ALICE ITS upgrade

From silicon to detector

Alwina Liu

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Physics 290E

Heavy-ion collisions and the quark-gluon plasma

- Heavy-ion collisions at the LHC produce a quark-gluon plasma
  - Temperature and energy density are high enough for deconfinement; hadrons "melt"
  - QGP existed in very very early universe (up to $\sim 10^{-6}$ seconds, 2×10^{12} K)
- We know some things about QGP
  - Strongly-coupled liquid described by hydrodynamics with extremely low shear viscosity
  - High-energy partons lose energy as they traverse the QGP
- Still many open questions about QGP
  - Effect on hadronization, thermalization, transport properties (and mass-dependence thereof), equation of state

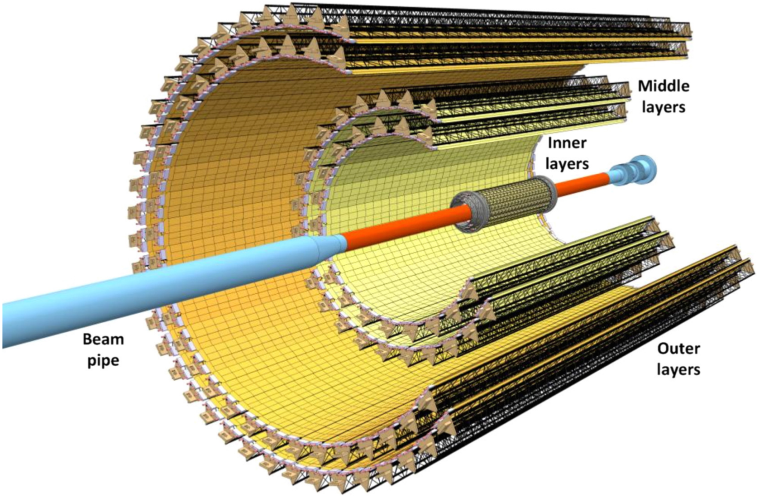
ALICE (A Large Ion Collider Experiment)

- ALICE mainly studies heavy-ion collisions at the LHC to study the properties of the QGP
- Main strengths:
    - Excellent tracking in a high-multiplicity environment
    - Particle identification across wide momentum range
- Many subsystems are being upgraded during the ongoing Long Shutdown 2
    - Significantly improved readout rate which will allow for continuous data taking

ALICE ITS upgrade overview

- Old ITS:
  - 6 layers of mixed silicon technologies (2 layers each of pixel, drift, and strip detectors)
  - located at radii 39–430mm, $|\eta| < 0.9$
  - $1.1\% X_0$ per layer (thickness 350 μm)
  - Pixel size 425×50 μm
- New ITS:
  - 7 layers of pixel detectors (Monolithic Active Pixel Sensors)
  - located at radii 22.4–391.8mm, $|\eta| < 1.22$
  - $0.3\% X_0$ per inner layer (0-2), $1.0\% X_0$ per outer layer (3-6) (thickness 50 μm)
  - Pixel size 30×30 μm

ALICE ITS upgrade overview

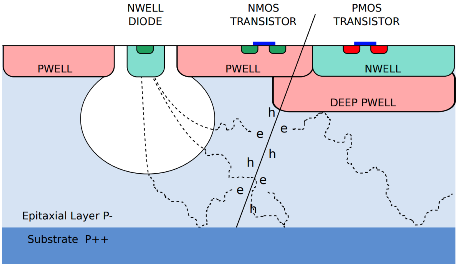


ALICE ITS upgrade: addressing open questions

- Improved primary vertex resolution
- Improved secondary vertex finding
- Improved momentum resolution
- Improved track finding down to very low ("zero") transverse momentum

- Heavy flavor measurements
  - Thermalization and hadronization of heavy quarks in the QGP
  - Heavy quark in-medium energy loss and the mass dependence thereof
- Measurement of dileptons: system lifetime, spacetime evolution, temperature

