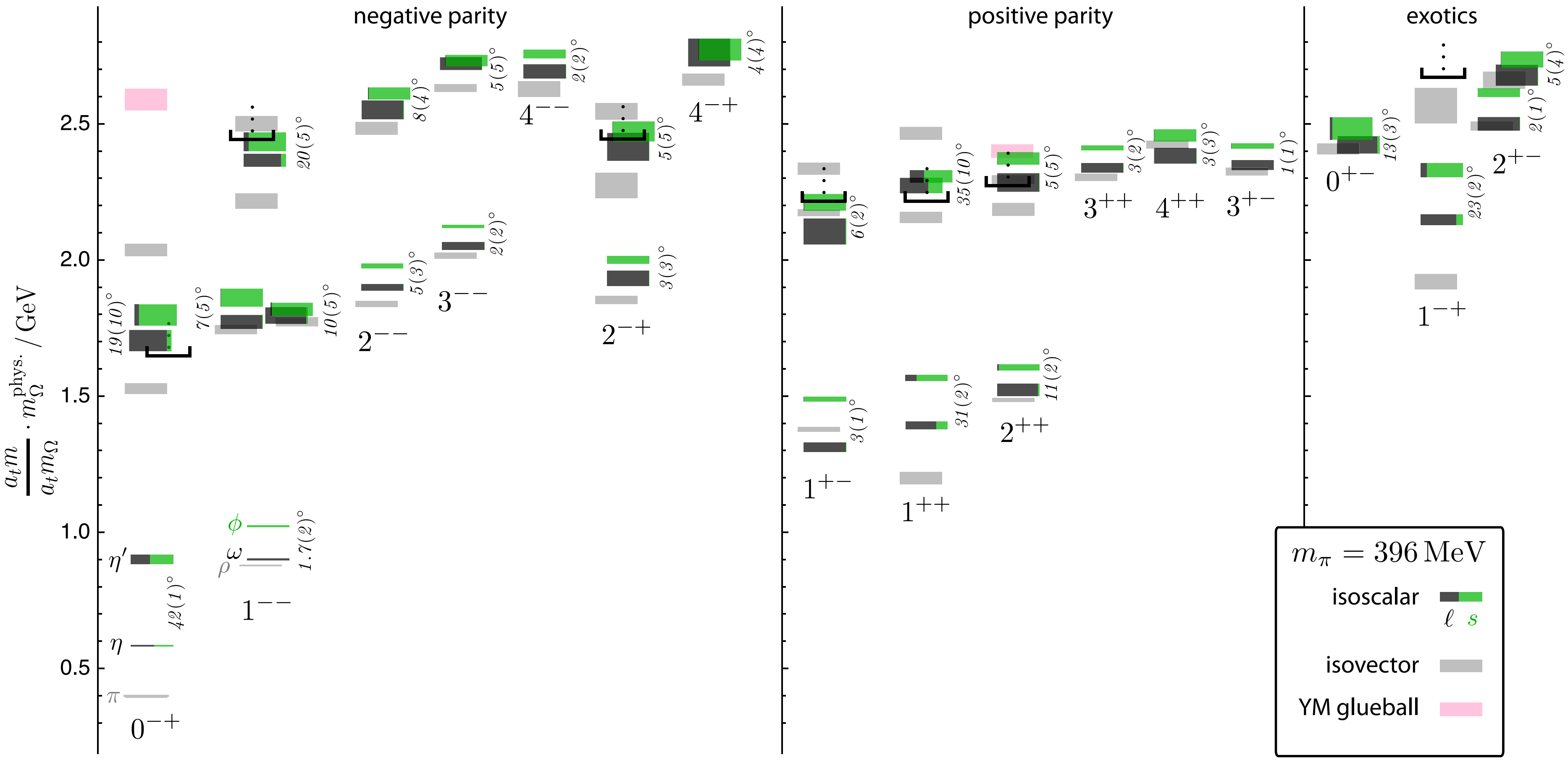
- Lattice QCD and the meson spectrum.
- The GlueX Physics Program.
- Cascade Baryons.
- The Baseline capabilities of the GlueX experiment.
- The initial strangeness program in GlueX.
- Event Rates.
- The Level-3 software trigger.

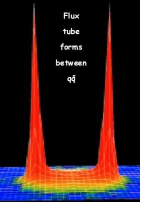


Spectroscopy and QCD

Lattice QCD Predictions

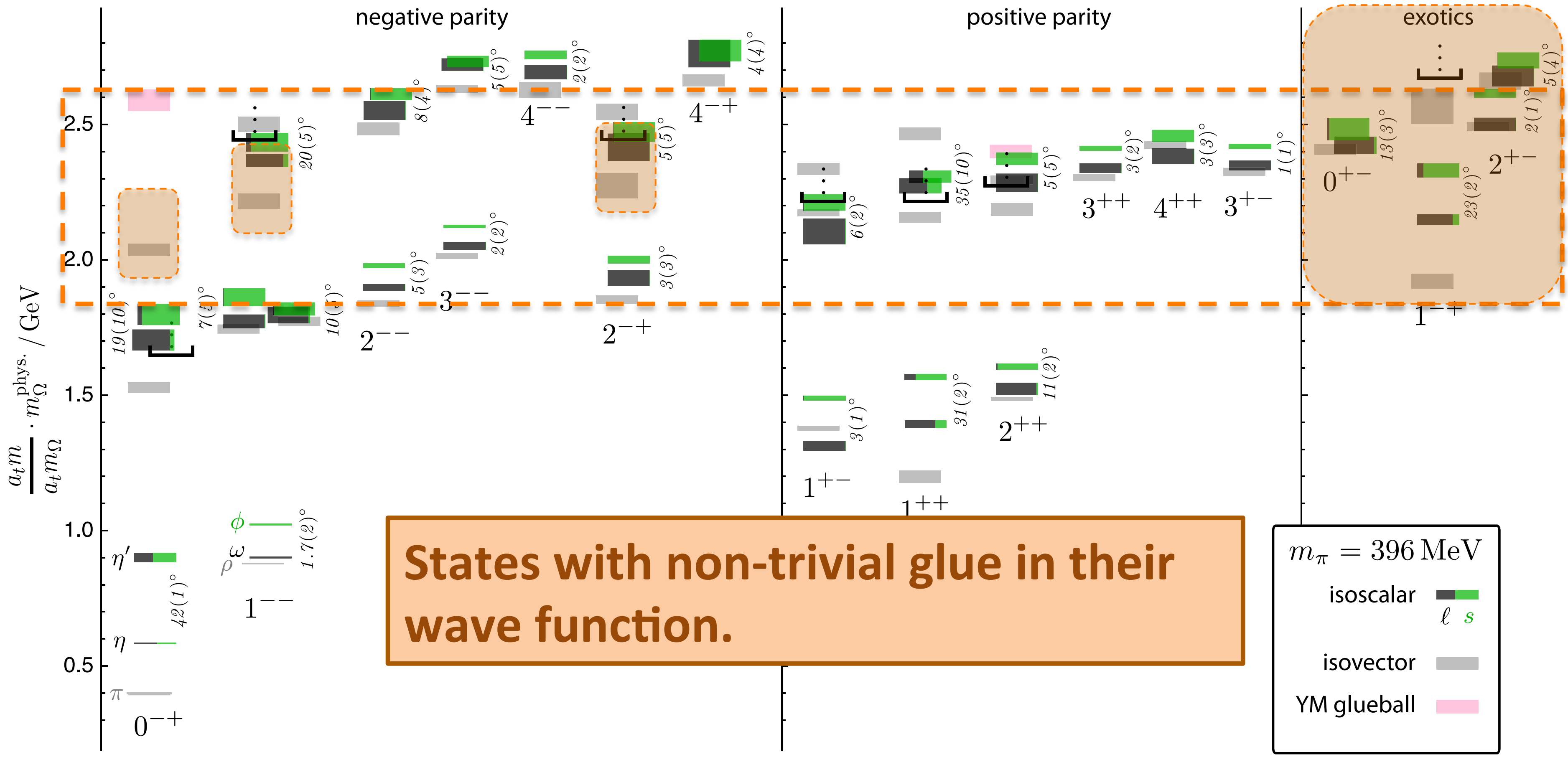
Phys. Rev. D83 (2011) 111502



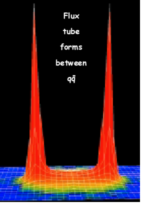


Spectroscopy and QCD

Lattice QCD Predictions



States with non-trivial glue in their wave function.



