

DELAVNICA BELLE II LAB

(FIZIKA OSNOVNIH DELCEV)

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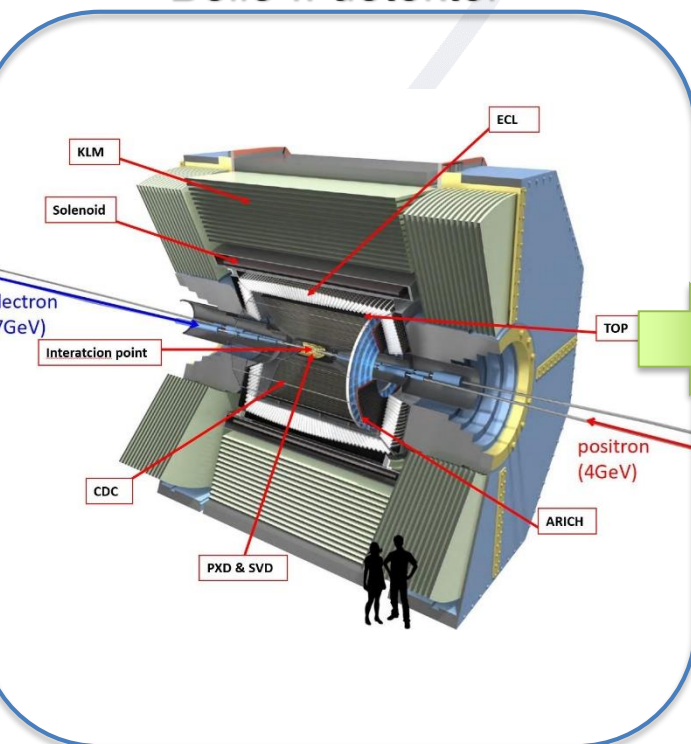
Poletna matematično-fizikalna šola 2022
FMF, Ljubljana, Slovenia



PREGLED

- Raziskovalci za nekaj ur
- Rekonstrukcija in analiza podatkov iz Belle II detektorja
- Spletno orodje: Belle II Lab <https://belle2.ijs.si/>
- Potek raziskovanja:

