Spin alignment measurements of vector mesons with ALICE detector at the LHC

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Outline:

- Physics Motivation
- Experimental observable
- ALICE detector setup
- Results
- Summary

The 18th International Conference on
Strangeness in Quark Matter (SQM 2019)
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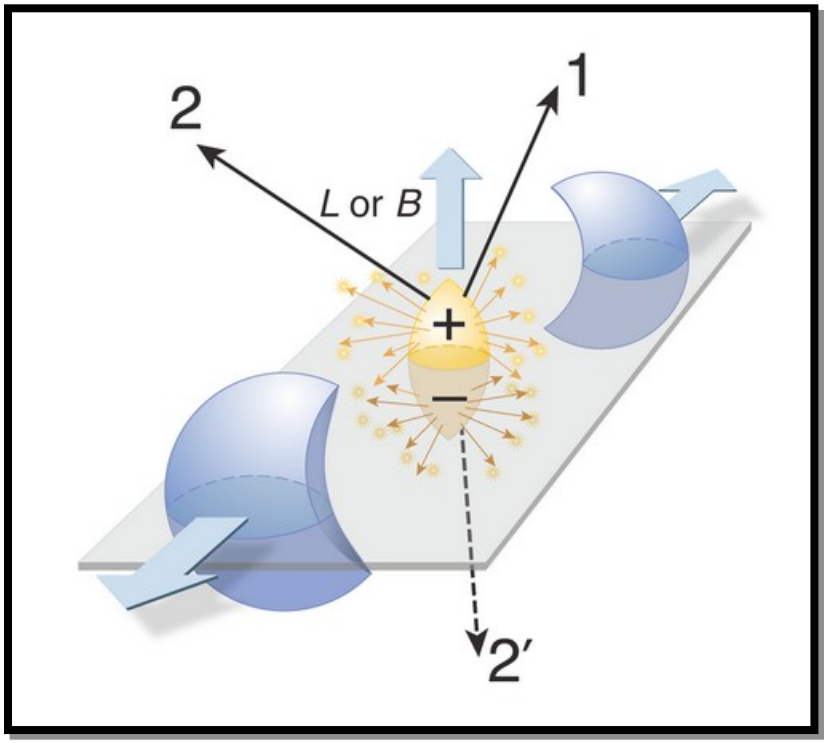
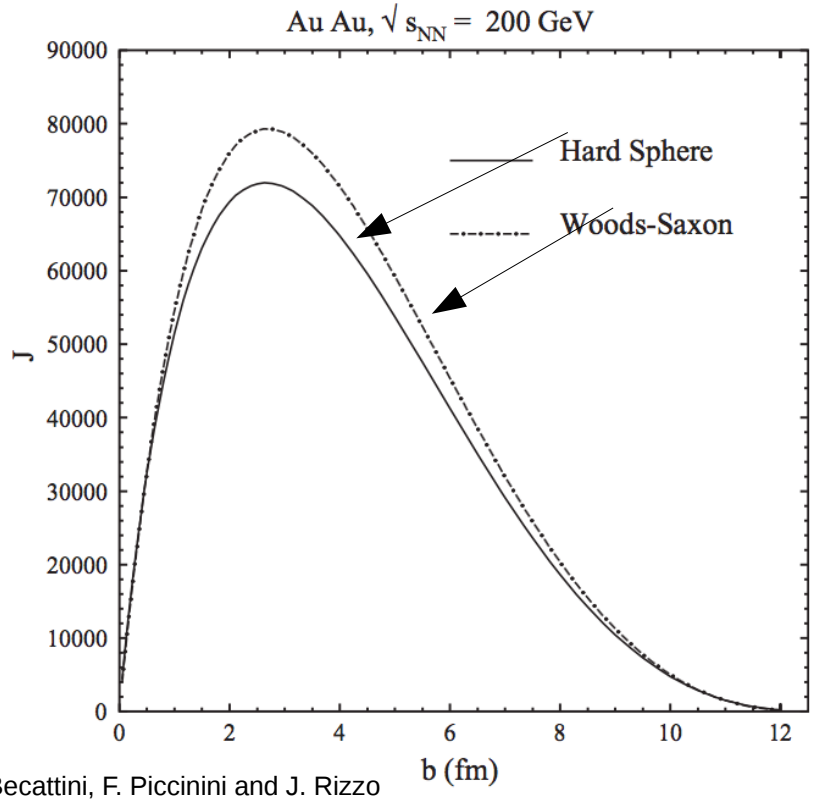
Motivation





F. Becattini, F. Piccinini and J. Rizzo
Phys.Rev.C 77, 024906 (2008)

- ✔ Large initial angular momentum is created in non-central heavy-ion collisions
- ✔ Vector mesons (spin=1) can be polarized due to spin-orbit interaction
- ✔ Spin alignment/polarization is a sensitive probe to vortical structure of QGP, and particle production mechanisms

Goal: Look for signature of these in measurements

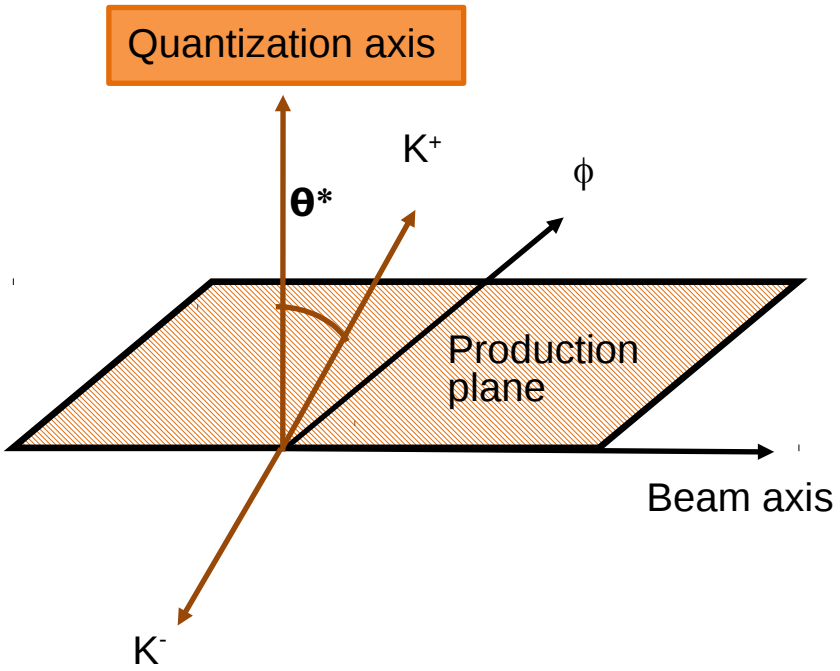
Angular distribution of vector mesons

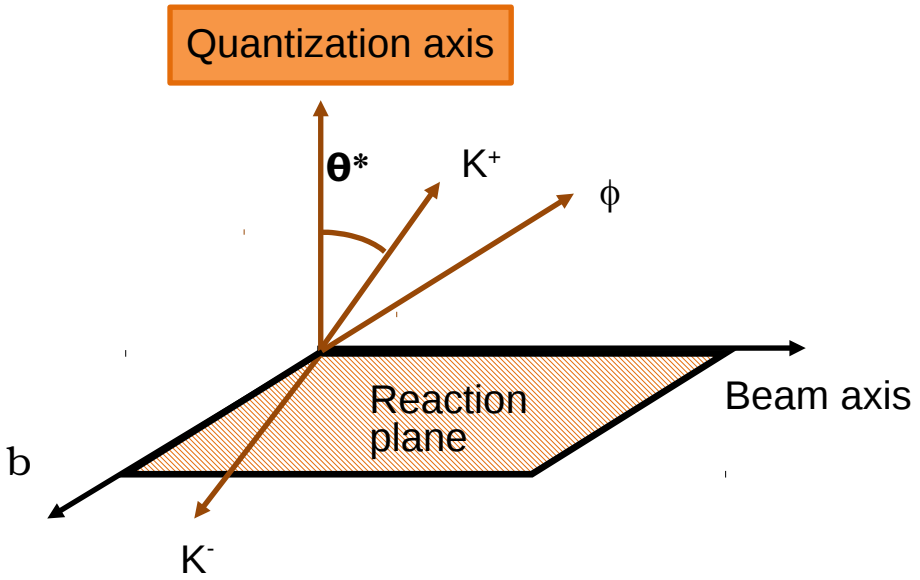
$$\frac{dN}{d\cos\theta^*} = N_0\left[1 - \rho_{00} + \cos^2\theta^*(3\rho_{00} - 1)\right]$$