Spectroscopy and QCD

Phys. Rev. D84 (2011) 074023

``Constituent gluon'' behaves like it has $J^{PC} = 1^{+-}$

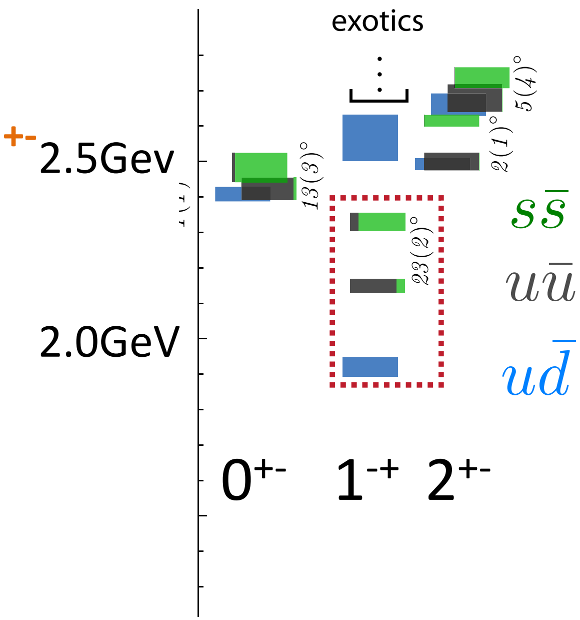
Mass ~ 1-1.5 GeV

Lightest hybrid nonets: 1^{--}, $(0^{-+}, 1^{-+}, 2^{-+})$

The 0+- and two 2+- exotic nonets:

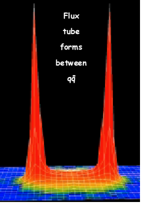
also a second 1^{-+} nonet

p-wave meson plus a ``gluon''



Several nonets predicted

The GlueX program is to map the nonets of hybrid mesons.

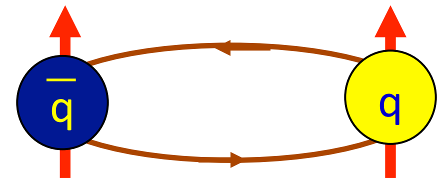


Spectroscopy and QCD

Experimental results on mixing:

$$J^{PC} = 0^{-+} : \pi, \eta, \eta', K \; : \; \theta = -11.5^\circ$$
$$J^{PC} = 1^{--} : \rho, \omega, \phi, K^* \; : \; \theta = 38.7^\circ$$
$$J^{PC} = 1^{+-} : b_1, h_1, h_1', K_{1B} \; : \; \theta = 34^\circ$$
$$J^{PC} = 1^{++} : a_1, f_1, f_1', K_{1A} \; : \; \theta = 13^\circ$$
$$J^{PC} = 2^{++} : a_2, f_2, f_2', K_2^* \; : \; \theta = 28^\circ$$
$$J^{PC} = 3^{--} : \rho_3, \omega_3, \phi_3, K_3^* \; : \; \theta = 31^\circ$$

Quarkonium



Ideal Mixing: **θ = 35.3º**

$$|u\bar{u} + d\bar{d} > \quad |s\bar{s} >$$

Measure through decay rates:

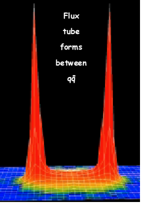
$f_2(1270) \rightarrow KK \,/\, f_2(1270) \rightarrow \pi\pi \sim 0.05$

$f'_2(1525) \rightarrow \pi\pi \,/\, f'_2(1525) \rightarrow KK \sim 0.009$

GlueX needs to observe the $s\bar{s}$ and $l\bar{l}$ states and see their decays to strange final states.

Lattice QCD suggests some nonets do not have ideal mixing:

0^{-+} ground state and radial
1^{--} $^3D_1$ ground state.
1^{++} ground state
1^{-+} exotic



Spectroscopy and QCD

Exotic Quantum Number Hybrids

$\pi_1 \to \pi b_1$, πf_1 , $\pi\rho$, ηa_1, $\eta' \pi$
$\eta_1 \to \pi(1300)\pi$, $a_1\pi$
$\eta'_1 \to K_1(1400)K$, $K_1(1270)K$, K^*K

1^{-+}

Initial GlueX searches.

Higher statistics needed.

Kaon identification

$b_2 \to a_1\pi$, $h_1\pi$, $\omega\pi$, $a_2\pi$
$h_2 \to b_1\pi$, $\rho\pi$, $\omega\eta$
$h'_2 \to K(1460)K$, $K_1(1270)K$, $h_1\eta$

2^{+-}

<u>**This proposal:**</u>

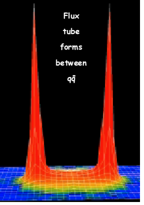
We will get higher statistics.

We begin the kaon program.

$b_0 \to \pi(1300)\pi$, $h_1\pi$
$h_0 \to b_1\pi$, $h_1\eta$
$h'_0 \to K_1(1400)K$, $K_1(1270)K$, K_2K

0^{+-}

$\gamma p \to p K^+ K^- \pi^+ \pi^-$
$\gamma p \to p K^+ K_S \pi^-$



Cascade Baryons

<u>PDG 2012</u>

$\Xi(1320)$ $J^P = (1/2)^{+?}$ ****

$\Xi^*(1530)$ $J^P = (3/2)^{+}$ ****

$\Xi^*(1620)$ $J^P = (?/2)^{?}$ *

$\Xi^*(1690)$ $J^P = (?/2)^{?}$ ***

$\Xi^*(1820)$ $J^P = (3/2)^{-}$ ***

$\Xi^*(1950)$ $J^P = (?/2)^{?}$ ***

$\Xi^*(2030)$ $J^P = (?/2)^{?}$ ***

$\Xi^*(2120)$ $J^P = (?/2)^{?}$ *

$\Xi^*(2250)$ $J^P = (?/2)^{?}$ **

$\Xi^*(2370)$ $J^P = (?/2)^{?}$ **

$\Xi^*(2500)$ $J^P = (?/2)^{?}$ *

Information is limited:

J^P is only known for 3 states.

PDG: Nothing of significance has been added since 1988.

Expectations that many are narrow.

Experimentally challenging:

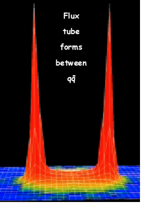
Produced through hyperon decay.

Many-particle final states.

Small cross sections.

GlueX acceptance and rates are ideal:

Production kinematics are challenging.



Cascade Baryons

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Ξ(1320) $J^P = (1/2)^{+?}$ ****

