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Dalitz plot

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Exercise class 3
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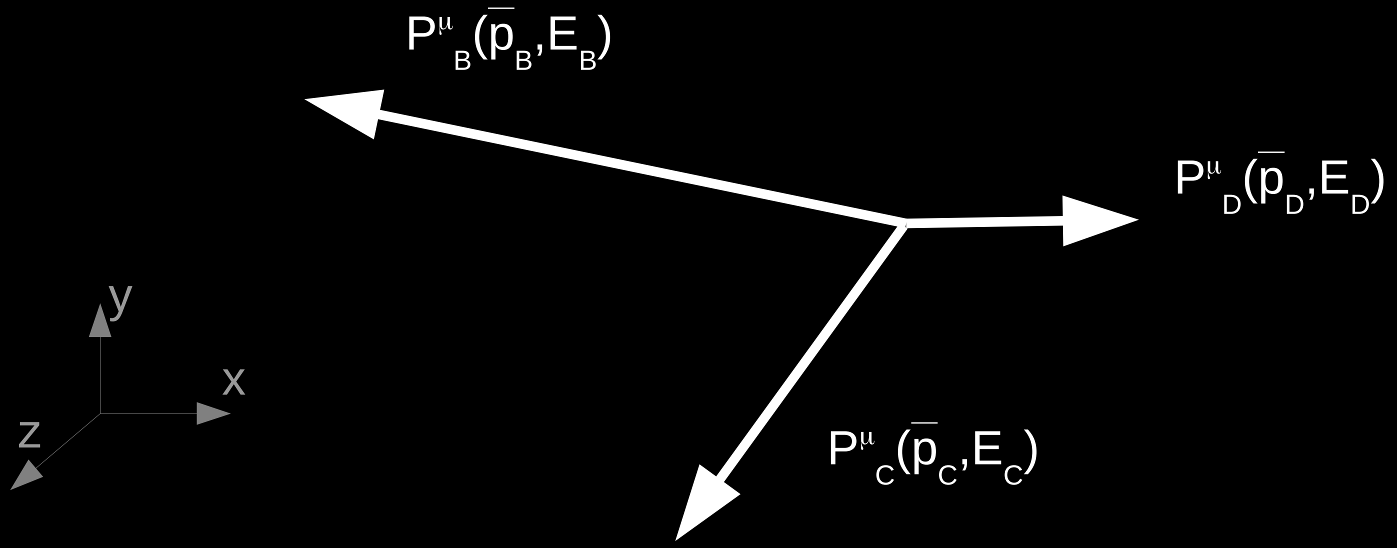
http://sdonato.web.cern.ch/sdonato/UZH

Dalitz plot

- The Dalitz plot is a 2D plot that is used in particle physics to study the kinematic of the three-body decay.
- It was introduced in 1953 by R.H. Dalitz to study the $K^+ \rightarrow \pi^+\pi^+\pi^-$ decay.
- How many degreees of freedom have a generic three-body decay $A \rightarrow B + C + D$?

