Analisi dei Dati di Belle II

… LA PRATICA :)

Belle II Masterclass ~ 2025 03 19

Giulia Casarosa

Ricostruirete alcuni Decadimenti…

… utilizzando i dati veri di *Belle II*

➡ potete fare la ricostruzione dei seguenti decadimenti attraverso 9 “missioni”

1 $\pi^0 \to \gamma\gamma$

2 $K_S \to \pi^+\pi^-$

3 $\phi \to K^+K^-$

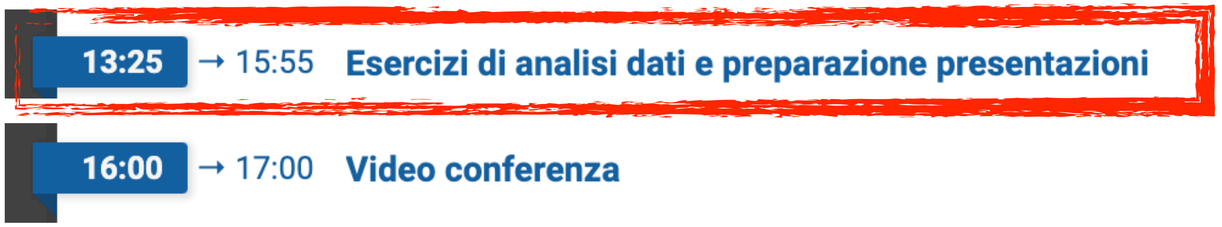
4 $D^{*+} \to D^0\pi^+; \quad D^0 \to K^\pm\pi^\mp$

5 $B^+ \to J/\psi K^+; \quad J/\psi \to \mu^+\mu^-, e^+e^-$

➡ vediamo l’organizzazione e gli strumenti che avrete a disposizione per l’analisi:

- ricostruzione, selezione, fit

Organizzazione



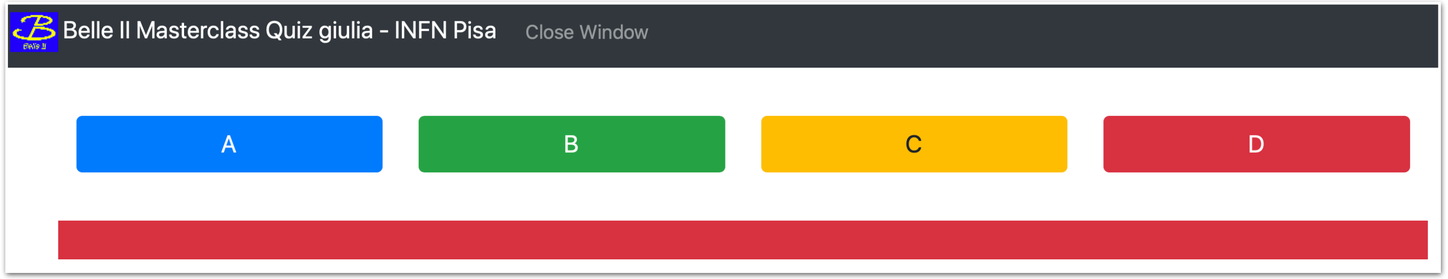
- colleghiamoci alla pagina https://belle2.ijs.si/masterclass/ (è linkata sull'agenda) su cui faremo l'analisi di dati di Belle II
  - si tratta di ricostruire decadimenti, produrre istogrammi e fare qualche fit, il tutto organizzato in 9 "missioni"
- siete suddivisi in gruppi di 2±1 persone (il lavoro di ricerca è un lavoro di team)
- se avete qualche dubbio (qualsiasi dubbio), problemi tecnici, curiosità, … alzate la mano e qualcuno arriva :)
- alla fine preparerete una piccola presentazione con il materiale da voi prodotto che verrà presentata (in inglese) durante la video conferenza con KEK e le altre scuole

Video Conferenza

13:25 → 15:55 **Esercizi di analisi dati e preparazione presentazioni**

16:00 → 17:00 **Video conferenza**

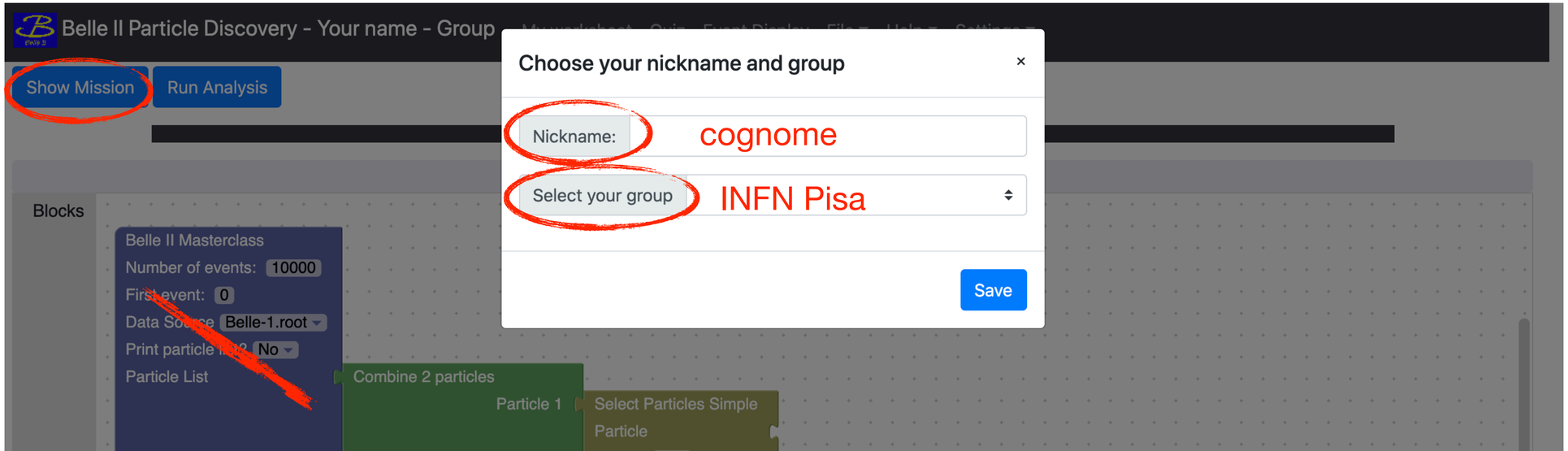
- Alla video conferenza parteciperanno le scuole che partecipano alla masterclass da altre città e ricercatori collegati da KEK
  - durante la video conferenza ci saranno le presentazioni del lavoro degli studenti
- Ci sarà anche un quiz (non si vince nulla!) a risposta multipla
  - collegandosi ad una pagina web si apre una finestra



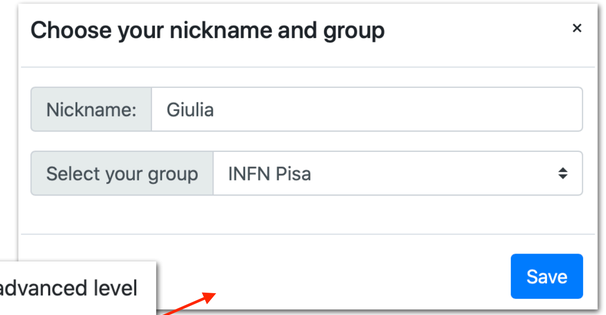
  - quando parte il cronometro dovrete cliccare sulla risposta che ritenete corretta (se cliccate prima la risposta non viene registrata!)

Iniziamo!

1. collegarsi a https://belle2.ijs.si/masterclass/
2. inserire un Nickname = cognome e selezionare il gruppo INFN Pisa
3. cancellare i blocchi sul piano di lavoro
4. cliccare su “Show Mission” per leggere il testo del primo esercizio



Gli Strumenti

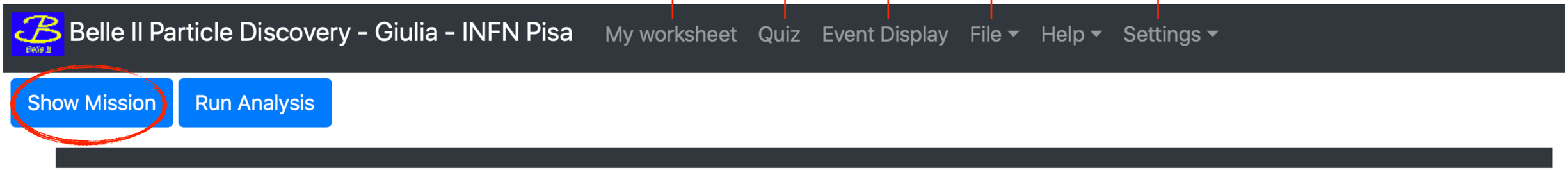


riassunto del lavoro

mostrato prima

Save
Load Diagram

Switch to advanced level
About
Preferences



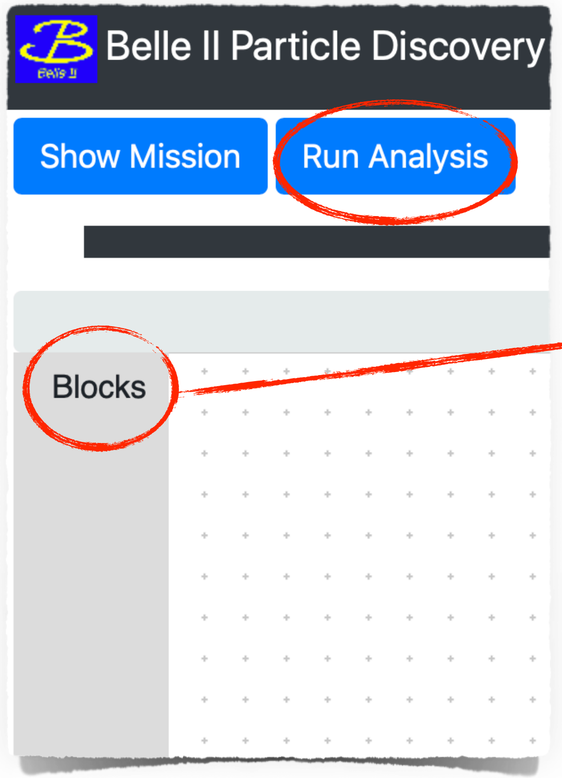
Blocks

piano di lavoro: blocchi da combinare per la ricostruzione e selezione,
e per la costruzione di istogrammi che potrete poi fittare

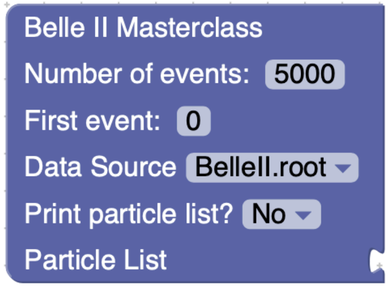
Blocchi da Combinare

strumenti base

1. trascinare il blocco desiderato nello spazio di lavoro
2. combinarlo con gli altri blocchi per costruire la vostra analisi
3. click on Run Analysis per eseguire l'analisi

