# Calorimetry detector R&D

**Outline**: ● Overview ● Sci-fiber ● Crystal ● Shashlyk ● HCal ● Sensor ● Simulation

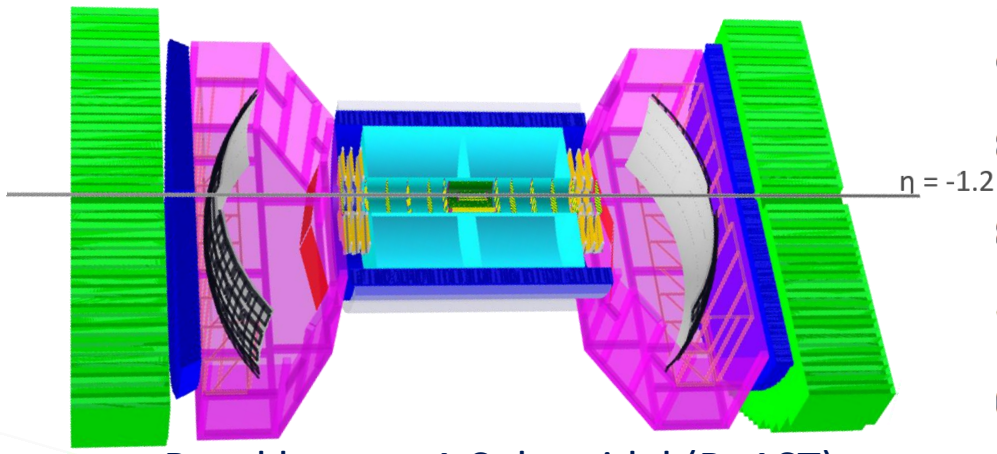
Jin Huang (Brookhaven National Lab)

for EIC detector eRD1 consortium

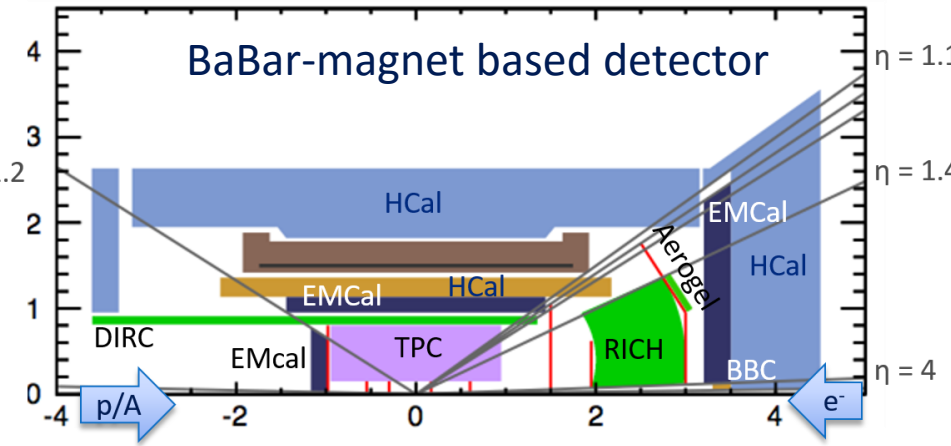
(BNL, Caltech, CUA, Jlab, Indiana U. UIUC, IPN Orsay,

PSU, TA&MU, UCLA, USTC, Yerevan Phys. Inst.)

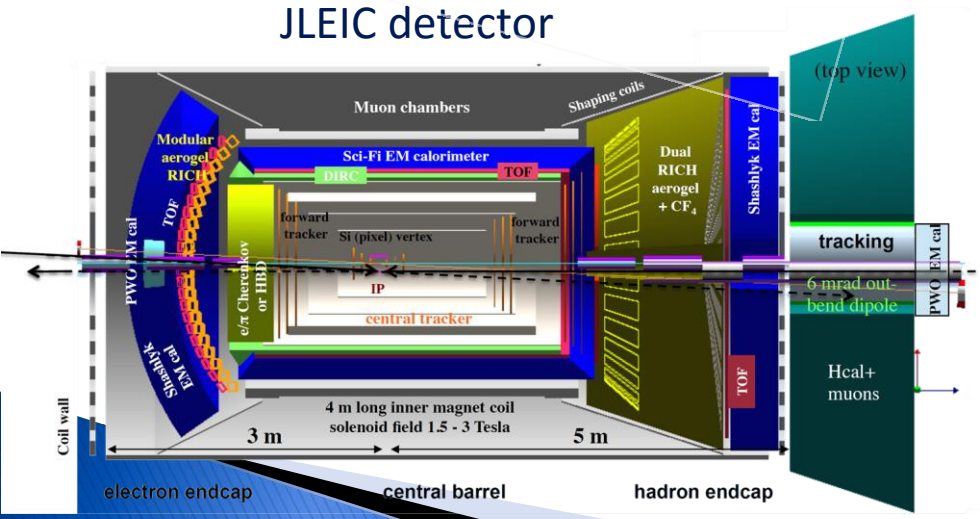
# Calorimeter in EIC detector concepts



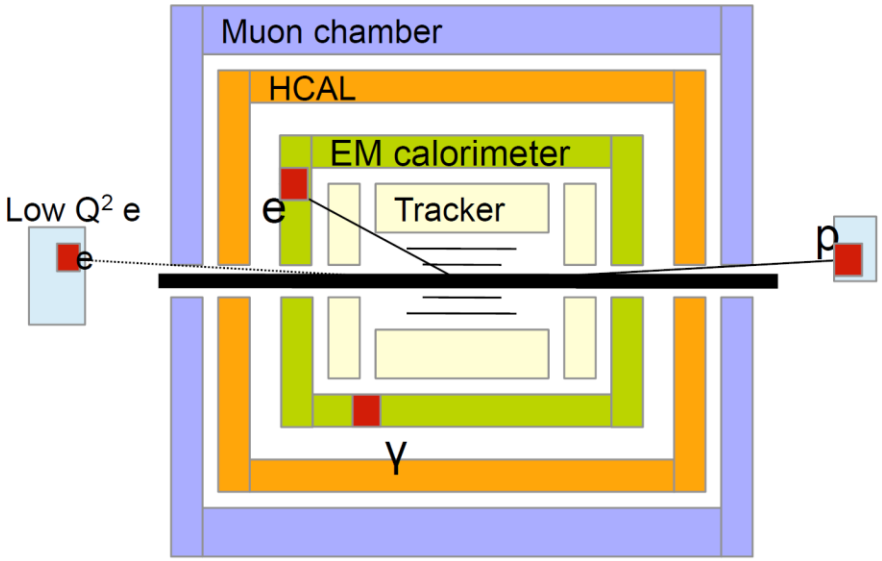

Brookhaven eA Solenoidal (BeAST)




JLEIC detector



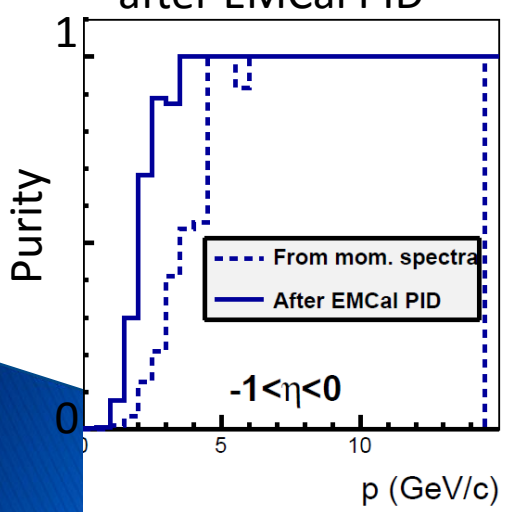

(JL)EIC 2nd detector



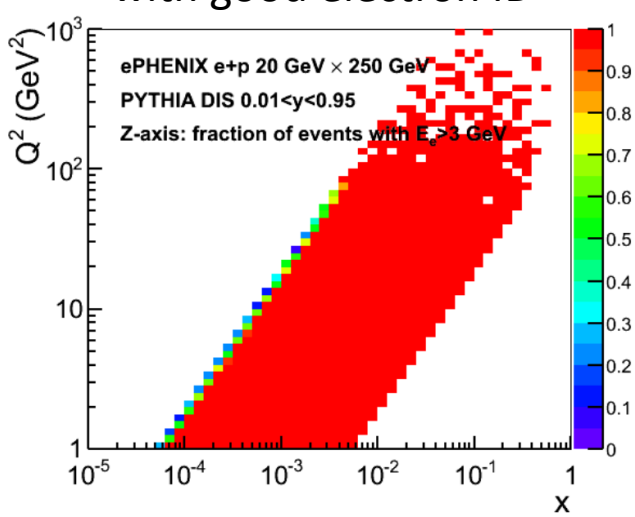
# Use of calorimeter for EIC measurements