Belle II detektor



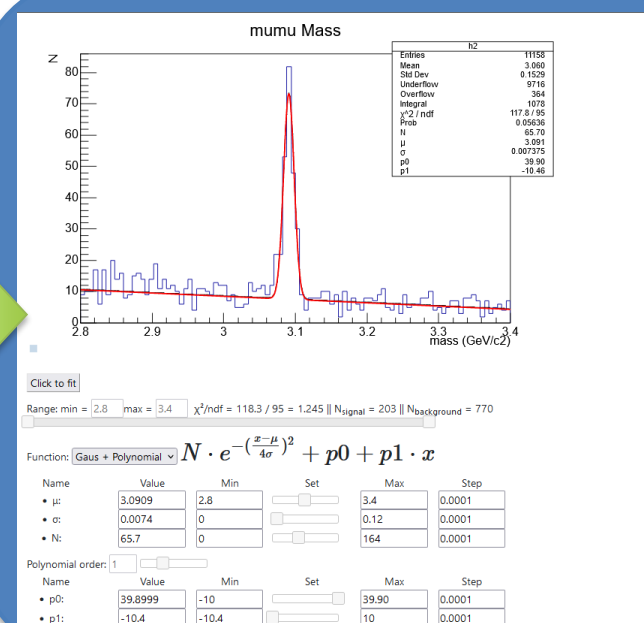
Podatki

Reconstructed particles of Event 100092									
N	pt(GeV/c)	py(GeV/c)	pz(GeV/c)	Energy(GeV)	Charge	ID			
1	0.493899	0.978685	0.536219	1.37138	1.45753	1			
2	-0.490319	-0.605026	0.0591857	0.781007	0.79338	-1			
3	-0.148989	0.727243	0.647969	0.965365	0.965366	-1			
4	-0.331178	-0.624265	-0.300131	0.767765	0.760348	-1			
5	0.127009	0.624614	0.00489556	0.837415	0.652516	-1			
6	0.150435	-0.615319	0.549407	0.838508	0.850045	1			
7	0.340787	0.29155	-0.250569	0.513733	1.06971	1			
8	0.019595	0.372722	-0.0764089	0.360978	0.405739	-1			
9	0.266858	0.246506	0.0811402	0.372239	0.397545	1			
10	0.1525	-0.282905	0.112128	0.340388	0.367891	1			
11	-0.031204	-0.273641	0.348796	0.371151	0.396326	1			
12	-0.159888	-0.141044	-0.150557	0.260893	0.29588	-1			
13	-0.139185	-0.0707428	-0.0668666	0.169847	0.169848	-1			
14	0.119075	-0.0242336	0.0027261	0.134767	0.194016	1			
15	0.101946	0.196486	0.252244	0.335599	0.335599	0			
16	0.160347	0.539565	0.492977	0.748243	0.748243	0			
17	0.0471326	0.202798	0.086351	0.2254	0.2254	0			
18	0.0268363	-0.348354	-0.0109992	0.349544	0.349544	0			
19	-0.522742	-0.886541	0.313339	1.07582	1.18558	0			
20	0.148804	0.398504	0.337968	0.543296	0.559811	0			
21	0.150832	0.223069	0.262827	0.362112	0.398824	-1			
22	0.233084	0.576309	0.546333	0.82916	0.840074	0			
23	0.207488	0.74239	0.579355	0.964285	0.973686	0			
24	-0.0266605	-0.56269	-0.0571573	0.568771	0.582621	0			

Reconstructed particles of Event 100093									
N	pt(GeV/c)	py(GeV/c)	pz(GeV/c)	Energy(GeV)	Charge	ID			
1	1.55281	0.0765988	1.82689	2.49123	2.40355	1			
2	1.02081	0.118295	0.250699	1.05778	1.06695	-1			
3	-0.878755	0.180482	0.0238094	0.887413	0.908202	-1			
4	0.444461	-0.338679	-0.224742	0.990771	0.815359	-1			
5	-0.549747	-0.00197336	0.287636	0.620452	0.630956	-1			
6	-0.409023	0.204315	0.243596	0.518057	0.715612	1			
7	-0.300179	0.0217481	0.139922	0.331901	0.360053	-1			
8	-0.0482556	-0.118202	-0.129676	0.180886	0.226409	1			

Reconstructed particles of Event 100092									
N	pt(GeV/c)	py(GeV/c)	pz(GeV/c)	Energy(GeV)	Charge	ID			
1	0.493899	0.978685	0.536219	1.37138	1.45753	1			
2	-0.490319	-0.605026	0.0591857	0.781007	0.79338	-1			
3	-0.148989	0.727243	0.647969	0.965365	0.965366	-1			
4	-0.331178	-0.624265	-0.300131	0.767765	0.760348	-1			
5	0.127009	0.624614	0.00489556	0.837415	0.652516	-1			
6	0.150435	-0.615319	0.549407	0.838508	0.850045	1			
7	0.340787	0.29155	-0.250569	0.513733	1.06971	1			
8	0.019595	0.372722	-0.0764089	0.360978	0.405739	-1			
9	0.266858	0.246506	0.0811402	0.372239	0.397545	1			
10	0.1525	-0.282905	0.112128	0.340388	0.367891	1			
11	-0.031204	-0.273641	0.348796	0.371151	0.396326	1			
12	-0.159888	-0.141044	-0.150557	0.260893	0.29588	-1			
13	-0.139185	-0.0707428	-0.0668666	0.169847	0.169848	-1			
14	0.119075	-0.0242336	0.0027261	0.134767	0.194016	1			
15	0.101946	0.196486	0.252244	0.335599	0.335599	0			
16	0.160347	0.539565	0.492977	0.748243	0.748243	0			
17	0.0471326	0.202798	0.086351	0.2254	0.2254	0			
18	0.0268363	-0.348354	-0.0109992	0.349544	0.349544	0			
19	-0.522742	-0.886541	0.313339	1.07582	1.18558	0			
20	0.148804	0.398504	0.337968	0.543296	0.559811	0			

