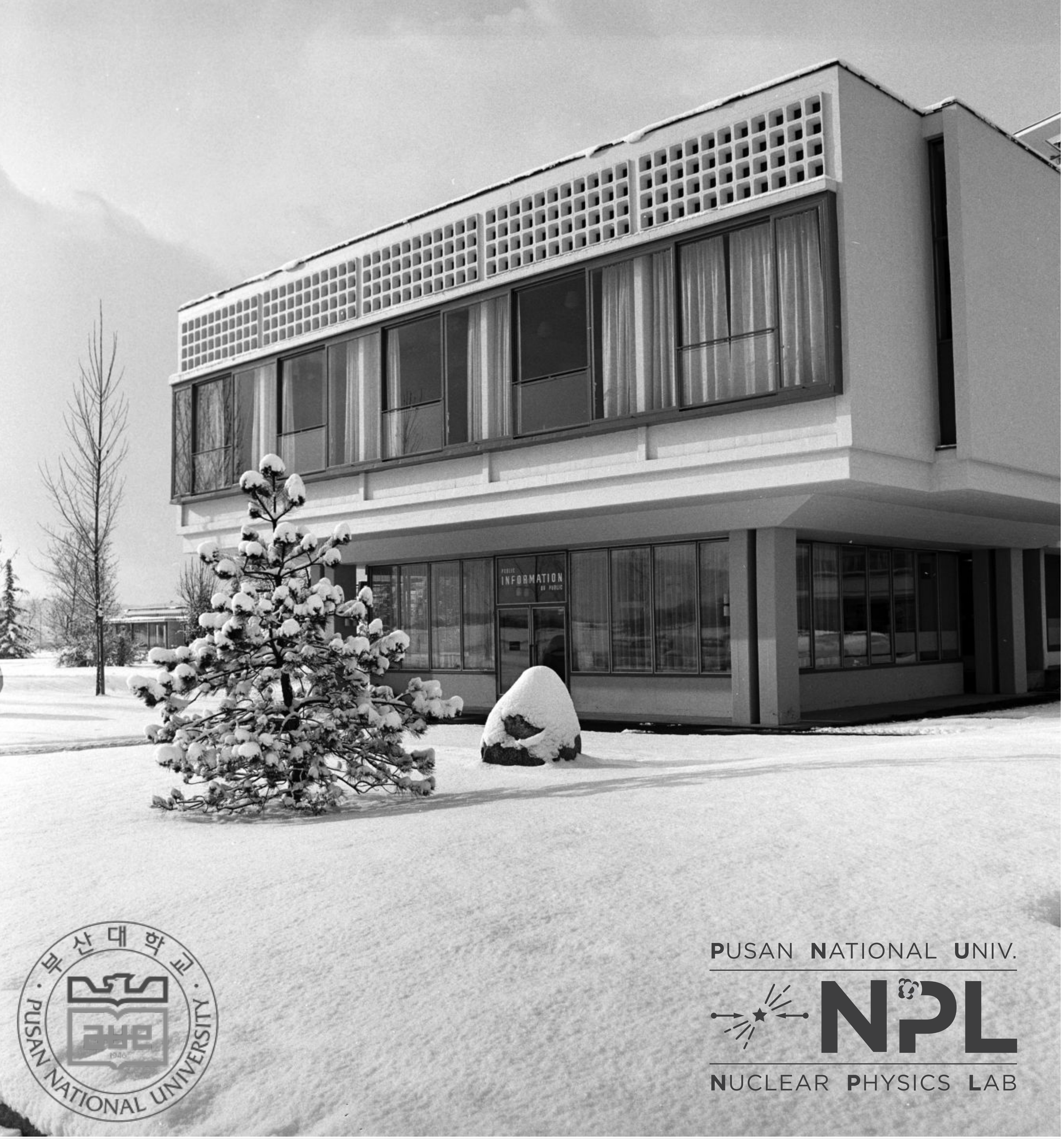


Snowy winter at CERN (near the Council Chamber)

ALICE

Resonance production in ALICE

Jihye Song
Nuclear **P**hysics **L**ab
Pusan National University

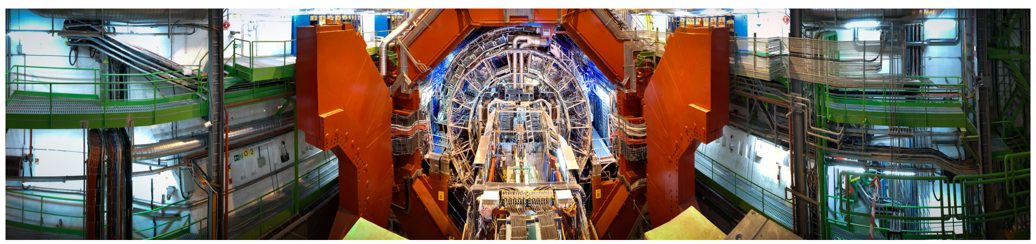
KoALICE workshop
Jan. 4-7, 2022

Outline

- A brief greeting
- What I have been doing
- Resonance production in ALICE
  - motivation
  - ongoing analysis
  - interests in Run3
- Summary & Outlook

A brief greeting

Good to see you and glad to perform the research **as KoALICE member**



Resonance production measured by ALICE at the LHC

Jihye Song
Inha University, Pusan National University
Korea

KoALICE

ALICE

KoALICE National Workshop 2018-2
7-9 January 2019 High1 Resort

Last presentation
at KoALICE workshop

Worked at department of Physics in University of Houston

PUSAN NATIONAL UNIV.
NPL
NUCLEAR PHYSICS LAB

Started do a research at **N**uclear **P**hysics **L**ab in PNU from Nov. 1

What I have been doing

ALICE

- Guide students
  - strange-pentaquark (1670, 1870, 2065, 2255, 2455)
  - strange multi-quark states
  - strange resonance (1820)

+ event by event multiplicity fluctuation
+ flow measurements
+ open charm measurement
+ O2 in ALICE

- Work as resonance PAG convener (2020 Jan. 1) **(published, submitted)**
  - PLB 802 (2020) 135225
  - Eur. Phys. J. C 80 (2020) 160
  - PLB 807 (2020) 135501
  - Phys. Rev. C 102 (2020) 024912
  - arXiv:2105.05760
  - arXiv:2106.13113
  - arXiv:2110.10042

The task was tough than I expected… still,…

What I have been doing

Work as resonance PAG convener **(IRC Review / preparation)**

- Strangeness enhancement in Jet and Medium via ϕ
- Multiplicity & rapidity dependence of $K^{*}(892)^{0}$ and ϕ
- $f_0(980)$ in pp at $\sqrt{s}$ = 5.02 TeV
- $\Sigma(1385)^{\pm}$ in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- Σ0 production in pp at $\sqrt{s}$ = 7 TeV

(Alexander Borissov, Jihye Song, Prof. In-Kwon Yoo, Angela Badala)

- $\Sigma(1385)^{\pm}$ and $\Xi(1530)^{0}$ in pp at $\sqrt{s}$ = 13 TeV

(PC chair(me), Bong-Hwi, Prof. In-Kwon Yoo, Prof. BeomKyu Kim, Enrico Fragiacomo)

+ f0(980) in p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
+ Λ* in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
+ Λ* in pp at $\sqrt{s}$ = 5.02 and 13 TeV
+ Charged K*(892) in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
+ Charged K*(892) in pp at $\sqrt{s}$ = 13 TeV vs. Spherocity

Resonances in ALICE

	quark content	Decay modes	B.R.
$\rho(770)^0$	$(u\bar{u}+d\bar{d})/\sqrt{2}$	$\pi^+\pi^-$	100
$K^*(892)^0$	$d\bar{s}$	$K^+\pi^-$	66.6
$K^*(892)^\pm$	$u\bar{s}$	$K^0_S\pi^+$	33.3
$f_0(980)$, $f_2(1270)$	unknown	$\pi^+\pi^-$	46(84)
$K^*_{0,2}(1430)^0$	$d\bar{s}$	$K^+\pi^-$	93(49.4)
$\phi(1020)$	$s\bar{s}$	K^+K^-	48.9

	quark content	Decay modes	B.R.
$\Sigma(1385)^+$	uus	$\Lambda\pi^+$	87
$\Sigma(1385)^-$	dds	$\Lambda\pi^-$	87
$\Lambda(1520)$	uds	pK^-	22.5
$\Xi(1530)^0$	uss	$\Xi^-\pi^+$	66.7
$\Xi(1820)^{\mp,0}$	dss (uss)	$\Lambda K^\mp$ (ΛK^0_S)	unknown
$\Omega(2012)^\mp$	sss	$\Xi^\mp K^0_S$	unknown

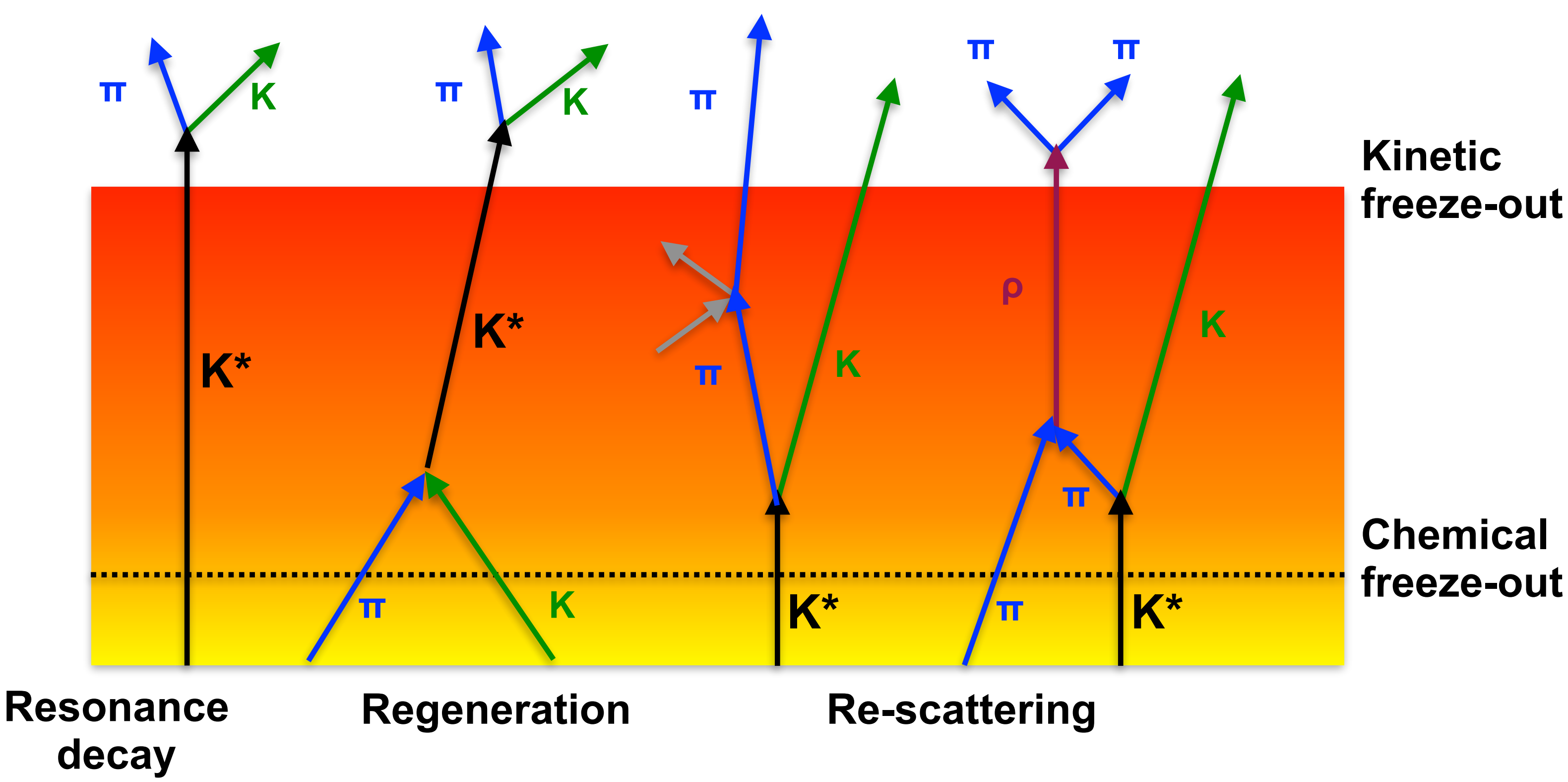
Lifetime(fm/c): **ρ(1.3) < K^{*0}(4.2) < Σ^*(5.0-5.5) < Λ^*(12.6) < Ξ^*(21.7) < ϕ(46.2)**

