sPHENIX Director's Review

EMCAL Subsystem

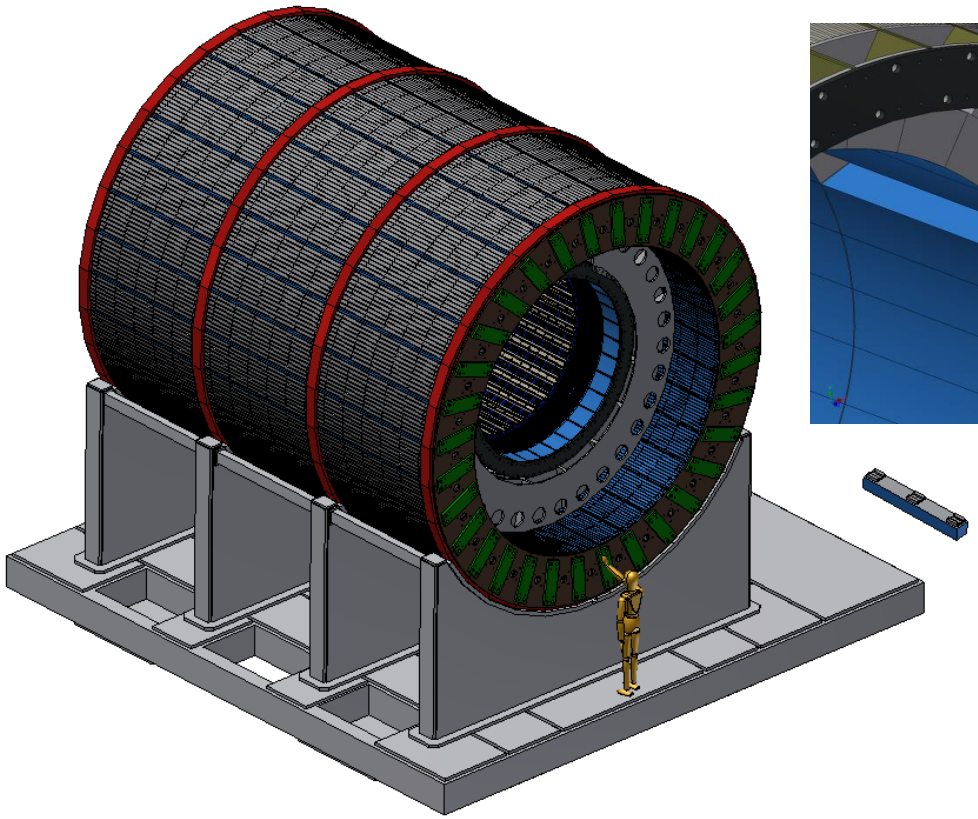
Craig Woody

BNL

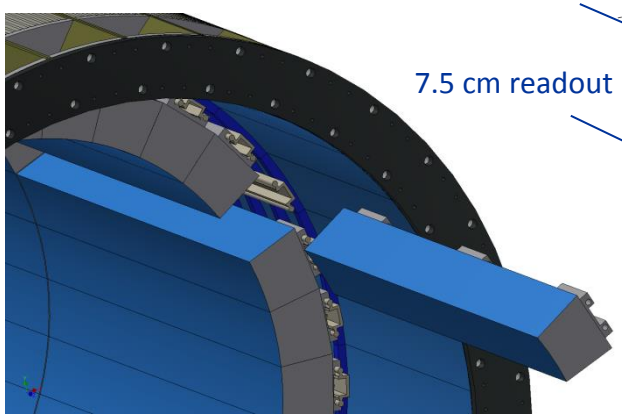
August 2-4, 2017

EMCAL Subsystem

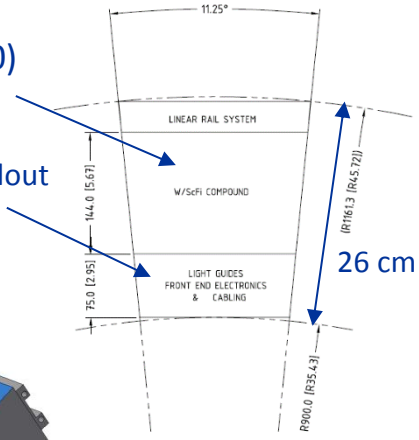
2(±η) x 32 (ϕ) = 64 Sectors



~14 cm absorber (η=0)



