sPHENIX - TPC Cost/Schedule/Management

KLAUS DEHMELT

ASSOCIATE LABORATORY DIRECTOR'S DESIGN REVIEW OF THE sPHENIX TRACKER

SEPTEMBER 07, 2016

Stony Brook University | The State University of New York

PHENIX

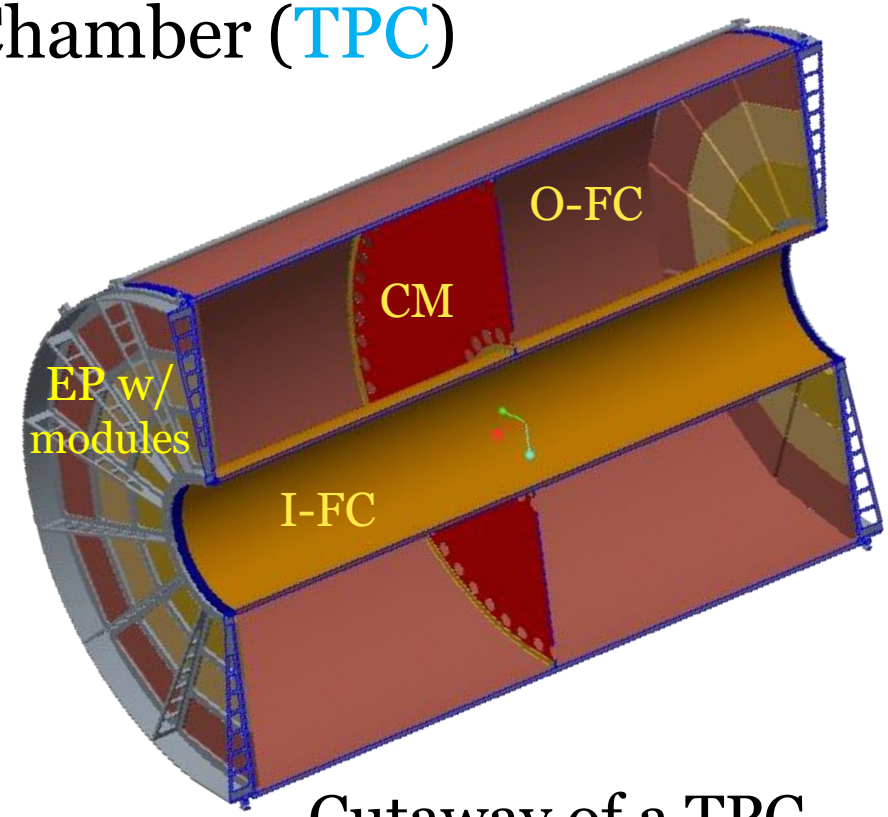
Project Scope

- Build a Time Projection Chamber (TPC)
  - Field Cage (FC)
  - Endplate (EP)
    - Modules
    - Electronics
  - Central Membrane (CM)
  - Readout Electronics

Field Cage subdivided in

Outer (O-FC)

Inner (I-FC)



Cutaway of a TPC

Project Scope

- Items of project scope for the TPC option

WBS	Task Name
1.3.2	Time Projection Chamber
1.3.2.1	TPC Prototyping
1.3.2.1.1	TPC Prototype v1
1.3.2.1.2	v1 Magnet Test (v1a module)
1.3.2.1.3	v1 Performance Review
1.3.2.1.4	TPC v1 Prototype Complete
1.3.2.1.5	TPC Prototype v2
1.3.2.1.6	Performance review v2 prototype
1.3.2.1.7	TPC Prototype v2 Complete
1.3.2.1.8	TPC Preproduction Prototype
1.3.2.2	TPC Production
1.3.2.3	TPC Electronics

Project Scope

- Items of project scope for the TPC option

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1.3.2	Time Projection Chamber
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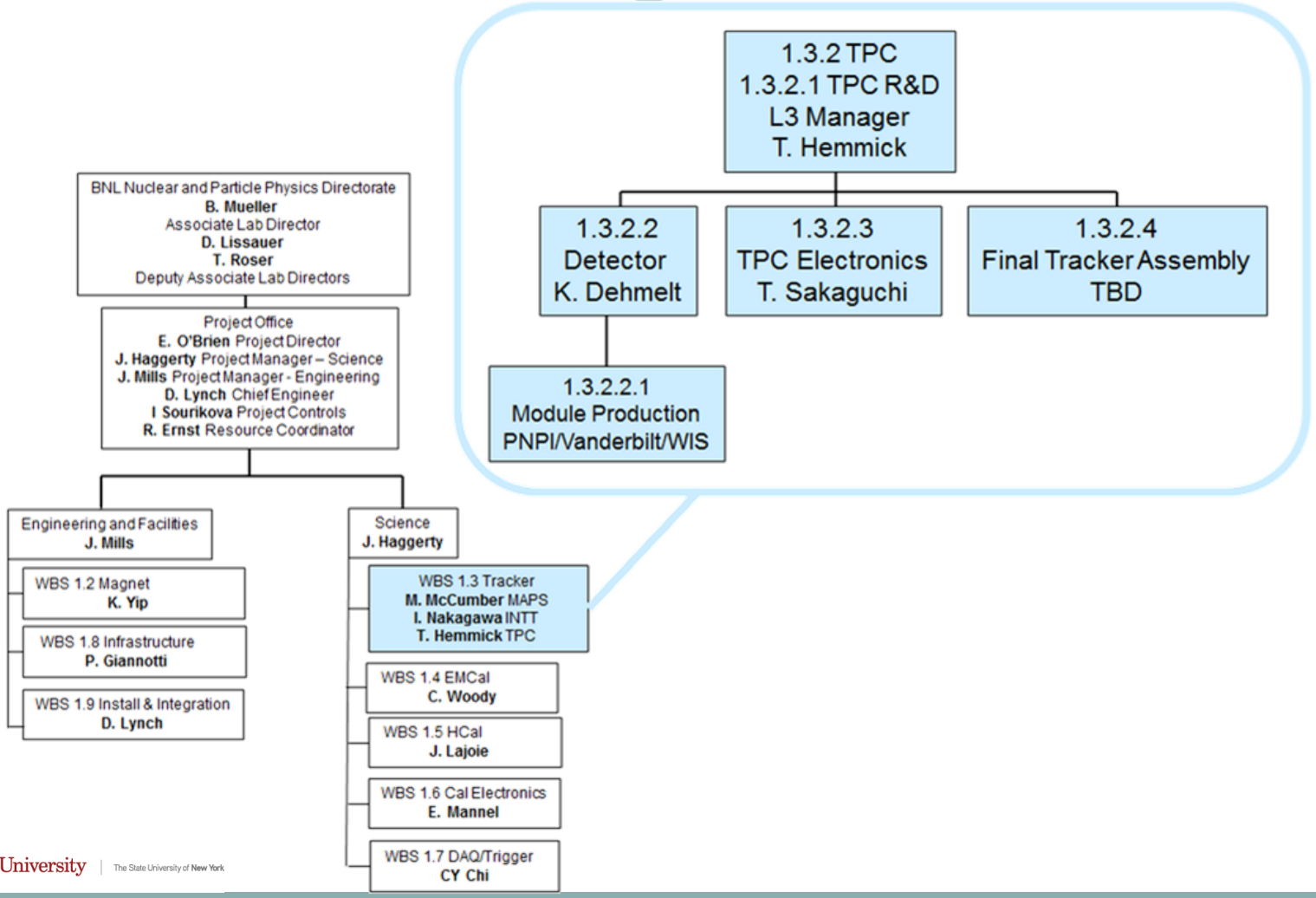
1.3.2.1.5	TPC Prototype v2
1.3.2.1.6	Performance review v2 prototype
1.3.2.1.7	TPC Prototype v2 Complete
1.3.2.1.8	TPC Preproduction Prototype
1.3.2.2	TPC Production
1.3.2.3	TPC Electronics

