

Introduction to the Belle II collaboration and feedback from its analyzers

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on behalf of the Belle II collaboration

Deutsches Elektronen Synchrotron, DESY
Belle II Experiment, KEK



- Users and Developers workshop 2023

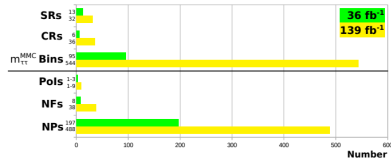
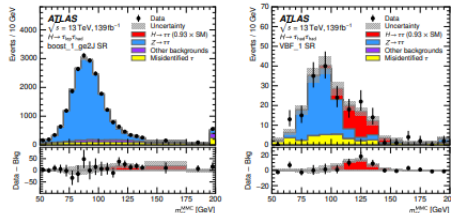


HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES



December 5, 2023

<https://cds.cern.ch/record/2812292>



→ 139 fb⁻¹: >500 model parameters and >1000 terms in likelihood to estimate 1-9 Poles
 → 36 fb⁻¹: complex analysis but 139 fb⁻¹ new level of complexity for the $H \rightarrow \tau\tau$ decay channel
 → Large amount of studies/effort to stabilize and verify likelihood model of 139 fb⁻¹ analysis

Bachelor, Master, PhD done within ATLAS (Freiburg):

- Focus on $H \rightarrow \tau\tau$ (Run 2 data-set)
 - ▶ Fit model/software (based on TRExFitter)

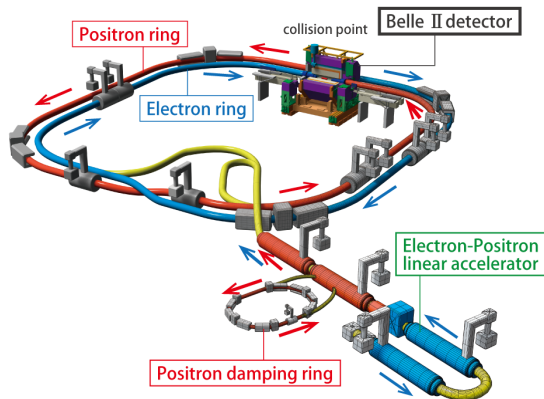
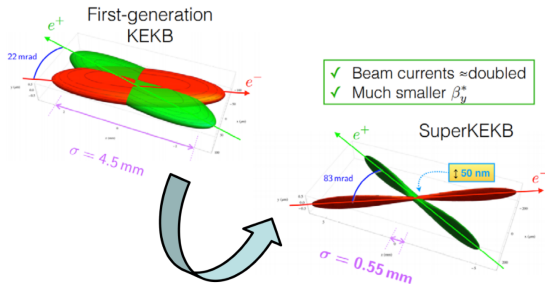
After PhD switched from ATLAS to Belle II (≈ 1.5 y ago)

- τ working group (focus: τ -lifetime)
 - ▶ Bring some in fitting exp. from LHC experiments
 - ▶ Try to bundle and to streamline fitting knowledge/tools
- Hardware project
 - ▶ Involvement into pixel detector upgrade
 - ▶ 5 months of intensive training at DESY
 - ▶ ≈ 9 months local coordination of pixel detector replacement at KEK
- Large focus on hardware until now (back since a few weeks)
 - Upgrade project finished
- Moving forward to new focus: fitting software (esp. in τ group)

