A Large Ion Collider Experiment

ALICE

Future measurements from ALICE Run 3 and Run 4

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Outline

- Introduction
- ALICE LS2 upgrade
- Preparations for Run 3
- Physics for Run 3 and Run 4
- Future upgrade in LS3
- Summary and Outlook

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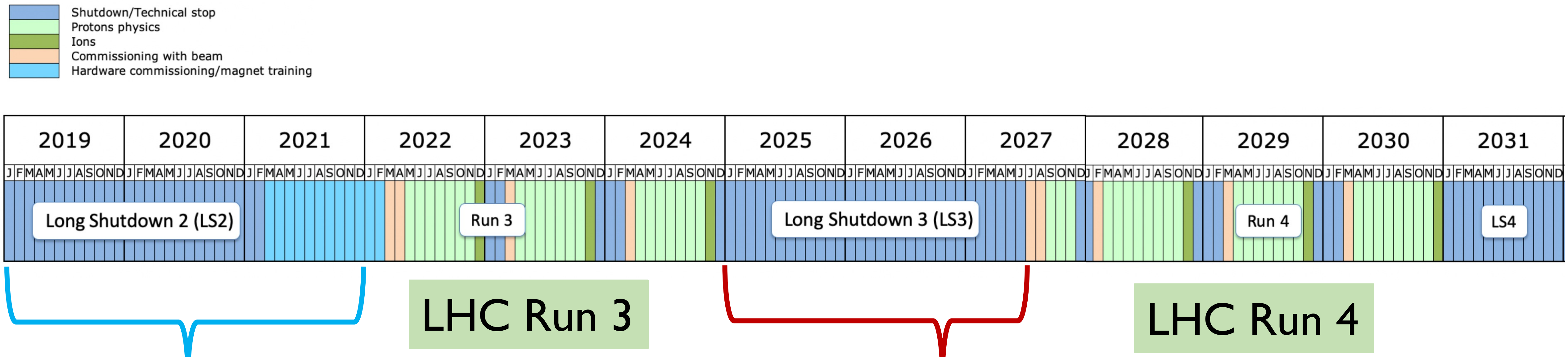
LHC Schedule and ALICE Plans



ALICE LS2 upgrade

- New silicon tracker (ITS2 & MFT)
- TPC Readout planes using GEM
- New Fast Interaction Trigger (FIT)
- New Online/Offline system (O2)
- Upgrade readout of all other detectors

Global Commissioning (July – Nov)

LHC pilot beam tests (18.10 – 31.10)

ALICE LS3 upgrade

- New silicon tracker (ITS3)
- Forward Calorimeter (FoCAL)

ALICE Run3 + Run4

- **13 nb^{-1} (0.5T, 0.2T) Pb-Pb collisions**
- Heavy flavor meson and baryon measurements down to very low p_T
- Thermal direct radiation via dielectrons
- Quarkonia
- Light nuceli, hyper-nuclei, dibayons
- Forward direct photons

ALICE upgrade performace:
CERN-LPCC-2018-07 arXiv:1812.06772 & ALICE-PUBLIC-2019-001

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ALICE LS2 Upgrade

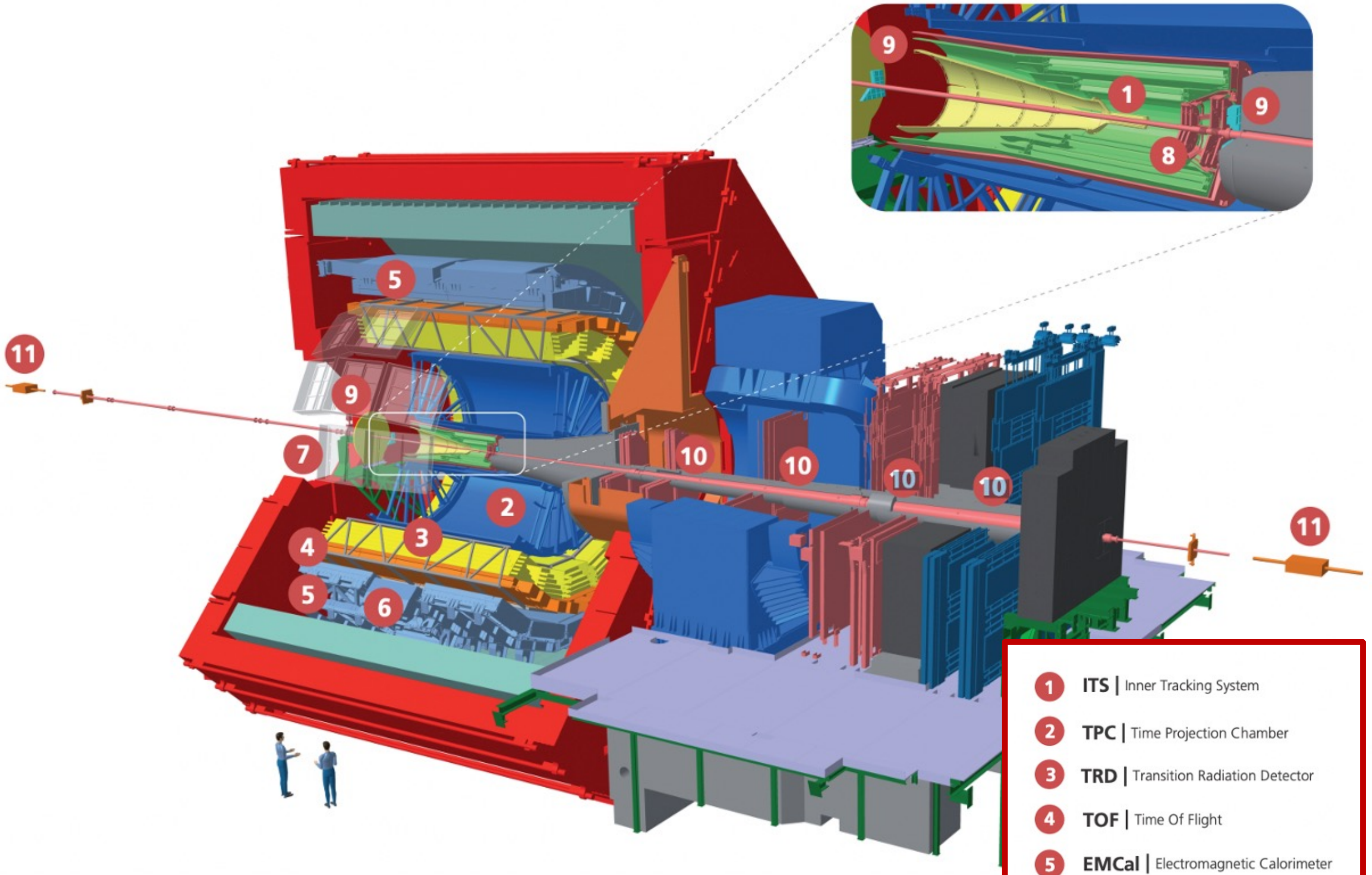
Runs 1 and 2: 1 nb^{-1} of Pb-Pb collisions
- Interaction rate ~8 kHz
- readout rate ≈ 1 kHz

ALICE LS2 Upgrade

- New silicon tracker (ITS & MFT)
- TPC Readout planes using GEM
- New Fast Interaction Trigger (FIT)
- New Online/Offline system (O2)
- Upgrade readout of all other detectors

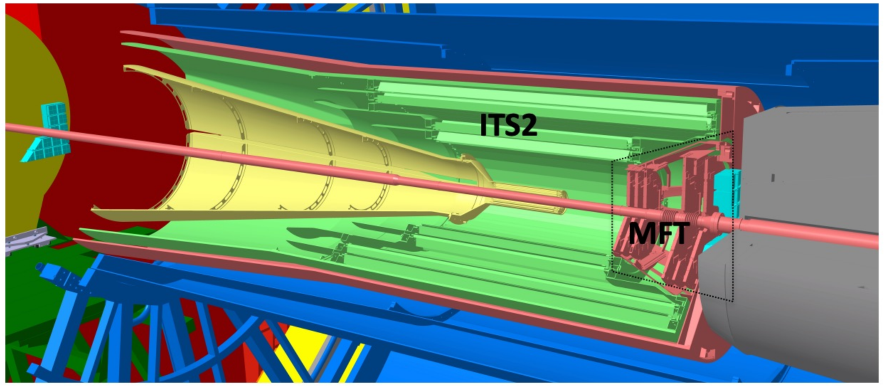
- Continuous readout and online reconstruction

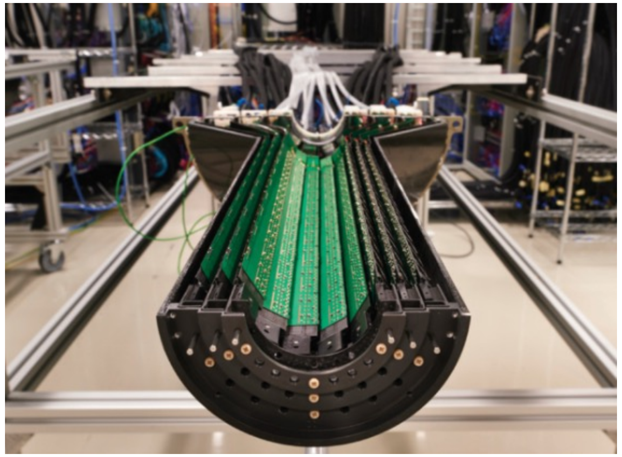
→ Inspect all MB Pb-Pb collisions at 50 kHz
- **x50 statistics increase for many observables**
- Improve tracking performance down to low p_T

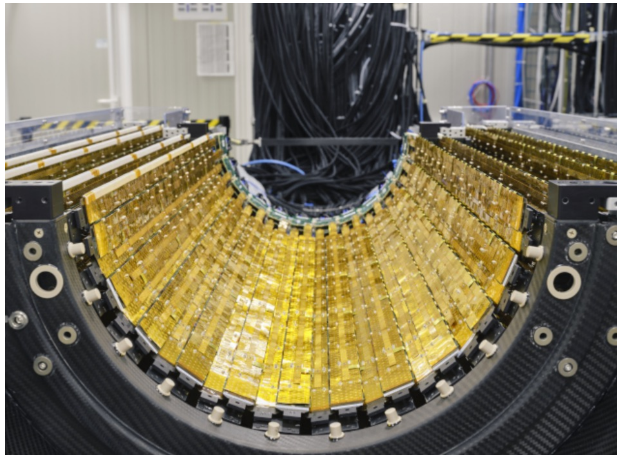


ALICE strategy for Run 3 + Run 4:
- **50 kHz Pb-Pb interaction rate**
- **Collect $L_{Pb\text{-}Pb}$ = 13 nb^{-1}**

ITS and MFT upgrade







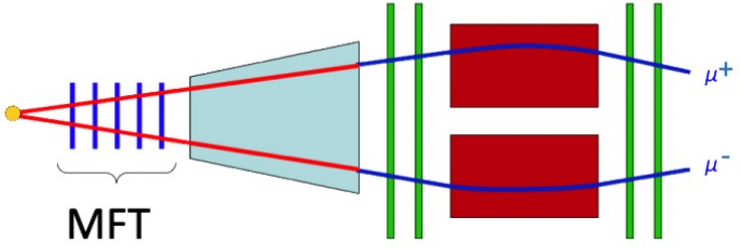
Inner Tracking System upgrade (ITS2)

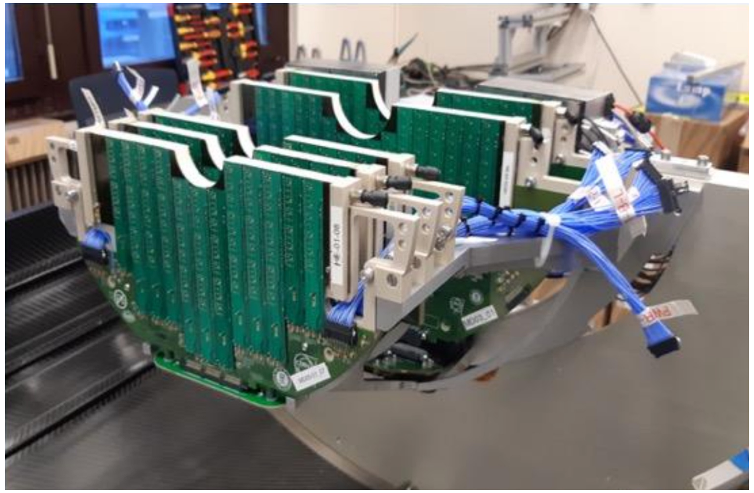
- 7 layers of Si pixel detectors
- Closer to the IP: first layer at ≈22 mm

Improved tracking efficiency at low p_T , improved pointing resolution (x3)

Muon Forward Tracker (MFT)

- New forward vertex detector upstream muon absorber
- 5 layers of Si pixel disks





ALPIDE (ALICE Pixel Detector)

- Thinner: for innermost layers ~0.30% X_0
- Smaller pixels: 27 × 29 μm^2
- Readout rate: 100 kHz
- 130 000 pixels/cm^2
- Max. particle rate: ~100 MHz/cm^2
- Spatial resolution: ~5 μm
- Thickness: 50 μm for the inner layers
- Fake-hit rate: < 10^{-9} per pixel per event

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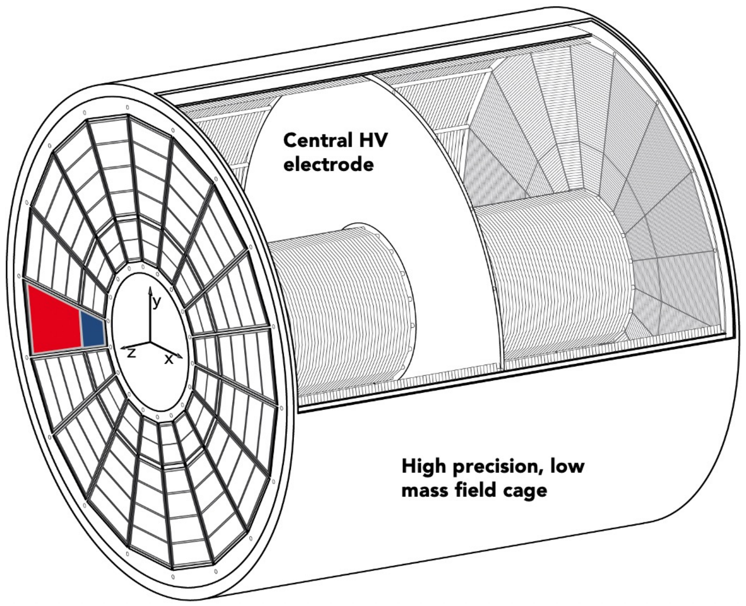
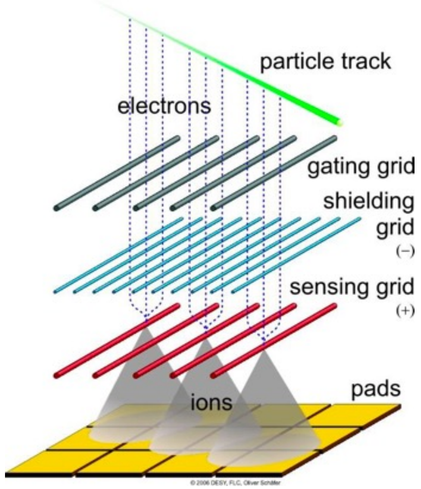
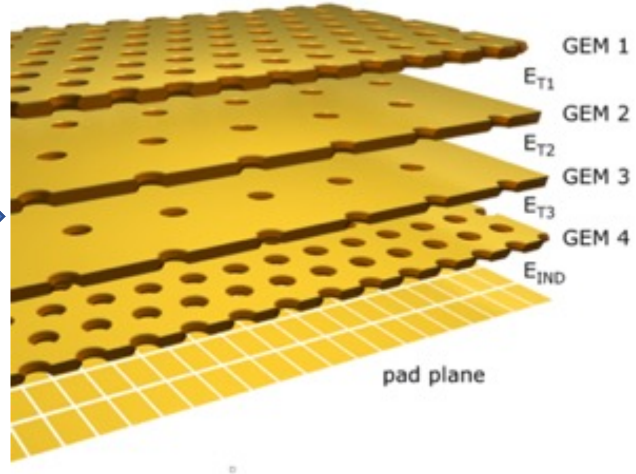
TPC upgrade

