A study of meson and baryon decays to strange final states with GlueX

A Proposal to Jefferson Lab PAC 39

from
the GlueX Collaboration

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(Indiana University)

Outline

- GlueX introduction and overview
  - summary of PAC-approved running
  - status of baseline detector construction
  - initial physics goals
- Physics motivation for additional high-luminosity running with kaon identification
  - search for $s\bar{s}$ hybrids
  - isoscalar hybrid mixing angles
  - cascade baryons
- Key components of proposed upgrade
  - forward particle identification system
  - level-three trigger to accommodate high-luminosity running

Hybrid Mesons

- have gluonic degrees of freedom, gluons as constituent particles
- patterns of states expected -- LQCD consistent with "constituent gluon" model
- In the light quark sector we expect an isovector triplet and two isoscalars for each J^{PC}

$$|\ell\bar{\ell}\rangle \equiv (|u\bar{u}\rangle + |d\bar{d}\rangle)/\sqrt{2} \qquad \text{(3+1 states)}$$

$$|s\bar{s}\rangle \qquad \text{(1 state)}$$

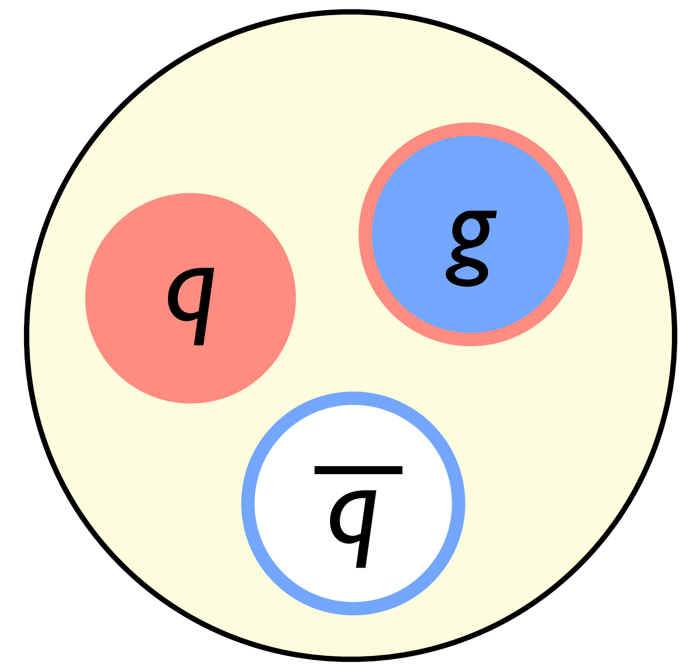
- complete understanding likely to only come from a mapping of the full spectrum

"constituent gluon"

$(J^{PC})_g = 1^{+-}$

mass ≈ 1.0-1.5 GeV

color-octet $q\bar{q}$ pair



<u>Lightest Hybrids</u>

	$S_{q\bar{q}} = 1$	$S_{q\bar{q}} = 0$
J^{PC}:	0^{-+}, 1^{-+}, 2^{-+}	1^{--}

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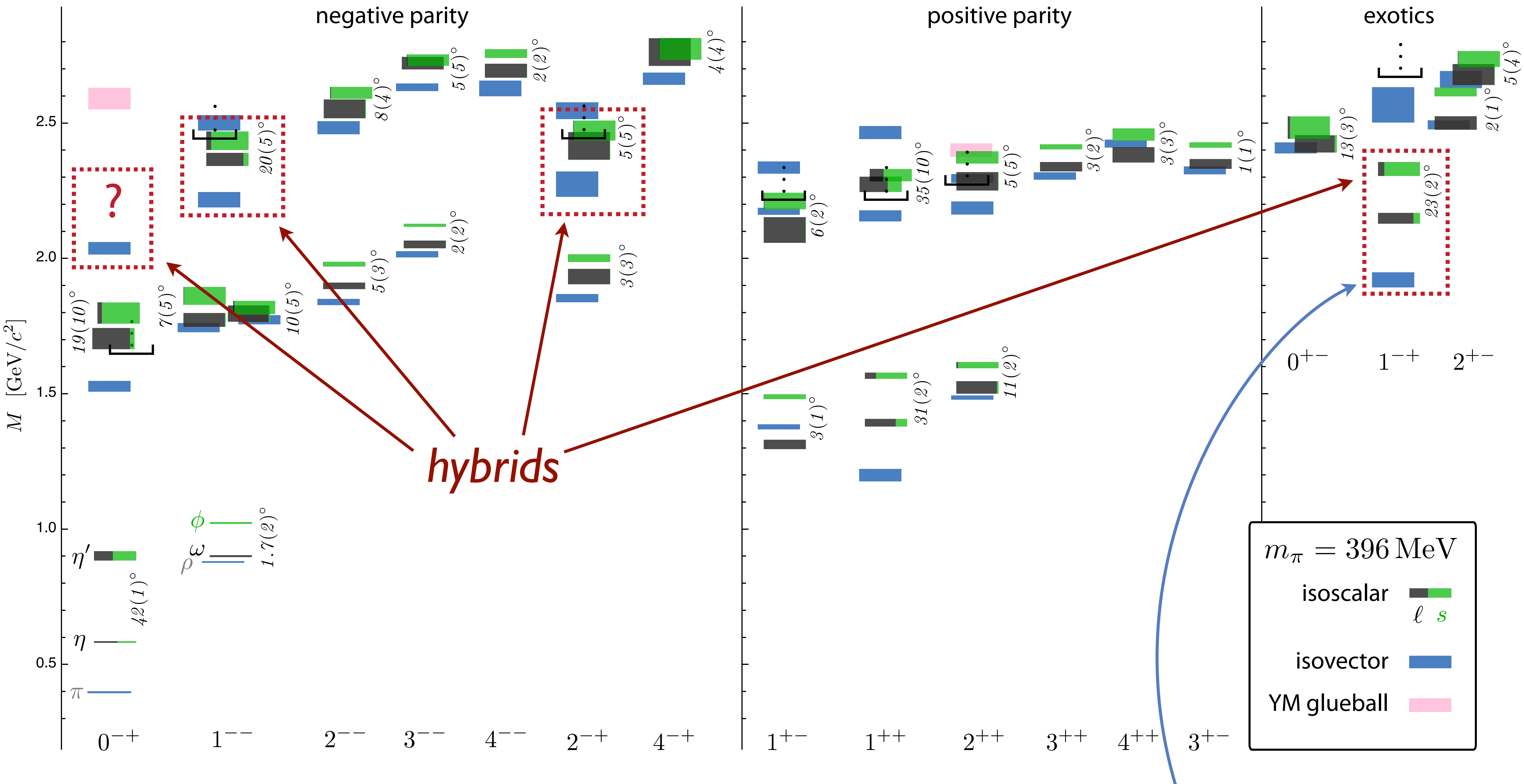
Lattice QCD Predictions

J. Dudek
PRD 84, 074023 (2011)



Majority of experimental data to date is related to one state, the π_1.

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Key (Exotic) Decay Modes

From LQCD → *Model Dependent*

	Approximate Mass (MeV)	J^{PC}	Total Width (MeV) PSS	Total Width (MeV) IKP	Relevant Decays	Final States
π_1	1900	1^{-+}	$80-170$	120	$b_1\pi^\dagger,\ \rho\pi^\dagger,\ f_1\pi^\dagger,\ a_1\eta,\ \eta'\pi^\dagger$	$\omega\pi\pi^\dagger,\ 3\pi^\dagger,\ 5\pi,\ \eta 3\pi^\dagger,\ \eta'\pi^\dagger$
η_1	2100	1^{-+}	$60-160$	110	$a_1\pi,\ f_1\eta^\dagger,\ \pi(1300)\pi$	$4\pi,\ \eta 4\pi,\ \eta\eta\pi\pi^\dagger$
η'_1	2300	1^{-+}	$100-220$	170	$K_1(1400)K^\dagger,\ K_1(1270)K^\dagger,\ K^*K^\dagger$	$KK\pi\pi^\dagger,\ KK\pi^\dagger,\ KK\omega^\dagger$
b_0	2400	0^{+-}	$250-430$	670	$\pi(1300)\pi,\ h_1\pi$	4π
h_0	2400	0^{+-}	$60-260$	90	$b_1\pi^\dagger,\ h_1\eta,\ K(1460)K$	$\omega\pi\pi^\dagger,\ \eta 3\pi,\ KK\pi\pi$
h'_0	2500	0^{+-}	$260-490$	430	$K(1460)K,\ K_1(1270)K^\dagger,\ h_1\eta$	$KK\pi\pi^\dagger,\ \eta 3\pi$
b_2	2500	2^{+-}	10	250	$a_2\pi^\dagger,\ a_1\pi,\ h_1\pi$	$4\pi,\ \eta\pi\pi^\dagger$
h_2	2500	2^{+-}	10	170	$b_1\pi^\dagger,\ \rho\pi^\dagger$	$\omega\pi\pi^\dagger,\ 3\pi^\dagger$
h'_2	2600	2^{+-}	$10-20$	80	$K_1(1400)K^\dagger,\ K_1(1270)K^\dagger,\ K_2^*K^\dagger$	$KK\pi\pi^\dagger,\ KK\pi^\dagger$

