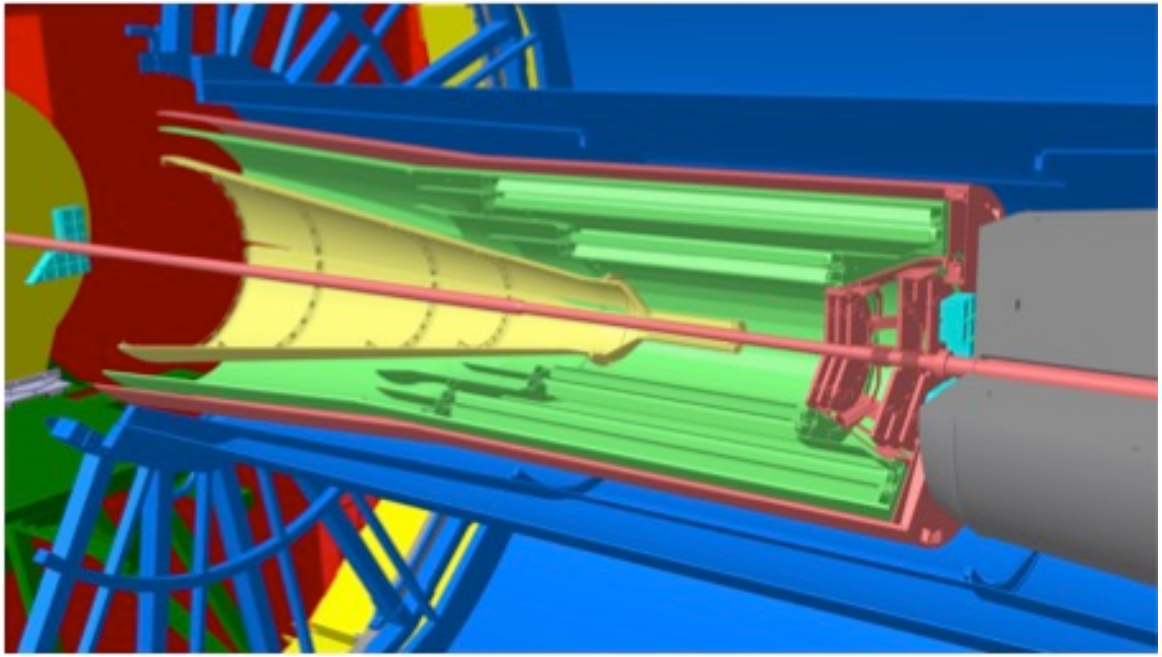


Upgraded Inner Tracking System for ALICE at the LHC: Status and Plans

***Grigory Feofilov* (on behalf of the ALICE collaboration)**
Saint-Petersburg State University

The 3rd International conference on particle physics and astrophysics (ICPPA-2017), Moscow, 2-5 October 2017, MEPhI, Moscow

Acknowledgement: This work was supported for the SPbSU participants in 2016 within the Program of Russian groups activities in the ALICE upgrade by the Ministry of Education and Science of Russian Federation, contract No14.610.21.0003, identification number RFMEFI61014X0003 (SPbSU identification number No. 11.19.1632.2014).

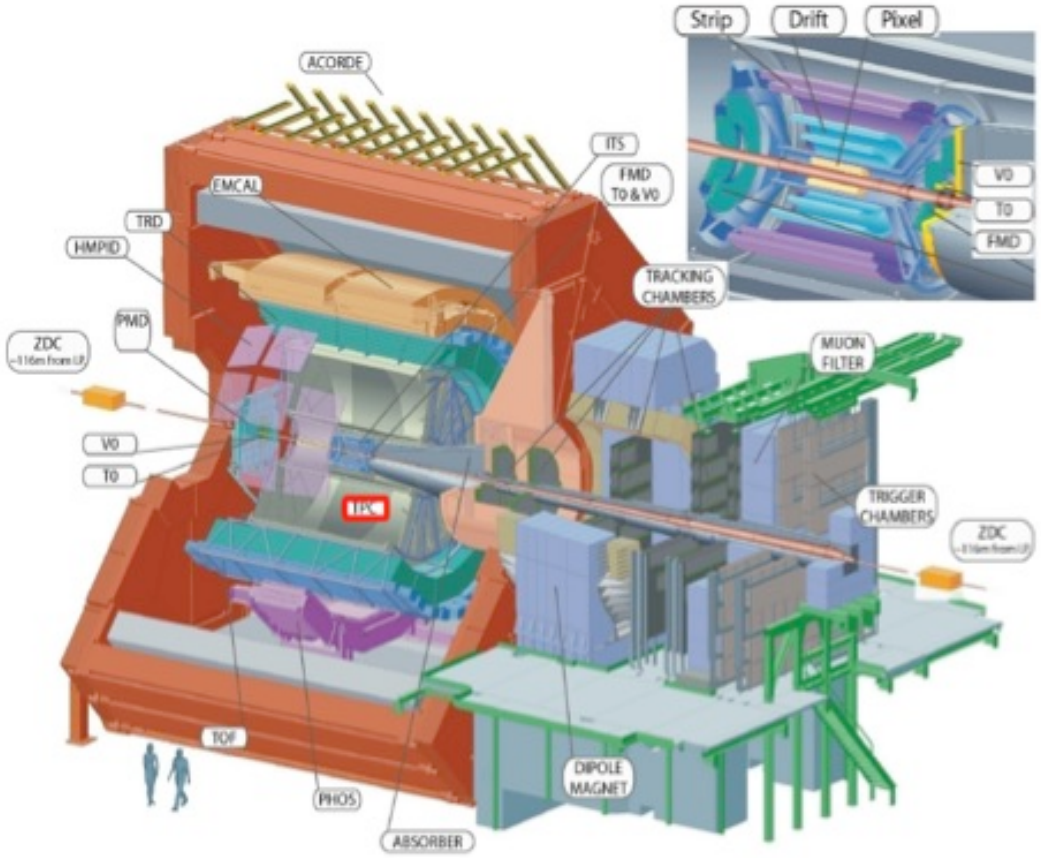
Outline

1) Motivation.

2) Upgrade of ALICE/ITS
   - General design
   - Detectors and readout
   - General layout
   - Production status

3) Plans and summary of new physics possibilities

ALICE installation at the LHC



Central Detectors:

Inner Tracking System
(SPD,SDD,SSD – 6 layers between 39 and 430 mm)
Time Projection Chamber
Time-of-Flight
Transition Radiation Detector

Spectrometers:

High Momentum PID (RICH)
Photon Multiplicity
Forward Multiplicity
Muon Spectrometer

Calorimeters:

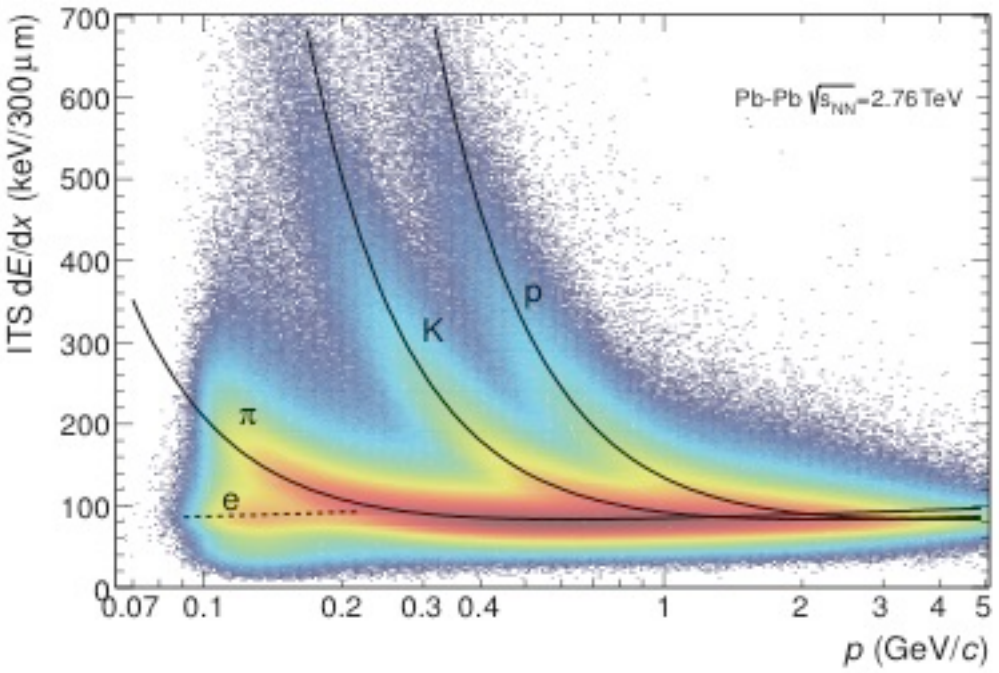
EM Calorimeter
Photon Spectrometer (PHOS)
Zero Degree Calorimeter

Trigger:

Trigger Detectors
pp High-Level-Trigger

Current ITS performance

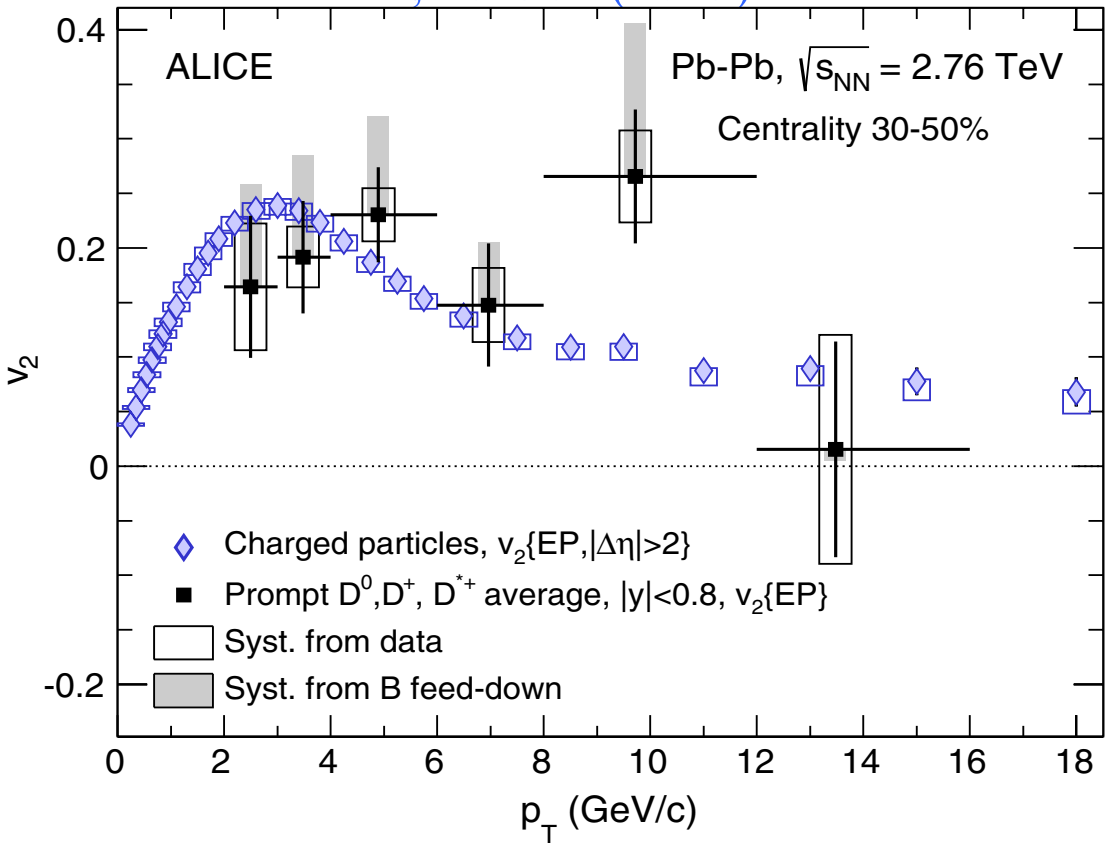
International Journal of Modern Physics A Vol. 29,
No. 24 (2014) 1430044



Distribution of the energy-loss signal in the ITS as a function of momentum.

Some physics results of Run-2: D meson elliptic flow puzzle

PRL 111, 102301 (2013)



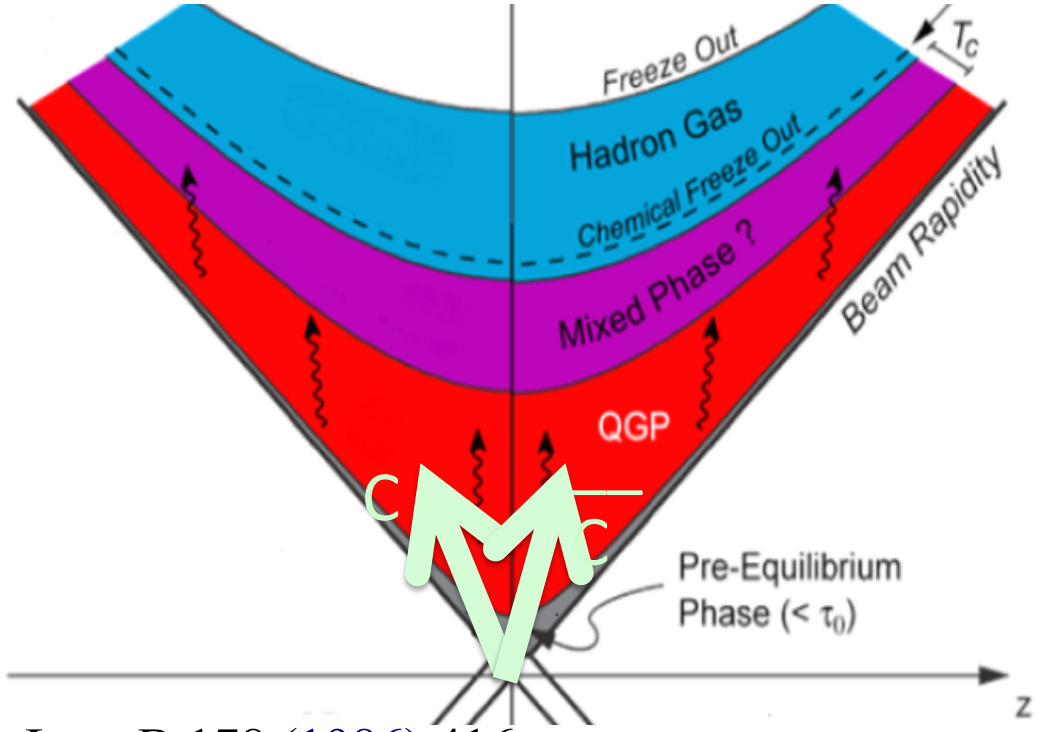
➢ Elliptic flow for D-mesons?

