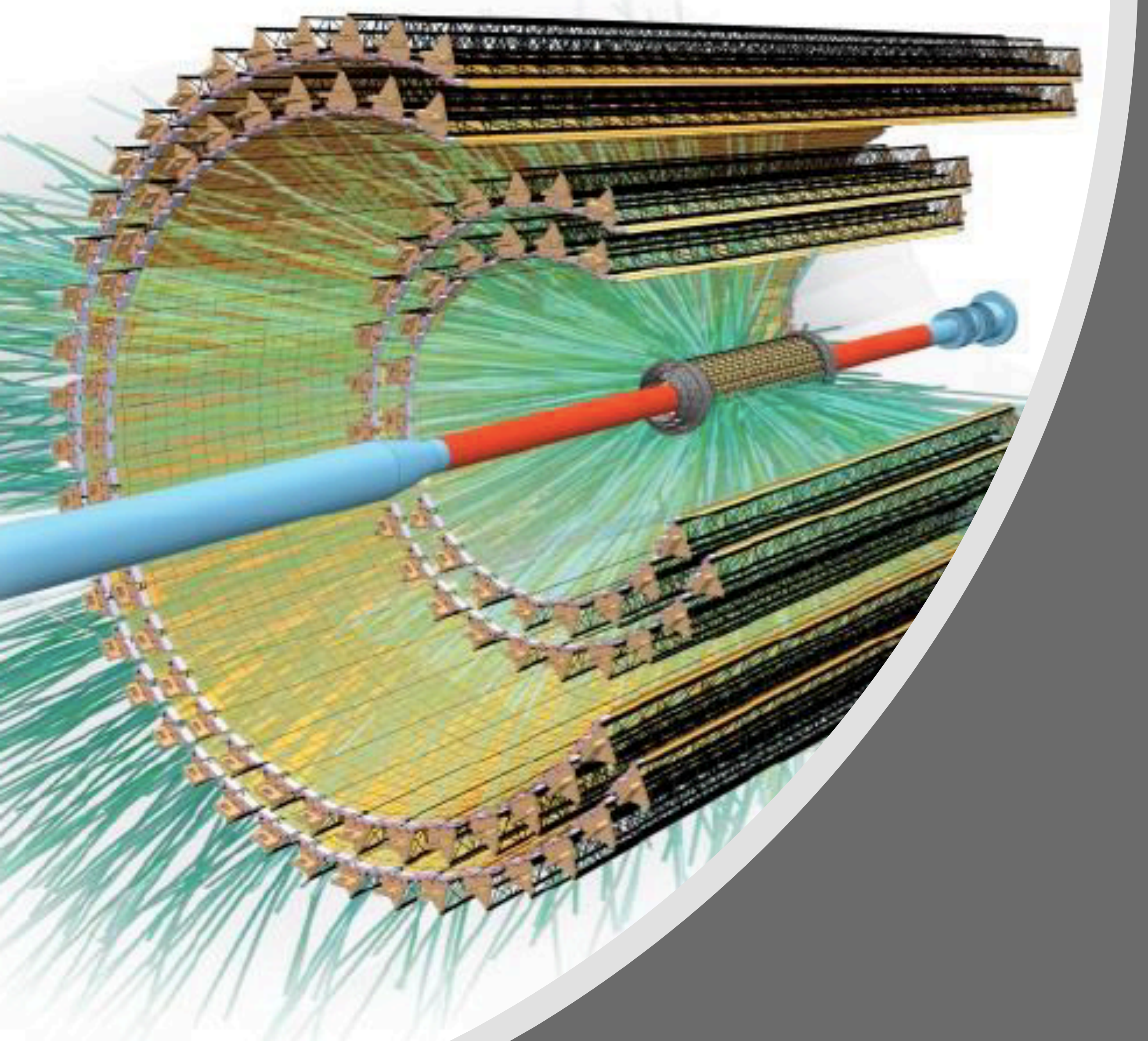


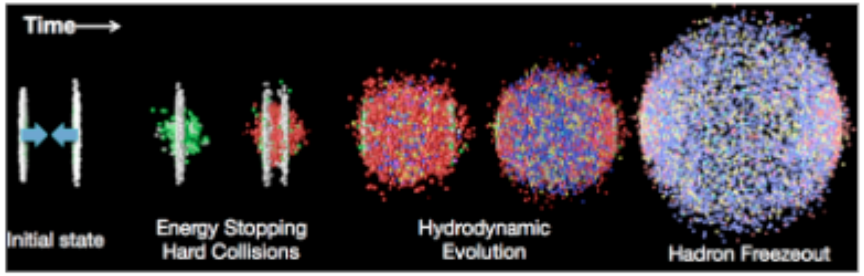
ALICE UPGRADE

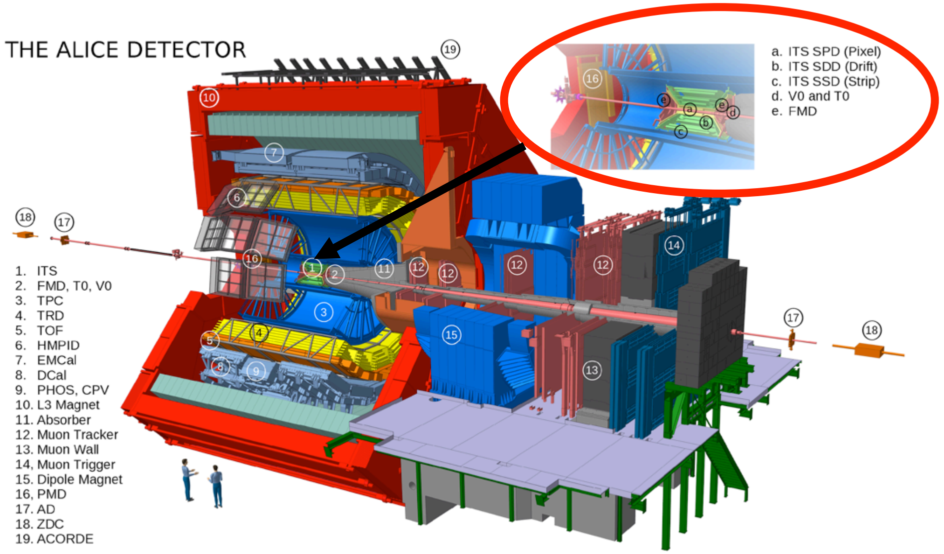
M. Chartier

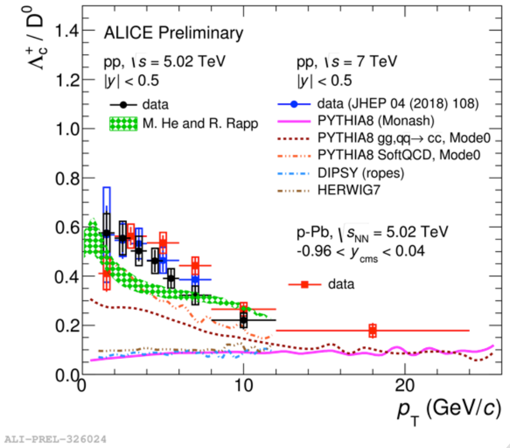
UK Nuclear Physics Community Meeting 2020

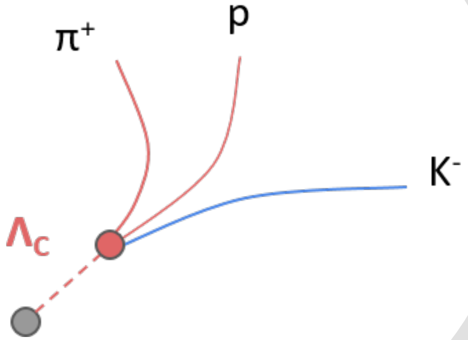
The ALICE experiment

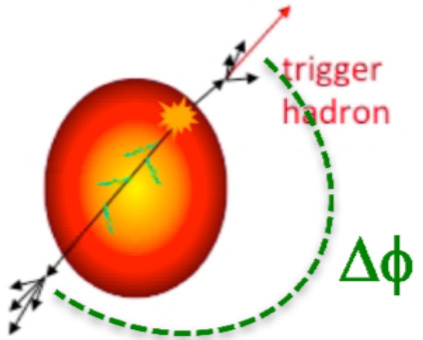
- ALICE is one of the 4 experiments on the LHC at CERN
- **Measurements of ultra-relativistic pp, p-Pb and Pb-Pb collisions**
- Optimised for heavy-ion collisions:
  - Track and identify particles in large p_T range down to low p_T (0.1-100 GeV/c)
  - Reconstruct short lived particles e.g. D and B mesons and other heavy-flavour probes
  - Very low material budget (<10% X_0 for R<2.5m)
  - Dipole magnet (0.5T) in mid rapidity range, |η|<0.9
- Particle identification through several techniques and multiple detector technologies
- **Major upgrades on-going during LS2 (Dec 2018-May 2021)**
  - **Increased LHC luminosity of Pb-Pb collisions (Run 3 & 4)**
  - **Interaction rate 50 kHz; Instantaneous L = $6x10^{27}$ cm^{-2} s^{-1}**

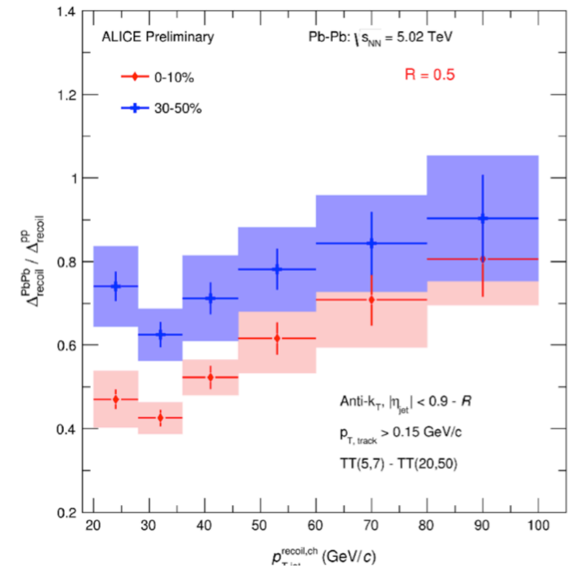





ALICE Preliminary
pp, √s = 5.02 TeV
|y| < 0.5
data
M. He and R. Rapp
pp, √s = 7 TeV
|y| < 0.5
data (JHEP 04 (2018) 108)
PYTHIA8 (Monash)
PYTHIA8 gg,qq→ cc, Mode0
PYTHIA8 SoftQCD, Mode0
DIPSY (ropes)
HERWIG7
p-Pb, √sNN = 5.02 TeV
-0.96 < ycms < 0.04
data
Λc+ / D0
pT (GeV/c)
ALI-PREL-326024


π+
p
K-
Λc

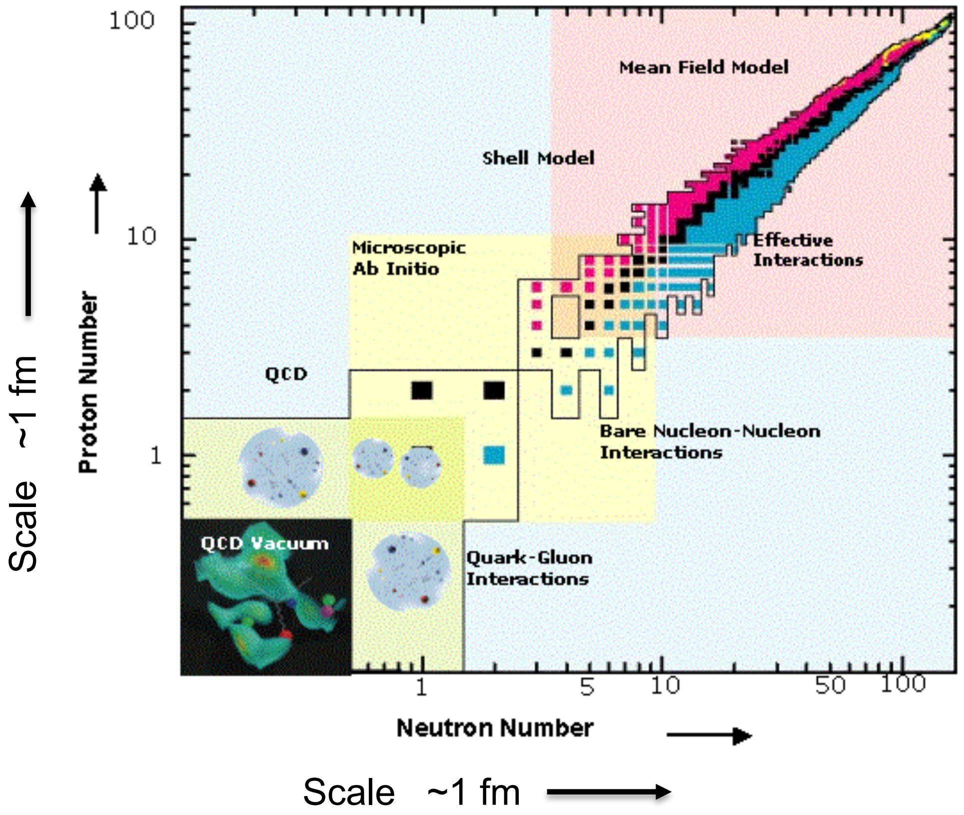

trigger
hadron
Δϕ

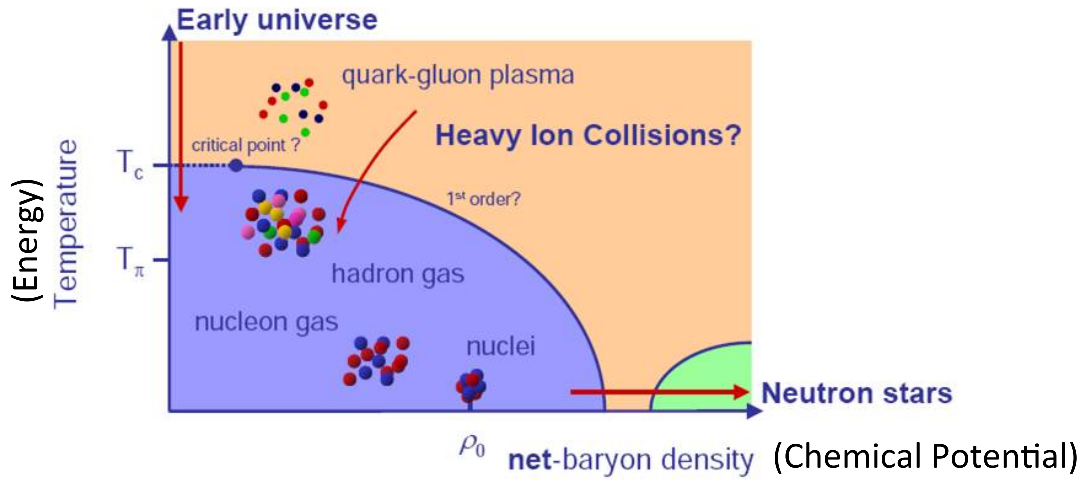

ALICE Preliminary
Pb-Pb: √sNN = 5.02 TeV
0-10%
30-50%
R = 0.5
Anti-kT, |ηjet| < 0.9 - R
pT, track > 0.15 GeV/c
TT(5,7) - TT(20,50)
Δrecoil PbPb / Δrecoil pp
(GeV/c)

Physics

Strongly Interacting Matter

How do the properties of hadrons and the quark-gluon plasma emerge from fundamental interactions?



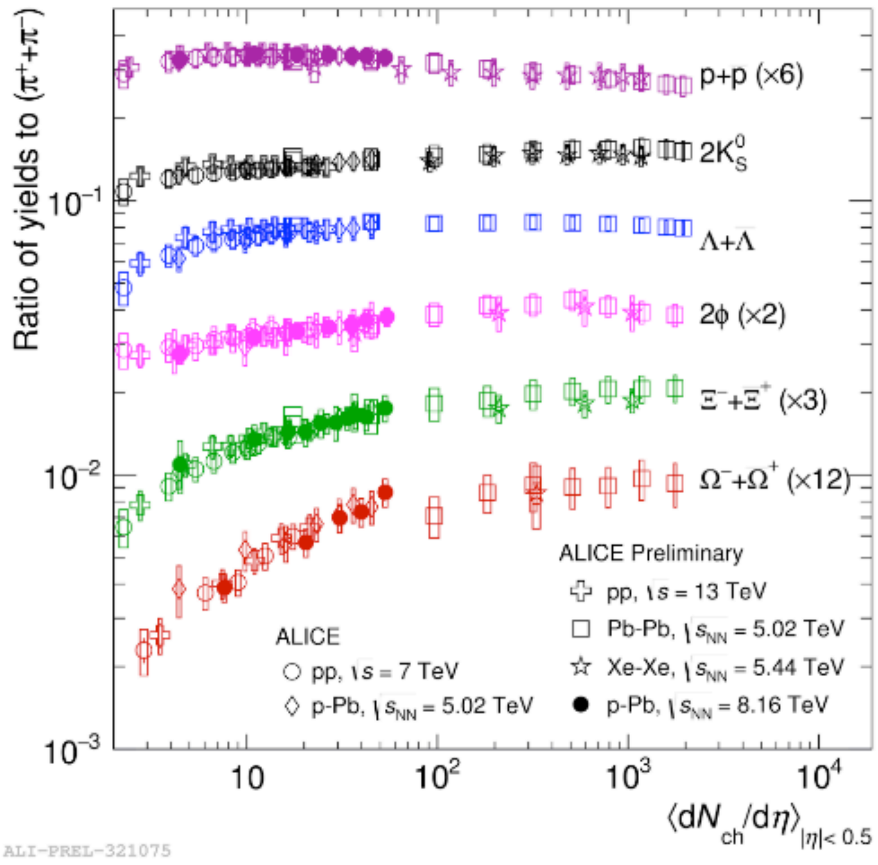


- **The place of chromodynamics in the SM of the Universe: $[SU(2) \times U(1)]_{EW} \times SU(3)_{colour}$?**
  - Phase diagram of non-abelian hadronic matter?
  - Degrees of freedom => probes scale
    - Quark mass/flavour
    - Confinement and colour
  - Nuclear force as a manifestation of Quantum ChromoDynamics?
- **SM/Chromodynamics ⬄ Dark sector?**

Strangeness Production

- Hadrochemistry: A measurement of relative abundances of different particle species
- Enhanced yields of strange particles was one of the earliest proposed signatures of QGP formation
- **Strange particle production as a function of multiplicity from pp to A-A collisions at the LHC**
- Charged particle multiplicity is biggest driver of strangeness enhancement
- **Results consistent for different colliding energies and collision systems measured by ALICE (pp, p-Pb, Pb-Pb, Xe-Xe)**
- Strangeness production increases until saturation levels are reached
- New Results in p-Pb at 8.16 TeV now included and are consistent with the smooth evolution between collision systems

E. Willsher



Charm Quark Hadronisation

C. Bartels, C. Hills, J. Norman

- Heavy-flavour production (charmed baryon):

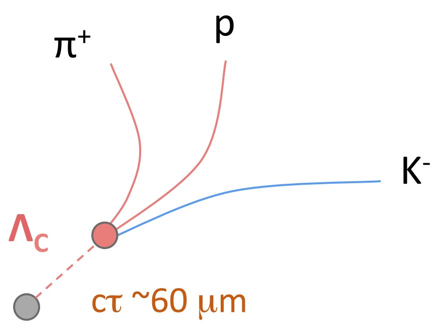
  $\boldsymbol{\Lambda_C \rightarrow p^+K^-\pi^+}$ BR = (6.28 ± 0.32)%

- Measured Λ_C (udc) production at LHC (Run1+Run2) higher than predicted (especially at low p_T) in pp, p-Pb and Pb-Pb.