- Electron identification and triggering (e-EMC, barrel EMC)
- Electron kinematics measurement (e-EMC, barrel EMC)
- Jet, DIS kinematics, and triggering via hadron final states (barrel EMC/HCal, h-EMC/HCal)
- Photon ID for DVCS (e-EMC, barrel EMC)
- Diffractive ID via rapidity gap (h-HCal)
- High momentum track energy measurement (h-HCal)

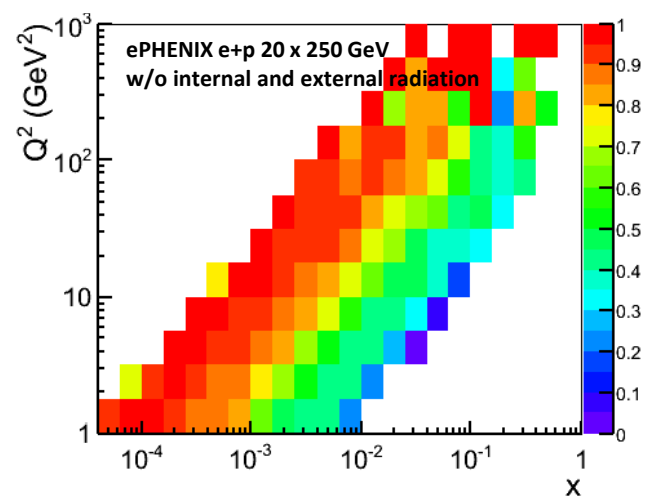
Electron purity after EMCal PID




Fraction of DIS event with good electron ID




DIS kinematics survivability Electron kinematic method



# On-going Calorimeter R&Ds

- Collaboration since 2012, funded by generic EIC det. R&D
- Sci-fiber EM calorimeter (SPACAL)
  - Compact W-scifi calorimeter, developed at UCLA
  - Investigating high resolution version for e-going endcap
  - Investigating large scale production and projectivity, driven by sPHENIX project
- Crystal EMCal
  - Option for high resolution e-going endcap calorimeter
- Shashlyk EMCal
  - Option for h-going endcap calorimeter
- HCal
  - Prototype development in collaboration with STAR forward upgrade and sPHENIX
- Sensor
  - SiPM and APDs, radiation studies and support electronics
- Simulation
  - Full detector simulation and analysis frameworks

# W-SciFi SPACAL

- Density - 10.17 g/cm$^3$, $X_0$ ~ 7 mm, $R_m$ ~ 2.3 cm
- Sampling fraction 2-3% (electrons), Resolution ~12%/√E
- Sc. Fibers -SCSF78 Ø 0.47 mm, Spacing 1 mm center-to-center
- Dimensions of single tower 2.5 x 2.5 x (12~16) cm
- Option for tapered module
  → Azimuthal projective for EIC barrel detector
- Solid object for ease of mechanical support

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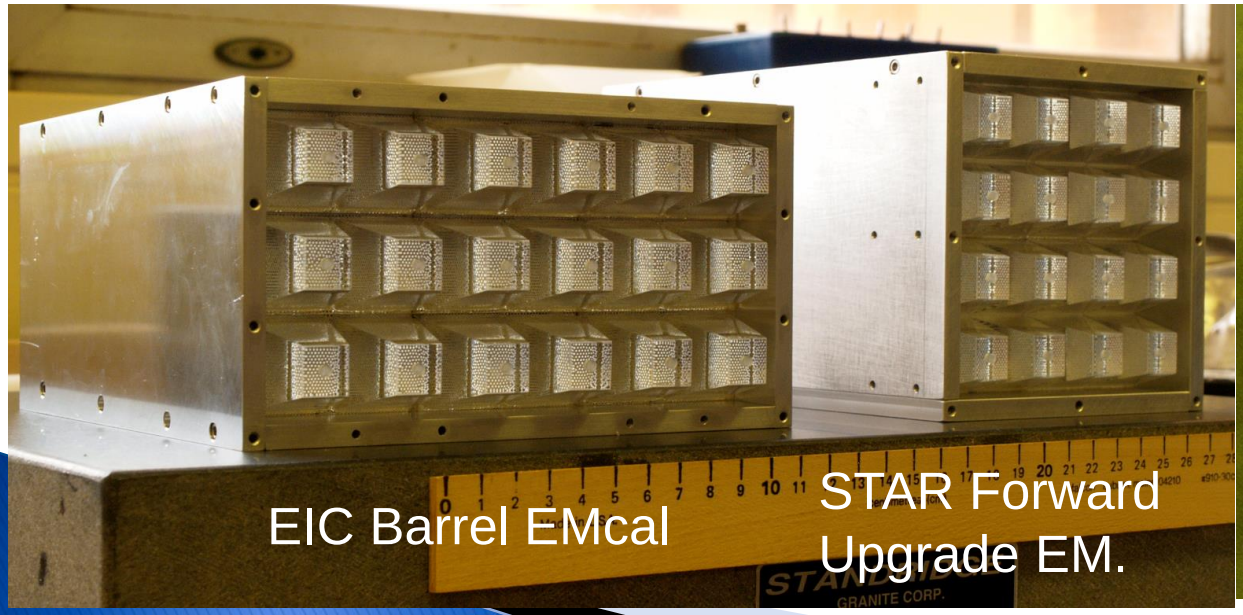
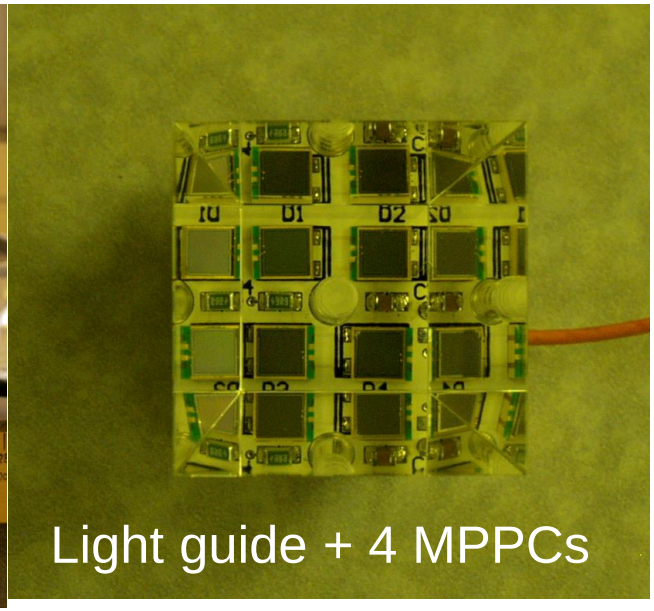
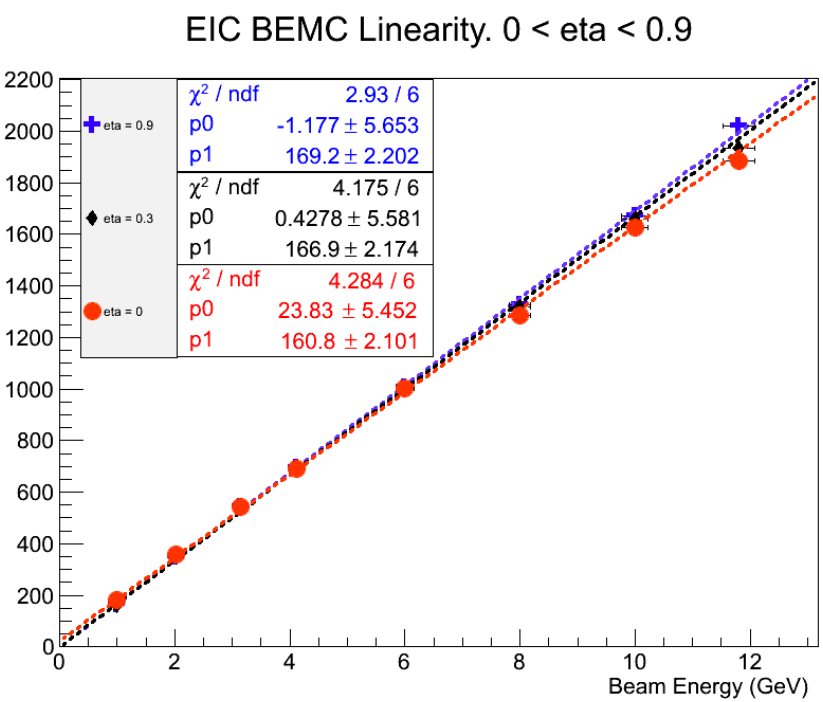
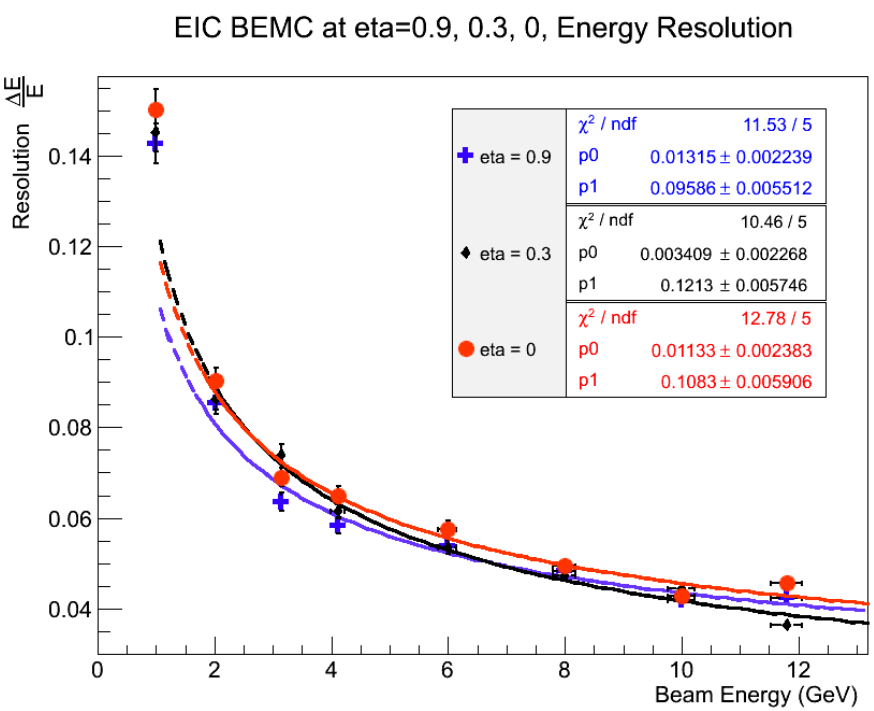