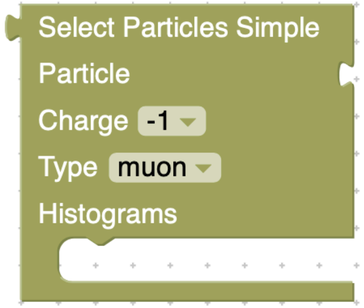


scelta del campione di dati

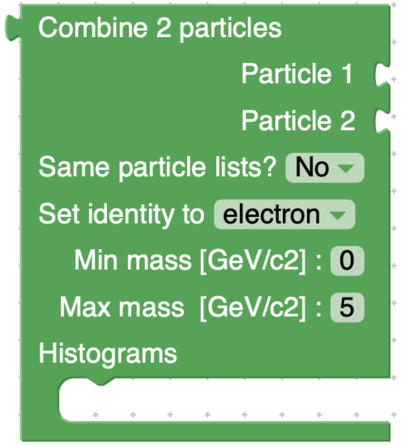


creazione dell'istogramma

selezione



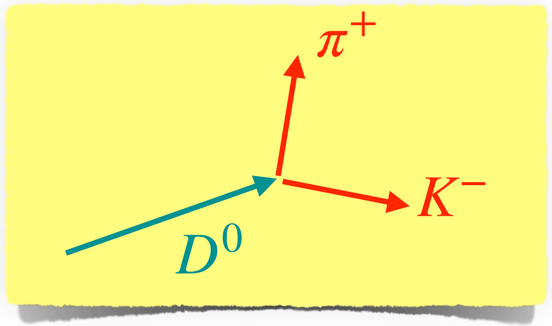
combinazione di 2 particelle



Esempio

selezionare **BelleII.root**

scrive a schermo la lista delle particelle finali in ogni per evento & crea l'istogramma del numero delle particelle finali



Mission 1: number of reconstructed particles

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

- momentum $p = (p_x, p_y, p_z)$,
- energy E,
- electric charge and
- identity.

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

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

Particle List

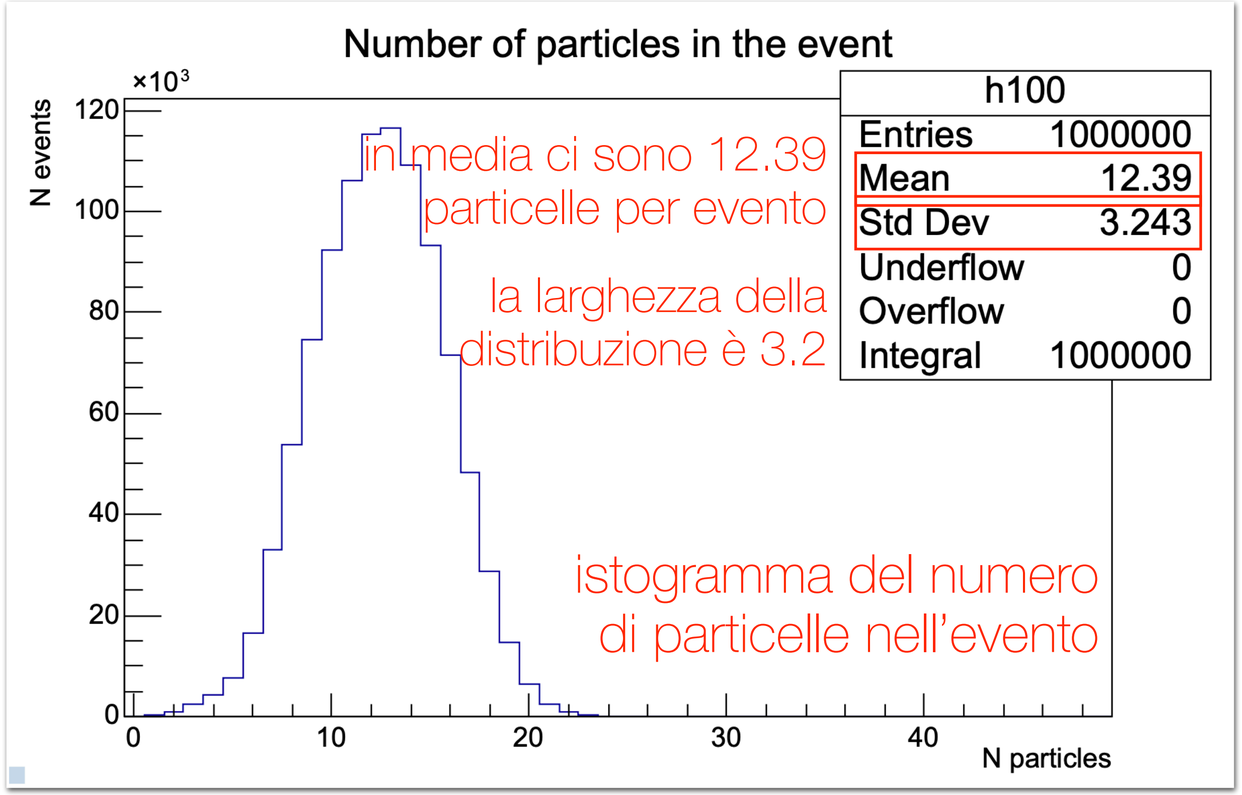
Print particle list? Yes

Particle properties

- momentum (px,py,pz) = (0.204516 , 0.139181 , -0.0325899) GeV/c
- energy = 0.970883 GeV/c2
- charge = 1
- identity = proton

ctrl-click su una particella

- momentum = 0.250 GeV/c
- transverse momentum = 0.25 GeV/c
- polar angle theta = 97.50 deg.
- cos(theta) = -0.131
- invariant mass = 0.938 GeV/c2



Number of Events in the file 7085107

lista di particelle

Reconstructed particles of Event 0

N	px(GeV/c)	py(GeV/c)	pz(GeV/c)	p(GeV/c)	Energy(GeV)	Charge	ID
1	-0.0432751	-0.963279	2.35054	2.54063	2.54446	1	pion
2	-0.0132683	-0.464986	0.329381	0.569982	1.09783	1	proton
3	0.332555	0.245834	0.543964	0.683318	0.697426	-1	pion
4	-0.00184963	0.10366	0.168331	0.197697	0.242	-1	pion
5	-0.0322308	0.14432	0.252137	0.292301	0.323913	1	pion
6	0.0373172	0.0630525	0.186629	0.200495	0.200495	0	photon
7	-0.0946252	-0.41141	1.04789	1.12973	1.12973	0	photon
8	-0.0623856	-0.197319	0.137847	0.248654	0.248654	0	photon

ctrl-click su due particelle

Particle properties combined from two particles

px [GeV/c]	py [GeV/c]	pz [GeV/c]	E [GeV/c2]	charge	ID
-0.0124157	0.0937047	0.233791	0.252177	0	photon
0.0639491	-0.321978	0.742094	0.811457	0	photon
0.0515	**-0.2283**	**0.9759**	**1.0636**	**0**	

Invariant mass = 0.3524 GeV/c2

che massa ha il fotone?

il μ^0 esiste? che massa ha?

Mission 2: invariant mass

The mass of a particle is defined in terms of particle energy E and its momentum p. The mass is invariant in any reference system an we call it invariant mass:

$$mc^2 = \sqrt{E^2 - p^2c^2}$$

In this application, the mass is always calculated automatically.

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.

il $\pi^{\pm}$ esiste? che massa ha?

il π^0 esiste? che massa ha?

che massa ha il fotone?

zero!

il μ^0 esiste? che massa ha?

no, non esiste

Mission 2: invariant mass

The mass of a particle is defined in terms of particle energy E and its momentum p. The mass is invariant in any reference system an we call it invariant mass:

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il $\pi^\pm$ esiste? che massa ha?

si, ha una massa di 139.6 MeV/c^2

il π^0 esiste? che massa ha?

esiste! ma decade in 2 fotoni e quindi va ricostruito, non si trova nella lista di particelle finali

Mission 3: decay of a neutral pion to photons

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

$$mc^2 = \sqrt{(E_1 + E_2)^2 - (p_1 + p_2)^2 c^2)}$$

"Combine two particles" (green) block calculates the mass of the combined particle for each combination of particles.

Plot the mass distribution of a neutral pion π^0 which decays to two photons:

$$\pi^0 \longrightarrow \gamma\gamma$$

You will find a peak at $0.135\ \mathrm{GeV}/c^2$, which is exactly the mass of a neutral pion π^0.

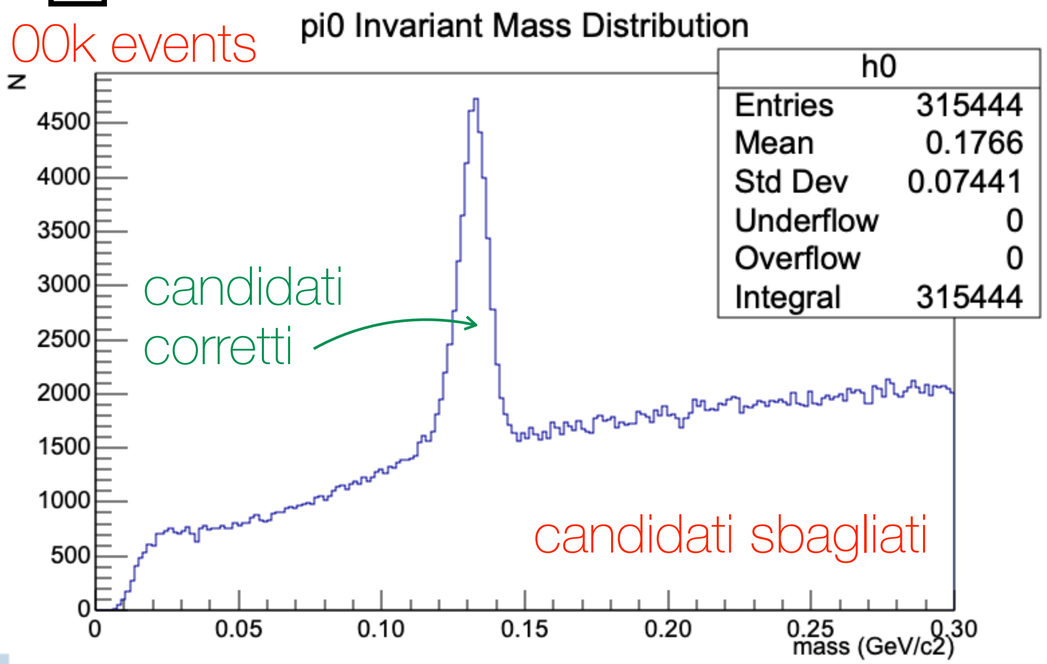
il π^0 esiste? che massa ha?