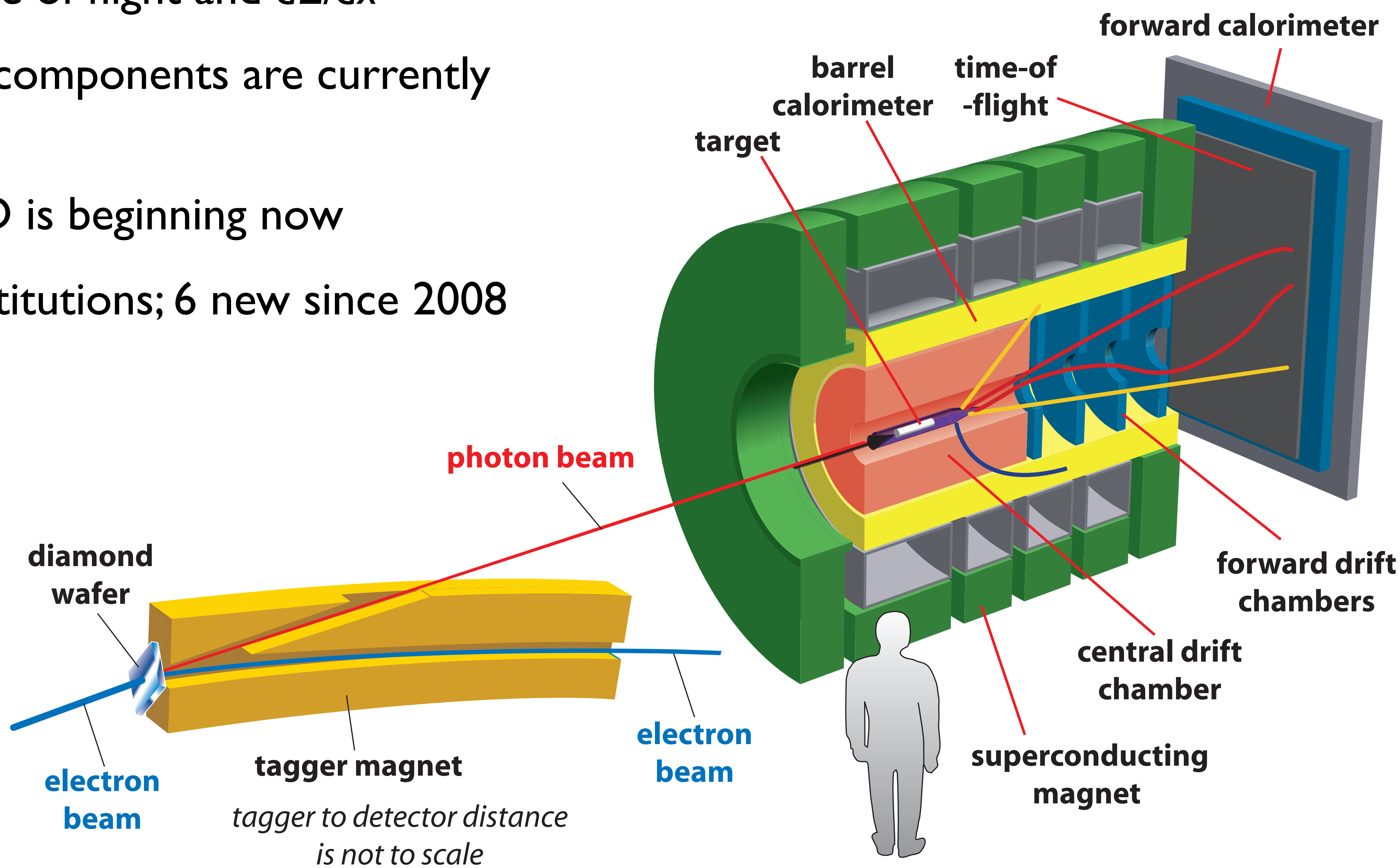
†*experimentally promising: few particles or narrow isobars*

High priority exotic search channels in initial running

- Experimental requirements:
  - ability to identify multiparticle final states
  - high statistics: production of heavy states is suppressed
  - excellent PID -- kaon final states will be impossible in Phases I-III

Baseline GlueX Detector

- Large acceptance for both charged and neutral particles
  - PID limited: time of flight and *dE/dx*
- All major detector components are currently under construction
- Installation in Hall D is beginning now
- 21 collaborating institutions; 6 new since 2008



Proposed Program

	Approved			*Proposed*
	Phase I	Phase II	Phase III	Phase IV
Duration (PAC days)	30	30	60	220[a]
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[b]	220	220	1100
Maximum beam emittance (mm$\cdot\mu$r)	50	20	10	10
Level-one (hardware) trigger rate (kHz)	2	20	20	200
Raw Data Volume (TB)	60	600	1200	2300[c]

- Key enhancements for the proposed Phase IV:
  - an order of magnitude more statistics than Phases I-III
  - kaon identification

[a] *includes 20 days PID commissioning*
[b] *may be taken with amorphous radiator*
[c] *assumes level-3 trigger*

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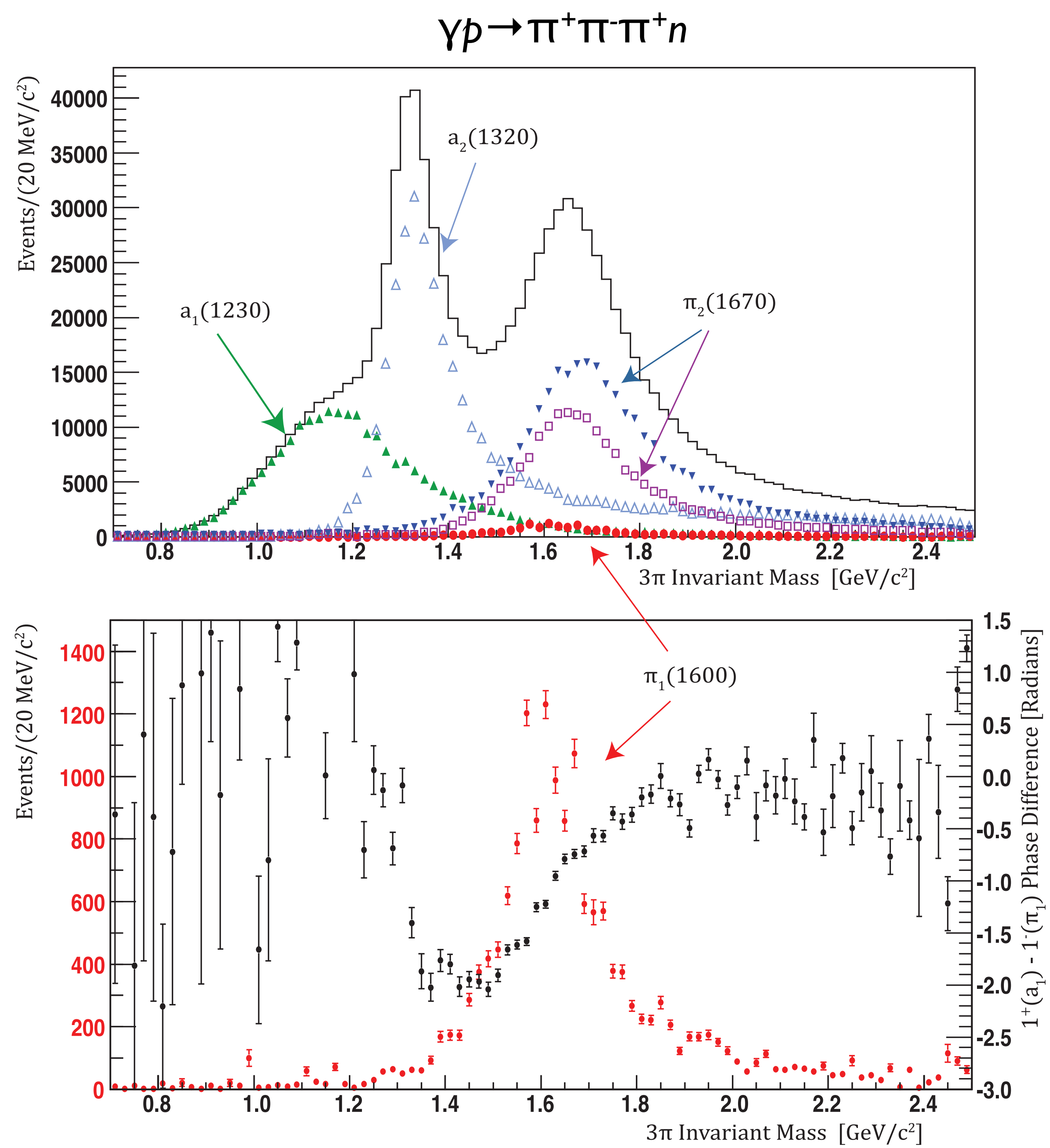
Progress and Limitations

- two-step analysis: event selection and amplitude analysis
- test event selection with inclusive photoproduction Monte Carlo
- Try to extract $\gamma p \rightarrow \pi^+\pi^-\pi^+ n$
  - then (2011) achieved S/N: 2/1
  - mis-ID particles and extra π^0's were dominant
  - motivated dramatic software improvements (still ongoing)
- test amplitude analysis using pure signal -- excellent ability to extract 1%-level exotic
- Conclusions:
  - improved reconstruction or PID (via detectors, kin. fitting, etc.) needed to reduce background
  - GlueX acceptance sufficient for amplitude analysis



Full "data challenges" also planned for the $b_1\pi$ channel.

