Institut
"Jožef Stefan"
Ljubljana, Slovenija

Belle II

Belle II Lab Manual

Rok Pestotnik

Jožef Stefan Institute, Ljubljana, Slovenia

You Tube introduction:
•Start: https://youtu.be/q6M2_dnp3pI
•Particle distribution: https://youtu.be/q6M2_dnp3pI
•J/psi to mumu: https://youtu.be/xUYmXoPfZOU
•J/psi to ee: https://youtu.be/3TGsHJ8j8pE
•Fit: https://youtu.be/wWbjWYHVaLU
•B to J/psi K http://youtube.com/watch?v=e-GErqzY3HM

Institut "Jožef Stefan" Ljubljana, Slovenija

Quick start to analyze the data

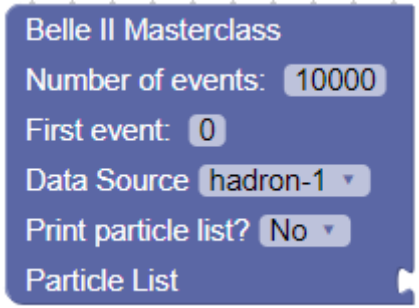
Belle II Masterclass: Describe process →Run analysis →Fit results →Save/load process locally

Run Analysis | Save Diagram | Load Diagram

Blocks

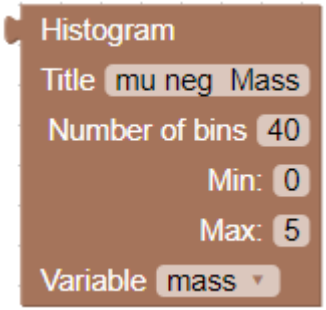
The exercises are any carried out by transferring blocks on the workspace and connecting them together. That represents parts of the data analysis code:

Inside “Blocks" we find:



A BLUE block that allows you to load events.

- You can choose between two data sources:
  - hadron-1 Which contains 629,000 events
  - hadron-2 Which contains 5 600 000 events
- You can select the number of events to analyze
- Note: processing of 10.000 events takes about 1 second.



A BROWN block that allows you to produce histograms – distributions of selected variables, you can define a range and a variable to plot

Institut "Jožef Stefan" Ljubljana, Slovenija

Quick start to analyze the data

Belle II

Belle II Masterclass: Describe process →Run analysis →Fit results →Save/load process locally

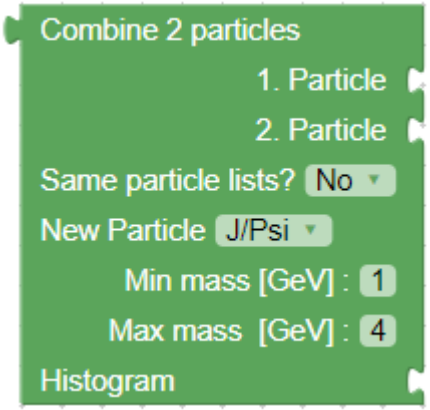
Run Analysis | Save Diagram | Load Diagram

Blocks

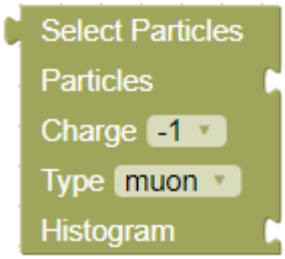
A GREEN block that allows you to combine two particles and to calculate their invariant mass

You can choose to combine different particles and avoid considering the same particle twice.

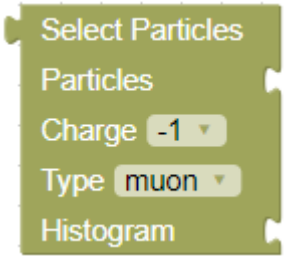
The minimum and maximum of the invariant mass can be specified for further analysis



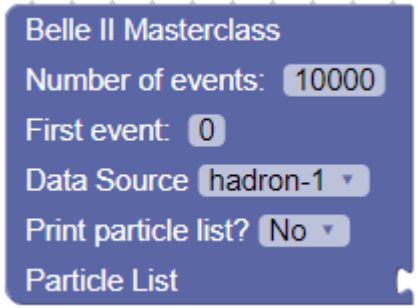
A MUSTARD block that allows to select only certain particles (electrons, muons, kaons, protons, photons) and also allows to choose the charge of the particle (-1, 0, +1, any).