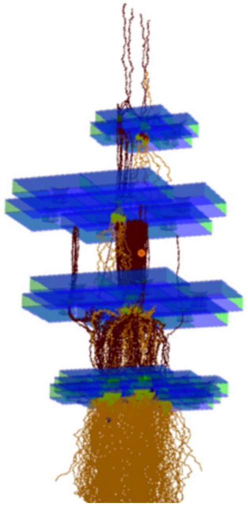


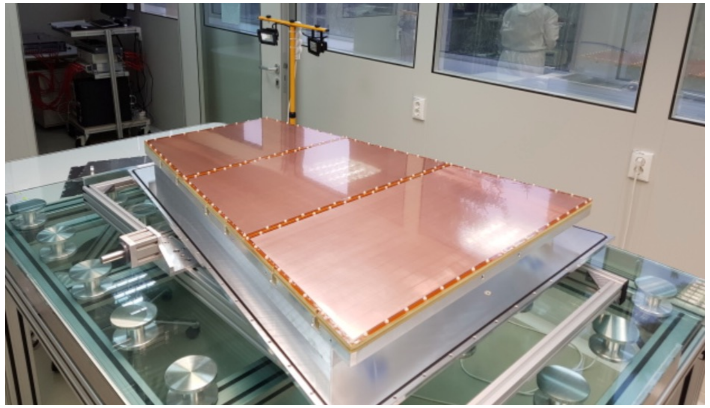
- Diameter: 5 m, length: 5 m
- Gas: Ne-CO_2-N_2, Ar-CO_2
- Max. drift time: ~100 μs
- 18 sectors on each side
- Inner and outer read out chambers: IROC, OROC
- Previous detector (Run 1, Run 2):
  - 72 MWPCs, ~550 000 readout pads
  - Wire gating grid (GG) to minimize Ion Back-Flow (IBF)
  - Rate limitation: few kHz

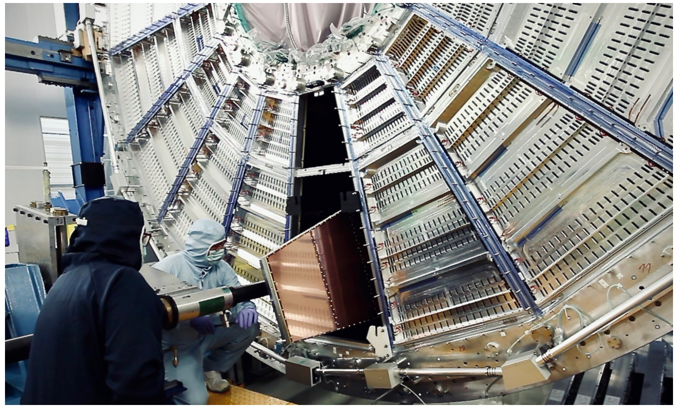
Operate TPC at 50 kHz Pb-Pb collisions
→ no gating grid (GG). ALICE maximum GG operation ~ 3 kHz
→ 4 GEMs to achieve good IBF and continuous readout











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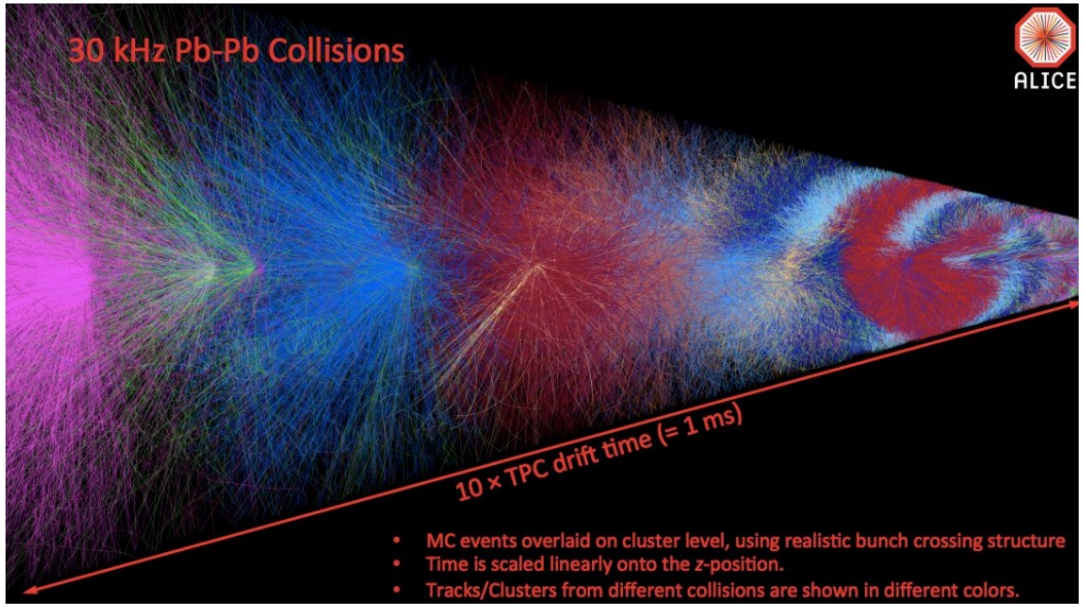
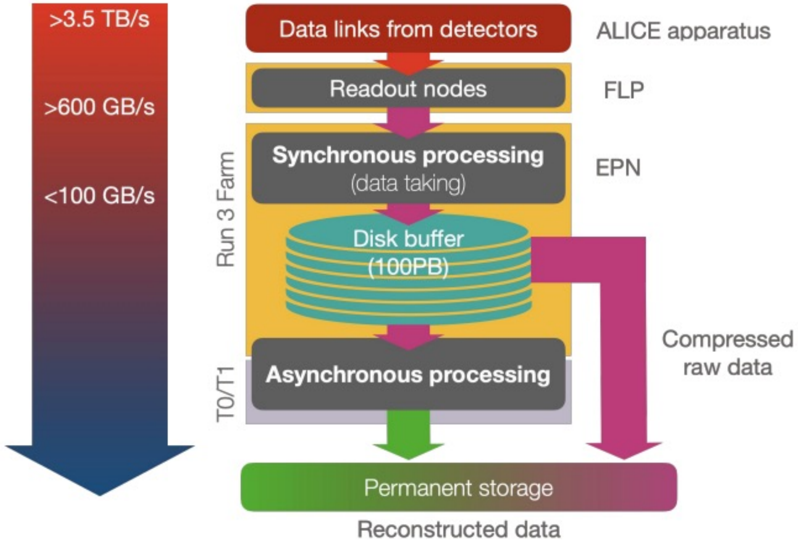
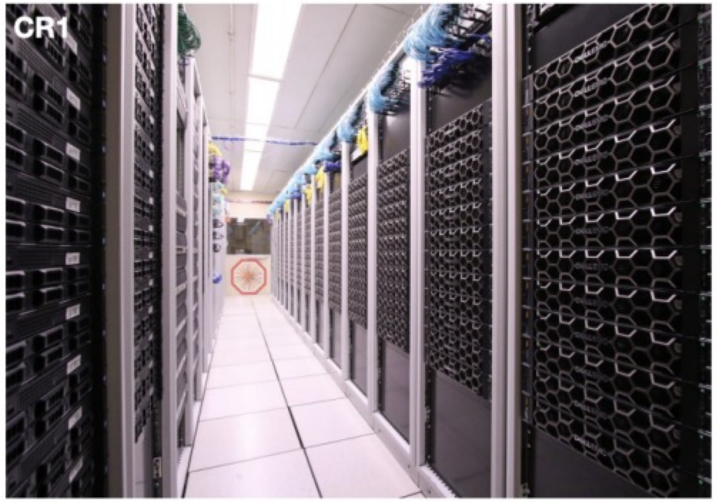
Online – Offline (O2)

Continous readout





200 First Level Processors (FLP) in CR1



Readout of detectors and raw data processing (ex, TPC baseline corrections)

Data compression
3.5 TB/s → 600 GB/s

250 Event Processing Nodes (EPN) with 2000 GPUs

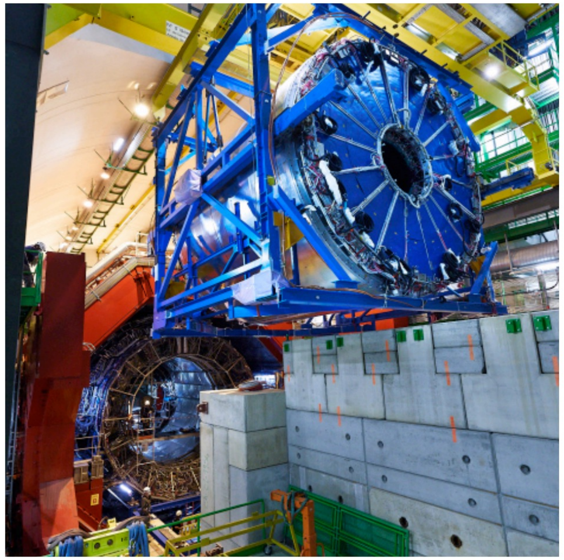
Synchronous processing

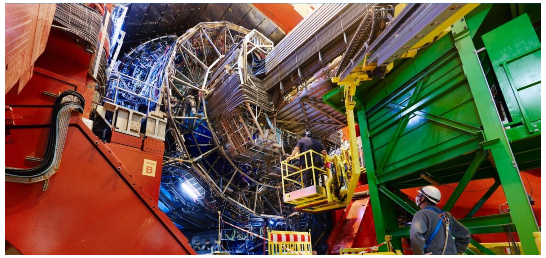
- Event/time frame building
- Online reconstruction and calibration (GPU)

Asynchronous reprocessing

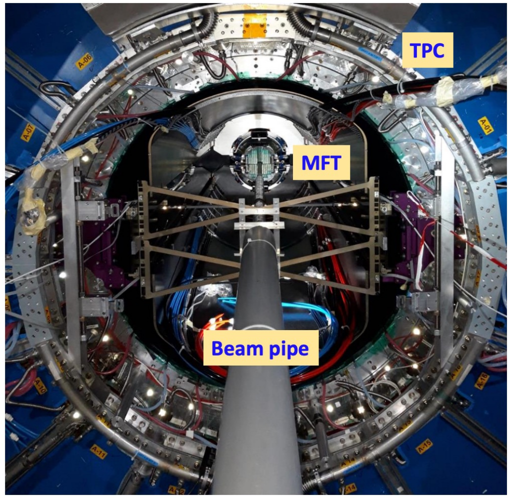
- Final calibration and full reconstruction

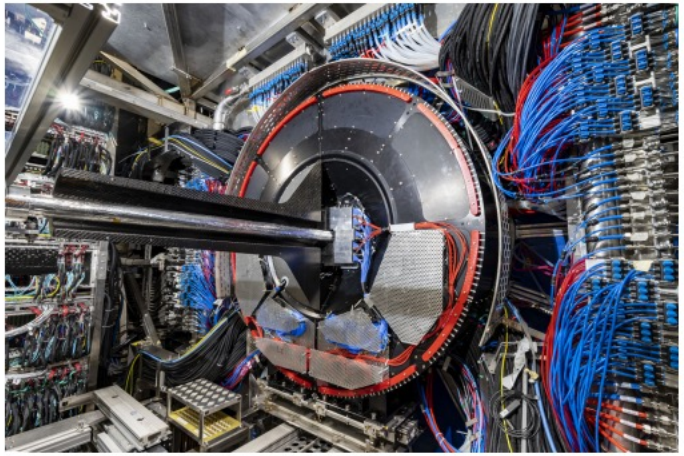
Installation





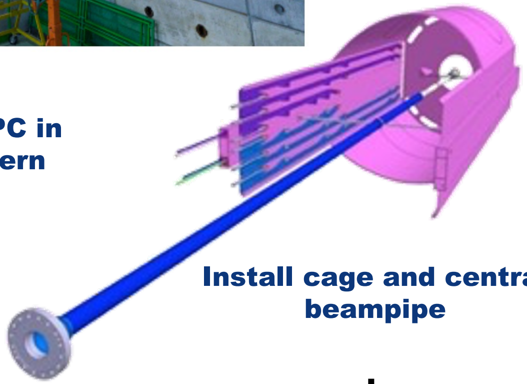
Reinstall Miniframe

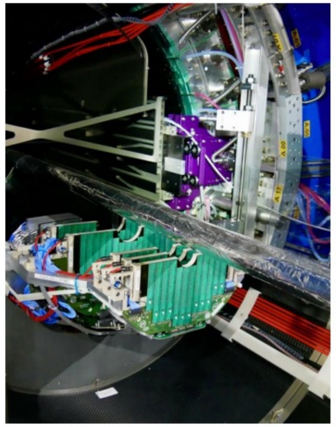


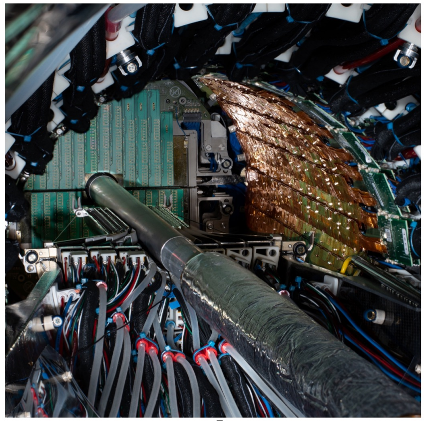


Install MFT and FIT-C

Install FIT-A







Reinstall TPC in ALICE Cavern

Global commissioning

Install cage and central beampipe

LS2 ends

- Jul-Aug '20
- Aug-Sep '20
- Oct-Nov
- Dec-Jan'21
- Feb-June
- July
- Feb? 22

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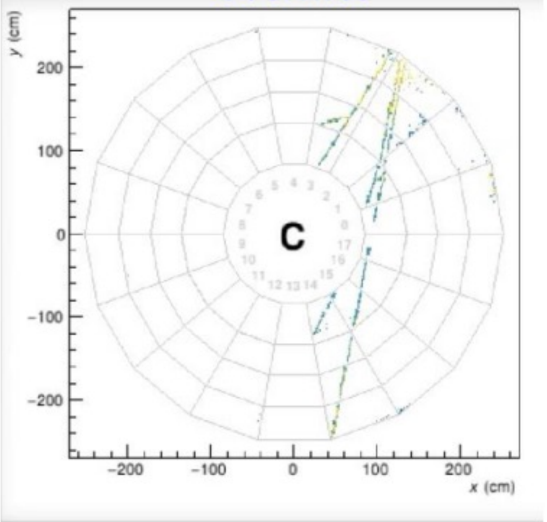
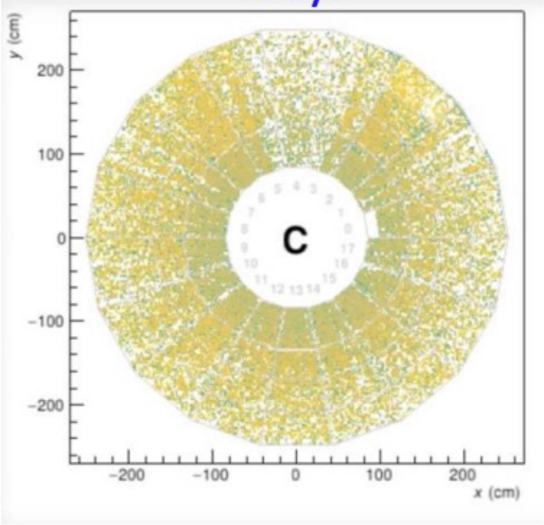
Global Commissioning

