

Analisi dei dati di Belle II

In pratica!

Belle II Masterclass 2024

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Ricostruirete alcuni Decadimenti...

... utilizzando i dati di *Belle II* !

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

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

1

$$K_S \rightarrow \pi^+\pi^-$$

2

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

3

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

4

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

5

→ vediamo l'organizzazione e gli strumenti che avrete a disposizione per l'analisi:

- ricostruzione, selezione, fit

Organizzazione

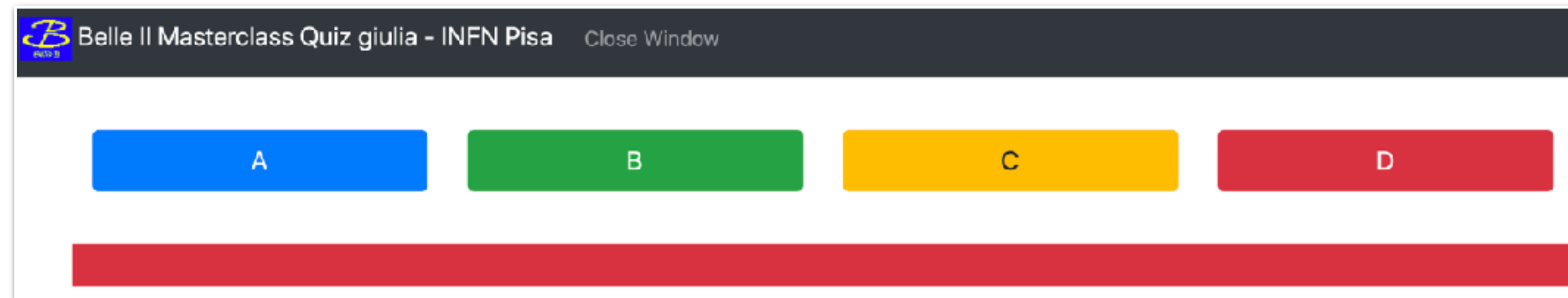
13:15	→ 15:45	Esercizi di analisi dati e preparazione presentazioni
15:45	→ 16:45	Video conferenza

- 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 arriverà in men che non si dica :)
- alla fine prepareremo 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

13:15	→ 15:45	Esercizi di analisi dati e preparazione presentazioni
15:45	→ 16:45	Video conferenza

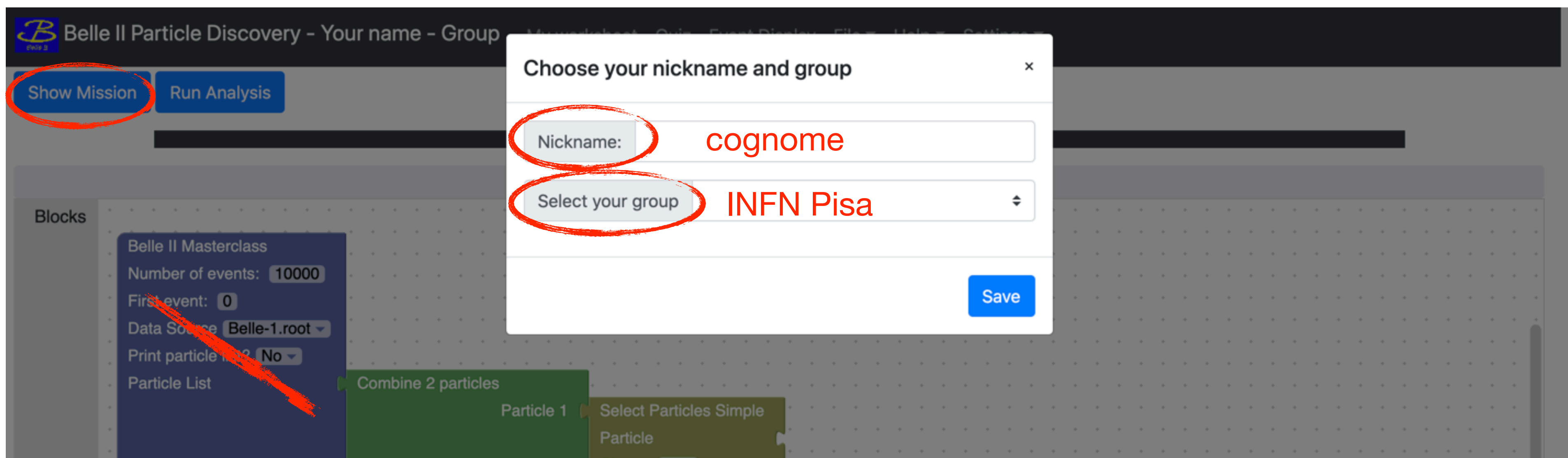
- Alla video conferenza parteciperanno le scuole che partecipano alla masterclass da altre città e ricercatori collegati da KEK
 - durante la video conferenza ci saranno le presentazioni del lavoro degli studenti
- Ci sarà anche un quiz, ma non si vince nulla :'-(,a risposta multipla
 - collegandosi 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

Choose your nickname and group

Nickname: Giulia

Select your group: INFN Pisa

Save

Belle II Particle Discovery - Giulia - INFN Pisa

My worksheet Quiz Event Display File Help Settings

Show Mission Run Analysis

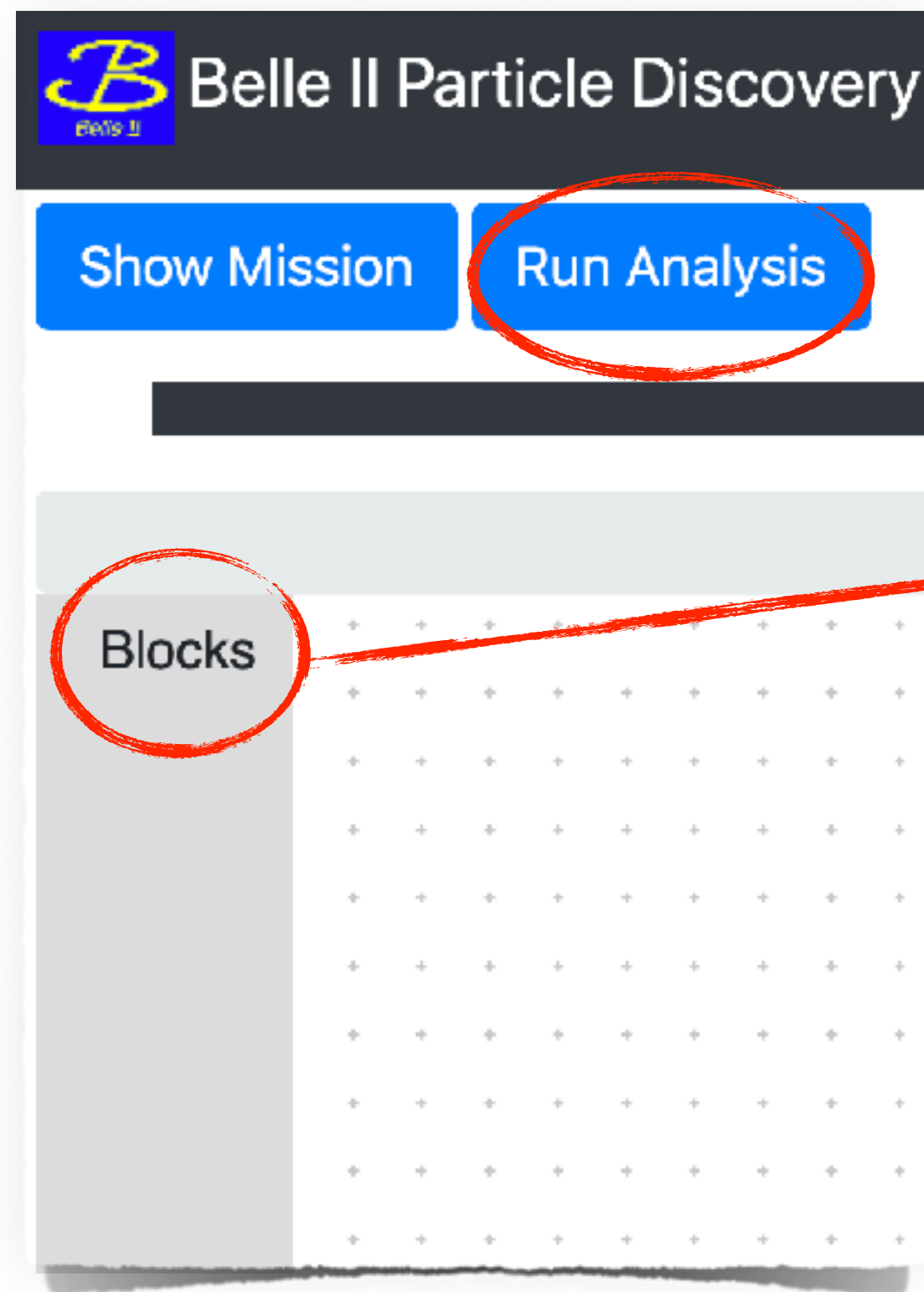
Blocks

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



sceita del campione di dati

Belle II Masterclass

Number of events: 5000

First event: 0

Data Source BelleII.root

Print particle list? No

Particle List

creazione dell'istogramma

Histogram Title Mass Number of bins 200 Min: 0 Max: 5 Variable mass

combinazione di 2 particelle

selezione

Select Particles Simple

Particle

Charge -1

Type muon

Histograms

Combine 2 particles

Particle 1

Particle 2

Same particle lists? No

Set identity to electron

Min mass [GeV/c²]: 0

Max mass [GeV/c²]: 5

Histograms

Esempio

piano di lavoro

selezionare
Belle-exp26.root

decide se scrivere a
schermo la lista delle
particelle finali per ogni
evento
& crea l'istogramma del
numero delle particelle
finali

The screenshot shows the Belle II Masterclass interface with the following settings:

- Belle II Masterclass**
- Number of events: 10000000
- First event: 0
- Data Source: BelleII-exp26.root
- Print particle list? No
- Particle List

Combine 2 particles

- Particle 1: Select Particles Simple, Particle, Charge 1, Type kaon, Histograms
- Particle 2: Select Particles Simple, Particle, Charge -1, Type kaon, Histograms

D^0

- Same particle lists? No
- Set identity to D meson
- Min mass [GeV/c²]: 0
- Max mass [GeV/c²]: 20
- Histograms

Histogram: Title D0 Mass Nbins 100 Min: 1.7000000000000002 Max: 2 Variable mass

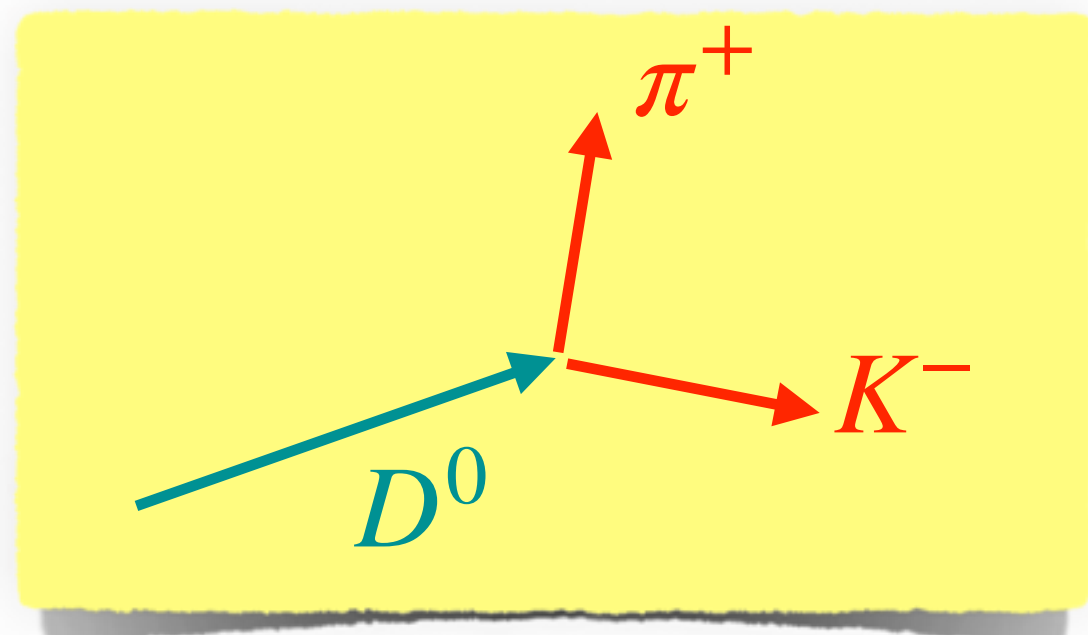
K^+

seleziono i K positivi

K^-

seleziono i K negativi

creo l'istogramma della massa
invariante delle coppie di K



Show Mission

Run Analysis

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 described 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

