ALICE upgrade and physics prospectives

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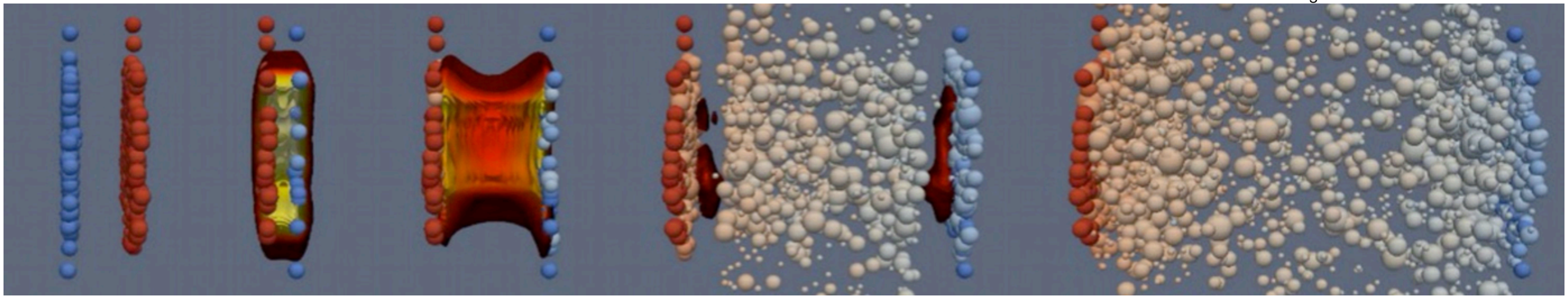
Istituto Nazionale di Fisica Nucleare, Sezione di Bari
on behalf of the ALICE Collaboration

QCD Future Physics Opportunities

Figure Credit: MADAI collaboration



<u>Future physics opportunities for high-density QCD with ions and proton beams</u>

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

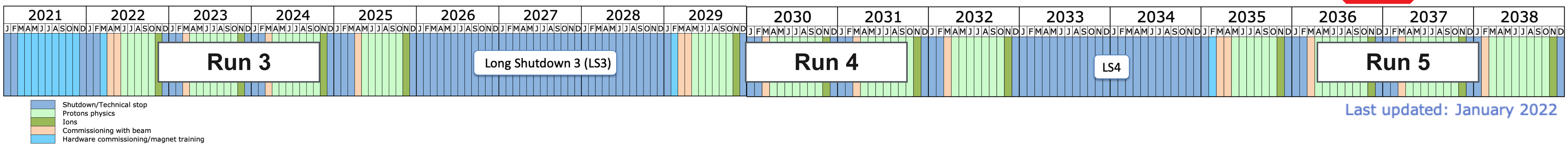
» Accessing the microscopic parton dynamics underlying QGP properties

» 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

Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams [arXiv:1812.06772v2]
Report from Working Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

ALICE 2 in Run 3 and Run 4



<u>Physics goals</u>

» Focus on high precision measurements of **rare probes at low p_T**

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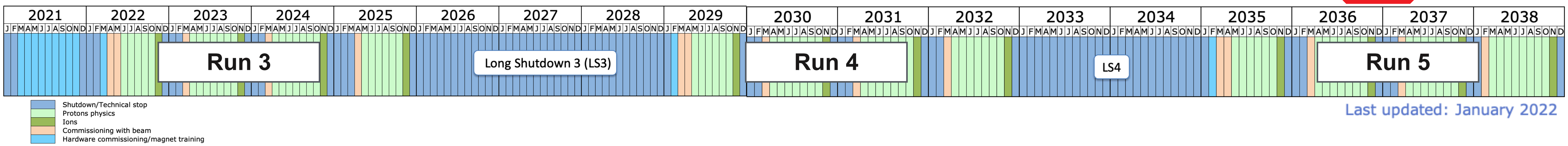

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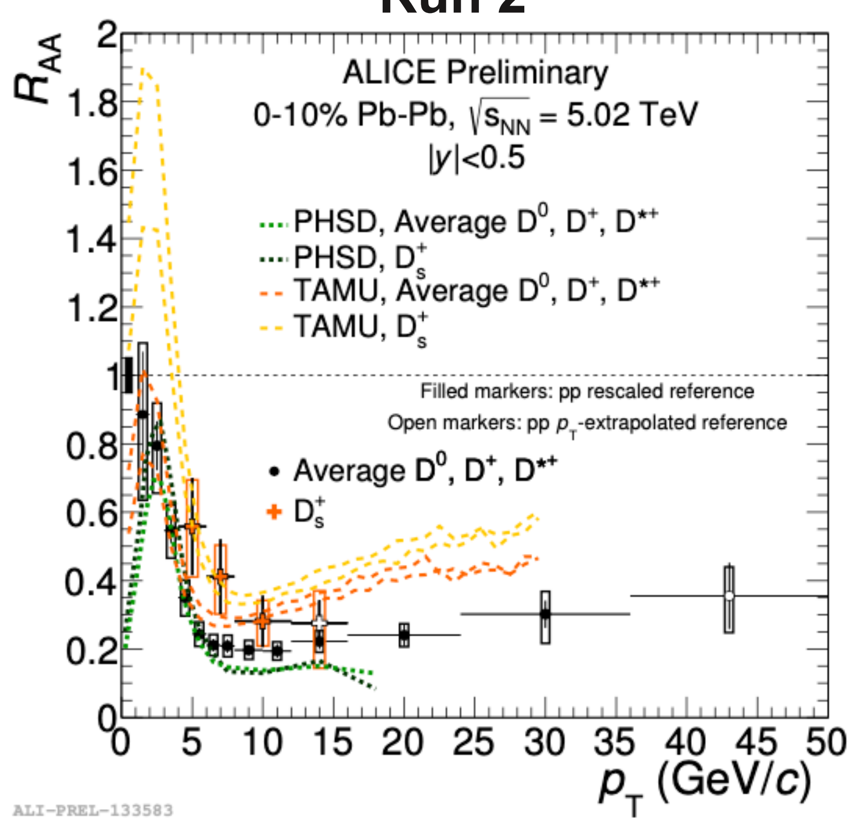
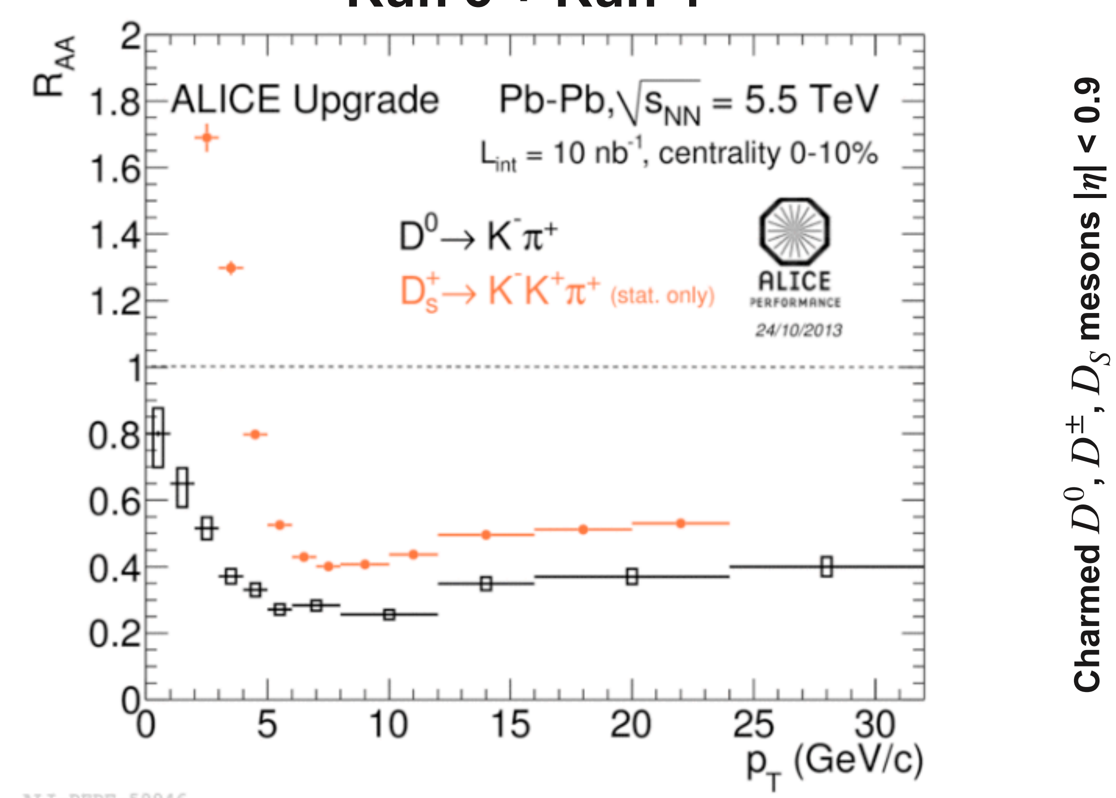
- **Heavy-flavour mesons and baryons (down to very low p_T)**

Run 2



Run 3 + Run 4



Comparison of different D-mesons is sensitive to the hadronization process of c quarks in the QGP

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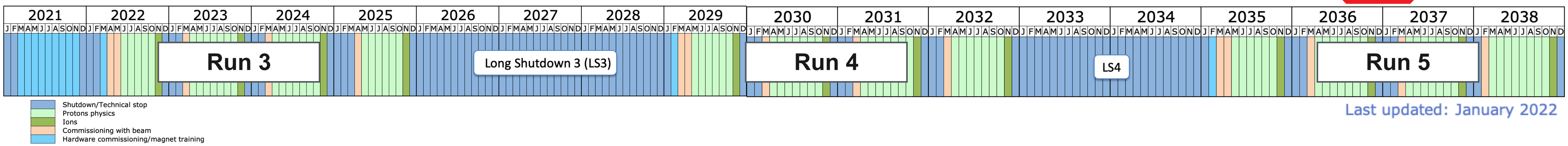

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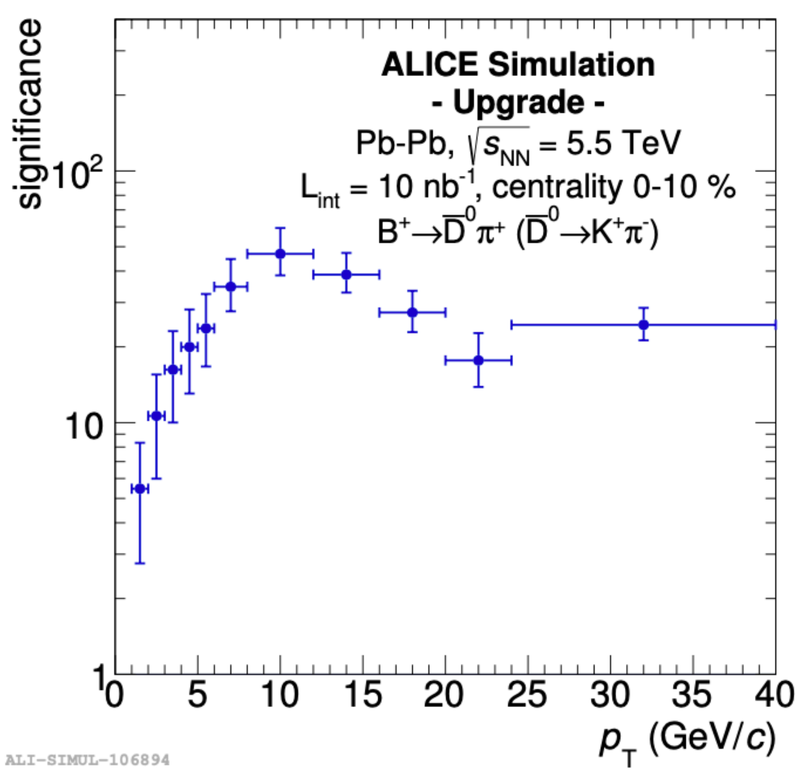

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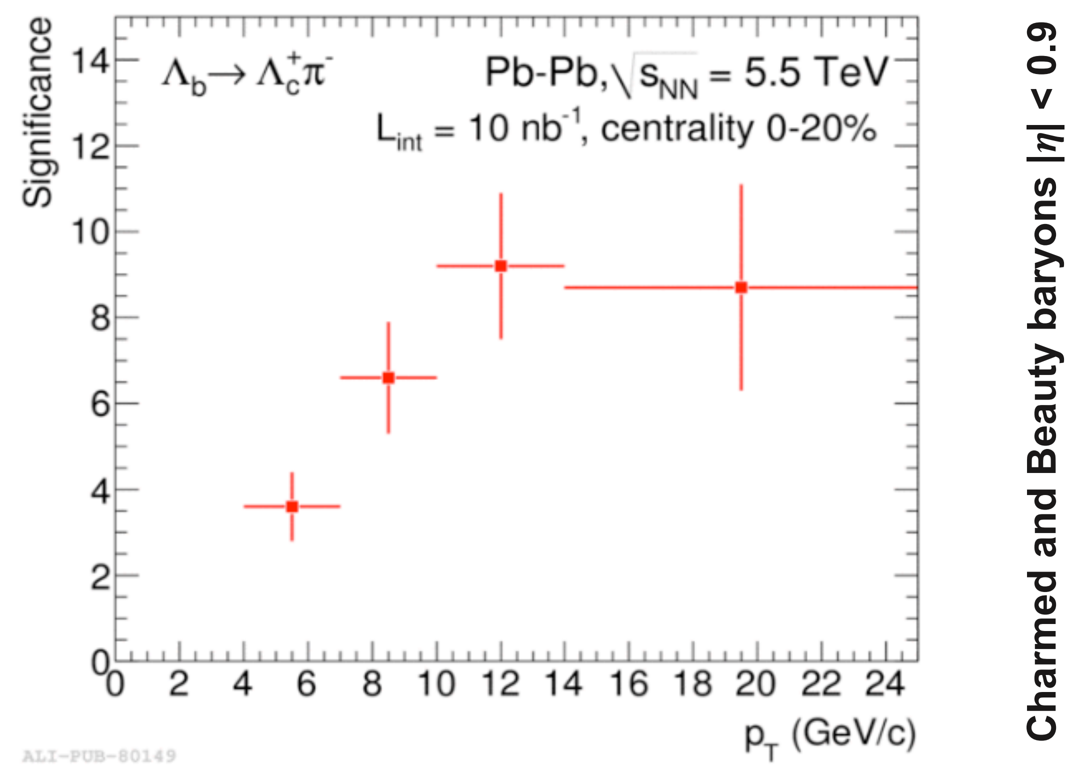
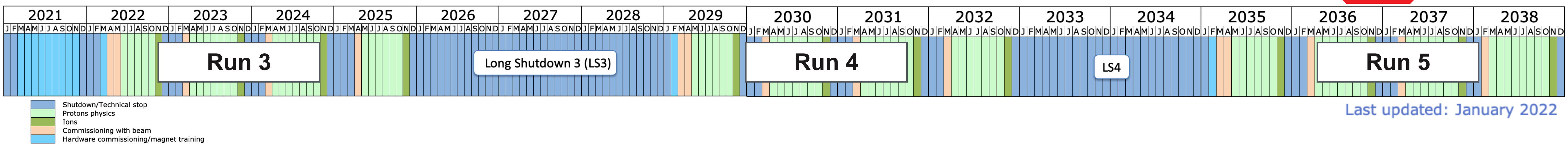


New observables in Pb-Pb: baryon production in the charm and beauty sector!
For the moment, only observed in pp and p-Pb collisions.

ALICE 2 in Run 3 and Run 4



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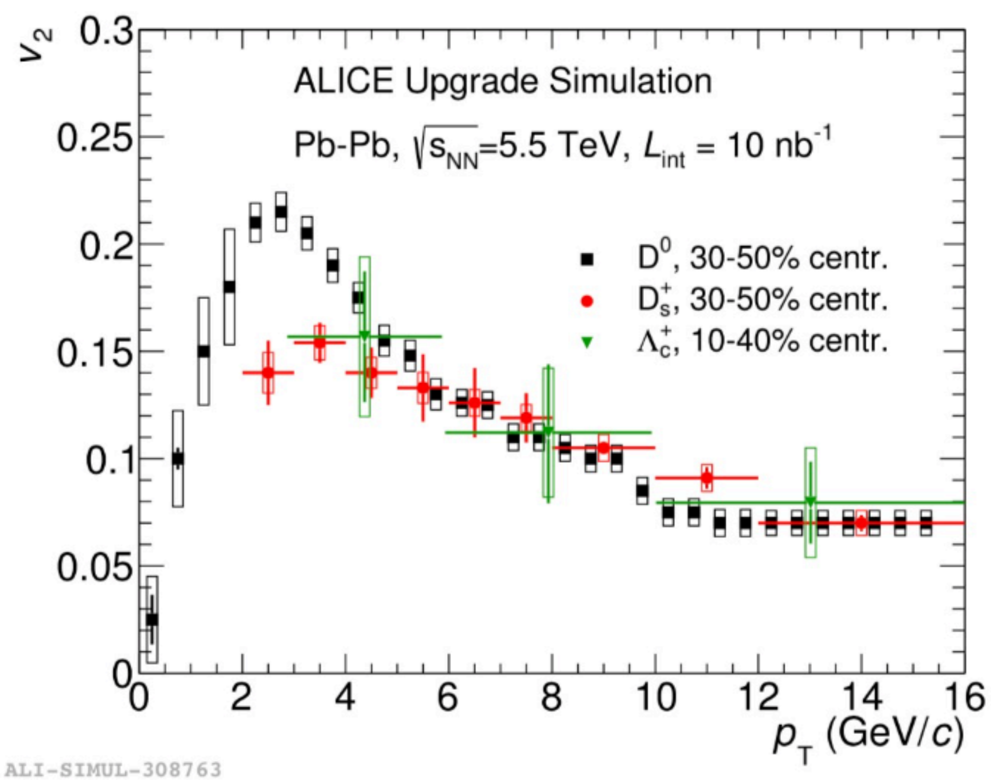

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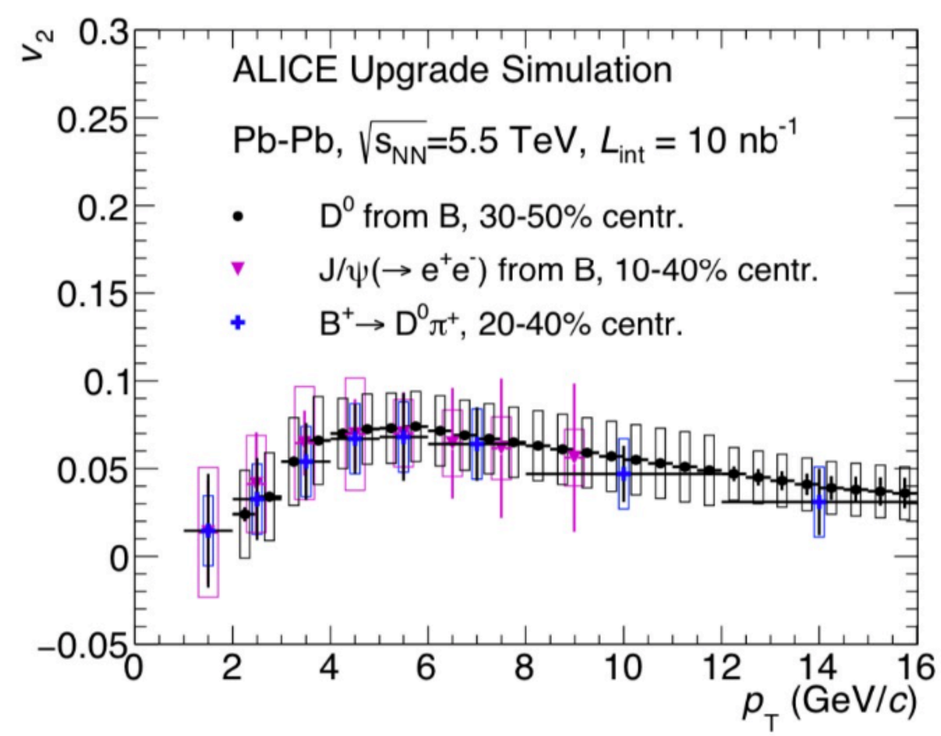
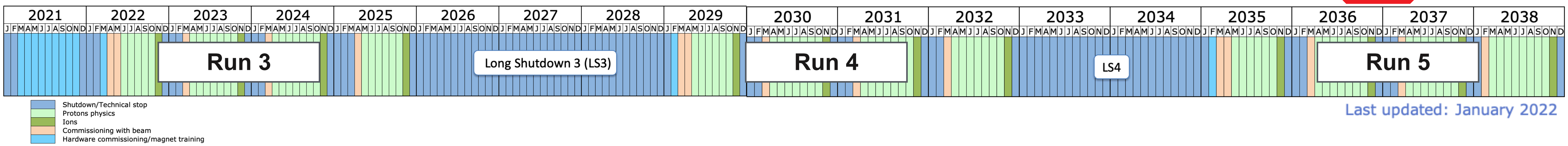


Charmed and Beauty baryons $|\eta| < 0.9$

Insight into the interactions with light quarks of the medium and reveal transport properties of the medium

ALICE 2 in Run 3 and Run 4



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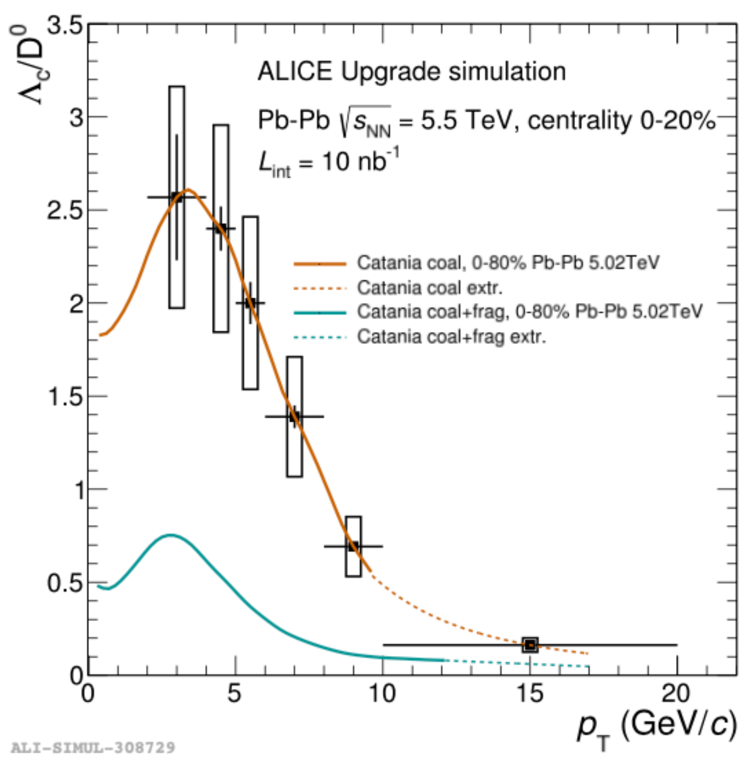

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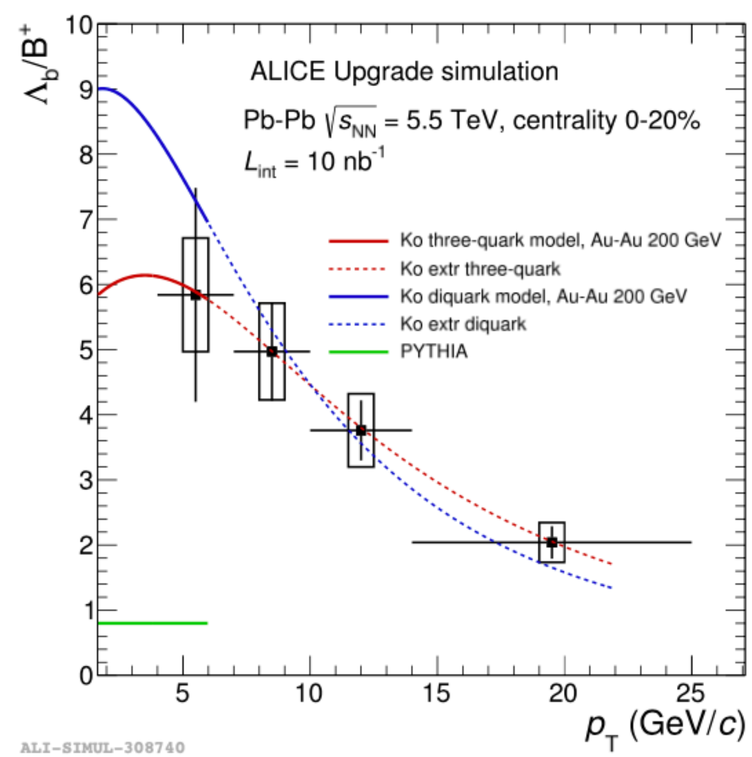

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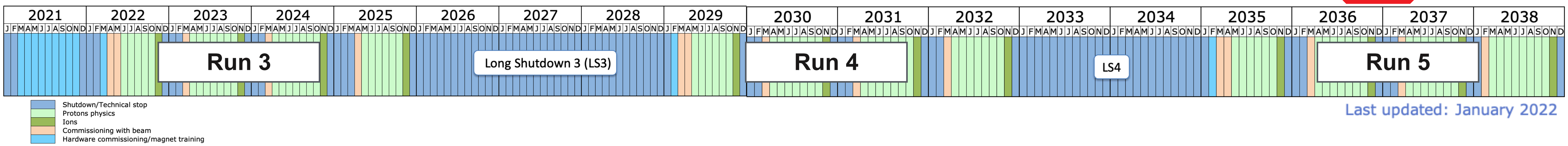
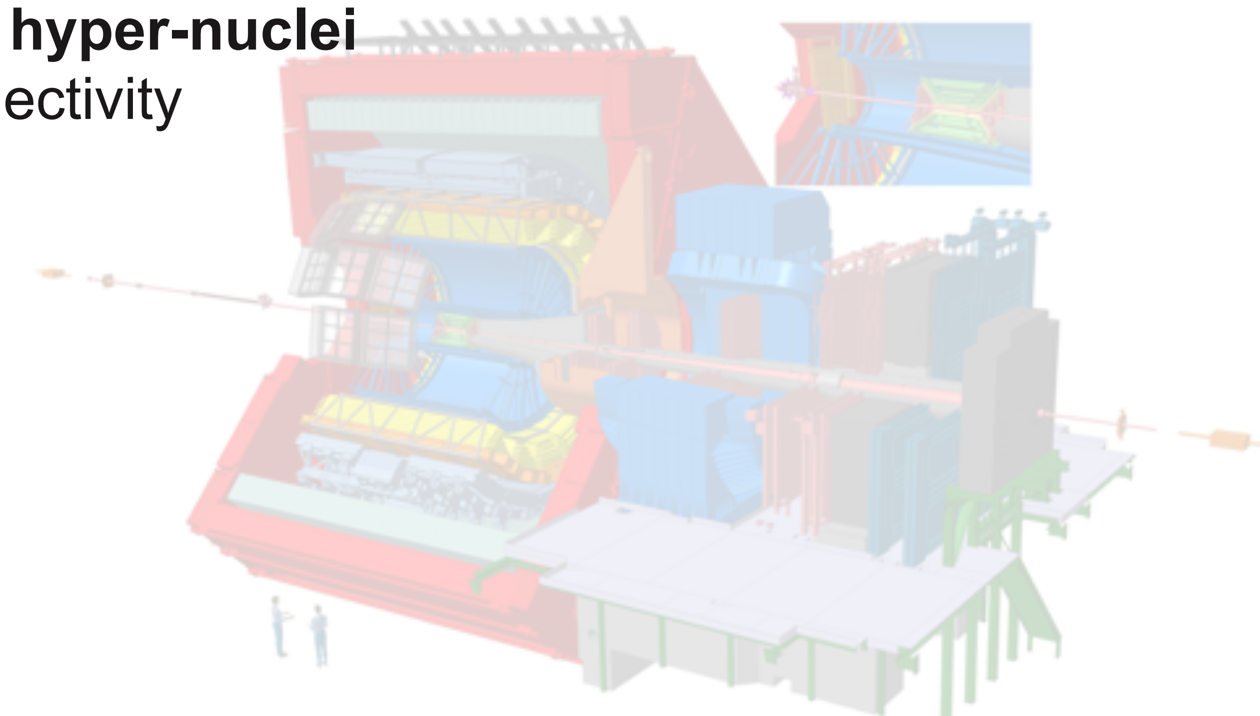


Physics goals

» Focus on high precision measurements of **rare probes at low p_T**

- **Heavy-flavour mesons and baryons (down to very low p_T)**
- **Charmonium states**
  → dissociation/regeneration as tool to study de-confinement and medium temperature
- **Dileptons from QGP radiation and low-mass vector mesons**
  → χ symmetry restoration, initial temperature
- **High precision measurement of light and hyper-nuclei**
  → production mechanism and degree of collectivity



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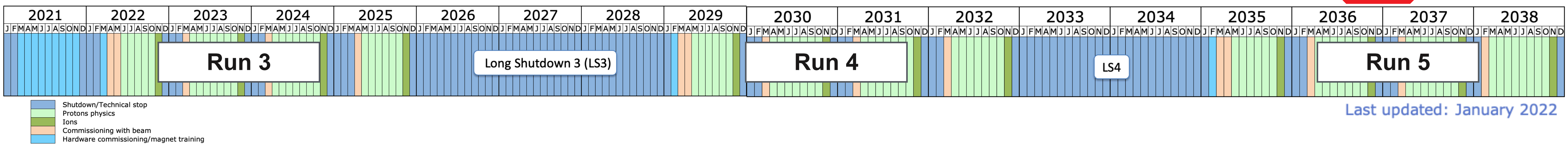

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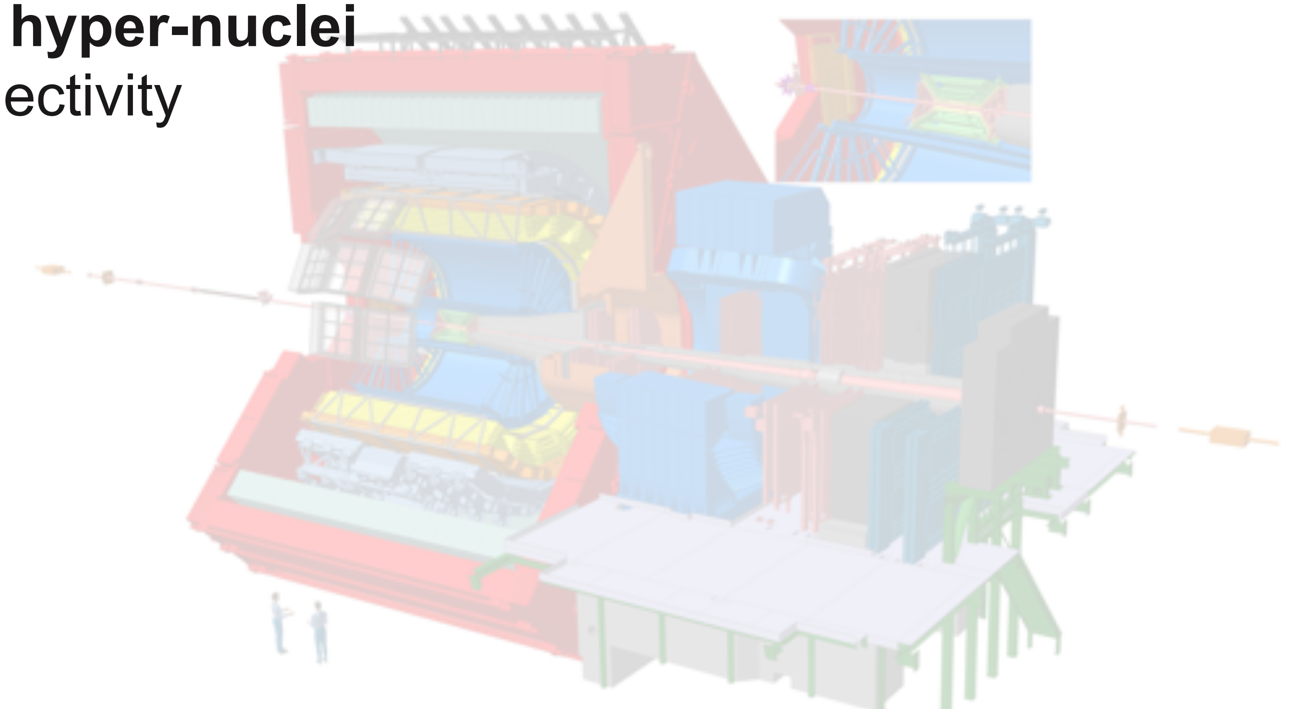
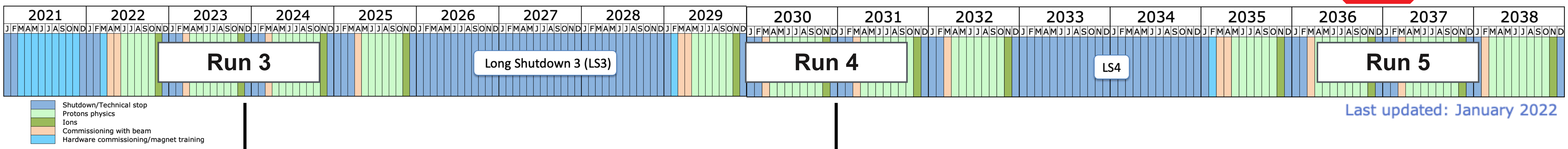


