Exploring the higher mass exotic resonances in pp collisions at LHC with ALICE

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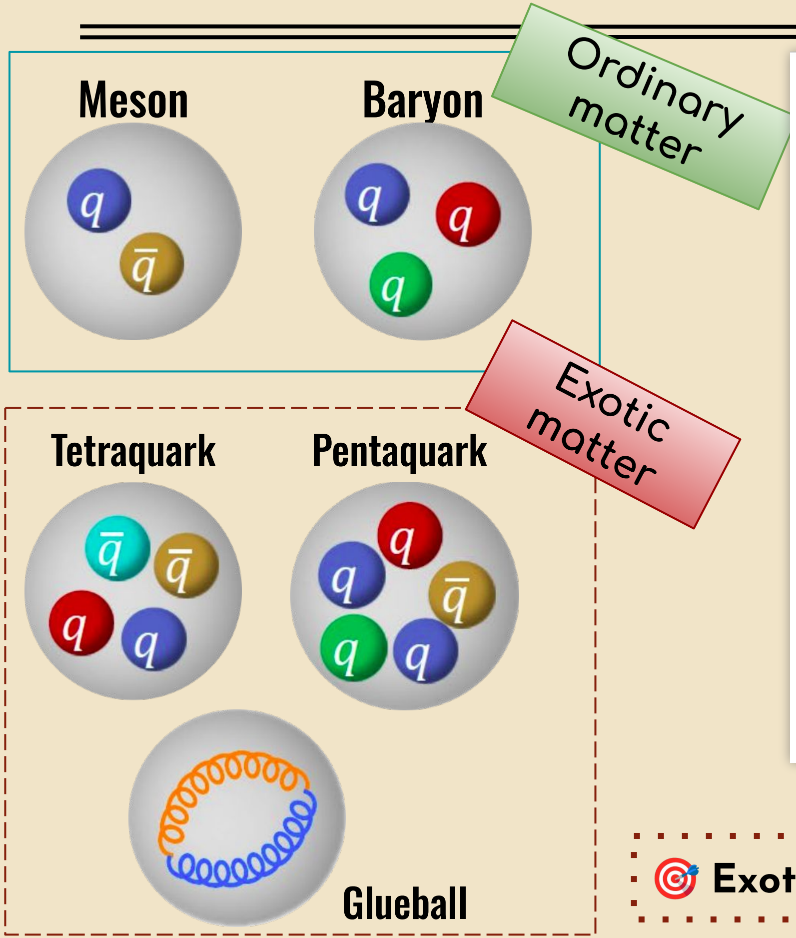
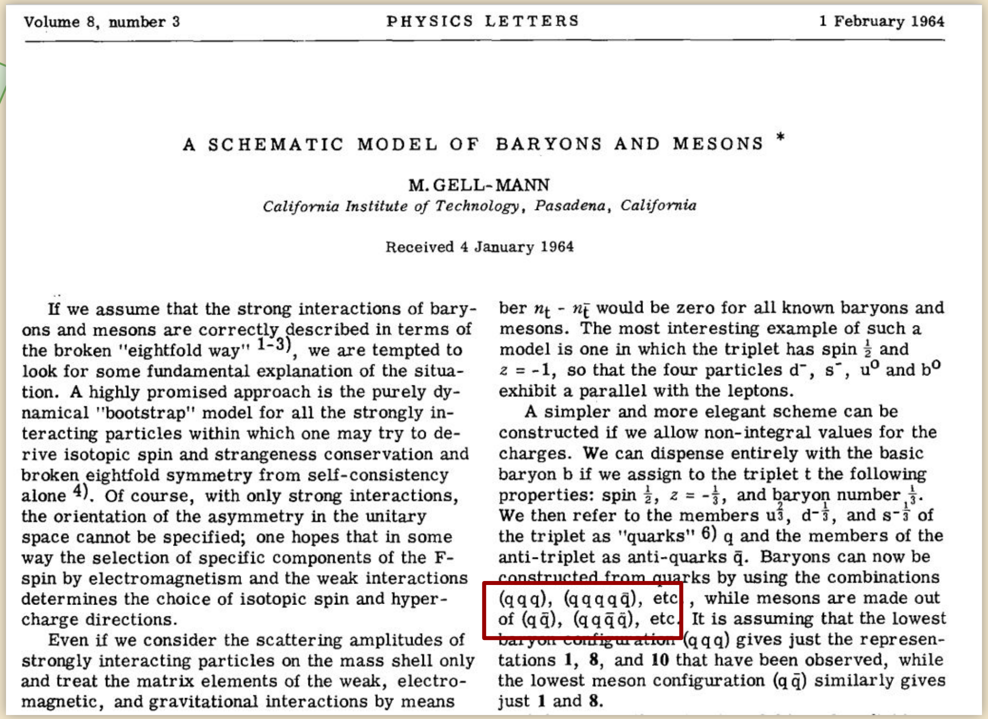
Outline

