MVTX Overview (WBS 3.2)

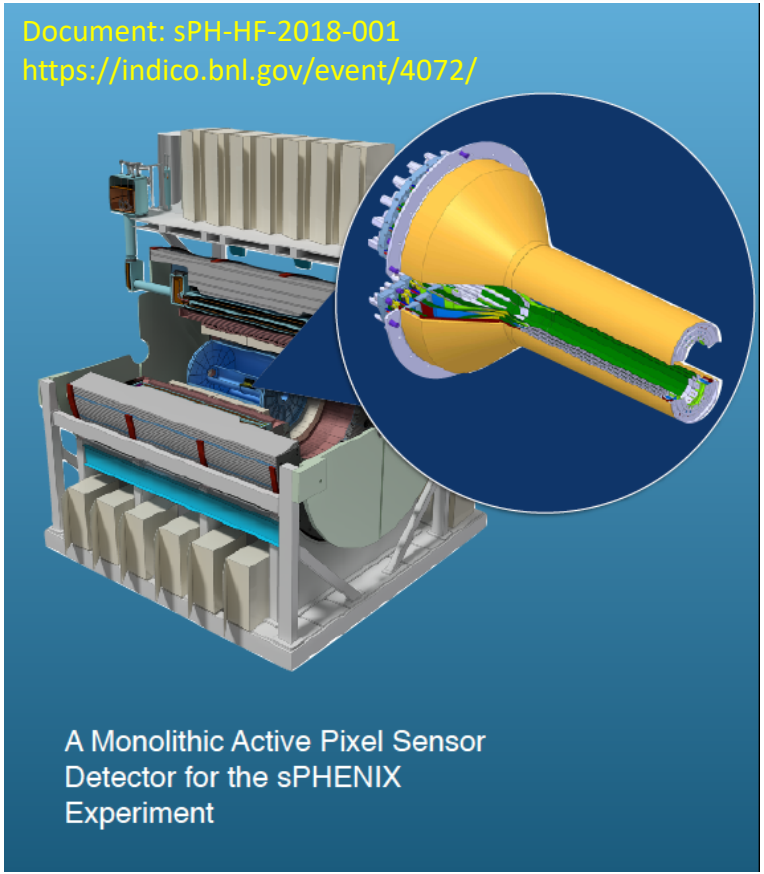
Ming Liu, LANL

April 9-11, 2019

BNL Director's Review

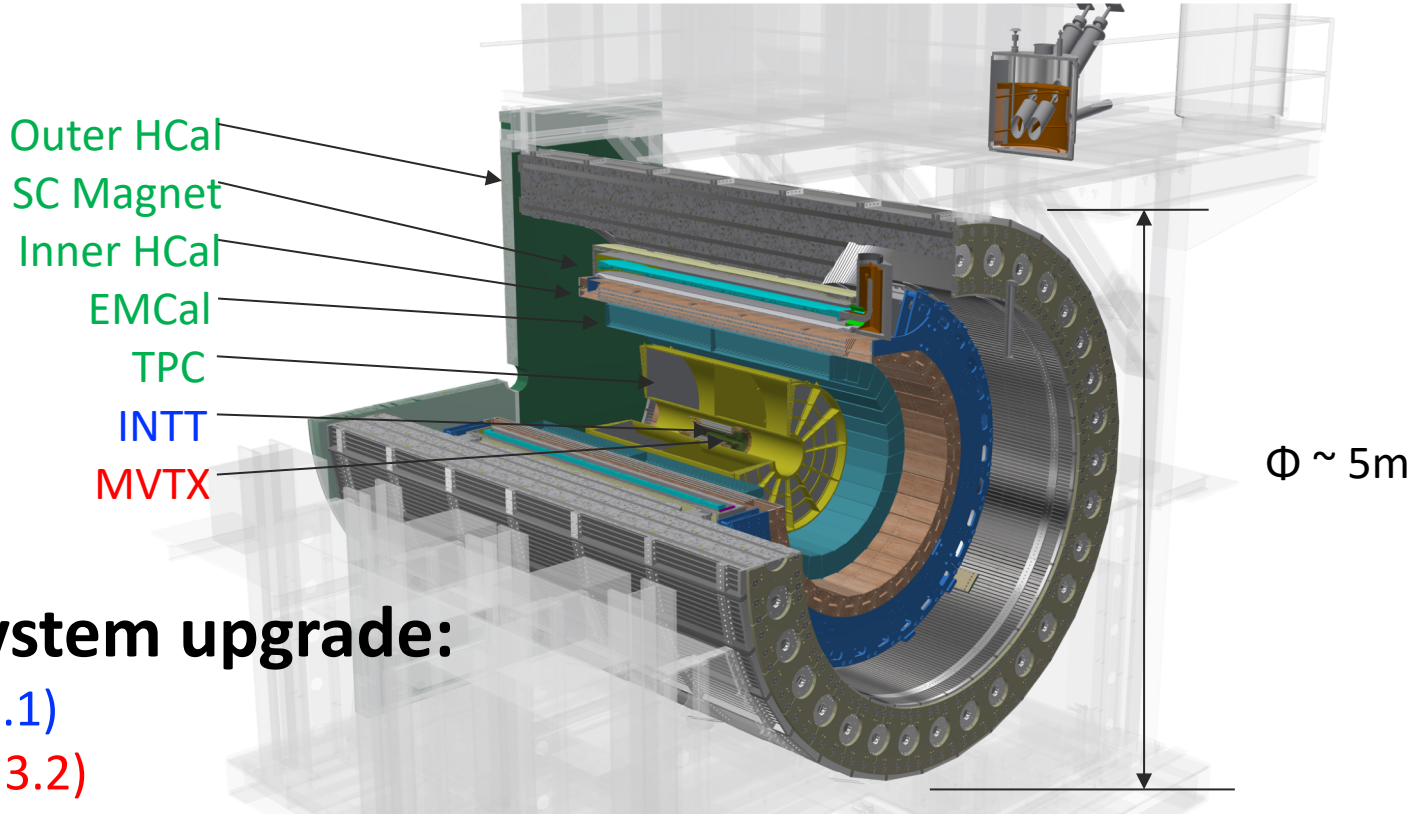
Outline

- MVTX science & technology
- MVTX scope
- Cost & schedule
- Status & highlights
- Issues and concerns



MVTX:
Monolithic-active-pixel-sensor based **V**er**T**e**X** detector

The sPHENIX Detectors



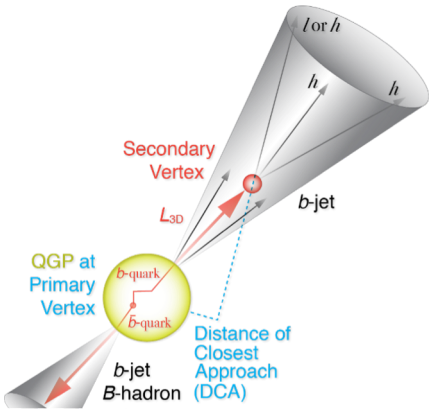
Tracking system upgrade:

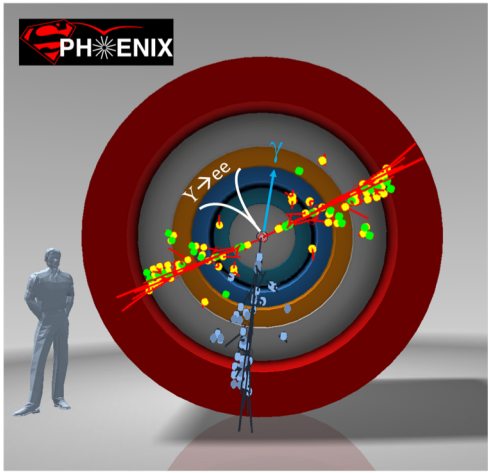
- INTT (WBS 3.1)
- MVTX (WBS 3.2)

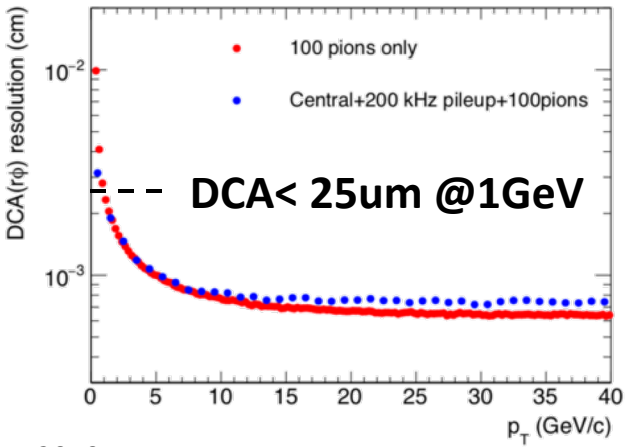
MVTX Enables the 3rd Science Pillar

1. Jets
2. Upsilons
3. Open Heavy Flavor

- Bottom quarks are heavy (4.2 GeV)
- Produced in initial collision, probe QGP evolution
- Well controlled in pQCD
- Access fundamental transport properties of QGP







- Precision tracker + High rate capability
  → Precision bottom observables over wide scales in p+p, p+A and A+A

- Initial observables:
  - ***B*-meson @ p_T <10 GeV/c**
  - ***b*-jet @ 15< p_T<50 GeV/c**

MVTX Technical Overview

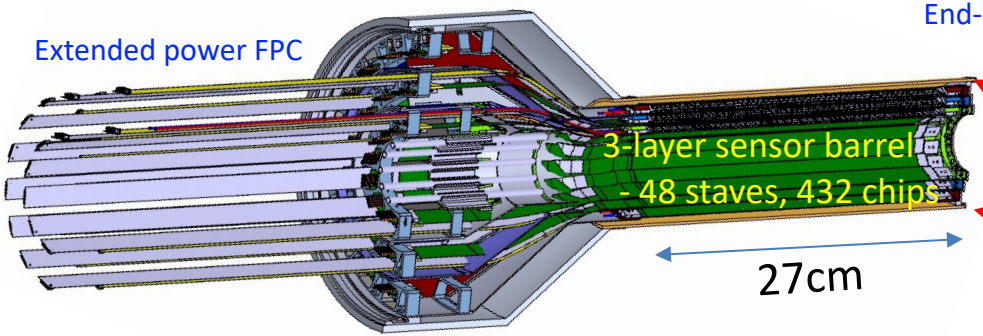
Ross & Yuan's talks

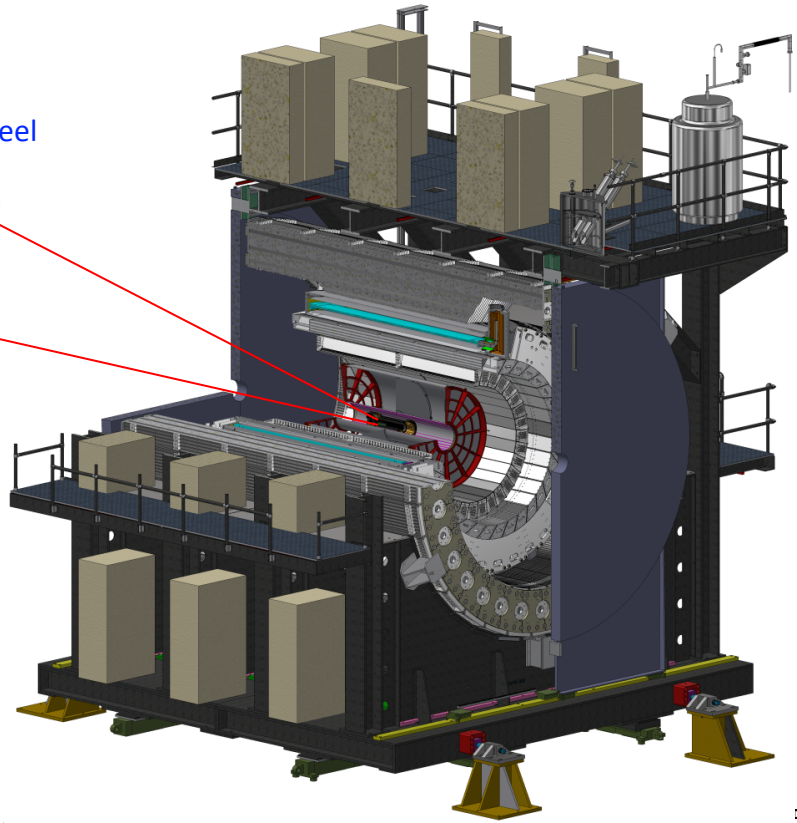
Service cone: signal, power, cooling
and mechanical support

CYSS: Cylindrical Shell Structure

End-Wheel

Extended power FPC





MVTX parameters

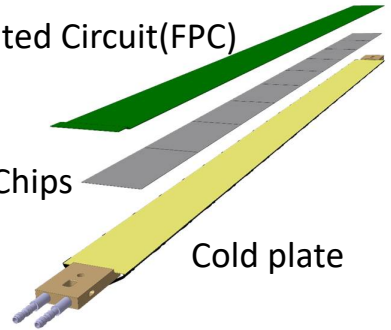
	Layer 0	Layer 1	Layer 2
Radial position (min.) (mm)	23.7	31.4	39.1
Radial position (max.) (mm)	28.0	35.9	43.4
Length (sensitive area) (mm)	271	271	271
Active area (cm^2)	421	562	702
Number of pixel chips	108	144	180
Number of staves	12	16	20

Monolithic Active Pixel Sensors (MAPS)

The Next-Generation, State-of-the-Art Pixel Tracker

Advantages of ALICE PIxel DEtector (ALPIDE) sensor:

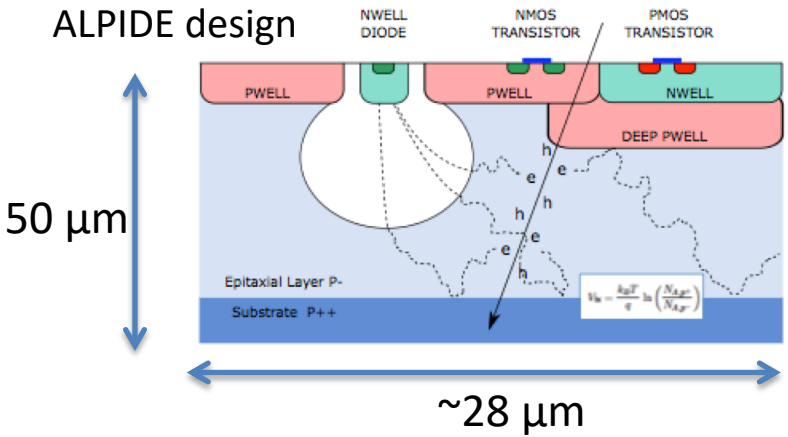
- Very fine pitch (27μm x 29μm), for superb spatial resolution
- High efficiency (>99%) and low noise (<10^{-6}), for excellent tracking
- Time resolution, as low as ~5 μs, for less pileup
- Ultra-thin/low mass, 50μm (~0.3% X_0), for less multiple scatterings
- 0.5M channels with on-pixel digitization, for zero-suppression and fast readout
- Low power dissipation, 40mW/cm^2, for minimal service materials



An ideal detector for QGP physics!

