First observation of f_1 (1285) resonance in ALICE

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Outline

- ☑ Motivation
- ☑ Literature survey
- ☑ Physics highlight
- ☑ Analysis details
- ☑ Summary

ALL RESULTS SHOWN ARE ALICE PRELIMINARY APPROVED

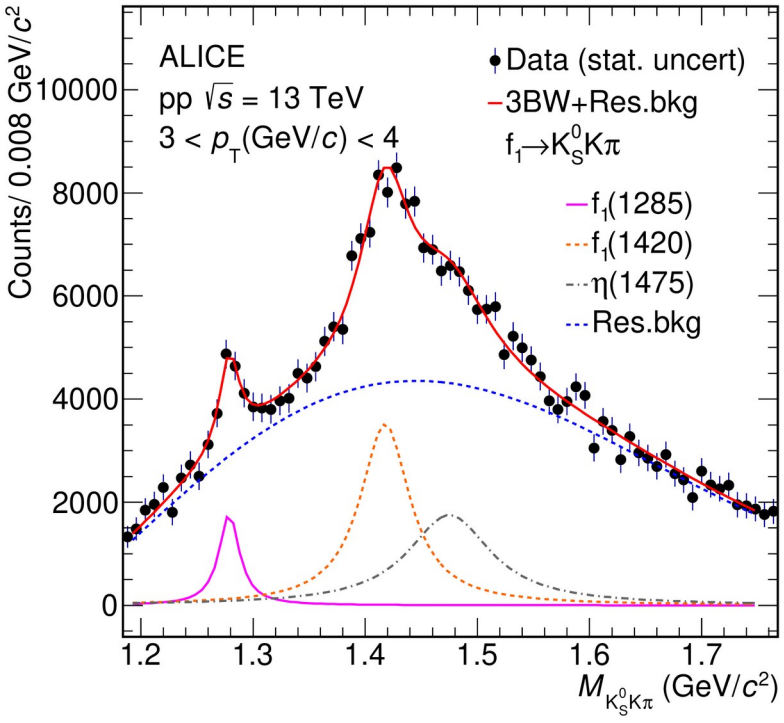
Motivation

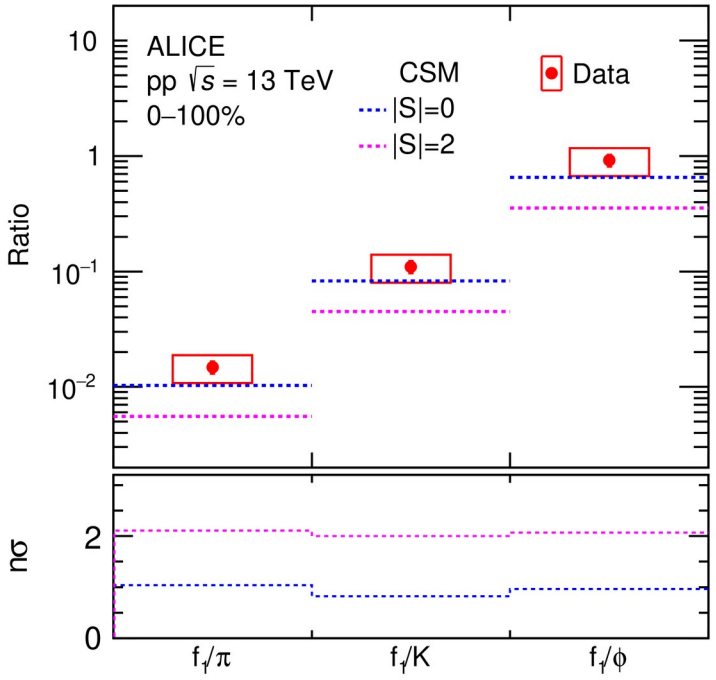
Physics	Remarks	This analysis
☑ Quark composition	☑ Linear combination of u and d quarks only (Phys.Rev.D 96 (2017), 054012) ☑ Consists of strange quarks (Z.Physc.C 76 (1997), 469-474)	☑ Quark composition is investigated by comparing experimental data with thermal model predictions
☑ Quark structure	☑ Diquark (Phys.Rev.D 96 (2017), 054012) ☑ Tetraquark (Phys.Rev.D71 (2005), 094005) ☑ Hybrid (Nucl.Phys.A 992 (2019) 121641) ☑ Molecule (Phys.Lett. B750 (2015) 609-614)	☑ Not possible (Can be done by femtoscopic studies)
☑ Chiral symmetry restoration	☑ Mass shift w.r.t its PDG value in heavy ion collisions (Physics Letters B 767 (2017) 336–340)	☑ Will act as a baseline for future heavy ion study

Literature survey

Collision system	Remarks	Experiments
☑ pp (Fixed Target)	☑ Z.Phys.C 52 (1991) 389-396 ☑ Phys.Lett.B 440 (1998) 225-232 ☑ Phys.Lett.B 413 (1997) 217-224	☑ WA76, WA102
☑ e^+e^-	☑ Phys.Lett.B 569 (2003) 129-139 ☑ Phys.Rev.D 86 (2012) 092010 ☑ Phys.Rev.C 93 (2016) 065202	☑ DELPHI, BABAR, CLAS
☑ pp (Collider)	☑ PRL 112 (2014) 091802 (b-hadron decay) ☑ First measurement of production cross section	☑ LHCb ☑ ALICE (This analysis)

Physics highlight





- ☑ Clear signal peak of $f_1(1285)$ resonance is observed in pp collisions at 13 TeV
- ☑ Canonical statistical model predictions compared with ALICE data
- ☑ |S|=2 is rejected with 99% confidence level

Hint of $f_1(1285)$ composed of u and d quarks only

Analysis details

Source	Period	Events	Trigger
☑ Real data set	LHC 16, 17, 18	~1.5 Billion	kINT7
☑ Monte carlo simulation	LHC 23d6a	~1.9 Million	kINT7

Properties of f_1

Mass (GeV/c^2)	1.285
Width (GeV/c^2)	0.022
Spin	1

☑ **System:** pp at √s = 13 TeV

☑ **p_T(GeV/c):** 1-2, 2-3, 3-4, 4-5, 5-6, 6-8, 8-12

☑ **Decay channel:** $K^0_S K\pi$ ➡ BR = 2.25%

☑ **Reconstruction technique:** Invariant Mass method ➡ $M = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i p_i\right)^2}$

☑ **Combinatorial bkg:** Like sign

☑ **Fitting function:** 3 BreitWigners (signal) + expol (Res.bkg)

Event and track selections

☑ **Event selection:**
Standard event selection cuts for run2
V_z position: $|V_z| < 10$ cm

☑ **Track selection:**
Standard ITS TPC track cuts 2011

☑ **Pair rapidity cut:**
$|y| < 0.5$

☑ **PID cuts:**
TPC 2 sigma TOF VETO 3 sigma

☑ Mass $K^0_S K$ pair < 1.04 GeV/c^2

Topological selections

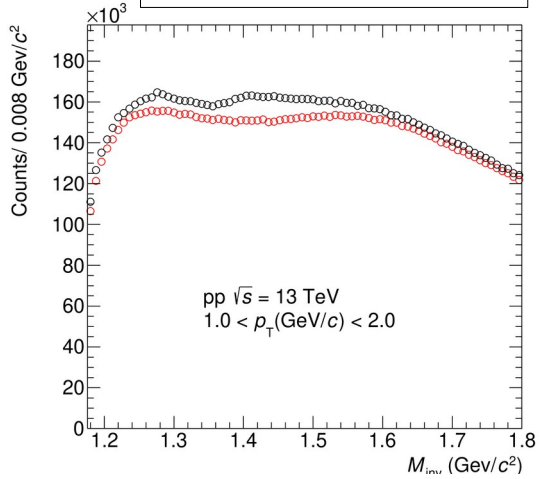
- ☑ $|\eta| < 0.8$
- ☑ Min DCA to $V_{xy} > 0.06$ cm
- ☑ $|n\sigma|_{TPC}$ (π) < 4
- ☑ DCA b/w daughters < 1.0 cm
- ☑ DCA K^0_s to primary vertex < 0.3 cm
- ☑ Cos Pointing angle > 0.97
- ☑ Lifetime < 15 cm
- ☑ Low radius > 0.5 cm
- ☑ Mass tolerance cut = M±6σ
- ☑ TPC Refit ->TRUE
- ☑ No. of crossed rows > 70
- ☑ Crossed rows /Findable cluster > 0.8
- ☑ Competing V0 rejection > 0.0043 GeV/c^2