TPC: Continuous readout with cosmics, x-rays, and laser

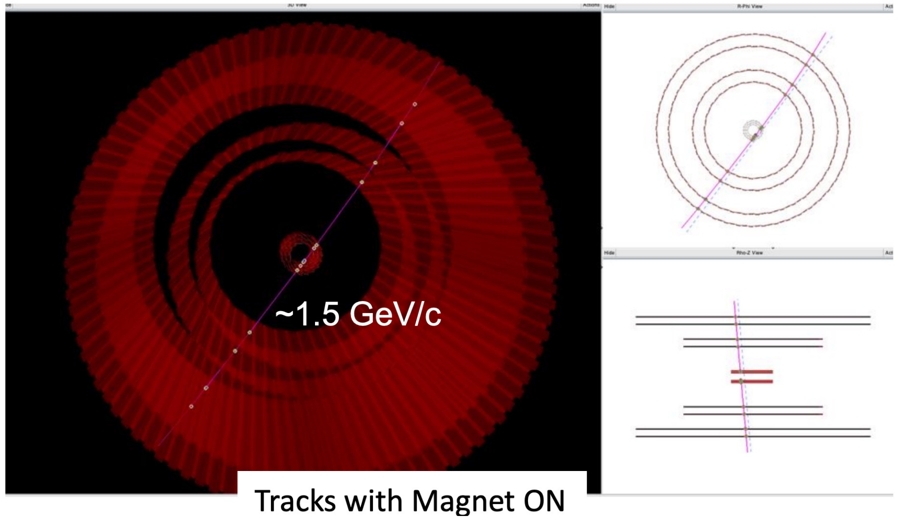
Cosmics

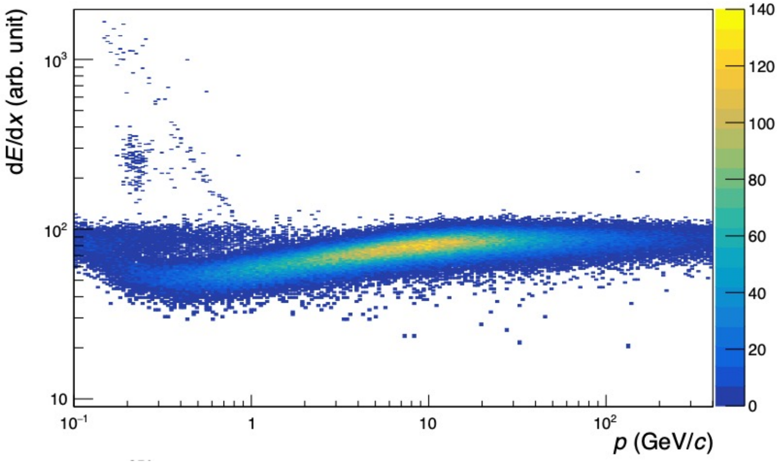


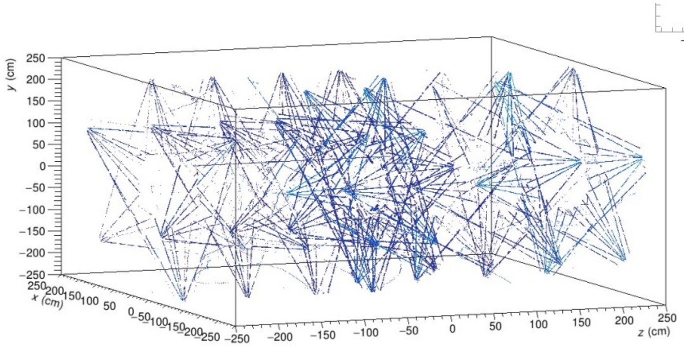
Xrays



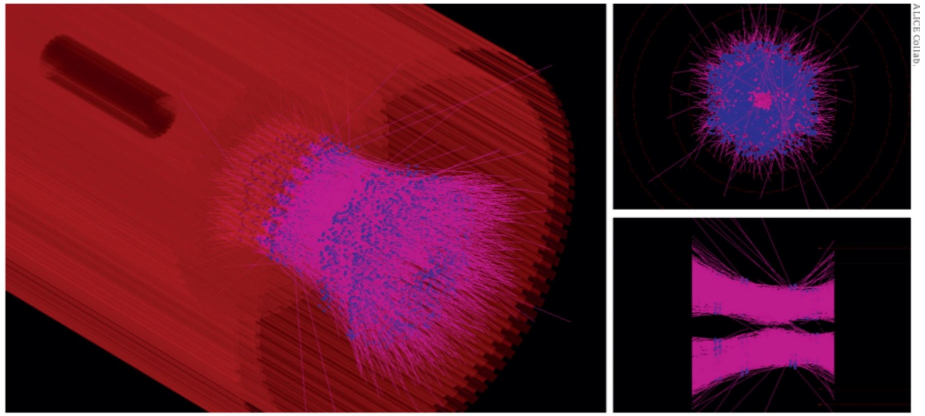
ITS: Cosmic ray







MFT: TED shots (proton beams on beam dumper)



Global cosmic runs with upgraded detectors and online processing

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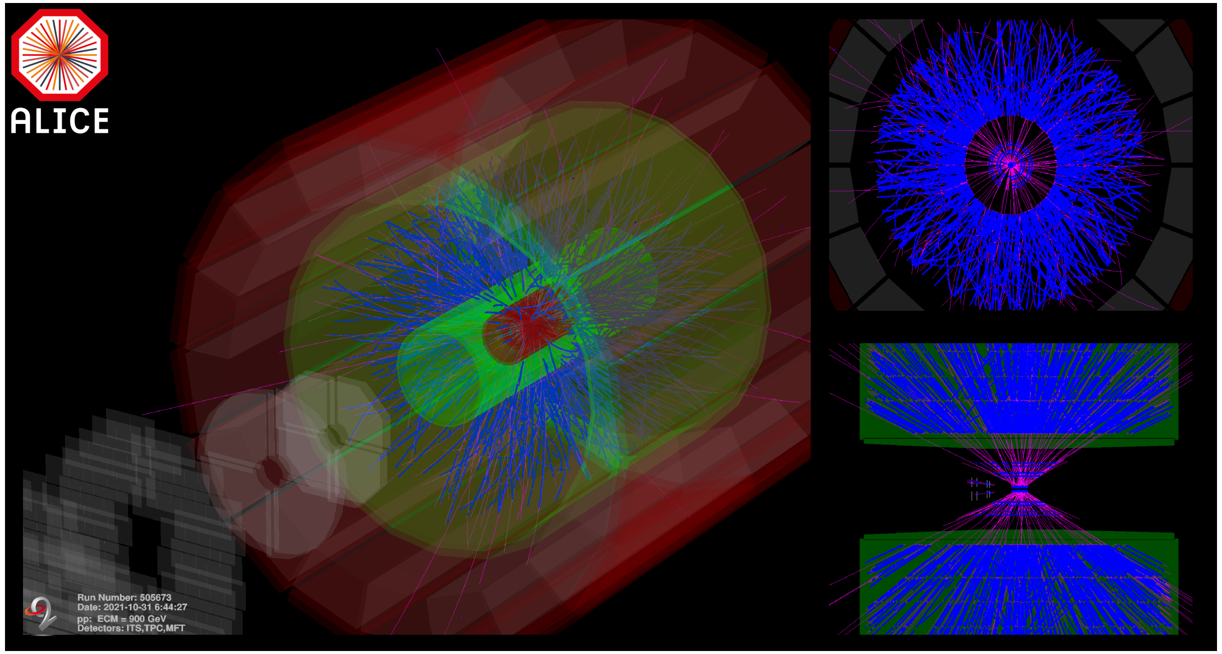
Pilot Beam Tests

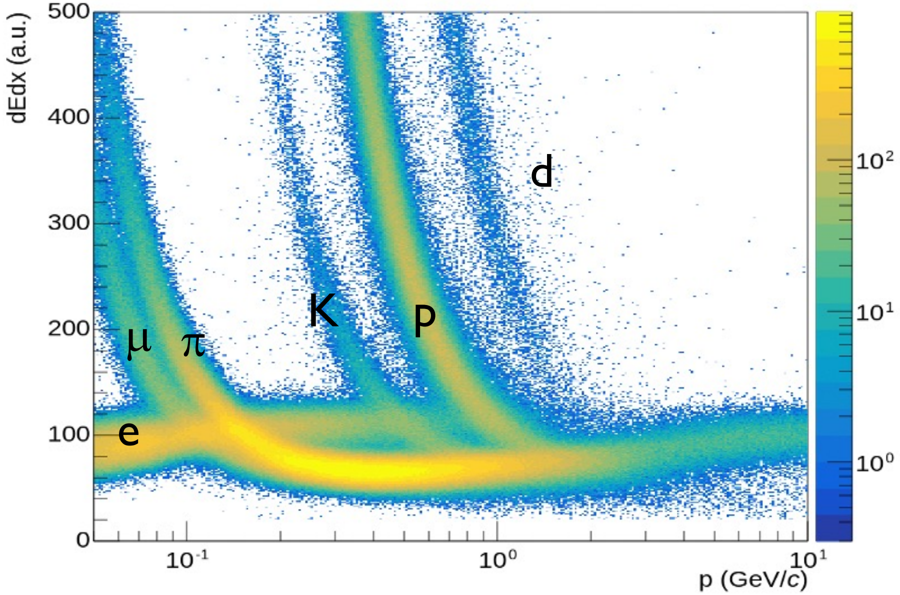


LHC provided collisions at injection energy during pilot beam test campaige (18.10 – 31.10)

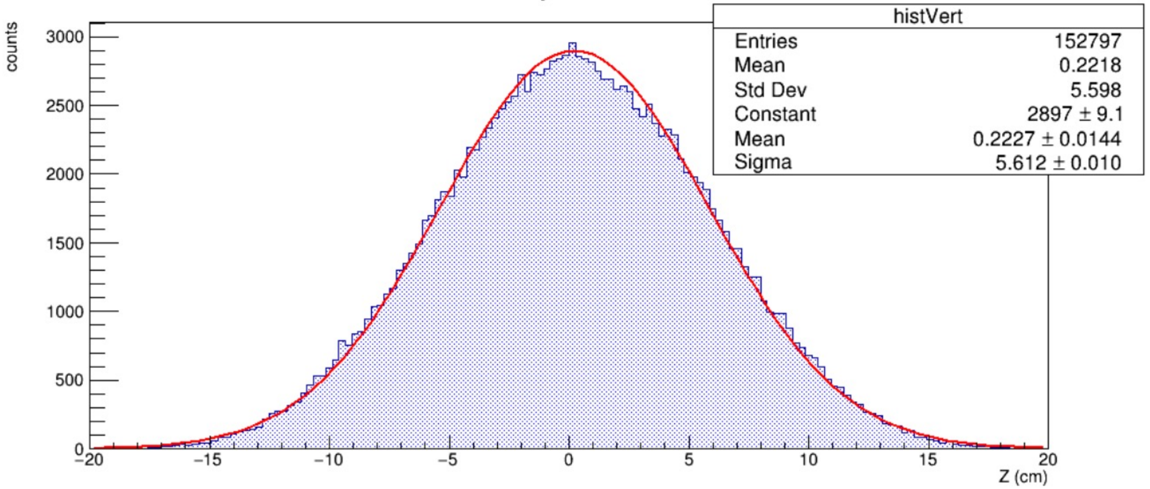
Pilot beams fully useful for commissioing ALICE

- ✓ Successful ALICE test campaign with LHC pilot Run
- ✓ Largely upgraded detector system (several detectors, new readout)
- ✓ New O2 system for continuous readout, online reconstruction and data reduction

PID by the dE/dx in the TPC from online reconstruction



reconstructed Primary Z-vertex by the ITS



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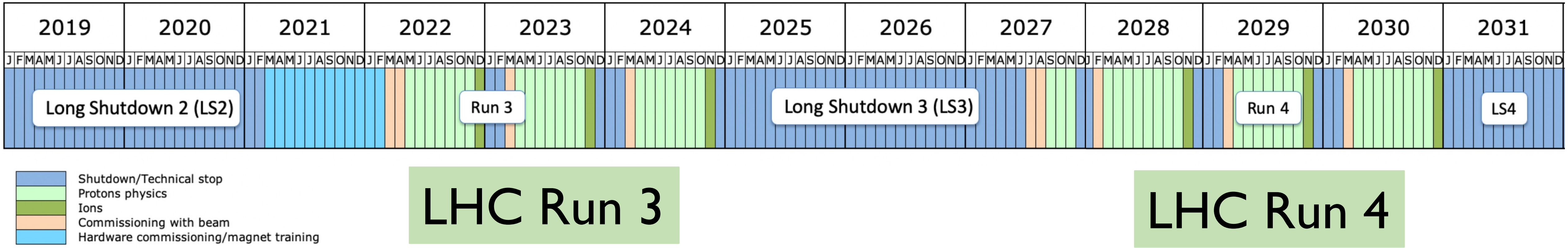
Physics topics for Run 3 and Run 4



ALICE Run 3 + Run 4

- **13 nb^{-1} (0.5T, 0.2T) Pb-Pb collisions**
- Heavy flavor meson and baryon measurements down to very low p_T
- Thermal direct radiation via dielectrons
- Quarkonia
- Light nuceli, hyper-nuclei, dibayons
- Forward direct photons

Characterizing the macroscopic long-wavelength QGP properties (transport properties, temperature, new phenomena related to strong EM fields)

Accessing the microscopic parton dynamics underlying QGP properties

Developing a unified picture of particle production from small (pp) to larger (p–A and A–A) systems

Probing parton densities in nuclei at small x and searching for the possible onset of parton saturation.

