HEP Model Initiative

Hadronic Cascade Decays in JSON

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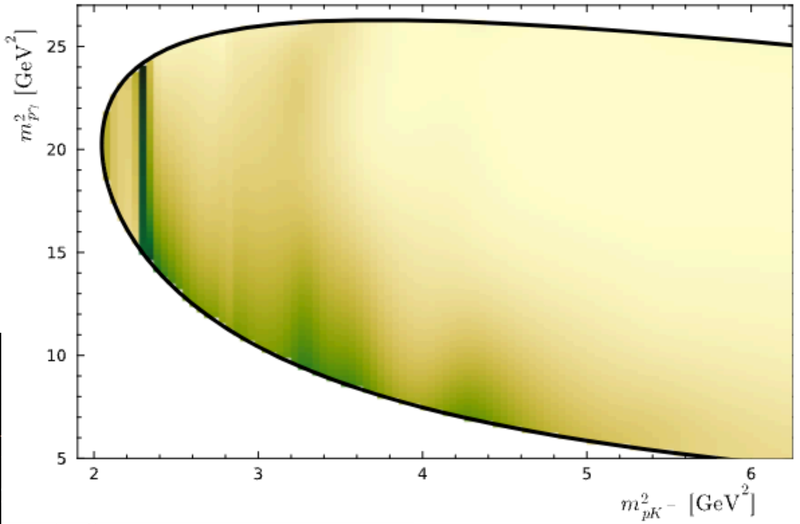
Preview

75 decay chains, 11 resonances

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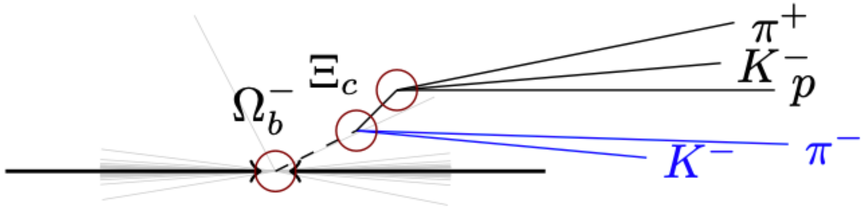
INTRODUCTION

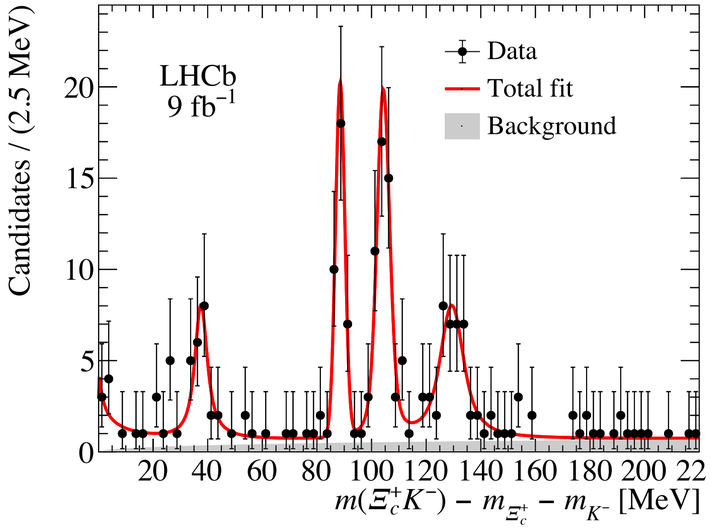
Excited baryons

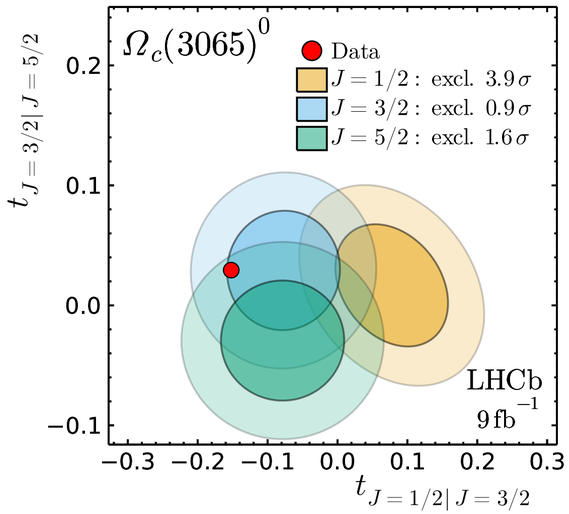
Need for input



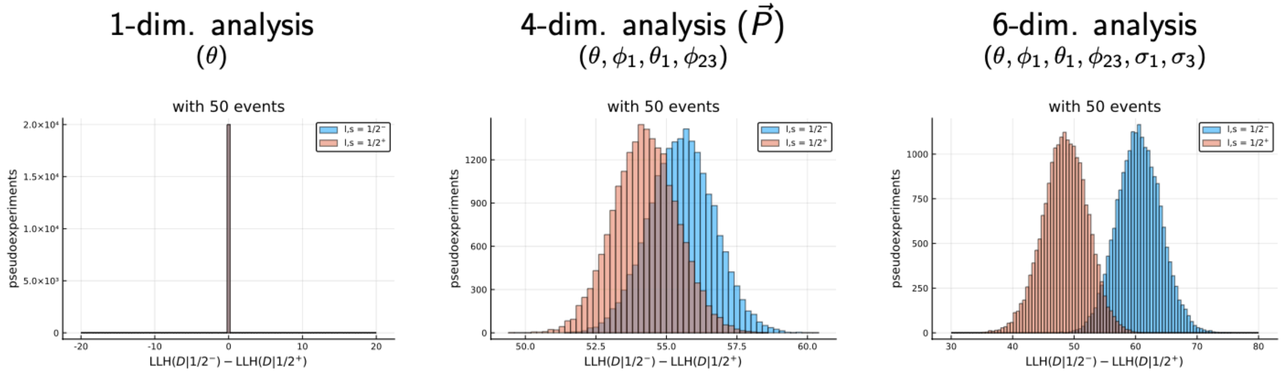
- Understanding
  1P multiplet “bad diquark”
  requires spin assignment