Invariant mass distributions

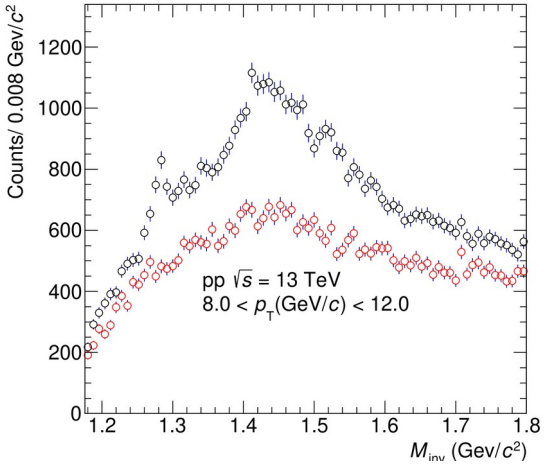
Before bkg. subtraction

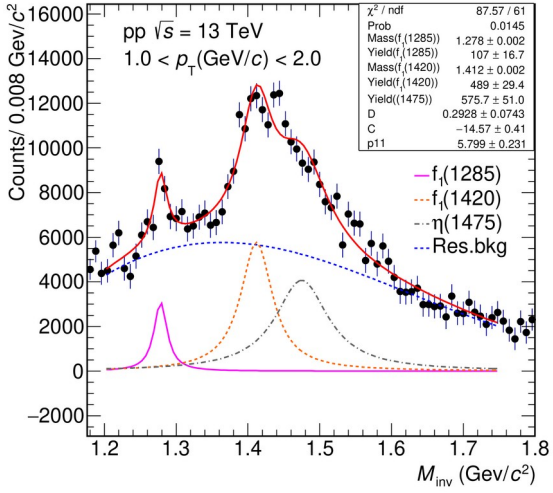
After bkg. subtraction

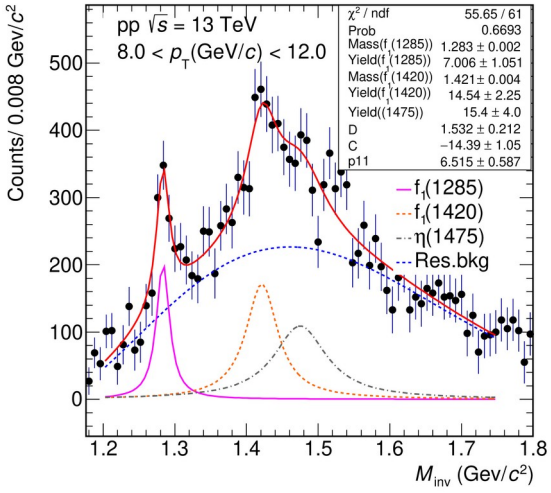
$1<p_T<2$ GeV/c



$8<p_T<12$ GeV/c







- ☑ **Black markers:** Unlike sign charge pairs
- ☑ **Red markers:** Like sign charge pairs

☑ During fitting width of three resonances are kept fixed to their PDG values

Branching Ratio (BR) estimation

Source	Decay channel	Branching ratio (BR)
PDG	$K\bar{K}\pi$	9%

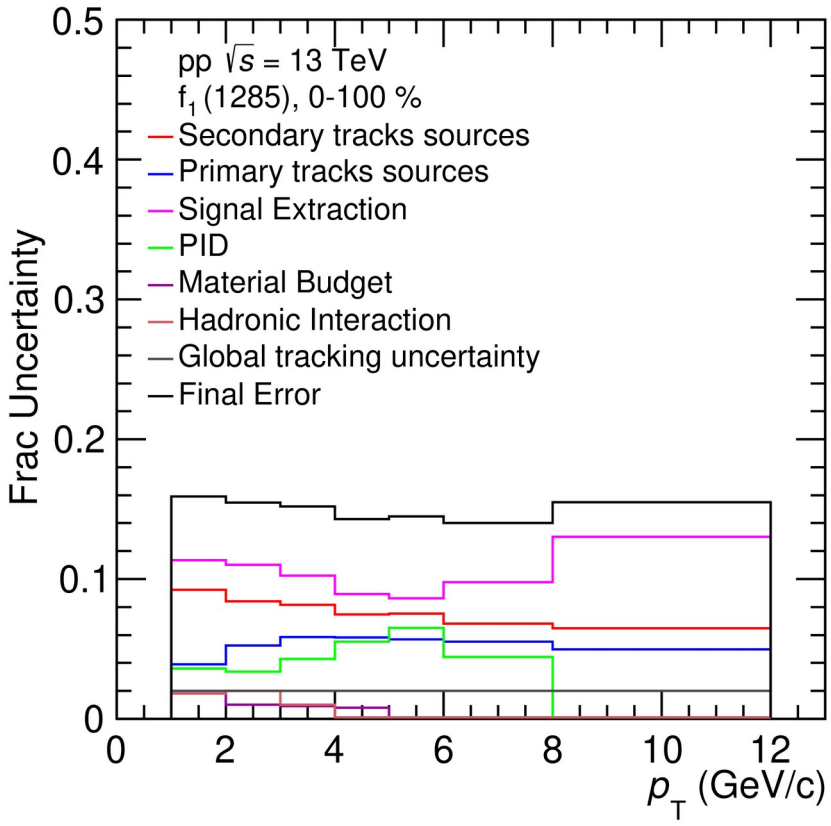
Decay channel	BR (%)	Observation
$K^+K^-\pi^0$	2.25	
$K^+\bar{K}^0\pi^-$	2.25	
$K^0K^-\pi^+$	2.25	
$K^0\bar{K}^0\pi^0$	2.25	

- ☑ The sum of the BR of the two decay channels = 4.5%
- ☑ K^0 can further decay to K^0_S and K^0_L with 0.5 probability
- ☑ Our analysis decay channel: f_1 -> $K^0_s K\pi$
- ☑ **Final BR = 4.5*0.5 = 2.25%**

