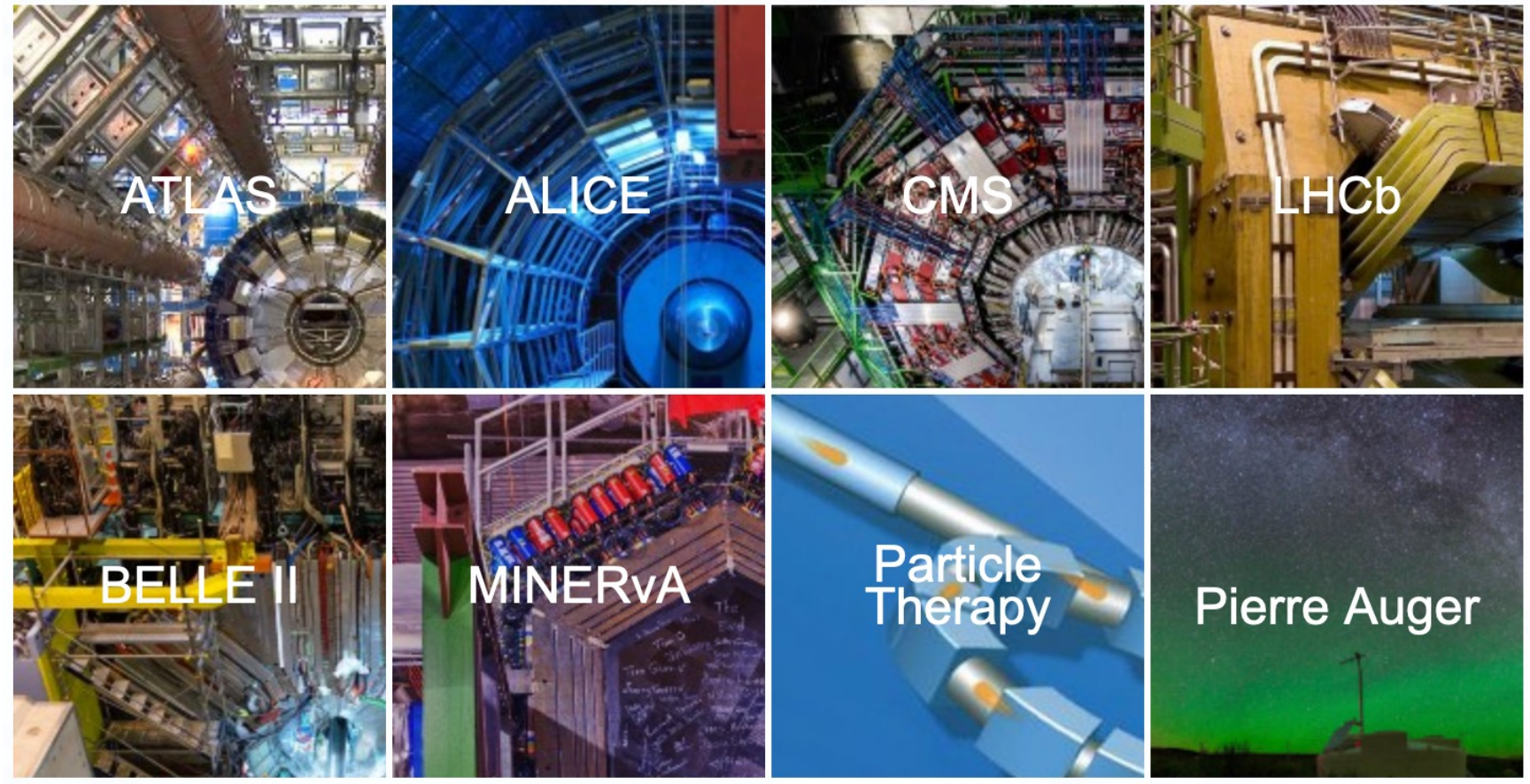
Einstein in the 21st Century
International Masterclass 2023

Istituto Nazionale di Fisica Nucleare

International Masterclasses

19th International Masterclasses 2023

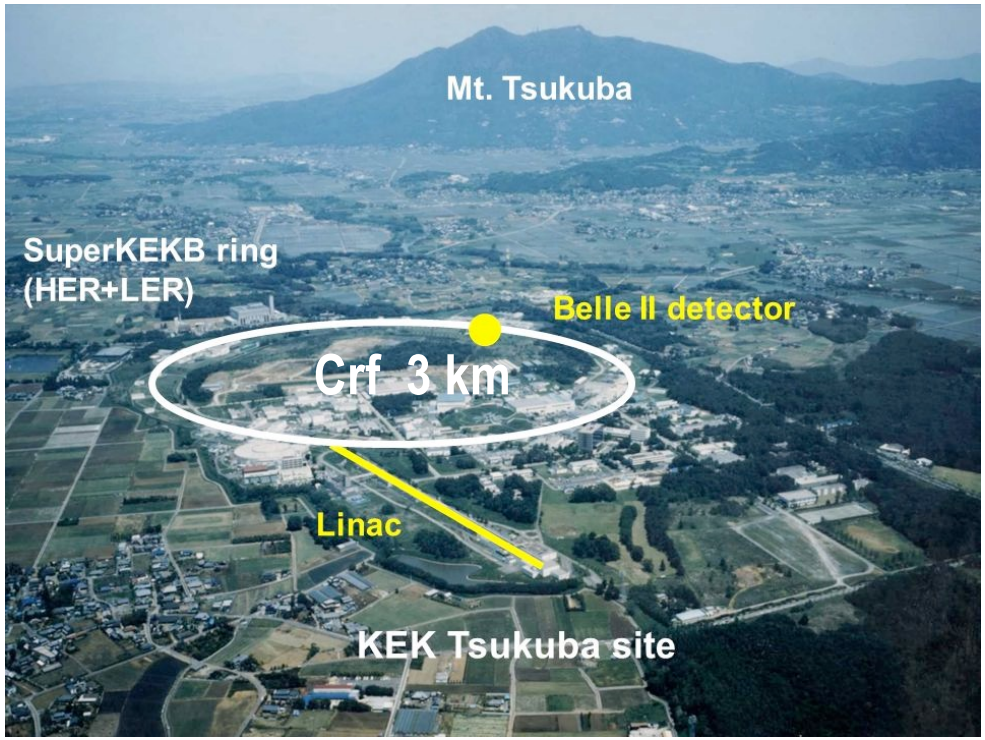
International Particle Physics Outreach Group