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Motivation for Enhanced Particle ID

- Enhanced sensitivity to small amplitudes in final states without kaons
  - obtain better signal purity
  - sensitivity to the smallest signal amplitude is limited by the largest background
  - *without excellent PID, increased statistics produce diminishing returns; we are limited by systematic uncertainties on background*

- Greatly expanded physics capability and discovery potential
  - $s\bar{s}$ exotic hybrids and measure isoscalar mixing angles
  - non-exotic hybrids in the spectrum of $s\bar{s}$ vector mesons; may aid in interpretation of charmonium data
  - cascade (Ξ) baryons

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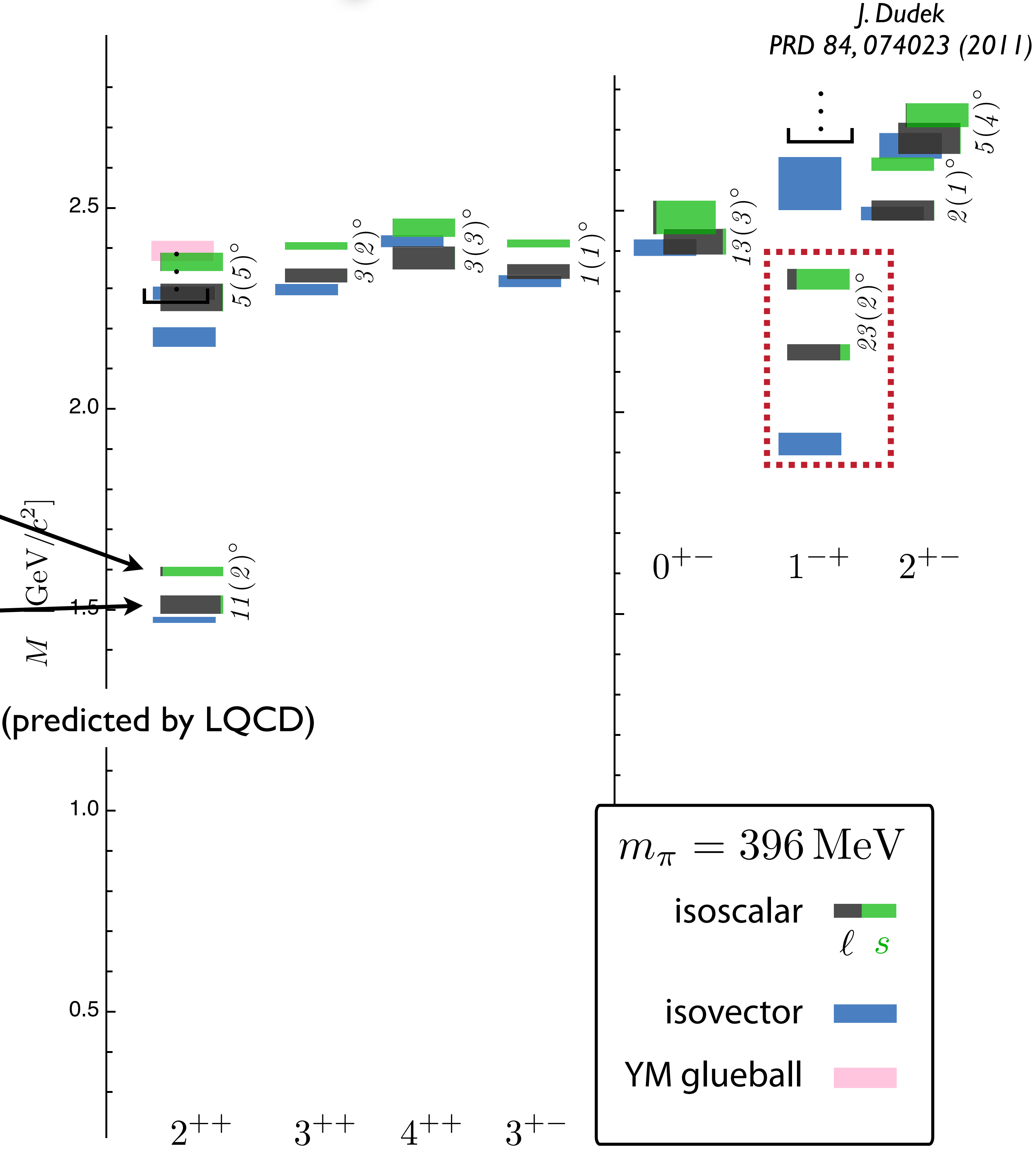
Isoscalar Exotic Hybrids

- Internal quark structure can be inferred by comparing decay modes, for example

$$\frac{\mathcal{B}(f_2'(1525) \to \pi\pi)}{\mathcal{B}(f_2'(1525) \to KK)} \approx 0.009$$

$$\frac{\mathcal{B}(f_2(1270) \to KK)}{\mathcal{B}(f_2(1270) \to \pi\pi)} \approx 0.05$$

(measured by experiment)



(predicted by LQCD)

- Lattice QCD predicts quark flavor mixing angles for isoscalar hybrids
- Need capability to identify both strange and non-strange decays to draw conclusions about either state

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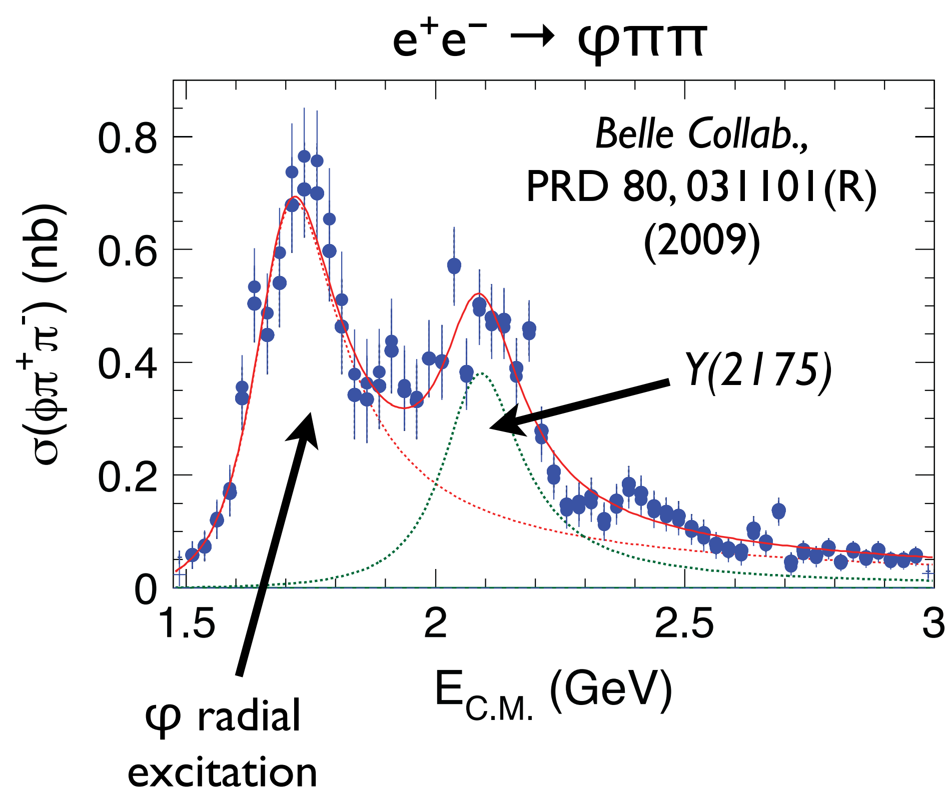
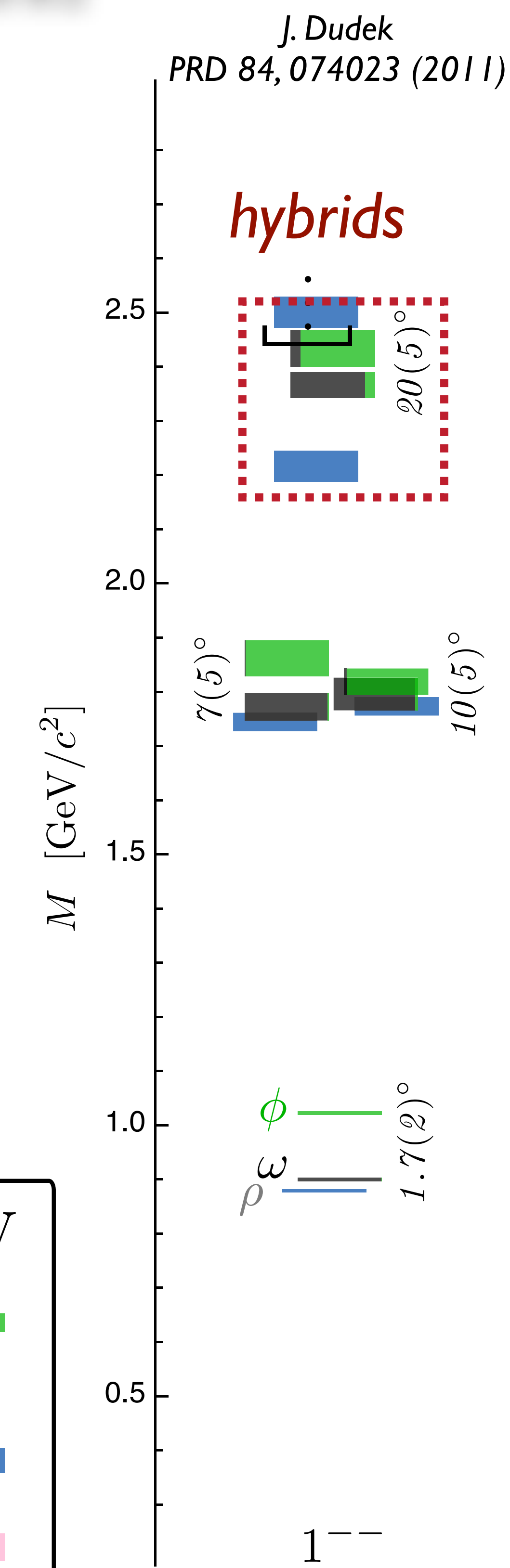
Y(2175): hybrid strangeonium?

