Strange-Meson Spectroscopy at COMPASS

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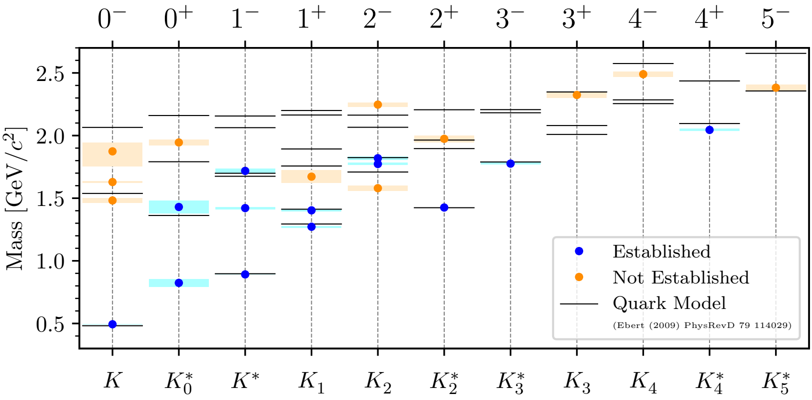
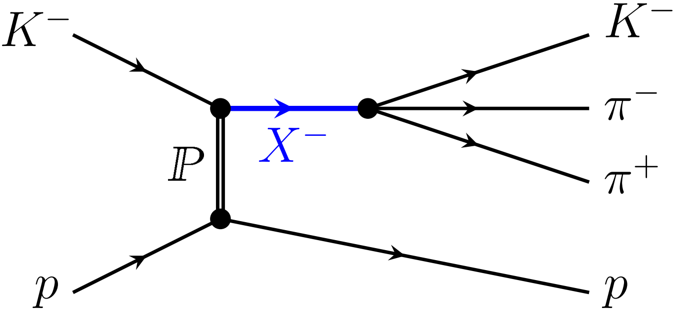
Strange-Meson Spectroscopy



PDG (2019)

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

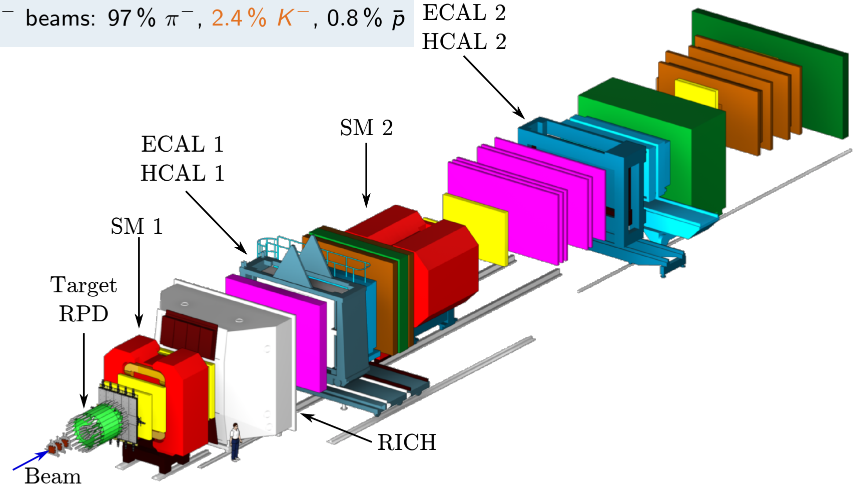
Diffractive Production



- Diffractive production in $K^- p$ scattering
- Strange mesons appear as intermediate states X^-
- Observed in decays into quasi-stable particles: $K^-\pi^-\pi^+$ final state
  - Access to all K and K^* states

M2 beam line

- Located at CERN (SPS)
- 190 GeV/c secondary hadron beams
  - h^- beams: 97 % π^-, 2.4 % K^-, 0.8 % $\bar{p}$

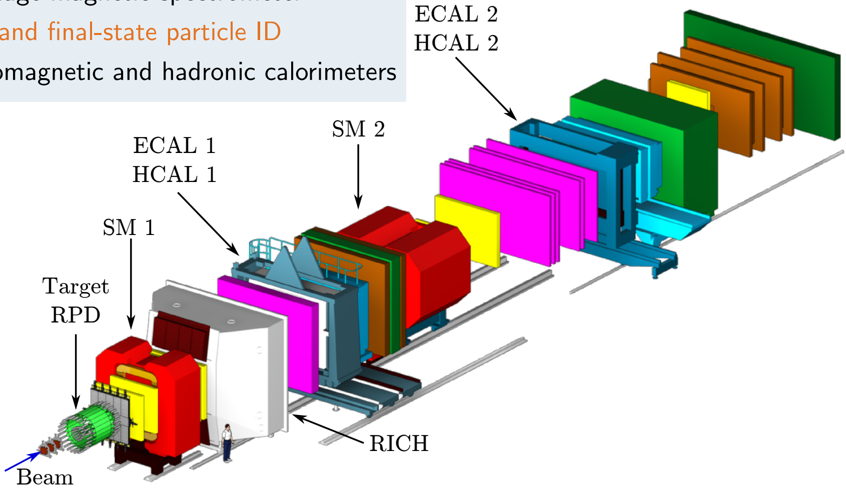


COMPASS Setup for Hadron Beams

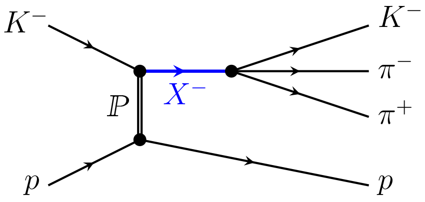
[NIMA 779 (2015) 69]