- ✔ Introduction
- ✔ Resonances
- ✔ ALICE detector
- ✔ Analysis details
- ✔ Results
- ✔ Summary

Introduction





Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" 1-3), we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone 4). Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

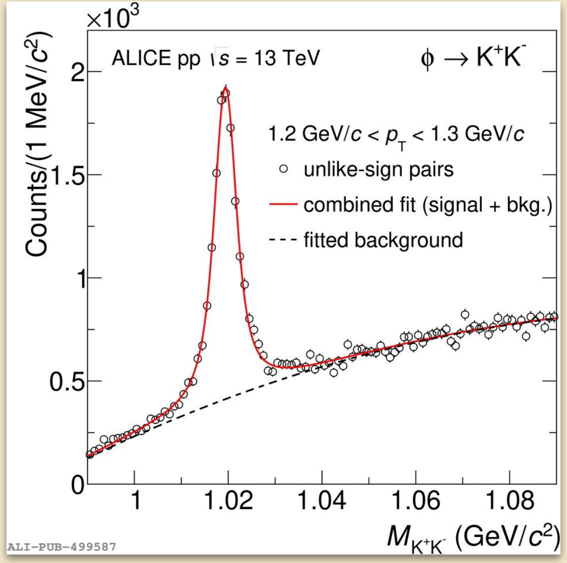
A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\,\bar{q})$ similarly gives just **1** and **8**.

M.Gell-Mann, Phys.Lett. 8 (1964) 214-215

🎯 **Exotic hadrons study -> Test and validate QCD predictions**

Resonances

- ✓ Short lived particles that decay via strong interaction
- ✓ In experiment, reconstructed via invariant mass method $M_{\text{inv}} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p}_i\right)^2}$
- ✓ **Open question:** Quark content of several resonances in the mass range 1-2 GeV/c^2



Eur. Phys. J. C 81 (2021) 256

Resonance	ρ (770)	K* (892)	f_0 (980)	ϕ (1020)	f_1 (1285)	f_2 (1270)	Σ (1385)	f_2' (1525)	Λ (1520)	f_0 (1710)
Quark content	$\frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$	$d\bar{s}$	???	$s\bar{s}$	???	???	uus	???	uds	???

Resonances under study

Properties of $f_0(980)$

Mass (MeV/c^2)	990 ± 20
Width (MeV/c^2)	10 - 100
Spin	0
Charge	0
Parity	1
Decay mode	$\pi^+\pi^-$
Branching ratio	46 ± 6 %
Quark composition	???

S. Stone et. al., PRL 111, 062001 (2013)

Properties of $f_1(1285)$

Mass (MeV/c^2)	1281.5 ± 0.5
Width (MeV/c^2)	23.0 ± 1.1
Spin	1
Charge	0
Parity	1
Decay mode	$K^0_s K \pi$
Branching ratio	2.25 ± 0.1 %
Quark composition	???

(PDG) Phys. Rev. D 110, 030001 (2024)

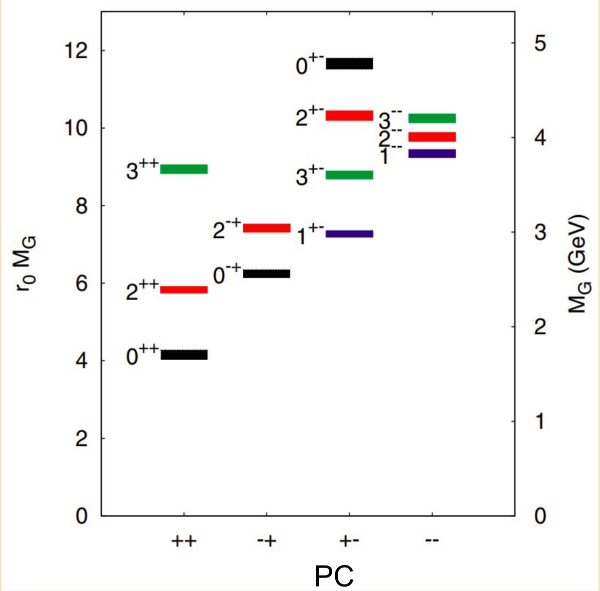
Focus of this presentation

Physics	This analysis
Quark composition	✓ Investigated via data–model comparison
Quark structure (Differentiate between Di-quark and Molecular states)	× Not possible (feasible via femtoscopic studies)

