The sPHENIX MAPS-based vertex detector (MVTX)

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Abstract

The sPHENIX detector at BNL's Relativistic Heavy Ion Collider (RHIC) will study QGP properties with heavy bottom quarks produced in high-energy heavy ion collisions. Bottom quarks are expected to offer a unique set of observables due to the large bottom quark mass, but need to be measured across an unexplored kinematic regime, particularly at low p_T where the expected mass-dependence effects are large but the underlying backgrounds are also high. We will use a three-layer Monolithic-Active-Pixel-Sensor (MAPS) based vertex detector, originally developed for the ALICE ITS upgrade, to identify the signal and suppress the background. The MVTX will serve as the innermost tracking system of sPHENIX, covering 2 cm to 4 cm radially and a pseudorapidity range of $|\eta| < 1.1$. The very fine 27 μm x 29 μm pixels allow us to identify B-decay secondary vertices and B-jets in heavy ion collisions with high efficiency and high purity. In this presentation, we show the current status of R&D efforts towards custom readout and mechanical systems to integrate the MVTX detector into the sPHENIX system.

Physics Motivation

The MVTX detector will enable us to use heavy quarks (charm and beauty) to probe the properties of QGP at RHIC. Exploring mass dependence of various observables in open charm and open bottom production offers insight into the inner workings of the QGP, allowing us to derive key QGP parameters and control systematic uncertainties in those measurements.
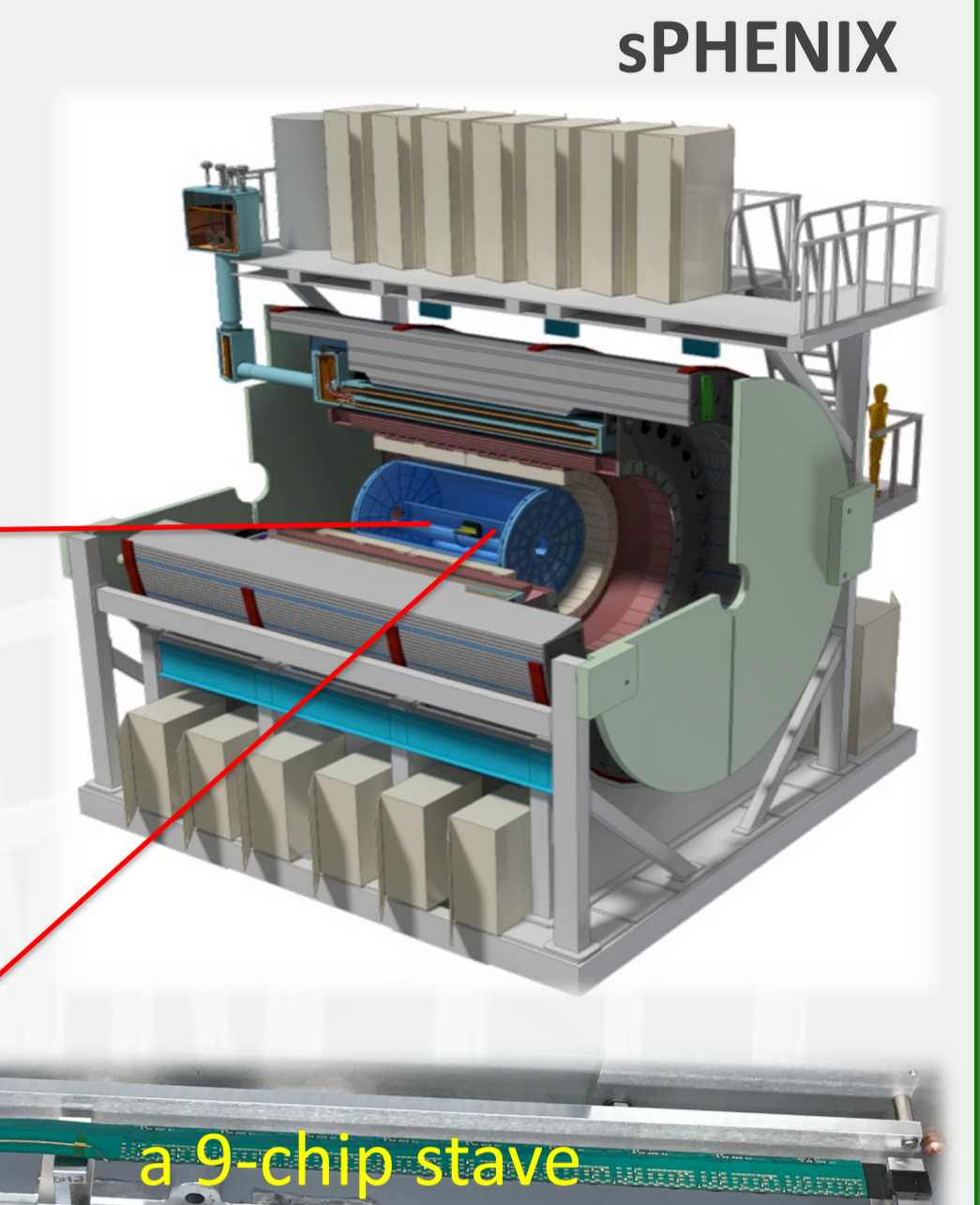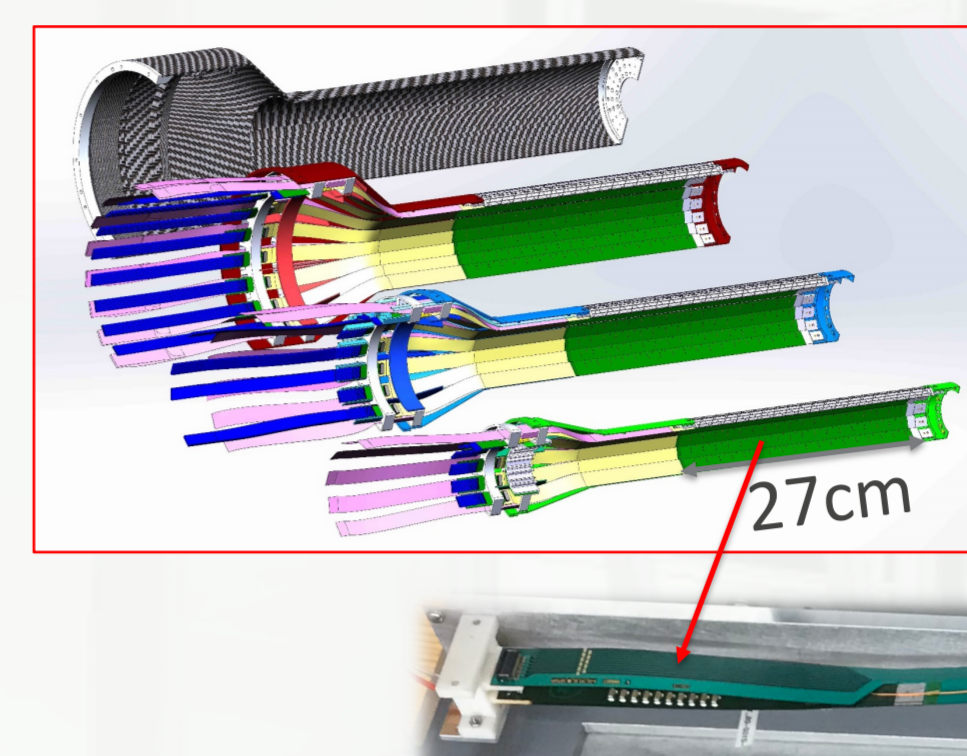