MAPS



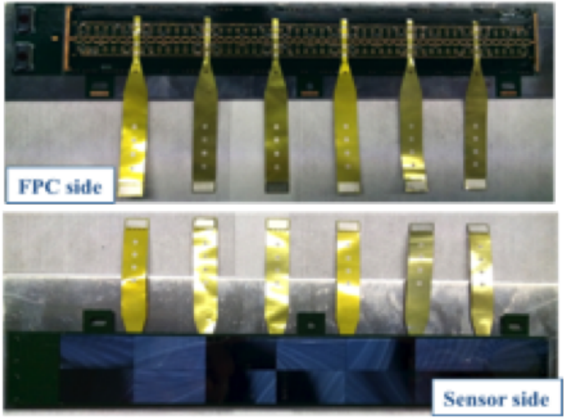
- Sensor and readout electronics integrated onto a single device
- 0.18μm CMOS technology from TowerJazz (now Tower Semiconductor)
- ALPIDE chip: signal is digitized within the pixel, which reduces power consumption and readout time

From silicon to chips

- Begin with wafer: epitaxial layer + substrate, 725 μm thick, 8-inch diameter
- TowerJazz does CMOS process
- Thinning: reducing the thickness of the silicon down to 50μm
- Dicing: reducing the silicon to a chip (die) size of 15mm$\times$30mm
- Inspect and characterize each chip: the highest-quality ones become part of the inner barrel, while the less-good-but-good-enough ones become part of the outer barrel

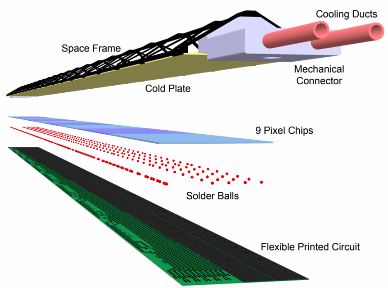
Hybrid integrated circuit (HIC)

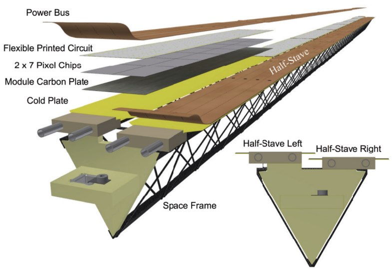
- Chips are bonded onto a Flexible Printed Circuit (FPC) to form a HIC
- Precisely line up the chips, then align the FPC, then bond chips to FPC
- The HIC is glued to a carbon plate to form a HIC Module



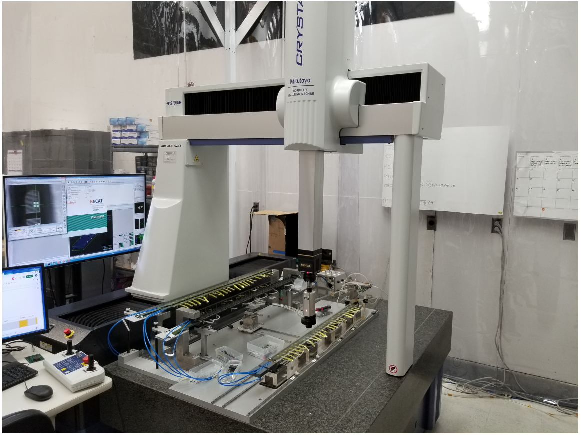
Stave components

- HIC module(s): 1 for IB, 4 or 7 per OB half-stave
- Space frame: carbon fiber mechanical support
- Cold plate: carbon fiber embedded with cooling pipes
- Power bus, bias bus, filter board (outer barrel only)