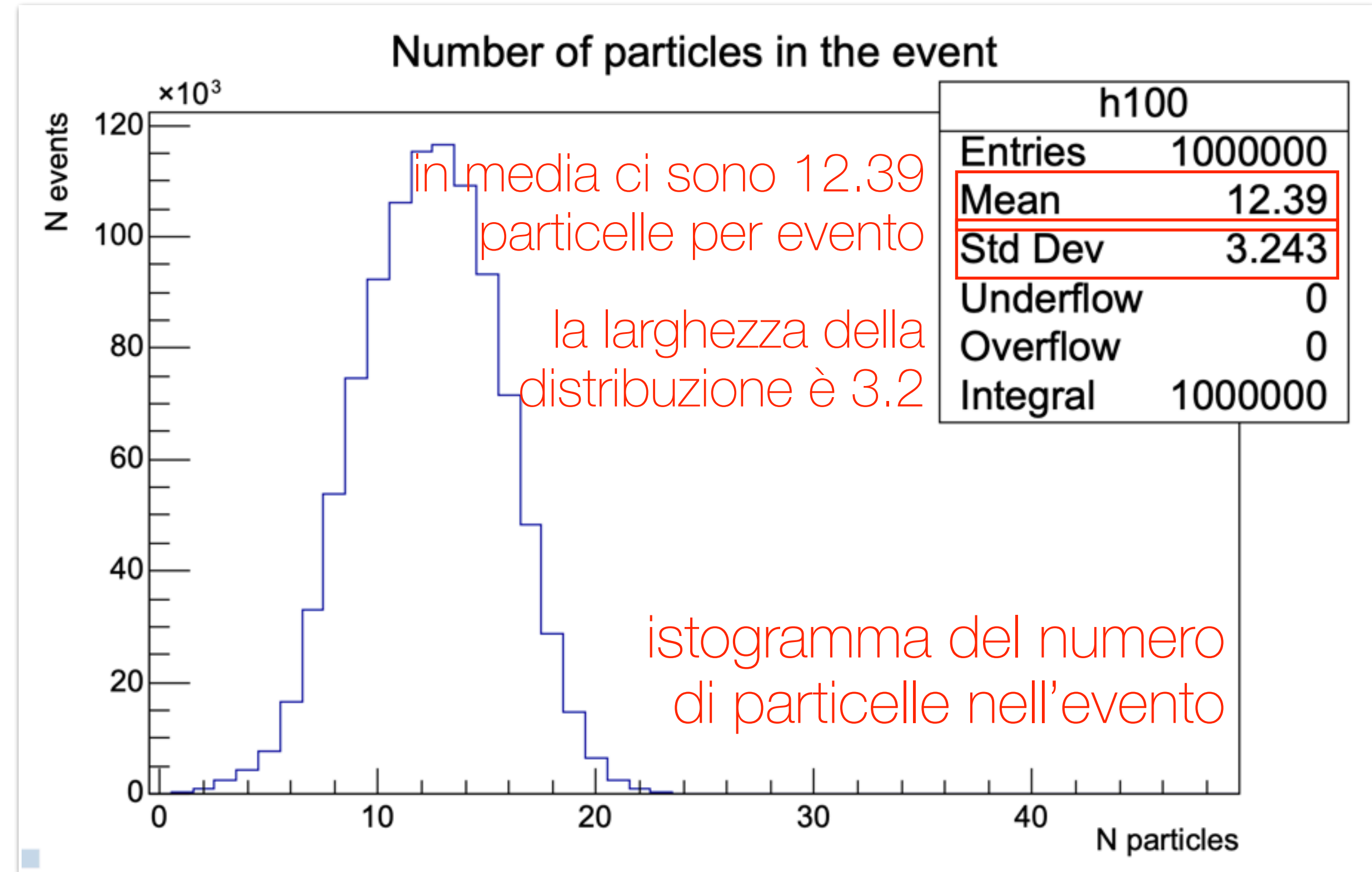
Print particle list? Yes

Particle properties x

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

- 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

ctrl-click su una
particella



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 x

px [GeV/c]	py [GeV/c]	pz [GeV/c]	E [GeV/c ²]	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

Next

Run Analysis

che massa ha il fotone?

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 and we call it invariant mass:

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

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/c²;
- From 0 to 0.0005 GeV/c².

il π^\pm esiste? che massa ha?

il π^0 esiste? che massa ha?

Next Run Analysis

che massa ha il fotone?

zero!

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 and we call it invariant mass:

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

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/c²;
- From 0 to 0.0005 GeV/c².

il π^\pm esiste? che massa ha?
si, ha una massa di 139.6 MeV/c²

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

Next

Run Analysis

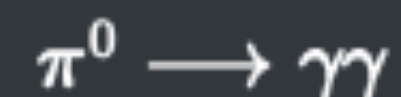
Mission 3: decay of a neutral pion to photons

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

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

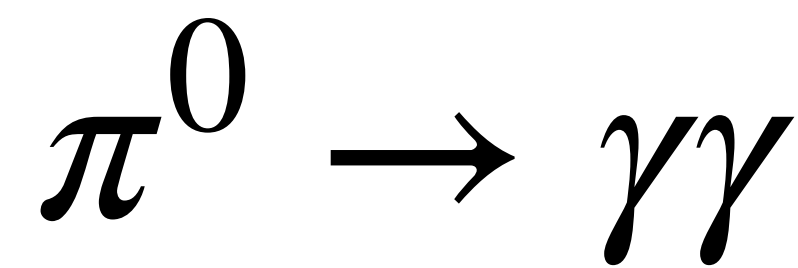
"Combine two particles" (green) block calculates the mass of the combined particle for each combination of particles.

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



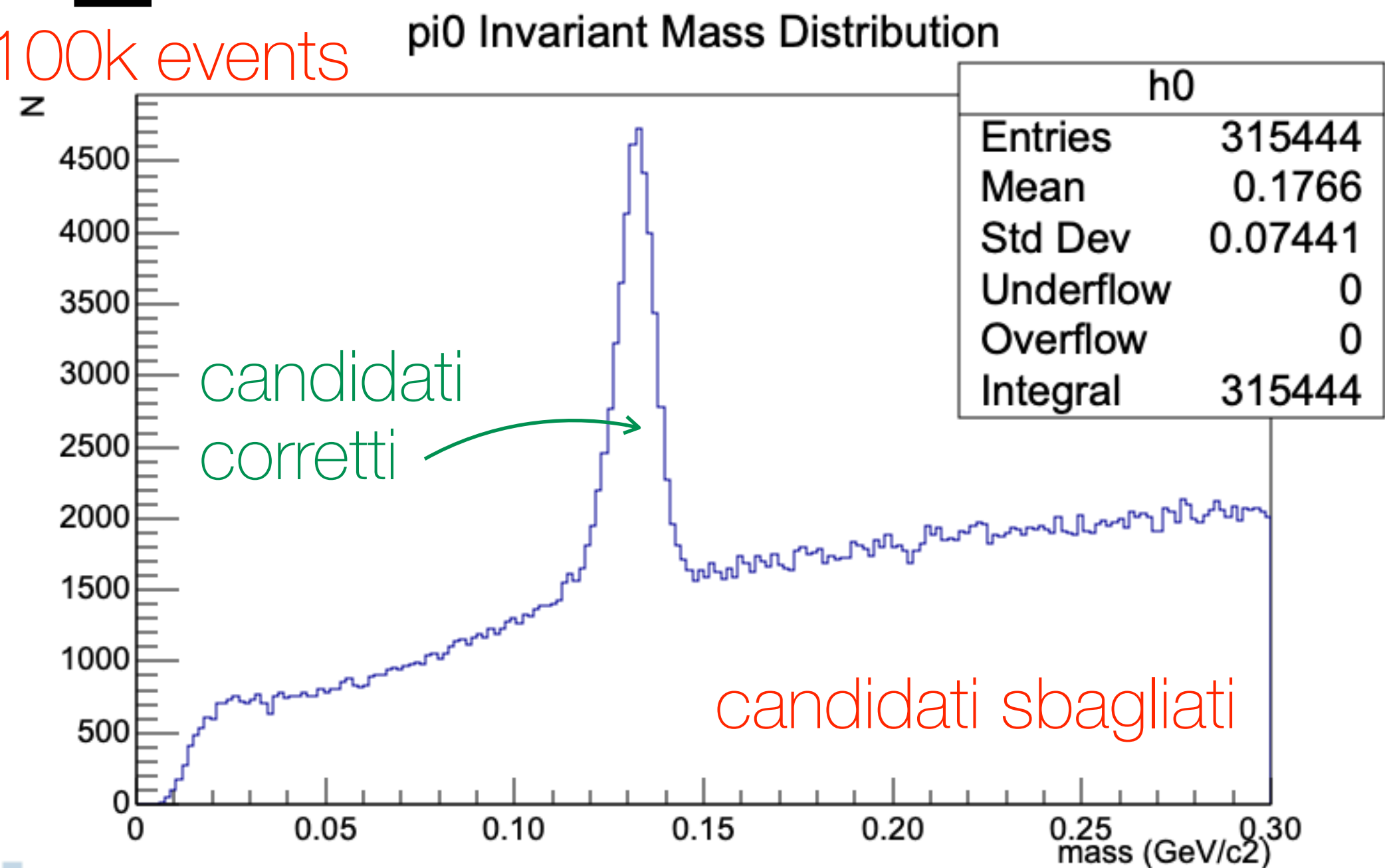
You will find a peak at $0.135 \text{ GeV}/c^2$, which is exactly the mass of a neutral pion π^0 .

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

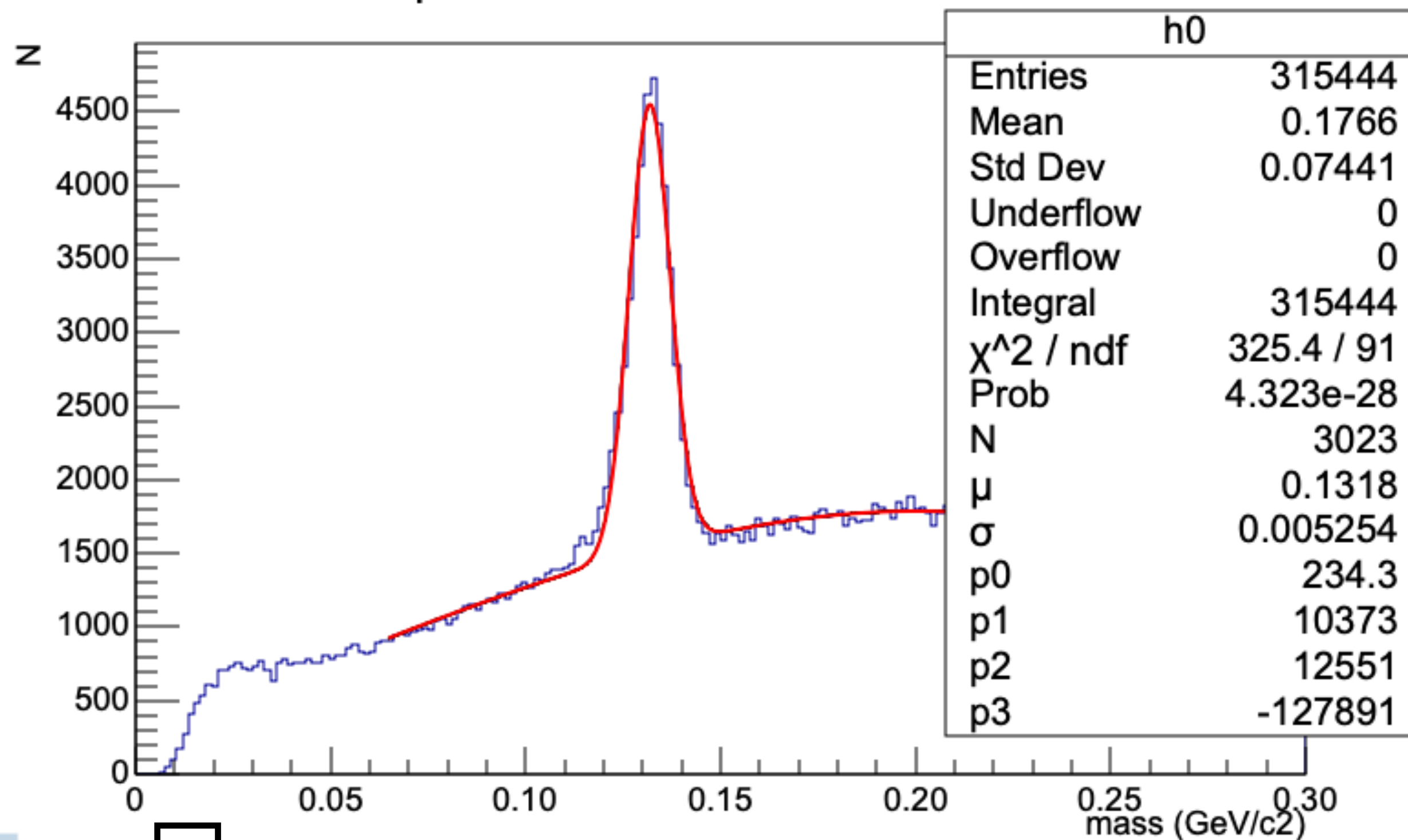


1 200 bins tra 0 GeV/c² e 0.3 GeV/c²:

100k events



pi0 Invariant Mass Distribution



3

Click to fit

Range: min = 0.0 max = 0.2 $\chi^2/\text{ndf} = 326.7 / 91 = 3.590$ || $N_{\text{signal}} = 26774$ || $N_{\text{background}} = 146765$

Function: Gaus + Polynomial $N \cdot e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2} + p_0 + p_1 \cdot x + p_2 \cdot x^2 + p_3 \cdot x^3$

Name	Value	Min	Set	Max	Step
μ :	0.1318	0.12	<input type="checkbox"/>	0.155959982	0.0001
σ :	0.0053	0	<input type="checkbox"/>	0.070925268	0.0001
N:	3023.0468	0	<input type="checkbox"/>	9458	0.0001

Polynomial order: 3

Name	Value	Min	Set	Max	Step
p0:	234.2675	0	<input type="checkbox"/>	1000	0.0001
p1:	10372.5148	0	<input type="checkbox"/>	100000	0.0001
p2:	12551.3793	-10	<input type="checkbox"/>	25548.09016	0.0001
p3:	-127890.661	-133260.806	<input type="checkbox"/>	10	0.0001
p4:	0	-10	<input type="checkbox"/>	10	0.0001