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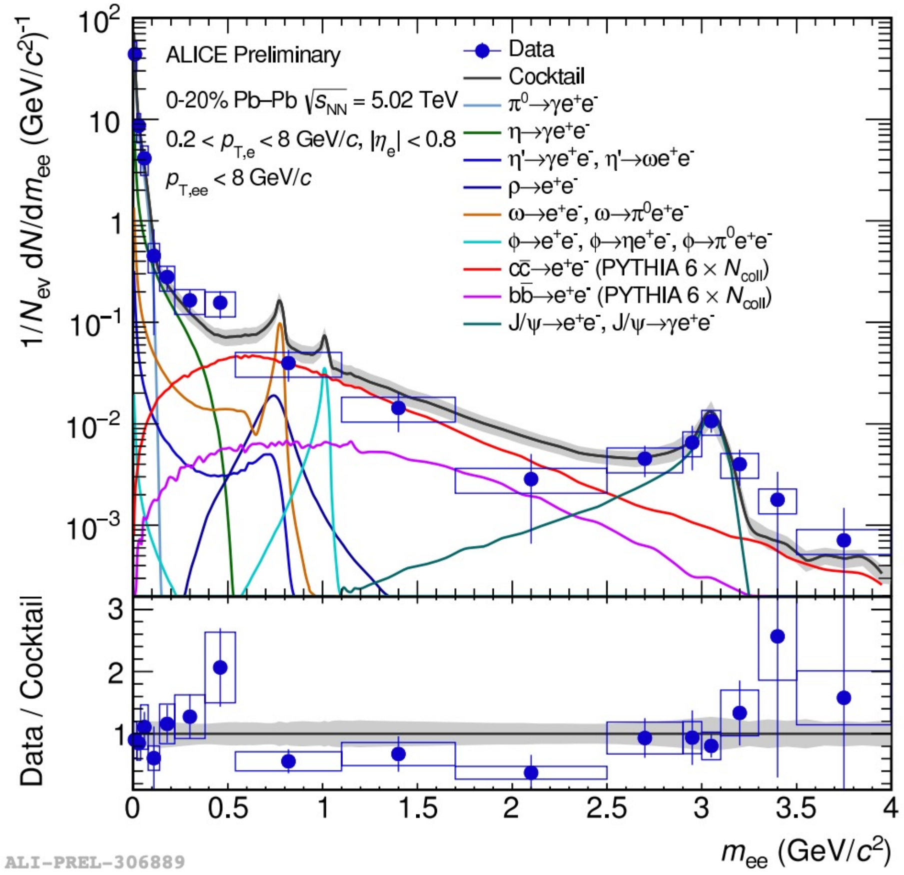
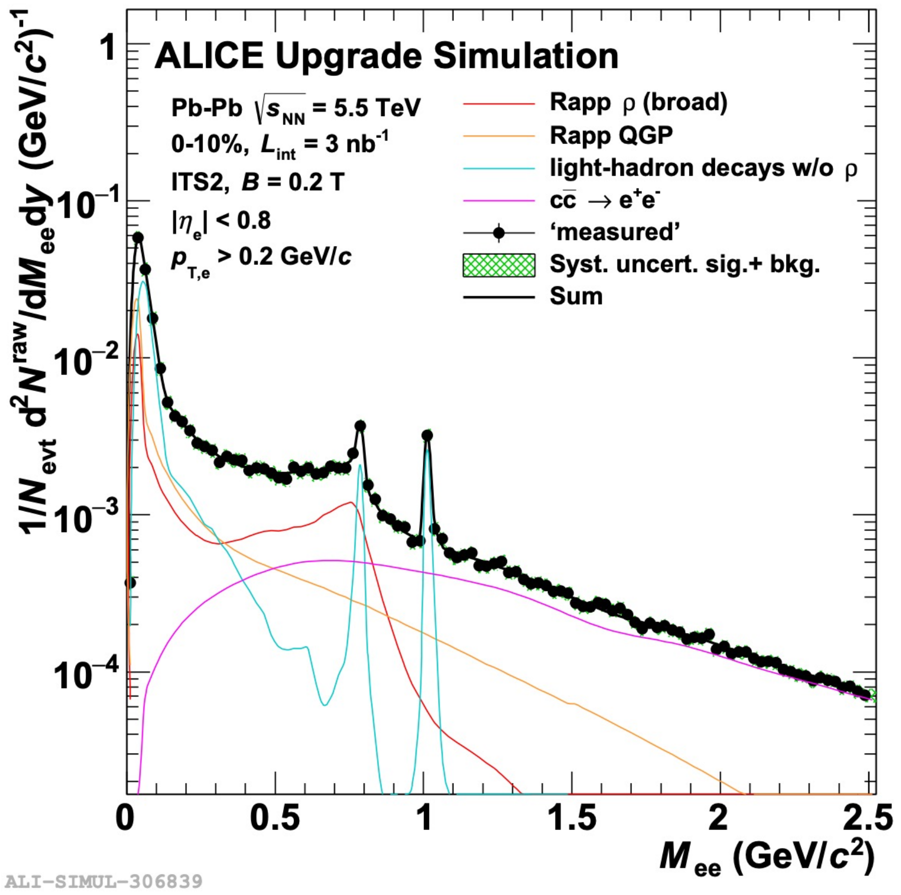
Dielectrons

Run 2



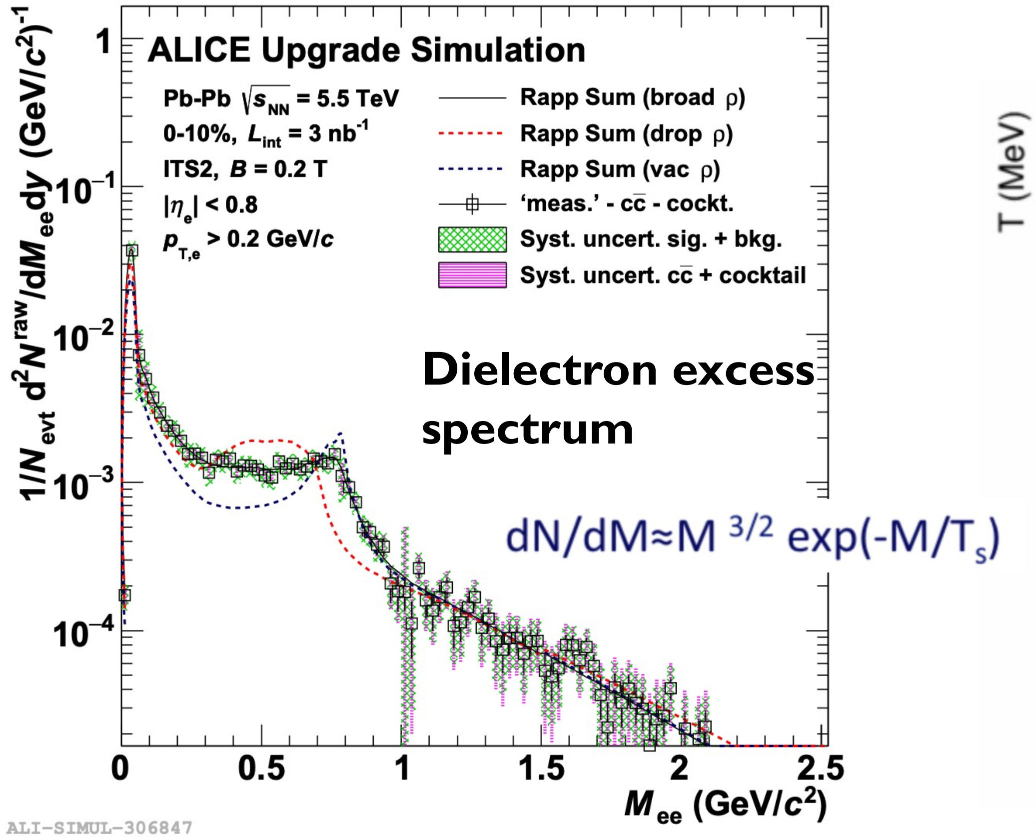
Run 3 + 4 with ITS2 (3 nb^{-1} at 0.2 T)

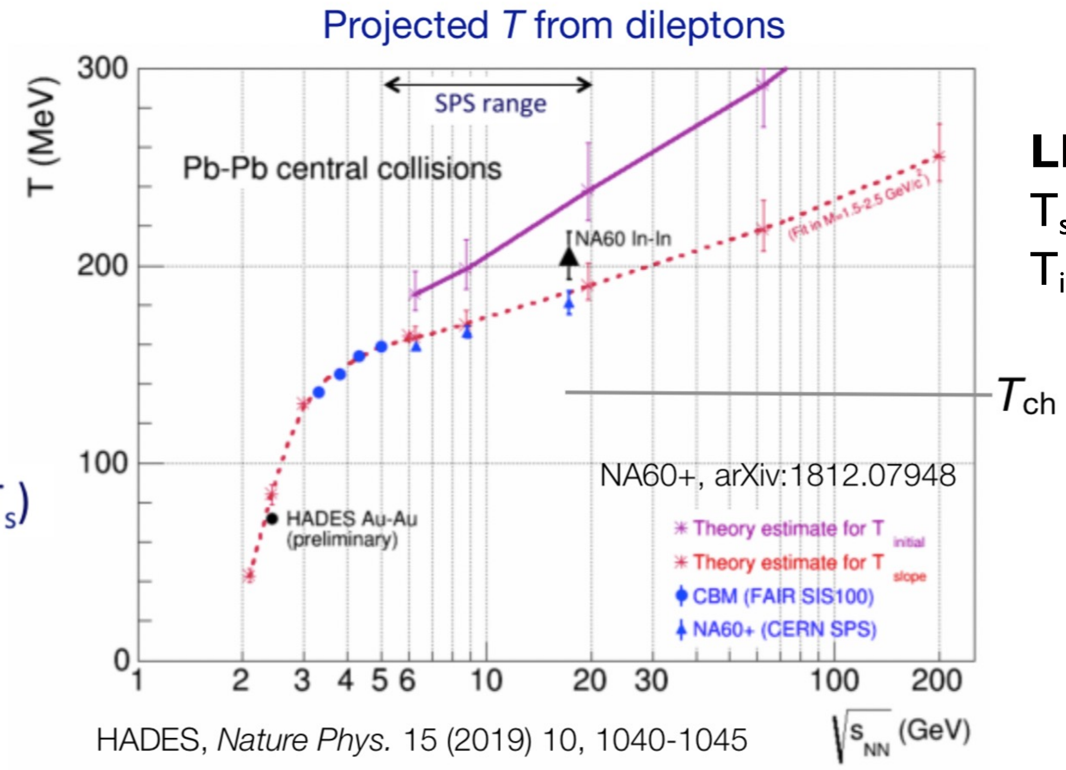


Improvement of dielectron mass spectrum expected in Run 3 + Run 4.
Background yields from know hadronic + HF decays can be subtracted precisely

Thermal Radiation

Yields at IMR after HF rejection = thermal radiation from partonic stage





LHC expectation

T_{slope} ~ 300 MeV

T_{init} ~ 600 MeV

Modification of spectral function of ρ meson visible.
Clear contributions from themal direct radiation visible in IMR.
Medium temperature not affected by blue shift can be extracted. Expected uncertainties : +10 – 20%

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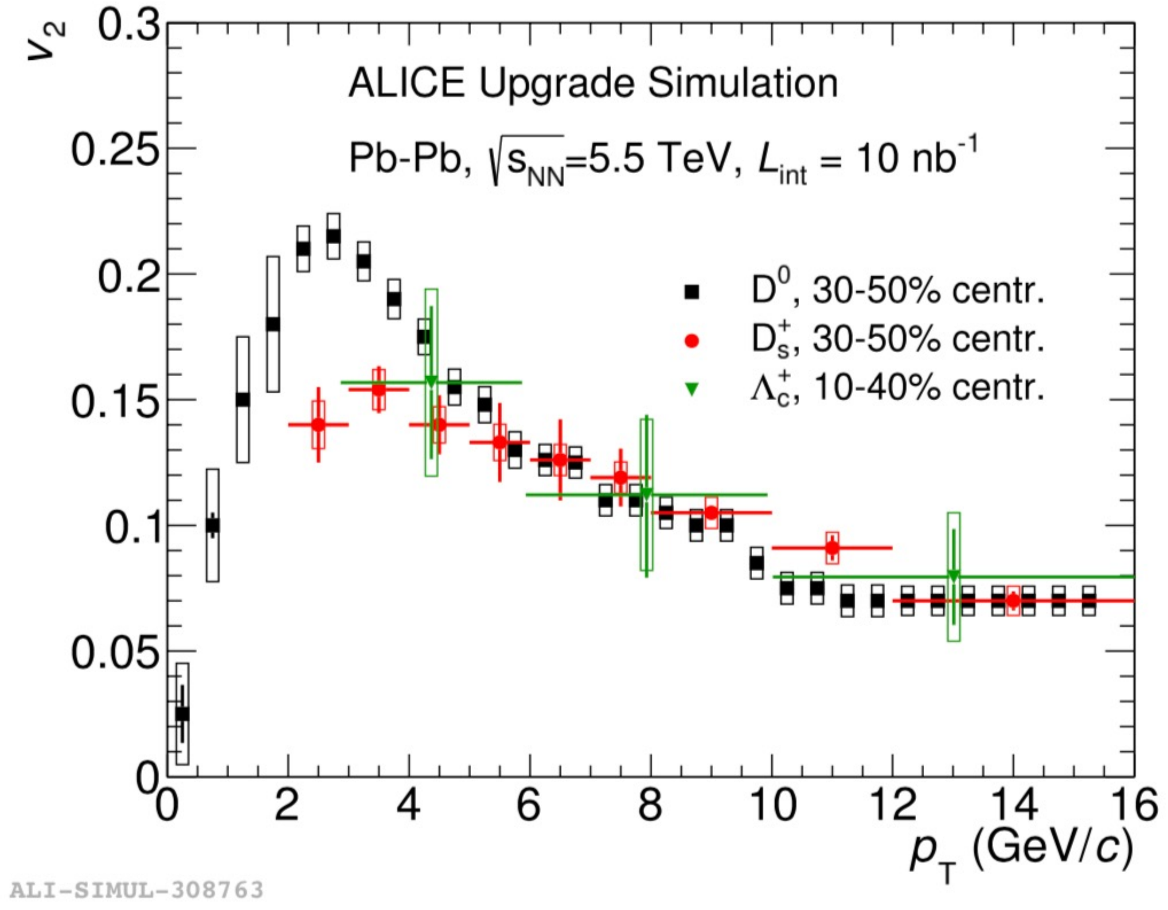
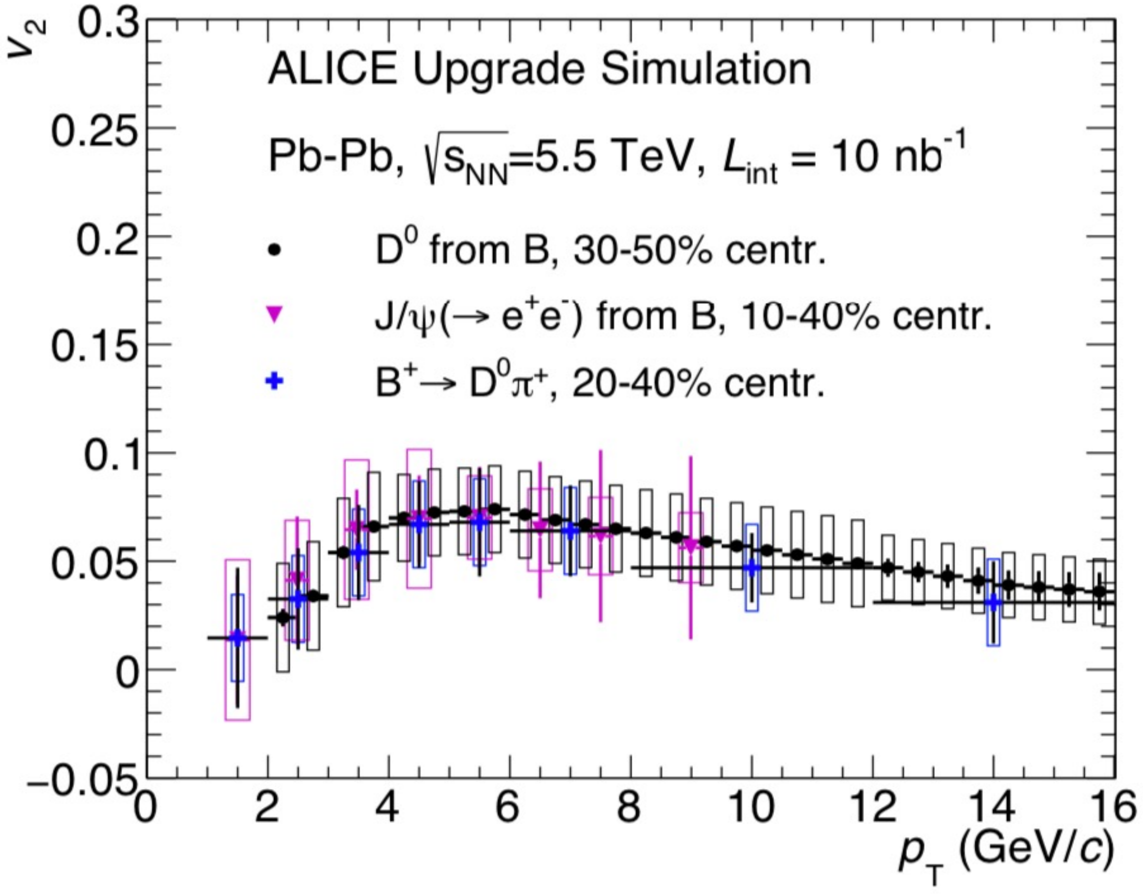
Charm and Beauty R_{AA} and v_2

Heavy-quark R_{AA} and v_2 give insight into the interactions with the light quarks of the medium and reveal transport properties of the medium.



