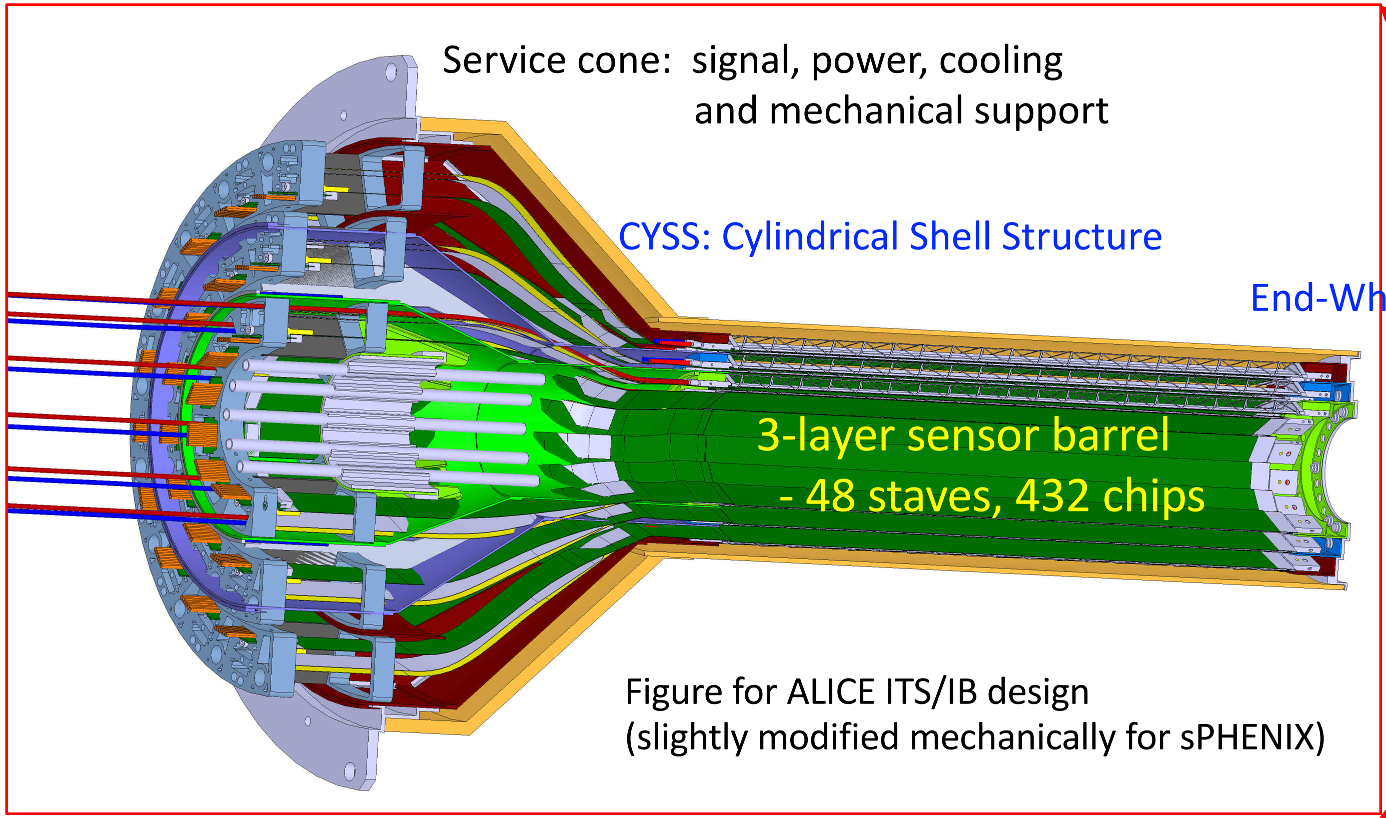
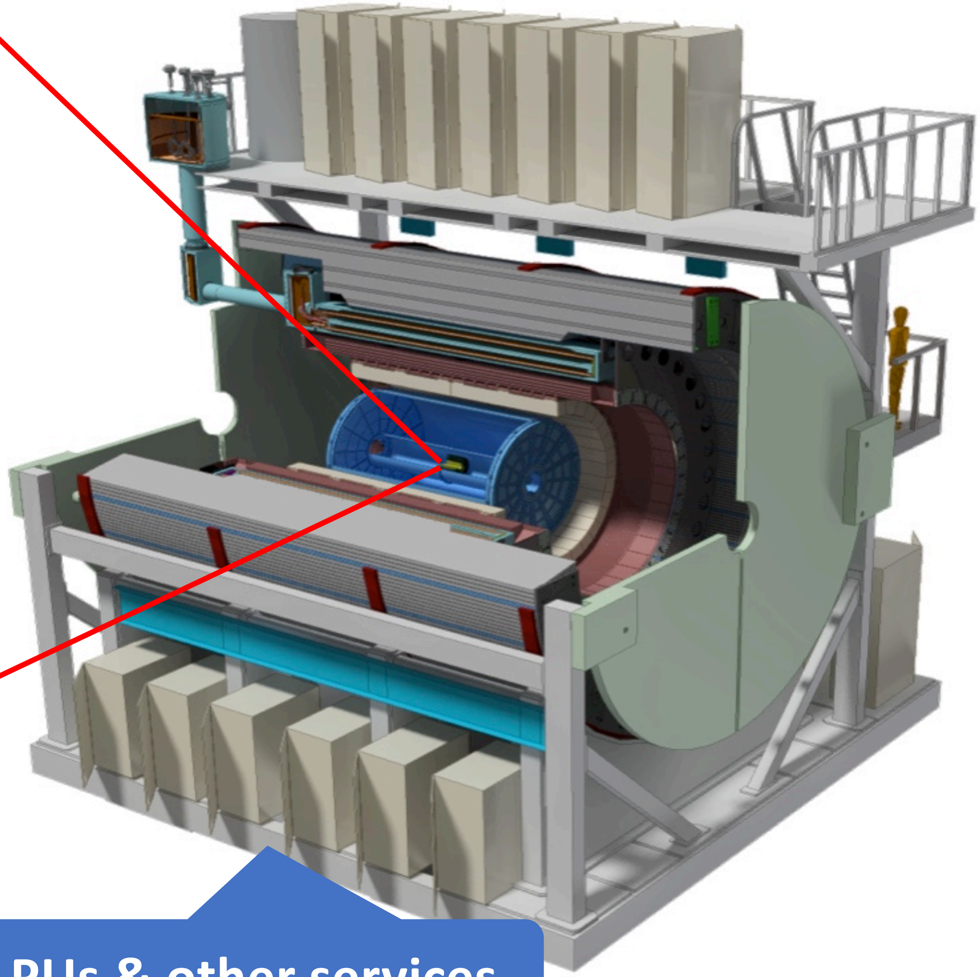
sPHENIX
Opportunities and Challenges

Ming Liu

sPHENIX MVTX Detector





MVTX RUs, PUs & other services

MVTX parameters

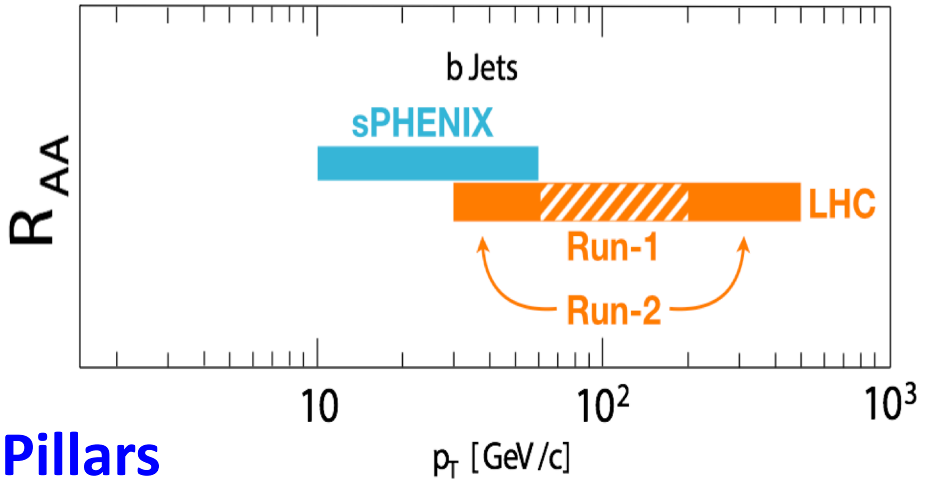
	Layer 0	Layer 1	Layer 2
Radial position (min.) (mm)	23.7	31.4	39.1
Radial position (max.) (mm)	28.0	35.9	43.4
Length (sensitive area) (mm)	271	271	271
Active area (cm^2)	421	562	702
Number of pixel chips	108	144	180
Number of staves	12	16	20

Exciting Science Enabled by MVTX @sPHENIX

– LANL's major long term NP program

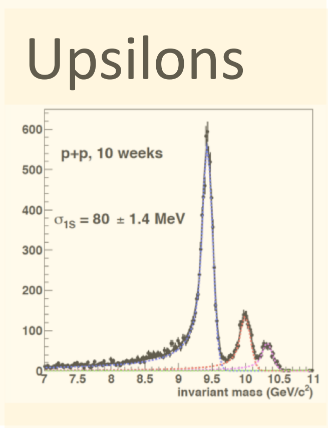
- sPHENIX is the next flagship heavy ion physics experiment in the US (NSAC LRP2015)
  - Jets
  - Upsilons
  - B-jets and B hadrons
- MVTX will complete QGP heavy flavor physics
  - Precision study of the "inner workings of QGP"(LRP15)
  - Unambiguous determination of key parameters of QGP properties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