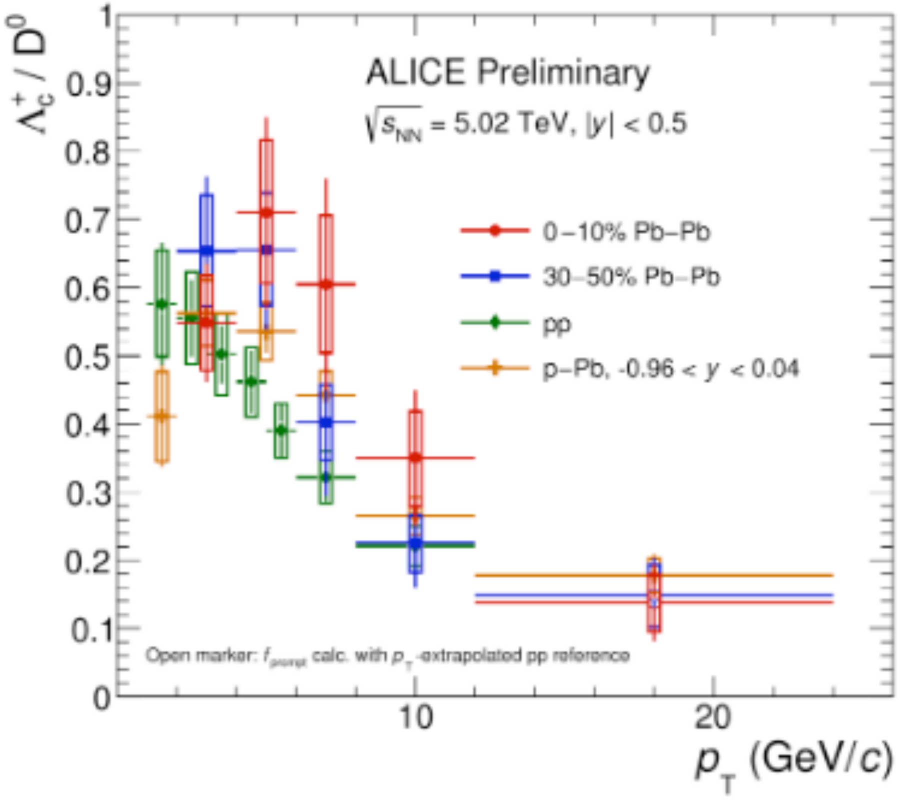
- Relative production of baryons and mesons probes hadronisation mechanisms in a ‘vacuum’ (pp) and a ‘medium’ (Pb-Pb) – formed in open colour/colour singlet environment?

- **Significant enhancement wrt e+e-/ep suggests significant modification to how baryons form in hadronic collisions**

- Pb-Pb 5.02 TeV new result for $\boldsymbol{\Lambda_C \rightarrow pK_s^0}$ published in Phys.Lett. B793 (2019) 212-223.



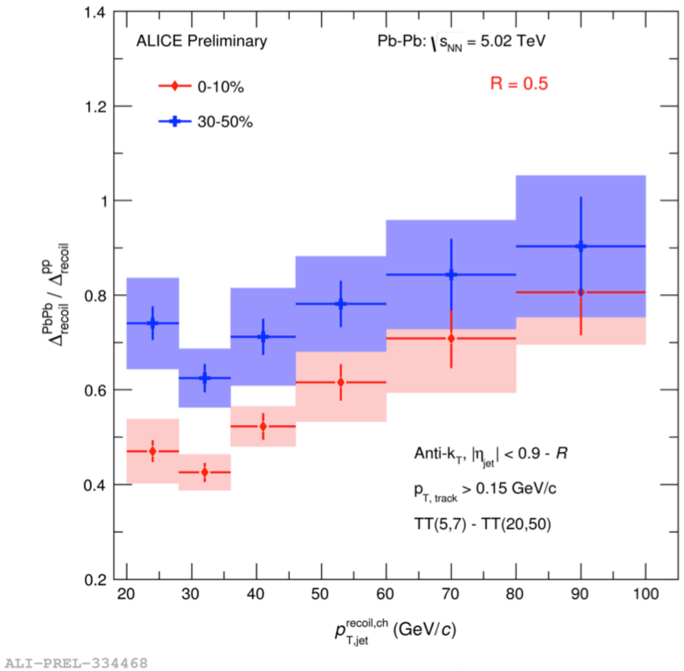
$$\frac{\Lambda_c^+}{D^0} = \frac{\frac{d\sigma}{dp_T}(\Lambda_c^+)}{\frac{d\sigma}{dp_T}(D^0)}$$

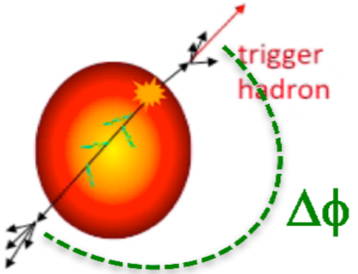


Parton Dynamics in Hot QCD Condensate

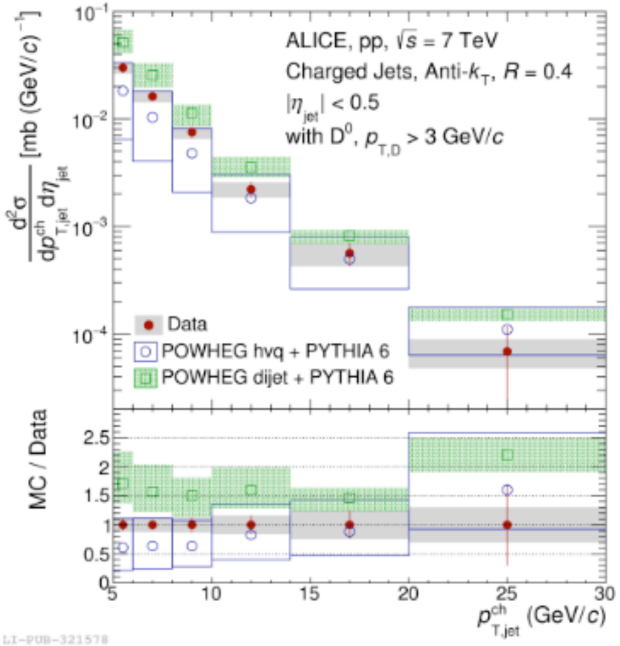
J. Kvapil, J. Norman

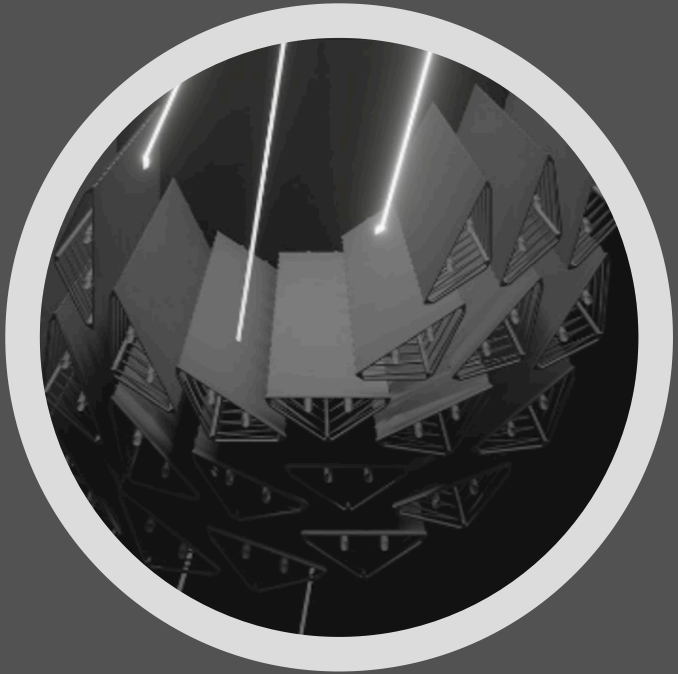
- Coincidence of jets recoiling from a high-p_T trigger hadron allows to study jet quenching mechanisms.
- Recoil jets suppressed in Pb-Pb collisions with respect to pp collision.
- **Precise measurement of jet quenching and jet topology.**
- p_T-differential cross sections of D-tagged jets measured over a wide kinematic region.
- D-meson-tagged jets significantly suppressed in Pb-Pb collisions with respect to pp and p-Pb collisions.
- **First step towards a detailed characterisation of how heavy-quark jets interact with the QGP.**
- Di-jet azimuthal correlation (jet yield vs Δϕ) on-going. Broadening of away side jet peak gives direct access to transport coefficient.

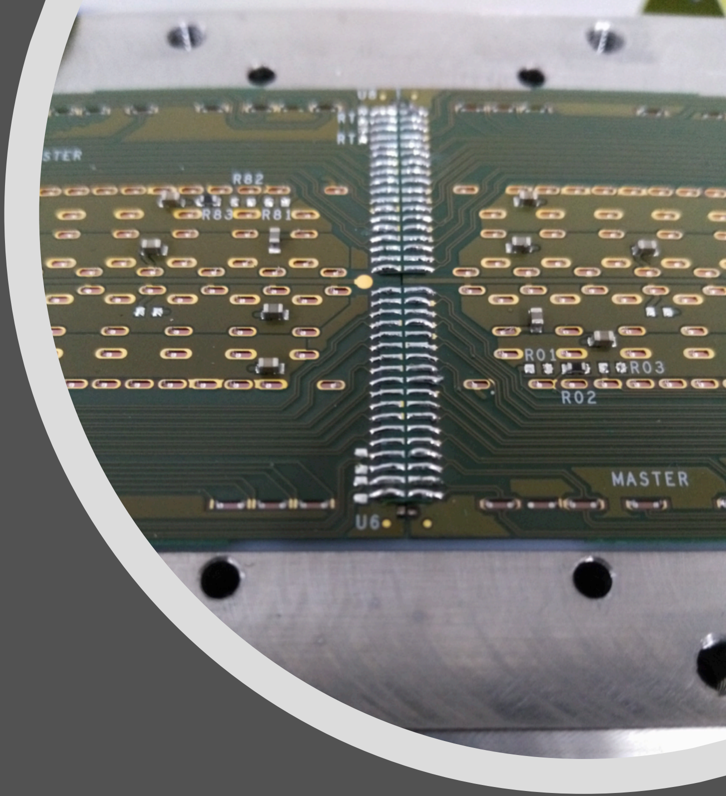


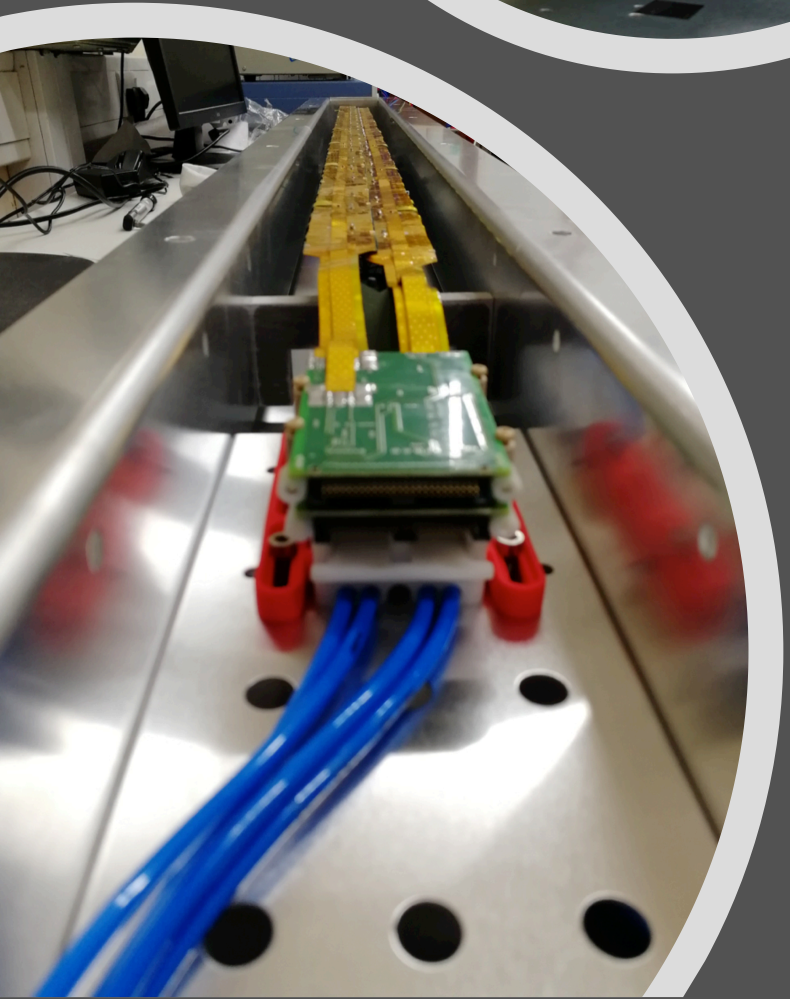


J. High Energ. Phys. (2019) 2019: 133









ALICE ITS Upgrade

Inner Tracking System Upgrade

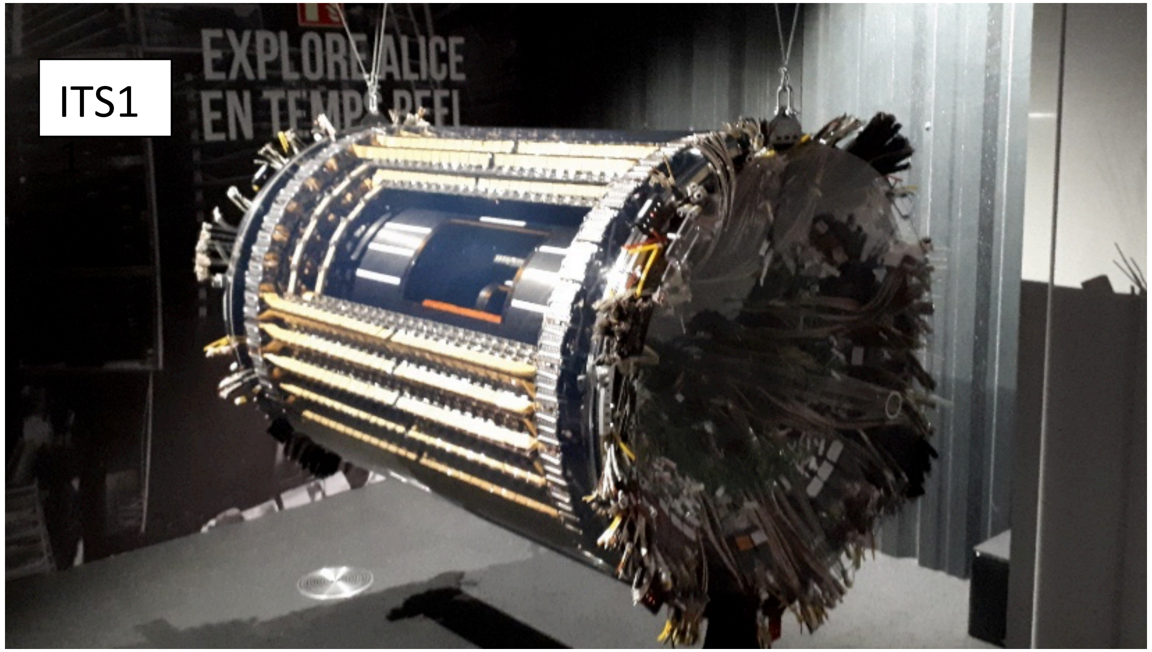
- **New ALICE ITS is the first large Si tracker entirely based on CMOS Monolithic Active Pixel Sensors (MAPS), ITS2**
- Requirements:
  - Improved tracking efficiency and p_T resolution
    - Increase granularity: 6 to 7 layers, all pixels
  - Improved impact parameter resolution
    - Closer to IP, new beam pipe
    - Reduce material budget
    - Reduce pixel size
  - Improved readout capabilities, x100
  - Fast removal/insertion for maintenance
- Replacement of ITS with ITS2 during LS2 (Dec. 2018 - May 2021)

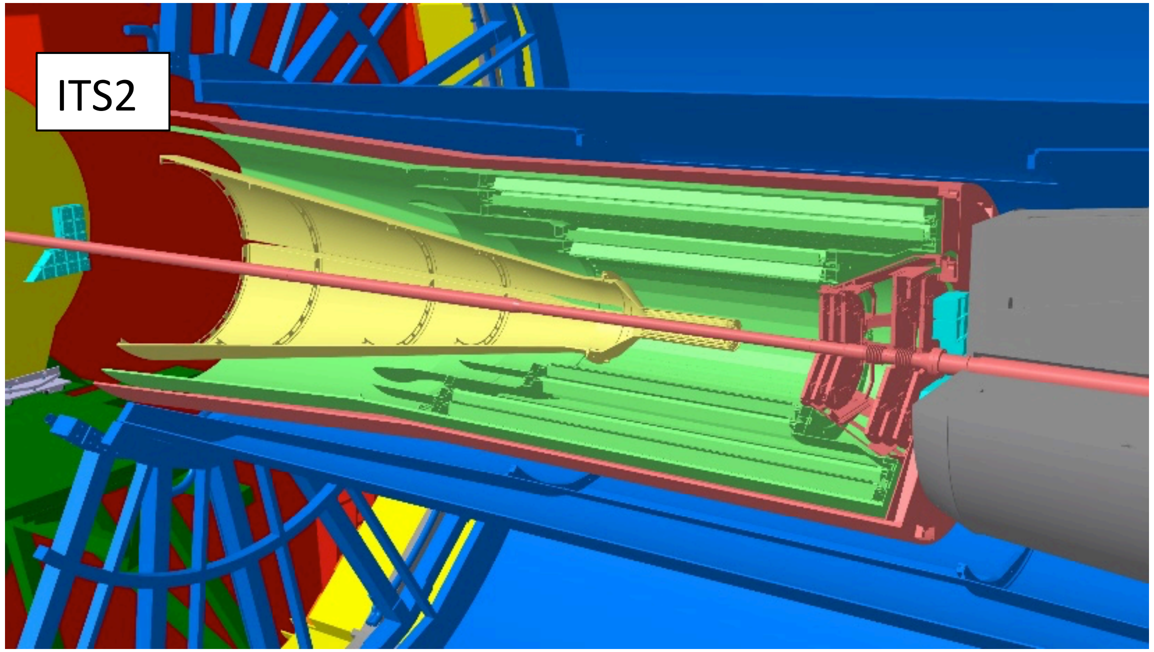
[1]

	ITS	ITS2
Technology	Hybrid pixel, drift, strip	MAPS
Max rate (Pb-Pb)	1 kHz	100 kHz
Thickness per layer	~ 1.14% X_0	Inner barrel: 0.3% X_0, Outer barrel: 1% X_0
Pixel size	425 µm x 50 µm	27 µm x 29 µm
Spatial res. (rΦ x z)	12 µm x 100 µm	5 µm x 5 µm
Radius	39 - 430 mm	22 – 395 mm
Rapidity range	|η| < 0.9	|η| < 1.3
Layers	6	7
Readout	Analog (drift, strip), Digital (pixel)	Digital

[1] "Technical Design Report for the Upgrade of the ALICE Inner Tracking". ALICE Collaboration, B. Abelev et al. System. J. Phys. G 41, 087002 (2014).

