Plan for Today

• Overview – 20+5’	Ming Liu	1:00-1:25
– Project Org, scope and plan, collaborations		
• Theory Status – 10+0’	Ivan Vitev	1:25-1:35
• Experimental technical aspects		
– Simulation progress - 10+5’	Sanghoon Lim	1:35-1:50
– Electronics readout – 15+5’	Pat McGaughey	1:50-2:10
– Mechanical R&D – 10+5’	Walt Sondheim	2:10-2:25
• Experimental Cost, Schedule, Risk and Procurements (II) – 25+10’	Cesar da Silva	2:25-3:00
• Summary - 5’	Ming Liu	3:00-3:05
• Committee discussion – 20’		3:05-3:25
• Closeout		3:25 – 3:35

LDRD Project Overview

Ming Liu, P-25, for the LDRD Team

December 5th, 2016

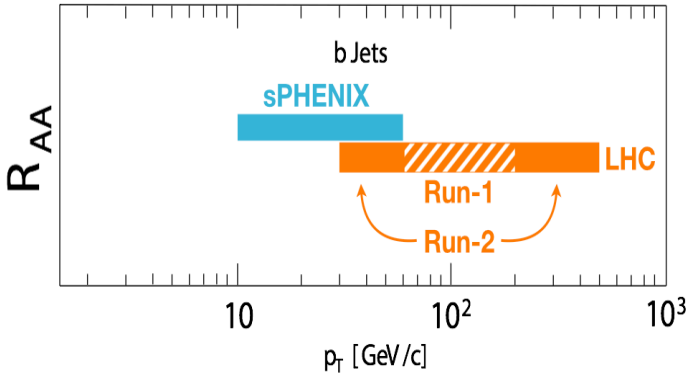
- LDRD Goals
  - Develop a new QGP physics program with heavy flavor b-jet measurements in sPHENIX at RHIC
  - Carry out key detector R&D and develop a new MIE proposal to DOE to build a state-of-the-art MAPS-based high precision vertex detector to support the b-jet physics program in sPHENIX
- Project Scope, Plan and Milestones
  - Experimental tasks
  - Theoretical tasks
- Cost, Schedule, Procurement and Risk Management
- Organization

Goal: Big Science to LANL

- sPHENIX is the next US NP flagship project in heavy ion physics, to study the properties of Quark-Gluon-Plasma (QGP); recently granted CD-0 (9/2016)

- This LDRD will allow LANL to take a leadership role in sPHENIX
  - Proposed innovation : develop a new b-jet physics program as a Major Pillar of the sPHENIX Program; novel Monolithic-Active-Pixel-Sensor (MAPS) based precision tracking; b-jet identification and theory
  - Bring new state of the art technical capability (MAPS) to LANL applied program, also future EIC program

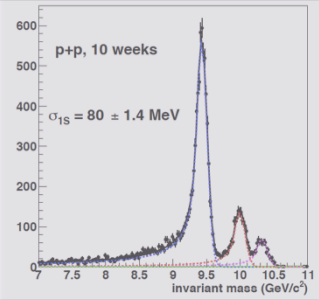
Cannot be done at the LHC for lack of low pT reach and huge backgrounds



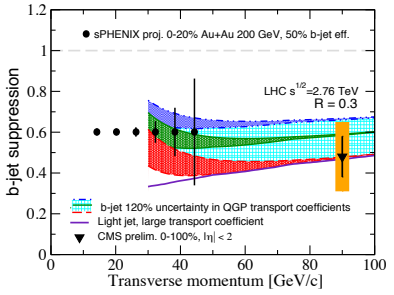
sPHENIX Three Physics Pillars

Jets

Upsilons



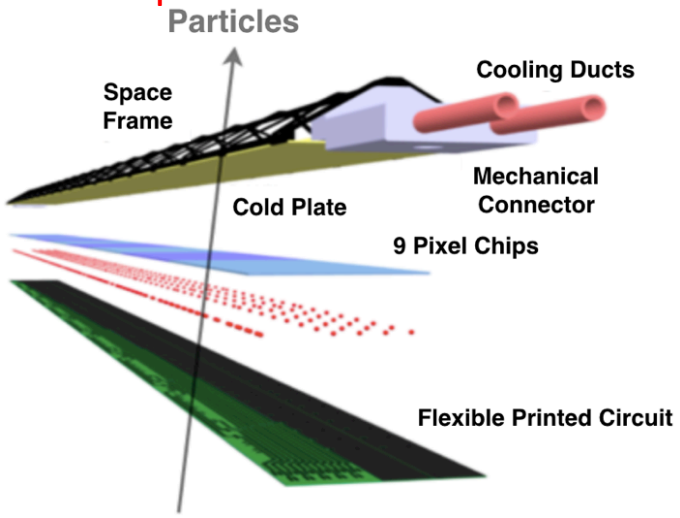
B-Jets ← this LDRD



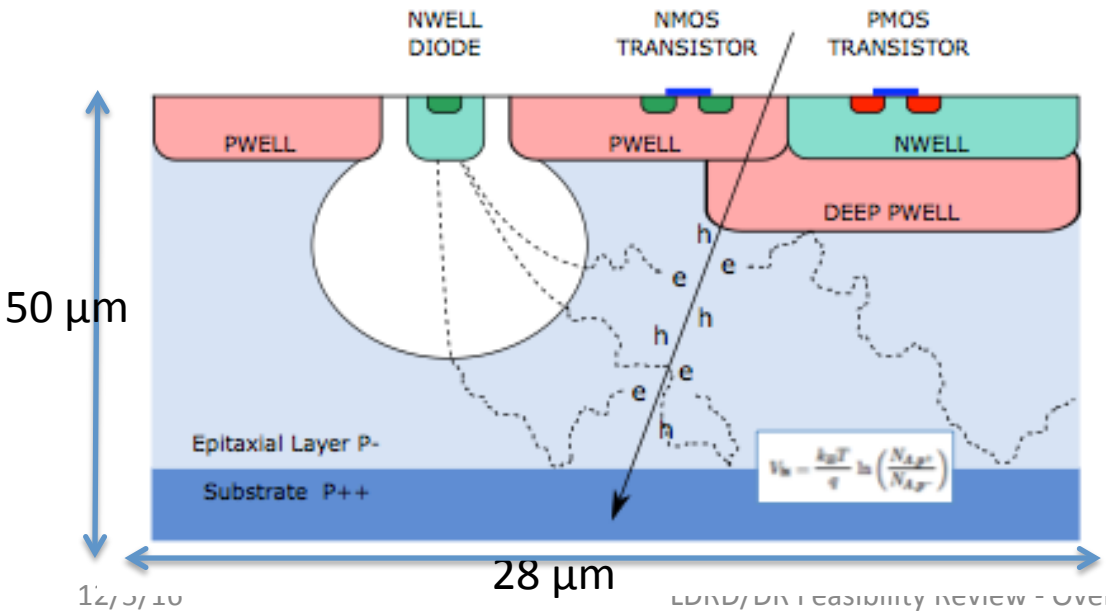
MAPS: a State of the Art Tracker

- Advantages of MAPS:
  - Very fine pitch (28x28 µm)
  - High efficiency (>99%) and low noise (<10^{-6})
  - High speed, 2~4 µS
  - Ultra-thin/low mass, 50µm (~0.3% X_0)
  - On-pixel digitization, low power dissipation
  - 15+ years of R&D at CERN for ALICE upgrade

A 9-chip MAPS stave



An ideal detector for QGP b-jet physics!