7.5 cm readout



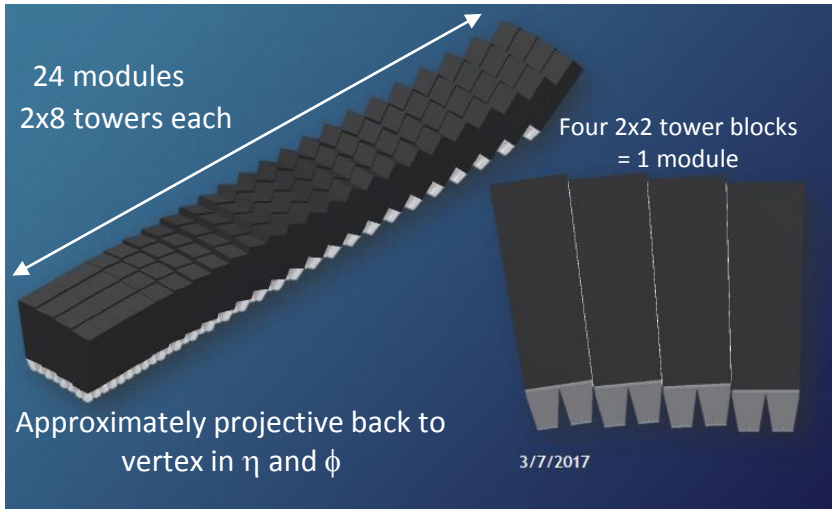
26 cm

26 cm total radial space

Designed to be compact to fit inside the BaBar magnet

1 Sector = 24 modules
= 96 Blocks
= 384 towers

EMCAL Sector



Design Specifications

EMCAL Design Specs:

- Coverage: $\pm$ 1.1 in η, 2π in ϕ
- Segmentation: $\Delta\eta$ x $\Delta\phi \approx 0.025$ x 0.025
- Readout channels: 96x256 = 24576 (towers)
- Energy Resolution: $\sigma_E/E < 15\%/\sqrt{E}$
- Provide an e/h separation > 100:1
- Approximately projective
- Compact (in order to fit inside Babar solenoid)
- Works inside a 1.5T magnetic field

Physics Contributions:

- Jet measurements (EM component)
- Photon measurements
- Y measurement

EMCAL Design

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

Absorber

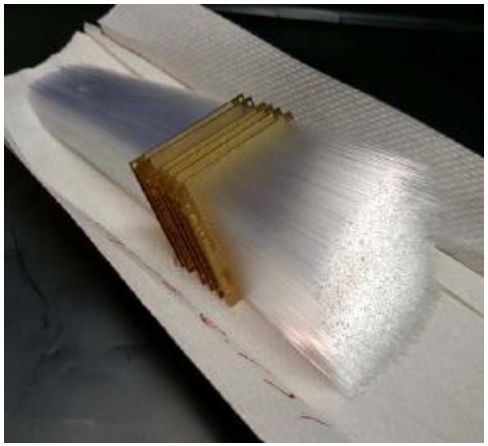
- Matrix of tungsten powder and epoxy with embedded scintillating fibers
- Density ~ 9-10 g/cm^3
- X_0 ~ 7 mm (18 X_0 total), R_M ~ 2.3 cm