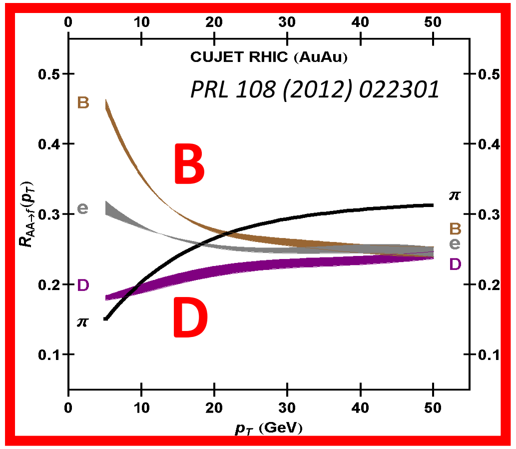
complement & extend current and future RHIC and LHC QGP programs



sPHENIX 3 Physics Pillars

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





sPHENIX 5-Year Run Plan: 2023 – 2027+

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

sPH-TRG-2018-001

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
Year-4	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
Year-5	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

Projected sPHENIX integrated luminosities after 5-year operation

- AuAu: Lum. = 214 nb^{-1} , Max collision rate ~200kHz
- pp+pAu: Lum. = 1340 pb^{-1} , Max collision rate ~13MHz

sPHENIX Trigger limit: <=15kHz

- AuAu: mostly MB w/ |Z| < 10cm
- p+p/A: high pT jet trigger, upsilons

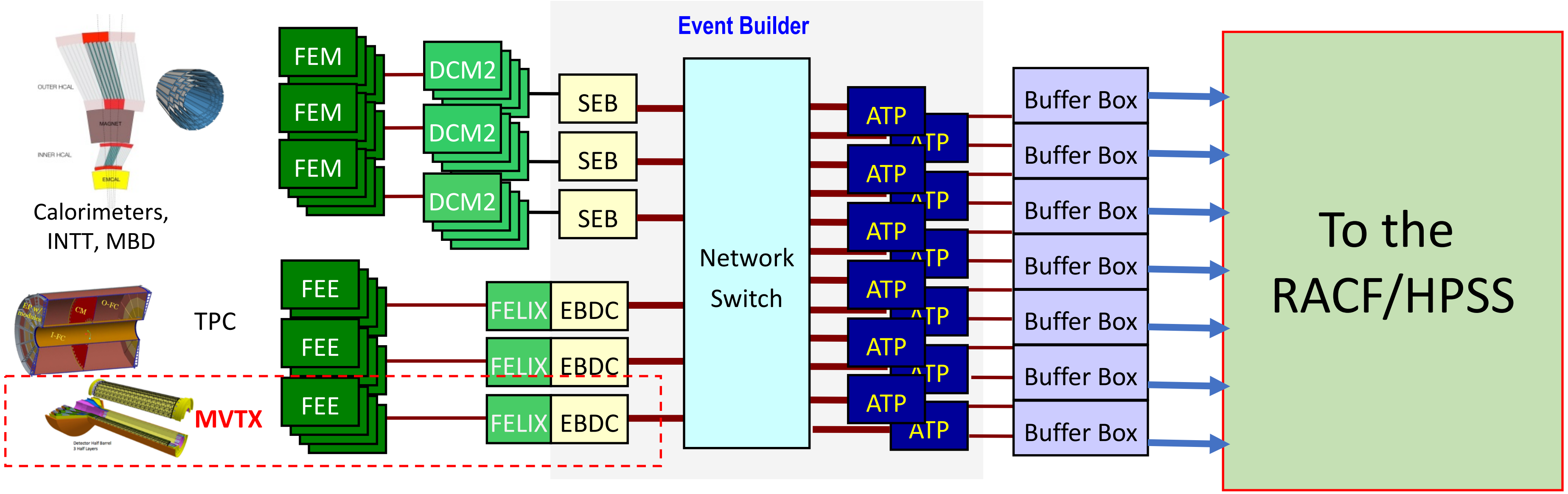
A new proposal:
develop displaced tracker triggers for open heavy flavor in pp/pA based on MVTX + INTT
- RU continues readout + trigger boards(FELIX based?)

Scope of the MVTX Project

- MAPS Staves & Electronics
  - Readout Integration R&D (LANL LDRD)
    - Frontend: ALICE/ITS, RU
    - Backend: ATLAS FELIX
    - Reprogram RU & FELIX for sPHENIX
  - Production:
    - **84 ALICE/ITS-IB staves from CERN**
      - Acceptance test @LBNL
        48+spares(36)
    - **58 ALICE/ITS-RU from CERN**
      - Acceptance test @UT-Austin, 48+spares(10)
    - sPHENIX production, 8 ATLAS/FELIX
      - Acceptance test @LANL
    - Final detector assembly in US
      - LBNL and BNL
  - Ancillary systems, “adopt” ALICE system

- Mechanics & Cooling
  - Changes to ALICE/ITS inner tracker mechanical structures,
    - End Wheels
    - Cylindrical structure shells
    - Detector half barrels
    - Detector and Service half barrels
  - Mechanical Integration,
    - Conceptual design by LANL LDRD
    - Prototype by sPHENIX R&D, MIT/LANL
    - Design integration frames
    - Composite structures, LBNL
    - Installation tooling etc.
  - Adopt ALICE cooling plant design
    - Modifications to fit sPHENIX
    - Much smaller heat load than ALICE ITS

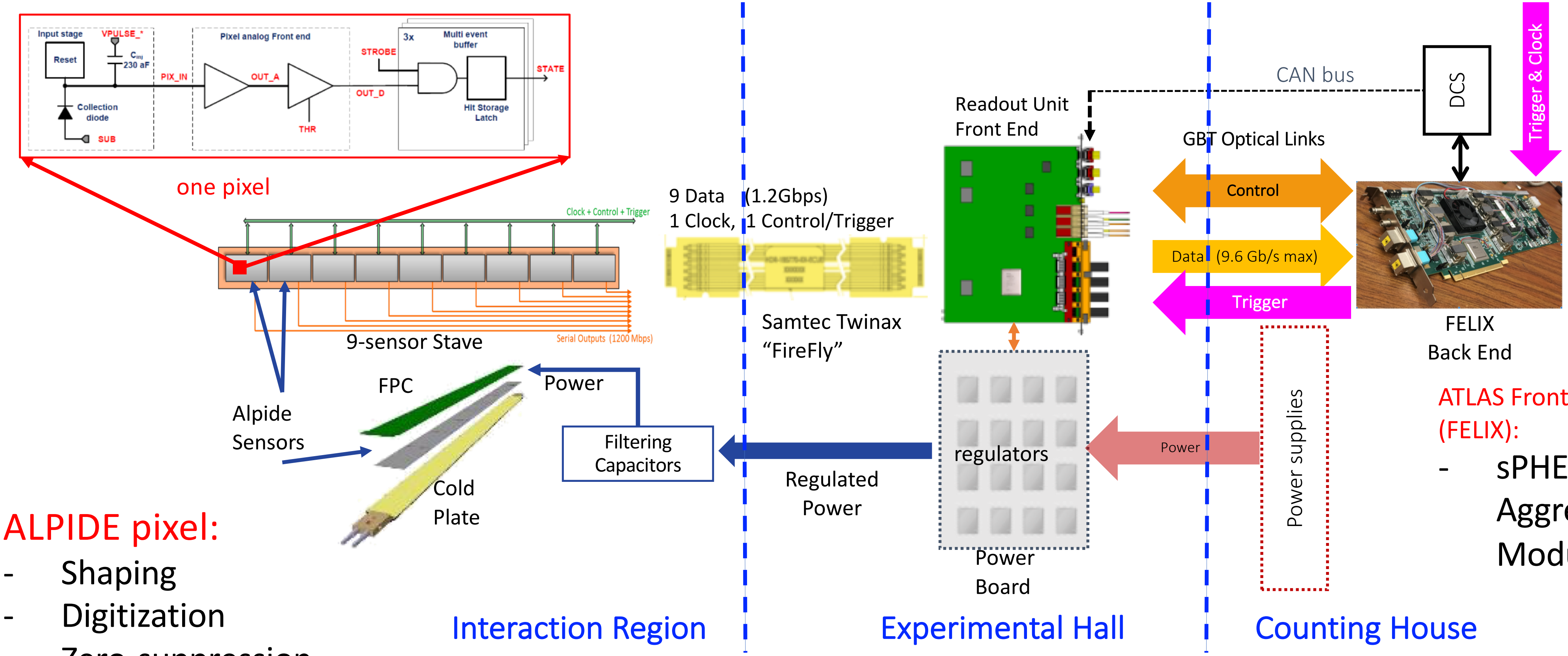
sPHENIX DAQ Architecture and MVTX Readout



- SEB Sub-Event Buffer
- EBDC Event Buffer and Data Compressor
- ATP Assembles events and compresses data
- Buffer Box Data interim storage before sending data to the computing center

MVTX Readout, Power and Controls

a key LDRD deliverable:
Demonstrate the full readout and control chain w/ "final" RU and FELIX



ATLAS Front-End Link eXchange (FELIX):

- sPHENIX Data Aggregation Module(DAM)

ALPIDE pixel:

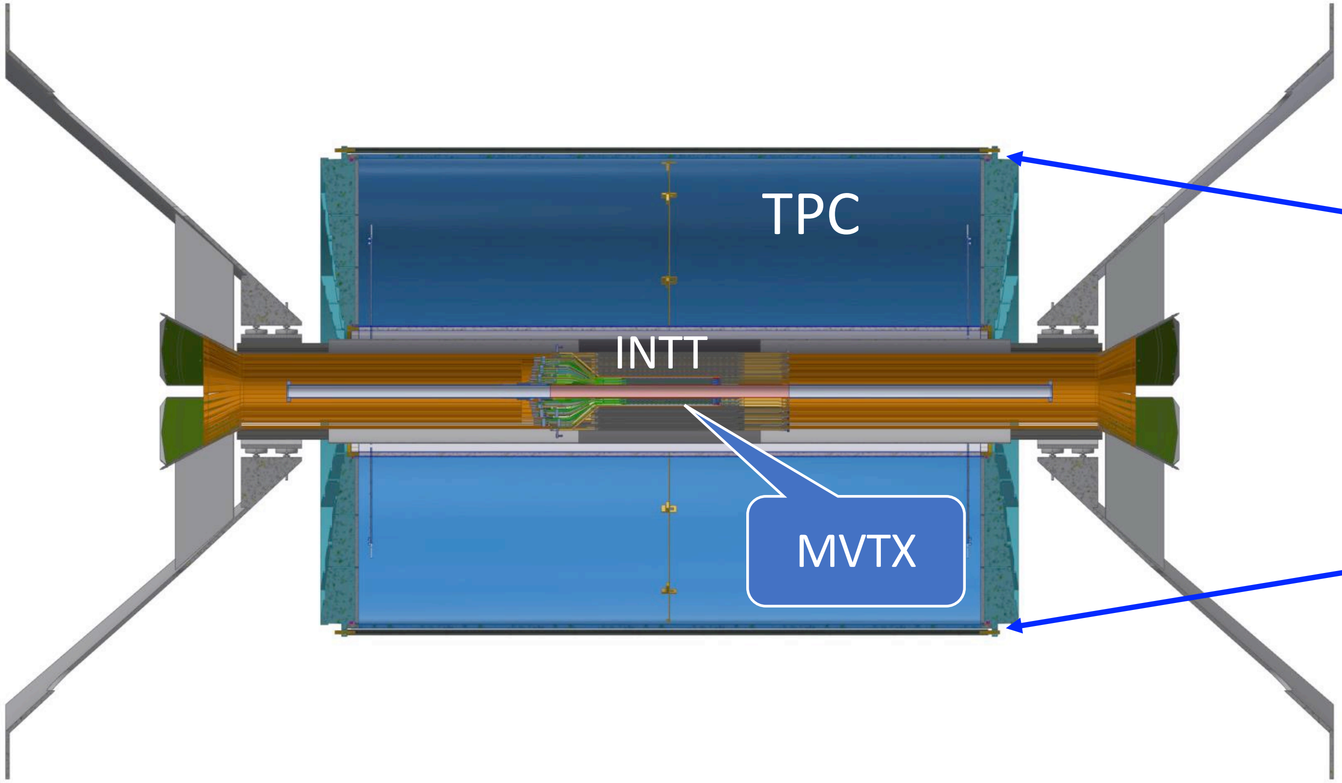
- Shaping
- Digitization
- Zero-suppression
- 3x buffer

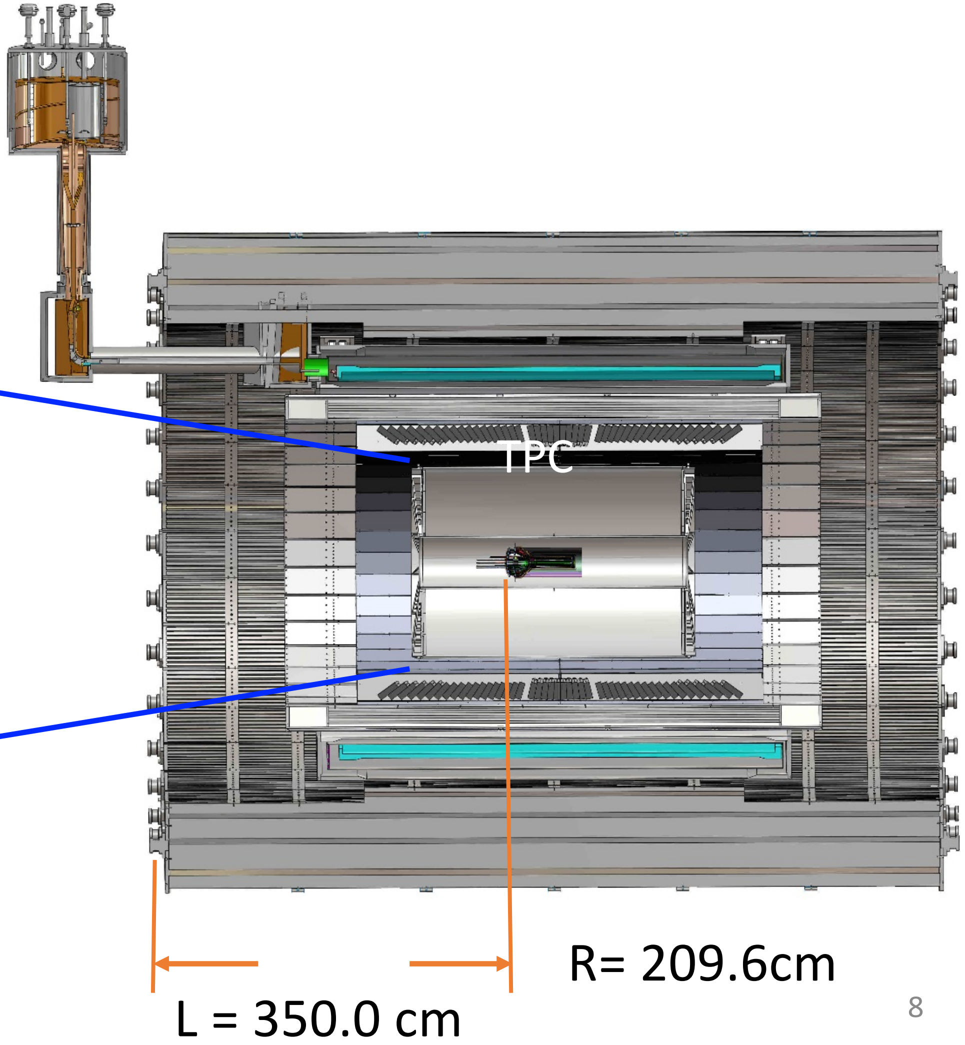
MVTX Detector Electronics consists of three parts

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

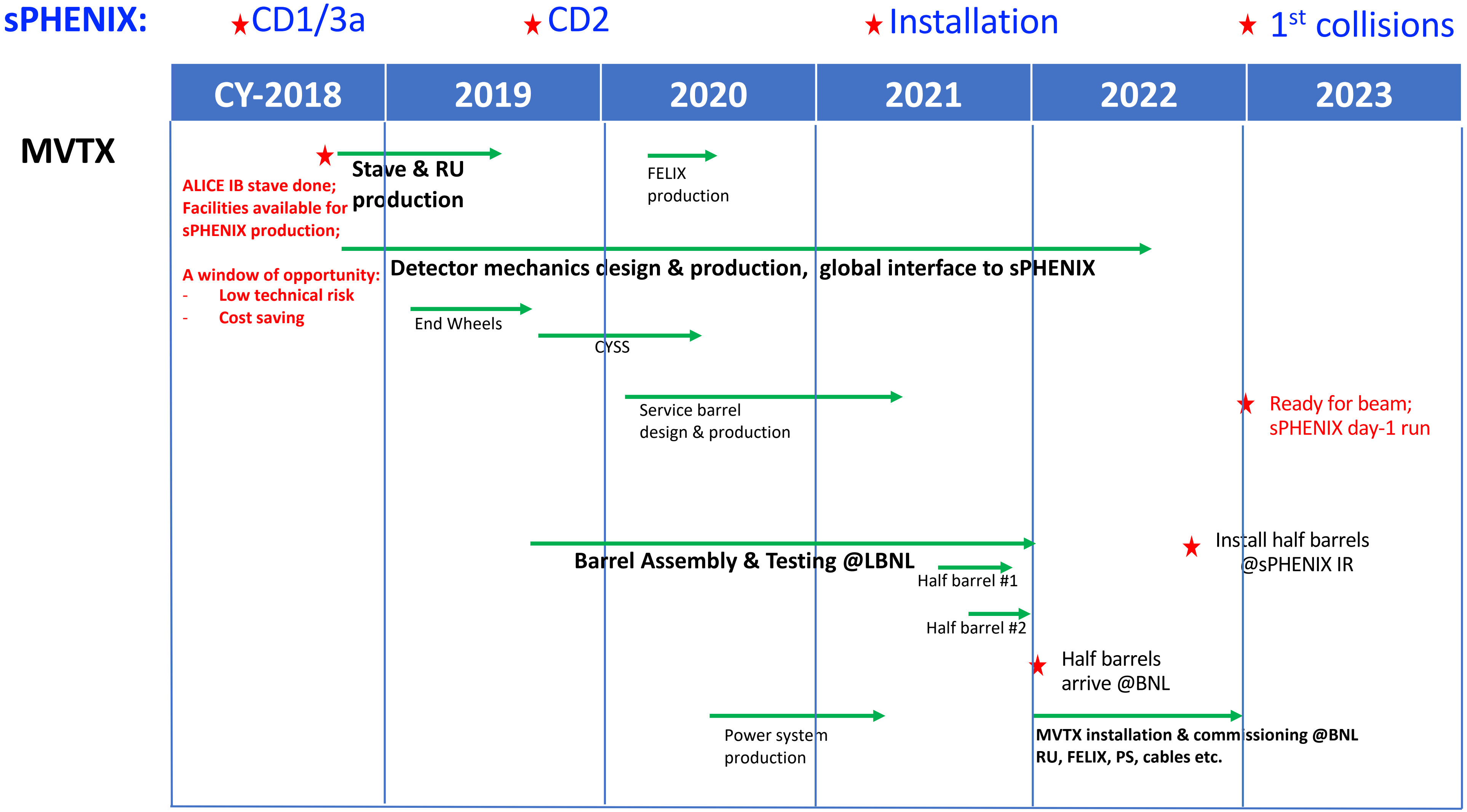
sPHENIX Mechanical System Integration

- MVTX, INTT and TPC/HCal
  - MVTX/INTT detector designs modified
  - Global interface being developed
  - Office of System Integration