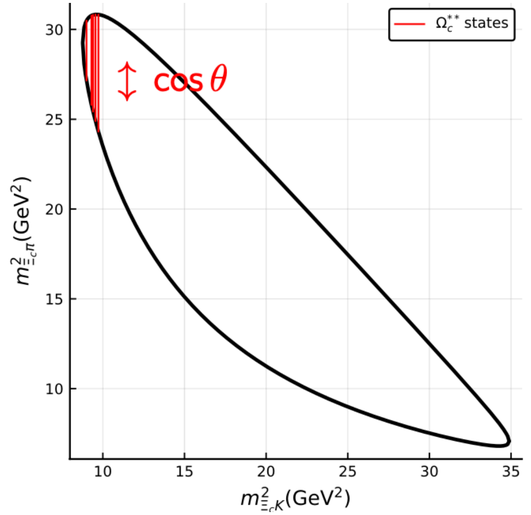
- $\Omega_b^- \to \Xi_c^+(\to pK^-\pi^+)\,\pi^-K^-$
  allows spin-parity determination





- If amplitude $\Xi_c^+ \to pK^-\pi^+$ were known, JP are separable

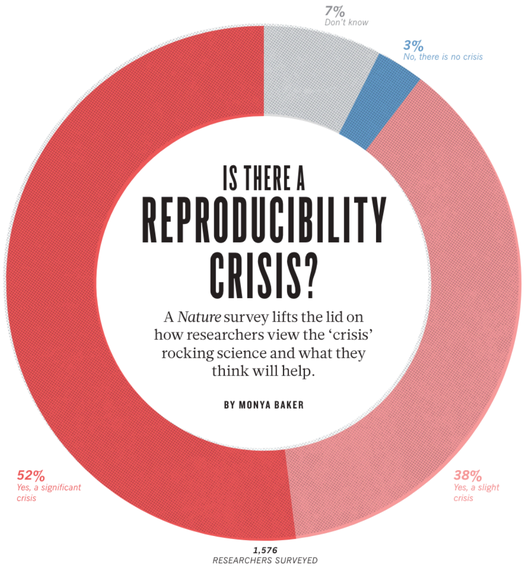




Other reasons preserving models

- Reproducibility and Open Science
  "More than 70% of researchers have tried and failed to reproduce another scientist's experiments", Nature Survey, 2016
  "We have tried implementing past amplitude analysis from papers many times, and have never succeeded.
  It's impossible, do not even try", Jonas Rademacker, 2024
- Correctness/Validity check for new Frameworks
  Many frameworks: 4 in COMPASS, ~10 in LHCb
  Every PWA research implements it own framework, it's ok. We need to have a way to validate it
- Inference from amplitude analysis results
  Get something not computed in original paper (parity violation / pole positions, couplings)
- Integration with Monte Carlo (MC) generators
- Benchmark of frameworks and new computational devices

  GPU/TPU speed up? jax is fast or not? does one need autodiff?

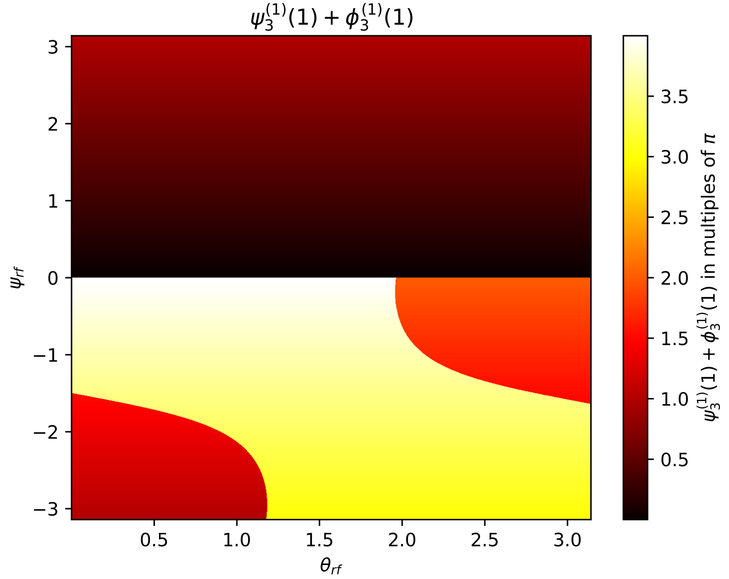


2016 Nature Survey

HEPMODEL (MISSING)

Note on correctness

Dalitz plot decomposition



Wigner azimuthal rotation is 2pi-discontinious.
See a talk by Kai Habermann (Mo, 20h45 CET)

- **2pi azimuthal** rotations is easy to screw, critical for baryons
- Dalitz-plot decomposition [PRD101(2020)] solves the problem by factoring (removing) azimuthal rotations for three-body decays (only)