arXiv:2409.11936v1

Glueball

Lattice QCD



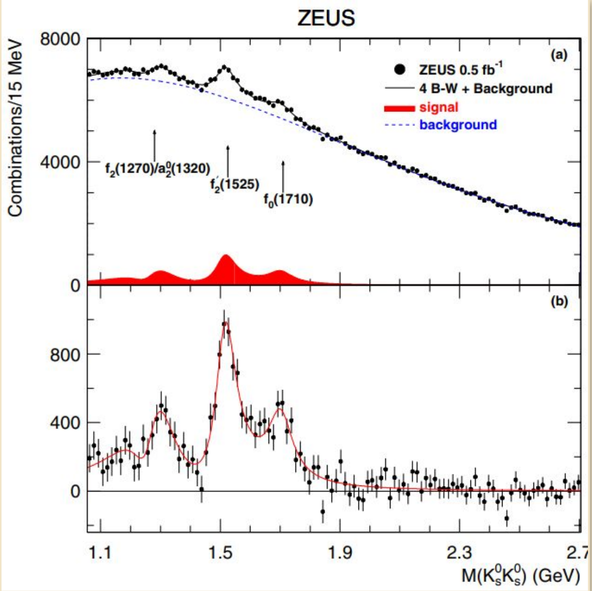
Phys. Rev. D 73, 014516 (2006)

⟹ Particles entirely composed of gluons.

⟹ Quark content, production mechanism and nature not understood yet.

⟹ Lightest scalar glueball mass range 1500 - 1700 MeV/c^2.

$K^0_s K^0_s$ invariant mass at HERA



Phys. Rev. Lett. 101, 112003 (2008)

✓ Lightest scalar glueball candidates: $f_0(1370)$, $f_0(1500)$, and $f_0(1710)$

✓ $f_0(1710)$ resonance observed in various experiments such as WA02, ZEUS, BES, etc.

