Participation in Hall C 12 GeV Energy Upgrade

(Design and construction Calorimeters and Aerogel Detectors for Hall C at 12 GeV)

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Main directions of my activities:

- ✓ ***Electromagnetic calorimeter for the SHMS magnetic spectrometer***
- ✓ ***Threshold Aerogel Cherenkov detectors for the SHMS***
- ✓ ***Neutral Particle spectrometer for pi0 and γ detection***

SHMS Electromagnetic Calorimeter

- The SHMS the electromagnetic calorimeter will play dominant role to separate electrons from hadrons.

- In combination with Gas Cerenkov and Aerogel detector calorimeter will provide a π/e rejection by factor of ~1000.

- Higher energy leads to larger probability for fluctuations of the energy deposited in a total-adsorption calorimeter.

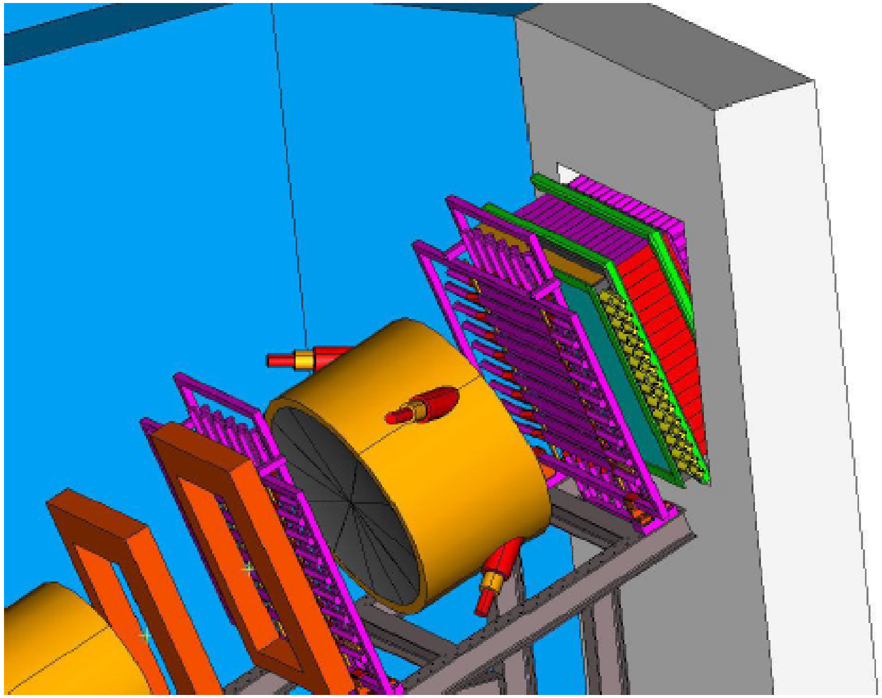
- Our studies allowed to select an alternative calorimeter geometry maintained the good energy resolution and pion rejection capabilities.

- Basic requirement for SHMS Calorimeter was effective area ~1.5 m^2 and resolution ~6% at 1 GeV.

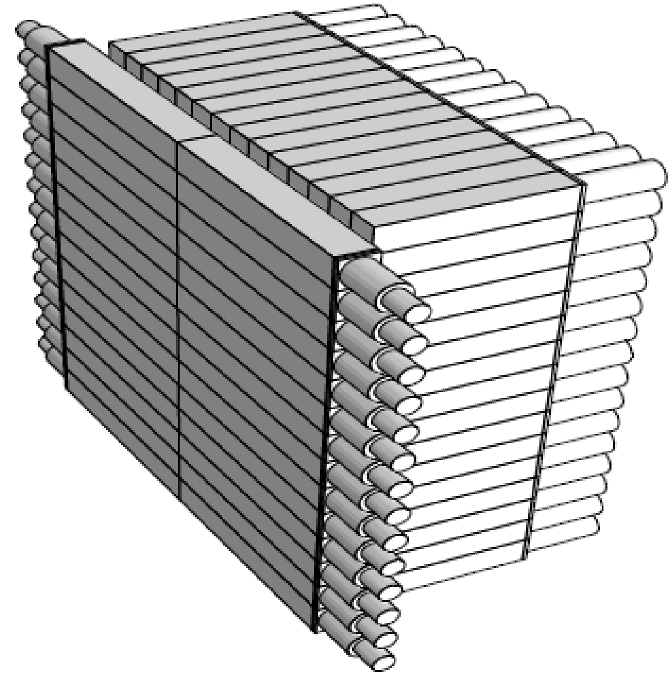
- **The YerPhI group are responsible for the design, construction and assembly of SHMS calorimeter, its calibration and software.**

SHMS

Detector Hut



Calorimeter



- Calorimeter is situated at the very end of SHMS detector stack
- With effective area 120cm x 140cm, it will cover SHMS acceptance
- Higher energy leads to thicker calorimeter than in HMS/SOS
- Energy resolution better than 7% (at 1 GeV energy) is expected
- π/e rejection 200:1 with Preshower & Shower (at 99.5% e^- efficiency)
- Preshower consists of 28 modules (TF-1) from the SOS calorimeter stacked back to back
- Shower part consists of 224 modules (F-101) from decommissioned HERMES detector

Calorimeter blocks revision and test

232 blocks for Shower part

Best 224 (+8) out of 250 available are selected & ready for installation.

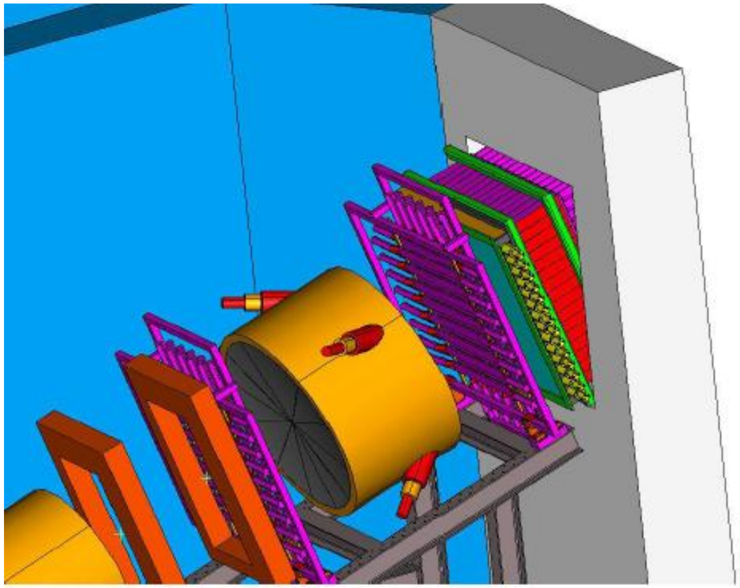
Preshower part assembling

28 blocks & PMTs from SOS calorimeter have been used for Preshower

SHMS Preshower

- Preshower is assembled and tested for light leaks
- Full-scale cosmic tests will start as soon as will have all electronics

Why we need Aerogel Cherenkov Detector ?