Inner Tracking System Upgrade



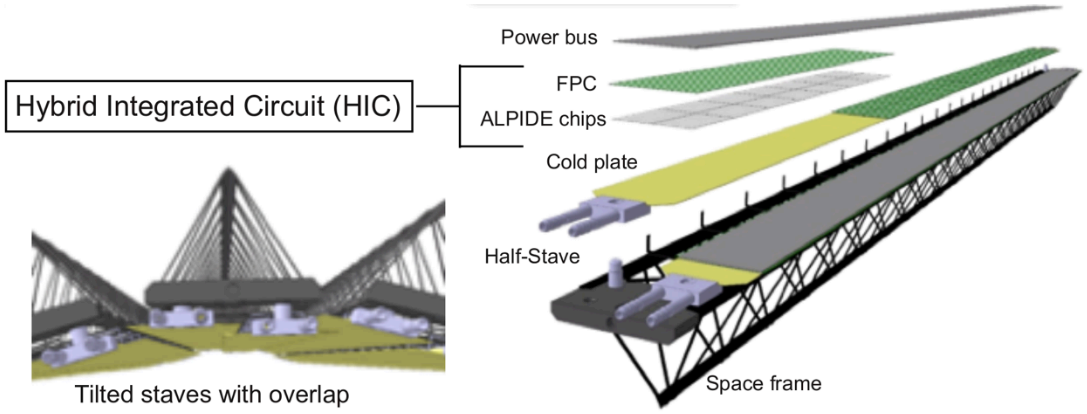


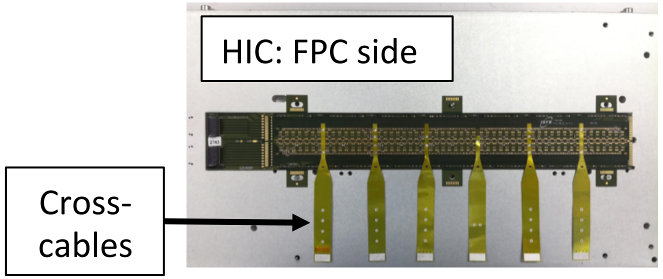
The ITS2 has a barrel geometry, constituted by:
- 7 layers; 3 (IL), 2 (ML), 2(OL)
- 192 staves; 48 (IL), 54 (ML), 90 (OL)

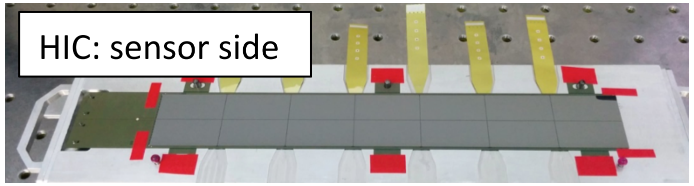
ITS2 Outer Barrel: Modules and Staves

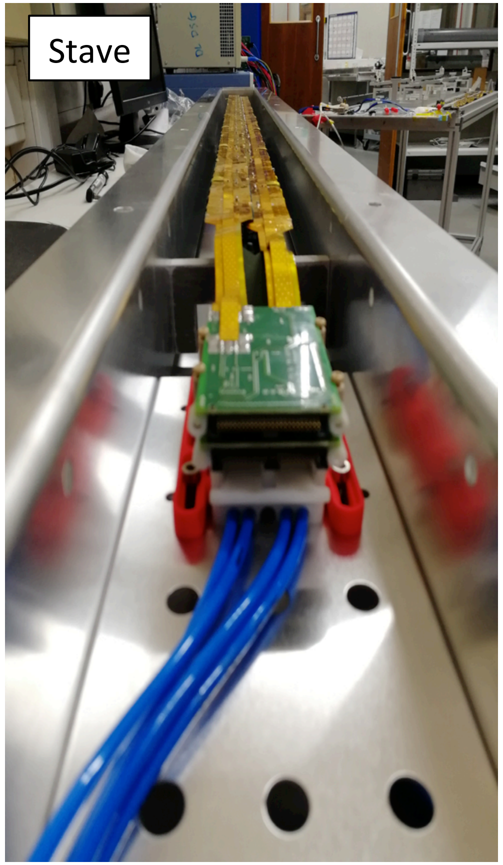
- Hybrid Integrated Circuit (HIC) consists of 14 ALPIDE chips (100 µm thick) glued to Cu FPC, 2 rows of 7
- Wirebonds electrically connect FPC to chips, data etc.
- Power delivered via 6 cross-cables soldered to the FPC
- 7 modules per half stave then glued to a space frame
- Staves are arranged in half barrels

Daresbury + Liverpool





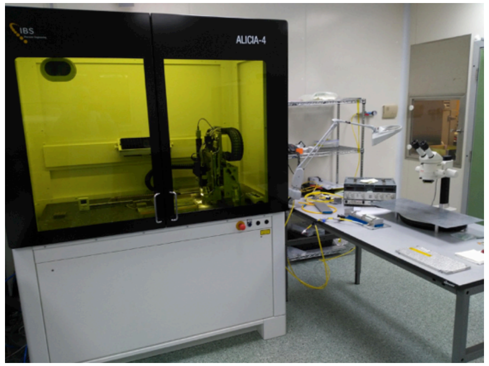


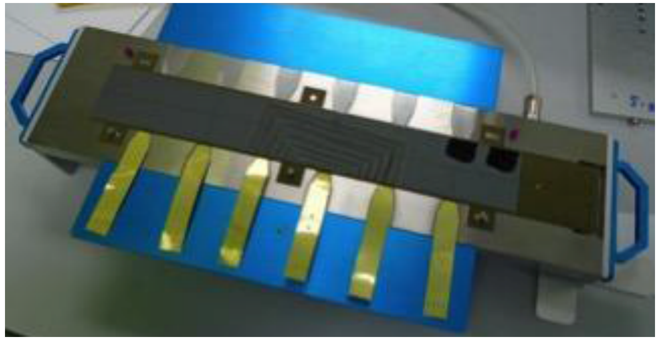


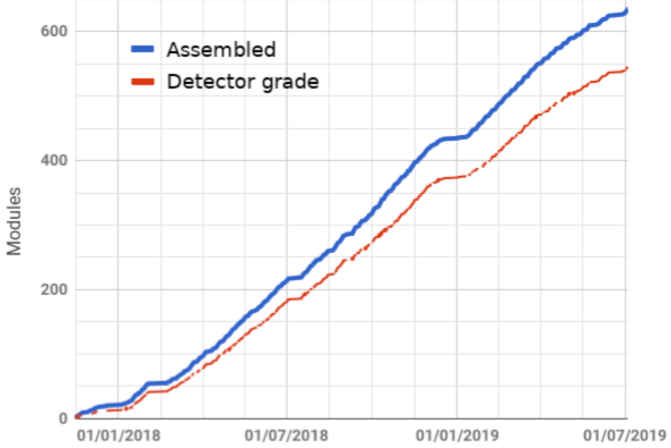
Outer Barrel Module Production at Liverpool

M. Borri, L. Boynton, M. Buckland, M. Chartier, N. Clague, G. Contin, J. Iddon, R. Lemmon, S. Lindsay, M. Poblocki

- One of 5 Module construction sites worldwide: Bari (IT), Liverpool (UK), Pusan (KR), Strasbourg (FR), Wuhan (CN)
- Assembly procedure:
  - Chips are aligned and glued to FPC (using pick and place ALICIA Module Assembly Machine)
  - Wire bonding
  - Functional and QA tests
  - Shipped to stave assembly sites
- 635 modules produced
- Production completed in July 2019
- Liverpool detector grade yield 85%
- Developed and carried out metrology procedures
- Developed short glue curing technique to make 1 more module a day, used by the all production sites
- Invaluable support and infrastructure from the Liverpool Semiconductor Detector Centre (LSDC)





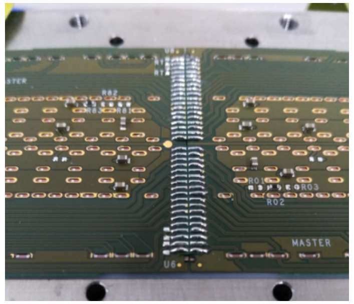


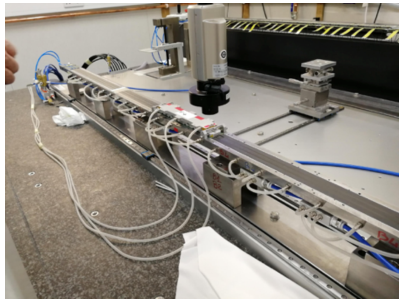
Outer Barrel Stave Production at Daresbury

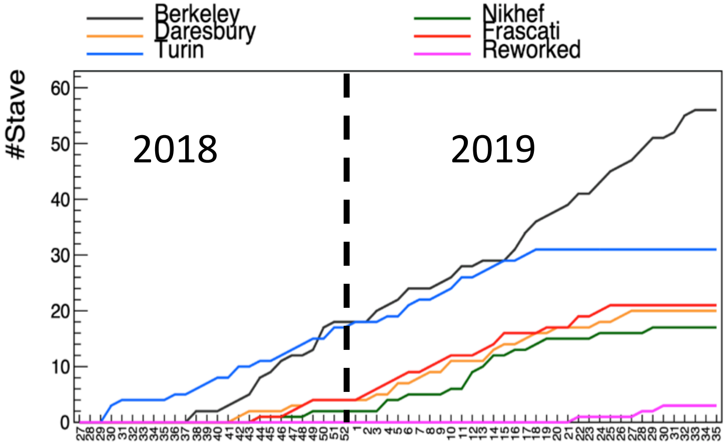
ALICE

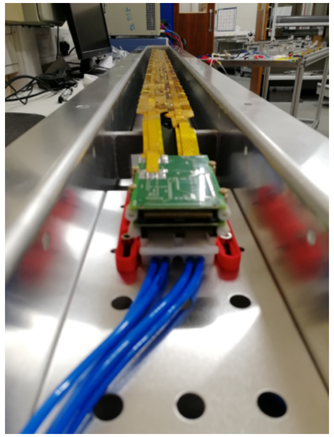
- One of 5 Stave construction sites worldwide: Berkeley (US), Daresbury (UK), Frascati (IT), Nikhef (NL), Turin (IT)
- Assembly procedure:
  - Modules are aligned and glued to cold plate
  - Inter-module connection (soldering)
  - Functional and QA tests
  - Aligned and glued onto space-frame
  - Power bus connection
  - Functional and QA tests
  - Packed and shipped to CERN
- 22 staves assembled
- Stave detector grade yield in Daresbury is 95.5%
- Invaluable support from the Engineering Technology Centre (ETC) and Detector System Group (DSG)

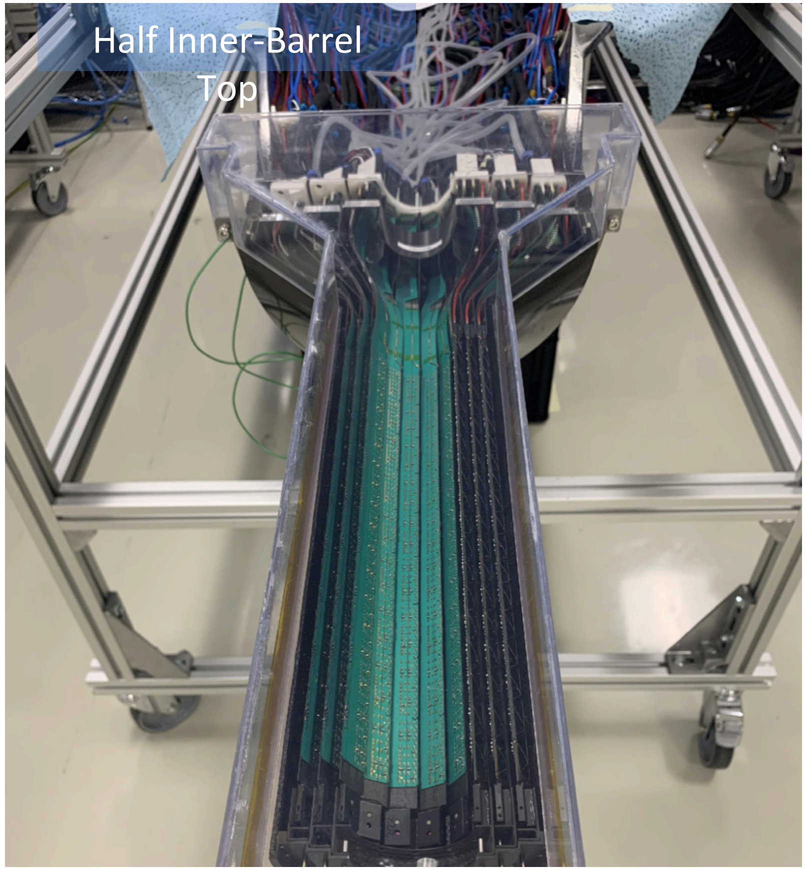
M. Borri, M. Buckland, M. Chartier, N. Clague, G. Contin, A. Hill, P. Hindley, J. Iddon, T. Lee, R. Lemmon, J. Liu, G. Markey, G. Morris, M. Poblocki

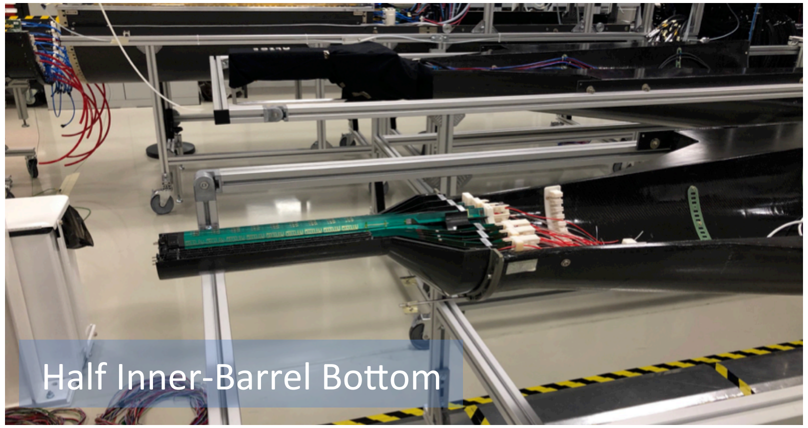


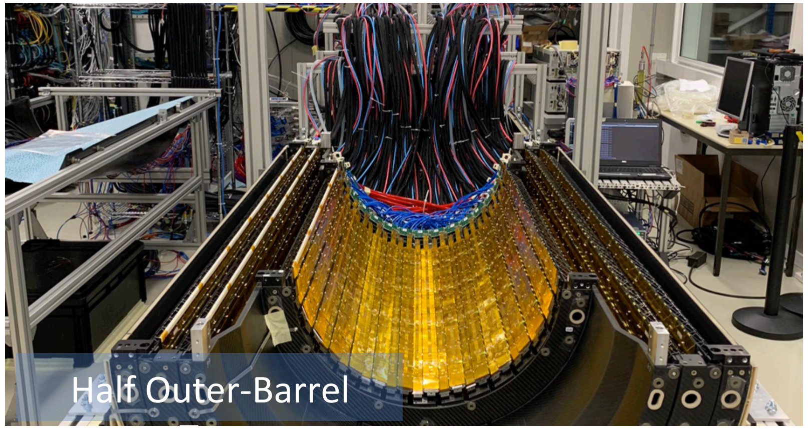


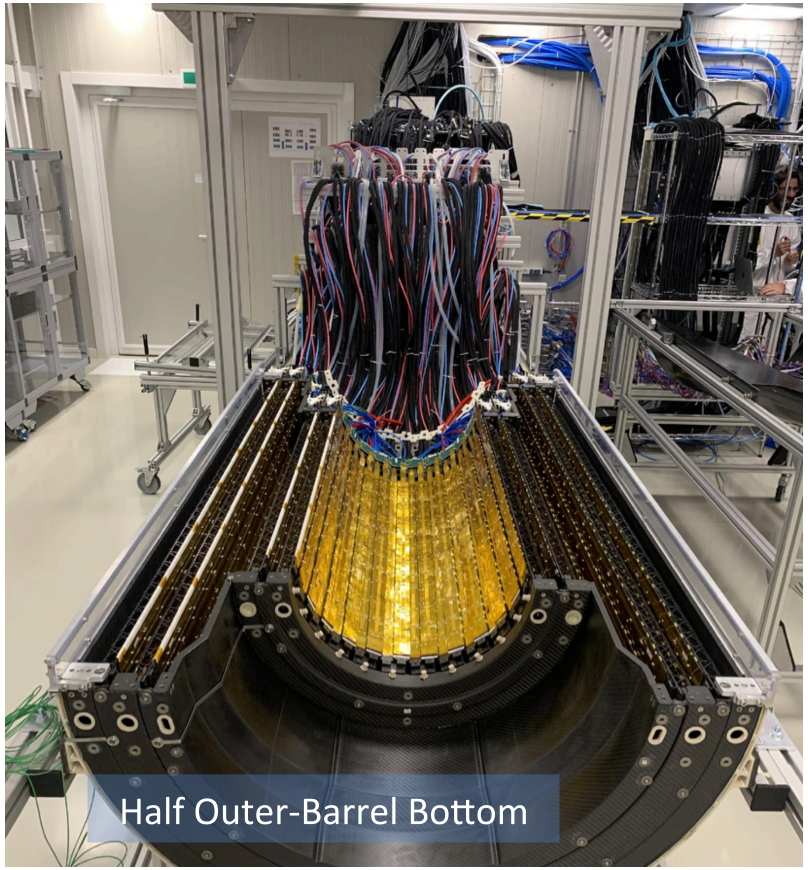












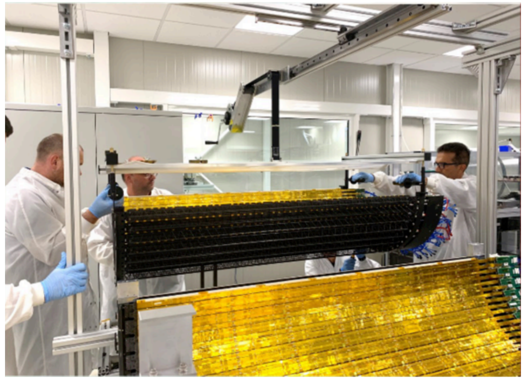
ITS2 Assembly Completed

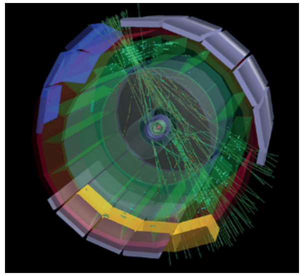
ITS2 Assembly and Commissioning Timeline

ALICE

- Dec '17
- Jun '19
- Nov '19
- Dec '19
- June '20
- Feb '21

- Detector Construction and Assembly:
  - HIC production completed
  - Stave production completed
  - Electronics production and testing done
  - Assembly complete
- Commissioning at the surface with final services:
  - Ongoing, operation 24/7
  - Data taking with cosmics, Sr-90 source and calibration
  - Fully automated data quality control flow under preparation
- Installation in cavern:
  - Start June 2020
  - 6-month Global commissioning

