Required Sites and Infrastructure for Assembly: The ALICE ITS Upgrade

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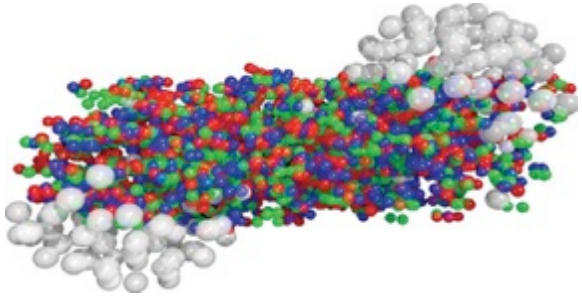
Lawrence Berkeley National Lab
EIC Silicon Workshop
September 4, 2020

Outline

- Background on the ALICE ITS upgrade
  - What & Why
- Scope of the project
  - What does it take to build something of this scale?
    - Time, manpower, sites
- LBL contribution to stave assembly

ALICE Upgrade: Motivation & Needs

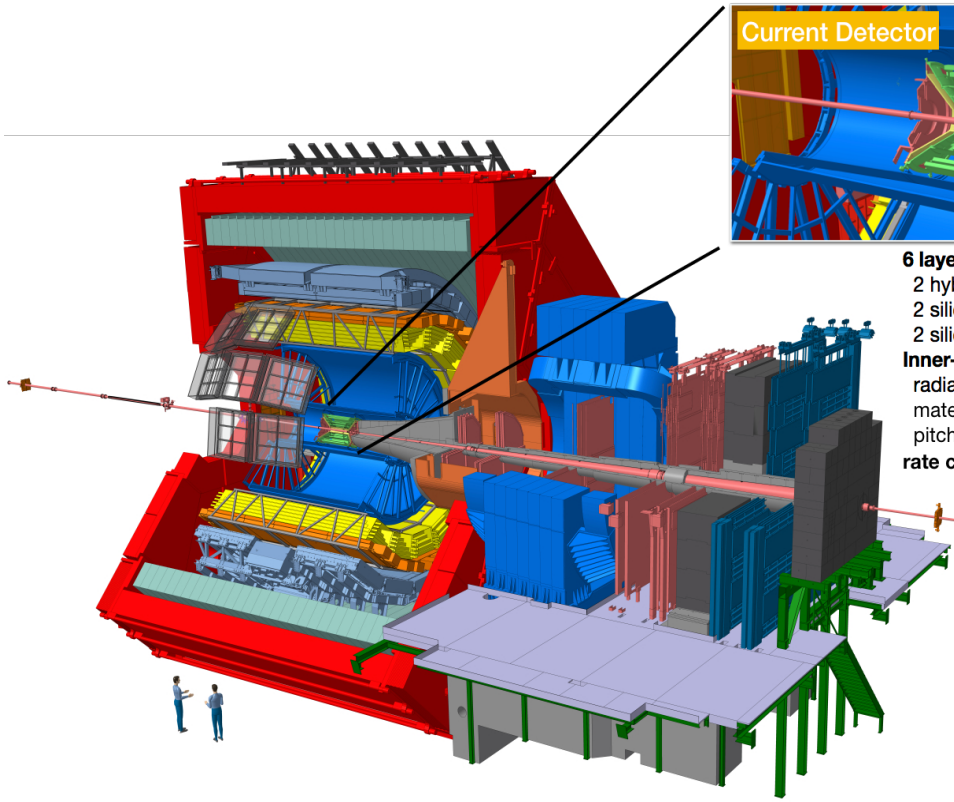


- **Motivation:** QGP precision study
  - High precision measurement of heavy flavor hadrons
    - Large range of p_T & rapidity, centrality & reaction plane binned
- **Requires:**
  - Excellent tracking efficiency & resolution at low pT
  - Large statistics with MB trigger
- **Strategy:**
  - Readout all Pb-Pb interactions at 50 kHz
  - Improve vertexing & tracking capabilities

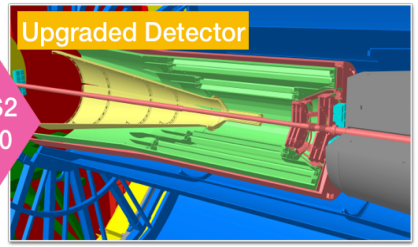
ALICE ITS: Design Requirements

- Higher resolution of impact parameter (Factor of 3 in $r\phi$, 5 in z)
  - Reduce beam-pipe diameter
    - 29 mm → 17.2 mm
  - Minimize distance between beam axis and first detector layer
    - 39 mm → 21 mm
  - Reduce pixel size
    - 50 μm x 425 μm → ~30 μm x 30 μm
- Increase tracking efficiency at low p_T (60% at 100 MeV/c)
  - Reduce material budget (sensors, power, cooling)
    - > 1% X_0 → < 0.5% X_0 inner layers
  - Added layer of silicon detectors
- More statistics
  - Faster read-out (100 kHz) for increased luminosity (10 nb^{-1})

ALICE Inner Tracking System



LHC LS2
2019/20



6 layers:
2 hybrid silicon pixel
2 silicon drift
2 silicon strip
Inner-most layer:
radial distance: 39 mm
material: $X/X_0 = 1.14\%$
pitch: 50 × 425 μm²
rate capability: 1 kHz

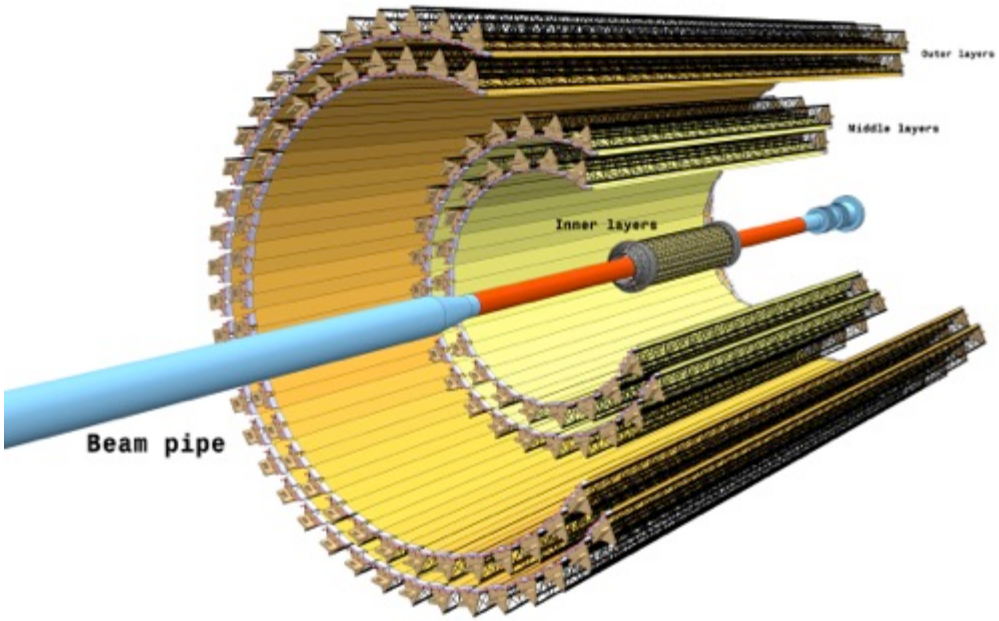
7 layers:
all Monolithic Active Pixel Sensors

Inner-most layer:
radial distance: 23 mm
material: $X/X_0 = 0.3\%$
pitch: O(30 × 30 μm²)
rate capability: 100 kHz (Pb-Pb)

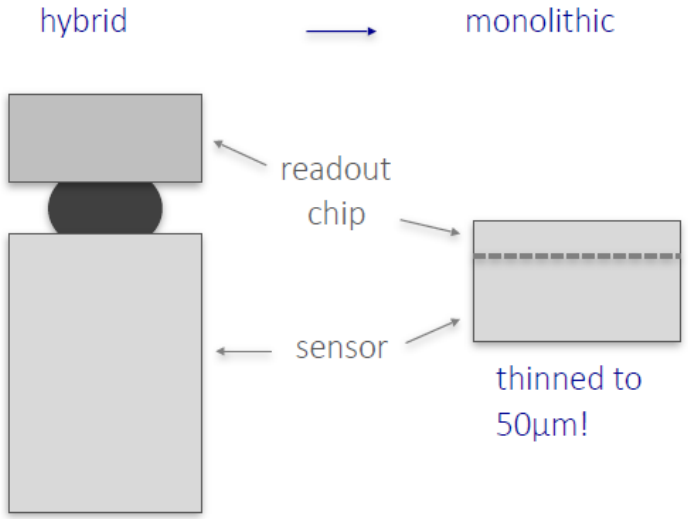
LoI: 2012
ITS CDR: 2012
ITS TDR: 2013

The ITS Upgrade

7 layer barrel geometry,
fully equipped (~24000 chips) with dedicated **MAPS:**
ALice PIxel DEtector (ALPIDE)
r-coverage: 23 – 400 mm
η coverage: $|\eta| \leq 1.3$