2

Show/Hide Fit Panel To Process Show/Hide Send result

Particle name: pi

Particle charge: 0

Mass [GeV/c²]: 0.1318

Width [GeV/c²]: 0.0053

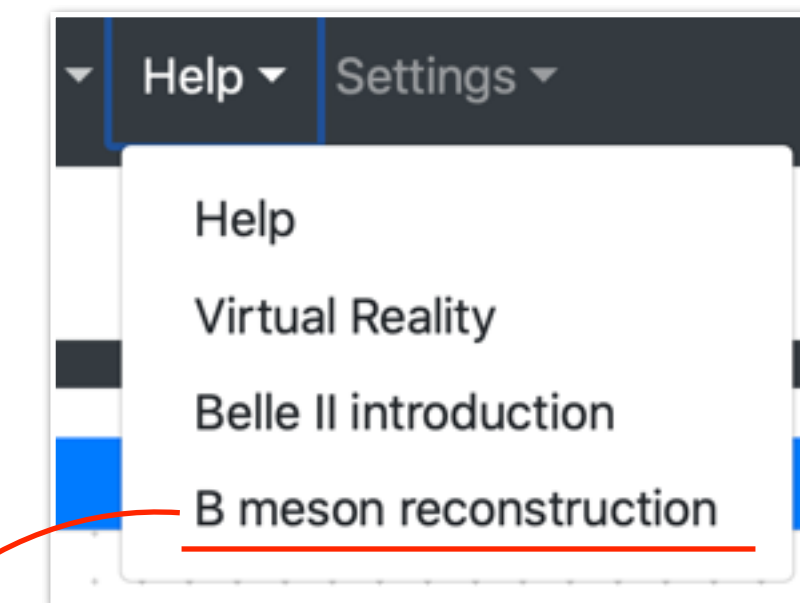
Events: 3023

Save to your worksheet

4

5

Controlla il Risultato e Spediscilo



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

On the way to a B meson

1. $\pi^0 \rightarrow ???$ π^0 mass GeV/c² Congratulations, you have reconstructed a π^0 meson!

→ poi sottomettete i risultati riempiendo i campi sotto:

Particle name:

Particle charge:

Mass [GeV/c²]:

Width [GeV/c²]:

Events:

inserite il 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

Send results to server **Clear worksheet** Close Window

per cancellare **tutte** le missioni attenzione!

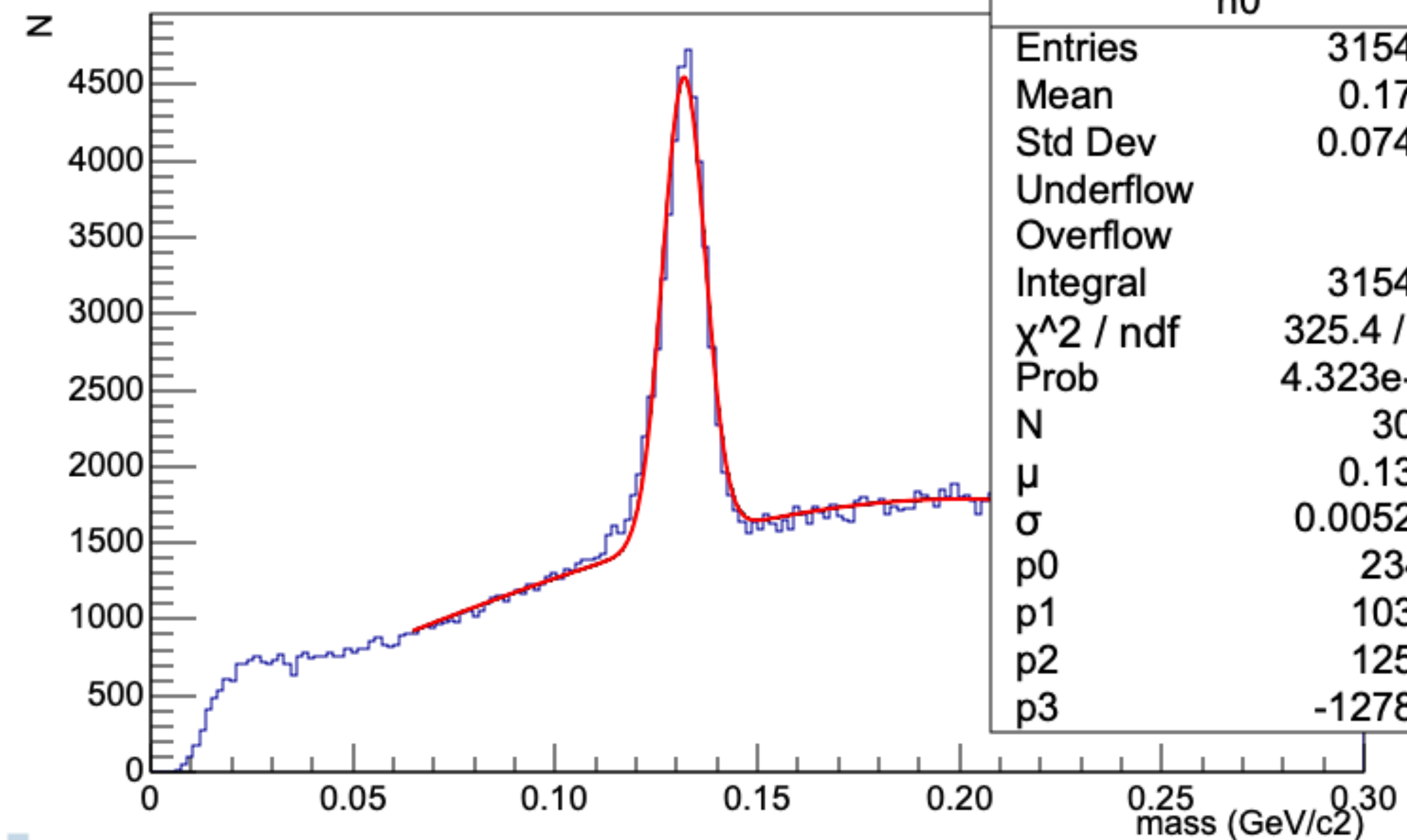
mission: 3
 level: beginner
 particle: pi
 charge: 0
 mass: 0.1318
 width: 0.0053
 events: 3023

Show diagram

Delete this mission

per cancellare i risultati di una missione

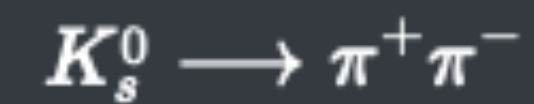
pi0 Invariant Mass Distribution



[Next](#) [Run Analysis](#)

Mission 4: decay of a neutral kaon to charged pions

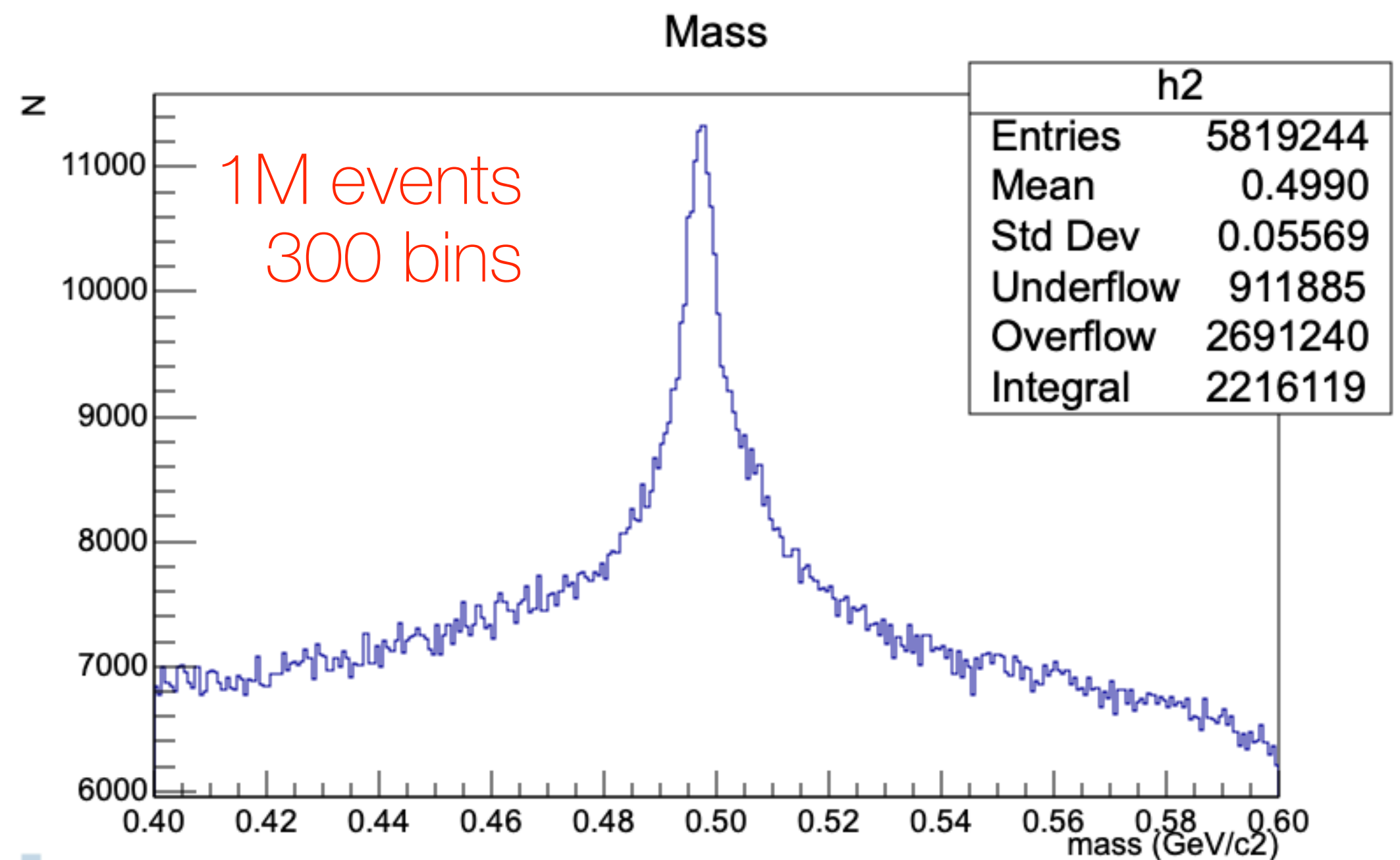
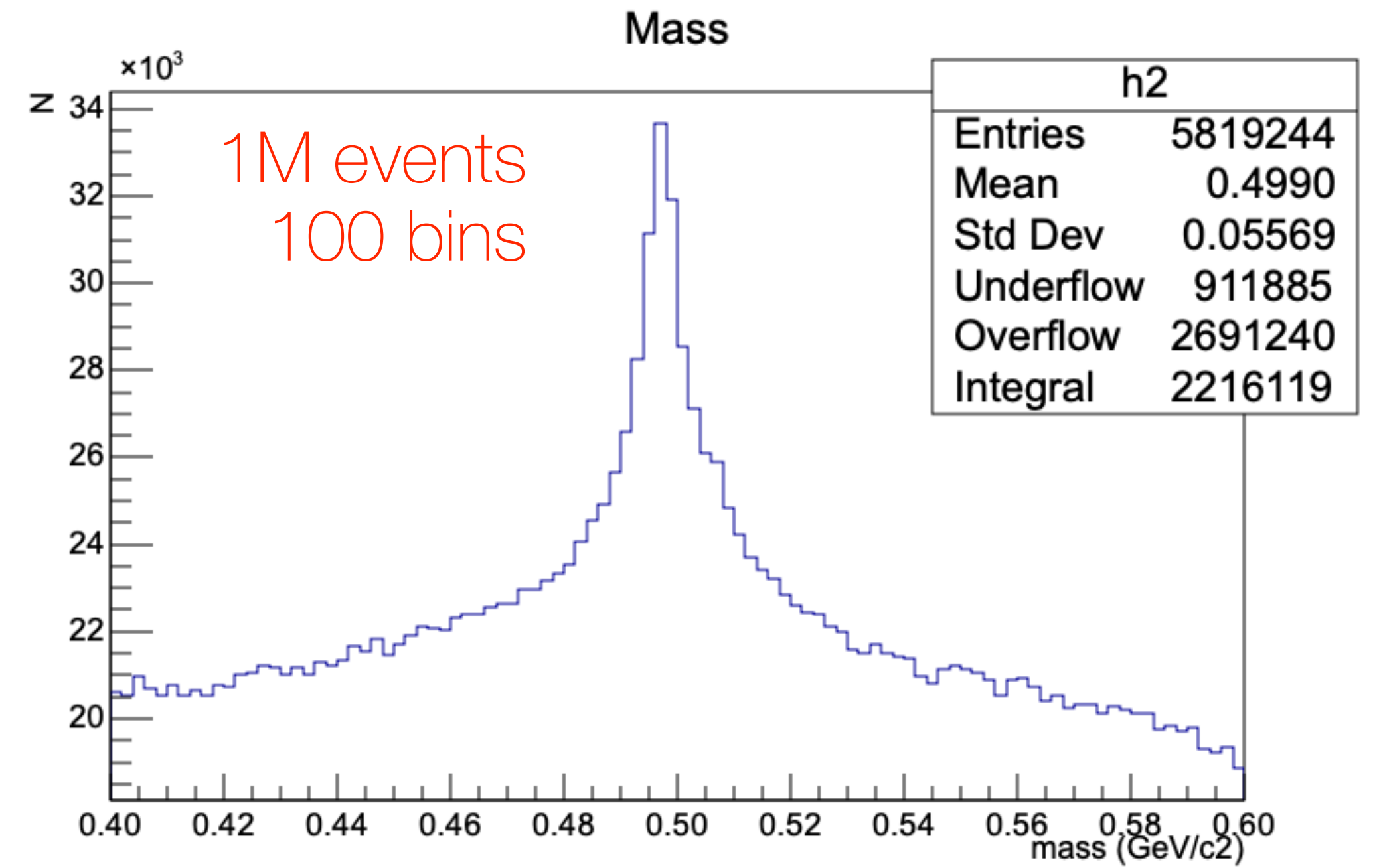
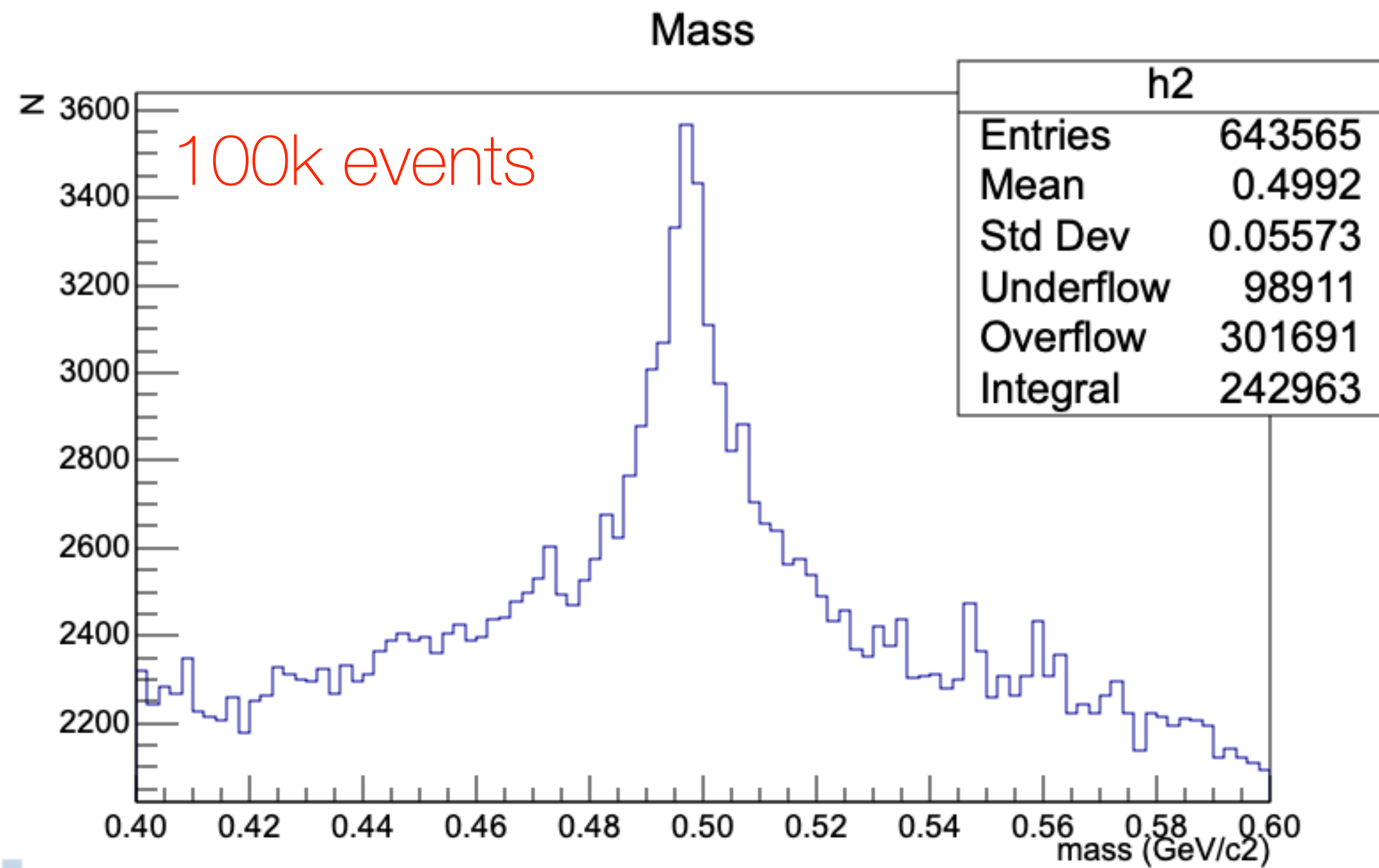
Plot the mass distribution of a neutral kaon K_s^0 which decays to two charged pions:



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

$$K_S \rightarrow \pi^+ \pi^-$$

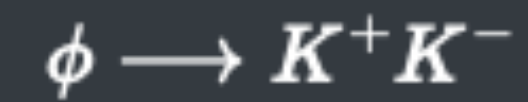
100 bins tra 0.4 GeV/c² e 0.6 GeV/c²:



[Next](#) [Run Analysis](#)

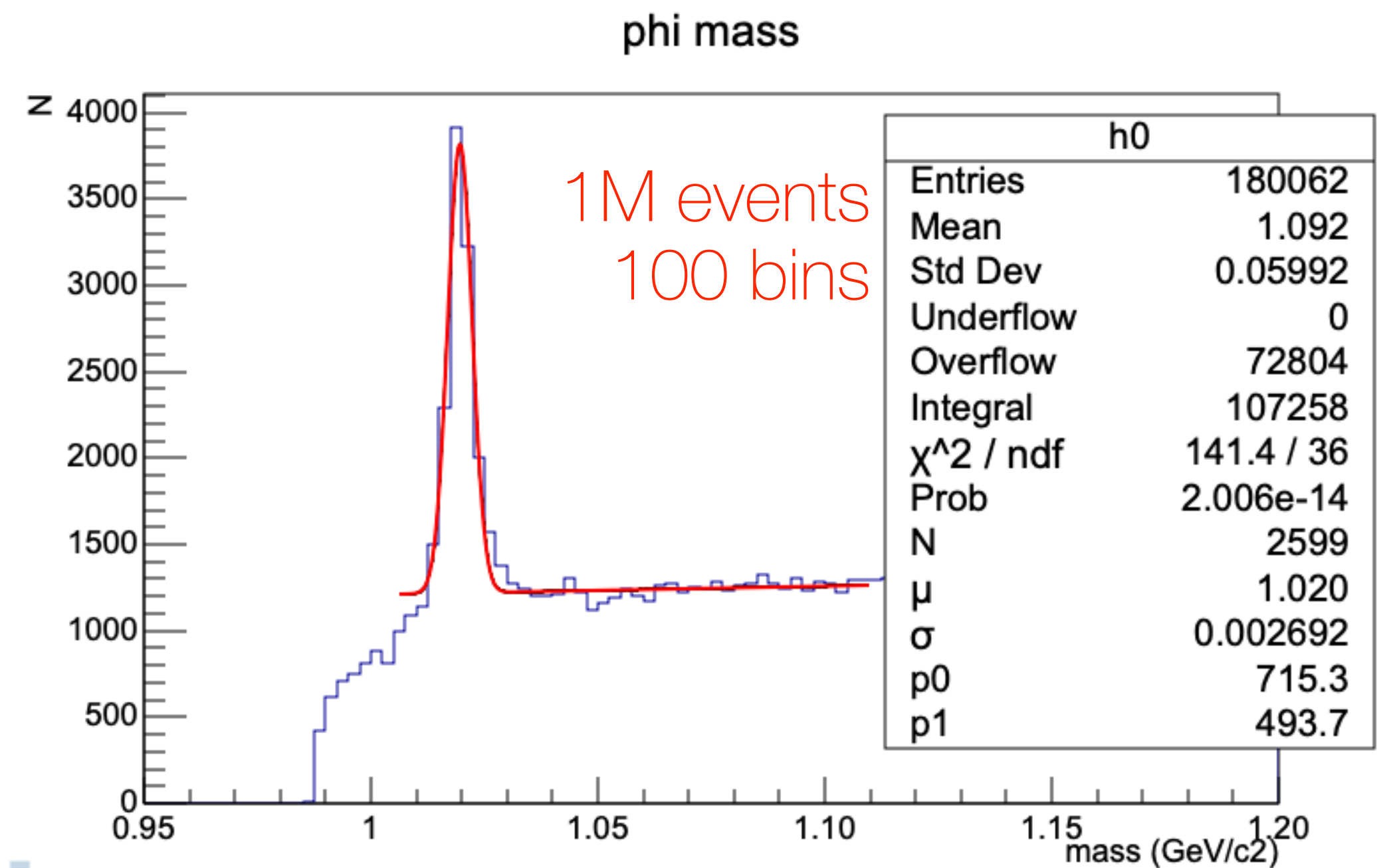
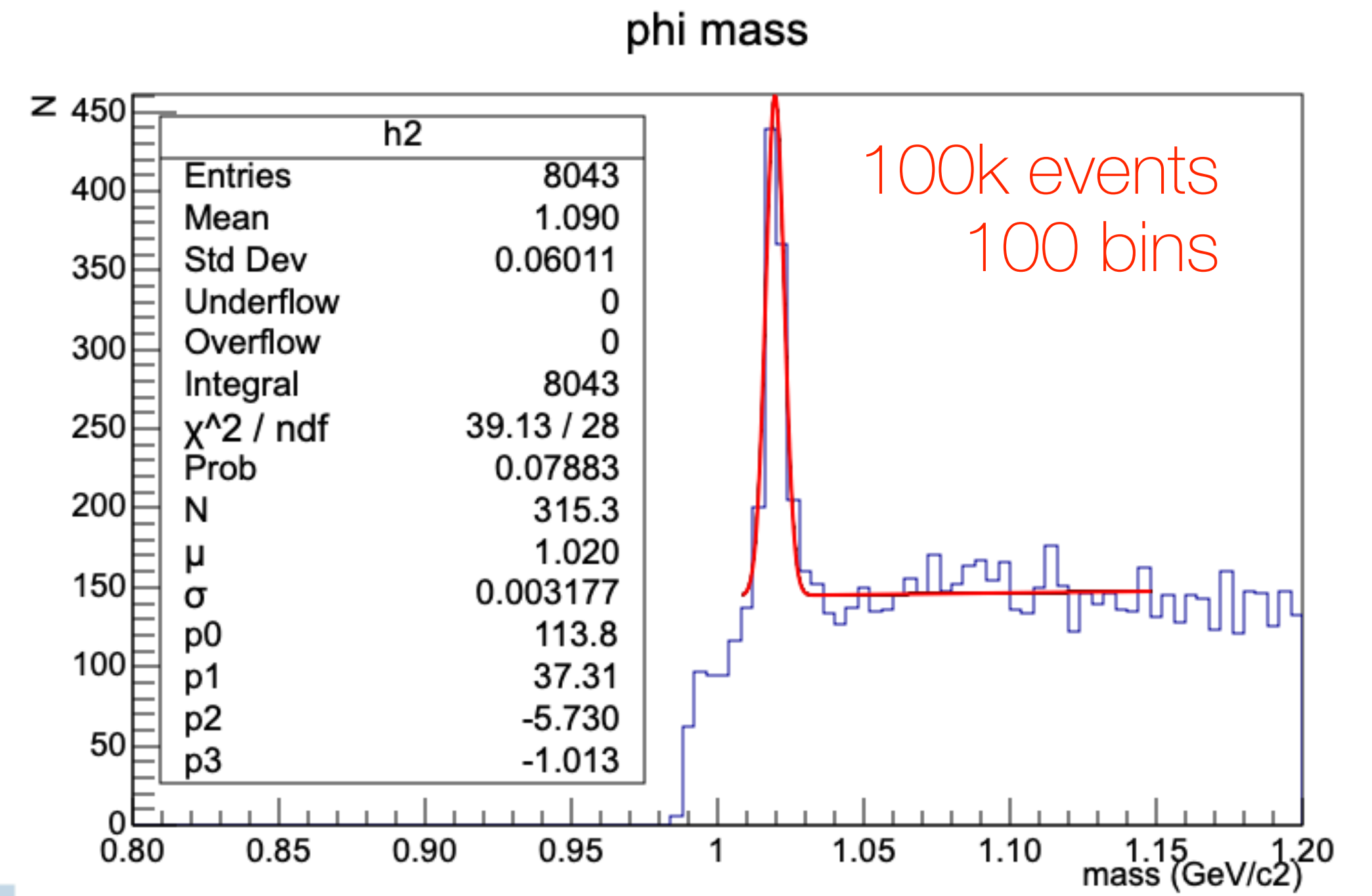
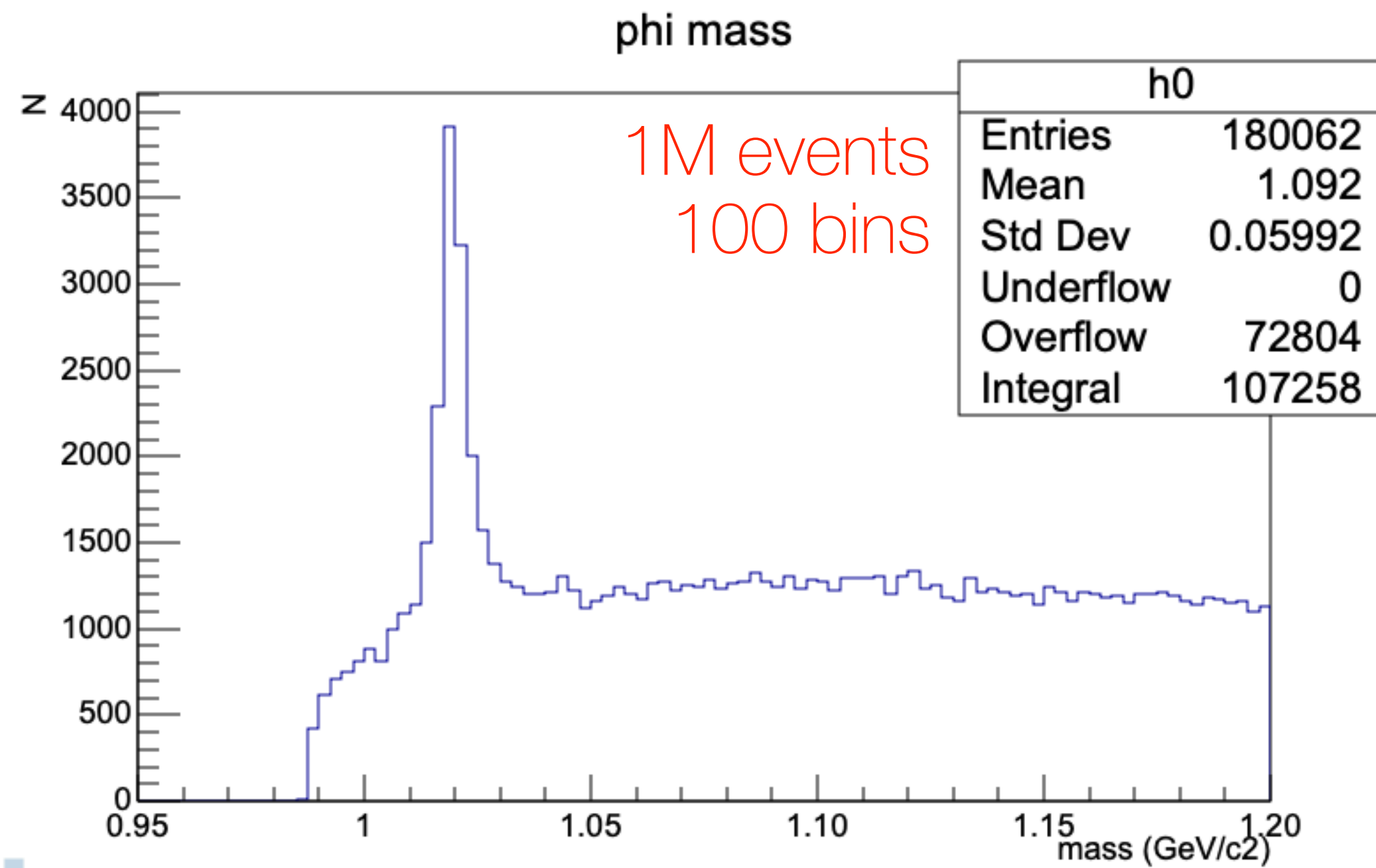
Mission 5: decay of a ϕ to charged kaons