Why heavy quarks as one of the main motivations?

→ Study the early stages in heavy-ion collisions

→ Probe to study thermalization of Quark Gluon Plasma (QGP)

→ Microscopic insight into transport properties of the medium



1] **T. Matsui and H. Satz,** Phys. Lett. B 178 (1986) 416.

[2] Helmut Satz, Calibrating the In-Medium Behavior of Quarkonia, arXiv: 1303.3493, 12 April 2013

[3] 2013 -- **Berndt Müller**, arXiv:1309.7616

Design goals to be met in the upgrade:

CERN-LHCC-2012-013 (LHCC-P-005)

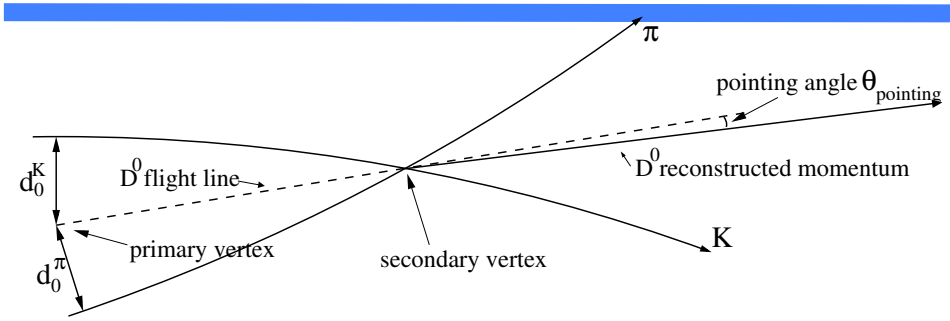
1. **Coverage in transverse momentum to be as complete as possible, in particular down to zero momentum**

2. **Very accurate identification of secondary vertices from decaying charm or beauty (D, J/psi, Λ_c, Λ_b).**

Comparison of ALICE,ATLAS and CMS upgrade

	current ALICE	ALICE upgrade	ATLAS upgrade	CMS upgrade
innermost point (mm)	39.0	22.0	25.7	30.0
x/X_0 (innermost layer)	1.14%	0.3%	1.54%	1.25%
d_0 res. $r\varphi$ (μm) at 1 GeV/c	60	20	65	60
hadron ID p range (GeV/c)	0.1−3	0.1−3	–	–

Identification of secondary vertices

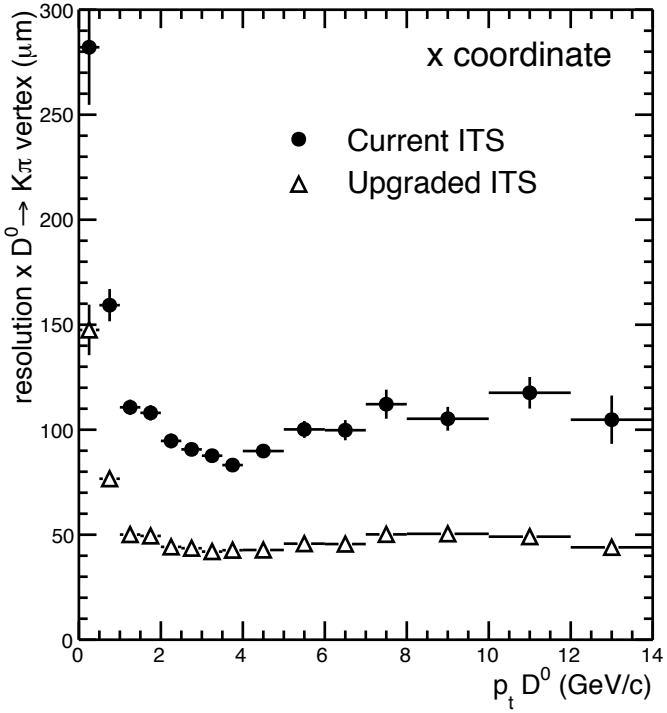


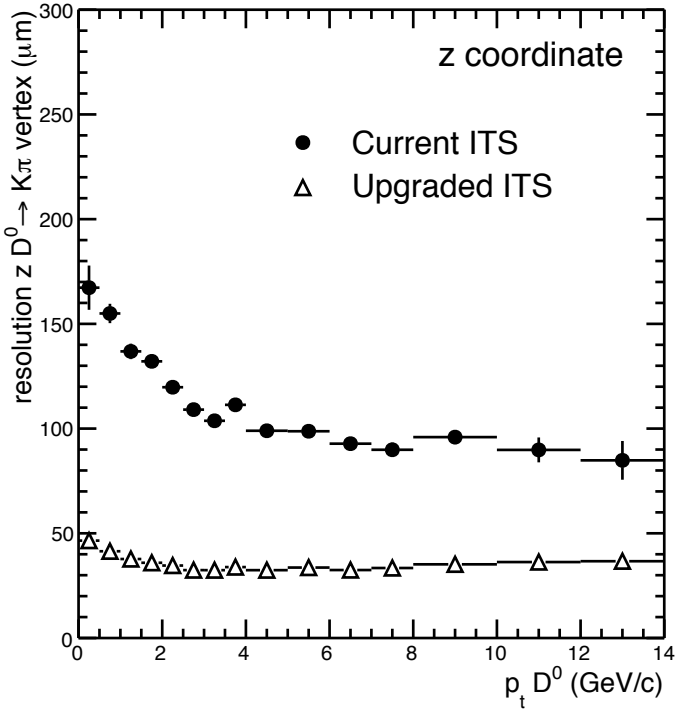
Impact parameter ~100μm

CERN-PH-EP-2012-XXX March 6, 2012

Schematic view of the D0 decay in the **D0 → K−π+** channel

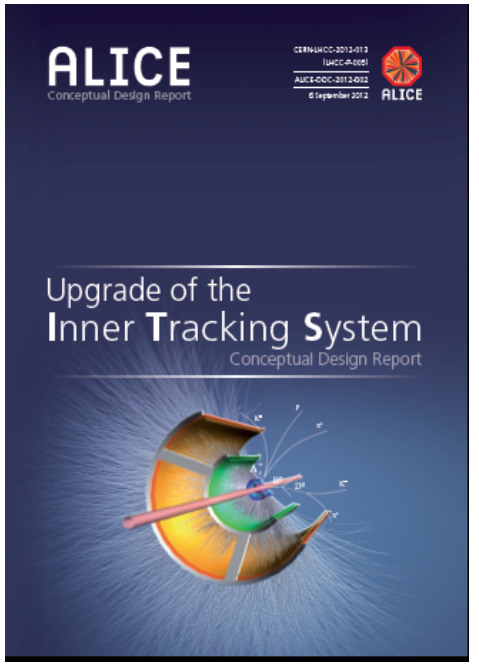
D0 → K−π+ secondary vertex position resolutions vs. p_T for current and upgrade scenarios: x (left) and z (right) coordinates.





Challenges and requirements:

- Improve impact parameter resolution factor of ~**3** in r-φ (z) at 500 MeV/c)
- First layer closer to interaction point: r0 = **39 mm → 22 mm**
- Smaller beam pipe radius: **29 mm → 18.2 mm**
- Smaller pixel size: **50 µm x 425 µm → 28 µm x 28 µm**
- Improve tracking efficiency and p_T resolution at low p_T
- Increase the number of layers **6 →7**
- Easier maintenance
- Fast readout : 1 kHz → 50 kHz in Pb-Pb, 200 kHz in pp
- Low-material budget (< 0.3% Xo for 3 inner layers)



CDR: Endorsed by LHCC in Sept. 2012

ITS Upgrade TDR: in March 2014

→ New, high-resolution, low-material, fully-monolithic inner tracker based on CMOS sensors!

Upgraded ALICE ITS design

Based on high resistivity epitaxial layer Monolithic Active Pixel Sensors (MAPS)

3 Inner Barrel layers (IB)
4 Outer Barrel layers (OB)

Radial coverage: 21-400 mm

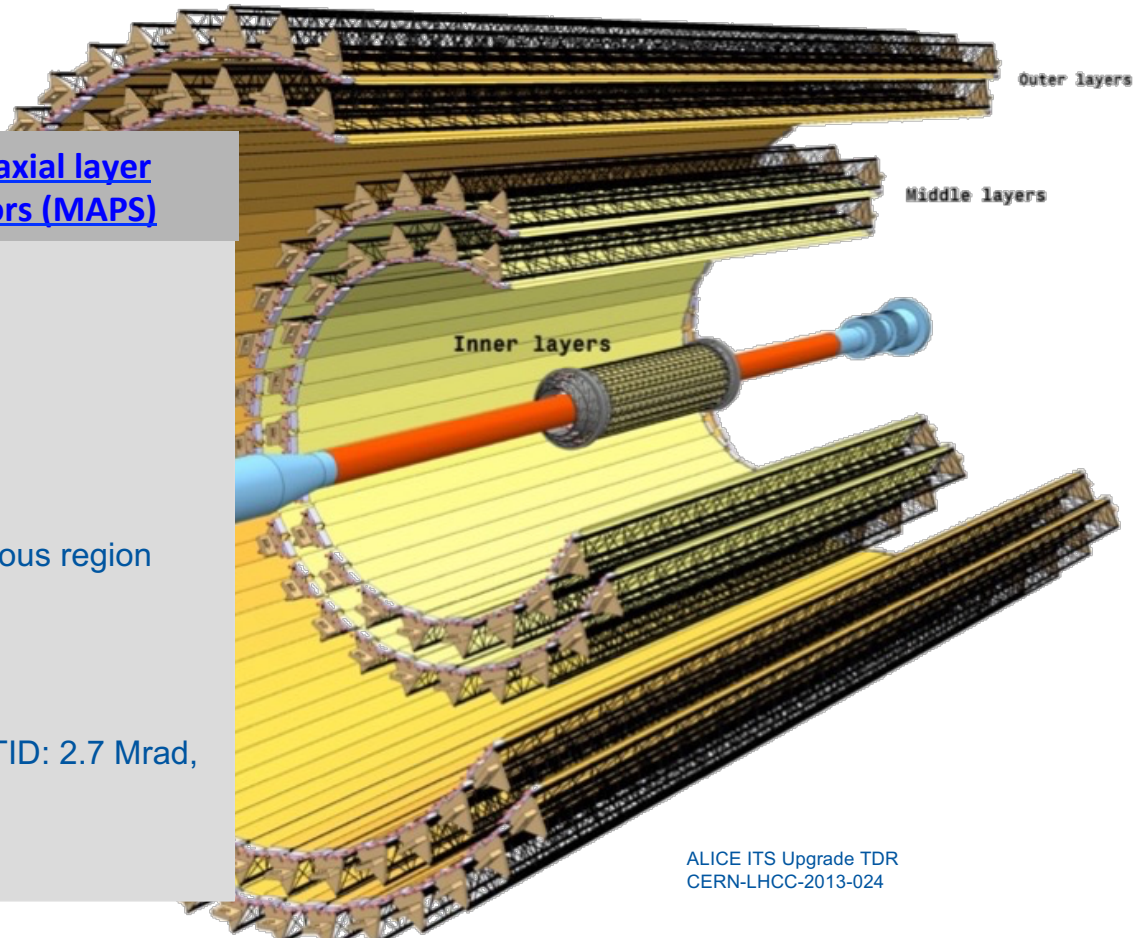
~ 10 m²

|η|<1.22 over 90% of the luminous region

0.3% X_0/layer (IB)
0.8 % X_0/layer (OB)