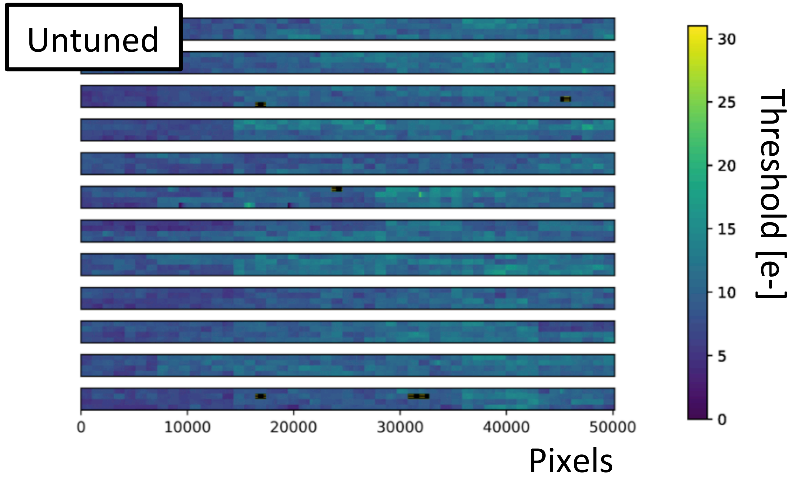

Outer barrel assembly

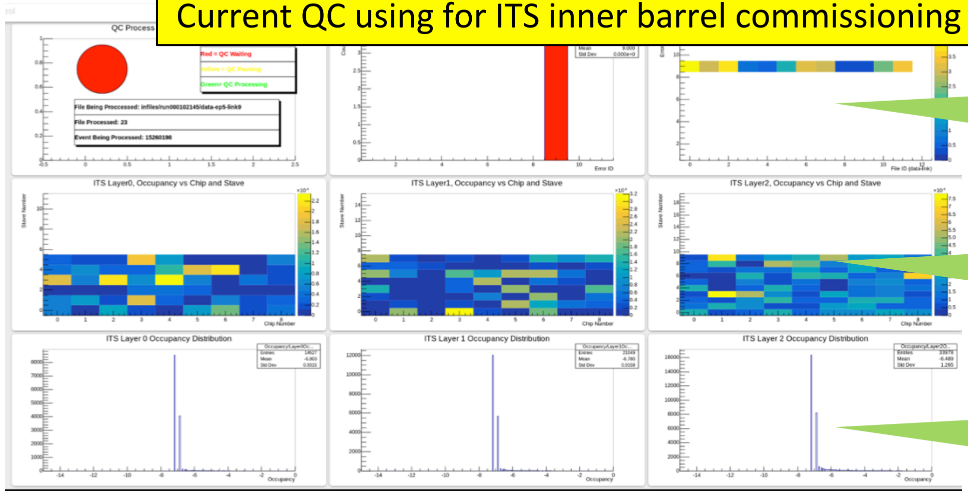

Global commissioning

ITS2 Commissioning Work by UK

- **Assembly, cabling and testing of Outer Barrel layers and services** (July-December 2019)
- **Production readout system**
  - Developing readout software
  - Writing code for threshold scans on multiple staves (half barrel)
  - Determine the threshold of the pixels then tune for uniformity
- **Data Quality Control (QC)**
  - Contribute to and coordinate software development
  - Optimised QC is running
  - Trying to extract noisy pixel addresses through QC results
  - QC parallelization is under development to speed up processing time
  - Moving from inner barrel to outer barrel

1 Technician, 1 PDRA, 1 PhD student at CERN + 1 PDRA in UK





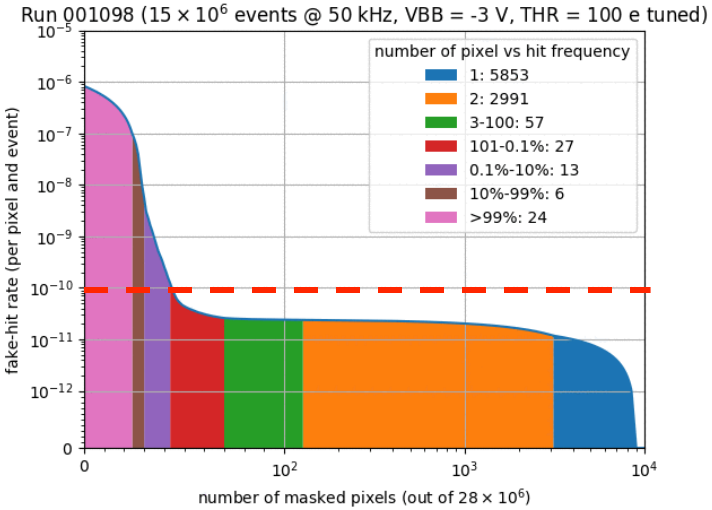
General info. and decoding error

Chip occupancy (1 histo / layer)

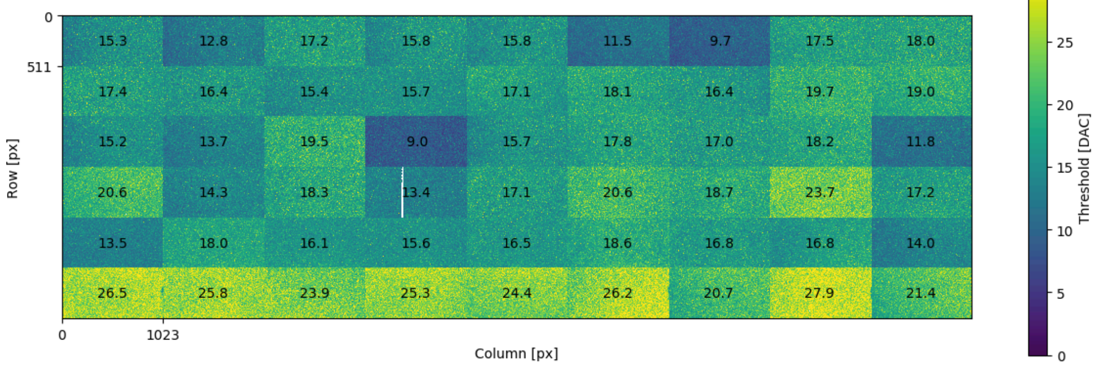
Pixel occupancy (1 histo / layer)

ITS2 Commissioning: Threshold and Noise

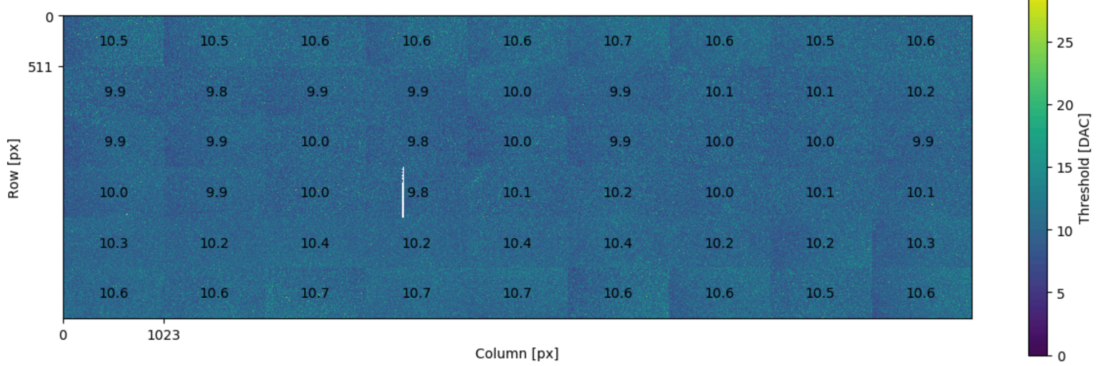
- Tests performed on IB half-layer
- Running at a fake hit rate below 10^{-10}/pixel/event seems very feasible
- Extremely quiet detector
- Threshold scans performed:
  - Adjustment of front-end parameters to equalise the charge thresholds
  - Achieving uniform response across the detector
  - Very satisfying threshold stability over time



Before tuning

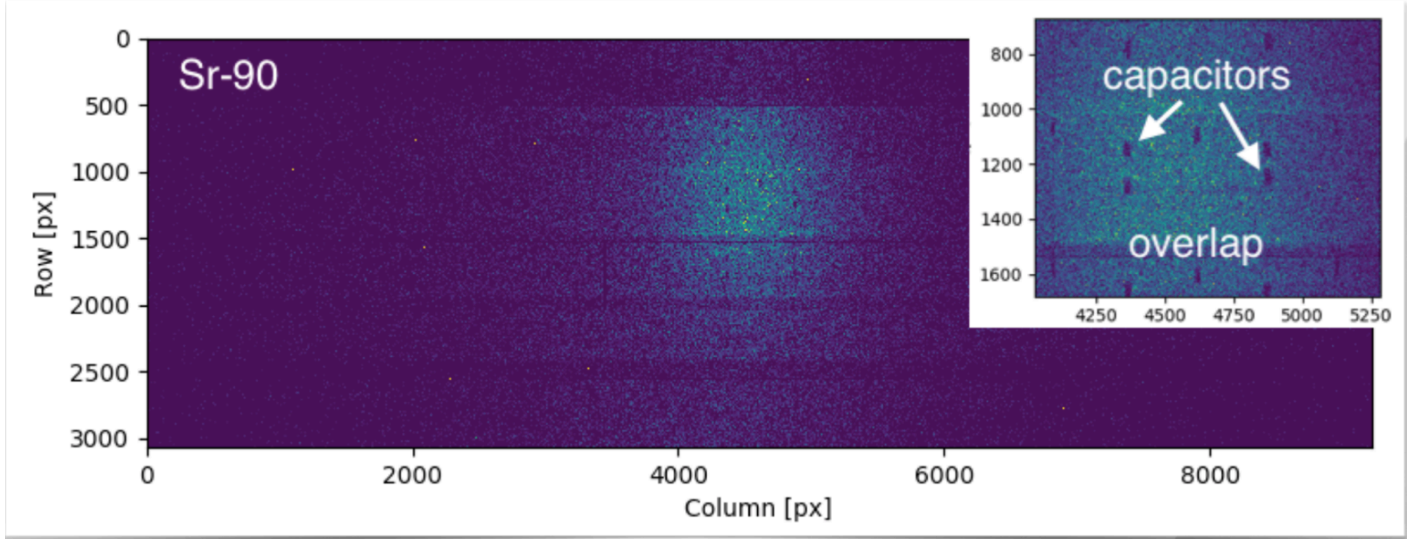


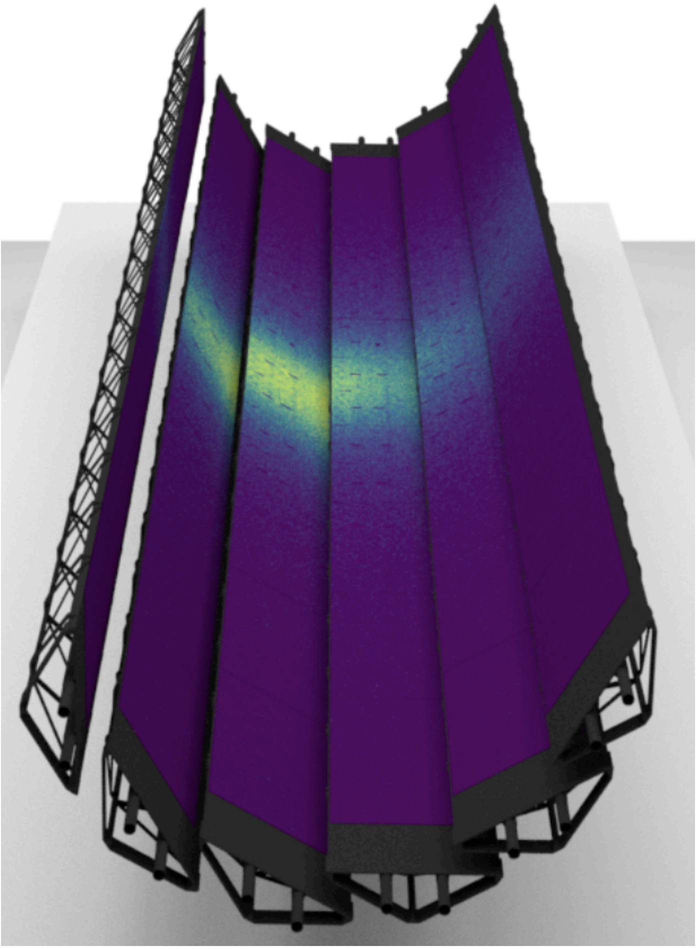
After tuning



ITS2 Commissioning: Sr-90

- Sr-90 scans performed with equalised threshold settings
- Verifies the threshold tuning
- Overlaps and gaps between chips are visible along with capacitors on the FPCs

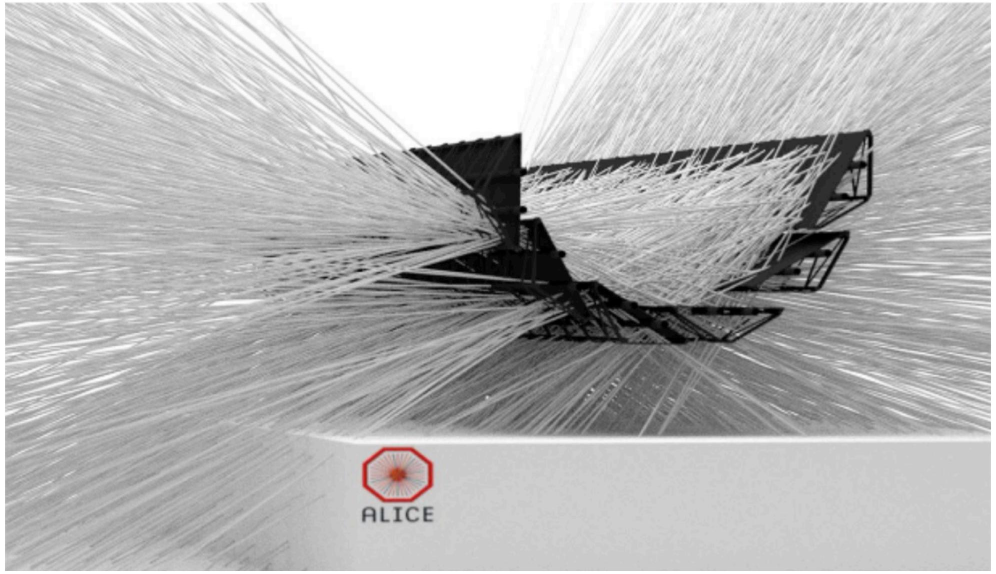


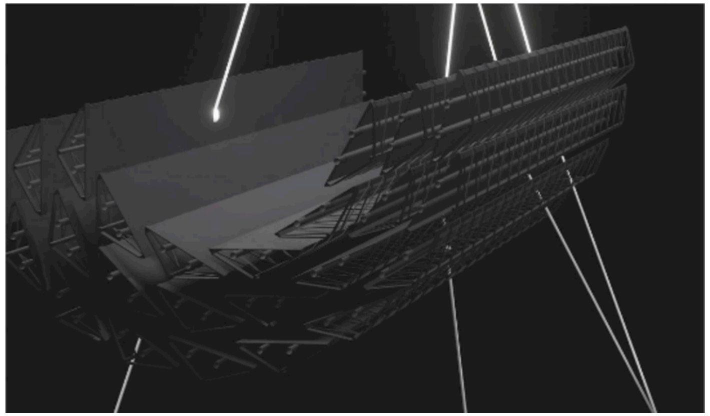


ITS2 Commissioning: Cosmic Rays

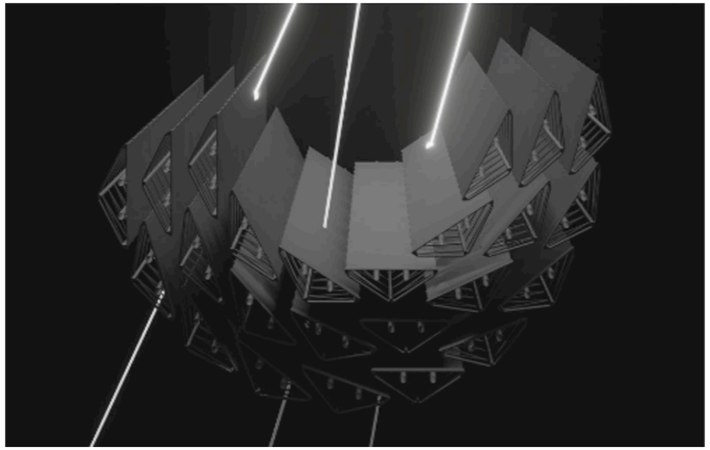
- Goals: check alignment, study track and cluster parameters
- Measure around 1 cosmic track per minute
- Along with cosmic tracks have seen first vertex

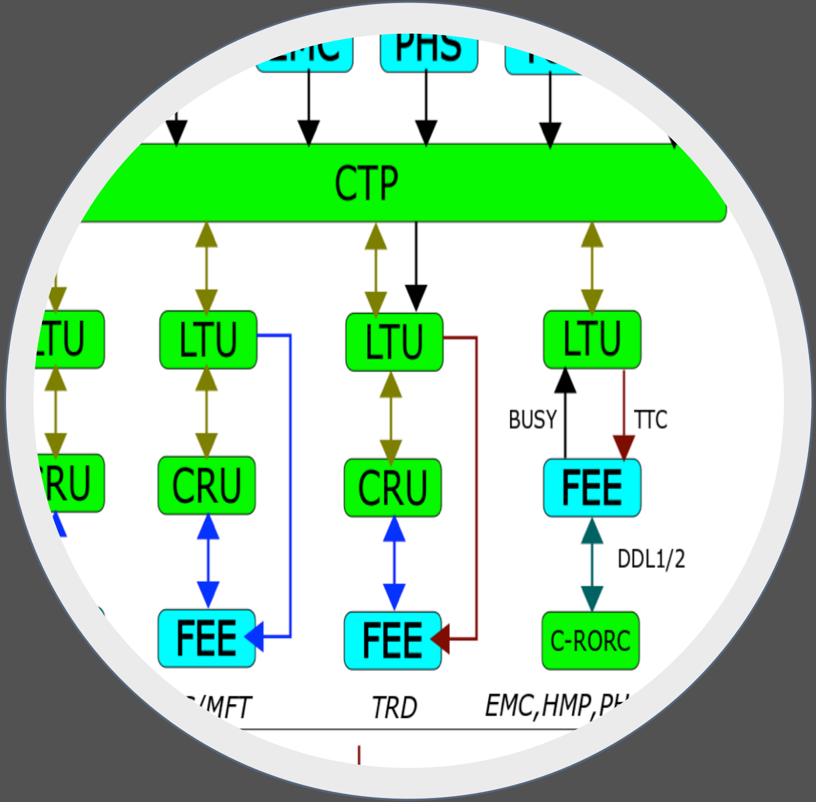
Cosmic tracks for one week of data

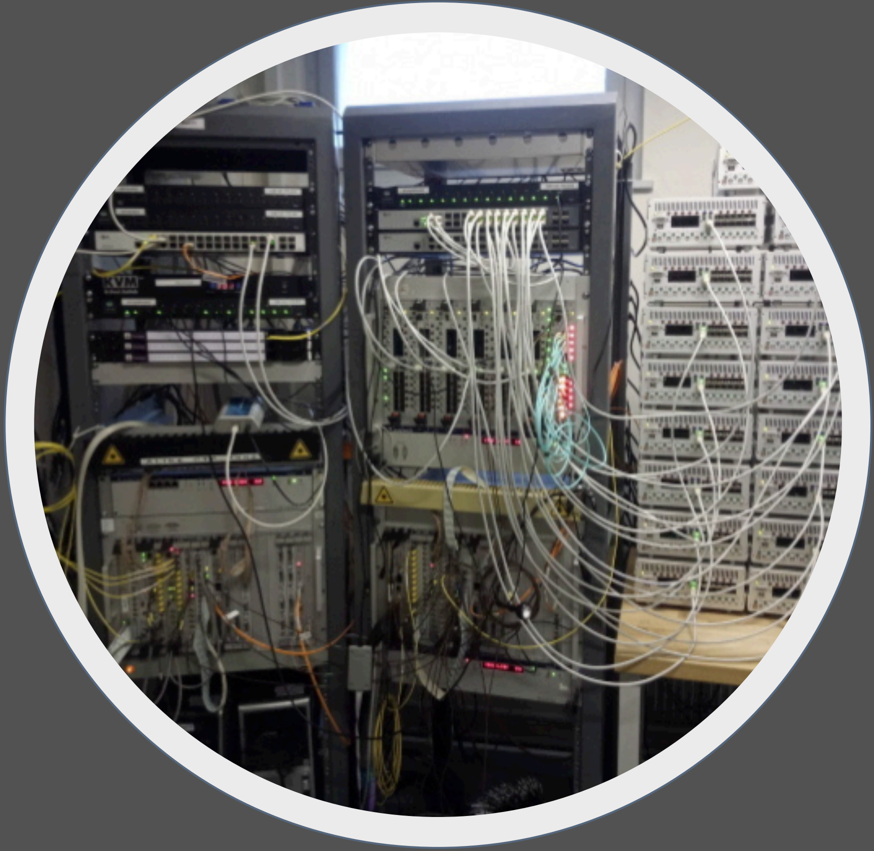




Cosmic track examples



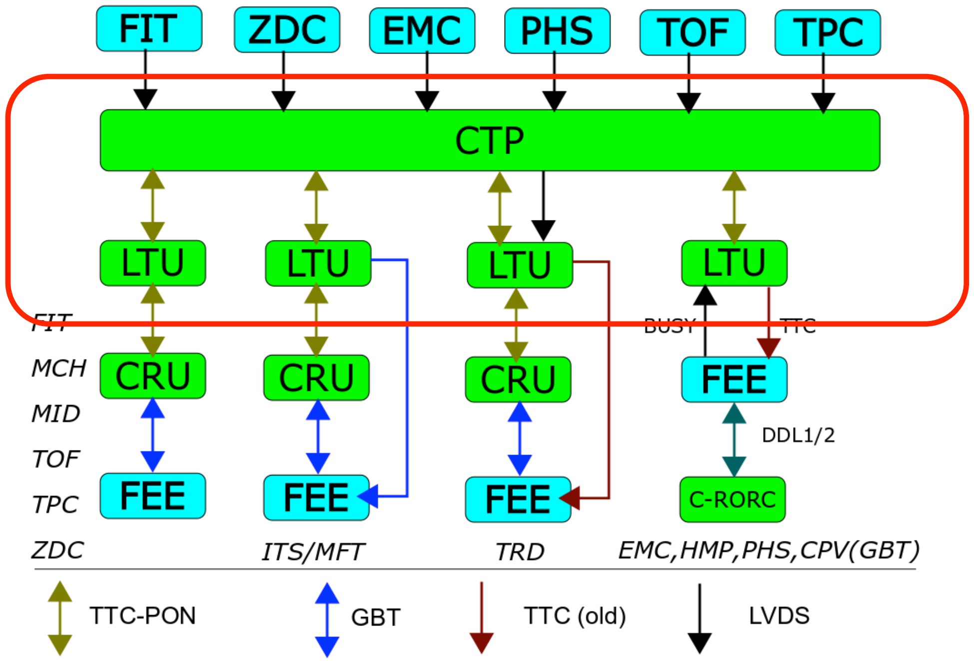




ALICE Trigger Upgrade

ALICE Trigger Upgrade at Birmingham

- Birmingham has sole responsibility for the design, building, commissioning, and maintenance of the new ALICE central trigger system for LHC Runs 3 and 4 (only central system not under CERN control).
- Consists of a Central Trigger Processor (**CTP**) and Local Trigger Units (**LTU**s) – one for each sub-detector.