Precise measurements of charm hadron v_2



The first precise measurements of B meson elliptic flow at the LHC

Charm and Beauty R_{AA} and v_2

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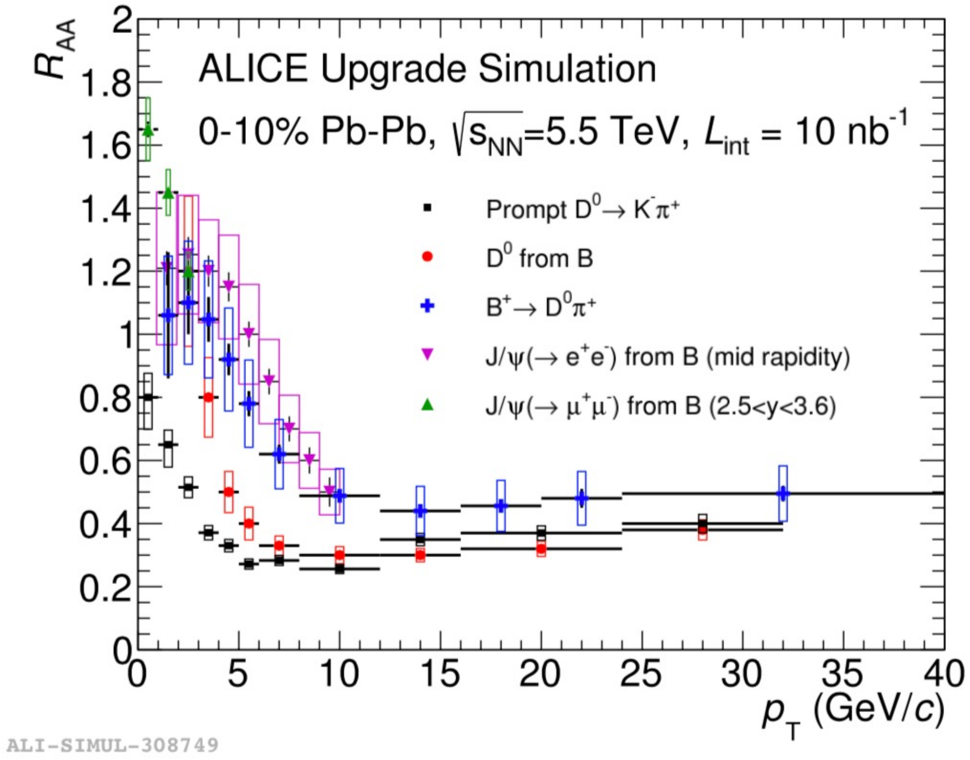
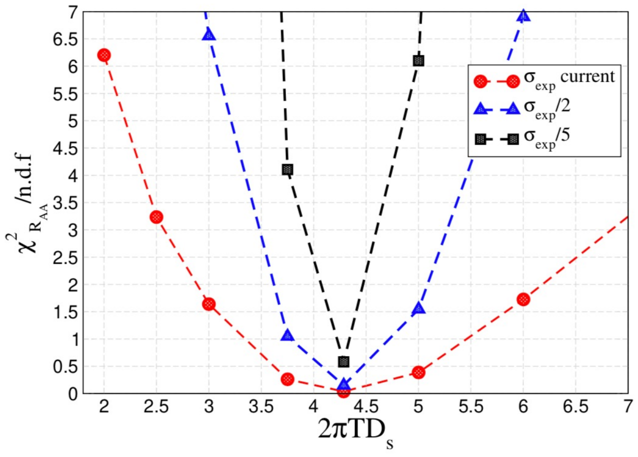
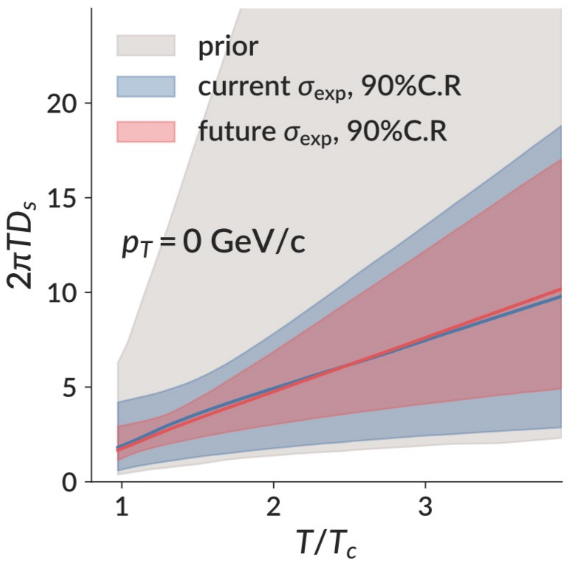
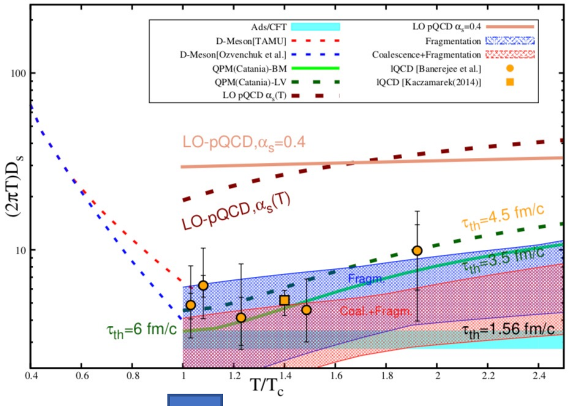


R_{AA} and v_2





Current data



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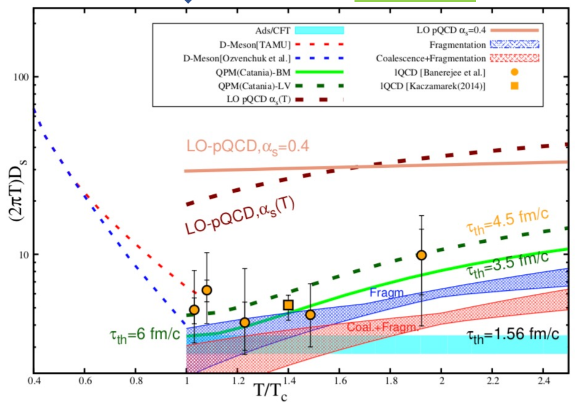
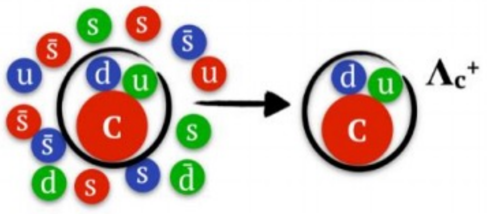


ALICE upgrade foresees a combination of beauty measurements at mid- and forward-rapidity, down to very small p_T

the diffusion coefficient around T_C could be constrained with an uncertainty of about 30–50% of current data

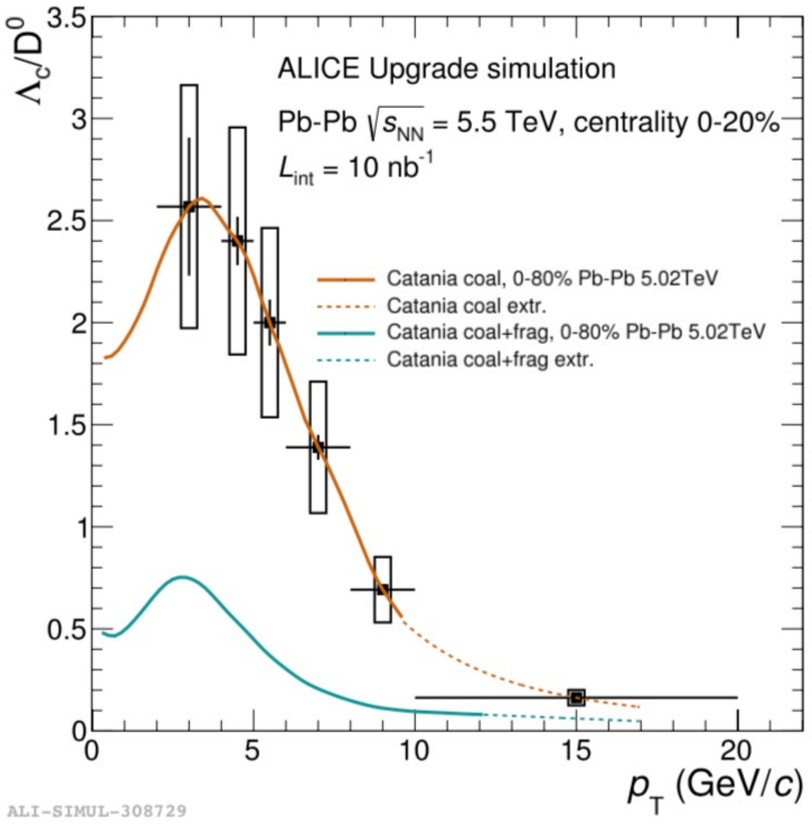
HF baryons



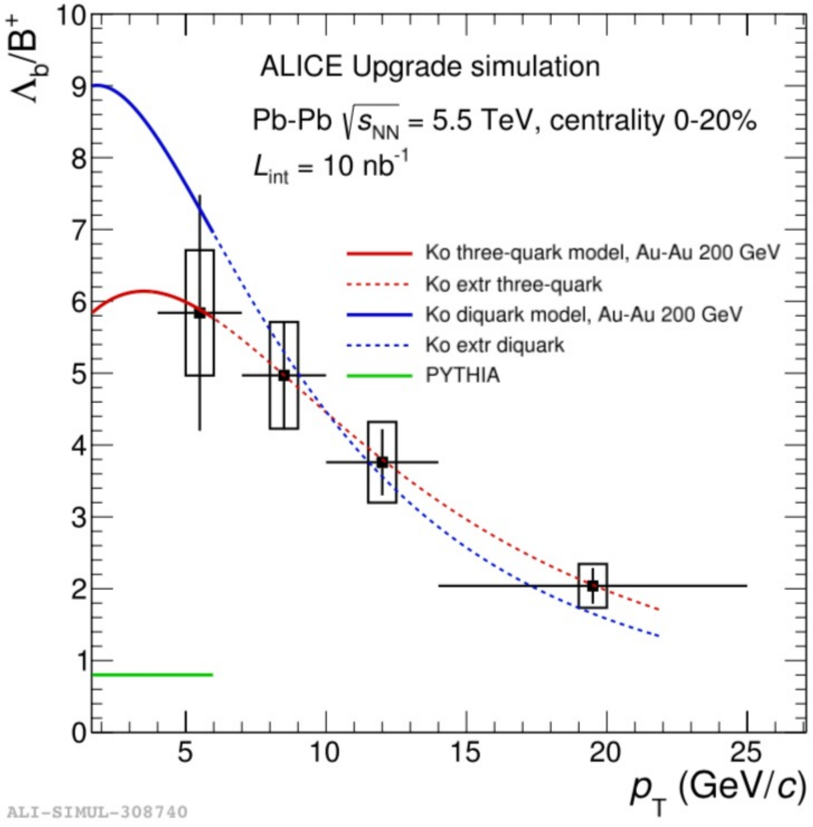
Enhanced production of charmed/beauty baryons relative to mesons
Insight into the hadronization mechanisms of heavy quarks in QGP and the existence of [ud] diquarks in the QGP

Oh et al., PRC79 (2009) 044905
Ghosh at al., PRD 90 (2014) 054018
He, Rapp et al. arXiv:1905.9216