Number of degrees of freedom

ndof = 12

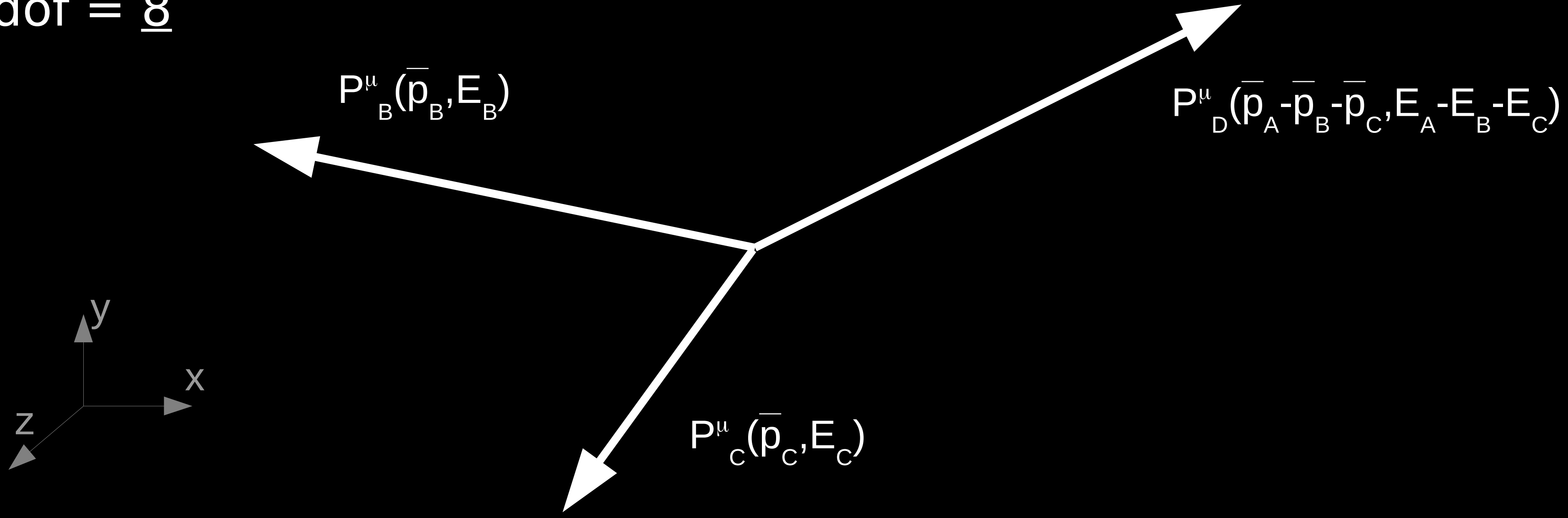


- We have three particles in the final state

  → 3 x 4 = 12 degrees of freedom

Number of degrees of freedom

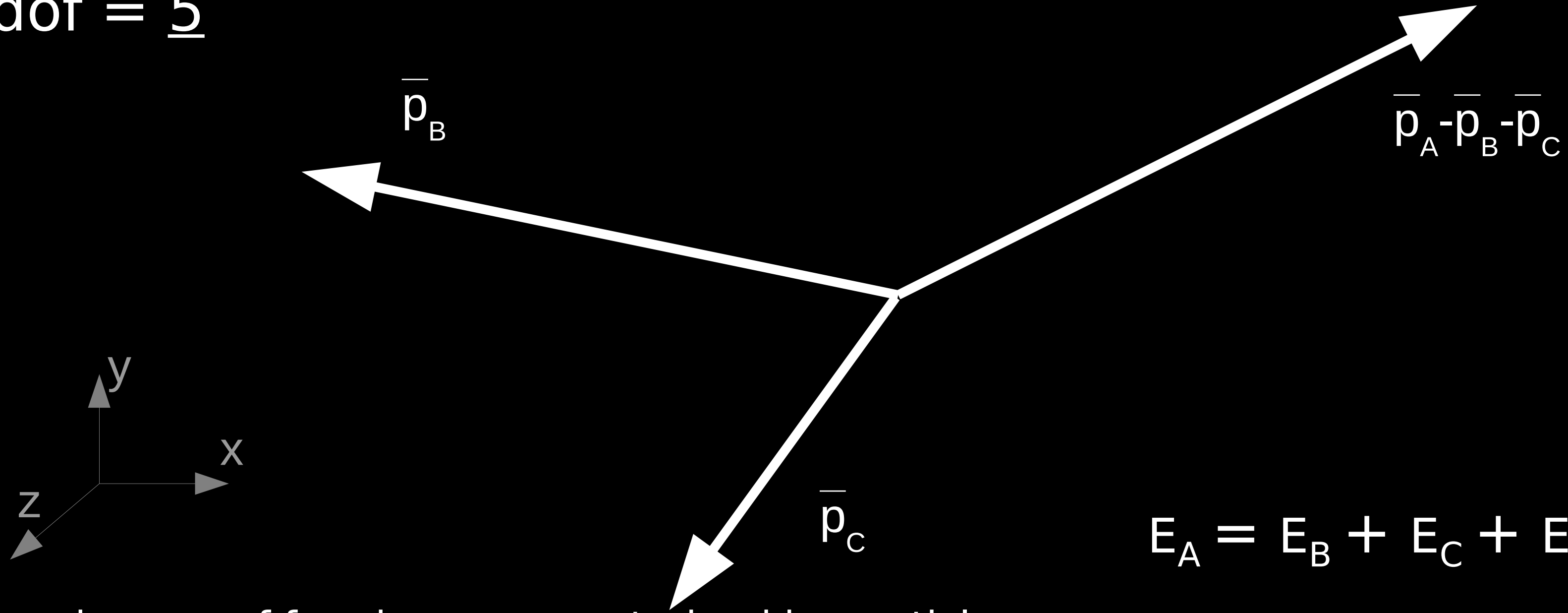
ndof = <u>8</u>



- Four degrees of freedom are constrained by the energy/momentum conservation:
  - $\overline{p}_A = \overline{p}_B + \overline{p}_C + \overline{p}_D$
  - $E_A = E_B + E_C + E_D$

Number of degrees of freedom

ndof = <u>5</u>

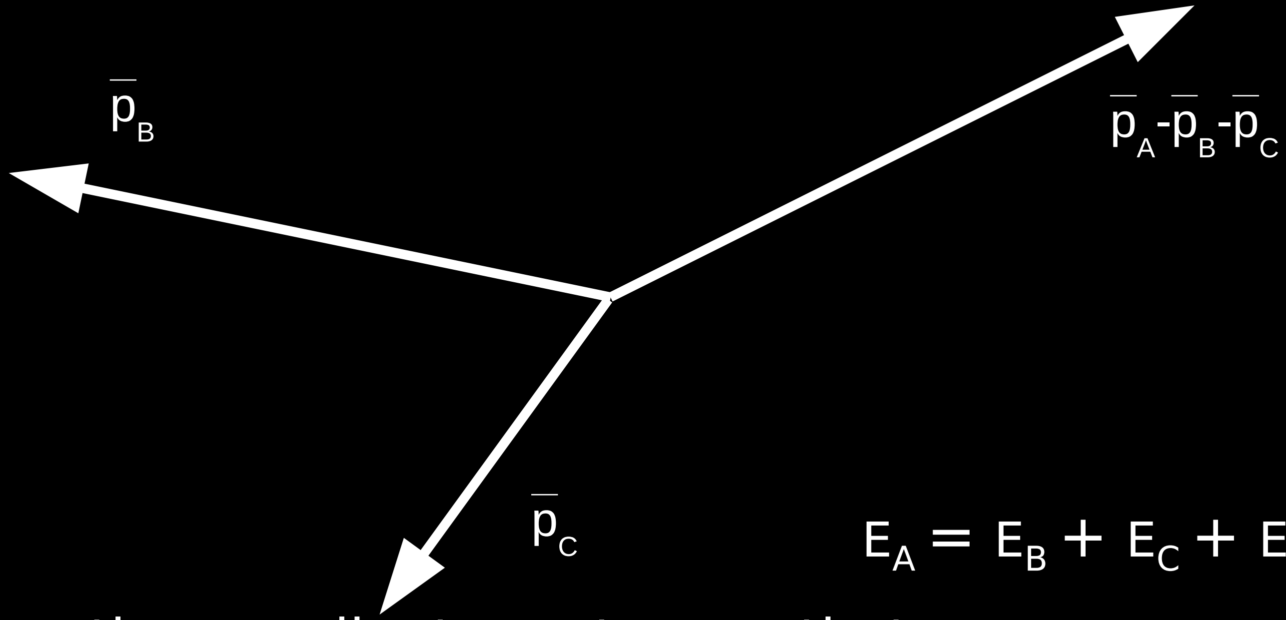


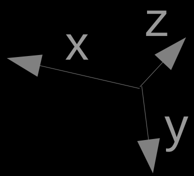
$E_A = E_B + E_C + E_D$

- Three degrees of freedom are constrained by particle masses:
  - $P^2{}_B = m^2{}_B$
  - $P^2{}_C = m^2{}_C$
  - $P^2{}_D = m^2{}_D$