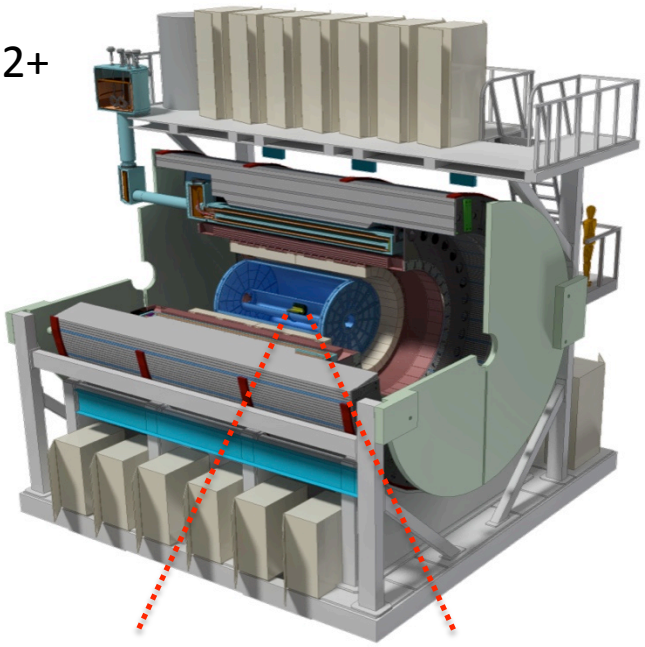
Tower Jazz 0.18 µm CMOS

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

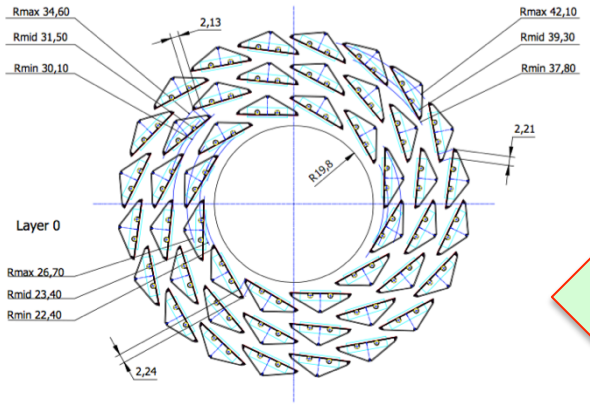
substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

LANL Proposed sPHENIX MAPS Inner Tracker

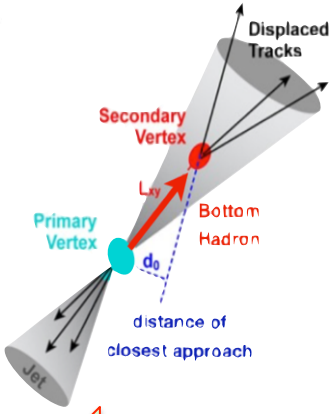
2022+



sPHENIX Inner Tracking

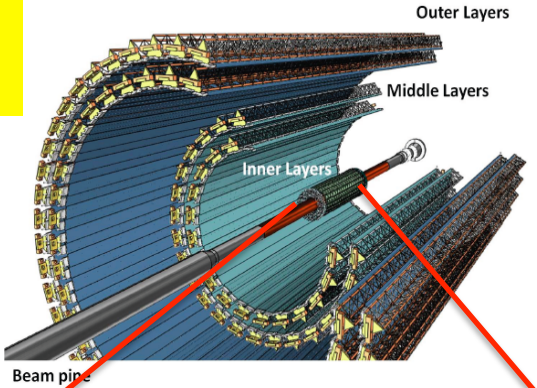


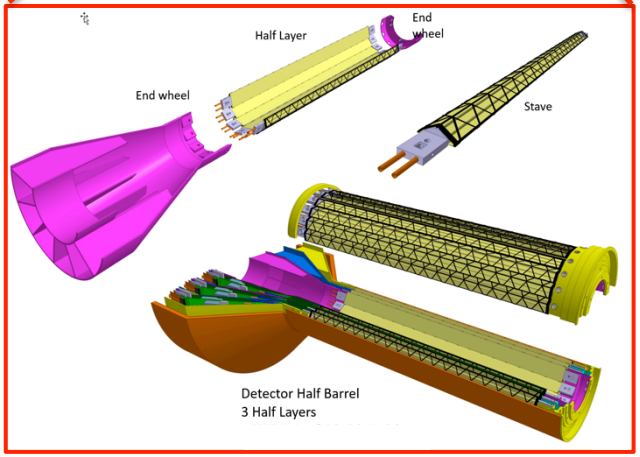
Key integration issues:
- Readout
- Mechanics



"Adopt" ALICE/ITS
Mini. risk,
Max. physics

ALICE ITS Upgrade (2021+);
Inner Tracker System

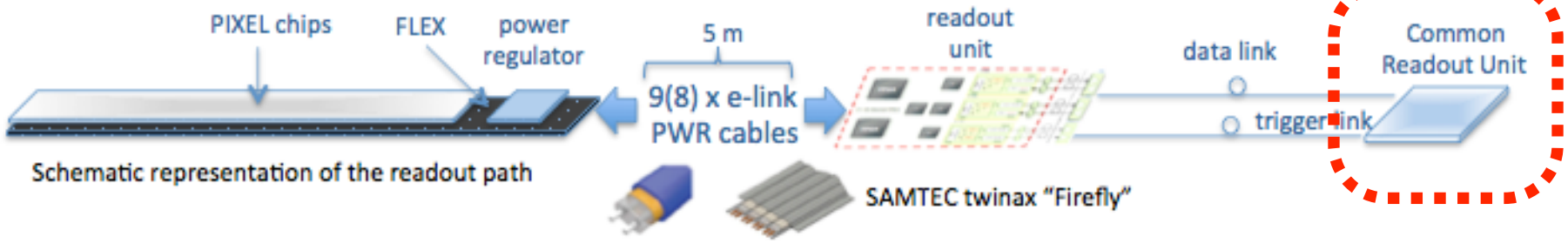




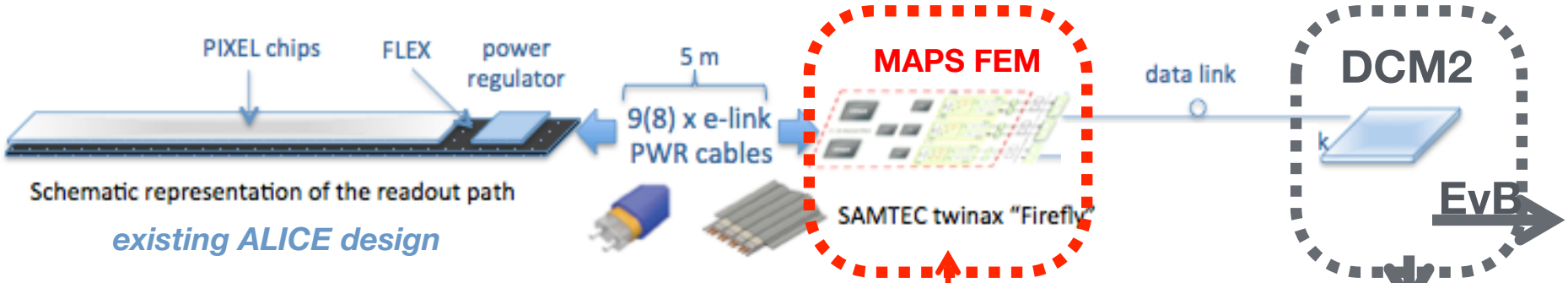
Goal: MAPS-sPHENIX Electronics Integration

ALICE readout path

Plan A: reprogram

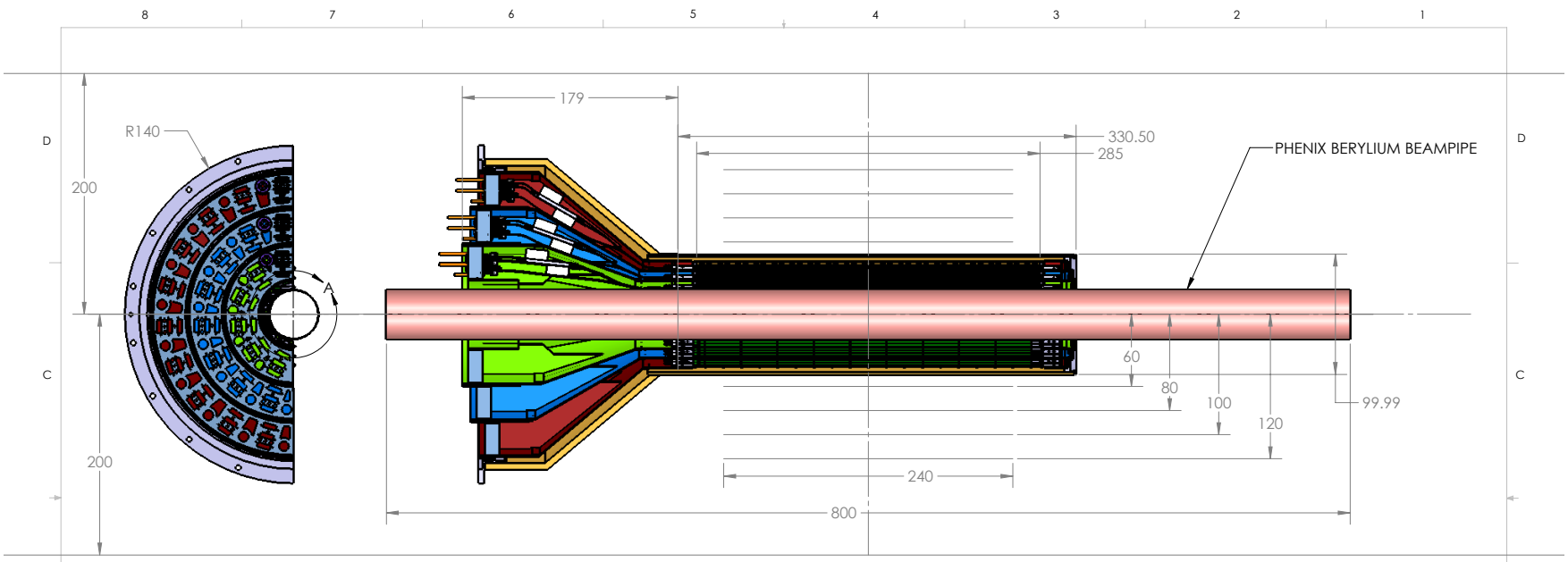


Plan B: sPHENIX readout path (held as contingency)



