LHC Upgrades

LHC two major upgrades to increase the luminosity:

- **LS2: L ≳ 2×10^{34} $cm^{-2}s^{-1}$, Lint ~350 fb^{-1}** (about 55 p+p interactions per bunch crossing)
- **LS3: L ~ 5-7$\times10^{34}$ $cm^{-2}s^{-1}$, final integrated luminosity: ~3000 fb^{-1}** (about 140-200 p+p interactions per bunch crossing)

LHC Upgrades

The basic goal of the upgrades is to maintain the excellent performance of the detectors in terms of efficiency, resolution, and background rejection .
The main challenges that must be overcome to achieve this goal are radiation damage to the detectors and the very high “pileup” that comes from the high instantaneous luminosity.

ATLAS : (LS2) new muon Small Wheels , several updates for the trigger system
(LS3) a new Inner Detector ITK, together with trigger (calorimeter , muon system) upgrades

CMS: upgrade of the Muon System, the endcap Calorimeters, the tracking System, the Trigger and Data Acquisition. (LS2+LS3)

LHCB: (LS2) replacement of the tracking system and significant modifications of the particle identification detectors. Remove the first-level hardware trigger reading out the detector at 40MHz, with a fully software trigger (LS2), PID enhancement (ECAL, RICH) (LS3). Upgrade II in LS4 for run 5,6 under discussion.

ALICE: The upgrades preserve the current particle identification capability while enhancing the vertex detectors, triggering and tracking capabilities. They include: Inner Tracking system ITS, Muon Forward Tracker MFT, Time-Projection Chamber (TPC). LoI for Run 5 upgrage submitted.

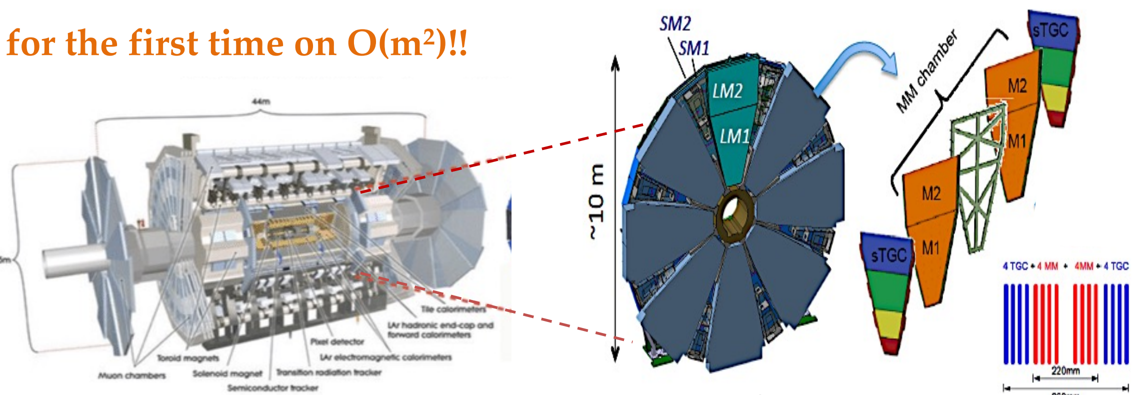
ATLAS New Small Wheel

ATLAS Muon New Small Wheel (NSW) Upgrade to cope with the increasing background particle flux (pileup) as the luminosity increases :

- Replace the Small Wheels, the innermost Muon station in the forward region **improving L1 trigger & maintain good tracking performances at End-cap** (HL-LHC runs with high background rates, up to 20 kHz/cm^2)
- Detector area: ~2400 m^2
- Higher channel granularity (**25x** old SW): MM: ~ 2.1 M, sTGC: ~ 280 k (strip) + 46 k (pads) + 28 k (wires) pics
- **Requirements**
  - **15% p_T resolution at ~1TeV**
  - **97% segment reconstruction efficiency** for muon p_T>10 GeV with 30 μm spatial resolution
  - **~100 μm spatial resolution per detector plane** with single layer efficiency > 90%
  - **segments measurements with up to 1 mrad pointing accuracy** (Phase-II requirement)

Two technologies (MM + sTGC) for precision trigger and tracking of muons in ATLAS forward region

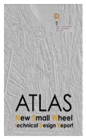
NSWs are composed of 16 sectors per each wheel and 16 layers (8 sTGC + 8 MM) to have high redundancy.**MM detectors are MPGD build for the first time on O(m^2)!!**

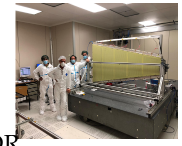


Giada Mancini (LNF INFN)

ATLAS New Small Wheel

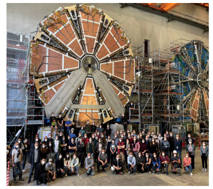
ATLAS TDR





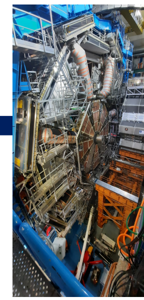
Module production 2018-2020

Integration at CERN 2019-2021



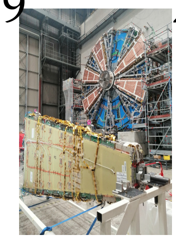
NSW A/C End Commissioning 10/2021

NSWs Underground Commissioning 10/21-04/22



2013 2019 2020 2021 **2023**

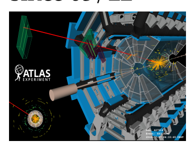
1° sector on the Wheel 12/2019



Surface Commissioning 2019-2021

NSW to the cavern 12/2021

NSWs Running in ATLAS since 05/22



Great construction challenge succesfully accomplished to be ready for the Run3 data-taking.

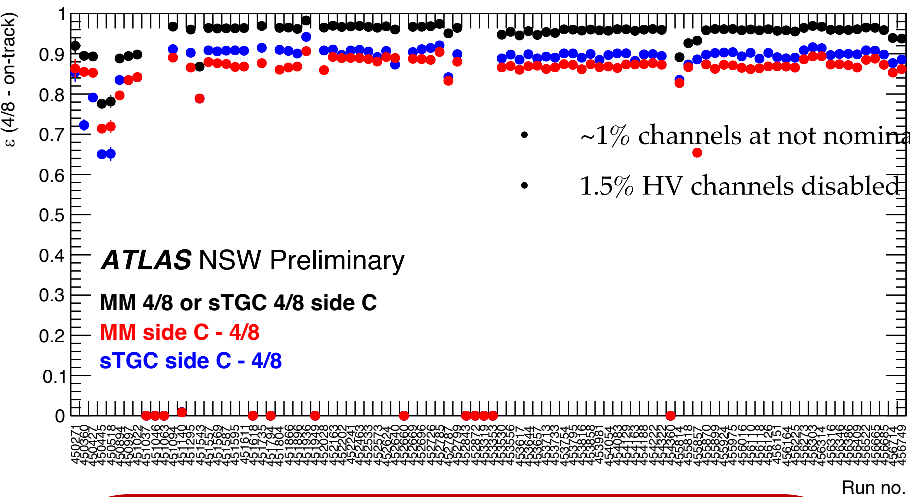
NSW Project and LNF contribution:

- responsible of the assembly of the SM1 chambers produced by INFN
- production manager of the chambers produced by the whole collaboration (Saclay, Munich, Dubna, INFN) thanks to the solutions proposed to cope with the HV issues
- project leader of the NSW Upgrade project
- responsible of the HV validation of the MM-sectors and of the assembly and testing of chambers from the whole collaboration
- responsible of the commissioning of the NSWs (NSW-C done in 3 months!)
- responsible of the underground commissioning
- YETS interventions to solve cooling, ICS, gas system and HV issues

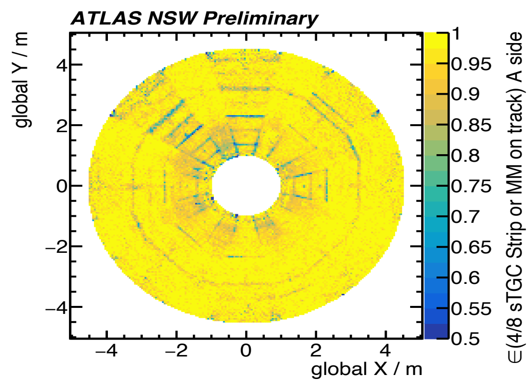
ATLAS New Small Wheel

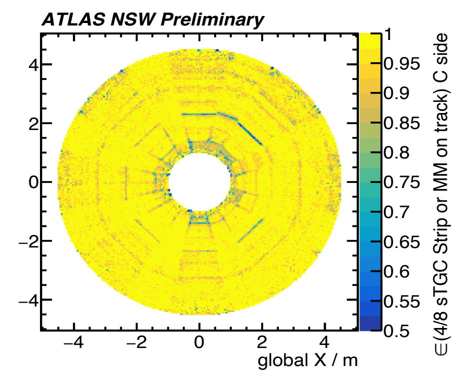
NSW employs new generation DAQ developed for the ATLAS Run-3: FELIX. will be the standard for Phase2! **Used for the first time at large-scale in ATLAS!**

Tracking efficiency by time

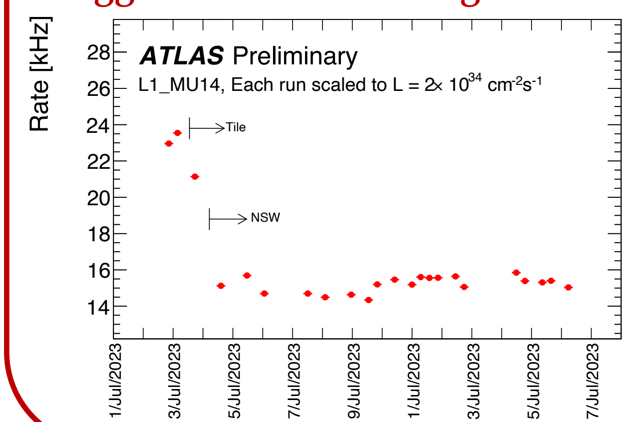


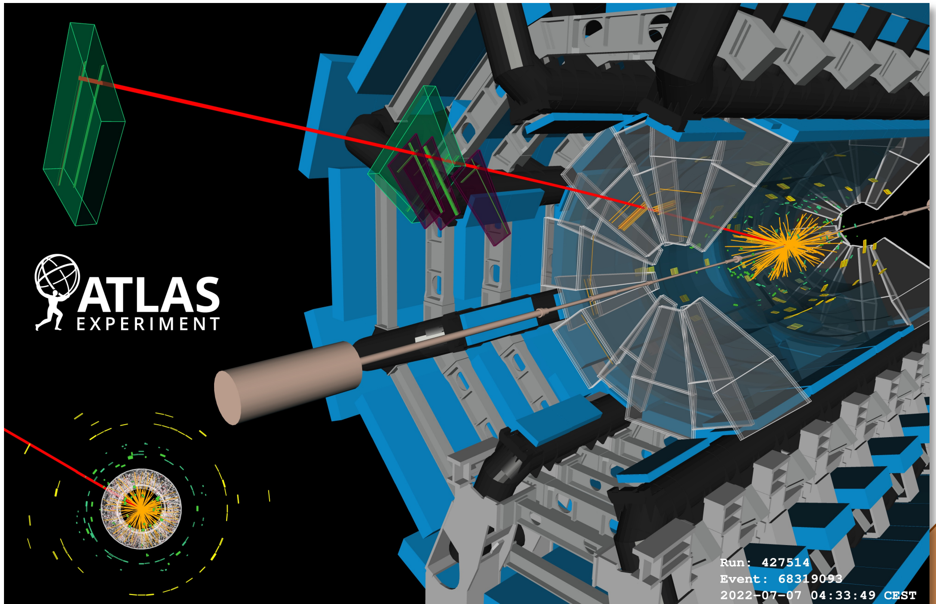
- ~1% channels at not nomina
- 1.5% HV channels disabled





