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

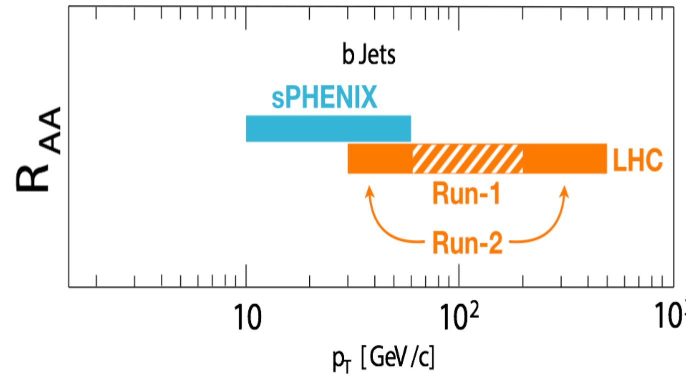
- LDRD Goals
  - Develop a new QGP physics program with heavy flavor b-jet measurements in sPHENIX at RHIC
  - Carry out key detector R&D and develop a new MIE proposal to DOE to build a state-of-the-art MAPS-based high precision vertex detector to support the b-jet physics program in sPHENIX
- Project 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

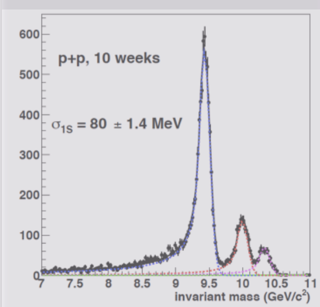
Cannot be done at the LHC for lack of low pT reach and huge backgrounds



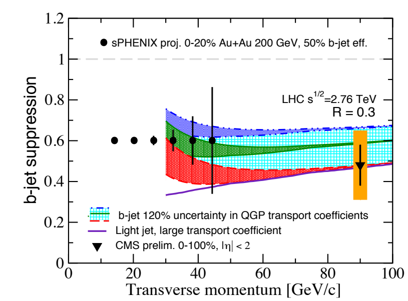
sPHENIX Three Physics Pillars

Jets

Upsilons



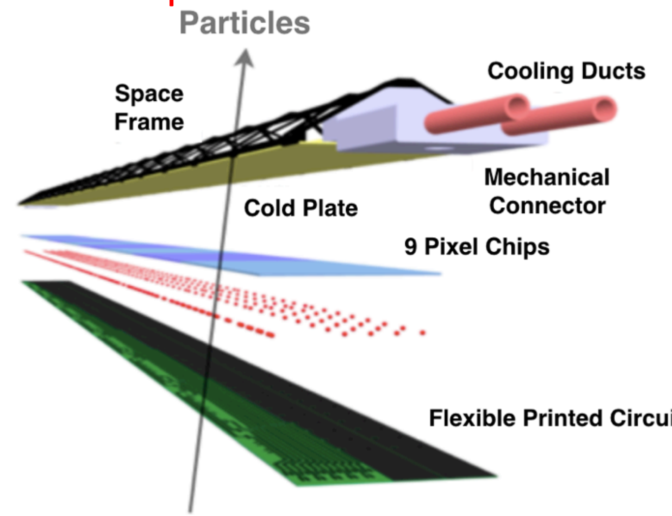
B-Jets ← this LDRD



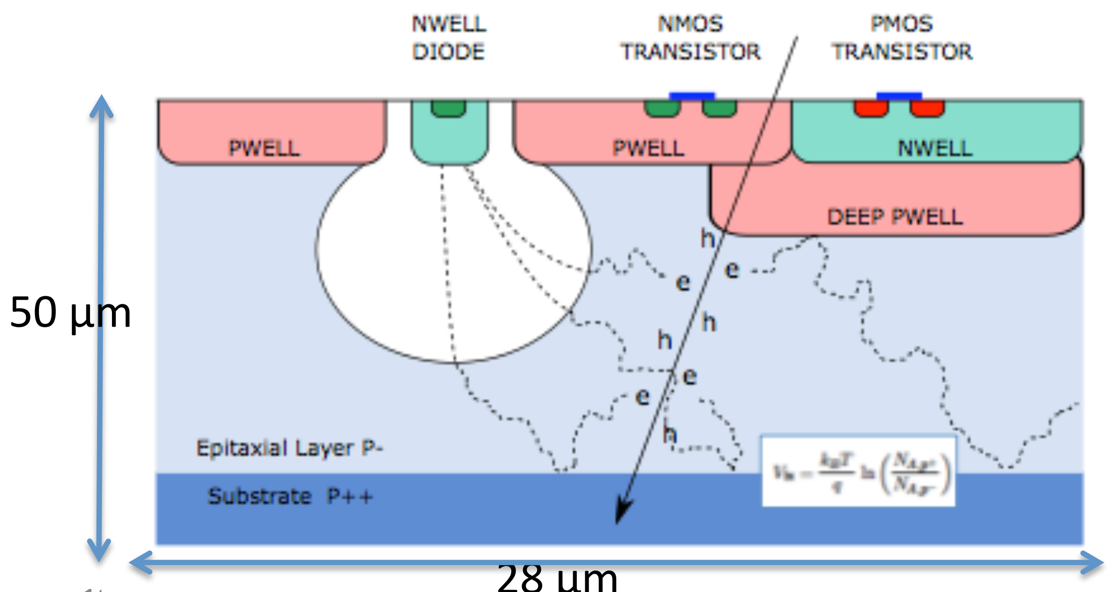
MAPS: a State of the Art Tracker

- 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!



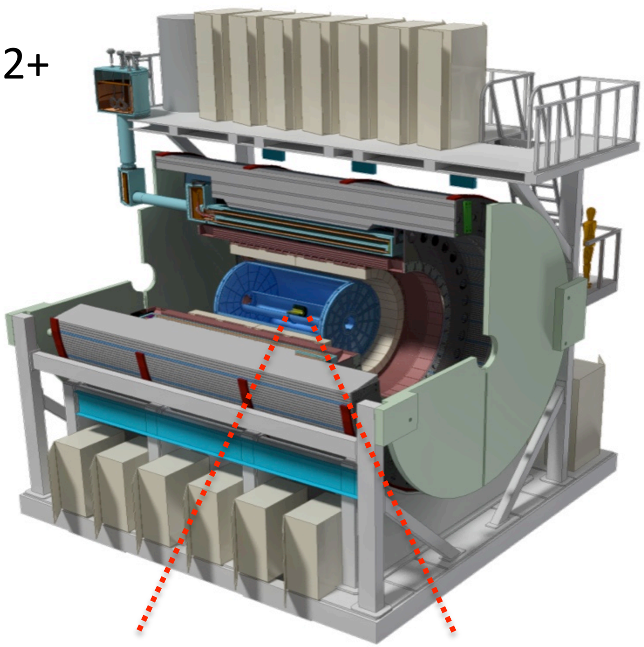
Tower Jazz 0.18 µm CMOS

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

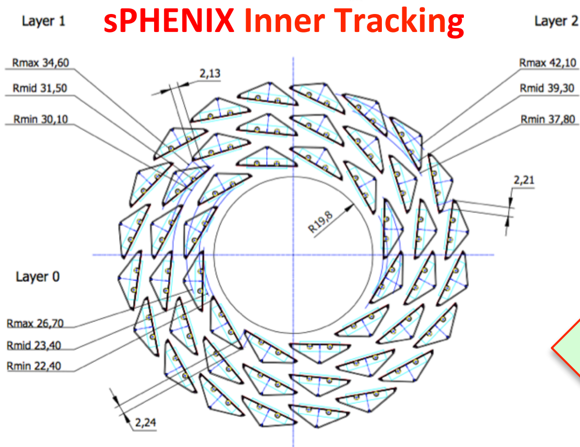
substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

LANL Proposed sPHENIX MAPS Inner Tracker

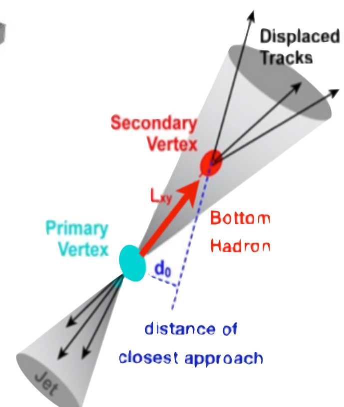
2022+



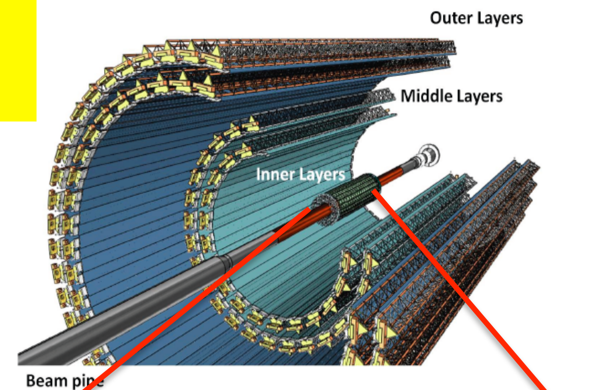
sPHENIX Inner Tracking

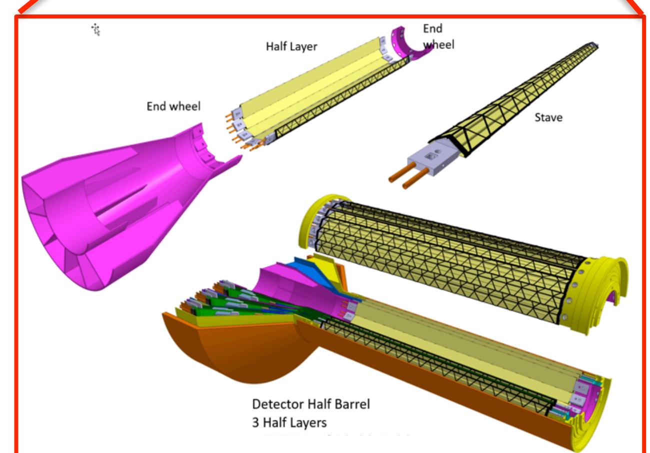


Key integration issues:
- Readout
- Mechanics



ALICE ITS Upgrade (2021+);
Inner Tracker System



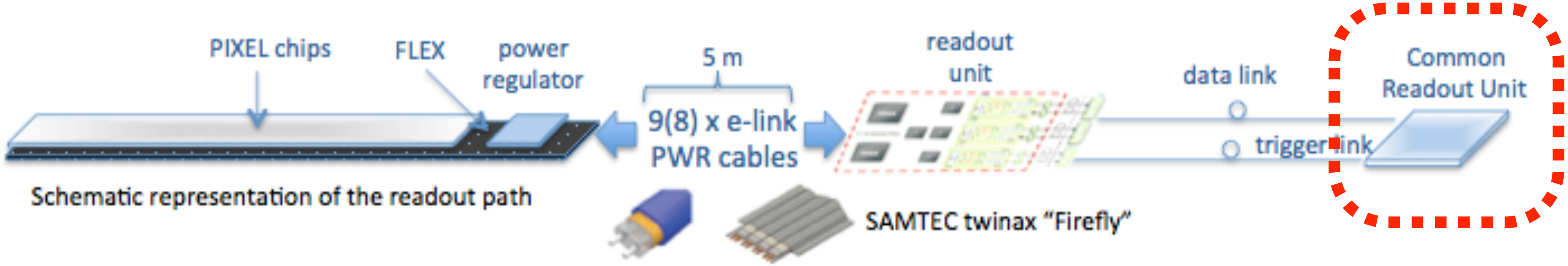


"Adopt" ALICE/ITS
Mini. risk,
Max. physics

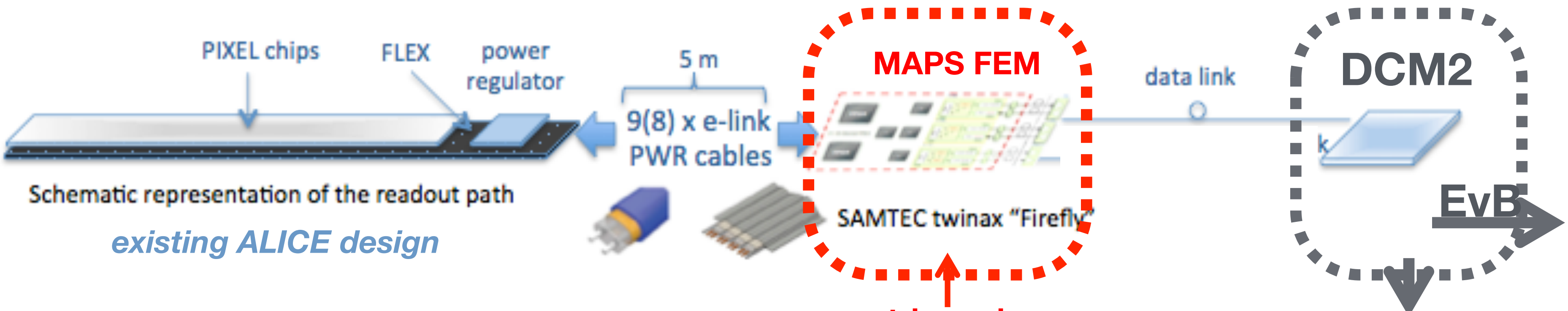
Goal: MAPS-sPHENIX Electronics Integration

Plan A: reprogram

ALICE readout path



Plan B: sPHENIX readout path (held as contingency)



existing ALICE design

trigger in

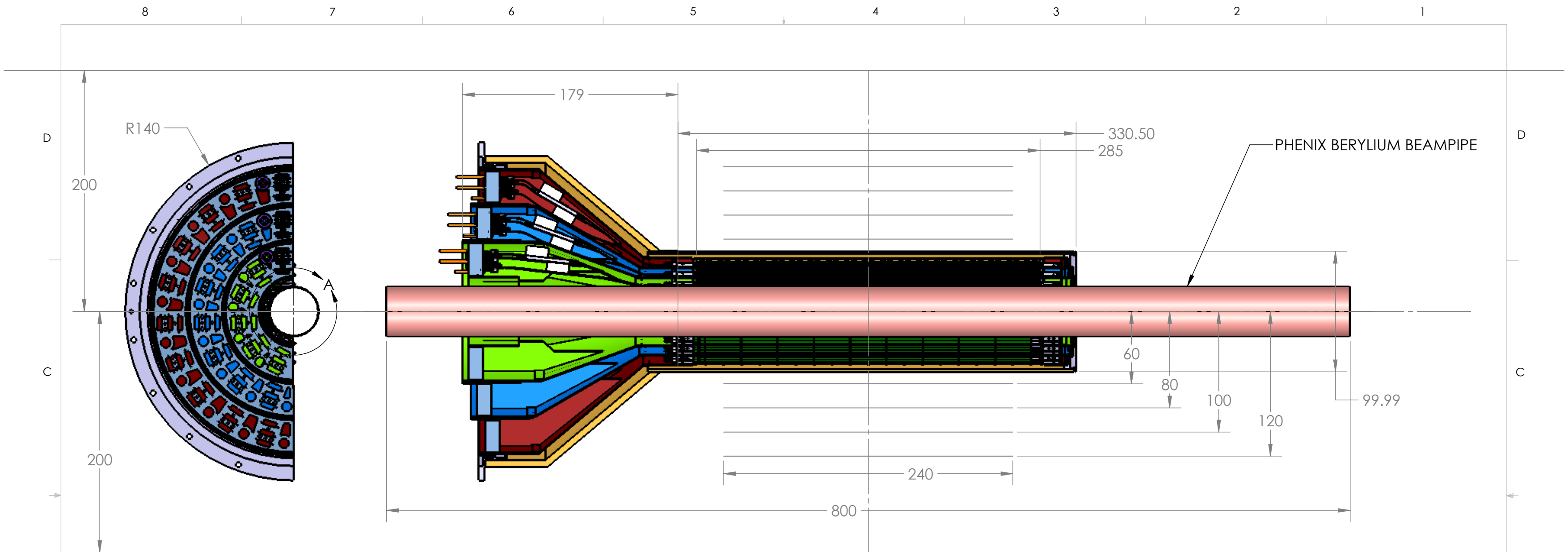
modified design, starting with ALICE boards

busy out

existing sPHENIX design

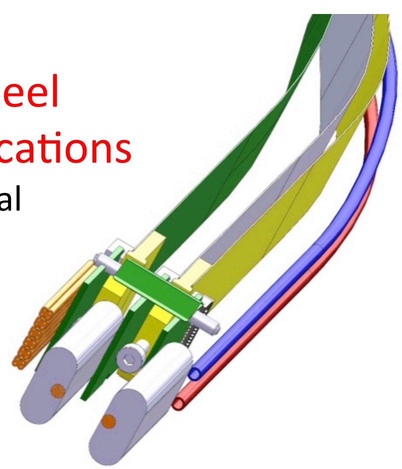
Pat's talk

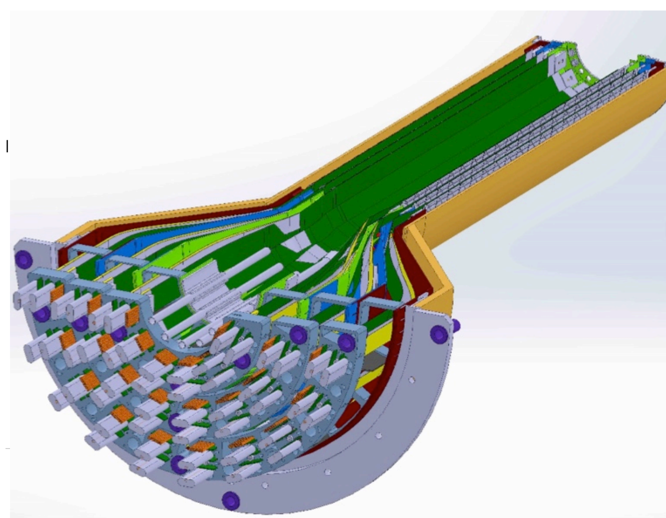
Goal: MAPS-sPHENIX Mechanical Integration



Service End Wheel
Possible modifications

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





ALICE inner tracker
B- staves + end wheels + panels 210416

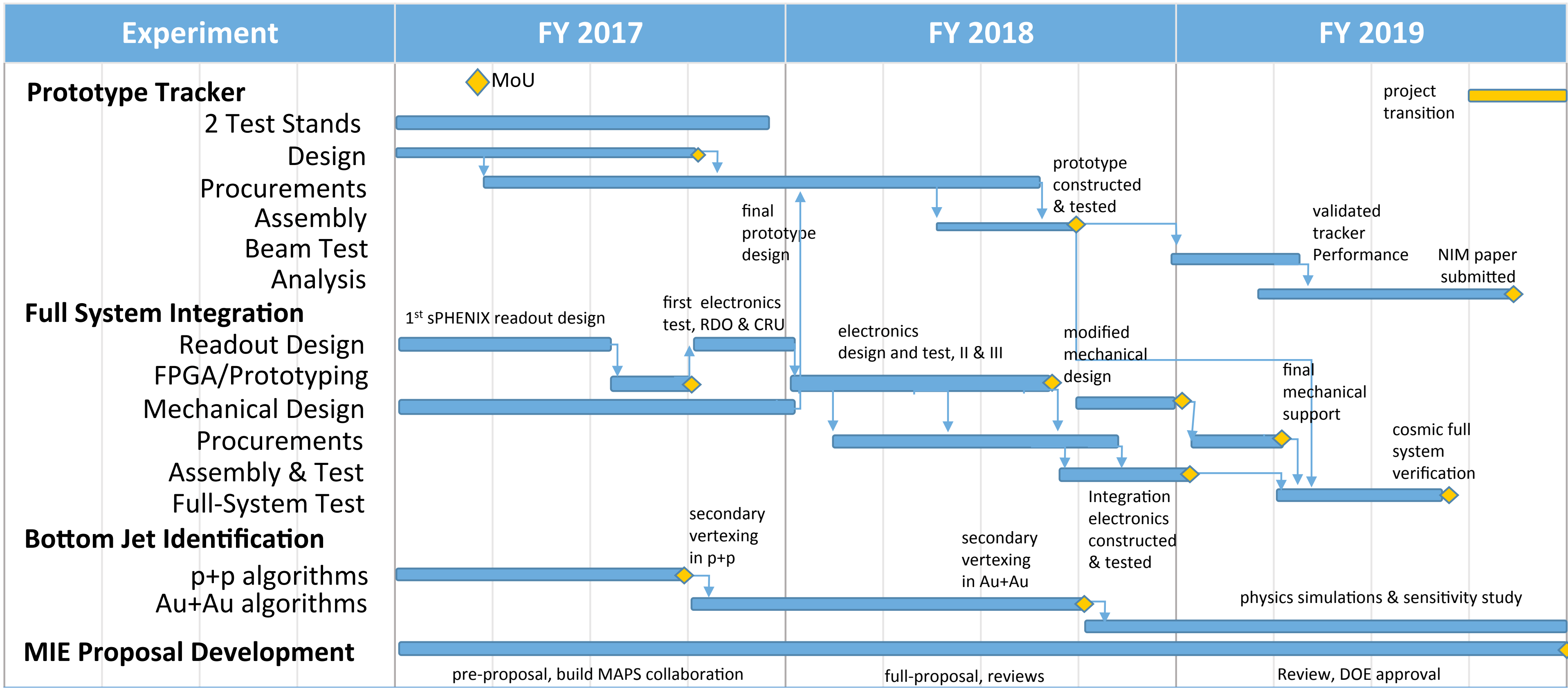
Walt's talk

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

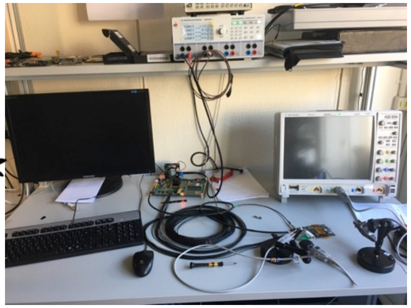


Closely tied to ALICE R&D and Production Schedule

Cesar's talk

1^{st} Milestone: MoU with ALICE/ITS

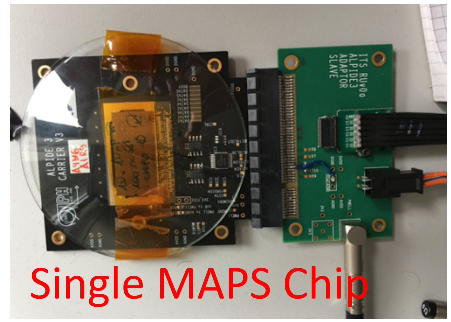
- CERN Visit to discuss MoU: November 10-15, 2016
  - Visited MAPS R&D and construction labs
  - Agreement on MoU achieved!
- MoU with ALICE/ITS
  - Associate member on the ALICE/ITS project at CERN
    - Access all technical design files and documents
    - Access other technical resources, including 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



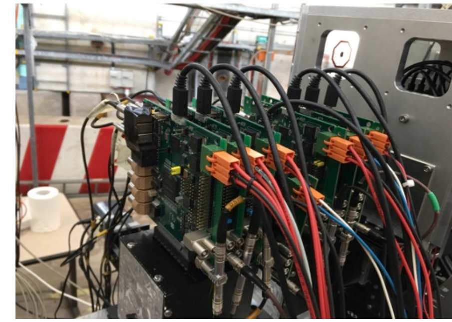
High speed readout test

Status of MAPS R&D at ALICE/CERN

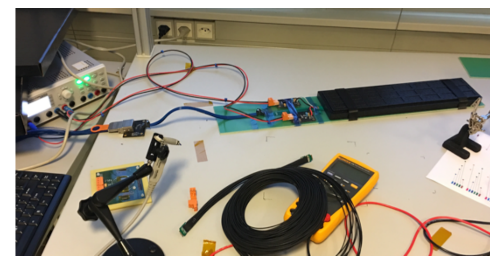
- MAPS chip readout with test board
  - Also tested at LANL
  - Telescope
- Multichip MAPS high speed readout
  - with the first prototype Readout Cards (RUv0)
  - MiniDAQ (MOSAIC board) test bench
- RU fiber optics communication established with a prototype Common Readout Unit (CRU)
- Stave space frame 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



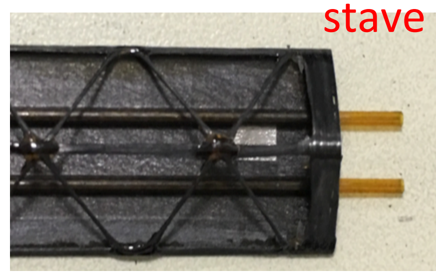
A 7-single-chip telescope



MOSAIC Test Bench



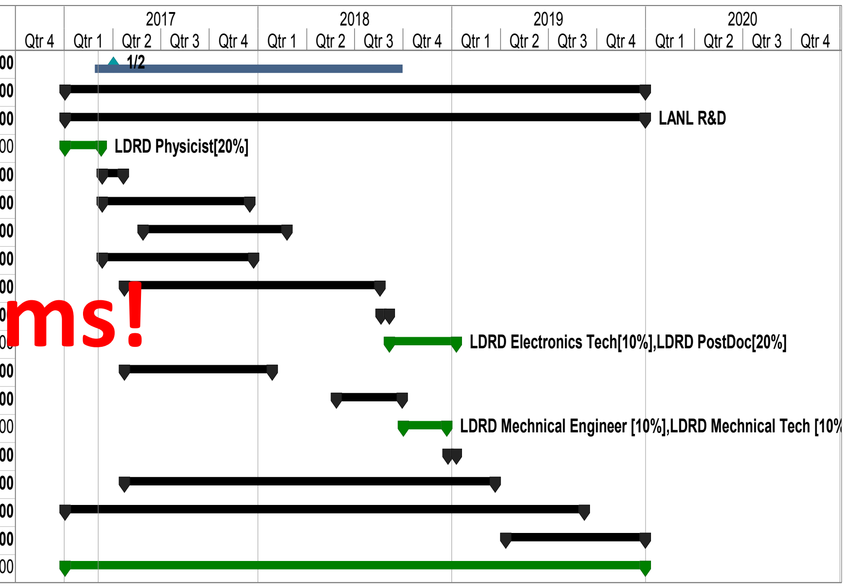
stave



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 [illegible]/23/17	Fri [illegible]/18/18	[illegible]	[illegible]		$0.00
51	3.7	Electronics Final Design Review	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
55	3.8	Prototype readout assembled and tested	[illegible]	Wed 6/6/18	[illegible]	[illegible]	[illegible]		[illegible]
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:

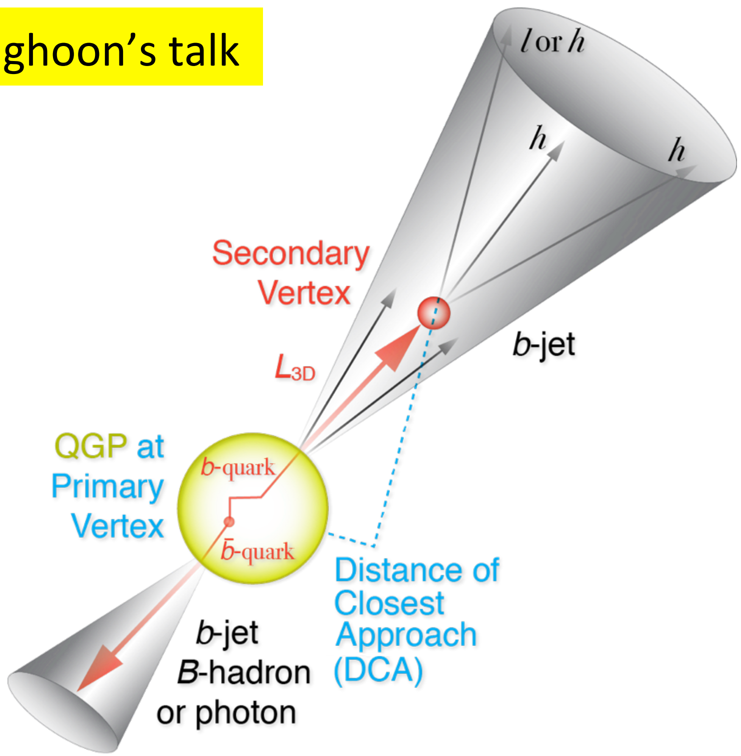
- Use early prototype staves to build LANL telescope for key integration and performance studies
- Early R&D on readout, also explore alternative approaches
  - CRU firmware integration at EvB level (Plan-A)
  - DCM-II readout via custom adaptor boards (Plan-B)
- Joint R&D with other sPHENIX subsystems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

Cesar's talk

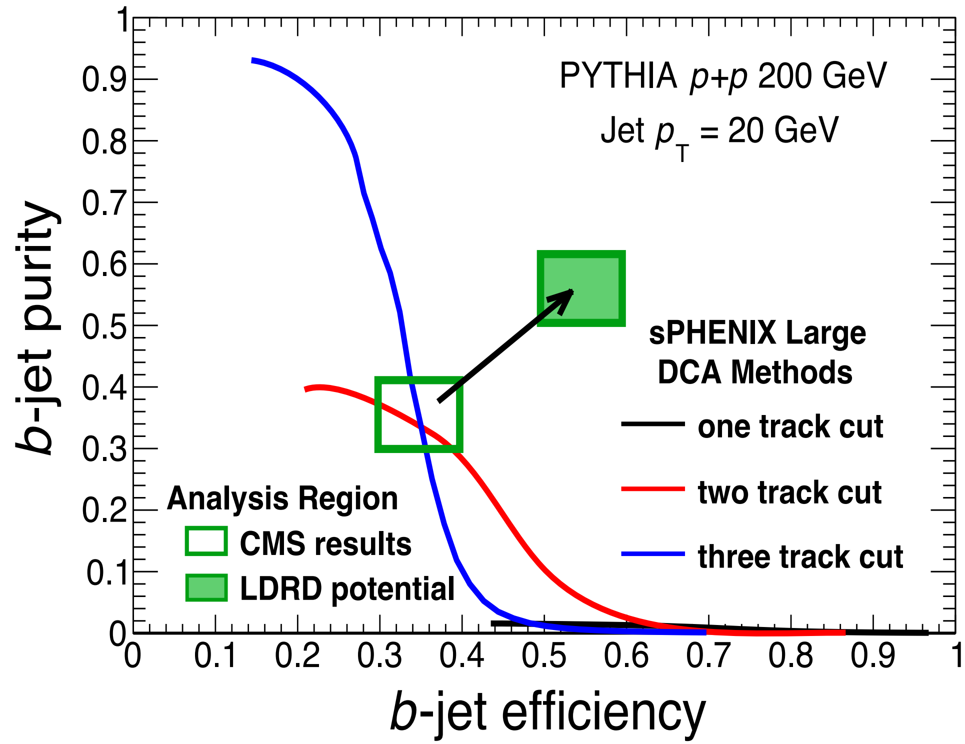
Experimental R&D Deliverables: Physics

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

Sanghoon's talk



Secondary Vertexing Possible!