Radiation level (IB, layer 0): TID: 2.7 Mrad, 1.7 x 10^{13} 1 MeV n_{eq} cm^{-2}

Installation during LS2

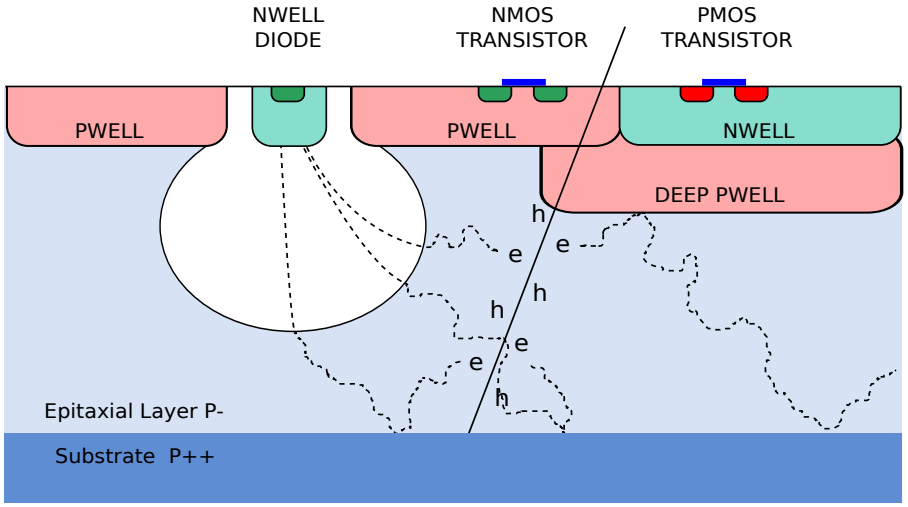


ALICE ITS Upgrade TDR
CERN-LHCC-2013-024

CMOS Pixel Sensor

J. Phys. G: Nucl. Part. Phys. **41** (2014) 087002

TowerJazz 0.18µm CMOS Imaging Process



Schematic of MAPS pixel in imaging CMOS TowerJazz 0.18 µm technology

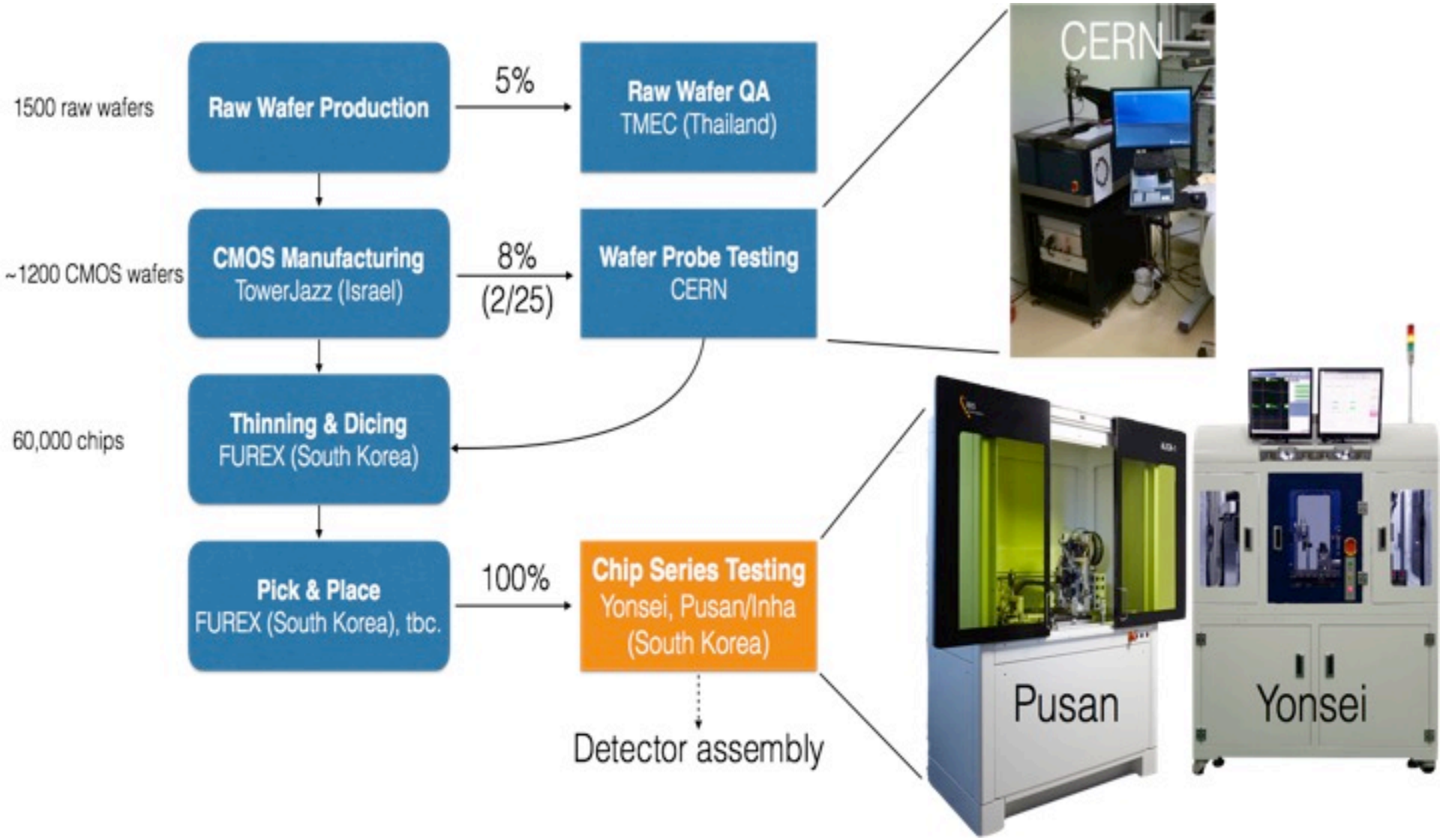
- Pixel pitch ~ 30 µm
- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25µm) on p-type substrate
- Small n-well diode (2 µm diameter), => low capacitance
- Reverse bias voltage to substrate (contact from the top) can be used to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS Transistors
- Very low power dissipation (<300nW/pixel)

PIXEL Chip – General Requirements and ALPIDE Specifications

Parameter	Inner Barrel (IB)	Outer Barrel (OB)
Chip size (mm x mm)	15 x 30	
Chip thickness (μm)	50	100
Spatial resolution (μm)	5	10 (5)
Detection efficiency	> 99%	
Fake hit rate	< 10^{-5} evt^{-1} pixel^{-1} (>> ALPIDE)	
Integration time (μs)	< 30 (< 10)	
Power density (mW/cm^2)	< 300 (~35)	< 100 (~20)
TID radiation hardness (krad) (*)	2700	100
NIEL radiation hardness (1MeV n_{eq}/cm^2) (**)	1.7 x 10^{13}	1.7 x 10^{12}

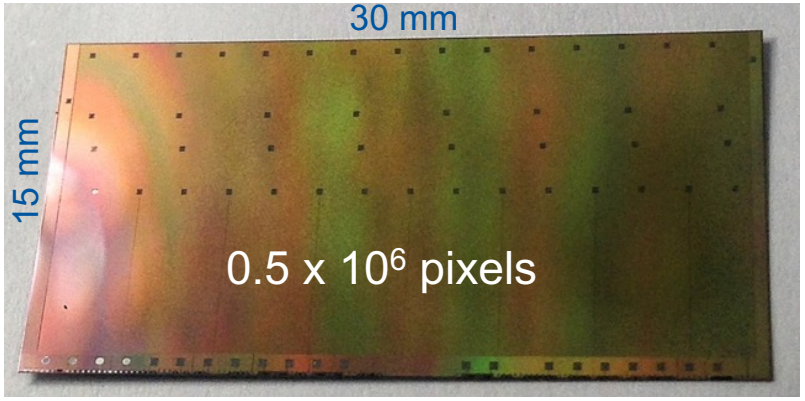
ALICE-TDR-017, Upgrade of the ALICE Inner Tracking System , CERN-LHCC-2013-024 02 December 2013

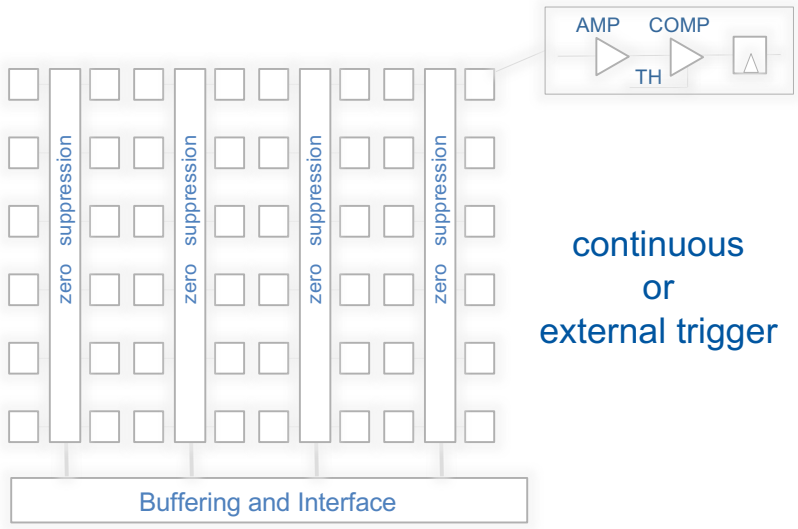
Chip Production – Overview



ALPIDE Chip

- Pixel size: 29 x 27 μm^2 with low power front-end (40 nW)
- Asynchronous sparsified digital readout
- **Power density ~300 nW/pixel**
- Minimized inactive area on the edge due to pads-over-matrix design (~ 1.1 x 30 mm^2)
- Full size prototypes produced on different epitaxial wafers
- **Partial depletion of the sensitive region due to back bias**
- Extensive tests before and after irradiation

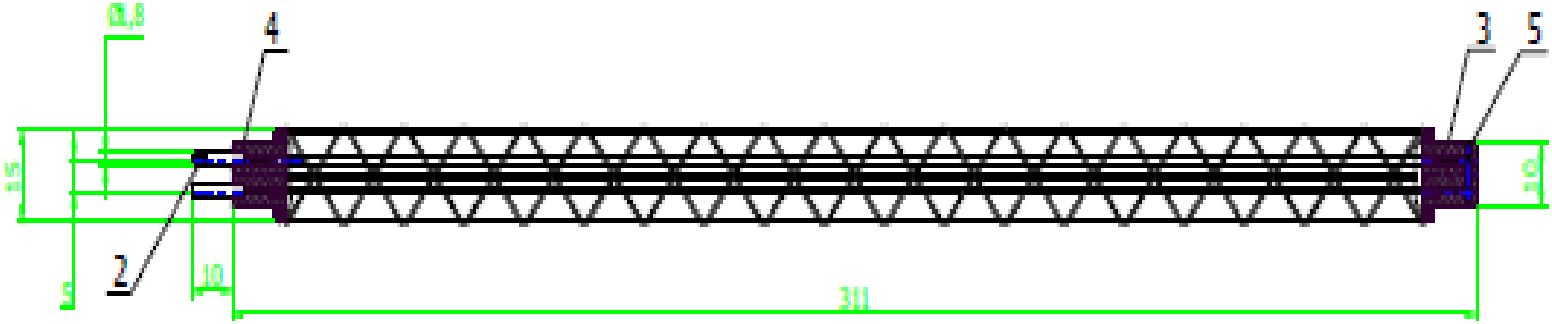


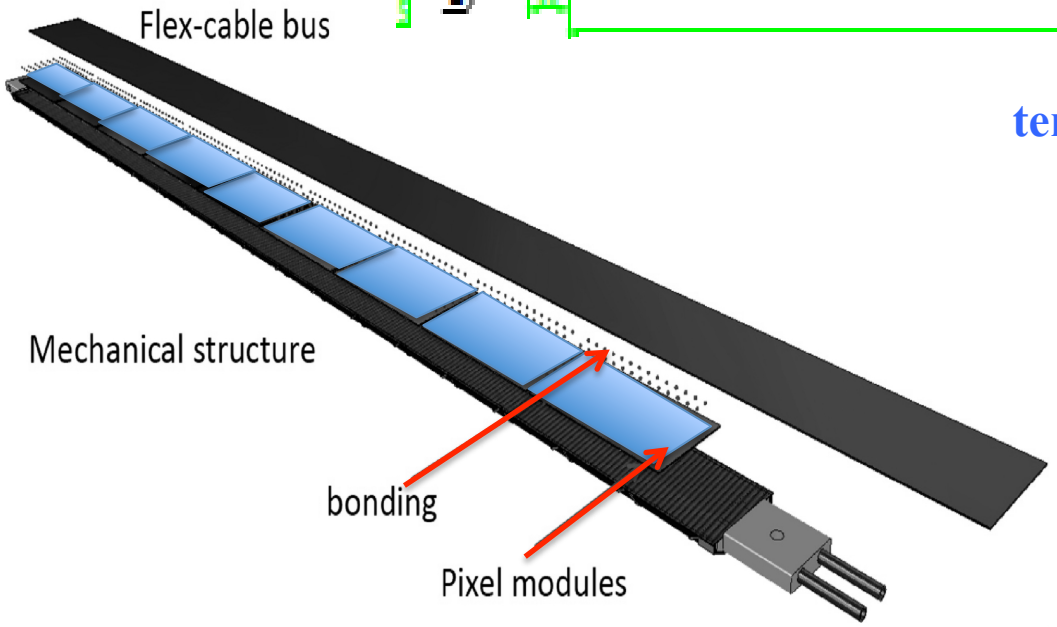


continuous
or
external trigger

ALICE technology for IB staves:

JINST 9 P06005(2014)





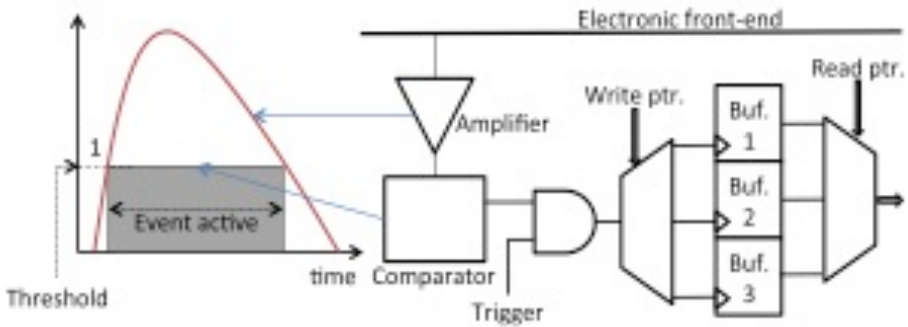
Thickness of detector components in terms of fraction of radiation length X/Xo

Material	Thickness (µm)	Xo (cm)	X/Xo (%)
Polyimide cooling pipe wall	25 µm	28.41	0.003
Carbon fleece	40 µm	106.8	0.004
Water	1mm	35.76	0.032
Carbon fiber plate K13D2U	70 µm	26.08	0.027
Graphite foil	30µm	26.56	0.011
Thermal greese (glue)	100µm	44.37	0.023
Si-sensor	50µm	9.36	0.064
Total (without FPC)			**0.154**
Total			**<0.3**

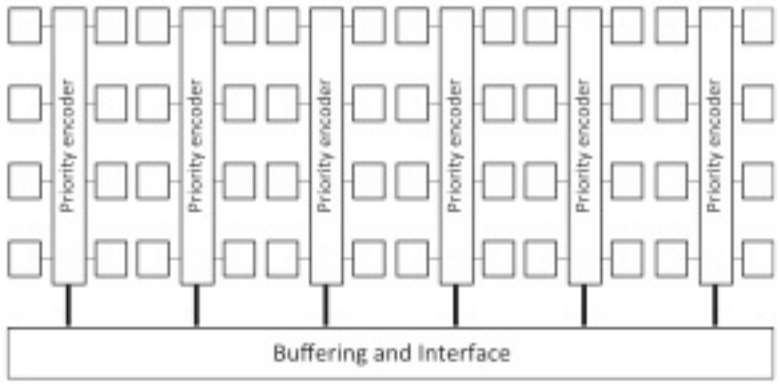
- **Record level of radiation transparency <0.3% Xo**

