sPHENIX Director's Review
MVTX Sensors/Staves/Assembly

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April 9–11, 2019

BNL

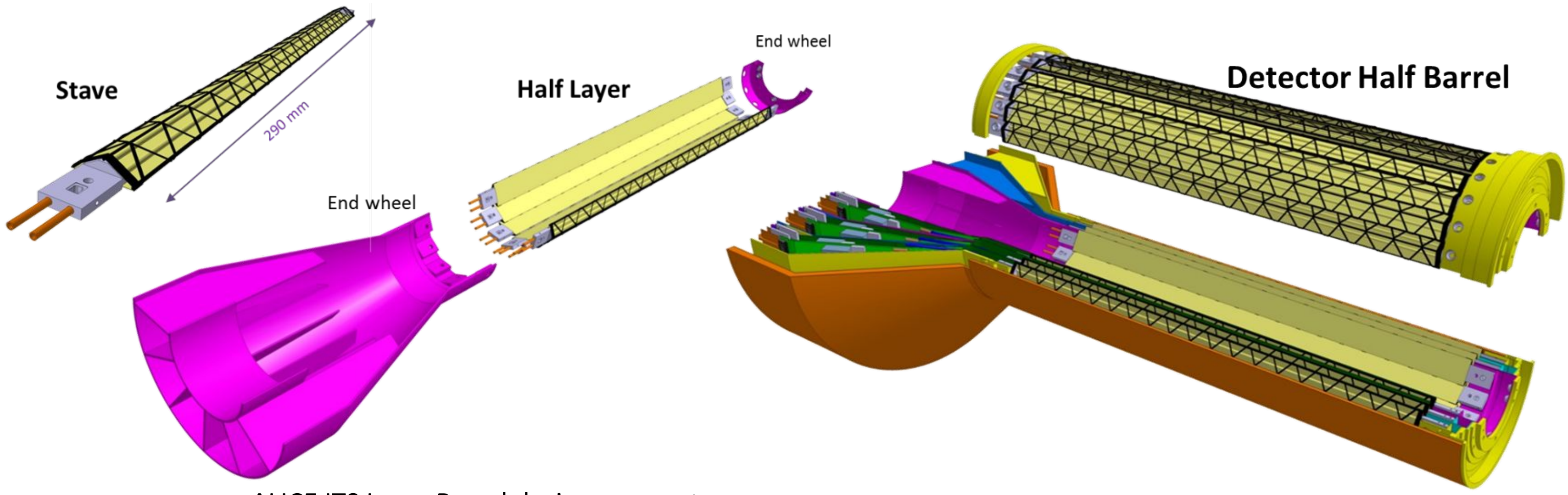
The L3 Component

- Staves (3.2.3.1)
  - Transportation from CERN to LBNL
  - Reception test & QA
  - Storage at LBNL
- Carbon composite structure (3.2.3.2)
  - Manufacture End Wheels, CYSS Cylindrical Structure, Service Barrel
    - Design and manufacture required tooling for carbon composite manufacturing
- Barrel assembly (3.2.3.3)
  - Assemble layers and two Half-Barrels
  - Test and qualification (both at LBNL and after shipping to BNL)
  - Metrology
  - Transportation to BNL
- MAPS power system (3.2.2.4)
  - Power boards
    - Manufacture, assemble, test power boards for MVTX
  - Power supplies
    - Procure and test COTS power supplies (from CAEN)
  - Integrate power system
    - Assemble into rack, cabling, test (both at LBNL and after shipping to BNL)

Technology Choices for MVTX

- Tracker design requirements:
  - **Short integration time** window to minimize the event pile-up
  - **Small segmentation** for good spatial resolution and to keep the occupancy low
  - **Reduction of material budget** to minimize multiple-scattering track distortion
  - **First detection layer** as **close** as possible to the beam line
  - **Three layers** give some redundancy against failure of detector modules
  - **Radial distance** between the three layers as small as possible
- Technology/design choices:
  - Monolithic Active Pixel Sensors (MAPS) □
    - Meets the MVTX detector requirements
    - Suitable for collider experiments in similar conditions (STAR HFT)
  - ALICE ITS Upgrade Inner Barrel design □
    - Meets MVTX design goals
    - Compatible with sPHENIX space constraints
    - ALICE timeline matches the sPHENIX schedule
- Leverage the ITS Upgrade R&D for:
  - Sensor design and production
  - Inner Barrel and Mechanics layout
  - Stave production & test
  - Power system design
  - Readout system