# SPACAL :
# Barrel 1-D projective SPACAL Performance

- Demonstrated performance in test beam: good linearity and dE/E ~ 12%/√E + few %

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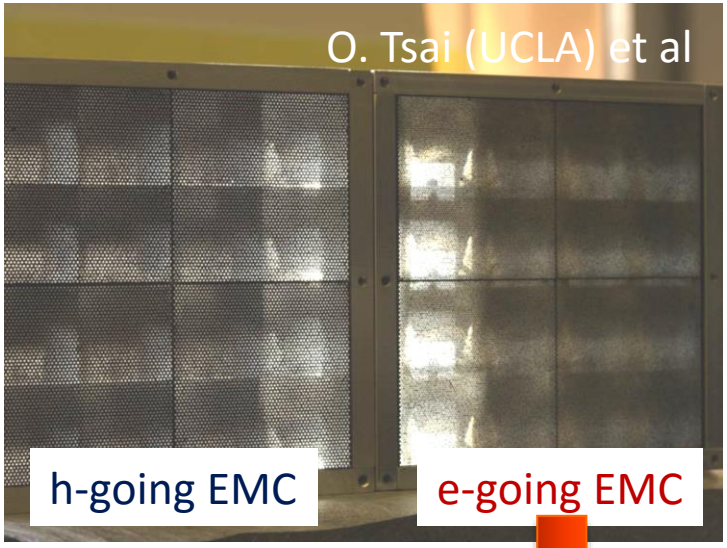
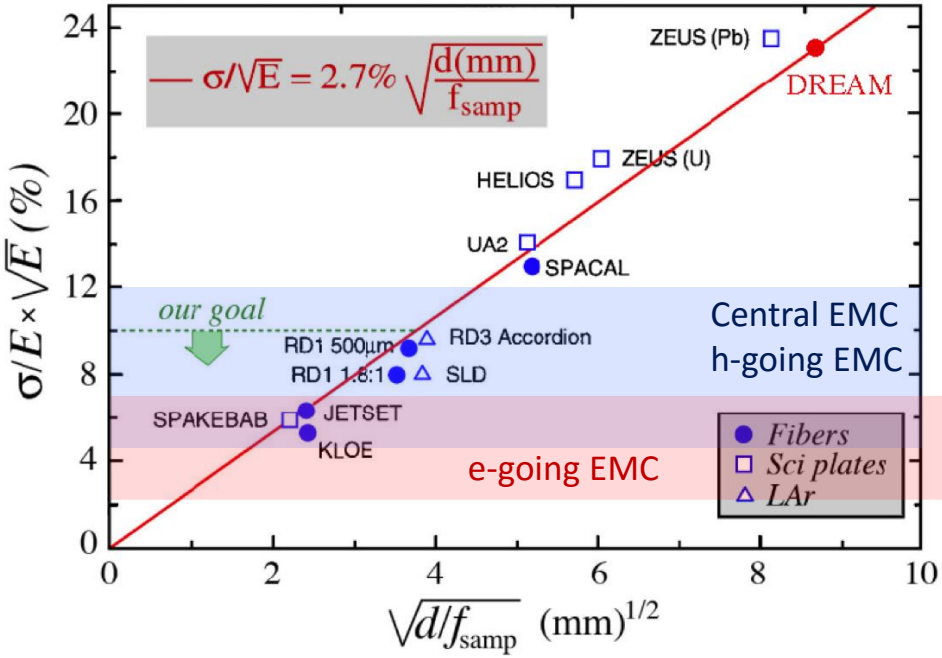
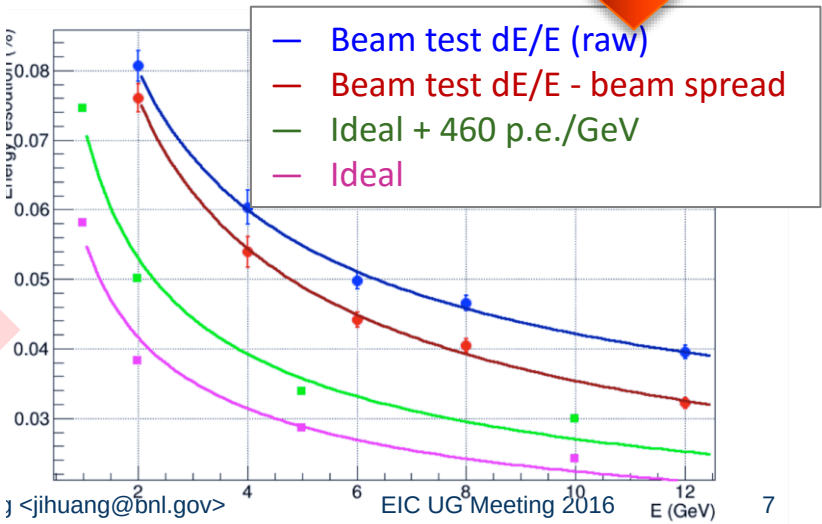
# SPACAL On-going R&D 1: Towards high energy resolution

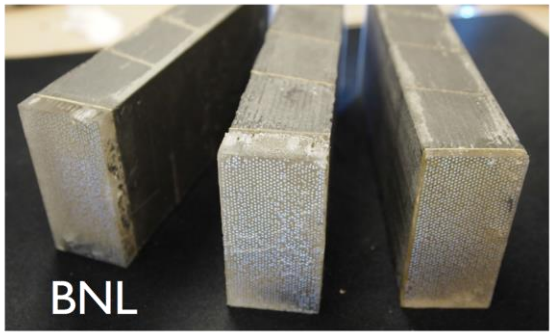
- For e-going endcap ECal, high resolution is preferred
- Via the SPACAL technology, higher resolution could be achieved with high sampling frequency and fraction
- UCLA tested W(75%)/Sb(25%) – SciFi SPACAL with d=0.67mm in 2015, although the light yield is low w.r.t. expectation. Investigation underway.
- Follow up study on high resolution SPACAL continues, including next test beam in May 2016

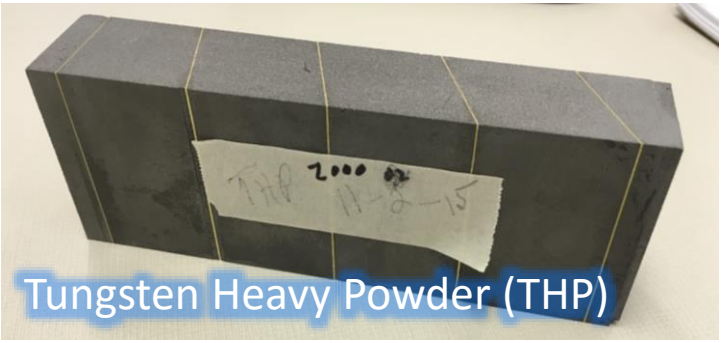


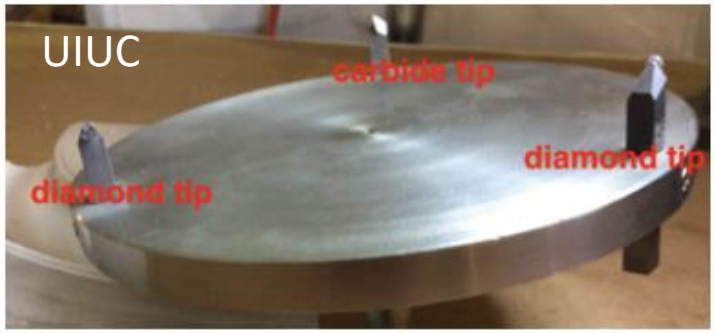



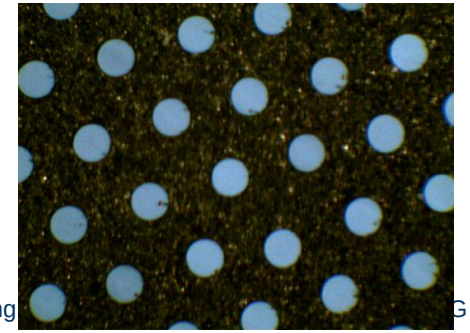
# SPACAL On-going R&D 2: Mass production