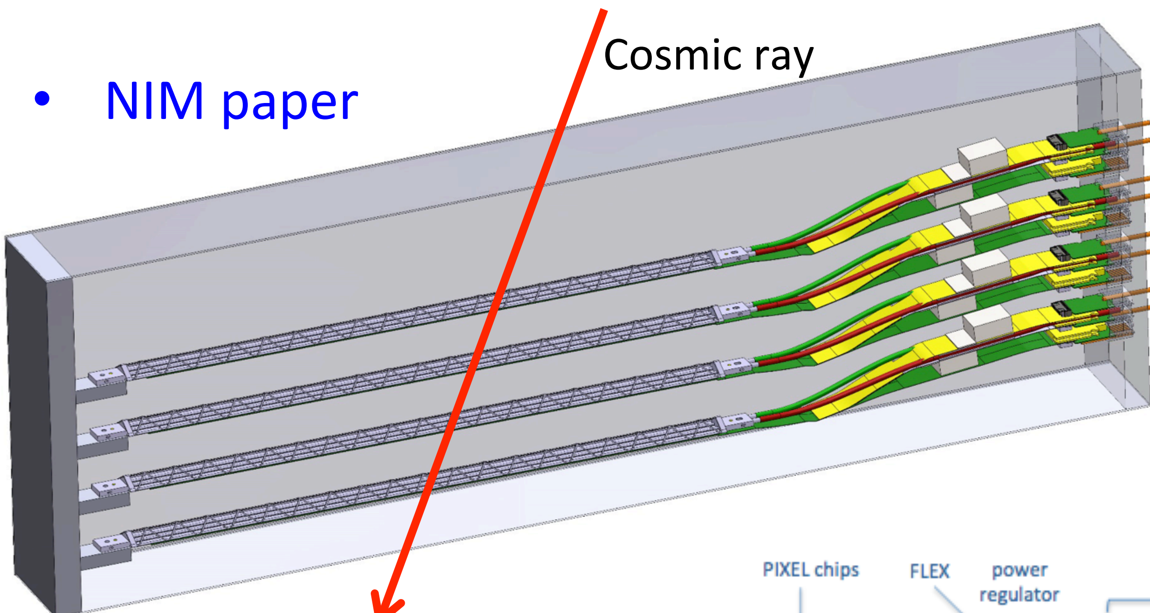


- A new b-jet identification with **high efficiency** and **high purity** is possible
- Figure of merit is ***efficiency x purity.*** Greatly enhancing the b-jet physics program, x4 improvement in FOM (compared to alternatives)

Experimental R&D Deliverables

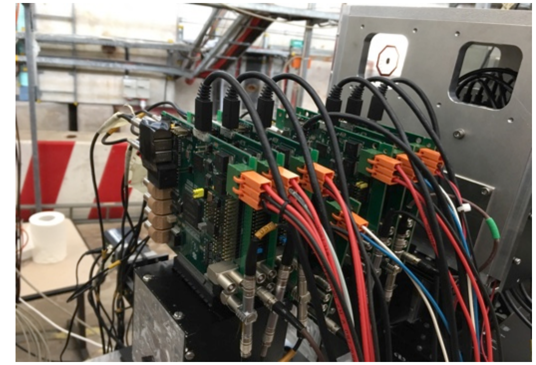
a 4-Stave Telescope

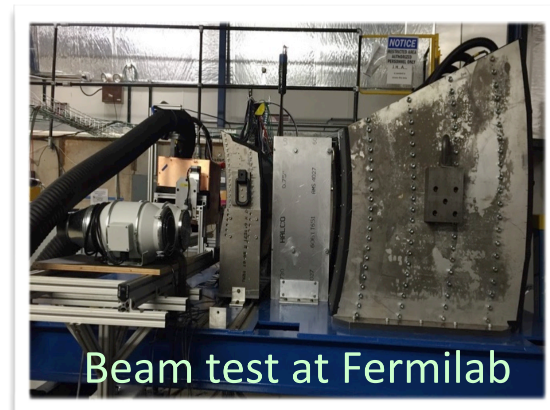
- Performance of prototype tracker
  - High speed readout of staves
  - Spatial resolution
  - Electrical and mechanical stability
  - Cooling etc.
- NIM paper



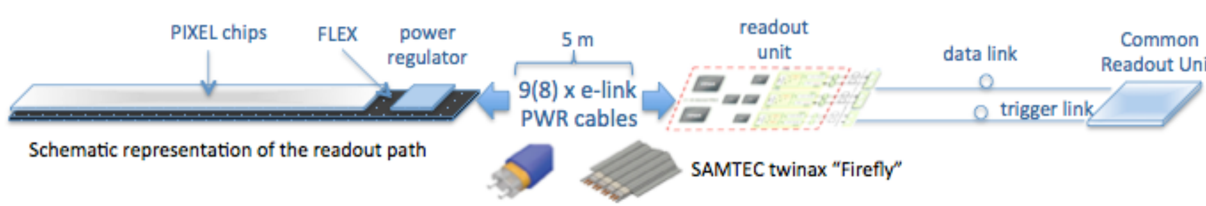
Pat and Walt's talks

A 5-single-chip telescope





sPHENIX Data Format

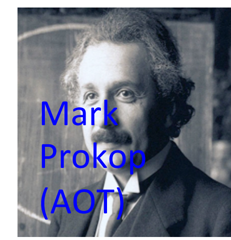


Experimental Project Organization

- 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







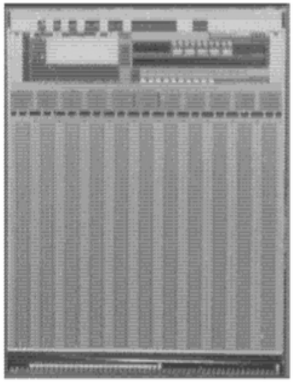
Cesar’s talk

Impact and Transition Plan

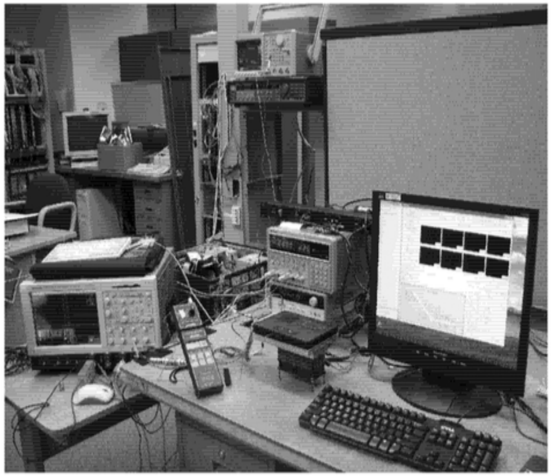
- Extend LANL's position as an international leader at the next generation QGP physics frontier, major discovery potential
- Develop a new long term (10Y) major DOE funded program ($3M/year) at LANL in line with the national priority, DOE funded QCD theory (~$1M/year)
- New in-house capabilities in low-mass 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

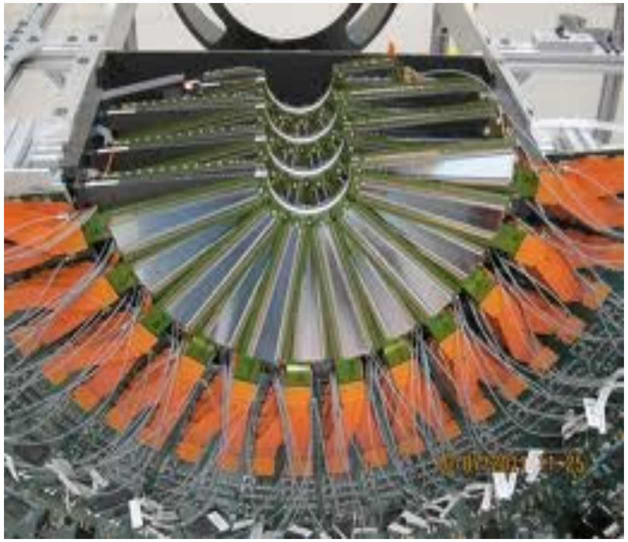
prototyping under LDRD DR:



FVTX prototype sensor & readout



final tracker supported by DOE:

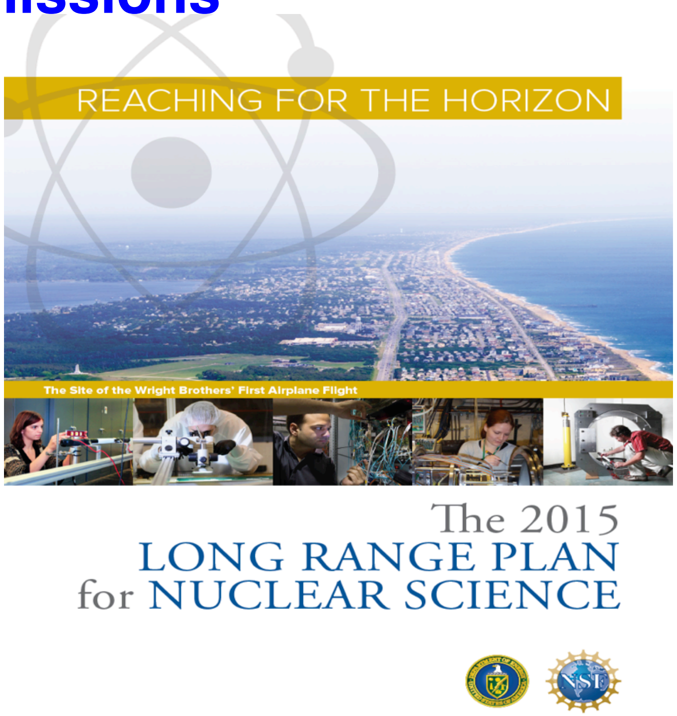


A Road Map

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



NSAC Long Range Plan

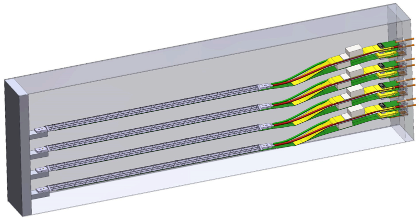
Recommendation #1 (RHIC):

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

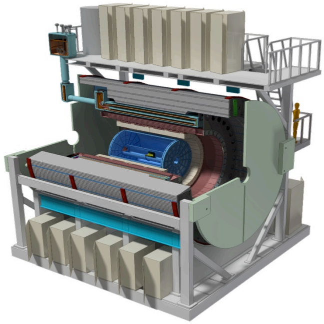
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

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

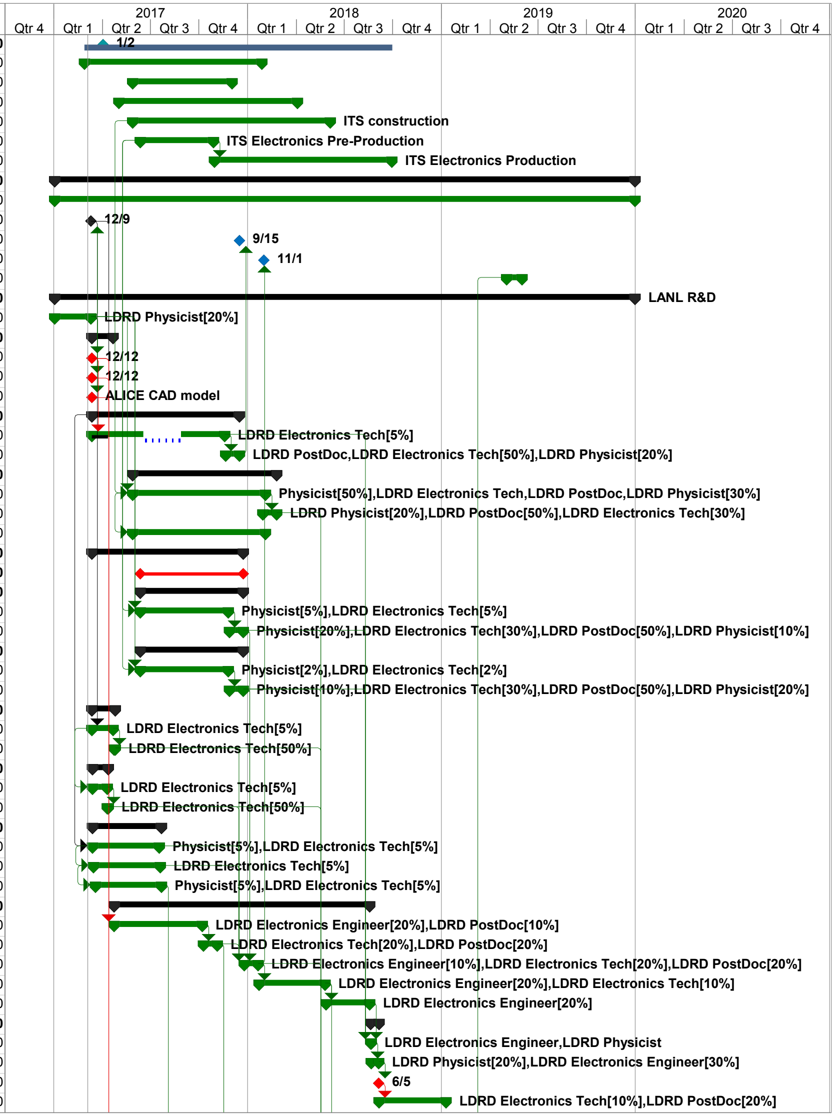
10. Are critical procurements identified?

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



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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

Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX - Theory

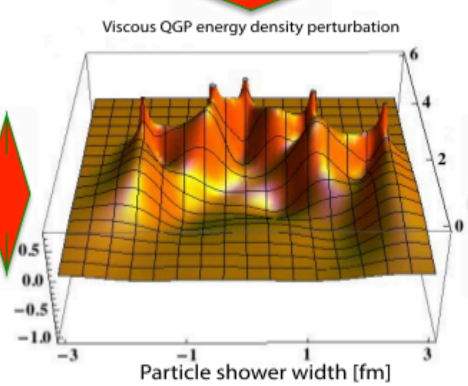
Expertise from T-2, T-5, CCS-7

Daligault, Gupta, Kang, Lee, Vitev (co-PI), Yoon

Theory budget ~ $600K/year

Perturbative QCD/SCET and jet simulations: most precise b-jet theory in proton collisions, new theory for heavy ion collisions, b-jet substructure, b-jet tomography of the QGP

QMD simulations: transport properties of plasmas, stopping power for heavy particles



Lattice QCD: EoS, input for hydro, charge number fluctuations near the phase transition

Experiment: Tracker design, prototype construction, jet finder development, ongoing and improved PHENIX and STAR BES II analyses






b-jet energy loss

pQCD / SCET

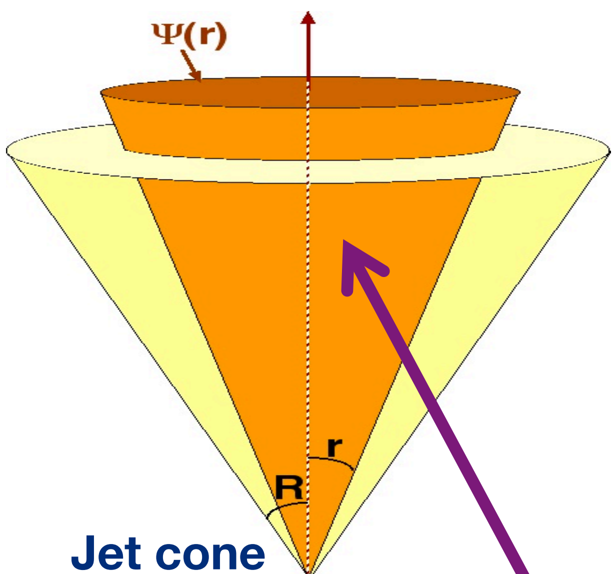
MD simulations / dE/dx

Lattice QCD / Hydro

Precision b-jets X sections and substructure

Kang, Lee, Vitev

- Powerful soft-collinear effective field theory (SCET) methods. Vast improvements in accuracy of jet cross sections in e^+e^-, *ep*, and *pp* collisions

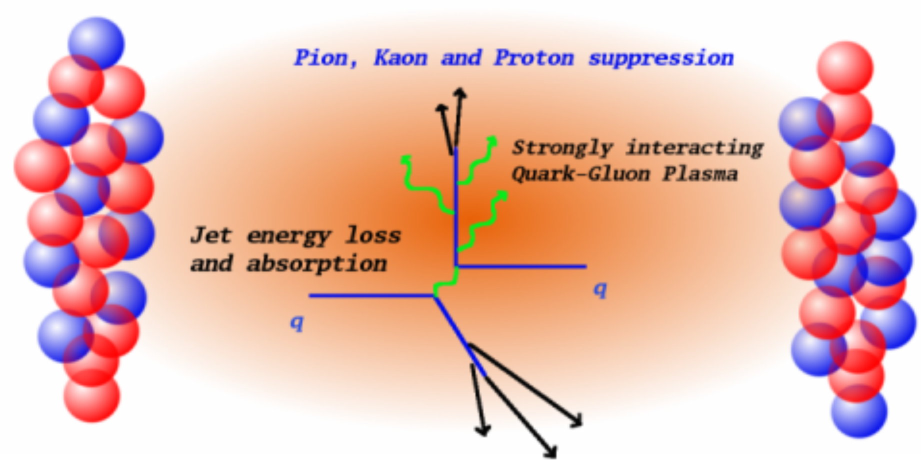


Improved formulations of SCET, compute b-jet cross sections with the highest accuracy to date

Phys. Rev. D90 (2014) 094503

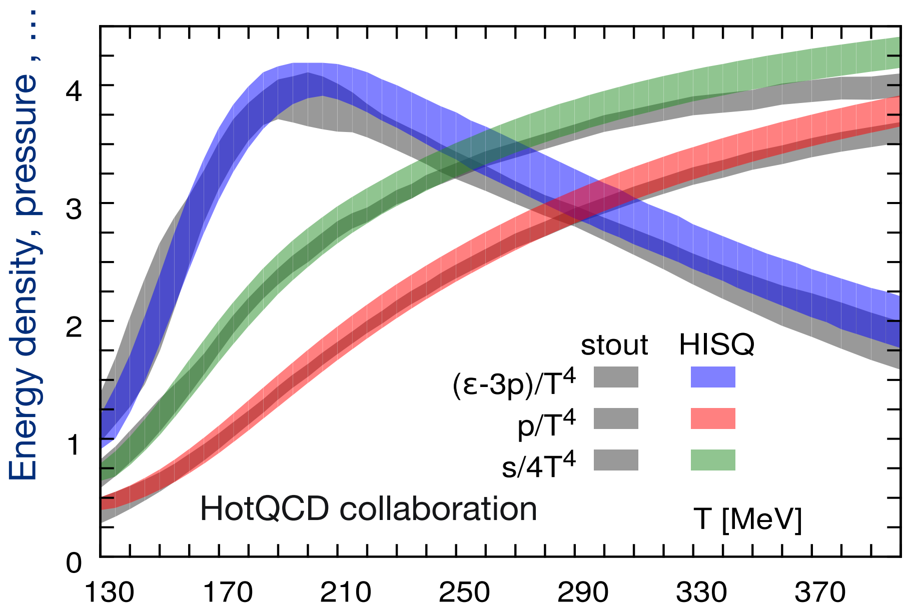
Develop first-principles theory of heavy quark propagation in nuclear matter and the process of shower formation

Evaluate jet substructure observables (shapes, fragmentation functions) and their modification in the QGP



Mass, charge, transport properties

Lattice QCD EoS and Charge Fluctuations



Phys. Rev. D90 (2014) 094503

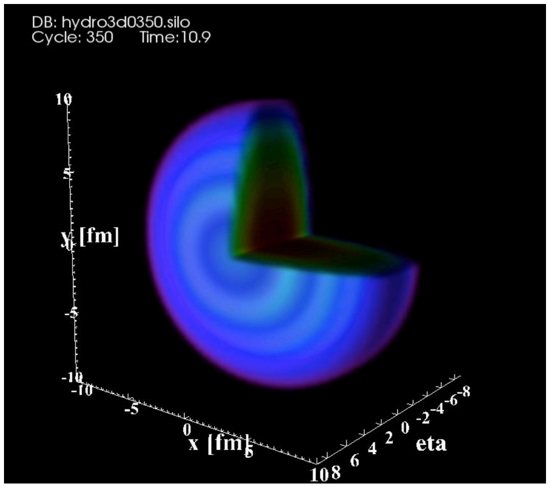
Gupta, Yoon

- Incorporate the current state-of-the art EoS in hydrodynamic simulations, describe time, temperature evolution of the QGP

Accurate medium dynamics for b-jet quenching simulations will be available

- Phase transitions near the critical point characterized by fluctuations (charge number fluctuation for QGP to ordinary nuclear matter) $\sim (\pi^+ - \pi^-)$

Evaluate charge fluctuations on the lattice and compare our results to measurements form Beam Energy Scan II at RHIC



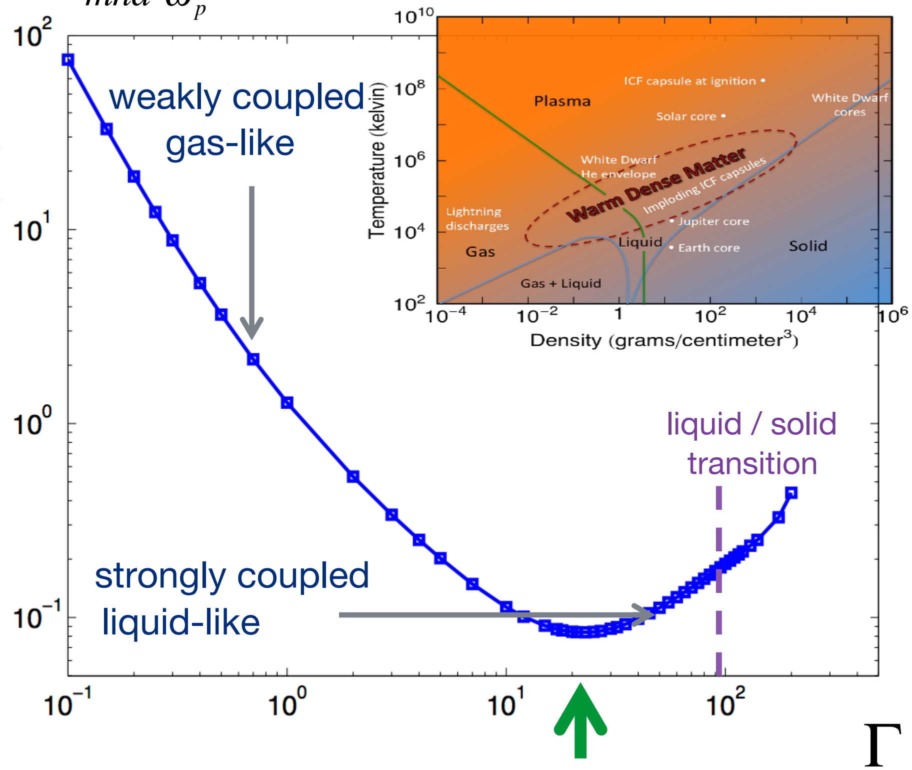
Hydro simulation of the QGP energy density at 10^{-23} s

dE/dx in Strongly-Coupled Plasmas

$$\eta^* = \frac{\eta}{mna^2\omega_p}$$

Phys. Rev. Lett.113, 155006 (2015)

Daligault, Vitev



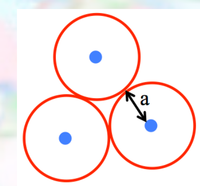
QGP-like minimum

- The strongly coupled nature of the QGP makes it tantalizingly similar to warm dense matter (WDM). Microscopic MD simulations

Coupling strength: $\Gamma = \frac{PE}{KE}$

$\Gamma > 1$ Interactions among particles dramatically affect their dynamics

In WDM, $\Gamma = \frac{Q^2 / a}{k_B T}$



In QGP, $\Gamma = few$

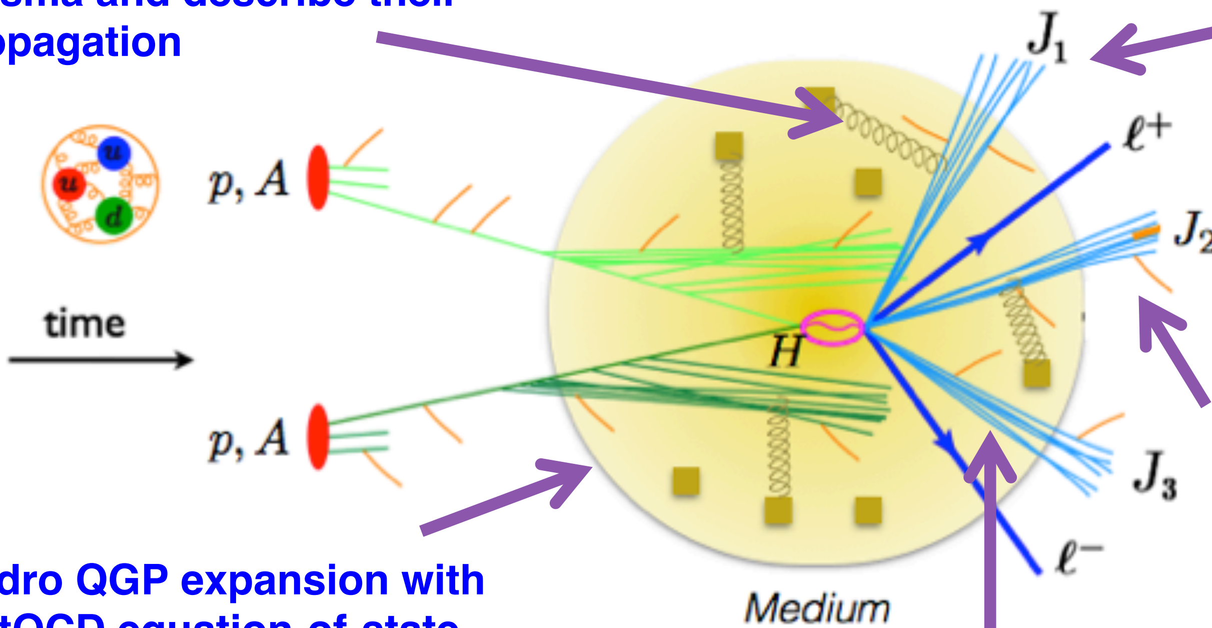
Perform molecular dynamics (MD) simulations of stopping power of charged particles in WDM near the viscosity minimum

Obtain much-needed physical insights and theoretical guidance for b-jet stopping power phenomenology in the QGP

Theory Deliverables: a Unified Picture

First-principles effective theory to couple b-jets to the plasma and describe their propagation

Most accurate resummed calculations of b-jet cross sections and b-jet substructure in proton-proton collisions at RHIC and LHC



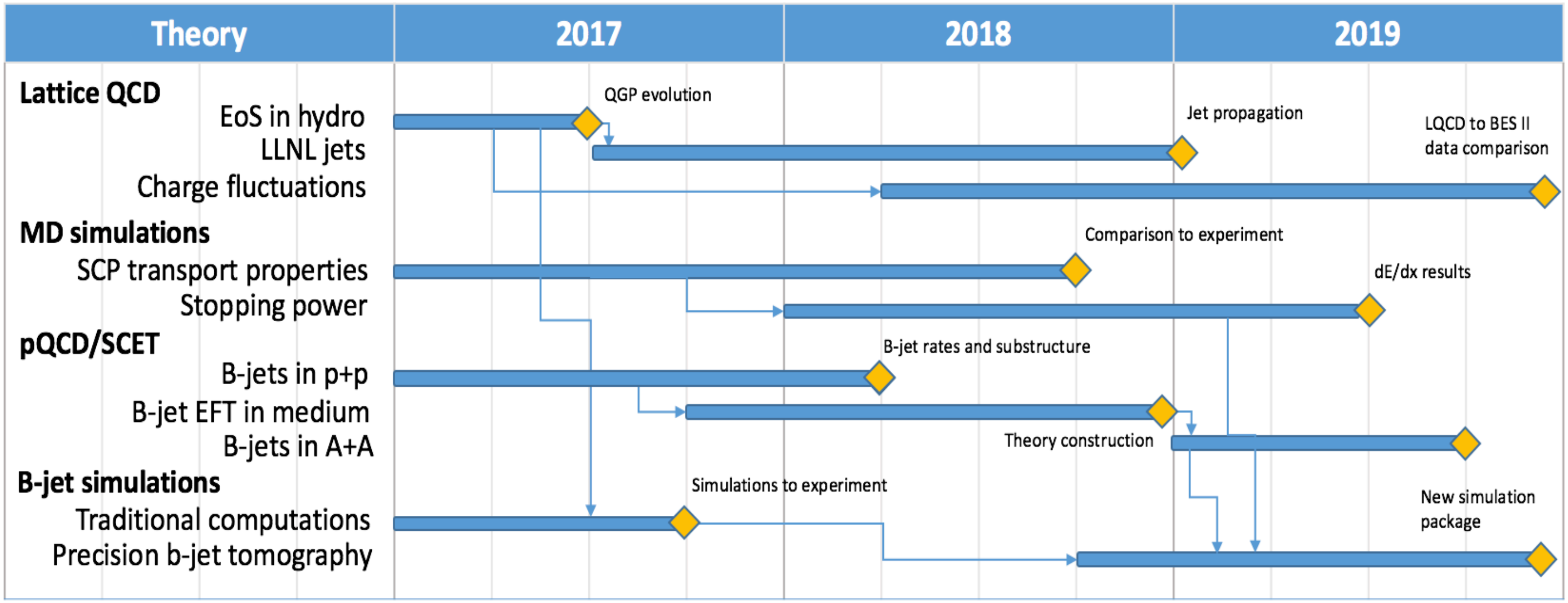
Set of observables sensitive to the transport properties and quasiparticle nature of the QGP

Hydro QGP expansion with HotQCD equation-of-state. LQCD for charge fluctuations

Stopping power for heavy particles in strongly-coupled plasmas form MD. Simulations validated against experiment

Package for precision b-jet tomography at sPHENIX and predictions to experiment

Theory Timetable



- **Individual theory discussion on weekly basis, keeping track of progress**
- **Well-defined responsibilities, researchers matched to tasks**
- **Monthly combined theory and experiment meetings**
- **Progress on items with milestones this year (hydro simulations with LQCD EoS and b-jet simulations with energy loss)**
- **One item completed ahead of schedule – EFT for heavy quark propagation in the QGP**

One Theory Highlight

Develop an effective theory of b-jet propagation in matter

FY 2018

- Develop first-principles theory of heavy quark propagation in nuclear matter and the process of shower formation

Earlier developments

Phys. Lett. B564 (2003) 231-234

JHEP 1106 (2011) 080

It was possible to carry this simplification since we realized the sectors of the theory decouple, very explicit in the hybrid gauge

LO SCET Lagrangian

$$\mathcal{L}_0 = \sum_{\tilde{p},\tilde{p}',\tilde{q}} e^{-ix\cdot\mathcal{P}}\, \bar{\xi}_{n,p'} \left[in\cdot D + (\mathcal{P}\!\!\!/_\perp + g A\!\!\!/^\perp_{n,q}) W_n \frac{1}{\bar{\mathcal{P}}} W_n^\dagger (\mathcal{P}\!\!\!/_\perp + g A\!\!\!/^\perp_{n,q'}) \right] \frac{\bar{n}\!\!\!/}{2} \xi_{n,p} + \mathcal{L}_m$$

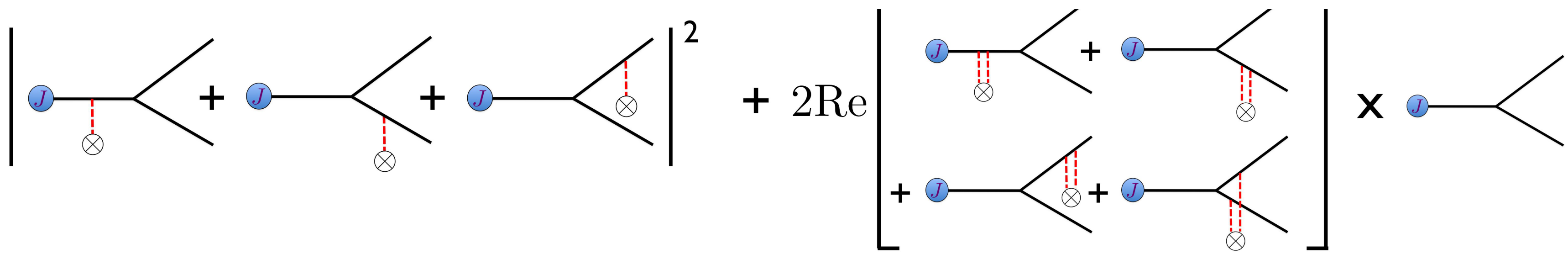
The mass term

$$\mathcal{L}_m = \sum_{\tilde{p},\tilde{p}',\tilde{q}} e^{-ix\cdot\mathcal{P}} \left[m\, \bar{\xi}_{n,p'} \left[(\mathcal{P}\!\!\!/_\perp + g A\!\!\!/^\perp_{n,q}), W_n \frac{1}{\bar{\mathcal{P}}} W_n^\dagger \right] \frac{\bar{n}\!\!\!/}{2} \xi_{n,p} - m^2\, \bar{\xi}_{n,p'} W_n \frac{1}{\bar{\mathcal{P}}} W_n^\dagger \frac{\bar{n}\!\!\!/}{2} \xi_{n,p} \right]$$

The mass $m/p^+ \sim \lambda$ in SCET_M already counts as the small parameter. So any term that will include mass and the Glauber field will be power suppressed

Necessary Ingredient - Massive Splittings

Diagrams corresponding to first order in opacity

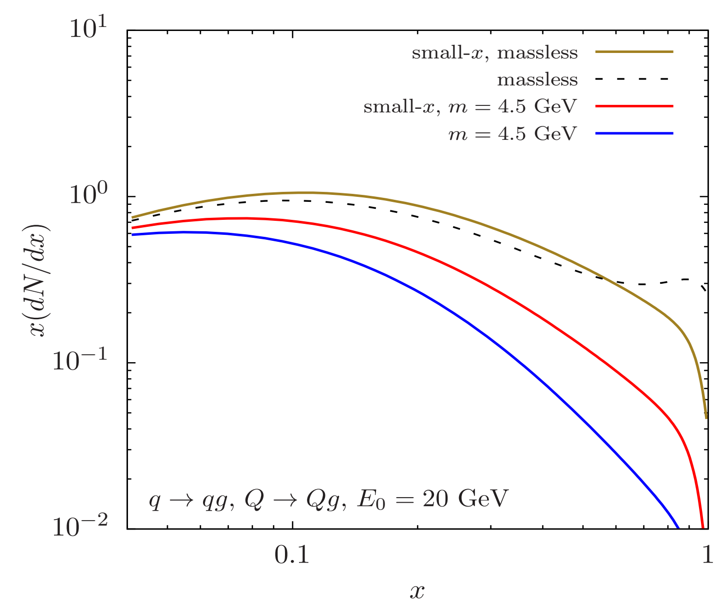


- First recover the massive vacuum splittings
- Evaluate the 3 massive in medium splittings

We have input for description of the in-medium parton showers of heavy quarks

One example. Can be evaluated numerically

$$
\begin{aligned}
\left(\frac{dN^{\mathrm{med}}}{dx d^2\boldsymbol{k}_\perp}\right)_{Q\to Qg} &= \frac{\alpha_s}{2\pi^2} C_F \int \frac{d\Delta z}{\lambda_g(z)} \int d^2\boldsymbol{q}_\perp \frac{1}{\sigma_{el}} \frac{d\sigma_{el}^{\mathrm{med}}}{d^2\boldsymbol{q}_\perp} \left\{ \left(\frac{1+(1-x)^2}{x}\right) \left[\frac{\boldsymbol{B}_\perp}{\boldsymbol{B}_\perp^2+\nu^2} \right.\right. \\
&\times \left(\frac{\boldsymbol{B}_\perp}{\boldsymbol{B}_\perp^2+\nu^2} - \frac{\boldsymbol{C}_\perp}{\boldsymbol{C}_\perp^2+\nu^2} \right) (1-\cos[(\Omega_1-\Omega_2)\Delta z]) + \frac{\boldsymbol{C}_\perp}{\boldsymbol{C}_\perp^2+\nu^2} \cdot \left(2\frac{\boldsymbol{C}_\perp}{\boldsymbol{C}_\perp^2+\nu^2} - \frac{\boldsymbol{A}_\perp}{\boldsymbol{A}_\perp^2+\nu^2} \right. \\
&\left. - \frac{\boldsymbol{B}_\perp}{\boldsymbol{B}_\perp^2+\nu^2} \right) (1-\cos[(\Omega_1-\Omega_3)\Delta z]) + \frac{\boldsymbol{B}_\perp}{\boldsymbol{B}_\perp^2+\nu^2} \cdot \frac{\boldsymbol{C}_\perp}{\boldsymbol{C}_\perp^2+\nu^2} (1-\cos[(\Omega_2-\Omega_3)\Delta z]) \\
&+ \frac{\boldsymbol{A}_\perp}{\boldsymbol{A}_\perp^2+\nu^2} \cdot \left(\frac{\boldsymbol{D}_\perp}{\boldsymbol{D}_\perp^2+\nu^2} - \frac{\boldsymbol{A}_\perp}{\boldsymbol{A}_\perp^2+\nu^2} \right) (1-\cos[\Omega_4\Delta z]) - \frac{\boldsymbol{A}_\perp}{\boldsymbol{A}_\perp^2+\nu^2} \cdot \frac{\boldsymbol{D}_\perp}{\boldsymbol{D}_\perp^2+\nu^2} (1-\cos[\Omega_5\Delta z]) \\
&\left. + \frac{1}{N_c^2} \frac{\boldsymbol{B}_\perp}{\boldsymbol{B}_\perp^2+\nu^2} \cdot \left(\frac{\boldsymbol{A}_\perp}{\boldsymbol{A}_\perp^2+\nu^2} - \frac{\boldsymbol{B}_\perp}{\boldsymbol{B}_\perp^2+\nu^2} \right) (1-\cos[(\Omega_1-\Omega_2)\Delta z]) \right] \\
&\left. + x^3 m^2 \left[\frac{1}{\boldsymbol{B}_\perp^2+\nu^2} \cdot \left(\frac{1}{\boldsymbol{B}_\perp^2+\nu^2} - \frac{1}{\boldsymbol{C}_\perp^2+\nu^2} \right) (1-\cos[(\Omega_1-\Omega_2)\Delta z]) + \ldots \right] \right\}
\end{aligned}
$$