Number of degrees of freedom

ndof = 3



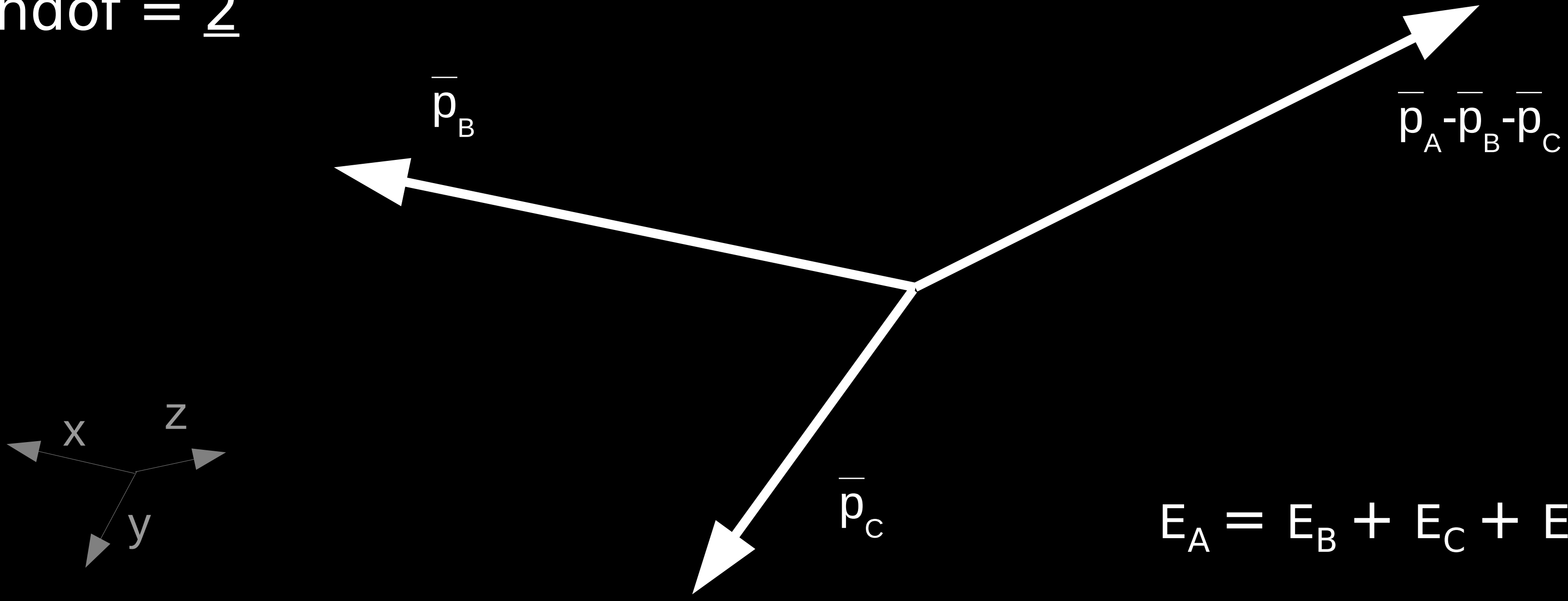


$$E_A = E_B + E_C + E_D$$

- We can choose the coordinate system so that
  - $P_{y,B} = 0$
  - $P_{z,B} = 0$

