Hadronic resonance production with ALICE at the LHC

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- Motivation
- ALICE detector
- ALICE papers
- Recent results:

  pp @ 13 TeV f_1 (1285), $\Omega(2012)^-$, $K^*(892)^\pm$, f_0 (980)

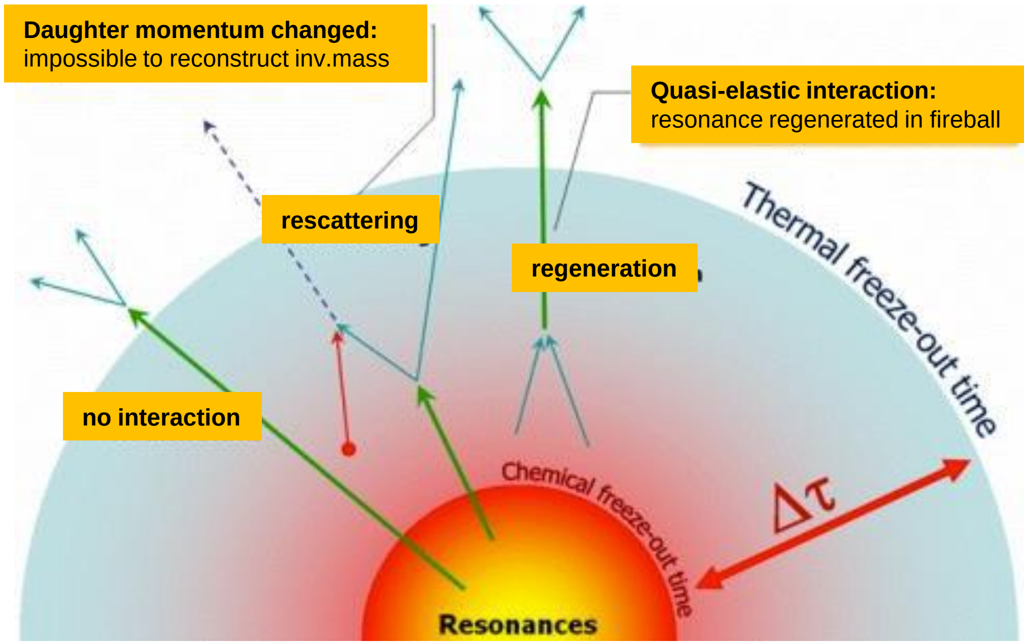
  Pb–Pb @ 13.6 TeV ϕ, K*0

  pp @ 13.6 TeV f_0 (1710)
- Summary

Motivation

- **pp and p–Pb collisions:**
  - ✓ baseline for heavy-ion collisions
  - ✓ system size dependence
  - ✓ role of cold nuclear matter
  - ✓ study of collectivity in small collision systems
- **A–A collisions**:
  - ✓ in-medium energy loss
    - → nuclear modification factor for resonances
  - ✓ restoration of chiral symmetry
    - → modification of width, mass and branching ratio
  - ✓ regeneration and rescattering effects
    - → modification of measurable yield and ratios to longer-lived hadrons
    - → timescale between chemical and kinetic freeze-out

Resonance	cτ (fm)	Decay	System @ energy (TeV)
$\rho(770)^0$	1.3	$\pi\ \pi$	pp/Pb–Pb @ 2.76
f_1 (1710)	1.4	$K_S^0\ K_S^0$	pp @ 13.6
$K^*(892)^0$	4.2	$K\ \pi$	pp/p–Pb/Pb–Pb/Xe–Xe @ all energies
$K^*(892)^{\pm}$	4.2	$K_S^0\ \pi$	pp @ 5.02/8/13 Pb–Pb @ 5.02
f_0 (980)	~ 5	$\pi\ \pi$	pp @ 5.02/13 p–Pb @ 5.02
$\Sigma(1385)^{\pm}$	5-5.5	$\Lambda\ \pi$	pp @ 7/13 p–Pb/Pb–Pb @ 5.02
$f_1(1285)$	8.7	$K_S^0\ K\ \pi$	pp @ 13
$\Lambda(1520)$	12.6	p K	pp @ 7 p–Pb @ 5.02 Pb–Pb@ 5.02
$\Xi(1530)^0$	21.7	$\Xi^-\ \pi$	pp @ 7/13 p–Pb@ 5.02
$\Omega(2012)^-$	32	$\Xi^- K^0_S$	pp @ 13
$\phi(1020)$	46.4	K K	pp/p–Pb/Pb–Pb/Xe–Xe @ all energies

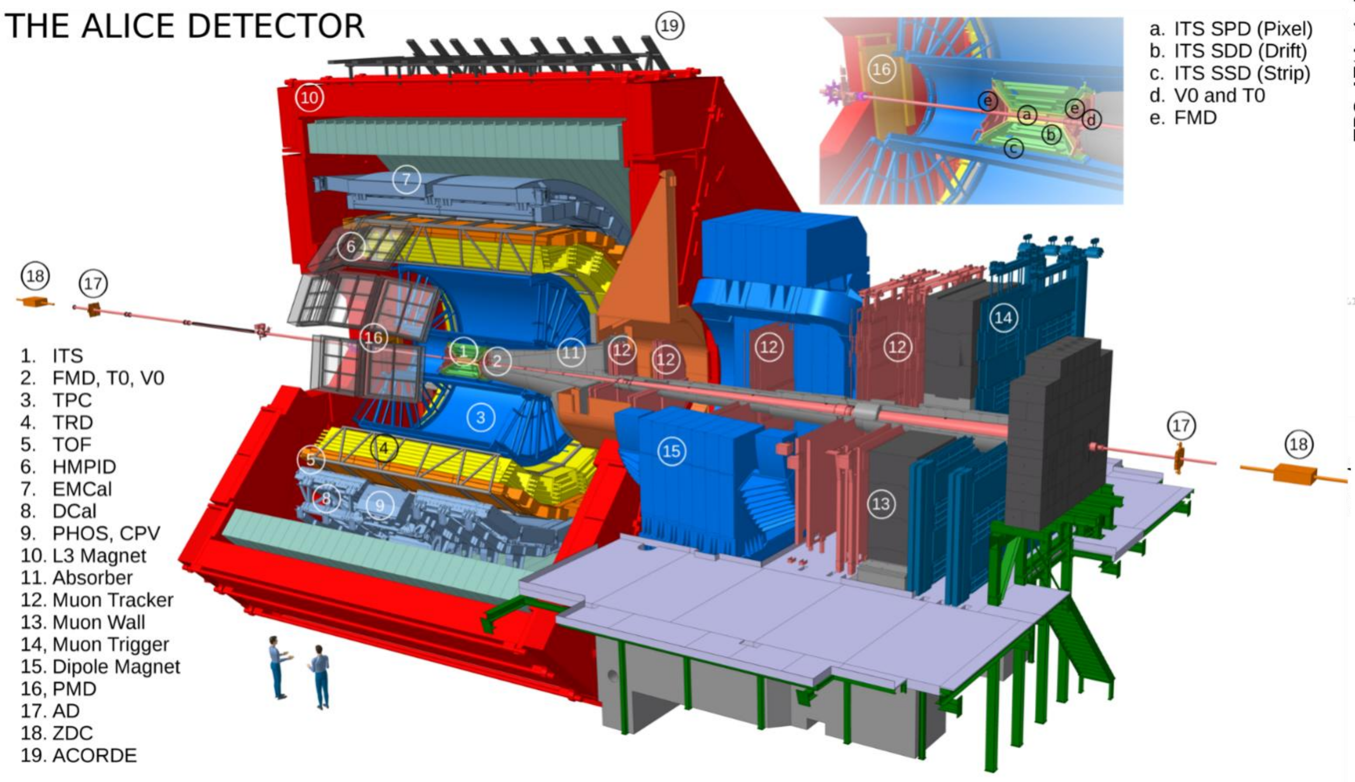


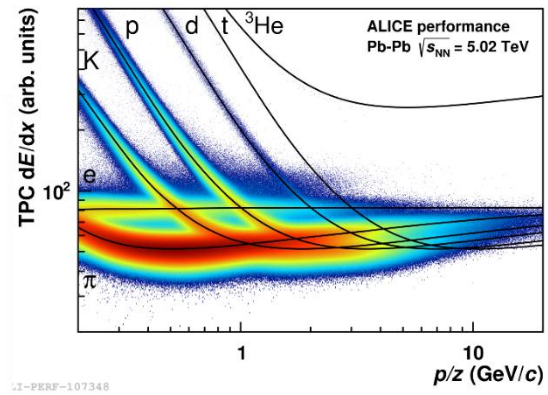
ALICE detector in Run1, 2 configuration

V0:
→ triggering minimum bias collisions
→ centrality/multiplicity estimator

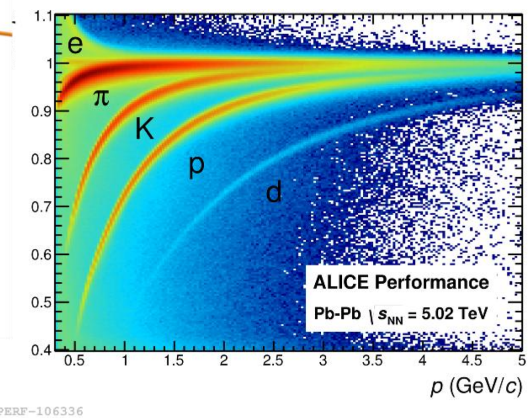
ITS: tracking and vertexing

TPC: tracking and PID through d*E*/dx





TOF: PID through particle time of flight



ALICE papers

recent papers

1. PLB866(2025)139562
Measurement of $f_1(1285)$ production in pp collisions at √s= 13 TeV
2. arXiv:2502.18063 (→ PRD)
Observation of the Ω(2012) baryon at the LHC
3. arXiv:2507.19332 (→ PLB)
Multiplicity dependence of $K^*(892)^{\pm}$ production in pp collisions at $\sqrt{s}$ = 13 TeV
4. arXiv:2507.19347 (→ JHEP)
Multiplicity dependence of $f_0(980)$ production in pp collisions at $\sqrt{s}$ = 13 TeV

previous papers

$K^*(892)^0$, φ(1020)