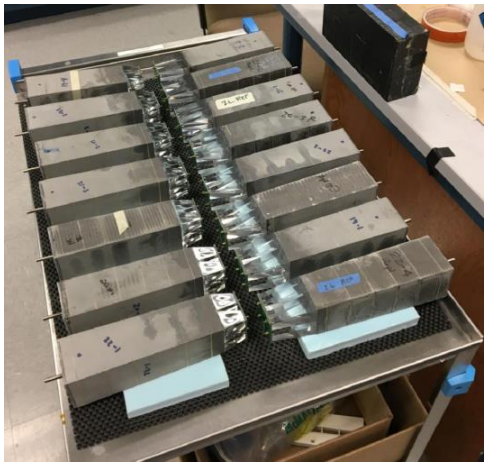
Scintillating fibers

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

Block fabrication area at UIUC

- 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



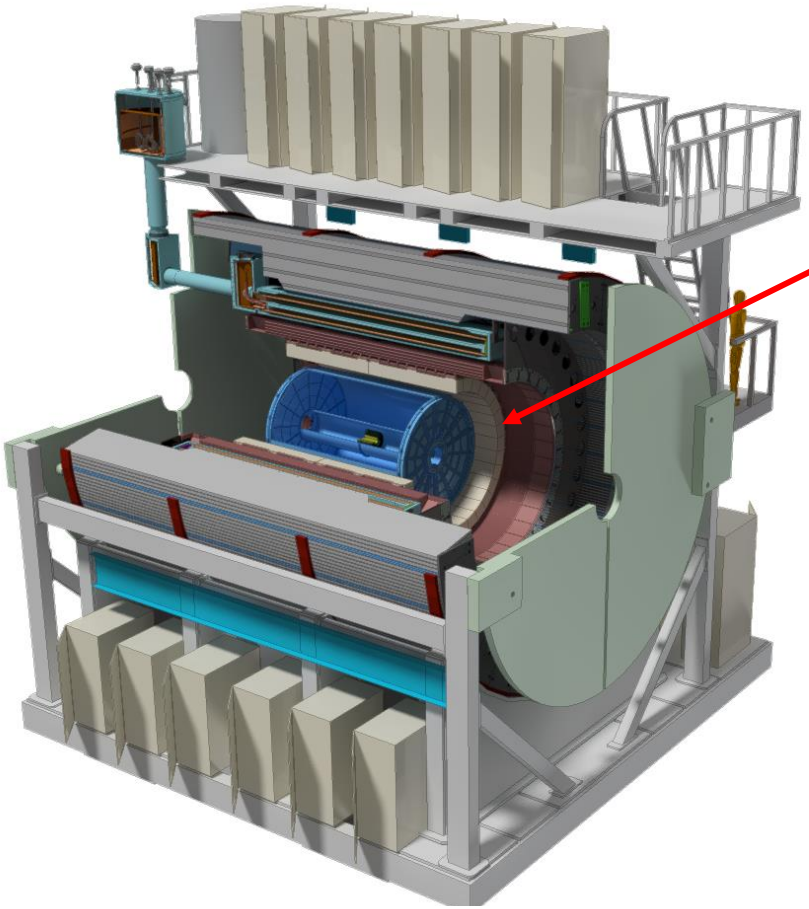


W/SciFi blocks built at UIUC for large η prototype

Status of the EMCAL Design

- The EMCAL subsystem is in an advanced conceptual design phase with detailed models and drawings of the absorber blocks, modules and sector assemblies.
- We have tested two prototype calorimeters in the beam at Fermilab ($\eta = 0$ and $\eta \sim 1$) and have shown that the proposed design will meet the physics requirements of the experiment. A third and final prototype will be tested in the beam in early 2018.
- Further work is needed on the design of the cooling system, cabling inside the sectors and support structure for the blocks. A full scale mechanical mockup is being constructed.
- A full scale preproduction prototype of a complete EMCAL sector will be constructed in 2018 and tested in the lab at BNL with its calibration system and cosmic rays.

EMCAL Scope (WBS)



WBS	sPHENIX MIE Project Elements
1.1	Project Management
1.2	Time Projection Chamber
1.3	Electromagnetic Calorimeter
1.4	Hadron Calorimeter
1.5	Calorimeter Electronics
1.6	DAQ-Trigger
1.7	Minimum Bias Trigger Detector

WBS	Infrastructure & Facility Upgrade
1.8	SC-Magnet
1.9	Infrastructure
1.10	Installation-Integration

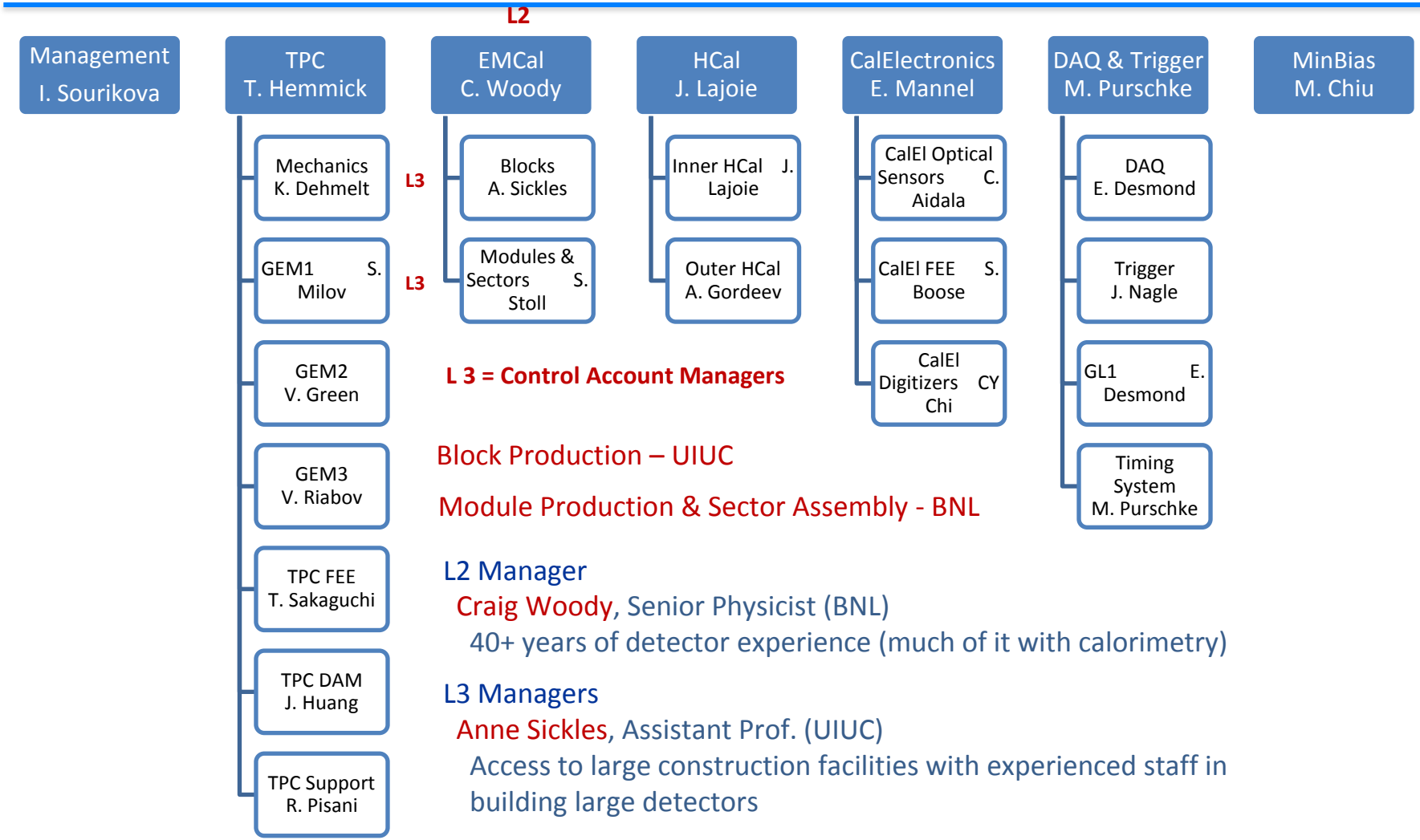
Not inside the EMCAL Scope

- Design, procurement and fabrication of readout electronics (WBS 1.5)
- Design, procurement and construction of external support structures (WBS 1.9,1.10)

