From Pions to Kaons - Hadron Spectroscopy from COMPASS to AMBER

Mathias Wagner
on behalf of the COMPASS collaboration
and COMPASS++/AMBER

HISKP, Bonn University

June 25, 2019
at the IWHSS19 Aveiro

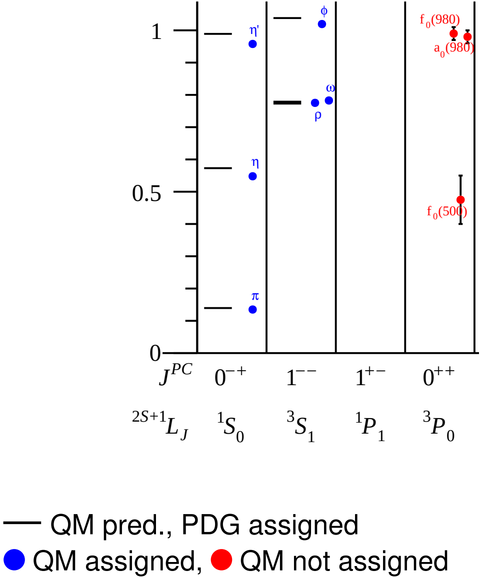
supported by BMBF

Content

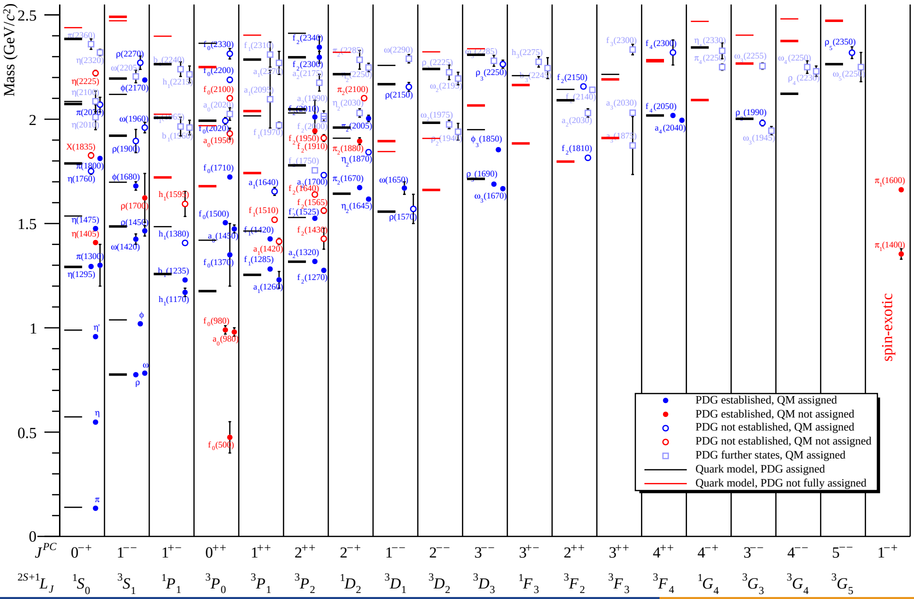
- Motivation
- The COMPASS experiment
- 3π PWA
- Freed-isobar analysis
- Exotic $\pi_1(1600)$
- RF-separated kaon beam
- Conclusion & outlook

Why Hadron Spectroscopy?

[To be published in Progress in Particle and Nuclear Physics]

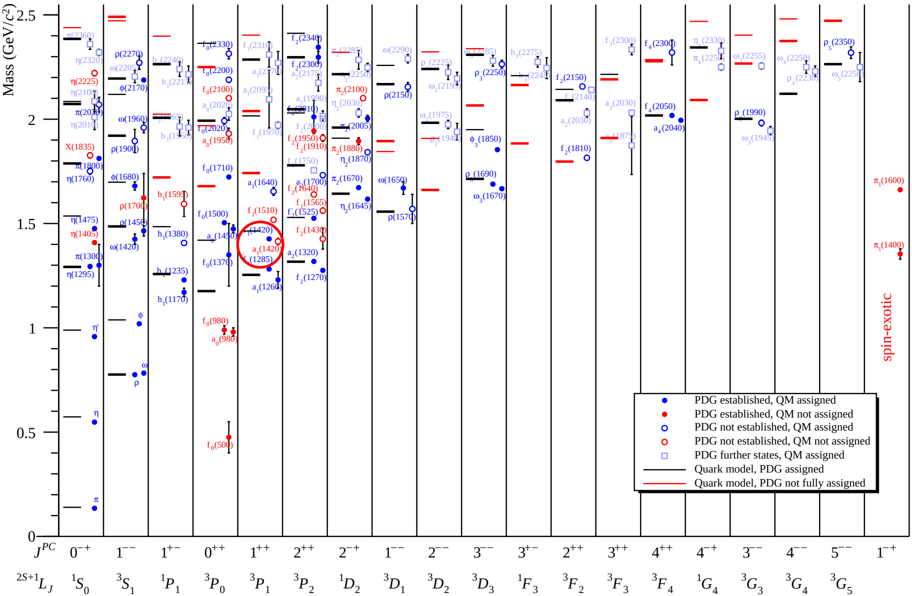


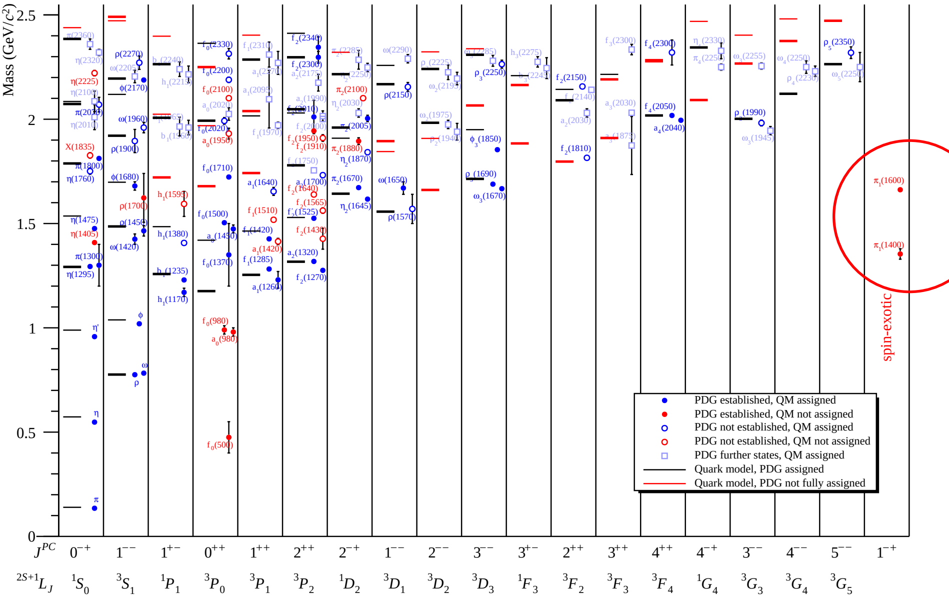
[To be published in Progress in Particle and Nuclear Physics]



