Polarization measurements of hyperons and vector mesons with ALICE at the LHC

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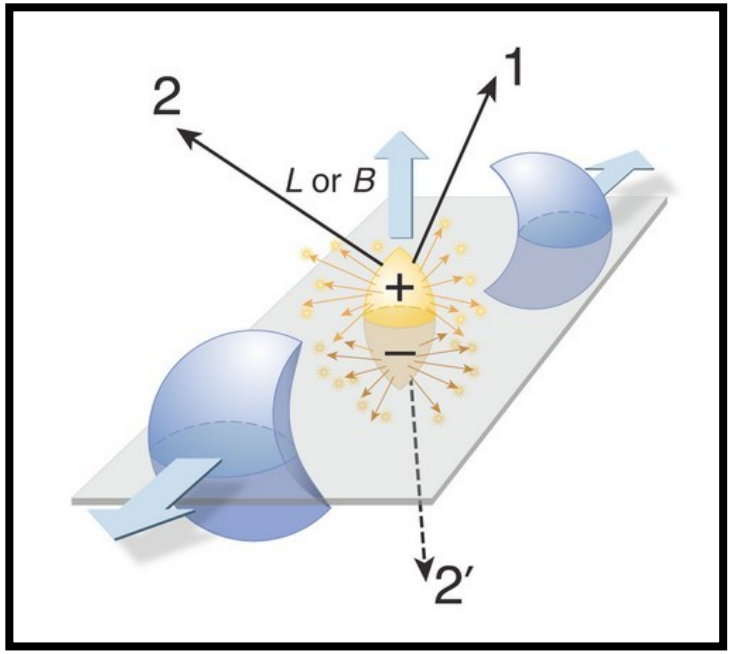
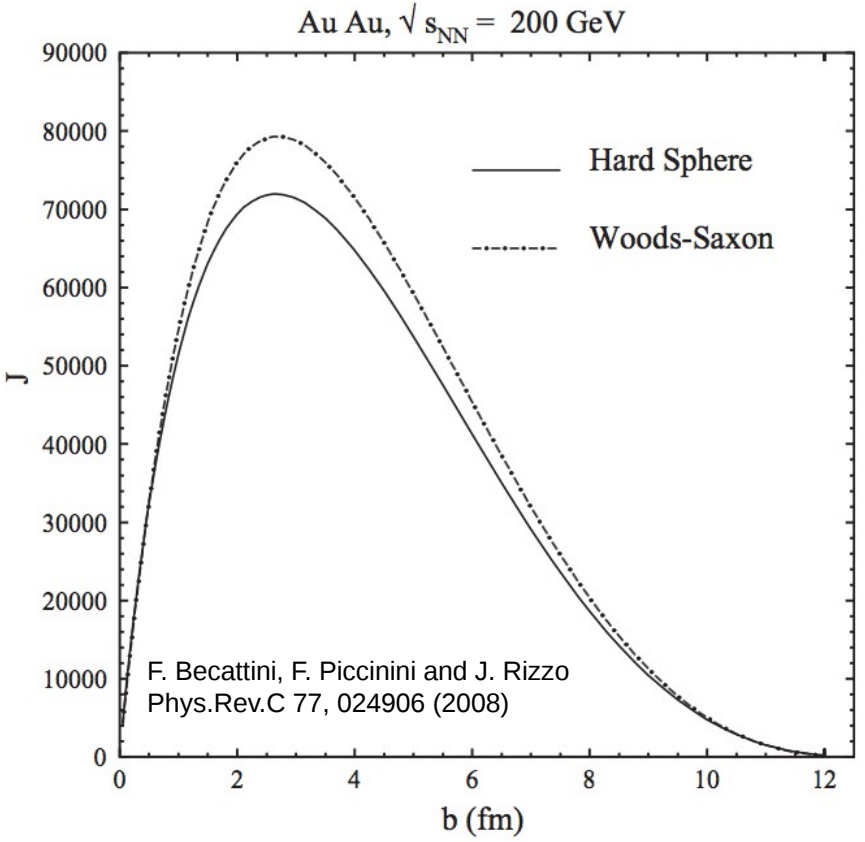
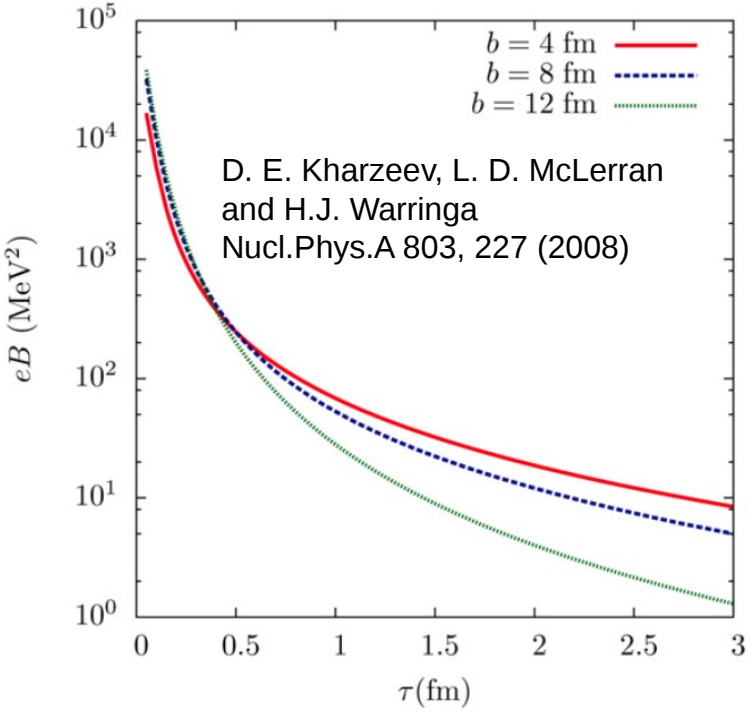
21st Particles and Nuclei International Conference 2017
IHEP, Beijing, China, 1-5 September, 2017

Initial conditions in heavy-ion collisions







- Large angular momentum and magnetic field are expected to be created in heavy-ion collisions

- Goal: Look for signatures of these effects

$M^2_p \sim 2 \times 10^4$ MeV^2 ~ 3×10^{14} Tesla ~ 3×10^{18} Gauss

Angular distribution of vector mesons and hyperons

K^{*0} Vector meson

- Mass: 896 MeV/c^2
- Lifetime: 1.38 × 10^{-23} s
- Spin: 1
- Decays to K^+ and π^- (B.R. ~ 66.6%)
- Quark content (d,sbar)

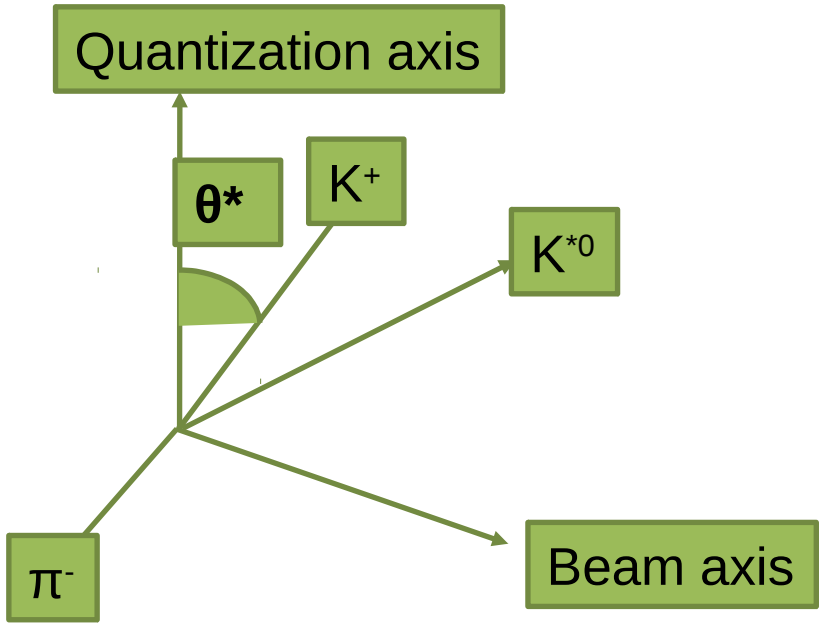
$$\frac{dN}{d\cos\theta^*} = N_0\left[1 - \rho_{00} + \cos^2\theta^*(3\rho_{00} - 1)\right]$$

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

Λ Hyperon

- Mass: 1115 MeV/c^2
- Lifetime: 2.632 × 10^{-10} s
- Spin: 1/2
- Decays to p and π^- (B.R. ~ 63.9%)
- Quark content (u,d,s)