Experiments (potentially) benefiting of the Aerogel detector

Approved 12 GeV experiments

E12-06-104	Measurement of the Ratio R=sigmaL/sigmaT in Semi-Inclusive Deep-Inelastic Scattering
E12-06-107	The Search for Color Transparency at 12 GeV
E12-09-011	Studies of the L-T Separated Kaon Electroproduction Cross Section from 5-11 GeV
E12-06-101	Measurement of the Charged Pion Form Factor to High Q2
E12-07-105	Scaling Study of the L-T Separated Pion Electroproduction Cross Section at 11 GeV

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

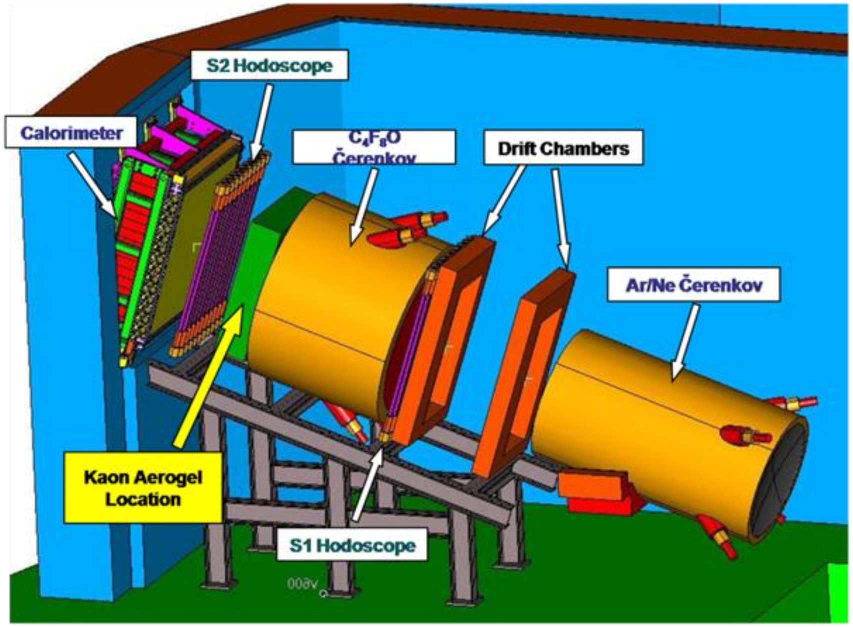
- Noble gas Cerenkov: e/π
- Heavy gas Cerenkov: π/K
- Lead glass: e/π

} But no K/p!

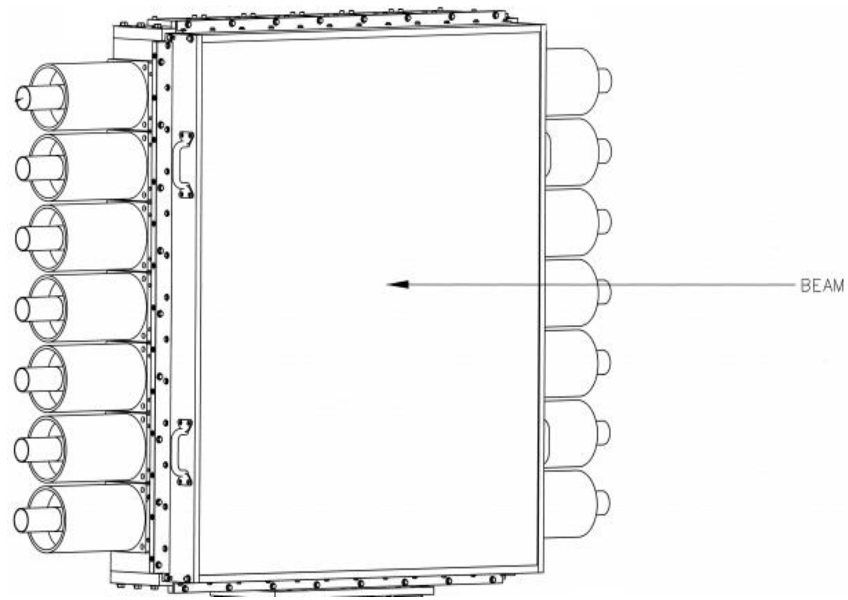
<u>Kaon x Proton</u>
AEROGEL CERENKOV DETECTOR