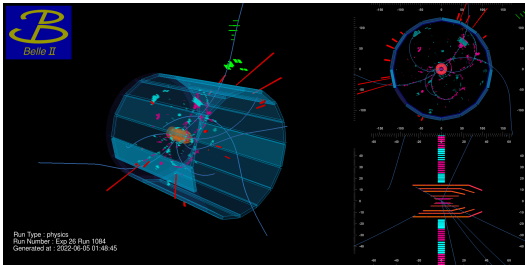
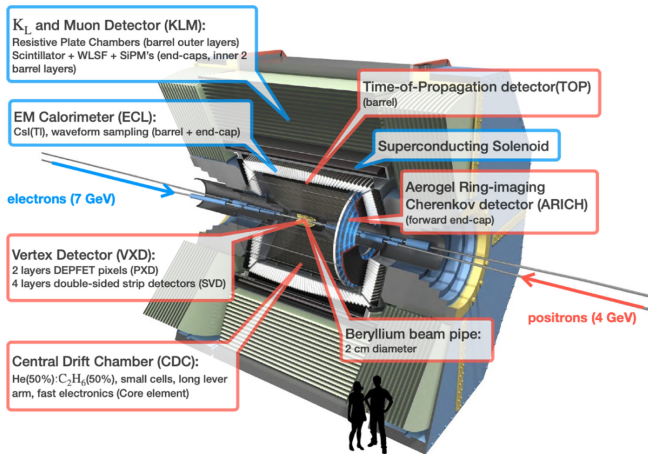
→ Still much more familiar with ATLAS (Higgs) analysis style

→ This talk gives an introduction into the Belle II structure (for me as well)

- Electron (e^-) - positron (e^+) ring accelerator
- Asymmetric beam energies e^+ : 4 GeV, e^- : 7 GeV
- $Y(4S)$ resonance (10.58 GeV) \rightarrow $>99\%$ BB
- Nano beams ($10 \mu\text{m} \times 59 \text{ nm}$) \rightarrow High luminosity
- Just one experiment (Belle II)
- Filling during operations

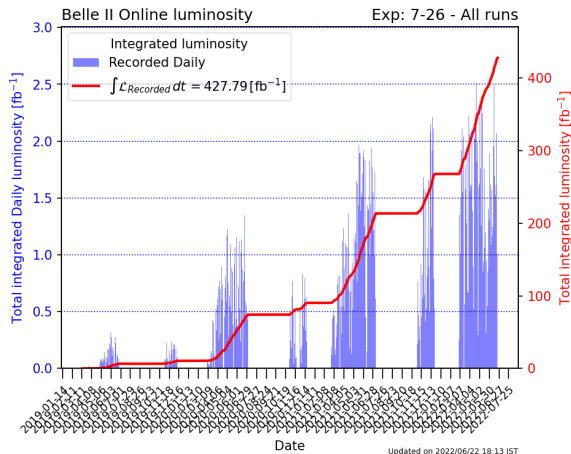


- Asymmetric (FWD \leftrightarrow BWD) detector
 - ▶ 7m diameter and 7.5m length
- Onion shape
 - ▶ Vertex detector
 - ▶ Tracking system + Particle identification
 - ▶ Calorimeter
 - ▶ K_L and muon detector
- Clean event environment
 - Resolves individual pions and photons (no jets)