Readout of ALPIDE chips

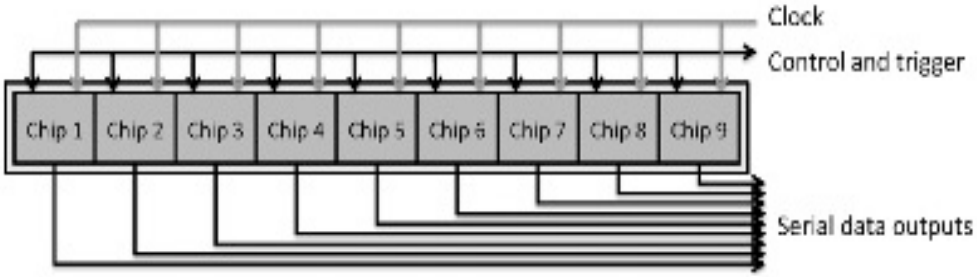
NIMA 824 (2016) 465–469



ALPIDE pixel cell

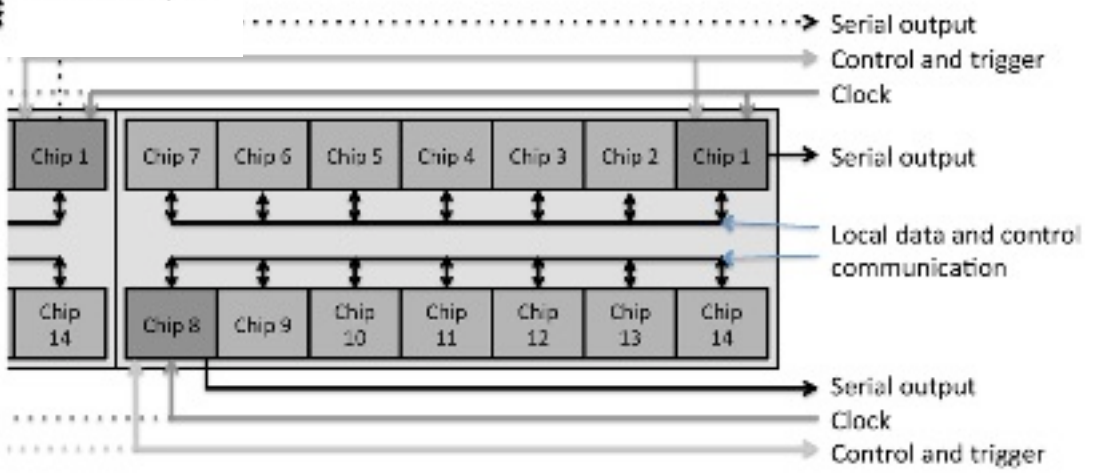


Sketch of the ALPIDE architecture

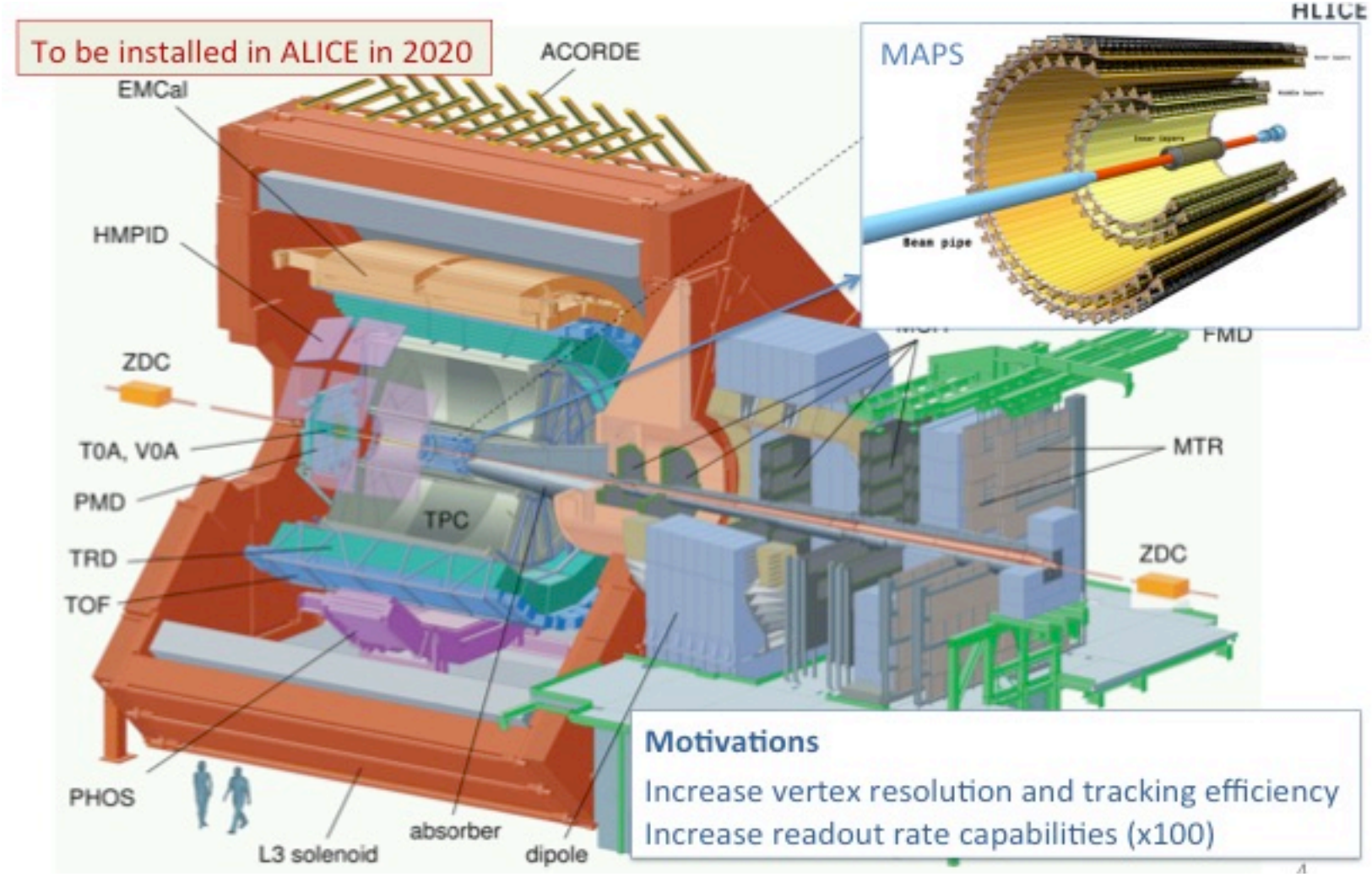


The Inner Barrel stave readout

The Outer Barrel half-stave readout

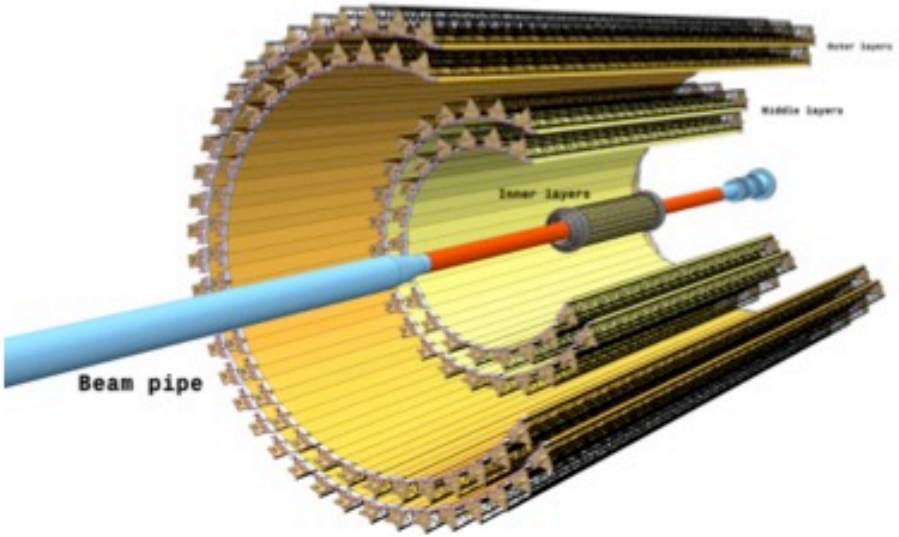


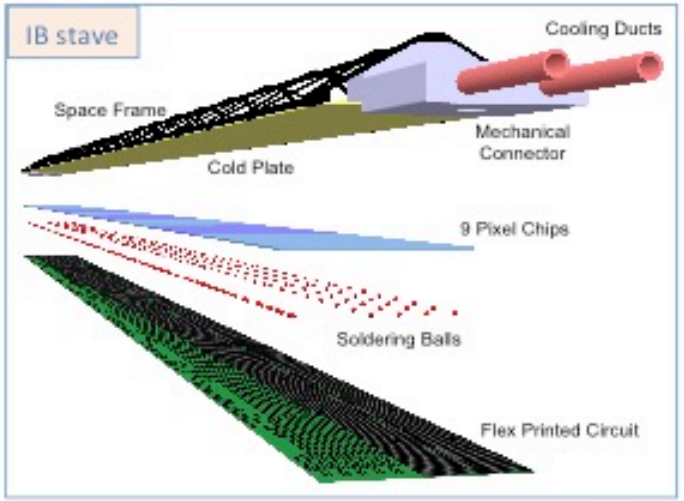
Upgrade of the ALICE Inner Tracking System



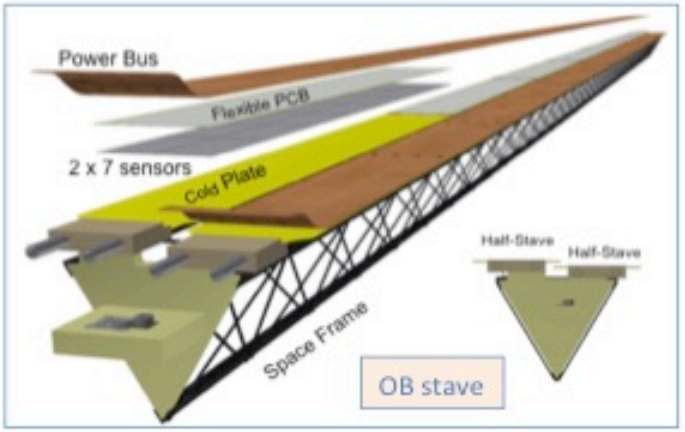
→ New, high-resolution, low-material, fully-monolithic inner tracker.

New ITS design



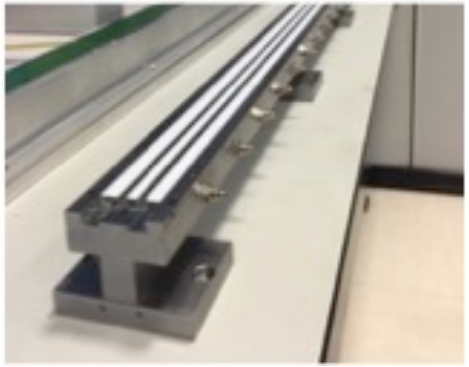


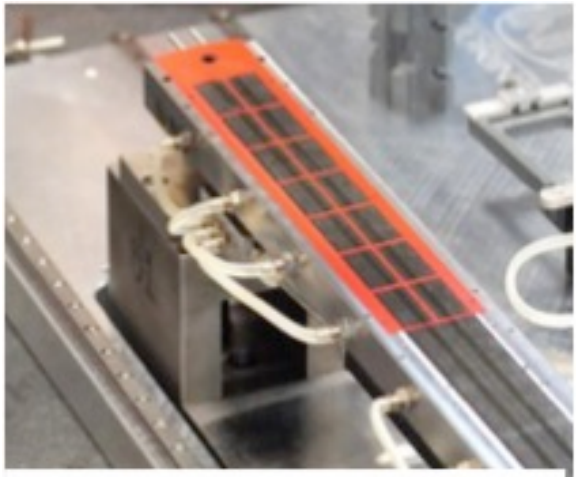
- Total active area ~10m^2
- ~ 24,000 pixel chips (12.5 G pixels)
- Stave components
  - Hybrid Integrated Circuit (HIC)
  - Cold plate
  - Space-frame



Hybrid Integrated Circuit (HIC) and Stave Production

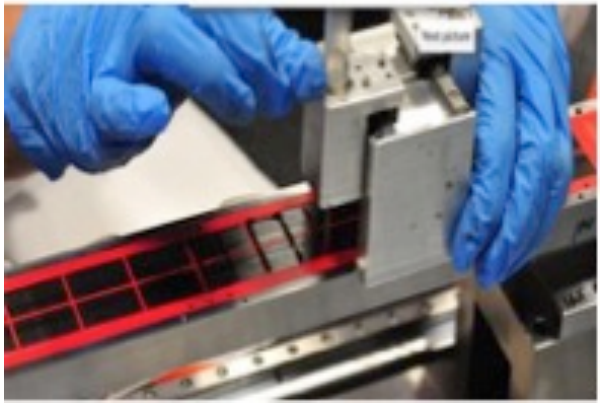
1. CP positioning on the HS base



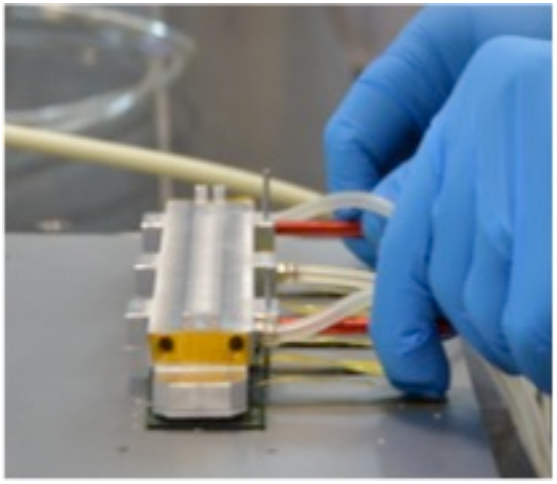


2. Glue mask on the CP

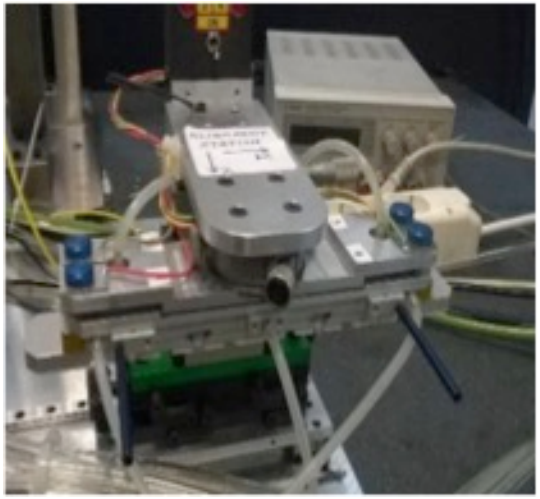
3. Glue spread on the CP



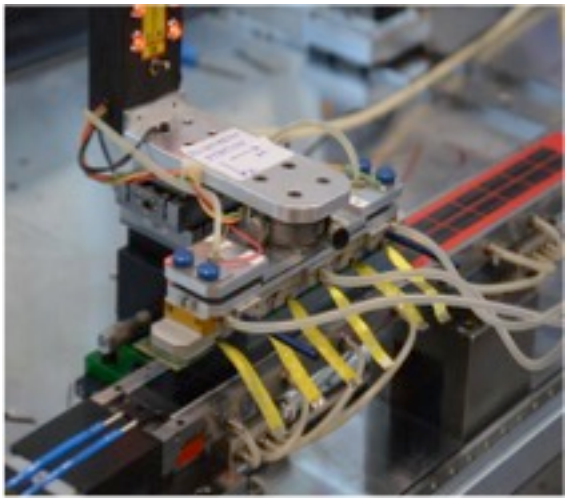
4. HIC gripped by the HIC gripper



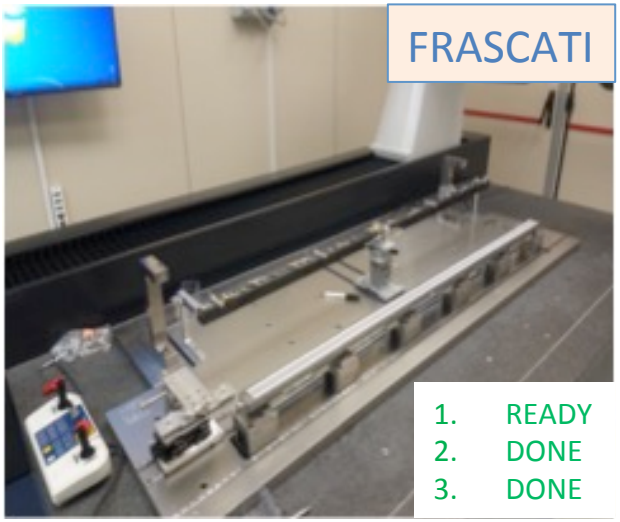
5. HIC gripper fixed to the Alignment station