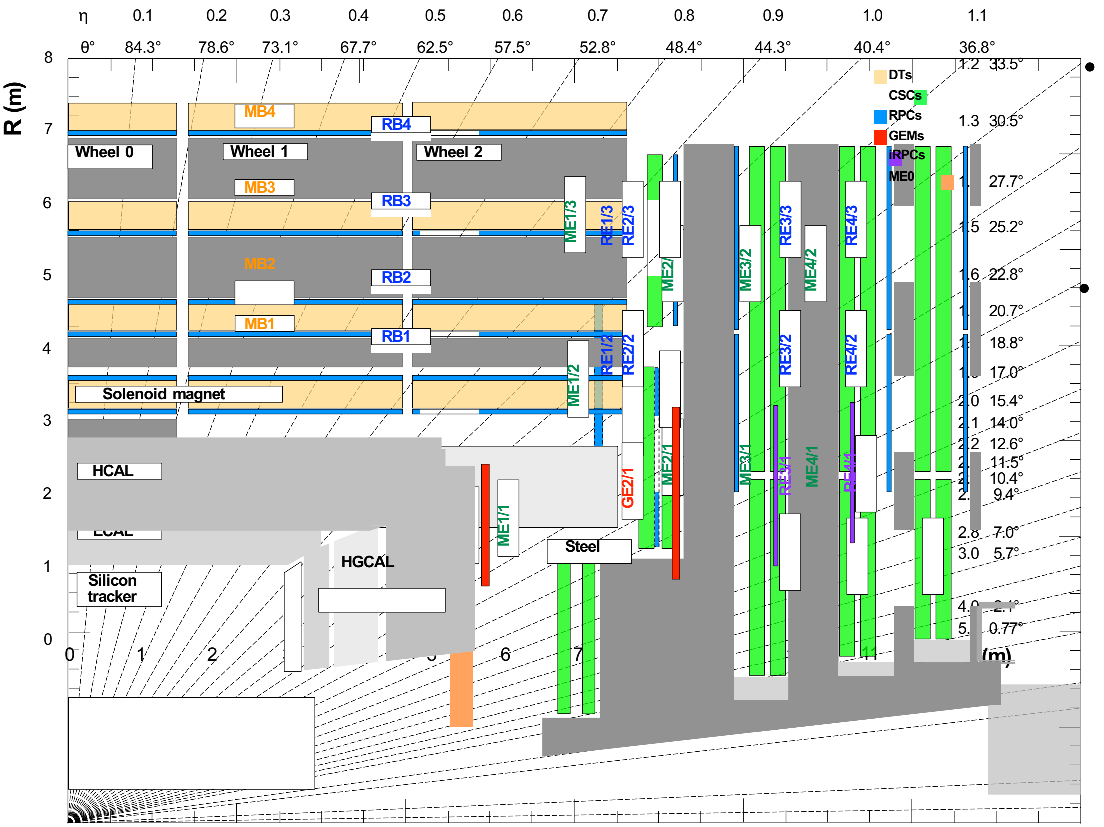
NSWs already taking part to the LVL1 trigger decision reducing the rate by 6kHz!





Upgrade of the CMS Muon System

prepare CMS for unprecedented high luminosity at a hadron collider



- Improved electronics for existing detectors: *Drift Tubes*, *Cathode Strip Chambers* & *Resistive Plate Chambers*
  - Deal with: Increased L1A (750kHz), latency (12.5us),…
- Instrument Forward spectrometer installing new detectors GE1/1, GE2/2 and ME0
  - Highest background – fewest measurements
  - Reduce steeply increasing trigger rate at L1
  - Add Features:
    - *Trigger on Long-lived particles with improved RPCs*
    - *Trigger on Displaced Muons with GEM-CSC tracklets*

LNF is involved in GE1/1, GE2/2 and ME0 construction, installation and commissioning

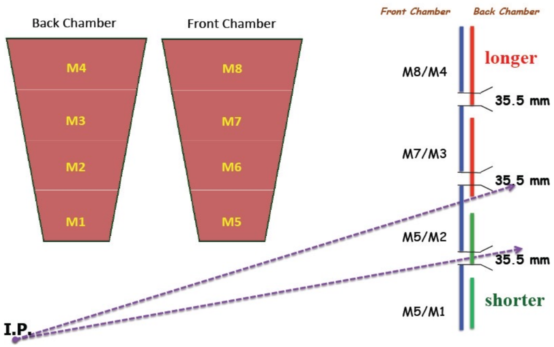
Upgrade of the CMS Muon System

GE SYSTEM

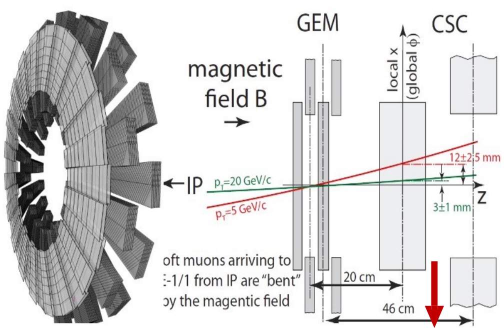
GEM technology (triple GEM foil), 36 trapezoidal super chambers per endcap, two layer per super chamber (about 1.5 m^2)

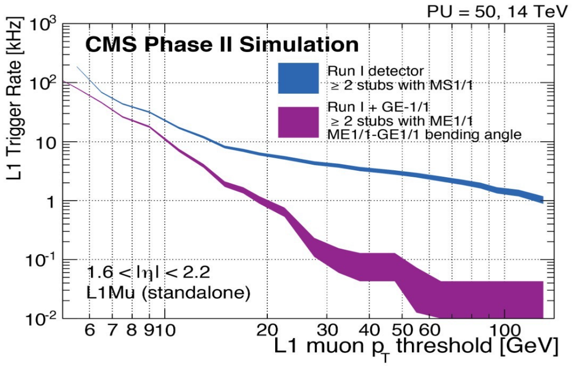
Two GE station per endcap GE1/1 and GE2/1: enhancing the overall redundancy of the muon system and allowing a standalone momentum measurement in the Level-1 trigger also in case of displaced vertices

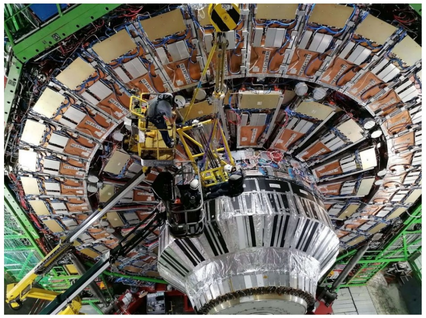
An additional GEM based system (ME0) extends coverage muon system up to $\eta \leq 2.8$



Most important: the Increased Bending-angle leverage (20-45cm) improves pT measurement at L1 leading to Trigger rate reduction reducing the rate of soft muons that pass the trigger threshold due to pT mismeasurement.





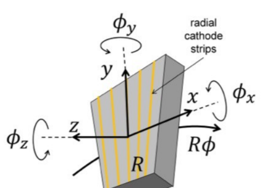


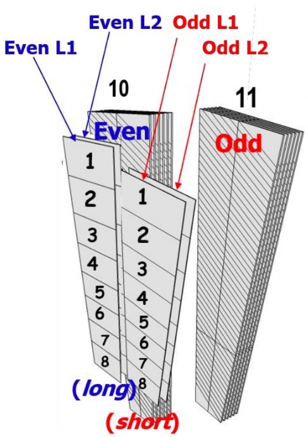
- **GE1/1 installed in LS2**
- **GE2/1 currently under construction**
  - Installation Negative Endcap in EYETS 23-24
  - Installation Positive Endcap in EYETS 24-25
  - 51 modules produced (144 needed / Endcap)
- **ME0 will be installed in LS3**

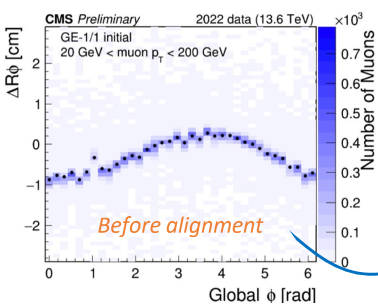
Performance of GE1/1 detectors

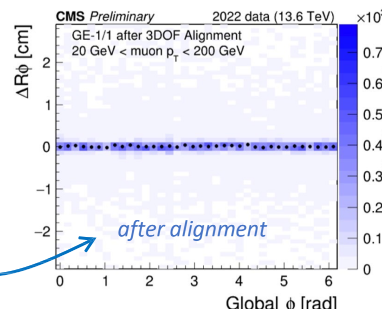
overview of 2022 data-taking

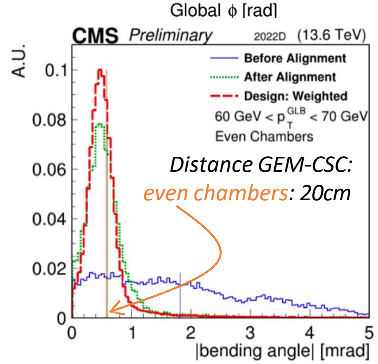
- Performed HV-scan to establish individual detector working points (*for 2023*) – *now detector only efficiency*
- Implemented Detector Alignment
- Bending Angle *(BA)* GEM-CSC measured – *Spatial Res ongoing*
- Alignment & BA important steps for GEM-CSC Trigger in 2023