Pat's talk

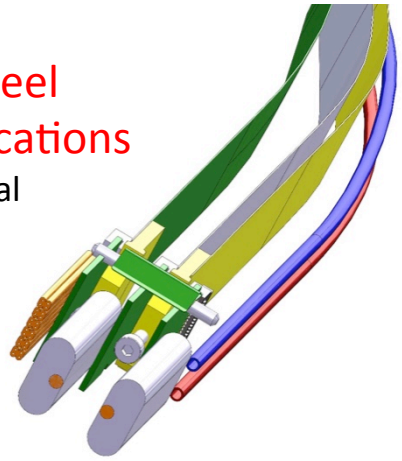
Goal: MAPS-sPHENIX Mechanical Integration

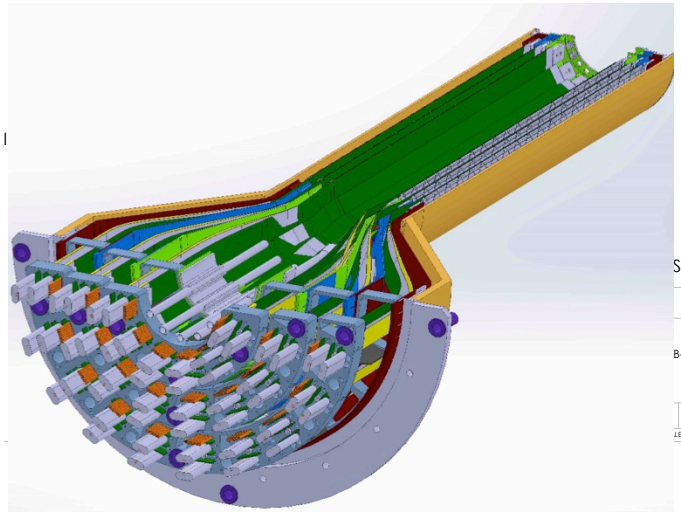


Service End Wheel
Possible modifications

- High speed signal
- Analogy power
- Digital power
- Cooling

Walt's talk



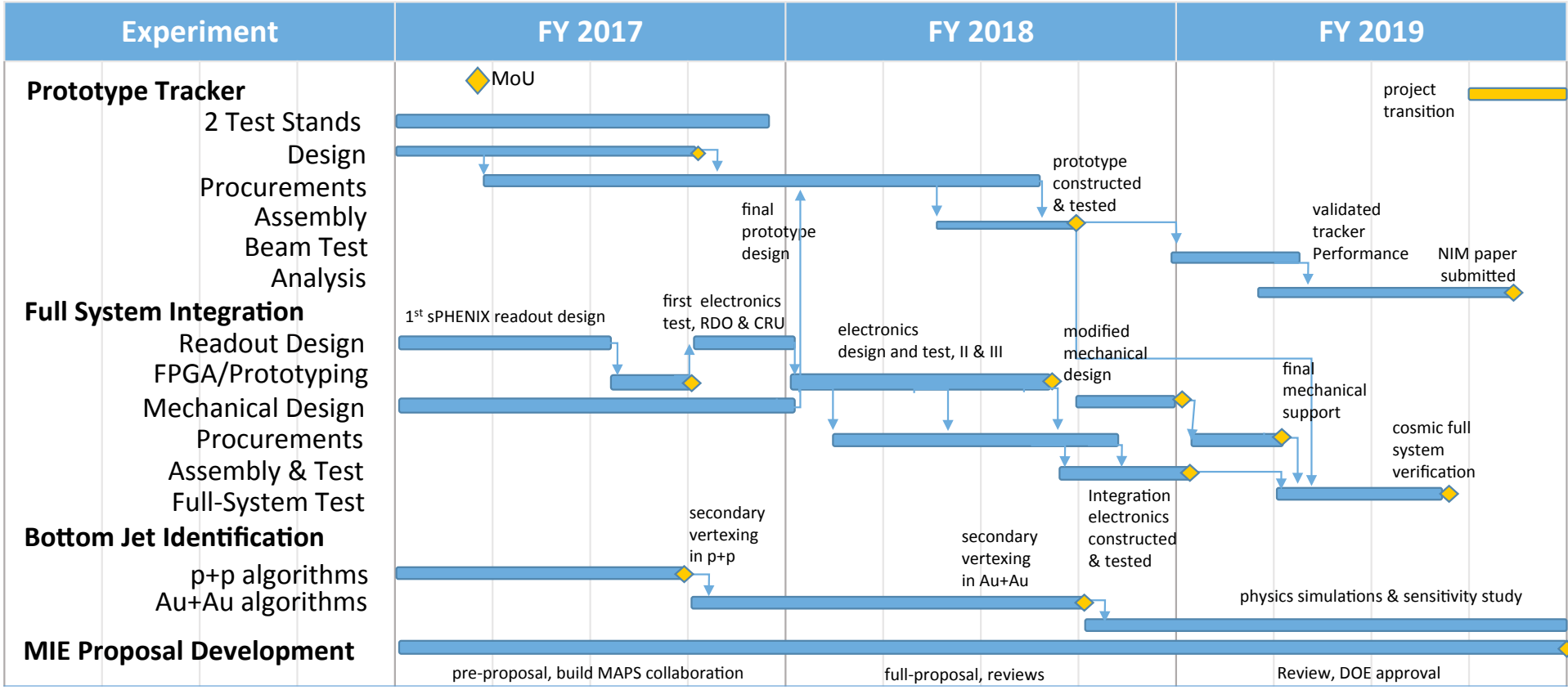


LDRD Project Scope and Plan

- Minimal scope
  - Develop a MAPS telescope with 2-4 early prototype staves with ALICE readout, sPHENIX DAQ integration
  - Complete R&D on Mechanics conceptual design, sPHENIX mechanical system integration
  - Develop b-jet tagging algorithms
  - DOE MIE proposal submitted to fund the full detector construction

- Desired scope
  - Develop a full 4-production-staves MAPS telescope, test beam run with integrated sPHENIX DAQ
  - DOE MIE proposal approved for the full detector construction

LDRD Experimental Key Tasks and Schedules



Closely tied to ALICE R&D and Production Schedule

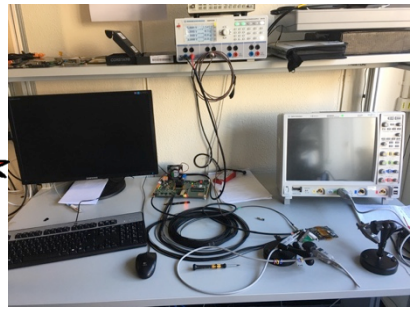
Cesar's talk

1st Milestone: MoU with ALICE/ITS

- CERN Visit to discuss MoU: November 10-15, 2016
  - Visited MAPS R&D and construction labs
  - Agreement on MoU achieved!