Motivation

[To be published in Progress in Particle and Nuclear Physics]

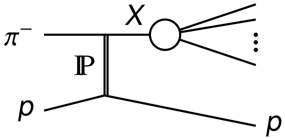


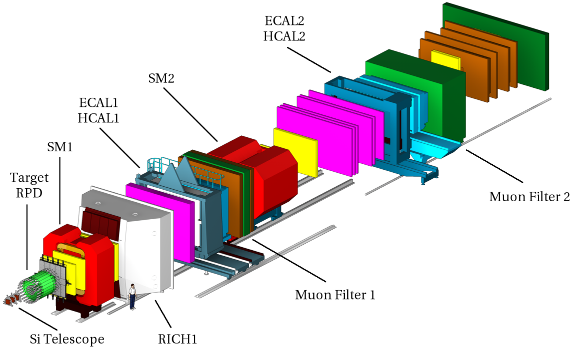


Mass (GeV/c^2)
0
0.5
1
1.5
2
2.5
J^{PC}
0^{-+} 1^{--} 1^{+-} 0^{++} 1^{++} 2^{++} 2^{-+} 1^{--} 2^{--} 3^{--} 3^{+-} 2^{++} 3^{++} 4^{++} 4^{-+} 3^{--} 4^{--} 5^{--} 1^{-+}
$^{2S+1}L_J$
$^1S_0$ $^3S_1$ $^1P_1$ $^3P_0$ $^3P_1$ $^3P_2$ $^1D_2$ $^3D_1$ $^3D_2$ $^3D_3$ $^1F_3$ $^3F_2$ $^3F_3$ $^3F_4$ $^1G_4$ $^3G_3$ $^3G_4$ $^3G_5$
PDG established, QM assigned
PDG established, QM not assigned
PDG not established, QM assigned
PDG not established, QM not assigned
PDG further states, QM assigned
Quark model, PDG assigned
Quark model, PDG not fully assigned
spin-exotic
$\pi_1(1600)$
$\pi_1(1400)$

The COMPASS Experiment

- Secondary hadron beam, mostly π^- ($\sim 97\,\%$)
  - $E_{\text{beam}} = 190\,\text{GeV}$
  - Liquid hydrogen target (40 cm)
  - $\pi^- + p \quad \rightarrow \quad \pi^- + \pi^- + \pi^+ + p$
  - $\pi^- + p \quad \rightarrow \quad \eta^{(\prime)} + \pi^- + p$





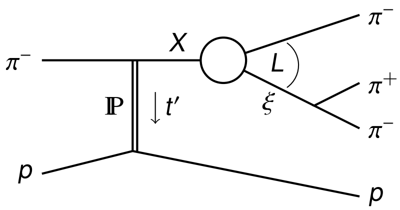
[COMPASS, NIM A**779**, 69-115 (2015)]

COMPASS

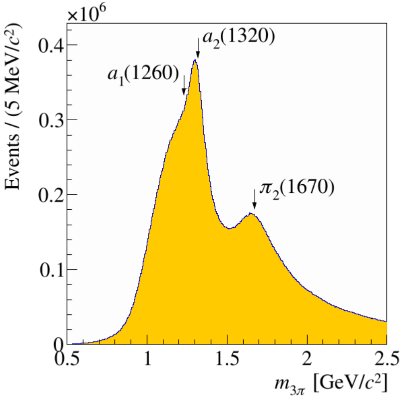
3π PWA

3π PWA

- Isobar model: $X^- \to \pi^- + \xi^0 \to \pi^- + \pi^+ + \pi^-$
- Data binned in 100 $m_{3\pi}$ and 11 $t' = |t| - |t|_{\text{min}}$ slices
- PWA with 88 waves [COMPASS, PRD **95**, 032004 (2017)]

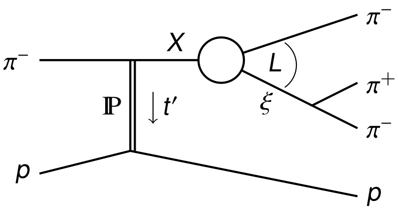


$\mathbb{P}$: Pomeron
X: Resonance with J^{PC}
ξ: Isobar

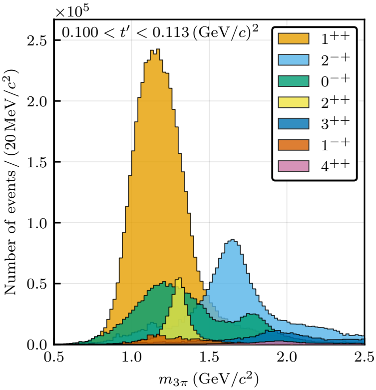


3π PWA

- Isobar model: $X^- \to \pi^- + \xi^0 \to \pi^- + \pi^+ + \pi^-$
- Data binned in 100 $m_{3\pi}$ and 11 $t' = |t| - |t|_{\text{min}}$ slices
- PWA with 88 waves [COMPASS, PRD **95**, 032004 (2017)]



$\mathbb{P}$: Pomeron
X: Resonance with J^{PC}
ξ: Isobar

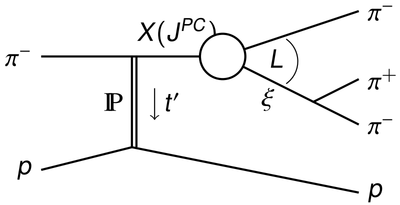


[To be published in Progress in Particle and Nuclear Physics]

Naming scheme:

$$I^G(J^{PC})M^{\varepsilon}\,\xi\pi L$$

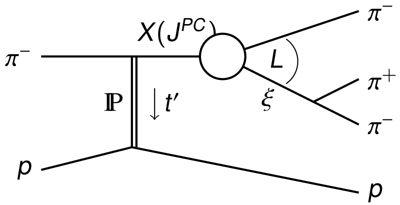
- $I^G = 1^-$
- $J \leq 6, M \in \{0, 1, 2\}$
- $PC = ++$ for $J \geq 1$,
  $PC = -+$ for $J \geq 0$
- 80 waves $\varepsilon = +$
- $L \leq 6$
- Isobars ξ:
  $(\pi\pi)_S$, $\rho(770)$, $f_0(980)$,
  $f_2(1270)$, $f_0(1500)$, $\rho_3(1690)$
  fixed shape (Breit-Wigner)



Naming scheme:

$$I^G(J^{PC})M^{\varepsilon}\,\xi\pi L$$

- $I^G = 1^-$
- $J \leq 6$, $M \in \{0, 1, 2\}$
- $PC = ++$ for $J \geq 1$,
  $PC = -+$ for $J \geq 0$
- 80 waves $\varepsilon = +$
- $L \leq 6$
- Isobars ξ:
  $(\pi\pi)_S$, $\rho(770)$, $f_0(980)$,
  $f_2(1270)$, $f_0(1500)$, $\rho_3(1690)$
  fixed shape (Breit-Wigner)



$1^-(1^{-+})1^+\ \rho\pi P$-wave!

