MVTX Overview

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For the sPHENIX MVTX Upgrade Group

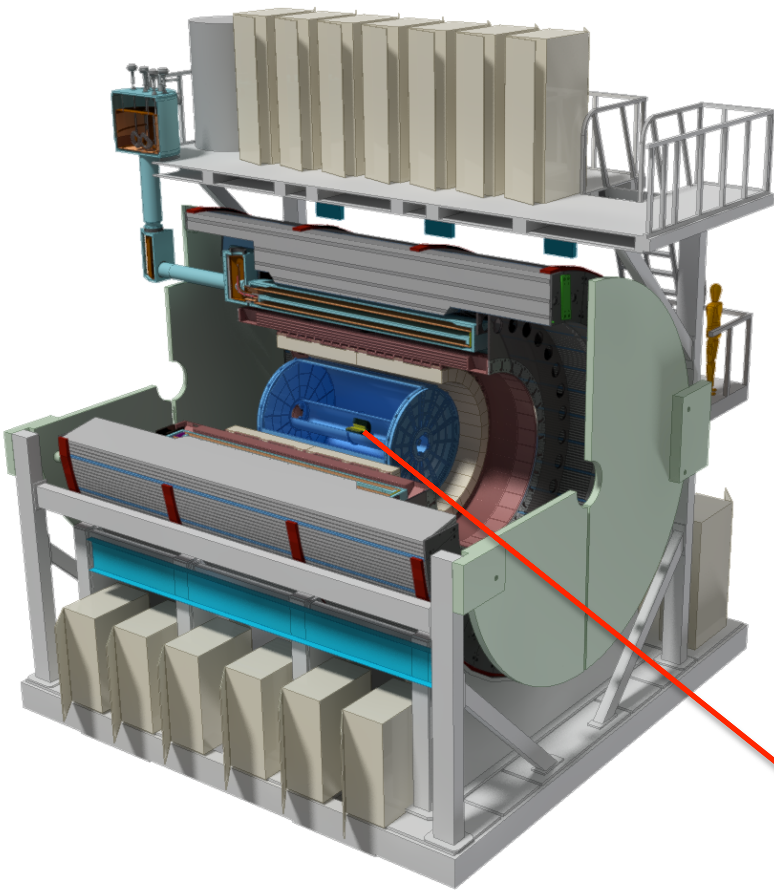
BNL Director's Review
August 2-4, 2017

MVTX: MAPS-based Vertex Detector for sPHENIX

A separate upgrade project for the baseline sPHENIX experiment, with

1) Compelling Science
2) Feasible Cost & Schedule

MVTX BNL Director's Review: July 10-11, 2017



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

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

Parallel Activities

- MAPS-based Vertex Detector (MVTX)
- Intermediate Silicon Strip Tracker (INTT)

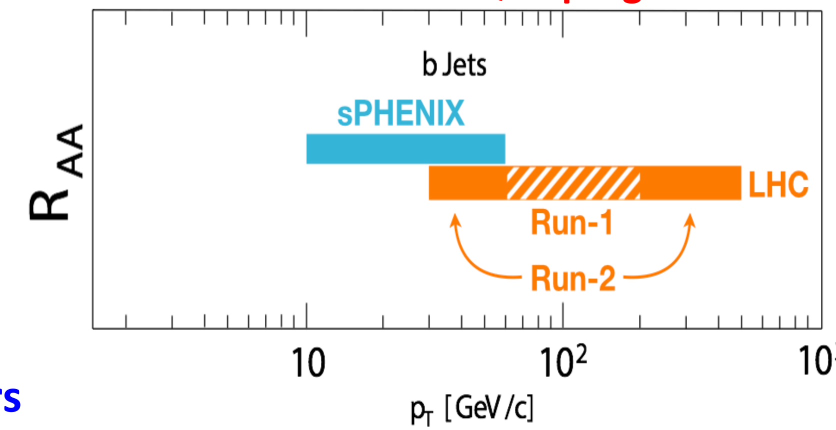
Outline

- Science of MVTX detector
- Scope of MVTX project
  - Readout
  - Integration
  - Cost & schedule
- Organization & plan

Exciting Science

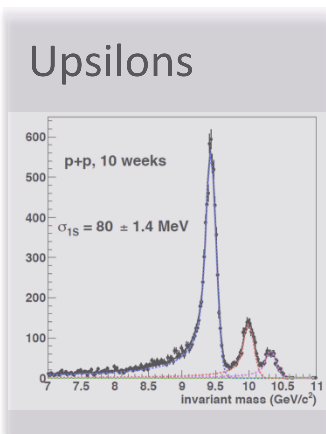
- sPHENIX is the next flagship heavy ion physics experiment in the US (NSAC LRP2015)
  - Jets
  - Upsilons
  - B-jets and B hadrons
- MVTX will complete QGP heavy flavor physics
  - Precision study of the "inner workings of QGP"(LRP15)
  - Unambiguous determination of key parameters of QGP properties and interactions

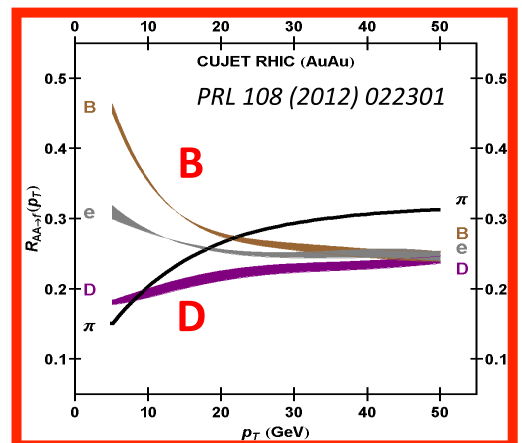
complement & extend current and future RHIC and LHC QGP programs



sPHENIX 3 Physics Pillars

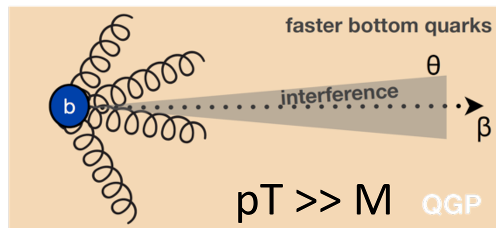
http://arxiv.org/pdf/1501.06197v1.pdf

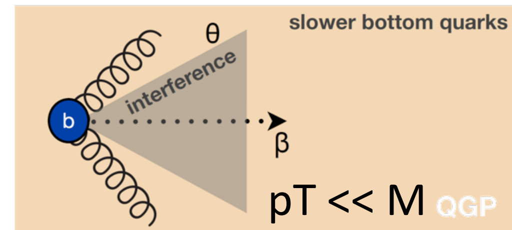




MVTX – Bring sPHENIX to a New Horizon

- Unambiguously determine quark energy loss mechanisms, particularly over the interesting transition region, pT ~ M
  - Radiative dE/dX
  - Collisional dE/dX
  - Other effects





Expectations @sPHENIX

Learned @CERN

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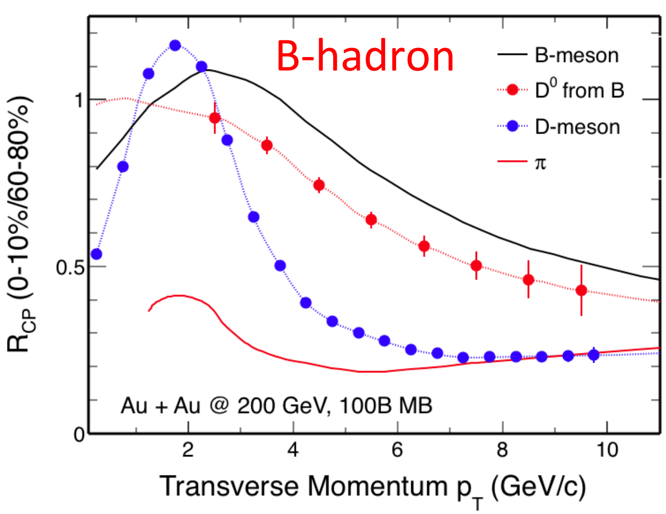

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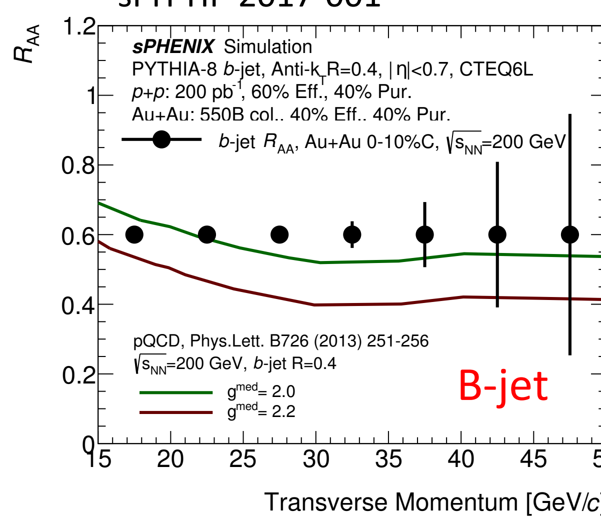
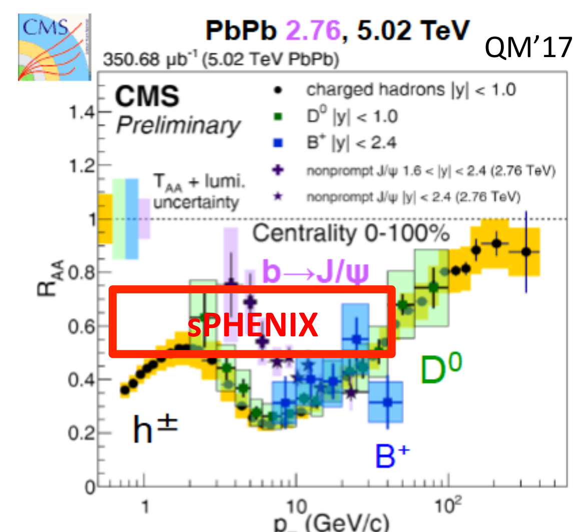
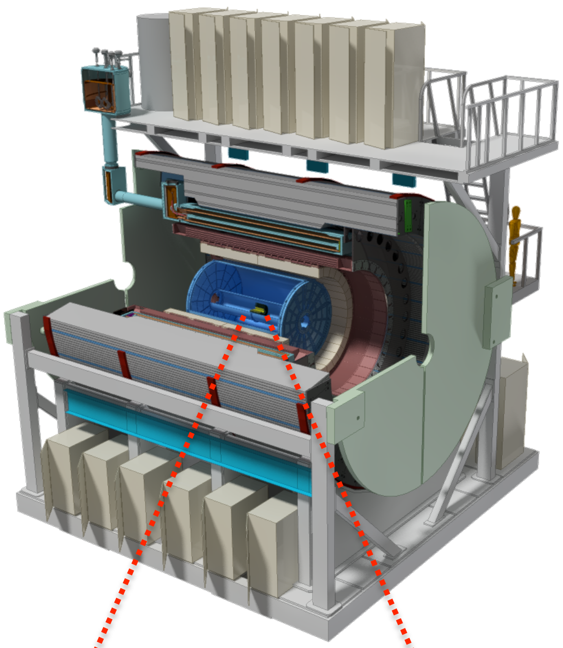
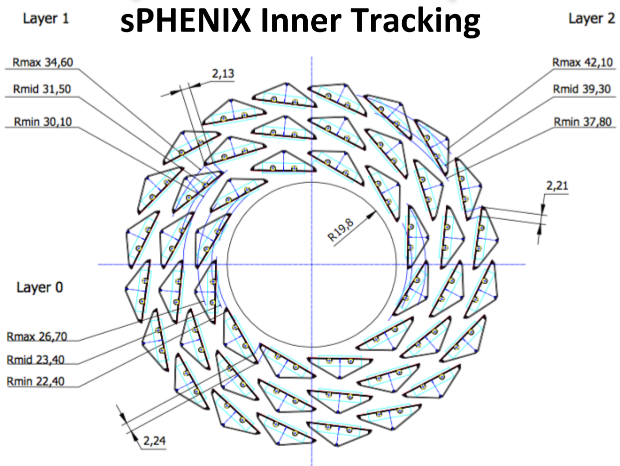




Our Approach: MVTX





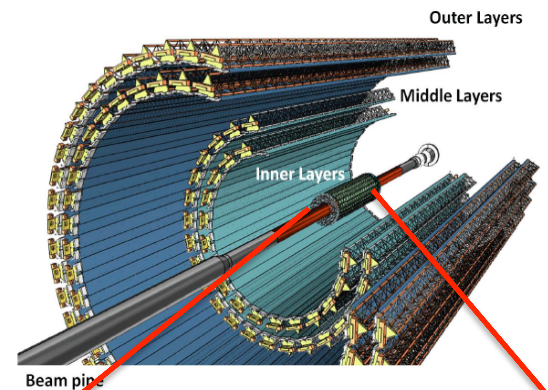
Major challenges:
- Readout
- Mechanics

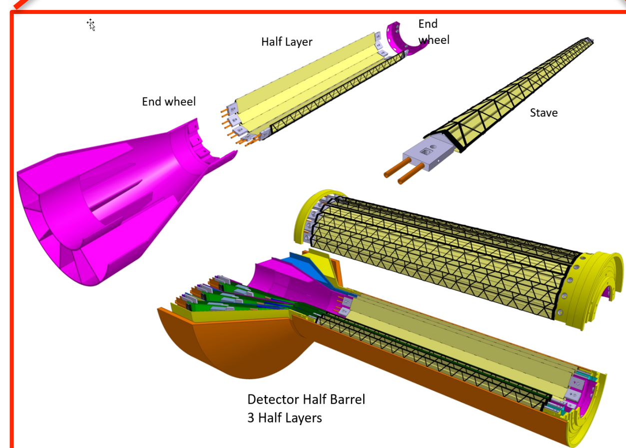
R = 23/32/39 mm
Z = 271 mm

ADAPT ITS/IB:
- MIN. RISKS
- MAX. PHYS.