- MoU with ALICE/ITS
  - Associate member on the ALICE/ITS project at CERN
    - Access all technical design files and documents
    - Access other technical resources, including Engineering and Computing support, joint R&D on LDRD project
    - Train LANL personnel on the job
  - Procurement of critical items from CERN
    - 5 single-chip MAPS readout evaluation boards
    - 1-2 high-speed readout out test boards (MOSAIC test bench)
    - 4+ Readout-Unit and 2+ Common-Readout-Unit prototypes and associated electronics components, including CERN GBT optical links
    - Mechanical support frame prototypes

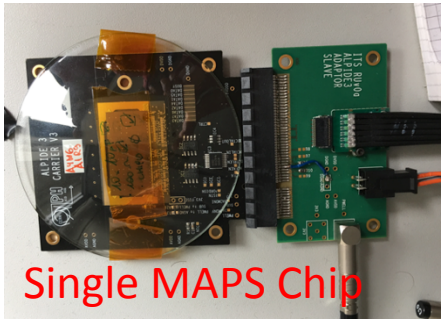
- LDRD milestones developed to match:
  - ALICE R&D and production schedule
  - sPHENIX proposed installation and run schedule



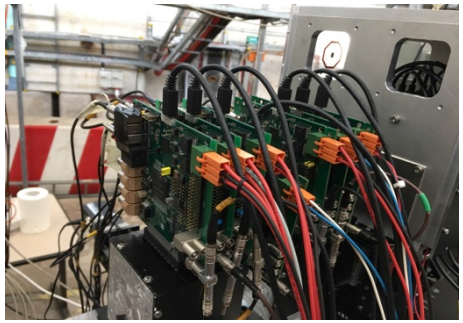
High speed readout test

Status of MAPS R&D at ALICE/CERN

- MAPS chip readout with test board
  - Also tested at LANL
  - Telescope
- Multichip MAPS high speed readout
  - with the first prototype Readout Cards (RUv0)
  - MiniDAQ (MOSAIC board) test bench
- RU fiber optics communication established with a prototype Common Readout Unit (CRU)
- Stave space frame being produced
- Service End Wheel being prototyped
- Procurement for LANL LDRD R&D items
  - Key test electronics and mechanic prototypes being produced for LANL LDRD

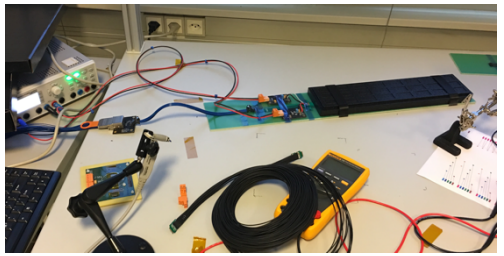

Single MAPS Chip

A 7-single-chip telescope

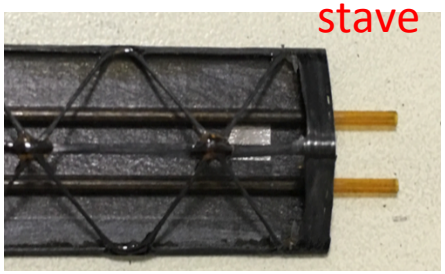



RUv0

MOSAIC Test Bench



stave

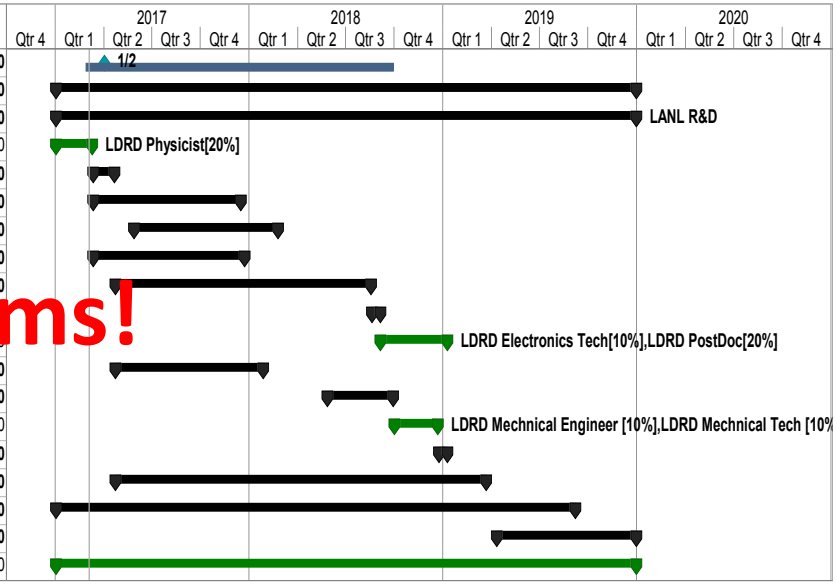



Service wheel

Major Item Cost, Schedule and Risks

Sun 12/4/16

ID	WBS	Task Name	Duration	Start	Finish	Fixed Cost	Cost	Activity	Cost per Unit
1	1	**ALICE ITS Key Tasks**	**0 days**	**Mon 1/2/17**	**Mon 1/2/17**	**$0.00**	**$0.00**		**$0.00**
8	2	**LDRD Milestones & Critical Tasks**	**781 days**	**Mon 10/3/16**	**Mon 9/30/19**	**$0.00**	**$0.00**		**$0.00**
14	3	**LANL LDRD**	**781 days**	**Mon 10/3/16**	**Mon 9/30/19**	**$0.00**	**$4,759,568.00**	**LANL**	**$0.00**
15	3.1	MOU btw LANL and ALICE for R&D	50 days	Mon 10/3/16	Fri 12/9/16	$0.00	$18,400.00		$0.00
16	3.2	**Obtain Designs from ALICE**	**30 days**	**Mon 12/12/16**	**Fri 1/20/17**	**$0.00**	**$82,800.00**		**$0.00**
20	3.3	**Setup Alice Readout Test Stand**	**200 days**	**Mon 12/12/16**	**Fri 9/15/17**	**$0.00**	**$135,760.00**		**$0.00**
23	3.4	**Procure R&D ALICE Staves**	**195 days**	**Mon 2/27/17**	**Fri 11/24/17**	**$0.00**	**$553,720.00**		**$0.00**
27	3.5	**Procure ALICE Electronics & Cables**	**205 days**	**Mon 12/12/16**	**Fri 9/22/17**	**$0.00**	**$150,020.00**		**$0.00**
45	3.6	**Readout R&D**	**345 days**	**Mon 1/23/17**	**Fri 7/18/18**	**$0.00**	**$117,840.00**		**$0.00**
51	3.7	**Electronics Final Design Review**	**1 day**	**Mon 2/19/18**	**Tue 2/20/18**	**$0.00**	**$3,088.00**		**$0.00**
55	3.8	Prototype readout assembled and tested	90 days	Wed 6/6/18	Tue 10/9/18	$0.00	$23,160.00		$0.00
56	3.9	**Mechanical Support and Cooling**	**200 days**	**Mon 1/23/17**	**Fri 10/27/17**	**$0.00**	**$236,160.00**		**$0.00**
74	3.10	**Prototype Assembly and Test**	**90 days**	**Mon 2/26/18**	**Fri 6/29/18**	**$0.00**	**$114,240.00**		**$0.00**
77	3.11	Mechanical Conceptual Design	60 days	Mon 7/2/18	Fri 9/21/18	$0.00	$18,240.00		$0.00
78	3.12	Mechanical Conceptual Design Review	**12 days**	**Mon 9/24/18**	**Tue 10/9/18**	**$0.00**	**$33,920.00**		**$0.00**
82	3.13	**Softrware Tool Development and Analysis**	**500 days**	**Mon 1/23/17**	**Fri 12/21/18**	**$0.00**	**$351,200.00**		**$0.00**
85	3.14	**Detector Optimizaation and Physics Simulations (MIE)**	**700 days**	**Mon 10/3/16**	**Fri 6/7/19**	**$0.00**	**$946,000.00**		**$0.00**
88	3.15	**Test Beam Operation**	**187 days**	**Fri 1/11/19**	**Mon 9/30/19**	**$0.00**	**$132,420.00**		**$0.00**
93	3.16	Theory R&D	781 days	Mon 10/3/16	Mon 9/30/19	$1,800,000.00	$1,800,000.00		$0.00



No high risk items!