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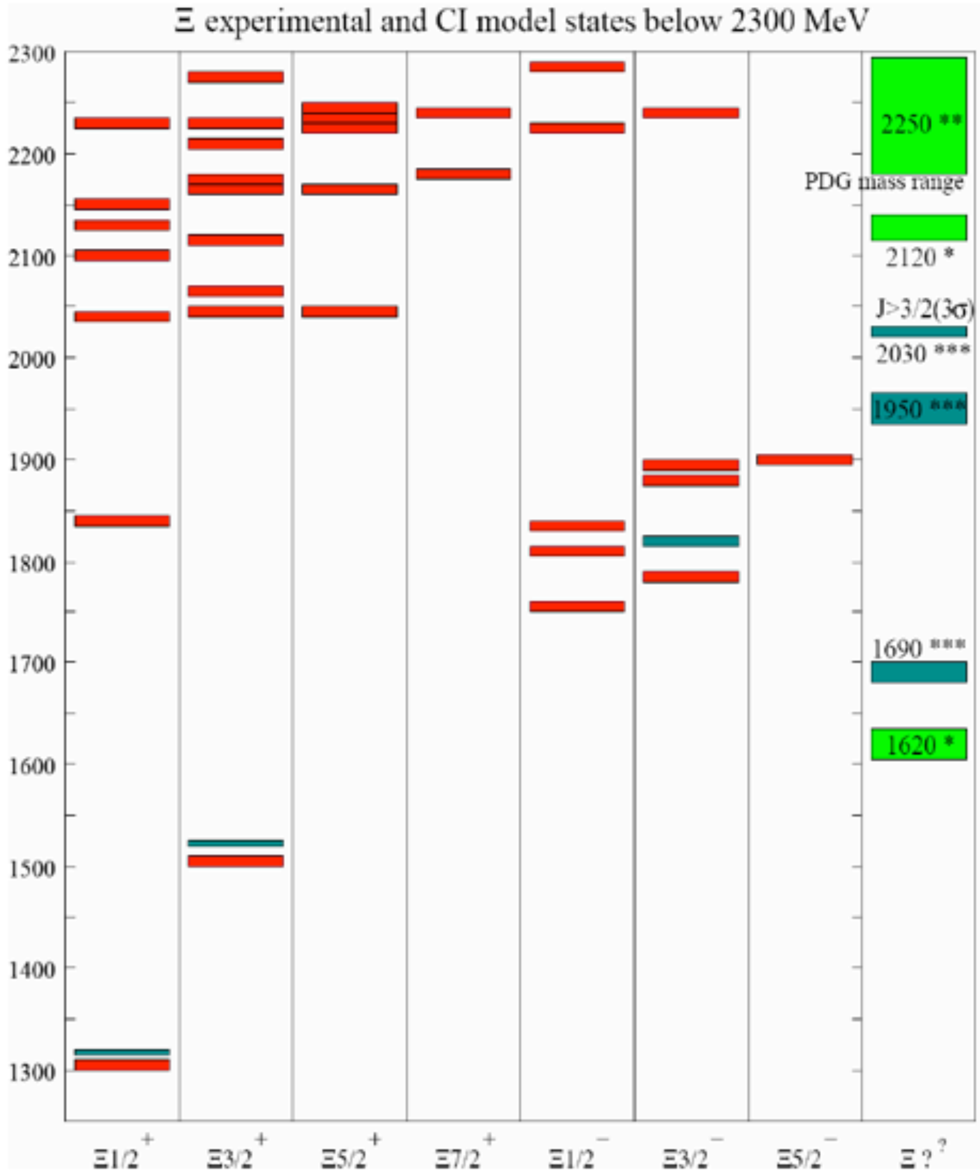
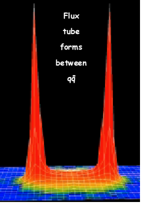
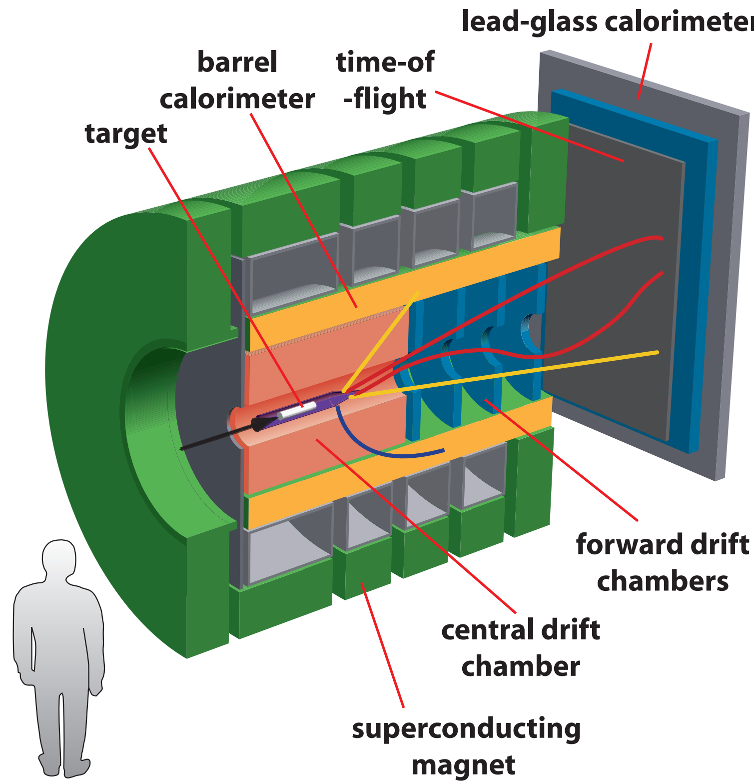




Baseline Kaon Identification



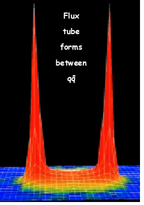
No one system can identify all kaons

- Time-of-flight wall
- Time-of-flight in BCAL
- dE/dx in the CDC

The Hermetic GlueX Detector allows for kinematic constraints

- Kinematic fitting
- Vertex constraints
- Secondary vertices
- Isolation tests in calorimeters

Use everything globally to take advantage of correlations between variables. Our studies have been carried out with a Boosted Decision Tree (BDT).



Baseline Kaon Identification

<u>Focus on reactions where the recoil **proton is detected**</u>

At least 4-constraint kinematic

Train a BDT to isolate final states with kaons.

$\gamma p \rightarrow pK^+K^-$

$\gamma p \rightarrow pK^+K^-\pi^+\pi^-$

$\gamma p \rightarrow pK^+K_S\pi^- \rightarrow pK^+\pi^+\pi^-\pi^-$

$\gamma p \rightarrow K^+Y^* \rightarrow K+\Xi^*K$

$\Xi^* \rightarrow \Xi\pi\ ,\ K\Lambda$

Focus on charged final states with kaons.

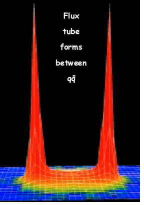
$\gamma p \rightarrow ph'_2(2600) \rightarrow pK_1{}^+K^- \rightarrow pK^+K^-\pi^+\pi^-$

$\gamma p \rightarrow p\eta'_1(2300) \rightarrow pK^{*0}K_S \rightarrow pK^+\pi^+\pi^-\pi^-$

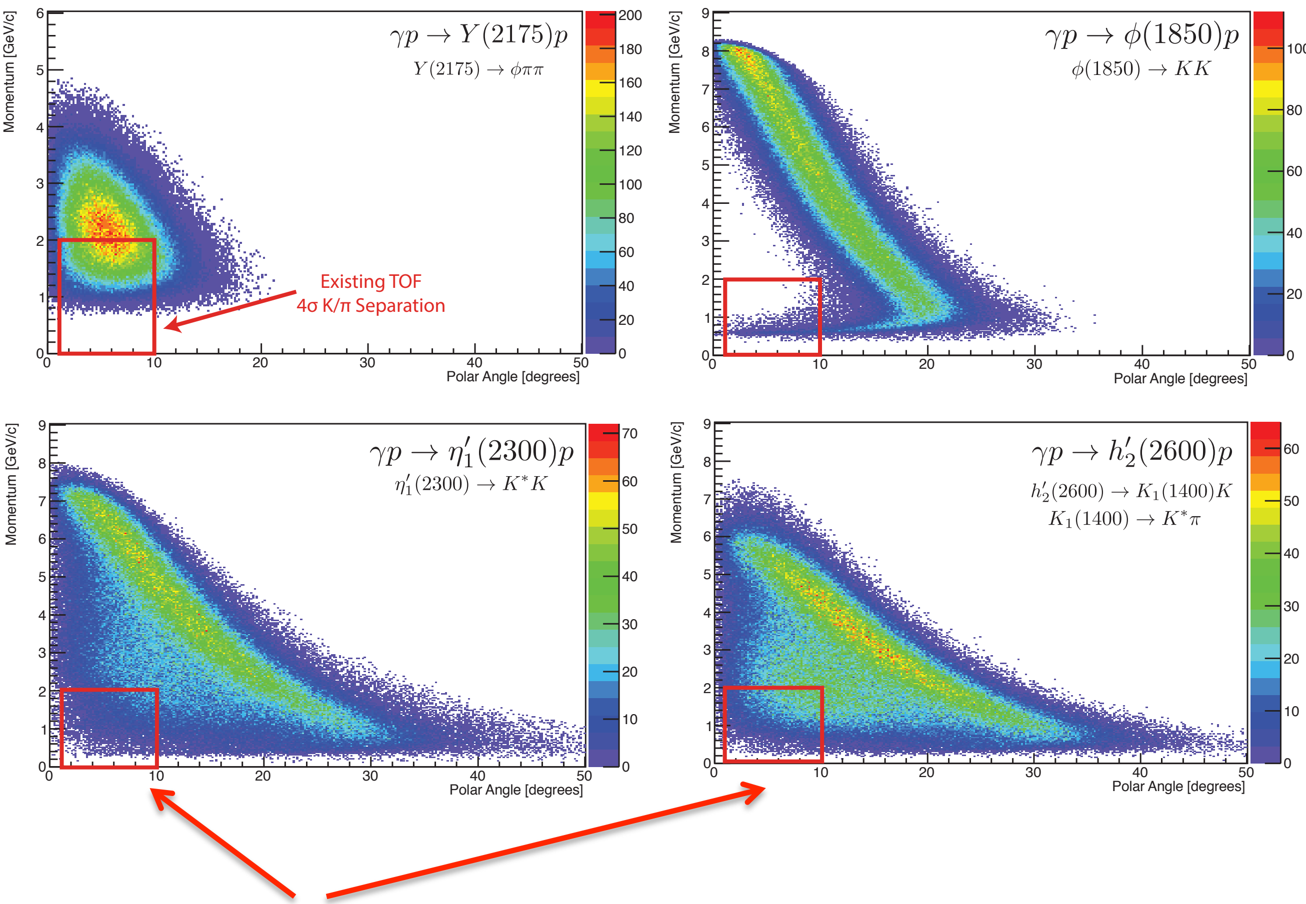
$\gamma p \rightarrow pY(2175) \rightarrow p\phi f_0 \rightarrow pK^+K^-\pi^+\pi^-$