K. Schilling, P. Seyboth and G. Wolf, Nucl. Phys. B 15, 397 (1970)

ρ_{00} = Element of spin density matrix
= 1/3 --> No spin alignment

Quantization axis
- Normal to production plane
- Normal to reaction plane





K*0 Vector meson
- Mass: 896 MeV/c^2
- Spin: 1
- Decays to K^+ and π^- (B.R. ~ 66.6%)
- Quark content (d,$\bar{s}$)

ϕ Vector meson
- Mass: 1020 MeV/c^2
- Spin: 1
- Decays to K^+ and K^- (B.R. ~ 48.9%)
- Quark content (s,$\bar{s}$)

Data set

pp collisions

Collision system and energy	pp at 13 TeV, Minimum bias
Rapidity	$\|y\| < 0.5$
No. of events	~ 43 M
Hadrons	K^{*0} and ϕ
Background	Mixed events
Efficiency x acceptance	Corrected
Quantization axis	Normal to Production plane

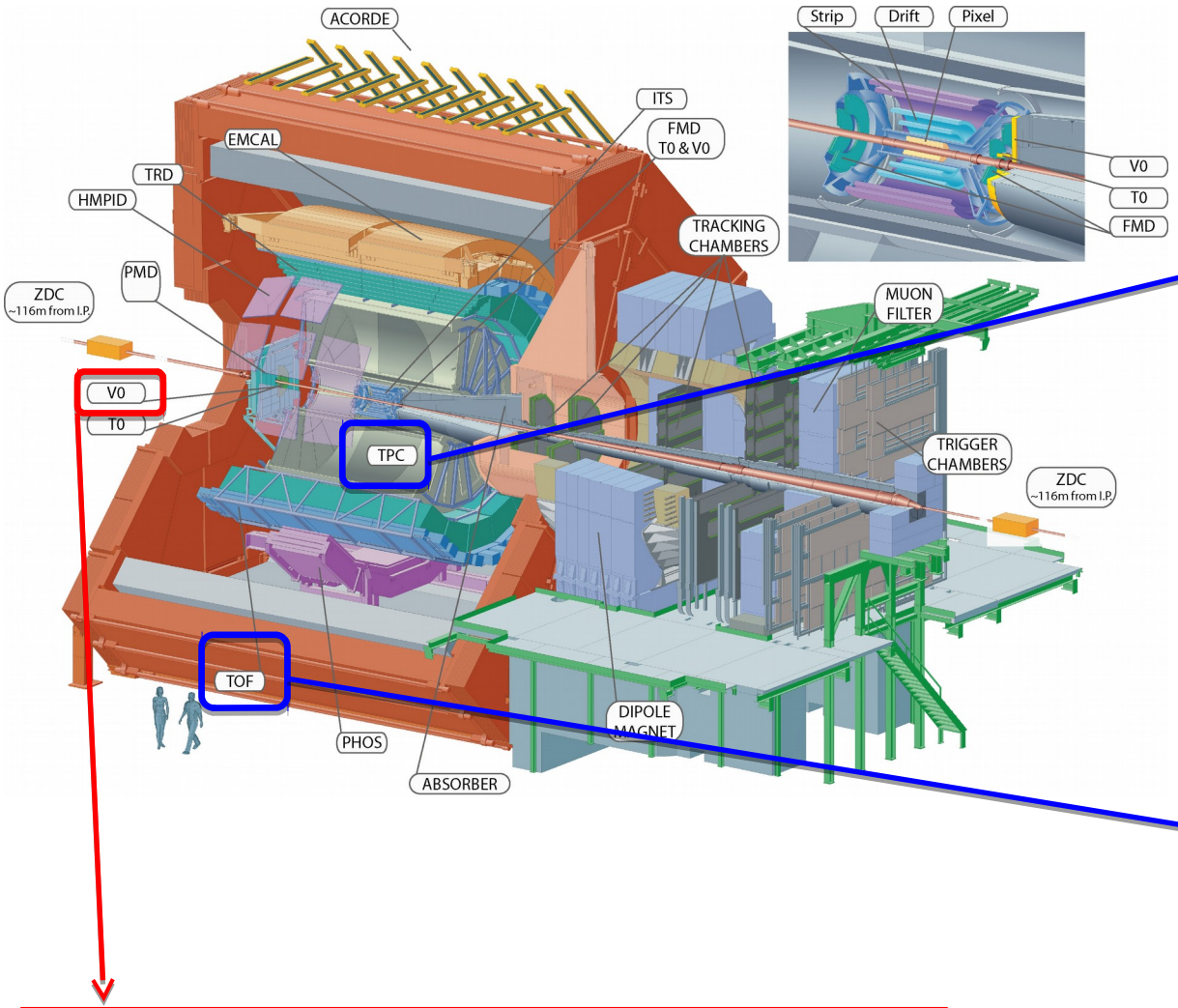
Heavy-ion collisions

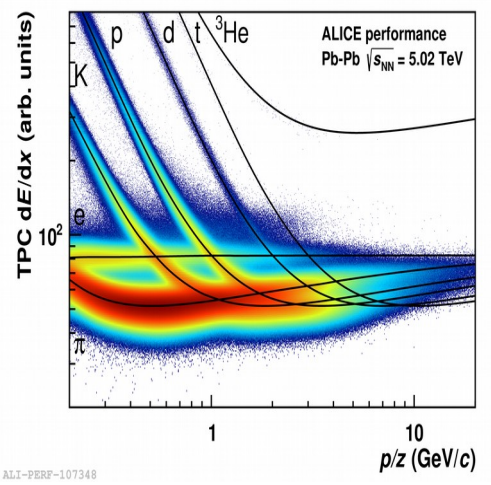
Collision system and energy	Pb-Pb at 2.76 TeV (K^{*0} and ϕ) and 5.02 TeV (K^{*0})
Rapidity	$\|y\| < 0.5$
No. of events	~ 14 M (2.76 TeV), ~30 M (5.02 TeV)
Hadrons	K^{*0} and ϕ
Background	Mixed events
Efficiency x acceptance	Corrected
Quantization axis	Normal to Production plane and Event plane

pp is used as a control experiment and that any effect would be most visible in Pb-Pb

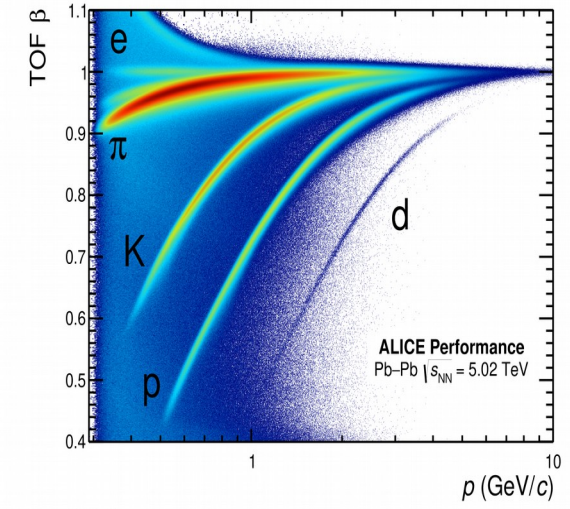
Goal: Measure $dN/d\cos\theta^*$ vs. $\cos\theta^*$ and extract ρ_{00} value as a function of p_T and centrality

ALICE detector





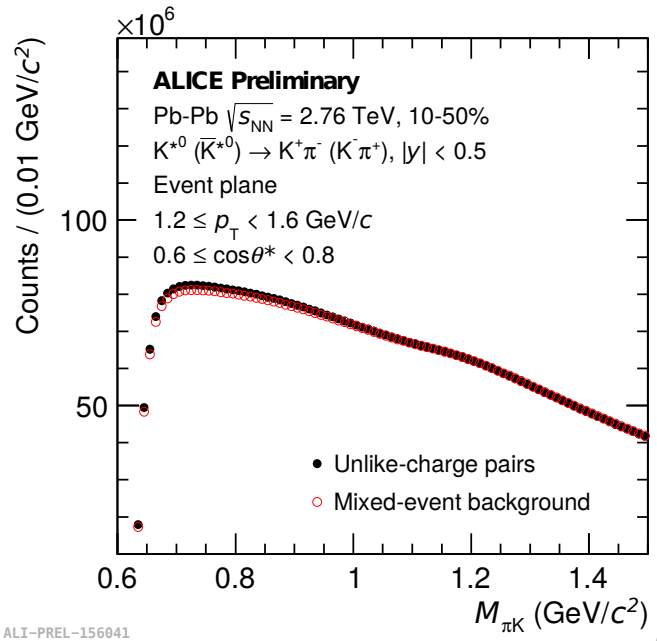
TPC : $|\eta| < 0.9$ Tracking and particle identification

