Results of R&D for sampling calorimeters for EIC.

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For EIC Calorimeter Collaboration.
(only small subset of R&D curried by Collaboration will be presented).
Conceptually, all of them look the same and similar to detector we are operating now, but details may be quite different... Similarity due to Physics and IR design and Cost considerations. Differences due to particular choice of technologies for a differently colored blocks in these conceptual designs.

**Calorimeters:**
- Full Coverage,
- Hermetic,
- Compact.
- Operate in the magnetic field.
- Good energy resolution.
- Good EM+HAD Performance.
- Fast.
- Affordable.
Motivation for W/ScFi R&D:
(Back in 2011)
Develop *simple, cost effective, flexible* techniques to build *compact* sampling calorimeters with *good characteristics*.

- **Simple** – to the level that a typical university group can build it without heavy investments in “infrastructure”.
- **Cost effective** – fraction of the cost of crystals.
- **Flexible** – tuneable for particular experimental requirements.

**Idea:**
Mix Tungsten Powder and Scintillating Fibers.

*Why SciFi type?*
Properties of ScFi Calorimeters - “Speed of response, compensation, linearity, good energy resolution for electromagnetic and hadronic showers, uniformity of response as a function of impact point and angle, hermeticity, ease of lateral segmentation, spatial resolution, low noise, and sensitivity to minimum ionizing particles”
Construction steps:

1. Put fibers in set of screens.
2. Spread meshes and put assemblies in container.
3. Epoxy both ends (photodetector and mirror end)
4. Fill container with W powder.
5. Replace air in detector with epoxy.
First SPACAL prototype. Year 1 R&D. FNAL 2012

Parameters:
Final Density - 10.17 g/cm$^3$,
$X_0 \sim 7$ mm, $R_m \sim 2.3$ cm,
$S_f = -2.4\%$ (electrons),
Sc. Fibers -SCSF78
  $\varnothing 0.47$ mm
Spacing 1 mm center-to-center.

Supermodule 2x2 towers.
Details:
Dimensions 16.6 $\times$ 5.33 $\times$5.33 cm$^3$
Weight of supermodules (4567, 4651, 4627, 4630 g.)
Number of fibers -3120

Resolution $\sim 12\%/\sqrt{E}$

Light yield 2000 p.e./GeV

RD1 Collaboration, EIC R&D
Proof of principle, Jan 2012
Test Run at FNAL T1018
EIC BEMC. Tapered towers (for inner radius of EMCal of 120 cm). 18 towers, each 18X0 deep. Dimensions of tower at the outer radius is 2.5 x 2.5 cm. Fibers SCSF78M, diameter 0.5 mm. Initial reflector at the front end of the fibers ESR glued with silicone.

STAR EMCal. 16 straight towers. 23X0 deep. Dimensions of single tower 2.5 x 2.5 cm. Fibers SCSF78, diameter 0.47 mm. Reflector at the back end of the fibers Bicron BS620.
• HCal is ~4 interaction lengths Pb/scintillator.
• Readout is from Hamamatsu S10931-025p 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
Assembling HCal Onsite. Feb 26, 2014. FNAL

After two hours first layer done.

After 8 hours they told me “next time let undergrads do that”.

Giessen, CALOR2014, April 10 2014
FCS response to hadrons. Preliminary Test Beam Results.

For completely compensated system one may expect that \( n=1 \) for
\[ E(\text{rec}) = n \cdot E(\text{em}) + E(\text{had}) \]

Below 10 GeV e/h deviates from 1 as was measured by ZEUS (decreases to 0.8 at 1 GeV)

To obtain best energy resolution in FCS we found that \( n \) should be energy dependent both in MC and test run data.

Optimal weighting factor and e/h for FCS.
FCS response to electrons. Preliminary Test Beam Results.

Initially had problems with ECal resolution due to non-uniformities in light collection in tower.

We measured the resolution with the detector diagonal to the beam to eliminate this effect, and later we could apply corrections during the data analysis to replicate these results with the detector face-on (impact points restricted to central part of towers, circle with diameter 14 mm).

No need to calibrate tower by tower with the beam.
Measured the resolution of the combined ECAL and HCAL system for beam energies between 3 GeV and 32 GeV. Fits show hadron resolution of 58% which is close to expectations from simulation.

Non linearity above ~16 GeV is probably due to method of weighting fraction of the energy deposited in the EM section in the total sum.
Uniformity of EMcal across the surface.

Each square is 4.8 mm x 4.8 mm, selected by Sc. hodoscope. Uniformity of SPACAL response is 1.4%. Test Run 2012. Light collection with 7" long light mixer.
Light collection scheme, EM prototypes.

(a) Non-uniformity.

- It was expected that we’ll need to iterate light collection scheme after the test run. But it was not clear how. It depends on absolute light yield.
- That was explained in our EIC R&D proposal (Dec. 2013). Funds for this iteration was requested and received from EIC R&D for FY2014.

Example of a scan with a single Sc. fiber across the face of the light guide with four SiPMs readout.

Difference between hottest and coldest spots is about 20%.

Now we know, that with the light yield of 400 p.e./ GeV for STAR EM prototype as was measured at FNAL we can create a simple mask which will be glued between fibers and light guide to make response flat.
Central EM Calorimeter (BEMC) for EIC.

- Young’s Modulus - $2 \times 10^{11}$ N/m$^2$
- Shear Modulus - $7.5 \times 10^{10}$ N/m$^2$
- Bulk Modulus - $2.4 \times 10^{11}$ N/m$^2$

Parameters close to construction steel.

- same tungsten powder + fibers technology as FEMC,
- towers are tapered, sampling fraction along the tower depth is not constant.
- non-projective geometry; radial distance from beam line [815 .. 980]mm

-> simulation does not show any noticeable difference in energy resolution between straight and tapered tower calorimeters

Giessen, CALOR2014, April 10 2014
18 Tapered towers for inner radius ~ 120 cm.

• Tower by tower calibration with the beam not required.

• Limited size of the prototype, and light collection non-uniformities required to limit impact points on Y within +- 5 mm.

• Small dependence of response vs. incident angle.

• Light yield measured for different configurations of light collection scheme: 430, 530 and 600 p.e./GeV
EIC BEMC, prototype performance at FNAL. Preliminary Results.

ESR glued with silicone.

BC-620, painted at FNAL.

About the same energy resolution for 430 p.e./GeV and 530 p.e./GeV. In both cases at shallow impact angles it becomes better.
Another intensive and productive test run at FNAL. Calorimeter systems performed near our expectations, and we have plenty of ideas how to improve for future iterations.

Tested three different calorimeter prototypes in six configurations and analyzed most of the data on-line.

(Tested two different EM calorimeter prototypes in 2012)

Average age of the team is probably smaller than that in Giessen 😊
We are almost there...

- One more iteration for light collection.
- Quite likely will push technology to build high resolution EM Cal. (at least two iterations)
- Number of different options is shrinking
- Collaboration is growing

Technology which was developed as a generic detector R&D three years ago now is applied for two concrete detectors.

And hopefully we will use it for a dedicated EIC detector in near future.

Thank you!
Backup
Setup on the beamline

STAR EMCal

EIC EMCal

MPPC Readout

Beam

Beam

Beam

STAR EM Diagonal