

Strange-Meson Spectroscopy with COMPASS

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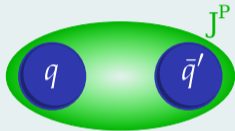
Max Planck Institute for Physics

20th International Conference on Hadron Spectroscopy and Structure
June 8, 2023



MAX PLANCK INSTITUTE
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Understanding the light-meson spectrum

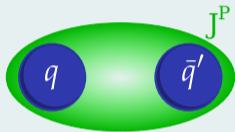


- ▶ Completing $SU(3)_{\text{flavor}}$ multiplets
- ▶ Identifying **supernumerous states**
 - ➔ Search for **exotic** strange mesons

Input to other fields of physics

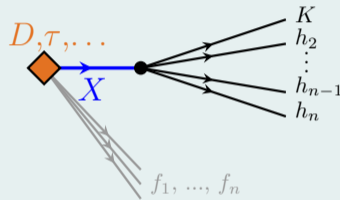
- ▶ Strange mesons appear as resonances in multi-body hadronic final states with kaons
- ▶ Searches for **CP violation**
- ▶ Searches for **physics beyond SM**

Understanding the light-meson spectrum

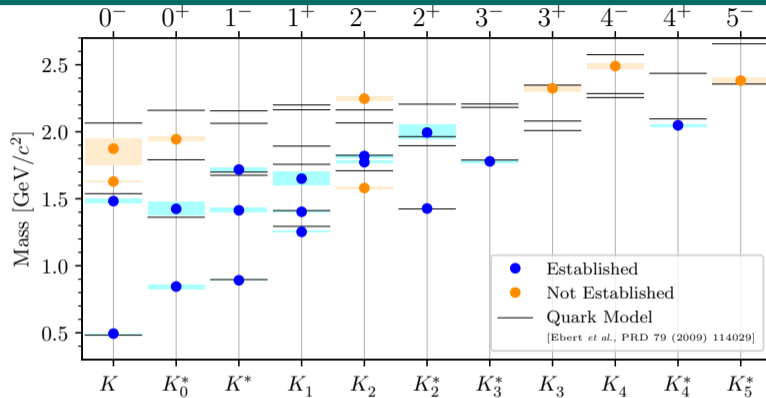


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Input to other fields of physics



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PDG lists 25 strange mesons

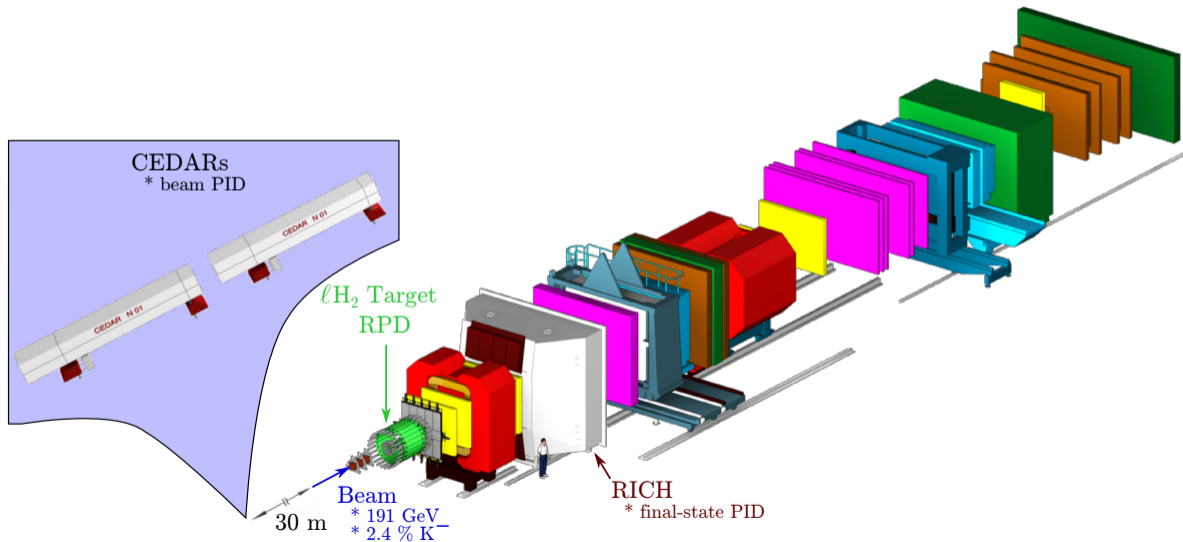
(2022)

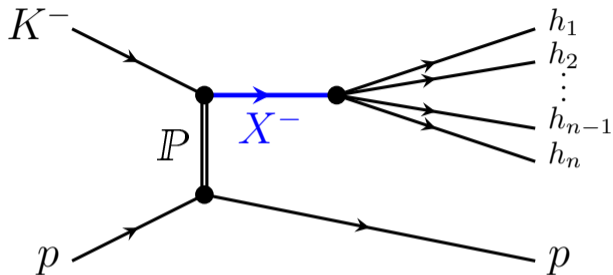
- ▶ 16 established states, 9 need further confirmation
- ▶ Missing states with respect to quark-model predictions
- ▶ Many measurements performed more than 30 years ago

Strange-Meson Spectroscopy with COMPASS

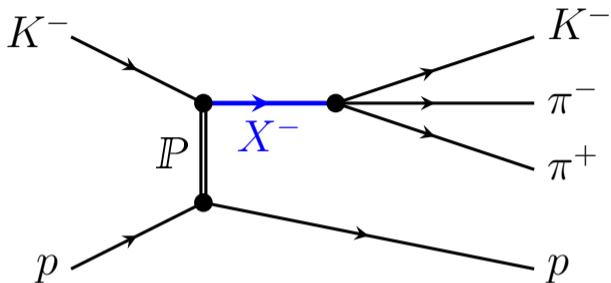
COMPASS Setup for Hadron Beams

[COMPASS, Nucl. Instrum. Methods 779 (2015) 69]