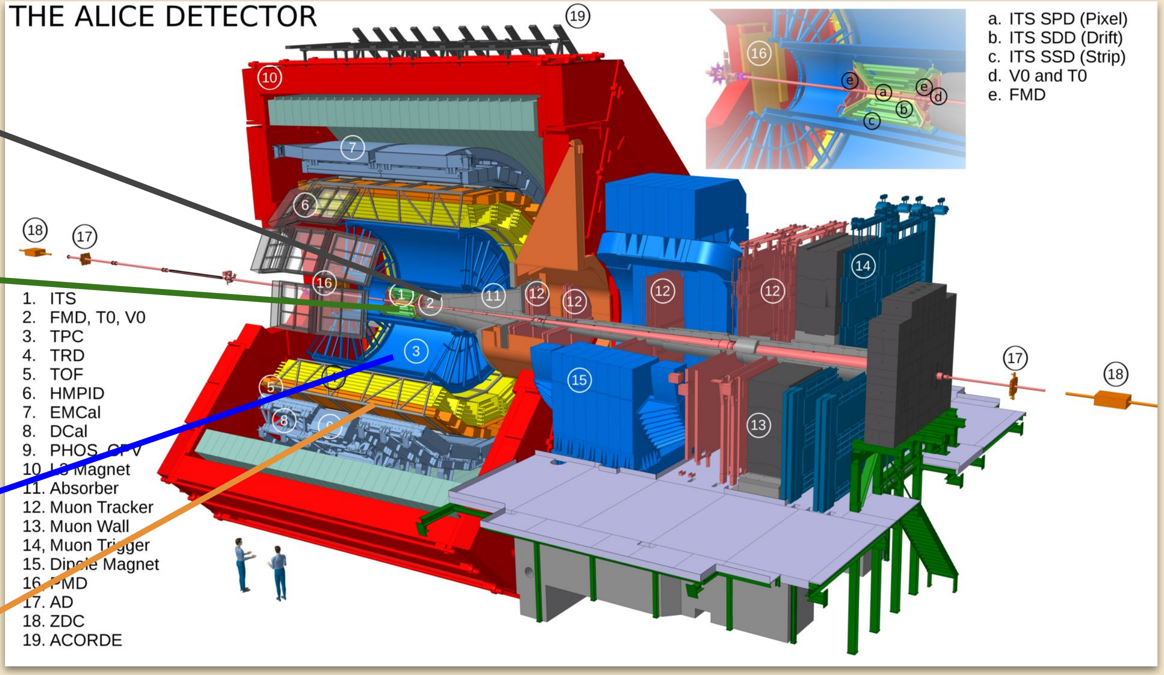
ALICE detector

✓ **V0 detectors**
- Centrality estimator
- Trigger

✓ **Inner Tracking System (ITS)**
- Tracking
- Vertexing

✓ **Time Projection Chamber (TPC)**
- Tracking and vertexing
- Momentum measurement
- Particle Identification (PID)

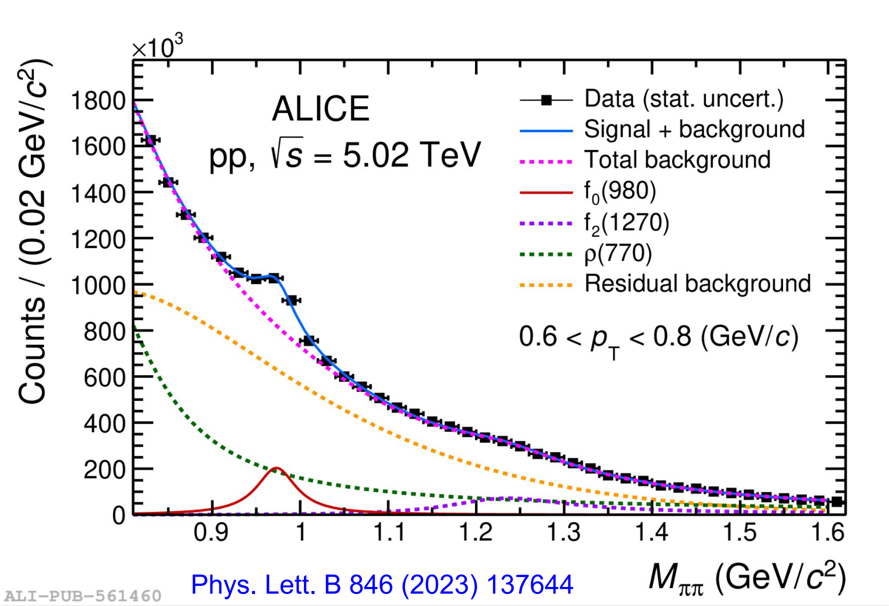
✓ **Time Of Flight (TOF)**
- Particle Identification (PID)



