The Catholic University of America

Instrumentation for K^+ and π^0 studies – JLab Hall C at 12 GeV

Marco Antonio Pannunzio Carmignotto

HUGS 2012 – June 21, 2012

Overview

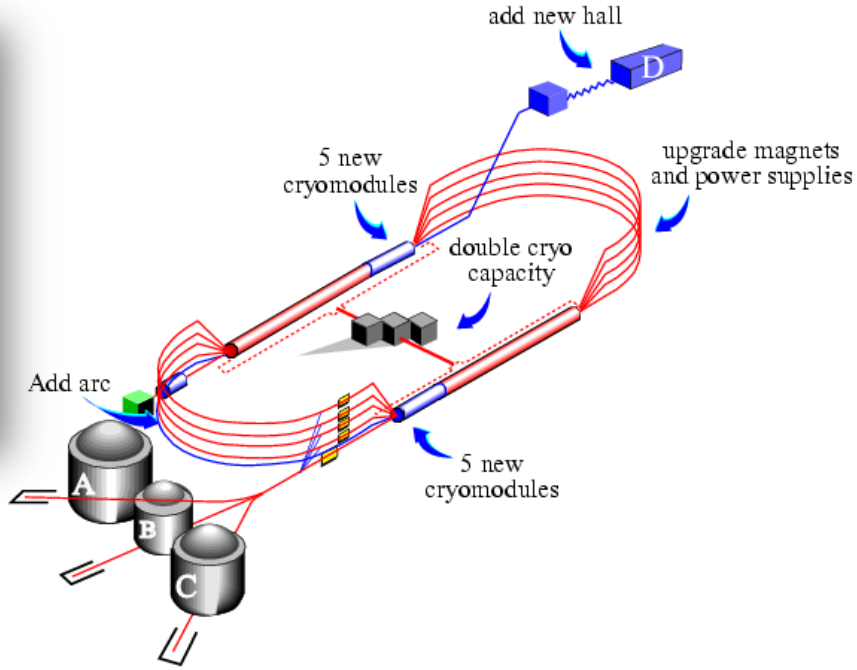
- **Jefferson Lab 12 GeV upgrade**
- **Scientific motivation**

Two main projects:

- **Exclusive Kaon Production – Kaon Aerogel Detector**
  - Detector construction
  - Detector components: PMT and aerogel
  - GEMC/GEANT4 simulations
  - Prototype construction
- **Exclusive and Semi-inclusive π^0 Production – π^0 Calorimeter**
  - GEMC/GEANT4 simulations
  - Hitting position reconstruction

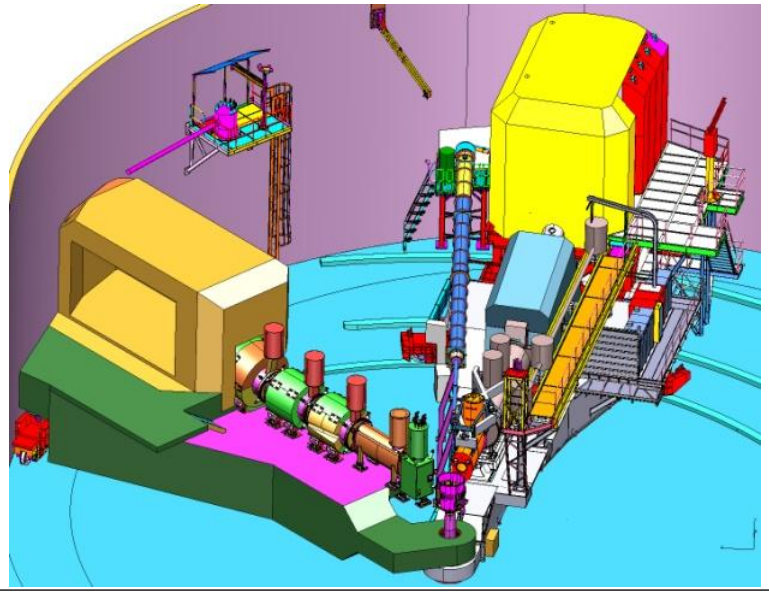
JLab 12GeV upgrade - Hall C

6 GeV era of Jlab



Main upgrades for the 12GeV era

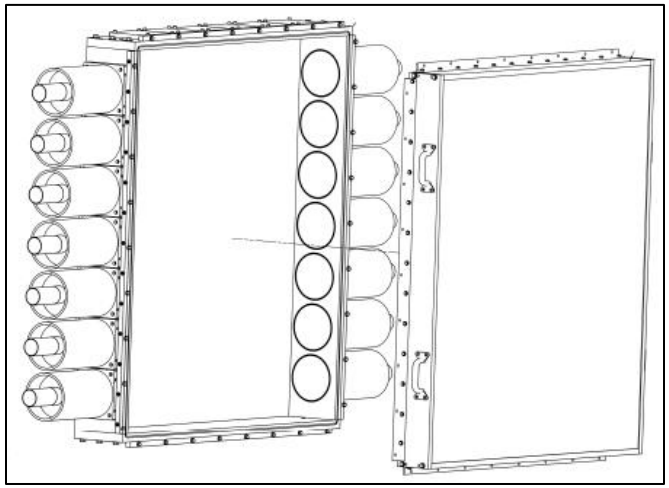
➢ **Hall C setup for the 12GeV era:**



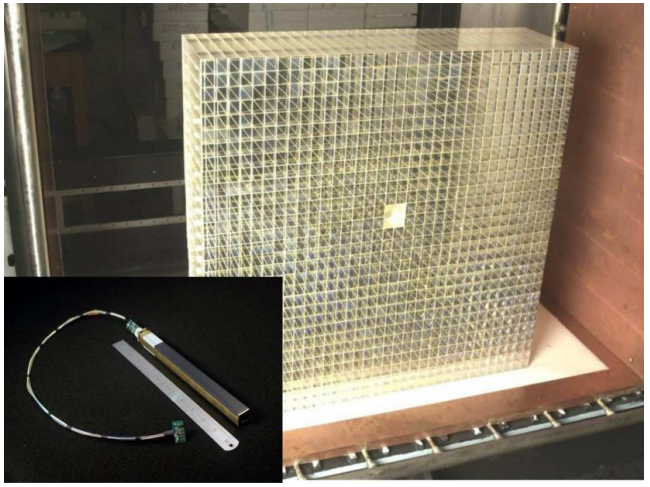
New design of the Hall C at 12 GeV era. Two spectrometers, the HMS (left) and the SHMS (right). The SHMS is the new spectrometer for this upgrade.

http://galileo.phys.virginia.edu/classes/sajclub/JLab_Upgrade.html

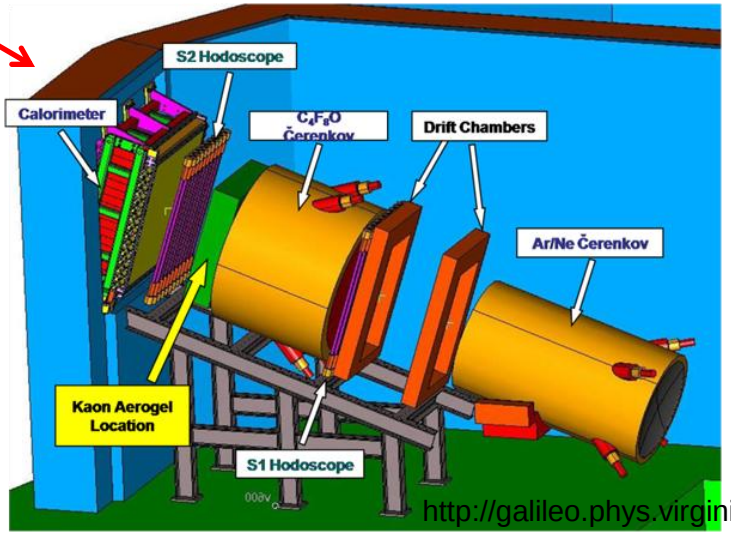
Two new detectors to be used in JLab Hall-C @ 12GeV



Kaon Aerogel Cerenkov Detector



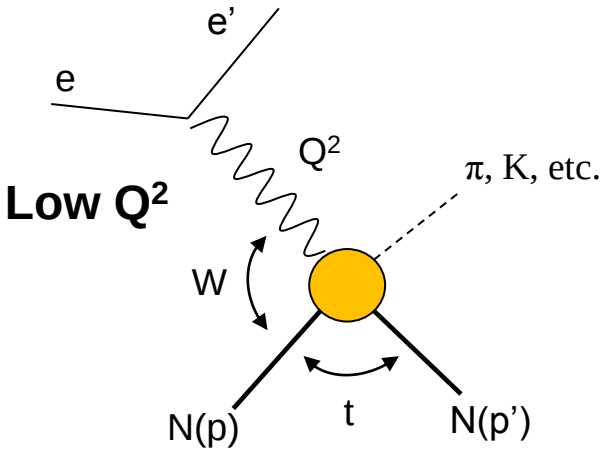
π^0 calorimeter



Detail of the Kaon Aerogel Cerenkov Detector inside the SHMS, in Hall C.