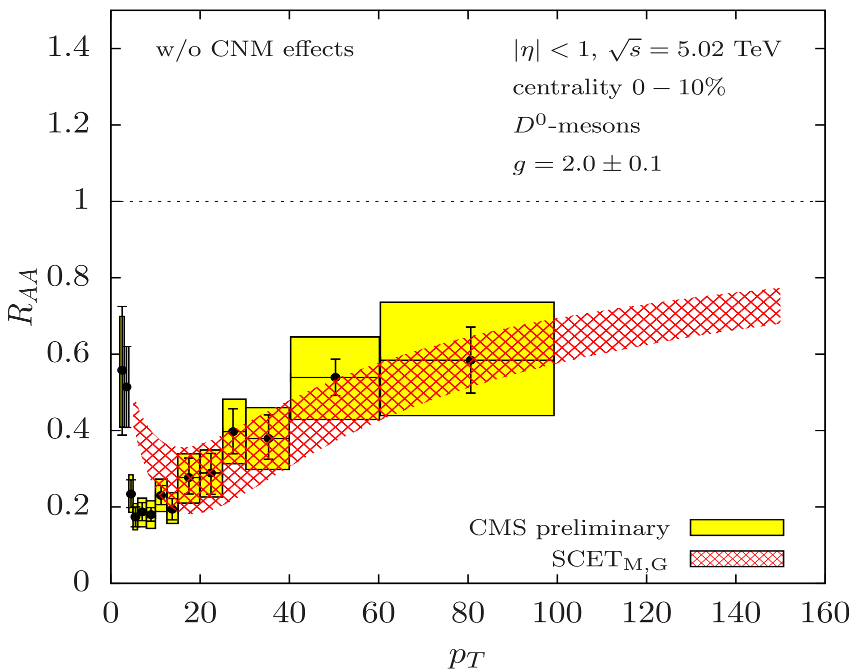
Largest mass effects in the sPHENIX b-jet acceptance range

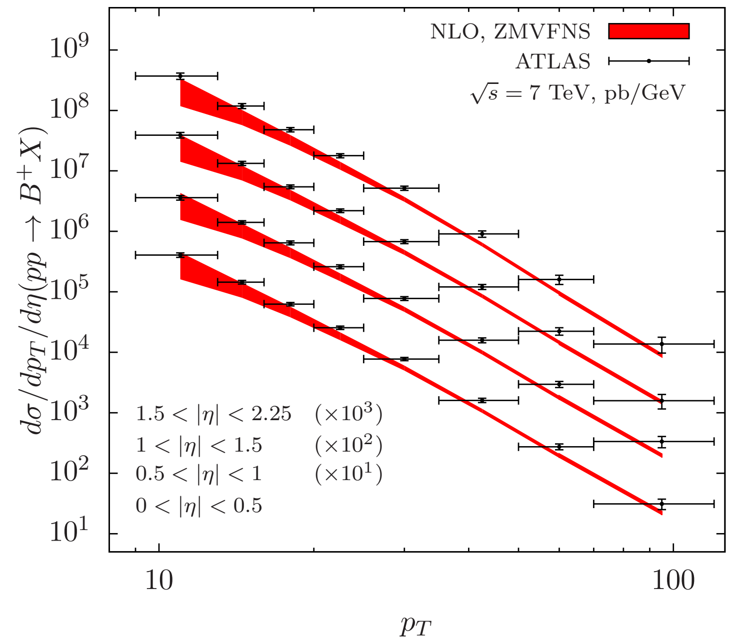
Application Consistent with NLO

Two advances – a) including gluon fragmentation contribution to heavy flavor, b) going beyond energy loss

$$\frac{d\sigma_{pp}^{H}}{dp_T d\eta} = \frac{2p_T}{s}\sum_{a,b,c}\int_{x_a^{\min}}^{1}\frac{dx_a}{x_a}f_a(x_a,\mu)\int_{x_b^{\min}}^{1}\frac{dx_b}{x_b}f_b(x_b,\mu) \times \int_{z_c^{\min}}^{1}\frac{dz_c}{z_c^2}\frac{d\hat{\sigma}_{ab}^{c}(\hat{s},\hat{p}_T,\hat{\eta},\mu)}{dvdz}D_c^H(z_c,\mu),$$

- Gluon fragmentation plays an important role ~50%





- First cascade contribution

$$d\sigma^{H}_{\mathrm{PbPb}} = d\sigma^{H,\mathrm{NLO}}_{pp} + d\sigma^{H,\mathrm{med}}_{\mathrm{PbPb}}$$

This leaves us time for a stretch goal – include collisional energy losses in the SCET framework. This can go well trough the second year

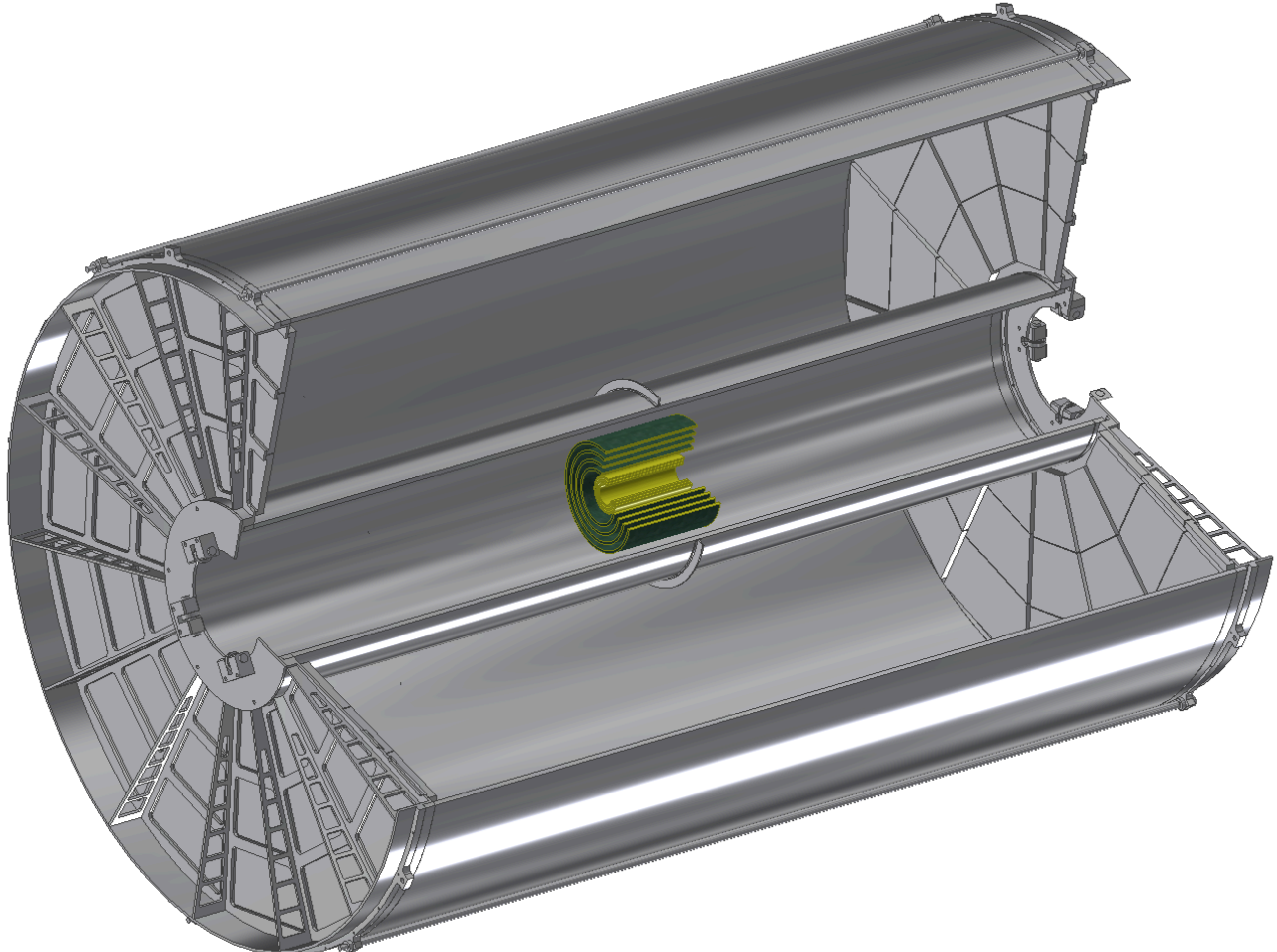
Conclusions

- **Theory is an integral part of this LDRD DR**

- **There are project management mechanisms in place and ways to track theory progress. Milestones, clear responsibilities assigned**

- **At present, the theory part is on schedule**
  [Hydro code installed, tests being run]
  [HF parton shower in the soft emission limit simulated]

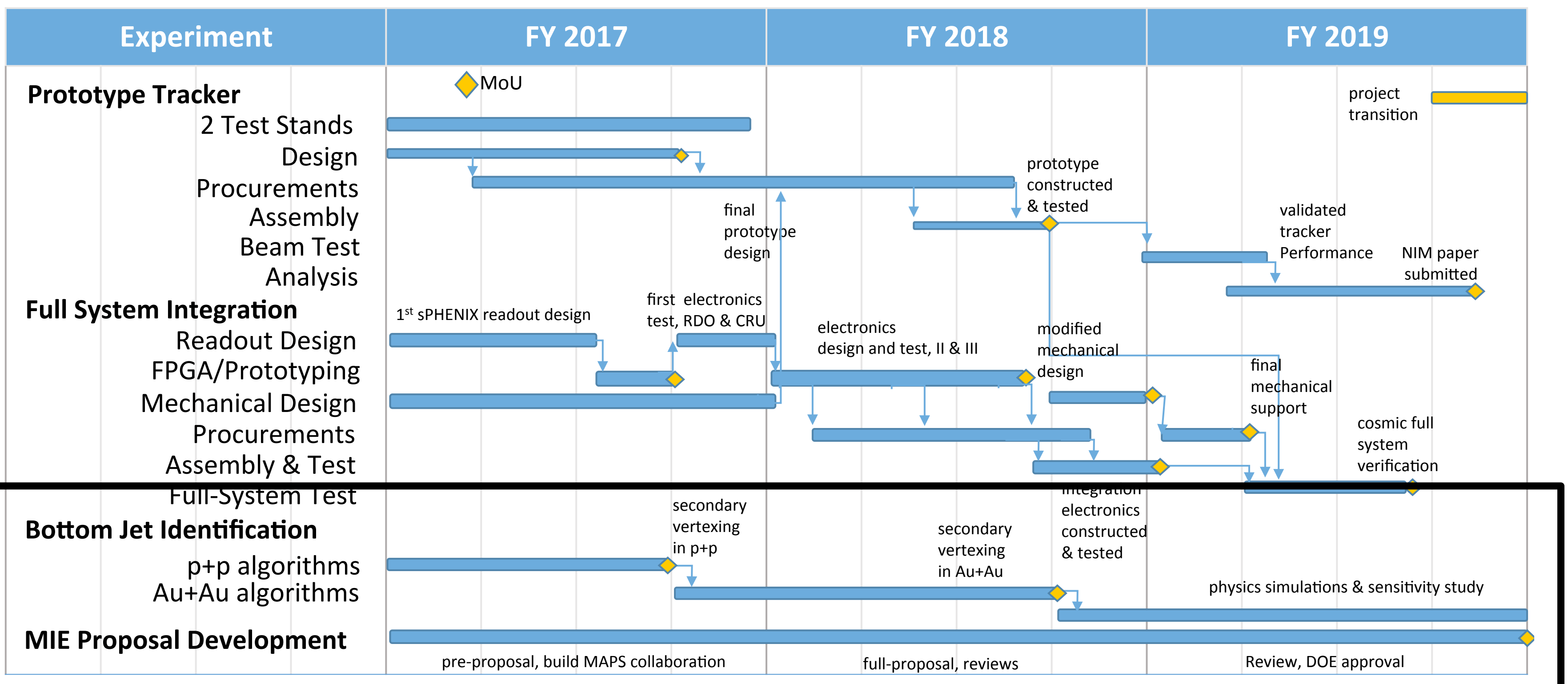
- **One milestone completed ahead of schedule [Effective theory for open heavy propagation in matter]**



Simulation study of b-jet measurement with MAPS
LDRD/DR feasibility review
Dec. 5, 2016

Sanghoon Lim / Mike McCumber

- Simulation study of b-jet measurement with MAPS
  - Develop b-jet tagging methods and evaluate performance in two years
  - MIE proposal development
  - Using sPHENIX simulation framework to evaluate MAPS performance
- People working on simulation
  - Mike McCumber, Sanghoon Lim, Xuan Li, Sho Uemura, Darren McGlinchey, and a new staff member



LANL proposed sPHENIX tracker configuration with MAPS

Specification for sPHENIX proposed program

Heavy-flavor jet measurement

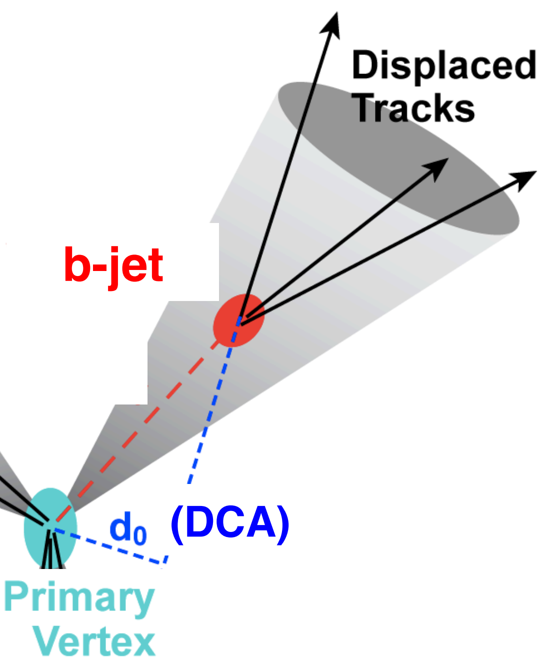
→DCA resolution<100 μm (<50 μm with MAPS)

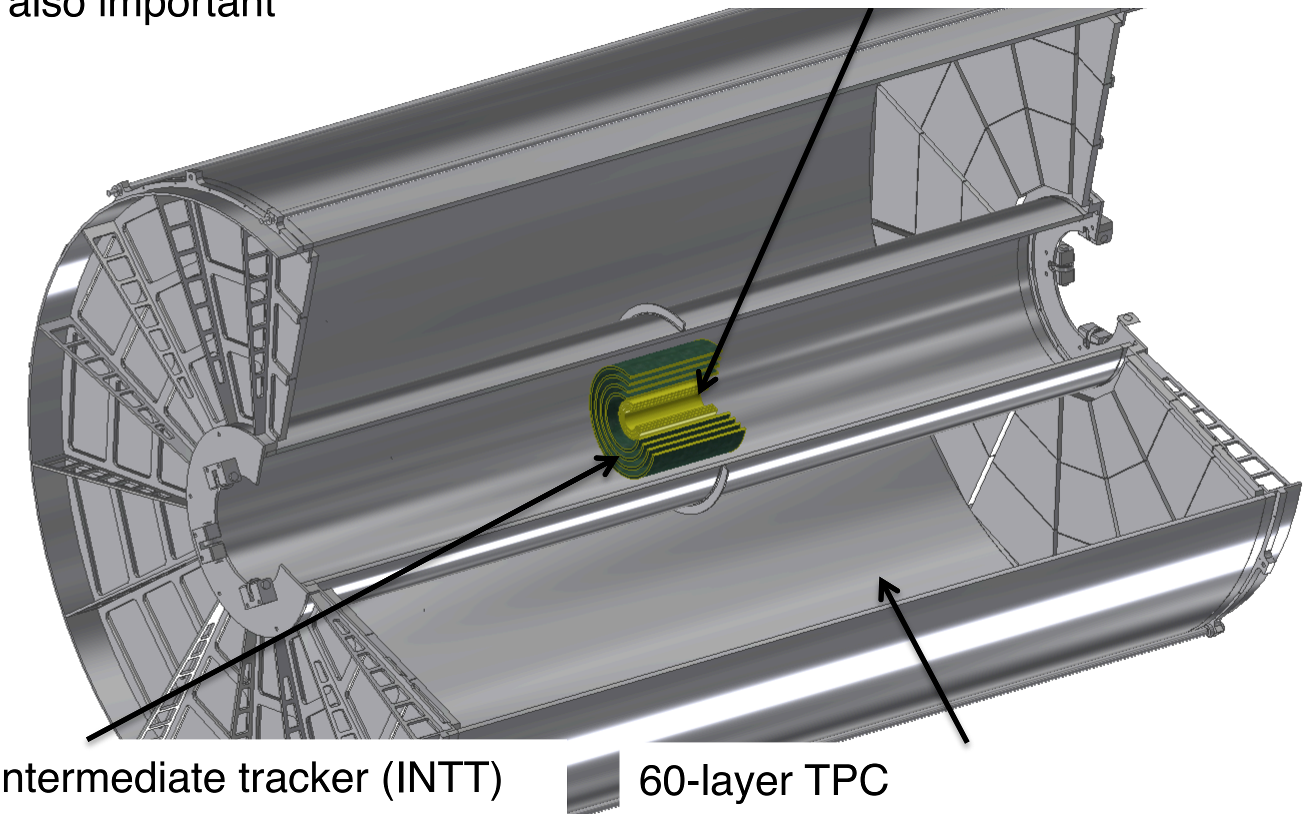
Upsilon (3 states) measurement

→Mass resolution<100 MeV (~80 MeV with MAPS)

Tracking efficiency & purity are also important

3-layer MAPS vertex tracker
R = 2.3, 3.2, 3.9 cm
Thickness: 50 μm (0.3% X_0) in each layer
Cell dimension: 28 μm x 28 μm





4-layer silicon strip intermediate tracker (INTT)
R = 6, 8, 10, 12 cm
Thickness: 120 μm (1% X_0) in each layer
Cell dimension: 80 μm x 1.2 cm

60-layer TPC
R = 30-80 cm
Thickness: 60 cm (2.2% X_0)
Cell dimension: 1.5 mm x 1.7 mm

Simulation framework

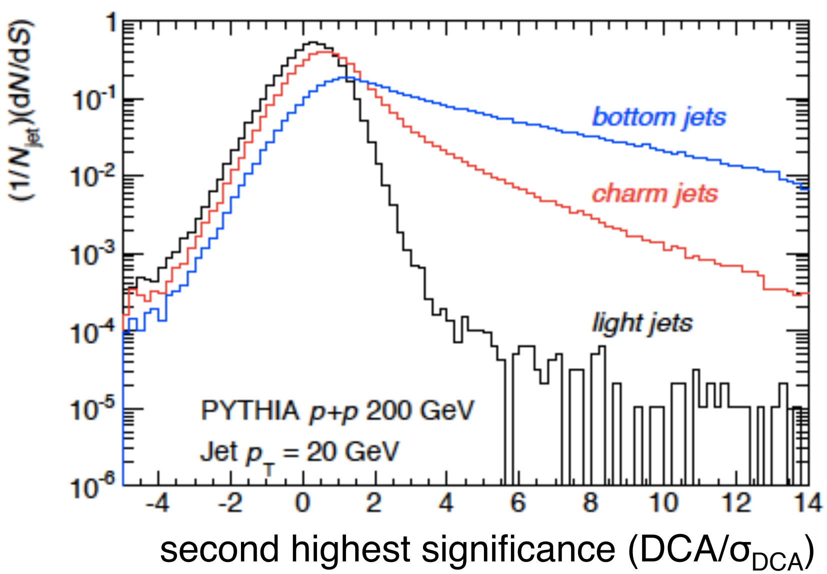
- Use existing sPHENIX simulation framework to evaluate MAPS performance
  uniform cylindrical tracking layers of sensitive material +
  uniform cylindrical layers of inactive support material
  →Realistic detector geometry will be implemented
  - Silicon tracker
    Layers of sensitive Si of pixel (MAPS) or strips (INTT)
    Layers of Cu for supporting materials
  - TPC
    60 layers of active gas (1.5 mm x 1.7 mm cell)
    Layers of inactive material for inner and outer field cage
    Layers of inactive gas at 20-30 cm radius

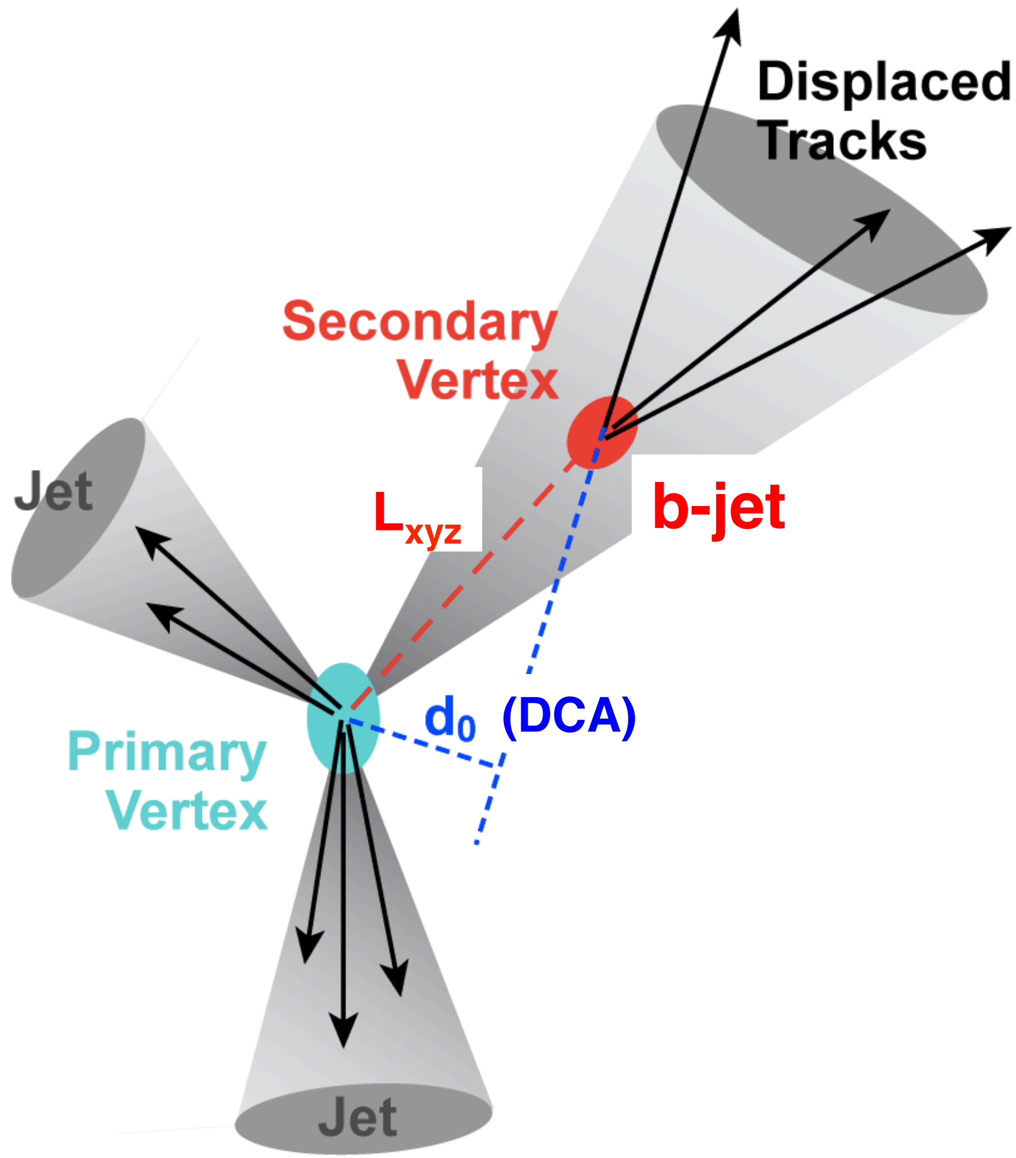
- Tracking procedure

Digitization of G4 hits → Clustering with threshold → Hough transform in helix parameter space → Kalman filter to fit tracks

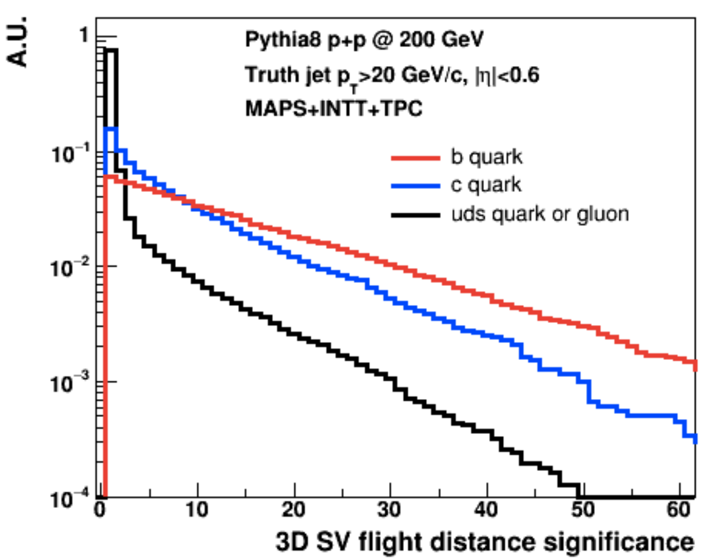
- Evaluation with truth information

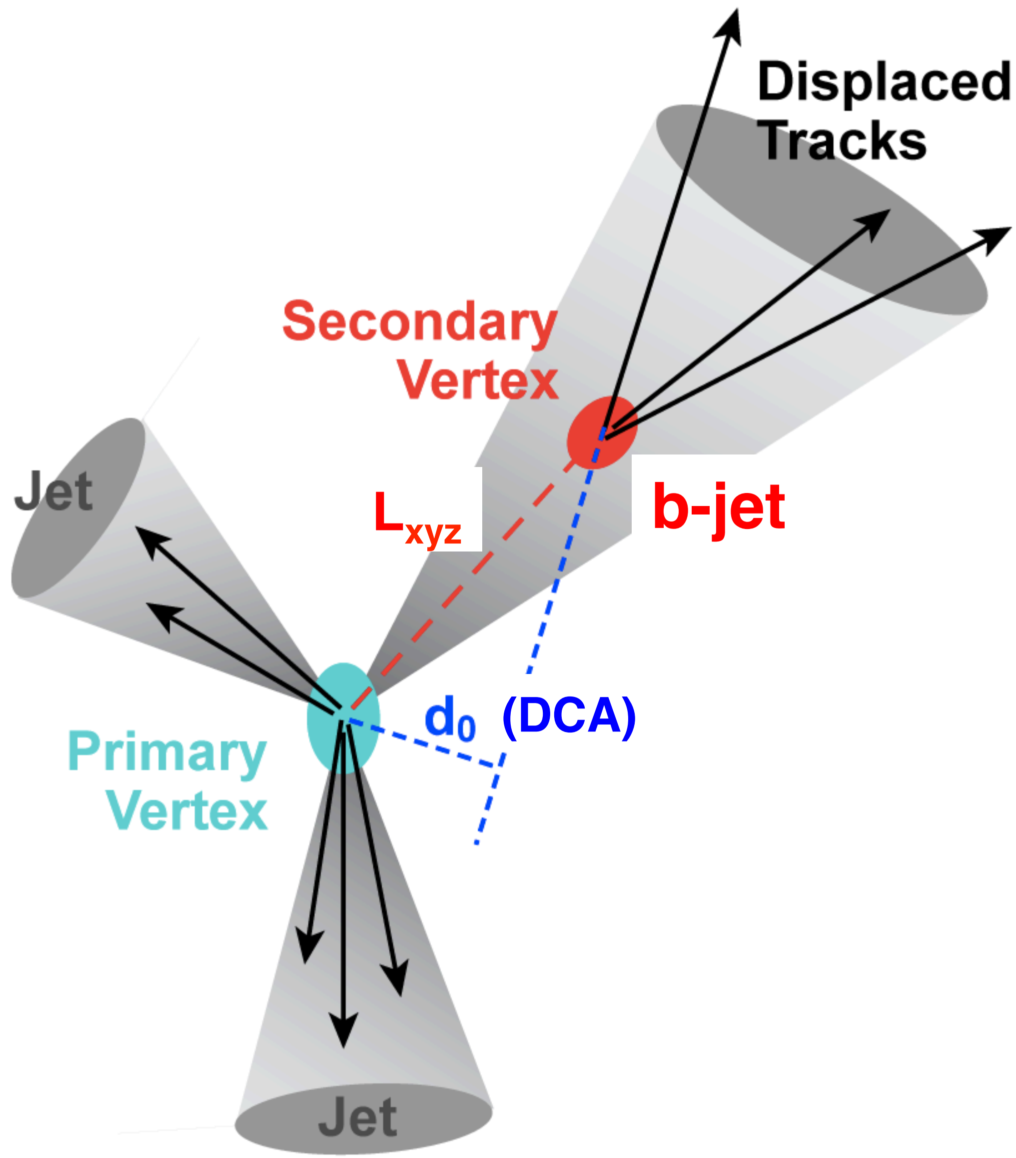
- Track counting method
  - Count the number tracks with large DCA (d_0)
  - Optimization of cuts and evaluation of b-jet tagging **purity vs. efficiency** in p+p collisions (w/ PYTHIA) are underway
  - Performance study in Heavy-ion collisions will be following





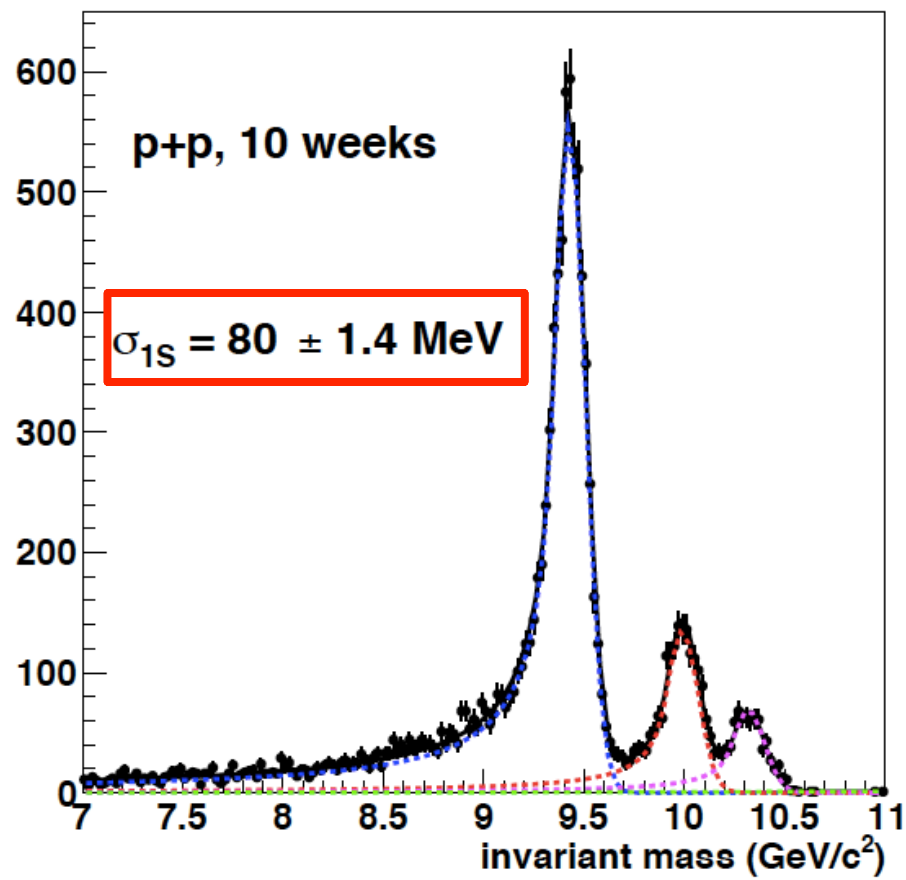
- Secondary vertex method
  - Reconstruct secondary vertex with in a heavy-flavor jet
  - Deviation from the primary vertex (L_{xyz}) of b-jets are expected to be larger than others
  - <20 μm of primary vertex resolution in x/y/z with MAPS





Upsilon mass distribution

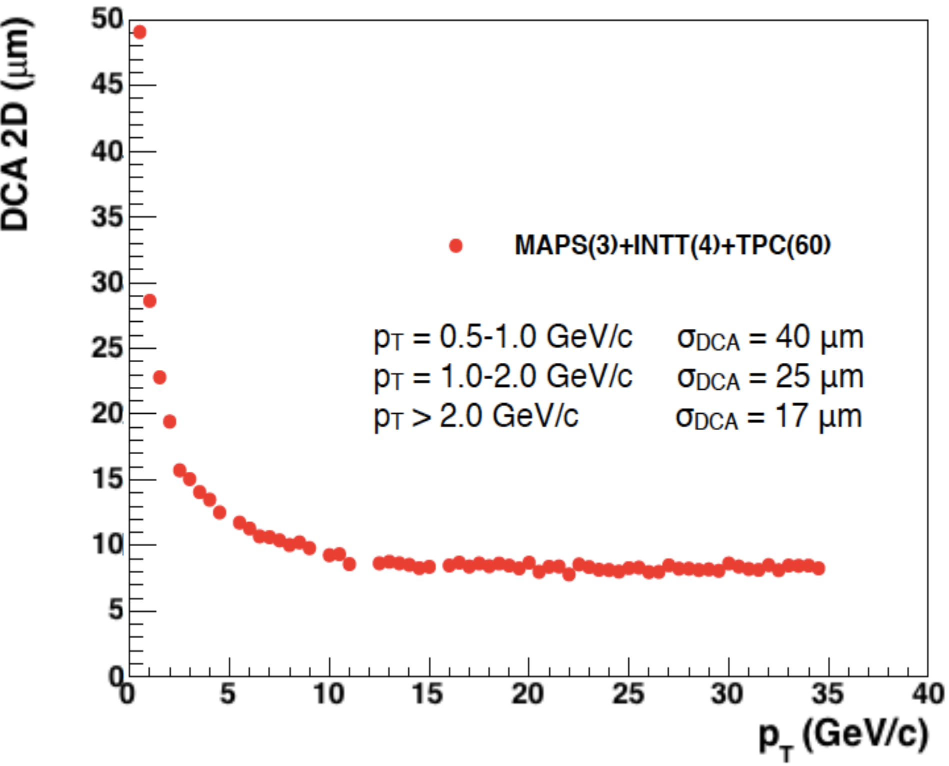
MAPS(3)+INTT(4)+TPC(60)