A 9-chip MAPS stave, 1.5cm x 27cm

ALPIDE design

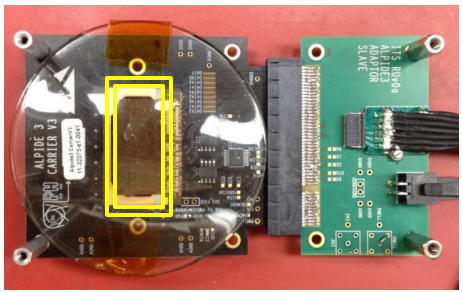


Tower Jazz 0.18 μm CMOS

- feature size 180 nm
- metal layers 6
- gate oxide 3nm

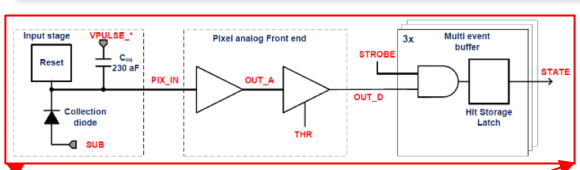
substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

ALPIDE sensor:
1.5cm x 3.0cm, 0.5M pixels

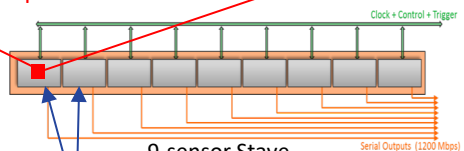


MVTX Readout, Power and Controls

Jo's talk



one pixel



9-sensor Stave

Alpide Sensors

FPC

Cold Plate

Power

Flex PCB Filtering Capacitors

9 Data (1.2Gbps)
1 Clock, 1 Control/Trigger

Samtec Twinax "FireFly"

Regulated Power

Readout Unit Front End

regulators

Power Board

Pow er

CAEN Power supplies

CAN bus

DCS

Trigger & Clock

GBT Optical Links

Control

Data (9.6 Gb/s max)

Trigger

FELIX Back End

ATLAS Front-End Link eXchange (FELIX):

sPHENIX Data Aggregation Module(DAM)

Interaction Region | Experimental Hall | Counting House

ALPIDE pixel:

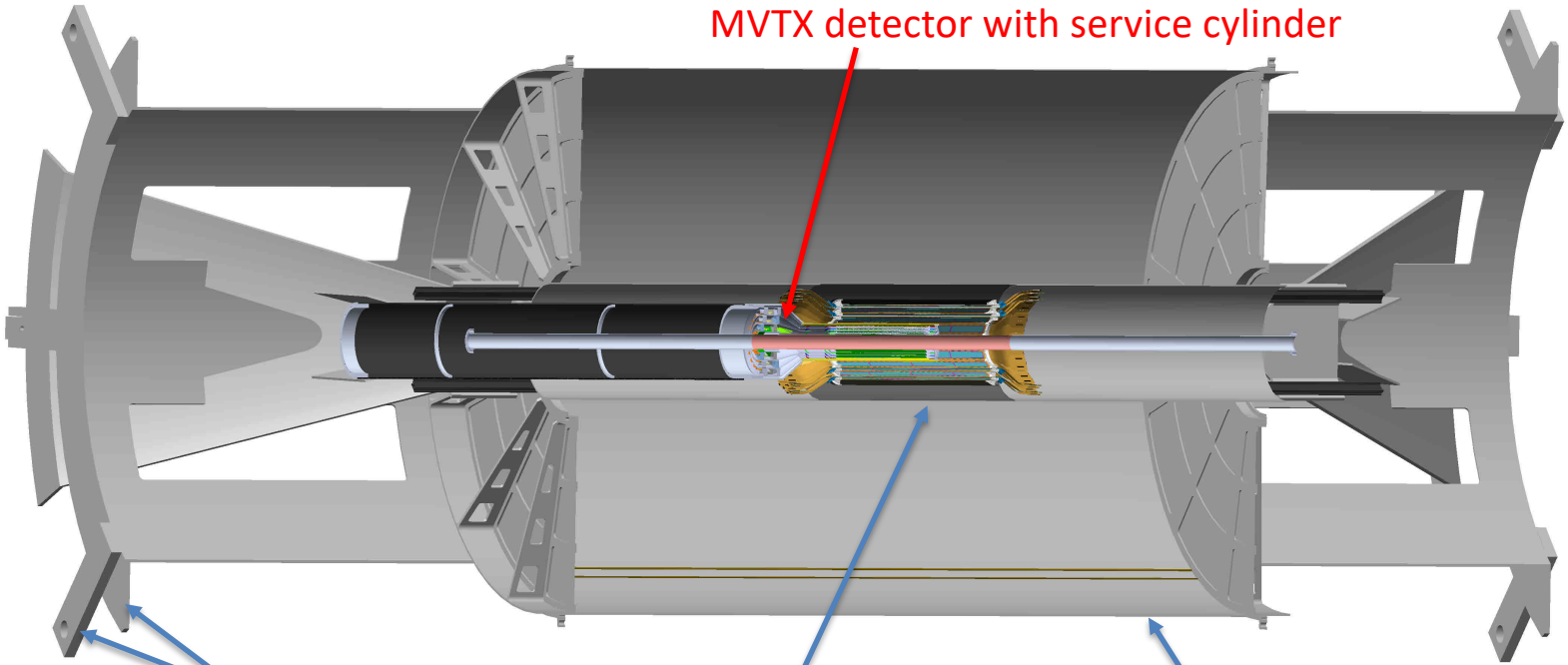
- Shaping
- Digitization
- Zero-suppression
- 3x buffer

MVTX Detector Electronics consists of three parts

Sensor-Stave (9 ALPIDE chips) | **Front End**-Readout Unit | **Back End**-FELIX/DAM

MVTX Detector in sPHENIX

Ross' talk

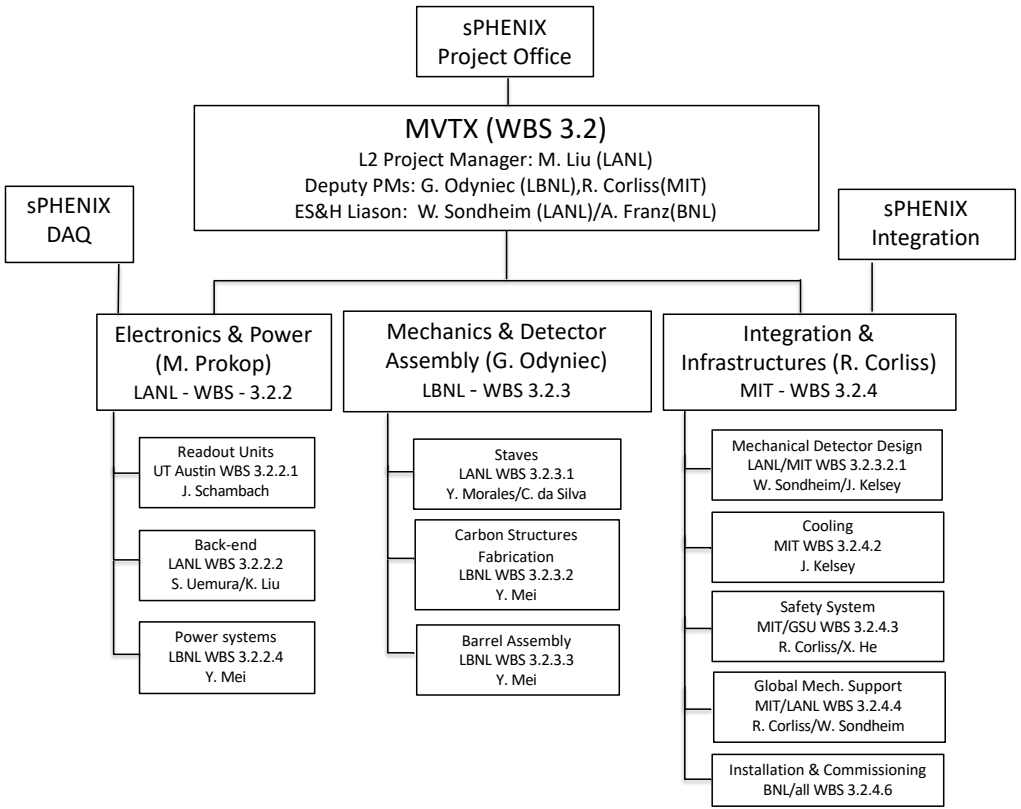


MVTX Scope

- Mechanical structure design
  - Design & FEA, LANL/MIT
  - End Wheels
  - Cylindrical structure shells
  - Detector service half barrels
  - Service patch panels
  - Global interface
- Mechanical structure fabrication
  - Composite structures, LBNL
  - Non-composite structures, MIT
  - Installation tooling etc., MIT/LANL/LBNL/BNL
- Ancillary systems – “adopt” ALICE/ITS
  - Cooling plant, MIT/BNL
  - Slow control & monitoring etc., MIT/GSU
- MVTX electronics
  - Backend FELIX and cables
  - Integration into sPHENIX DAQ
  - Power system
- Detector assembly & test
  - Stave QA & half detector assembly @LBNL
  - System test & integration @LBNL/BNL
- Installation & commissioning, by all
  - Pre-installation commissioning @BNL
  - Installation @IR

Early generic R&D accomplished through LANL LDRD
- Readout integration
- Detector conceptual design

MVTX Collaborators & Institution Roles



Los Alamos National Laboratory (LANL) : Overall readout electronics and mechanical system integration, project management.

Brookhaven National Laboratory (BNL) : Global system integration and services, safety and monitoring, project management.

Lawrence Berkley National Laboratory (LBNL) : Carbon structure production, LV and HV power system, full detector assembly and test, project management.

Massachusetts Institute of Technology (MIT/Bates) : Global mechanical system integration and cooling.

Massachusetts Institute of Technology (MIT) : Stave assembly and test at CERN.

University of California at Los Angeles (UCLA) : Simulation and readout testing.

University of California at Riverside (UCR) : Detector assembly and test, simulations.

Central China Normal University (CCNU/China): MAPS chip and stave test at CERN and/or CCNU.

Charles University (CU/Czech) : MAPS stave production and QA.

University of Colorado (UCol) : *b*-jet simulations and future hardware.

Czech Technical University (CTU/Czech) : MAPS stave production and QA at CERN.

Florida State University (FSU) : Offline software and simulations.

Georgia State University (GSU) : Online software and trigger development.

Iowa State University (ISU) : Detector assembly and test, simulations.

National Central University (NCU/Taiwan)* : Stave assembly and test, simulations.

University of New Mexico (UNM) : Cabling & connectors.

New Mexico State University (NMSU) : Tracking algorithm and physics simulations.

Purdue University (PU): Detector assembly and test, simulations.

Univ. of Science and Technology of China (USTC/China) : MAPS chip and stave test, simulations.

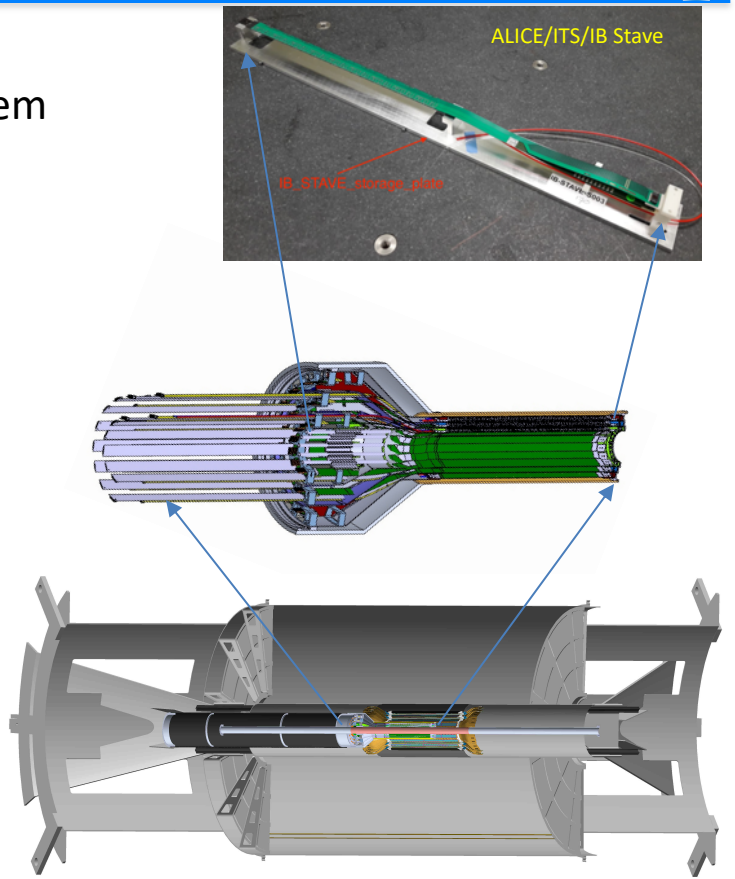
Sun Yat-Sen University (SYSU/China) : MVTX detector and physics simulations.

University of Texas at Austin (UTA) : MVTX readout electronics integration, Readout Units production and test.

Yonsei University (YSU/Korea) : MAPS chip production QA, readout electronics test and simulations

Schedule Drivers

- Budget availability
  - Final engineering design of the mechanical system
  - Production of support structures
- Mechanical structures
  - Detector and interface system design
  - Carbon structure fabrication
- Detector assembly and test
  - Assembly jigs design and fabrication
  - Detector assembly & QA
  - Metrology
- Final installation in IR
  - Last detector to be installed



Cost Drivers

MVTX Budget by L3 in AYk$		Burdened /Esc.		
WBS	**Level 2 WBS Description**	**OPC**	**TEC**	**Total**
3.2.01	Project Management	$0	$642	**$642**
3.2.02	Electronics	$0	$665	**$665**
3.2.03	Mechanics and Assembly	$0	$2,001	**$2,001**
3.2.04	Integration and Installation	$0	$1,023	**$1,023**
	Sub-total	**$0**	**$4,331**	**$4,331**
	Contingency	$0		**$0**
	Total Project Cost	**$0**	**$4,331**	**$4,331**

Mechanical design and fabrication

- CYSS
- End wheels
- Service barrel
- Global interface

Basis of Estimate & Resource-Loaded Schedules

- Electronics: production
  - FELIX: ATLAS/sPHENIX production, LANL/LDRD
  - RU services, cables: ALICE/ITS production, LANL/LDRD
  - Power boards: ALICE/ITS production , LANL/LDRD
  - CAEN bulk PS: Quotes from CAEN, ALICE/ITS production, LANL/LDRD

- Mechanics & Integration: design and production
  - CYSS, End wheels, Service barrel: ALICE/ITS
  - Integrations: Recent experience at RHIC, HFT/STAR, FVTX/PHENIX

WBS Number: 3.2.2.3 Backend Electronics - FELIX

MVTX BoE Doc

Technical scope:
This item contains all the backend readout electronics FELIX boards required for MVTX readout.