Aerogel Detector in the SHMS

Detector Hut



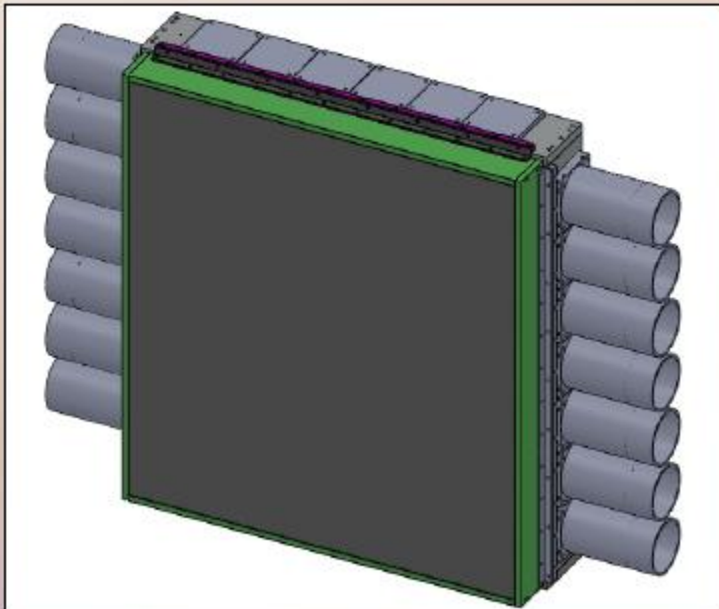
Aerogel Detector



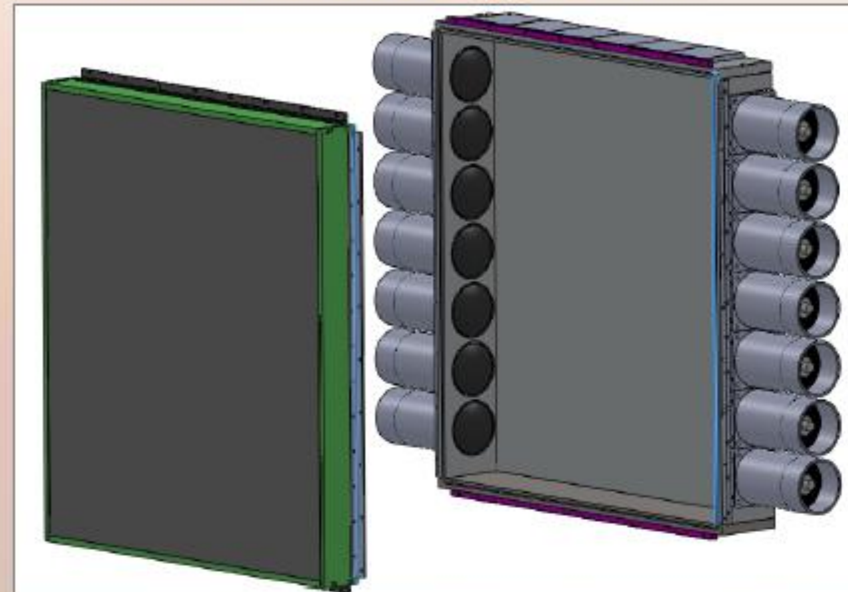
- **The Aerogel detector is situated between heavy gas (C_4F_8O) Čerenkov detector and S2 Hodoscopes of the SHMS detector stack**
- **A dedicated kaon PID detector**
- **With dimensions 113x103x28 cm^3, covers SHMS acceptance**
- **2 detectors possible**
- **Consists of a diffusion box with 14 PMTs (plus optional 6 on top) and 4 replaceable trays with Aerogel of different indexes: 1.03, 1.02, 1.015, 1.011**

Aerogel detector characteristics

PMTs to collect Cerenkov light radiated in the aerogel



Inner surfaces covered with diffusive reflector

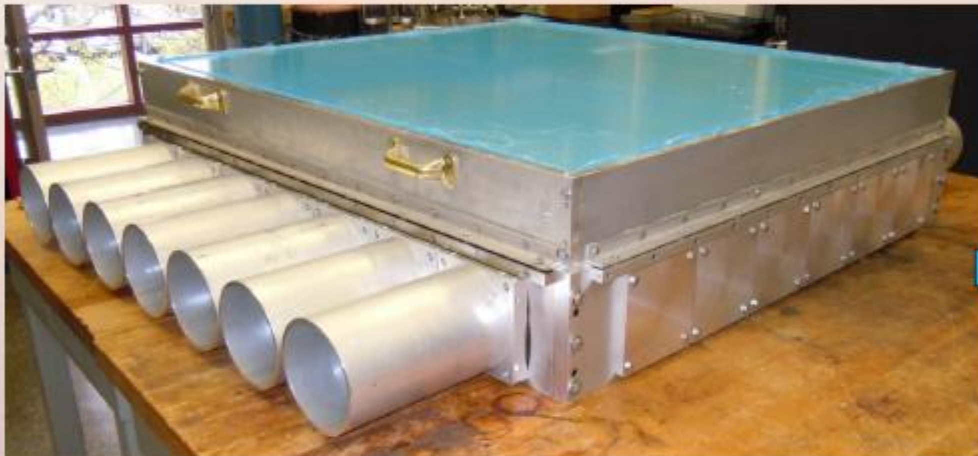


4 exchangeable aerogel trays, possibility of different momentum ranges:

Refractive Index	π threshold (GeV/c)	K threshold (GeV/c)	P threshold (GeV/c)
1.030	0.57	2.00	3.80
1.020	0.67	2.46	4.67
1.015	0.81	2.84	5.40
1.011	0.94	3.32	6.31

Status of detector construction

Machined at CUA



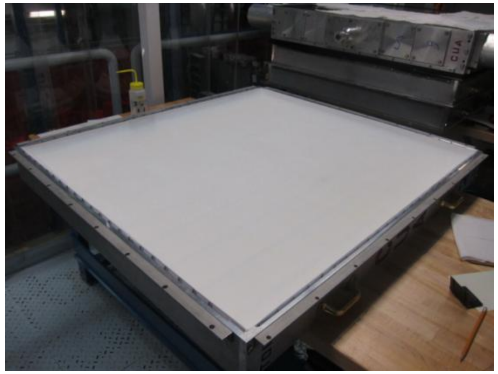
Brought to Jlab for assembly and tests

Aerogel tiles stacking

Ongoing tests with cosmic rays

(More details on these tests in Simon Zhamkochyan talk)