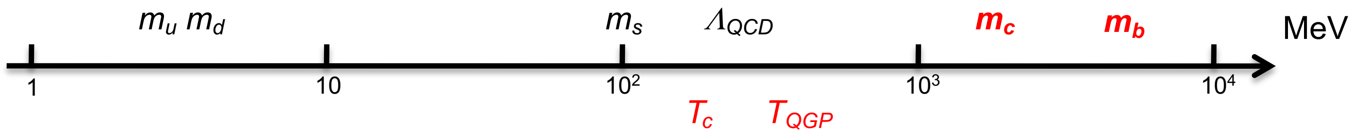


MVTX Schedules and Milestones



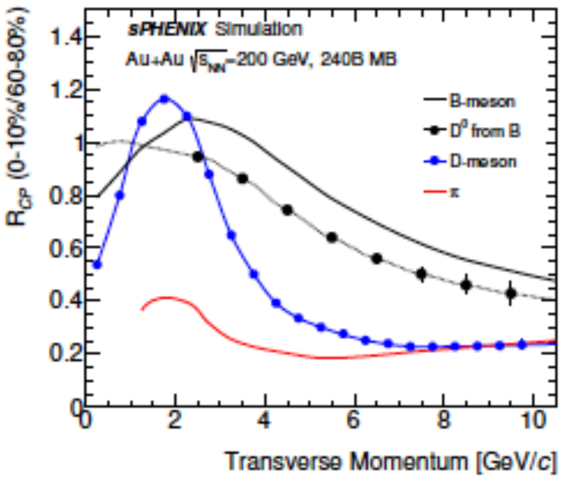
Key MVTX Physics Deliverables:~2027

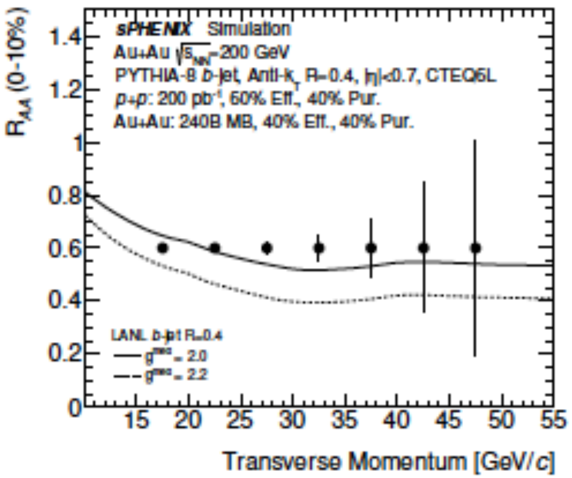
- Heavy quarks – unique probe of QGP w/ new scales, **m_c, m_b**
  - Study mass dependence
    - Jet quenching & energy loss
    - Flow – interaction with medium
  - Access QGP properties
    - Parton density, coupling, transport coefficients, viscosity etc.



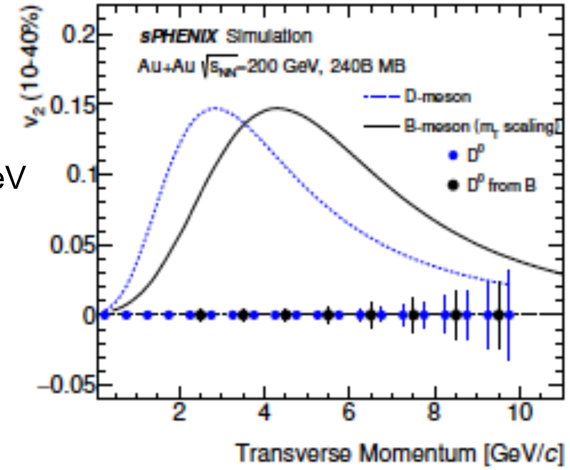
Note: B-hadron trigger desired for p+p/A, new physics capability R_{AA} vs R_{CP}; v2 in p+p/A etc.

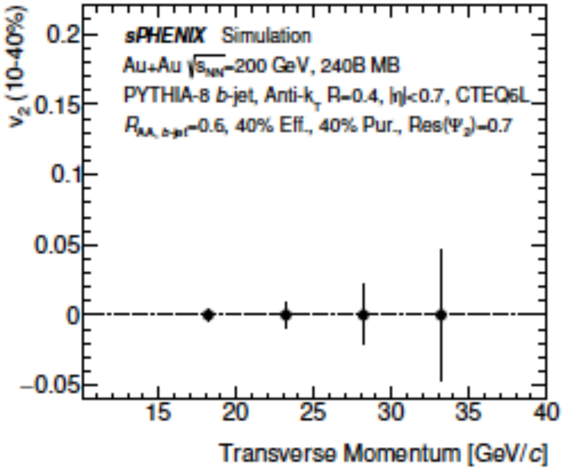
"B meson and b-jet modification"





"B meson and b-jet flow"

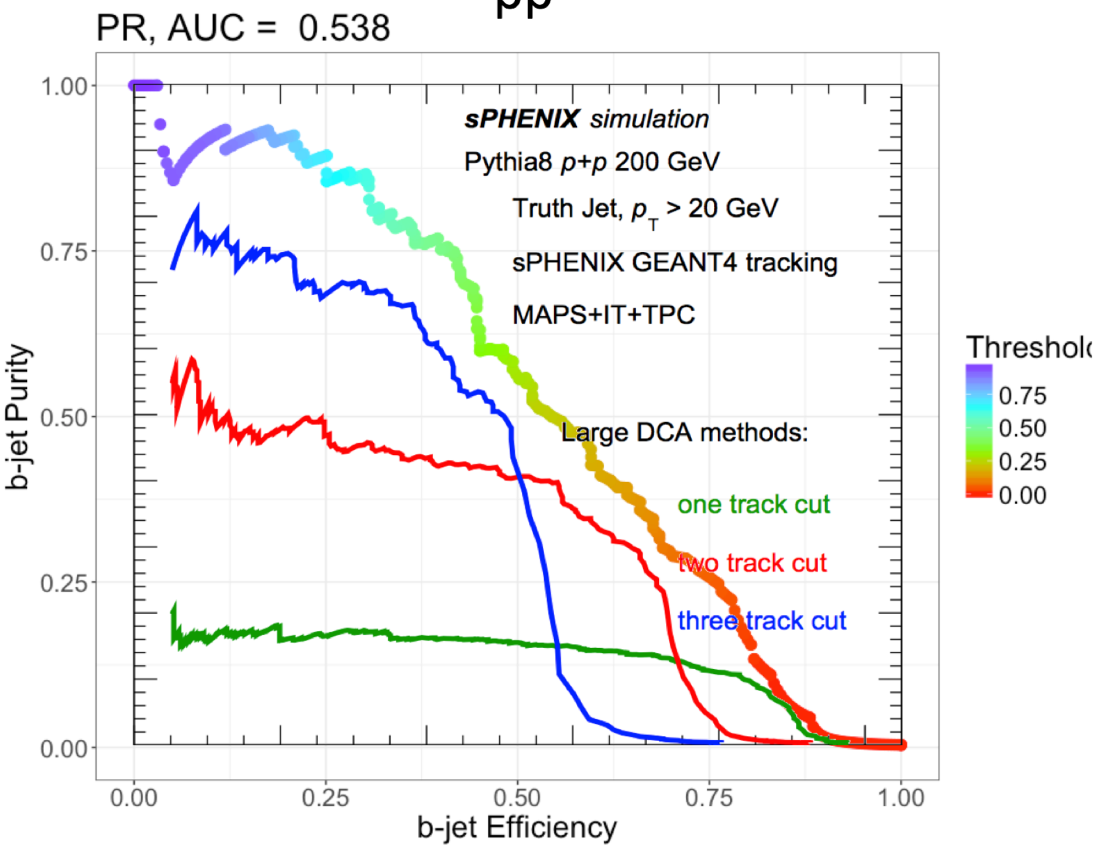




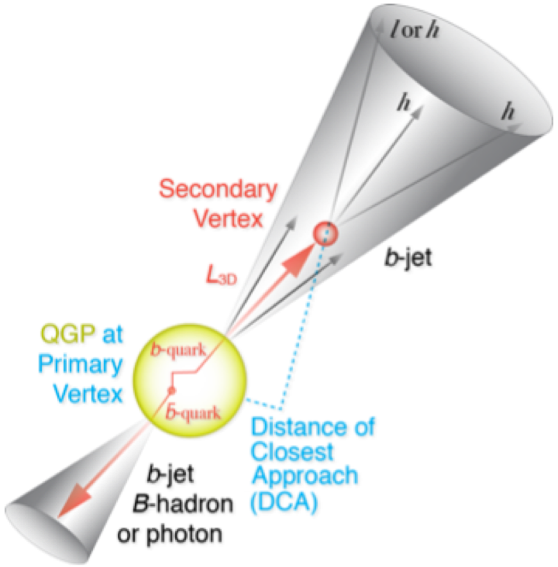
Analysis/Simulation Efforts: B-tagging 2019 – 2023+

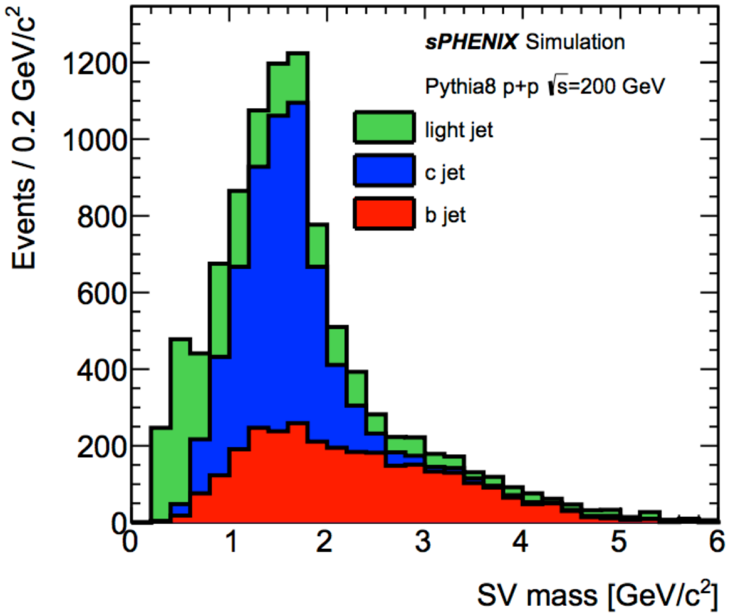
Further improve the b-tagging (B-hadrons and b-jets) in p+p/A and A+A

