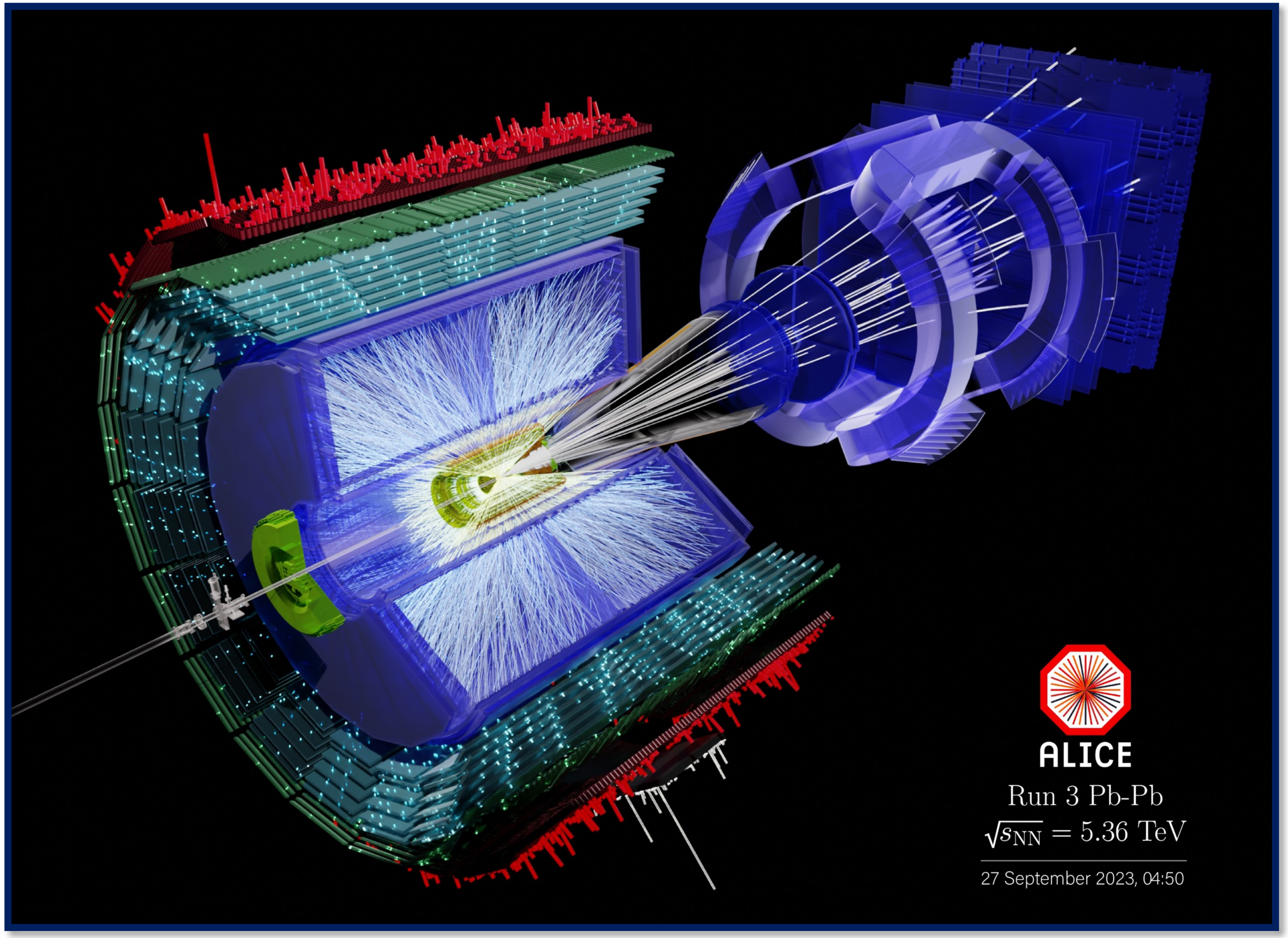
ALICE Status Report

Sarah Porteboeuf Houssais
CERN
UCA LPC CNRS
on behalf of the ALICE collaboration



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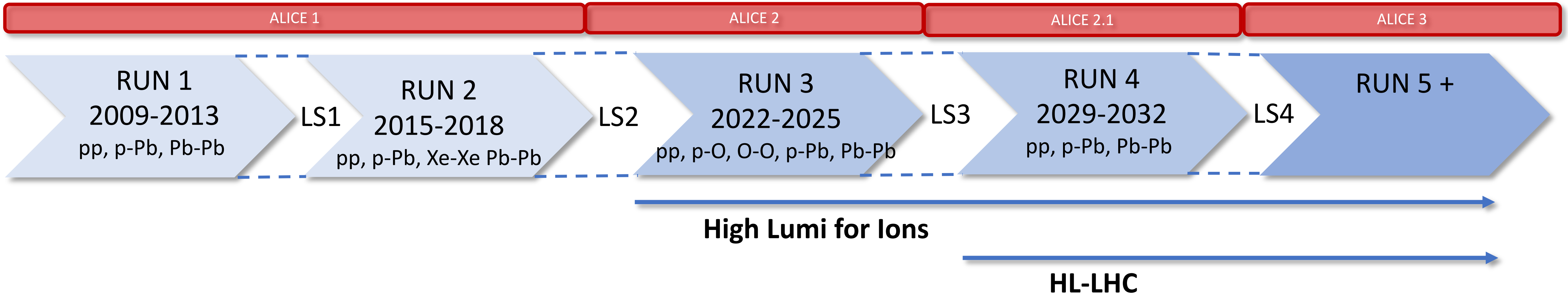
Outline



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Outline

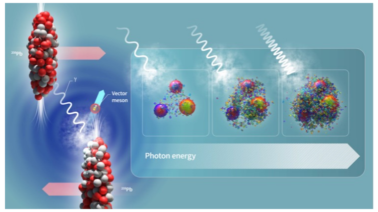
ALICE 1 | ALICE 2 | ALICE 2.1 | ALICE 3

RUN 1 2009-2013 pp, p-Pb, Pb-Pb → LS1 → RUN 2 2015-2018 pp, p-Pb, Xe-Xe Pb-Pb → LS2 → RUN 3 2022-2025 pp, p-O, O-O, p-Pb, Pb-Pb → LS3 → RUN 4 2029-2032 pp, p-Pb, Pb-Pb → LS4 → RUN 5 +

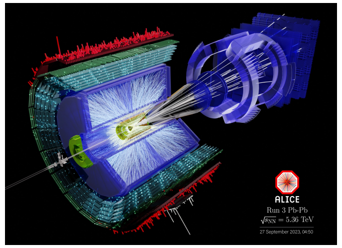
High Lumi for Ions

HL-LHC

1. Recent Physics publications

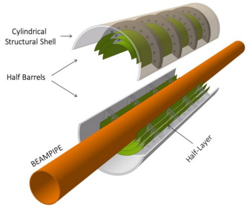


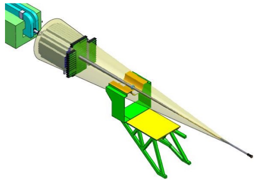
2. The first Run 3 Pb-Pb data sample



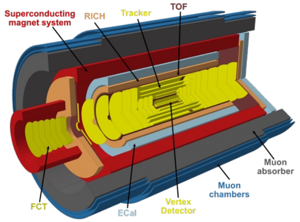
3. ITS 3 Technical Design Report

4. FoCal

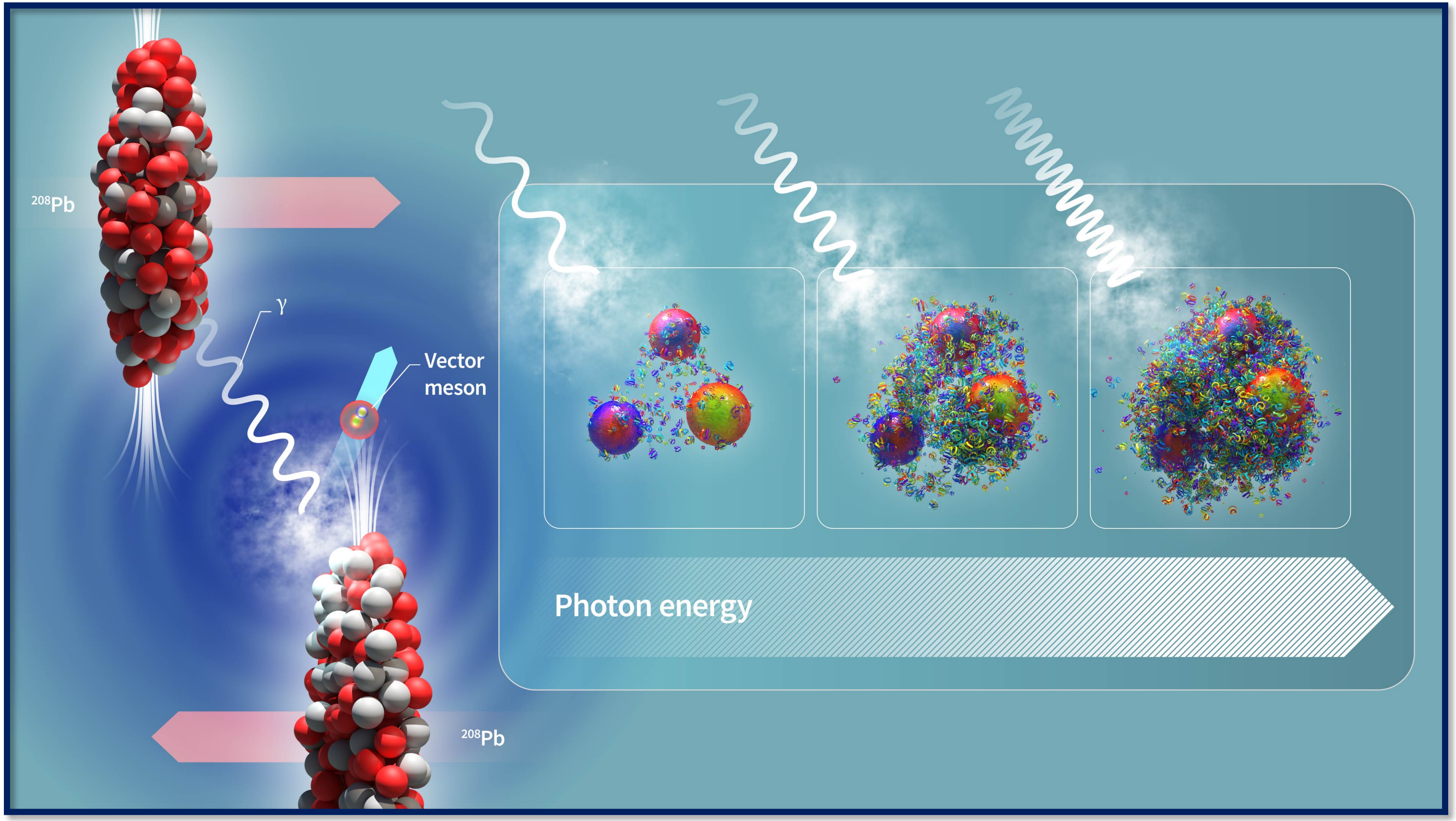




5. ALICE 3



Photoproduction of kaons



https://home.cern/news/news/physics/alice-shines-light-nucleus-probe-its-structure

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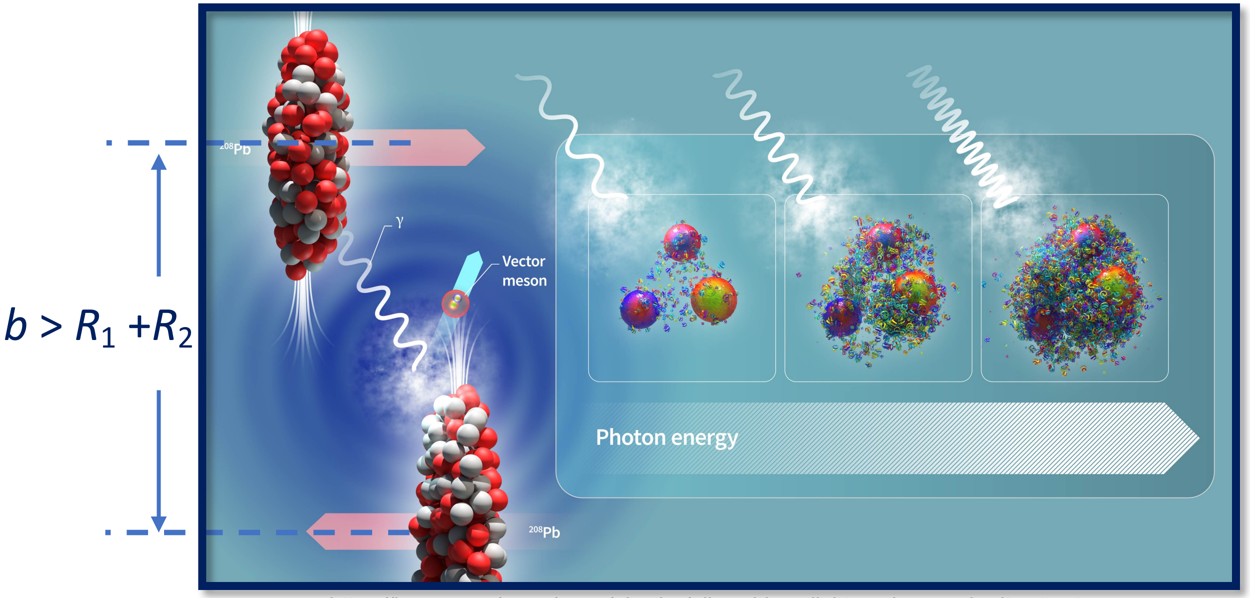
Photoproduction of kaons

- Impact parameter b is large ($b > R_1 + R_2$) : ultra-peripheral collisions
- No hadronic interactions
- Electromagnetic field of one nucleus forms an intense virtual photon beam which interacts with nuclei from opposite beam