Mechanics

Organization Chart

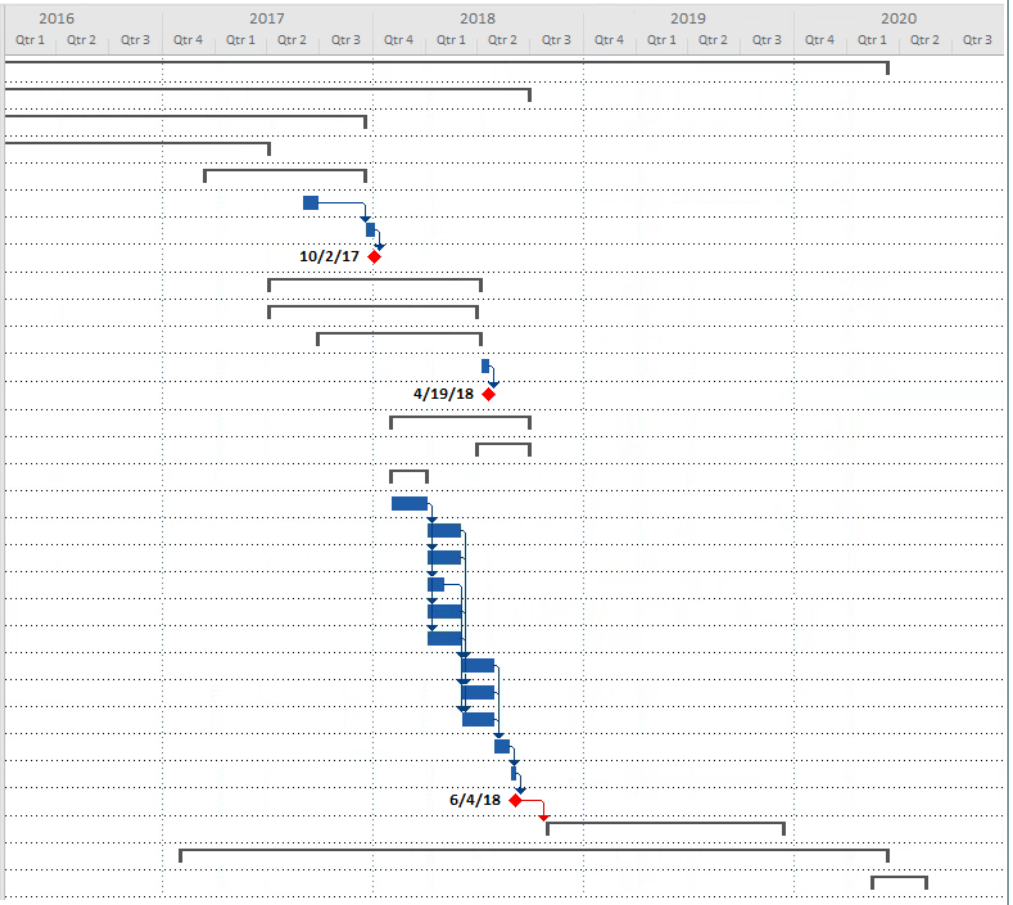


Description of Project Plan

- All sPHENIX detector systems require multi-stage R&D program:
  - *v1* prototype
  - *v2* prototype
  - *Pre-production* prototype
- Much R&D on GEM-based detectors done via the eRD6 program
- R&D should address "scaling issue" of large MPGD already at v1 level
- Propose to keep and use the *v2 (v1?)* field cage for the actual sPHENIX experiment
- *v1* phase has received funds from SBU and LDRD → must be considered in MS Project file correctly

Project Schedule

WBS	Task Name	Finish
1.3.2	**Time Projection Chamber**	**Wed 3/11/20**
1.3.2.1	**TPC Prototyping**	**Fri 6/29/18**
1.3.2.1.1	**TPC Prototype v1**	**Mon 9/18/17**
1.3.2.1.1.1	**v1 Field Cage Prototype**	**Tue 4/4/17**
1.3.2.1.1.2	**v1 Module Prototyping**	**Mon 9/18/17**
1.3.2.1.2	v1 Magnet Test (v1a module)	Wed 6/28/17
1.3.2.1.3	v1 Performance Review	Mon 10/2/17
1.3.2.1.4	TPC v1 Prototype Complete	Mon 10/2/17
1.3.2.1.5	**TPC Prototype v2**	**Thu 4/5/18**
1.3.2.1.5.1	**v2 Field Cage Prototype**	**Thu 3/29/18**
1.3.2.1.5.2	**v2 Module Prototyping**	**Thu 4/5/18**
1.3.2.1.6	Performance review v2 prototype	Thu 4/19/18
1.3.2.1.7	TPC Prototype v2 Complete	Thu 4/19/18
1.3.2.1.8	**TPC Preproduction Prototype**	**Fri 6/29/18**
1.3.2.1.8.1	**v2 Field Cage Modifications**	**Fri 6/29/18**
1.3.2.1.8.2	**Site Prep for Production Factories**	**Wed 1/3/18**
1.3.2.1.8.3	Design R1,R2,R3 Modules (strongback, frame, grid, pad, GEMs	Wed 1/3/18
1.3.2.1.8.4	Procure R1,R2,R3 Stongbacks	Fri 3/2/18
1.3.2.1.8.5	Procure R1,R2,R3 Frames	Fri 3/2/18
1.3.2.1.8.6	Procure R1,R2,R3 Grids	Thu 2/1/18
1.3.2.1.8.7	Procure R1,R2,R3 Pad Planes	Fri 3/2/18
1.3.2.1.8.8	Procure R1,R2,R3 GEMs	Fri 3/2/18
1.3.2.1.8.9	Assemble R1 Module in R1 Factory	Fri 4/27/18
1.3.2.1.8.10	Assemble R2 Module in R2 Factory	Fri 4/27/18
1.3.2.1.8.11	Assemble R3 Module in R3 Factory	Fri 4/27/18
1.3.2.1.8.12	Test R1,R2,R3 Modules after Shipping to BNL	Fri 5/25/18
1.3.2.1.8.13	Production Readiness Review	Mon 6/4/18
1.3.2.1.8.14	Preproduction Prototype Accepted	Mon 6/4/18
1.3.2.2	**TPC Production**	**Fri 9/13/19**
1.3.2.3	**TPC Electronics**	**Wed 3/11/20**
1.3.3	**Final Tracker Assembly/Testing Integration**	**Mon 5/18/20**



Project Milestones

WBS	Task Name	Date of Milestone
1.3.2.1.1.1.1	Start v1 Field Cage Prototype	Thu 10/1/15
1.3.2.1.1.1.6	Mandrel Complete	Thu 8/25/16
1.3.2.1.1.1.10	v1 Outer Field Cage Complete	Wed 11/30/16
1.3.2.1.1.1.14	v1 Inner Field Cage Complete	Thu 12/29/16
1.3.2.1.1.1.17	v1 End Cap Complete	Wed 12/14/16
1.3.2.1.1.1.21	v1 Central Membrane Complete	Fri 10/28/16
1.3.2.1.1.1.24	v1 Field Cage Prototype Complete	Tue 4/4/17
1.3.2.1.1.2.1.5	v1 Gas Enclosure Complete	Wed 12/14/16
1.3.2.1.1.2.3.9	v1a Module Prototype Complete	Tue 5/2/17
1.3.2.1.1.2.4.9	v1b Module Prototype Complete	Mon 9/18/17
1.3.2.1.1.2.5	v1 Module Prototyping Complete	Mon 9/18/17
1.3.2.1.4	TPC v1 Prototype Complete	Mon 10/2/17
1.3.2.1.7	TPC Prototype v2 Complete	Thu 4/19/18
1.3.2.1.8.1.5	v2 Field Cage Modifications Complete	Fri 6/29/18
1.3.2.1.8.14	Preproduction Prototype Accepted	Mon 6/4/18
1.3.2.2.1.11	TPC Ready to install	Fri 9/13/19

