Investigating the hidden strangeness content of exotic resonance with ALICE

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Outline

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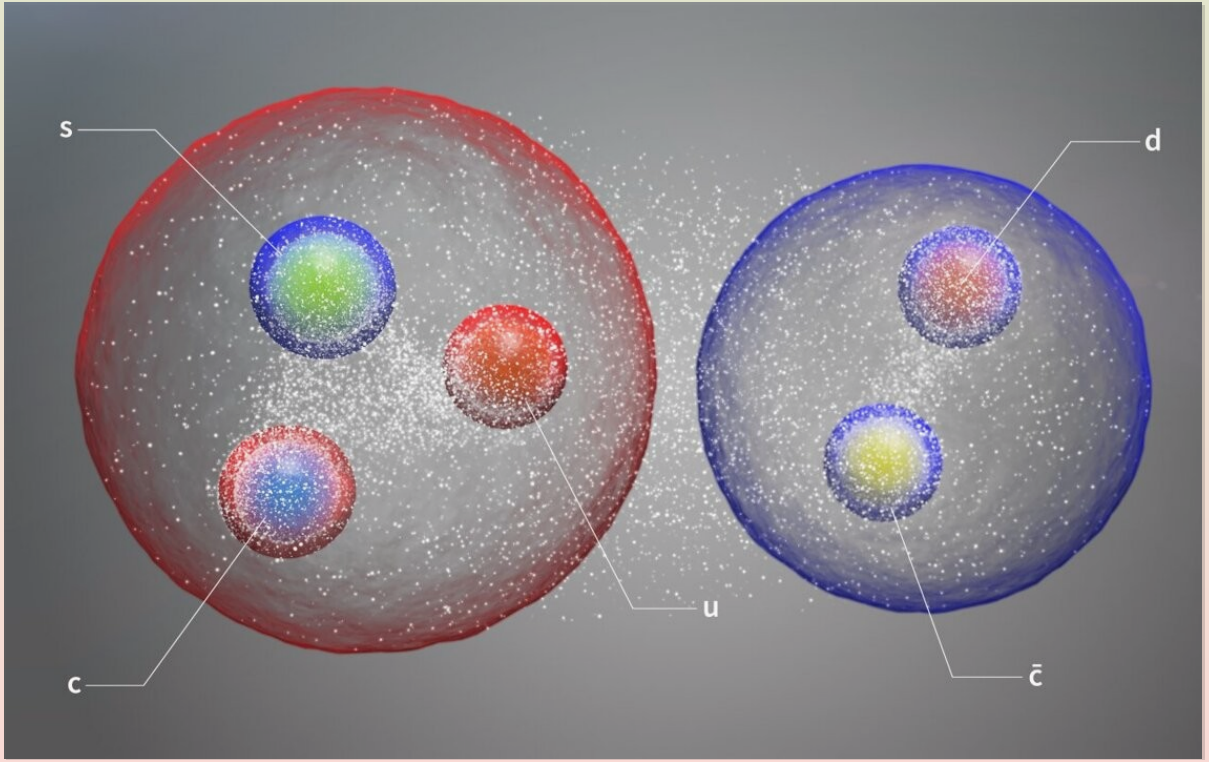
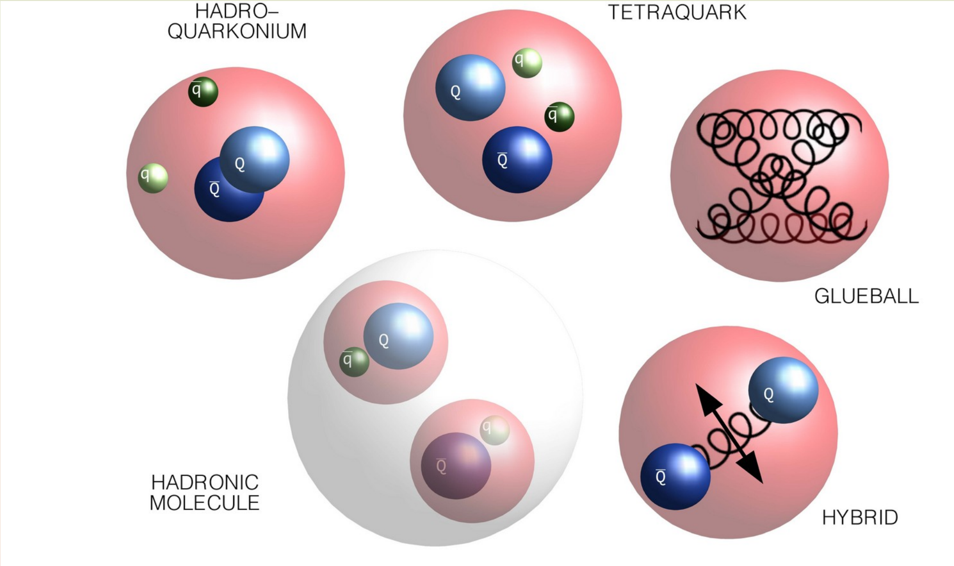
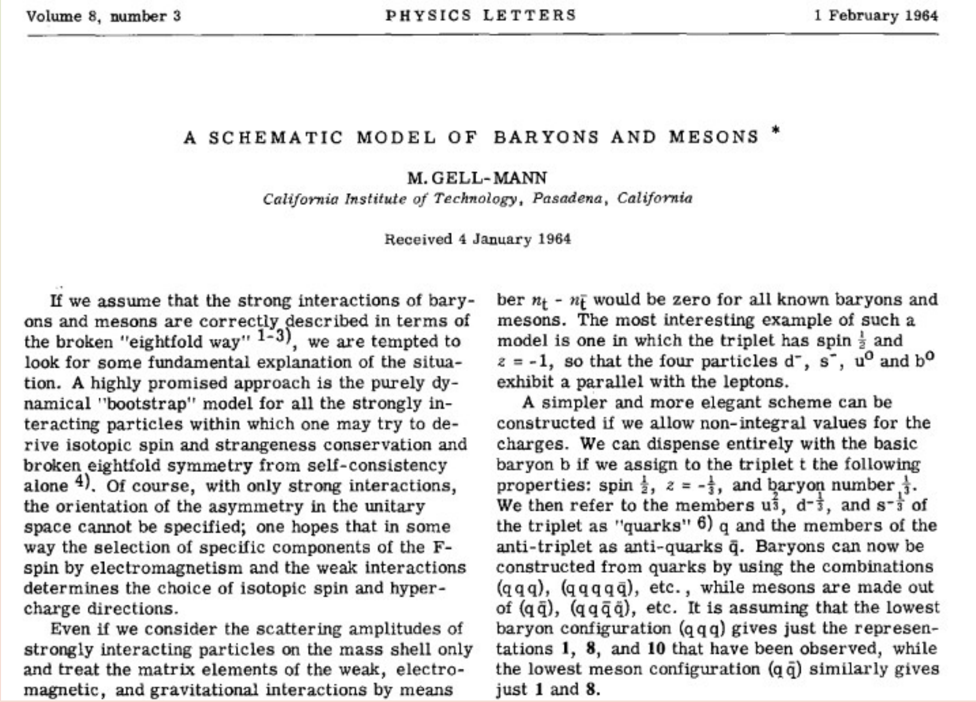


