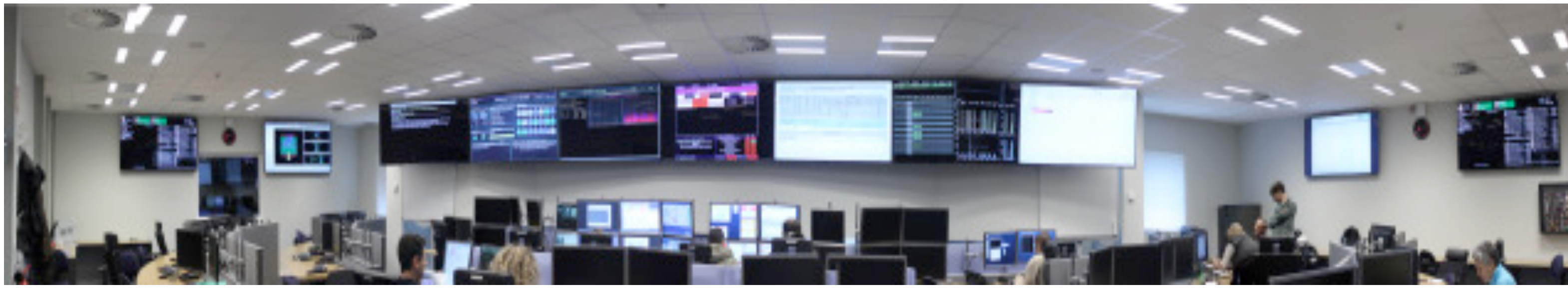

Some highlights on studies of strangeness and charm in heavy ion collisions by ALICE at LHC

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The XXVth International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics", **September 18 to 23, 2023,** Dubna, Russia
https://relnp.jinr.ru/ishepp/

Layout of this talk

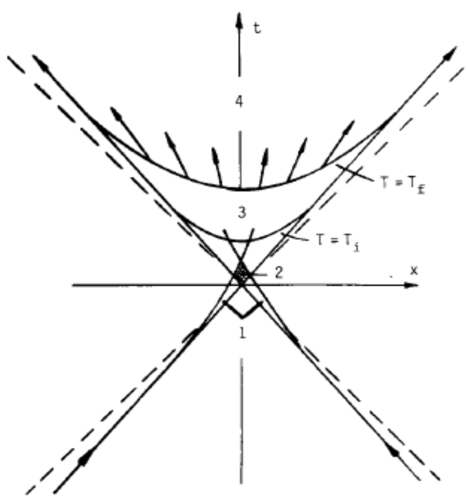
- Introduction.
- Strangeness and charm in collisions of large and small systems
  - Strangeness in hadronic collisions
  - Charm in pp, p-Pb and Pb-Pb collisions
  - Two-body scattering involving *strange* and *charm* hyperons
- Flow of identified particles in small systems
- ALICE @LHC Schedule

"Relativistic heavy ion physics"- why ?: a bit of history

Cabibbo, N. & Parisi, G. , Exponential hadronic spectrum and quark liberation. Phys. Lett. B 59, 67–69 (1975).

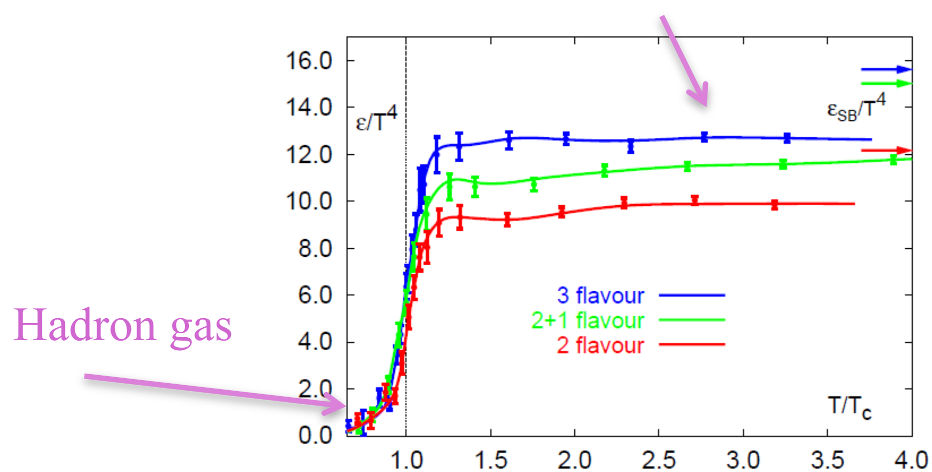
Collins, J. C. & Perry, M. J. Superdense matter: neutrons or asymptotically free quarks? Phys. Rev. Lett.34, 1353–1356 (1975).

E.V.Shuryak, Quark-gluon plasma and hadronic production of leptons, photons and psions, Phys. Lett. *B78* (*1978*) *150.*



E.V.Shuryak, Phys. Lett. *B78* (*1978*) *150*

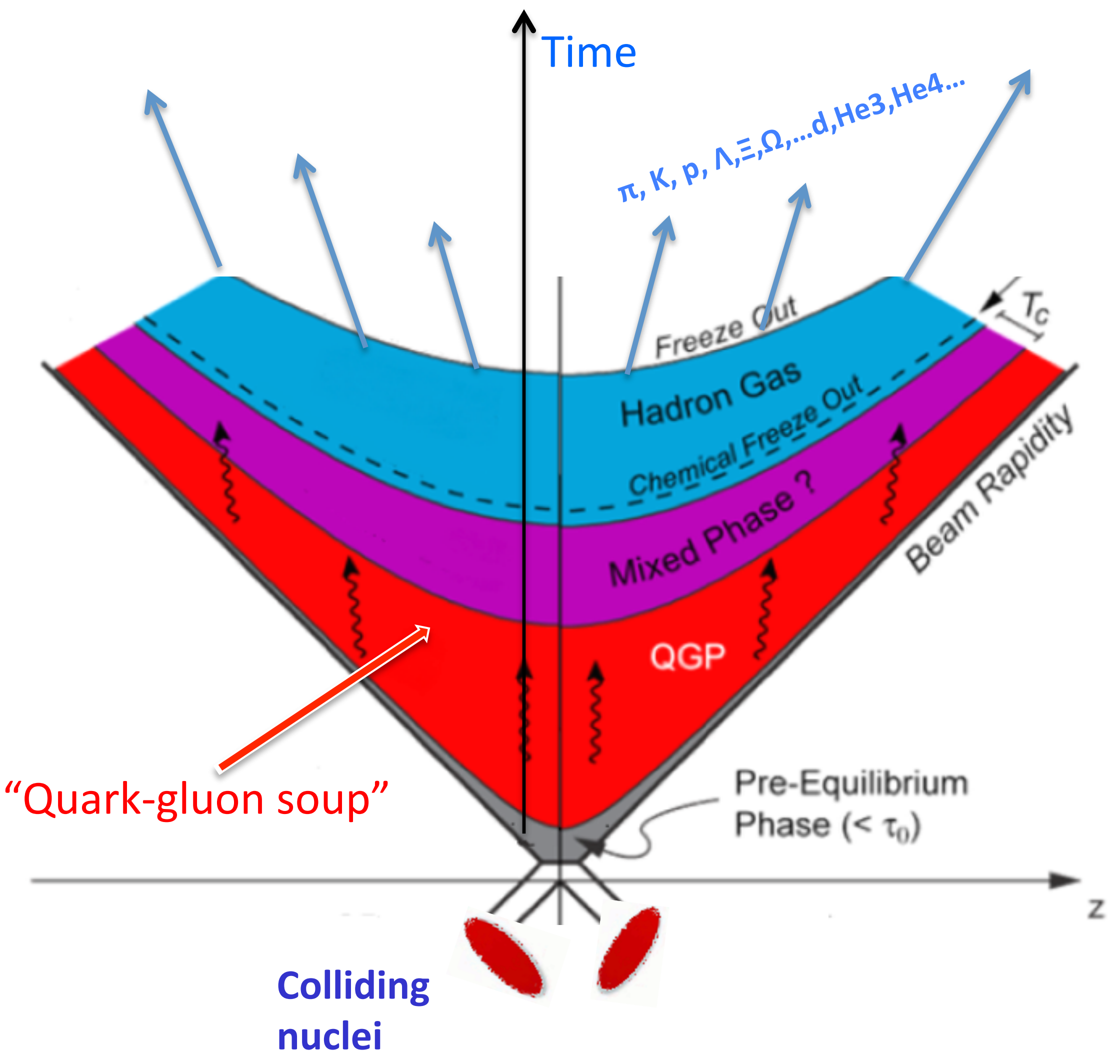
Lattice QCD results QGP



F. Karsch, Lect. Notes Phys. 583 (2002) 209

➢ *Early expectations: QGP* like an ideal gas of quarks and gluons

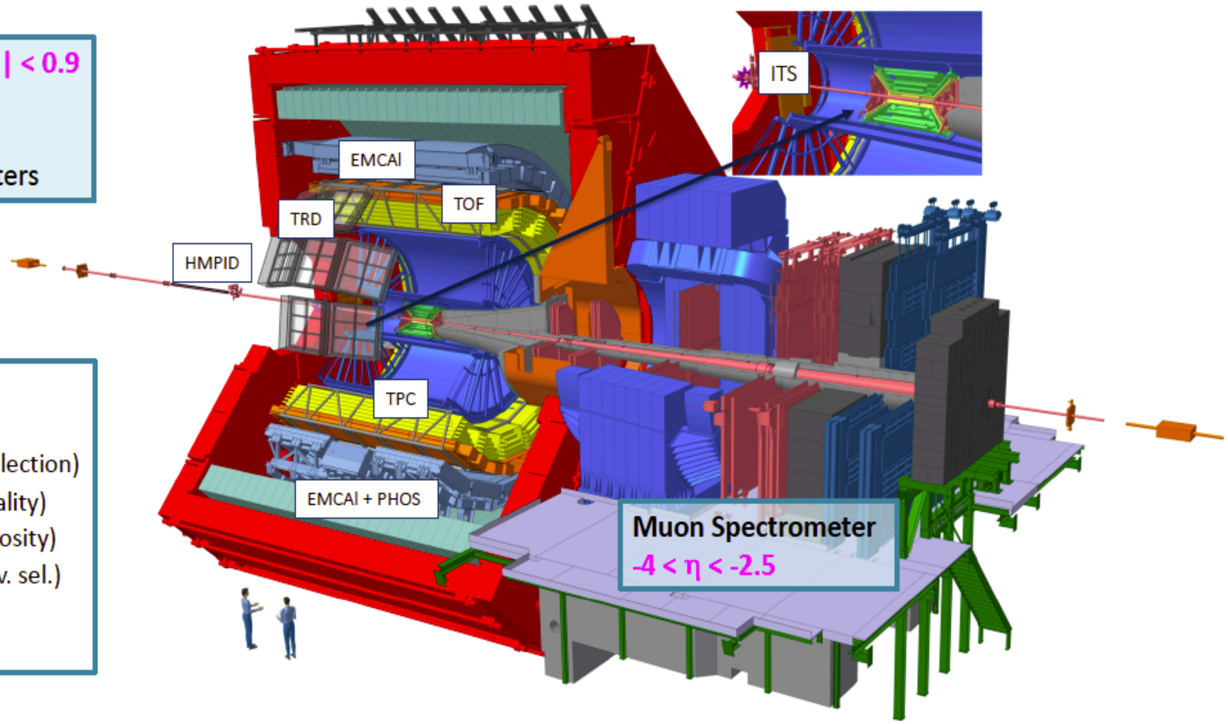
Space-time stages of nucleus-nucleus collision



- Pre-equilibrium phase
  τ_{eq} < 0.5 fm/c
- QGP medium
  - Almost perfect liquid: η/s ~ 0.1
  - Temperature: ~300 MeV from the photon spectrum inverse slope
  - Large volume: ~5000 fm^3
  - Mean life time: τ ~ 10 fm/c
  - Energy density (in central Pb-Pb collisions at 5.02 TeV): ≈20 GeV/fm^3 (>>ε_{crit} ≈ 1 GeV/fm^3)
- Mixed phase
- Chemical freeze-out:
  particle composition is fixed at T_{ch} ~ 155 MeV
- Thermal freeze-out:
  particle p_T spectra are fixed at T_{tfo} ~ 100 MeV

ALICE in Run 1 and Run 2

Central Barrel $|\eta| < 0.9$
- Tracking
- PID
- EM-Calorimeters



ACORDE (cosmics)

Forward detectors:
- AD (diffraction selection)
- V0 (trigger, centrality)
- V0 (timing, luminosity)
- ZDC (centrality, ev. sel.)
- FMD (N_{ch})
- PMD ($N\gamma$, Nch)

- ALICE is optimized for Heavy-Ion Physics - excellent tracking of low momenta particles
- Efficient registration of the hadrons, electrons, muons, and photons. produced in pp, p-Pb and Pb-Pb collisions at the LHC.

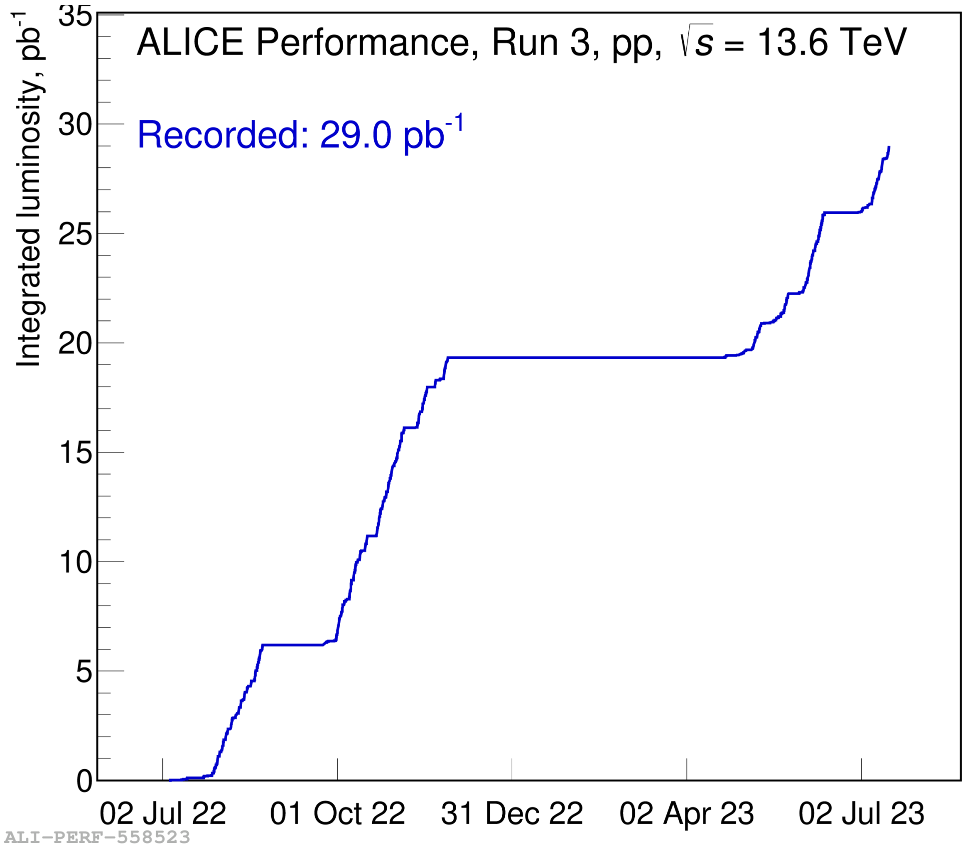
ALICE data in Runs 1,2 in 2009-2018

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010, 2011 2015, 2018	2.76 5.02	~75 μb^{-1} ~800 μb^{-1}
Xe-Xe	2017	5.44	~0.3 μb^{-1}
p-Pb	2013 2016	5.02 5.02, 8.16	~15 nb^{-1} ~3 nb^{-1}, ~25 nb^{-1}
pp	2009-2013 2015, 2017 2015-2018	0.9, 2.76, 7, 8 5.02 13	~200 mb^{-1}, ~100 nb^{-1} ~1.5 pb^{-1}, ~2.5 pb^{-1} ~1.3 pb^{-1} ~36 pb^{-1}

Run 1 Run 2

- **ALICE Collaboration: 40 countries, 172 institute2, 2002 members**
  Publications: total > 400

ALICE data taking in Run 3 (July 2022 – July 2023



Recorded integrated luminosity in pp@13.6 TeV, Run 3

- Data taking at 500 kHz in pp collisions at 13.6 TeV
- Improvement in luminosity:
  - x 100 Pb-Pb
  - x 1000 pp and p-Pb
- Already recorded in pp collisions (900 GeV and 13.6 TeV): ~30 pb^{-1}
- Small data set in Pb-Pb collisions at 5.02 TeV

✓Strangeness in hadronic collisions

Motivation

The early predictions:

- J. J.Rafelski in 1980: QGP should be visible in relative yield measurements
- J J. Rafelski and B.Müller , “Strangeness production in the quark-gluon plasma,” Phys. Rev. Lett. 48 (1982) 1066–1069.