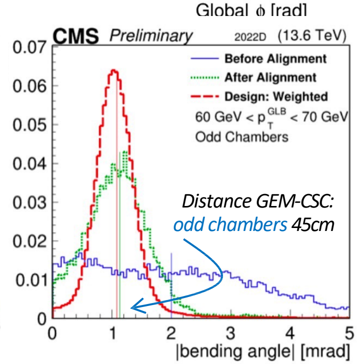


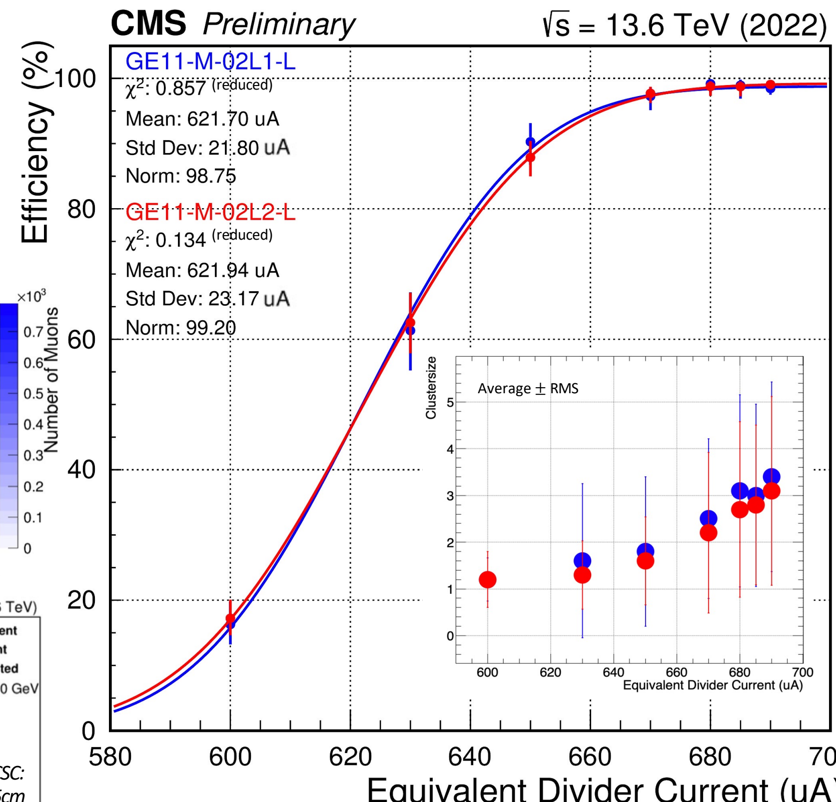












High-Voltage Scan in October 2020

data: Z-Mu skim (2pb⁻¹ / point) - curve fitted with Erf(x)

Norm = ε @ Plateau – Mean = I @ 50% ε - Std Dev = width

The CMS GEM upgrade activities @LNF

the past, the present and the future

The LNF CMS groups has been involved in the CMS GEM project since the very early stage with the responsibility of the R&D detector coordination and after with the production coordination for the GE1/1 and GE2/1 subsystems

- Frascati was a production site for GE1/1 project and assembled 20 (out of 144 of the total) chambers presently installed in CMS
- Frascati Is a production site for the GE2/1 chambers (15 chambers already assembled as July 2023 out of the 45 expected at the end of the whole production)
- Will be production site for the ME0 chambers (number of requested assembled chamber tbd)

The Frascati GEM assembly laboratory is equipped with clean room (class 100), gas leak test station (QC3) HV integrity test station (QC4) and an X-ray bunker for the gain uniformity test (QC5)

The LNF CMS Team participated in the assembly of the GE1/1 super-chambers (each super chamber is made of two GE1/1 chambers coupled) at CERN and to the implementation of the Gas system in assembly lab at CERN (Bldg 904). The team worked on the retrofitting of the cooling system of GE1/1 and has the responsibility of the installation of the FBG sensors (Fibers Bragg Grating) for the temperature monitor for the whole GEM CMS detector

The team helped in the assembly of 10 GE2/1 chambers and to the retrofitting of 5 GE2/1 at CERN

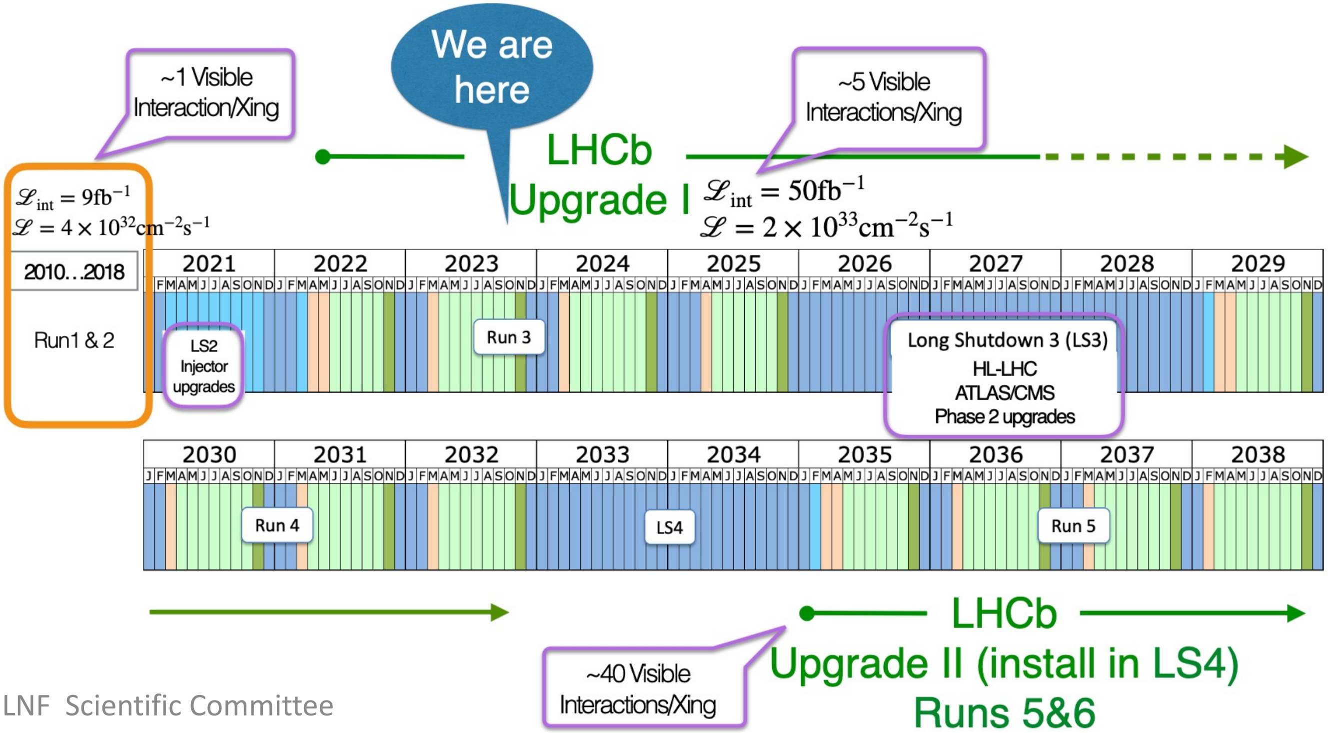
LHCb, a successful adventure so far

LHCb has lived up to its promises and more, delivering many world record and sometimes unexpected results (exotic spectroscopy, CPV in charm,...). For some topics LHCb has moved from exploration to precision measurements and it can still gain by increasing the sample sizes.

About 700 physics papers (most per author of any LHC experiment)
Breadth of physics program: Heavy ions, Electroweak, Fixed target (He, Ne, Ar,...)...

The detector has been upgraded in LS2 and many innovative technological ideas have been implemented.

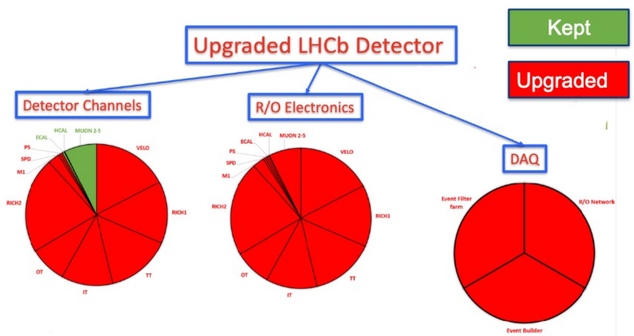
Upgrade 2 is part of CERN baseline plan: to be installed in LS4, with some detector installation and infrastructure work anticipated to LS3



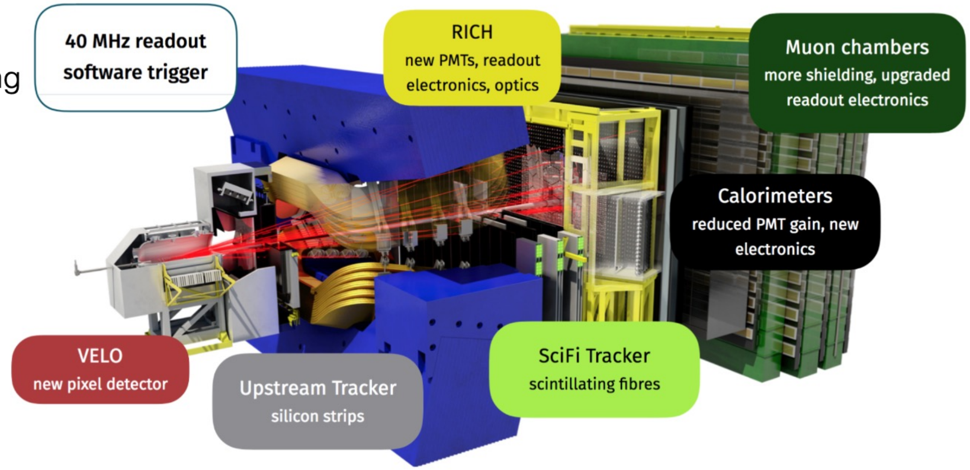
[LHCb - B. Sciascia]

LHCb at Run 3

- Full software trigger
- Raise $\mathscr{L}$ to $2\text{x}10^{33}\text{cm}^{-2}\text{s}^{-1}$(5x Run2) maintaining the current reconstruction performance
- Major redesign of all sub-detectors and ambitious readout upgrade



It's an all-together new detector!



