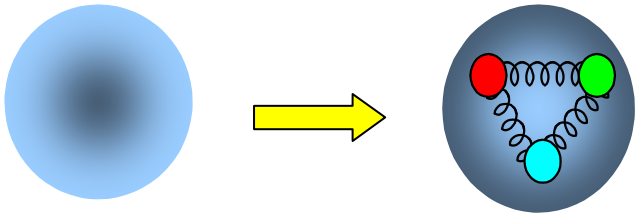
The Regina Hadronic/QCD Program at Jefferson Lab

G.M. Huber, G.J. Lolos, Z. Papandreou
University of Regina

CINP Town Hall Meeting, Edmonton, AB June 13, 2015

The Scientific Question



Our ability to answer the question:

How do the nucleon's properties
(mass, spin, charge radius, etc.)
arise from its quark and gluon constitutents?

requires that we develop a quantitative (as opposed to qualitative) understanding of non-perturbative QCD.

Transition from pQCD to Strong QCD needs data with high precision for a quantitative understanding of confinement.

JLab 12 GeV Upgrade will play a crucial role of our better understanding of nucleon structure and QCD at short and long distance scales.

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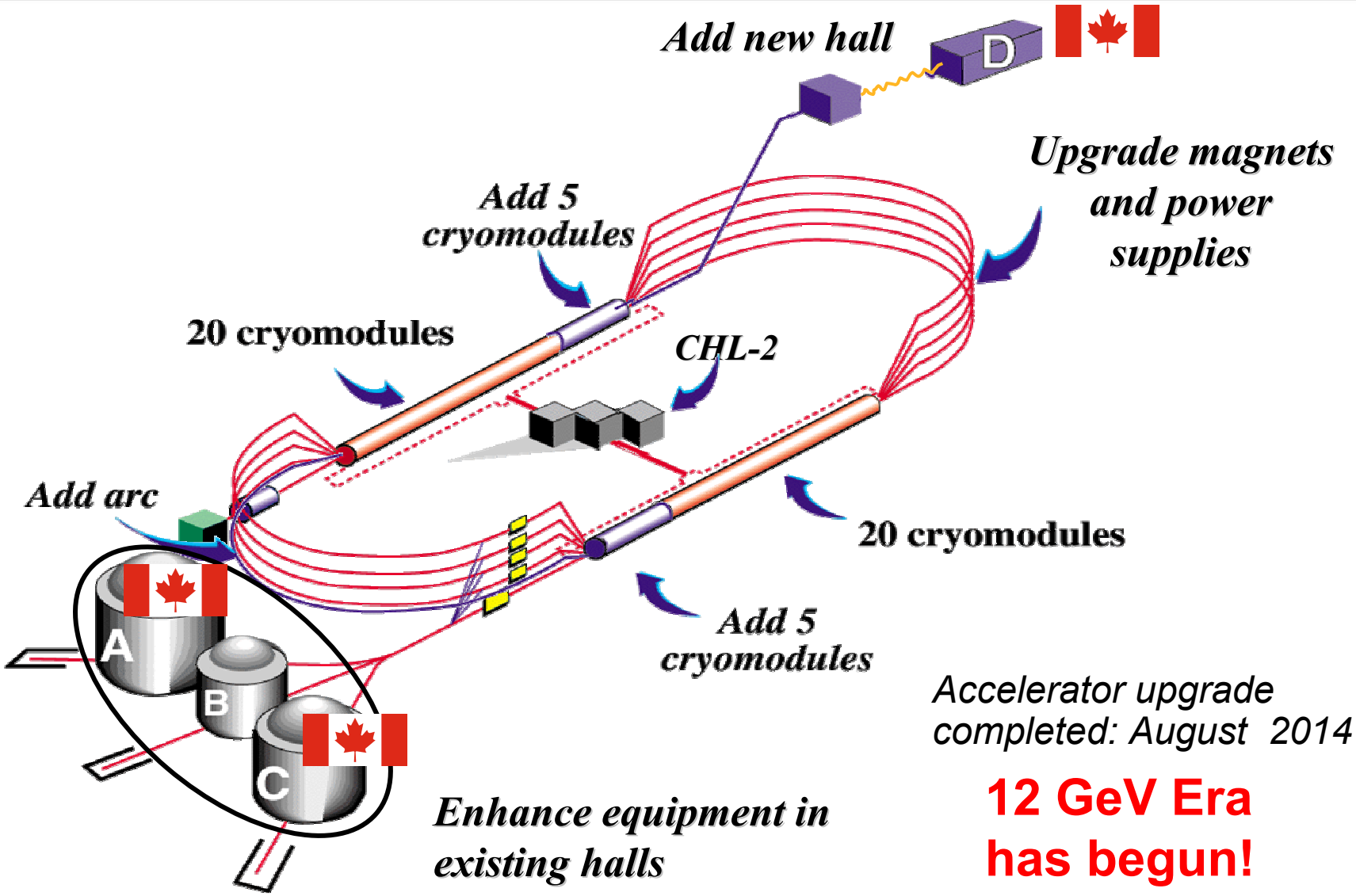
JLab 12 GeV Upgrade