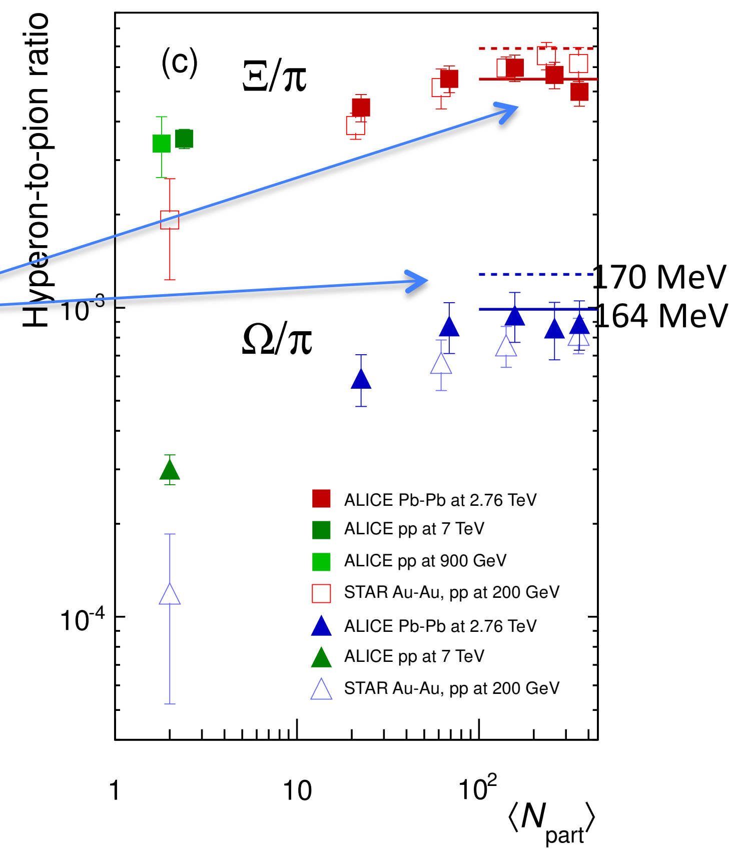
”…enhanced abundances of rare, strange hadrons , , etc.) as indicators for the formation of the plasma state in nuclear collisions. ”

Hyperon-to-pion ratios as a function of <N_{part}>, for A-A and pp collisions at LHC and RHIC energies.

Early predictions and results:

- General smooth increase of h/π ratio with system size (centrality)
- Flattening after <N_{part}>~150
- Ratios are similar at RHIC and LHC
- Increase in h/π ratios with energy is noticeable for pp collisions
- Lines – predictions of thermal statistical models based on a grand canonical approach [1],[2]

Phys. Lett. B 728 (2014) 216-227

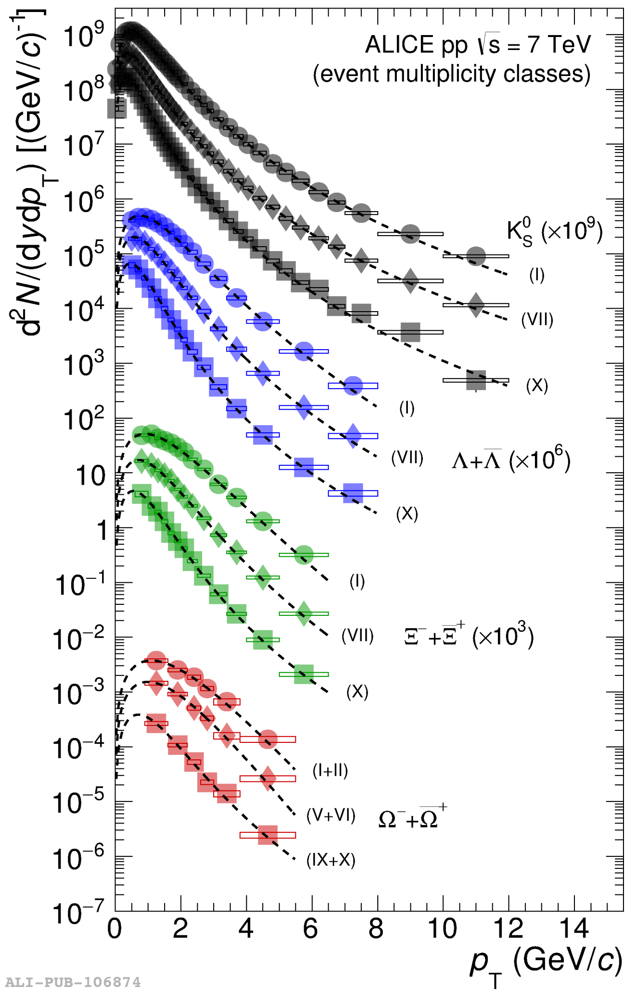


[1] A. Andronic , P. Braun-Munzinger J. Stachel Phys. Lett. B 673 (2009), p. 142

[2] J. Cleymans, I. Kraus, H. Oeschler, K. Redlich, S.Wheaton, Phys. Rev. C,74 (2006) 03490

p_T-differential yields of K^0_s,Λ,Ξ and Ω by ALICE in pp collisions at √s= 7 TeV

Nature Physics 13,535–539 (2017)



Some observations:

- hardening of p_T spectra with increasing multiplicity
- the hardening of p_T spectra is more pronounced for higher-mass particles
- the appearance of collective behaviour at high multiplicity - ?
- particle emission from a collectively expanding thermal source in pp collisions - ?

U.Heinz, https://inspirehep.net/record/714564

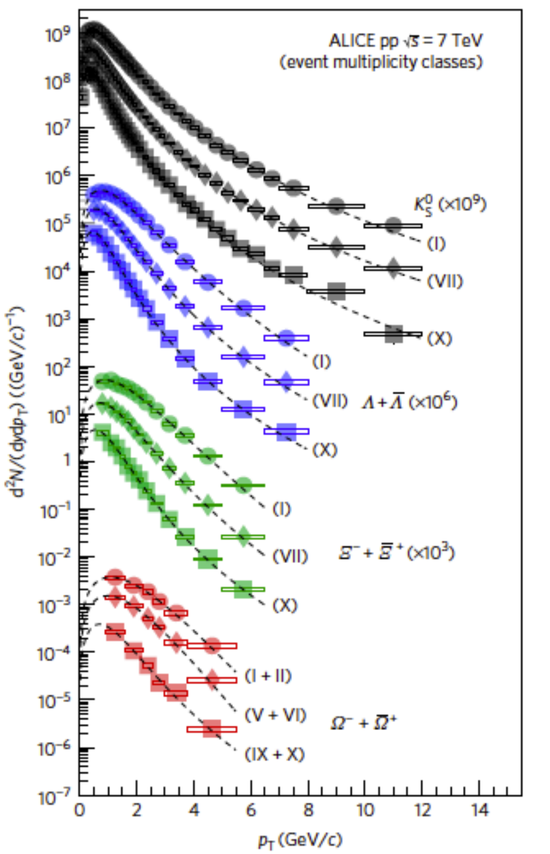
Some event multiplicity classes in pp collisions, 7 TeV

Class name	I	...	VII	...	X
$\sigma / \sigma_{inel} > 0$	0 - 0.95%		28 - 38%		68 – 100%
$<dN_{ch}/d\eta>$	21.3+-0.6		6.72+-0.21		2.26+-0.01

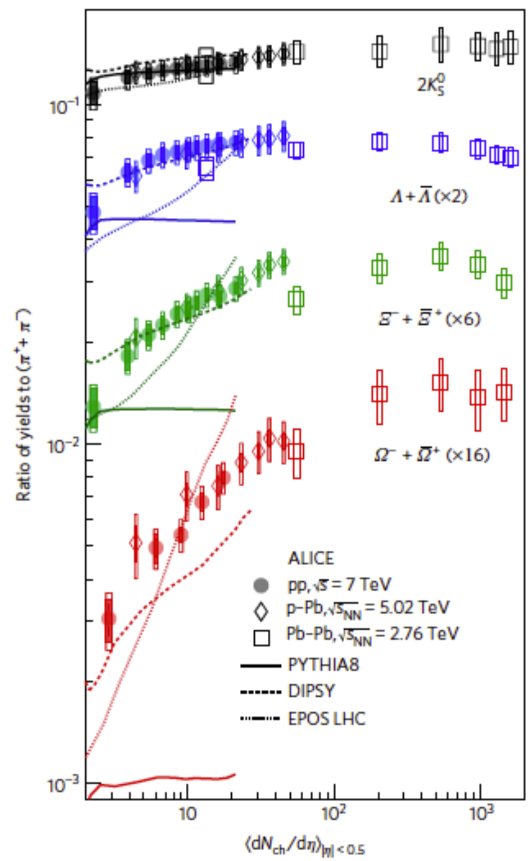
Enhanced production of multi-strange particles in high-multiplicity pp, p–Pb and Pb-Pb collisions

Nature Physics 13,535–539 (2017)

p_T-differential yields



p_T-integrated yield ratios to pions ($\pi^+ + \pi^-$) as a function of $\langle dN_{ch}/d\eta \rangle$ measured in $|y| < 0.5$.



pp, p-Pb and Pb–Pb collisions

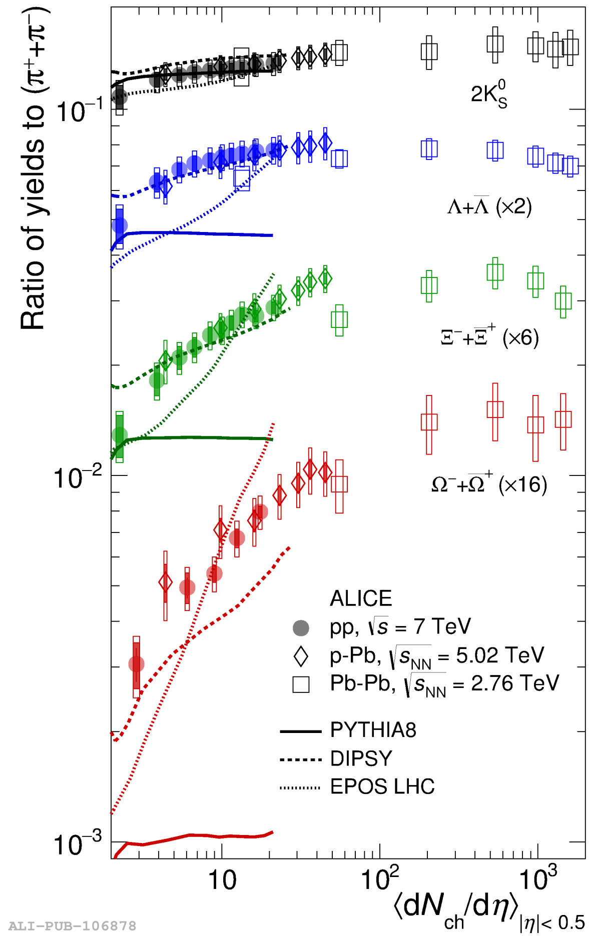
- Hardening of spectra
- The enhancement is larger for particles with larger strangeness content
- No dependence on the LHC collision energy

- Striking similarities in strangeness production for large and small systems
- Origin of strangeness enhancement?

p_T-integrated yield ratios to pions as a function of the <dN_{ch}/dη>

- A significant enhancement of strange to non-strange hadron production with increasing <dN_{ch}/dη>
- Enhancement is proportional to the strangeness content in the hadron
- Smooth behavior of particle ratios with the <dN_{ch}/dη> regardless of colliding system and energy
- DIPSY rope hadronization model [1,2]

  is providing the best description
- PYTHIA8 [3] fails completely



DOI:10.1038/NPHYS/4111

[1] C.Bierlich, G.Gustafson, L.Lonnblad, A.Tarasov, https://inspirehep.net/record/1335149 (2015)

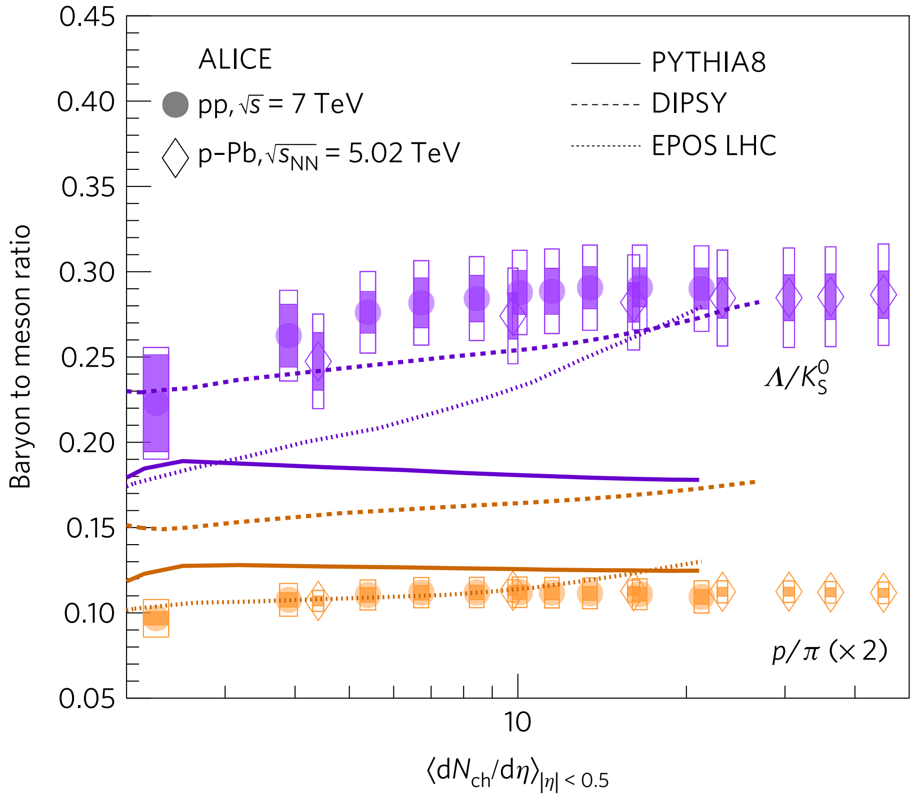
[2] Bierlich, C. & Christiansen, J. R. *Phys. Rev. D* **92,** 094010 (2015).

[3] Sjöstrand, T., Mrenna, S. & Skands, P. Z. *Comput. Phys. Commun.* **178,** 852–867 (2008).

[4] EPOS LHC:T. Pierog et al., Phys. Rev. C 92, 034906 (2015).

Mass dependence of particle ratios?
Baryon to meson yields ratio vs. multiplicity

DOI:10.1038/NPHYS/4111



- Data shows practically no changes with multiplicity for proton/pion yields ratio
- None of the MC models can describe all particle ratios simultaneously.
- For example DIPSY [1] fails in describing p/π ratio in its original formulation, but qualitatively describes Λ/K^0_s
- EPOS[2] that uses Core/Corona model-- is OK for p/π ratio , PYTHIA8 [3] fails completely

[1] C.Bierlich, G.Gustafson, L.Lonnblad, A.Tarasov, https://inspirehep.net/record/1335149 (2015); Bierlich, C. & Christiansen, J. R. *Phys. Rev. D* **92,** 094010 (2015);

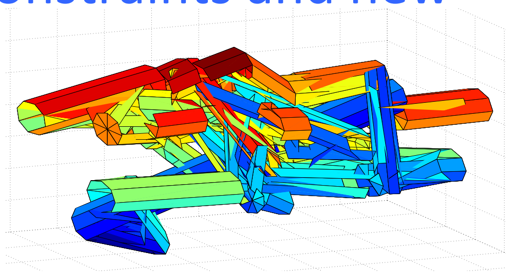
[2] Pierog,et al.,*Phys. Rev. C* **92,** 034906 (2015).

[3] Sjöstrand, T., Mrenna, S. & Skands, P. Z. *Comput. Phys. Commun.* **178,** 852–867 (2008).