https://phys.org/news/2022-07-lhcb-exotic-particles-pentaquark-first-ever.html

Introduction



https://home.cern/news/news/physics/lhcb-discovers-three-new-exotic-particles



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 of dispersion theory, there are still meaningful and important questions regarding the algebraic properties of these interactions that have so far been discussed only by abstracting the properties from a formal field theory model based on fundamental entities 3) from which the baryons and mesons are built up.

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.

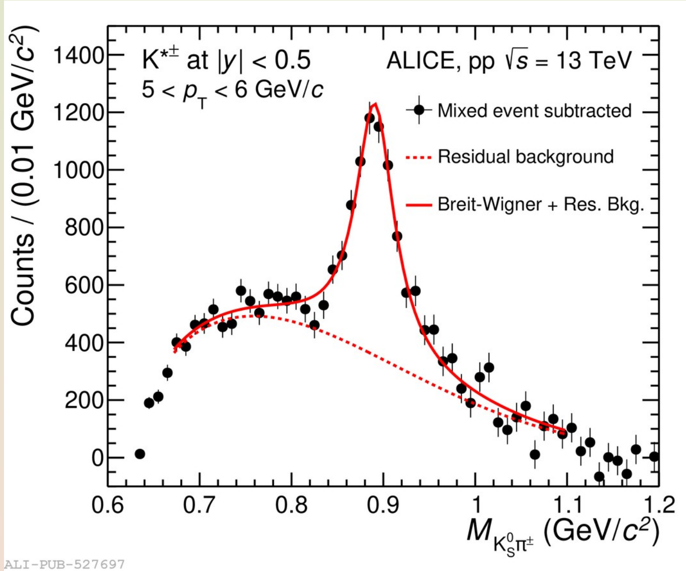
A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the 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

- ✓ *Ordinary hadrons*: Baryons and mesons
- ✓ *Exotic hadrons*: Unusual composition of quarks and anti-quarks such as tetraquarks, pentaquarks etc. → To validate and test the predictions of QCD

Resonances

- ✓ Short lived particles that decay via strong interaction
- ✓ Reconstructed using invariant mass method
- ✓ The width of the peak determines the particles' lifetime
- ✓ *Open problem*: Quark content of several resonances in the range ~1-2 GeV/c^2



Phys. Lett. B 828 (2022) 137013

	ρ (770)	K* (892)	f_0 (980)	ϕ(1020)	f_1(1285)	Σ(1385)	Λ(1520)	Ξ(1530)	f_0(1710)
Quark contents	$\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$	$d\bar{s}$	???	$s\bar{s}$	???	uus	uds	dds	???

Exotic resonance f_0 (980)

Properties of f_0 (980)

Mass (MeV/c^2)	980±20
Width (MeV/c^2)	10-100
Spin	0
Charge	0
Parity	1
Decay mode	ππ
B.R. (%)	46±6
Quark composition	???