New pixel-based **VELO**
New **RICH** mechanics, optics, photodetectors
New Silicon strip upstream tracker **UT**
New **SciFi** tracker
New electronics for **MUON** and **CALO**
New luminometer **PLUME**
New **SMOG2** system for fixed target physics

Remove the first-level hardware trigger reading out the detector at 40MHz, with a fully software trigger

Upgrade of electronics of the muon system under LNF responsability

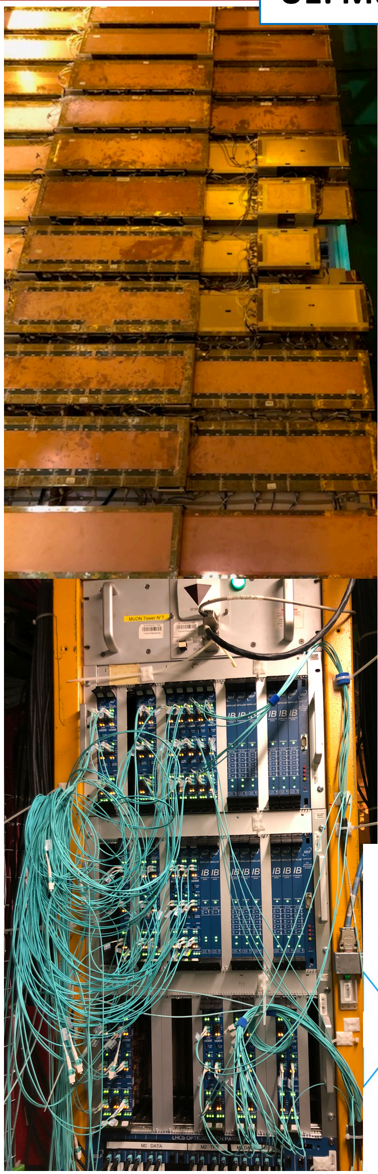
All detectors installed by 2022, but UT in 2023
Commissioning in full swing despite the limited data from LHC

LHC VELO vacuum control system incident
- Happened on Jan 2023, during a VELO warm-up in neon.
- No damage to the detector but the very thin RF foils separating the LHC and VELO vacua have to be replaced (started last Oct 30th)
- VELO could not be fully closed in 2023 data taking

[LHCb - B. Sciascia]

Frascati contributions

U1: Muon System



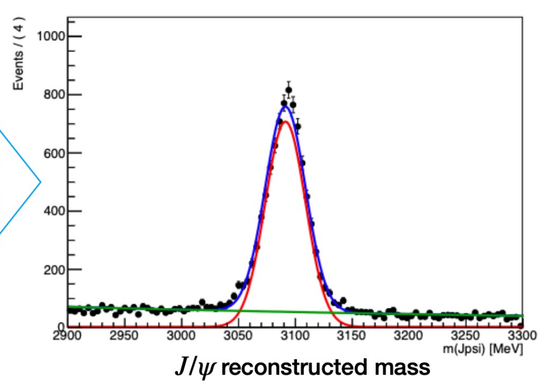
Main changes for the Run 3:

ront of the inner region of M2

- **redesign of the off-detector electronic to be compliant with the 40 MHz full software trigger: boards tested and fully operational (~100k channels)**

Operations in Run 3:

- the detector is time-aligned with LHC clock and a fix has been found for the DAQ stability affecting the GBT protocol.
- PID performance are still below Run 2 one due to the not perfect fine-time alignment; it needs the reconstruction of special (TAE) data in preparation for early 2024



LHCb has shown its capability as a Fixed Target experiment

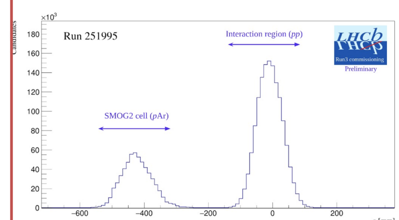
U1: SMOG2 System

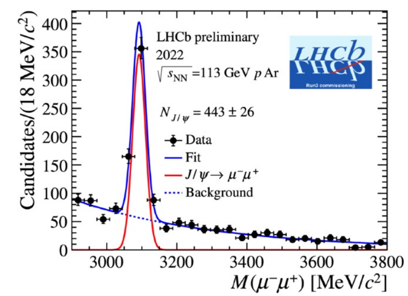
New gas injection system, upstream of the VELO possibility of injection of many species (H2, He, Ne, Ar,…) , and study pN and PbN collisions

System operated smoothly throughout the 2023 LHC Ion Run

Beam-gas and beam-beam data taking simultaneously

Primary vertex location well separated!

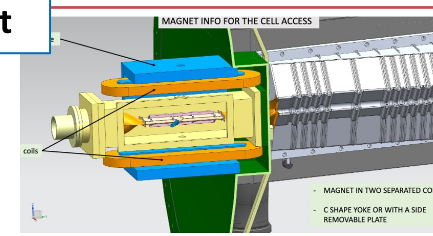




Plot from few minutes of data taking

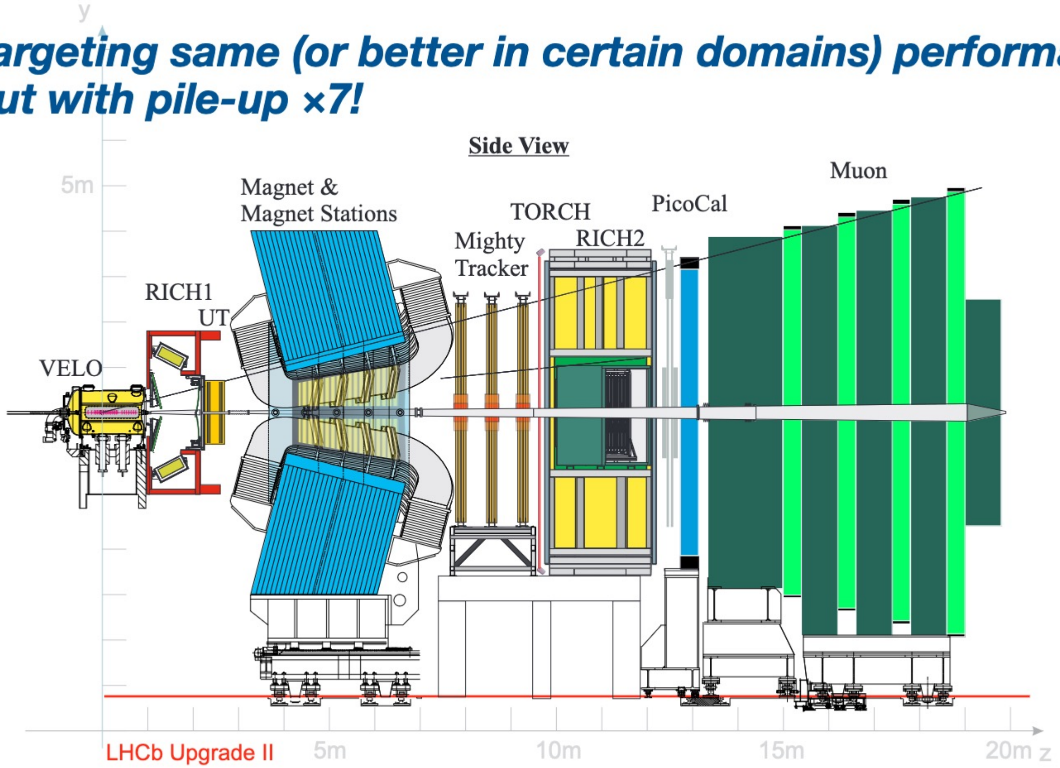
U2: Polarised target

Bring the polarised target physics at the LHC.



LHCb towards future Upgrades: Run 5

Targeting same (or better in certain domains) performance as in Run 3, but with pile-up ×7!



Same spectrometer footprint, innovative technology for detector and data processing

Key ingredients:

- *granularity*
- *fast timing (few tens of ps)*
- *radiation hardness (up to few $10^{16} n_{eq}/cm^2$)*

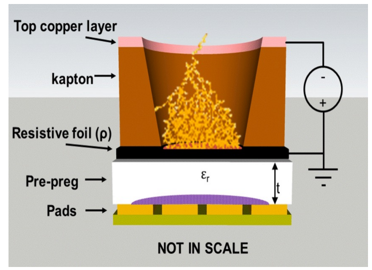
LNF deeply involved in the Upgrade of the Muon system developing new micro pattern gas detectors with high rate capability (µ-RWELL)
rates up to 1 MHz/cm^2 in some region

[LHCb - B. Sciascia]

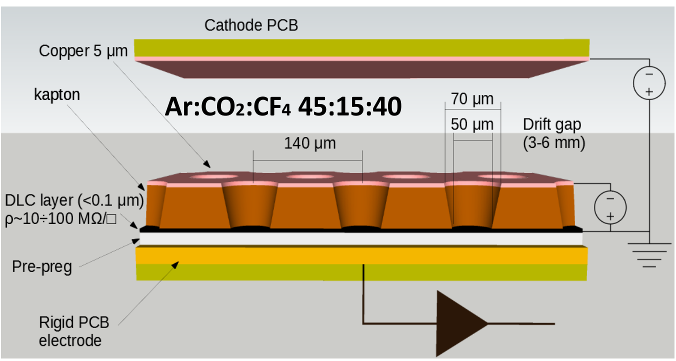
The µ-RWELL for the LHCb-Muon upgrade

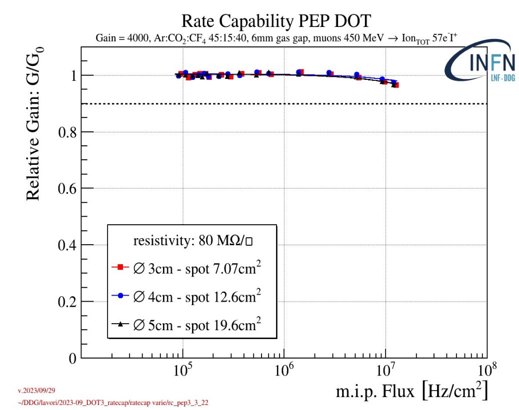
G. Bencivenni, E. De Lucia, G. Felici, M. Gatta, M. Giovannetti, G. Morello, G. Papalino, M. Poli Lener

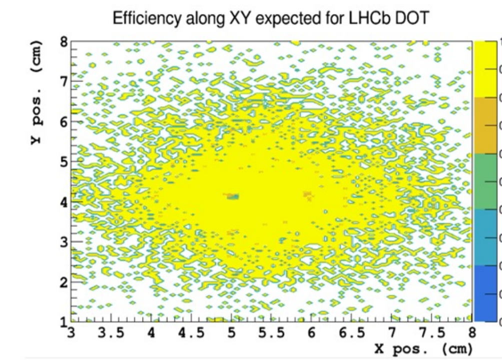
The µ-RWELL is a Micro Pattern Gaseous Detector (MPGD) composed of only two elements: the µ-RWELL_PCB and the cathode. **The core is the µ-RWELL_PCB.**

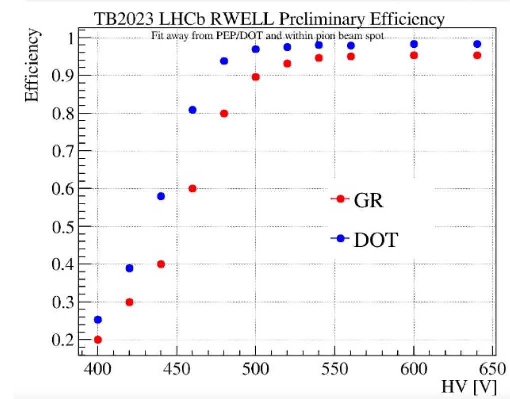


Applying a suitable voltage between the **top Cu-layer and the DLC** the WELL acts as a **multiplication channel for the ionization** produced in the conversion/drift gas gap.