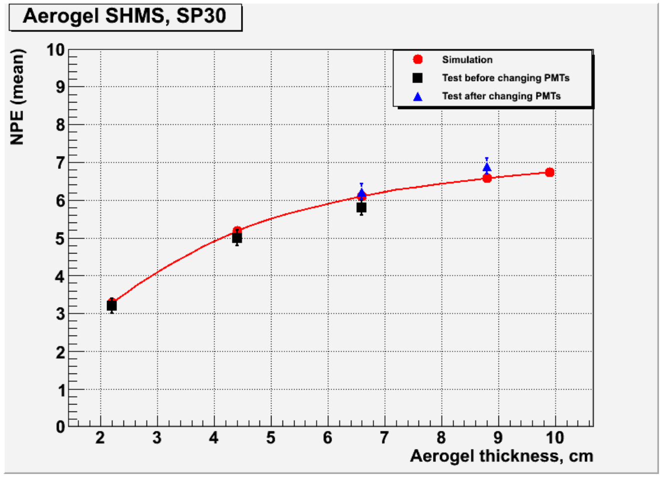
Update on the Status



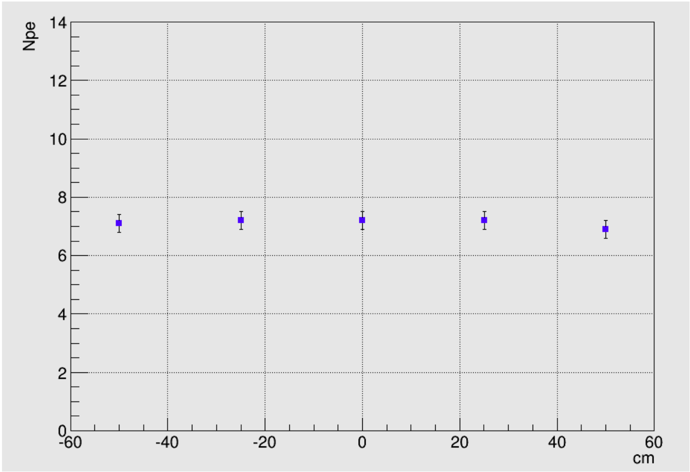
Stainless
steel wires

- The Diffusion box and the trays were covered with reflector (Millipore)
- An electronics setup for cosmic tests has been set up (Thanks to Brad Sawatsky)
- **SP30 (n = 1.03) tray: Filled with 8 layers, tested, wired; FINISHED**
- **SP20 (n = 1.02) tray: Filled with 7 layers, tests with cosmics are being finalized**
- Two trays for the lower indexes (n = 1.015 and n = 1.011) are machined and ready for installation of the tiles and testing

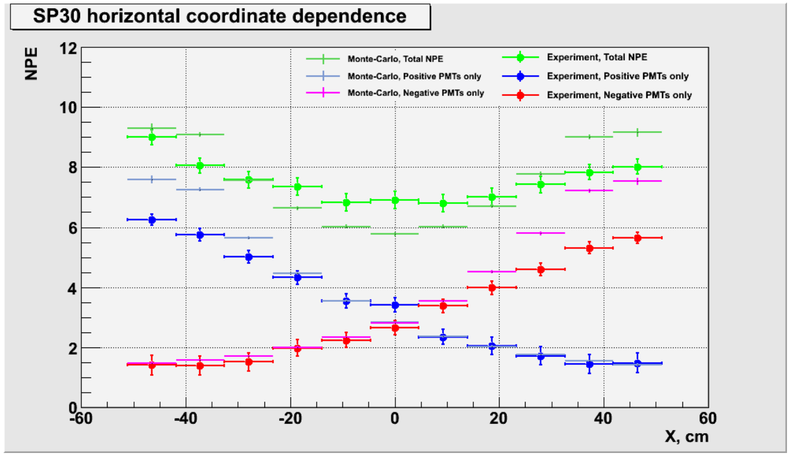
Thickness and coordinate dependence (SP-30)



SP30, Signal dependence on aerogel thickness

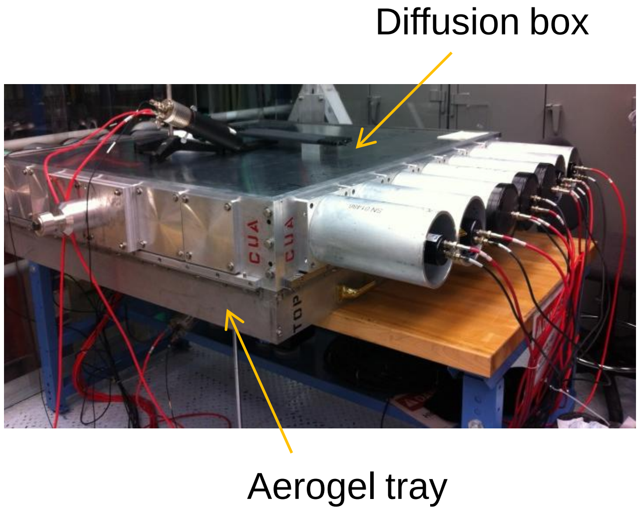


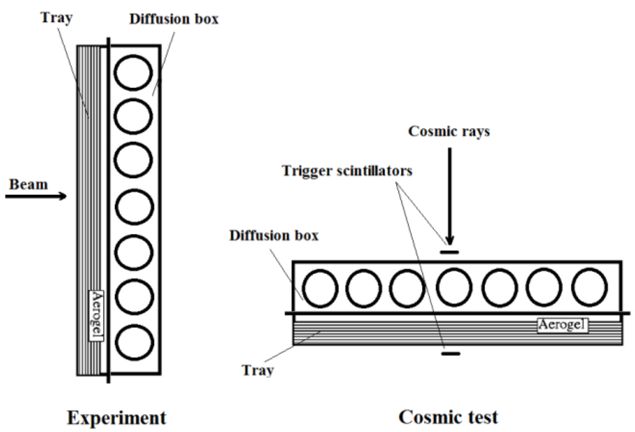
SP30, 8 layers, Vertical coordinate dependence