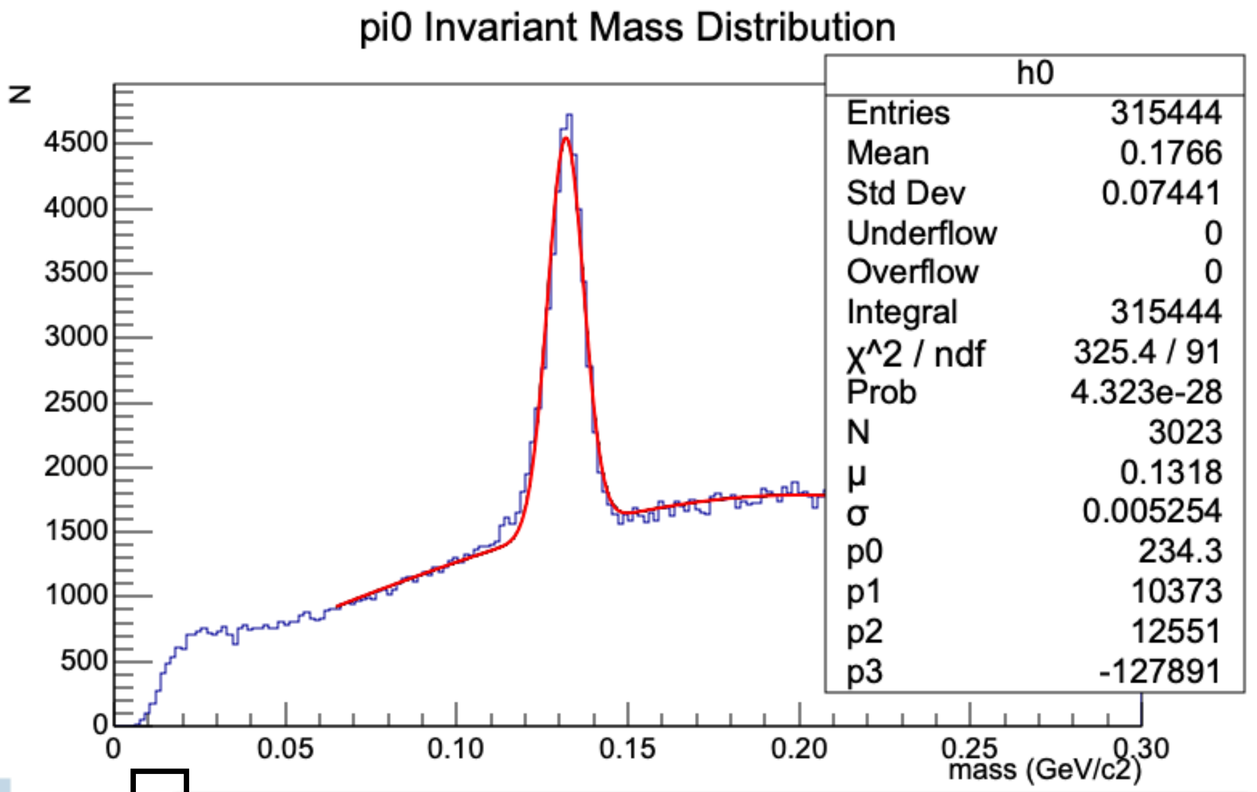
esiste! ma decade in 2 fotoni e quindi va ricostruito, non si trova nella lista di particelle finali

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

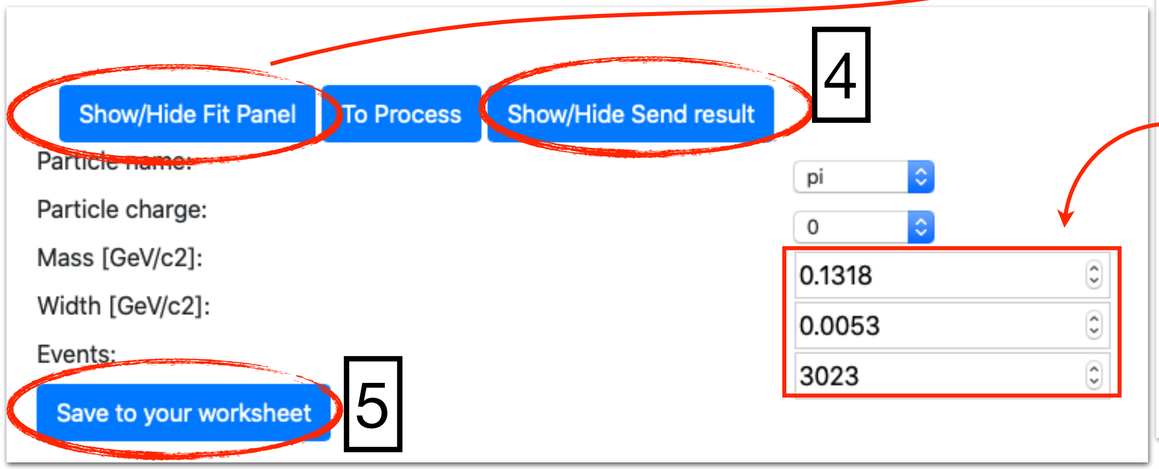
1 200 bins tra 0 GeV/c² e 0.3 GeV/c²:

100k events





2



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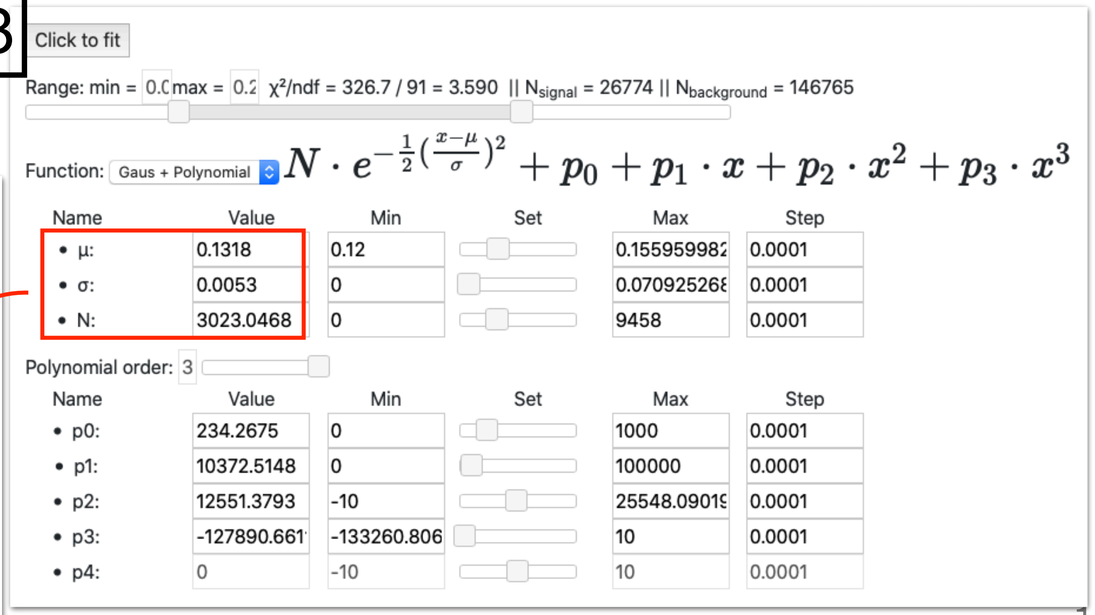
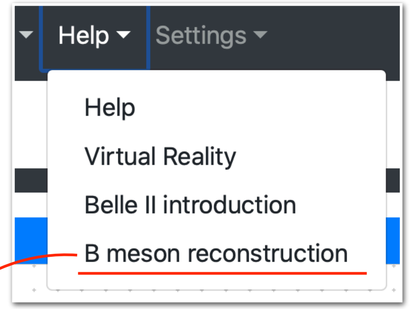


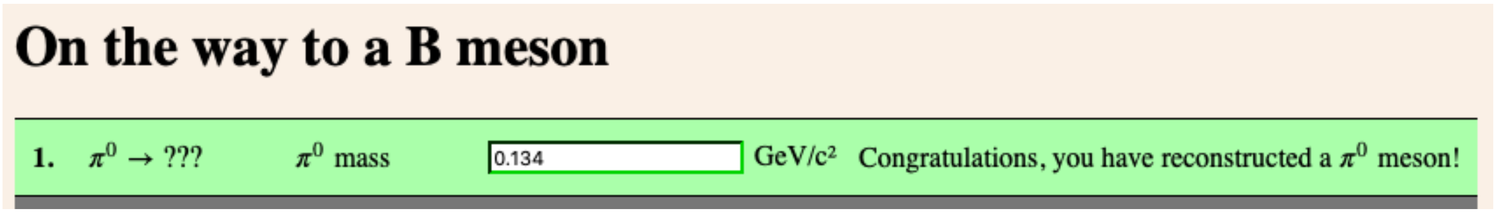
4

5

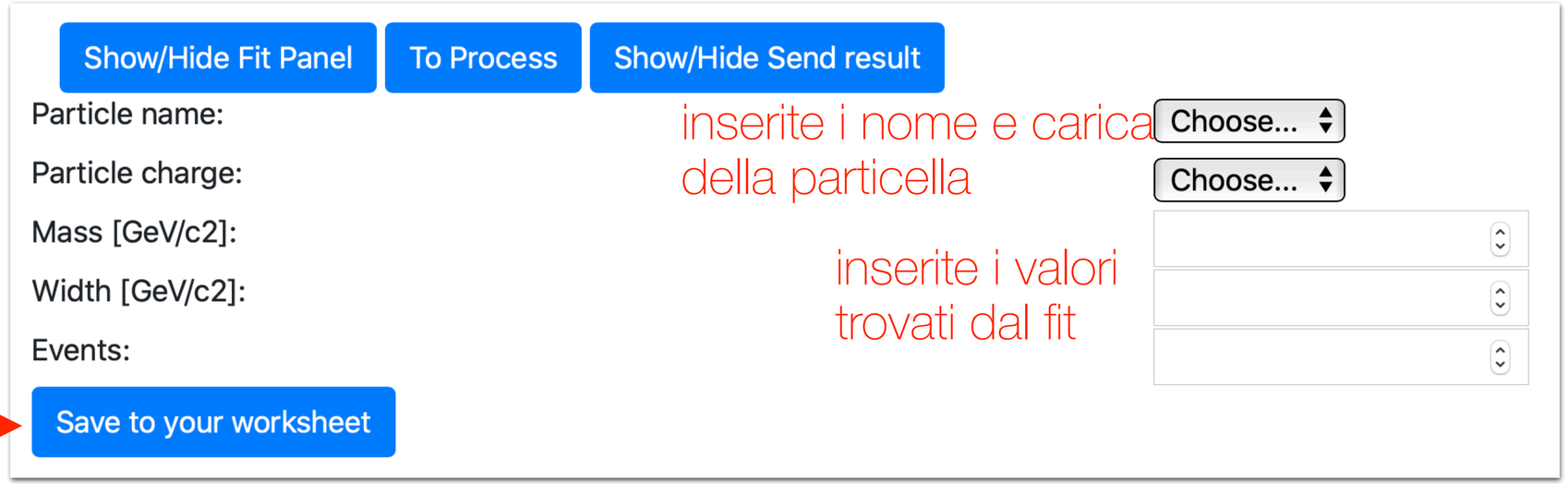
Controlla il Risultato e Spediscilo



- quando siete contenti della vostra stima potete controllare il valore della massa estratto (non è obbligatorio farlo)