- Intriguing discovery in $e^+e^- \to \varphi\pi\pi$ consistent with 1^{--} state *Y*(2175)
  - observed in three different experiments
  - similar decay mode as the *Y*(4260) observed in $e^+e^- \to J/\psi\pi\pi$
- *Y*(4260)
  - no place in spectrum of $c\bar{c}$ vector mesons
  - does not decay to $D\bar{D}$ like other vector charmonia
  - charmonium hybrid?
- With kaon ID GlueX can
  - map the $s\bar{s}$ vector meson spectrum; is Y(2175) supernumerary?
  - study the decays of the *Y*(2175)
  - search for exotic $s\bar{s}$ hybrid members (η_1') of the lightest hybrid multiplet





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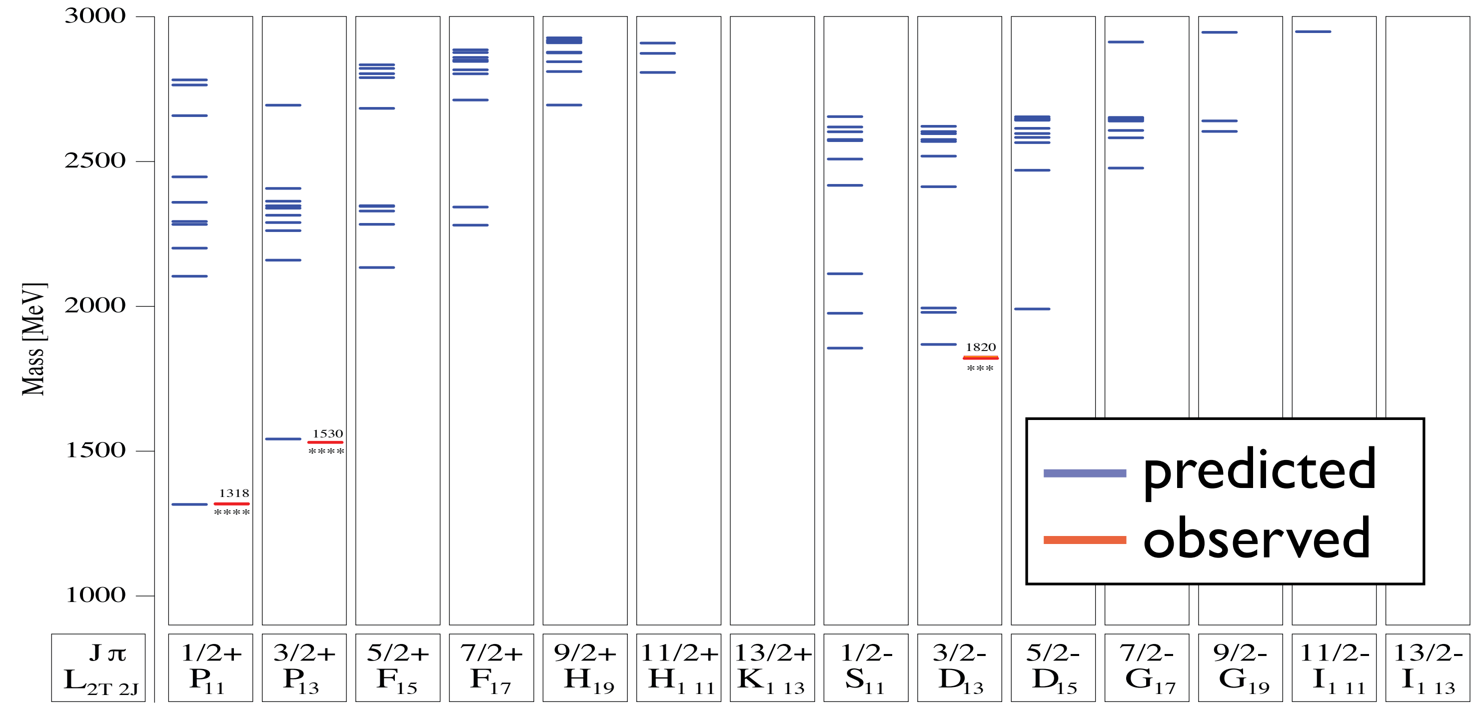
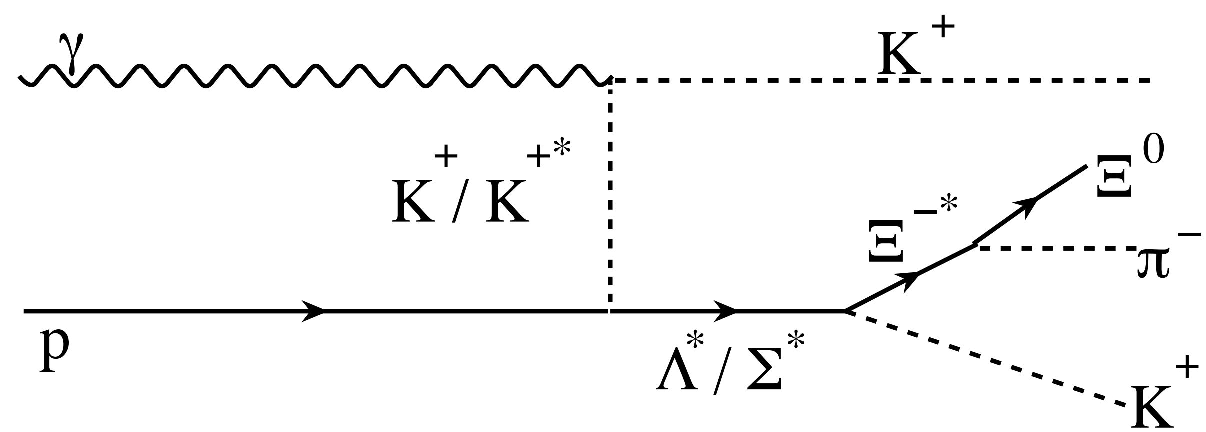
Cascades

- Very little is known about doubly-strange cascade baryons
    - J^P is only known for three established states
    - expected to be narrow
    - PDG: "nothing of significance...added since our 1988 edition"
- Experimentally challenging -- produced typically only in decay of hyperon
    - many particle final state; large acceptance needed to determine J^P
    - small cross sections
- GlueX acceptance and intensity is ideal
    - production kinematics present a challenge to forward kaon ID