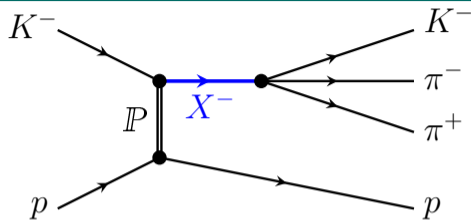
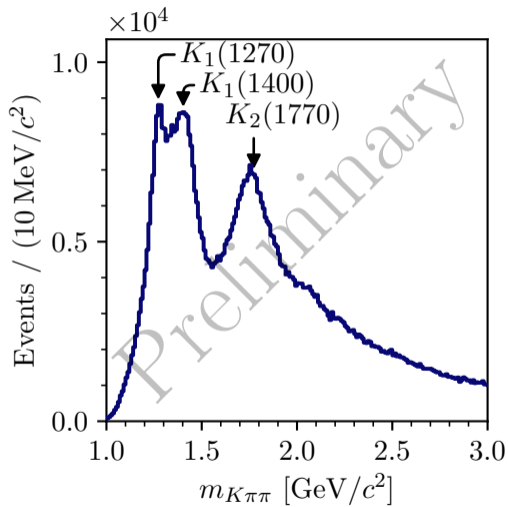
- ▶ Diffractive scattering of high-energy kaon beam
- ▶ Strange mesons appear as **intermediate resonances** X^-
- ▶ Decay to multi-body hadronic final states
- ▶ $K^- \pi^- \pi^+$ final state
 - ▶ Study in principle all strange mesons
 - ▶ Study a wide mass range
 - ▶ Study different decay modes



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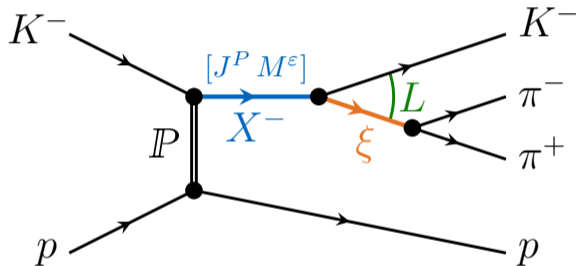
The $K^- \pi^- \pi^+$ Data Sample



- ▶ World's largest data set of about 720 k events
- ▶ Rich spectrum of **overlapping and interfering** X^-
 - ▶ Dominant well known states
 - ▶ States with lower intensity are "hidden"

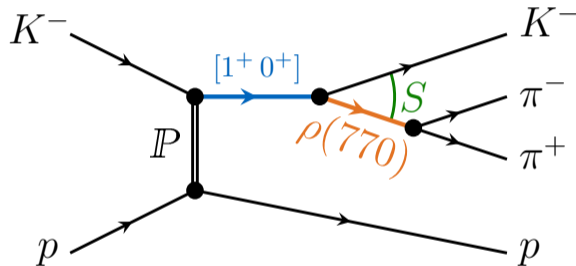
Partial wave: $J^P M^\epsilon \xi b^- L$

- ▶ J^P spin and parity
- ▶ M^ϵ spin projection
- ▶ ξ isobar resonance
- ▶ b^- bachelor particle
- ▶ L orbital angular momentum



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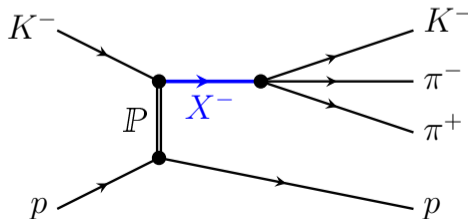
Data: 720 k diffractively produced $K^- \pi^- \pi^+$ candidates

Data: 720 k diffractively produced $K^-\pi^-\pi^+$ candidates

(I) Partial-Wave Decomposition

Performed independently in narrow $(m_{K\pi\pi}, t')$ cells
No assumption about $K\pi\pi$ resonances

Partial waves: Intensities and relative phases as a function of $(m_{K\pi\pi}, t')$

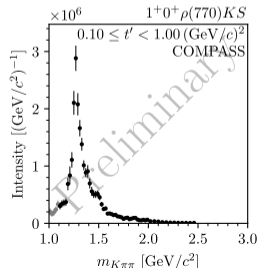
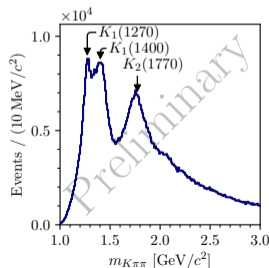


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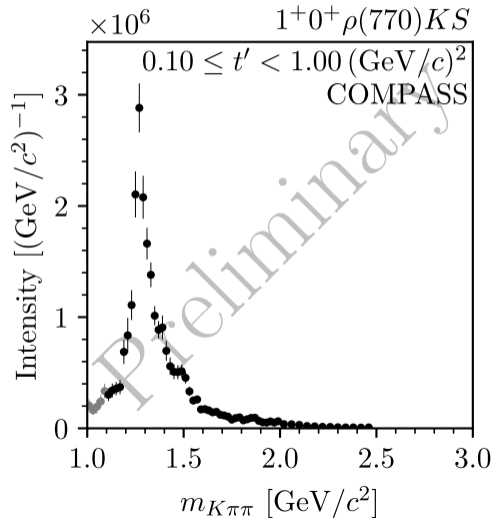
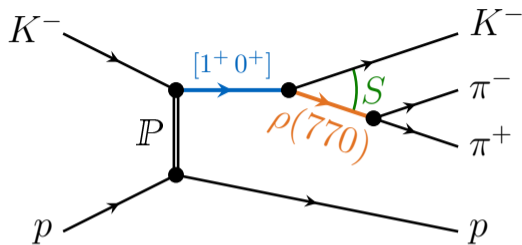
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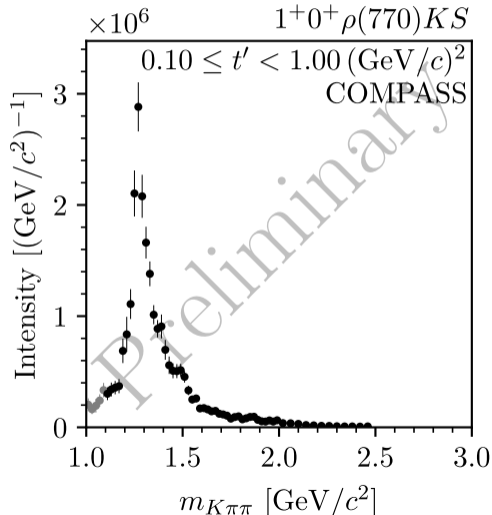
(II) Resonance-Model Fit

Model $m_{K\pi\pi}$ dependence of partial waves
 $K\pi\pi$ resonances and background