PRL 111 (2013), 062001

Physics	Predictions	References	Current study
Quark composition	**(1) Diquark (Linear combination of u and d quarks)**	**Chuan-Hung Chen, Phys. Rev. D 67 (2003), 094011**	✓
	(2) Tetraquark (Consist of strange quarks)	**N.N. Achasov *et al.*, Phys. Rev. D 103, 014010 (2021), Eef van Beveren *et al.*, Phys.Lett.B 495 (2000) 300-302,**	✓
	(3) Molecule	Hiwa A. Ahmed and C. W. Xiao, Phys. Rev. D 101 (2020), 094034	✗

Exotic resonance f_1 (1285)

Properties of f_1 (1285)

Mass (MeV/c^2)	1285±0.5
Width (MeV/c^2)	22±1.1
Spin	1
Charge	0
Parity	1
Decay mode	$K^0_s K\pi$
B.R. (%)	2.25±0.1
Quark composition	???

Physics	Predictions	References	Current study
Quark composition	(1) Diquark (Linear combination of u and d quarks)	A.A. Osipov *et al.*, Phys.Rev.D 96 (2017), 054012	✗
	(2) Tetraquark (Consist of strange quarks)	**Y. Kanada-En'yo *et al.*, Phys.Rev.D71 (2005), 094005**	✓
	(3) Molecule	F. Aceti *et al.*, Phys.Lett. B750 (2015) 609-614	✗

Glueball search

- ✓ Particles composed entirely of gluons

Phys.Rev.Lett.101 (2008) 112003

- ✓ Lattice QCD predicts the existence of scalar glueballs in the mass range 1550-1750 MeV/c^2

Properties of f_2 (1270)

Mass (MeV/c^2)	1275±0.8
Width (MeV/c^2)	185.8±2.8
Spin	2
Charge	0
Parity	1
Decay mode	$K^0_s K^0_s$

Properties of f_2 (1525)

Mass (MeV/c^2)	1525±2.4
Width (MeV/c^2)	112
Spin	2
Charge	0
Parity	1
Decay mode	$K^0_s K^0_s$

Properties of f_0 (1710)

Mass (MeV/c^2)	1710±8
Width (MeV/c^2)	123±12
Spin	0
Charge	0
Parity	1
Decay mode	$K^0_s K^0_s$