Systematic sources

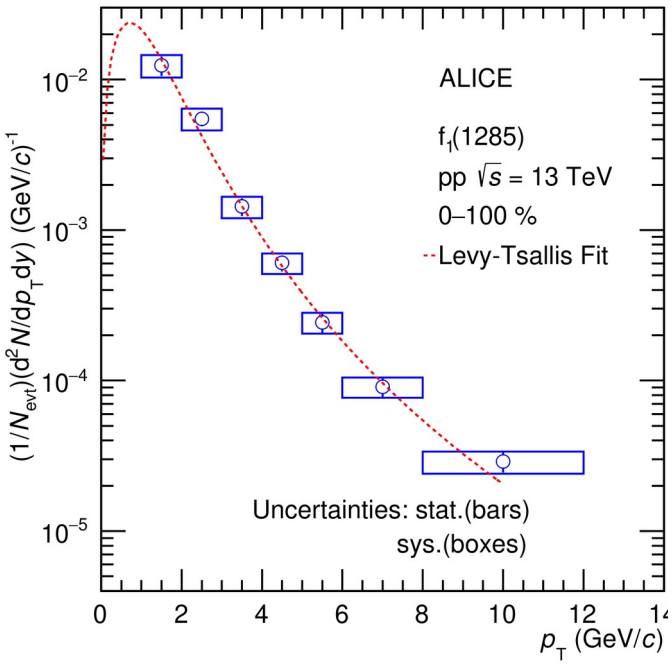
- ☑ Signal extraction
- ☑ Track selections
- ✔ Primary
- ✔ Secondary
- ☑ PID
- ☑ Global tracking uncertainty
- ☑ Hadronic interaction
- ☑ Material Budget

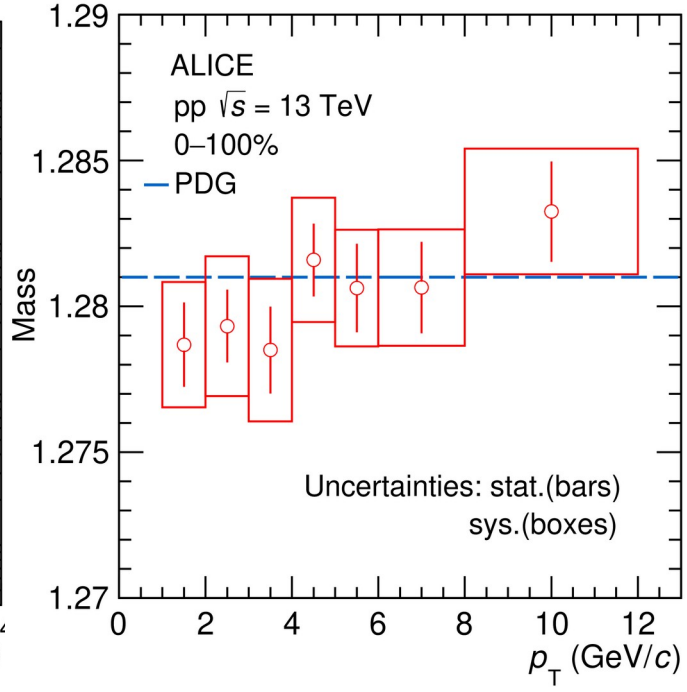
Resultant fractional uncertainty

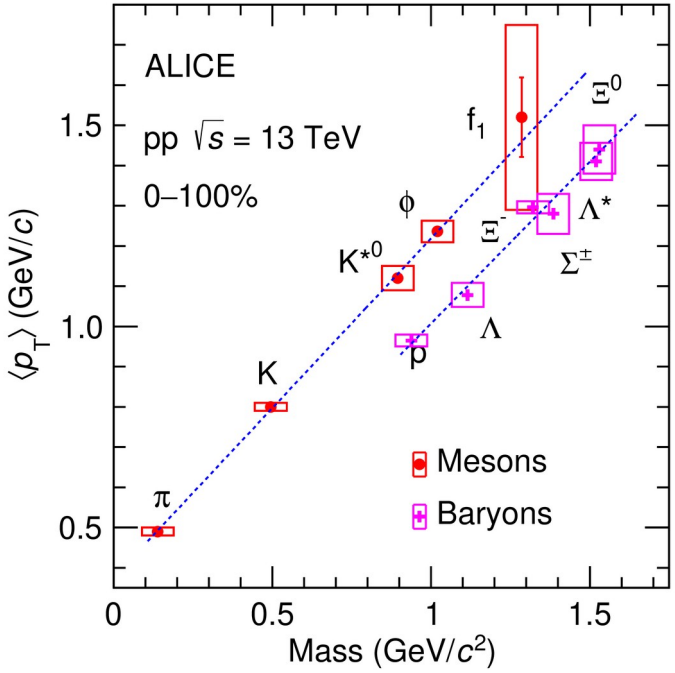


- ☑ Final uncertainty obtained from quadrature sum of all sources
- ☑ Hadronic interaction, material budget and Global tracking uncertainty is obtained from Eur. Phys. J. C 81 (2021) 256

p_T spectra, mass and $\langle p_T \rangle$







- ☑ p_T spectra of f_1 is obtained from 1 – 12 GeV/*c*
- ☑ Mass is consistent with the PDG value within uncertainties
- ☑ $\langle p_T \rangle$ increases with mass of the particle
- ☑ Two different linear trends for mesons and baryons

Quark composition

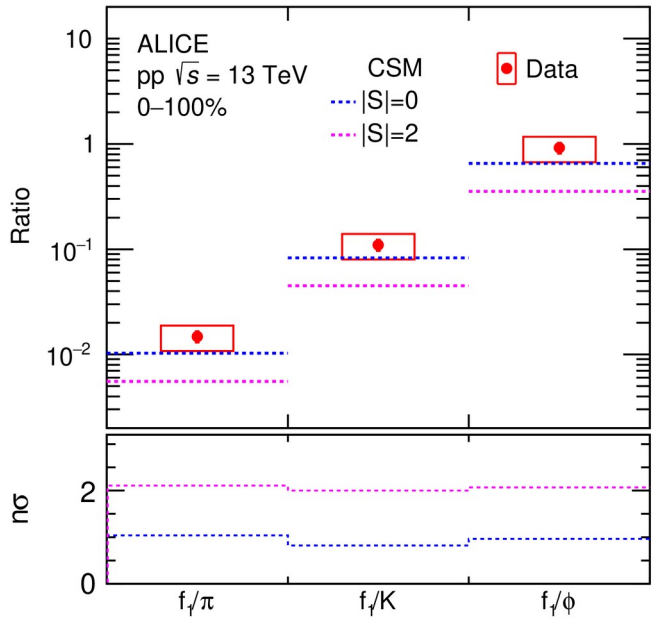
Ensemble	Statistics	Particles used	Parameters of the fit
Canonical	Quantum	π, K, p, ϕ, Λ, Ω, K*, K^0_S, Ξ	T, R, R_C, γ_S