Basic blocks

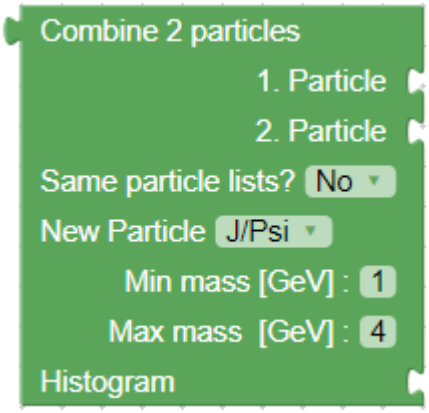


Select particle type for analysis and append histogram for plotting the properties

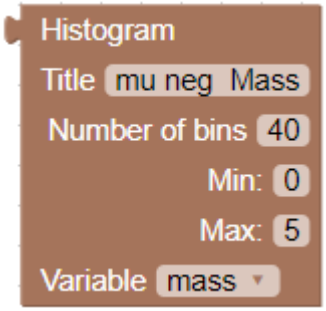


Define main analysis parameters

- ❑ 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



Make a combination of particles from two lists

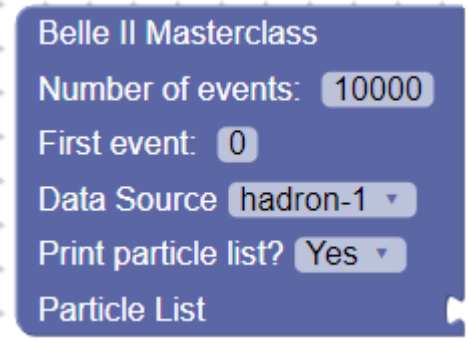


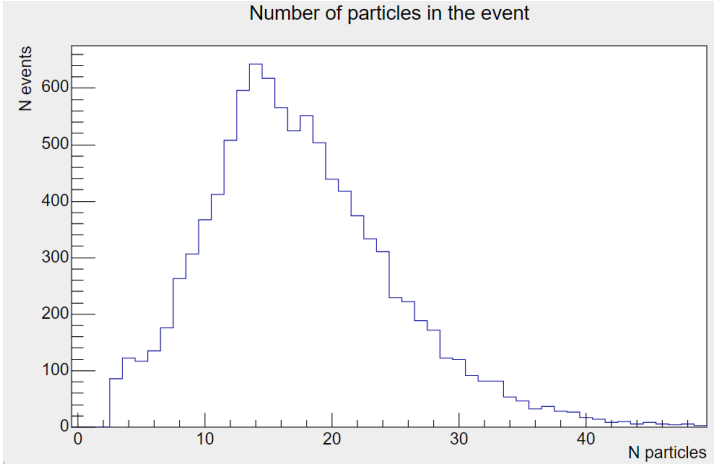
Plot a distribution

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





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

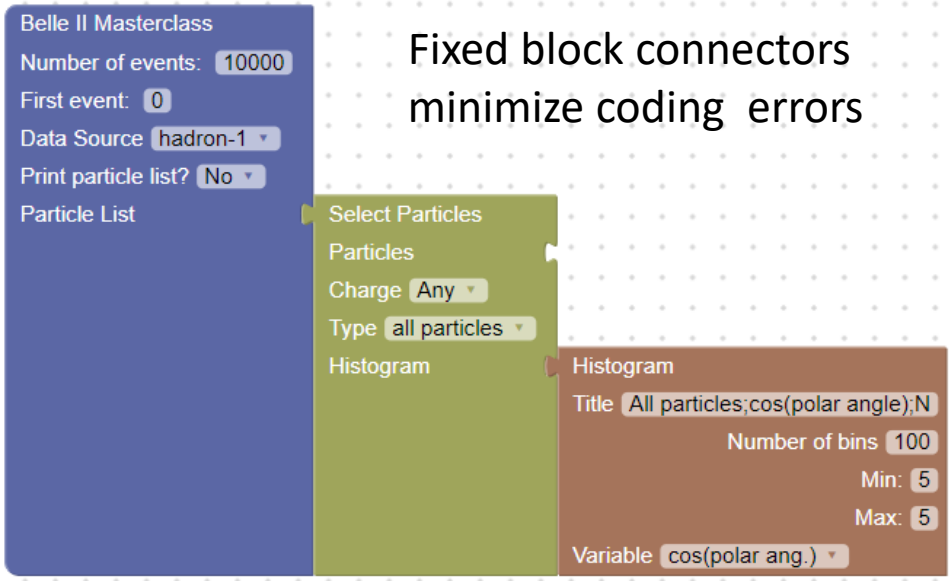
The particle lists for each event are stored in an ROOT tree.