ALICE detector

✓ <u>V0 detectors (V0A & V0C)</u>
- *Centrality estimator*
- *Trigger*

JINST 8 (2013) P10016

✓ <u>Inner Tracking System (ITS)</u>
- *Tracking*
- *Vertexing*

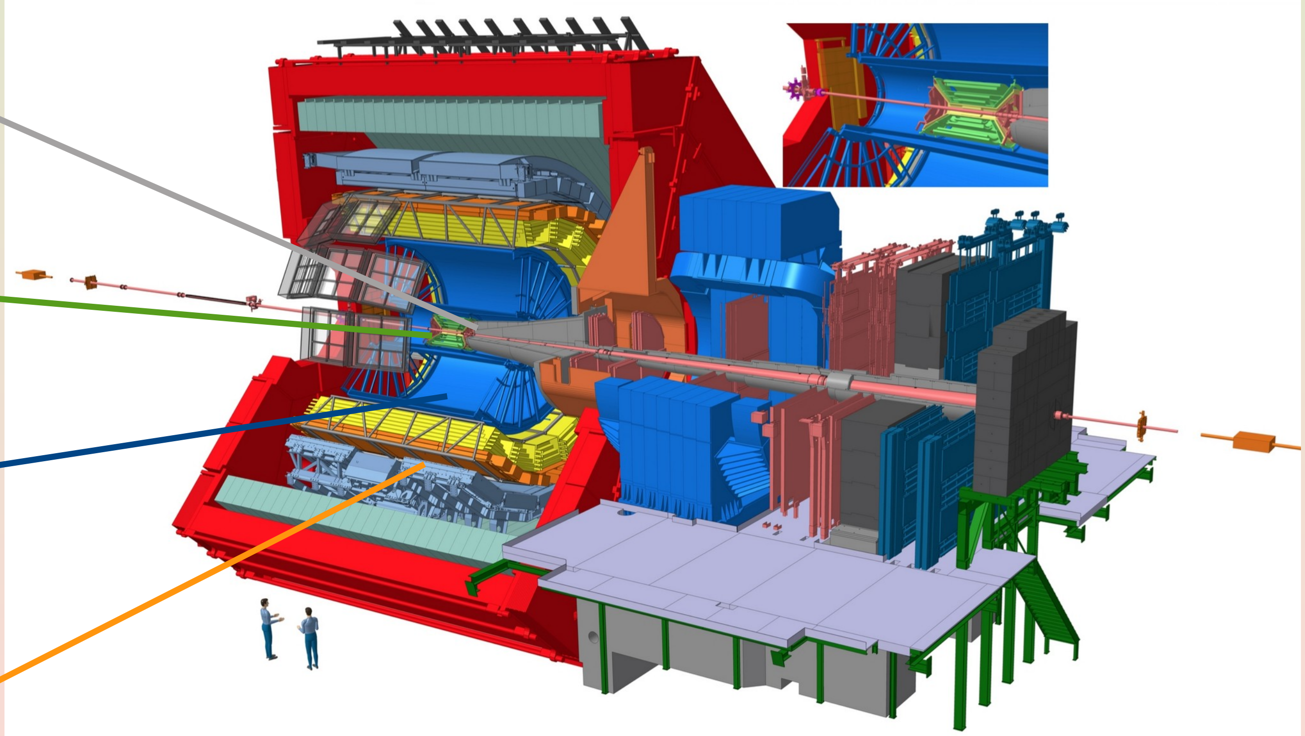
JINST 3 (2008) S08002

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

Nucl.Instrum.Meth.A 622 (2010) 316-367

✓ <u>Time Of Flight (TOF)</u>
- *Particle Identification (PID)*

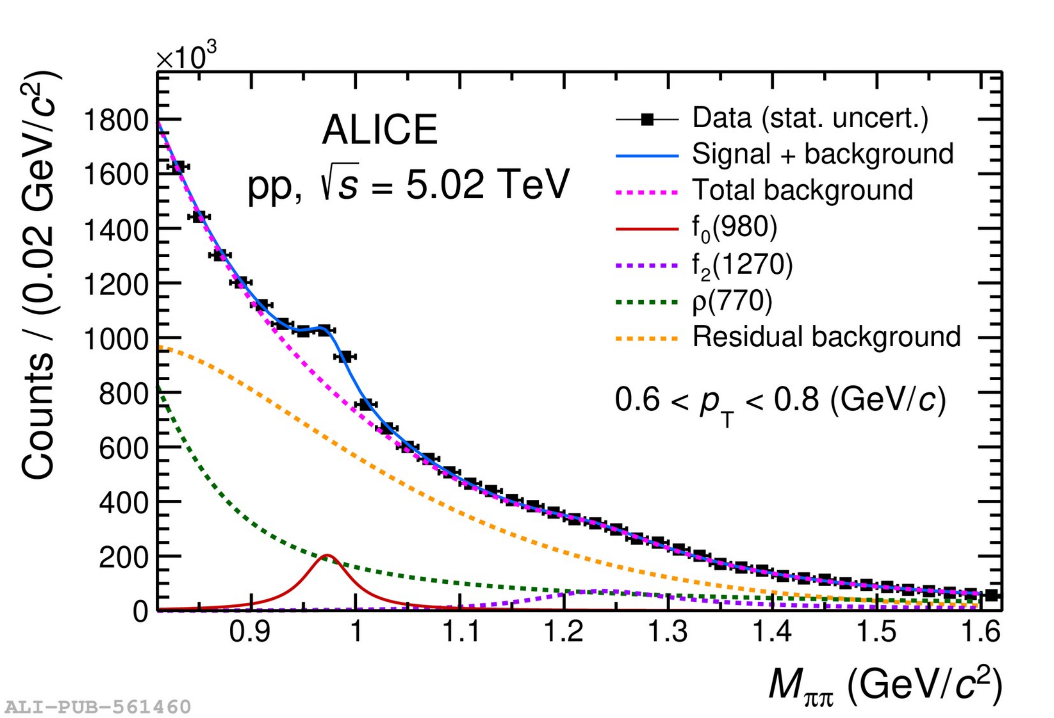
CERN-LHCC-2000-012

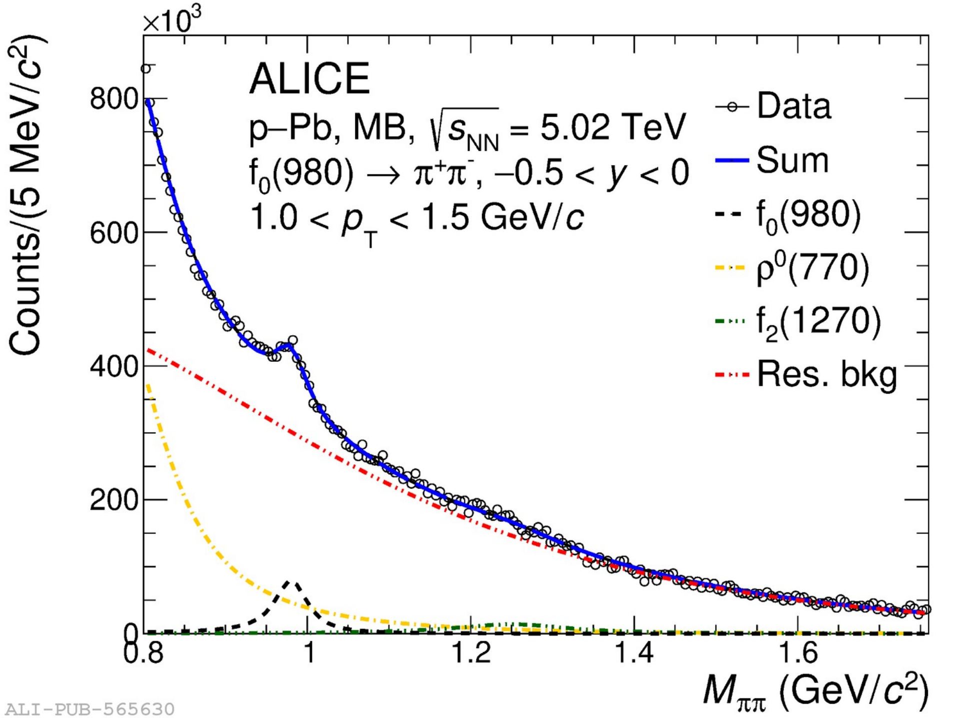


Dataset and analysis details

System	pp and p-Pb
Center of mass energy (TeV)	13 (pp), 5.02 (pp and p-Pb)
No. of events	O (~10^9), O (~10^8)
Reconstruction technique	Invariant mass method $M = \sqrt{(\sum_i E_i)^2 - (\sum_i p_i)^2}$
Rapidity (|*y*|)	< 0.5
Resonances	$f_0(980)$, $f_1(1285)$, $f_2(1270)$, $f_2(1525)$ and $f_0(1710)$