ALICE ITS Upgrade Inner Barrel Detector Layout

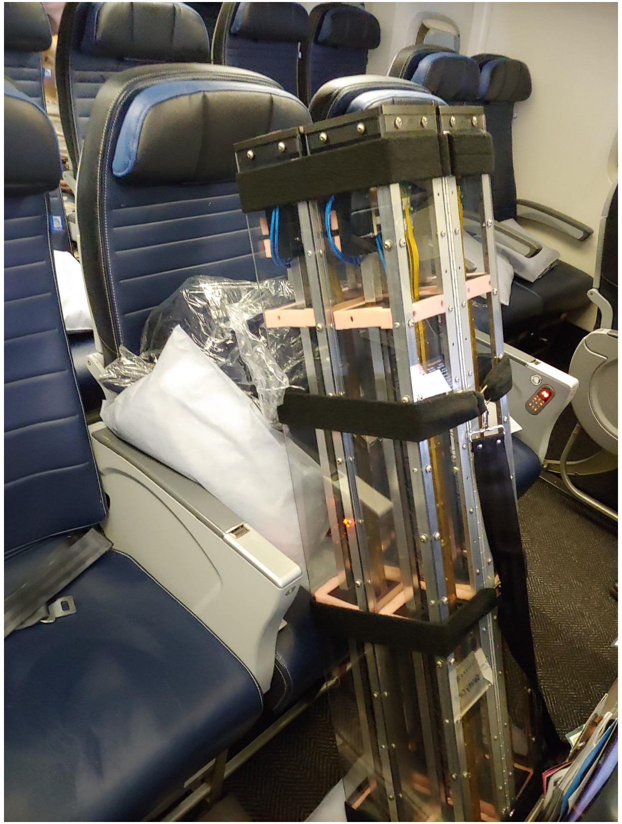


ALICE ITS Inner Barrel design parameters

	Layer 0	Layer 1	Layer 2
Radial position (min.) (mm)	22.4	30.1	37.8
Radial position (max.) (mm)	26.7	34.6	42.1
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

MVTX is adopting the ALICE ITS inner barrel design with small sPHENIX modifications.

Stave transportation



ALICE ITS middle-layer staves

Shipping from LBNL to CERN

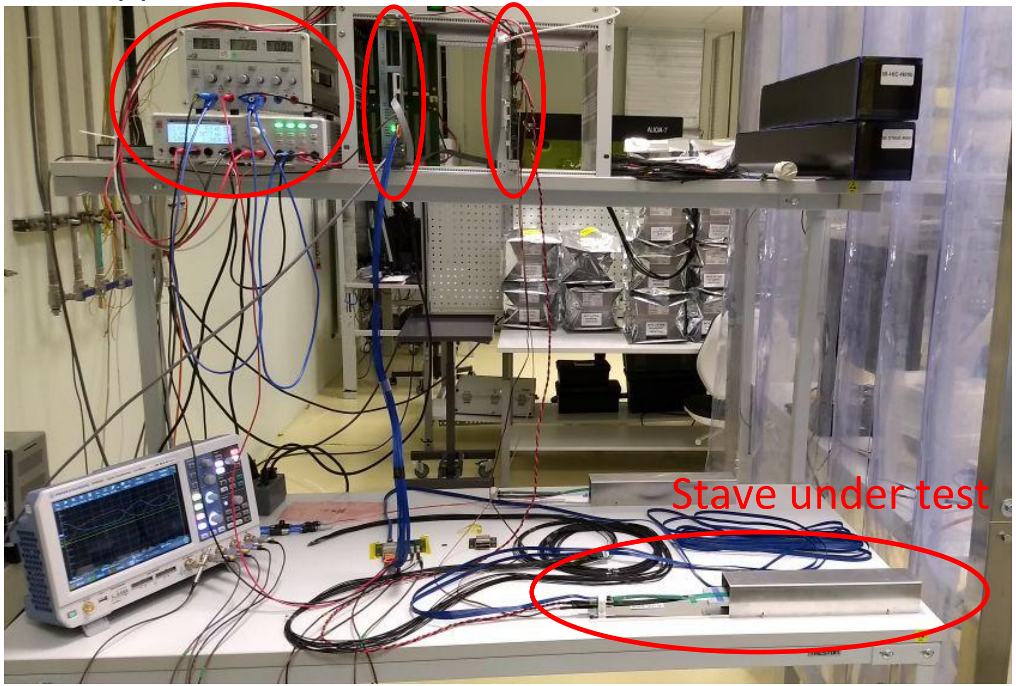
Will do similar things but different design for MVTX

4 shipments for MVTX

Staves – QA plan – ITS testing system adopted by MVTX

ITS stave testing hardware (all run by testing program)

Power supplies RDO board Power board



Staves – QA plan

Tests run on sensors / staves

Parameter	Gold	Silver	Bronze	Not working/ No back bias	
Iddd clocked	500 to 850 mA	otherwise	-	--	→ Power Test
Idda clocked	120 to 250 mA	otherwise	--	--	
Ibb @ 3V	Up to 10 mA	otherwise	--	--	
Max. bias voltage	4V	--	--	Otherwise	
FIFO errors	0	--	--	Otherwise	→ FIFO Test
FIFO exceptions	0	--	--	Otherwise	
Timeouts	0	-	-	Otherwise	→ Digital Scan
Corrupt events	0	-	-	Otherwise	
Bad pixels per chip	< 50	< 2100	< 5243	Otherwise	
Pixels without threshold per chip	< 5243	< 26214	< 52429	Otherwise	→ Threshold Scan
Dead pixels per chip	< 50	< 2100	< 5243	Otherwise	
Average HIC noise	< 10 e	Otherwise	--	--	
Deviation of chip threshold	< 20%	< 30%	Otherwise	--	
Threshold RMS	< 30 e	--	Otherwise	--	
Threshold RMS / Threshold mean	< 0.3	--	< 0.5	Otherwise	