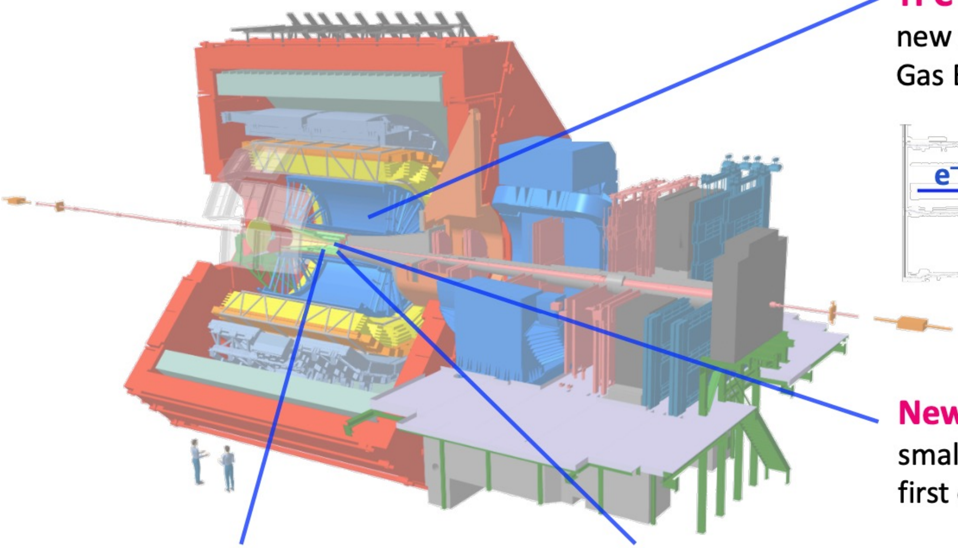
High-rate version tested with high intensity **X-ray** and **particle beams** (NA-H8 SpS CERN, PSI). Detectors **co-produced by ELTOS-CERN** under supervision DDG-LNF (**TT supported by AIDAInnova**)

Production cycle (~22 m²) :

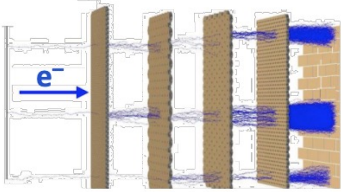
- Layout design: LNF
- DLC foil production: CERN (DLC Magnetron Sputtering machine co-funded by INFN)
- PCB production: ELTOS
- Final manufactoring: CERN

ALICE detector **in Run 3**

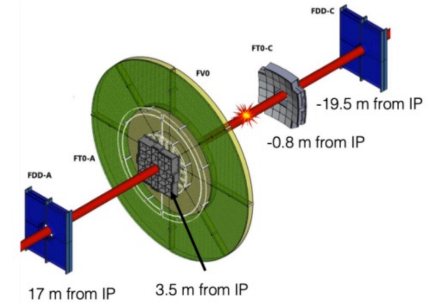
ALICE upgrades during LS2
arXiv:2302.01238



TPC
new readout chambers with
Gas Electron Multipliers (**GEM**s)

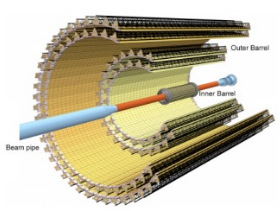


New Fast Integration Trigger (FIT)
interaction trigger, online luminometer,
forward multiplicity

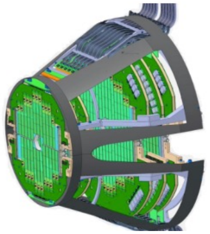


New beampipe
smaller diameter (36.4 mm),
first detection layer at 20 mm

New Inner Tracking System (ITS2)
7 layers, 10 m^2 silicon tracker
based on MAPS (12 G pixels)

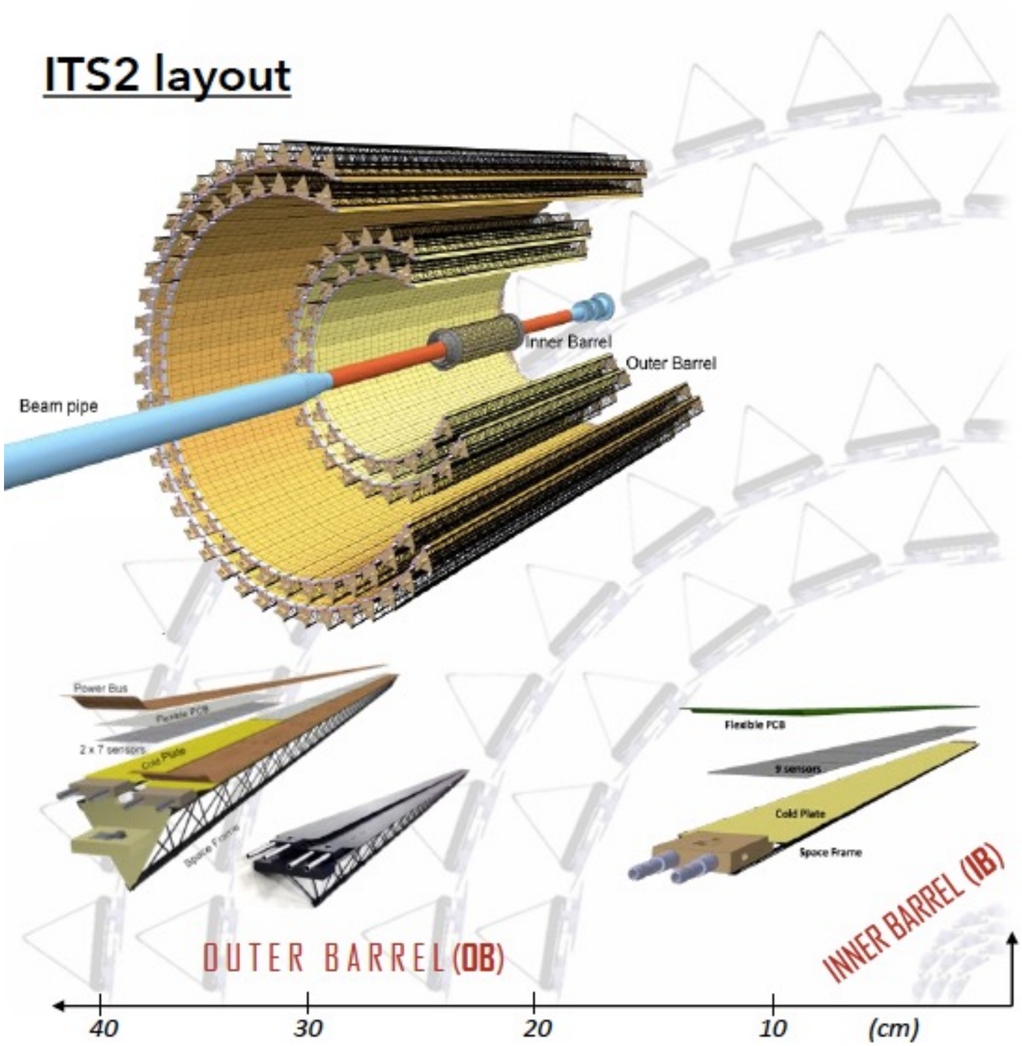


New Muon Forward Tracker (MFT)
5 planes of MAPS
forward vertexing for muons



- operation at much **higher interaction rate**
- improved **vertexing** (central and forward) and tracking **resolution at low p_T**

ITS2 layout



12.5 Gigapixel
10 m² active area

ALICE

7 cylindrical layers of monolithic CMOS pixel sensors

24k ALPIDE chips (1024 x 512 pixels) → 12.5 Gpix

Inner Barrel (3 layers)

- 48 staves made of 9 ALPIDE chips each
- Length: 27 cm
- Material budget: 0.36 X_0 per layer
- Readout at 1200 Mb/s per chip

Outer Barrel (2+2 layers) **=> LNF contribution**

- 54 + 90 staves made of up to 196 chips each
- Length: from ~85 to ~150 cm
- Material budget: ~1.10 X_0 per layer
- Readout at 400 Mb/s per link grouping 7 chips

ITS2 design objectives

Improved impact parameter resolution compared with Run 1+2 (ITS1)

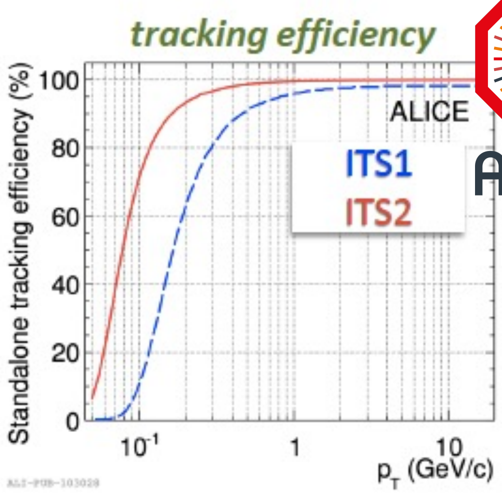
- ❑ Closer to the interaction vertex *39 mm → 22 mm*
- ❑ Reduced material budget *~1.14 X_0 → ~0.36 X_0 (per innermost layer)*
- ❑ Reduced pixel size *50x425 μm² → ~ 30x30 μm²*