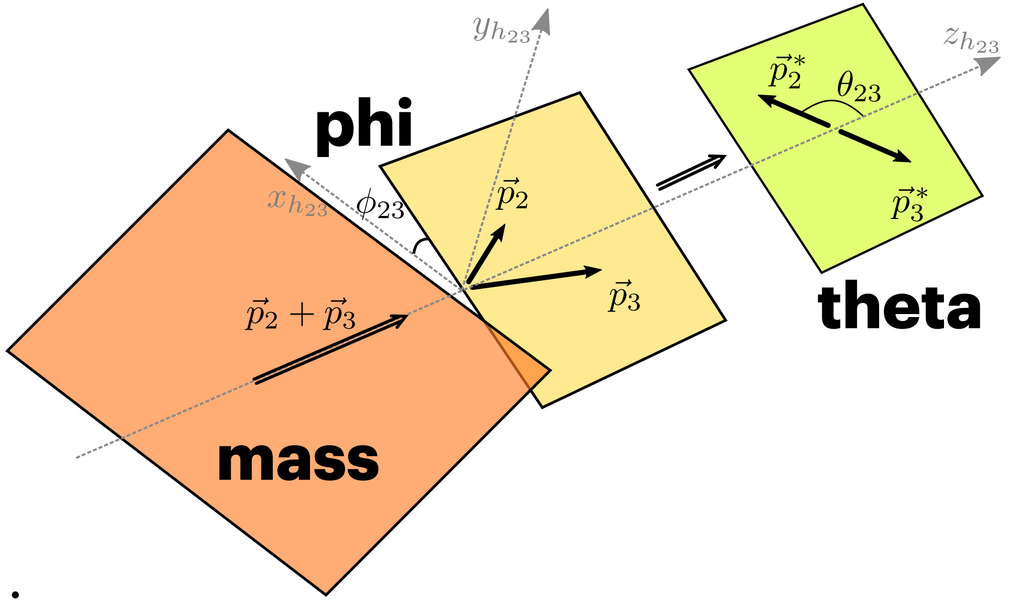
$$A_{\lambda;\dots}(\text{variables}) = \sum_{\lambda'} D^{j}_{\lambda,\lambda'}(\text{angles})\ O_{\lambda';\dots}(\text{invariants})$$

- **Particle ordering** might be an issue, [CPC45(2021)]
- Identical particle **symmetrization** can be cumbersome [PRD104(2021)]

DECAY DESCRIPTION

Kinematics

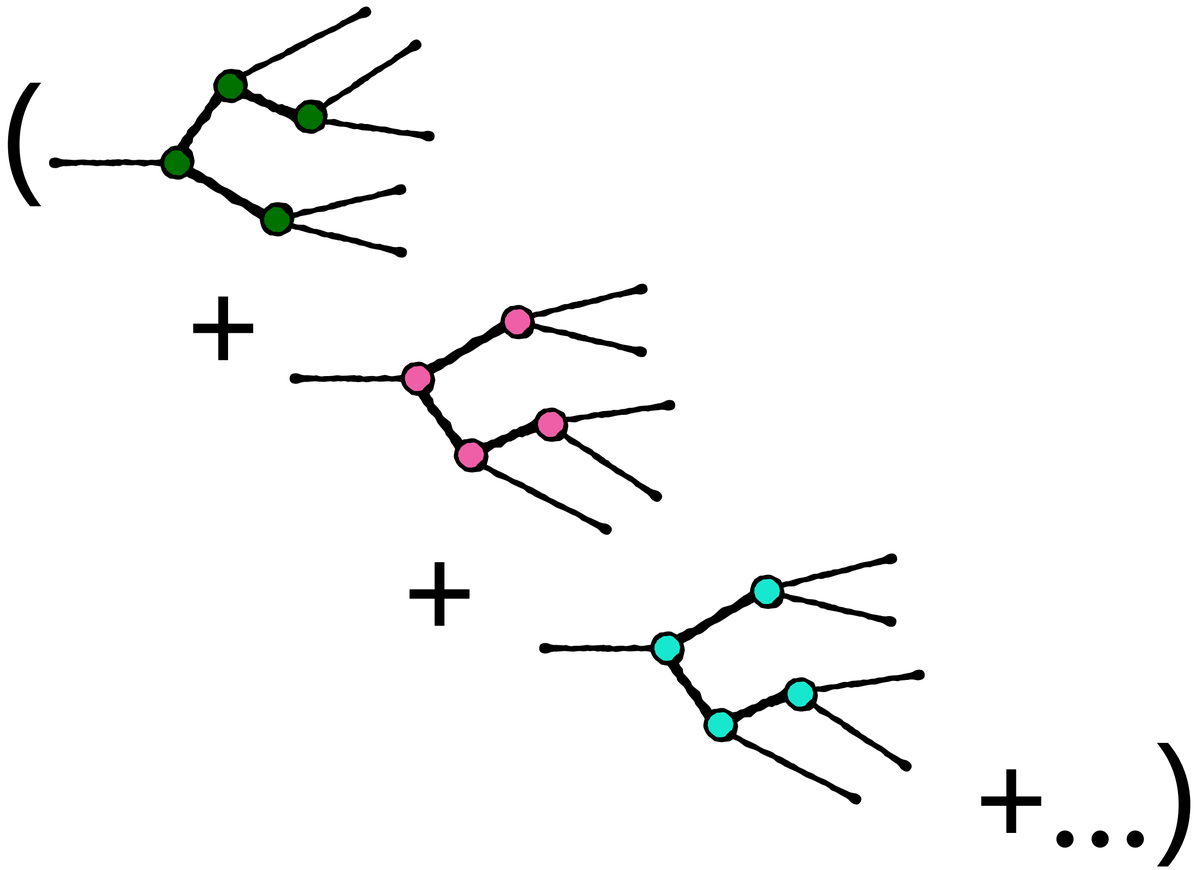
Phase space parametrization



- n-body decay needs 3n-10 variables
  (+3 for polarization)
- A topology can be used to specify the choice
  - (**mass, theta, phi**) for every node
- **reference_topology** must be given specified
- By our convention: reference topology is used for spin alignment
  - no Wigner rotations for chains with reference topology