We have access to exotic mesons

- Maximize the likelihood function:

$$\mathcal{L} = \underbrace{\frac{N_e^N}{N!}\exp(-N_e)}_{\text{Prob. for } N \text{ events}} \prod_{k=1}^{N} \underbrace{\frac{I(\tau_k)}{N_e}}_{\text{Prob. for event } k}, \qquad N_e = \int I(\tau)\zeta(\tau)\mathrm{d}\tau,$$

with $\tau = (s_0, m_{3\pi}^2, t, \Omega_X, m_{2\pi}^2, \Omega_\xi)$

- Maximize the likelihood function:

$$\mathcal{L} = \underbrace{\frac{N_e^N}{N!}\exp(-N_e)}_{\text{Prob. for } N \text{ events}} \prod_{k=1}^{N} \underbrace{\frac{I(\tau_k)}{N_e}}_{\text{Prob. for event } k}, \qquad N_e = \int I(\tau)\zeta(\tau)\mathrm{d}\tau,$$

with $\tau = (s_0, m_{3\pi}^2, t, \Omega_X, m_{2\pi}^2, \Omega_\xi)$

- Define intensity function (strongly simplified!):

$$I(\tau) = |A(\tau)|^2 = \left| \sum_{JMLS} A_{LS}^{JM}(\tau) \right|^2$$

with the amplitude A separated in partial waves ($J^{PC} M^\varepsilon \xi \pi L$):

$$A_{LS}^{JM}(\tau) = \underbrace{F_{LS}^{JM}(s_0, m_{3\pi}^2, t)}_{\text{const per } (m_{3\pi}, t')\text{-bin}} \cdot \Psi_{LS}^{JM}(m_{2\pi}^2, \Omega_X, \Omega_\xi)$$

- Maximize the likelihood function:

$$\mathcal{L} = \underbrace{\frac{N_e^N}{N!}\exp(-N_e)}_{\text{Prob. for } N \text{ events}} \prod_{k=1}^{N} \underbrace{\frac{I(\tau_k)}{N_e}}_{\text{Prob. for event } k}, \qquad N_e = \int I(\tau)\zeta(\tau)\mathrm{d}\tau,$$

with $\tau = (s_0, m_{3\pi}^2, t, \Omega_X, m_{2\pi}^2, \Omega_\xi)$

- Define intensity function (strongly simplified!):

$$I(\tau) = |A(\tau)|^2 = \left|\sum_{JMLS} A_{LS}^{JM}(\tau)\right|^2$$

with the amplitude A separated in partial waves ($J^{PC}M^\varepsilon \xi\pi L$):

$$A_{LS}^{JM}(\tau) = F_{LS}^{JM}(s_0, m_{3\pi}^2, t) \cdot f_S^\xi(m_{2\pi}^2) Z_{LS}^{JM}(\Omega_{\mathrm{GJ}}, \Omega_{\mathrm{H}})$$

- Maximize the likelihood function:

$$\mathcal{L} = \underbrace{\frac{N_e^N}{N!}\exp(-N_e)}_{\text{Prob. for } N \text{ events}} \prod_{k=1}^{N} \underbrace{\frac{I(\tau_k)}{N_e}}_{\text{Prob. for event } k}, \qquad N_e = \int I(\tau)\zeta(\tau)\mathrm{d}\tau,$$

with $\tau = (s_0, m_{3\pi}^2, t, \Omega_X, m_{2\pi}^2, \Omega_\xi)$

- Define intensity function (strongly simplified!):

$$I(\tau) = |A(\tau)|^2 = \left| \sum_{JMLS} A_{LS}^{JM}(\tau) \right|^2$$

with the amplitude A separated in partial waves ($J^{PC}M^{\varepsilon}\xi\pi L$):

$$A_{LS}^{JM}(\tau) = F_{LS}^{JM}(s_0, m_{3\pi}^2, t) \cdot f_S^{\xi}(m_{2\pi}^2) Z_{LS}^{JM}(\Omega_{\mathrm{GJ}}, \Omega_{\mathrm{H}})$$

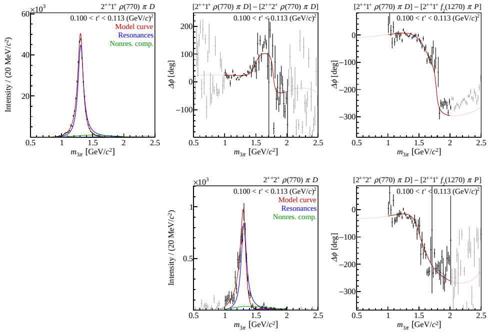
- Extract the spin density matrix

$$\rho_{(LS)(L'S')}^{(JM)(J'M')} := F_{LS}^{JM}\left(F_{L'S'}^{J'M'}\right)^* = \begin{pmatrix} I_{\mathrm{w1}} & \Phi_{\mathrm{w1}}^{\mathrm{w2}} & \dots \\ (\Phi_{\mathrm{w1}}^{\mathrm{w2}})^* & I_{\mathrm{w2}} & \dots \\ \dots & \dots & \dots \end{pmatrix}$$

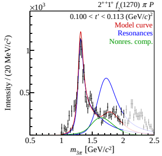
Fit of $m_{3\pi}$-Dependence (Example)

Example: $a_2(1320)$

- $2^{++}1^{+}\rho\pi D$
- $2^{++}2^{+}\rho\pi D$
- $2^{++}1^{+}f_2(1270)\pi P$



$$\rho = \begin{pmatrix} I_{w1} & \Phi^{w2}_{w1} & \Phi^{w3}_{w1} \\ & I_{w2} & \Phi^{w3}_{w2} \\ & & I_{w2} \end{pmatrix}$$



