



Public analysis of Belle II Data

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For the Belle II collaboration

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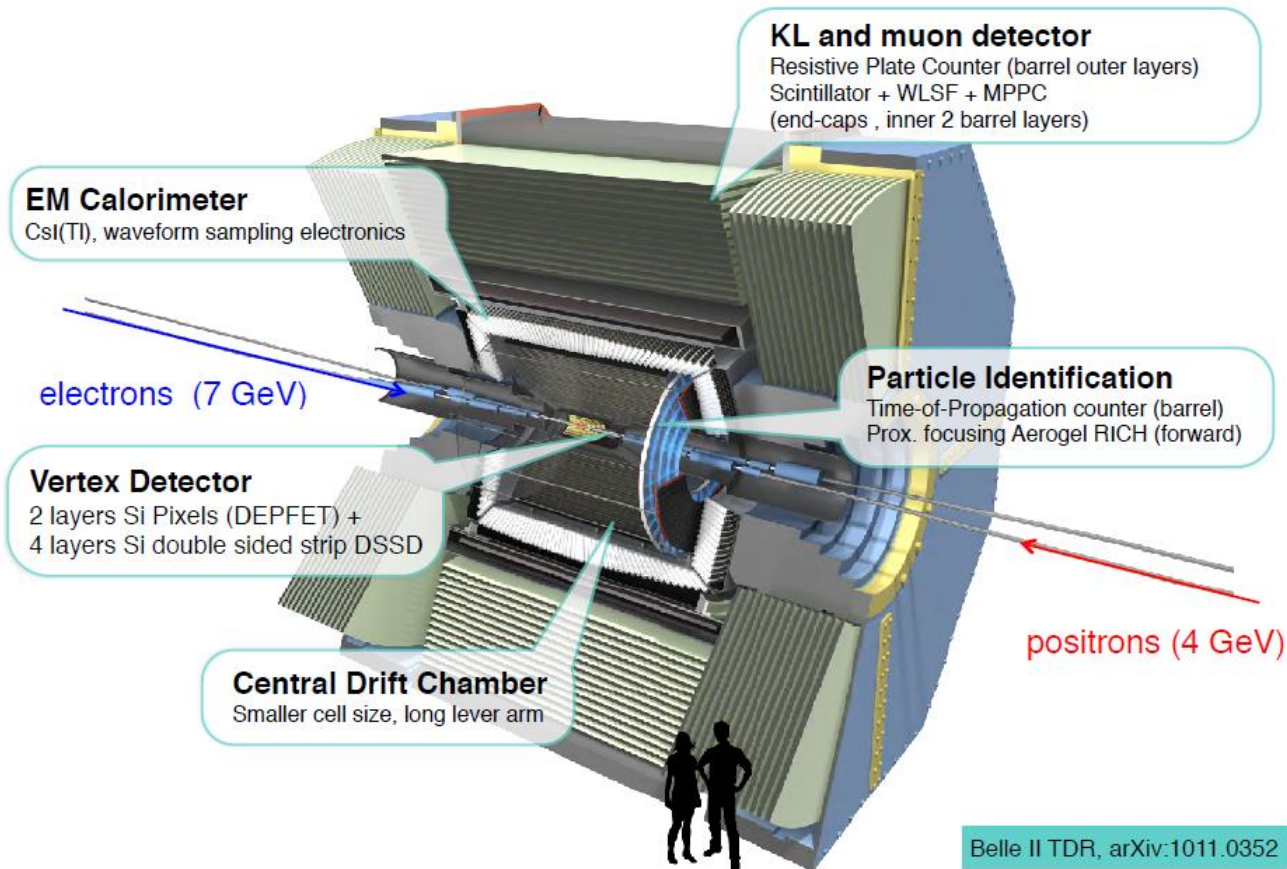
²*Virginia Tech, Blacksburg, USA*

Contents

- Introduction – Belle II experiment
- Dissemination
- Design
- Implementation of interface
- Usage

Belle II experiment

Study of rare decays of B, D and τ



Dissemination of our work

Disseminate our knowledge to the general public

- What are we doing ?
- How does the Belle II detector look like?
- What are our research methods?
- What do we expect to see?
- What are our results?