Analiza





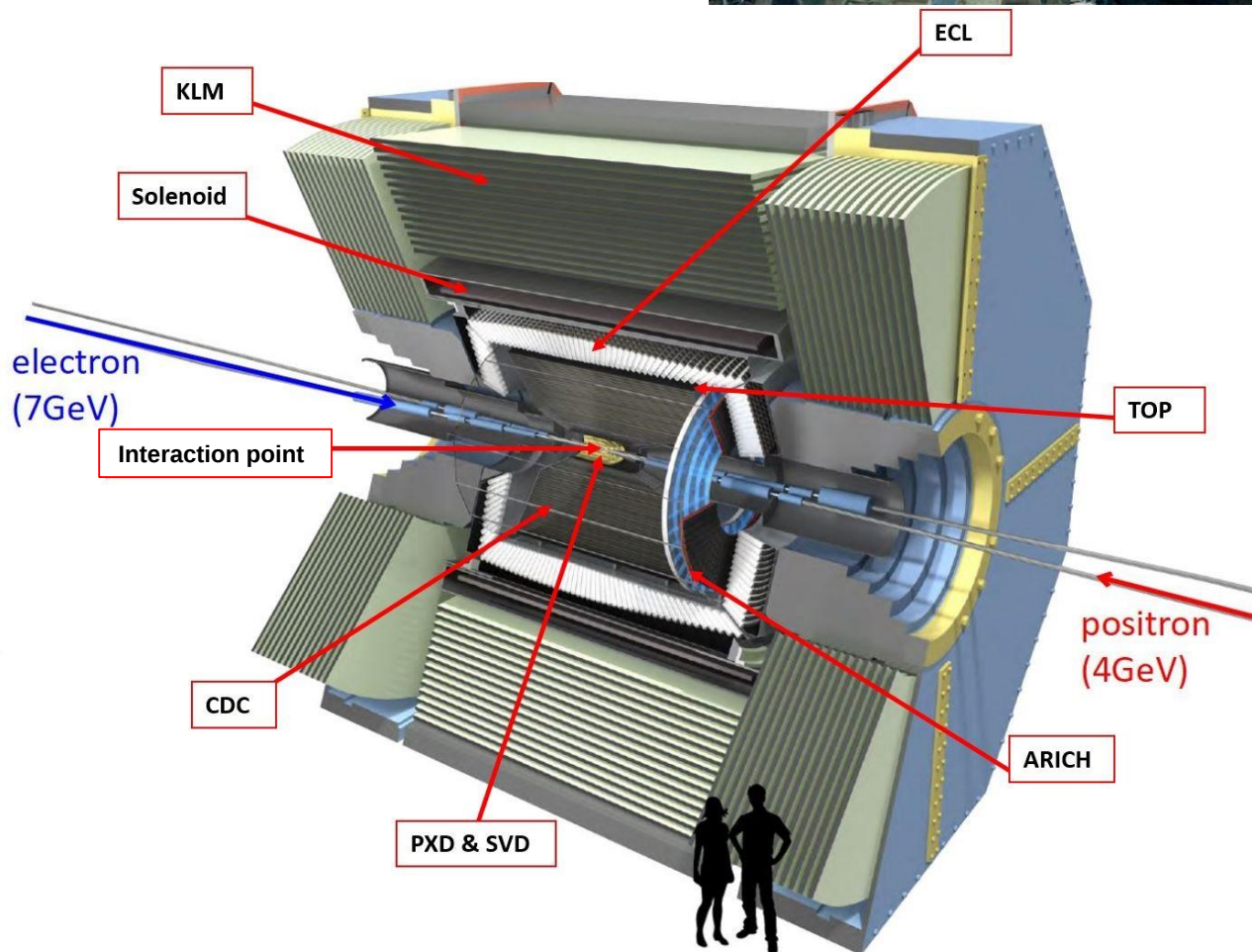
BELLE II

- Measurements of:
 - Momentum
 - Energy
 - Identity
- Long lived particles
 - $e, \mu, \pi, K, p, \gamma, K_L$

Reconstruction



B, D mesons
 τ leptons,
...