U. Loering *et al.*, EPJ A10, 447 (2001)



GlueX production mechanism



Use this and previous physics examples to benchmark the detector design

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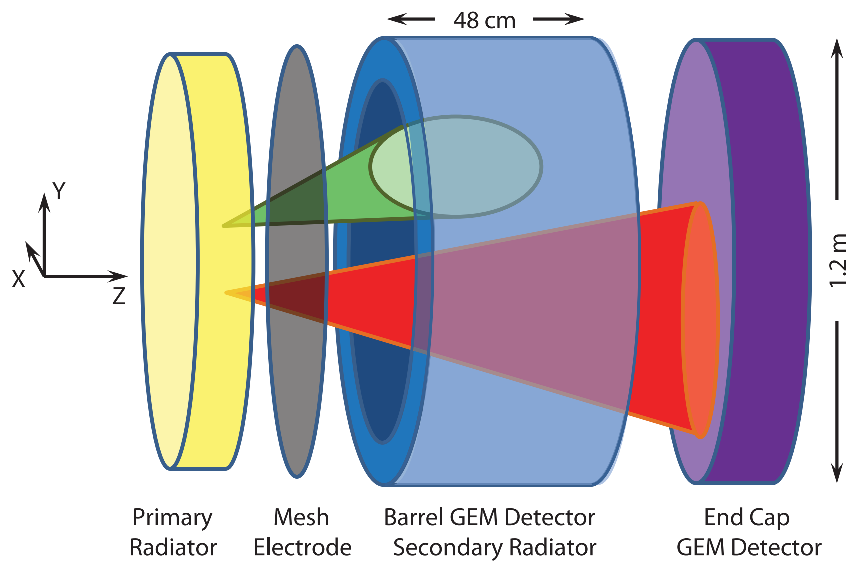
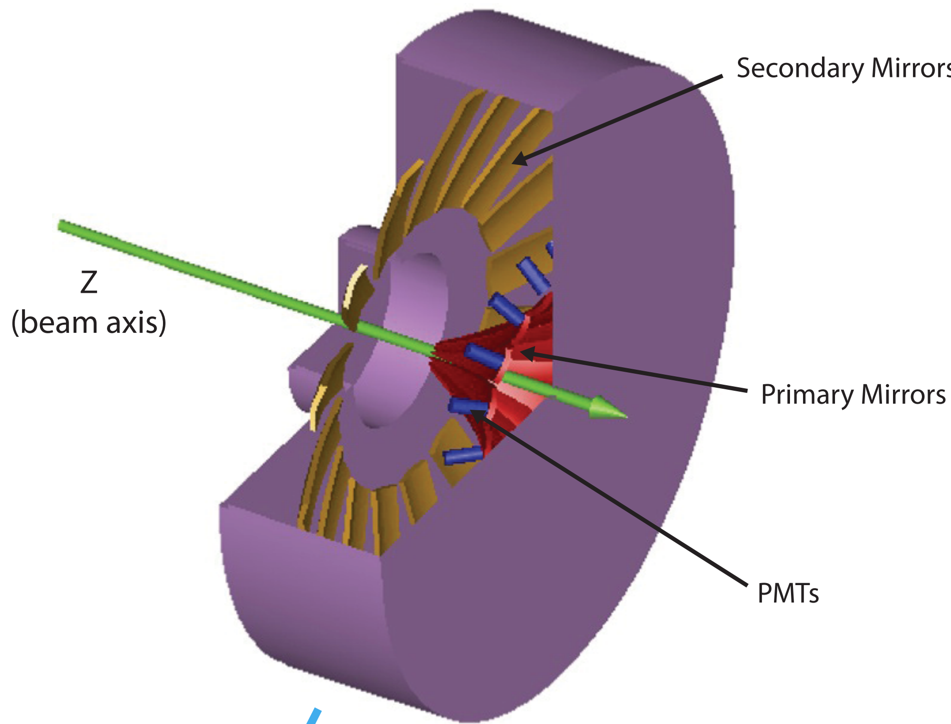
PID Designs

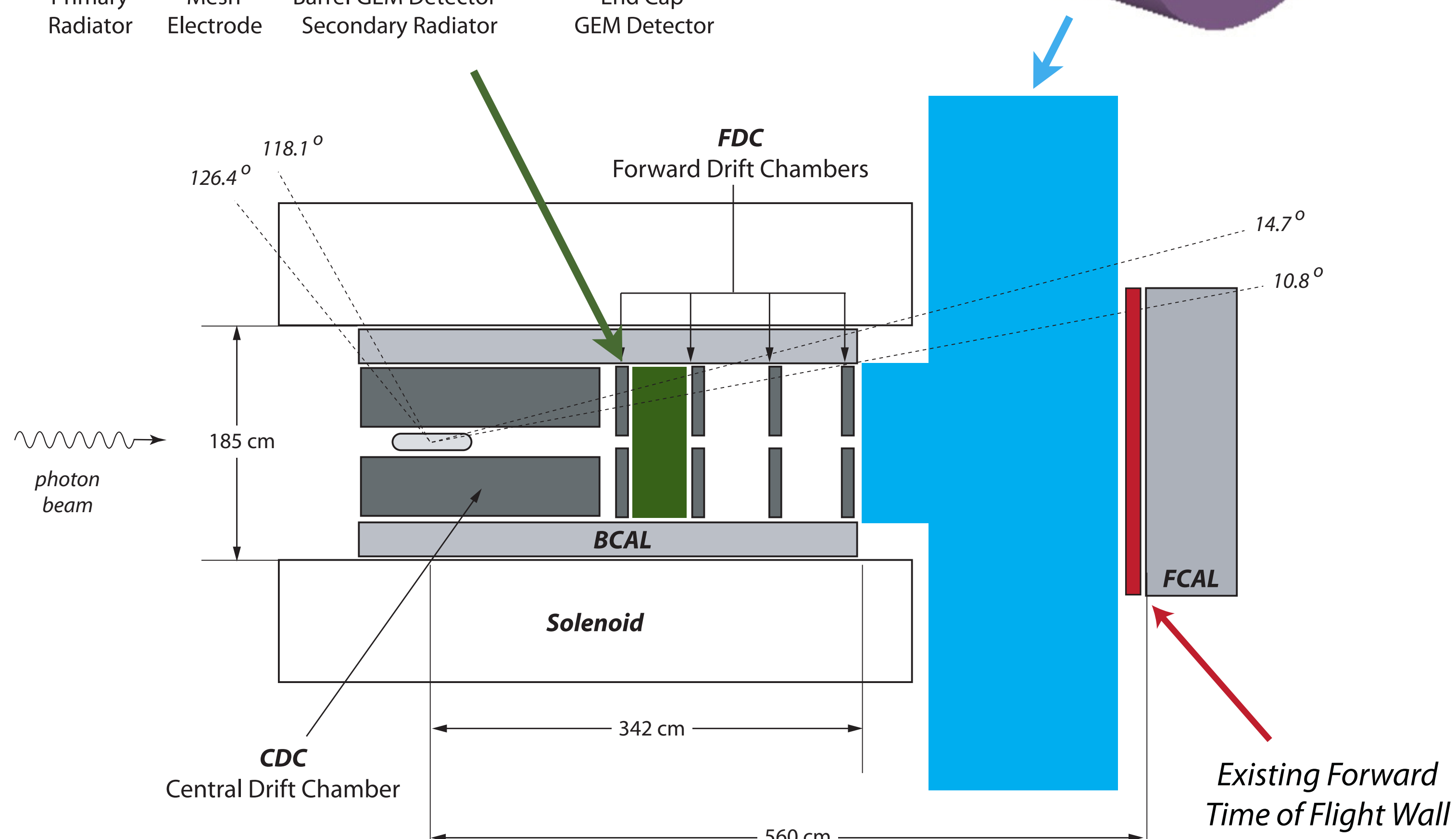
- Gas Cherenkov Pion Veto
  - original GlueX design
  - limited coverage
  - low technical risk
- GEM-based RICH
  - conceptual only
  - better coverage
  - technically challenging
- *Other designs are being studied by the collaboration, e.g., LCHb style RICH in place of the gas Cherenkov.*