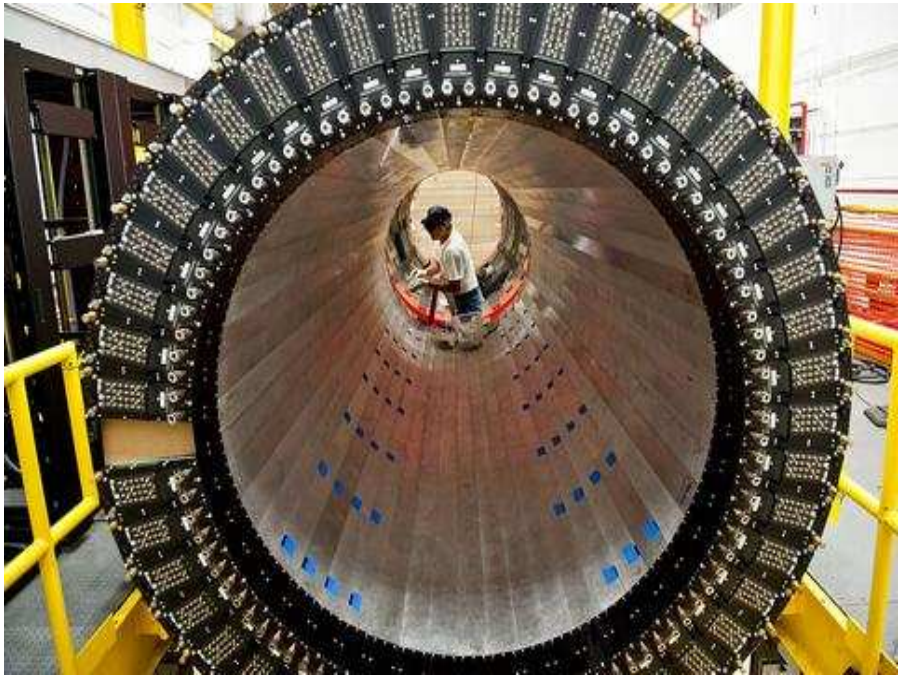


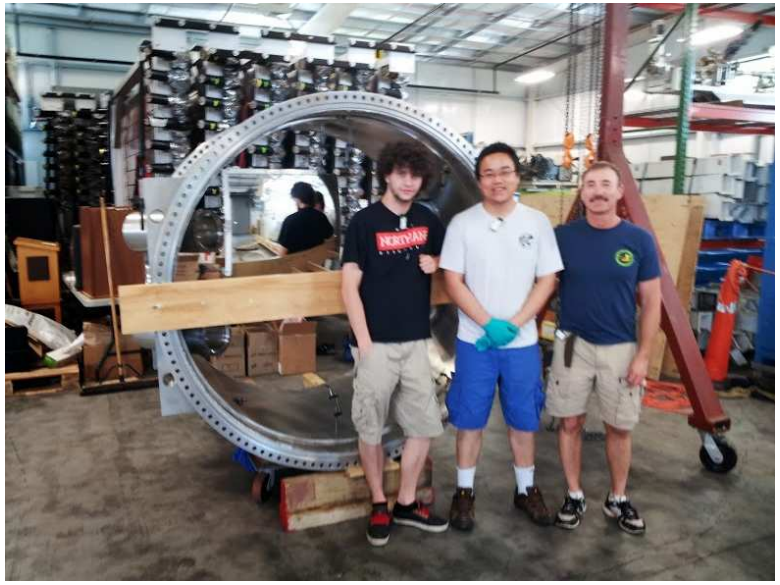
Accelerator upgrade completed: August 2014

12 GeV Era has begun!

Regina-Built Detectors @ JLab 12 GeV

- **Hall D Barrel Calorimeter**
  - US$5.0M detector funded by USDOE and NSERC.
  - Designed and constructed in Regina, 5 months ahead of schedule.
  - BCAL installed in bore of superconducting solenoid and cabling completed in December, 2013.
  - Commissioning underway.
- **Hall C Heavy Gas Cherenkov**
  - Funded by NSERC.
  - Designed and constructed by Regina group.
  - Installed in SHMS focal plane in April, 2015.
  - Commissioning to begin March, 2016.





The GlueX Collaboration

Regina Group

- In top 4 groups in size and impact (after JLab, CMU, Indiana)
- Significant contributions since inception of project.
- Lolos was Deputy Spokesman, past Board Chair and past member.
- Papandreou is Calorimetry Co-coordinator, Board Member, past Board Chair.

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GlueX Key Physics (2016-2021 "Flat out" Running)

GlueX = Gluonic excitations eXperiment

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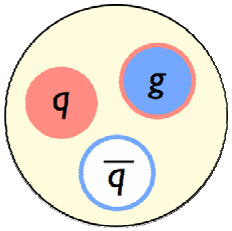
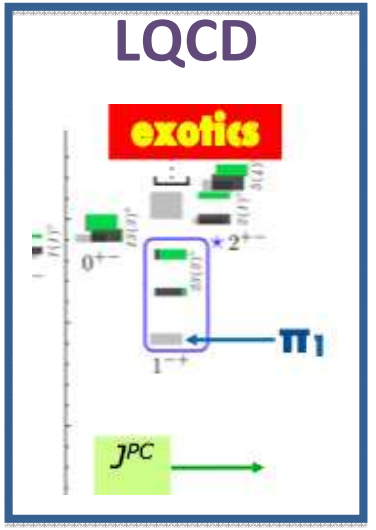
Hybrid mesons: Resonances with gluonic field excitations

- Q: How do LQCD quark and gluon d.o.f. manifest themselves in the hadron spectrum?
- Discover **exotic J^{PC}**: Cannot arise from valence q-qbar alone, rather gluonic d.o.f. are needed. Gluon behaves as a constituent particle.
- LQCD-predicted exotic states are 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}
- So far experimental evidence for only the π_1 (shaky)
- **Lin pol + J^{PC}: Unambiguous signal for exotic states!**
- Elucidate the phenomenon of confinement in QCD
- Other physics (closer to 2021): Charged pion polarizability, rare eta decays





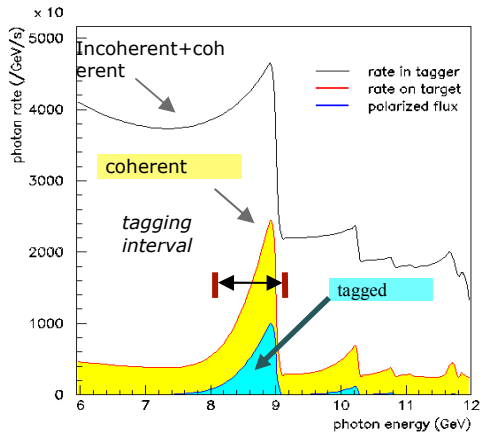
Rated `A' scientific priority/early high impact by JLab PAC and as one of two potential "Discovery" experiments by DoE S&T review committee.

FLAGSHIP/
DISCOVERY/
HIGH IMPACT
EXPERIMENT

GlueX at Jefferson Lab

Hermetic detector
Large figure of merit for hybrids
Linearly polarized γ beam for J^{PC}

1st 12 GeV detector delivered



$40M

Tagged γ's 3.0-11.8 GeV
10^7 γ/s on target → 10^8 γ/s

Jefferson Lab

Accelerator Facility

JSA

BCAL Construction in Regina

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ROLLING

GLUING

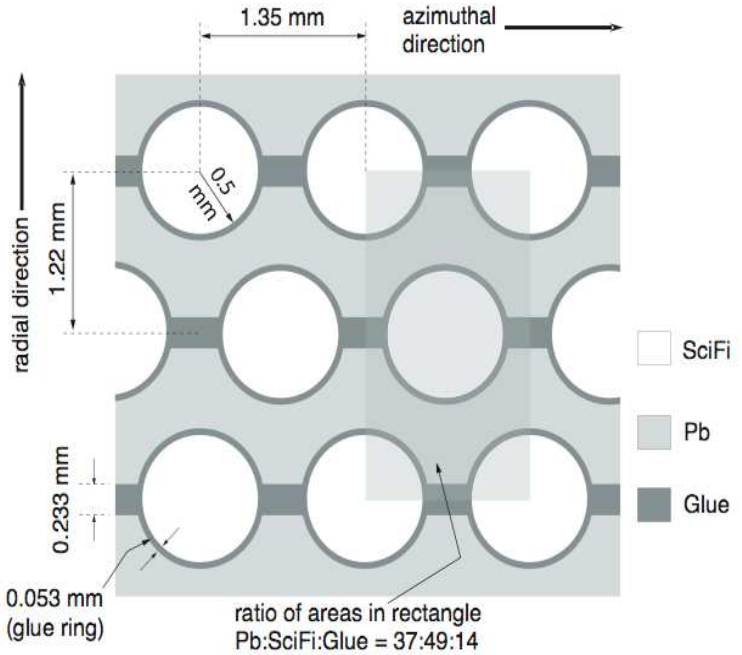
QUALITY CONTROL AT EVERY STEP

SWAGGING

PRESSING

Excellent finish of end faces & transmission uniformity:
48+1 modules and 3 prototypes were built

BCAL Construction in Regina



Geometry & Configuration

- BCAL: 28 tonnes
- 48 azimuthal sections (modules)
- Sampling calorimeter (9.5% sampling fraction) made out of lead and scintillating fibers
- 780,000 fibers, 4m long = 3,120 km!