EPJC72(2012)2183
PRC91(2015)024609
EPJC76(2016)245
PRC95(2017)064606
PRC99(2019)024906
PLB802(2020)135225
PLB807(2020)135501
PRC102(2020)024912
EPJC81(2021)256
EPJC81(2021)584
PRC106(2022)034907
PRC107(2023)055201
EPJC83(2023)540
PRC109(2024)014911

$\Sigma(1385)^{\pm}$, $\Xi(1530)^0$

EPJC75(2015)1
EPJC77(2017)389
EPJC83(2023)351
JHEP5(2024)317

Λ(1520)

PRC99(2019)024905
EPJC80(2020)160

$\rho(770)^0$

PRC99(2019)064901

$K^*(892)^{\pm}$

PLB828(2022)137013
PRC109(2024)044902

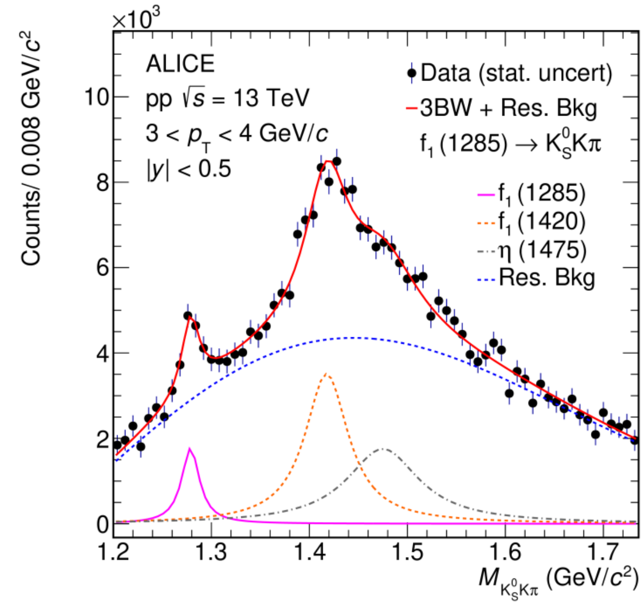
$f_0(980)$

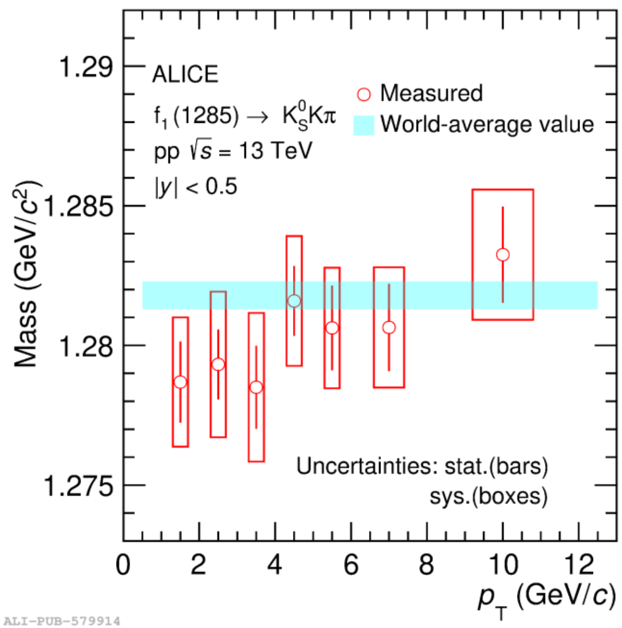
PLB846(2023)137644
PLB853(2024)138665

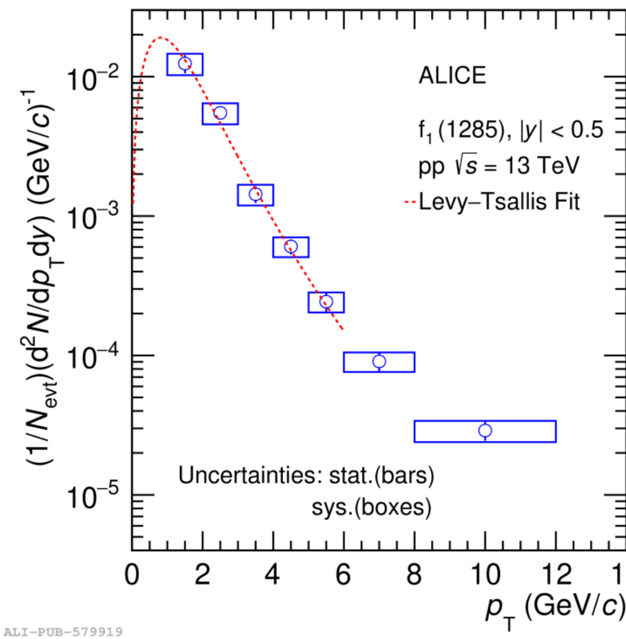
$f_1(1285)$ in pp at 13 TeV

PLB866(2025)139562

quark structure of $f_1(1285)$ is still unknown
possible configurations: u and d; u, d and s; tetraquark; hadronic molecules
10^9 minimum-bias pp events at 13 TeV
$f_1(1285) \to K^0_S K^{\pm}\pi^{\mp}$ (BR=2.25%)
$\tau = 8.7$ fm/c → regeneration and rescattering effects

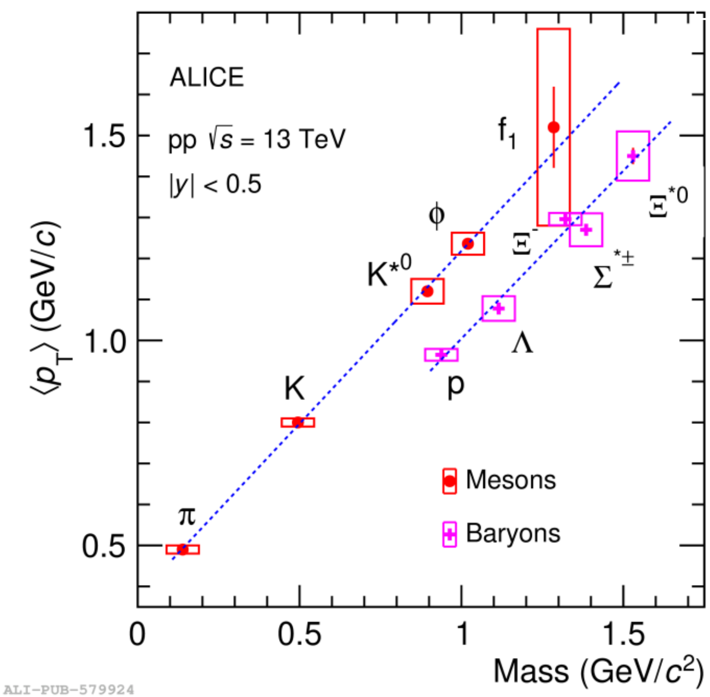


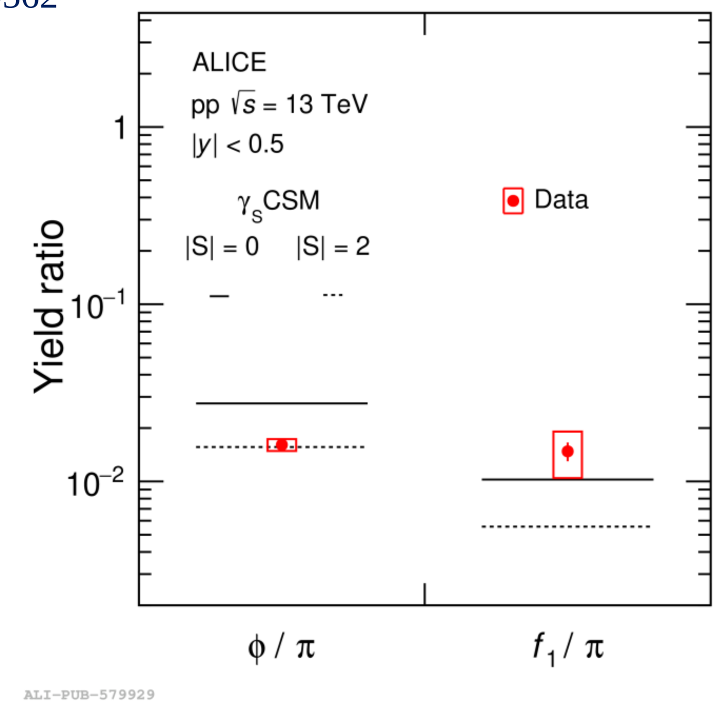




f_1(1285) in pp at 13 TeV

PLB866(2025)139562





aligns with the linear trend with mass observed for other mesons

→ f_1 may have an ordinary meson structure

γ_s-CSM (PRC100(2019)054906, no rescattering effects):

- φ/π agrees with |S|=2
- f_1/π agrees with |S|=0

→ f_1 is a conventional meson, disfavors the tetraquark hypothesis and aligns with LHCb findings (PRL112(2014)091802)