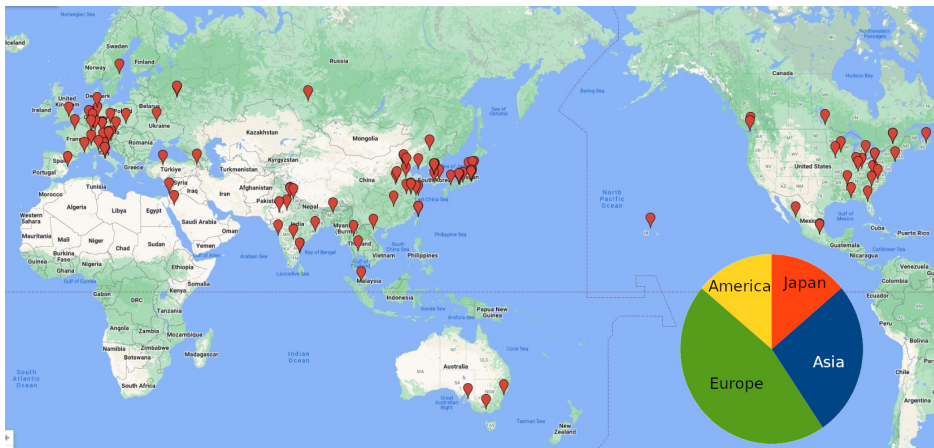


<https://evdisp.belle2.org/>

- Run 1 from 2019-2022
- Integrated luminosity of 428 fb^{-1} recorded
- Largest instantaneous luminosity of $4.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - ▶ World record
 - ▶ Target luminosity $6.4 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
- From 2022 until end of 2023 shutdown
 - ▶ Upgrade and maintenance
 - ▶ Upgrade of pixel detector
 - ▶ Upgrade of interaction beam pipe
 - ▶ Upgrade of beam monitoring
 - ▶ ...
- Start of Run 2 in January 2024
 - ▶ Goal for 2024: 150 fb^{-1} per month



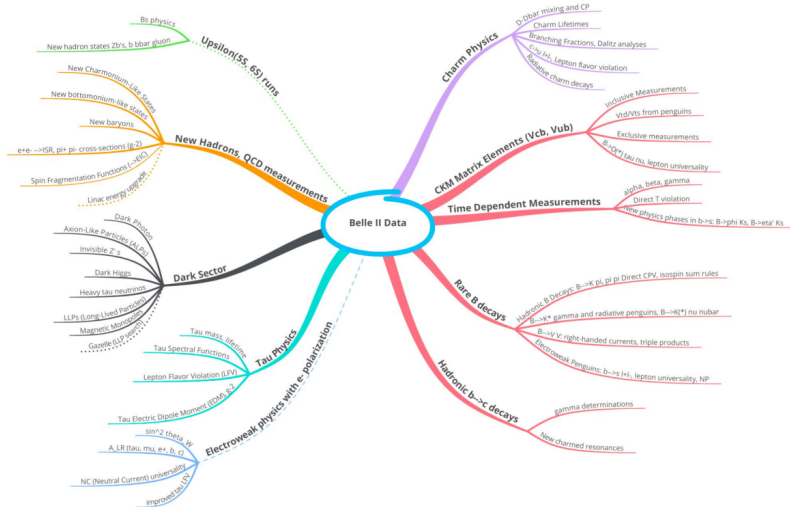
<https://confluence.desy.de/display/BI/Belle+II+Luminosity>



<https://confluence.desy.de/display/BI/Belle+II+Collaboration+Map>

- \approx 1200 members
- 27 countries
- 124 institutions
- Strong contribution from Europe and Japan

- Broad physics program
- 8 working groups
 - ▶ Semileptonic & Missing Energy Decay
 - ▶ Radiative & Electroweak Penguin
 - ▶ Time Dependent CP Violation
 - ▶ Hadronic B decays
 - ▶ Quarkonium
 - ▶ Charm
 - ▶ Low Multiplicity & Dark Sector
 - ▶ τ -lepton
- ≈ 30 published analyses (>20 in 2023, goal 40-50 per year)
- ≈ 100 ongoing analyses
 - ▶ Most often 1-2 persons per analyses



<https://confluence.desy.de/display/BI/Belle+II+Collaboration+Map>



- Basf2 framework for all aspects in data-processing

- ▶ Generating simulated data
- ▶ Unpacking of real raw data
- ▶ Reconstruction (tracking, clustering, ...)
- ▶ High-level analysis recon. (vertex-fitting, applying cuts, ...)

- Basf2 is not normally used for the offline analysis steps

- ▶ Histogramming
- ▶ Fitting
- ▶ ...

- Basf2 provides documentation for all Belle II software

- ▶ Section for offline analysis as well
- ▶ Section for fitting still empty
→ Maybe input from pyhf-developers?



basf2 light-2309-munchkin documentation

Search the docs ...