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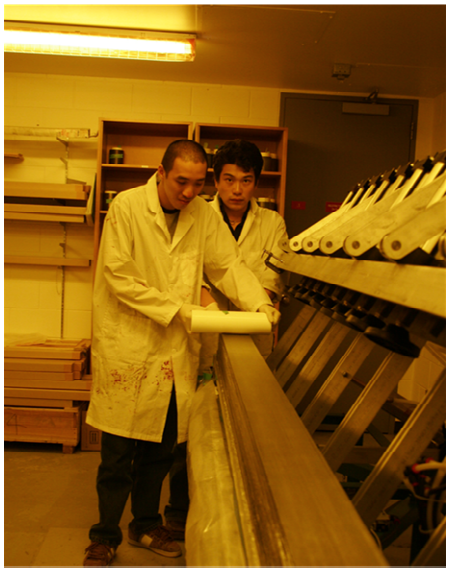
HQPs on BCAL Construction

- 20 Students drove construction and fiber QA
  (Supervised daily by Construction Manager and Research Scientist)
- 2.5 years of construction
  R&D Phase (2000-9): ~25 ugrads, 5 grads, 6 PDFs, 4 faculty
- Skill set: mechanical techniques, QA&QC, record keeping, databases, project management, DAQ, detectors, analysis
- Where are they now: U Heidelberg, BNL, CLS, Cameco, Engineering and software companies (e.g. iQMetrix)

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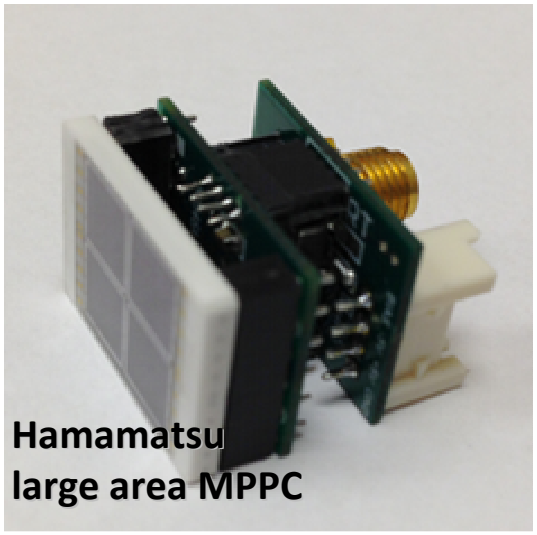
BCAL Readout: Large area SiPMs

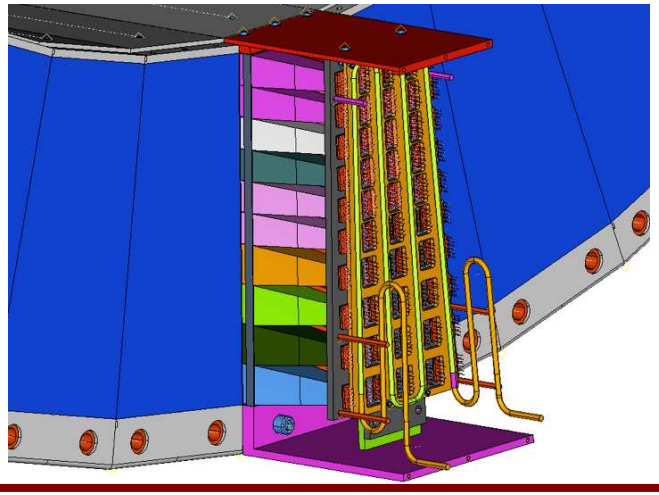


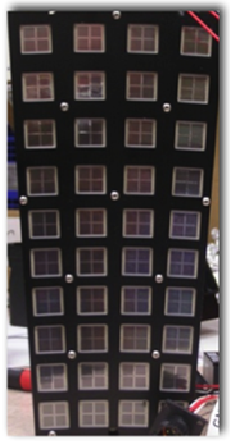
Our group guided industry!

Impact: Worked with photonics industry (SenSL) and developed large area SiPM for BCAL photosensor readout, with huge potential in medical imaging and radiation safety.

- 4 years R&D with SensL funded by DOE: US$500,000
- Contract eventually awarded to Hamamatsu

Outcome: New faculty member in Medical Imaging.