Inside the EMCAL Scope

- Fabrication of absorber blocks and assembly into modules & sectors
- Design, procurement and installation of light guides
- Design, procurement and construction of mechanical structures for modules and sectors
- Design, procurement and installation of cooling system
- Installation of front end readout electronics

Level 2/Level 3 Managers and CAMs



L 3 = Control Account Managers

Block Production – UIUC

Module Production & Sector Assembly - BNL

L2 Manager

Craig Woody, Senior Physicist (BNL)

40+ years of detector experience (much of it with calorimetry)

L3 Managers

Anne Sickles, Assistant Prof. (UIUC)

Access to large construction facilities with experienced staff in building large detectors

Sean Stoll, Physics Associate I (BNL)

25+ years in building and operating many kinds of detectors (including the PHENIX EMCAL)

Resource Loaded Schedule (EMCAL Project File)

WBS	Task Name	Duration	Start	Finish	Total Cost	Fixed Cost	Labor
1.3.1	EMCAL Management	645 days	Wed 2/1/17	Fri 8/30/19	$0	$0	$0
1.3.2	EMCAL Block Production	1096 days	Fri 3/31/17	Mon 8/23/21	$4,836,685	$4,091,318	$745,366
1.3.2.1	EMCAL Prototype V2.1 Block Production	100 days	Thu 4/6/17	Mon 8/28/17	$41,530	$23,250	$18,280
1.3.2.2	EMCAL Preproduction Prototype Block Production	144 days	Fri 3/31/17	Tue 10/24/17	$220,681	$167,745	$52,936
1.3.2.3	EMCAL Final Block Production	1057 days	Thu 5/25/17	Mon 8/23/21	$4,574,474	$3,900,324	$674,150
1.3.3	EMCAL Module Production and Sector Assembly	1168 days	Wed 3/1/17	Tue 11/2/21	$3,574,881	$1,048,728	$2,526,153
1.3.3.1	Set up module production, sector assembly and test area	50 days	Fri 6/9/17	Mon 8/21/17	$67,043	$29,500	$37,543
1.3.3.2	EMCAL Module Production	1143 days	Wed 3/1/17	Tue 9/28/21	$1,013,259	$221,343	$791,916
1.3.3.3	EMCAL Sector Assembly	1145 days	Mon 4/3/17	Tue 11/2/21	$2,494,579	$797,885	$1,696,694
1.3.4	Install sectors into sPHENIX	0 days	Tue 11/2/21	Tue 11/2/21	$0	$0	$0

Main Schedule Driver:

Production of absorber blocks at UIUC

Main Cost Drivers:

W-Powder: $2.225M

Scintillating Fiber: $1.28M

Fixed Costs	$K
UIUC	
Materials	4091
Paid Labor	745
Total UIUC	4836
BNL	
Materials	1049
Total Fixed Costs	5885

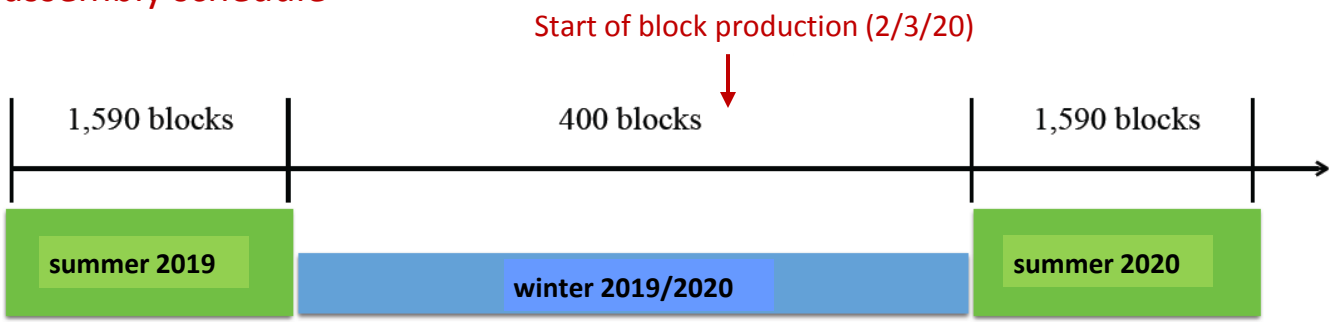
Key Milestones

1.3.3.3.1.11	Completion of v2.1 prototype	Tue 4/10/18
1.3.3.3.2.20	Completion of preproduction prototype	Fri 5/25/18
1.3.2.3.2	Readiness and Safety Review for final block production	Wed 8/12/19
1.3.3.2.3.2	Readiness Review for final module production	Thu 8/12/19
1.3.3.3.3.5	Readiness Review for final sector production	Thu 8/12/19
1.3.4	Install Emcal sectors into sPHENIX	Mon 11/1/21

CD-3a Procurement

- Schedule is being driven by the production of absorber blocks at UIUC.
- This is in turn being driven by the filling of the fiber assemblies. This will be done by students that are mainly available during the summer academic break.
- We must make use of the summer break period in 2019 to create a stockpile of fiber assemblies so that full scale production can begin in early February 2020.
- This requires ordering sufficient fiber and screens (~ ½ the total order) in early 2019 such that they will be delivered by spring of 2019 and available for making fiber assemblies in the summer of 2019.