https://alice-figure.web.cern.ch/node/11218

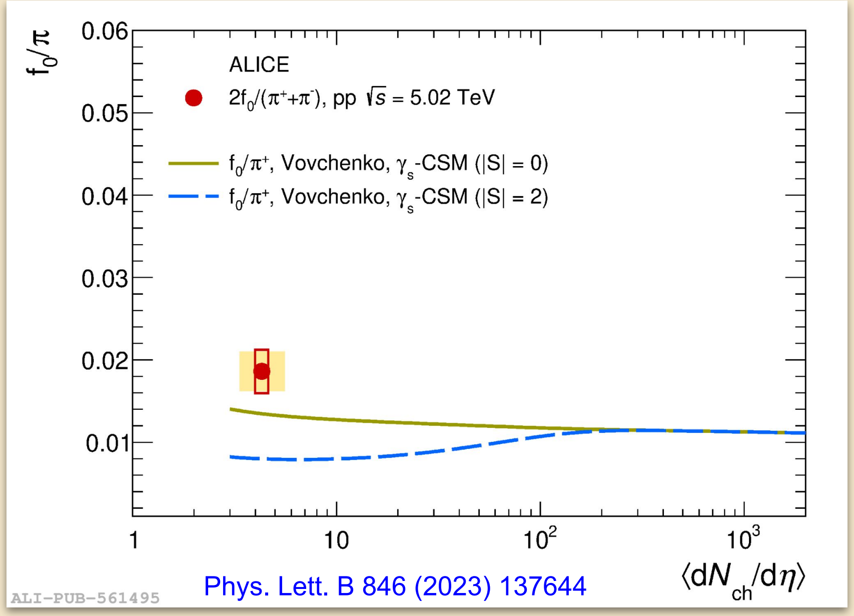
Dataset and Analysis details

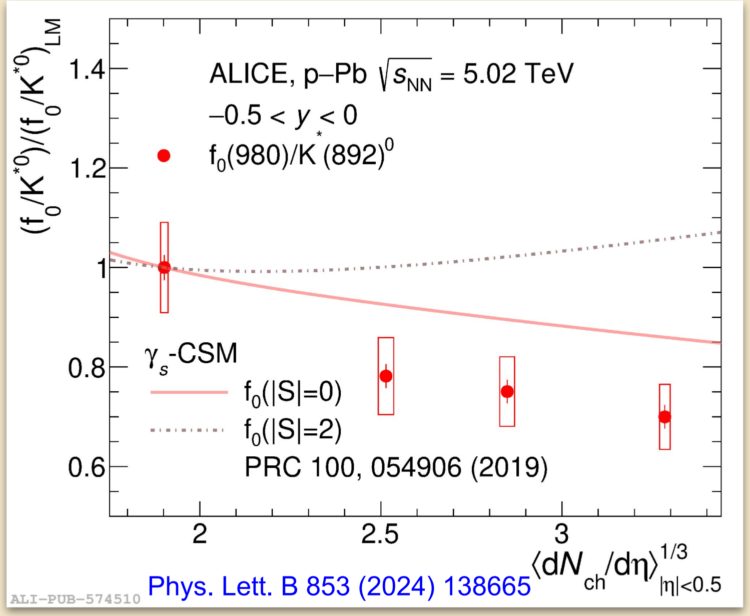
Collision system	pp and p−Pb
Center of mass energy (TeV)	13 (pp), 5.02 (pp and p−Pb)
No. of events	~10^9 (pp), 10^8 (pp and p−Pb)
Rapidity (|y|)	< 0.5
Reconstruction technique	$M_{\mathrm{inv}} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p}_i\right)^2}$
Resonances under study	$f_0(980)$, $f_1(1285)$, $f_0(1270)$, $f_2(1525)$ and $f_0(1710)$



- ✓ $f_0(980)$ observation in pp collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.
- ✓ Invariant mass reconstruction via ππ decay channel.

$f_0(980)$ measurements in ALICE





γ_s-CSM: Canonical statistical model with incomplete equilibration of strangeness

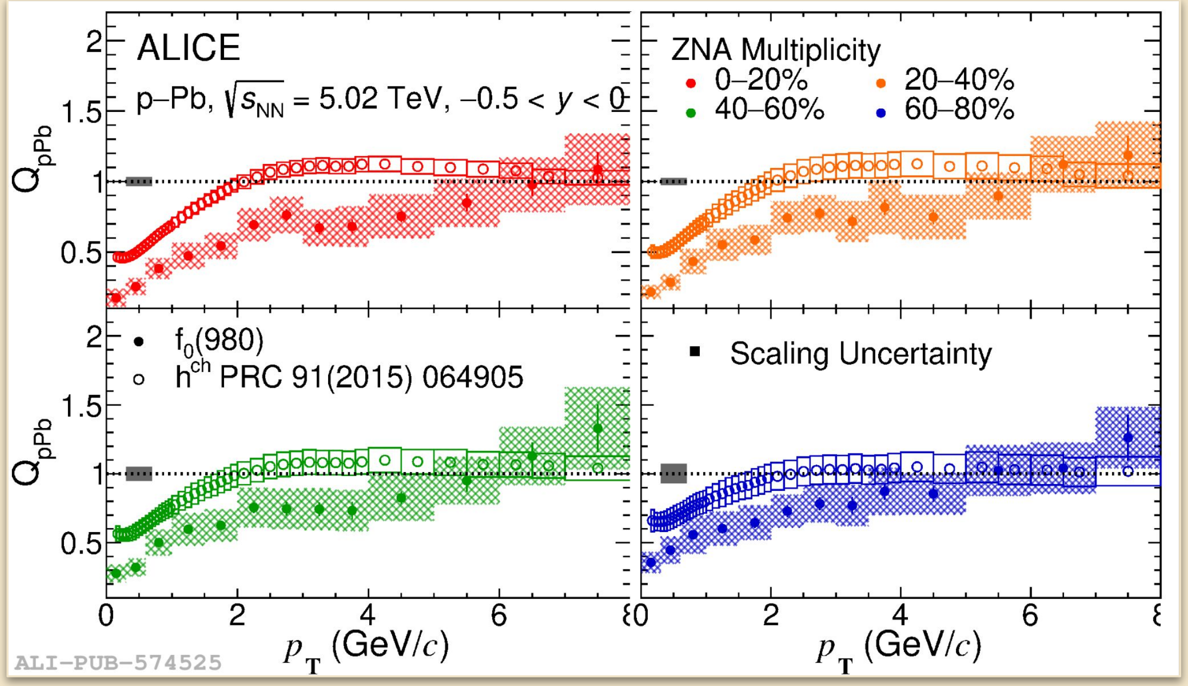
|S| = 0 -> No strange quark (1.9σ deviation)