Parameters	T (MeV)	R (fm)	R_C (fm)	γ_S	χ^2/Ndf
	187.7	1.1	1.7	0.71	1.10

☑ **|S| = 0**
- ✔ χ^2 = 2.69
- ✔ Ndf = 3-1 = 2
- ✔ p value = 0.25

☑ **|S| = 2**
- ✔ χ^2 = 12.73
- ✔ Ndf = 3-1 = 2
- ✔ p value = 0.001

☑ Rejected with 99% confidence level

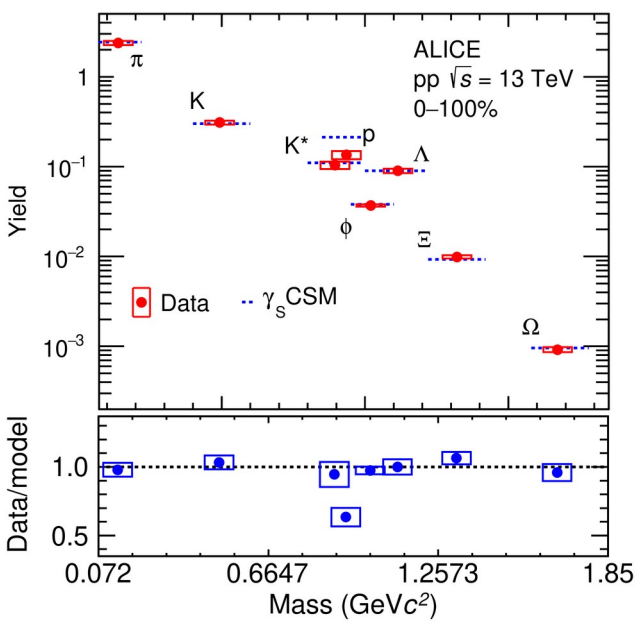


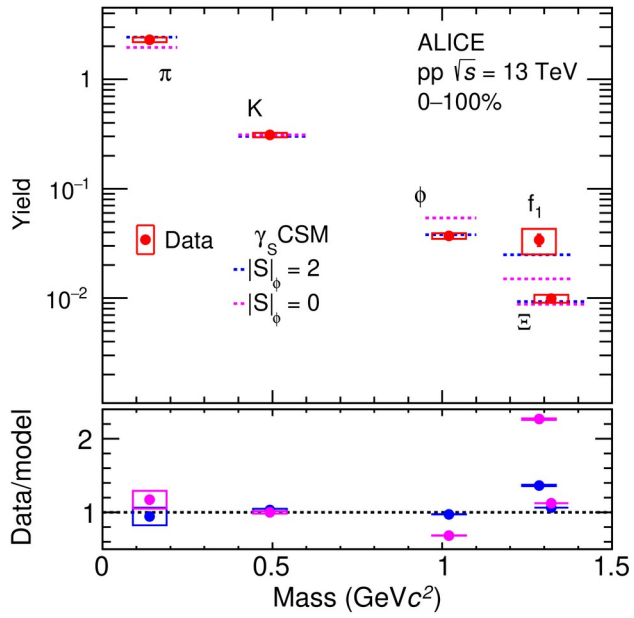
Summary

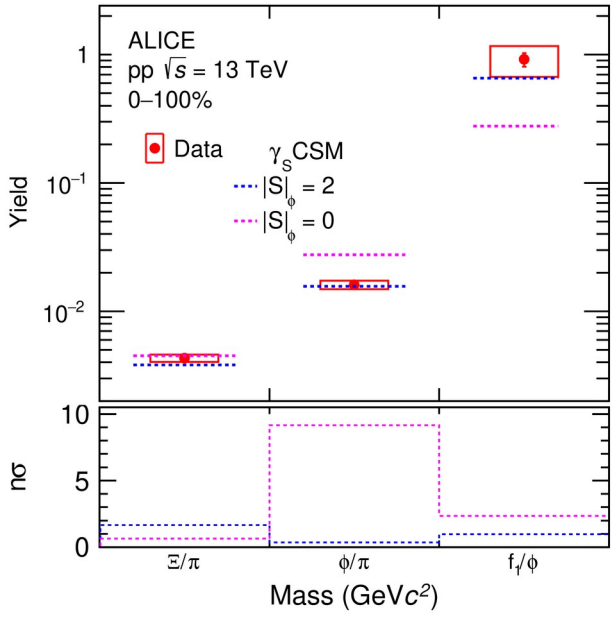
- ☑ Inaugural measurement of production cross section of $f_1(1285)$ resonance in pp collisions
- ☑ Comparison of thermal model predictions with experimental data rules out $|S|=2$ quark composition of f_1 with 99% confidence level
- ☑ Suggests f_1 is composed of only up and down quarks
- ☑ No mass shift is observed with respect to its PDG value in pp collisions

Backup

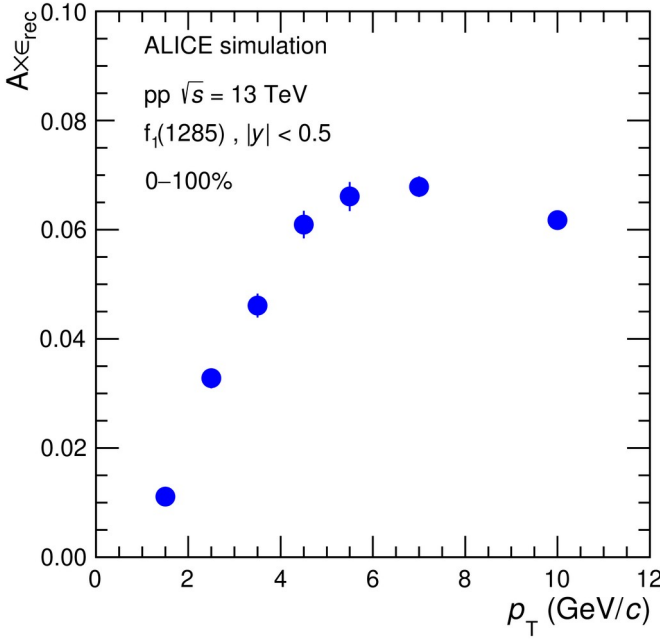
Checks

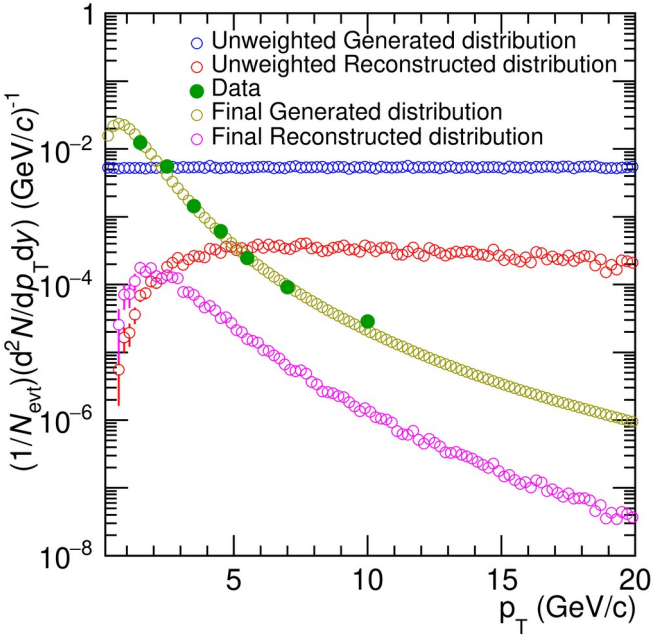

ALICE
pp $\sqrt{s}$ = 13 TeV
0–100%
π
K
K*
p
Λ
ϕ
Ξ
Ω
Data
γ_SCSM
Yield
Data/model
Mass (GeVc^2)

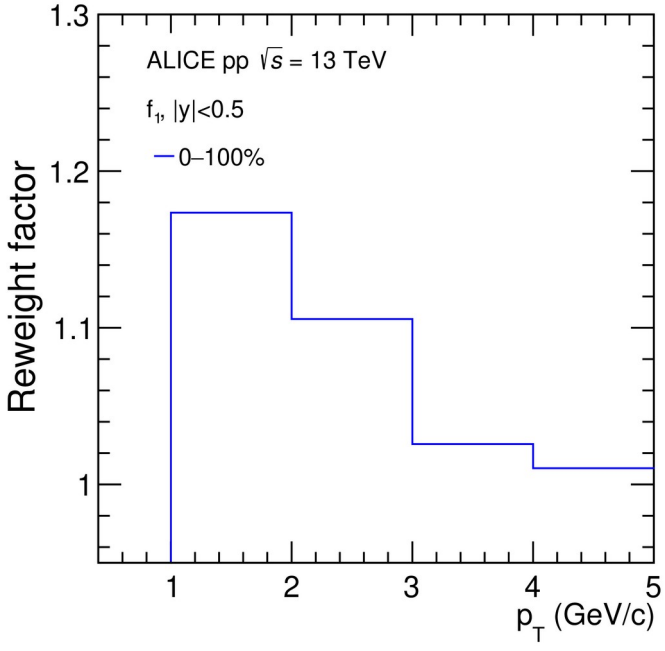

ALICE
pp $\sqrt{s}$ = 13 TeV
0–100%
π
K
ϕ
f_1
Ξ
Data
γ_SCSM
$|S|_\phi$ = 2
$|S|_\phi$ = 0
Yield
Data/model
Mass (GeVc^2)