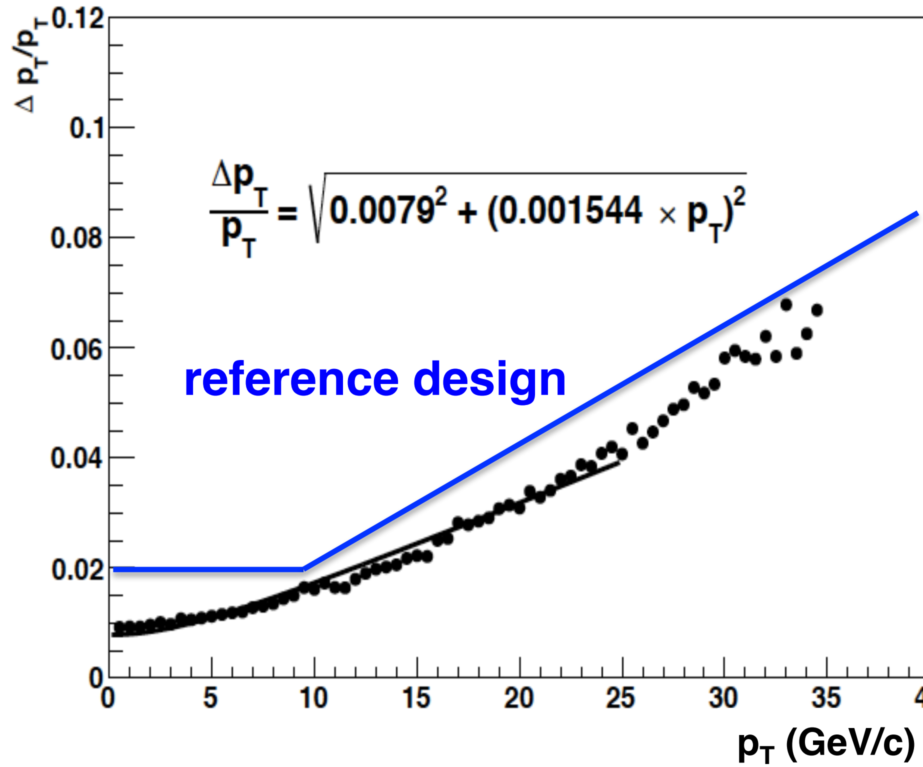
- 80 MeV Upsilon mass resolution in simulation (<100 MeV of sPHENIX specification)
Higher efficiency (~99%) and less material budget (0.3% X_0 per layer) than the alternative option

DCA and momentum resolution

- Embedded simulation
  100 pions embedded into central HIJING events (0-4 fm Au+Au collision)
- DCA resolution in simulation **(<50 μm)** is much better than the sPHENIX specification **(<100 μm)**

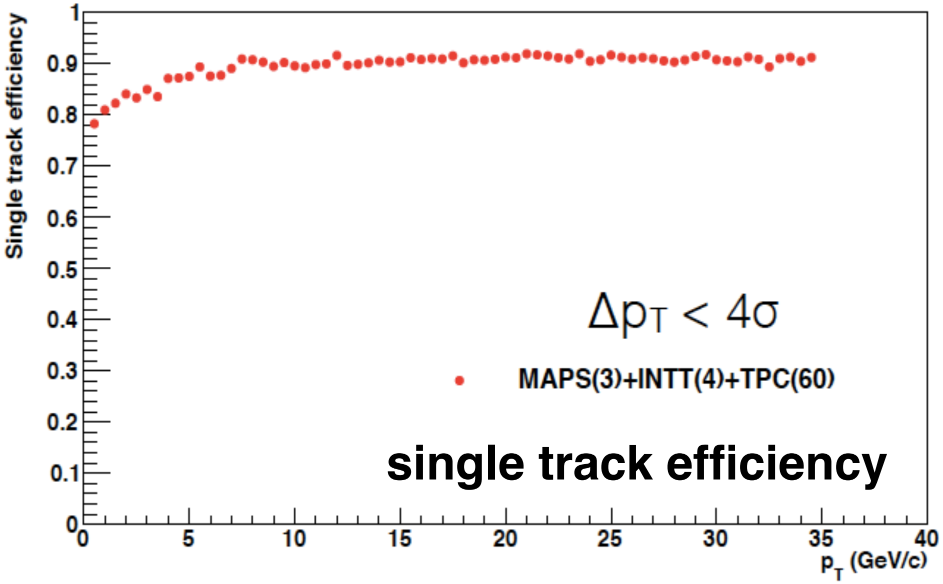


DCA resolution

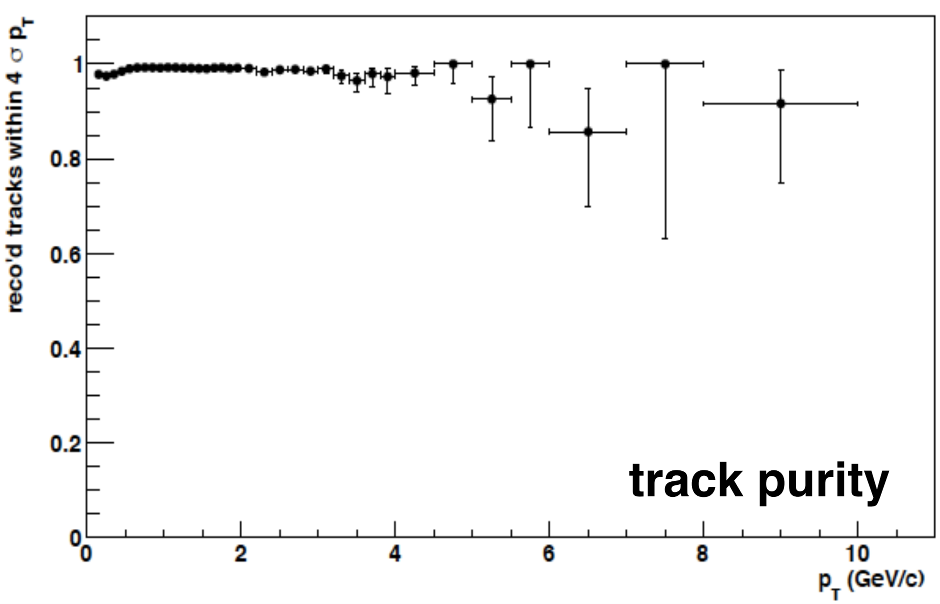


momentum resolution

Single track efficiency and purity



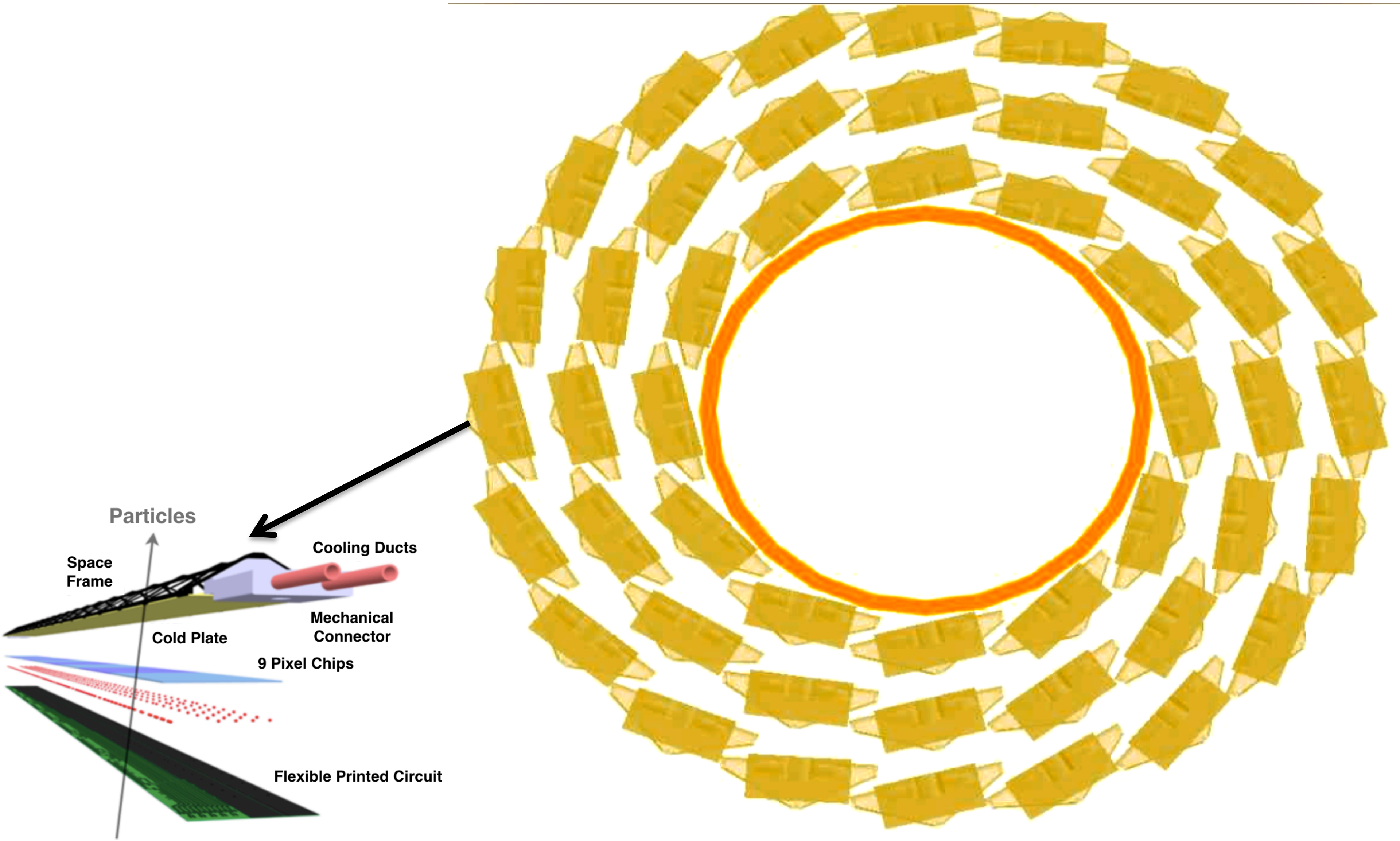
- Embedded pions in central Au+Au events from HIJING
  – Loop over truth tracks and try to find matching reconstructed track
  – Quality cut of reconstructed p_T<4σ from true p_T



- Purity in central Au+Au events from HIJING
  – Loop over reconstructed track and check reconstructed p_T is within 4σ of true p_T
  – Fake tracks at high p_T are from low p_T tracks of incorrectly reconstructed momentum

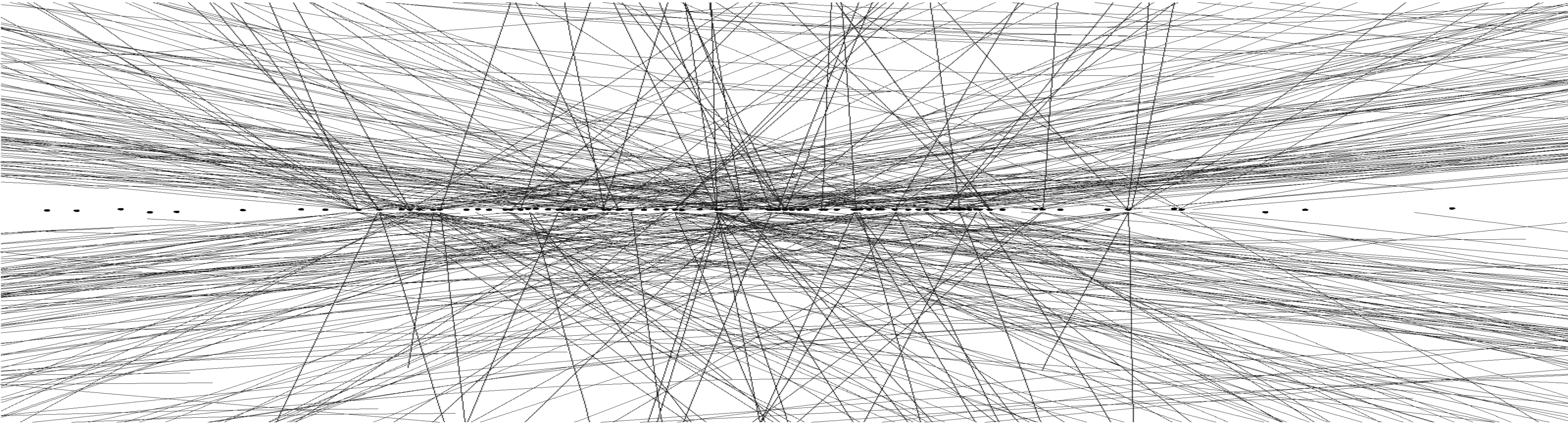
Implementation of MAPS ladder geometry

- Import ALICE ITS stave geometry



- Estimation of event pile-up
  - MAPS (~2 μs integration time)
    8 (0.4) events of pile-up in p+p (Au+Au)
    → Multi-vertex tagging (<20 μm vertex resolution in 27 cm length of MAPS)
  - TPC (~18 μs integration time)
    72 (3.6) events of pile-up in p+p (Au+Au)
    → Precise tracking (low (<0.1%) occupancy in MAPS)

- A framework to simulate event pile-up has been developed and implemented
  - Not much degradation of tracking performance in Au+Au collisions (momentum & DCA resolution, tracking efficiency)



Summary and Outlook

- Study of MAPS performance by using sPHENIX simulation framework has been initiated
  - Two b-jet tagging methods are studied in p+p collisions
  - ~80 MeV of Upsilon mass resolution
  - DCA resolution of <30 µm for p_T>1 GeV/c in central Au+Au events
  - Single track efficiency of ~90% in central Au+Au events

- Future plans
  - Realistic geometry will be used for further performance evaluation
  - New tracking and vertex finding (GenFit + RAVE packages) will be implemented
  - The performance of physics measurements in p+p and Au+Au collisions will be evaluated
    →effect of background hits
    →pile-up effect

BACK UP

Event pile-up

- Estimation of event pile-up
  - Peak luminosity
    p+p: 2 MHz → 0.21 chance of an interaction per beam crossing
    Au+Au: 100 kHz → 0.011 chance of an interaction per beam crossing
  - MAPS (~2 μs integration time → 37 beam crossings)
    p+p: 8 events of pile-up → Multi-vertex tagging with MAPS
    Au+Au: 0.4 events of pile-up
  - TPC (~18 μs integration time → 340 beam crossings)
    p+p: 72 events of pile-up
    Au+Au: 3.6 events of pile-up → Precise tracking with MAPS

- A framework to simulate event pile-up has been developed and implemented
  - Not much degradation of tracking performance in Au+Au collisions (momentum & DCA resolution, tracking efficiency)
  - Further study for physics measurement will be done

MAPS Readout Electronics

Cesar Da Silva, Andi Klein, Xuan Li, Sanghoon Lim, Ming Liu, Mike McCumber, Pat McGaughey, Mark Prokop

Los Alamos National Laboratory

LDRD DR Feasibility Review 12/5/16

Participants and Expertise

LANL P-25 (Physics), AOT (EE) Groups

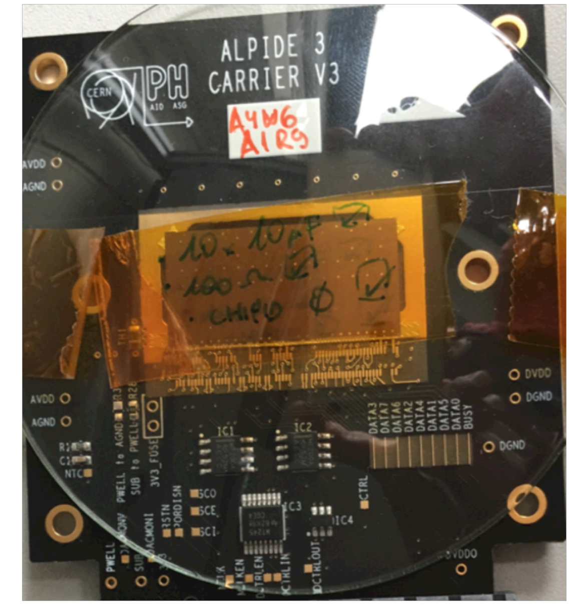
Expertise gained from $5M PHENIX FVTX project + others:

- Si pixel sensors and custom ASIC readout
- Analog / digital electronics design and layout
- High speed differential and fiber optic data transmission
- Use of modern FPGAs from Xilinx, Actel
- FPGA programming with Verilog and VHDL
- Custom high density interconnects (FPC)
- Event building and formatting

Have joined ALICE collaboration as associate member

With expert help from BNL, LBNL, MIT, UNM, UT Austin

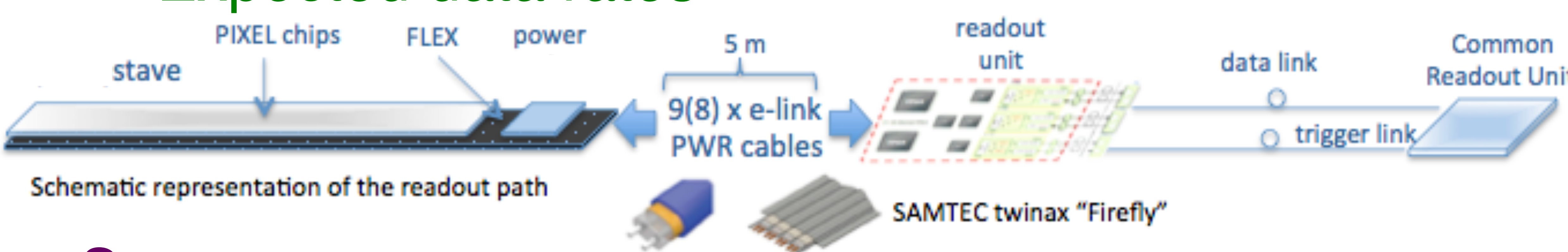
Outline



ALPIDE monolithic Si pixel sensor
 (ALICE Pixel Detector)

MAPS readout:

- General design
- Readout Unit
  - Radiation hard design and fiber optic
- Common Readout Unit
  - Development board
- Test bench
- Expected data rates

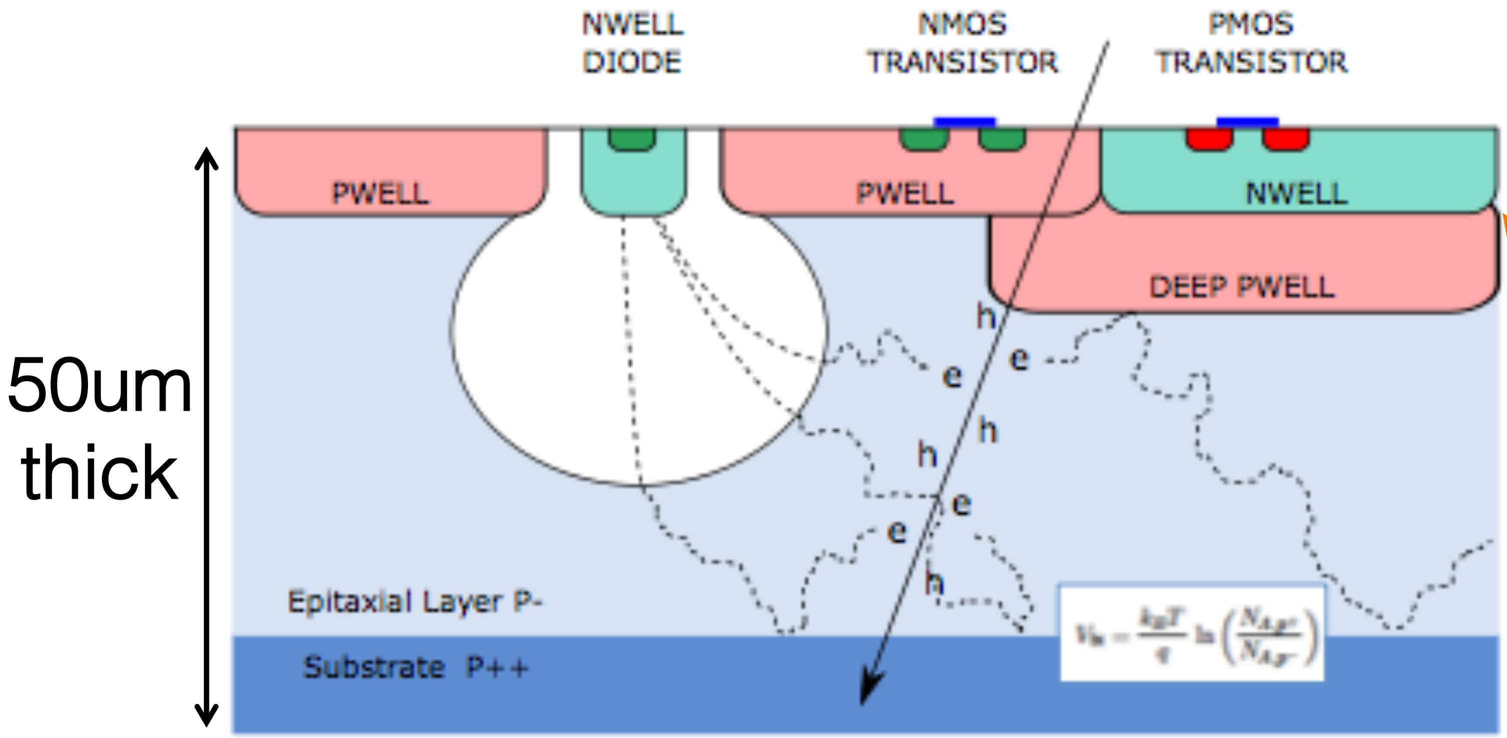


Summary

5 meter cable

ALPIDE Monolithic Pixel Technology

CMOS Pixel Sensor using TowerJazz 0.18μm CMOS Imaging Process



deep p-well allows for circuitry

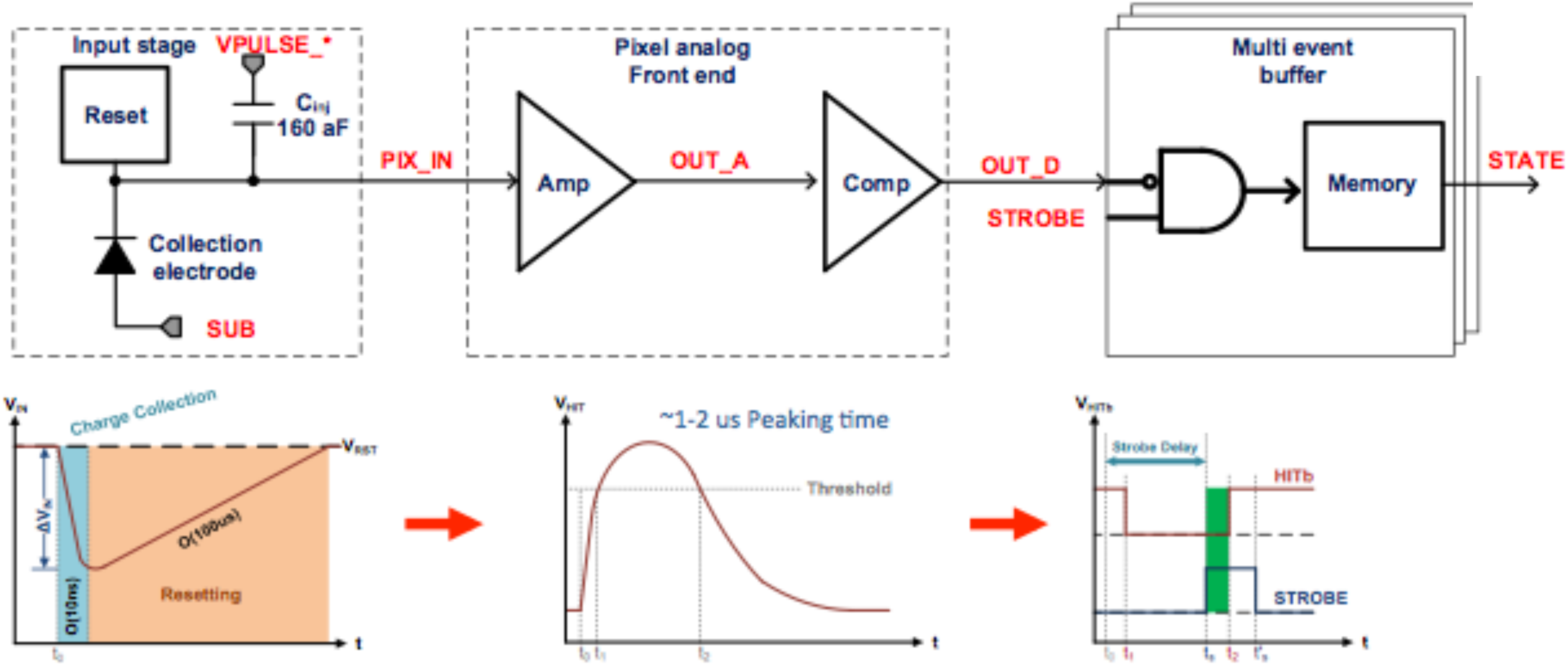
Tower Jazz 0.18 μm CMOS

- 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: $N_A \sim 10^{16}$

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (18μm to 30μm) on p-type substrate
- Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance
- Application of (moderate) reverse bias voltage to substrate (contact from the top) can be used to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors to allow for full CMOS circuitry within active area

ALPIDE Operation



ultra low-power front-end circuit
40nW / pixel

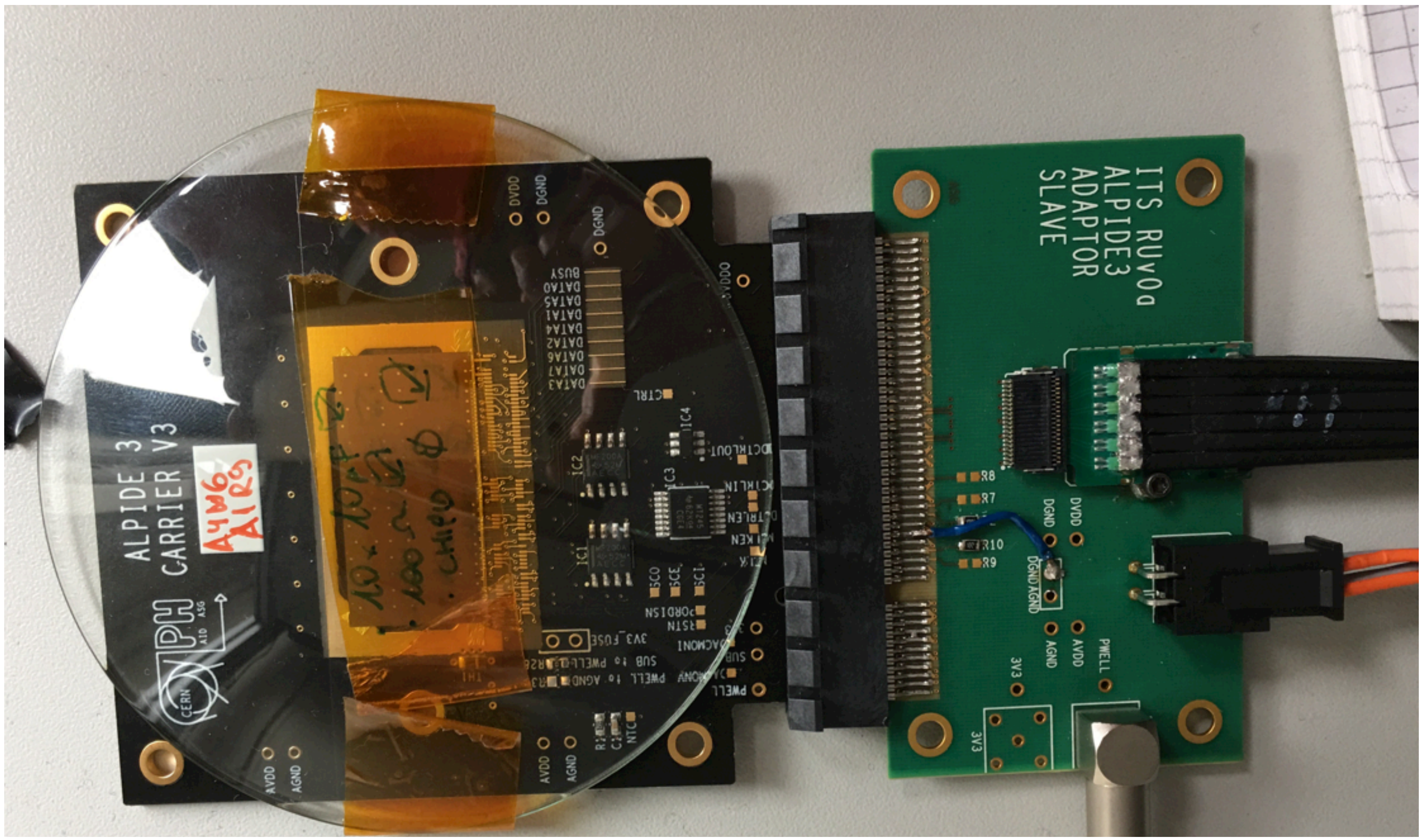
Front-end acts as delay line

- Sensor and front-end continuously active
- Upon particle hit front-end forms a pulse with ~1-2μs peaking time
- Threshold is applied to form binary pulse
- Hit is latched into a (3-bit) memory if strobe is applied during binary pulse

MAPS chip

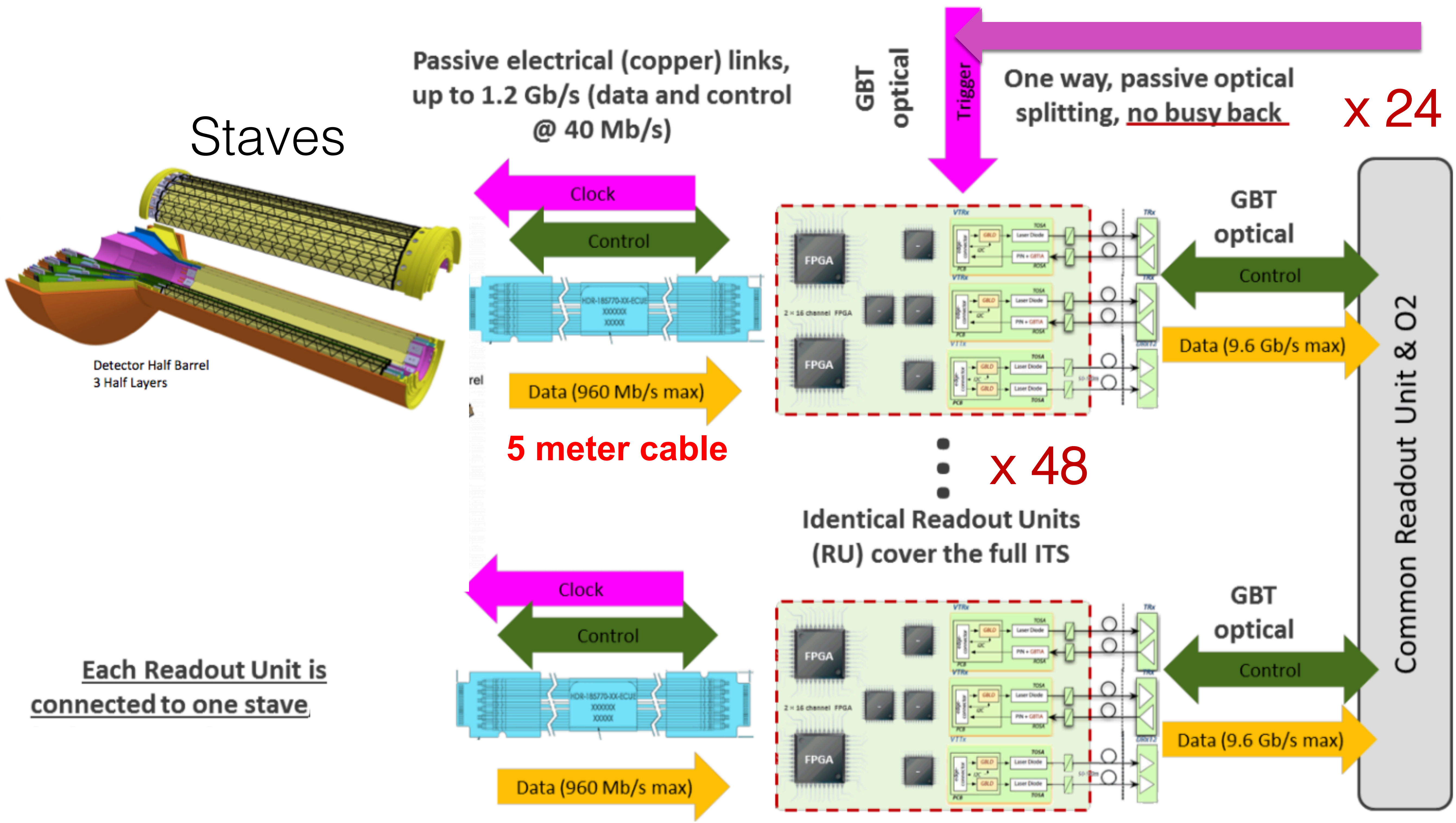
Single Chip High Speed Readout

15x30mm
active area



Have one MAPS chip and slow readout working at LANL, more on the way

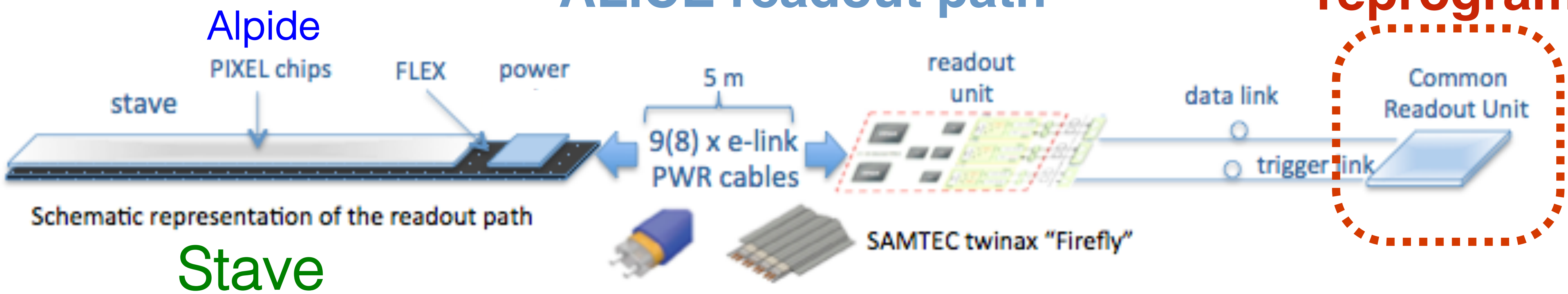
MAPS Readout Description



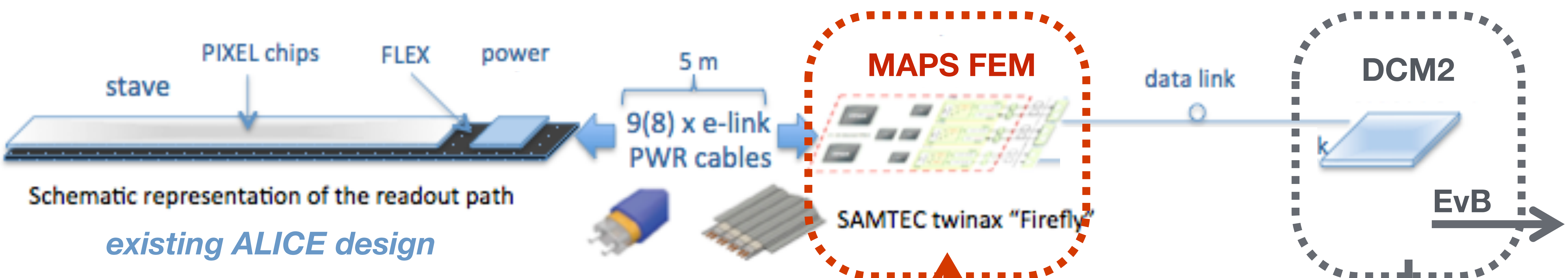
MAPS Electronics

Plan A: reprogram

ALICE readout path



Plan B: sPHENIX readout path (held only as contingency)



trigger in

busy out

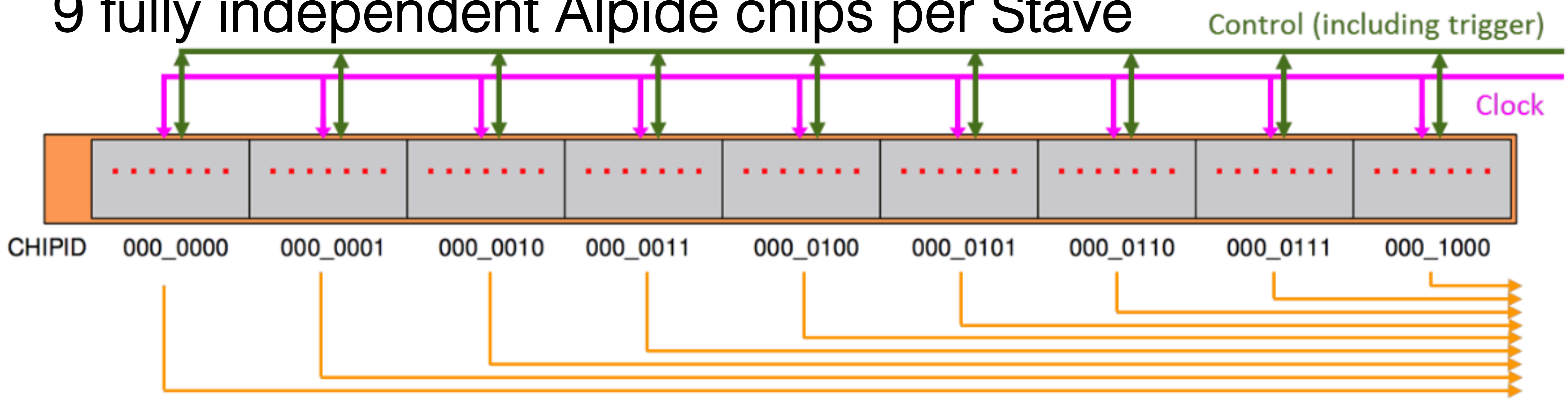
Larger effort, requires new hardware and FPGA code!

