Parametrization of light baryons

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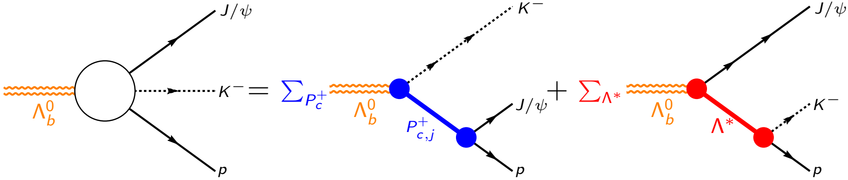
October 29, 2020

Introduction & Motivation

∗) Consider isobar-decomposition for the decay $\Lambda_b^0 \to J/\psi K^- p$: [LHCb arXiv:1507.03414]



$$= \sum_{P^+_{c,j}} [P^+_{c,j}\text{-chain}] + \sum_{\lambda_\psi} \sum_{\Lambda^*_n} \mathcal{H}^{\Lambda_b^0\to\Lambda_n^*\psi}_{\lambda_{\Lambda^*},\lambda_\psi} D^{\frac{1}{2}}_{\lambda_{\Lambda_b^0},\lambda_{\Lambda^*}-\lambda_\psi}\left(0,\theta_{\Lambda_b^0},0\right)^* \mathcal{H}^{\Lambda_n^*\to Kp}_{\lambda_p,0}$$
$$\times D^{J_{\Lambda_n^*}}_{\lambda_{\Lambda_n^*},\lambda_\psi}\left(\phi_K,\theta_{\Lambda^*},0\right)^* \mathcal{R}_{\Lambda_n^*}\left(m_{Kp}\right) D^1_{\lambda_\psi,\Delta\lambda_\mu}\left(0,\theta_{\Lambda_b^0},0\right)^*$$

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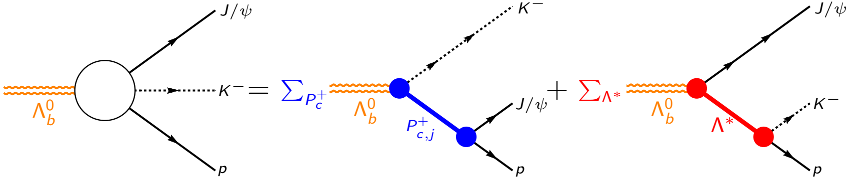

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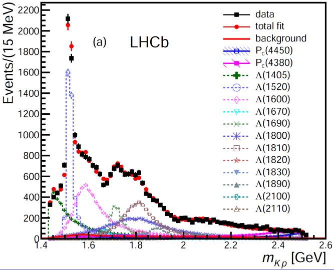
∗) Isobar-lineshapes: Breit-Wigner amplitudes

$$\mathcal{R}_{\Lambda_n^*}\left(m_{Kp}\right) = \left[\frac{p}{M_{\Lambda_b^0}}\right]^{L_1} \frac{B'_{L_1}\left(p, p_0, d\right) B'_{L_2}\left(q, q_0, d\right)}{M_{0,\Lambda_n^*}^2 - m_{Kp}^2 - i M_{0,\Lambda_n^*} \Gamma\left(m_{Kp}\right)} \left[\frac{q}{M_{0,\Lambda_n^*}}\right]^{L_2} .$$

Blatt-Weisskopf factors: $B'_L(p, p_0, d)$,

Mass-dependent width: $\Gamma\left(m\right)$.



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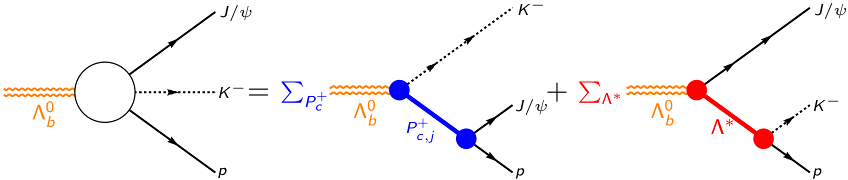

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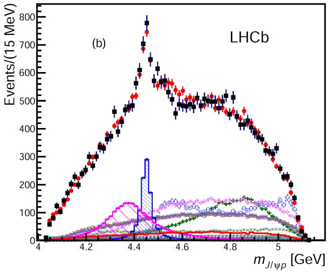