1. What's New
2. Installation and Setup
3. Beginners' tutorials
4. Command Line Tools
5. Belle II Python Interface
6. List of Core Modules
7. Analysis
8. B2Bill
9. Belle II File Format
10. MVA package
11. Skims
12. Fitting training
13. Software development
14. How to document your code with Sphinx



Belle II Software Documentation

This document contains documentation of the Belle II software, its command line tools and the Python programming interface.

Note

Generated on Oct 11, 2023 for release light-2309-munchkin, commit f91695aba.

In case of questions regarding the Belle II software or for additional information, please check [Belle II Questions](#).

Tip

If you are new to the Belle II software, you should start with a series of lessons that get you started:

- 1. What's New
- 2. Installation and Setup
 - 2.1. Setup of the Belle II Software
 - 2.2. Belle II Software Tools
 - 2.3. Local Installation
- 3. Beginners' tutorials
 - 3.1. Welcome!
 - 3.2. Fundamentals
 - 3.3. Software Prerequisites

3.5. Offline analysis

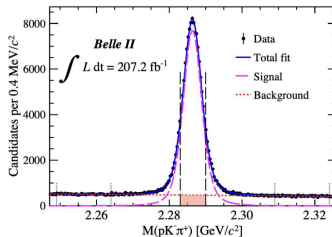
This chapter describes how to do offline analysis. We introduce root-based and pandas-based pipelines. We should include fitting here. Analysis reproducibility also goes here. Besides, a generic tool for the event type analysis of inclusive MC samples is involved here.

- 3.5.1. ROOT
 - RDataFrames
 - Functionality for data analysis
 - Experimental new feature: Systematic variations
 - Interoperability
 - Inspection
 - Scaling up
- 3.5.2. Dask
- 3.5.3. Fitting
- 3.5.4. Reproducibility
- 3.5.5. Topology analysis
 - Introduction
 - Basics of the program
 - Install the software
 - Get the input data
 - Prepare the card file
 - Run the program
 - Exercises

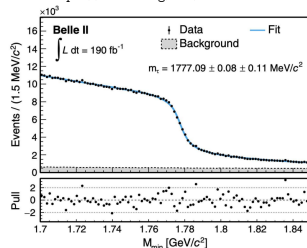
<https://software.belle2.org/light-2309-munchkin/sphinx/index.html>

- Basf2 provides root-files
- Most analysis transform these into other formats
 - ▶ Most common pandas data-frames stored in pickle, parquet, ...
- Analysis frameworks fully based on python (Some exception for "older" users)
- Many analysis use jupyter notebooks

<https://arxiv.org/abs/2206.15227>

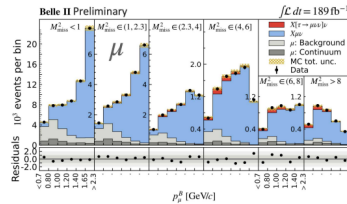
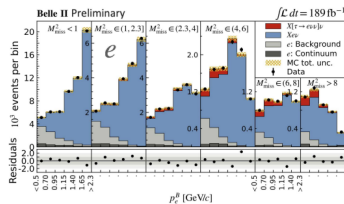


<https://arxiv.org/abs/2305.19116>



Various fitting models:

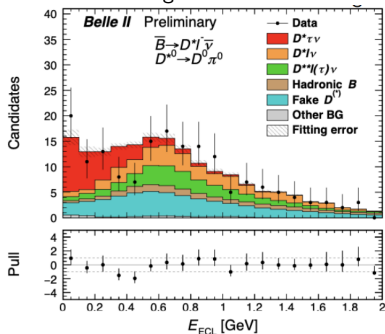
- Unbinned likelihood fits
- Binned likelihood fits
 - ▶ Single (multi)-poi
 - ▶ Template based (E.g. Set of diff. models)
 - ▶ ≈ 50 ongoing analysis use binned fits
 - ▶ ≈ 15 ongoing analysis use pyhf