Fiber assembly schedule



Filling fiber assemblies

CD-3a Procurement (1/23/19)

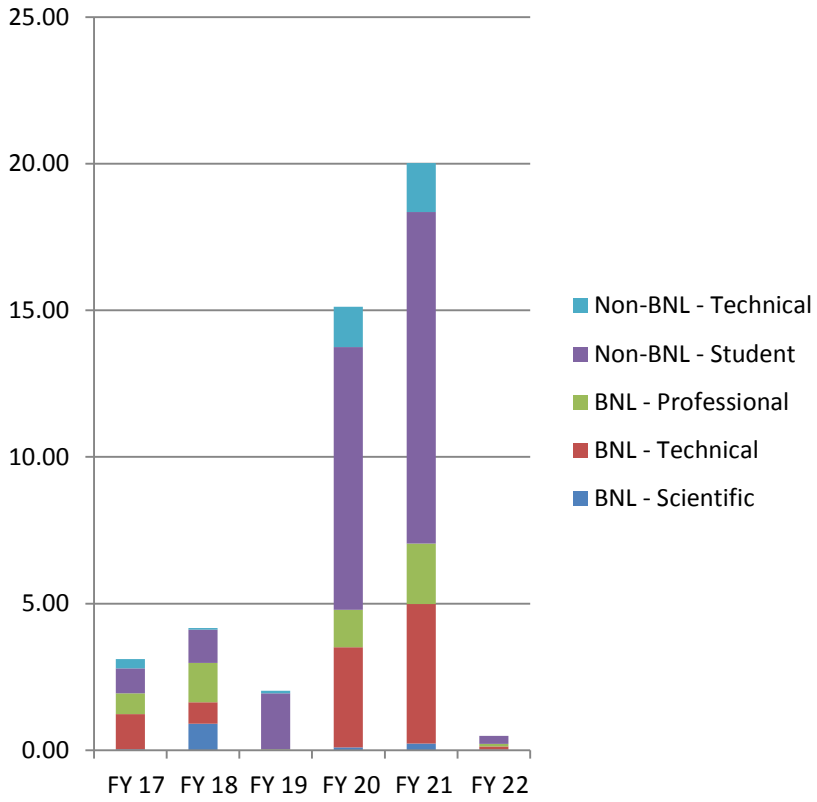
- ½ fiber order - $640K
- Screens - $176K