- Low Risk for most items
- Medium risk on stave and readout electronics production schedule

Risk mitigation:

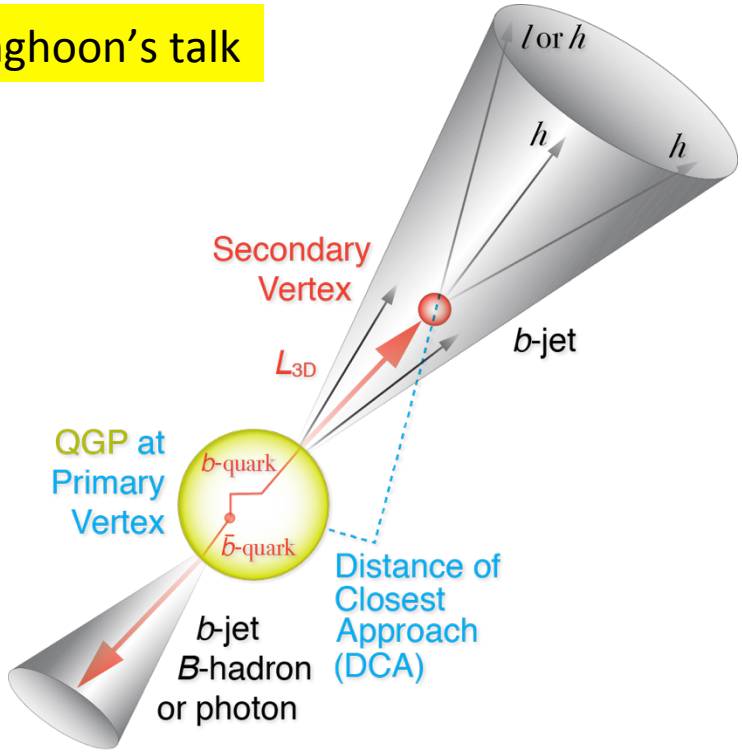
- Use early prototype staves to build LANL telescope for key integration and performance studies
- Early R&D on readout, also explore alternative approaches
  - CRU firmware integration at EvB level (Plan-A)
  - DCM-II readout via custom adaptor boards (Plan-B)
- Joint R&D with other sPHENIX subsystems for MAPS DAQ and mechanical system integration

Cesar's talk

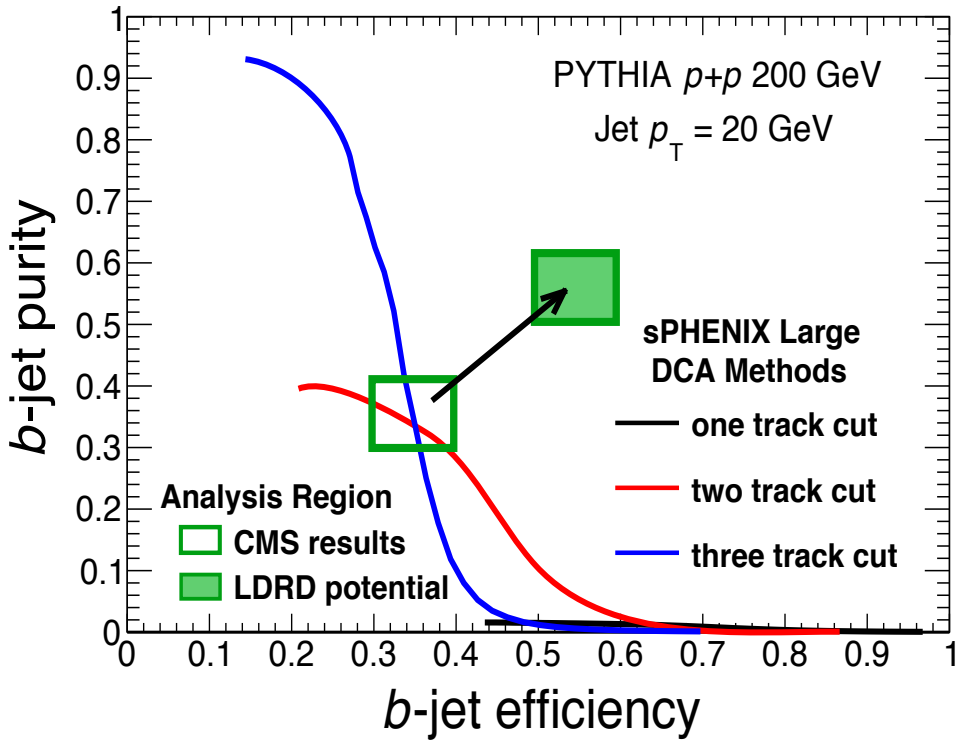
Experimental R&D Deliverables: Physics

LDRD Goal: much improved B-jet Identification in Heavy Ion Collisions

Sanghoon's talk



Secondary Vertexing Possible!

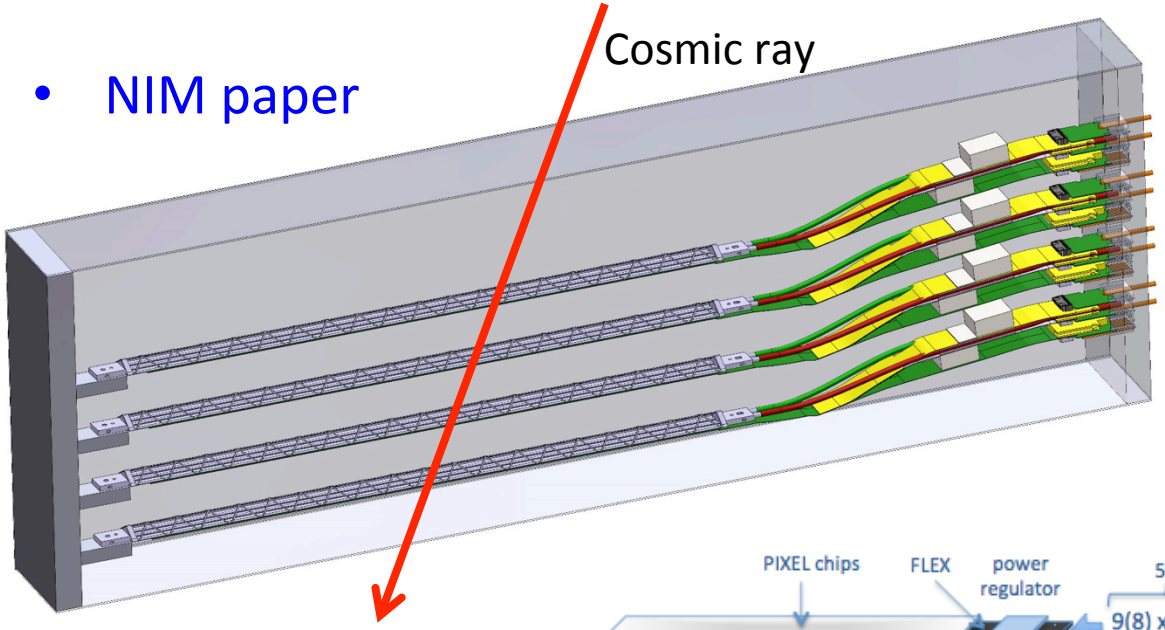


- A new b-jet identification with **high efficiency** and **high purity** is possible
- Figure of merit is ***efficiency*** *x* ***purity.*** Greatly enhancing the b-jet physics program, x4 improvement in FOM (compared to alternatives)

Experimental R&D Deliverables

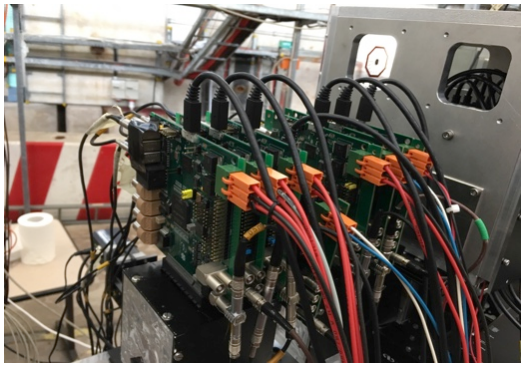
a 4-Stave Telescope

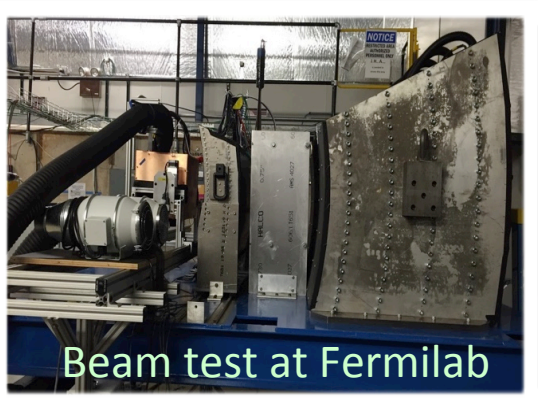
- Performance of prototype tracker
  - High speed readout of staves
  - Spatial resolution
  - Electrical and mechanical stability
  - Cooling etc.
- NIM paper



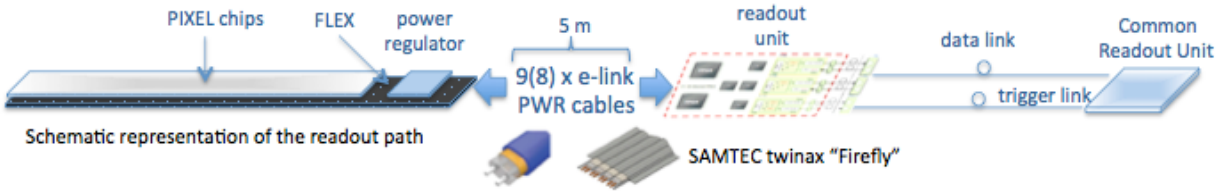
Pat and Walt's talks

A 5-single-chip telescope





sPHENIX
Data Format



Experimental Project Organization

- LALN internal
  - Simulations
  - Electronics
  - Mechanics
- External collaboration
  - CERN/ITS group
  - ALICE US groups
- Lead people identified for key tasks
  - Team of experts
- Job AD out for a new staff
  - Several outstanding candidates