|S| = 2 -> ss quarks (4σ deviation)

- ✓ No signs of strangeness enhancement in $f_0(980)$
- ✓ Measurements disfavours |S| = 2 quark configuration

$f_0(980)$ measurements in ALICE

Nuclear modification factor in four centrality classes



Phys. Lett. B 853 (2024) 138665

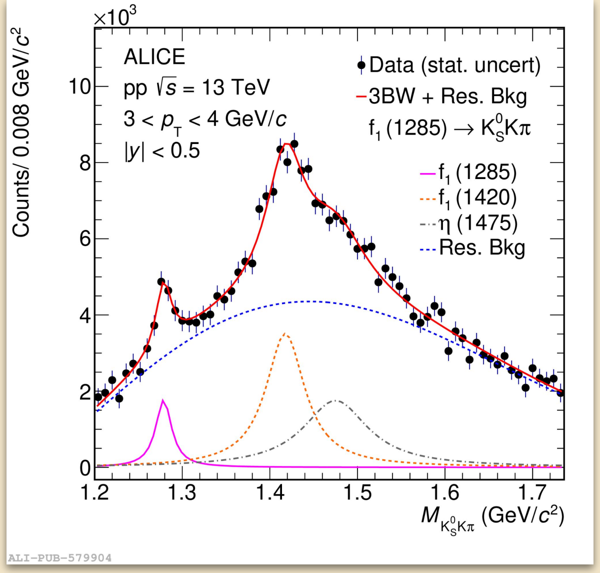
$$Q_{pPb} = \frac{d^2N^{pPb}_{f_0(980)}/dp_T dy}{\langle T_{pPb}\rangle \, d^2\sigma^{pp}_{f_0(980)}/dp_T dy}$$

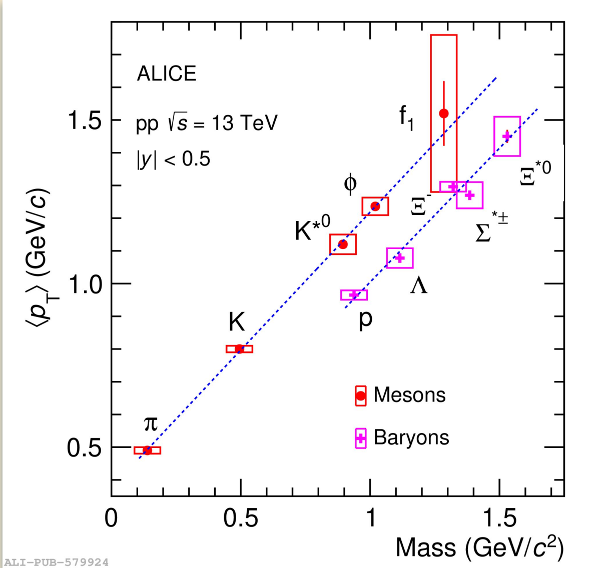
$$\langle T_{pPb}\rangle = N_{coll}/\sigma_{pPb}$$

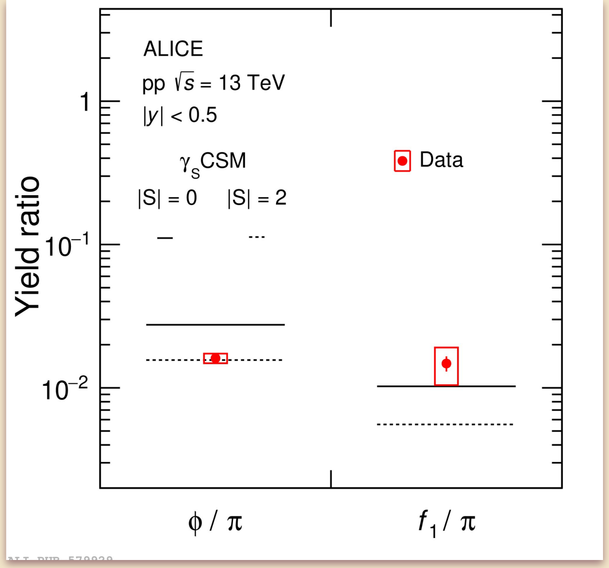
$$\sigma_{NN} = (70 \pm 5)\ \mathrm{mb}$$