Quantization axis
- Normal to production plane
- Normal to event plane

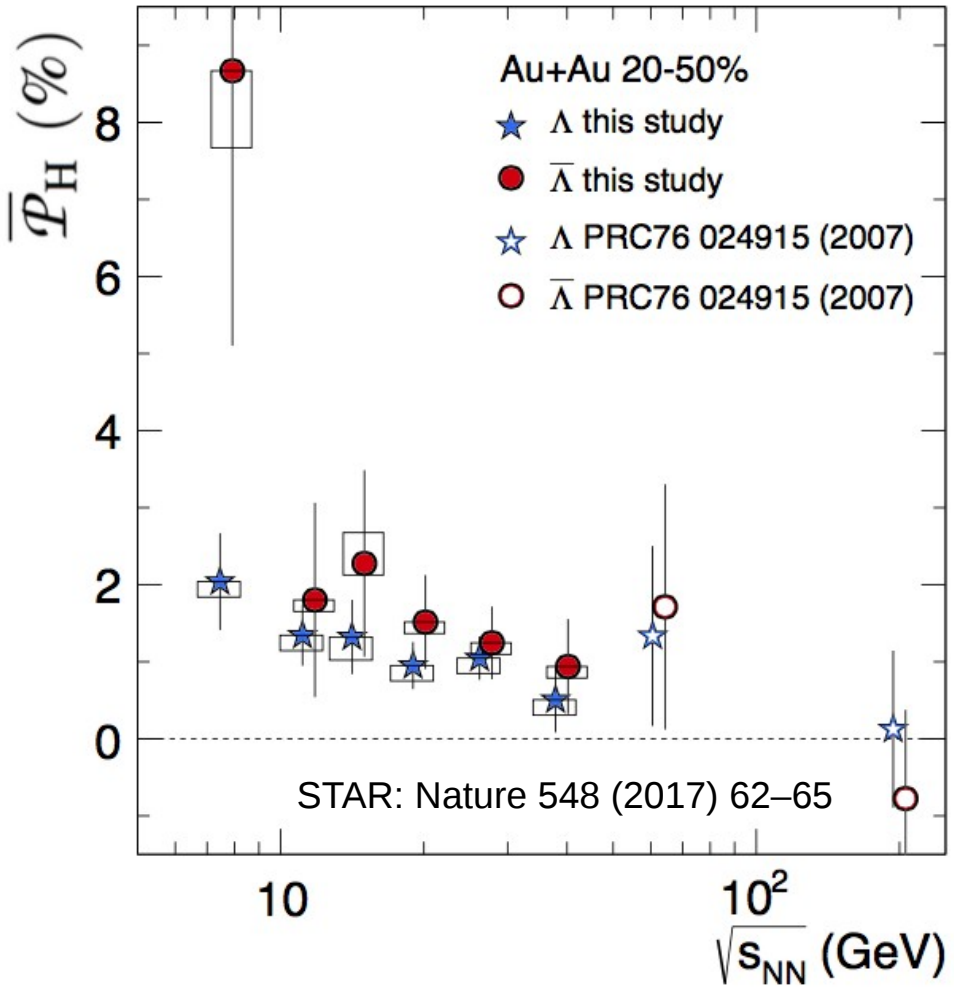
$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1 + \alpha_H |\vec{P}_H| \cos\theta^*\right)$$

STAR: Phys.Rev.C 76, 024915 (2007)

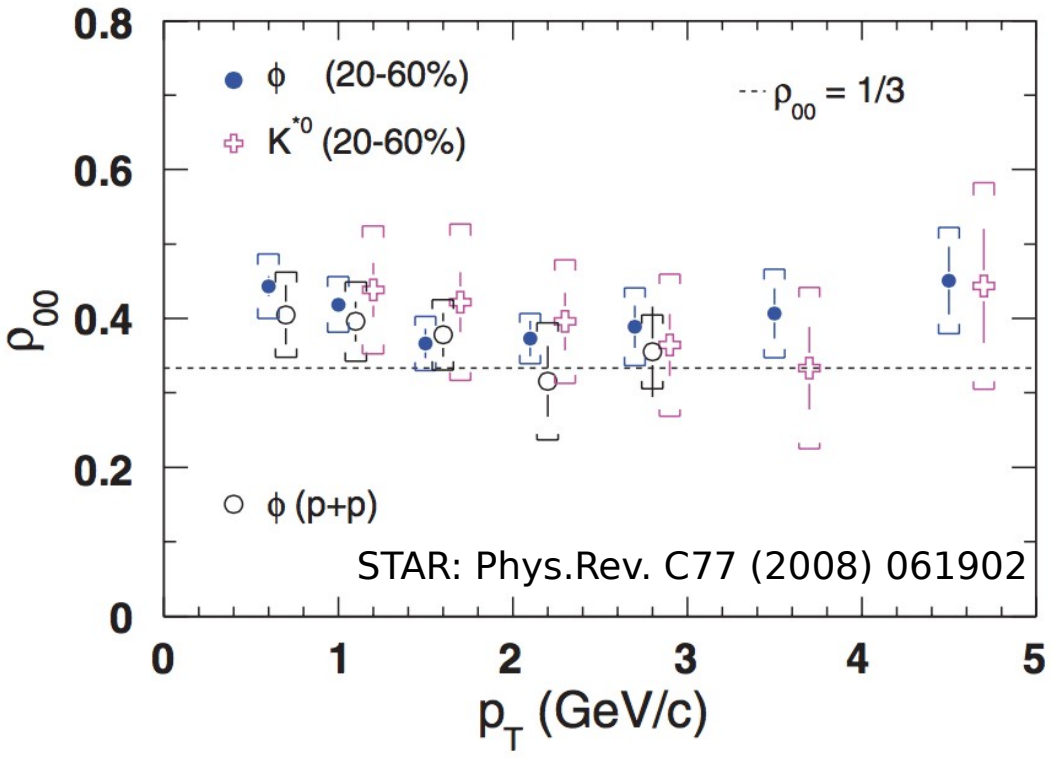
$|P_H|$ ⟶ Polarization
= 0 ⟶ No polarization
α_H ⟶ Decay parameter