Monolithic Active Pixel Sensors

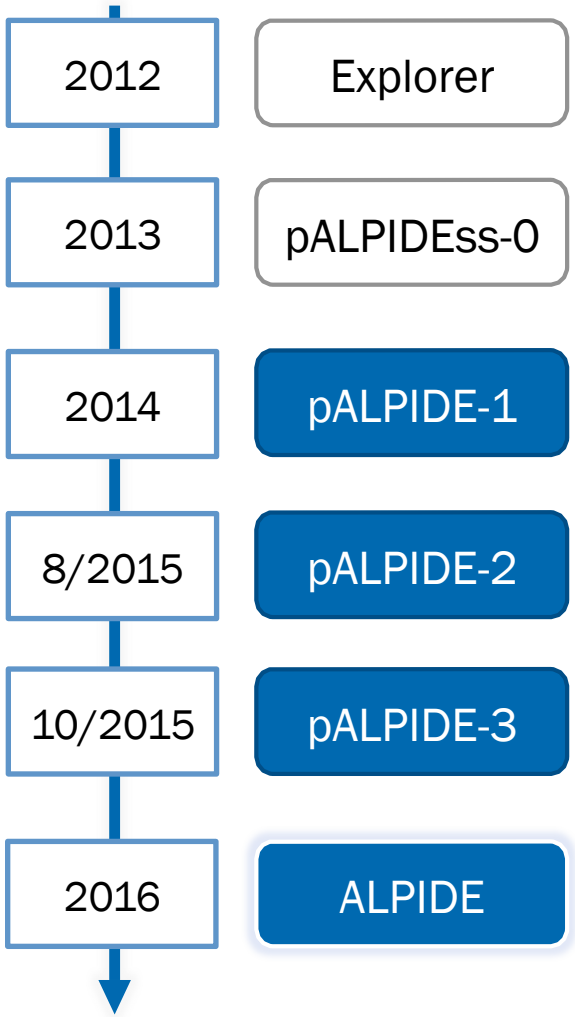


Material /layer : 0.3% X_0 (IB), 1% X_0 (OB)

12.5 G-pixel camera (~10 m^2 active Si)
Binary read-out

Chip Development

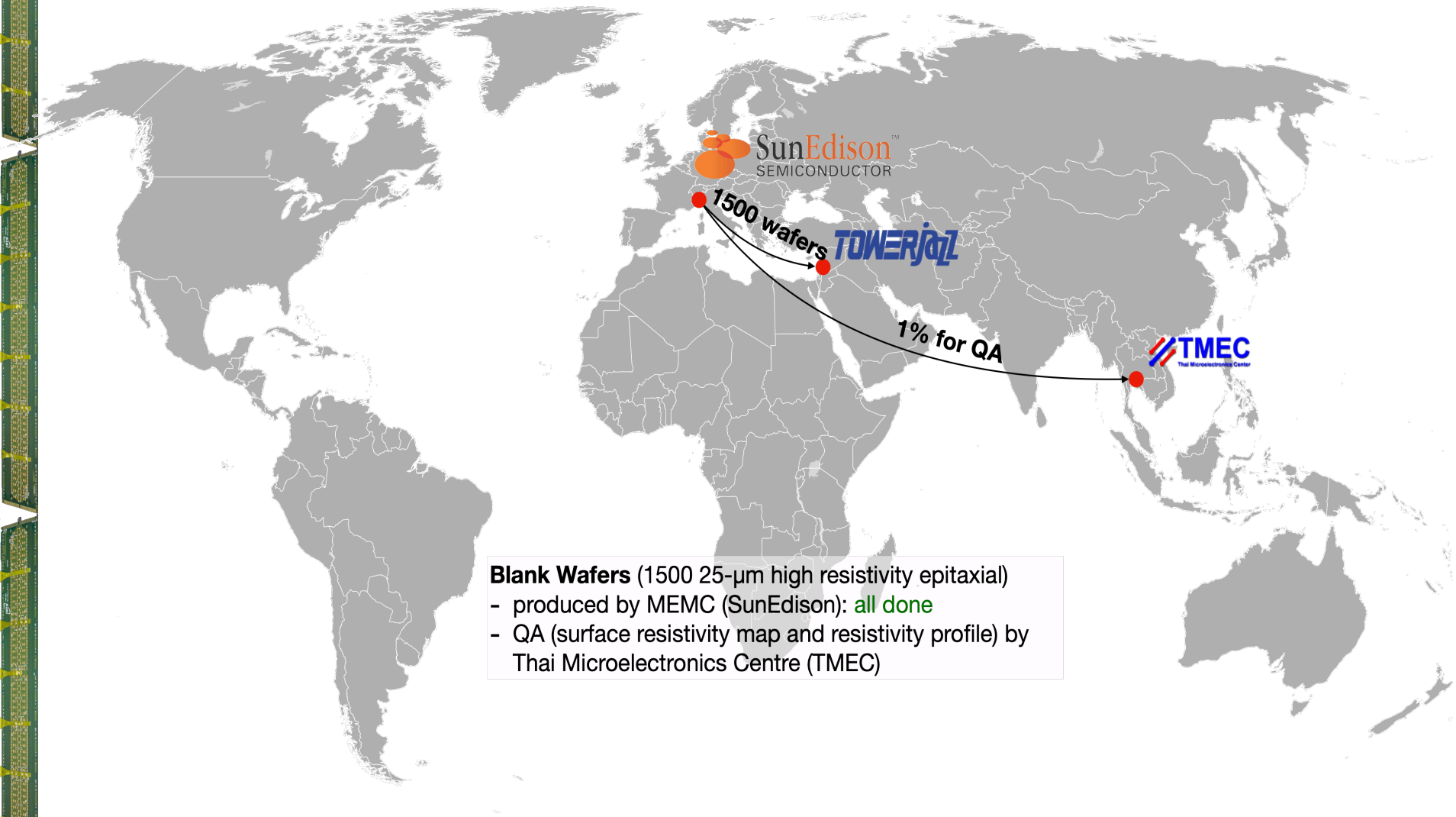
Design team from CERN, INFN, CCNU, YONSEI, NIKHEF, IRFU, IPHC



2012	Explorer	20 µm x 20 µm and 30 x 30 µm pixels (analogue readout) 1.8 x 1.8 mm^2, study of pixel geometry, starting material, radiation
2013	pALPIDEss-0	Matrix with 64 columns x 512 rows, 22 µm x 22 µm pixels, 11 x 1.8 mm^2, in-pixel discrimination and buffering, zero suppression
2014	pALPIDE-1	**First full scale prototype!** 28 µm x 28 µm pixels, 15 x 30 mm^2, four sectors with variants, 1 register/pixel, no final interface
8/2015	pALPIDE-2	**Full scale prototype,** four sectors with variants, optimisation of circuits, integration in modules, no high speed serial output
10/2015	pALPIDE-3	**Full scale prototype,** eight sectors with variants, all communincation features, no ADC, no temperature sensor)
2016	ALPIDE	**Final chip**

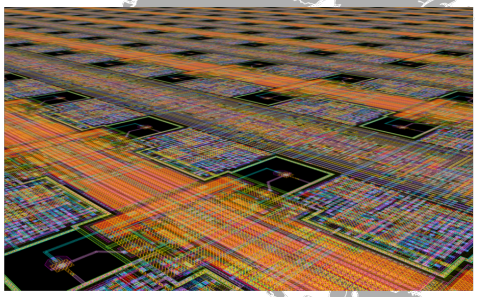
Detector Construction:

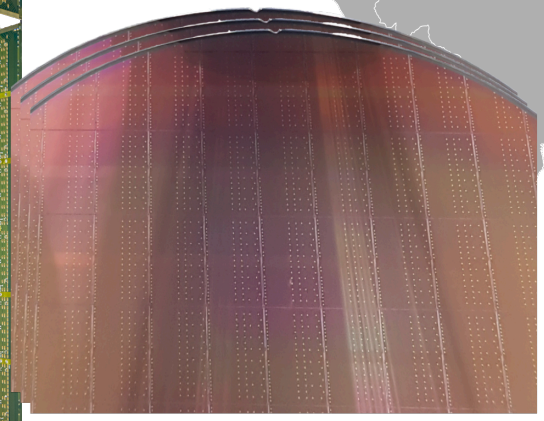
Blank Wafers



Blank Wafers (1500 25-µm high resistivity epitaxial)
- produced by MEMC (SunEdison): all done
- QA (surface resistivity map and resistivity profile) by Thai Microelectronics Centre (TMEC)