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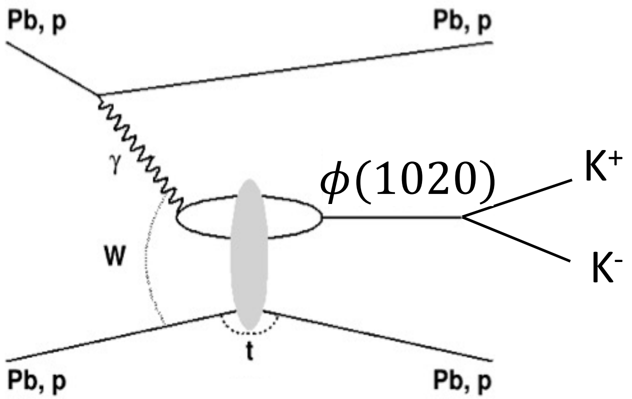
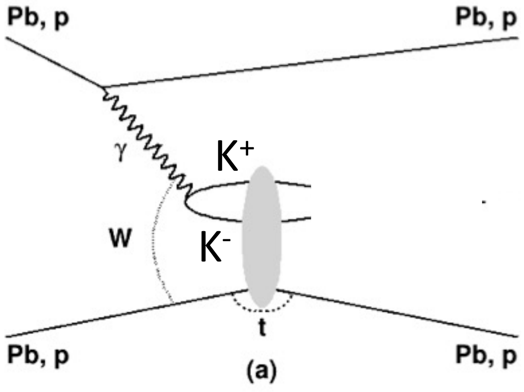
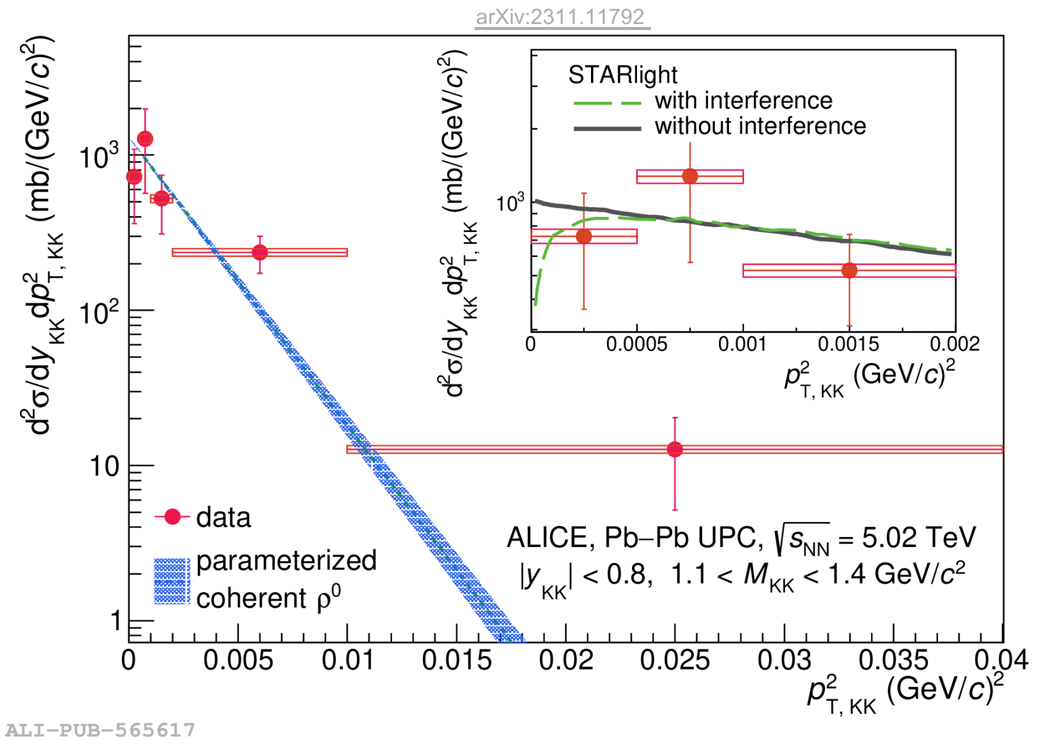
Vector meson decay into a kaon pair

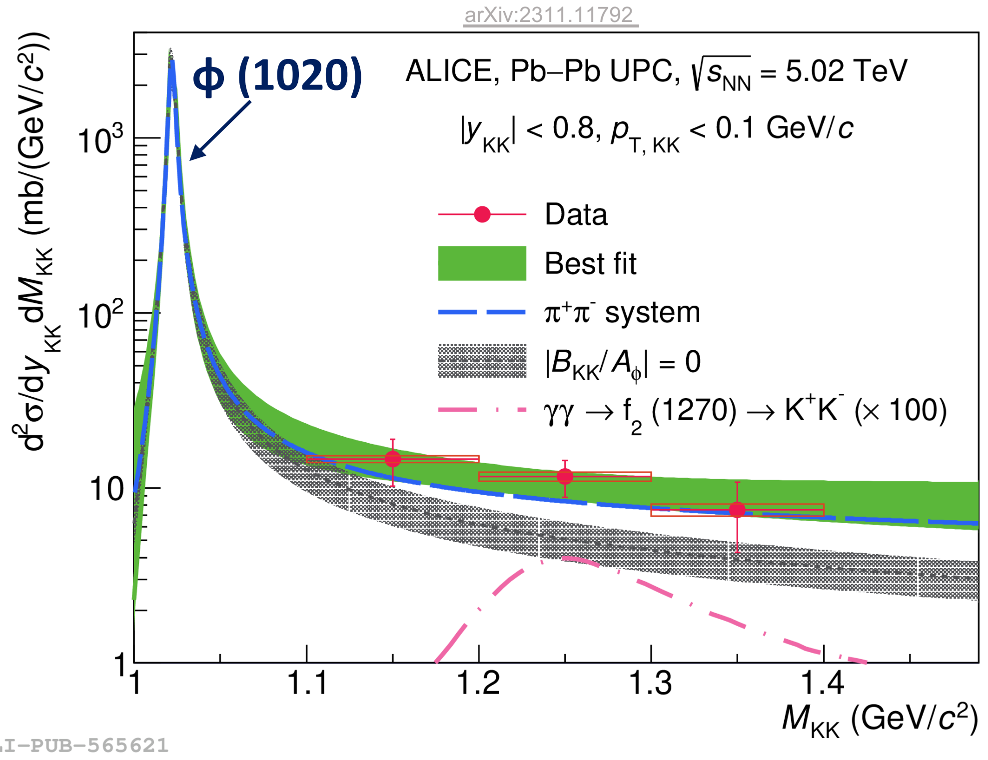




Direct production
The photon fluctuates into a virtual kaon pair which scatters elastically on target making the pair real

Photoproduction of kaons





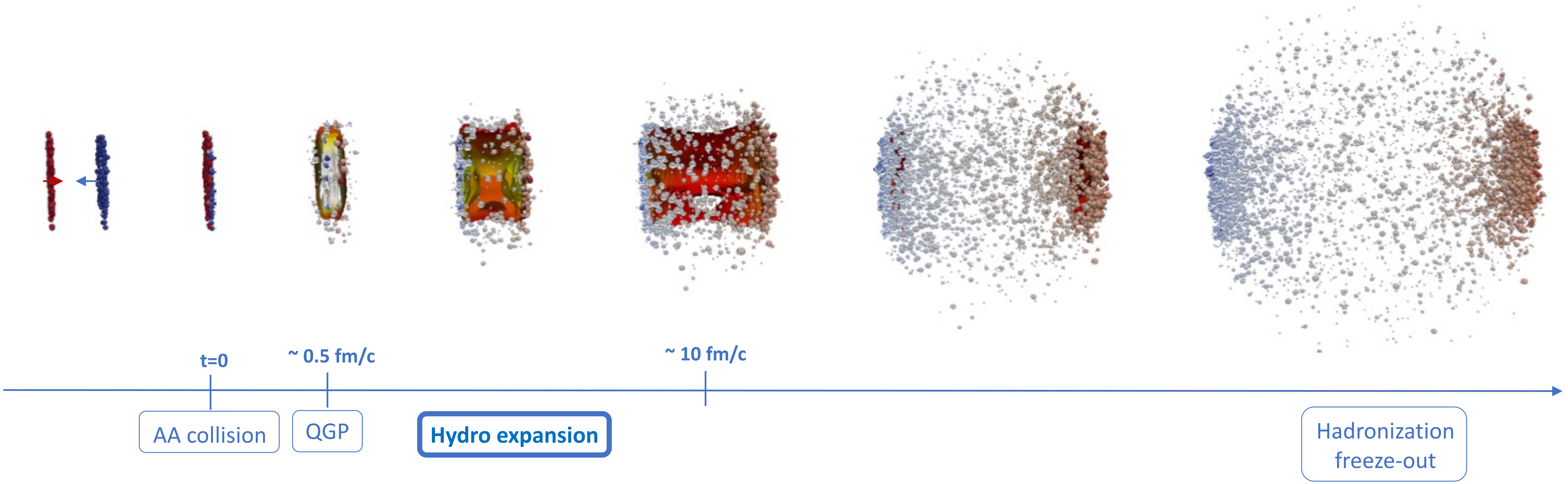
- **First measurement of kaon pairs in ultra-peripheral collisions**
- Compatible with **photoproduction at very low p_T**

- Kaons measured in the tail of the ϕ (1020)
- The **measured cross section is about 2.1σ above** the expected ϕ (1020) → K^+K^- cross section alone

Kaon pairs are produced as a mixture of direct production and ϕ(1020) decay

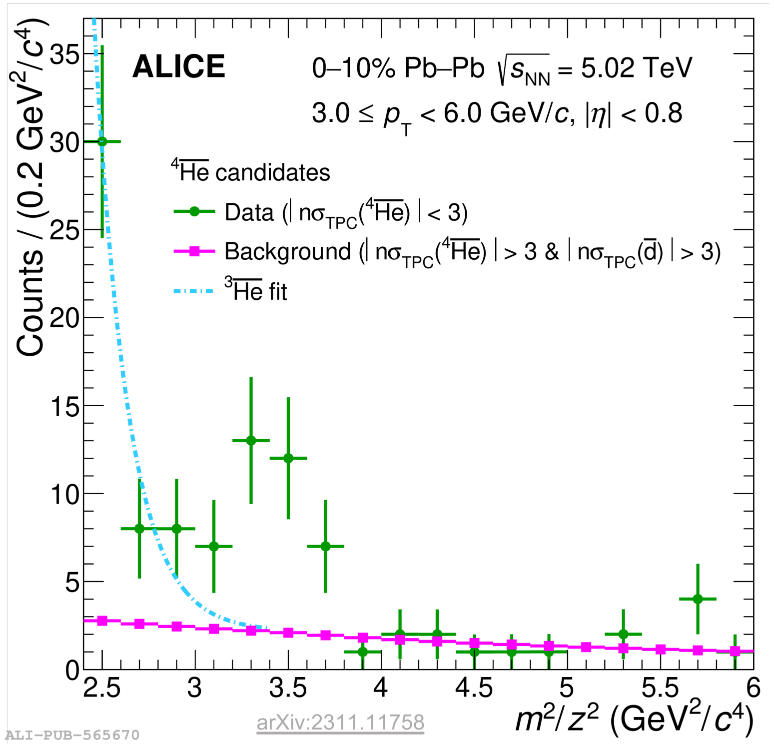
Studying the quark-gluon plasma with HI collisions

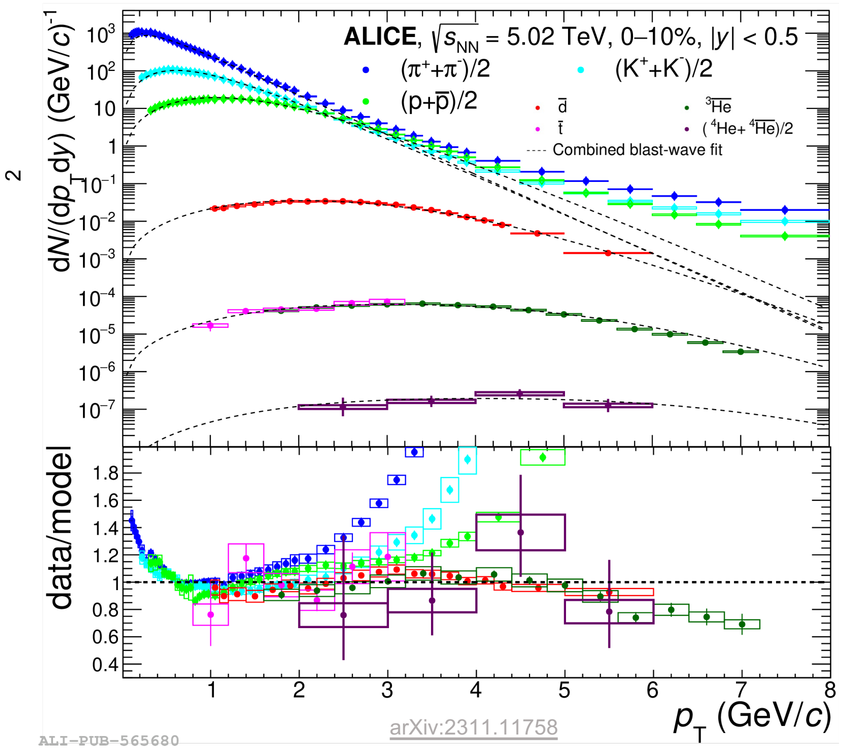
Quark-gluon plasma (QGP) is a deconfined state of quarks and gluons (asymptotic freedom regime) predicted by QCD and studied in high-energy heavy-ion collisions



Rendering by H. Elfner & J.E. Bernhard arXiv:1804.06469

(anti-)alpha production in central Pb-Pb collisions





- **First differential measurement of the (anti-)alpha transverse-momentum distribution.**
- Common blast-wave fit to the p_T-distributions. Spectra consistent with common radial flow.
- **(Anti-)Alpha are described with same parameter set as all other light flavour particles.**

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Antimatter/matter imbalance at the LHC

- New measurement of the antimatter/matter imbalance at the LHC
- Statistical Hadronization Model fits the measurements

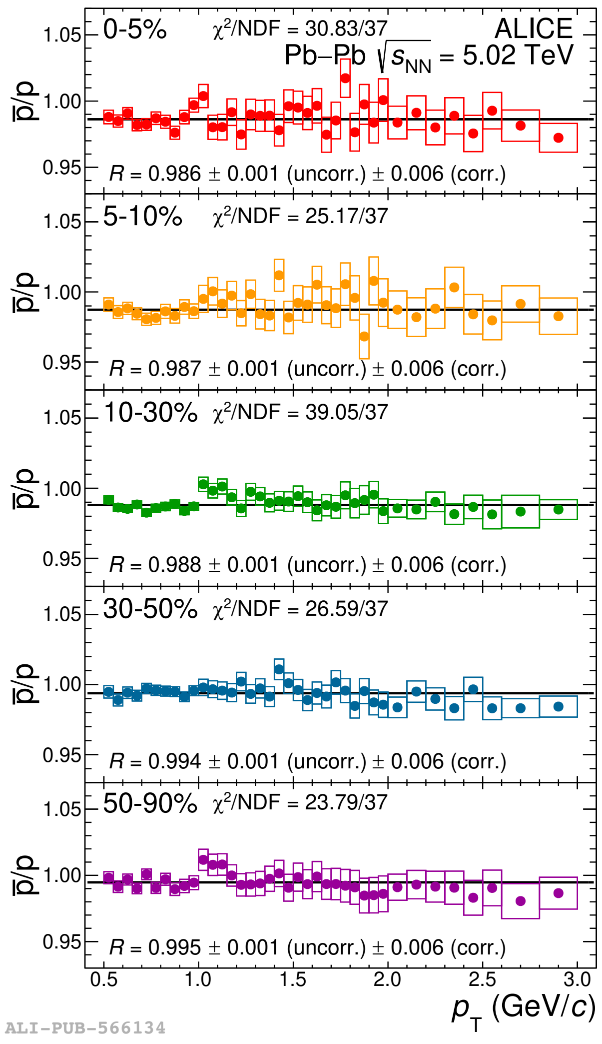
μ_B = baryon chemical potential, the net-baryon density of the system