Work statement:
Produce 8 FELIX boards to integrate MVTX readout electronics into the sPHENIX DAQ system.

Assumptions used in developing estimate:
We will use the ATLAS FELIX v2.0 PCIe board developed by the BNL group for the ATLAS upgrade. The FELIX board production quote for sPHENIX was obtained in 2018, about $8K per board. A total of 8 FELIX boards (6 + 2 spares) are required for MVTX.

Cost Summary:

Total (K)	M&S	Labor	Contingency (average)
122	103	19	25%

FELIX

Labor, M&S

POM02B_3.02.3.02.02.02 FELIX 2.0		254	01-Apr-19	03-Apr-20	392	186	88400	$18,588	$103,640	$122,229
S103000	Produce Felix 2.0 first production unit - Labor	Liu, Ming	57	01-Apr-19	19-Jun-19	218	16	0	[illegible]	$3,073
S103100	Procure Optical Fiber - Labor	Liu, Ming	121	01-Apr-19	19-Sep-19	414	2	0	$307	$0	$307
S103200	Produce Felix 2.0 first production unit - M&S	Liu, Ming	57	01-Apr-19	19-Jun-19	218	0	20000	$0	$22,778	$22,778
S103300	Procure Optical Fiber - M&S	Liu, Ming	121	01-Apr-19	19-Sep-19	414	0	50	$0	$63	$63
S103400	Test/QA 1st Felix Unit and Fibers	Liu, Ming	10	20-Sep-19	03-Oct-19	414	40	0	$0	$0	$0
S103500	Procure 7 Felix 2.0 Remaining Units -Provide Requirements to Procurement	Liu, Ming	5	06-Nov-19	13-Nov-19	392	6	0	$1,187	$0	$1,187
S103600	Procure 57 Optical Fiber Sets - Labor	Liu, Ming	20	06-Nov-19	06-Dec-19	462	2	0	$396	$0	$396
S103700	Procure 57 Optical Fiber Sets M&S	Liu, Ming	20	06-Nov-19	06-Dec-19	462	0	2850	$0	$3,634	$3,634

BROOKHAVEN NATIONAL LABORATORY

sPHENIX MVTX Project Detailed Schedule
Budgeted Cost Included
Data Date: 01-Oct-18 Published: 02-Apr-19 12:38

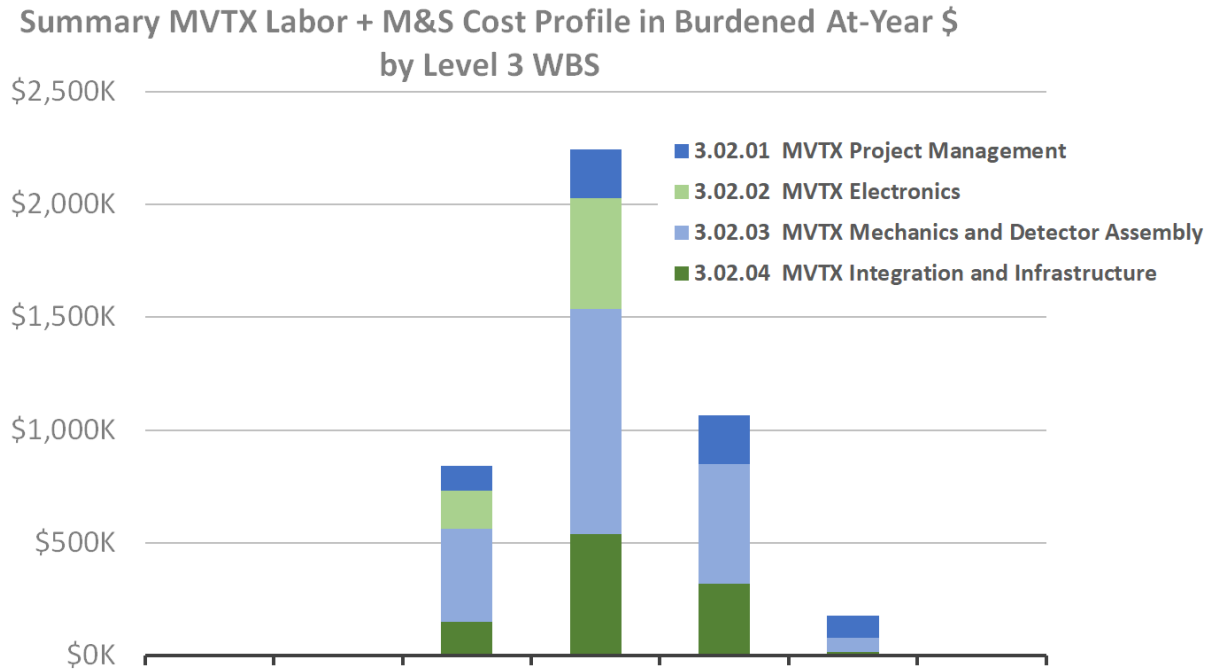
Carbon Structures

Labor, M&S

Activity ID	Activity Name	CAM	At Compl. Duration	Start	Finish	Total Float	Hours	Direct FY19$ - M&S	Burd AY$ - Labor	Burd AY$ - M&S	Burd AY$ - Total
S110400	ship from CERN to LBNL - Batch 1	Liu, Ming	7	27-Jun-19	08-Jul-19	318	0	600	$0	$7,500	$7,500
S110500	ship from CERN to LBNL - Batch 2	Liu, Ming	7	25-Sep-19	03-Oct-19	268	0	600	$0	$7,564	$7,564
S110600	ship from CERN to LBNL - Batch 3	Liu, Ming	7	27-Dec-19	07-Jan-20	219	0	600	$0	$7,650	$7,650
S110700	ship from CERN to LBNL - Batch 4	Liu, Ming	7	27-Mar-20	06-Apr-20	169	0	600	$0	$7,650	$7,650
POM02B_3.02.3.02.03.02	Carbon Structures		741	01-Apr-19	17-Mar-22	0	5774	368511	$910,025	$472,154	$1,382,179
POM02B_3.02.3.02.03.02.01	Mechanics Detector Design		80	01-Apr-19	23-Jul-19	0	640	0	[illegible]	$0	$167,952
S110800	Develop MAPS inner tracker mechanical model	Liu, Ming	80	01-Apr-19	23-Jul-19	0	640	0	$167,952	$0	$167,952
POM02B_3.02.3.02.03.02.02	End Wheels		277	24-Jul-19	28-Aug-20	54	502	72000	$73,964	$90,875	$164,839
S110900	Design End-wheels	Liu, Ming	15	24-Jul-19	13-Aug-19	54	120	0	$36,658	$0	$36,658
S111000	Prototype End-wheels - M&S	Liu, Ming	30	14-Aug-19	25-Sep-19	54	0	10000	$0	$12,500	$12,500
S111100	Prototype End-wheels - Labor	Liu, Ming	30	14-Aug-19	25-Sep-19	54	12	0	$2,305	$0	$2,305

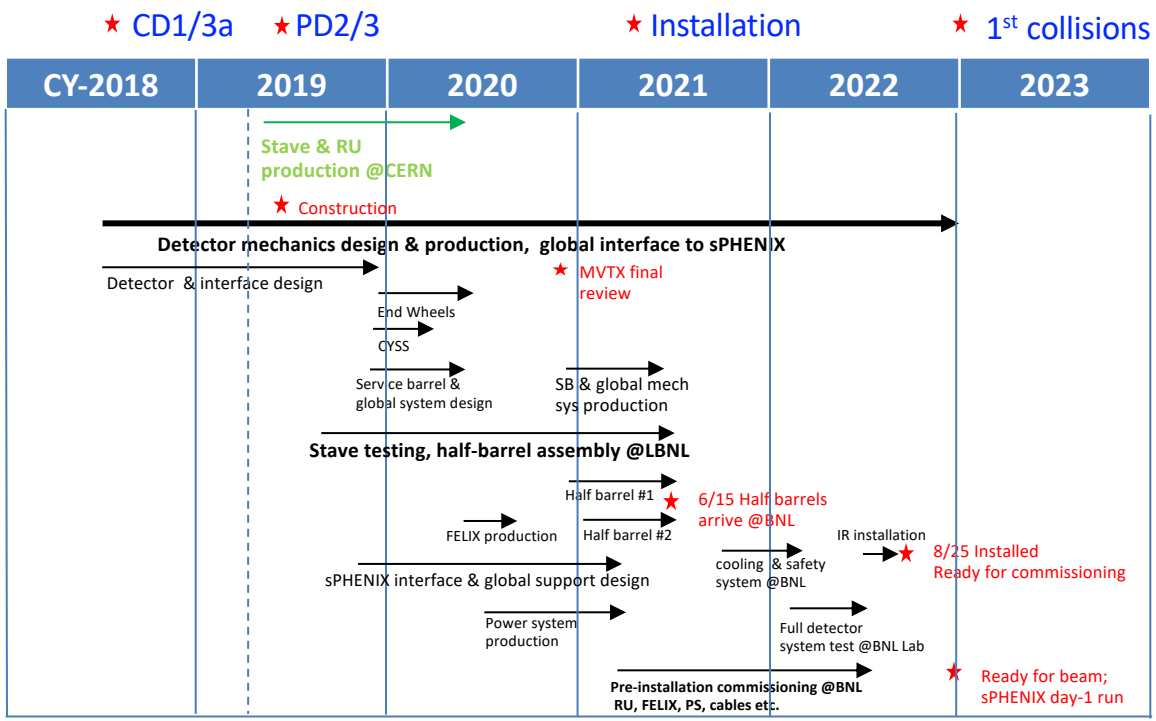
Resource Distribution

MVTX in P6



WBS Code and Name	FY17	FY18	FY19	FY20	FY21	FY22	FY23	Burdened AY$	Direct FY19$
3.02.01 MVTX Project Management			$ 110,219	$ 216,751	$ 216,269	$ 98,244		$ 641,483	$ 373,537
3.02.02 MVTX Electronics			$ 171,762	$ 493,205				$ 664,967	$ 506,824
3.02.03 MVTX Mechanics and Detector Assembly			$ 409,513	$ 997,208	$ 529,814	$ 64,163		$ 2,000,698	$ 1,289,696
3.02.04 MVTX Integration and Infrastructure			$ 150,963	$ 538,325	$ 317,878	$ 15,892		$ 1,023,058	$ 651,708
Grand Total			**$ 842,457**	**$ 2,245,489**	**$ 1,063,961**	**$ 178,298**		**$ 4,330,205**	**$ 2,821,765**

MVTX Schedules and Milestones

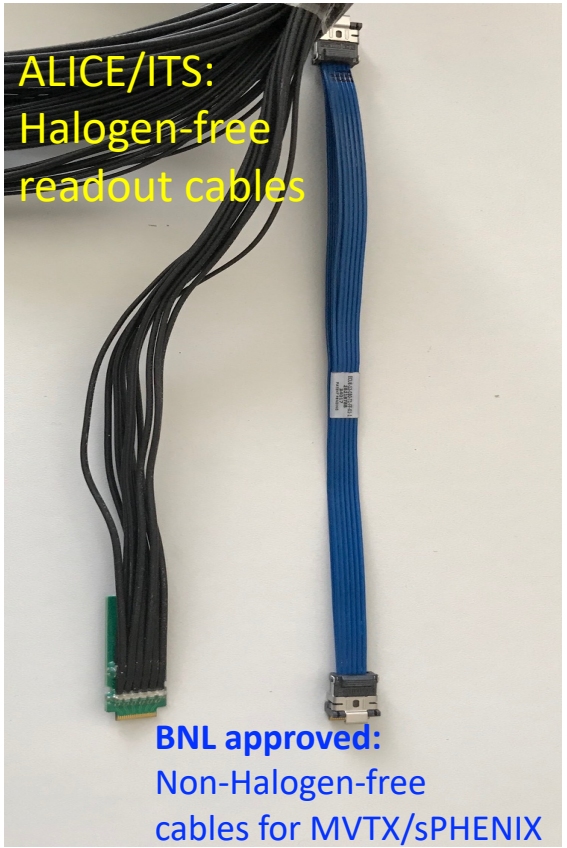


Feb. 2019, in P6

Today

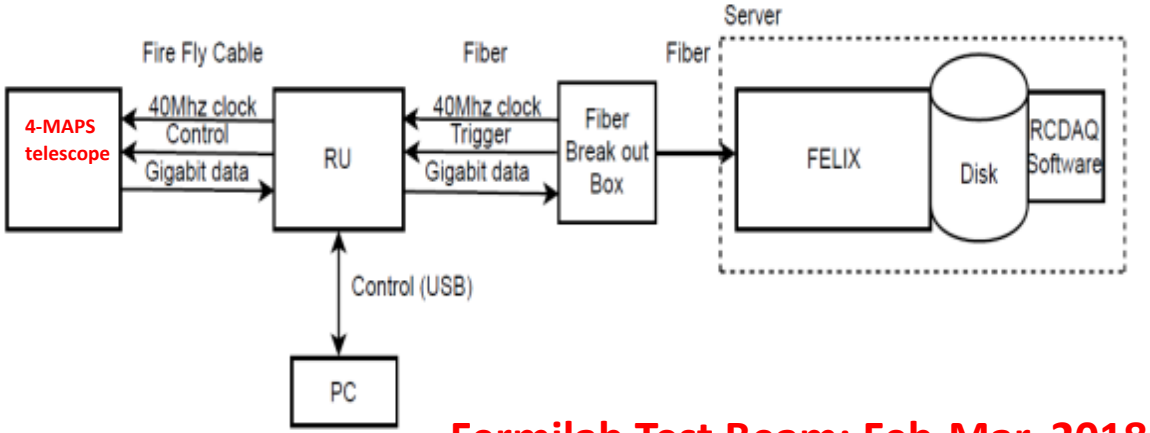
Status and Highlights

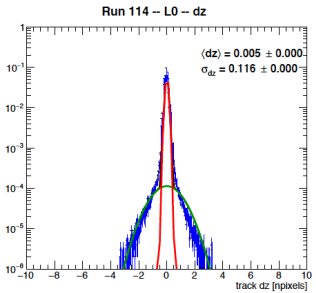
- Full readout chain demonstrated through LANL LDRD
  - Successful Fermilab Test Beam run in 2018
- Modified stave certified through LANL LDRD
  - Successfully tested at CERN
  - Radiation hardness verified at CERN
- Mechanical system integration MVTX+INTT
  - sPHENIX tracking optimized with 2-layer INTT configuration
  - Mechanical design being updated and 3-D mockup demonstrated
- Readout cables
  - BNL approved the use of SamTec non-Halogen-free cables
    - Electrically better & mechanically compact
    - ALICE confirmed performance with 8m long Halogen-free cables
    - For MVTX, ~10m very likely work (30AWG/sPHENIX vs 32AWG/ALICE)
  - Samples (6.5 ~ 11.5m long) ordered for R&D test at LANL
    - To be tested in coming months