Detector Construction:
CMOS production

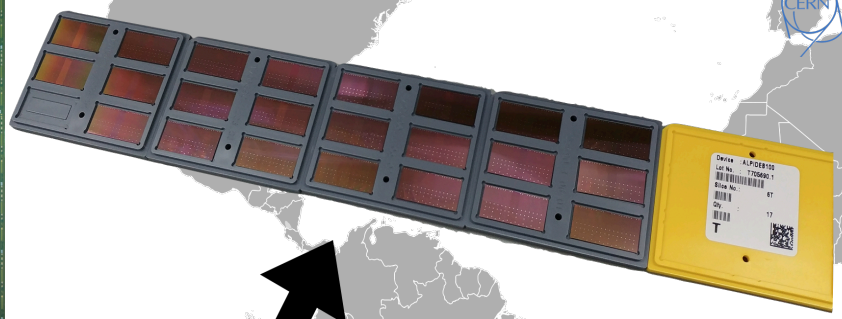


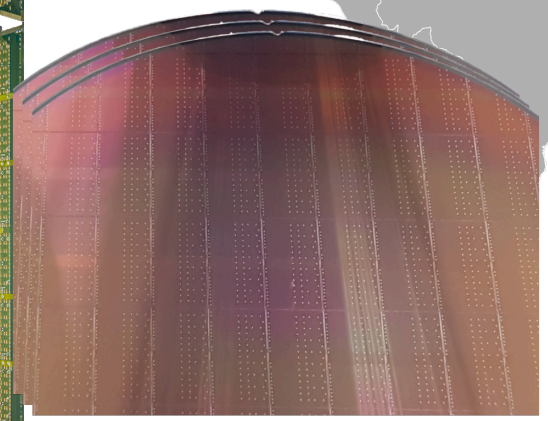


CMOS Production (baseline: 1200 wafers)
- produced by TowerJazz: all done
  waiting for yield numbers
  + requests from other projects
- shipped to Furex for thinning and dicing
- 2 wafers per lot to CERN for wafer probe testing and quick feedback to foundry

Detector Construction:

Chip thinning and dicing

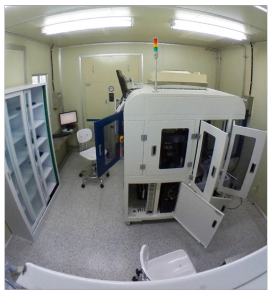


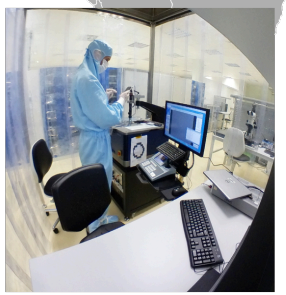


Thinning and Dicing (50 µm for Inner, 100 µm for Outer Barrel)
- done by FuRex: production ongoing
- 50% of 100 µm chips to Seoul (Yonsei University)
- 50% of 100 µm chips to Pusan (Pusan and Inha Universities)
- 100% of 50 µm chips to CERN

Detector Construction:

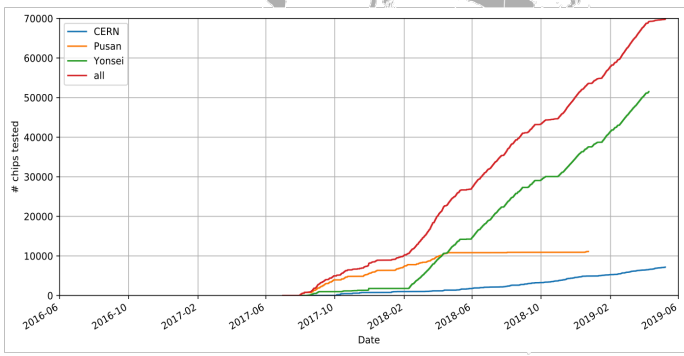
Chip testing





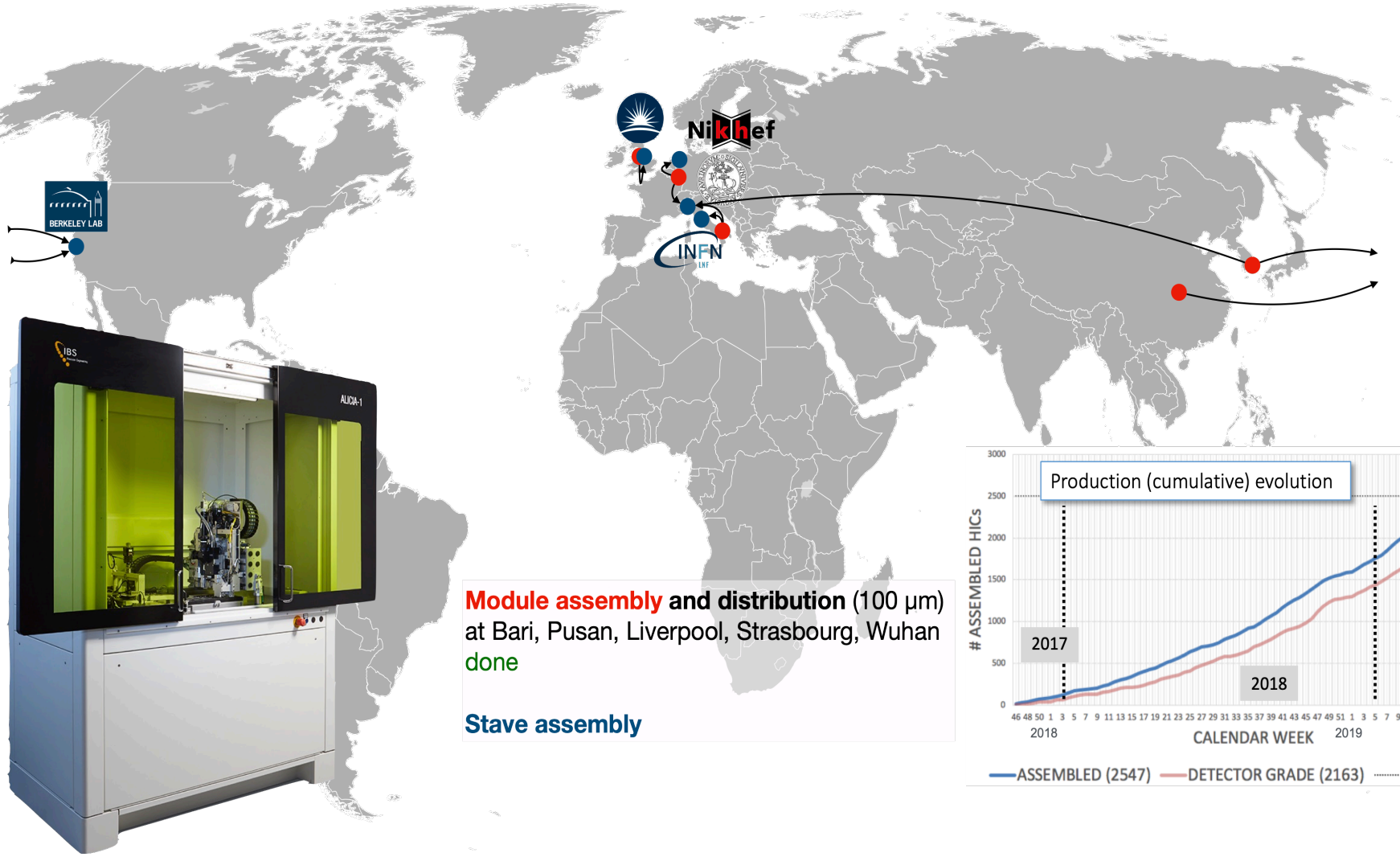
Chips Testing & Distribution (tests of single chips)

- 50 µm at CERN
- 100 µm to Bari, Liverpool, Pusan, Strasbourg, Wuhan



Detector Construction:

Module assembly

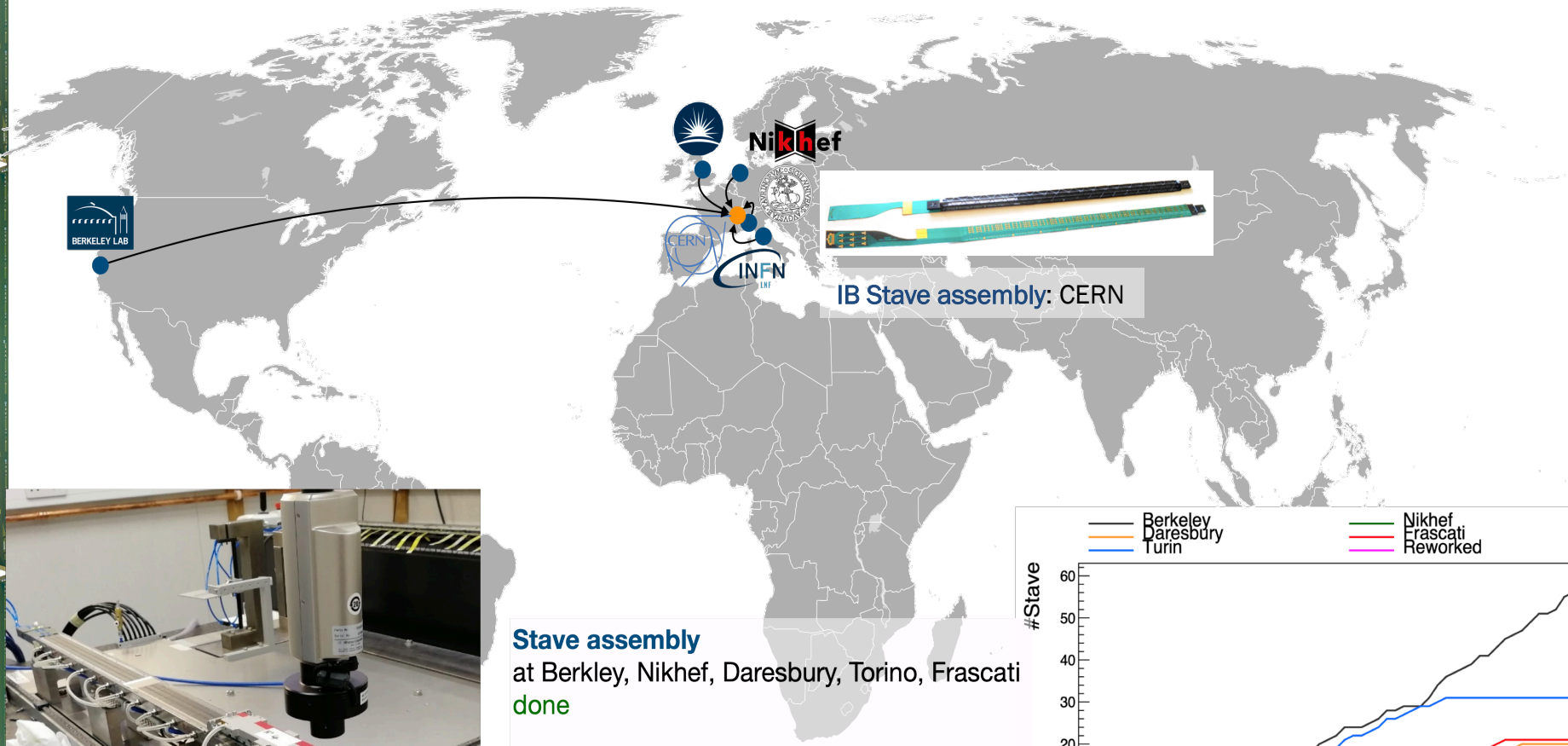


Module assembly and distribution (100 µm)
at Bari, Pusan, Liverpool, Strasbourg, Wuhan
done

Stave assembly

Detector Construction:

Stave assembly, detector integration



IB Stave assembly: CERN

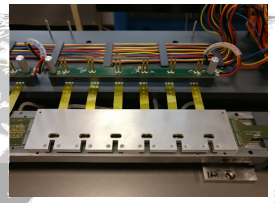
Stave assembly
at Berkley, Nikhef, Daresbury, Torino, Frascati
done

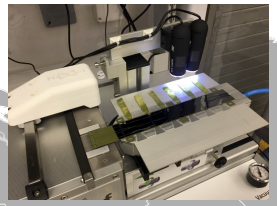
Detector integration
at CERN
done, to be installed at P2

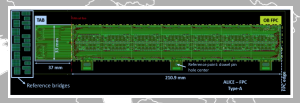
Detector Construction:

Extras (PB, RB, FPC, CP, SF, small parts)

Testing apparatus



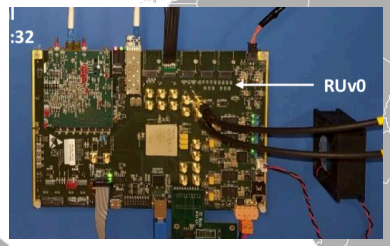




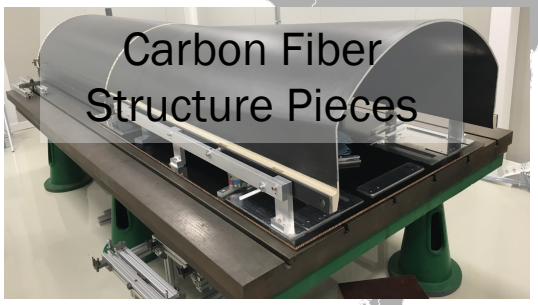
Carbon Fiber Cold Plates & Space Frames from CERN

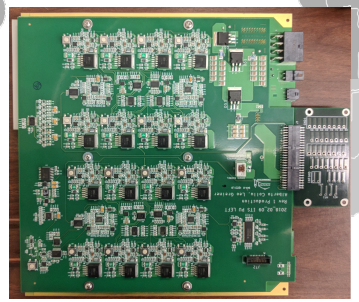
Assembly pieces, FPC

Readout Electronics



Carbon Fiber Structure Pieces

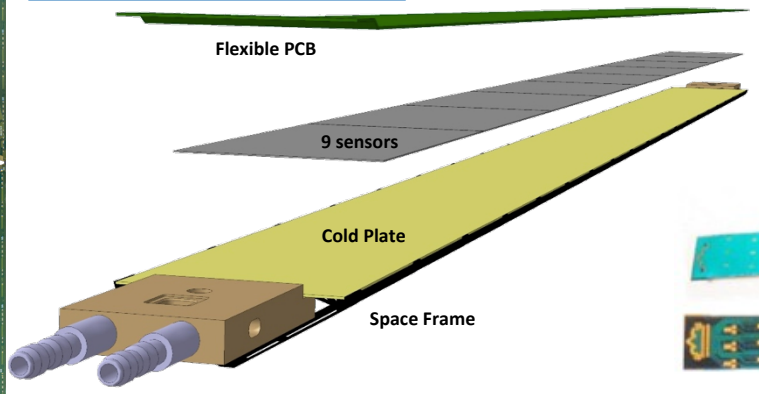




Power Distribution - Bus, Board, Etc.