- poi sottomettete i risultati riempiendo i campi sotto:



inserite i nome e carica della particella

inserite i valori trovati dal fit

se salvate una seconda volta i risultati, vengono sovrascritti

Worksheet

- i risultati di tutte le vostre missioni vengono visualizzati nel worksheet
- alla fine di ogni esercizio, mandate i risultati al server cliccando su:

Send results to server

Belle II Masterclass Student worksheet

Send results to server | Clear worksheet | Close Window

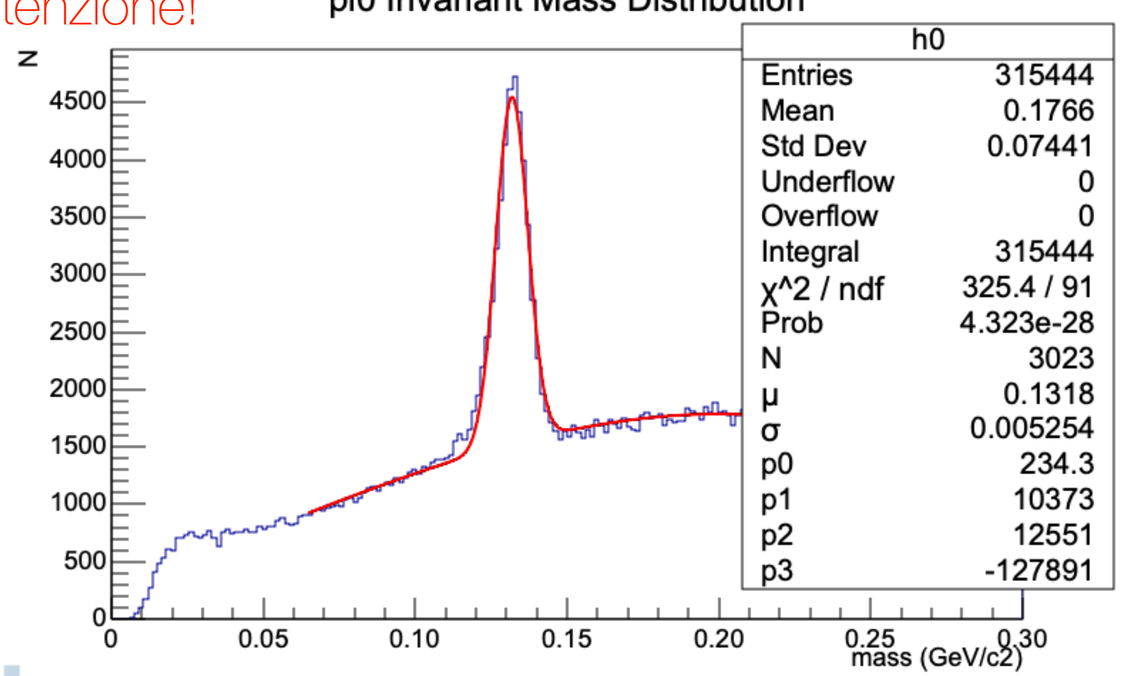
per cancellare **tutte** le missioni attenzione!

mission: 3
level: beginner
particle: pi
charge: 0
mass: 0.1318
width: 0.0053
events: 3023

Show diagram

Delete this mission

per cancellare i risultati di una missione



Mission 4: decay of a neutral kaon to charged pions

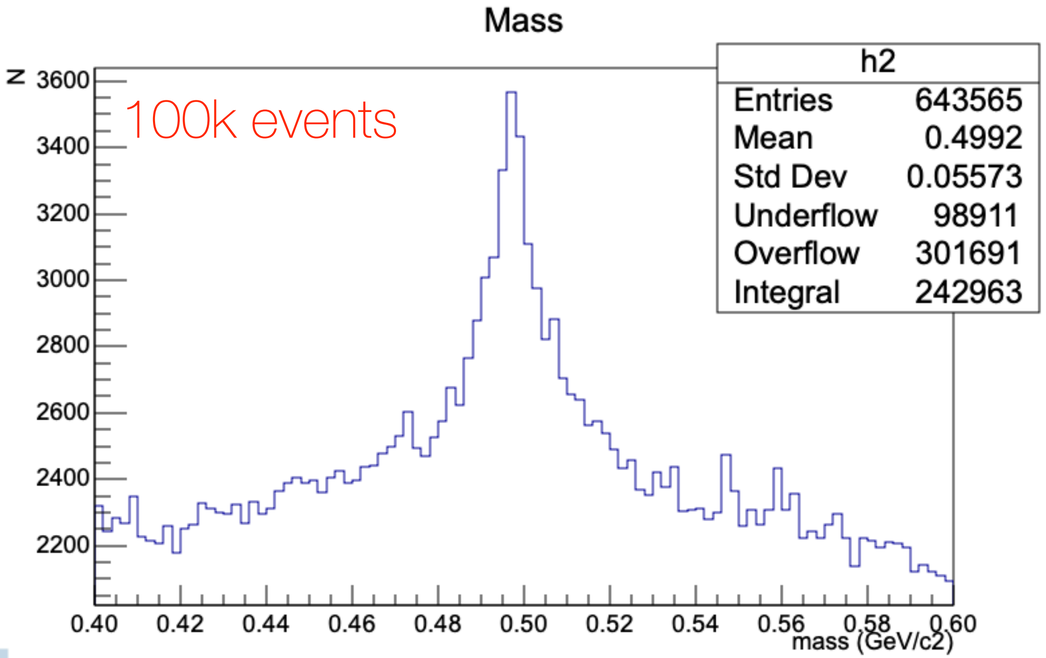
Plot the mass distribution of a neutral kaon K_s^0 which decays to two charged pions:

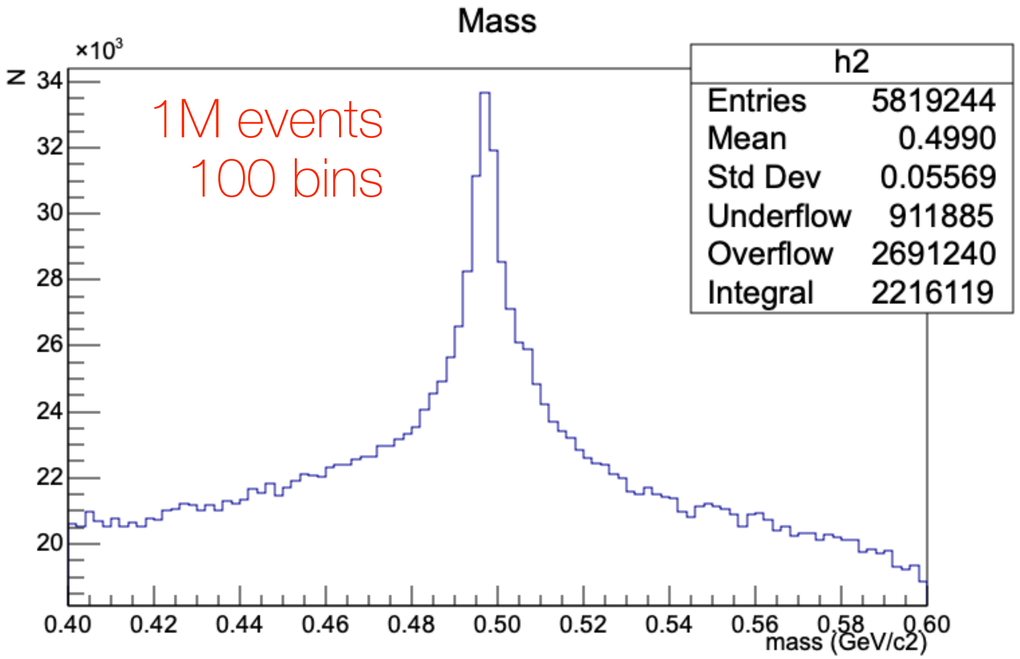
$$K_s^0 \longrightarrow \pi^+\pi^-$$

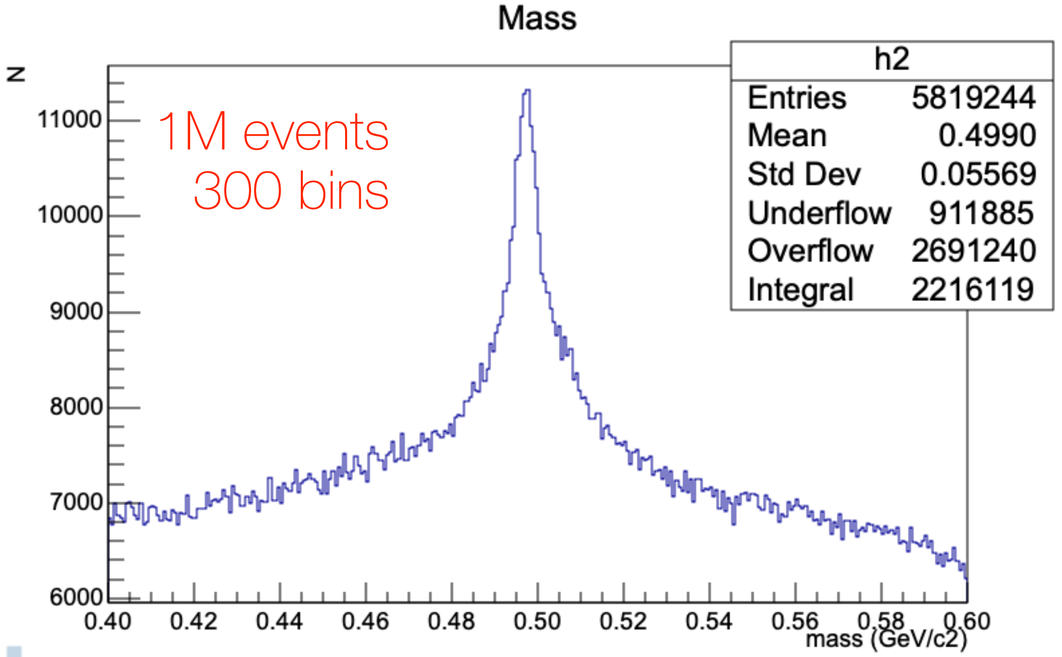
You will find a peak at $0.498\ \mathrm{GeV}/c^2$, which is exactly the mass of a K_s^0.