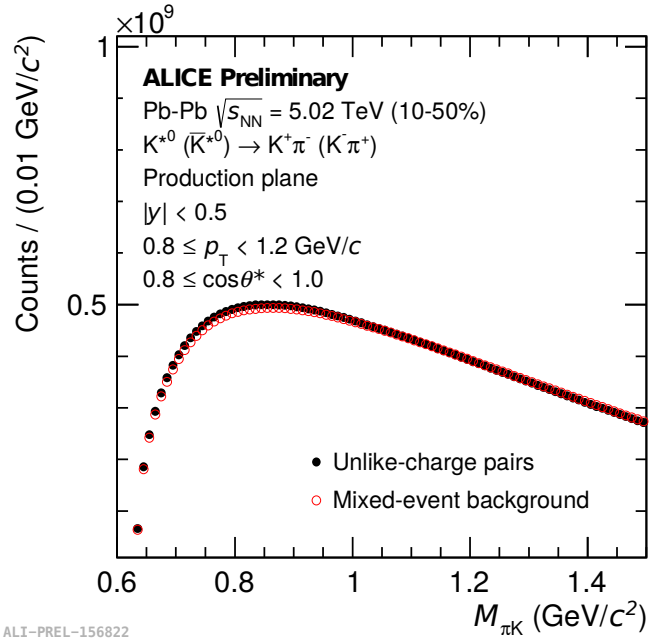


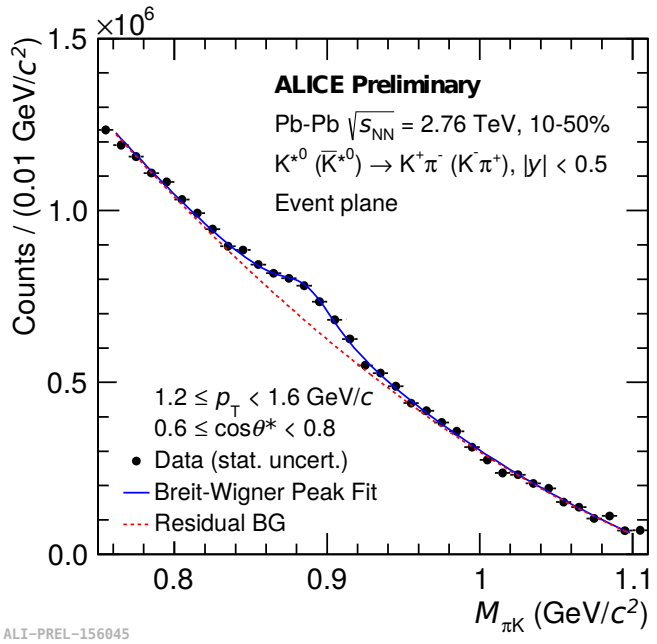
V0 : $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$
Trigger, event centrality and event plane estimation

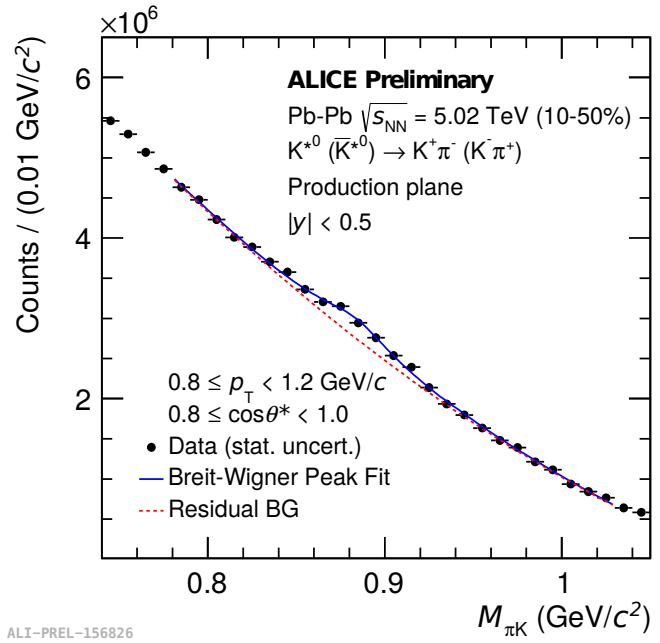
Time of Flight : $|\eta| < 0.9$ Particle identification

Invariant mass reconstruction of K*0 vector meson







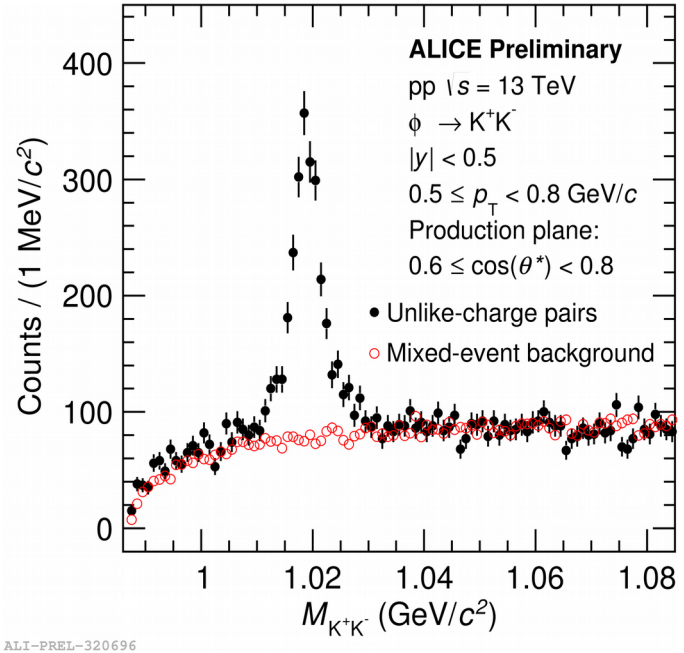


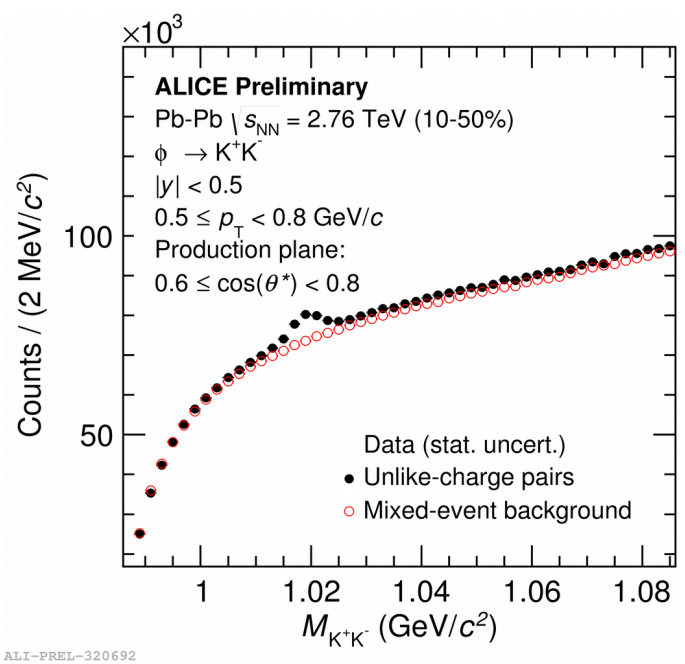
Same event (signal+bkground) and mixed event (bkground) distributions

Same event distribution after mixed event background subtraction

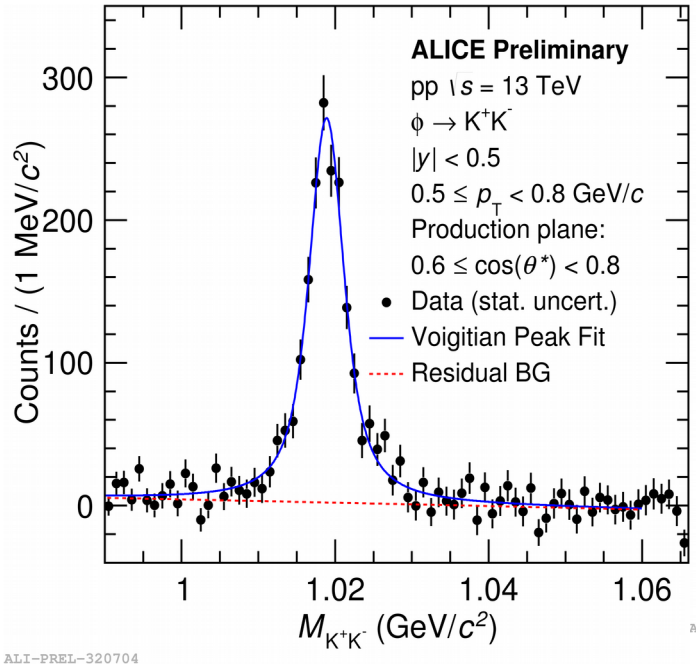
Yield is the area under Breit-Wigner distribution