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BnGa-approach for analysis of hyperon resonances

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[Matveev et al., arXiv:1907.03645]

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- *) Coupled-channels approach using K-matrix (actually: D-matrix):

$$K_{ij} = \sum_{\alpha} \frac{g_i^{\alpha} g_j^{\alpha}}{m_{\alpha}^2 - m^2} + c_{ij}.$$

- *) Many (i.e. 15) channels: $i, j = K^- p, \pi^0 \Lambda, \pi^0 \Sigma^0, \ldots, \pi^0 \pi^0 \Lambda, \ldots$.
- *) Database (23000 points): σ_0 for 7 reactions; asymmetry P for 5 reactions; data-'points' for 6 three-body final states (event-sets for 2 final states)

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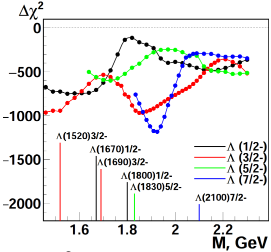
*) Fit-strategy:

(i) Primary fit: fit only hyperons listed with $***$ and $****$ by the PDG, using BW's

(ii) Many exploratory fits: include candidate-resonance with fixed mass (and J^P) $\rightarrow$ fit remaining parameters $\rightarrow$ vary mass $\rightarrow$ re-fit ...
$\Rightarrow$ 'mass-scans'



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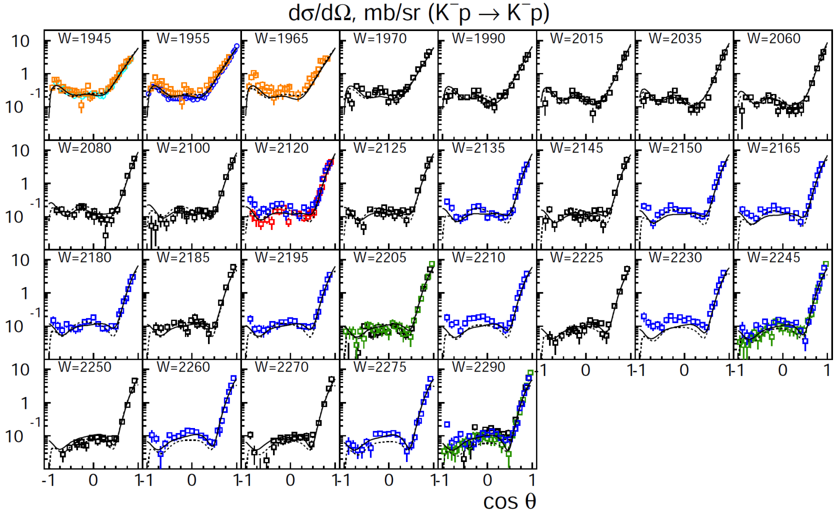
$\hookrightarrow$ Final fit: use resonance-configuration with best $\Delta\chi^2$ as initial condition for the final big K- (or D-) matrix fit

Description of data in the BnGa-approach

∗) Cross sections (mostly) very well-described for all energies:



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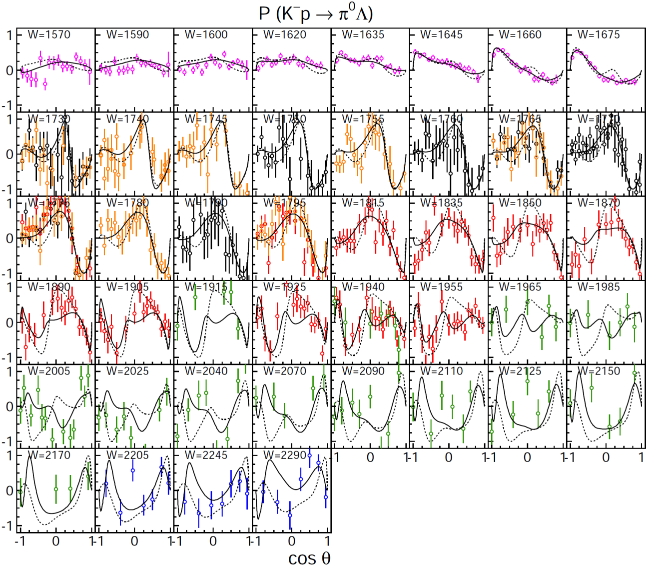
Description of data in the BnGa-approach