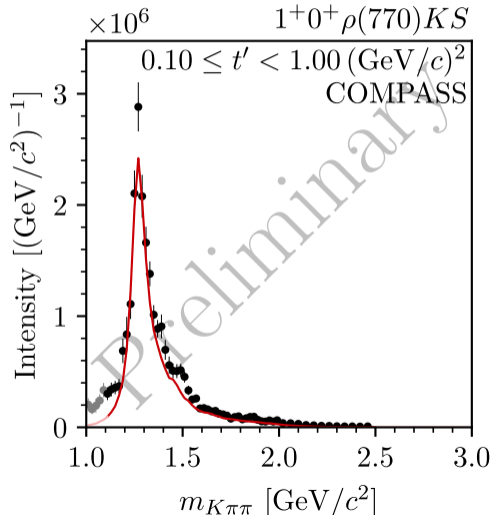
Resonance parameters: Masses and widths of the strange-meson resonances



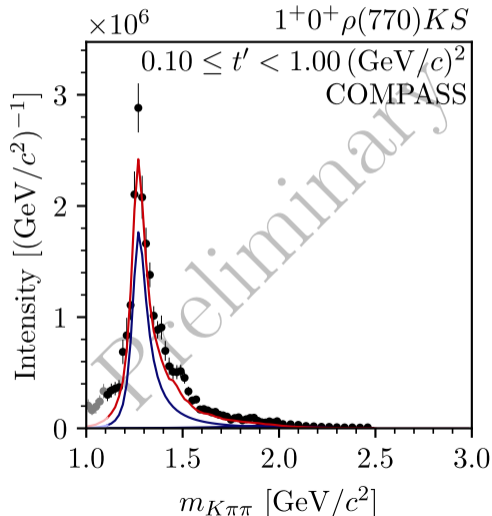
- ▶ Partial-wave amplitudes in $(m_{K\pi\pi}, t')$ bins
 - ▶ Inferred wave set from data using regularization-based model-selection techniques
 - ▶ Bootstrap resampling to improve uncertainty estimates
 - ▶ Detailed Monte Carlo input-output studies
- ▶ Model $m_{K\pi\pi}$ dependence of partial-wave amplitudes
- ▶ Breit-Wigner amplitudes for $K^-\pi^-\pi^+$ resonance components
- ▶ Coherent non-resonant component parameterizing other $K^-\pi^-\pi^+$ production mechanisms
- ▶ Developed scheme to handle incoherent backgrounds
 - ▶ Incoherent background from $\pi^-\pi^-\pi^+$ diffraction to $\pi^-\pi^-\pi^+$ explicitly modeled by COMPASS $\pi^-\pi^-\pi^+$ analysis
 - ▶ Incoherent effective background component parameterizing other background processes



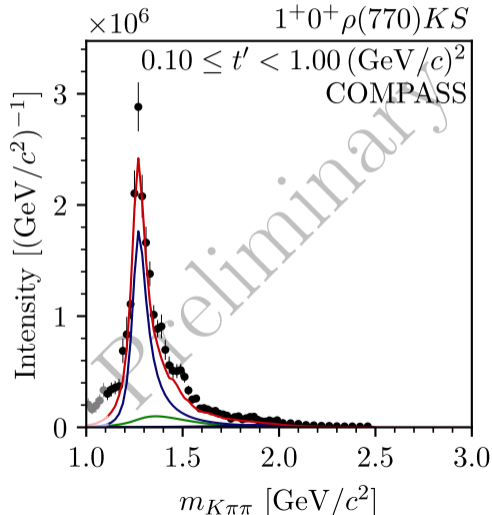
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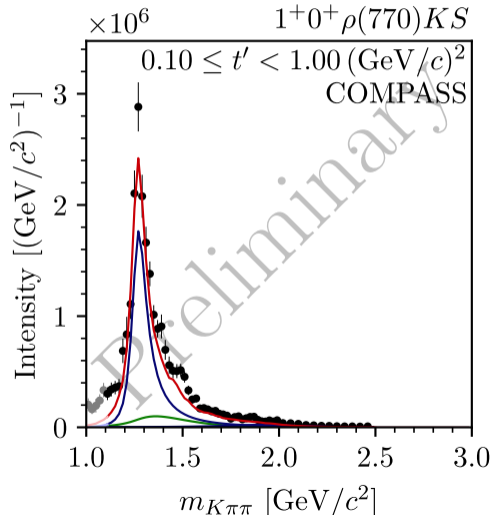
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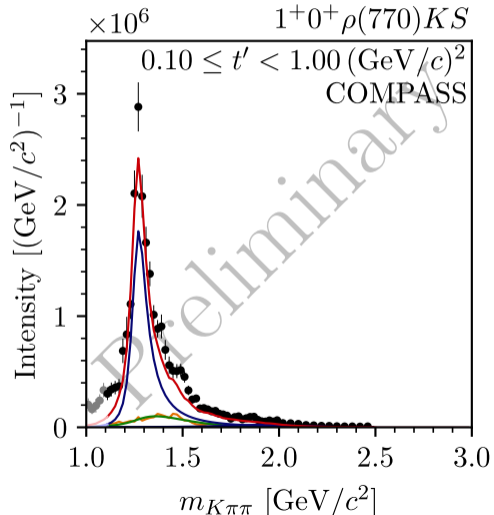
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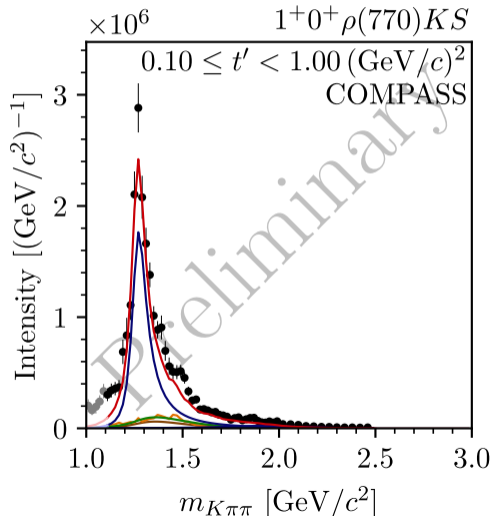
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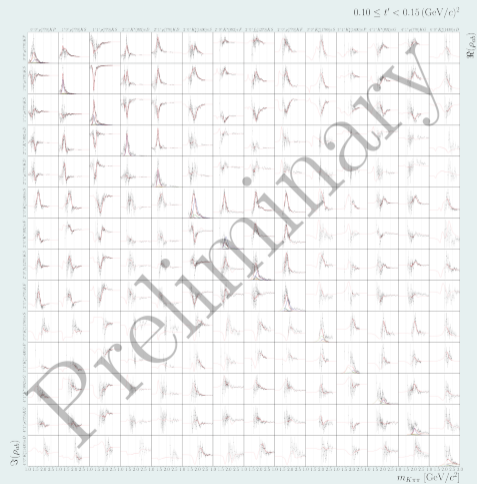
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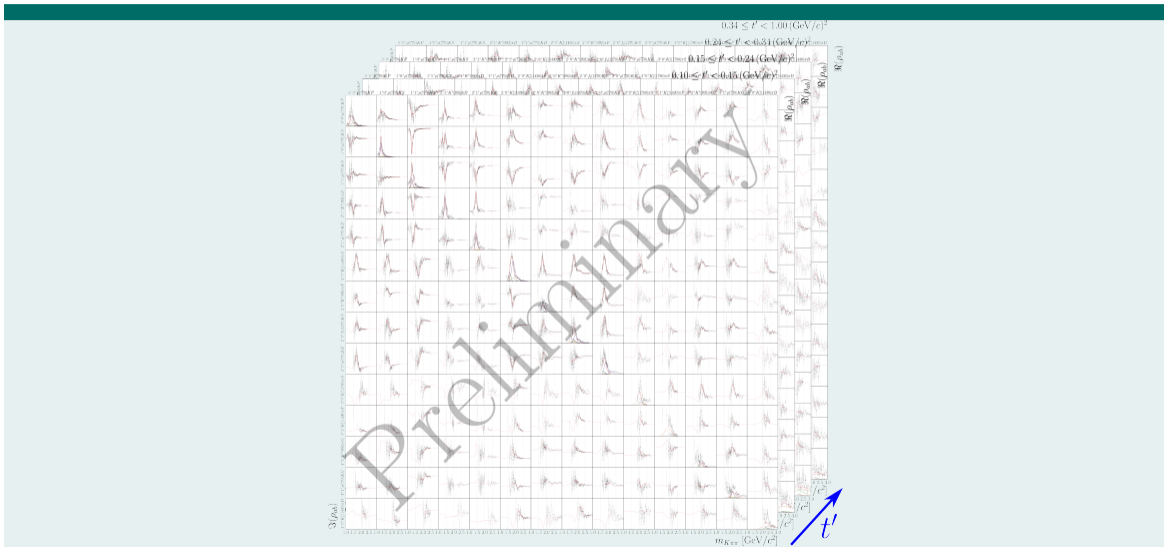