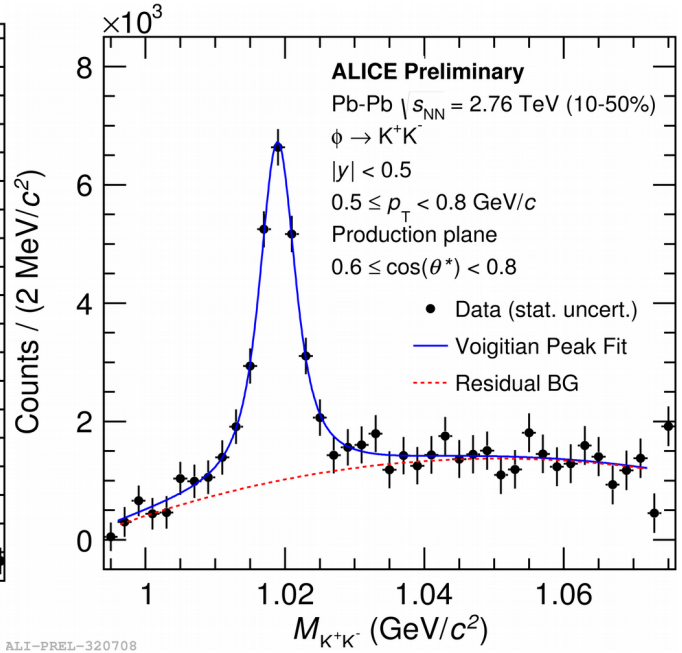
Invariant mass reconstruction of ϕ vector meson





Same event (signal+bkground) and mixed event (bkground) distributions

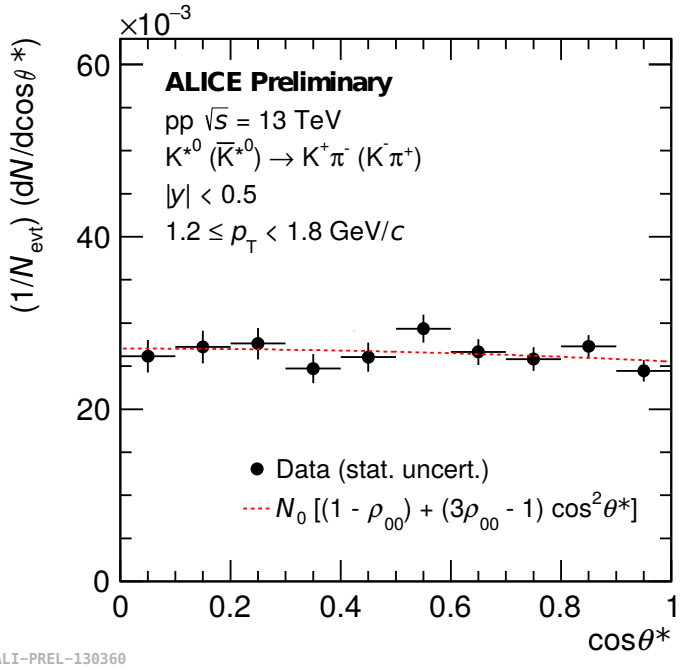


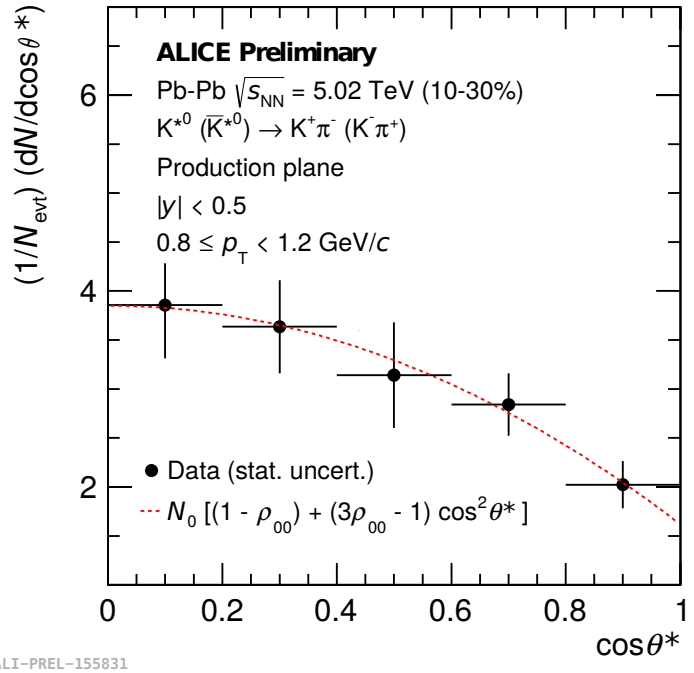


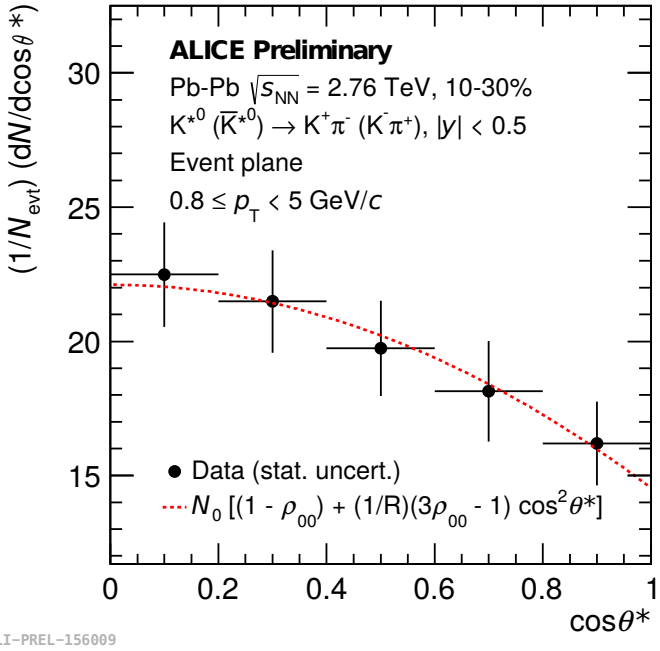
Same event distribution after mixed event background subtraction

Yield is the area under Voigitian distribution

Angular distribution: K^{*0}







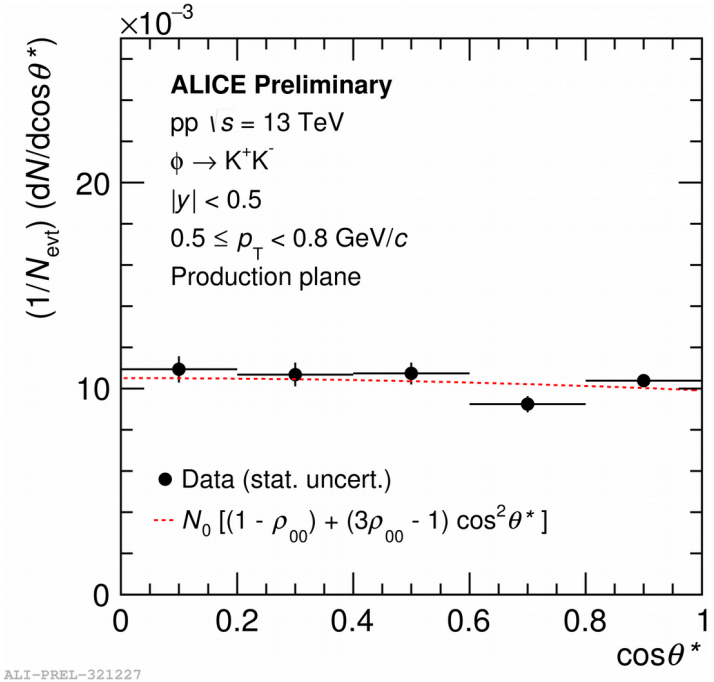
Two parameters (N_0 and ρ_{00}) fit to cosθ* distributions measured in different p_T bins