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

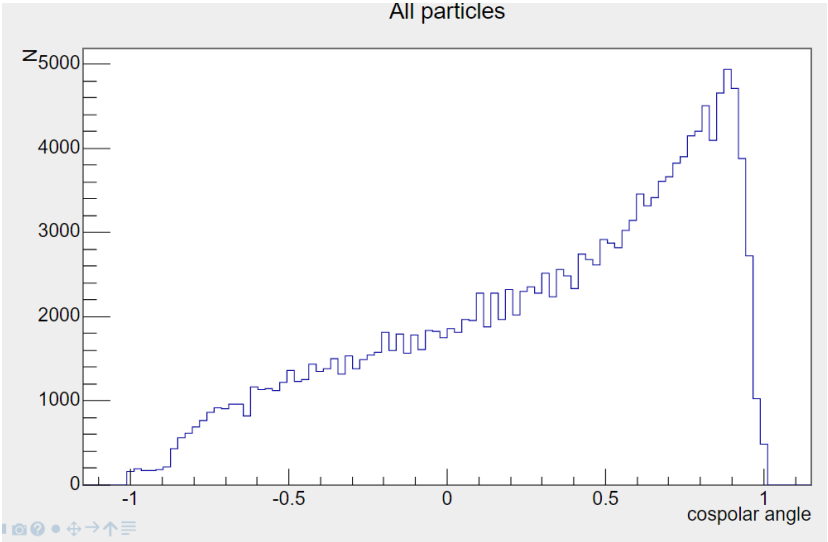
Distribution of different particle quantities can be plotted

Plot different variables :

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



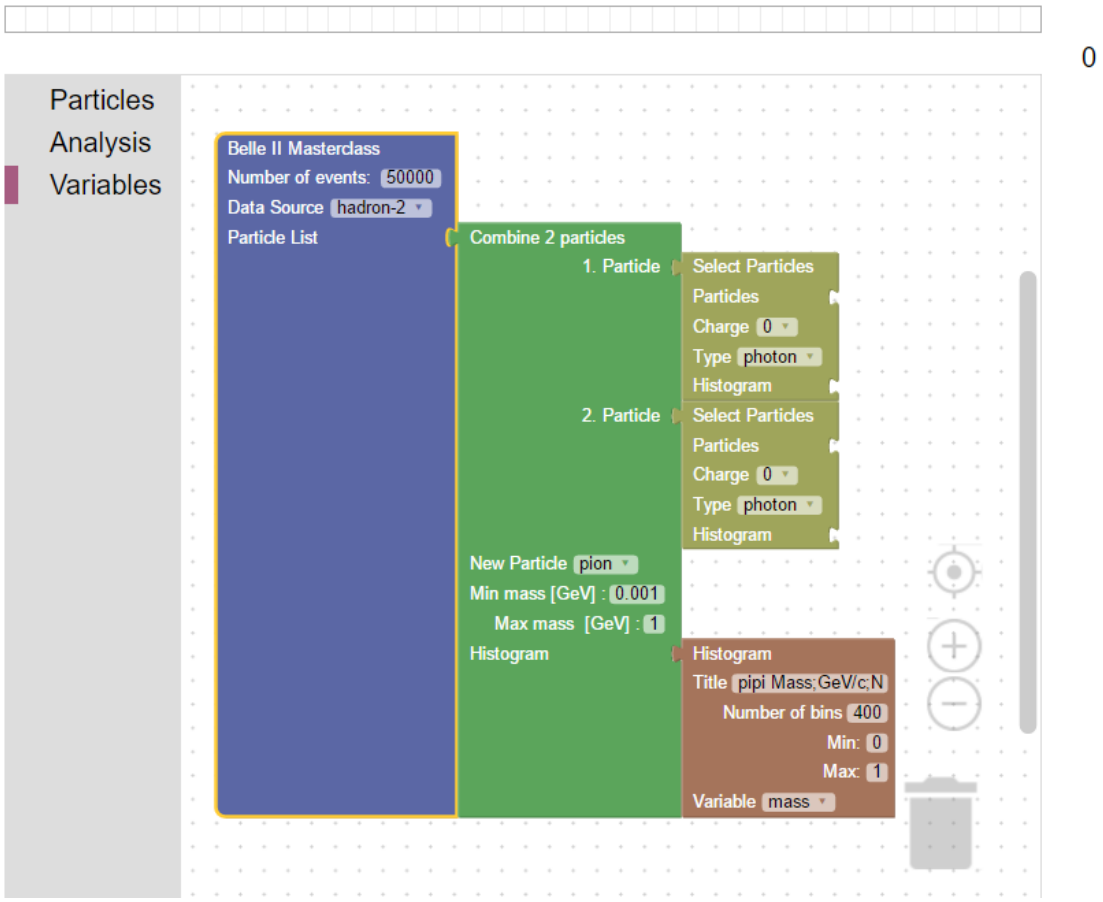
Fixed block connectors minimize coding errors