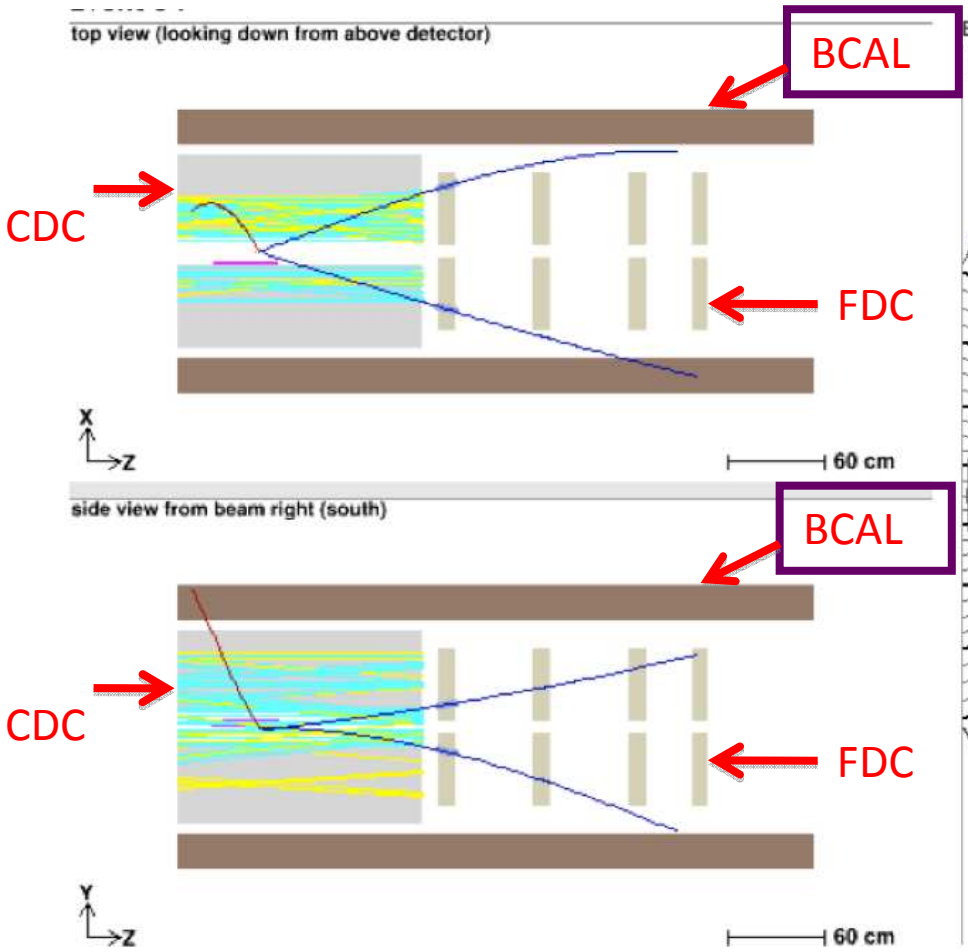


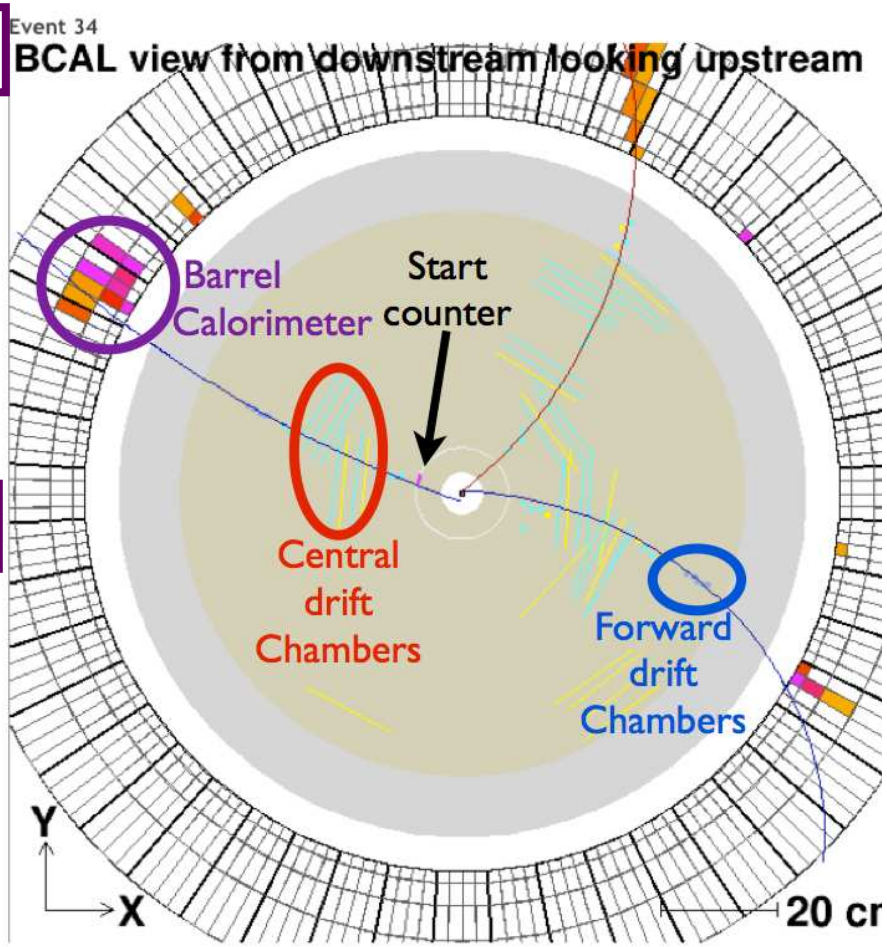
Assemblies: made by JLab; tested by UofR/JLab personnel
LED pulser system: made by Athens, large Regina contribution

JLab Experimental Hall D

Nov 2014 Commissioning Run

- Reconstruction: Tracks, calorimeter showers
  - From online reconstruction, **first few days of beam**





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π^0 and η Reconstruction

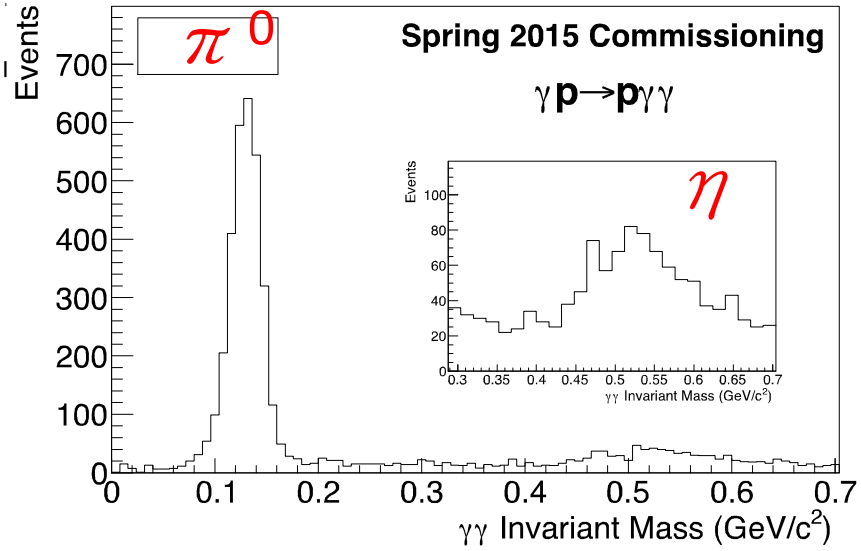
Reconstruct decays:

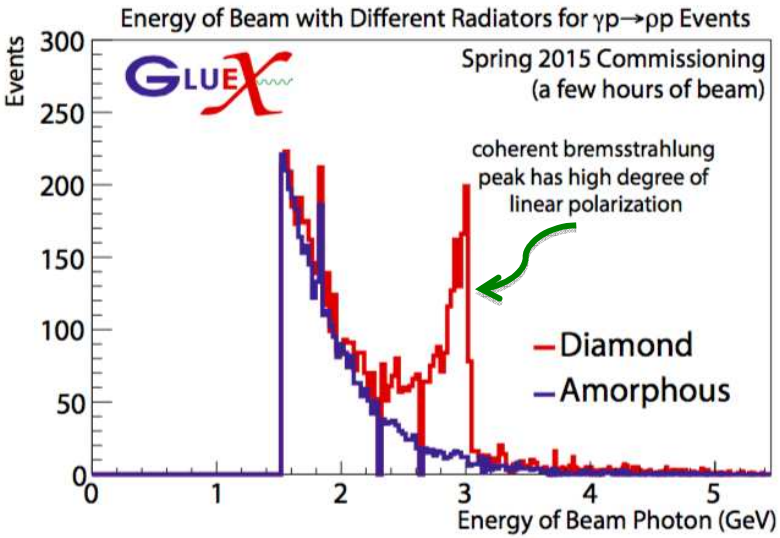
- $\pi^0 \rightarrow \gamma\gamma$
- $\eta \rightarrow \gamma\gamma$

π^0 resolution (preliminary):

- BCAL ~8 MeV (meets spec)
- FCAL ~12 MeV

Using Regina Calibration





Polarized ρ^0 Production

~3 hrs: Match previous world data at E_γ = 2.8 GeV

Key Performance Parameters of GlueX Experiment achieved!

GlueX Goals for FIRST 5 YEARS of running

- Establish the existence of a $J^{PC}=1^{-+}$ or 2^{+-} exotic meson in several decay channels if present at few % level of conventional mesons.
- If exotics are not present, the few % level exclusion limit would indicate problems with the QCD-based models made to date.
- Measure branching modes for established exotic states to validate QCD predictions.
- Add to knowledge of conventional meson spectroscopy that straddles light and heavy quark sectors.

Simulations (standalone and full HD package)