Audience

- students of physics
- high school students
- primary school students
- general public (assume finished high school)

How do we do it?

Exercises at a different level of complexity

Make **part of the data** available to the public + **Graphical user interface**

Graphical user interface generates pseudocode which runs the analysis in the backend

- user friendly
- expose physics of particles
- minimize the starting errors made during coding

Educational app which can be used on the web and also runs on the PC

Web version runs on a single web server

- enables access to everyone

Virtual appliance with data and the software pre-installed

- allows download → for schools & workshops

Our approach

Data sample: Belle data, in 2019, switch to Belle II data

Several exercises:

- spectroscopy examples
- Based on the feedback and our experiences we will extend it later with more complex examples.

Design the exercises to be used by larger groups of people

Underlying code based on Belle educational B-lab exercises:

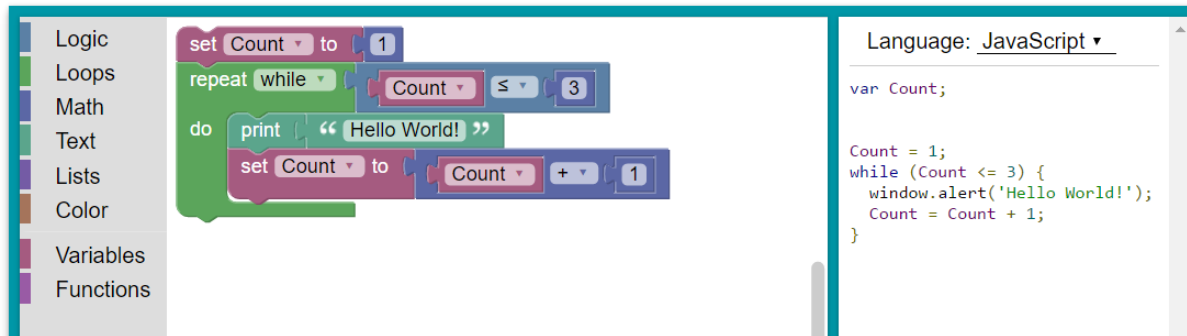
<http://belle.kek.jp/b-lab/b-lab-english/>

Web interface

The graphical user interface based on Blockly -

Design

Based on a Blockly google graphical library <http://developers.google.com/blockly/>



Inspired by MIT Scratch
<https://scratch.mit.edu>

User describes a decay by blocks:

- Blockly JavaScript generates JSON text strings
- The strings are sent to the server
- Converted into the computer code ROOT macro
- The code is executed on the server
- histograms are sent back to the client
- displayed using JSROOT JavaScript.

```
{ "analysis": { "neve": "50000", "first": "0", "print": "0", "datasource": "2", "list": { "combiner": { "list1": { "selector": { "list1": "", "charge": "-1", "pid": "PION", "histogram": { "h1d": { "varname": "GetMass", "name": "pion Mass", "nbins": "100", "min": "0", "max": "1" } } }, "list2": { "selector": { "list1": "", "charge": "1", "pid": "PION", "histogram": "" } }, "sameparticles": "0", "pid": "KAON", "m0": "0", "m1": "1", "histogram": { "h1d": { "varname": "GetMass", "name": "pipi Mass/GeV/c;N", "nbins": "400", "min": "0", "max": "1" } } } } }
```



```
.L BParticle.cc+ .L BEvent.cc+ .L Blab2.cc void Blab2::event(){ combiner(selector(-1,-1,PION,0,2),selector(-1,1,PION,-1,3),0,KAON,0,1,1,1); } void Blab2::Init(){ fNeve=50000; fNfirst=0; fData=2; fPrint=0; h1d("GetMass","pipi Mass/GeV/c;N",400,0,1,1); h1d("GetMass","pion Mass",100,0,1,0); plist(1); plist(2); plist(3); } Blab2 *blab2 = new Blab2();
```