Measurement of $f_0(980)$

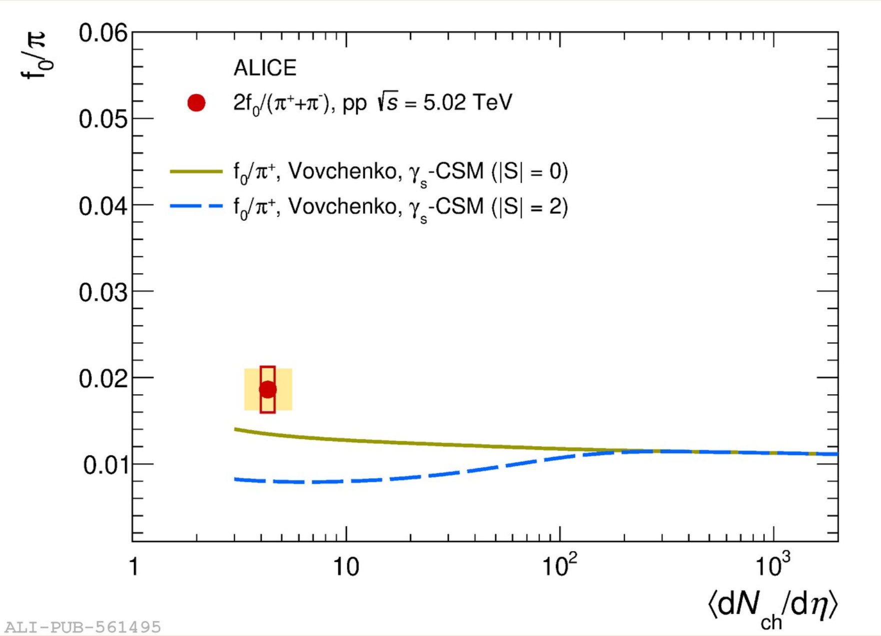


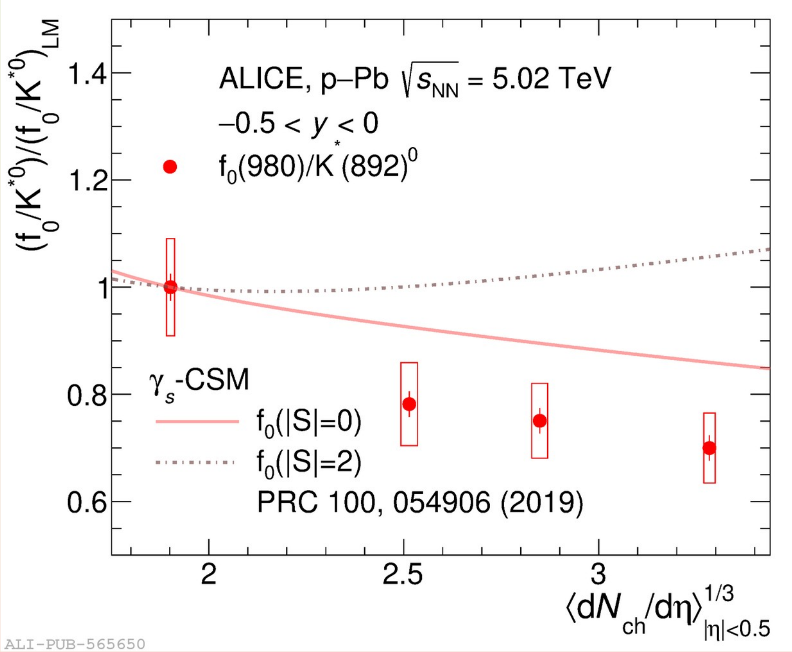


- ✓ Signal extraction carried out using invariant mass method
- ✓ A clear signal of $f_0(980)$ is observed