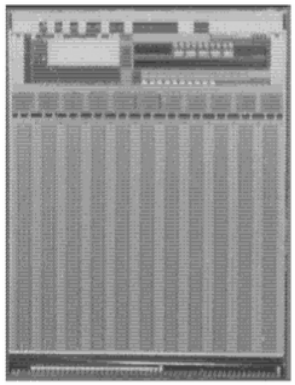

Cesar's talk

Impact and Transition Plan

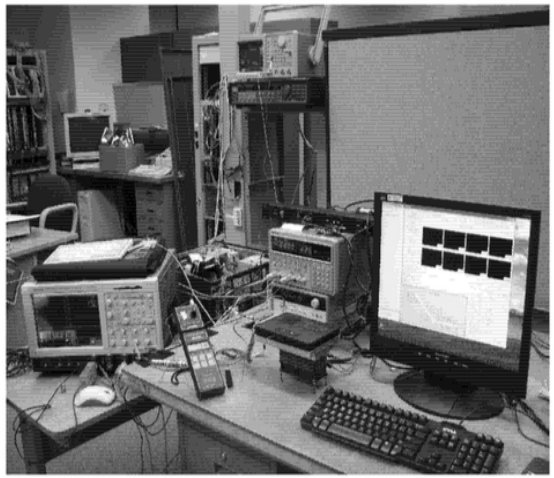
- Extend LANL's position as an international leader at the next generation QGP physics frontier, major discovery potential
- Develop a new long term (10Y) major DOE funded program ($3M/year) at LANL in line with the national priority, DOE funded QCD theory (~$1M/year)
- New in-house capabilities in low-mass high resolution tracking/imaging technology. Benefit other future programs, such as the EIC and applied missions at LANL
- Expect high Return On Investment, above 6:1

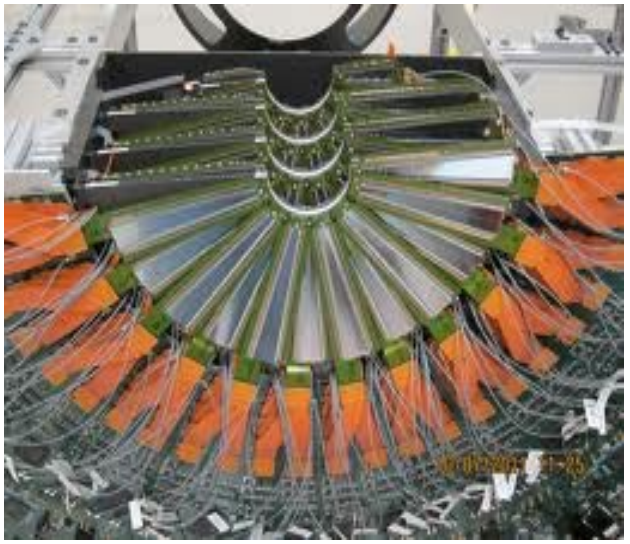
Previous successful path followed by LANL's FVTX silicon tracker

prototyping under LDRD DR: **final tracker supported by DOE:**



FVTX prototype sensor & readout



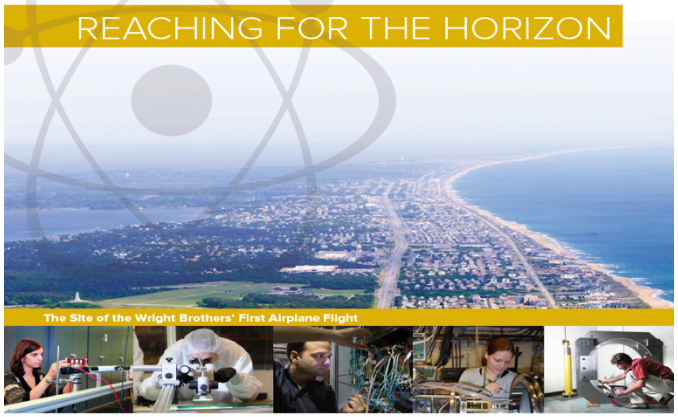


A Road Map

Excellent strategic Alignment

At the heart of the recently released LANL NP strategy, by Rej, Wilburn, Carlson, 2016

Our projects are pipelines for talent to applied LANL missions



The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE

NSAC Long Range Plan

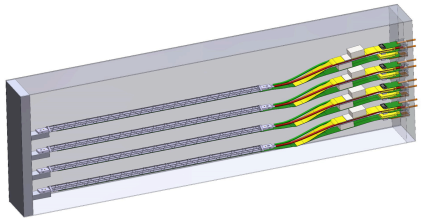
Recommendation #1 (RHIC):

The highest priority in this 2015 Plan is to capitalize on the investments made.

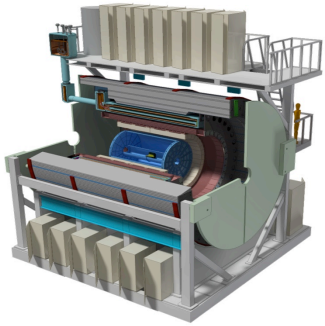
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

Recommendation #3 (EIC):

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.



Project Status



- MoU with ALICE/ITS achieved (in advance)
- Initial cost, schedule and risk management plan developed
- Key R&D item procurement in progress
- Physics and detector simulation work underway
- MIE pre-proposal writing in progress
- Low Risk on theory

Project is on schedule!

backups

Appendix

Typical criteria for a feasibility review.

Project Organization

1. In your estimation, does the project have an effective organizational structure?
2. Do you have any concerns and/or suggestions regarding project roles and responsibilities?

- Experimental group
  - Lead persons on major tasks
- Theory group

Project Plan

3. In your estimation, is the proposed project plan an effective tool to guide the project from inception to completion?
4. Does the project plan include relevant portions, appropriate to the size and phase of project, such as the Statement of Work (SOW), Work Breakdown Structure (WBS), Project Execution Plan (PEP), Risk Management Plan, and the Budget and Schedule Estimates?

Experimental MS Project:
- Tasks & resources, WBS etc.
- Milestones

Theory:
- Milestones

Technical Aspects

5. Does the project have a clear development plan for all the technical goals?
6. Are technical tests and anticipated results stated?

- Milestones

Cost

7. Is the Budget Estimate comprehensive and verifiable?

- MoU with CERN, by mid Decemebr
- Local R&D

Schedule

8. Are schedule milestones clearly identified, and are the milestones frequent enough to gauge progress? Does this schedule include sufficient time for scientific exploitation of the instrument, once it is commissioned?

MS Project:
- Tasks & resources, WBS etc.
- Milestones

Risk

9. Does the plan include a method for managing technical risk, budget risk, and schedule risk?

Risk mitigation:
- Technical, early R&D
- Budget, MoU, early R&D
- Schedule, collaboration with ALICE/ITS R&D,

Procurement

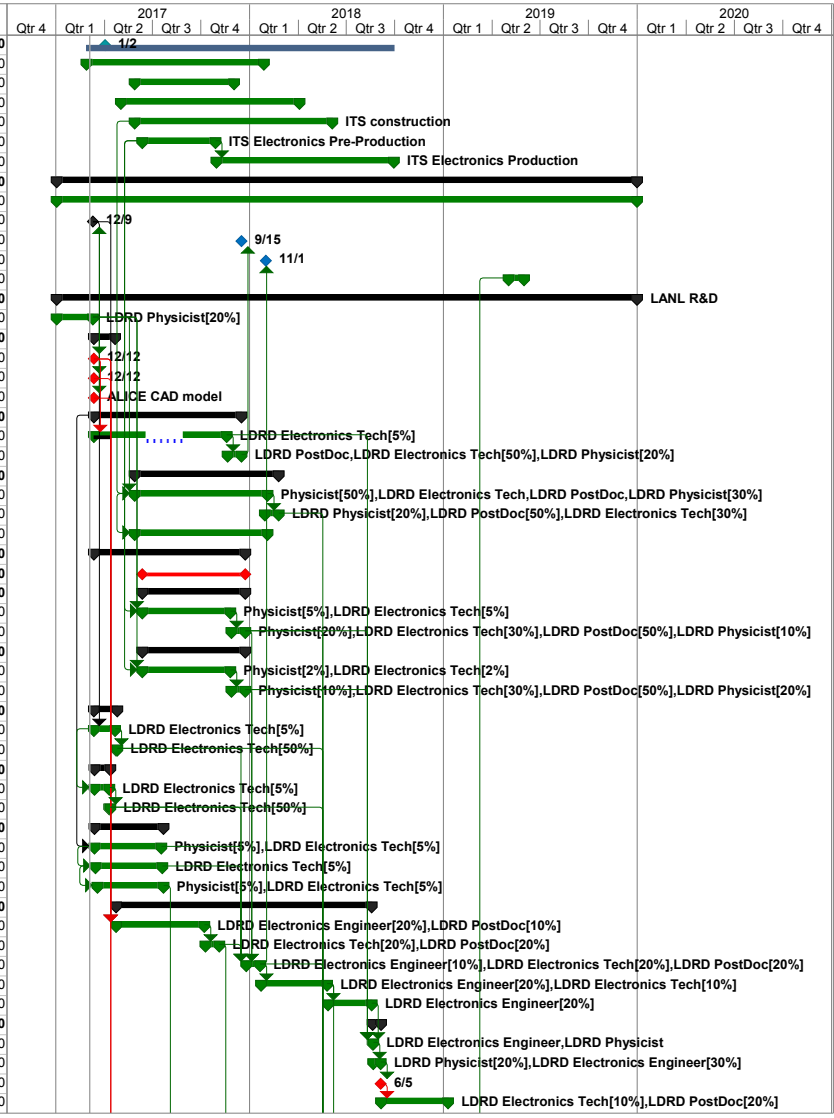
10. Are critical procurements identified?