- ✓ **Absence of Cronin-like enhancement at intermediate p_T**
- ✓ **Indication of a two-quark structure**

$f_1(1285)$ measurements in ALICE







arXiv:2409.11936v1

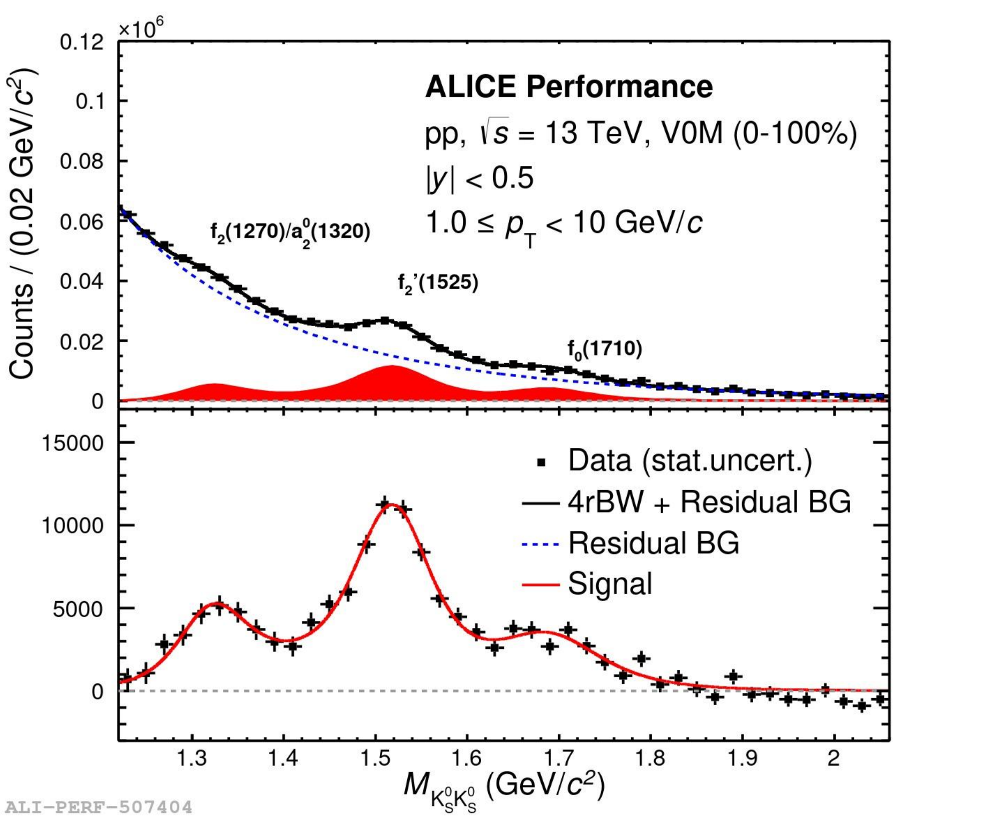
- ✓ First measurement of $f_1(1285)$ resonance in ALICE
- ✓ Resonances: $f_1(1285)$, $f_1(1420)$, and η(1475) (fit by Breit-Wigner distribution)

- ✓ Distinct linear trends for mesons and baryons
- ✓ $f_1(1285)$ aligns with mesons but overlaps baryons within 1σ

|S| = Total strange quarks

- ✓ f_1/π consistent with |S| = 0 within 1σ
- ✓ Indication of absence of strange quarks in quark composition

Glueball hunt in ALICE



Lattice QCD: Lightest scalar glueball existence in mass range 1500 - 1700 MeV/c^2