[COMPASS, PRD **98** (2018) 092003]

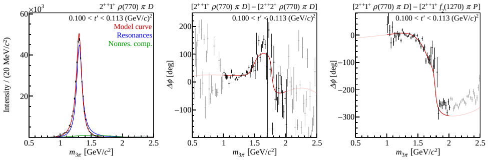
Example: $a_2(1320)$

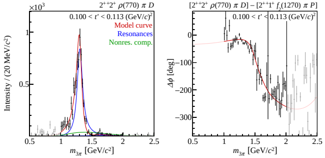
- $2^{++}1^{+}\rho\pi D$
- $2^{++}2^{+}\rho\pi D$
- $2^{++}1^{+}f_2(1270)\pi P$

Parametrized by relativistic Breit-Wigner

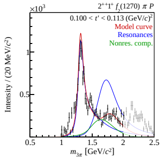
$$\frac{m\,\Gamma}{m^2 - m_{3\pi}^2 - i\,m\,\Gamma_{\text{tot}}(m_{3\pi})}$$

Good approximation if isolated resonance

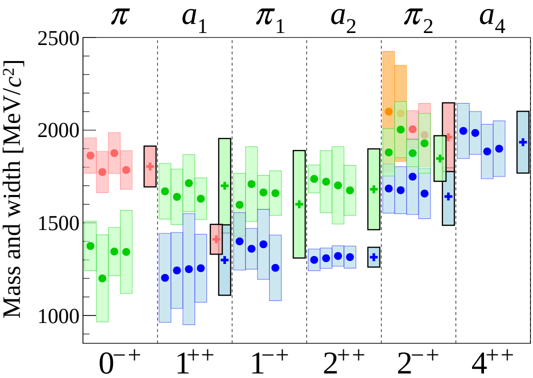




$$\rho = \begin{pmatrix} I_{w1} & \Phi^{w2}_{w1} & \Phi^{w3}_{w1} \\ & I_{w2} & \Phi^{w3}_{w2} \\ & & I_{w2} \end{pmatrix}$$



[COMPASS, PRD **98** (2018) 092003]



[COMPASS, PRD **98** (2018) 092003]

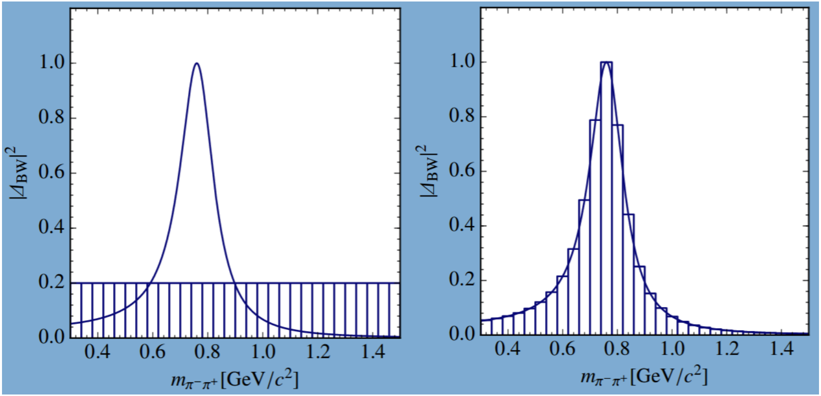
- ● previous measurements
- + COMPASS
- ☐ decay width

color: different excitations

COMPASS

Freed-Isobar Analysis

- Not only slices in $m_{3\pi}$ and t', but also in $m_{2\pi}$



[F. Krinner]

- Not only slices in $m_{3\pi}$ and t', but also in $m_{2\pi}$
- Keep F and f as free complex fit parameters

$$A_{LS}^{JM}(\tau) = \underbrace{F_{LS}^{JM}(s_0, m_{3\pi}^2, t) \cdot f_S^{\xi}(m_{2\pi}^2)}_{\text{fixed per } (m_{3\pi}, t', m_{2\pi})\text{-bin}} Z_{LS}^{JM}(\Omega_{\mathrm{GJ}}, \Omega_{\mathrm{H}})$$

- Freed partial waves include $[\pi\pi]_{0^{++}}$, $[\pi\pi]_{1^{--}}$, $[\pi\pi]_{2^{++}}$

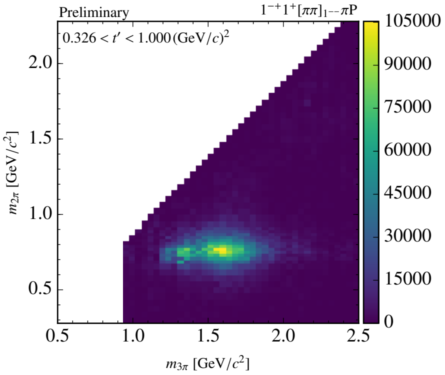
- Not only slices in $m_{3\pi}$ and t', but also in $m_{2\pi}$
- Keep F and f as free complex fit parameters

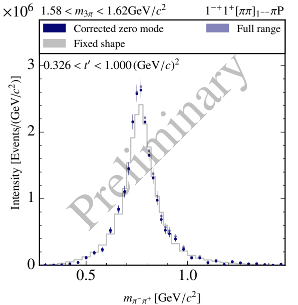
$$A_{LS}^{JM}(\tau) = \underbrace{F_{LS}^{JM}(s_0, m_{3\pi}^2, t) \cdot f_S^{\xi}(m_{2\pi}^2)}_{\text{fixed per } (m_{3\pi}, t', m_{2\pi})\text{-bin}} Z_{LS}^{JM}(\Omega_{\mathrm{GJ}}, \Omega_{\mathrm{H}})$$

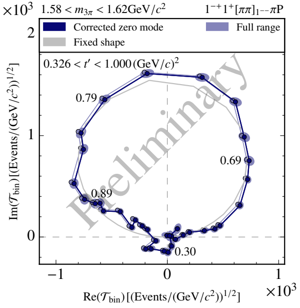
- Freed partial waves include $[\pi\pi]_{0^{++}}$, $[\pi\pi]_{1^{--}}$, $[\pi\pi]_{2^{++}}$

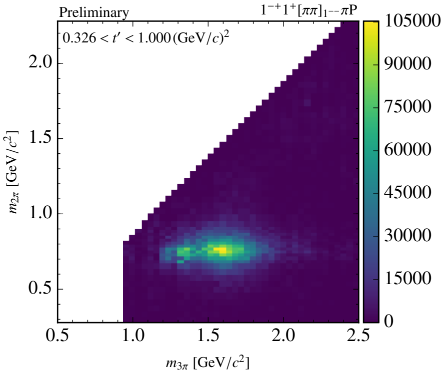
What do we gain from this?