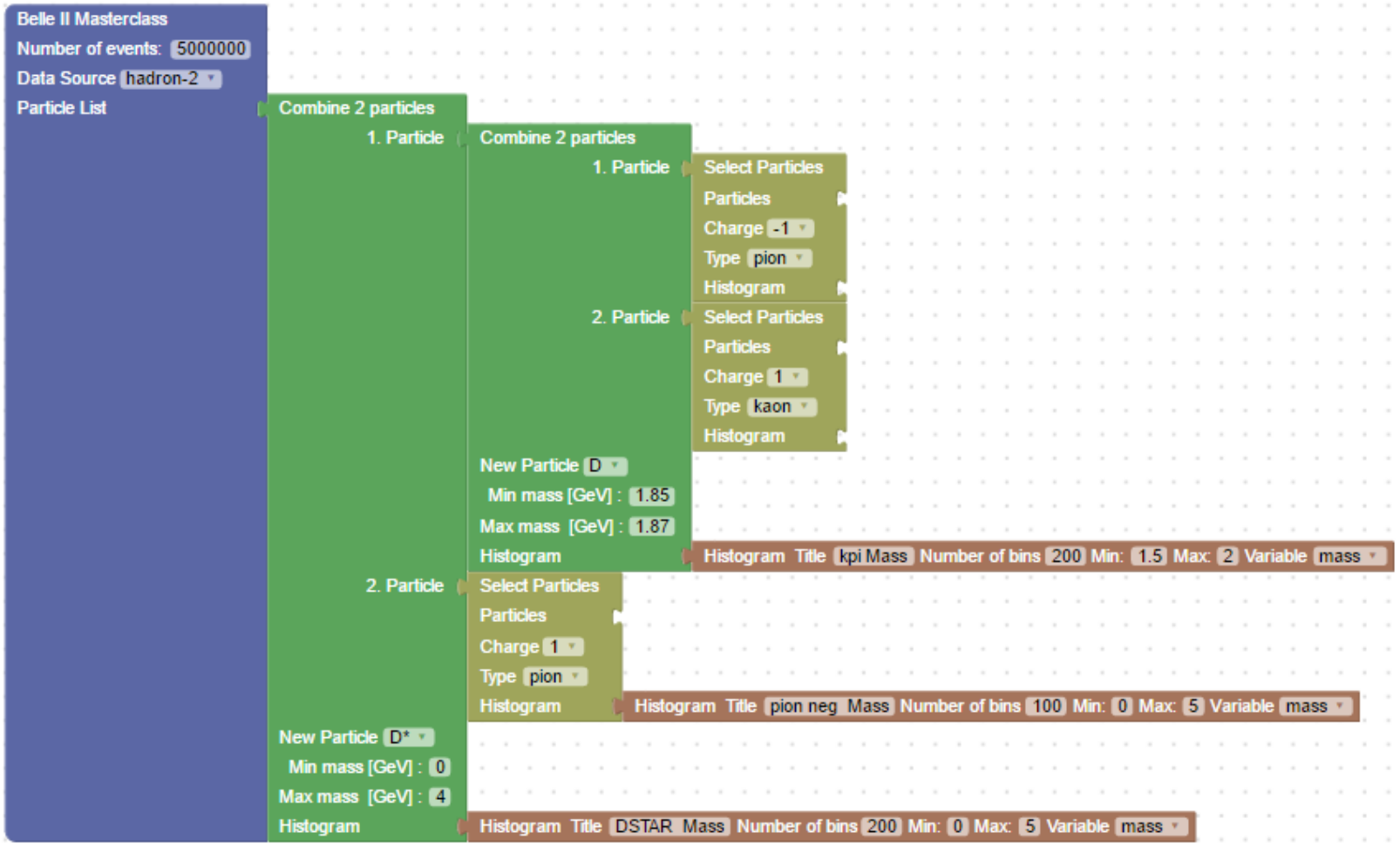
Decay to two particles

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

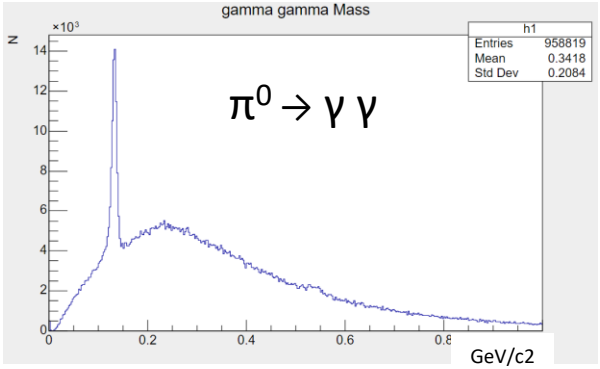


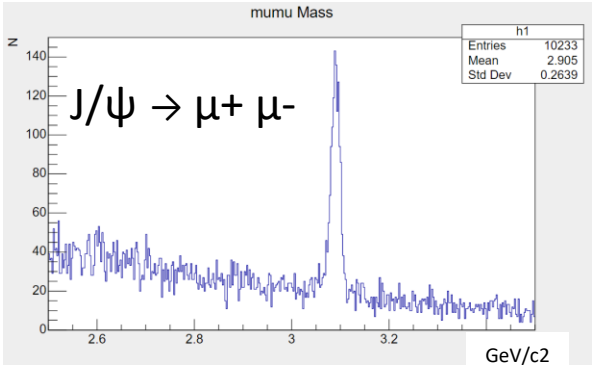