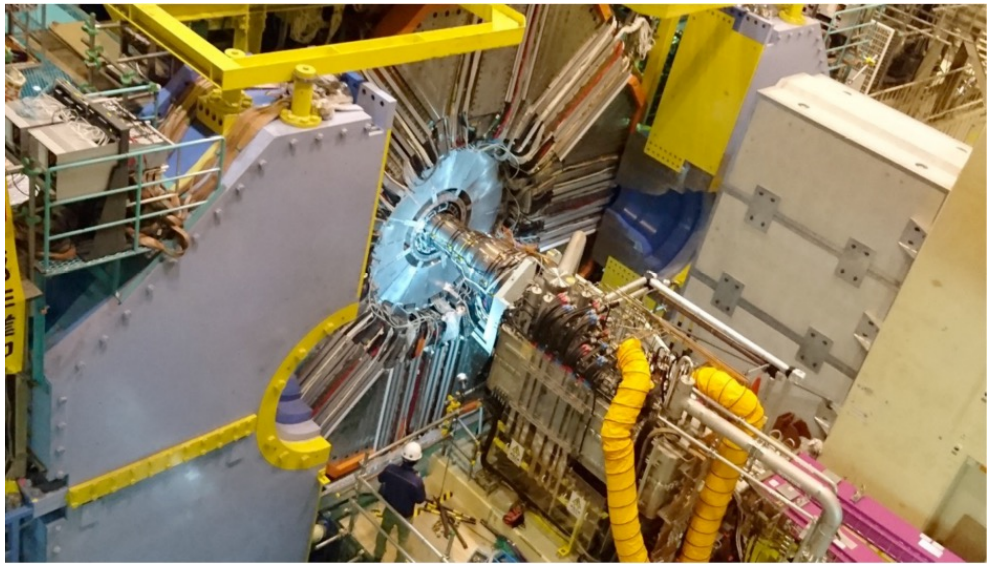


14 marzo 2023

Masterclass 2023

Einstein in the 21st Century
Belle II Masterclass 2023





Il rivelatore Belle II si trova nel punto di collisione dell'acceleratore SuperKEKB.

L'acceleratore SuperKEKB è un anello circolare di 3 km di circonferenza in cui collidono elettroni e positroni. Sostituisce l'acceleratore KEKB che ha operato dal 1999 al 2010 producendo 1.5 miliardi di coppie di mesoni B. SuperKEKB è situato nel laboratorio KEK di Tsukuba, a circa 60 km di distanza da Tokyo. Ha iniziato a funzionare nel 2018 e produrrà 50 miliardi di coppie di mesoni B entro il 2030.

L'esperimento Belle II, grazie al notevole incremento di statistica e ad un rivelatore migliorato, potrà misurare diversi parametri del Modello Standard con estrema precisione con l'obbiettivo di evidenziare discrepanze rispetto ai valori attesi causate dalla possibile presenza di nuova fisica.