Some theoretical approaches: *string fusion* in DIPSY[1]

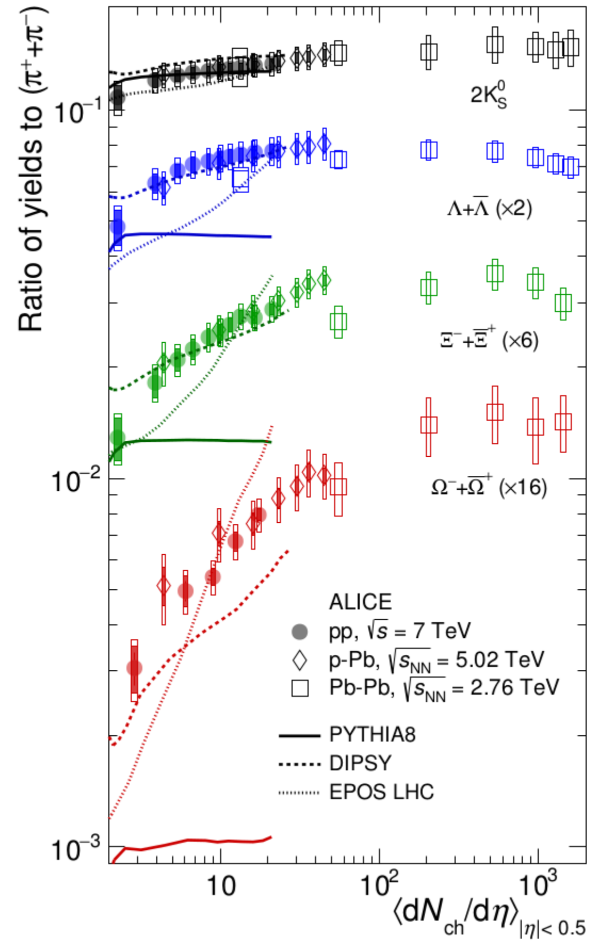
DOI:10.1038/NPHYS/4111

Data are bringing new constraints and new questions to the models



DIPSY:

- ➢ Strings close in space can fuse [2] to form "the colour ropes"
- ➢ New type of particle emitting sources -- strings with higher tension
- ➢ Increased production of strange particles and baryons
- ➢ Pre-Equilibrium Phase for QGP formation - ?
- ➢ A reminiscent of a thermal system - ?



[1] C.Bierlich, J. R.Christiansen, Effects of Colour Reconnection on Hadron Flavour Observables, arxiv:1507.02091; Christian Bierlich et al., arXiv:1412.6259

[2] **String fusion model**: **M.Braun,C.Pajares, Phys. Lett. B 287, (1992) 154-158**

Some theoretical approaches: Multi-Pomeron Exchange Model with *string fusion[1]*

DOI:10.1038/NPHYS/4111

Schwinger mechanism of production of particles species of type *ν* production mass m_ν, momentum p_t *and* spin - S_ν,

Here, $$g_\nu \exp\left(-\frac{\pi\left({p_t}^2 + {m_\nu}^2\right)}{n^\beta t}\right)$$

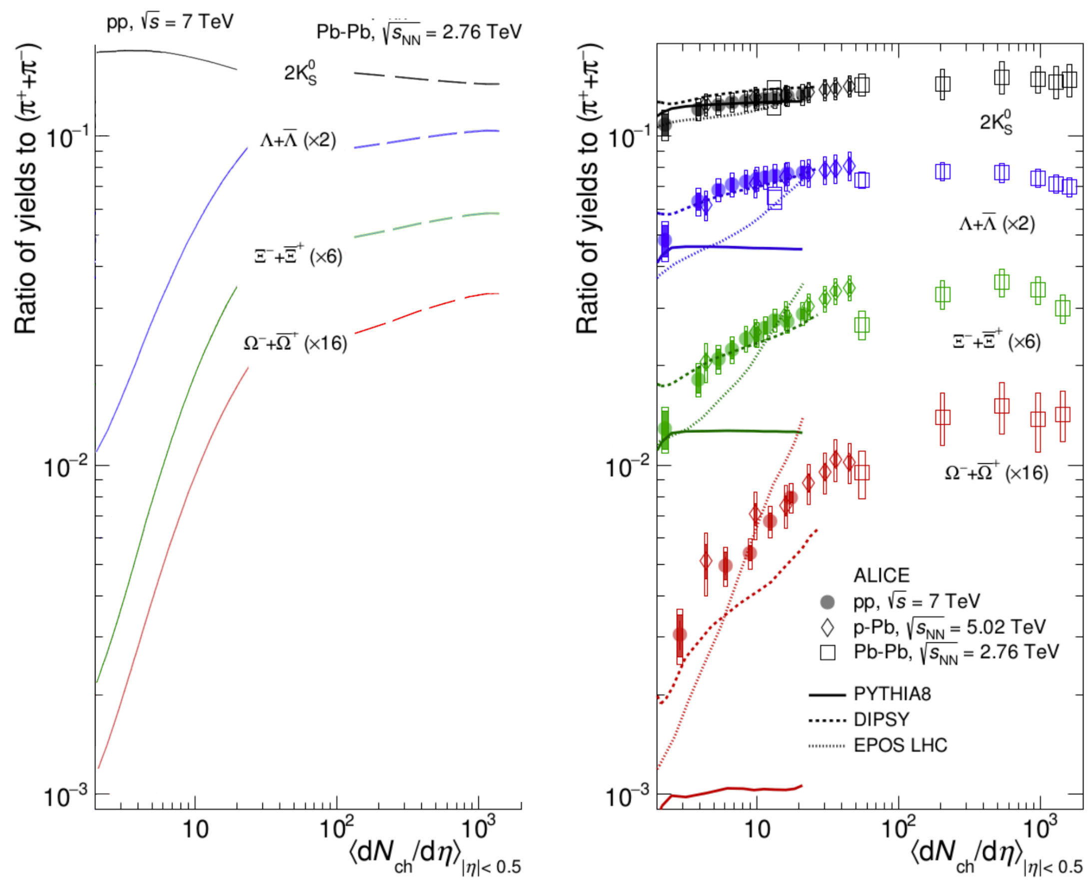
n - number of Pomerons,

t- string tension,

β – model collective parameter

$$g_\nu = 2S_\nu + 1$$

- Large set of hadron resonances with cascade decays
- The model [1] qualitatively describes the data from p-p to p-Pb and Pb-Pb



[1] V.Kovalenko et al., *Universe* **2022**, *8*(4), 246) https://doi.org/10.3390/

The strange hadron hierarchy in pp and p-Pb collisions

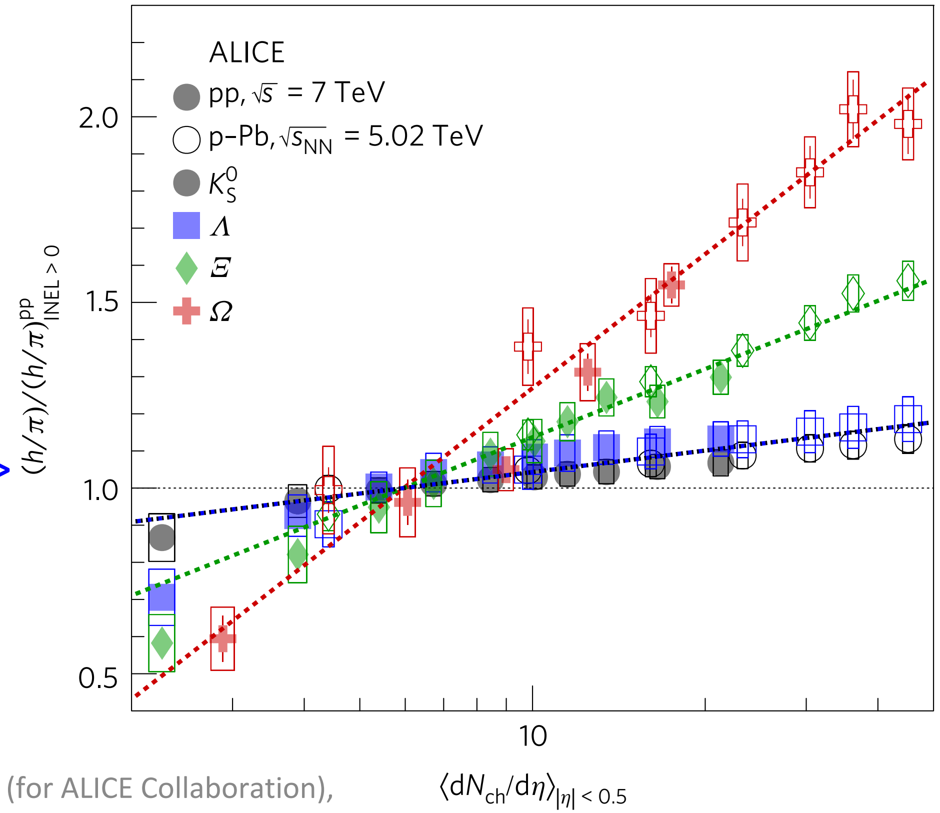
$$\frac{(h/\pi)}{(h/\pi)^{pp}_{INEL>0}} = 1 + a\, S^b \log\left[\frac{\langle dN_{ch}/d\eta\rangle}{\langle dN_{ch}/d\eta\rangle^{pp}_{INEL>0}}\right]$$

(DOI:10.1038/NPHYS/4111)

- *S* is the number of strange or anti-strange valence quarks
- *a* and *b* are free parameters:

  $a = 0.083 \pm 0.006$,

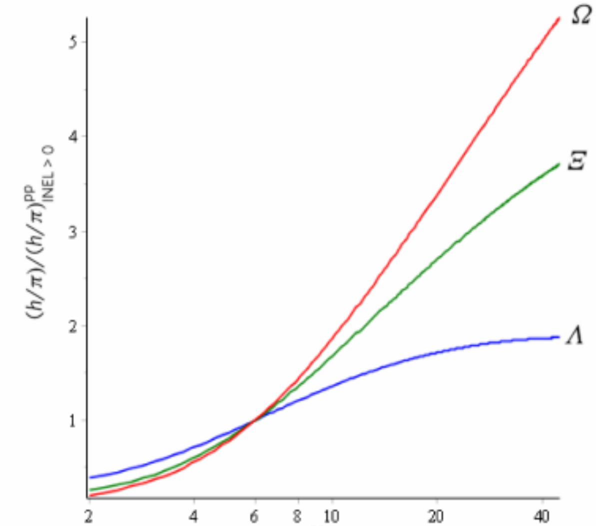
  $b = 1.67 \pm 0.09$

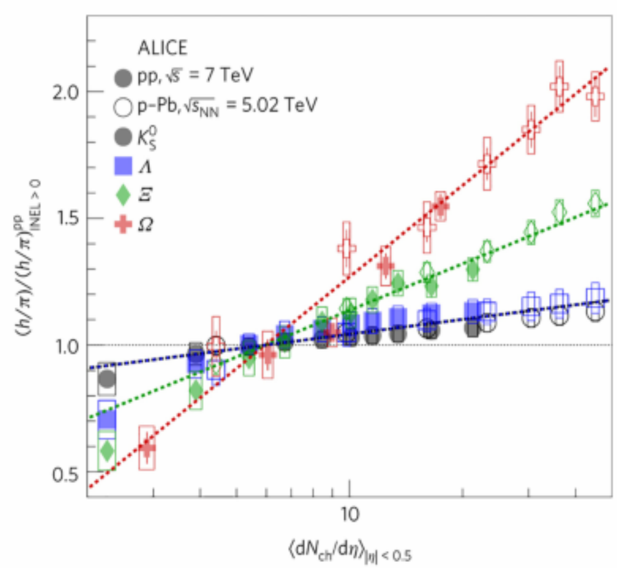


➢ No enhancement with the $<dN_{ch}/d\eta>$ is observed for particles without no strangeness

➢ Enhancement with the $<dN_{ch}/d\eta>$ depends on strange quark content

Some theoretical approaches:
Multi-Pomeron Exchange Model
with *string fusion[1]*





[1] G.Feofilov,V.Kovalenkro, A.Puchkov
arxiv: 1710.08895 [hep-ph](2017)

DOI:10.1038/NPHYS/4111

- The model qualitatively describes the data on Enhancement
- What are the factors or effects with the main contribution to Enhancement:

----- strangeness-related effects?

----- initial stages effects and energy density?

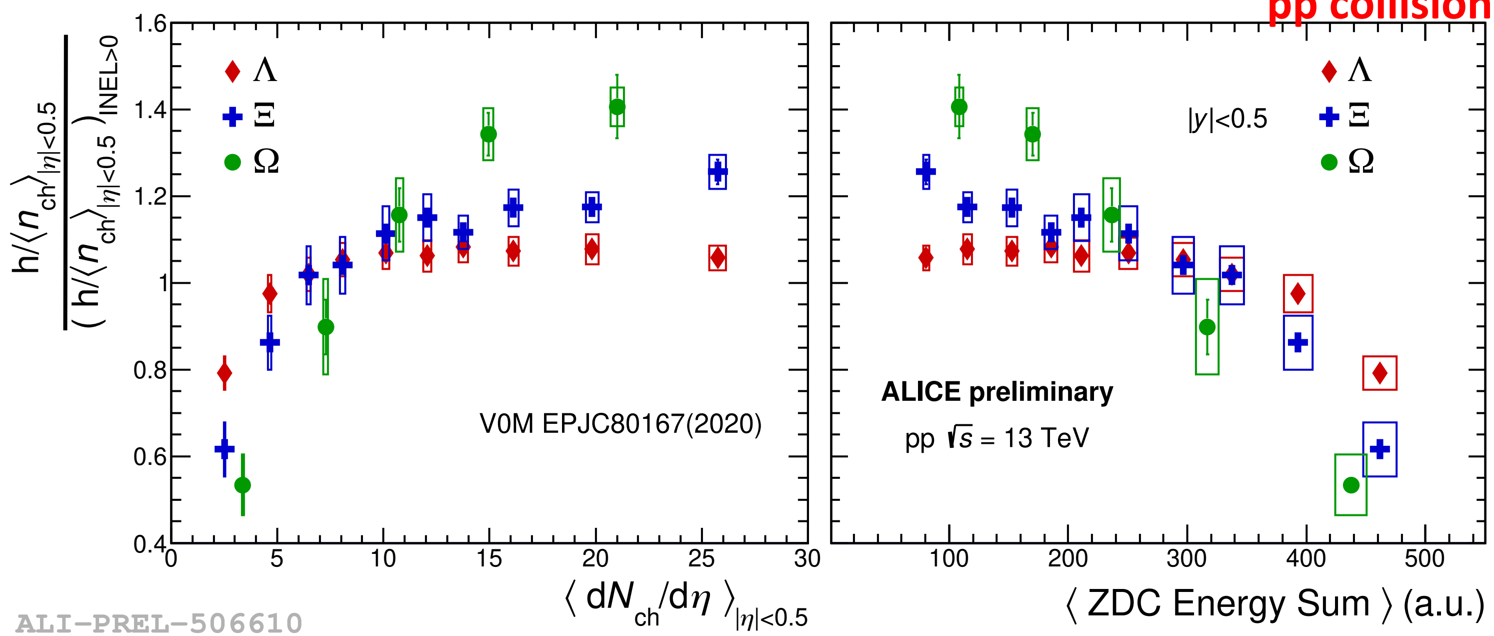
----- baryon-related effects?

….?

New!

Strangeness at midrapidity vs multiplicity and effective energy

pp collisions, √s= 13 TeV



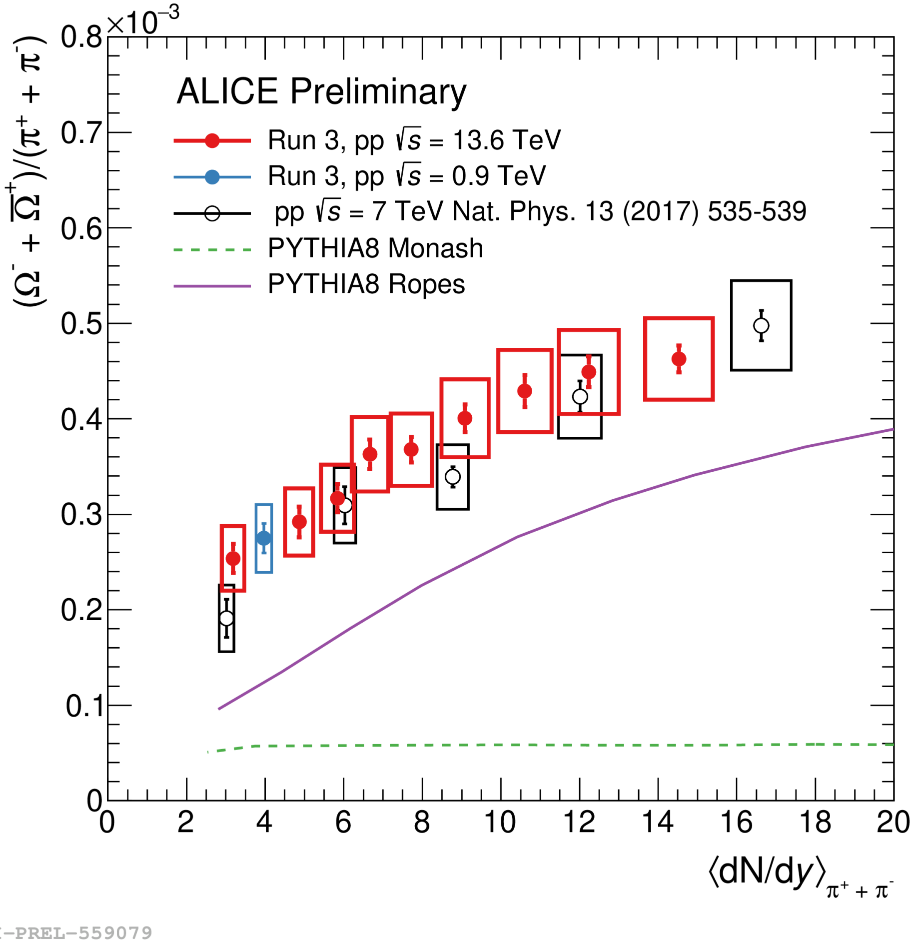
Λ: (uds)
Ξ: (dss)
Ω: (sss)

effective energy

- Λ, Ξ and Ω production vs midrapidity multiplicity -(left) and vs. energy deposited in ALICE's Zero Degree Calorimeters (ZDC) –(right)
- Yields of multistrange baryons are anticorrelated with the forward energy, measured by ZDC
- Correlated with the effective energy available in the event for particle production
- Role of the initial stages and number of partonic collisions (MPI) in strangeness production?