<https://arxiv.org/abs/2311.07248>

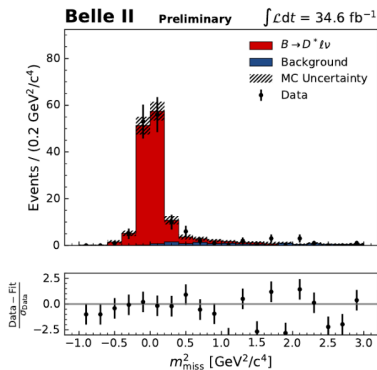
- Low stat. measurements (searches)
- High stat. precision measurements
- Signal region can be very pure ($\gg 90\%$)

Signal: red



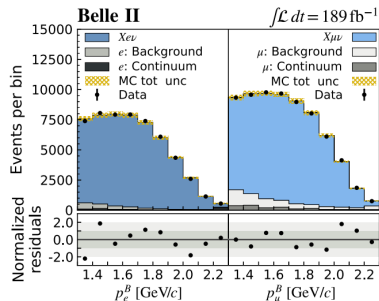
<https://docs.belle2.org/record/3943>

Signal: red



<https://arxiv.org/abs/2008.10299>

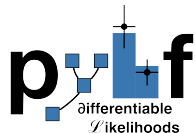
Signal: blue



<https://doi.org/10.1103/PhysRevLett.131.051804>

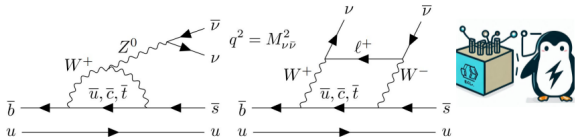
Various different fitting frameworks in use:

- zfit (+hepstats)
<https://zfit.readthedocs.io/>
<https://scikit-hep.org/hepstats/>
- BinFit (self developed)
<https://github.com/ianhbell/binfit>
- RooStats (HistFactory)
https://root.cern/doc/master/group__Roostats.html
https://root.cern/doc/master/group__HistFactory.html
- pyhf (+cabinetry)
<https://pyhf.readthedocs.io>
<https://cabinetry.readthedocs.io>
- ...



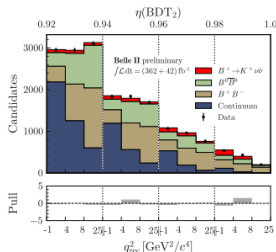
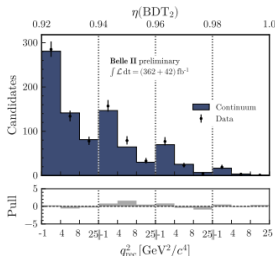
$B^+ \rightarrow K^+ \bar{\nu} \nu$ (<https://arxiv.org/abs/2311.14647>)

- Flavour-changing neutral current process
- Known with high accuracy in the SM
- Extensions beyond SM may lead to sig. rate increase
 - ▶ (Scalar) leptoquarks
 - ▶ Axions
 - ▶ Dark-sector mediators
- Interesting interplay of $B^+ \rightarrow K^+ \bar{\nu} \nu$ and $B^+ \rightarrow K^* \bar{\nu} \nu$ (Common explanations of $R(D^{(*)})$, μ g-2 anomalies?)



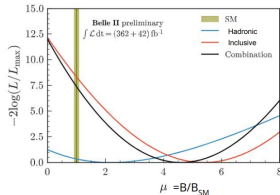
Inclusive and hadronic tagging analyses:

- Small overlap \rightarrow combination
- Use two-dimensional signal and control region
 - ▶ Squared mass of the neutrino pair and BDTs
 - ▶ 174 bins
 - ▶ 63 nuisance parameters
- One of most complex models I have seen so far in Belle II
- Extensive background and systematic studies



Talk by Sasha Glazov (<https://indico.desy.de/event/41728/contributions/154056/attachments/86905/>)

Combination of the inclusive and hadronic tag



Full pyhf model of the data will be released when paper is accepted by the journal