Einstein in the 21st Century
Rivelatore Belle II

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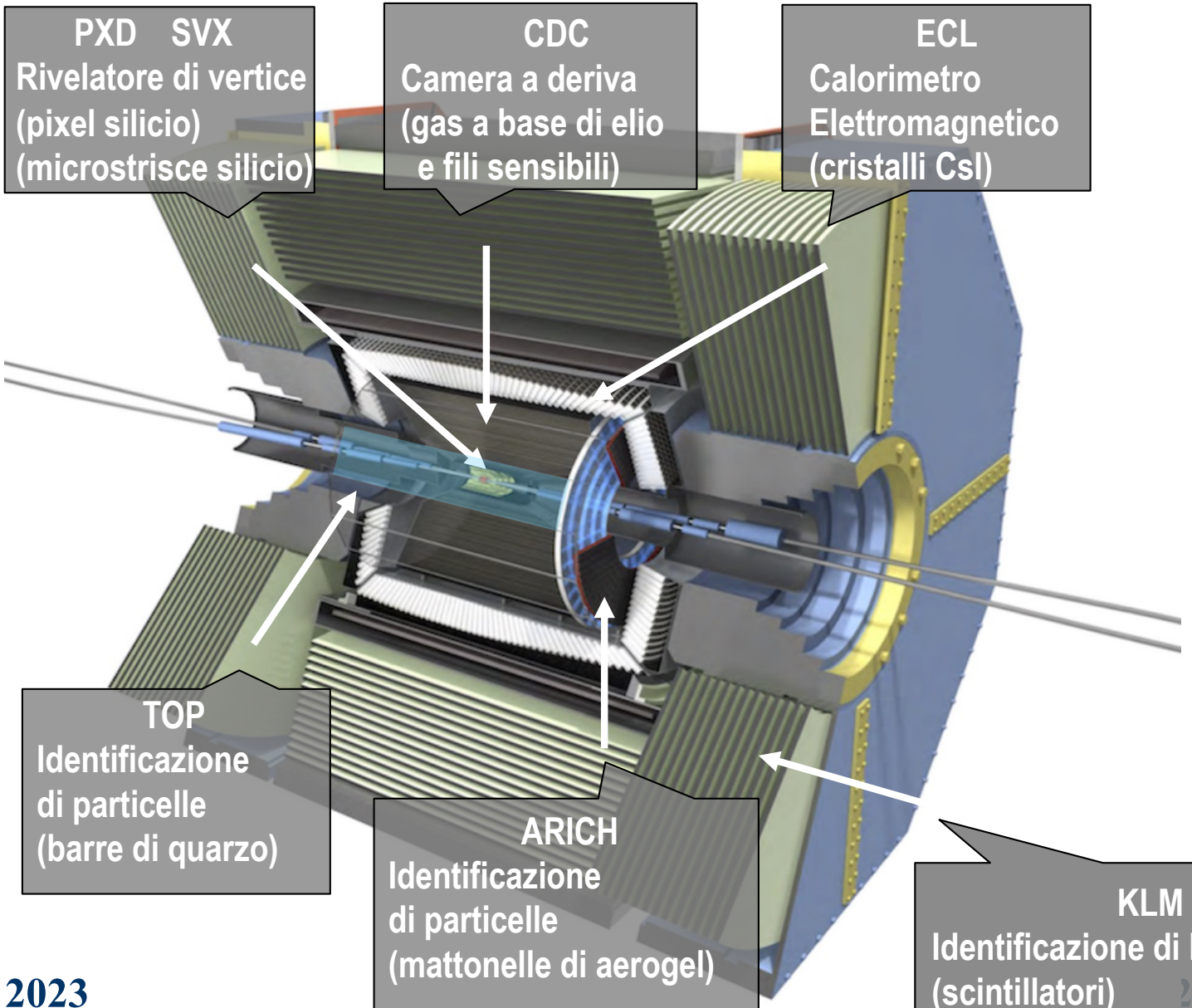
Belle II

PXD SVX
Rivelatore di vertice
(pixel silicio)
(microstrisce silicio)

CDC
Camera a deriva
(gas a base di elio
e fili sensibili)

ECL
Calorimetro
Elettromagnetico
(cristalli CsI)

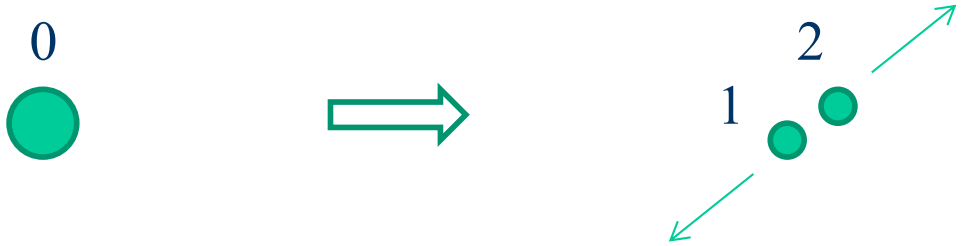


TOP
Identificazione
di particelle
(barre di quarzo)

ARICH
Identificazione
di particelle
(mattonelle di aerogel)

KLM
Identificazione di K_L e muoni
(scintillatori)

Massa invariante



Consideriamo una particella 0 a riposo che decade in due particelle 1 e 2.

Una parte di m_0 si è trasformata in m_1 ed m_2 ed una parte in energia.
Conoscendo l'identità (dunque la massa) delle particelle 1, 2
ed il loro impulso si può risalire (con le formule relativistiche) ad m_0

$$m_0 = \sqrt{\left(\frac{E_1 + E_2}{c^2}\right)^2 - \left(\frac{m_1 v_1 + m_2 v_2}{c}\right)^2}$$

La massa originaria è detta MASSA INVARIANTE

Sito: https://www2.pd.infn.it/masterclasses/

Agenda: https://www2.pd.infn.it/masterclasses/agenda.htm

AGENDA

10:00	**Preparazione agli esercizi di Laboratorio (LHCb e Belle II)** Alessandro Bertolin, Ezio Torassa
10:30	**Esercizi** Misure con i dati di LHC e SuperKEKb (LHCb, Belle II) Tutor CMS: Alessandro Bertolin, Ezio Torassa ... Laboratorio di informatica - Plesso Paolotti LabP140 e LabP036
13:00	**Fine Esercizi**
15:00	**Discussione dei risultati degli esercizi (LHCb e Belle II)** Alessandro Bertolin, Ezio Torassa Laboratorio di informatica - Plesso Paolotti LabP140 e LabP036
16:00	**Videoconferenza Belle II (LabP036)**
16:00	**Progettare gli acceleratori del futuro, aMuse (LabP140)** Laura Buonincontri
17:00	**Fine**