Very low S/B ratio prevents selection with hardware trigger

ALICE 2 in Run 3 and Run 4



Run 3: $\mathscr{L}_{\text{Pb-Pb}}$ = 6.0 nb^{-1}

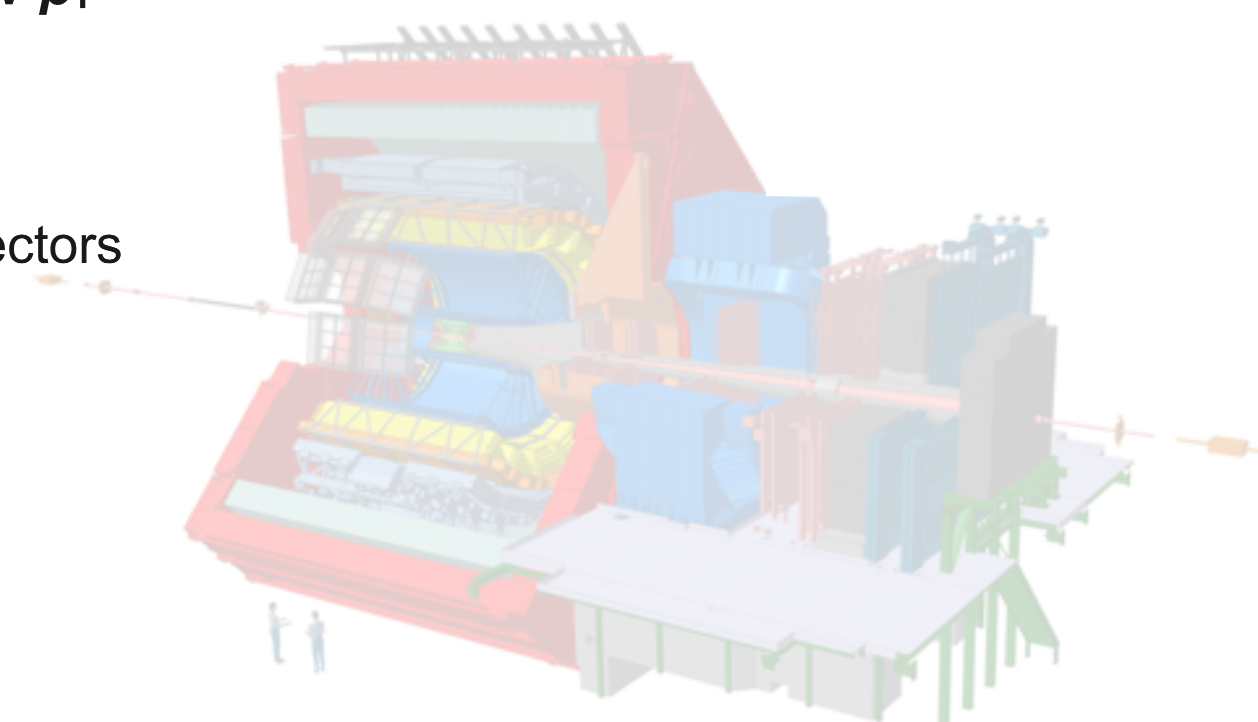
Run 4: $\mathscr{L}_{\text{Pb-Pb}}$ = 7.0 nb^{-1}

<u>Data taking strategy</u>

» **Record large minimum-bias data sample**
- → read out all Pb-Pb interactions up to maximum LHC collision rate of 50 kHz
- → collect $\mathscr{L}_{\text{Pb-Pb}}$ = 13 nb^{-1} (increase Run 2 minimum-bias sample by factor 50-100)

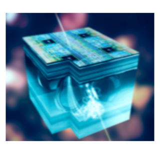
» **Improve tracking efficiency and resolution at low-p_T**
- → increase tracking granularity
- → reduce material thickness

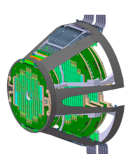
» **Preserve Particle IDentification (PID)**
- → Consolidate and speed-up main ALICE PID detectors

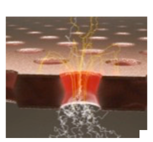


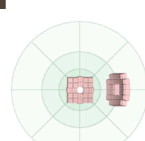
ALICE 2 in Run 3 and Run 4

LS2 upgrades

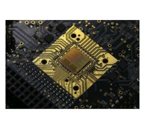
 New Inner Tracking System (ITS2)

 New Muon Forward Tracker (MFT)

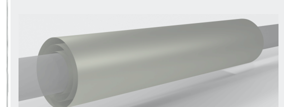
 New TPC Readout Chambers (ROCs)

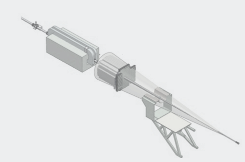
 New Fast Interaction Trigger (FIT) detector

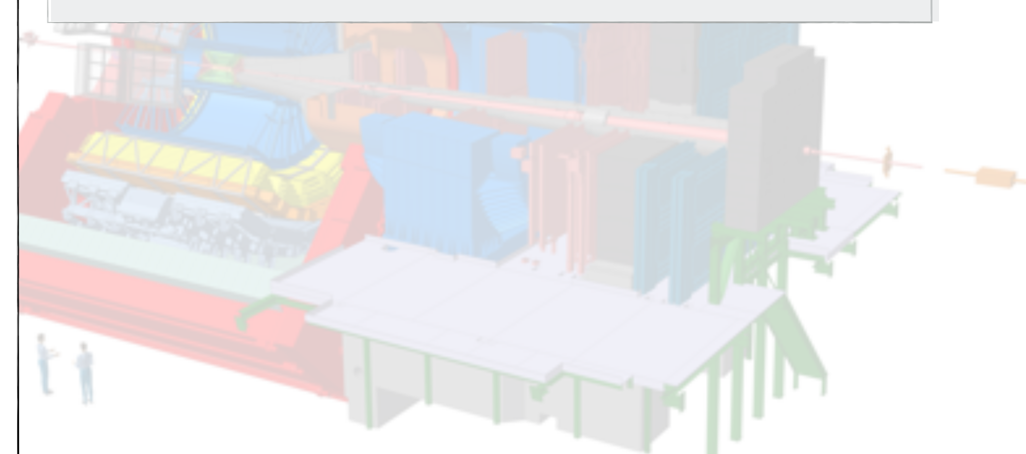
Integrated Online-Offline system (O^2)

 Readout upgrade for other detectors

LS3 upgrades

 New Inner Tracking System (ITS3)

 New Forward Calorimeter (FoCal)



ALICE 2 - LS2 upgrade

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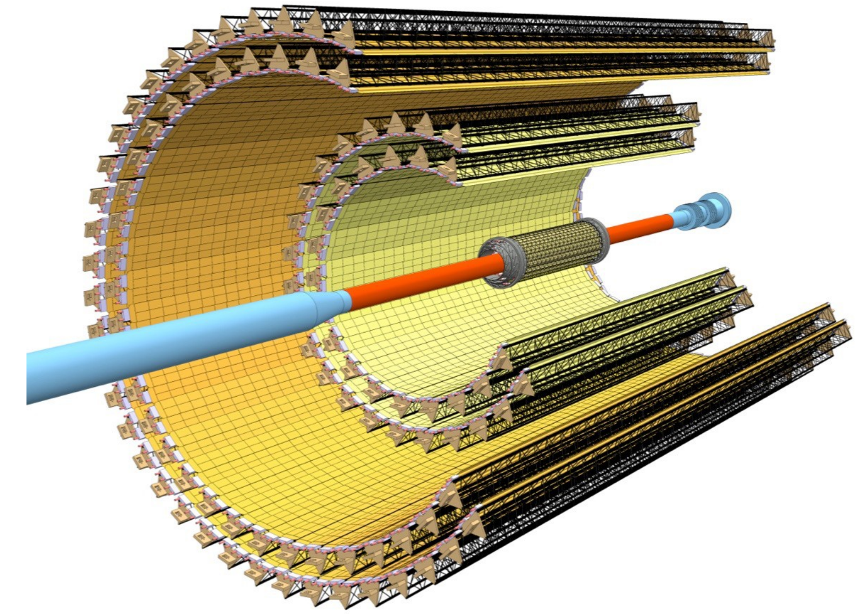


10 m² active silicon area
12.5×10⁹ pixels

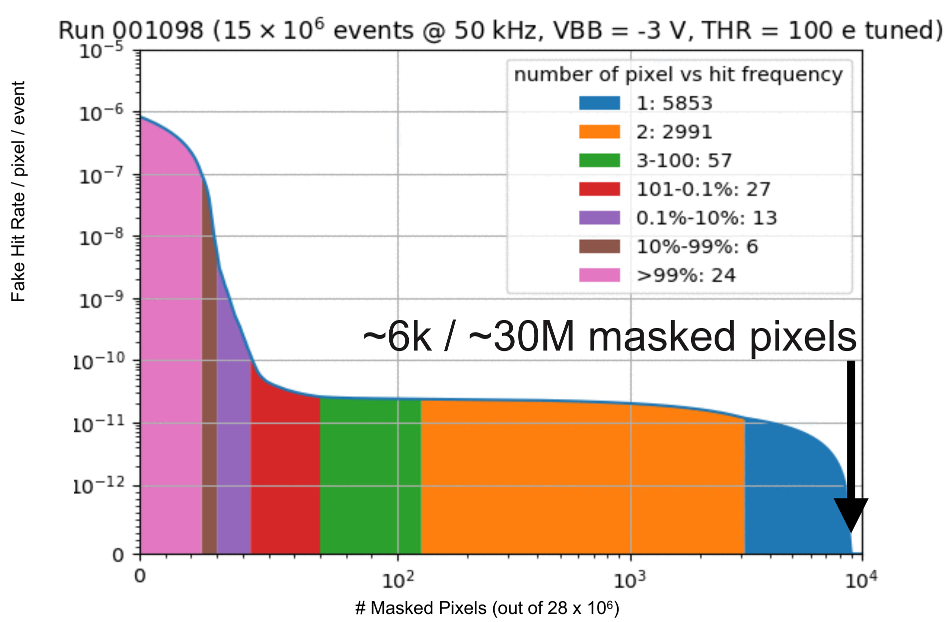
<u>ITS upgrade **requirements**</u>

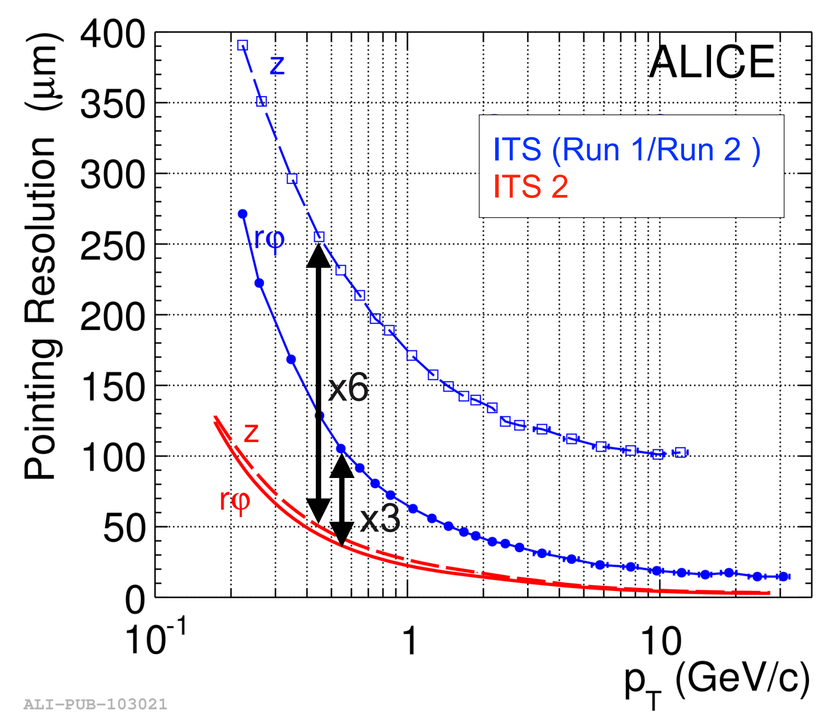
» Improve impact parameter resolution
- Reduce IP-to-first layer distance (new beam pipe) → *22 mm*
- Reduce material budget → *0.35%* X_0 *(Innermost layers)*
- Reduce pixel size → *~30 x 30 μm²*

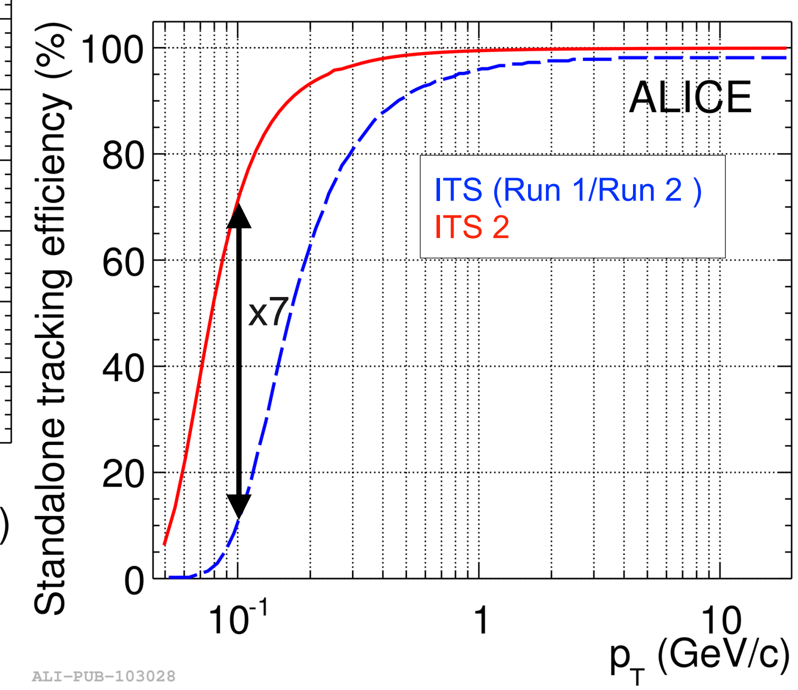
» Improve tracking efficiency and p_T resolution at low p_T
- Increase granularity → *from 6 to 7 layers, all pixels*
- Increase readout capabilities → *100 kHz*

<u>ALPIDE Monolithic Active Pixel Sensor</u>

» High detection efficiency (>99%)
» Low fake-hit rate (<< 10^{-6} /pixel/event)







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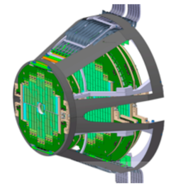
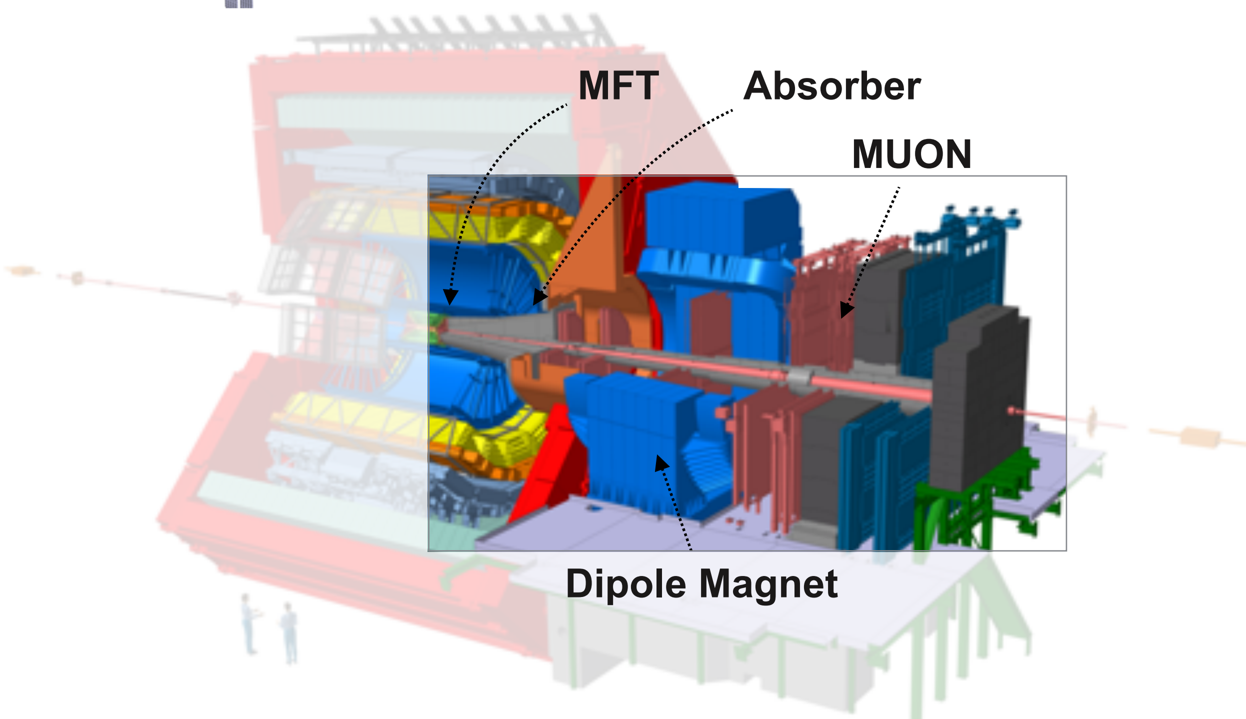
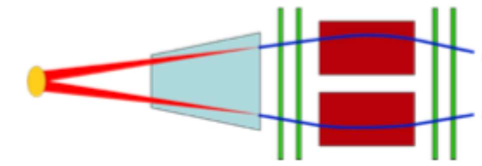


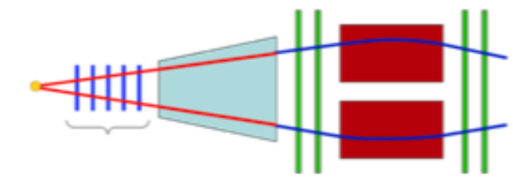
New Muon Forward Tracker (MFT)

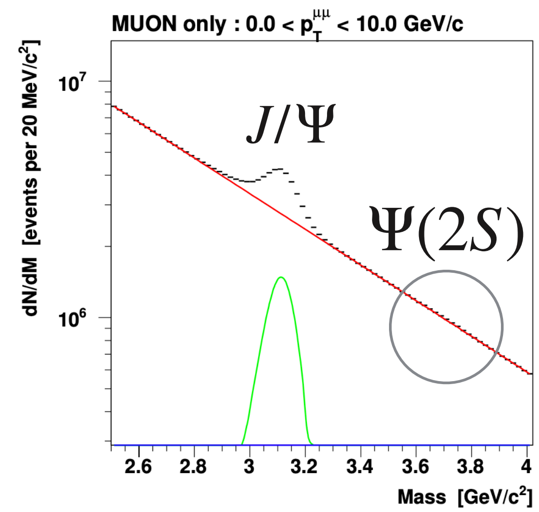


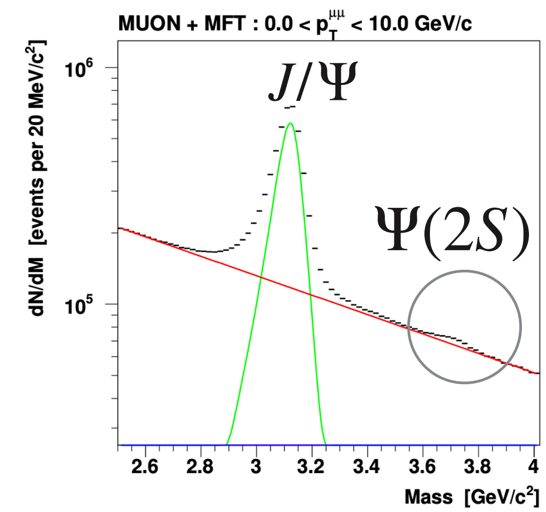
MUON Spectrometer Only



MUON + MFT



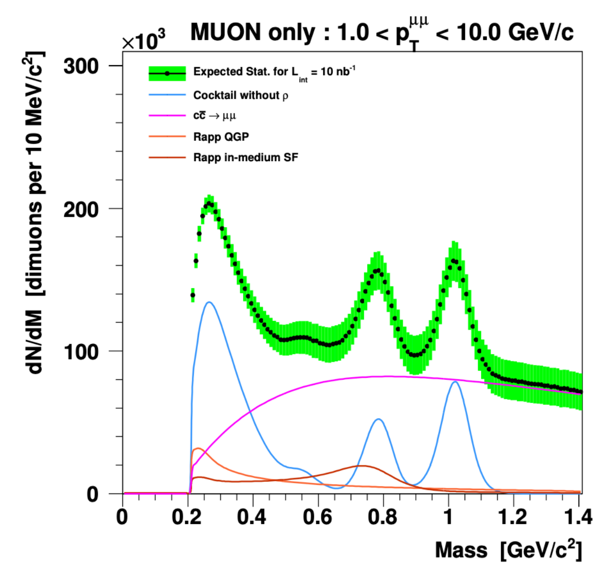


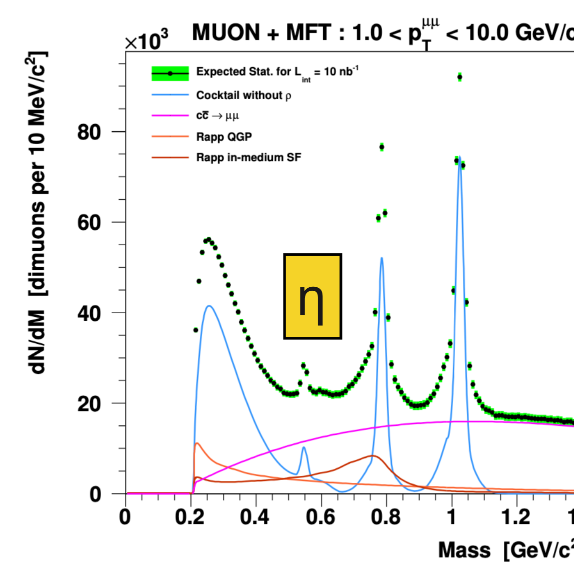


→ J/ψ background reduced by a factor 6-7
→ ψ(2S) visible even in central Pb-Pb

Muon Spectrometer (MUON)
» Absorber suppresses all particles except muons
» **Limitation**: multiple scattering in absorber smears track information at vertex

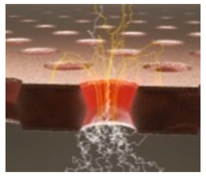
Muon Forward Tracker (MFT)
» Add vertexing and tracking capabilities to MUON
→ matching muon track with MFT tracks
→ prompt and displaced J/ψ disentangling
→ precise measurement of low-mass dimuons



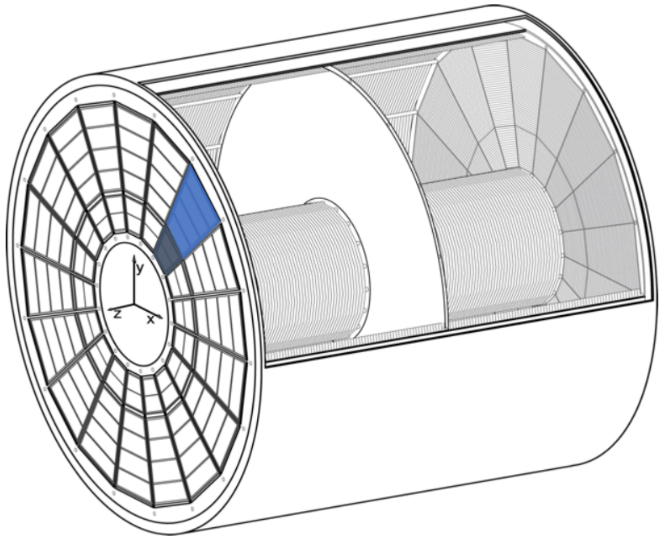


→ Low-mass region: mass resolution improved
→ η peak visible

Fully based on ALPIDE MAPS



New TPC Readout Chambers (ROCs)

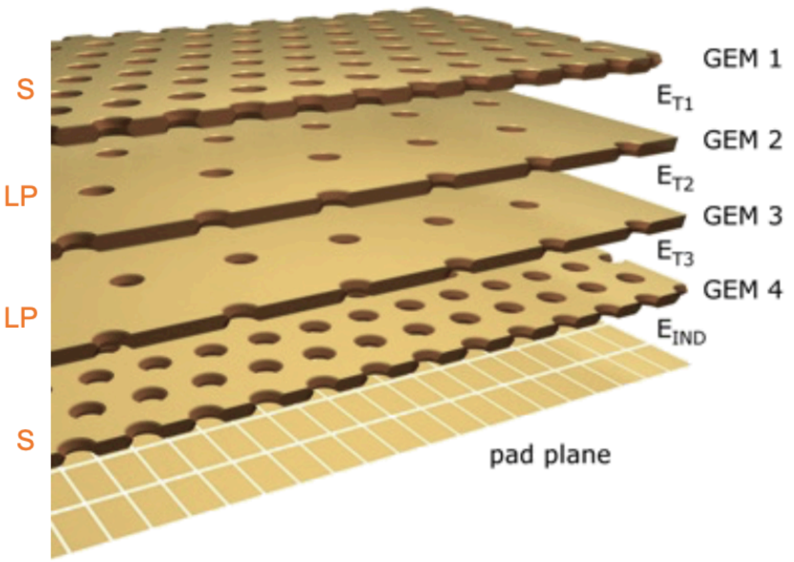


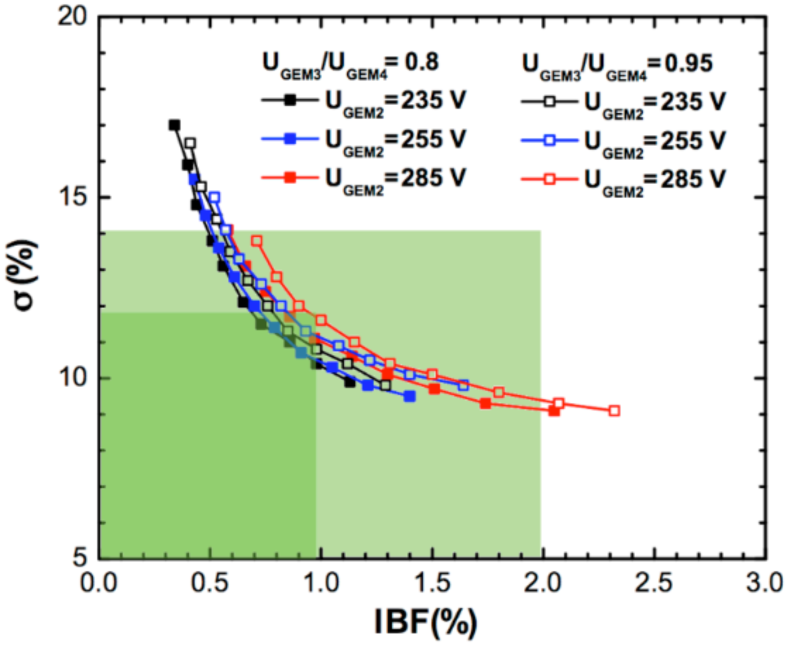
<u>Readout chambers replacement: **MWPC → GEM stack**</u>
» Removes rate restriction (due to the usage of Gating Grid)
» Reduces ion back-flow to under 1% → no Gating Grid
» Space charge distortions are minimised preserving PID capabilities

» Diameter/Length: 5 m/5 m
» Gas: Ne-CO_2-N_2, Ar-CO_2
» Max. drift time: ~100 μs

Continuous readout TPC at 50 kHz → average pileup of 5 events
• more than 3 TB/s → GPU-based data reduction

<u>New readout chambers: 4-GEM stack</u>
» Combination of standard (S) and large pitch (LP) GEM foils
» Highly optimised HV configuration

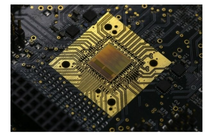




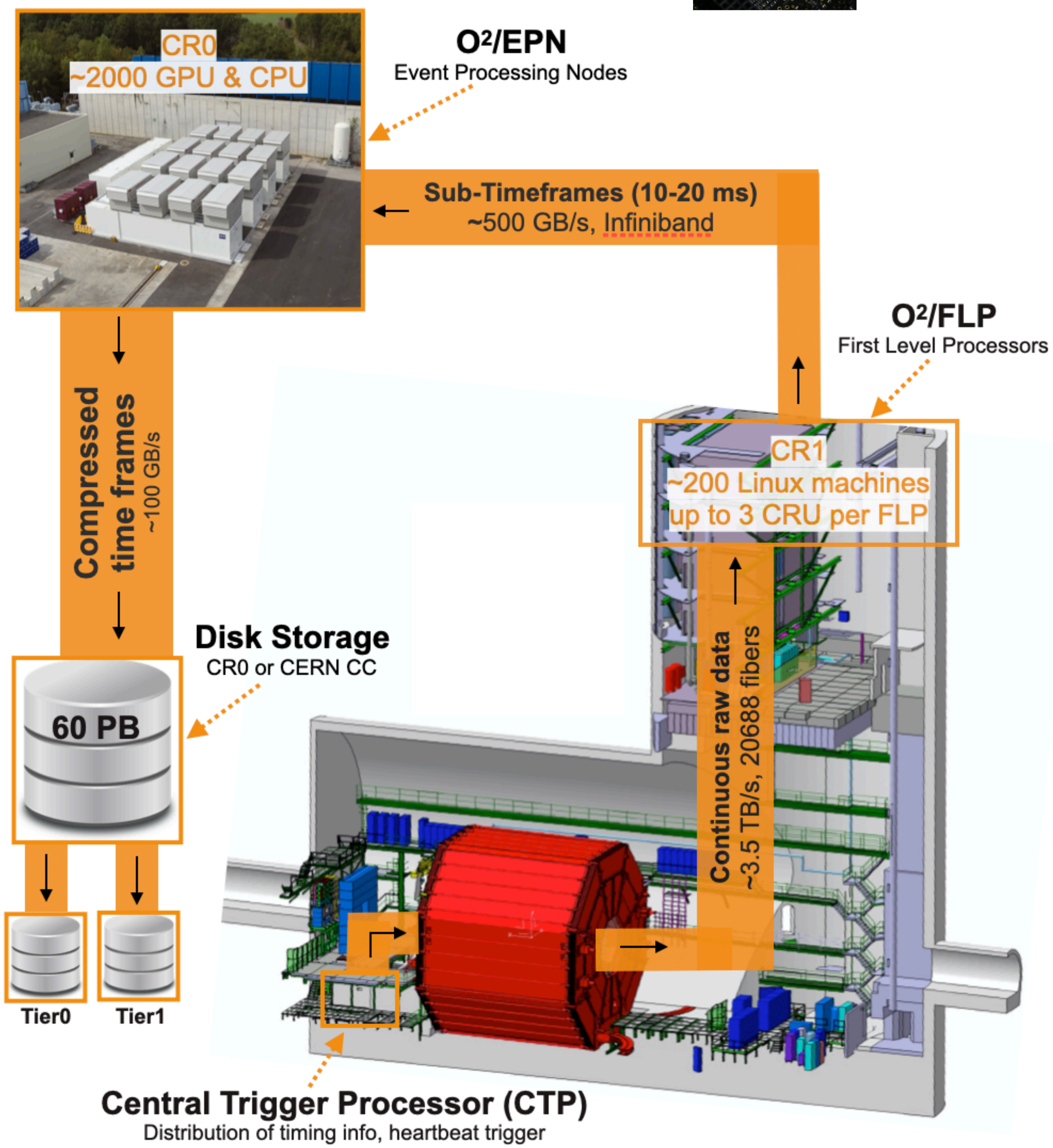
Conservative operational limits: IBF < 1 %, local energy resolution < 12 %
Extended operational range: IBF < 2 %, energy resolution < 14 %

ALICE 2 - LS2 upgrade

Integrated Online-Offline system (O^2)



Readout upgrade for other detectors

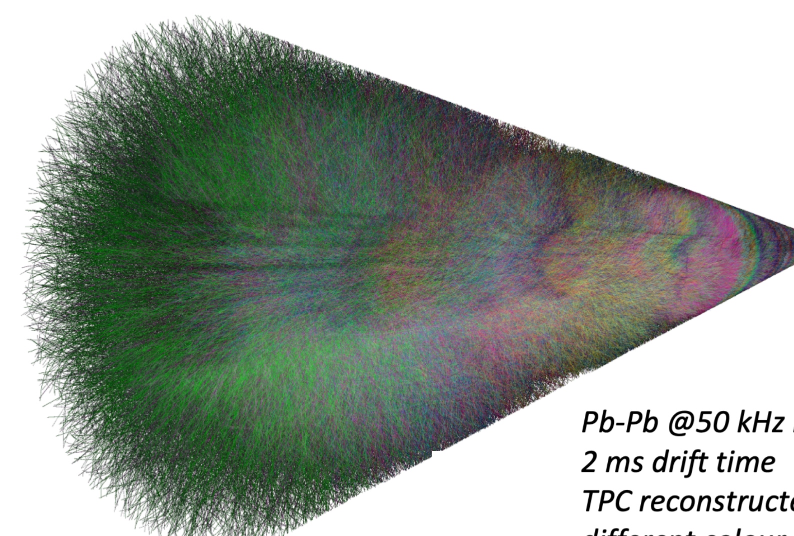


» **Continuous readout**
- Upgrade of all detector readout boards
- Heartbeat from CTP
- Timeframe (instead of events)