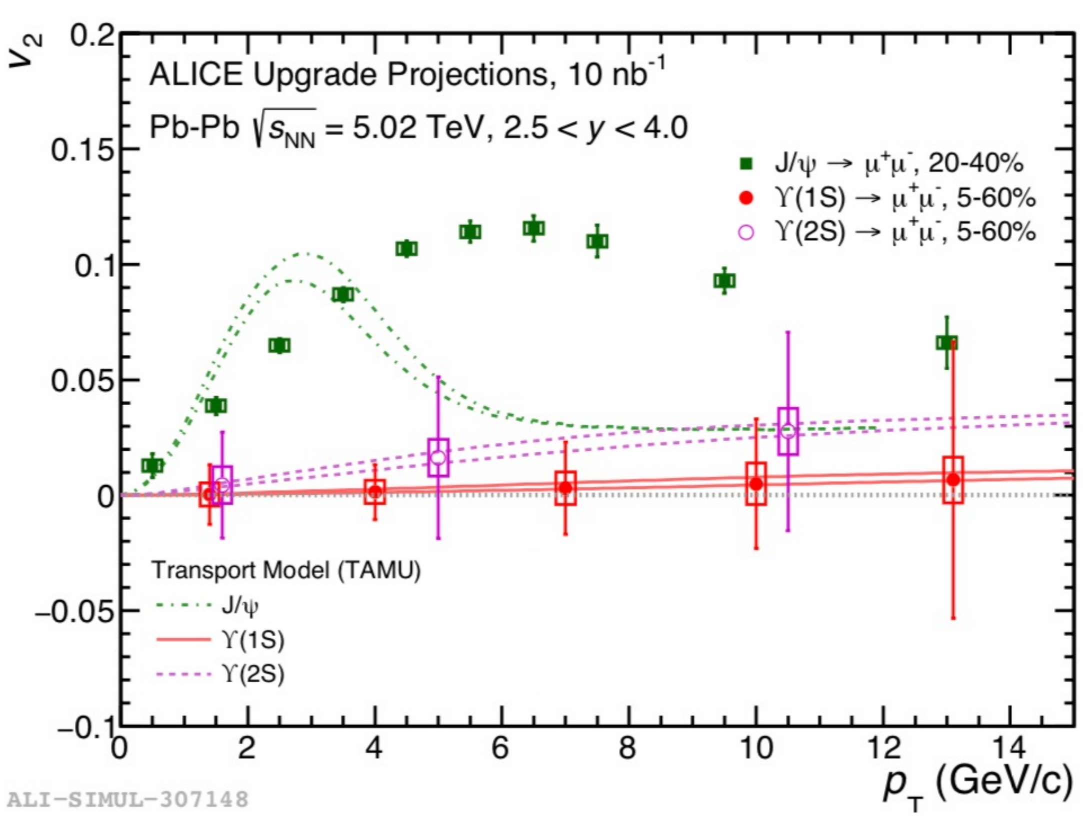
Λ_c/D^0 ratio

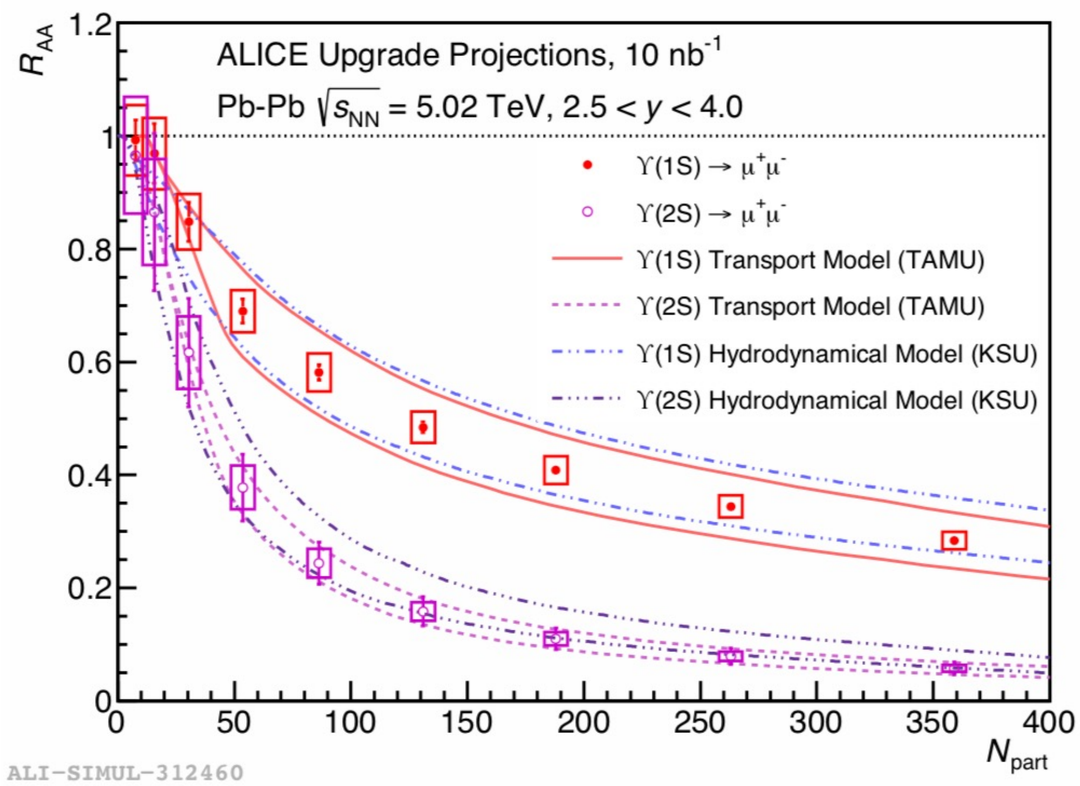


Λ_b/B^+ ratio



Quarkonia



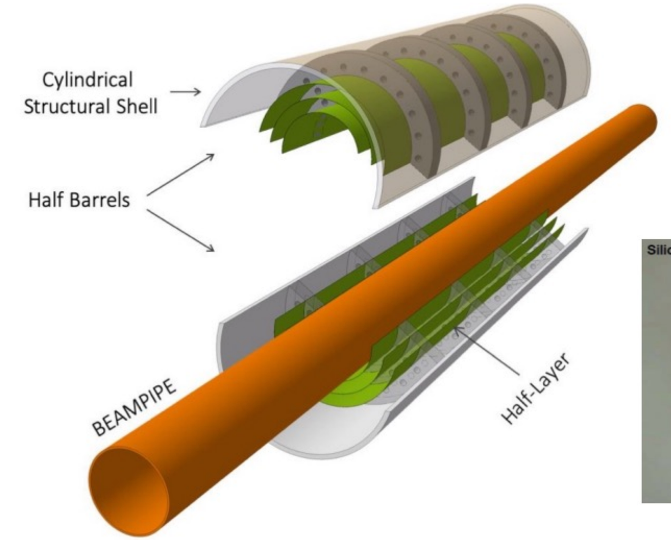


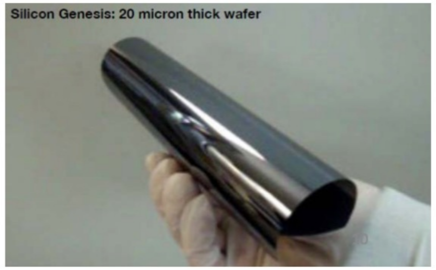
Precise comparison of charmonium and bottomonium states: **mass/flavor dependence of color screening, medium interaction of qqbar system, dynamics of charm quark regeneration**

ITS3 upgrade

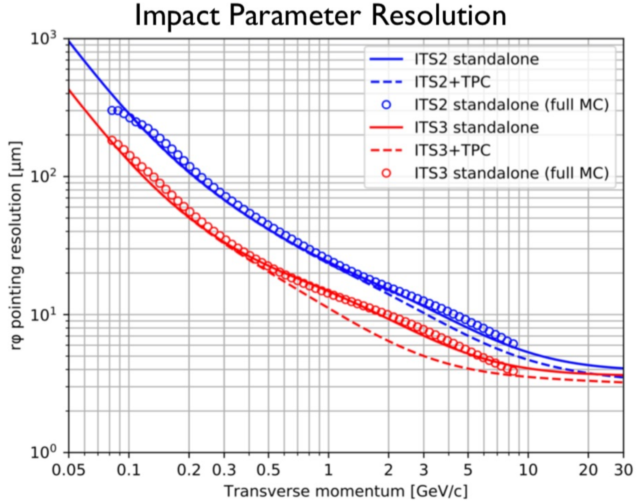
ITS3: Truly cylindrical, wafer-size sensors for inner barrel
homogeneous inner tracker with ultra-low material budget

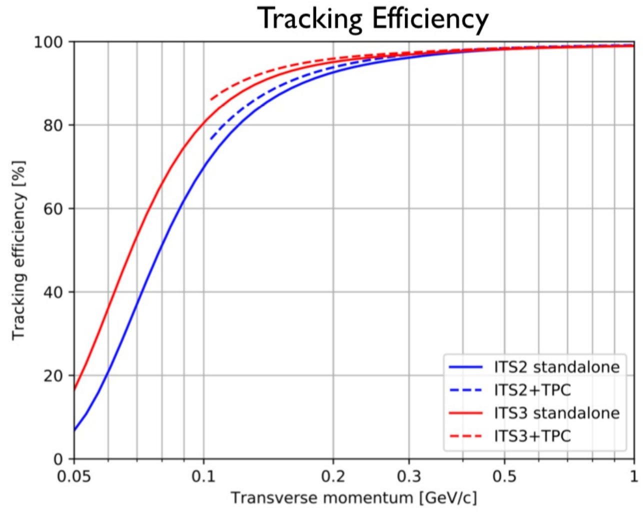
LoI: CERN-LHCC-2019-018



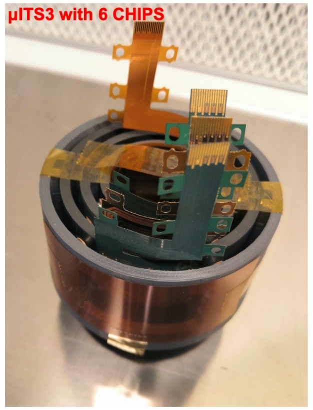


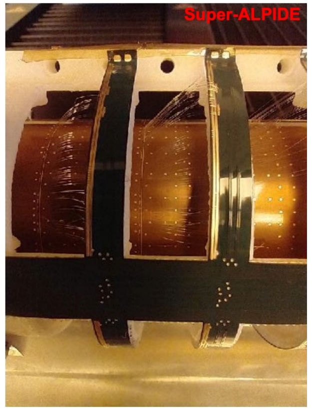
inner layers	ITS1	ITS2	ITS3
X/X_0	1.14%	0.38%	0.05%
innermost radius	39 mm	22 mm	18 mm
pixel size	50x425 μm^2	30x30 μm^2	O(15x15 μm^2)





Bent MAPS operated in various test beams
(DESY + SPS in July)



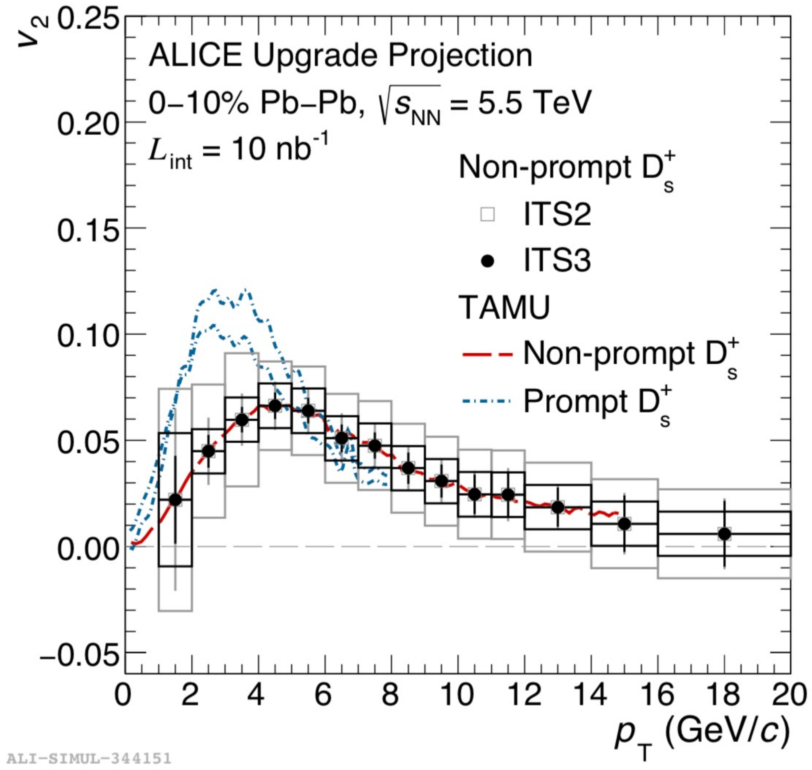


- Better pointing angle resolution by x2
- Low p_T (<100 MeV/c) tracking efficiency improves by x1.2-2

ITS3 upgrade

Ds/Bs production and flow

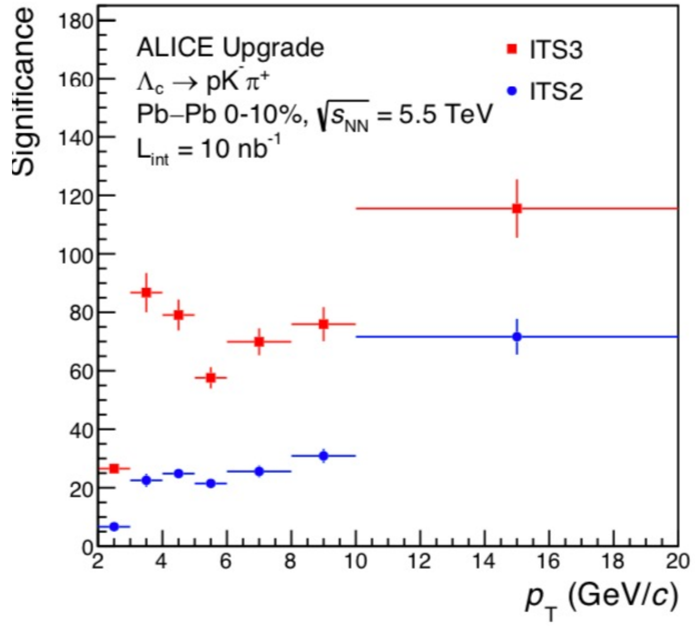
- hadronisation of charm and beauty quarks via recombination + enhanced strange-quark production in the QGP

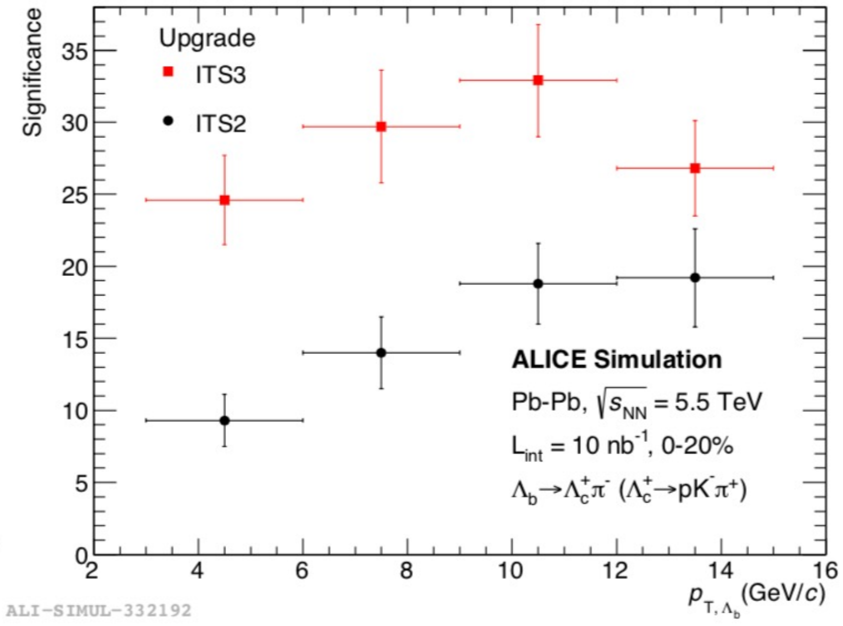


sensitivity to discriminate azimuthal anisotropy for prompt and non-prompt Ds+ (charm vs. beauty)

Charm and beauty baryons

- Enhanced production of HF baryons in Pb-Pb collision and probes of diquark correlation and heavy-quark hadronisation and baryon formation





Expected improvement of statistical significance by a factor of 2-4 with ITS3

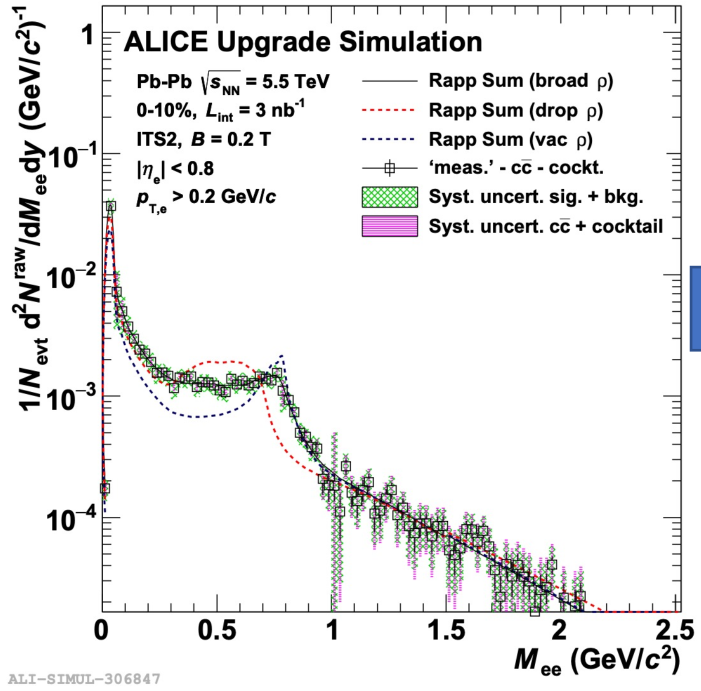
ITS3 upgrade

Low mass dielectrons

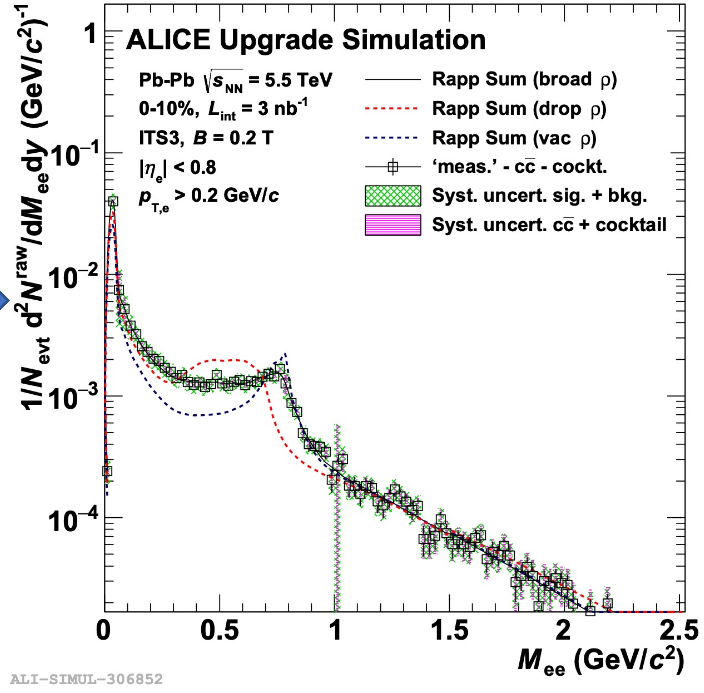
- Less material: fewer conversions
- Better pointing angle resolution : rejection of HF background
- Better tracking at low pT: conversion rejection