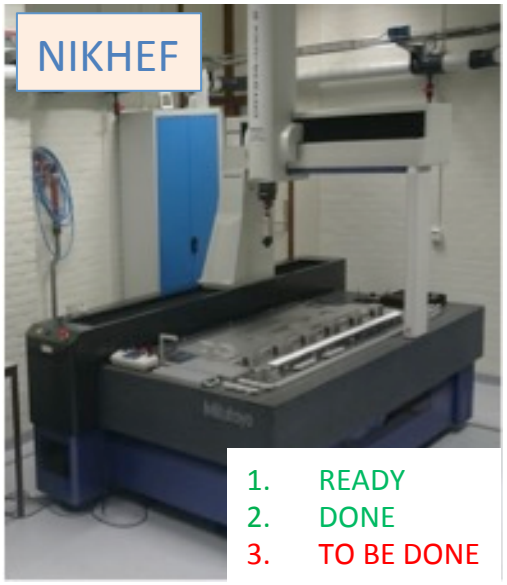


6. HIC alignment



Stave Assembly – Production Sites



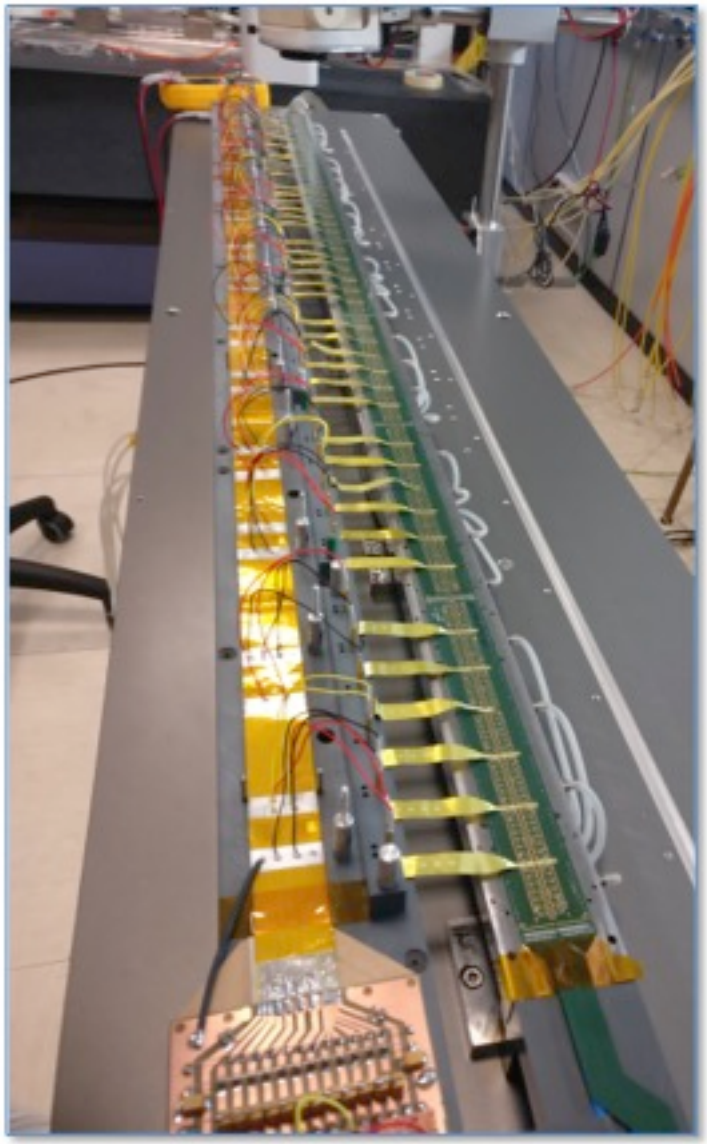


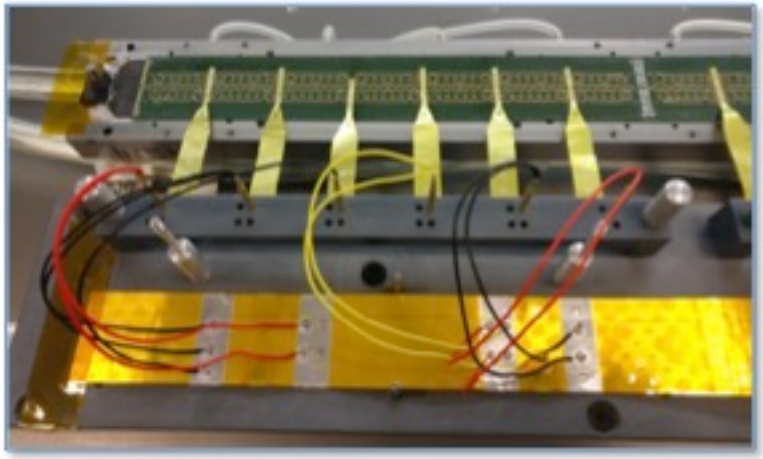
Readiness of laboratories:

1. Infrastructures and tooling
2. Training on assembly procedures
3. Training on test procedures

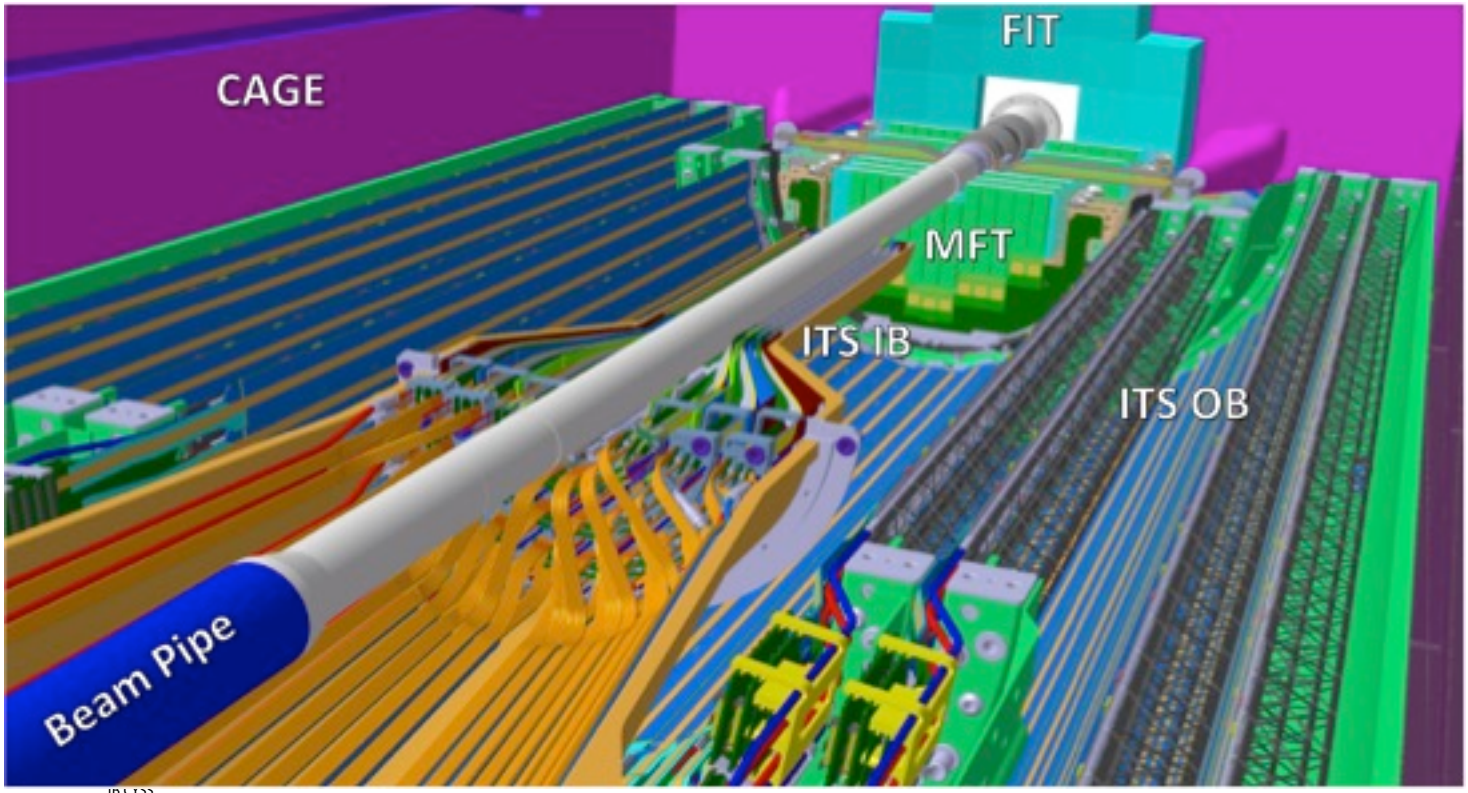
Stave prototypes

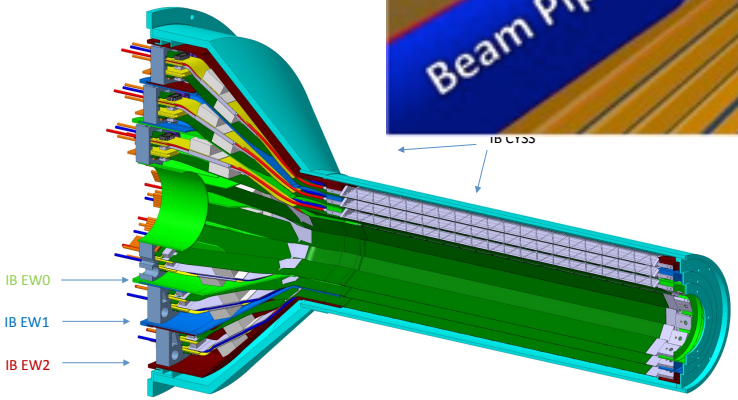
- Assembly of Stave-0 completed using prototype HICs
- Used to validate design and layout for production readiness review; characterisation results reproduced performance measured on single HICs
- Assembly of Stave-1 ongoing; first half-stave completed, tests show all 98 chips fully functional





3D view of the new ITS layout

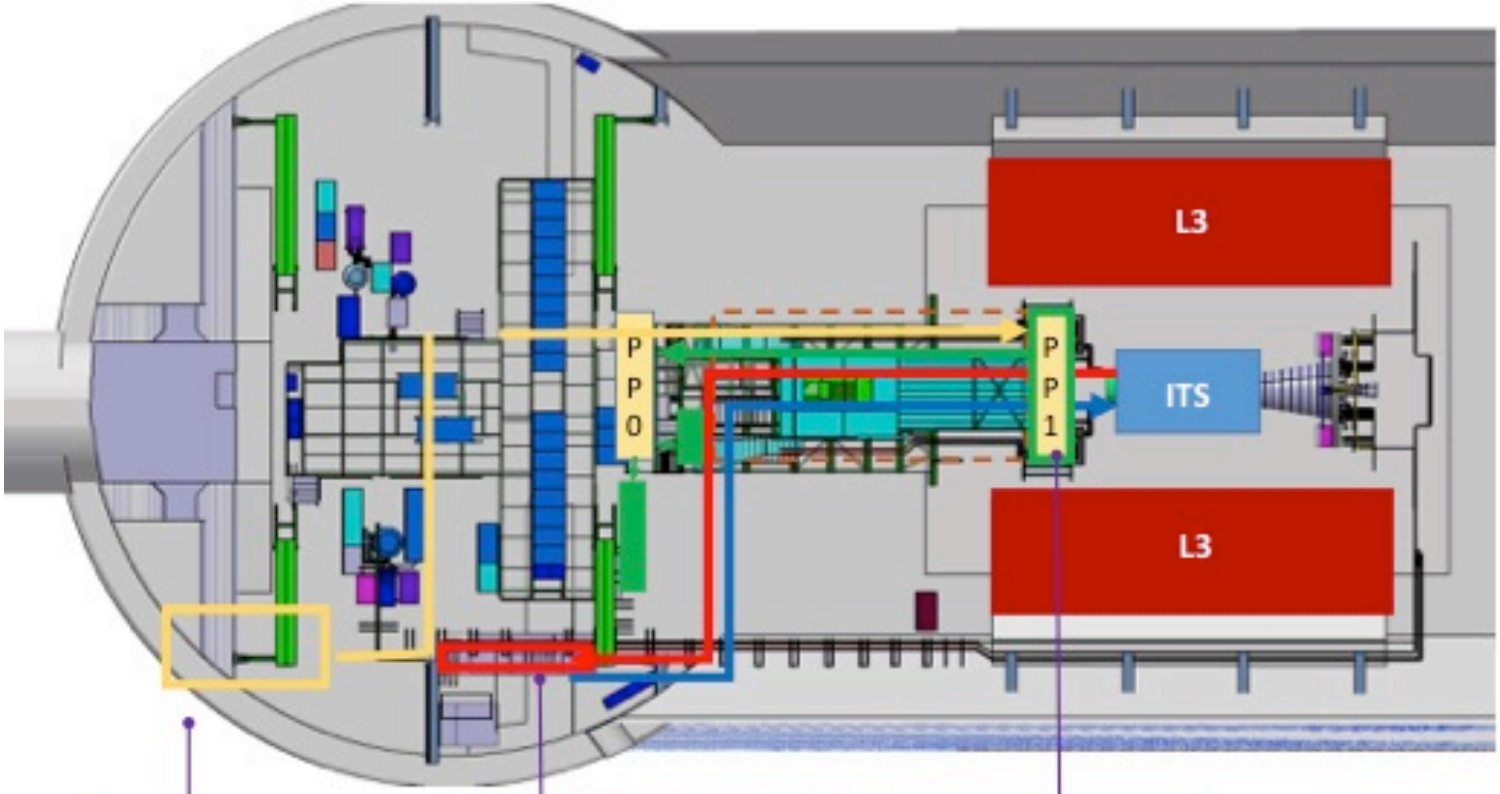




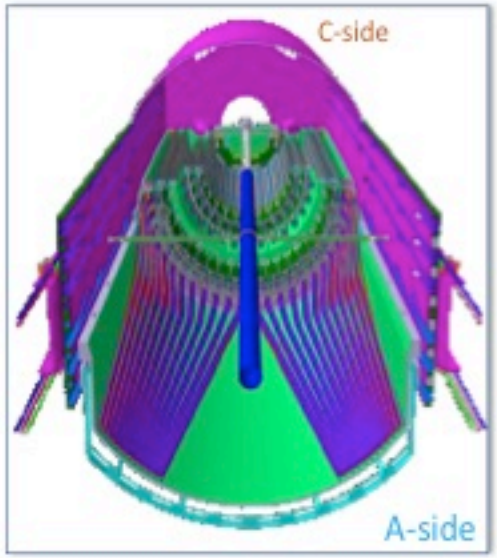
Inner Barrel (ITS IB)