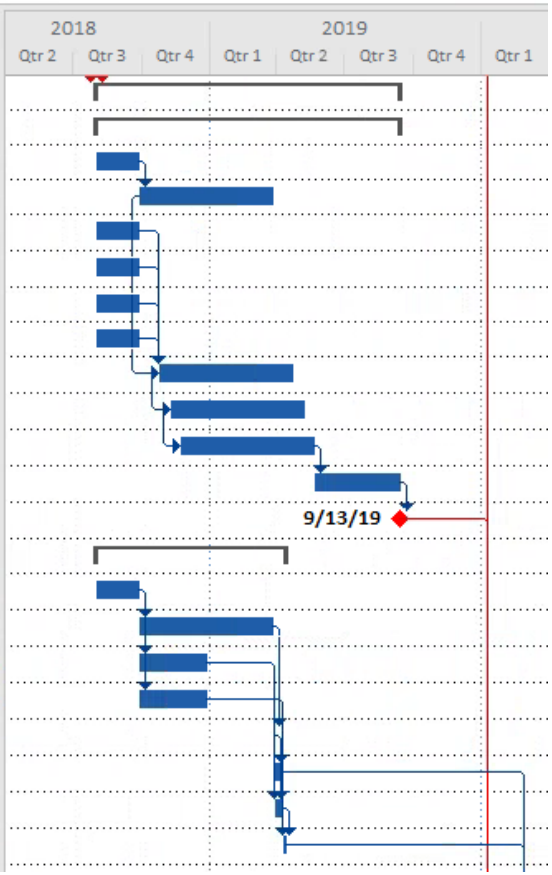
Project Milestones

WBS	Task Name	Date of Milestone
1.3.2.1.1.1.1	Start v1 Field Cage Prototype	Thu 10/1/15
1.3.2.1.1.1.6	Mandrel Complete	Thu 8/25/16
1.3.2.1.1.1.10	v1 Outer Field Cage Complete	Wed 11/30/16
1.3.2.1.1.1.14	v1 Inner Field Cage Complete	Thu 12/29/16
1.3.2.1.1.1.17	v1 End Cap Complete	Wed 12/14/16
1.3.2.1.1.1.21	v1 Central Membrane Complete	Fri 10/28/16
1.3.2.1.1.1.24	v1 Field Cage Prototype Complete	Tue 4/4/17
1.3.2.1.1.2.1.5	v1 Gas Enclosure Complete	Wed 12/14/16
1.3.2.1.1.2.3.9	v1a Module Prototype Complete	Tue 5/2/17
1.3.2.1.1.2.4.9	v1b Module Prototype Complete	Mon 9/18/17
1.3.2.1.1.2.5	v1 Module Prototyping Complete	Mon 9/18/17
1.3.2.1.4	TPC v1 Prototype Complete	Mon 10/2/17
1.3.2.1.7	TPC Prototype v2 Complete	Thu 4/19/18
1.3.2.1.8.1.5	v2 Field Cage Modifications Complete	Fri 6/29/18
1.3.2.1.8.14	Preproduction Prototype Accepted	Mon 6/4/18
1.3.2.2.1.11	TPC Ready to install	Fri 9/13/19

Critical Path

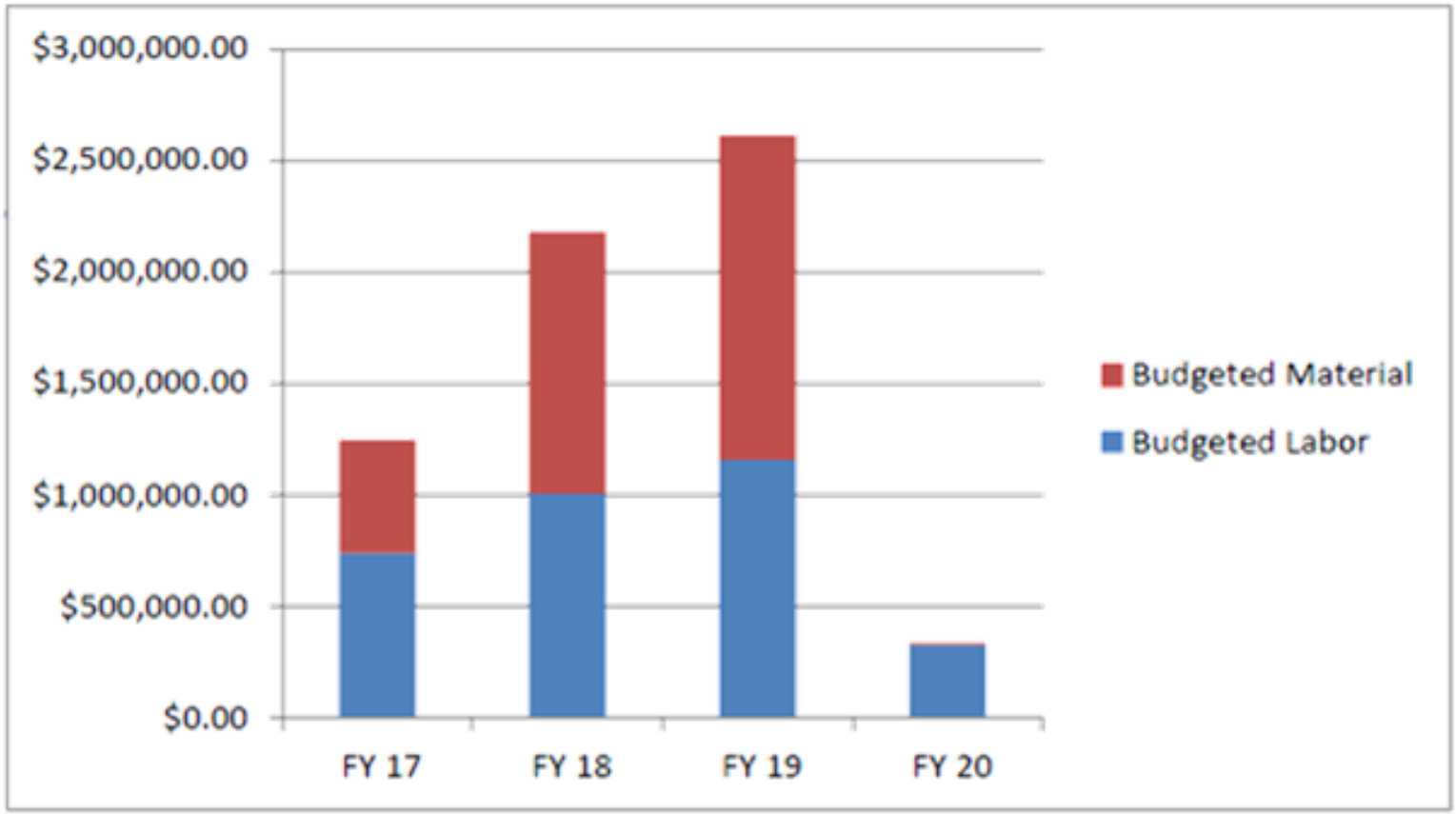
- Perform tasks in parallel

WBS	Task Name	Finish
1.3.2.2	**TPC Production**	**Fri 9/13/19**
1.3.2.2.1	**TPC Module Production**	**Fri 9/13/19**
1.3.2.2.1.1	Train Technician to work in CERN Shop	Wed 9/26/18
1.3.2.2.1.2	Production of GEM foils (includes Technician)	Mon 3/25/19
1.3.2.2.1.3	Procure frames	Wed 9/26/18
1.3.2.2.1.4	Procure strongbacks (R1, R2, R3 modules)	Wed 9/26/18
1.3.2.2.1.5	Procure Pad Planes	Wed 9/26/18
1.3.2.2.1.6	Procure Grids	Wed 9/26/18
1.3.2.2.1.7	Build modules	Mon 4/22/19
1.3.2.2.1.8	Test modules	Mon 5/6/19
1.3.2.2.1.9	Assemble detector	Mon 5/20/19
1.3.2.2.1.10	Test Detector Prior to installation	Fri 9/13/19
1.3.2.2.1.11	TPC Ready to install	Fri 9/13/19
1.3.2.2.2	**TPC Laser System**	**Fri 4/12/19**
1.3.2.2.2.1	Design Laser System & Safety	Wed 9/26/18
1.3.2.2.2.2	Procure lasers	Mon 3/25/19
1.3.2.2.2.3	Procure optics with mirrors	Wed 12/26/18
1.3.2.2.2.4	Procure mirror bundles with supports	Wed 12/26/18
1.3.2.2.2.5	Install lasers	Thu 3/28/19
1.3.2.2.2.6	saftey interlocks and paper work	Tue 4/9/19
1.3.2.2.2.7	Install optics with mounts	Tue 4/9/19
1.3.2.2.2.8	Install mirror bundles and supports	Fri 4/12/19