Example for building ML/OL modules but the tests run are the same for all sensors

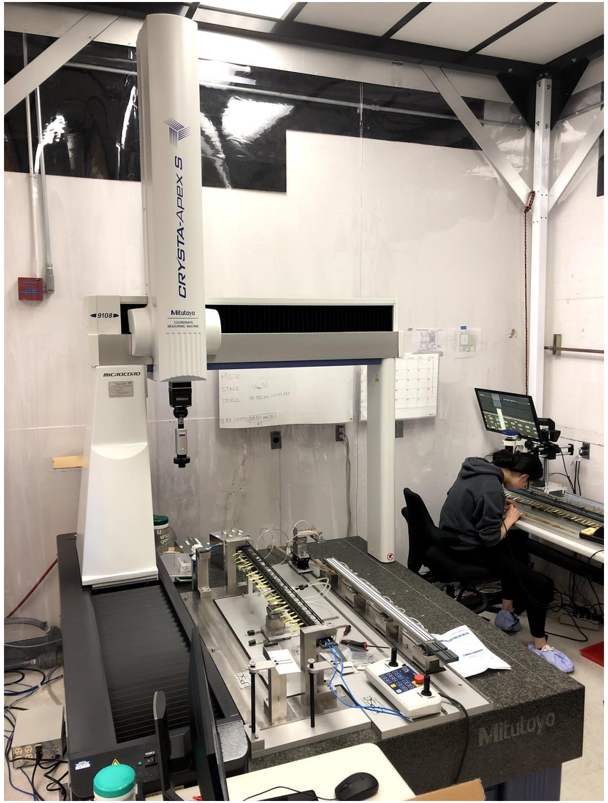
Staves – QA plan inspections/test records

- The MVTX will receive fully tested staves from ALICE.
- The full history including testing results and measurements of all of the parts of the stave are preserved in the ITS databases.
- This data is available for download.
- For simplicity, we will continue using the ALICE database for the testing that happens at LBNL. The software is already set up for this interface.
- After completion of all testing, the full set of data for the MVTX staves could then be pulled from the ALICE server.
- In any case, a full record of building and testing results will be preserved.

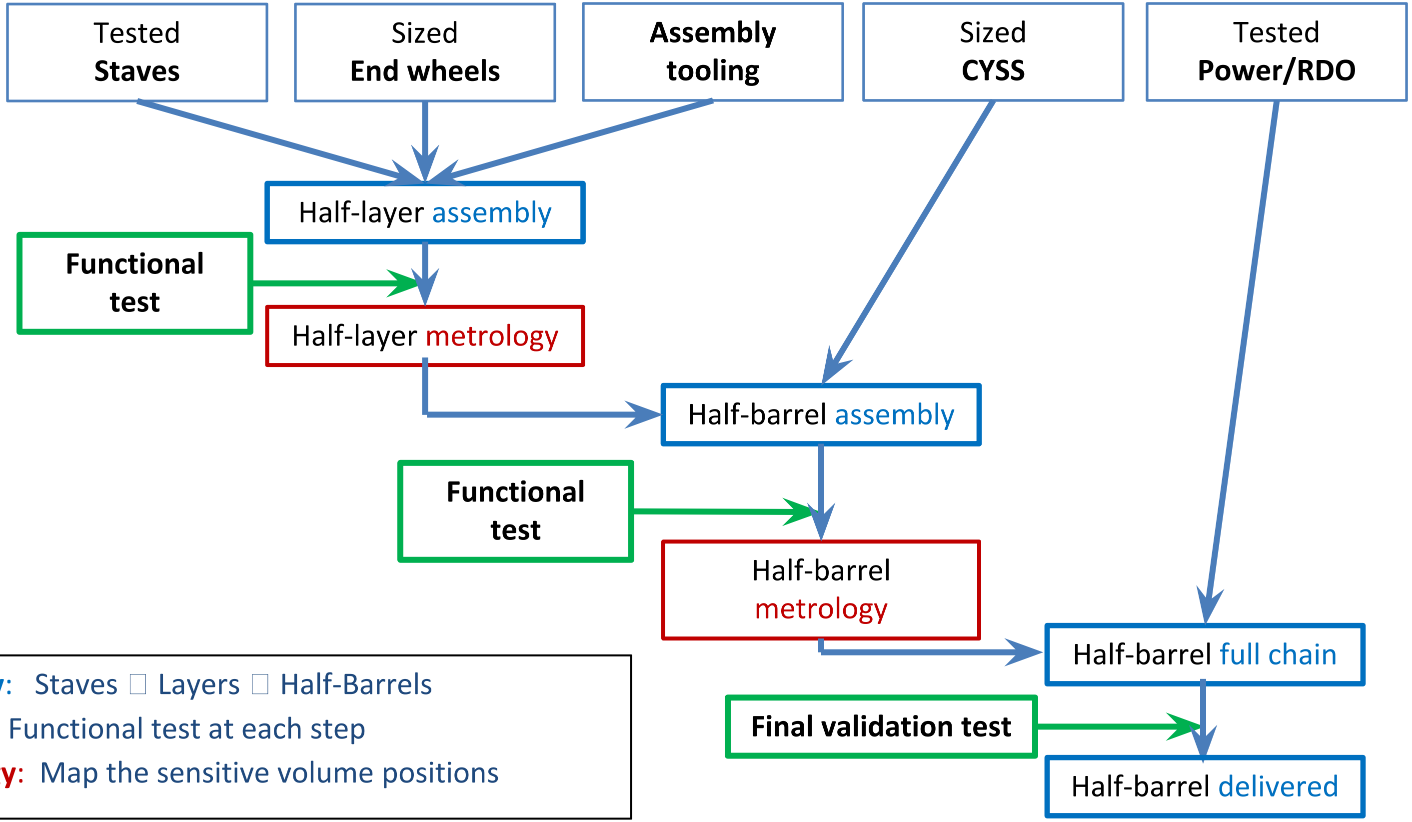
Carbon composite structure and detector assembly