New!

Ω/π ratio vs. multiplicity in pp collisions at √s= 0.9, 7 and 13 TeV

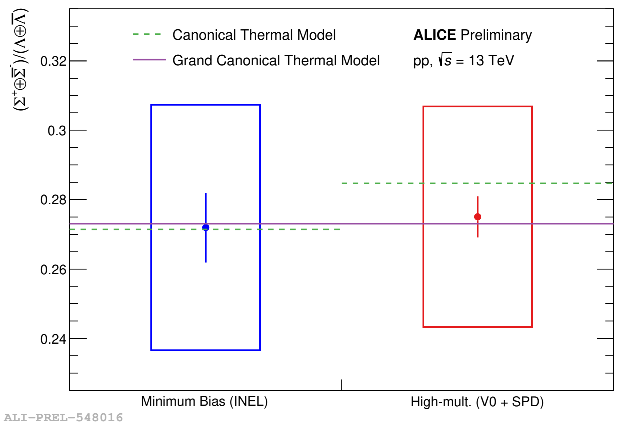


- Dependence on multiplicity for **Ω/π** ratio
- First Ω yield measurement at 0.9 TeV in pp collisions at the LHC
- Higher statistics for Ω production will be further obtained in Run 3
- PYTHIA Monash fails to describe growth with multiplicity
- PYTHIA with color ropes is in qualitative agreement

New!

First measurement of (anti)Σ± baryons to Λ ratio in pp collisions at √s=13 TeV

ALICE
A JOURNEY OF DISCOVERY



- No dependence on multiplicity for **Σ /Λ** ratio
- A new test for the models

- The sigma baryons are closely related to the Lambda baryons

Σ^+ (uus) mass: 1,189.37 ± 0.07 GeV/c^2
Σ^+ --> p + π^0 (51.57±0.30)%
--> n + π^+ (48.31±0.30)%

Σ^- (dds) mass: 1,192.642 ± 0.024
Σ^- --> n + π^- (99.848±0.005)%

Σ^0 (uds) mass: 1,197.449 ± 0.030
Σ^0 -->Λ0+γ (100)%

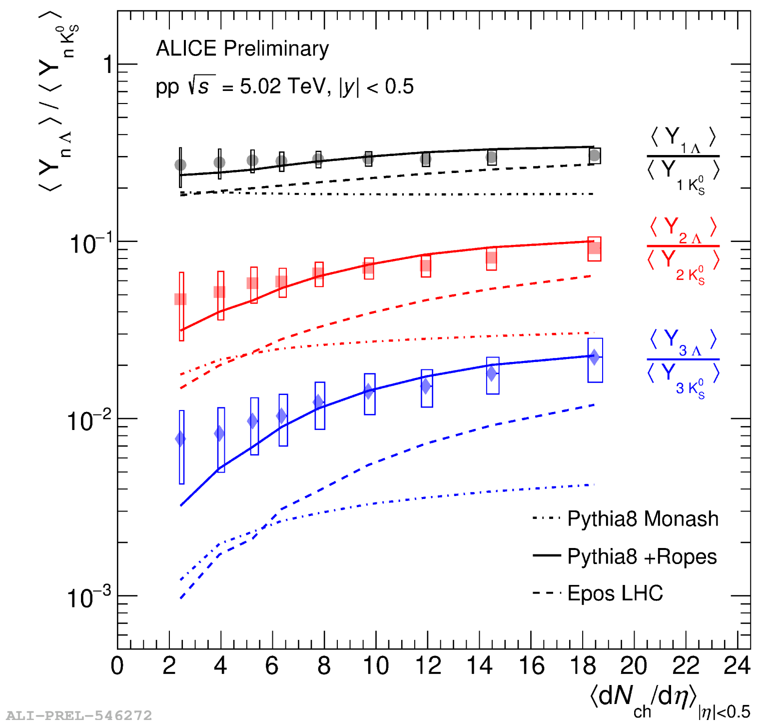
....

Λ^0 (uds) mass:1,115.683±0.006
Λ^0 --> p+π^- (64,1 ± 0,5 %)
--> n+ π^0 (35,9 ± 0,5 %)

https://cds.cern.ch/record/2848098/files/2302.00454.pdf
ALI-PREL-548016

New!

<Number of strange particles>/event First measurementin pp at √s= 5.02 TeV



- Ratios of mean values of multiple particle production numbers of 2Λ to $2K^0_S$ and of 3Λ to $3K^0_S$ are growing with the mean multiplicity of events
- Baryon-related effect?
- Test with models show good performance of PYTHIA+color ropes

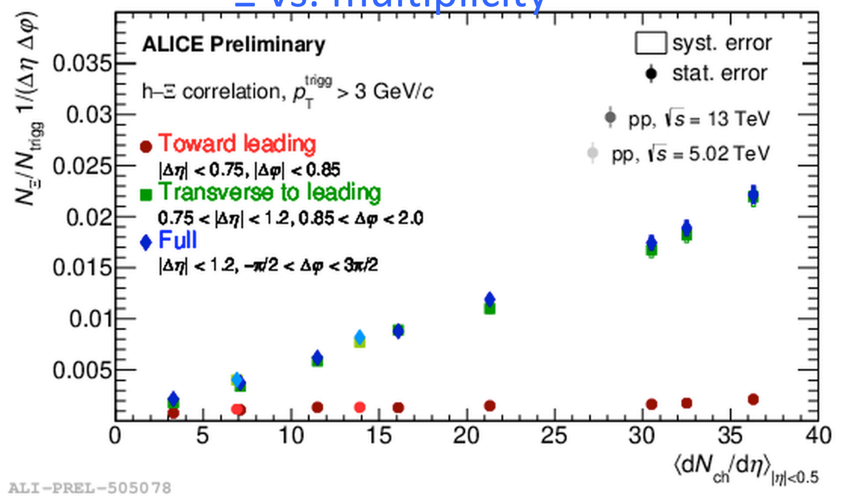
nΛ / nK^0_S as a function of the charged particle multiplicity compared with models

New!

Strangeness production in jets and out of jets

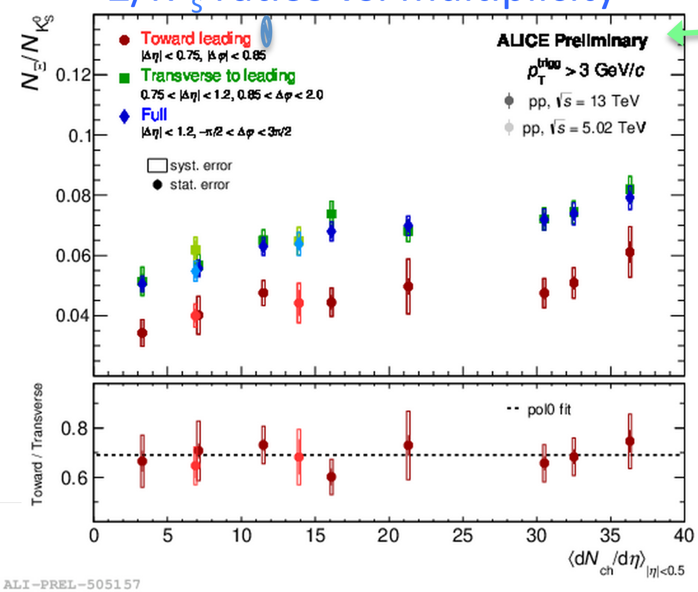
pp collisions at √s=13 TeV and √s =5.02 TeV

Ξ vs. multiplicity



Near-side jet, out-of-jet and full yield of Ξ vs. multiplicity of charged particles produced at midrapidity

Ξ/K^0_s ratios vs. multiplicity



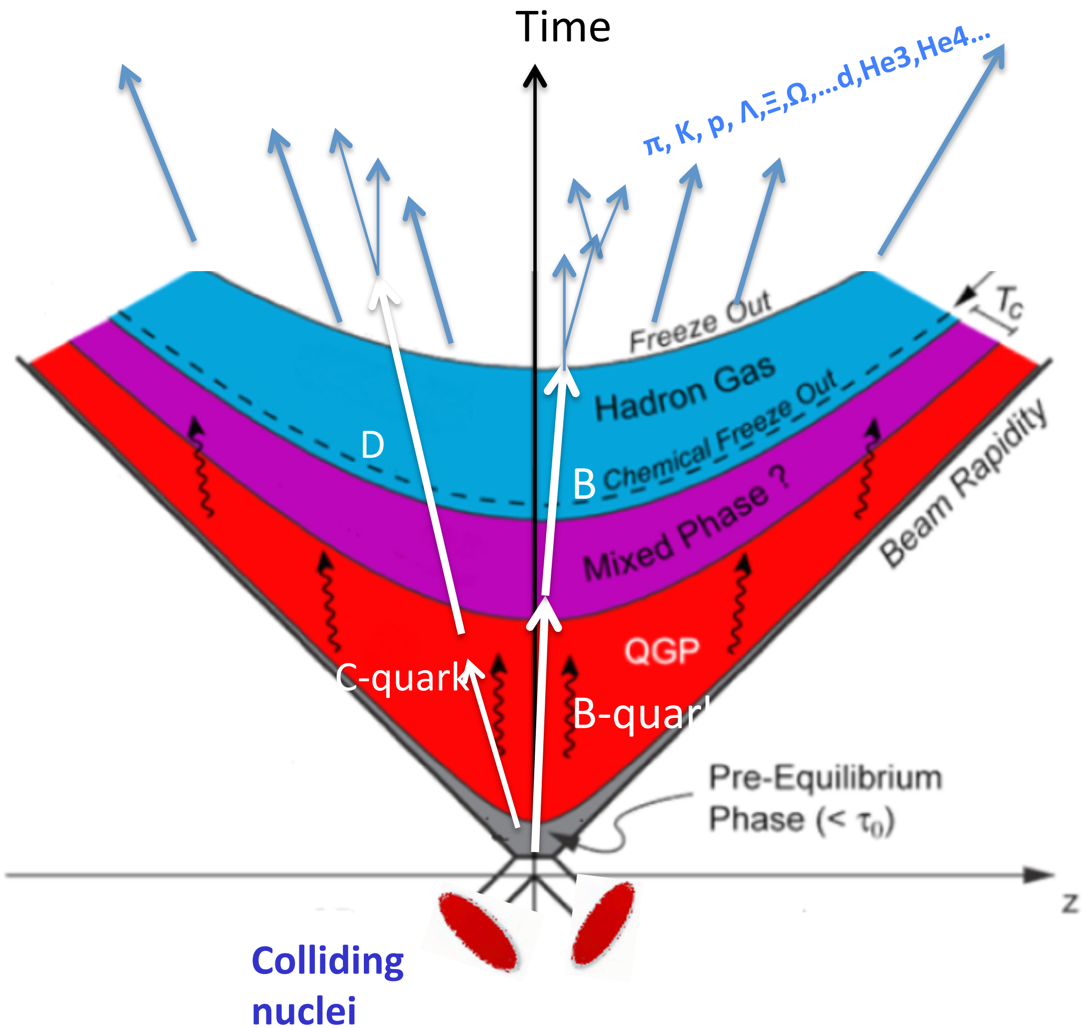
Near-side jet, out-of-jet and inclusive Ξ/K0s yield ratios vs. multiplicity of charged particles

- **For Ξ mesons the near-side leading jet yield is practically flat with multiplicity**
- **Linear growth** of Ξ yield with multiplicity **in transverse** to leading

https://cds.cern.ch/record/2848098/files/2302.00454.pdf

✓ Charm in pp, p-Pb and Pb-Pb collisions

Charm in pp, p-Pb and Pb-Pb collisions



Why open heavy flavour is interesting?

- ✓ Production is relevant to early collision stages
- ✓ Theoretical calculation of production in perturbative QCD
- ✓ Transport of c-quark through the medium: collisions and radiative e-losses ?
- ✓ Hadronisation mechanism?

Charm measurements in ALICE:

$D^0 \longrightarrow K^- \pi^+$

$D^+ \longrightarrow K^- \pi^+ \pi^+$

$D_s^+ \longrightarrow \phi\, \pi^+ \longrightarrow K^+ K^- \pi^+$

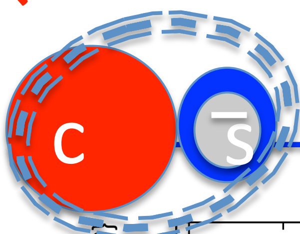
$D^{*+} \longrightarrow D^0 \pi^+ \longrightarrow K^- \pi^+ \pi^+$

$\Lambda_c^+ \longrightarrow K_s^0\, p \longrightarrow \pi^+ \pi^-\, p$

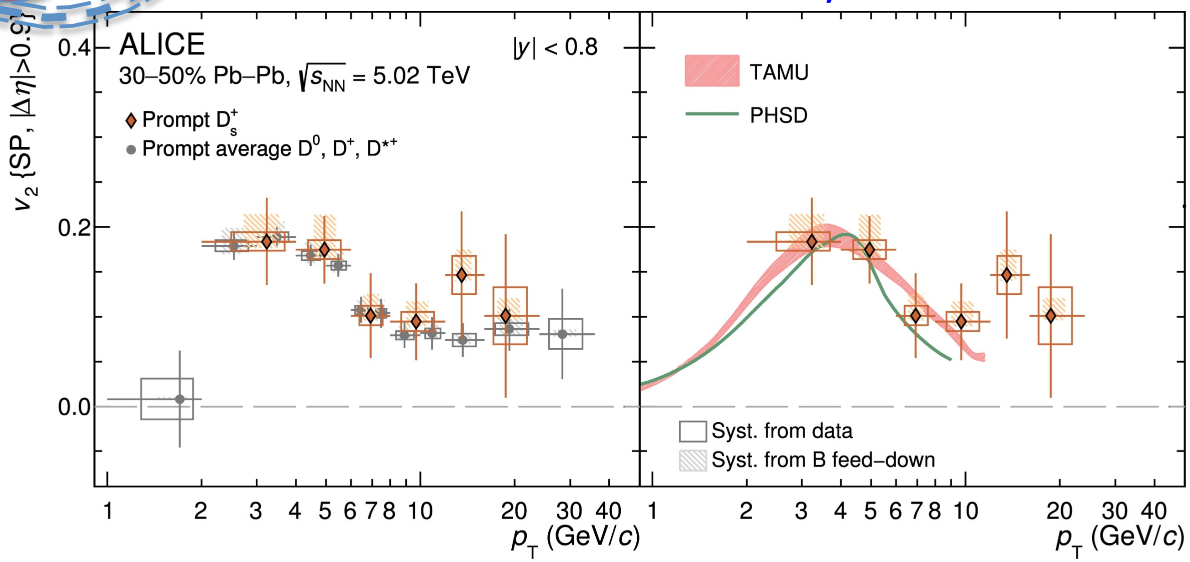
$c \longrightarrow \mu^\pm X$ (with muon spectrometer)

New!

