Experimental Challenges:

Going beyond isobar

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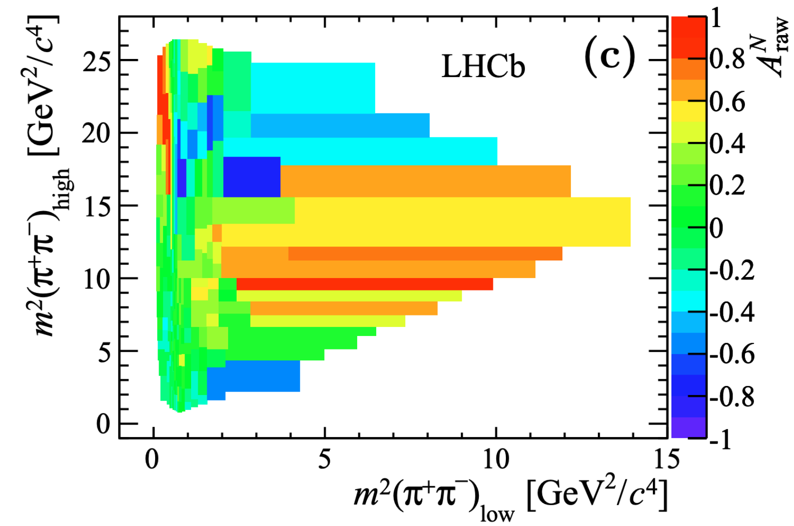
Currently three approaches:

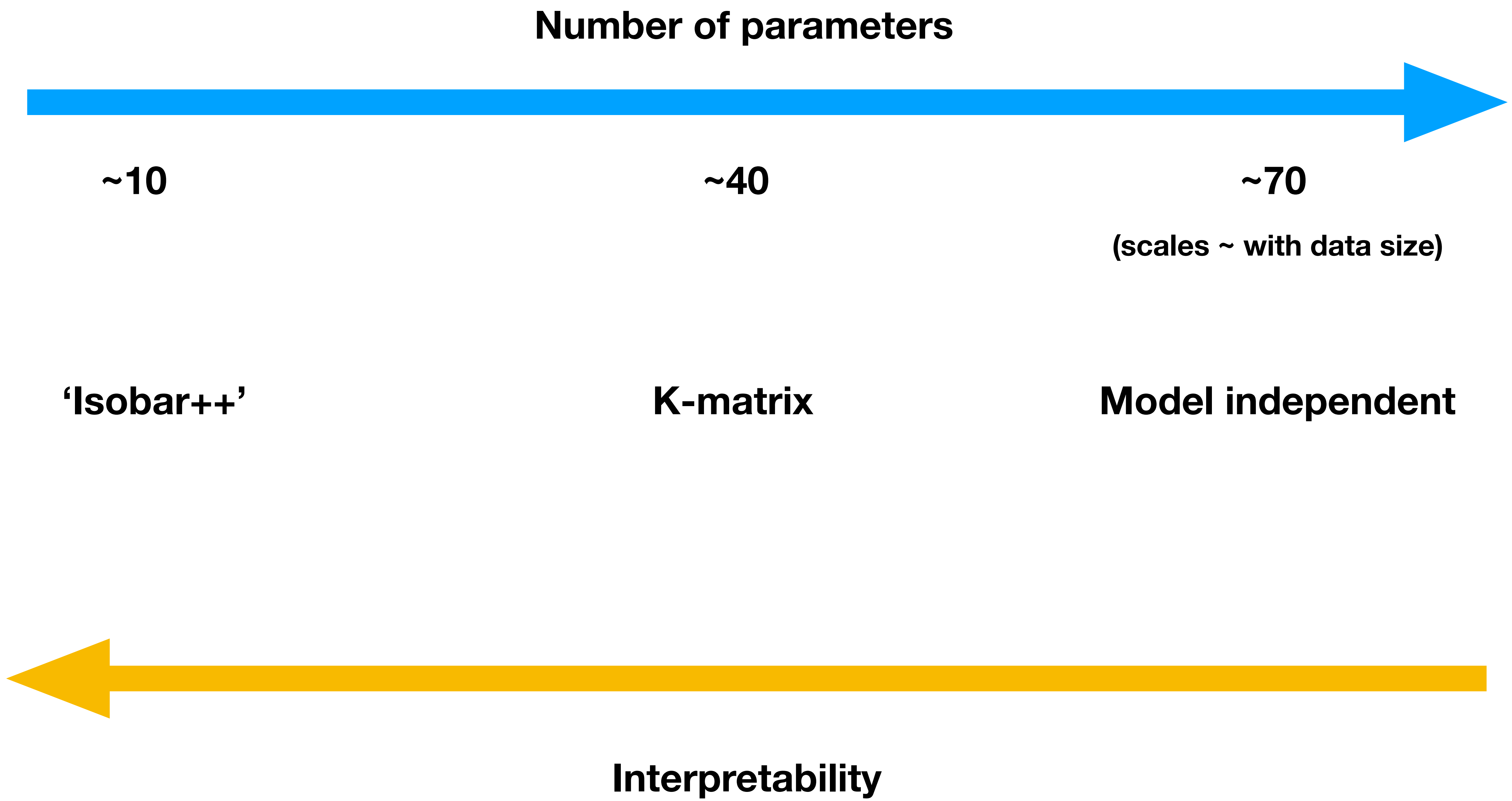
(I will mostly focus on B -> 3pi, but probably this is more generally applicable)



'Isobar'++: Individual resonance models that take into account open channels

K-Matrix: Single model for all scalar resonances, taking into account overlapping resonances and open channels

(Quasi) model independent (PWA, QMIPWA,…): Fit for the amplitude independently in bins of phase space


Number of parameters
~10
~40
~70
(scales ~ with data size)
'Isobar++'
K-matrix
Model independent
Interpretability

K-matrix:

(Specific implementation for LHCb B -> 3pi can be found in arXiv:1711.09854)

Phase space factor

States u, v
Poles α

$$\mathcal{F}_u = \sum_{v=1}^{n} [I - i\hat{K}\rho]^{-1}_{uv} \cdot \hat{P}_v \, .$$

'pole' component **'slowly varying' component**

$$\hat{K}_{uv}(s) = \left(\sum_{\alpha=1}^{N} \frac{g_u^{(\alpha)} g_v^{(\alpha)}}{m_\alpha^2 - s} + f_{uv}^{\rm scatt} \frac{m_0^2 - s_0^{\rm scatt}}{s - s_0^{\rm scatt}} \right) f_{A0}(s)$$

$$\hat{P}_v(s) = \sum_{\alpha=1}^{N} \frac{\beta_\alpha g_v^{(\alpha)}}{m_\alpha^2 - s} + f_v^{\rm prod} \frac{m_0^2 - s_0^{\rm prod}}{s - s_0^{\rm prod}} \, ,$$

Fixed from scattering data

Obtained from B decay fit

K-matrix:

Five poles: f0(500), f0(980), f0(1370), f0(1500), f0(1710)

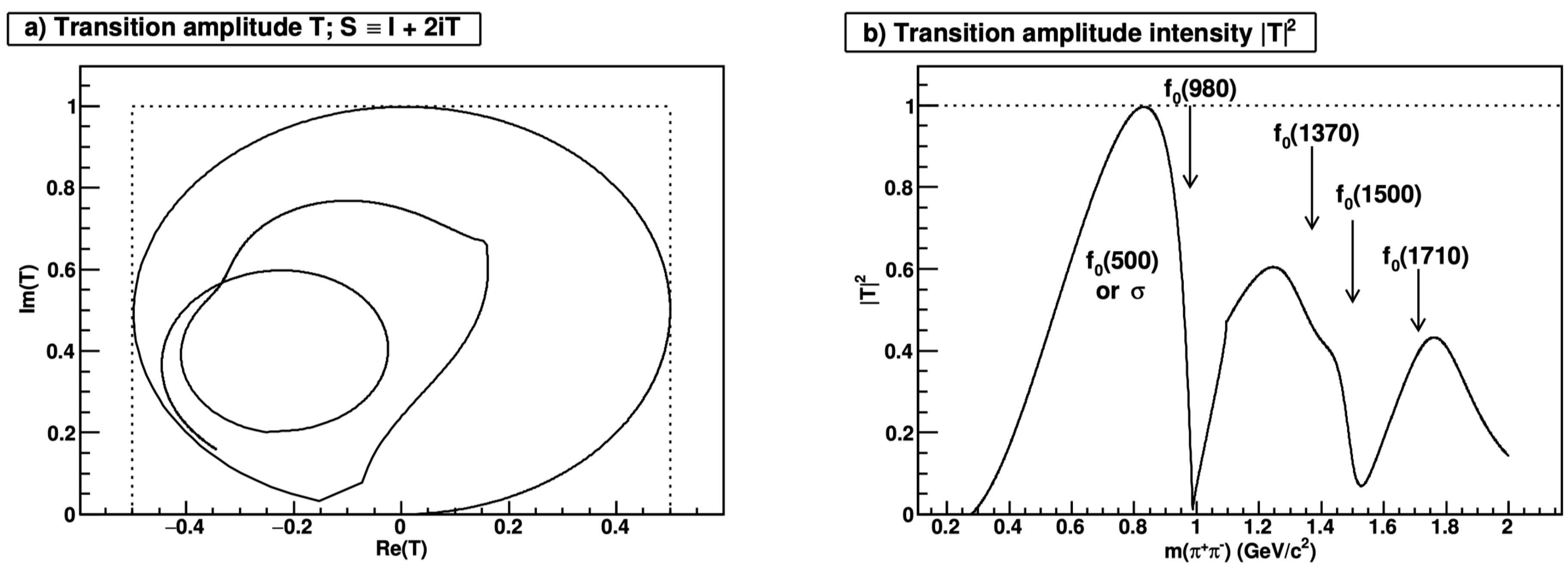
Five channels: pipi, KK, 4pi (multibody), eta eta, eta eta’

Parameters from Anisovich & Sarantsev: **arXiv:hep-ph/0204328, arXiv:0804.2089**

α	m_α	$g_1^{(\alpha)}[\pi\pi]$	$g_2^{(\alpha)}[K\bar{K}]$	$g_3^{(\alpha)}[4\pi]$	$g_4^{(\alpha)}[\eta\eta]$	$g_5^{(\alpha)}[\eta\eta']$
1	0.65100	0.22889	−0.55377	0.00000	−0.39899	−0.34639
2	1.20360	0.94128	0.55095	0.00000	0.39065	0.31503
3	1.55817	0.36856	0.23888	0.55639	0.18340	0.18681
4	1.21000	0.33650	0.40907	0.85679	0.19906	−0.00984
5	1.82206	0.18171	−0.17558	−0.79658	−0.00355	0.22358
	s_0^{scatt}	f_{11}^{scatt}	f_{12}^{scatt}	f_{13}^{scatt}	f_{14}^{scatt}	f_{15}^{scatt}
	−3.92637	0.23399	0.15044	−0.20545	0.32825	0.35412
	s_0^{prod}	m_0^2	s_A	s_{A0}		
	−3.0	1.0	1.0	−0.15		

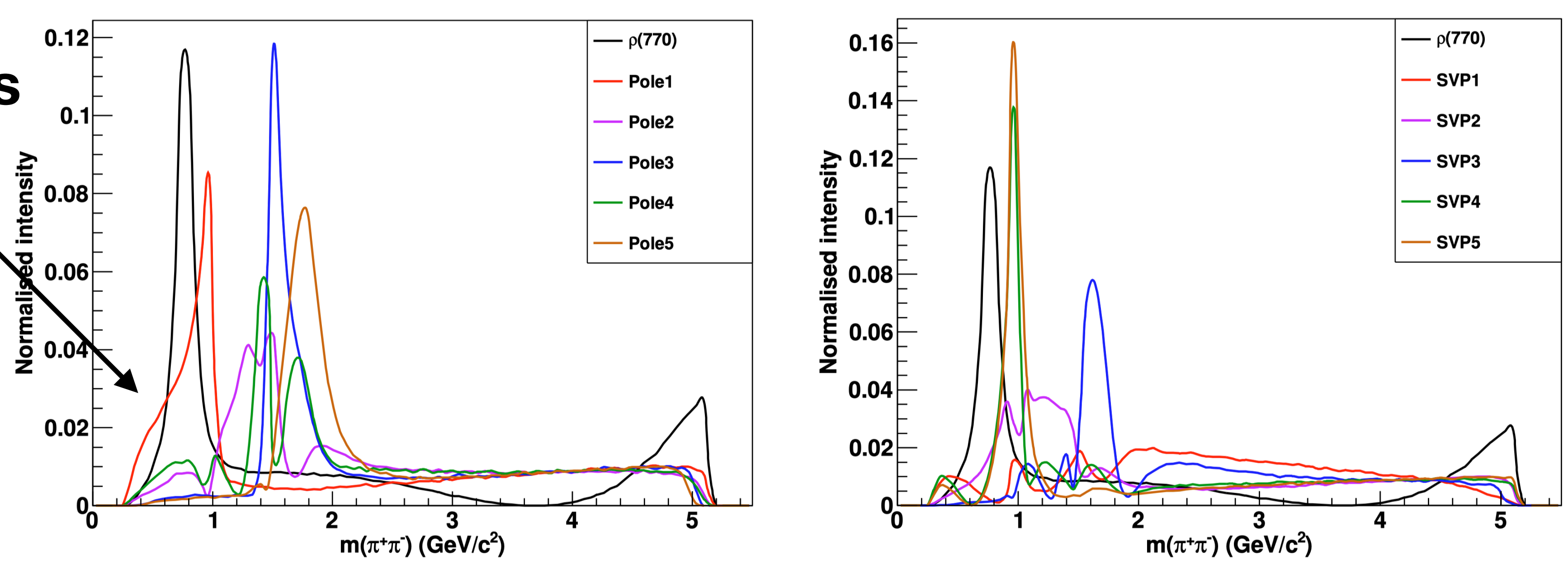
K-matrix:

- **Amplitude for P = 1**



- **Decomposition of P into pole and slowly varying parameters**

Huge correlations



K-matrix:

Pros:

- **Better theoretically motivated than isobar, conserves unitarity**
- **Empirical model of pipi S-wave with from scattering data**

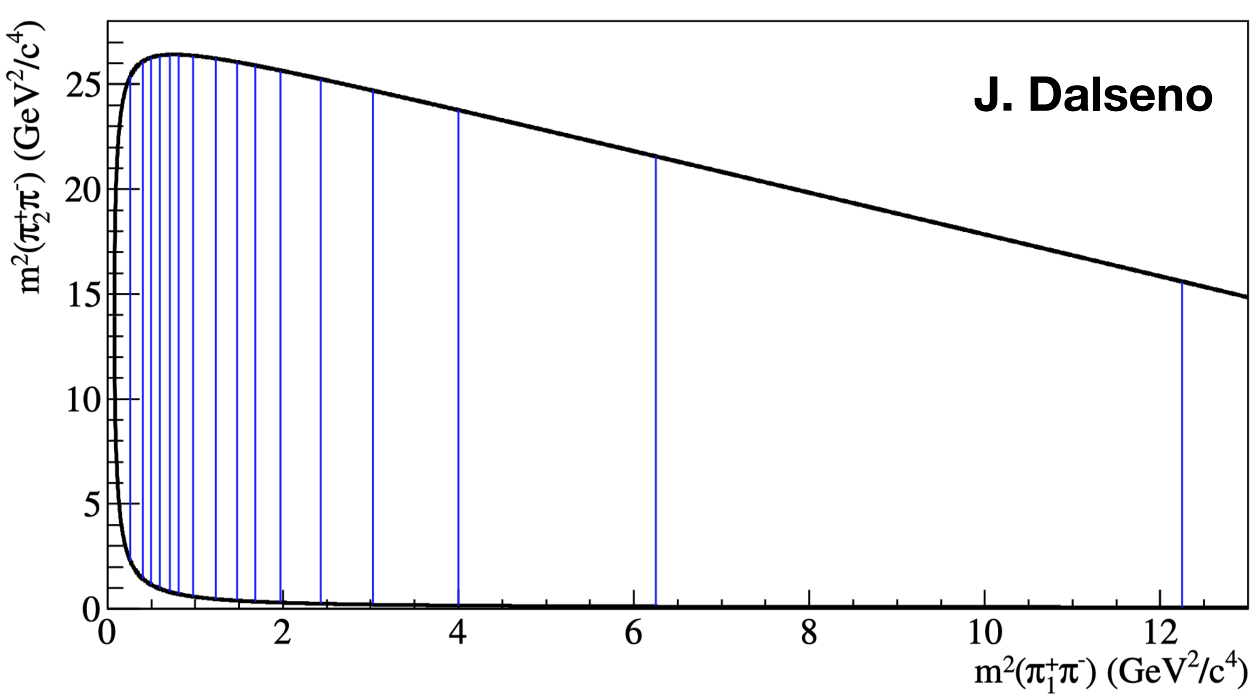
Cons:

- **‘Pole’ terms do not correspond to physical poles, cannot separate out resonances (‘monolithic’)**
- **Difficult to fit to data: Many (correlated) parameters, multiple solutions**

Model independent:

- **Fit for amplitude values for a single partial wave at specific points in the phase space, assumed to be independent**
- **Total amplitude is piecewise-constant, or interpolated (linear, cubic spline etc) between these values**
- **No other assumptions on the amplitude (for this partial wave)**

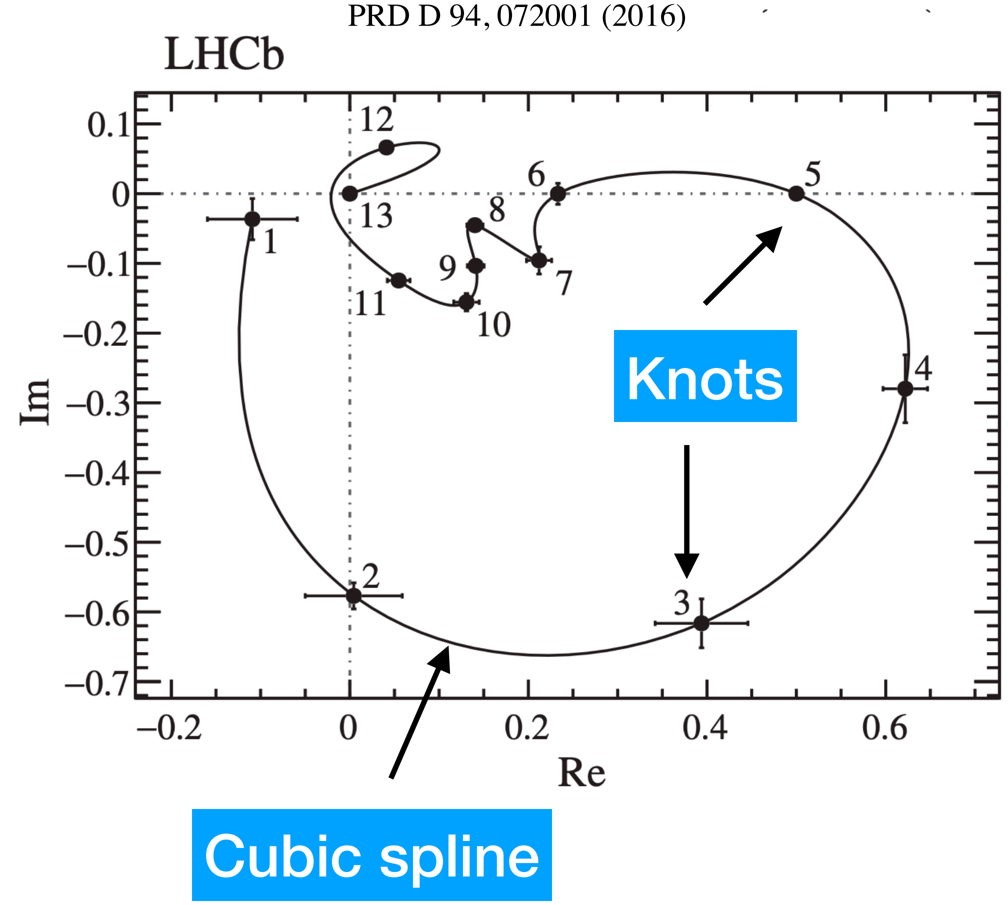
$B^+ \to \pi^+\pi^+\pi^-$ **binning scheme**



(piecewise constant amplitude, rather than interpolated)

$B^- \to D^+\pi^-\pi^-$, $D^+\pi^-$ **S-wave**

PRD D 94, 072001 (2016)



Model independent:

Pros:

- **No (potentially bad) modelling assumptions**

Cons:

- **Huge number of parameters, usually need multiple CPUs or GPU to converge on human timescales**
- **No good way of choosing the binning in an unbiased way**
- **These result in a increase in statistical and systematic uncertainties that could possibly be avoided**

The future:

- **Coupled channel analysis - pipi and KK final states?**

  An obvious way to do this is by freeing the coupled the K-matrix parameters currently fixed from scattering data

  Is there a better motivated formalism for this?

- **Model independent methods are useful if we don't want to worry so much about the model**

  Are these also useful for building models using the experimental data?

  Lots of methods for 'selecting' the number and location of bins/spline knots (arXiv:1207.5578, L1 regularisation, other Bayesian methods)

  Requires a change in formulation, but may be worth it if these are useful outputs of the experimental analysis?

- **Start worrying about P (and higher) wave?**

  LHCb has many times more data on disk….