ALICE
pp $\sqrt{s}$ = 13 TeV
0–100%
Data
γ_SCSM
$|S|_\phi$ = 2
$|S|_\phi$ = 0
Yield
nσ
Ξ/π
ϕ/π
f_1/ϕ
Mass (GeVc^2)

Efficiency and reweighting

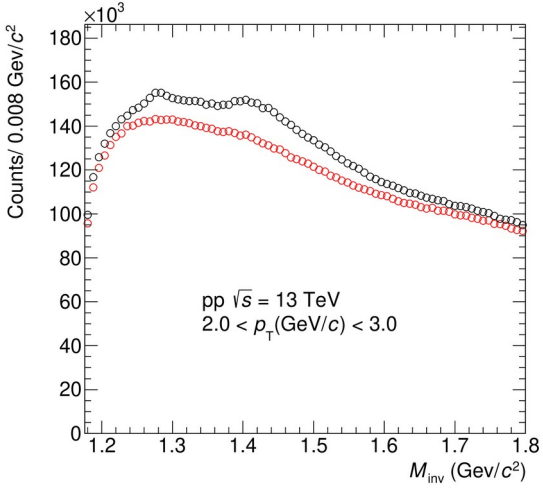


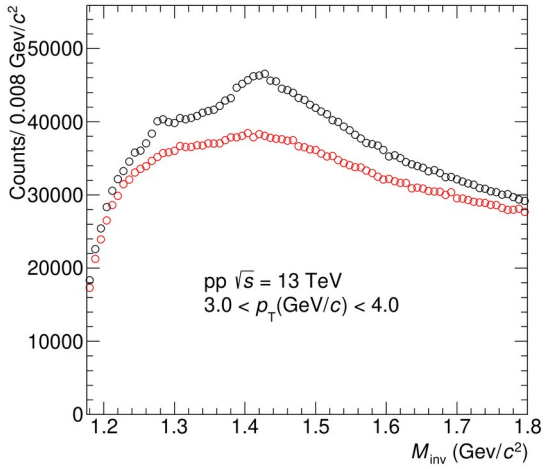


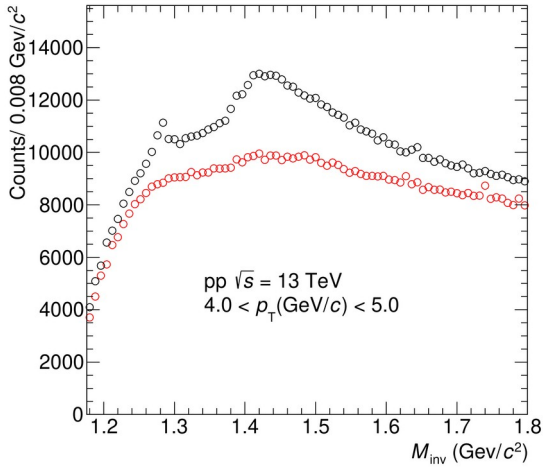


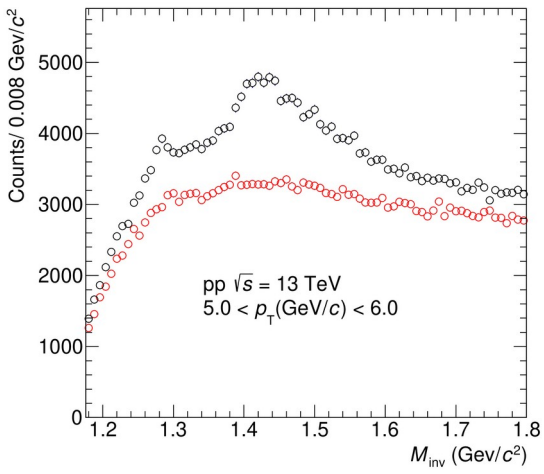
- ☑ Efficiency time acceptance varies from 1-7% across the measured p_T range
- ☑ The reweighting factor is found to be negligible after 4 GeV/c
- ☑ The reweighting factor is multiplied to the corrected spectra