J. Phys. G 41 (2014) 087002

ALICE ITS Upgrade:
Inner Barrel Tracker



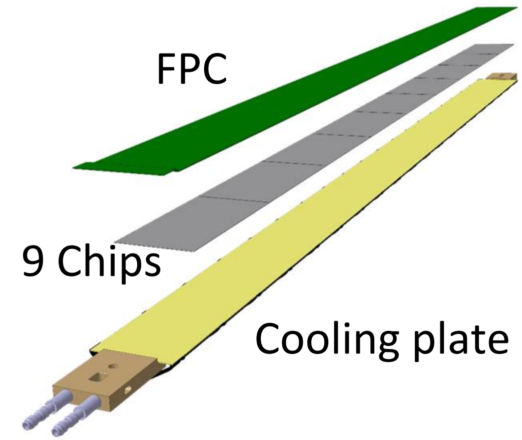


Monolithic-Active-Pixel-Sensors (MAPS)

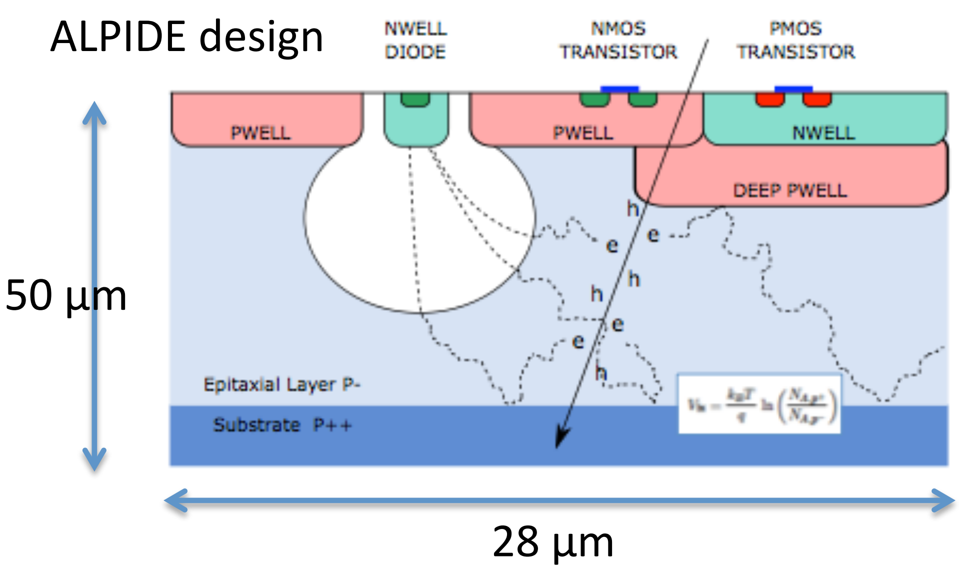
The next Generation State of the Art Pixel Tracker

- Advantages of ALICE MAPS/ALPIDE:
  - Very fine pitch (28x28 µm)
  - High efficiency (>99%) and low noise ($<10^{-6}$)
  - Time resolution, as high as ~5 µs
  - Ultra-thin/low mass, 50µm (~0.3% X_0)
  - On-pixel digitization, low power dissipation

An ideal detector for QGP physics!



A 9-chip MAPS stave, 1.5 x 27cm^2



Tower Jazz 0.18 µm CMOS

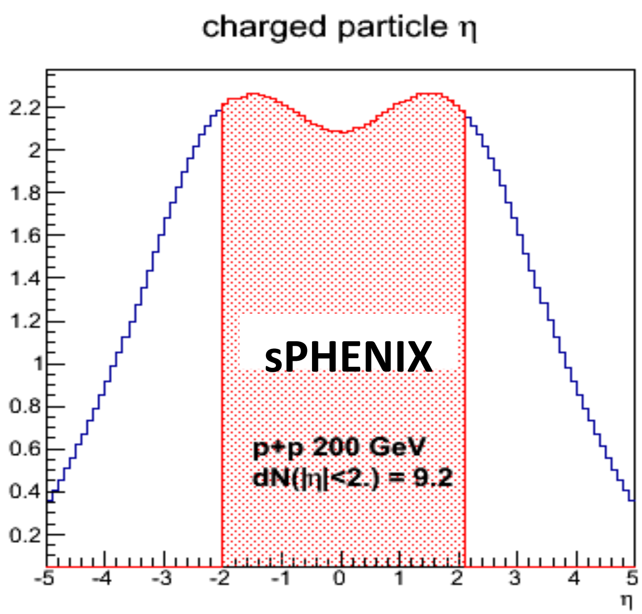
- feature size 180 nm
- metal layers 6
- gate oxide 3nm

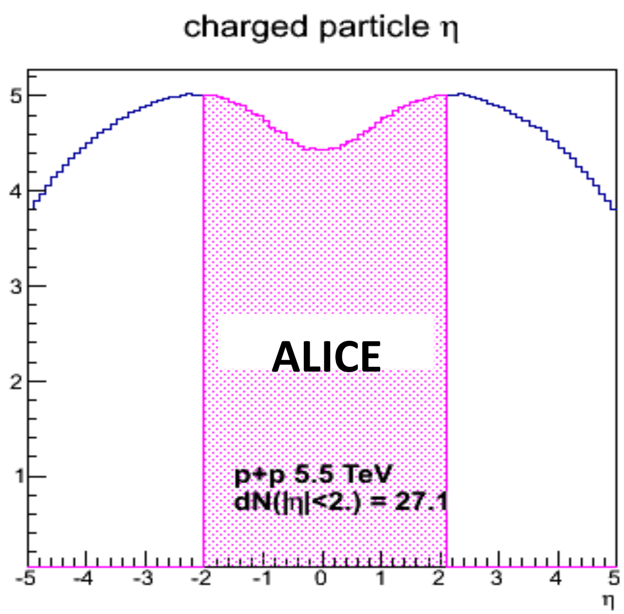
substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

sPHENIX MVTX vs ALICE ITS/IB

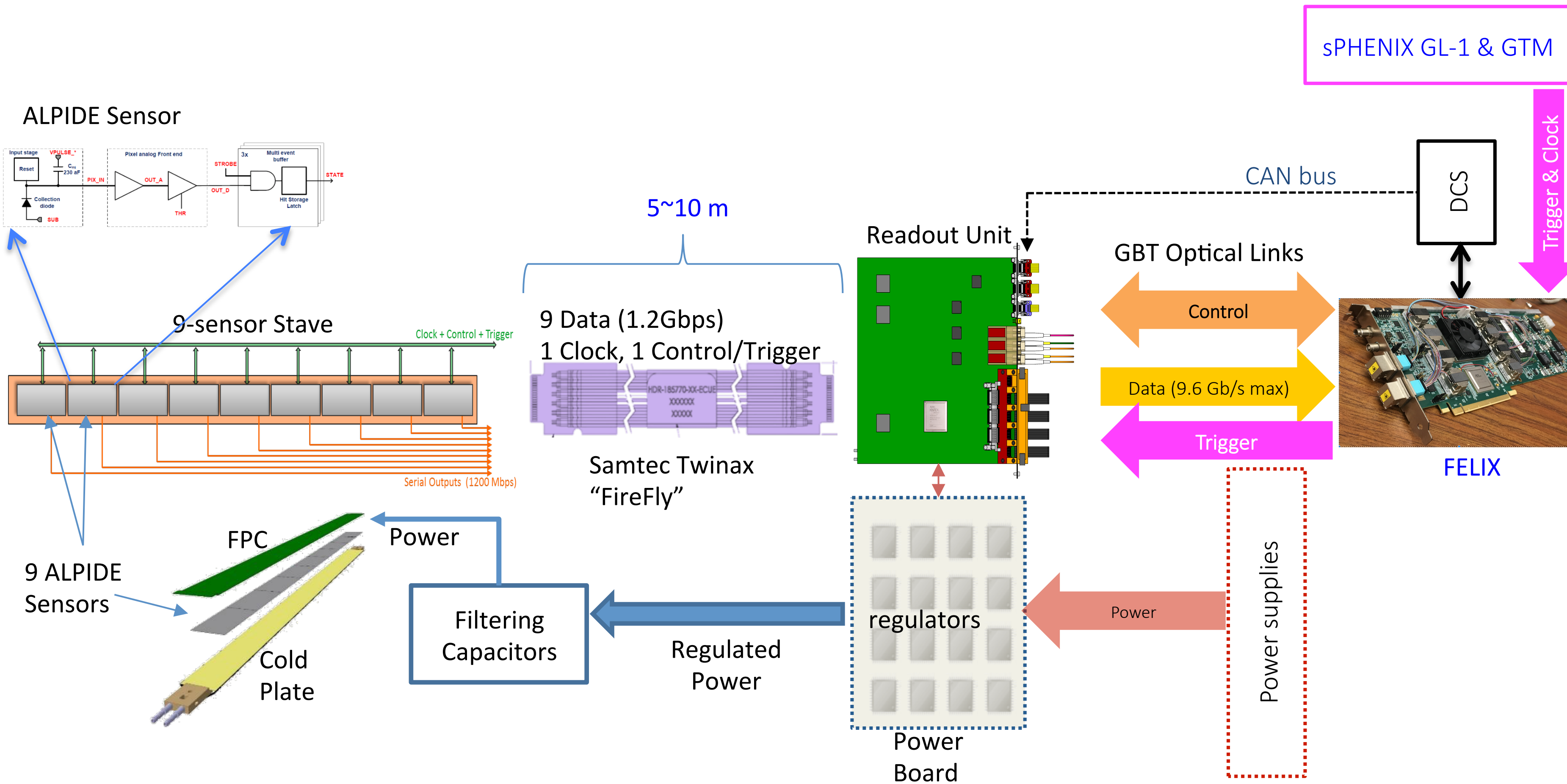
	ALICE (Run3)	sPHENIX (Max Collis.)
Pb+Pb / Au+Au	100 kHz (50kHz)	200 kHz
p+p	400 kHz (200kHz)	13 MHz
Trigger/Readout	>50 kHz	15 kHz

Event track multiplicity dN/dη: sPHENIX = 1/3 ALICE (pp), 1/5 ALICE(AA)





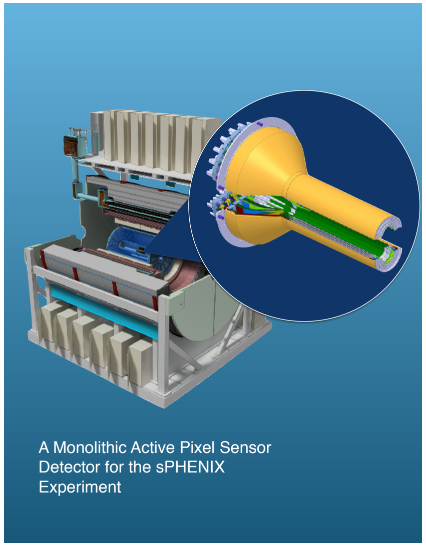
MVTX Readout and Control System



LANL, UT-Austin, LBNL, BNL, ALICE/ITS …

MVTX Pre-proposal Submitted!

- Pre-proposal submitted to DOE, 2/2017
  - Follow-up discussions with DOE and BNL managers
  - Weekly proj. leaders' meeting, BNL/LANL/LBNL/MIT
- Plan to update proposal to DOE, late 2017
  - Expanded science + Cost & Schedule
  - Assumed funding starts in FY18
  - BNL Director's Review, 7/10-11, 2017
- A growing collaboration
  - 15+ institutions from US and abroad



- Adapt ALICE ITS Upgrade Inner Barrel 3-layer MAPS detector
  - Mini. risk, Max. Physics

- Precision vertexing for b-jet/B-hadron tagging in HI with high efficiency and high purity
- B-jet modification in QGP at low-medium pT to determine QGP properties, study mass-dependence on collisional vs radiative energy loss, flow etc.

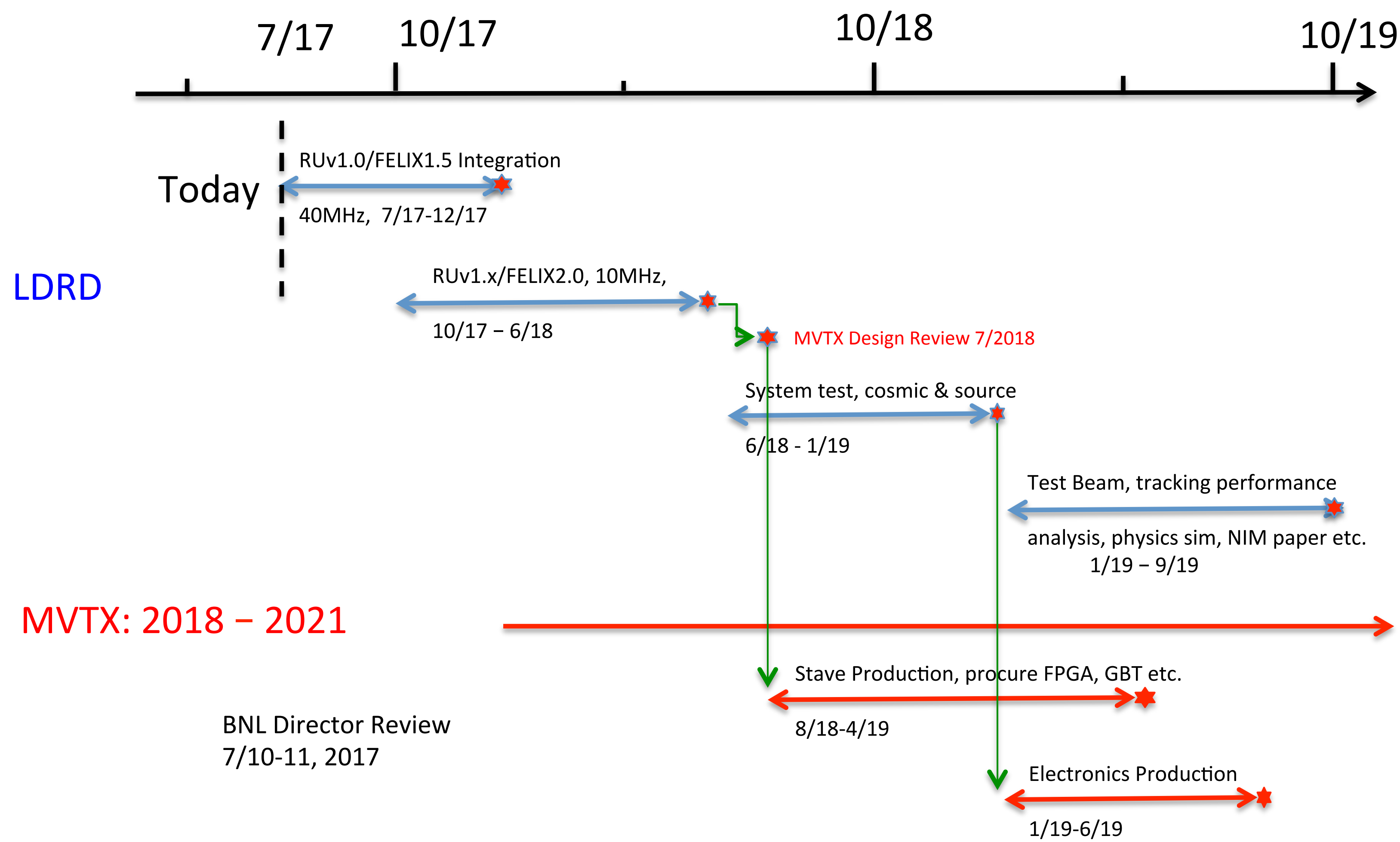
- Early R&D by LANL LDRD, $5M, FY17-19, readout, mechanical design and physics; established LANL-ALICE MoU for joint R&D and training