Total: $816K

- 2.2 hrs/block
- 7 hrs/day, 5 days/week
- 10 students
- 10 weeks over summer

EMCAL Staffing

FTE Profile by Category



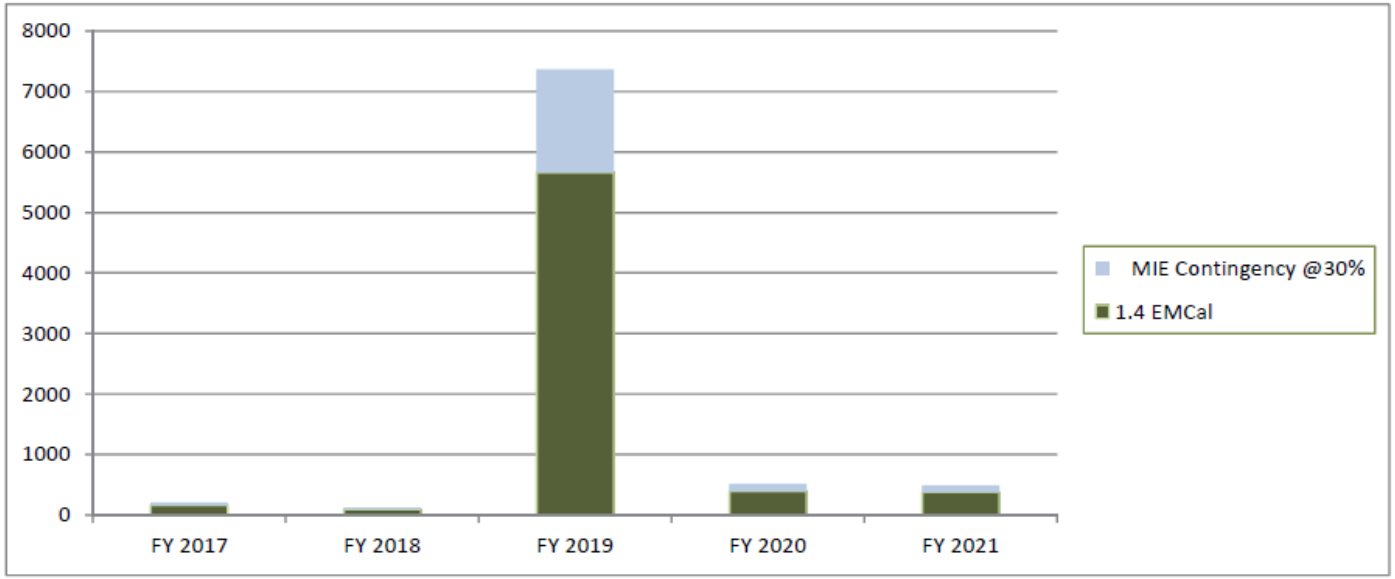
FTE Profile by Fiscal Year

WBS Level	Org Sort	Group	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22
1.3	**BNL**	Scientific	0.03	0.90	0.00	0.10	0.23	0.02
		Technical	1.20	0.73	0.01	3.41	4.76	0.11
		Professional	0.71	1.34	0.02	1.28	2.07	0.08
	BNL Sum		**1.94**	**2.98**	**0.03**	**4.79**	**7.05**	**0.22**
	Non-BNL	Student	0.85	1.13	1.91	8.95	11.30	0.27
		Technical	0.32	0.06	0.09	1.37	1.67	0.00
	Non-BNL Sum		**1.17**	**1.19**	**2.00**	**10.33**	**12.97**	**0.27**
Grand Total			**3.11**	**4.17**	**2.03**	**15.12**	**20.02**	**0.49**

EMCAL Funding

Baseline Scenario

AY k$'s - with Extraordinary Construction Overhead Application (PM Labor in Ops Support)



Baseline Scenario

AY k$'s - with Extraordinary Construction Overhead Application (PM Labor in Ops Support)

WBS	SYSTEM	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Total
1.4	**EMCal**	161	96	5665	396	380	6,698
	MIE Contingency @30%	48	29	1,700	119	114	2,009
	MIE Total	209	125	7365	515	494	8707

WBS	SYSTEM	Baseline	Contingency(30%)	Total
1.4	**EMCal**	6,698	2009	8,707

EMCAL Risk Registry

1.3 EmCal	Loss of W powder supplier	Failure of the primary supplier of W powder (Tungsten Heavy Powder) to sign a contract and deliver the powder for the final	Would need to obtain a quote and sign a contract with a different supplier for the powder. This will cause a delay in the schedule and possibly an increase in cost.	production	Low 20%	High. Cost: price increase > $500k. Schedule: 9 mo to	Moderate	Find another source of W powder which can meet our specs. Some have already been investigated. Attempt to identify primary source of raw powder in China and identify new distributor. Accept degraded detector performance if new
1.3 EmCal	Loss of SciFi supplier	Failure of fiber vendor to sign a contract or deliver fiber on time.	Would cause a delay in the schedule and result in higher cost for the fiber	production	Moderate 30%	Moderate Cost: $1.4M higher cost for alternate supplier	Moderate	Two suppliers have been identified. We believe both can meet our specs, but one is roughly 2X high cost. If the lower priced supplier cannot deliver then we must use contingency to purchase from the other supplier.
1.3 EmCal	Loss of primary production site for blocks (University of Illinois Urbana Champaign)	UIUC decides to not fabricate the absorber blocks	Would cause a delay in schedule and a significant increase in labor resources required to build the blocks at BNL.	production	Low 10%	High Cost: Slight cost increase to relocate factory to BNL	High	Blocks would have to be built at BNL. However, we would also loose scientific oversight provided by UIUC, student labor, free use of facilities, space, etc.
1.3 EmCal	delay of block production at UIUC due to component supplies or technical issues - critical path	production rate is not on schedule	delay in schedule	production	moderate	Low	Low	Add shifts or additional production when supplies are available or technical issues are resolved. Schedule early purchase & delivery of W powder, fibers, screens, epoxy .
1.3 EmCal	delay of module production or sector assembly rate due to component supplies or technical issues - critical path	production/assembly rate is not on schedule	delay in schedule	production	moderate	Low	Low	Add shifts or additional production when supplies are available or technical issues are resolved. Store partially assembled sectors until they can be completed. Use planned sector storage time as float.
1.3 EmCal	Cannot find a cost effective solution for making light guides	R&D studies and beam tests do not lead to improvements in the light collection uniformity from the modules	Will require position dependent correction for obtaining the desired energy resolution from the detector	R&D phase	High 75%	Low - Scope: Poorer detector energy resolution	Moderate	We will have optical quality injection molded light guides produced with what we believe will be the optimal shape given the space constraints of the detector. The resulting energy resolution will be measured in a beam test.