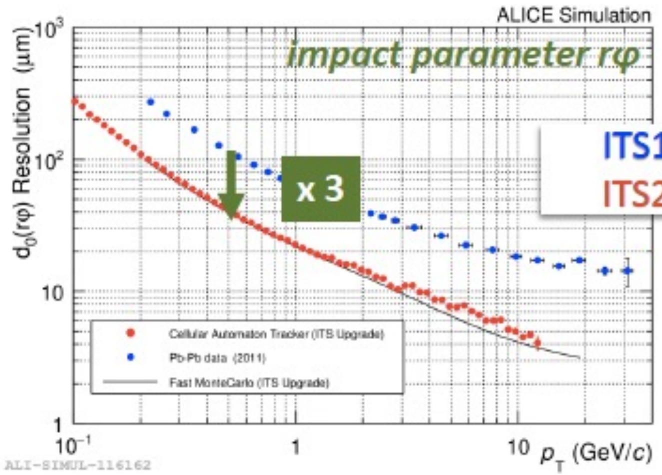
Improved tracking efficiency and p_T resolution at low p_T

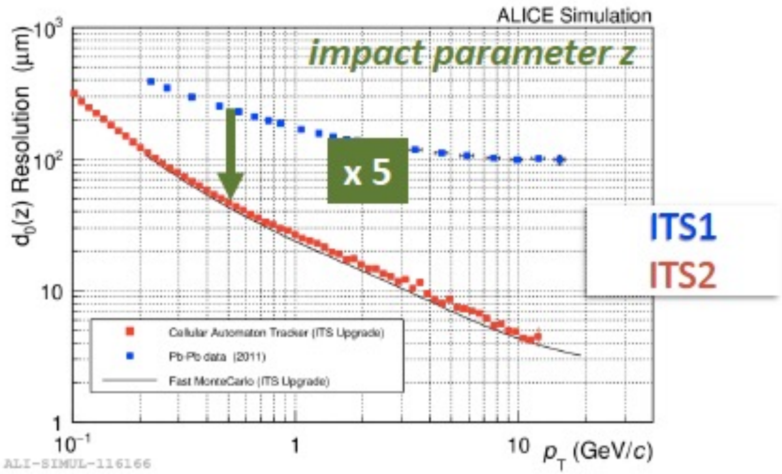
- ❑ Higher granularity *6 layers → 7 pixel layers*

Fast readout, continuous mode

Pb-Pb read out at up to 100 kHz (previously 1 kHz); pp up to 400 kHz







ITS2@LNF: SENSOR CHARACTERIZATION AT BTF

ALICE

LABORATORI NAZIONALI DI FRASCATI
SIDS-Pubblicazioni

INFN-17-16/LNF
May 6, 2017

BEAM TEST OF ALPIDE SENSOR

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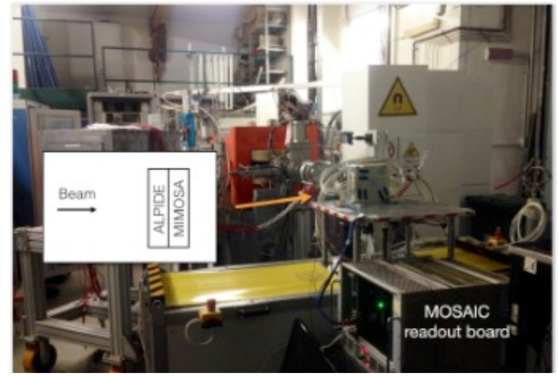
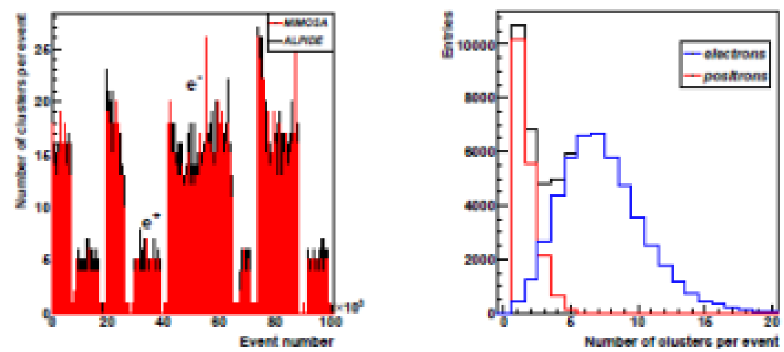
[3] *Instituto de Física da Universidade de São Paulo, 05508-090 São Paulo, Brazil*

Abstract





(a) (b)

Figure 5: (a): Distributions of the number of clusters per event versus the event number for both the sensors. (b): Distribution of the number of clusters per event for ALPIDE.

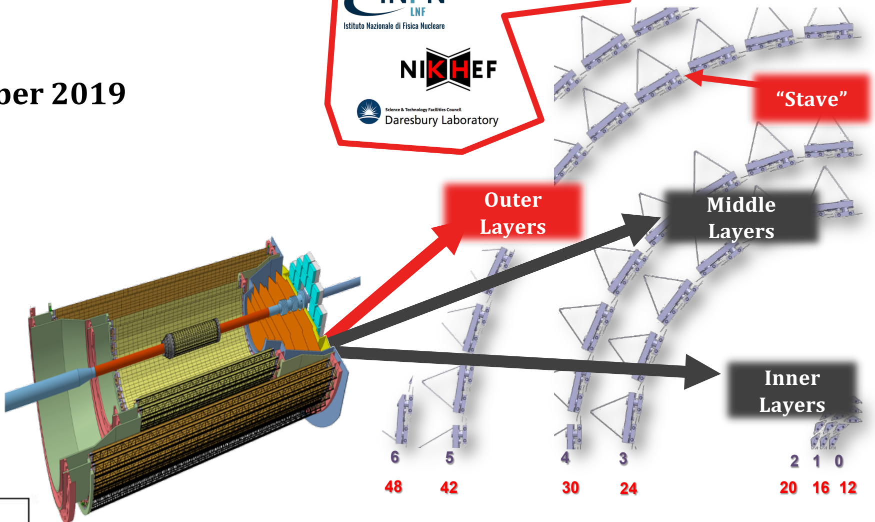
ITS2@LNF: OUTER LAYERS STAVE PRODUCTION

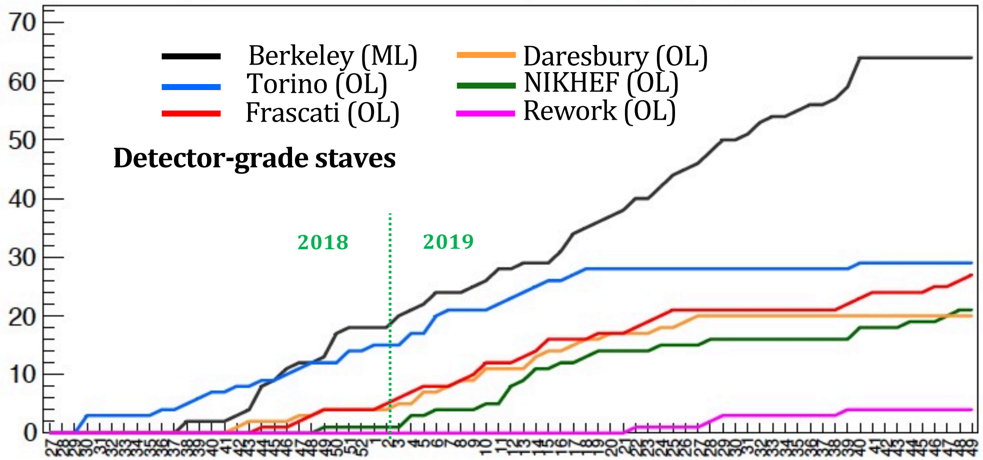
ALICE

Full production at LNF started in Feb 2018 and ended in September 2019 with the construction and assembly of 27 staves
Spare production + rework till December 2019

The LNF group contributed to the development and debug of the procedures:

- Debug of the readout system
- Development of wire bond repairs using conductive glues
- Development of mechanical procedures and tooling to rework finished staves



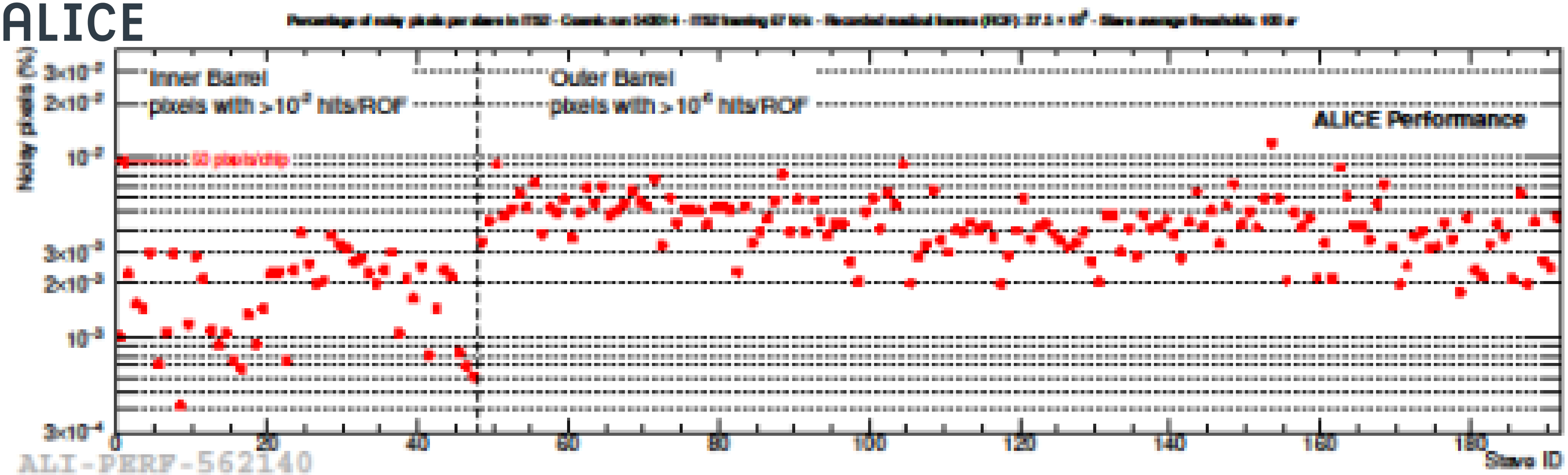


OL Staves Total: 101
OL completed in September
Spares followed in December

- **LNF only available site for spare production & reworking, with dedicated tools developed at LNF**
- **LNF site for ITS2 sensor characterization**

Internal Note INFN-17-16/LNF for ALPIDE sensors
https://www.lnf.infn.it/sis/preprint/getfilepdf.php?filename=INFN-17-16-LNF.pdf