$K_S \to \pi^+\pi^-$

100 bins tra 0.4 GeV/c² e 0.6 GeV/c²:







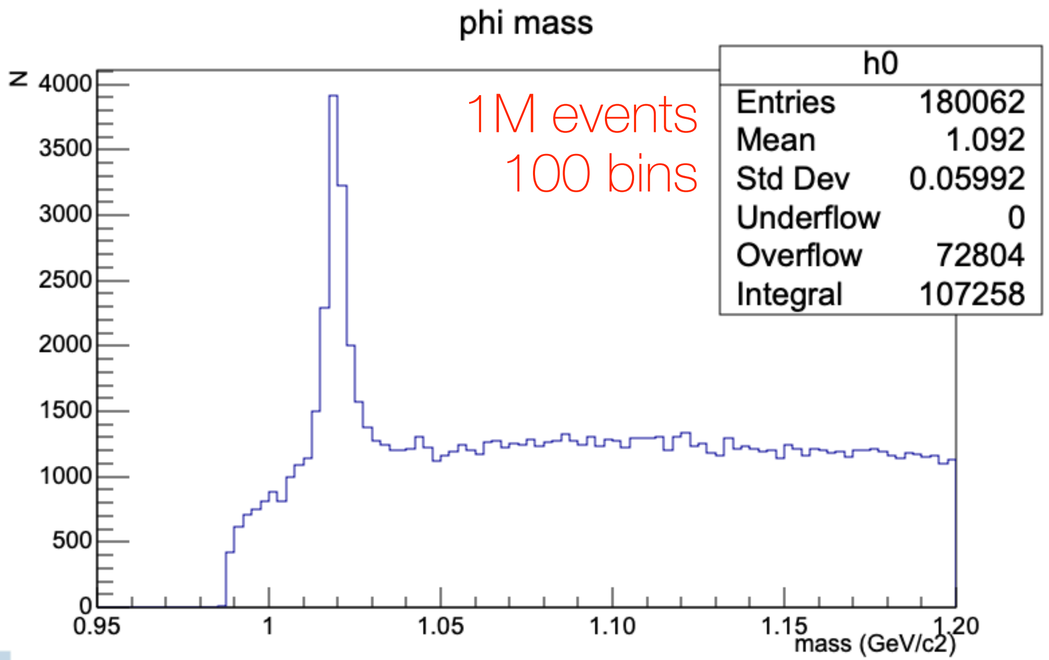
Mission 5: decay of a ϕ to charged kaons

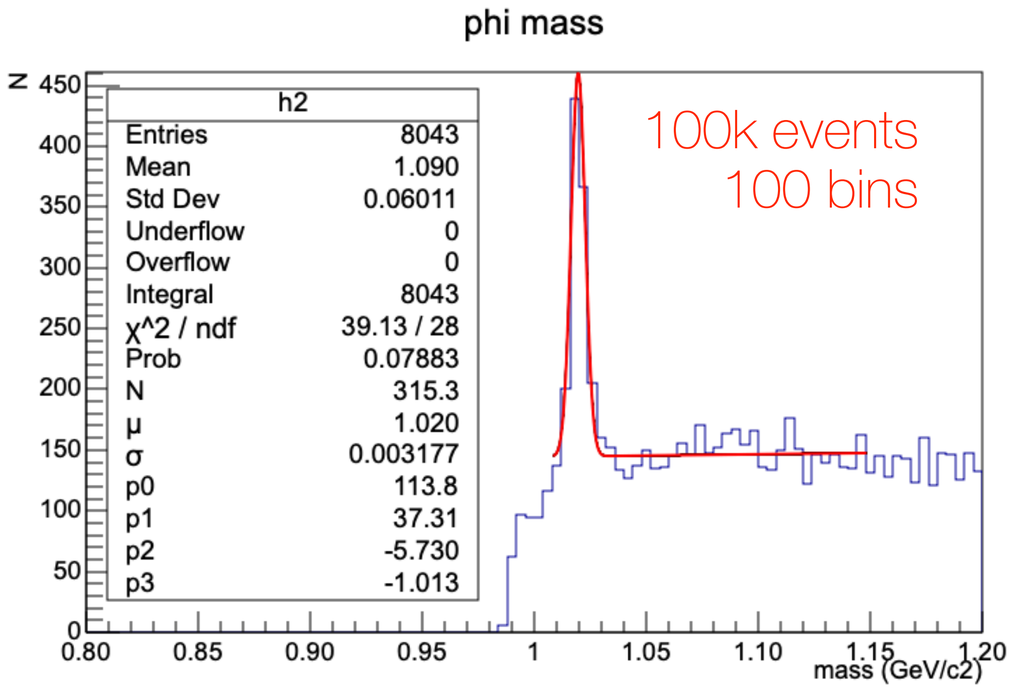
Plot the mass distribution of a ϕ meson which decays to two charged kaons:

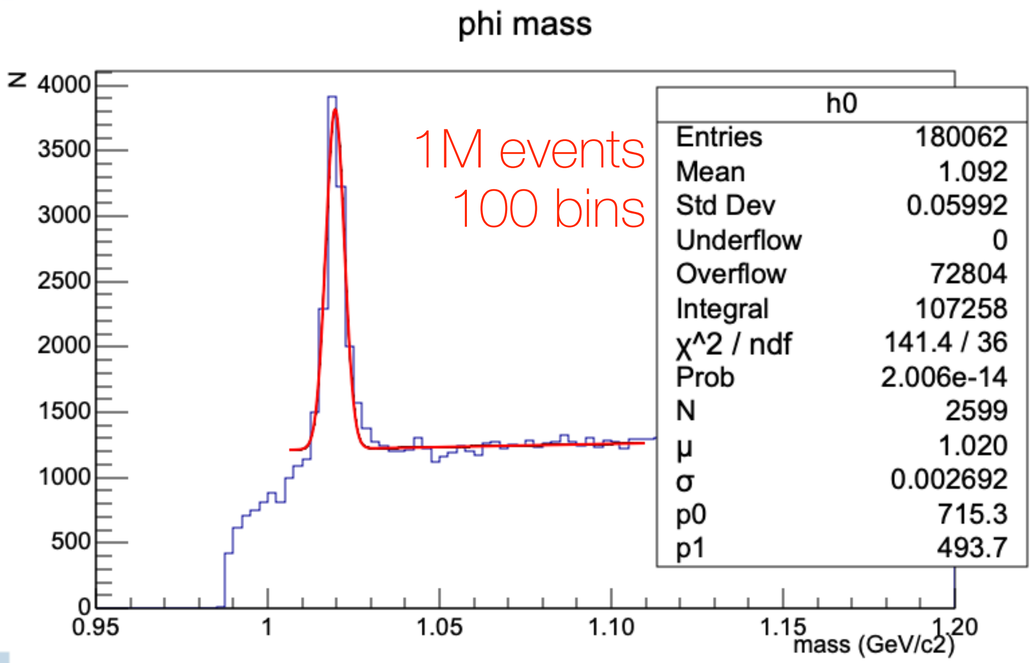
$$\phi \longrightarrow K^+K^-$$

You will find a peak at 1.02 GeV/c^2, which is exactly the mass of the ϕ.

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







Mission 6: decay of a J/ψ to charged leptons

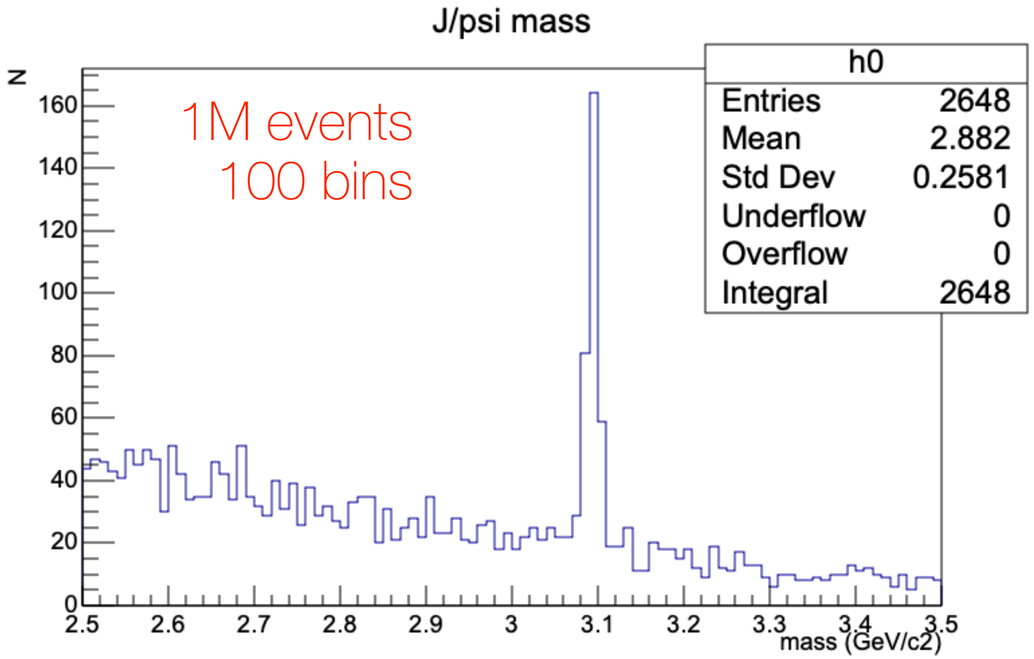
Plot the mass distribution of a J/ψ meson which decays to two leptons:

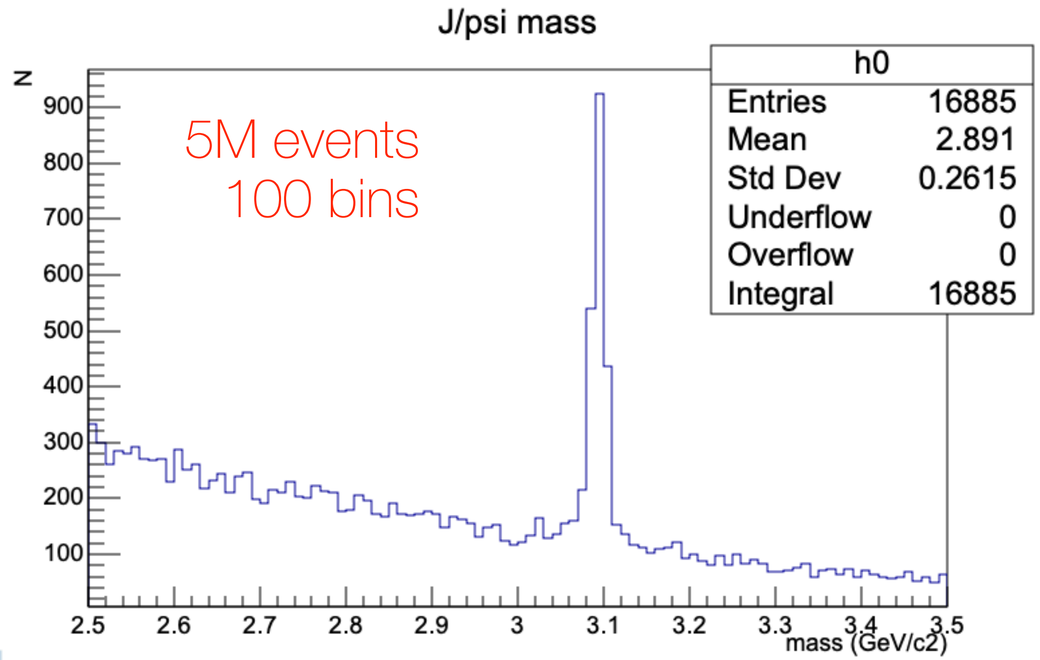
$$J/\psi \longrightarrow e^+e^- \quad \text{or} \quad J/\psi \longrightarrow \mu^+\mu^-$$