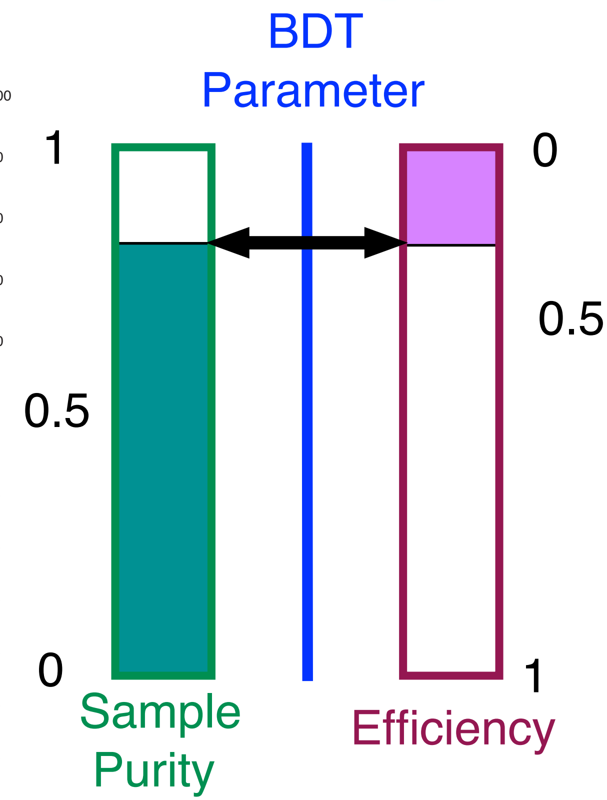
$\gamma p \rightarrow p\phi_3(1850) \rightarrow pK^+K$

A sampling of related final states

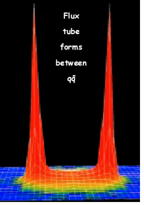


Global Particle Identification





The red boxes show the 4σ coverage of the exiting TOF system in GlueX.



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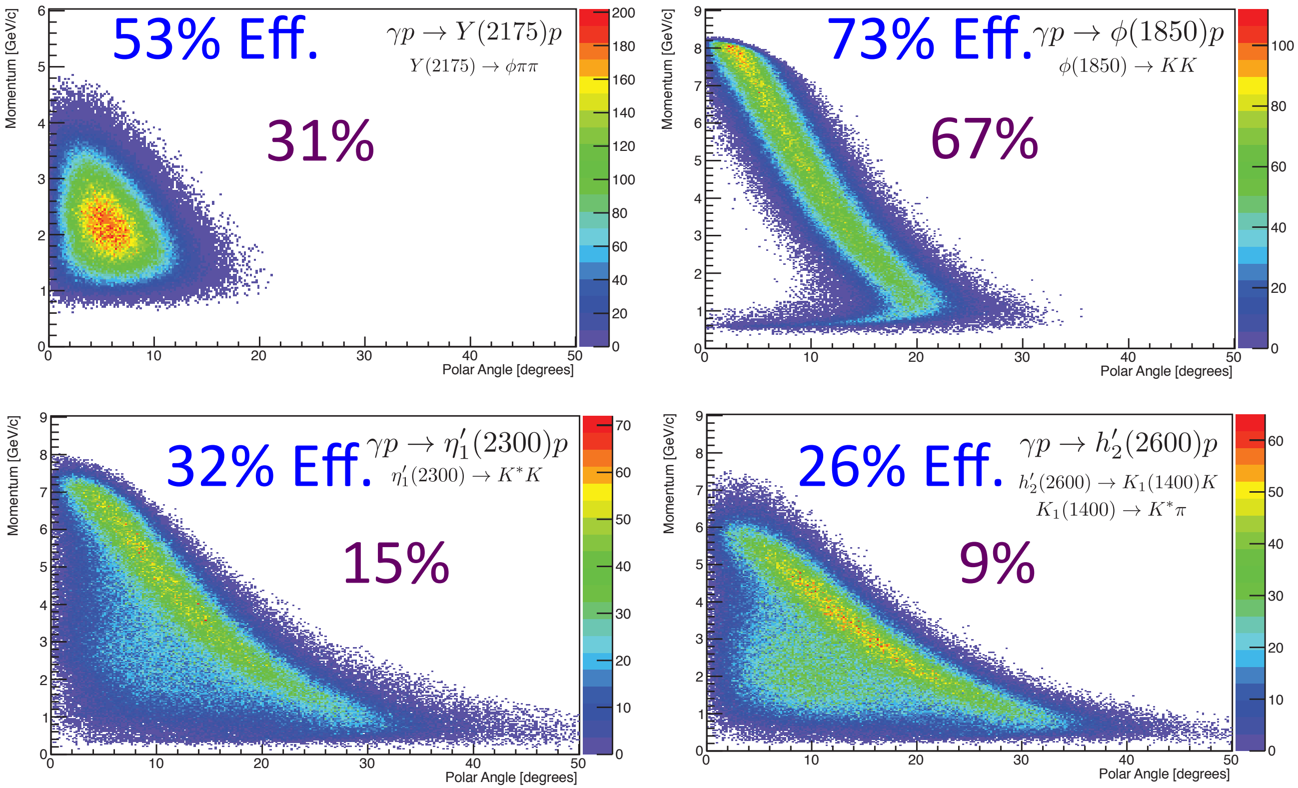
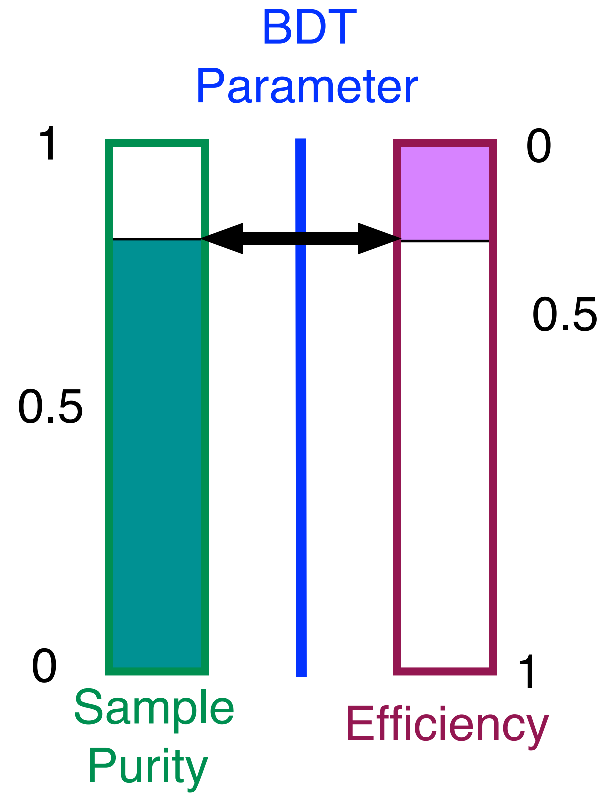
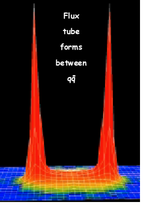