Decay model

Decay chains



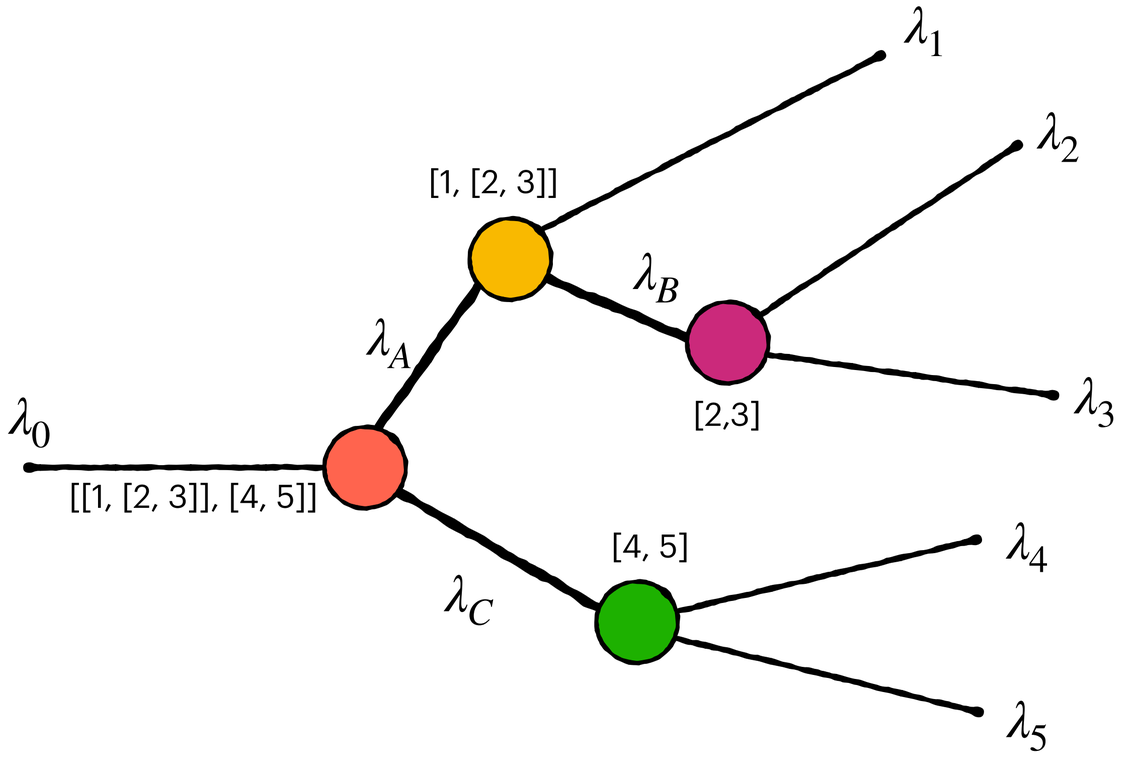
- **distribution** (pdf)**:**
  - unpolarized $$I(\tau) = \sum_{\{\lambda\}} |A_{\{\lambda\}}(\tau)|^2$$
  - polarized $$I(\tau \,|\, P) = \sum_{\lambda_0,\lambda_0'} \rho_{\lambda_0,\lambda_0'}(P) \sum_{\{\lambda_i\}}^{i!=0} A^*_{\lambda_0';\{\lambda\}} A_{\lambda_0;\{\lambda\}}$$

- **model_description:**
  array of chains

$$A_{\{\lambda\}}(\tau) = \sum_i A^i_{\{\lambda\}}(\tau)$$

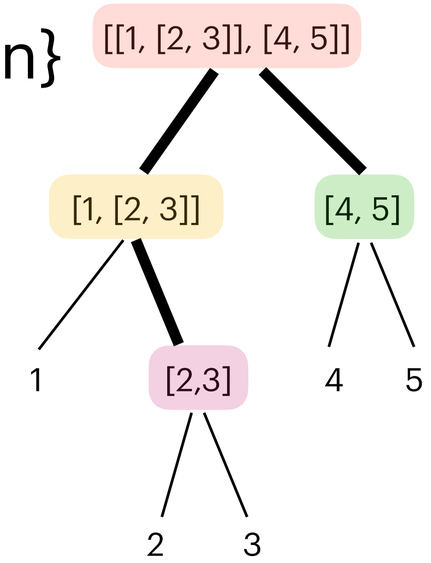
Decay chain

Topology and Nodes



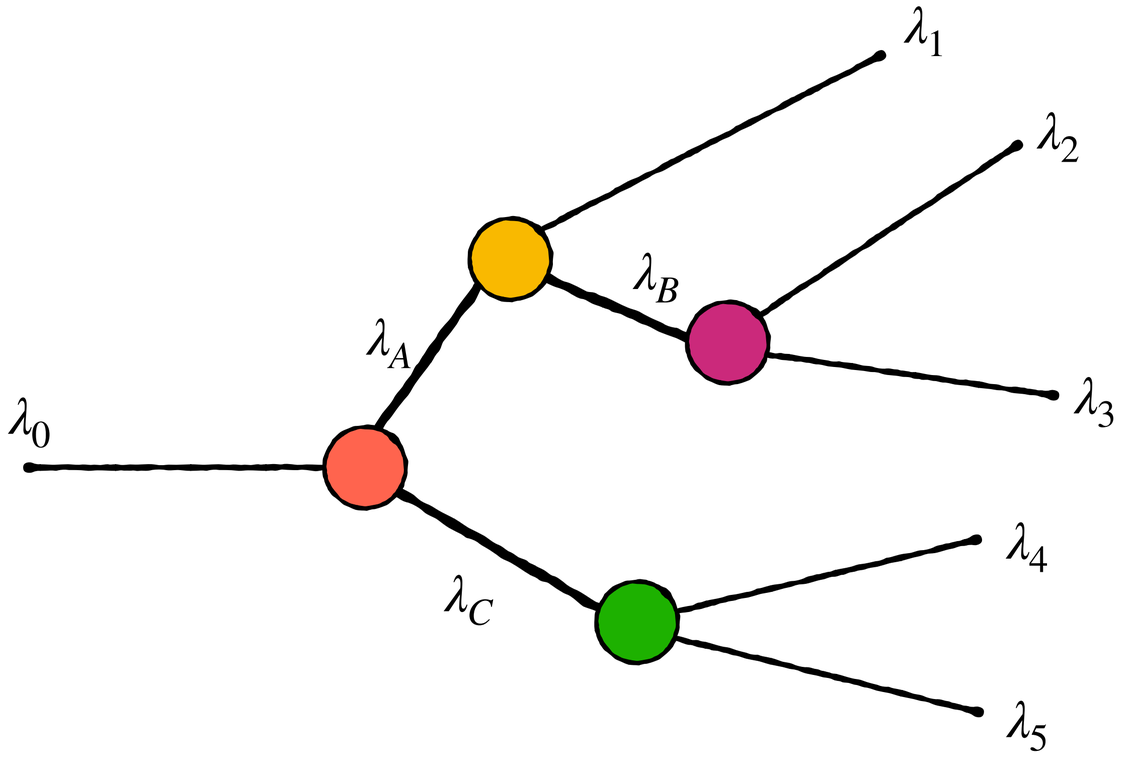
The chain gives prescription to every

- **verteces:**
  {node, recoupling, form-factor}
- **propagators:**
  {spin, parametrization}
- **topology**