$\Omega(2012)$ in pp at 13 TeV

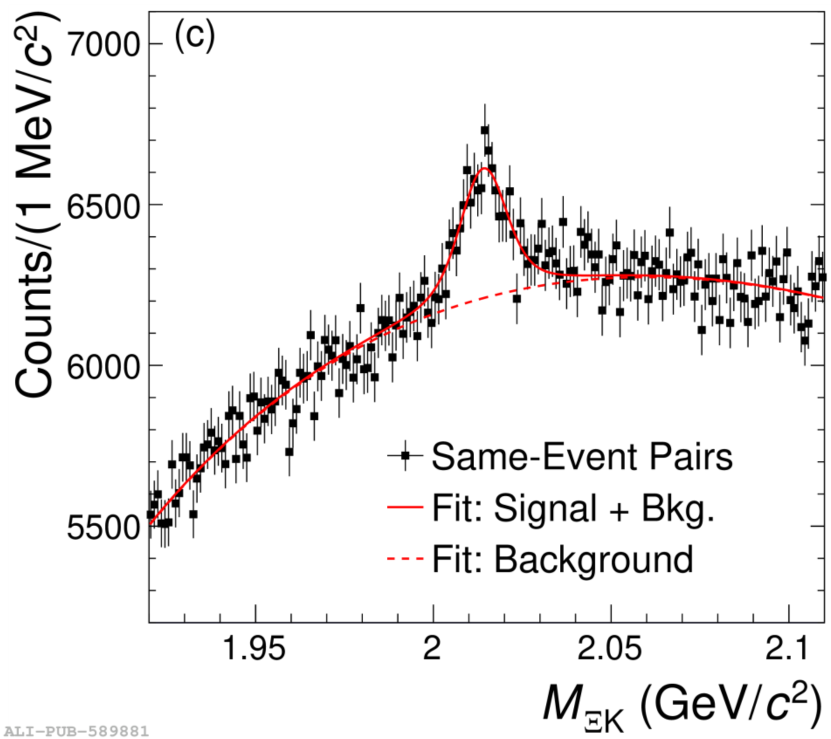
arXiv:2502.18063

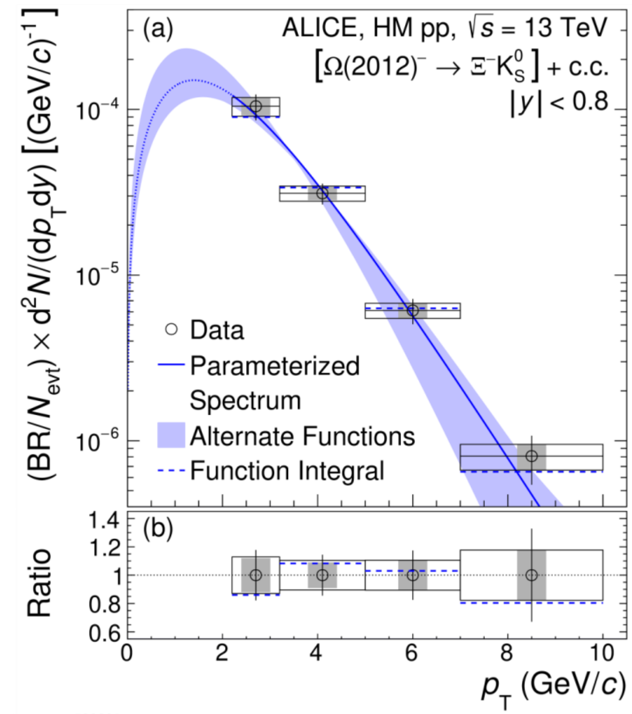
Belle : first observation of $\Omega(2012)^{-} \to \Xi^{0}K^{-}$ and $\Xi^{-}K^{0}_{S}$ (PRL121(2018)052003)

τ = 32 fm/c → regeneration and rescattering effects ?

ALICE: 10^{9} HM-triggered pp events at 13 TeV, $dN_{ch}/d\eta(y=0)$ =31.5 (0-0.01% of c.s.)