Pieces for Stave Assembly

Inner Barrel

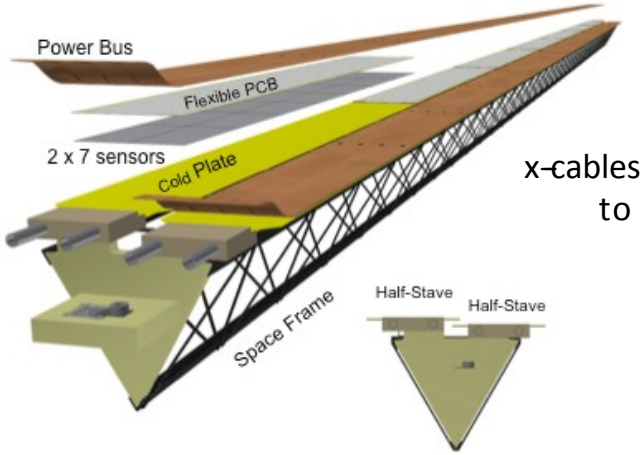


All inner barrel staves made at CERN

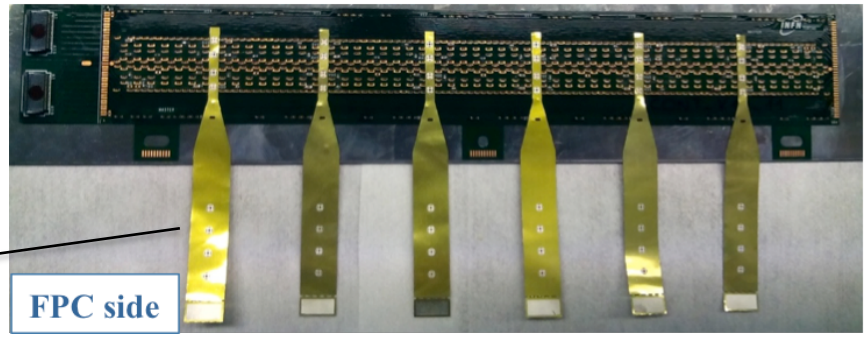
sensors thinned to 50 μm

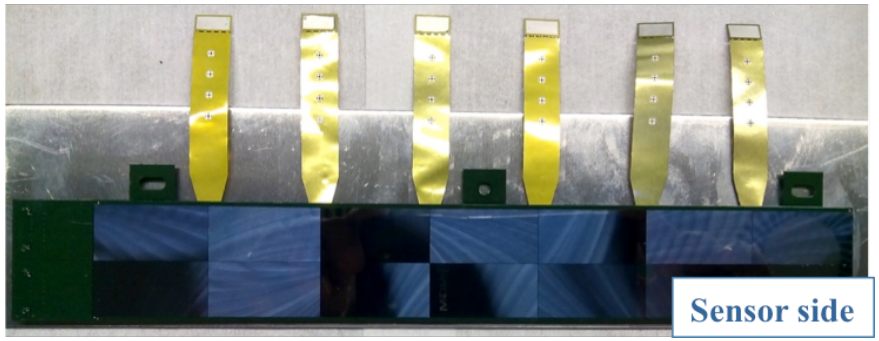
9 chips, stave length ~450 mm

Outer Barrel



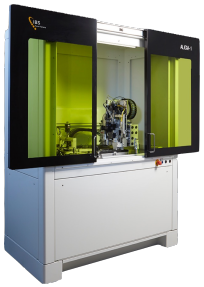
x-cables for connection to power bus

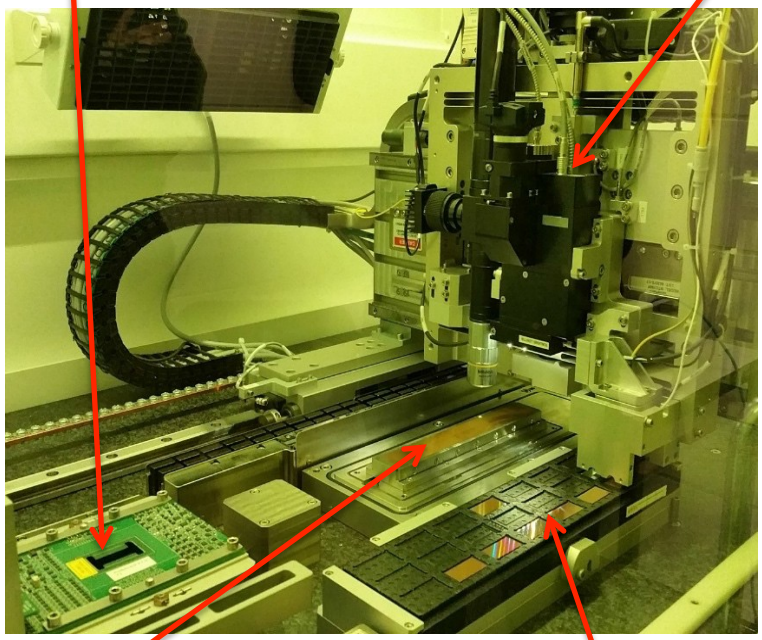




2x7 chips
length 245 mm

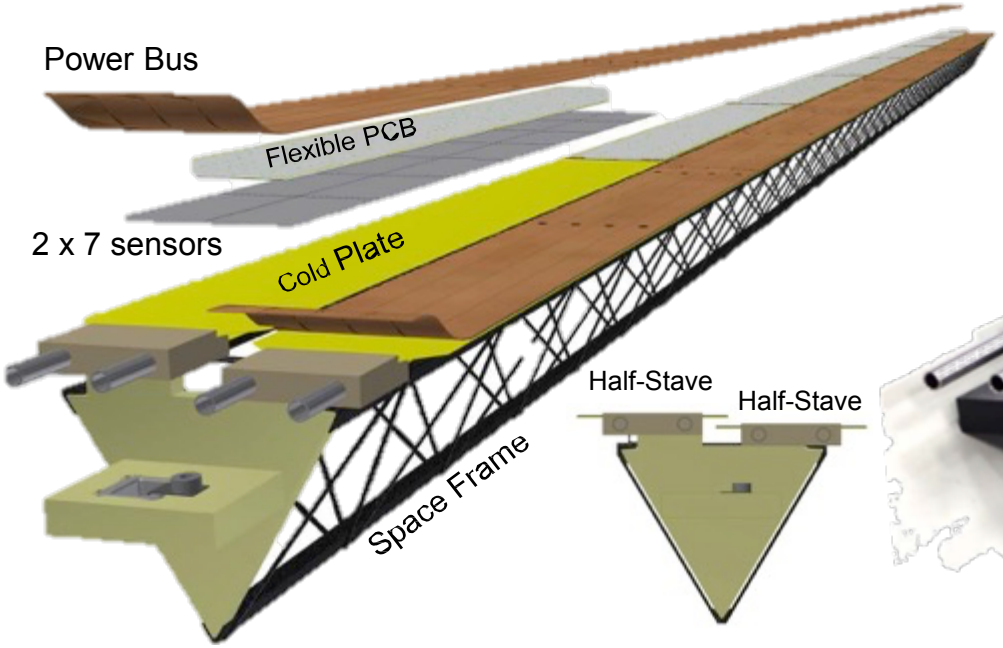
OB Module Production





- Modules assembled with custom machine (ALICIA)
  - Aligned chips with +/- 5 μm precision
  - Can probe & automatic visual inspection
- Produced at 5 sites worldwide
  - Strasbourg, Bari, Liverpool, Pusan, Wuhan

ITS Outer Barrel Structure



Outer Barrel (OB)

LBL built Middle Layers in Red

<radius> (mm): 194, 247, 353, 405

Nr. staves: 24, 30, 42, 48

Nr. Chips/layer: 6048 (ML), 17740 (OL)

Power density < 100 mW / cm^2

Length (mm): 900 (ML), 1500 (OL)

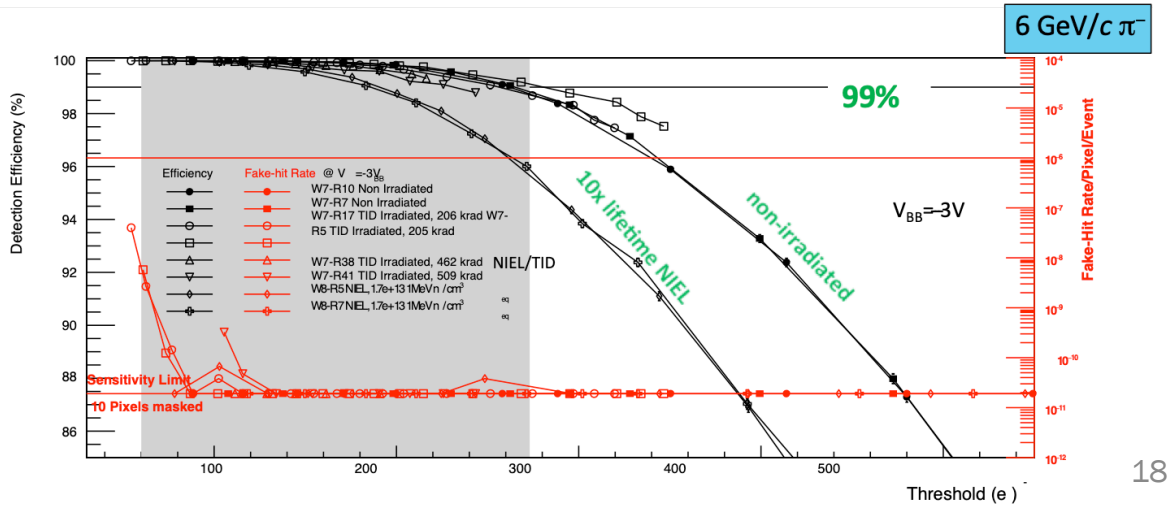
Nr. modules/stave: 4 (ML), 7 (OL)

Material thickness: ~ 1% X_0

Throughput (@100kHz): < 3Mb/s × cm^{-2}

Stave Assembly Requirements

- OL (4 sites): 30 staves per site, 1 stave every 2 weeks
- ML (LBL): 60 staves, 1 per week
- > 90% production yield
  - > 10 assembly steps → each must have ~99% yield
- Within 1 mm tolerance for planarity
  - Clearance for neighboring staves
- Noisy pixel rate below 10^{-5}



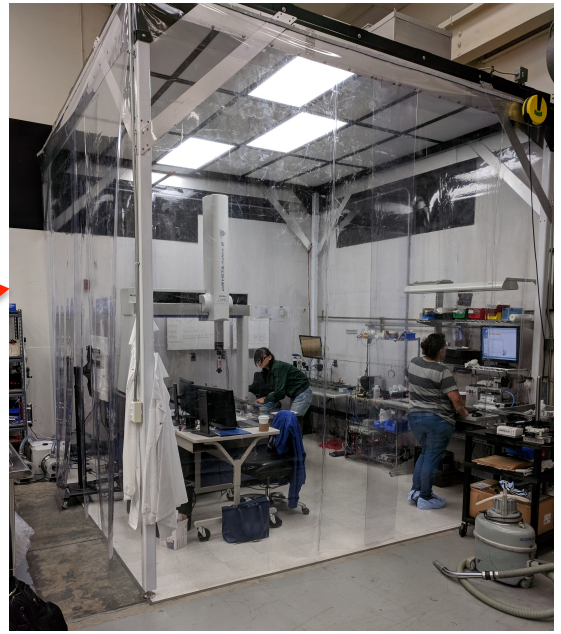
Stave Assembly Dependencies

- Each Stave takes ~5-6 days to complete
  - 1 per week requirement for ML
- Modules arriving from 5 different sites
- Carbon Fiber Cold Plates & Space Frames from CERN
- Power & Bias Bus shipped through CERN