Flow of prompt D_s^+-mesons in Pb-Pb collisions



Physics Letters B 827 (2022)



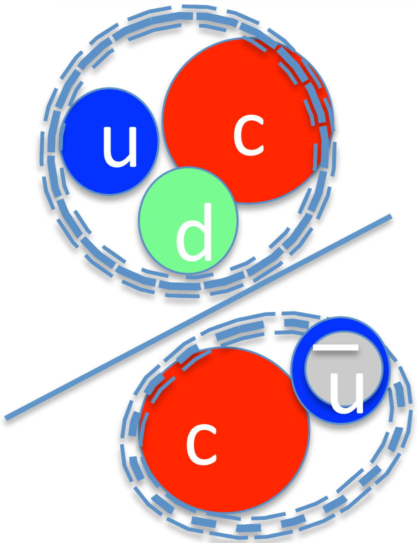
Pb–Pb collisions

- For prompt D^+_s mesons v_2 is compatible with that of non-strange D mesons
- Charm participates in collective expansion/motion: noticeable elliptic flow is in line with TAMU and PHSD models with charm-quark coalescence
- Future data samples will be collected in Run 3 extended to lower p_T with the upgraded ALICE detector

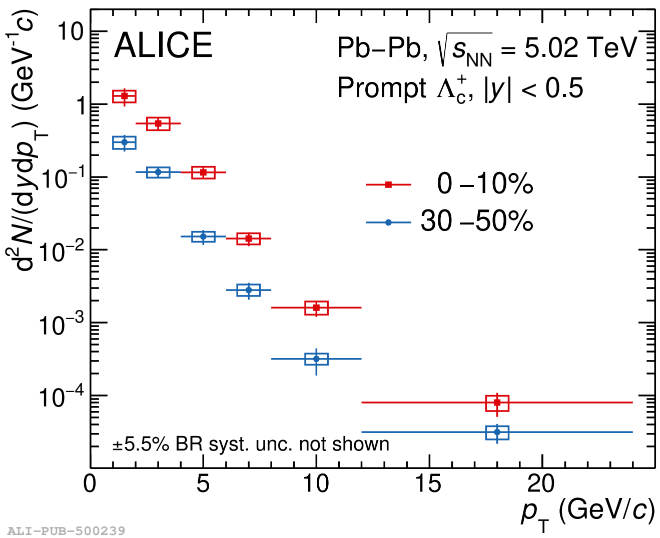
New!

Constraining hadronization mechanisms with Λ^+_c/D^0 production ratios[1]

pp and Pb–Pb collisions

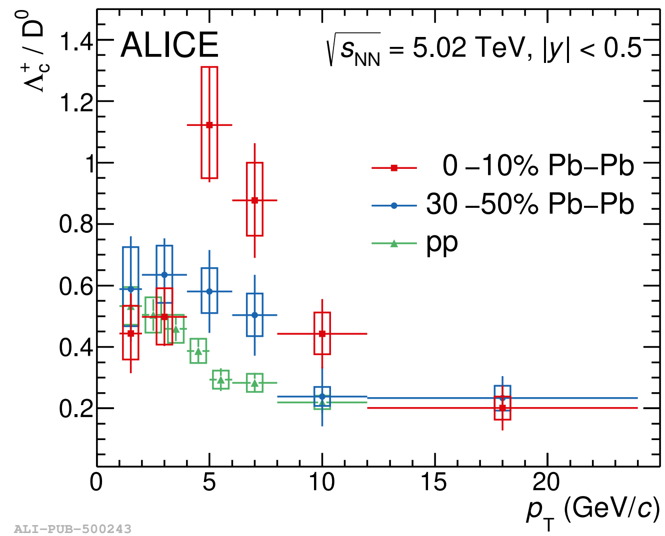


Prompt Λ^+_c



The p_T-differential production yields of prompt Λ^+_c in central (0–10%) and mid-central (30–50%) Pb–Pb collisions at √sNN = 5.02 TeV.

Λ^+_c/D^0



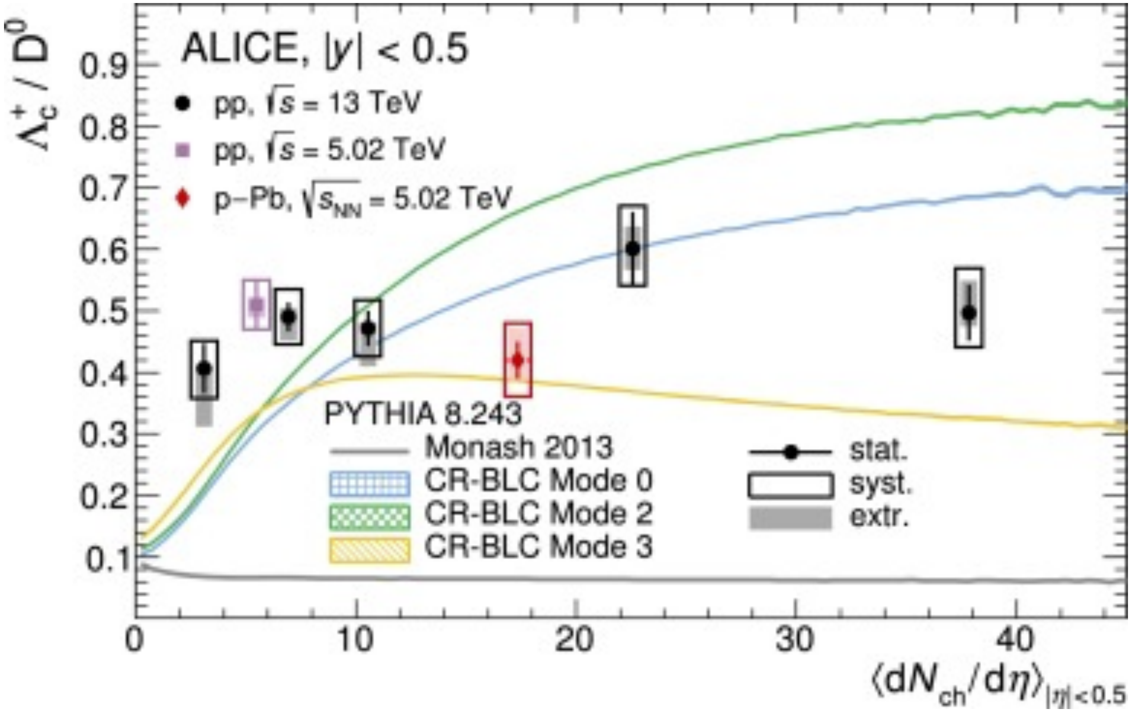
The Λ^+_c/D^0 ratio in central and mid-central Pb–Pb collisions at √sNN = 5.02 TeV compared with the results obtained from pp collisions [2]

- Λ^+_c/D^0 - ratio is sensitive to hadronisation mechanism

[1] ALICE Collabjration, Phys.Lett.B 839 (2023) 137796
[2] ALICE Collaboration, Phys. Rev. C 104 (2021) 054905

New!

Charm baryon-to-meson ratios in pp collisions at √s = 13 TeV[1]



- No dependence on multiplicity for Λ_c^+/D^0 ratio

[1] ALICE Collaboration, Phys.Lett.B 829 (2022) 137065

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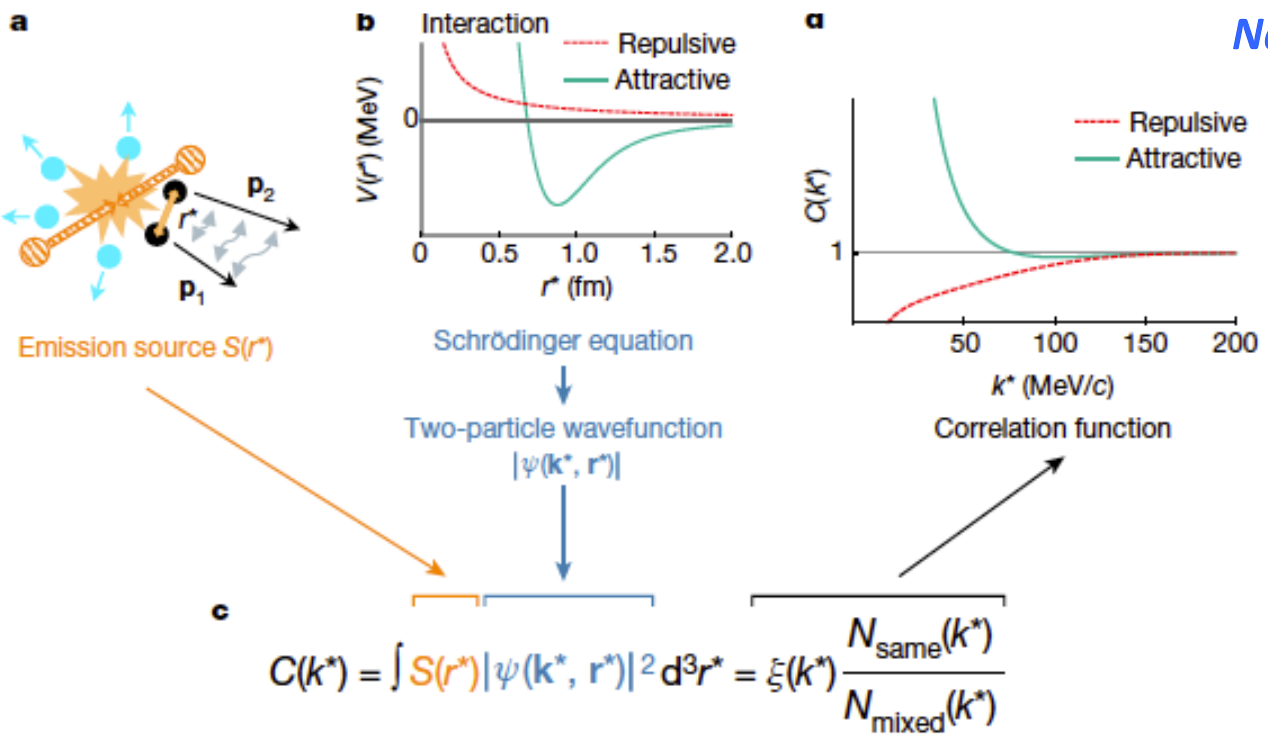
✓Two-body scattering involving *strange* and *charm* hyperons

Two-body scattering and study of strong interaction involving *strange* hyperons

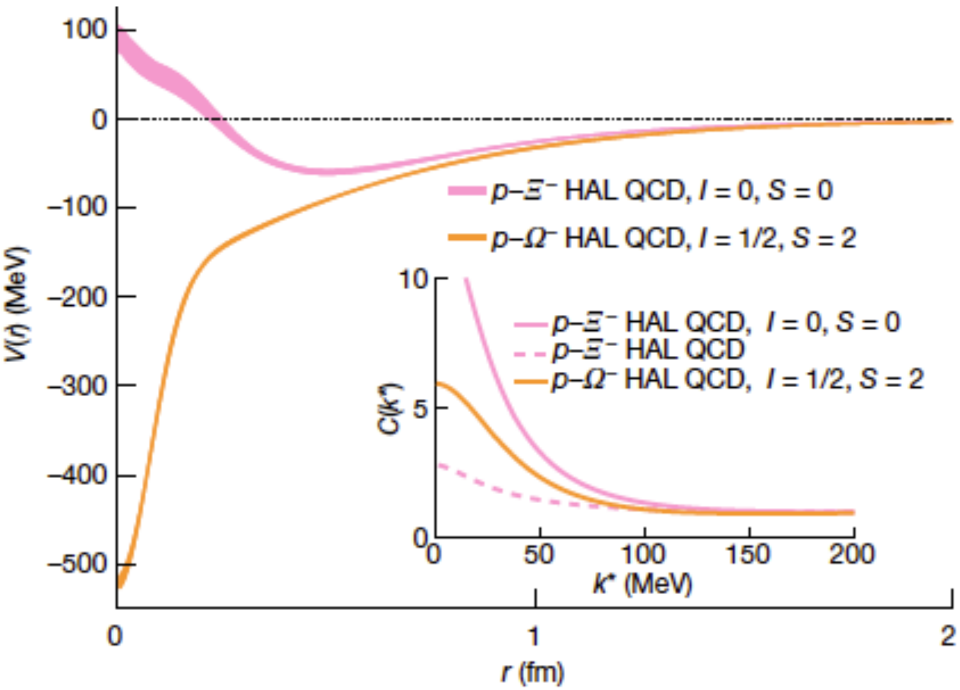
***Nature* 588, 232–238 (2020)**

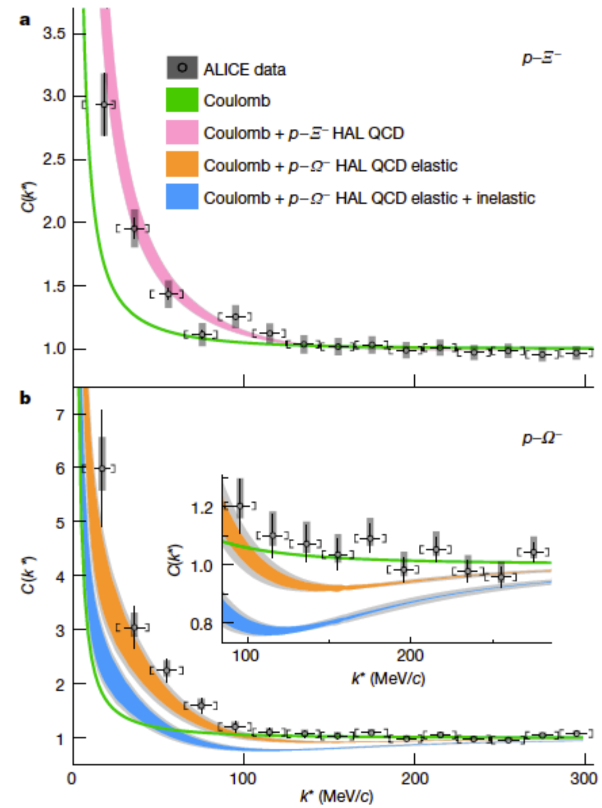


- ➢Absence of interaction C(k*) = 1
- ➢Attractive potential C(k*) > 1
- ➢Repulsive potential C(k*) < 1
- ➢Bound-state formation C(k*) <> 1

Two-body scattering and study of strong interaction involving ***strange*** hyperons

***Nature* 588, 232–238 (2020)**





Potentials for the p-Ξ⁻ and p-Ω⁻ interactions predicted by the HAL QCD collaboration.

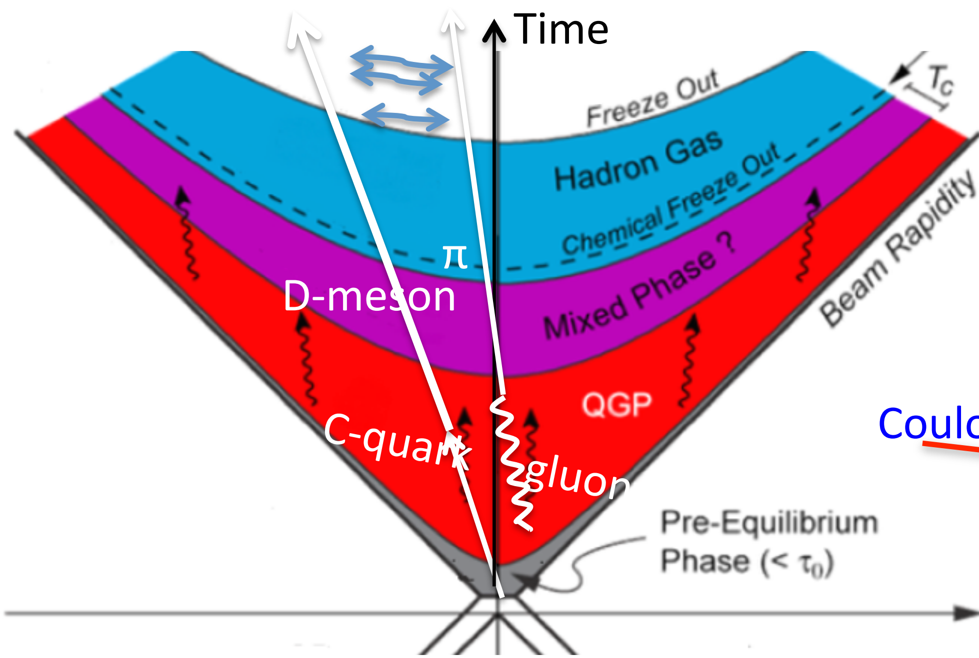
[Phys.Lett. B 792, 284–289 (2019); Nucl.Phys. A 998, 121737 (2020)].

- Important input for the equation of state of neutron stars

New!