Visual programming environment

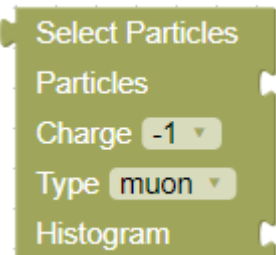
The screenshot shows a web browser window at `belle2.ijs.si/masterclass/`. The page title is "Belle II Masterclass: Describe process → Run analysis → Fit results → Save/load process locally". Below the title are four blue buttons: "Run Analysis", "Interrupt", "Save Diagram", and "Load Diagram". A progress bar below the buttons shows a value of 0. The main workspace is a grid with a blue dialog box titled "Belle II Masterclass" containing the following settings:

- Number of events: 10000
- First event: 0
- Data Source: hadron-1
- Print particle list?: No
- Particle List

On the left side of the workspace, there is a sidebar with the labels "Particles", "Analysis", and "Variables". At the bottom of the browser window, the address bar shows `belle2.wrl` and `BelleII_Slide.key`, along with a "Show all" button.

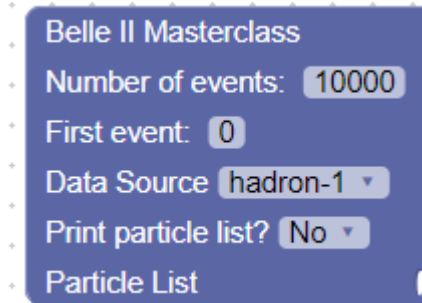
Basic blocks

Limited number of blocks:



Select Particles
Particles
Charge
Type
Histogram

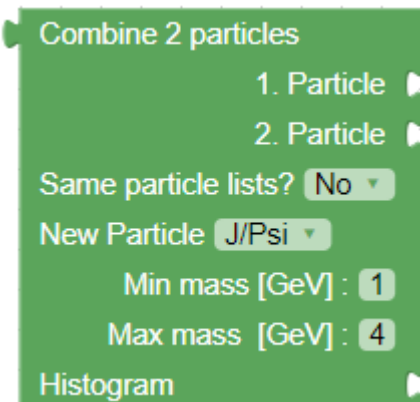
Select particle type
for analysis and
append histogram for
plotting the
properties



Belle II Masterclass
Number of events:
First event:
Data Source
Print particle list?
Particle List

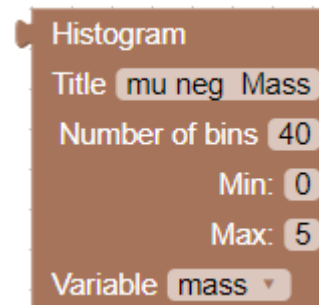
**Define main analysis
parameters**

- Number of events to process
- First event to process
- Data Source
- Print particle list for first 100 events
- Particle list to process/
by default the list from
the file is used



Combine 2 particles
1. Particle
2. Particle
Same particle lists?
New Particle
Min mass [GeV] :
Max mass [GeV] :
Histogram

Make a combination
of particles from two
lists



Histogram
Title
Number of bins
Min:
Max:
Variable

Plot a distribution

Define a range and
a variable to plot

Particle list

- Without any connected blocks the particle list is listed if only a main block is included in the sketch