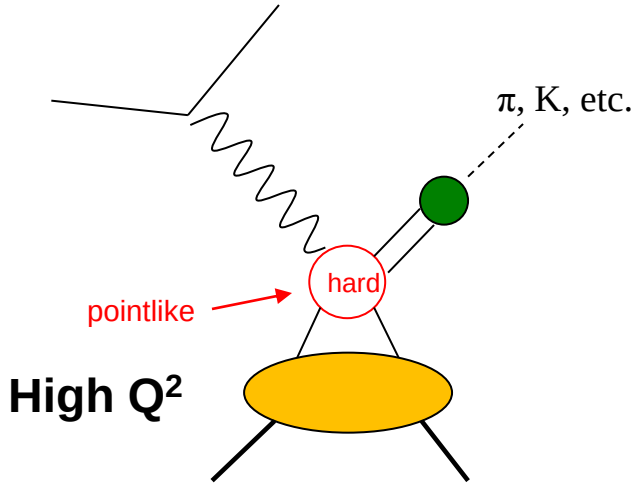
http://galileo.phys.virginia.edu/classes/sajclub/JLab_Upgrade.html

Meson Reaction Dynamics



t-channel process

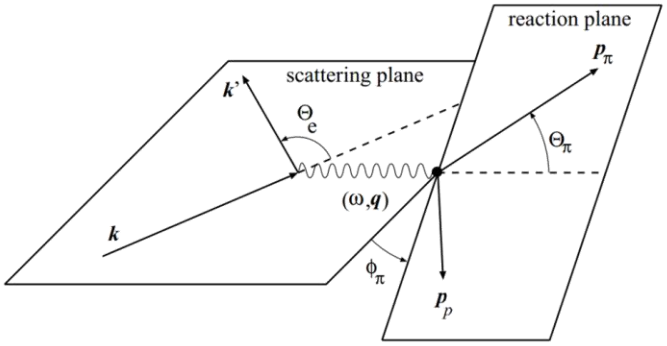
- Meson production can be described by the t-channel exchange meson pole term in the limit of small –t and large W
  - Pole term is dominated by longitudinally polarized photons
  - Meson form factor describes the spatial distribution of the nucleon



handbag

- At sufficiently high Q^2, the process should be understandable in terms of the "handbag" diagram
  - The non-perturbative (soft) physics is represented by the GPDs
    - Shown to factorize from QCD perturbative processes for longitudinal photons *[Collins, Frankfurt, Strikman, 1997]*

K^+ (π^0) L/T separated electroproduction cross section



$$\frac{d^5\sigma}{d\Omega_e dE_e' d\Omega_{K,\pi^0}} = J\left(\phi_k \rightarrow \Omega_{K,\pi^0}\right)\cdot\Gamma_v \cdot \frac{d^2\sigma}{dt\,d\phi}$$

Jacobian of the transformation from dtdΦ to $d\Omega_k$

Virtual photon flux factor

Virtual photon cross section

➢ Virtual photon cross section:

$$2\pi\frac{d^2\sigma}{dt\,d\phi} = \frac{d\sigma_T}{dt\,d\phi} + \varepsilon\frac{d\sigma_L}{dt\,d\phi} + \sqrt{2\varepsilon(1+\varepsilon)}\frac{d\sigma_{LT}}{dt\,d\phi}\cos(\phi) + \varepsilon\frac{d\sigma_{TT}}{dt\,d\phi}\cos(2\phi)$$

Interference terms

Longitudinal and Transverse cross section

Can be separated measuring different Energy:

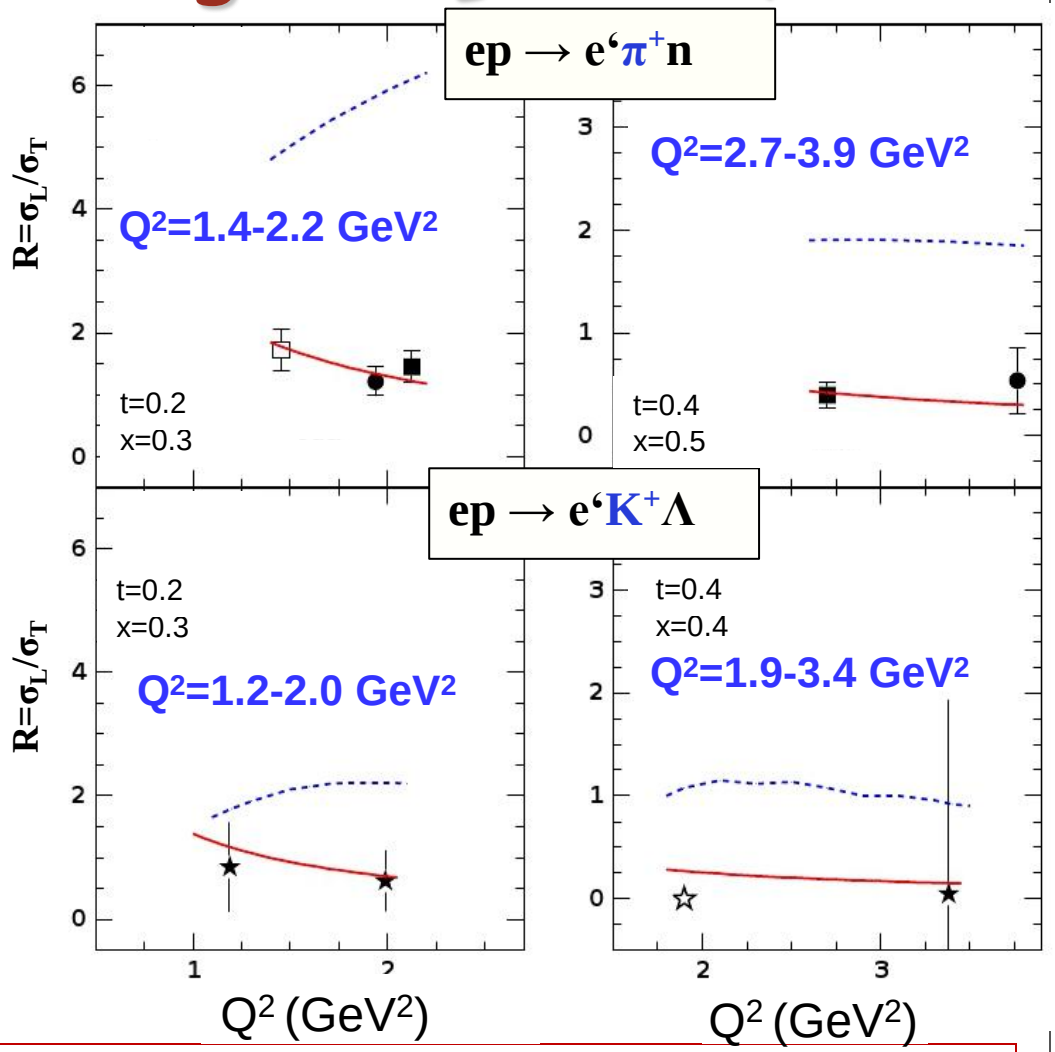
$$\varepsilon = \left(1 + 2\frac{\left|\vec{q}\cdot\vec{q}\right|}{Q^2}\tan^2\left(\frac{\theta_e}{2}\right)\right)^{-1}$$

L/T separations require good control of systematic uncertainties. Focusing spectrometers are best suited for measurements

High Q^2: Q^{-n} scaling of σ_L and σ_T

- To access physics contained in GPDs, one is limited to the kinematic regime where hard-soft factorization applies