Cost Profile in FY16$

- MIE Project and Support Labor Cost Profile



Fixed Cost Items

10

Sum of Fixed Cost		Column Labels					
Row Labels	Task Name	FY 16	FY 17	FY 18	FY 19	FY 20	Grand Total
1.3.2.1.1.1.12	procure v1 Inner Field Cage Parts	28,799					28,799
1.3.2.1.1.1.16	v1 End Cap Procurement	30,000					30,000
1.3.2.1.1.1.19	procure v1 Central Membrane Parts	8,000					8,000
1.3.2.1.1.1.4	Procure Mandrel Parts	51,852					51,852
1.3.2.1.1.1.8	procure v1 Outer Field Cage Parts	70,067					70,067
1.3.2.1.1.2.1.2	Procure v1 Gas Enclosure Parts		3,000				3,000
1.3.2.1.1.2.2.2	Procure v1 Strongback		6,000				6,000
1.3.2.1.1.2.2.4	procure v1 Frames		2,000				2,000
1.3.2.1.1.2.2.6	procure v1 Grid Parts		2,000				2,000
1.3.2.1.1.2.3.3	Procure v1a GEMs		10,000				10,000
1.3.2.1.1.2.4.3	Procure v1b GEMs		10,000				10,000
1.3.2.1.2	v1 Magnet Test (v1a module)		3,000				3,000
1.3.2.1.5.1.11	procure v2 Inner Field Cage Parts		28,799				28,799
1.3.2.1.5.1.15	v2 End Cap Procurement		30,000				30,000
1.3.2.1.5.1.18	procure v2 Central Membrane Parts		8,000				8,000
1.3.2.1.5.1.3	Procure Mandrel Replacement Parts		51,852				51,852
1.3.2.1.5.1.7	procure v2 Outer Field Cage Parts		70,067				70,067
1.3.2.1.5.2.1.2	Procure v2 Gas Enclosure Parts		3,000				3,000
1.3.2.1.5.2.2.2	Procure v2 Strongback		6,000				6,000
1.3.2.1.5.2.2.4	procure v2 Frames		2,000				2,000
1.3.2.1.5.2.2.6	procure v2 Grid Parts		2,000				2,000
1.3.2.1.5.2.3.3	Procure v2a GEMs		[illegible]				[illegible]
1.3.2.1.5.2.4.3	Procure v2b GEMs						
1.3.2.1.8.1.2	Procure v2 Field Cage Modification Parts						
1.3.2.1.8.2.1	R1 Factory Preparation						
1.3.2.1.8.2.2	R2 Factory Preparation						
1.3.2.1.8.2.3	R3 Factory Preparation						
1.3.2.1.8.4	Procure R1,R2,R3 Stongbacks						
1.3.2.1.8.5	Procure R1,R2,R3 Frames						
1.3.2.1.8.6	Procure R1,R2,R3 Grids						

Sum of Fixed Cost		Column Labels					
Row Labels	Task Name	FY 16	FY 17	FY 18	FY 19	FY 20	Grand Total
1.3.2.1.8.7	Procure R1,R2,R3 Pad Planes			2,000			2,000
1.3.2.1.8.8	Procure R1,R2,R3 GEMs			10,000			10,000
1.3.2.2.1.1	Train Technician to work in CERN Shop			39,080			39,080
1.3.2.2.1.2	Production of GEM foils (includes Technician)			191,089			191,089
1.3.2.2.1.3	Procure frames			40,000			40,000
1.3.2.2.1.4	Procure strongbacks (R1, R2, R3 modules)			45,000			45,000
1.3.2.2.2.2	Procure lasers				90,000		90,000
1.3.2.2.2.3	Procure optics with mirrors			50,000			50,000
1.3.2.2.2.4	Procure mirror bundles with supports			15,000			15,000
1.3.2.2.2.6	saftey interlocks and paper work				2,000		2,000
1.3.2.2.3.2	Procure mass flow meters				9,000		9,000
1.3.2.2.3.3	Procure gas analyzer, 2 for rudundancy				60,000		60,000
[illegible]	Procure scrubbers				4,000		4,000
[illegible]	Procure oxygen and water sensors				4,000		4,000
[illegible]	Set up computer control system				3,000		3,000
[illegible]	plumbing and assembly				7,000		7,000
[illegible]	Set up interlocks				3,000		3,000
1.3.2.2.4.2	Procure equipment(pumps,heat exchanger, PH control, end cap manifolds, tanks...)				30,000		30,000
1.3.2.2.4.8	Install plumbing				4,000		4,000
1.3.2.2.4.9	Set up controls				3,000		3,000
1.3.2.3.1.2.1.1	Procure components: prototype v1		6,500				6,500
[illegible]	[illegible]		22,000				22,000
[illegible]	[illegible]		12,000				12,000
[illegible]	[illegible]		150,000				150,000
[illegible]	[illegible]			5,000			5,000
[illegible]	[illegible]			22,000			22,000
[illegible]	[illegible]			6,500			6,500
[illegible]	[illegible]			22,000			22,000
[illegible]	[illegible]			8,000			8,000

LDRD+MIE funds

Sum of Fixed Cost		Column Labels					
Row Labels	Task Name	FY 16	FY 17	FY 18	FY 19	FY 20	Grand Total
	Assemble and test prot[illegible]ics:						
1.3.2.3.1.2.2.5	preproduction prototype				3,000		3,000
1.3.2.3.1.2.2.6	Review and write desi[illegible]ge specifications				43,000		43,000
1.3.2.3.1.3.2	Procure components: production				750,000		750,000
1.3.2.3.1.3.3	Procure components: power supply				84,000		84,000
1.3.2.3.1.3.4	Fabricate all boards: production				220,000		220,000
1.3.2.3.1.3.5	QA TPC FEC					40,000	40,000
1.3.3.2	Install Pixel Detector					1,000	1,000
1.3.3.3	Install 3 Si Barrels or TPC					1,000	1,000
1.3.3.4	Integrate Inner and Outer Layers					1,000	1,000
1.3.3.5	Cable and Plumb Final Detector Assembly					1,000	1,000
1.3.3.6	Test and Debug Final Detector Assembly					1,000	1,000
Grand Total		188,718	438,218	522,669	1,319,000	45,000	2,513,605

MIE funds

	Column Label				
	FY 16	FY 17	FY 18	FY 19	FY 20	Grand Total
Sum of Fixed Cost		324,866	736,169	893,000	5,000	1,959,035