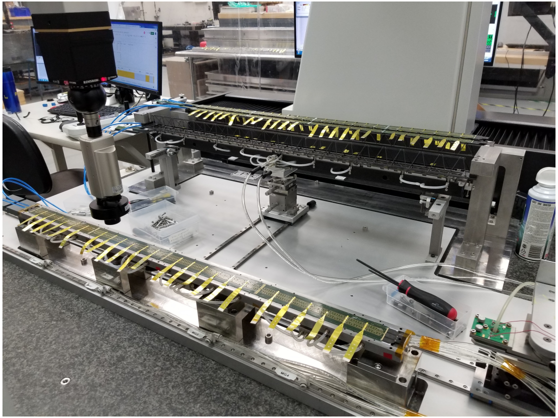


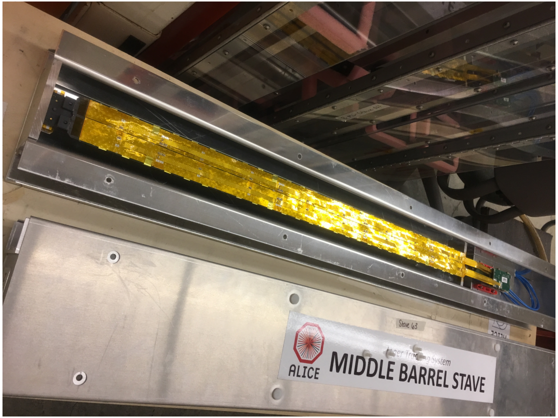
Stave assembly steps (OB)



- Inspect/measure/test all components
- Precisely place and glue HIC modules onto cold plate, solder, and test
- Align and glue half stave to space frame (and measure)
- Solder power bus to stave (and test)
- Fold power bus over stave (and test)

Middle layer stave





Transport to CERN

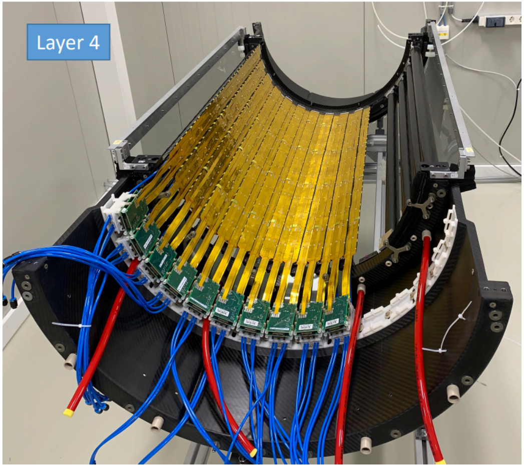
- 5 outer barrel stave assembly sites (including LBL, which built all 60+ middle layer staves)
- Completed staves needed to be transported from assembly sites to CERN
- For European sites, staves were shipped/driven by ground
- For staves assembled at LBL, staves were hand-carried on passenger planes, as aerial shipping was found to be too rough

Transport from LBL to CERN

- A custom box was built to transport 4 staves at a time – total weight was $\sim$ 20 lbs
- A person would buy 2 tickets, one for themselves and one for the box
- https://newscenter.lbl.gov/2019/09/19/how-to-get-a-particle-detector-on-a-plane/

Half barrels

- Inner barrel and outer barrel were further split in half (top and bottom)
- Half-barrels have detector portion and services portion (cables, cooling)
- End-wheels help precisely position staves within half-barrels