Taken from ALICE ITS

LBNL facility for testing, assembly, metrology, etc.



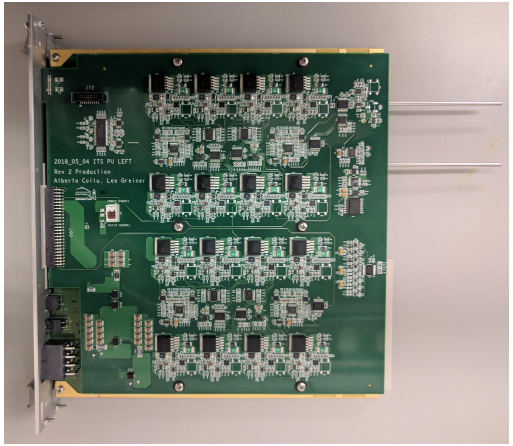
Barrel Assembly - Procedure



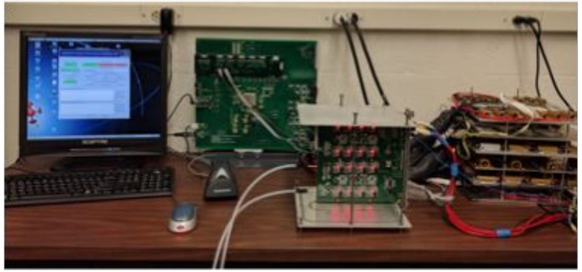
- **Assembly**: Staves □ Layers □ Half-Barrels
- **QA**: Functional test at each step
- **Metrology**: Map the sensitive volume positions

Power system

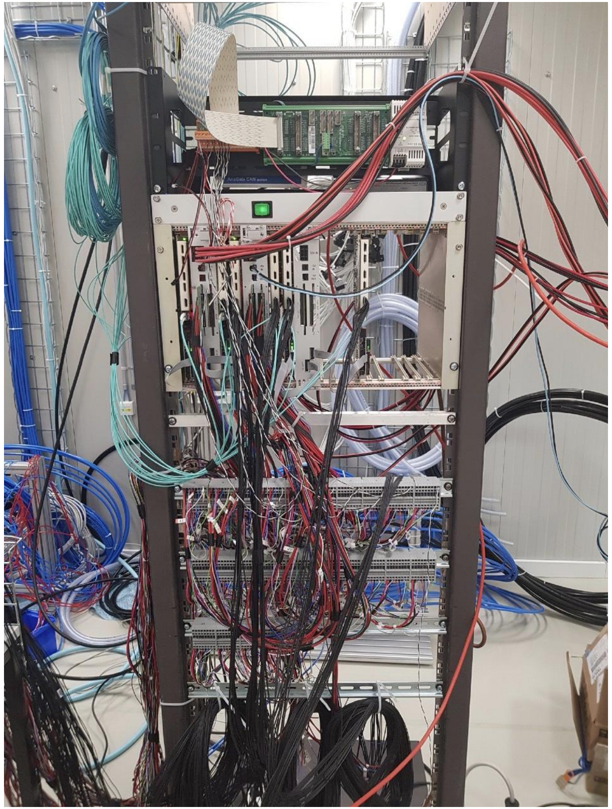
Power board



Test system at LBNL



Power boards & RDO in rack

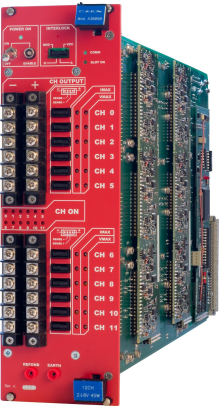


Power supplies

Taken from ALICE ITS

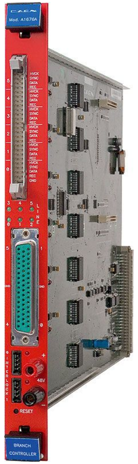
A3009B
Eur 7750
8V/9A/45W
12-ch floating