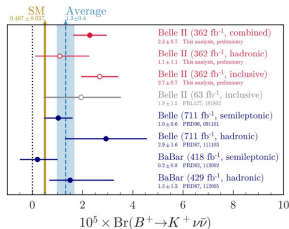
Inclusive and hadronic measurements are combined, taking into account common correlated uncertainties. The resulting branching fraction is

$$B_{\text{comb}}(B^+ \rightarrow K^+ \nu \bar{\nu}) = (2.3 \pm 0.7) \times 10^{-5} = [2.3 \pm 0.5(\text{stat})^{+0.5}_{-0.4}(\text{syst})] \times 10^{-5}$$

Significance of **observation** is 3.5σ the result is within 2.7σ vs standard model

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Comparison with other measurements



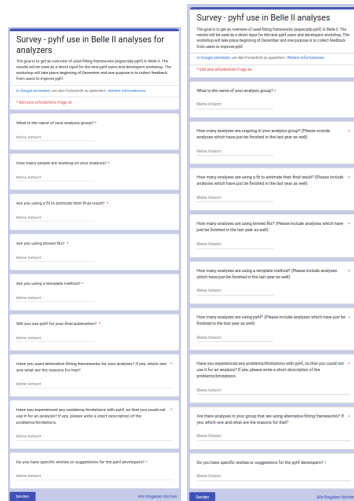
- Belle reports upper limits only: for this comparison branching fractions are computed using published number of events and efficiency
- Inclusive result has comparable accuracy to previous best measurements, hadronic tag is the best among hadronic tag measurements
- Some tensions between inclusive and semileptonic results for Belle and BaBar, however overall compatibility of the results is good with $\chi^2/\text{dof} = 5.6/5$

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- Fit for both analyses separated and combined performed
- 3.5σ evidence for combined BR and 2.7σ larger than SM BR
- Compatibility with old measurements: $\chi^2/\text{dof} = 5.6/5$
- Combination with old measurements: $\approx 2\sigma$ larger than SM BR
- After paper is accepted by journal full pyhf model will be released

- Feedback from Belle II community
- Collected via anonymous survey
 - ▶ One survey for group conveners
 - ▶ One directly for analyzers
- Feedback is just sorted and summed up
 - ▶ Not the opinion/feedback of the speaker
 - ▶ Not checked/cleared if some suggestions are already available in pyhf
 - If so maybe the functionality should be more highlighted in documentation
- Less feedback than hoped (<10 analyzers)
 - With a bit more time maybe possible to get more feedback by contacting individual analyses

→ Open to discuss individual points during a coffee



Survey - pyhf use in Belle II analyses for analyzers

The goal is to get an overview of your fitting frameworks (especially pyhf) in Belle II. The results will be used as a direct input for the next pyhf user and developer meetings. The workshops will take place beginning of December and one purpose is to collect feedback from users to improve pyhf.

[In English, available on the French site as well.](#) [Belle II Information](#)

[*Make sure you're logged in](#)

What is the name of your analysis group? *

Mini Answer

How many people are working on your analysis? *

Mini Answer

Are you using a fit to estimate their final result? *

Mini Answer

Are you using binless fit? *

Mini Answer

Are you using a template method? *

Mini Answer

Will you use pyhf for your final publication? *

Mini Answer

Have you used alternative fitting frameworks for your analysis? If yes, which one and what are the reasons for that? *

Mini Answer

Have you experienced any problems/limitations with pyhf, so that you could not use it for an analysis? If yes, please write a short description of the problems/limitations.