Decay chain

Vertices and propagators



- **vertex**: node, recoupling, form-factor
- **propagator**: spin, parametrization

$$A^{i}_{\lambda_0;\lambda_1,\lambda_2,\lambda_3,\lambda_4,\lambda_5} =$$

$$D^{j_0*}_{\lambda_0,\lambda_A-\lambda_C} H_{\lambda_A,\lambda_C} \; D^{j_A*}_{\lambda_A,\lambda_1-\lambda_B} H_{\lambda_1,\lambda_B} \; D^{j_B*}_{\lambda_B,\lambda_2-\lambda_3} H_{\lambda_2,\lambda_3} \; D^{j_C*}_{\lambda_C,\lambda_4-\lambda_5} H_{\lambda_4,\lambda_5}$$

$$\times P_A(s_A)\, P_B(s_B)\, P_C(s_C)$$

$$\times D^{j_1}_{\lambda'_1,\lambda_1}(R^w_1)\, D^{j_2}_{\lambda'_2,\lambda_2}(R^w_2)\, D^{j_3}_{\lambda'_3,\lambda_3}(R^w_3)\, D^{j_4}_{\lambda'_4,\lambda_4}(R^w_4)\, D^{j_5}_{\lambda'_5,\lambda_5}(R^w_5)$$

Validation block

Reliability of implementation

- values of registered **distributions** at a phase-space **point** must match

- Workflow when coding new model:
  1. produces validation values
  2. write **json**
  3. match
- Fine-component validation [WIP]

Validation

The integrity of the model is checked by validating the value of distributions at a few phase space points. The table lists the validation checks and their status. The marks "🟢", "🟡", and "🔴" indicate an accuracy of $< 10^{-10}$, $< 10^{-2}$, or $\geq 10^{-2}$, respectively, for the difference between the reference and computed values.

▶ A loop over validation points

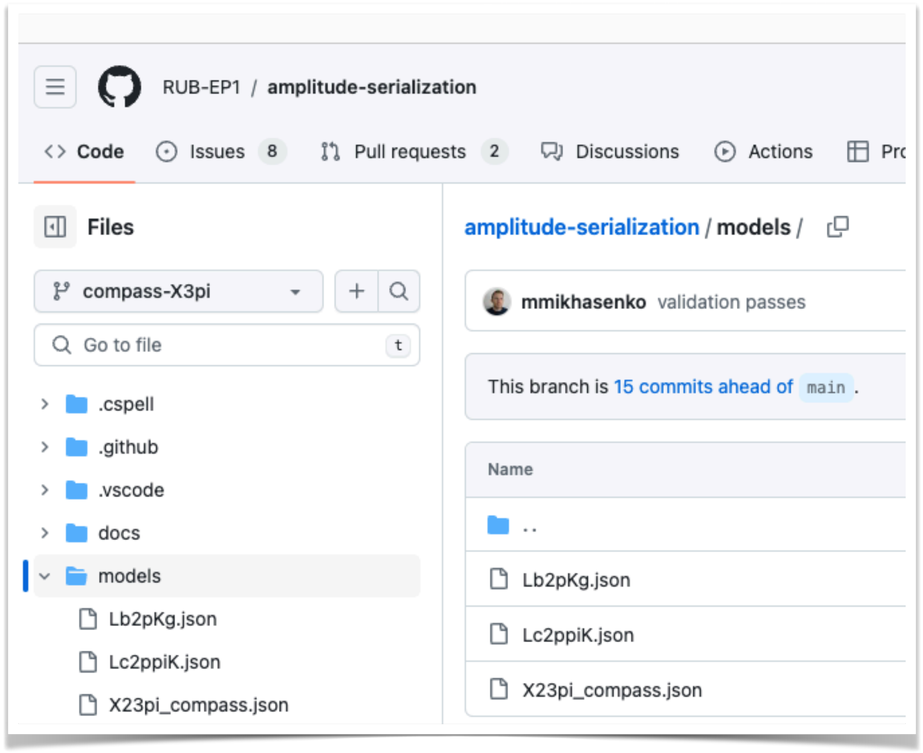
16×5 DataFrame

Row	Distribution	Point	computed_value	value	Status
	String	String	Float64	Float64	Char
1	compass_3pi_JP=1+_M=0_1540_1560	validation_point1	0.557753	0.557753	🟢
2	compass_3pi_JP=1+_M=0_1540_1560	validation_point2	1.43625	1.43625	🟢
3	compass_3pi_JP=1+_M=0_1540_1560	validation_point3	0.108395	0.108395	🟢
4	compass_3pi_JP=1+_M=0_1540_1560	validation_point4	0.791847	0.791847	🟢
5	compass_3pi_JP=1-_M=1_1540_1560	validation_point1	0.0452047	0.0452047	🟢
6	compass_3pi_JP=1-_M=1_1540_1560	validation_point2	0.010651	0.010651	🟢
7	compass_3pi_JP=1-_M=1_1540_1560	validation_point3	0.01857	0.01857	🟢
8	compass_3pi_JP=1-_M=1_1540_1560	validation_point4	0.0900839	0.0900839	🟢
9	compass_3pi_JP=2+_M=1_1540_1560	validation_point1	0.0170822	0.0170822	🟢
10	compass_3pi_JP=2+_M=1_1540_1560	validation_point2	0.0579535	0.0579535	🟢
11	compass_3pi_JP=2+_M=1_1540_1560	validation_point3	0.035384	0.035384	🟢
12	compass_3pi_JP=2+_M=1_1540_1560	validation_point4	0.112218	0.112218	🟢
13	compass_3pi_JP=4+_M=1_1540_1560	validation_point1	0.0205558	0.0205558	🟢
14	compass_3pi_JP=4+_M=1_1540_1560	validation_point2	0.0118184	0.0118184	🟢
15	compass_3pi_JP=4+_M=1_1540_1560	validation_point3	0.0175504	0.0175504	🟢
16	compass_3pi_JP=4+_M=1_1540_1560	validation_point4	0.105833	0.105833	🟢