pp



Control of B-tagging methods' systematics
- DCA vs 2nd vtx mass





Beyond the Baseline sPHENIX: f/sPHENIX and EIC

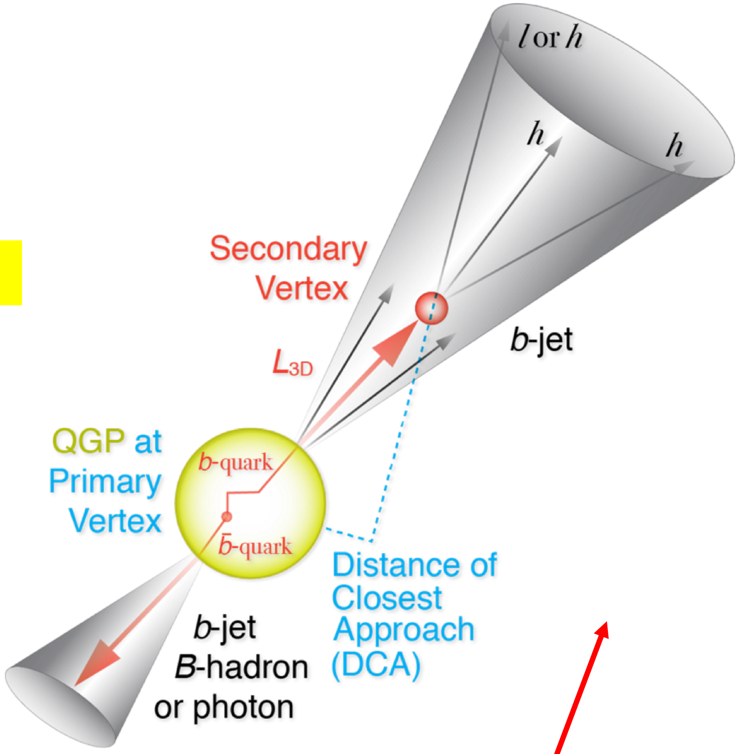
- sPHENIX cold QCD – new TMD physics
  - Spin physics with f/sPHENIX
  - p+A and p+p,
  - Forward tracking detector R&D (aim for EIC/eRHIC)

- EIC/eRHIC physics program after sPHENIX, 2027+
  - EIC project:
    - Site selection: ~2019
    - CD-0 ~2019
  - LANL EIC program – 2019+
    - Define physics focus - TMD, saturation etc.
    - Detector R&D

Open HF Trigger for p+p/A:
based on DCA & High Multiplicity

https://www.phenix.bnl.gov/WWW/publish/mxliu/sPHENIX/HF-Trigger/sPHENIX-HF-Trigger-Study-042018.pptx

3+4+5 RU -> 1 FELIX/Trigger in continuous readout mode,



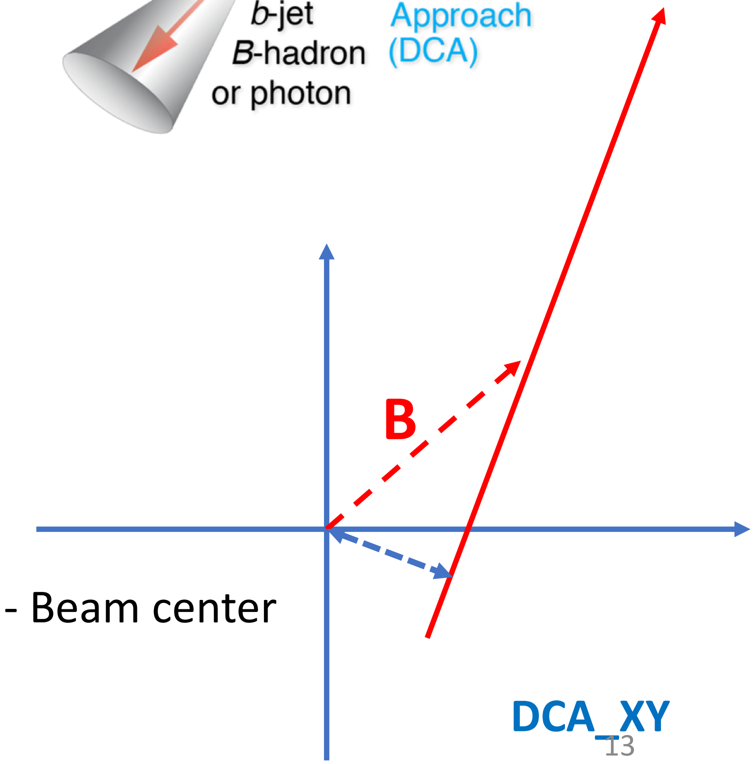
ALPIDE readout: ~<5uS,

APLIDE->RU timing:

- rising time above threshold ~1 uS
- Strobe length = 0.1uS
- Readout time = hits N_x per region x 80bits @1.2Gbps = 0.1xN_x uS <~ 2uS
- Readout frame gap ~ 50nS
- Direct passthrough data from RU to FELIX/Trigger board: @1.2Gbps, a few ~0.1uS

- Total delay @Trigger board: ~3uS
  - Can we get INTT hits?

- B-Trigger decision to be made at trigger board: 4~5uS
  - Some kind of lookup table for DCA,
  - possibly for multiple tracks, N>=2
- Very high multiplicity sum for fast trigger (INTT?), most ~1% central event



Summary: sPHENIX/MVTX Efforts at RHIC

- LDRD: FY19, (FTE= 1 staff + 1.5PD)
    - Sensor and readout R&D
    - Telescope & cooling
    - Transition into sPHENIX program
    - Open HF trigger R&D for p+p and p+A

Engineering support:
- 0.5FTE electronics
- 0.2FTE mechanical

- sPHENIX MVTX detector construction: FY2019 - 2023
    - 3+ staff / 3+ postdoc
    - Electronics and mechanical integration
    - Detector installation and commissioning
    - Physics and detector simulations
    - Develop open HF trigger

Engineering support:
- 0.5 FTE mechanical
- 0.5 FTE electronics

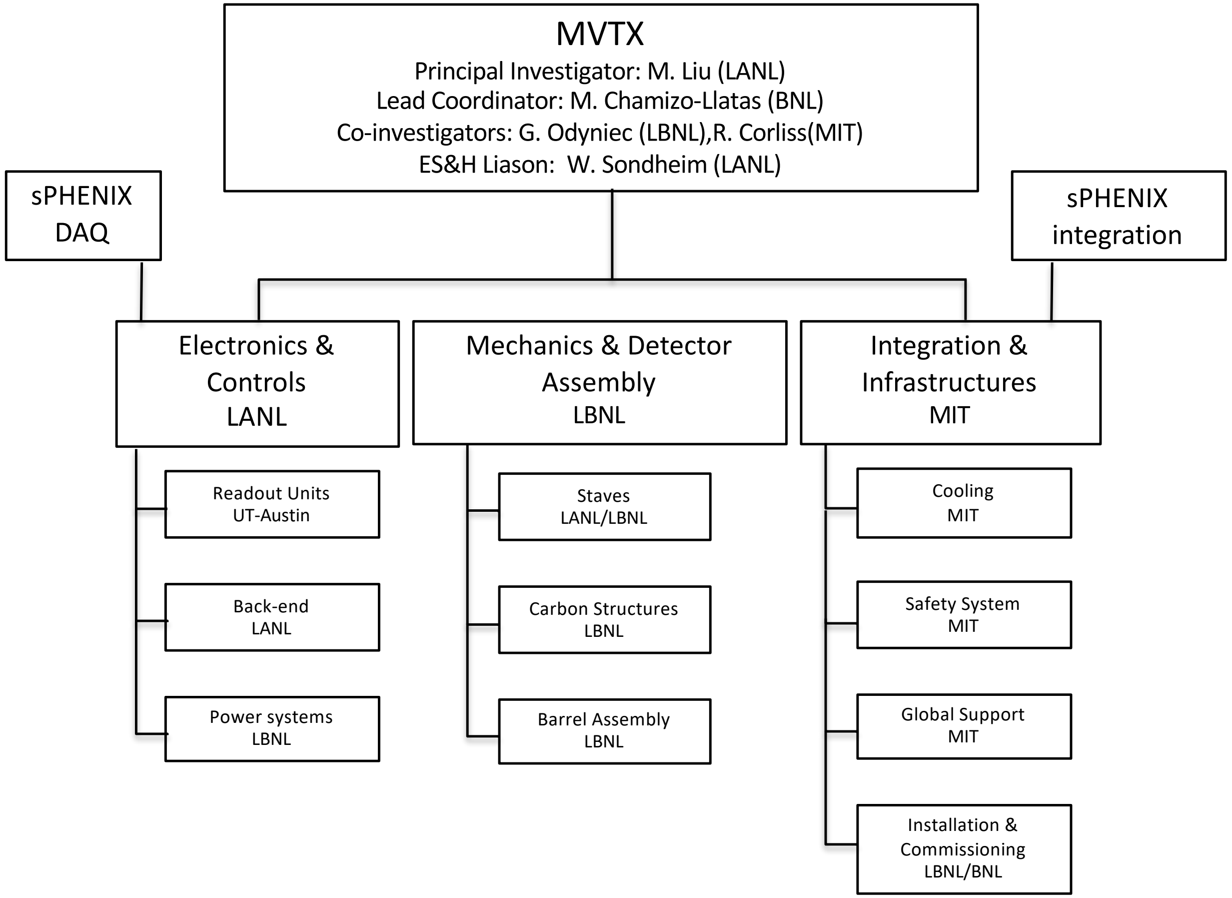
- sPHENIX operation & physics analysis: 2023 – 2027+
    - 3.5+ staff/3+ postdocs
    - MVTX operation and maintenance
    - Physics analysis and publication
    - Future f/sPHENIX & EIC program development

Engineering support:
- 0.2FTE mechanical
- 0.2FTE electronics

Backup slides

sPHENIX MVTX Group: Institution Roles

- Growing number of institutions
  - Major institutions lead key tasks



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Stave and RU Production QA Plan