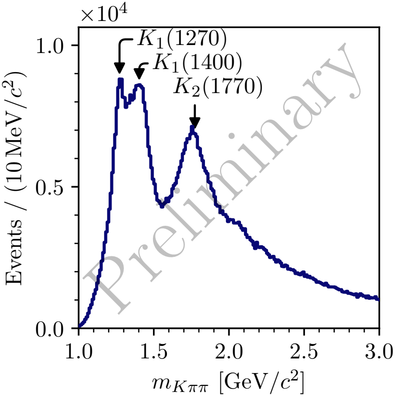
COMPASS setup

- ℓH_2 target
- Two-stage magnetic spectrometer
- Beam and final-state particle ID
- Electromagnetic and hadronic calorimeters



Kinematic Distributions

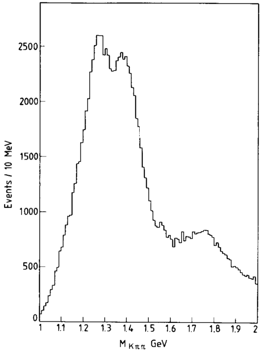


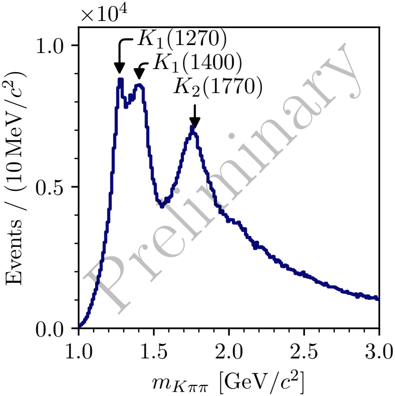


- Rich spectrum of overlapping and interfering X^-
  - Dominant well known states
  - States with lower intensity are "hidden"
- Largest data set of diffractively produced $K^-\pi^-\pi^+$
  - $\approx$ 720 000 exclusive events

Kinematic Distributions

WA03 (CERN)
200 000 events
ACCMOR, NPB **187**
(1981)





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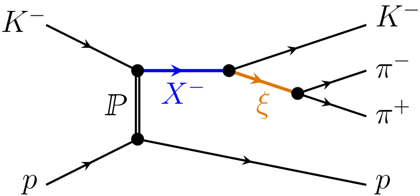

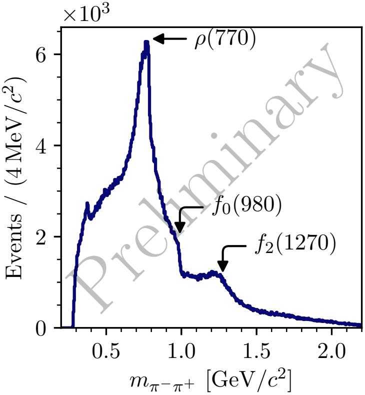

- Also structure in $\pi^-\pi^+$ and $K^-\pi^+$ subsystems
  - ➥ Successive 2-body decay via $\pi^-\pi^+$ / $K^-\pi^+$ resonance called isobar

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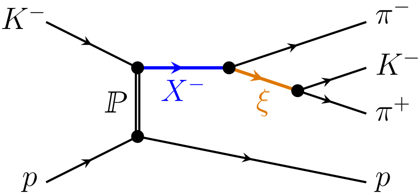

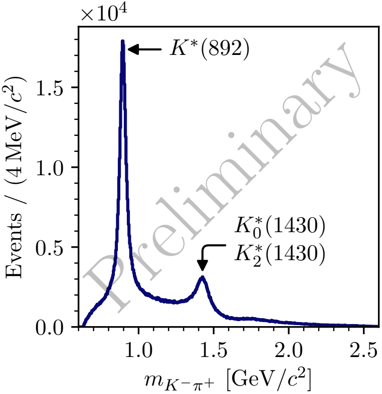

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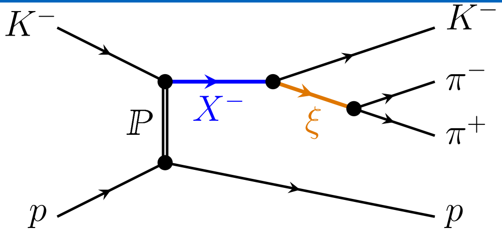
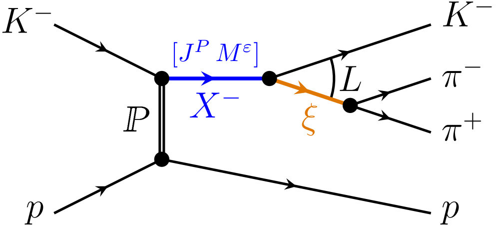