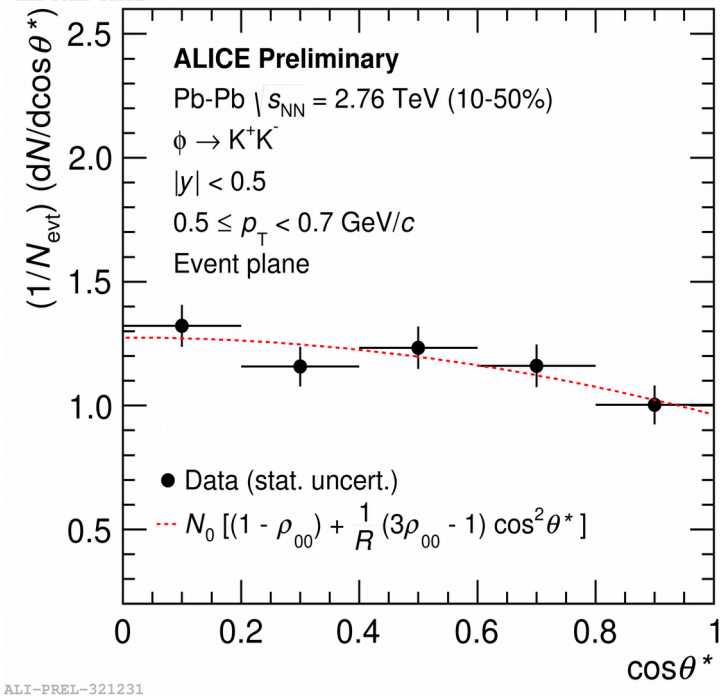
$$\frac{dN}{d(\cos\theta^*)} = N_0 \times \left[(1-\rho_{00}) + (1/R)(3\rho_{00}-1)\cos^2\theta^*\right]$$

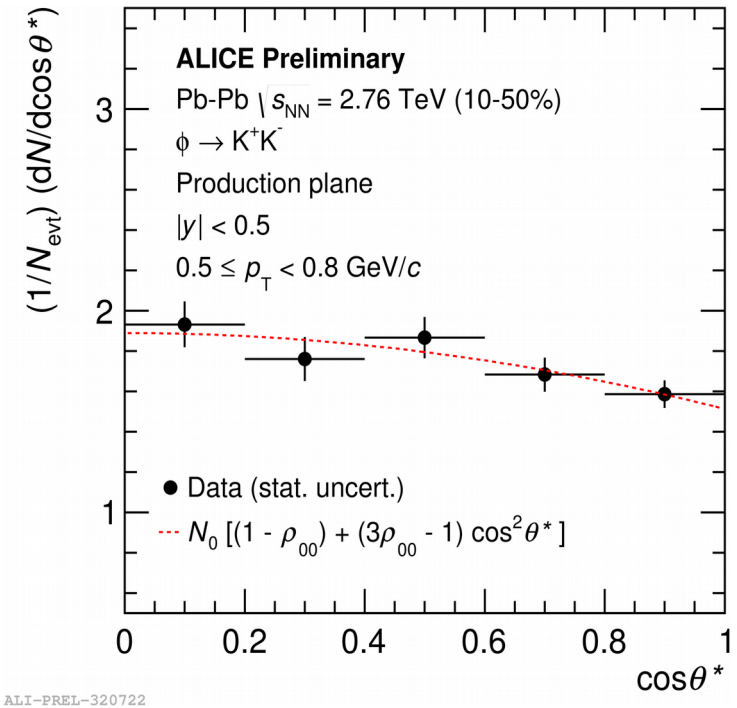
R=1 for Production plane measurement

R is the second order event plane resolution for event plane measurement

Angular distribution: ϕ







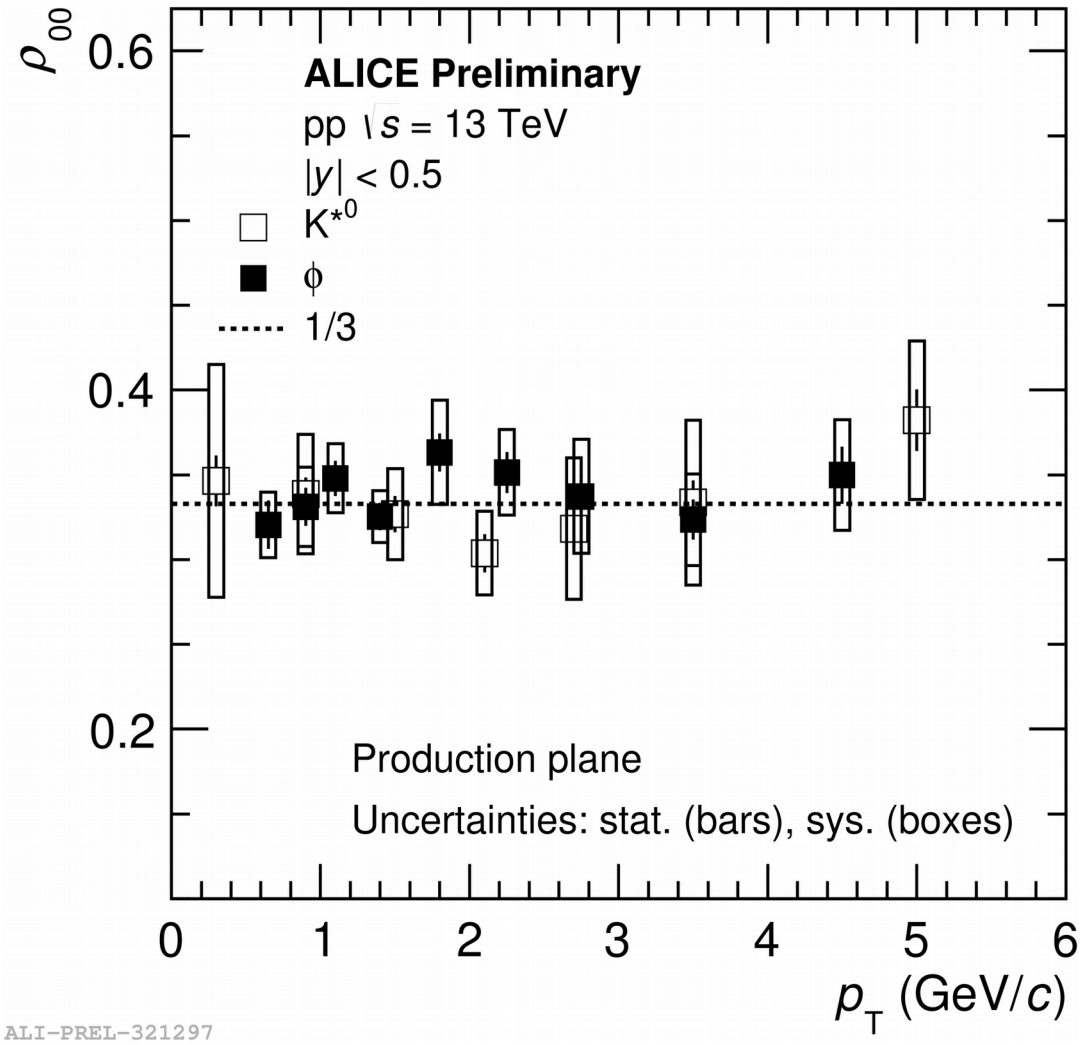
Two parameters (N_0 and ρ_{00}) fit to cosθ* distributions measured in different p_T bins

$$\frac{dN}{d(\cos\theta^*)} = N_0 \times \left[(1-\rho_{00}) + (1/R)(3\rho_{00}-1)\cos^2\theta^*\right]$$