Previous measurements

All results from the STAR Experiment

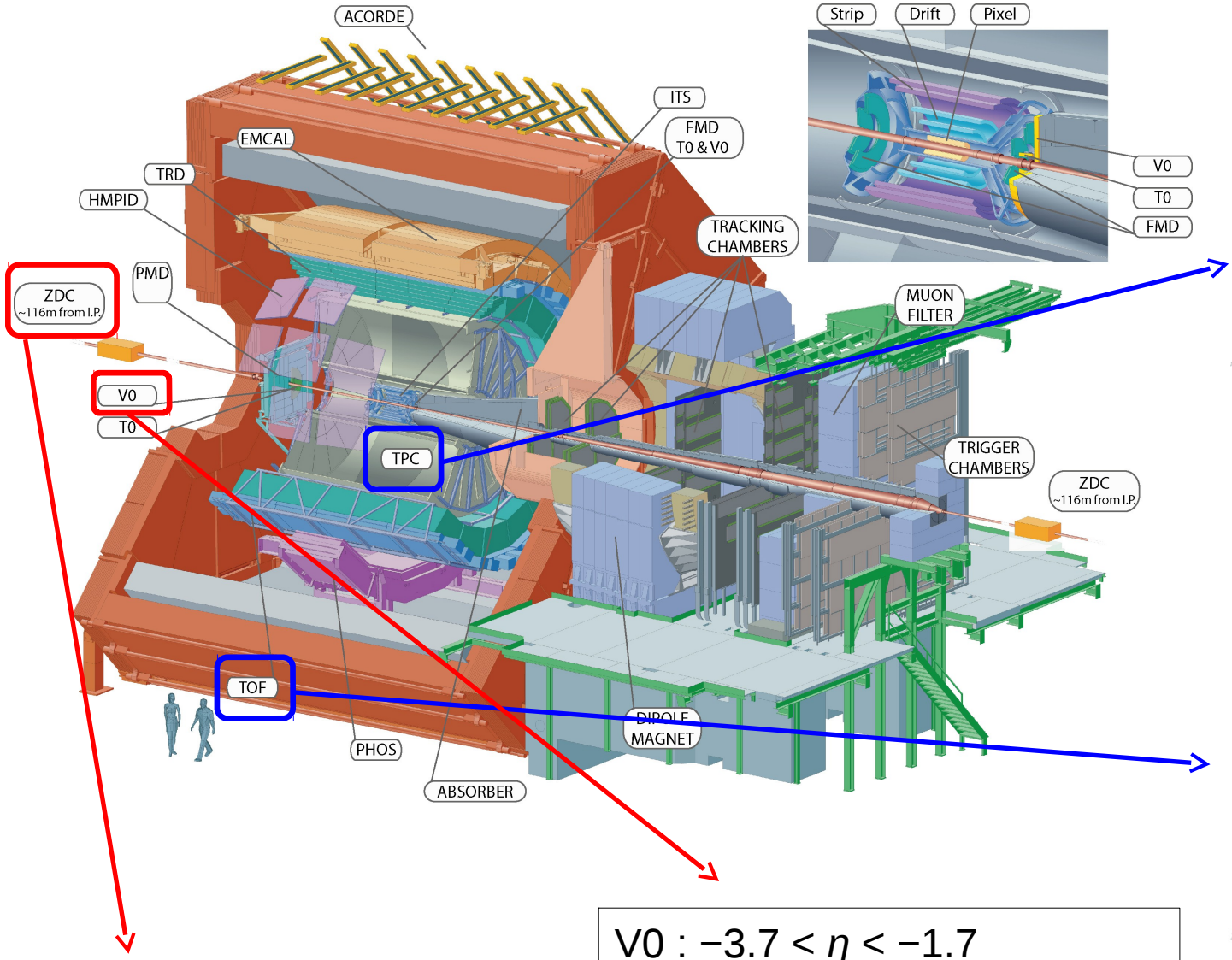


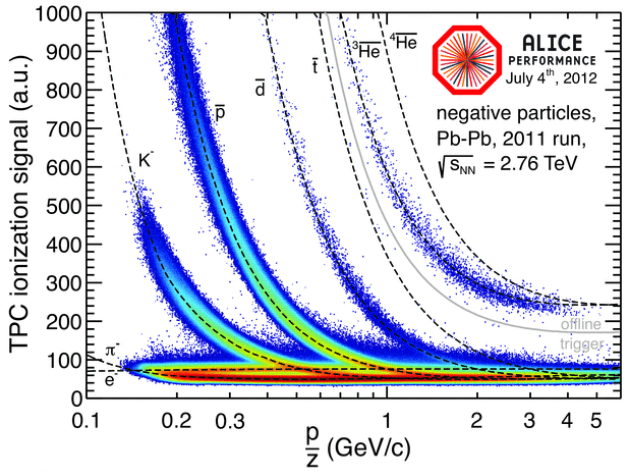
Global Λ hyperon polarization
Results w.r.t event plane



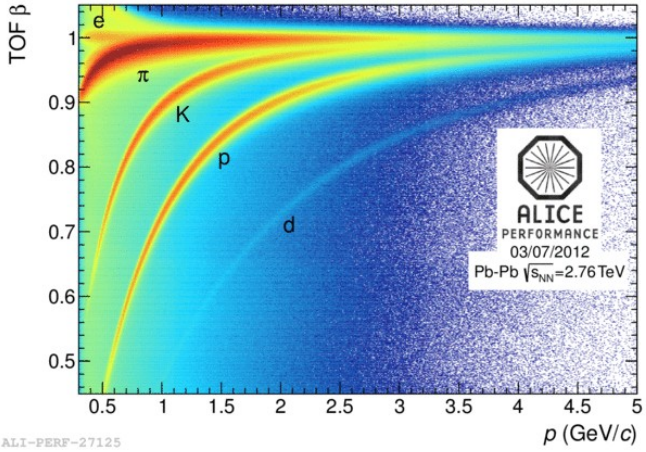
Spin alignment of vector mesons
Results w.r.t production plane

ALICE detector





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



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

ZDC : $|\eta| > 8.7$
Event plane estimation

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

ALICE: Int. J. Mod. Phys. A 29 1430044 (2014)

Global polarization of Λ hyperon

Data set and analysis

Collision system and energy	Pb-Pb at 2.76 TeV
Rapidity	$\|y\| < 0.5$
No. of events	~49 M
Collision centrality	5-15% , 15-50%
Hadrons	Λ-hyperons
Background	Side bands
Quantization axis	First order event plane from ZDC

Measurement observable

$$\frac{dW}{d\sin\theta_p^* \, d\phi_p^*} = \frac{1}{4\pi}\left(1 + \alpha_{\Lambda,\bar{\Lambda}} |\vec{P}_H| \cos\theta_p^*\right)$$

Angles are of daughter proton in rest frame of hyperon

Component perpendicular to reaction plane and averaged over all events

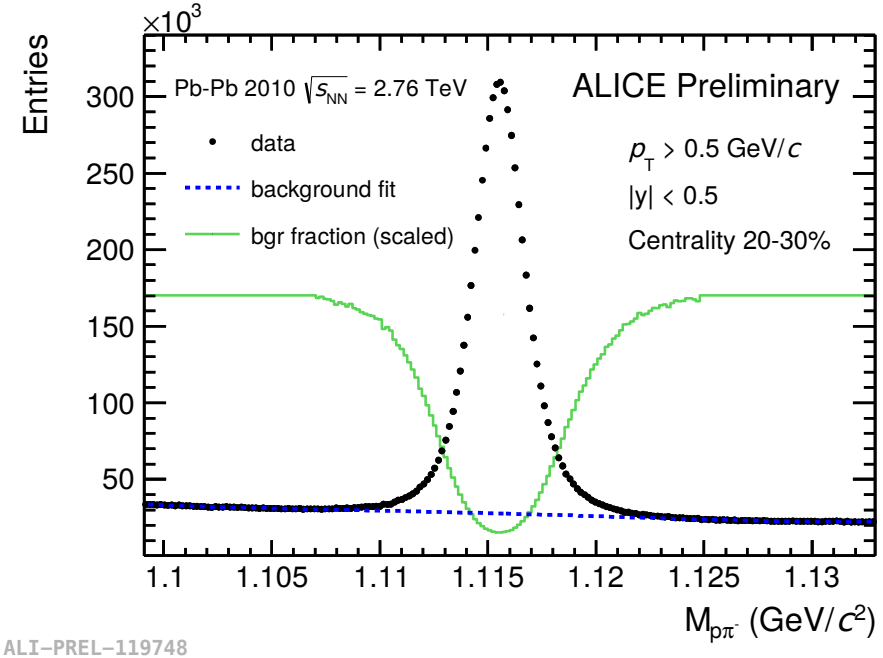
$$P_{\Lambda,\bar{\Lambda}} = \frac{8}{\pi \alpha_{\Lambda,\bar{\Lambda}}} \times \frac{\left\langle \sin(\phi_p^* - \psi_{EP}^{(1)}) \right\rangle}{R_{EP}^{(1)}}$$

Statistical uncertainty

$$\approx \frac{8}{\pi \alpha_{\Lambda,\bar{\Lambda}}} \times (2R_{EP}^{(1)} \sqrt{\#\text{hyperons}})^{-1}$$

Event plane using the two neutron ZDCs

Signal extraction and EP resolution



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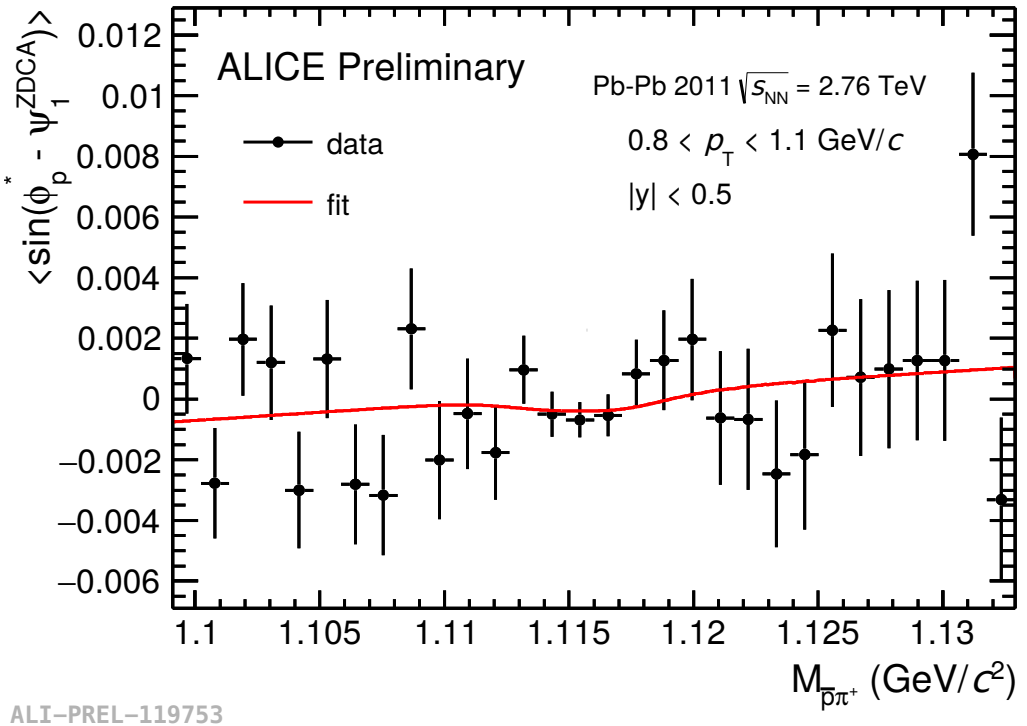