» **Multi-step reconstruction chain**
- Detector → FLP → EPN → Storage

» **Synchronous processing (EPN farm)**
- Data volume reduction (factor 35)
- Online calibration
- Clusterization and tracking (using GPUs)
  → Compressed Time Frames (CTF)

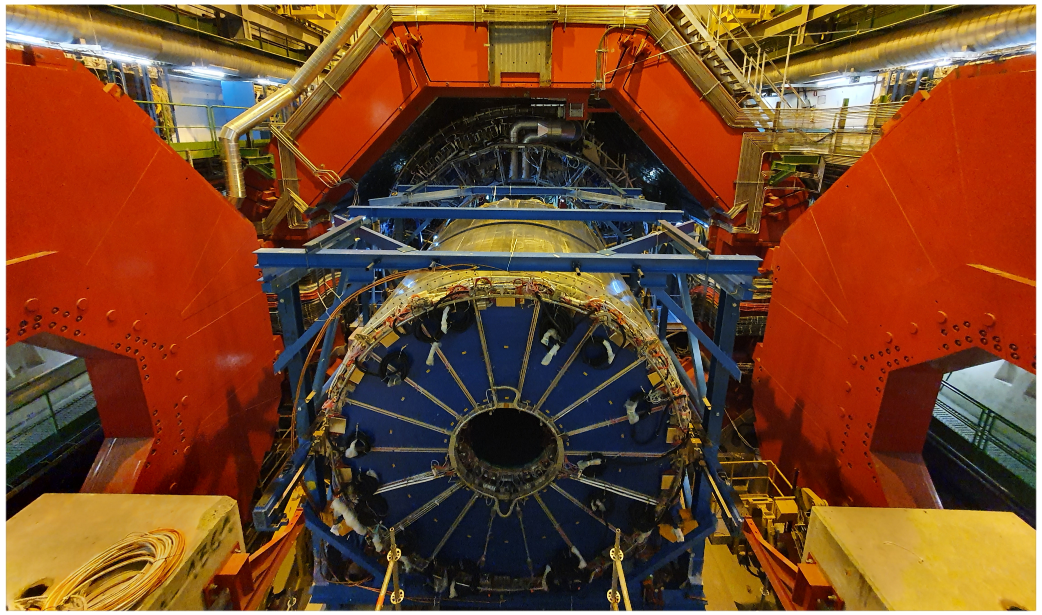
» **Asynchronous processing (EPN farm/T0/T1)**
- Final refined reconstruction
  → Analysis Object Data (AOD)



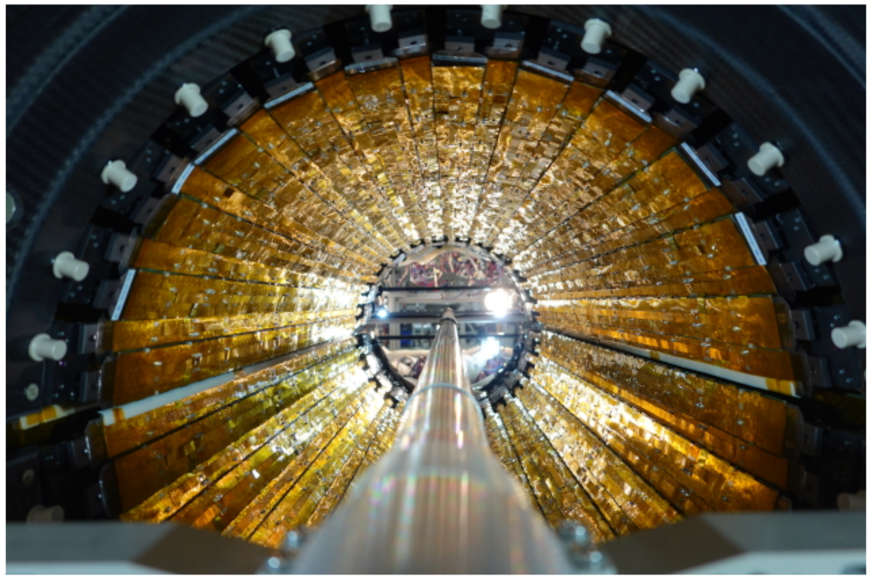
Pb-Pb @50 kHz IR
2 ms drift time
TPC reconstructed tracks from
different colour-coded events

ALICE 2 - LS2 upgrade

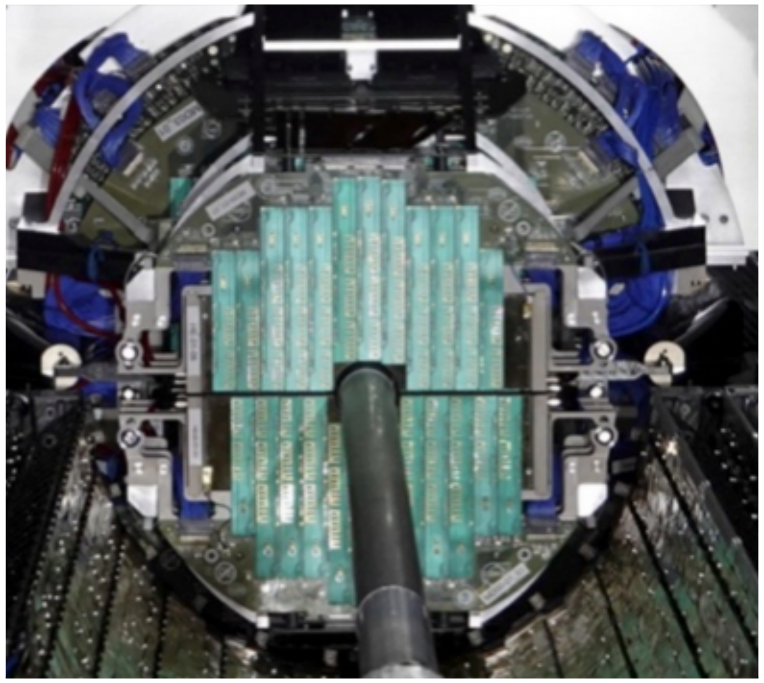
TPC installation (Aug 2020)



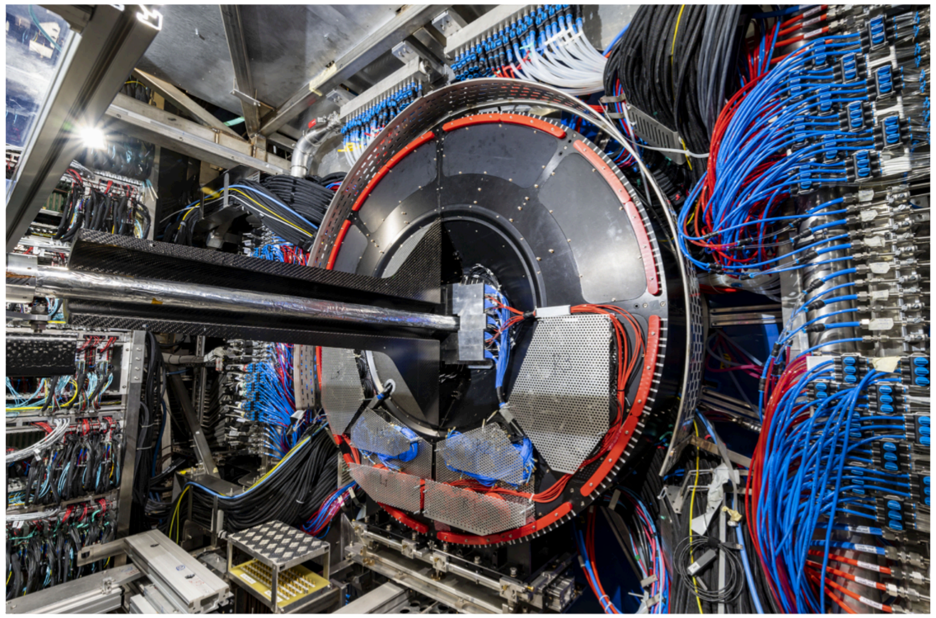
ITS installation (Feb-Jun 2021)



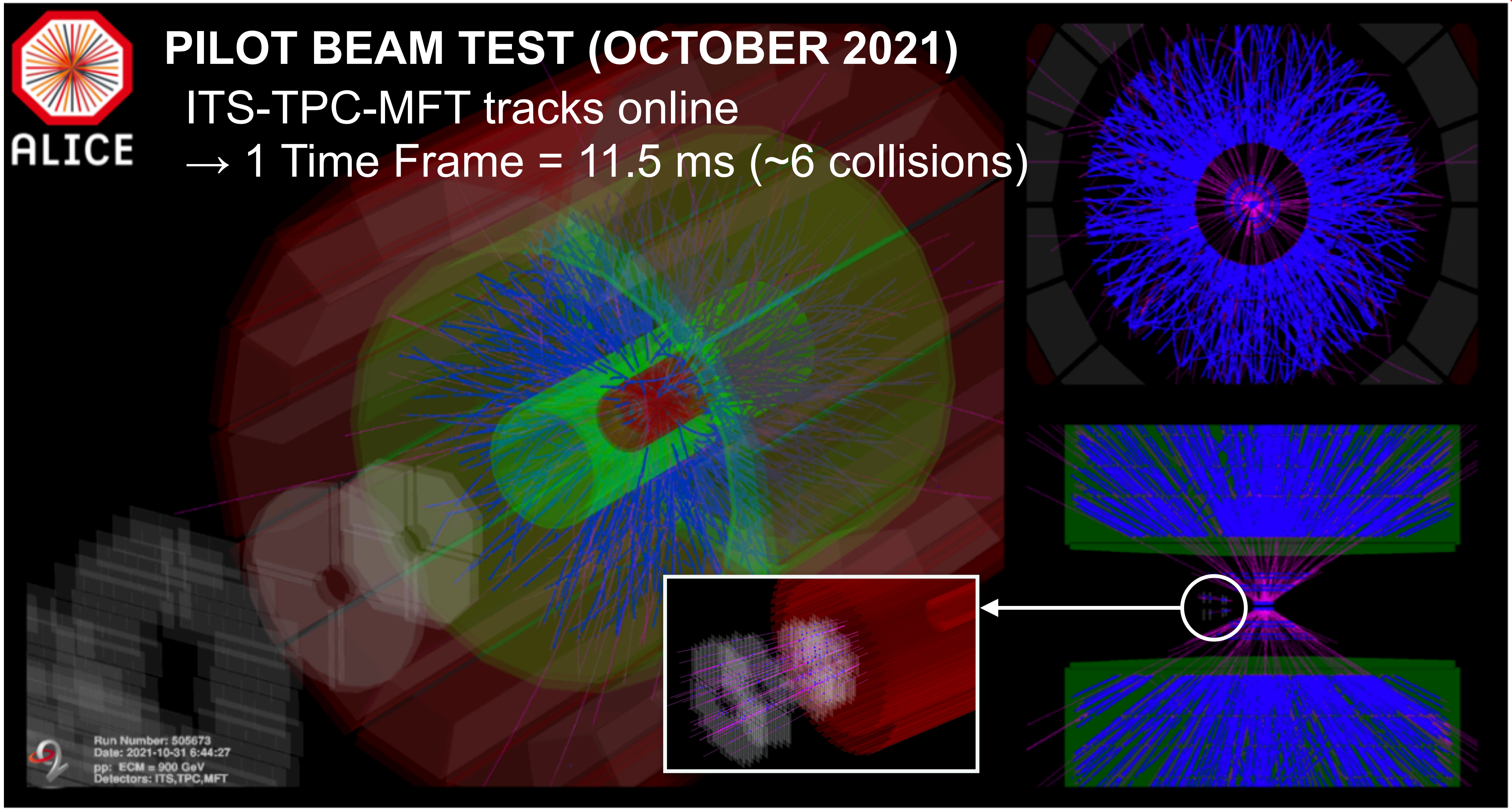
MFT installation (Jan 2021)

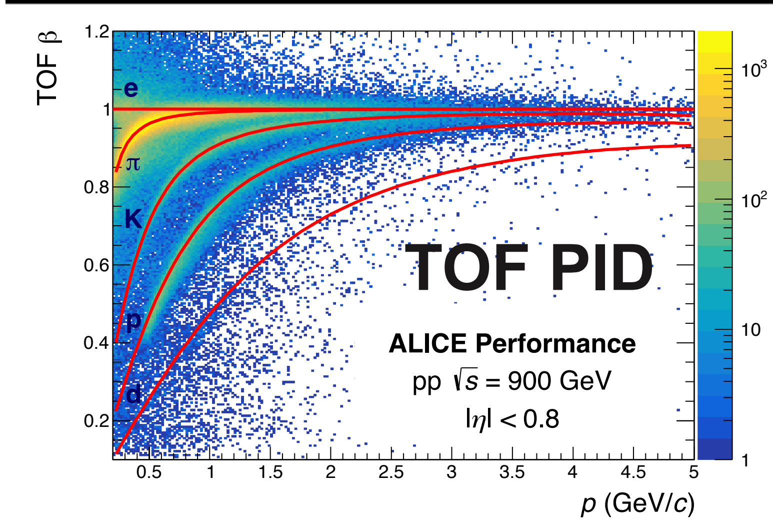


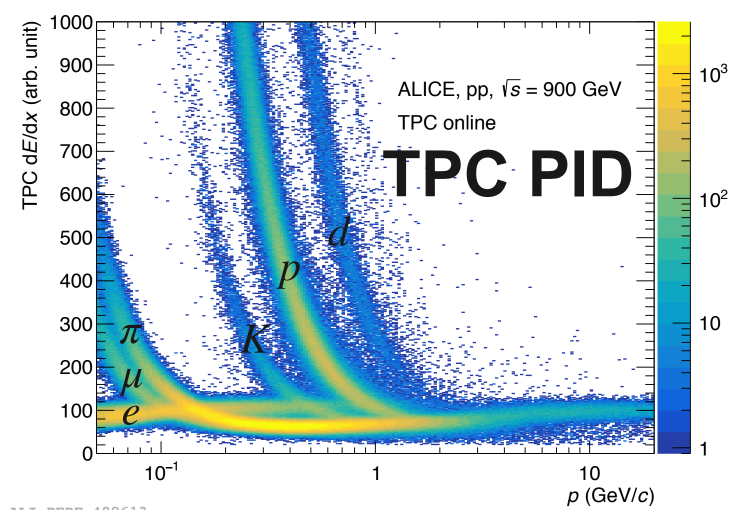
FIT installation (Jan-Jul 2021)

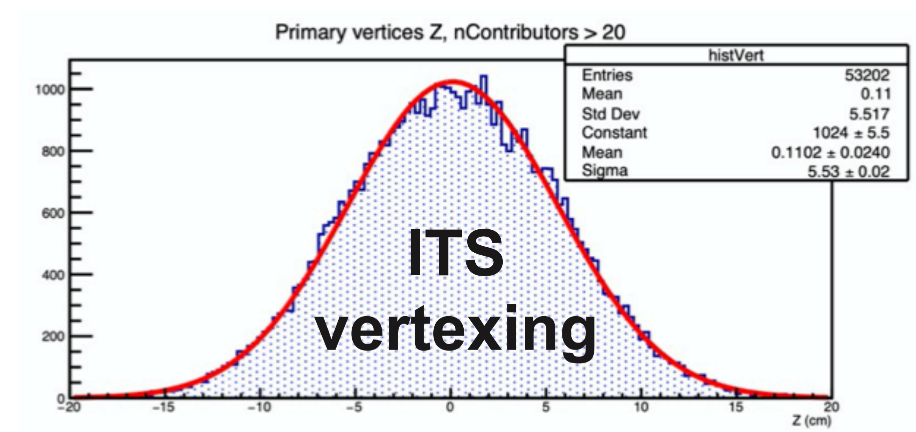


ALICE 2 - LS2 upgrade



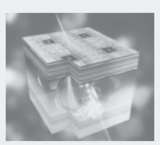






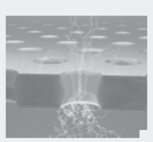
ALICE 2 in Run 3 and Run 4

LS2 upgrades

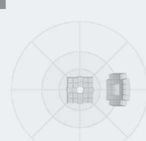


New Inner Tracking System (ITS2)

New Muon Forward Tracker (MFT)

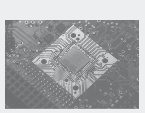


New TPC Readout Chambers (ROCs)



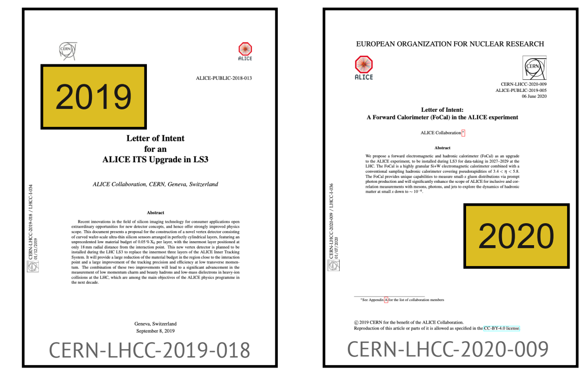
New Fast Interaction Trigger (FIT) detector

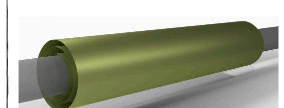
Integrated Online-Offline system (O²)



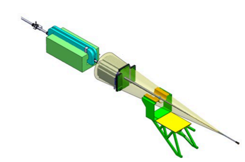
Readout upgrade for other detectors

LS3 upgrades

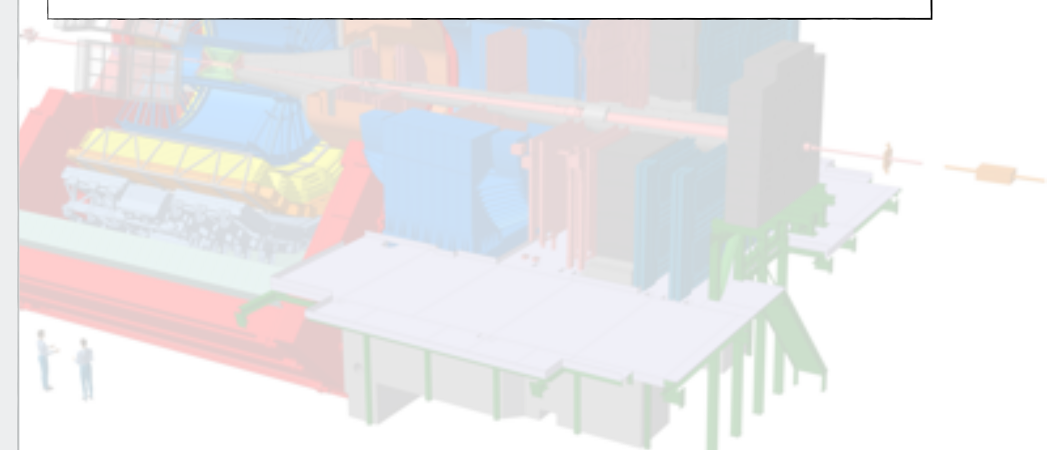




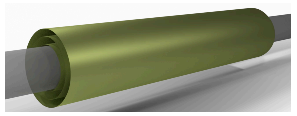
New Inner Tracking System (ITS3)



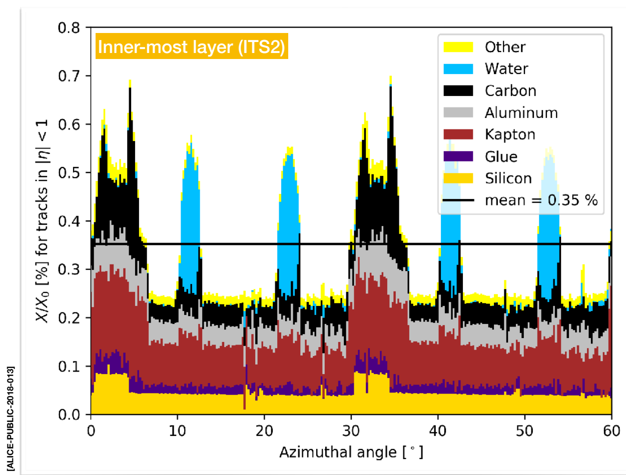
New Forward Calorimeter (FoCal)

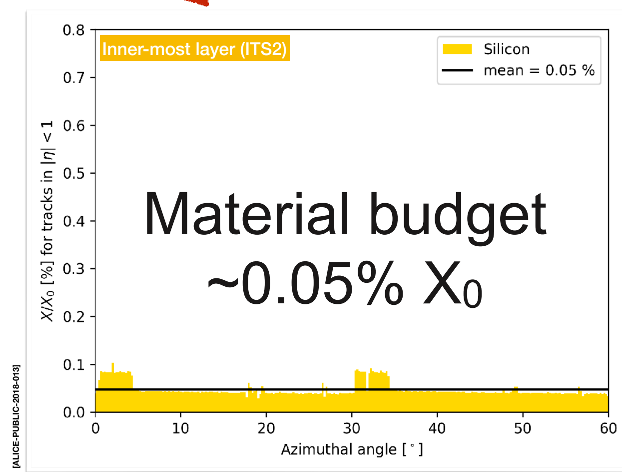


ALICE 2 - LS3 upgrade

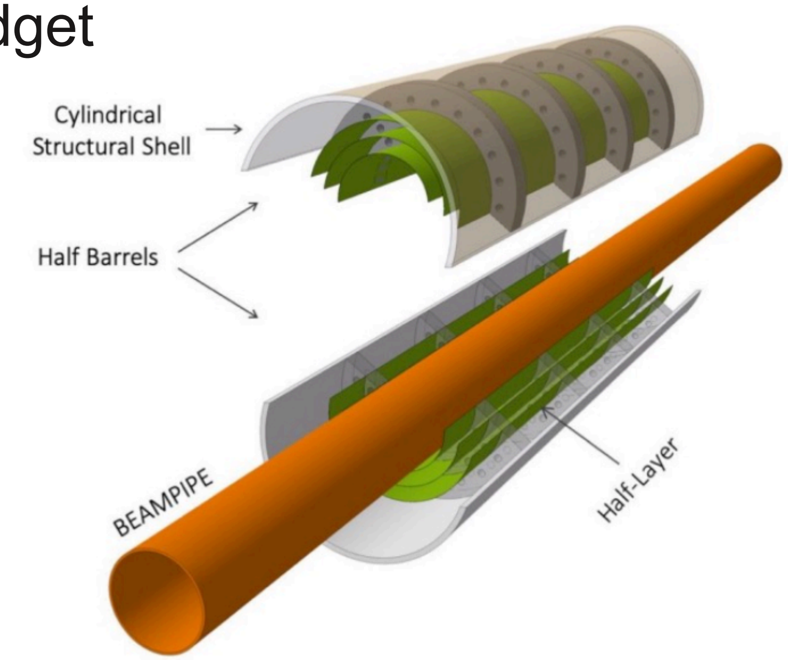


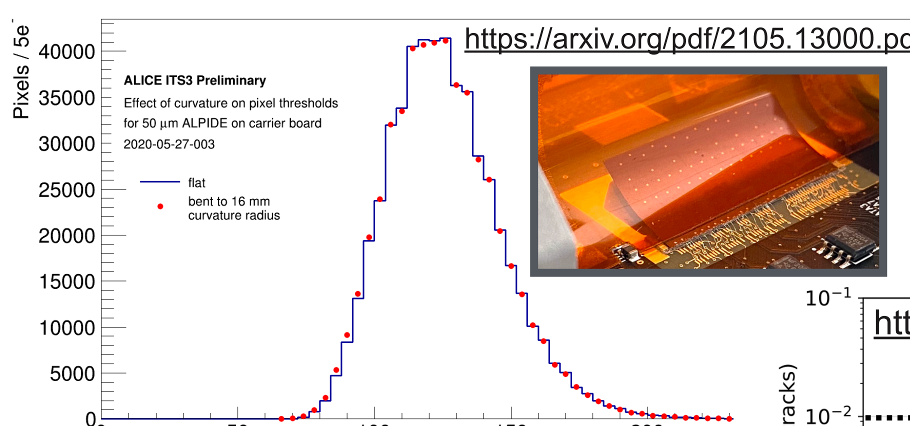
New Inner Tracking System (ITS3)

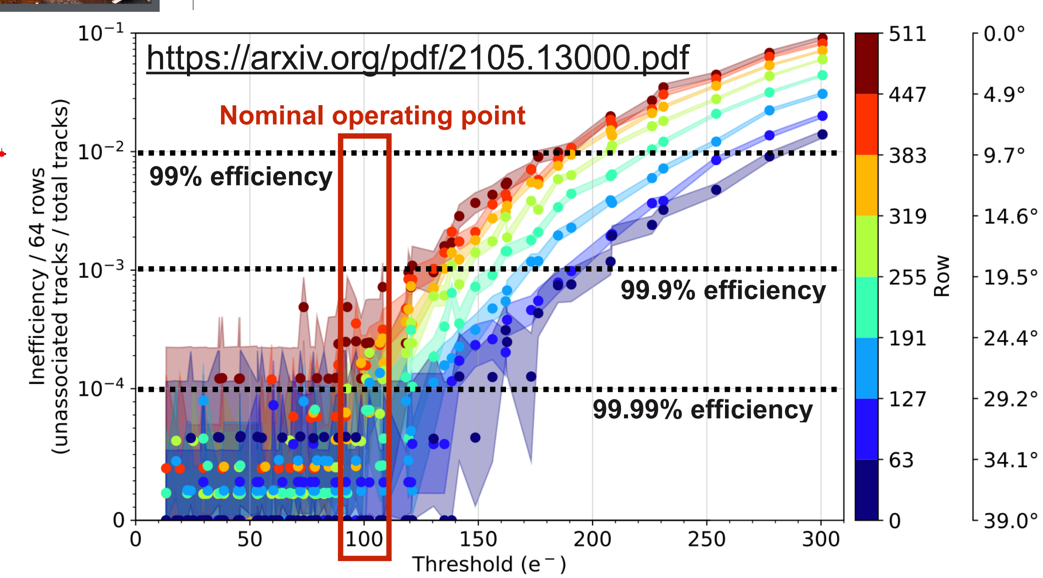




Truly cylindrical, wafer-size sensors for homogeneous inner tracker with ultra-low material budget



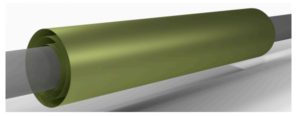




Well advanced R&D

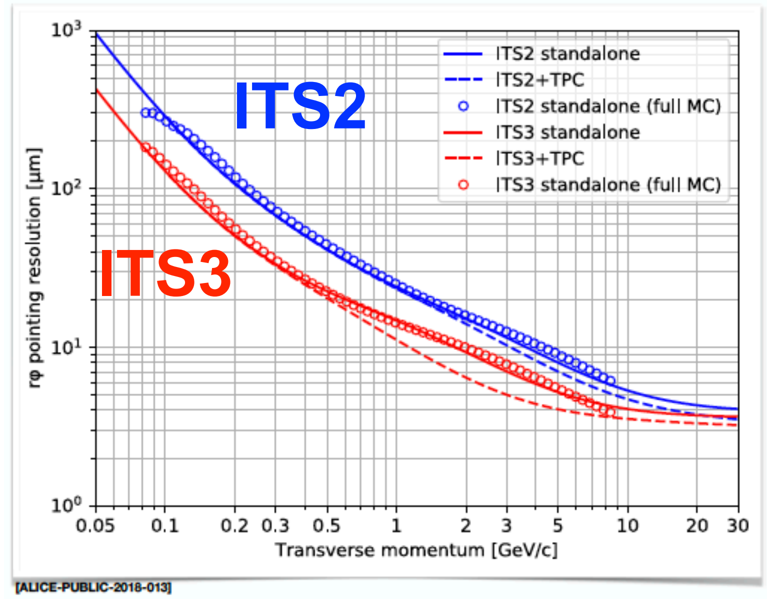
» Bent ALPIDE (18 mm radius) as efficient as when flat
» Silicon bending procedure developed (thickness <50 µm)
» New chip (65 nm technology)
  • First digital/analog structures under characterisation
  • First stitching application submitted for production

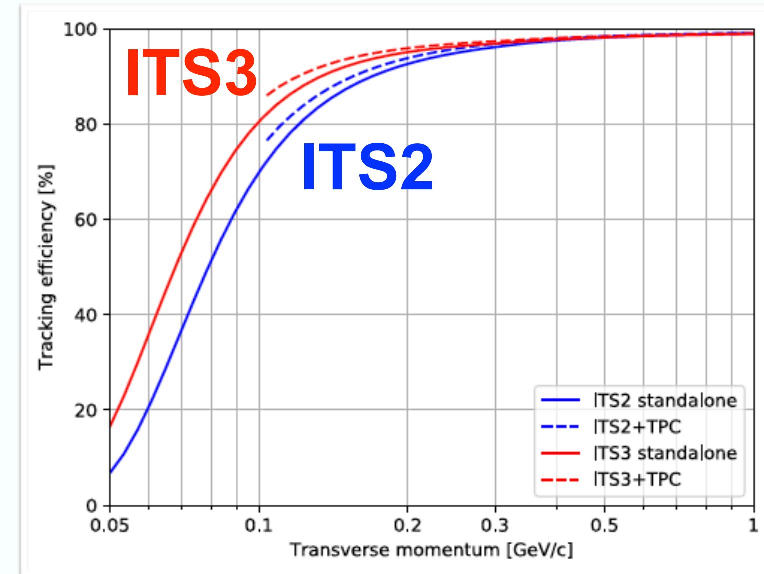
ALICE 2 - LS3 upgrade

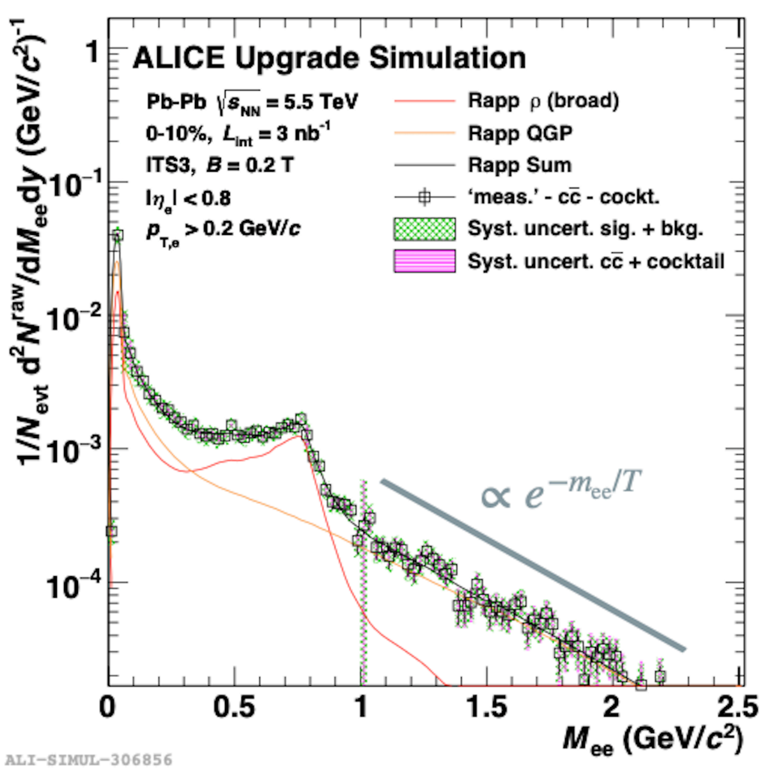


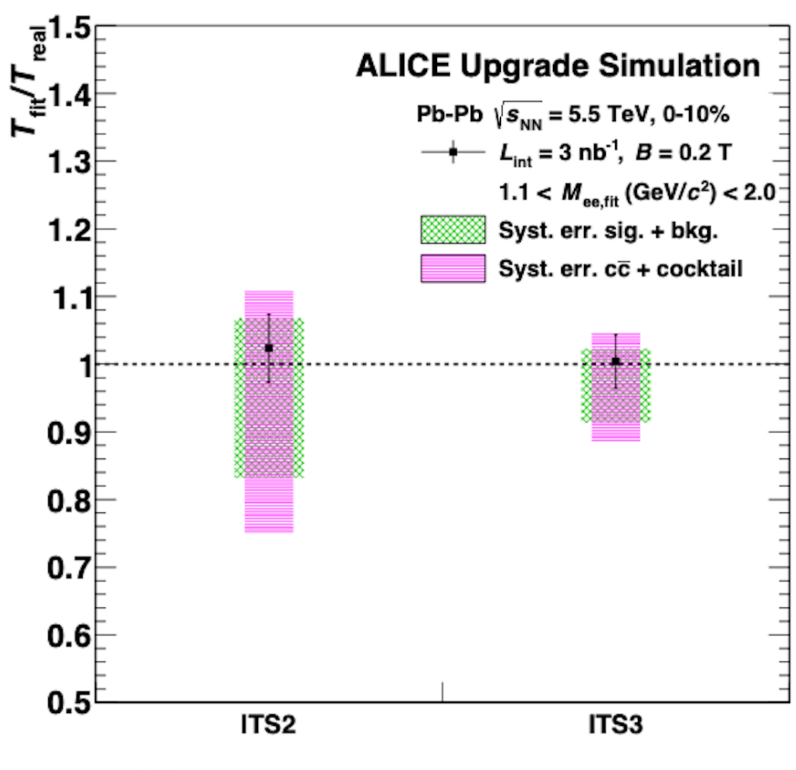
New Inner Tracking System (ITS3)