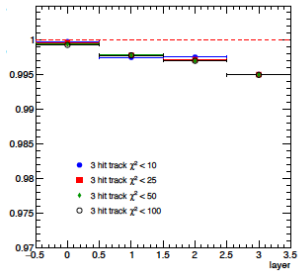


BNL approved:
Non-Halogen-free
cables for MVTX/sPHENIX

MVTX Full Readout Chain Demonstrated (3/2018)

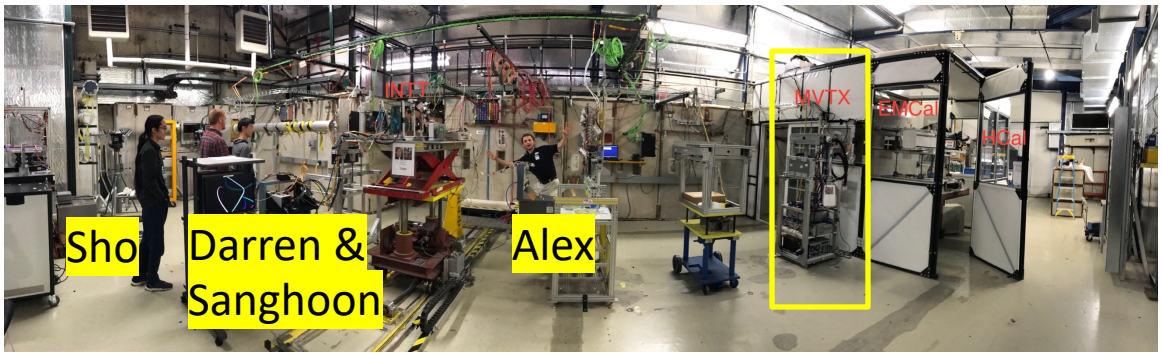


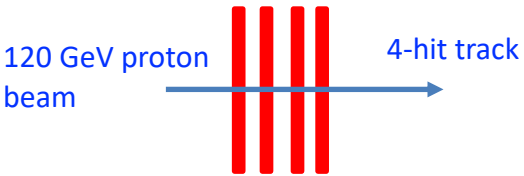




- **Tracking spatial resolution: <5 um**
- **Hit efficiency: > 99.5%**

Fermilab Test Beam: Feb-Mar, 2018

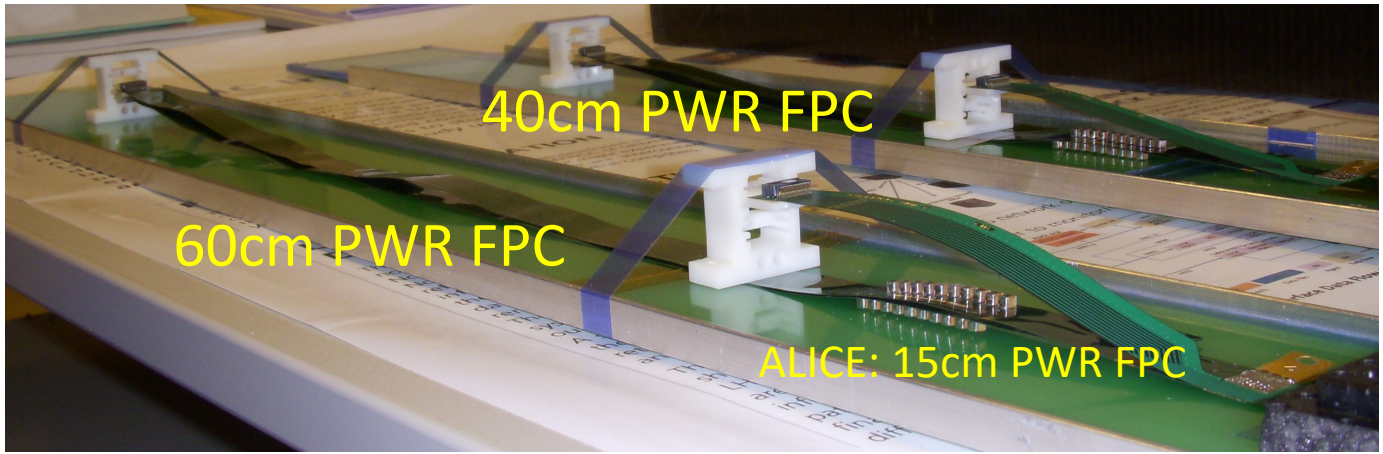


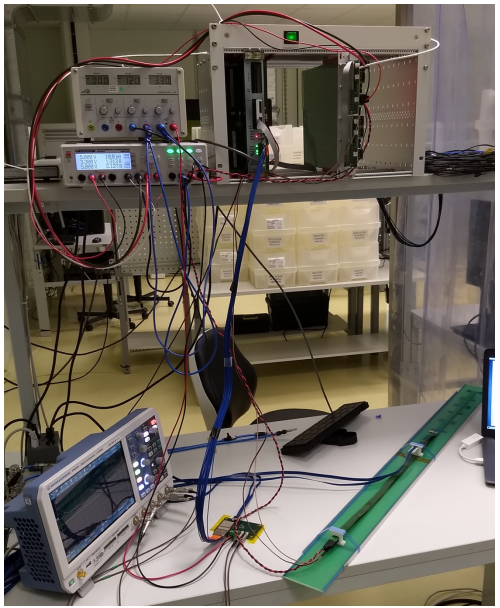


4-MAPS telescope

Confirmed HIC with Extended 40(60)cm Power FPC

- Built and tested two HICs at CERN in 9/2018
  - **No change in sensor performance (noise, threshold) observed, as expected;**





Followed identical ALICE IB QA test procedure, with a 8m SamTec cable!

Sensor Irradiation Test – OK at 2.7MRad

- Continuous effort by ALICE (@NPI, Czech)
- BNL Director's review recommendation:
  - **Test sensors up to 1MRad**

ALICE/ITS report: 2.7 MRad

https://indico.cern.ch/event/758048/

Conclusion

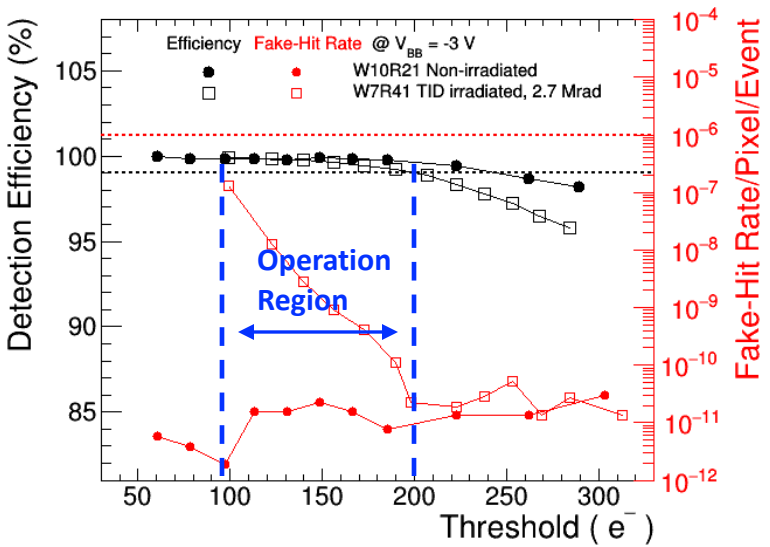
Irradiated ALPIDE sensor (2700 krad) over a large range of threshold settings

has :

1) good efficiency up to threshold ~190 e (Ithr = 100 DAC units)
at Vbb = - 3 V, Vcasn = 90, Vcasn2 = 102

2) fake hit rate remains orders of magnitude
smaller than the requirement (<< 10^{-6})

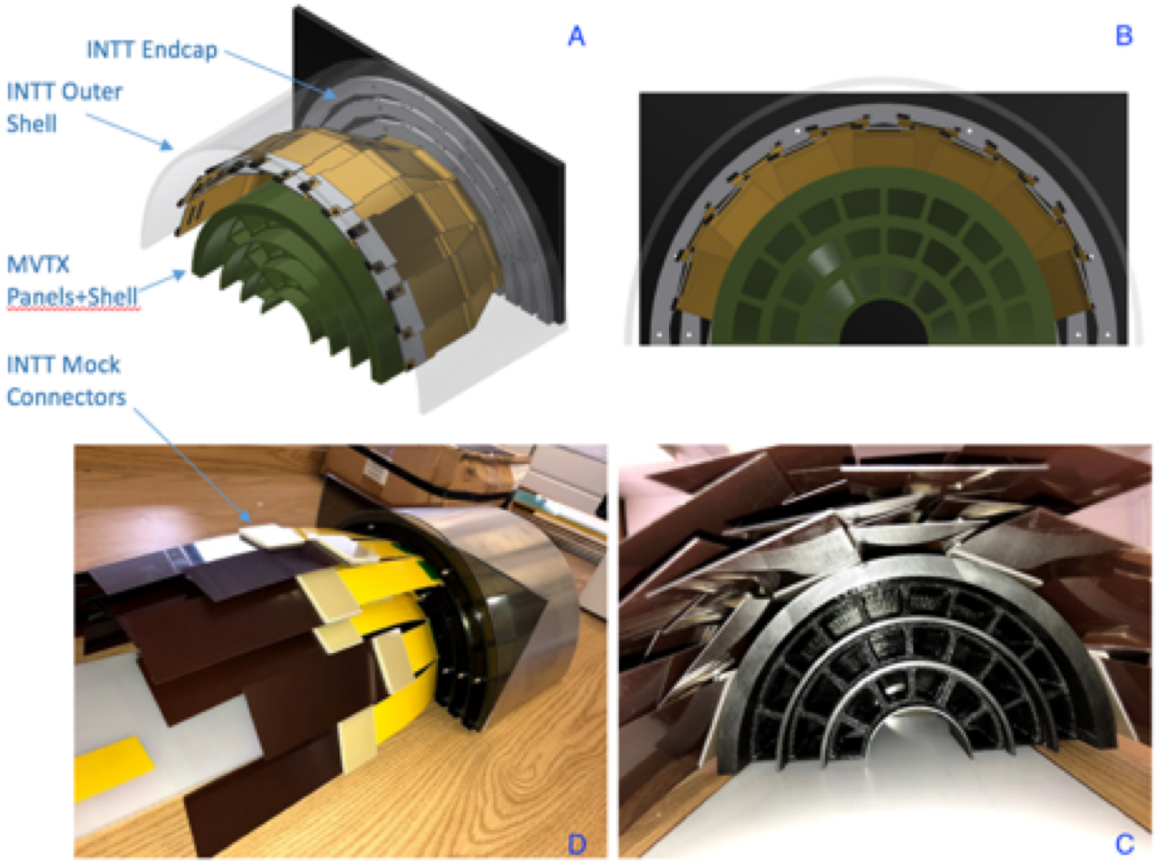
Irradiated chip#41 (2.7Mrad) : efficiency & fake hit rate



red line - fake hit rate- sensitivity limit of ALPIDE
black line - efficiency - the project goal (99%)

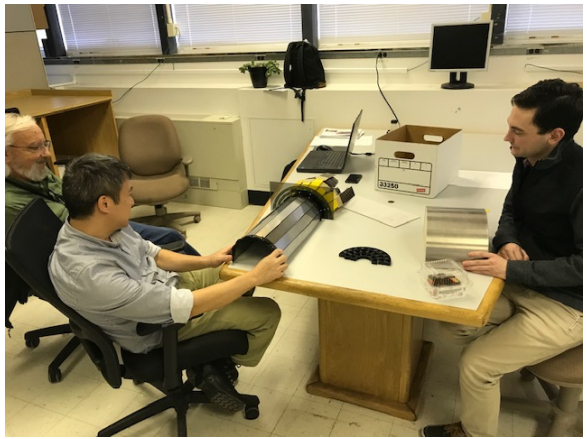
For non irradiated 2 noisy pixels were masked out.
No pixel was masked out for the 2.7Mrad chip.

MVTX + INTT 3-D Mockup (11/2018)



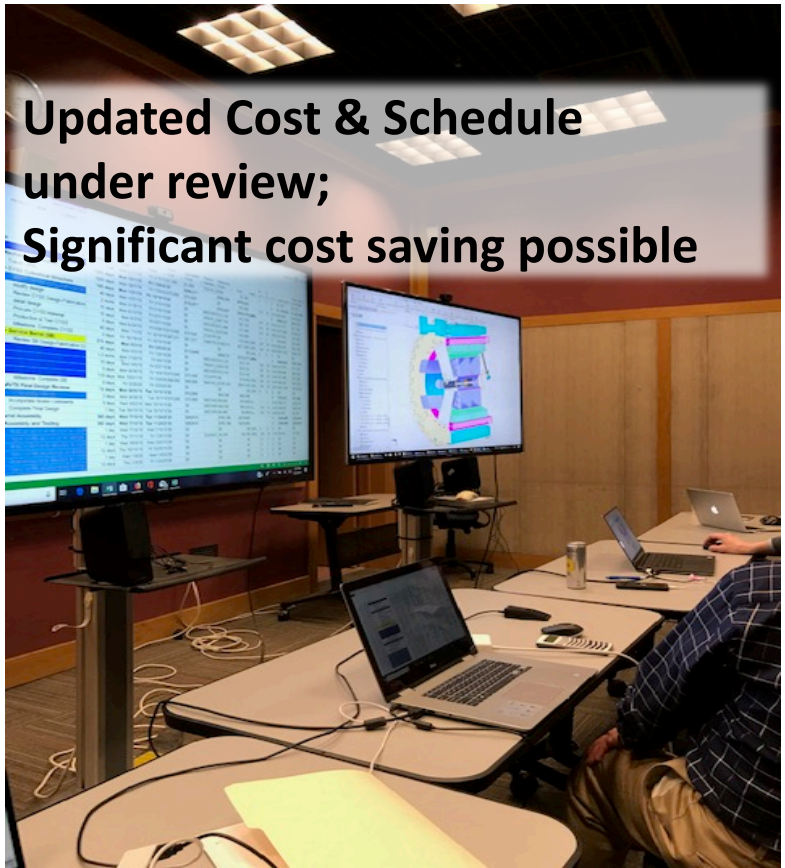
Office of System Integration
– led by Mickey & Bob,
a team of engineers and physicists

MVTX and INTT
Space conflict resolved!