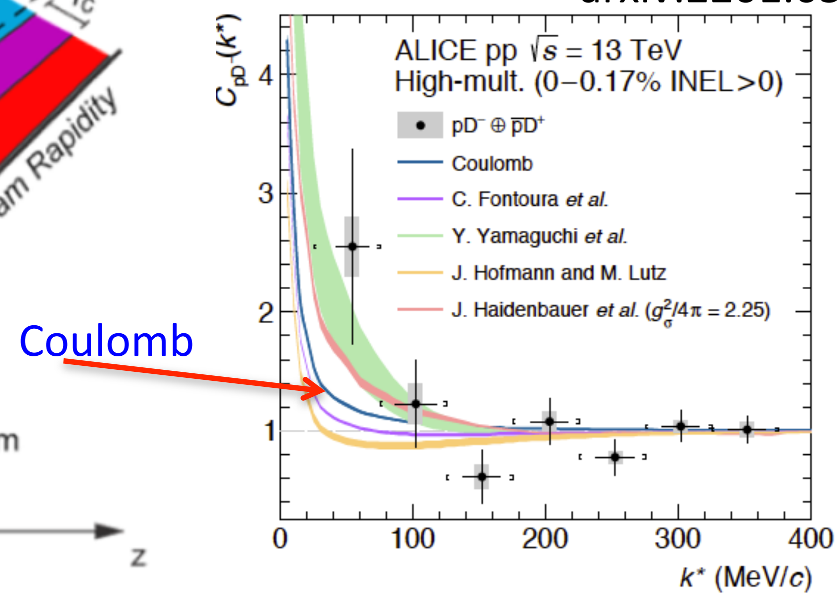
Two-body scattering involving ***charm*** hadrons

ALICE
A JOURNEY OF DISCOVERY



pp collisions

arxiv:2201.05352



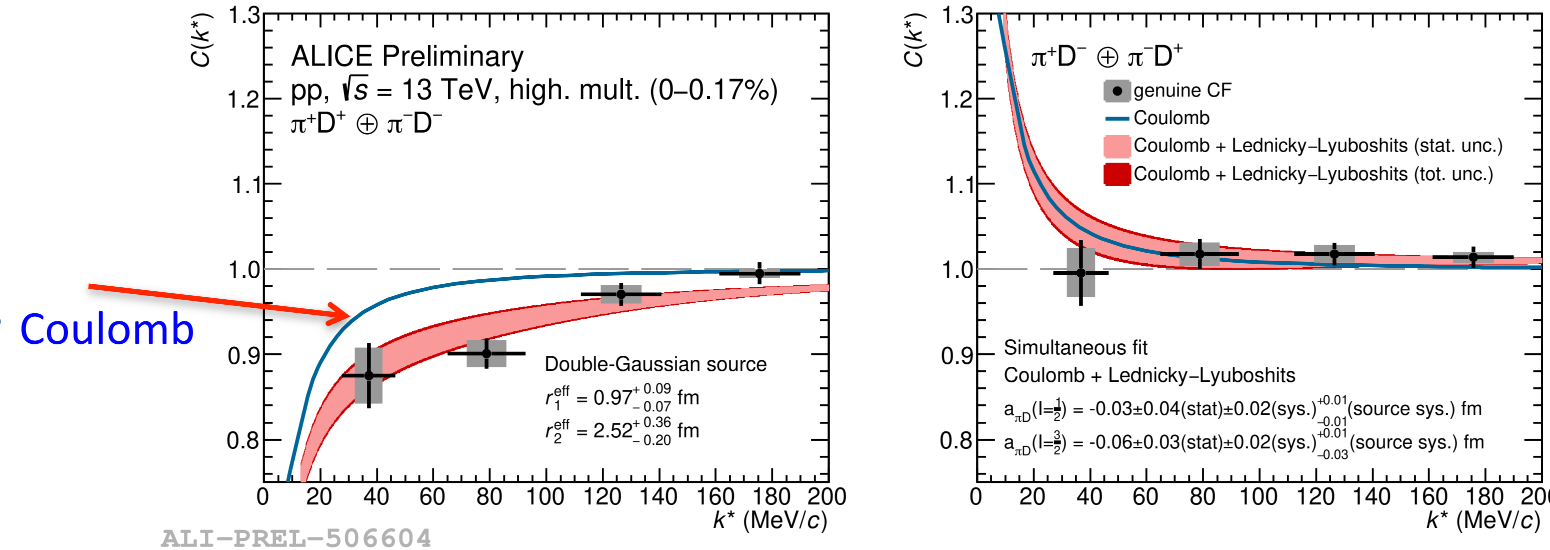
- The data are compatible with the Coulomb-only interaction hypothesis within (1.1–1.5) σ.
- The scattering parameters of charm hadrons with non-charm hadrons are important for models based on charm-quark transport in the expanding QGP
- Precision studies during the LHC Runs 3 and 4 are planned with 10 times increased statistics

New!

Two-body scattering involving *charm* hadrons

$\pi^+D^+ \oplus \pi^-D^-$ $\pi^+D^- \oplus \pi^-D^+$

pp collisions



D-π femtoscopy in high multiplicity pp collisions at √s=13 TeV

- The first studies of residual strong interaction between charm and light hadrons performed with Run 2 data
- Some deviation from the Coulomb baseline, indication on a shallow repulsive potential (left)
- **Significant improvement is foreseen with Run 3 data**

✓Flow of identified particles

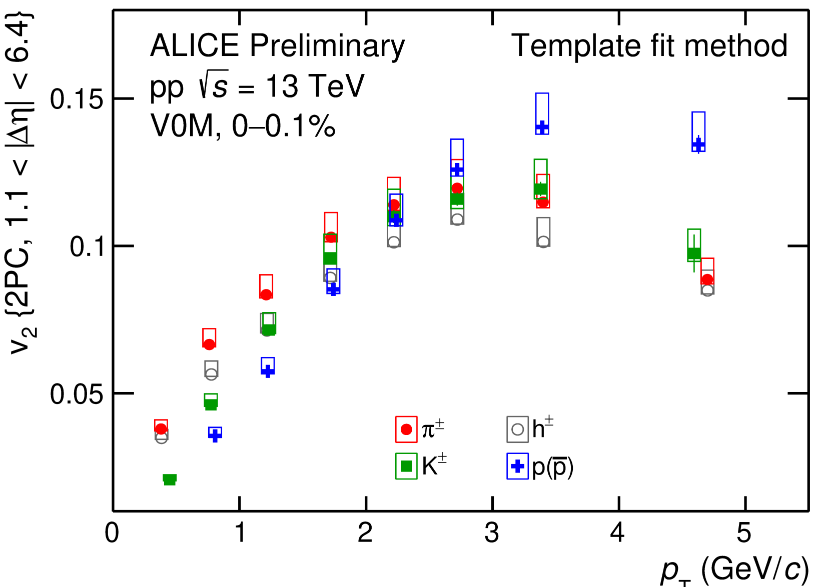
in pp and p-Pb collisions

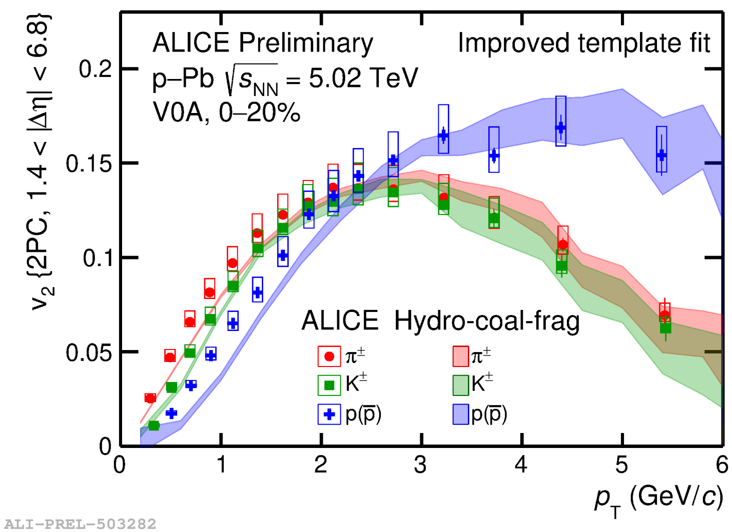
New!

Flow of identified particles in pp and p-Pb collisions: close similarity to Pb+Pb

ALICE
A JOURNEY OF DISCOVERY

pp and p-Pb collisions





v_2 in High Multiplicity pp collisions with h, pi, K, p

- ➢ Collective effects in small systems
- ➢ Baryon-meson splitting - both in High Multiplicity pp and in p-Pb collisions
- ➢ Partonic flow + coalescence + fragmenation?

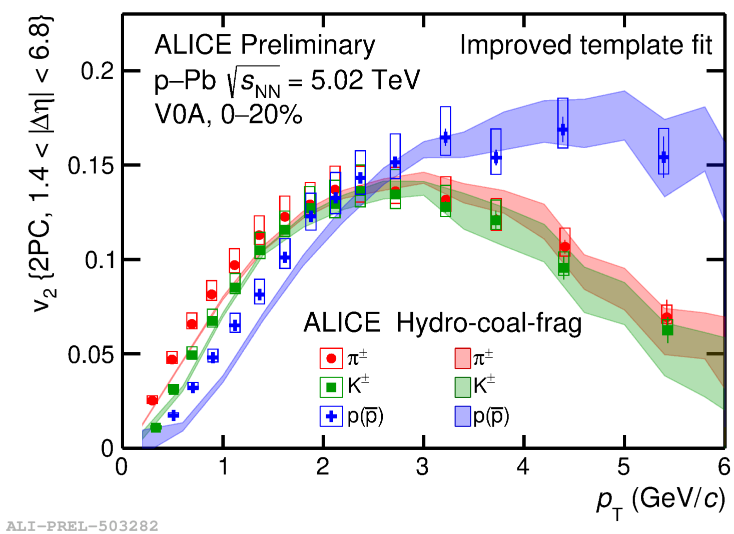
Hydro-coal-frag model from Phys. Rev. Lett. 125, 072301 (2020)

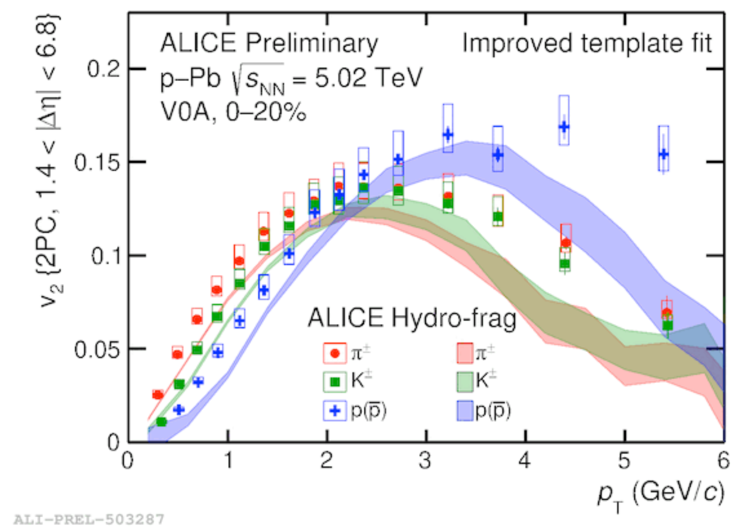
New!

Flow of identified particles in pp and p-Pb collisions: models

ALICE
A JOURNEY OF DISCOVERY

- Partonic flow + coalescence + fragmenation -- works OK here
- No quark coalescence – fails for p_T> 2,5 GeV/c



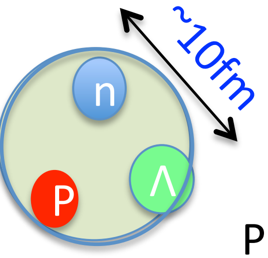


W.Zhao et al., “Probing the Partonic Degrees of Freedom in High-Multiplicity p-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV” Hydro-coal-frag model from Phys. Rev. Lett. 125, 072301 (2020)

- Results indicate for the existence of the partonic degrees of freedom and the possible formation of the QGP in high-multiplicity p-Pb collisions at 5.02 TeV.

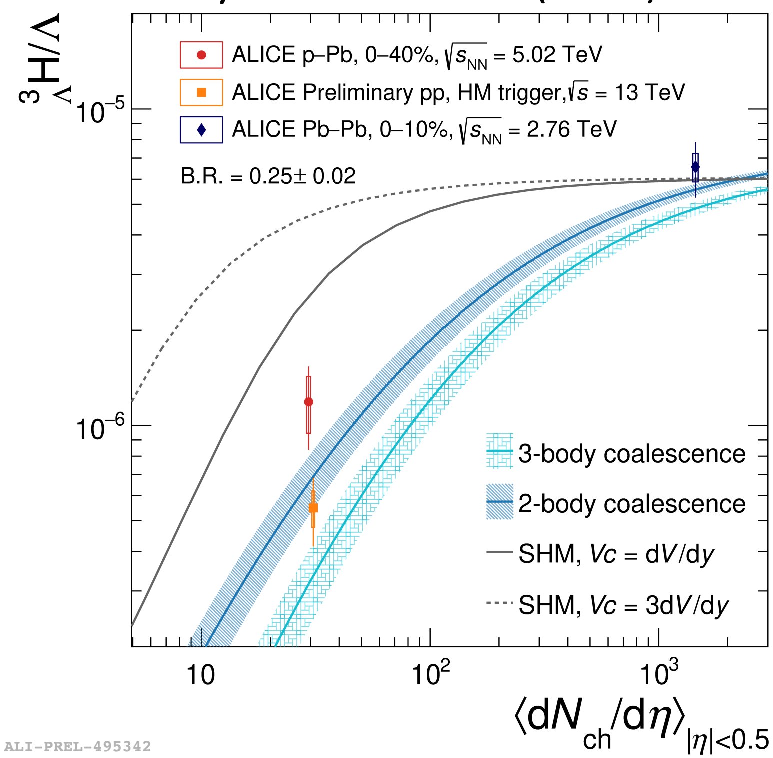
✓QGP and formation of light (anti) (hyper) nuclei

Formation of light (anti) (hyper) nuclei in pp, p--Pb and Pb--Pb collisions: hypertriton



pp, p-Pb and Pb–Pb collisions

Phys.Rev.Lett. 128 (2022) 252003



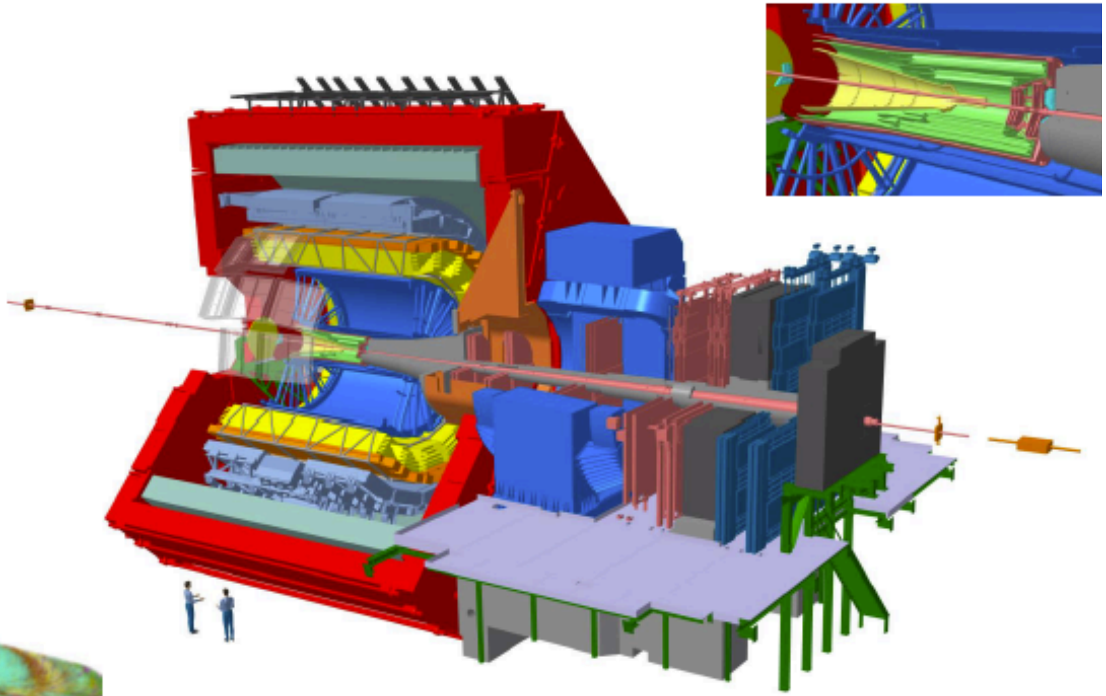
- The 1st measurement in p–Pb collisions at the LHC of hypertriton, reconstructed via the decay channel $^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$
  - The lightest hypernucleus (p,n, Λ) (mass ≈ 2.991 GeV/c^2)
  - The binding energy : B_{Λ} ≈ 130 keV
- **Fragile but surviving at chemical freeze-out temperature T_{ch} = 156 MeV ?**
- Important to discriminate between nucleosynthesis mechanisms in dense and hot environments
- Results are currently in favour of coalescence
- Improved statistics – is expected in the LHC Run 3 with the upgraded ALICE