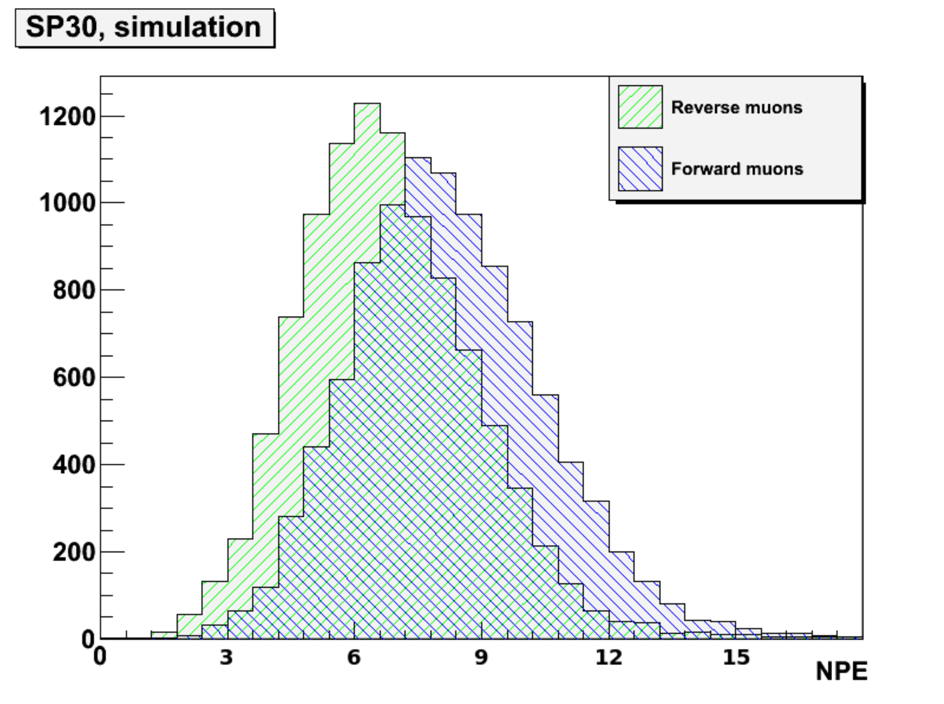


SP30, 8 layers: Comparison of data to a Monte Carlo simulation of the detector

Charged particle direction

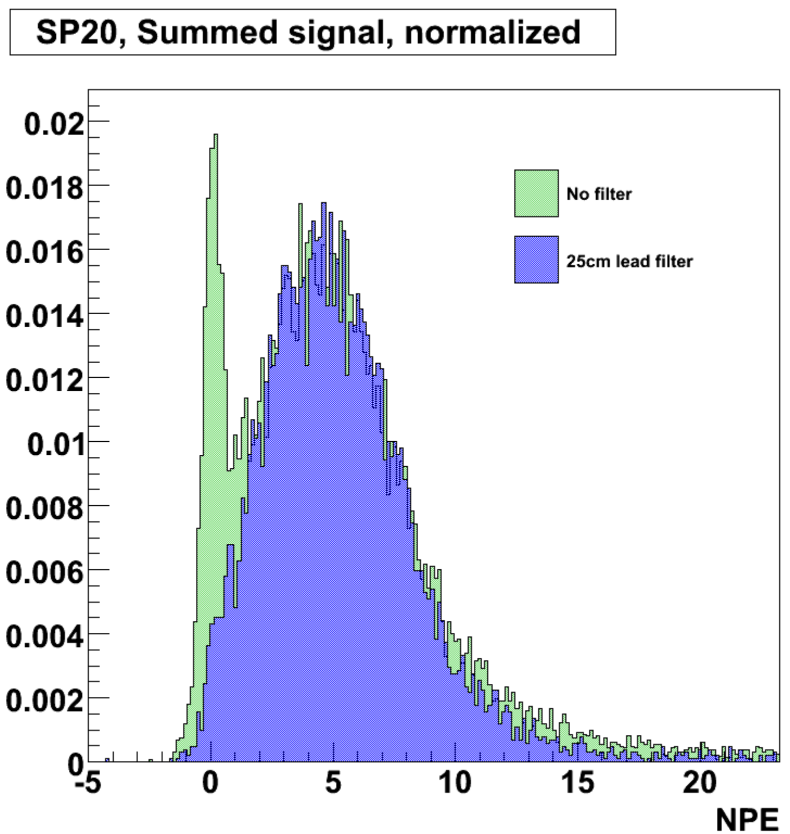






The cosmic tests are performed in reverse geometry. In actual experiment the signal is expected to be ~20% higher

Sub-threshold particles (SP-20)