Open HF and Jet Measurements

B-tagging in p+p and Au+Au: displaced tracks and 2nd vertex mass
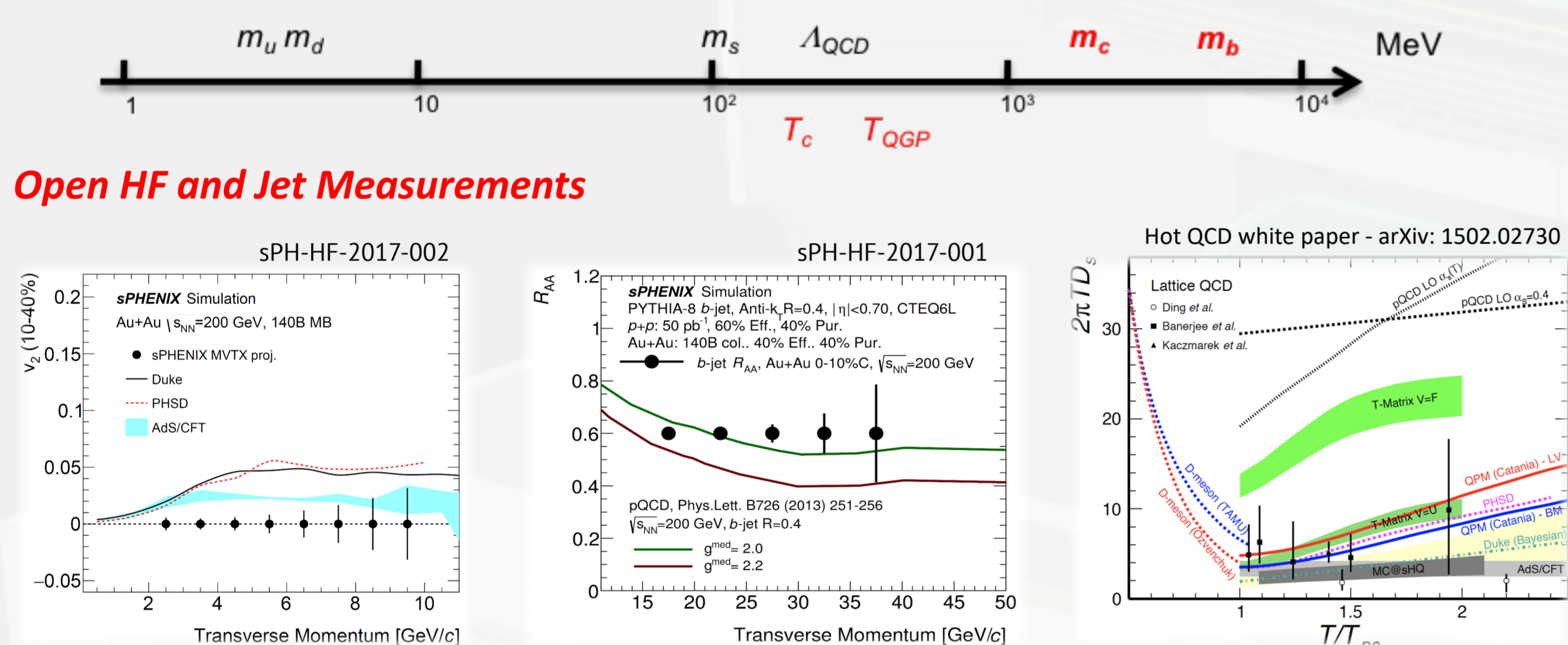
MVTX Detector Design

sPHENIX

MVTX detector:

- 3-layer MAPS sensors
- Full azimuthal coverage: 2π
- $|\eta| < 1.1$
- R: 2.5 – 4.0 cm
- 48 9-chip-staves