Combination of three particles

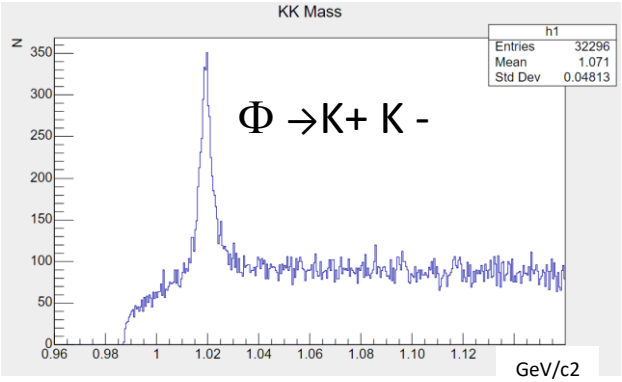


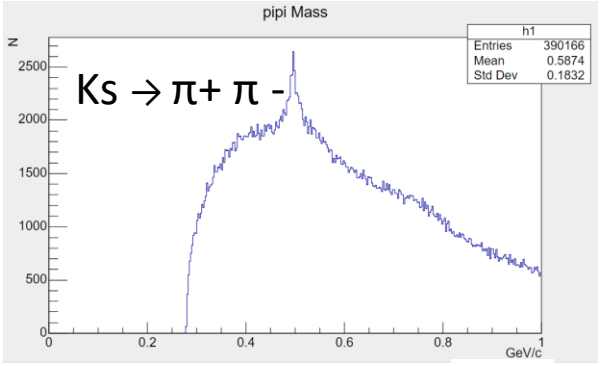
Different decays

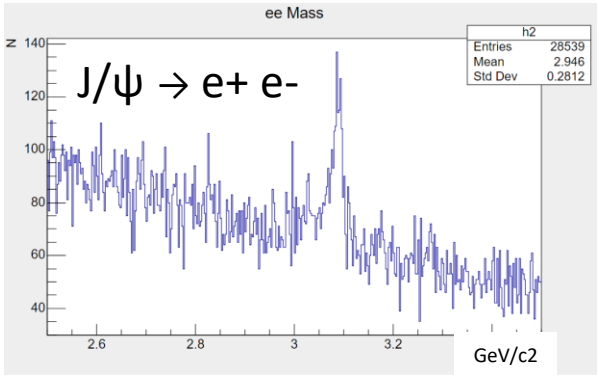
Invariant mass plots for different decays