Phys. Lett. B 846 (2023) 137644
Phys. Lett. B 853 (2024) 138665

Quark content of $f_0(980)$



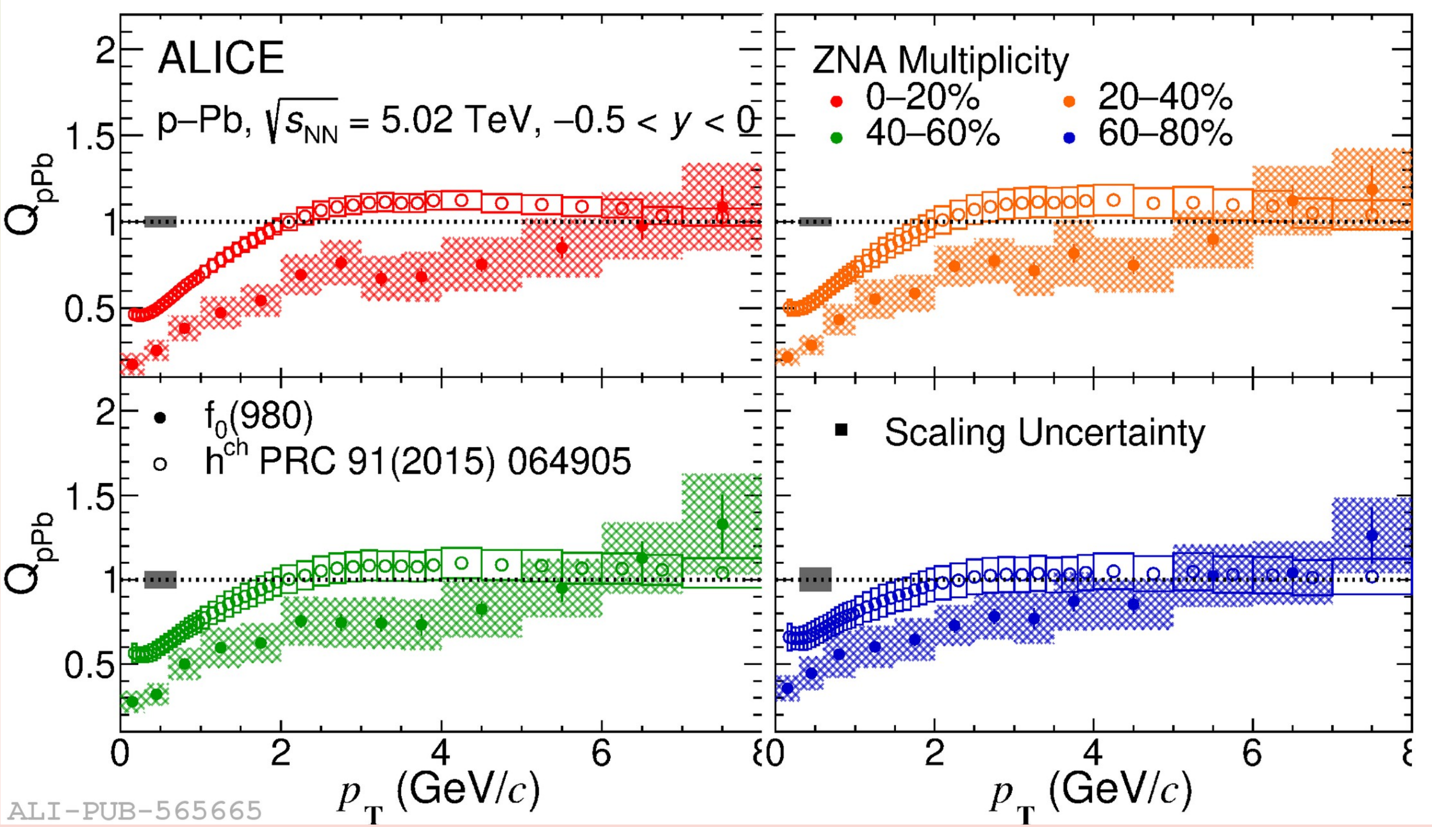


- ✓ f_0/π: Canonical statistical model underestimates the ratio
- ✓ Measurements disfavor |S| = 2 quark configuration of f_0

|S| = Total number of strange/anti-strange quarks inside the hadron

Volodymyr Vovchenko et al., Phys. Rev. C 100 (2019) 054906
Phys. Lett. B 846 (2023) 137644
Phys. Lett. B 853 (2024) 138665

Quark structure of $f_0(980)$



$$Q_{pPb}(p_T, cent) = \frac{d^2 N^{cent}_{pPb}/dydp_T}{\langle T^{cent}_{pPb} \rangle d^2 \sigma^{INEL}_{pp}/dydp_T}$$

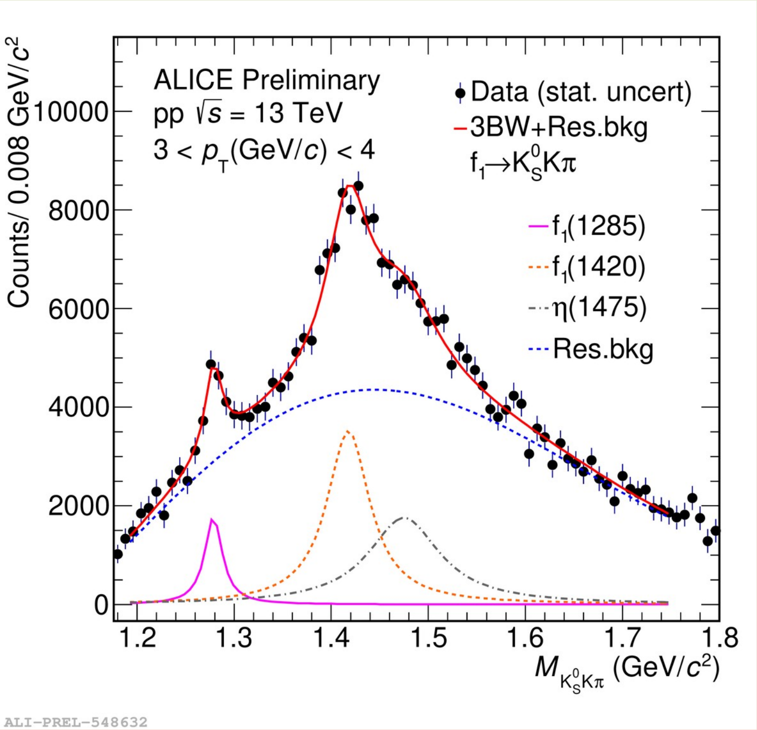
$$\langle T^{cent}_{pPb} \rangle = N^{cent}_{coll} / \sigma_{NN}$$