EXAMPLES

Webpage
[GitHub]

- **models/*.json:** collection
- **docs/*.qmd:** demo



Julia

$\Lambda_c^+ \to pK^-\pi^+$

$\Lambda_b^0 \to pK^-\gamma$

$X \to \pi^-\pi^+\pi^-$

Python

$\Lambda_c^+ \to pK^-\pi^+$c

Cascade amplitude models in json format

The zero version of the model tries to keep the structures as flatt as possible for readability purpose.

Any value in the dictionary can be replaced by string, that corresponds to a key translated later in the file. It enables keeping consistent numerical values for masses, and lineshape parametrizations.

- Detailed description of the format!
- Notes on HS3

Example

A realistic decay description for Lc2pKpi amplitude is produced with `ThreeBodyDecayIO.jl` using the default model of the Lc2ppiK decays, `Lc2ppiKSemileptonicModelLHCb.jl`.

For a description of a three body decay amplitude, one must provide several mandatory section at the root of the object, `"kinematics"`, `"chains"`, `"reference_topology"`, and `"validation"` sections.

Kinematics Overview

The `kinematics` section details the particle states involved in decay processes:

- `initial_state`: Specifies the decaying particle at the start of the process. Contains keys for `index` (unique identifier), `name` (label), `spin` (quantum spin number), and `mass` (in GeV/c²).
- `final_state`: An array detailing each resulting particle from the decay. Each entry includes the same keys as `initial_state`, defining the properties of these particles.

For example, the kinematics of the decay Lc2pKpi would look like,

```
"kinematics": {
    "initial_state" : {
        "index" : 0,
        "name" : "Lc",
        "spin" : "1/2",
        "mass" : 2.28646
    },
```

On this page

Cascade amplitude models in json format

Example

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View source

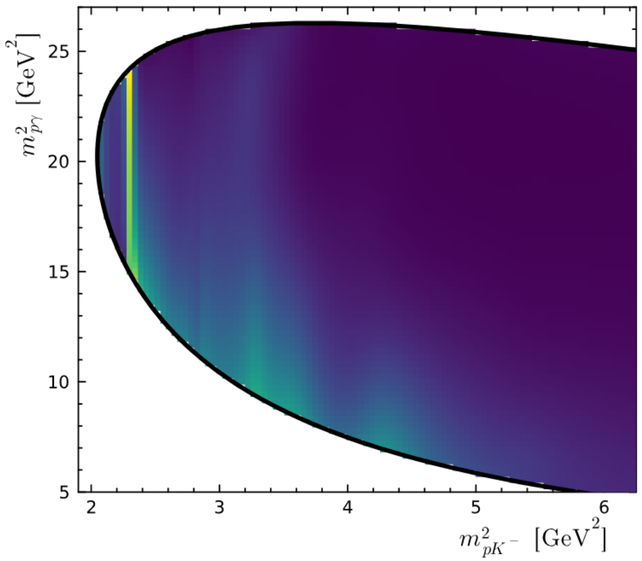
LHCb-PAPER
-2023-036 [3]