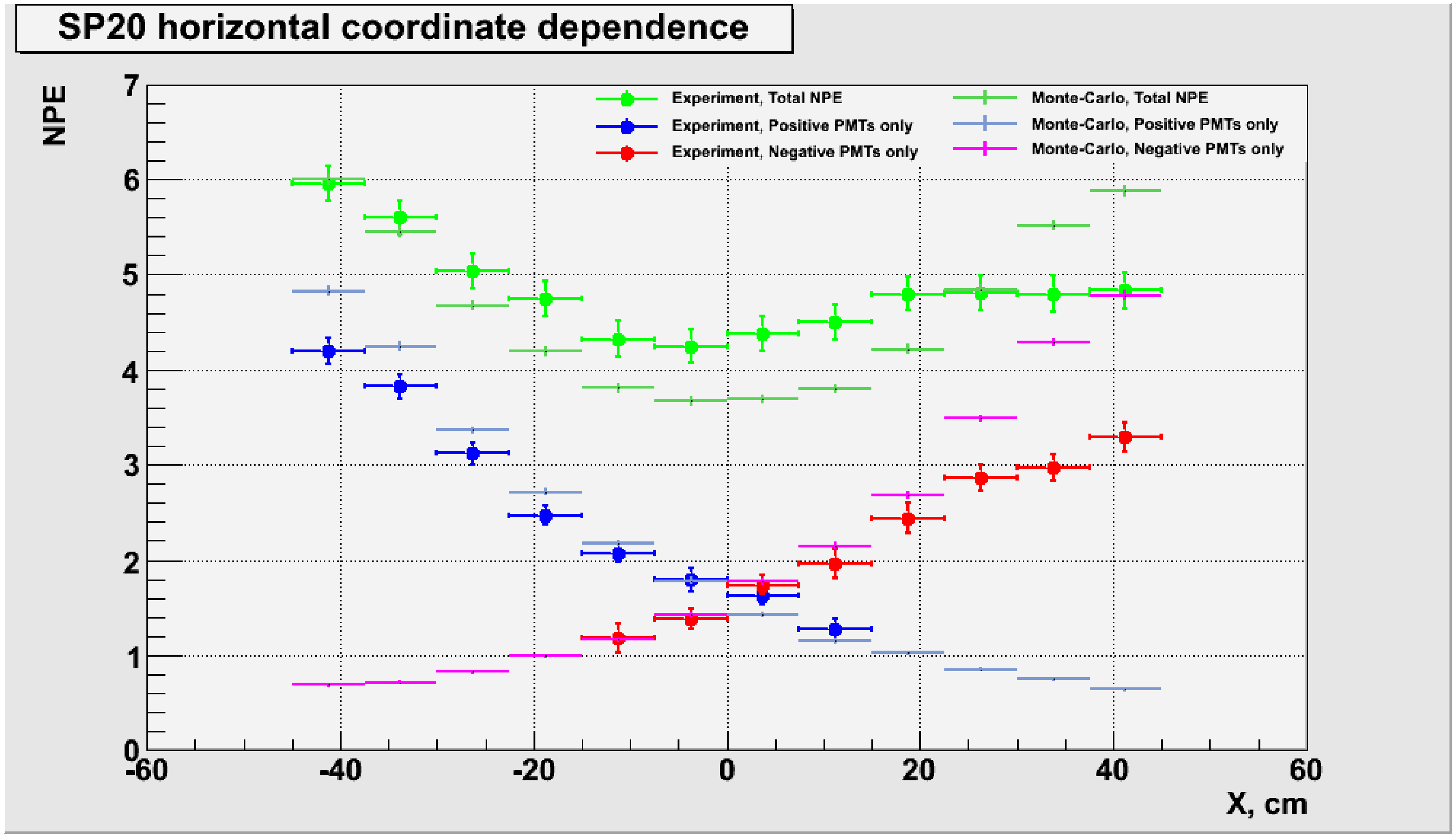
SP20, Test with 25cm thick lead filter

Stack of lead blocks

$E_{thr(\mu)}^{SP\text{-}20} \approx 540$ MeV

The peak around zero, caused by sub-threshold particles, is filtered out by 25cm of lead put between the trigger scintillators

Horizontal coordinate dependence (SP-20)



SP-20, 7 layers

Why we need Neutral Particle Spectrometer ?

At a 12-GeV JLab, the Hall C base experimental equipment will consist of two magnetic spectrometers: the High Momentum Spectrometer (HMS) and Super High Momentum Spectrometer (SHMS).

Depending on the specific requirements of the experiments, they can detect either negatively or positively charged particles by choosing the magnetic field and the trigger configuration.

This pair of spectrometers will allow to conduct a wide program precision measurements of exclusive, inclusive and semi-inclusive reactions (single arm or coincidence).

Construction of a Neutral Particle Spectrometer in Hall C will open new opportunities and will extend physics program to the processes where in coincidence with scattered electron one must detect photons (γ, π^0).

Parameter	HMS	SHMS
P range (GeV/c)	0.4 - 7.3	2.0 - 11.0
ΔP(%)	±10	-10 - +20
Momentum res. (%)	0.10 -0.15	0.03 - 0.08
Horiz. angle range (mrad)	±32	±18
Vert. angle range (mrad)	±85	±50
Max. angle (degrees)	90	40
Min. angle (degrees)	10.5	5.5
Horiz. angl. res. (mrad)	0.8	0.5-1.1
Vert. Angl. res. (mrad)	1.0	0.3-1.1
Solid angle (msr)	8.1	4.5
Vertex reconstr. res. (cm)	0.3	0.1-0.3

Why we need Neutral Particle Spectrometer ?

The NPS is envisioned as a facility in Hall C, utilizing the well-understood HMS and the new SHMS infrastructure, to allow for precision (coincidence) cross section measurements of neutral particles (γ, π^0).

Proposals interested in the facility so far:

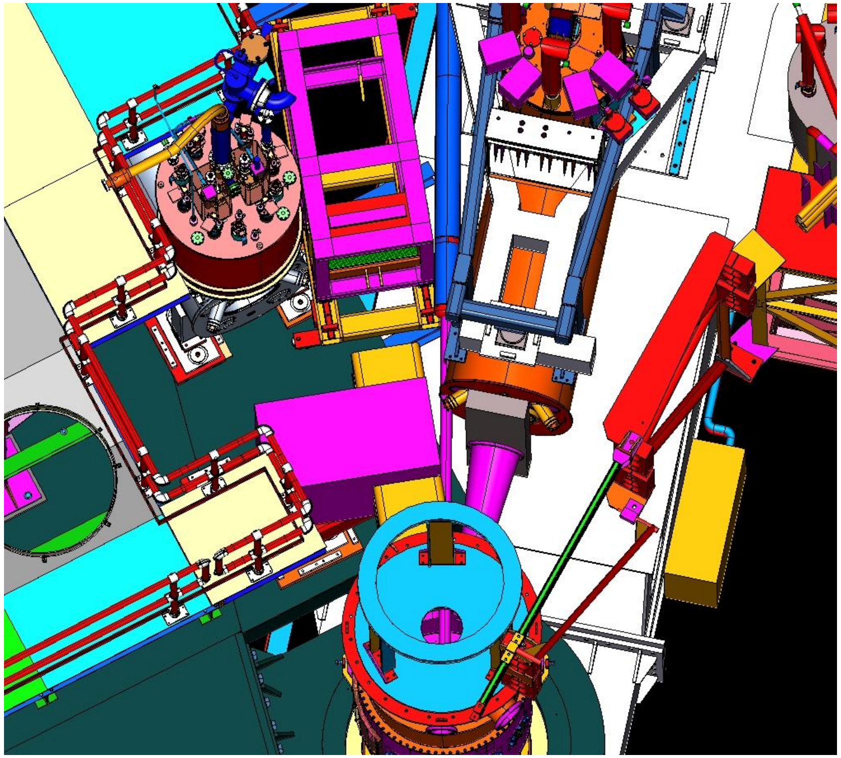
- E12-13-007, Measurement of Semi-Inclusive π^0 Production as Validation of Factorization. (25 days, PAC40 approved, A- rating).

- E12-13-010, Exclusive Deeply Virtual Compton and Neutral Pion Cross-Section Measurements in Hall C. (53 days, PAC40 approved, A rating).

- PR12-13-009, Wide-angle Compton scattering at 8 and 10 GeV photon energies . (Deferred by PAC40, hopefully will be back).

- LOI12-13-003 – Large Center-of-Mass Angle, Exclusive Photoproduction of π^0 Mesons at Photon Energies of 5-11 GeV.

NPS Facility



- a ~25 msr neutral particle detector consisting of 1116 $PbWO_4$ crystals in a temperature-controlled frame – using PRIMEx crystals or other options.