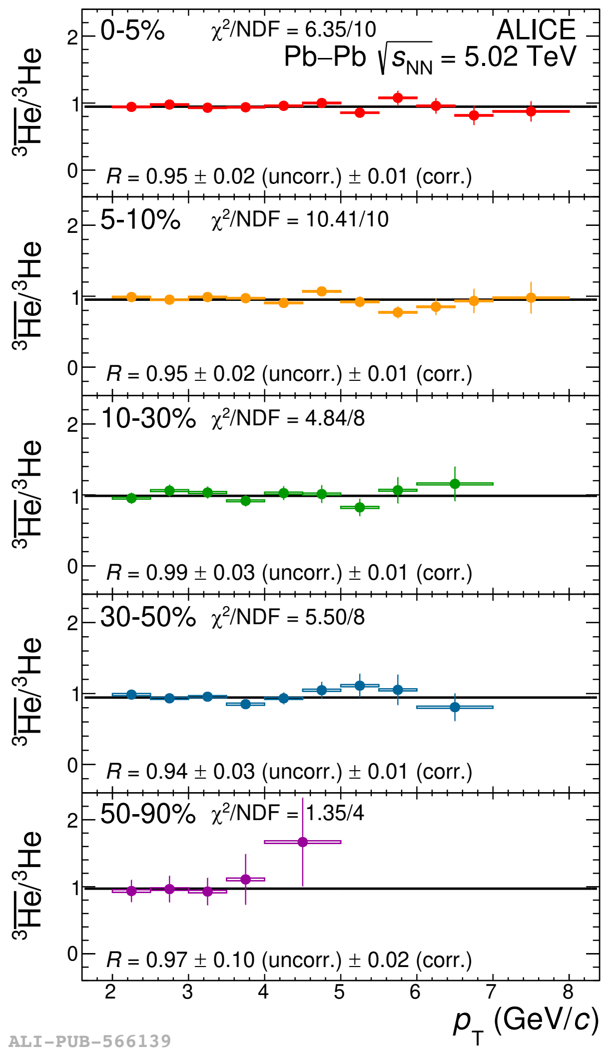
μ_Q= electric charge potential, positive-negative charge imbalance of the gas

$$\frac{\bar{h}}{h} \propto e^{-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T}-2Q\frac{\mu_Q}{T}}$$

T = 156.2 ± 2 MeV from LQCD

arXiv:2311.13332





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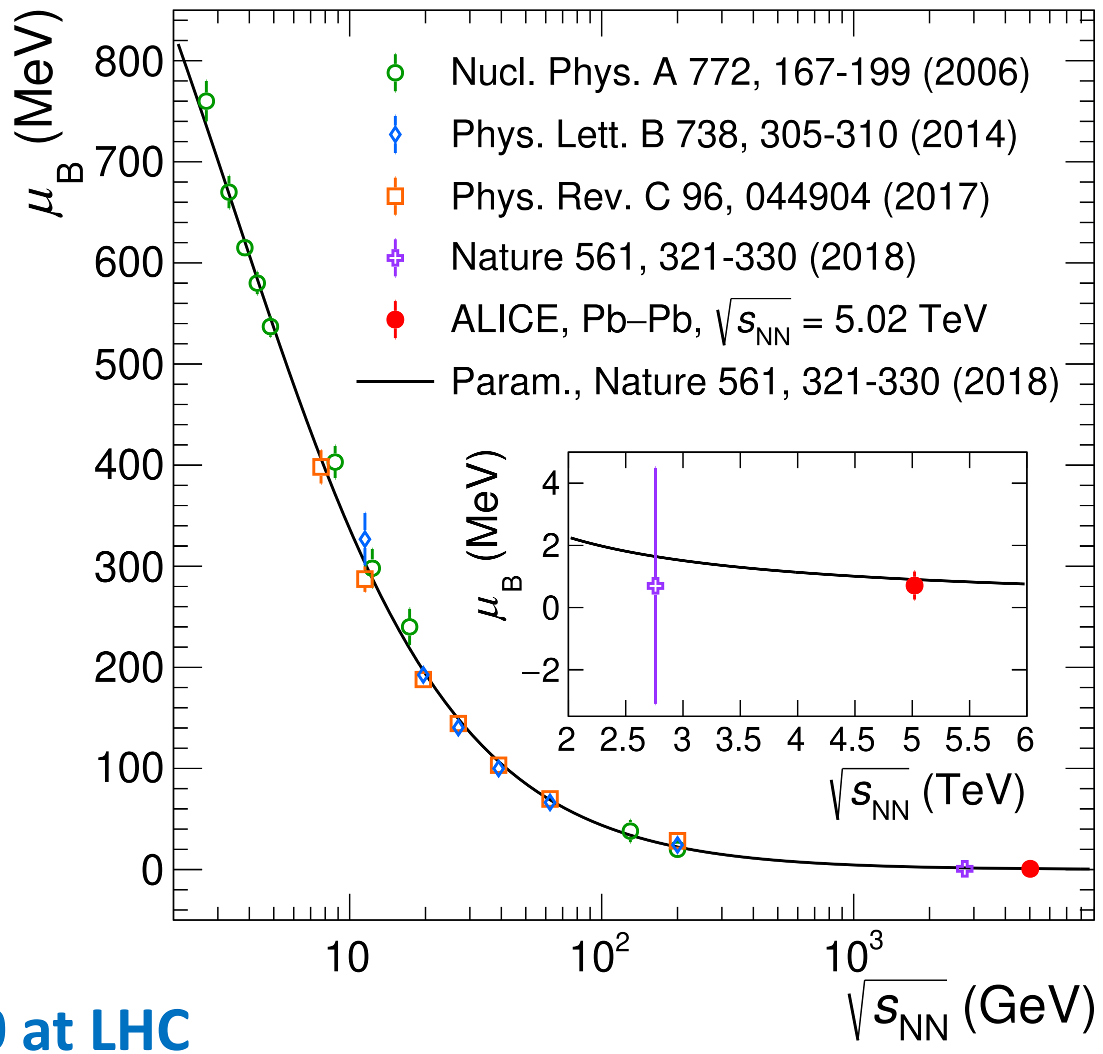
$$\frac{\bar{h}}{h} \propto e^{-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T}-2Q\frac{\mu_Q}{T}}$$

- **From the fits : new determination of the baryochemical potential at hadronization with unprecedent precision**

$$\mu_B = 0.71 \pm 0.45\ \mathrm{MeV}$$

- Net-baryon free system at the LHC for $|y| < 0.5$

arXiv:2311.13332



μ_B close to 0 at LHC

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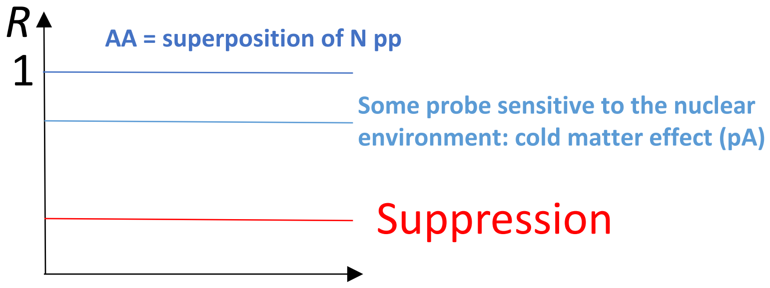
f_0(980) : abnormal suppression in p-Pb collisions

Nuclear modification factor in AA collisions

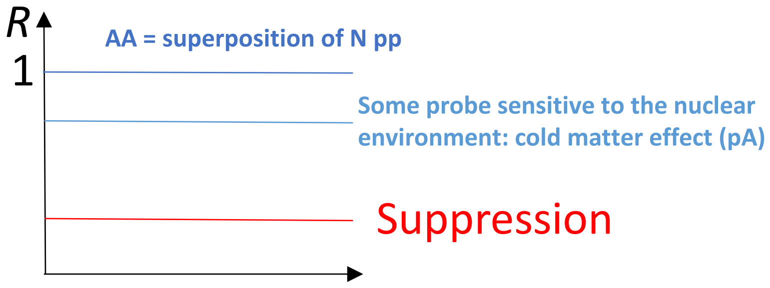


$$Q_{\mathrm{pPb}} = \frac{\mathrm{d}^2 N^{\mathrm{pPb}}_{\mathrm{f}_0(980)}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}{\langle T_{\mathrm{pPb}}\rangle\, \mathrm{d}^2\sigma^{\mathrm{pp}}_{\mathrm{f}_0(980)}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y},$$

Nuclear modification factor adapted to p-Pb collisions

$f_0(980)$: abnormal suppression in p-Pb collisions

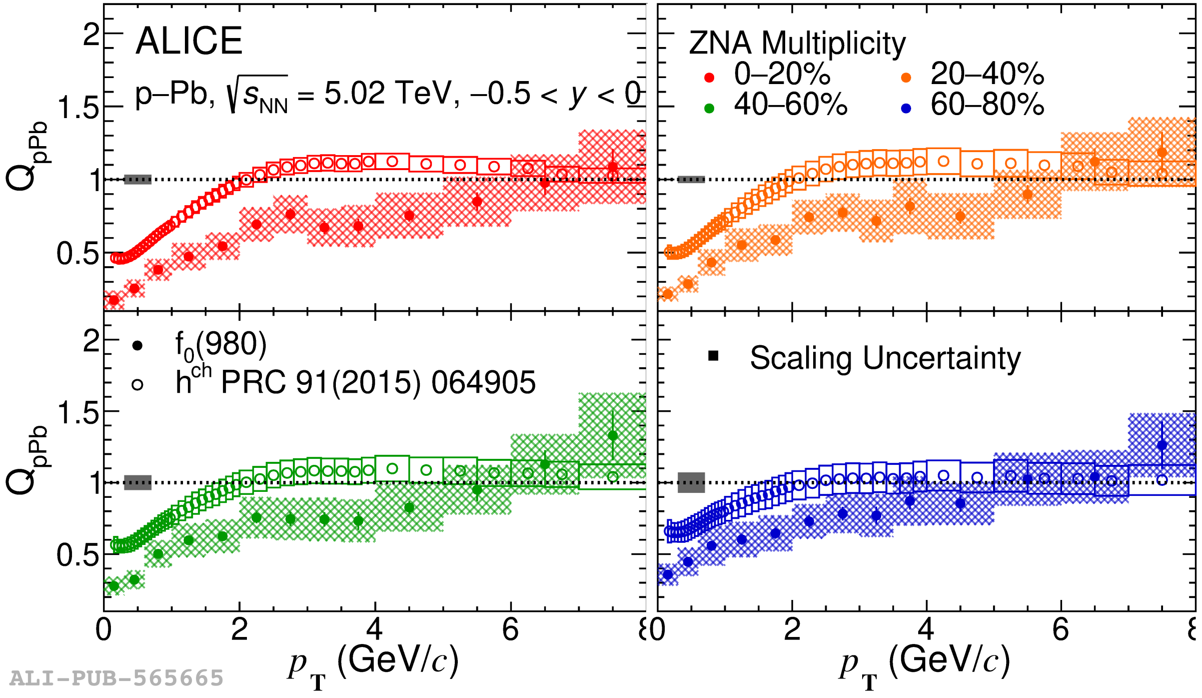
Nuclear modification factor in AA collisions



$$Q_{\mathrm{pPb}} = \frac{\mathrm{d}^2 N^{\mathrm{pPb}}_{\mathrm{f_0(980)}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}{\langle T_{\mathrm{pPb}}\rangle\, \mathrm{d}^2\sigma^{\mathrm{pp}}_{\mathrm{f_0(980)}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y},$$

Nuclear modification factor adapted to p-Pb collisions

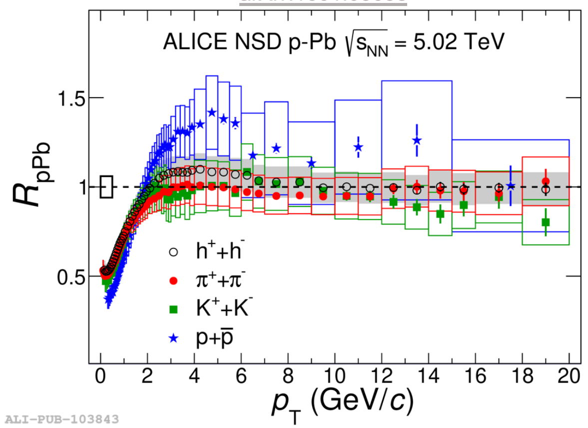
arXiv:2311.11786



- $f_0(980)$ nuclear modification factor is lower than unity : suppression
- for p_T < 4 GeV/c
  - lower than charged hadrons
  - difference increases with increasing multiplicity
- No enhancement, Cronin-like (coalescence), at intermediate p_T => hints at two-quark instead of tetraquark structure

f_0(980) : abnormal suppression in p-Pb collisions

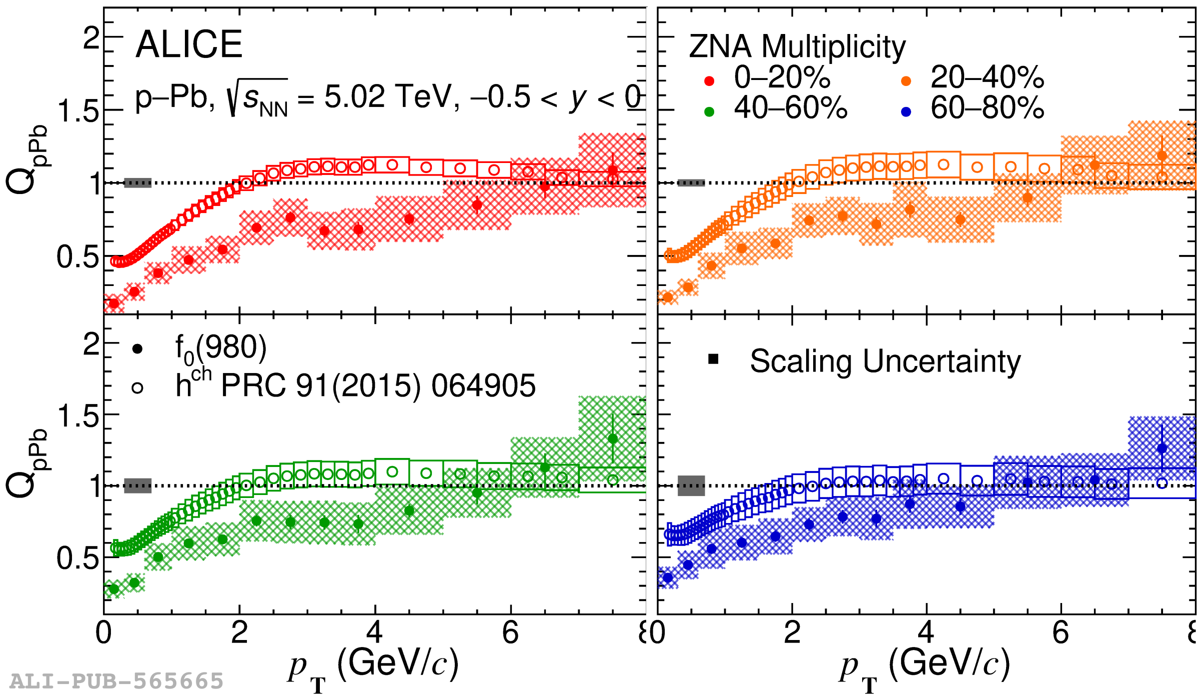
arXiv:1601.03658



$$Q_{pPb} = \frac{d^2N^{pPb}_{f_0(980)}/dp_T dy}{\langle T_{pPb}\rangle d^2\sigma^{pp}_{f_0(980)}/dp_T dy},$$

Nuclear modification factor adapted to p-Pb collisions

arXiv:2311.11786



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Clear suppression of f_0 production suggests impact of final state scattering and meson like structure

ALICE

Density effects seen in pp and p-Pb

- **Signs of collectivity observed in small systems**
  - What mechanism produces collective effects in pp and p-Pb collisions ?
  - Is it the same mechanism for all systems ?
  - Do we form a “QGP droplet” in small systems ?
  - Review *A Journey through QCD* arXiv:2211.04384
- **Need for new event classifiers**

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STRONG INTERACTIONS | NEWS

Collectivity in small systems produced at the LHC

3 November 2023

A report from the ALICE experiment.

