Strange-Meson Spectroscopy at COMPASS and Beyond

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Strange-Meson Spectroscopy

PDG

- PDG lists 25 strange mesons
- 13 established states, 12 need further confirmation
- Missing states with respect to quark-model prediction

Strange-Meson Spectroscopy

$K^*_J$ states

- 8 of 11 listed $K^*_J$ states are established
- Decay to $K\pi$ and other final states
- From precise measurements of
  - $K\pi$ scattering, e.g. from $K^\pm p \rightarrow K^{\pm} \pi^+ n$
  - heavy-meson ($J/\psi$, $D$, $B$, $\eta_c$) and $\tau$ decays

$K_J$ states

- Only 5 of 14 listed $K_J$ states are established
- Cannot decay to $K\pi$ final state
  - Observed in decays to multi-body final states: $K\pi\pi$, $K\phi$, $K\omega$, $\Lambda\bar{p}$
- From measurements of
  - heavy-meson and $\tau$ decays
  - various production experiments
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Production Experiments

- Production in scattering of high-energy beam
  - $K^\pm$, $\gamma$, $K^0_L$
- Strange mesons appear as intermediate states $X$
- Observed in decays into quasi-stable particles
  - $K^-\pi^-\pi^+$ final state produced in diffractive $K^-$ scattering at COMPASS
  - Access to all $K^*_J$ and $K_J$ states (except for $J^P = 0^+$)
Production Experiments

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  - Access to all $K_j^*$ and $K_J$ states (except for $J^P = 0^+$)
Rich spectrum of overlapping and interfering $X^-$
- Dominant well-known states
- States with lower intensity are “hidden”
- Largest data set of diffractively produced $K^-\pi^-\pi^+$
  - $\approx 720\,000$ exclusive events (cf. ACCMOR $200\,000$ exclusive events)
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  - $\approx 720,000$ exclusive events (cf. ACCMOR 200,000 exclusive events)
- Successive 2-body decay via $\pi^-\pi^+ / K^-\pi^+$ resonance called isobar
- Structures in angular distributions of $X^-$ and isobar decays
- Characteristic signature for spin and parity of the decaying state

Preliminary
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Structures in angular distributions of $X^-$ and isobar decays

Characteristic signature for spin and parity of the decaying state
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Kinematic Distributions

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**Kinematic Distributions**

**Partial wave**

\[ J^P M^\varepsilon \xi b L \]

- **\( J^P M^\varepsilon \):** Spin, parity, and spin projection of \( X^- \)
- **\( \xi \):** Isobar
- **\( b \):** Bachelor particle. Here: Spectator \( K^- \)
- **\( L \):** Angular momentum between bachelor and isobar

Partial-wave amplitudes extracted from data in maximum-likelihood fit.
**Kinematic Distributions**

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Selected Partial Waves

$J^P = 2^+$

$2^+ 1^+ K^*(892) \pi D$

- Signal in $K_2^*(1430)$ mass region
- Clear phase motion in $K_2^*(1430)$ region
- Characteristic of narrow isolated resonances

![Graph showing intensity vs. $m_{K\pi\pi}$ for $2^+ 1^+ K^*(892) \pi D$ resonance]
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$J^P = 2^+$

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- In agreement with previous measurement of $K^-\pi^+\pi^+$ final state at WA03
- Recent precise measurement from BES III
  - $J/\psi \rightarrow K^+K^-\pi^0$
- Various measurements in $K\pi$ scattering
  - $K^+p \rightarrow K_S^0\pi^+p$
  - $K^-p \rightarrow K^-\pi^+n$
- PDG lists different parameters for charged and neutral $K_2^*(1430)$
- Different cluster of parameters
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BESIII, 183 000 events, Phys. Rev. D 100 (2019)
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PDG, Prog. Theor. Exp. Phys. 2020, 083C01 (2020)
Selected Partial Waves

\( J^P = 2^- \)

\[ 2^- 0^+ K_2^* (1430) \pi S \]

- Strongest 2\(^-\) wave
- Two resonances in signal region
  - \( K_2(1770), K_2(1820) \)
- Bump in high-mass shoulder
  - Potential \( K_2(2250) \)

\[ 2^- 0^+ \rho(770) K F / 2^- 0^+ K^* (892) \pi F \]

- Similar signals also in \( \rho(770) K \) and \( K^* (892) \pi \) decays

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S. Wallner
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- Recent measurement from LHCb in \( B^+ \rightarrow J/\psi\phi K^+ \)
- Mass and width determined from these two measurements only
- Further observations from decays to \( K2\pi, K\phi, K\omega \) final states from production experiments at CERN, SLAC, ...