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PHENIX

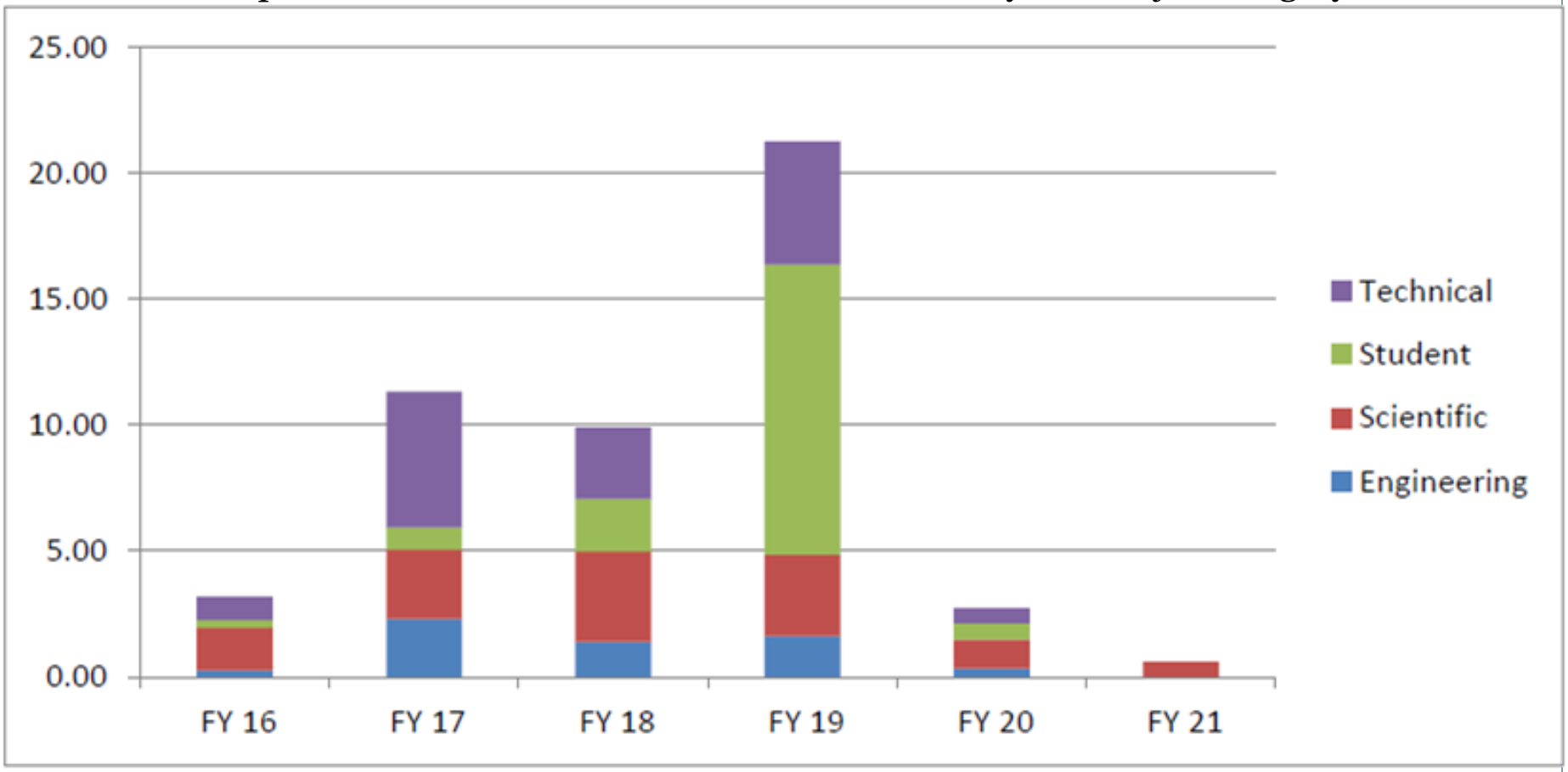
Labor Profile

- TPC Labor profile from resource-loaded schedule sorted by FY and job category/source
- BNL and SBU labor identified. “Other” refers to other collaborating institutions
- Students come from multiple sPHENIX institutions

Row Labels	FY 16	FY 17	FY 18	FY 19	FY 20	FY 21
Engineering	**0.25**	**2.30**	**1.39**	**1.61**	**0.34**	**0.00**
PROF3 BNL E	0.00	0.00	0.00	0.08	0.00	0.00
PROF4 BNL E	0.00	0.99	0.67	1.09	0.29	0.00
PROF4 BNL M	0.00	0.00	0.27	0.25	0.05	0.00
PROF4 Other	0.25	1.31	0.44	0.19	0.00	0.00
Scientific	**1.72**	**2.71**	**3.60**	**3.22**	**1.16**	**0.59**
SCI 4 SBU	1.72	1.11	1.95	0.23	0.23	0.17
SCI3 BNL	0.00	0.08	0.07	0.08	0.00	0.00
SCI3 Other	0.00	1.52	1.59	2.91	0.94	0.42
Student	**0.30**	**0.87**	**2.07**	**11.52**	**0.63**	**0.00**
STUDENT	0.30	0.87	2.07	11.52	0.63	0.00
Technical	**0.92**	**5.39**	**2.84**	**4.86**	**0.62**	**0.00**
Tech 4 SBU	0.67	2.24	1.15	0.54	0.00	0.00
TECH3 BNL D	0.00	1.08	0.61	0.36	0.00	0.00
TECH3 BNL E	0.00	0.26	0.22	0.14	0.00	0.00
TECH3 BNL M	0.00	0.00	0.00	0.55	0.55	0.00
TECH3 Other	0.25	1.81	0.85	3.26	0.08	0.00
Grand Total	**3.19**	**11.27**	**9.89**	**21.22**	**2.74**	**0.59**

Labor Profile

- TPC Labor profile from resource-loaded schedule sorted by FY and job category



Institution Responsibilities

- Participating institutions
  - Brookhaven National Lab - BNL
  - Petersburg Nuclear Physics Institute - PNPI
  - Stony Brook University - SBU
  - Weizmann Institute of Science - WIS
  - Vanderbilt University - Vanderbilt

Institution Responsibilities

- Contributions
  - BNL:
    - BNL leads electronics effort
    - Prior to module production → engaged in design and measurements of pad plane segmentation for optimizing detector performance
    - During production → working with SBU for module insertion into TPC
    - During production → working with SBU on mechanical, laser, gas, and cooling aspects
  - PNPI:
    - Prior to module production → work on theoretical calculations of new IBF strategies, working hand-in-hand with WIS efforts
    - During production → build modules of one of three sizes

Institution Responsibilities

- Contributions
  - SBU:
    - Prior to module production → engaged in software & field cage
    - During production → working on module insertion into TPC
    - During production → working with SBU on mechanical, laser, gas and cooling aspects
    - L2/L3 management for TPC project
  - WIS:
    - Prior to module production → engaged in measurements of IBF to verify current and future design issues
    - During production → build modules of one of three sizes
  - Vanderbilt:
    - Prior to module production → engaged in software & field cage
    - During production → build modules of one of three sizes
- Module producing institutes need to be prepared with production capability (clean-room upgrades)

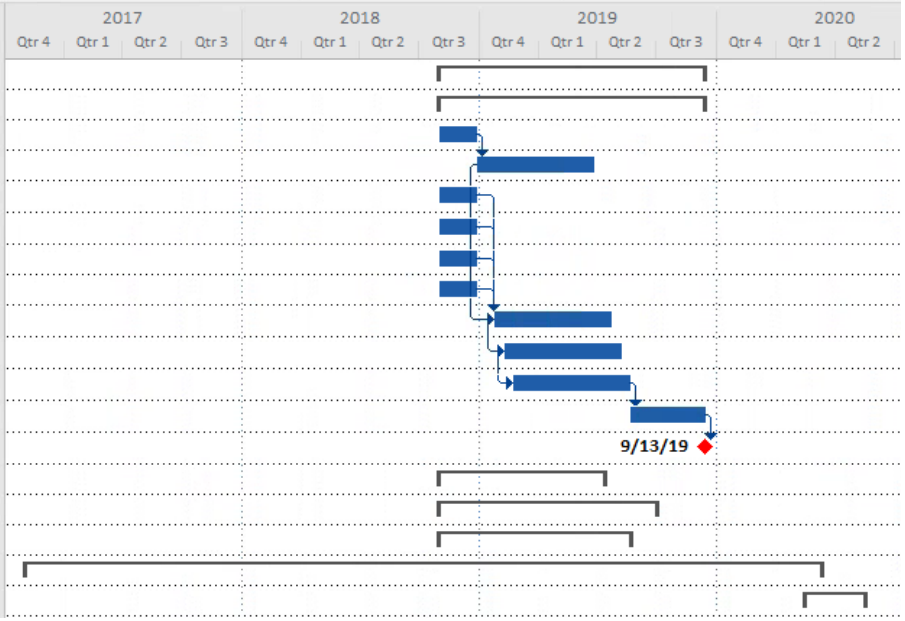
Production Plan

- After prototyping phase→TPC production phase
- Propose to keep and use the *v2 (v1?)* field cage for the actual sPHENIX experiment

WBS	Task Name	
1.3.2.2	TPC Production	
1.3.2.2.1	TPC Module Production	
1.3.2.2.1.1	Train Technician to work in CERN Shop	
1.3.2.2.1.2	Production of GEM foils (includes Technician)	
1.3.2.2.1.3	Procure frames	
1.3.2.2.1.4	Procure strongbacks (R1, R2, R3 modules)	Wed 9/26/18
1.3.2.2.1.5	Procure Pad Planes	Wed 9/26/18
1.3.2.2.1.6	Procure Grids	Wed 9/26/18
1.3.2.2.1.7	Build modules	Mon 4/22/19
1.3.2.2.1.8	Test modules	Mon 5/6/19
1.3.2.2.1.9	Assemble detector	Mon 5/20/19
1.3.2.2.1.10	Test Detector Prior to installation	Fri 9/13/19
1.3.2.2.1.11	TPC Ready to install	Fri 9/13/19
1.3.2.2.2	TPC Laser System	Fri 4/12/19
1.3.2.2.3	TPC Gas System	Tue 7/2/19
1.3.2.2.4	TPC Cooling System	Wed 5/22/19
1.3.2.3	TPC Electronics	Wed 3/11/20
1.3.3	Final Tracker Assembly/Testing Integration	