~7200 $\Omega(2012)^{-} \to \Xi^{-}K^{0}_{S}$

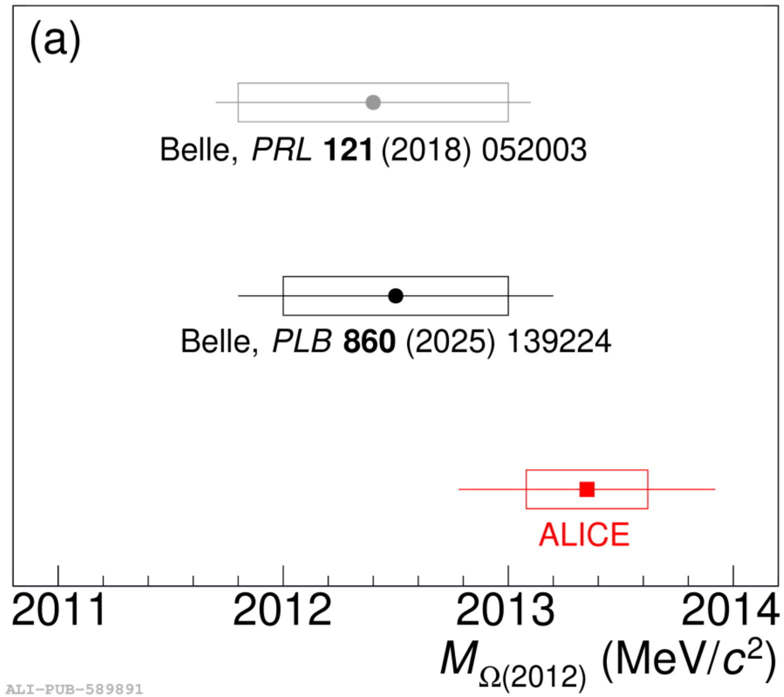


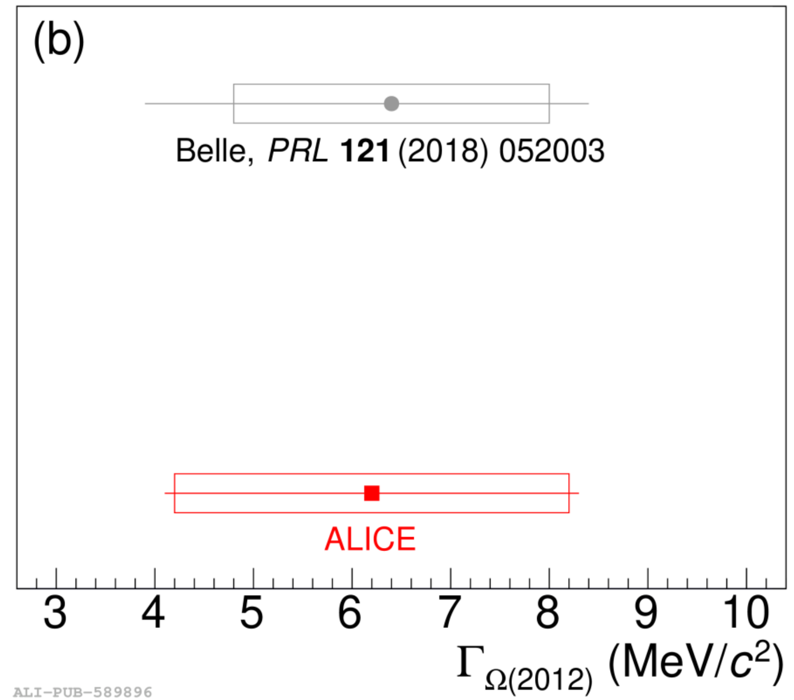


first measurement of the p_T spectrum

$\Omega(2012)$ in pp at 13 TeV

arXiv:2502.18063





consistent with the previous measurements by Belle

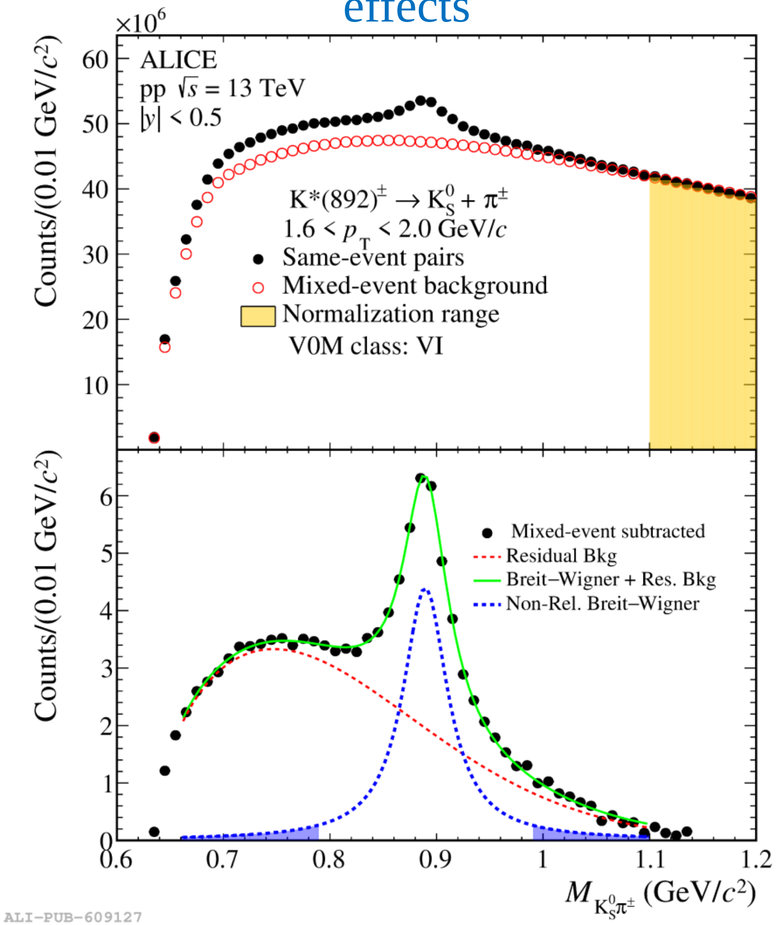
K*(892)$^{\pm}$ in pp at 13 TeV

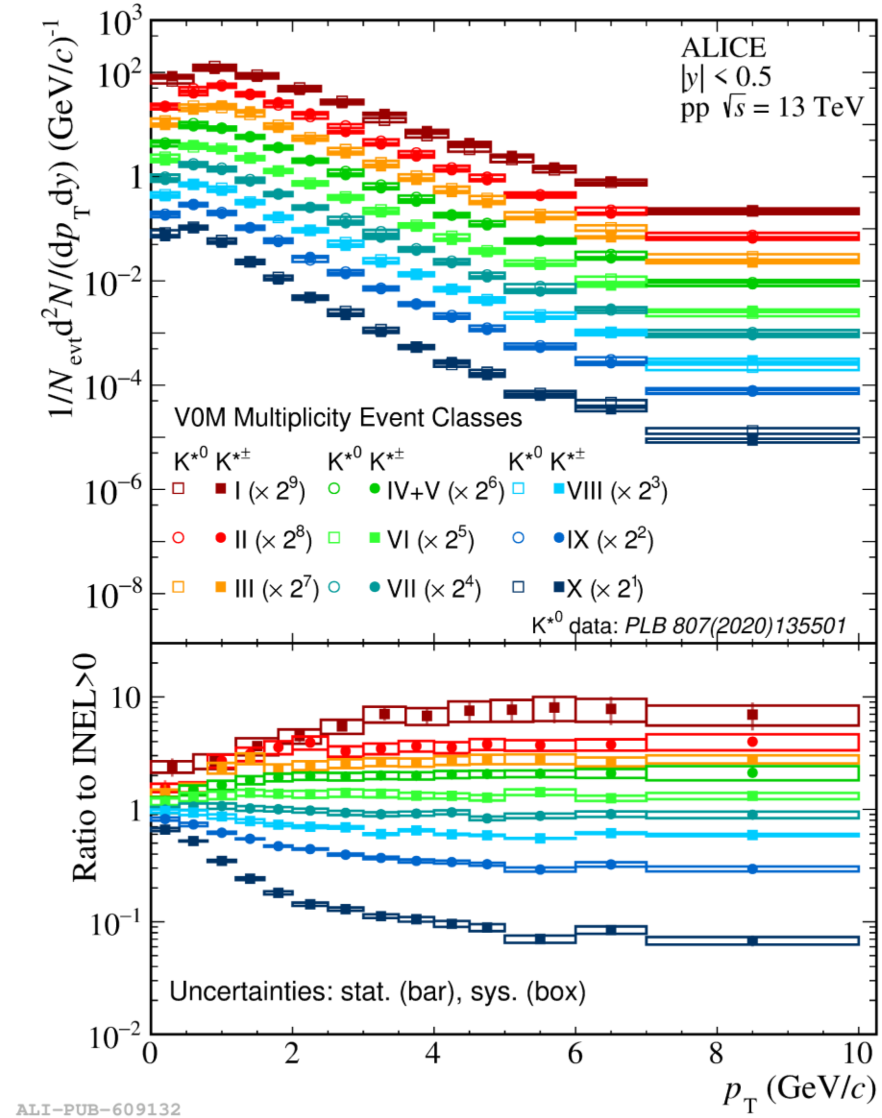
arXiv:2507.19332

1.3 10^9 minimum-bias pp events at 13 TeV

K*(892)$^{\pm}$ → K_S^0 π (BR=0.33)

τ = 4.2 fm/c → regeneration and rescattering effects





in $p_T < 4$ GeV/c spectra become harder from low to high multiplicity collisions, as for other hadron species.

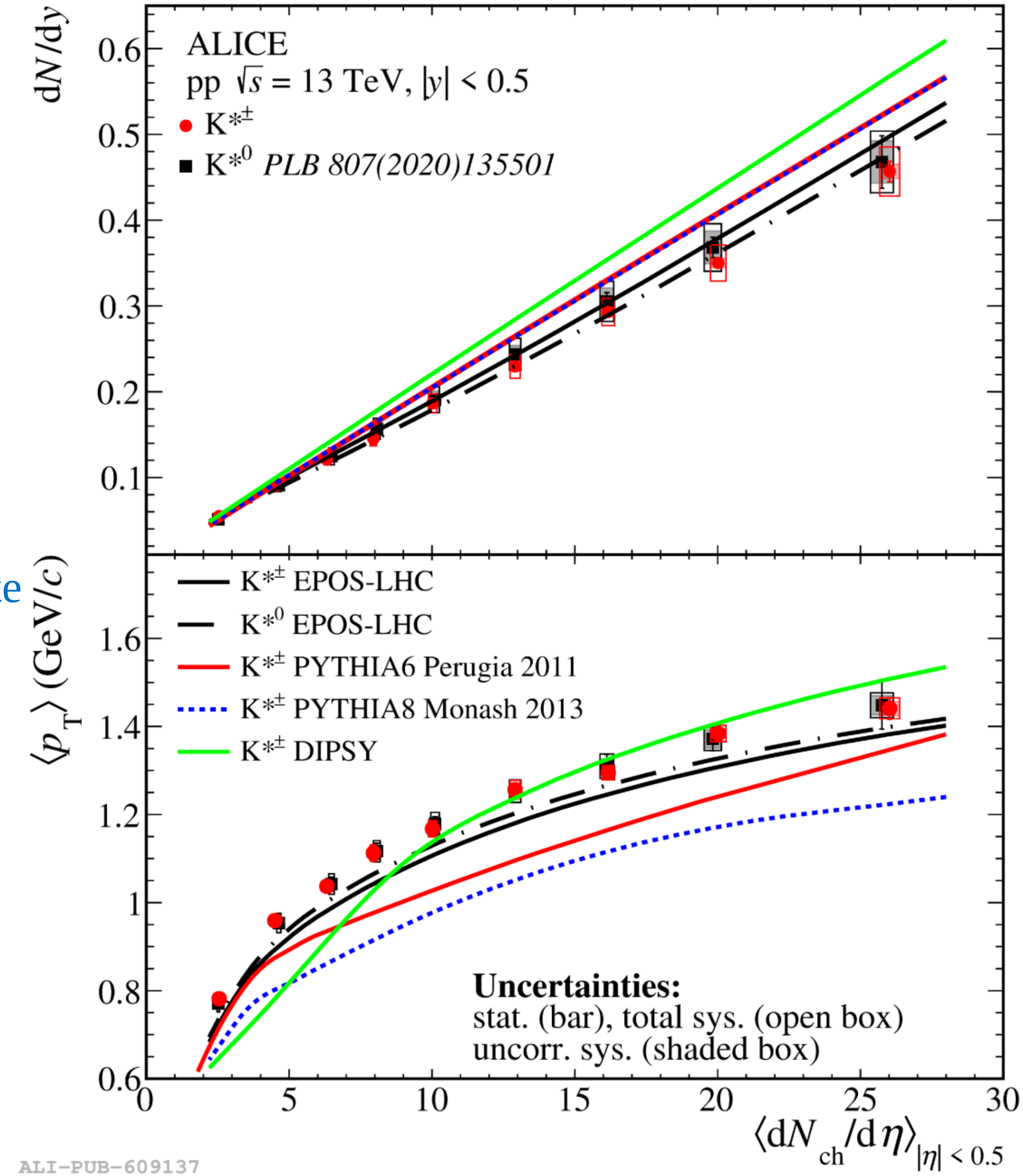
K*(892)$^{\pm}$ in pp at 13 TeV

arXiv:2507.19332

for K*(892)$^{\pm}$ and K*(892)^{0} both dN/dy and ‹ p_T › are in agreement within uncertainties

dN/dy:
- an approximately linear increase
- well described by EPOS-LHC
  PYTHIA and DIPSY tend to overestimate