Server Lubiana Belle II: https://belle2.ijs.si/masterclass/

Server Padova Belle: http://masterclass.pd.infn.it/belle2/ (backup)

Belle II Particle Discovery - Ezio_test2 - INFN Padova My worksheet Quiz Event Display File Help Settings

Show Mission Run Analysis

Blocks

Belle II Masterclass
Number of events: 10000
First event: 0
Data Source BelleII.root
Print particle list? No
Particle List
Combine 2 particles
Particle 1
Select Particles Simple
Particle
Charge -1
Type muon
Histograms
Histogram Title mu neg Mass Number of bins 40 Min: 0 Max: 5 Variable mass
Particle 2
Select Particles Simple
Particle
Charge 1
Type muon
Histograms
Histogram Title 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
Histogram Title mumu Mass Number of bins 100 Min: 1 Max: 4 Variable mass

Esercizio Belle II

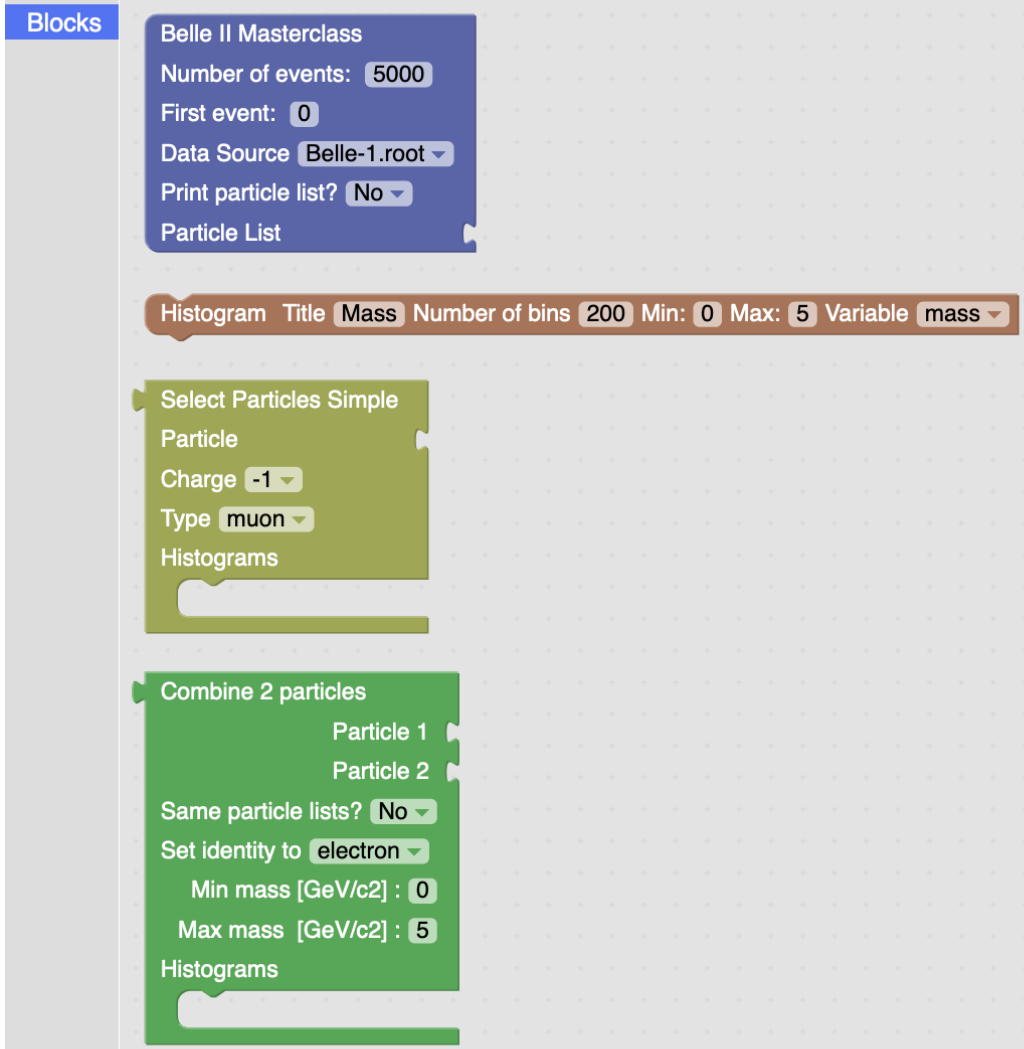
Gli esercizi si effettuano trasferendo sulla lavagna ed incastrando tra loro dei blocchi che rappresentano delle parti di codice di analisi dati:

Dentro Blocks troviamo:

- Un blocco **BLU** che permette di caricare eventi.
  Si possono scegliere tre sorgenti di dati:
  Belle-1 che contiene 629 000 eventi
  Belle-2 che contiene 5 600 000 eventi
  BelleII che contiene 7 085 000 eventi
  Utilizzate i dati BelleII selezionando il numero di eventi necessari.

- Un blocco **MARRONE** che permette di produrre istogrammi di masse (masse delle particelle selezionate o masse invarianti).

Esercizio Belle II



- Un blocco **VERDE** che permette di combinare due particelle ricavandone la massa invariante. Si può scegliere di combinare solo particelle diverse evitando di considerare due volte la stessa particella.
Si può impostare il minimo ed il massimo della massa invariante.