modified design, starting with ALICE boards

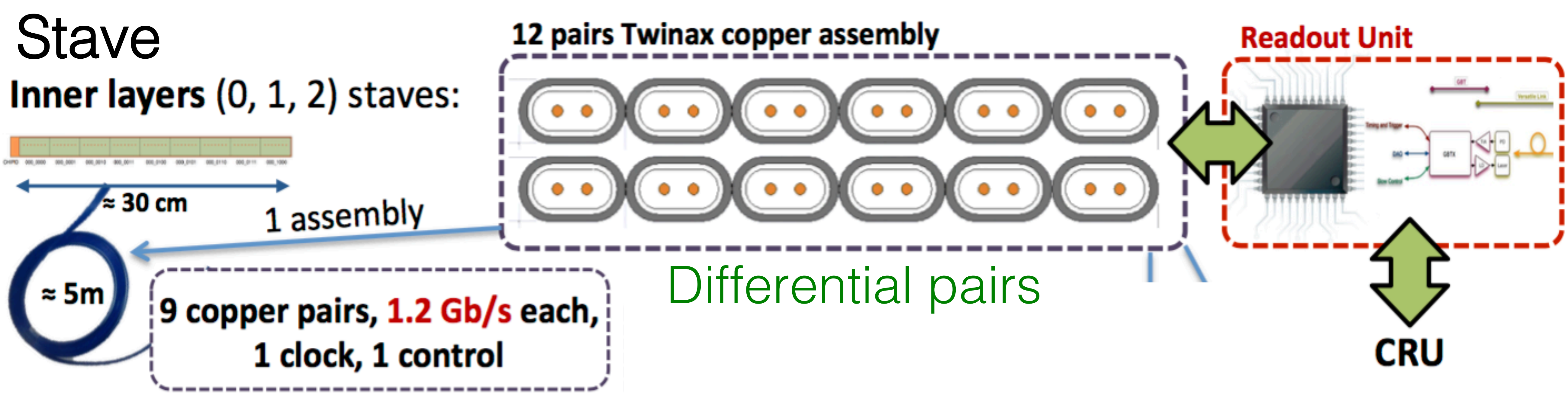
existing sPHENIX design

Stave Readout

9 fully independent Alpide chips per Stave

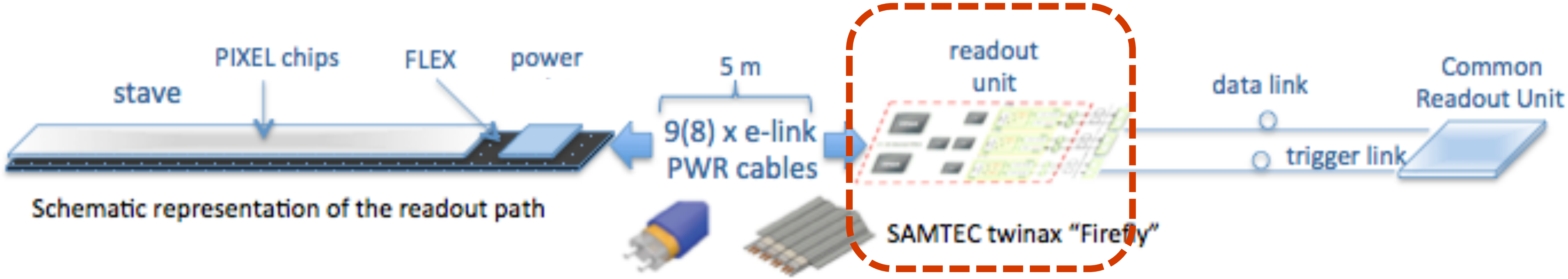


Continuous readout ➔



Medium Risk - Staves available in Summer, 2017

ALICE Readout Unit Logic



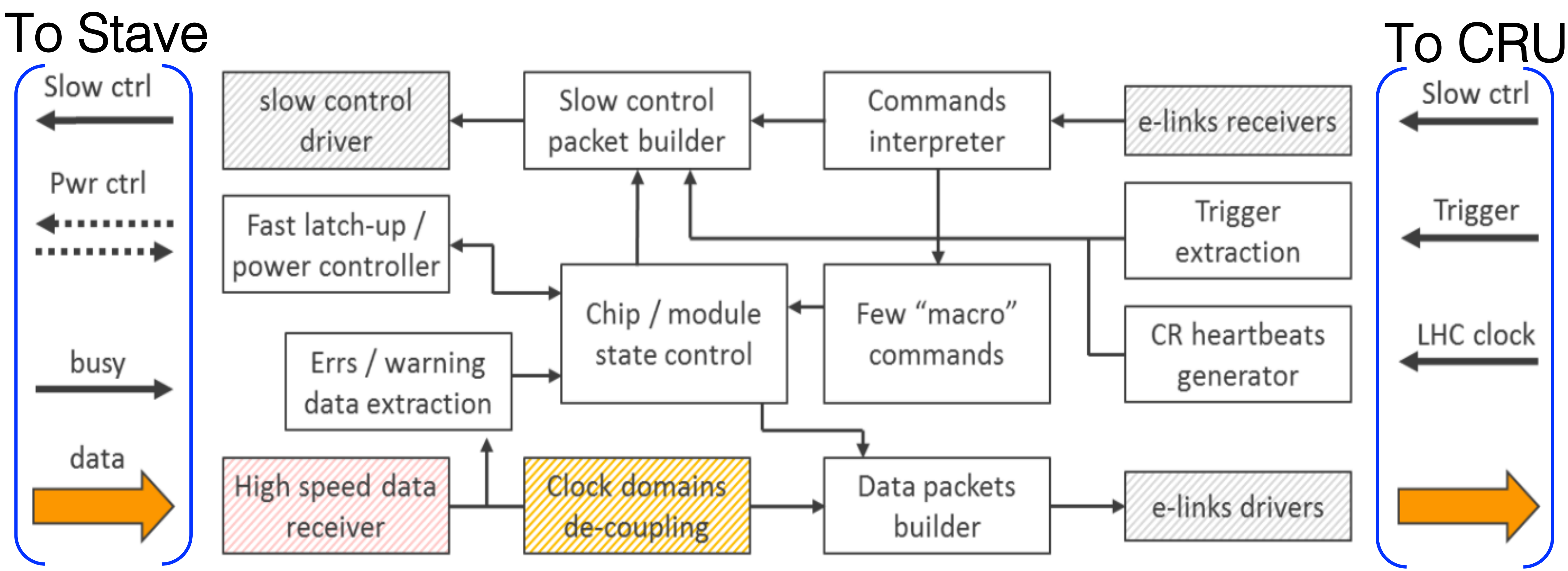
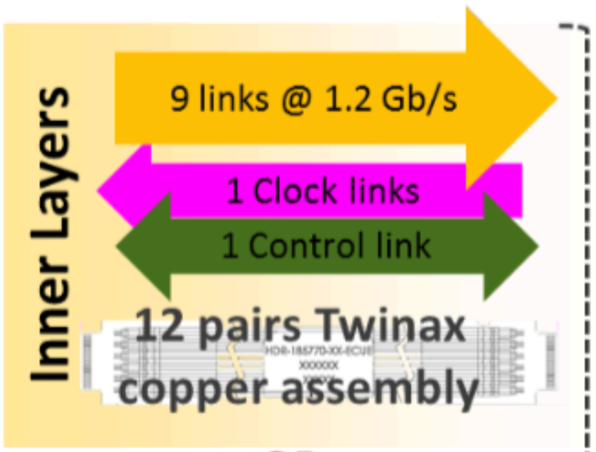
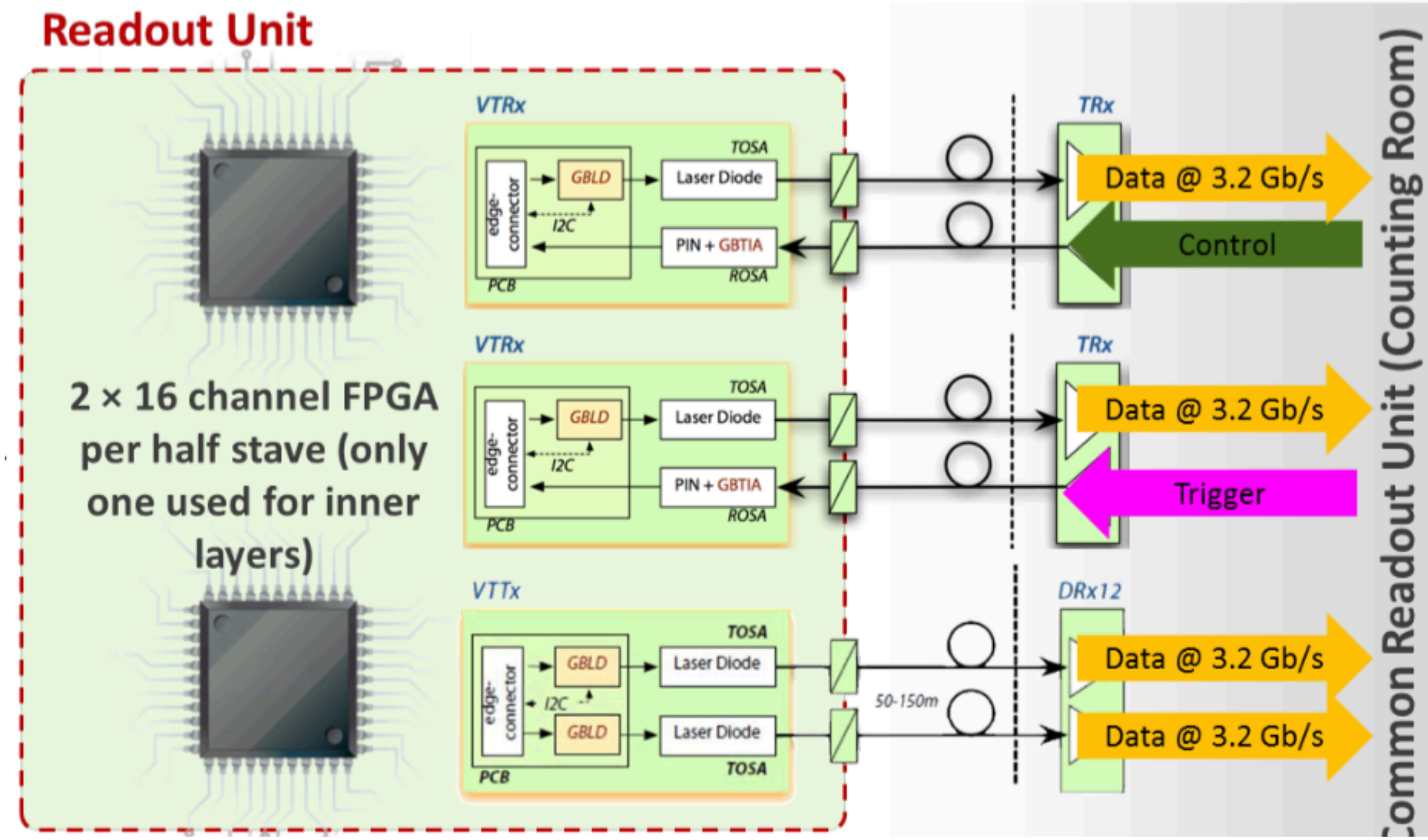


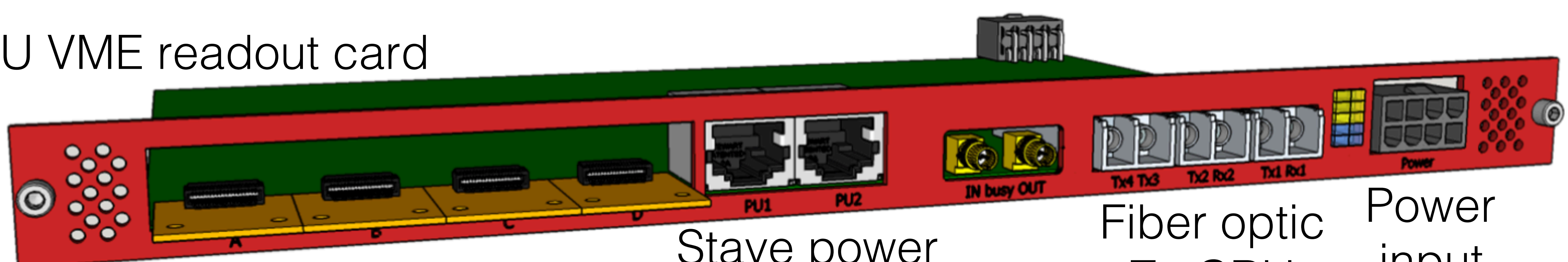
Figure 9 –Readout Electronics main functions.

ALICE Readout Units





6U VME readout card



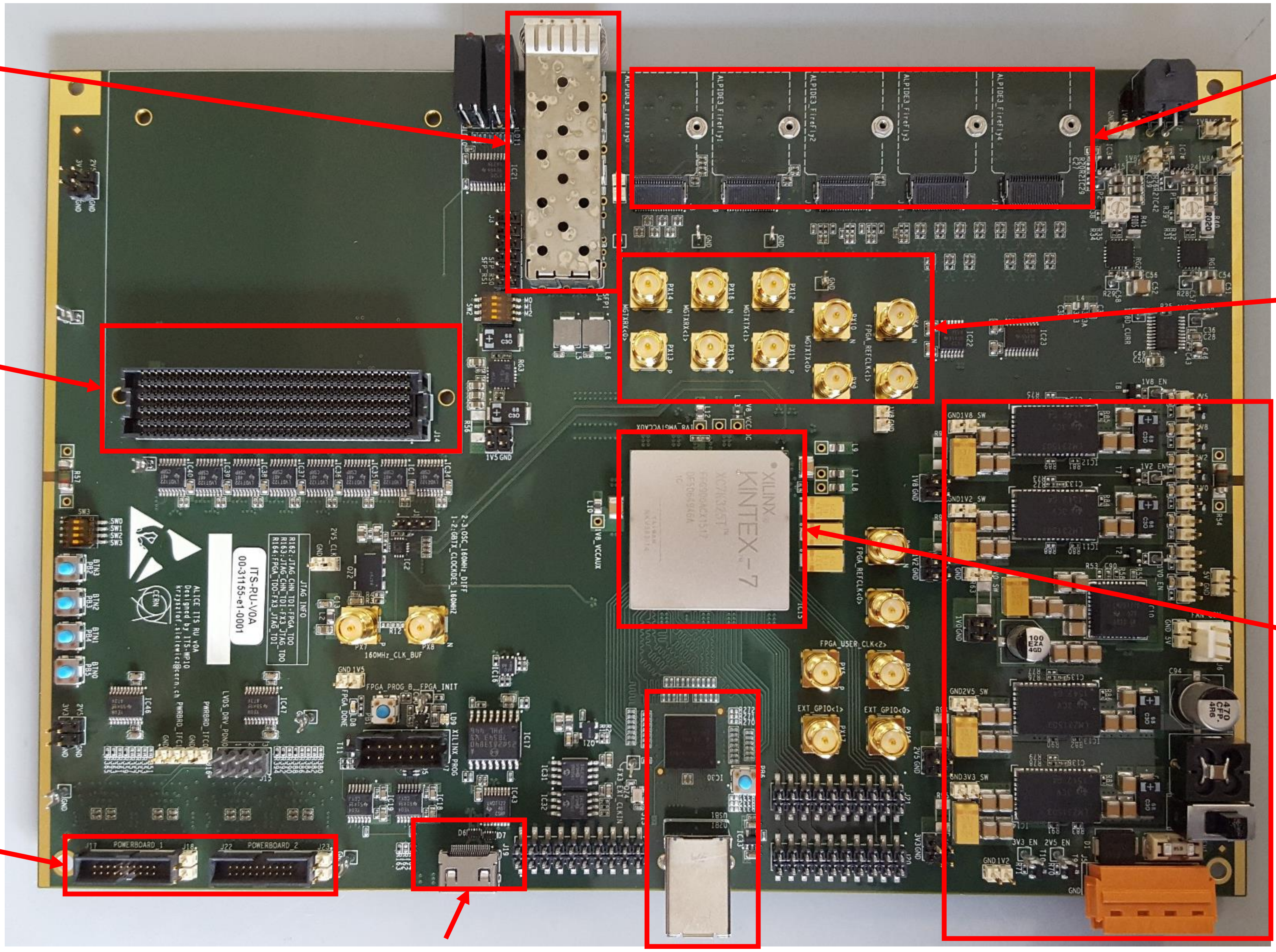
Twinax link to one stave

Stave power control

Fiber optic To CRU

Power input

Readout Unit Prototype Version 0a ("RUv0a")



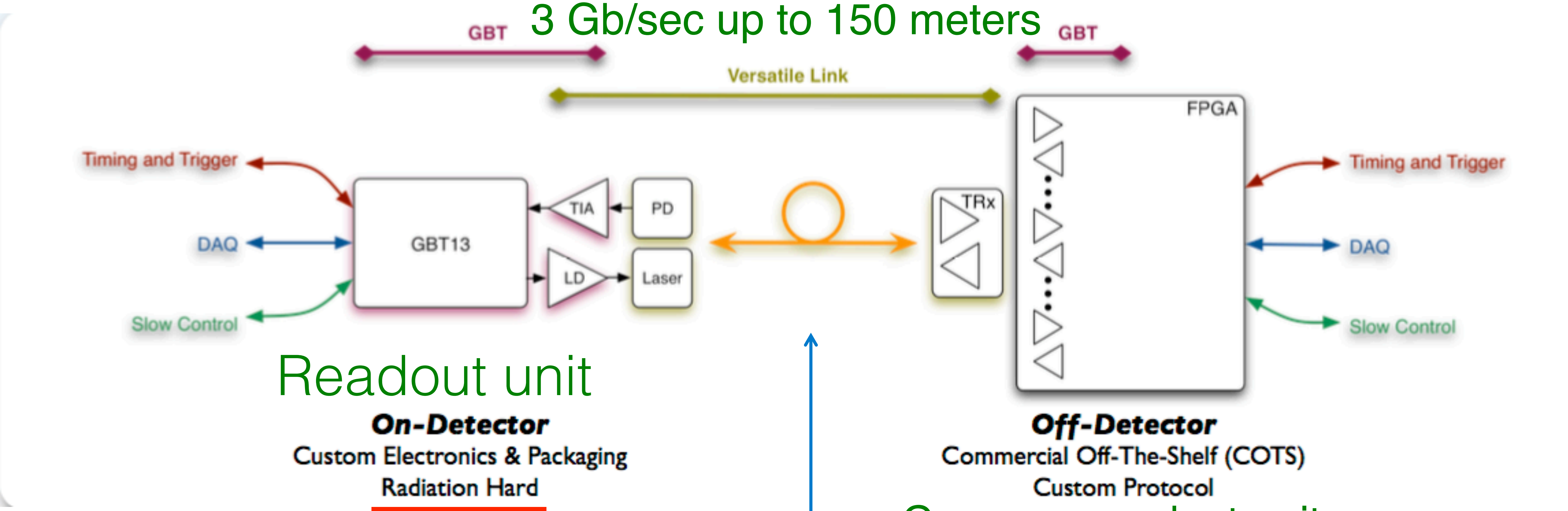
6U VME card

Low risk, currently being tested by ALICE

Expect version '0' readout unit at LANL in spring, 2017

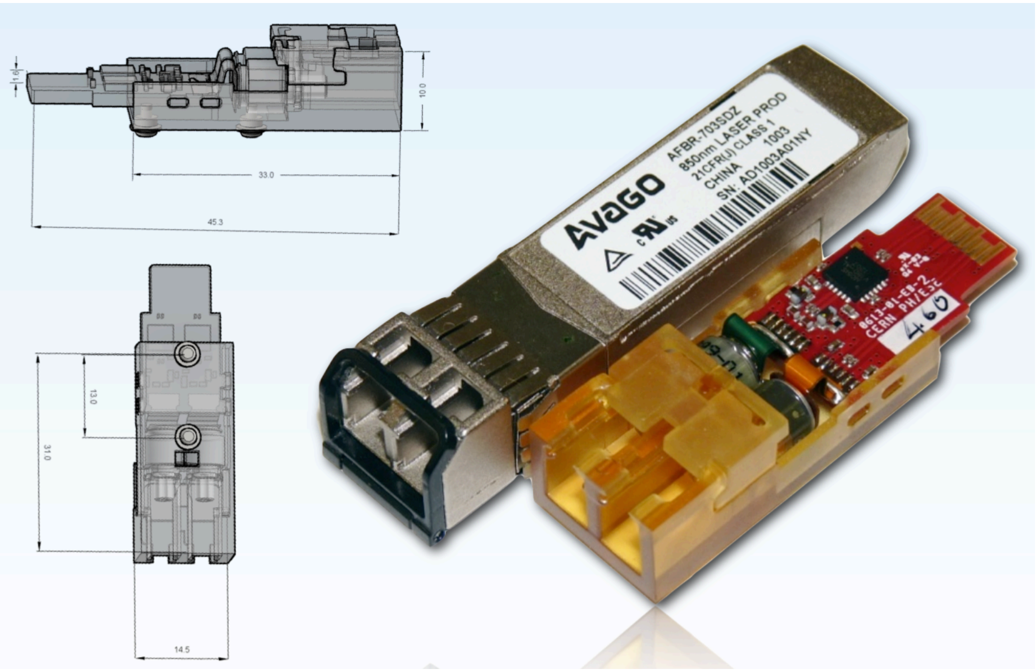
CERN Versatile Link – Bidirectional Fiberoptic

3 Gb/sec up to 150 meters



Readout unit

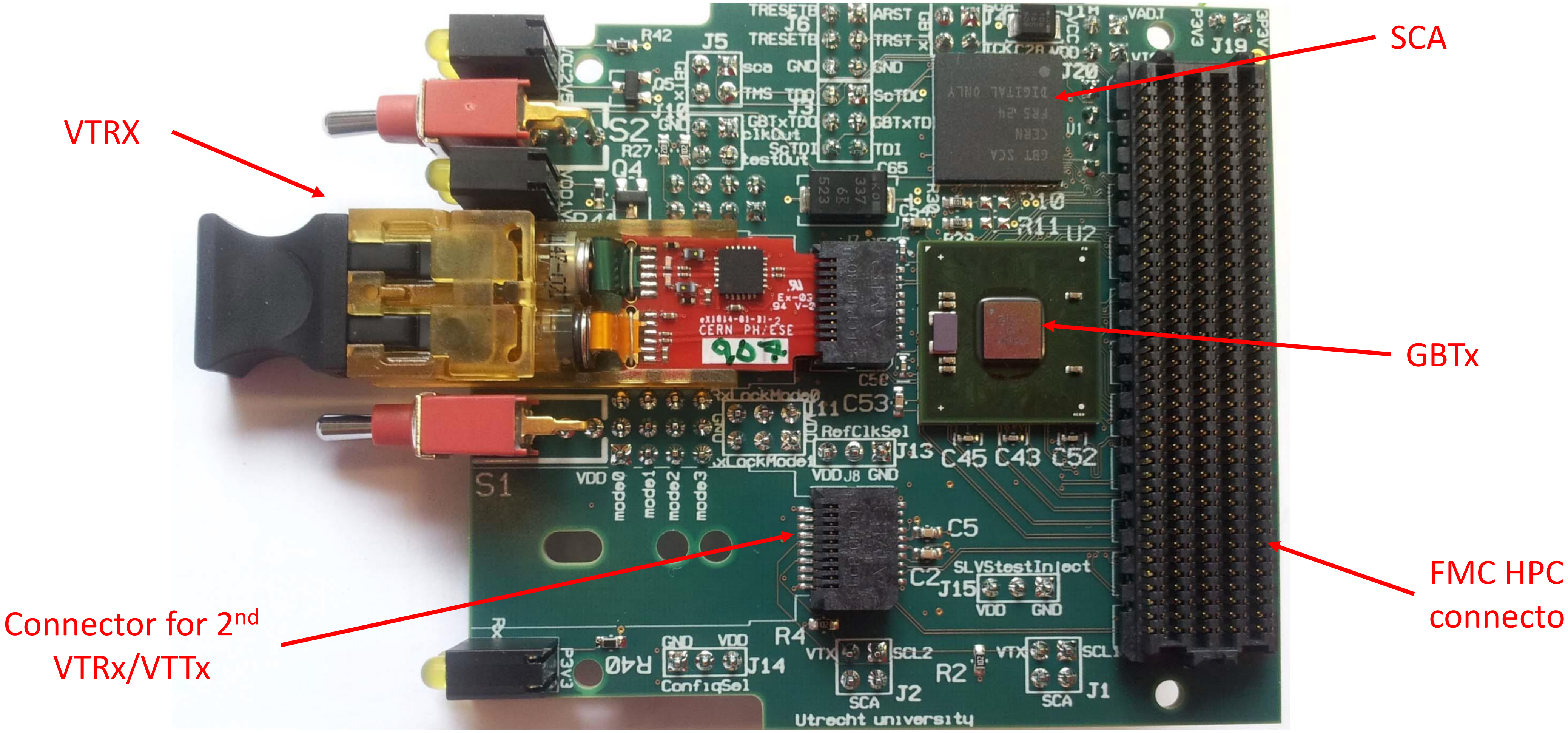
Common readout unit
In counting house



Long fiber run from Hall to Rack Room
over custom CERN optical link

Fiber optic transceiver daughterboard for readout unit

GBT FMC Mezzanine ("GBTxFMC")



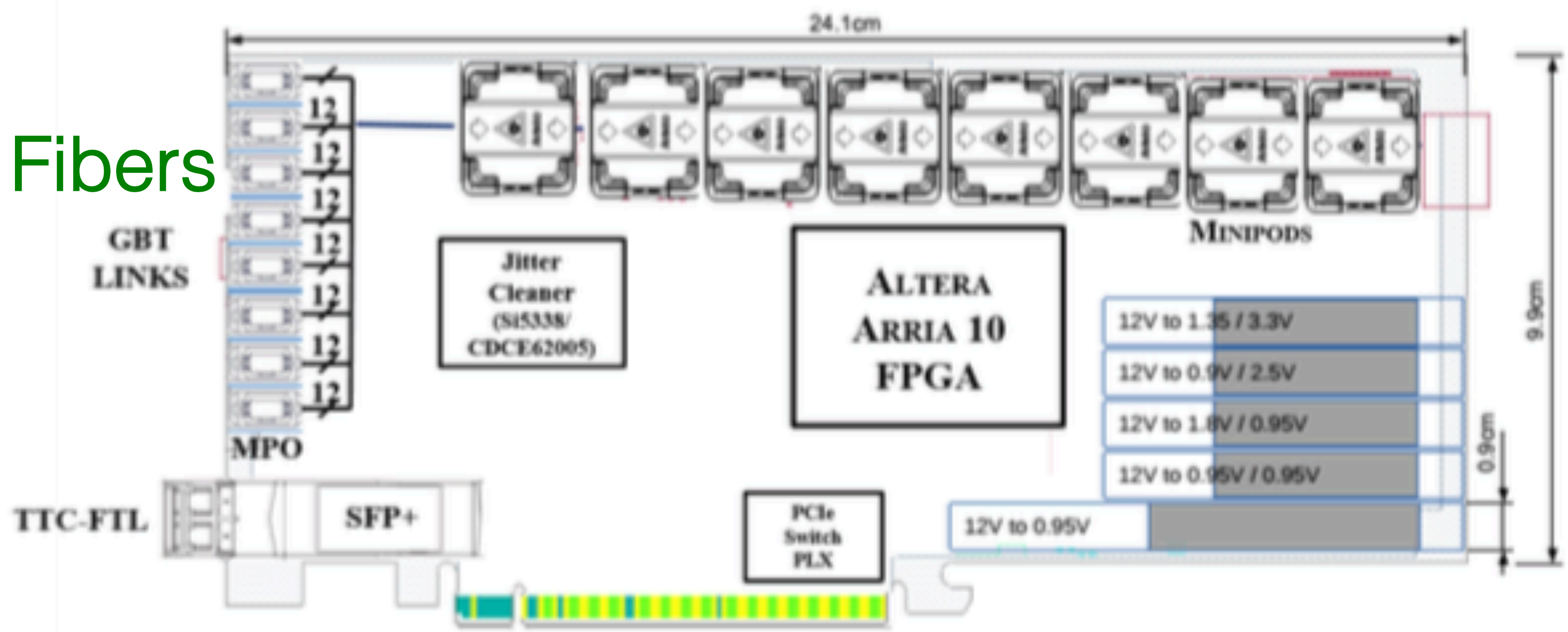
Low risk, tested and operational order for LANL in process

ALICE Common Readout Units

PCI express card

(a) PCie40.

Avago optical engines



(b) PCIe40 Schematic.