$*$) *P*-asymmetry data sometimes scarce, leave room for improvement:



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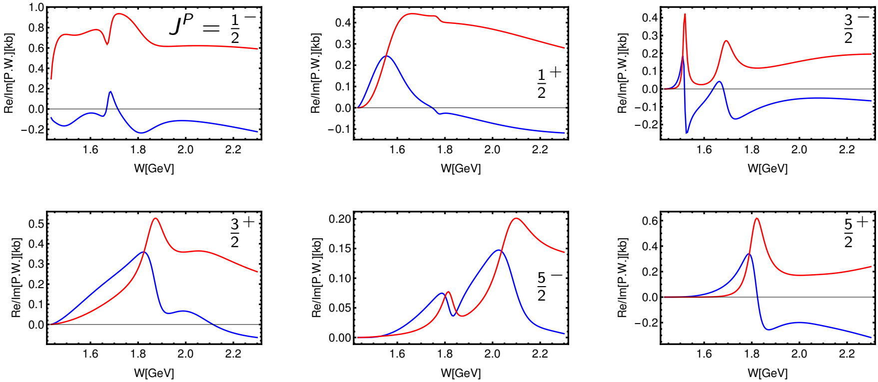
Comparing BnGa partial-waves to Breit-Wigner amplitudes

$*)$ Consider BnGa $\bar{K}N \rightarrow \bar{K}N$ partial waves for isospin $I = 0$: [pwa.hiskp.uni-bonn.de]



——— : real part BnGa, ——— : imaginary part BnGa

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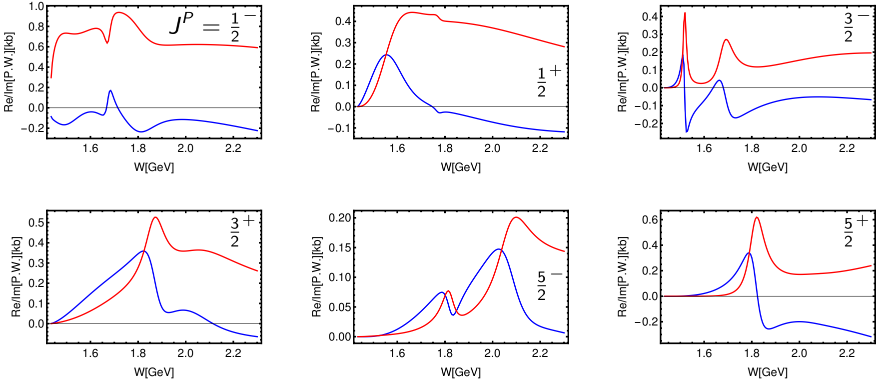

——: real part BnGa, ——: imaginary part BnGa

<u>Idea:</u> Try to reproduce BnGa partial-waves using:

$$\mathcal{M}(W) = c_1 * \mathrm{BW}_1(M_0^1, \Gamma_0^1; W) + c_2 * \mathrm{BW}_2(M_0^2, \Gamma_0^2; W) + \ldots,$$

with $c_i \in \mathbb{C}$ ('helicity-couplings') and $\left\{ M_0^i, \Gamma_0^i \right\}$ fixed to LHCb-values.

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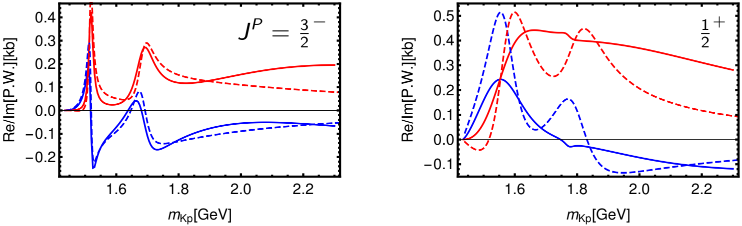

: Re[BnGa], : Im[BnGa], : Re[BW], : Im[BW]

∗) $J^P = \frac{3}{2}^-$: sum of $\Lambda(1520)$ and $\Lambda(1690)$.