WBS Dictionary

1.3				SPHENIX EMCAL	The Electromagnetic Calorimeter for the sPHENIX Experiment at RHIC
1.3	1.3.1			EMCAL Block Production	Production of Tungsten powder/epoxy/scintillating fiber "SPACAL" absorber blocks for EMCal prototypes and final detector. Includes assembling fiber arrays, casting the blocks, and machining to design dimensions.
1.3	1.3.1	1.3.1.1		EMCAL Prototype V2.1 Block Production	Produce 16 Tungsten powder/epoxy/scintillating fiber "SPACAL" absorber blocks for the v2.1 prototype
1.3	1.3.1	1.3.1.2		EMCAL Preproduction Prototype Block Production	Produce 96 Tungsten powder/epoxy/scintillating fiber "SPACAL" absorber blocks for the Pre-Production prototype
1.3	1.3.1	1.3.1.2	1.3.1.2.1	Order Material for preproduction prototype	Procure materials necessary to produce preproduction prototype, including: scintillating fiber, tungsten powder, screens, epoxy
1.3	1.3.1	1.3.1.2	1.3.1.2.2	Fabricate blocks for preproduction prototype	Fabricate (cast and machine) 96 EMCal blocks. Four blocks of each shape.
1.3	1.3.1	1.3.1.2	1.3.1.2.3	Pack and ship preproduction blocks to BNL	Securely pack and ship finished, dimensioned blocks to BNL for assembly into prototype.
1.3	1.3.1	1.3.1.3		EMCAL Final Block Production	Produce 6144 Tungsten powder/epoxy/scintillating fiber "SPACAL" absorber blocks for the final sPHENIX EMCalorimeter
1.3	1.3.1	1.3.1.3	1.3.1.3.1	Fabricate final blocks	Fabricate (cast and machine) 6144 EMCal blocks. 256 blocks of each shape.
1.3	1.3.1	1.3.1.3	1.3.1.3.2	Pack and ship final blocks to BNL	Securely pack and ship finished, dimensioned blocks to BNL for assembly into prototype.
1.3	1.3.2			EMCAL Module Production and Sector Assembly	Assembly of EMCal blocks into "modules" of 4 blocks, and then modules into sectors of 24 modules. Sectors are the assembled calorimeter unit that contains the blocks, electronics, and cooling. Sixty-four finished sectors will be assembled into the final sPhenix calorimeter in the experimental hall.
1.3	1.3.2	1.3.2.1		Set up module production, sector assembly and test area	Set up and organize space and furnishing for module and sector production work. This includes areas for receiving/unpacking, preparation and storage of blocks, assembly of modules, assembly of sectors, testing of assembled sectors, and storage of 64 completed sectors prior to installation. Equipment necessary to move ~900lb sectors.
1.3	1.3.2	1.3.2.2		EMCAL Module Production	Assembly of EMCal absorber blocks, received from UIUC, into modules of 4 blocks. This includes preparation of the blocks: attaching mouting hardware and reflectors, light guides, and readout electronics to each block.
1.3	1.3.2	1.3.2.2	1.3.2.2.1	EMCAL Prototype V2.1 Module Production	Assembly of the 16 delivered EMCal blocks, after the addition of the lightguides, reflectors, optical sensors, and mounting hardware, into "modules" of 4 blocks each.
1.3	1.3.2	1.3.2.2	1.3.2.2.2	EMCAL Preproduction Prototype Module Production	Assembly of the 96 delivered PreProduction EMCal blocks, after the addition of the lightguides, reflectors, optical sensors, and mounting hardware, into 24 "modules" of 4 blocks each.
1.3	1.3.2	1.3.2.2	1.3.2.2.3	EMCAL Final Module Production	Assembly of the 6144 delivered Final Production EMCal blocks, after the addition of the lightguides, reflectors, optical sensors, and mounting hardware, into "modules" of 4 blocks each.
1.3	1.3.2	1.3.2.3		EMCAL Sector Assembly	Assembly of EMCAL sectors: installation of modules into sector boxes, including attaching modules to backplane, installation of readout electronics, cabling, and cooling. This BOE covers the cost of construction of the EMCal Sectors. 64 sectors are required . The sectors are stainless steel sheet metal construction connected to a strongback and are supported by bearing blocks mounted to two rails.
1.3	1.3.2	1.3.2.3	1.3.2.3.1	EMCAL Prototype v2.1 Sector Assembly	Assembly of 4 modules into the detector housing. Includes the addition of the readout electronics and cooling.
1.3	1.3.2	1.3.2.3	1.3.2.3.2	EMCAL Preproduction Prototype Sector Assembly and testing	Assembly of 24 modules into a sector enclosure, the addition of readout electronics, and cooling. Testing will include checking LED signals, thermal stability, electronic functionality, cosmic ray testing.
1.3	1.3.2	1.3.2.3	1.3.2.3.3	EMCAL Final Sector Assembly	Production assembly of 24 modules into each of 64 sector enclosures, the addition of readout electronics, and cooling. Testing will include checking LED signals, thermal stability, electronic functionality, cosmic ray testing.