Latest Project Update: MVTX Workshop

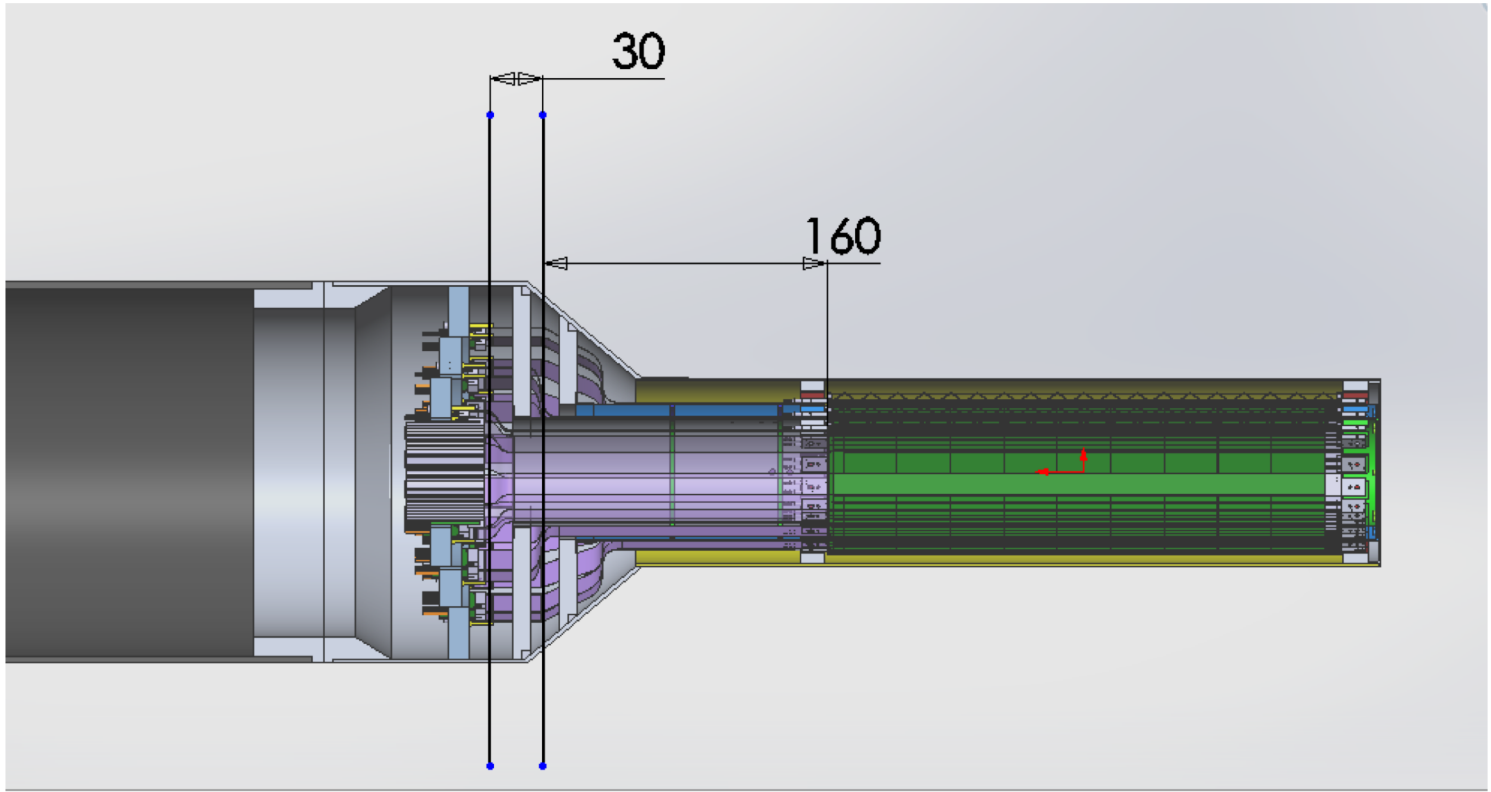
Feb. 28 – Mar. 2, 2019, MVTX/HF Workshop @LBNL



Carbon Structures – Work in Progress

Ross' talk

- Conical sectors are expensive!
- A new design under development to avoid the conical structures, MIT/LANL



Issues and Concerns

- Budget availability
  - Funding for final mechanical system design work
    - Early R&D to reduce high production contingency
  - Preparation for Stave acceptance test/QA/storage at LBNL (3 months lead time)
  - Schedule is closely tied to the funding level

- Carbon structures
  - Cost and schedule, high contingency in cost
  - Window of opportunity at LBNL before ATLAS production
  - Other possible production sites (Italy, France, Korea …)

- Mechanical system integration
  - sPHENIX beam pipe modification, under discussion with CAD
  - Readout cables, cooling etc.
  - MVTX+INTT+TPC… global support structure design

Summary

- MVTX enables the 3rd science pillar
- MVTX detector design & construction
  - As a separate upgrade project from the baseline sPHENIX MIE
  - Engineering design work in progress, MIT/LANL/LBNL et al
    - **Need budget now for the final engineering design work**
  - Construction and assembly work planned for late 2019
- Project integrated into the sPHENIX P6
  - Latest Cost & Schedule under review, significant cost saving possible
  - To be implemented in P6 after this review
- Successful generic R&D through LANL LDRD support
  - Readout integration
  - Stave modification
  - Mechanical system conceptual design
- MVTX is ready to receive project funding

backup

Address July 2018 Review Recommendations

Stave and RU procurement readiness

- Completed sensor/HIC/stave evaluations at CERN
  - **Built, tested and confirmed two HICs with 40cm and 60cm long power FPC**
  - **Sensors irradiated up to 2.7MRad, no issues (updated 9/18/2018).**
- **Addressed all recommendations on stave/sensor R&D**

https://docs.google.com/document/d/1vsm_G7ZLgqv-kBZqK0jF69T_Nx2Uwk0Zxv86jRVxybw/edit?usp=sharing

Cost are set for staves & RUs, procurement through US-ALICE/UTK

  - **Technical specs document completed for production, BNL/DOE agreed**
  - **sPHENIX RU and stave production starts ~May 2019**
- MVTX/INTT mechanical integration
  - **Mechanical design being updated and 3-D mockup demonstrated**
  - **Inner tracking task force completed evaluation, preferred INTT-layers =2**
- Readout cables
  - **BNL approved the use of SamTec blue cables**
    - **Electrically better & mechanically compact**
    - **ALICE confirmed signal performance with 8m long readout cables. For MVTX, 10m very likely works (30AWG/sPHENIX vs 32AWG/ALICE), to be confirmed by on-going R&D at LANL**
  - **Samples ordered for system integration mockup and test**

Stave and RU Production QA Plan Documents Available

https://indico.bnl.gov/event/4729/

Staves

- Purchase 84 staves from ALICE/CERN
  - **48 + 28(spares for 2 inner layers) + 8 spares**
  - **Production following the completion of ALICE ITS/IB**
  - **Starting ~Oct. 2018, will last 6-12 months**
  - **Fully tested at CERN before shipping to US**
    - **All Gold/Silver staves (same as ALICE IB)**
    - **A LANL postdoc (Dr. Yasser Morales) oversees production QA at CERN**
- Acceptance QA at LBNL
  - **Full test and QA**
    - **Electrical**
    - **Mechanical**
  - **Detector assembly at LBNL**

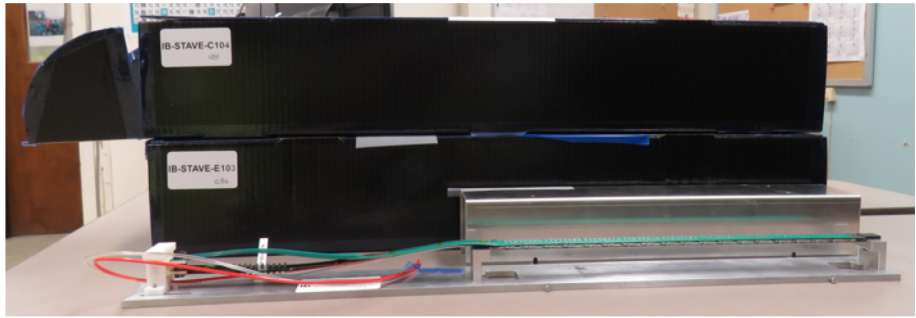
Readout Units

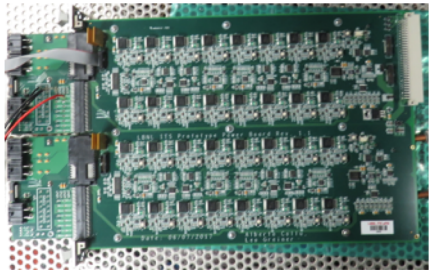
- Purchase 60 RUs from ALICE/CERN
  - **48 + 12 spares(20%)**
  - **To be part of ALICE production**
    - **Cost saving**
    - **Minimize technical risks**
  - **Initial test at CERN**
- Acceptance QA at UT-Austin
  - **Full test**
  - **LANL as the 2nd test site**

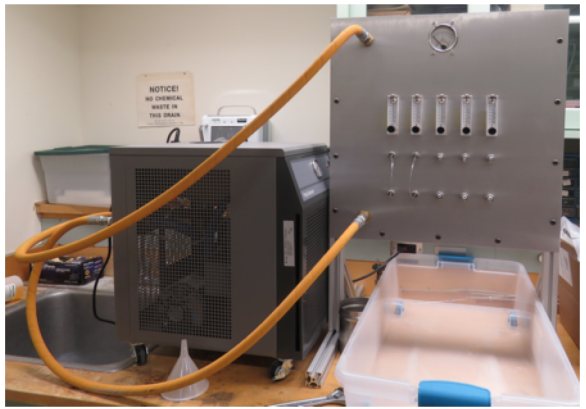
2019 Test Beam: 4-stave Telescope

Jo's talk

- Scheduled for May 22-29, at Fermilab
- Additions compared to the 2018 test beam:
  - Staves (from single chips)
  - Full-length MVTX signal cables (from 5 m off-the-shelf cables)
  - FELIX v2.0 (from v1.5)
  - Cooling system
  - Power board
  - sPHENIX GTM



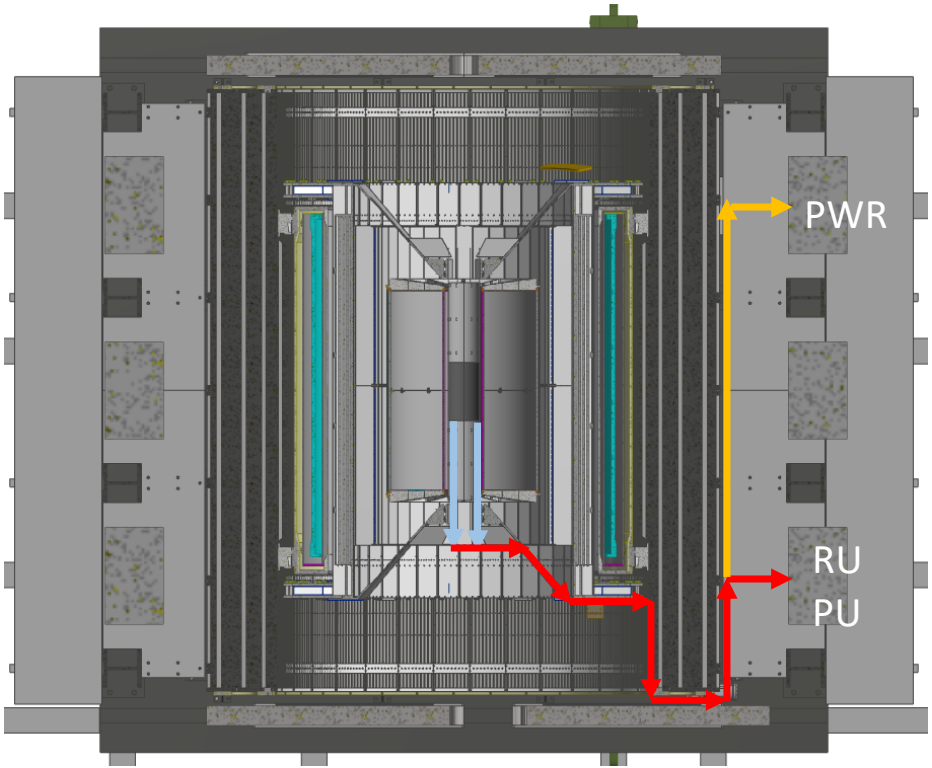




Full test of all components of the MVTX detector - LDRD "stretch goal"

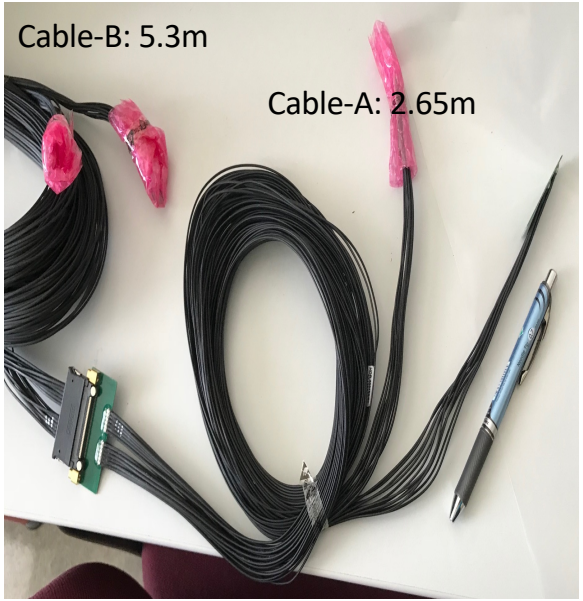
MVTX Readout and Power Cable Rout

Jo's talk



BNL has approved "non-halogen free" cables for sPHENIX

ALICE ITS/IB final readout cables: ~8m



sPHENIX MVTX: 7.9+m

Cable-A: 1.4 m

Cable-B: 6.5+ m

Power cable:4.7+ m

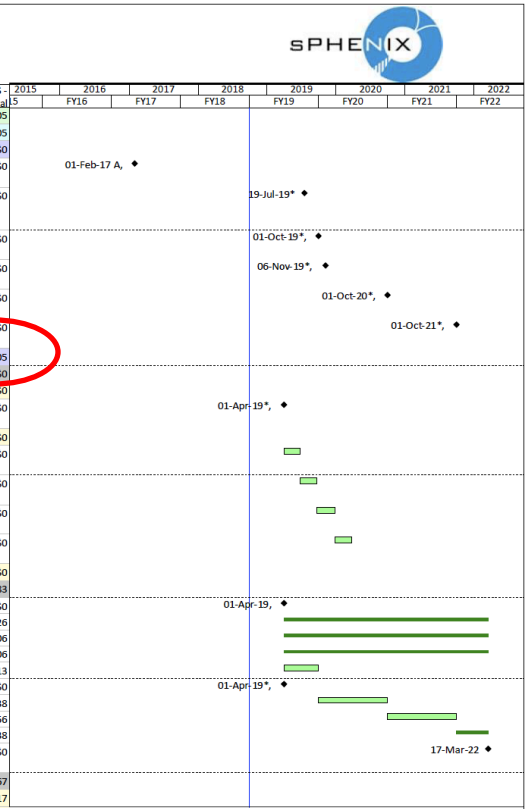
On-going R&D for ~10m

MVTX in P6 (fully Burd. & Esca.)