Scope of the MVTX Project

- MAPS Staves & Electronics
  - Produce 68 ITS inner Barrel Staves
    - No modification
  - Readout Electronics R&D (LANL LDRD)
    - Frontend: ALICE/ITS, RU
    - Backend: ATLAS FELIX
    - Modify/reprogram RU & FELIX for sPHENIX
  - Production:
    - Extend ALICE/ITS MAPS stave production
      - WBS 1.5.3.1, LANL
      - sPHENIX personnel help at CERN
    - Reproduce additional ALICE/RU & ATLAS/ FELIX
      - WBS 1.5.2.1, UT-Austin
      - WBS 1.5.2.2 , LANL
    - Final assembly and test in US
      - WBS 1.5.3, LBNL
  - Ancillary systems, “adopt” ALICE system
    - Power distribution, cables, crates, racks etc.,
      - WBS 1.5.2.3, LBNL
    - Slow control, safety and monitoring

- Mechanics & Cooling
  - Some changes to ALICE/ITS inner tracker mechanical structures, WBS 1.5.3
    - End Wheels
    - Cylindrical structure shells
    - Detector half barrels
    - Detector and Service half barrels
  - Mechanical Integration, WBS 1.5.4
    - **Conceptual design by LANL LDRD**
    - Prototype by sPHENIX R&D, MIT/LANL
    - Design integration frames
    - Carbon frames etc., LBNL
    - Installation tooling etc.
  - Adopt ALICE cooling plant design
    - Minor modification to fit sPHENIX
    - Smaller heat load than ALICE ITS
  - Metrology and Survey

LDRD – MVTX Key Tasks/Milestones



LANL LDRD Progress Highlights

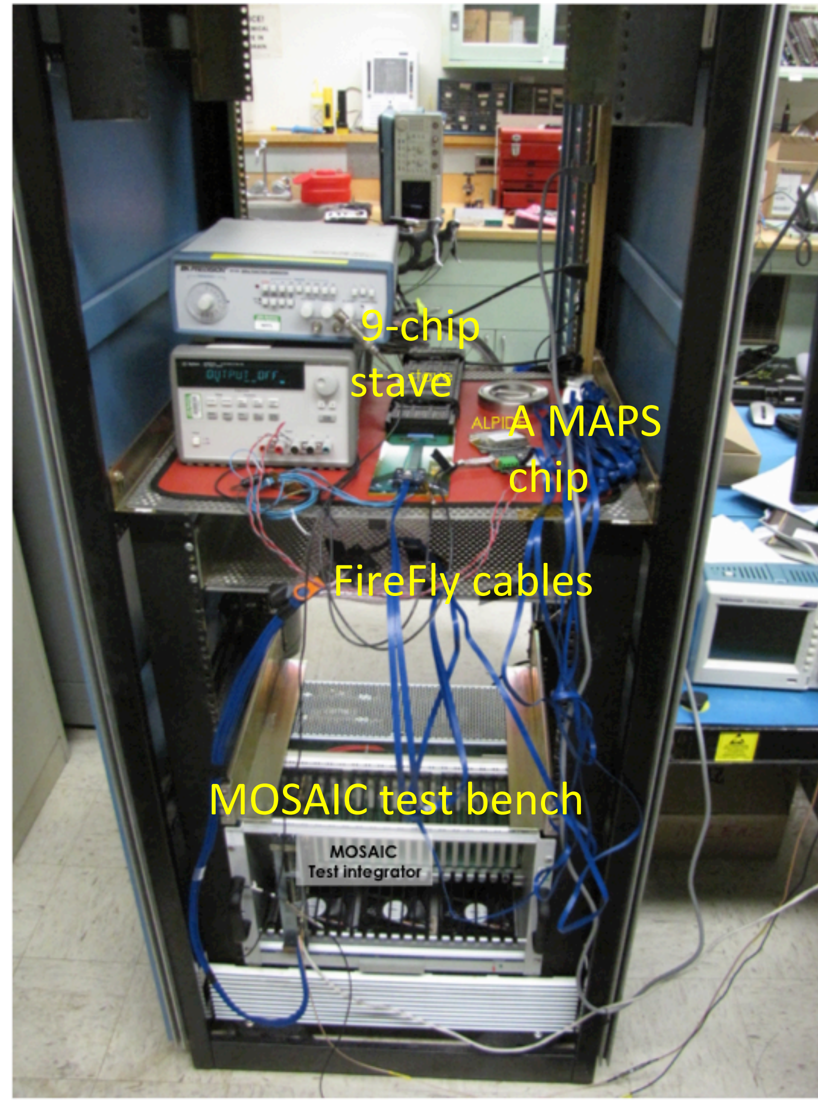
LDRD Goals:

- Complete MVTX readout design and development
- Preliminary conceptual design of mechanical system integration

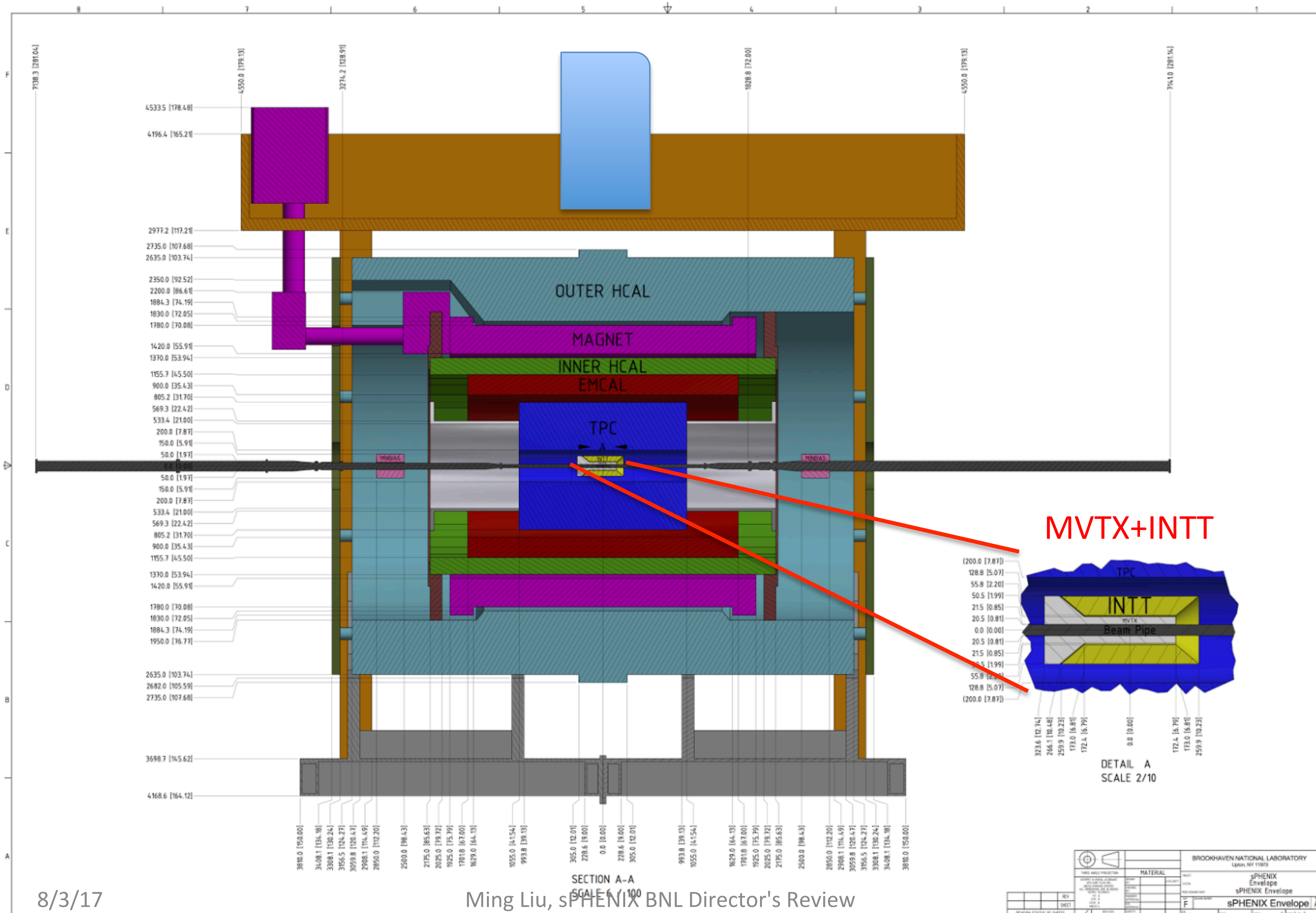
R&D status:

- MOSAIC test bench in operation
  - Single MAPS chip high-speed readout
  - 9-chip HIC/"stave" readout
  - External trigger, cosmic and source
  - Test data readout performance
    - 0.4, 0.6, 1.2Gb/sec
- Firefly cable performance test
  - 5m (ALICE default)
  - 7m, 10m (favored for sPHENIX)
  - Short extension cables, 20~30cm (share space with INTT), for mechanical system integration

- Back end FELIX board installed & being tested
- Front end Readout Unit boards available soon

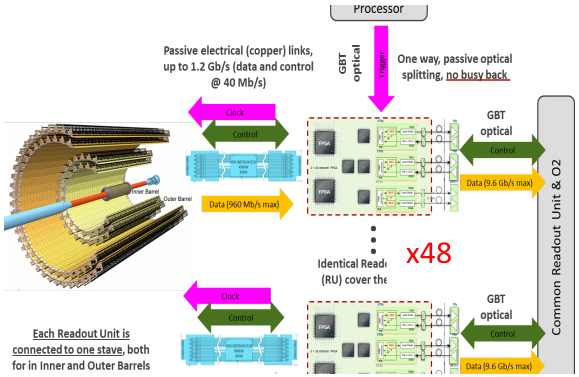


System Integration

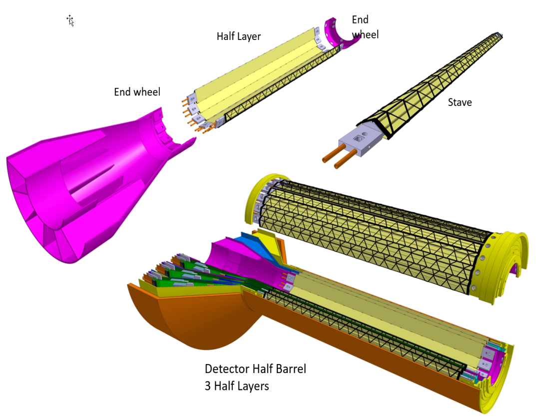


Cost Basis – Major Items

- Electronics (WBS 1.5.2): $1,285K
  - ALICE ITS RU & PS
  - ATLAS FELIX
  - Power system and controls
  - PHENIX/STAR/ALICE experience



- MAPS and Detector (WBS 1.5.3): $2,900K
  - ALICE ITS/IB production
  - PHENIX/ALICE/STAR experience



- Mechanical integration (WBS 1.5.4): $910K
  - ALICE ITS inner tracker design modification
  - FVTX/PHENIX, HFT/STAR experience

Total project cost: $5.7M, w/ 35% Cont.

Updated material and labor cost and contingency from pre-proposal

- latest quotes on electronics and other R&D items

MVTX

Principal Investigator: M. Liu (LANL)
Lead Coordinator: M. Chamizo-Llatas (BNL)
Co-investigators: G. Odyniec (LBNL),R. Redwine(MIT)
ES&H Liason: W. Sondheim (LANL)

- sPHENIX DAQ
  - Electronics LANL WBS - 1.5.2
    - Readout Units UT Austin WBS 1.5.2.1
    - Back-end LANL WBS 1.5.2.2
    - Power systems LBNL WBS 1.5.2.3
- Mechanics & Detector Assembly LBNL - WBS 1.5.3
  - Staves LANL WBS 1.5.3.1
  - Carbon Structures LBNL WBS 1.5.3.2
  - Barrel Assembly LBNL WBS 1.5.3.3
- sPHENIX integration
  - Integration & Infrastructures MIT - WBS 1.5.4
    - Cooling MIT WBS 1.5.4.2
    - Safety System MIT WBS 1.5.4.3
    - Global Support MIT WBS 1.5.4.4
    - Installation & Commissioning LBNL/BNL WBS 1.5.4.6

Major institutions lead key tasks

A growing collaboration!

From MVTX pre-proposal

new sPHENIX/MVTX members:

- Czech groups: Charles Univ. and Inst. of Phys. of the Czech Academy of Sciences
  - Stave production at CERN
- CCNU – MAPS lab
  - HICs assembly and test
  - Mechanic integration

Potential collaborators:

- USTC
  - Physics simulations w/ LBNL
- Peking Univ.
  - Physics and detector simulations w/LANL
- NCU, Taiwan

7 Organization and Collaboration

Here we discuss the current collaborating institutions and their focus areas. Based on their technical expertise and available resources, LANL, LBNL and MIT/Bates groups are leading the three major technical tasks of the project: 1) readout electronics integration; 2)carbon mechanical support frames production and 3) cooling and mechanical system integration, respectively.

Los Alamos National Lab (LANL) : Readout electronics and mechanics integration.

Lawrence Berkeley National Lab (LBNL) : Carbon structure, production, LV and HV power system, full detector assembly and test.