3.3V output
that powers 1.8V
digital and
analog rails



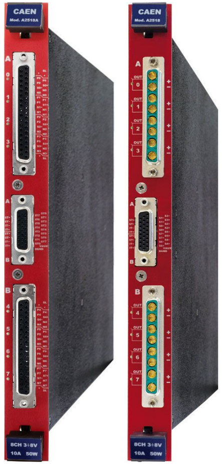
EASY3000
Eur 2850
Crate for hostile
area

A1676A
Eur 1470
Branch controller
Up to 6 crates



A3486
Eur 13000
220/400Vac->48Vdc
2ch/2kW / 1ch/4kW

A2518
Eur 2050
8V/10A 8-ch
individual floating



SY4527
Eur 5900
Basic 600W model

LBNL Scope

- Staves (3.2.3.1)
  - Transportation from CERN to LBNL
  - Reception test & QA
  - Storage at LBNL
- Carbon composite structure (3.2.3.2), depend on LANL/MIT mechanical design
  - Manufacture End Wheels, CYSS Cylindrical Structure, Service Barrel
    - Design and manufacture required tooling for carbon composite manufacturing
- Barrel assembly (3.2.3.3), depend on MIT assembly and metrology tooling
  - Assemble layers and two Half-Barrels
  - Test and qualification (both at LBNL and after shipping to BNL)
  - Metrology
  - Transportation to BNL
- MAPS power system (3.2.2.4)
  - Power boards
    - Manufacture, assemble, test power boards for MVTX
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  - Integrate power system
    - Assemble into rack, cabling, test (both at LBNL and after shipping to BNL)
- Detector commissioning — shared responsibility

L3 Collaborators (dependencies)

- Carbon composite structure (3.2.3.2)
  - Depend on LANL/MIT to finalize the mechanical design of the final detector
    - LBNL feeds back to ensure manufacturability. Subject to LBNL review/approval
    - LBNL fabricate the carbon composite structure
    - LBNL design and manufacture required tooling for carbon composite manufacturing

- Barrel assembly (3.2.3.3)
  - Depend on MIT to complete the design and fabrication of assembly and metrology tooling
  - Assembly procedure and tooling subject to LBNL review/approval

Schedule Drivers

- Staves (3.2.3.1)
  - CERN stave production
  - Funding to start test/storage preparation (3 months lead time)
- Carbon composite structure (3.2.3.2)
  - Completion of MVTX detector design
- Barrel assembly (3.2.3.3)
  - Completion of carbon composite structure (1st set of end-wheels)
  - Assembly and metrology tooling (MIT)
- MAPS power system (3.2.2.4)
  - PCBA manufacturer's speed
  - CAEN lead time

And funding in general

Cost Drivers

- Staves (3.2.3.1)
  - Airfare
  - Transportation/storage design and manufacturing cost
  - Test system
- Carbon composite structure (3.2.3.2)
  - MVTX detector design
    - Impacts significantly the manufacturability, cost, tooling etc.
  - Materials and machining
  - Engineering and technician time
- Barrel assembly (3.2.3.3)
  - Technician time
- MAPS power system (3.2.2.4)
  - PCBA manufacturing cost
  - CAEN price tag
  - Technician time

Status and Highlights

- Staves (3.2.3.1)
  - Waiting on CERN production
  - Waiting on funding to start test/transportation/storage preparation
- Carbon composite structure (3.2.3.2)
  - Waiting on MVTX detector design to complete
  - Recent workshop at LBNL cleared many issues on manufacturability and cost due to the design choices. Points to new design direction.
- Barrel assembly (3.2.3.3)
  -
- MAPS power system (3.2.2.4)
  - ALICE ITS power boards in production. MVTX will copy production boards.

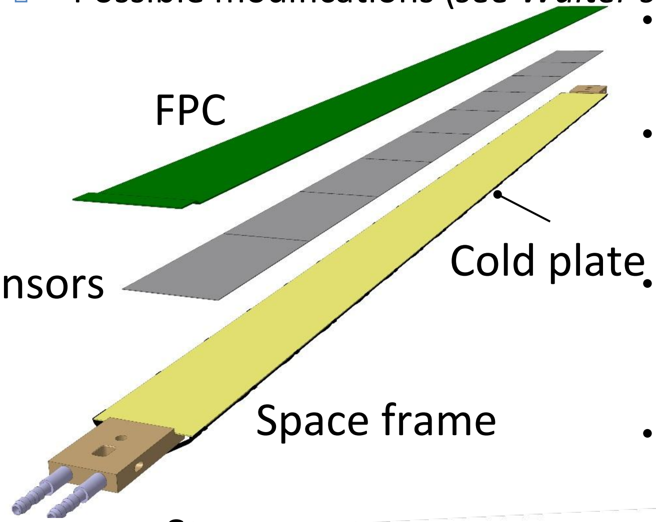
Issues and Concerns

- Staves (3.2.3.1)
  - Funding to start test/transportation/storage preparation (3 months lead time)
- Carbon composite structure (3.2.3.2)
  - The completion of MVTX detector design
  - Funding to pay for LBNL engineers for consultation (ensure manufacturability)
- Barrel assembly (3.2.3.3)
  - Schedule on the completion of carbon composite structure (1st set of end-wheels)
- MAPS power system (3.2.2.4)
  - No immediate concerns