» Improved pointing resolution and tracking efficiency for low momenta (×2 at all p_T)





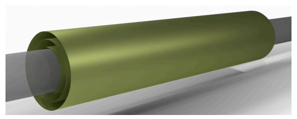




Low-mass dileptons and thermal radiation

» Better charm rejection (vertexing)
» Reduced contribution from conversion (low material budget)
» Reduced systematic uncertainties by a factor of 2
» Reduced statical uncertainties by a factor of 1.3

ALICE 2 - LS3 upgrade



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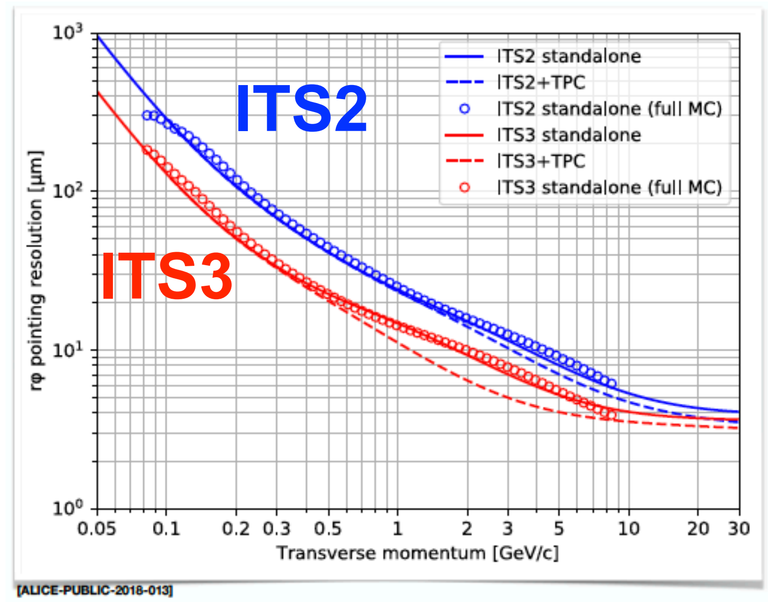
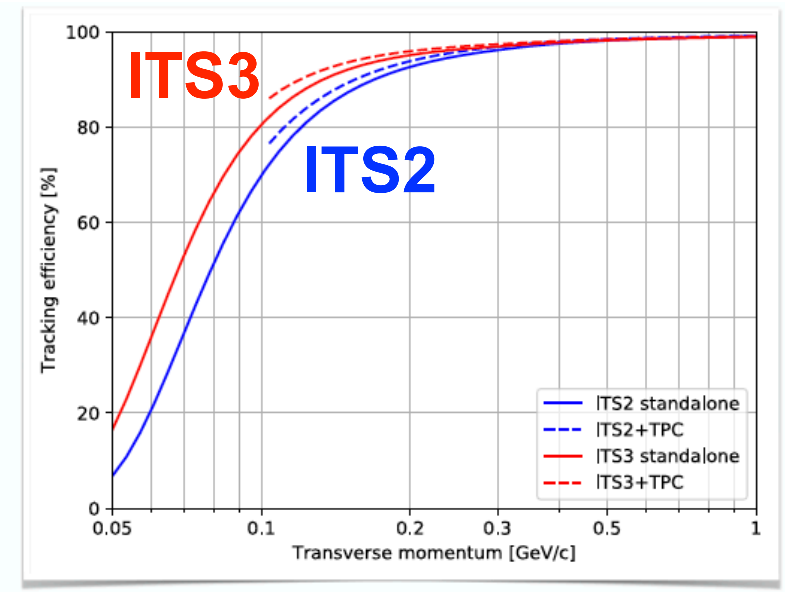
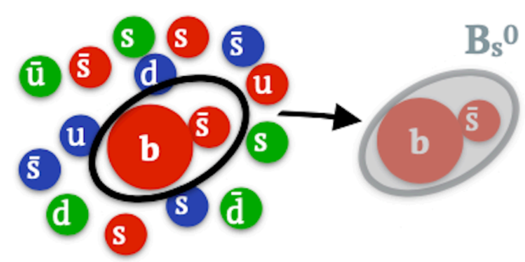


[ALICE-PUBLIC-2018-013]

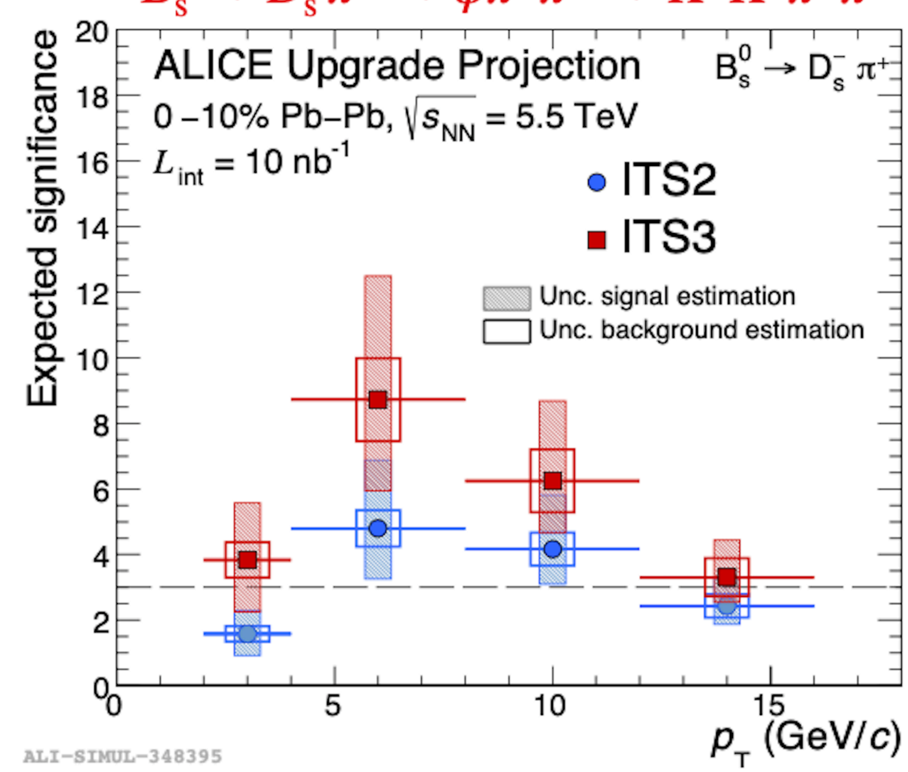


Beauty-quark hadronisation

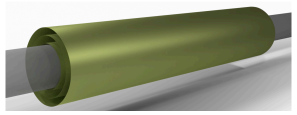


» B_S^0 production expected to be enhanced
- hadronisation of beauty quarks via recombination + enhanced strange-quark production in the QGP

$B_s^0 \rightarrow D_s^-\pi^+ \rightarrow \phi\pi^-\pi^+ \rightarrow K^+K^-\pi^-\pi^+$

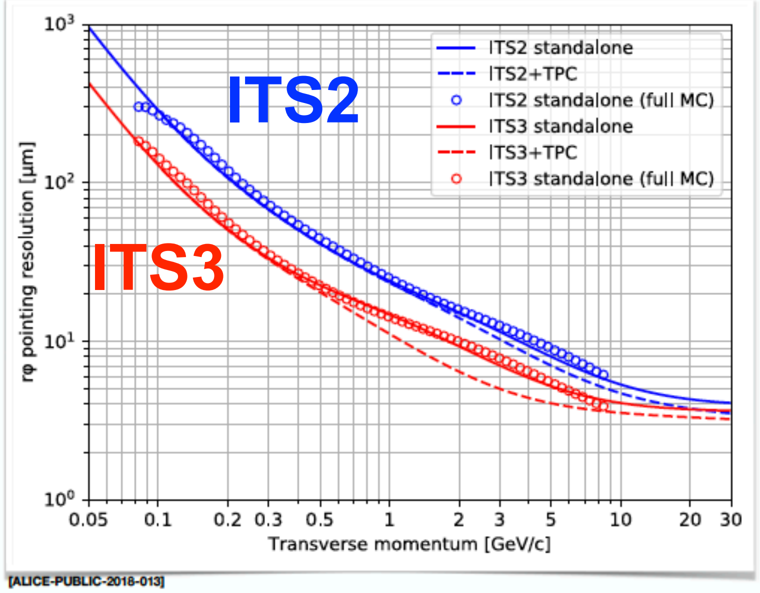


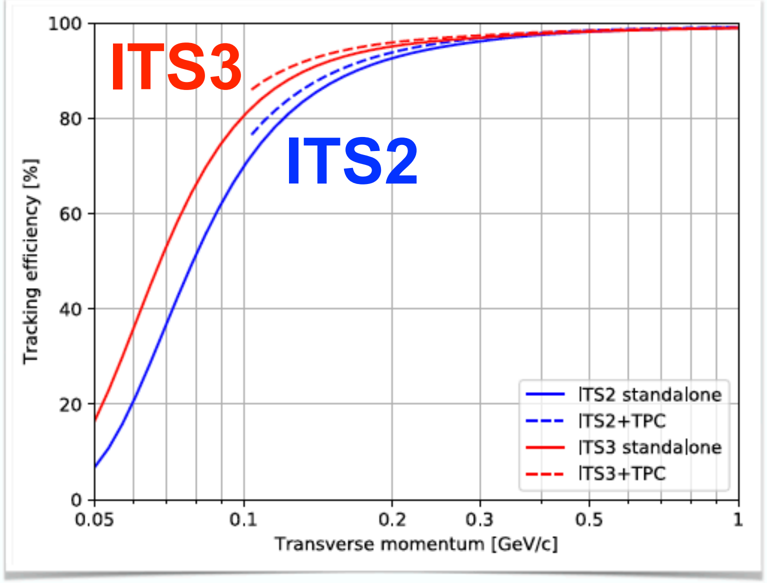
» Significance improvement by a factor 2 with ITS3
→ access to B_S^0 at very low p_T



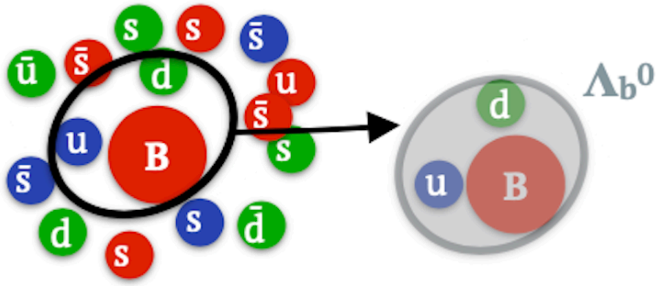
New Inner Tracking System (ITS3)

» Improved pointing resolution and tracking efficiency for low momenta (×2 at all p_T)

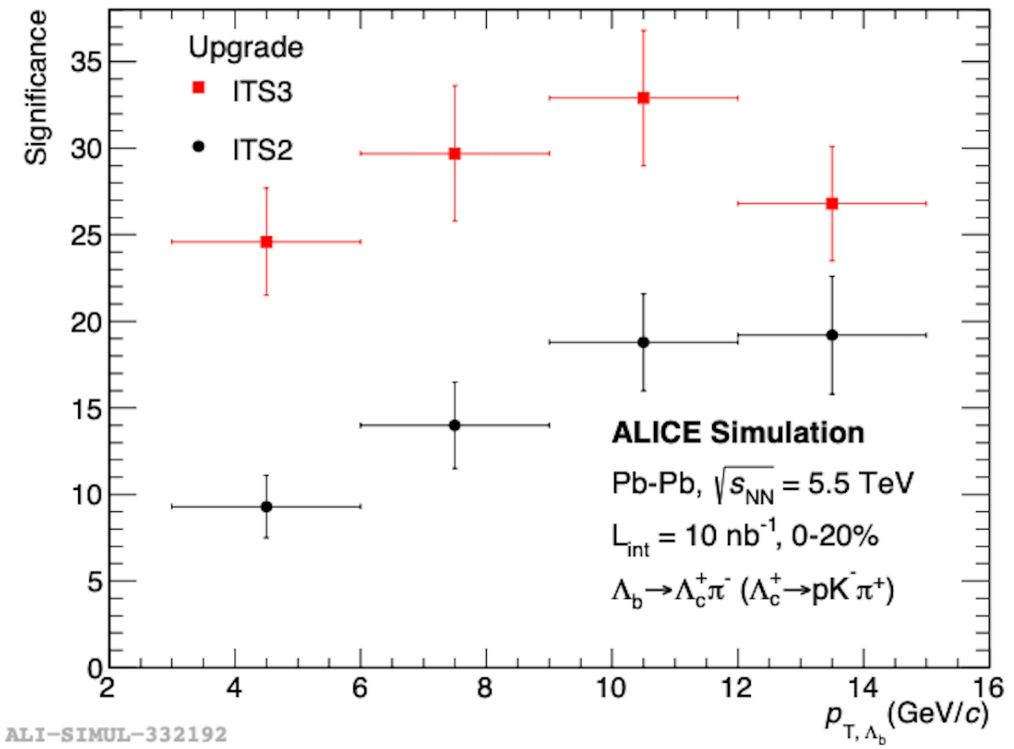




Λ_b^0 baryons



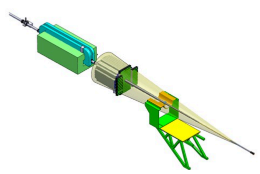
$\Lambda_b^0 \to \Lambda_c^+\pi^- \to pK^-\pi^+\pi^-$



» Measurement of Λ_b^0 in Pb-Pb collisions already accessible with ITS2

» Expected improvement of statistical significance up to factor 2.5 with ITS3

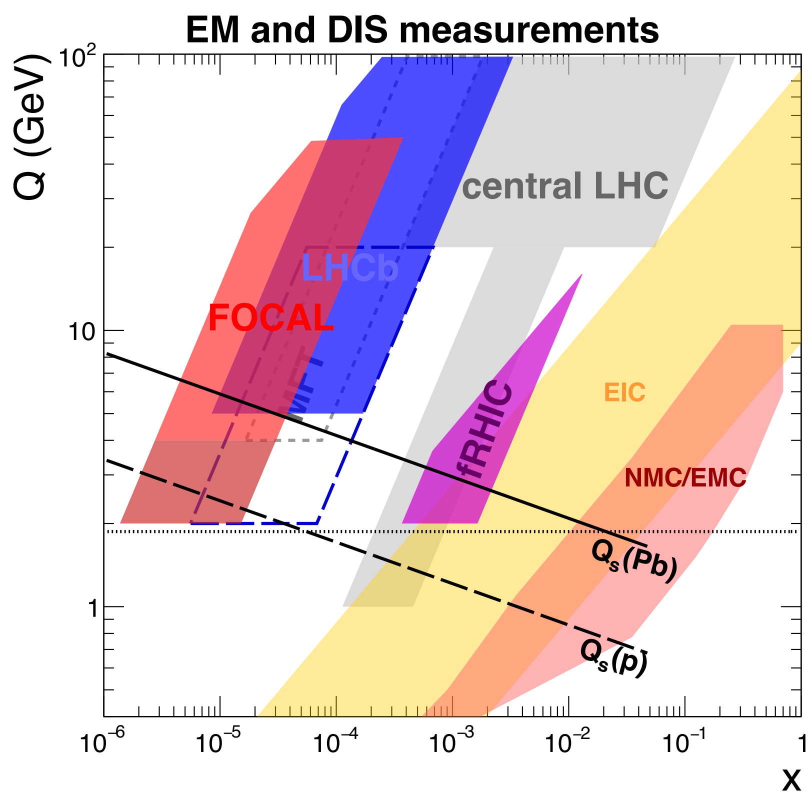
ALICE 2 - LS3 upgrade



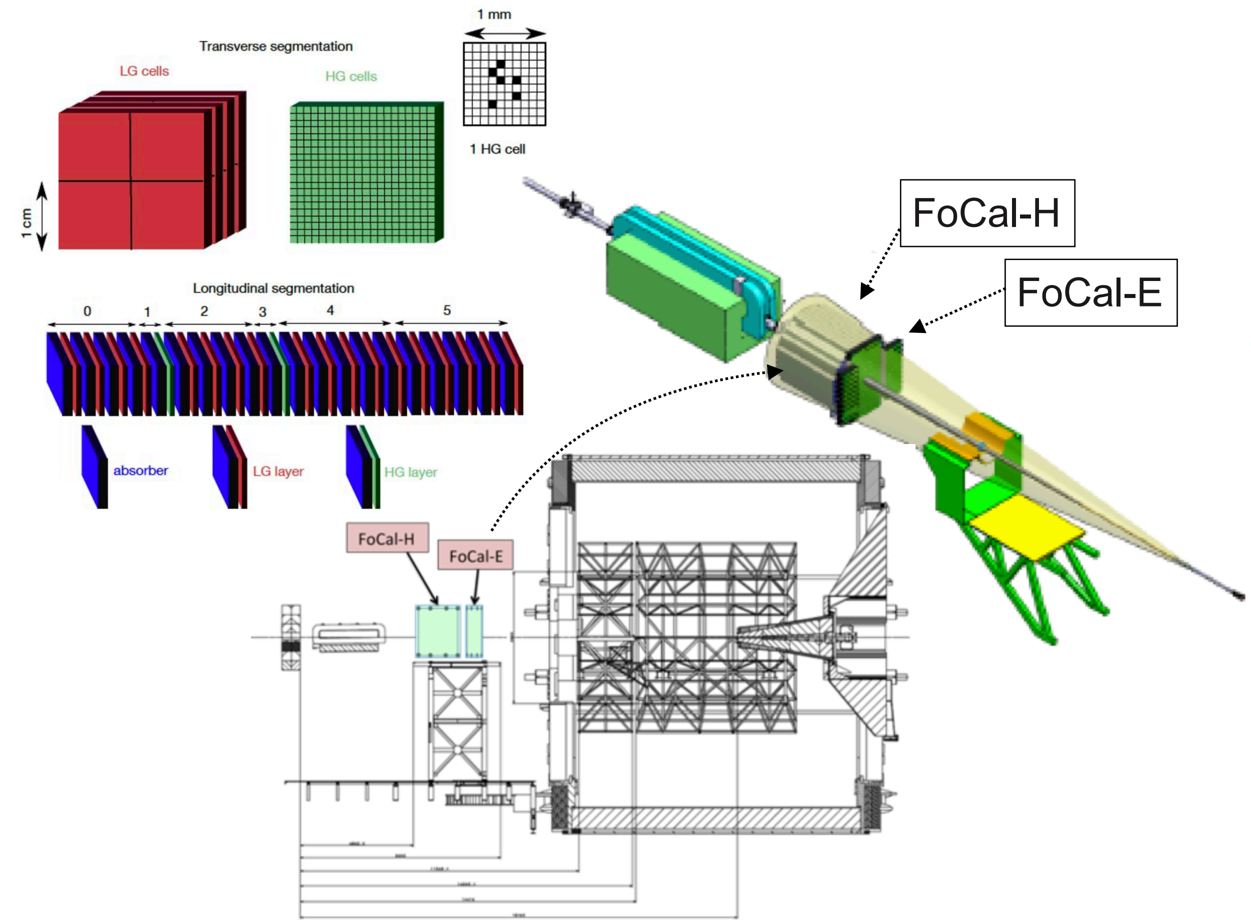
New Forward Calorimeter (FoCal)

Main goal
» Constrain gluon nuclear PDF at small Bjorken-x
→ Measure isolated photons at forward rapidity

Main challenge
» Separate photons and π^0 at high energy
→ two photon separation from π^0 decay ~2 mm
→ small Molière radius and high granularity readout



LoI (CERN-LHCC-2020-009):
https://cds.cern.ch/record/2719928?ln=en

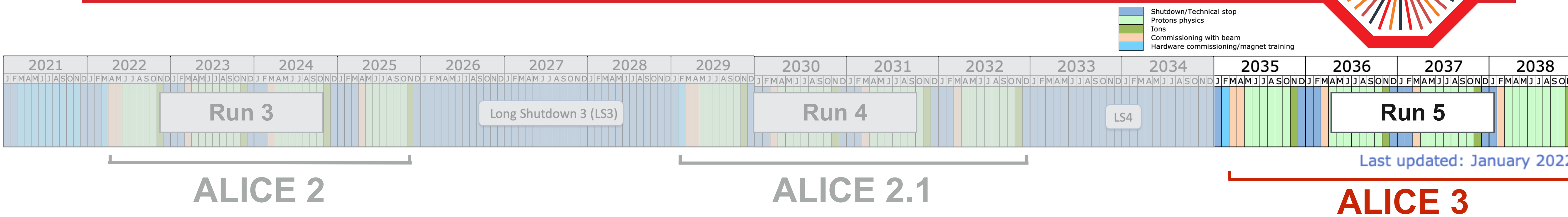


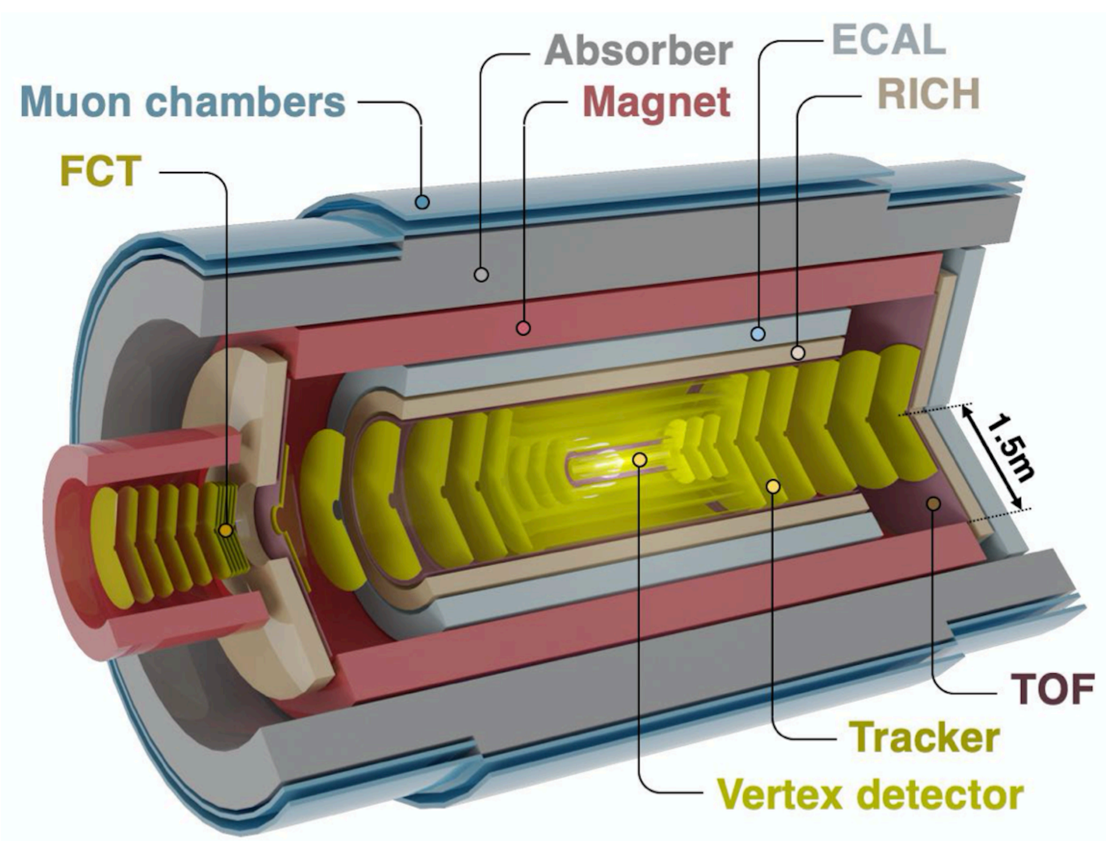
At z ~ 7 m from IP, 3.2 < η < 5.8

FoCal-E
→ high granularity electromagnetic calorimeter for γ and π^0
→ Tungsten alloy plates (3.5 mm ~ 1 X_0)
→ Silicon sensors with hybrid design
- Si-pads (~1 cm^2) for energy measurement
- MAPS (~30×30 μm^2) for two-shower separation

FoCal-H
→ conventional Pb-Sc sampling hadronic calorimeter for photon isolation and jets

ALICE 3





"Ambition to design a new experiment to continue with a rich heavy-ion programme at the HL-LHC" mentioned in the Update of the European strategy for particle physics

A next-generation LHC HI (soft-QCD) experiment

» Compact, all-silicon "nearly massless" detector with excellent low-p_T tracking performance

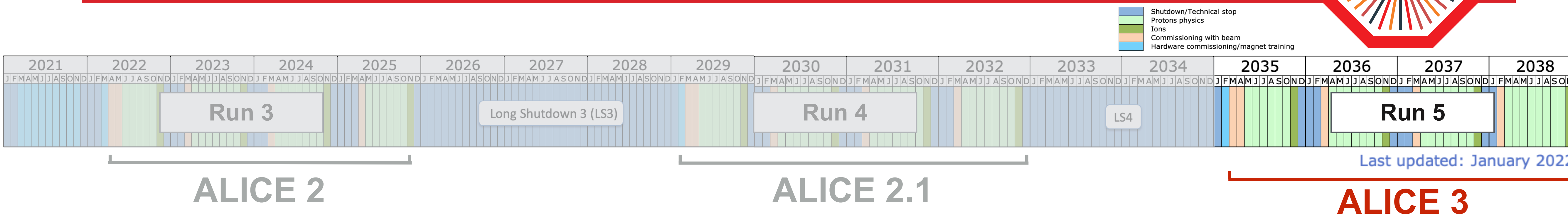
» Increase rate capabilities: luminosities x20 - x50 higher than in ALICE 2

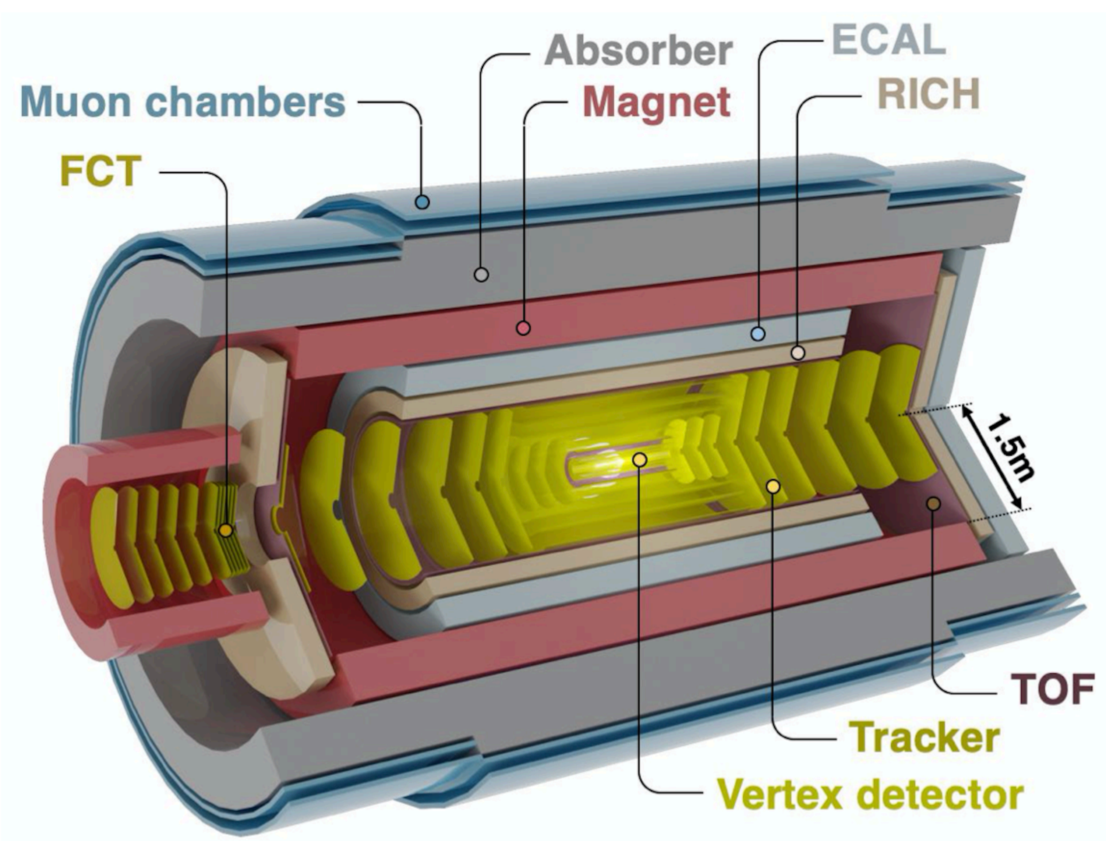
» **Unprecedented insight into QGP**

Expression of Interest (2019): https://arxiv.org/abs/1902.01211

LoI (2022) [LHCC-2022-009]: https://cds.cern.ch/record/2803563?ln=fr

ALICE 3





Physics program

» **Charm and beauty hadrons correlation** over a wide rapidity range

» Systematic measurements of **multiply heavy-flavoured hadrons** (expected enhanced production from the QGP)

» Production and behaviour of the **charmed exotic states** in the QGP and their structure

» **Multi-differential measurements of electromagnetic radiation** from the QGP (probe early evolution and restoration of chiral symmetry)

» Measurements of **net-quantum number fluctuations** over a wide rapidity range (constrain susceptibilities of QGP and to test the realisation of a cross-over phase transition)

Expression of Interest (2019): https://arxiv.org/abs/1902.01211
LoI (2022) [LHCC-2022-009]: https://cds.cern.ch/record/2803563?ln=fr

ALICE 3

A next-generation Heavy Ion experiment

» Ultra-lightweight silicon tracker with excellent vertexing

→ 12 tracking barrel layers + disks based on MAPS

» Particle identification

→ TOF determination (20 ps time resolution), Cherenkov, pre-shower/calorimeter

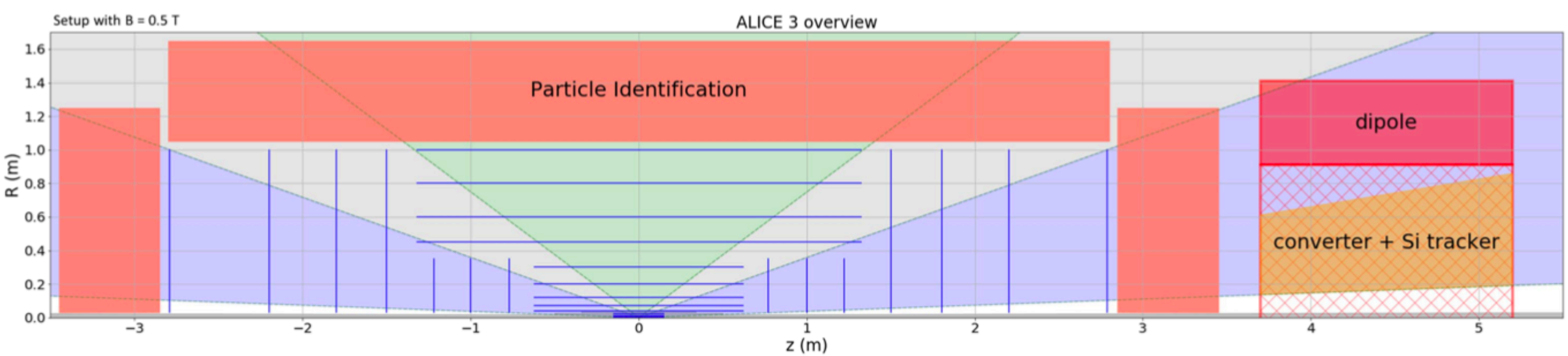
» Dedicated forward detector for soft photons (conversion + Si tracker)

» Fast to profit from higher luminosity (x20 - x50 higher than in ALICE 2)

» Kinematic range down to very low p_T: 50 MeV/c (central barrel), 10 MeV/c (forward dedicated detector)

» Transverse momentum resolution : $\sigma_p/p \sim 1\,\%$

» Large acceptance: barrel + end-caps $\Delta\eta$ = 8



ALICE 3

Main R&D challenges

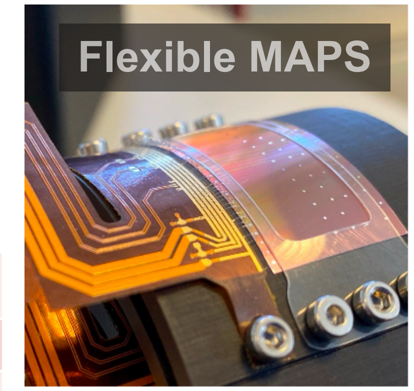
» *Inner tracker*
- → ultra-thin layout: flexible wafer-scale sensors (MAPS/ITS3)
- → minimal distance from IP requires retractable detector
- → position resolution O(1 μm) requires small pixel pitch