Brookhaven National Lab (BNL) : System integration and services, safety and monitoring.

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

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

University of Texas at Austin (UT Austin) : MVTX readout electronics integration and testing.

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

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

Florida State University (FSU) : Offline and simulations.

University of New Mexico (UNM) : LV cabling & connectors.

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

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

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

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

Yonsei University (Korea) : MAPS chips QA and readout, simulations

RIKEN/RBRC (Japan) : Mechanical integration, cooling, cabling, simulation, patter recognition.

Purdue: Detector assembly and testing, analysis. Silicon lab available.

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

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

Status, Plans and Issues

- LANL- ALICE MoU
  - Associate member of ALICE ITS Upgrade project
  - Obtained ALICE readout test stand, MAPS sensors, staves and electronics for early R&D
  - Obtained design files, electronics and mechanics
  - Training sPHENIX personnel
- High Level Agreement with ALICE – on going discussions
  - Produce 68 staves for sPHENIX using ALICE/CERN facilities
- Potential schedule/funding gap of stave production
  - ITS/IB production: 7/2017 - 6/2018
  - If funding significantly delayed, concerns over the availability of CERN facilities
  - Risk Mitigation:
    1. Early training through LDRD effort, maintain activity at low level
    2. External foreign funding, CCNU Pixel Lab etc.
    3. Possible "mortgage" for sPHENIX production from ALICE/CERN with "Agreement"
- sPHENIX readout and mechanical integration R&D
  - Schedule risks due to unavailability of key R&D elements like staves and readout electronics
  - MVTX/INTT integration
  - Risk mitigation:
    - Early joint R&D with ALICE as associate members
    - Early R&D with prototype staves, RU and FELIX
    - Early mechanical system integration R&D

Project Tasks and Timeline

FY2016 FY2017 FY2018 FY2019 FY2020 FY2021

sPHENIX baseline

CD-0
9/2016

CD-1?

Ready for
Beam, 2022?

ALICE ITS/IB
prod. ends

Readout R&D
Mech. design
@LANL/ALICE/UT-A

Key R&D
LDRD@LANL

Mech. Integr.
& Prototype
@LANL/MIT/LBNL

A schedule driven project!

Production

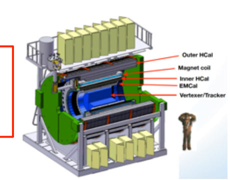
MAPS Prod. & QA
@ALICE

Stave prod.&test @CERN;
C-Stru. Prod. @LBNL

"RU" & "FELIX"
Prod. @US

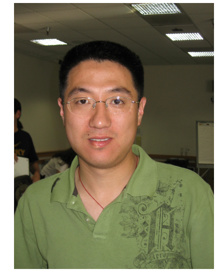
Detector Assembly
& Test @LBNL

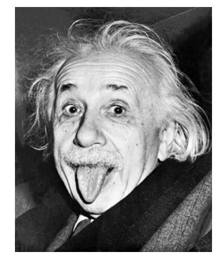
Det. Install.
@BNL



Summary from July 2017 MVTX BNL Directors Review

- Exciting science - Xin
  - New B-physics program @RHIC
- Early ALICE & ATLAS R&D investment
  - Reduce technical risk and R&D cost
- LANL LDRD critical - Cesar
  - mitigate risks and minimize contingency
- No high risk R&D – Mark, Giacomo, Walt
  - Readout
  - Mechanics
  - MVTX integration
- Ready for sPHENIX Day-1 – Ed, Dave
  - sPHENIX integration
  - Cost & Schedule







Backup

A Multi-Year Plan: sPHENIX 2022-2026

http://www.rhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf

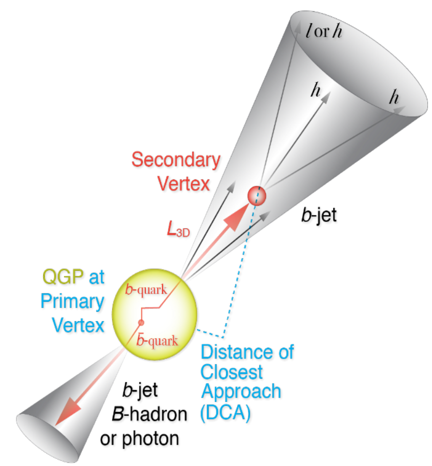
Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
2022	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
2023	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
2023	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
2024	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
2025	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
2026	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

- Projected maximum collision rates:
  - Au+Au: 200 kHz (~50 kHz, |Z|<10cm)
  - p+p: 13 MHz (~3 MHz, |Z|<10cm)
  - p+A: 2.8 MHz (~0.7 MHz, |Z|<10cm)

  sPHENIX DAQ: 15kHz

- Precision vertexing for B-tagging w/ MVTX:
  - Tracking resolution better than 60um @pT=1GeV
  - High multiplicity HI collisions
  - Low multiplicity but high rate p+p collisions
  - Tag B w/ high efficiency and high purity

B hadrons/pT<15GeV: *O(1M)*
b-jets/pT>15GeV: *O(100K)*



Assumptions about Funding & Schedule

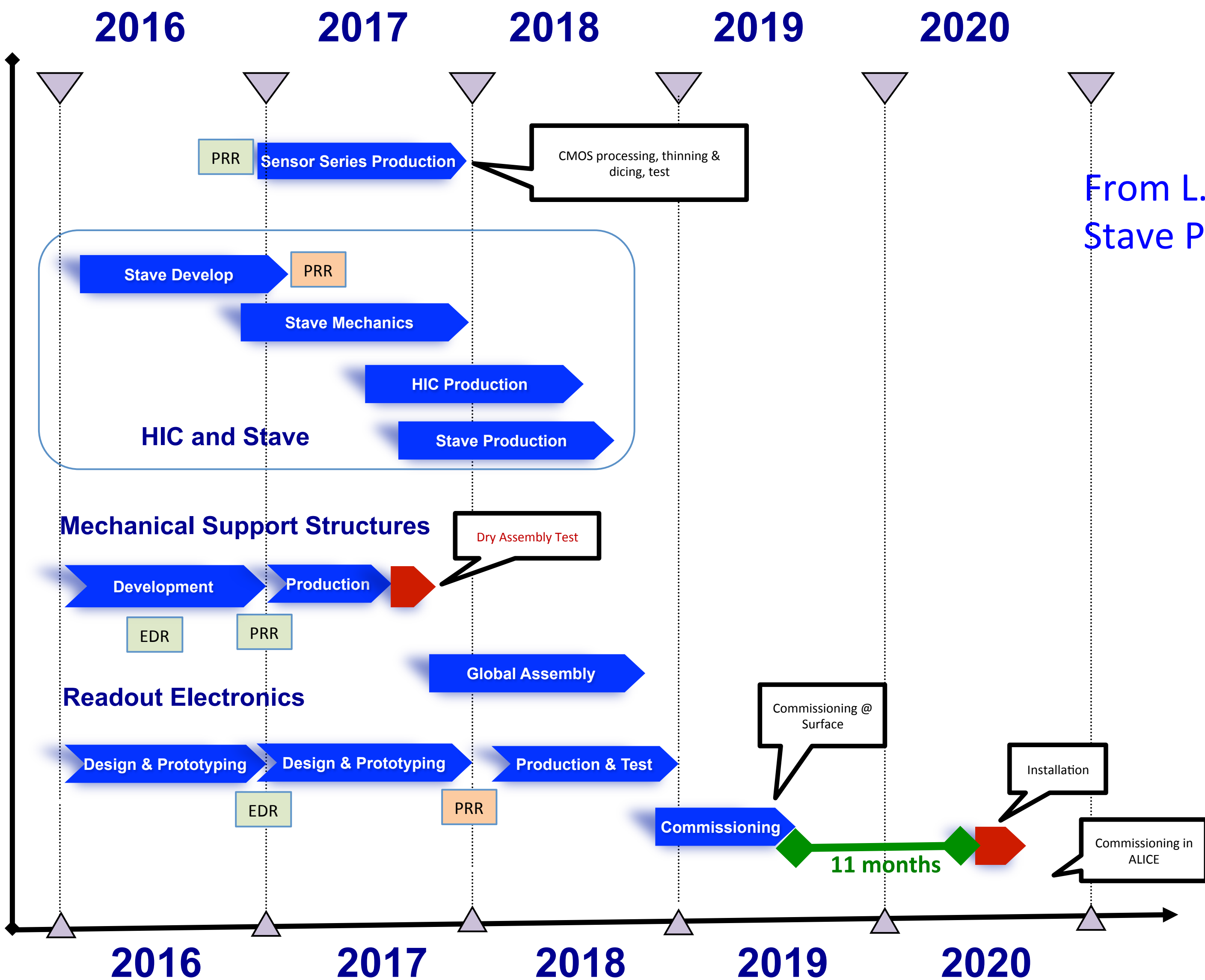
- Tied to sPHENIX and ALICE schedule
  - Stave production
  - Readout electronics

  To minimize technical risk and cost

- Funding available when needed, no manpower smoothing

- Cost based on ALICE/ITS and recent STAR & PHENIX upgrade projects at RHIC
  - STAR HFT
  - PHENIX FVTX

Overall ITS Planning (Simplified Global View)



From L. Musa, 4/27/2017
Stave PRR Presentation

Project Review Milestones

ALICE

From L. Musa, 4/27/2017

① Pixel Sensor Chip - EDR (Oct' 15)

② Stave - EDR (May' 16)

③ Detector Barrel Mechanics - EDR (Jul '16)

④ Cooling – EDR (Jul '16)

⑤ Pixel Sensor Chip - PRR (Nov '16)

⑥ Detector Barrel Mechanics - PRR (Dec '16)

⑦ Service Barrel Mechanics - EDR (Dec '16): done

⑧ Cooling – PRR (Dec '16): done

⑨ Readout Electronics – EDR (Jan '17): done

⑩ Stave - PRR (Apr '17)

11 Service Barrel Mechanics – PRR (May '17)

12 Readout Electronics – PRR (Dec '17)

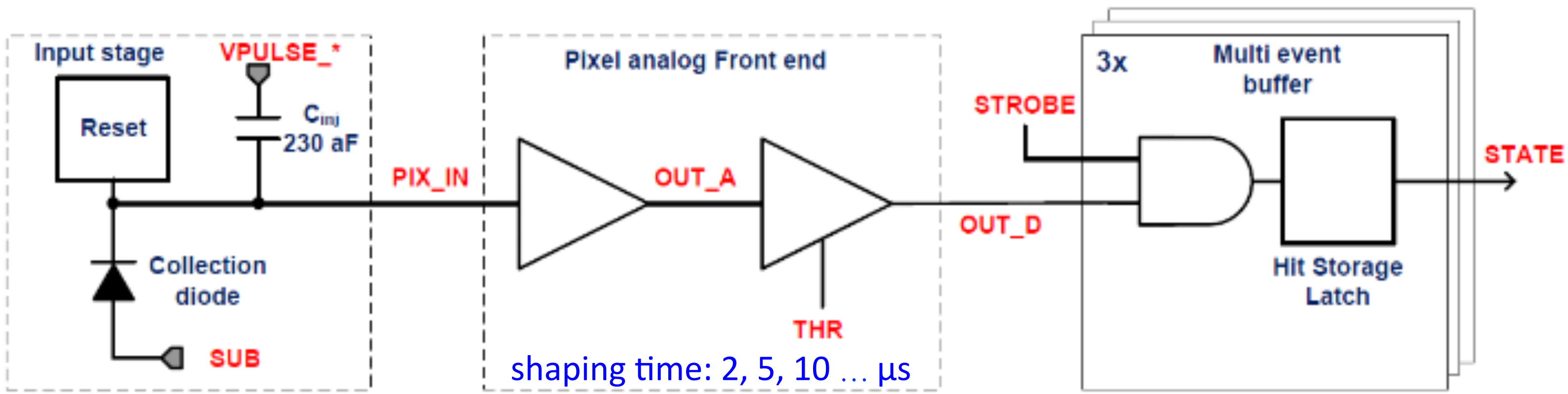
Stave Production Readiness Review: 4/27/2017

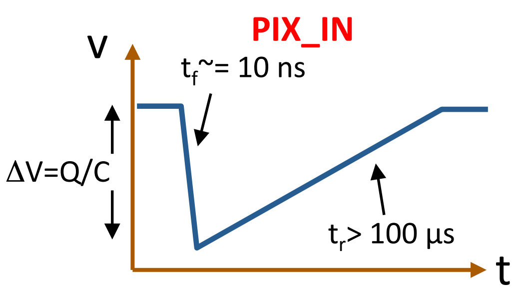
- Stave production starts ~May/June;
- 1st set of IB by Jan 2018;
- 2nd set of IB by July 2018
- LANL people + others/MVTX work on stave production from May 2017 at CERN, prototype available soon at LANL

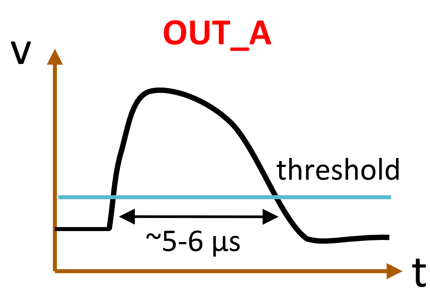
- Fully working staves for R&D available ~Jan 2018;
- Near final readout RU/CRU: ~12/2017

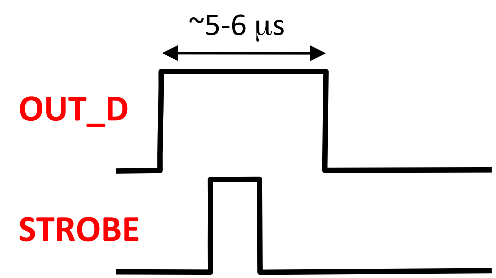
ALPIDE/MAPS Timing & Operation

Well fit sPHENIX/RHIC environment, 10MHz Clock (LHC 40MHz)



