Overview of the EMCAL System

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Overview of the EMCAL Design

EMCAL Design Specs:

- Coverage: $\pm 1.1$ in $\eta$, $2\pi$ in $\phi$
- Segmentation: $\Delta \eta \times \Delta \phi \approx 0.025 \times 0.025$
- Readout channels: $96 \times 256 = 24576$ (towers)
- Energy Resolution: $\sigma_E/E < 16\%/\sqrt{E} \oplus 5\%$
- Provide an e/h separation $> 100:1$
- Approximately projective
- Compact (in order to fit inside Babar solenoid)
- Works inside a 1.4T magnetic field

Contributions to sPHENIX physics measurements:

- Jet measurements
- Photon measurements
- $\Upsilon$ measurements
Jet measurements
- Measure the EM component of the jet energy along with HCAL
- Requirements on energy resolution and segmentation are determined mainly by the underlying event

For a 5 GeV electron from $\Upsilon$ decay
$15%/\sqrt{E} \Rightarrow \sim 335$ MeV

$\Upsilon$ measurements

$\gamma$-jet and direct photon measurements
- True jets begin to dominate fake jets for $p_T > 20$ GeV/c
- Provide electron id ($e:h > 100:1$)
- Tag and measure photons for $p_T > 20$ GeV
EMCAL Subsystem

Electromagnetic calorimeter covering $\pm 1.1$ in $\eta$ and $2\pi$ in $\phi$

$2(\pm \eta) \times 32(\phi) = 64$ Sectors

~14 cm absorber ($\eta=0$)

7.5 cm readout

26 cm total radial space

Designed to be compact to fit inside the BaBar magnet

1 Sector = 96 Blocks
= 384 towers

96 modules
2x2 towers each

Approximately projective back to vertex in $\eta$ and $\phi$
Tilted Block Configuration

- Sectors consist of 96 blocks each of which consist of 2x2 projective towers
- The blocks are tilted in both \( \eta \) and \( \phi \) in order to avoid channeling of particles along projective lines

- Blocks are tilted in \( \eta \)
- Sectors are tilted in \( \phi \)

\[ \phi \text{ tilt } = 9.1^\circ \]
\[ \eta \text{ tilt } = 9.4^\circ \]
Sawtooth support structure for blocks

First three $\phi$ slices are 1D projective

Remainning $\phi$ slices are 2D projective

Electronics, cables and cooling
EMCAL Absorber Blocks

Design driver: Must be compact to fit inside Babar magnet & minimize cost of HCAL ⇒ **W/SciFi SPACAL**

**Absorber**
- Matrix of tungsten powder and epoxy with embedded scintillating fibers
- Density ~ 9-10 g/cm³
- $X_0 \sim 7$ mm ($18 \times X_0$ total), $R_M \sim 2.3$ cm

**Scintillating fibers**
- Diameter: 0.47 mm, Spacing: 1 mm
- Sampling Fraction ~ 2%

- Modules are formed by pouring tungsten powder into a mold containing an array of scintillating fibers and infusing with epoxy
- Fibers are held in position with metal meshes spaced along the module
Fabrication of Absorber Blocks

2D Projective Block with Screens

Fiber Assembly

Fibers are tapered inward at readout end to improve light collection

Mold for casting blocks

Finished 2D projective block
The University of Illinois at Urbana Champaign will produce all absorber blocks for the calorimeter covering $\eta < 0.85$.
Production of Absorber Blocks in China

Fudan University and Peking University are planning to produce all the absorber blocks for large rapidity (0.85 < \(\eta\) < 1.1)

One of the first 2D projective absorber block produced at Fudan University

1st Sample
Blocks are read out in individual towers using optical light guides and SiPMs.

Light guide focuses light onto four 3x3 mm² SiPMs.

Important factors affecting the energy resolution are light collection efficiency and uniformity:

- Area matching between tower readout area and 4 SiPMs is only 6.4%.
- Short light guide is a poor mixer.
- Photostatistics gives ~500 p.e./GeV.

\[ \Rightarrow \sim 4.5\%/\text{VE} \text{ contribution to energy resolution} \]
\[ \Rightarrow 0.5 \text{ pixels}/\text{MeV (each SiPM has 40K pixels)} \]
Prototyping and Testing

The EMCAL design has undergone 3 stages of prototyping and testing in the test beam at Fermilab.