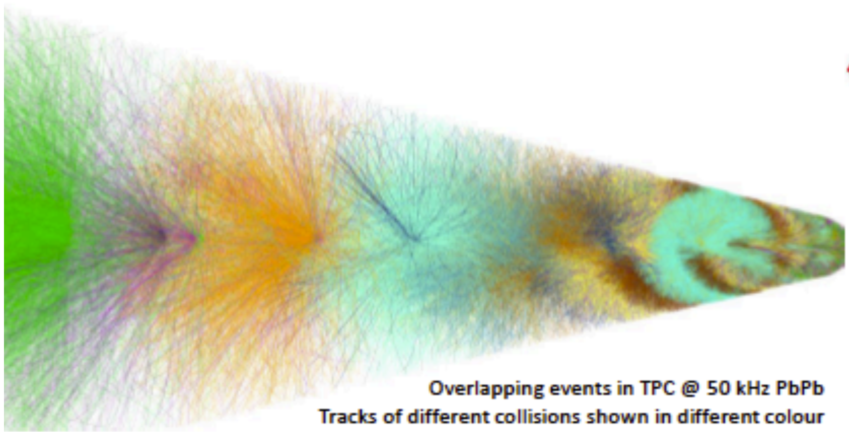
See the latest news from **Run 3** on **(anti) (hyper) nuclei** in pp collidions presented at QM-2023: https://indico.cern.ch/event/1139644/contributions/5541458/

✓ **ALICE LS2 Upgrade (ITS,TPC,MFT and FIT)**

ALICE in Run 3

- All-pixel Inner Tracking System
- GEM-based TPC readout
- Pixel Muon Forward Tracker
- Fast Interaction trigger
- New Online-Offline system
- Readout upgrade of all detectors





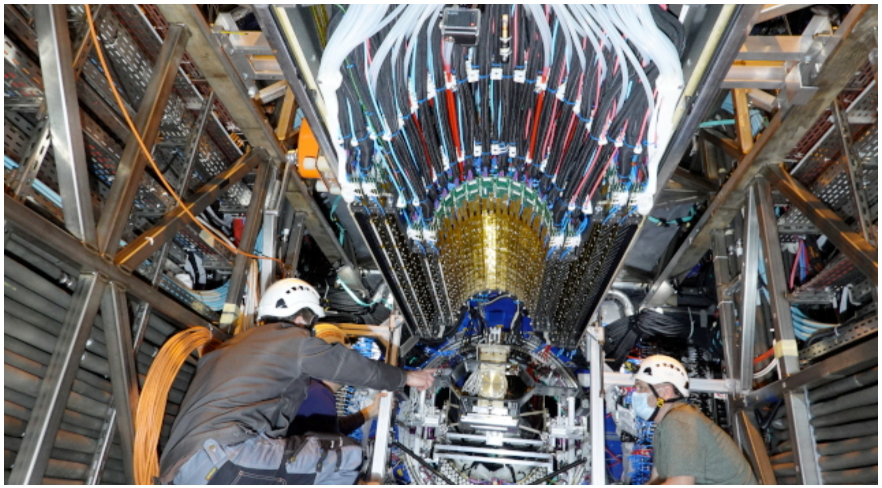
Overlapping events in TPC @ 50 kHz PbPb
Tracks of different collisions shown in different colour

Main goals:

- Collect 13/nb in Run 3 and 4
  (x100 larger minimum bias statistics)
- Improve tracking precision by a factor 3-6

ALICE upgrade:
Inner Tracking System (ITS2) for Run 3

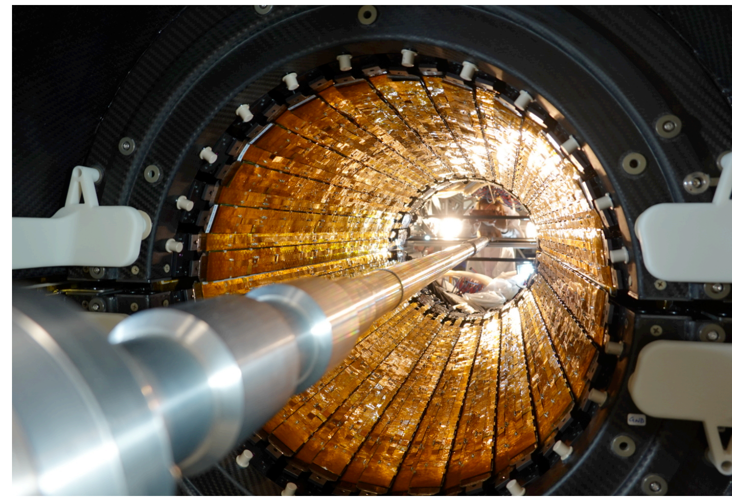
26 May, 2021



ALICE, the new Inner Tracking System

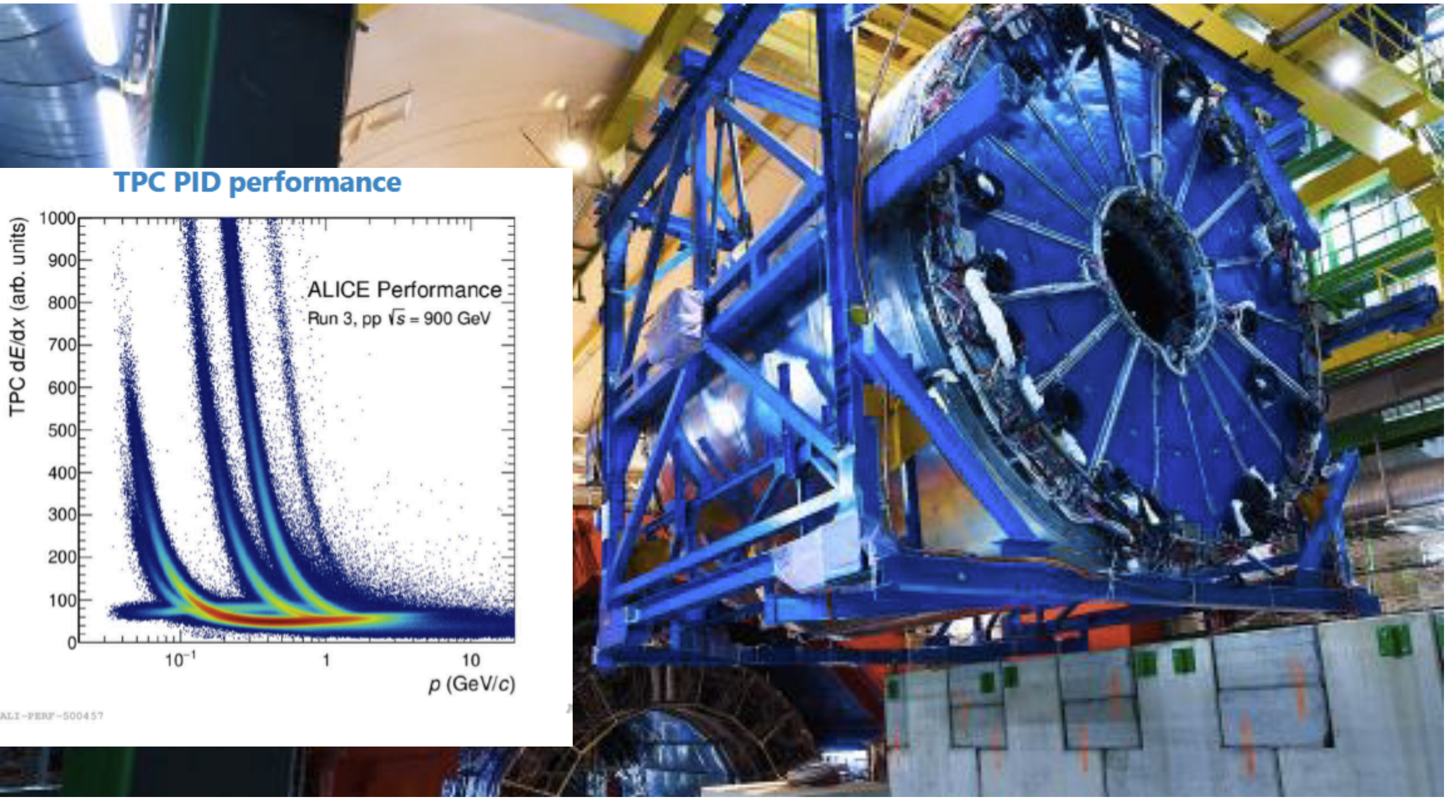
Installation of the Outer Barrel of the new ITS. (Image: CERN)

ITS2 in the process of installation



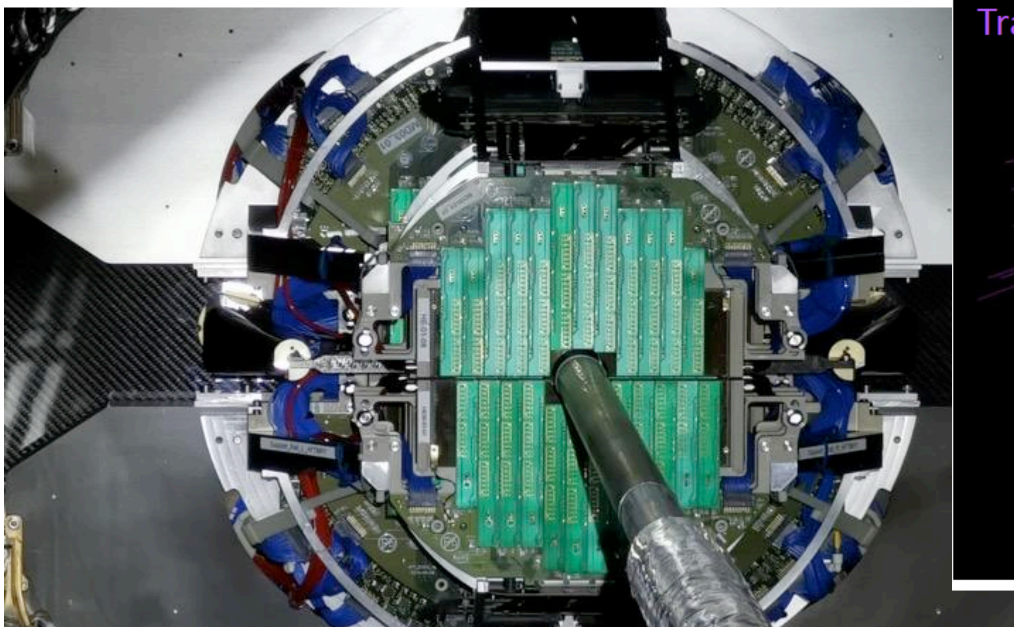
- The new ITS is the largest pixel detector ever built in CMOS Monolithic Active Pixel Sensor (MAPS) technology: 12,5 Gpixel camera of ~10 m^2 of active silicon area.
- High tracking precision and vertex resolution, fast readout
- Closer to the IP: first layer at ≈22 mm
- Smaller pixels: 28 x 29 μm^2
- Lower material budget of the Inner Barrel: 0.35% X_0

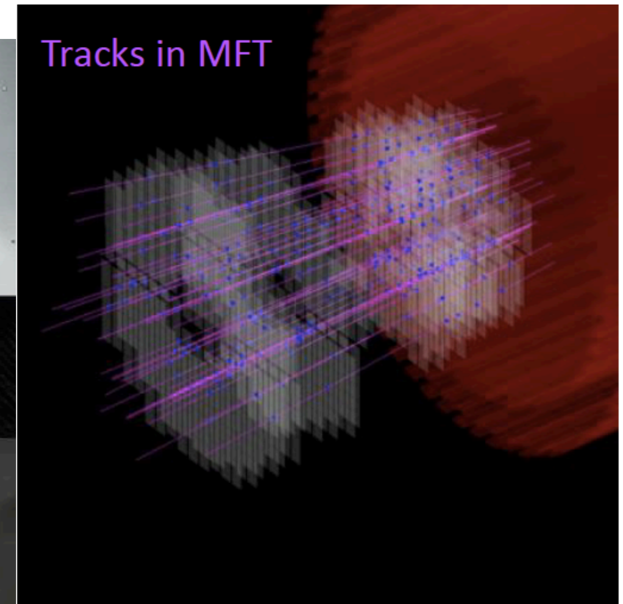
GEM TPC in the pilot beam in October 2021



- ➢ Photo: Installation of the TPC
- ➢ TPC with new Gas Electron Multiplier (GEM) technology
- \- New electronics (SAMPA),
- \- continuous readout

Pixel Muon Forward Tracker (MFT) in the pilot beam in October 2021





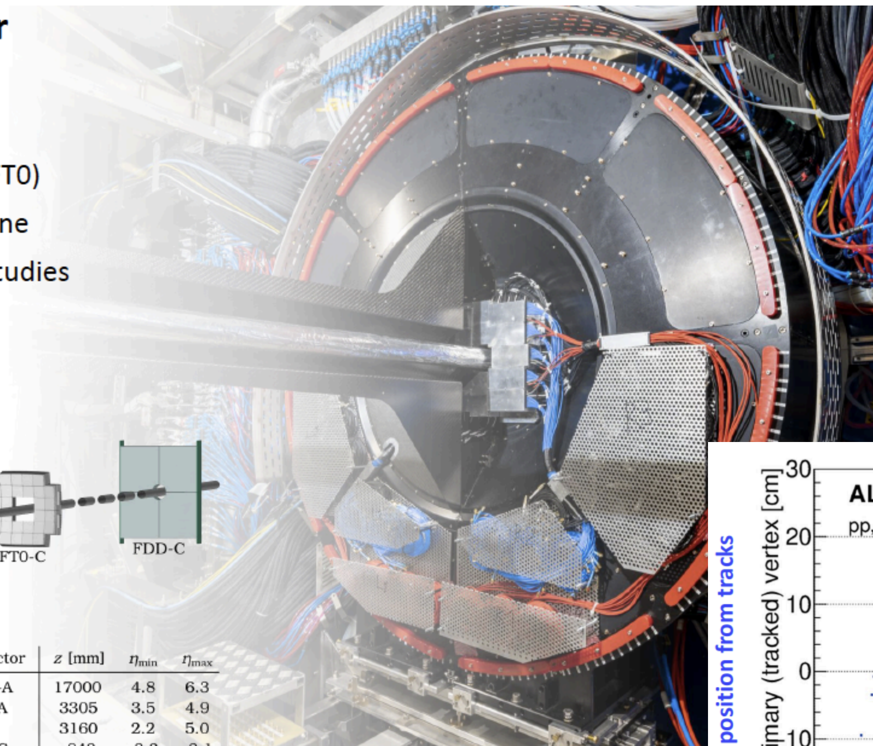
. Good performance of the new MFT in the pilot beam

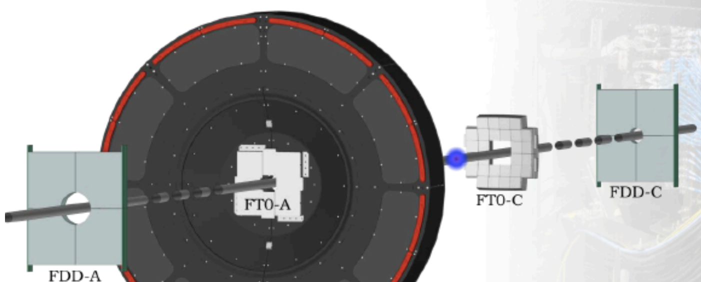
- ➢ The new Muon Forward Tracker, one of ALICE’s main subdetectors, was installed in the cavern in December 2020
- ➢ Substantial increase in pseudorapidity coverage for ALICE
- ➢ High pointing resolution for muon tracking

Fast Interaction Trigger (FIT) in October 2021 run

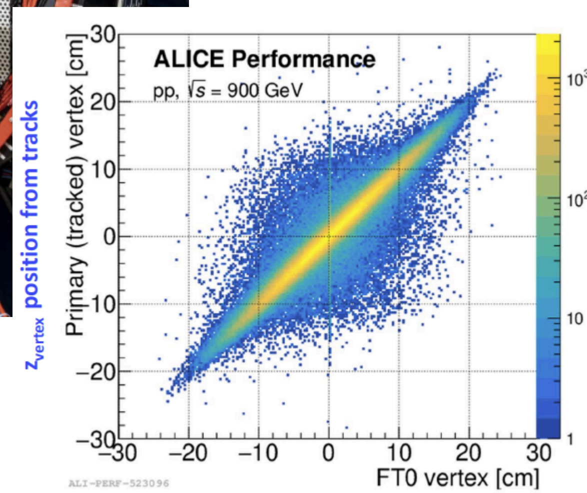
Fast Interaction Trigger

- Minimum bias trigger
- Timing signal for TOF (13 ps in FT0)
- Centrality, luminosity, event plane
- Forward vetoes for diffractive studies