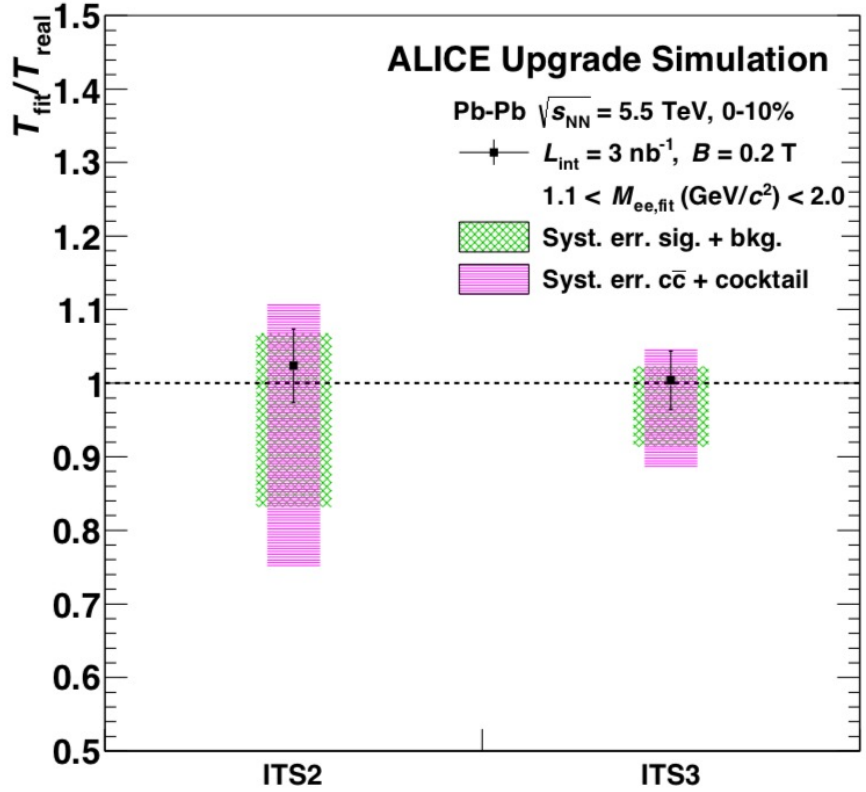
ITS3 improves systematic uncertainties on T by a factor of 2

ITS 2



ITS 3

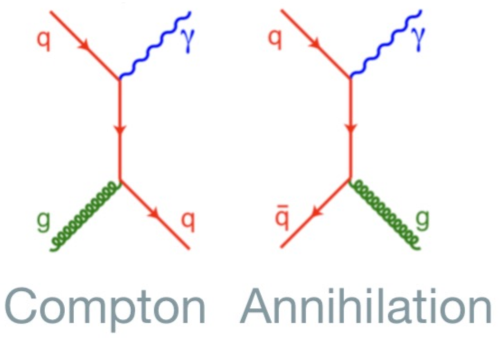


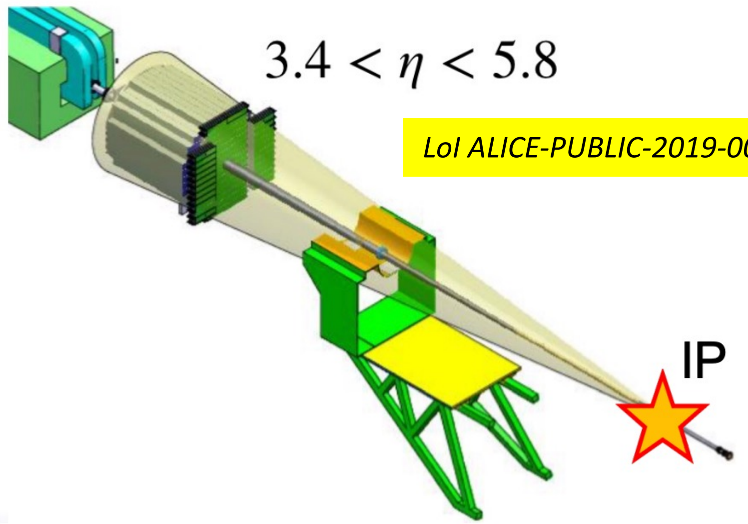


FOCAL upgrade

FOCAL: forward electromagnetic and hadronic calorimeters

- FoCal-E: high-granularity Si-W sampling calorimeter for the measurement of direct γ and π^0
- FoCal-H: Pb-Sc sampling calorimeter for photon isolation and jets

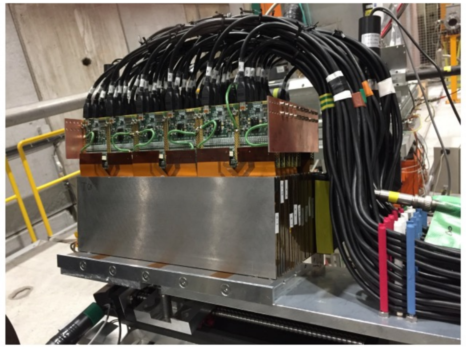


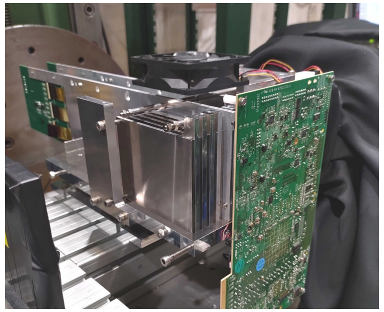


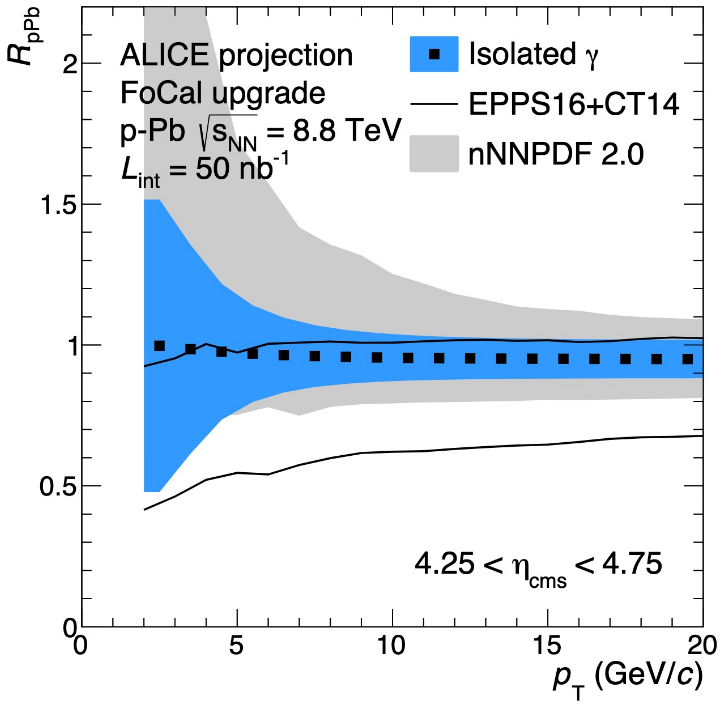
LoI ALICE-PUBLIC-2019-005

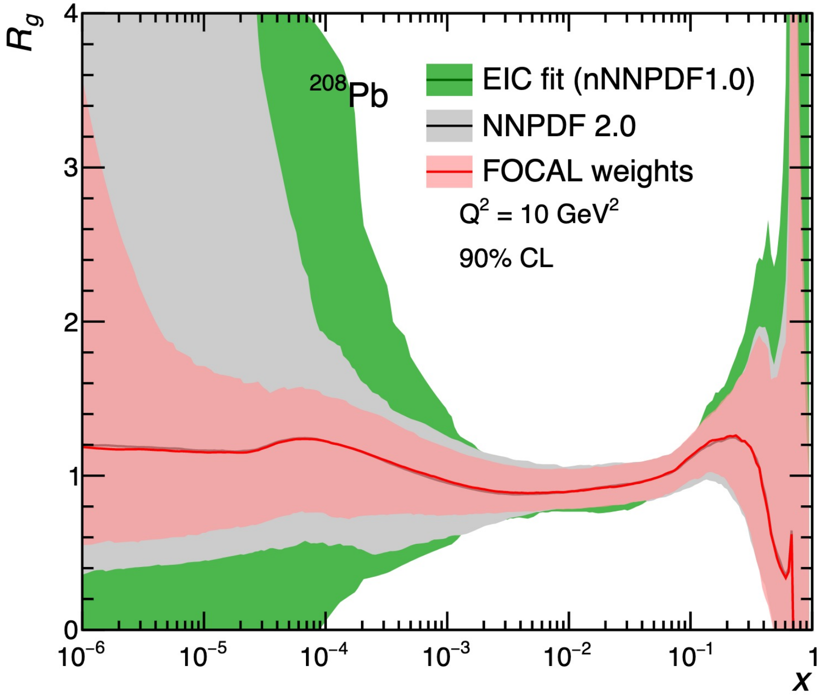
Measure isolated γ forward

- at LO more than 70% from Compton
- direct sensitivity to gluon density









A Large Ion Collider Experiment

Summary

- The ALICE experiment completed the upgraded detector installation and is about to complete the global commissioning.
- **LHC pilot beams at the end of October key for successful commissioning of ALICE with beam collisions**
  - **Upgraded detectors and systems were fully tested with collisions**

- Run 3 + Run 4 will allow to study the detailed properties of the QGP with high-luminosity Pb-Pb collisions and with upgraded ALICE detectors.
- Rich physics programs will be conducted in Run 3 + Run 4
  - Thermal radiation via dielectrons
  - Transport properties by charm and bottom hadron measurements down to very low p_T
  - Hadronization, dissociation and recombination mechanisms of heavy quarks in the medium
  - **and more…**

ALICE upgrade performace:
CERN-LPCC-2018-07 arXiv:1812.06772 & ALICE-PUBLIC-2019-001

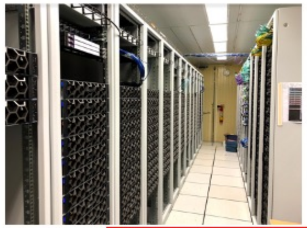
ALICE

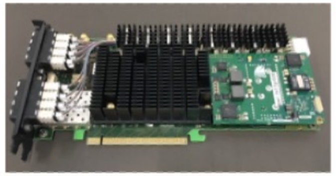
backup

Online – Offline (O2)

O2/FLP

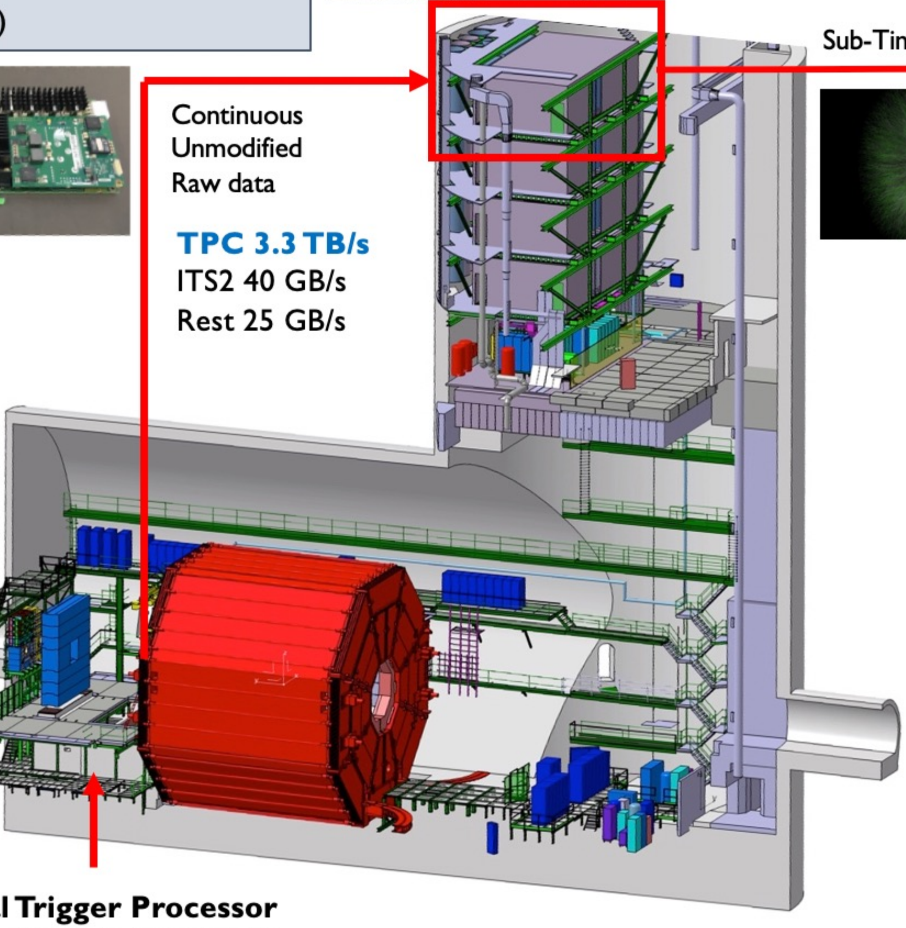
CR1 – First Level Processors
Receive detector data and processing on PCIe-based FPGA board (CRU)





Continuous
Unmodified
Raw data

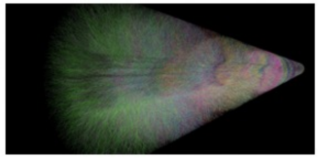
TPC 3.3 TB/s
ITS2 40 GB/s
Rest 25 GB/s



CTP
Central Trigger Processor
Distribution of timing info, heartbeat trigger

TPC 570 GB/s
ITS 40 GB/s
Rest 5 GB/s

Sub-Timeframes (10-20ms)



O2/EPN

CR0 - Event Processing Nodes
~2000 GPU & CPU

Compressed Timeframes (CTF)
Calibration data

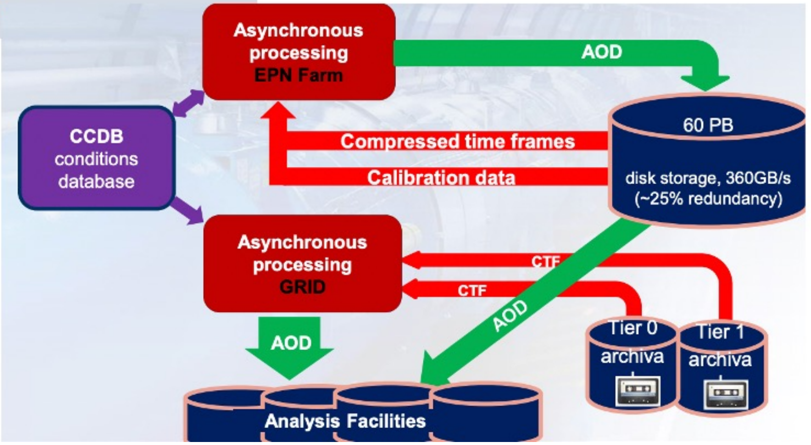
60 PB
disk storage, 360 GB/s

2/3 CTF
1/3 CTF

Tier0 archival
Tier1 archival

O2/PDP

Physics and Data Processing on EPN
- **Synchronous reconstruction**
- **Calibration & asynchronous reconstruction (and event selection only for pp)**
- **Utilize ~2000 GPU and HPC**