- Partial wave $a = J^P\, M^\varepsilon\, \xi^0\, b^\pi\, L$ at fixed invariant mass of $K^-\pi^-\pi^+$ system
  - ➥ Calculate 5D decay phase-space distribution of final state
- $\Psi(\tau)$ describes distribution of wave a in decay phase-space variables τ
  - ➥ Total intensity distribution: Coherent sum of partial-wave amplitudes
  - ➥ Perform maximum-likelihood fit in cells of $(m_{K\pi\pi}, t')$
    - ➥ Extract $m_{K\pi\pi}$ and t' dependence of transition amplitudes T_a

Partial-Wave Decomposition

Isobar Model



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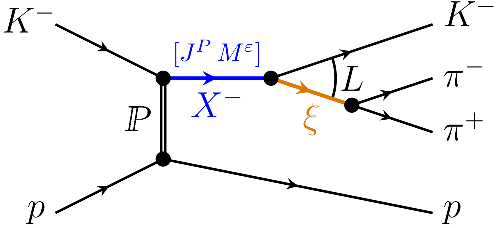

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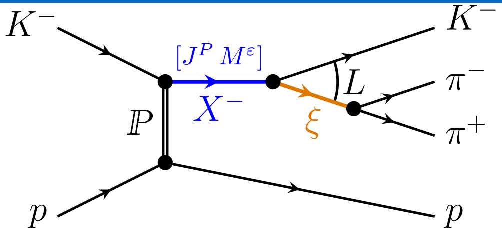

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Systematically construct set of allowed partial waves

- Spin $J \leq 7$
- Angular momentum $L \leq 7$
- Positive naturality of exchange particle
- 12 isobars
  - $[K\pi]_S^{K\pi}$, $[K\pi]_S^{K\eta}$, $K^*(892)$, $K^*(1680)$, $K_2^*(1430)$, $K_3^*(1780)$
  - $[\pi\pi]_S$, $f_0(980)$, $f_0(1500)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$

$\Rightarrow$ "Wave pool" of 596 waves

Regularization (see talk by F. Kaspar, session 5)

- Fit wave pool to data
- Impose penalty on $|\mathcal{T}_a|^2$
- Suppress insignificant waves

$\Rightarrow$ Find the "best" subset of waves that describe the data

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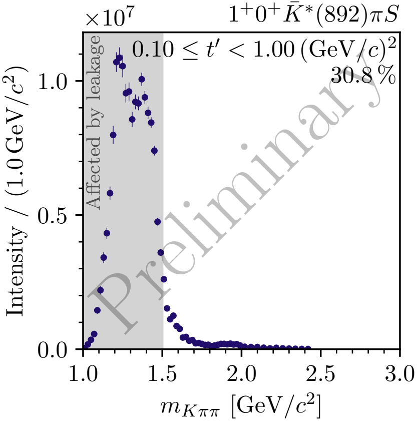
$1^+ 0^+ K^*(892)\,\pi\, S$

- Dominant signal
- $K_1(1270)$, $K_1(1400)$ double peak
- In agreement with previous observations

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

- 3.4 % of total intensity
- Dominated by $K_1(1270)$
- Small potential signal from $K_1(1650)$
- Structure in rel. phase



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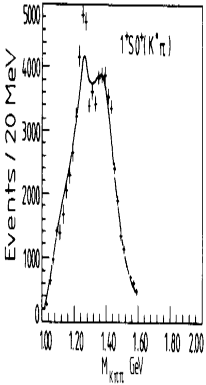

WA03 (CERN), 200 000 events, ACCMOR, NPB **187** (1981)

Selected Partial Waves

$J^P = 1^+$

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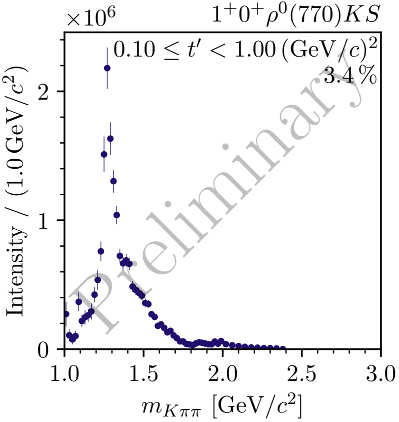

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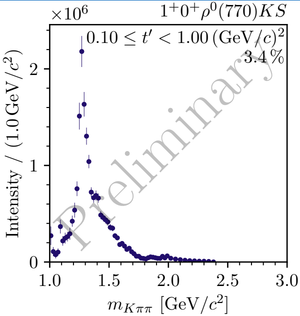
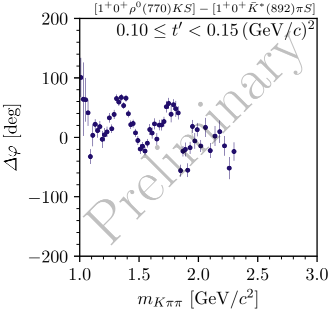