Public analysis of 6M events from Belle

Interactive web application

<http://belle2.ijs.si/masterclass>

Describe decays, make simple cuts,
"discover" particles

Runs on a **web server** or in a **virtual appliance**



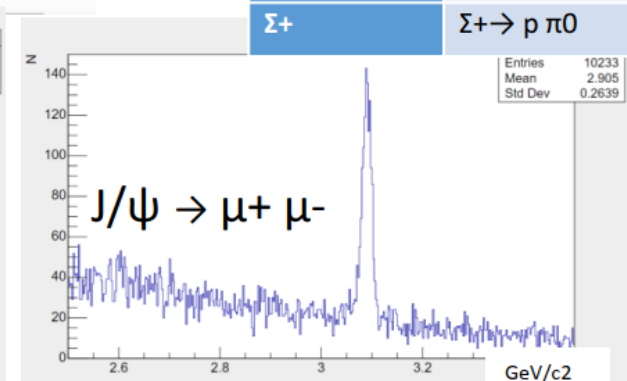
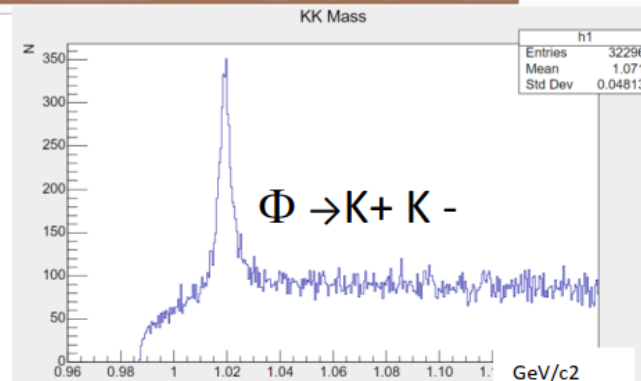
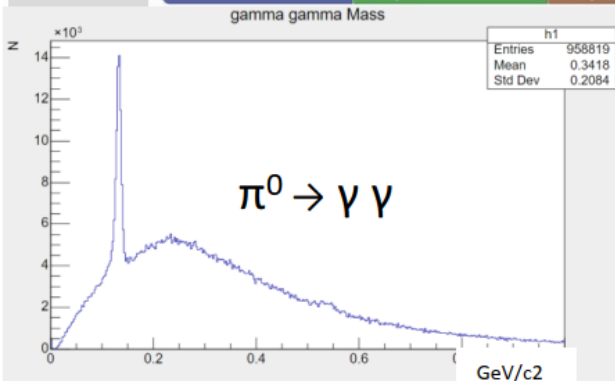
Particle	Process
π^0	$\pi^0 \rightarrow \gamma \gamma$
K_s	$K_s \rightarrow \pi^+ \pi^-$
ϕ	$\phi \rightarrow K^+ K^-$
J/ψ	$J/\psi \rightarrow e^+ e^-$
	$J/\psi \rightarrow \mu^+ \mu^-$
D^0	$D^0 \rightarrow K^+ \pi^-$
	$D^0 \rightarrow K^- \pi^+$
D^{*+}	$D^{*+} \rightarrow D^0 \pi^+$
D^{*-}	$D^{*-} \rightarrow D^0 \pi^-$
B^+	$B^+ \rightarrow J/\psi K^+$
B^-	$B^- \rightarrow J/\psi K^-$
Λ	$\Lambda \rightarrow p \pi^-$
Σ^+	$\Sigma^+ \rightarrow p \pi^0$

Particles
 Analysis
 Variables

Belle II Masterclass
 Number of events: 50000
 First event: 0
 Data Source: hadron-2
 Print particle list? No
 Particle List

Combine 2 particles
 1. Particle
 Select Particles
 Particles
 Charge 0
 Type photon
 Histogram
 2. Particle
 Select Particles
 Particles
 Charge 0
 Type photon
 Histogram
 Same particle lists? No
 Set identity to pion
 Min mass [GeV/c²]: 0.001
 Max mass [GeV/c²]: 1
 Histogram

Histogram Title: π^0 Mass; GeV/c²; N: 50000; Number of bins: 400; Min: 0; Max: 1; Variable: mass