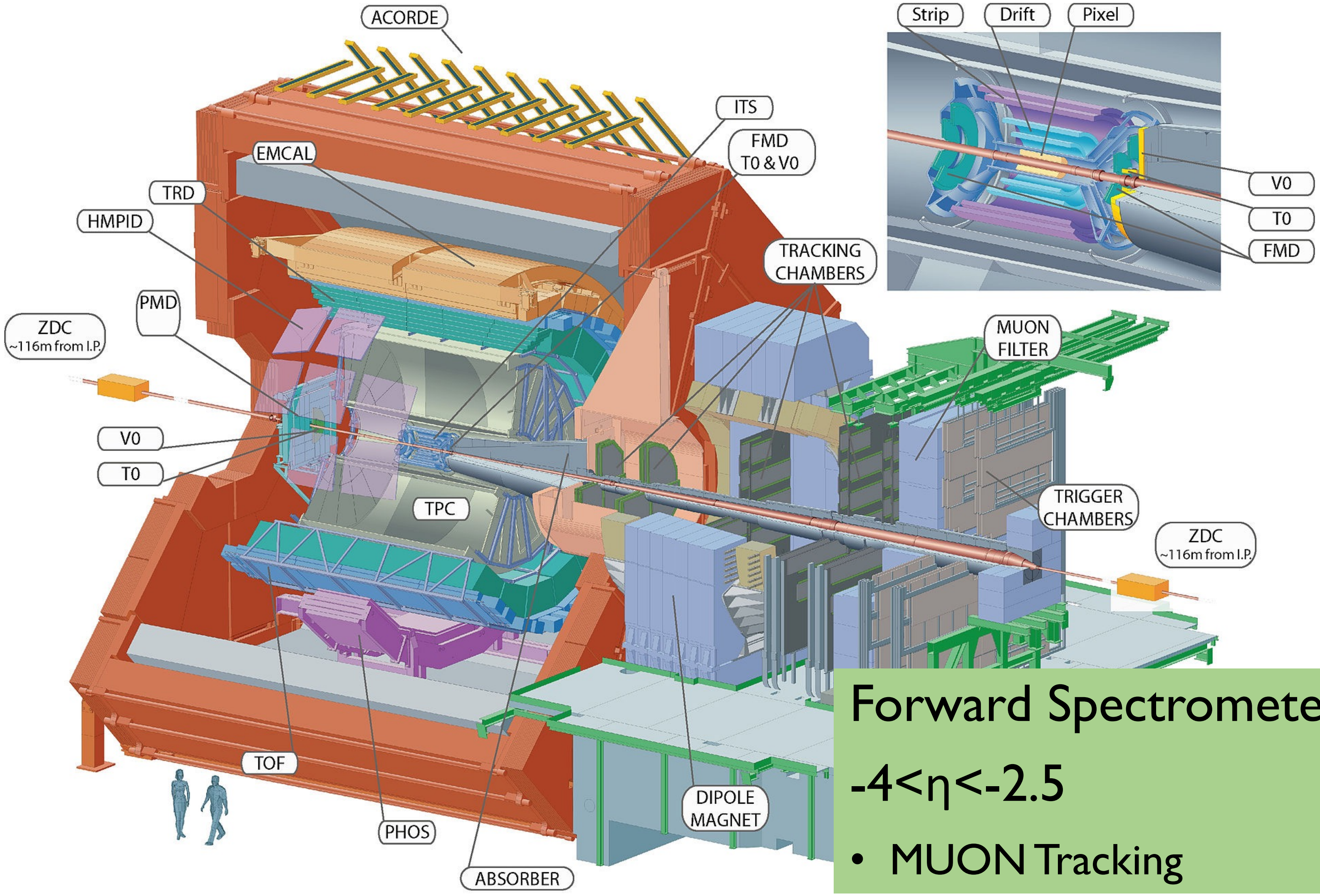
A Large Ion Collider Experiment

ALICE Detectors in Run2

Central Barrel (|η|<0.8)

(ITS, TPC, TRD, TOF, HMP, EMC, PHOS)

- Tracking
- PID
- EM Calorimeters



Forward Detectors

(V0, T0, FMD, PMD, ZDC)

- Luminosity
- Centrality
- Multiplicities

Forward Spectrometer

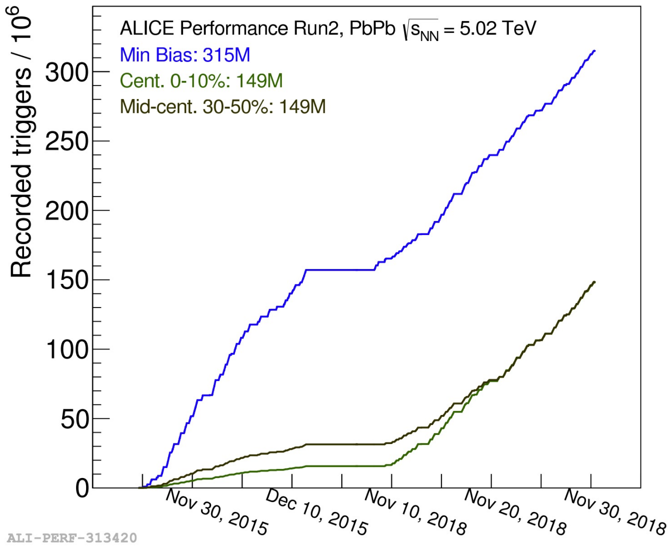
-4<η<-2.5

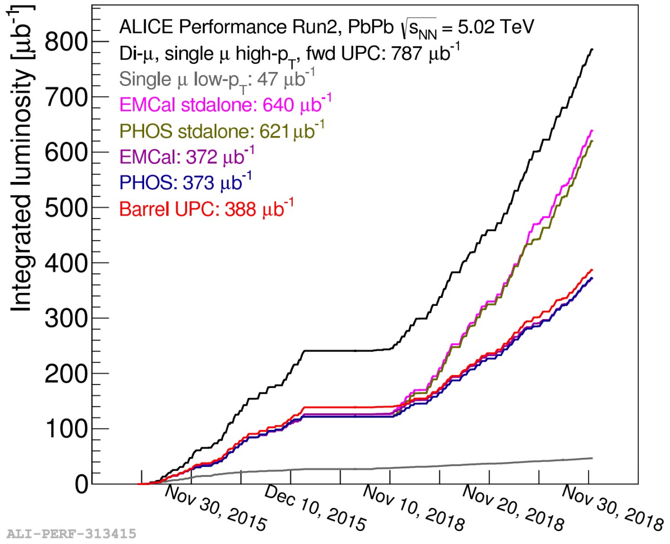
- MUON Tracking

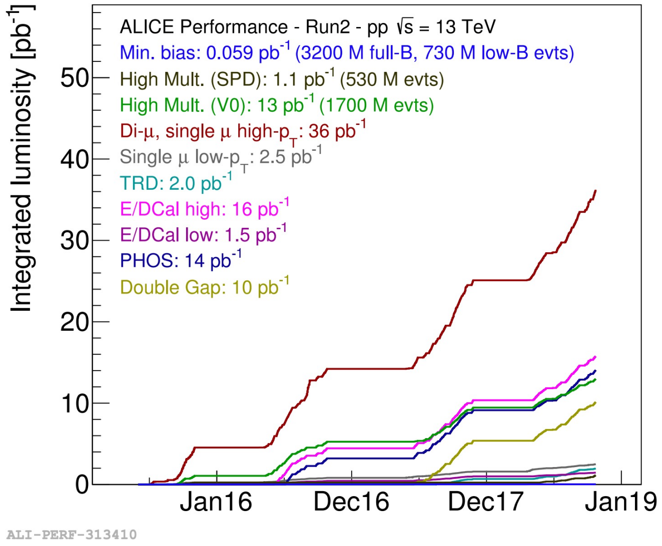
A Large Ion Collider Experiment

ALICE Data Taking History

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	Recorded L_{int} (for muon triggers)
Pb–Pb	2010,2011	2.76	~75 μb^{-1}
	2015	5.02	~0.25 nb^{-1}
	2018	5.02	~0.79 nb^{-1}
Xe–Xe	2017	5.44	~0.3 μb^{-1}
p–Pb	2013	5.02	~15 nb^{-1}
	2016	5.02, 8.16	~3 nb^{-1}; ~25 nb^{-1}
pp	2009-2013	0.9,2.76,7, 8	~200 μb^{-1}; ~100 nb^{-1}; ~1.5 pb^{-1}; ~2.5 pb^{-1}
	2015,2017	5.02	~1.3 pb^{-1}
	2015-2018	13	~36 pb^{-1}

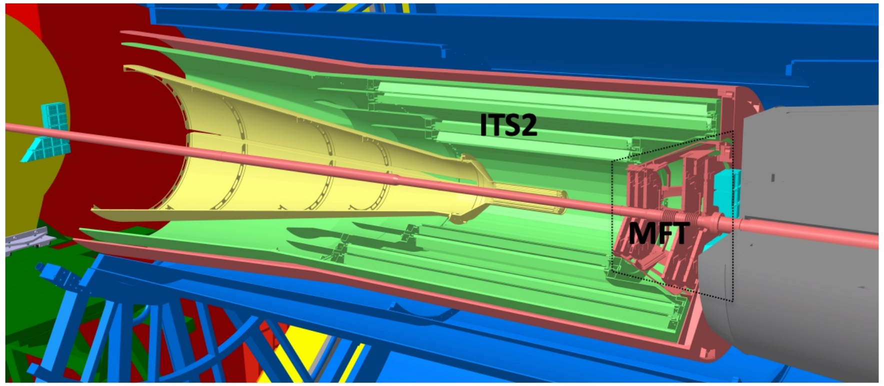


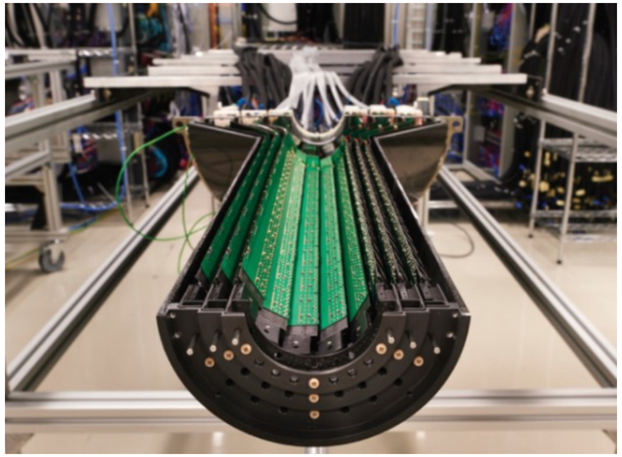


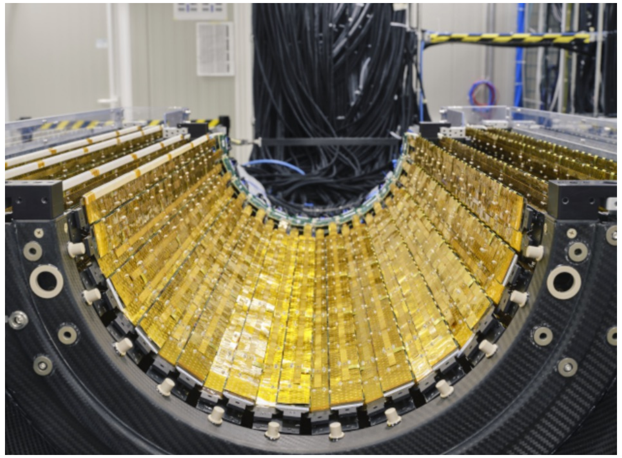


ALICE inspected ~ 1nb^{-1} Pb-Pb collisions in Run1 + Run2

ITS upgrade





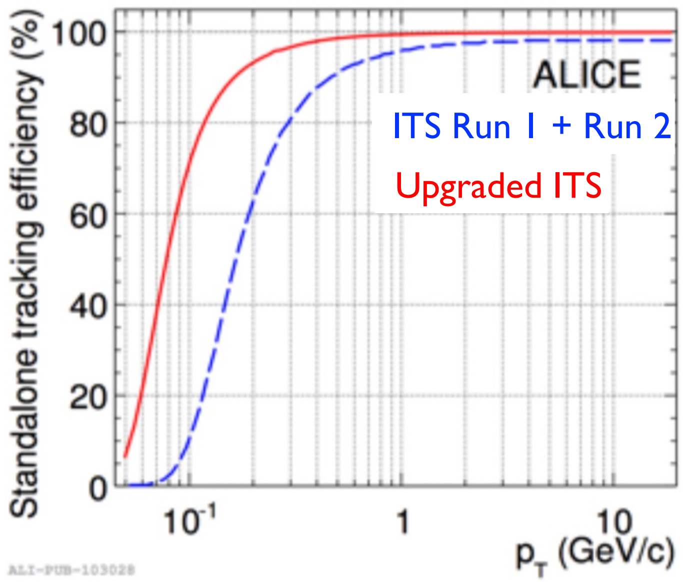


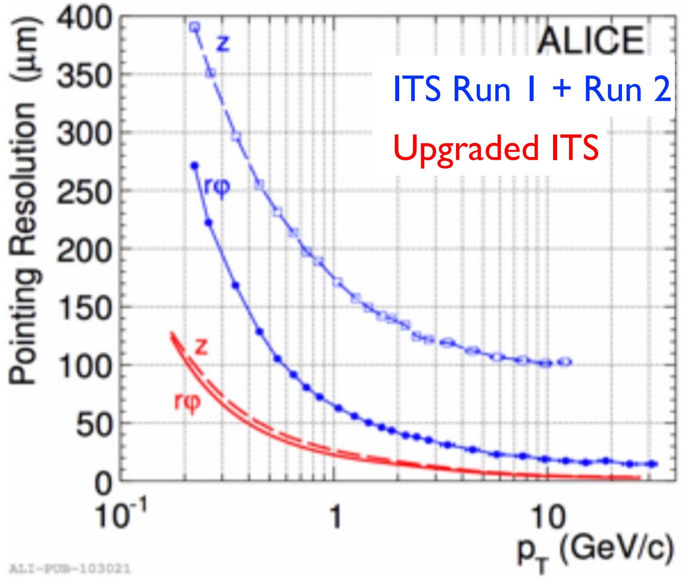
Inner Tracking System upgrade (ITS2)

- 7 layers of Si pixel detectors
- Closer to the IP: first layer at ≈22 mm

ALPIDE (ALICE Pixel Detector)

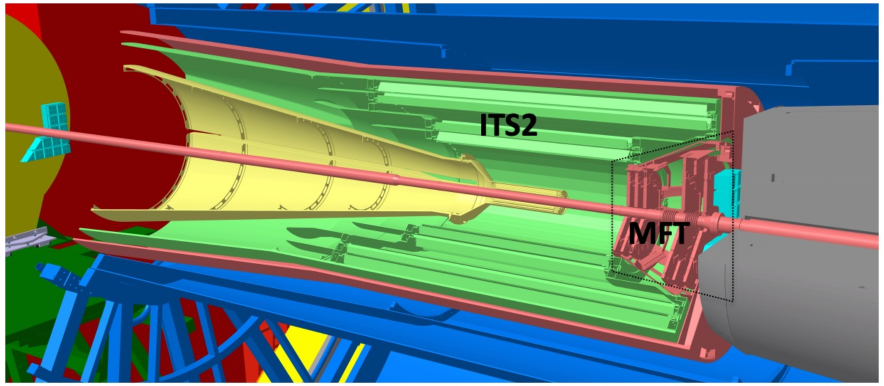
- Thinner: for innermost layers ~0.30% X_0
- Smaller pixels: 27 × 29 μm²
- Readout rate: 100 kHz
- 130 000 pixels/cm²
- Max. particle rate: ~100 MHz/cm²
- Spatial resolution: ~5 μm
- Thickness: 50 μm for the inner layers
- Fake-hit rate: < 10^{-9} per pixel per event

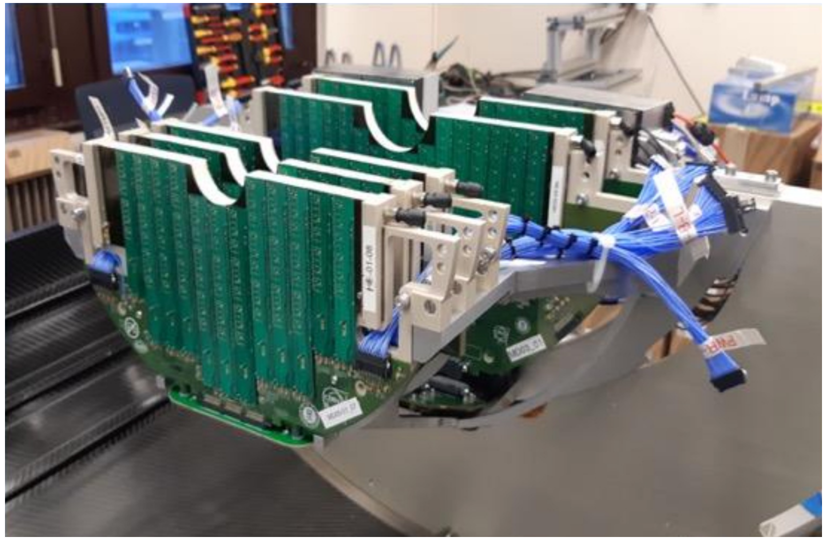




Improved tracking efficiency at low p_T , improved pointing resolution (x3)

MFT upgrade





Muon Forward Tracker (MFT)

- New forward vertex detector upstream muon absorber
- 5 layers of Si pixel disks