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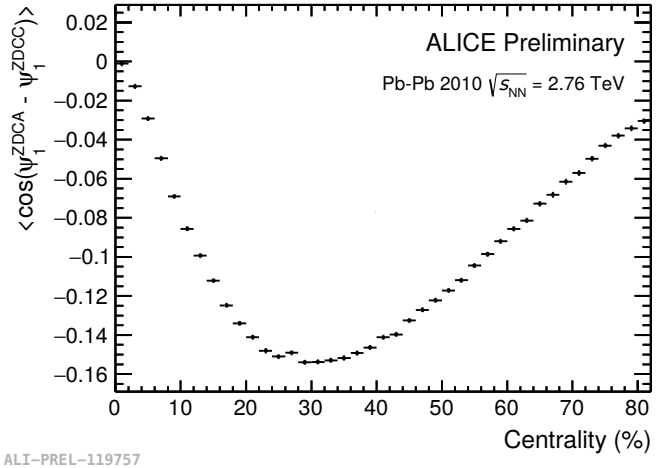
- Λ M_{inv} distribution and
- Λ background distribution



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Fit distribution

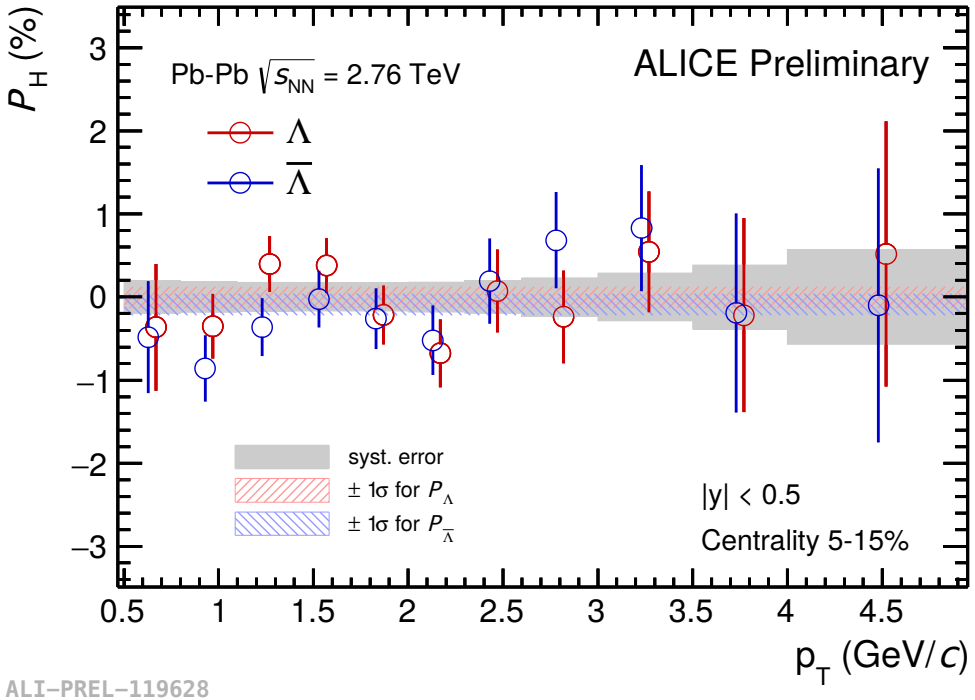
$$(1 - \mathrm{f}(M)) \times P_{\mathrm{H}} + \mathrm{f}(M) \times [\text{linear function}]$$

P_H is the polarization signal

Event plane resolution ~ 0.39 (Max)

$$R_{\mathrm{EP}}^{(1)} \approx \sqrt{-\langle \cos(\psi_1^{\mathrm{ZDCA}} - \psi_1^{\mathrm{ZDCC}}) \rangle}$$

Hyperon polarization measurements: p_T dependence



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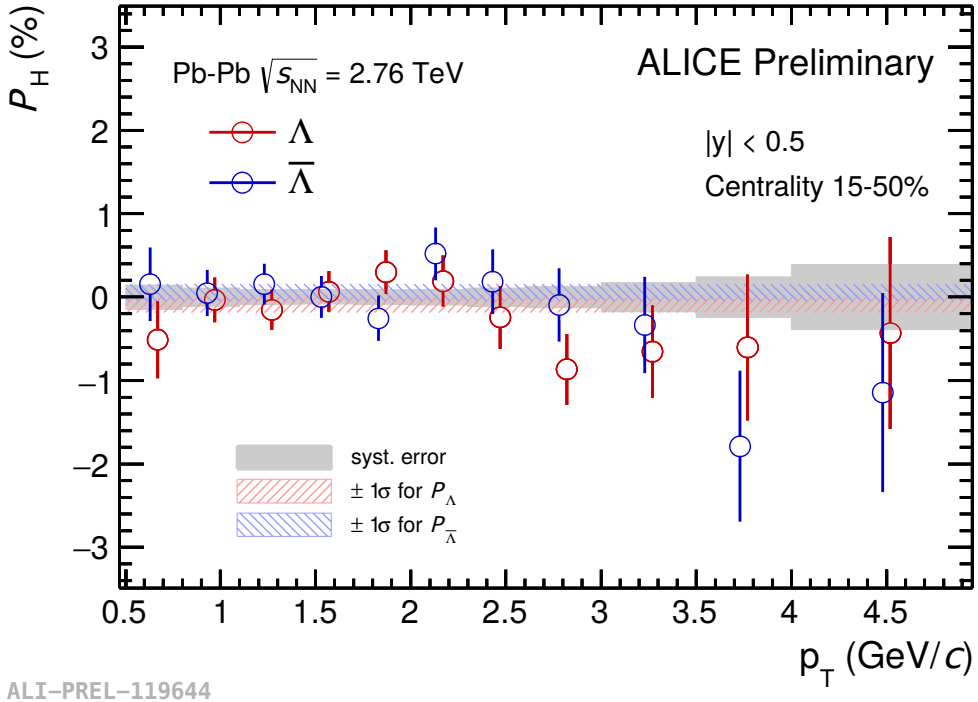

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p_T integrated results

5-15% →

$$P_\Lambda\,(\%) = -0.01 \pm 0.13(\text{stat}) \pm 0.04(\text{syst})$$
$$P_{\bar{\Lambda}}\,(\%) = -0.09 \pm 0.13(\text{stat}) \pm 0.08(\text{syst})$$

15-50% →

$$P_\Lambda\,(\%) = -0.08 \pm 0.10(\text{stat}) \pm 0.04(\text{syst})$$
$$P_{\bar{\Lambda}}\,(\%) = 0.05 \pm 0.10(\text{stat}) \pm 0.03(\text{syst})$$

Feed down corrections underway (model dependent)
Scale factor ~ 1.7±0.5

Summary of global polarization results

- P_H consistent with zero within 0.15 % for Pb-Pb collisions at midrapidity for $\sqrt{s_{NN}} = 2.76$ TeV in ALICE @ LHC
- 1σ significance for combined Λ and anti-Λ results
- 10 times more event statistics needed for a 3σ significance result

Spin alignment of K^{*0} vector meson

Data set and analysis

pp collisions

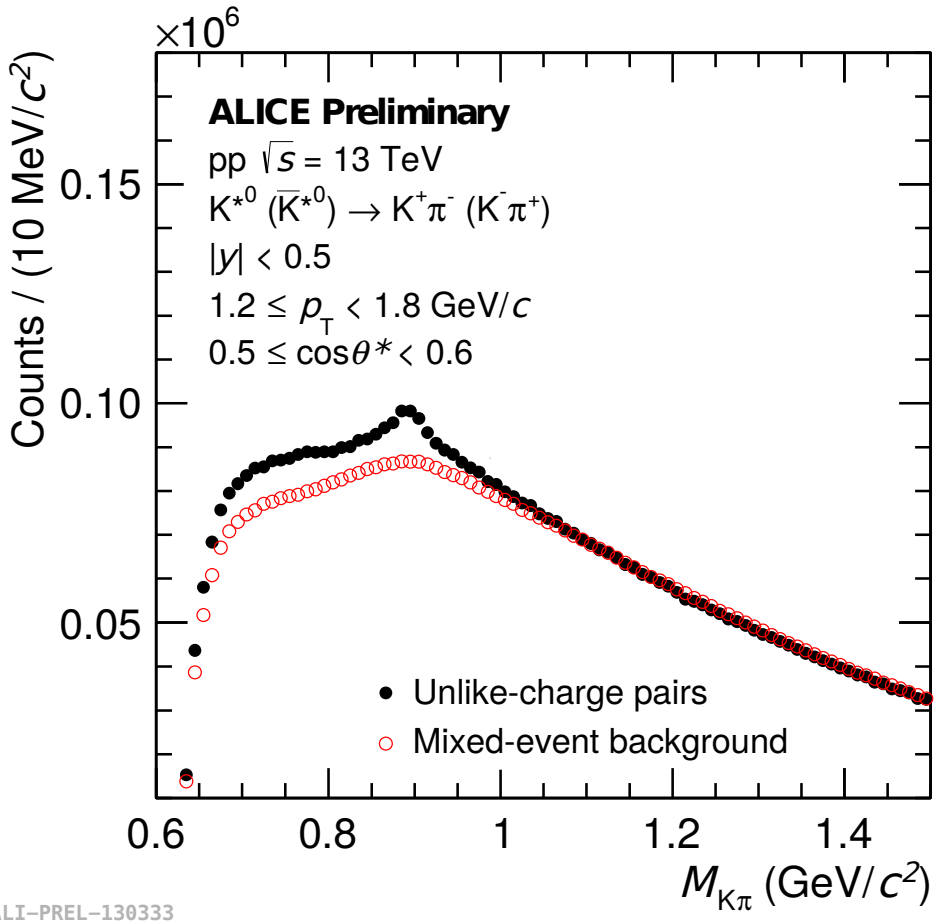
Collision system and energy	pp at 13 TeV, Minimum bias
Rapidity	$\|y\| < 0.5$
No. of events	~ 43 M
Hadrons	K^{*0}
Background	Mixed events
Efficiency x acceptance	Corrected
Quantization axis	Production plane