» *Outer tracker*
- → large areas to instrument O(100 m^2): develop cost-effective sensors
- → low material budget requires low-weight support and services

» *Time of Flight*
- → TOF resolution < 20 ps needed on the system level requires advances both on sensors and microelectronics
- → large areas to instrument: develop cost-effective sensors

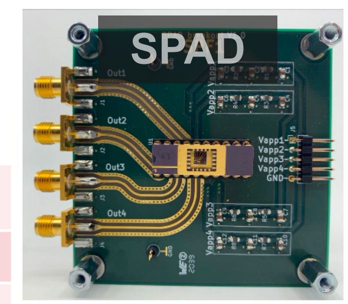
Inner tracker

Position resolution	~1 μm
X/X_0 per layer	~0.1%
MAPS pitch	< 10 μm
Innermost radius	5 mm



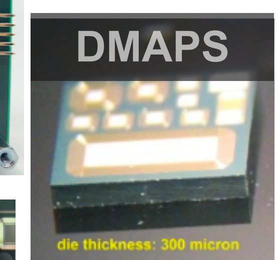
Outer tracker

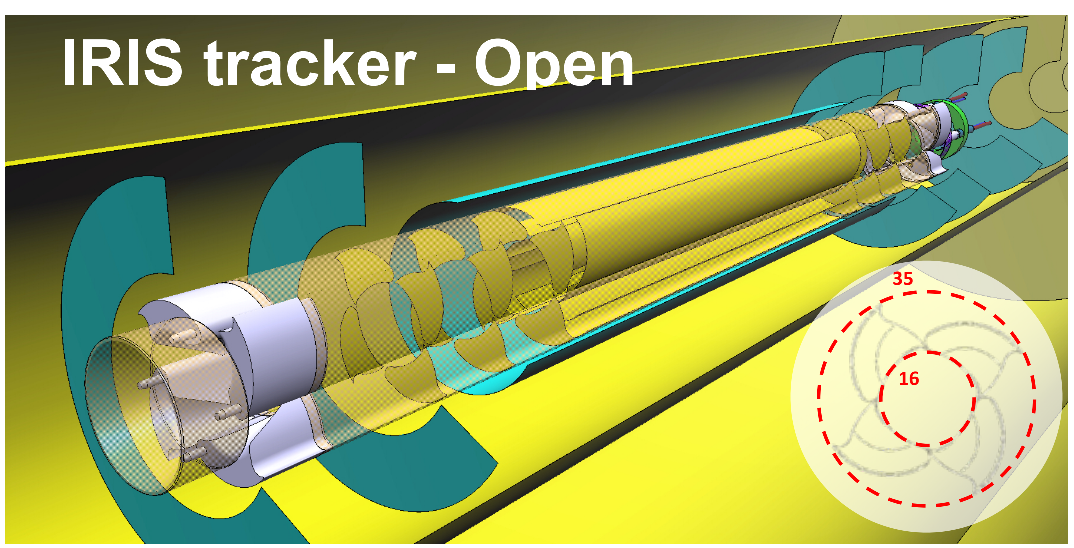
Position resolution	~10 μm
X/X_0 per layer	~1%
MAPS pitch	30 - 50 μm

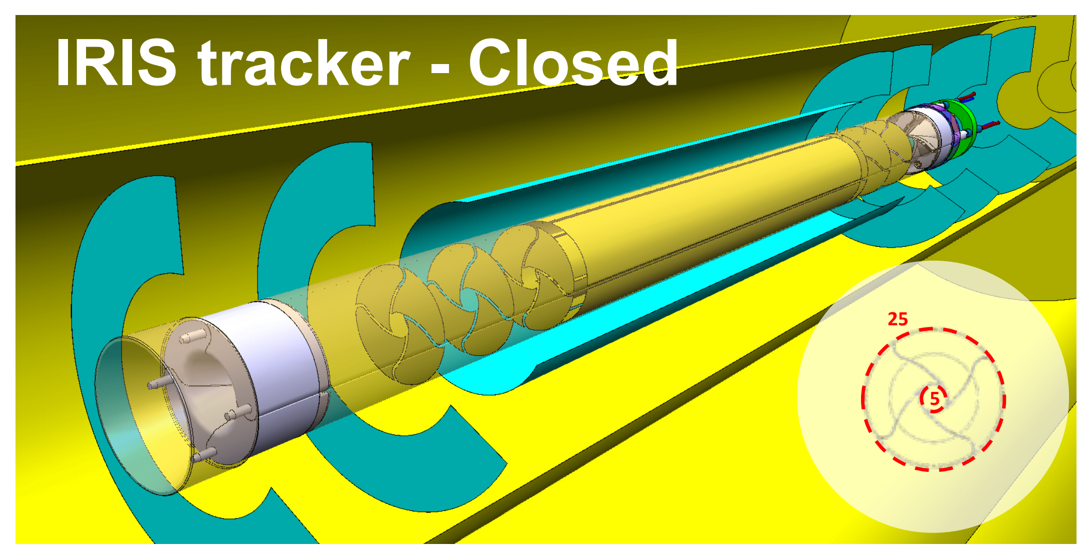


Time of Flight

Radial position	20 - 100 cm
Time resolution	~20 ps
X/X_0 per layer	1 - 3%
Cell pitch	~1 mm





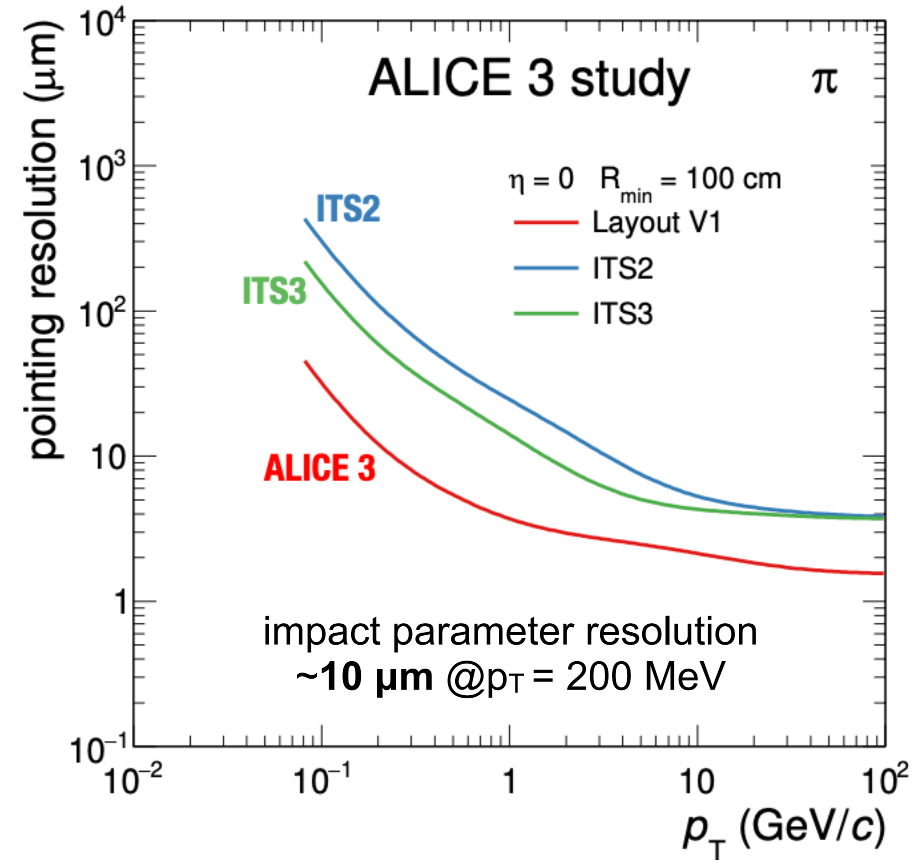


ALICE 3

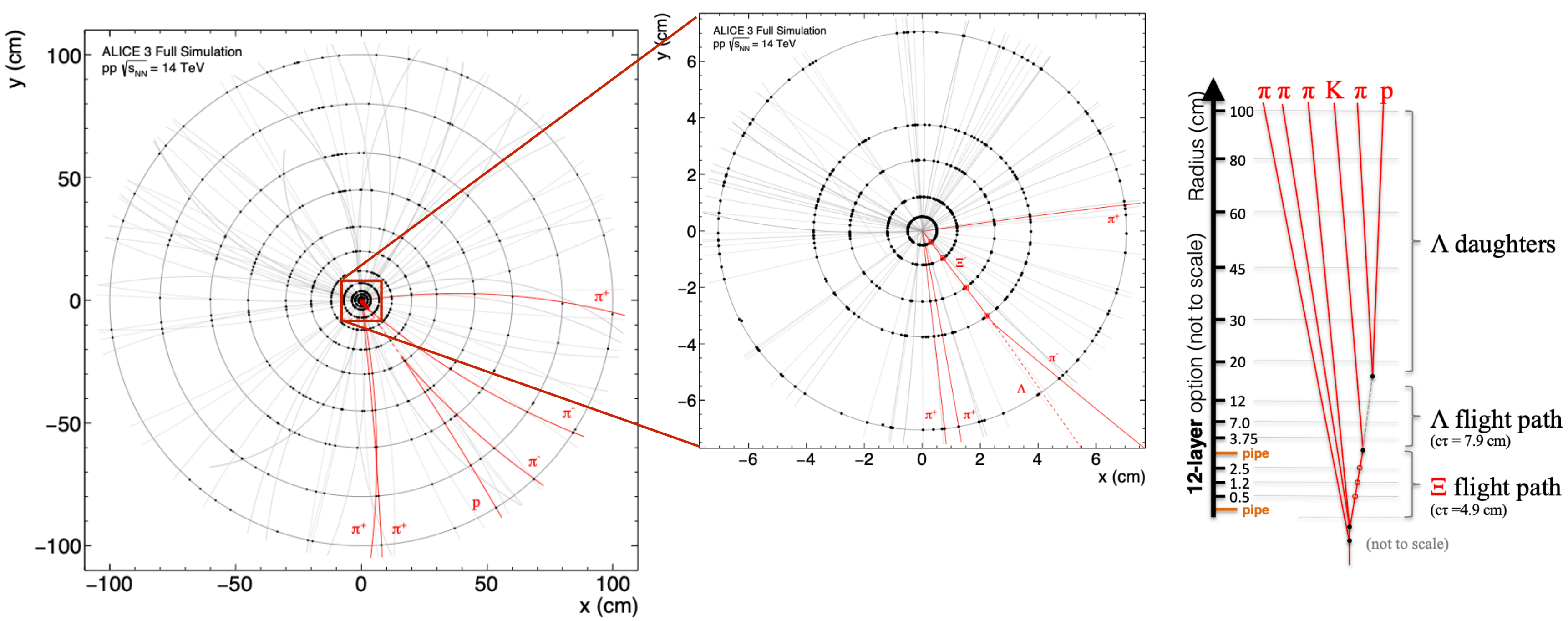
Multi-charm baryons

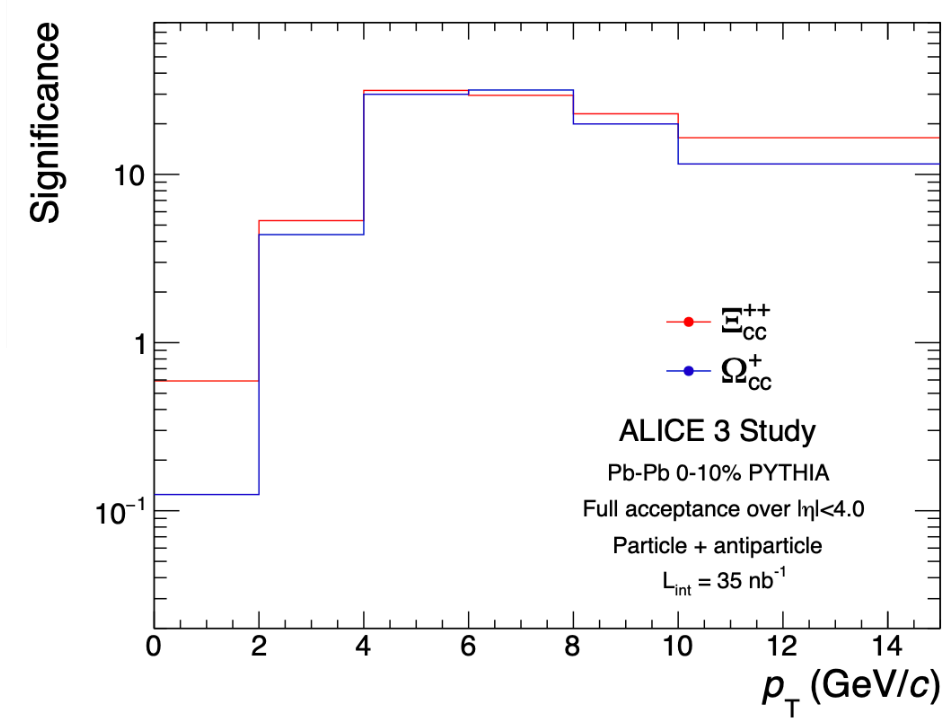
» Extreme benchmarks for hadronization mechanisms in small and large systems
  - Large enhancement (up to x1000) w.r.t. SPS if formed by coalescence of uncorrelated charm quarks

» Ω_{CC} and Ω_{CCC} not yet observed



Identification through topological reconstruction





Impact parameter, momenta resolution and PID are key technologies to be pushed at the state of art

SUMMARY

ALICE 2 - LS2 (now) → Upgrade of ALICE on track

ALICE 2 - LS3 (2029) → New upgrades for Run 4

» FoCal: photons, π^0, jets in the forward region to constrain gluon nPDF at low Bjorken-x

» ITS3: truly cylindrical silicon layers made of ultra-thin wafer-size MAPS

- low-mass dielectrons (→ QGP temperature)
- improve HF-particle performance + search for exotic charm nuclei

ALICE 3 (beyond 2035) → Continue heavy-ion programme in HL-LHC era

» Possibility of a “nearly-massless” silicon detector

- multi-HF particles
- low-mass dielectrons and soft photons

Plasma di quark e gluoni II

- Inspecting the charm hadronization via measurements of charm baryon production in hadronic collisions with the ALICE experiment at the LHC - M. Faggin (Tuesday 11:05)
- Strange hadron production in and out of jets in proton-proton collisions with ALICE - C. De Martin (Tuesday 11:25)
- Charged particle production as a function of underlying event-activity and search for jet-like modifications in small systems with ALICE - S. Tripathy (Tuesday 11:45)
- Measurement of light (anti)nuclei production with ALICE - A. Balbino (Tuesday 12:05)
- Strangeness production in pp as a function of particle multiplicity and effective energy with ALICE - F. Ercolessi (Tuesday 12:25)

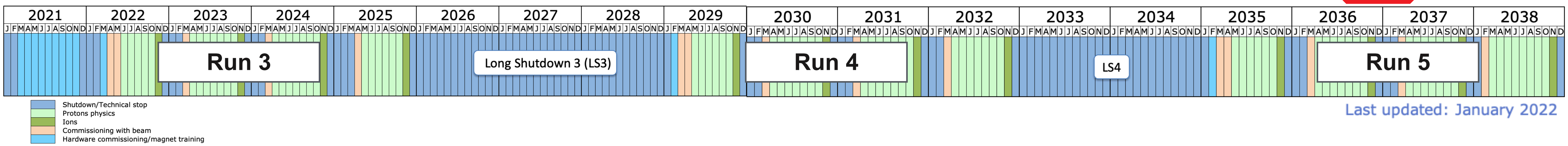
Poster session

- ALICE Muon Spectrometer upgrade and commissioning for the LHC Run 3 - L. Terlizzi
- First bent wafer-scale sensor in truly-cylindrical geometry for the ALICE ITS3 detector - A. G. Torres Ramos
- Light flavour production at the LHC: latest results from Run 2 and towards Run 3 - N. Jacazio
- Measuring μ_B at the LHC with ALICE via antiparticle-over-particle ratios - M. Ciacco
- Hypertriton production in large and small systems - F. Mazzaschi
- Non-prompt D_S^+ mesons production in pp and Pb-Pb collisions with ALICE - S. Politano
- Charged $K*$ multiplicity dependent analysis in pp collisions at $\sqrt{s} = 13\,TeV$ with ALICE - A. Rosano
- Produzione di lesioni D in collisioni pp con ALICE a $\sqrt{s} = 13\,TeV$ in LHC in funzione della molteplicità - M. Giacalone
- Investigating heavy-flavour fragmentation and hadronization with jets and correlation measurements with ALICE - A. Palasciano
- Inclusive muon elliptic flow measurement in pp collision at $\sqrt{s} = 13\,TeV$ with ALICE experiment - S. Boi

More from ALICE at this conference

Backup

ALICE 2 in Run 3 and Run 4

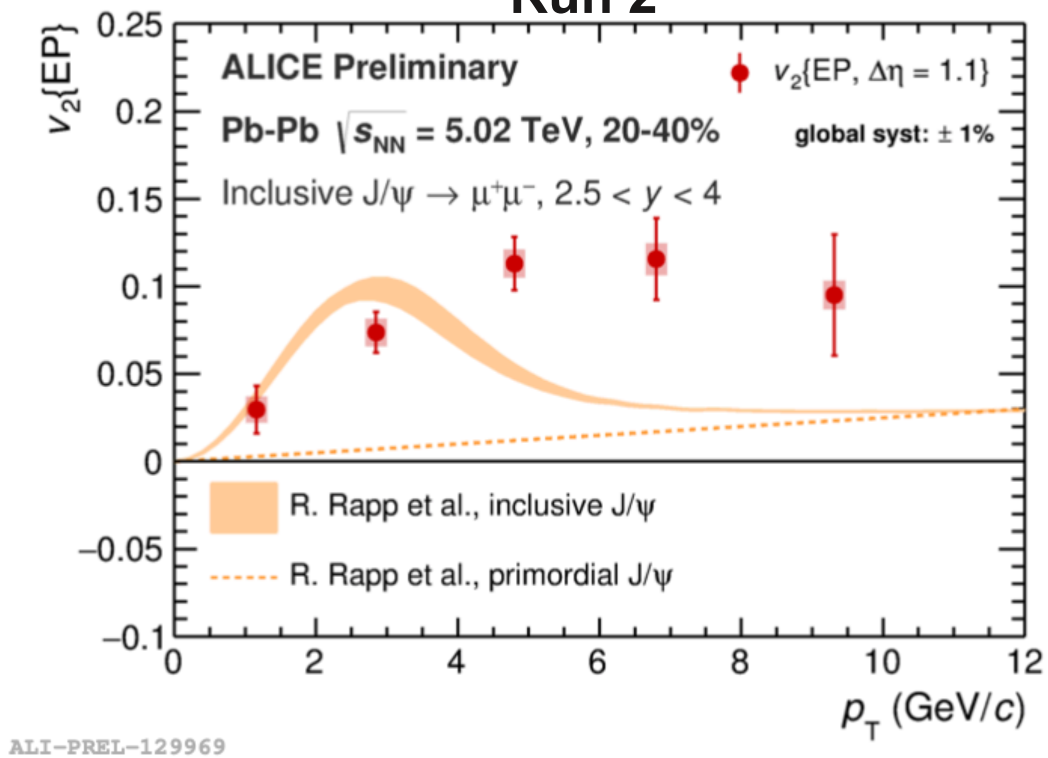


Physics goals

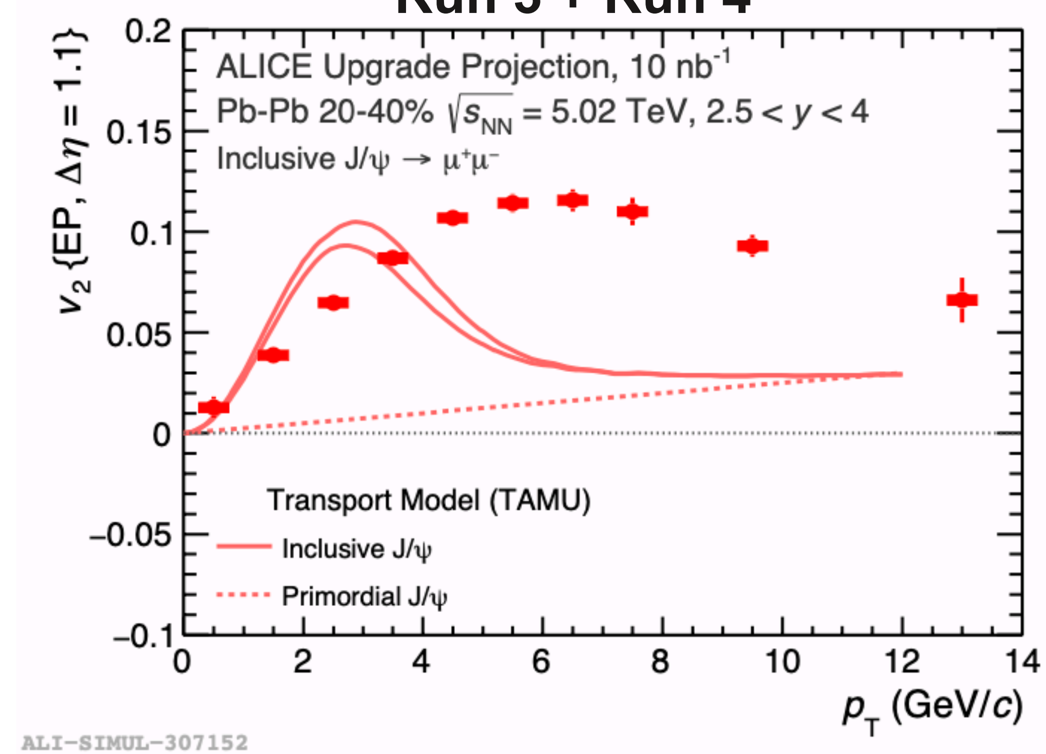
» Focus on high precision measurements of **rare probes at low p_T**

- **Heavy-flavour mesons and baryons (down to very low p_T)**
- **Charmonium states**

Run 2

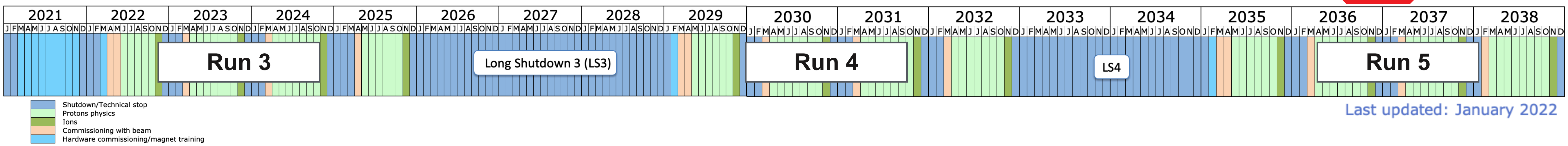


Run 3 + Run 4



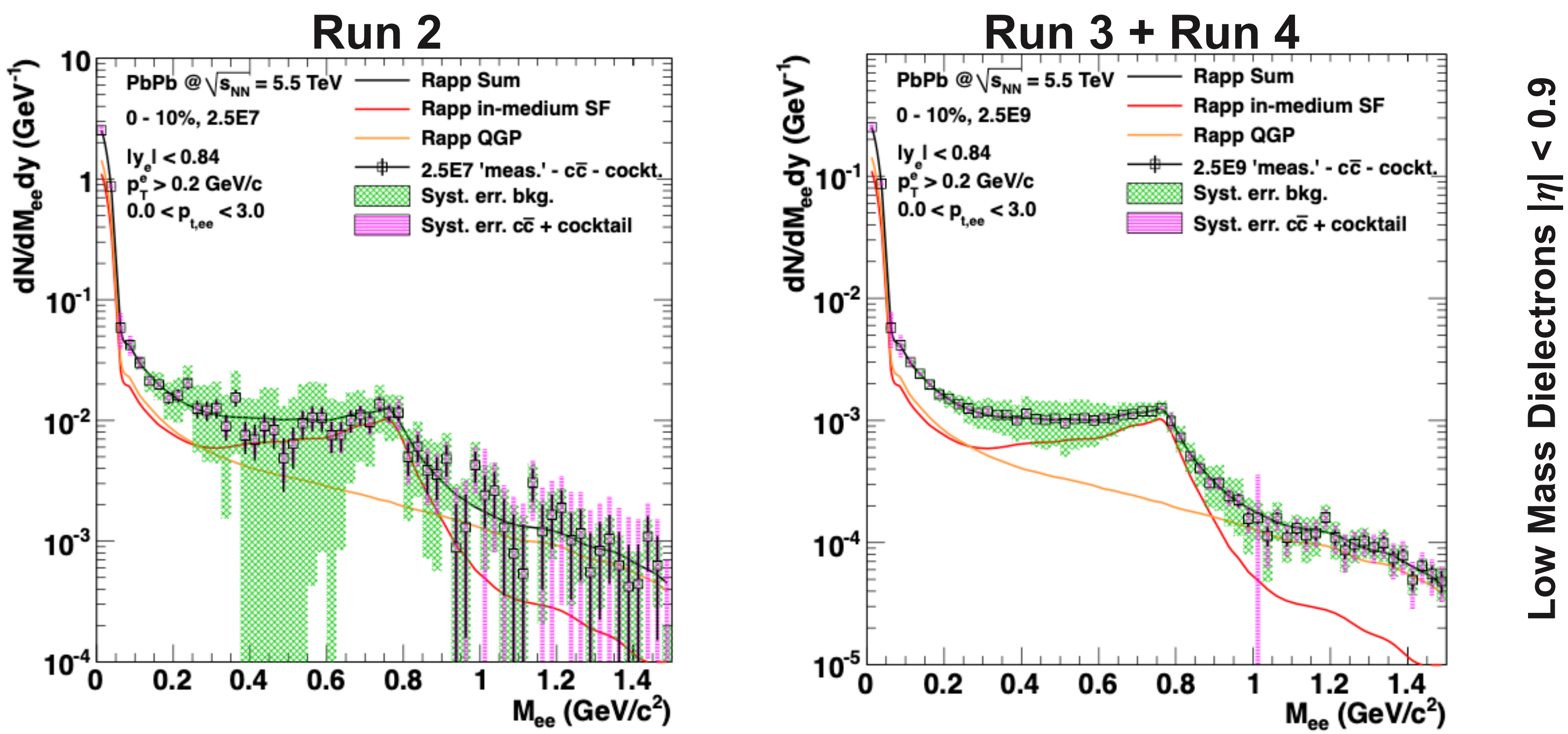
J/Ψ prompt - decay separation thanks to improved vertexing capabilities

ALICE 2 in Run 3 and Run 4



Physics goals

» Focus on high precision measurements of **rare probes at low p_T**
- **Heavy-flavour mesons and baryons (down to very low p_T)**
- **Charmonium states**
- **Di-leptons from QGP radiation and low-mass vector mesons**

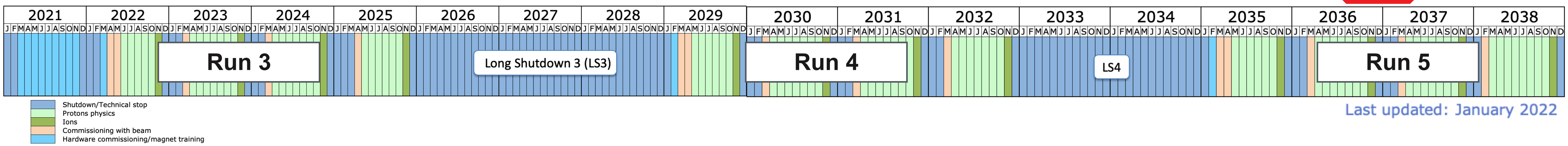


Observable sensitive to:

» The modification of the ρ meson spectral function due to chiral symmetry restoration

» Thermal radiation from QGP

ALICE 2 in Run 3 and Run 4



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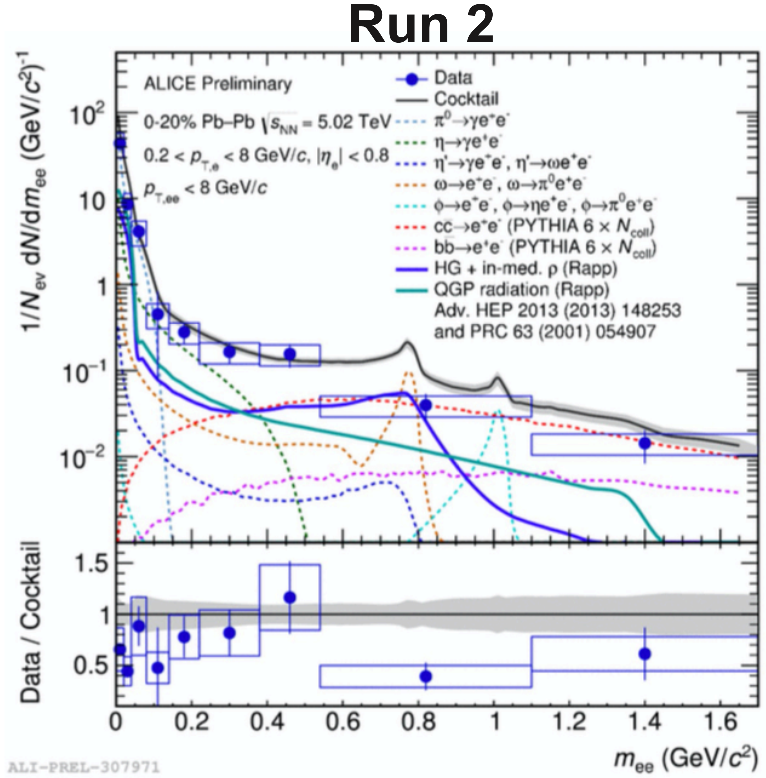
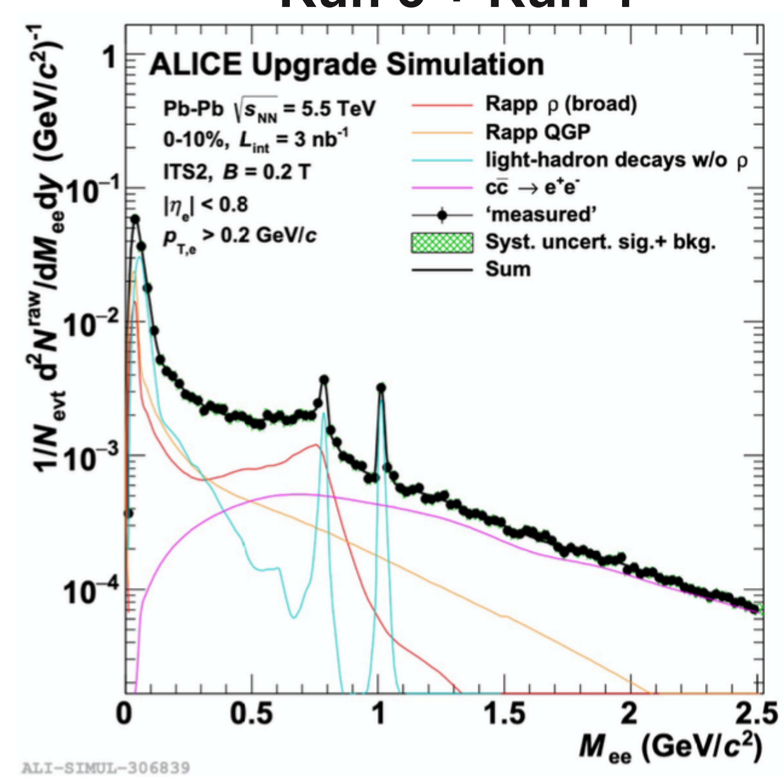
- **Charmonium states**
- **Di-leptons from QGP radiation and low-mass vector mesons**

Run 2



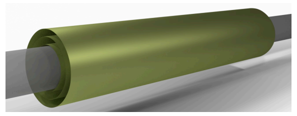
Run 3 + Run 4



Low Mass Dielectrons $|\eta| < 0.9$

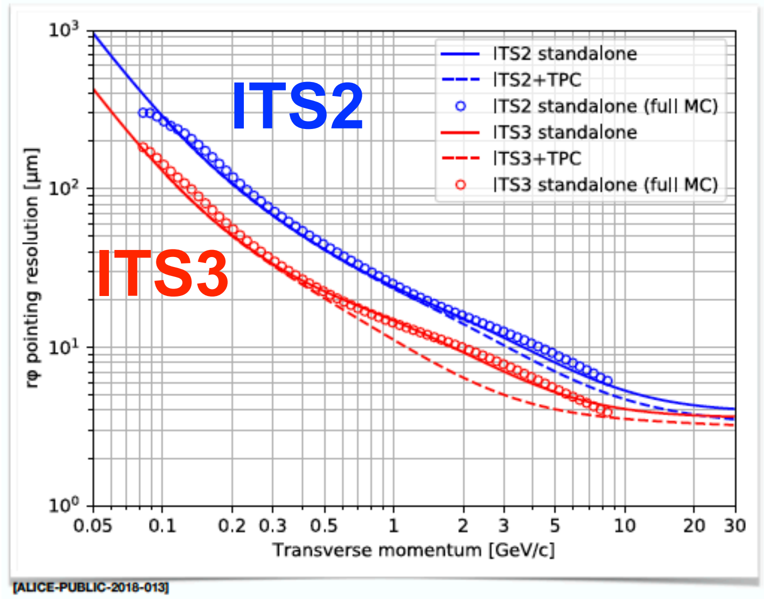
Improvement of dielectron mass spectrum
Background yields from know hadronic + HF decays can be subtracted precisely