- Un blocco **SENAPE** che permette di selezionare solo determinate particelle (elettroni, muoni, kaoni, protoni, fotoni) ed anche di scegliere la carica della particella (-1, 0, +1, qualsiasi).

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Belle II Particle Discovery

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 desribed by its:

momentum $\mathrm{p} = (\mathrm{p_x}, \mathrm{p_y}, \mathrm{p_z})$,
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.

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:

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

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 $\mathrm{GeV/c^2}$;
From 0 to 0.0005 $\mathrm{GeV/c^2}$.

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.

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.

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 $1.02\ \mathrm{GeV/c^2}$, which is exactly the mass of the ϕ.

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.

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 $K^-\pi^+$:

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

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.

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.

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.

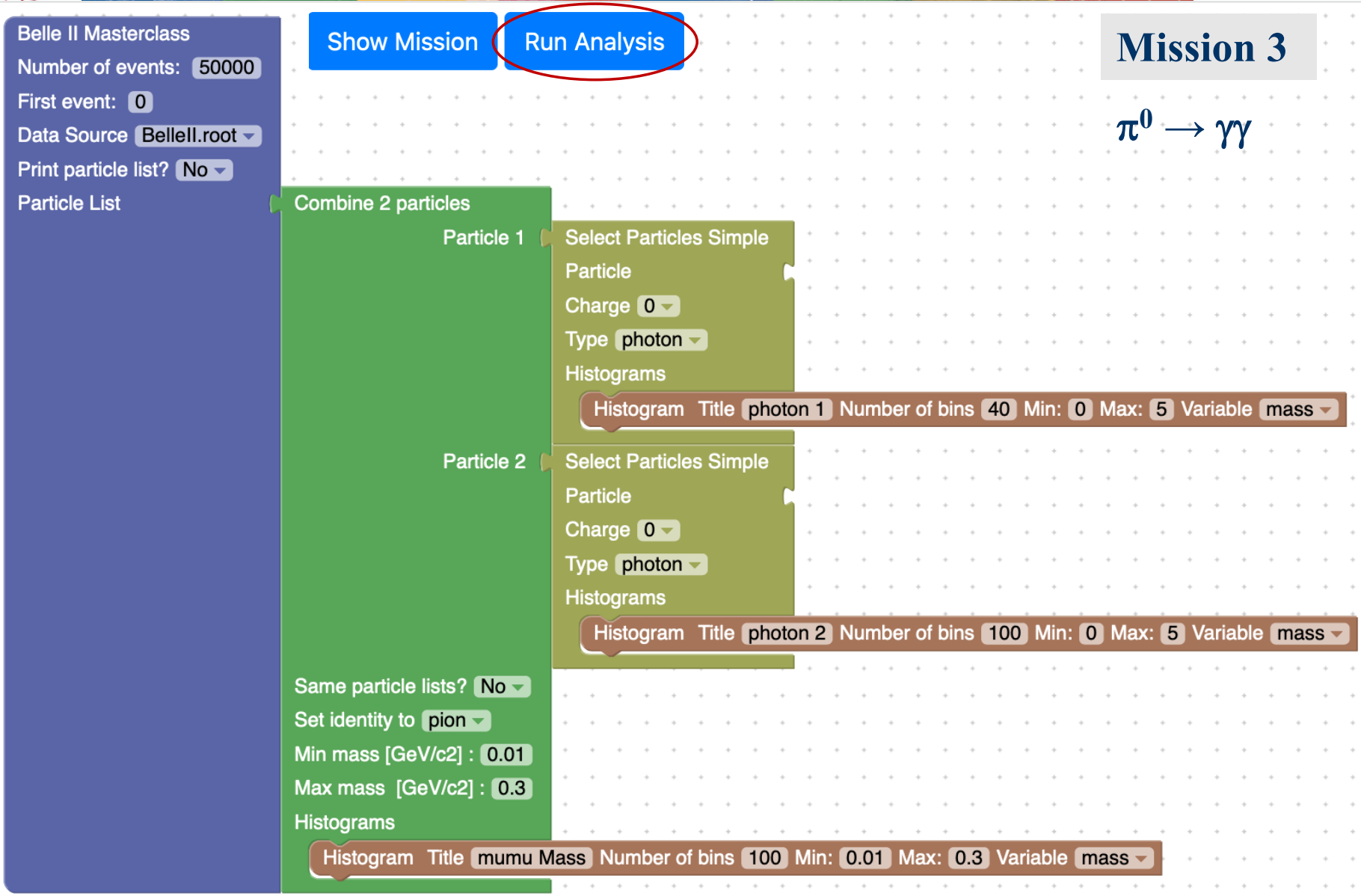
Be sure to select only the particles with an invariant mass very close to the D^0 mass for further analysis.