	R_min (mm)
Layer 0	24.61
Layer 1	31.98
Layer 2	39.93

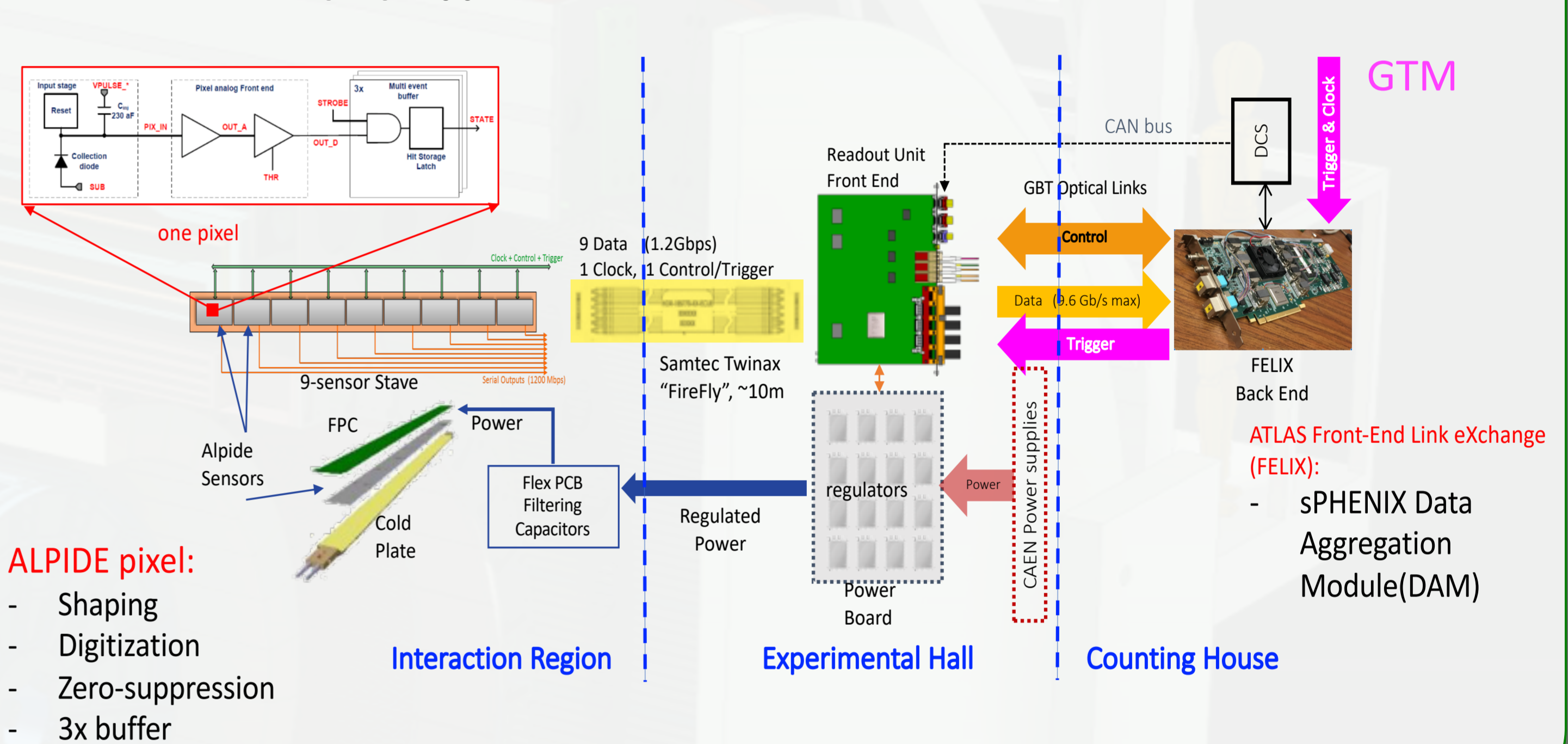**MVTX Detector Sensors**

27cm

a 9-chip stave

MVTX Readout Integration

One Readout Unit (RU) per stave, 48 total
- 9 x 1.2 Gb/s firefly links, 1 clock, 1 control
- 3 GBT optical to FELIX per RU

8 RUs per FELIX, 6 FELIX in total
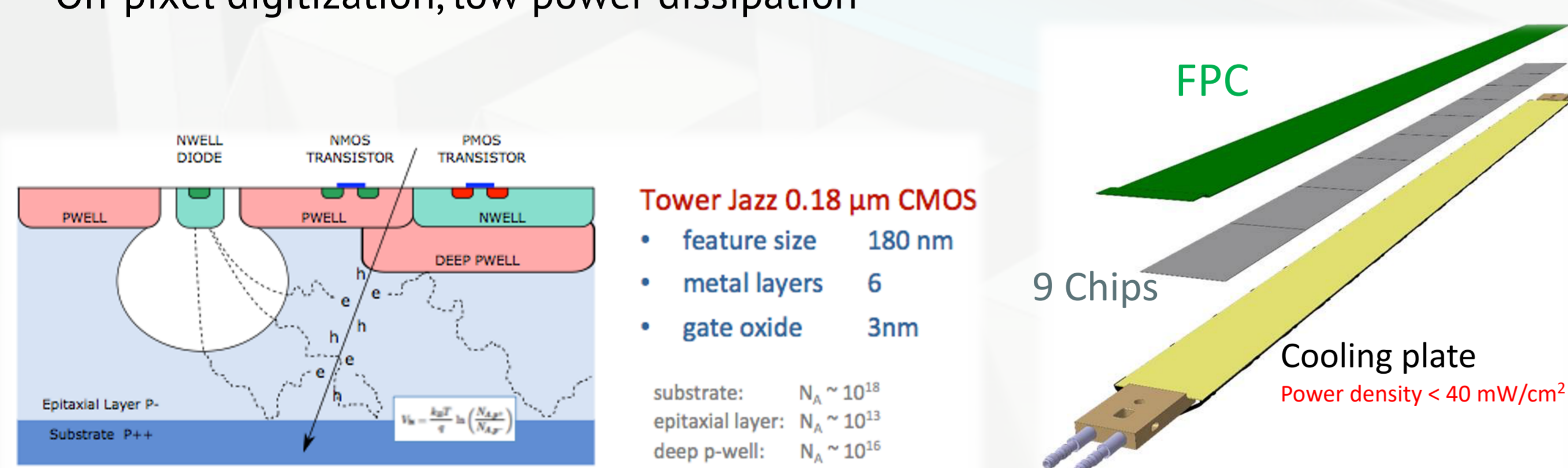
One Power Unit (PU) supports 2 RUs and 2 Staves

All sensor stave and readout electronics hardware designs are final and fully tested, ready for production or already produced