Hadron Blind RICH Concept for GlueX Kaon Identification

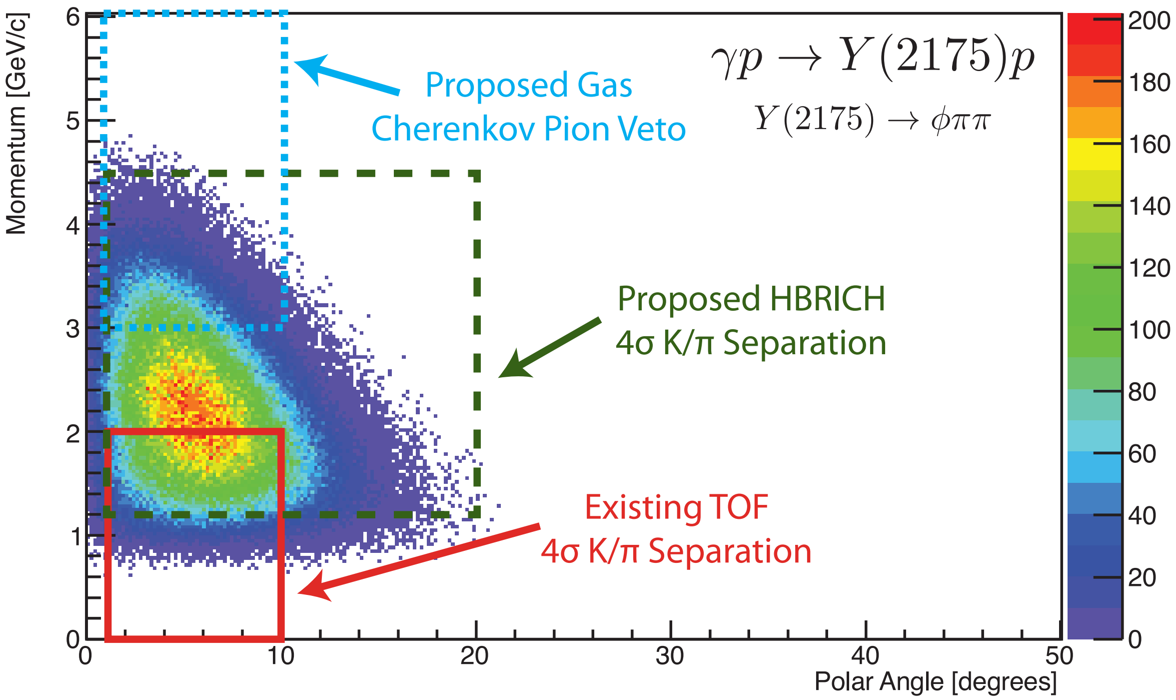


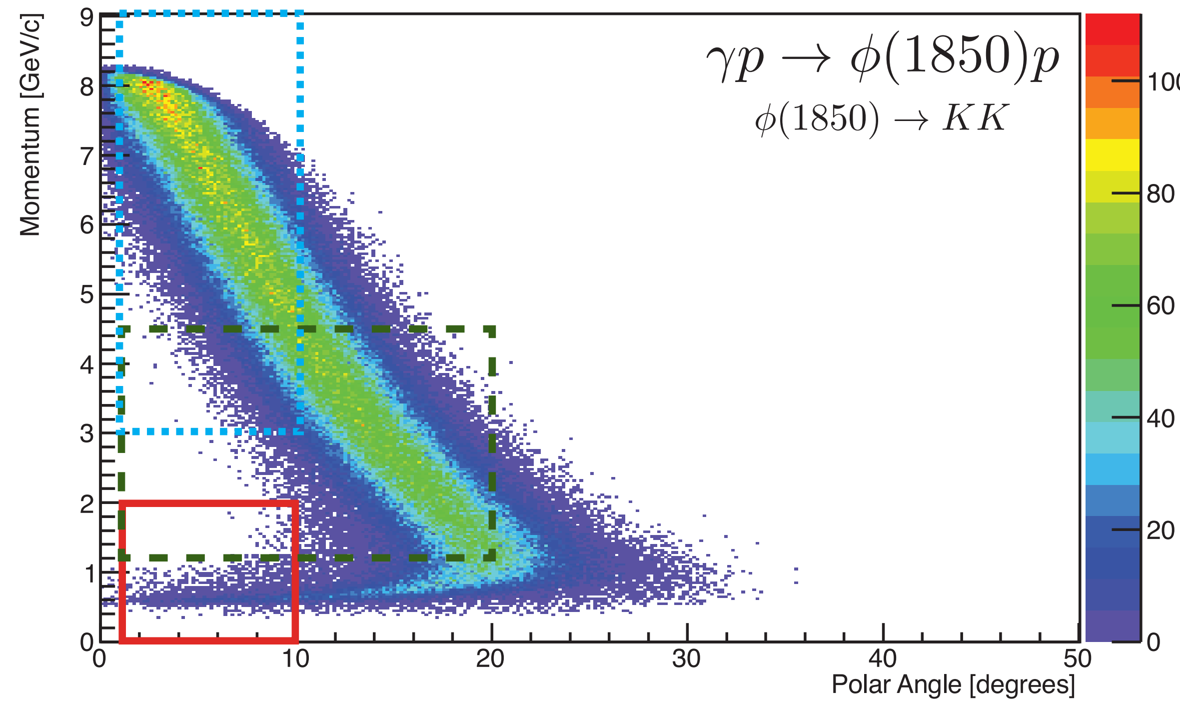
Gas Cherenkov Concept for GlueX Pion Veto