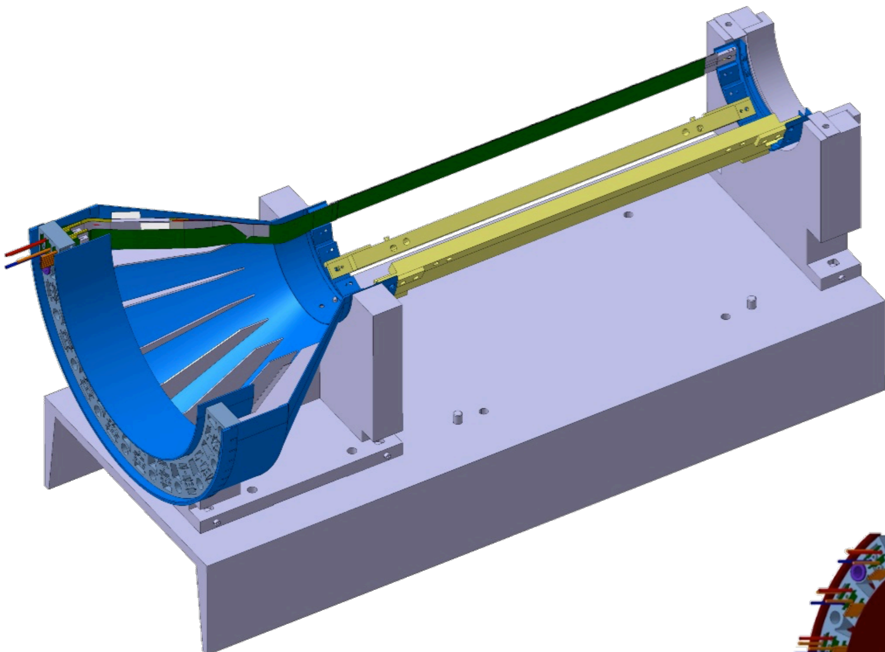




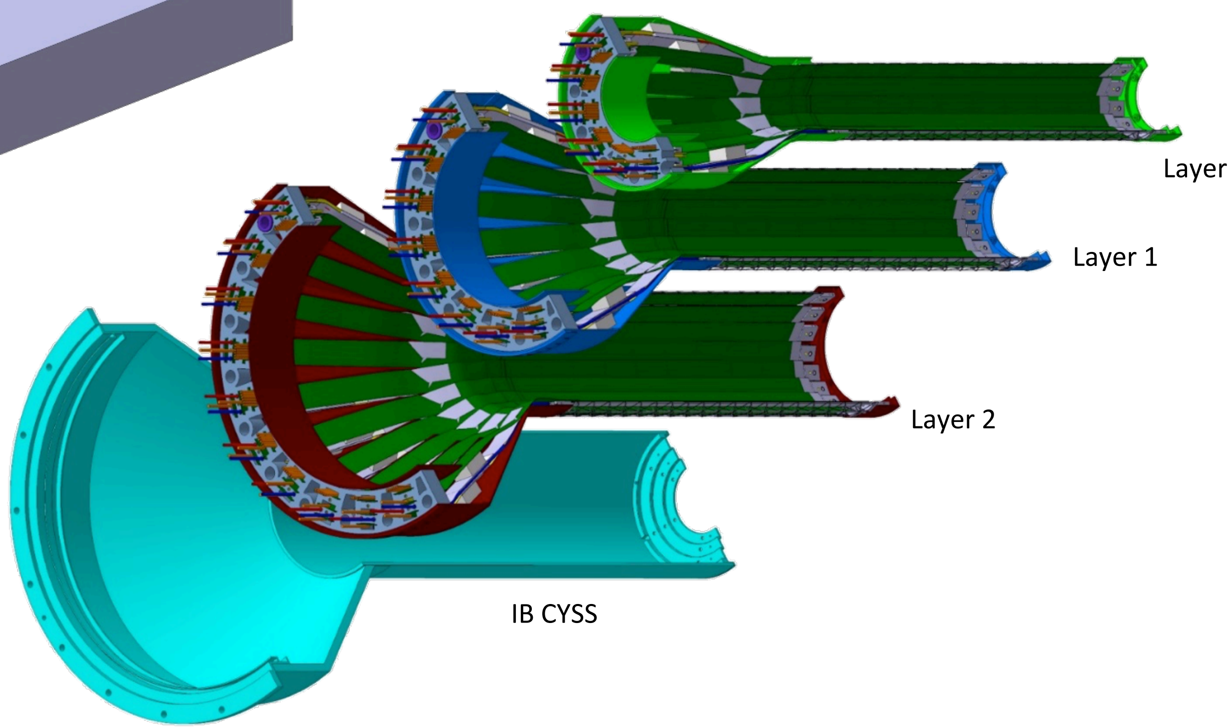


sPHENIX trigger latency: ~4 μs

Detector Assembly



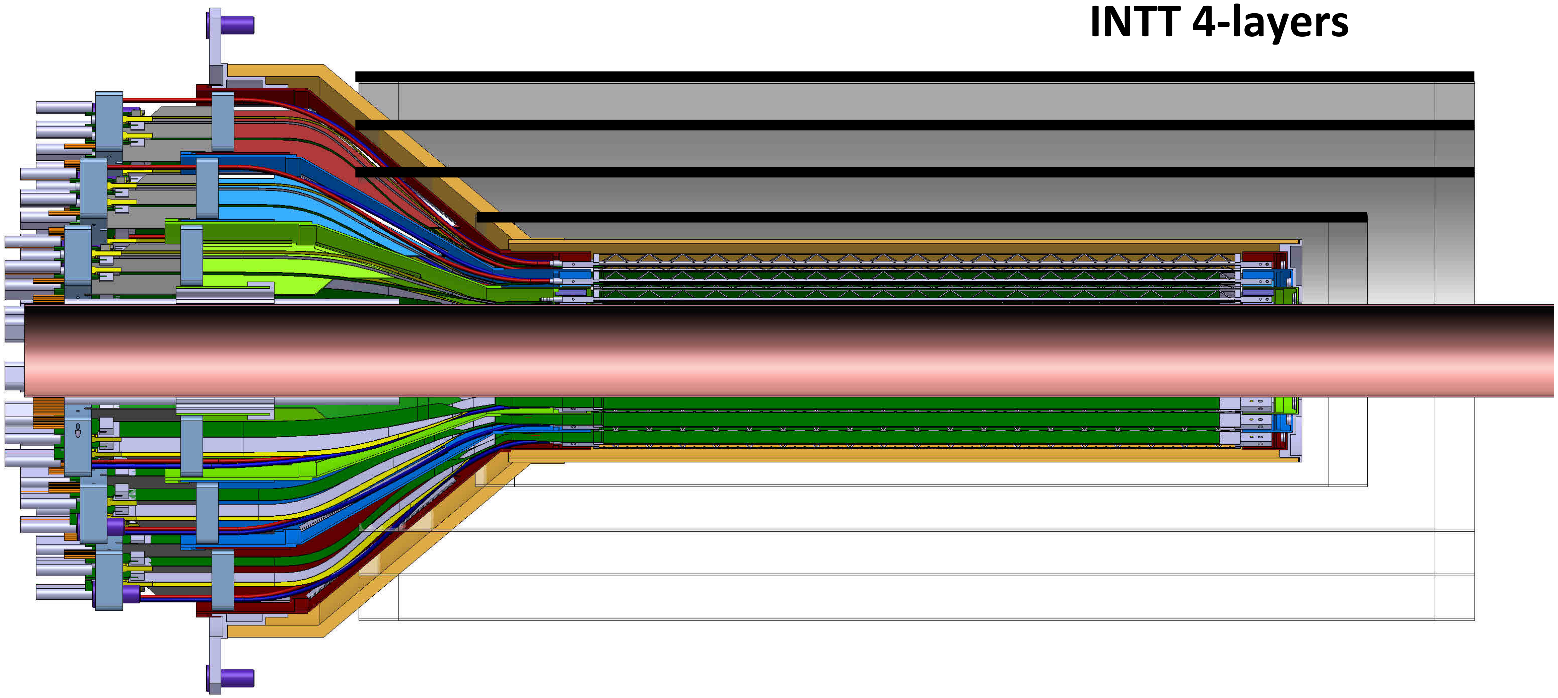
- Precision positioning and installation of staves on end-wheels



- Assembly of layers and carbon fiber structure into half-detector
- Stave testing at each step
- Metrology survey

INTT-MVTX Conflict

INTT Acceptance
@ |z|=10



|η|<0.95

|η|<1.09

|η|<1.28

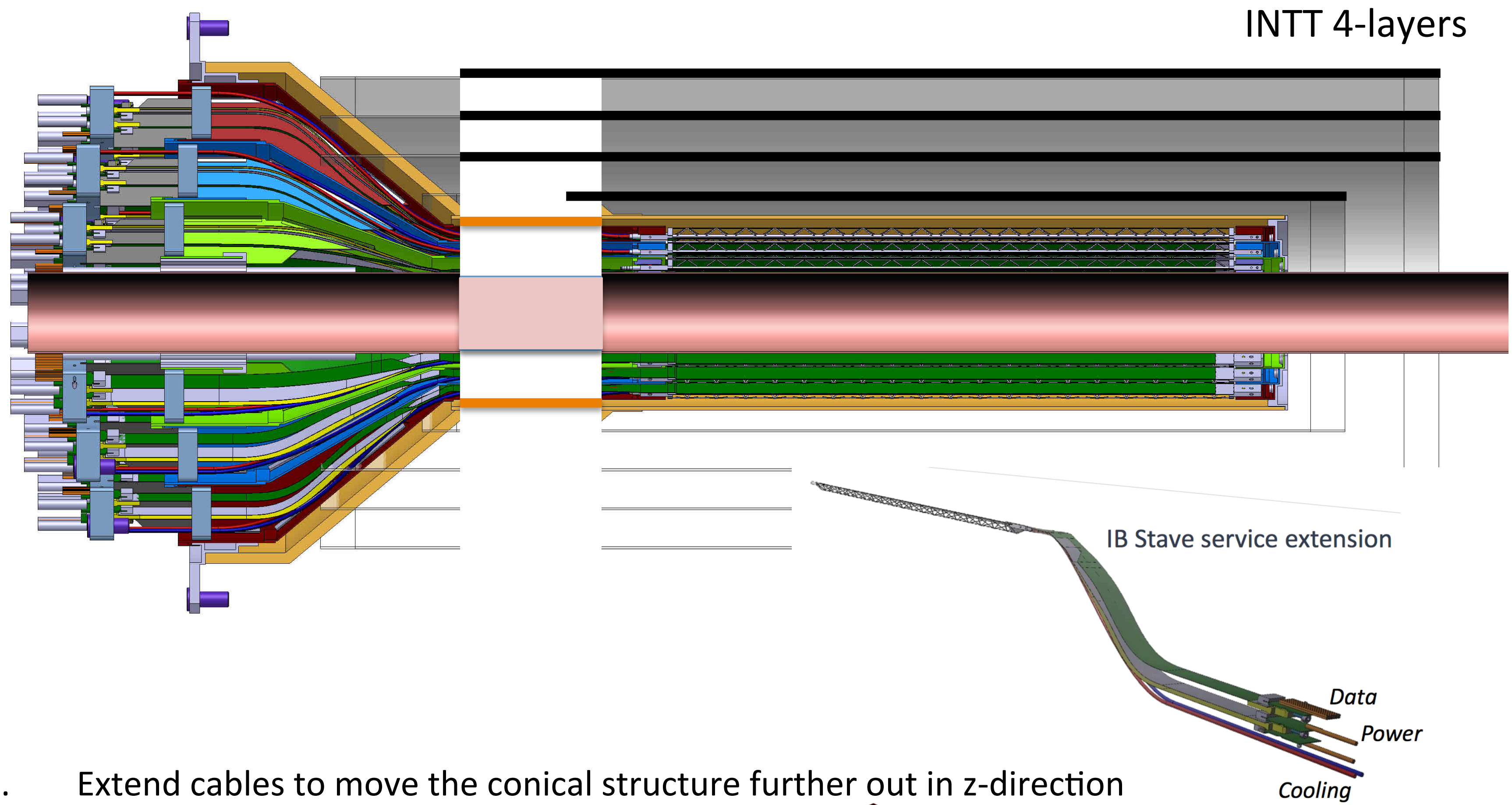
|η|<1.12

- Currently a clear conflict between the INTT and MVTX
  - INTT only includes ladder, no connectors, cooling barbs, etc

R&D items: 1) Extend cables to move the conical structure further out in z-direction; 2) Design/optimize INTT layers to fit current MVTX geometry;

- FPC data cable is the HDI and can't be easily extended, short "firefly" cables possible?
- Reduce angle of cone – redesign C-structures and connectors