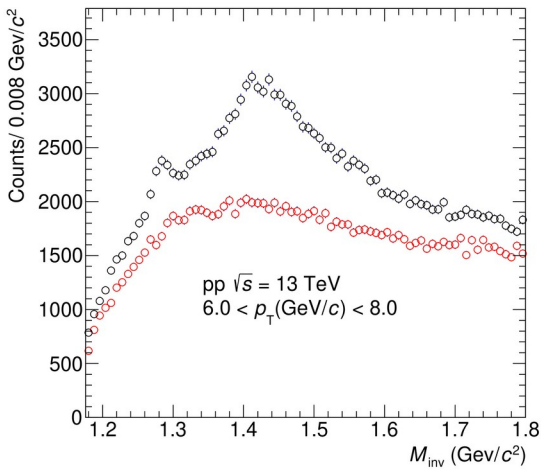
Invariant mass distributions



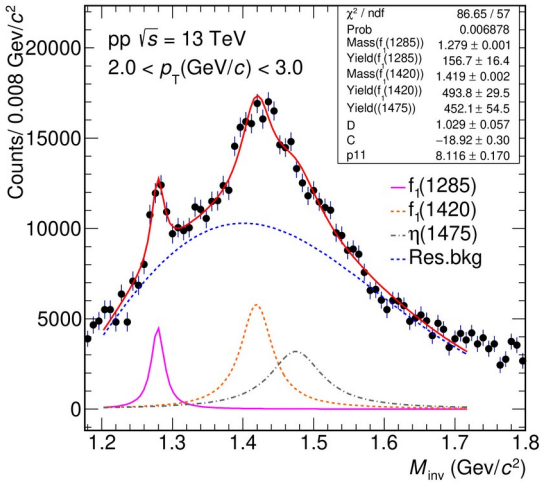


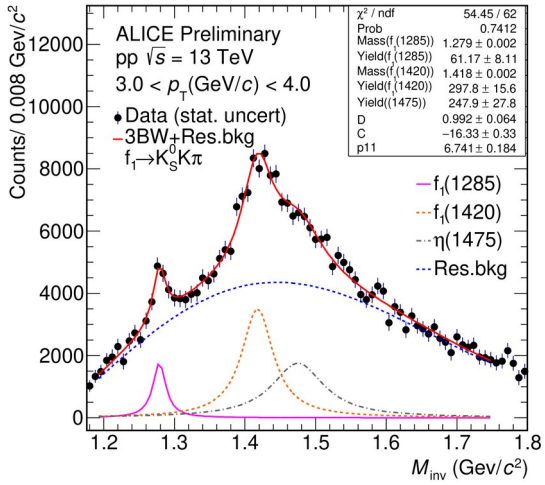


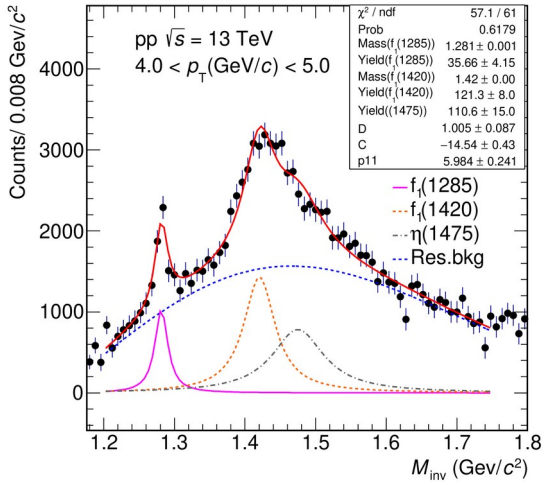


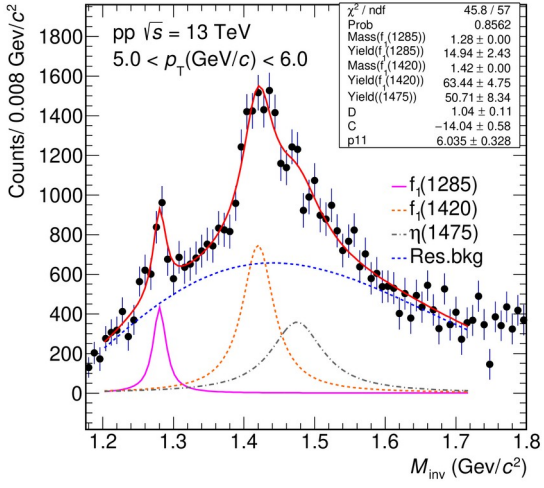


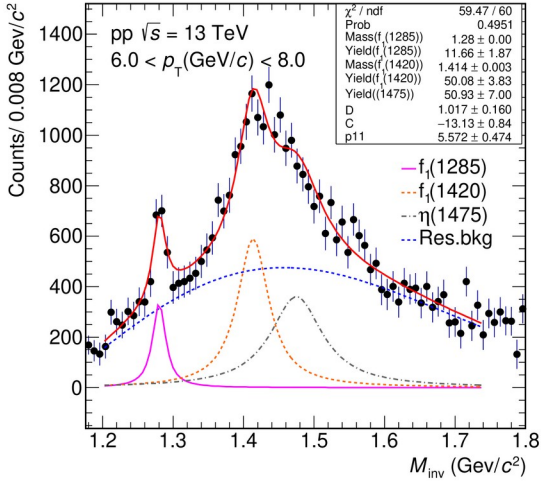
Invariant mass distributions







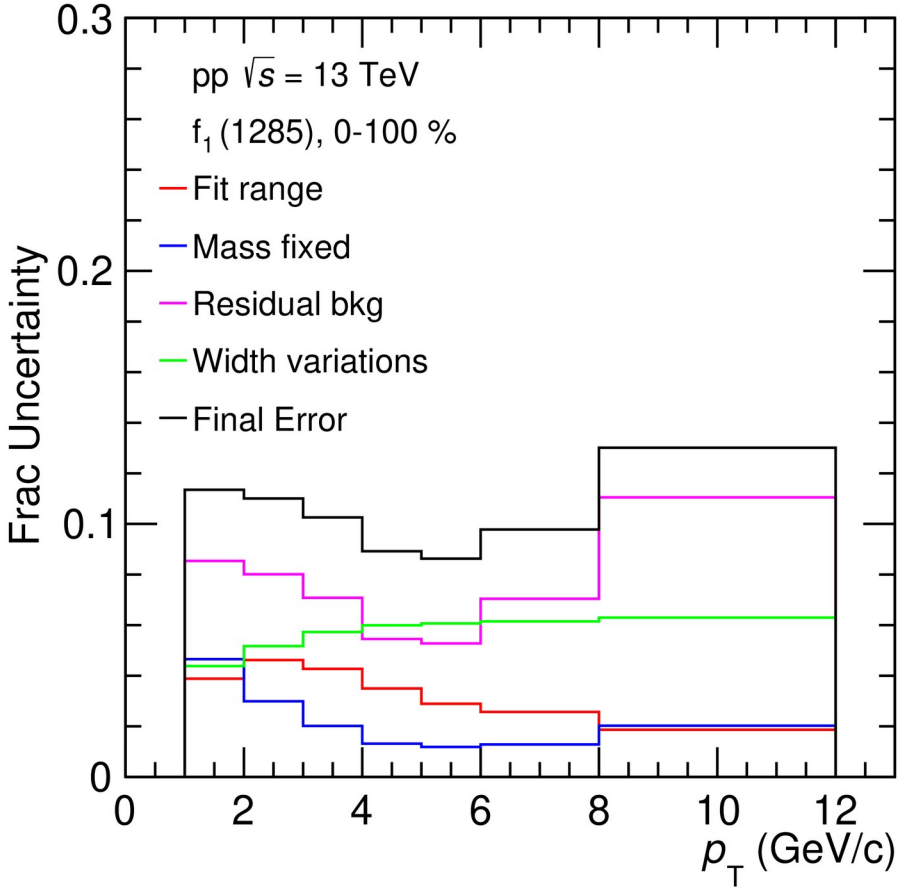




Signal extraction sources

Source	Default	Variations
Fitting range (GeV/c^2)	Depends on bkg shape	+/- 20 MeV/c^2
Residual background	Expol	pol2, pol3
Masses	Mass of f1 (1285) and f1(1420) is kept free	only mass of f1 (1285) is kept free
Width	Fixed	(a) f1 (1285) -> +/- uncertainty (b) f1 (1420) -> +/- uncertainty

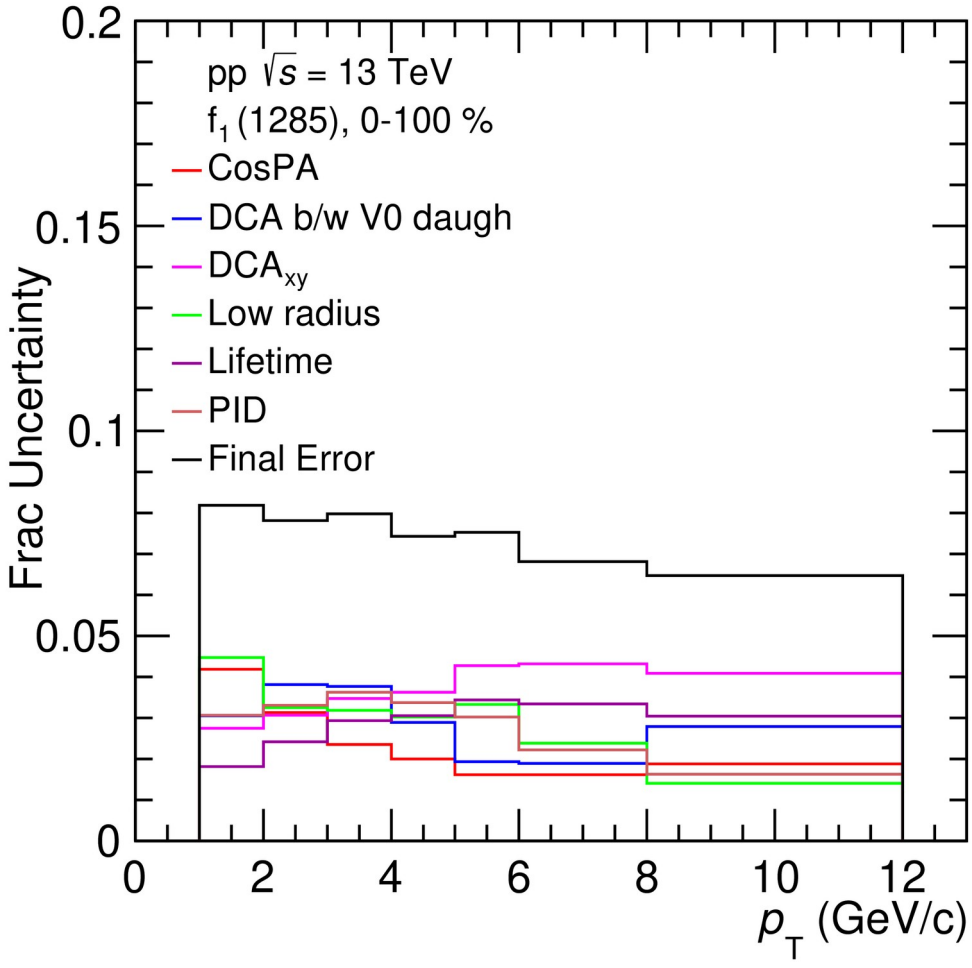
Signal extraction sources



Topological sources

Source	Default	Variations
dca_{xy}	> 0.06 cm	0.08 cm
Cosine Pointing angle	> 0.97	0.98
Lifetime	< 15 cm	12 cm
Low radius	> 0.5 cm	0.8 cm
DCA b/w V0 daughters	> 1.0 cm	0.8 cm
PID	< 4	< 5