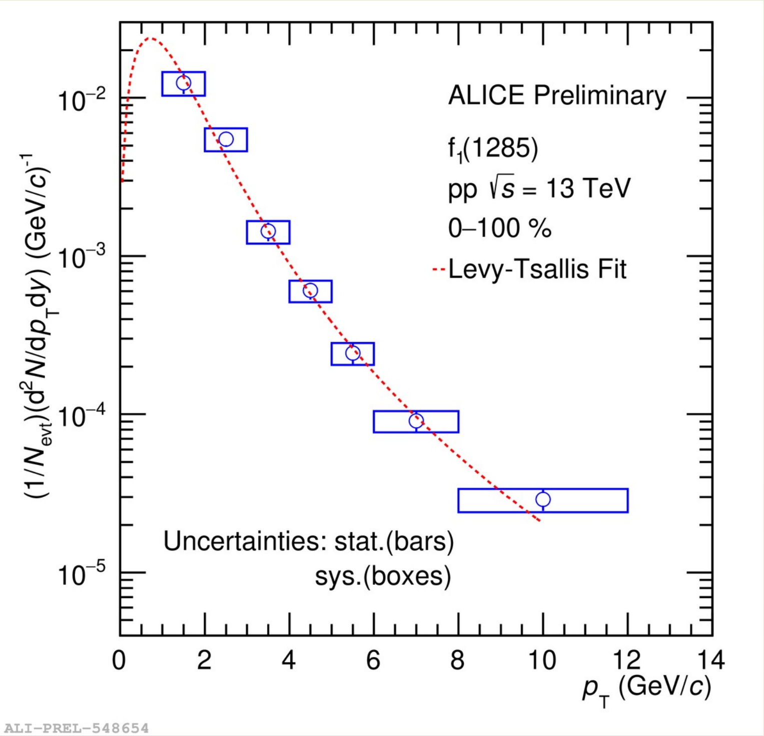
$$\sigma_{NN} = (70 \pm 5) \text{ mb}$$

- ✓ Dominance of rescattering effect at low p_T and effect of radial flow
- ✓ No Cronin enhancement is observed -> may suggest a di-quark structure

Phys. Lett. B 853 (2024) 138665

Measurement of $f_1(1285)$



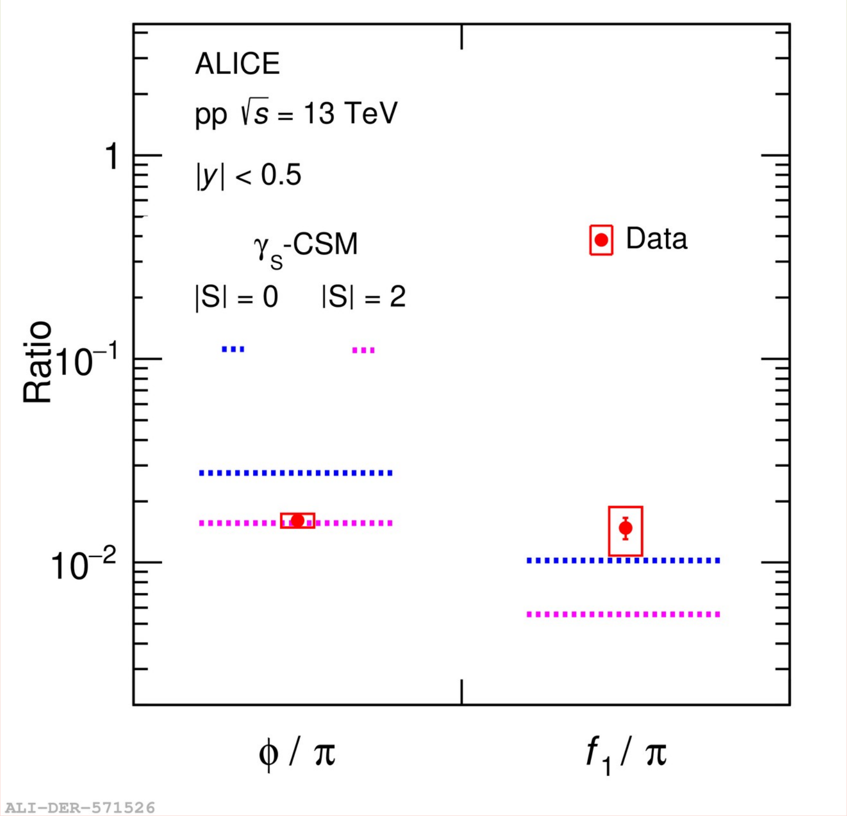


- ✓ First observation of $f_1(1285)$ in ALICE
- ✓ Invariant mass distribution modelled using 3 Breit-Wigner (*BW*) + Residual function (*Res.fun*) →

$$BW = \frac{A}{2\pi} \frac{\Gamma_0}{(M_{K^0_S K\pi} - M_0)^2 + \Gamma_0^2/4}$$

$$Res.fun = [M_{K^0_S K\pi} - (m_\pi + m_{K^0_S K})]^n \exp(A + BM_{K^0_S K\pi} + C M^2_{K^0_S K\pi})$$