- HV distribution bases with built-in amplifiers for operation in a high-rate environment – new

- Essentially deadtime-less digitizing electronics to independently sample the entire pulse form for each crystal – JLab-developed Flash ADCs

- Two new sweeping magnets, one horizontal bending with ~0.3 Tm field strength, and one vertical bending with ~0.6 Tm field strength for larger angles/WACS. Both designed to use an existing power supply.

- Cantelevered platforms off the SHMS carriage to allow for remote rotation (in the small angle range), and platforms to be on the SHMS carriage (in the large angle range) – new

- A beam pipe with as large critical angle as possible to reduce beamline-associated backgrounds – further study showed only a small section needs modification (JLab/Hall C)

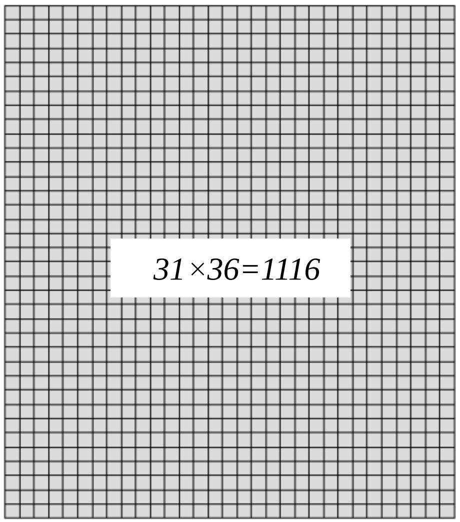
HV and cabling is assumed from JLab, and similar as for BigCal

Possible options for the NPS calorimeter

Original concept: use 1116 of PrimEx crystals

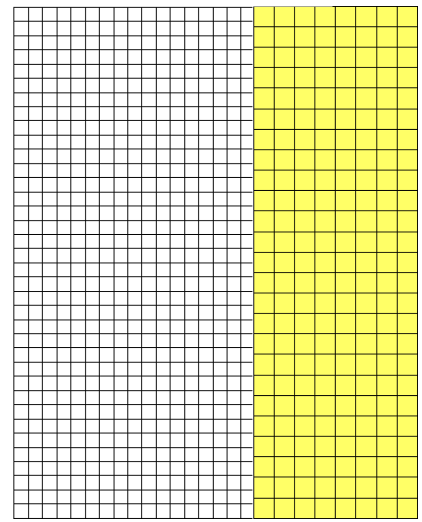
Alternate option to alleviate scheduling issues: a mix of ~600 PrimEx/$PbWO_4$ crystals and the existing PbF_2 blocks of Hall A/DVCS

64×74 cm²



All block are $PbWO_4$

59×75 cm²



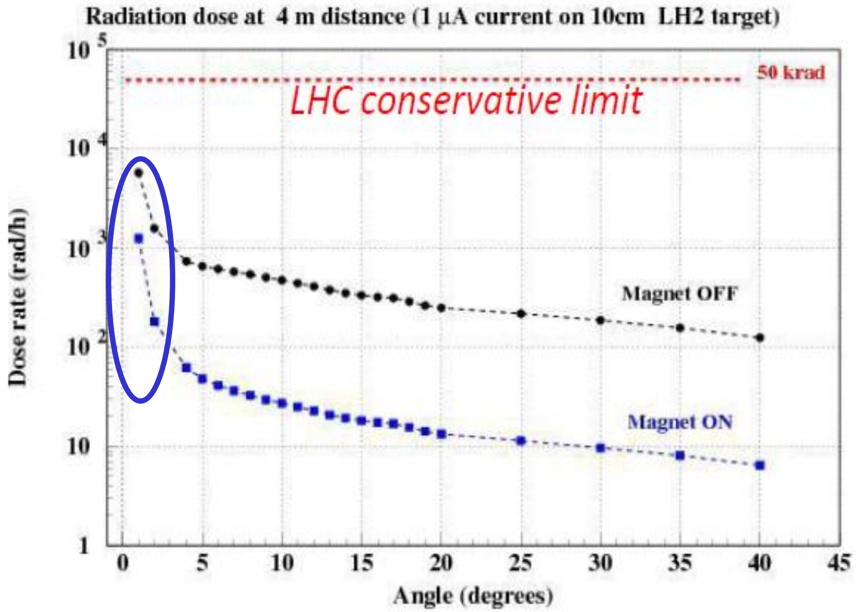
612 $PbWO_4$ + *200* PbF_2

$PbWO_4$ blocks dimensions: 2.05×2.05 cm²
PbF_2 blocks dimensions: 3.0×3.0 cm²

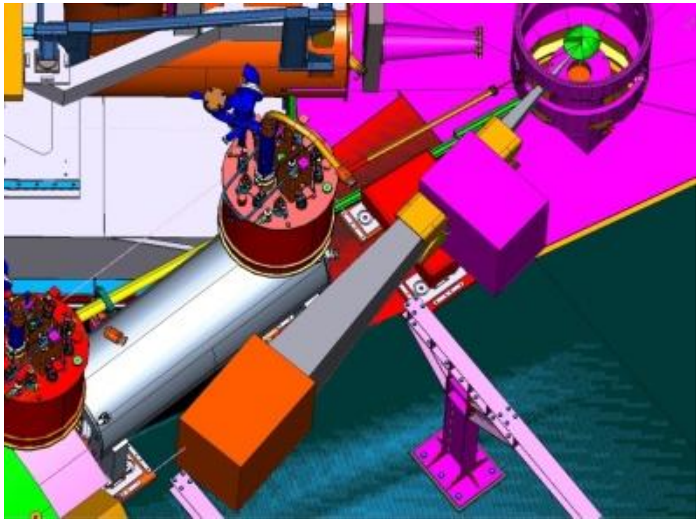
Final geometry of the calorimeter will be selected based on availability of the blocks and results of MC studies.

Radiation conditions in Hall C

The damage to crystals is a limiting factor for beam current !



Expected dose rate versus angle
(Based on P. Degtiarenko's simulations.)