BROOKHAVEN NATIONAL LABORATORY

sPHENIX MVTX Project Detailed Schedule
Budgeted Cost Included
Data Date: 01-Oct-18 Published: 02-Apr-19 12:38

Activity ID	Activity Name	CAM	At Compl. Duration	Start	Finish	Total Float	Hours	Direct FY19$ - M&S	Burd AY$ - Labor	Burd AY$ - M&S	Burd AY$ - Total
POM02B_3.02	POM02 sPHENIX WBS 3.02 Preliminary Baseline [MVTX]		1281	01-Feb-17 A	17-Mar-22	0	26695	1266751	$2,760,452	$1,569,754	$4,330,205
POM02B_3.02.3	Silicon Detectors		1281	01-Feb-17 A	17-Mar-22	0	26695	1266751	$2,760,452	$1,569,754	$4,330,205
POM02B_3.02.3.00	(Temporary) External Placeholder Milestones in WBS 3x		1169	01-Feb-17 A	01-Oct-21	112	0	0	$0	$0	$0
EXT100090	[External Activity] Initial Project Funding Release	Sourikova, Irina	0	01-Feb-17 A			0	0	$0	$0	$0
EXT317000	[External Activity] Design/Safety Reviews Complete, Internal Detector Structural Support Released for Production	Pontieri, Chris	0		19-Jul-19*	319	0	0	$0	$0	$0
EXT101010	[External Activity] FY20 Funding Available	Sourikova, Irina	0	01-Oct-19*		417	0	0	$0	$0	$0
EXT147100	[External Activity] Procure TPC DAM Felix 2.0 Boards - Contract Award(s)	Hemmick, Tom	0	06-Nov-19*		392	0	0	$0	$0	$0
EXT101015	[External Activity] FY21 Funding Available	Sourikova, Irina	0	01-Oct-20*		362	0	0	$0	$0	$0
EXT101016	[External Activity] FY22 Funding Available	Sourikova, Irina	0	01-Oct-21*		112	0	0	$0	$0	$0
POM02B_3.02.3.02	MVTX		741	01-Apr-19	17-Mar-22	0	26695	1266751	$2,760,452	$1,569,754	$4,330,205
POM02B_3.02.3.02.00	Temporary		248	01-Apr-19	26-Mar-20	169	0	0	$0	$0	$0
POM02B_3.02.3.02.00.01	ALICE ITS Key Tasks		0	01-Apr-19	01-Apr-19	255	0	0	$0	$0	$0
S100000	ALICE ITS RU Production Start	Liu, Ming	0	01-Apr-19*		255	0	0	$0	$0	$0
POM02B_3.02.3.02.00.02	MVTX Stave Production at CERN		248	01-Apr-19	26-Mar-20	169	0	0	$0	$0	$0
S100100	Stave Production - Batch 1	Liu, Ming	62	01-Apr-19	26-Jun-19	169	0	0	$0	$0	$0
S100200	Stave Production - Batch 2	Liu, Ming	62	27-Jun-19	24-Sep-19	169	0	0	$0	$0	$0
S100300	Stave Production - Batch 3	Liu, Ming	62	25-Sep-19	26-Dec-19	169	0	0	$0	$0	$0
S100400	Stave Production - Batch 4	Liu, Ming	62	27-Dec-19	26-Mar-20	169	0	0	$0	$0	$0
POM02B_3.02.3.02.00.03	sPHENIX Milestones		0			0	0	0	$0	$0	$0
POM02B_3.02.3.02.01	MVTX Project Management		741	01-Apr-19	17-Mar-22	0	1858	37762	$592,839	$48,644	$641,483
S100500	Milestone Start MVTX	Liu, Ming	0	01-Apr-19		0	0	0	$0	$0	$0
S100600	Project Manager	Liu, Ming	741	01-Apr-19	17-Mar-22	0	1238	0	$395,226	$0	$395,226
S100700	Mechanical Integration Engineer	Liu, Ming	741	01-Apr-19	17-Mar-22	0	310	0	$98,806	$0	$98,806
S100800	Electronics Integration Engineer	Liu, Ming	741	01-Apr-19	17-Mar-22	0	310	0	$98,806	$0	$98,806
S100900	Travel FY19	Liu, Ming	128	01-Apr-19	30-Sep-19	112	0	6250	$0	$7,813	$7,813
S101000	MVTX Construction Start Approval	Liu, Ming	0	01-Apr-19*		0	0	0	$0	$0	$0
S101100	Travel FY20	Liu, Ming	251	01-Oct-19	30-Sep-20	112	0	12500	$0	$15,938	$15,938
S101200	Travel FY21	Liu, Ming	250	01-Oct-20	30-Sep-21	112	0	12500	$0	$16,256	$16,256
S101300	Travel FY22	Liu, Ming	112	01-Oct-21	17-Mar-22	0	0	6512	$0	$8,638	$8,638
S101400	MVTX Assembly Complete and Ready for Installation	Liu, Ming	0		17-Mar-22	0	0	0	$0	$0	$0
POM02B_3.02.3.02.02	MVTX Electronics		286	01-Apr-19	19-May-20	363	3863	395448	$195,007	$469,960	$664,967
POM02B_3.02.3.02.02.01	Readout Unit (RU)		193	01-Apr-19	07-Jan-20	453	1137	82428	$85,282	$100,435	$185,717



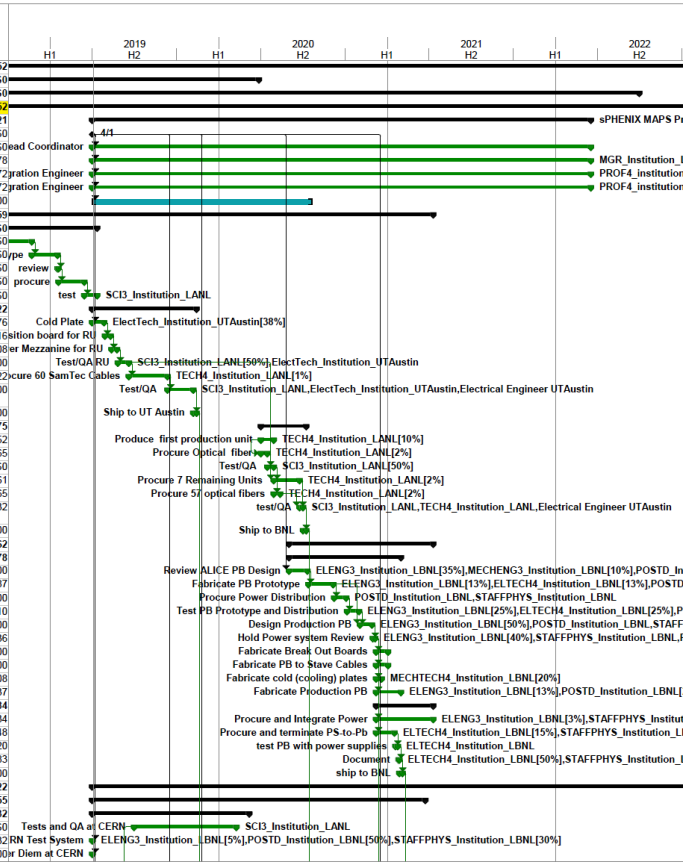
Page 1 of 11

Actual Work | Critical Rem. Work | Remaining Work | Actual LoE | Remaining LoE | Milestone

MVTX MS Project 1/4(for estimation)

Thu 4/4/19 — MVTX-Barrel-120718-04042019

ID	Task Mode	WBS	Task Name	Duration	Start	Finish	Fixed Cost	Calculated Fixed Cost	Resource Names	Resource Costs	Cost
1		3	**MVTX Inner Barrel**	1596 days	Mon 11/28/16	Fri 1/27/23	$0	$1,263,825		$2,902,127	$4,165,952
2		3.0	**ALICE ITS Key Tasks**	856 days	Mon 11/28/16	Fri 3/27/20	$0	$0		$0	$0
14		3.1	**sPHENIX Milestones**	1332 days	Mon 5/8/17	Fri 7/1/22	$0	$0		$0	$0
21		3.2	**MVTX Project**	1173 days	Wed 8/1/18	Fri 1/27/23	$0	$1,263,825		$2,902,127	$4,165,952
22		3.2.1	**MVTX Project Management**	774 days	Mon 4/1/19	Thu 3/17/22	$0	$50,000		$591,621	$641,621
23		3.2.1.1	Milestone Start MVTX	0 days	Mon 4/1/19	Mon 4/1/19	$0	$0		$0	$0
24		3.2.1.2	lead Coordinator	774 days	Mon 4/1/19	Thu 3/17/22	$0	$0		$0	$0
25		3.2.1.3	Project Manager	774 days	Mon 4/1/19	Thu 3/17/22	$0	$0	MGR_Ins	$394,478	$394,478
26		3.2.1.4	Mechanical Integration Engineer	774 days	Mon 4/1/19	Thu 3/17/22	$0	$0	PROF4_i	$98,572	$98,572
27		3.2.1.5	Electronics Integration Engineer	774 days	Mon 4/1/19	Thu 3/17/22	$0	$0	PROF4_i	$98,572	$98,572
28		3.2.1.6	Travel	342 days	Mon 4/1/19	Tue 7/21/20	$0	$50,000		$0	$50,000
29		3.2.2	**Electronics**	703 days	Wed 8/1/18	Fri 4/9/21	$0	$395,448		$203,311	$598,759
30		3.2.2.1	**Stave Extension Cable**	182 days	Wed 8/1/18	Thu 4/11/19	$0	$0		$0	$0
31		3.2.2.1.1	design	4 mons	Wed 8/1/18	Tue 11/20/18	$0	$0		$0	$0
32		3.2.2.1.2	prototype	2 mons	Wed 11/21/18	Tue 1/15/19	$0	$0		$0	$0
33		3.2.2.1.3	review	2 days	Wed 1/16/19	Thu 1/17/19	$0	$0		$0	$0
34		3.2.2.1.4	procure	2 mons	Fri 1/18/19	Thu 3/14/19	$0	$0		$0	$0
35		3.2.2.1.5	test	20 days	Fri 3/15/19	Thu 4/11/19	$0	$0	SCI3_Ins	$0	$0
36		3.2.2.2	**RU**	162.63 days	Mon 4/1/19	Wed 11/13/19	$0	$82,428		$89,994	$172,422
37		3.2.2.2.2	Cold Plate	4 wks	Mon 4/1/19	Fri 4/26/19	$12,104	$12,104	ElectTec	$5,472	$17,576
38		3.2.2.2.8	Transition board for RU	2 wks	Mon 4/29/19	Fri 5/10/19	$8,716	$8,716		$0	$8,716
39		3.2.2.2.9	Power Mezzanine for RU	2 wks	Mon 5/13/19	Fri 5/24/19	$22,108	$22,108		$0	$22,108
40		3.2.2.2.3	Test/QA RU	141 hrs	Mon 5/27/19	Wed 6/19/19	$7,500	$7,500	SCI3_Ins	$3,600	$11,100
41		3.2.2.2.5	Procure 60 SamTec Cables	60 days	Wed 6/19/19	Wed 9/11/19	$30,000	$30,000	TECH4_I	$922	$30,922
42		3.2.2.2.6	Test/QA	40 days	Wed 9/11/19	Wed 11/6/19	$0	$0	SCI3_Ins Engineer	$80,000	$80,000
43		3.2.2.2.7	Ship to UT Austin	1 wk	Wed 11/6/19	Wed 11/13/19	$2,000	$2,000		$0	$2,000
44		3.2.2.3	**FELIX**	70.33 days	Wed 4/1/20	Wed 7/8/20	$0	$88,400		$20,275	$108,675
45		3.2.2.3.1	Produce first production unit	4 wks	Wed 4/1/20	Tue 4/28/20	$20,000	$20,000	TECH4_I	$3,152	$23,152
46		3.2.2.3.2	Procure Optical fiber	2 wks	Wed 4/1/20	Tue 4/14/20	$50	$50	TECH4_I	$315	$365
47		3.2.2.3.3	Test/QA	2 wks	Wed 4/15/20	Tue 4/28/20	$0	$0	SCI3_Ins	$0	$0
48		3.2.2.3.4	Procure 7 Remaining Units	8 wks	Wed 4/29/20	Tue 6/23/20	$56,000	$56,000	TECH4_I	$1,261	$57,261
49		3.2.2.3.5	Procure 57 optical fibers	2 wks	Wed 4/29/20	Tue 5/12/20	$2,850	$2,850	TECH4_I	$315	$3,165
50		3.2.2.3.6	test/QA	5.33 days	Wed 6/24/20	Wed 7/1/20	$7,500	$7,500	SCI3_Ins Engineer	$15,232	$22,732
51		3.2.2.3.7	Ship to BNL	1 wk	Wed 7/1/20	Wed 7/8/20	$2,000	$2,000		$0	$2,000
52		3.2.2.4	**MAPS Power System**	225 days	Mon 6/1/20	Fri 4/9/21	$0	$224,620		$93,042	$317,662
53		3.2.2.4.1	**Power Boards**	175 days	Mon 6/1/20	Fri 1/29/21	$0	$117,320		$80,958	$198,278
54		3.2.2.4.1.1	Review ALICE PB Design	30 days	Mon 6/1/20	Fri 7/10/20	$0	$0	ELENG3	$19,800	$19,800
55		3.2.2.4.1.2	Fabricate PB Prototype	40 days	Mon 7/13/20	Fri 9/4/20	$5,750	$5,750	ELENG3	$12,637	$18,387
56		3.2.2.4.1.3	Procure Power Distribution	20 days	Mon 9/7/20	Fri 10/2/20	$1,000	$1,000	POSTD_S	$0	$1,000
57		3.2.2.4.1.4	Test PB Prototype and Distributi	20 days	Mon 10/5/20	Fri 10/30/20	$1,150	$1,150	ELENG3	$12,960	$14,110
58		3.2.2.4.1.5	Design Production PB	20 days	Mon 11/2/20	Fri 11/27/20	$2,000	$2,000	ELENG3	$20,800	$22,800
59		3.2.2.4.1.6	Hold Power system Review	5 days	Mon 11/30/20	Fri 12/4/20	$0	$0	ELENG3	$3,136	$3,136
60		3.2.2.4.1.7	Fabricate Break Out Boards	20 days	Mon 12/7/20	Fri 1/1/21	$15,000	$15,000		$0	$15,000
61		3.2.2.4.1.8	Fabricate PB to Stave Cables	20 days	Mon 12/7/20	Fri 1/1/21	$5,000	$5,000		$0	$5,000
62		3.2.2.4.1.10	Fabricate cold (cooling) plates	2 wks	Mon 12/7/20	Fri 12/18/20	$3,420	$3,420	MECHTE	$2,288	$5,708
63		3.2.2.4.1.9	Fabricate Production PB	40 days	Mon 12/7/20	Fri 1/29/21	$84,000	$84,000	ELENG3	$9,337	$93,337
64		3.2.2.4.2	**Power Supplies**	90 days	Mon 12/7/20	Fri 4/9/21	$0	$107,300		$12,084	$119,384
65		3.2.2.4.2.1	Procure and Integrate Power	90 days	Mon 12/7/20	Fri 4/9/21	$94,800	$94,800	ELENG3	$4,234	$99,034
66		3.2.2.4.2.2	Procure and terminate PS-to-Pb	30 days	Mon 12/7/20	Fri 1/15/21	$10,500	$10,500	ELTECH	$2,048	$12,548
67		3.2.2.4.2.3	test PB with power supplies	1 wk	Mon 1/18/21	Fri 1/22/21	$0	$0	ELTECH	$5,120	$5,120
68		3.2.2.4.2.4	Document	1.33 days	Mon 1/25/21	Tue 1/26/21	$0	$0	ELTECH	$683	$683
69		3.2.2.4.2.5	ship to BNL	1 wk	Tue 1/26/21	Tue 2/2/21	$2,000	$2,000		$0	$2,000
70		3.2.3	**Mechanics and Detector Assembly**	1000 days	Mon 4/1/19	Fri 1/27/23	$0	$544,177		$1,258,945	$1,803,122
71		3.2.3.1	**Staves**	517 days	Mon 4/1/19	Tue 3/23/21	$0	$146,852		$126,403	$273,255
72		3.2.3.1.1	**Production**	245 days	Mon 4/1/19	Fri 3/6/20	$0	$57,360		$72	$57,432
73		3.2.3.1.1.2	Tests and QA at CERN	160 days	Mon 7/1/19	Fri 2/7/20	$0	$0	SCI3_Ins	$0	$0
74		3.2.3.1.1.3	CERN Test System	1 day	Mon 4/1/19	Mon 4/1/19	$7,360	$7,360	ELENG3	$72	$7,432
75		3.2.3.1.1.4	Travel and Per Diem at CERN	1 day	Mon 4/1/19	Mon 4/1/19	$50,000	$50,000		$0	$50,000