Esercizio Belle II

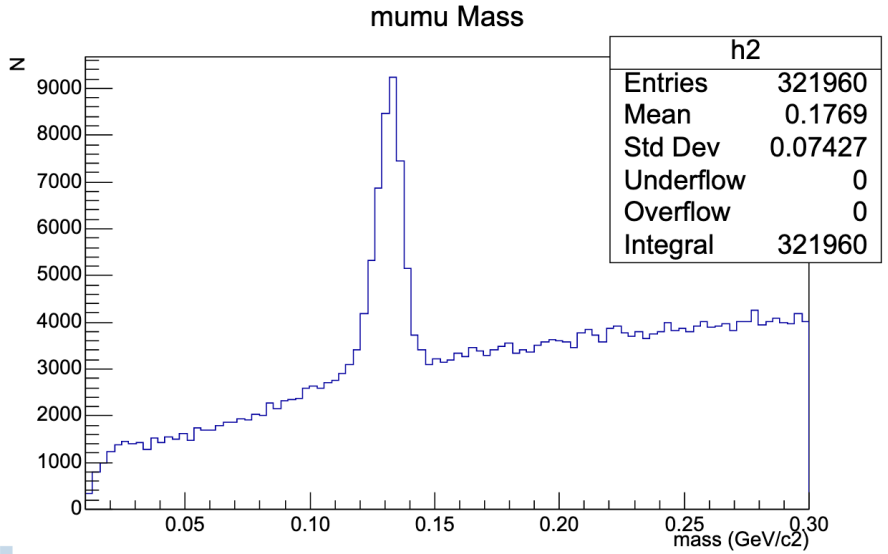
Show Mission | Run Analysis

Mission 3

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



Esercizio Belle II



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

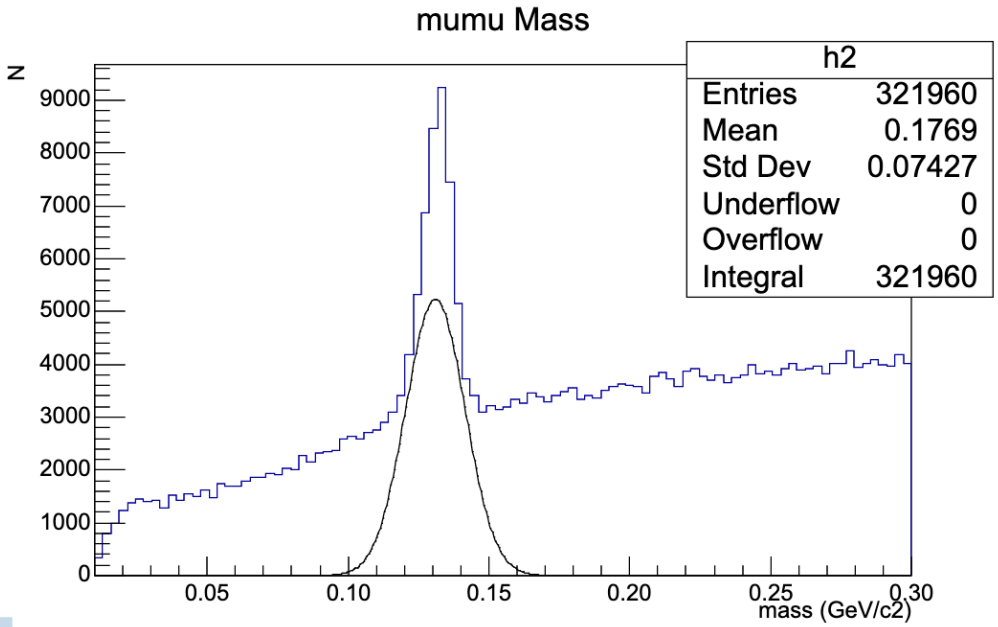
Click to fit

Range: min = 0.01 max = 0.3 χ^2/ndf = / = || N_{signal} =

Function: Gaus $N \cdot e^{-(\frac{x-\mu}{4\sigma})^2}$

Name	Value	Min	Set	Max	Step
• μ:	0.155	0.01		0.3	0.0001
• σ:	0.0145	0		0.05799999	0.0001
• N:	9232	0		18464	0.0001

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



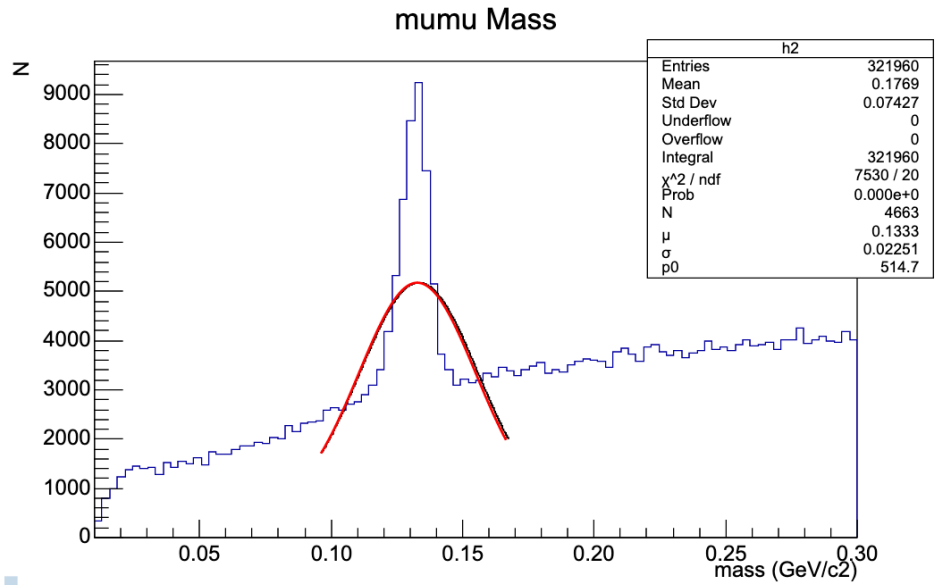
Click to fit

Range: min = 0.01 max = 0.3 χ^2/ndf = 2.578e+5 / 97 = 2658 || N_{signal} = 47484

Function: Gaus $N \cdot e^{-(\frac{x-\mu}{4\sigma})^2}$

Name	Value	Min	Set	Max	Step
• μ:	0.131	0.01		0.3	0.0001
• σ:	0.0105	0		0.05799999	0.0001
• N:	5232	0		18464	0.0001