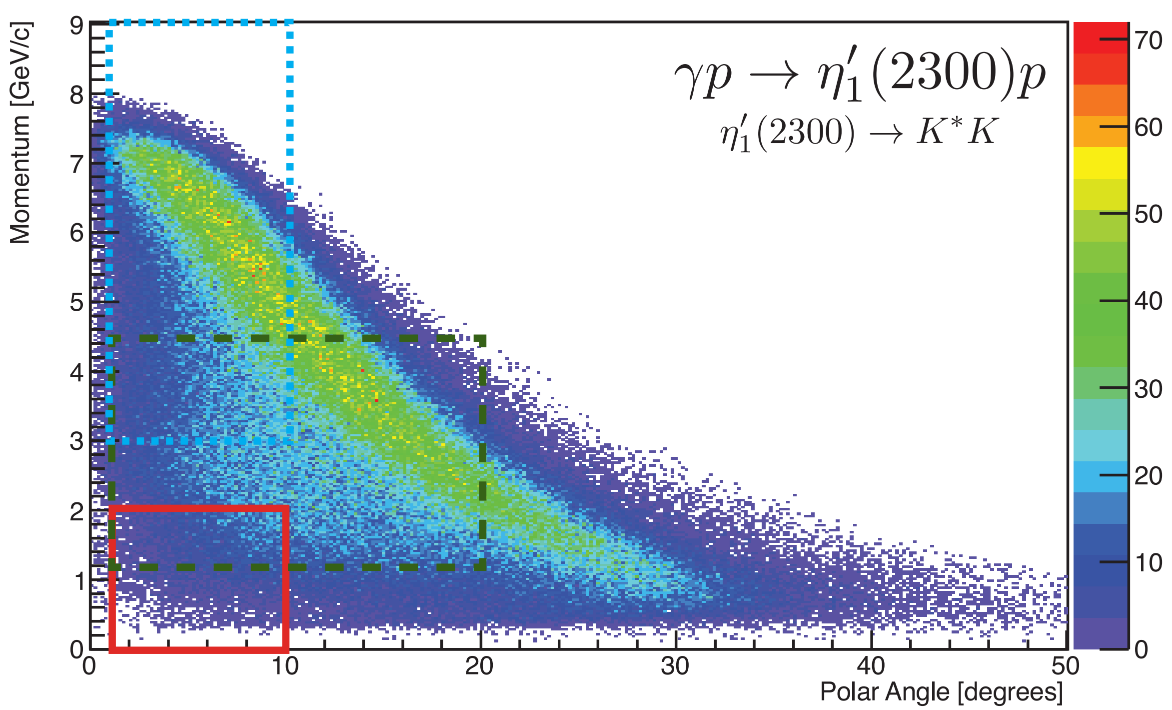




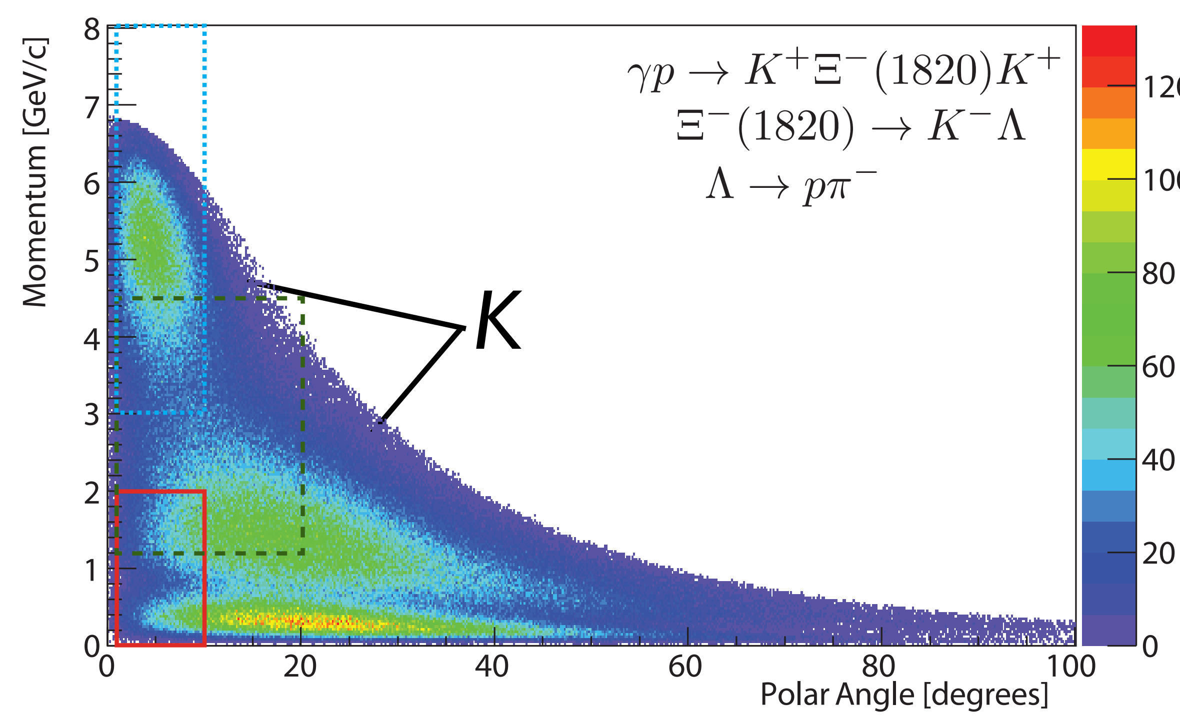
K kinematics in meson photoproduction







t-channel Ξ production



All plots: momentum vs. polar angle

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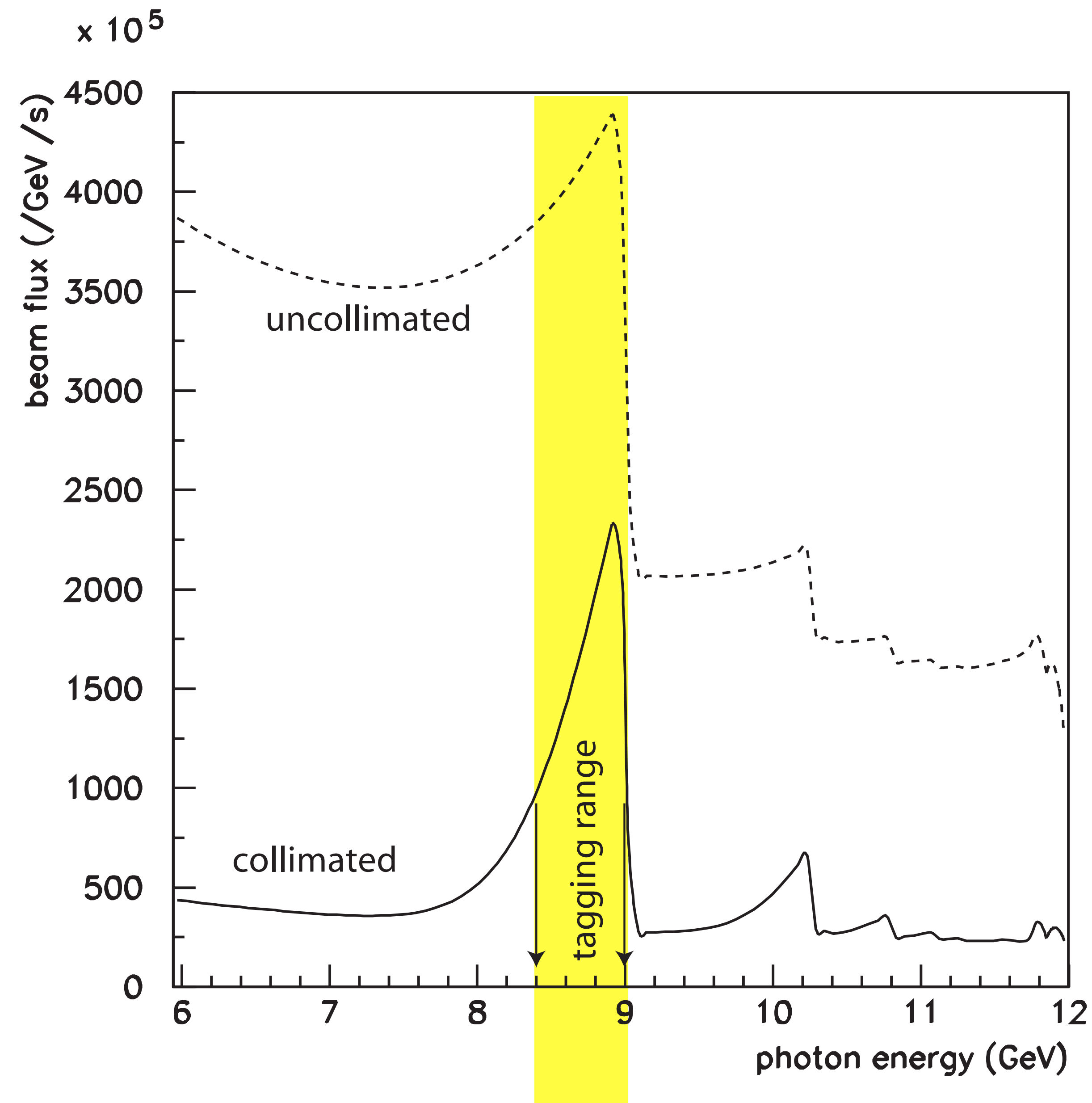
Rates and Level-3 Trigger

- Phase IV average flux of 5 x 10^7 γ/s in the coherent peak
  - instantaneous rates up to design limit of 10^8 γ/s
- At 10^8 γ/s level-one trigger rate is 200 kHz; *only 15 kHz comes from the coherent peak photons*
- Need software trigger to match reconstructed energy with tagged energy
  - reduction in rate by factor of 10
  - 3 GB/s → 300 MB/s
- Many benefits
  - reduced tape consumption
  - increased analysis efficiency
- Estimate 2000 of today's cores would work; less expensive than tape



maximum linear polarization

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Development Plan

- Forward PID
  - mature gas Cherenkov concept; also taking a fresh look at new technology
  - Established a new PID upgrade technical working group chaired by Mike Williams from MIT; participation from Florida State, Connecticut, Carnegie Mellon, Indiana, and JLab
    - how does material affect tracking and photon reconstruction efficiency?
    - what π/K separation, when combined with analysis, is sufficient?
    - consider technical risk, schedule, and cost of options
    - finalize conceptual design by the end of the calendar year

- Level-3 trigger
  - current DAQ software and architecture supports level-three concept
  - develop, test, and deploy event selection algorithms on the online monitoring farm during initial phases of GlueX running
  - based on initial testing, determine the resources needed for Phase IV level-three farm

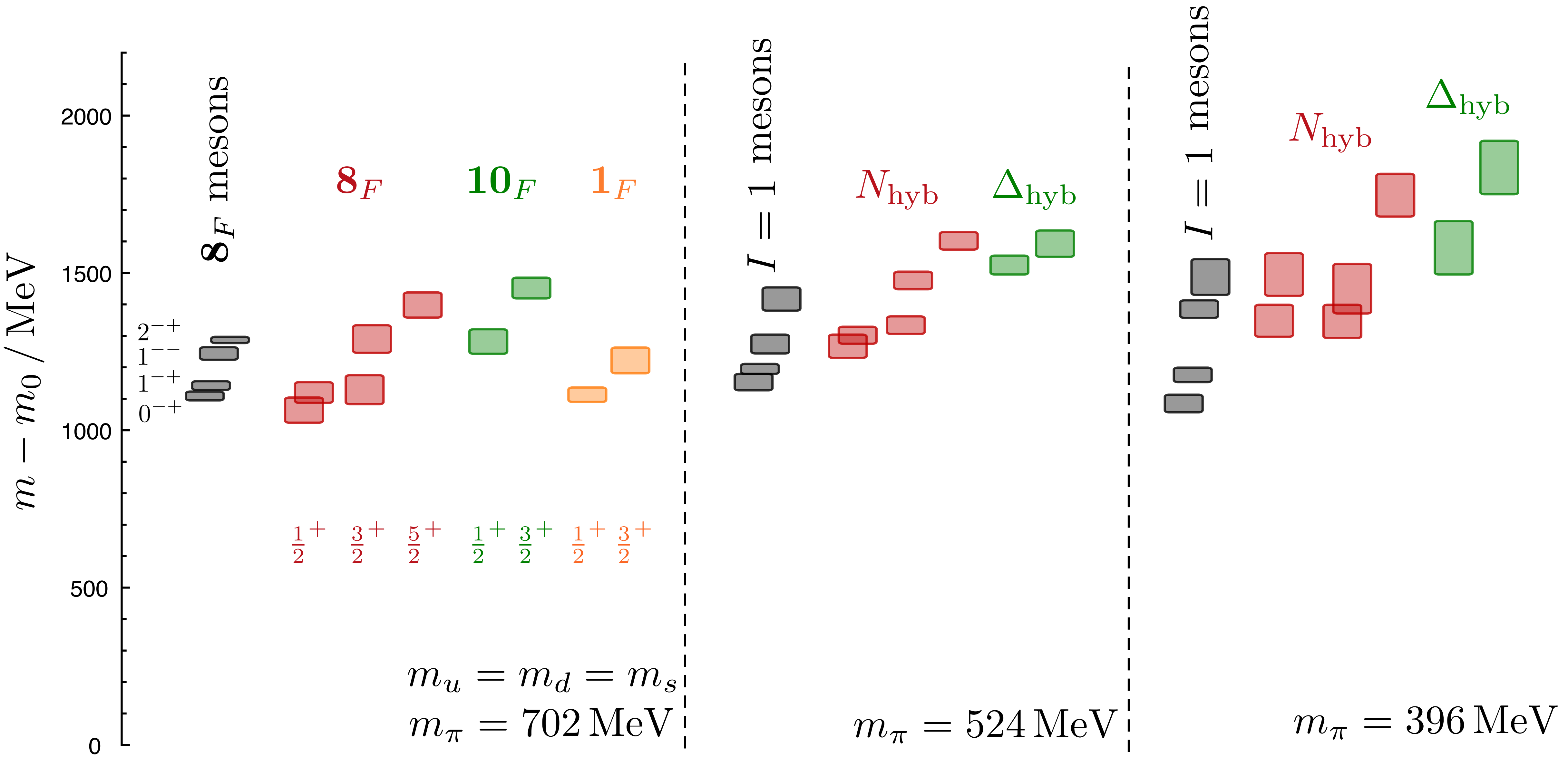
Summary

- unique experimental opportunities for GlueX with existing program
  - conduct high-statistics study of all channels in which hadron beam experiments found any evidence for exotic hybrids
- Phase IV greatly expands the physics reach and statistical precision of the baseline program
  - order of magnitude gain in statistics over Phase I-III program
  - ability to study mesons and baryons with explicit and hidden strangeness