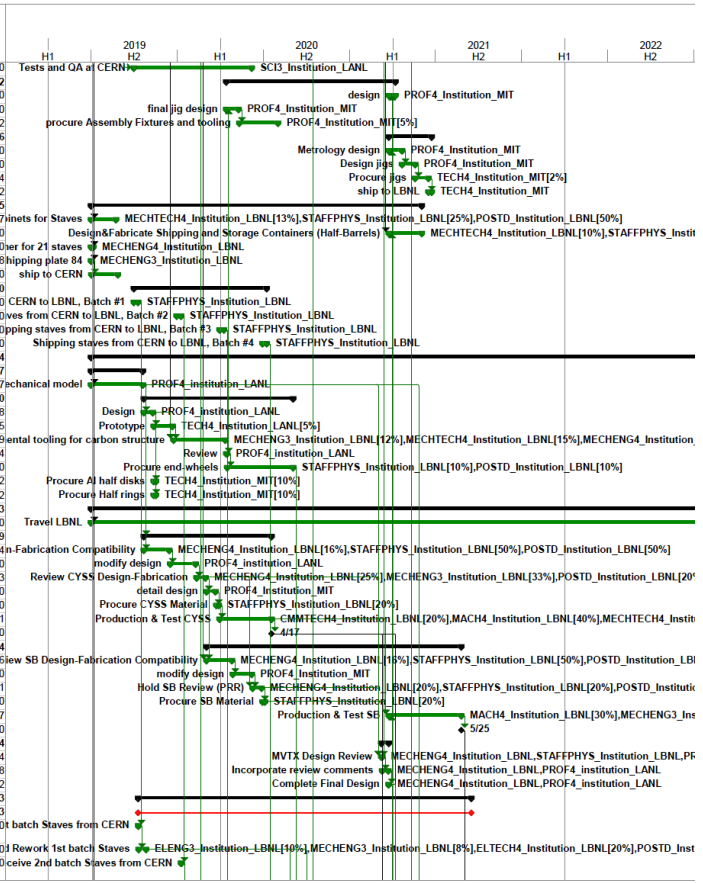


Page 1

MVTX MS Project 2/4

Thu 4/4/19 — MVTX-Barrel-120718-04042019

ID	Task Mode	WBS	Task Name	Duration	Start	Finish	Fixed Cost	Calculated Fixed Cost	Resource Names	Resource Costs	Cost
76		3.2.3.1.1.7	Tests and QA at CERN	180 days	Mon 7/1/19	Fri 3/6/20	$0	$0	SCI3_Ins	$0	$0
77		**3.2.3.1.2**	**Stave Assembly Tooling**	**257 days**	**Mon 1/13/20**	**Tue 1/5/21**	**$0**	**$25,000**		**$44,752**	**$69,752**
78		3.2.3.1.2.1	design	2 wks	Wed 12/23/20	Tue 1/5/21	$0	$0	PROF4_I	$13,840	$13,840
79		3.2.3.1.2.3	final jig design	20 days	Mon 1/13/20	Fri 2/7/20	$0	$0	PROF4_I	$26,880	$26,880
80		3.2.3.1.2.4	procure Assembly Fixtures and t	60 days	Mon 2/10/20	Fri 5/1/20	$25,000	$25,000	PROF4_I	$4,032	$29,032
81		**3.2.3.1.3**	**Metrology**	**65 days**	**Wed 12/23/20**	**Tue 3/23/21**	**$0**	**$7,000**		**$59,736**	**$66,736**
82		3.2.3.1.3.1	Metrology design	1 mon	Wed 12/23/20	Tue 1/19/21	$0	$0	PROF4_I	$27,680	$27,680
83		3.2.3.1.3.2	Design jigs	20 days	Wed 1/20/21	Tue 2/16/21	$0	$0	PROF4_I	$27,680	$27,680
84		3.2.3.1.3.3	Procure jigs	4 wks	Wed 2/17/21	Tue 3/16/21	$5,000	$5,000	TECH4_I	$324	$5,324
85		3.2.3.1.3.4	ship to LBNL	1 wk	Wed 3/17/21	Tue 3/23/21	$2,000	$2,000	TECH4_I	$4,052	$6,052
86		**3.2.3.1.4**	**Shipping and Storage Container**	**502 days**	**Mon 4/1/19**	**Tue 3/2/21**	**$0**	**$33,492**		**$21,843**	**$55,335**
87		3.2.3.1.4.1	Design&Fabricate Storage Cabi	39 days	Mon 4/1/19	Thu 5/23/19	$6,992	$6,992	MECHTE	$5,355	$12,347
88		3.2.3.1.4.2	Design&Fabricate Shipping and	50 days	Wed 12/23/20	Tue 3/2/21	$11,500	$11,500	MECHTE	$5,720	$17,220
89		3.2.3.1.4.3	Design shipping container for 21	1 wk	Mon 4/1/19	Fri 4/5/19	$0	$0	MECHEN	$9,480	$9,480
90		3.2.3.1.4.6	procure stave shipping plate 84	1 day	Mon 4/1/19	Mon 4/1/19	$10,000	$10,000	MECHEN	$1,288	$11,288
91		3.2.3.1.4.4	ship to CERN	2 mons	Tue 4/2/19	Mon 5/27/19	$5,000	$5,000		$0	$5,000
92		**3.2.3.1.5**	**Shipping staves to LBNL**	**202 days**	**Mon 7/1/19**	**Tue 4/7/20**	**$0**	**$24,000**		**$0**	**$24,000**
93		3.2.3.1.5.15	Shipping staves from CERN to L	7 days	Mon 7/1/19	Tue 7/9/19	$6,000	$6,000	STAFFPI	$0	$6,000
94		3.2.3.1.5.16	Shipping staves from CERN to L	7 days	Mon 9/30/19	Tue 10/8/19	$6,000	$6,000	STAFFPI	$0	$6,000
95		3.2.3.1.5.17	Shipping staves from CERN to L	7 days	Mon 12/30/19	Tue 1/7/20	$6,000	$6,000	STAFFPI	$0	$6,000
96		3.2.3.1.5.18	Shipping staves from CERN to L	7 days	Mon 3/30/20	Tue 4/7/20	$6,000	$6,000	STAFFPI	$0	$6,000
97		**3.2.3.2**	**Carbon Structures**	**1000 days**	**Mon 4/1/19**	**Fri 1/27/23**	**$0**	**$368,511**		**$936,513**	**$1,305,024**
98		**3.2.3.2.1**	**Mechanics Detector Design**	**80 days**	**Mon 4/1/19**	**Fri 7/19/19**	**$0**	**$0**		**$195,507**	**$195,507**
99		3.2.3.2.1.1	Develop MAPS inner tracker me	4 mons	Mon 4/1/19	Fri 7/19/19	$0	$0	PROF4_I	$195,507	$195,507
100		**3.2.3.2.2**	**End Wheels**	**227 days**	**Mon 7/22/19**	**Tue 6/2/20**	**$0**	**$72,000**		**$73,810**	**$145,810**
101		3.2.3.2.2.1	Design	15 days	Mon 7/22/19	Fri 8/9/19	$0	$0	PROF4_I	$36,658	$36,658
102		3.2.3.2.2.2	Prototype	30 days	Mon 8/12/19	Fri 9/20/19	$10,000	$10,000	TECH4_I	$2,305	$12,305
103		3.2.3.2.2.7	Experimental tooling for carbon	4 mons	Mon 9/23/19	Fri 1/10/20	$25,000	$25,000	MECHEN	$29,059	$54,059
104		3.2.3.2.2.3	Review	2 days	Mon 1/13/20	Tue 1/14/20	$0	$0	PROF4_I	$5,024	$5,024
105		3.2.3.2.2.4	Procure end-wheels	100 days	Wed 1/15/20	Tue 6/2/20	$35,000	$35,000	STAFFPI	$0	$35,000
106		3.2.3.2.2.5	Procure Al half disks	1 wk	Mon 8/12/19	Fri 8/16/19	$1,000	$1,000	TECH4_I	$382	$1,382
107		3.2.3.2.2.6	Procure Half rings	1 wk	Mon 8/12/19	Fri 8/16/19	$1,000	$1,000	TECH4_I	$382	$1,382
108		**3.2.3.2.3**	**Mechanics Fabrication**	**1000 days**	**Mon 4/1/19**	**Fri 1/27/23**	**$0**	**$286,511**		**$611,612**	**$898,123**
109		3.2.3.2.3.1	Travel LBNL	1000 days	Mon 4/1/19	Fri 1/27/23	$70,000	$70,000		$0	$70,000
110		**3.2.3.2.3.2**	**CYSS Cylindrical Structure**	**195 days**	**Mon 7/22/19**	**Fri 4/17/20**	**$0**	**$102,871**		**$342,688**	**$445,559**
111		3.2.3.2.3.2.1	Review CYSS Design-Fabrica	40 days	Mon 7/22/19	Fri 9/13/19	$0	$0	MECHEN	$12,134	$12,134
112		3.2.3.2.3.2.2	modify design	2 mons	Mon 9/16/19	Fri 11/8/19	$0	$0	PROF4_I	$99,730	$99,730
113		3.2.3.2.3.2.3	Review CYSS Design-Fabrica	15 days	Mon 11/11/19	Fri 11/29/19	$0	$0	MECHEN	$14,023	$14,023
114		3.2.3.2.3.2.7	detail design	15 days	Mon 12/2/19	Fri 12/20/19	$0	$0	PROF4_I	$20,160	$20,160
115		3.2.3.2.3.2.4	Procure CYSS Material	5 days	Mon 12/23/19	Fri 12/27/19	$15,640	$15,640	STAFFPI	$0	$15,640
116		3.2.3.2.3.2.5	Production & Test CYSS	80 days	Mon 12/30/19	Fri 4/17/20	$87,231	$87,231	CMMTEC	$196,640	$283,871
117		3.2.3.2.3.2.6	Milestone: Complete CYSS	0 days	Fri 4/17/20	Fri 4/17/20	$0	$0		$0	$0
118		**3.2.3.2.3.3**	**Service Barrel (SB)**	**387 days**	**Mon 12/2/19**	**Tue 5/25/21**	**$0**	**$113,640**		**$268,924**	**$382,564**
119		3.2.3.2.3.3.1	Review SB Design-Fabricatior	40 days	Mon 12/2/19	Fri 1/24/20	$0	$0	MECHEN	$12,646	$12,646
120		3.2.3.2.3.3.2	modify design	1.5 mons	Mon 1/27/20	Fri 3/6/20	$0	$0	PROF4_I	$40,320	$40,320
121		3.2.3.2.3.3.3	Hold SB Review (PRR)	15 days	Mon 3/9/20	Fri 3/27/20	$0	$0	MECHEN	$12,581	$12,581
122		3.2.3.2.3.3.4	Procure SB Material	5 days	Mon 3/30/20	Fri 4/3/20	$15,640	$15,640	STAFFPI	$0	$15,640
123		3.2.3.2.3.3.5	Production & Test SB	110 days	Wed 12/23/20	Tue 5/25/21	$98,000	$98,000	MACH4_	$203,377	$301,377
124		3.2.3.2.3.3.6	Milestone: Complete SB	0 days	Tue 5/25/21	Tue 5/25/21	$0	$0		$0	$0
125		**3.2.3.2.4**	**MVTX Final Design Review**	**12 days**	**Mon 12/7/20**	**Tue 12/22/20**	**$0**	**$10,000**		**$55,584**	**$65,584**
126		3.2.3.2.4.1	MVTX Design Review	2 days	Mon 12/7/20	Tue 12/8/20	$10,000	$10,000	MECHEN	$9,264	$19,264
127		3.2.3.2.4.2	Incorporate review comments	9 days	Wed 12/9/20	Mon 12/21/20	$0	$0	MECHEN	$41,688	$41,688
128		3.2.3.2.4.3	Complete Final Design	1 day	Tue 12/22/20	Tue 12/22/20	$0	$0	MECHEN	$4,632	$4,632
129		**3.2.3.3**	**Barrel Assembly**	**505 days**	**Wed 7/10/19**	**Tue 6/15/21**	**$0**	**$28,814**		**$196,029**	**$224,843**
130		**3.2.3.3.1**	**Assembly and Testing**	**505 days**	**Wed 7/10/19**	**Tue 6/15/21**	**$0**	**$28,814**		**$196,029**	**$224,843**
131		3.2.3.3.1.1	Receive 1st batch Staves from CERN	1 day	Wed 7/10/19	Wed 7/10/19	$0	$0		$0	$0
132		3.2.3.3.1.2	Test and Rework 1st batch Stav	12 days	Thu 7/11/19	Thu 7/26/19	$0	$0	ELENG3	$5,240	$5,240
133		3.2.3.3.1.7	Receive 2nd batch Staves from CERN	1 day	Wed 10/9/19	Wed 10/9/19	$0	$0		$0	$0