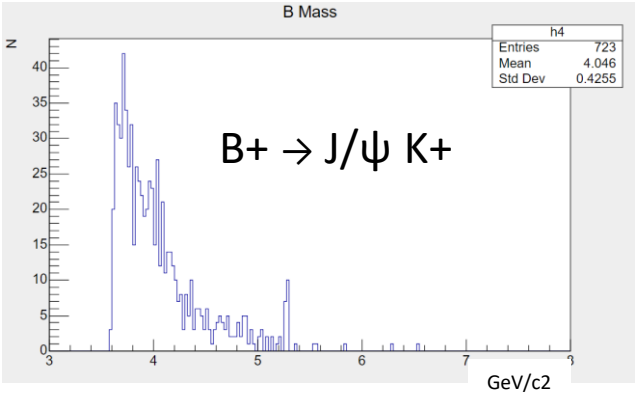






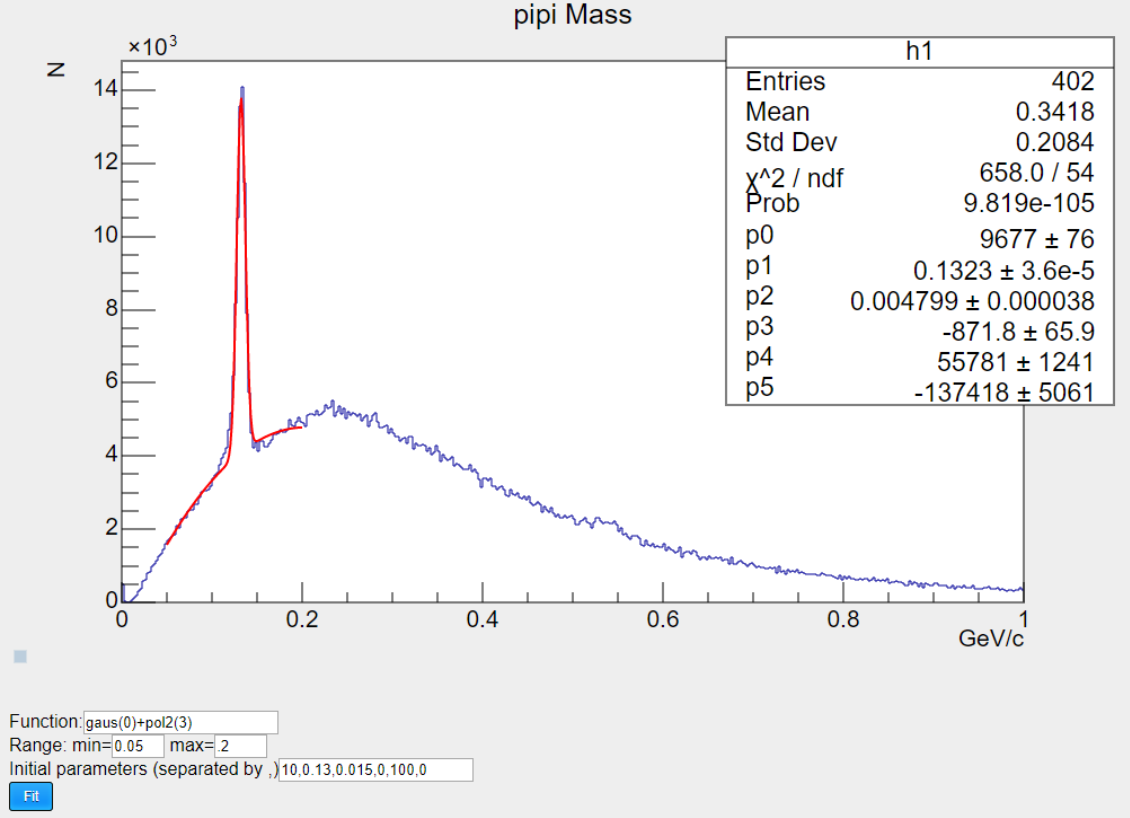






Advanced level

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



Exercises

Worksheet

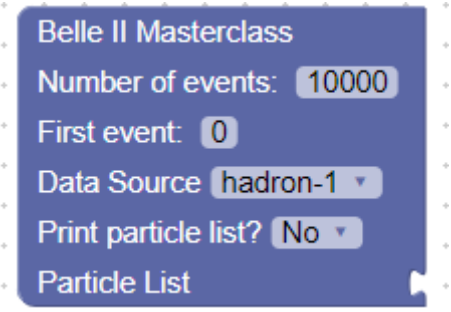
Exercise table with the list of decays to examine