- Shower/cluster properties & reconstruction

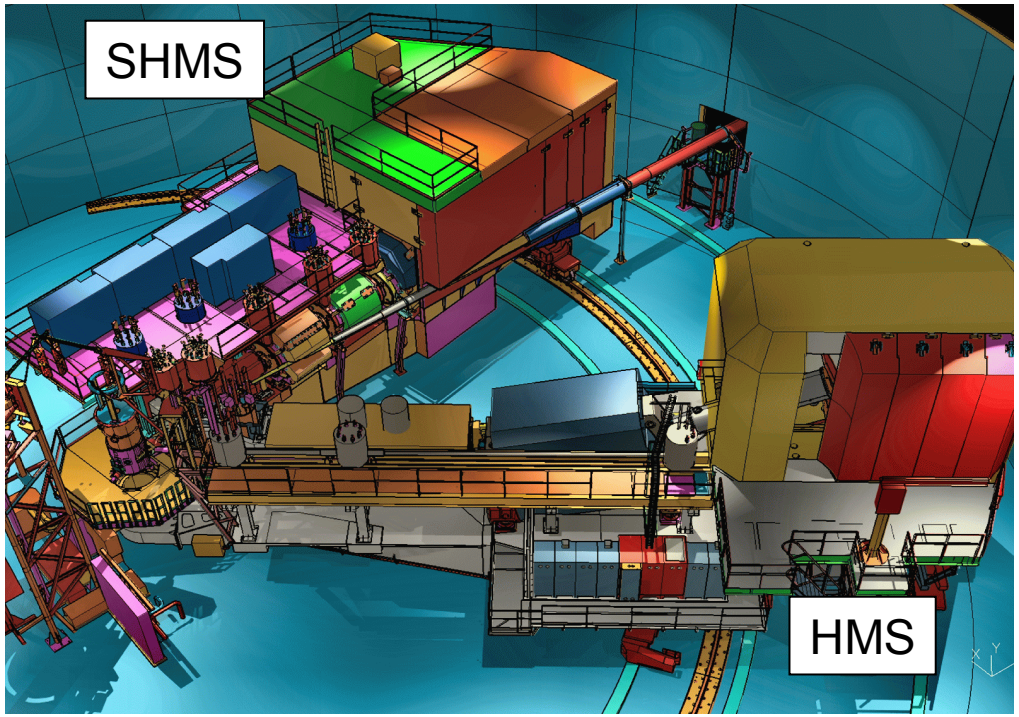
Calibration/Commissioning Analysis

Physics Analyses – 2016 and beyond

- Polarized photons and Partial-Wave-Analysis with Boosted-Decision-Tree to disentangle J^{PC} combinations
- Study P-wave mesons such as b_1 or f_1 that prefer to decay into the $\eta'\pi$ over the $\eta\pi$ channel
- Focus on reconstructing neutral final states (e.g. $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow 3\pi^0$, $\eta' \rightarrow 2\pi^0\gamma$)
- Regina Ph.D.s: T. Beattie (PWA, BDT), A. Foda (PWA), N. Ochoa (Calibration/Detector)

Regina Efforts

Upgrade of JLab Hall C



Hall C will provide 2 moderate acceptance, magnetic focusing spectrometers:

High Momentum Spectrometer:
$d\Omega \sim 6$ msr, $P_{max} = 7$ *GeV/c*
$\Theta = 10.5$ *to 80 degrees*

Super-HMS (new):
$d\Omega \sim 4$ msr, $P_{max} = 11$ *GeV/c*
$\Theta = 5.5$ *to 40 degrees*

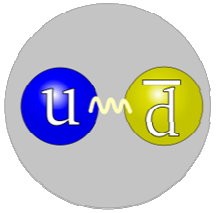
- Both spectrometers provide excellent control of systematic uncertainties
- Kinematic reproducibility, well-understood acceptance

Ideal for:

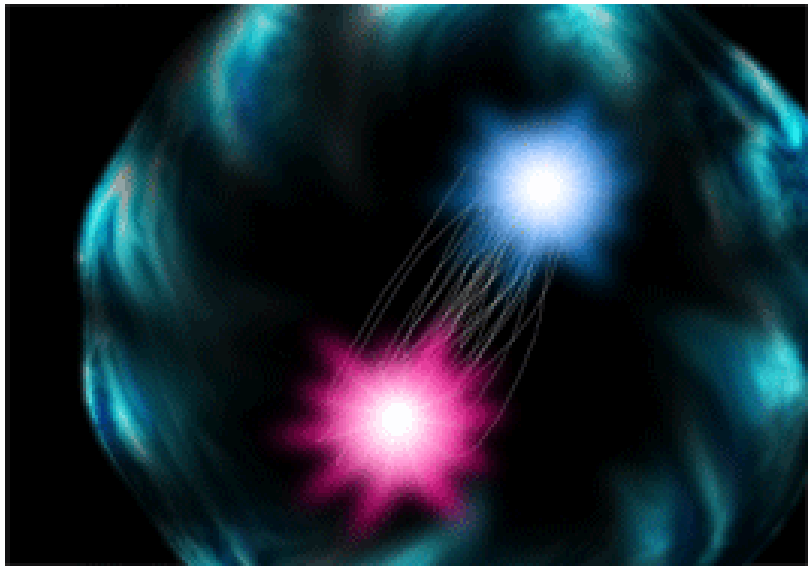
- precision cross section measurements and response function separations,
  - in single arm or coincidence,
  - at high luminosity (~10^{38}/cm^{2}sec).

Charged Pion Form Factor

- **The pion is attractive as a QCD laboratory:**
- Simple, 2 quark system



- Electromagnetic form factor can be calculated exactly at very large momentum transfer (small distances).
- For moderate Q^2, it remains a theoretical challenge.
  - "the positronium atom of QCD"



Pion's structure is determined by two valence quarks, and the quark-gluon sea.

Downside for experimentalists:

- No "free" pion targets.
- Measurements at large momentum transfer difficult.

The pion as a QCD Laboratory:

F_π is a good observable to study the transition of QCD between short (hard) and long (soft) distance scales.

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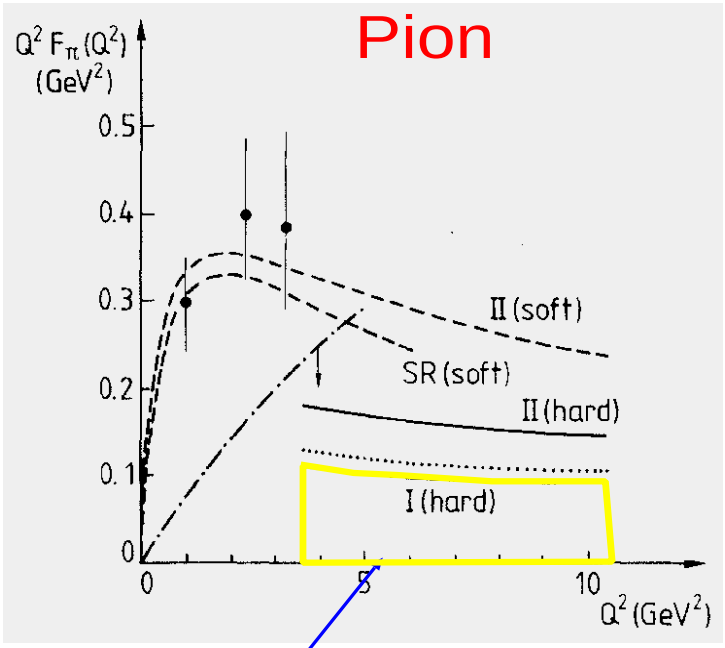
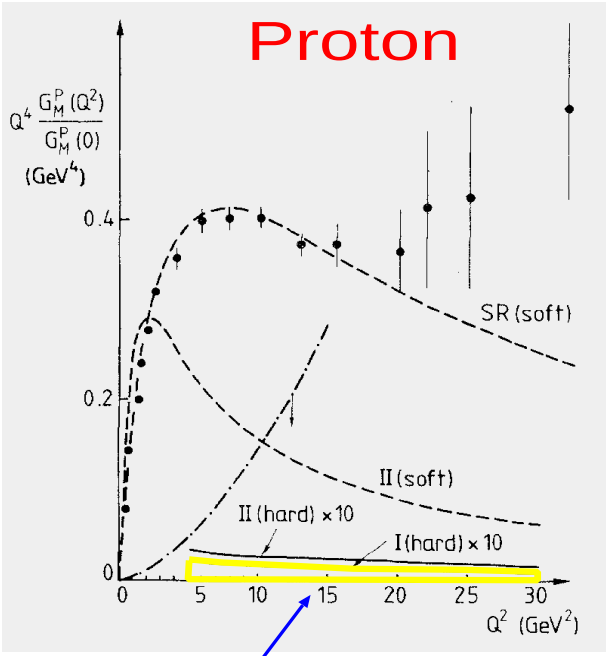