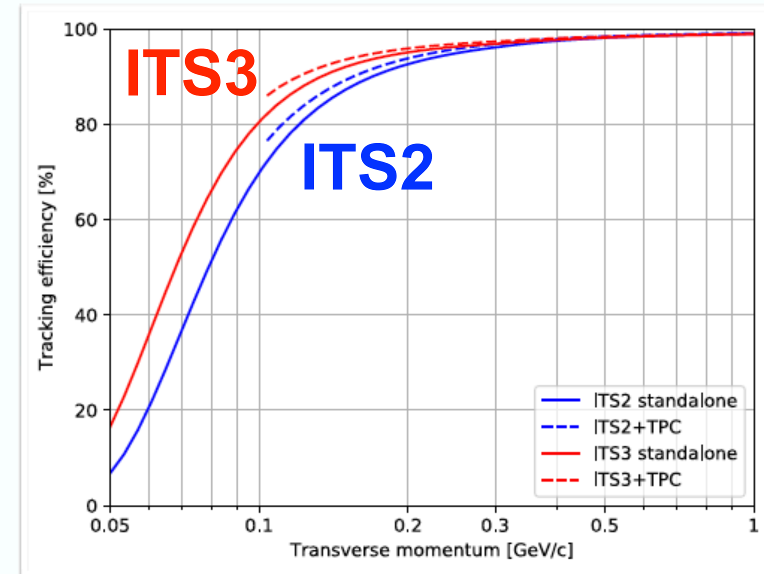
ALICE 2 - LS3 upgrade



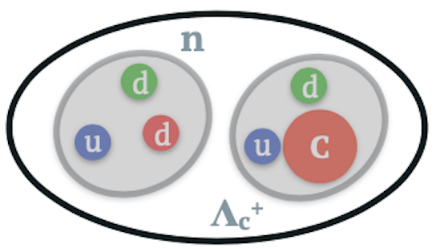
New Inner Tracking System (ITS3)

» Improved pointing resolution and tracking efficiency for low momenta (×2 at all p_T)





c-deuteron

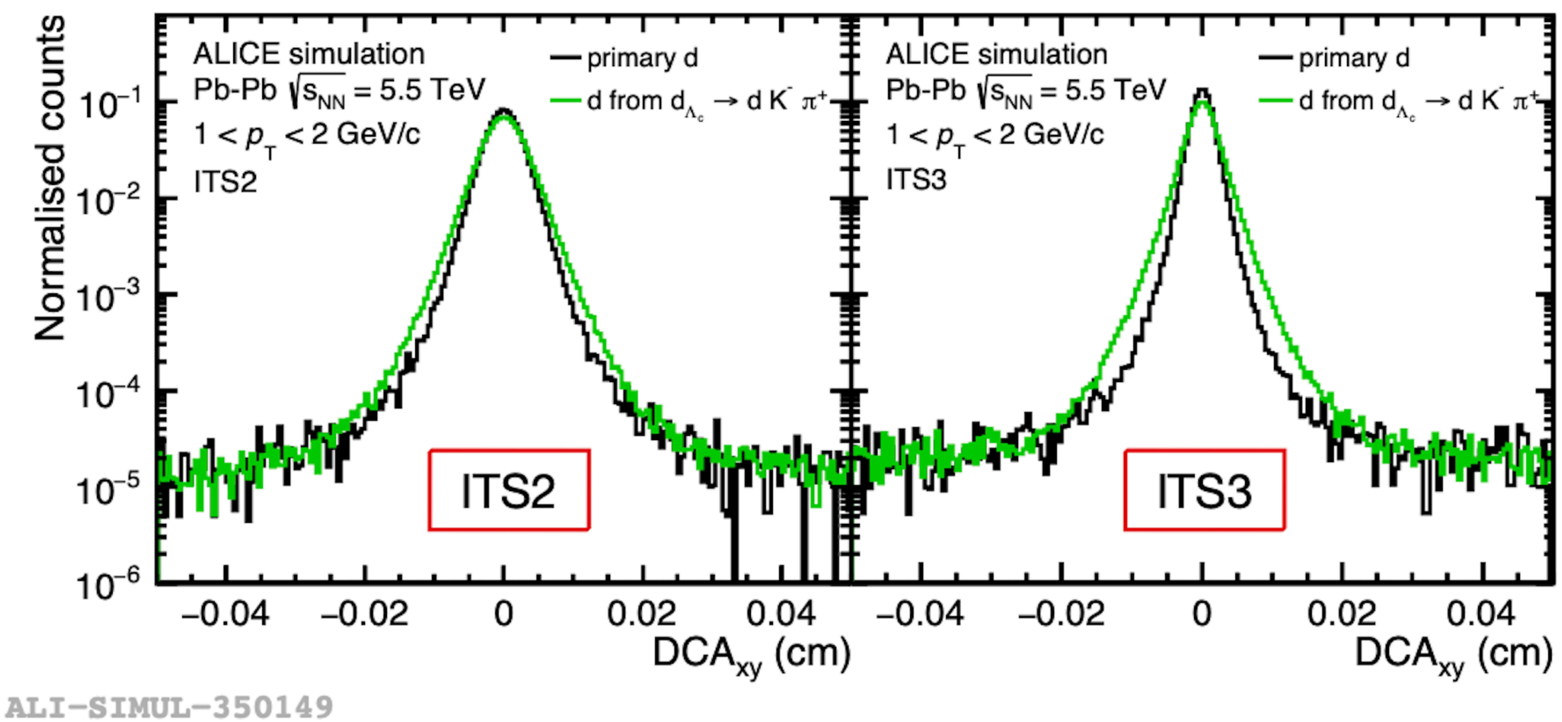


» Predicted in ’70 [PRL 39, 1506 (1977)] → Never observed

» Bound state of Λ_c^+ and a neutron

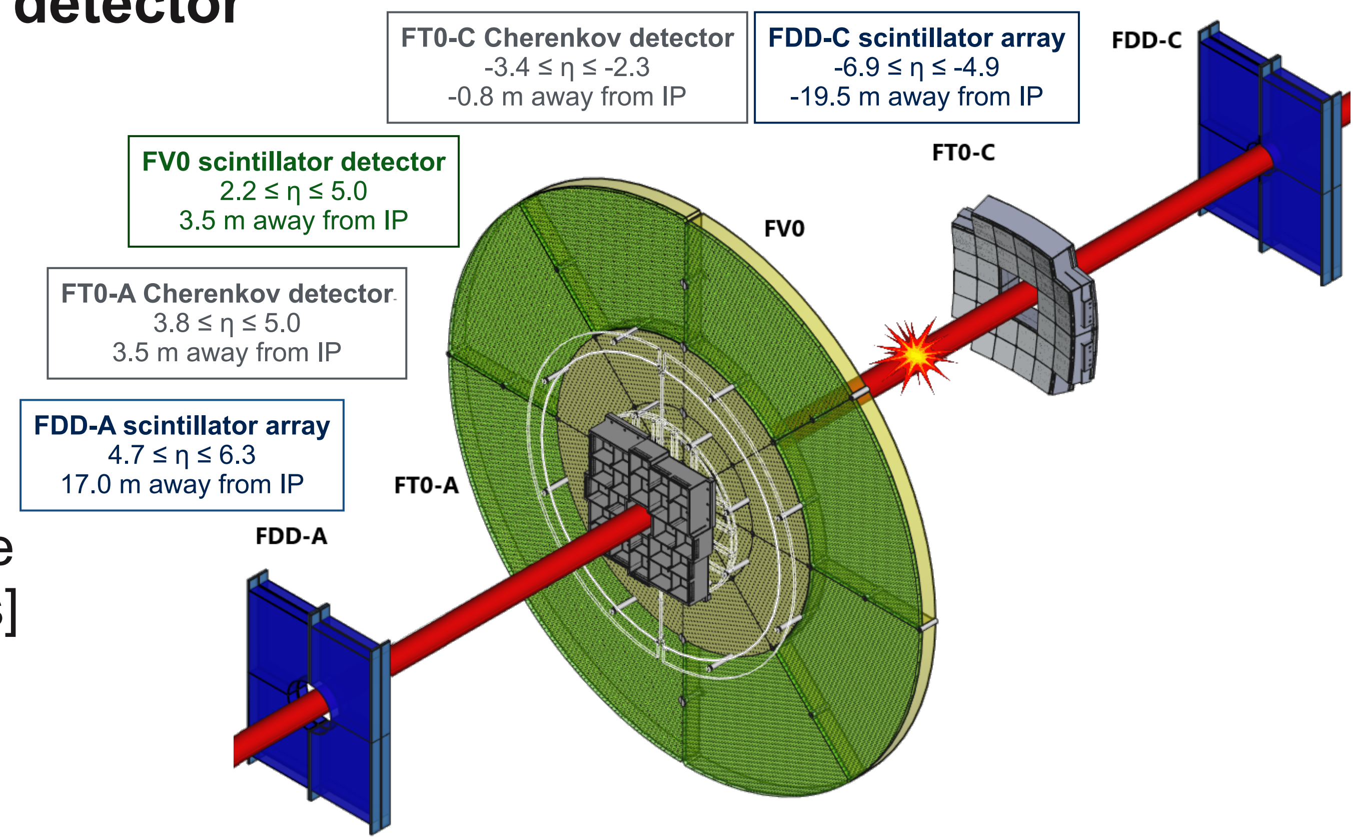
» Impact parameter distribution of decay deuteron crucial to discriminate signal from background

$$(\Lambda_c^+ n) \to d\, K^- \pi^+$$



ALICE 2 - LS2 upgrade

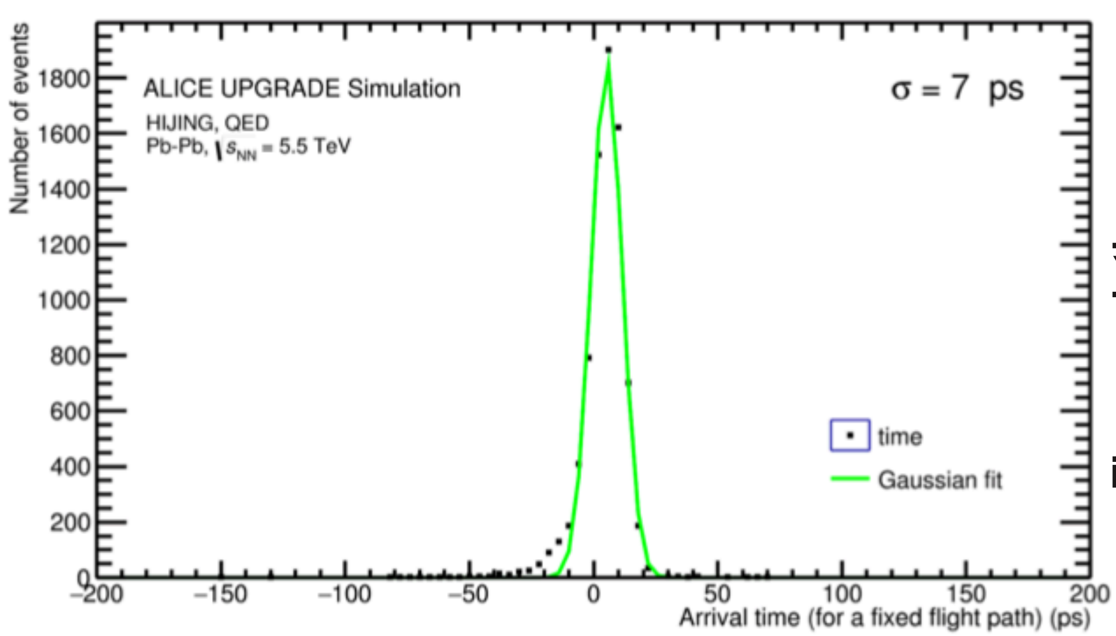
New Fast Interaction Trigger (FIT) detector



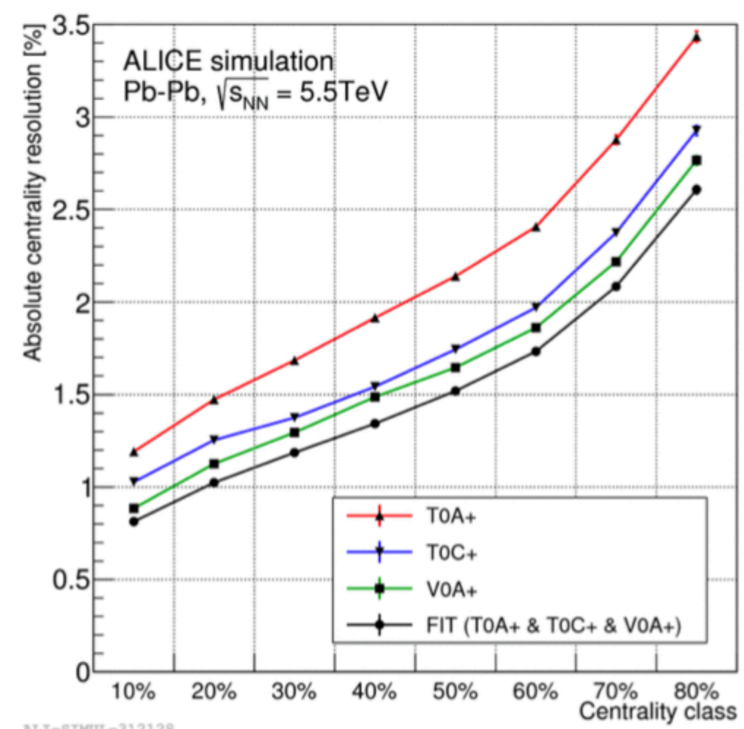
FIT is the upgrade of the **T0**, **V0** and **AD detectors**: triggers, luminosity monitoring, background reduction, collision time for PID, centrality and event plane determination

» Cherenkov radiators (quartz) + Micro-channel plate PMTs [latency < 425 ns and time resolution < 20 ps]

» Large area scintillators [latency < 425 ns and time resolution ~250 ps]

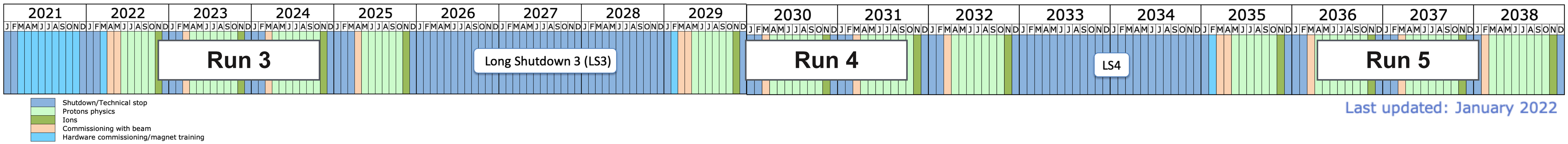


Time resolution



Centrality resolution

ALICE 2 in Run 3 and Run 4

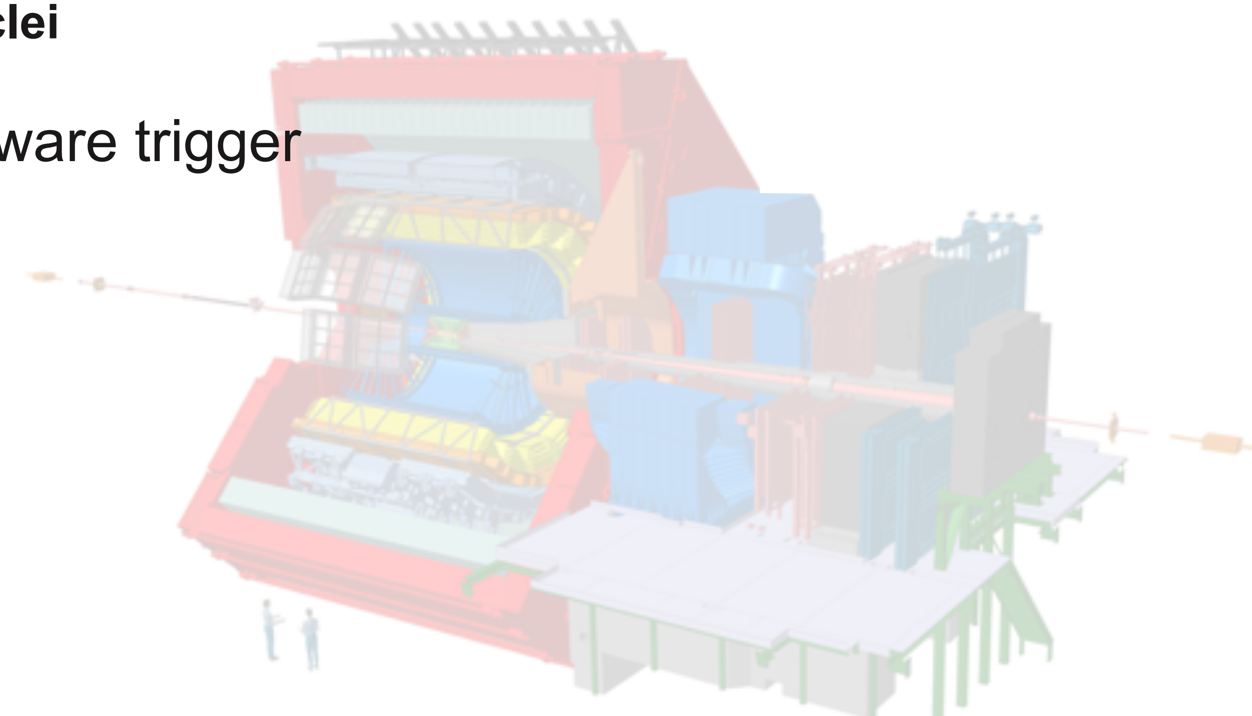


Physics goals

» Focus on high precision measurements of **rare probes at low p_T**

- **Heavy-flavour mesons and baryons (down to very low p_T)**
  → mechanisms of quark-medium interaction
- **Charmonium states**
  → dissociation/regeneration as tool to study de-confinement and medium temperature
- **Di-leptons from QGP radiation and low-mass vector mesons**
  → χ symmetry restoration, initial temperature
- **High precision measurement of light and hyper-nuclei**
  → production mechanism and degree of collectivity

» **Very low S/B ratio** prevents selection with hardware trigger



ALICE 2 - LS 2 upgrade

New Inner Tracking System (ITS 2)

Based on the ALPIDE Monolithic Active Pixel Sensor

» In-pixel amplification, shaping discrimination and Multiple-Event Buffers (MEB)

» In-matrix data sparsification

» High detection efficiency (>99%) and low fake-hit rate ($<< 10^{-6}$ /pixel/event)

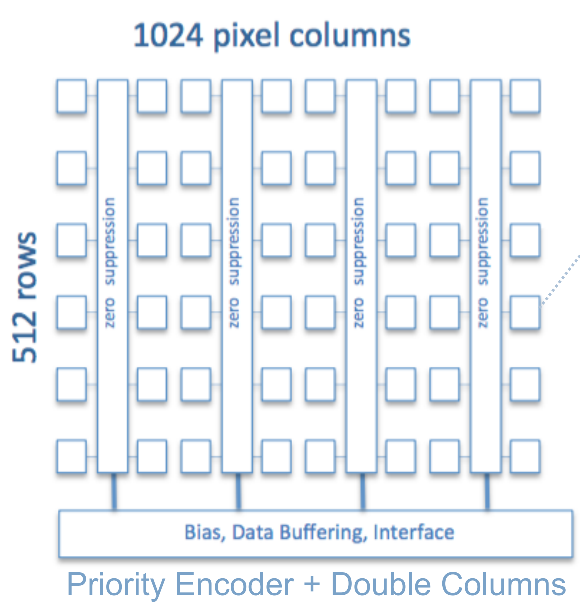
» Radiation tolerant:

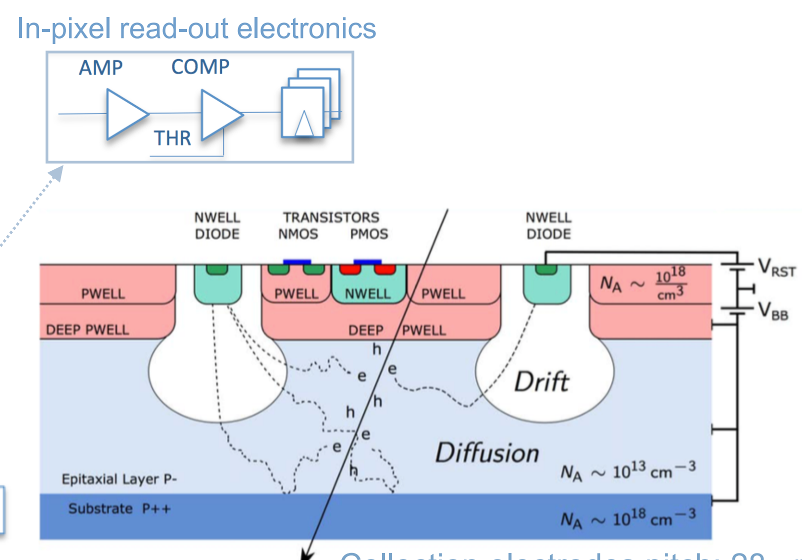
> 270 krad TID

> 1.7×10^{12} 1 MeV/n_{eq} NIEL

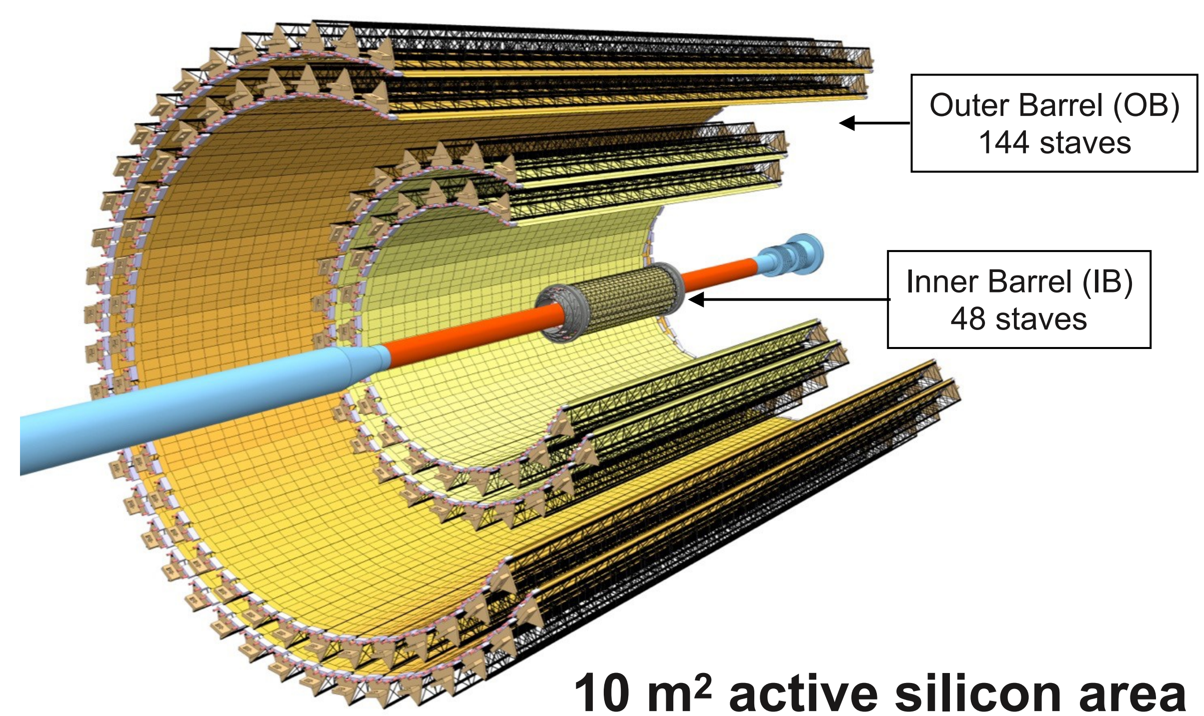
» Low power consumption ~40 mW/cm^2

	ITS (Run 1/Run 2)	ITS 2
Number of layers	6 (pixel, drift, μstrip)	7 (MAPS)
Rapidity range	$\lvert\eta\rvert < 0.9$	$\lvert\eta\rvert < 1.3$
Material budget per layer	1.14% (SPD)	0.35% (IB)
Distance to interaction point	39 mm	22 mm
Pixel size	50 x 425 μm^2	29 x 27 μm^2
Spatial resolution	12 μm x 100 μm	5 μm x 5 μm
Max. readout speed Pb-Pb	1 kHz	100 kHz





Collection electrodes pitch: 28 μm
Input capacitance Cin = 5 fF
Input charge Q_{in}(MIP) = 1300 e$^-$ → V = 40 mV



10 m^2 active silicon area
12.5×10^9 pixels

ALICE 2 - LS 2 upgrade

New Inner Tracking System (ITS 2)

Jan '20

Dec '20

Mar '21

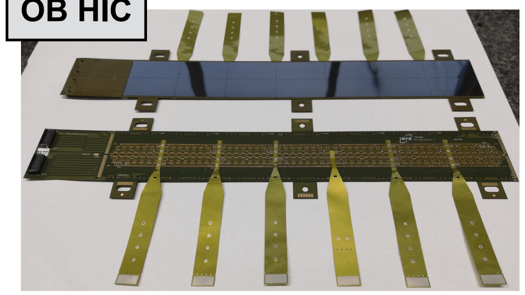
Detector Construction and Assembly
» ~72000 chips → ~2600 Hybrid Integrated Circuits (HIC) → ~280 Staves
(chip yield ~ 65%, HIC yield ~ 85%, Stave yield ~ 95%)
» >10 production sites in Asia, Europe and Unites States of America
» Stave integration completed in January 2020

On-surface commissioning with final services ongoing until December 2020

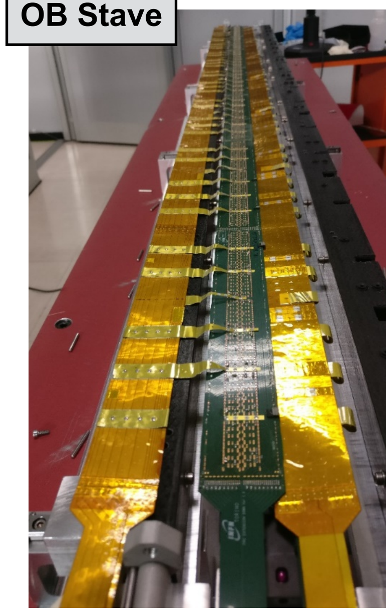
Installation in ALICE cavern

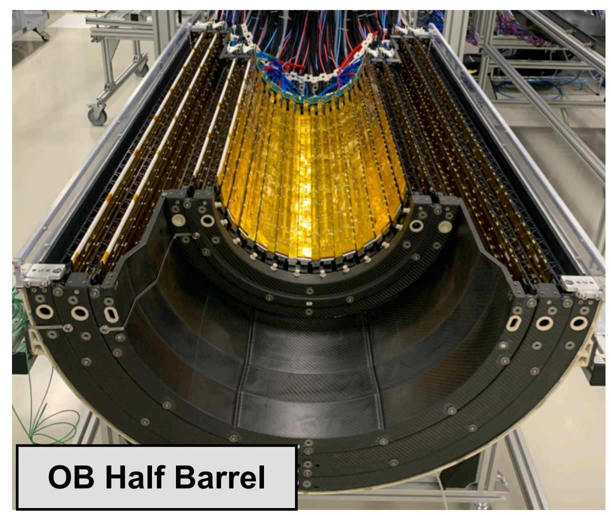
Global commissioning in ALICE

OB HIC

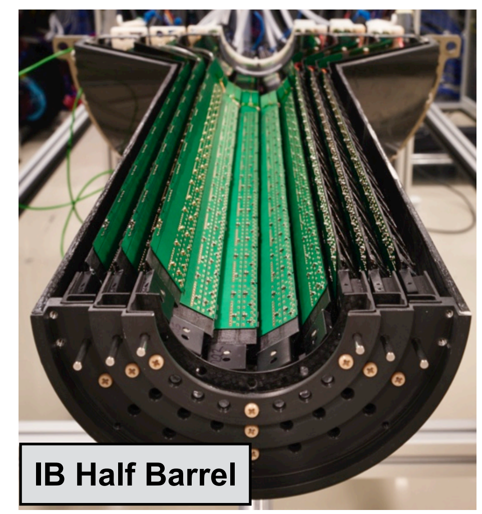


OB Stave



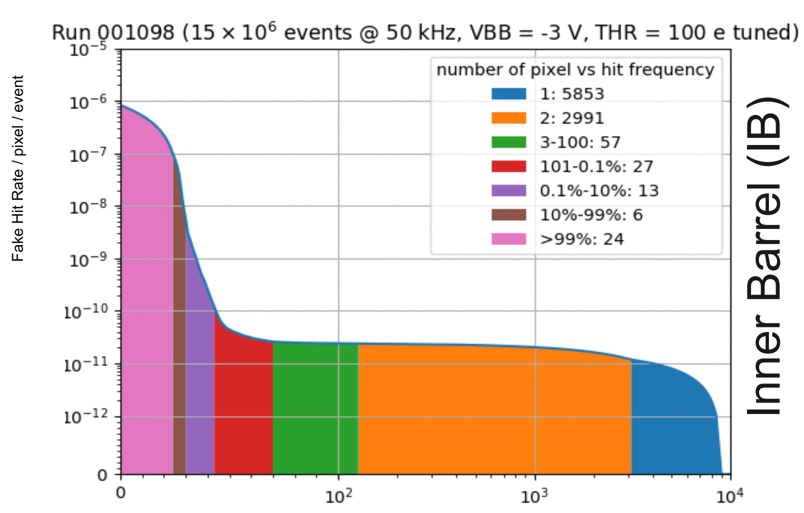


OB Half Barrel

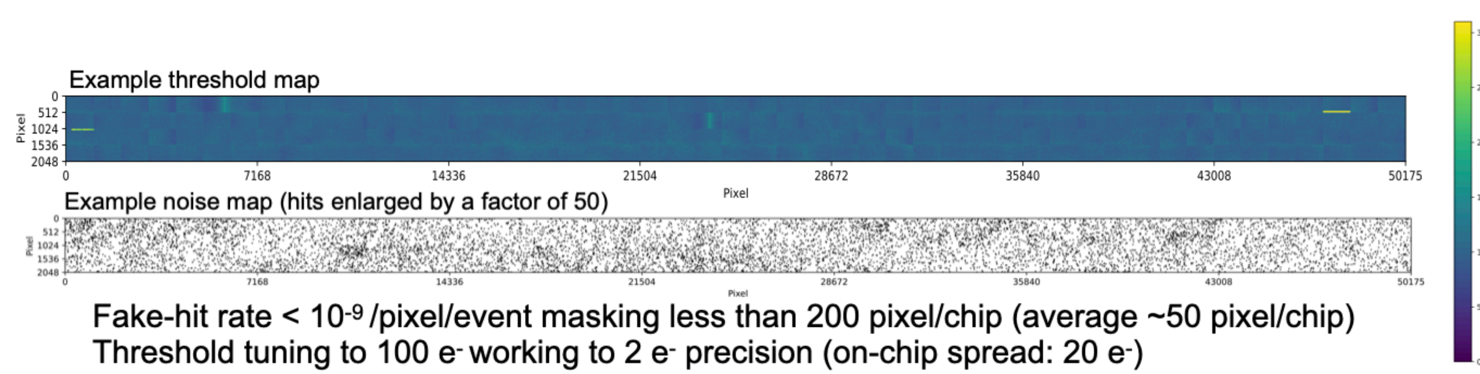


IB Half Barrel

Performance



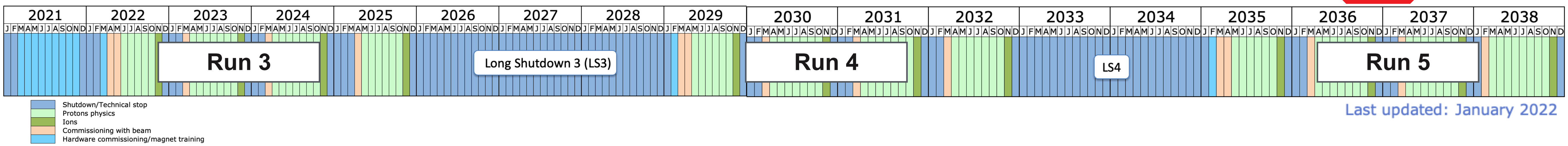
Inner Barrel (IB)



Fake-hit rate < 10^{-9} /pixel/event masking less than 200 pixel/chip (average ~50 pixel/chip)
Threshold tuning to 100 e^- working to 2 e^- precision (on-chip spread: 20 e^-)

Outer Barrel (OB)