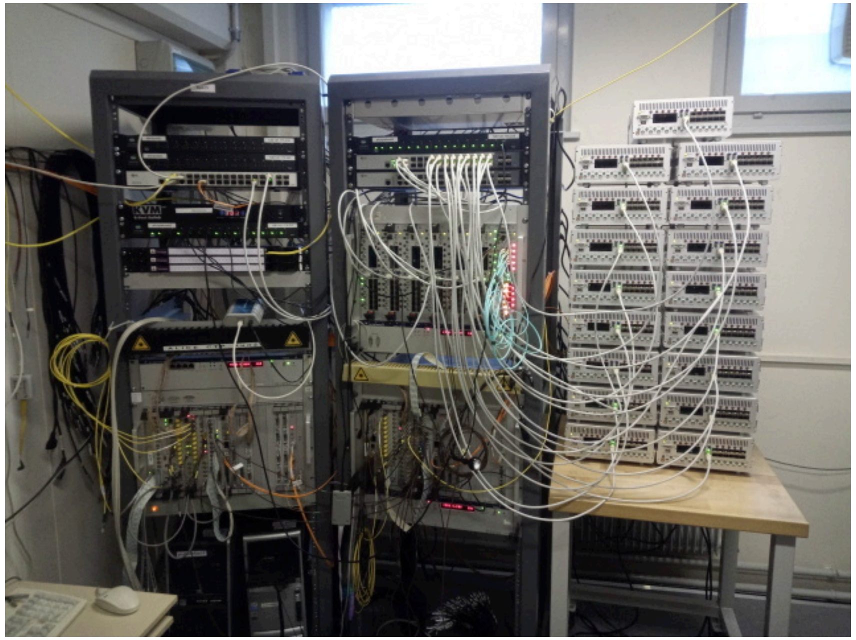


- System not only triggers detectors but monitors and controls readout rate of upgraded detectors.
- System also has zero dead-time (can receive inputs and deliver triggers every bunch crossing (25 ns)).

ALICE Trigger Upgrade Status

- Phase I production completed (23 LTU boards)
- Extensive testing carried out, including aging tests
- Boards exceed ALICE specifications
- 15 boards delivered to sub-detector groups (with Firmware and software)
- Two LTUs already installed in ALICE cavern for detector tests

- Simulations of CTP board (higher power FPGA) showed currents in some vias could exceed specifications + possibility of noise.
- Modifications made to PCB design (to be on the safe side).
- Phase II production has begun (31 boards (25 LTUs + 6 CTP) + 5 spare PCBs)



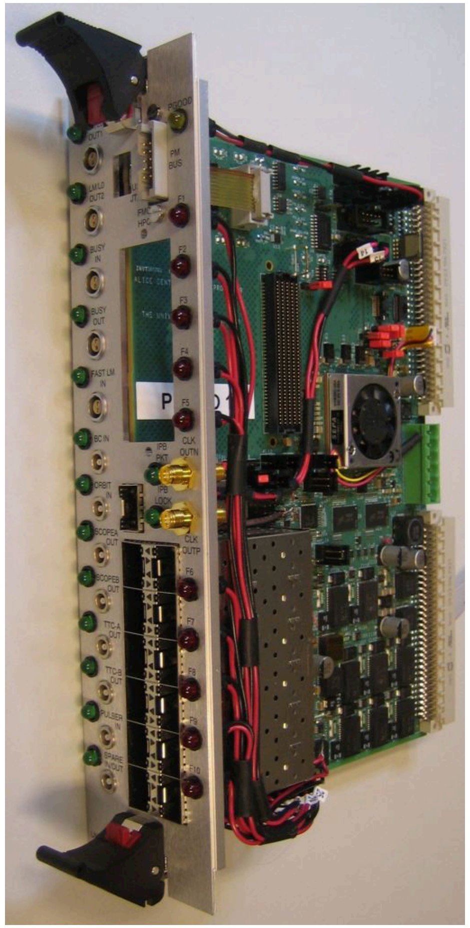
Test setup at CERN

Status of Trigger Phase II Production

- All 36 PCBs have been produced
  - Tests show them to be of good quality
- Soldering problem with first two assembled boards
  - Sent back to manufacturer after tests and investigations from us
  - One board re-worked and returned to us in December and tests show the board working well.
- Final production to start this month.

- LTU firmware and software ready, CTP firmware and software developing well.

- Plan to have entire system installed in ALICE cavern for full integration tests in May.



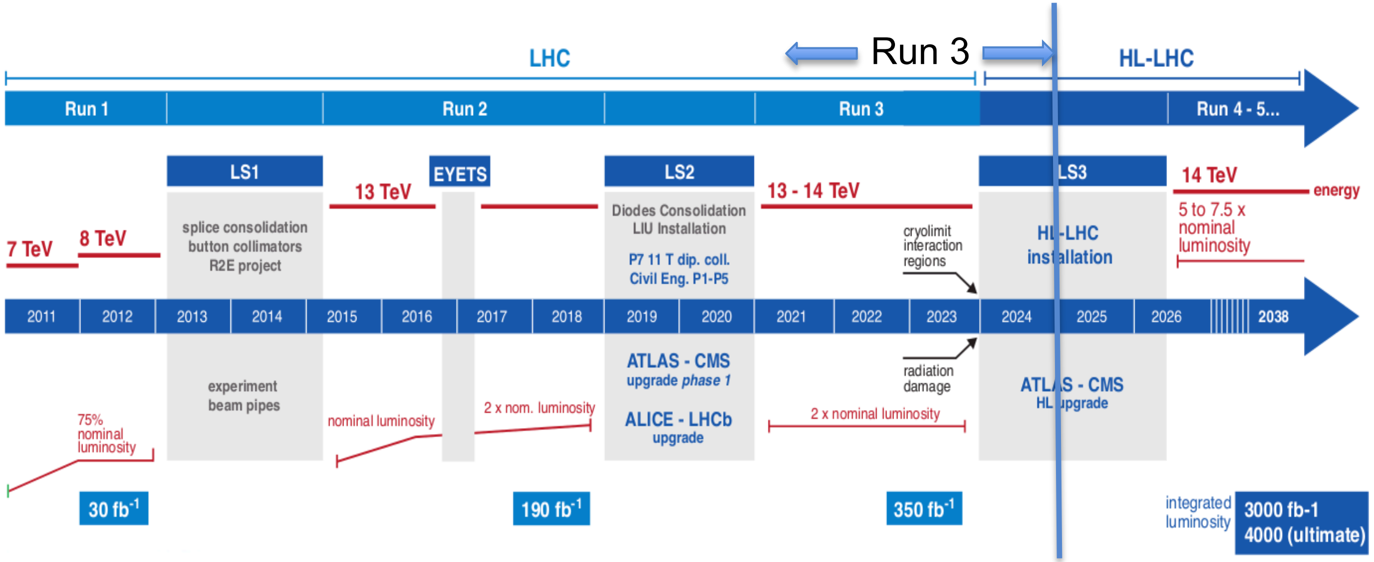
Summary

- **ITS Upgrade**
  - UK deliverables completed in September 2019
  - All staves delivered to CERN
  - Project in assembly, integration and commissioning phase now
  - UK staff fully involved in this phase at CERN
  - Derby colleagues joined UK effort, involved in development of tracking algorithms
  - Project on track for Run 3 data-taking (May 2021-end 2024)

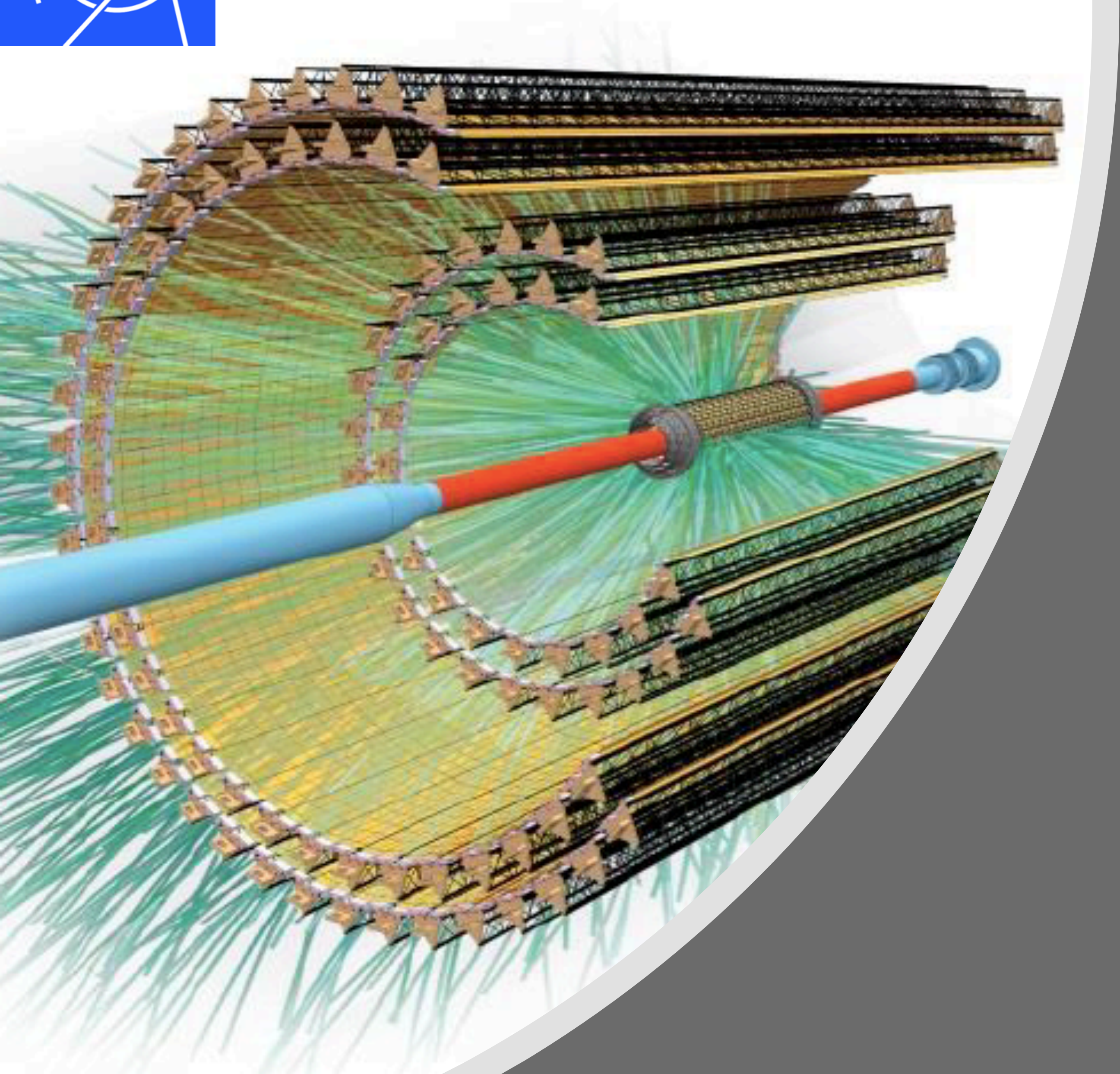
- **Trigger Upgrade**
  - Final production of Phase II boards begins January 2020
  - Plan for trigger integration tests in cavern in May 2020

New LHC schedule: RUN 3 from May 2021 to End 2024 (+1 year!)
https://home.cern/news/news/accelerators/new-schedule-lhc-and-its-successor

Opportunity for an increased exploitation of the ALICE Upgrade investment! (N.B. Run 3 matches nearly exactly next CG period)



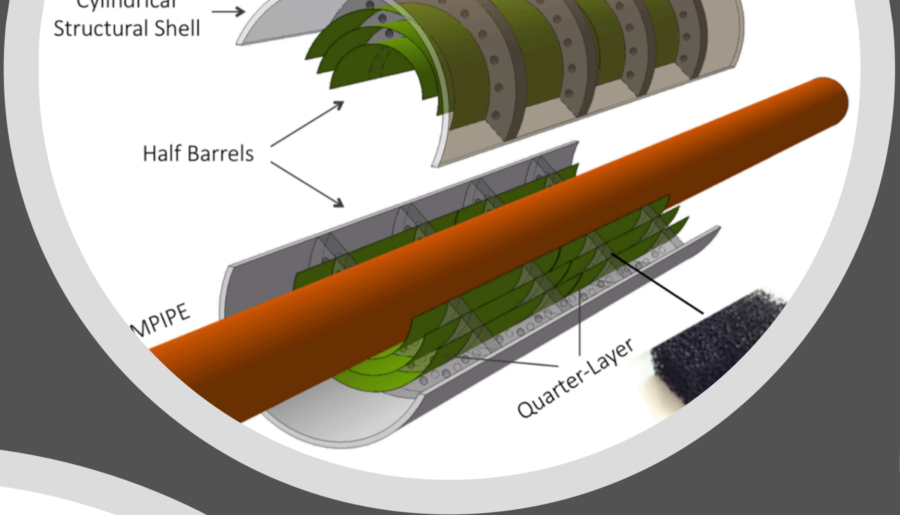
The project construction phase is coming to a close but lifetime of these projects is linked to the LHC and ALICE experiment schedules!
Commissioning, Maintenance and Operation is the next phase of the project (UK expected to continue its contributions and responsibilities).

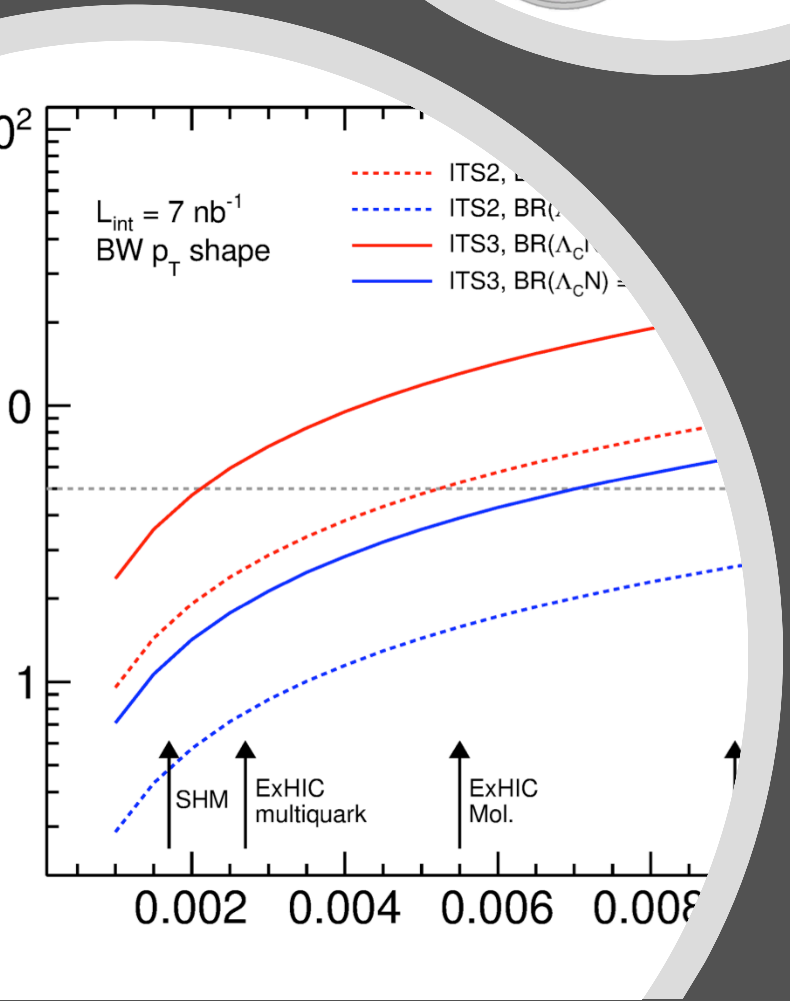


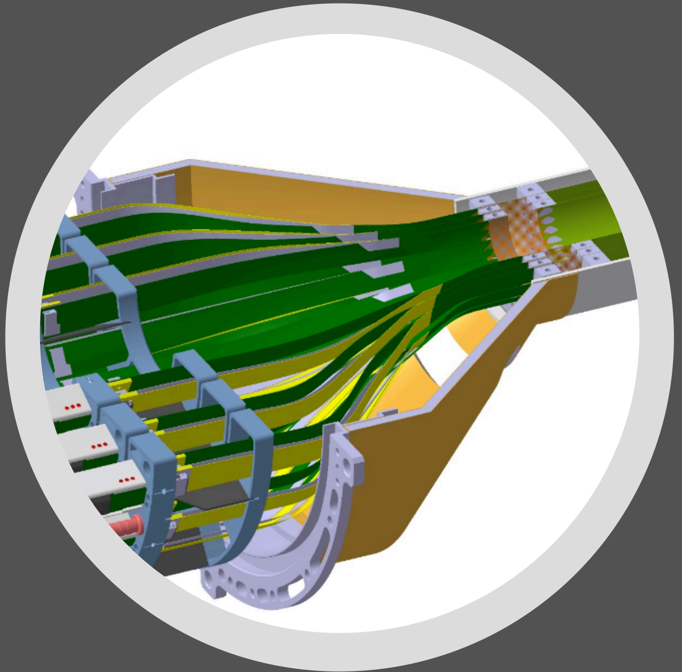
FUTURE ALICE UPGRADES

M. Chartier

UK Nuclear Physics Community Meeting 2020







ALICE ITS Upgrade

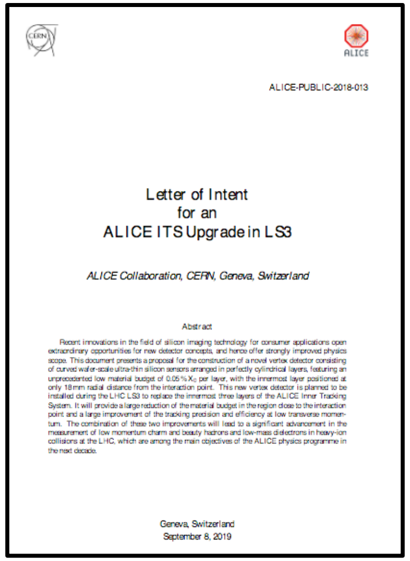
ALICE proposes a new inner tracker
Can we get closer? Can we get lighter?