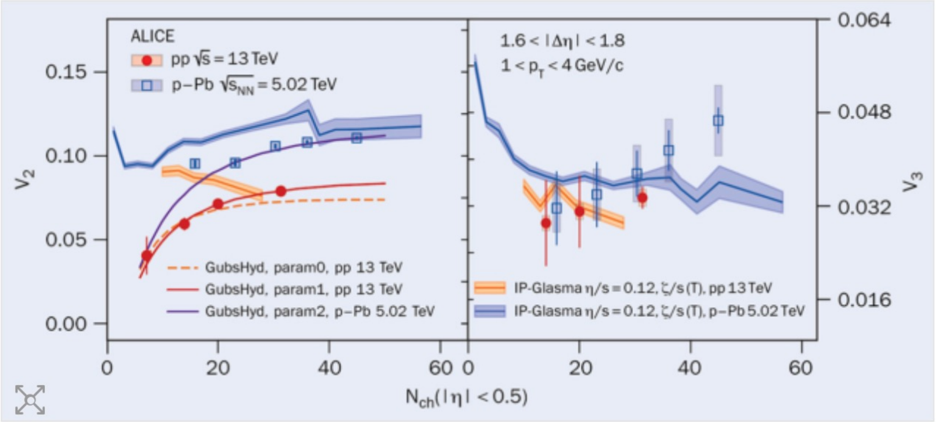

Fig. 1. The measured and calculated evolution of elliptic (left) and triangular (right) flow in pp and pPb collisions as a function of charged-particle multiplicity at midrapidity. The measurements are compared to the state-of-the-art hydrodynamic calculations. Source: arXiv:2308.16591

https://cerncourier.com/a/collectivity-in-small-systems-produced-at-the-lhc/

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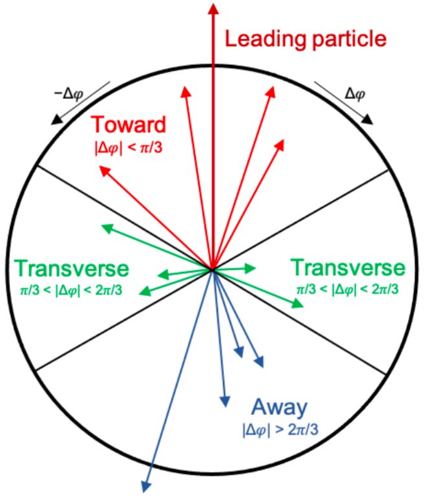
Event classifier : R_T, spherocity and femtoscopy

Classify events by underlying event activity

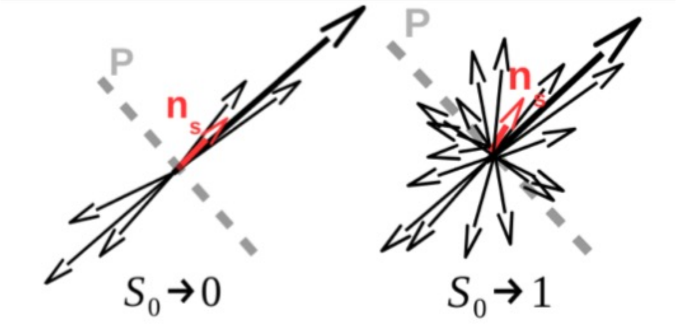


The transverse activity classifier R_T built as a jet-free multiplicity estimator

$$R_T = \frac{N_{\text{inclusive}}}{\langle N_{\text{inclusive}} \rangle}\Big|_{\text{Transverse}}$$

R_T classifies events in term of high (R_T >> 1) or low UE (R_T < 1)

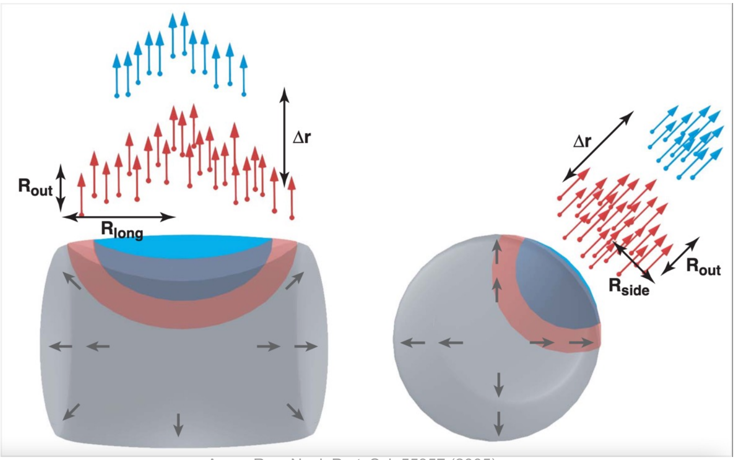
Classify events with geometry jetty vs. isotropic events



$$S_0 = \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left(\frac{\sum_i |\vec{p}_{T_i} \times \hat{n}|}{\sum_i p_{T_i}} \right)^2$$

$$S_0 = \begin{cases} 0 \text{ "jetty" limit (hard events)} \\ 1 \text{ "isotropic" limit (soft events)} \end{cases}$$

Classify events based on source size

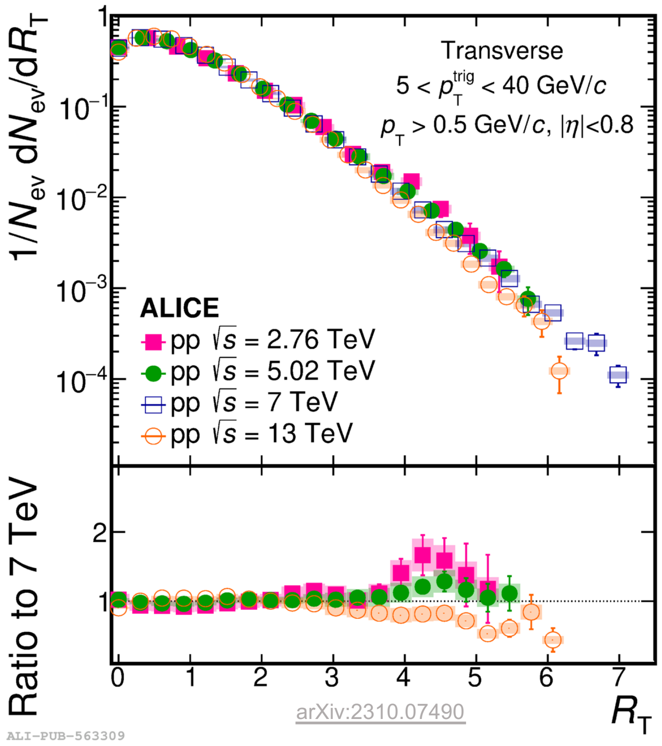


Annu. Rev. Nucl. Part. Sci. 55357 (2005)

Measuring particle correlations allow to access to the source size with two-particle Hanbury-Brown-Twiss (HBT) interferometry

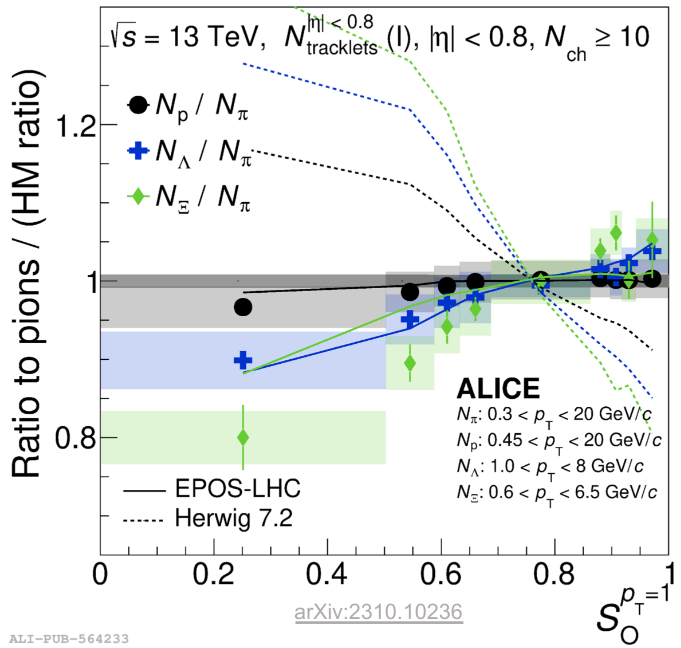
Event classifier : R_T, spherocity and femtoscopy

Classify events by underlying event activity



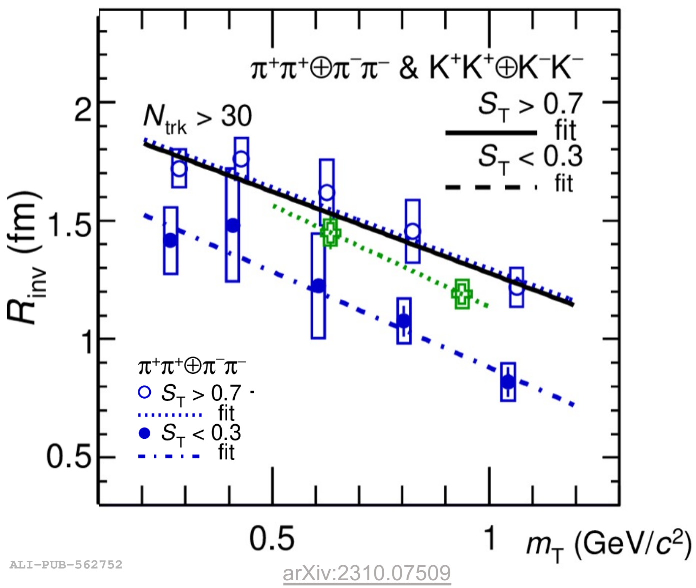
Approximate KNO scaling for low multiplicity in the transverse region

Classify events with geometry jetty vs. isotropic events



Enhancement of strange hadrons in isotropic events

Classify events based on source size



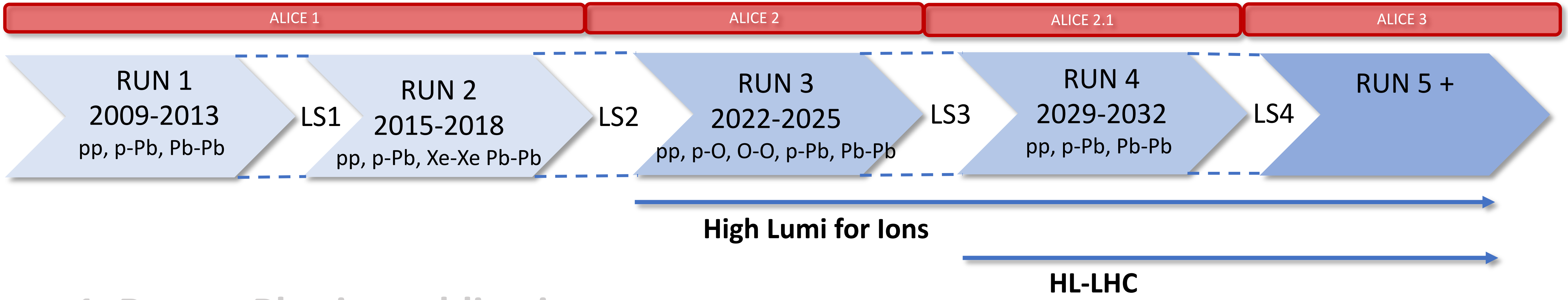
Spherical events have larger emitting source