Belle II Masterclass

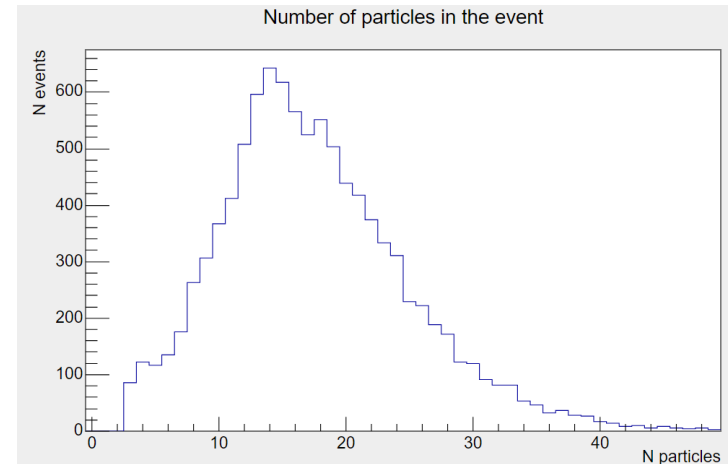
Number of events: 10000

First event: 0

Data Source hadron-1

Print particle list? Yes

Particle List



Primary particle list for Event 1

| N | px(GeV/c) | py(GeV/c) | pz(GeV/c) | p(GeV/c) | Energy(GeV) | Charge | ID |
|----|------------|-------------|-----------|-----------|-------------|--------|----------|
| 1 | -0.99205 | 0.255215 | -0.298016 | 1.06682 | 1.06682 | -1 | electron |
| 2 | 0.379417 | 0.416063 | 0.292391 | 0.634475 | 0.634475 | -1 | electron |
| 3 | 0.448819 | 0.279332 | 0.857395 | 1.00727 | 1.01689 | 1 | pion |
| 4 | -0.381274 | 0.317797 | 0.666425 | 0.830956 | 0.842596 | -1 | pion |
| 5 | -0.404262 | 0.0618774 | 0.419536 | 0.58589 | 0.602285 | -1 | pion |
| 6 | 0.0363708 | -0.337713 | 0.696636 | 0.775032 | 0.787499 | 1 | pion |
| 7 | -0.125205 | 0.251112 | 0.201202 | 0.345276 | 0.372418 | -1 | pion |
| 8 | 0.111522 | 0.10243 | 0.139017 | 0.205559 | 0.248464 | 1 | pion |
| 9 | 0.0599534 | 0.0198644 | 0.0726116 | 0.0962364 | 0.169532 | -1 | pion |
| 10 | -0.0335806 | 0.0421883 | 0.0666954 | 0.0857659 | 0.163816 | 1 | pion |
| 11 | 0.180846 | -0.00941455 | 0.265317 | 0.321227 | 0.321227 | 0 | photon |
| 12 | 0.354789 | 0.0498766 | 0.227253 | 0.424272 | 0.424272 | 0 | photon |
| 13 | 0.393443 | -0.310244 | 0.28901 | 0.578425 | 0.578425 | 0 | photon |
| 14 | 0.254512 | -0.0893971 | 0.113315 | 0.29259 | 0.29259 | 0 | photon |
| 15 | 0.152624 | -0.0325375 | 0.296991 | 0.335494 | 0.361627 | 0 | pion |
| 16 | 0.650451 | -0.401558 | 0.403939 | 0.864582 | 0.875054 | 0 | pion |

Combine the blocks

The particle lists for each event are stored in an ROOT tree.

By combining different blocks the event loop is generated. Inside the loop, new particle lists can be generated by combining the existing lists.

Distribution of different particle quantities can be plotted

Plot different variables :

- mass,
- momentum,
- energy,
- charge,
- identity,
- px,py,pz,pT
- cos(theta),
- theta