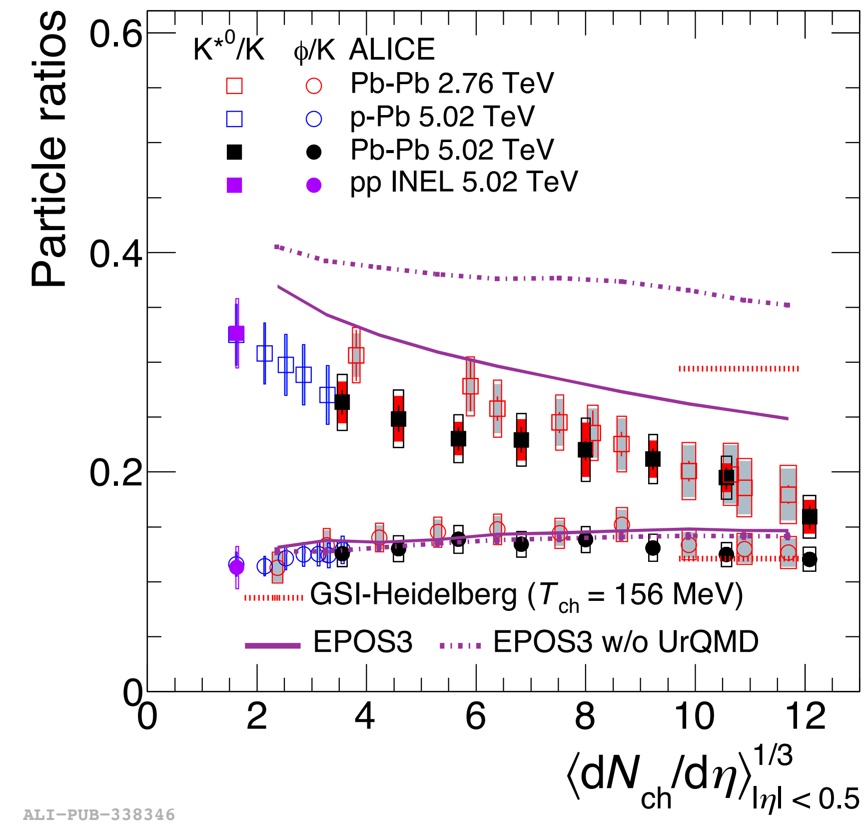
Phys. Lett. B 509, 239 (2001)
Phys. Lett. B 530, 81 (2002)
PLB 802 (2020) 135225

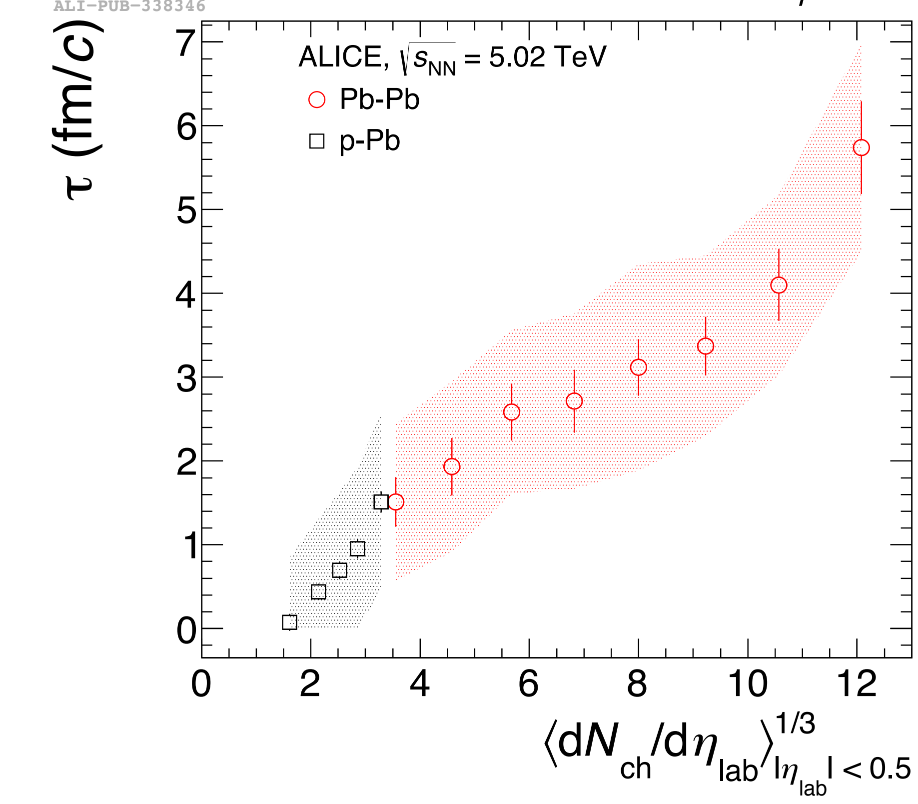
Why Resonances

ALICE

- Resonances have different **short lifetimes** similar to **Hadronic phase**
  - allows the study of properties of hadronic phase in terms of **regeneration and re-scattering** effects
  - estimate the duration between chemical and kinetic freeze-out



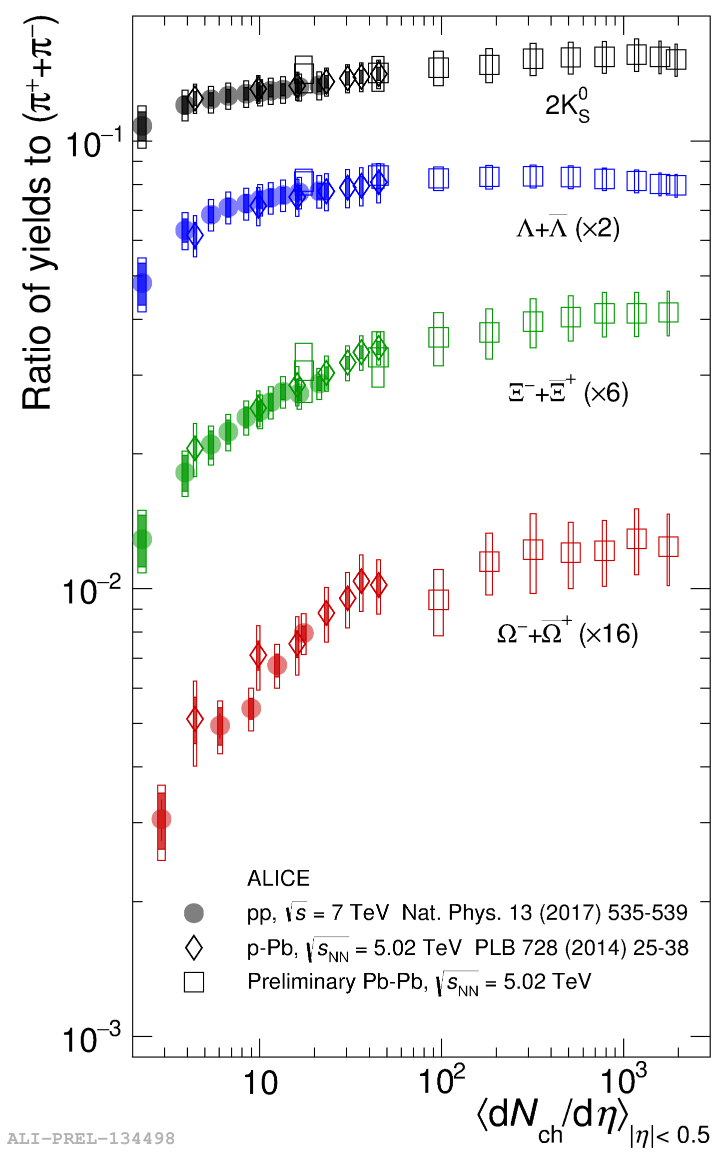


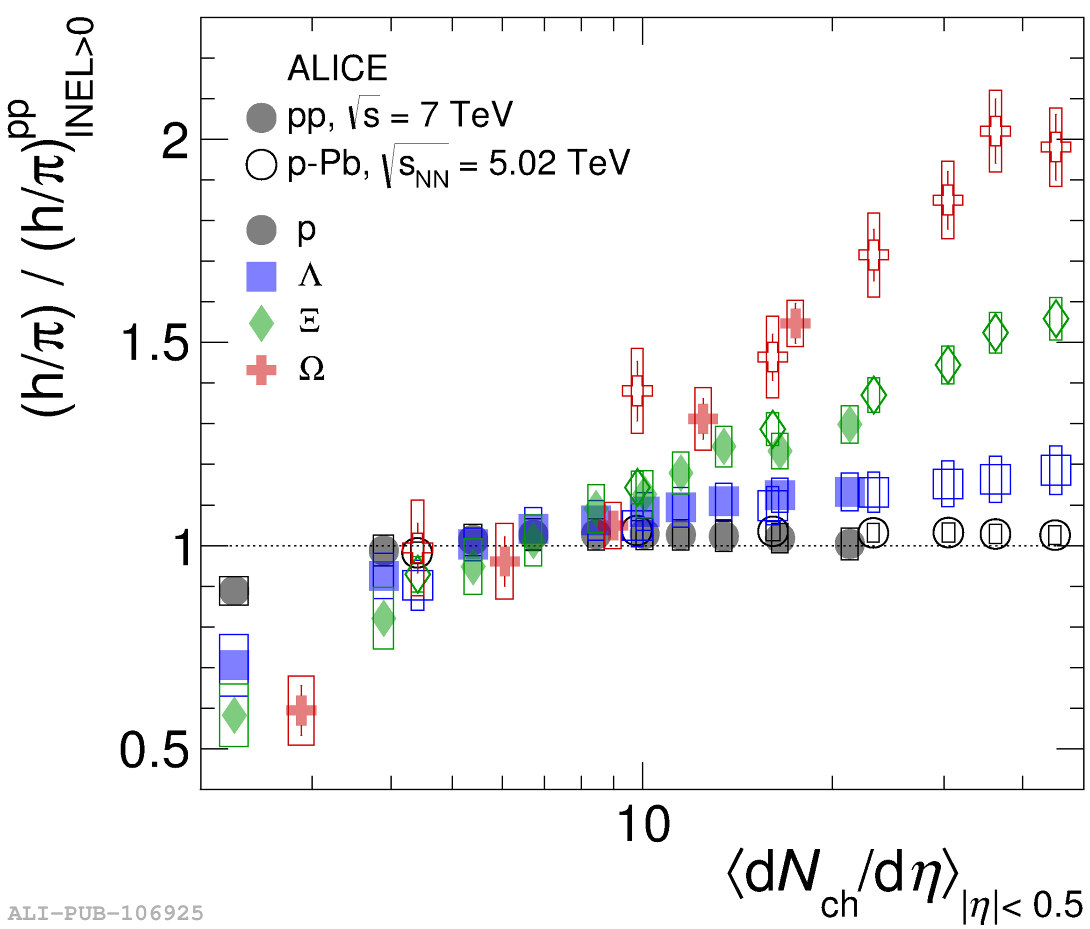


$[K^{*0}/K]_{kinetic} = [K^{*0}/K]_{chemical} \times e^{-\tau/\tau_{K^{*0}}}$

Why Resonances

- Same quark content as the ground state particles, but different masses - help to understand **strangeness production** by factorizing mass and strangeness related effects





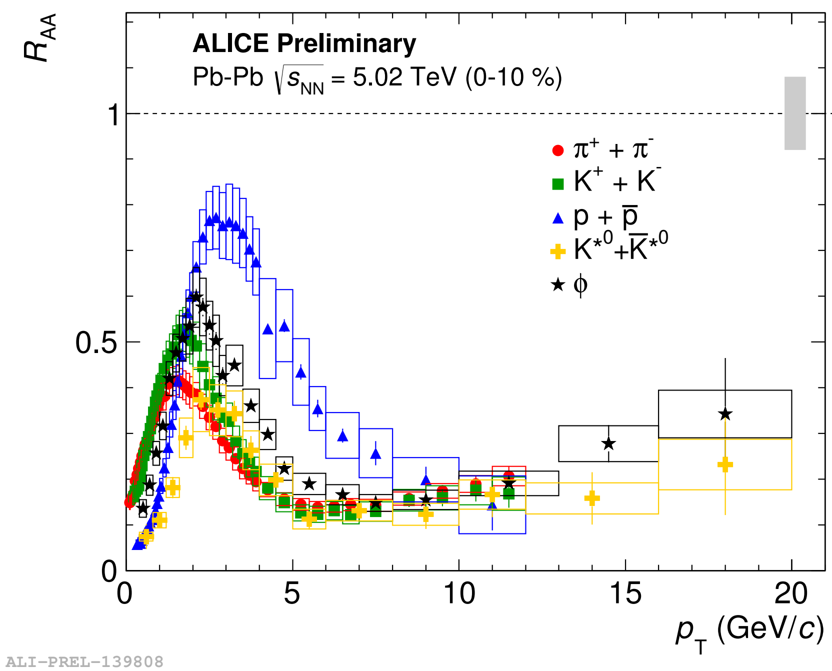
s=1: Λ(1116)
s=2: Ξ(1320)
s=3: Ω(1670)

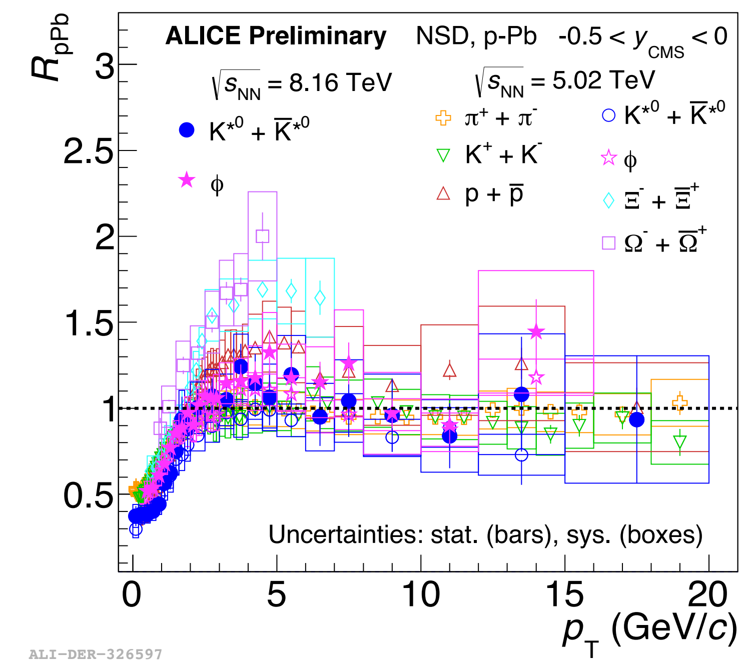
s=1: Σ*(1385)±, Λ*(1520)
s=2: Ξ*(1530)⁰
s=3: Ω(2012)∓

Why Resonances

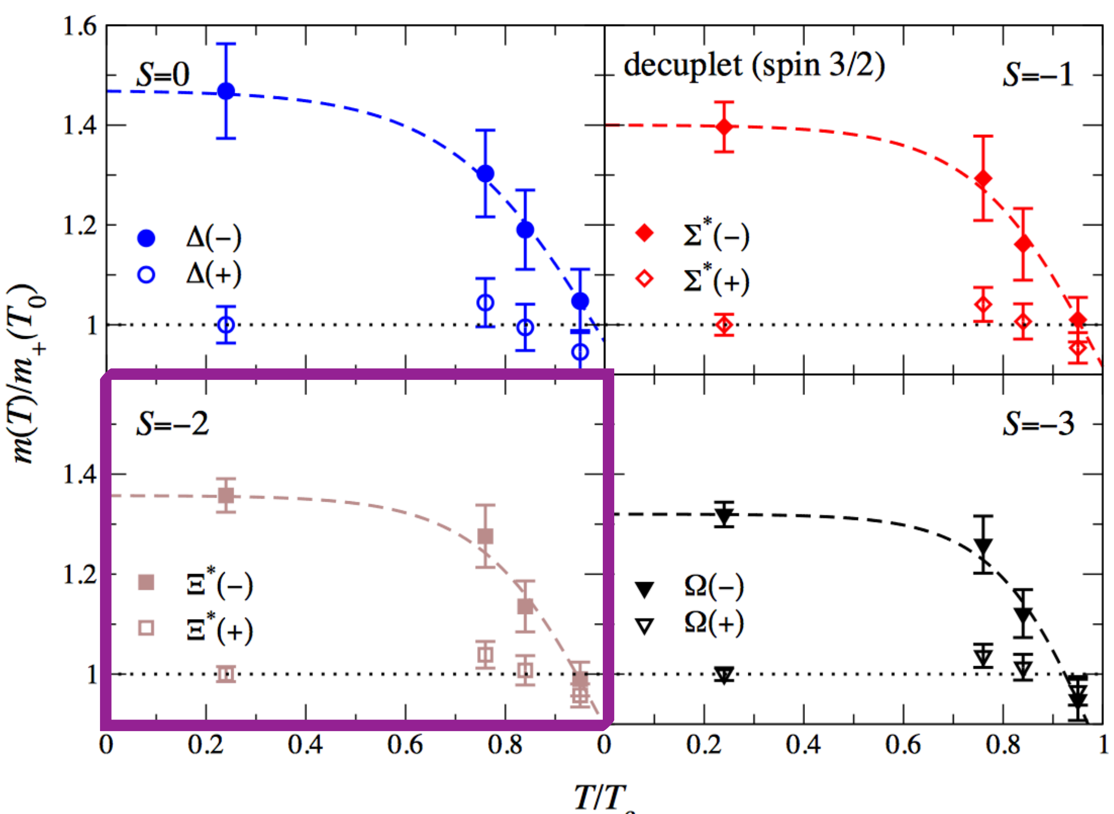
Resonance production contributes

☆ ***In medium energy loss + CNM effects***





☆ ***Chiral symmetry restoration***



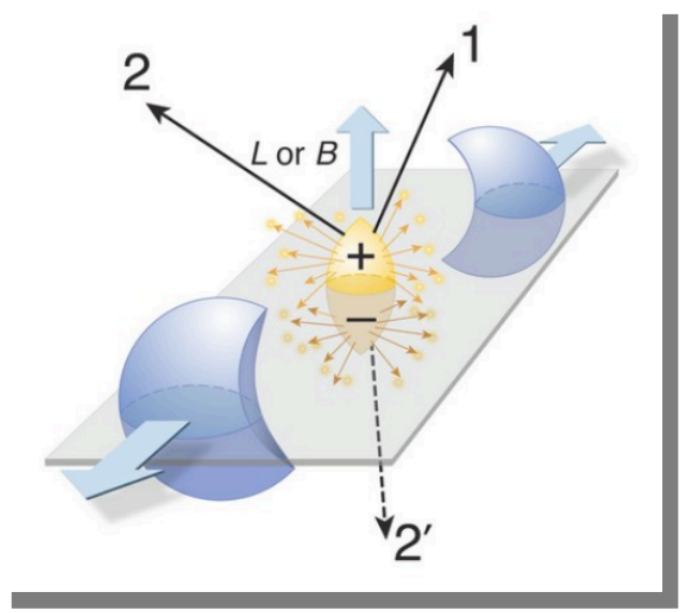
- Calculation from FASTSUM Collaboration shows potential parity doubling
  - signature of chiral symmetry restoration in heavy-ion collisions
  - expected signal: mass shift, width broadening or change in yield ratio between Ξ(1820) and Ξ(1530)

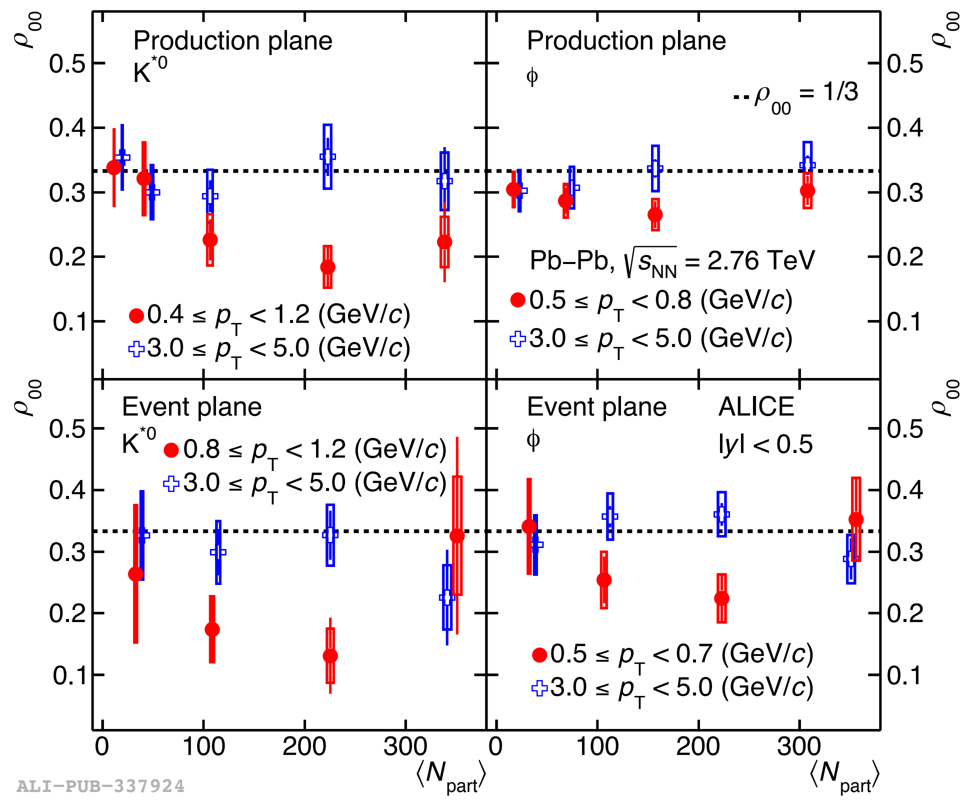
10.1051/epjconf/201817114005

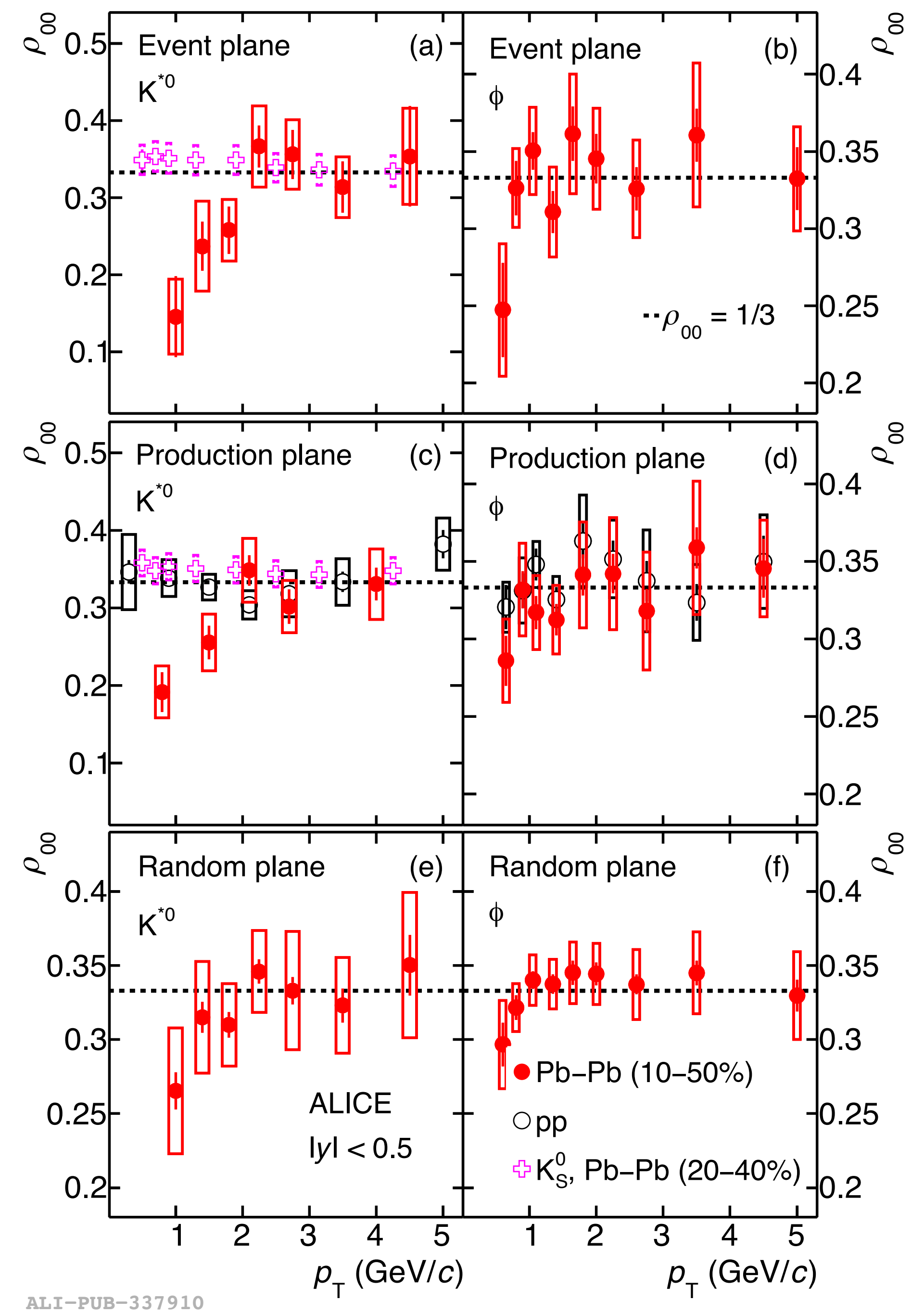
Why Resonances

Resonance production contributes

☆ ***Spin alignment in heavy-ion collisions***







- Large angular momentum [1] and intense magnetic field [2] is expected in initial stage of heavy-ion collisions
  - spin alignment of vector meson could occur

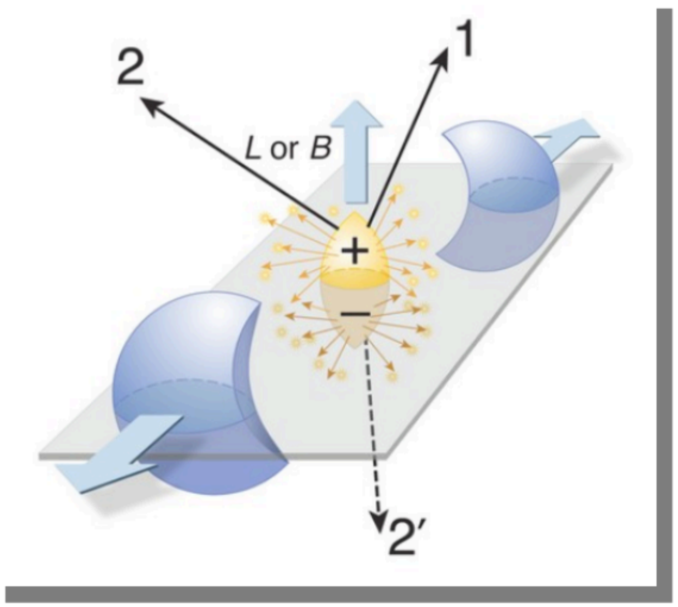
[1] F. Becattini et al.,Phys.Rev.C 77 (2008) 024906
[2] D. E. Kharzeev et al., Nucl.Phys.A 803 (2008) 227

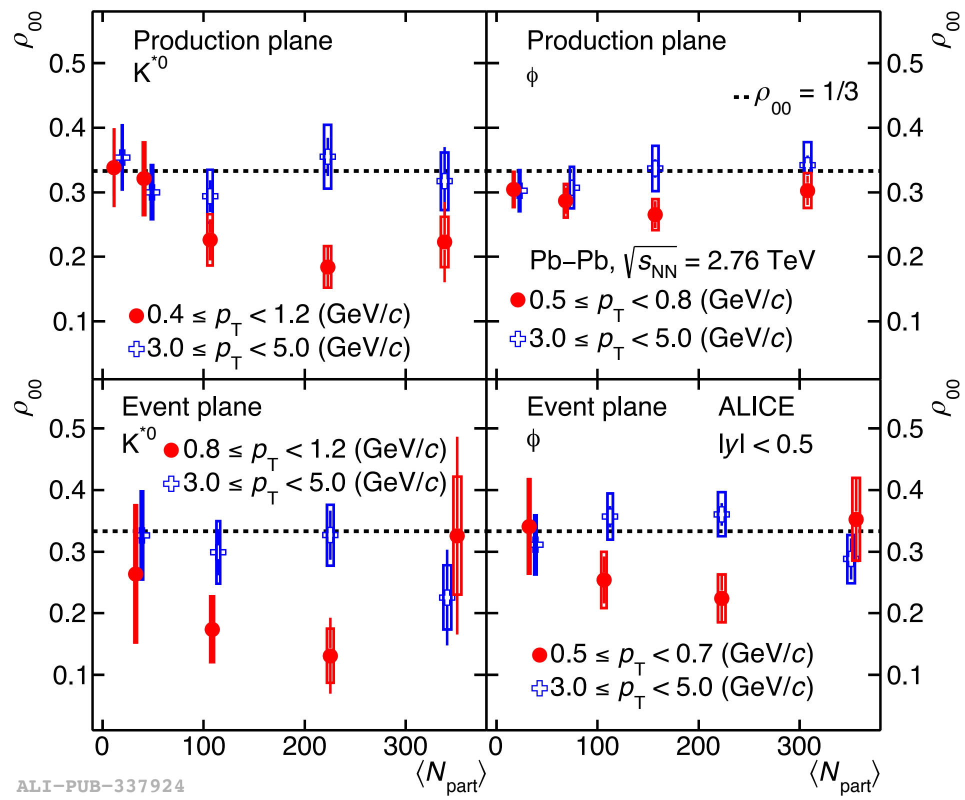
Why Resonances

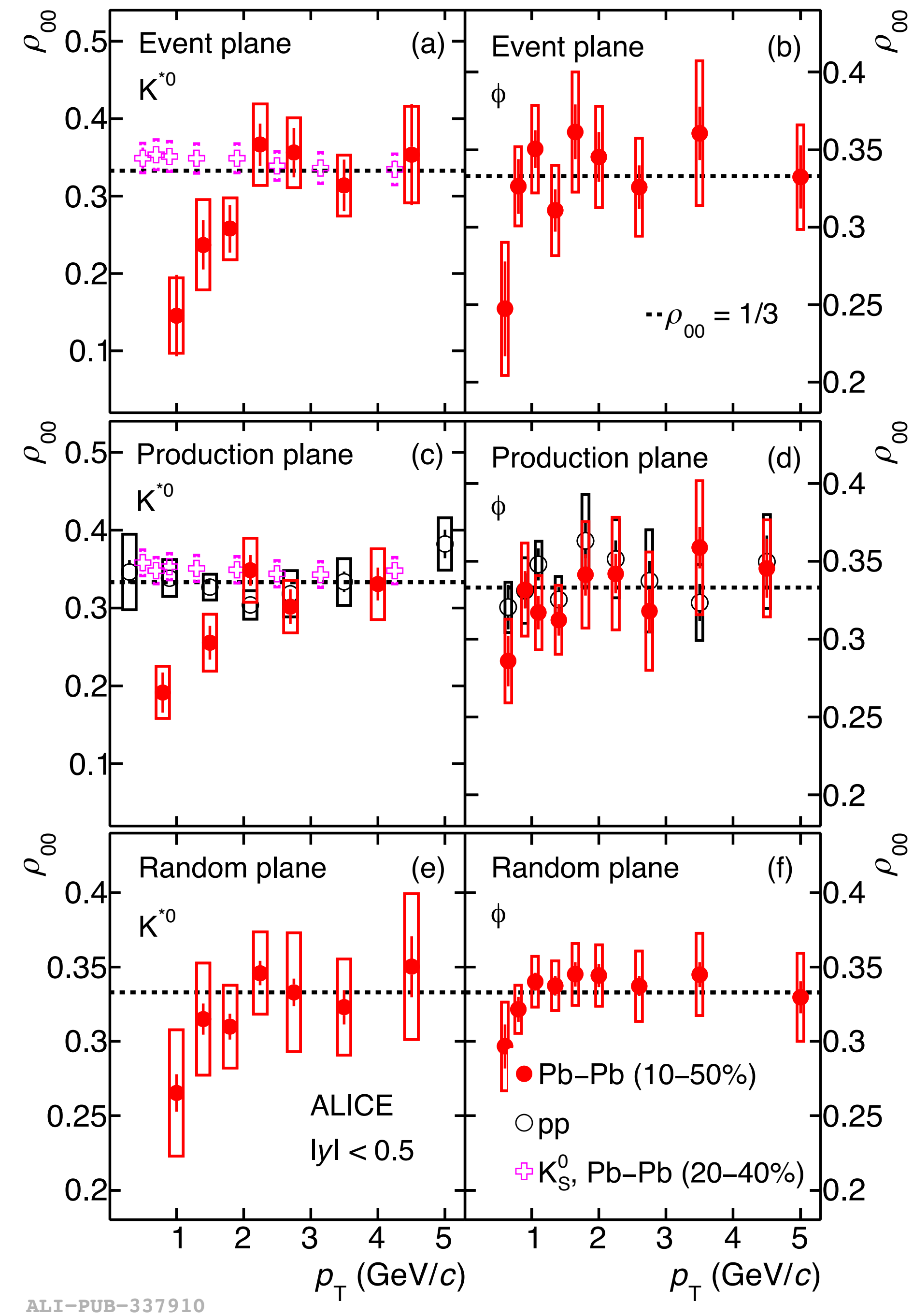
ALICE

Resonance production contributes

⭐ ***Spin alignment in heavy-ion collisions***







Experimental observable

$$\frac{dN}{d(\cos\theta^*)} \propto (1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*$$

- ... se magnetic ... eavy-ion
  - spin alignment of vector meson could occur

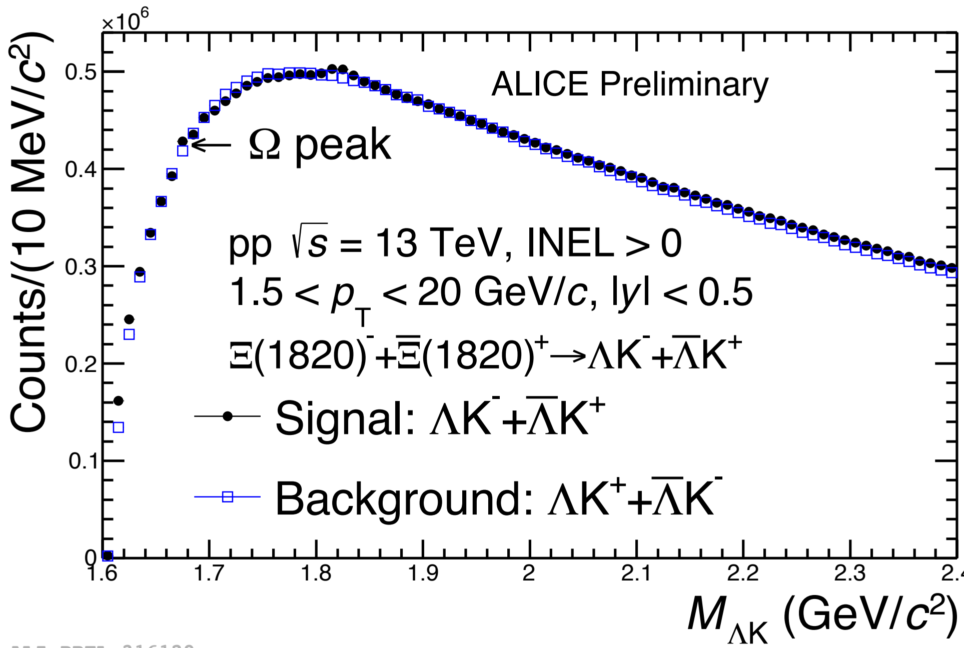
ρ_{00}: Element of spin density matrix
if ρ_{00} = 1/3, No spin alignment

[1]
[2]

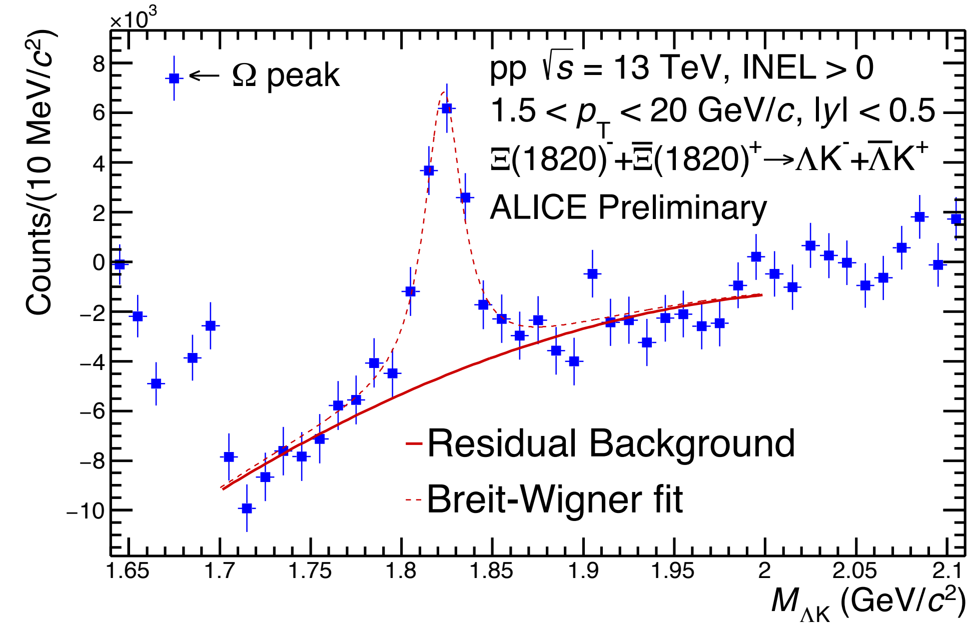
PhysRevLett.125.012301 (2020)

Reconstruction of $\Xi(1820)$

Charged decay channel



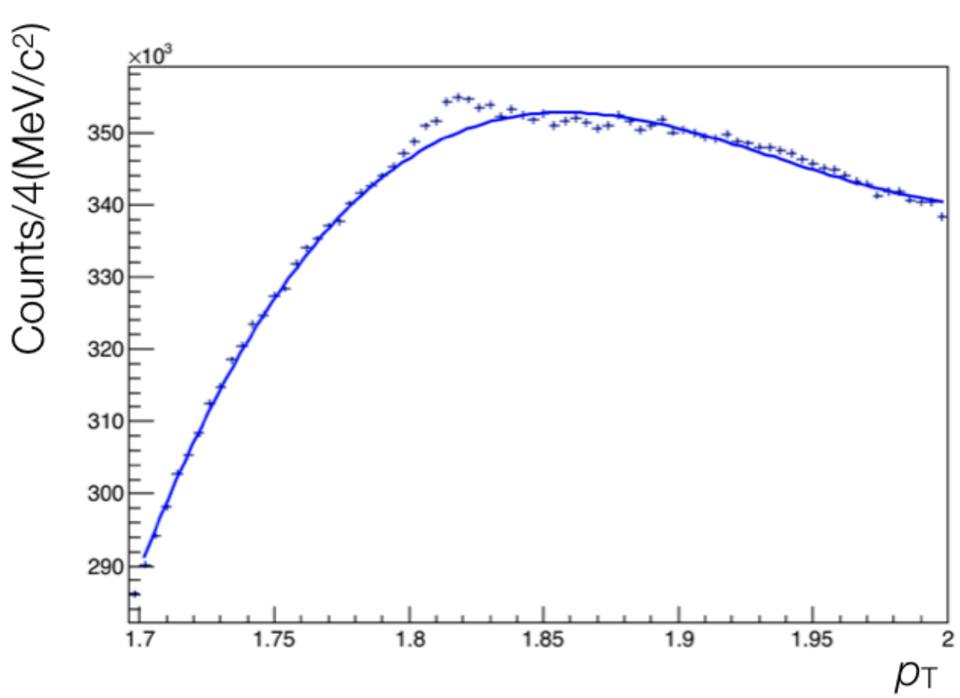
ALI-PREL-316129



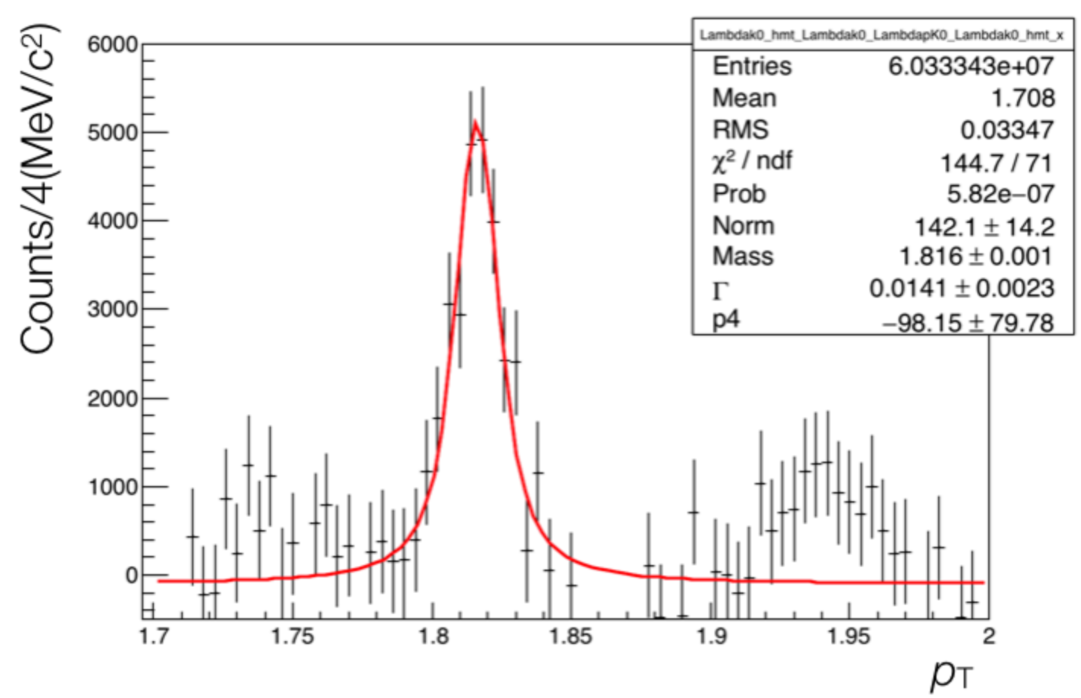
ALI-PREL-316134

Neutral decay channel

$X \to \Lambda(\bar{\Lambda})K_S^0$ 0-100%, $1.5 < p_T < 20$ GeV/c



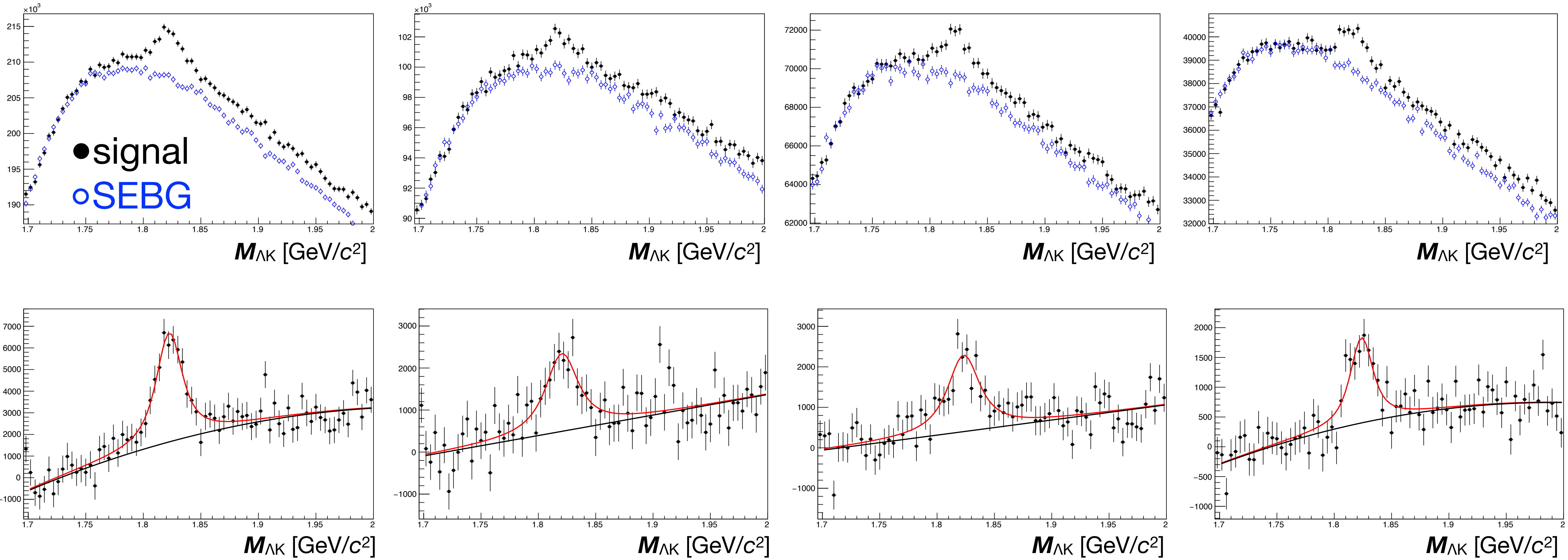
$X \to \Lambda(\bar{\Lambda})K_S^0$ 0-100%, $1.5 < p_T < 20$ GeV/c



Signal extraction(pp): $\Xi(1820)^{\mp}$

Minimum-bias events (1.0 < p_T < 20 GeV/c) Inv. mass vs. Multiplicity

0-100% **0-10%** **10-30%** **30-100%**



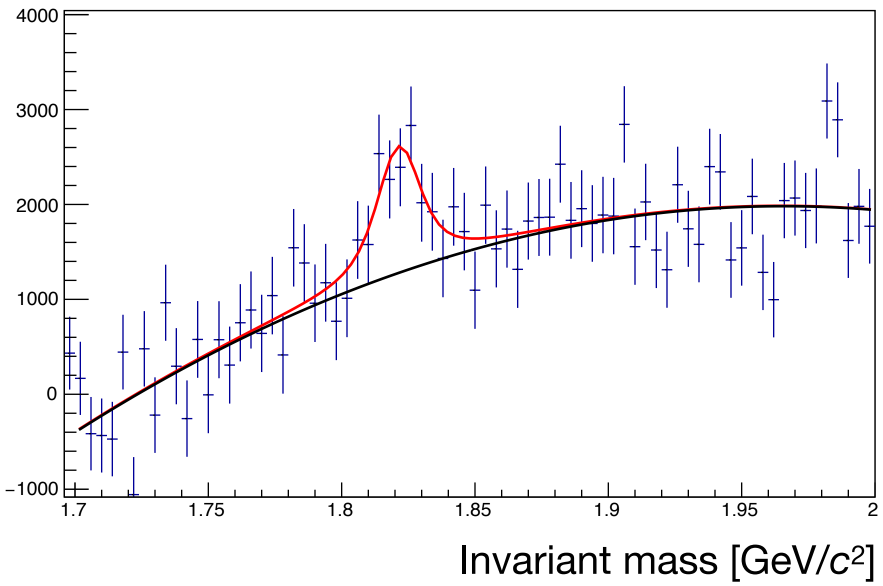
- Invariant mass distribution in different multiplicity classes

Signal extraction(pp): Ξ(1820)$^{\mp}$

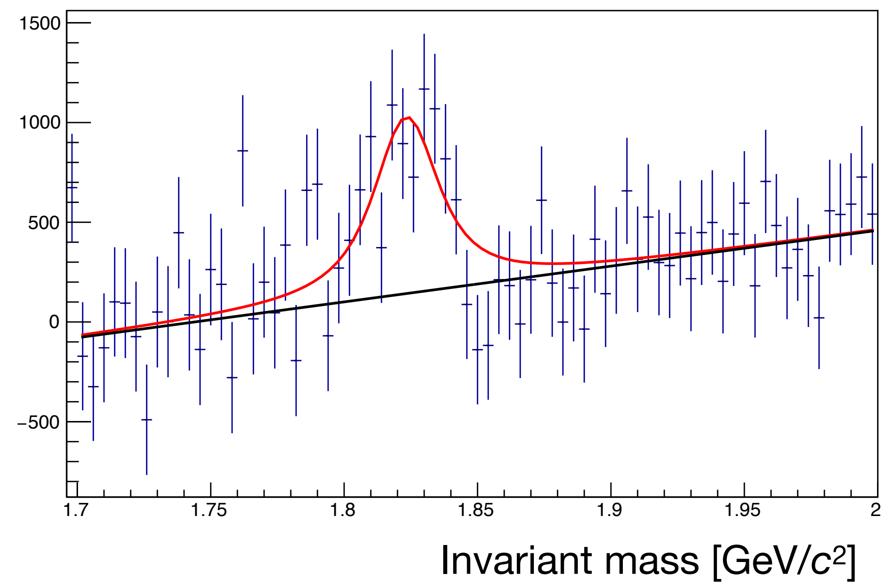
ALICE

Minimum-bias events (Inv. mass vs p_T)

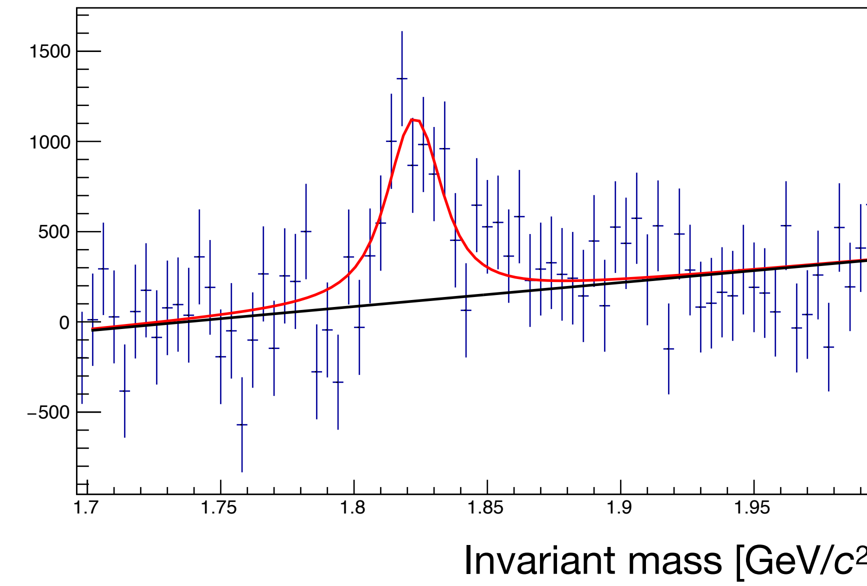
1-2.1 GeV/*c*



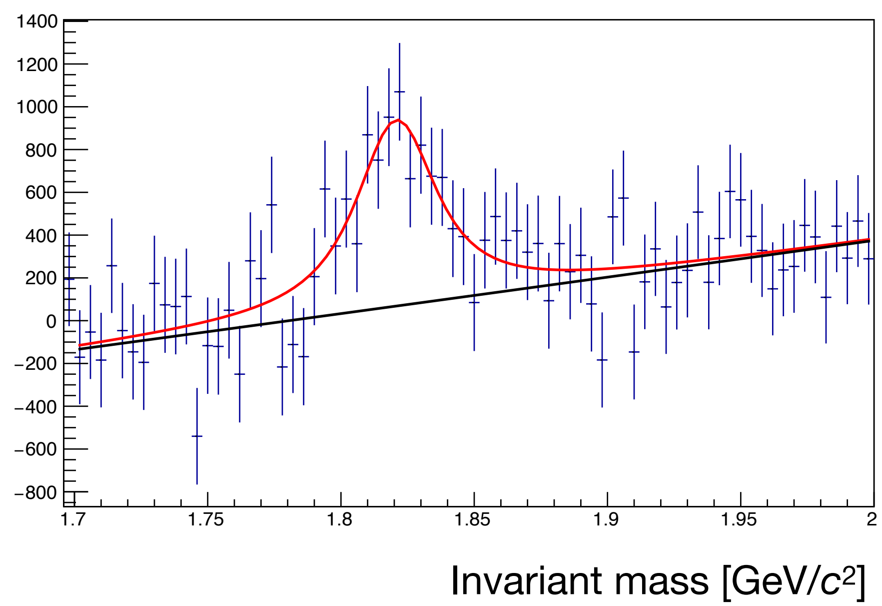
2.1-2.5 GeV/*c*



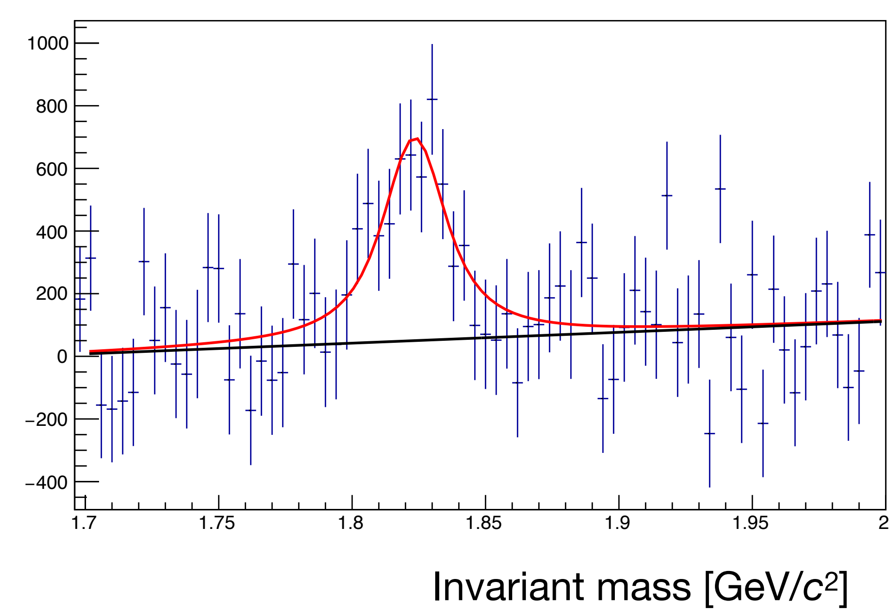
2.5-3 GeV/*c*



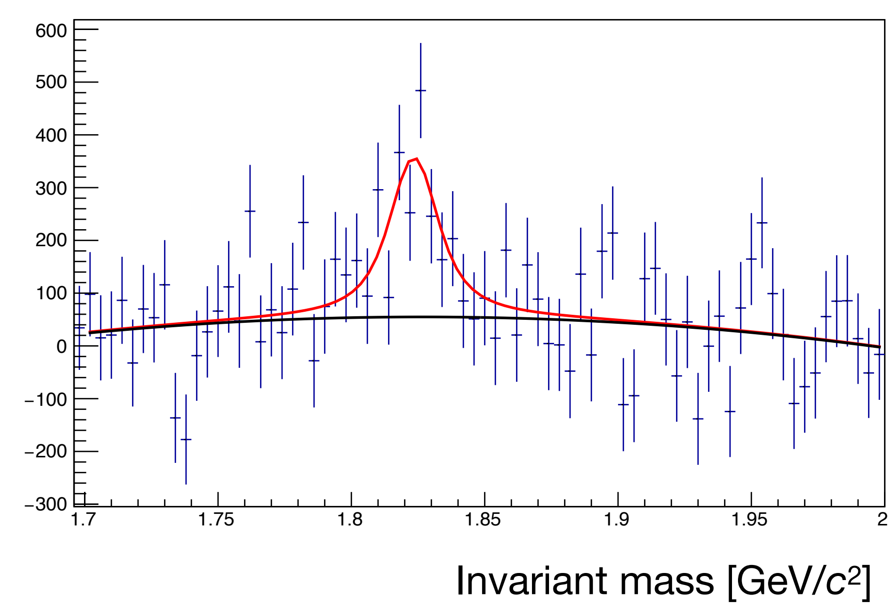
3-3.7 GeV/*c*



3.7-5 GeV/*c*



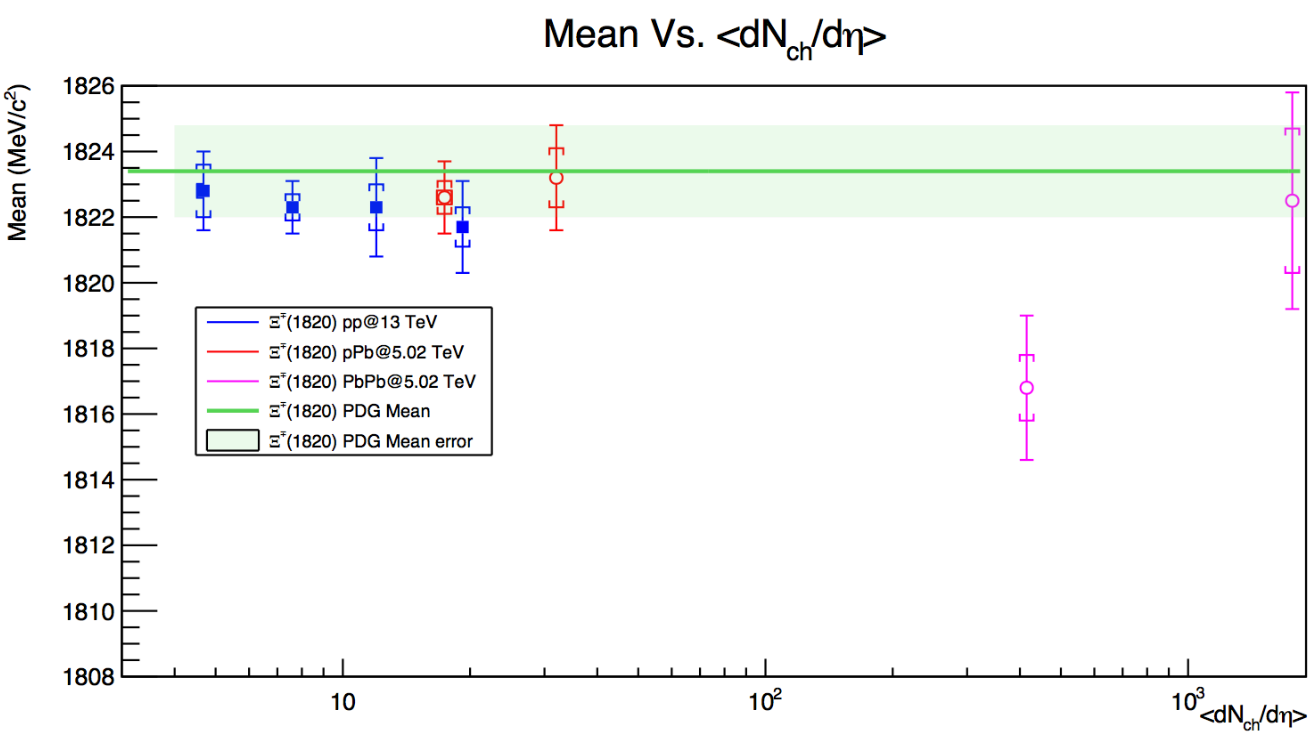
5-7 GeV/*c*

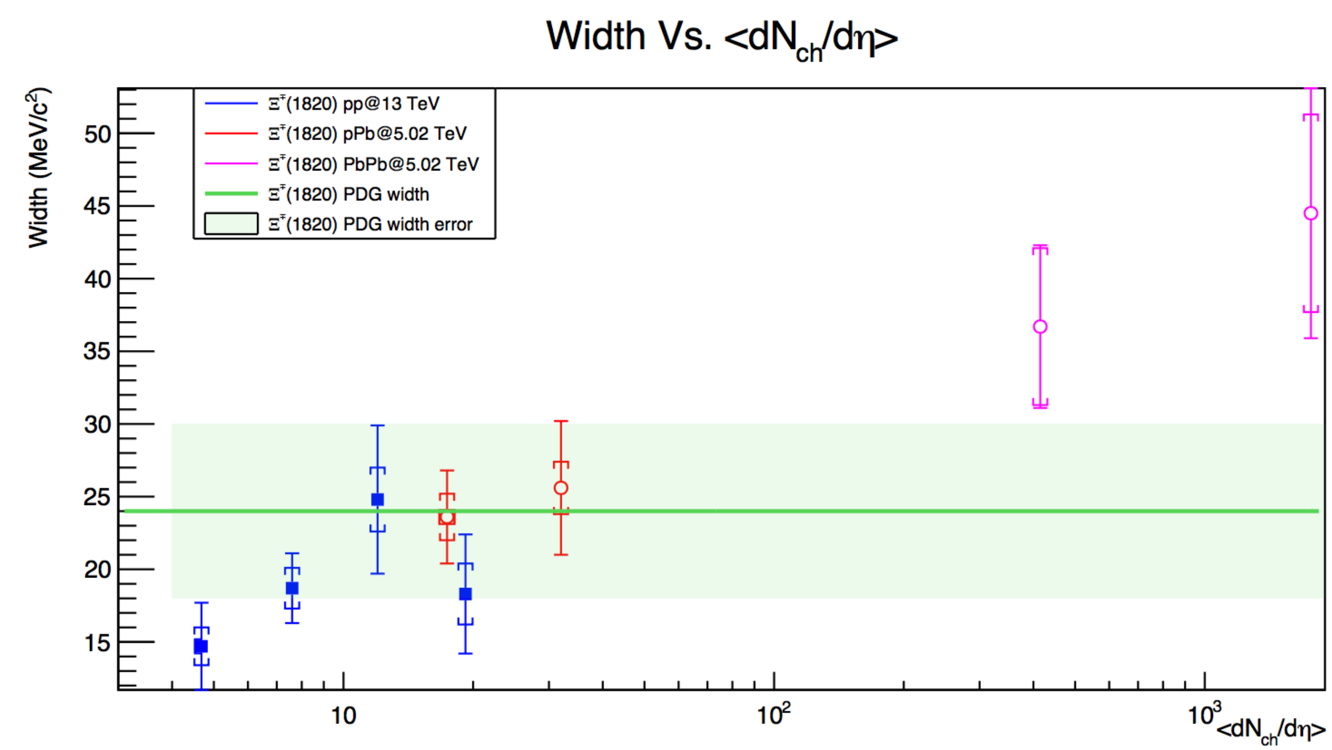


Signal: Voigtian fit (free mass, fix σ, free Γ)

- Invariant mass distribution in different p_T bin with pp

Mass & Width of Ξ(1820)$^{\mp}$

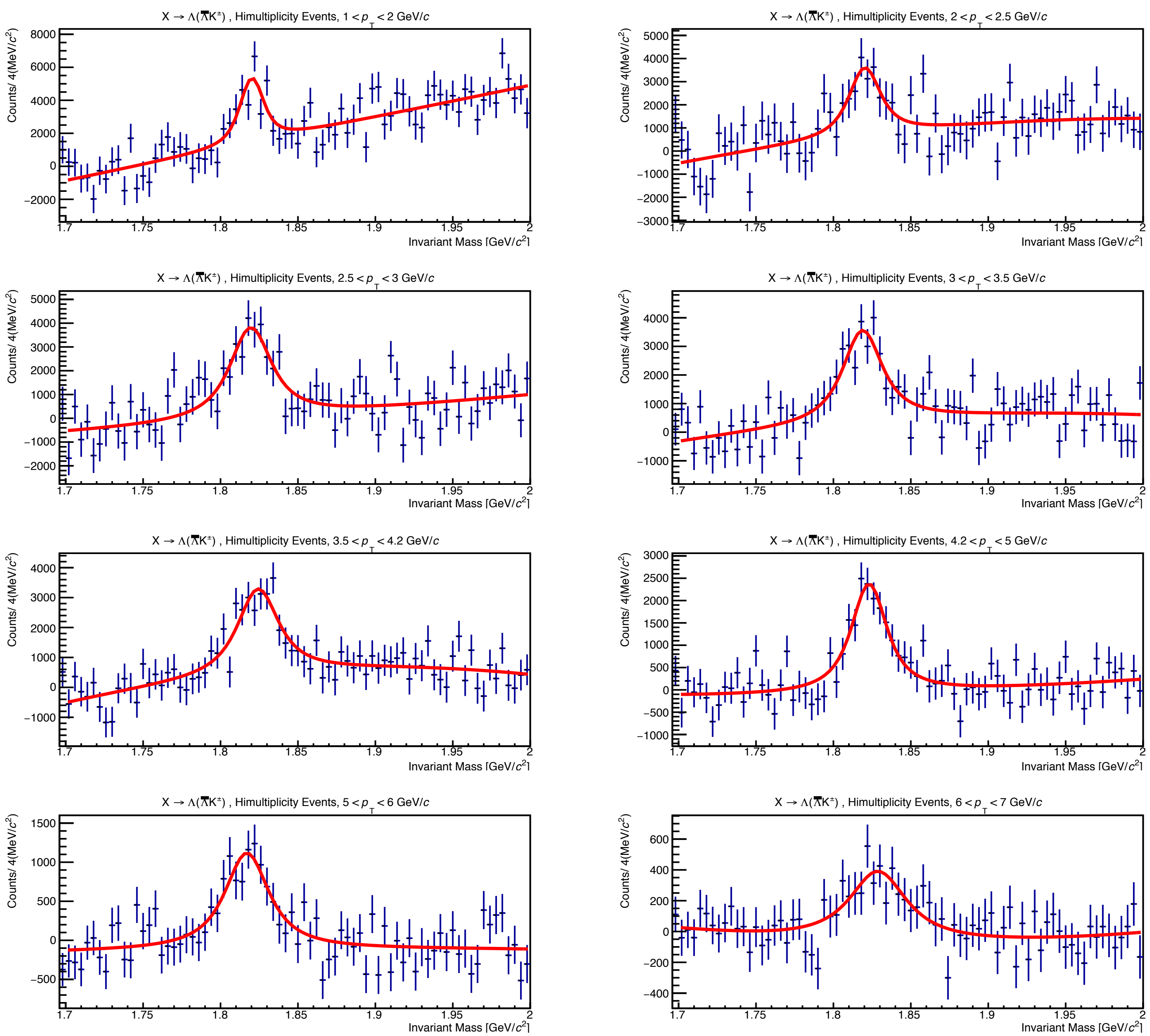


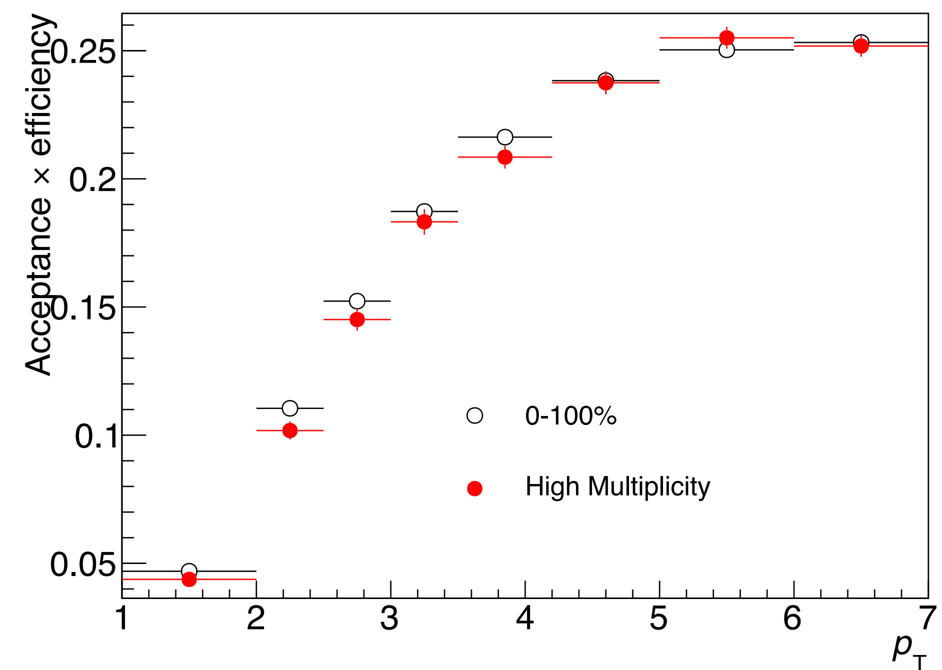


- Mass & width vs. multiplicity

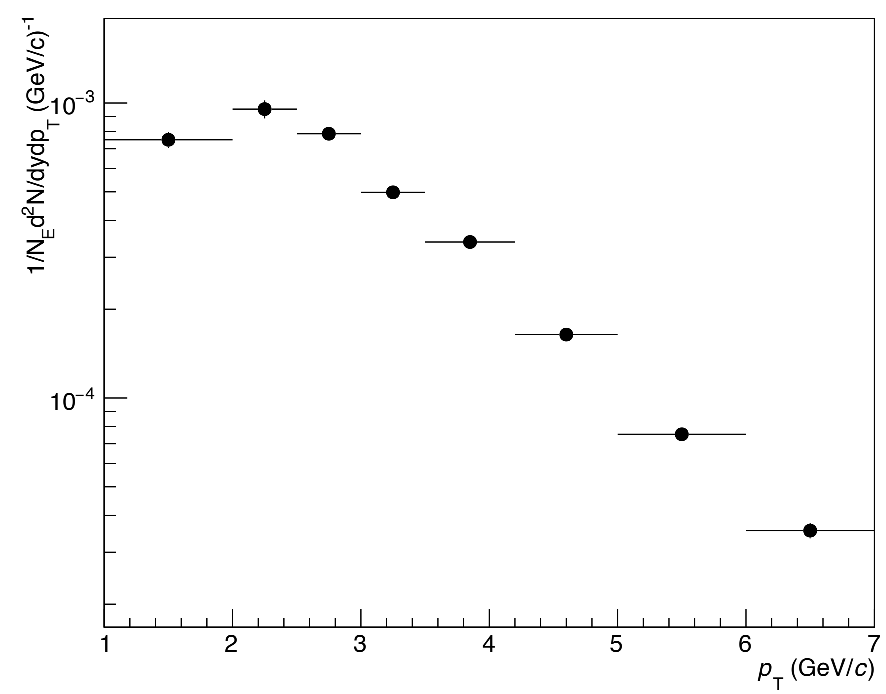
- 2.22σ difference between pp 100% and Pb-Pb 0-10% for width
  - might be a signal of chiral symmetry restoration
  - need to do a more precise measurement

Reconstruction of $\Xi(1820)^{\mp}$



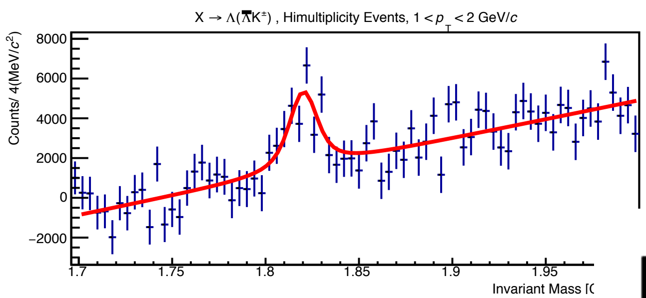


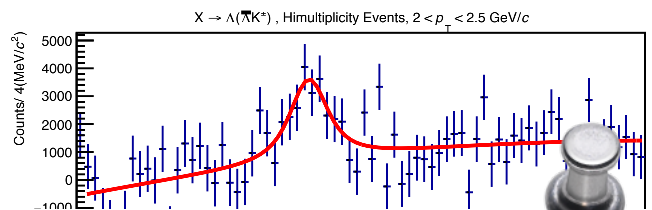
Ξ(1820) spectrum

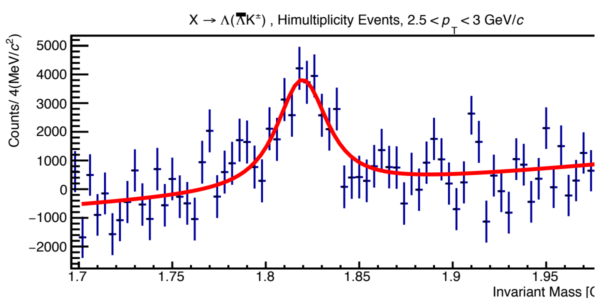


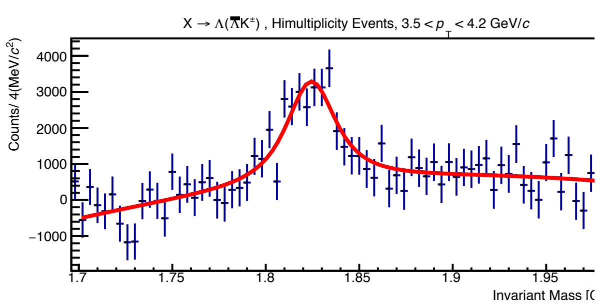
- Spectrum is obtained with pp @ 13 TeV data sample with HM trigger

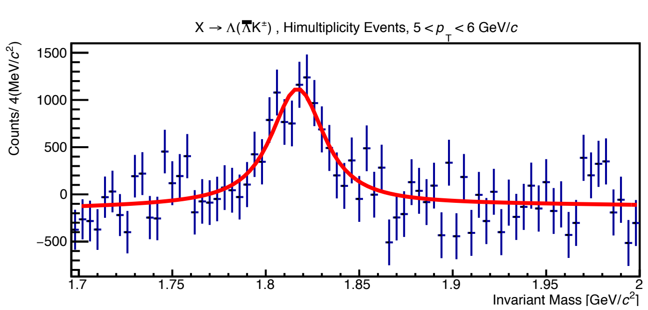
Reconstruction of $\Xi(1820)^{\mp}$

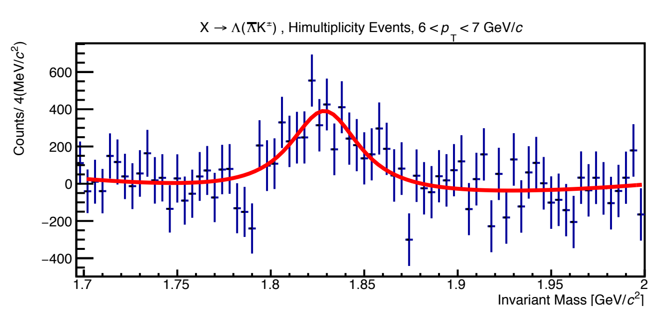


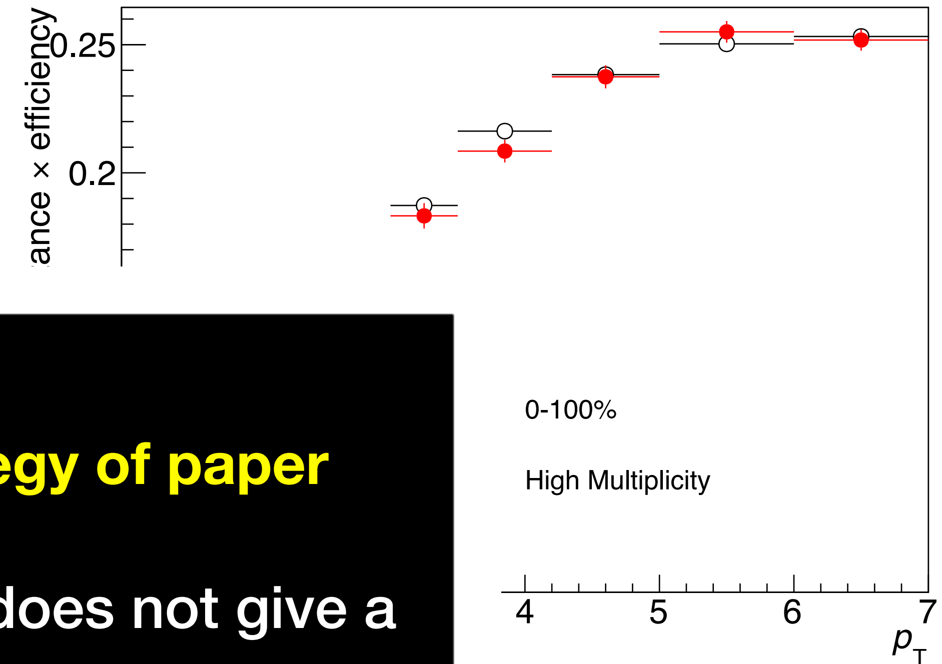




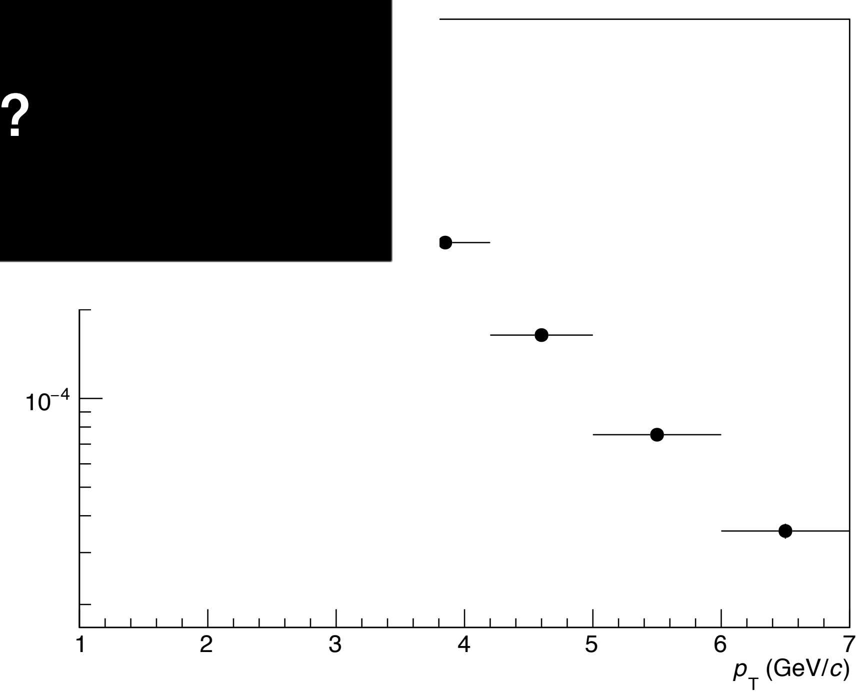








) spectrum



Need to think on the strategy of paper

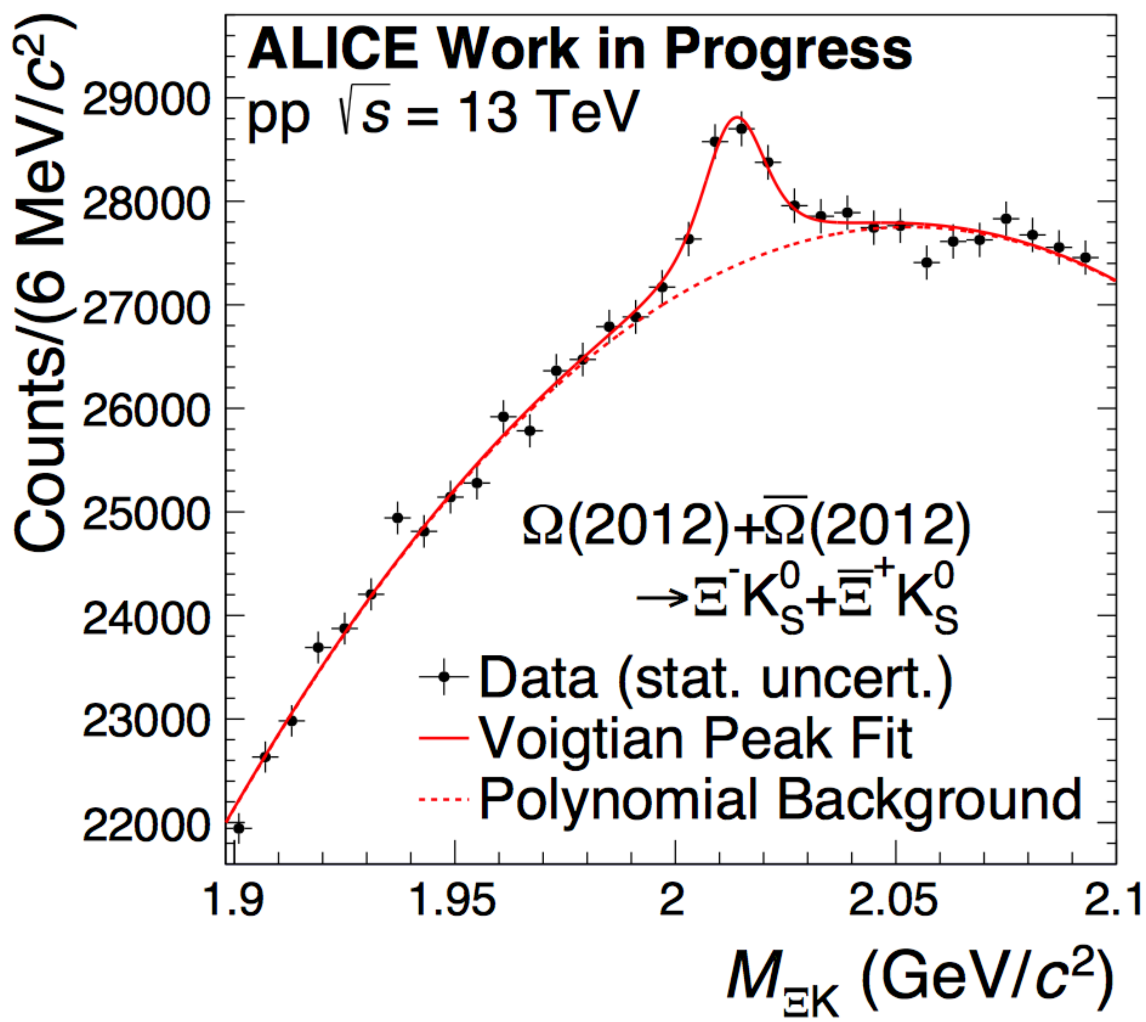
- Branching ratio is not defined
- Direct measurement of yields does not give a physics message
- Mass and width ?
- Spectrum compared with model ?

- Spectrum is obtained with pp @ 13 TeV data sample with HM trigger

Higher mass resonances

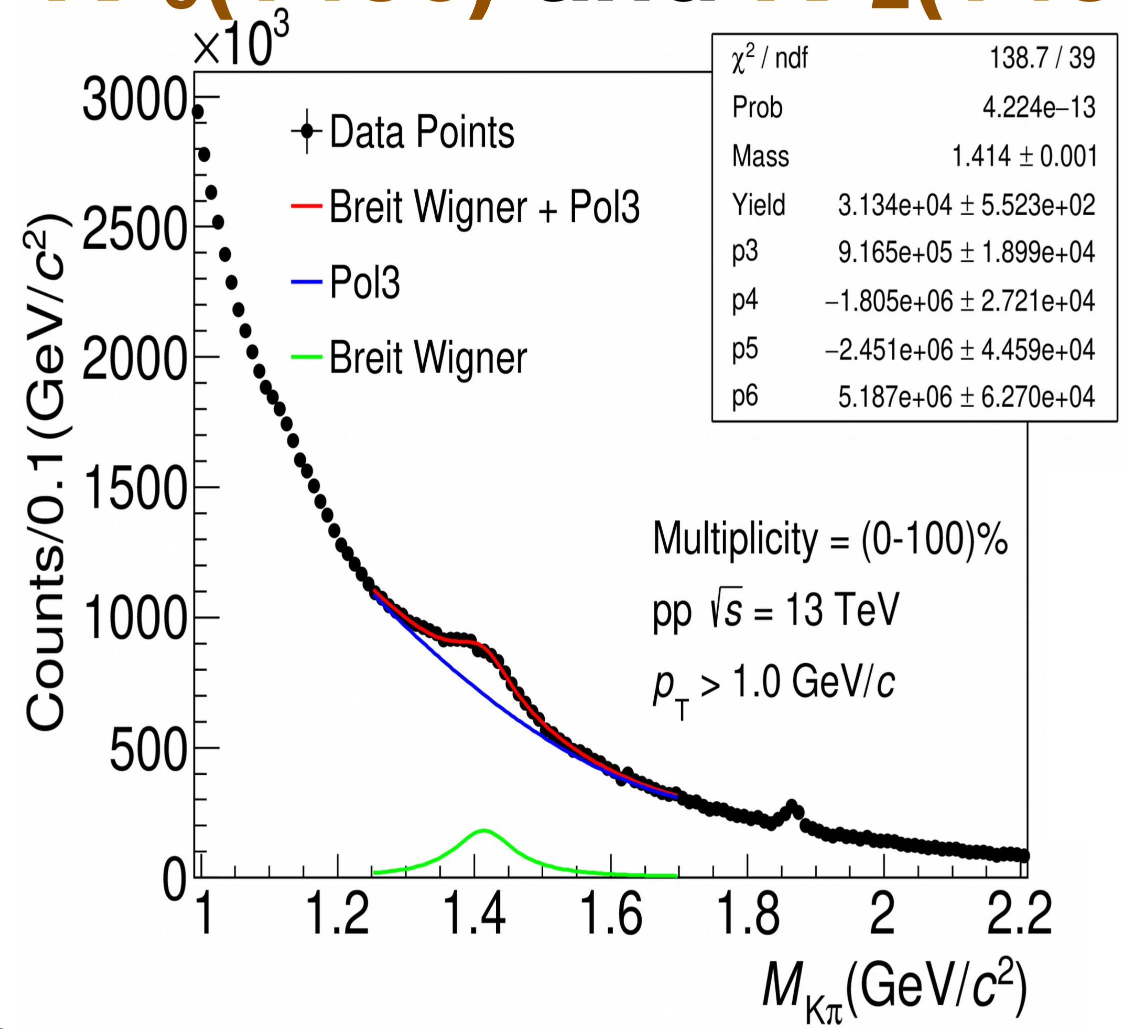
ALICE

Ω(2012)$^{\mp}$



- Could contribute to the study of strangeness production
- attempt to study of parity doubling for Ω(2012)(3/2$^-$) and ground-state Ω(3/2$^+$)

K*$_0$(1430) and K*$_2$(1430)



- Challenge to separate two resonance states
  - Currently mass and width of K*$_0$ have larger uncertainties. The measurement of K*$_0$ could help to reduce them

	K$_0$*	K$_2$*
Mass [MeV/c²]	1425±50	1432±1.5
Width [MeV/c²]	270±80	109±5

Jihye Song

Higher mass resonances

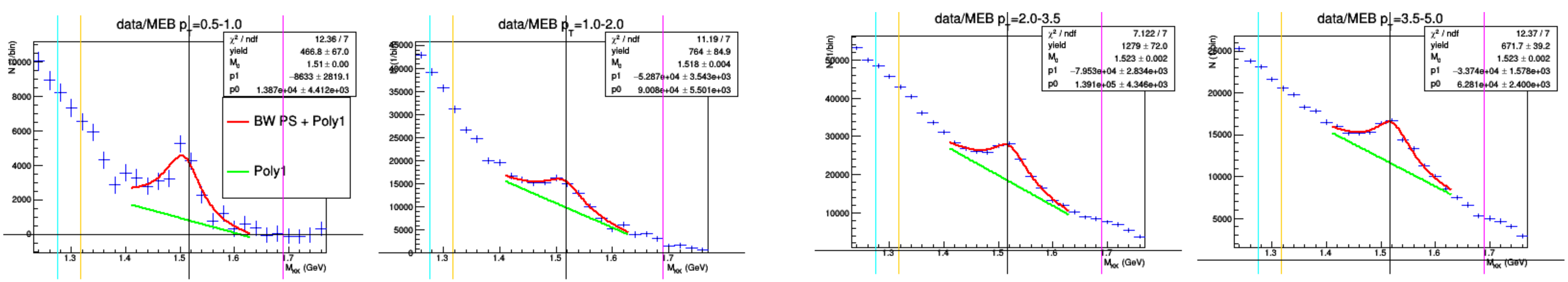
Table 1: K^+K^- resonances in the region $m_{f'_2} \pm 3\Gamma_{f'_2}$

	$f_2(1270)$	$a_2(1320)$	$f_0(1500)$	$f'_2(1525)$	$\rho_3(1690)$	$a_2(1700)$
Γ (MeV/c)	186.7 ± 2.5	107 ± 5	112 ± 9	86 ± 5	161 ± 10	258 ± 40
BR(%)	4.6	4.9	8.5	87.6	1.6	1.9

$f'_2(1525)$

- Other K^+K^- resonance: 10 times smaller BR and larger width than $f'_2(1525)$
- will be difficult to rectangle f0(1500) and f'2(1525) (close mass and width)

Signal extraction $1.25 < M_{KK} < 1.75$ GeV/c^2



- Signal is promising with LHC16kl data sample (~ 76M events)
- Q. State belongs to a system of mesons with hidden strangeness?

DOI: 10.1134/1.568160

Summary & outlook

- Hadronic resonances are valuable probes to study the properties of hadronic phase and strangeness production (+chiral symmetry restoration, in medium energy loss, spin alignment, flow, etc.)
- Ξ(1820) has been analyzed with pp, p-Pb and Pb-Pb data sample
- Measurements of higher mass resonances are very interesting with RUN3 data
  - Ξ(1820) and Ω(2012) can contribute to study chirality and strangeness enhancement
  - signal extraction of $K^*_{0,2}(1430)$ and $f'_2(1525)$ mesons are challenging but might be able to analyze with new data sample