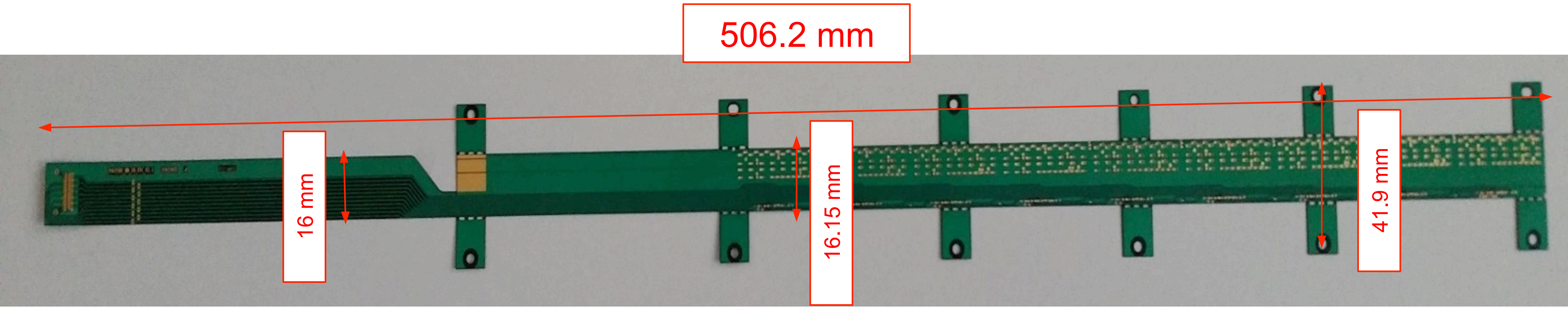
INTT-MVTX Conflict

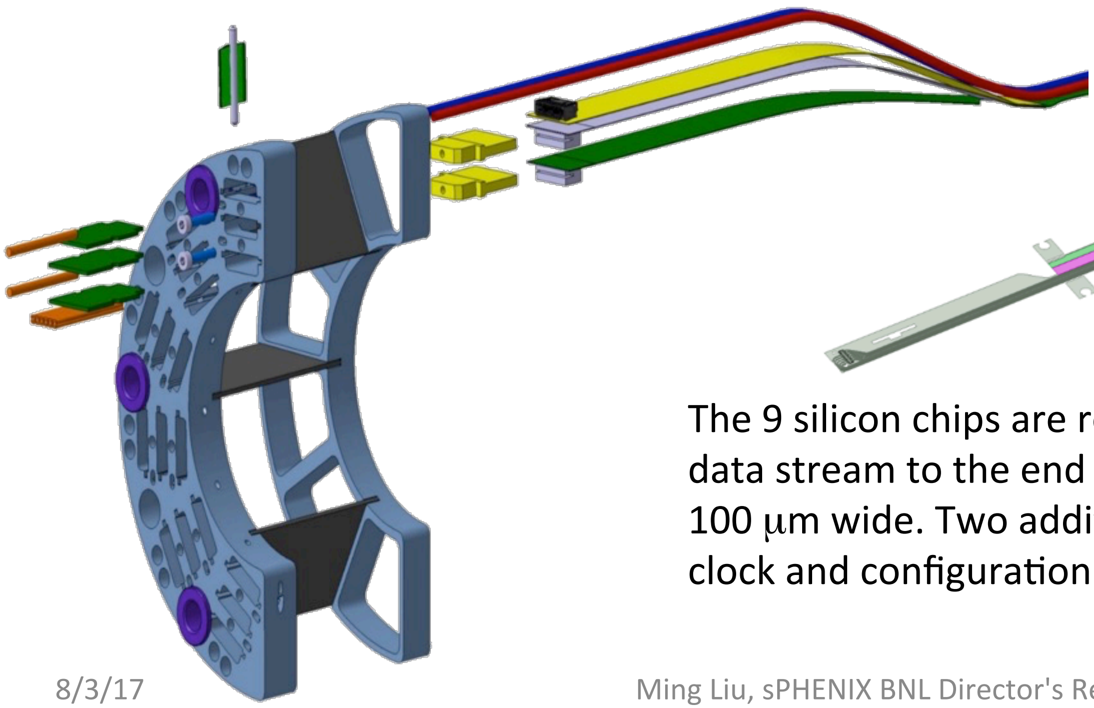


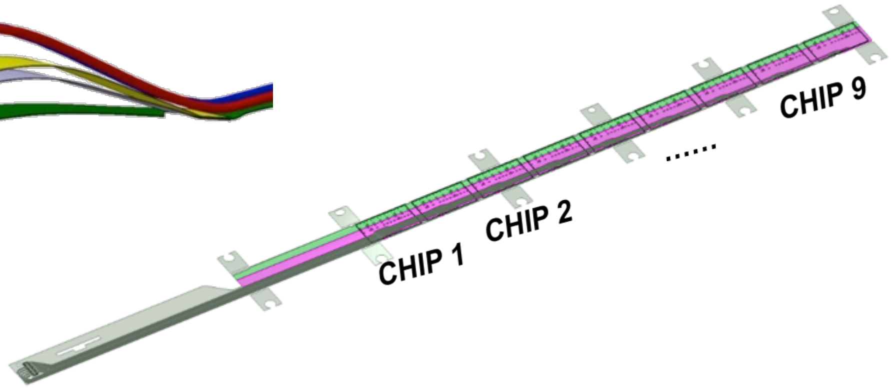
1. Extend cables to move the conical structure further out in z-direction
   - FPC data cable is the HDI and can't be easily extended
   - Possibly add short "firefly" cables to hook up to patch panel, R&D needed
2. Reduce angle of cone – redesign

MVTX/INTT Integration

Extend MVTX Service Cables?



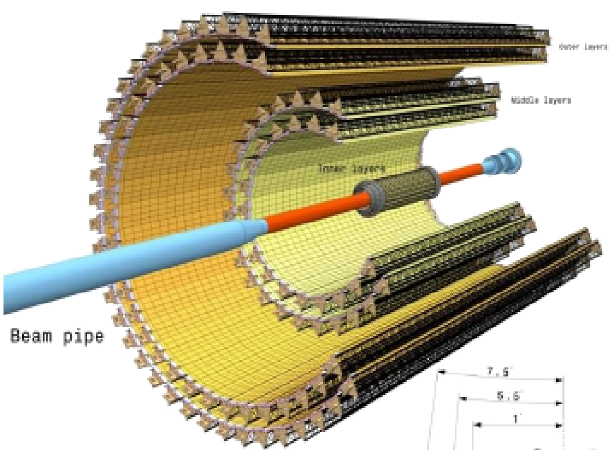


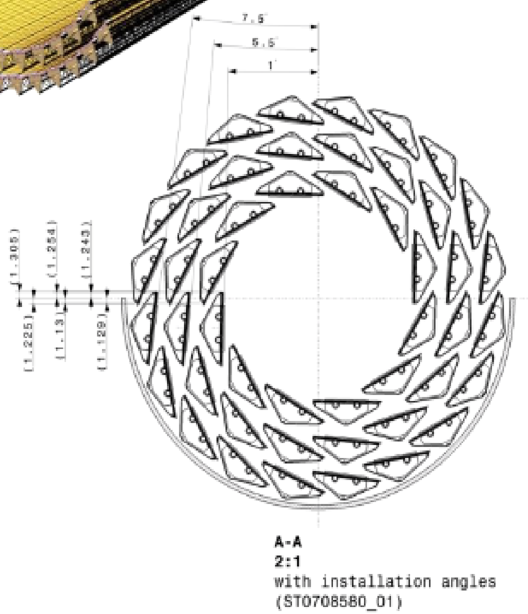


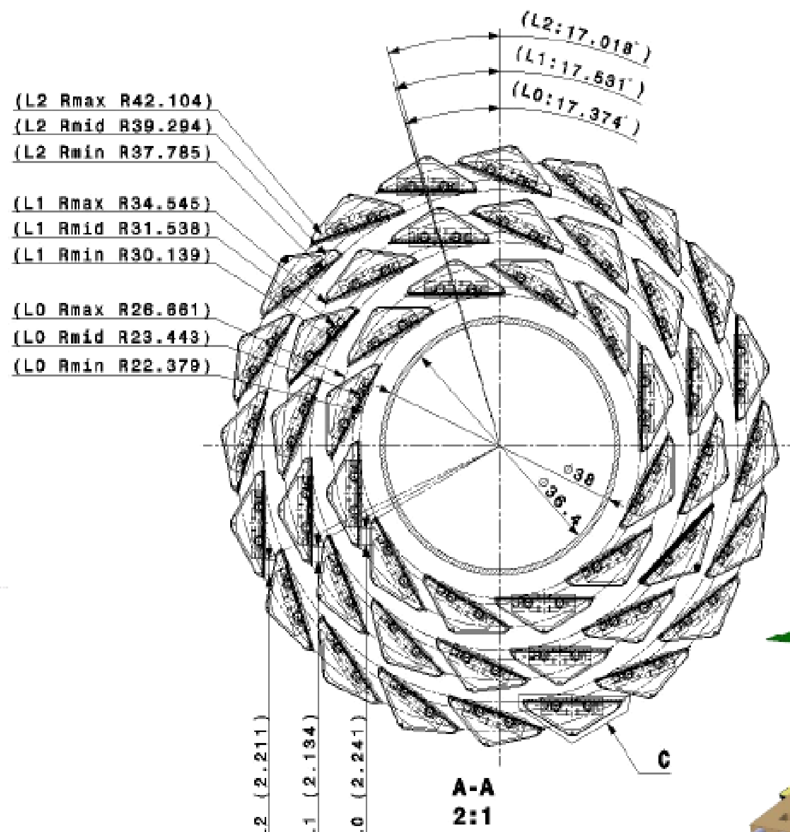
The 9 silicon chips are read out in parallel: each chip sends its data stream to the end of Stave by a dedicated differential pair, 100 μm wide. Two additional differential pairs distribute the clock and configuration signals.

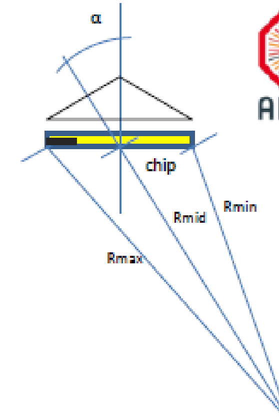
ITS layout: coverage, layers 0-1-2

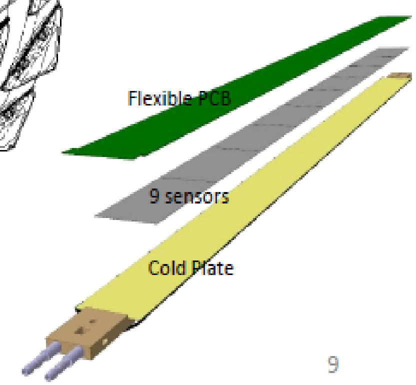
…from 22mm to 42mm radius











Expected Luminosities and Collision Rates

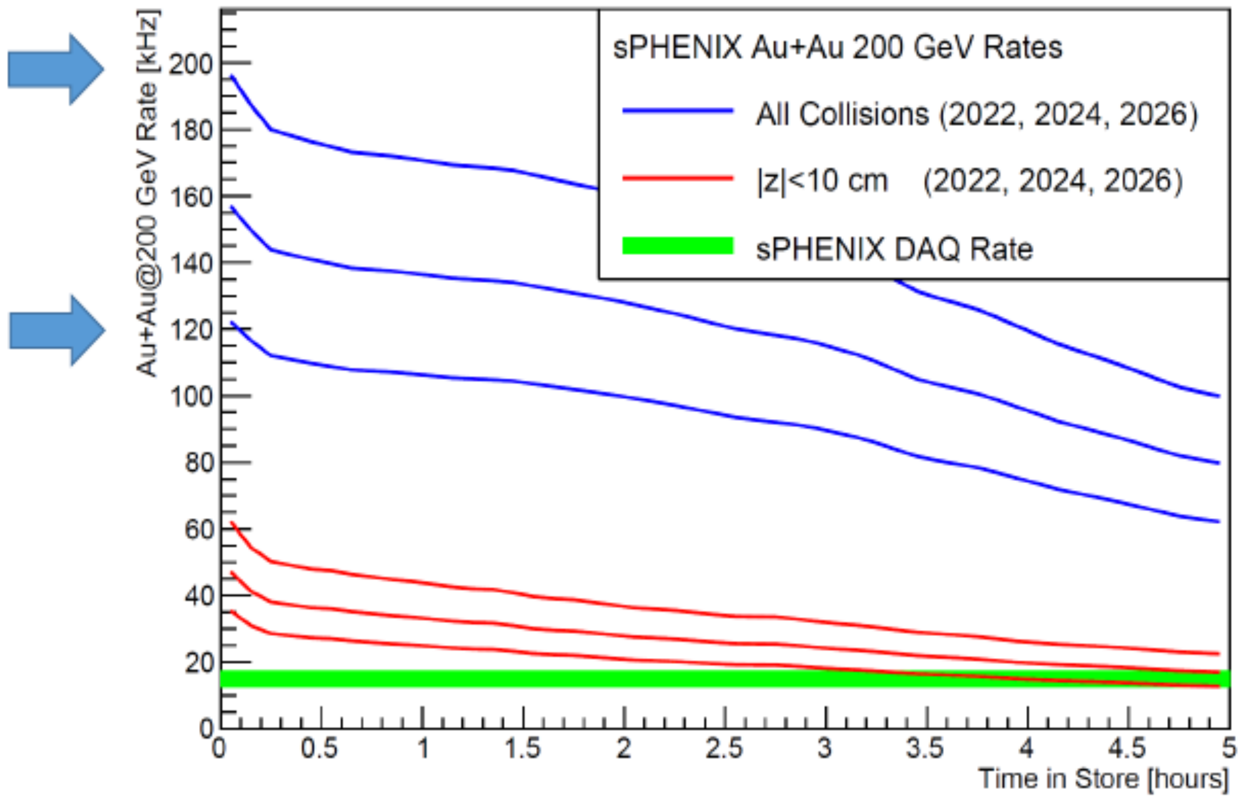


Figure 3: Estimated Au+Au at 200 GeV collision rate as a function of time in store for all collisions (blue) and collisions within ± 10 cm (red). The bottom to top set of curves in each color are for the mean luminosity and f_{z10} for the 2022, 2024, 2026 projected Au+Au at 200 GeV running periods. Also shown as a green band is the sPHENIX DAQ Rate of 15

Trigger Requirements…

In particular for p+p and p+Au, we need to sample the luminosity with selective Level-1 triggers.

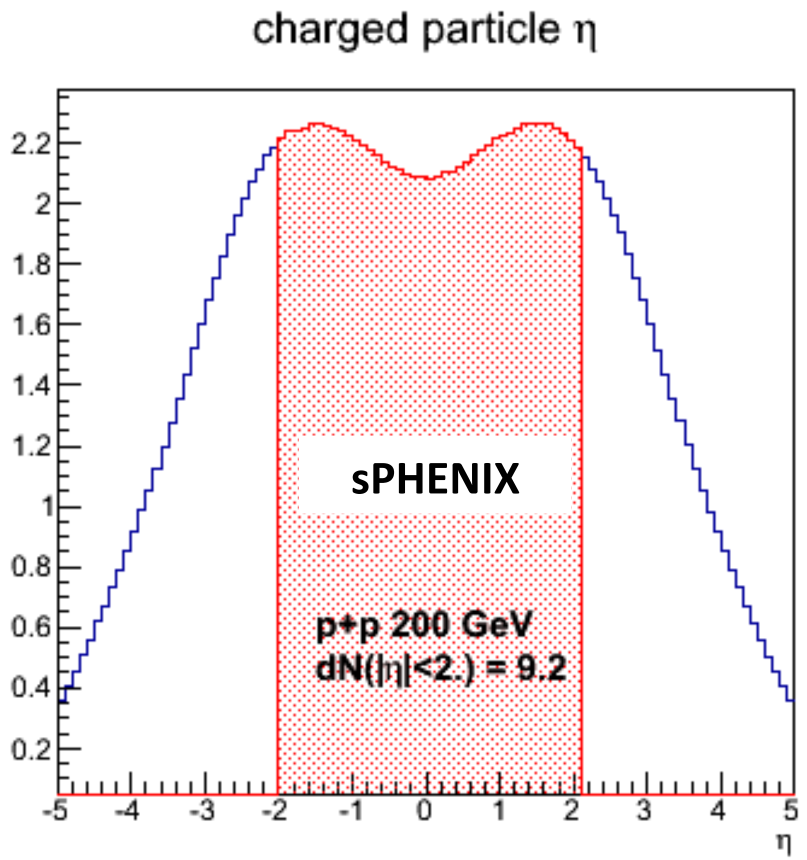
First pass update on Level-1 trigger simulations for single photons, jets, single hadrons, and Upsilons.