Number of degrees of freedom

ndof = $\underline{2}$

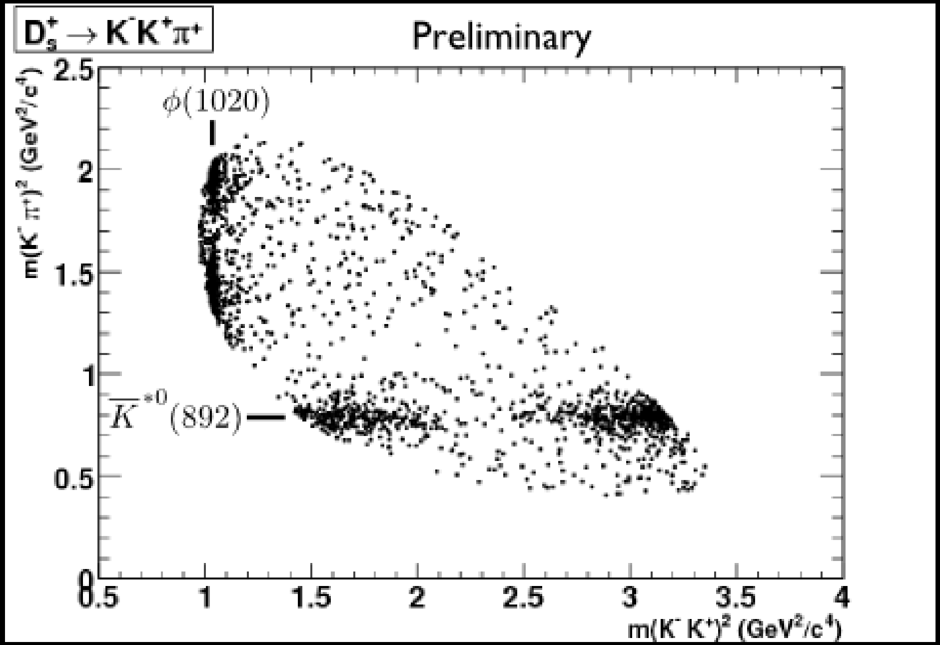


$$E_A = E_B + E_C + E_D$$

- We can choose the coordinate system so that we have also
  - $P_{z,C} = 0$

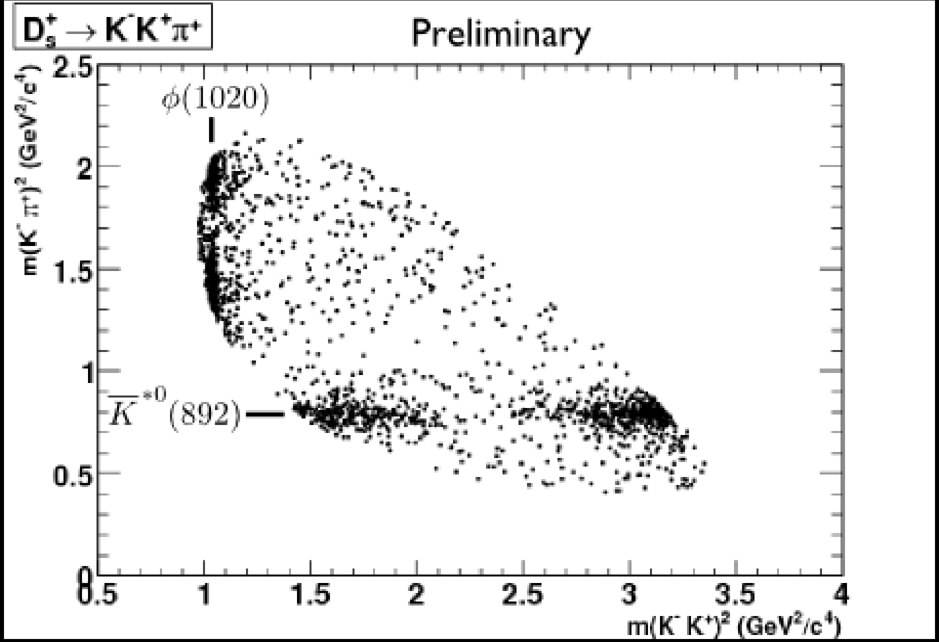
Dalitz plot

- We can describe the kinematic of the three body decay using only two variables.
- In the Dalitz plot, we use:
  - $m^2_{BC} = (p^\mu_B + p^\mu_C)^2$
  - $m^2_{BD} = (p^\mu_B + p^\mu_D)^2$