Back Up

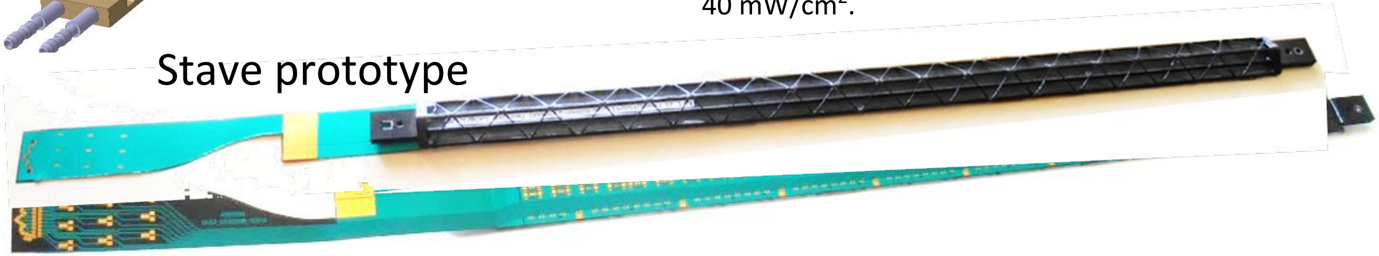
Staves - General layout

- Stave design developed by ALICE at no cost for MVTX project
- Possible modifications (*see Walter's talk*)



- **Staves:** detector modules consisting of a Hybrid Integrated Circuit (HIC) mounted on carbon fiber mechanical support structure
- **HIC:** a row of 9 ALPIDE sensors wire-bonded to a Flexible Printed Circuit (FPC). Area covered by the chips: 15x271.2 mm^2, including a gap of 150 μm between adjacent chips.
- **Mechanical support:** single light structure composed of a Space Frame, providing the required stiffness, and a Cold Plate, high-thermal conductivity carbon fiber sheet with embedded polyamide cooling pipes.
- **Heat Dissipation** – The ALPIDE sensors dissipate only 40 mW/cm^2.

Stave prototype



Staves - Specification

- *MVTX requirements (from Table 1 in proposal)*

Item	Requirement
Acceptance	Vertex $\|z\| < 10$ cm, $\|\eta\| < 1$, full azimuthal coverage
Readout speed	Matching the sPHENIX DAQ 15 kHz event trigger rate
DCA resolution	$< 50\ \mu$m for charged pions at $p_T = 1$ GeV/c
Tracking efficiency	$> 80\%$ efficiency for charged pions at $p_T = 1$ GeV/c in the 10% most central Au+Au collisions

Table 1: Summary for the vertex detector requirements

Acceptance - Covered by the ITS inner stave geometry.

Readout speed – Sensors/staves designed and validated for 50 kHz ALICE ITS readout.

DCA resolution – The staves X/X_0 (0.3%) and geometry are effectively the same as the ALICE ITS inner barrel, so DCA resolution is similar at ~ 25 µm.

Tracking efficiency – The ALPIDE measured sensor efficiency for MIPs is >99% for a large range of threshold settings (for ITS doses, more later).

Issues and Concerns for this director's review

- Management adhering to the CDx gates
  - Would not appear to allow funding in time to carry out the tasks as scheduled. How do we resolve this?
- Using sPHENIX template/logo for MVTX?
- Reporting requirements?

Staves – Specification/radiation tolerance

Expected radiation levels in ALICE based on physics program after LS2:

- IP collisions: 13nb^{-1} Pb-Pb + 50nb^{-1} p-Pb + 6pb^{-1} pp
- Beam-gas interactions: scales with vacuum pressure

ITS

Element	Radius [cm]	TID [krad]	NIEL [1Mev n/cm^2]	Number of chips
L0	2.2	273	1.7×10^{12}	108
L1	2.8	221	1.2×10^{12}	144
L2	3.6	134	8.0×10^{11}	180
L3	20	10	1.0×10^{11}	2688
L4	22	10	1.0×10^{11}	3360
L5	41	2.4	8.3×10^{10}	8232
L6	43	2	8.1×10^{10}	9408