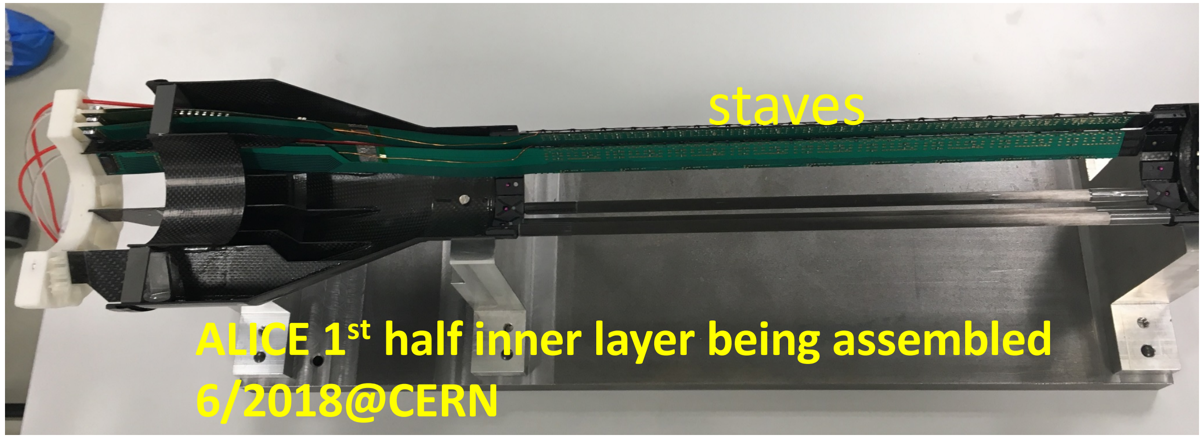
Staves

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

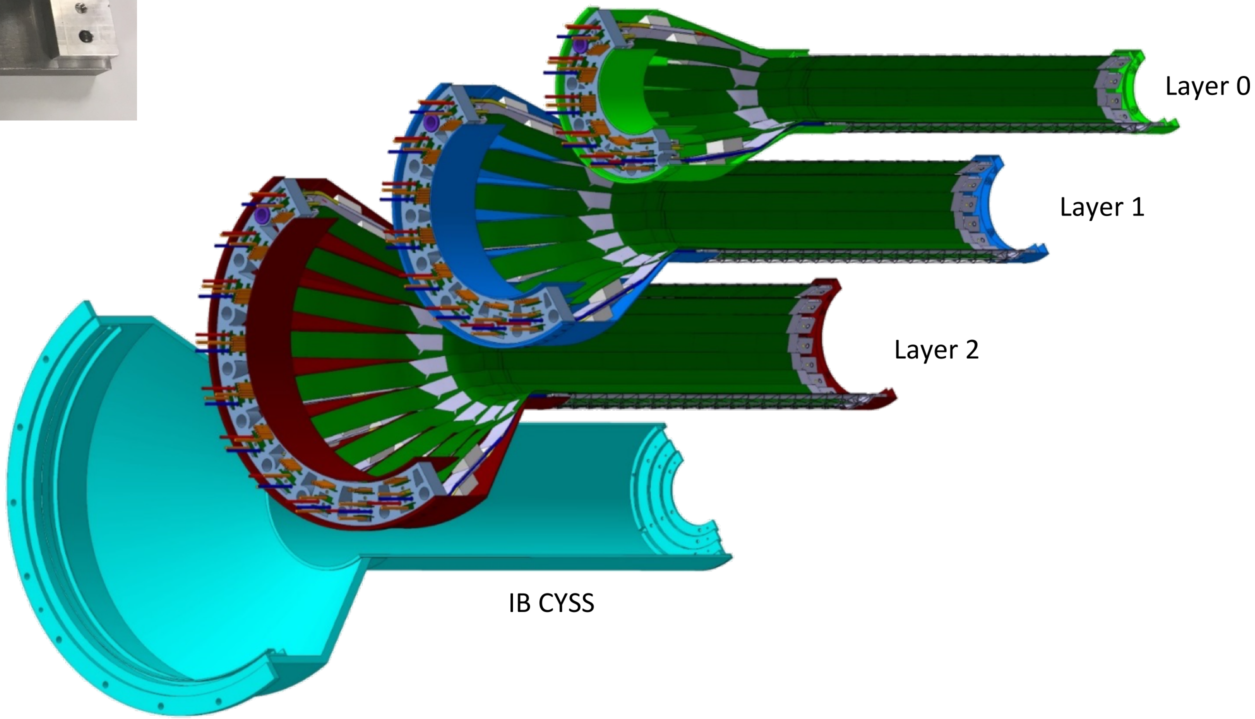
Readout Units

- Purchase 58 RUs from ALICE/CERN
  - 48 + 10 spares(20%)
  - To be part of ALICE production
    - Cost saving
    - Minimize technical risks
  - Initial test at CERN
- Acceptance QA at UT-Austin
  - Full test
  - LANL as the 2nd test site

Detector Assembly Plan at LBNL



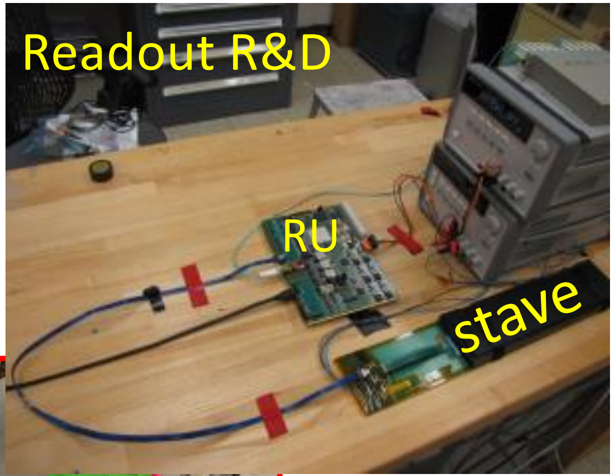
Precision positioning and installation of staves on end-wheels

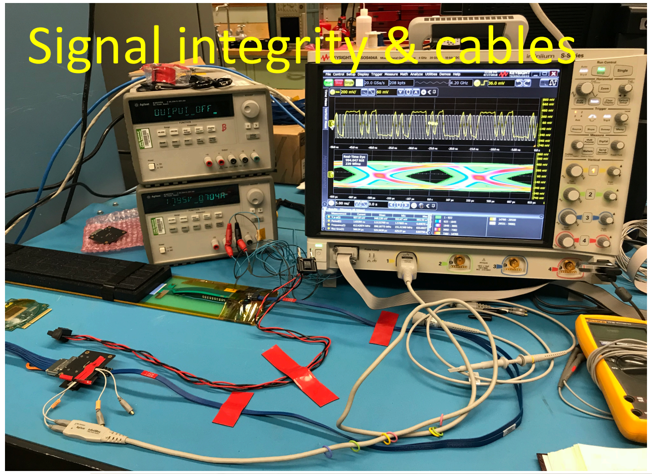


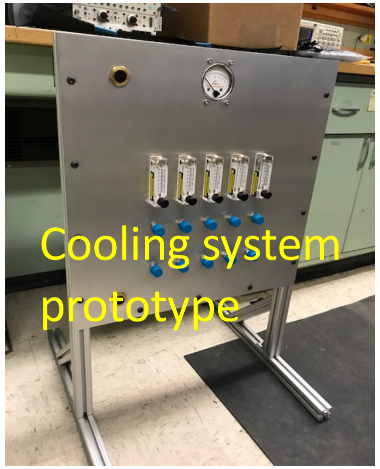
- Follow ALICE IB assembly procedures to build half-detectors for MVTX
- QA records in DB, travelers
- Modified jigs for MVTX

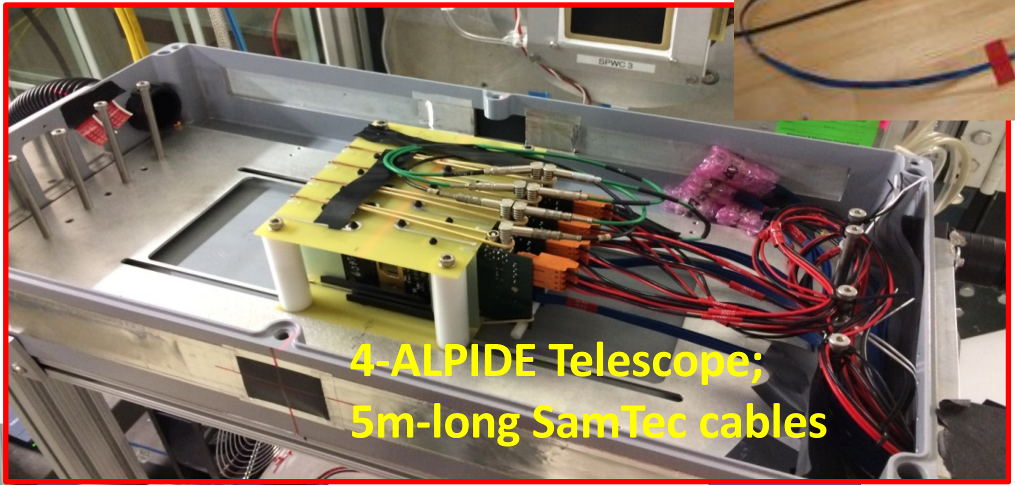
LANL LDRD Activity Highlights

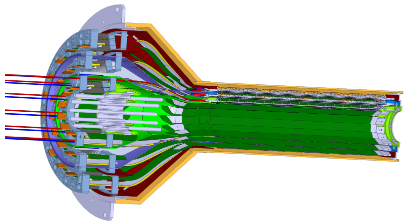
- MAPS evaluation
- Readout integration
- 4-sensor telescope
- Test beam at Fermilab
- Mechanical & cooling