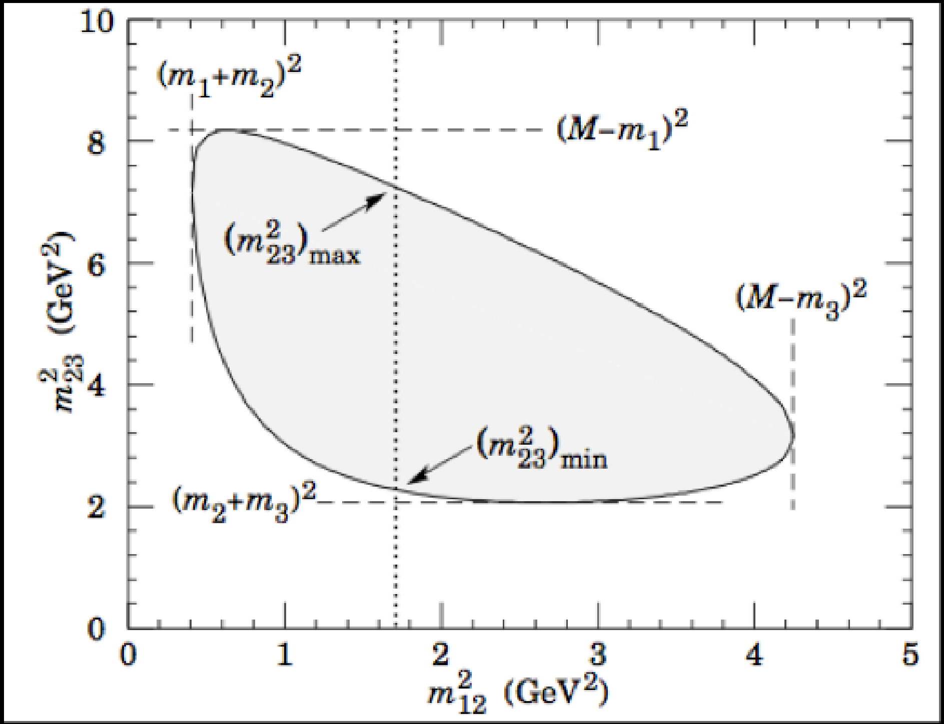
Dalitz plot

- Example: $D_s^+ \rightarrow K^+ + K^- + \pi^+$
- The Dalitz plot shows the presence of two resonance:
  - $D_s^+ \rightarrow \phi(1020) + \pi^+$
  - $D_s^+ \rightarrow \overline{K}^{*0+}(892) + K^+$



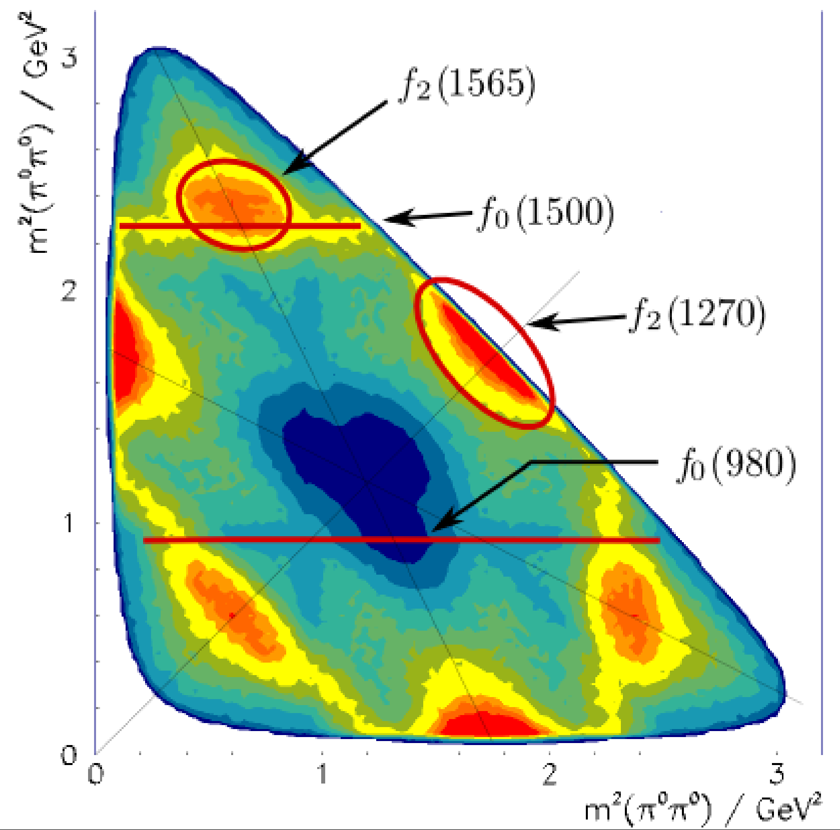
Dalitz plot

- The boundary of the phase space are fixed by the kinematic and depends only on the masses.
- The plot shows the phase space of a particle with mass M decaying into three particles with masses m1, m2, and m3.