Belle II Masterclass

Number of events: 10000

First event: 0

Data Source hadron-1

Print particle list? No

Particle List

Select Particles

Particles

Charge Any

Type all particles

Histogram

Histogram

Title All particles;cos(polar angle);N

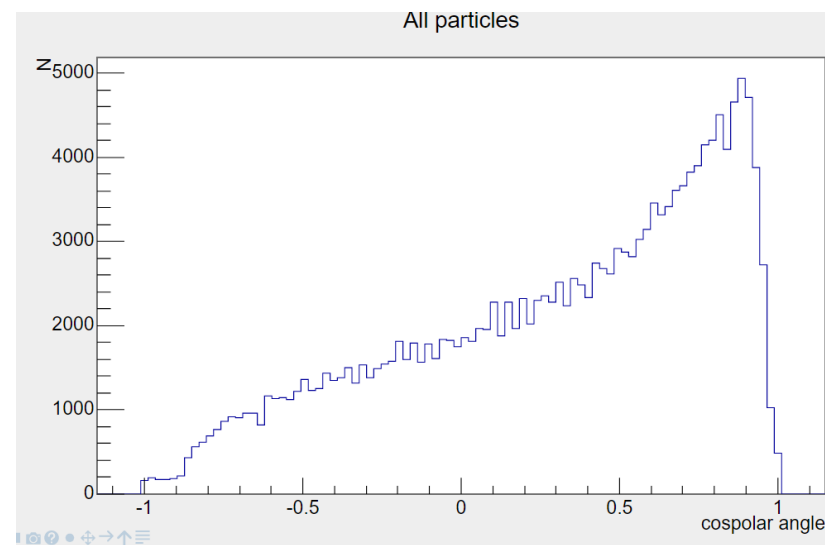
Number of bins 100

Min: 5

Max: 5

Variable cos(polar ang.)

Fixed block connectors
minimize coding errors



Decay to two particles

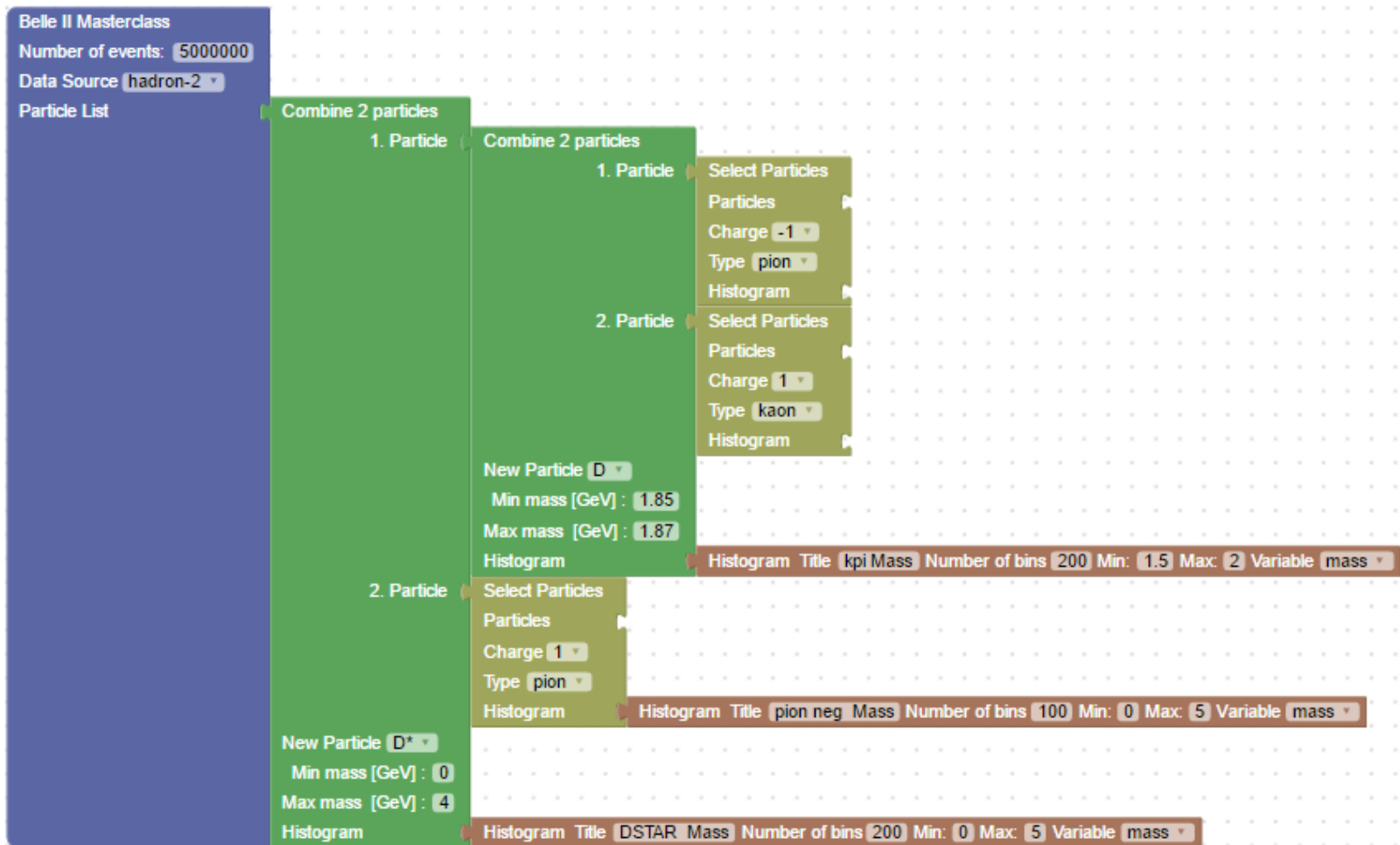
Belle II Masterclass: Define process → Analyse data → Visualise results → Save/load process locally