Hard contributions
~30-50% at Q^2=5 GeV^2



Hard contributions
≤1% at Q^2=5 GeV^2

Isgur & Llewellyn-Smith, PRL **52**(84)1080

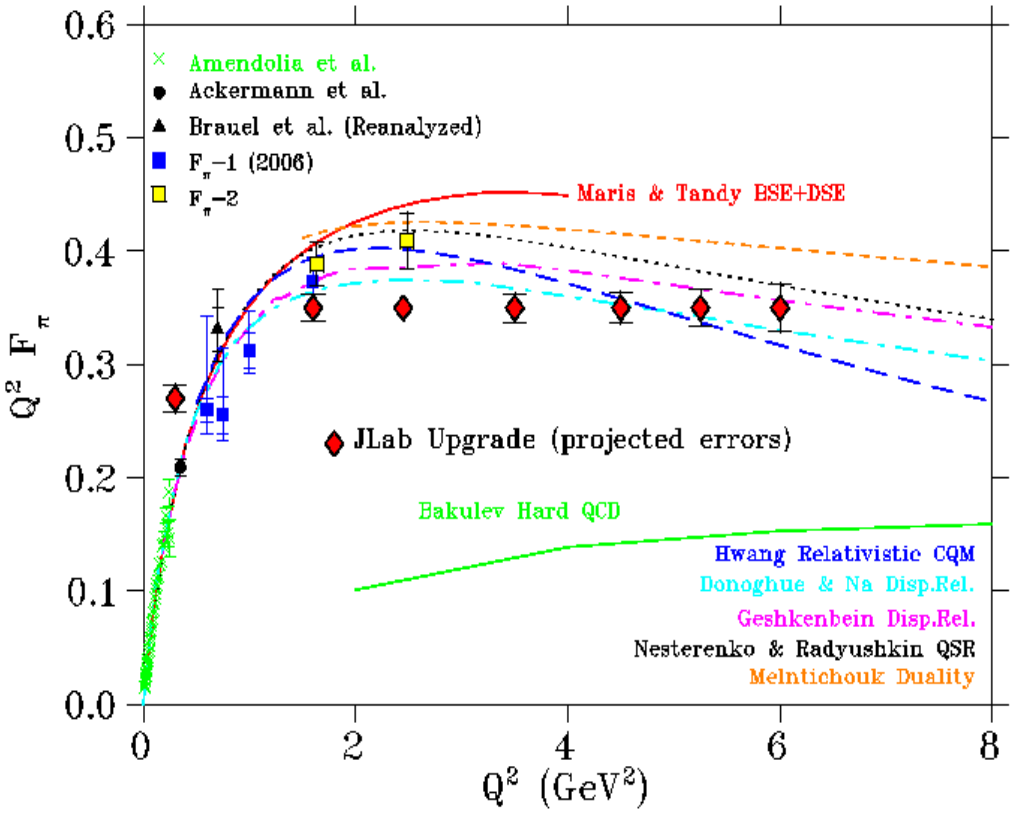
Transition of form factor to pQCD regime probably cannot be experimentally accessed with any system other than the π^+.

→ Cannot access hard contributions with nucleons.

$F_\pi(Q^2)$ after JLab 12 GeV Upgrade

JLab Upgrade will allow our measurements to be extended shorter distance scales to discover the scale where valence quarks dominate the pion's structure.

No other facility worldwide can perform this measurement.

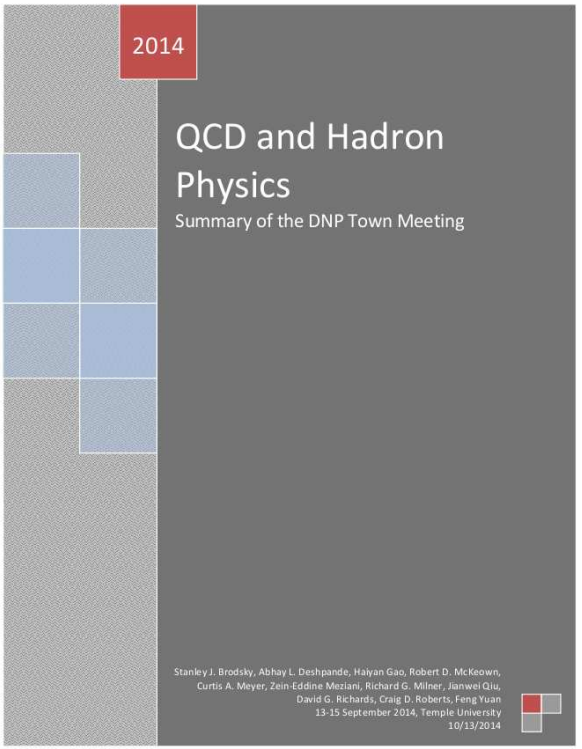


Approved with "A" scientific rating and identified by JLab PAC41 as "high impact".

- ***(E12-06-101: G. Huber and D. Gaskell, spokespersons)***
- ***Expected to take data in several periods from 2018-2021***

Recent Endorsement in QCD White Paper

Section 2: **Major steps toward understanding the pion, the long-range messenger in nuclear physics**

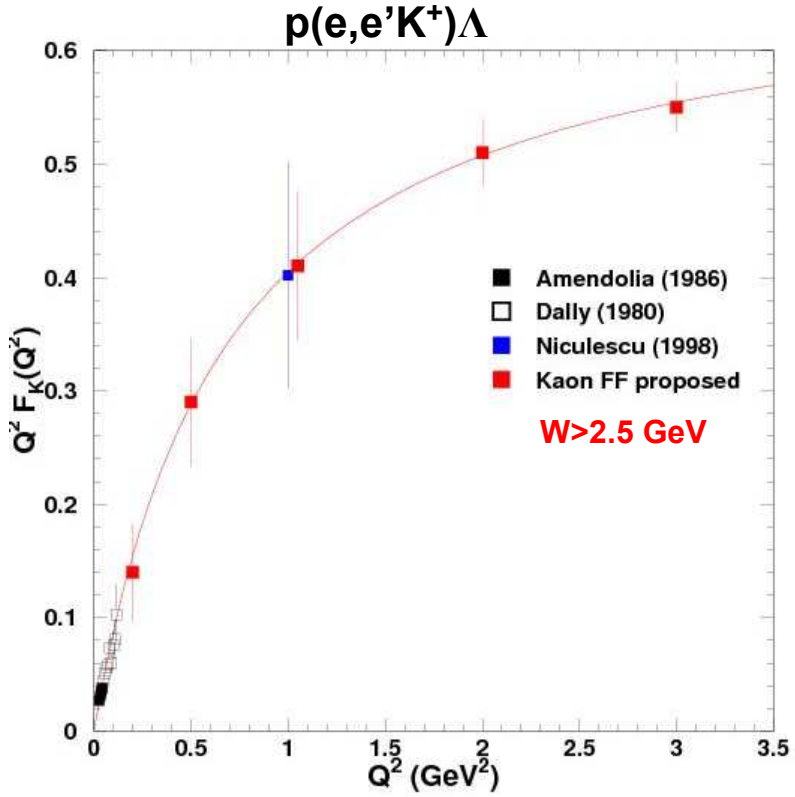


- Pion properties are intimately connected with dynamical chiral symmetry breaking (DCSB), which explains the origin of more than 98% of the mass of visible matter in the universe.
- measurement of the electromagnetic form factor of the pion, $F_\pi(Q^2)$, presents an extraordinary opportunity for charting the transition from confinement-dominated physics at large length-scales to the short-distance domain upon which aspects of perturbative QCD become apparent.