- Phase IV GlueX is an essential component of a global meson spectroscopy program to experimentally study the role that gluons play in the structure of matter by searching for hybrid mesons -- several key goals
  - identify both exotic and supernumerary non-exotic mesons in the spectrum
  - measure masses and widths of both isovector and isoscalar hybrids
  - use decay modes to infer internal quark structure
  - validate predictions from lattice QCD and models

Supplemental Figures and Tables

Single Mass Scale for Constituent Gluons



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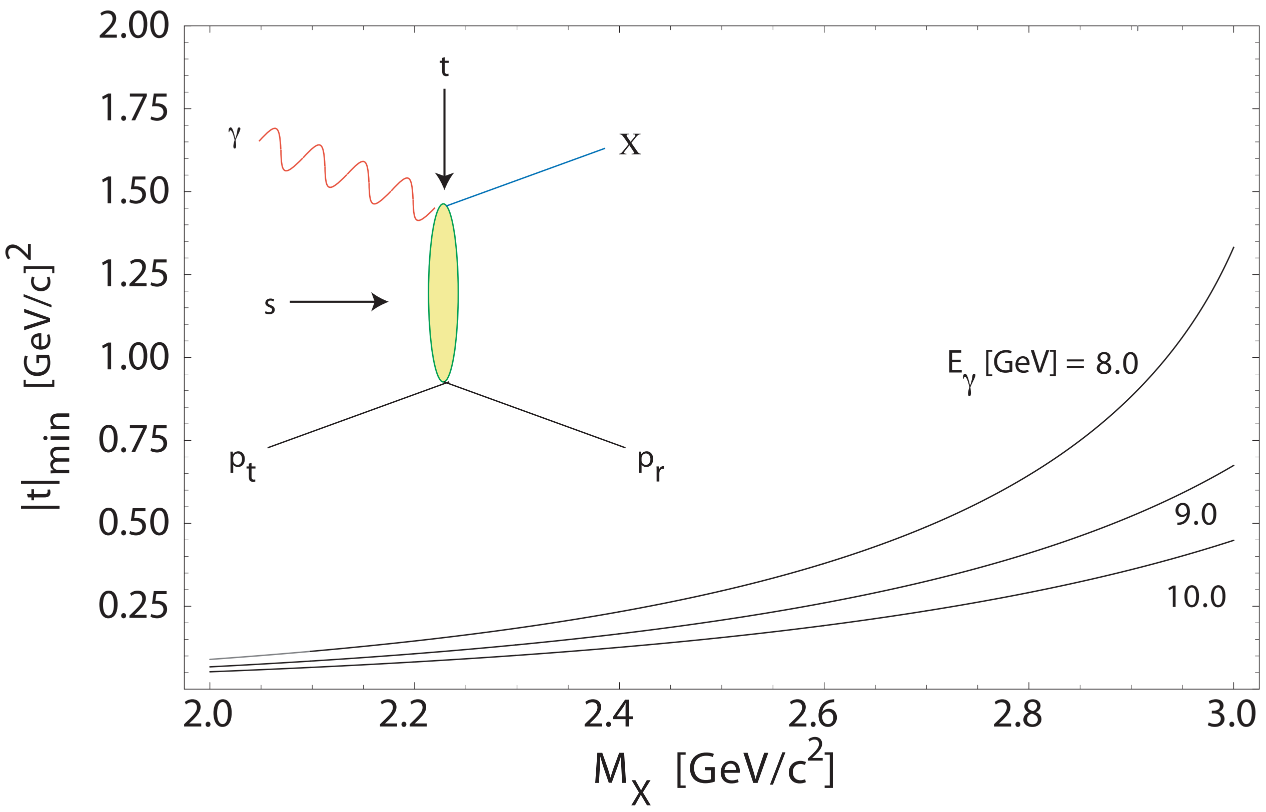
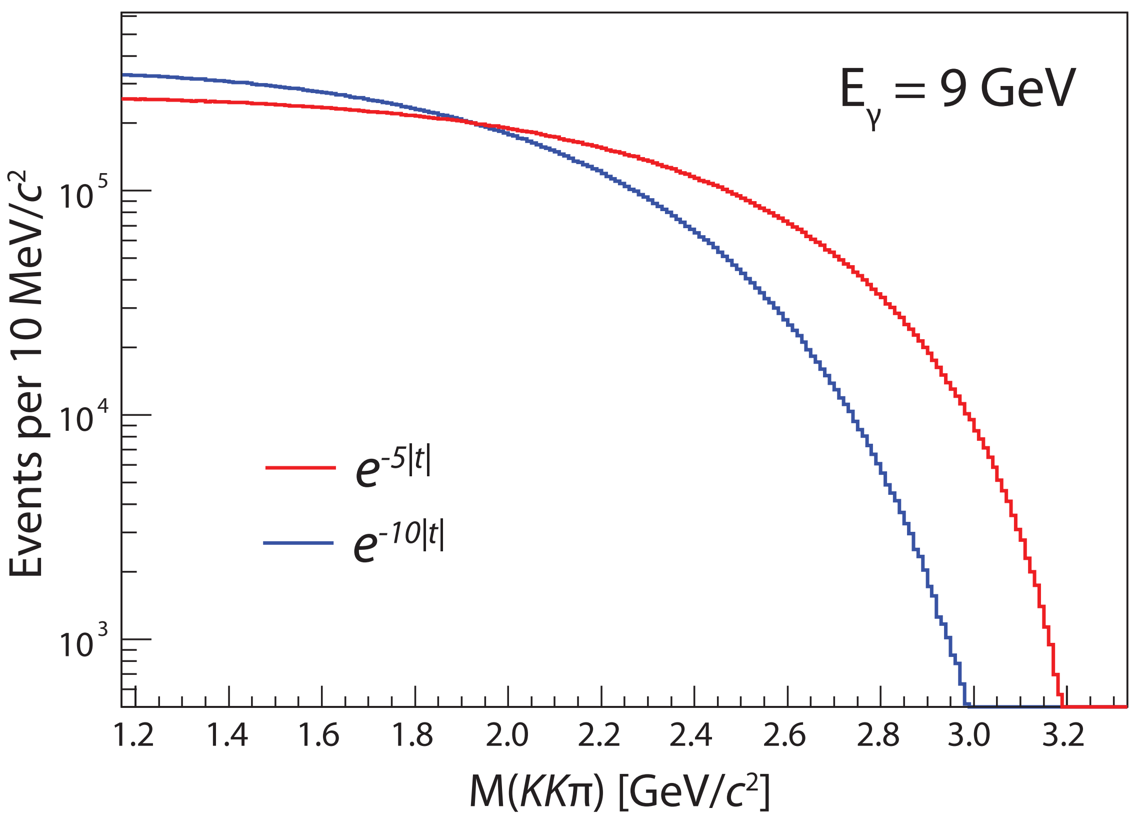
GlueX Hardware Contributions

TABLE I. A summary of GlueX institutions and their responsibilities. The star ($\star$) indicates that the group has joined GlueX after 2008.

Institution	Responsibilities
Arizona State U.*	beamline polarimetry, beamline support
Athens	BCAL and FCAL calibration
Carnegie Mellon U.	CDC, offline software, management
Catholic U. of America	tagger system
Christopher Newport U.	trigger system
U. of Connecticut	tagger microscope, diamond targets, offline software
Florida International U.	start counter
Florida State U.	TOF system, offline software
U. of Glasgow*	goniometer, beamline support
Indiana U.	FCAL, offline software, management
Jefferson Lab	FDC, data acquisition, electronics, infrastructure, management
U. of Massachusetts *	target, electronics testing
Massachusetts Institute of Technology*	forward PID, offline software
MEPHI*	offline and online software
U. of North Carolina A&T State*	beamline support
U. of North Carolina, Wilmington*	pair spectrometer
U. Técnica Federico Santa María	BCAL readout
U. of Regina	BCAL, SiPM testing

$|t|_{min}$ Suppression





Cross Sections and Yields

Final State	Cross Section (μb)	Approved Phase II and III ($\times 10^6$ events)	*Proposed* Phase IV ($\times 10^6$ events)
$\pi^+\pi^-\pi^+$	10	300	3000
$\pi^+\pi^-\pi^0$	2	50	600
$KK\pi\pi$	0.5	–	100
$\omega_{3\pi}\pi\pi$	0.2	4	40
$\omega_{\gamma\pi}\pi\pi$	0.2	0.6	6
$\eta_{\gamma\gamma}\pi\pi$	0.2	3	30
$\eta_{\gamma\gamma}\pi\pi\pi$	0.2	2	20
$\eta'_{\gamma\gamma}\pi$	0.1	0.1	1
$\eta'_{\eta\pi\pi}\pi$	0.1	0.3	3
$KK\pi$	0.1	–	30

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