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



Click to fit

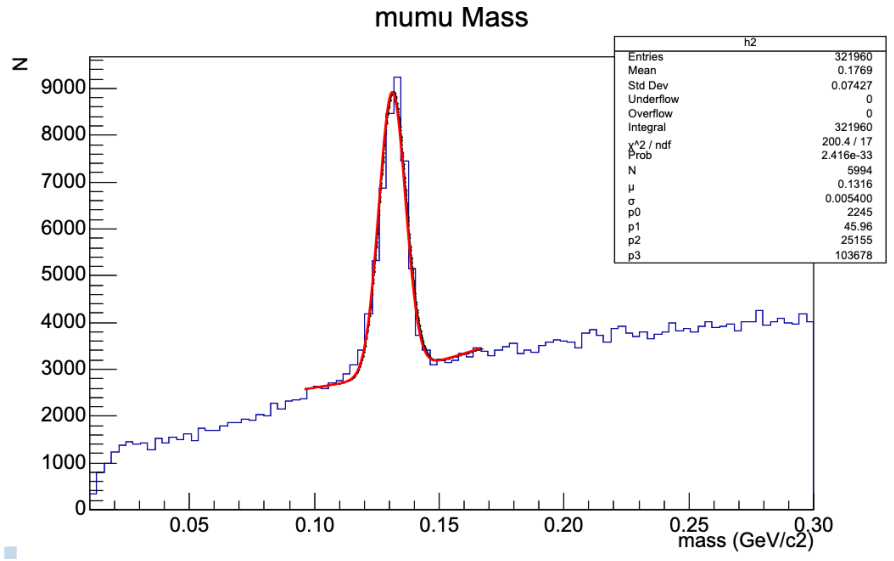
Range: min = 0.0961 max = 0.16747 χ^2/ndf = 7530 / 20 = 376.5 || N_{signal} = 90681 || $N_{background}$ = 12866

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

Name	Value	Min	Set	Max	Step
• μ:	0.1333	0.01		0.3	0.0001
• σ:	0.0225	0		0.12807236	0.0001
• N:	4662.7669	0		18464	0.0001

Polynomial order: 0

Name	Value	Min	Set	Max	Step
• p0:	514.675060	-137.217639		514.675094	0.0001
• p1:	3.5267	-10		10	0.0001
• p2:	0	-10		10	0.0001



Click to fit

Range: min = 0.0961 max = 0.16747 χ^2/ndf = 201.0 / 17 = 11.82 || N_{signal} = 27977 || $N_{background}$ = 74044

Function: Gaus + Polynomial $N \cdot e^{-(\frac{x-\mu}{4\sigma})^2} + p0 + p1 \cdot x + p2 \cdot x^2 + p3 \cdot x^3$

Name	Value	Min	Set	Max	Step
• μ:	0.1316	0.01		0.3	0.0001
• σ:	0.0054	0		0.12807236	0.0001
• N:	5994.0188	0		18464	0.0001

Polynomial order: 3

Name	Value	Min	Set	Max	Step
• p0:	2245.33836	-137.217639		2245.33840	0.0001
• p1:	45.9562	-10		45.9562012	0.0001
• p2:	25155.227	-10		25155.2270	0.0001

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Belle II Particle Discovery - Ezio_test2 - INFN Padova | My worksheet | Quiz | Event Display | File | Help | Settings

3

Function: Gaus + Polynomial $N \cdot e^{-(\frac{x-\mu}{4\sigma})^2} + p0 + p1 \cdot x + p2 \cdot x^2 + p3 \cdot x^3$

Name	Value	Min	Set	Max	Step
• μ:	0.1317	0.01		0.3	0.0001
• σ:	0.0053	0		0.05799999	0.0001
• N:	5973.8807	0		18464	0.0001

Polynomial order: 3

Name	Value	Min	Set	Max	Step
• p0:	2092.5023	-10		2559.31788	0.0001
• p1:	5681.8944	-10		5692.37833	0.0001
• p2:	3592.01146	-5734.3019		3592.01154	0.0001
• p3:	27179.07216	-33562.327		27179.07219	0.0001
• p4:	0	-10		10	0.0001