Will be used by several ALICE and sPHENIX subsytems

Each CRU reads out two Readout units, sends slow controls, trigger back

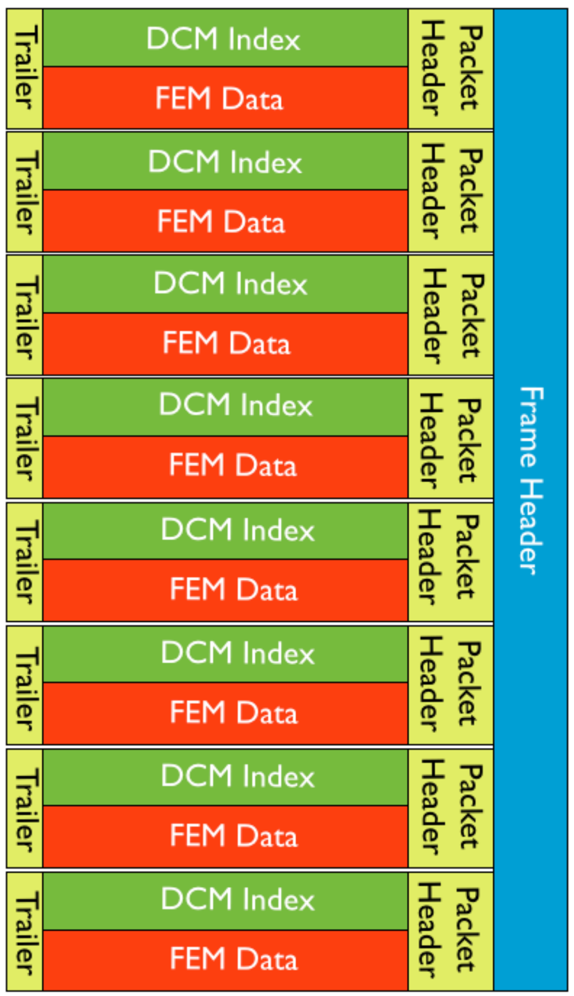
CRU cards reside in CPU chassis

Medium risk, CRU still in development at LHCb experiment

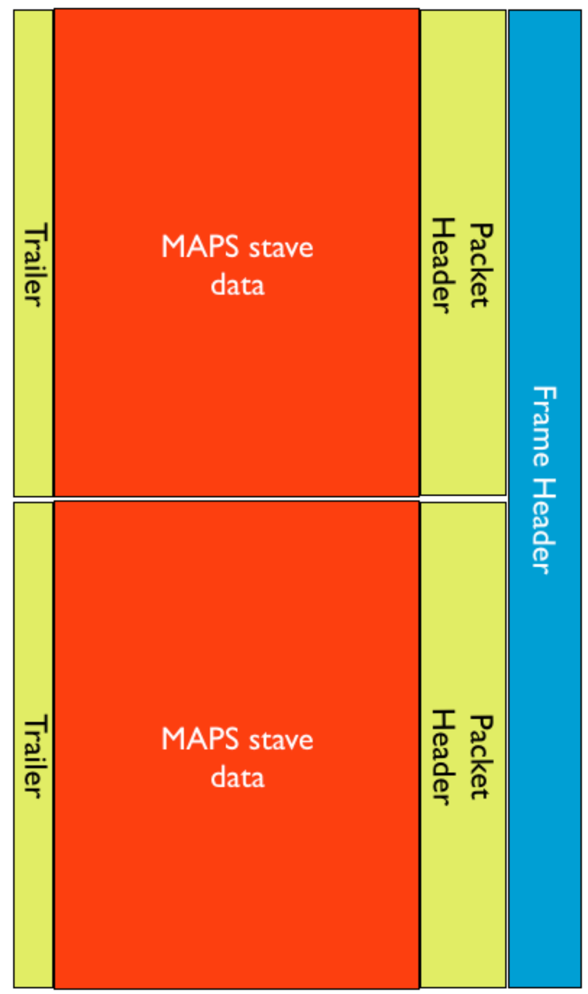
Expected at LANL in summer, 2017

Data Stream Reformatting

Traditional sPHENIX Frame



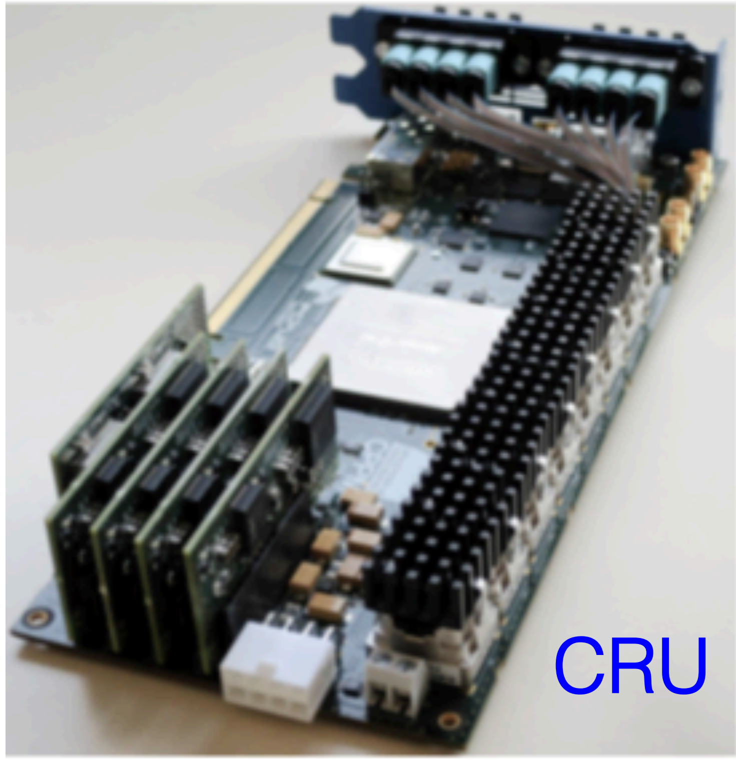
sPHENIX MAPS Common Readout Frame



ALICE Format Data

Transport Headers and Trailers

Reformat options: FPGA or CPU…

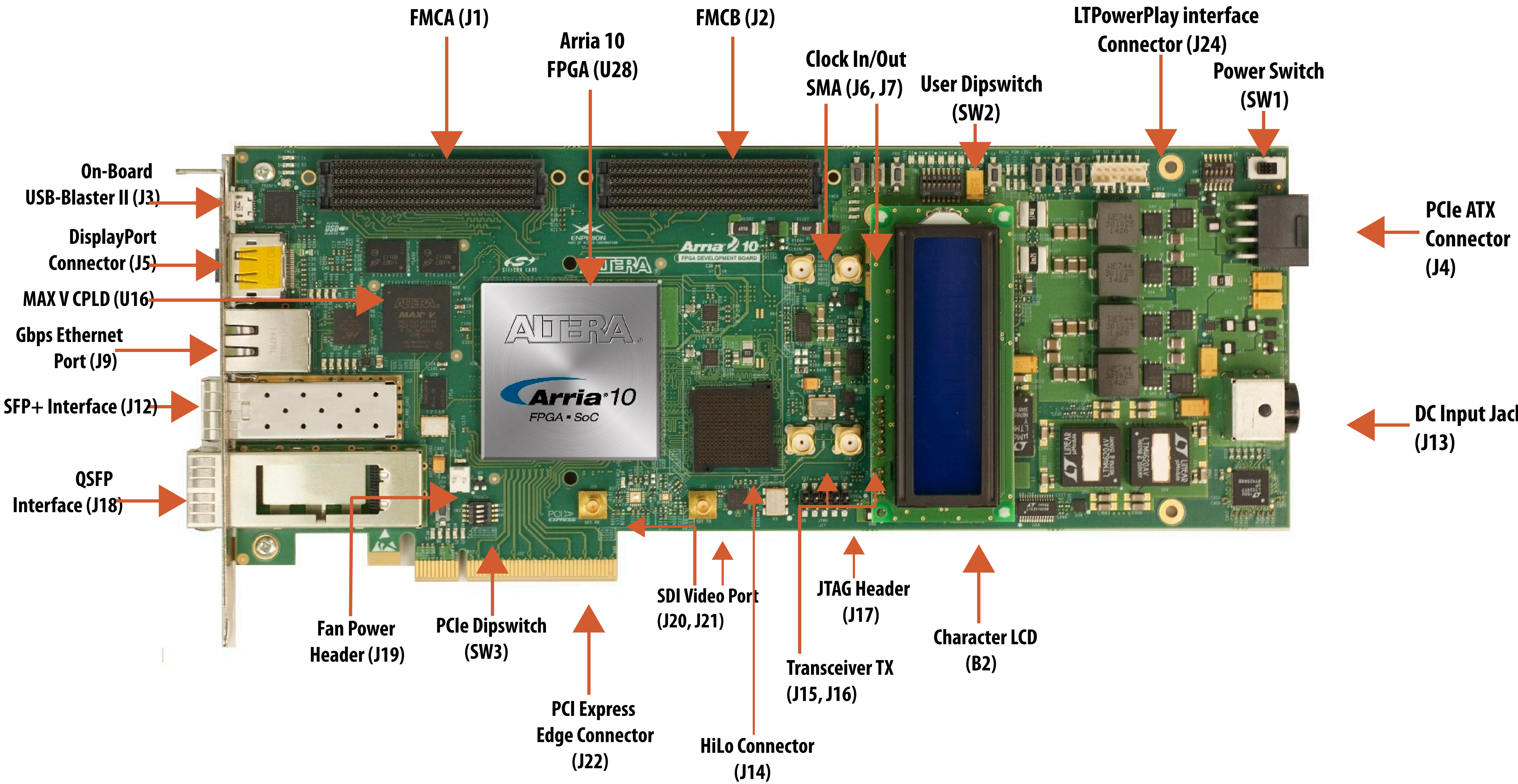


(a) PCie40.

Medium risk – mainly an FPGA programming effort, plus integration of clock, trigger, busy

Commercial Altera Development board for Common Readout Unit Prototyping and Programming

Figure 1-2: Overview of the Development Board Features

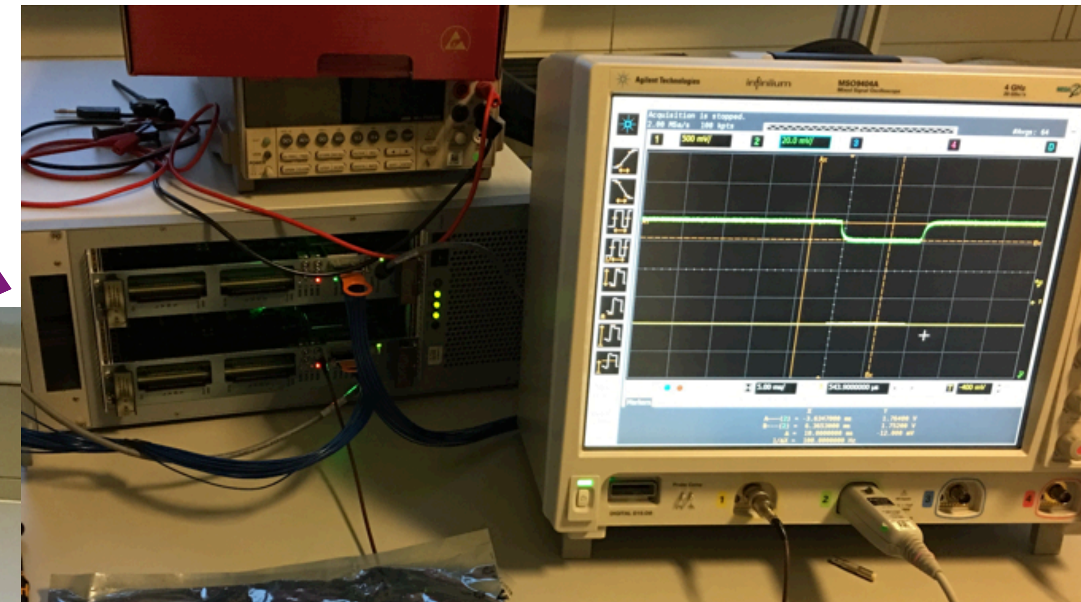


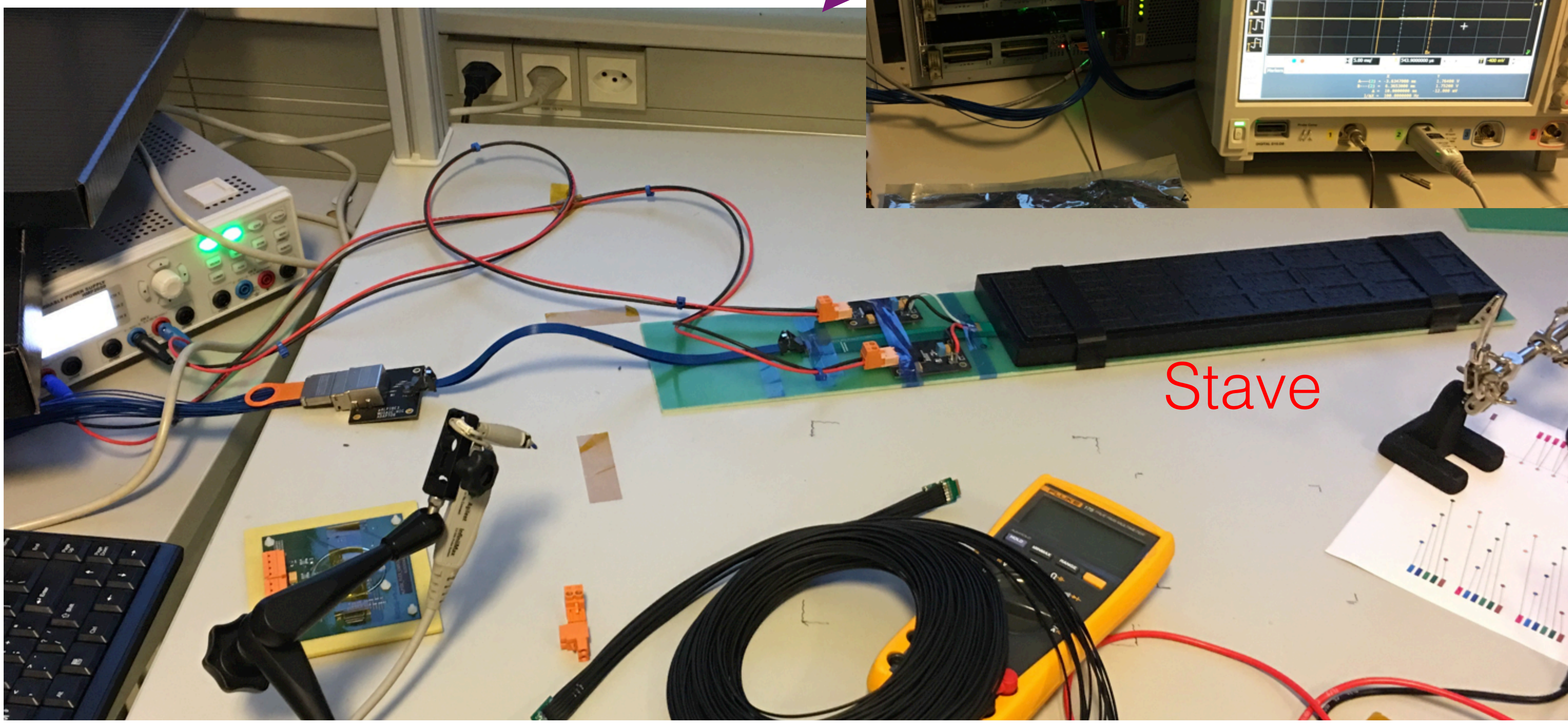
Risk reduction – Allows FPGA code development with same FPGA, fiber optic and PCI-x readout. Ordered

Alice Test Bench

9-Chip Module High Speed Readout

Test Bench: MOSAIC Card

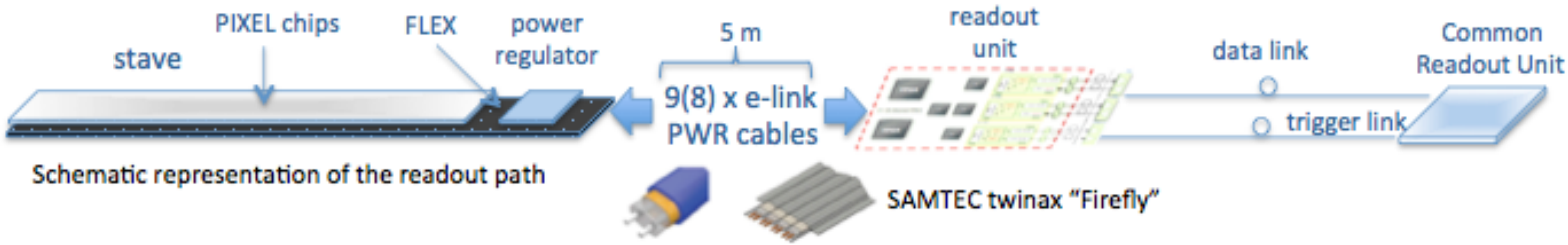




Stave

Risk reduction – provides high speed readout of stave now

Au+Au Relative Bandwidth



ALICE ITS IB is physical signal dominated

Event multiplicity reduction: RHIC / LHC = 7000/20000 = 0.35
Collision rate increase: RHIC / LHC = 200 kHz / 150 kHz = 1.33

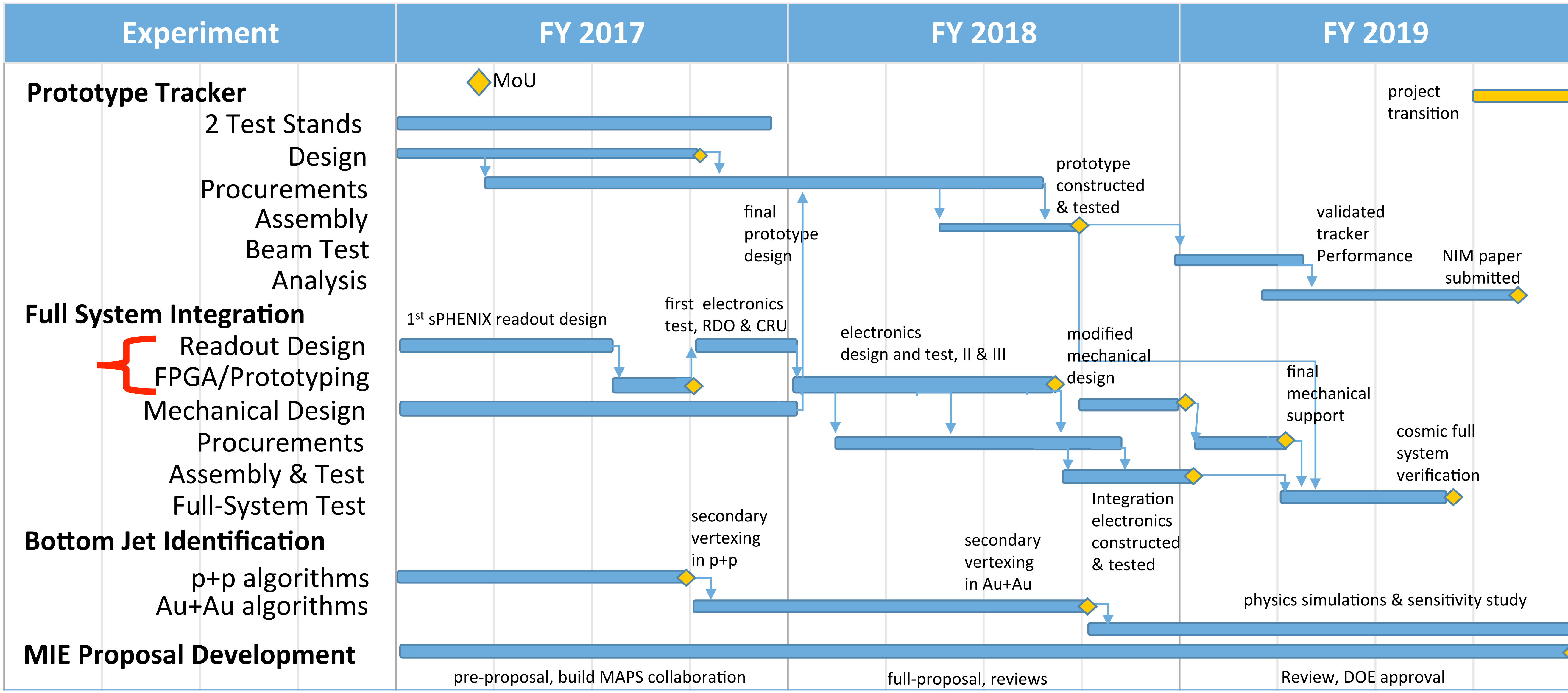
Continuous Stave-to-ROU link is ~50% bandwidth of ALICE ITS IB

Trigger rate reduction: RHIC / LHC = 15 kHz / 50 kHz = 0.30

Triggered ROU-to-CRU link is only ~15% bandwidth of ALICE ITS IB

Risk reduction – Easily manageable data rates

Schedule


Experiment
FY 2017
FY 2018
FY 2019
Prototype Tracker
2 Test Stands
Design
Procurements
Assembly
Beam Test
Analysis
Full System Integration
Readout Design
FPGA/Prototyping
Mechanical Design
Procurements
Assembly & Test
Full-System Test
Bottom Jet Identification
p+p algorithms
Au+Au algorithms
MIE Proposal Development
MoU
project transition
prototype constructed & tested
final prototype design
validated tracker Performance
NIM paper submitted
1st sPHENIX readout design
first electronics test, RDO & CRU
electronics design and test, II & III
modified mechanical design
final mechanical support
cosmic full system verification
Integration electronics constructed & tested
secondary vertexing in p+p
secondary vertexing in Au+Au
physics simulations & sensitivity study
pre-proposal, build MAPS collaboration
full-proposal, reviews
Review, DOE approval

Summary

Use all of existing MAPS readout infrastructure!

Reprogram Common Readout Unit for sPHENIX
- Add sPHENIX trigger and clock
- Add sPHENIX data formatting
- New FPGA coding

Have formed a large team of experts
- Are now associate members of ALICE
- Have access to ALICE hardware and collaborators

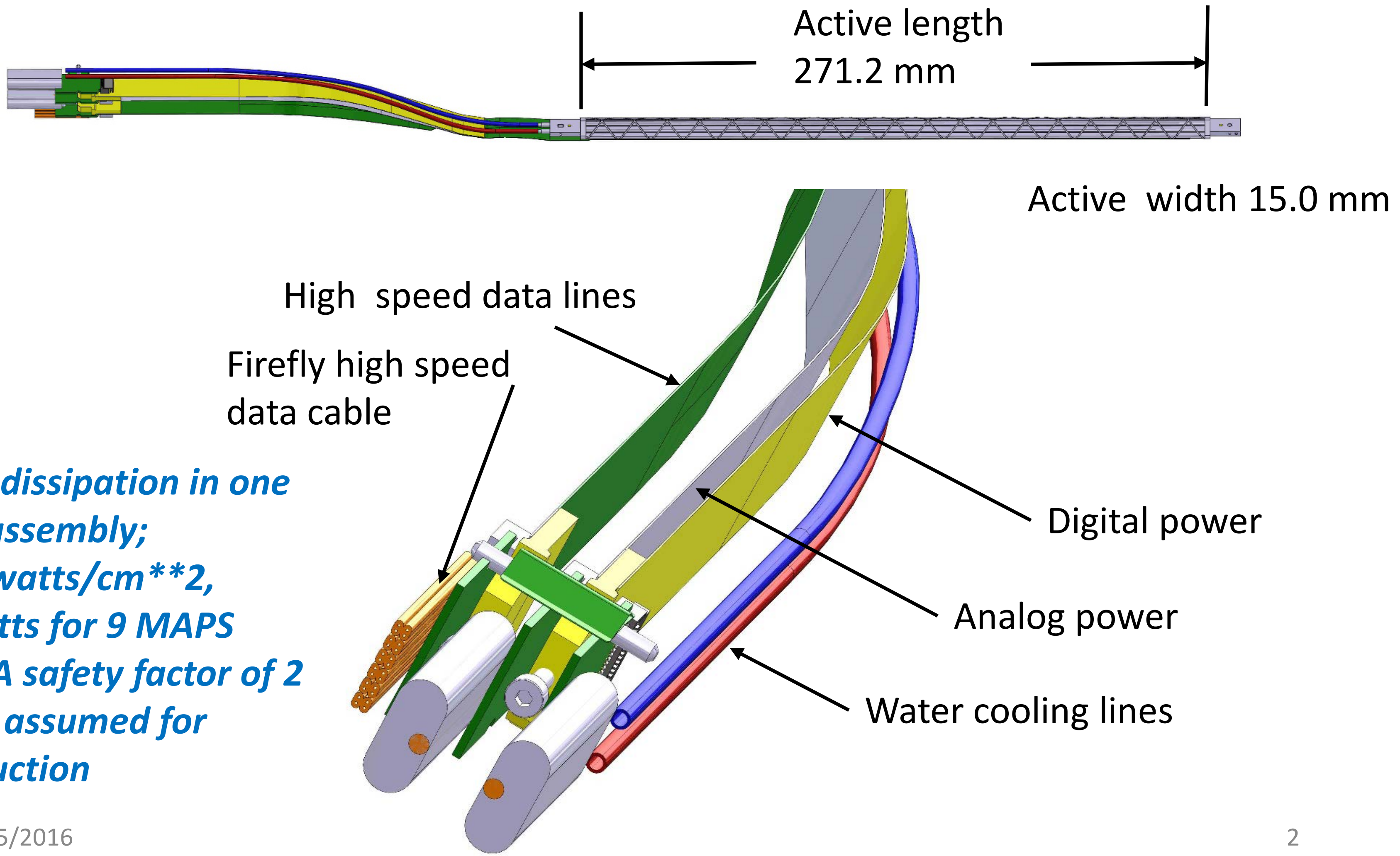
Low to medium risk with many paths to risk reduction

Develop telescope with ALICE inner tracker staves for LDRD project. Followed up by the mechanical integration of ***LANL*** *MAPS inner tracker for the proposed sPHENIX experiment*

Walter Sondheim, Hubert Van Hecke, P-25

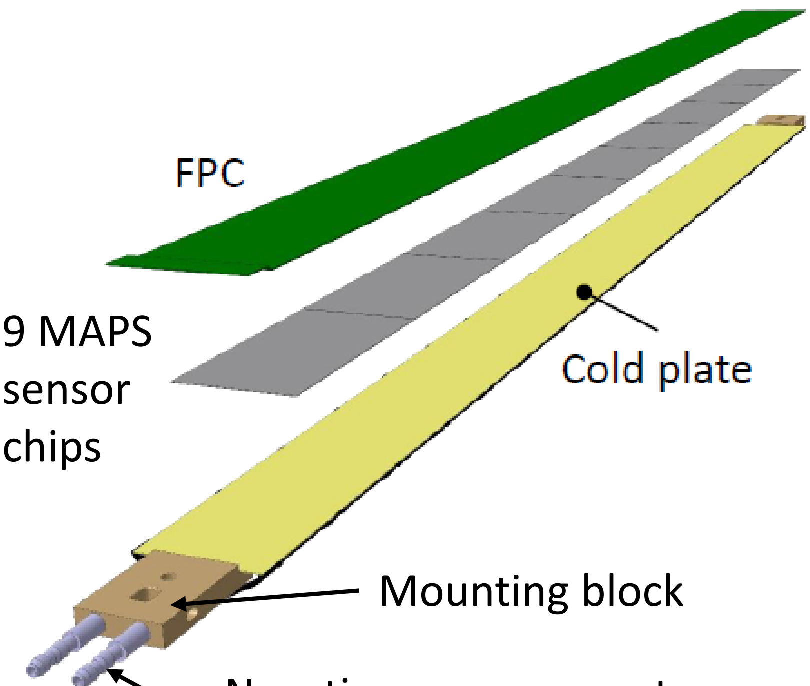
December 5th, 2016

ALICE inner tracker stave:

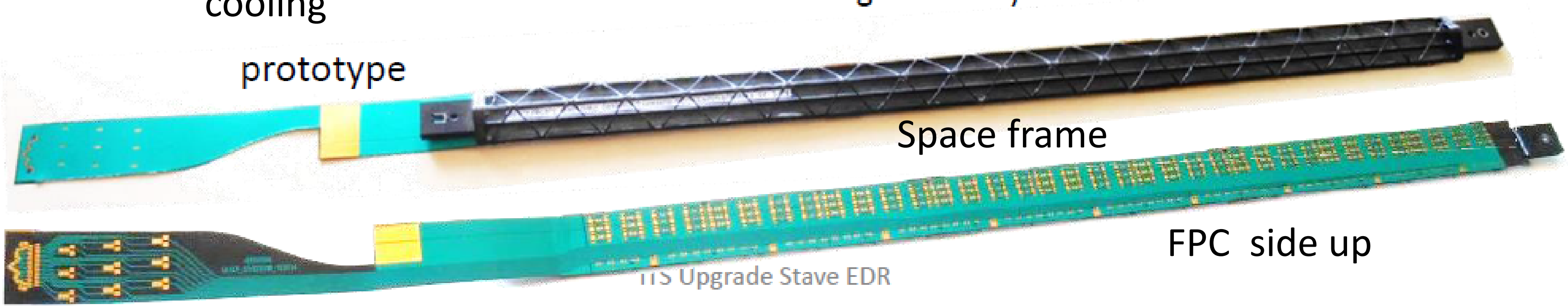


Power dissipation in one stave assembly; 0.041 watts/cm**2, 1.7 watts for 9 MAPS chips. A safety factor of 2 will be assumed for construction

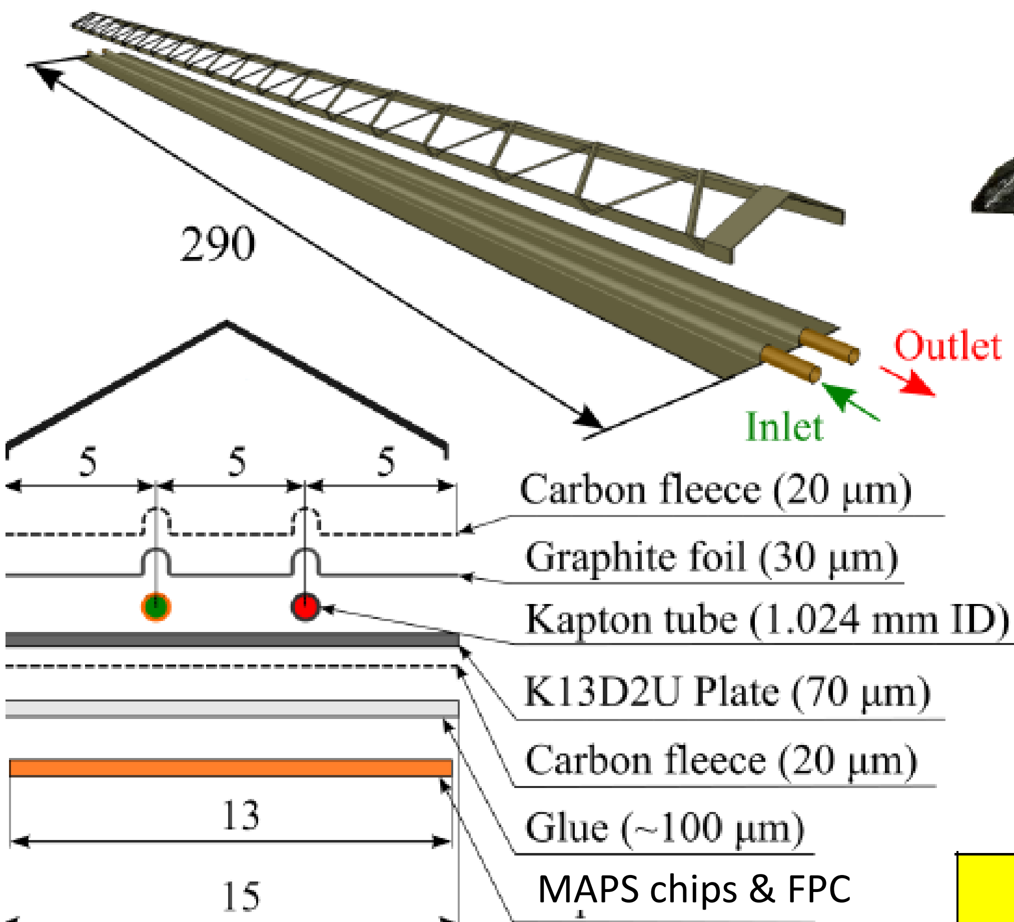
ALICE inner tracker stave assembly:

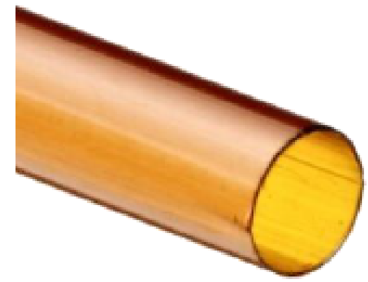


- The three Layers of the IB are segmented in the azimuthal direction in identical detector modules called Staves, consisting of an Hybrid Integrated Circuit (HIC) mounted on a carbon fibre mechanical support structure.
- The HIC includes a row of 9 silicon pixel sensors bonded to a Flexible Printed Circuit (FPC). The area covered by the chips is 15x271.2 mm^2, including a gap of 150 μm between adjacent chips.
- The mechanical support is conceived as a single light structure integrating a Space Frame, providing the required stiffness, and a Cold Plate, a sheet of high-thermal conductivity carbon fibre with embedded polyimide cooling pipes, on top of which the HIC is glued with the chips facing it, in order to maximize the cooling efficiency.



Detail of construction stave assembly:



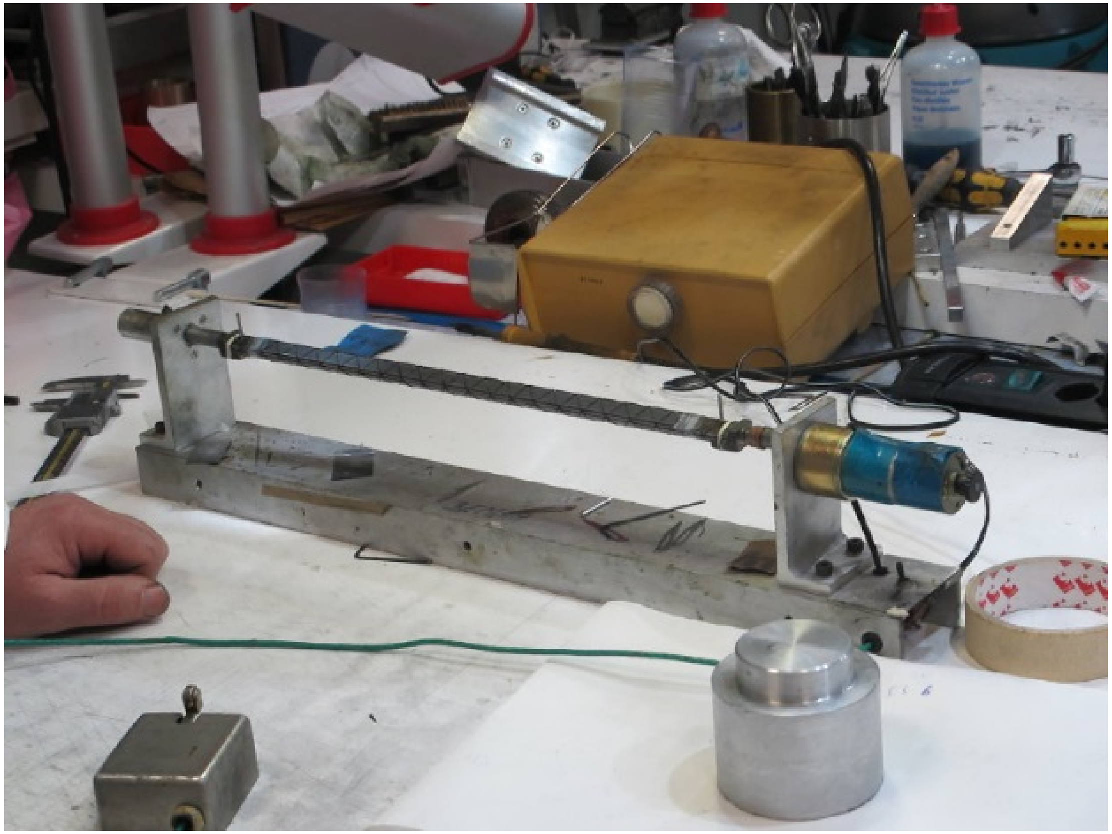


Weight: 1.7 g *(structure only*)*

ALICE inner tracker stave production:

ALICE inner tracker production stave with cooling tubes and filament support

ALICE inner tracker stave filament winding



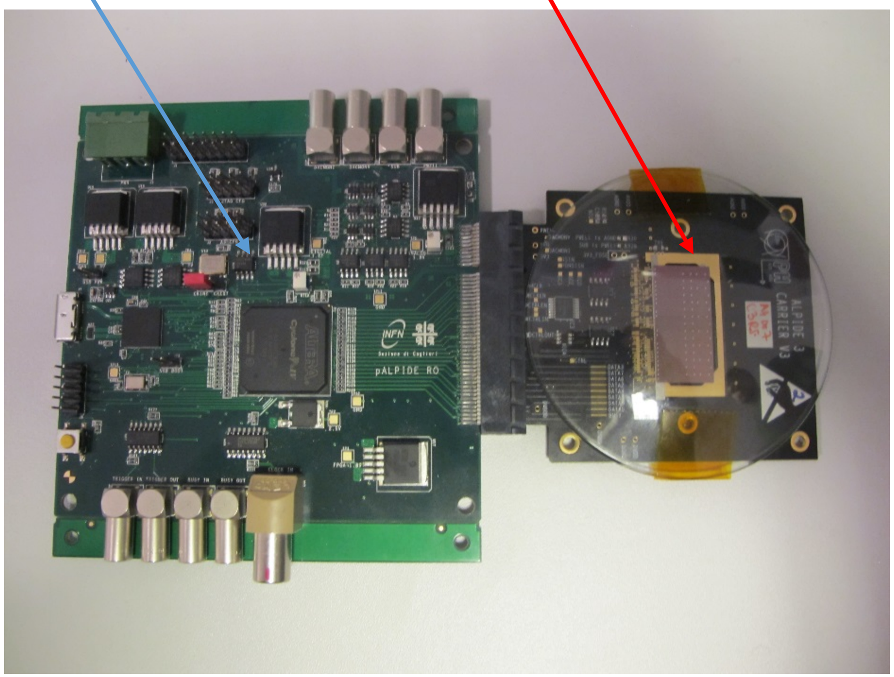
ALICE prototype inner barrel assembly:

Prototype inner tracker half barrel layers showing staggered layer overlap to maintain continuous coverage in *phi*

ALICE single chip module & single chip modules in a telescope configuration:

Slow speed readout board

15 X 30 mm MAPS chip

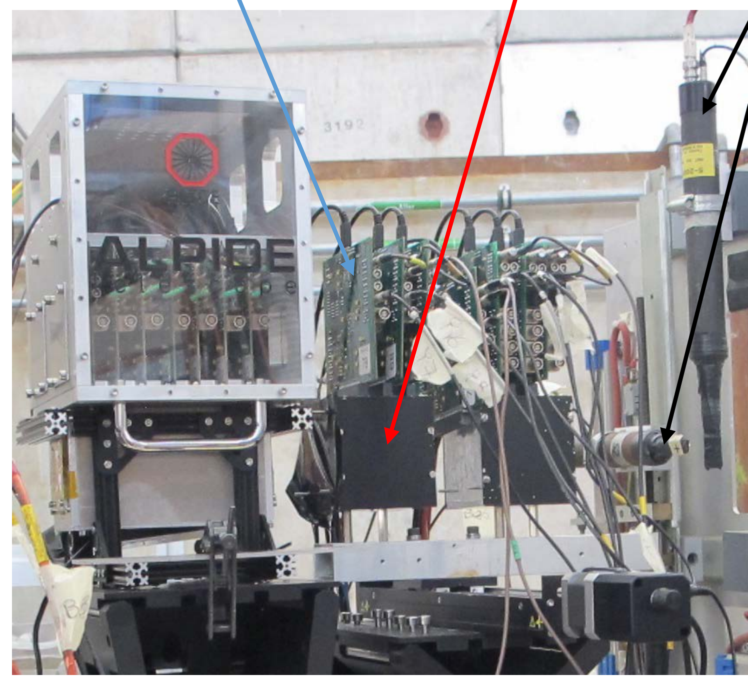


Single MAPS chip test module

Read-out boards

MAPS chip boards in box

Scintillator counters



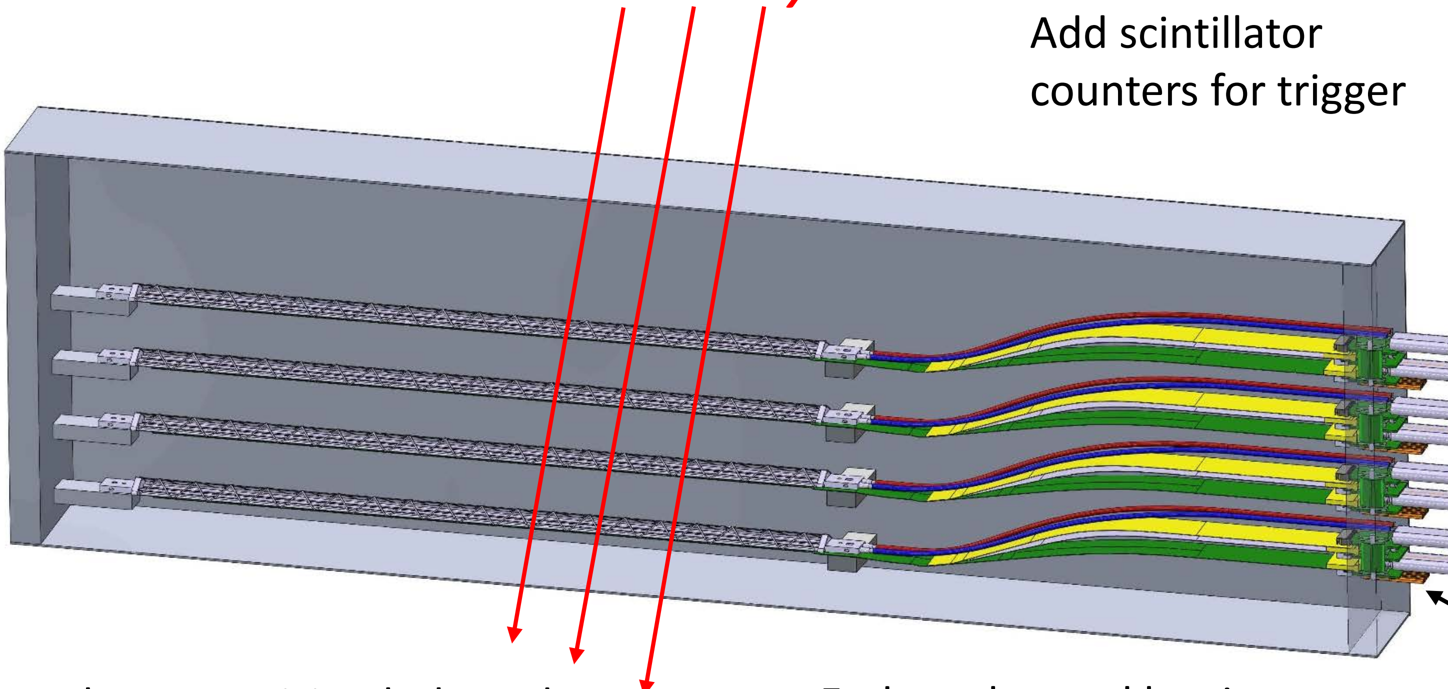
6 single MAPS chip modules in test beam.