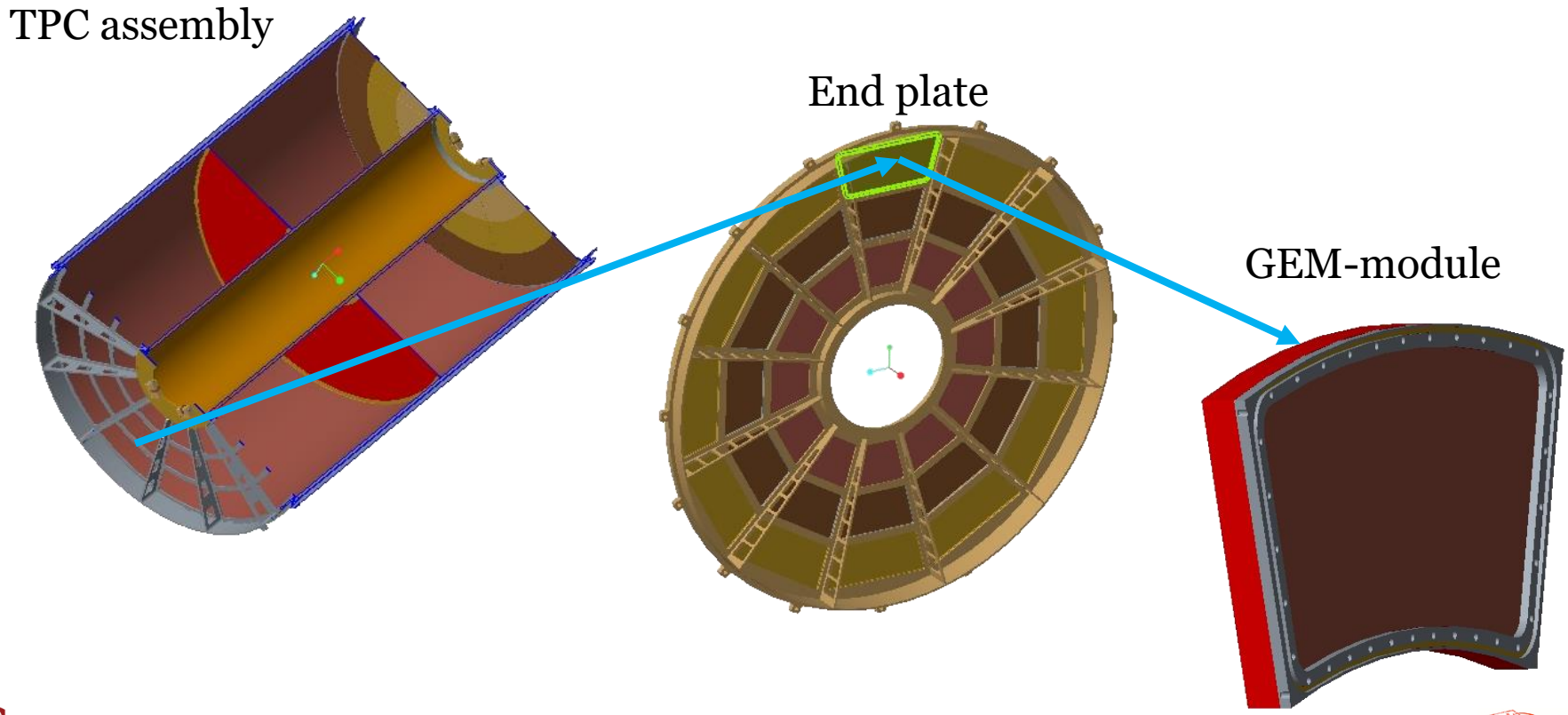
PNPI
Vanderbilt
WIS

SBU/BNL



Production Plan

- Module production

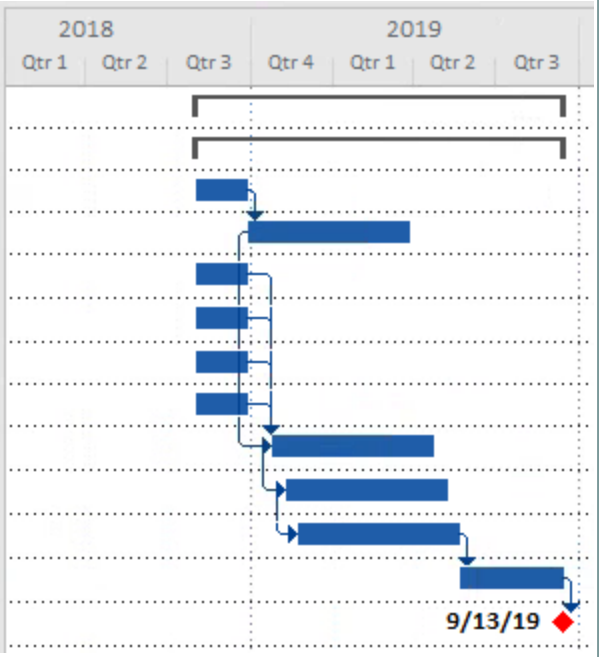


Production Plan

- Module production
  - Equal number of GEM-modules per radius
  - Three different radii per end-plate
  - Twelve GEM-modules per radius
  - Total of 3 x 12 x 2 = 72 GEM-modules
- Each GEM-module will be produced at one of the three institutes for one of the three sizes

Production Plan

WBS	Task Name	Duration
1.3.2.2	**TPC Production**	**280 days**
1.3.2.2.1	**TPC Module Production**	**280 days**
1.3.2.2.1.1	Train Technician to work in CERN Shop	2 mons
1.3.2.2.1.2	Production of GEM foils (includes Technician)	6 mons
1.3.2.2.1.3	Procure frames	40 days
1.3.2.2.1.4	Procure strongbacks (R1, R2, R3 modules)	40 days
1.3.2.2.1.5	Procure Pad Planes	40 days
1.3.2.2.1.6	Procure Grids	40 days
1.3.2.2.1.7	Build modules	6 mons
1.3.2.2.1.8	Test modules	6 mons
1.3.2.2.1.9	Assemble detector	6 mons
1.3.2.2.1.10	Test Detector Prior to installation	80 days
1.3.2.2.1.11	TPC Ready to install	0 days



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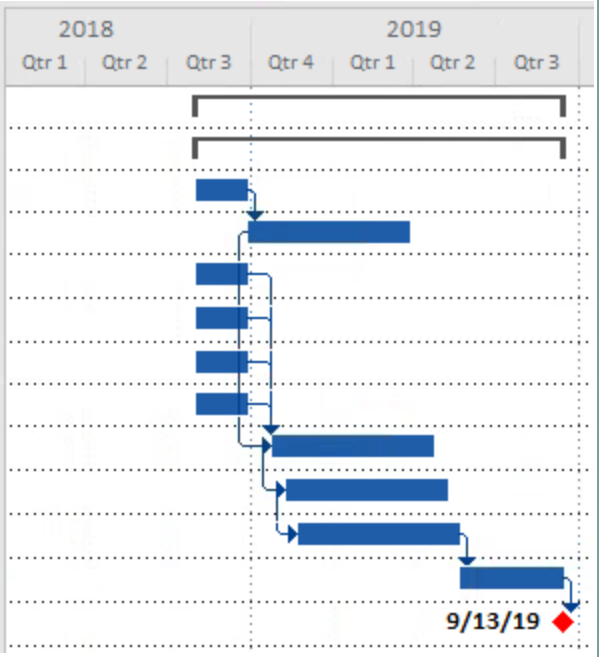

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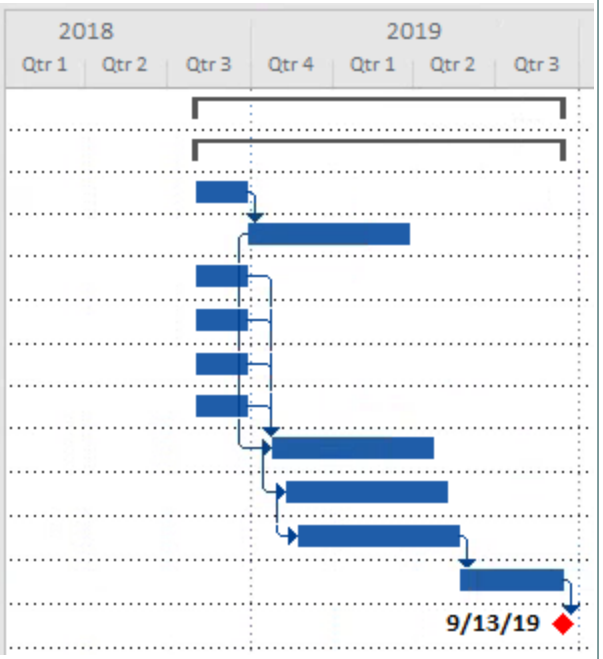