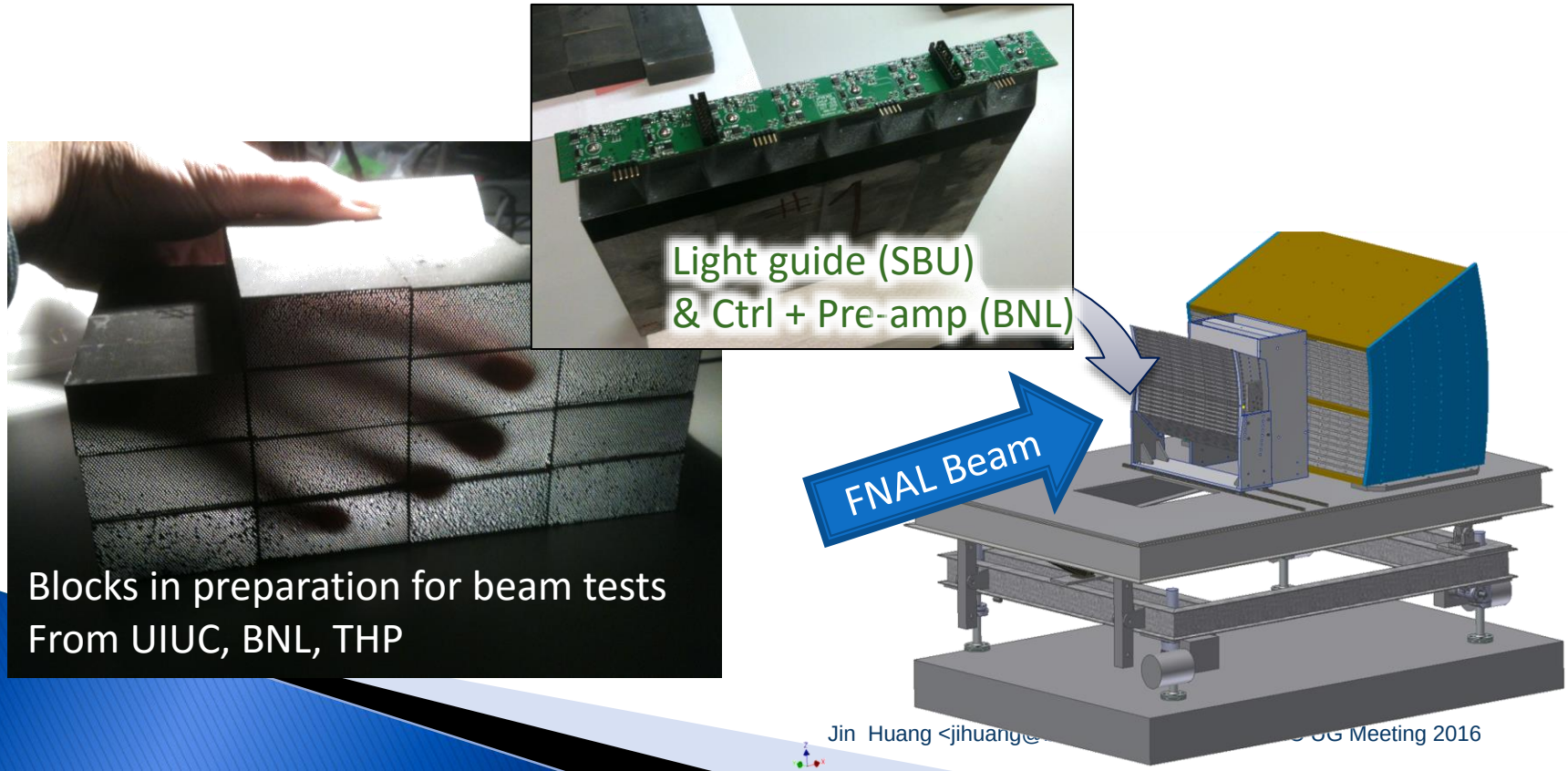

- Near-term mass production need from sPHENIX project
  - UIUC/BNL also exercise UCLA production technique
  - Tungsten Heavy Powder (THP) experiments filling of W/epoxy mix to fiber matrix + centrifuge, to produce high density w/ variation <1%
- UIUC also demonstrated technique of cutting W/scifi composite to produce the optical end



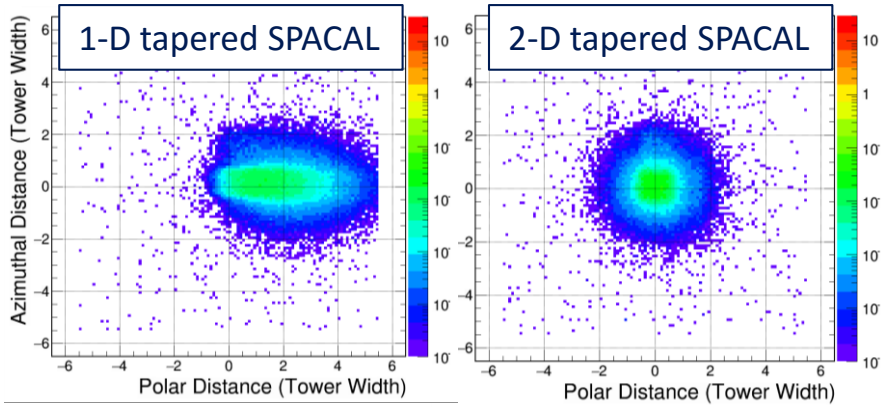
# SPACAL On-going R&D 2: Beam test of mass production prototype

- sPHENIX beam test Apr 2016: testing SPACAL blocks from new production technique towards mass production
- sPHENIX electronics (SiPM, pre-AMP, temp. stabilization, 14bits-65MHz digitizer)



# SPACAL On-going R&D 3: Towards full projectivity

8 GeV electron shower @ |η|~0.9
Distribution in units of tower ID



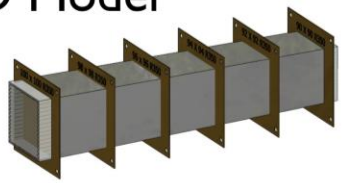

Considerations for full projectivity:

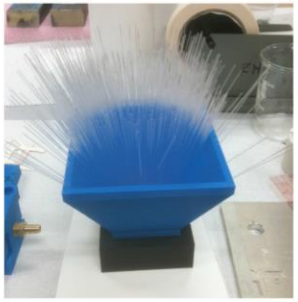
Pro: compact cluster, cluster separation pi0/DVCS, calibration

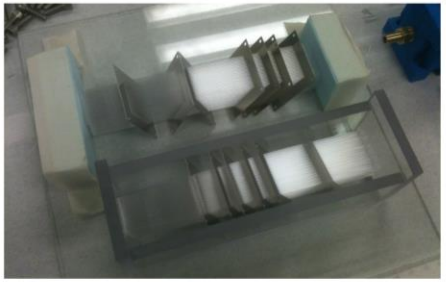
Con: minor higher constant term in dE/E (2.3%->2.9%), additional R&D

Fully projective SPACAL using 2-D tapered modules

3D Model

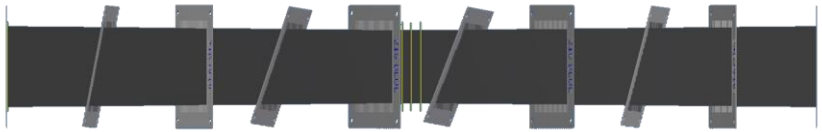






First 2-D tapered modules

Two 2-D tapered construction methods in development



# Crystal calorimeters

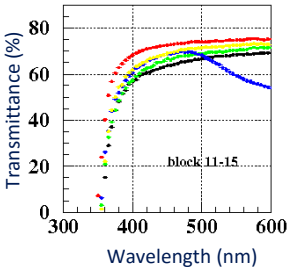
- One option for e-going detection would be high precision calorimetry (few%/√E) + fringe field tracking for e-track pointing.
- Crystal calorimeter desired for this role
- PWO crystal is one attractive option while reliable vendor needed
  - Shanghai Institute of Ceramics (SIC):
    - CMS vendor, continue as supplier of large (20cm) crystals
    - Positive progress in crystal quality from recent batch
  - Crytur (Czech Republic):
    - Potential supplier for PANDA, capable of producing 20cm crystal
    - 10cm crystal sample being tested at CUA
  - Bogorodisk Technical Chemical Plant (BTCP):
    - CMS vendor, currently out of business
  - North Crystals in Apatity, Russia:
    - ALICE vendor, currently out of business

# Crystal calorimeters: eRD1 focus

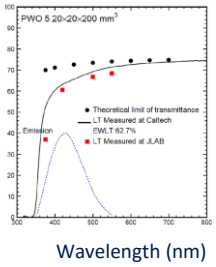
- Evaluation crystal quality of the two current PWO vendors (SIC/Crytur) for EIC use
- Evaluation of variation and possibly determining the origin
- Study options of EIC readout

SIC 20cm, Long. Trans.