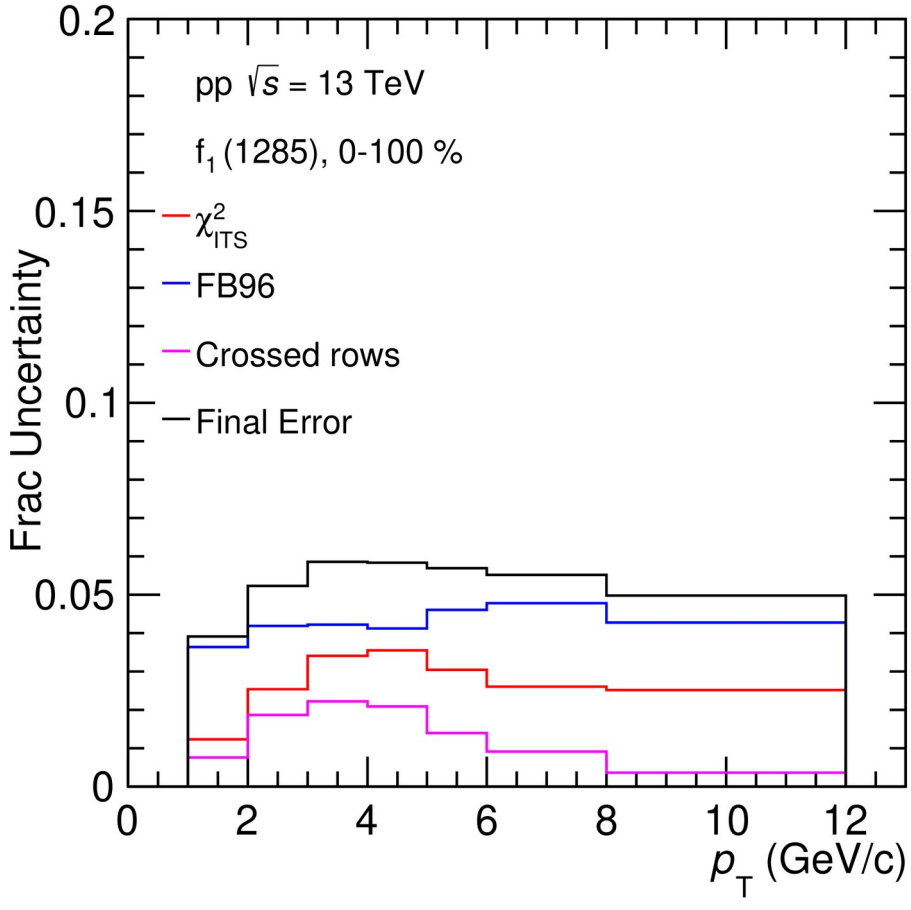
Topological sources



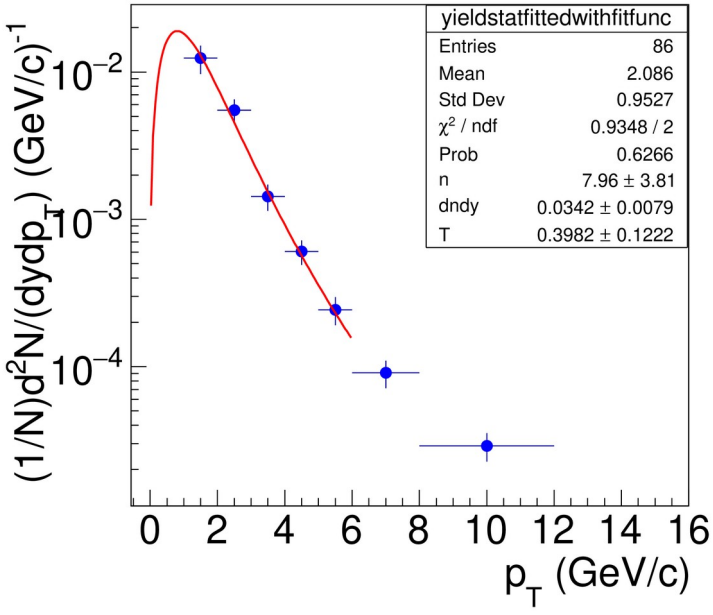
Primary track sources

Source	Default	Variations
FB	32	96
Crossed rows	> 70	90
χ^2/ITS	< 36	4

Primary track sources



dN/dy and <p_T>



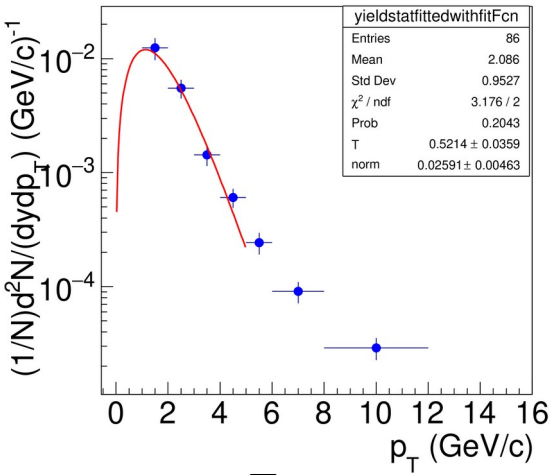
- ✔ pT spectra (with total uncertainty) is fitted with Levy-Tsallis function from 0-6 GeV/c
- ✔ Low pT extrapolation ~ 41%
- ✔ dN/dy = 0.034 +/- 0.004 +/- 0.005
  <pT> = 1.52 +/- 0.099 +/- 0.075

Low p_T extrapolation

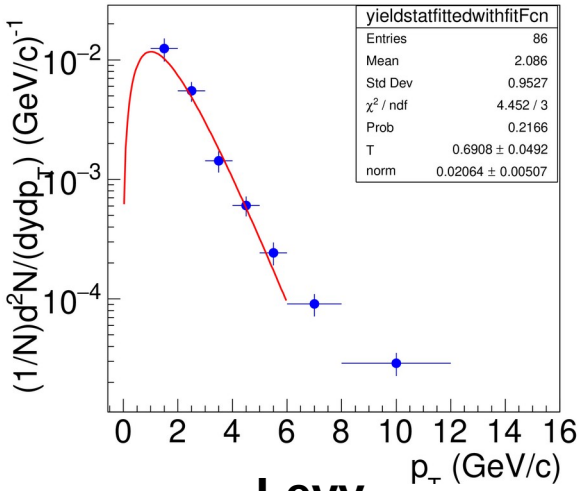
Fit functions	dN/dy	Stat	Sys	<pT>	Stat	Sys	χ2/Ndf
Bose-Einstein	0.028	0.002	0.004	1.72	0.052	0.067	1.484
Exponential	0.032	0.002	0.005	1.56	0.065	0.073	1.04
Boltzmann	0.027	0.002	0.004	1.74	0.056	0.06	1.58