		9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30
DAY 1	CMM BASE STATION	HSR METR.		CP PLANARITY							HSL ASSEMBLY						GLUE DRYING		
	HS TEST STATION			HSR SOLDERING				TEST	UARM GLUING		TEST								
	CMM SPACE FRAME																		
	CMM METROLOGY																		
	STAVE TEST STATION																		
DAY 2	CMM BASE STATION	HSL METR.									HSR TO SF								
	HS TEST STATION			HSL SOLDERING				TEST	UARM GLUING		TEST								
	CMM SPACE FRAME												HSR TO SF		GLUE DRYING				
	CMM METROLOGY																		
	STAVE TEST STATION																		
DAY 3	CMM BASE STATION	HSL TO SF				CP PLANARITY		HSR ASSEMBLY						GLUE DRYING					
	HS TEST STATION																		
	CMM SPACE FRAME			HSL TO SF		GLUE DRYING													
	CMM METROLOGY																		
	STAVE TEST STATION																		
DAY 4	CMM BASE STATION	HSR METR.						CP PLANARITY			HSL ASSEMBLY						GLUE DRYING		
	HS TEST STATION			HSR SOLDERING				TEST	UARM GLUING		TEST								
	CMM SPACE FRAME																		
	CMM METROLOGY			STAVE METROLOGY															
	STAVE TEST STATION							PB/BB/FB SOLDERING				STAVE TEST							
DAY 5	CMM BASE STATION	HSL METR.									HSR TO SF								
	HS TEST STATION												HSR TO SF		GLUE DRYING				
	CMM SPACE FRAME			HSL SOLDERING				TEST	UARM GLUING		TEST								
	CMM METROLOGY																		
	STAVE TEST STATION	PB FOLDING & U-ARM GLUING										STAVE TEST							

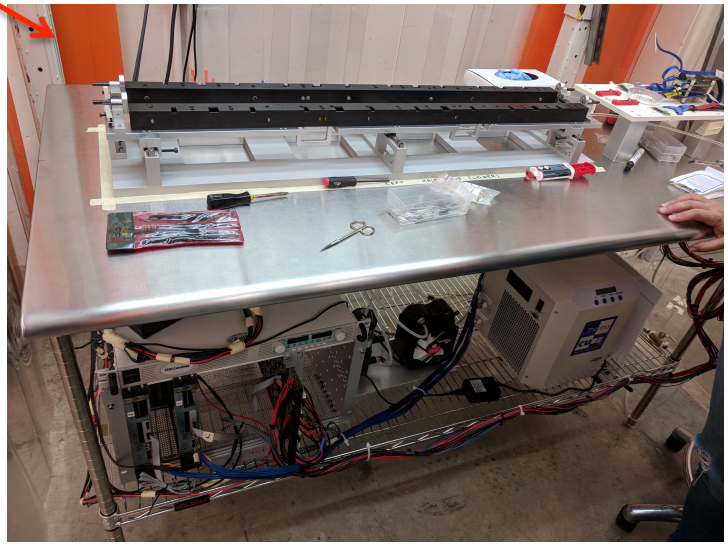
Infrastructure for Stave Assembly

- 3 separate spaces
  - Module testing (small)
  - HS assembly
  - Stave completion



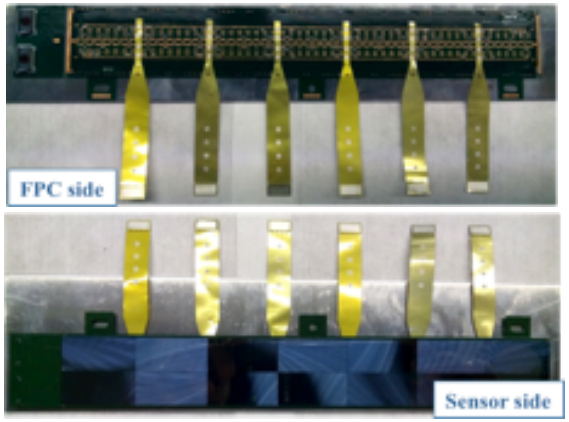
CRYSTA-Apex S 900 Series

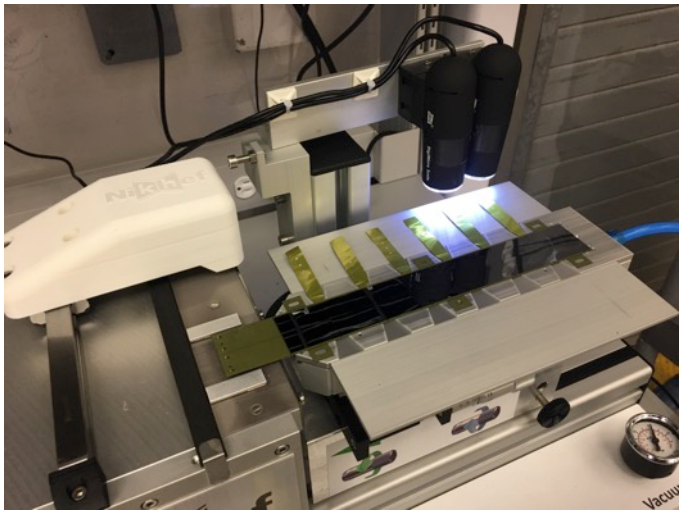
NOTE: PC and workstation differ from those shown.



ITS ML Assembly at LBL

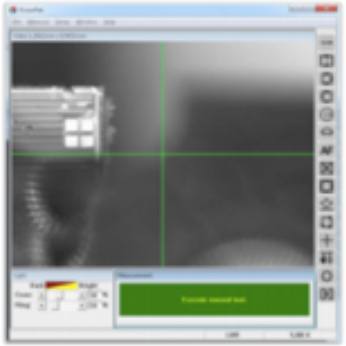
- HIC arrives
  - Tested and tab cut

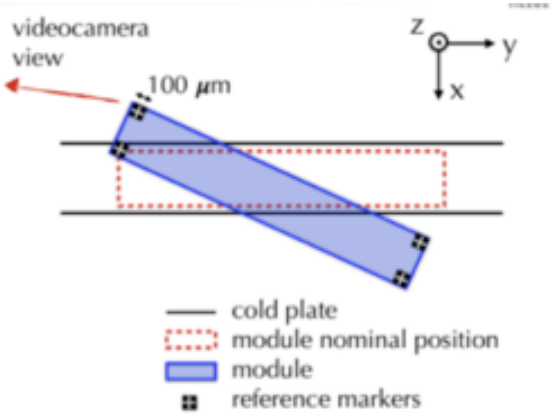


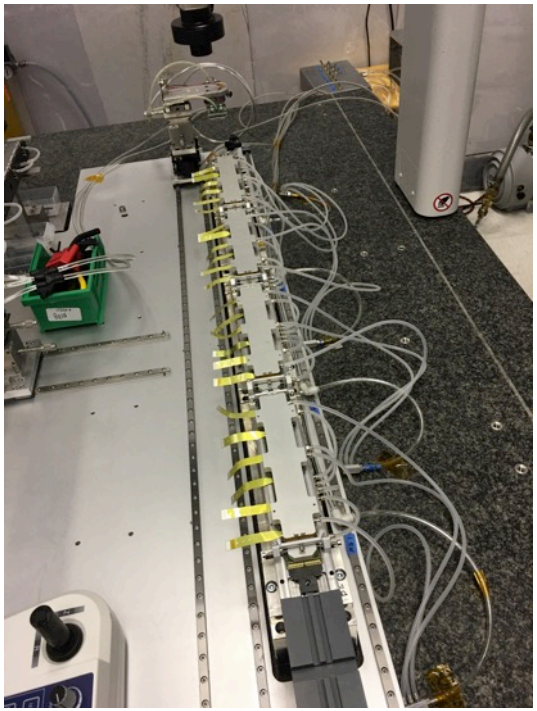


ITS ML Assembly at LBL

- HIC arrives
  - Tested and tab cut
- 4 HICs glued to CP (1 HS)
  - Aligned within 20 μm of nominal