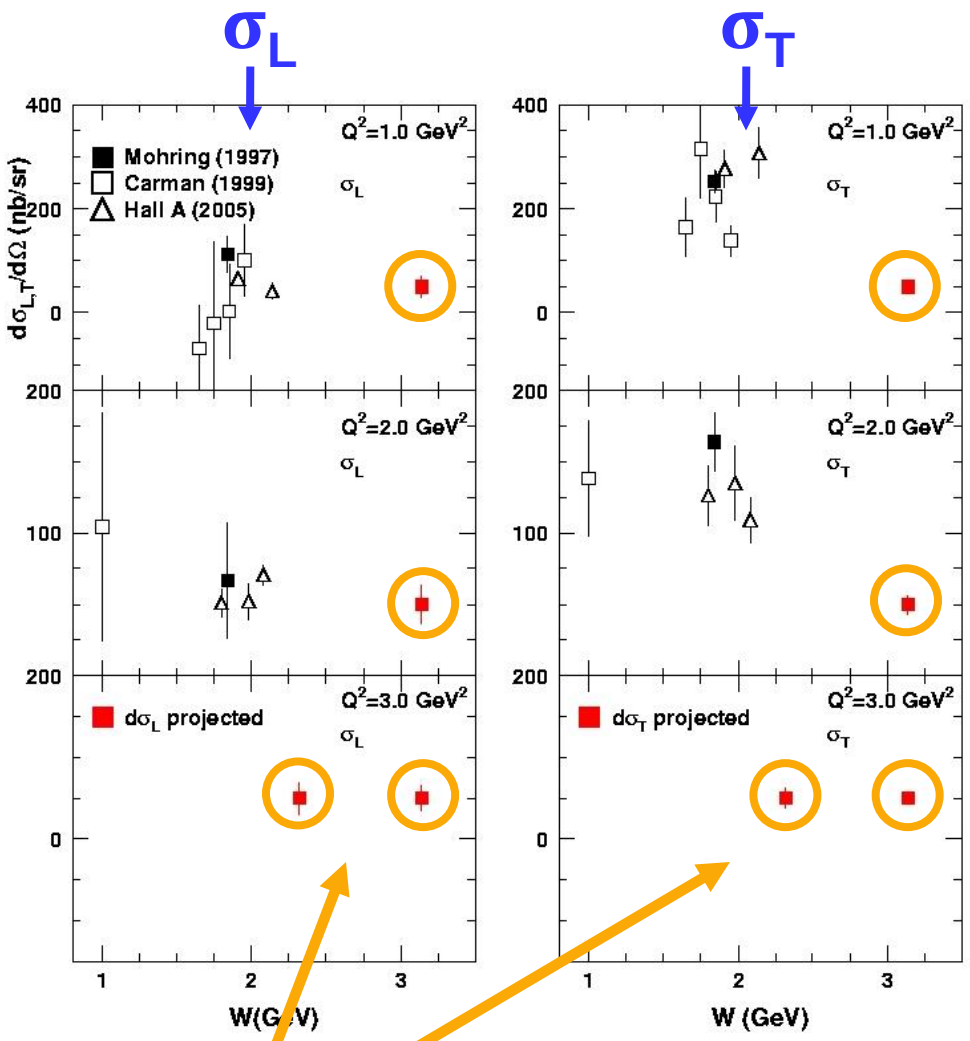
- A test is the Q^2 dependence of the cross section:
  - $-\sigma_L \sim Q^{-6}$ to leading order
  - $-\sigma_T \sim Q^{-8}$



High quality σ_L and σ_T data for both kaon and pion would provide important information for understanding the meson reaction mechanism

JLab 12 GeV: L/T separated **kaon** cross sections

- Approved experiment E12-09-011 will provide first L/T separated **kaon** data *above* the resonance region (W>2.5 GeV)
- Onset of factorization
- Understanding of hard exclusive reactions
  - QCD model building
  - Coupling constants

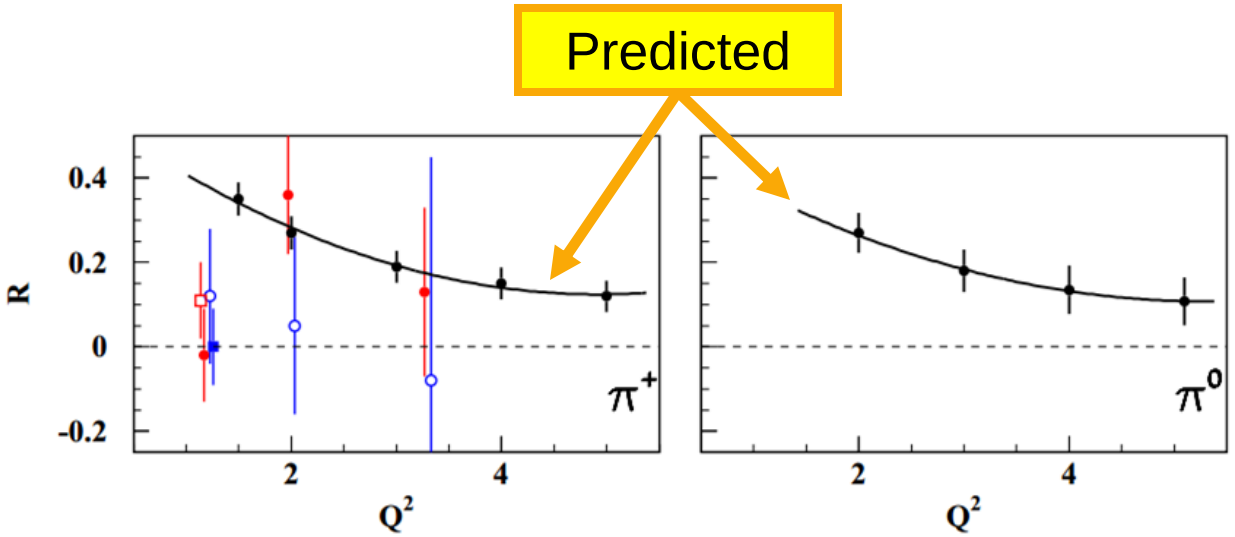


Predicted precision data for W > 2.5 GeV

JLab 12 GeV: L/T separated π^0 cross sections

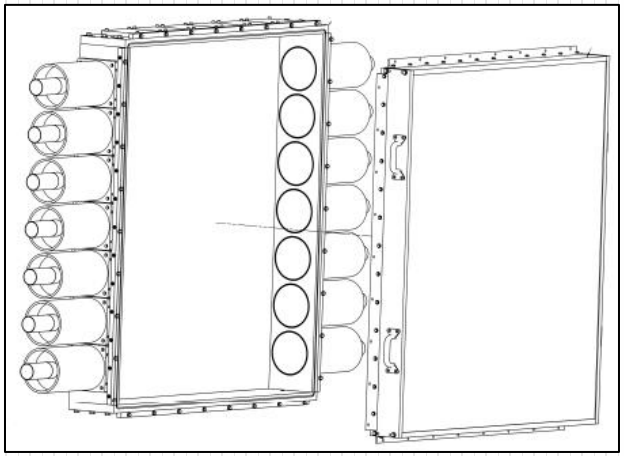
- Charged pion and kaon procresses feature a meson exchange contribution in the t-channel (pole term), whose impact on factorization has to be understood

- Recent π^0 (unseparated) data suggest that transversely polarized photons play an important role in pion electroproduction



- No data for separated L/T cross section for π^0!

Kaon Aerogel Detector



Consortium of universities/institutes

The Catholic University of America

University of South Carolina

Mississippi State University

Florida International University

Yerevan Physics Institute

Why an Aerogel detector? (PID)