LANL four stave telescope assembly:

Aluminum box with 4 ALICE inner tracker layer 0 stave assemblies.
Box overall dimension 572.4 X 169.7 X 50.8 mm, inert gas atmosphere @ STP

Cosmic rays

Add scintillator counters for trigger



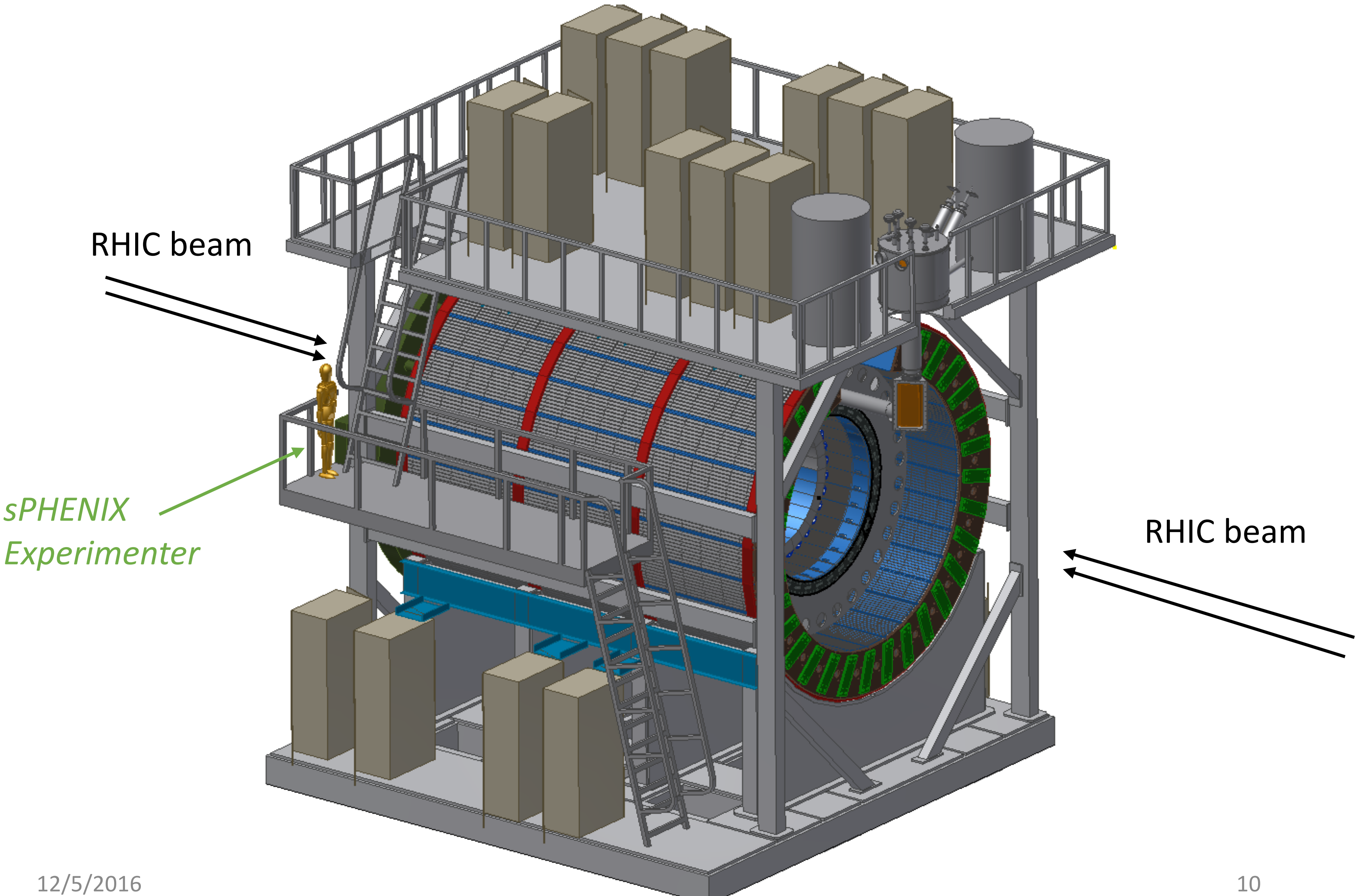
Each stave has a precision hole and slot at either end for precise location to mounting blocks

End patch panel has interconnects for;
Analog power
Digital power
High speed data lines
Water cooling

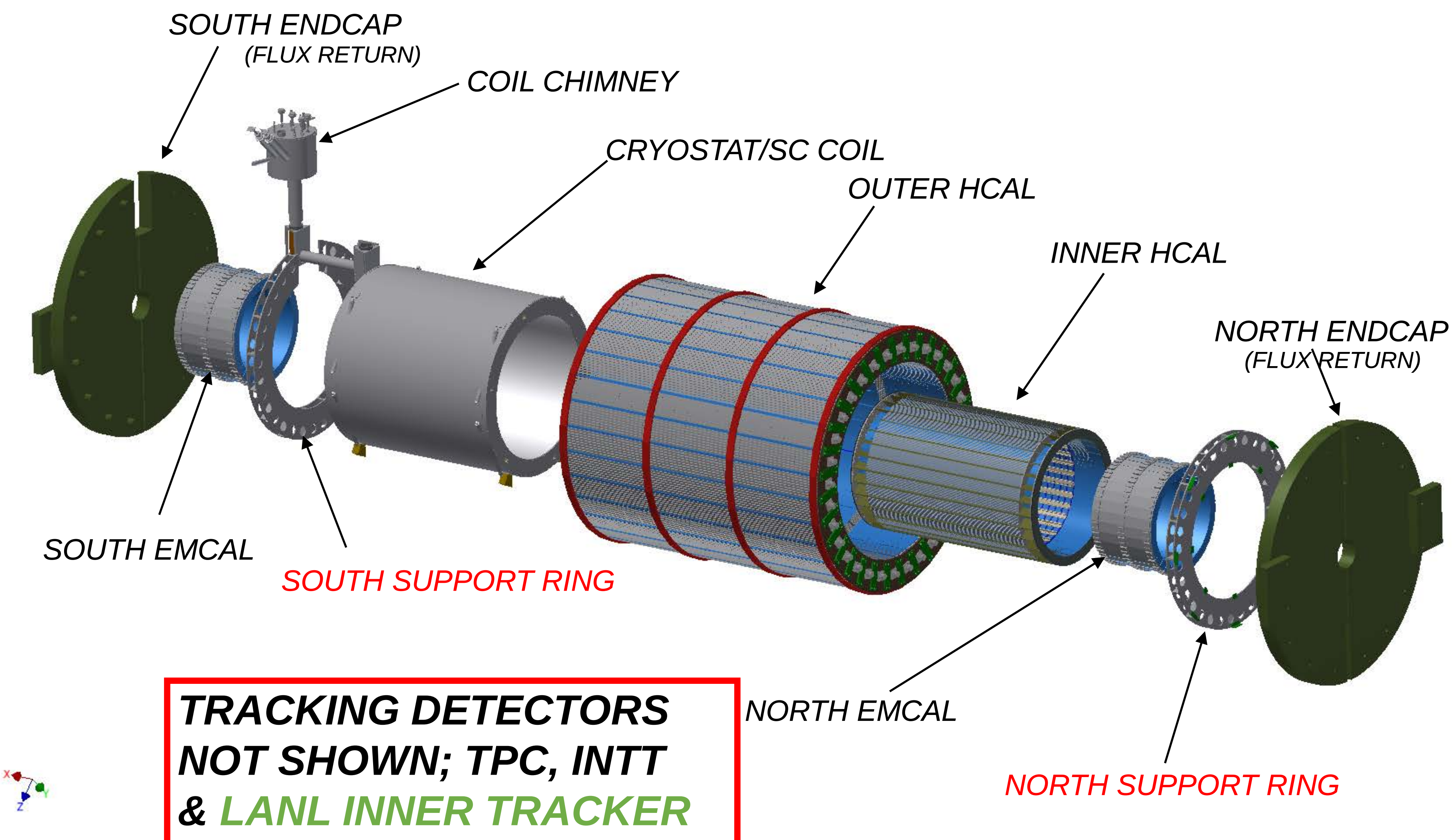
LANL telescope stave design parameters:

- Material budget: Material/layer: ~0.3%X0
- Geometrical:
  - Lengths in Z: 271.2 mm for each layer.
  - Number of MAPS chips/layer: 9
- Chip power dissipation < 50.0 mW/cm**2
  - total power per stave 1.7 watts, 6.8 watts for telescope assembly, add 100% overhead for a total of 13.6 watts
- Operational T <30 °C, max. Negative pressure water cooling, 1.02 mm diameter polyimide (Kapton) tubing.
  - Tested at flow rates from 3 to 7.5 L/hr, ΔT 2.4 – 1.7°K/chip
  - Verified pressure drop <4.35 psi @ 3.0 L/hr flow
  - 4 loops, 12 liters/hour flow rate each loop

Current sPHENIX proposed layout:

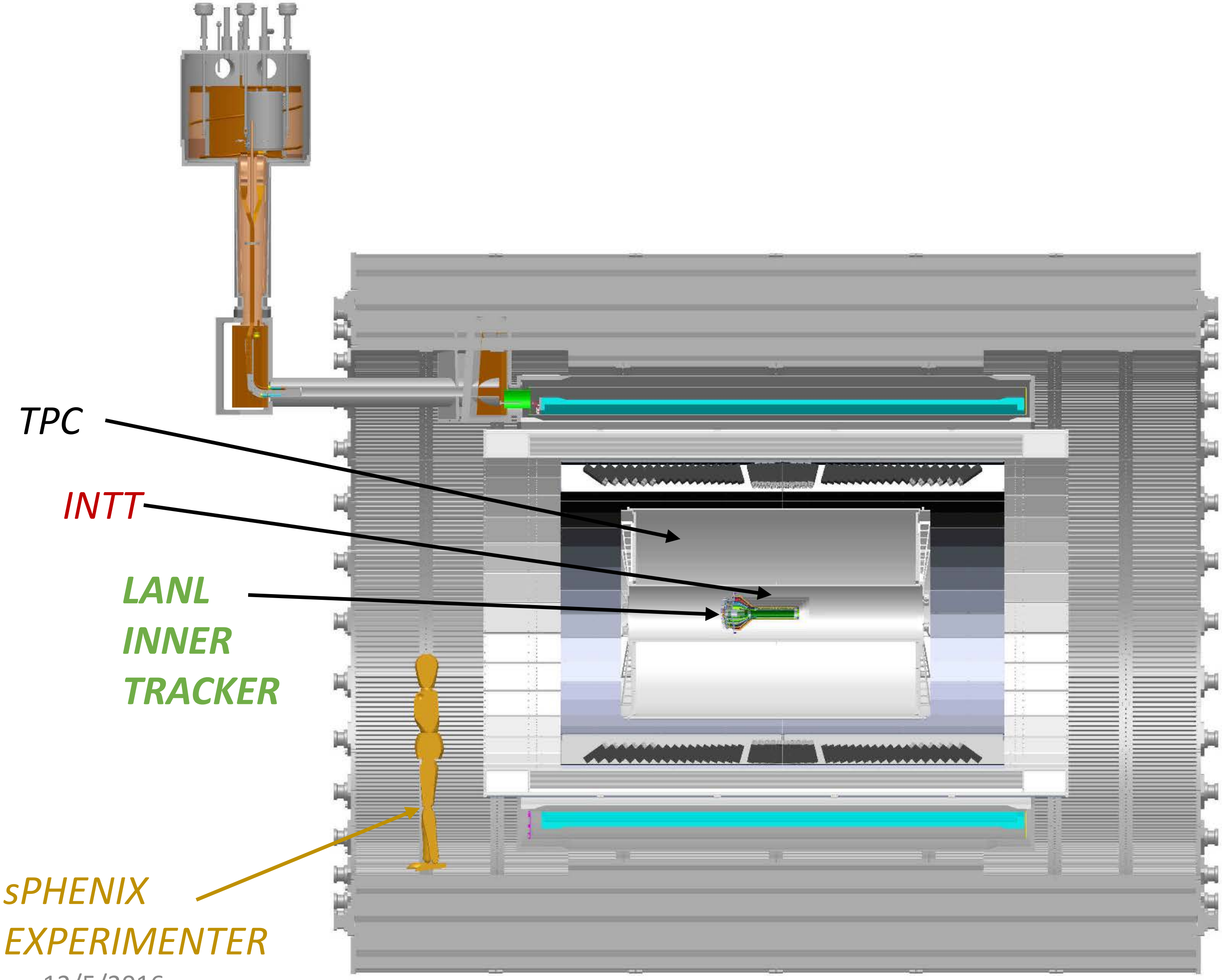


Current sPHENIX detector exploded view:

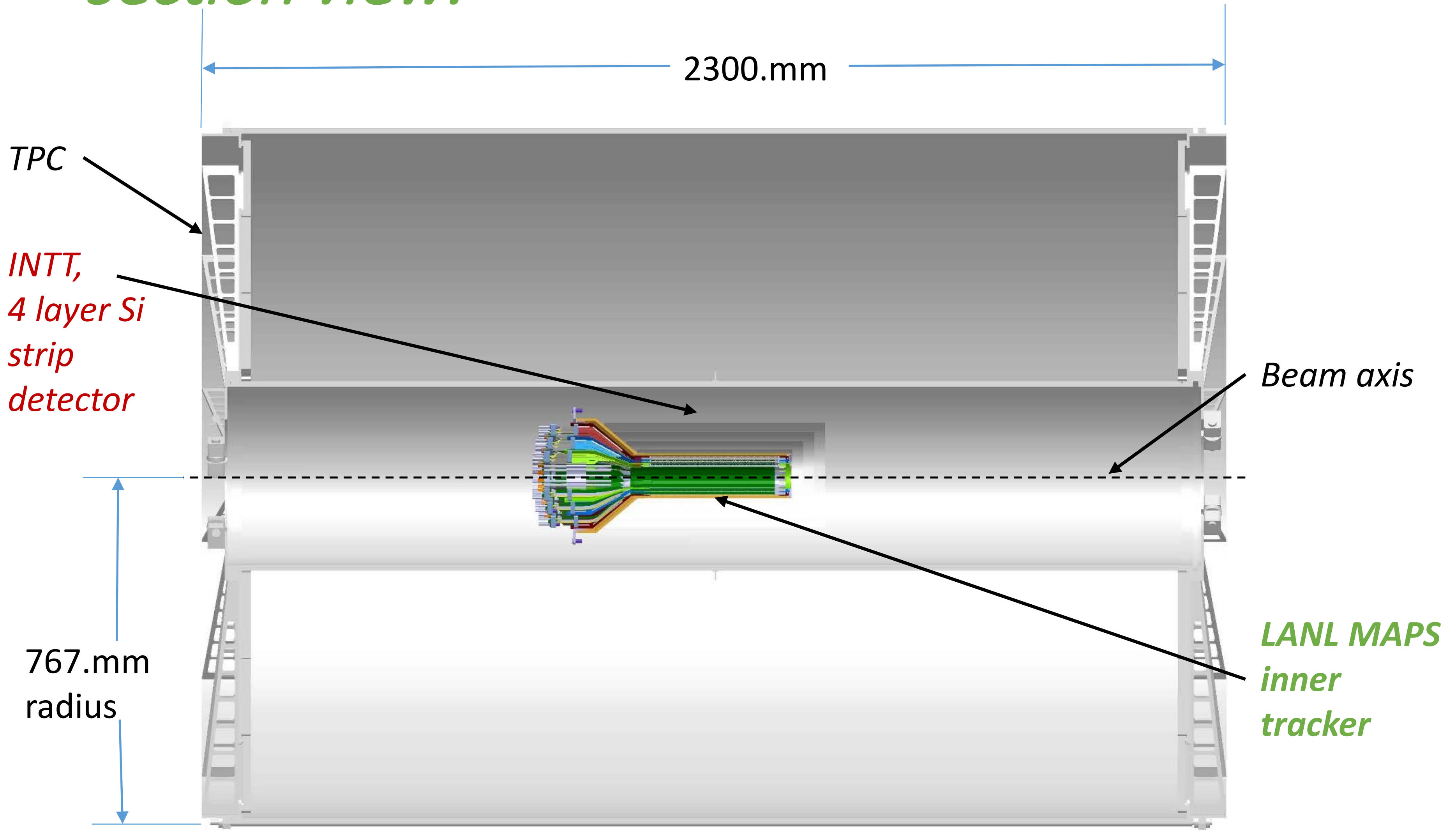


TRACKING DETECTORS NOT SHOWN; TPC, INTT & LANL INNER TRACKER

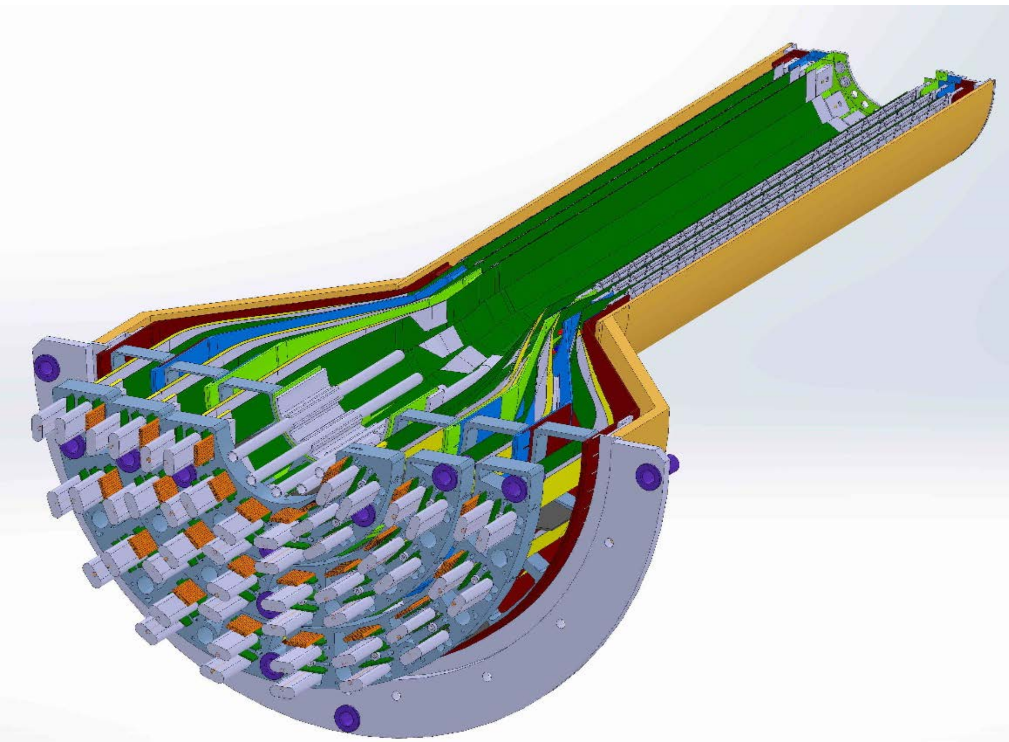
CAD model for sPHENIX detector sectioned, with tracking elements:



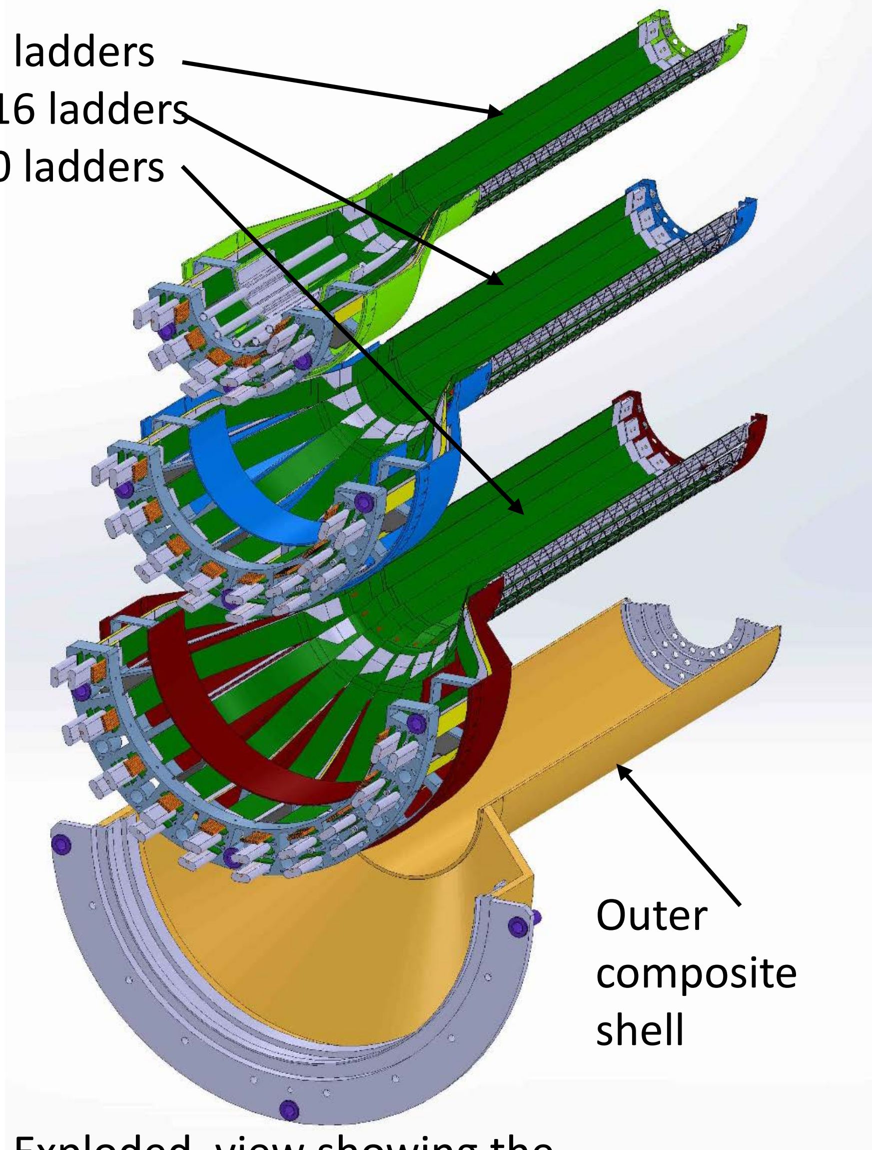
CAD model of the three tracking systems, section view:



LANL MAPS inner tracker, exploded view of layers, section view:

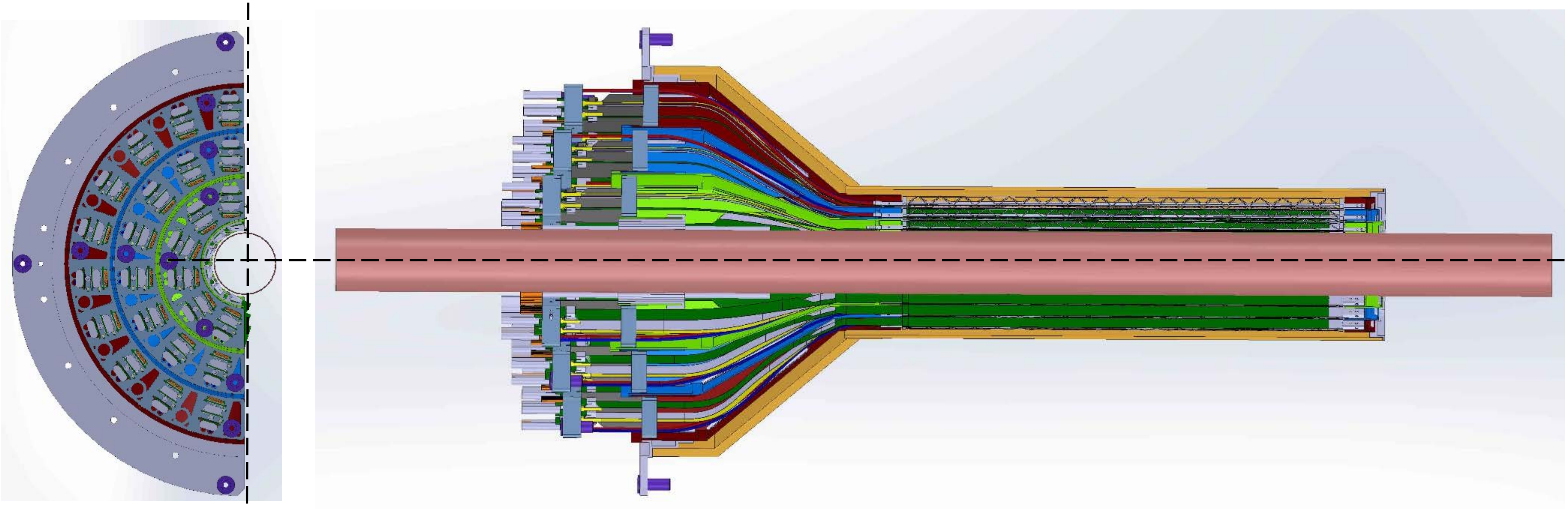


Half assembly view

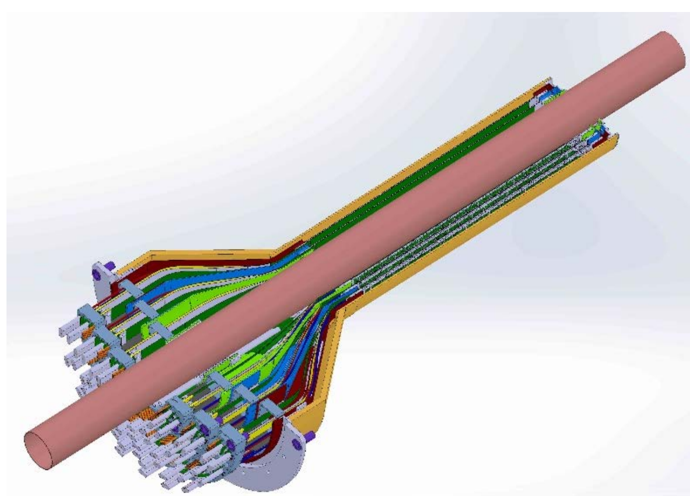


Exploded view showing the three layers

3 layer LANL MAPS inner tracker:



LANL inner tracker, 3 layers of silicon MAPS detectors with sPHENIX beryllium beampipe, OD of beampipe is 41.5 mm, ID of LANL inner tracker 42.9 mm.

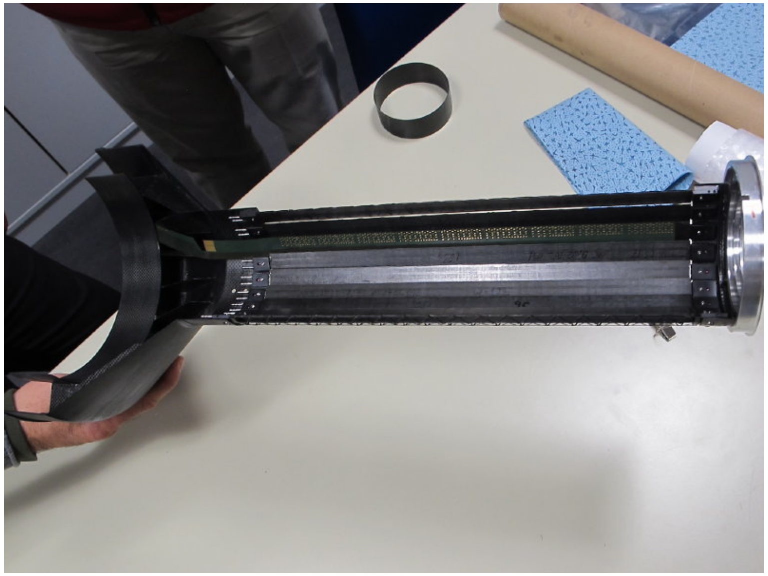


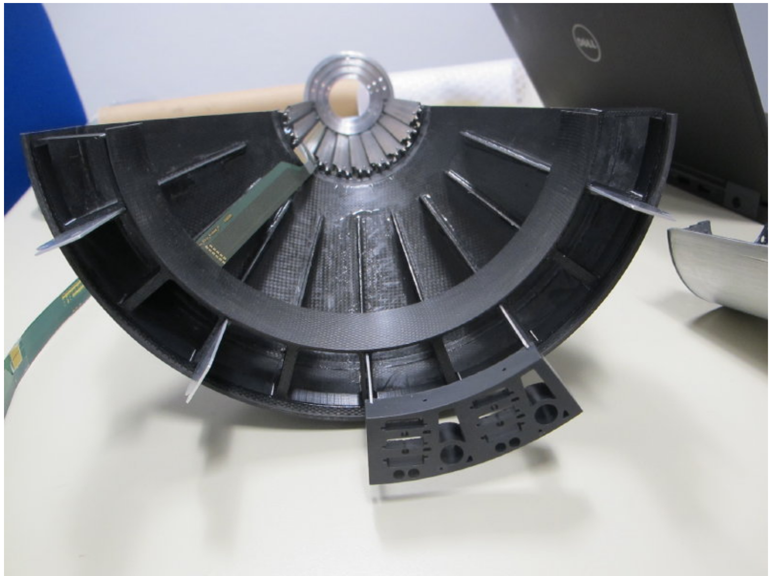
Summary:

- Mechanical construction of the carbon composite stave/space-frame is well underway at CERN
  - *Much work needed on perfecting stave assembly between MAPS chips and FPC to give highest yield after adhesive bonding and wire bonding, in process at CERN*
- Integration of entire tracking assembly with sPHENIX needs development – *risk level medium but requires full participation of sPHENIX to mitigate*
- Can a single cooling system be implemented for entire sPHENIX tracking system - *this will be a part of the entire integration of the sPHENIX detector system*

Backup:

Prototype ALICE inner tracker composite stave assembly:

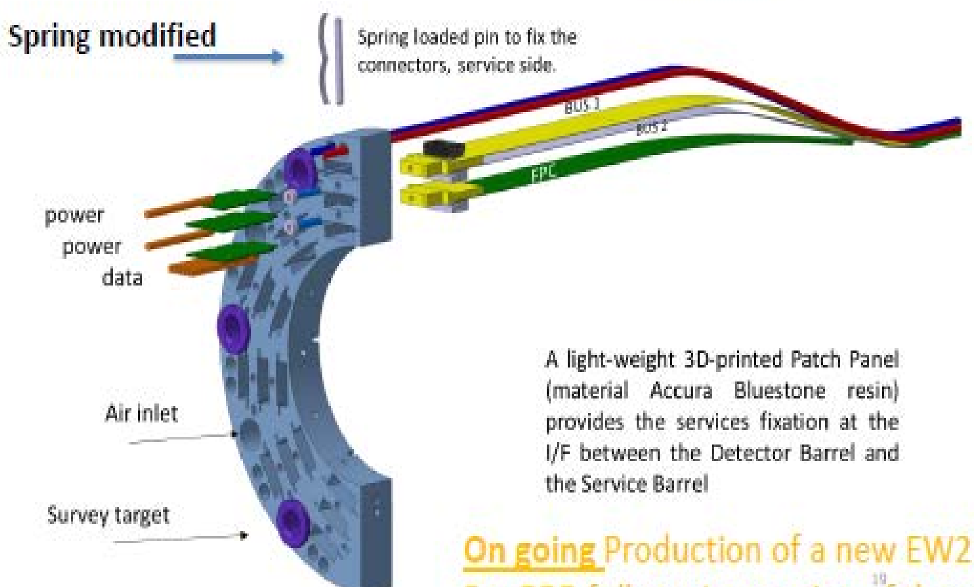




Inner tracker staves mounted to prototype support ends.