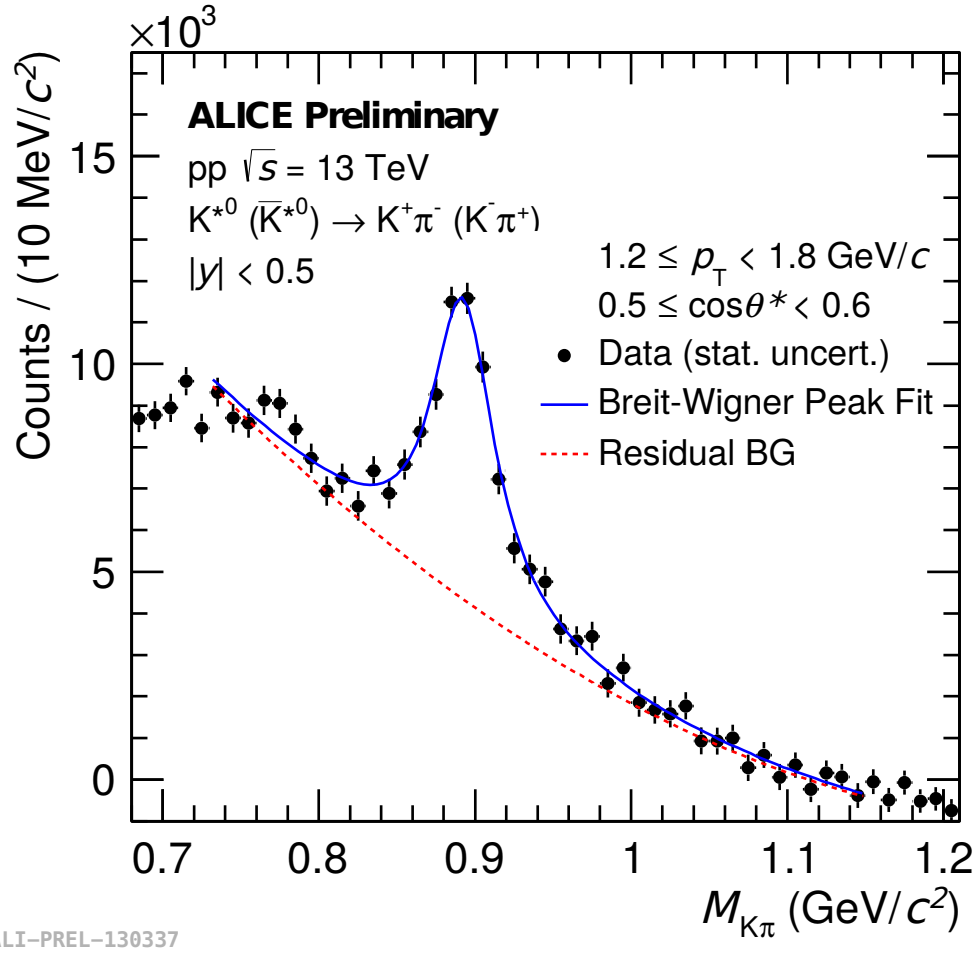
Heavy-ion collisions

Collision system and energy	Pb-Pb at 2.76 TeV
Rapidity	$\|y\| < 0.5$
No. of events	~ 14 M
Collision centrality	10-50% (K^{*0}), 20-40% (K^0_S)
Hadrons	K^{*0} and K^0_S
Background	Mixed events
Efficiency x acceptance	Corrected
Quantization axis	Production plane

Goal: Measure $dN/d\cos\theta^*$ vs. $\cos\theta^*$ and extract ρ_{00} value as a function of p_T for K^{*0}.