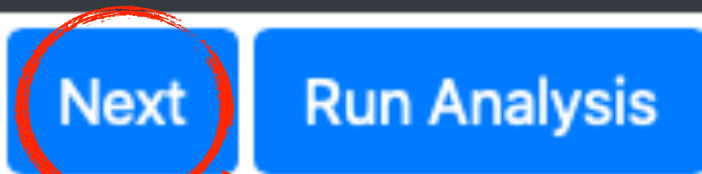
Plot the mass distribution of a ϕ meson which decays to two charged kaons:



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

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





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

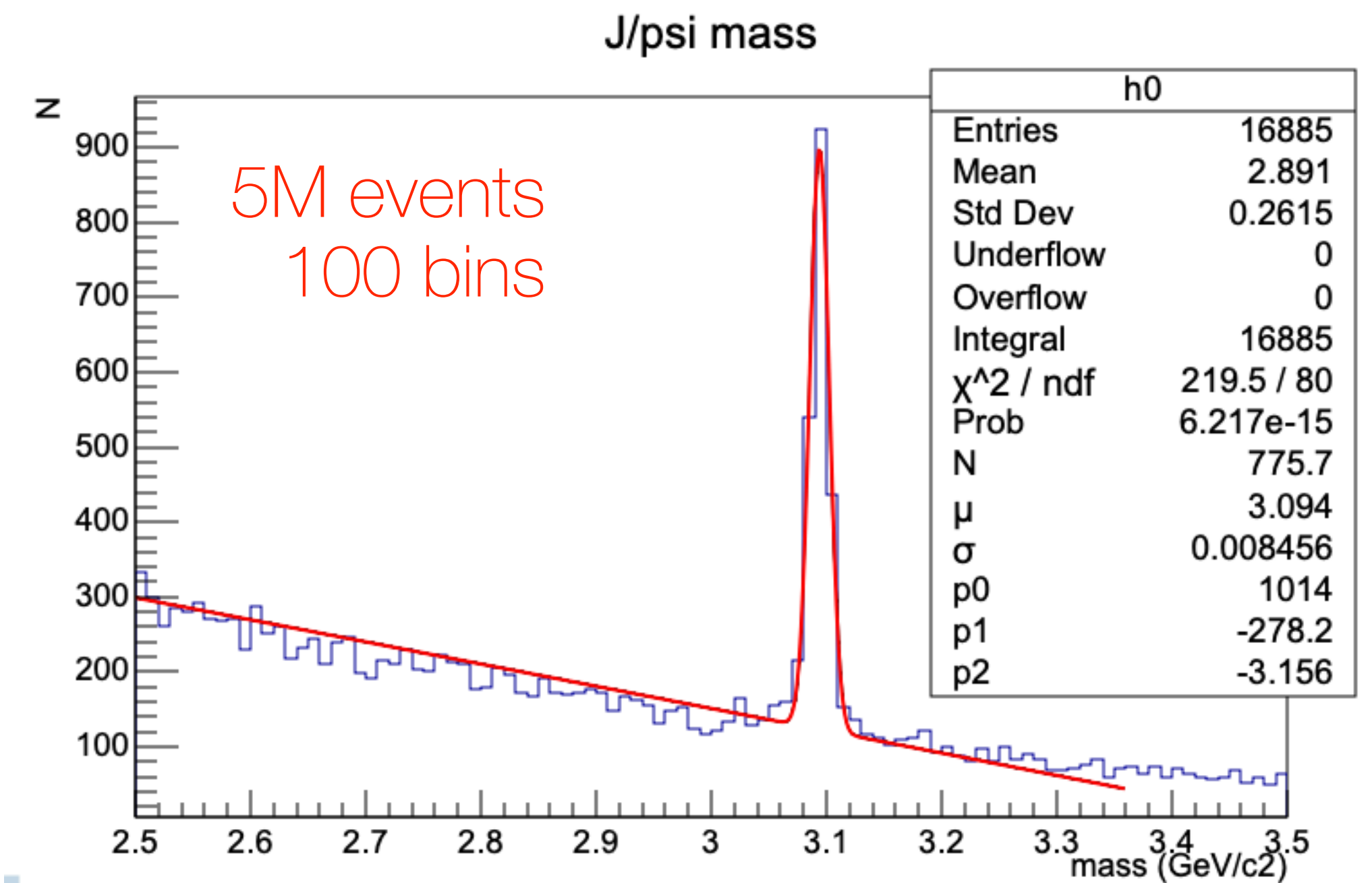
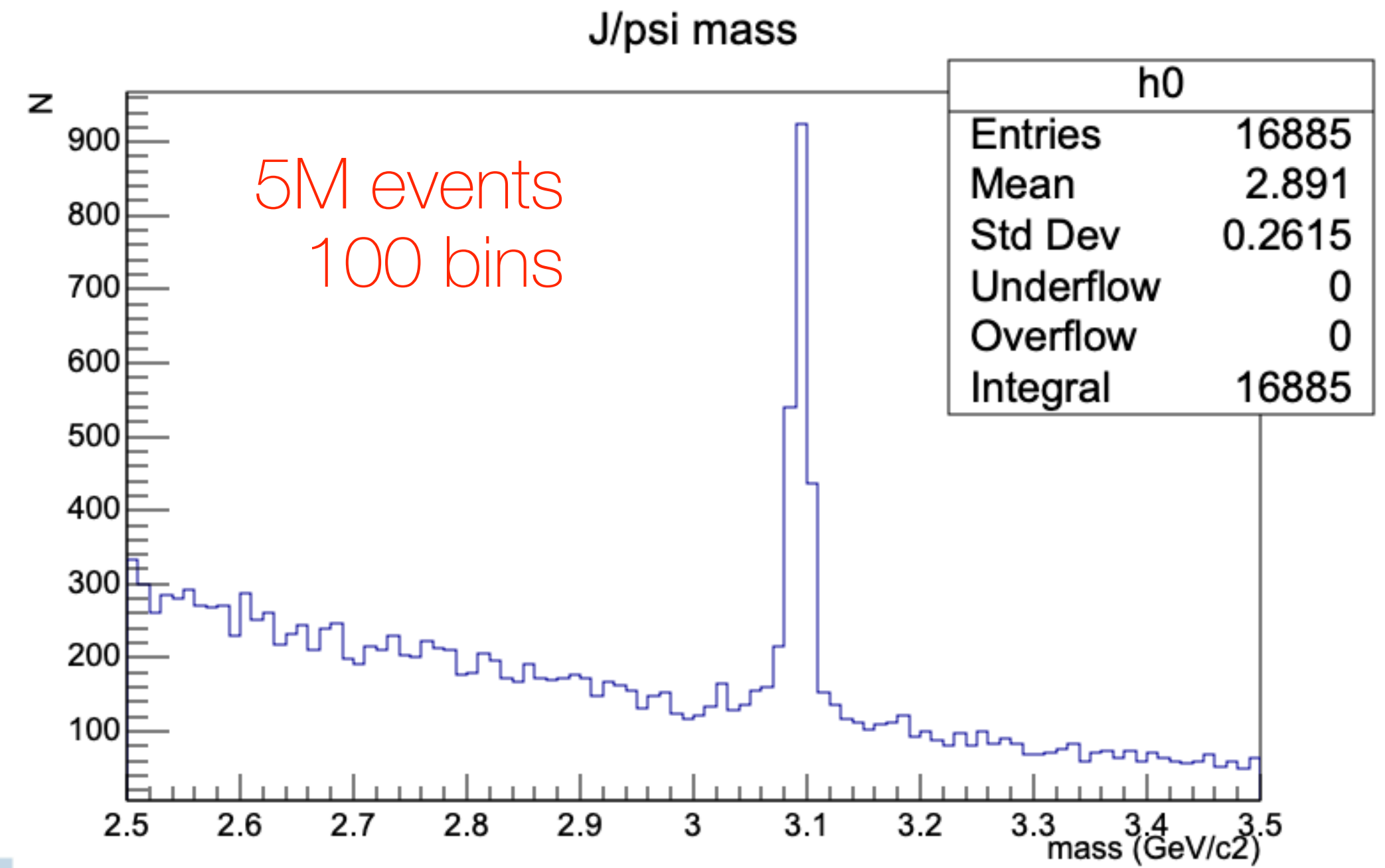
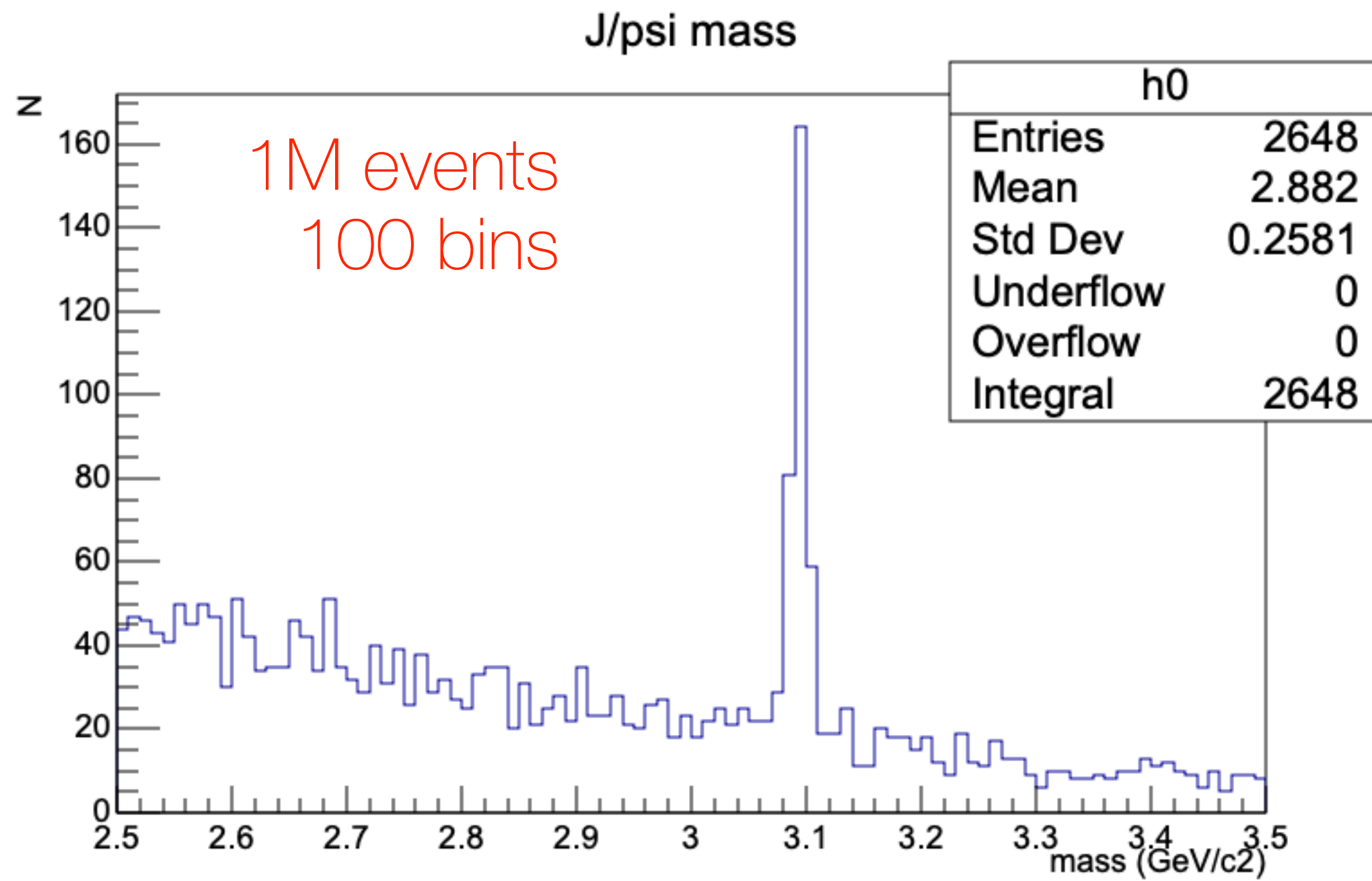
Plot the mass distribution of a J/ψ meson which decays to two leptons:

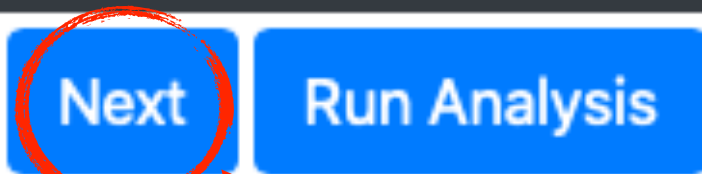
$$J/\psi \longrightarrow e^+e^- \quad \text{or} \quad J/\psi \longrightarrow \mu^+\mu^-$$

You will find a peak at $3.10 \text{ GeV}/c^2$, 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.