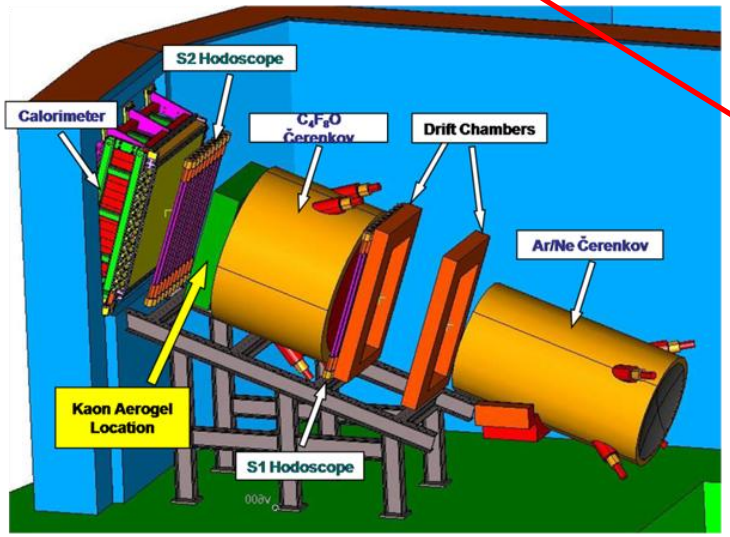
Access to strangeness physics

Particle IDentification

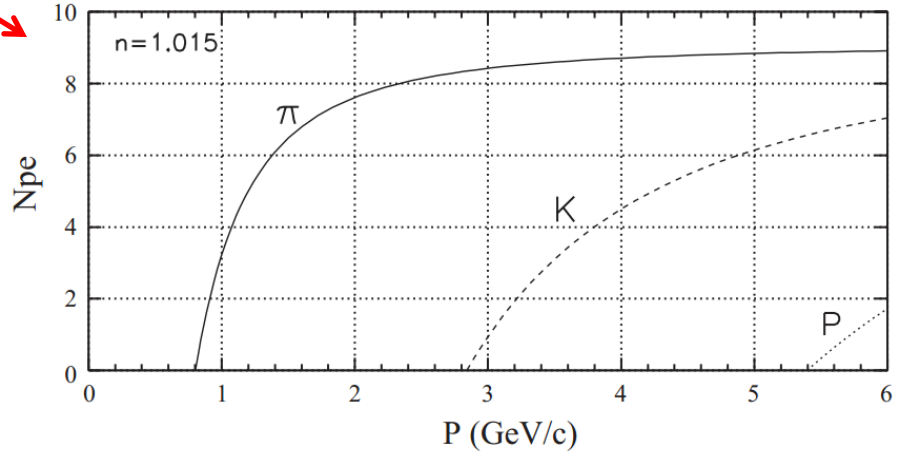
SHMS base detector system provides particle identification for *e*, π, *p* over the full momentum range

- Noble gas Cerenkov: e/π
- Heavy gas Cerenkov: π/K
- Lead glass: e/π

But no K/p!

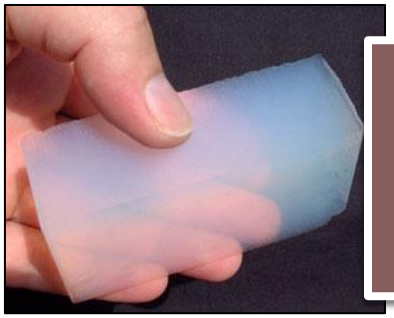


Kaon x Proton → **AEROGEL CERENKOV DETECTOR**



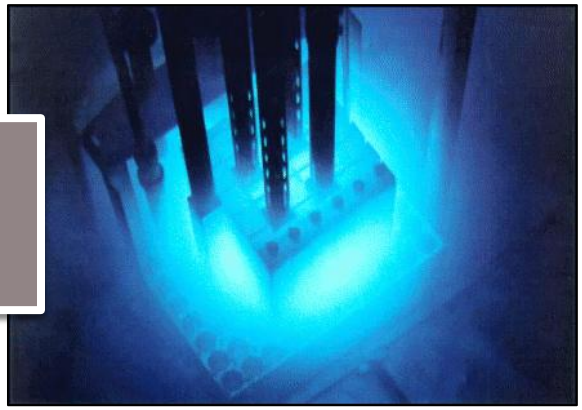
R. Asaturyan *et al*, "The aerogel threshold Cherenkov detector for the High Momentum Spectrometer in Hall C at Jefferson Lab", NIM-A (2005)