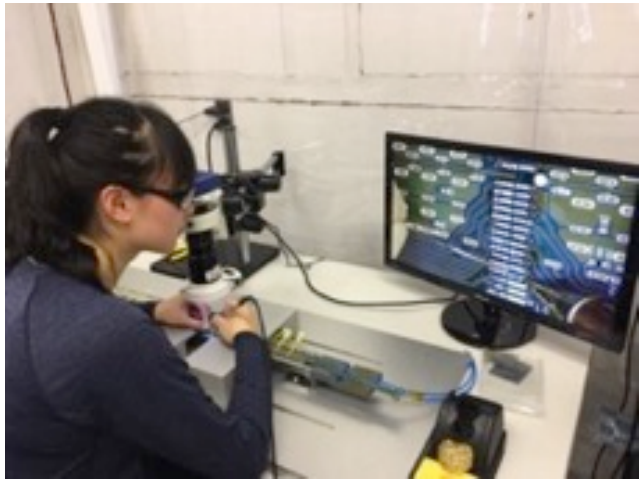


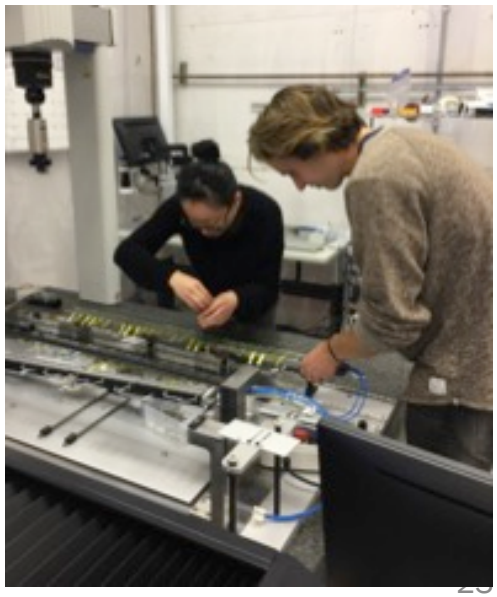




ITS ML Assembly at LBL

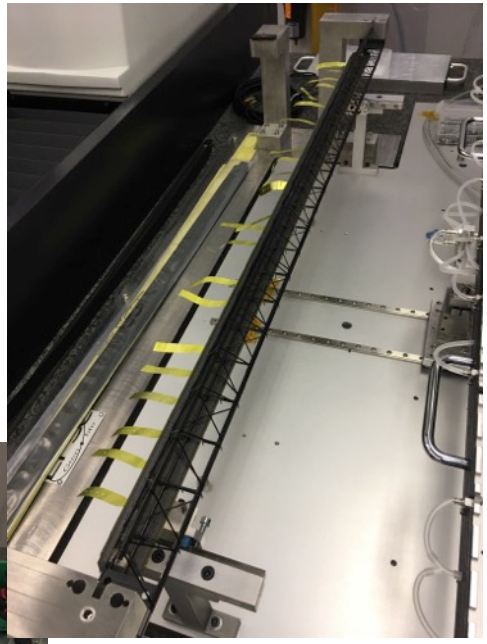
- HIC arrives
  - Tested and tab cut
- 4 HICs glued to CP (1 HS)
  - Aligned within 20 μm of nominal
- HS soldered & tested

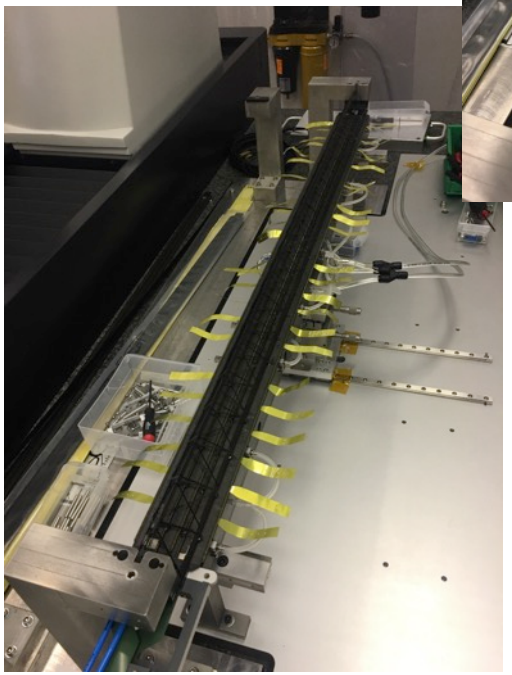




ITS ML Assembly at LBL

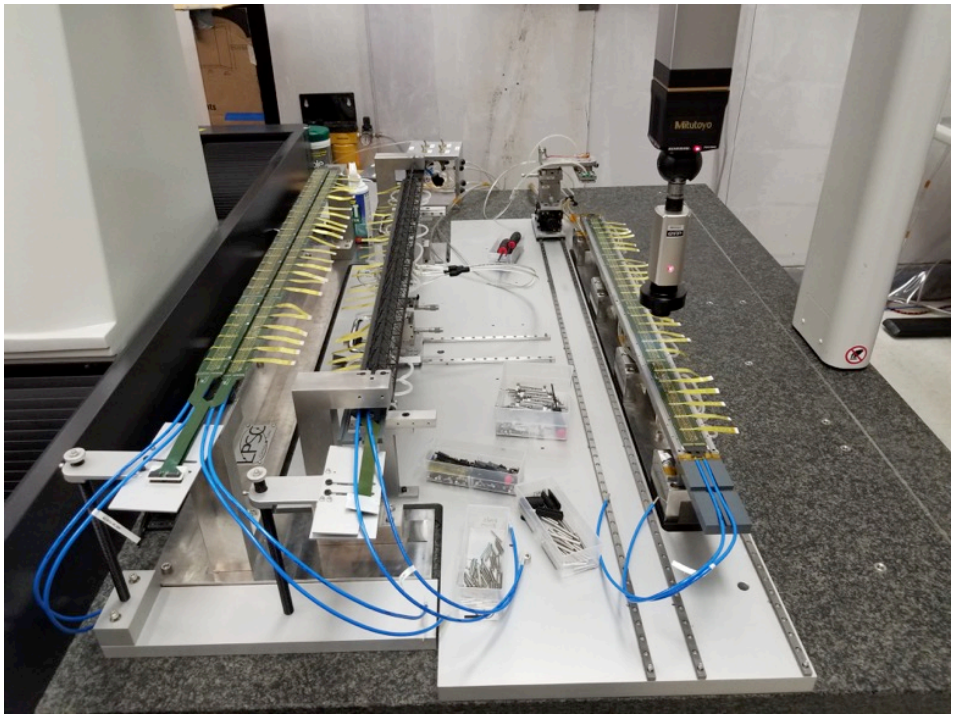
- HIC arrives
  - Tested and tab cut
- 4 HICs glued to CP (1 HS)
  - Aligned within 20 μm of nominal
- HS soldered & tested
- HS aligned & glued under SF





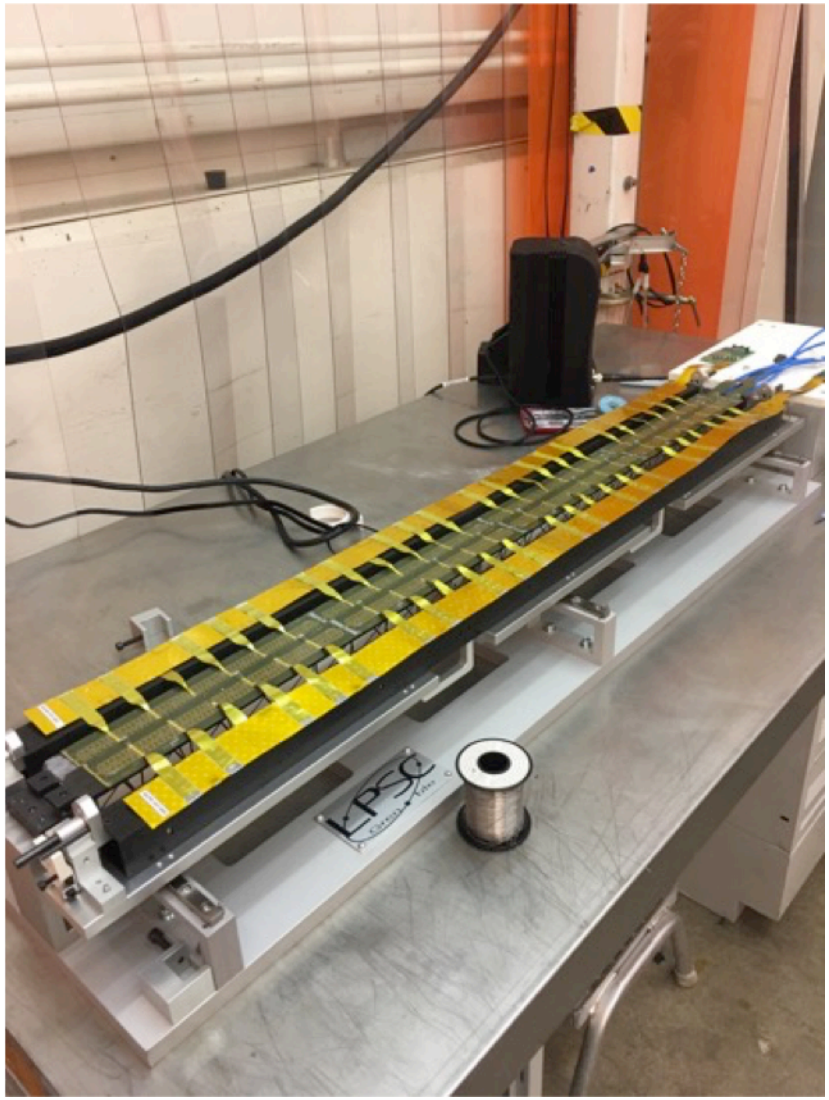
ITS ML Assembly at LBL

- HIC arrives
  - Tested and tab cut
- 4 HICs glued to CP (1 HS)
  - Aligned within 20 μm of nominal
- HS soldered & tested
- HS aligned & glued under SF
- Stave gets final metrology