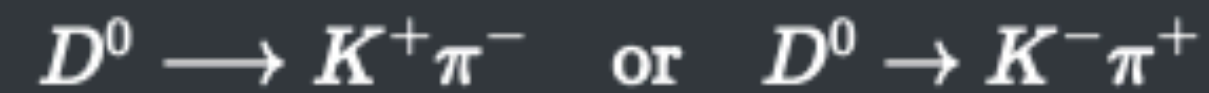
$$J/\psi \rightarrow \mu^+ \mu^-$$





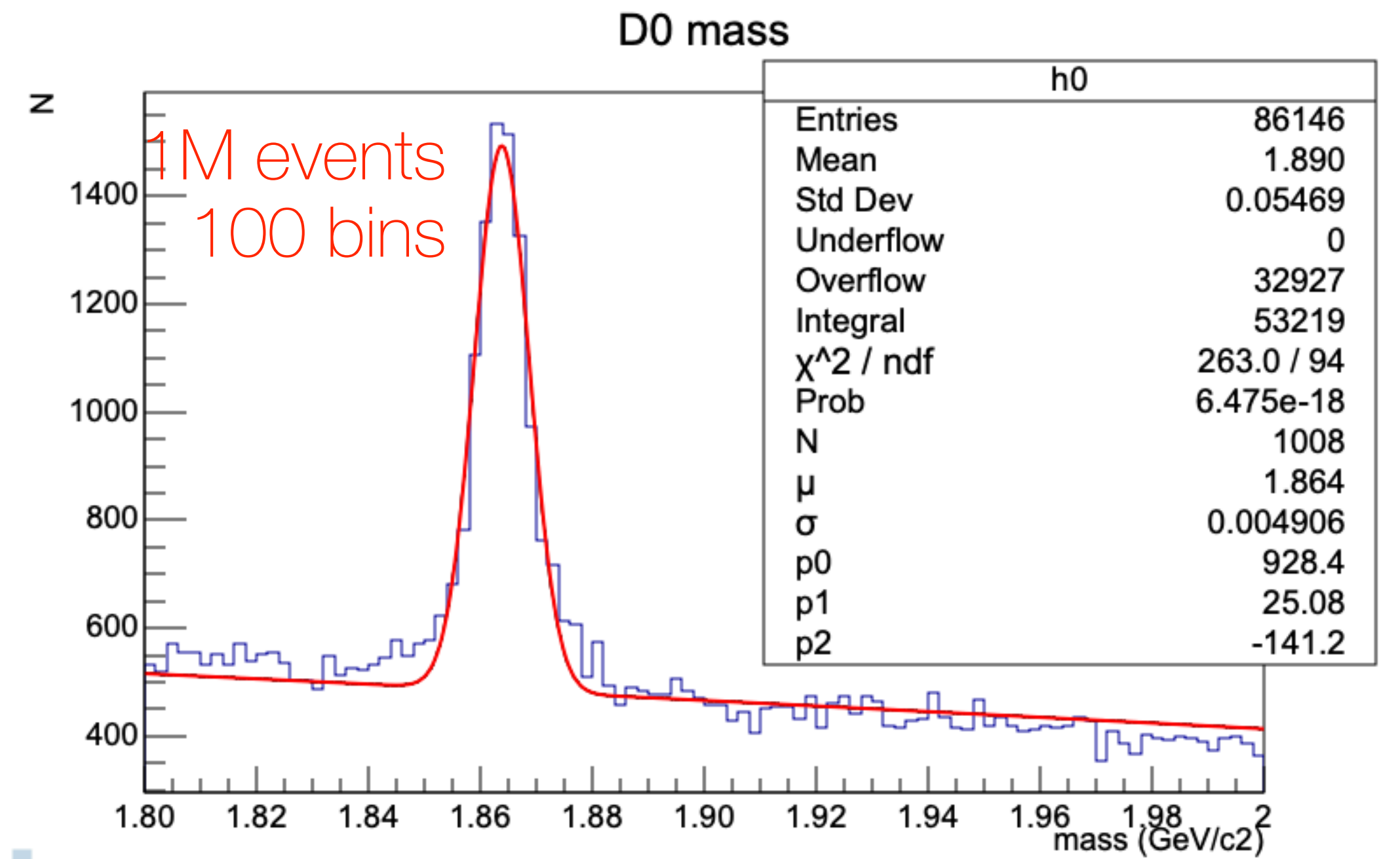
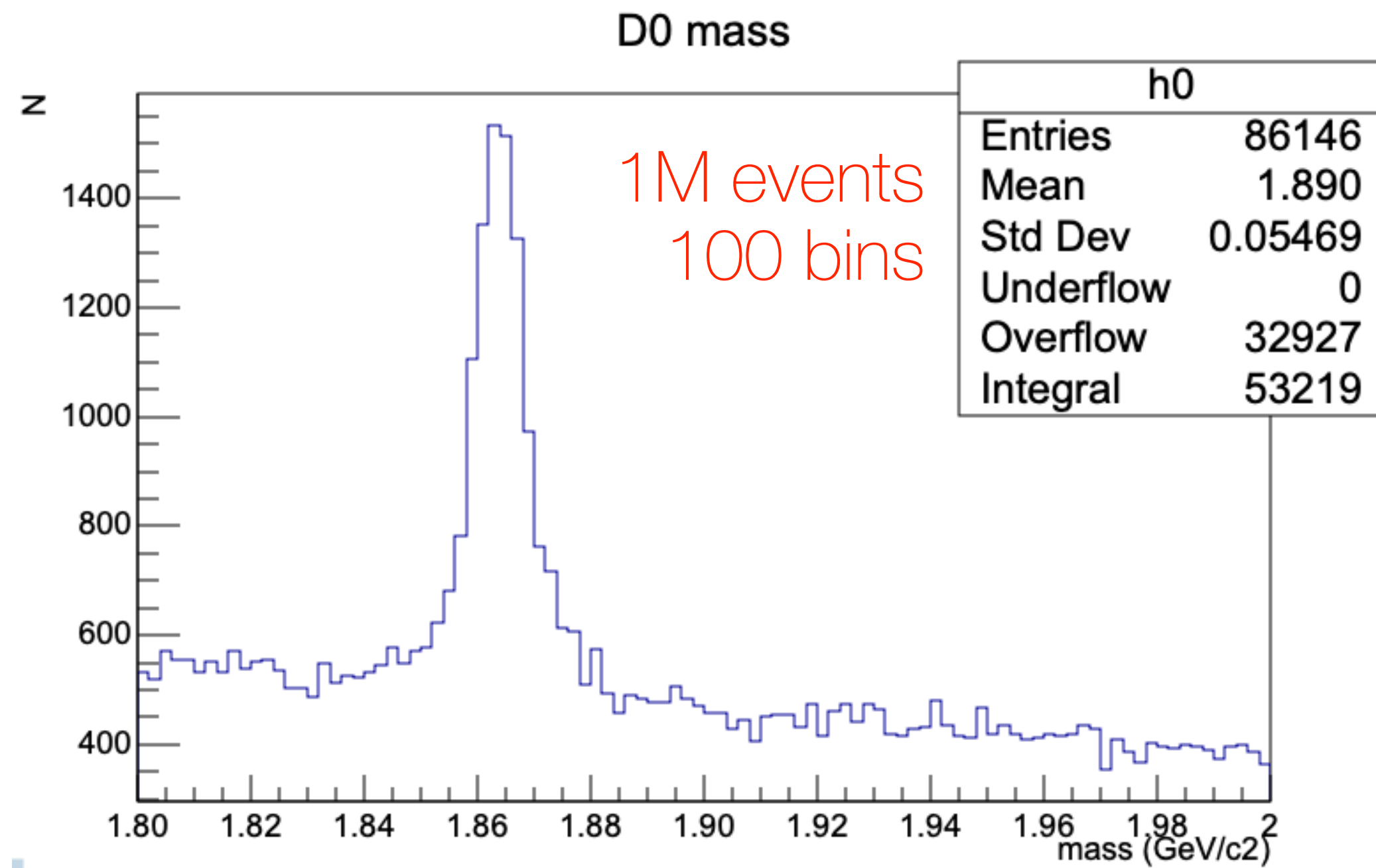
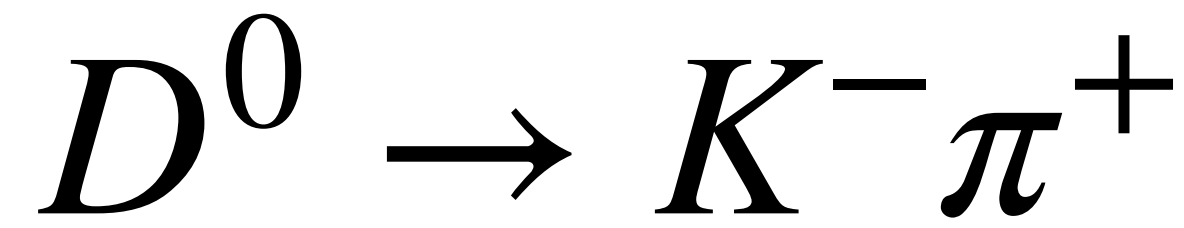
Mission 7: decay of a D^0 to charged kaons and pions

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



You will find a peak at $1.86 \text{ GeV}/c^2$, 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.