Run Analysis Interrupt Switch between Diagram and Results Save Diagram Load Diagram

0

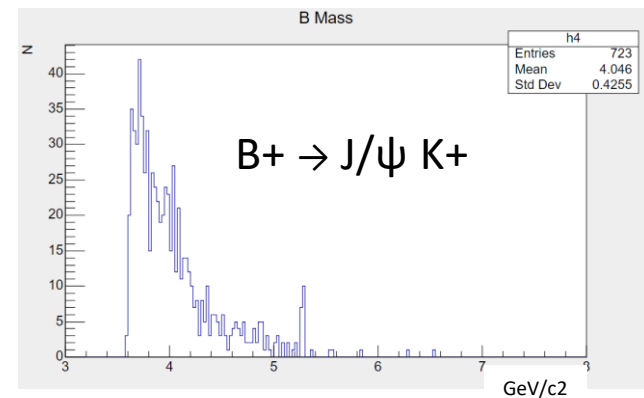
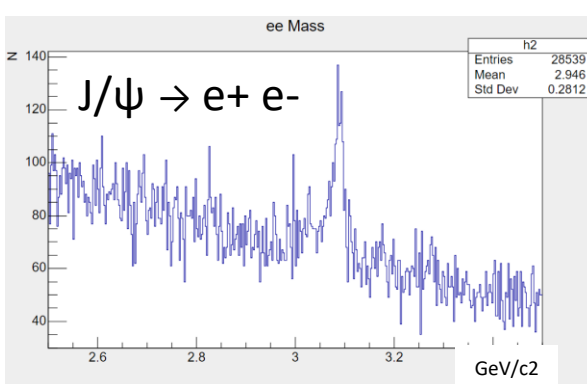
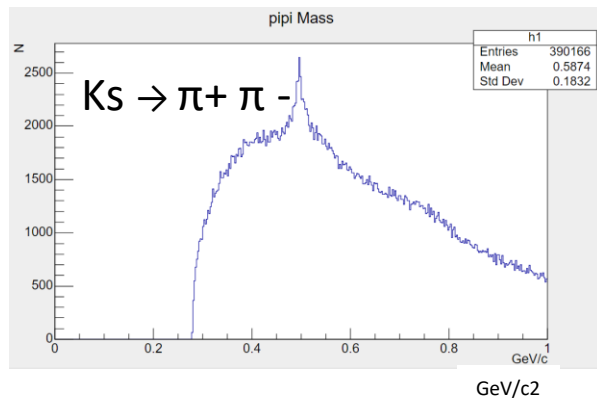
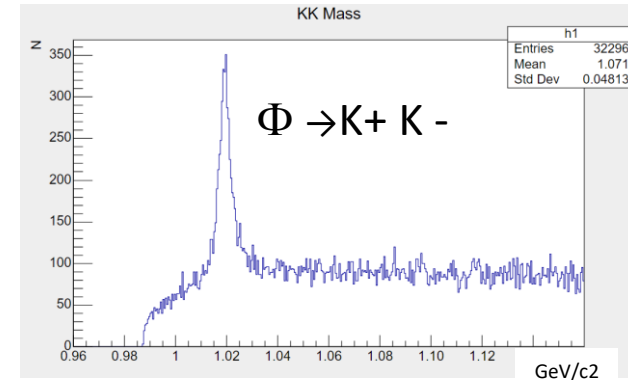
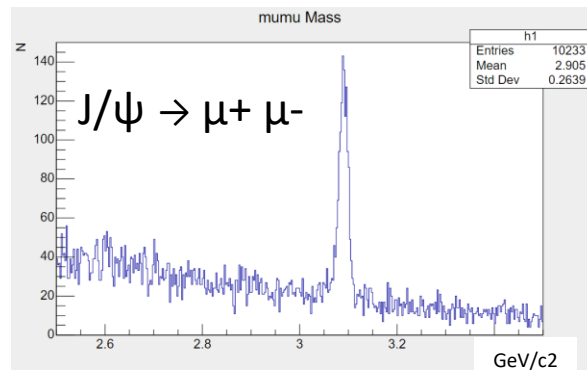
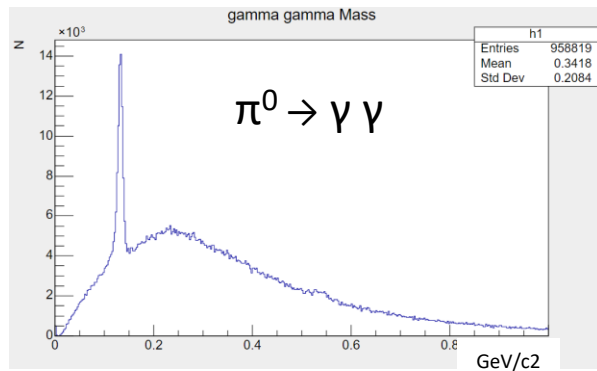
The screenshot shows the Belle II Masterclass software interface. On the left, there is a sidebar with 'Particles', 'Analysis', and 'Variables'. The main workspace contains a workflow diagram on a grid. The workflow starts with a blue box labeled 'Belle II Masterclass' containing 'Number of events: 50000', 'Data Source: hadron-2', and 'Particle List'. This is followed by a green box labeled 'Combine 2 particles'. This box has two inputs, '1. Particle' and '2. Particle', each connected to a 'Select Particles' block. Each 'Select Particles' block has 'Particles', 'Charge: 0', and 'Type: photon' settings. Below the 'Combine 2 particles' box is a 'New Particle' block with 'pion' selected, 'Min mass [GeV]: 0.001', and 'Max mass [GeV]: 1'. This is followed by a 'Histogram' block with 'Title: ppi Mass; GeV/c; N', 'Number of bins: 400', 'Min: 0', 'Max: 1', and 'Variable: mass'. On the right side of the workspace, there are zoom controls (a magnifying glass, a plus sign, and a minus sign) and a trash icon.