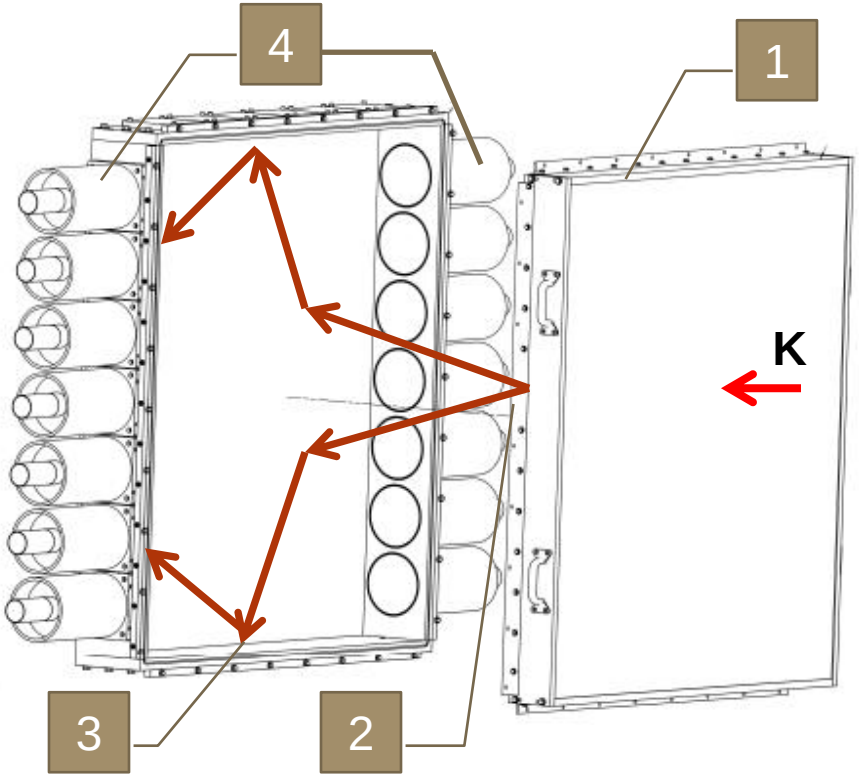
Aerogel detector concepts



Aerogel is the lightest solid, almost as light as gas

Cerenkov radiation in a nuclear reactor

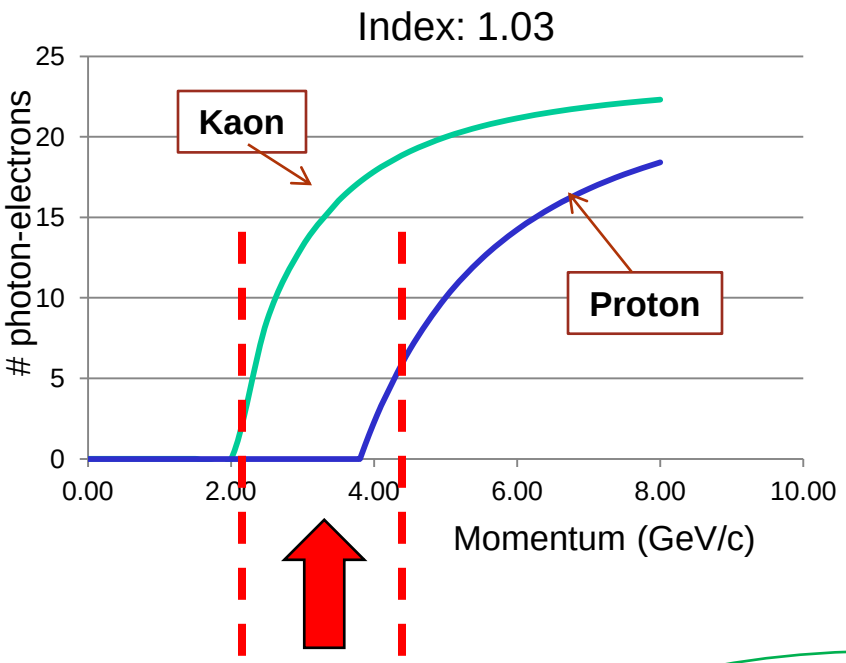


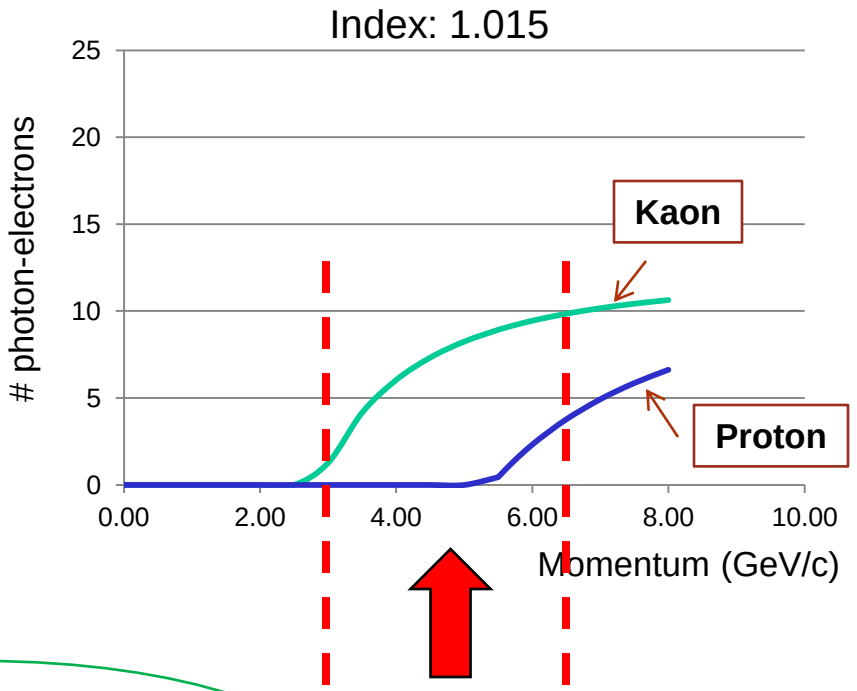


1. Particle passes through aerogel box
2. If $v > \frac{c}{\sqrt{n}}$, Cerenkov radiation (photons) is emitted
3. Reflections of photons on the wall, covered with Millipore
4. Some photons hit the PMTs giving a trigger signal

Aerogel refractive indexes

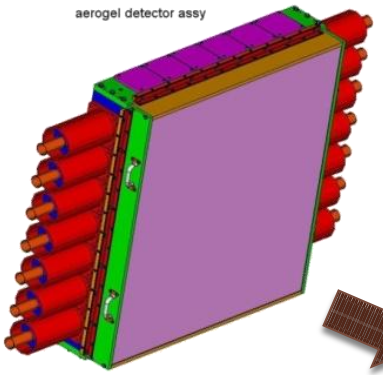
➢ Selecting the refractive index of the aerogel, one can select the range for Proton/Kaon distinguish



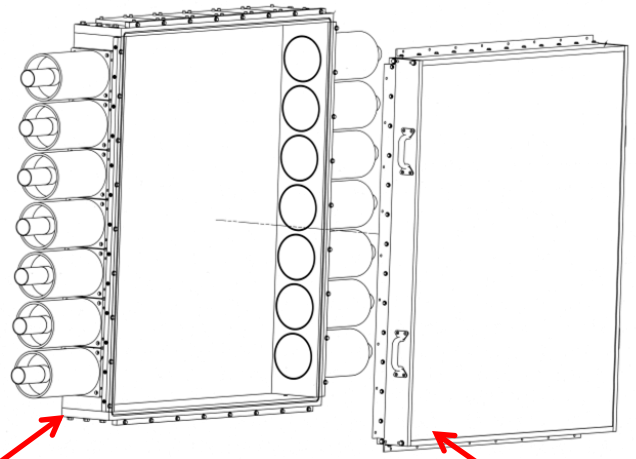


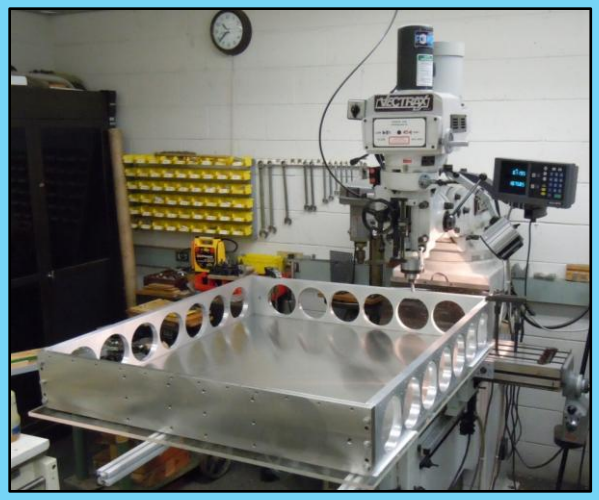
Cover the full Kaon momentum range: from 2.5 to 7.1 GeV/c

SHMS aerogel detector design



Design drawing
[B. Metzger]





Kaon Aerogel Detector being machined at The Catholic University of America

Diffusion box, covered with reflective material

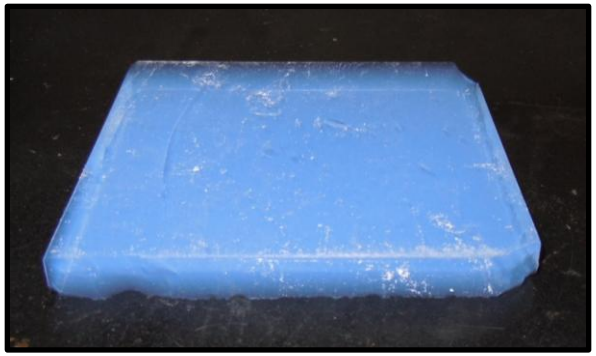
Replaceable aerogel tray, with a ~10cm layer of aerogel

MF-Millipore Membrane Filters

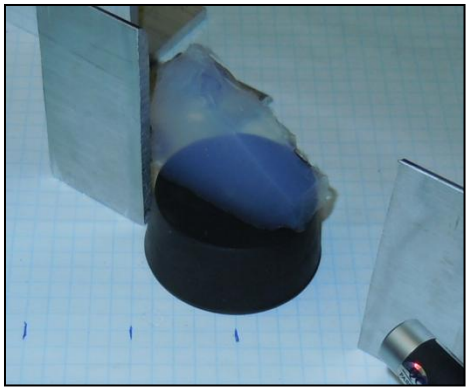
External dimensions of the detector box:
1.10 x 1.00 x 0.45 m^3