Next Inner Tracker: ITS3

- **Installation planned for LS3 (after Run 3, i.e. >2025)**
- New beam pipe with IR = 16 mm, ΔR = 0.5 mm
- **3 truly cylindrical Si monolithic pixel layers using ultra-thin curved sensors**:
  - Material budget per layer: ≈ 0.05% X_0
  - Inner-most layer at R = 18 mm
- Air cooling => low power consumption, < 20 $mWcm^{-2}$
- Readout circuitry at the periphery, outside the acceptance
- **Wafer scale chips that are stitched (RAL technology!)**
- Thin down to 20-40 μm and bent

https://cds.cern.ch/record/2703140

ALICE-PUBLIC-2018-013



ALICE-PUBLIC-2018-013

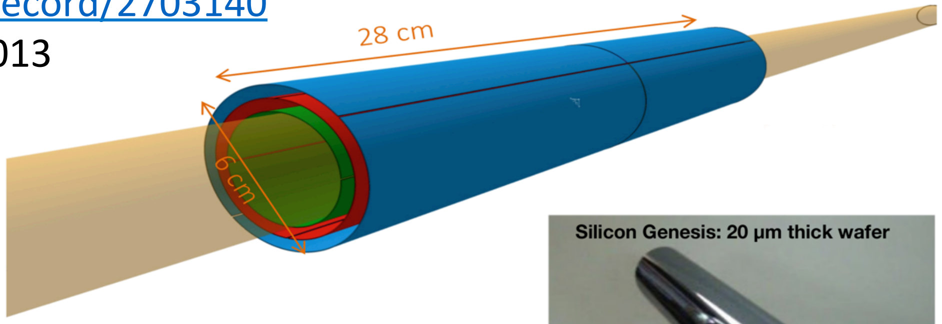
Letter of Intent
for an
ALICE ITS Upgrade in LS3

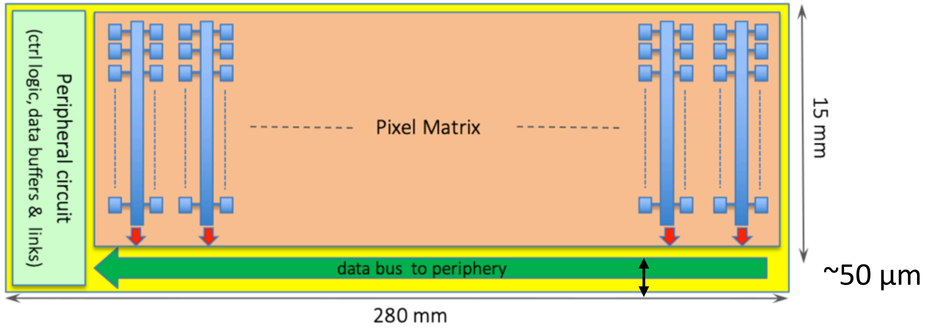
ALICE Collaboration, CERN, Geneva, Switzerland

Abstract

Recent innovations in the field of silicon imaging technology for consumer applications open extraordinary opportunities for new detector concepts, and hence offer strongly improved physics scope. This document presents a proposal for the construction of a novel vertex detector consisting of curved wafer-scale ultra-thin silicon sensors arranged in perfectly cylindrical layers, featuring an unprecedented low material budget of 0.05 % X_0 per layer, with the innermost layer positioned at only 18 mm radial distance from the interaction point. This new vertex detector is planned to be installed during the LHC LS3 to replace the innermost three layers of the ALICE Inner Tracking System. It will provide a large reduction of the material budget in the region close to the interaction point and a large improvement of the tracking precision and efficiency at low transverse momentum. The combination of these two improvements will lead to a significant advancement in the measurement of low momentum charm and beauty hadrons and low-mass dielectrons in heavy-ion collisions at the LHC, which are among the main objectives of the ALICE physics programme in the next decade.

Geneva, Switzerland
September 8, 2019

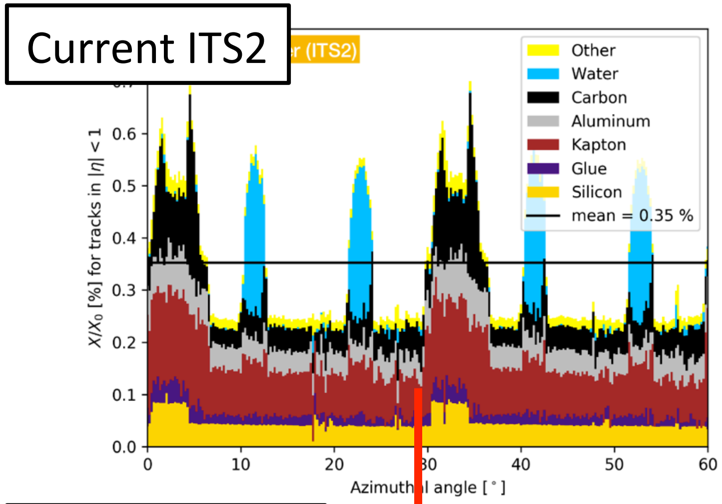


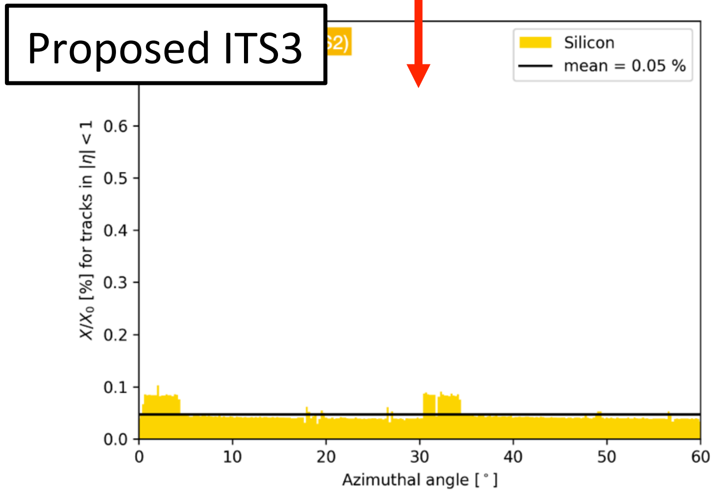


Lead to significant advancement in the measurement of low p_T heavy flavour hadrons and low-mass di-electrons

ITS3 Material Budget

- Si only 1/7th of total material
- Irregularities due to overlaps and support and cooling
- Remove water cooling
  - Possible by reducing power consumption to < 20 mWcm^{-2}
- Remove external data lines and power distribution
  - Possible by making single large chip and integrated on chip
- Move mechanical support outside the acceptance
  - Benefit from increased stiffness by rolling Si wafer



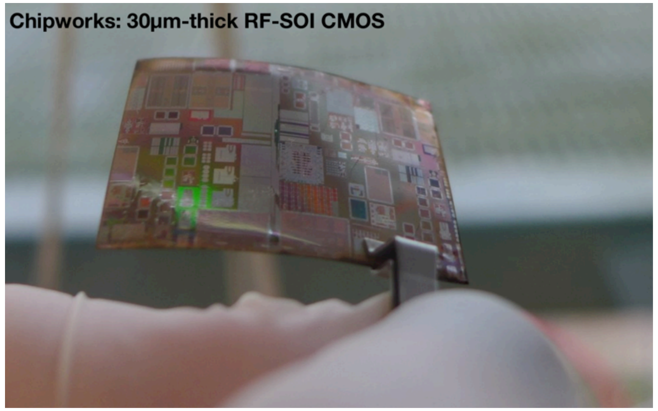


ITS3 Si Bending

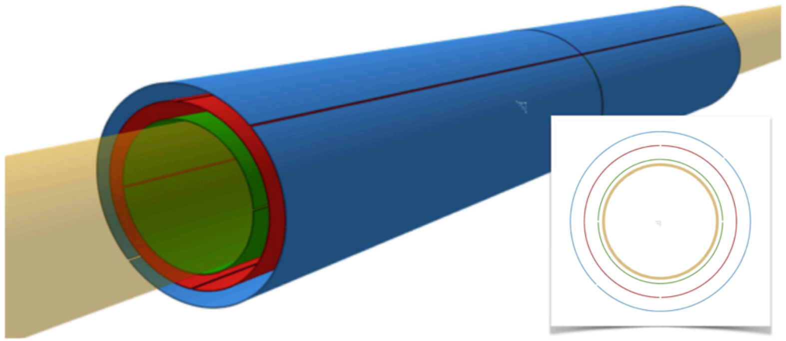
- Bending Si wafers and circuits is possible
- Radii much smaller than ALICE needs are obtained
- Investigate options starting with ALPIDE chips and wafers

Die type	Front/back side	Ground/polished/plasma	Bumps	Die thickness (μm)	CDS (MPa)	Weibull modulus	MDS (MPa)	r_{min} (mm)
Blank	Front	Ground	No	15–20	1263	7.42	691	2.46
Blank	Back	Ground	No	15–20	575	5.48	221	7.72
IZM28	Front	Ground	Yes	15–20	1032	9.44	636	2.70
IZM28	Back	Ground	Yes	15–20	494	2.04	52	32.7
Blank	Back	Polished	No	25–35	1044	4.17	334	7.72
IZM28	Back	Polished	Yes	25–35	482	2.98	107	24.3
Blank	Back	Plasma	Yes	18–22	2340	12.6	679	2.50
IZM28	Front	Plasma	Yes	18–22	1207	2.64	833	2.05
IZM28	Back	Plasma	Yes	18–22	2139	3.74	362	4.72

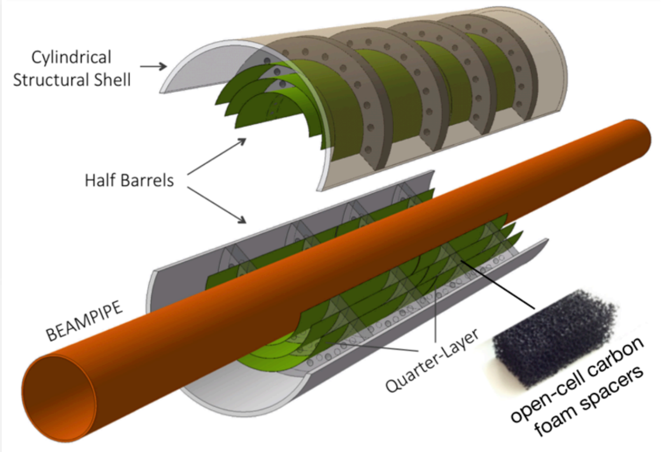
D.A. van den Ende et al., Microelectronics Reliability, vol. 54, pp. 2860-2870, 2014
http://dx.doi.org/10.1016/j.microel.2014.07.125



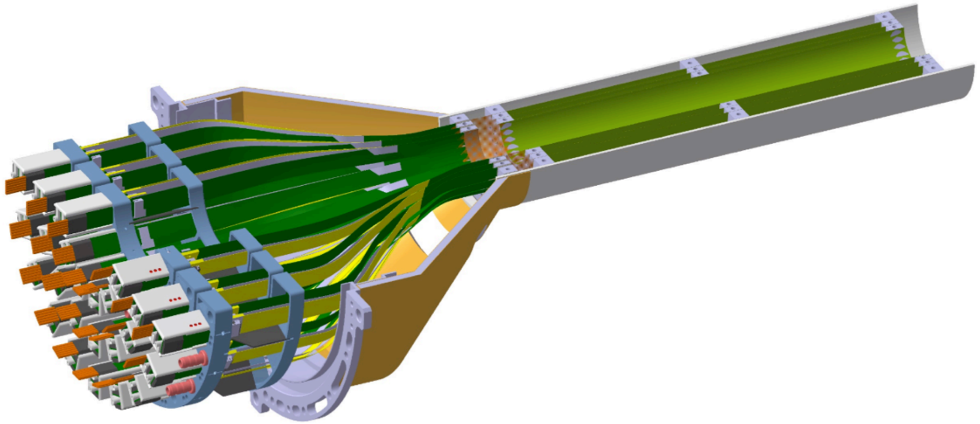
ITS3 Layout and Mechanics



Beam pipe Inner/Outer Radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	300		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active area (cm^2)	610	816	1016
Pixel sensors dimensions (mm^2)	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm^2)	O (10 x 10)		



- New beampipe
- Material homogeneously distributed
- Essentially zero systematic error from material distribution
- Sensors held in place with low density carbon foam
- Cooling at the extremities (chip periphery)



ITS3 R&D Phase (2020-2024)

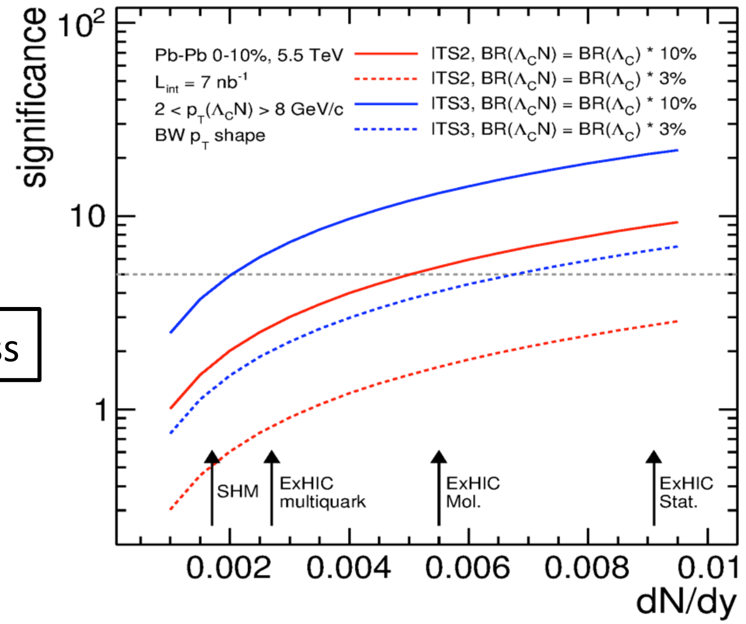
ALICE

- Presented to LHCC in September 2019, approved
- Project Kick-off meeting at CERN on 3rd December 2019 (open to other experiments, not just ALICE)
- Major CERN EP generic R&D programme launched in November 2019 includes ITS3
- Broad UK interest from ALICE groups + Particle Physics groups (discussion with Lancaster, Liverpool, QMUL…) + STFC Labs (Technology Division: Daresbury DSG, RAL Microelectronics…)
- **Opportunity for UK/STFC to contribute and lead in this innovative detector development!**
- TDR ~ 2023, Construction ~ 2025

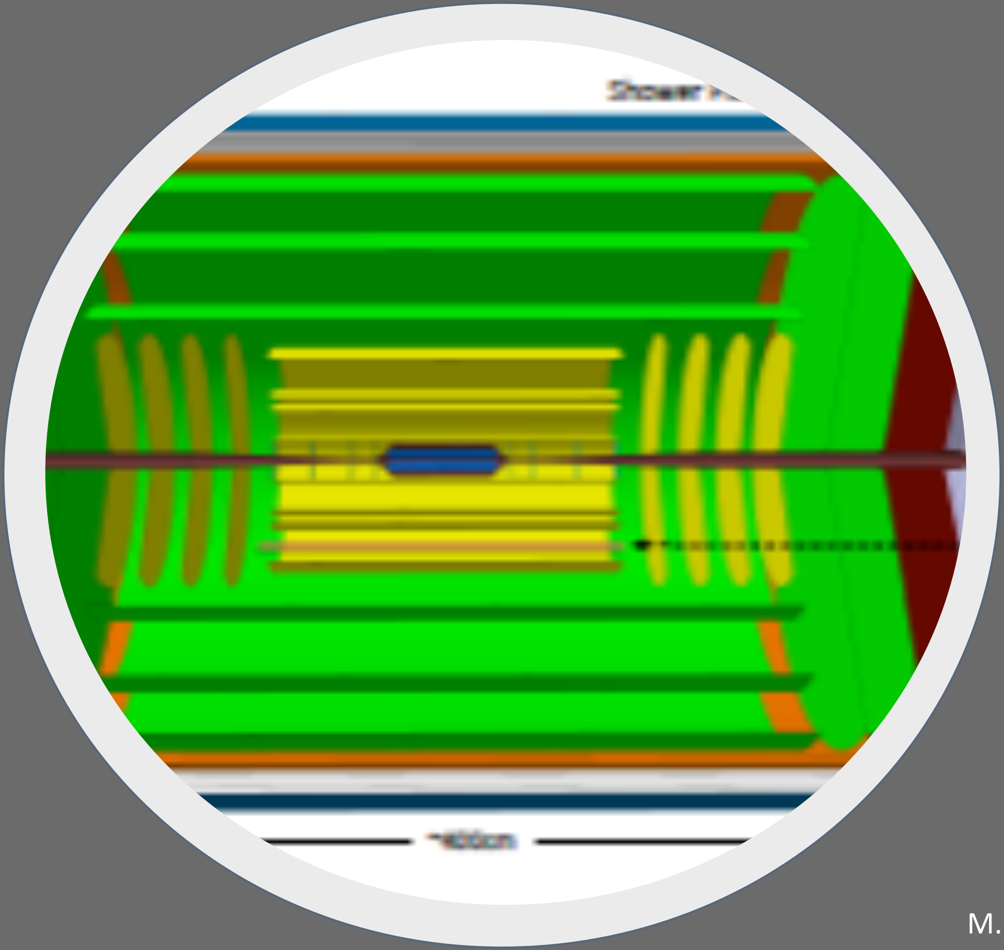
C-deuteron search ($\Lambda_c n$ bound state, m = 3.226 GeV/c^2)

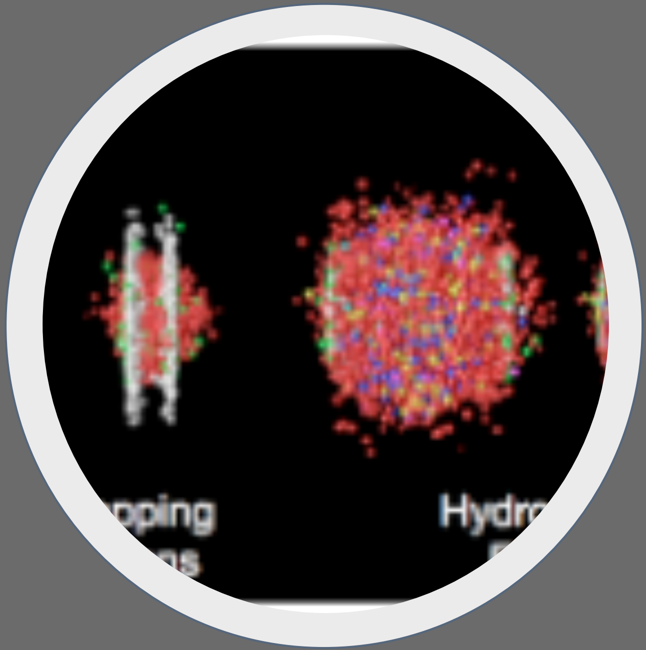
M. Buckland,
J. Norman

Work in progress



- CMOS sensor design
- Sensor characterisation
- Mechanics
- Physics performance studies