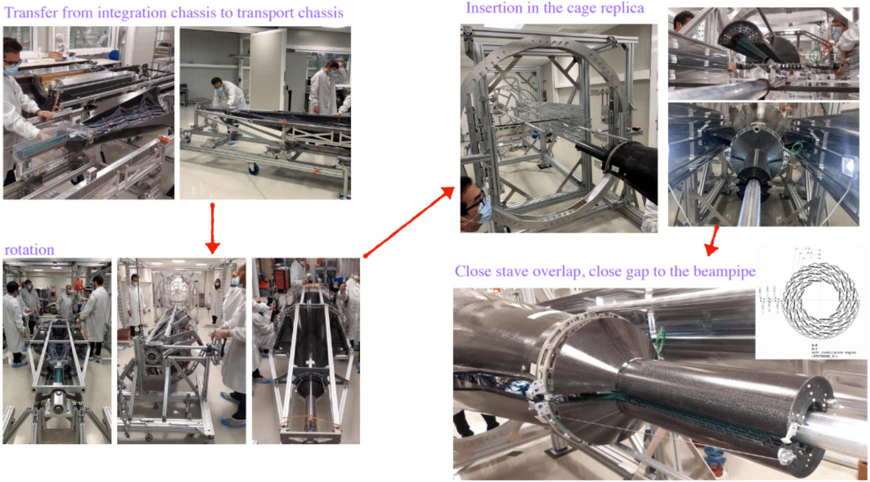


Half barrels

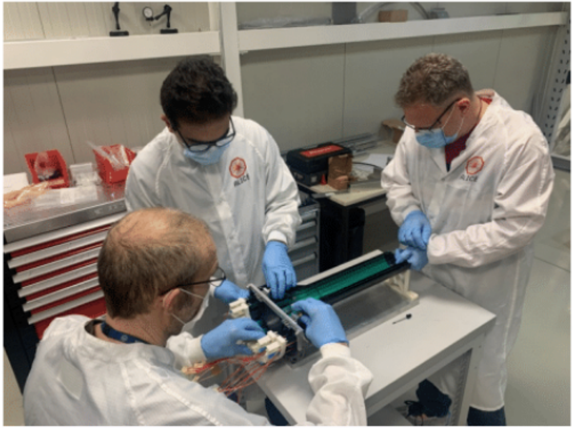
Considerations of detector installation

- The half-barrels are inserted inside the TPC and around the beampipe
- Services are all on one side to make it possible to extract ITS without moving TPC during year-end shutdowns
- Outer barrel inserted first, followed by inner barrel

IB insertion tests



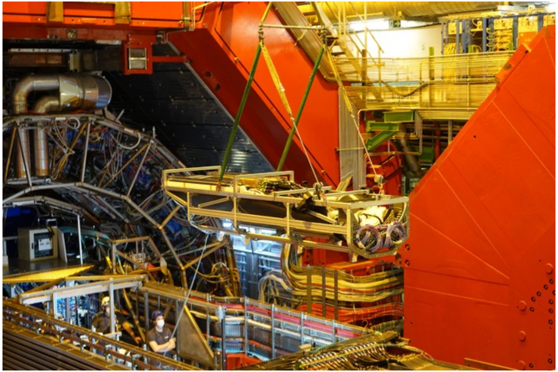
IB insertion tests

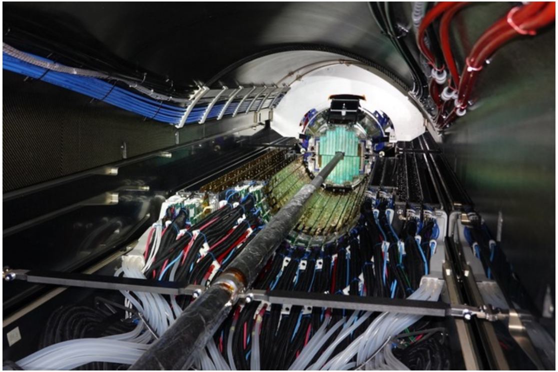


- A mock setup was built to practice insertion/extraction of inner barrel
- One insertion test resulted in damage to a stave in the inner barrel
- More practice: replacing a broken stave

Detector installation

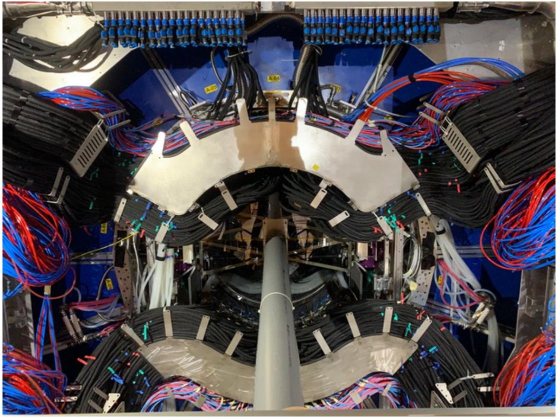
Services (cooling, power, etc) installed first, then install one half-barrel at a time