ALPIDE pixel:
- Shaping
- Digitization
- Zero-suppression
- 3x buffer

ATLAS Front-End Link eXchange (FELIX):
- sPHENIX Data Aggregation Module(DAM)

Interaction Region   Experimental Hall   Counting House

MVTX Performance from Simulations

Advantages of ALICE MAPS (ALPIDE):

- Very fine pitch (27x29 μm^2)
- High efficiency (>99%) and low noise (<10^{-6})
- Time resolution, as high as ~5 μs
- Ultra-thin/low mass, (50μm)
- On-pixel digitization, low power dissipation

A 9-chip MAPS stave:
- 0.3% X$_0$,
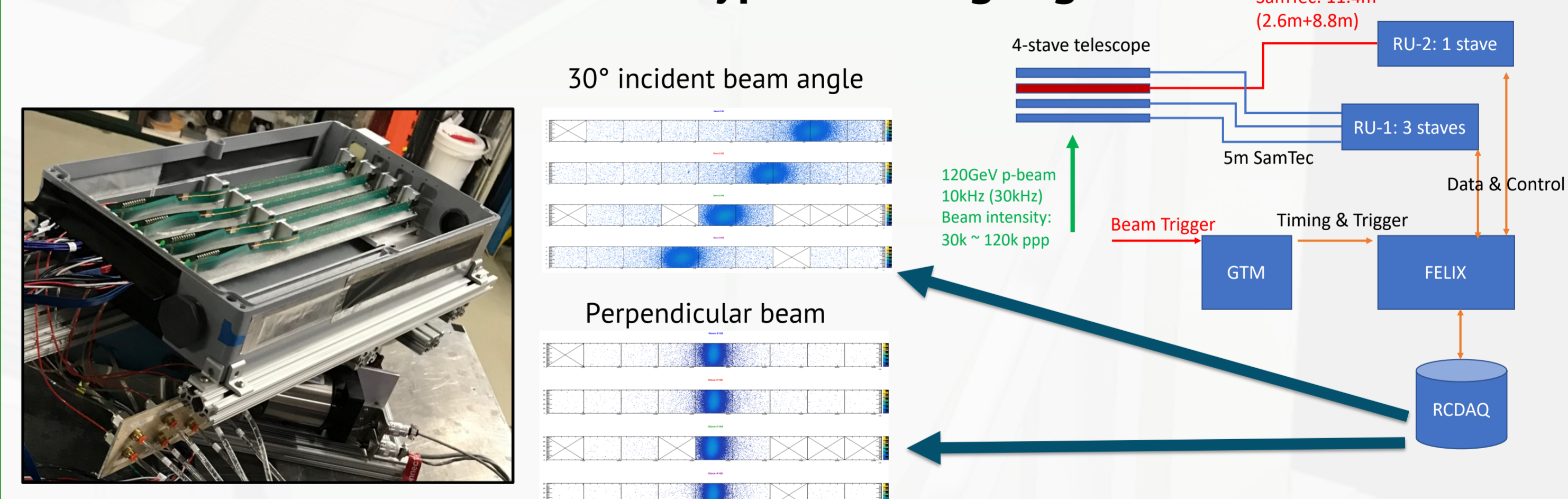- active area (1.5 x 3 cm^2) x 9

FPC

9 Chips

Cooling plate
Power density < 40 mW/cm^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: $N_A \sim 10^{18}$

MVTX Prototype R&D Highlights

30° incident beam angle

Perpendicular beam

- A MVTX prototype telescope made of 4 production sensor staves, with the final readout electronics (RU, FELIX, PU), was tested during test beam runs using 120GeV proton beams at Fermilab in the summer of 2019.
- With the test beam data, we have verified the performance of all hardware, from sensor staves, high-speed readout cables to the readout electronics.
- Work to implement new features and improve existing firmware is in progress.
  - Implementation of slow control communication with the front-end electronic.

Summary and Outlook

- 84 staves (full 3-layer MVTX and full spare of inner two layers) production restarted after COVID-19 pandemic lockdown at CERN. At least 48 staves expected to be ready for the starting of the MVTX assembly in early of 2021.
- 60 frontend RU produced; FELIX and PU production in preparation.
- Mechanical support carbon structure preliminary design completed, in the process of vendor-selection for pre-production.
- Final installation in mid 2022, ready for sPHENIX day-1 physics in 2023.
- Next test beam runs to test the readout capabilities of an independent MVTX readout chain (8 Staves + 8 RUs + 1 FELIX) and the new features in the latest firmware version are programmed for later of this year.