ALICE 2 in Run 3 and Run 4



Physics goals

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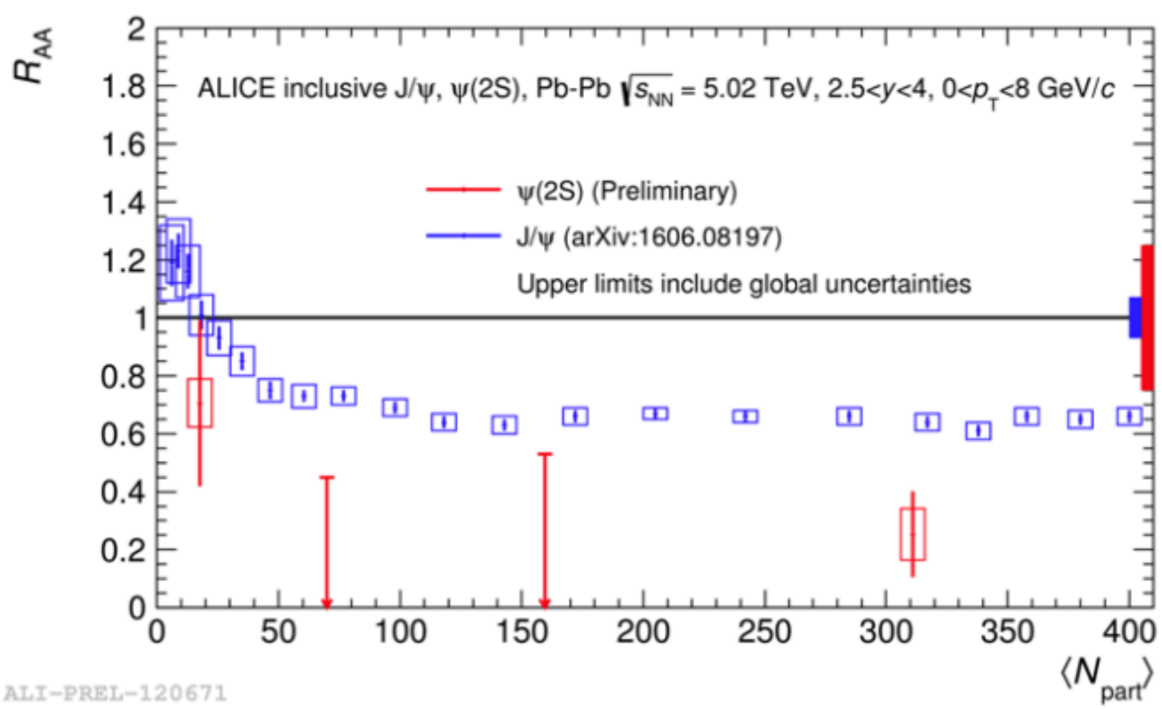
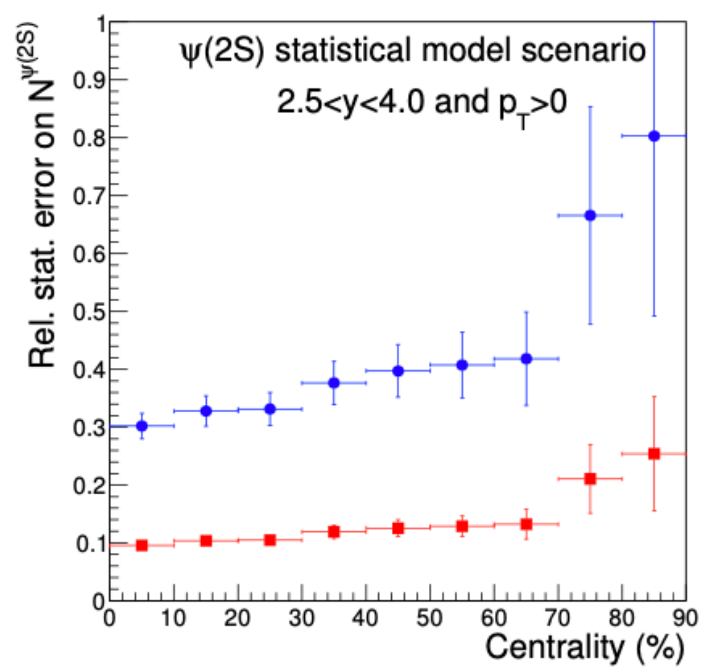
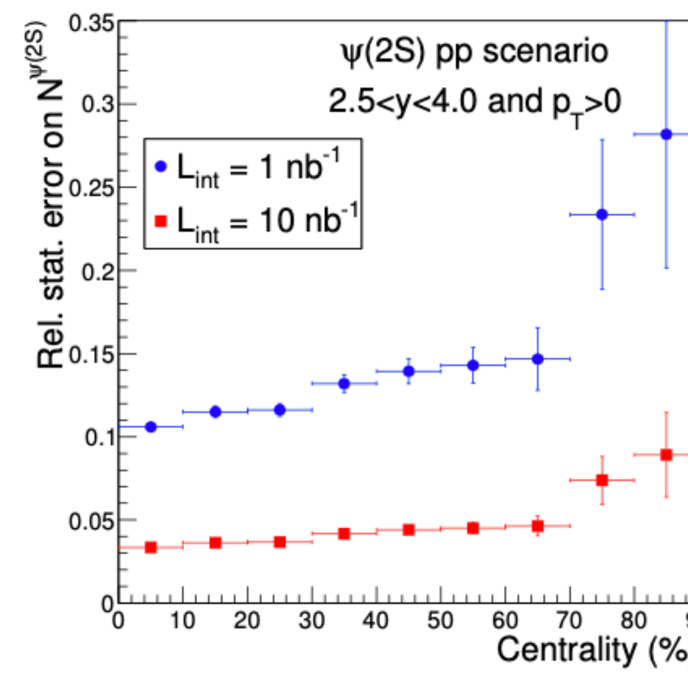
- **Charmonium states**







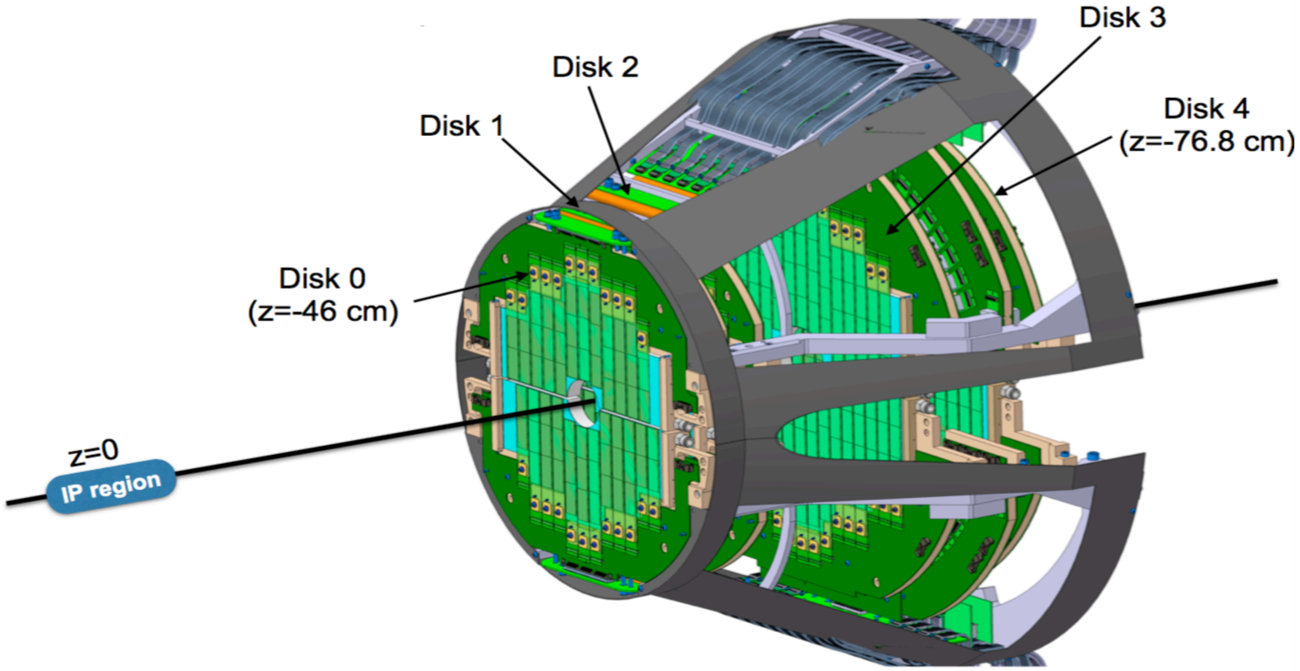
ALICE 2 - LS 2 upgrade

New Muon Forward Tracker (MFT)

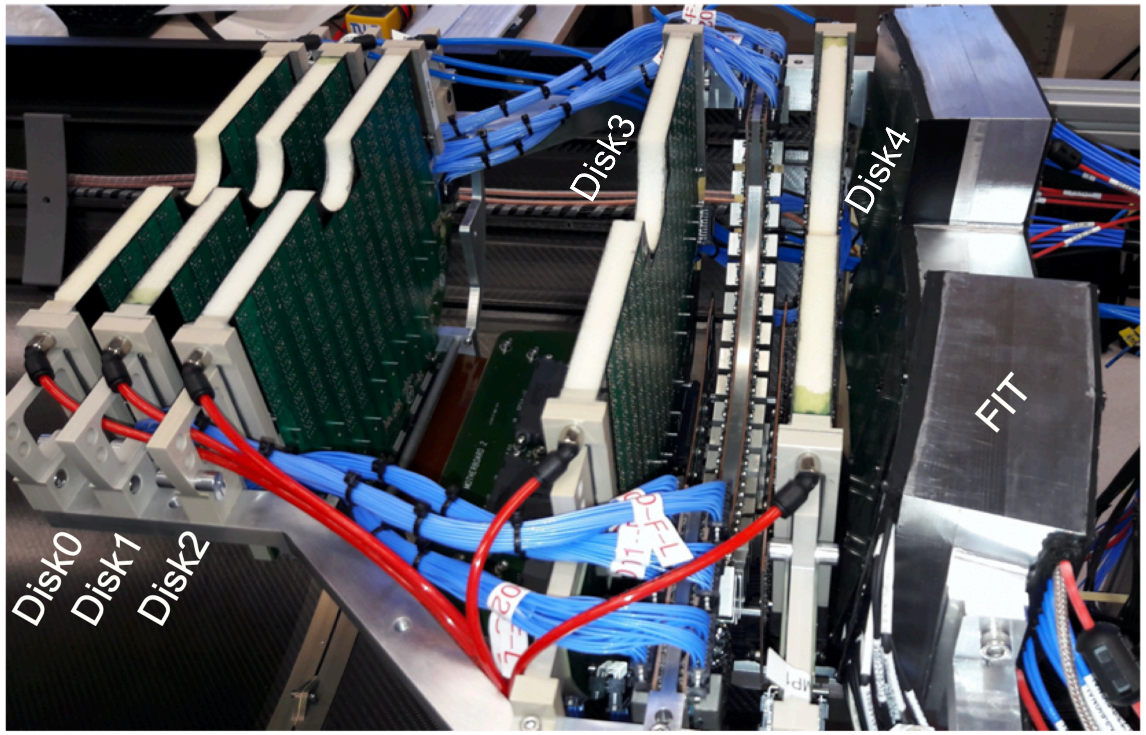
» Based on ALPIDE chips
→ 920 chips assembled on 280 ladders
→ 10 half-disks, 2 detection planes each
→ total surface = 0.4 m^2

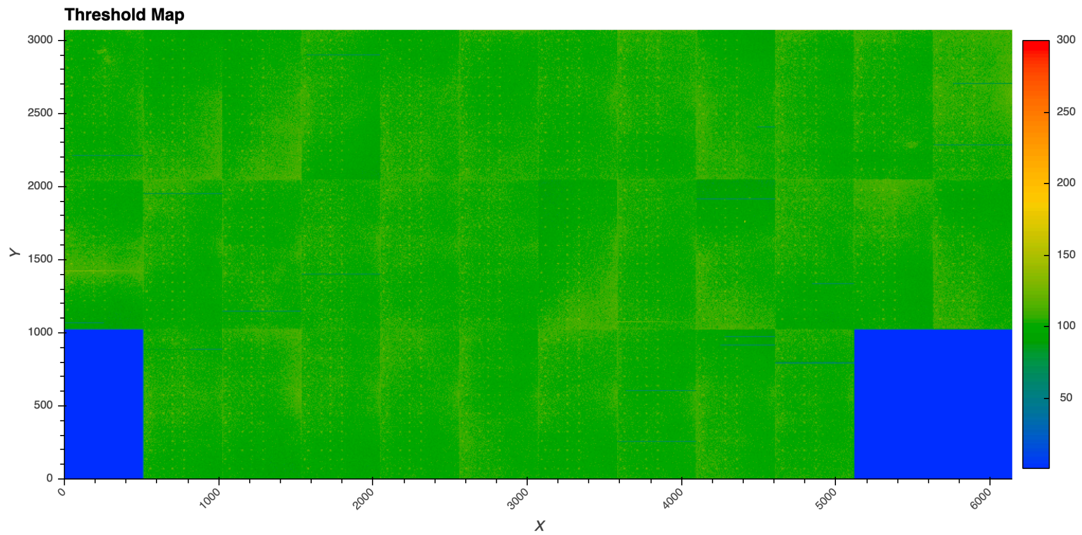
» Pseudorapidity coverage: $-3.6 < \eta < -2.45$

» Expected doses:
→ < 300 krad TID
→ $< 2\times10^{12}$ 1 MeV/n_{eq} NIEL

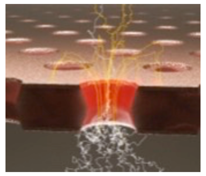


Assembly and integration completed





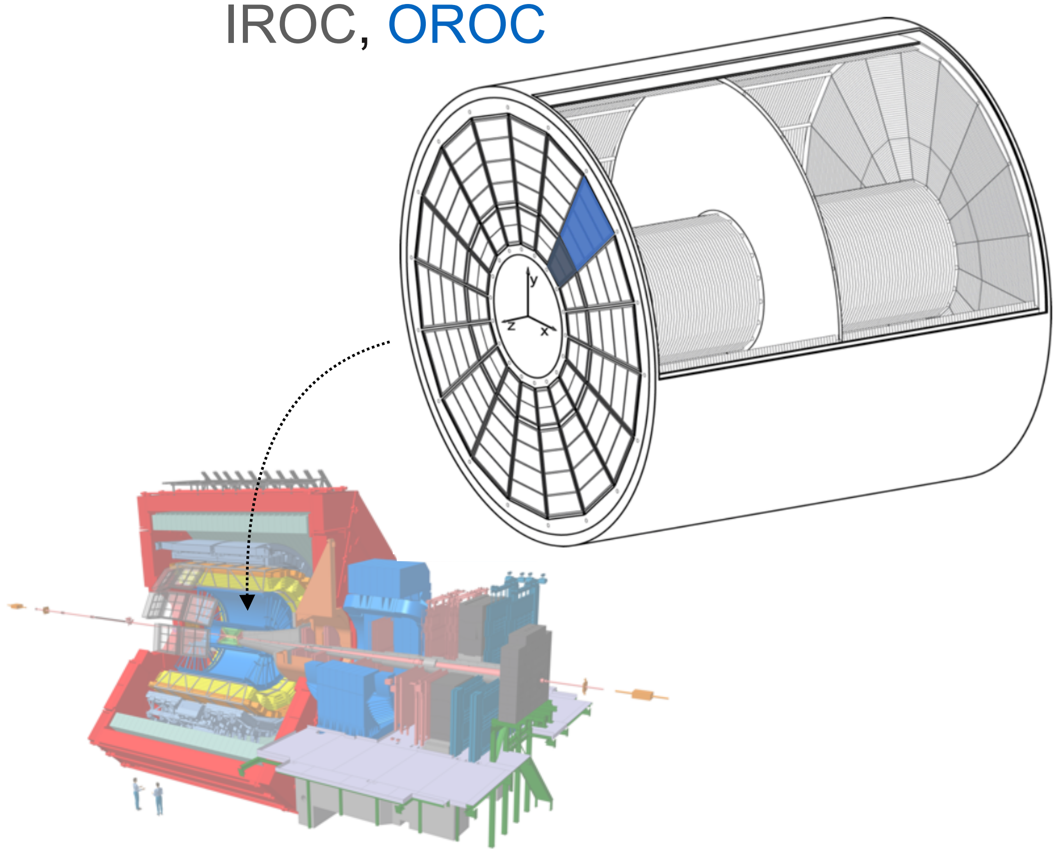
ALICE 2 - LS 2 upgrade



New TPC Readout Chambers (ROCs)

Time Projection Chamber

» Diameter/Length: 5 m/5 m
» Gas: Ne-CO_2-N_2, Ar-CO_2
» Max. drift time: ~100 μs
» 18 sectors on each side
» Inner/outer readout chamber:
IROC, OROC



Previous detector (Run 1 and Run 2)

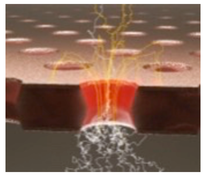
- 72 MWPCs
- ~550000 readout pads
- Wire Gating Grid to minimize Ion Back-Flow (IBF)
- Rate limited to few kHz

TPC Upgrade **requirements**

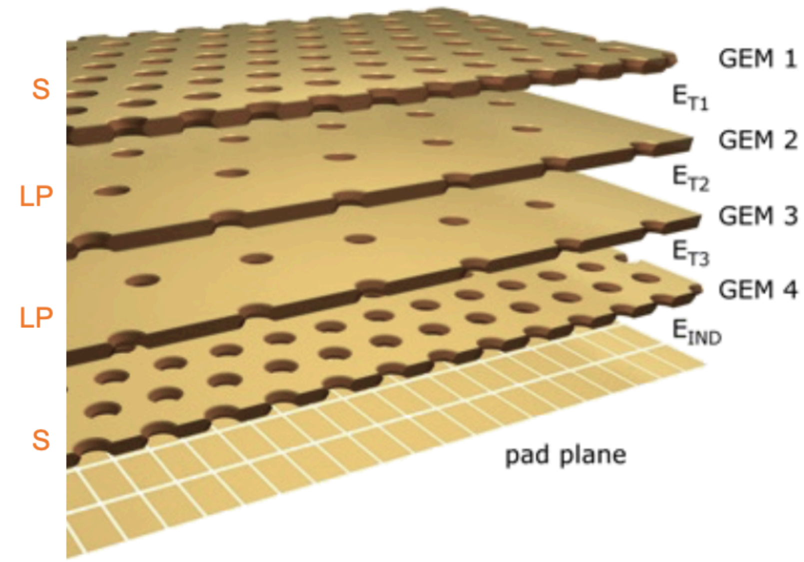
- Nominal gain = 2000 in Ne-CO_2-N_2 (90-10-5)
- Ion Back-Flow (IBF) < 1% (ε = 20)
- Energy resolution: σ_E/E < 12% for X-ray from ^{33}Fe
- Stable operation under LHC Run 3 condition
- Unprecedented challenges in terms of loads and performance

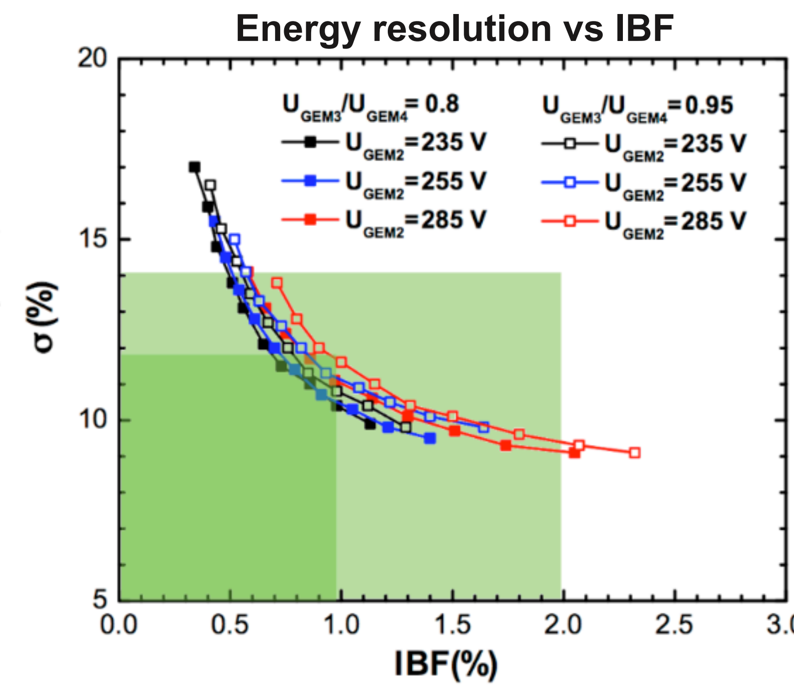
Operate the new TPC at 50 kHz → no Gating Grid

ALICE 2 - LS 2 upgrade



New TPC Readout Chambers (ROCs)

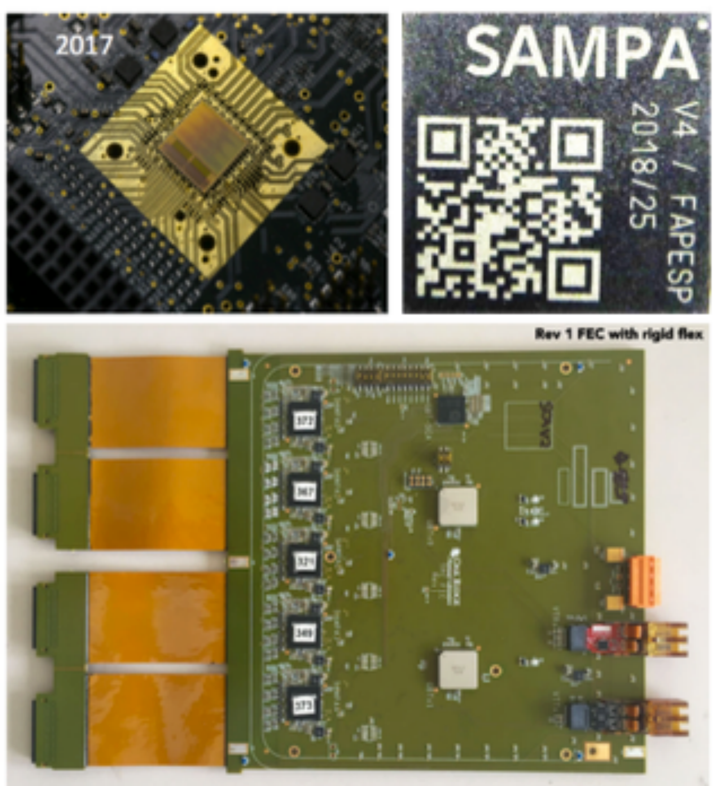




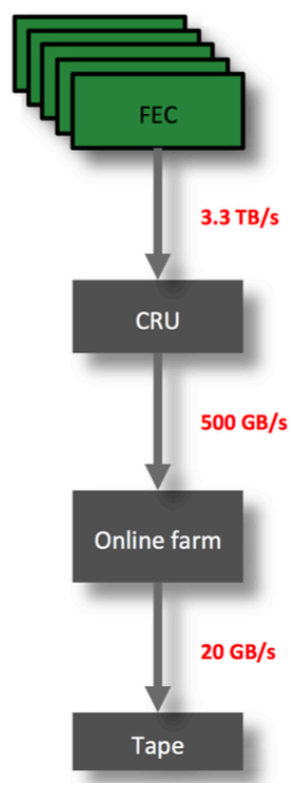
Conservative operational limits: IBF < 1 %, local energy resolution < 12 %
Extended operational range: IBF < 2 %, energy resolution < 14 %

<u>New readout chambers: 4-GEM stack</u>

- Combination of standard (S) and large pitch (LP) GEM foils
- Highly optimised HV configuration
- Result of intensive R&D



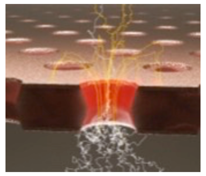
Yield = 97.4%



<u>Readout Electronics</u>

- Newly developed FE SAMPA ASIC (130 nm CMOS by TSMC)
  - 32 channels, PASA pre-amplifier + 10-bit ADC
  - Programmable conversion gain and peaking times
  - Readout mode: continuous or triggered
- Front-End Cards (FECs)
  - 5 SAMPA chips per FEC (3276 FECs in total)
  - System continuously digitises signals at 5 MHz
  - All ADC values read at 3.3 TB/s and sent to CRU

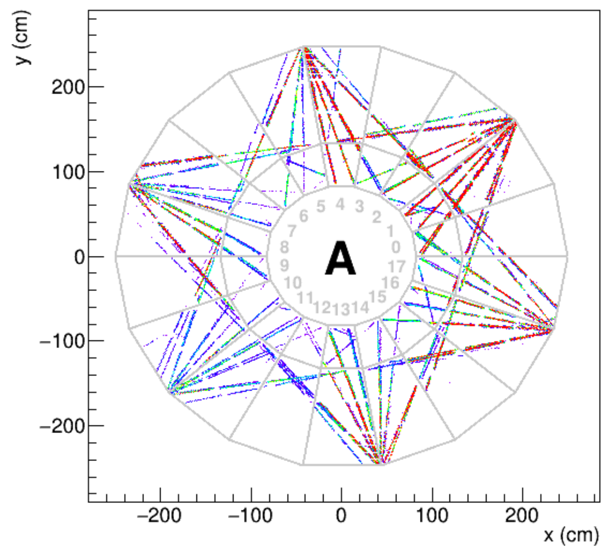
ALICE 2 - LS 2 upgrade



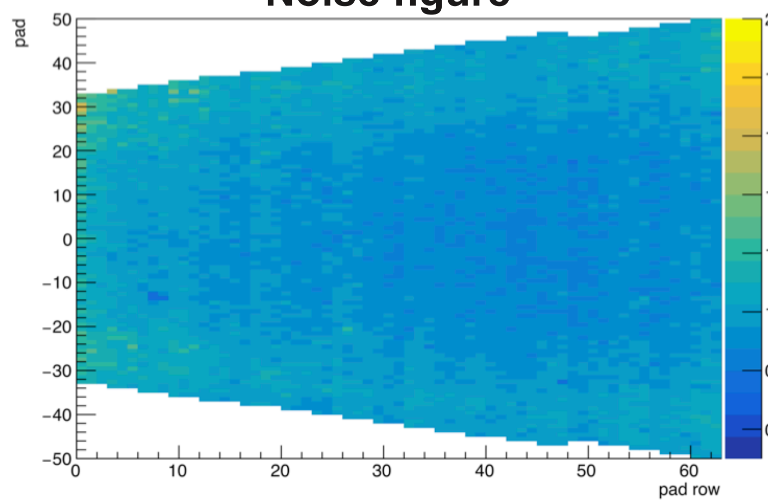
New TPC Readout Chambers (ROCs)

Perfomance

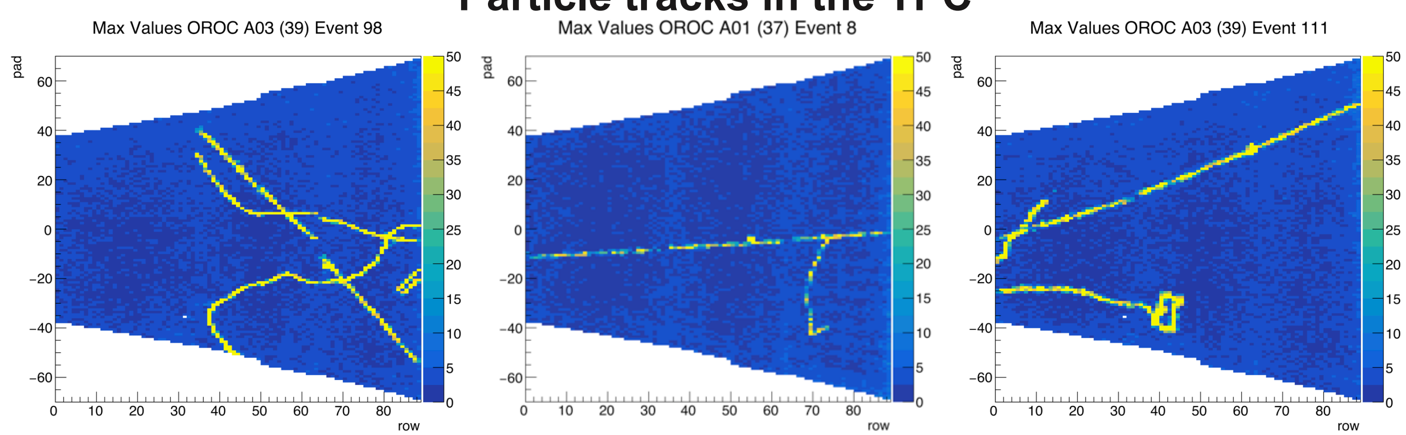
Laser tracks in the TPC

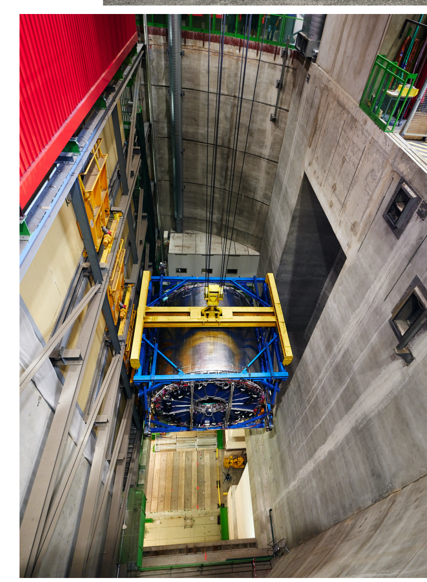


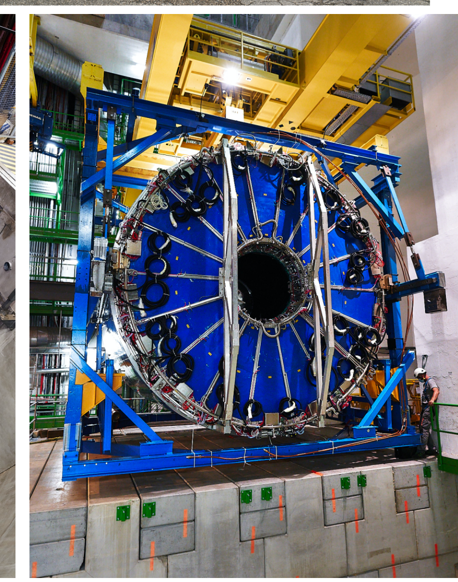
Noise figure

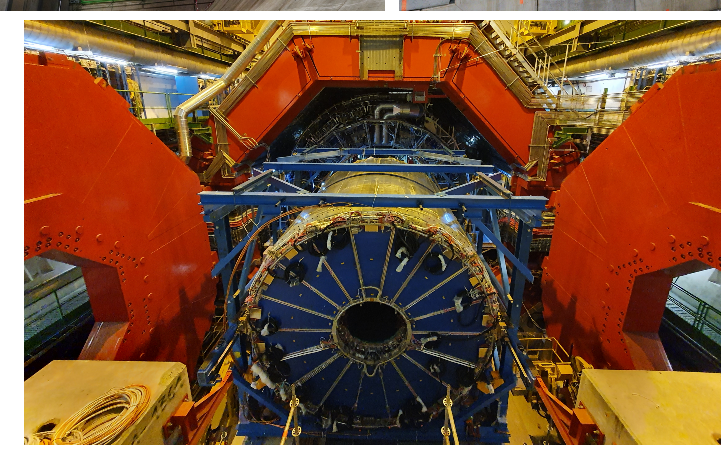


Particle tracks in the TPC





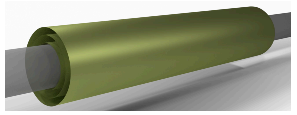




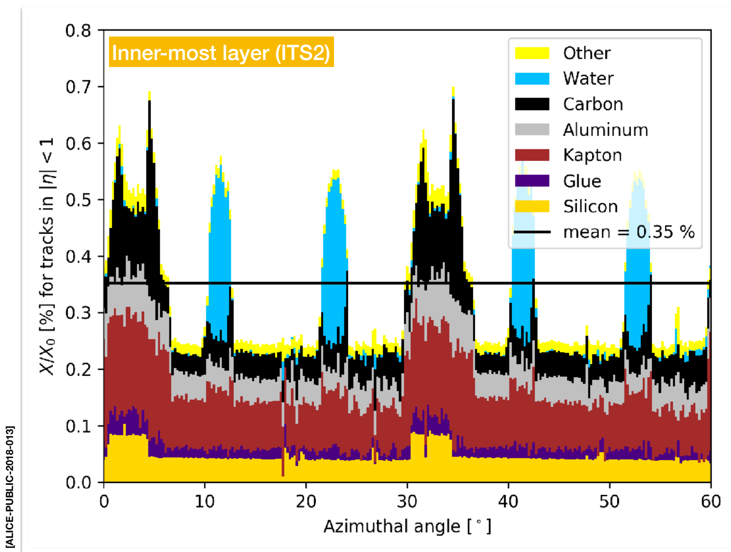
TPC installed in the Cavern

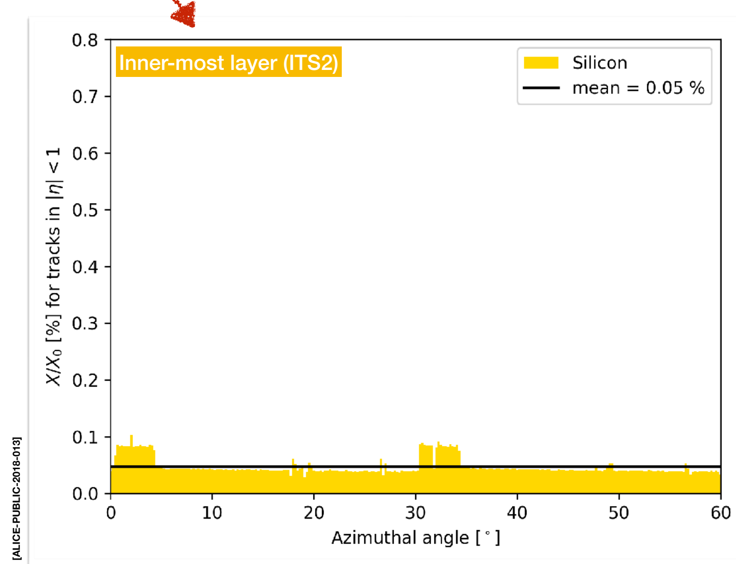
3-16 August 2020

ALICE 2 - LS 3 upgrade



New Inner Tracking System (ITS3)