R=1 for Production plane measurement

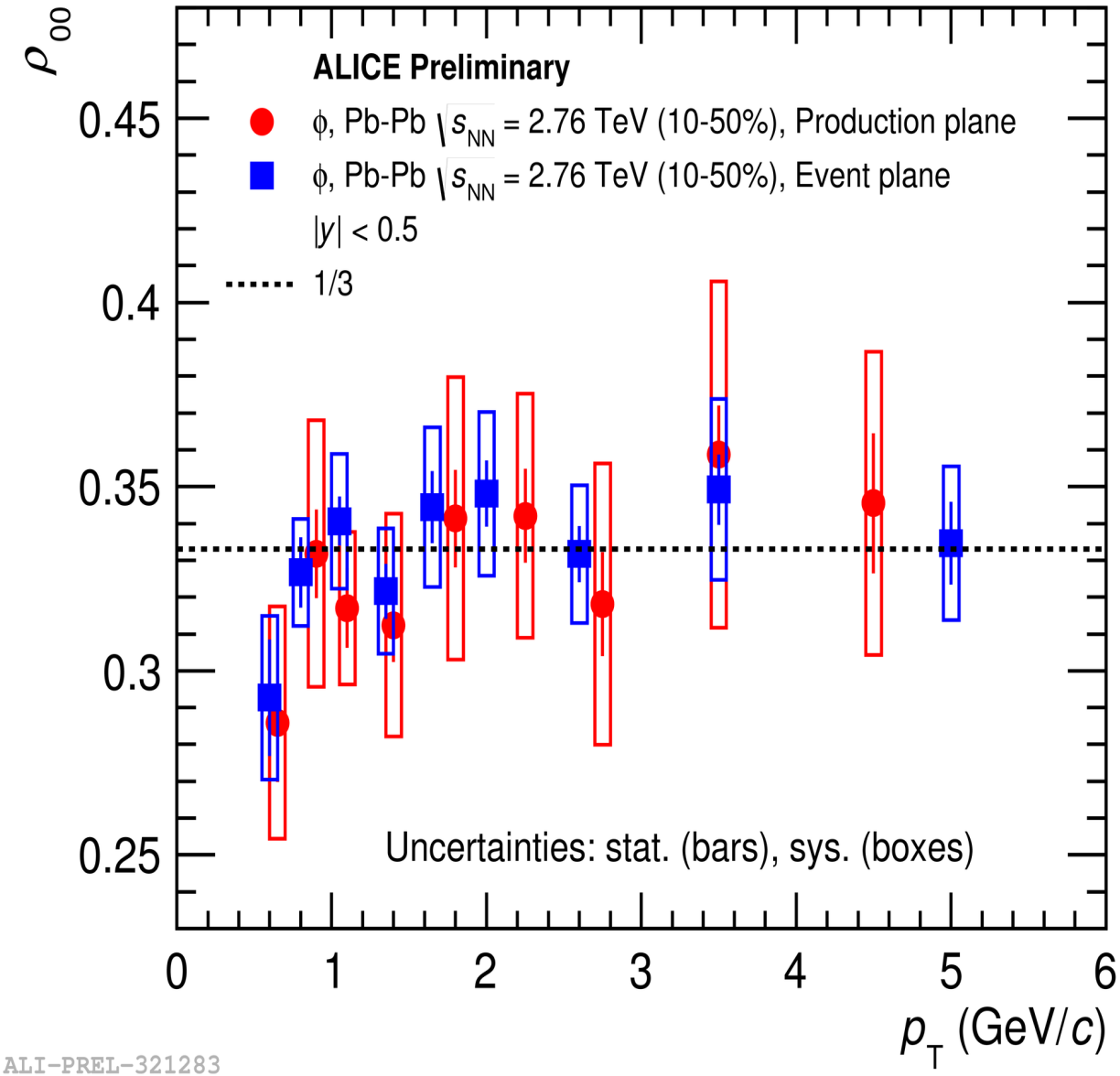
R is the second order event plane resolution for event plane measurement

ρ_{00} vs. p_T : pp collisions



- ✔ ρ_{00} = 1/3 in pp collisions at all measured p_T region for both K^{*0} and ϕ vector meson
- ✔ No spin alignment observed for vector mesons in pp collisions

ρ_{00} vs. p_T: Pb-Pb collisions (ϕ)



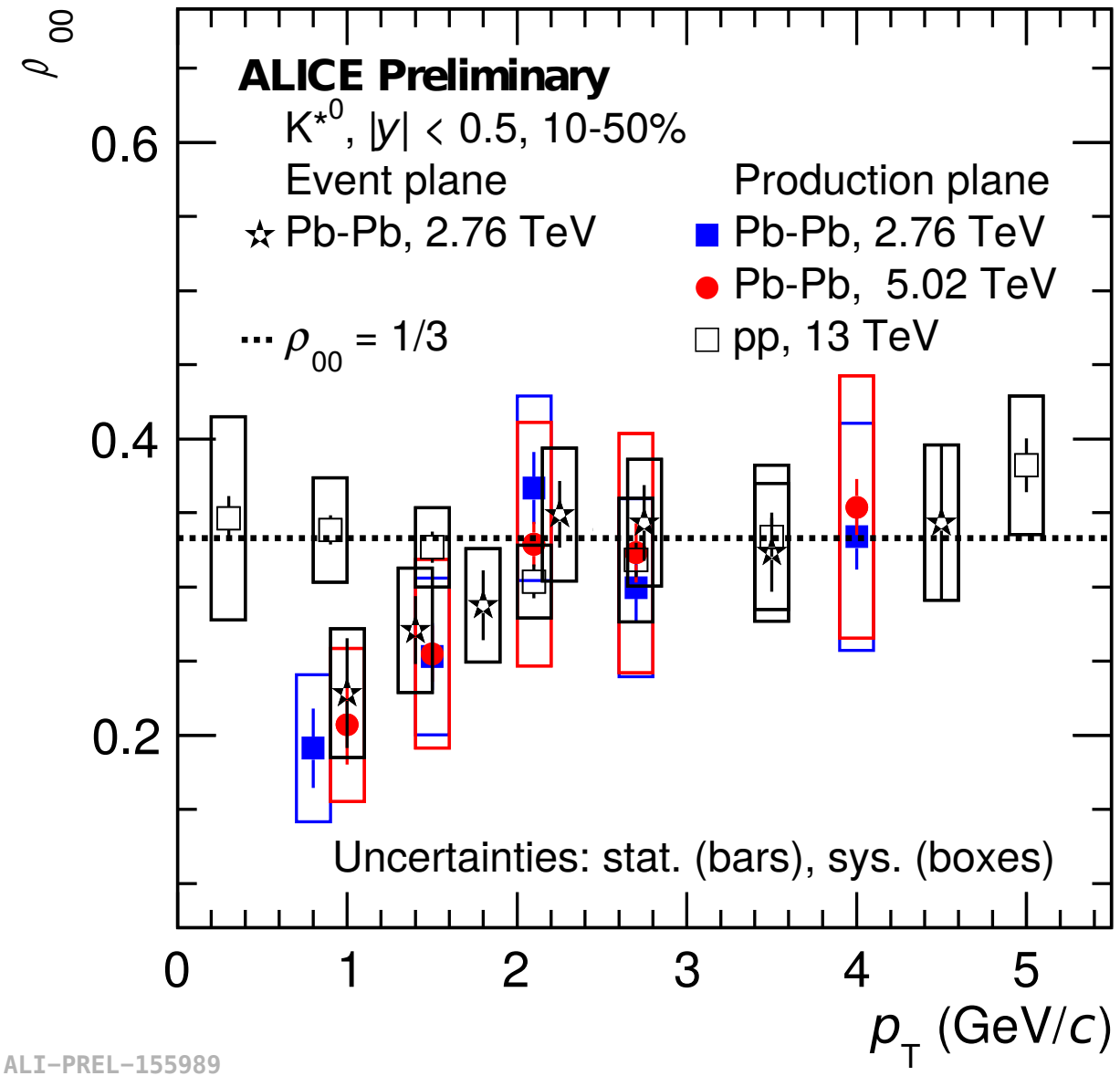
ALI-PREL-321283

- ✔ ρ_{00} = 1/3 at p_T > 0.8 GeV/c
- ✔ ρ_{00} < 1/3 in Pb-Pb collisions at p_T < 0.8 GeV/c for ϕ meson

  Production plane: 1.3σ deviation from 1/3 for lowest p_T bin

  Event plane: 1.4σ deviation from 1/3 for lowest p_T bin
- ✔ Measurements from production and event plane are consistent with each other within errors

ρ_{00} vs. p_T : Pb-Pb collisions (K^{*0})