ITS ML Assembly at LBL

- HIC arrives
  - Tested and tab cut
- 4 HICs glued to CP (1 HS)
  - Aligned within 20 μm of nominal
- HS soldered & tested
- HS aligned & glued under SF
- Stave gets final metrology
- PB soldered to Stave & tested



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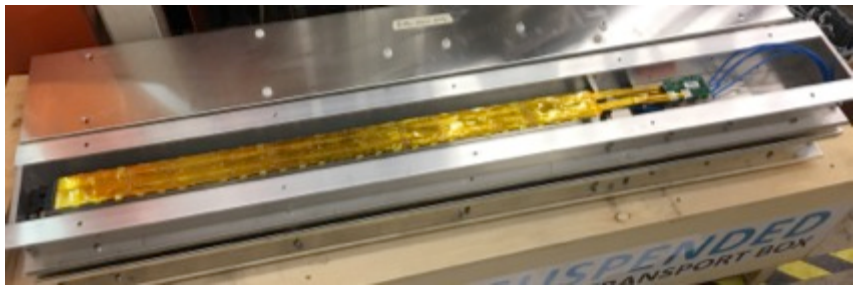
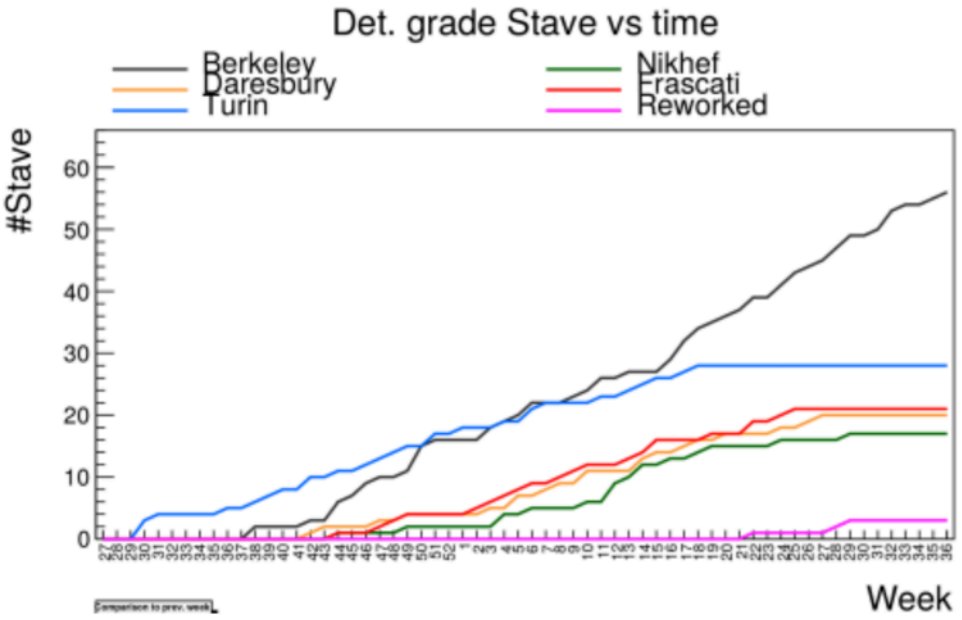
  - Aligned within 20 μm of nominal
- HS soldered & tested
- HS aligned & glued under SF
- Stave gets final metrology
- PB soldered to Stave & tested
- Stave is folded & tested
- Stave is boxed & stored/shipped to CERN

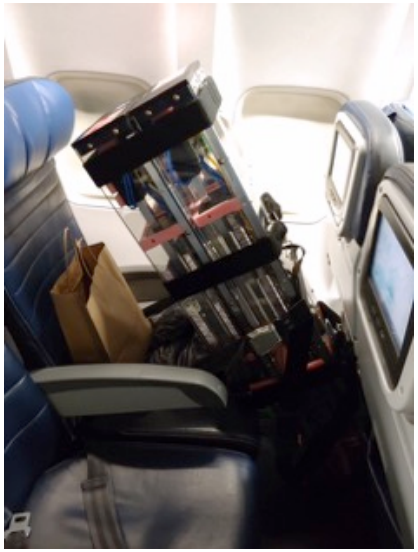
Production completed in October '19

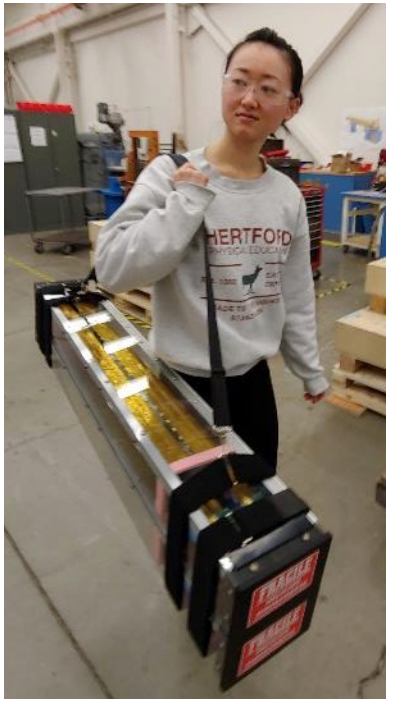


ITS ML Assembly at LBL

- Planned deliverables: 60 staves (54 + 6 spares)
  - Constructed 68 staves, 64 detector grade (no more than 1 dead chip per HS)
  - Rate ~1/week
- 17 trips made – delivered 4 at a time
  - Last trip made October 2019



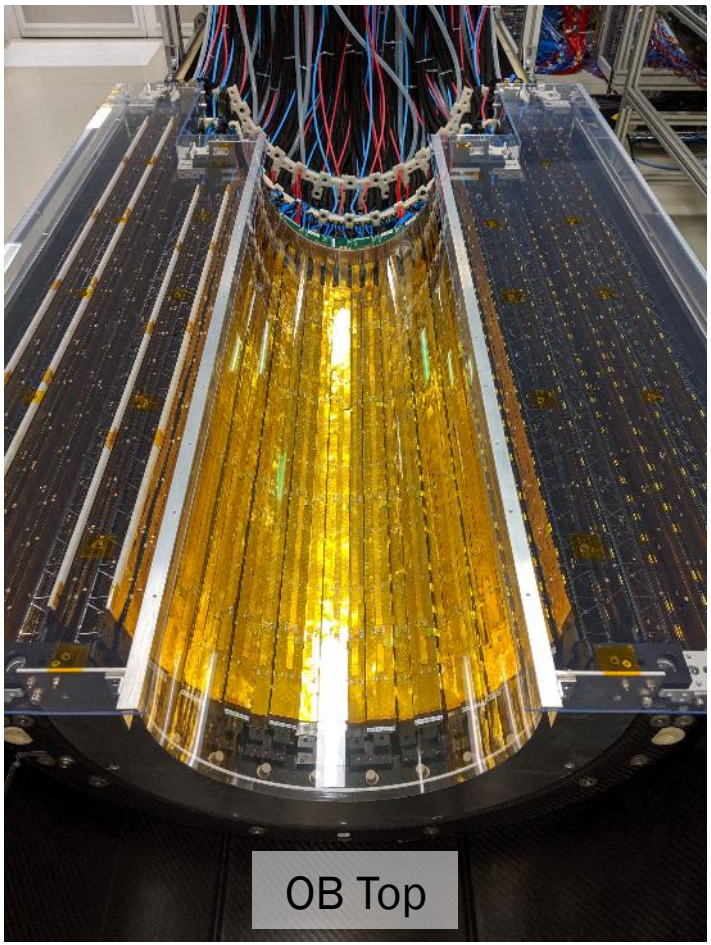




https://newscenter.lbl.gov/2019/09/19/how-to-get-a-particle-detector-on-a-plane/

Activity at CERN

- Both half barrels complete
- Commissioning shifts restarted ~ 2 weeks ago
- Installation planned for Jan



Summary

- Expect any EIC silicon detector to be similar
  - Power, mechanics, silicon, detector assembly
  - Requires investment in expensive machine infrastructure
    - E.g. CMM, probe testing, other assembly tooling