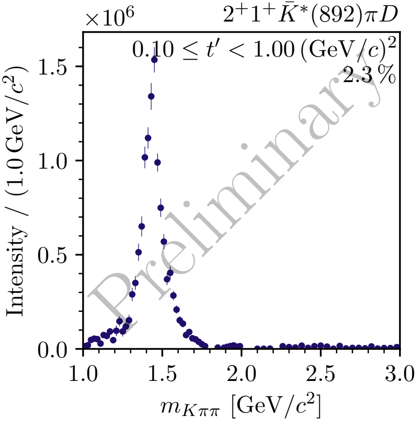


$2^+ \, 1^+ \, K^*(892) \, \pi \, D$

- Signal in $K_2^*(1430)$ mass region
- In agreement with previous observations

$2^+ \, 1^+ \, \rho(770) \, K \, D$

- Signal in $K_2^*(1430)$ mass region
- Clear phase motion in $K_2^*(1430)$ region



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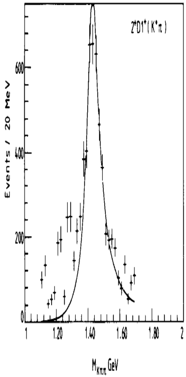

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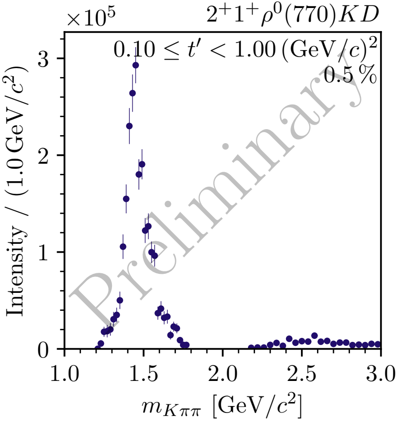

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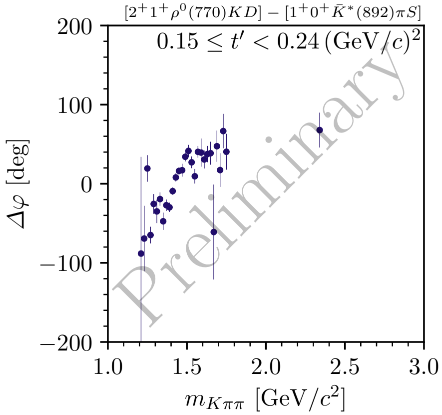
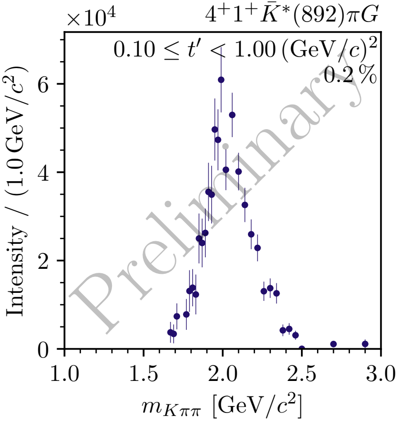


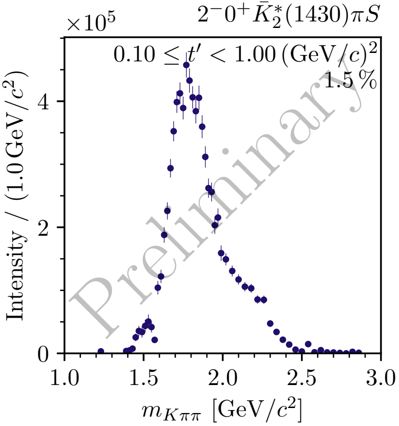
$4^+\, 1^+\, K^*(892)\, \pi\, G$

- Small intensity
- Signal in $K_4^*(2045)$ mass region



$2^- \, 0^+ \, K_2^*(1430) \, \pi \, S$

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



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

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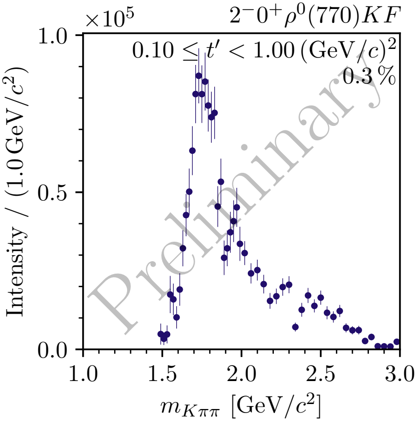

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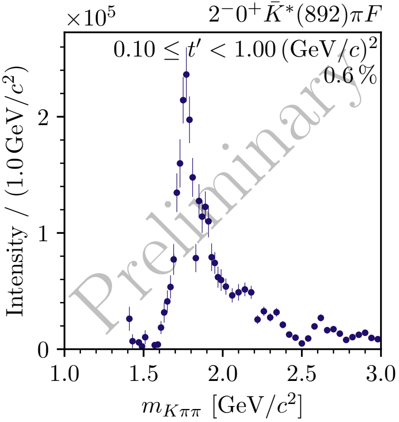