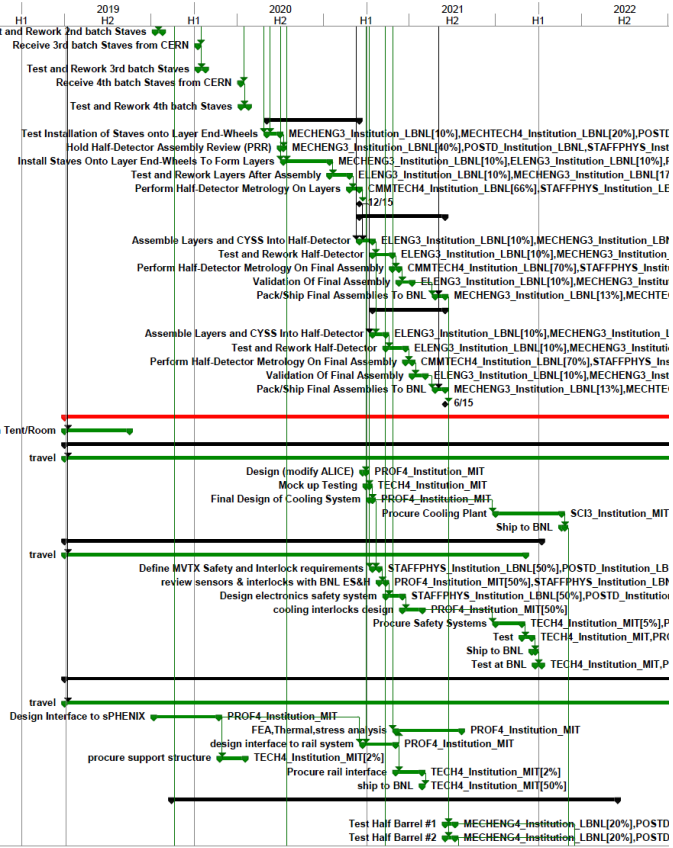


Page 2

MVTX MS Project 3/4

Thu 4/4/19 — MVTX-Barrel-120718-04042019

ID	Task Mode	WBS	Task Name	Duration	Start	Finish	Fixed Cost	Calculated Fixed Cost	Resource Names	Resource Costs	Cost
134		3.2.3.3.1.6	Test and Rework 2nd batch Stav	12 days	Thu 10/10/19	Fri 10/25/19	$0	$0		$0	$0
135		3.2.3.3.1.11	Receive 3rd batch Staves from CERN	1 day	Wed 1/8/20	Wed 1/8/20	$0	$0		$0	$0
136		3.2.3.3.1.10	Test and Rework 3rd batch Stav	12 days	Thu 1/9/20	Fri 1/24/20	$0	$0		$0	$0
137		3.2.3.3.1.9	Receive 4th batch Staves from CERN	1 day	Wed 4/8/20	Wed 4/8/20	$0	$0		$0	$0
138		3.2.3.3.1.8	Test and Rework 4th batch Stav	12 days	Thu 4/9/20	Fri 4/24/20	$0	$0		$0	$0
139		**3.2.3.3.1.3**	**Layer Assembly and Test**	**140 days**	**Wed 6/3/20**	**Tue 12/15/20**	**$0**	**$5,336**		**$69,923**	**$75,259**
140		3.2.3.3.1.3.1	Test Installation of Staves onti	20 days	Wed 6/3/20	Tue 6/30/20	$0	$0	MECHEN	$7,056	$7,056
141		3.2.3.3.1.3.2	Hold Half-Detector Assembly I	5 days	Wed 7/1/20	Tue 7/7/20	$0	$0	MECHEN	$2,672	$2,672
142		3.2.3.3.1.3.3	Install Staves Onto Layer End	70 days	Wed 7/8/20	Tue 10/13/20	$2,760	$2,760	MECHEN	$33,836	$36,596
143		3.2.3.3.1.3.4	Test and Rework Layers After	30 days	Wed 10/14/20	Tue 11/24/20	$2,576	$2,576	ELENG3	$14,875	$17,451
144		3.2.3.3.1.3.5	Perform Half-Detector Metrolo	15 days	Wed 11/25/20	Tue 12/15/20	$0	$0	CMMTEC	$11,484	$11,484
145		3.2.3.3.1.3.6	Milestone: Complete Layers	0 days	Tue 12/15/20	Tue 12/15/20	$0	$0		$0	$0
146		**3.2.3.3.1.4**	**Half Barrel #1 Assembly and Test**	**130 days**	**Wed 12/16/20**	**Tue 6/15/21**	**$0**	**$11,739**		**$60,433**	**$72,172**
147		3.2.3.3.1.4.1	Assemble Layers and CYSS I	20 days	Wed 12/16/20	Tue 1/12/21	$2,760	$2,760	ELENG3	$14,192	$16,952
148		3.2.3.3.1.4.2	Test and Rework Half-Detectc	30 days	Wed 1/13/21	Tue 2/23/21	$2,576	$2,576	ELENG3	$19,200	$21,776
149		3.2.3.3.1.4.3	Perform Half-Detector Metrolo	10 days	Wed 2/24/21	Tue 3/9/21	$0	$0	CMMTEC	$8,120	$8,120
150		3.2.3.3.1.4.4	Validation Of Final Assembly	20 days	Wed 3/10/21	Tue 4/6/21	$2,576	$2,576	ELENG3	$13,976	$16,552
151		3.2.3.3.1.4.5	Pack/Ship Final Assemblies T	15 days	Wed 5/26/21	Tue 6/15/21	$3,827	$3,827	MECHEN	$4,945	$8,772
152		**3.2.3.3.1.5**	**Half Barrel #2 Assembly and Test**	**110 days**	**Wed 1/13/21**	**Tue 6/15/21**	**$0**	**$11,739**		**$60,433**	**$72,172**
153		3.2.3.3.1.5.1	Assemble Layers and CYSS I	20 days	Wed 1/13/21	Tue 2/9/21	$2,760	$2,760	ELENG3	$14,192	$16,952
154		3.2.3.3.1.5.2	Test and Rework Half-Detectc	30 days	Wed 2/10/21	Tue 3/23/21	$2,576	$2,576	ELENG3	$19,200	$21,776
155		3.2.3.3.1.5.3	Perform Half-Detector Metrolo	10 days	Wed 3/24/21	Tue 4/6/21	$0	$0	CMMTEC	$8,120	$8,120
156		3.2.3.3.1.5.4	Validation Of Final Assembly	20 days	Wed 4/7/21	Tue 5/4/21	$2,576	$2,576	ELENG3	$13,976	$16,552
157		3.2.3.3.1.5.5	Pack/Ship Final Assemblies T	15 days	Wed 5/26/21	Tue 6/15/21	$3,827	$3,827	MECHEN	$4,945	$8,772
158		3.2.3.3.1.5.6	Milestone: Complete Barrel (R	0 days	Tue 6/15/21	Tue 6/15/21	$0	$0		$0	$0
159		**3.2.4**	**Integration and Infrastructure**	**1000 days**	**Mon 4/1/19**	**Fri 1/27/23**	**$0**	**$274,200**		**$848,250**	**$1,122,450**
160		3.2.4.1	Clean Tent/Room	100 days	Mon 4/1/19	Fri 8/16/19	$50,000	$50,000		$0	$50,000
161		**3.2.4.2**	**Cooling System**	**1000 days**	**Mon 4/1/19**	**Fri 1/27/23**	**$0**	**$87,000**		**$19,556**	**$106,556**
162		3.2.4.2.1	travel	1000 days	Mon 4/1/19	Fri 1/27/23	$25,000	$25,000		$0	$25,000
163		3.2.4.2.2	Design (modify ALICE)	1 wk	Wed 12/23/20	Tue 12/29/20	$0	$0	PROF4_I	$6,920	$6,920
164		3.2.4.2.3	Mock up Testing	1 wk	Wed 12/30/20	Tue 1/5/21	$20,000	$20,000	TECH4_I	$4,052	$24,052
165		3.2.4.2.4	Final Design of Cooling System	5 days	Wed 1/6/21	Tue 1/12/21	$0	$0	PROF4_I	$6,920	$6,920
166		3.2.4.2.5	Procure Cooling Plant	100 days	Fri 10/1/21	Thu 2/17/22	$40,000	$40,000	SCI3_Ins	$1,664	$41,664
167		3.2.4.2.6	Ship to BNL	1 wk	Fri 2/18/22	Thu 2/24/22	$2,000	$2,000		$0	$2,000
168		**3.2.4.3**	**Safety Systems**	**724 days**	**Mon 4/1/19**	**Thu 1/6/22**	**$0**	**$35,200**		**$100,206**	**$135,406**
169		3.2.4.3.1	travel	700 days	Mon 4/1/19	Fri 12/3/21	$25,000	$25,000		$0	$25,000
170		3.2.4.3.2	Define MVTX Safety and Interlock	2 wks	Wed 1/13/21	Tue 1/26/21	$0	$0	STAFFPI	$6,920	$6,920
171		3.2.4.3.3	review sensors & interlocks with BI	10 days	Wed 1/27/21	Tue 2/9/21	$0	$0	PROF4_I	$6,920	$6,920
172		3.2.4.3.4	Design electronics safety system	5.14 wks	Wed 2/10/21	Wed 3/17/21	$0	$0	STAFFPI	$14,234	$14,234
173		3.2.4.3.5	cooling interlocks design	30 days	Wed 3/17/21	Wed 4/28/21	$0	$0	PROF4_I	$20,760	$20,760
174		3.2.4.3.6	Procure Safety Systems	8 wks	Fri 10/1/21	Thu 11/25/21	$10,000	$10,000	TECH4_I	$9,069	$19,069
175		3.2.4.3.7	Test	3 wks	Fri 11/26/21	Thu 12/16/21	$0	$0	TECH4_I	$19,742	$19,742
176		3.2.4.3.8	Ship to BNL	1 wk	Fri 12/17/21	Thu 12/23/21	$200	$200		$0	$200
177		3.2.4.3.9	Test at BNL	2 wks	Fri 12/24/21	Thu 1/6/22	$0	$0	TECH4_I	$22,560	$22,560
178		**3.2.4.4**	**Stave Support Frame & MVTX Interface to sPHENIX**	**1000 days**	**Mon 4/1/19**	**Fri 1/27/23**	**$0**	**$102,000**		**$343,480**	**$445,480**
179		3.2.4.4.1	travel	1000 days	Mon 4/1/19	Fri 1/27/23	$20,000	$20,000		$0	$20,000
180		3.2.4.4.2	Design Interface to sPHENIX	100 days	Mon 10/7/19	Fri 2/21/20	$0	$0	PROF4_I	$134,400	$134,400
181		3.2.4.4.3	FEA,Thermal,stress analysis	100 days	Wed 3/3/21	Tue 7/20/21	$0	$0	PROF4_I	$138,400	$138,400
182		3.2.4.4.4	design interface to rail system	10 wks	Wed 12/23/20	Tue 3/2/21	$0	$0	PROF4_I	$69,200	$69,200
183		3.2.4.4.5	procure support structure	8 wks	Mon 2/24/20	Fri 4/17/20	$40,000	$40,000	TECH4_I	$629	$40,629
184		3.2.4.4.6	Procure rail interface	8 wks	Wed 3/3/21	Tue 4/27/21	$40,000	$40,000	TECH4_I	$648	$40,648
185		3.2.4.4.7	ship to BNL	0.1 wks	Wed 4/28/21	Wed 4/28/21	$2,000	$2,000	TECH4_I	$203	$2,203
186		**3.2.4.5**	**Half detector Assembly Readout and Cooling Test at BNL**	**676.38 days**	**Wed 11/13/19**	**Thu 6/16/22**	**$0**	**$0**		**$58,064**	**$58,064**
187		3.2.4.5.1	Test Half Barrel #1	15 days	Wed 6/16/21	Tue 7/6/21	$0	$0	MECHEN	$6,144	$6,144
188		3.2.4.5.2	Test Half Barrel #2	15 days	Wed 6/16/21	Tue 7/6/21	$0	$0	MECHEN	$6,144	$6,144



Page 3

MVTX MS Project 4/4

Thu 4/4/19 — MVTX-Barrel-120718-04042019

ID	Task Mode	WBS	Task Name	Duration	Start	Finish	Fixed Cost	Calculated Fixed Cost	Resource Names	Resource Costs	Cost
189		3.2.4.5.3	Assemble & Test Cooling System a	20 days	Fri 2/25/22	Thu 3/24/22	$0	$0	TECH4_I	$16,640	$16,640
190		3.2.4.5.8	Complete System Test at BNL	3 mons	Fri 3/25/22	Thu 6/16/22	$0	$0	SCI3_Ins	$0	$0
191		3.2.4.5.4	test RU at BNL	0.8 wks	Wed 11/13/19	Tue 11/19/19	$0	$0	SCI3_Ins Engineer	$12,608	$12,608
192		3.2.4.5.5	test FELIX at BNL	0.8 wks	Wed 7/8/20	Tue 7/14/20	$0	$0	SCI3_Ins Engineer	$12,608	$12,608
193		3.2.4.5.6	PS tests at BNL	0.5 wks	Tue 2/2/21	Thu 2/4/21	$0	$0	POSTD_	$3,920	$3,920
194		**3.2.4.6**	**Installation and Commissioning**	**387 days**	**Wed 7/7/21**	**Thu 12/29/22**	**$0**	**$0**		**$326,944**	**$326,944**
195		3.2.4.6.1	Installation Prep	10 days	Wed 7/7/21	Tue 7/20/21	$0	$0	Mech Tech,Phy	$15,520	$15,520
196		3.2.4.6.2	Installation Review	1 day	Wed 7/21/21	Wed 7/21/21	$0	$0	Physicist Engineer	$2,320	$2,320
197		3.2.4.6.3	Install FELIX	2 days	Thu 7/22/21	Fri 7/23/21	$0	$0	SCI3_Ins	$5,168	$5,168
198		3.2.4.6.4	Install Optical fibers	1 wk	Mon 7/26/21	Fri 7/30/21	$0	$0	TECH4_I	$8,120	$8,120
199		3.2.4.6.5	Install RU	1 wk	Mon 8/2/21	Fri 8/6/21	$0	$0	SCI3_Ins Engineer	$19,320	$19,320
200		3.2.4.6.6	Install Samtec Cables	1 wk	Mon 8/9/21	Fri 8/13/21	$0	$0	TECH4_I	$8,120	$8,120
201		3.2.4.6.10	Electronics Integration	6 mons	Mon 8/16/21	Fri 1/28/22	$0	$0	PROF4_i	$158,136	$158,136
202		3.2.4.6.7	Install Half-Barrel 1	1 mon	Fri 7/1/22	Thu 7/28/22	$0	$0	MECHTE	$26,320	$26,320
203		3.2.4.6.8	Install Half-Barrel 2	1 mon	Fri 7/29/22	Thu 8/25/22	$0	$0	MECHTE	$26,320	$26,320
204		3.2.4.6.9	Commissioning	90 days	Fri 8/26/22	Thu 12/29/22	$0	$0	Physicist Engineer	$57,600	$57,600
205		3.2.5	Ready for beam	0 days	Thu 12/29/22	Thu 12/29/22	$0	$0		$0	$0