Inner tracker service patch panel prototypes:

IB service PPanel mockup

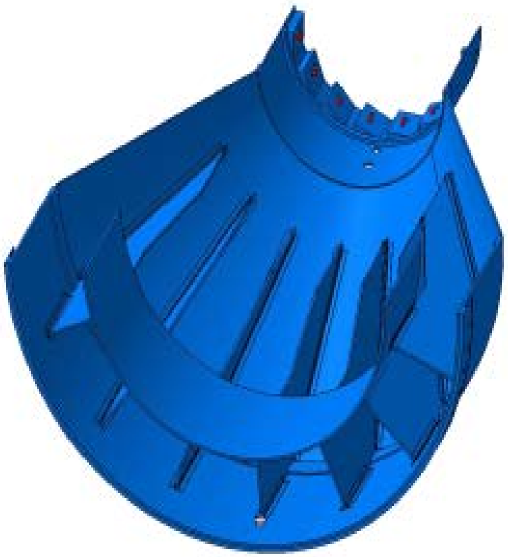


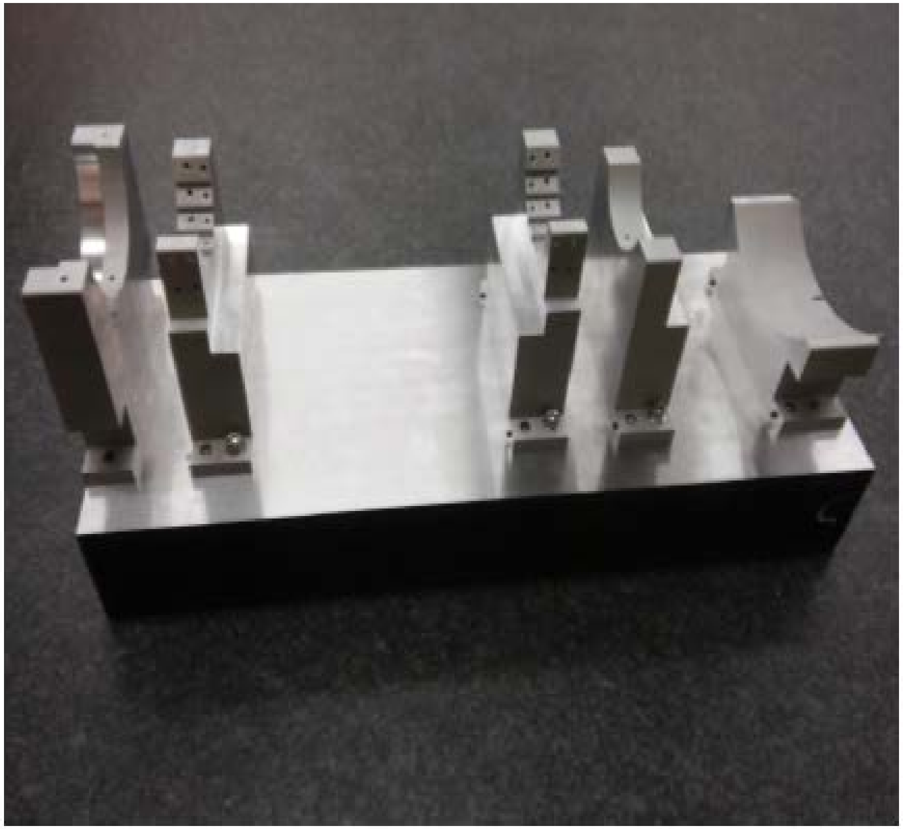
A light-weight 3D-printed Patch Panel (material Accura Bluestone resin) provides the services fixation at the I/F between the Detector Barrel and the Service Barrel

3d printed

<u>On going</u> Production of a new EW2 PP by the end of the week (Accura 25)
<u>For PRR</u> full service routing of three staves of EW2

Inner tracker composite shell prototypes:





On going Composite parts and mould production for EW1
For PRR EW 1 metrology and ruby pads gluing

MAPS LDRD Experimental Cost, Schedule, Risk and Procurements

Cesar da Silva , Ming Liu

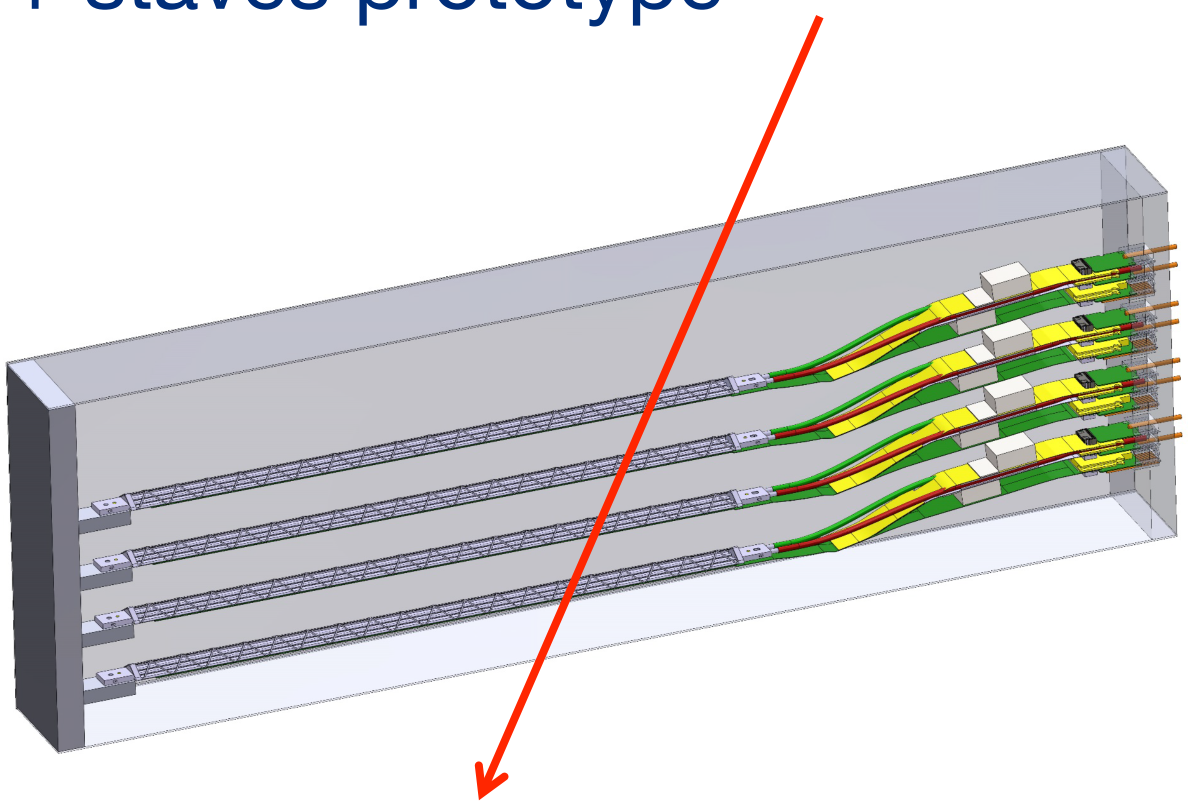
Charge

- Project Organization
- Project Plan
- Technical Aspects
- Cost
- Schedule
- Risk
- Critical Procurements

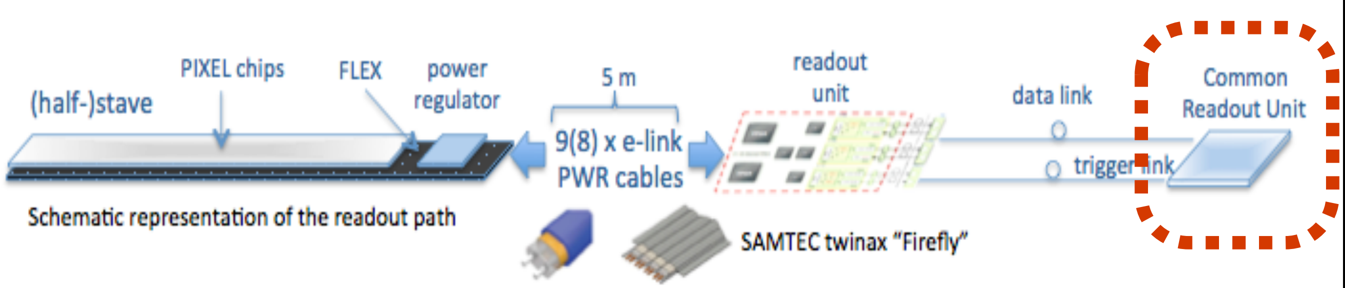
Technical Goals

LDRD GOAL

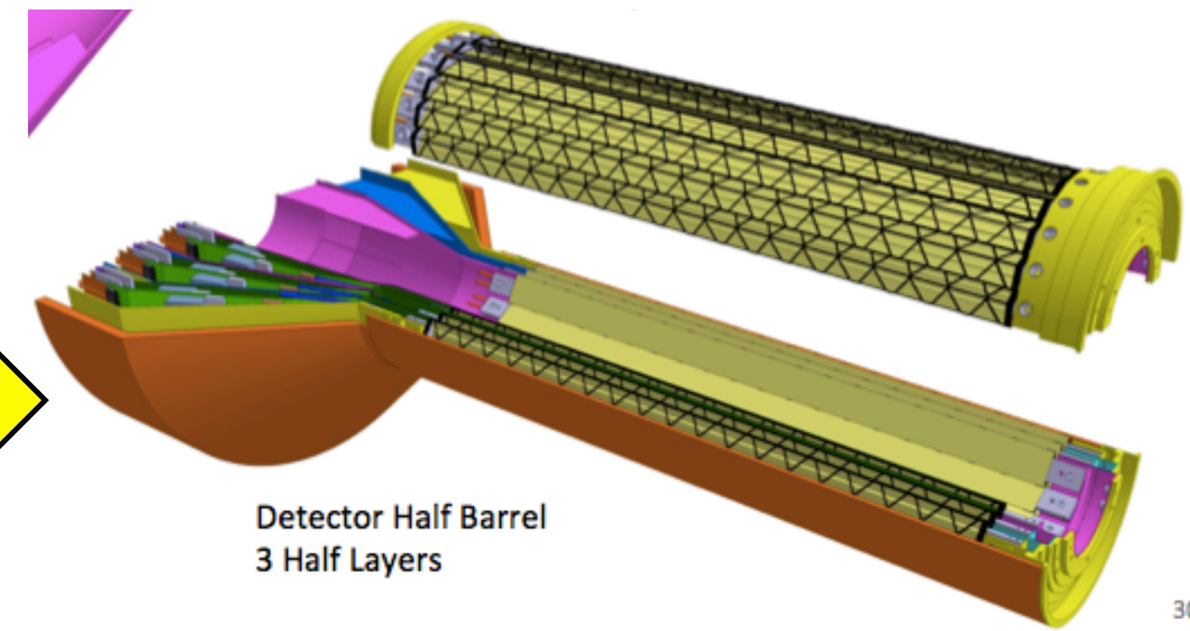
4-staves prototype

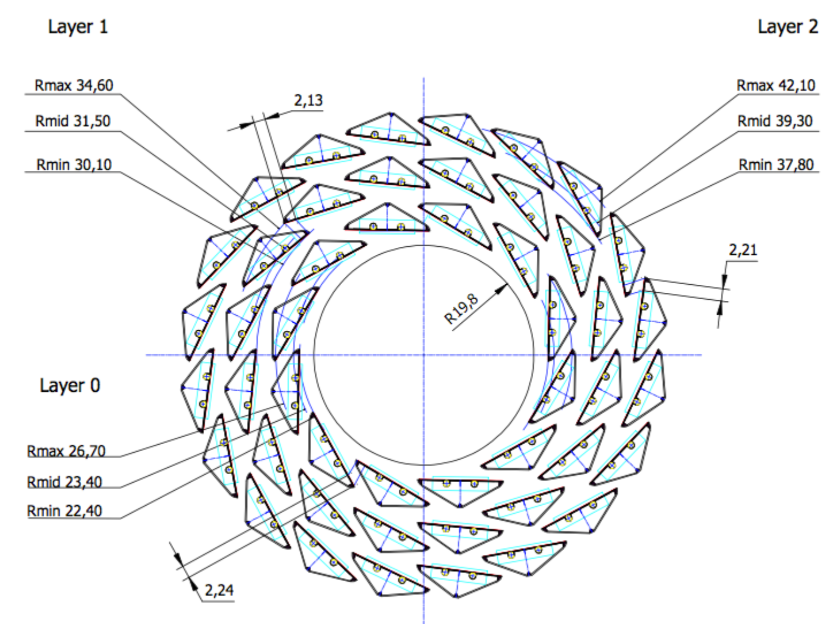


Readout firmware



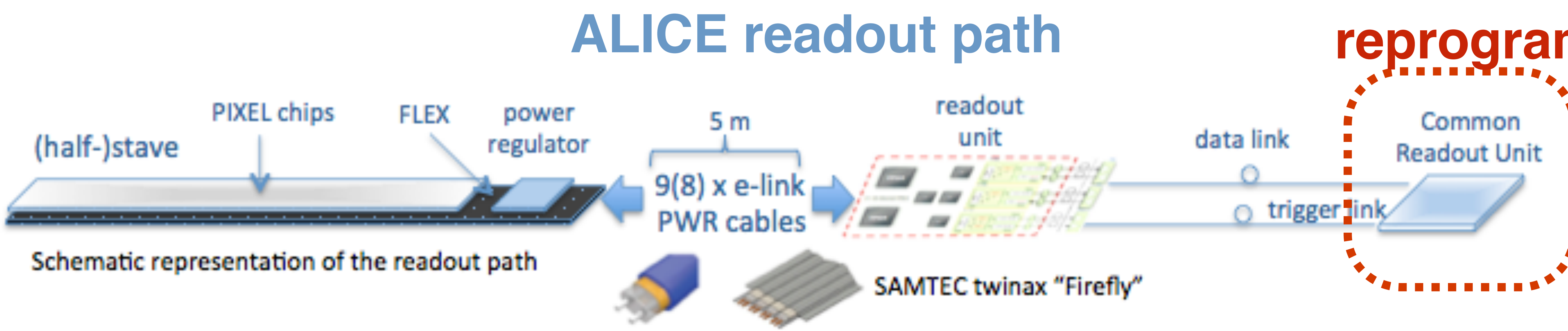
DOE MAPS PROJECT GOAL





LDRD MAPS Electronics Goal

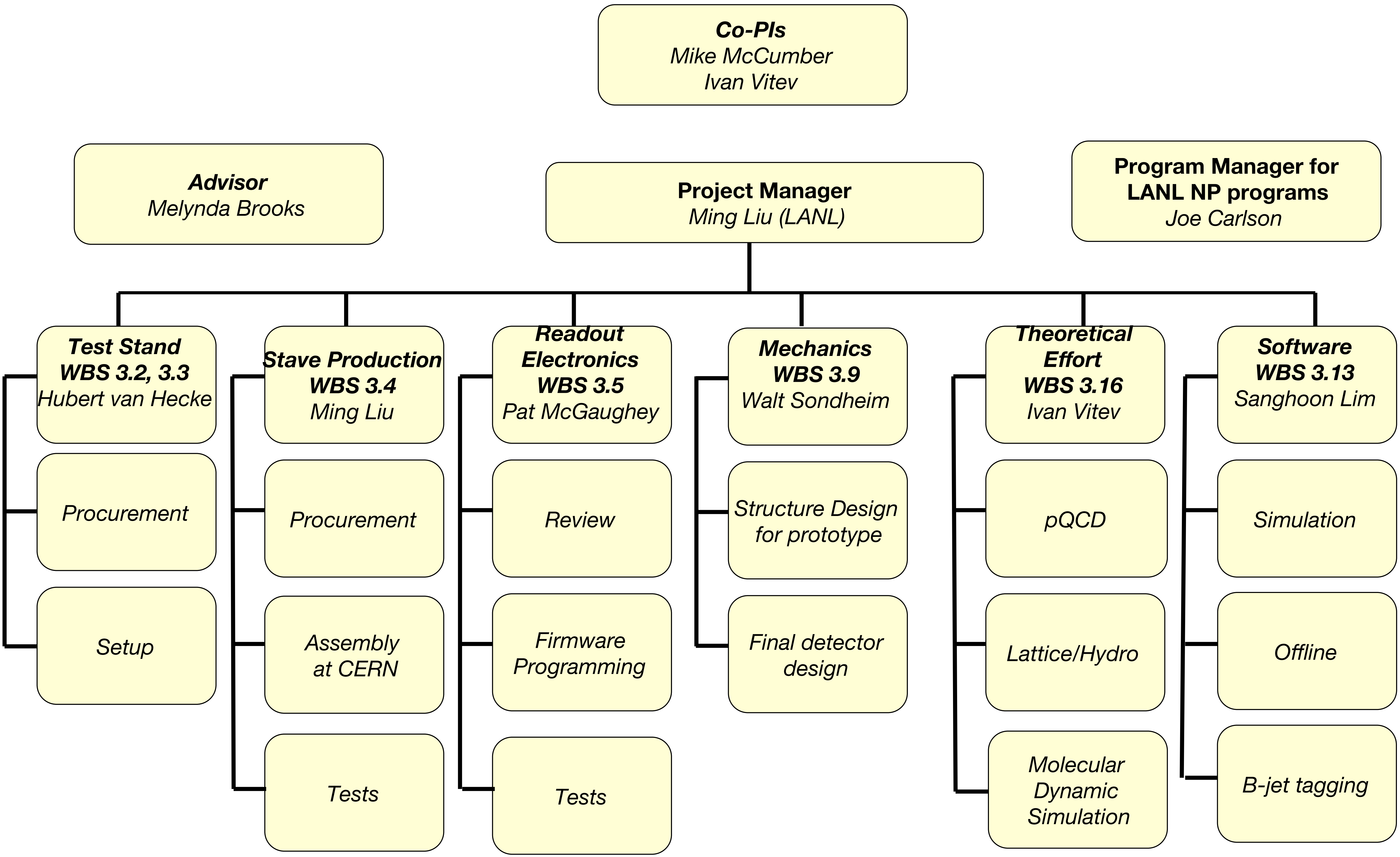
Plan A: reprogram



- Obtain 4 staves from CERN, get readout board and common readout unit chain working at LANL
- rewrite the FPGA code to wrap the data with the sPHENIX formatting
- test it with sPHENIX readout system

- Plan B: design a readout interface board to convert ALICE data format into sPHENIX standard

Project Organization



Initial Assignments

① sPHENIX readout and trigger requirements (DCM2, JSEB etc) – Mike and Ming

② MAPS CRU readout - Mark, Ming, Pat
- Physical parameters (PCIex4)
- Data format
- Electrical signal, lack of busy etc
- sPHENIX trigger/busy inputs and clock

③ Detailed specs/understanding of MAPS/ ALIPED-3(4 ~ final) test card – Pat, Cesar and Andi

④ BNL specifies cabling/material electrical and fire safety etc – Walt, Hubert, Eric*

⑤ Radiation enviroenment, damage, occupancy, SEU; Configuration and Operation, programing and initializatio etc – Mark, Xuan

⑥ Power needs:
- (LANL LDRD) Hubert and Ming;
- (BNL sPHENIX) Hubert, Eric*
- Staves, readout control etc. (A, V)

* From BNL

⑦ Mechanics – Walt, Hubert, Jin*
- Structure, cooling, alignment, assembly and integration

⑧ Integration into sPHENIX – Walt, Eric

⑨ Test stands setup and operation
- Single chip readout – Mike, Pat
- Staves and cosmic ray - Xuan Cesar
- Mockup, electrical, readout, power – Sanghoon, Hubert, Walt

⑩ FPGA firmware – Andi, Mark, Cesar, Ming and Pat
- VHDL, Verilog

11 Software – Sanghoon and Andi
- Slow controls, electronics
- Test software, root-based

12 Beam test – Ming and team
- LANL, FNAL, rad damage at LANSCE

13 Web page – Hubert, Pat
- R+W access
- Tree structure
- https://p25ext.lanl.gov/maps/

Project Management

Work Breakdown Structure

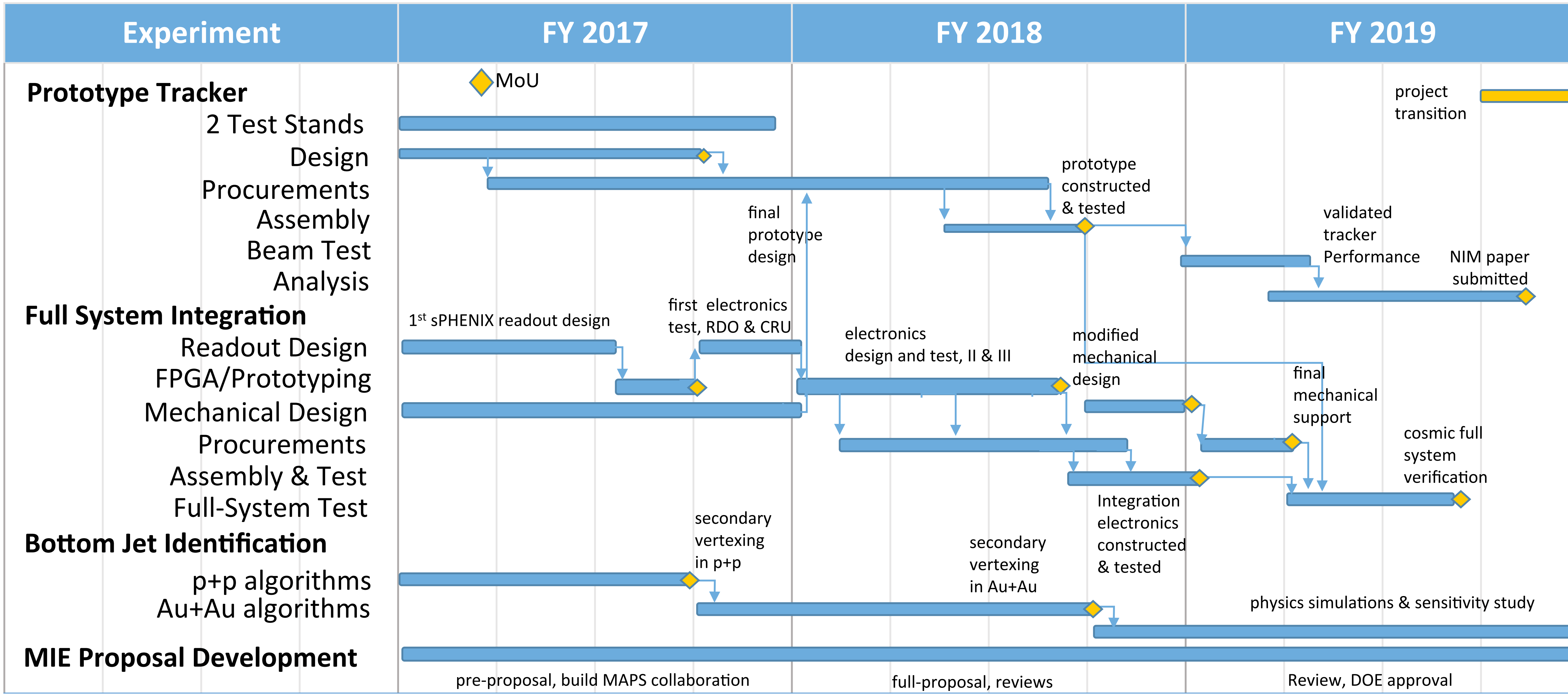
WBS	Task Name	Duration	Start	Finish	Fixed Cost	Cost	Activity	Cost per Unit	Resource Cost
1	**ALICE ITS Key Tasks**	**0 days**	**Mon 1/2/17**	**Mon 1/2/17**	**$0.00**	**$0.00**		**$0.00**	**$0.00**
1.1	ALICE MAPS Production (7/17)	240 days?	Mon 11/28/16	Fri 10/27/17	$0.00	$0.00		$0.00	$0.00
1.2	ALICE ITS IB FPC Production (9/17)	135 days	Mon 2/27/17	Fri 9/1/17	$0.00	$0.00		$0.00	$0.00
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	$0.00
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	$0.00
1.5	ALICE ITS Electronics Pre-Production (7/17)	100 days	Mon 3/13/17	Fri 7/28/17	$0.00	$0.00	ITS El	$0.00	$0.00
1.6	ALICE ITS Electronics Production (6/18)	240 days	Mon 7/31/17	Fri 6/29/18	$0.00	$0.00	ITS El	$0.00	$0.00
2	**LDRD Milestones & Critical Tasks**	**781 days**	**Mon 10/3/16**	**Mon 9/30/19**	**$0.00**	**$0.00**		**$0.00**	**$0.00**
2.1	LDRD Start and End	781 days	Mon 10/3/16	Mon 9/30/19	$0.00	$0.00		$0.00	$0.00
2.2	Complete MoU LANL-ALICE	0 days	Fri 12/9/16	Fri 12/9/16	$0.00	$0.00		$0.00	$0.00
2.3	Setup ALICE Readout Test Stands	0 days	Fri 9/15/17	Fri 9/15/17	$0.00	$0.00		$0.00	$0.00
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	$0.00
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	$0.00
3	**LANL LDRD**	**781 days**	**Mon 10/3/16**	**Mon 9/30/19**	**$0.00**	**$2,959,568.00**	**LANL**	**$0.00**	**$2,579,068.00**
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	$18,400.00
3.2	**Obtain Designs from ALICE**	**30 days**	**Mon 12/12/16**	**Fri 1/20/17**	**$0.00**	**$82,800.00**		**$0.00**	**$82,800.00**
3.3	**Setup Alice Readout Test Stand**	**200 days**	**Mon 12/12/16**	**Fri 9/15/17**	**$0.00**	**$135,760.00**		**$0.00**	**$75,760.00**
3.4	**Procure R&D ALICE Staves**	**195 days**	**Mon 2/27/17**	**Fri 11/24/17**	**$0.00**	**$553,720.00**		**$0.00**	**$466,720.00**
3.5	**Procure ALICE Electronics & Cables**	**205 days**	**Mon 12/12/16**	**Fri 9/22/17**	**$0.00**	**$150,020.00**		**$0.00**	**$71,520.00**
3.6	**Readout R&D**	**345 days**	**Mon 1/23/17**	**Fri 5/18/18**	**$0.00**	**$137,840.00**		**$0.00**	**$137,840.00**
3.7	**Electronics Final Design Review**	**12 days**	**Mon 5/21/18**	**Tue 6/5/18**	**$0.00**	**$25,088.00**		**$0.00**	**$15,088.00**
3.8	Prototype readout assembled and tested	90 days	Wed 6/6/18	Tue 10/9/18	$0.00	$23,760.00		$0.00	$23,760.00
3.9	**Mechanical Support and Cooling**	**200 days**	**Mon 1/23/17**	**Fri 10/27/17**	**$0.00**	**$236,160.00**		**$0.00**	**$181,160.00**
3.10	**Prototype Assembly and Test**	**90 days**	**Mon 2/26/18**	**Fri 6/29/18**	**$0.00**	**$114,240.00**		**$0.00**	**$114,240.00**
3.11	Mechanical Conceptual Design	60 days	Mon 7/2/18	Fri 9/21/18	$0.00	$18,240.00		$0.00	$18,240.00
3.12	Mechanical Conceptual Design Review	**12 days**	**Mon 9/24/18**	**Tue 10/9/18**	**$0.00**	**$33,920.00**		**$0.00**	**$23,920.00**
3.13	**Softrware Tool Development and Analysis**	**500 days**	**Mon 1/23/17**	**Fri 12/21/18**	**$0.00**	**$351,200.00**		**$0.00**	**$351,200.00**
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**	**$896,000.00**
3.15	**Test Beam Operation**	**187 days**	**Fri 1/11/19**	**Mon 9/30/19**	**$0.00**	**$132,420.00**		**$0.00**	**$102,420.00**

Costs

WBS	Task	T&E	M&S	RISK
3.1	MOU btw LANL and ALICE	19K		Low
3.2	Obtain design from ALICE	83K		Low
3.3	Setup Alice Readout Test Stand	10K	100K	Low
3.4	Procure ALICE staves	260K	290K	Medium
3.5	Procure ALICE electronics & cables	70K	80K	Medium
3.6	Readout R&D	140K		
3.8	Prototype Readout Assembled	24K		
3.9	Mechanical Support and Cooling	130K	110K	Low
3.10	Prototype Assembly and Test	55K	55K	Low
3.13	Software (FPGA, online, controls)	350K		Low
3.14	Detector optimization and physics simulations (MIE)	850K	50K	Low
3.15	Test beam operations	50K	80K	Low
3.16	Theoretical Effort	1.8M		Low

20% contingencies applied. Except electronics with 40% contingency.
Estimates based on ALICE ITS procurements and recent FVTX experience.

Schedule



- MAPS sensors by mid 2018
- 2 test stands by August 2017
- 4 fully assembled staves for system test, by the end of 2018
- Preliminary mechanical design by Nov 2018

Major Procurement I: Stave Production

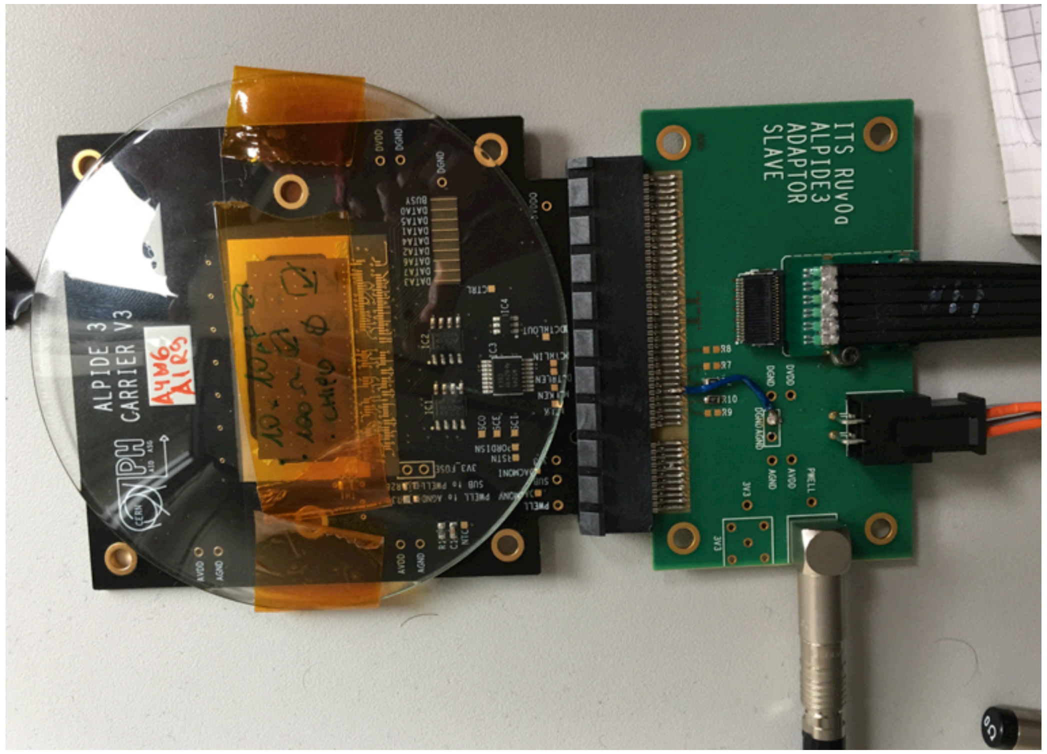
- Procure 4 production staves at CERN (3/2017 – 10/2017)
  - Produce staves from the ALICE stave production line
  - Pay CERN Materials and Labor ($290K)

- Train LANL personnel on the job (3/2017 -10/2017)
  - MAPS chips QA at CERN
  - MAPS chips assembly on the Flexible Printed Circuit (FPC) at CERN
  - Module QA at CERN labs
  - Mount FPC modules to space frame, test and QA staves at CERN
  - Test staves at LANL
  - LANL labor T&E ($260K)

Risk I: ALICE Staves Procurement

- ALICE stave production officially ends on March 2018
- Medium risk on ALICE stave production schedule
  MAPS chip production review just done (~mid Nov. 2016)
  Mechanic review scheduled ~Dec. 2016
  Flexible Printed Circuit production review early 2017

Risk Mitigation on LANL telescope staves:
- develop and test the readout with a 5-layer single chip MAPS telescope
- ALPIDE chips with fast readout already available
- Readout system may be ready by the time the 4 staves are available
- Use early prototype staves for LANL R&D



Single-chip MAPS with fast readout

Major Procurement II : Readout Electronics

- Produce readout electronics and cables at CERN, LANL-ALICE MoU
  - part of the ALICE readout electronics production
  - Pay CERN Materials and Labor ($80K)
- Train LANL personnel on the job
  - MAPS chips readout at CERN
  - MAPS 9-chips stave high speed readout at CERN
  - Electronics module QA at CERN labs
  - LANL labor T&E ($70K)
- LANL Readout R&D (1/2017 – 6/2018)
  - Programing FPGA with prototype CRU (a commercial test board)
  - LANL T&E ($140K)

Risk II: Readout Electronics

- Common Readout Unity (CRU) development for the sPHENIX trigger, busy and data format requirements

- Medium risk on ALICE readout electronics production schedule:
  RU v0 being tested, next version expected spring 2017
  CRU being prototyped, key components tested, first prototype expected summer 2017

PCie40

Risk Mitigation on readout electronics:

- A pre-final version of the CRU has been used by ALICE

- A CRU board or the design file (Gerber file) can already be obtained for our single-chip MAPS telescope for tests and FPGA programming

- Possibility to deal with data formatting in computers trough regular software

Summary

- Tasks, organization and schedule of the work established
- ALICE ITS previous work and our experience with FVTX will help in the accomplishment of this project
- We are already ALICE Associated Member with access to drawings and boards
- Two moderated risks and mitigations identified