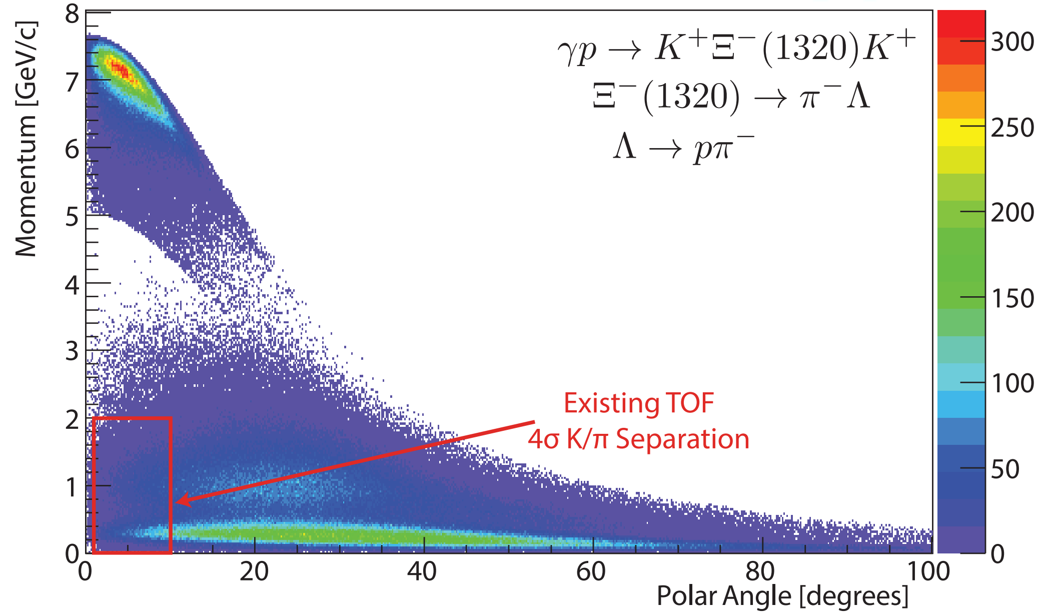
Request 90% purity in the event sample.

Request 95% purity in the event sample.

The baseline GlueX detector can provide pure kaonic event samples with good efficiency.

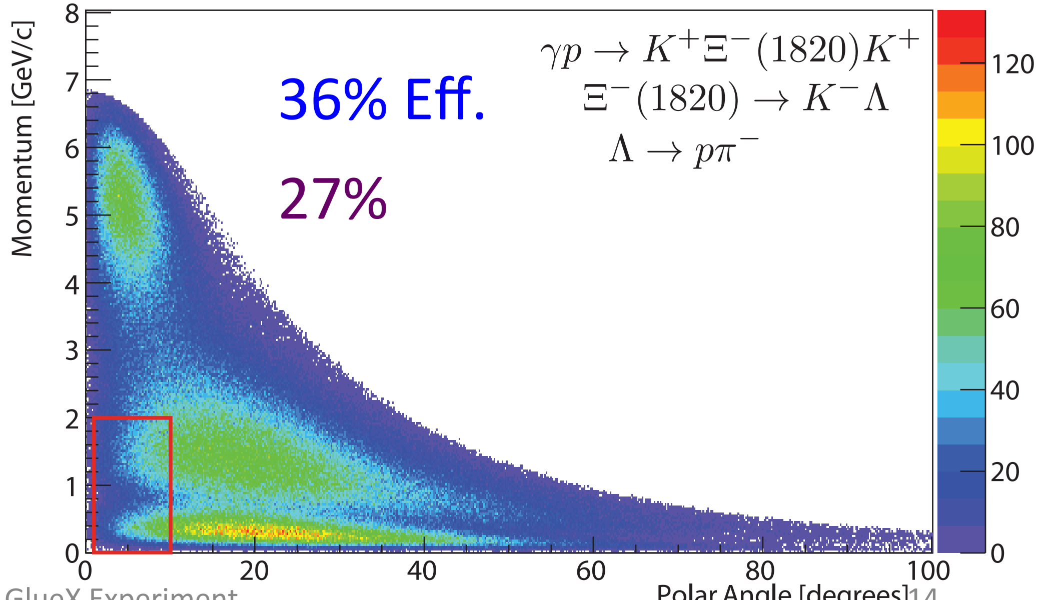


Global Particle Identification



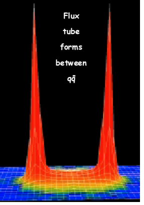
$\gamma p \rightarrow K^+Y^* \rightarrow K+\Xi^*K$

$\Xi^* \rightarrow \Xi\pi$, $K\Lambda$



Request 90% purity.

Request 95% purity.

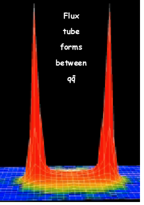


The GlueX Program

Key enhancements for Phase IV running:

- Implementation of the level-3 (software) trigger.
- An order of magnitude more statistics than Phases I-III.

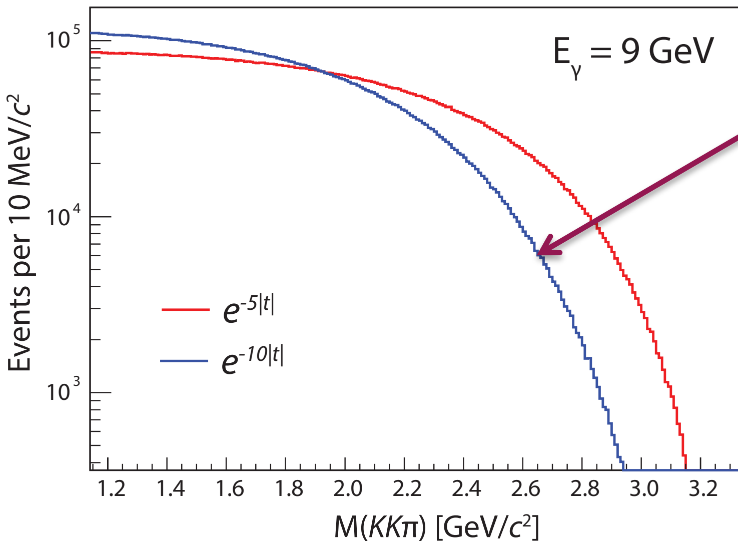
	Approved			Proposed
	Phase I	Phase II	Phase III	Phase IV
Duration (PAC Days)	30	30	60	200
Date of running (nominal)	2014	2015	2016	2017+
Minimum electron energy (GeV)	<10	11	12	12
Average photon flux (γ/s)	10^6	10^7	10^7	5×10^7
Average beam current (nA)	50-200	220	220	1100
Maximum beam emittance (mm-μr)	50	20	10	10
Level-1 (hardware) trigger rate (kHz)	2	20	20	200
Raw Data Volume (TB)	60	600	1200	2300



Event Rates

10^4 events per 10-MeV bin for analysis.

Energy distribution of events depends on meson mass and t-slope.



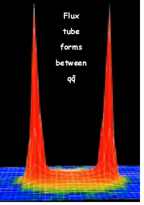
10^7 events detected over all masses. Allows analysis in the 2.5-3.0 GeV mass range.

If only 4×10^6 events detected over all masses, we can do analysis in the 2.0-2.5 GeV mass range.

Two methods to estimate the number of events:

Use track reconstruction efficiency based on software performance and final states coupled with estimated cross sections.

Events from PYTHIA generator through GEANT simulation and reconstructed by the full GlueX software.



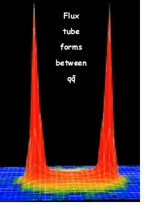
Event Rates

Use track reconstruction efficiency based on software performance and final states coupled with estimated cross sections.

Final State	Cross Section (μb)	Phase I-III ($\times 10^6$)	Phase IV ($\times 10^6$)	
$\pi^+\pi^-\pi^0$	10	**300**	**3000**	Phase III
$\pi^+\pi^-\pi^+$	4	**120**	**1200**	
$\omega_{3\pi}\pi\pi$	0.2	**4**	**40**	
$\omega_{\gamma\pi}\pi\pi$	0.2	0.6	**6**	Higher statistics
$\eta_{\gamma\gamma}\pi\pi$	0.2	**3**	**30**	
$\eta_{\gamma\gamma}\pi\pi\pi$	0.2	2	**20**	
$\eta'_{\pi\pi\pi}\pi\pi$	0.1	0.3	**3**	
$KK\pi\pi$	0.5	**4**	**40**	Kaons
$KK\pi$	0.1	1	**10**	

Estimates (rows $\omega_{\gamma\pi}\pi\pi$ through $KK\pi$)

A factor 10 increase in statistics allows access to small signals from initial running.

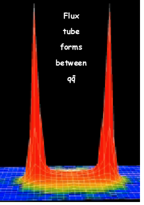


Event Rates

Events from PYTHIA generator through GEANT simulation and reconstructed by the full GlueX software.

GlueX Data Challenge: (December 2012) We simulated and reconstructed 5.3 x 10^9 events. These were based on the full hadronic cross section in the 8.4-9.0 GeV photon energy window and represent 70% of phase III running in GlueX. Trained and used BDTs to extract final states of interest.