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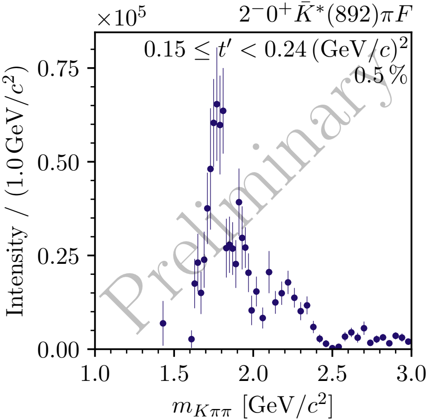

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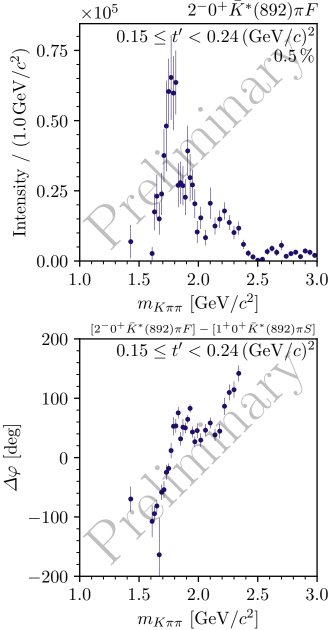
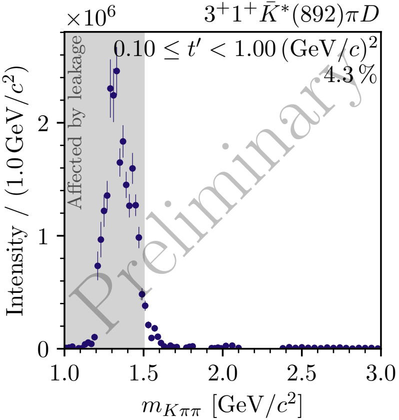


Leakage Effect

- Unexpected low-mass enhancement in $3^+ \, 1^+ \, K^*(892) \, \pi \, D$ wave
- Similar to dominant 1^+ wave
- Sensitive to systematic effects
- Loss of orthogonality taking acceptance into account
- Limited acceptance due to limited kinematic range of final-state PID
- Only a small sub-set of partial waves affected



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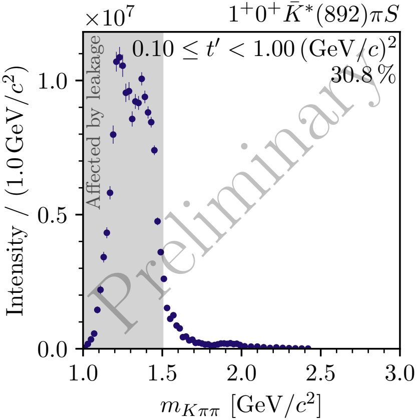

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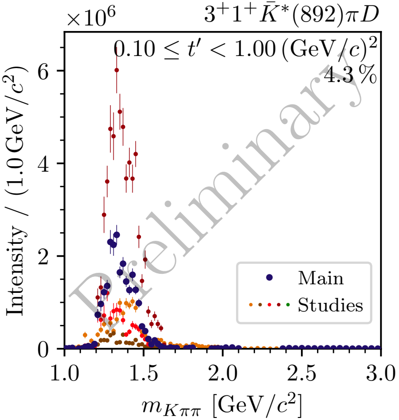

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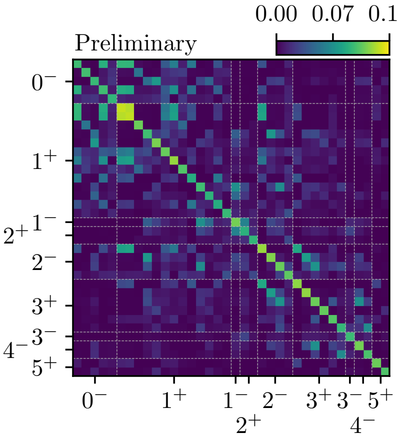

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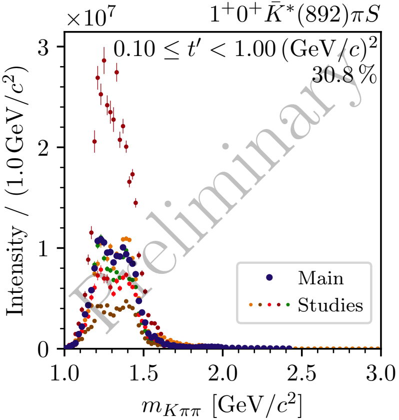

Summary

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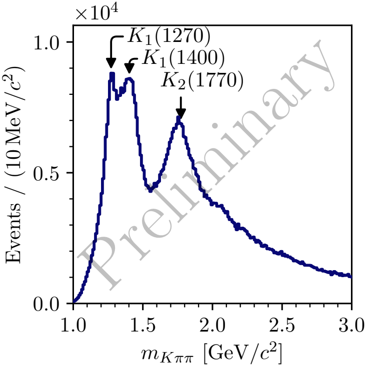
- Observation of well-known states
- Observation of signals at 0.1 % level
- Potential signals from excited states