Dalitz plot

- Example: $p+\bar{p}\rightarrow \pi^0+\pi^0+\pi^0$
- Three identical particles in the final state:
  - three symmetry axes in the Dalitz plot.
- Four resonances:
  - $f_0(1500)$ spin-0 resonance
    - similar to the previous example,
  - $f_2(1270)$,$f_2(1565)$ spin-2 resonance
    - special signature,
  - $f_0(980)$ spin-0 resonance
    - observed as a distructive interference!



Exercise

Preliminary step

1) Please reboot the PC to Linux
2) Open konsole (terminal)
3) source /app/cern/root_v5.34.34/bin/thisroot.sh
test ROOT
4) root -l ## type .q to exit
test python
5) emacs test.py &
6) write “print 'test' ” in the file
7) save it
8) python test.py
or you try to use iPython notebook
9) open Firefox
10) ipython notebook test.ipnb
11) write “print 'test' ” and press play
download ThreeBodyDecay.py
12) wget http://sdonato.web.cern.ch/sdonato/UZH/ThreeBodyDecay.py

Exercise 1

- In an experiment we detect three particles.
  - What is the pt,eta,phi, mass of each particle?
  - What is total momentum of the original particle?
- http://sdonato.web.cern.ch/sdonato/UZH/ThreeBodyDecay.py

```
from ThreeBodyDecay import exp1
(part1,part2,part3) = exp1()
print type(part1) #TLorentzVector
help(part1)
```

```
from ROOT import TLorentzVector
fourVector = TLorentzVector()
fourVector.SetPtEtaPhiM(10,0.52,0,1.)
fourVector.SetPtEtaPhiE(10,0.52,0,5.)
fourVector.SetPxPyPzE(2.3,0.,1.,5.)

print fourVector.Pt(),fourVector.Px()
print fourVector.E(),fourVector.M()

fourVector2 = TLorentzVector()
sum = fourVector+fourVector2
```

Exercise 1

- We repeat the exp1 100 times:
  - Do the the pt,eta,phi, mass of each particle change?
  - How is distributed the invariant mass of the three particles?

```
from ROOT import TH1F
help(TH1F)
histo = TH1F(“histo”,”My histogram”, 100,0,1) #nbins, xmin, xmax

for i in range(1000):
	x = 0.2 + 1./2000
	histo.Fill(x)

histo.Draw()
```

Exercise 1

- Produce the Dalitz plot of the three particles!
  - Did you find any two-body resonance?

    (repeat the experiment at least 1000 times)

```
from ROOT import TH1F
help(TH2F)
histo2D = TH2F(“histo2D”,”My 2D histogram”, 100,0,1,50,0,2)
#nbinsx, xmin, xmax, nbinsy, ymin, ymax

for i in range(1000):
	x = 0.2 + 1./2000
	y = 1 + 1./1000
	histo.Fill(x,y)

histo.Draw(“”) #draw scatter-plot like
histo.Draw(“COLZ”) #draw colored 2D plot
```

Exercise 2

- Let's move to a more realistic experiment...
  - Do you notice any difference?
- What is the resolution of the invariant mass of the three body decay?

```
from ThreeBodyDecay import exp2
(part1,part2,part3) = exp2()
print type(part1) #TLorentzVector
help(part1)
```

```
from ROOT import TF1

fnc_gaus = TF1("MyGaus", "[0]*
exp (-0.5*((x-[1])/[2])**2)", 0., 1.)
#formula. xmin, xmax

fnc_gaus.SetParameter(1, 91.5)
fnc_gaus.SetParameter(2, 2.45)
histo.Fit("MyGaus")
```

Exercise 3

- Let's move to an even more realistic experiment...
  - What is the difference?
- How can we improve the quality of the Dalitz plot?

```
from ThreeBodyDecay import exp3
(part1,part2,part3) = exp3()
print type(part1) #TLorentzVector
help(part1)
```

```
for i in [1,2,3,4,5,6,7,8]:
	if i>3 and i<6:
		print i
```

Exercise 4

- What are the particle in the final state of this experiment?
- Have you found any three-body resonance?
- What is the Dalitz plot?
  - Is there any symmetry? Why?
  - Have you found any two-body resonance?

```
from ThreeBodyDecay import exp4
(part1,part2,part3) = exp4()
print type(part1) #TLorentzVector
help(part1)
```

Exercise 5

- Let's look at the ThreeBodyDecay.py code!