Fit functions

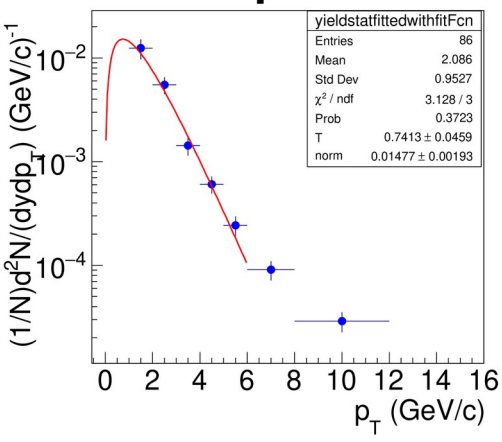
Boltzmann



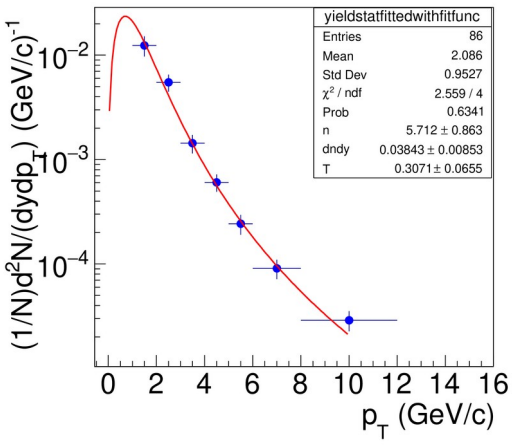
Bose



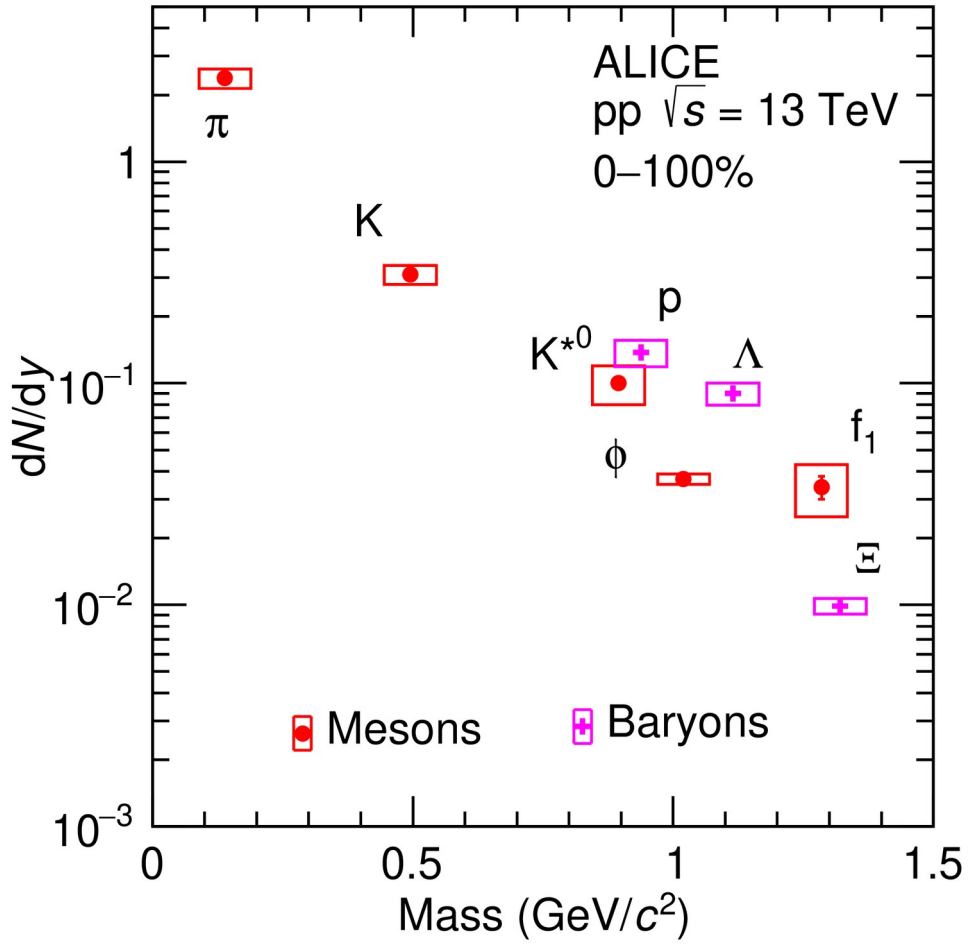
Exp



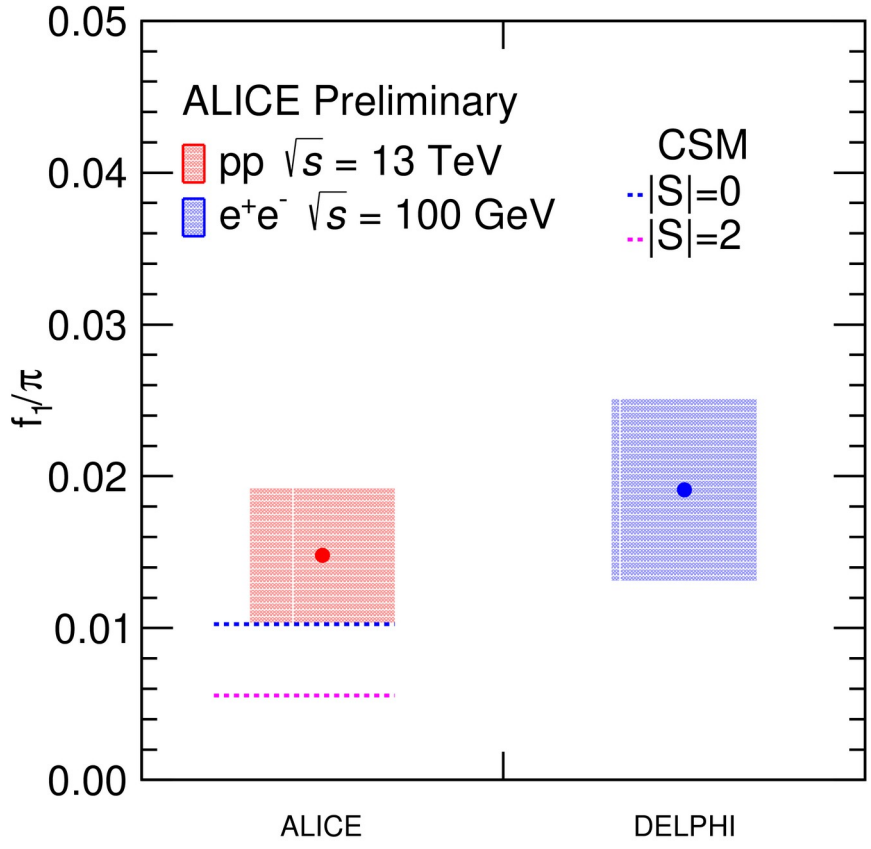
Levy



dN/dy


ALICE
pp $\sqrt{s}$ = 13 TeV
0–100%
π
K
p
K*0
Λ
ϕ
f1
Ξ
Mesons
Baryons
dN/dy
Mass (GeV/c^2)
1
10^{-1}
10^{-2}
10^{-3}
0
0.5
1
1.5

Comparison with DELPHI



Branching ratio = 9 %

LEP data model