JLab

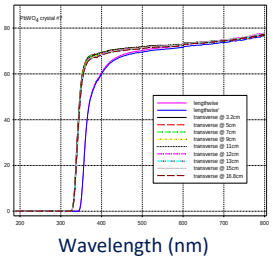



Caltech



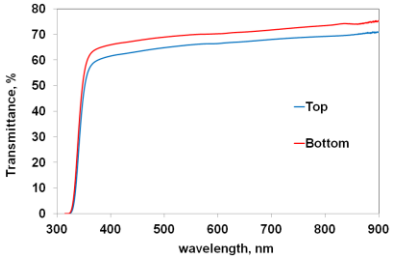

SIC 20cm, Lateral Trans.

BNL



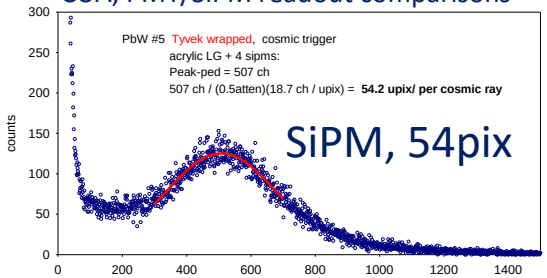

Crytur 20cm, Long. Trans.

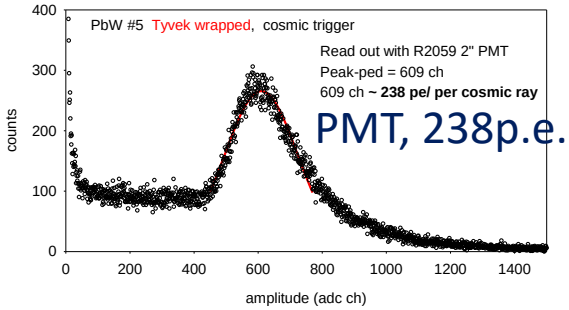
PANDA data, courtesy R. Novotny




Note: systematic difference in setup, implication in study

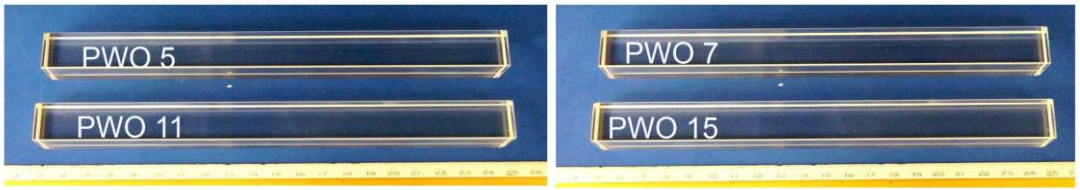
CUA, PMT/SiPM readout comparisons



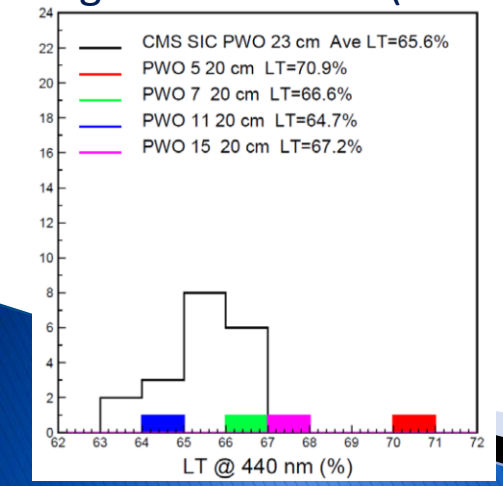
# Crystal calorimeters: recent results

- Both SIC and Crytur crystals promising to produce high quality crystals
- Recent delivered crystals from SIC for JLab/NPS project show concerns of crystal-to-crystal variation and batch-to-batch variation
- Continue study in quality control and search for source of variation

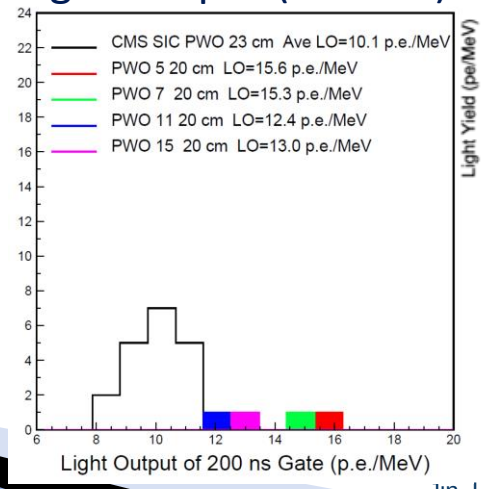



20x20x200 mm$^3$ SIC PWO crystals, produced for JLab NPS

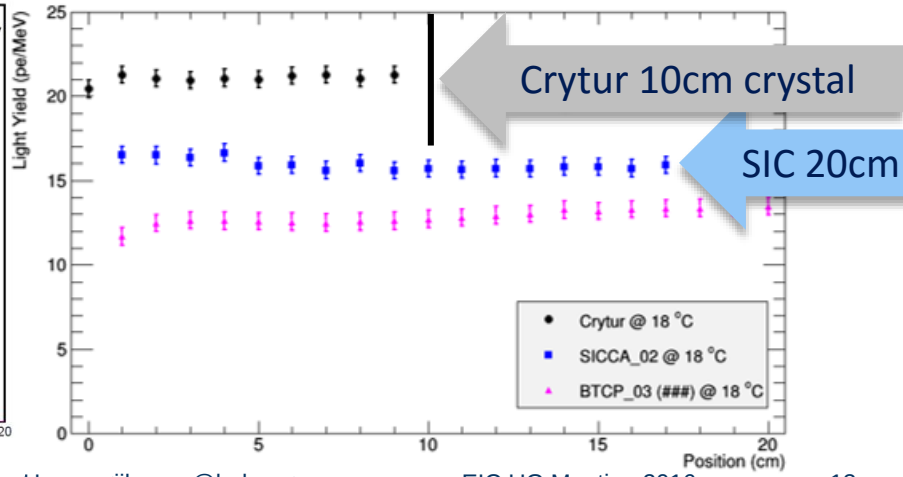
Long. Transmission (Caltech)




Light Output (Caltech)




Light Yield Uniformity (CUA)

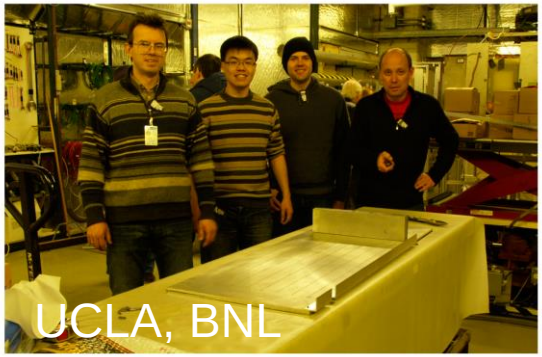


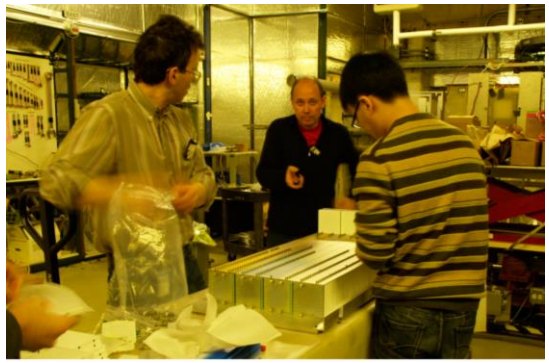
# Shashlyk Calorimeters

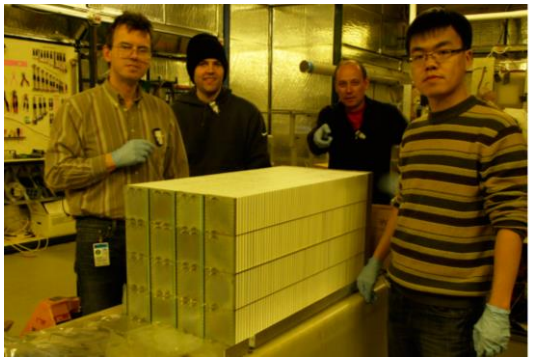
- Well used technology
- Tunable performance:
  - dE/E = (a few - 10%)/sqrt(E)
  - Molière radius of several cm
  - Fast in timing response (100ps)