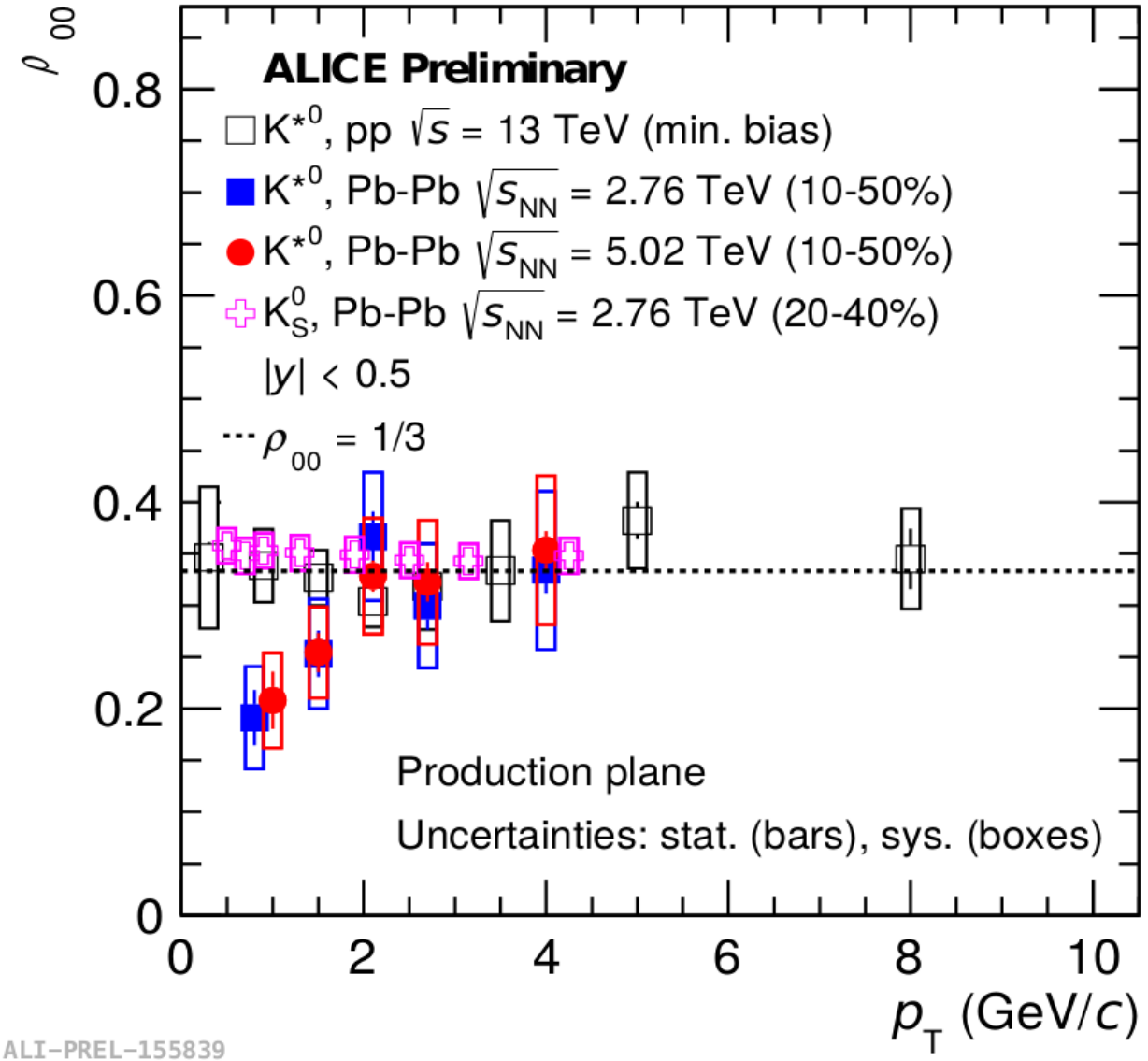
ALI-PREL-155989

- ✔ ρ_{00} = 1/3 at p_T > 2.0 GeV/c
- ✔ ρ_{00} < 1/3 in Pb-Pb collisions at p_T < 2.0 GeV/c for K^{*0}

  Production plane: 2.5σ deviation from 1/3 for lowest p_T bin

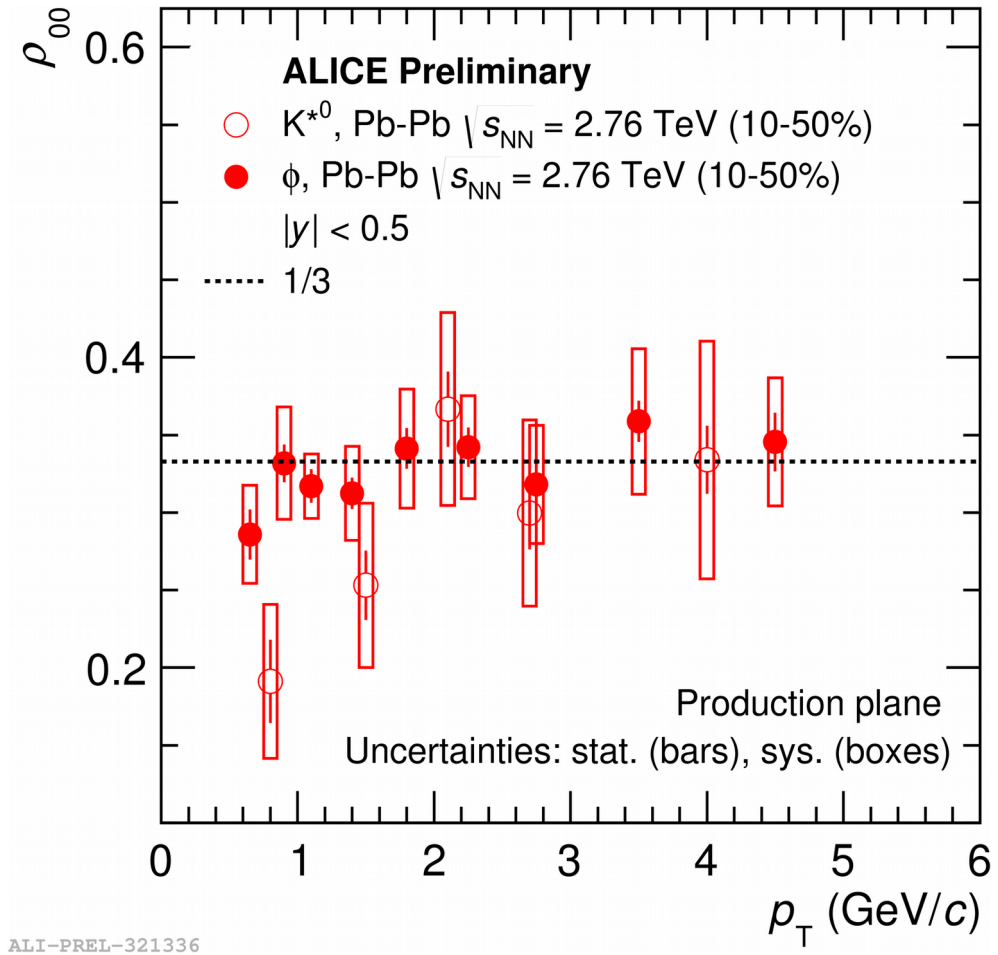
  Event plane: 1.8σ deviation from 1/3 for lowest p_T bin
- ✔ Measurements from production and event plane are consistent with each other within errors
- ✔ Measurements from 2.76 and 5.02 TeV are consistent with each other

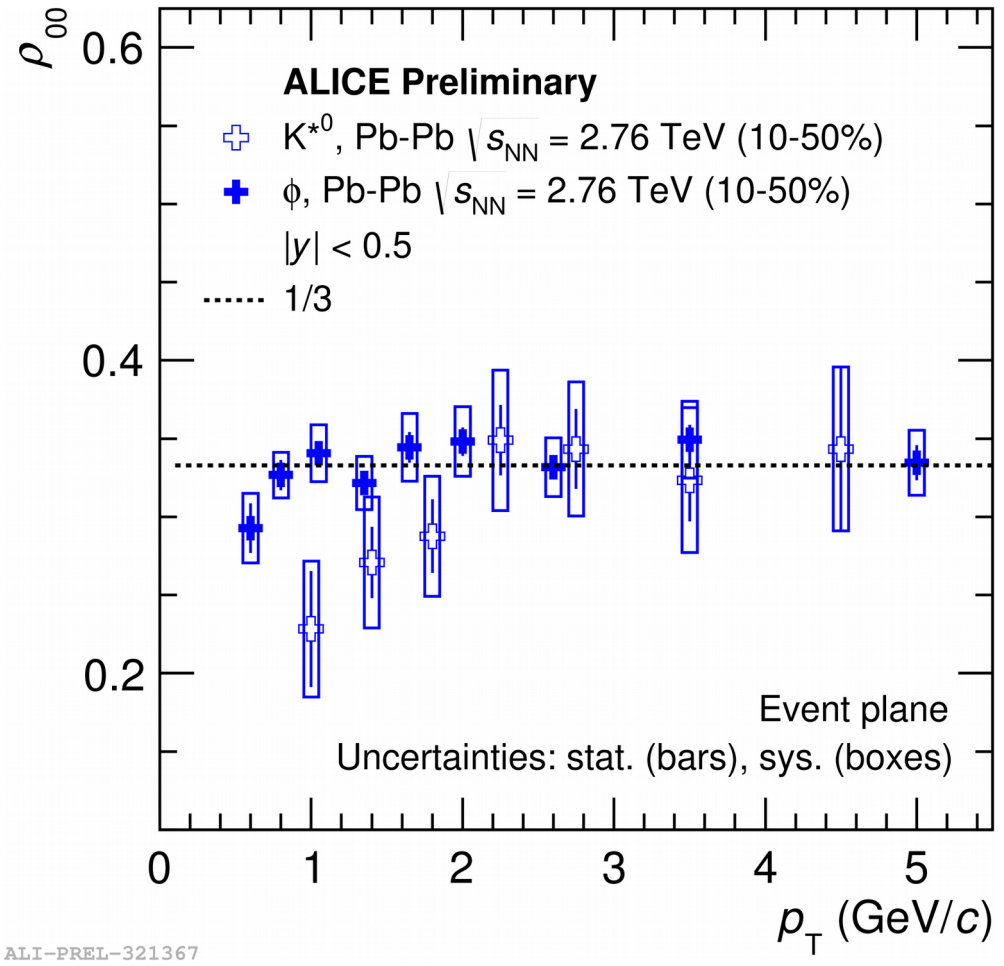
ρ_{00} vs. p_T: Pb-Pb collisions (Comparison with K_S^0)