BOE Cost Breakdown

Example: EMCAL Module Production - Materials

WBS	Description	Item	Vendor	Total	Status	Basis of Estimate	Contingency	Item Contingency	Wt Contingency	Total'	Contingency	Total w/ Contingen
		per part $ 6.83 x 1000		$6,830		quote	0.25	$1,708				
1.3.3.2.1.5	**Procure Mechanical parts for v2.1 prototype blocks**	subtotal		$218				$44		$218		
		3M DP460 epoxy	McMaster	$25		catalog/web	0.20	$5.00				
		1/4" spherical washers	McMaster	$68		catalog/web	0.20	$13.66				
		10-32 ss nuts and washers	McMaster	$9		catalog/web	0.20	$1.88				
		2-56 set screws and nuts	McMaster	$15		catalog/web	0.20	$3.00				
	design & produce LG gluing fixtures	light guide glueing fixtures	BNL	$100		3D printed	0.20	$20.00				
	modify V2.0 enclosure for V2.1											
1.3.3.2.1.8	**Install light guides on v2.1 prototype blocks**	Saint Gobain BC600 optical epoxy	Saint Gobain	$65		catalog	0.20	$13.00				
1.3.3.2.1.9	**Install reflectors and glue v2.1 prototype blocks**	Vikuity Mirror film	Vikuity	$52		catalog	0.20	$10.40				
		Saint Gobain BC600 optical epoxy	Saint Gobain	$65		catalog	0.20	$13.00				
1.3.3.2.1.10	**Install SiPMs & daughterboards on v2.1 prototype blocks**	Momentive RTV615 couplant	Momentive	$350		catalog	0.20	$70.00				
1.3.3.2.2	**EMCAL PreProduction Prototype Module Production**			$6,603				$1,321	#DIV/0!			$7,924
1.3.3.2.2.4	**Procure light guides for preproduction prototype modules**	subtotal		$5,000				$1,000		$5,000		$6,000
	(assuming v2.1 design is OK, we don't need additional pcs)	**mold cost (repolish?)**	NN Inc			quote	0.20	$0.00				
		part cost - use remainder from V2.1	NN Inc	$5,000		quote	0.20	$1,000.00				
1.3.3.2.2.5	**Procure mechanical parts for preproduction prototype modules**	subtotal		$915				$183		$915		$1,098
		set screw 10-32 ss 1.25" mounting stud	McMaster	$40		catalog	0.20	$8.00	0.00		$0	$40
		10-32 ss nuts and washers	McMaster	$72		catalog/web	0.20	$14.40				
		3M DP460 epoxy	McMaster	$200		catalog	0.20	$40.00				
		1/4" spherical washers	McMaster	$544		catalog	0.20	$108.80				
		set screws 2-56 ss	McMaster	$48		catalog/web	0.20	$9.60				
		nuts 2-56 ss	McMaster	$11		catalog/web	0.20	$2.20				
1.3.3.2.2.8	**Iinstall light guides on preproduction prototype blocks**	subtotal		$130				$26		$130		$156
		light guide gluing fixtures	BNL									
		Saint Gobain BC600 optical epoxy	Saint Gobain	$130		catalog/web	0.20	$26.00				
1.3.3.2.2.9	**Install reflectors and glue preproduction prototype blocks**	Vikuity Mirror film	Vikuity	$208		catalog/web	0.20	$41.60				
		Saint Gobain BC600 optical epoxy										
1.3.3.2.2.10	**Install SiPMs & daughterboards on preproduction prototype blocks**	*2-56 set screws and nuts*										
		Momentive RTV615 couplant	Momentive	$350		catalog	0.20	$70.00		$420		
1.3.3.2.2.11	**Glue preproduction blocks together into modules**											
1.3.3.2.3	EMCAL Final Module Production			**$153,355**				**$71,751**	0.00	$153,355		**$225,106**
1.3.3.2.3.1	**Revise module production procedure based on preproduction prototype**											
1.3.3.2.3.2	**Readiness Review for Final module production**											
1.3.3.2.3.3	**Procure mechanical parts for final modules**	subtotal		$28,455				$36,891		$28,455		$65,346

Issues and Concerns

- The EMCAL is on the critical path and therefore determines the entire installation schedule for sPHENIX.
- We have only one production site for the absorber blocks (UIUC) and one site for module production and sector assembly (BNL). Both of these sites must keep up with a very aggressive schedule of producing one complete sector every 6 days and sustain this schedule without slippage for 1.5 years.
- Possible funding shortfall could affect the amount of EMCAL coverage that could be constructed. If so, we would need to identify additional funds before the final design review (CD-3b) and before we begin final production in order to include the entire η coverage in the final sectors.
- We need ~ $800K in CD-3a funds in early 2019 to order fibers and screens in order to start final block production in Feb 2020
- We need ~ $5.0M in CD-3b funds in mid September 2019 to order the remaining materials necessary to begin full scale production of the final blocks, modules and sectors in Feb 2020.

Summary

- We have been working on the EMCAL design for over 4 years and have brought it to a very advanced stage. Several prototypes have been built and tested and have been shown to meet the design requirements for sPHENIX.
- We have developed a procedure for mass producing the large number of absorber blocks that will be required, and these blocks will be produced by our collaborating institution (UIUC) which has a great deal of experience and expertise in building and delivering large detector systems for nuclear and high energy physics.
- We have assembled a competent team that is committed to designing, building, testing and delivering the EMCAL subsystem on time and within budget to the sPHENIX project.
- Given the present schedule, we will expect to finish our remaining system development and testing and complete our engineering design before the CD-1 Review.

Back Up