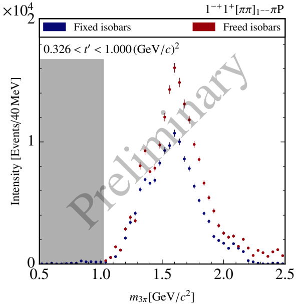
- Less model dependence during the PWA
- Enables to fit 2π spectrum
- Study rescattering effects → collab. with C. Hanhart, B. Kubis


Preliminary
1−+1+[ππ]1−−πP
0.326 < t′ < 1.000 (GeV/c)2
m2π [GeV/c2]
m3π [GeV/c2]
105000
90000
75000
60000
45000
30000
15000
0


×106
1.58 < m3π < 1.62GeV/c2
1−+1+[ππ]1−−πP
Corrected zero mode
Full range
Fixed shape
0.326 < t′ < 1.000 (GeV/c)2
Preliminary
Intensity [Events/(GeV/c2)]
mπ−π+ [GeV/c2]


×103
1.58 < m3π < 1.62GeV/c2
1−+1+[ππ]1−−πP
Corrected zero mode
Full range
Fixed shape
0.326 < t′ < 1.000 (GeV/c)2
0.79
0.69
0.89
0.30
Preliminary
Im(Tbin) [(Events/(GeV/c2))1/2]
Re(Tbin) [(Events/(GeV/c2))1/2]
×103





Signal not an artifact of fixed isobar shape!

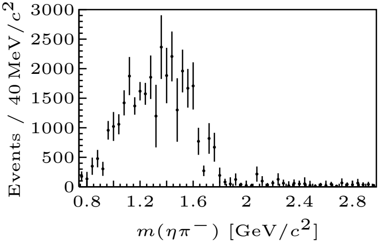
COMPASS

Exotic $\pi_1(1600)$

Two pseudo scalars $\rightsquigarrow$ waves with odd L are spin-exotic

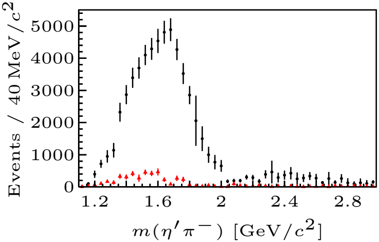
The π_1 is a puzzle!

$\eta\pi$ *P*-wave



@1400?

$\eta'\pi$ *P*-wave



@1600?

But: Fit not stable, strongly model dependent!

[COMPASS, PLB 740 (2015) 303]

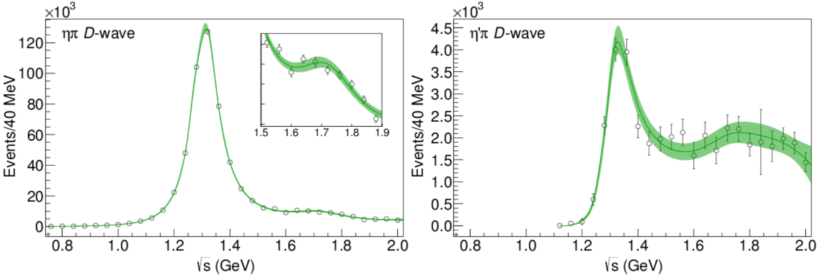
Improvement over simple Breit-Wigner fit:

- Unitary model (K-matrix approach)
- $\eta\pi$ and $\eta'\pi$ coupled-channel (N/D formalism)
- Analytic (extract pole positions)

Improvement over simple Breit-Wigner fit:

- Unitary model (K-matrix approach)
- $\eta\pi$ and $\eta'\pi$ coupled-channel (N/D formalism)
- Analytic (extract pole positions)

D-wave with a_2 and a_2'

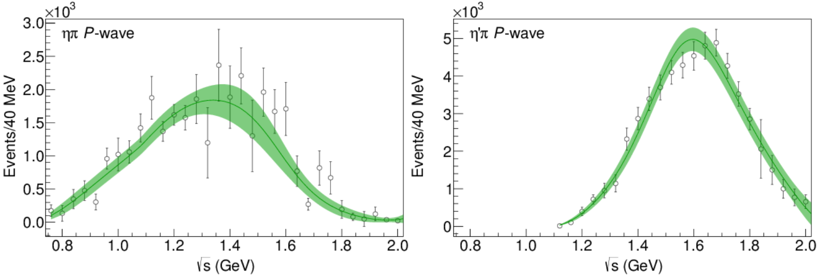


[JPAC, PRL 122, 042002 (2019)]

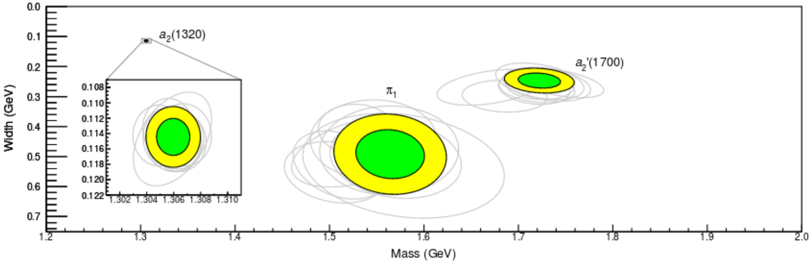
Improvement over simple Breit-Wigner fit:

- Unitary model (K-matrix approach)
- $\eta\pi$ and $\eta'\pi$ coupled-channel (N/D formalism)
- Analytic (extract pole positions)

P-wave with π_1



[JPAC, PRL 122, 042002 (2019)]



[JPAC, PRL 122, 042002 (2019)]

Result:

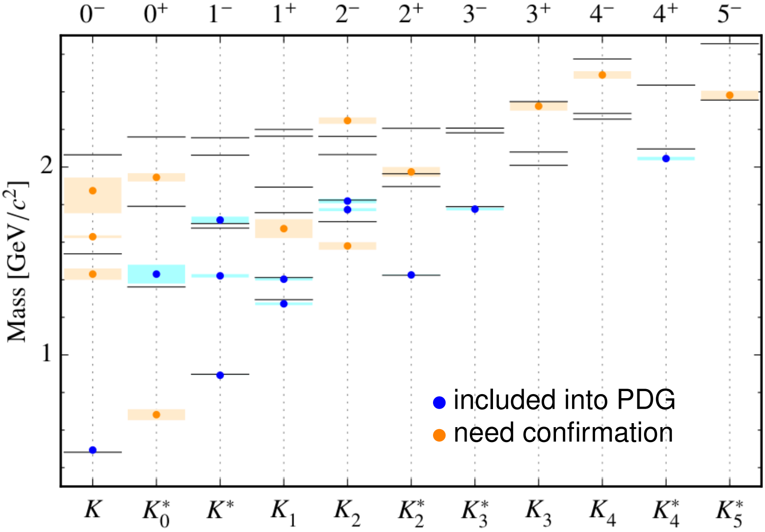
- 2 poles in *D*-wave: a_2 and a_2'
- Only 1 pole in *P*-wave: π_1!