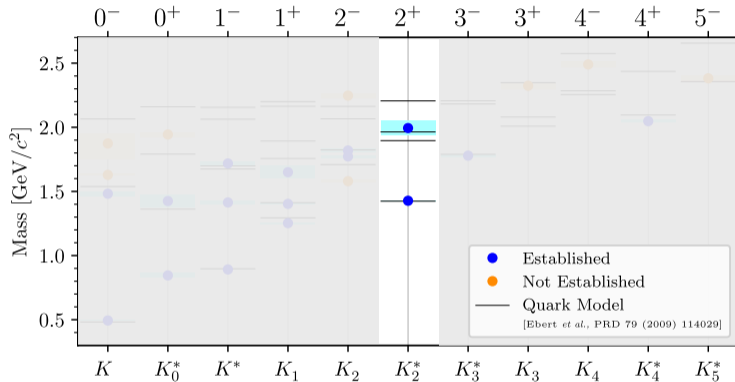
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- ▶ Simultaneously included 14 partial waves in resonance-model fit
- ▶ Modeled by 13 strange-meson resonance components
- ▶ Using measured intensities and interference terms (relative phases)



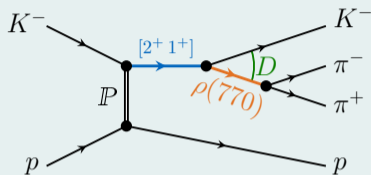




PDG

(2022)