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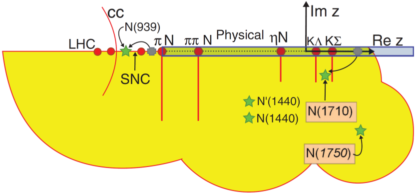

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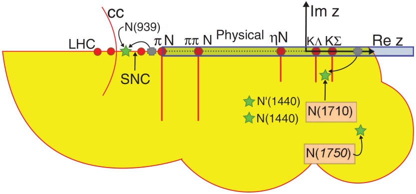

↪ Try to model analytic structure using L+P- ('Laurent+Pietarinen'-) Ansatz:

$$\mathcal{M}(W) = \underbrace{\sum_{j}^{N_{\text{pole}}} \frac{x_j + i y_j}{W_j - W}}_{\text{'Laurent'}} + \underbrace{\sum_{k=0}^{N_1} \boldsymbol{c}_k X(\alpha, x_P; W)^k + \sum_{l=0}^{N_2} \boldsymbol{d}_l Y(\beta, x_Q; W)^l + \ldots}_{\text{'Pietarinen'}}$$

- Pole-position: $W_j \in \mathbb{C}$; Residue: $a_{-1}^{(j)} = x_j + i y_j$
- Pietarinen-functions: $X(\alpha, x_P; W) := \frac{\alpha - \sqrt{x_P - W}}{\alpha + \sqrt{x_P - W}}$, with:
  - *) 'shape-parameter': $\alpha \in \mathbb{R}$; branch-point coordinate: $x_P \in \mathbb{C}$.

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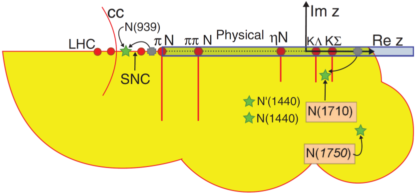

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$\hookrightarrow$ Could something like this work for the LHCb lineshape-functions?

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∗) Try 1 Pole + 1 Pietarinen-function:

$$\mathcal{R}(m_{Kp}) = \frac{a_{-1}}{\left(\mathrm{Re}m_{Kp}^{\mathrm{pole}} - i\,\mathrm{Im}m_{Kp}^{\mathrm{pole}}\right) - m_{Kp}} + \sum_{k=0}^{4} \boldsymbol{c}_k X\left(\alpha, \nu; m_{Kp}\right)^k.$$

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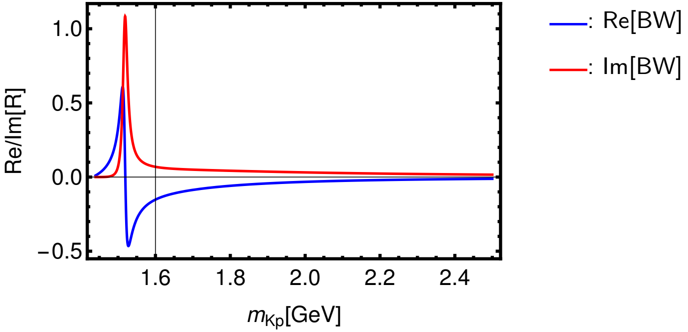

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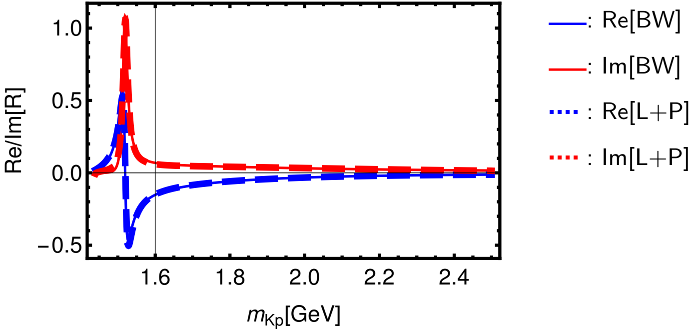
Fit I: fix $\mathrm{Re}\, m_{Kp}^{\mathrm{pole}} = M_0 = 1.5195$ GeV, $\mathrm{Im}\, m_{Kp}^{\mathrm{pole}} = \Gamma_0/2 = 0.0078$ GeV, $\nu = 1.44$ GeV.



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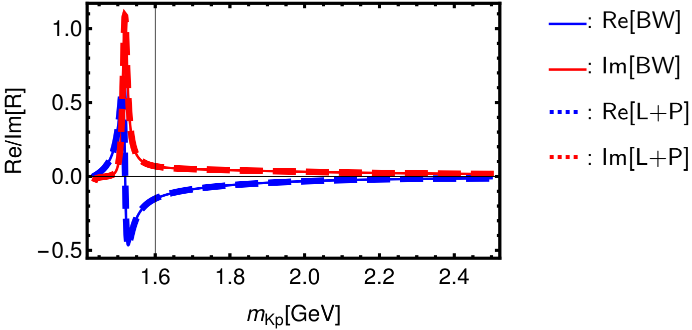
Fit II: $\left\{\mathrm{Re}\, m_{Kp}^{\mathrm{pole}}, \mathrm{Im}\, m_{Kp}^{\mathrm{pole}}\right\}$ float freely, $\nu = 1.44$ GeV.



↪ $\mathrm{Re}\, m_{Kp}^{\mathrm{pole}} = (1.518 \pm 0.201)$ GeV, $\mathrm{Im}\, m_{Kp}^{\mathrm{pole}} = (0.0074 \pm 0.1920)$ GeV.

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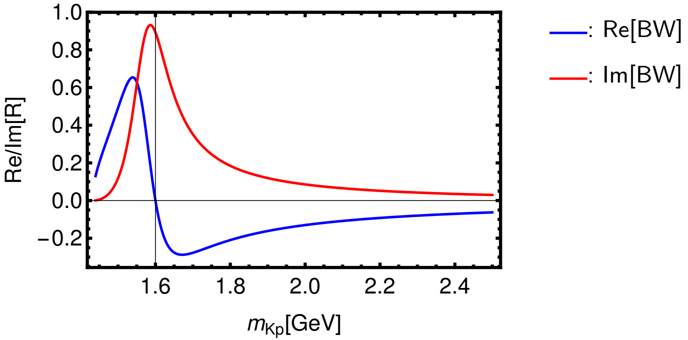

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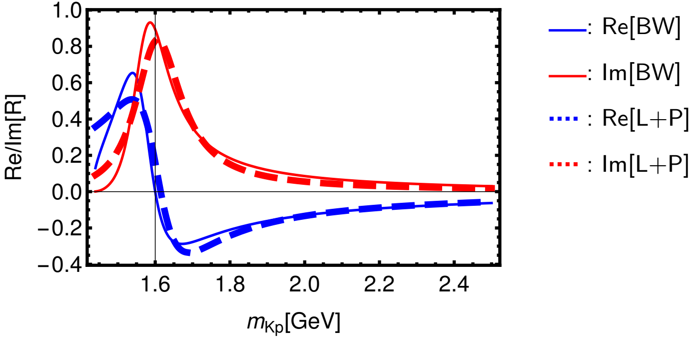

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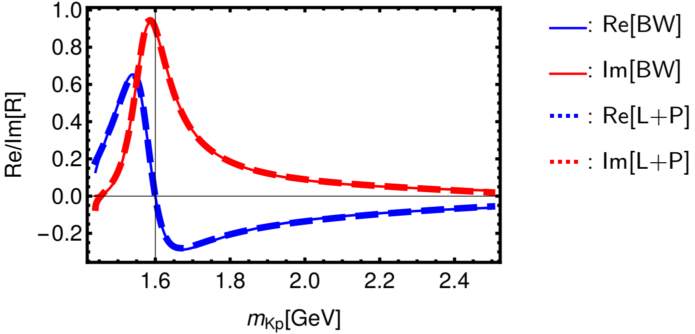
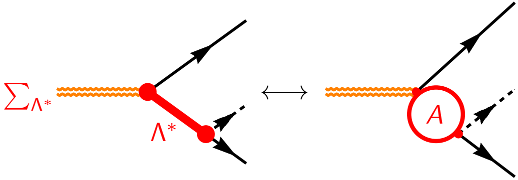


$\hookrightarrow$ $\mathrm{Re}\,m_{Kp}^{\mathrm{pole}} = (1.5705 \pm 0.7930)$ GeV, $\mathrm{Im}\,m_{Kp}^{\mathrm{pole}} = (0.0554 \pm 0.6844)$ GeV.
cf.: PDG-BW par.: mass $\in [1.560, 1.700]$ GeV, width$/2 \in [0.025, 0.125]$ GeV.

P-vector approach

$*$) Consider replacement of the sum over Breit-Wigner's for the Λ^*'s:



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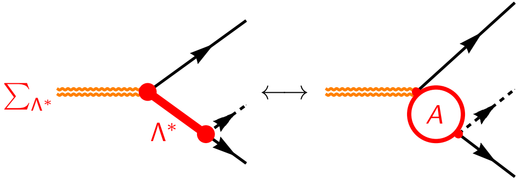
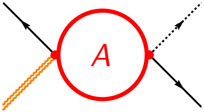


*) Which Ansatz to choose for A?



$= ?$

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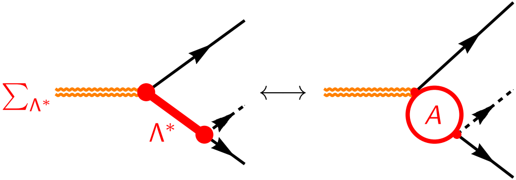
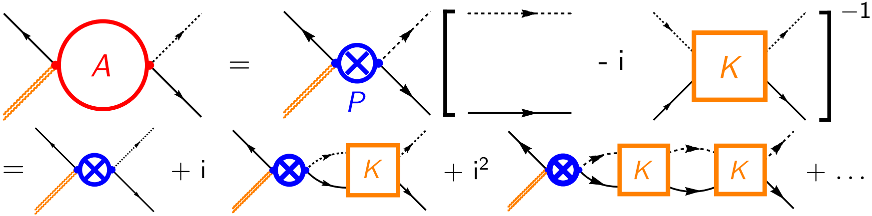


$*$) Possibility: introduce K-matrix from PWA-model (e.g. BnGa) using the P-vector approach $\hat{A} = \hat{P}\left(\mathbb{1} - i\rho\hat{K}\right)^{-1}$

[Aitchison Nucl. Phys. A 189, 417 (1972)]



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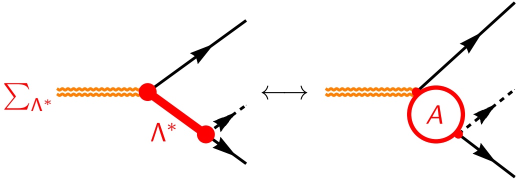

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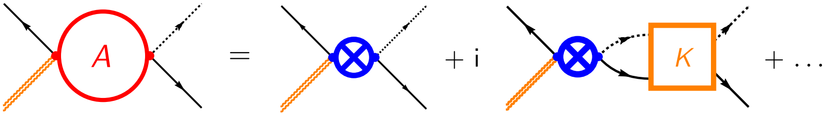
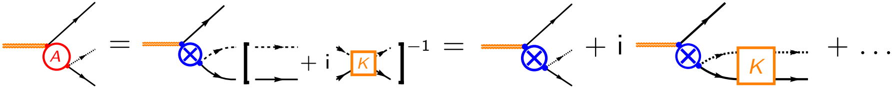


$*)$ Modify the Λ^*-part of the decay-amplitude accordingly:



Possible applications of the P-vector approach

$*$) Use K-matrix as 'background' for fits of P_c^+-states:

$$A_k = P_j \left(\mathbb{1} - i \rho \hat{K} \right)^{-1}_{jk} = P_k + i P_j \rho_j K_{jk} + \ldots$$

- K_{ij}: p.w. matrix-elements of 'frozen' K-matrix imported from the PWA-model
- $P_j = \sum_\alpha \frac{G_\alpha g_j^\alpha}{m_\alpha^2 - m^2} + \underbrace{f_j}_{= ?}$

$\hookrightarrow$ Unknowns $\{G_\alpha\}$ (and possibly f_j) need to be fitted, together with parameters for P_c^+-states

Possible applications of the P-vector approach

$*)$ Use K-matrix as 'background' for fits of P_c^+-states:

$$A_k = P_j \left(\mathbb{1} - i \rho \hat{K} \right)^{-1}_{jk} = P_k + i P_j \rho_j K_{jk} + \dots$$

- K_{ij}: p.w. matrix-elements of 'frozen' K-matrix imported from the PWA-model
- $P_j = \sum_\alpha \frac{G_\alpha g_j^\alpha}{m_\alpha^2 - m^2} + \underbrace{f_j}_{= ?}$

$\hookrightarrow$ Unknowns $\{G_\alpha\}$ (and possibly f_j) need to be fitted, together with parameters for P_c^+-states

$*)$ Use LHCb-data in order to fit Λ^*-resonances: minimize (simplification!)

$$-2 \ln \left[\mathcal{L}_{\mathrm{LHCb}} \left(\vec{\omega}_{P_c^+}, \vec{\omega}_{\Lambda^*} \right) \right] + \chi^2_{\mathrm{BnGa}} \left(\vec{\omega}_{\Lambda^*} \right)$$

- $\vec{\omega}_{P_c^+}$: masses, widths, hel.-couplings of P_c^+'s
- $\vec{\omega}_{\Lambda^*}$: parameter-vector from (BnGa) light-baryon analysis

$\hookrightarrow$ Quite difficult, but more promising than using just LHCb-events for light-baryon spectroscopy ...

Conclusion and Outlook

For the example-reaction $\Lambda_b^0 \to J/\psi K^- p$, we discussed:

$*$) Introducing the L+P-parametrization for the lineshape-fcts $\mathcal{R}(m_{Kp})$:

- ✓ Introduce (or extract) pole- instead of Breit-Wigner Parameters
  $\to$ in principle less model-dependent
- ✓ In principle possible to model complicated analytic structures using multiple Pietarinen-functions, ...
- ✗ ... however: this would introduce too many new parameters. Instead: try at most 1 Pietarinen per lineshape-function
- ✗ Issue: do helicity-couplings factorize around L+P-parametrization, or not?

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$*$) Import the K-matrix of a reaction-model (e.g. BnGa) using the P-vector approach (or variants thereof):

- ✓ Can improve the description of Λ^*-contributions ('background')
- ✓ K-matrix related ideas can open window towards usage of LHCb-data for light-brayon spectroscopy
- ✗ Implementation is probably time-consuming (i.e. not easy)

$\hookrightarrow$ Final suggestion: maybe use K-matrix for Λ^*'s and L+P for P_c^+'s?

Thank You!

Additional Slides

BnGa-results for Λ^*-resonances

Negative-parity Λ-hyperons:

	Mass	Width	$\Delta\chi^2$	Status
$\Lambda(1405)1/2^-$	1420±3 $1405.1^{+1.3}_{-1.0}$	46±4 50.5±2.0	4070	**** ****
$\Lambda(1670)1/2^-$	1677±2 1660 to 1680	33±4 25 to 50	3610	**** ****
$\Lambda(1800)1/2^-$	1811±10 1720 to 1850	209±18 200 to 400	1896	*** ***
$\Lambda(2000)1/2^-$	2085±14 ≈2060	428±16 100 to 300	845	* *
$\Lambda(1520)3/2^-$	1518.5±0.5 1519.5±1.0	15.7±1.0 15.6±1.0	>10 000	**** ****
$\Lambda(1690)3/2^-$	1689±3 1685 to 1695	75±5 50 to 70	>10 000	**** ****
$\Lambda(1830)5/2^-$	1821±3 1810 to 1830	64±7 60 to 110	1790	*** ****
$\Lambda(2080)5/2^-$	2082±13 -	181±29 -	770	** new
$\Lambda(2100)7/2^-$	2090±15 2090 to 2110	290±30 100 to 250	5412	**** ****

[M. Matveev, NSTAR2019]

BnGa-results for Λ^*-resonances

Positive-parity Λ-hyperons:

	Mass	Width	$\Delta\chi^2$	Status
$\Lambda(1600)1/2^+$	1605±8 1560 to 1700	245±15 50 to 250	>10 000	**** ***
$\Lambda(1810)1/2^+$	1773±5 1750 to 1850	36±6 50 to 250	46	* ***
$\Lambda(1890)3/2^+$	1873±5 1850 to 1910	103±10 60 to 200	4480	**** ****
$\Lambda(2070)3/2^+$	2070±24 -	370±50 -	1144	** new
$\Lambda(1820)5/2^+$	1822±4 1815 to 1825	80±8 70 to 90	>10 000	**** ****
$\Lambda(2110)5/2^+$	2086±12 2090 to 2140	274±25 150 to 250	1418	** ***

[M. Matveev, NSTAR2019]