Poles	Mass (MeV)	Width (MeV)
$a_2(1320)$	$1306.0 \pm 0.8 \pm 1.3$	$114.4 \pm 1.6 \pm 0.0$
$a_2'(1700)$	$1722 \pm 15 \pm 67$	$247 \pm 17 \pm 63$
π_1	$1564 \pm 24 \pm 86$	$492 \pm 54 \pm 102$

COMPASS

Meson Spectrum of Excited Kaons

Meson Spectrum of Excited K



COMPASS LoI [arXiv:1808.00848v6, 25 Jan 2019]

K at COMPASS

Already from 2008/2009 run:

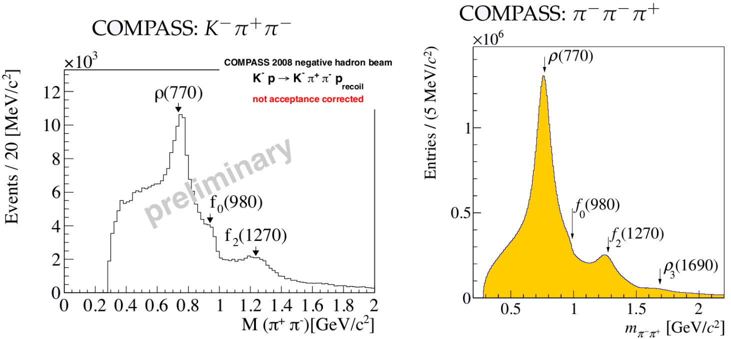
- $K^- + p \to K^-\pi^+\pi^- + p_{\text{recoil}}$
- Only 2.5 % K^- fraction in beam
- Results from 2008-data consistent with previous experiments

K at COMPASS

Already from 2008/2009 run:

- $K^- + p \to K^-\pi^+\pi^- + p_{\text{recoil}}$
- Only 2.5 % K^- fraction in beam
- Results from 2008-data consistent with previous experiments

Comparison $\pi\pi$ for $K \leftrightarrow \pi$:

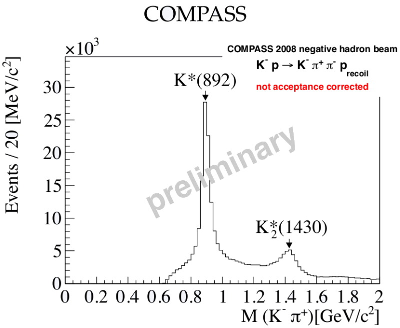


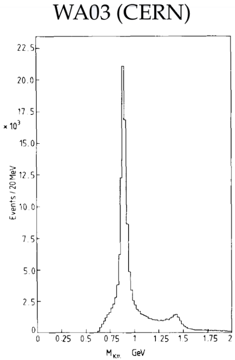
COMPASS, PRD **95** (2017) 032004

Already from 2008/2009 run:

- $K^- + p \rightarrow K^-\pi^+\pi^- + p_{\text{recoil}}$
- Only 2.5 % K^- fraction in beam
- Results from 2008-data consistent with previous experiments

Comparison $K\pi$:





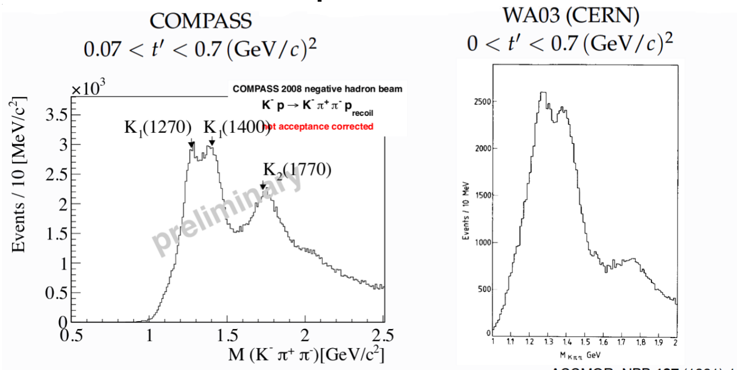
ACCMOR, NPB **187** (1981) 1

K at COMPASS

Already from 2008/2009 run:

- $K^- + p \to K^-\pi^+\pi^- + p_{\text{recoil}}$
- Only 2.5 % K^- fraction in beam
- Results from 2008-data consistent with previous experiments

Comparison $K\pi\pi$:



ACCMOR, NPB **187** (1981) 1

COMPASS++/AMBER

Apparatus for **M**eson and **B**aryon **E**xperimental **R**esearch

Improve our knowledge of the spectrum of excited Kaons

K at COMPASS++/AMBER

What do we need?

- Clean, high-intensity K beam
- 10x more statistics than currently available

K at COMPASS++/AMBER

What do we need?

- Clean, high-intensity K beam
- 10x more statistics than currently available

What do we gain?

- Improved precision
- Access to higher-mass kaon states
- PWA in (m, t)-bins
- Freed-isobar analysis $\rightarrow$ study $K\pi$
- Will revolutionize the K-spectrum!

K at COMPASS++/AMBER

What do we need?

- Clean, high-intensity K beam
- 10x more statistics than currently available

What do we gain?

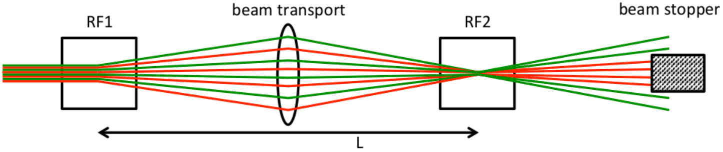
- Improved precision
- Access to higher-mass kaon states
- PWA in (m, t)-bins
- Freed-isobar analysis $\rightarrow$ study $K\pi$
- Will revolutionize the K-spectrum!

How can we achieve this?