► $K_2^*(1430)$ well known resonance



► $K_2^*(1430)$ signal

► $m_0 = (1430.9 \pm 1.4^{+3.1}_{-1.5}) \text{ MeV}/c^2$

► $\Gamma_0 = (111 \pm 3^{+4}_{-16}) \text{ MeV}/c^2$

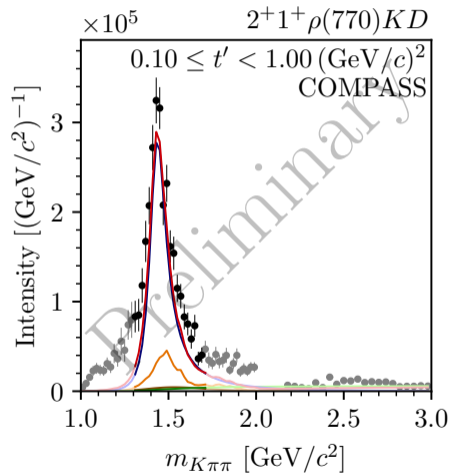
► In different decays

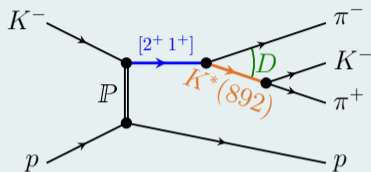
► $\rho(770) K D$

► $K^*(892) \pi D$

► In agreement with previous measurements

► Cleaner signal in COMPASS data





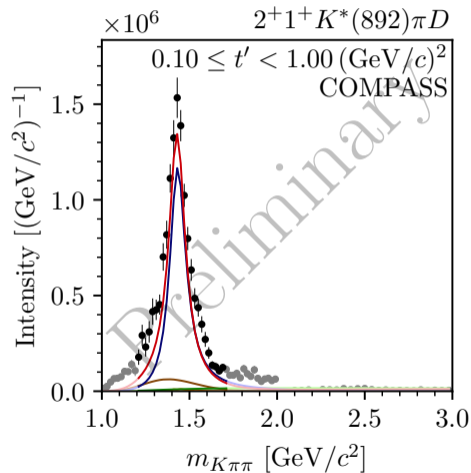
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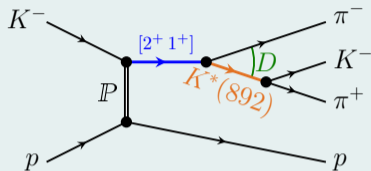
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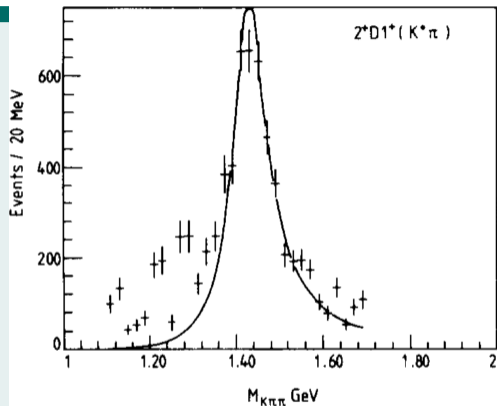
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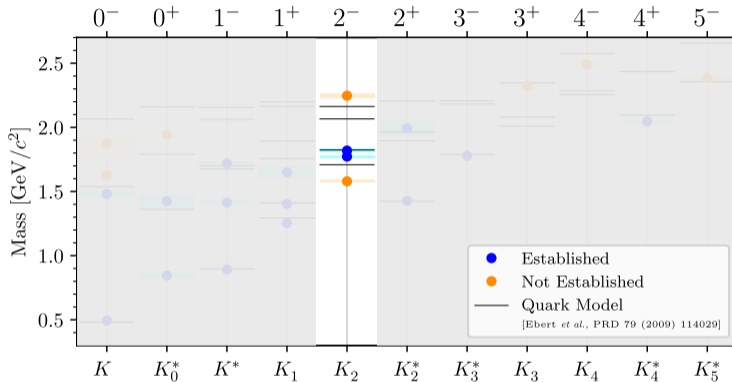
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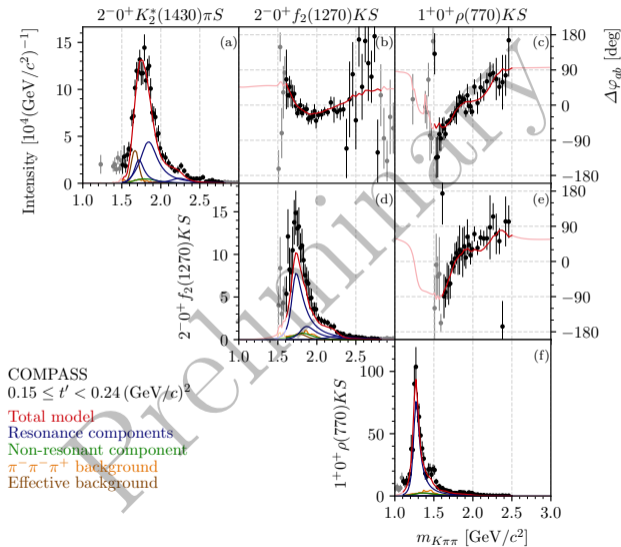


PDG

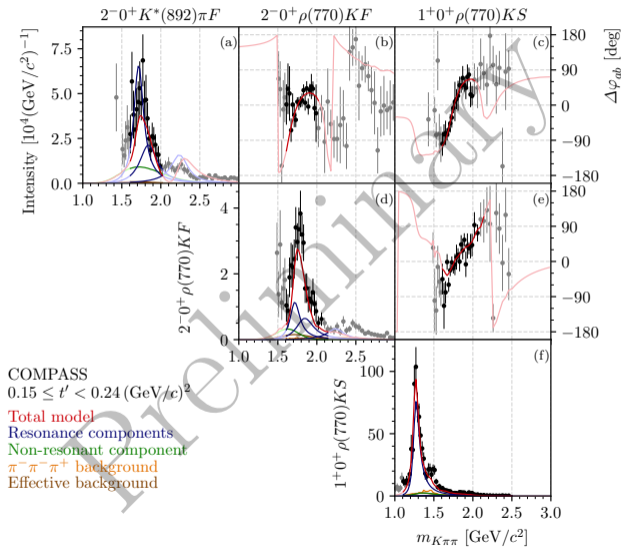
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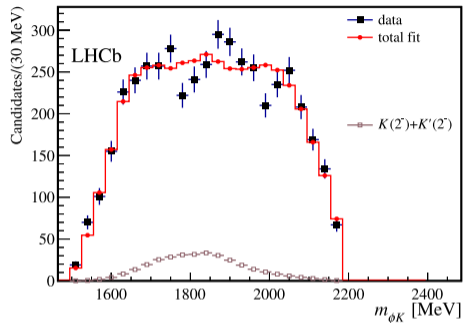
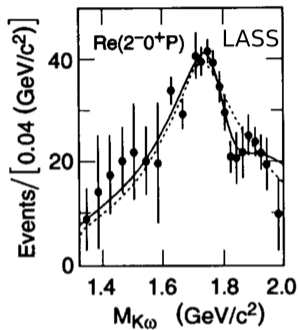
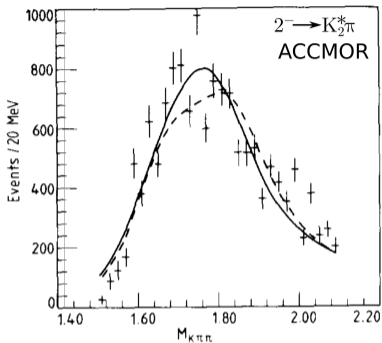
- ▶ Established $K_2(1770)$ and $K_2(1820)$
- ▶ $K_2(2250)$ need further confirmation

- ▶ Simultaneously fit 4 waves with $J^P = 2^-$
- ▶ $1.8 \text{ GeV}/c^2$ peak modeled by $K_2(1770)$, $K_2(1820)$
- ▶ High-mass shoulder modeled by $K_2(2250)$
- ▶ Different intensity spectra and large phase motions among 2^- waves