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Selected Partial Waves

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\( K_2(1820) \)

- Observed only in
  - \( K\omega \) final state at LASS
  - \( \phi K^+ \) final state at LHCb
  - \( K^-\pi^-\pi^+ \) final state at WA03

Selected Partial Waves

$J^P = 2^-$

$K_2(2250)$

- Observed mainly in $\Lambda\bar{p}$ final state from production experiments

CERN $\Omega'$ spectrometer, 10 000 events, Nucl. Phys. B 227 (1983)
$J^P = 1^+$

$1^+ 0^+ \rho(770) K S$

- 3.4% of total intensity
- Dominated by $K_1(1270)$
- Small potential signal from $K_1(1650)$
Selected Partial Waves

\( J^P = 1^+ \)

**K\(_1\)(1270) / K\(_1\)(1400)**

- Recent measurements in
  - \( D^0 \rightarrow K^{±}\pi^{±}\pi^{±}\pi^{±} \) from LHCb
  - \( B^+ \rightarrow J/\psi K^{+}\pi^{+}\pi^- \) at Belle
  - \( \tau^- \rightarrow K^-\pi^+\pi^-\nu_\tau \) at Cleo II

- Potential bi-modality in the width of the \( K_1(1270) \)
  - Proposals that \( K_1(1270) \) has two-pole structure similar to \( \Lambda(1405) \) coupling differently to different decay modes

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Belle, 11 000 events, Phys. Rev. D 83 (2011)
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**$K_1(1650)$**

- Cannot be accessed in $D$ or $\tau$ decays
  - $K_1(1650)$ low-mass tails can contribute
- Observed in
  - $B^+ \to J/\psi\phi K^+$ decays at LHCb
  - $\phi K$ and $K \pi \pi$ final states from production experiments at CERN
- Parameters driven by one measurement
- Further confirmation needed
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Leakage Effect in COMPASS Data

- Unexpected low-mass enhancement in $3^+ 1^+ K^*(892)\pi D$ wave
- Sensitive to systematic effects
- Final-state PID does not cover full kinematic range
  - Reduced distinguishability of partial waves
- Only a small sub-set of partial waves affected

\[
\begin{align*}
\text{Intensity} \times 10^6 & = \frac{1^+ 1^+ K^*(892)\pi D}{1.0 \text{ GeV/c}^2} \\
0.10 \leq t' < 1.00 \text{ (GeV/c)}^2 & \quad 4.3 \% \\
\end{align*}
\]

Affected by leakage

Preliminary
Unpacking the Leakage Effect in COMPASS Data

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Graphical representation:

- Intensity / $(1.0 \text{ GeV/c}^2) \times 10^6$
- Mass $m_{K\pi\pi}$ [GeV/c$^2$]
- $3^+ 1^+ \bar{K}^* (892) \pi D$
- $0.10 \leq t' < 1.00 \text{ (GeV/c)}^2$
- Main Studies
- Preliminary
Leakage Effect in COMPASS Data

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Strange-meson spectroscopy

- Many states need further clarification
- Many measurements performed more than 30 years ago
- Most of the recent measurements from heavy-meson or $\tau$ decays

$K^-\pi^-\pi^+$ final state at COMPASS

- World’s largest data set of diffractively produced $K^-\pi^-\pi^+$
- Observation of well-known states
- Potential signals from excited states
- Few signals were identified to be affected by large systematic effects
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Spectroscopy of strange mesons

- Radio-frequency separated high-intensity high-energy kaon beam
  - Series of workshops at CERN
- At least $\times 10$ larger data set than collected by COMPASS
- Map out strange-meson spectrum with similar precision as unflavored light-meson spectrum
- Proposal for phase-1: CERN-SPSC-2019-022
  - Recommended by SPSC
  - Formation of new collaboration in process
Backup