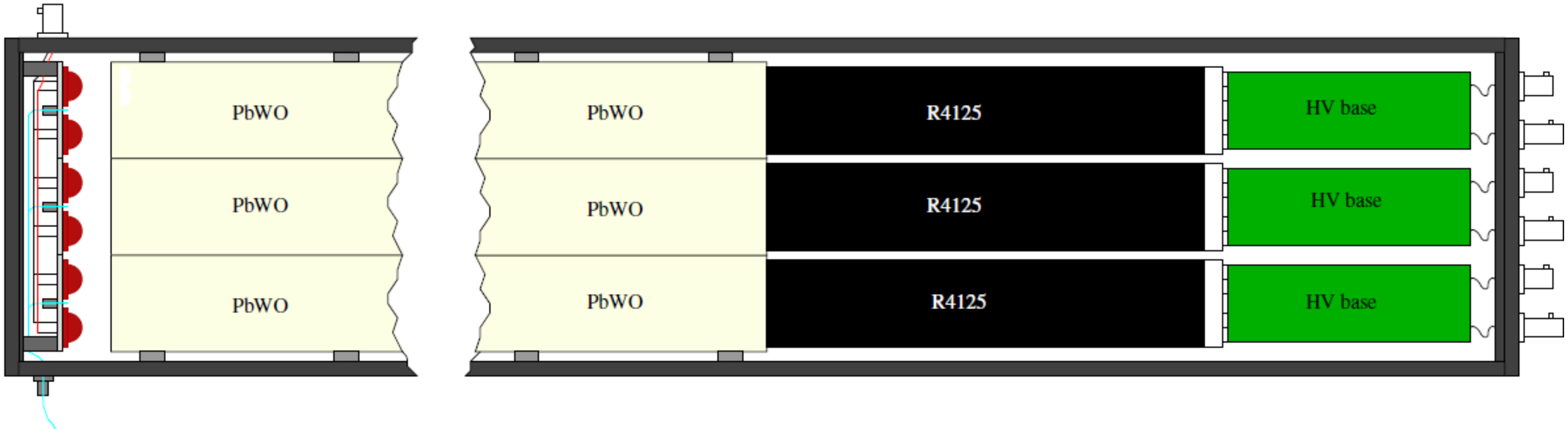


- **The radiation background is strongly angular (and energy) dependent.**
- **The magnet will sweep off most of the charged background below 300 MeV.**
- **Remaining low energy photon flux is capable to damage crystals (darkening, mostly in the first few cm).**

- **The detector will be operated in open geometry, prone to radiation damage.**
- **Curing of the crystals needed once per 2-3 weeks (after ~50 krad dose accumulation at rates <100-150 rad/h).**

NPS Calorimeter Prototype

Since many technical aspects of the calorimeter are new, and some are at the development stage, we are planning to build a prototype, in order to study all technical problems before finalizing the design of the NPS calorimeter.



- The prototype would be matrix of 3×3 $PbWO_4$ crystals, each 2.0×2.0×20.0 cm^3
- It will have Monitoring system based on Blue Light source (matrix of LEDs)
- For the curing of the crystals we are considering to build two separate systems:
  - traditional, based on a blue light source (λ~460 nm), and
  - new and currently at development stage, Infra-Red curing (λ>800 nm)
- Currently we are working on design of the prototype, and looking for the components of monitoring and curing systems.
- We also are working on the list of proposed tests, and equipments needed.

Publications in 2013

1) Bucking coil implementation on PMT for active canceling of magnetic field,
T Gogami et al., A. Mkrtchyan et al., Nucl. Instr. and Methods 729 (2013) p.816-824

2) First Determination of the Weak Charge of the Proton,
D Androic et al., A. Mkrtchyan et al., Phys. Rev. Lett. 111 (2013) 141803, 7 pages

3) Electro-production of light Lambda hypernuclei, S.N. Nakamura et al., A. Mkrtchyan et al., Procc, Few-Body-Problem, DOI:10.1007/s00601-013-0688-z, 2013, 8 pages

4) The Qweak experiment. A search for physics beyond the standard model via a measurement of the proton's weak charge. A.Androic et al., A. Mkrtchyan et al., Hyperfine Interact (2013) 214, p.21-30

5) Electroproduction of K+ Λ at JLab Hall-C, T. Gogami et al., A. Mkrtchyan et al., Proceed, Few-Body-Syst. 54 (2013) 1227-1230, DOI:10.1007/s00601-013-0670-9, 4 pages

6) The lead-glass electromagnetic calorimeters for the magnetic spectrometers in Hall C at Jefferson Lab, H. Mkrtchyan et al., A. Mkrtchyan et al., Nucl. Instr. And Methods, 719 (2013) 85-100

7) Observation of the ${}_{\Lambda}^{7}$He Hypernucleus by the $(e, e'K^{+})$ Reaction, S. N. Nakamura et al., A. Mkrtchyan et al., Phys. Rev. Lett, 110, 012502 (2013), 5 pages

8) A $PbWO_4$ based Neutral Particle Spectrometer in Hall C at 12 GeV JLab, A. Mkrtchyan et al., Bulletin APS 88 (2013)

9) A measurement od the weak charge of the proton through parity violating electron scattering using the Qweak apparatus, Rakitha S. Beminiwattha for Qweak Collaboration Int. Conf. Hadron Structure 2013, Nucl. Phys. B, (Procc. Suppl.) 345 (2013) pp.117-121

10) Early results from the Qweak experiment, D. Androic et al., arXiv:1311.6437 (2013)

11) Q-weak: First direct measurement of the weak charge of the proton, Nuruzzaman for the Qweak collaboration, Procc. Int. Conf., New Front. In Phys., Kolymbari, Crete, Greece, 28 Aug. – 5 Sept. 2013

Proposed activities in 2014-2016

- ✓ *Construction and test of the PbWO calorimeter prototype*
- ✓ *Development light monitoring and curing systems for the NPS calorimeter*
- ✓ *Cosmic tests of the SHMS Preshower*
- ✓ *Cosmic test of the Aerogel detectors*
- ✓ *Installation Preshower and Shower in SHMS spectrometer and cosmic tests*
- ✓ *Construction LED based curing system for the NPS PbWO calorimeter*
- ✓ *Assembling SP15 & SP11 trays for the SHMS aerogel detectors. Cosmic tests*
- ✓ *Participation in installation of the SHMS detectors and in commissioning*
- ✓ *Participation in Hall C commissioning experiments*