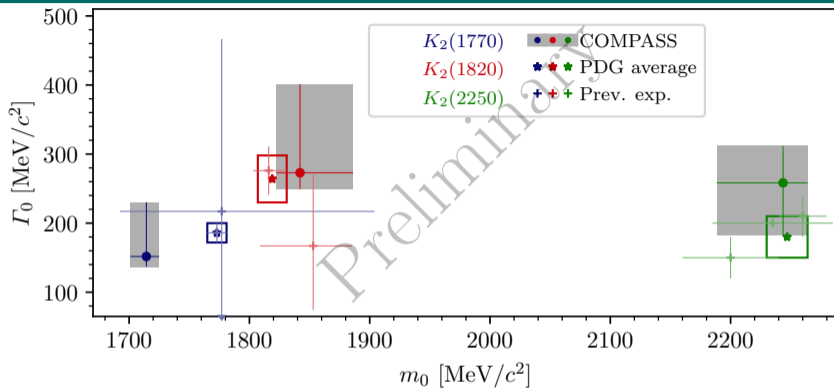
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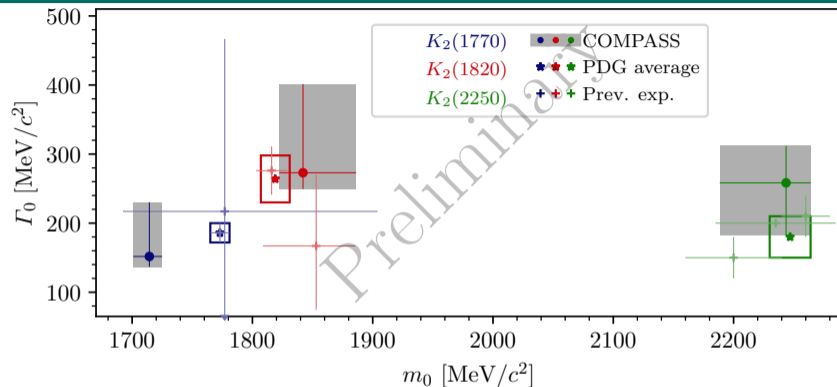
$K_2(1770)$ and $K_2(1820)$

- ▶ Two states were considered by only three measurements ACCMOR, LASS, LHCb
- ▶ Only LHCb measurement could confirm two states (3σ statistical significance)
- ▶ We observe two states with 11σ statistical significance



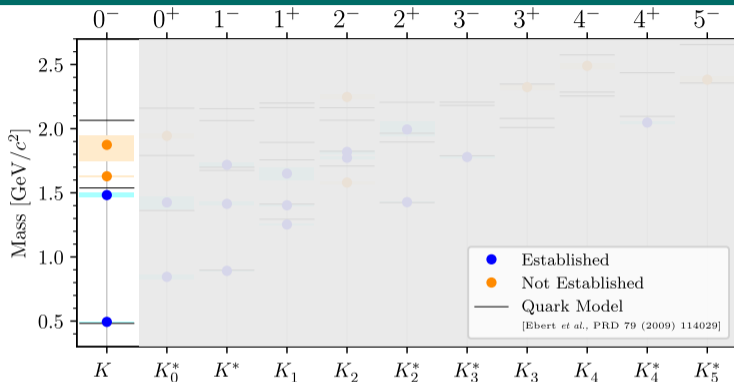
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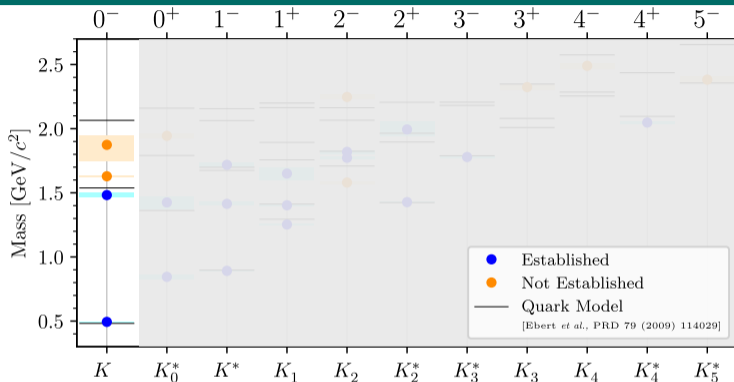


$K_2(2250)$

- ▶ Studied so far mainly in $(\bar{\Lambda}^0 \bar{p})$ final states
- ▶ First simultaneous measurement of $K_2(1770)$, $K_2(1820)$, and $K_2(2250)$
- ▶ Resonance parameters consistent with previous observations



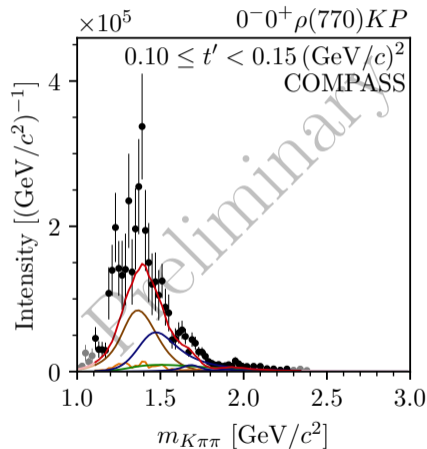
- ▶ K(1460) and K(1830)
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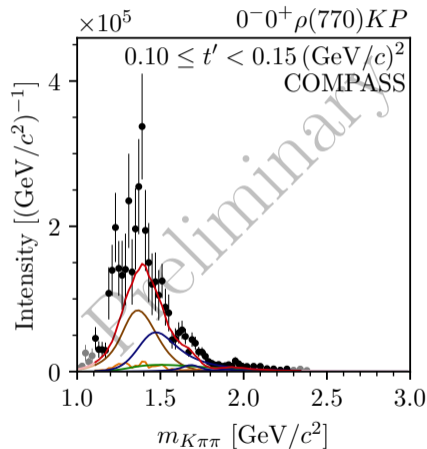
COMPASS $K^-\pi^-\pi^+$ data

- ▶ Peak at about $1.4 \text{ GeV}/c^2$
 - ▶ Established $K(1460)$
 - ▶ But, $m_{K\pi\pi} \lesssim 1.5 \text{ GeV}/c^2$ region affected by known analysis artifacts
- ▶ Second peak at about $1.7 \text{ GeV}/c^2$
 - ▶ $K(1630)$ signal with 8.3σ statistical significance
 - ▶ Accompanied by rising phase
- ▶ Weak signal at about $2.0 \text{ GeV}/c^2$
 - ▶ $K(1830)$ signal with 5.4σ statistical significance