MVTX*

radius	TID	NIEL
2.6	1060	6.6×10^{12}
3.4	650	4.0×10^{12}
4.1	460	2.8×10^{12}

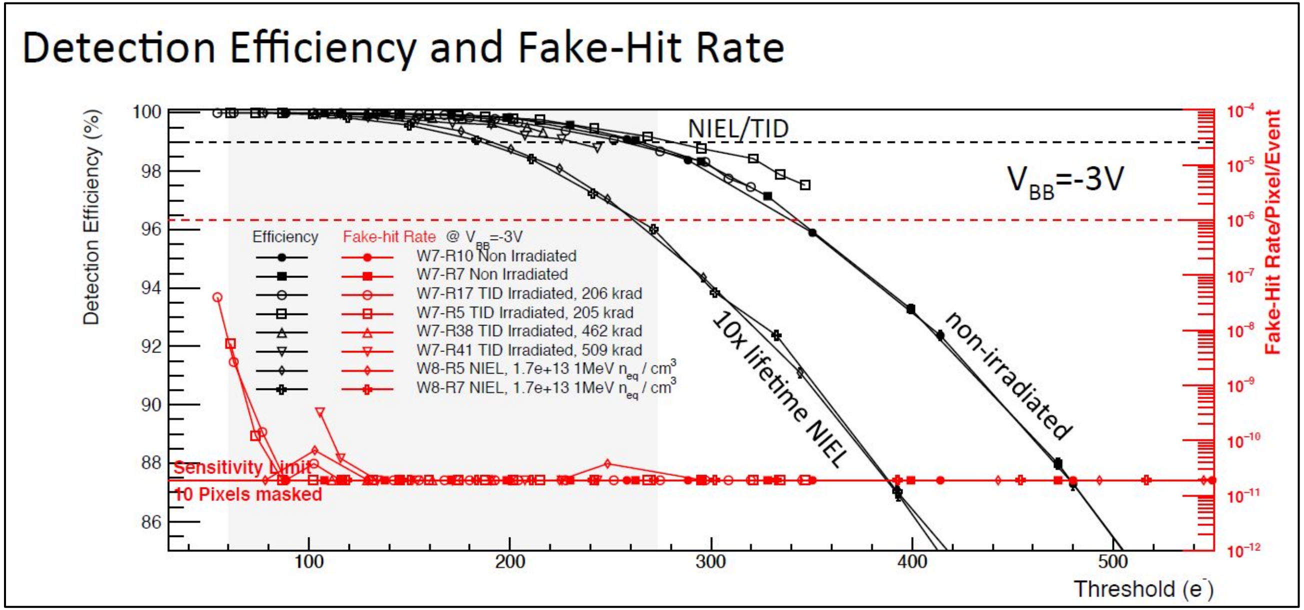
Outer Barrel: 98.2 % of all chips, low radiation levels

- For details see: *Radiation Dose and Fluence in ALICE after LS2*, W. Riegler et al., ALICE internal note (PUB-2443)

sPHENIX TID and NIEL radiation levels (5 years) are shown above.

* From M.Liu calculation 2017_07_11

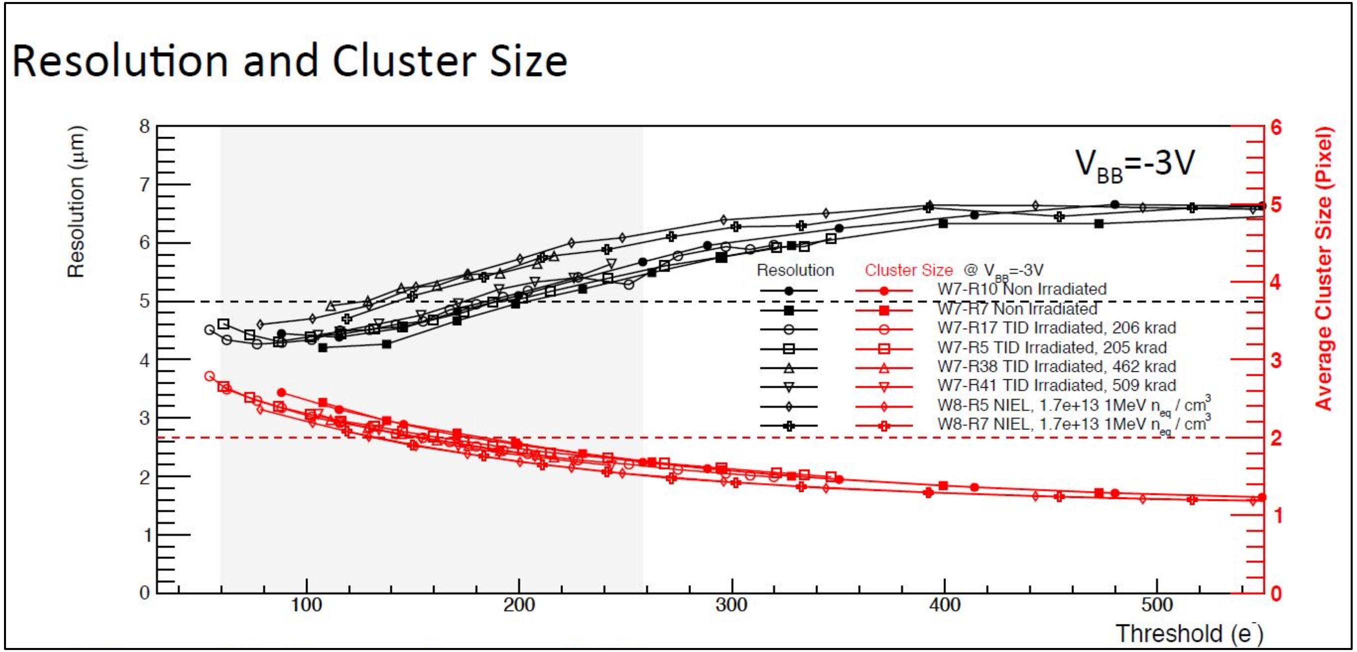
Staves – Specification/radiation tolerance