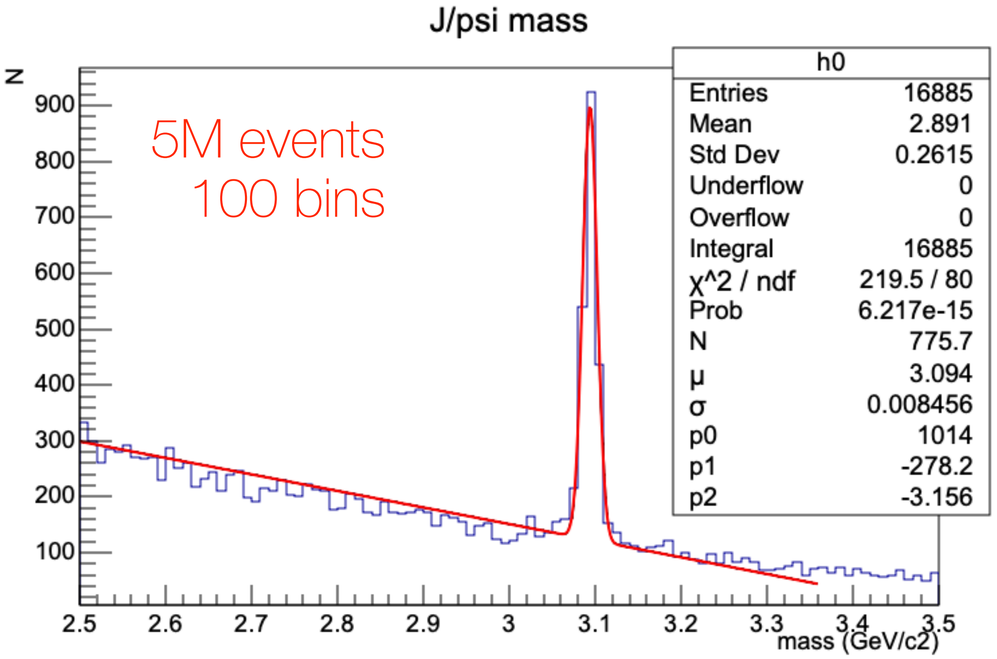
You will find a peak at $3.10\ \mathrm{GeV}/c^2$, which is exactly the mass of the J/ψ.

The probability for the production of a J/ψ is very small, so you will have to process at least 100000 events.

$J/\psi \rightarrow \mu^+\mu^-$







Mission 7: decay of a D^0 to charged kaons and pions

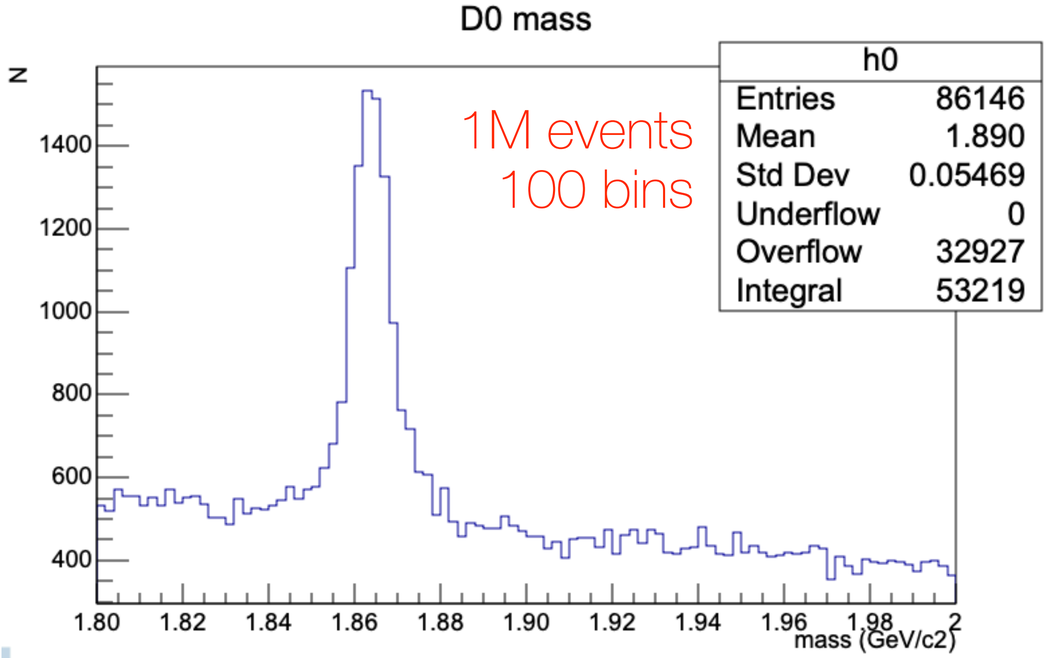
Plot the mass distribution of a neutral D^0 meson which decays to a combination of $K^+\pi^-$ or $K^-\pi^+$:

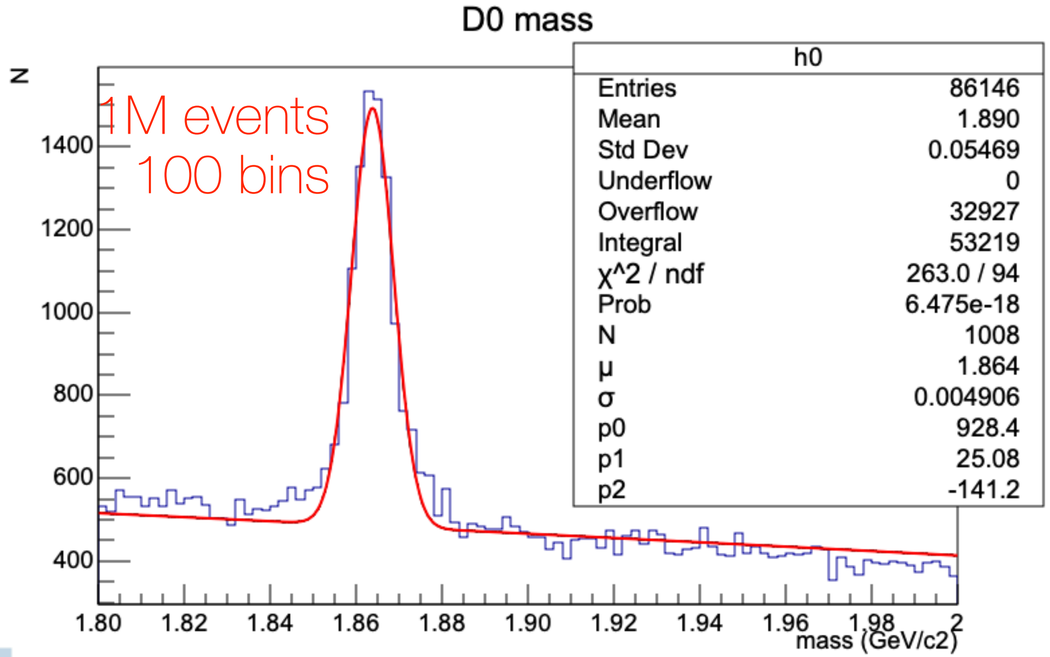
$$D^0 \longrightarrow K^+\pi^- \quad \text{or} \quad D^0 \to K^-\pi^+$$

You will find a peak at $1.86\ \mathrm{GeV}/c^2$, which is exactly the mass of the D^0.

The probability for a production of a D^0 is very small, so you will have to process at least 100000 events.

$$D^0 \to K^- \pi^+$$


D0 mass
N
1M events
100 bins
h0
Entries 86146
Mean 1.890
Std Dev 0.05469
Underflow 0
Overflow 32927
Integral 53219
1400
1200
1000
800
600
400
1.80 1.82 1.84 1.86 1.88 1.90 1.92 1.94 1.96 1.98 2
mass (GeV/c2)


D0 mass
N
1M events
100 bins
h0
Entries 86146
Mean 1.890
Std Dev 0.05469
Underflow 0
Overflow 32927
Integral 53219
χ^2 / ndf 263.0 / 94
Prob 6.475e-18
N 1008
μ 1.864
σ 0.004906
p0 928.4
p1 25.08
p2 -141.2
1400
1200
1000
800
600
400
1.80 1.82 1.84 1.86 1.88 1.90 1.92 1.94 1.96 1.98 2
mass (GeV/c2)

Mission 8: decay of a B^+ to a J/ψ and a charged kaon

Plot the mass distribution of a charged B meson which decays to a combination of J/ψ and K^+

$$B^+ \longrightarrow J/\psi K^+ \quad \text{or} \quad B^- \longrightarrow J/\psi K^-$$

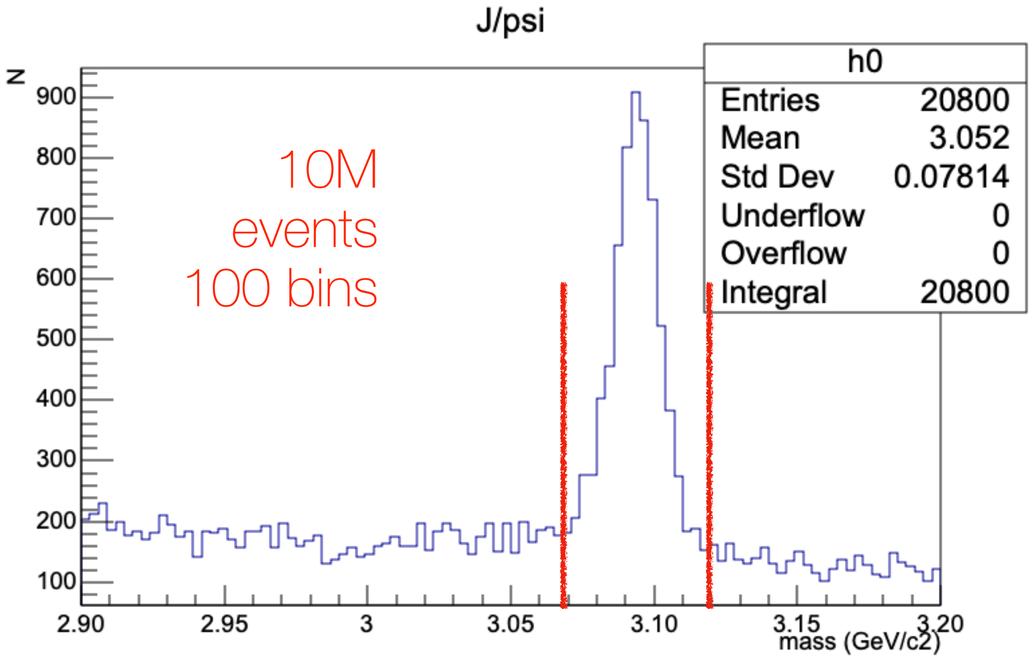
You will find a peak at $5.28\ \mathrm{GeV}/c^2$, which is exactly the mass of the B^+.