Material thickness per detector layer: ~ 0.3% X/X_0)

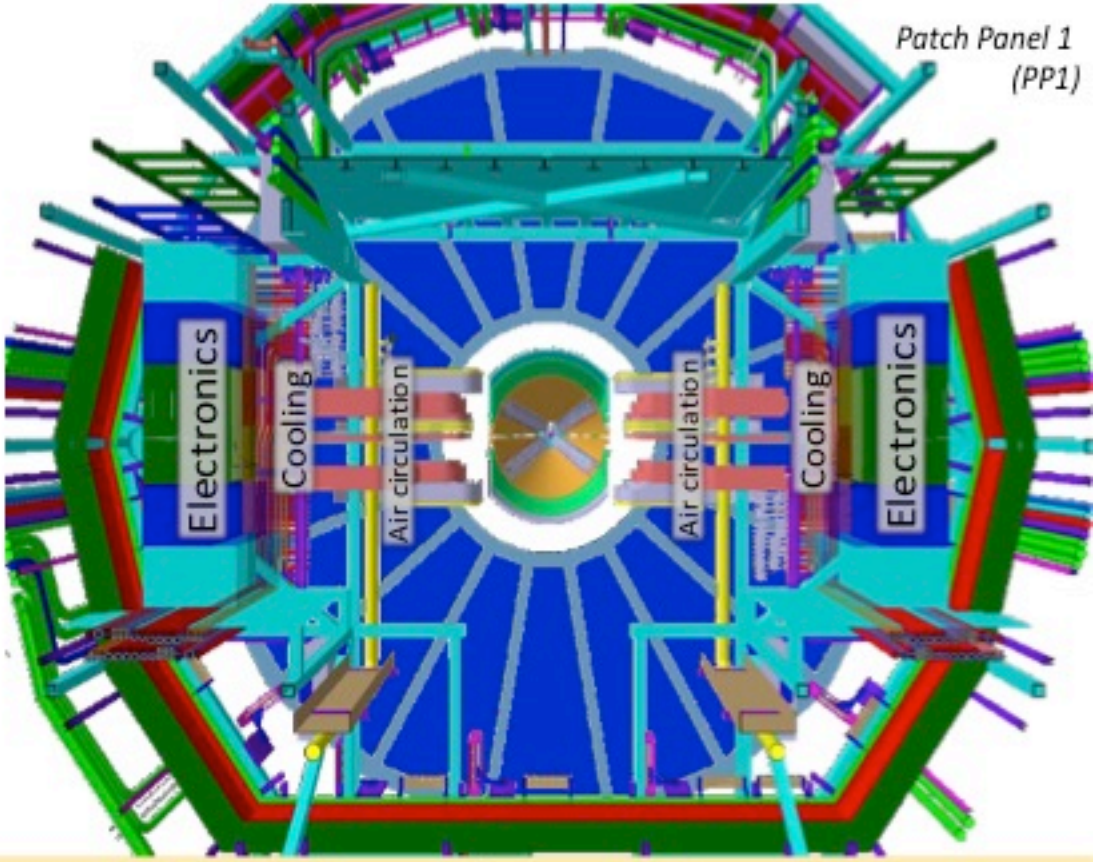
Services Layout in the ALICE Cavern



Services: Interface Cage of New ITS

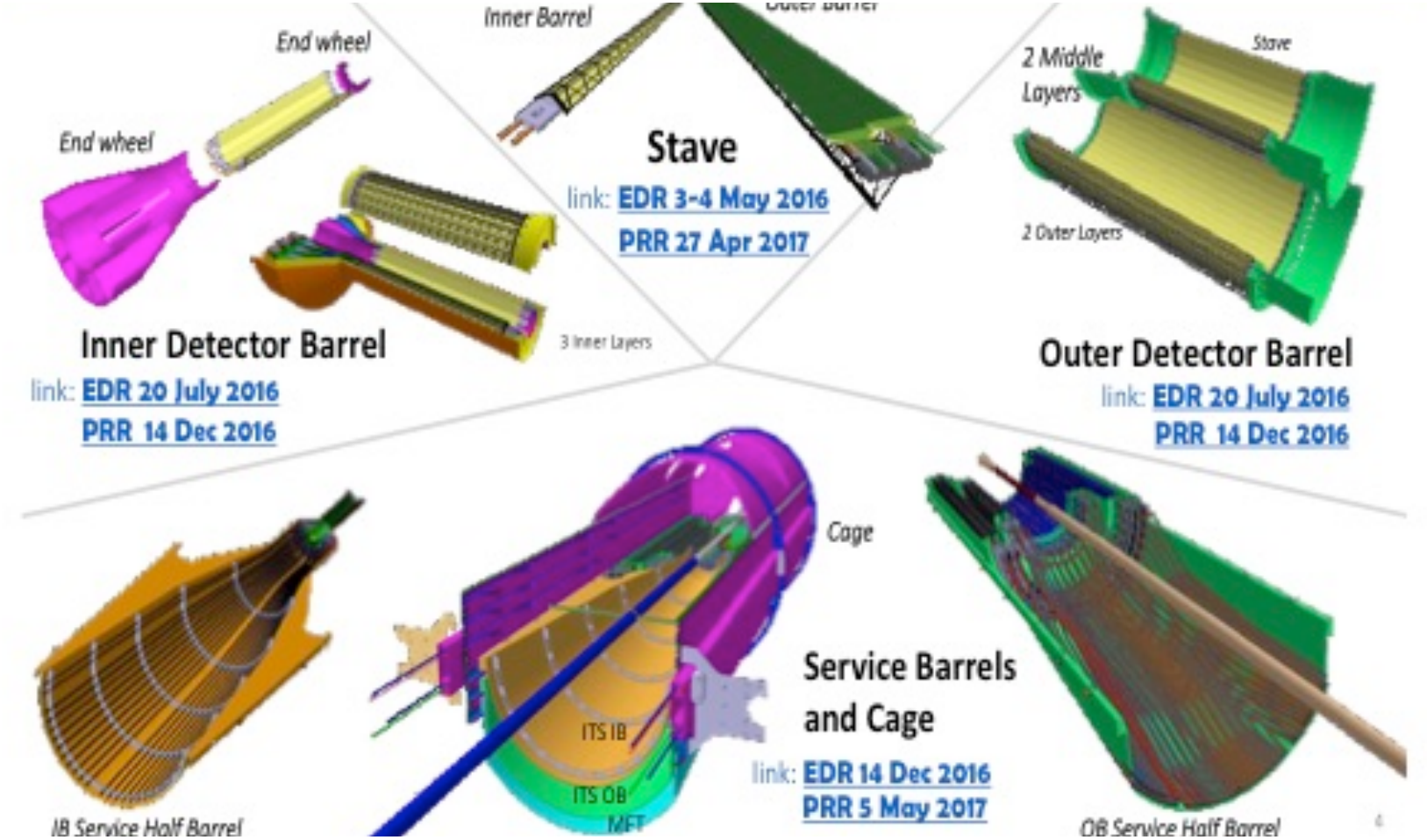


	Services	to	n.
ITS IB	Air ducts	A-side	30
	Water pipes	A-side	96
	Power	A-side	48
	Data	A-side	48
IT OB	Air ducts	A-side	46
	Water pipes	A-side	288
	Power	A-side	144
	Data	A-side	576



Cage/ITS Interface and Services

Services, Mechanics and Cooling Overview



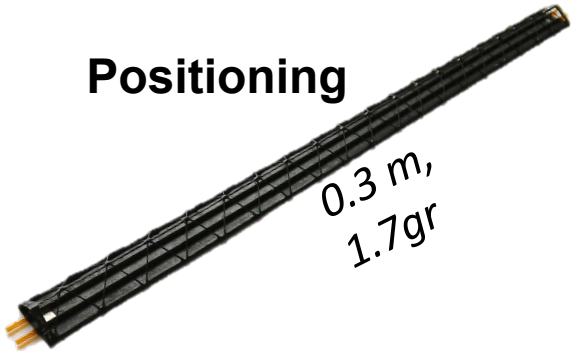
- **IN PRODUCTION PHASE**
- **Dry Assembly Test at the end of 2017**

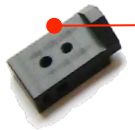
2017: Spaceframe production status: IB

PRR 27 April 2017

CARBON PARTS PRODUCTION FINISHED

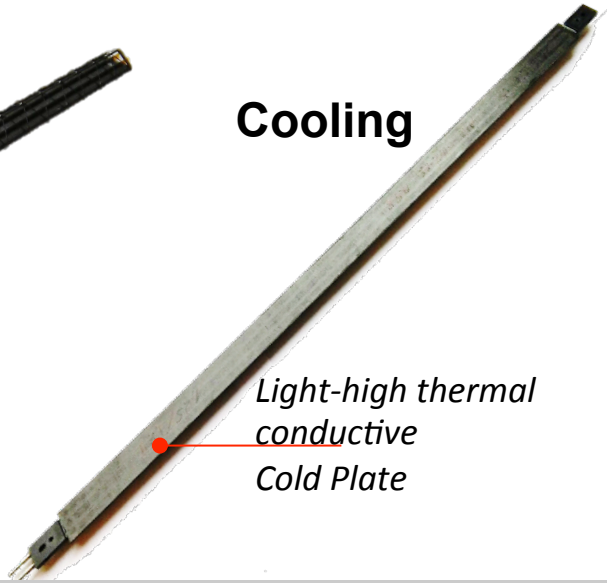
Positioning





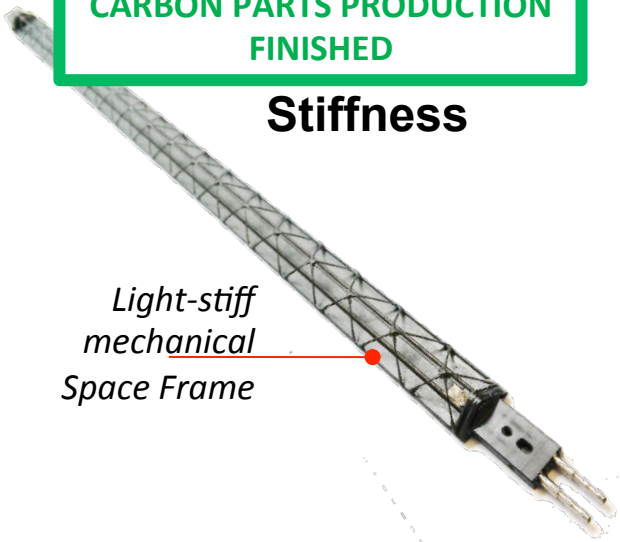
Stave Precise positioning end pieces

Cooling



Light-high thermal conductive Cold Plate

Stiffness



Light-stiff mechanical Space Frame

Production at CERN

Number of Space Frame produced to date for the ITS Inner Barrel are **170** out of 106 (40*)

* with connectors and

Manual Layup

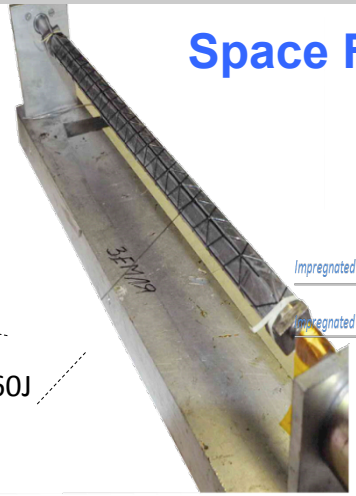
Cold Plate

Water leak-less cooling (-- below atmospheric pressure).
Pipe Burst pressure at 51bar

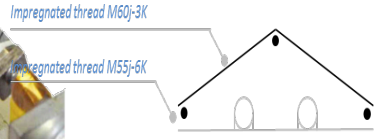
***Embedded polyimide pipes** Pyre M.L.®*

fleece

Space Frame



Filament winding



M60J

2017: OB Spaceframe Production

ALICE ITS Upgrade

Spaceframe CARBON PARTS PRODUCTION FINISHED

Positioning

Stave Precise positioning

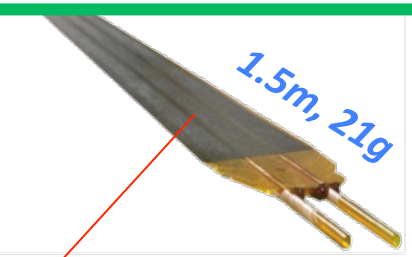
End Pieces

Stiffness

Light-stiff mechanical

Space Frame

Connection between Space Frame and Cold Plate



Light - high thermal conductive

Cold Plate

Production at CERN

Number of Space Frames (SF) and Cold Plates (CP) produced to date

-- for the **Middle** Layers: **82** SF out of 65 (9*), 140 CP out of 130

--for the **Outer** Layers: **140** SF out of 108 (12*), 230 CPout of 216 (75*)