- Recent examples:
  - PANDA: (0.3mm Pb + 1.5mm Scint.) x 378 layer, $\Delta E/E \sim 2.8\%/\sqrt{E} \oplus 1.3\%$
  - COMPASS: (0.8mm Pb + 1.5mm Scint.) × 109 layer, $\Delta E/E \sim 6.5\%/\sqrt{E} \oplus 1\%$
  - ALICE: (1.4mm Pb + 1.8mm Scint.) × 77 layer, $\Delta E/E \sim 10\%/\sqrt{E} \oplus 2\%$
- Considered as options for h-going ECal and outer rim of e-going ECal
- Interest to join research with JLab/SoLID collaborators

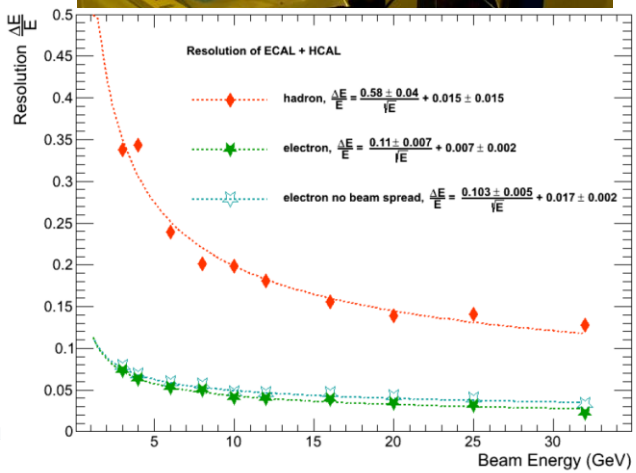
# Forward hadron calorimeter





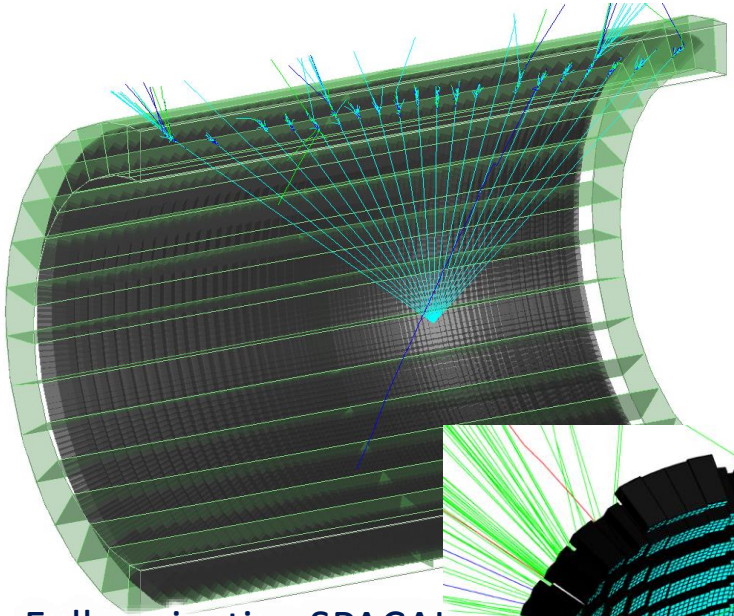
- A forward Hcal prototype was tested
  - ~4 interaction lengths Pb/scintillator tested in joint with STAR HCal prototype.
  - Readout: SiPMs attached to wavelength shifting plates which run the length of the detector
  - 16 individual towers,
    Total Volume 0.4 m x 0.4 m x 0.8 m
  - Beam test resolution (EMCal+HCal)
    $\Delta E/E \sim 60\%/\sqrt{E}$ for hadrons
- sPHENIX prototype serve as good example of barrel HCal



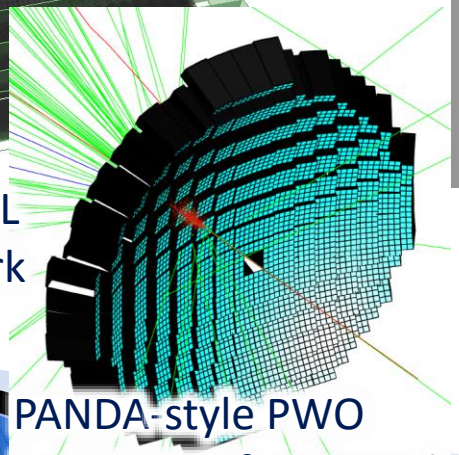
# Full detector simulation and analysis

eRD1 also plays major roles in maintaining two simulation&analysis framework, that is open source for full EIC detector sim

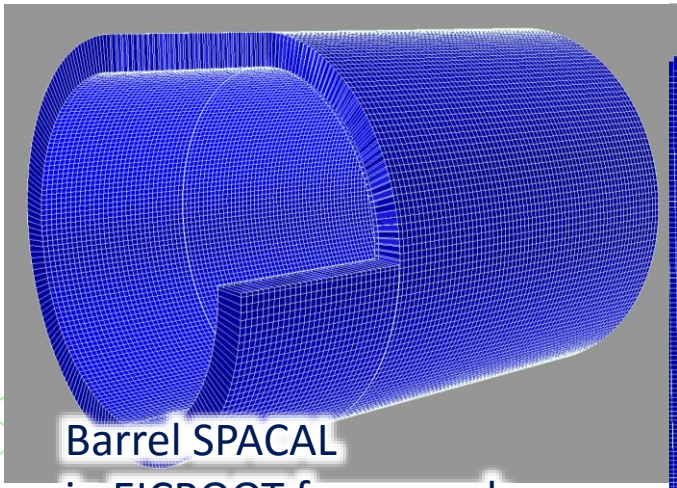
- EICRoot: https://wiki.bnl.gov/eic/index.php/Eicroot
- sPHENIX: https://github.com/EIC-Detector/coresoftware



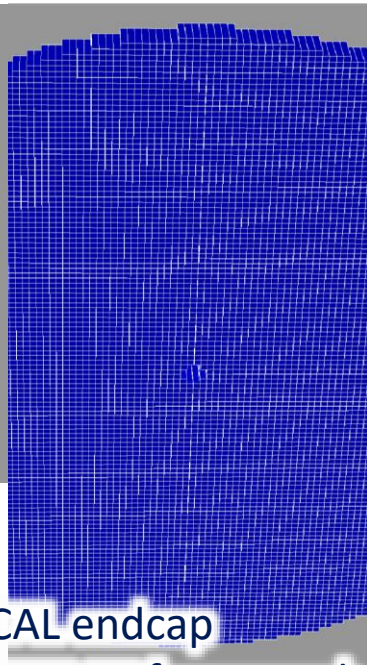
Full projective SPACAL
in sPHENIX framework



PANDA-style PWO
in sPHENIX framework



Barrel SPACAL
in EICROOT framework



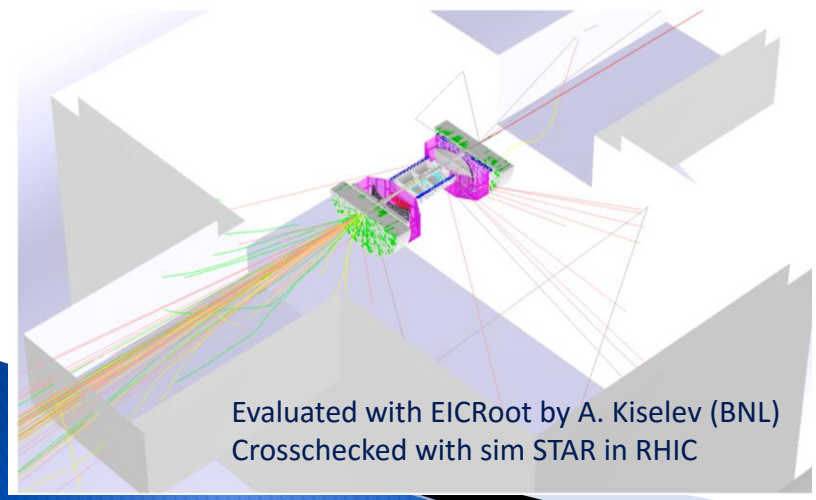
SPACAL endcap
in EICROOT framework

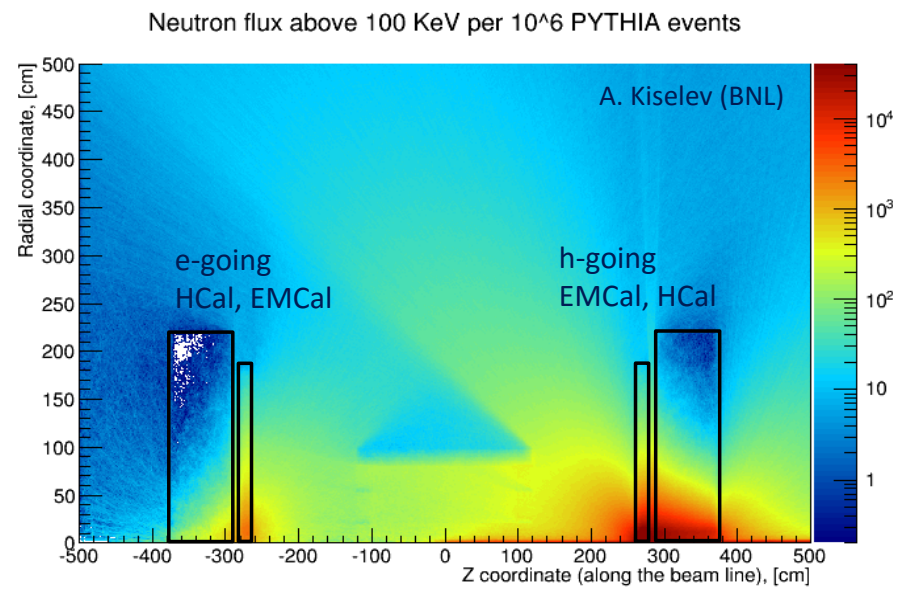
# Sensor development
# neutron radiation background ≤ RHIC