Detector installation

As of Friday, outer barrel is fully installed, connected, and tested

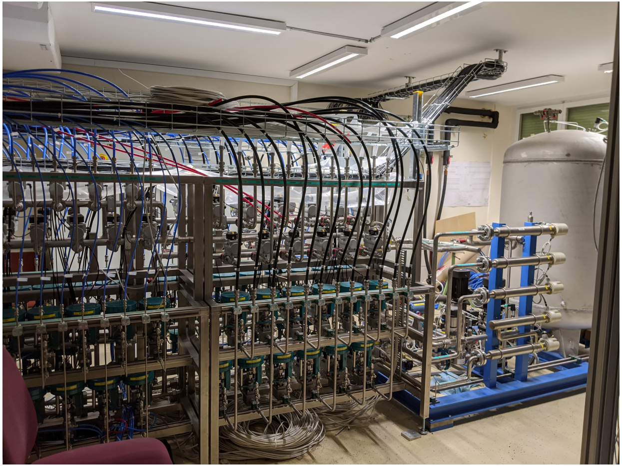


Services

- Besides the staves themselves, there are additional systems (and corresponding hardware) needed to actually operate the detector
- Cooling plant
- Powering
- Readout units (specific to ITS)
- Common readout units (shared across all detector subsystems)
- Detector safety system (automatic interlock)

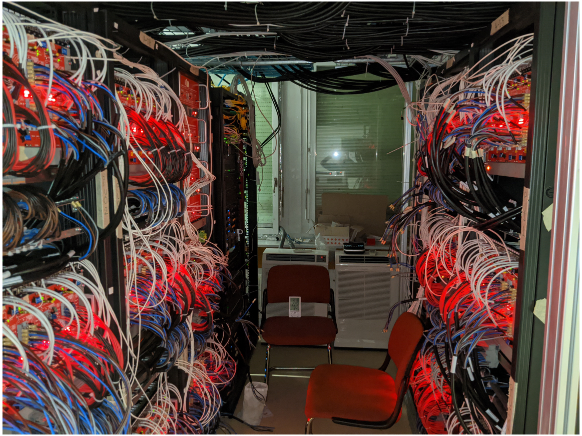
Cooling

Water is used for cooling; operates at room temperature ($\sim 30^{\circ}$C)



Powering

Power boards were designed and tested at LBL



Commissioning

- Commissioning = getting a system into a functional state
- Surface commissioning in clean room (half-barrels)
- Full-ITS commissioning at Point 2
- Global commissioning with all other detectors at Point 2

Surface commissioning

24/7 shifts; after COVID shutdown, restarted with partially-remote commissioning shifts

Surface commissioning shifts

- Inner Barrel
  - Threshold stability
  - Fake-hit rate analysis
  - Dead pixel maps
  - Readout runs (data transmission)
  - Data quality control
  - Monitoring of staves, powering, cooling
- Outer Barrel
  - Monitoring of staves with “real” system

Running the detector

- For surface commissioning, standalone scripts were written to interface with detector
- For data taking with full detector, need to integrate with global framework
- ALICE has specific software and user interface systems for detector control, run control, and quality control — need to integrate with them all
- Calibration and configuration: determining what parameters are needed to configure the detector for data taking

Making sense of the data

- Ultimately, the detector reads out whether a pixel was fired or not based on the threshold, which needs to be tuned
- From these pixel hits, need to reconstruct tracks (cosmics, test beams)
- Precise metrology is a start, but still need to align detector, both within the ITS itself and with the TPC and the rest of ALICE

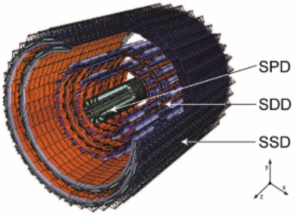
Summary

- There's a lot that goes into building and commissioning a detector
- End goal: physics, which will be coming soon
- And yet...

Evolution of the ALICE ITS

2009-2019

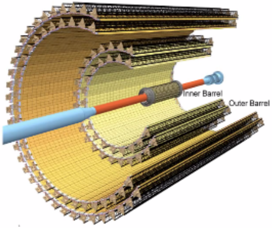
ALICE ITS-1



Readout rate: 1 kHz
Thickness of first layer: 1.14%X_0

2021+

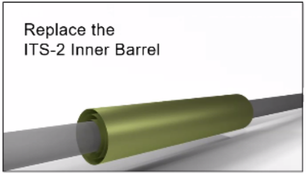
ALICE ITS-2



Integration time: <20 μs
Thickness IB layer: 0.35%X_0

2026+

ALICE ITS-3



Innermost layer: at R = 18 mm
Thickness of each layer: 0.05%X_0

- Constant search for a thinner and simpler geometry...