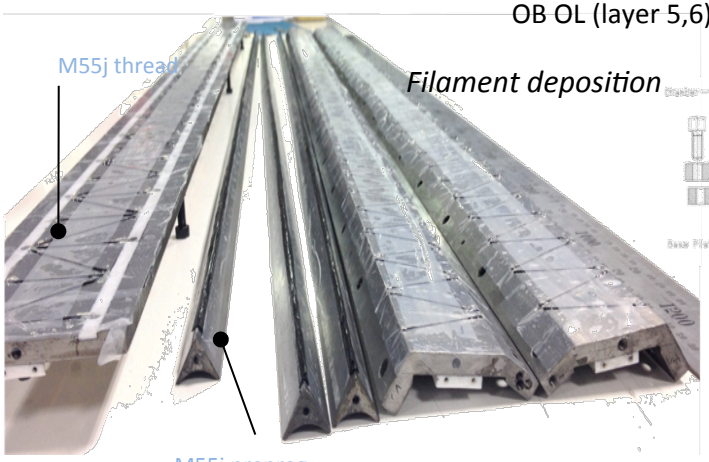
* with connectors and fittings

➢ **A set of structures is ready for delivery to the integration centers**

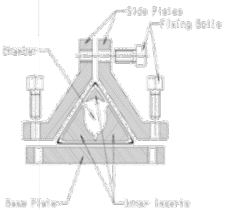
Total number of structures needed: OB ML (layer 3,4): 24+30 pc = 54pc; spare 20%; total **65 SF (130 CP)**

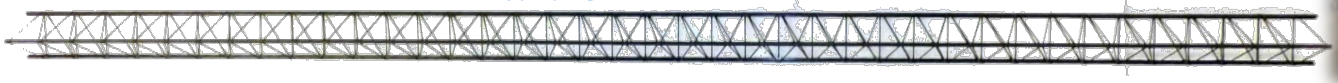
OB OL (layer 5,6): 42+48 pc = 90pc; 20%spare; total **108 SF (216 CP)**

Carbon peek machined part

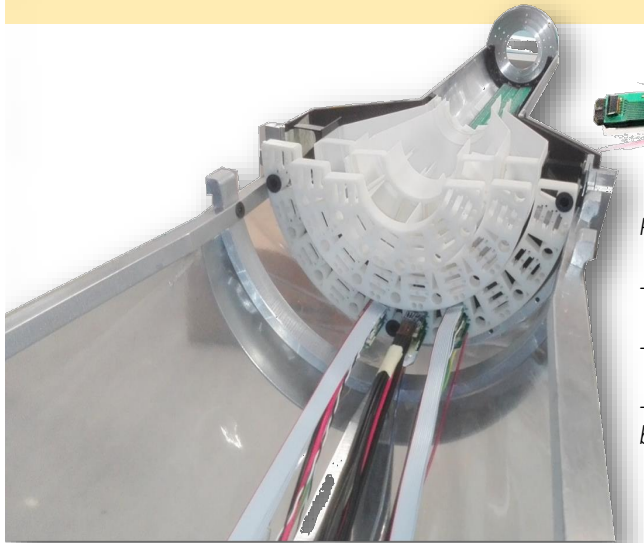


Filament deposition





Inner Barrel (IB) mock-up and prototype

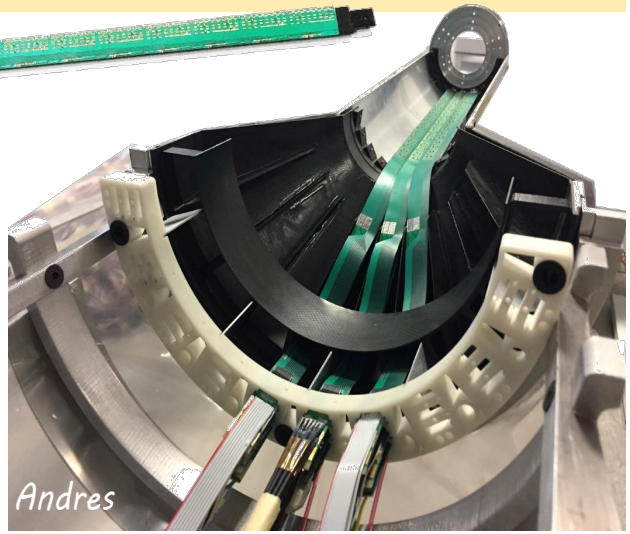


Patch Panel optimization:

-Firefly PCB opening: 15.1 mm

-Spring-plate locking system: 0.07 mm thick

- Connector support opening: modified to block rotation of connector

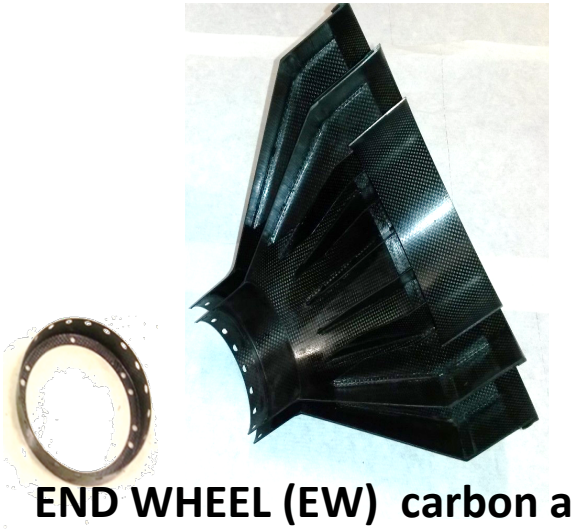


➢ **Composite parts production is well advanced**

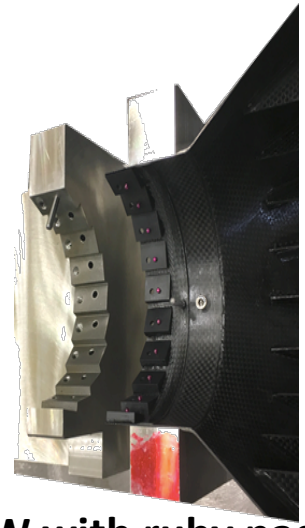
DETECTOR BARREL Mechanics production status: IB

PRR 27 Dec 2016

END WHEEL carbon parts



END WHEEL (EW) carbon assembly



EW with ruby pads

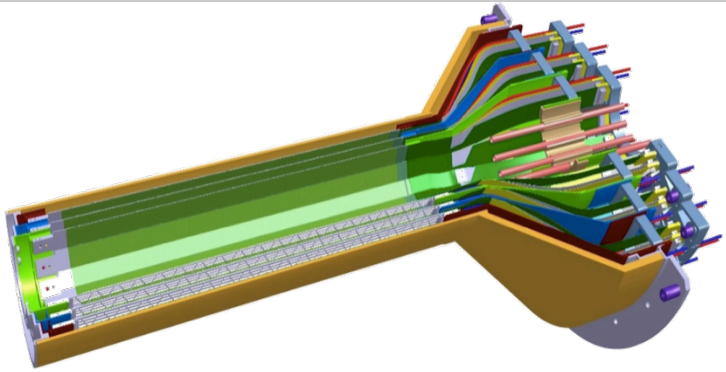
Production at CERN

Number of		
END WHEEL carbon parts	produced to date	3x EW0, 3x EW1, 3x EW2
END WHEEL carbon assembly	produced to date	1x EW1, 0.5x EW2
END WHEEL with ruby pads	produced to date	0.5x EW2

All assembly jig for ruby pads gluing produced

Total number of structures needed

Nominal=1 EW0, 1 EW1, 1 EW2 + 1 CYSS; spare 120%; total **3 EW0, 3 EW2, 3 EW3, 3 CYSS**

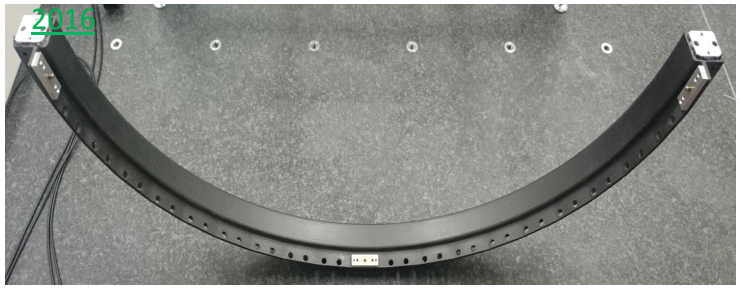


CYSS

Cylindrical Structural Shell.

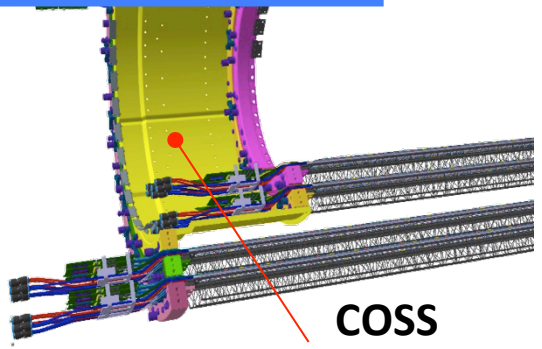
DETECTOR BARREL Mechanics production status: OB

PRR 27 Dec 2016



END WHEEL carbon parts

END WHEEL with ruby pad



COSS

Conical Structural Shells

Prototype phase completed, tender closed, contract assigned LOSON, Carbon Material procured, Moulds produced

Production at Loson Compositi

Production at BERKELEY LAB

Number of:

END WHEEL (EW) carbon parts and

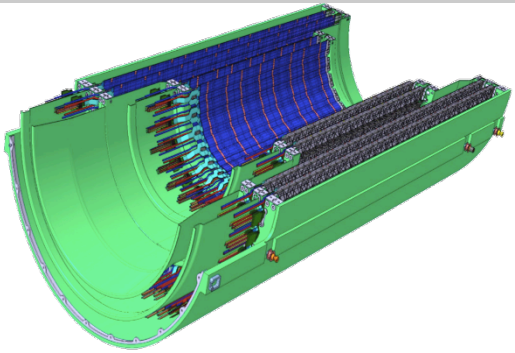
END WHEEL with ruby pads produced to date # end production foreseen

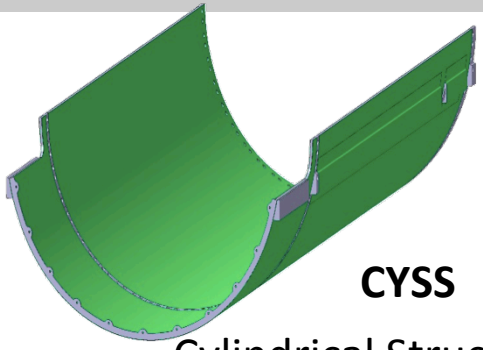
EW6 **Jul**, EW 4 **Sept**, EW3 5 **October 2017**

Cylindrical Structural Shells (**CYSS**) produced to date # end production was foreseen in **July 2017**

Conical Structural Shells (COSS)

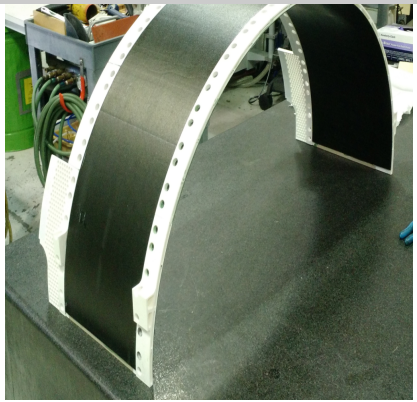
Prototype phase completed, Carbon Material procured, use of existing mould





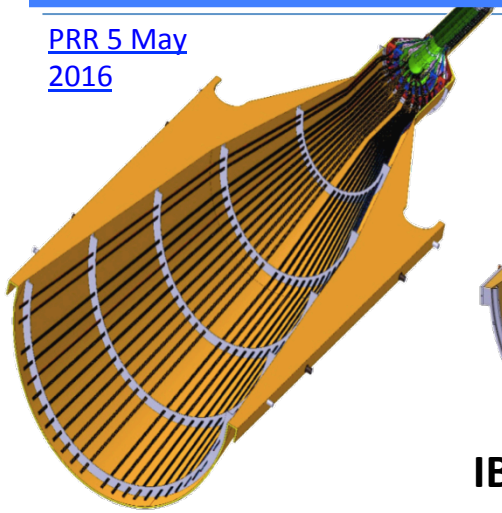
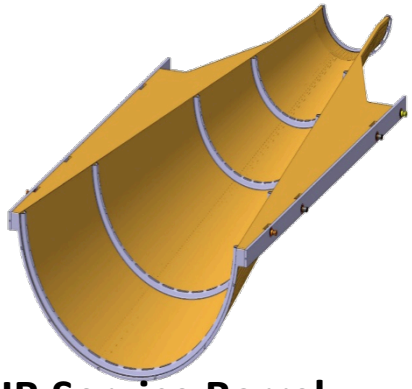
CYSS

Cylindrical Structural Shells

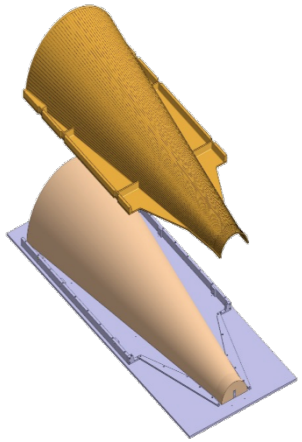
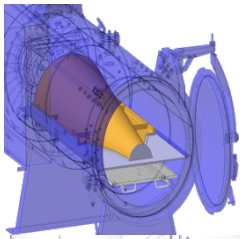
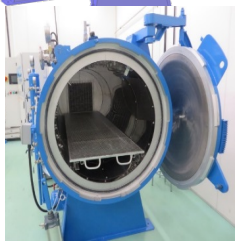
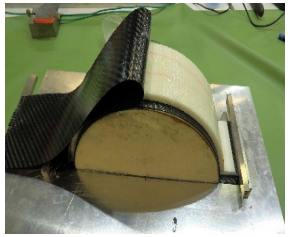


Service Barrel Mechanics production status: IB and OB

PRR 5 May 2016

IB Service Barrel


Prototype phase completed, Carbon Material procured, Mould material procured, Mould machining done in May 2017.