Observations

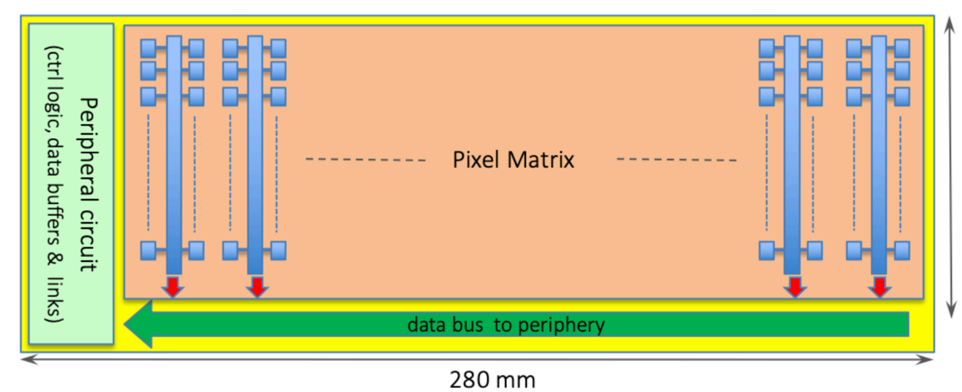
» Silicon makes only about 15% of total material
» Irregularities due to support/cooling and overlap

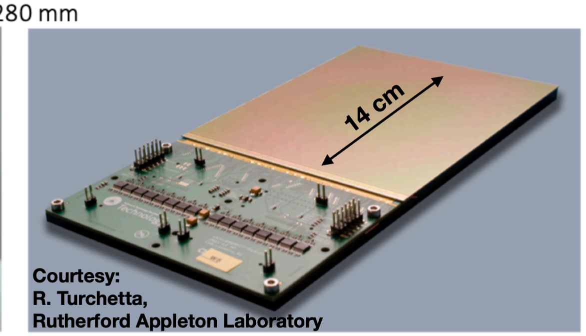
Improvements

» *Removal of water cooling*
→ **possible** if power consumption stays below 20 mW/cm^2
» *Removal circuit board* (power+data)
→ **possible** if integrated on chip
» *Removal of mechanical support*
→ **benefit** from increased stiffness by rolling Si wafers

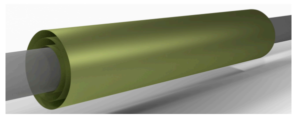
Implementation

» Air cooling
→ possible below 20 mW/cm^2 and if peripheral outside fiducial volume
» Wafer-scale chip
→ Stitching to overcome reticle size limit
→ Neither support structure nor electrical substrate necessary
» Thinning and bending
→ Currently 50 μm (25 μm active area)
→ Below 50 μm Si wafers become flexible, “paper like”
→ Smaller pixels would allow shallower active volume





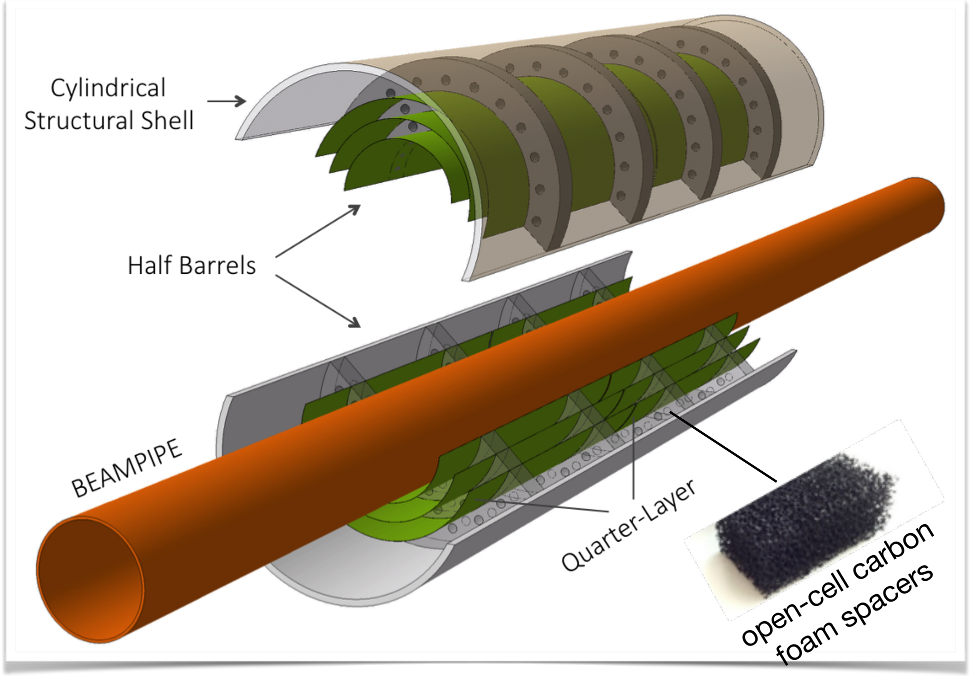
ALICE 2 - LS 3 upgrade



New Inner Tracking System (ITS3)

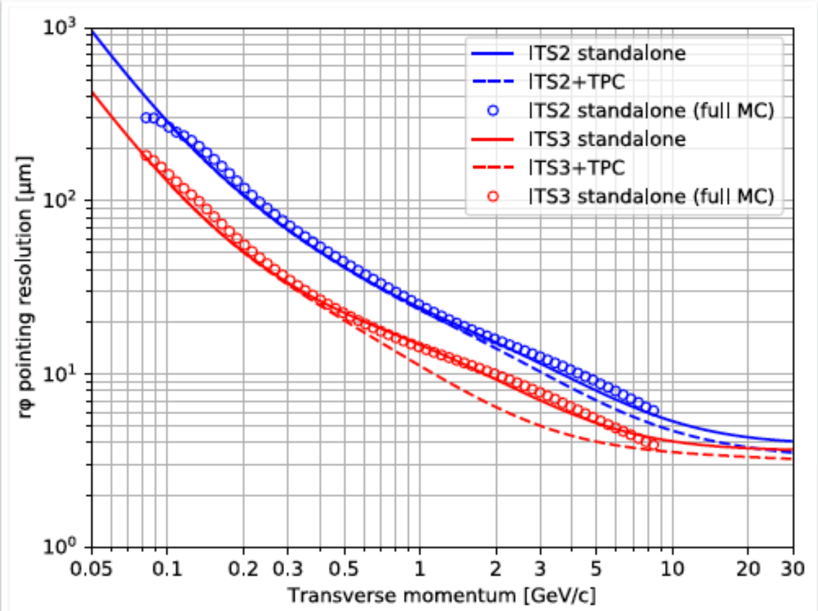
Layout and Mechanics

- *Smaller beam pipe* diameter and wall thickness (0.14% X_0)
- *Sensor thickness* 20-40 μm (0.02 - 0.04% X_0)
- Total material reduced by a factor 3
- *Material homogeneously distributed*
  → essentially zero systematic error from material distribution
- Sensors held in place by low-density *carbon foam*
- Cooling at the extremities (chip peripheries)

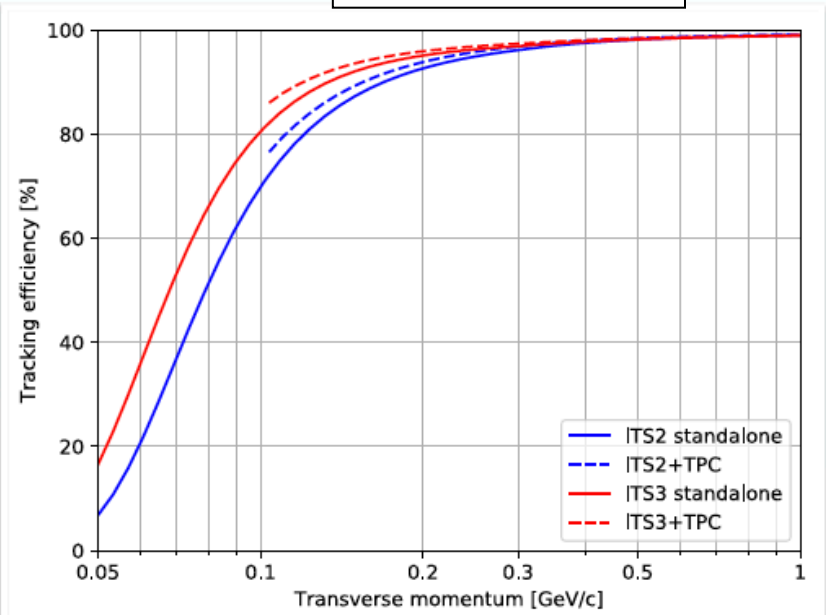


Performance

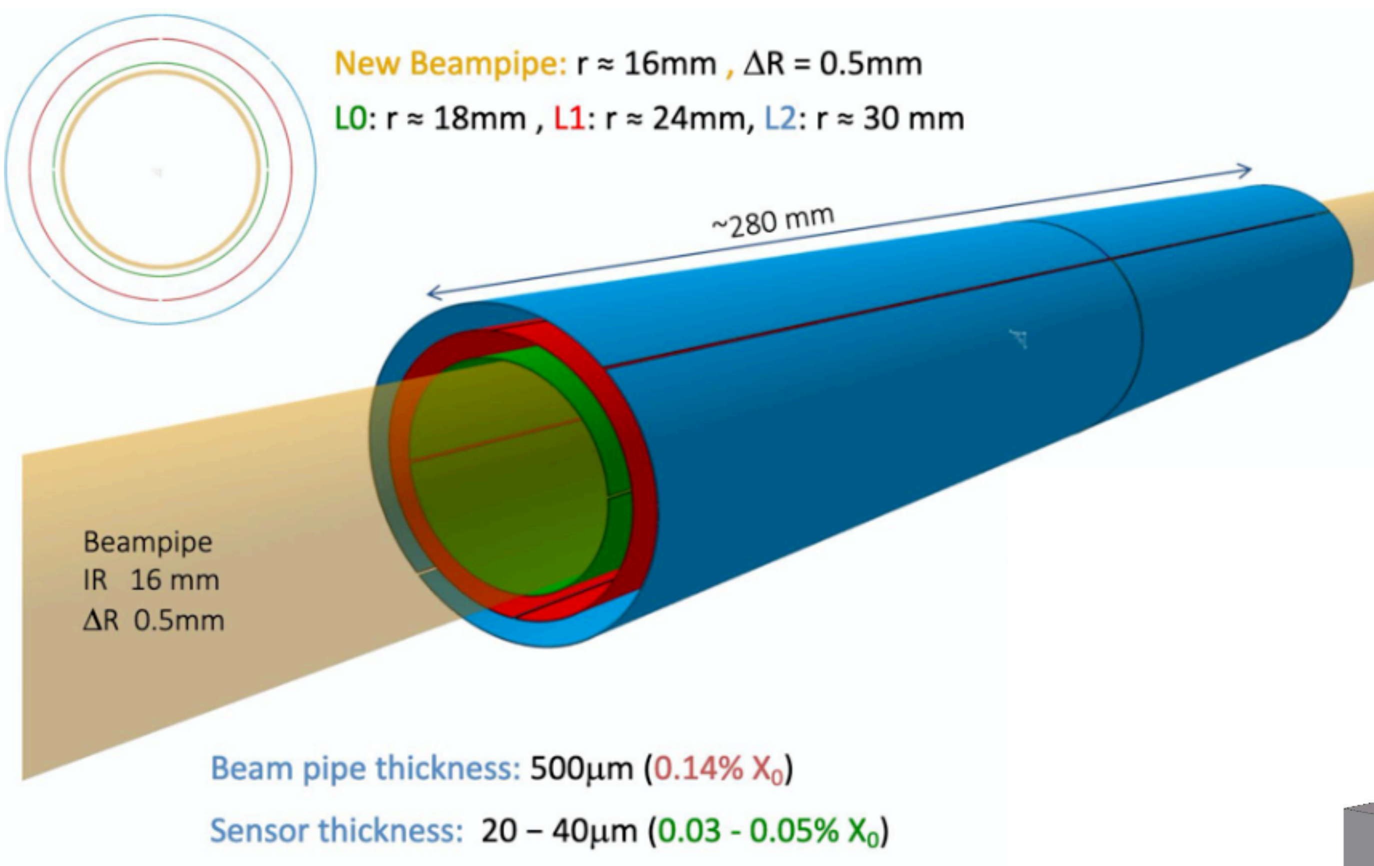
- Improved pointing resolution and tracking efficiency for low momenta (×2 at all p_T)
- Improved physics measurements for heavy-flavour baryons and low-mass dielectrons



[ALICE-PUBLIC-2018-013]

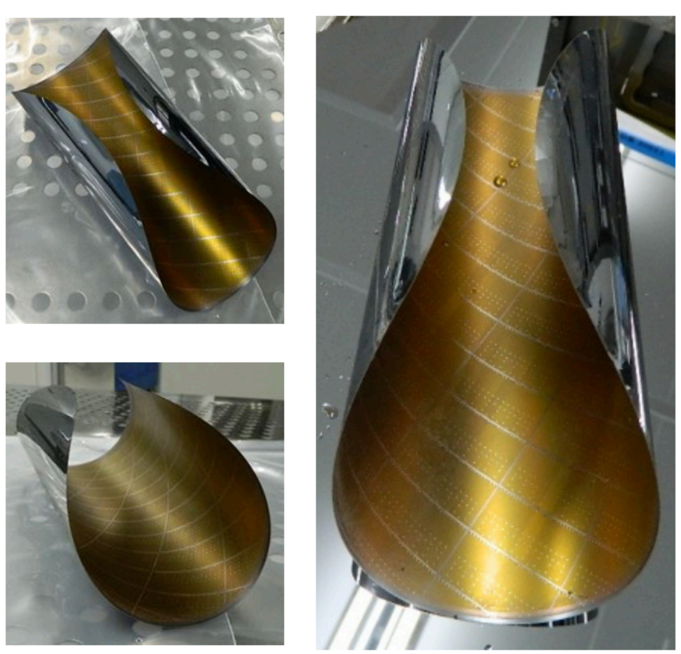


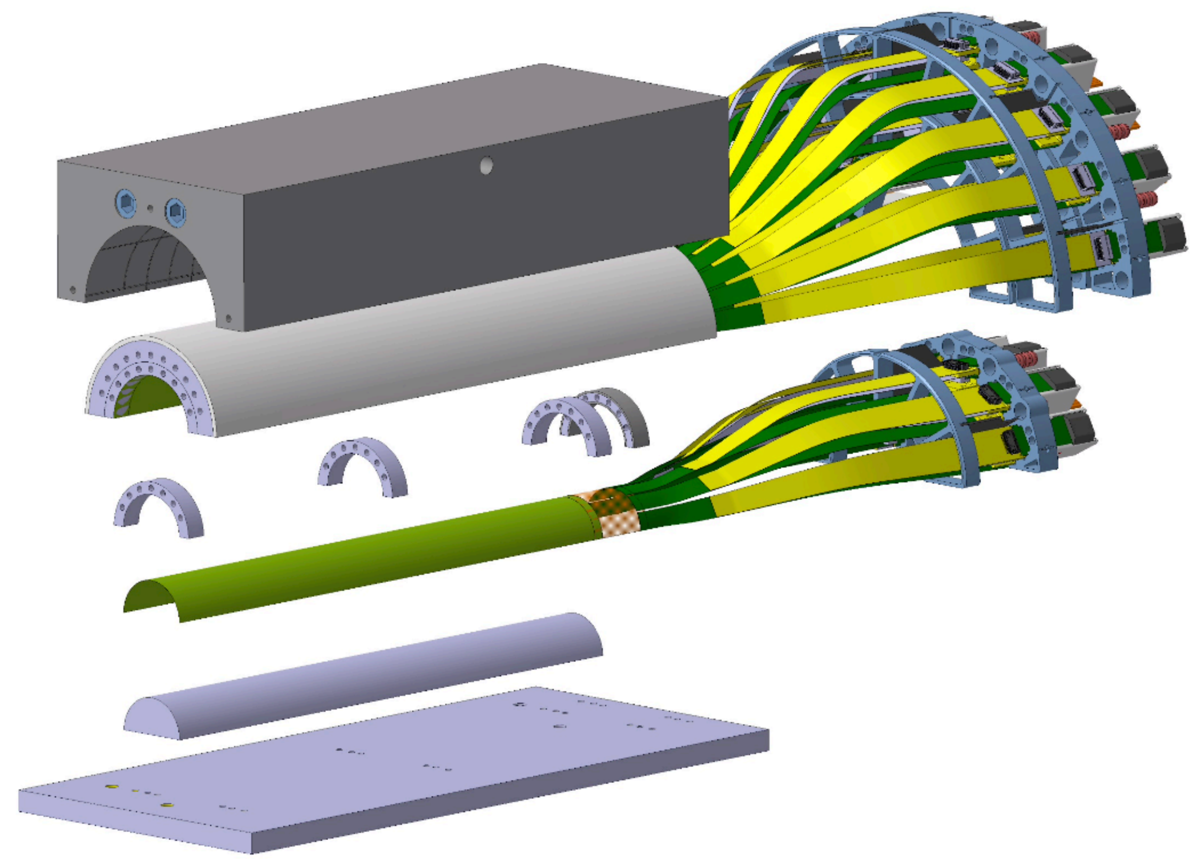
Backup - ITS 3 details



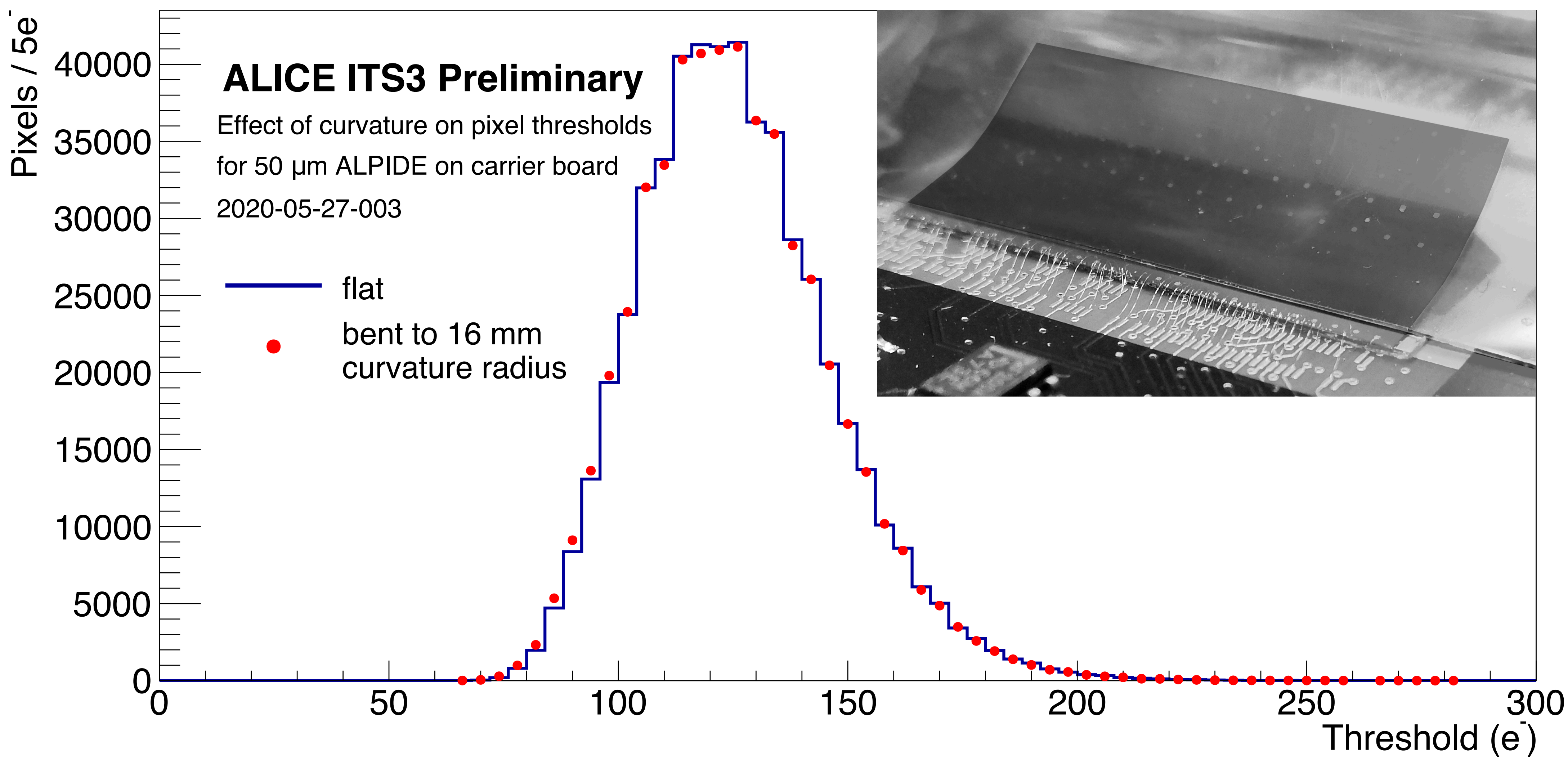
Beampipe inner/outer radius (mm)	16.0/16.5		
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm^2)	280 × 56.5	280 × 75.5	280 × 94
Number of pixel sensors / layer	2		
Pixel size (µm^2)	$O(15 \times 15)$[b]		

[a] The pseudorapidity coverage of the detector layers refers to tracks originating from a collision at the nominal interaction point ($z = 0$).
[b] For the fallback solution the pixel size is about a factor two larger ($O(30 \times 30)$ µm^2).

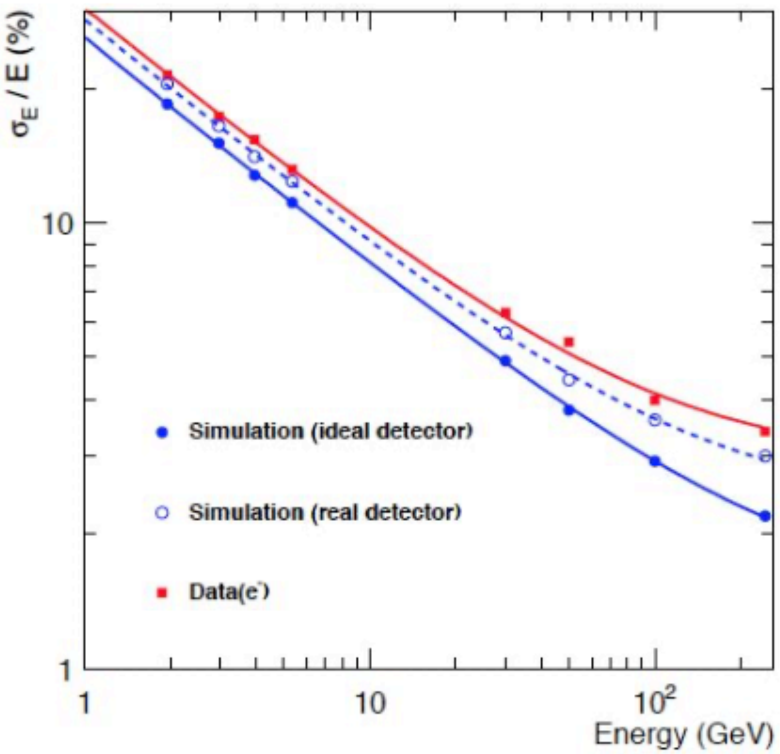


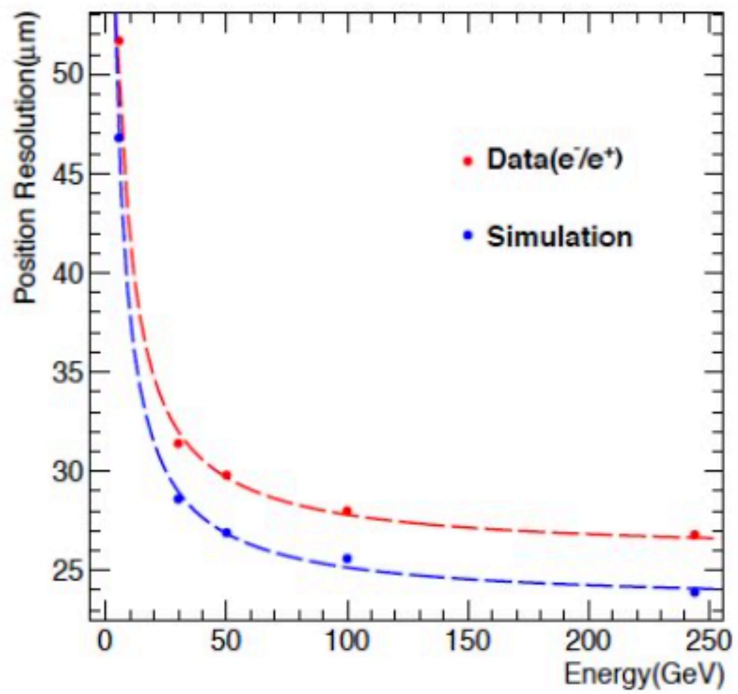


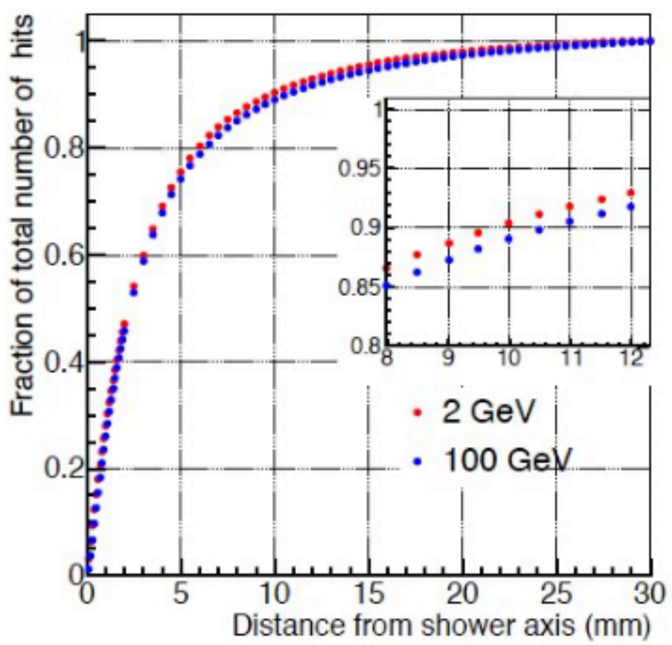
Backup - ITS 3 details



Backup - FOCAL-E performance





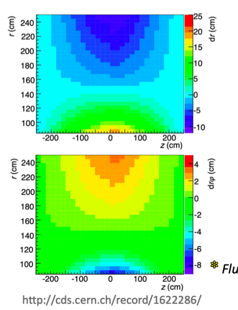


Backup - ALICE 2 Tracking in central barrel ($|\eta| < 0.9$)

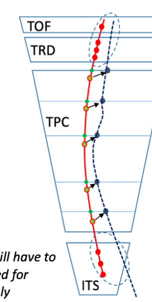
Space-Charge Distortions in the TPC

TPC GEM configuration designed to reduce to the minimum the ion backflow (< 1%)
- Still, positive charge accumulating and moving in the TPC → modified E-field → distortions in the TPC

Expectations for Pb-Pb @ 50 kHz:



Run 2 strategy for average (*) distortions:



→ Interpolation of refitted ITS, TRD and TOF track segments to the TPC as reference points for the true track position (sync)

→ Collect ΔY, ΔZ between distorted clusters and references in TPC sub-volumes (voxels) (sync)

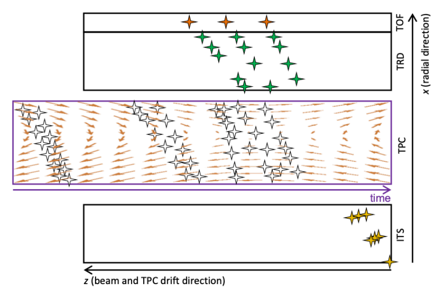
→ Extract 3D distortion vector in every voxel (offline)

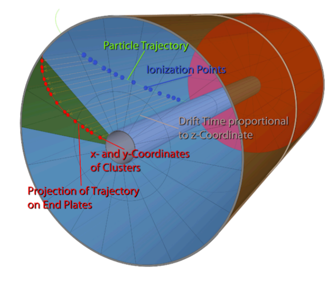
→ Use during asynchronous reconstruction (async)

Full ITS-TPC-TRD-TOF reconstruction of a fraction (~0.6%) of the tracks at synchronous stage

Tracking in the central barrel

Challenge in Run 3 + 4!
- **overlap** of multiple collisions (5 collisions in the TPC drift time @50 kHz Pb-Pb)
- with TPC clusters without a well-defined *z* coordinate, but **just a time** (*t*)
- presence of **distortion** corrections that are position dependent





$z = (t - t_{vertex}) * v_{drift}$

Tracking in the central barrel

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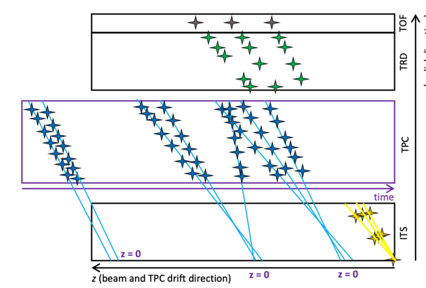

- Standalone ITS tracking
- Standalone TPC tracking, scaling *t* linearly to an arbitrary *z*.
- Extrapolate to *x* = 0, define *z* = 0 as if the track was primary
  → good enough at this stage (sync!)
- Track following to find missing clusters

Tracking in the central barrel

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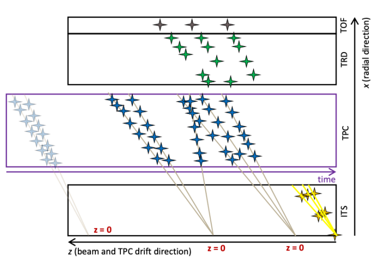

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- Refine *z* = 0 estimate, refit track with best precision
- Find ITS-TPC track compatibility using times

Tracking in the central barrel

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- **overlap** of multiple collisions (5 collisions in the TPC drift time @50 kHz Pb-Pb)
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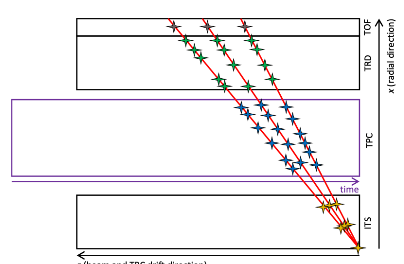

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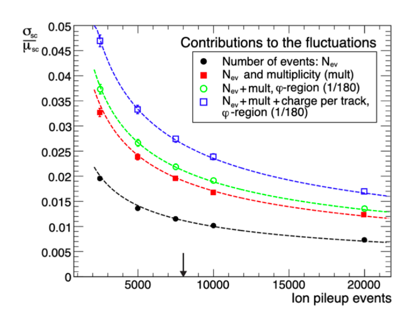
- Extrapolate to *x* = 0, define *z* = 0 as if the track was primary
  → good enough at this stage (sync!)
- Track following to find missing clusters
- Refine *z* = 0 estimate, refit track with best precision
- Find ITS-TPC track compatibility using times
- Match TPC track to ITS track, fixing *z*-position and *t* of the TPC track
- Refit ITS + TPC track outwards and inwards
- Prolong into TRD / TOF

More on TPC Space-Charge Distortions

Ion Back Flow
$t_{drift,\,ion}$ = 160 – 200 ms
IR = 50 kHz

→ Ions from 8000 – 10000 events in the TPC drift volume

→ Space-charge fluctuations ~2 – 3% (5 – 7 mm >> intrinsic resolution, 200 µm)



http://cds.cern.ch/record/1622286/

Synchronous processing

Required resolution: O(mm)

Will use → Average distortion map, scaled to occupancy. Fluctuations corrected in 1D.

Will produce → History of digital currents (charge at the readout plane) integrated over 1 ms.

Asynchronous processing

Required resolution: O(100 µm)

Will use → Distortion map from ITS-TPC-TRD-TOF interpolation. Fluctuations corrected in 3D every 5 ms with the digital currents' history from previous 160 ms.