<https://belle2.ijs.si/masterclass>



EVENT DISPLAY

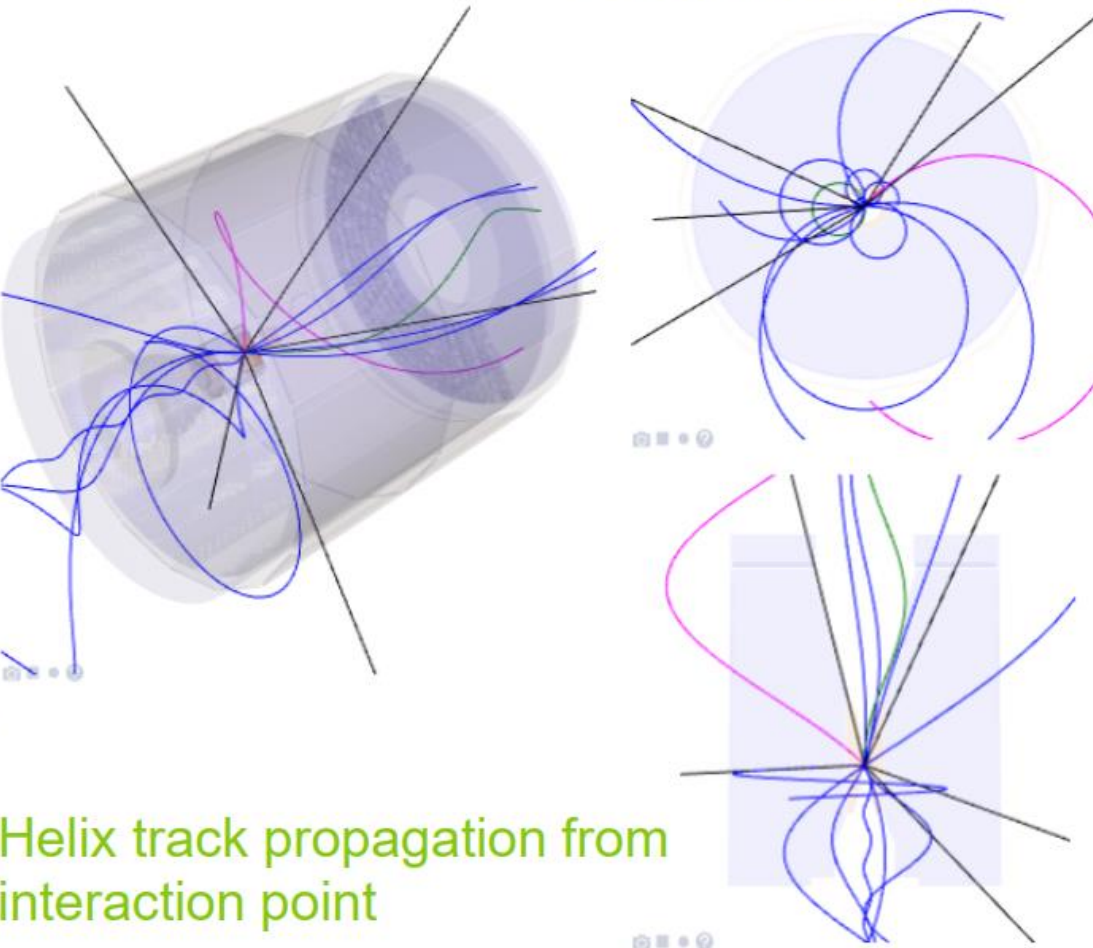
<https://belle2.ijs.si/masterclass/eventDisplay.html>