Risk Registry

Bottoms-up Contingency

- TPC MIE and Support Labor Costs fully burdened with BNL Project rates as applicable, escalated, and 40% contingency applied across the board. BNL Labor rates where appropriate. Reductions for BNL LDRD and SBU funding were applied.

sPHENIX TPC Tracking

Summary Estimate

	2016	2017	2018	2019	2020	2021	2022	Grand Total
sPHENIX Labor								
Fixed FY16 Direct Labor w/fringe		372,981	493,559	551,504	149,820			$1,567,864
Estimated Composite Indirect on Labor@36.9%	0	137,630	182,123	203,505	55,284	0	0	578,542
Fixed FY16 Fully Loaded Labor	0	510,611	675,682	755,009	205,104	0	0	2,146,406
Escalation @ 3.0%	0	15,318	41,149	69,989	25,740	0	0	152,197
Subtotal AY $	0	525,929	716,831	824,998	230,844	0	0	2,298,603
Contingency at 40%	0	210,372	286,733	329,999	92,338	0	0	919,441
Budgeted Labor	0	736,301	1,003,564	1,154,998	323,182	0	0	3,218,044
Adjusted sPHENIX M&S - TPC		$324,866	$736,169	$893,000	$5,000			$1,959,035
Estimated Composite Indirect	0	30,635	69,421	84,210	472	0	0	184,737
Subtotal FY 16 $	$0	$355,501	$805,590	$977,210	$5,472	$0		$2,143,772
Escalation @ 2% per FY	0	7,110	32,546	59,813	451	0		99,920
Estimate with Escalation	$0	$362,611	$838,136	$1,037,023	$5,923	$0		$2,243,692
Contingency at 40%	0	145,044	335,254	414,809	2,369	0	0	897,477
Budgeted Material	$0	$507,655	$1,173,390	$1,451,832	$8,292	$0	$0	$3,141,169
Total AY $ with Contingency Estimate	$0	$1,243,956	$2,176,954	$2,606,830	$331,473	$0	$0	$6,359,213
Overall contingency %								40.0% TPC
								40.0% TEC

Issues and Concerns

- Concern regarding GEM-foil production
  - At present ONE reliable facility world-wide→CERN
  - Concern mitigated: make person available @ CERN exclusively for our production

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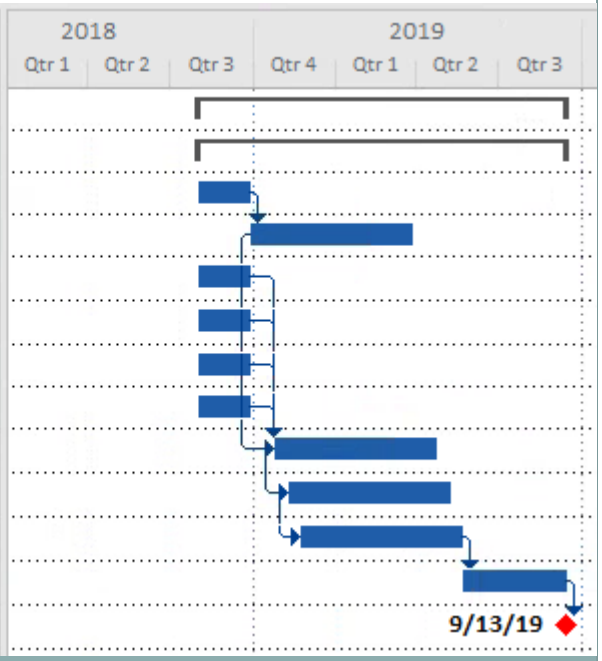


Summary

Backup

Project Scope

- Tracking in sPHENIX → Two toughest constraints for the physics program
  - Mass resolution sufficient to resolve Y-states

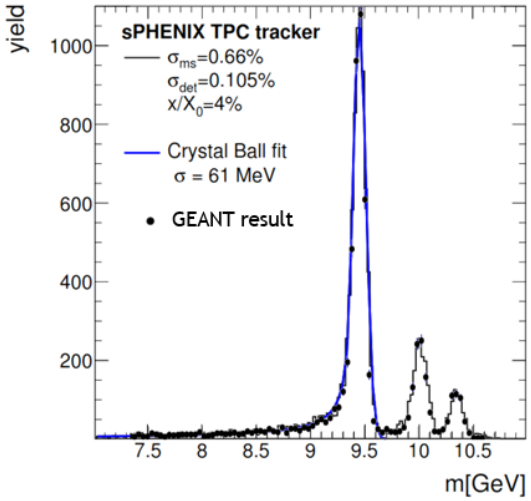
$$\sigma_m < 100\ \frac{MeV}{c^2}\ @\ m \approx 9\ \frac{GeV}{c^2} \rightarrow \sigma_{r\phi} < 250\mu m$$

  - DCA Resolution sufficient for tagging heavy flavor secondary vertices

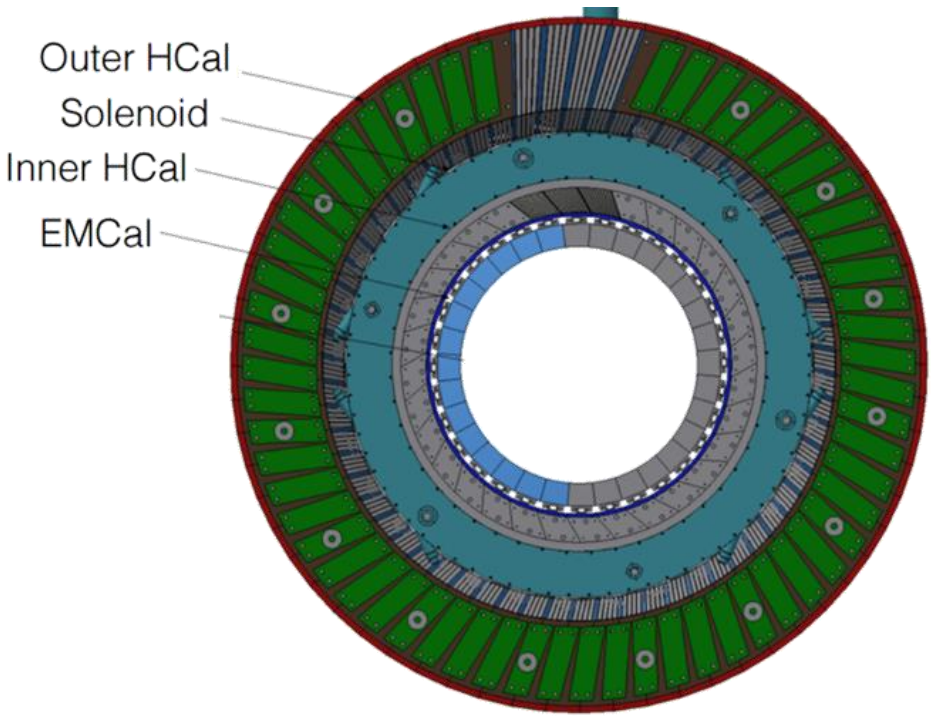
$$c\tau(D) = 123\ \mu m;\ \ c\tau(B) = 457\ \mu m$$