<u>Refractive index options</u>:
n = 1.03
n = 1.02
n = 1.010 or 1.015

Aerogel material characterization

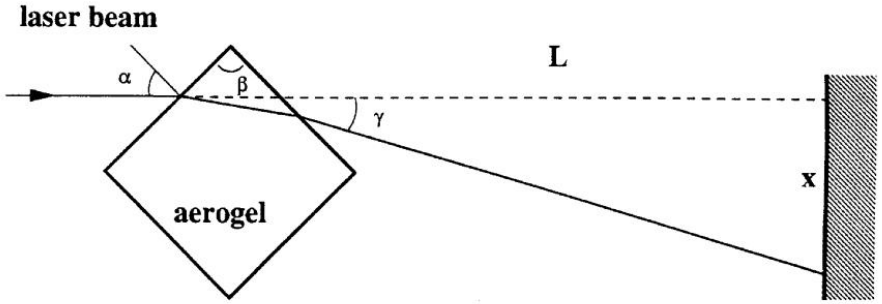


n = 1.030 aerogel tile

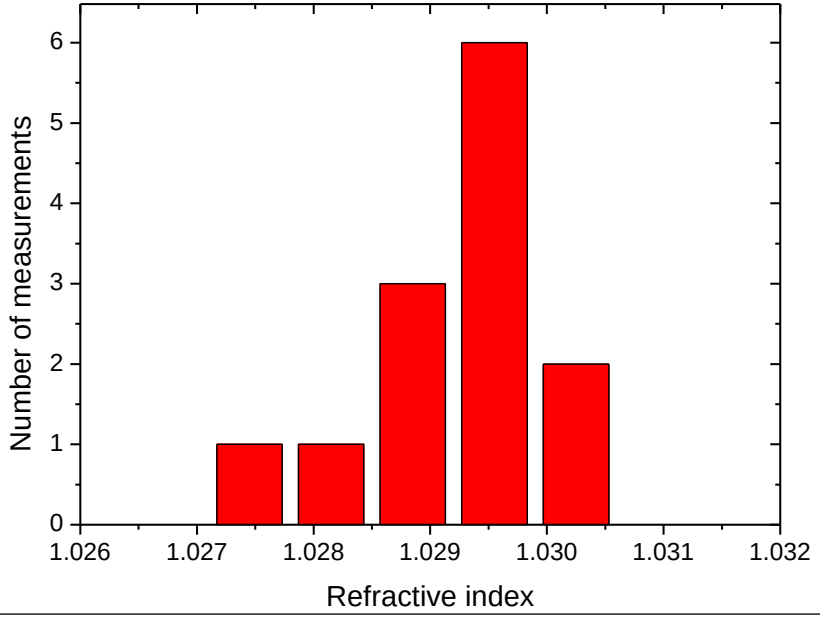


n = 1.010 aerogel tile

- Analysis of a sample of tiles with nominal refractive index 1.030

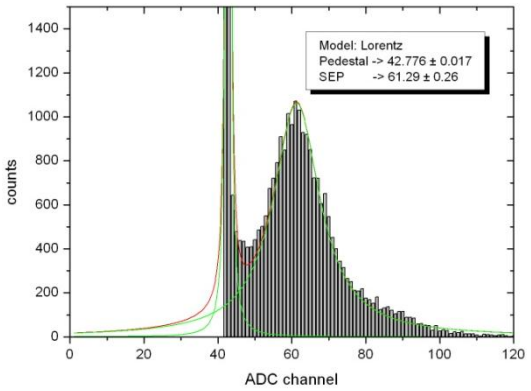


Method used to measure the refractive index of the aerogel tiles

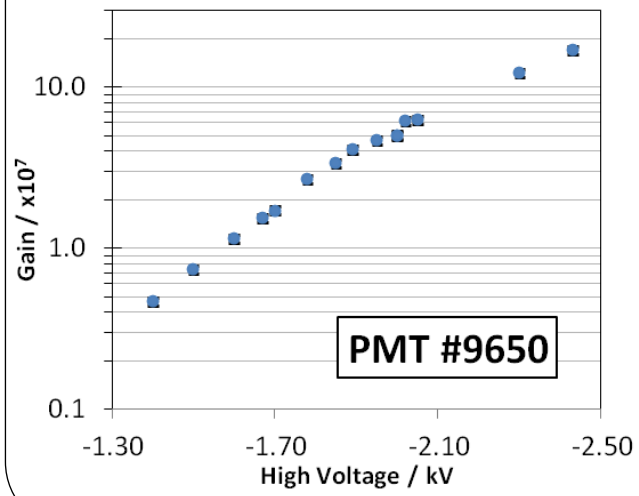


Characterization of large diameter PMTs

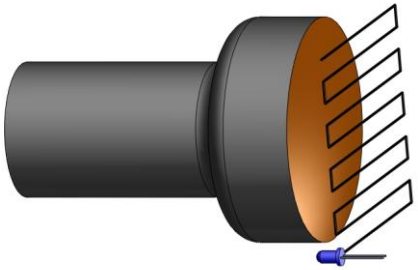
GAIN ANALYSIS



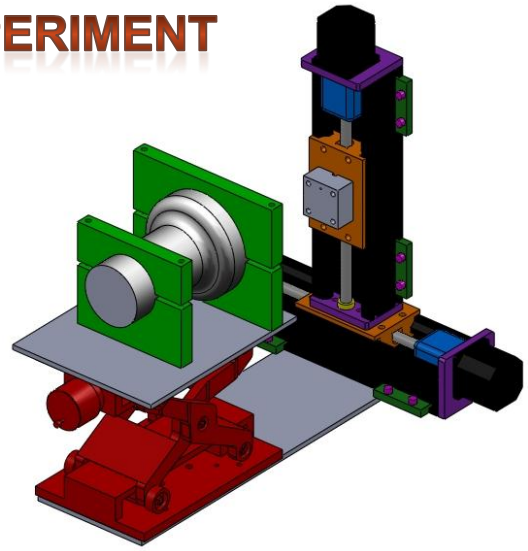
Single electron peak analysis for different supplied voltages



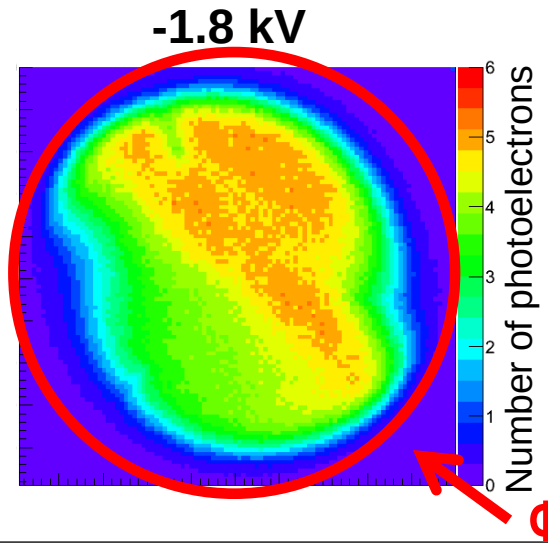
SCANNING EXPERIMENT

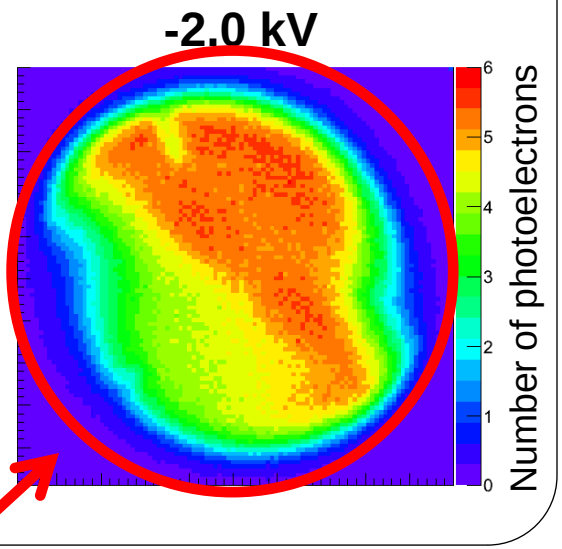


Scanning experiment



Step motors to position a blue LED in front of the PMT



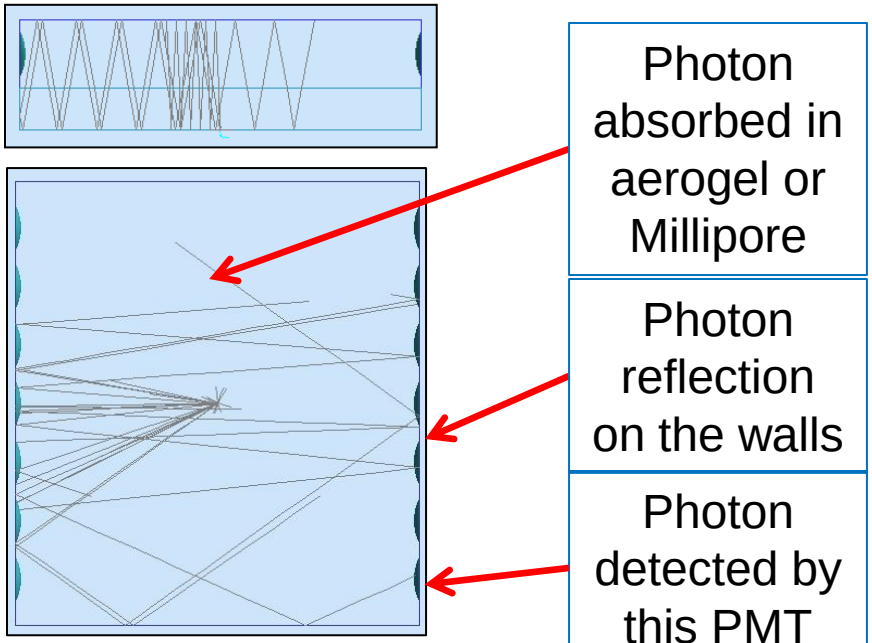


Ongoing preparation of other tools

- Simulations and tests of (possible) changes in components of the detector:
  - Internal cover material (Millipore, Reflective Paint, Mylar, ...)
  - Aerogel change in transparency