Event display with mouse interactions

 Belle II Masterclass Event Display

Event: < 1 > Close Window

Load event data



Helix track propagation from interaction point

Reconstructed particles of Event 1

N	px(GeV/c)	py(GeV/c)	pz(GeV/c)	p(GeV/c)	Energy(GeV)	Charge	ID
1	0.0294873	-0.273614	0.194669	0.337091	0.353262	1	muon
2	-0.229449	-0.00589037	0.243925	0.334934	0.362851	1	pion
3	0.249353	0.138971	-0.133726	0.315234	0.34475	-1	pion
4	0.617004	0.147713	-0.0178898	0.634691	0.649856	-1	pion
5	-0.852846	-0.013393	0.58309	1.03321	1.04259	-1	pion
6	0.542409	0.00413217	-0.207596	0.580793	0.597328	-1	pion
7	-0.0786903	-0.0881519	-0.0326394	0.12259	0.185764	1	pion
8	-0.0337178	-0.35194	-0.0885627	0.364475	0.390284	1	pion
9	-0.269283	-0.331059	0.736212	0.850954	0.862324	1	pion
10	-0.342041	0.433614	-0.520645	0.759002	0.771728	-1	pion
11	-0.0889358	0.20194	0.351623	0.415124	0.437959	-1	pion
12	0.417001	0.488208	0.280684	0.700729	0.717106	1	proton
13	0.180873	0.288436	0.716277	0.793071	0.793071	0	photon
14	-0.12108	-0.00755525	0.261905	0.288637	0.288637	0	photon
15	0.15715	0.128819	-0.00759161	0.203342	0.203342	0	photon
16	-0.211126	-0.125556	-0.0770802	0.257449	0.257449	0	photon
17	-0.134099	0.0615151	-0.140303	0.203597	0.203597	0	photon

List of reconstructed particles

EXERCISE

- Display missions
- Describe process
- Run

 Belle II Particle Discovery

My worksheet Event Display File ▾ Help ▾ Settings ▾

Next Run Analysis

Mission 1

In the data you will find a list of reconstructed particles with their properties stored for each event. Each particle is described by its:

- momentum $\vec{p} = (p_x, p_y, p_z)$,
- energy E ,
- electric charge and
- identity

List the particles in the data for several events and plot a frequency histogram of a number of reconstructed particles per event. This is done by using the "main block" and by pressing "Run Analysis" button

Try to change the number of events and a data source file and observe how the distribution changes.