Reconstruction of K^{*0} in pp collisions at ALICE



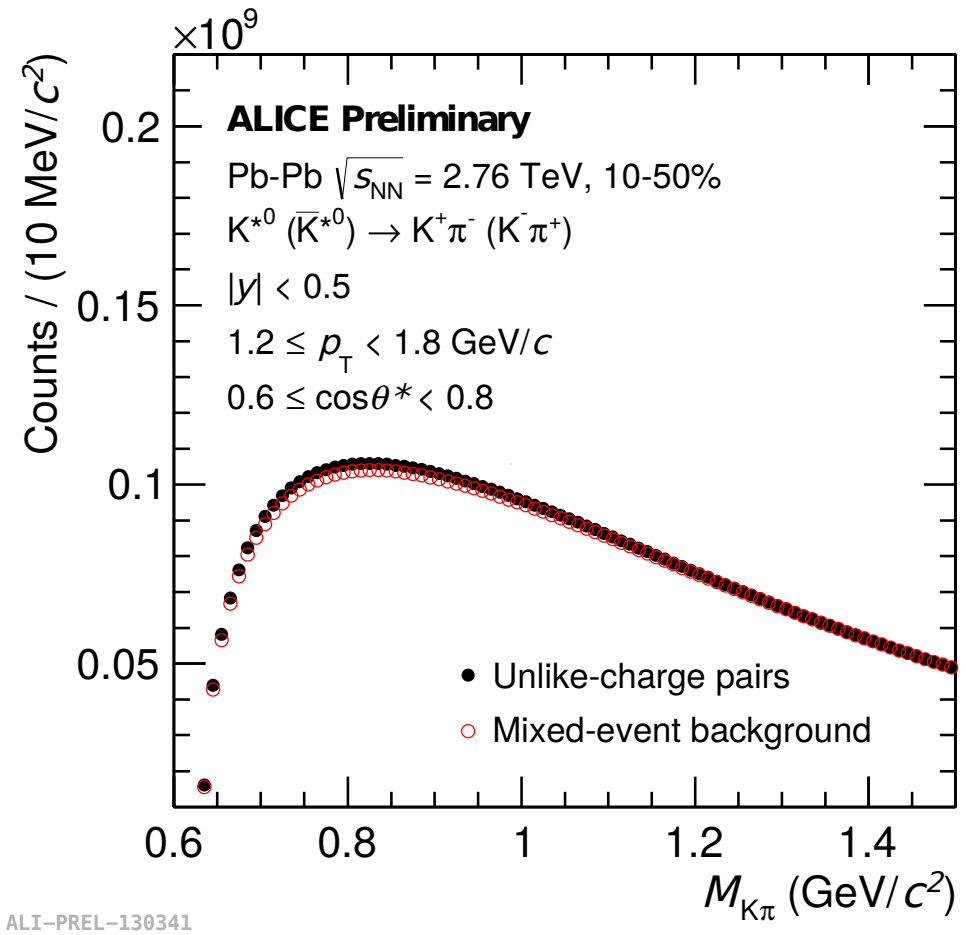


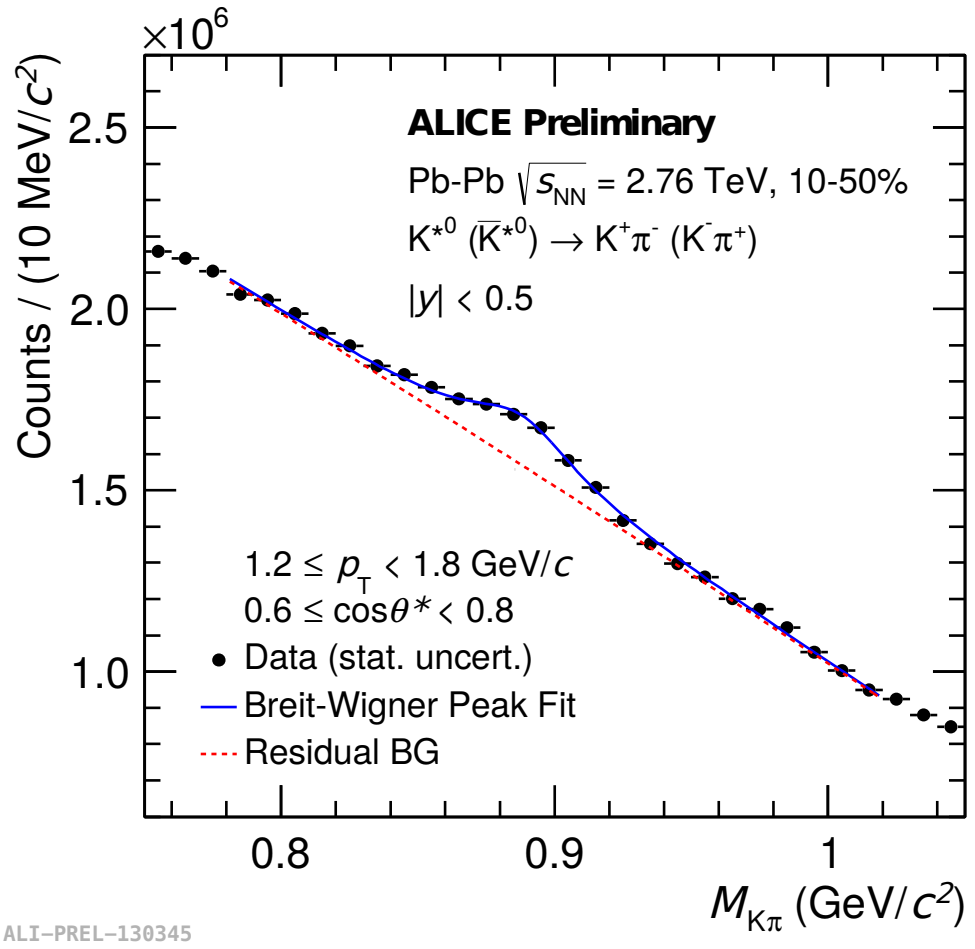
Same event (sig+bkg) and mixed event (bkg) distributions

Same event distribution after mixed event background subtraction

Yield is the area under Breit-Wigner distribution

Reconstruction of K^{*0} in Pb-Pb collisions at ALICE





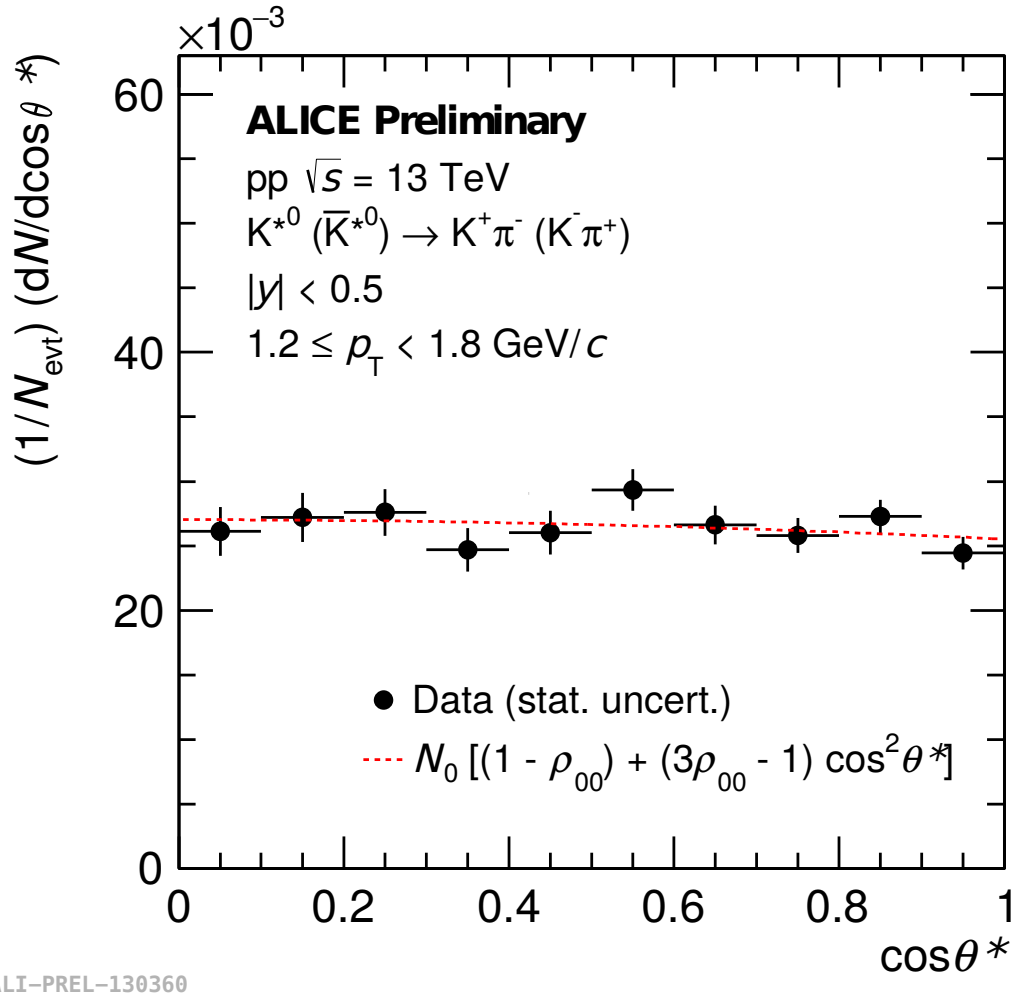
Same event (sig+bkg) and mixed event (bkg) distributions

Same event distribution after mixed event background subtraction

Yield is the area under Breit-Wigner distribution

Angular distribution

pp collisions



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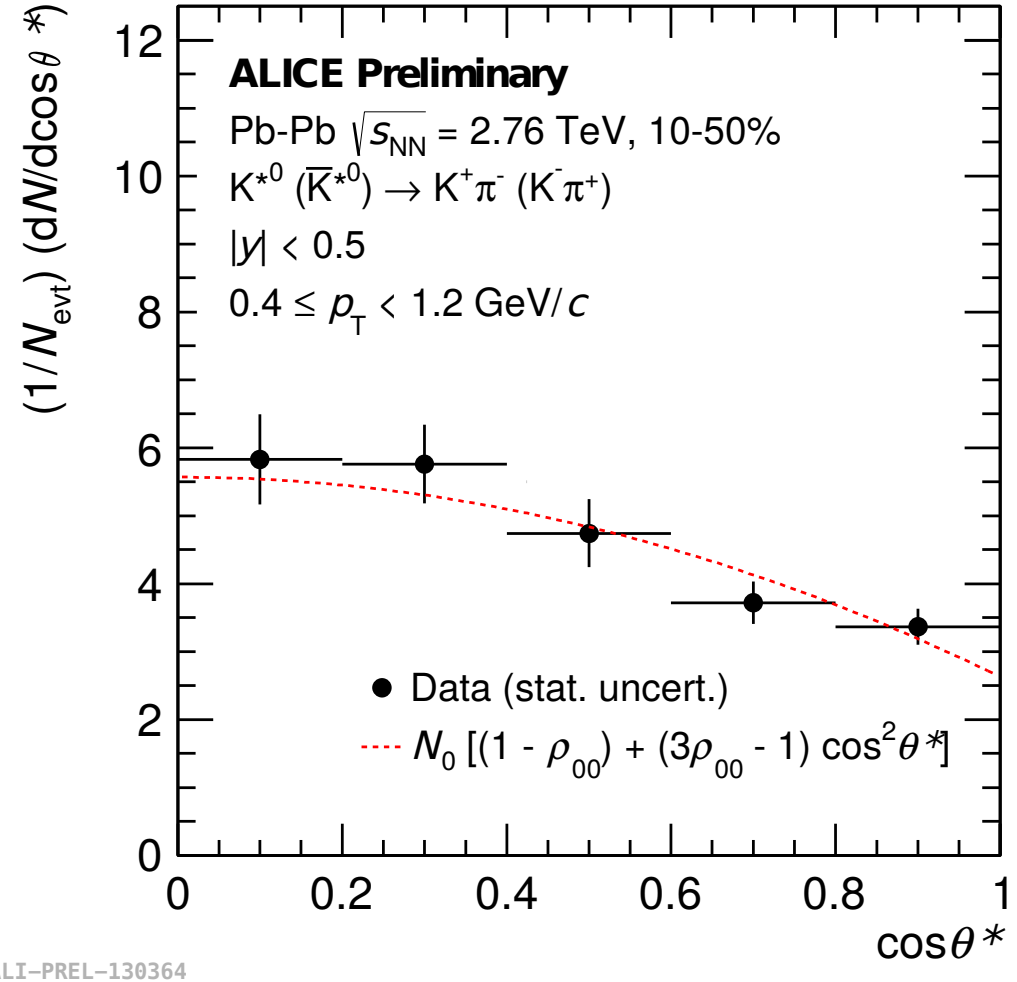
Heavy-ion collisions