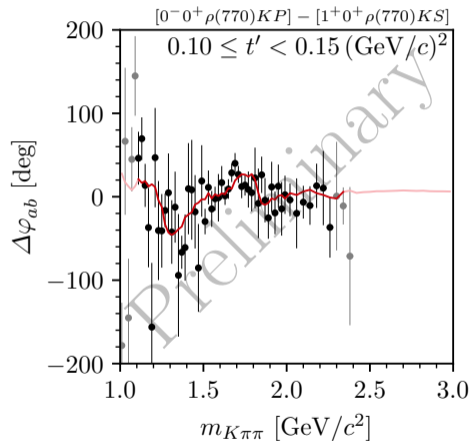
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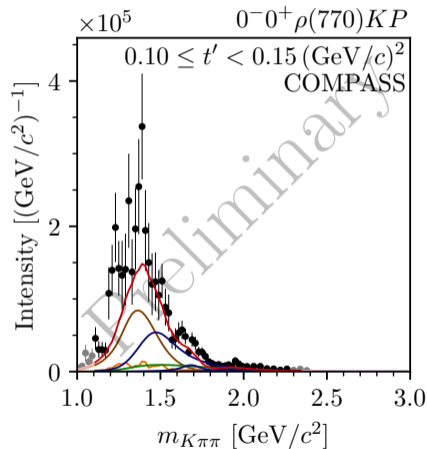
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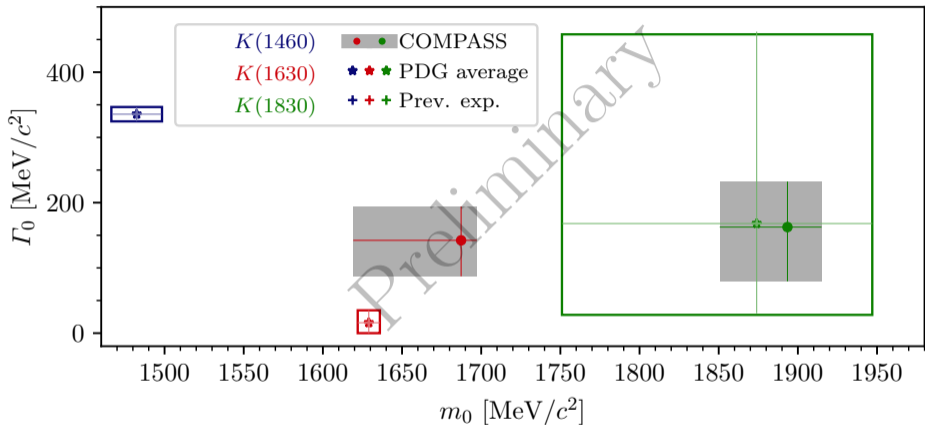
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- ▶ Weak signal at about $2.0 \text{ GeV}/c^2$
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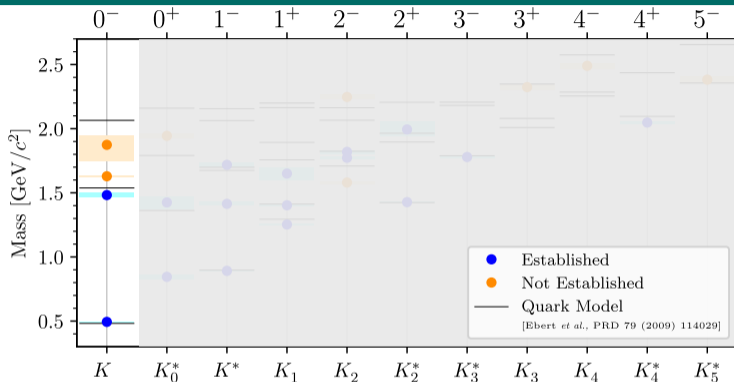
COMPASS $K^-\pi^-\pi^+$ data

- ▶ Peak at about $1.4 \text{ GeV}/c^2$
 - ▶ Established $K(1460)$
 - ▶ But, $m_{K\pi\pi} \lesssim 1.5 \text{ GeV}/c^2$ region affected by known analysis artifacts
- ▶ Second peak at about $1.7 \text{ GeV}/c^2$
 - ▶ $K(1630)$ signal with 8.3σ statistical significance
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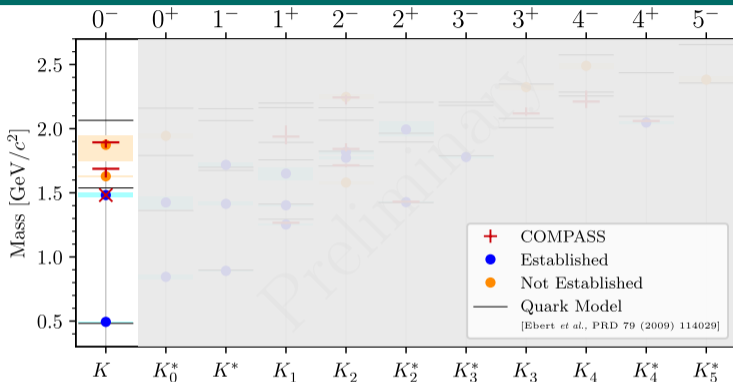




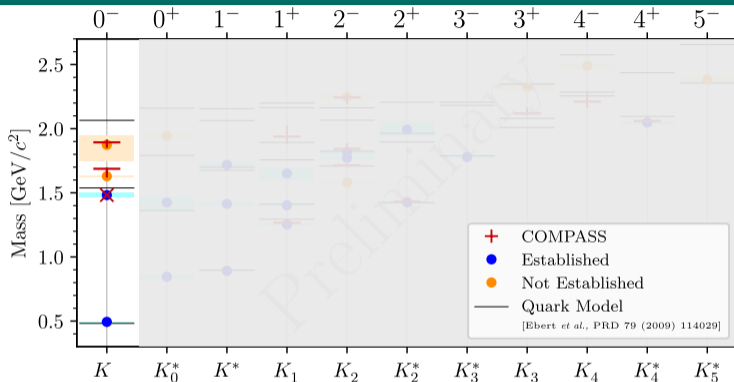
- ▶ $K(1830)$ parameters in good agreement with LChb measurement [PRL 118 (2017) 022003]
- ▶ Expected $K(1630)$ width of about 140 MeV/c²