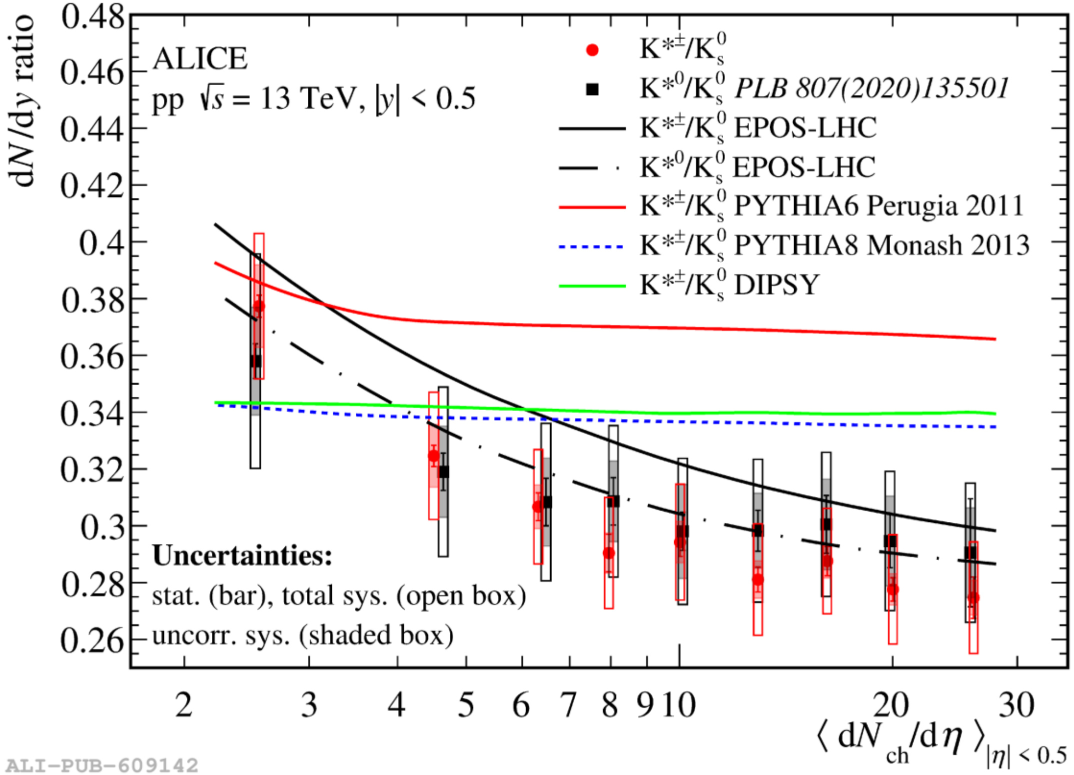
‹ p_T ›:
- increase with saturation
- EPOS-LHC underestimates
  PYTHIA largely underpredicts
  DIPSY more pronounced increase

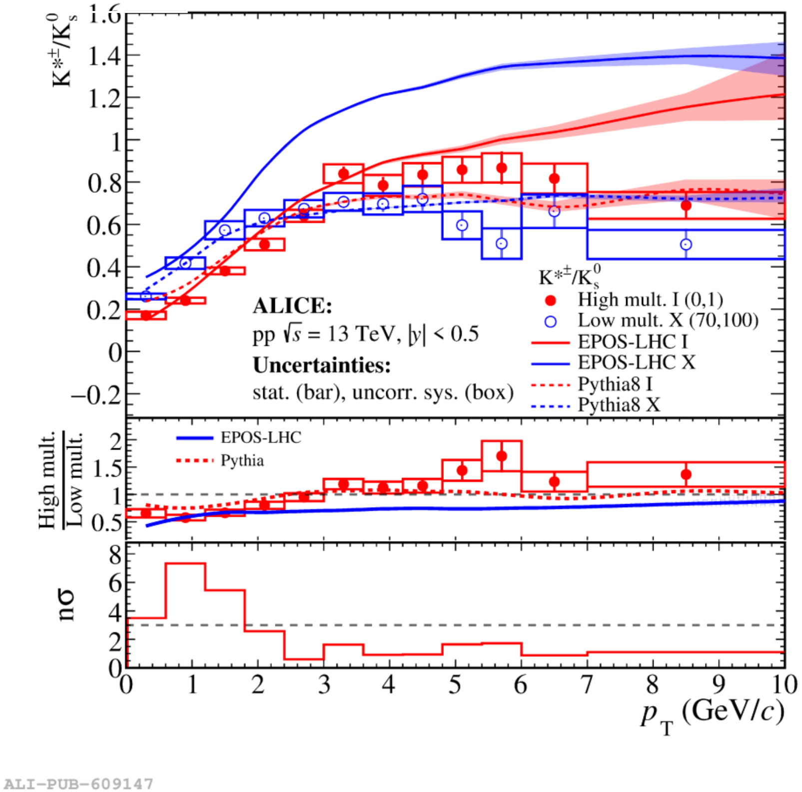


EPOS-LHC PRC92(2016)034906
PYTHIA6 PRD82(2010)074018
PYTHIA8 EPJC74(2014)3024
DISPY JHEP8(2011)103

K*(892)$^{\pm}$ in pp at 13 TeV

arXiv:2507.19332





suppression at a ~ 7σ level passing from low to high multiplicity pp collisions (taking into account the multiplicity-uncorrelated uncertainties), ~ 2σ level for K*^{0}

a low p_T dominant process for $p_T \lesssim 2$ GeV/c, the double ratio deviates from unity by more than 3σ

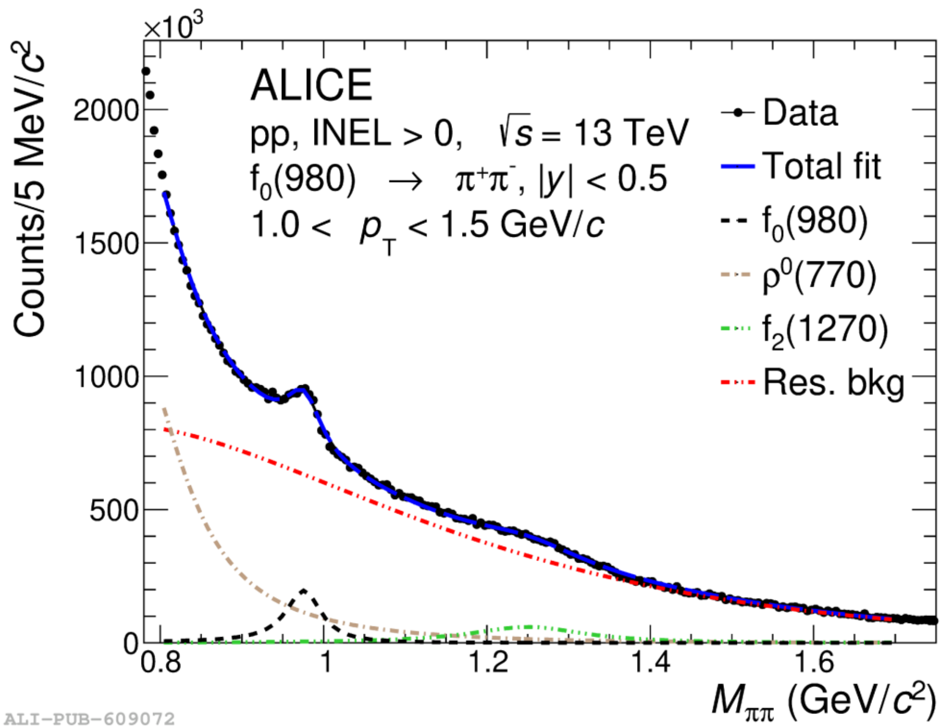
- suggest the presence of a finite lifetime hadronic phase
- but EPOS-LHC without a hadronic phase reproduces the decreasing trend

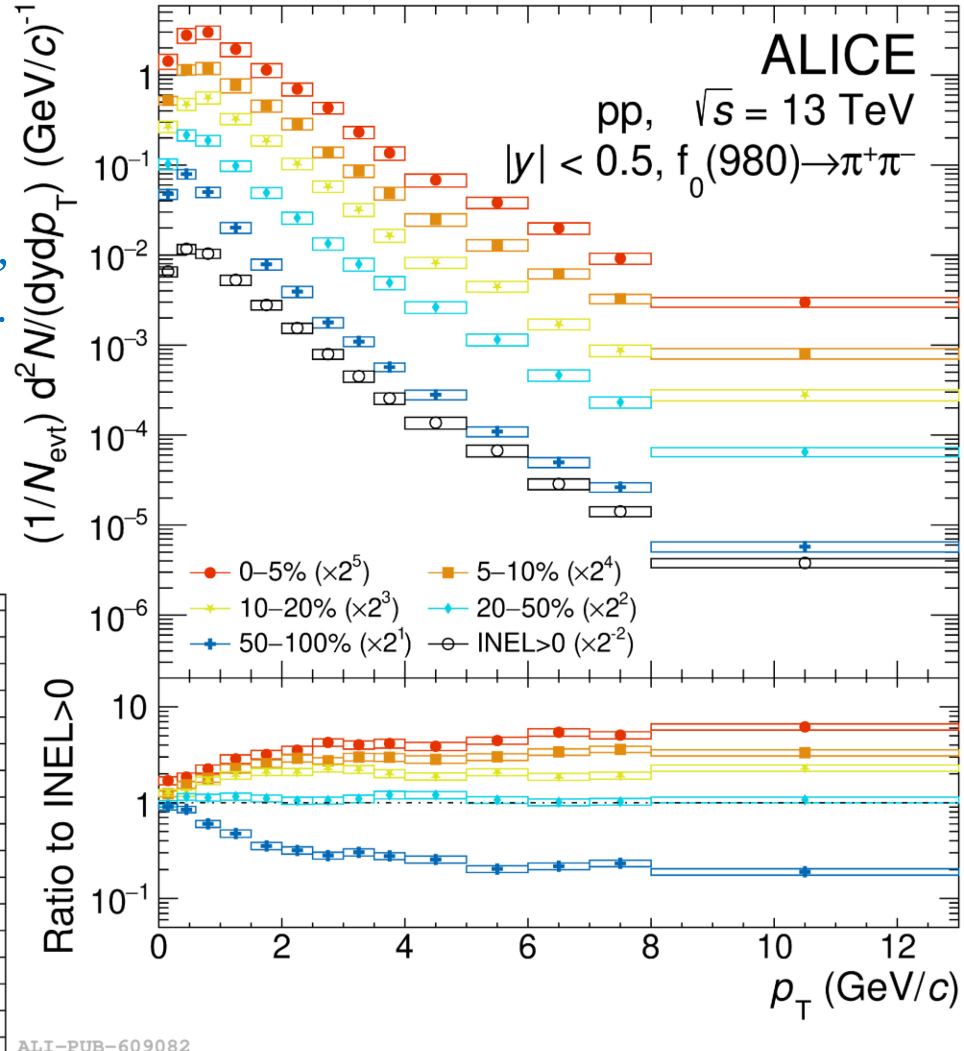
$f_0(980)$ in pp at 13 TeV

arXiv:2507.19347

quark structure of f_0 is still unknown
possible configurations: qqbar, (qq)(qbar qbar), hadronic molecules, ..