Meson	Final State	Mass Window	Events	Events/10MeV
$h'_2(2600)$	$KK\pi\pi$	2.42-2.79	$1.5x10^6$	$4.0x10^4$
$\eta'_1(2300)$	$K\pi\pi\pi$	2.00-2.60	$0.46x10^6$	$1.5x10^4$
$\phi_3(1850)$	KK	1.72-1.98	$5.3x10^6$	$21.x10^4$
Y(2175)	$KK\pi\pi$	2.06-2.29	$0.12x10^6$	$0.52x10^4$
$\Xi^*(1820)$	$KKK\Lambda$		$90x10^3$	



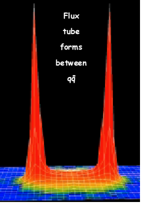
Level-3 Software Trigger

Coherent bremsstrahlung leads to 40% linear polarization for 8.4-9.0 GeV photons. GlueX has a rate limit of 10^8 γ/s in this range.
GlueX is limited to 10^7 γ/s in this range without a Level-3 trigger.

GlueX was designed to have a software trigger to allow for higher rates, and to reduce data volume and increase analysis efficiency.
The trigger should reduce the data rate by a factor of 10:

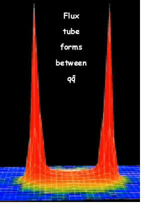
3GB/s ➔ 300 MB/s

The infrastructure for the trigger exists in the baseline GlueX. The compute farm is needed to enable the trigger.
Needed hardware is estimated at ~2000 of today's compute cores (@64 per box ~32 blades), less expensive than tape storage.
The GlueX MIT group developed the LHCb software trigger and have taken on the GlueX trigger.

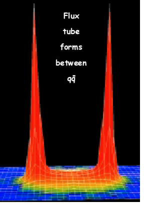


Summary

- This request will allow GlueX to move into its main production running and acquire data that will afford the study many of the important final states for exotic hybrid mesons.
- Implementation of the GlueX Level-3 trigger is necessary to achieve the beam rates necessary to collect these data. We are working with the lab to try and have some test capability available early. The MIT group has been funded to develop and implement the trigger algorithms.
- The capabilities of the baseline GlueX will allow us to start the kaon physics needed for a full hybrid search, but additional kaon-identification capabilities will be needed to complete this (our conditionally approved proposal from last year).



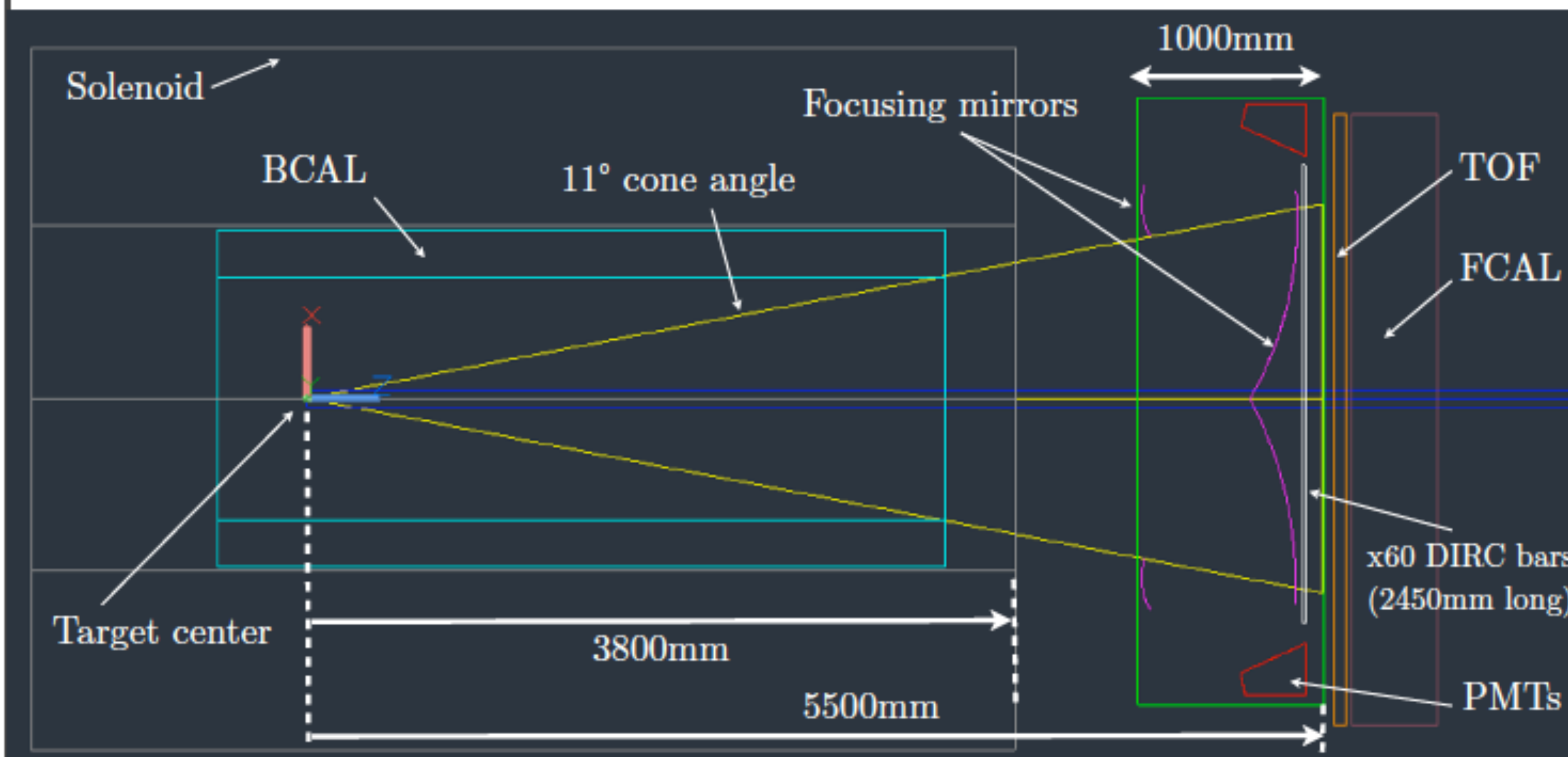
Backup Slides on PID

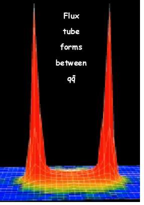


GlueX Forward Particle Identification

Threshold gas Cherenkov combined with a DIRC system.

gDIRC

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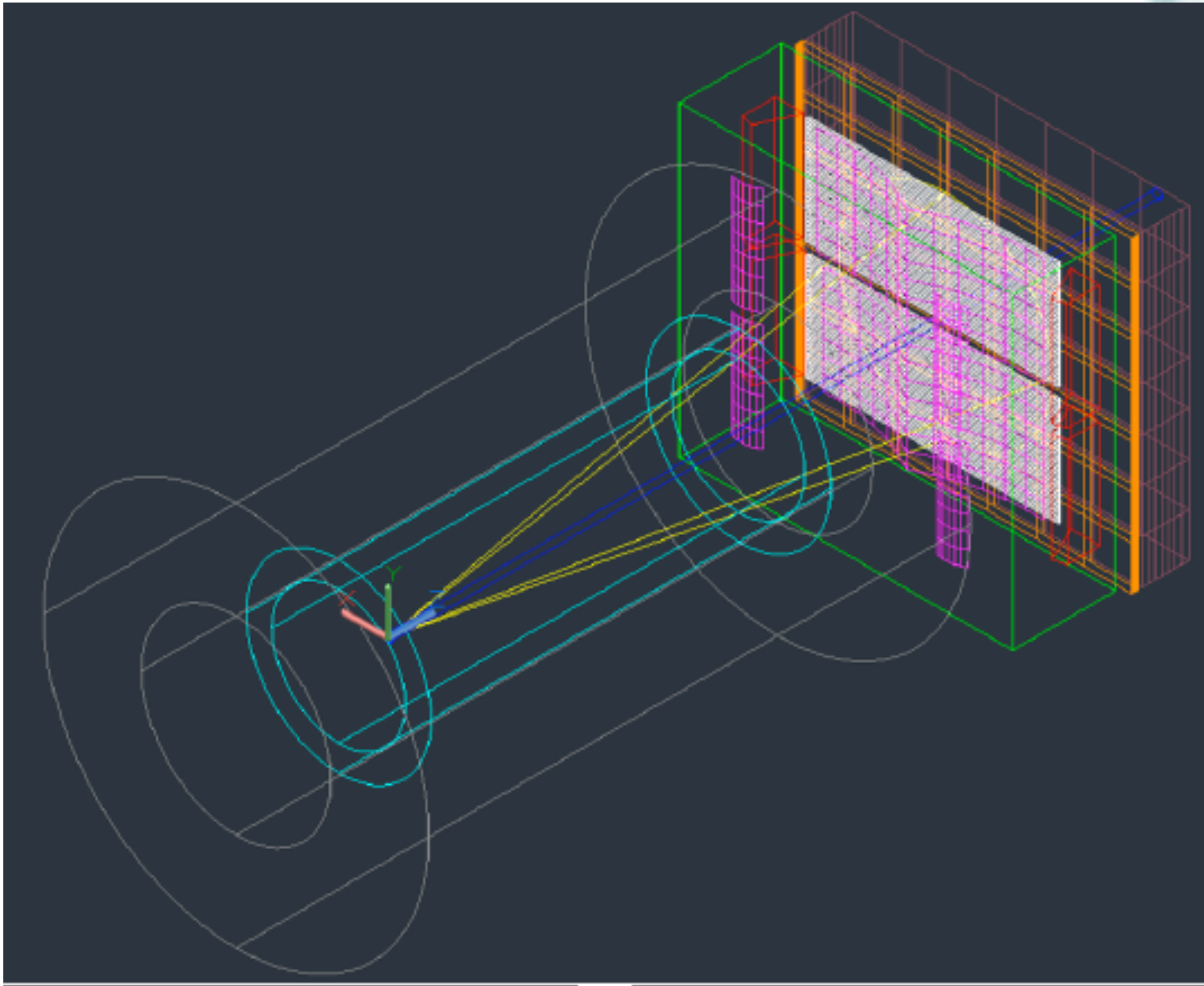
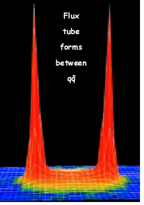