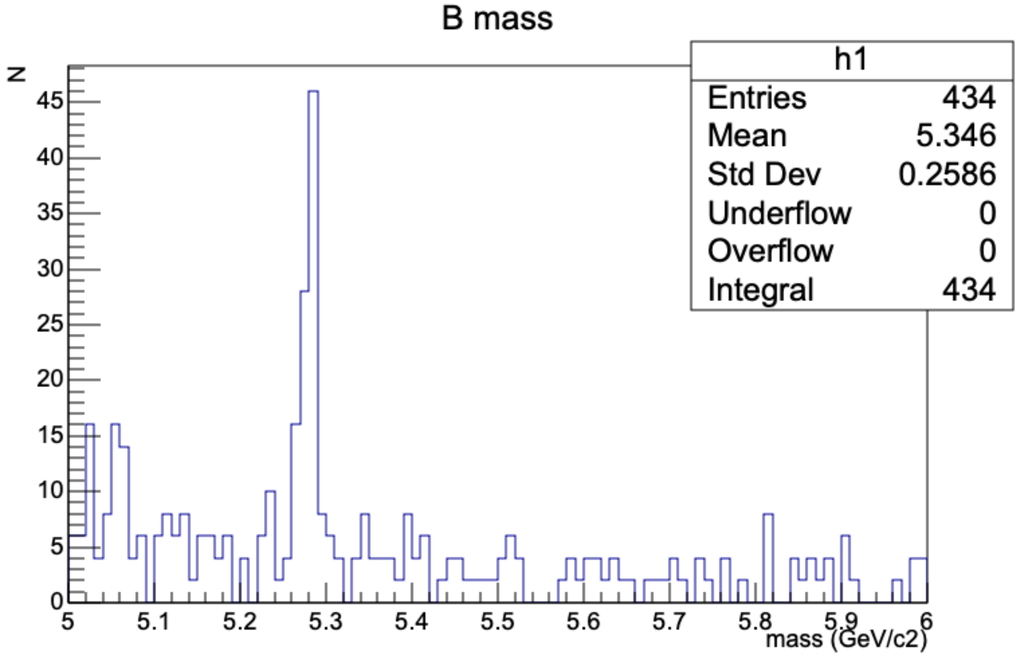
Use the green block "Combine two particles" and describe the process in two stages.

Be sure to select only the particles with an invariant mass very close to the J/ψ mass for further analysis.

$J/\psi \rightarrow \mu^+\mu^-$

$B^+ \rightarrow J/\psi K^+$





Mission 9: decay of a D^{*+} to a D^0 and a charged pion

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

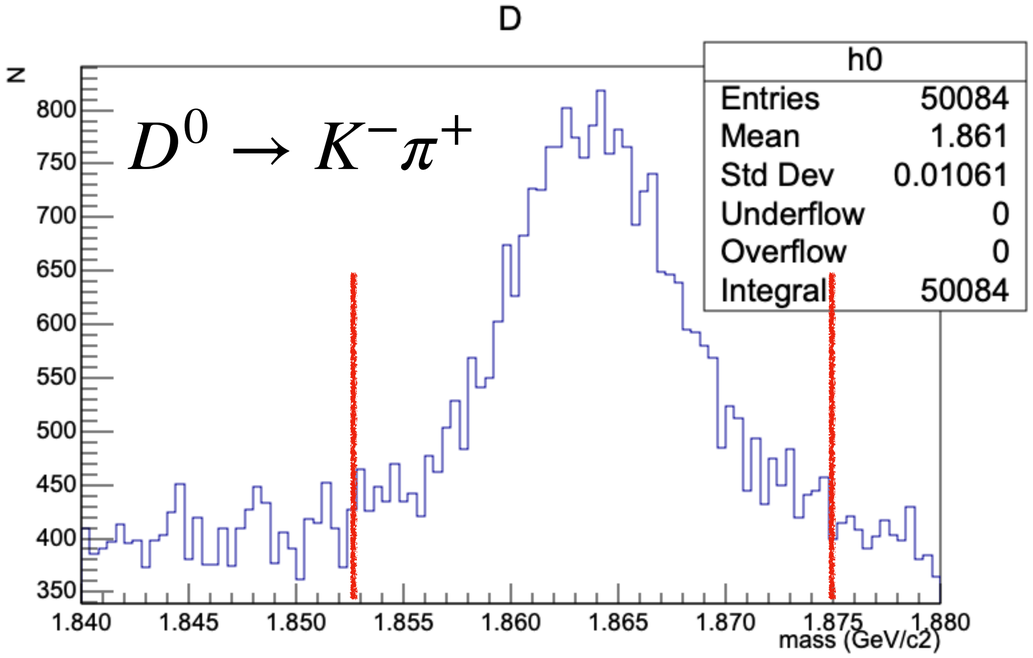
$$D^0 \longrightarrow K^+\pi^- \quad \text{or} \quad D^0 \longrightarrow K^-\pi^+$$

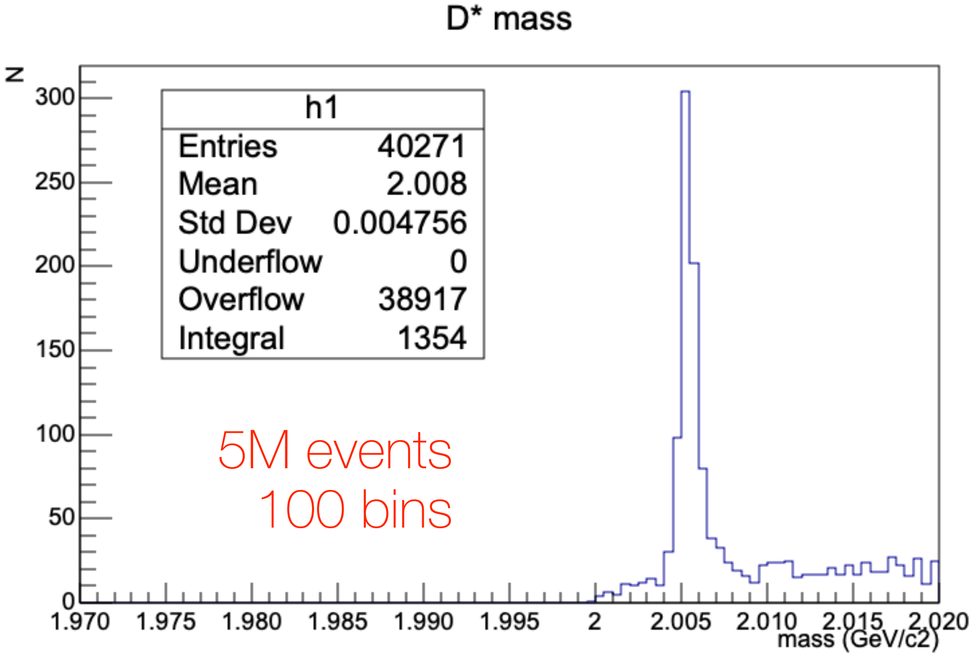
You will find a peak in the D^{*+} mass distribution at at $2.01\ \mathrm{GeV}/c^2$.

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

Be sure to select only the particles with an invariant mass very close to the D^0 mass for further analysis.

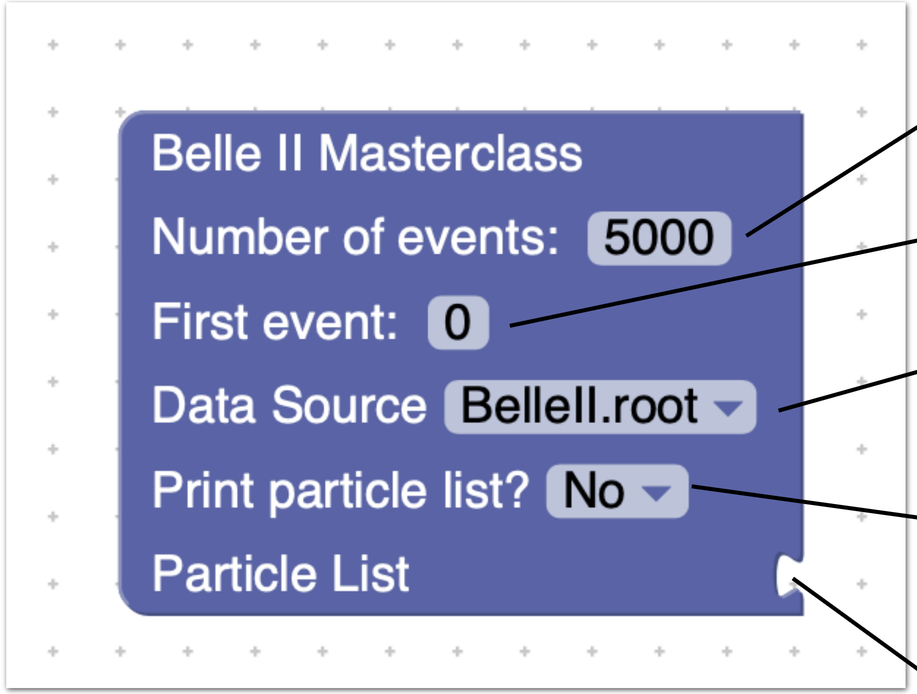
$D^{*+} \to D^0\pi^+, D^0 \to K\pi$





Blocco Viola

scelta del campione di dati



nel file ci sono poco meno di 8 milioni di eventi,
provate prima con pochi eventi (5000) e poi quando siete contenti delle vostre scelte, aumentate il numero di eventi ad esempio a 1 milione di eventi