From L. Musa – 7/26/2017 DOE review

- Sensors have been tested to full MVTX NIEL levels and ~1/2 of the TID.
- TID mitigation strategy – 36 spare staves are available (2 full inner layers + 8 spares) for replacement of staves that show degradation.

Staves – Specification/radiation tolerance



From L. Musa – 7/26/2017 DOE review

- Resolution and cluster size are only moderately affected by radiation and meet requirements

Staves – fabrication, testing and acceptance

- Responsibility - The RNC group at LBNL has accepted responsibility for:
  - The tracking of the stave production at CERN.
  - Reception testing of staves fabricated at CERN.
  - The assembly of the staves into tested and working detector halves.
  - The shipment of these halves to BNL.
  - Reception testing at BNL.
  - Reasonable remediation of any problems that arise in these tasks.

Staves – QA plan

- The full MVTX Stave Acceptance and Detector Construction QA plan is complete in Draft form and available as part of the backup documentation.
- Basic Description:
  - Staves go through an extensive QA/QC regimen as they are constructed at CERN.
    - » Sensors are mechanically checked for size, cracks, and edge integrity, then probe tested and electrically characterized.
    - » The mechanical stave components are fabricated and go through equally established QA checking. The cold plates and space frames are checked for size, shape, pressure and leak testing for the cooling tubes.
    - » The aluminum conductor FPC is dimensionally and electrically checked.
    - » After these components are assembled into a stave. The stave is functionally checked and the sensors are again characterized.
- All of this information is saved into the ALICE ITS database.

Staves – ALICE Fabrication Status

IB HIC/STAVE production summary tables

Assembled HICs	HICs to be bonded	HICs NOK	HICs to be glued	Assembled STAVES	STAVES NOK	STAVES to be tested
57 A001, A004, G002, G005, B005, B006, F002, F003, F005, G003, G004, A006, B001, B002, Q001, Q002, Q003, Q004, Q005, Q006, R001, R002, R003, R004, R005, R006, N001, N003, N004, N005, N006, O001, O002, O003, O004, O005, O006, X001, X002, X003, X004, X005, X006, P002, P003, P004, P005, P006, W001, W002, W003, W004, J002, J003, J004, J005, J006	**4** J003, J004, J005, J006	**13** • F003*: chip 1 damaged • Q005*: chip 6 damaged • R003: R/O failure • R004: high currents, hot spots in chips 4, 5, 7, 8 • N005*: chip 8 damaged • O003: chip 5 very hot (i~766 mA) • X001: CTRL line damaged next to connector • X002: data world dead in all chips • P002: damaged chip 1 after WB • W002: glue seepage on AT • W003: closed eye chip 2 • W004: closed eyes chips 1, 5, 7 • J002: closed eyes chips 2, 3, 7 * used in ageing test	**1** P004 (bronze) # not bonded + no R/O test	**39**	**3** • A001: R/O issue (?) • A004: R/O issue (?) • G002: communication issue (control interface error)	**0**

36 tested STAVES, classification based on R/O test to be confirmed with eye diagram

24 used in half-1 of IB-1

GOLD	SILVER	BRONZE
A006, Q002, Q004, R001, Q003, Q006, N003,N004, R005, G004 19/06/2018	B006, F002, F005, G003, B001, B002, Q001, R002, N001, N006, O002, O005	B005, G005

10 available for half-2 of IB-1 (w/o bronze ones)

GOLD	SILVER	BRONZE
O006, X003, X004, X006	O001, O004, W001, P003, P005, P006	R006, X005

A. Di Mauro – June 18 – ITS Plenary

Summary

- MVTX will extensively leverage the ALICE ITS R&D and production
- The ITS staves meet the MVTX requirements for sensor efficiency, geometry, readout speed and DCA pointing resolution. (CE # 1)
- The NIEL radiation tolerance has been tested and ALPIDE and is sufficient. The TID radiation tolerance has not been tested to full MVTX specification, but spare staves are included for replacement needs. (CE # 1)
- A complete QA plan has been produced and is available. (CE # 5)
- A complete inspection/test record archive plan has been presented and is part of the QA plan. (CE # 6)
- The RNC group at LBNL has taken full responsibility for stave reception testing and detector construction. (CE # 4)
- The ITS stave design is fully mature and in an advanced state of production at CERN. (CE # 7)

Thank you for your attention!