COMPASS++/AMBER

RF-Separated Kaon Beam

- First employed at CERN in the 1960s

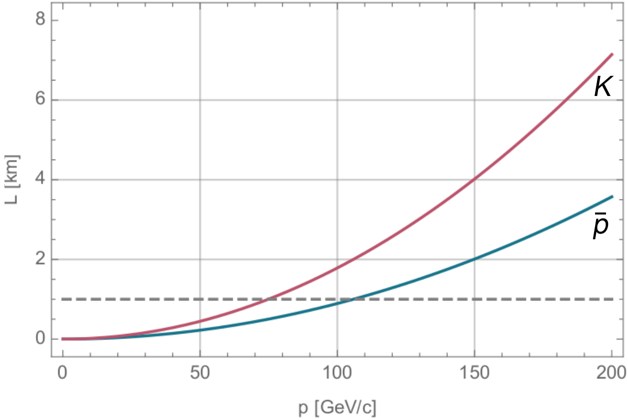


COMPASS LoI [arXiv:1808.00848v6, 25 Jan 2019]

- Two dipole RF-cavities at frequency f and phase φ
- Different particles at same beam momentum have phase difference:

$$\Delta\Phi = 2\pi \frac{Lf}{c} \left(\frac{m_1^2 - m_2^2}{2p^2} \right)$$

$$\Delta\Phi_{p\pi} = 2\pi \quad \Rightarrow \quad \Delta\Phi_{K\pi} \approx \pi/2$$



COMPASS LoI [arXiv:1808.00848v6, 25 Jan 2019]

Beam line limit $L = 1.1\,\text{km}$ yields $p_{\text{max}} \sim 75\,\text{GeV}/c$ (for fixed f)

$\rightsquigarrow$ high enough forward boost, recoil proton angle sufficiently large

Pions:

- 3π PWA improved mass and width parameters
- Freed-isobar analysis further removes model dependence from PWA, independent of the isobar shape
- Enables fits to 2π subsystems, rescattering effects
- Coupled-channel analysis of $\eta^{(\prime)}\pi$ yields precise $\pi_1(1600)$ pole position $\Rightarrow$ Puzzle solved!

Kaons:

- Limited data set of $K^- + p \rightarrow K^-\pi^+\pi^- + p_{\text{recoil}}$

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–003
SPSC-I-250
January 28, 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS*

COMPASS++†/AMBER‡

*email: NQF-M2@cern.ch
†COmmon Muon Proton Apparatus for Structure and Spectroscopy
‡Apparatus for Meson and Baryon Experimental Research

[arXiv:1808.00848v6, 25 Jan 2019]

RF-separated K beam for spectroscopy

- Only way to achieve a high-intensity K beam
- Same quantum leap as for π expected
- Knowledge exists for π, can easily be adapted to K
- Nowhere else possible at this high intensity and energy

RF-separated K beam for spectroscopy

- Only way to achieve a high-intensity K beam
- Same quantum leap as for π expected
- Knowledge exists for π, can easily be adapted to K
- Nowhere else possible at this high intensity and energy

RF-separated K beam will also give insight in:

- Kaon valence-quark distribution (Drell-Yan → *Marco Meyer, yesterday 12:10*)
- Separation of valence- and sea-quark contribution ($K^{\pm}$ cross-section asymmetry → Yann Bedfer, today 15:00)
- Study of gluon content inside the kaon via J/Ψ and prompt photon production
- Kaon polarizability (Primakoff)

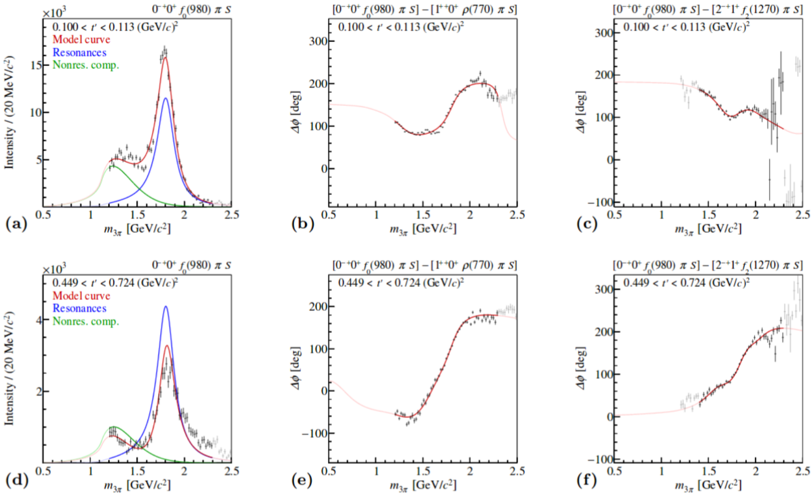
Also possible: RF-separated $\bar{p}$ beam

- Spin structure of the nucleon
- Drell-Yan with high-intensity antiproton beam

Thank you for your attention!

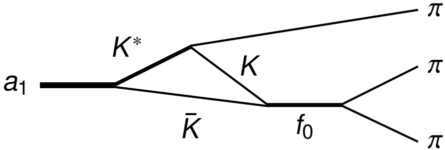
Back-Up

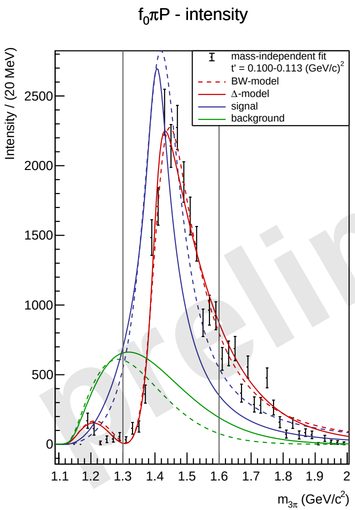
$\pi(1300)$? Back-Up

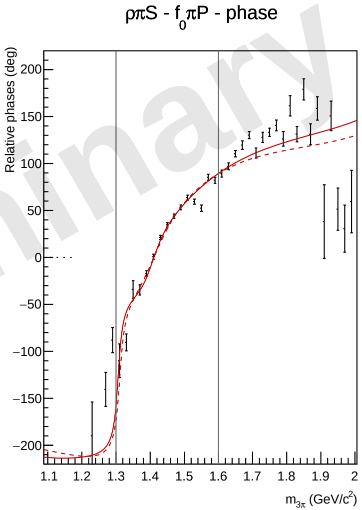


[COMPASS, PRD 98 (2018) 092003]

$a_1(1420)$ - Triangle Singularity




f0πP - intensity
Intensity / (20 MeV)
mass-independent fit
t' = 0.100-0.113 (GeV/c)2
BW-model
Δ-model
signal
background
0
500
1000
1500
2000
2500
1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2
m3π (GeV/c2)
preliminary