$2\ 10^9$ minimum-bias pp events at 13 TeV
$f_0(980) \rightarrow \pi^+\pi^-$ (BR=?)
$\tau \sim 5$ fm/c → regeneration and rescattering effects

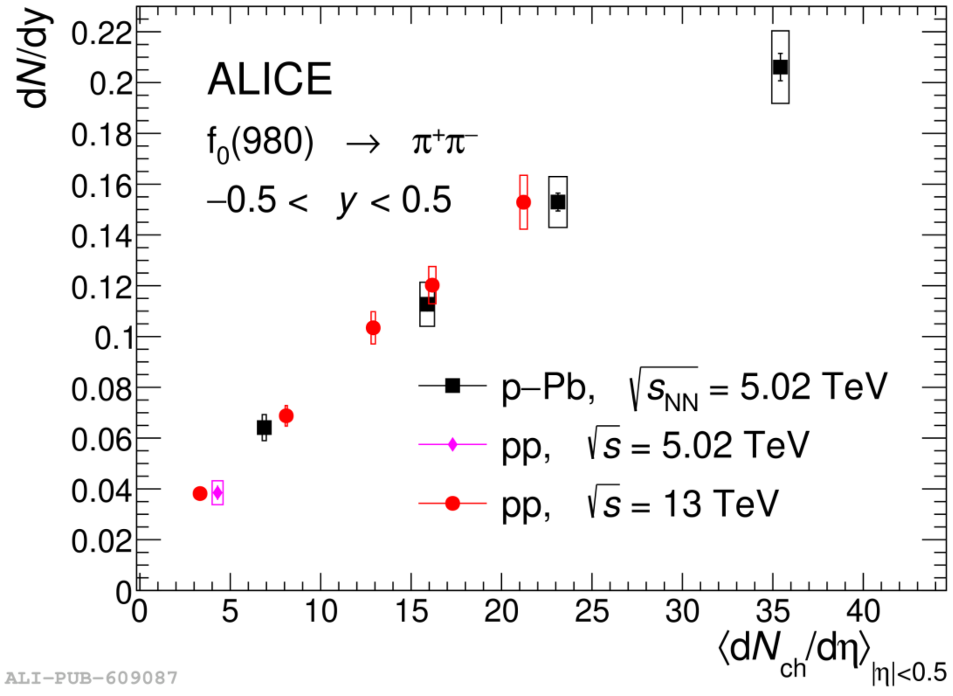


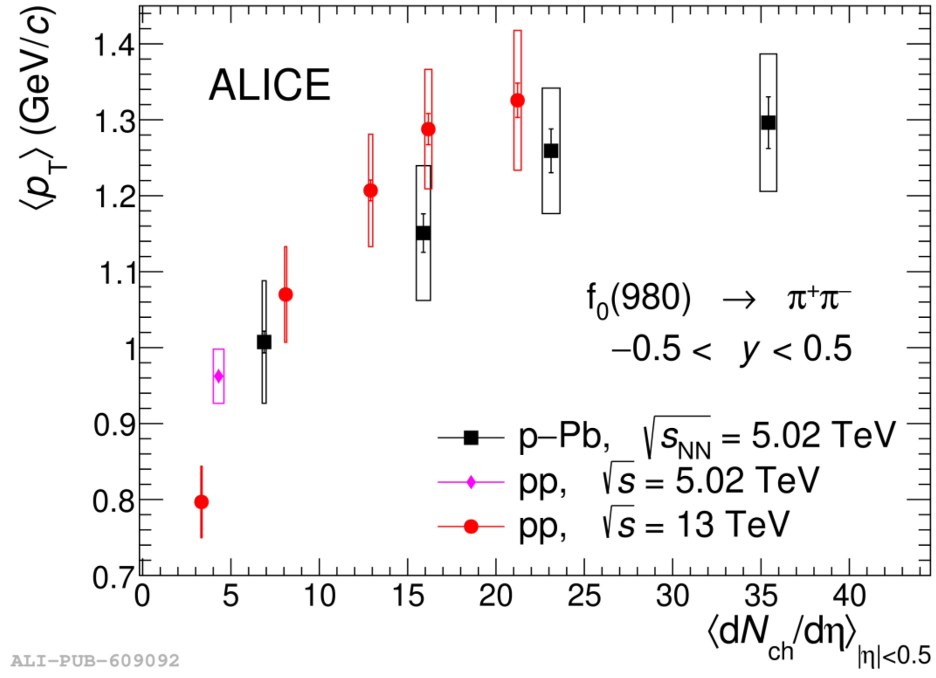


in $p_T < 4$ GeV/c spectra become harder from low to high multiplicity collisions, as for other hadron species.

f_0(980) in pp at 13 TeV

arXiv:2507.19347

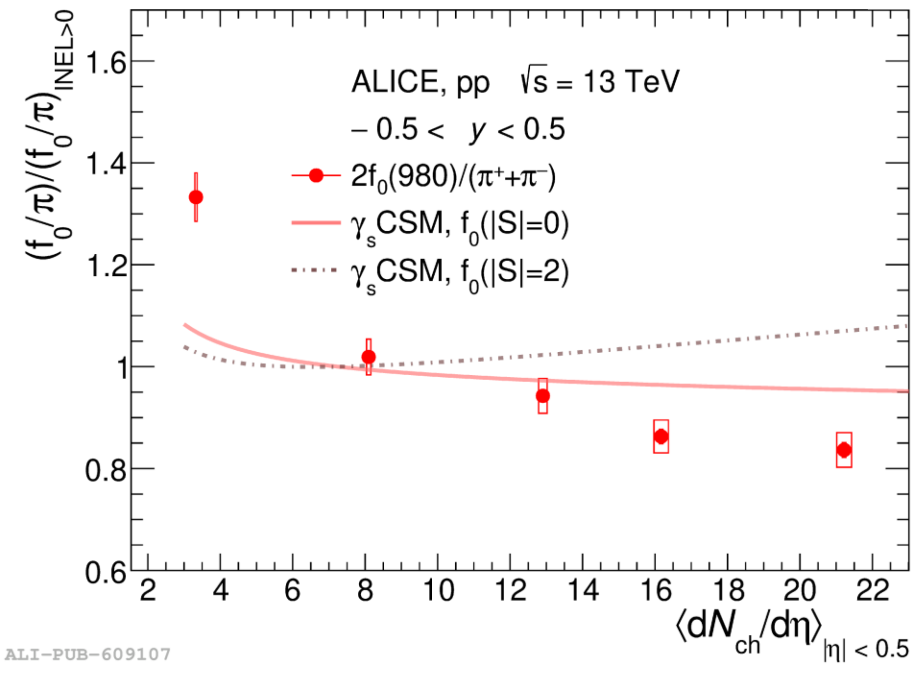


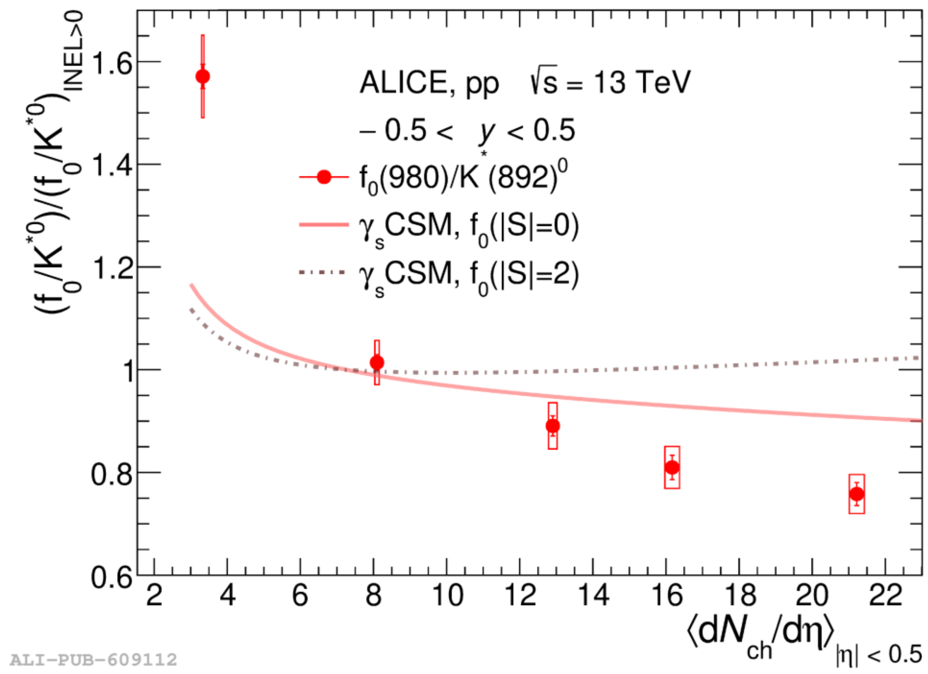


as for other hadron species,
yields : independent of collision system
appear to be driven by event multiplicity
mean p_T : pp vs p–Pb - steeper increase with multiplicity

f_0(980) in pp at 13 TeV

arXiv:2507.19347





f_0/π: decreases with increasing multiplicity
→ rescattering is the dominant effect, exists at low p_T

f_0/K^{*0}: decreases with increasing multiplicity
τ (f_0)~ 5 fm/c close to $\tau(K^{*0})$ = 4.2 fm/c
differs by decay products $f_0 \rightarrow \pi\pi$, $K^{*0} \rightarrow K\pi$
if $\sigma_{\pi\pi} > \sigma_{K\pi}$ the rescattering effect for f_0 may be stronger than for K^{*0}