ALICE

10 new publications since last LHCC

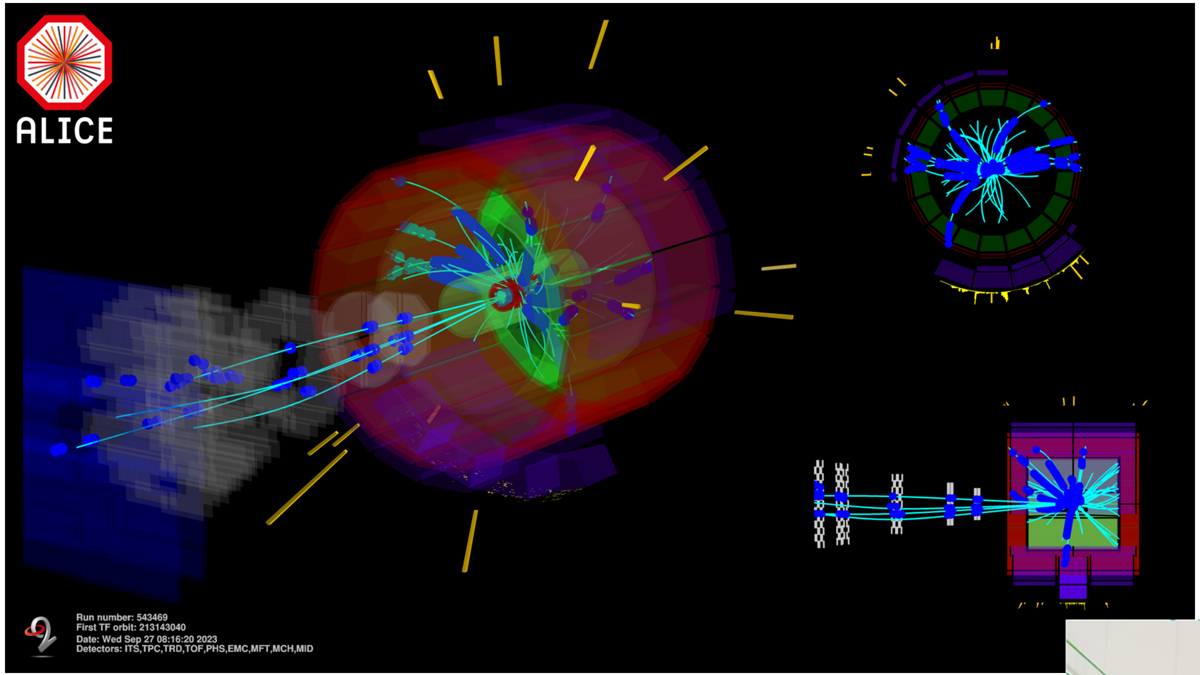
- **Light-flavor particle production in high-multiplicity pp collisions at √*s* = 13 TeV as a function of transverse spherocity** arXiv:2310.10236
- **Femtoscopic correlations of identical charged pions and kaons in pp collisions at √*s* = 13 TeV with event-shape selection** arXiv:2310.07509
- **Charged-particle production as a function of the relative transverse activity classifier in pp, p–Pb, and Pb–Pb collisions at the LHC** arXiv:2310.07490
- **Photoproduction of K+K− pairs in ultra-peripheral collisions** arXiv:2311.11792
- **Measurement of (anti)alpha production in central Pb–Pb collisions at √*s*NN = 5.02 TeV** arXiv:2311.11758
- **Observation of abnormal suppression of f_0(980) production in p–Pb collisions at √*s*NN = 5.02 TeV** arXiv:2311.11786
- **Measurements of chemical potentials in Pb-Pb collisions at $\sqrt{s_{NN}}$ =5.02 TeV** arXiv:2311.13332
- Multiplicity dependence of charged-particle intra-jet properties in pp collisions at √*s* = 13 TeV arXiv:2311.13322
- Common femtoscopic hadron-emission source in pp collisions at the LHC arXiv:2311.14527
- Emergence of long-range angular correlations in low-multiplicity proton-proton collisions arXiv:2311.14357

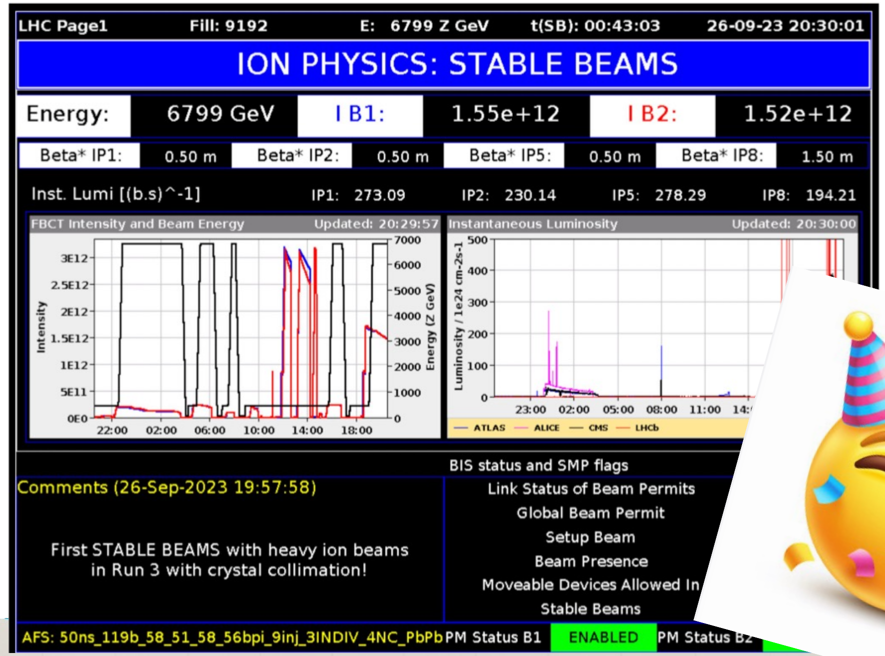
Outline

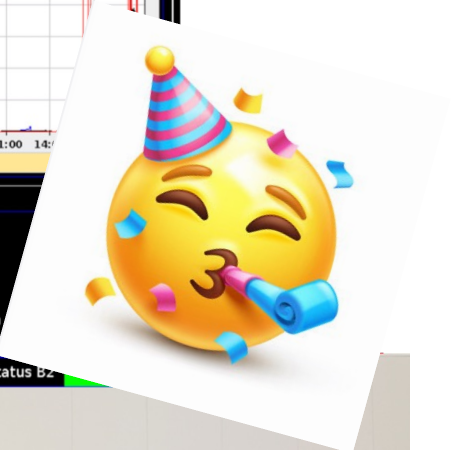


1. Recent Physics publications
2. The first Run 3 Pb-Pb data sample
3. ITS 3 Technical Design Report
4. FoCal
5. ALICE 3

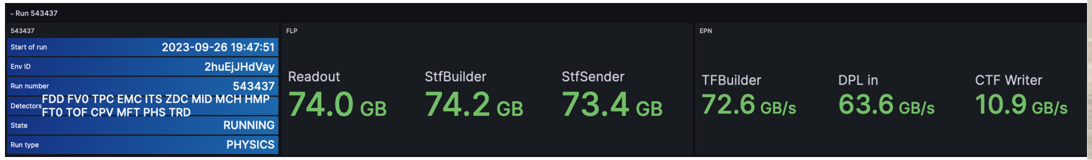
A new Heavy Ion sample



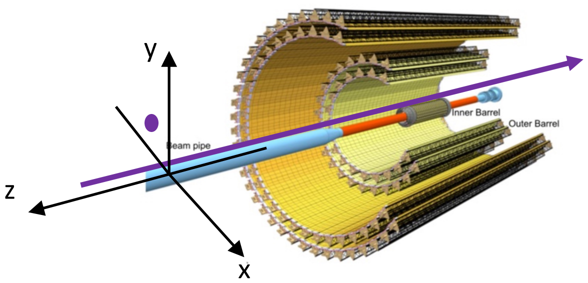




FIRST HI STABLE BEAM Tuesday 26th September
just before 8PM
2 kHz hadronic interaction rate



Beam Background in ALICE



- In the first minutes of operations ALICE identifies a **background jeopardizing the ion physics program**
- Compatible with a **collimated flux of particle, locally parallel to the beam pipe, arising from losses on the TCTs**
- Once identified, **losses deviated to another collimator, optimal settings immediately in production,** after 0.2 nb^{-1} delivered
- To be followed-up for next year, RUN 3 and beyond

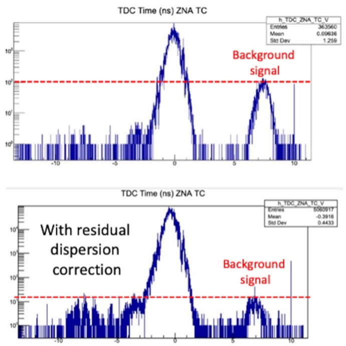
Accelerator Report: Optimisation for greater success (and new challenges)

12 OCTOBER, 2023 | By Rende Steerenberg

On Friday, 6 October, the LHC completed the stepwise intensity ramp-up of the lead-ion beams and reached 1240 bunches per beam. However, this achievement came with two main challenges: beam losses during the last part of the acceleration ramp, causing the beam to be dumped, and a high level of background noise in the ALICE detector, in an area where the circulating beam interacts with the collimators.

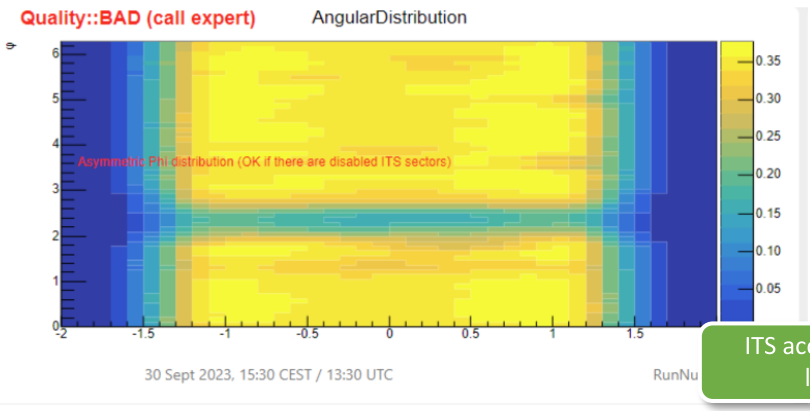
To address the beam loss issue, the thresholds of the beam loss monitors that are distributed around the LHC and serve as input to the beam dump system have been increased. This allows more lead ions to be lost, especially in the areas with collimators, without compromising the safety and reliability of the accelerators. This and other adjustments allowed the losses during acceleration to be kept below the dump threshold and beams with 1240 bunches each to be collided.

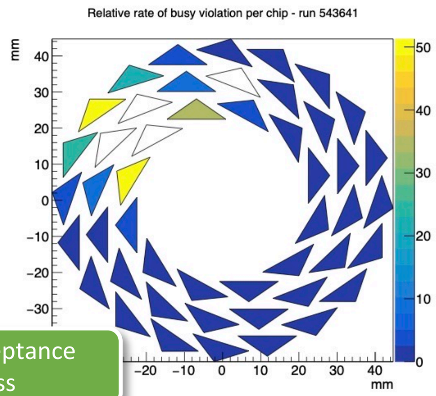
Experts from the ALICE experiment and the LHC machine collaborated closely to tackle the issue of background noise in the ALICE detector: many different remedial strategies were studied and tested during several fills over a period of more than 30 hours. Finally, the correction of residual dispersion (see the box below) reduced the background noise to a satisfactory level for ALICE to take physics data in the coming weeks.



These graphs from the ALICE collaboration show the level of background noise before and after the correction of the residual dispersion. The peak in the middle represents the level of beam signal.(Image: CERN)

https://home.cern/news/news/accelerators/accelerator-report-optimisation-greater-success-and-new-challenges





ITS acceptance loss

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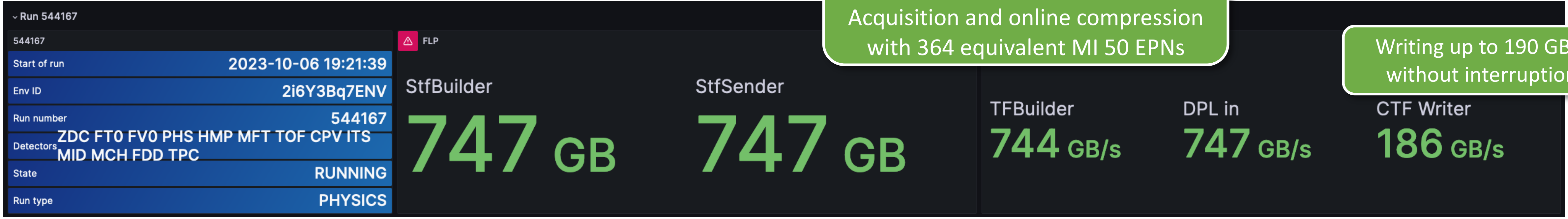
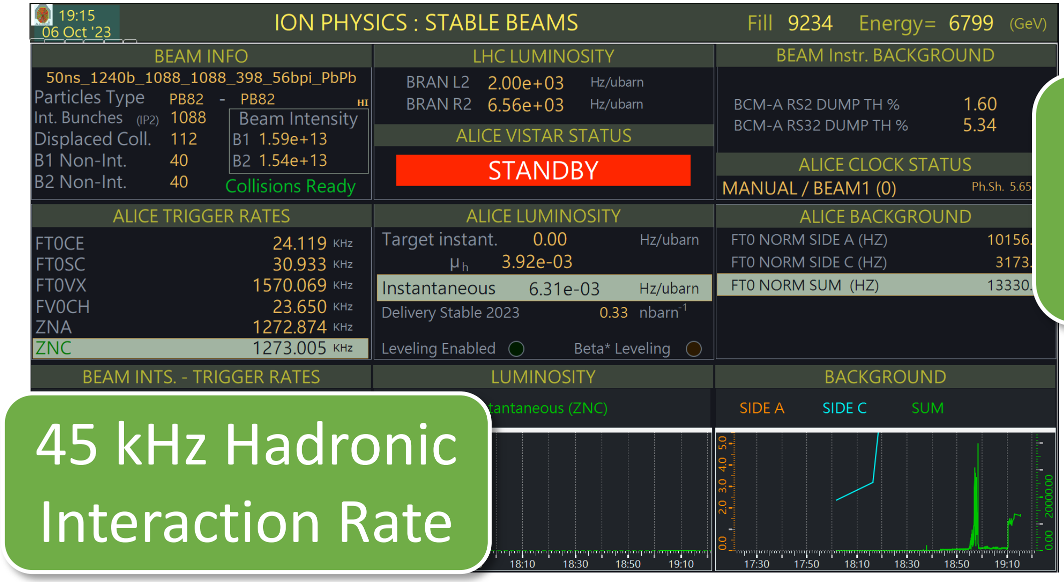
ALICE 2 opens a new era

15 detectors
Data Volume as predicted
Acquisition and online compression
with 364 equivalent MI 50 EPNs

Writing up to 190 GB/s
without interruption





45 kHz Hadronic Interaction Rate

EPN input data rate showing the natural fluctuations from centrality distributions