1D Projective ($\eta \sim 0$) 2016

Large $\eta$ prototype with Inner and Outer HCAL prototypes in 2017

2D Projective ($\eta \sim 0.9$) 2017 & 2018

4x4 array of 2x2 towers blocks

The V2.1 prototype was constructed as part of an actual sector in terms of mechanics, electronics and cooling and was tested at Fermilab in 2018.
Test Beam Results

Position scan and energy resolution for the V2.1 prototype measured in the test beam at Fermilab in spring of 2018

Strong position dependence due to block boundaries and light guide boundaries

Average energy resolution including block and tower boundaries

13.3%/$\sqrt{E}$ $\oplus$ 3.5%

Energy resolution measured over two different regions of the calorimeter including block and light guide boundaries
• First pre-production prototype of a complete sector (Sector 0) is currently under construction. This sector is not intended to be used in the final detector, but will allow us to finalize the overall block and sector design.

• Block production is under way at UIUC and should be completed by the early April.

• Assembly of the blocks into the mechanical structure for the sector has begun at BNL.
Blocks are delivered to BNL where end reflectors, light guides and SiPMs are installed.

SiPMs are tested on their daughter boards.

Blocks with their SiPM daughter boards are mounted for a test fit on their sawtooth support structure.
Additional Pre-Production Sectors

• After the completion of Sector 0, any subsequent design changes will be implemented for the final blocks and sectors.

• We then plan to build 12 complete additional preproduction sectors (Sectors 1-12). These will be built to cover the full rapidity range to $\eta=1.1$. It is envisioned that these sectors will be used in the final detector.

• Fibers for these and all remaining sectors have been ordered. All screens have also been ordered and most have already been delivered to UIUC.

• Powder for Sectors 1-3 is at UIUC and the powder for Sectors 4-12 and the first half of the remaining production sectors is planned to be ordered this spring.
# sPHENIX Schedule

**Preliminary (as of 3/23/19)**

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**Legend**

- **Actual**
- **Completed**
- **Planned**
- **Today**
- **Level 1 Milestone**
- **Schedule Contingency**

C.Woody, EMCAL Overview, sPHENIX Asia Meeting, March 26, 2019
Current Status and Summary

• The engineering design for the EMCAL is in a very mature state. Full 3D models exist for all major components.

• We have gone through numerous design reviews and prototype testing and the final design is essentially complete.

• Construction of the first pre-production sectors is under way.

• We are now preparing for the PD-2/3 OPA review that will take place on May 29-31, 2019 at BNL.

• Approval of PD-2/3 will allow us to begin construction of the all the remaining sectors for the calorimeter.
Projectivity in 2 dimensions is required to minimize the transverse size of the showers at large rapidity.

Energy from the underlying event is a large background in central heavy ion collisions and having a small transverse shower size helps to reduce this.

Improves energy resolution and e/h separation.
Electron Hadron Separation

Transverse energy distribution of 4 GeV electrons and pions

Pion rejection vs electron id probability

Central Au+Au Hijing

C.Woody, EMCAL Overview, sPHENIX Asia Meeting, March 26, 2019
Energy resolution for single electrons and photons embedded in Central Hijing events

J. Osborn (UMich)
EMCAL Schedule (as of Feb 2019)

- Start module production and sector assembly for Sectors 1-12 in September 2019 and complete by June 2020.
- All EMCAL sectors ready to install by Oct 2021
Descoping of the EMCAL

In order to stay within the $32M spending cap, it was necessary to reduce the EMCAL acceptance from $|\eta|=1.1$ to $|\eta|\sim 0.85$ in the MIE.

**Impact on EMCAL**

- We needed to save $\sim$ $1$M from the total cost of the EMCAL (not including electronics).
- The main savings would have come from purchasing less materials for fabricating the blocks (W powder, fibers) + labor. However, many of the fixed costs would remain the same.

Note: A geometrical cut from $|\eta|=1.1$ to $|\eta|=0.85$ implies a fiducial cut from $|\eta|\sim 1.0$ to $|\eta|\sim 0.75$ for jet physics.

Jet acceptance - $\sim 25\%$ loss in statistics.

$\Upsilon \rightarrow e^+e^-$ acceptance - $\sim 35\%$ loss in statistics.

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Descoped Sectors

Descoping plan eliminates blocks 19-24 at large rapidity

Once final production begins, it would be essentially impossible to add the missing blocks after assembly of the sectors.

Producing the large rapidity blocks in China will allow us to restore the full acceptance of sPHENIX and carry out our originally proposed physics program with much greater sensitivity and improved measurement quality.