il numero del primo evento, 0 va bene

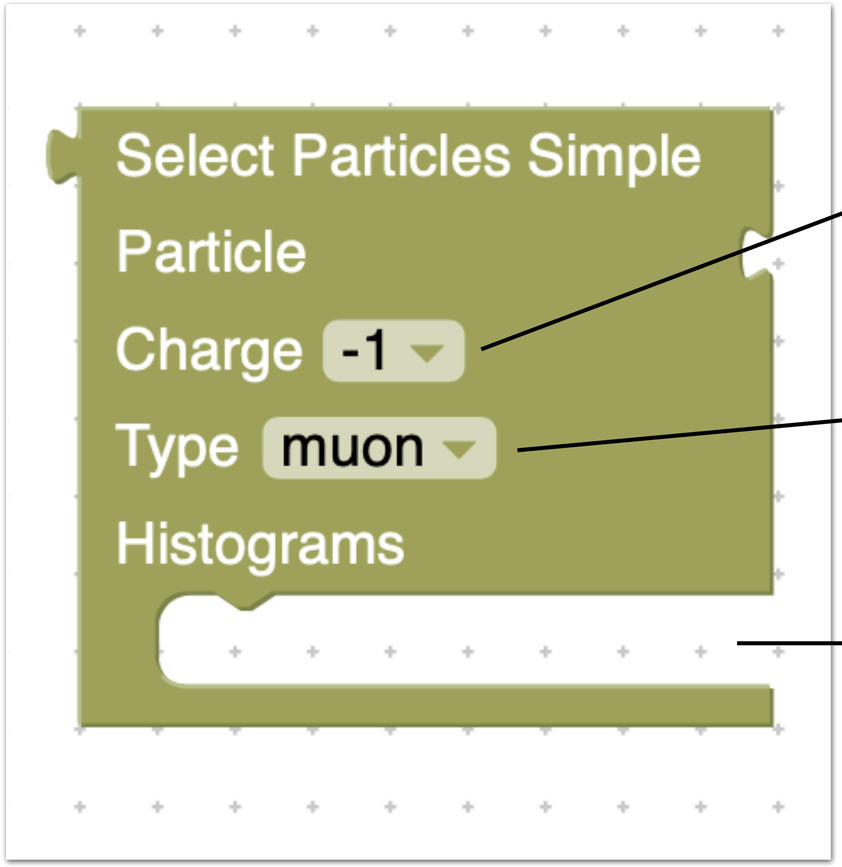
dovete selezionare il file BelleII.root

scegliete se stampare la lista di particelle finali per i primi eventi

ci attacherete il blocco verde che ricostruisce il decadimento di una particella in 2 particelle finali

Blocco Verde Felce

selezione delle particelle



scegliete la carica della particella

-1
0
1
Any

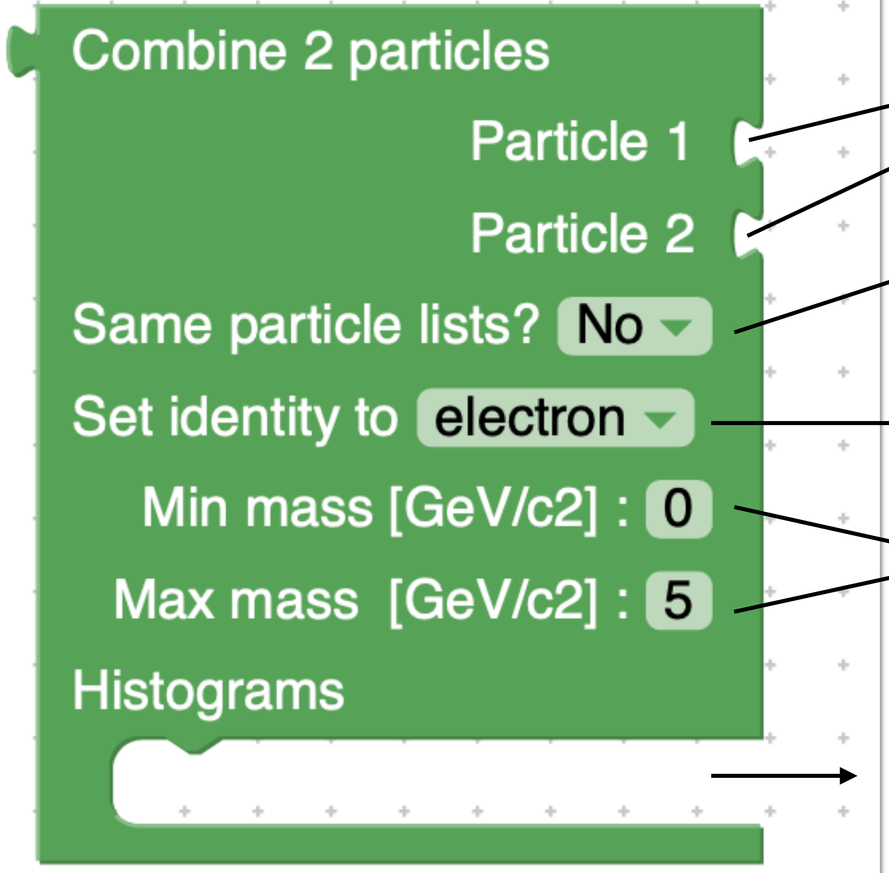
scegliete il tipo di particella

electron
muon
pion
kaon
proton
photon
Phi meson
D meson
D* meson
J/Psi meson
B meson
all particles

ci attaccherete il blocco marrone per la creazione di un istogramma per la particella selezionata

Blocco Verde

combinazione di due particelle



ci attaccherete il blocco verde felce per la selezione alle particelle finali in cui decade la particella che volete ricostruire

Particle1 & Particle2 non possono essere scelti dalla stessa la lista di particelle se sono diverse (carica, identità…)

selezionate l'identità della particella ricostruita

selezione delle particelle ricostruite utilizzando la loro massa invariante

ci attaccherete il blocco marrone per la creazione di un istogramma per la particella selezionata

Blocco Marrone

creazione istogrammi

scegliete il titolo dell'istogramma

scegliete il numero di bin dell'istogramma

scegliete il minimo e massimo dell'istogramma

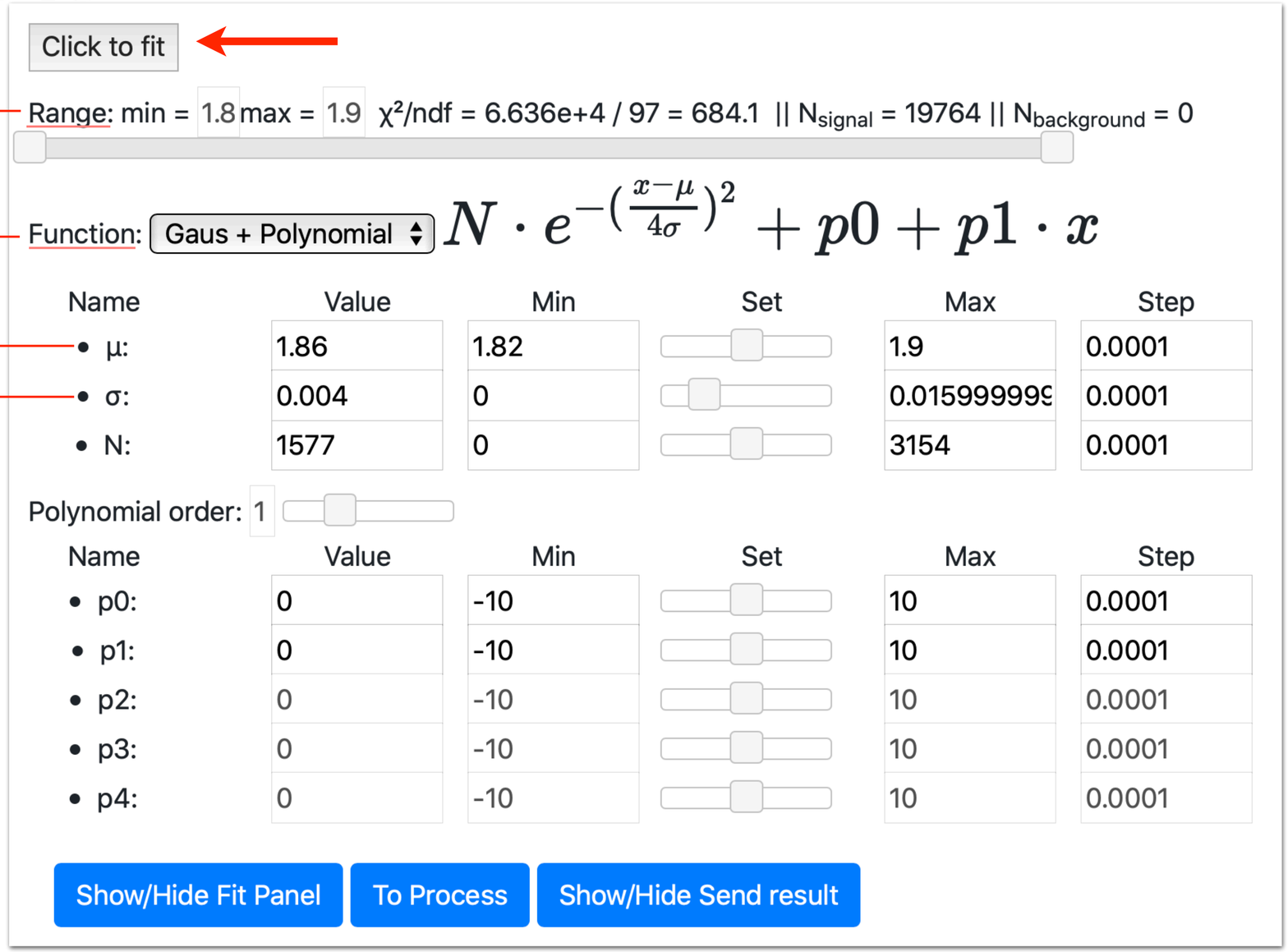
scegliete la variabile di cui fare l'istogramma

variabili di cui si possono fare istogrammi

- mass
- momentum
- energy
- charge
- identity
- polar angle
- cos(polar ang.)
- px
- py
- pz
- pT

Strumenti per il Fit

non è obbligatorio fare il fit a tutte le distribuzioni di massa invariante



scelta del dominio della funzione

scelta della funzione di fit

- Gaus
- Polynomial
- ✓Gaus + Polynomial

media

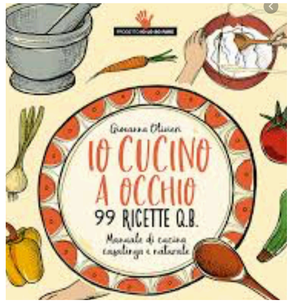
larghezza

prima di fare il fit bisogna aggiustare:

1. minimo e massimo valore che il parametro può acquistare
2. il valore di partenza di parametri (deve stare tra min e max!)
3. step: passi del fit per quel parametro

Stima dei Parametri

prima di fare il fit!



➡ funzione di fit:

$$N \cdot e^{-(\frac{x-\mu}{4\sigma})^2} + p0 + p1 \cdot x$$

- $1.86 < \mu < 1.87, \quad \mu_{\text{init}} = 1.85$
- $0.001 < \sigma < 0.01, \quad \sigma_{\text{init}} = 0.004$
- $600 < p_0 < 1000, \quad p_{0_{\text{init}}} = 800$
- $-10 < p_1 < 10, \quad p_{1_{\text{init}}} = 0$