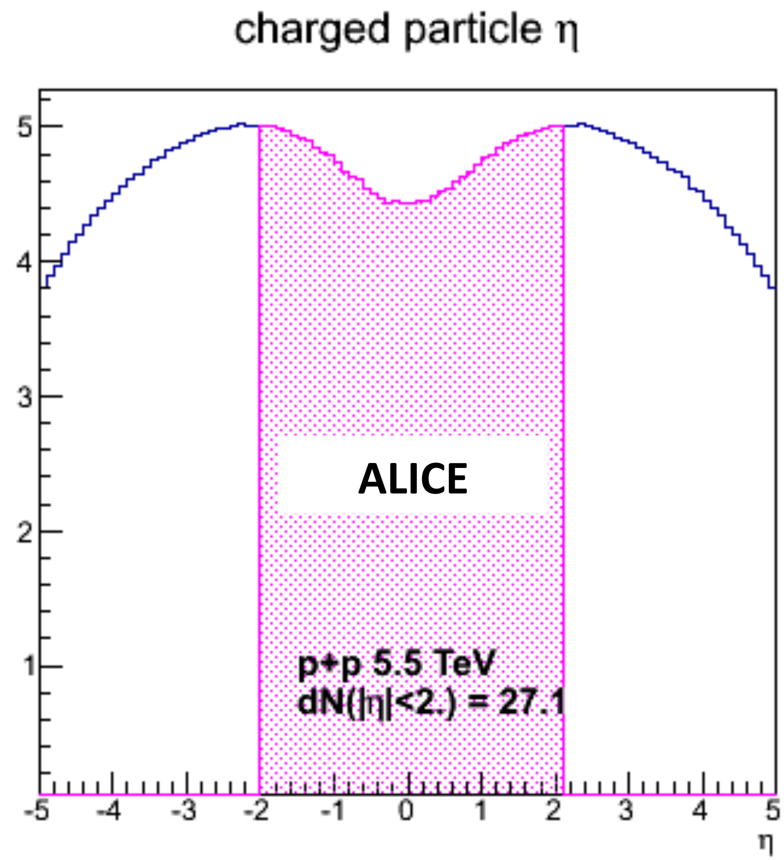
System	Energy	$dN_{ch}/d\eta$	Highest Rate
p+p	200 GeV	2.29	12.9 MHz
p+Au	200 GeV	9.16	2.8 MHz
Au+Au	200 GeV	190	219 kHz

Rejections of order 5,000 - 10,000 are needed to get down to 1-2 kHz of bandwidth allocation for different physics topics.

dN/dη in p+p collisions

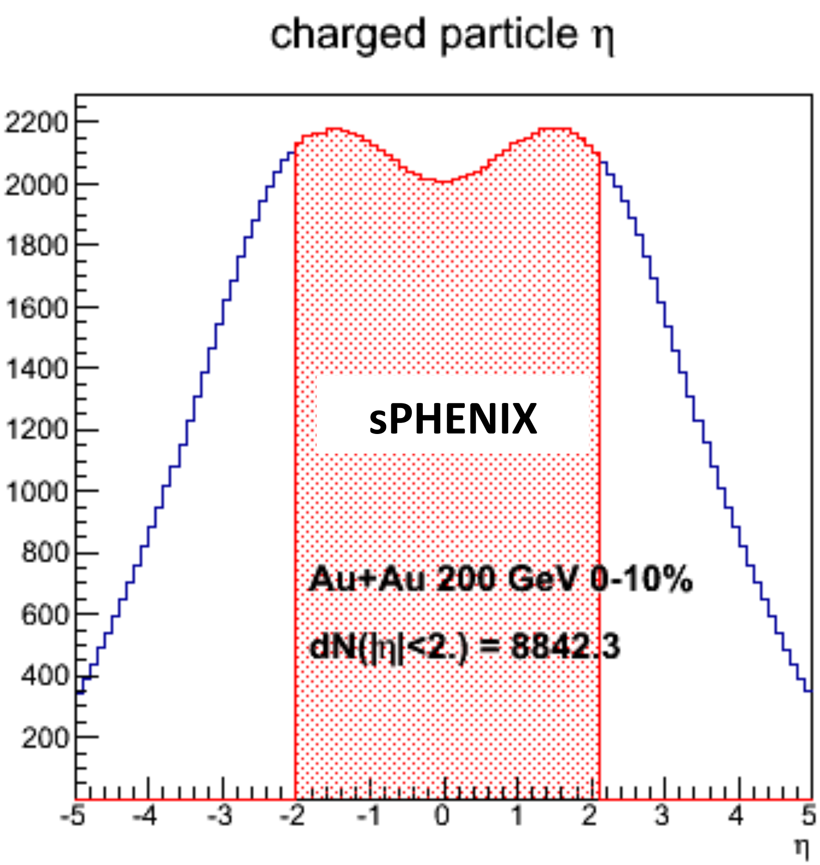
- With |η|<2.0 region, dN(ALICE) ~2.9*dN(sPHENIX).

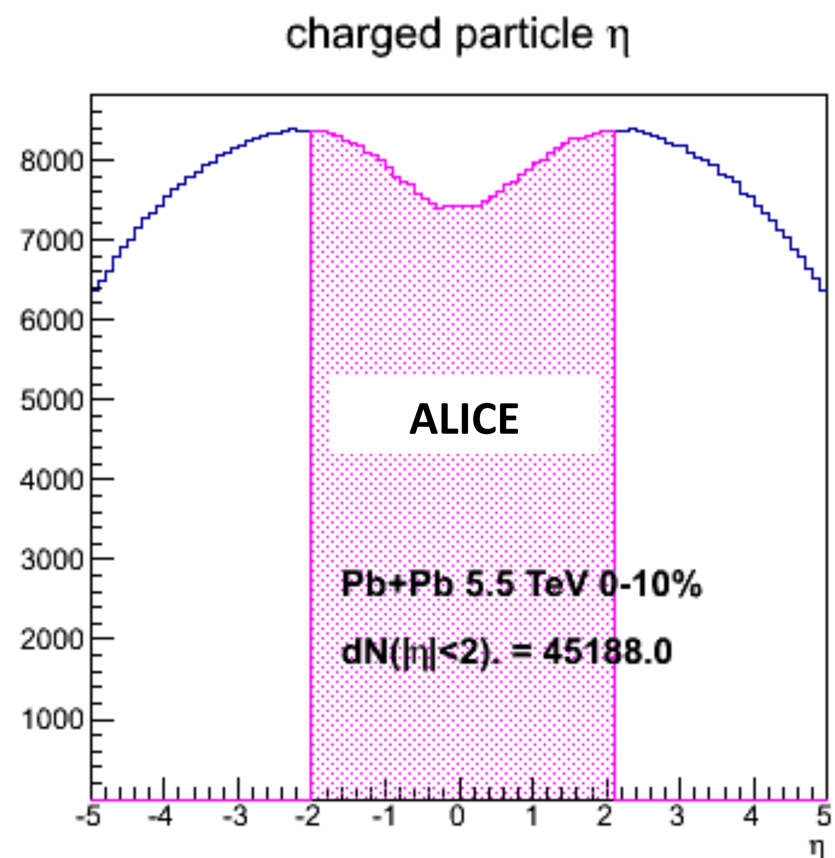




dN/dη in 0-10% Au+Au/Pb+Pb collisions

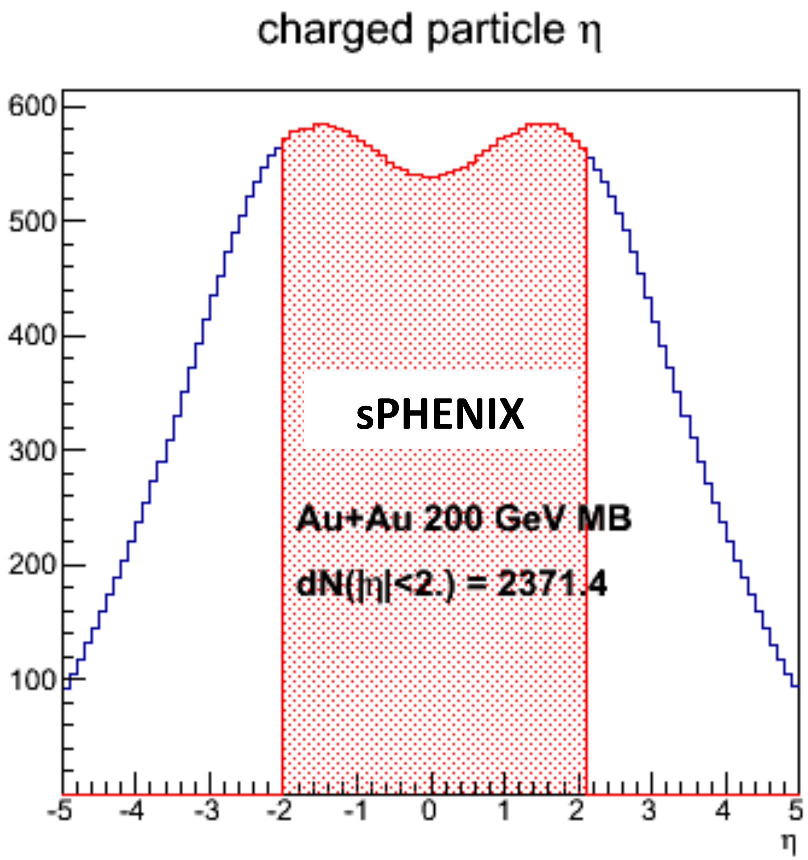
- With |η|<2.0 region, dN(ALICE) ~5.1*dN(sPHENIX).
- Ncoll(Au+Au)=962, Ncoll(Pb+Pb)=1670.

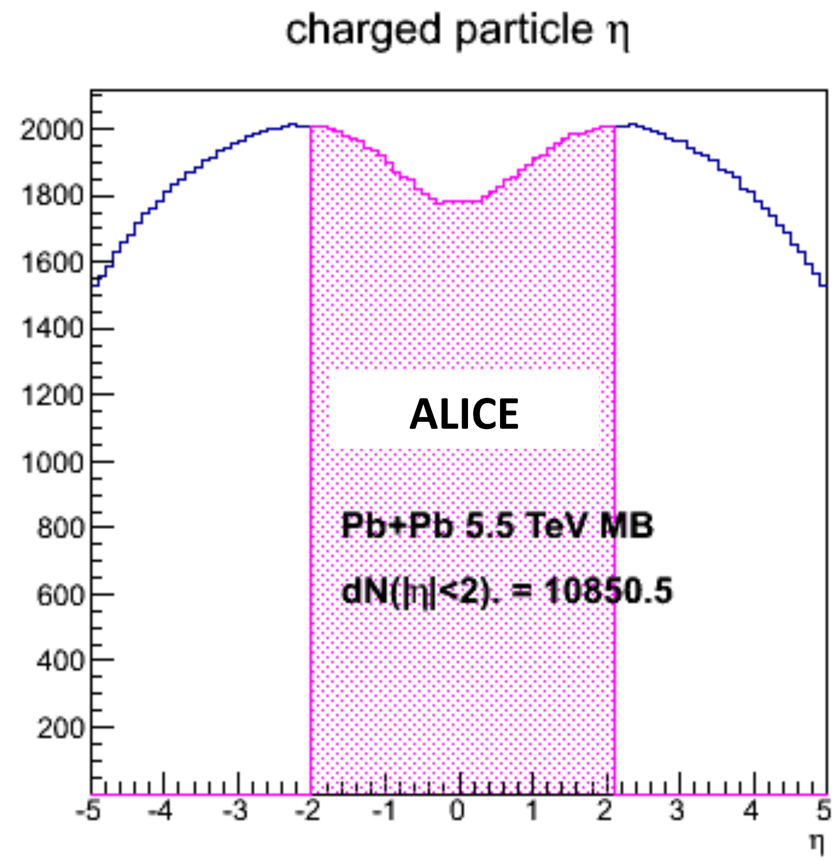




dN/dη in MB Au+Au/Pb+Pb collisions

- With |η|<2.0 region, dN(ALICE) ~4.6*dN(sPHENIX).
- Ncoll(Au+Au)=258, Ncoll(Pb+Pb)=401.





Hit Density on STAR PXL at RHIC Environment

Simulation@50kHz

	PXL inner	PXL outer
Radius (cm)	2.8	8
MB pileup hits (cm^{-2})	13	~3
UPC electrons (cm^{-2})	33	~3
Total bkgd hits (cm^{-2})	46	~6
MB signal Au+Au (cm^{-2})	~8	~1
Au+Au MB real data (cm^{-2})	~50	~5

Xin's talk

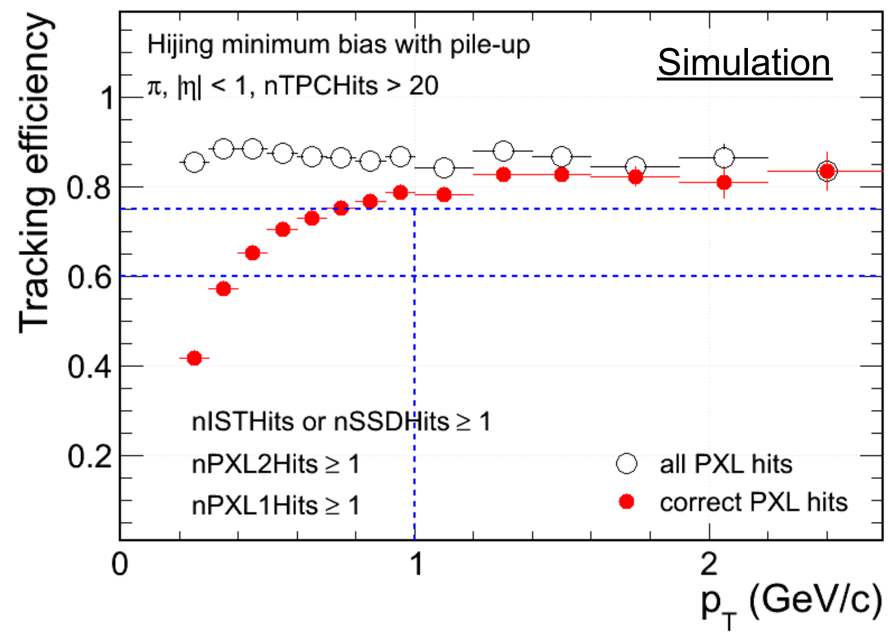
- Ming's note:
With ~5uS integration time, BG rate can be reduced by a factor of, 5/200 = 1/40

S/B ~ 8/1 for sPHENIX

Signal hits fraction in MB (Central) events: ~15% (~30%) at PXL inner

Increasing fake matches in low p_T

Technology chosen considering both physics and technology readiness



Hits and Event Data Rate

- Event size: sPHENIX = 1/3 ALICE
- Identical geometry for MVTX and ITS/IB(layer 0-2)
- sPHENIX integration time ~5uS, less noise compared with ALICE with 10~20uS.