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

Particle name: pi

Particle charge: 0

Mass [GeV/c2]: 0.1317

Width [GeV/c2]: 0.0053

Events: 5973

1

Save to your worksheet

2

Saved to your worksheet

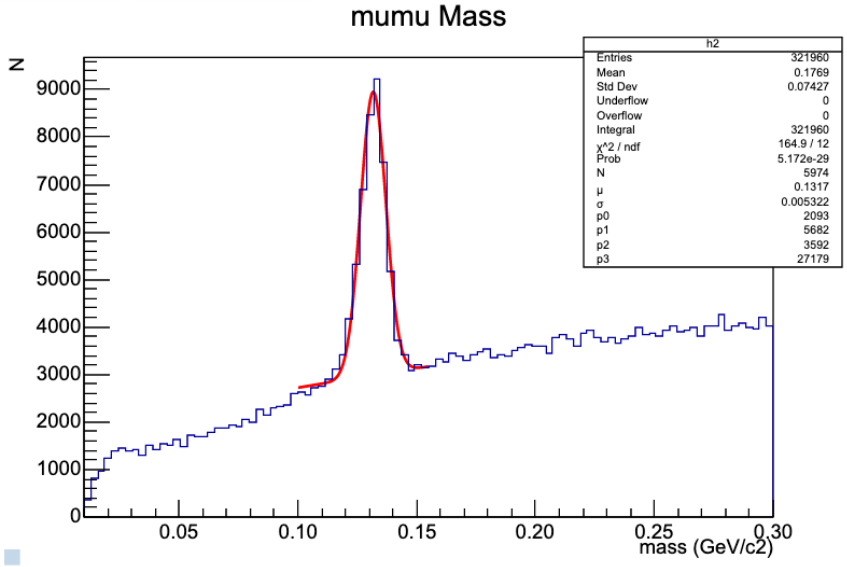
Belle II Masterclass Student worksheet

Send results to server | Clear worksheet | Close Window

mission: 3
particle: pi
charge: 0
mass: 0.1317
width: 0.0053
events: 5973

Show diagram

Delete this mission



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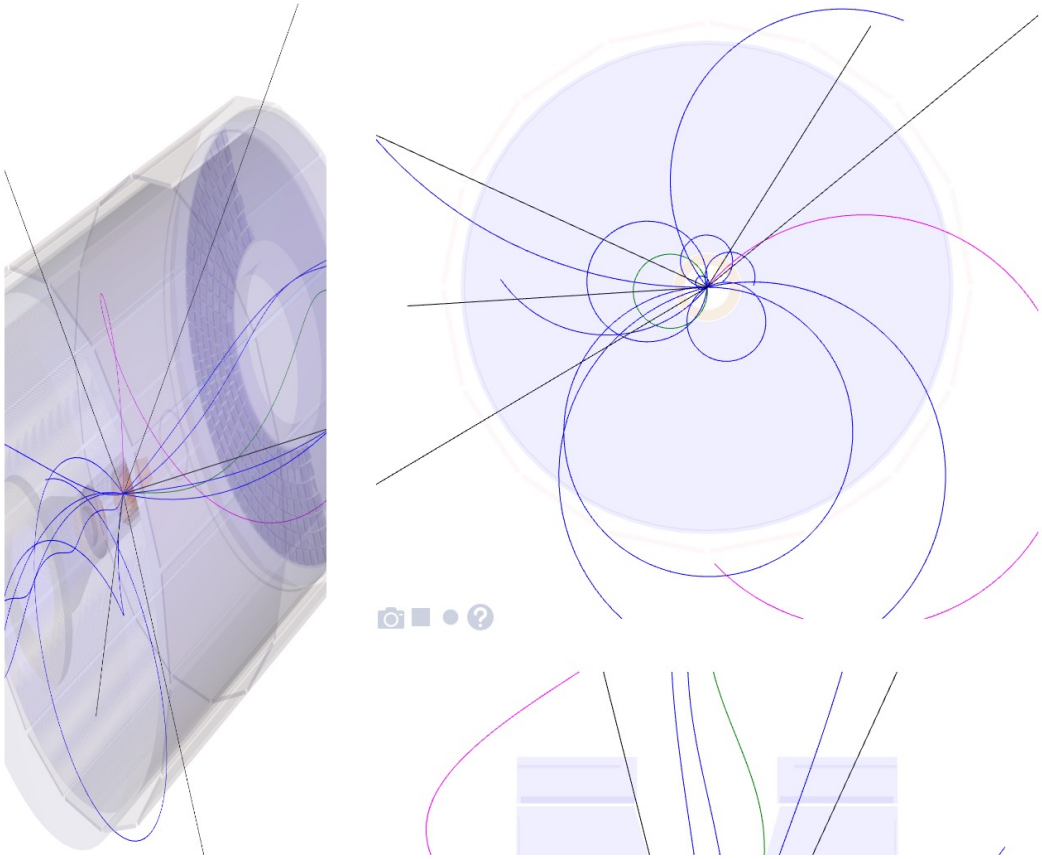
Belle II Particle Discovery - Ezio_test2 - INFN Padova | My worksheet | Quiz | Event Display | File | Help | Settings

- Con l'Event Display potete vedere il rivelatore e le tracce di alcuni eventi

Event: < 1 > Close Window

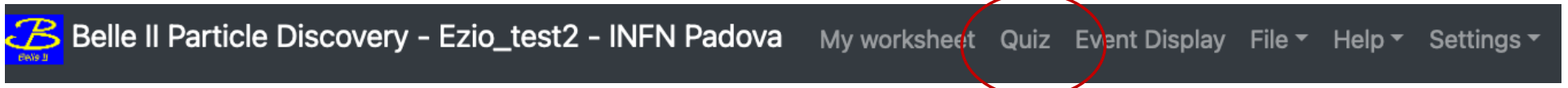


Reconstructed particles of Event 1

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	1.17106	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

Esercizio Belle II

Einstein in the 21st Century



- Il Quiz verrà svolto durante la videoconferenza, occorre farlo partire dal server di Lubiana

- Sarete collegati insieme a:

Göttingen

- Al termine della Masterclass anche dopo qualche giorno, potete compilare il questionario di gradimento (anonimo) per aiutarci a migliorare le prossime edizioni.