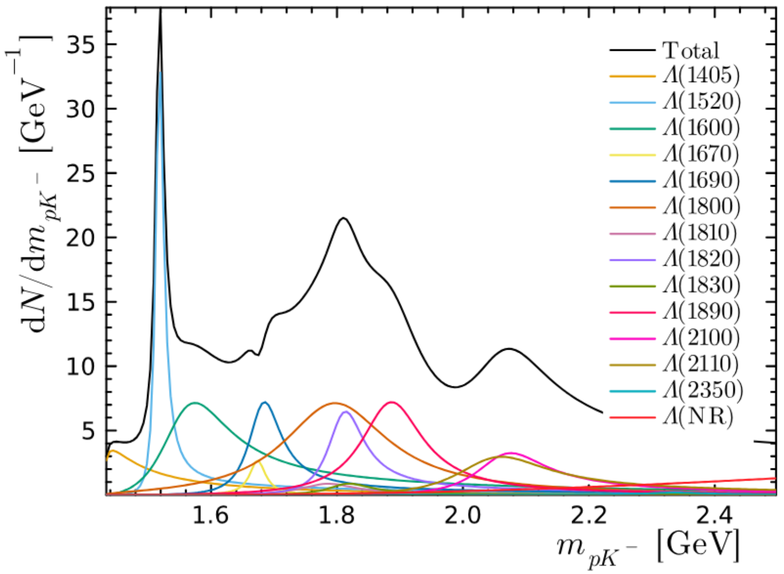
Examples-I

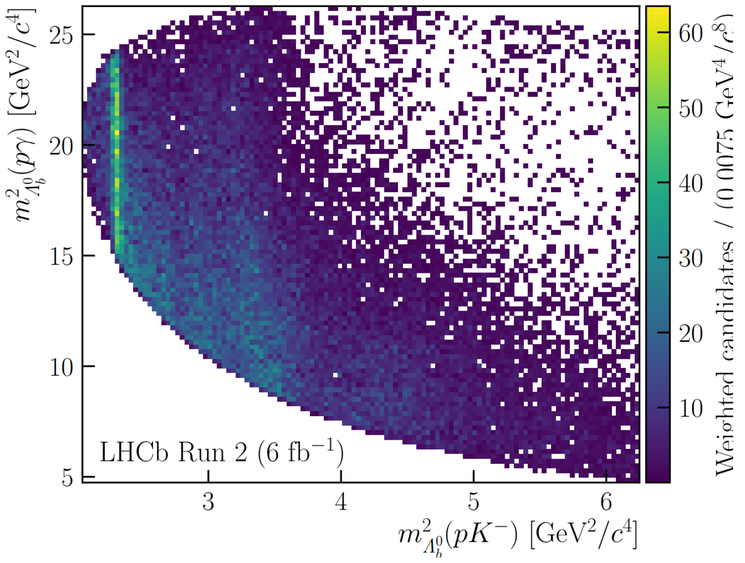
lb2pkg-lhcb-2765817

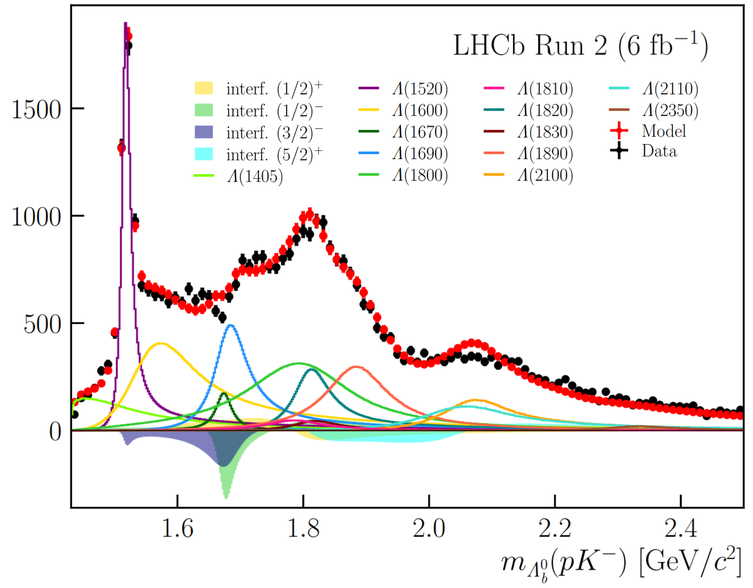
[LHCb-PAPER-2023-036]

- Analysis of Λ baryons in $\Lambda_b^0 \to pK^-\gamma$
- Search for pentaquarks
- 74 decay chains
- orbital momentum <= 6



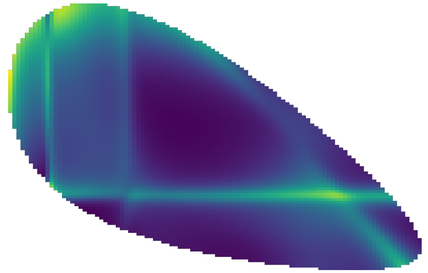


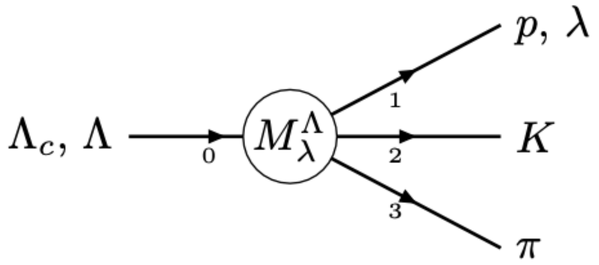




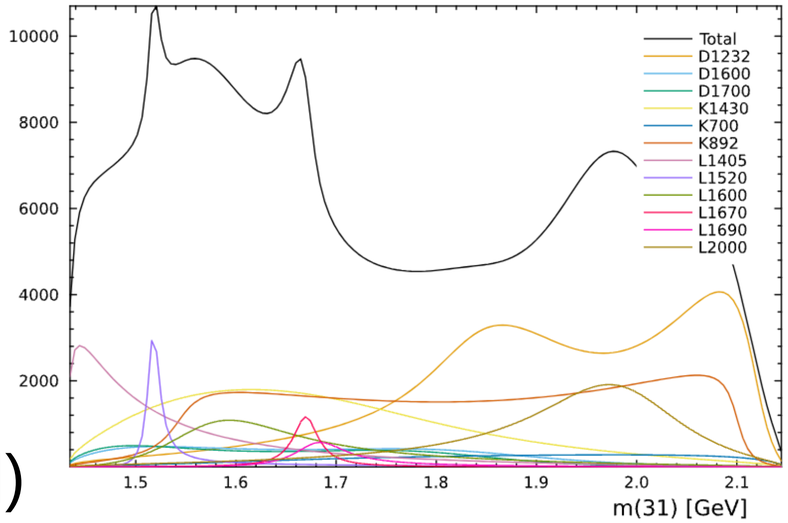
Example-II
lc2pkpi-lhcb-2683025

[LHCb-PAPER-2022-002]
[LHCb-PAPER-2022-044]



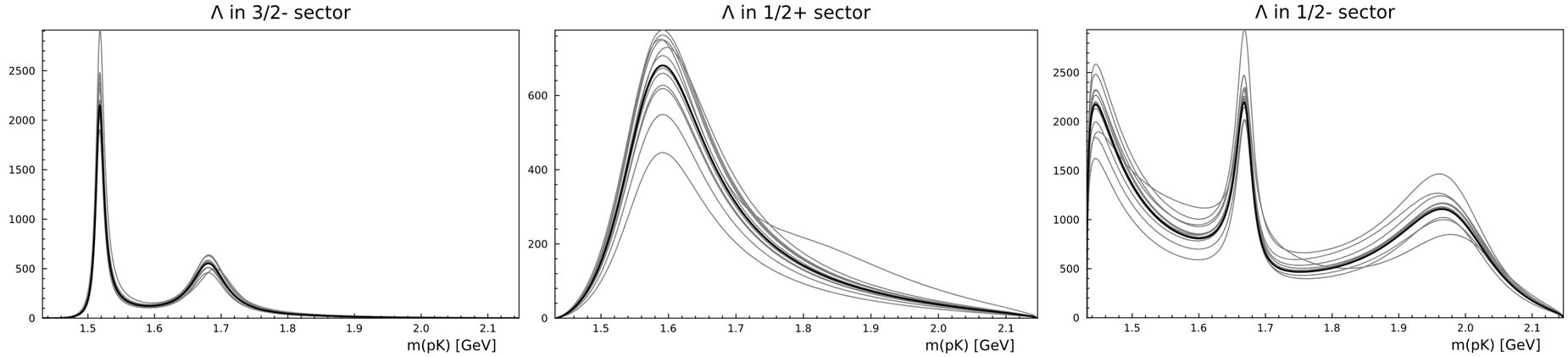


- 800k decays of $\Lambda_c^+ \to pK^-\pi^+$
- 26 decay chains with Λ^{**}, Δ^{**}, and K^{**}