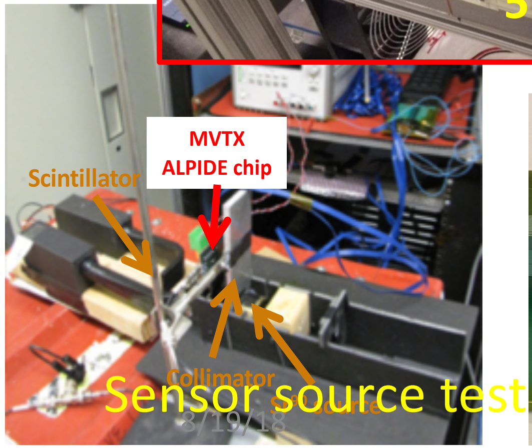


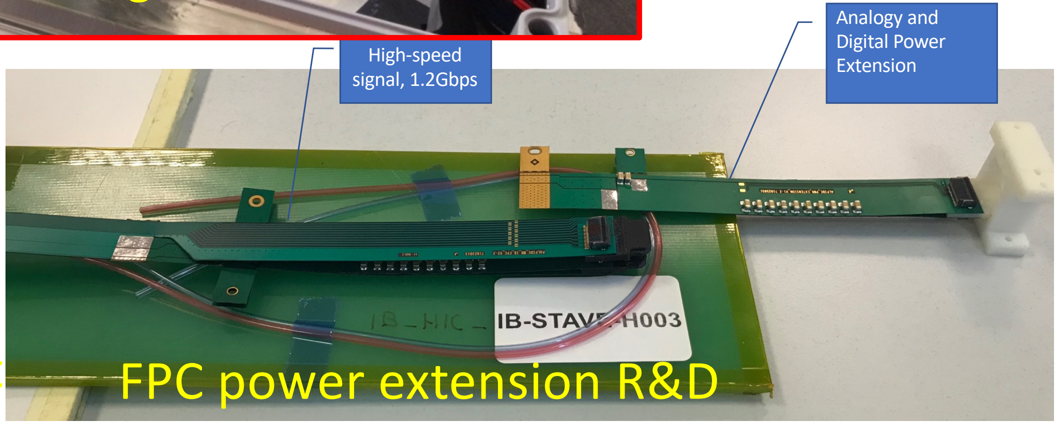












sPHENIX LDRD Manpower in general for FY19

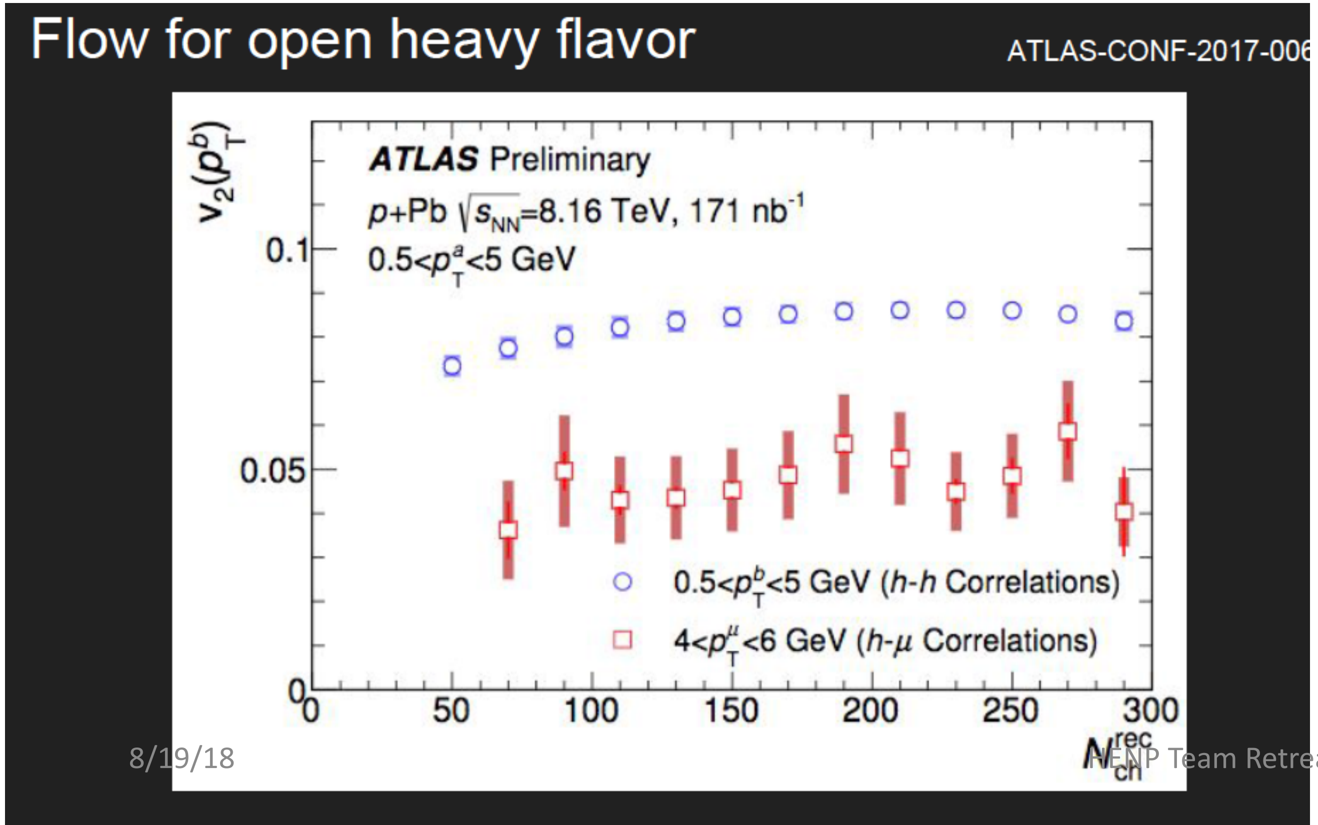
- Ming
  - 0.3, overall, readout & integration
- Cesar
  - 0.1, slow control, stave production
- Walt/Chris
  - 0.2, mechanical
- AlexT.
  - 0.5, readout
- Sho
  - 0.5, readout & controls
- Yasser
  - 1.0, stave production, offline simulation
- Hubert
  - 0.1, mechanical mockup
- Xuan
  - 0.1, ALPIDE evaluation
- AlexW
  - 0.5, testing & simulation
- Mark
  - 0.2, readout
- T-2/CCS etc.
  - Theory modeling
- Exp. FTEs & Budget:
  - Staff: 1.0
  - PD/Students: 2.0
  - Engineer/contractor: 0.5
  - Budget: $1054K, w/ $330K for M&S

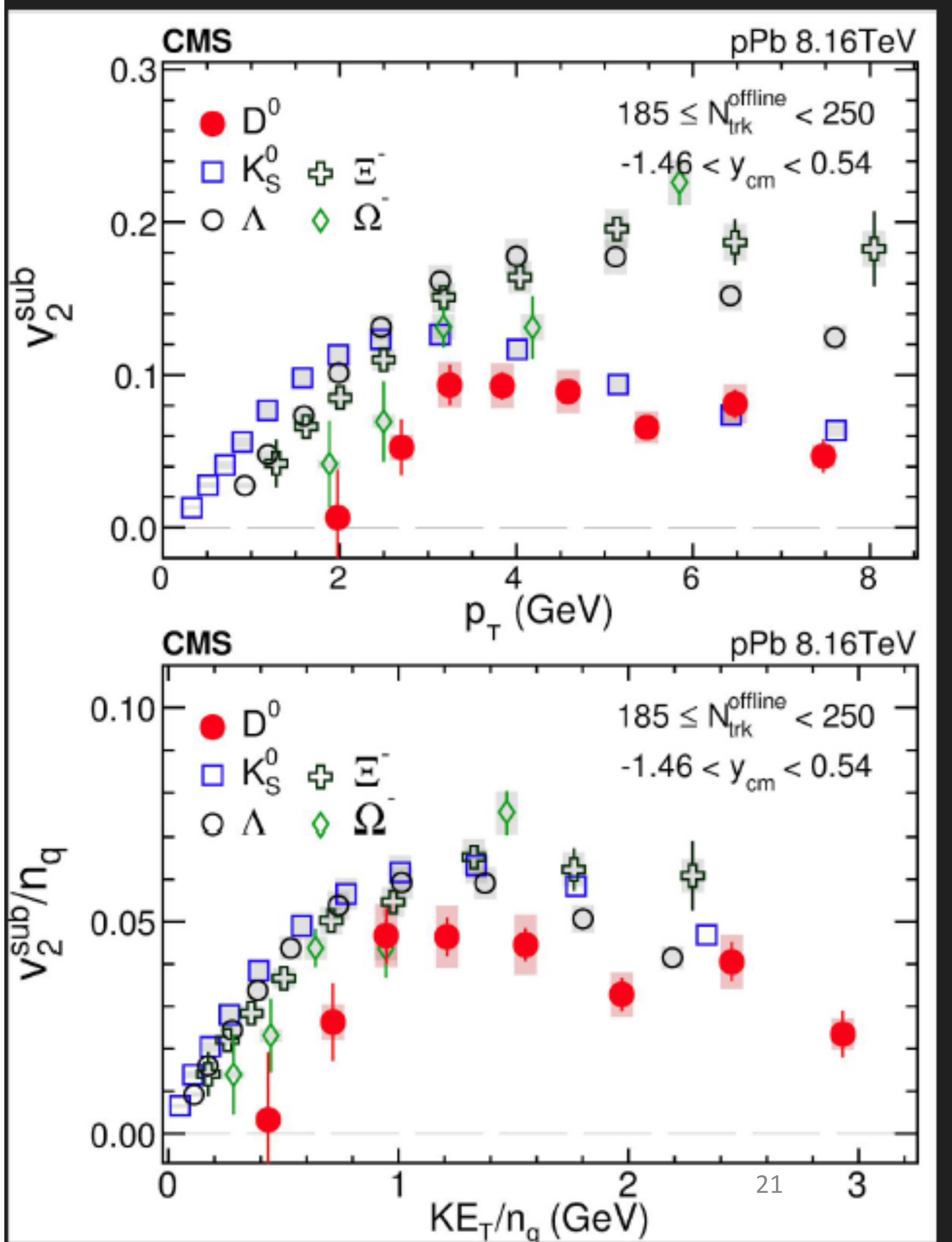
B-hadron trigger: pp and pA

https://www.phenix.bnl.gov/WWW/publish/mxliu/sPHENIX/HF-Trigger/sPHENIX-HF-Trigger-Study-042018.pptx