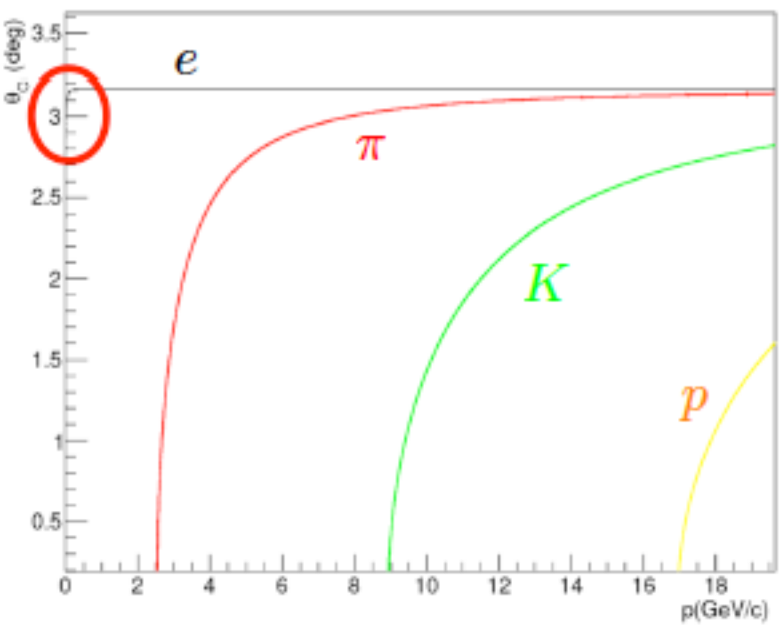
gDirc Particle Identification

DIRC: 3σ K/π Separation up to ~4GeV/c

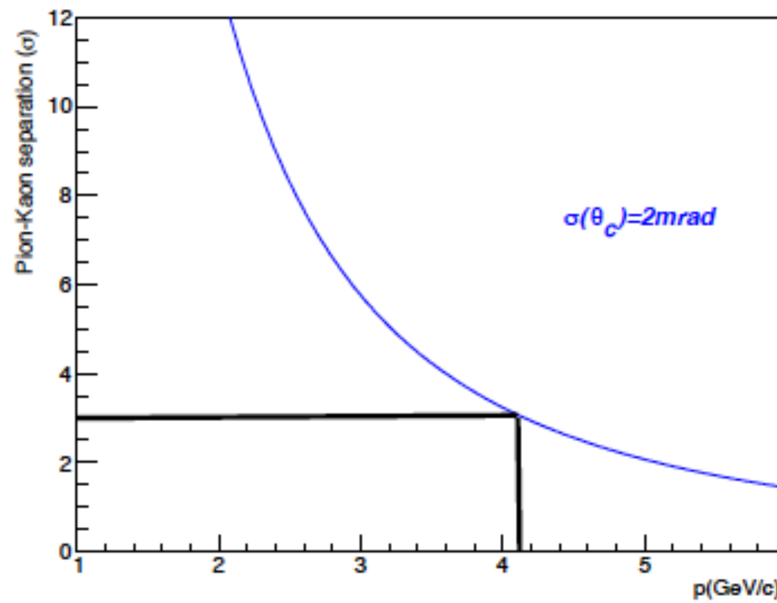
Threshold Gas Cherenkov: 3σ K/π Separation from ~3GeV/c up to 9GeV/c

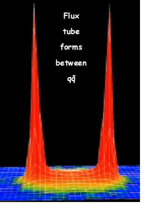
Existing TOF: 3σ K/π Separation up to ~2GeV/c