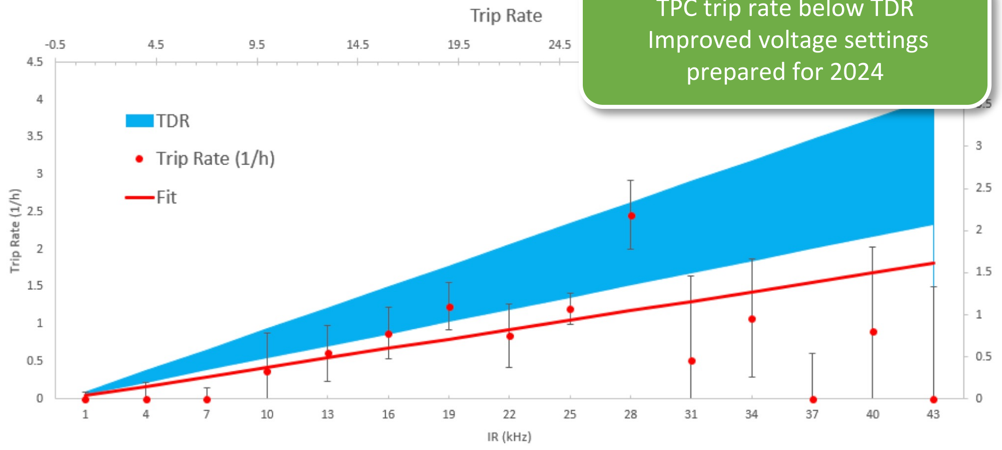
Online processing stable

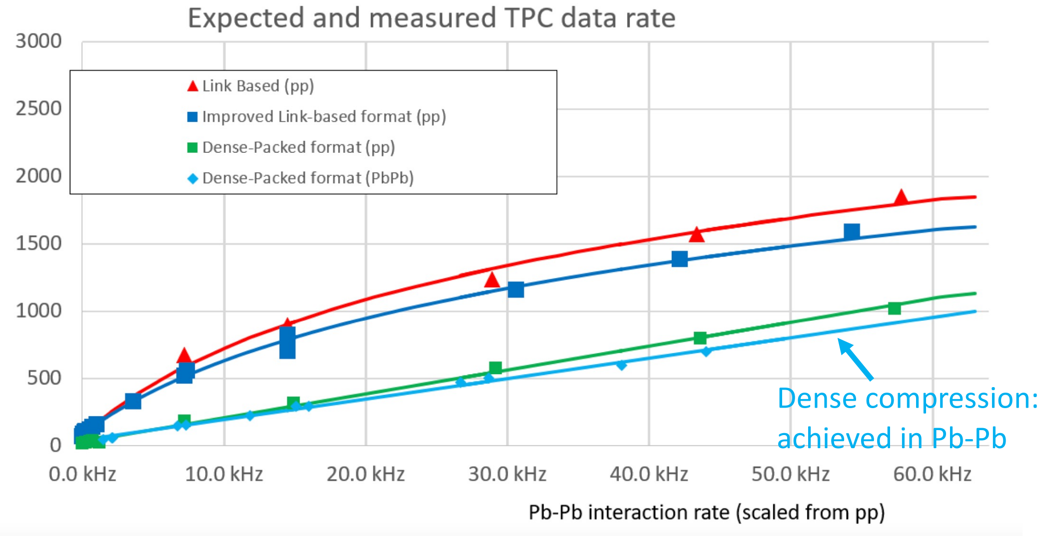
Upgrade fully operational

GOOD detector stability

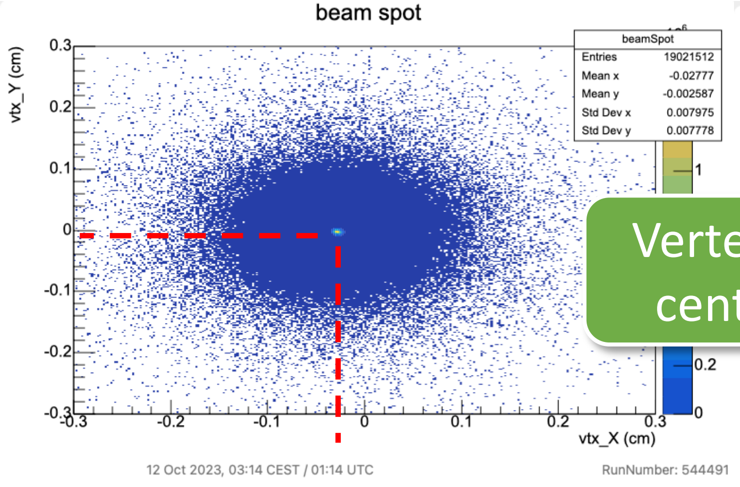
- **208h of data HI data taking**
- **Detector hardware stable**, including TPC, MCH and TRD
- **Protection against data corruption and adaptation to event-by-event fluctuations**
- Raw rate as estimated with TPC data volume < 900 GB/s at 47 kHz (770 GB/s)

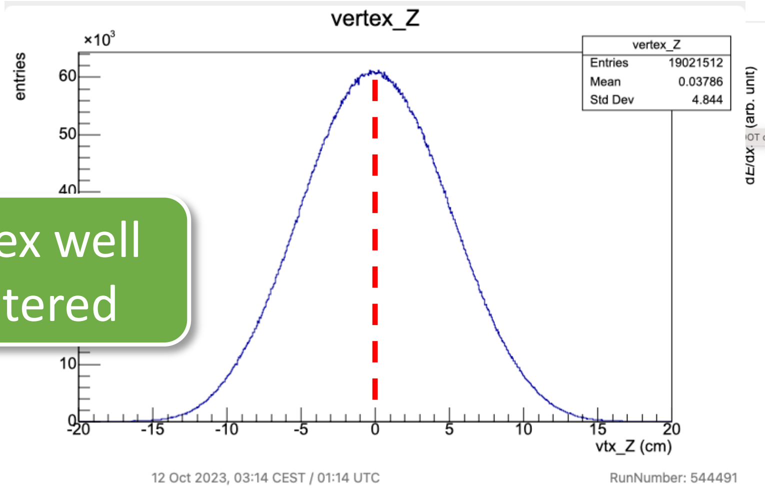
TPC trip rate below TDR
Improved voltage settings prepared for 2024





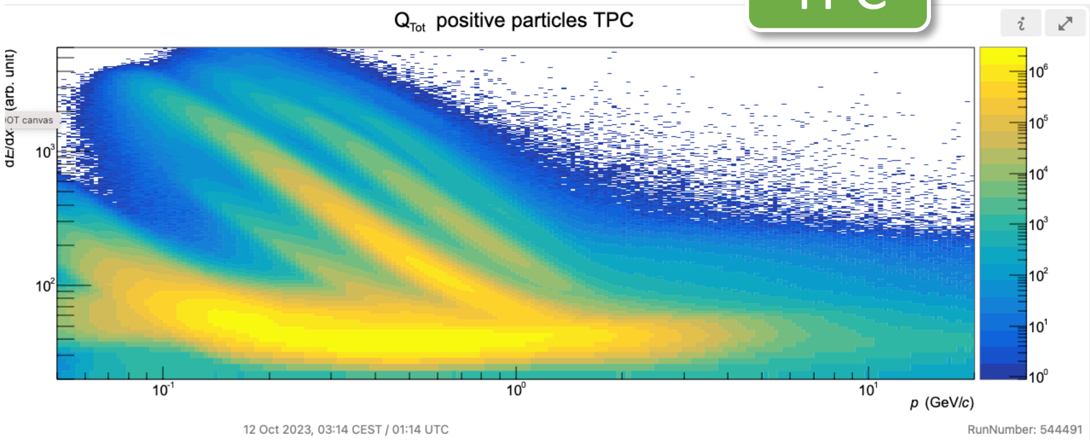
New Pb-Pb sample : good quality monitored online



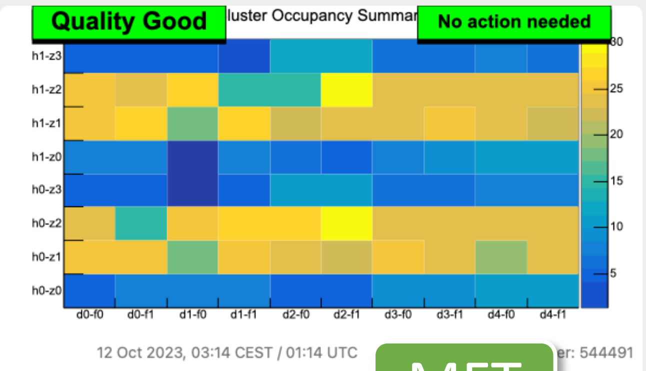


Vertex well centered

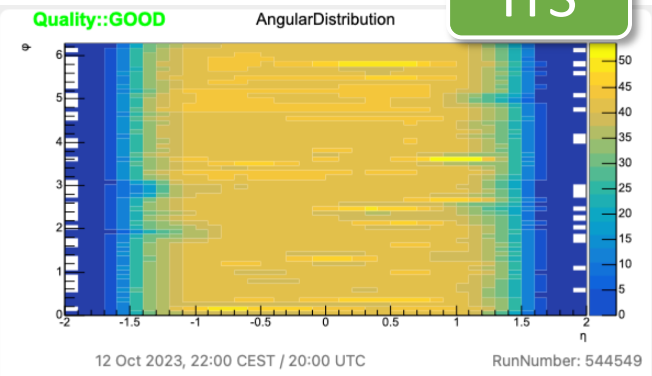
TPC

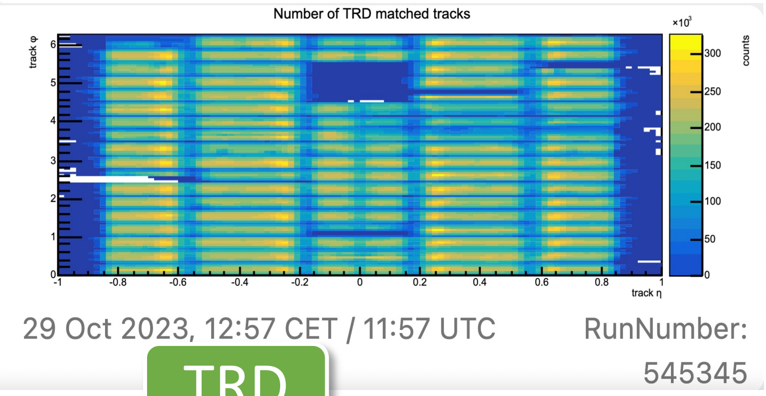


ITS

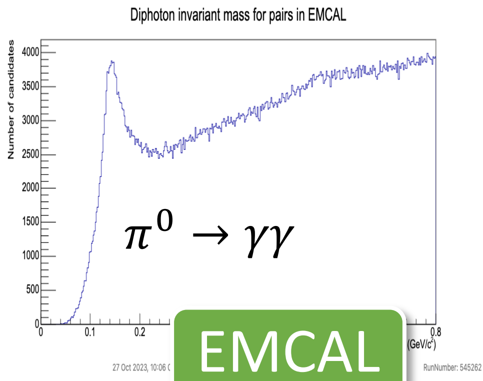


MFT



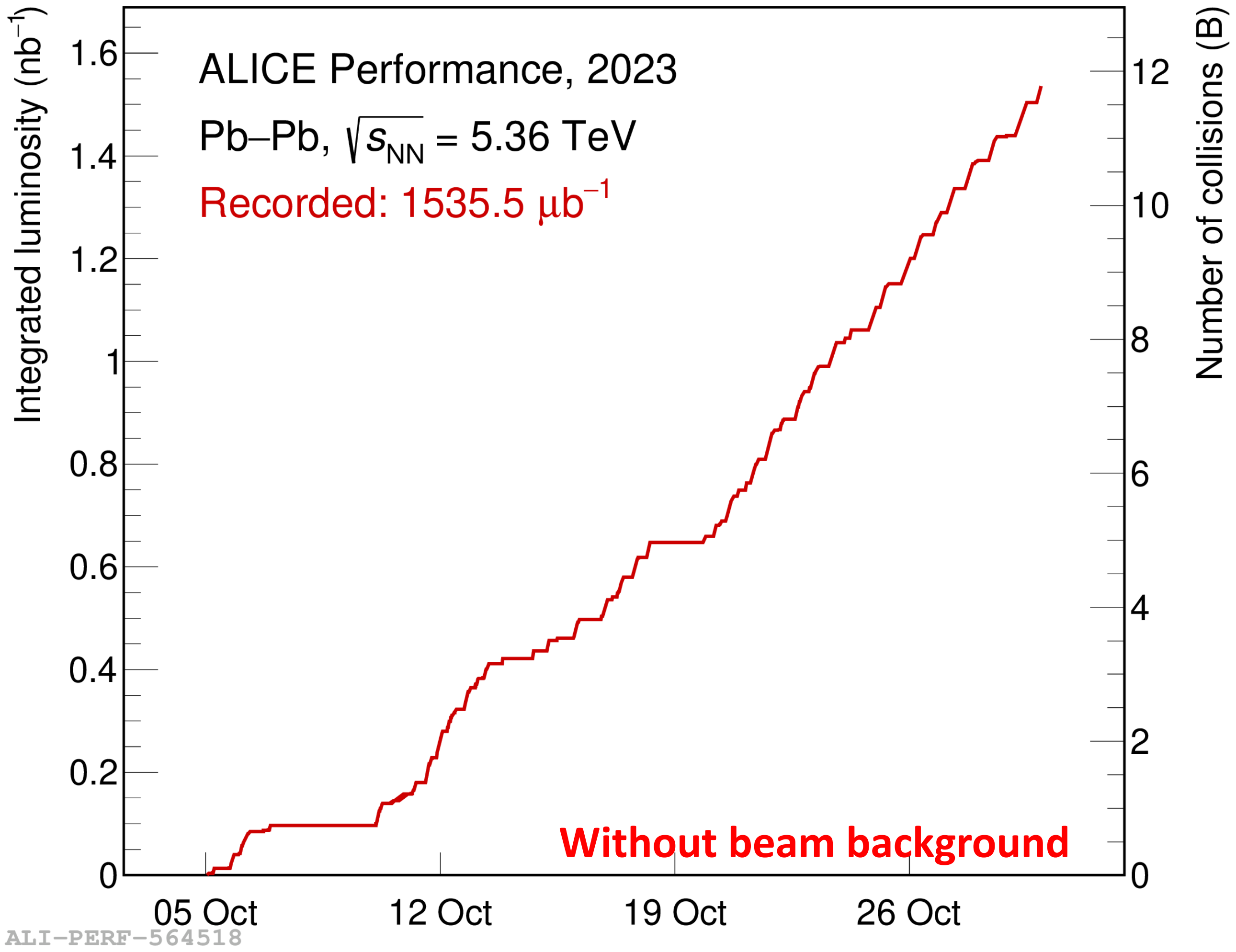


TRD



EMCAL

2023 Pb-Pb data sample



12 Billion Pb-Pb collisions recorded

Successful run

Collected sample much larger than RUN 1+2
Delivered without background 1.96 nb^{-1} Represent 30% of total RUN 3 goal for Pb-Pb (6.5 nb^{-1})