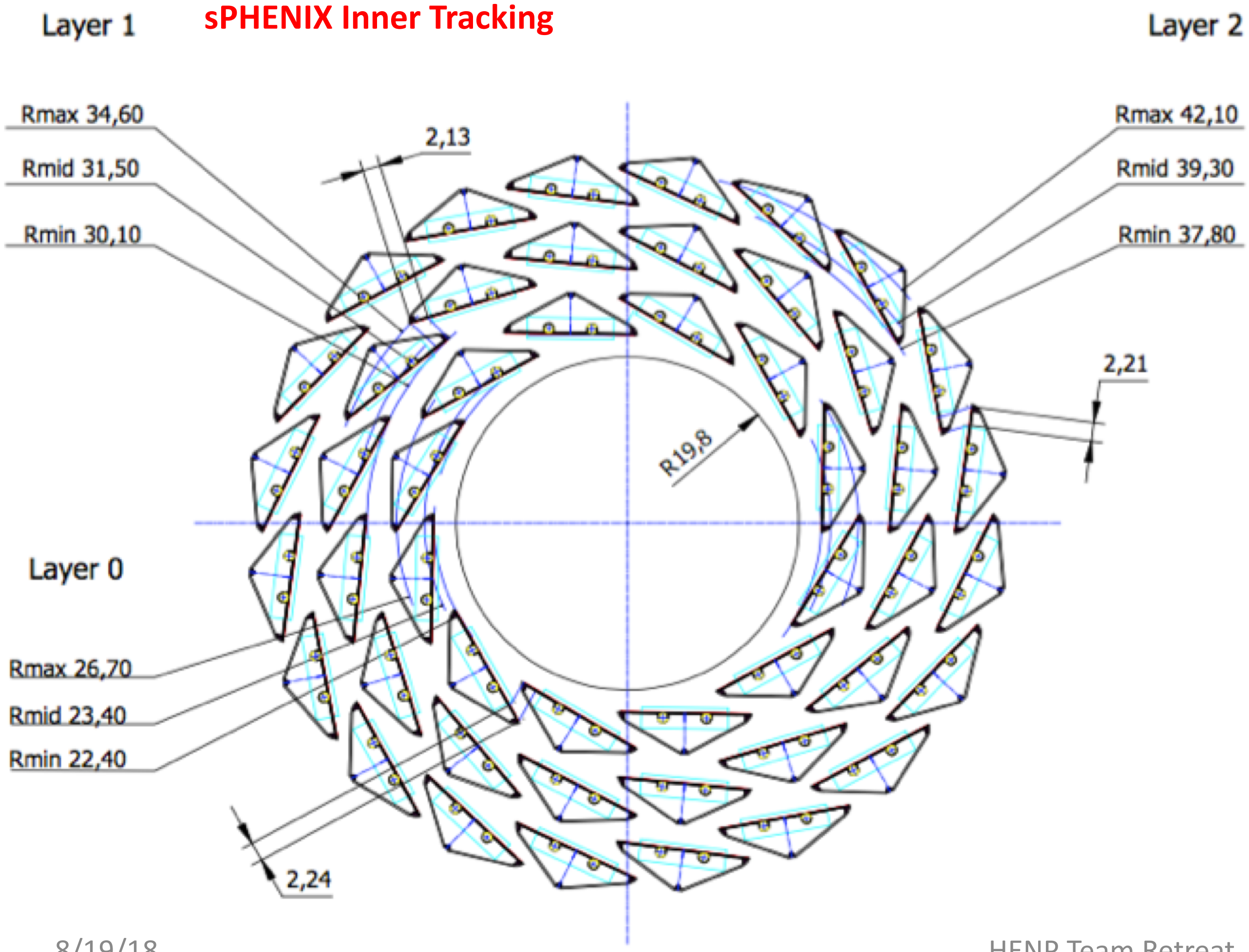
- STAR can't do it, no trigger
- sPHENIX, needs HF trigger for full D/B reconstruction
- Track-based trigger MVTX+INTT+TPC, B-hadron measurements

Very high event multiplicity ~ <1%

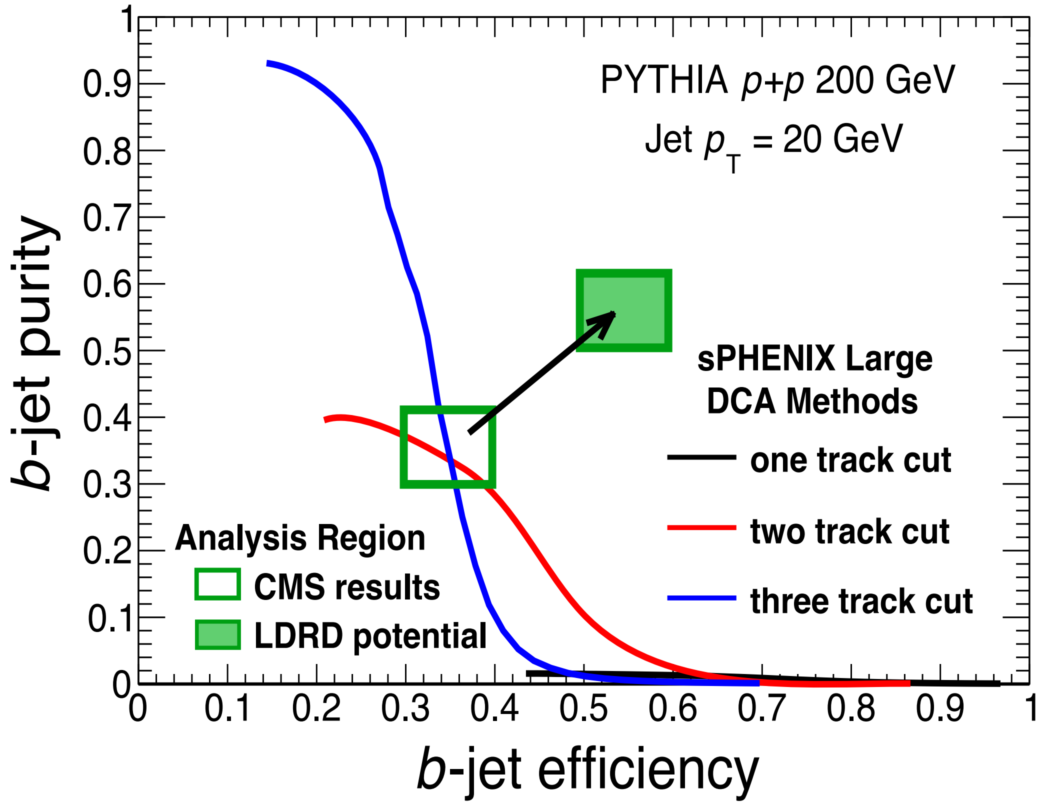




Quadrant based trigger logic: 3+4+5 RUs feed 1 FELIX/Trigger baord



Offline B-tagging



Expected beam spot size

obtained parameters from CAD's web page: http://www.rhichome.bnl.gov/RHIC/Runs/

Mode 2B: $^{197}Au^{79+}$ on $^{197}Au^{79+}$ at 100.0 GeV/nucleon particle energy [Run-11 Au-Au web site]

Summary paper: Summary paper: G. Marr, L. Ahrens, M. Bai, J. Beebe-Wang, I. Blackler, M. Blaskiewicz, J.M. Brennan, K.A. Brown, D. Bruno, J. Butler, C. Carlson, R. Connolly, T. D'Ottavio, K.A. Drees, A.V. Fedotov, W. Fischer, W. Fu, C.J. Gardner, D.M. Gassner, J.W. Glenn, X. Gu, M. Harvey, T. Hayes, L.T. Hoff, H. Huang, P.F. Ingrassia, J.P. Jamilkowski, N. Kling, M. Lafky, J.S. Laster, C. Liu, Y. Luo, M. Mapes, A. Marusic, K. Mernick, R.J. Michnoff, M.G. Minty, C. Montag, J. Morris, C. Naylor, S. Nemsures, S. Polizzo, V. Ptitsyn, G. Robert-Demolaize, T. Roser, P. Sampson, J. Sandberg, V. Schoefer, C. Schultheiss, F. Severino, T. Shrey, K. Smith, D. Steski, S. Tepikian, P. Thieberger, D. Trbojevic, N. Tsoupas, J.E. Tuozzolo, B. Van Kuik, G. Wang, M. Wilinski, A. Zaltsman, K. Zeno, and S.Y. Zhang, "RHIC performance for FY2011 Au+Au heavy ion run", proceedings International Particle Accelerator Conference 2011, San Sebastian, Spain, pp. 1894-1896 (2011).

Beam operation: 05/02/2011 - 06/20/2011 [49 days total, 45 days for physics]

Run Coordinator: Greg Marr

Major accomplishments and events: changed frequency of Blue vertical stochastic cooling system to avoid cross-talk between Blue and Yellow vertical systems; Yellow longitudinal stochastic cooling kicker repaired (became stuck in Run-10); installed new horizontal stochastic cooling pick-up; 4 days setup to physics; 4 h store length; EBIS Au beam tested in Booster

Achieved beam parameters:

no of bunches	ions/bunch [10^9]	β^* [m]	emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week} [nb^{-1}]
111	1.30	0.75	15 → 10	50×10^{26}	30×10^{26}	1.0

injection: γ = 10.52   store: γ = 107.396

Total delivered integrated luminosities:

experiment	β^* [m]	luminosity [nb^{-1}]	luminosity [rel. to Run-10]
PHENIX	0.75	4.97	1.0×
STAR	0.75	4.82	0.9×

Time in store: 59% of calendar time

definition of emittance
$\varepsilon = (\beta\gamma) * (6\sigma^2)/\beta^*$
$(\beta\gamma)$: relativistic factors
σ : RMS beam size
β^* : amplitude function
ε :95% normalized emittance

RUN11 AuAu 200GeV

β^* = 0.75 m (PHENIX)

$$\sigma^{lumi} = \frac{\sigma^{beam}}{\sqrt{2}} = \sqrt{\frac{\epsilon\beta^*}{2*6\gamma}} = 76\ \mu m\ \ (\varepsilon = 10\ \mu m)$$
$$= 93\ \mu m\ \ (\varepsilon = 15\ \mu m)$$

RUN12 pp 200GeV

β^* = 0.85 m (PHENIX)

$$\sigma^{lumi} = \frac{\sigma^{beam}}{\sqrt{2}} = \sqrt{\frac{\epsilon\beta^*}{2*6\gamma}} = 115\ \mu m\ \ (\varepsilon = 20\ \mu m)$$
$$= 129\ \mu m\ \ (\varepsilon = 25\ \mu m)$$

Average 122um

ASANO 2012/07/17

will check vernier scan result