Example of inference:

- model uncertainty (18 alternative models preserved)



Example-III

x2pipipi-compass-1391643

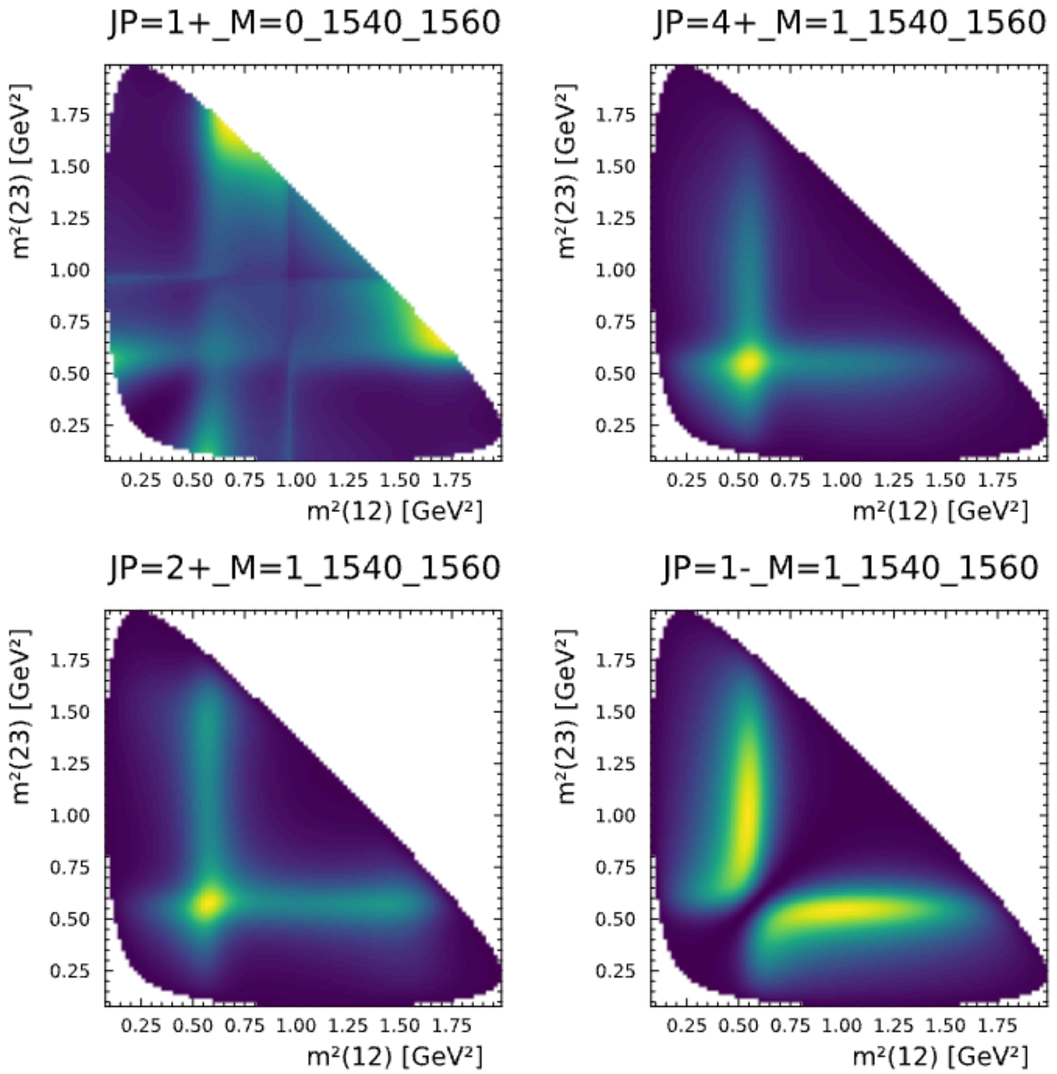
[CERN-PH-EP-2015-233]

- Partial-wave analysis is performed of bins of m3pi x t’ (100 * 10 bins)
- Every analysis contains ~170 chains with JP in [0+, 1-, 1+, ...]
- decay

Dalitz plot

The Dalitz plot shows the probability distribution across two dimensional phase space of the decay. Below the distribution is shown for all models in the file

▶ Dalitz plot plotting



Implementation by frameworks

Reading and writing .json

- Start with three-body decays (~80% of all PWA)
- Working with dynamic languages is simpler (TBDs.jl, ComPWA, TFA2, ...),
- but also possible with static (Laura++, AmpTool, PAWIAN, RootPWA)

- Compatible with HS3 (ROOT)

- ComPWA ✅
- RootPWA 🕒
- AmpTool 🕒
- ThreeBodyDecays.jl ✅
- EvtGen 🌓
- PAWIAN 🕒
- TFA2 🌓
- Laura++ 🕒

(Forecast curtesy Ilya Segal)

EXPLORE. USE. PRESERVE

Internals
GitHub and CI

- GitHub hosts the collection of json files
- Automatic running using Continuous Integration (CI)
- Pixi fixes environment (Python / Julia versions) ()
- Quarto for mixing text and computation (no jupyter)
- Scripts demoing **reading** model description, **visualizing, computing**