Particle	Quark content	Process	Mass (GeV/c^2)	Number of processed events	Number of detected particles	Decay width (GeV/c^2)
π^0	$\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	$\pi^0 \rightarrow \gamma\,\gamma$				
Ks	$\frac{1}{\sqrt{2}}(d\bar{s} + \bar{s}s)$	Ks → π+ π -				
ϕ	$s\bar{s}$	ϕ → 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-				

Exercise 1 – Particles in the data sample

- In the data we have a list of reconstructed particles for each event with the following information:
  - momentum p=(px,py,pz), energy E, charge and identity
- List the particles in the data and plot number of reconstructed particles in each event
- This is done by using the main block and pressing

  Run Analysis button



- Try to change number of events and a data source file

Exercise 2 – Mass distributions for different particles

- Mass of the particle defined as
  - $mc^2 = \sqrt{E^2 - p^2c^2}$
  - In the application it is already calculated
- Plot the distribution of particles according to their mass
- Change particle identity and see how the distribution changes in the following ranges:
  - From 0 to 3 GeV/c^2
  - From 0 to 0.0005 GeV/c^2

Exercise 3 – Decay of a particle to two particles

- From the measured momentum and energy of two particles (p_1, E_1) and (p_2, E_2) the mass of the mother particle can be calculated as
- $mc^2 = \sqrt{(E_1 + E_2)^2 - (p_1 + p_2)^2 c^2}$
  - By using a particle combiner block, the mass of the particle can be calculated for each combination of particles.
- Plot the mass distribution of neutral pion π_0 which decay to two γ photons:

$$\pi^0 \rightarrow \gamma\ \gamma$$

- You will find a peak at 0.135 GeV/c2, which is exactly the mass of the pion

Exercise 4 – Decay of a kaons to charged pions

- Plot the mass distribution of neutral kaon Ks which decays to two charged pions:

$$Ks \rightarrow \pi+ \pi -$$

- You will find a peak at 0.498 GeV/c2 , which is exactly the mass of the neutral kaon Ks

Exercise 5 – Decay of a Phi to charged kaons

- Plot the mass distribution of neutral kaon Ks which decays to two charged kaons:

$$\phi \rightarrow K+ K-$$

- You will find a peak at 1.02 GeV/c2, which is exactly the mass of the ϕ

Exercise 6 – Decay of a J/ψ to leptons

- Plot the mass distribution of a J/ψ which decays to two leptons:

J/ψ → e+ e- or J/ψ → μ+ μ-

You will find a peak at a mass of J/ψ at 3.10 GeV/c2

Probability for a production of J/ψ is very small.
You will have to process at least 100.000 events.

Exercise 7 – Decay of a D^0 to charged kaons and leptons

- Plot the mass distribution of a neutral D^0 which decays to a combination of $K^+\pi^-$ or $K^-\pi^+$:

$D^0 \rightarrow K^+\pi^-$ or $D^0 \rightarrow K^-\pi^+$

You will find a peak at a mass of D^0 at 1.86 GeV/c^2

Probability for a production of D^0 is very small.

You will have to process at least 100.000 events.

Exercise 8 – Decay of $B^+ \rightarrow J/\psi\, K^+$

- Plot the mass distribution of a charged B which decays to a combination of J/ψ K

$B^+ \rightarrow J/\psi\, K^+$ or $B^- \rightarrow J/\psi\, K^-$

You will find a peak at a mass of charged B at 5.28 GeV/c^2

Use the block Combine 2 particles and describe the process in two stages.

Be sure to select only the particles with a correct invariant mass of J/ψ for further analysis.

Exercise 9 – Decay of $D^*(2010) \rightarrow D^0 \pi$

- Plot the mass distribution of a charged D^* which decays to a combination of $D^0 \pi$- or $D^0 \pi$+:

$D^0 \rightarrow K^+\pi^-$ or $D^0 \rightarrow K^-\pi^+$

You will find a peak at a mass of D* at 2.01 GeV/c^2

Use the block Combine 2 particles and describe the process in two stages.

Be sure to select only the particles with a correct invariant mass of D^0 for further analysis.