EIC neutron fluence (as BeAST in eRHIC) calibrated to STAR

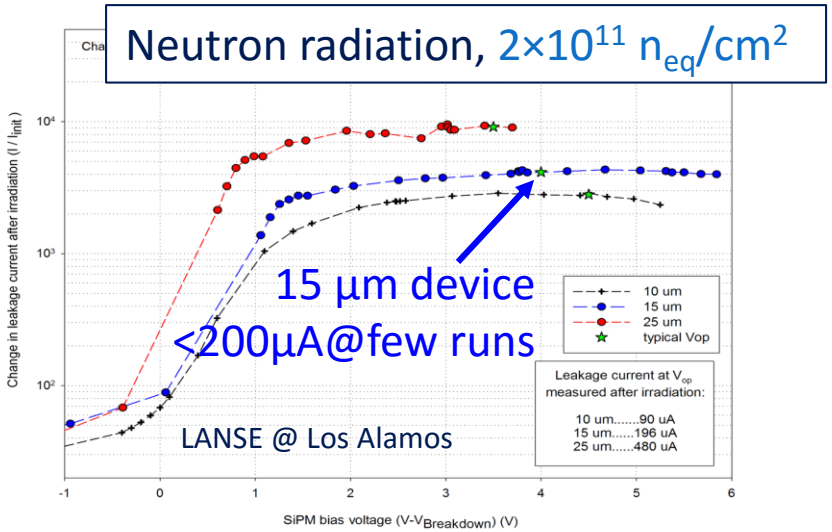
- Worst region in h-going calorimeter
  - 1 year EIC run ~ a few $10^{10}$ $n_{eq}/cm^2$ ~ 1 RHIC run
  - Challenging but possible for SiPM, also considering APD options
- e-going calorimeter and barrel calorimeter
  - ~ two order magnitude lower n-flux
  - Safe for SiPM operation

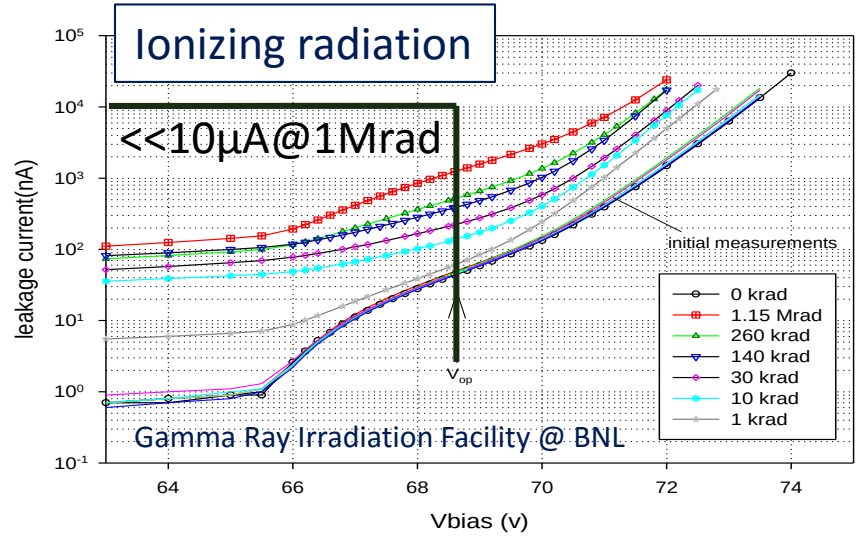
BeAST detector placed in STAR hall

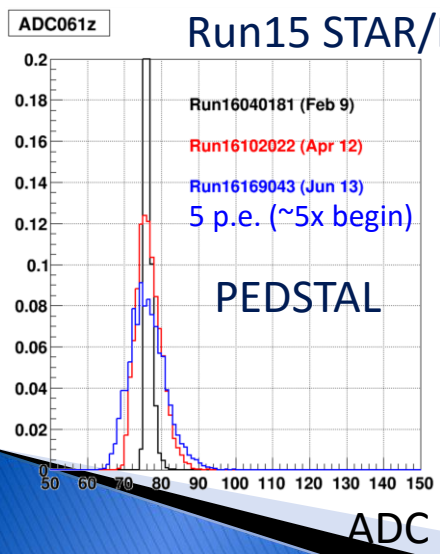


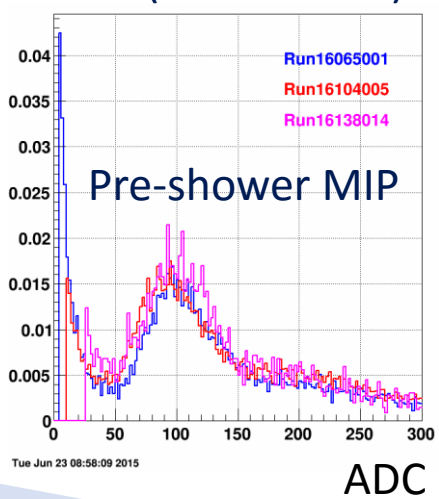



# Sensor development – SiPM



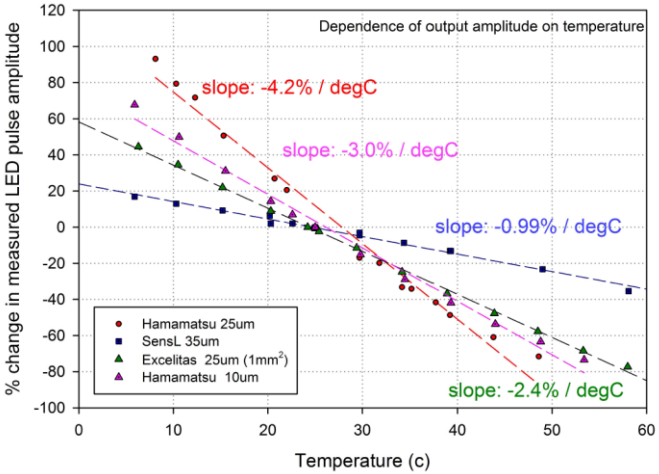



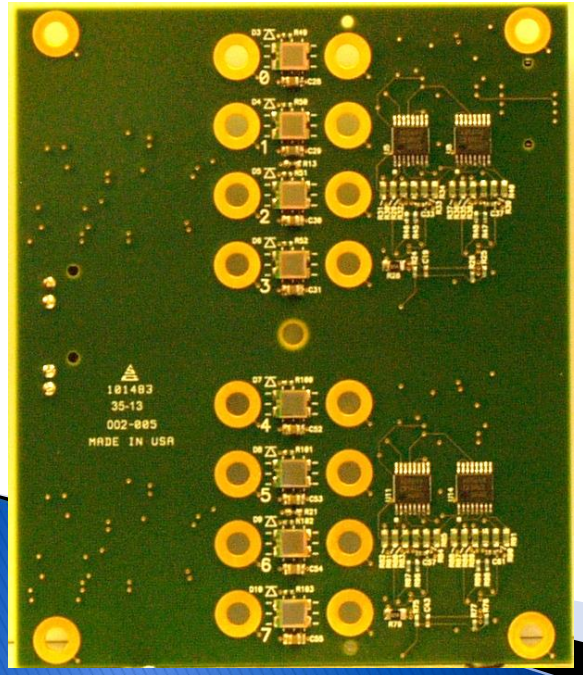

- Beam test of SiPM in neutron & ionizing radiations
- Run15 STAR/FPS data with SiPM
- Further test of electronics and SiPM in Run16 @ RHIC/STAR
- Options of APD also considered