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^+



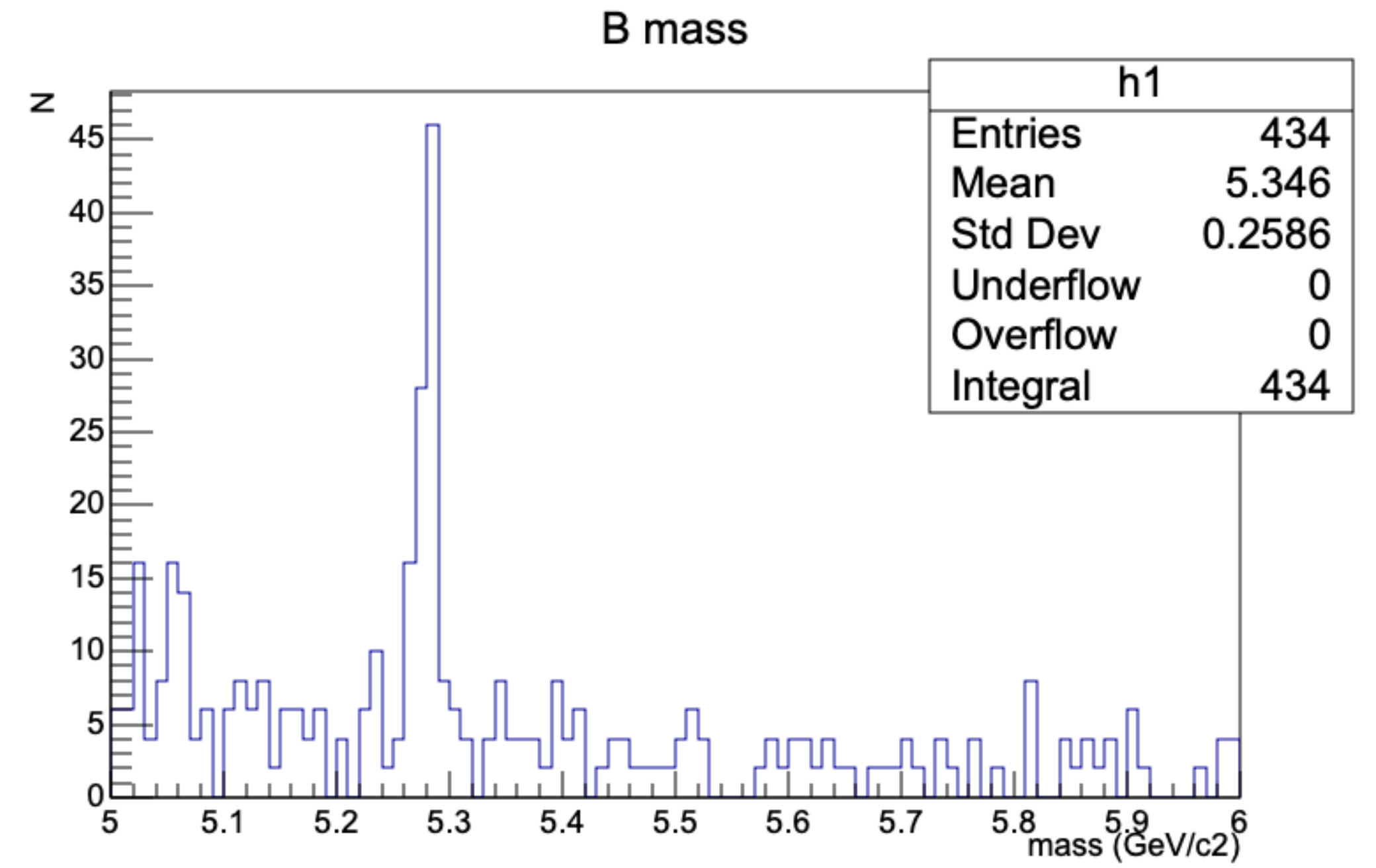
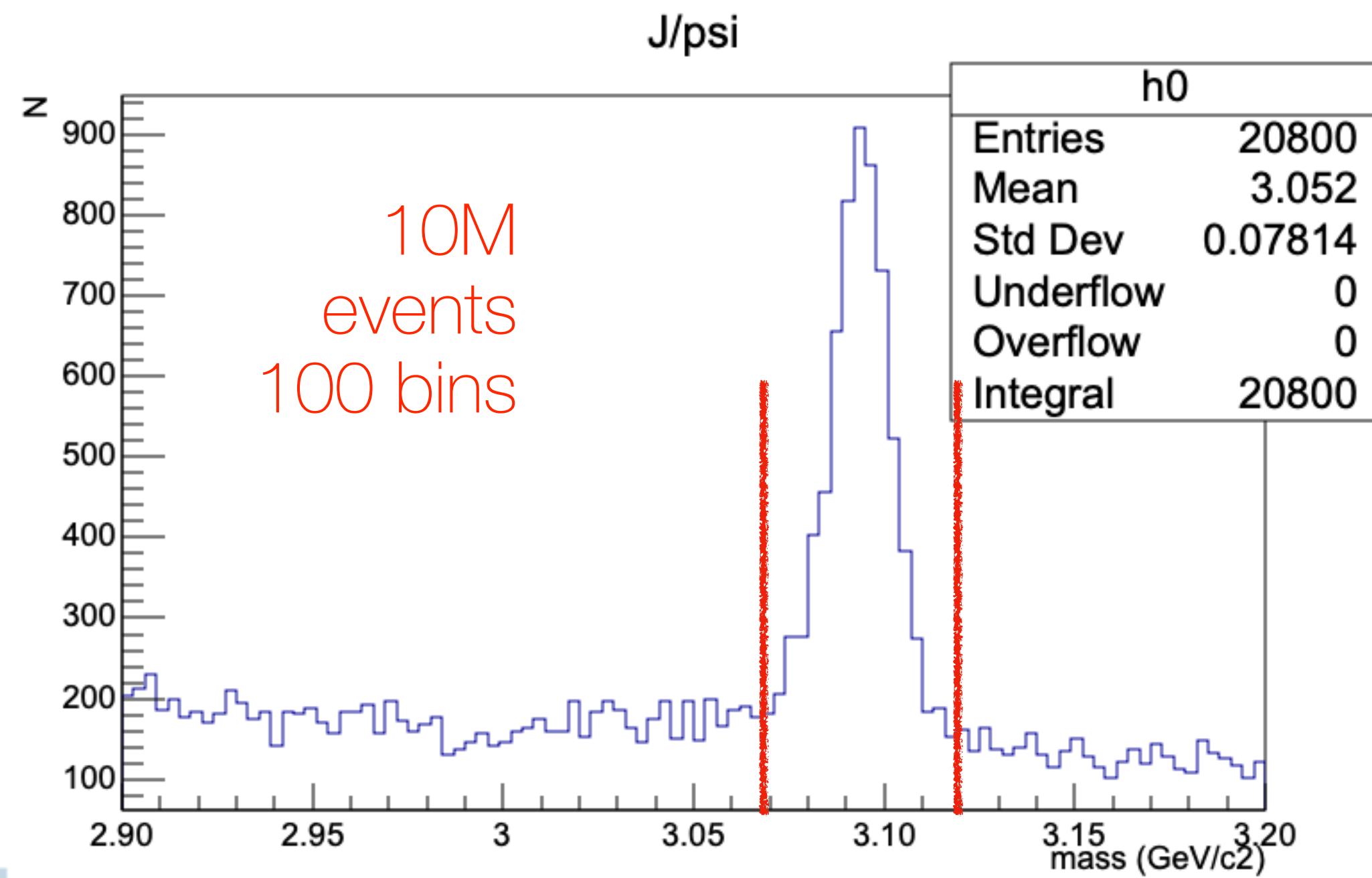
You will find a peak at $5.28 \text{ GeV}/c^2$, which is exactly the mass of the B^+ .

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 $D^0\pi^+$:

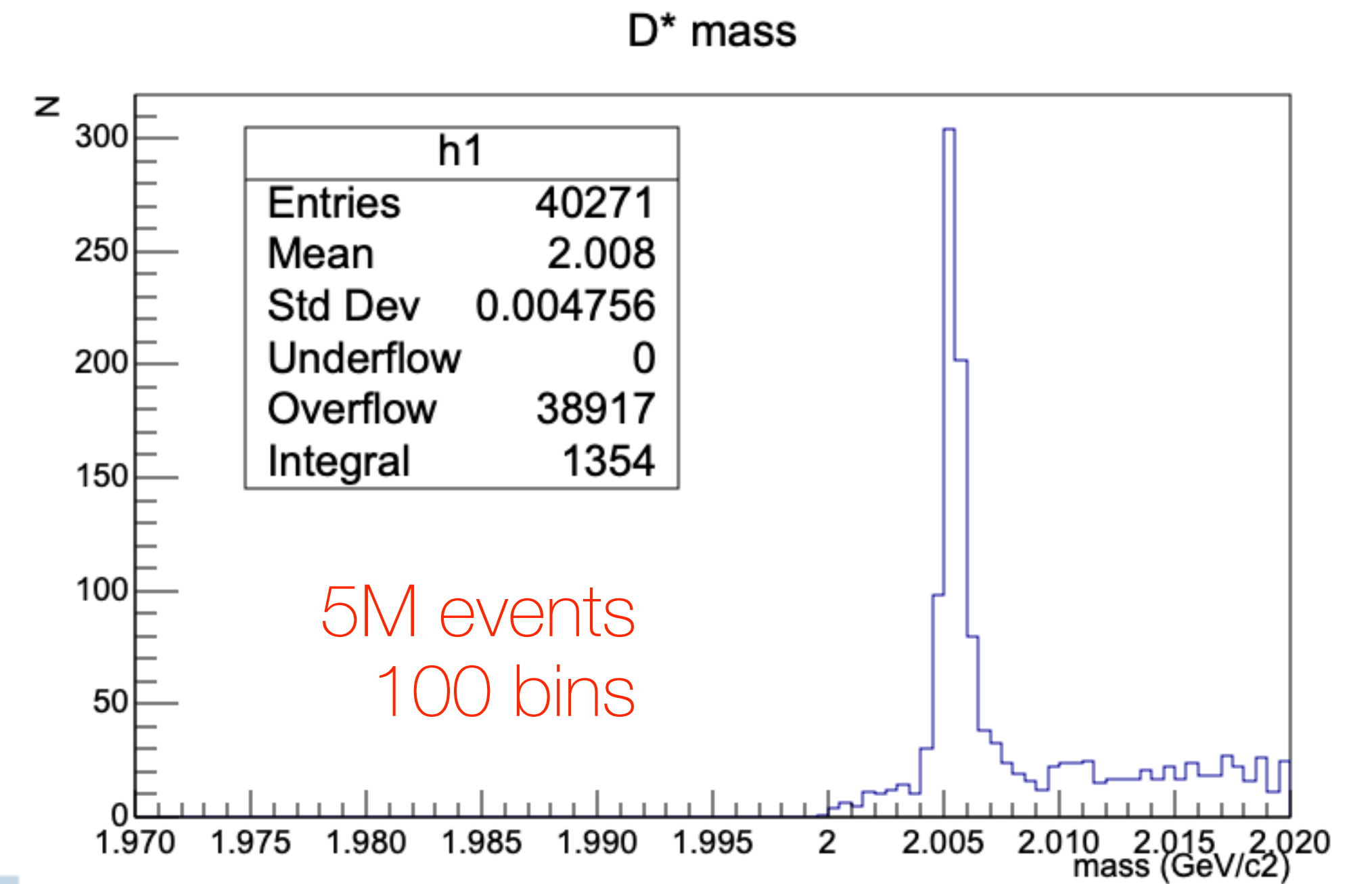
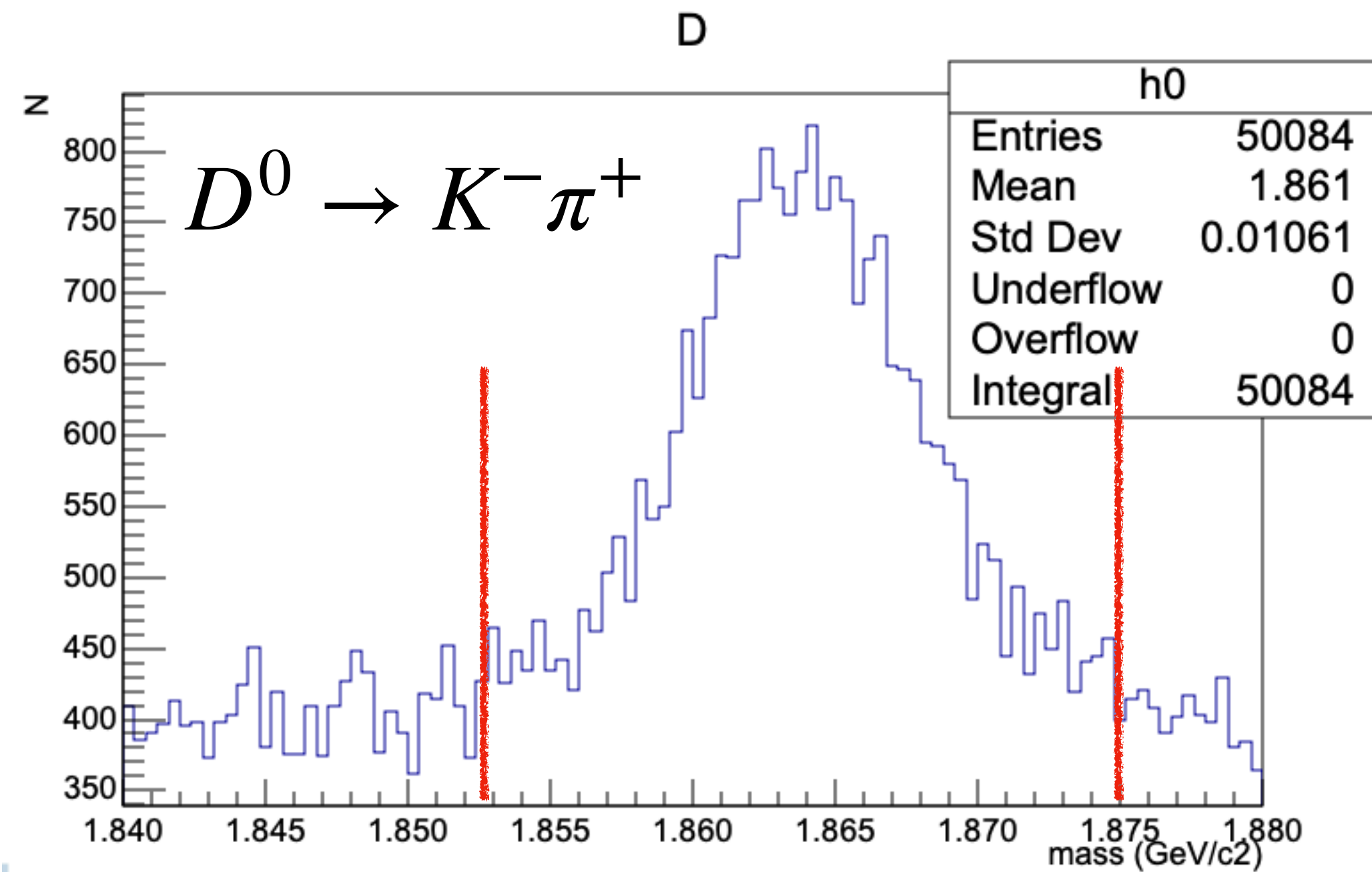
$$D^0 \longrightarrow K^+\pi^- \quad \text{or} \quad D^0 \longrightarrow K^-\pi^+$$