Table 6.1: ITS geometrical parameters, sensors count and maximum hit density ($|\eta| = 0$) for a minimum-bias Pb–Pb event. The hit density figure is derived considering Pb–Pb collisions at 100 kHz rate and accounts for both primary and secondary hadronic interaction, QED background assuming an integration time of 30 μs and a detector noise of 10^{-5} fake hits/pixel.

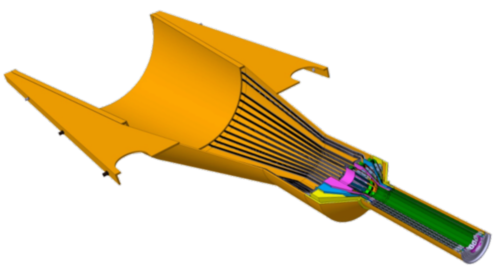
Layer	Length (mm)	Radius (mm)	(Half-)Staves[a] (#)	Chips (#)	Hit density (cm^{-2})
0	271	23	12	108	18.6
1	271	31	16	144	12.2
2	271	39	20	180	9.1
3	843	194	44	2464	2.8
4	843	247	56	3136	2.7
5	1475	353	80	7840	2.6
6	1475	405	92	9016	2.6

[a] Staves for Inner Layers (0–2), Half-Staves for Middle and Outer Layers (3–6)

Readout Units Required for ITS & sPHENIX

Readout Units and GBT links for maximum design rates

Layer	Staves	Copper assemblies	Copper capacity	RUs per stave	RUs per layer	VTRx count	VTTx count	Data fibers	Control fibers	Data fibers capacity	Data fibers usage
			[Gb/s]							[Gb/s]	[%]
0	12	12	103.7	1	12	24	12	36	12	115.2	90.0
1	16	16	138.2	1	16	32	16	48	16	153.6	90.0
2	20	20	172.8	1	20	40	20	60	20	192	90.0
3	24	48	122.9	1	24	48	24	48	24	153.2	80.0
4	30	60	153.6	1	30	60	30	60	30	192	80.0
5	42	168	376.3	1	42	84	42	126	42	403.2	93.3
6	48	196	430.1	1	48	96	48	144	48	460.8	93.3
Total		520	1497.6		192	384	192	576	192	1670	

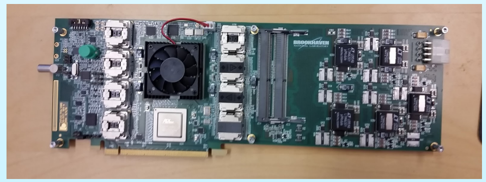


- 48 inner staves;
- 48 RU boards;
- 6 FELIX boards;
  - 8RU ->1 FELIX

MVTX options: 6x (PCIe card + server)

Data Aggregation Module (DAM):
PCIex8 or x16 card with multiple (48x) GBT fiber IO

Option 1: ATLAS FELIX

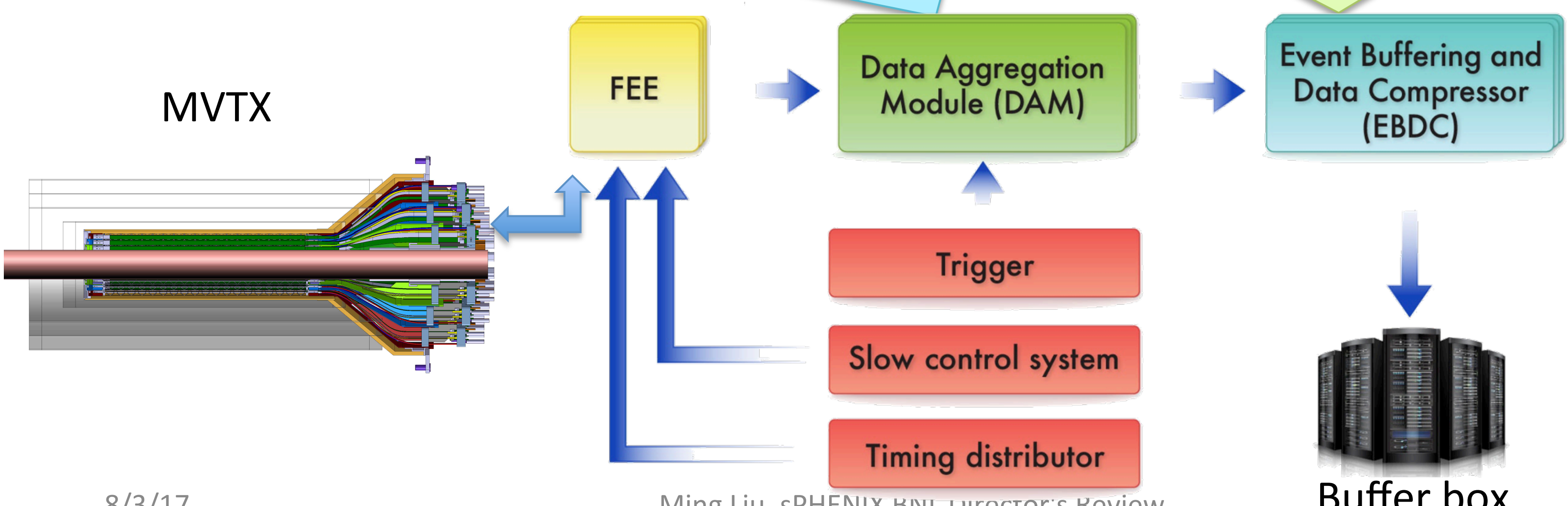


Option 2: LHCb/ALICE CRU

Option 3: build our own based on ALICE/ATLAS exp.

Event Buffering and Data Compressor (EBDC): Rack server that can host at 1x PCIex16 cards + 2x 10 Gbps Ethernet port

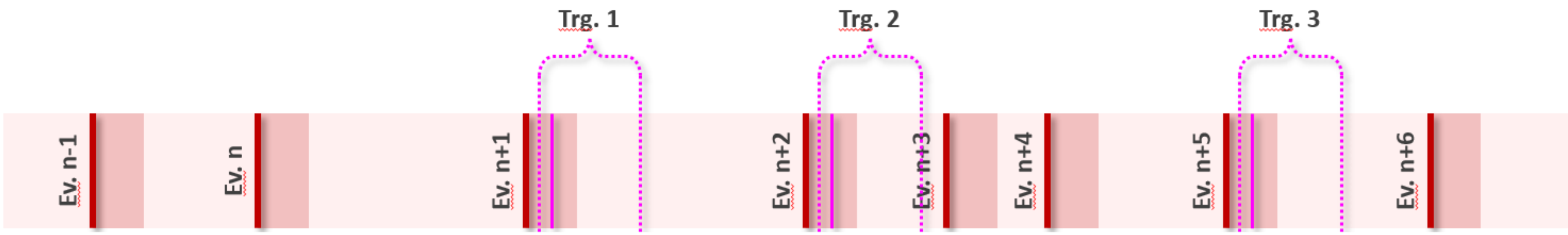
Example: Dell PowerEdge R830
2x12 cores, 2x10 GBps, ~ 10k$



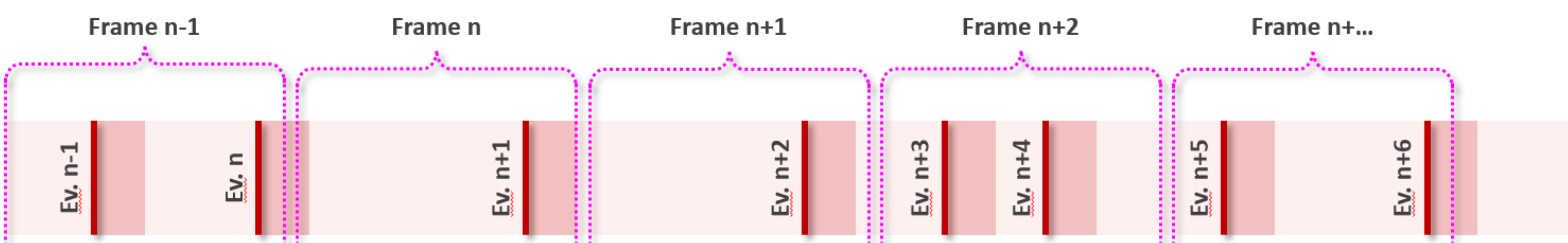
ALPIDE Modes of Operation

- The ITS is planned to be operated in two modes:

Triggered mode: Pixels are latched with a short strobe window and read out based on an external trigger.



Continuous mode: Pixels are latched using a long, periodic strobe window and read out.



Multi-Event buffering

- This is what makes the DAQ as fast as it is
- Or, in other words: that keeps the dead time in the low 90%'s
- Comes down to dealing with your data from various events in parallel
- Our hardware is designed to deal with 5-event buffering
- More is a diminishing return for $$$
- We actually mostly ran 4-event buffering in PHENIX

ALICE Data Rate and Dead Time

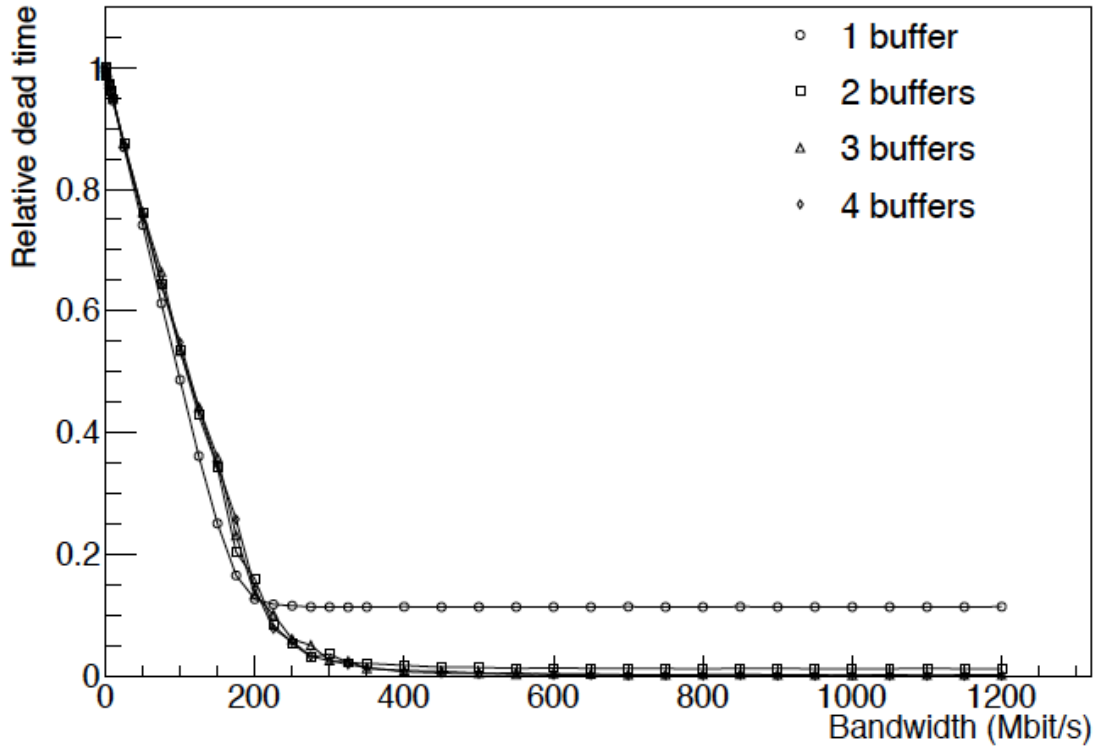


Figure 6.2: Relative dead-time for different output bandwidths and the number of front-end latches.

ITS Readout - Radiation Load

Position respect to beam			Radiation levels (total)			
r	z	Name	TID	1 MeV neq fluence	**High energy hadron flux***	Charged particle flux
[cm]	[cm]		[krad]	[cm^{-2}]	[kHz cm^{-2}]	[kHz cm^{-2}]
2.2	[-13.5 ÷ 13.5]	ITS L0	2734	1.7×10^{13}	765 (770)	890 (910)
43	[-73.7 ÷ 73.7]	ITS L6	20	8.1×10^{11}	3.4 (4.9)	4.5 (6.7)
79	[-260 ÷ 260]	TPC In	5.6	7.0×10^{11}	1.35 (1.8)	1.7 (3.45)
100	330	RE	≈ 5	$\approx 1.6 \times 10^{11}$	0.86	1.7
258	[-260 ÷ 260]	TPC Out	0.86	1.4×10^{11}	0.27 (0.37)	0.2 (0.3)
290	[-290 ÷ 290]	TRD	0.6	1.2×10^{11}	0.23 (0.31)	0.15 (0.23)

- TID & fluence = (table 1 × $1.3_{\text{data taking efficiency}}$ + Table 2 / $10_{\text{better vacuum}}$) × $10_{\text{safety factor}}$
- Safety factor of 10 on top of TID and fluence calculated as in the above line.
- **Hadrons and charged particles as for 50 kHz Pb-Pb collisions** (table 1, worst case scenario).
- The average value within the z span is reported first, in brackets the peak value within the z interval.
- * Momentum > 20 MeV.