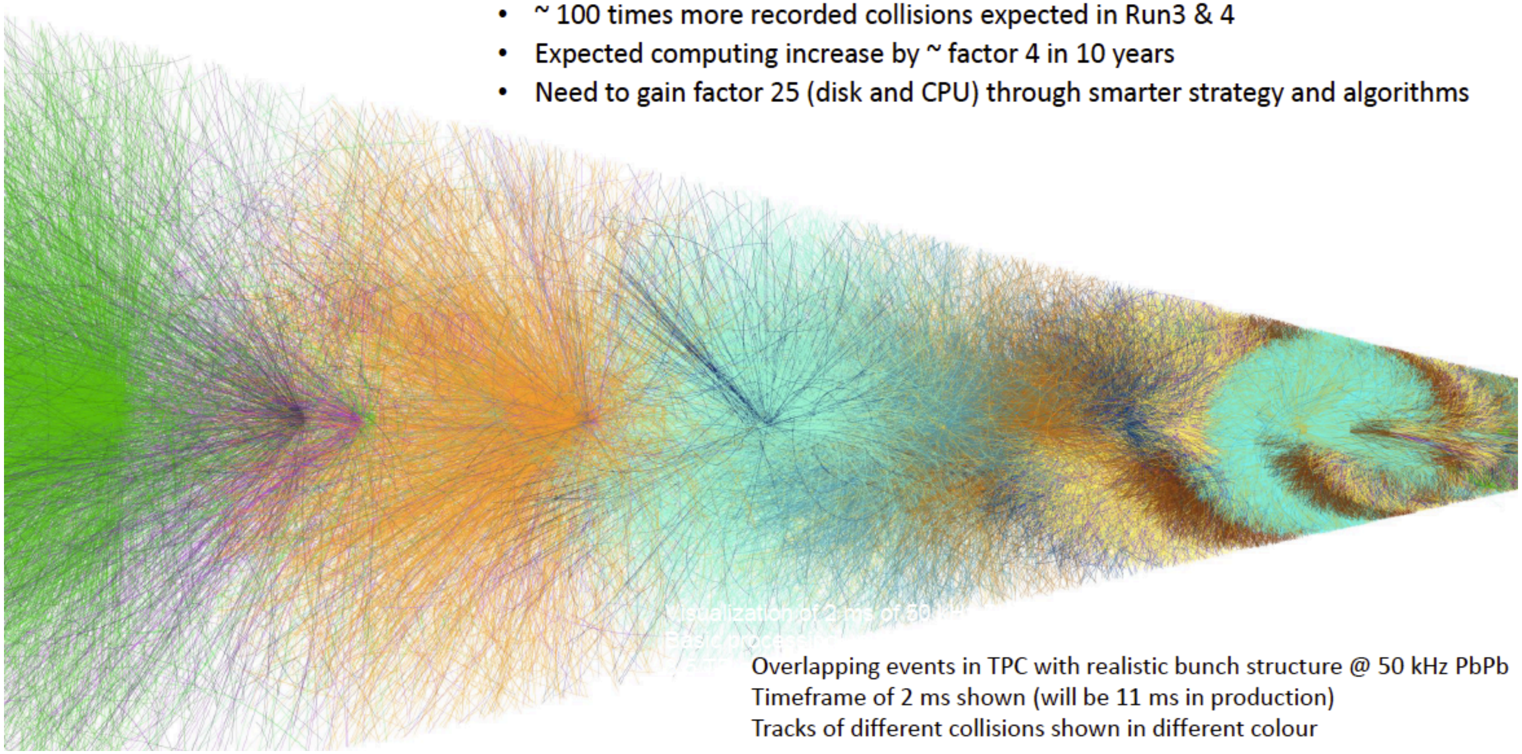
Detector	z [mm]	η_{min}	η_{max}
FDD-A	17000	4.8	6.3
FT0-A	3305	3.5	4.9
FV0	3160	2.2	5.0
FT0-C	-843	-3.3	-2.1



z_{vertex} position based on FT0 timing

ALICE upgrade for Runs 3 and 4: Integrated Online-Offline System (O^2)

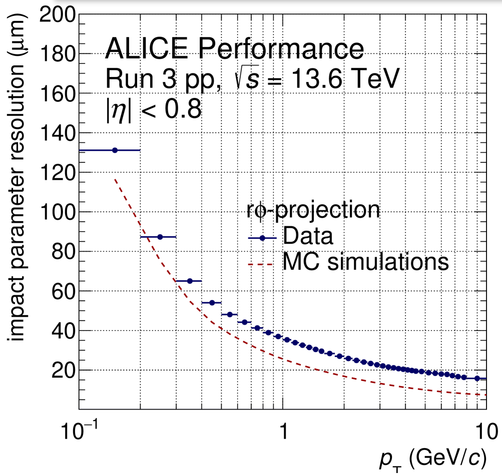
- ~ 100 times more recorded collisions expected in Run3 & 4
- Expected computing increase by ~ factor 4 in 10 years
- Need to gain factor 25 (disk and CPU) through smarter strategy and algorithms



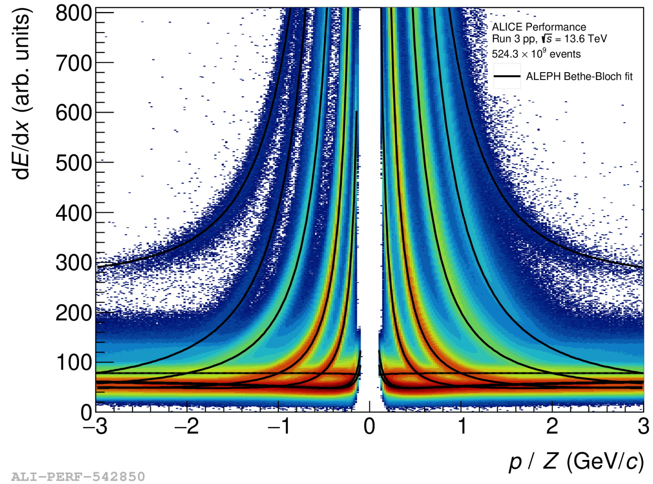
Overlapping events in TPC with realistic bunch structure @ 50 kHz PbPb
Timeframe of 2 ms shown (will be 11 ms in production)
Tracks of different collisions shown in different colour

- **Goal: record Pb-Pb collisions at 50 kHz (vs. 1 kHz in Runs 1 & 2)**
- **Collect 13 /nb in Runs 3&4 – gain factor 100 in statistics!**
- **Continuous readout**

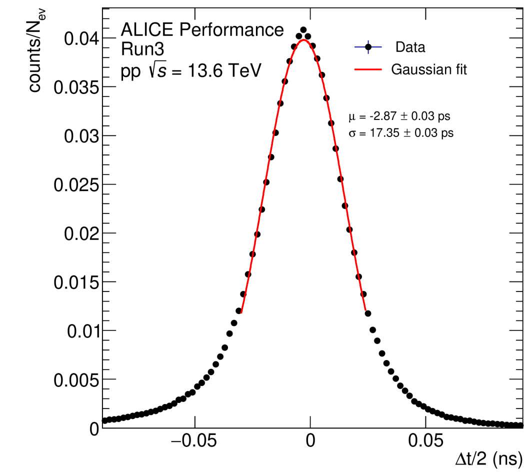
ALICE Performance in Run 3



Impact parameter resolution in rφ vs. p_T (Run 3 data)



TPC dE/dx vs. p/Z performance -



Fast Interaction Trigger (FIT) time resolution

- Factor 3 improvement in impact parameter resolution
- Clear signal of (anti)nuclei in pp collisions
- Factor 50 improvement in readout rate (continuos readout)

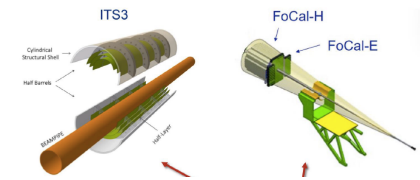
✓ALICE @LHC Schedule

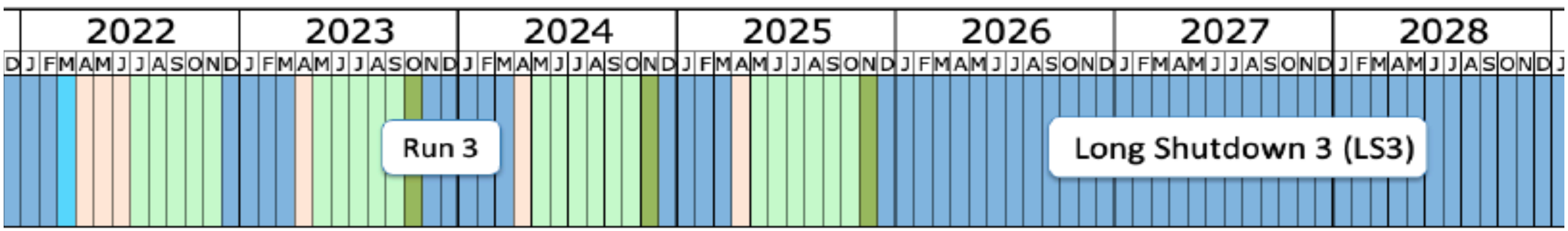
ALICE @LHC Schedule

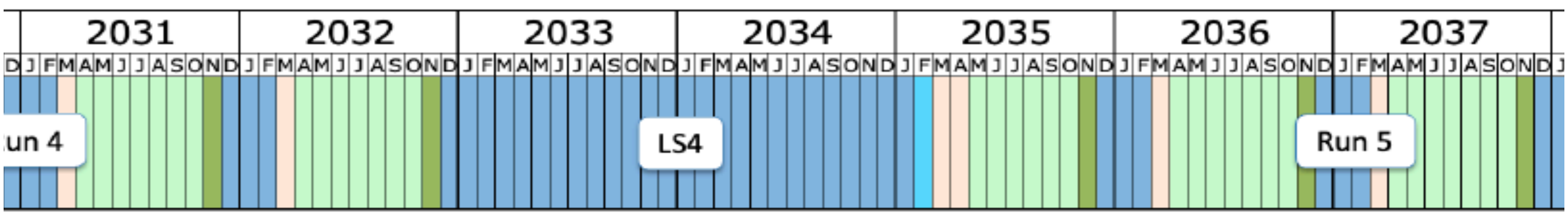
ALICE LS2 Upgrade finished

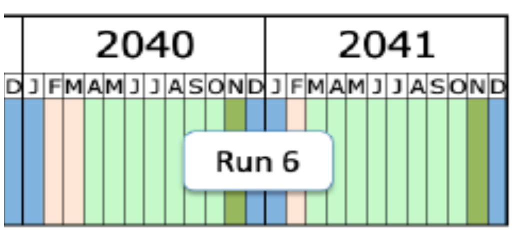
Today

ALICE LS3 Upgrade

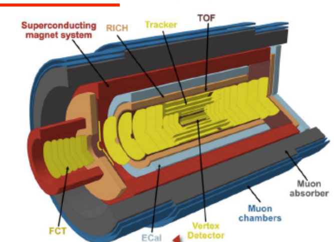


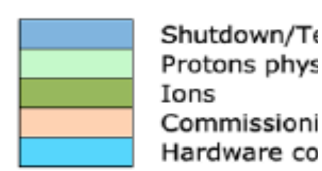




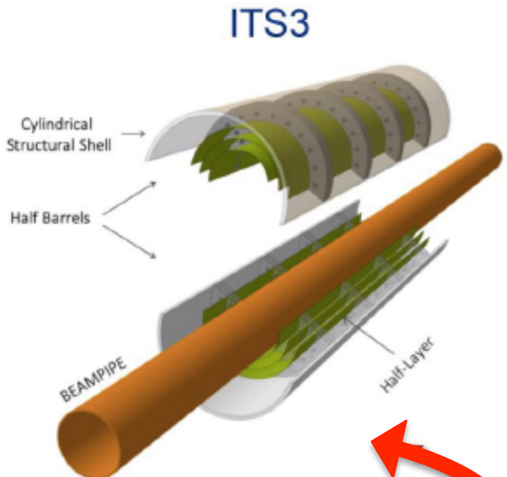


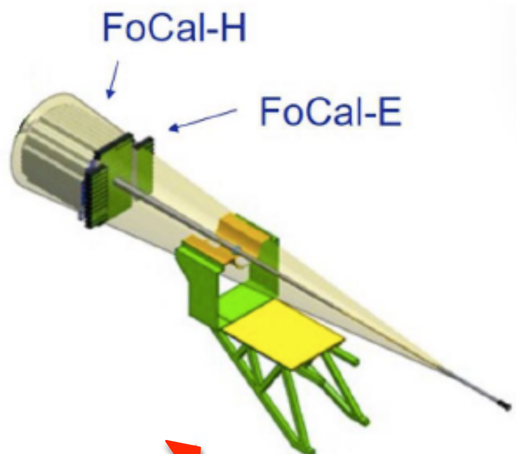
ALICE LS4 Upgrade ALICE 3





ALICE upgrade in 2026-2028: is under preparations





- Large area, thin bent Si pixel MAPS sensors

ITS3

- Ultra-light, a truly-cylindrical Inner Barrel
- x3 less material
- Improves measurement of low p_T charm and beauty hadrons and low-mass dielectrons .

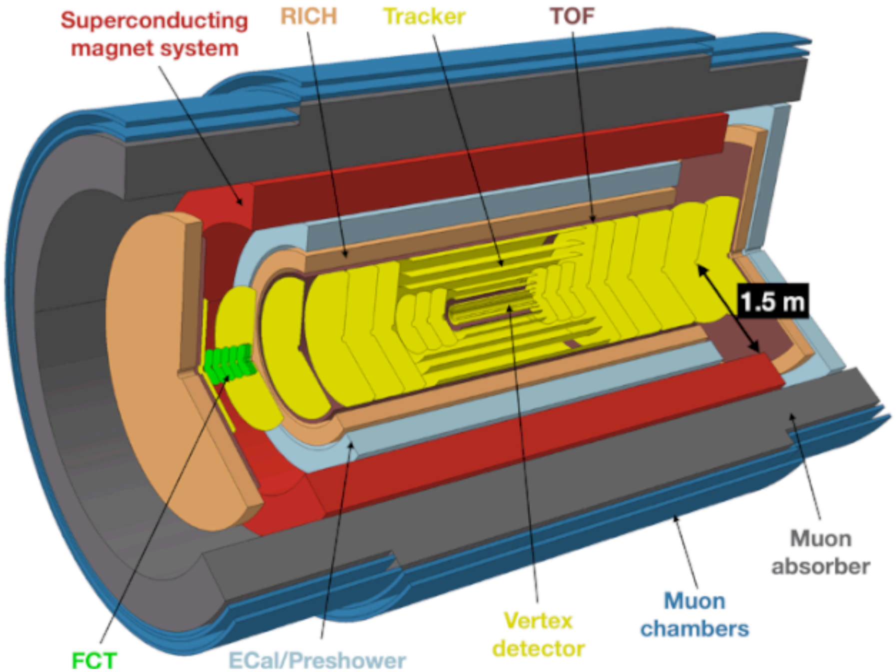
Forward Calorimeter

- high-granularity readout for direct photons at $3.2 < \eta < 5.8$
- to probe gluon density down to x ~ 5×10^{-6}

[LoI: CERN-LHCC-2019-018]

ALICE 3 in Run 5
expected > 2034–?

- ALICE 3 -- a completely new experiment, fast with precise tracking and timing.
- A large-acceptance, ultra-low material budget, all-pixel silicon tracking system



- Future HI programme at the LHC:
  - ✧ Low-mass dileptons and soft hadrons (<50 MeV)
  - ✧ Evolution of QGP and chiral symmetry restoration
  - ✧ Exotic (multi-)heavy-flavoured hadrons, hadronisation mechanisms
  - ✧ Hadron correlations and interaction potentials
  - ✧ Searches beyond-the-Standard-Model

Letter of Intent for ALICE 3 was reviewed by the LHCC in March 2022

Summary

- Run 1 and Run 2 data brought a wealth of experimental data in p-p, p-Pb and Pb-Pb collisions with ALICE at the LHC with strong indications on QGP formation in collisions of small systems (strangeness enhancement as QGP signature, flows of identified particles)
- Run 3 is ongoing, high statistics results are to come in Run 3 and Run 4
- ALICE is preparing for a major detector upgrade for future Run 5

THANK YOU FOR ATTENTION!

ALICE results at this conference "NUCLEUS–2022" :

who	talk	when
Sergey Kiselev	Hadronic resonance production with ALICE at the LHC	2023,
Alexander Borissov	Σ hyperons production in pp and p-Pb collisions at LHC with ALICE	
Vladislav Kuskov	Recent neutral meson and direct photon measurements with ALICE	

Back-up slides