Longer-Term Horizon

A next-generation LHC heavy-ion experiment

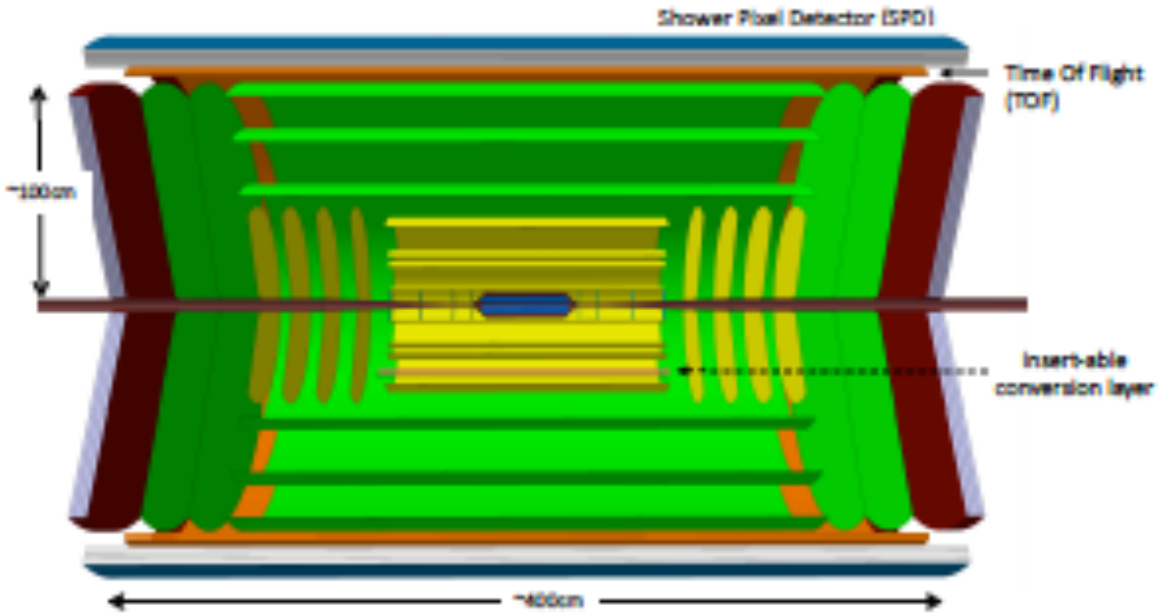
ALICE2 – 10 year horizon

- **Foreseen installation during LS4 (2031?), input to the European Particle Physics Strategy Update 2018-2020**

- Compact, next-generation, multi-purpose detector at the LHC (to follow up the present ALICE experiment at Point 2)
- New ‘massless’ barrel detector, truly cylindrical layers based on curved wafer-scale ultra-thin silicon sensors with MAPS technology (cf ITS3!)
- Unprecedented low material budget 0.05% X_0 per layer, inner most layers inside beam pipe?

- Superior tracking and vertexing capabilities over wide range of momentum down to few 10s of MeV/c

- Particle identification via TOF with 20 ps resolution



pp, pA, AA collisions at luminosities 20-50 higher than possible with ALICE – electromagnetic probes at ultra-low p_T, precision physics in the charm and beauty sector

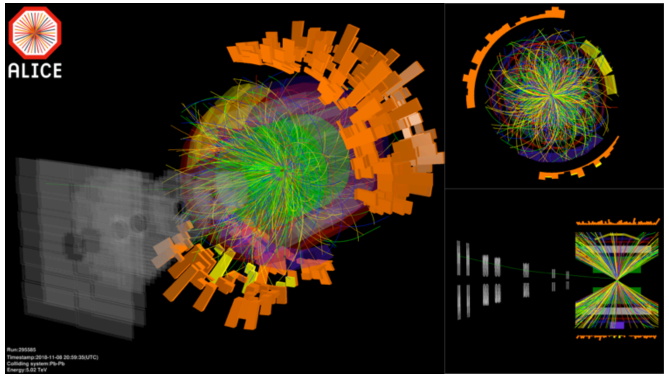
https://arxiv.org/abs/1902.01211

UK Roadmap

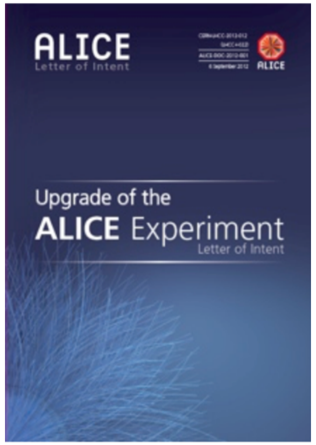
Backup

ALICE Upgrade for Run 3

- Main physics goals, high precision measurements at low p_T:
  - Heavy-flavour hadrons
  - Quarkonia
  - Low-mass dileptons
- Main requirements:
  - Continuous readout (un-triggered) to cope with larger statistics (x100) from interaction rate of 50 kHz for Pb-Pb collisions
  - Significant improvement in vertexing and tracking efficiency at low p_T
- Upgrade includes:
  - Smaller diameter beampipe
  - High resolution, low material new Inner Tracking System (ITS) and muon forward tracker
  - New TPC readout chamber, based on GEMs, and readout electronics
  - New readout for TRD, TOF and muon spectrometer
  - New Fast Interaction Trigger
  - Integrated online and offline system (O^2 project)
- Detector upgrades + increased luminosity (x10) greatly enhance physics capabilities



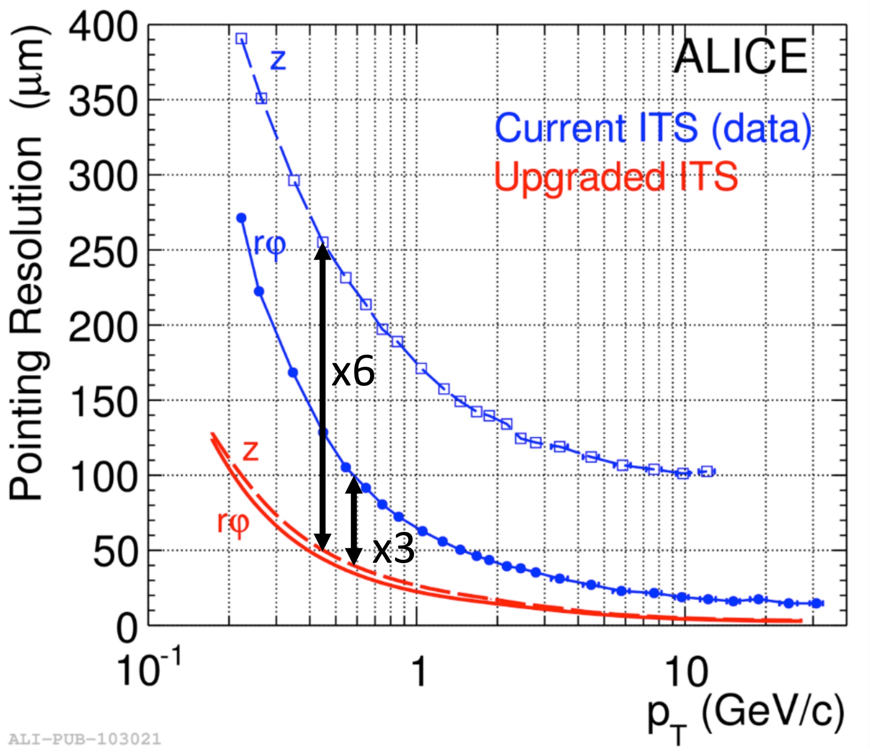
ALICE event display



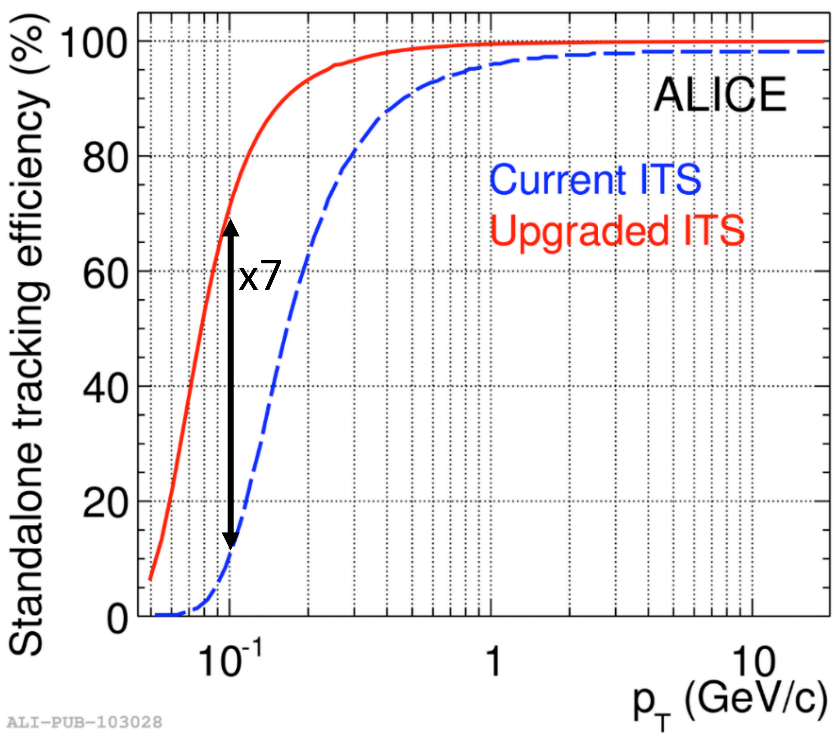
CERN-LHCC-2012-012

ITS2 Simulated Performance

- Pointing resolution: x3 improvement in rφ-direction and x6 in the z-direction for p_T < 1 GeV/c

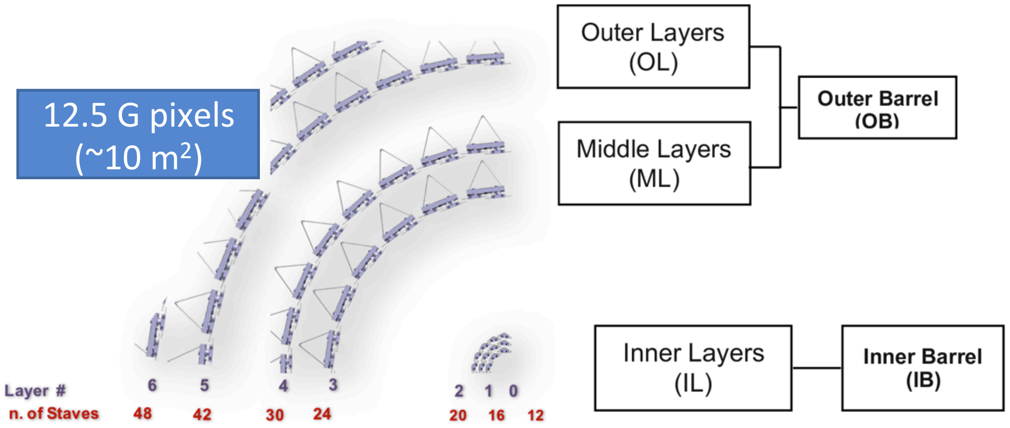


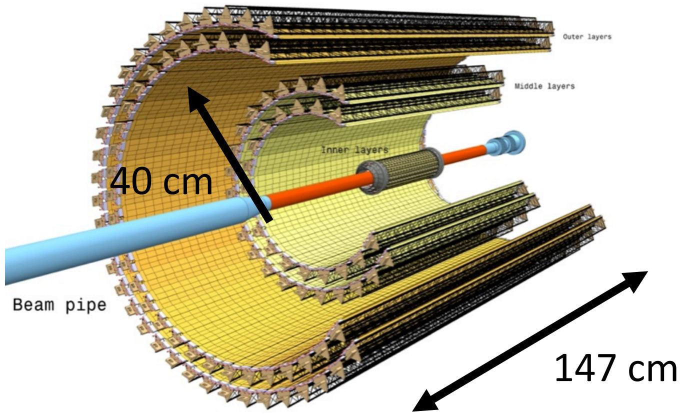
- Standalone tracking efficiency: x7 improvement at p_T 0.1 GeV/c



ITS2 Upgrade Layout

- Consists of 7 concentric layers split into two barrels
- Inner barrel (IB):
  - 3 layers
  - Material budget per layer ~ 0.35% X_0
  - 48 x 9 chip staves
  - 50 μm thick chips
- Outer barrel (OB):
  - 2 middle layers, 54 staves x 8 module each
  - 2 outer layers, 90 staves x 14 module each
  - Material budget per layer ~ 1% X_0
  - 100 μm thick chips

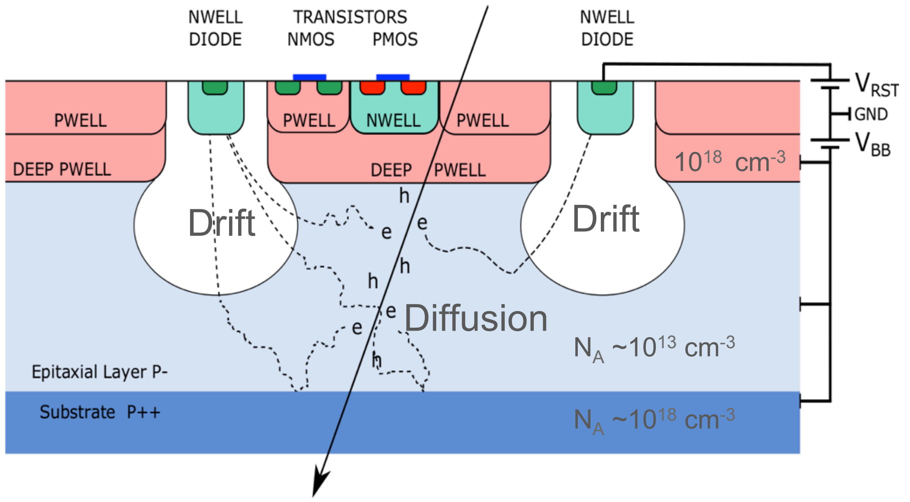




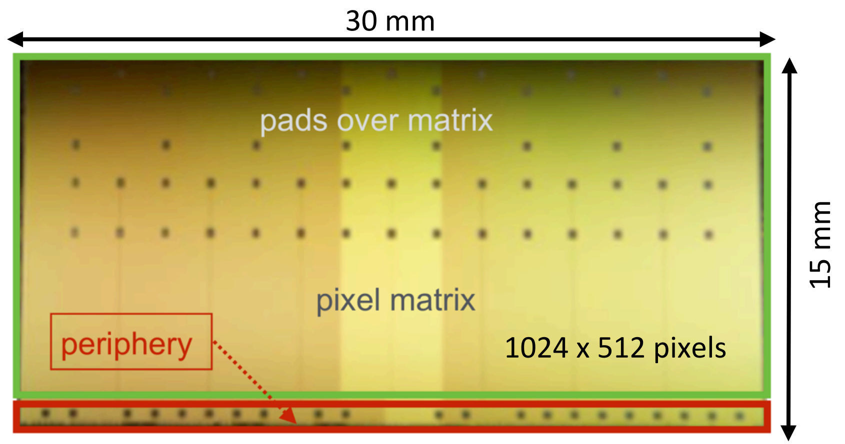
"Technical Design Report for the Upgrade of the ALICE Inner Tracking". ALICE Collaboration, B. Abelev et al. System. J. Phys. G 41, 087002 (2014).

ALPIDE chip

- Monolithic chip produced by Tower Jazz in 180 nm CMOS imaging process technology
- Full CMOS circuitry implemented in each pixel exploiting the deep technology feature
- High resistivity (>1 kΩcm) p-type epitaxial layer (25 µm thick) on p-type substrate
- Small reverse bias possible (< -6 V), increase depletion region

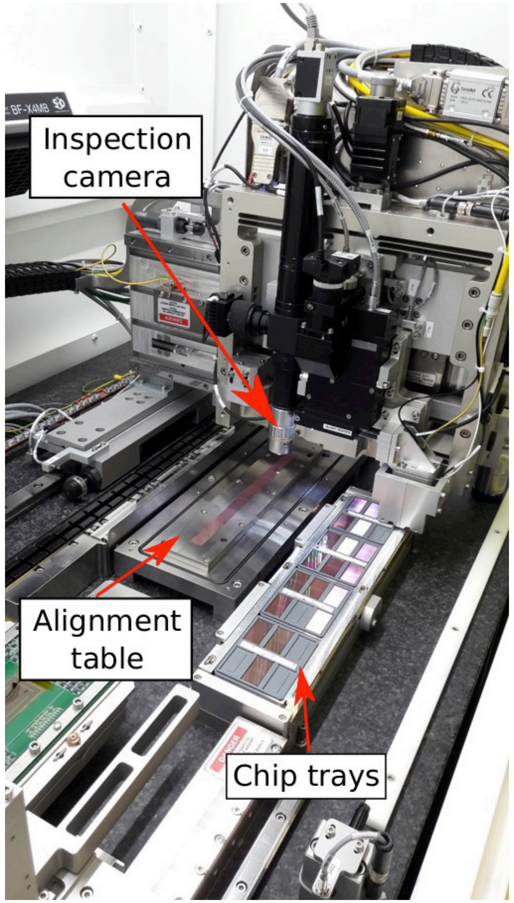


- Features:
  - In-pixel amplification, discrimination and multi-event buffer
  - Low power consumption, 40 $mWcm^{-2}$
  - Small periphery for control and readout functions
  - Hits readout using priority encoder
  - Event time resolution < 20 µs
  - High speed readout of up to 1.2 Gbit/s



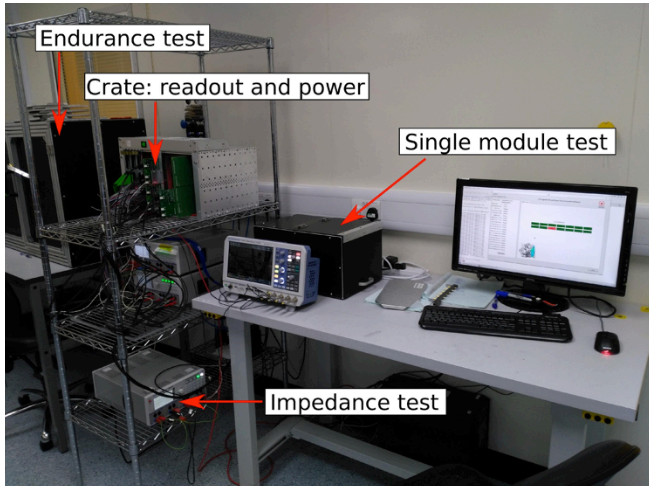
Outer Barrel Module Production Liverpool

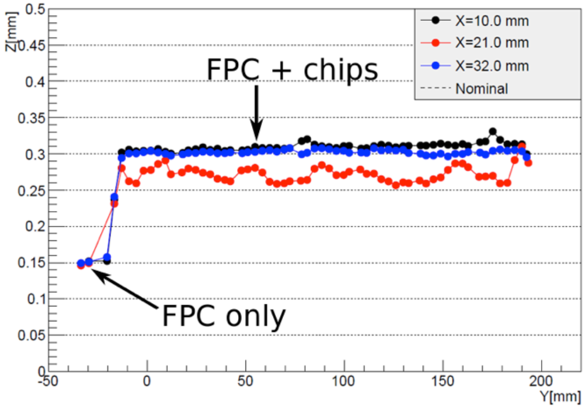
- Custom designed machine by IBS (NL) built to the project specifications
- So-called Module Assembly Machine (MAM):
  - Automatic chip pick up and placement
  - < 5 µm alignment precision
  - Automatic chip inspection
- Wirebonding on site