Combination of three particles



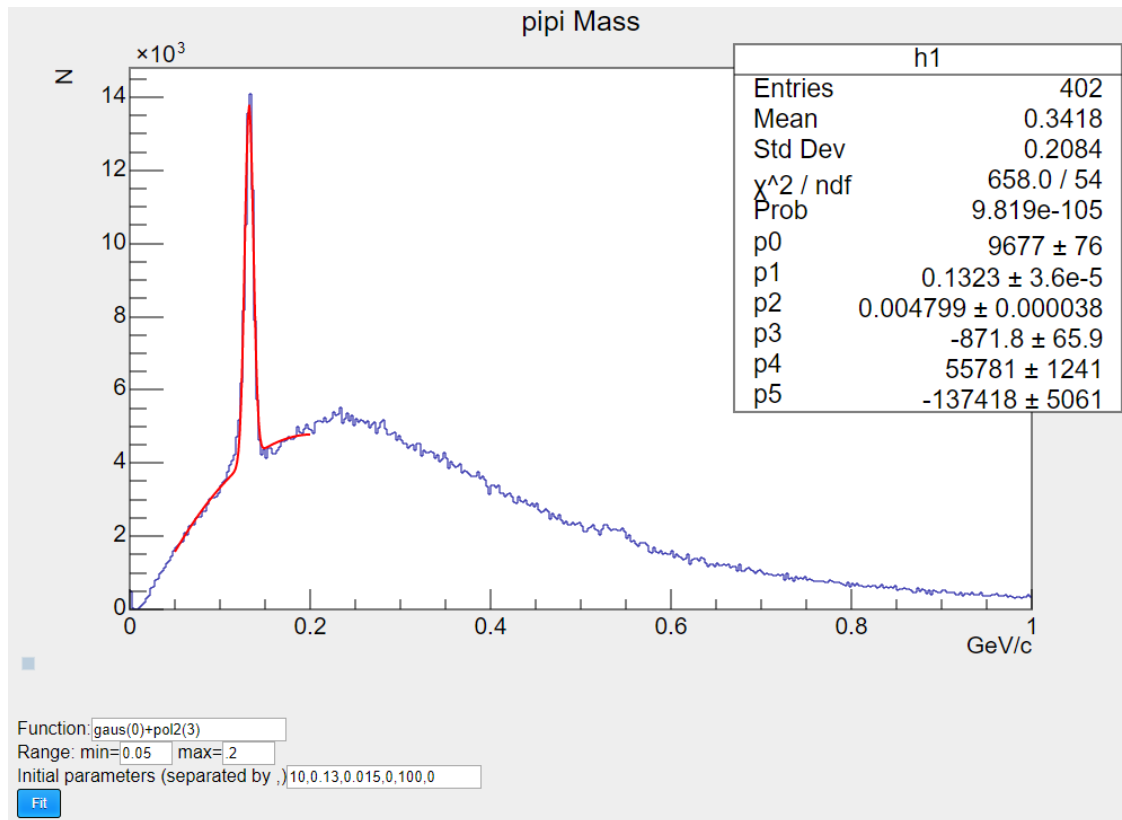
Different decays

Invariant mass plots for different decays



Advanced level

A resulting panel offers the possibility to **fit a resulting distribution** with a ROOT function and calculate width and number of events in the peaks



Worksheet

Exercise table with the list of decays to examine

| Particle | | Proces | Mass (GeV/c ²) | Number of entries | Number of detected particles | Probability | Decay width (GeV) |
|-----------------|--|---|-------------------------------|----------------------|------------------------------------|-------------|-------------------------|
| π^0 | $\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$ | $\pi^0 \rightarrow \gamma\gamma$ | | | | | |
| Ks | $\frac{1}{\sqrt{2}}(ds\bar{s} + \bar{d}s)$ | $K_s \rightarrow \pi^+ \pi^-$ | | | | | |
| ϕ | $s\bar{s}$ | $\phi \rightarrow K^+ K^-$ | | | | | |
| J/ψ | $c\bar{c}$ | J/ψ → e ⁺ e ⁻ | | | | | |
| | | J/ψ → μ ⁺ μ ⁻ | | | | | |
| D ⁰ | $c\bar{u}$ | D ⁰ → K ⁺ π ⁻ | | | | | |
| | | D ⁰ → K ⁻ π ⁺ | | | | | |
| D ^{*+} | | D ^{*+} → D ⁰ π ⁺ | | | | | |
| D ^{*-} | $d\bar{c}$ | D ^{*-} → D ⁰ π ⁻ | | | | | |
| B ⁺ | $u\bar{b}$ | B ⁺ → J/ψ K ⁺ | | | | | |
| B ⁻ | $\bar{u}b$ | B ⁻ → J/ψ K ⁻ | | | | | |

Conclusions

Part of the Belle II data will be publically available

Simple interface has been designed for analysis, which allows

- To combine different particles together
- To plot different distributions
- To fit the results

Try the web version at <http://belle2.ijs.si/masterclass>