LDRD MS Project(I)

Closely Tied to ALICE/ITS Upgrade Schedule

Sun 12/4/16

ID	WBS	Task Name	Duration	Start	Finish	Fixed Cost	Cost	Activity	Cost per Unit
1	**1**	**ALICE ITS Key Tasks**	**0 days**	**Mon 1/2/17**	**Mon 1/2/17**	**$0.00**	**$0.00**		**$0.00**
2	1.1	ALICE MAPS Production (7/17)	240 days?	Mon 11/28/16	Fri 10/27/17	$0.00	$0.00		$0.00
3	1.2	ALICE ITS IB FPC Production (9/17)	135 days	Mon 2/27/17	Fri 9/1/17	$0.00	$0.00		$0.00
4	1.3	ALICE ITS IB Stave Frame Production Ends (1/18)	240 days?	Wed 2/1/17	Tue 1/2/18	$0.00	$0.00		$0.00
5	1.4	ALICE ITS IB Stave Assembly (3/18)	266 days	Mon 2/27/17	Mon 3/5/18	$0.00	$0.00	ITS co	$0.00
6	1.5	ALICE ITS Electronics Pre-Production (7/17)	100 days	Mon 3/13/17	Fri 7/28/17	$0.00	$0.00	ITS Ele	$0.00
7	1.6	ALICE ITS Electronics Production (6/18)	240 days	Mon 7/31/17	Fri 6/29/18	$0.00	$0.00	ITS Ele	$0.00
8	**2**	**LDRD Milestones & Critical Tasks**	**781 days**	**Mon 10/3/16**	**Mon 9/30/19**	**$0.00**	**$0.00**		**$0.00**
9	2.1	LDRD Start and End	781 days	Mon 10/3/16	Mon 9/30/19	$0.00	$0.00		$0.00
10	2.2	Complete MoU LANL-ALICE	0 days	Fri 12/9/16	Fri 12/9/16	$0.00	$0.00		$0.00
11	2.3	Setup ALICE Readout Test Stands	0 days	Fri 9/15/17	Fri 9/15/17	$0.00	$0.00		$0.00
12	2.4	Preliminary readout design to interface sPHENIX DAQ	0 days	Wed 11/1/17	Wed 11/1/17	$0.00	$0.00		$0.00
13	2.5	Prototype Test during sPHENIX Test Beam Run	21 days	Fri 2/1/19	Fri 3/1/19	$0.00	$0.00		$0.00
14	**3**	**LANL LDRD**	**781 days**	**Mon 10/3/16**	**Mon 9/30/19**	**$0.00**	**$4,759,568.00**	**LANL**	**$0.00**
15	3.1	MOU btw LANL and ALICE for R&D	50 days	Mon 10/3/16	Fri 12/9/16	$0.00	$18,400.00		$0.00
16	**3.2**	**Obtain Designs from ALICE**	**30 days**	**Mon 12/12/16**	**Fri 1/20/17**	**$0.00**	**$82,800.00**		**$0.00**
17	3.2.1	Obtain Test Stand Design from CERN	30 days	Mon 12/12/16	Fri 1/20/17	$0.00	$27,600.00		$0.00
18	3.2.2	Obtain ALICE Readout Unit Design	30 days	Mon 12/12/16	Fri 1/20/17	$0.00	$27,600.00		$0.00
19	3.2.3	obtain ALICE CAD model	30 days	Mon 12/12/16	Fri 1/20/17	$0.00	$27,600.00	ALICE	$0.00
20	**3.3**	**Setup Alice Readout Test Stand**	**200 days**	**Mon 12/12/16**	**Fri 9/15/17**	**$0.00**	**$135,760.00**		**$0.00**
21	3.3.1	Procure 2 Test Stands and MAPS Evaluation Modules	180 days	Mon 12/12/16	Fri 8/18/17	$50,000.00	$92,000.00		$25,000.00
22	3.3.2	Setup Test Stands	20 days	Mon 8/21/17	Fri 9/15/17	$10,000.00	$43,760.00		$0.00
23	**3.4**	**Procure R&D ALICE Staves**	**195 days**	**Mon 2/27/17**	**Fri 11/24/17**	**$0.00**	**$553,720.00**		**$0.00**
24	3.4.1	Procure and Produce 4 Staves	180 days	Mon 2/27/17	Fri 11/3/17	$60,000.00	$504,960.00		$15,000.00
25	3.4.2	Test Staves at LANL	20 days	Mon 10/30/17	Fri 11/24/17	$0.00	$21,760.00		$0.00
26	3.4.3	Travel and Per Diem Support	180 days	Mon 2/27/17	Fri 11/3/17	$27,000.00	$27,000.00		$0.00
27	**3.5**	**Procure ALICE Electronics & Cables**	**205 days**	**Mon 12/12/16**	**Fri 9/22/17**	**$0.00**	**$150,020.00**		**$0.00**
28	**3.5.1**	**ALICE Readout Electronics Boards**	**140 days**	**Mon 3/13/17**	**Fri 9/22/17**	**$0.00**	**$75,920.00**		**$0.00**
29	**3.5.1.1**	**Readout Units (RDOs)**	**140 days**	**Mon 3/13/17**	**Fri 9/22/17**	**$0.00**	**$41,280.00**		**$0.00**
30	3.5.1.1.1	Procure 4 RDOs	120 days	Mon 3/13/17	Fri 8/25/17	$16,000.00	$23,200.00		$4,000.00
31	3.5.1.1.2	Test RDOs	20 days	Mon 8/28/17	Fri 9/22/17	$0.00	$18,080.00		$0.00
32	**3.5.1.2**	**Common Readout Units (CRUs)**	**140 days**	**Mon 3/13/17**	**Fri 9/22/17**	**$0.00**	**$34,640.00**		**$0.00**
33	3.5.1.2.1	Procure 2 CRUs	120 days	Mon 3/13/17	Fri 8/25/17	$10,000.00	$12,880.00		$5,000.00
34	3.5.1.2.2	Test CRUs at LANL	20 days	Mon 8/28/17	Fri 9/22/17	$0.00	$21,760.00		$0.00
35	**3.5.2**	**SamTec Cables**	**32 days**	**Mon 12/12/16**	**Tue 1/24/17**	**$0.00**	**$5,000.00**		**$0.00**
36	3.5.2.1	Procure 10 SamTec Cables	30 days	Mon 12/12/16	Fri 1/20/17	$2,000.00	$3,800.00		$285.00
37	3.5.2.2	Test Cables	2 days	Mon 1/23/17	Tue 1/24/17	$0.00	$1,200.00		$0.00
38	**3.5.3**	**Optical Cables**	**22 days**	**Tue 12/13/16**	**Wed 1/11/17**	**$0.00**	**$2,900.00**		**$0.00**
39	3.5.3.1	Procure 5 Optical Cables	20 days	Tue 12/13/16	Mon 1/9/17	$500.00	$1,700.00		$100.00
40	3.5.3.2	Test Optical Cables	2 days	Tue 1/10/17	Wed 1/11/17	$0.00	$1,200.00		$0.00
41	**3.5.4**	**Procure Ancillaries**	**94 days**	**Tue 12/13/16**	**Fri 4/21/17**	**$0.00**	**$66,200.00**		**$0.00**
42	3.5.4.1	Procure LV,HV, controls	90 days	Tue 12/13/16	Mon 4/17/17	$30,000.00	$35,400.00		$0.00
43	3.5.4.2	Procure Racks	90 days	Thu 12/15/16	Wed 4/19/17	$10,000.00	$15,400.00		$0.00
44	3.5.4.3	Procure Chiller	90 days	Mon 12/19/16	Fri 4/21/17	$10,000.00	$15,400.00		$0.00
45	**3.6**	**Readout R&D**	**345 days**	**Mon 1/23/17**	**Fri 5/18/18**	**$0.00**	**$137,840.00**		**$0.00**
46	3.6.1	Preliminary readout design and FPGA programing	120 days	Mon 1/23/17	Fri 7/7/17	$0.00	$52,800.00		$0.00
47	3.6.2	Preliminary test of RDO with test bench	20 days	Mon 7/10/17	Fri 8/4/17	$0.00	$7,680.00		$0.00
48	3.6.3	Test Preliminary Readout Design with RDO and CRU	20 days	Mon 9/25/17	Fri 10/20/17	$0.00	$11,360.00		$0.00
49	3.6.4	Readout design and test II	90 days	Mon 10/23/17	Fri 2/23/18	$0.00	$43,920.00		$0.00
50	3.6.5	Readout final design	60 days	Mon 2/26/18	Fri 5/18/18	$0.00	$22,080.00		$0.00
51	**3.7**	**Electronics Final Design Review**	**12 days**	**Mon 5/21/18**	**Tue 6/5/18**	**$0.00**	**$25,088.00**		**$0.00**
52	3.7.1	Electronics Design Review	1 day	Mon 5/21/18	Mon 5/21/18	$10,000.00	$13,680.00		$0.00
53	3.7.2	Incorporate Review Comments	10 days	Tue 5/22/18	Mon 6/4/18	$0.00	$9,200.00		$0.00
54	3.7.3	Complete Final Electronics Design	1 day	Tue 6/5/18	Tue 6/5/18	$0.00	$2,208.00		$0.00
55	3.8	Prototype readout assembled and tested	90 days	Wed 6/6/18	Tue 10/9/18	$0.00	$23,760.00		$0.00