Quark content and structure of $f_1(1285)$



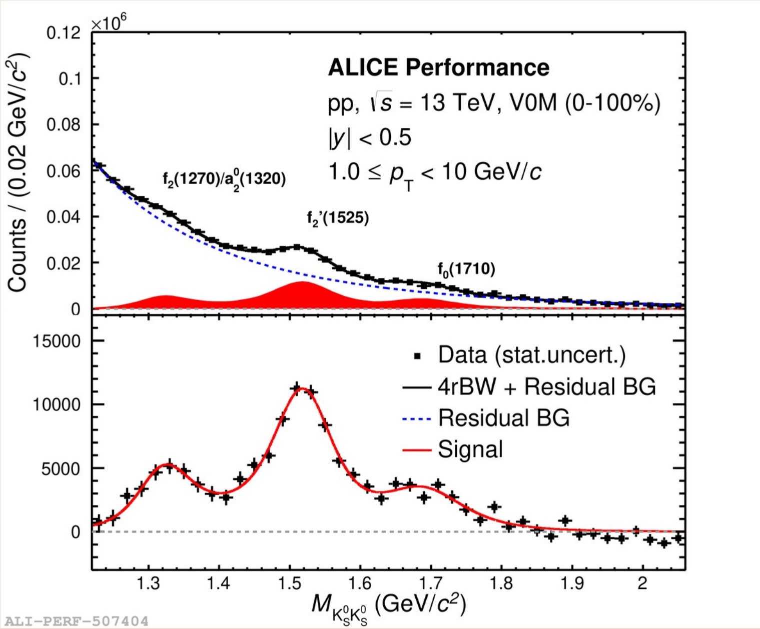
|S| = Total number of strange/anti-strange quarks inside the hadron

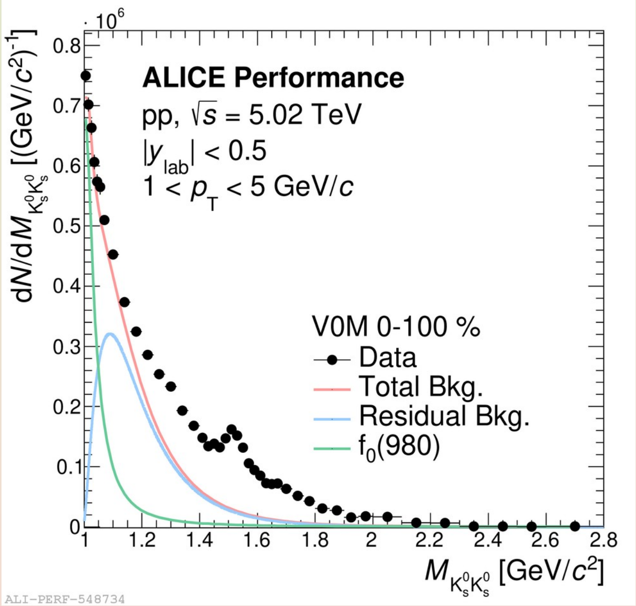
For baseline:

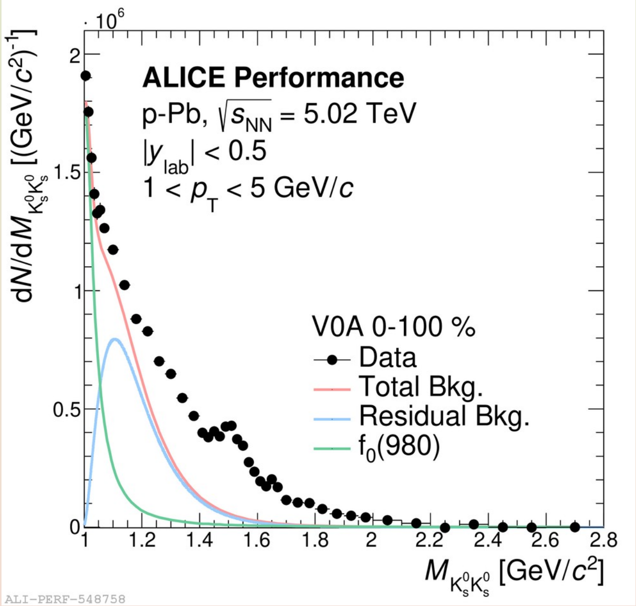
- ✓ ϕ is a double strange particle in γ_S-CSM
- ✓ ϕ/π is consistent with |S| = 2
- ✓ f_1/π is consistent with |S| = 0 within 1σ
- ✓ Disfavors tetraquark structure

Volodymyr Vovchenko et al., Phys. Rev. C 100 (2019) 054906
PRL 112 (2014), 091802

Glueball hunt







- ✓ Possible glueball candidate in $K^0_S K^0_S$ decay channel
- ✓ Invariant mass distribution modelled using Relativistic Breit-Wigner + Maxwell-Boltzmann distribution

Summary

- ✓ ALICE continues to measure a varied set of exotic resonances
- ✓ First measurement of inclusive f_0 (980) and f_1 (1285) resonances in ALICE
- ✓ Comparison of experimental data with thermal model calculations rules out the presence of strange quarks in f_0 (980) and f_1 (1285) resonances
- ✓ No Cronin like enhancement is observed for f_0 (980), indicating an ordinary meson structure
- ✓ Promising signal of scalar glueball candidate f_0 (1710) in ALICE
- ✓ More exciting results await with large statistics Run 3 data

Thank you

Backup