C4F10: n=1.00153



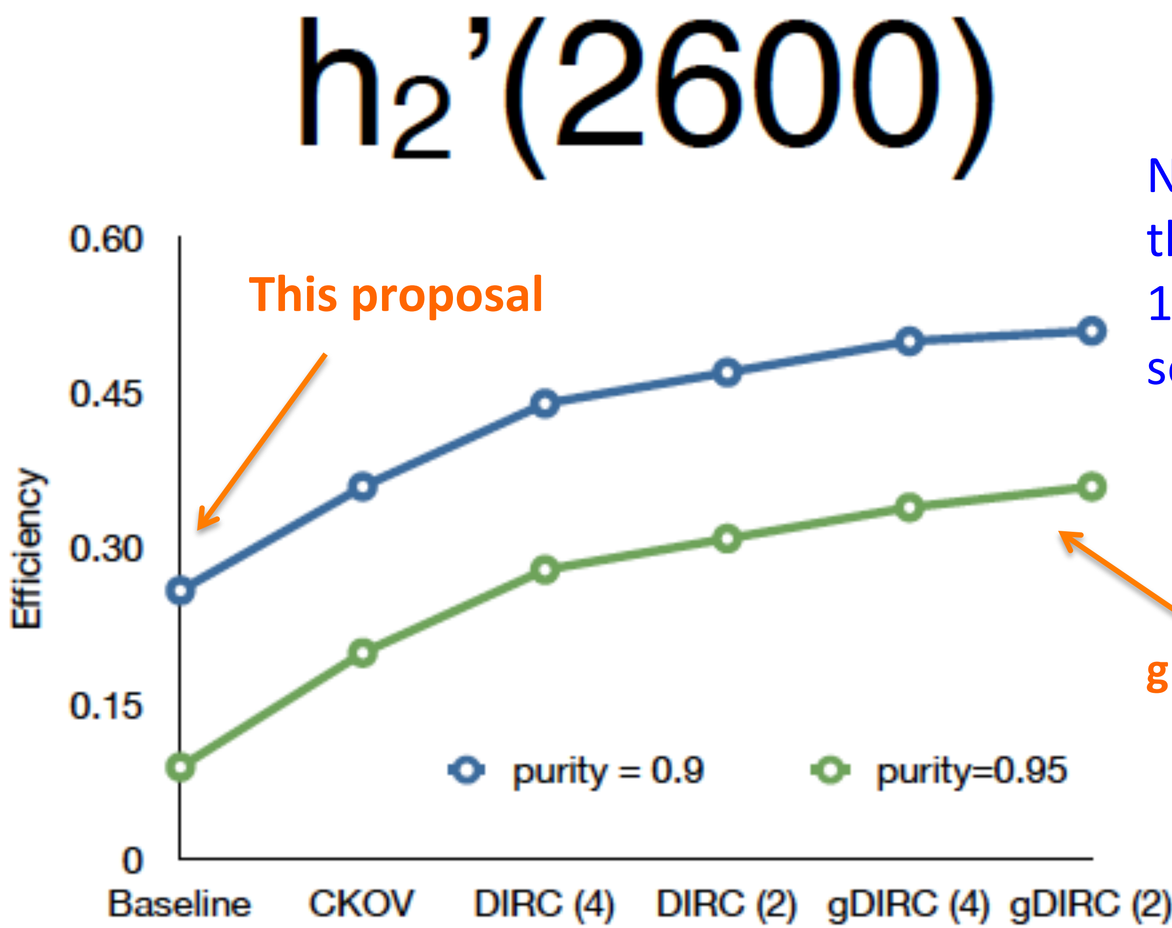
DIRC/Quartz Bars





gDirc Particle Identification

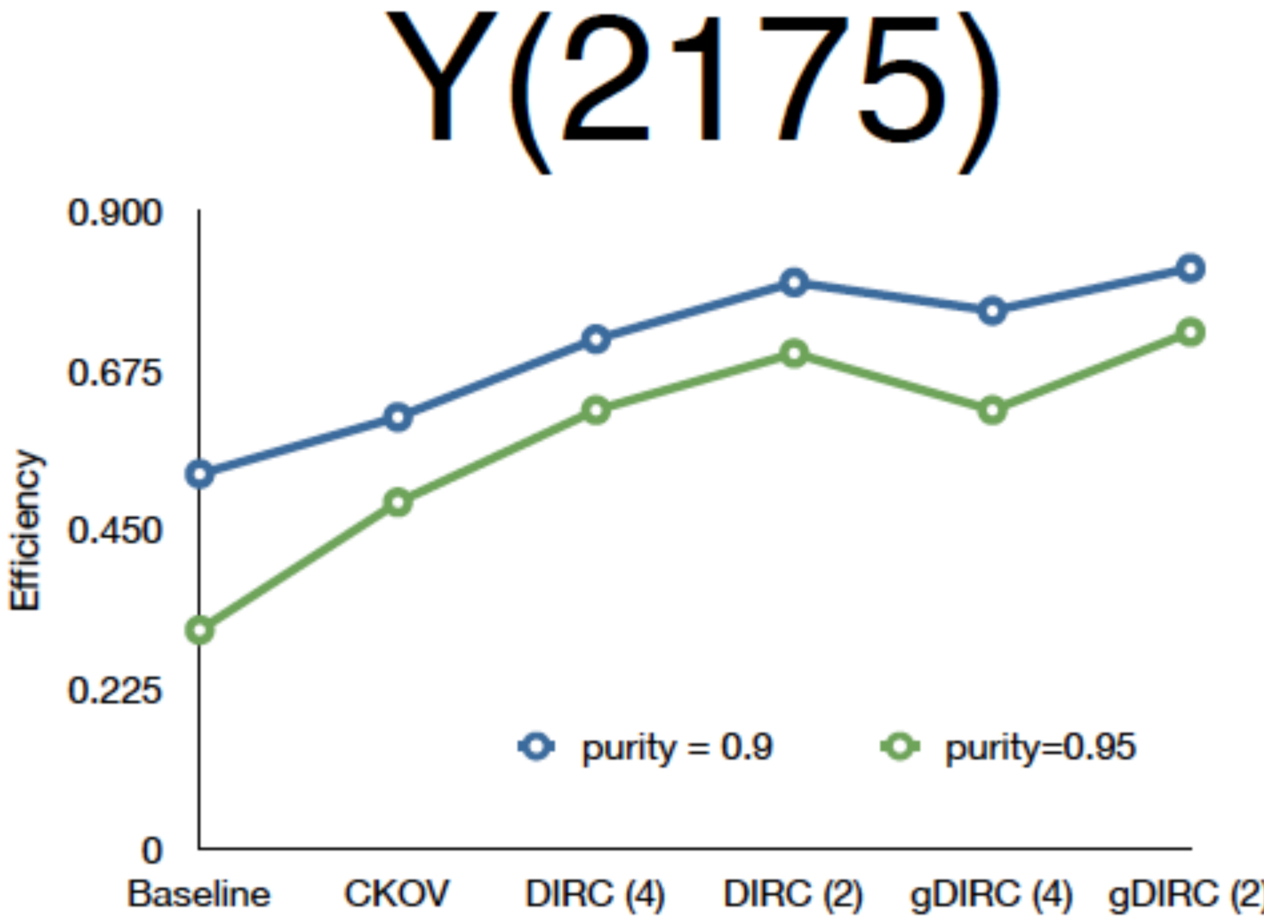
Going from 90% to 95% purity doubles the experiments sensitivity.

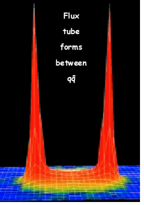


Not shown, but we can push the purity to 99%, which is a 10-fold improvement in sensitivity.

gDIRC PID System

gDirc Particle Identification

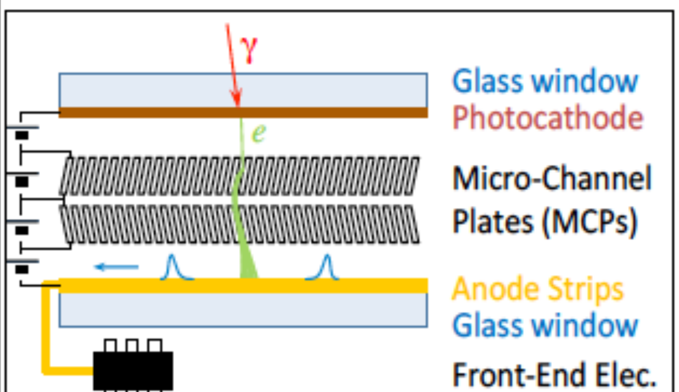


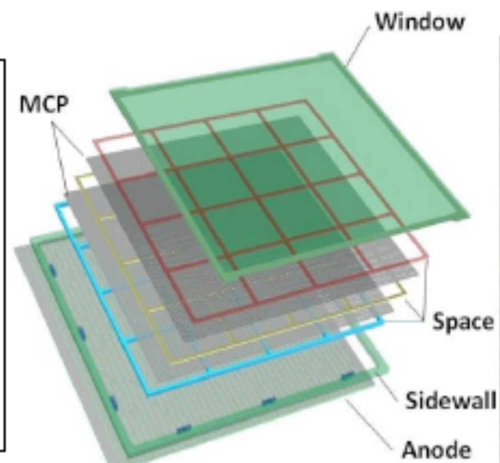


Common Readout

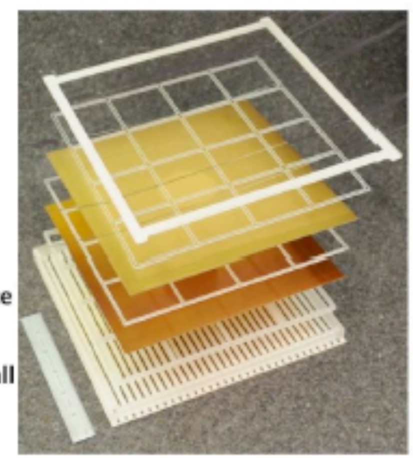
MCP-PMT

- Large-area picoseconds photo-detector (LAPPD) collaboration since 2009 (funded by DOE and NSF)
- Micro-channel plate (MCP) technology to produce large-area photo-detectors with excellent space and time resolution.
- These MCP-PMTs provide much better timing resolution (<10 ps), similar spatial resolution compared to Multi-anode PMTs (MaMPT) at a much lower cost





20×20 cm^2



Very Preliminary Cost Estimate

Expected cost

- Two times 20x210cm = $126,000 (approximately 22 MCP-PMTs)
- 22x80 =1760 channels -> $105,600 ($60 per channel for front-end electronics + DAQ)
- $22,000 (HV/LV power and cables)
- $250,000 (the gas system, including tank, gas system and C4F10)
- $100,000 (DIRC assembly and the end box)
- $100,000 (mirrors for C4F10) 4m2
- $50,000 supporting structure

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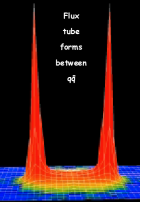
= $753,600

Items are missing, but we believe we can keep to TPC below $2million.

Saving money: A 17mm*35mm*1200mm bar costs about $20k

⟶ 60 BaBar bars: 17mm*35mm*4900mm ~ $5million

15 Baptiste GUEGAN



gDirc Particle Identification

The enhanced Kaon-identification allows us to improve sensitivity to small signals by a factor of up to 10 over the baseline GlueX detector.

The enhanced Kaon-identification makes possible analyses in which the recoil baryon is not detected (neutron or missing proton).

Depending on timeline and funding, this would likely run (partially) in parallel with the current proposal.