γ_s-CSM (PRC100(2019)054906, no rescattering effects):
- not reproduces the ratios at low multiplicity
- predictions with zero hidden strangeness, |S|=0, are closer to the data

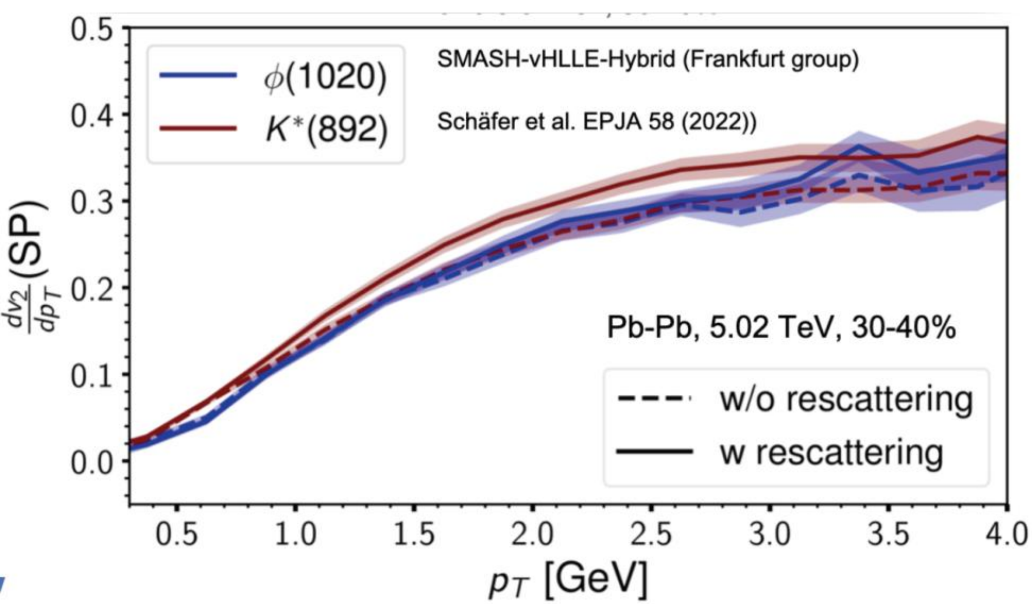
Run 3

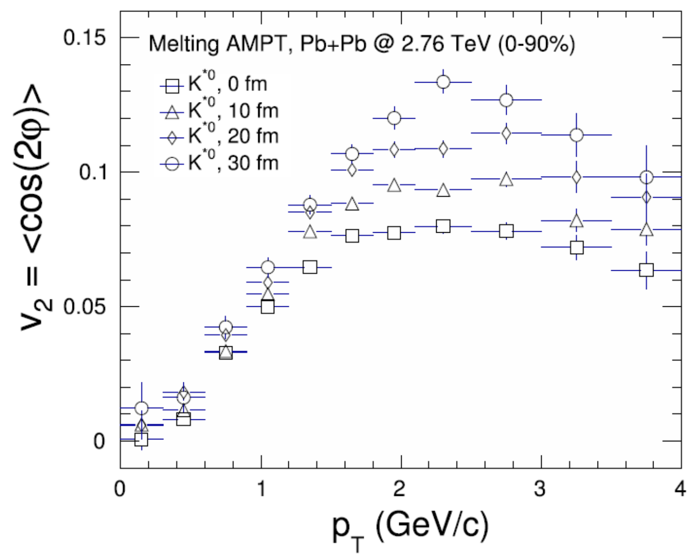
ITS →ITS2: improved pointing resolution (~35 μm at 1 GeV/*c*)
TPC/MWPC → TPC/GEM: reduce the ion backflow
and resulting space charge in the drift volume
high rates up to 50 kHz in Pb-Pb with continuous readout
FT0A ($3.5 < \eta < 4.9$) and FT0C ($-3.3 < \eta < -2.1$) :
precise timing for continuous readout,
centrality estimation, event selection, and collision time.
continuous readout
a novel online-offline software framework (O2)

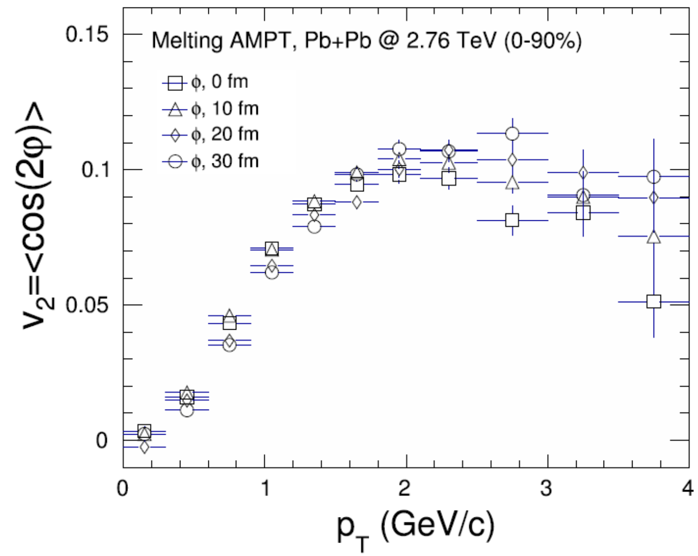
K*(892)^0 and ϕ flow: model predictions

JPG45(2018)025102

hadronic interactions modify resonance flow







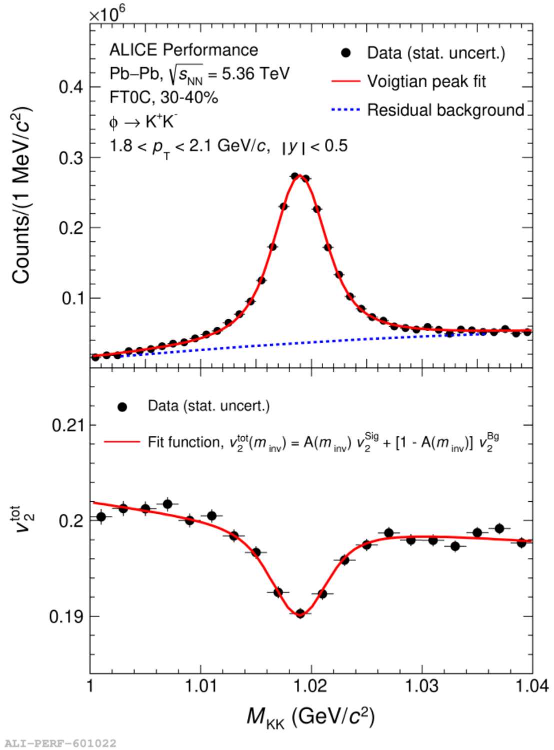
- enhanced flow for K*^{0} with rescattering
- no changes for ϕ flow

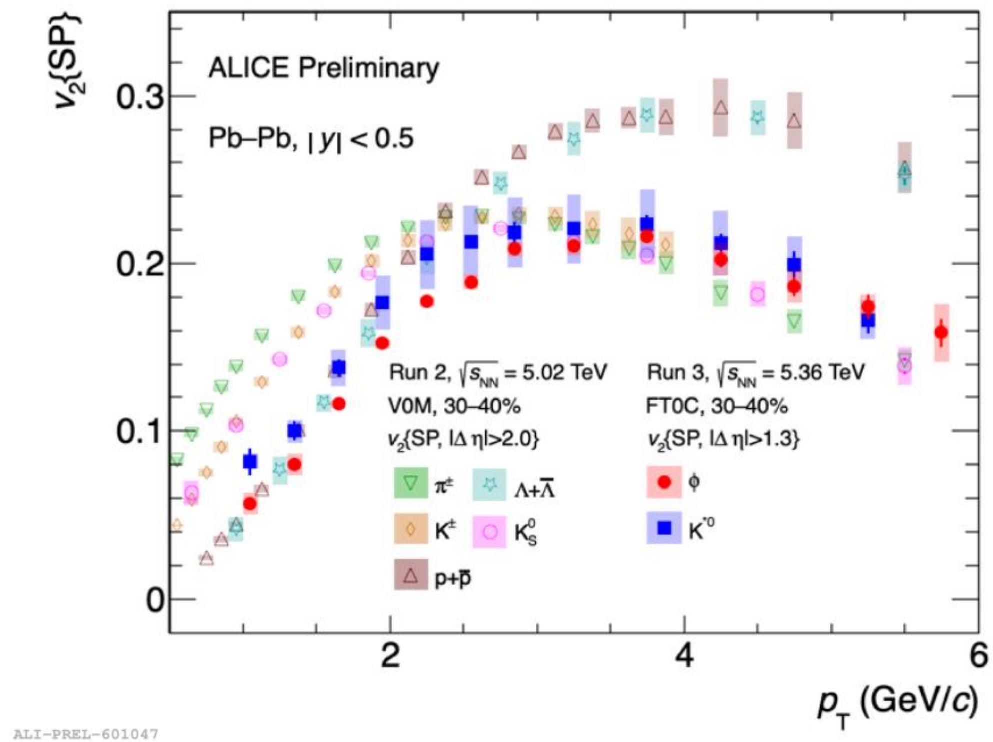
systematically increasing flow with longer duration of hadronic phase only for K*^{0}