# Sensor development – SiPM Control

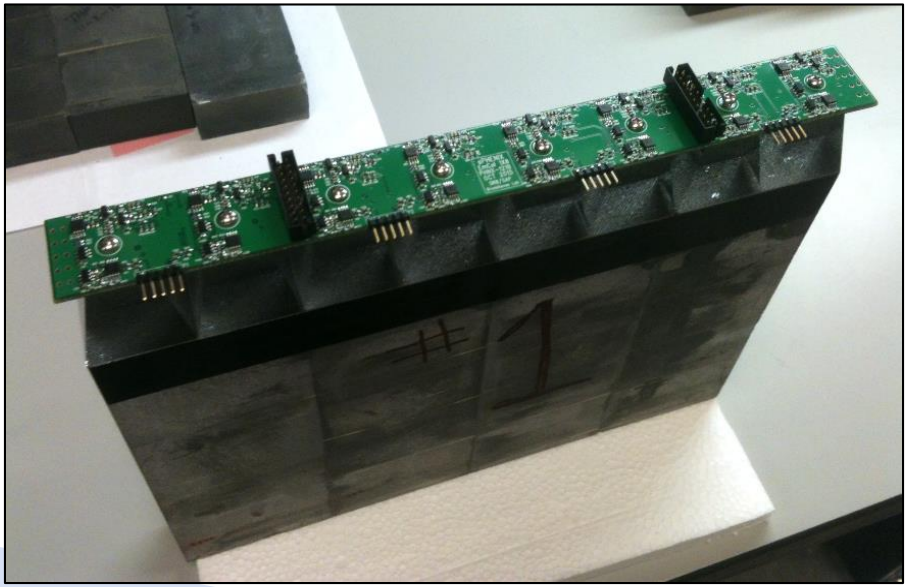
Pre-amplifiy, temperature regulator and slow control circuits for SiPM used/to be used in eRD1 tests




STAR, HCal upgrade prototype




sPHENIX, Barrel SPACAL prototype



# Summary

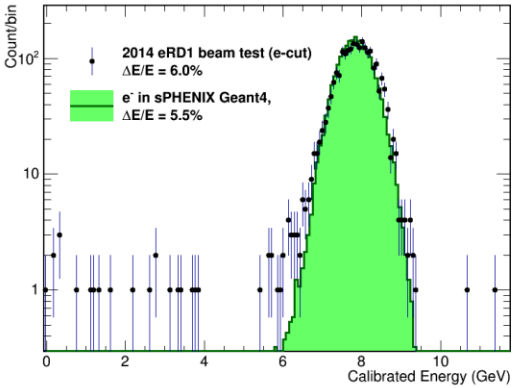
- eRD1 explores calorimeter technology for EIC in multiple fronts
- Scintillation fiber calorimeter
  - Developed by UCLA group for EIC barrel and endcaps. $\Delta E/E \sim 12\%/\sqrt{E}$ in beam tests
  - On-going R&D focus on higher energy resolution, mass-production capabilities and projectivities
- Positive development from PWO crystal from SIC/Crytur vendors, R&D focus on stability & sensor tests
- Forward and barrel HCal prototype tested
- SiPM radiation tests, neutron background ≤ RHIC
- Full detector simulation environment open to users

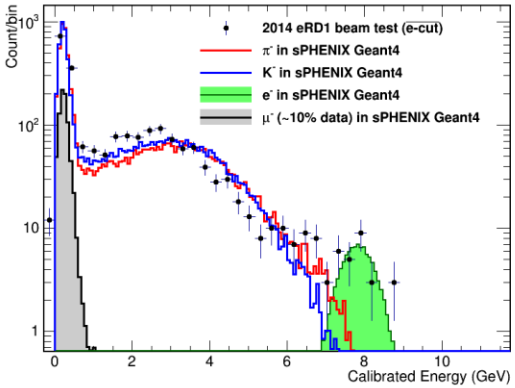
# Extra Information

# Example studies in sPHENIX framework

eRD1 test beam setup simulation

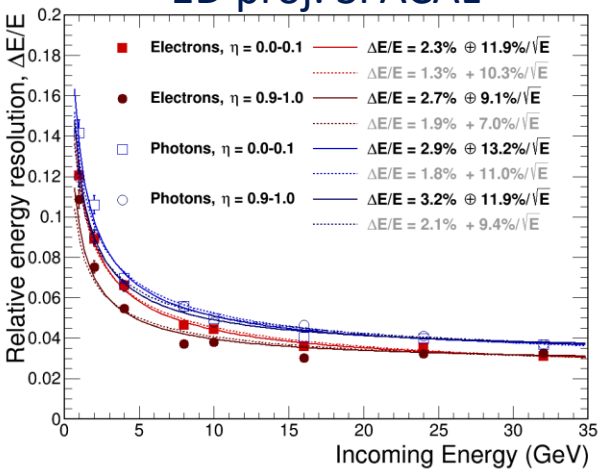
Validation with eRD1 2014 test beam



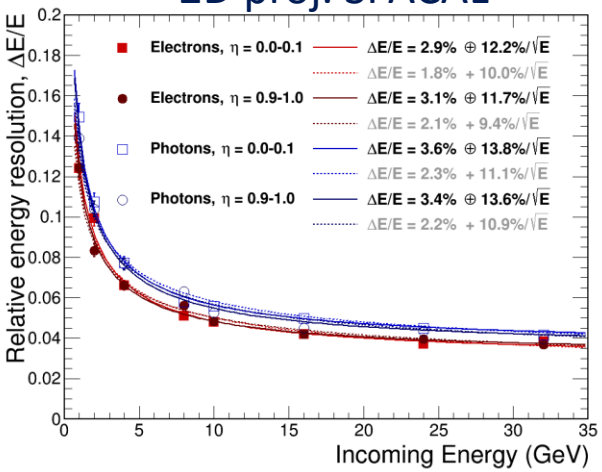
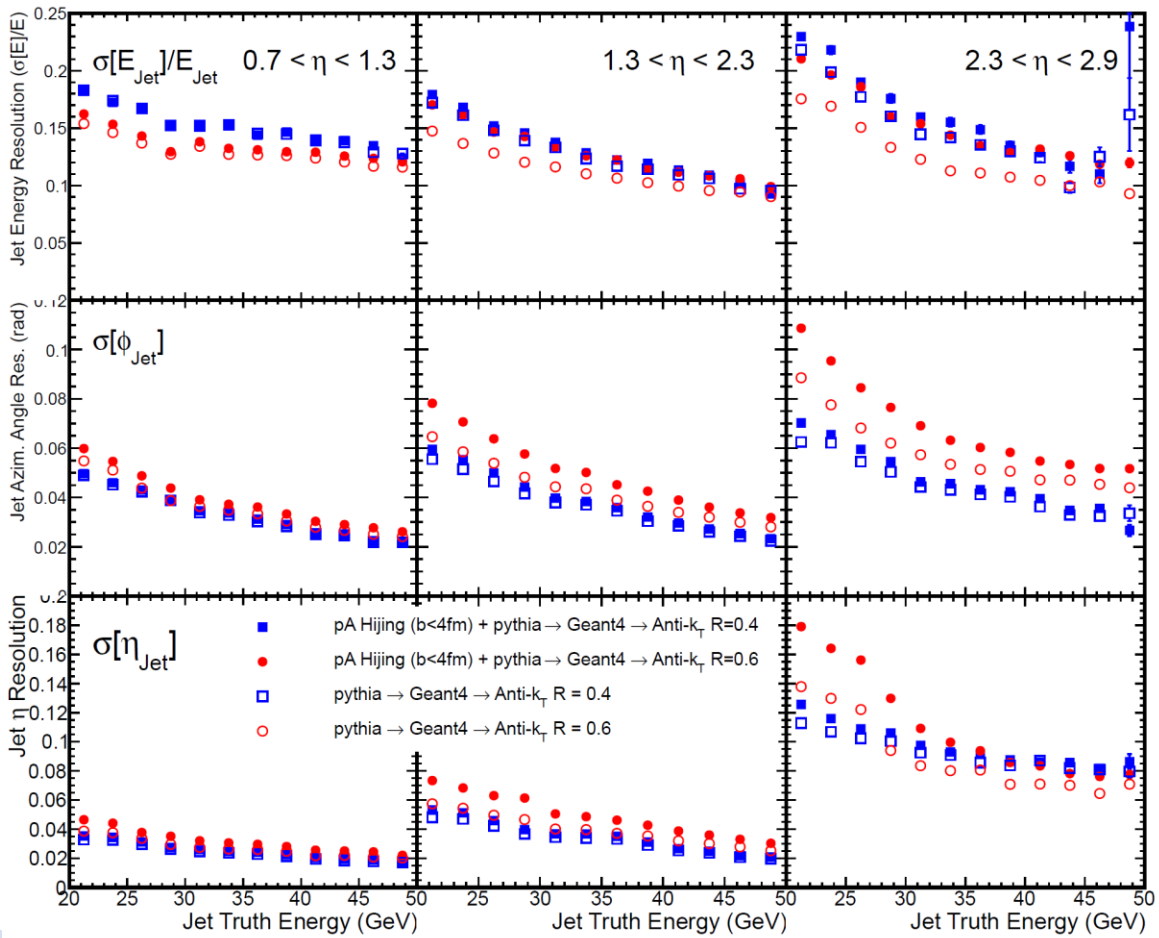




Resolution @ full detector simulation

1D proj. SPACAL




2D proj. SPACAL



# Jets resolution in sPHENIX + forward Hcals (z= 2.0m)