- ✓ Search for glueball candidates in $K_s^0 K_s^0$ decay channel
- ✓ Three resonance peaks identified
- ✓ Distribution modelled via relativistic Breit-Wigner (signal) + Maxwell-Boltzmann distribution (background)

f_0(1710): Possible candidate for lightest scalar glueball

Summary and Outlook

Summary

- ✓ Production measurement of $f_0(980)$ and $f_1(1285)$ in inelastic pp collisions in ALICE.
- ✓ Experimental data compared with Canonical Statistical Model calculations rules out strange quark content in the $f_0(980)$ and $f_1(1285)$ resonances.
- ✓ The absence of Cronin-like enhancement in the Q_{pPb} vs. p_T plot favours the mesonic structure of $f_0(980)$.
- ✓ In the $\langle p_T \rangle$ vs. mass plot, $f_1(1285)$ aligns with the meson trend but also fits the baryon trend within 1σ.
- ✓ Hint of possible Glueball candidate $f_0(1710)$ signal in $K^0_s K^0_s$ decay channel.

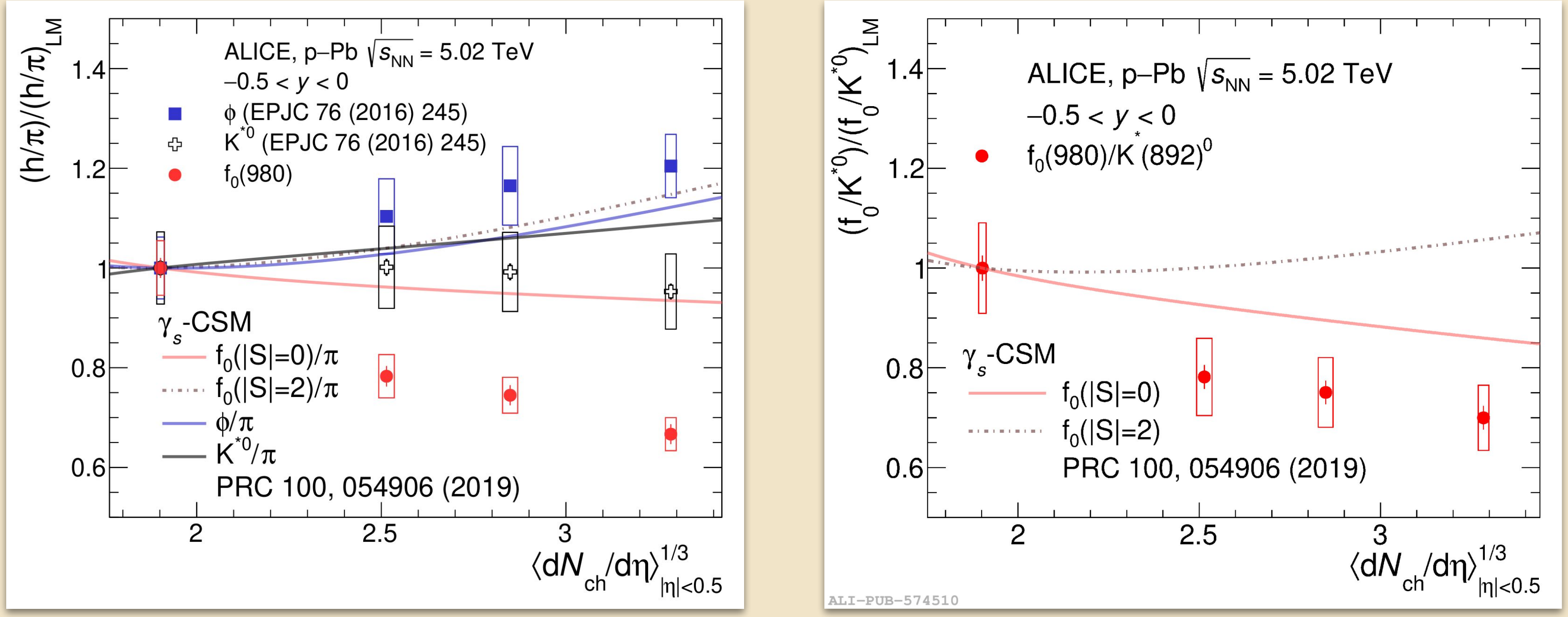
Outlook

- ✓ Higher mass resonance measurements in high statistics pp and Pb–Pb run 3 data.

Thank you for your kind attention!

BACKUP SLIDES

$f_0(980)$ measurements in ALICE



Double ratio: hadron to pion for given multiplicity to the lowest multiplicity

$K^*(892)^0$: Competing effect of strangeness enhancement and rescattering (dominant over regeneration)