K*(892)^0 and ϕ flow in Pb-Pb at 5.36 TeV

Enhanced statistics in Run 3 (~6.5 10^9 analyzed events)

- precise measurement of ϕ
- first measurement of K*(892)^0





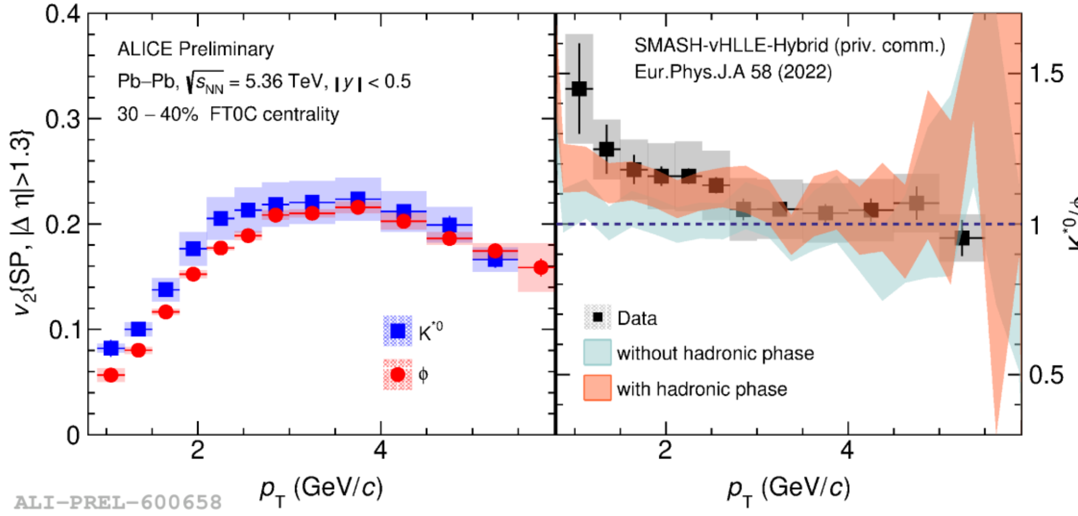
for short-lived particles:
invariant mass fit method
PRC70(2004)064905

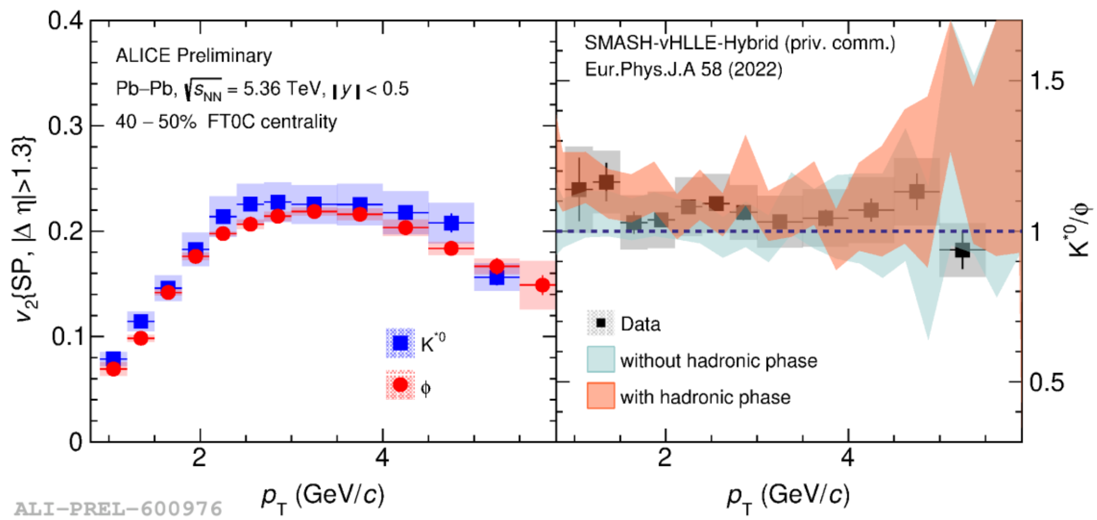
both K*(892)^0 and ϕ:

- mass ordering at low p_T
- baryon-meson grouping at higher p_T

K*(892)^0 and ϕ flow in Pb-Pb at 5.36 TeV

higher K*(892)^0 flow than ϕ flow
- sizable difference at low p_T
- consistent at intermediate p_T
- discrepancy more significant in 30–40% than 40–50%
- model with hadronic phase describes the trend

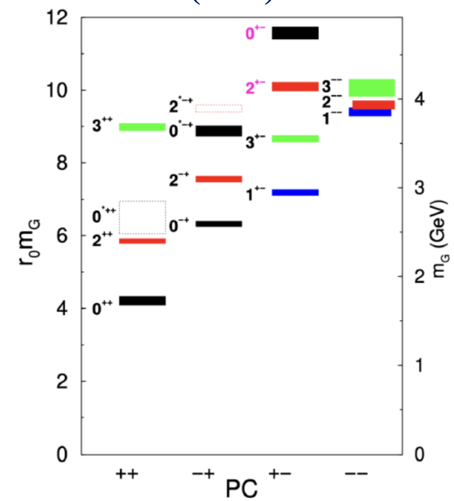




$f_0(1710)$ in pp at 13.6 GeV

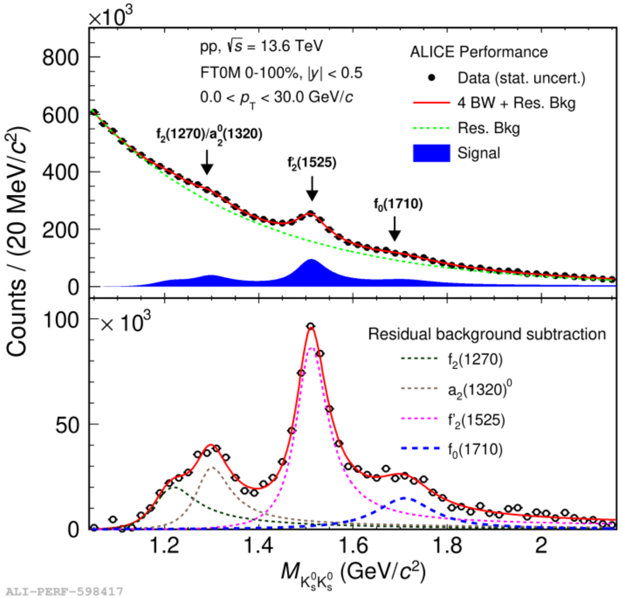
Lattice QCD calculations predict the mass of the lightest scalar glueball:1500 -1800 MeV, with $J^{PC} = 0^{++}$. Candidates $f_0(980)$, $f_0(1370)$, $f_0(1500)$, and $f_0(1710)$.

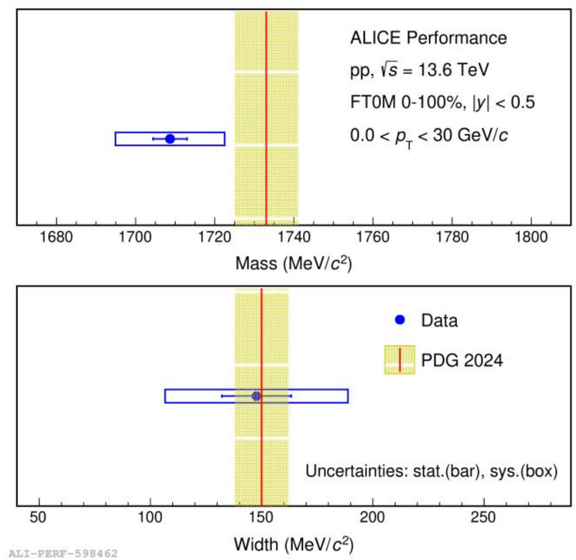
PRD60(1999)034509



~ 5 10^{10} min-bias pp events at 13.6 TeV

$f_0(1710) \rightarrow K^0_S K^0_S$





Summary

pp @ 13 TeV

f_1 (1285) - ‹ p_T › aligns with the linear trend with mass observed for other mesons
→ f_1 may have an ordinary meson structure

Ω(2012)⁻ - mass and width of are consistent with the previous measurements by Belle
- first measurement of a spectrum

K*(892)± - the first evidence of a K*/K suppression measured in pp collisions
- EPOS-LHC without any hadronic afterburner is able to reproduce the measured suppression.

f_0 (980) - both the f_0/π and f_0/K^{*0} ratios decrease with increasing multiplicity
- f_0/π suppression could be explained by the dominance of the rescattering effect
- the rescattering effect for f_0 can be stronger than for K^{*0} if $\sigma_{\pi\pi} > \sigma_{K\pi}$

Pb–Pb @ 13.6 TeV

ϕ, K*0 - the elliptic flow for ϕ and K^{*0} follow mass ordering at low p_T and baryon-meson grouping at intermediate p_T
→ participate in the collective expansion of the medium and undergo hadronization via quark coalescence in QGP

pp @ 13.6 TeV

f_0 (1710) - mass and width are close to the PDG values