- **Greater urgency is now attached to measurement of $F_\pi(Q^2)$ following recent theoretical progress.**
- **These measurements hold great promise: it is possible that they will be the first to sight parton model scaling in an elastic form factor.**

Projected Uncertainties for K^+ Form Factor

- If the contribution of the Kaon pole can be isolated, ours will be the first high Q^2 measurement of F_K above the resonance region.
- Measure form factor to Q^2=3 GeV^2 with good overlap with elastic scattering data.
- Data will provide an important second $q\bar{q}$ system for theoretical models, this time involving a strange quark.



For VGL/Regge calculation, assume Λ^2_K=0.67 GeV^2, and $\Lambda^2_{K^*}$=1.5 GeV^2,

Scheduled as an early SHMS commissioning experiment (2017-18)
(E12-09-011: T. Horn, G. Huber and P. Markowitz, spokespersons)

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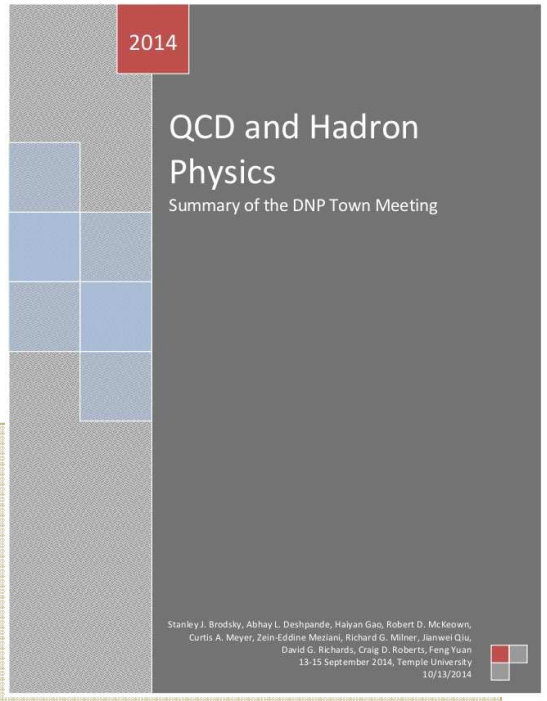
Second Endorsement from QCD White Paper

Section 3c: **Meson Form Factors**

- The form factors of pions and kaons are of special interest owing to the dichotomous nature of these mesons as both bound-states of strongly-dressed constituents and the pseudo-Goldstone modes through dynamical chiral symmetry breaking (DCSB) in QCD.



- Experimentally, pion elastic form factor measurements at JLab are made indirectly, using exclusive pion electroproduction, $p(e,e'\pi^+)n$, to gain access to the proton's "pion cloud". This approach is reliable in forward kinematics.
- Analogously, in order to extract information on the kaon's elastic form factor it might be feasible to sample the proton's "kaon cloud" via $p(e,e'K^+)\Lambda$. In this instance, **JLab at 12 GeV is essential for the measurements at low *t* that would allow for a clean interpretation of the kaon pole contribution.**
- **This data could allow for valuable comparisons between the Q^2 dependence and magnitude of the π^+ and K^+ form factors.**

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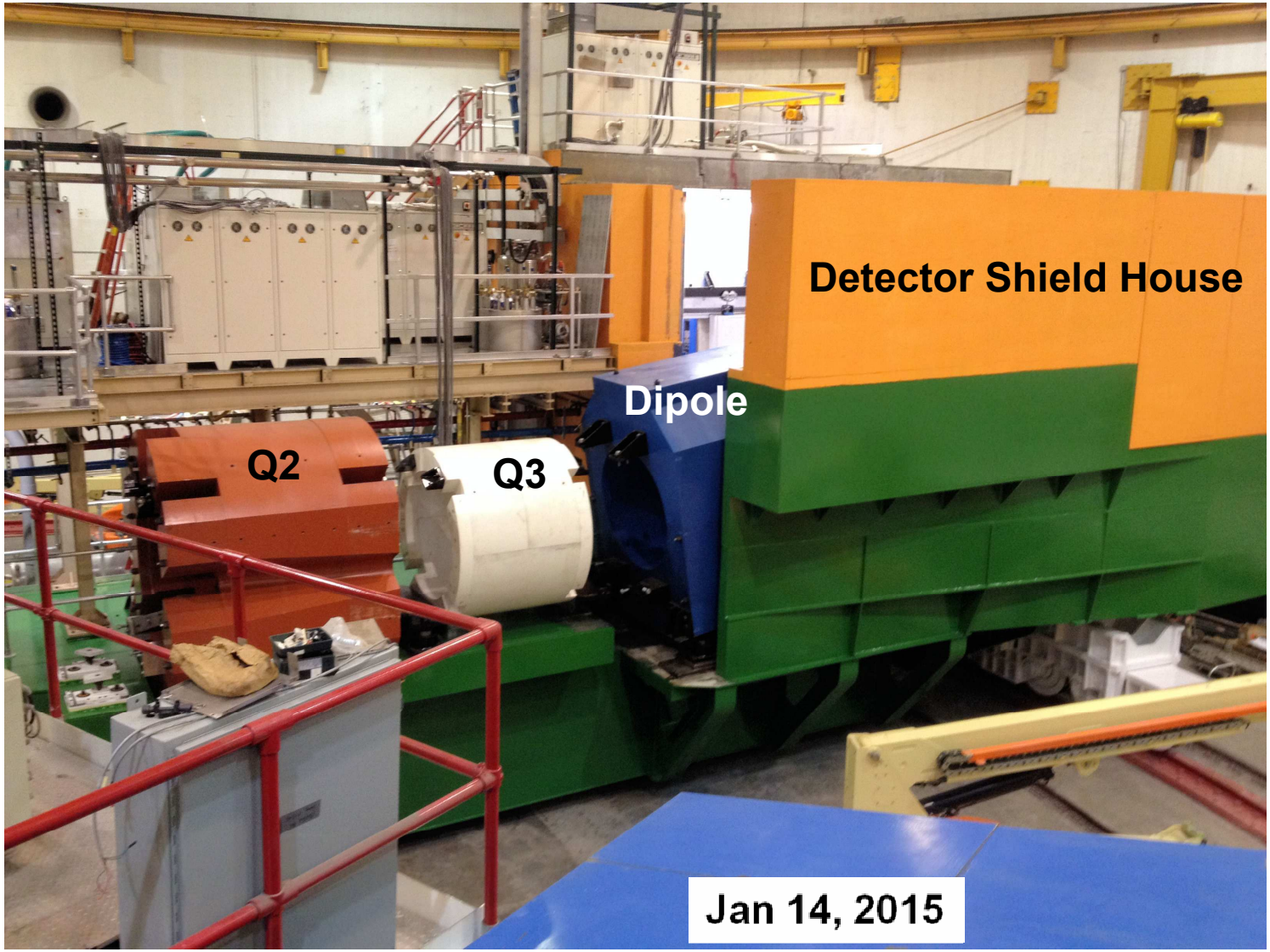
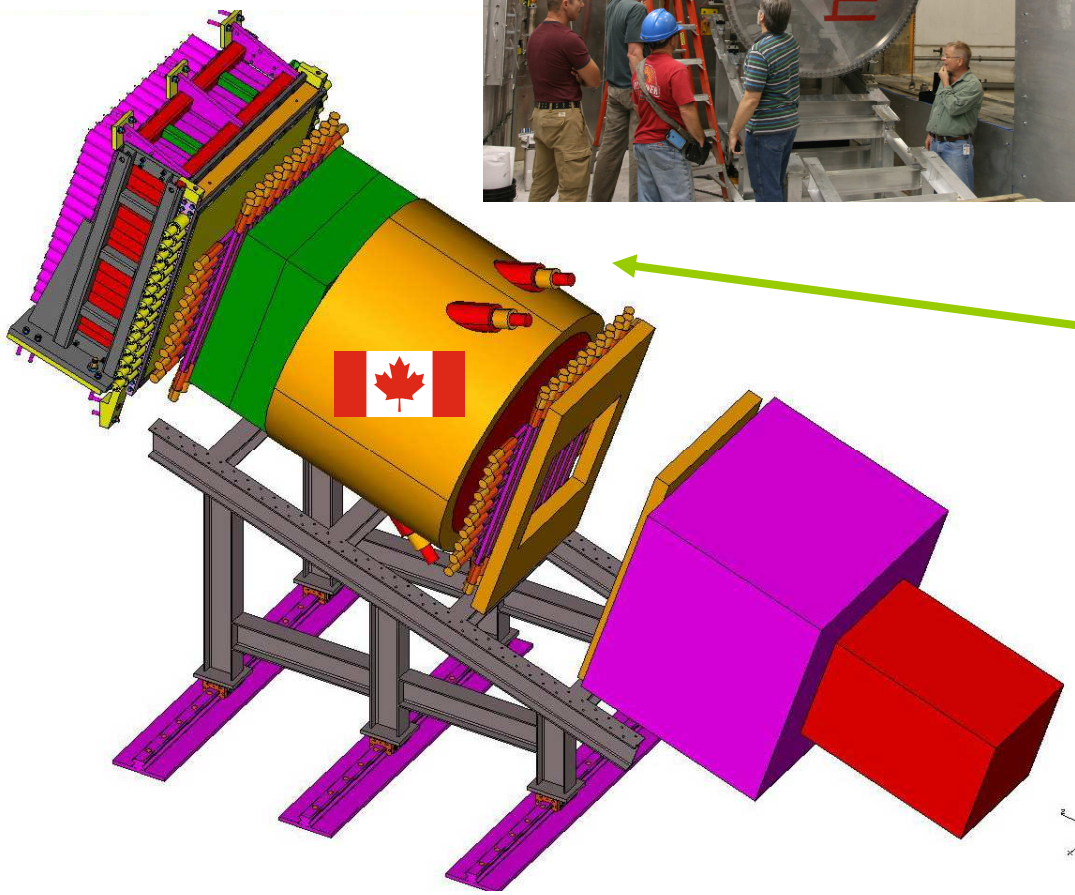
SHMS Installation Status