LDRD MS Project(II)

Closely Tied to ALICE/ITS Upgrade Schedule

Sun 12/4/16

ID	WBS	Task Name	Duration	Start	Finish	Fixed Cost	Cost	Activity	Cost per Unit
56	**3.9**	**Mechanical Support and Cooling**	**200 days**	**Mon 1/23/17**	**Fri 10/27/17**	**$0.00**	**$236,160.00**		**$0.00**
57	**3.9.1**	Specifications	**60 days**	**Mon 1/23/17**	**Fri 4/14/17**	**$0.00**	**$65,120.00**		**$0.00**
58	3.9.1.1	Review & Simulate Heat Load	40 days	Mon 1/23/17	Fri 3/17/17	$0.00	$42,560.00		$0.00
59	3.9.1.2	review mechanical tolerances/distortions	10 days	Mon 3/20/17	Fri 3/31/17	$0.00	$11,040.00		$0.00
60	3.9.1.3	review disassembly/repair options	10 days	Mon 4/3/17	Fri 4/14/17	$0.00	$11,520.00		$0.00
61	3.9.2	Prototype Stave Space Frame Design	20 days	Mon 4/17/17	Fri 5/12/17	$0.00	$32,960.00		$0.00
62	**3.9.3**	**Safety Systems**	**60 days**	**Mon 8/7/17**	**Fri 10/27/17**	**$0.00**	**$35,440.00**		**$0.00**
63	3.9.3.1	review sensors & interlocks	20 days	Mon 8/7/17	Fri 9/1/17	$0.00	$7,200.00		$0.00
64	3.9.3.2	electrical interlock design	20 days	Mon 9/4/17	Fri 9/29/17	$5,000.00	$12,200.00		$0.00
65	3.9.3.3	cooling interlocks design	20 days	Mon 10/2/17	Fri 10/27/17	$5,000.00	$16,040.00		$0.00
66	**3.9.4**	**Cooling System**	**50 days**	**Mon 5/15/17**	**Fri 7/21/17**	**$0.00**	**$54,280.00**		**$0.00**
67	3.9.4.1	Prototype Design (modify ALICE)	10 days	Mon 5/15/17	Fri 5/26/17	$0.00	$9,200.00		$0.00
68	3.9.4.2	Chiller	30 days	Mon 5/29/17	Fri 7/7/17	$20,000.00	$21,800.00		$0.00
69	3.9.4.3	Mock up Testing	10 days	Mon 7/10/17	Fri 7/21/17	$10,000.00	$23,280.00		$0.00
70	**3.9.5**	**Stave Assembly Tooling**	**60 days**	**Mon 5/29/17**	**Fri 8/18/17**	**$0.00**	**$48,360.00**		**$0.00**
71	3.9.5.1	Jig Design (modify ALICE)	10 days	Mon 5/29/17	Fri 6/9/17	$0.00	$7,360.00		$0.00
72	3.9.5.2	Prototype Jigs	30 days	Mon 6/12/17	Fri 7/21/17	$5,000.00	$20,120.00		$0.00
73	3.9.5.3	Final Jigs Design and Production	20 days	Mon 7/24/17	Fri 8/18/17	$10,000.00	$20,880.00		$0.00
74	**3.10**	**Prototype Assembly and Test**	**90 days**	**Mon 2/26/18**	**Fri 6/29/18**	**$0.00**	**$114,240.00**		**$0.00**
75	3.10.1	Assemble prototype	30 days	Mon 2/26/18	Fri 4/6/18	$0.00	$35,040.00		$0.00
76	3.10.2	Prototype Full System Test	60 days	Mon 4/9/18	Fri 6/29/18	$0.00	$79,200.00		$0.00
77	3.11	Mechanical Conceptual Design	60 days	Mon 7/2/18	Fri 9/21/18	$0.00	$18,240.00		$0.00
78	**3.12**	Mechanical Conceptual Design Review	**12 days**	**Mon 9/24/18**	**Tue 10/9/18**	**$0.00**	**$33,920.00**		**$0.00**
79	3.12.1	Mechanics Design Review	1 day	Mon 9/24/18	Mon 9/24/18	$10,000.00	$13,680.00		$0.00
80	3.12.2	Incorporate Review Comments	10 days	Tue 9/25/18	Mon 10/8/18	$0.00	$18,400.00		$0.00
81	3.12.3	Complete Mechanical Conceptual Design	1 day	Tue 10/9/18	Tue 10/9/18	$0.00	$1,840.00		$0.00
82	**3.13**	**Softrware Tool Development and Analysis**	**500 days**	**Mon 1/23/17**	**Fri 12/21/18**	**$0.00**	**$351,200.00**		**$0.00**
83	3.13.1	FPGA, Online Monitoring and Contorls	200 days	Mon 1/23/17	Fri 10/27/17	$0.00	$176,000.00		$0.00
84	3.13.2	Offline Software and Analysis	300 days	Mon 10/30/17	Fri 12/21/18	$0.00	$175,200.00		$0.00
85	**3.14**	**Detector Optimizaation and Physics Simulations (MIE)**	**700 days**	**Mon 10/3/16**	**Fri 6/7/19**	**$0.00**	**$946,000.00**		**$0.00**
86	3.14.1	MIE preproposal development	300 days	Mon 10/3/16	Fri 11/24/17	$20,000.00	$404,000.00		$0.00
87	3.14.2	MIE full proposal development and reviews	400 days	Mon 11/27/17	Fri 6/7/19	$30,000.00	$542,000.00		$0.00
88	**3.15**	**Test Beam Operation**	**187 days**	**Fri 1/11/19**	**Mon 9/30/19**	**$0.00**	**$132,420.00**		**$0.00**
89	3.15.1	Shipping/Transport	10 days	Fri 1/11/19	Thu 1/24/19	$10,000.00	$12,400.00		$0.00
90	3.15.2	Setup	5 days	Fri 1/25/19	Thu 1/31/19	$0.00	$8,720.00		$0.00
91	3.15.3	Operations	10 days	Fri 2/1/19	Thu 2/14/19	$20,000.00	$45,600.00		$0.00
92	3.15.4	Test Beam Data Analysis & Publication	152 days	Fri 3/1/19	Mon 9/30/19	$0.00	$65,700.00		$0.00
93	3.16	Theory R&D	781 days	Mon 10/3/16	Mon 9/30/19	$1,800,000.00	$1,800,000.00		$0.00