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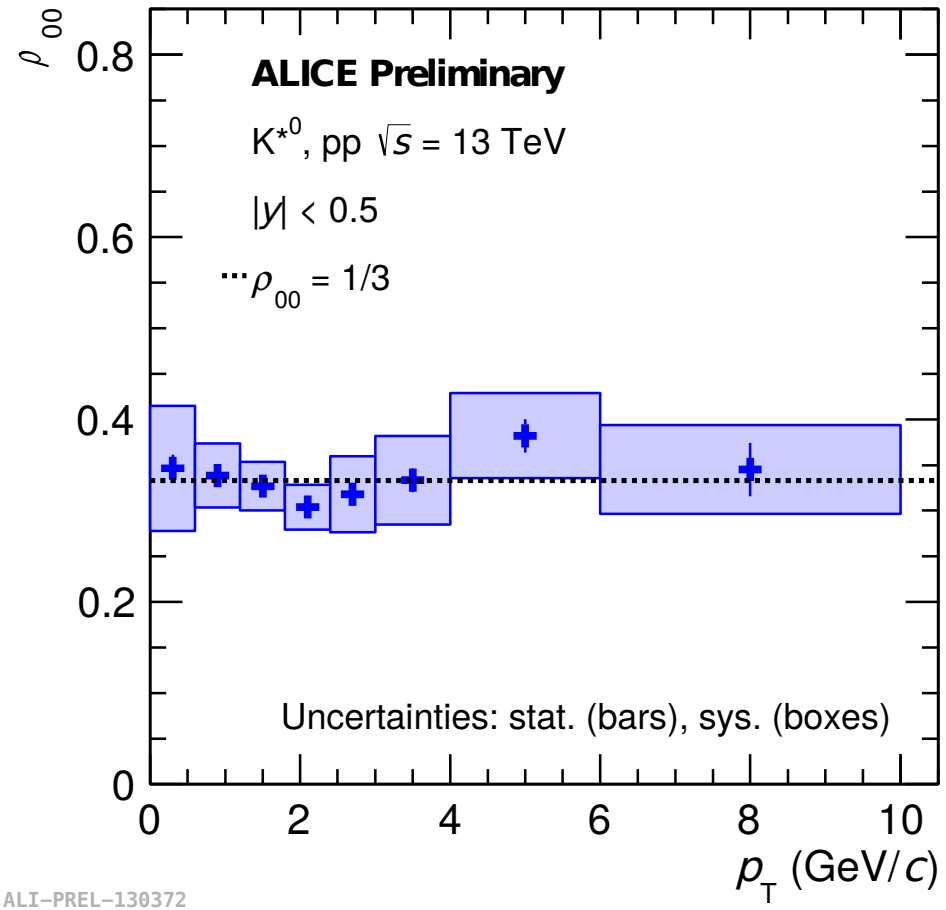
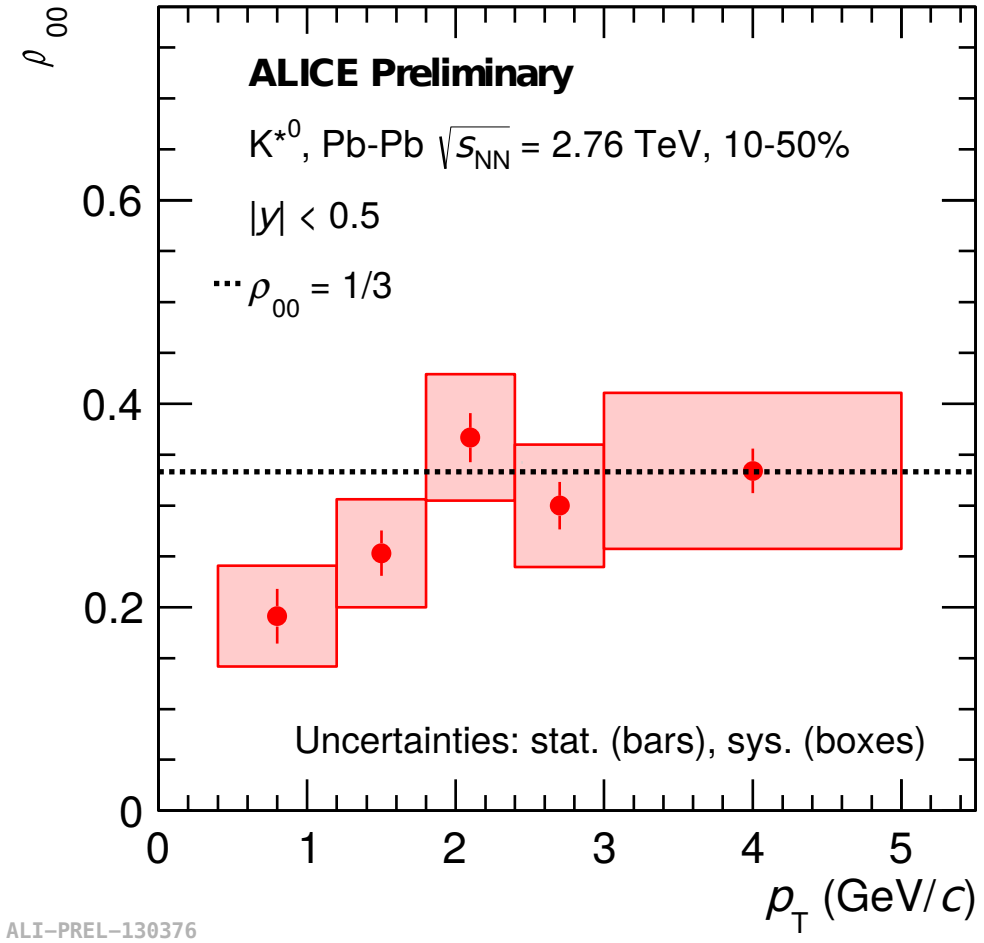
Two parameters (N_0 and ρ_{00}) fit to cosθ* distributions measured in different p_T bins

Spin density matrix element (ρ_{00}) measurements

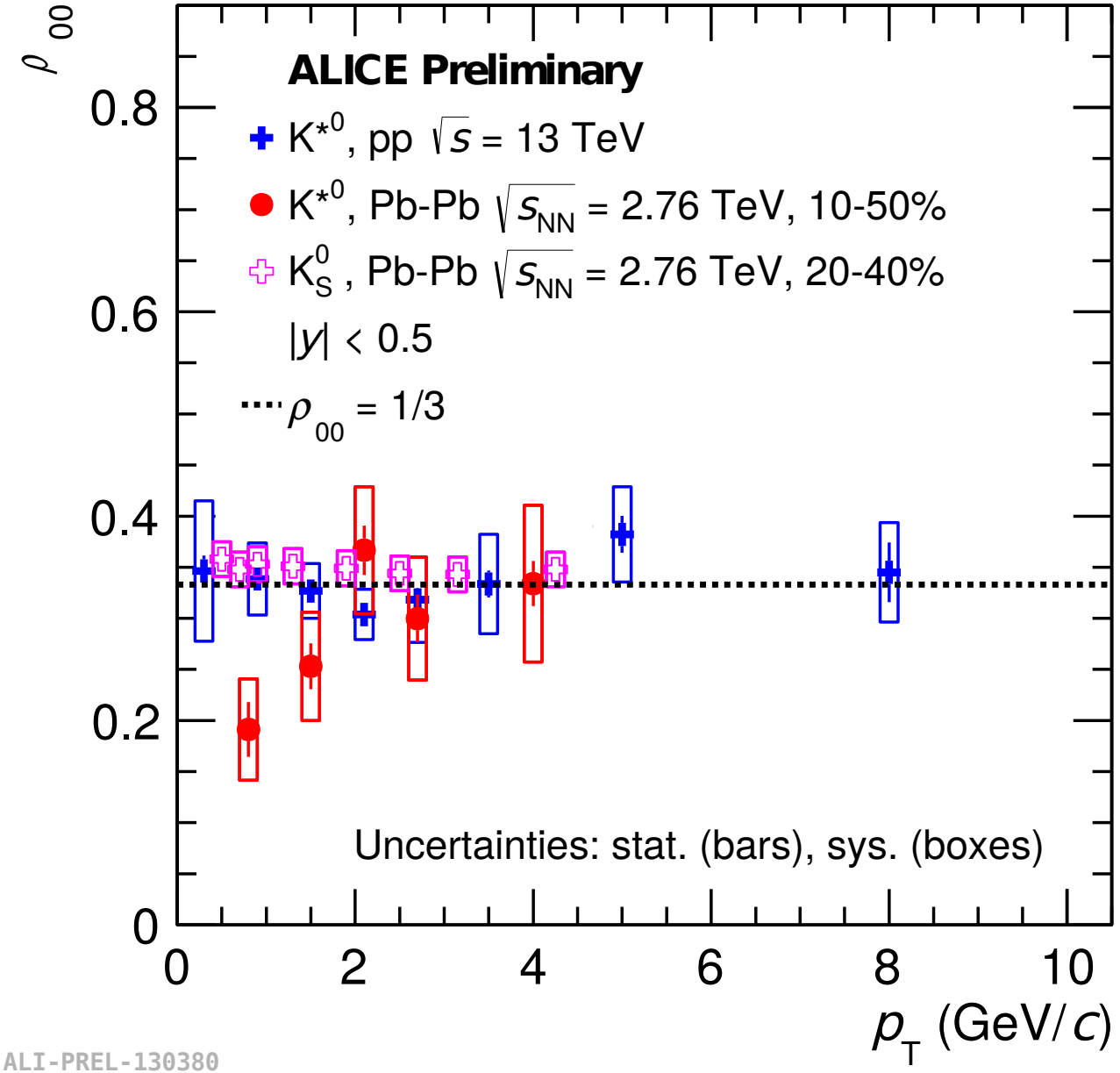




pp collisions: $\rho_{00} = 1/3$

Pb-Pb collisions: ρ_{00} values about 2.5σ below 1/3 for $0.4 \le p_T < 1.2$ GeV/c and 1.4σ for $1.2 \le p_T < 1.8$ GeV/c