Mini Answer

Do you have specific wishes or suggestions for the pyhf developers? *

Mini Answer

[Send](#) [via English Server](#)

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What is the name of your analysis group? *

Mini Answer

How many analyses are ongoing in your analysis group? (Please include analyses which have just been finished in the last year as well)

Mini Answer

How many analyses are using a fit to estimate their final result? (Please include analyses which have just been finished in the last year as well)

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Are there analyses in your group that are using alternative fitting frameworks? If yes, which one and what are the reasons for that? *

Mini Answer

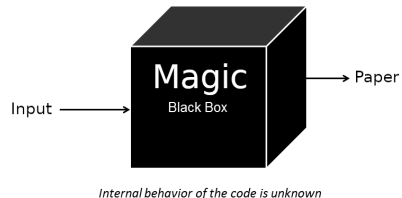
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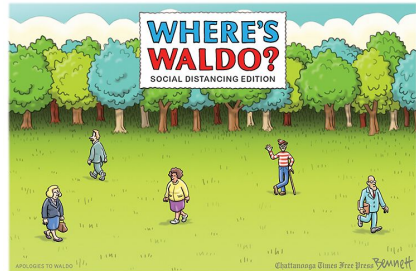
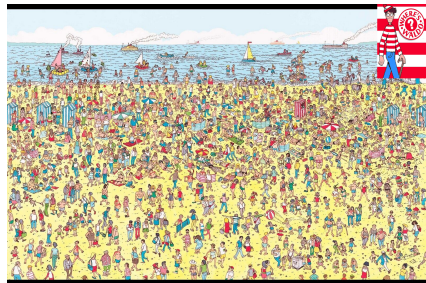
Feedback to functionalities:

- Support of multi-Pol fits
- Arbitrary functional constraints between parameters
- Functionality of grouped impact calculations
- Pruning of stat. error (bin-by-bin pruning)
- Plotting functionality
 - ▶ E.g. pre-/post-fit plots out of the pyhf model
- Use of smooth analytic PDFs along with histogram templates
 - ▶ E.g. Bkg data-driven (poly. fit) and signal modeled as histograms
- Integrate pyhf and zfit to build more complicated likelihoods
- Separate the hypotest and inference part (use of hepstats)
- Accelerate development of cabinetry
- Extend cabinetry to other input formats (pandas data-frames or python histograms)



Feedback to documentations and examples:

- Some documentation/introduction to asymmetric uncertainties
 - ▶ Good/Bad work examples
- More information for the correct procedure for toys
 - ▶ Suggestions how to deal with non closure
- Template fit examples
- How to define a Pol based on template interpolation
- Example of implementation of several systematic uncertainties
 - ▶ In general some examples of more advanced config files / analysis
- Examples of fit validation studies
- Include some of the outreach tutorial as examples, hard to find in all of the talks/tutorial the right example (sort them more by topic)



SuperKEKB and Belle II:

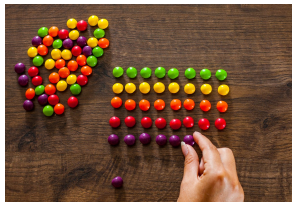
- Integrated luminosity of 428 fb^{-1} recorded
- Largest instantaneous luminosity of $4.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Target luminosity $6.4 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
- Belle II and SuperKEKB upgraded and maintained during long shutdown
- Run 2 in January 2024: 150 fb^{-1} per month
- ≈ 1200 members in 27 countries



Belle II analyses:

- ≈ 30 published papers but >20 in 2023
- ≈ 100 ongoing analyses and start of new data taking period this winter
- ≈ 50 using binned likelihood models \rightarrow 15 using pyhf
- Pyhf gets more and more to a standard tool in Belle II analyses
 - ▶ Still very separated efforts and no common development

- Clearly feedback shows that there is interest in pyhf and cabinetry
 - ▶ Many features of both seems not to be known in Belle II
 - ▶ Troubles to find functionalities and/or examples?
 - Collect talks/examples in a way which is more sorted by topics?
(Great examples shown at this workshop!)
- Especially τ and Semileptonic & Missing Energy Decay working groups show interest in pyhf
- Summary talk of this workshop in a common analysis tools meeting
- Start of a more combined effort to incorporate pyhf into Belle II software?!
 - Existing features and examples will be more known in Belle II



Backup