- SHMS Structure complete
- Services (Power, LCW, AC) installed
- signal, HV install in progress
- Magnet power supplies tested, DC cables ready for Q1 and HB
- Cryogenic system ready for Q1 and HB
- Steel for Q2, Q3, Dipole installed



Super-High Momentum Spectrometer (SHMS) Focal Plane Detectors



Noble Gas Čerenkov:
e/π separation at high momenta, where multiple-scattering is less of an issue.

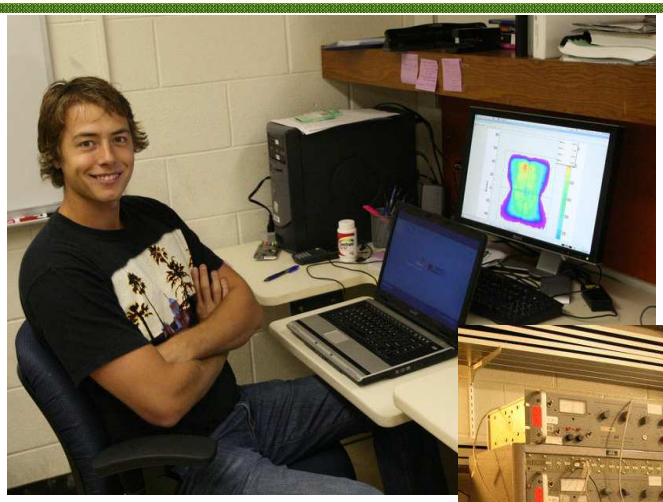
Trigger Hodoscopes:
Time-of-Flight at low momenta; insensitive to photon or low-energy background.

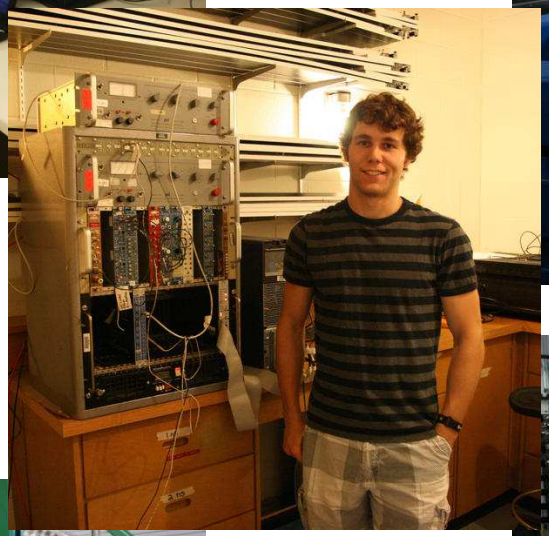
Heavy Gas Čerenkov:
π/K separation for P>3.4 GeV/c.

Aerogel Čerenkov(s):
Depending on the n used, K/p separation or π/K separation at low momenta.

Lead Glass Calorimeter:
e/π separation.

HQPs on SHMS Heavy Gas Čerenkov





NSERC+CINP support:
RTI grant, 5 undergrads,
1 grad student, 0.5 PDF.

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Hall C Exclusive Meson Production Timeline

SHMS detector installation	Feb, 2015 – Jan, 2016
SHMS superconducting magnet installation and testing	April, 2015 – Mar, 2016
First Hall C beam (beamline commission, initial detector checkout)	Mar, 2016
SHMS commissioning run	Oct – Dec, 2016
First physics-quality run in Hall C	Feb – May, 2017

Data Reconstruction Software (hcana)

- Z. Ahmed (PDF), since 2013, nearly completed

Detector Checkout & Commissioning

- W. Li (Ph.D.), E. Avila (M.Sc.), work underway

p(e,e'K^+)Λ Kaon Form Factor

- L/T commissioning experiment (Fall 2017-Winter 2018)
- E. Avila (Ph.D.)

Pion Form Factor and π^+ QCD-Scaling Experiments

- Interleaved run-plans (Fall 2018-Winter 2021)
- Two Ph.D. students, starting 2016 and 2017

Transverse Single-Spin Asymmetry Experiment

- Exclusive π^+ production for polarized GPD $\tilde{E}$ (2022+)

Regina Efforts

Regina JLab - Budget Scenarios

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Program	Status-Quo Funding	Effective Funding	Missed Opportunity without Effective Funding
GlueX (Hall D)	$135k (2 FTE)	$175k (2 FTE)	Lose leading Role in GlueX data analysis & physics publications.
Exclusive Meson Production (Hall C)	$75k (1 FTE)	$110k (1 FTE)	Lose leading Role in Pion Form Factor data analysis & physics publications.