Outlook

- Further systematic studies of leakage effect
- Resonance-model fit of selected partial waves
- Freed-isobar analysis (see talk by F. Krinner, session 5)
  - Study amplitude of $[K\pi]_P$, $[K\pi]_S$, ... sub-systems

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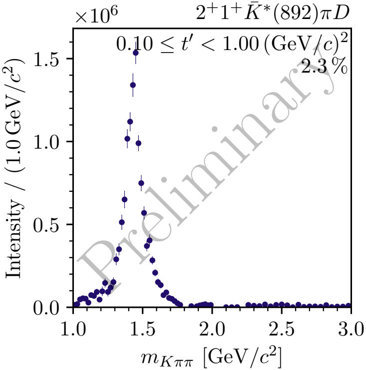

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- Worlds largest data set of diffractively produced $K^-\pi^-\pi^+$
- Observation of well-known states
- Observation of signals at 0.1 % level
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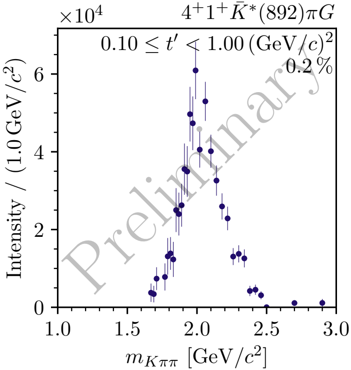

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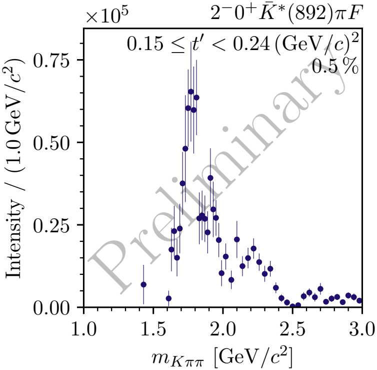

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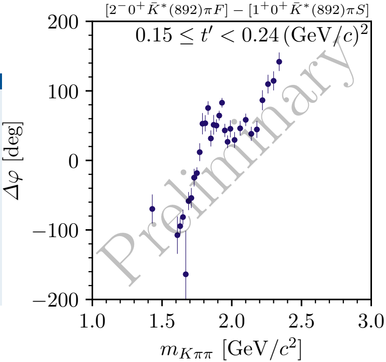

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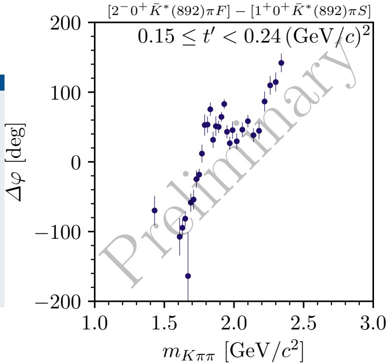

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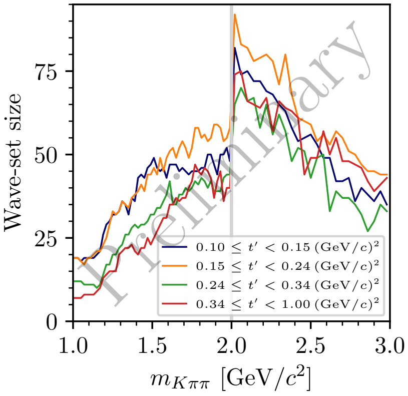
Spectroscopy of strange mesons

- Radio-frequency separated high-intensity high-energy kaon beam
- At least $\times 10$ larger data set than world's largest data set
- Map out strange-meson spectrum with similar precision as unflavored light-meson spectrum
- Letter of intent: arXiv:1808.00848
- Proposal for phase-1: CERN-SPSC-2019-022

Backup

Outline

- 20 to 70 waves per $(m_{K\pi\pi}, t')$ cell
- Larger wave set for larger binning in $m_{K\pi\pi}$
- Larger wave set in t' bins with more events



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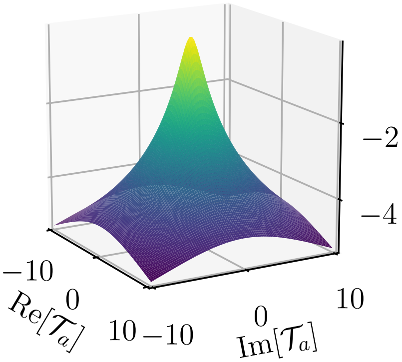
$$\ln \mathcal{L}_{\mathrm{reg}}(|T_a|; \Gamma) = -\ln \left[1 + \frac{|T_a|^2}{\Gamma_a^2} \right]$$

- "Cauchy prior"
- Scale depends on acceptance

$$\Gamma_a = \frac{\Gamma}{\sqrt{\bar{\eta}_a}} \quad \Rightarrow \quad \frac{|\mathcal{T}_a|^2}{\Gamma_a^2} = \frac{\bar{N}_a}{\Gamma^2}$$