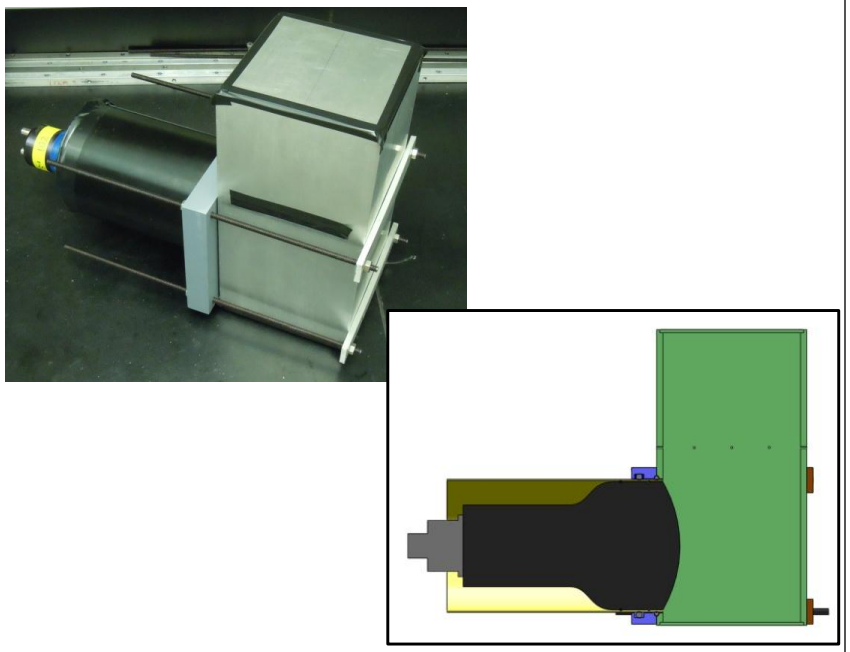
GEANT4 simulations

Detector view of a simulation, showing just a few Cerenkov photons



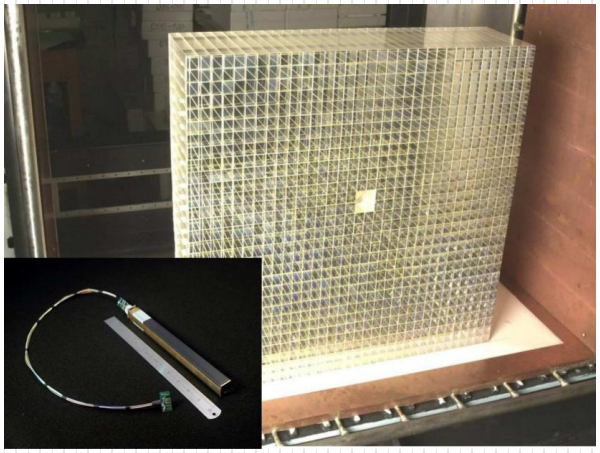
Upper view of the simulation

Detector prototype



Prototype of the detector for experimental analysis

π^0 Calorimeter



Consortium of universities/institutes

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Old Dominion University

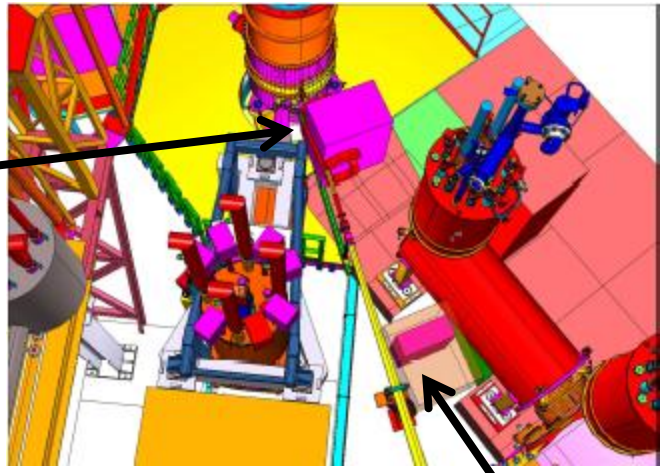
Florida International University

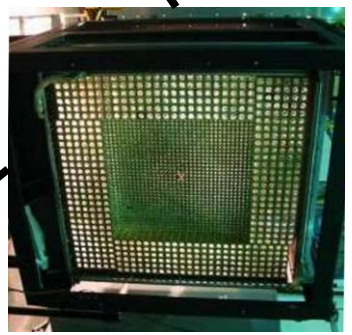
Yerevan Physics Institute

Concepts the π^0 calorimeter

Experiment was conditionally approved at Jefferson Lab PAC38 and was re-submitted for full approval to PAC39 (June/2012)

- The detector system will consist of
  - PbWO4 blocks of the PRIMEX setup in a new temperature controlled frame
  - A sweeping magnet
  - Essentially deadtime-less digitizing electronics
  - HV bases with built-in amplifiers





- **Measurement of the photons from π^0 decay**

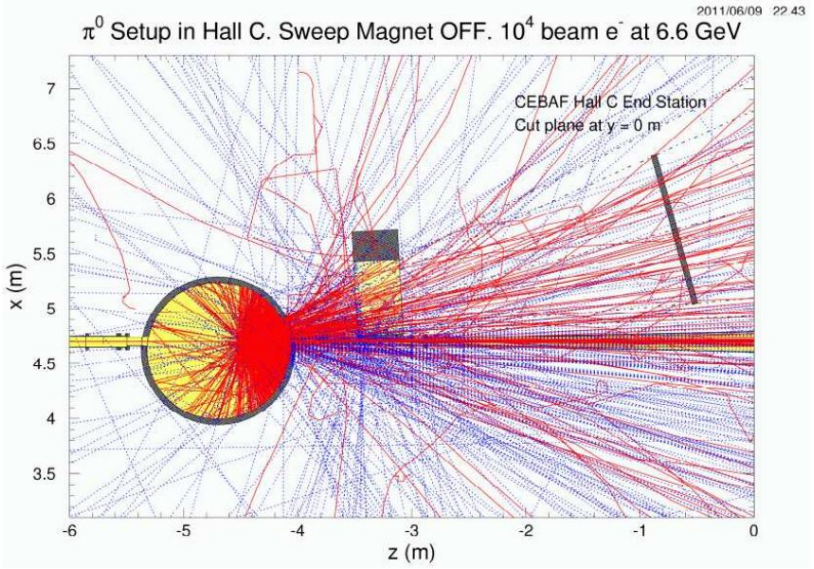
Detector features:

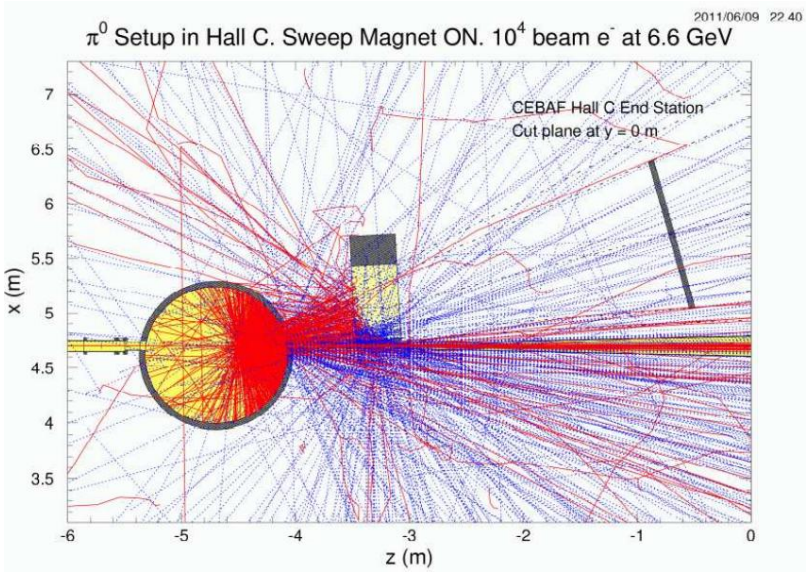
31 x 36 matrix of $PbWO_4$ crystals

2.05 x 2.05 x 18 cm^3 each crystal

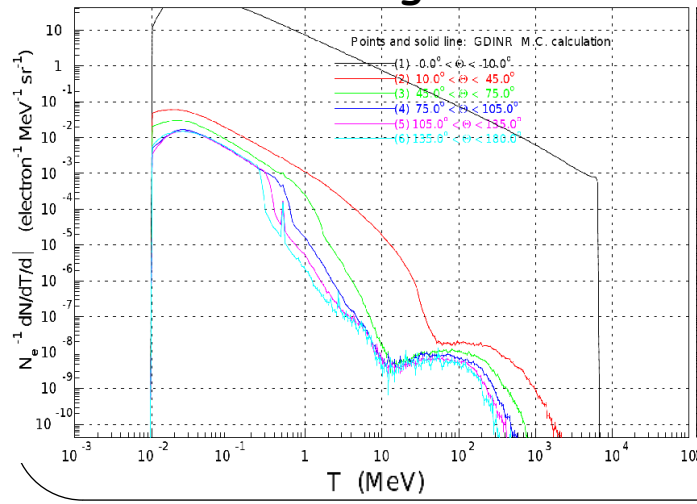
Simulations of the π^0 calorimeter

- **Magnetic field before the detector to reduce charged particles background**

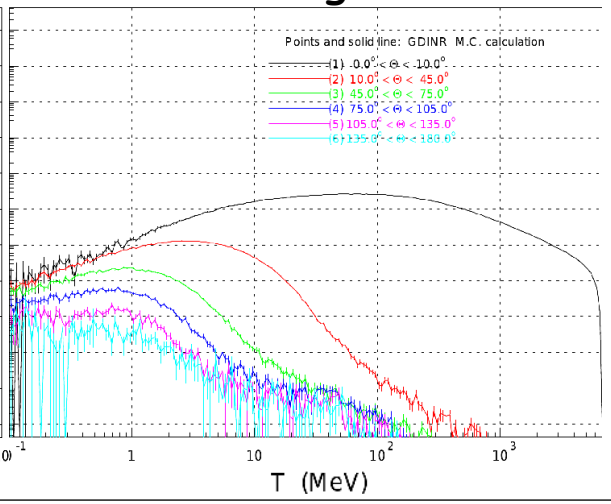




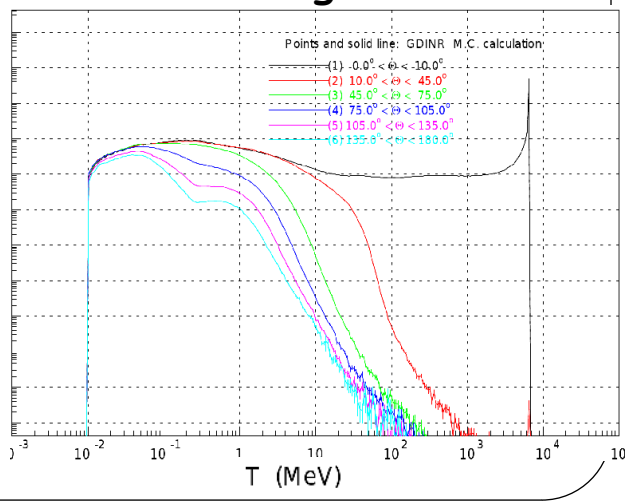
γ background



e^+ background

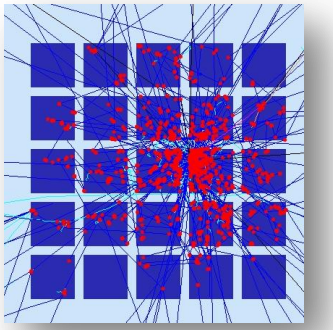


e^- background



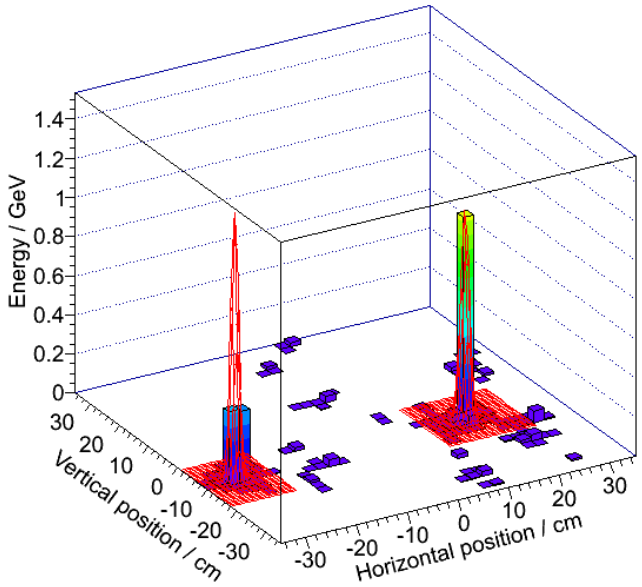
Simulation of the calorimeter

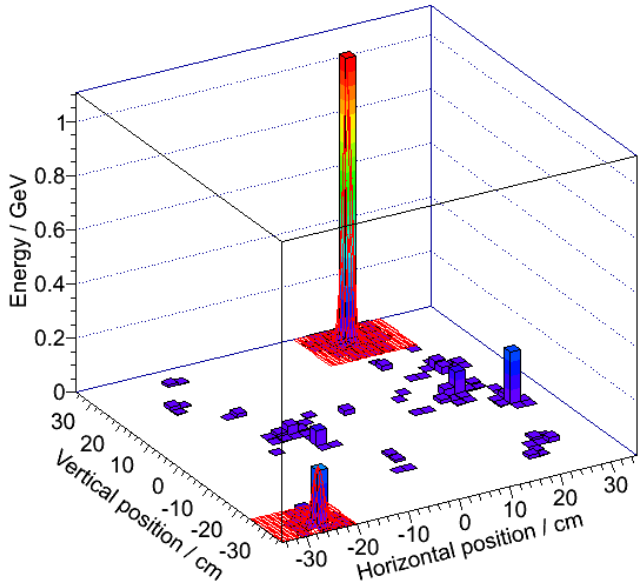
- **Single photon hitting the small detector in GEANT4**



Shower spreads in the neighbor crystals, making possible a sub-crystal resolution

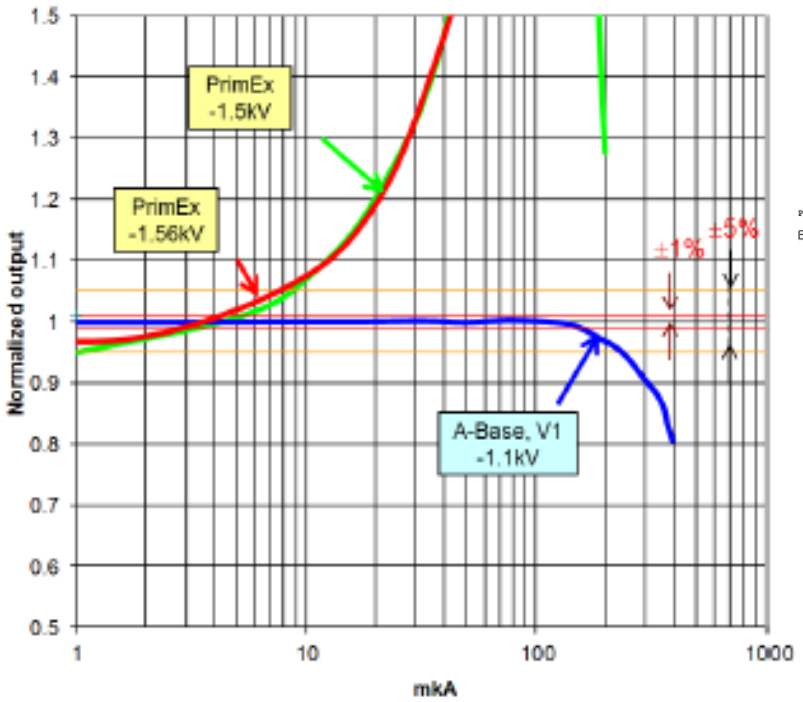
- **Events with two photons from π^0 decay and background**

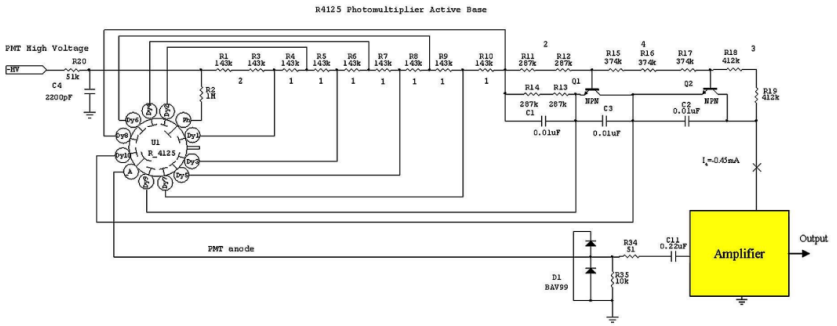




Active bases for PMTs

- Adding two high-voltage transistors to the last two dynodes:
  - Drain current and do not change the division ratio





- The new active base design out performs the Primex PMT/base by a factor of ~25:
  - Increases the maximum linear count rate: from 30kHz to 1.2MHz
  - Changes the gain stability from ±5% to ±1%

Conclusions

- The Kaon Aerogel Detector and the π^0 calorimeter will allow studies on K^+ and π^0 electroproduction cross section, for understanding of the onset of factorization

- These projects will provide L/T separated cross section above the resonance region (W>2.5GeV) in the 12GeV era of Jefferson Lab

- Kaon Aerogel Detector entering the final stage of construction; its components are being characterized for the final assembly and tests of the detector

- π^0 calorimeter pre-design tests are ongoing; MRI/NSF has been submitted in January/2012.