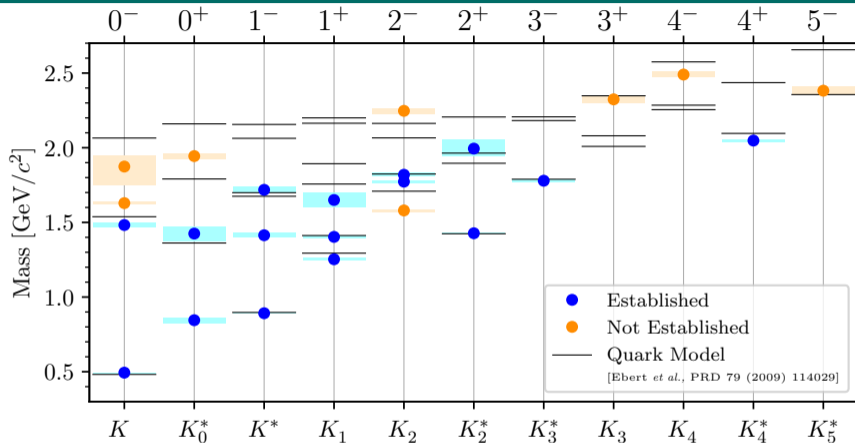
- ▶ Indications for 3 excited K from a single analysis
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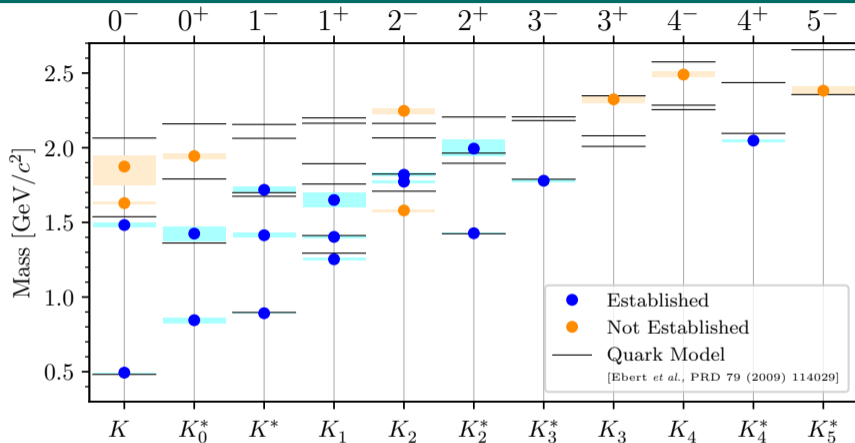


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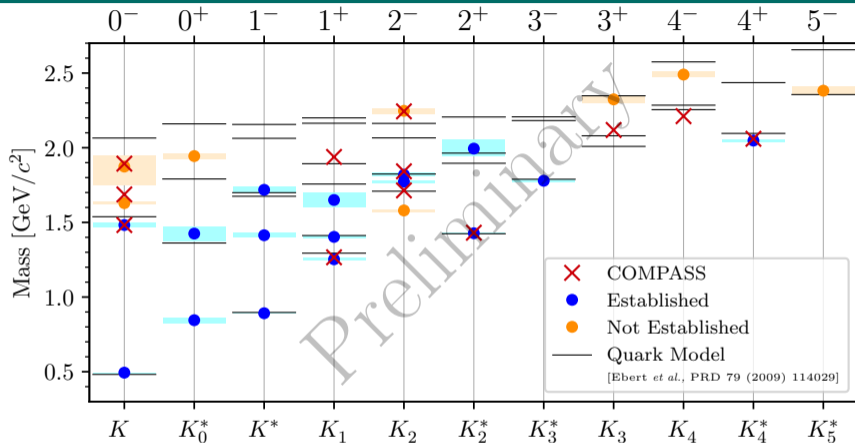
The Strange-Meson Spectrum

- ▶ Many strange mesons require further confirmation
- ▶ Search for strange partners of exotic non-strange light mesons



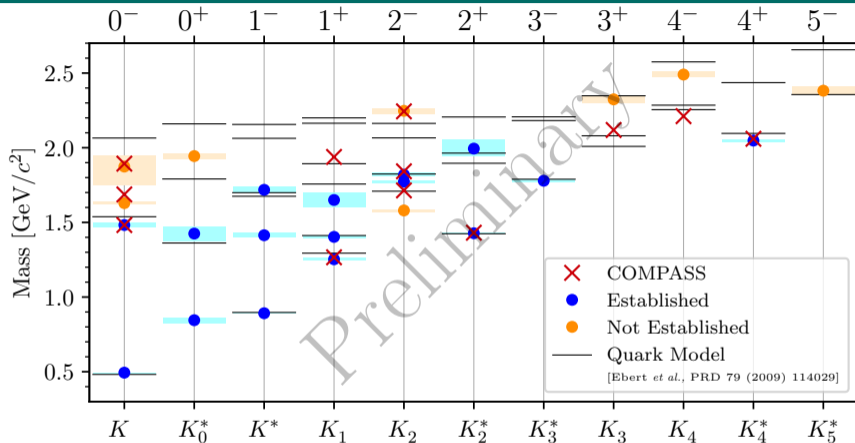
COMPASS

- ▶ World's largest data sample on $K^- \pi^- \pi^+$ \Rightarrow Most detailed and comprehensive analysis
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COMPASS

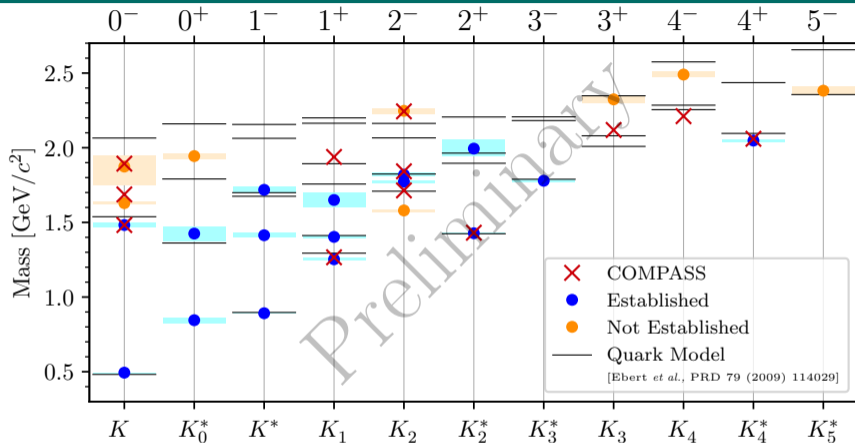
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AMBER: Proposal for High-Precision Strange-Meson Spectroscopy

[O. Denisov, Friday 14:00]

- ▶ Goal: Collect $10 - 20 \times 10^6$ $K^- \pi^- \pi^+$ events using high-intensity and high-energy kaon beam
- ▶ AMBER is open for interested collaborators to join



COMPASS

- ▶ World's largest data sample on $K^- \pi^- \pi^+$ \Rightarrow Most detailed and comprehensive analysis
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