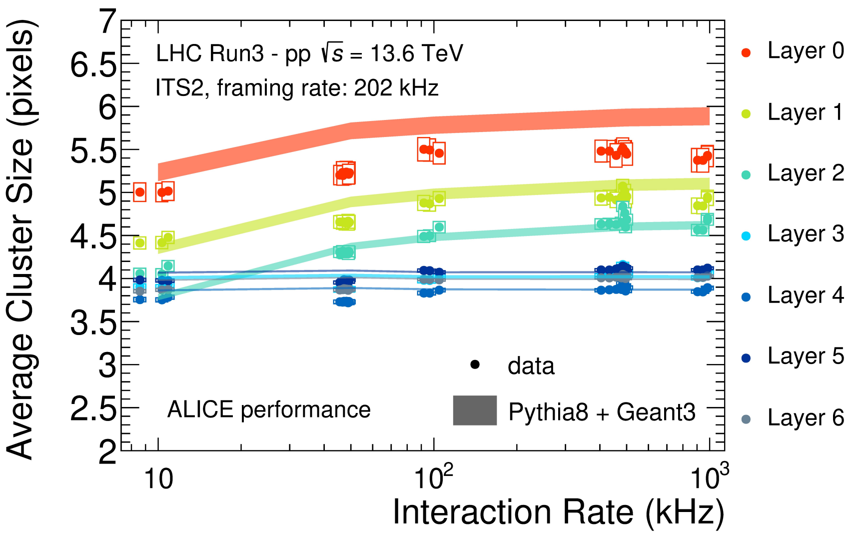
Performance Results in Run3

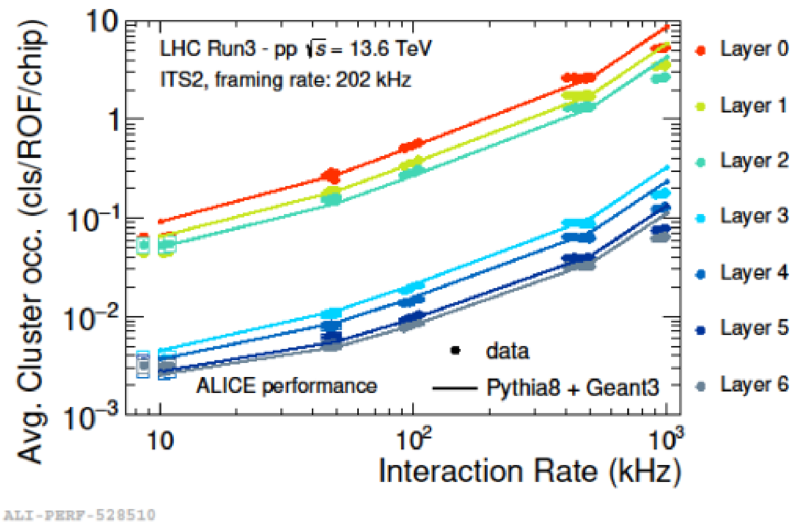


Percentage of noisy pixels for each stave of ITS2.
The vertical dashed line separate the Inner Barre staves from the Outer Barrel ones.
The red arrow indicates the percentage corresponding to 50 noisy pixels per chip =>
=> The measured percentage is much less than this, hence very small
=> Percentage of noisy pixels masked per stave is extremely small: 2-5 x 10^{-5}

Preliminary Performance Results in Run3

Cluster size and cluster occupancy vs interaction rate in p-p



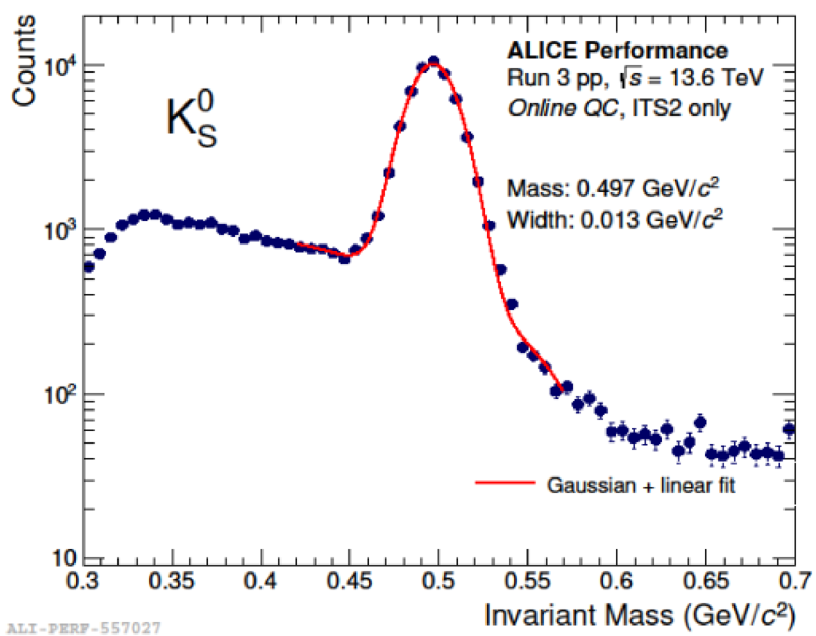


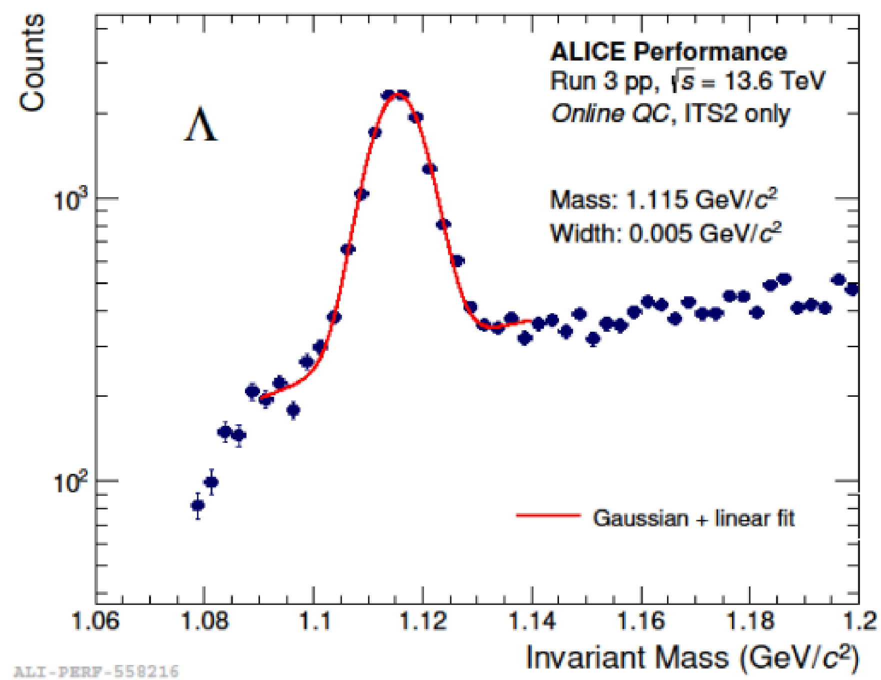
- Between 3 and 8 pixels depending on η
- Observed to be stable over time
- Independent of the interaction rate

- Between 0.1 and 10 clusters per readout frame (ROF) and per chip
- Observed to be stable over time
- Dependent of the interaction rate

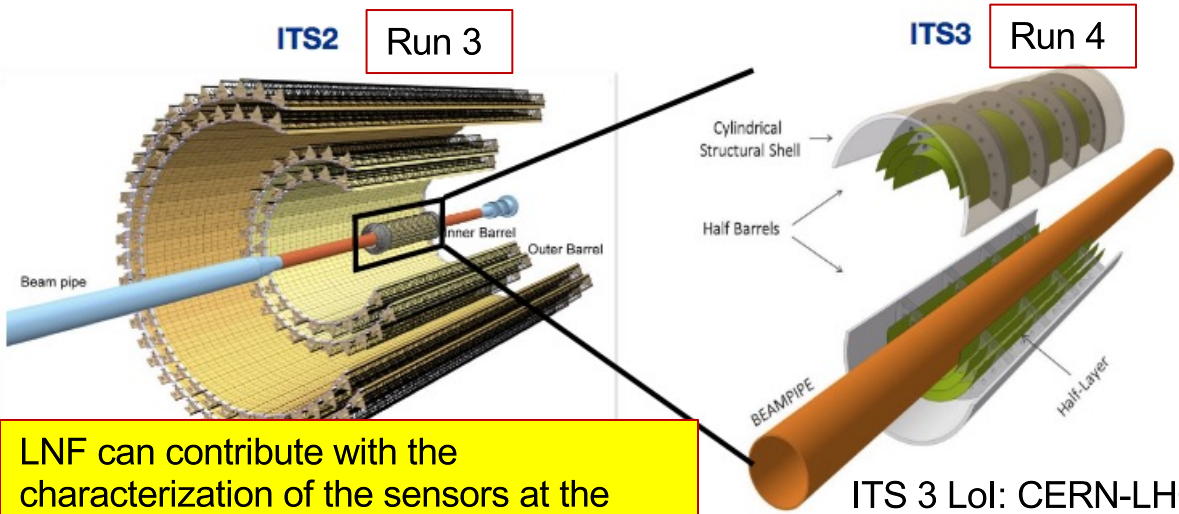
Preliminary Performance Results in Run3

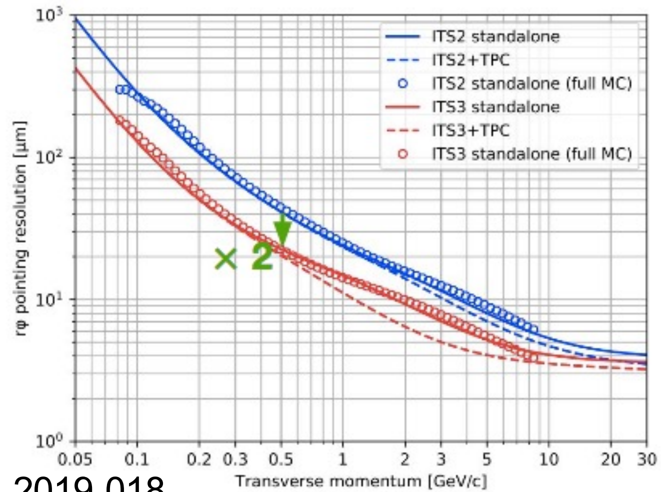
Excellent tracking performance:
Online QC from ITS2 standalone tracks





ITS3: a new inner barrel for the ITS2





LNF can contribute with the characterization of the sensors at the BTF (as previously done for ITS2)