Outer Barrel Module Production Liverpool

- Extensive functional and mechanical testing for Quality Assurance (QA)
- Functional QA:
  - Impedance test, identify shorts
  - Single module, set of scans (e.g. threshold, nosie) to determine functionality of the readout, analogue and digital circuitry
  - Endurance test to determine the stability of the module over the expected number of power cycles during the detector operation
- Mechanical QA:
  - Pull tests on wirebonds to determine quality, 1 in 10 modules tested
  - Metrology: developed and carried out by Liverpool, determine mechanical properties and quality of assembly





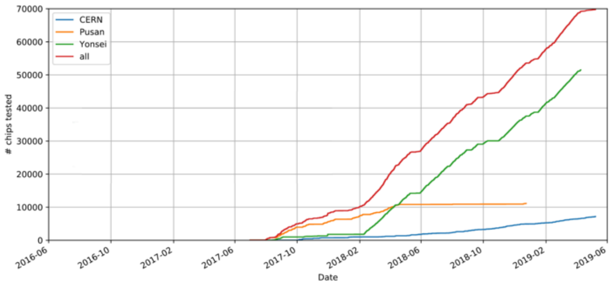
Thickness + flatness metrology

Component Production Status

ALPIDE chips

Production completed

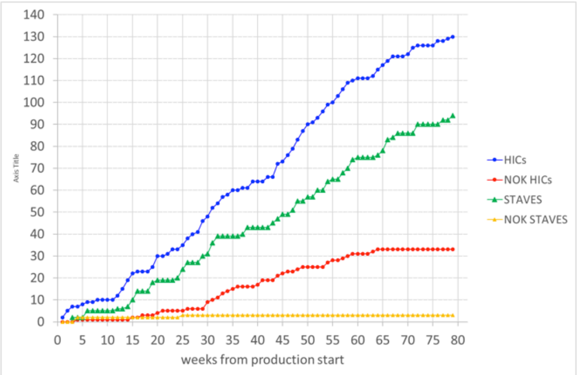
- Institutes: 50 µm: CERN, 100 µm: Yonsei, Pusan
- Total chips tested ~70000
- Total wafers ~1700
- Yield 64%
- Series test ended mid 2019



Inner barrel HICs and staves

Production completed

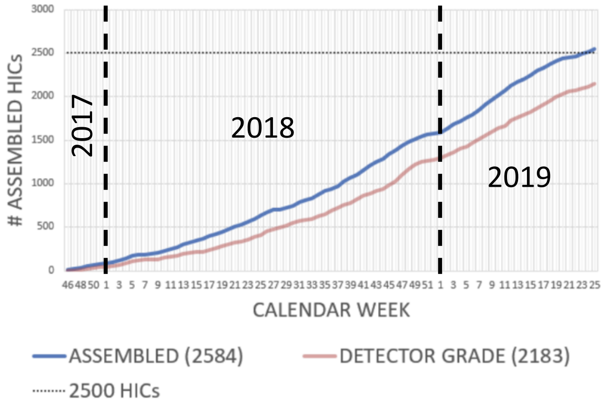
- Institutes: CERN
- 140 staves assembled
- Yield 73%
- Enough for 2 fully working copies of the IB



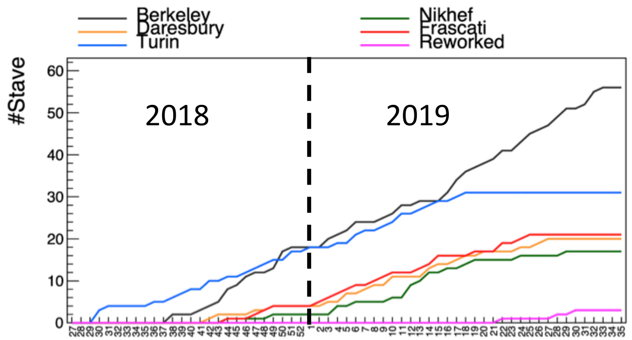
Outer barrel HICs and staves

Production completed

- HIC institutes: Bari (IT), Liverpool (UK), Pusan (KR), Strasbourg (FR), Wuhan (CN)
- FPCs: Trieste (IT)
- >2500 HICs assembled
- Yield ~85%



- Stave institutes: Berkeley (US), Daresbury (UK), Frascati (IT), Nikhef (NL), Turin (IT)
- 148 staves assembled
- Yield > 90%
- Rework yield ~50%

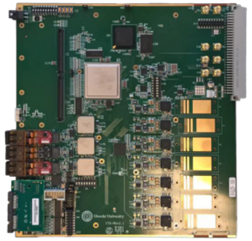


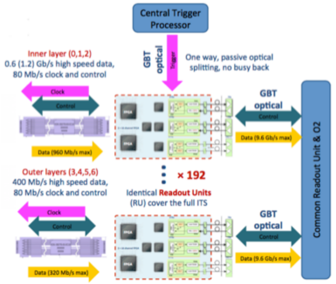
Component Production Status

Readout electronics

Production completed

- Institutes: Austin (US), Bergen (NO), CERN, Nikhef (NL), Padova (IT)
- 192 FPGA based RUs, operating in a mild radiation environment (<10 krad, 10^{11} 1 MeV/n_{eq})

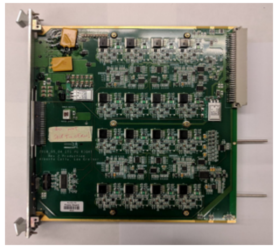


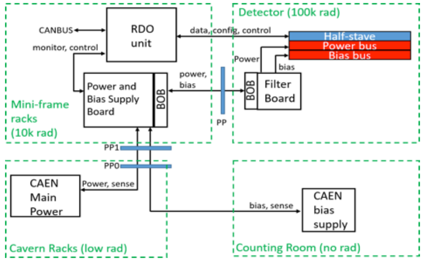


Power system

Production completed

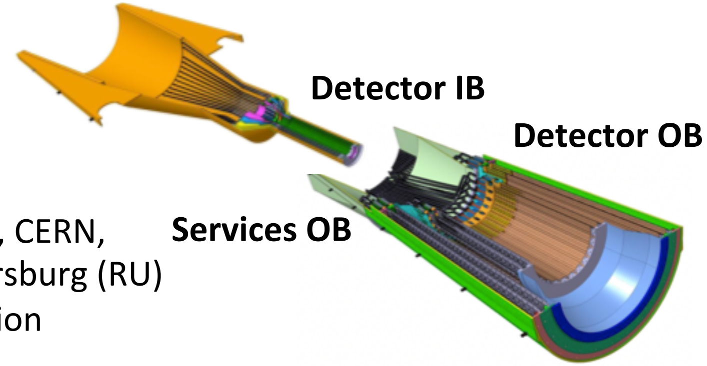
- Institutes: LBNL (US), Bari (IT)
- CAEN powering modules available and in use in commissioning setup



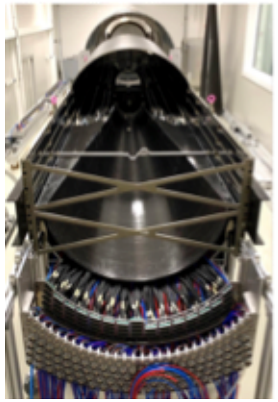


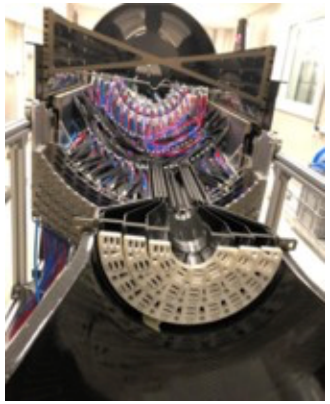
Support structures

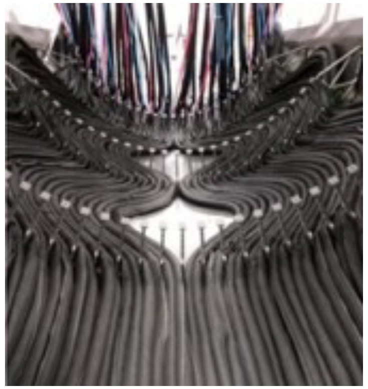
Production completed



- Institutes: LBNL (US), CERN, Padova (IT), St. Petersburg (RU)
- Component production completed
- Insertion dry test performed

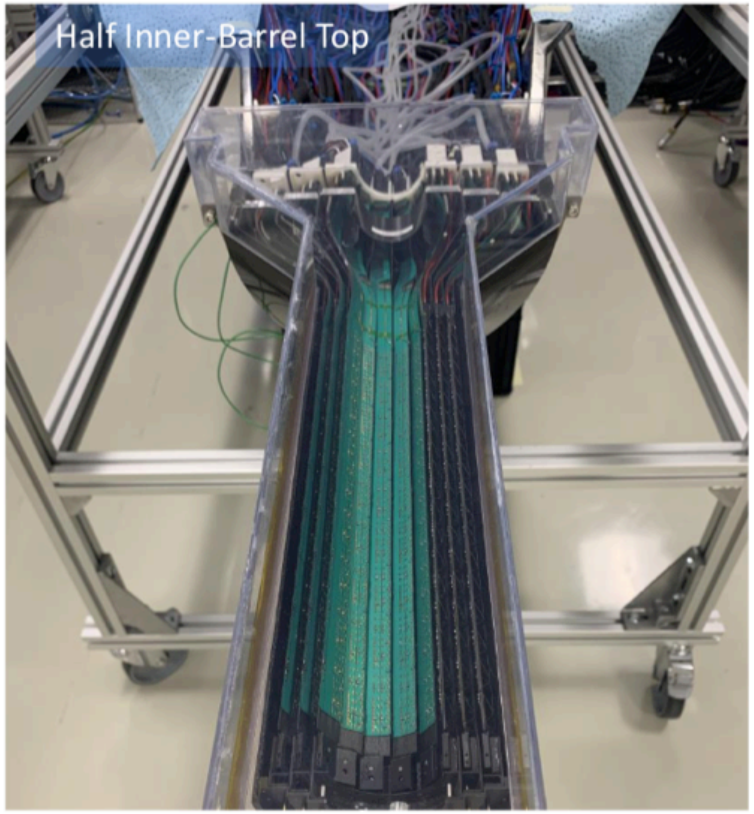


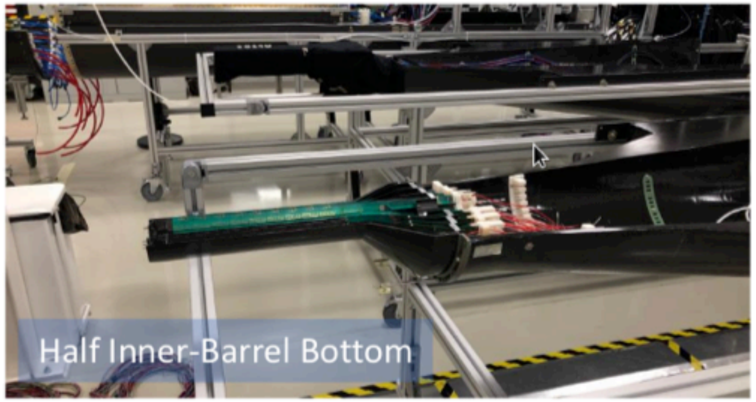


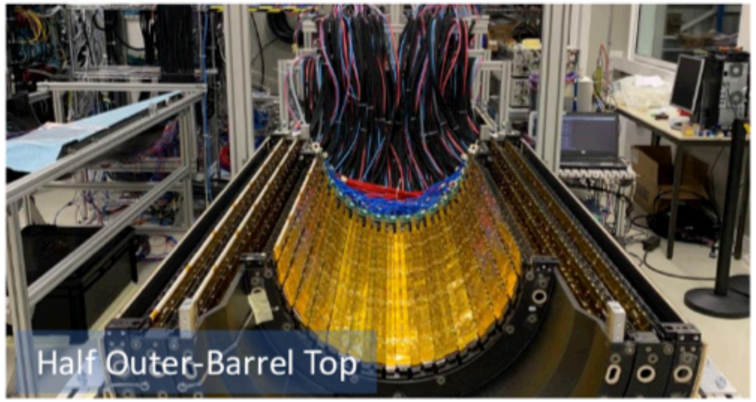


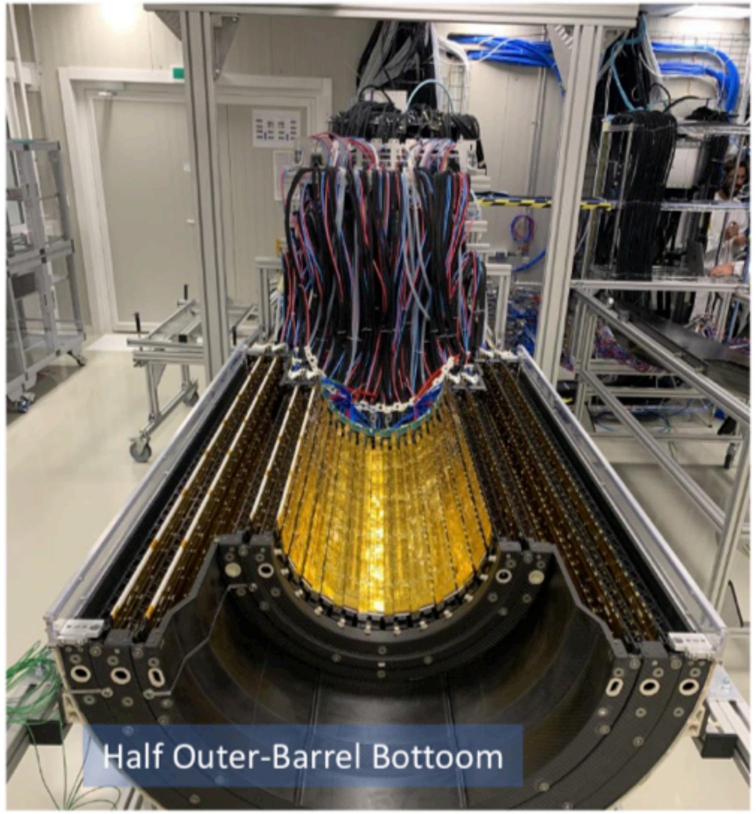
ITS2 Assembly

- Assembly and commissioning in a fully equipped clean room at CERN
- Assembly completed



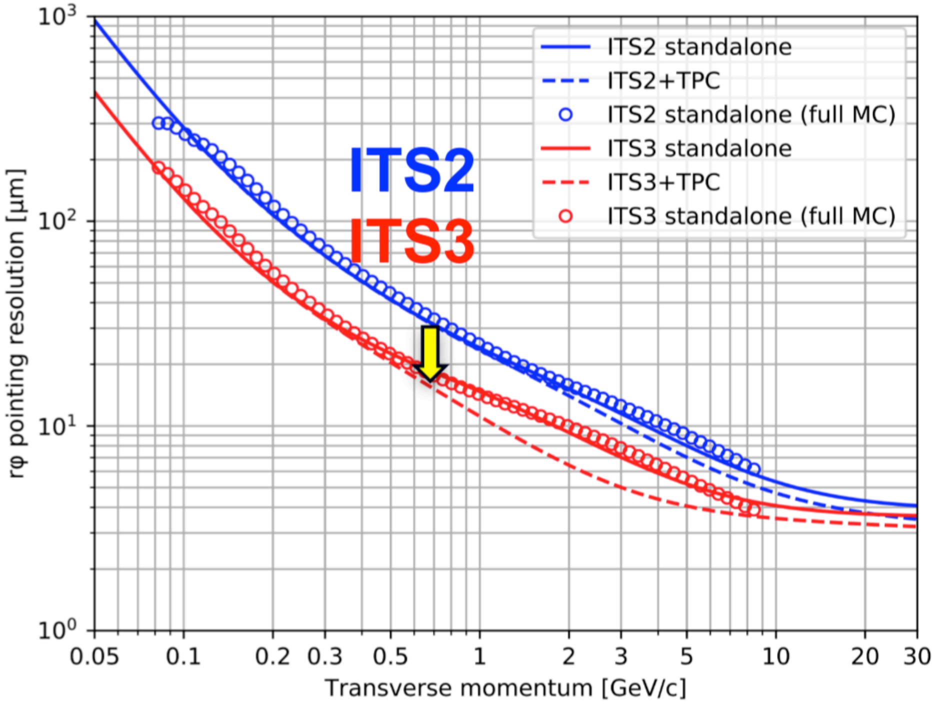


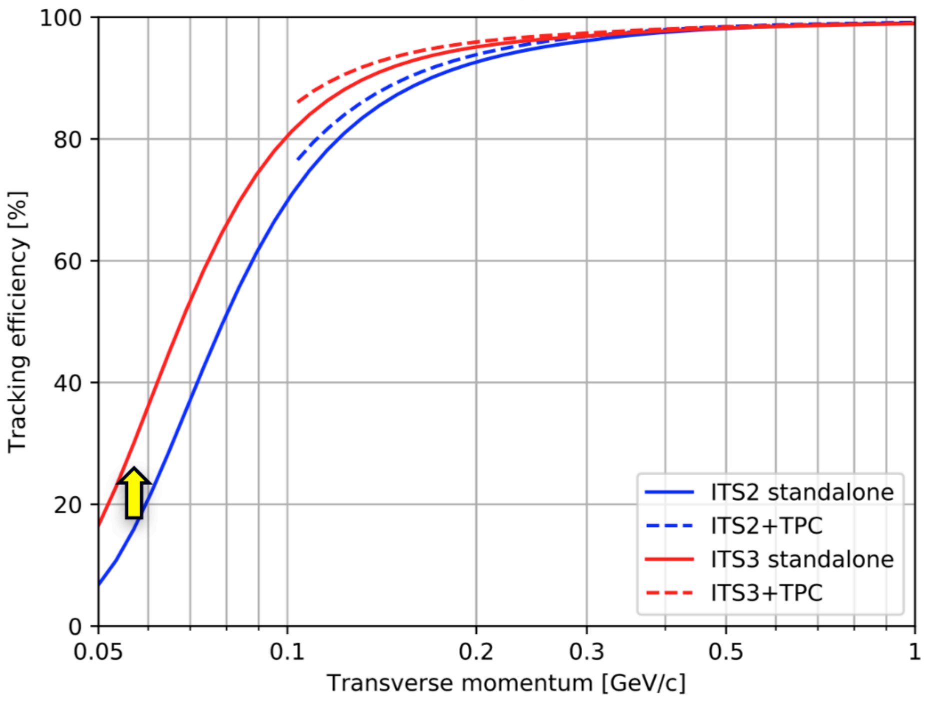




ITS3 Tracking Performance

ALICE





- Resolution improved by factor 2 at all p_T's
- Tracking efficiency at low p_T (50-60 MeV/c) improved by a factor of 2

ITS3 Performance Studies

- Heavy ion collisions can be used as a laboratory to study/search for exotic heavy hadrons
- C-deuteron search
- Λ_cn bound state, m = 3.226 GeV/c^2
- Observation would provide information on hadronization and hadron-hadron interactions
- Decay, c-deuteron -> dKπ:
  - Λ_c decays with a cτ ≈ 60 µm, e.g. -> pKπ (BR~6%)
  - BR must be multiplied by the probability that p binds with n to form a deuteron, estimate 3-10%
- Different prediction models for yield: SHM [Phys Lett B797 (2019) 134836] and ExHIC [Prog.Part.Nucl.Phys. 95 (2017) 279-322]
- Study to see if c-deuteron is within reach
- Significance > 5 with ITS3, x2.5 improvement wrt ITS2
- Good potential to observe c-deuteron if it exists

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