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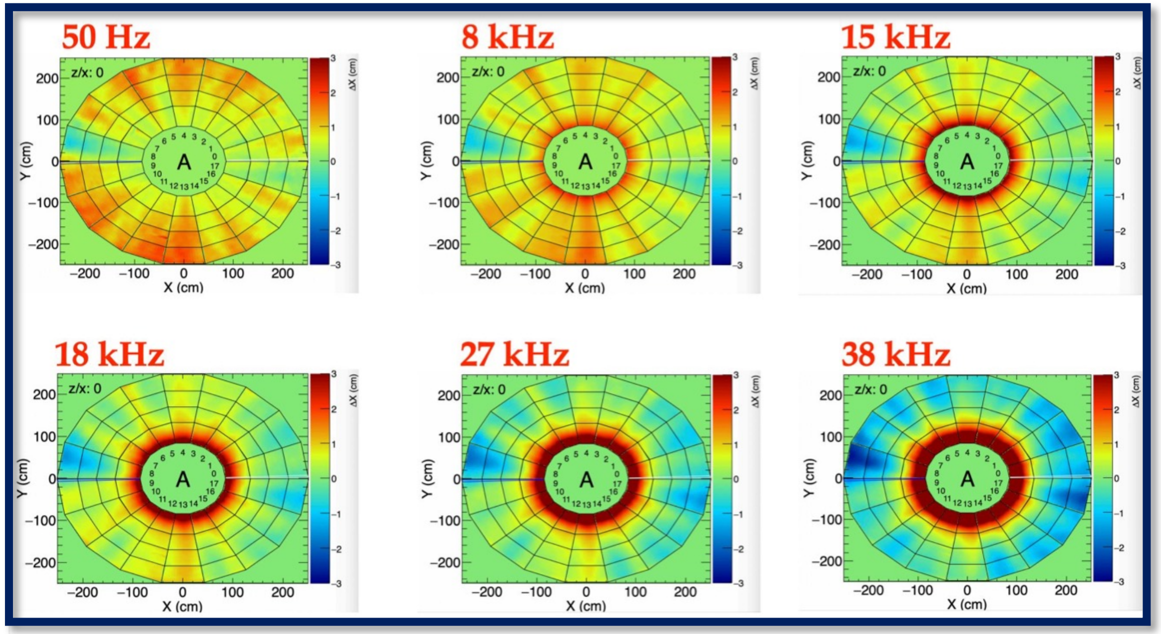
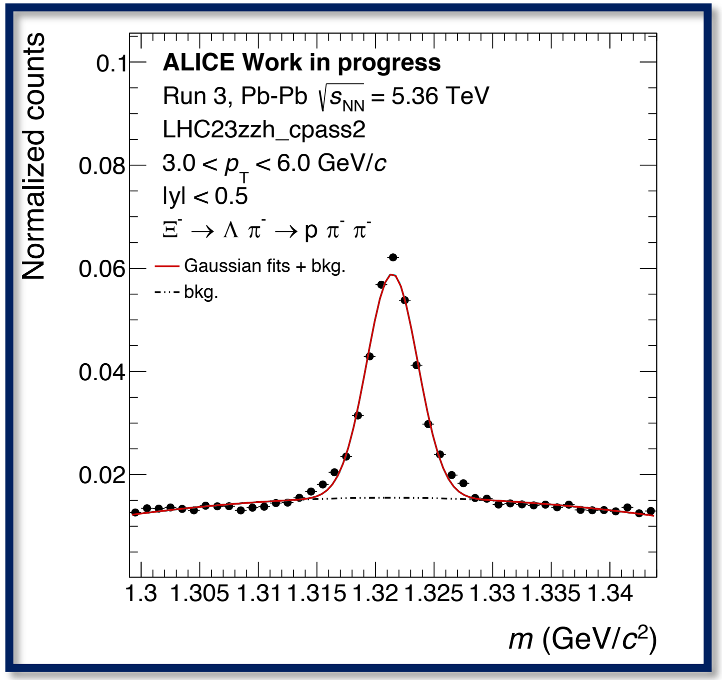
Physics preparation of Run 3 data





- **New distortion maps** based on average difference between extrapolated ITS tracks and TPC space points (w.r.t. analytical map)
- Calibrating rate evolution

- **Physics signals already visible in early test production**

Outline

ALICE 1		ALICE 2		ALICE 2.1		ALICE 3
RUN 1 2009-2013 pp, p-Pb, Pb-Pb	LS1	RUN 2 2015-2018 pp, p-Pb, Xe-Xe Pb-Pb	LS2	RUN 3 2022-2025 pp, p-O, O-O, p-Pb, Pb-Pb	LS3	RUN 4 2029-2032 pp, p-Pb, Pb-Pb
LS4	RUN 5 +					

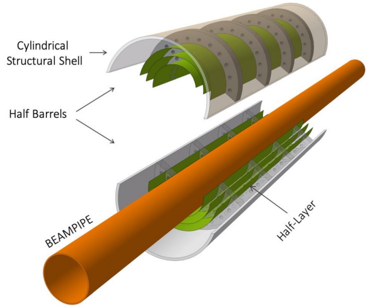
ITS3 & FoCal

- Prototype tests in laboratory and with beam
- TDR submission: FoCal in October, ITS3 in December
- **FoCal TDR review by LHCC ongoing, Cost Review started this week**

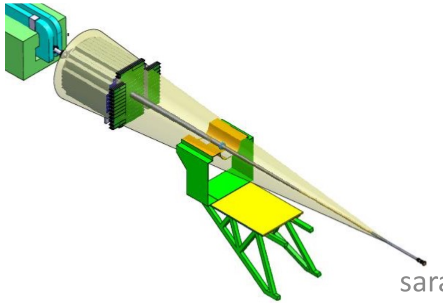
ALICE 3

- Scoping Document preparation
- R&D, test beams of prototype sensors

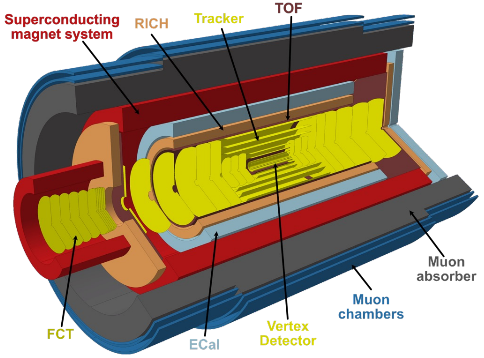
ITS3 LoI: CERN-LHCC-2019-018



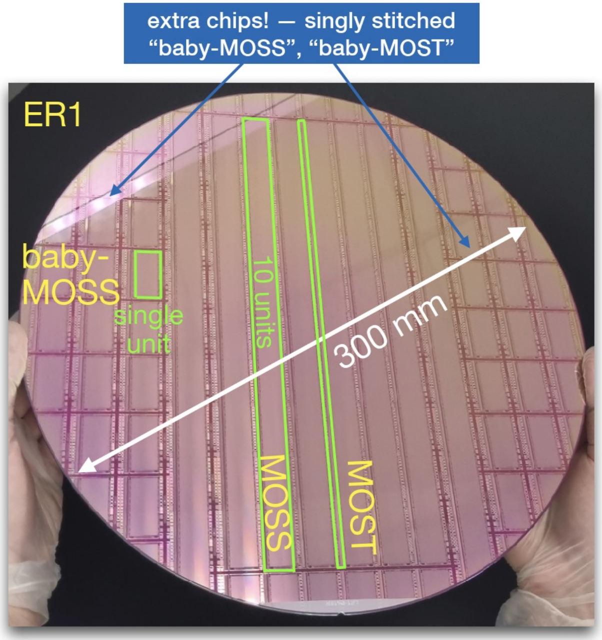
FoCal LoI: CERN-LHCC-2020-009

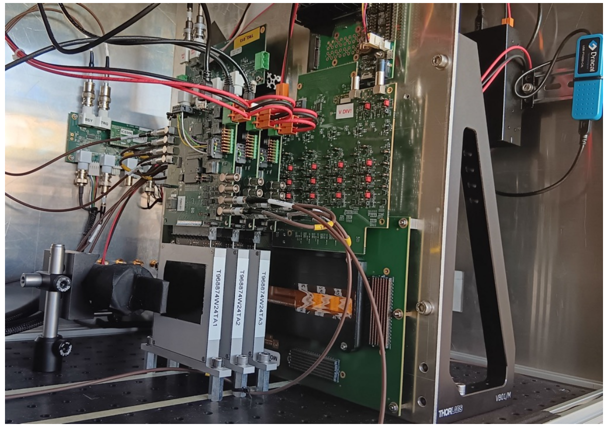


ALICE 3 LoI: CERN-LHCC-2022-009

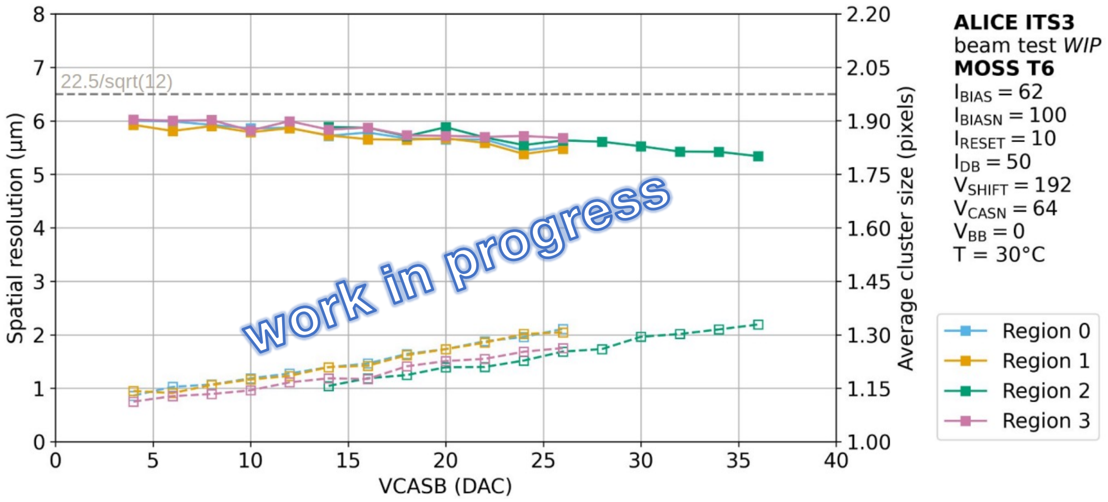


ITS 3 – First stitched sensor test



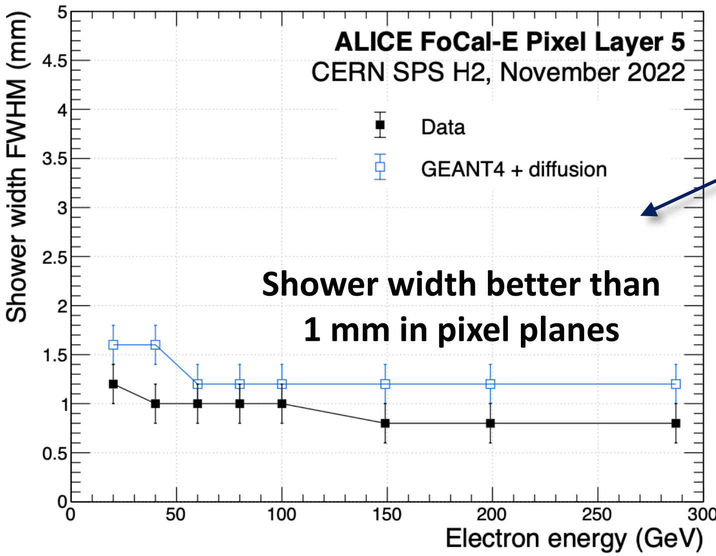


- **3 test beam campaigns at PS** (Jul, Aug, Sept) on MOSS and baby-MOSS
- **First results confirm** extrapolated performance from small test structures (MLR1) in terms of **detection efficiency and spatial resolution**, analysis ongoing
- **Lab tests in progress** for full characterization and yield estimate

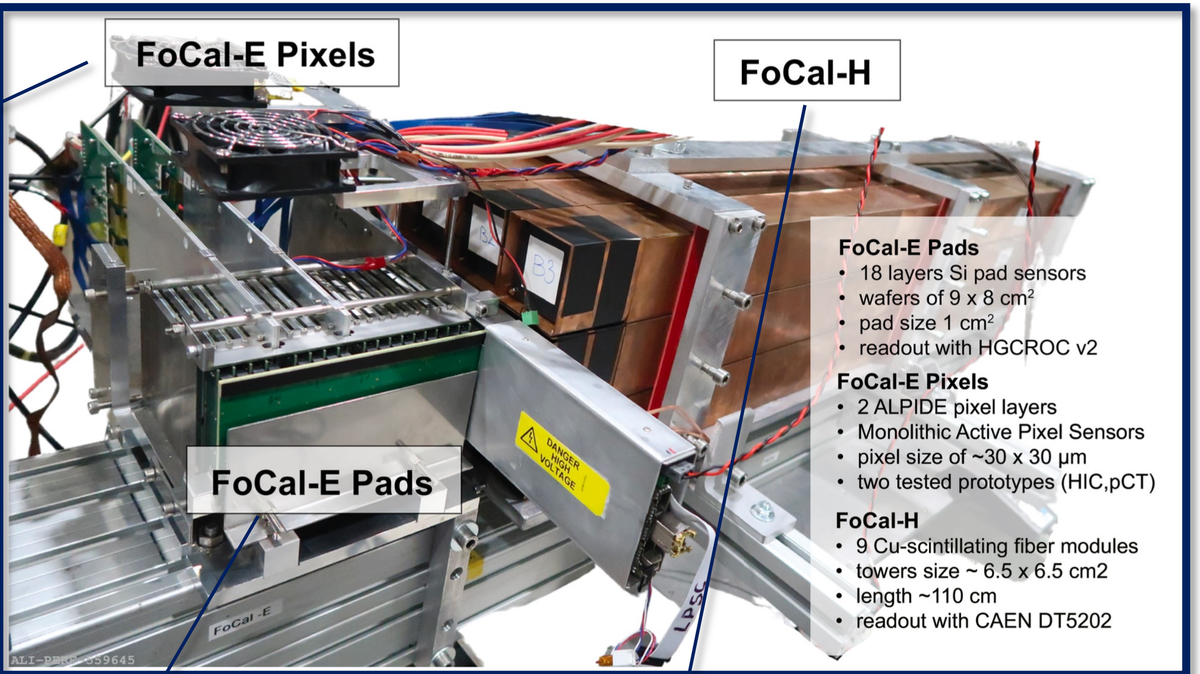


ER1 stitched sensors (MOSS, MOST) tested and working

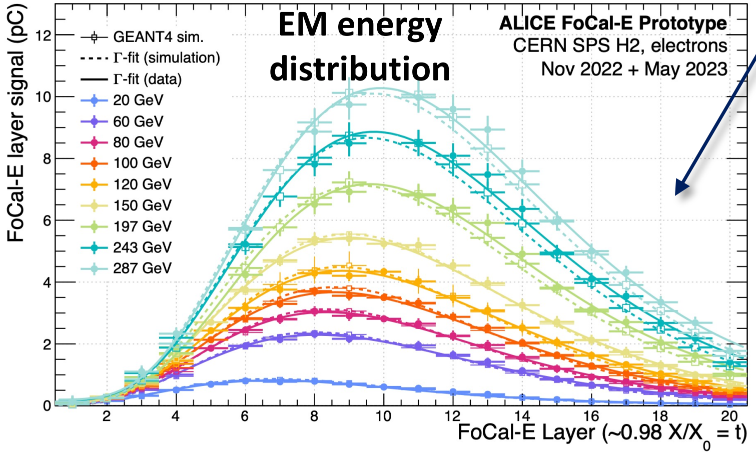
FoCal prototype test beam

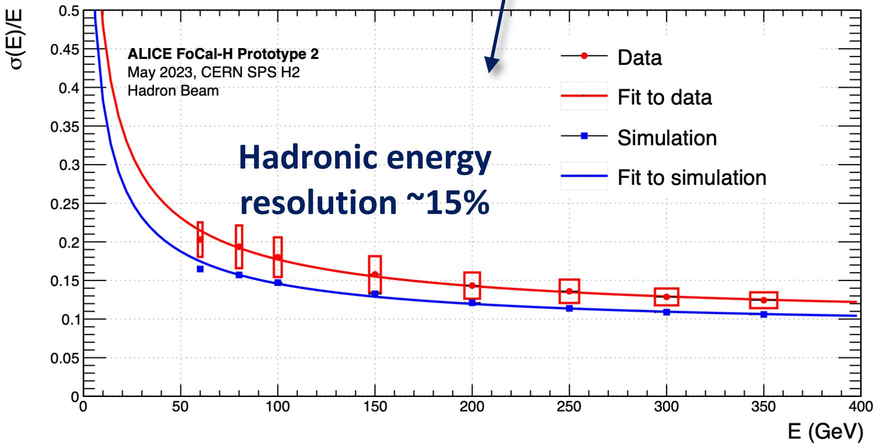


New paper
arXiv:2311.07413



Performance of the electromagnetic and hadronic prototype segments of the ALICE Forward Calorimeter