ITS 3 LoI: CERN-LHC-2019-018

https://cds.cern.ch/record/2703140 TDR endorsed by Q1 2024

- Main goals: improve vertexing performance and reduce backgrounds for heavy-flavour signals (largest impact on charm baryons and D_s) and for low-mass dielectrons
- Detection layers closer to the interaction point, reduced beam pipe diameter, reduce material thickness (no supporting and cooling materials)

ALICE 3 concept

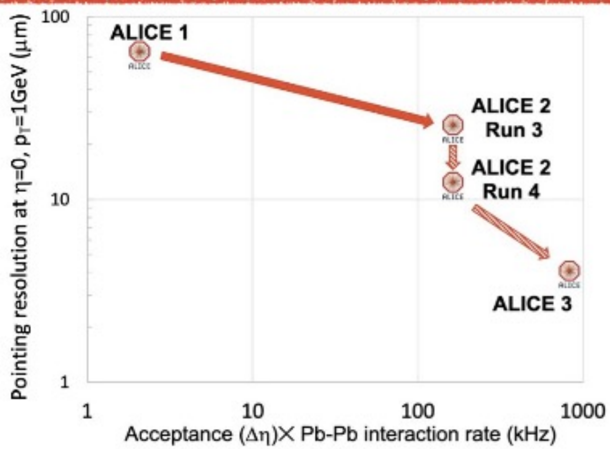
Run 5

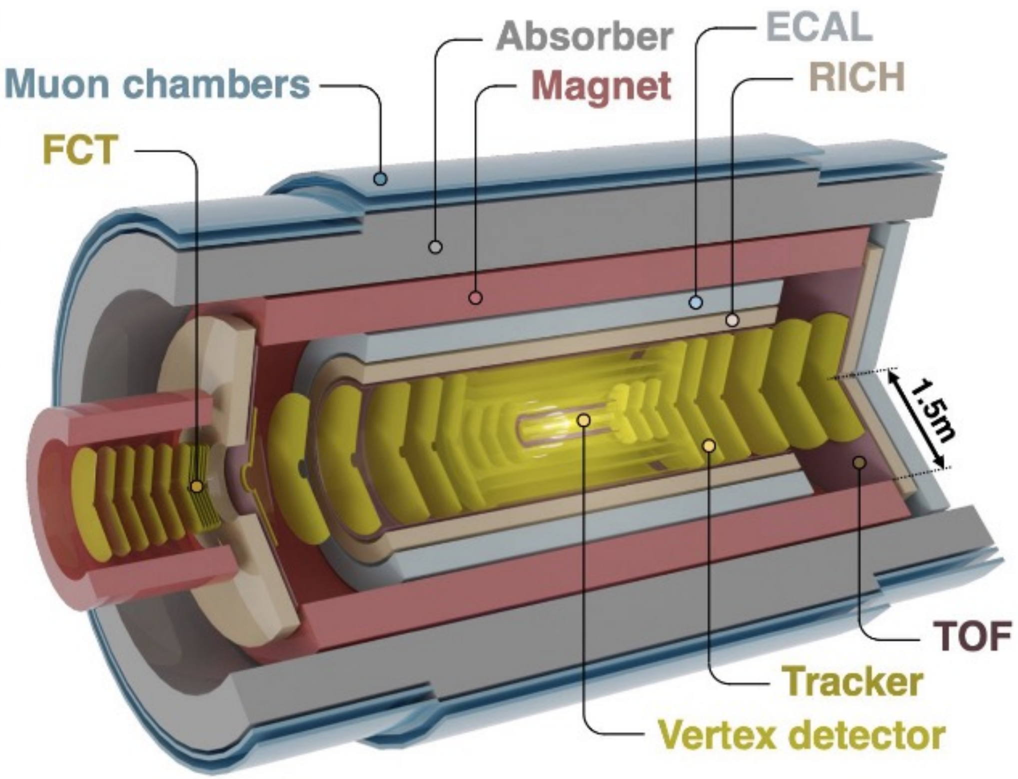
=> ITS 3

ALICE 3 LoI: CERN-LHC-2022-009
https://cds.cern.ch/record/2803563

➡ **Novel and innovative detector concept**

- Compact and lightweight all-silicon tracker
- Retractable vertex detector
- Extensive particle identification
- Large acceptance
- Superconducting magnet system
- Continuous read-out and online processing





CONCLUSION

We are approcching the HL-LHC era , this will represent a great challenge for the LHC experiments, they will have to cope with unprecedent track densities, from the high instantaneous luminosity, and with extremely high radiation levels.

Major upgrade has been done and will continue in the next shutdowns

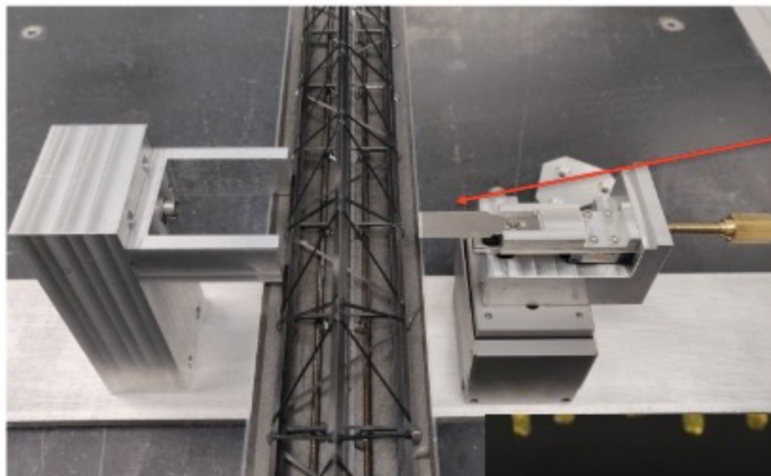
Frascati has a leading role on most of that upgrade work thanks to the robusteness of the research groups, to the high level technical competence on detectors R&D and construction and the presence of hight quality infrastucture

ITS2@ LNF : SPARE PRODUCTION and REWORK

OB STAVE PRODUCTION ISSUES - HARD REWORK

ALICE ITS Upgrade

REWORK JIG



INFN TO + LNF
Tool for the U-legs cutting
CMM programs devoted to the rework

Analysis of the Staves during LS
Rework to be done directly at CERN
LNF CMM available in case of need

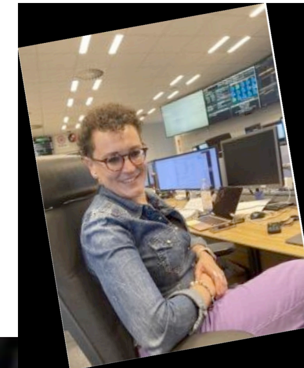
INFN TO + LNF
Mechanical bases specially machined

05/07/19 S.Beolè - INFN Referee Meeting TORINO/LNF 30

Run3 Overview

- Started on 2022, July 5th with first pp collisions at $\sqrt{s}$ = 13.6 TeV (*stable beams*)
- Integrated luminosity so far (pp collisions): ~28 pb^{-1}
- Integrated luminosity Oct/2023 Pb-Pb: ~2 nb^{-1}
- ITS fully operational modulo 0.4% of pixels
- ALICE & ITS2 numbers in data taking
  - Nominal ITS framing rate: 202 kHz (pp) – 67 kHz (Pb-Pb)
  - ALICE standard luminosity: 500 kHz (pp) – 47 kHz (Pb-Pb)
    → Instantaneous luminosity: ~10^{31} (pp) – 10^{27} (Pb-Pb) cm^{-2}s^{-1}
  - ITS2 successfully tested up to 4 MHz interaction rate in pp (~ 50 GB/s data rate).
  - Loss of acceptance during runs auto-recovered by DCS
  - Very sporadic data corruption events not affecting overall performance
- At every beam dump: fast ITS threshold scan on 2% of the pixels to evaluate the quality of the detector calibration

LNF run manager@Pb-Pb



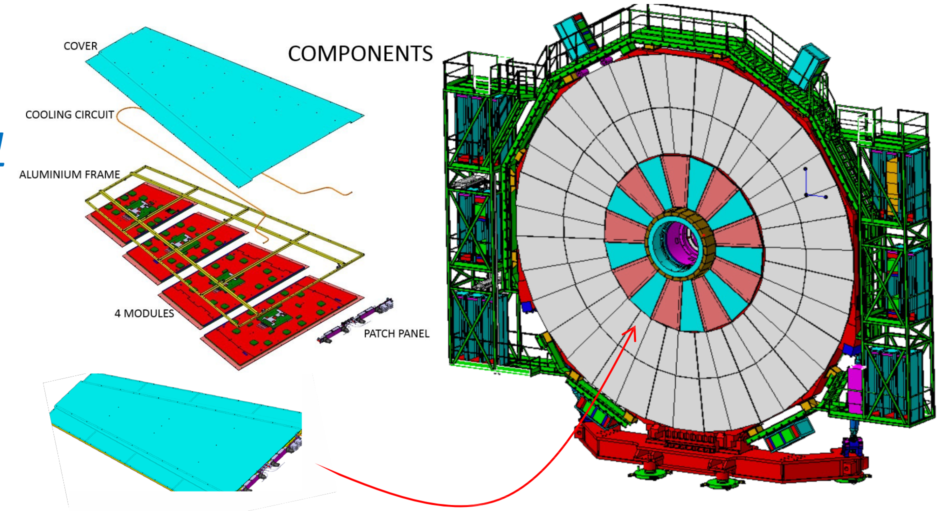
Alice Newsletter 277 (6/10/2023)
https://twiki.cern.ch/twiki/bin/view/ALICE/AliceNewsletter6Oct2023

The GE2/1 project

System overview – lessons learnt from GE1/1

GE21 Detector System

- 72 chambers arranged in 2 layers (Front & Back chamber)
  - 4 triple GEM modules per chamber *(8 different modules for overlap)*
  - 20° chambers (small overlap) – Large area 185 x 115 cm $1.6 < \eta < 2.4$
  - Button spacer in large modules to prevent "ballooning"
- Same solution as for GE1/1 (3/1/2/1 mm gaps – Ar:CO2 70:30)
- FE: wire-bonded hybrids with glob-top -> packaged VFAT3 chip
- Plugin-card with VFAT3 chip and flex to HRS 140 connector
- Improved grounding in Readout board and Electronic board
- Each detector module has own Opto-Hybrid with GBT chip
- *50% GEM Foils produced by Mecaro (Korea) – 50% CERN MPT Workshop*



- **GE2/1 currently under construction**
  - Installation Negative Endcap in EYETS 23-24
  - Installation Positive Endcap in EYETS 24-25
  - Currently 51 modules produced (144 needed / Endcap)

See Poster Balashangar Kailasapathy