ρπS - f0πP - phase
Relative phases (deg)
200
150
100
50
0
−50
−100
−150
−200
1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2
m3π (GeV/c2)

Probability to measure N events:

$$P(N; N_e) = \frac{N_e^N}{N!} \exp(-N_e)$$

with expected events

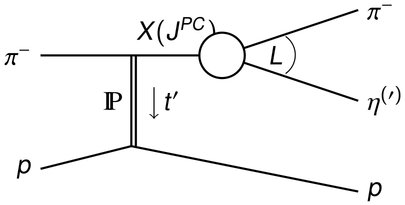
$$N_e = \int I(\tau)\, \zeta(\tau)\, \mathrm{d}\tau$$

with the kin. variables chosen as $\tau = (s_0, m^2_{3\pi}, t, \Omega_{\mathrm{GJ}}, m^2_{2\pi}, \Omega_{\mathrm{H}})$.
Probability to find measured event at given kinematics:

$$P_k(\tau_k) = \frac{I(\tau_k)}{N_e}$$

Maximize likelihood: $\mathcal{L} = \frac{N_e^N}{N!} \exp(-N_e) \prod_{k=1}^{N} \frac{I(\tau_k)}{N_e}$

Or minimize: $-\log \mathcal{L} = \underbrace{\int I(\tau)\, \zeta(\tau)\, \mathrm{d}\tau}_{\text{acceptance with MC}} - \underbrace{\sum_{k=1}^{N} \log\big(I(\tau_k)\big)}_{\text{real data}}$



simpler: angular dependence → spherical harmonics

$$J = L,\ P = (-1)^L,\ C = +1 \quad \Rightarrow \quad J^{PC} = 1^{-+},\ 2^{++},\ (3^{-+}),\ 4^{++}, \ldots$$

giving access to $\pi_1, a_2, (\pi_3)$ and a_4

[arXiv:1810.04171v2 [hep-ph] 16 Jan 2019]

N/D formalism:

$$A_i^J(s) \sim \sum_k n_k^J(s) \left[D^J(s)^{-1} \right]_{ki}$$

n_k^J effective expansion in Chebyshev polynomials

$$D^J = \begin{pmatrix} \eta\pi \to \eta\pi & \eta\pi \to \eta'\pi \\ \eta'\pi \to \eta\pi & \eta'\pi \to \eta'\pi \end{pmatrix}$$

containing right-hand cuts constrained by unitarity

$$D^J_{ki}(s) = \left[K^J(s)^{-1}\right]_{ki} - \frac{s}{\pi}\int_{s_k}^{\infty} \mathrm{d}s' \frac{\rho N^J_{ki}(s')}{s'(s'-s-i\varepsilon)}$$

effective description of left-hand singularities via

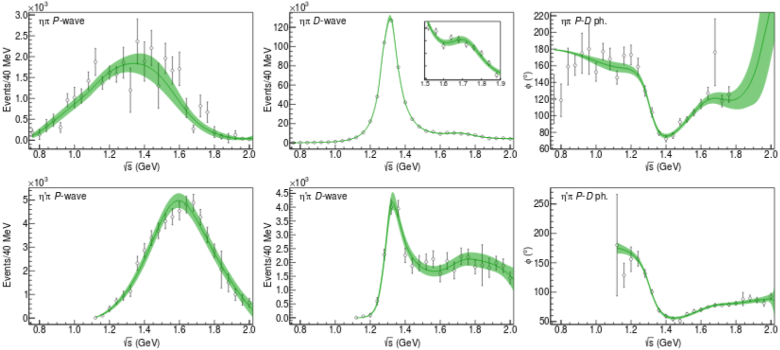
$$\rho N^J_{ki}(s') = \delta_{ki} \frac{\lambda^{J+1/2}\left(s', m^2_{\eta^{(\prime)}}, m^2_\pi\right)}{(s'+s_L)^{2J+1+\alpha}}$$

($s_L = 1\,\mathrm{GeV}^2, \alpha = 2$) and standard K-matrix parametrization

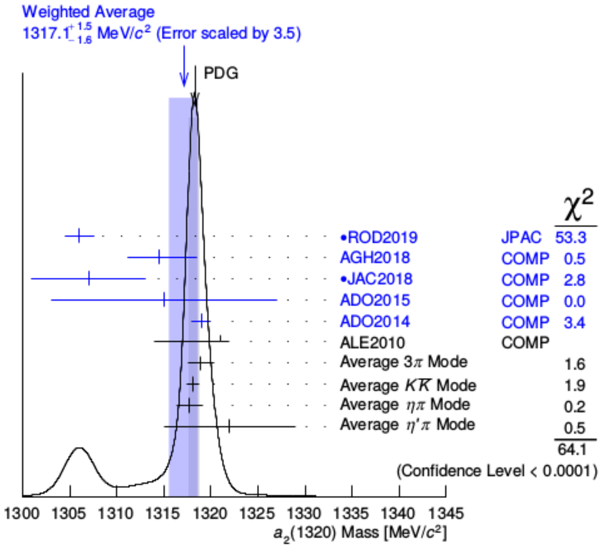
$$K^J_{ki}(s) = \sum_R \frac{g^{J,R}_k g^{J,R}_i}{m^2_R - s} + c^J_{ki} + d^J_{ki} s$$

2 poles in D-wave, 1 pole in P-wave (c and d are symmetric)

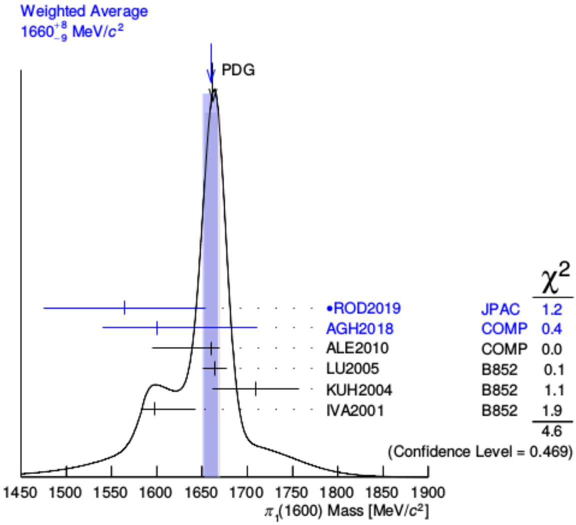
pole in $K \rightsquigarrow$ zero in $D \rightsquigarrow$ pole in a



[JPAC, PRL 122, 042002 (2019)]



[To be published in Progress in Particle and Nuclear Physics]



[To be published in Progress in Particle and Nuclear Physics]