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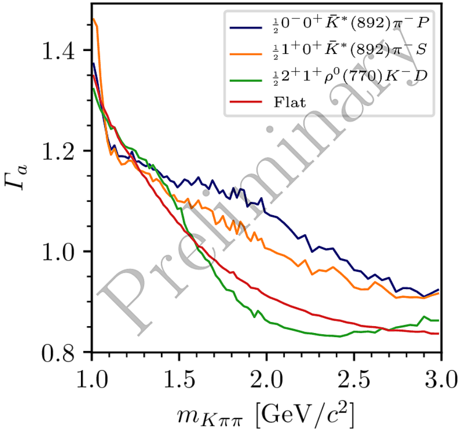

Palano-Pennington Parameterization for $[K\pi]_S$ Isobars

- Two-channel K-matrix ansatz: $K\pi$ and $K\eta$
- $K\pi$ scattering (LASS, SLAC), η_c decays, χ-PT
- Contains three poles
  - $K_0^*(700)$, $K_0^*(1430)$, $K_0^*(1950)$
- Use $T_{K\pi\to K\pi}$ and $T_{K\eta\to K\pi}$
  - $K\pi$ dominated by $K_0^*(1430)$
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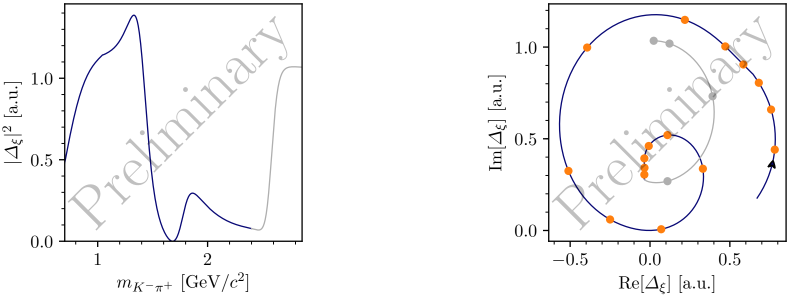
  - Set amplitude to zero

$K\pi \to K\pi$



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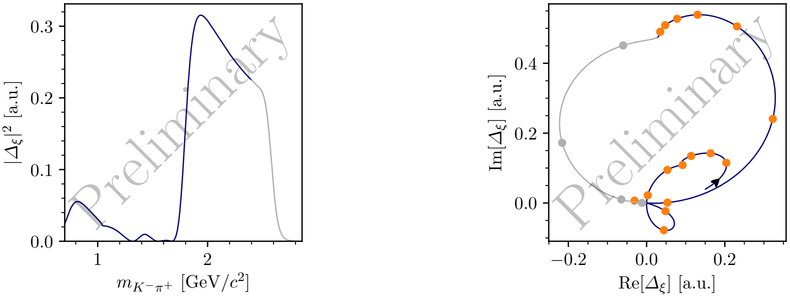
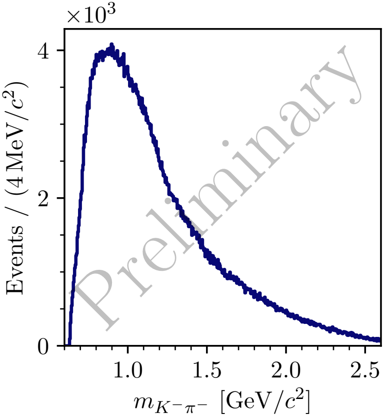


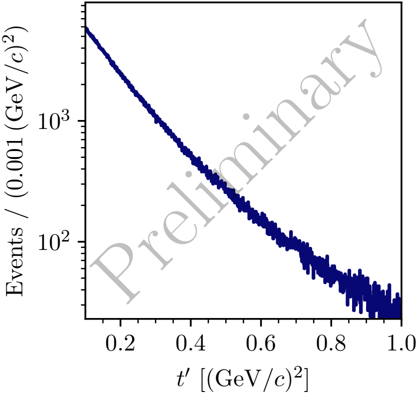
$m_{K^-\pi^-}$

- No dominant resonant structures

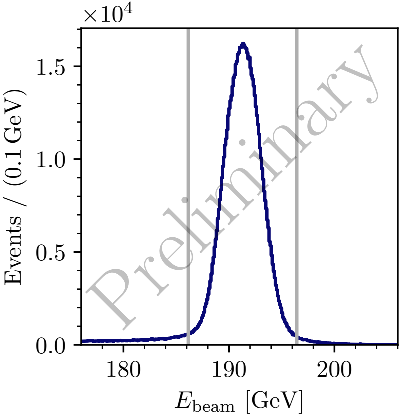


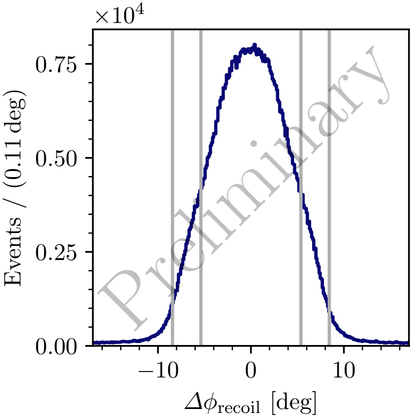
t' Spectrum

- Exponential shape
- Shallower for larger t'