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

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

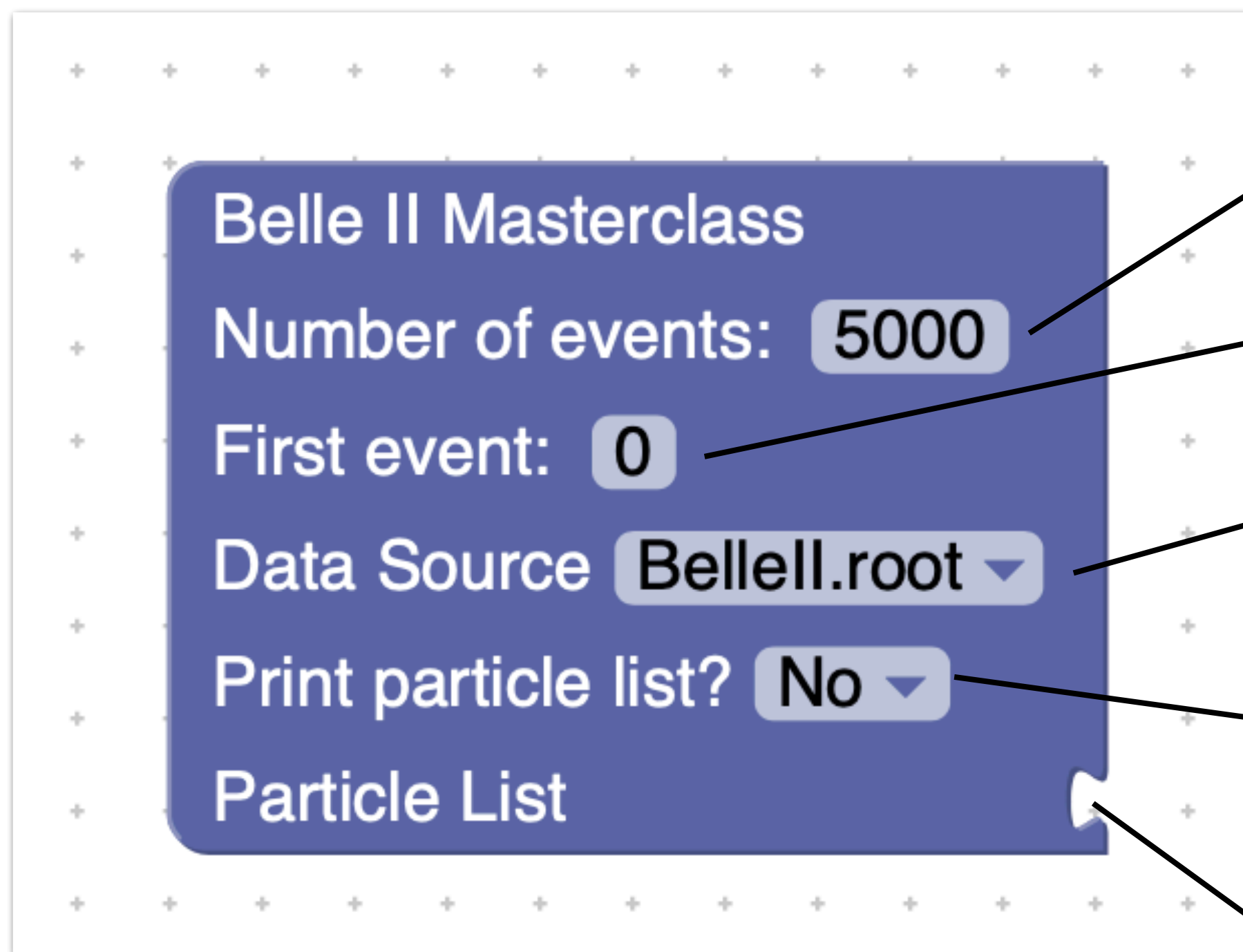
Be sure to select only the particles with an invariant mass very close to the D^0 mass for further analysis.

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



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 Bellell.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

The image shows a 'Select Particles Simple' block in a programming environment. The block is olive green and contains the following fields:

- Particle**: A field for selecting the particle type.
- Charge**: A dropdown menu currently set to **-1**.
- Type**: A dropdown menu currently set to **muon**.
- Histograms**: A field for creating a histogram for the selected particle.

Annotations with arrows point to these fields:

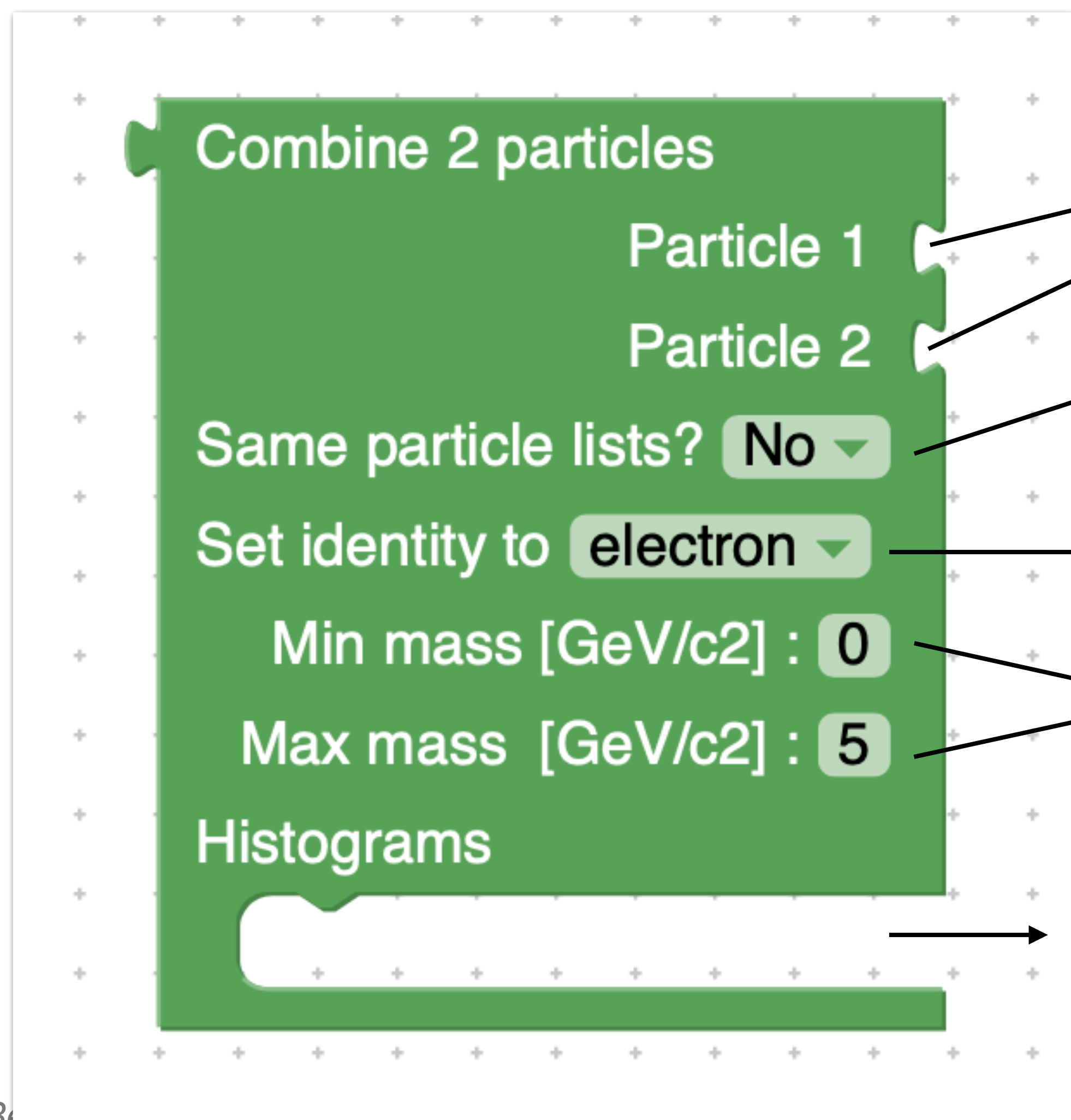
- An arrow points to the **Charge** dropdown with the text: "scegliete la carica della particella".
- An arrow points to the **Type** dropdown with the text: "scegliete il tipo di particella".
- An arrow points to the **Histograms** field with the text: "ci attaccherete il blocco marrone per la creazione di un istogramma per la particella selezionata".

To the right of the block, there are two lists of options:

- A small dropdown menu showing the options: **-1**, **0**, **1**, and **Any**.
- A larger dropdown menu showing the particle types: **electron**, **muon**, **pion**, **kaon**, **proton**, **photon**, **Phi meson**, **D meson**, **D* meson**, **J/Psi meson**, **B meson**, and **all particles**.

Blocco Verde Smeraldo

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 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

Histogram Title **Mass** Number of bins **200** Min: **0** Max: **5** Variable **mass** ▾

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

Click to fit

Range: min = 1.8 max = 1.9 $\chi^2/\text{ndf} = 6.636\text{e}+4 / 97 = 684.1$ || $N_{\text{signal}} = 19764$ || $N_{\text{background}} = 0$

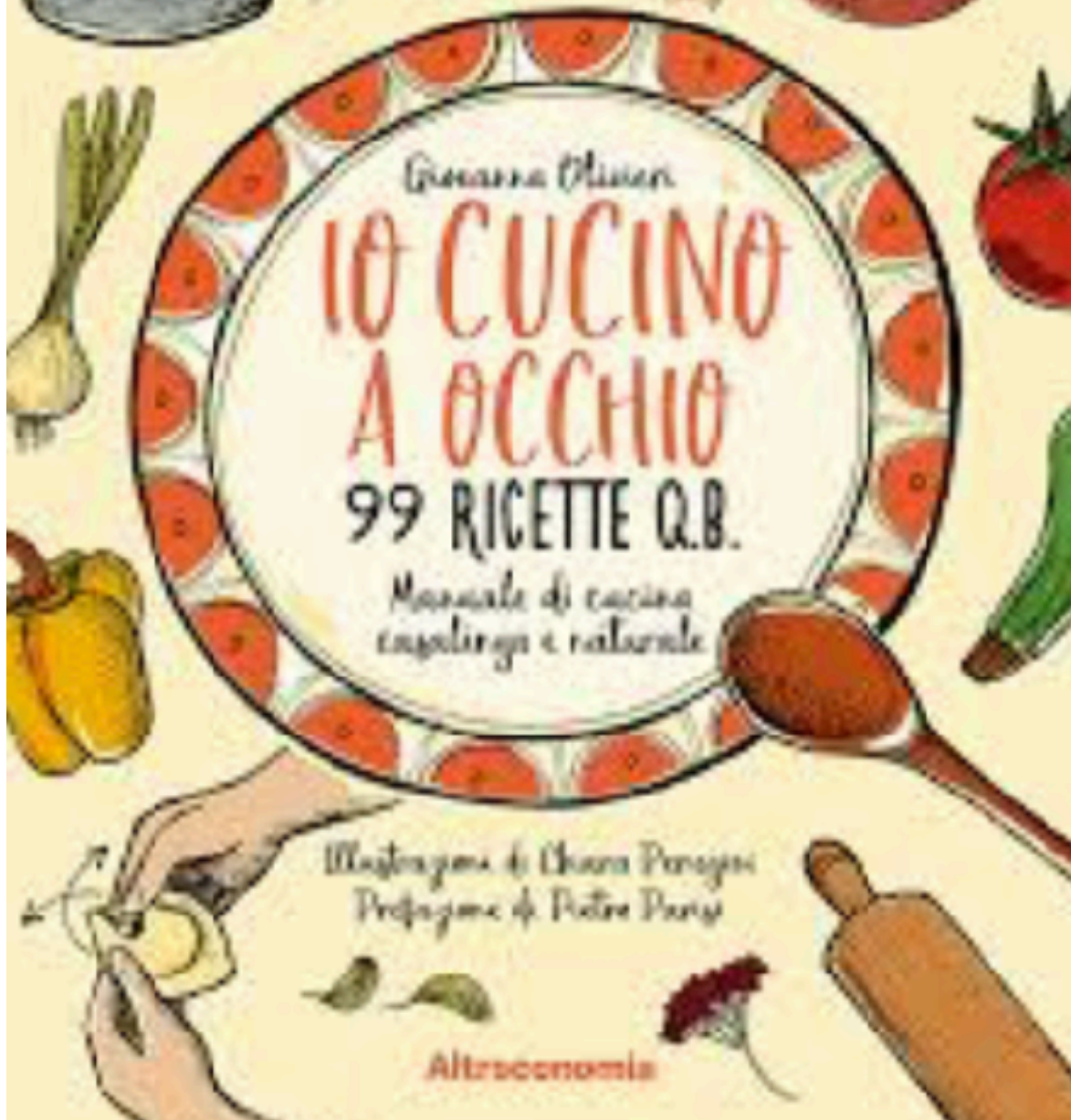
Function: Gaus + Polynomial $N \cdot e^{-\left(\frac{x-\mu}{4\sigma}\right)^2} + p0 + p1 \cdot x$

Name	Value	Min	Set	Max	Step
• μ :	1.86	1.82	<input type="range"/>	1.9	0.0001
• σ :	0.004	0	<input type="range"/>	0.015999999	0.0001
• N:	1577	0	<input type="range"/>	3154	0.0001

Polynomial order: 1

Name	Value	Min	Set	Max	Step
• p0:	0	-10	<input type="range"/>	10	0.0001
• p1:	0	-10	<input type="range"/>	10	0.0001
• p2:	0	-10	<input type="range"/>	10	0.0001
• p3:	0	-10	<input type="range"/>	10	0.0001
• p4:	0	-10	<input type="range"/>	10	0.0001

Show/Hide Fit Panel To Process Show/Hide Send result



Stima dei Parametri

prima di fare il fit!

➔ funzione di fit:

$$N \cdot e^{-\left(\frac{x-\mu}{4\sigma}\right)^2} + p_0 + p_1 \cdot x$$

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