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ALICE 3 detector for Runs 5-6

Novel detector concept

- Compact and lightweight all-silicon tracker
- Retractable vertex detector with R_{min}= 5 mm
- Extensive particle identification
- Large acceptance $|\eta|$<4
- Superconducting solenoid, B=2T
- Continuous read-out and online processing

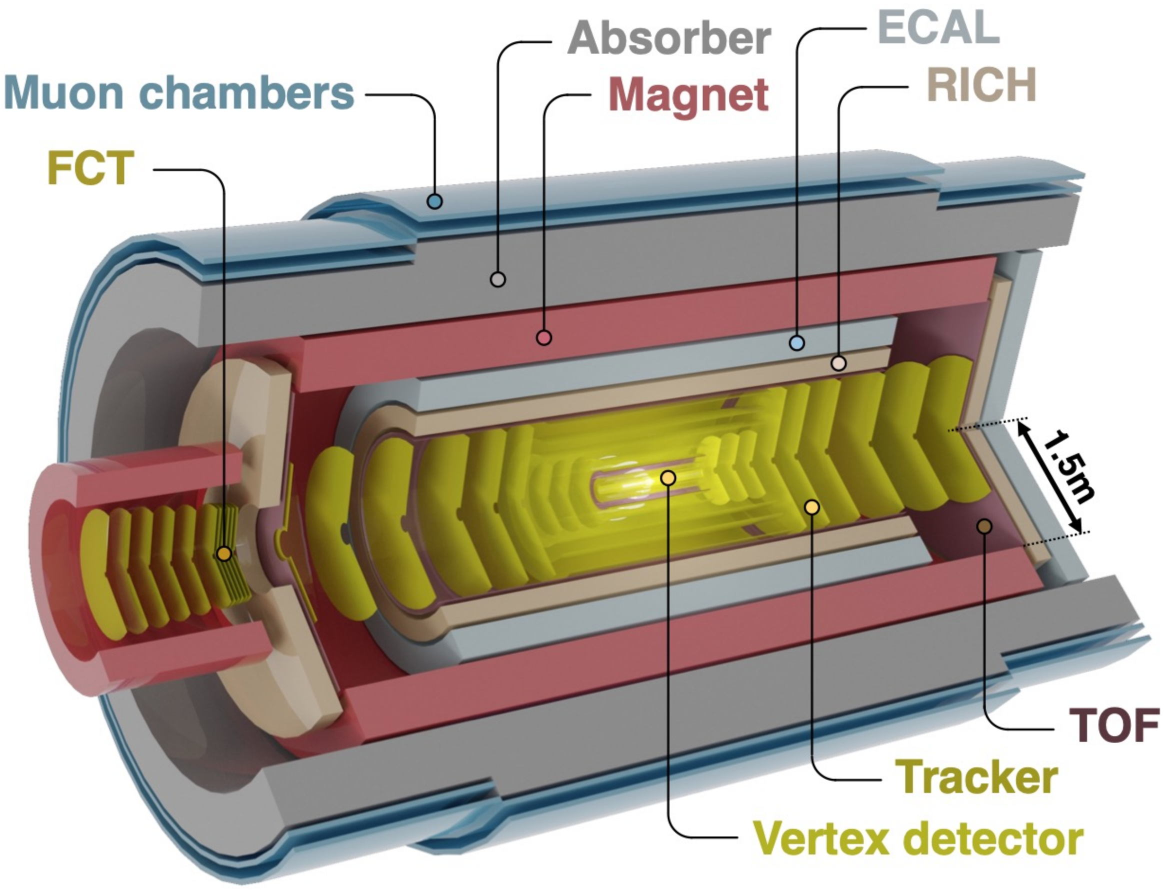
Scoping Document in preparation

- Definition of reference configuration
- Scoping options: without ECal, reduced magnetic field
- Detailed assessment of resources and schedule

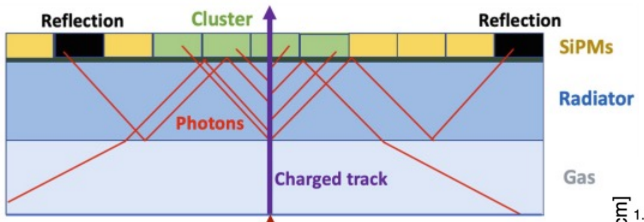
Intense R&D on innovative sensors

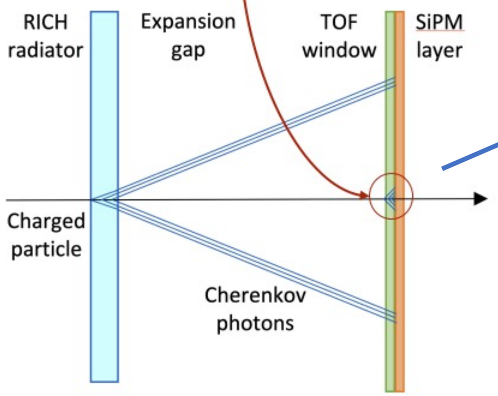
- Several test beams June-November at PS/SPS

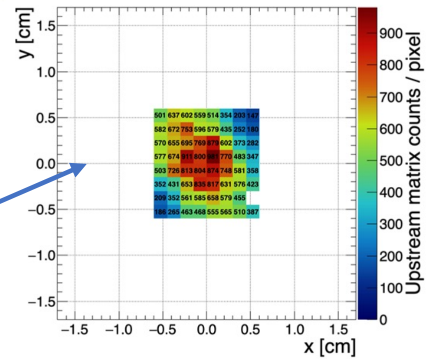
ALICE 3 LOI arXiv:2211.02491



R&D for RICH Detector



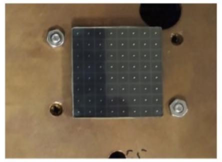


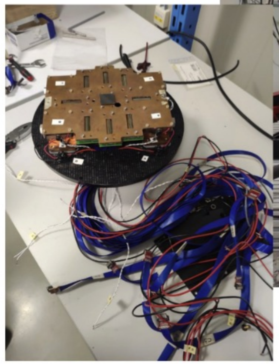


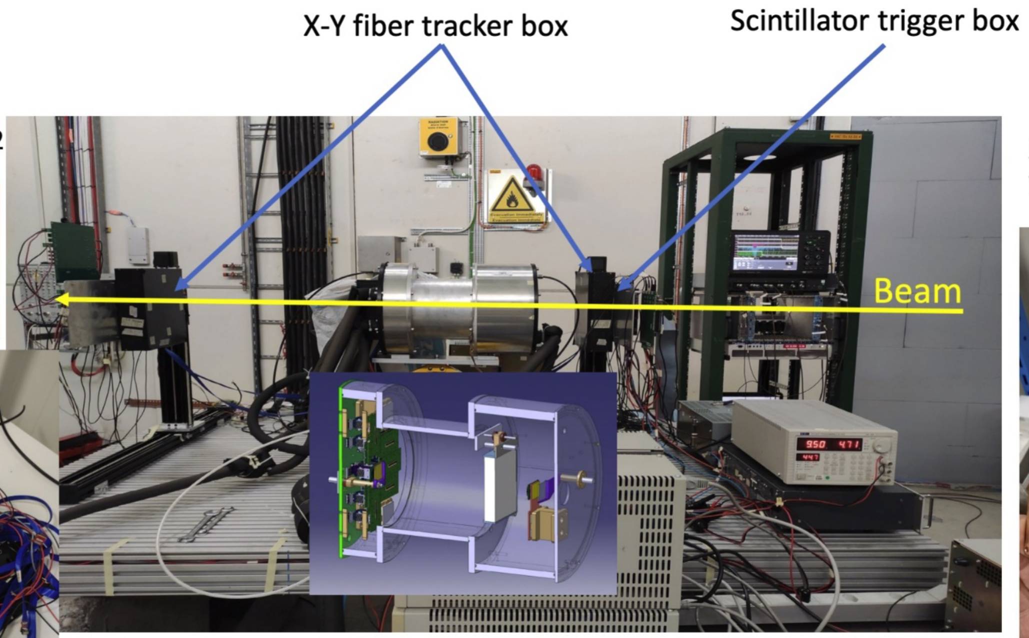
Test beam in October at CERN PS

- Aerogel radiator by Aerogel Factory LTD (Japan)
- 8x8 SiPM matrices from HPK and FBK, various pixel sizes
- Different radiator windows (material, thickness) coupled to SiPM to test timing resolution for TOF+RICH integrated concept

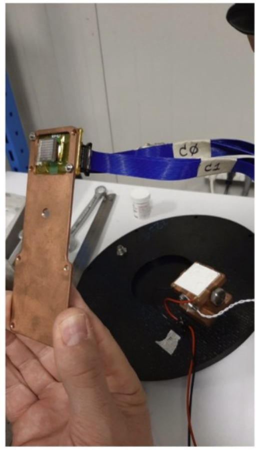
S13361-3075
With 1 mm of SiO2



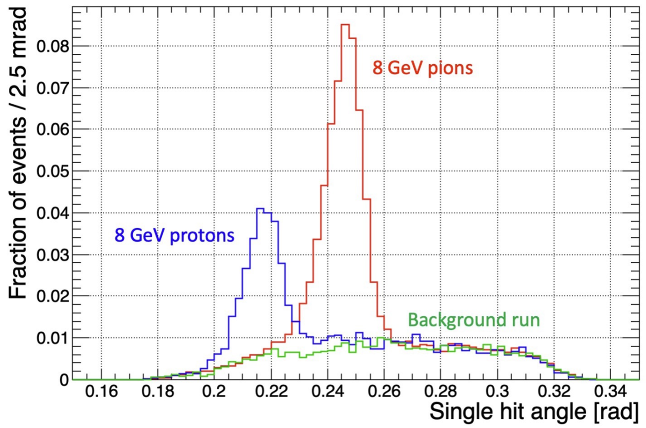




S13361-1350
With 2 mm of SiO2



Reconstructed Cherenkov angle of pions and protons



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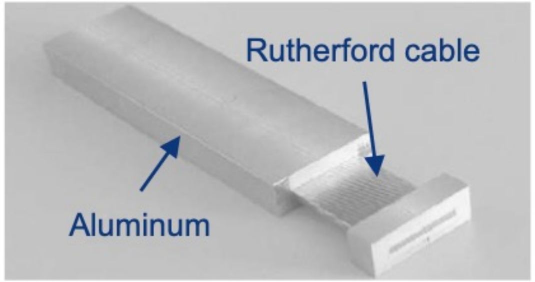
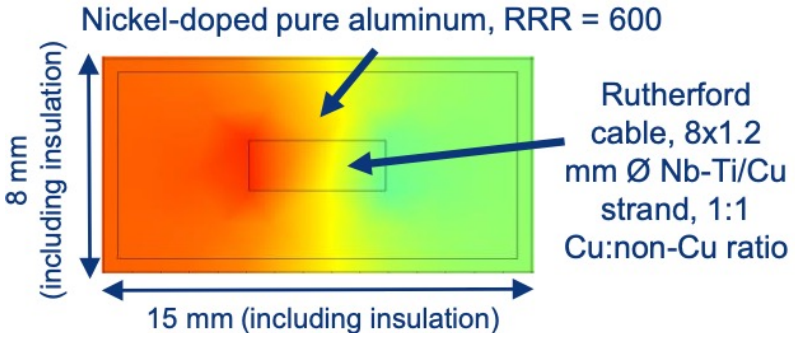
Superconducting magnet design

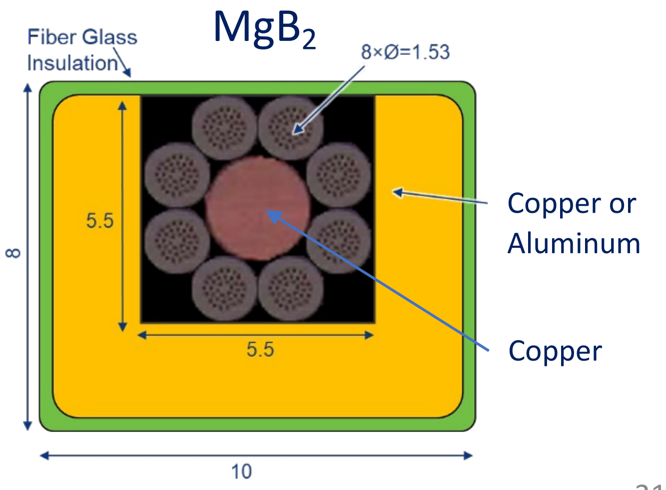
- Baseline: solenoid with *B* = 2 Tesla
- Also considered: solenoid 1 Tesla

- Needs ~30 km of superconducting cable, to be kept at *T* ~ 5-15 K

- Two cable options:
  - **Nb-Ti** (~5° K): used for several detector magnets; considered also for EIC-EPIC with Cu stabilizer; re-establish production with Al stabilizer
  - **MgB_2** (~15° K): used in NMR magnets; add Al as stabilizer







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Conclusions : ALICE a journey through QCD

ALICE 1 | ALICE 2 | ALICE 2.1 | ALICE 3

RUN 1 2009-2013 pp, p-Pb, Pb-Pb → LS1 → RUN 2 2015-2018 pp, p-Pb, Xe-Xe Pb-Pb → LS2 → RUN 3 2022-2025 pp, pO, O-O, p-Pb, Pb-Pb → LS3 → RUN 4 2029-2032 pp, p-Pb, Pb-Pb → LS4 → RUN 5 +

Publications of RUN 2 data enriching our understanding of small systems, ultraperipheral collisions and nucleus production

First successful RUN 3 Pb-Pb data taking
(47 kHz, continuous readout) thanks the ALICE upgrades
Preparation of RUN 3 data for physics (reconstruction, calibrations)

LS3 upgrades : **FoCal & ITS 3** on track
LS4 upgrades : **ALICE 3** scoping document under preparation

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Perspective from Run 2

- **Run 1+2 : 1.5 nb^{-1} delivered**