Exclusivity





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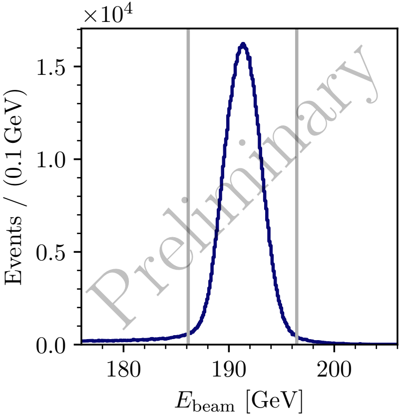

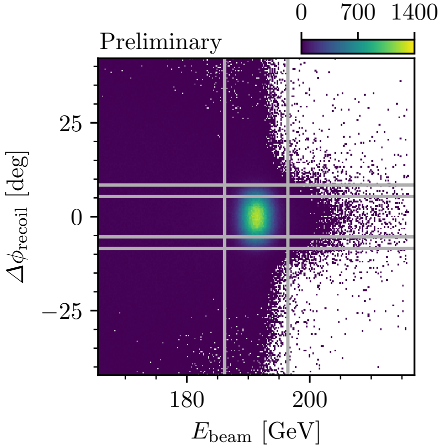

- Unexpected low-mass enhancement in $3^{+}\,1^{+}\,K^{*}(892)\,\pi\,D$ wave
- Similar to dominant 1^{+} wave
- Sensitive to systematic effects
- Decay amplitudes of different J^{P} are orthogonal
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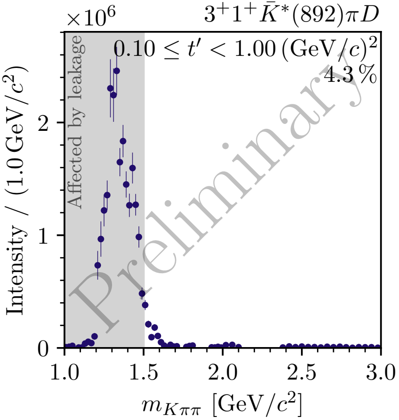

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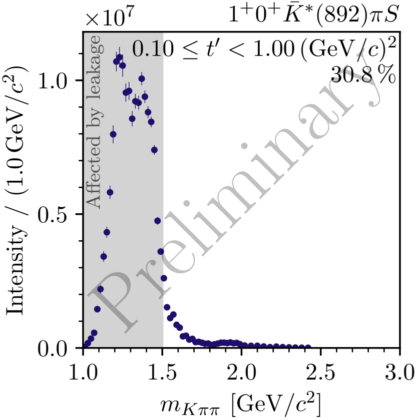

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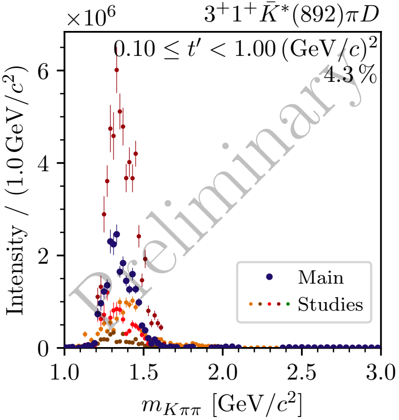

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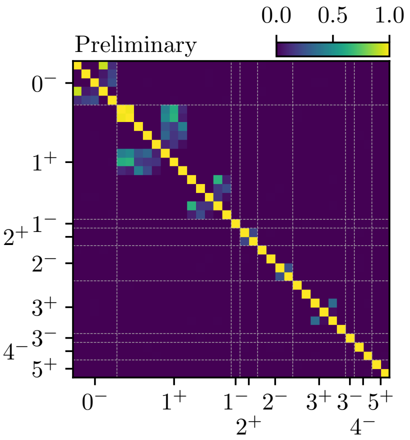

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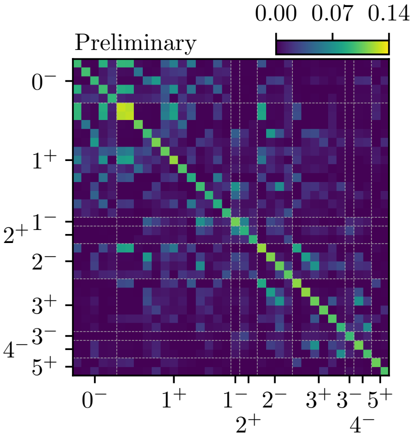

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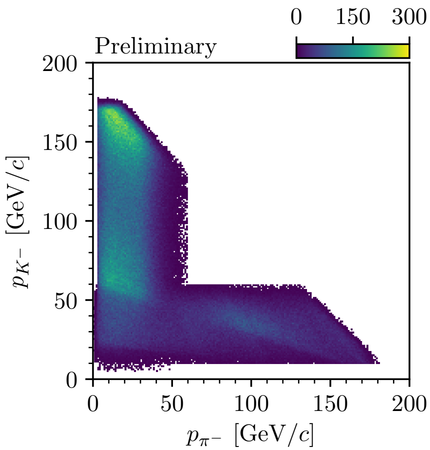

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