Production at CERN EP DT Composite

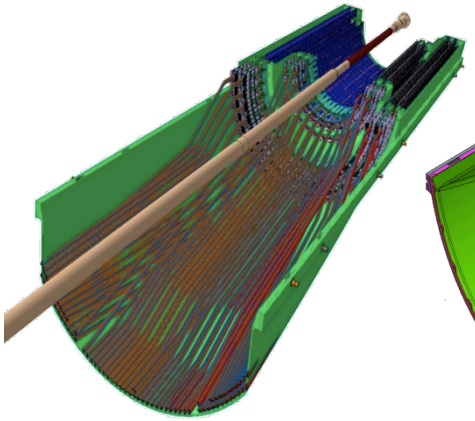
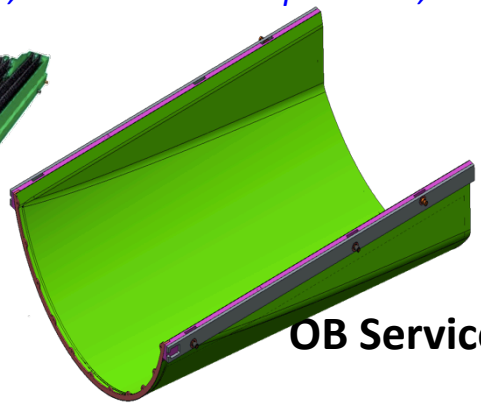
IB SERVICE BARREL — production in progress

Total number of structures needed: 1 IB Service Barrel, 1 OB Service Barrel

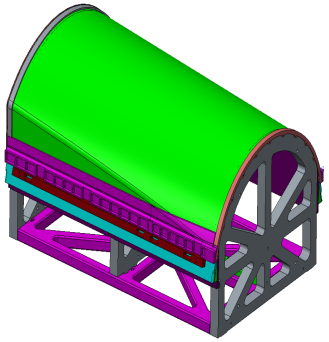
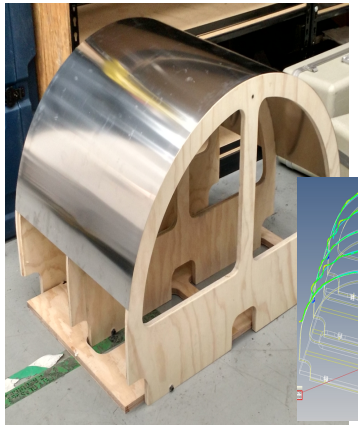
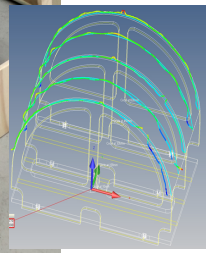
Production at BERKELEY LAB

OB SERVICE BARREL — production in progress

Prototype phase completed, Carbon Material procured, Mould production next

OB Service Barrel

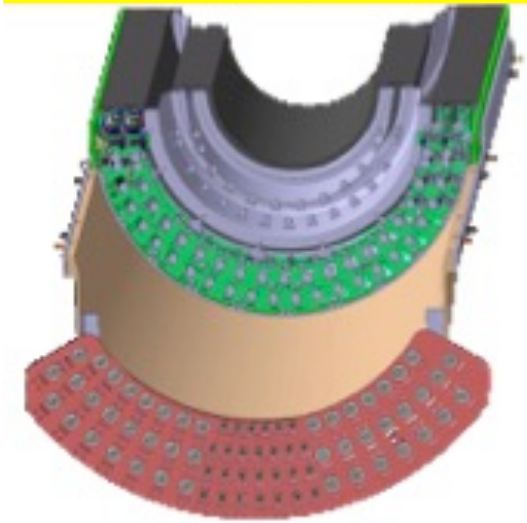




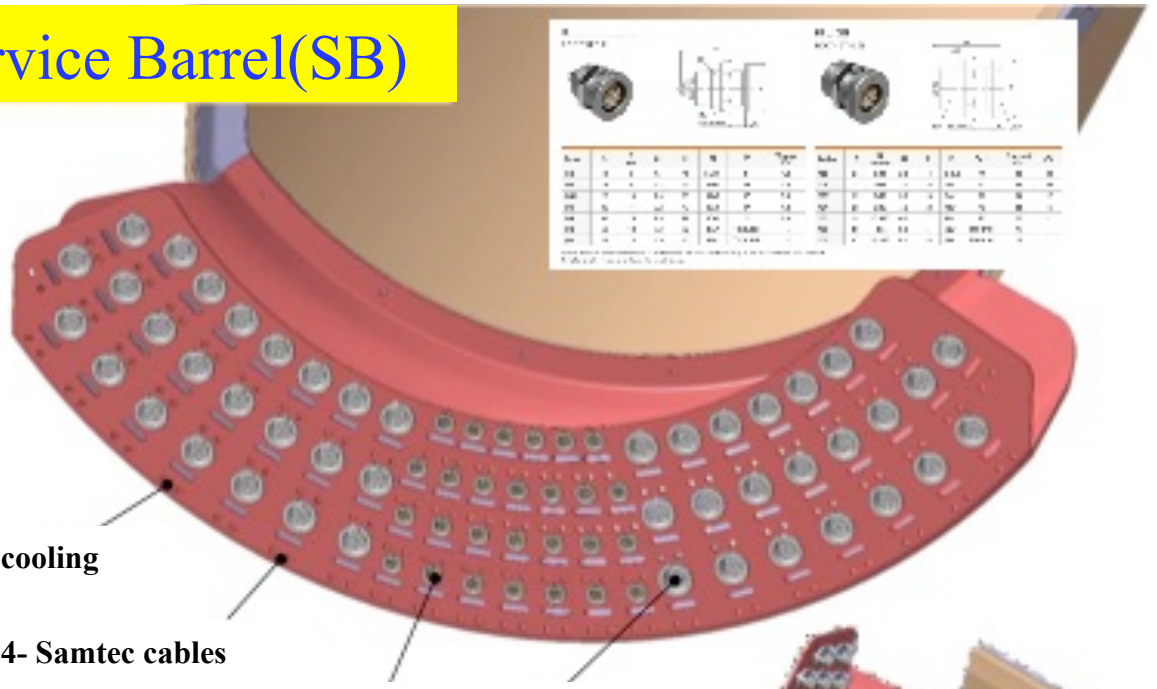
Outer Barrel Mechanics at LBNL

- Fabrication of large composite structures is progressing well, expected to be completed by October 2017
- Will be shipped to CERN
- Dry assembly test will take place in Nov-Dec 2017

Service Barrel Patch Panels (PP)

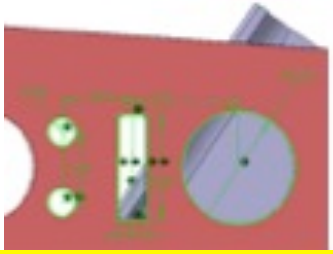
Patch Panel (PP) at OB Service Barrel(SB)



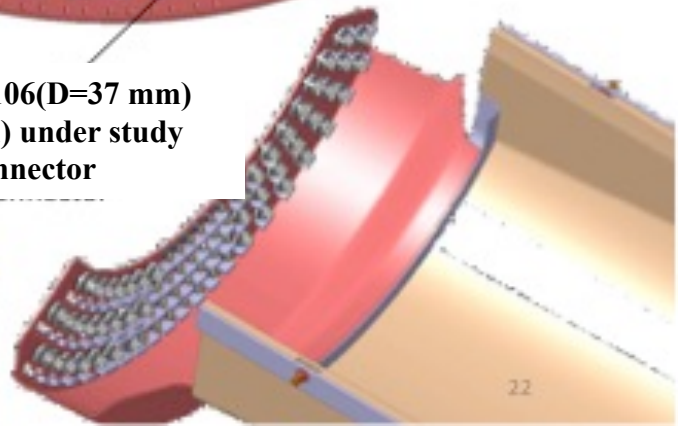


cooling

4- Samtec cables



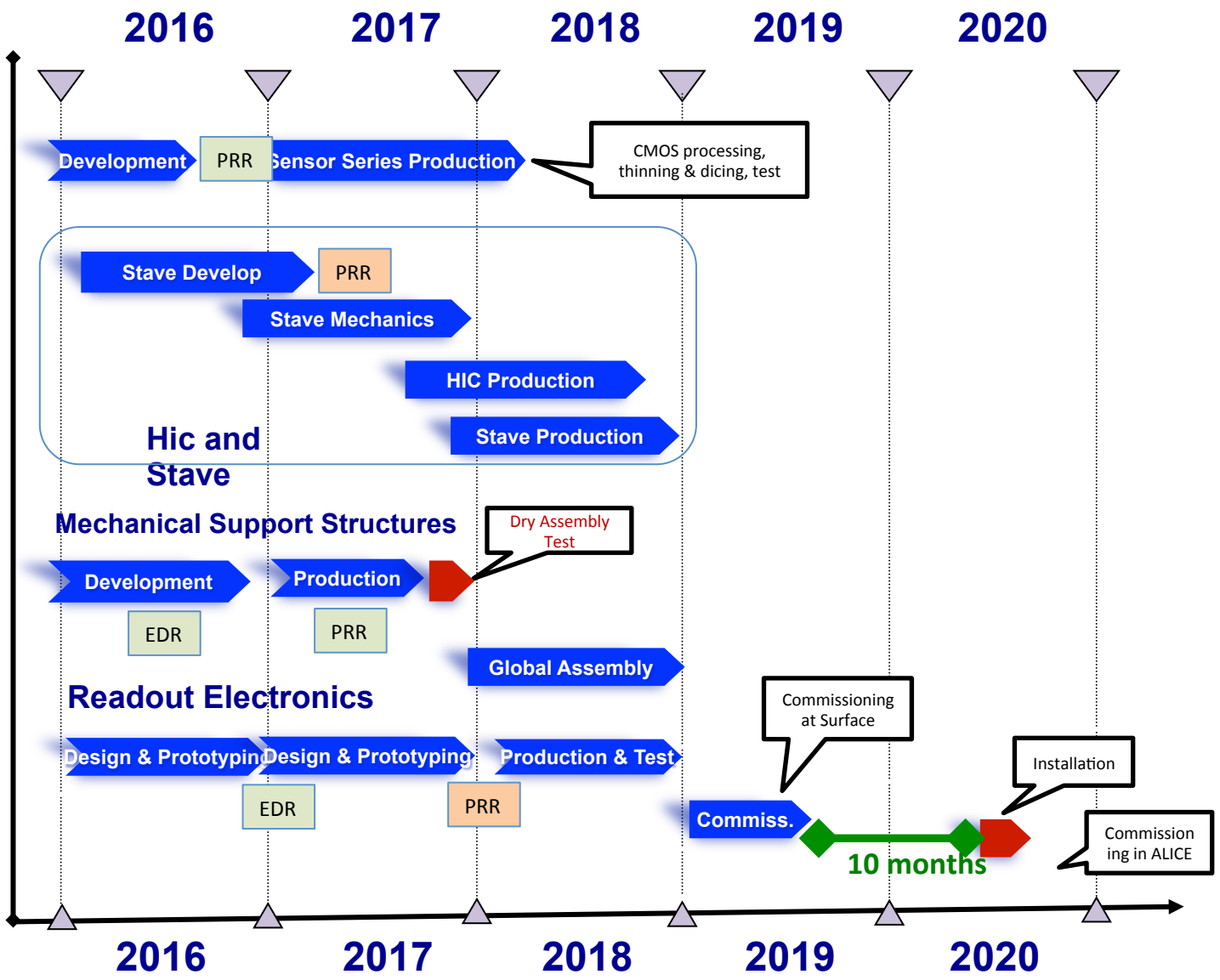
Power connectors OB-ML (D=22mm), OB-OL 106(D=37 mm)
Increase of connector size (D=24mm),(D=40mm) under study
Final assessment needs definition of Samtec Connector



The room available at the end of the OB service barrel is limited compared to the number of services and connectors
The patch panel needs to be displaced away from the end of the SB in order to gain more room for the connectors. Samtec connectors to be decided.

➢ **PP layout under study**

Production readiness reviews(PRRs)



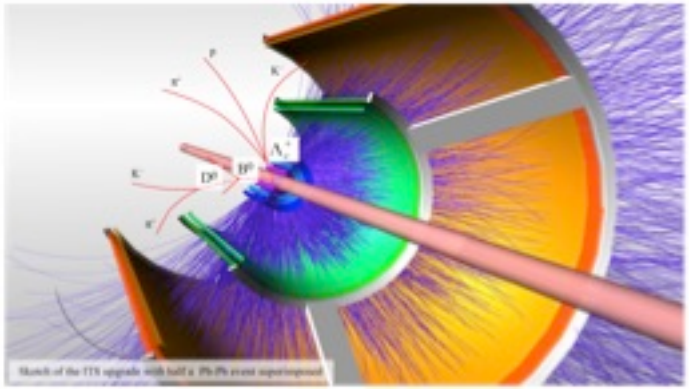
Summary

- **The following results were provided by the ITS/ALICE collaboration for the upgrade preparation during the LS1:**
  - the Research and Design was completed in 2012–2014;
  - the evaluation of technologies & prototypes, selection of technologies, engineering, design, TDR, final design - were finished in 2014 -- 2016 .
- **2017 – Production phase started to provide:**
  - The extremely low material budget for the ITS (~ 0.3% Xo for 3 innermost layers).
  - Improvement of the impact parameter resolution by a factor of ~3;
  - Reconstruction of charged particles starting from a p_T of ~50 MeV/c, and measurements of charm and beauty mesons down to zero p_T ;
  - Increase of the rate of data taking in Pb–Pb collisions from 1 kHz to ~50 kHz.
- **The project is well on track to meet the very challenging and ambitious schedule of 2018-2019!**
- **New physics studies in Pb-Pb at the LHC will be opened by ALICE after 2020!**

New physics by ALICE at the LHC
With Pb beams of high luminosity L=7x10^{27}cm^{-2}

ALICE

- Thermalization of partons in the QGP, with focus on the massive charm and beauty quarks.
- In-medium parton energy loss mechanism
- Quarkonium dissociation as a probe of deconfinement
- Production of thermal photons and low-mass dileptons
- Production of D mesons, including Ds, down to zero p_T will be accessible **for the first time**.
- Charm and beauty baryons Λ_c and Λ_b. **For the first time** via the decay $\Lambda_b \rightarrow \Lambda_c + X$.
- Baryon/meson ratios for charm (Λ_c /D) and for beauty (Λ_b/B), will be accessible **for the first time**.
- The elliptic flow (v2) of charmed and beauty mesons and baryons down to low p_T will also be accessible **for the first time.**
- Measurement of beauty via displaced D0 → Kp which will be accessible **for the first time**.
- Measurement of beauty via displaced J/psi → ee, which will also be accessible **for the first time**.



Technical Design Report for the Upgrade of the ALICE Inner Tracking System
J. Phys. G: Nucl. Part. Phys. 41 (2014) 087002

Gain a factor of **100** in statistics over original programme (Run1 + Run2)

Back-up slides

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)
8/2016	ALPIDE	**Final chip**

ITS Collaboration

ITS Collaboration (32 institutes, 15 countries)

CERN, France (Grenoble, Strasbourg), Czech Republic (Prague), Slovakia (Kosice),

Italy (Aless., Bari, Cagliari, Catania, Frascati, Padova, Roma, Trieste, Torino),

Netherlands (Nikhef, Utrecht), UK (Daresbury, Liverpool, RAL)

Ukraine (Kharkov), Russia (St. Petersburg),

China (Wuhan), Indonesia (LIPI), Korea (Pusan, Inha, Yonsei), Pakistan (CIIT-Islamabad), Thailand (Suranaree, SLRI, TMEC),

USA (Austin, Berkeley)