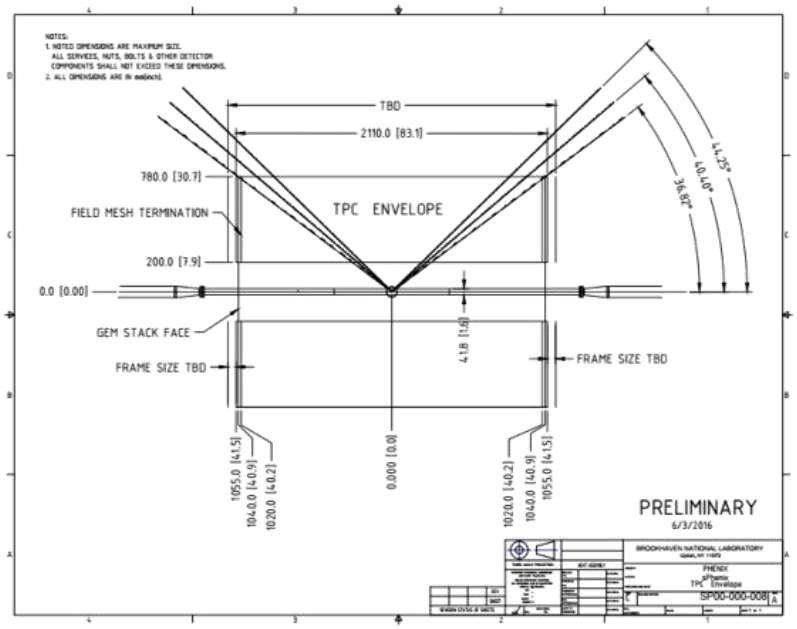
$$\sigma_{DCA} < 100\ \mu m$$

- Environmental constraints
  - Central Au+Au multiplicity @ full RHIC Energy
  - Full RHIC-II Luminosity
    - 100 kHz raw, 15 kHz w/in vertex
  - Requires gateless TPC



Project Scope

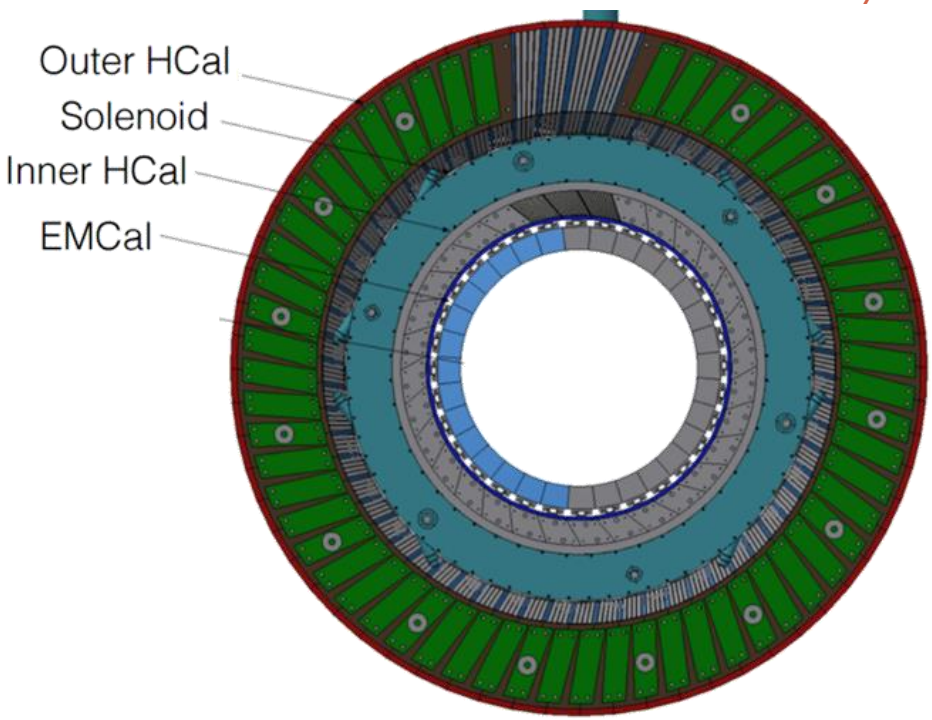


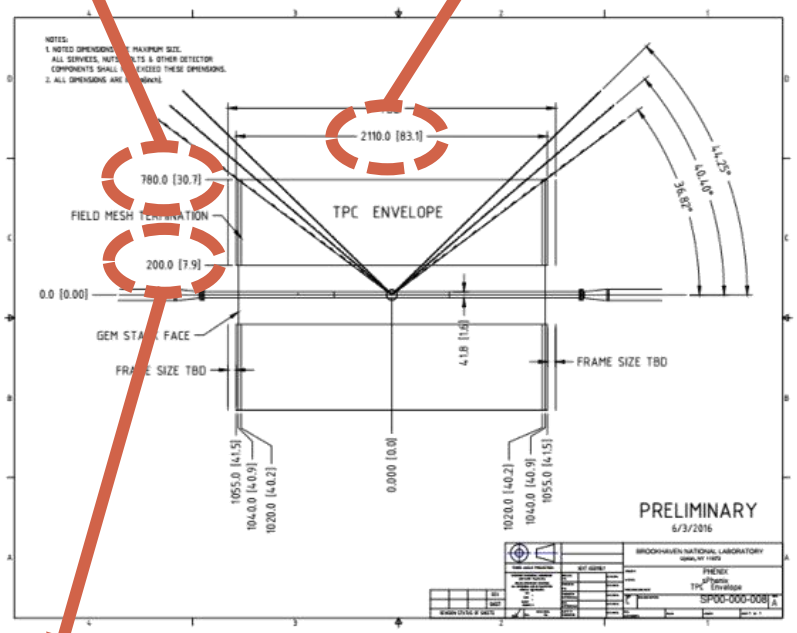


Project Scope

l = 2110.0 mm (83.1 in)

OR = 780.0 mm (30.7 in)





IR = 200.0 mm (7.9 in)

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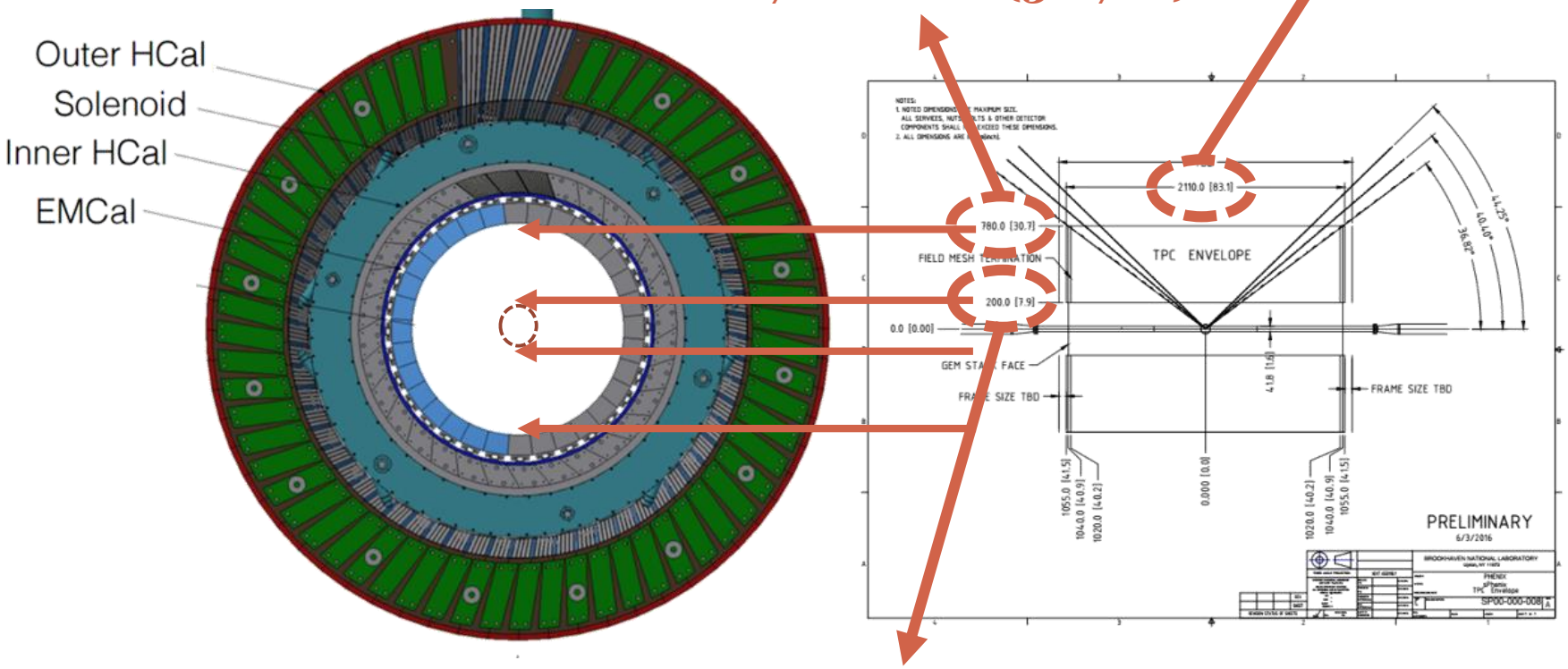

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