Blocks

Belle II Masterclass

Number of events: 10000

First event: 0

Data Source: Belle-1.root ▾

Print particle list? No ▾

Particle List

Combine 2 particles

Particle 1

Select Particles Simple

Particle

Charge -1 ▾

Type muon ▾

Histograms

mu neg Mass

Number of bins 40

Min: 0

Max: 5

Variable mass ▾

Particle 2

Select Particles Simple

Particle

Charge 1 ▾

Type muon ▾

Histograms

mu pos Mass

Number of bins 100

Min: 0

Max: 5

Variable mass ▾

Same particle lists? No ▾

Set identity to J/Psi meson ▾

Min mass [GeV/c2]: 1

Max mass [GeV/c2]: 4

Histograms

mumu Mass

Number of bins 100

Min: 1

Max: 4

Variable mass ▾

Basic 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

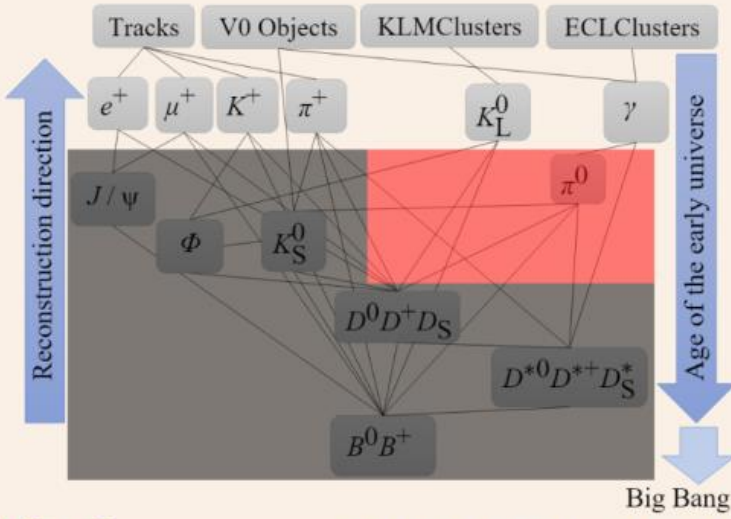
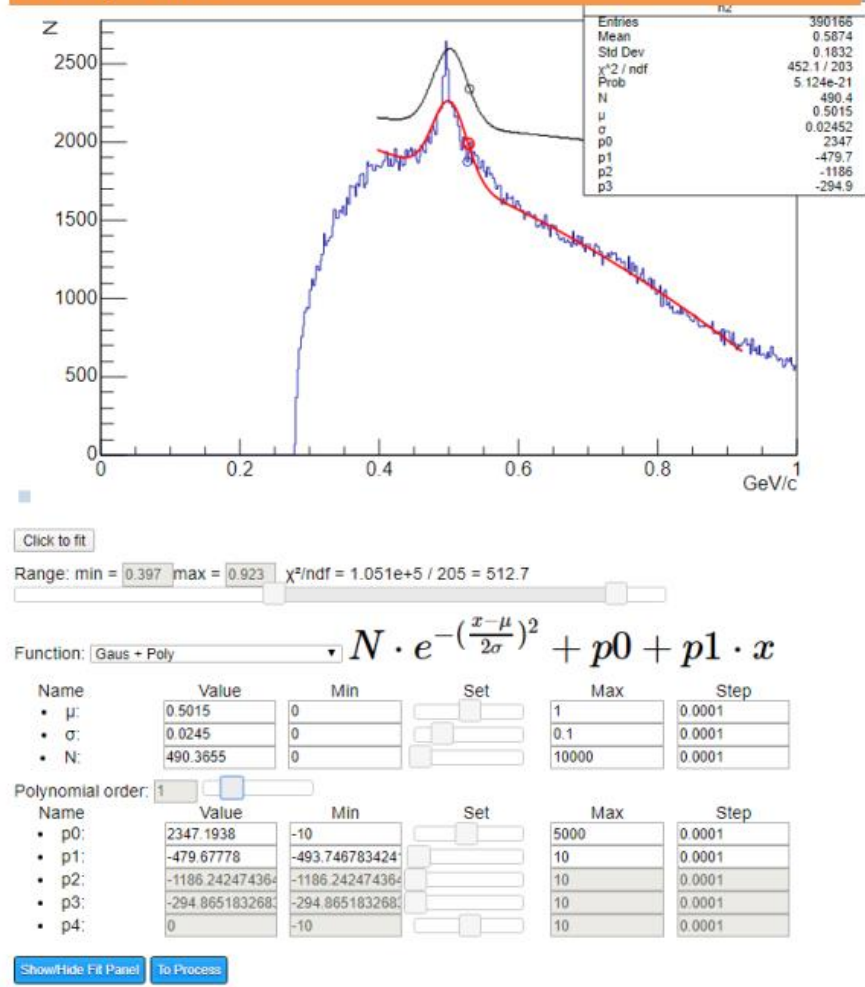
Advanced features

Fitting tools for interactive fitting to calculate width and number of events in the peaks

Check your results

On the way to a B meson

1.	$\pi^0 \rightarrow \gamma\gamma$	π^0 mass	1	GeV/c ²	Sadly not correct. Did you find the right peak?
2.	$K_S \rightarrow \gamma\gamma$	K_S mass		GeV/c ²	Please start to enter a number!
3.	$\Phi \rightarrow \gamma\gamma$	Φ mass		GeV/c ²	Please start to enter a number!
4.	$J/\psi \rightarrow \mu^+\mu^-$	J/ψ mass		GeV/c ²	Please start to enter a number!
5.	$J/\psi \rightarrow e^+e^-$	J/ψ mass		GeV/c ²	Please start to enter a number!
6.	$D^0 \rightarrow K^+\pi^-$ $D^0 \rightarrow K^-\pi^+$	avg. D^0 mass		GeV/c ²	Please start to enter a number!
7.	$D^{*+} \rightarrow D^0\pi^+$ $D^{*-} \rightarrow D^0\pi^-$	D^{*+} mass D^{*-} mass		GeV/c ²	Please start to enter a number!
8.	$B^+ \rightarrow J/\psi K^+$ $B^- \rightarrow J/\psi K^-$	avg. B^+ mass		GeV/c ²	Please start to enter a number!



Different decays

Invariant mass plots for different decays