Spin alignment of K^{*0}(spin 1) and K^{0}_{s}(spin 0)



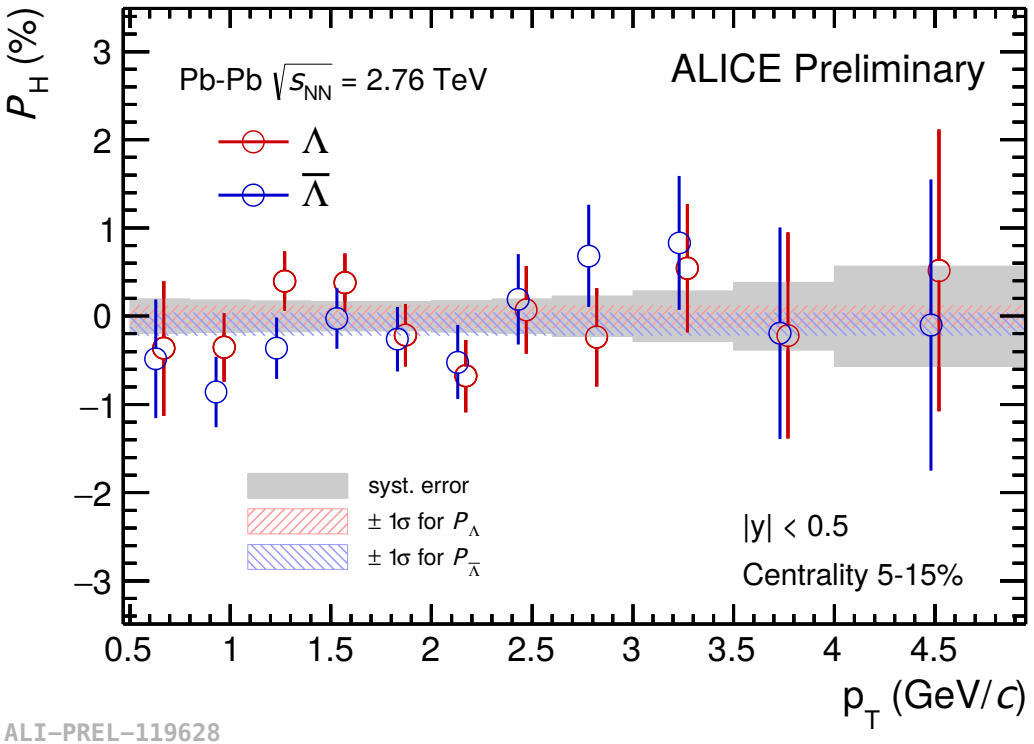
Summary of spin alignment results

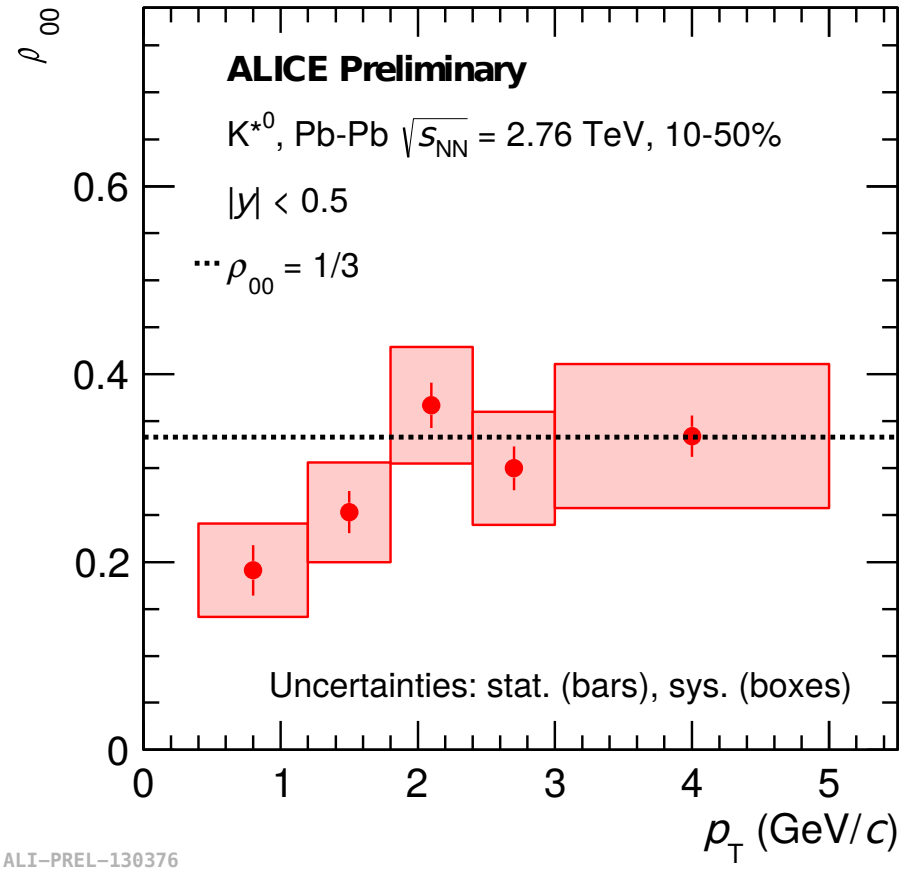
- $\rho_{00} < 1/3$ by about 2.5σ for the lowest p_T range (0.4-1.2 GeV/c) studied, about 1.4σ for the p_T range (1.2-2.4 GeV/c) and consistent with 1/3 for higher p_T in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in ALICE @ LHC

- $\rho_{00} \sim 1/3$: Spin alignment **not** observed in proton-proton collisions at 13 TeV

- $\rho_{00} \sim 1/3$ (within systematic errors) : Spin alignment **not** observed for K^0_s (spin 0) in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

Outlook





- ✓Analysis with $\sqrt{s_{NN}}$ = 5.02 TeV Pb-Pb data with higher statistics underway
- ✓Centrality dependence of ρ_{00} study ongoing
- ✓Spin alignment studies with respect to event plane ongoing

BACK UP

Feed-down correction

A majority of Λ are feed-down daughters of heavier particles (the very same for $\bar{\Lambda}$):

$X \to \Lambda + \ldots$ channel	Br($\Lambda + \ldots$), %	fraction f_X	$4/3 \times s(s+1)$	spin transfer t_X
$\Sigma^0 \to \Lambda + \gamma$	100	0.3 ± 0.2	1	$-1/3$
$\Sigma(1385)^{\pm,0} \to \Lambda + \pi^{\pm,0}$	87	0.3 ± 0.2	5	$1/3$
$\Omega^- \to \Lambda + K^-$	67.8	< 0.17	5	$1/3$
$\Xi^{\pm,0} \to \Lambda + \pi^{\pm,0}$	≈ 100	< 0.23	1	0.900 or 0.927

$$P^{\text{meas}}_{\Lambda,\bar{\Lambda}} = (1 - \sum_X f_X) P^{\text{true}}_{\Lambda,\bar{\Lambda}} + \sum_X f_X \times t_X \times P^{\text{true}}_X$$

Assuming the thermal vorticity model (P^{true}_X are proportional to $s(s+1)$, where s is particle's spin

$$P^{\text{true}}_{\Lambda,\bar{\Lambda}} = P^{\text{meas}}_{\Lambda,\bar{\Lambda}} \times \left(1 - \frac{4}{3} f_{\Sigma^0} + 0.87 \times \frac{2}{3} f_{\Sigma(1385)} + 0.68 \times \frac{2}{3} f_{\Omega^-} - 0.1\, f_{\Xi}\right)^{-1}$$

Ω^- and Ξ contributions are negligible, the contribution of $\Sigma(1385)$ is large only due to the model-dependent coefficient 5. A conservative estimate:

$$[\Lambda \text{ and } \bar{\Lambda} \text{ polarization scale feed-down}] = (1 - 4/3 \times f_{\Sigma^0})^{-1} = 1.7 \pm 0.5.$$

F. Becattini, I. Karpenko, M. Lisa, I. Upsal and S. Voloshin, arXiv:1610.02506 [nucl-th]