- ✔ No spin alignment is observed for spin 0 hadron K_S^0

Comparison between K^{*0} and ϕ

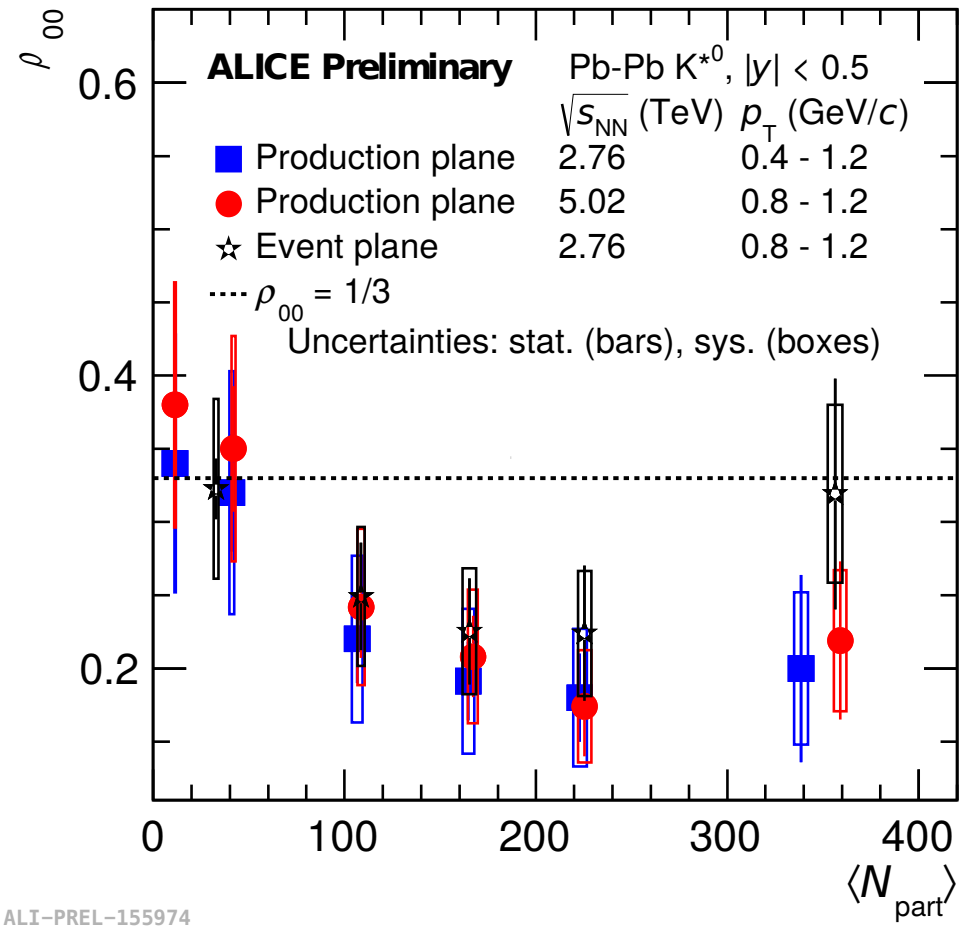




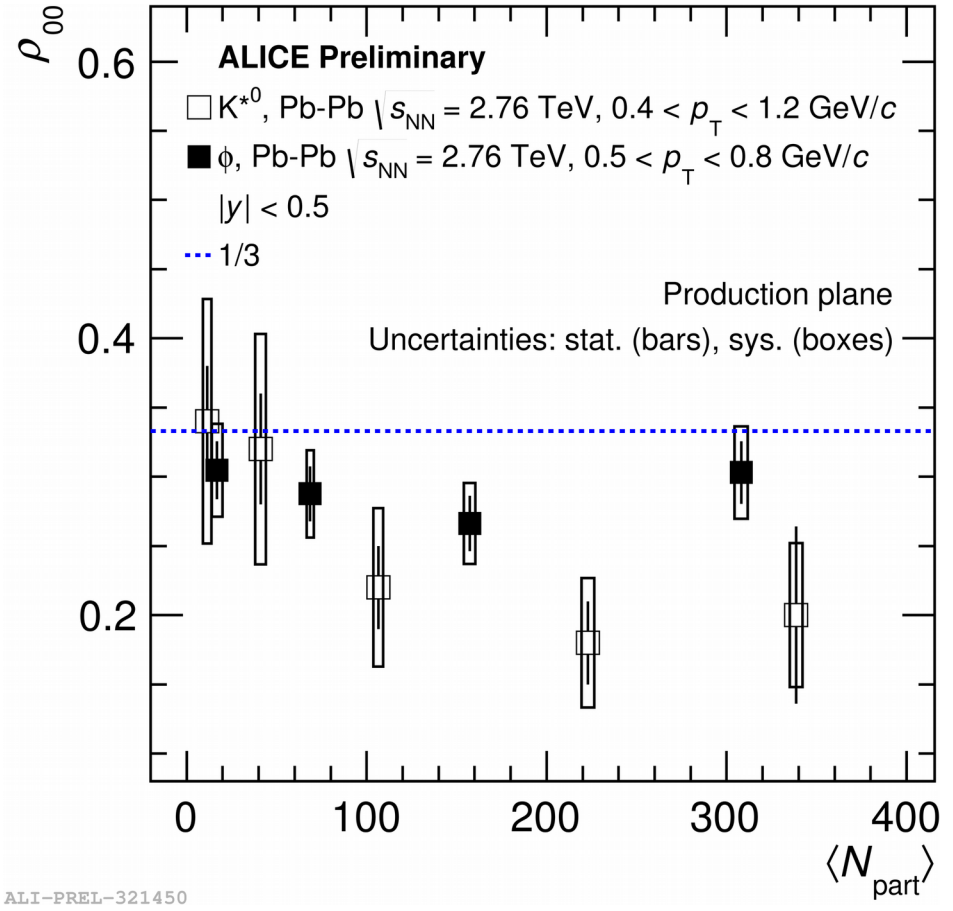
- ✔ $\rho_{00} < 1/3$ at low p_T and consistent with 1/3 at high p_T for both K^{*0} and ϕ
- ✔ For lowest p_T bin, ρ_{00} values are about 2.5σ (1.8σ) away from 1/3 w.r.t. production plane (event plane) for K^{*0} and 1.3σ (1.4σ) away from 1/3 w.r.t. production plane (event plane) for ϕ respectively

Centrality dependence of ρ_{00}

K^{*0} : production and event plane



K^{*0} and ϕ: production plane



- ✔ ρ_{00} shows centrality dependence and maximum deviation from 1/3 at mid-central collisions for both K^{*0} and ϕ
- ✔ Within statistical and systematic uncertainties ρ_{00} values are similar in both Production and Event plane method

Summary

- ✔ ρ_{00} ~ 1/3 : Spin alignment **not** observed in proton-proton collisions at 13 TeV
- ✔ ρ_{00} consistent with 1/3 at high p_T in Pb-Pb collisions for both K^{*0} and ϕ vector mesons
- ✔ ρ_{00} < 1/3 w.r.t. both Event and Production plane in Pb-Pb collisions at low p_T for both K^{*0} and ϕ vector mesons in mid-central collisions
- ✔ ρ_{00} shows centrality dependence and maximum deviation for mid-central collisions in both Event and Production plane
- ✔ In mid-central collisions, for lowest p_T bin, ρ_{00} values are about 2.7σ (1.7σ) away from 1/3 w.r.t. production plane (event plane) for K^{*0} and 1.8σ (1.4σ) away from 1/3 w.r.t. production plane (event plane) for ϕ respectively
- ✔ ρ_{00} values are similar at both $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV