reactionchecker

April 8, 2024

[ ]:
```
import numpy as np
import pandas as pd
import pdg
from fractions import Fraction
import itertools

api = pdg.connect()
```

0.1 PDG dataset

I use PDG's python api to get the main data. Here is some code showing how to use the api.

[ ]:
```
p = api.get_particle_by_name('p')
print(p.name,p.mass,p.charge,p.quantum_I,p.quantum_J)

Sigma_puls = api.get_particle_by_name('Sigma+')
print(Sigma_puls.name,Sigma_puls.mass,Sigma_puls.charge,Sigma_puls.
  ↪quantum_I,Sigma_puls.quantum_J)
```

```
p 0.93827208816 1.0 1/2 1/2
Sigma+ 1.18937004127302 None 1 1/2
```

0.2 My own addition

However PDG do not give some simple informaition such as Isospin third component I_3.

[ ]:
```
path = 'Dataset.xlsx'
selfdefine = pd.read_excel(path)
selfdefine.index=selfdefine['name'].values
selfdefine
```

[ ]:

	name	mass	J	B	S	Q	I	I3
pi+	pi+	139.570	0	0.0	0	1.0	1	1
pi0	pi0	134.980	0	0.0	0	0.0	1	0
pi-	pi-	139.570	0	0.0	0	-1.0	1	-1
K+	K+	493.690	0	0.0	1	1.0	1/2	+1/2
K0	K0	497.690	0	0.0	1	0.0	1/2	-1/2
K-	K-	493.680	0	0.0	-1	-1.0	1/2	-1/2
-K0	-K0	497.690	0	0.0	-1	0.0	1/2	+1/2

```
eta          eta   547.300    0  0.0  0  0.0    0     0
p              p   938.272  1/2  1.0  0  1.0  1/2  +1/2
n              n   939.567  1/2  1.0  0  0.0  1/2  -1/2
Lambda0  Lambda0  1115.630  1/2  1.0 -1  0.0    0     0
Sigma+    Sigma+  1189.370  1/2  1.0 -1  1.0    1     1
Sigma0    Sigma0  1192.550  1/2  1.0 -1  0.0    1     0
Sigma-    Sigma-  1197.430  1/2  1.0 -1 -1.0    1    -1
Xi0          Xi0  1314.900  1/2  1.0 -2  0.0  1/2  +1/2
Xi-          Xi-  1321.320  1/2  1.0 -2 -1.0  1/2  -1/2
Omega-    Omega-  1672.430  3/2  1.0 -3 -1.0    0     0
s              s       NaN  NaN  NaN  1  NaN  NaN   NaN
```

You can get data for a paticular particle by this way

[ ]:
```
selfdefine.loc['p']
```

[ ]:
```
name          p
mass    938.272
J           1/2
B           1.0
S             0
Q           1.0
I           1/2
I3         +1/2
Name: p, dtype: object
```

You can search particles with paticular property by this way

[ ]:
```
selfdefine.loc[selfdefine['Q'] == 1]
```

[ ]:
```
          name      mass    J    B  S    Q    I    I3
pi+        pi+   139.570    0  0.0  0  1.0    1     1
K+          K+   493.690    0  0.0  1  1.0  1/2  +1/2
p            p   938.272  1/2  1.0  0  1.0  1/2  +1/2
Sigma+  Sigma+  1189.370  1/2  1.0 -1  1.0    1     1
```

0.3 My reaction checker

I will primarily utilize PDG's data. However, for S and I_3, I rely on my own dataset.

This task proves more challenging than anticipated, as PDG's dataset API does not provide all the required data. Additionally, verifying I_3 violation necessitates expertise in angular momentum coupling techniques.

The names of particles align primarily with PDG conventions. However, for anti-particles, I prepend a '-' before their names. Regarding neutrinos, PDG combines three flavors into one name, 'mu', perhaps due to neutrino oscillation. For the verification of lepton number, I opt to use 'nu_e', 'nu_nu', and 'nu_tau'.

[ ]:
```python
def get_baryon_number(name):
    # a small assistant function to get baryon number
    if api.get_particle_by_name(name).is_baryon:
        return 1
    if api.get_particle_by_name(name).is_quark:
        return 1/3
    return 0

def get_lepton_number(name):
    if name in ['e','nu_e','e-']:
        L_e=1
    elif name in ['e+']:
        L_e=-1
    else:
        L_e=0
    if name in ['mu','nu_mu','mu-']:
        L_mu=1
    elif name in ['mu+']:
        L_mu=-1
    else:
        L_mu=0
    if name in ['tau','nu_tau','tau-']:
        L_tau=1
    elif name in ['tau+']:
        L_tau=-1
    else:
        L_tau=0
    return L_e,L_mu,L_tau

def convert_parity(parity): #'+' to 1, '-' to -1
    if parity=='+':
        return 1
    if parity=='-':
        return -1
    return None
convert_parity = np.vectorize(convert_parity)

# convert_bool=lambda x:False if x=='False' else True
# convert_bool = np.vectorize(convert_bool)

def get_isospin(name):
    if name == 'gamma':
        return 0
    # In PDG's data, the isospin of gamma is '0,1'


    isospin = api.get_particle_by_name(name).quantum_I
```

```
    if isospin == None:
        return 0
    return Fraction(isospin)

def sum_isospin(I):
    # I is a list of isospin I not I3
    # get the result of all possible total isospin
    # In order to avoid floating-point errors, the result is doubled to␣
 ↪discribe the half-interger well.
    I = np.array(I)
    possible_result = set()
    for i in itertools.product([-2, 2], repeat=len(I)):
        possible_result.add(int(abs((I*np.array(i)).sum())))
    return possible_result

def check_isospin(I_reactant,I_product):
    return bool(sum_isospin(I_reactant) & sum_isospin(I_product))

def get_charge(name):
    # As you see, PDG think that the charge of 'Sigma+' is None. So strange!
    PDGdata = api.get_particle_by_name(name)
    is_hardon = PDGdata.is_baryon or PDGdata.is_meson
    if is_hardon:
        return selfdefine.loc[name]['Q']
    if PDGdata.charge==None:
        return 0
    return PDGdata.charge


def find_subscript_index(input_string):
    if input_string[:2]=='nu':
        return input_string.find('_')
    for i in range(len(input_string) - 1, -1, -1):
        if input_string[i].isalpha():
            return i+1
    return 0

def get_particle_Latex(name):
    # from particle name in ASCII code to LaTeX code. For example, 'pi+' to␣
 ↪'\pi^+'
    anti = ''
    if name[0]=='-':
        anti = r'\bar '
        name=name[1:]
    index = 0
    if name[:2]=='nu':
        index = name.find('_')
```

```
        nametext = name[:index]
        subscript = name[index+1:]
        nametext = '\\' + nametext
        if len(subscript)>1:
            subscript = '\\' + subscript
        final = anti + nametext+'_'+subscript
    else:
        for i in range(len(name) - 1, -1, -1):
            if name[i].isalpha():
                index = i
                break
        nametext = name[:index+1]
        subscript = name[index+1:]
        if len(nametext)>1:
            nametext = '\\' + nametext
        if subscript:
            subscript = '^'+subscript
        final = anti + nametext +subscript
    return final


def get_reaction_Latex(reactant,product):
    # from reaction information to get the equation for reaction in latex
    reactantlatex_list=[]
    for i in reactant:
        reactantlatex_list.append(get_particle_Latex(i))
    productlatex_list=[]
    for i in product:
        productlatex_list.append(get_particle_Latex(i))

    reactantlatex = ' + '.join(reactantlatex_list)
    productlatex = ' + '.join(productlatex_list)
    return reactantlatex+r' \to '+productlatex

def reaction_checker(reactant,product):
    # print('CCCCCCCCCCCCHHHHHHHHHHH')
    # get in reaction datas
    reactant_df = pd.DataFrame({'name':reactant})
    reactant_df.index = [f'reactant{i+1}' for i in range(len(reactant))]
    product_df = pd.DataFrame({'name':product})
    product_df.index = [f'product{i+1}' for i in range(len(product))]

    # anti-particle, because PDG do not give some data about anti-particles
    anti_reactant = [1 for _ in range(len(reactant))]
    for i in range(len(reactant)):
        if reactant[i][0]=='-':
            anti_reactant[i]=-1
```

```
            reactant[i]=reactant[i][1:]
    anti_reactant = np.array(anti_reactant)
    anti_product = [1 for _ in range(len(product))]
    for i in range(len(product)):
        if product[i][0]=='-':
            anti_product[i]=-1
            product[i]=product[i][1:]
    anti_product = np.array(anti_product)

    # neutrino: PDG gives three flavors of neutrino in one particle data 'nu'
    # don't worry, the information with neutrino flavor is backed up and␣
↪seemingly only used in lepton number
    neu_reactant = reactant[:]
    for i in range(len(reactant)):
        if reactant[i][:2]=='nu':
            reactant[i]='nu'
    neu_product = product[:]
    for i in range(len(product)):
        if product[i][:2]=='nu':
            product[i]='nu'
    # print(reactant,product)
    # print(neu_reactant,neu_product)
    # print('CCCCCCCCCCCCHHHHHHHHHHH')

    # check em-charge
    reactant_df['Q']=[get_charge(i) for i in reactant]
    product_df['Q']=[get_charge(i) for i in product]
    reactant_df['Q']*=anti_reactant
    product_df['Q']*=anti_product
    # print('CCCCCCCCCCCCHHHHHHHHHHH')
    check_charge = ((abs(reactant_df['Q'].values.sum()-product_df['Q'].values.
↪sum()))<1e-3)
    # print('CCCCCCCCCCCCHHHHHHHHHHH')
    # check baryon number
    reactant_df['B']=[get_baryon_number(i) for i in reactant]
    product_df['B']=[get_baryon_number(i) for i in product]
    reactant_df['B']*=anti_reactant
    product_df['B']*=anti_product
    check_B = ((abs(reactant_df['B'].values.sum()-product_df['B'].values.
↪sum()))<1e-3)

    # check lepton number
  ␣
↪reactant_df['L_e'],reactant_df['L_mu'],reactant_df['L_tau']=[[get_lepton_number(row)[i]␣
↪for row in neu_reactant] for i in range(3)]
```

```
␣
↪product_df['L_e'],product_df['L_mu'],product_df['L_tau']=[[get_lepton_number(row)[i]␣
↪for row in neu_product] for i in range(3)]

   reactant_df['L_e']*=anti_reactant
   product_df['L_e']*=anti_product
   reactant_df['L_mu']*=anti_reactant
   product_df['L_mu']*=anti_product
   reactant_df['L_tau']*=anti_reactant
   product_df['L_tau']*=anti_product

   check_L_e = (reactant_df['L_e'].values.sum()==product_df['L_e'].values.
↪sum())
   check_L_mu = (reactant_df['L_mu'].values.sum()==product_df['L_mu'].values.
↪sum())
   check_L_tau = (reactant_df['L_tau'].values.sum()==product_df['L_tau'].
↪values.sum())
   # print(check_L_e,check_L_mu,check_L_tau)

   # check strange number
   reactant_df['S']=[(0 if not(i in set(selfdefine.index.values))
                      else selfdefine.loc[i]['S'])
                      for i in reactant]
   product_df['S']=[(0 if not(i in set(selfdefine.index.values))
                      else selfdefine.loc[i]['S'])
                      for i in product]
   reactant_df['S']*=anti_reactant
   product_df['S']*=anti_product
   check_S = ((abs(reactant_df['S'].values.sum()-product_df['S'].values.
↪sum()))<1e-3)


   # check isospin: total isospin cannot be added directly
   reactant_df['I']=[get_isospin(i) for i in reactant]
   product_df['I']=[get_isospin(i) for i in product]
   check_I = check_isospin(reactant_df['I'].values,product_df['I'].values)

   # check I3
   reactant_df['I3']=[(0 if not(i in set(selfdefine.index.values))
                      else Fraction(selfdefine.loc[i]['I3']))
                      for i in reactant]
   product_df['I3']=[(0 if not(i in set(selfdefine.index.values))
                      else Fraction(selfdefine.loc[i]['I3']))
                      for i in product]
   reactant_df['I3']*=anti_reactant
   product_df['I3']*=anti_product
   reactant_df.fillna(0, inplace=True)
```

```
    product_df.fillna(0, inplace=True)
    check_I3 = ((abs(reactant_df['I3'].values.sum()-product_df['I3'].values.
↪sum()))<1e-3)

    # check C-parity
    reactant_df['C']=[api.get_particle_by_name(i).quantum_C for i in reactant]
    product_df['C']=[api.get_particle_by_name(i).quantum_C for i in product]
    if (None in reactant_df['C'].values) or (None in product_df['C'].values):
        check_C = None
    else:
        # pass
        reactant_parity = convert_parity(reactant_df['C']).prod()
        product_parity = convert_parity(product_df['C']).prod()
        check_C=(reactant_parity == product_parity)

    # check G-parity
    reactant_df['G']=[api.get_particle_by_name(i).quantum_G for i in reactant]
    product_df['G']=[api.get_particle_by_name(i).quantum_G for i in product]
    if (None in reactant_df['G'].values) or (None in product_df['G'].values):
        check_G = None
    else:
        # pass
        reactant_parity = convert_parity(reactant_df['G']).prod()
        product_parity = convert_parity(product_df['G']).prod()
        check_G=(reactant_parity == product_parity)


    # form result
    analy_df=pd.concat([reactant_df,product_df])
    analy_df.loc['checking']=['checking',
                              str(check_charge),
                              str(check_B),
                              str(check_L_e),
                              str(check_L_mu),
                              str(check_L_tau),
                              str(check_S),
                              str(check_I),
                              str(check_I3),
                              str(check_C),
                              str(check_G)]


    Possibility = 'Yes'
    strong = 'Yes'
    EM = 'Yes'
    weak = 'Yes'
    # checking weather and how the reaction can happen
```

```
    possi = analy_df.loc['checking']['Q':'L_tau']
    violations = possi[possi=='False']
    if len(violations)!=0:
        Possibility=','.join(violations.index)+' violation'
        strong = 'No'
        EM = 'No'
        weak = 'No'

    if Possibility=='Yes':
        # checking strong interaction
        strong_data = analy_df.loc['checking']['S':'G']
        violations = strong_data[strong_data=='False']
        if len(violations)!=0:
            strong =','.join(violations.index)+' violation'

        # checking EM interaction
        EM_data = analy_df.loc['checking'][['S','I3','C']]
        violations = EM_data[EM_data=='False']
        if len(violations)!=0:
            EM =','.join(violations.index)+' violation'


    Checking_result = pd.DataFrame({'reaction':
↪['$'+get_reaction_Latex(reactant_df['name'].values,product_df['name'].
↪values)+'$'],
                                    'Possibility':[Possibility],
                                    'Strong':[strong],
                                    'EM':[EM],
                                    'Weak':[weak]})


    return analy_df,Checking_result
```

0.4 HW

My reaction checker generates two lists: one containing reactants and the other containing products.

It returns two dataframes. The first dataframe indicates the violated quantum numbers and the nature of the violations. The second dataframe provides information on the types of interactions in which the reaction can occur.

1

$$p + p \to n + \pi^+ + p$$

[ ]:
```
reactant = ['p','p']
product = ['n','pi+','p']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
```

```
total_result = pd.DataFrame()
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
              name     Q     B   L_e  L_mu L_tau     S     I    I3     C  \
reactant1        p   1.0     1     0     0     0     0   1/2   1/2  None
reactant2        p   1.0     1     0     0     0     0   1/2   1/2  None
product1         n   0.0     1     0     0     0     0   1/2  -1/2  None
product2       pi+   1.0     0     0     0     0     0     1     1  None
product3         p   1.0     1     0     0     0     0   1/2   1/2  None
checking  checking  True  True  True  True  True  True  True  True  None

             G
reactant1  None
reactant2  None
product1   None
product2      -
product3   None
checking   None

                  reaction Possibility Strong   EM Weak
0  $p + p \to n + \pi^+ + p$         Yes    Yes  Yes  Yes
```

2

$$p + p \to \overline{n} + p + p + \pi^0$$

[ ]:
```
reactant = ['p','p']
product = ['-n','pi+','p','pi0']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
              name     Q      B   L_e  L_mu L_tau     S     I     I3     C  \
reactant1        p   1.0      1     0     0     0     0   1/2    1/2  None
reactant2        p   1.0      1     0     0     0     0   1/2    1/2  None
product1        -n  -0.0     -1     0     0     0     0   1/2    1/2  None
product2       pi+   1.0      0     0     0     0     0     1      1  None
product3         p   1.0      1     0     0     0     0   1/2    1/2  None
product4       pi0   0.0      0     0     0     0     0     1      0     +
checking  checking  True  False  True  True  True  True  True  False  None

             G
reactant1  None
reactant2  None
product1   None
product2      -
product3   None
product4      -
checking   None
```

```
                                reaction  Possibility Strong  EM Weak
0  $p + p \to \bar n + \pi^+ + p + \pi^0$  B violation     No  No   No
```

3

$$\pi^+ + p \to \Sigma^+ + p$$

[ ]:
```
reactant = ['pi+','p']
product = ['Sigma+','p']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
              name     Q      B   L_e  L_mu L_tau      S     I    I3     C  \
reactant1       pi+   1.0      0     0     0     0      0     1     1  None
reactant2         p   1.0      1     0     0     0      0   1/2   1/2  None
product1     Sigma+   1.0      1     0     0     0     -1     1     1  None
product2          p   1.0      1     0     0     0      0   1/2   1/2  None
checking   checking  True  False  True  True  True  False  True  True  None

              G
reactant1     -
reactant2  None
product1   None
product2   None
checking   None

                      reaction  Possibility Strong  EM Weak
0  $\pi^+ + p \to \Sigma^+ + p$  B violation     No  No   No
```

4

$$\pi^+ + p \to \Sigma^+ + K^+$$

[ ]:
```
reactant = ['pi+','p']
product = ['Sigma+','K+']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
              name     Q     B   L_e  L_mu L_tau     S     I    I3     C  \
reactant1       pi+   1.0     0     0     0     0     0     1     1  None
reactant2         p   1.0     1     0     0     0     0   1/2   1/2  None
product1     Sigma+   1.0     1     0     0     0    -1     1     1  None
product2         K+   1.0     0     0     0     0     1   1/2   1/2  None
checking   checking  True  True  True  True  True  True  True  True  None

              G
reactant1     -
reactant2  None
```

```
product1   None
product2   None
checking   None

                          reaction Possibility Strong   EM Weak
0  $\pi^+ + p \to \Sigma^+ + K^+$          Yes    Yes  Yes  Yes
```

5

$$\pi^+ + p \to \Sigma^+ + p + \pi^0$$

[ ]:
```
reactant = ['pi+','p']
product = ['Sigma+','p','pi0']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q      B   L_e  L_mu L_tau      S     I    I3     C  \
reactant1       pi+   1.0      0     0     0     0      0     1     1  None
reactant2         p   1.0      1     0     0     0      0   1/2   1/2  None
product1     Sigma+   1.0      1     0     0     0     -1     1     1  None
product2          p   1.0      1     0     0     0      0   1/2   1/2  None
product3        pi0   0.0      0     0     0     0      0     1     0     +
checking   checking  True  False  True  True  True  False  True  True  None

              G
reactant1     -
reactant2  None
product1   None
product2   None
product3      -
checking   None

                               reaction  Possibility Strong  EM Weak
0  $\pi^+ + p \to \Sigma^+ + p + \pi^0$  B violation     No  No   No
```

6

$$\pi^+ + p \to \Xi^0 + \cdots$$

[ ]:
```
reactant = ['pi+','p']
product = ['Xi0']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name      Q     B   L_e  L_mu L_tau      S     I     I3     C  \
reactant1       pi+   1.0      0     0     0     0      0     1      1  None
reactant2         p   1.0      1     0     0     0      0   1/2    1/2  None
product1       Xi0    0.0      1     0     0     0     -2   1/2    1/2  None
checking   checking  False  True  True  True  True  False  True  False  None
```

```
              G
reactant1     -
reactant2  None
product1   None
checking   None
```

```
                reaction  Possibility Strong  EM Weak
0  $\pi^+ + p \to \Xi^0$  Q violation     No  No   No
```

7

$$\Sigma^+ + p \to \Lambda^0 + \pi^+ + p$$

[ ]:
```
reactant = ['Sigma+','p']
product = ['Lambda0','pi+','p']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau     S     I    I3     C  \
reactant1    Sigma+   1.0     1     0     0     0    -1     1     1  None
reactant2         p   1.0     1     0     0     0     0   1/2   1/2  None
product1    Lambda0   0.0     1     0     0     0    -1     0     0  None
product2        pi+   1.0     0     0     0     0     0     1     1  None
product3          p   1.0     1     0     0     0     0   1/2   1/2  None
checking   checking  True  True  True  True  True  True  True  True  None
```

```
              G
reactant1  None
reactant2  None
product1   None
product2      -
product3   None
checking   None
```

```
                                    reaction Possibility Strong   EM Weak
0  $\Sigma^+ + p \to \Lambda^0 + \pi^+ + p$         Yes    Yes  Yes  Yes
```

8

$$\Sigma^- + p \to \Xi^- + p$$

[ ]:
```
reactant = ['Sigma-','p']
product = ['Xi-','p']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau     S     I    I3     C  \
reactant1    Sigma-  -1.0     1     0     0     0    -1     1    -1  None
```

```
reactant2         p   1.0     1     0     0     0      0    1/2    1/2  None
product1       Xi-  -1.0     1     0     0     0     -2    1/2   -1/2  None
product2          p   1.0     1     0     0     0      0    1/2    1/2  None
checking   checking  True  True  True  True  True  False  False  False  None

              G
reactant1  None
reactant2  None
product1   None
product2   None
checking   None

                       reaction Possibility            Strong              EM  \
0  $\Sigma^- + p \to \Xi^- + p$         Yes  S,I,I3 violation  S,I3 violation

  Weak
0  Yes
```

9

$$\Xi^0 \to e^- + p + \bar{\nu}_e$$

[ ]:
```
reactant = ['Xi0']
product = ['e-','p','-nu_e']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S     I    I3     C  \
reactant1       Xi0   0.0     1     0     0     0     -2   1/2   1/2  None
product1          e-  -1.0     0     1     0     0      0     0     0  None
product2          p   1.0     1     0     0     0      0   1/2   1/2  None
product3      -nu_e  -0.0     0    -1     0     0      0     0     0  None
checking   checking  True  True  True  True  True  False  True  True  None

              G
reactant1  None
product1   None
product2   None
product3   None
checking   None

                           reaction Possibility       Strong           EM Weak
0  $\Xi^0 \to e^- + p + \bar \nu_e$         Yes  S violation  S violation  Yes
```

10

$$\Xi^0 \to \Lambda^0 + \pi^0$$

[ ]:
```
reactant = ['Xi0']
product = ['Lambda0','pi0']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1       Xi0   0.0     1     0     0     0     -2    1/2    1/2  None
product1    Lambda0   0.0     1     0     0     0     -1      0      0  None
product2        pi0   0.0     0     0     0     0      0      1      0     +
checking   checking  True  True  True  True  True  False  False  False  None

              G
reactant1  None
product1   None
product2      -
checking   None

                        reaction Possibility            Strong  \
0  $\Xi^0 \to \Lambda^0 + \pi^0$         Yes  S,I,I3 violation

               EM Weak
0  S,I3 violation  Yes
```

11

$$\Xi^- \to \Lambda^0 + \pi^-$$

[ ]:
```
reactant = ['Xi-']
product = ['Lambda0','pi-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1       Xi-  -1.0     1     0     0     0     -2    1/2   -1/2  None
product1    Lambda0   0.0     1     0     0     0     -1      0      0  None
product2        pi-  -1.0     0     0     0     0      0      1     -1  None
checking   checking  True  True  True  True  True  False  False  False  None

              G
reactant1  None
product1   None
product2      -
checking   None

                        reaction Possibility            Strong  \
0  $\Xi^- \to \Lambda^0 + \pi^-$         Yes  S,I,I3 violation
```

```
                EM Weak
0  S,I3 violation  Yes
```

0.5 12

$$\Omega^- \to \Lambda^0 + \pi^-$$

[ ]:
```
reactant = ['Omega-']
product = ['Lambda0','pi-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
                name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1    Omega-  -1.0     1     0     0     0     -3      0      0  None
product1    Lambda0   0.0     1     0     0     0     -1      0      0  None
product2         pi-  -1.0     0     0     0     0      0      1     -1  None
checking    checking  True  True  True  True  True  False  False  False  None

               G
reactant1   None
product1    None
product2       -
checking    None

                            reaction Possibility            Strong  \
0  $\Omega^- \to \Lambda^0 + \pi^-$         Yes  S,I,I3 violation

                EM Weak
0  S,I3 violation  Yes
```

13

$$\Omega^- \to \Lambda^0 + K^-$$

[ ]:
```
reactant = ['Omega-']
product = ['Lambda0','K-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
                name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1    Omega-  -1.0     1     0     0     0     -3      0      0  None
product1    Lambda0   0.0     1     0     0     0     -1      0      0  None
product2         K-  -1.0     0     0     0     0     -1    1/2   -1/2  None
checking    checking  True  True  True  True  True  False  False  False  None

               G
reactant1   None
product1    None
```

```
product2   None
checking   None

                          reaction Possibility            Strong  \
0  $\Omega^- \to \Lambda^0 + K^-$         Yes  S,I,I3 violation

                EM Weak
0  S,I3 violation  Yes
```

14

$$\Omega^- \to \Xi^0 + \pi^-$$

[ ]:
```
reactant = ['Omega-']
product = ['Xi0','pi-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
                name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1    Omega-  -1.0     1     0     0     0     -3      0      0  None
product1        Xi0   0.0     1     0     0     0     -2    1/2    1/2  None
product2         pi-  -1.0     0     0     0     0      0      1     -1  None
checking    checking  True  True  True  True  True  False  False  False  None

               G
reactant1   None
product1    None
product2       -
checking    None

                        reaction Possibility            Strong              EM  \
0  $\Omega^- \to \Xi^0 + \pi^-$         Yes  S,I,I3 violation  S,I3 violation

   Weak
0  Yes
```

15

$$\Omega^- \to \Xi^0 + K^-$$

[ ]:
```
reactant = ['Omega-']
product = ['Xi0','K-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
                name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1    Omega-  -1.0     1     0     0     0     -3      0      0  None
product1        Xi0   0.0     1     0     0     0     -2    1/2    1/2  None
product2         K-  -1.0     0     0     0     0     -1    1/2   -1/2  None
```

```
checking   checking  True  True  True  True  True  True  True  True  None
```

```
              G
reactant1  None
product1   None
product2   None
checking   None
```

```
                    reaction Possibility Strong   EM Weak
0  $\Omega^- \to \Xi^0 + K^-$         Yes    Yes  Yes  Yes
```

16

$$\Xi^- \to \Sigma^0 + \mu^- + \bar{\nu}_\mu$$

[ ]:
```
reactant = ['Xi-']
product = ['Sigma0','mu-','-nu_mu']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1        Xi-  -1.0     1     0     0     0     -2    1/2   -1/2  None
product1     Sigma0   0.0     1     0     0     0     -1      1      0  None
product2        mu-  -1.0     0     0     1     0      0      0      0  None
product3     -nu_mu  -0.0     0     0    -1     0      0      0      0  None
checking   checking  True  True  True  True  True  False  False  False  None
```

```
              G
reactant1  None
product1   None
product2   None
product3   None
checking   None
```

```
                                      reaction Possibility            Strong  \
0  $\Xi^- \to \Sigma^0 + \mu^- + \bar \nu_\mu$         Yes  S,I,I3 violation

               EM Weak
0  S,I3 violation  Yes
```

17

$$\Xi^- \to e^- + p + \bar{\nu}_e + \pi^-$$

[ ]:
```
reactant = ['Xi-']
product = ['e-','p','-nu_e','pi-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S     I    I3     C  \
reactant1       Xi-  -1.0     1     0     0     0     -2   1/2  -1/2  None
product1         e-  -1.0     0     1     0     0      0     0     0  None
product2          p   1.0     1     0     0     0      0   1/2   1/2  None
product3      -nu_e  -0.0     0    -1     0     0      0     0     0  None
product4        pi-  -1.0     0     0     0     0      0     1    -1  None
checking   checking  True  True  True  True  True  False  True  True  None

              G
reactant1  None
product1   None
product2   None
product3   None
product4      -
checking   None

                                    reaction Possibility       Strong  \
0  $\Xi^- \to e^- + p + \bar \nu_e + \pi^-$         Yes  S violation

            EM Weak
0  S violation  Yes
```

18

$$\Sigma^0 \to \Lambda^0 + \gamma + \gamma$$

[ ]:
```
reactant = ['Sigma0']
product = ['Lambda0','gamma','gamma']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau     S      I    I3     C  \
reactant1    Sigma0   0.0     1     0     0     0    -1      1     0  None
product1    Lambda0   0.0     1     0     0     0    -1      0     0  None
product2      gamma   0.0     0     0     0     0     0      0     0     -
product3      gamma   0.0     0     0     0     0     0      0     0     -
checking   checking  True  True  True  True  True  True  False  True  None

              G
reactant1  None
product1   None
product2   None
product3   None
checking   None

                                   reaction Possibility       Strong   EM  \
0  $\Sigma^0 \to \Lambda^0 + \gamma + \gamma$         Yes  I violation  Yes
```

```
  Weak
0  Yes
```

19

$$\Sigma^0 \to \Lambda^0 + e^- + e^+$$

[ ]:
```
reactant = ['Sigma0']
product = ['Lambda0','e-','e+']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau     S      I    I3     C  \
reactant1    Sigma0   0.0     1     0     0     0    -1      1     0  None
product1    Lambda0   0.0     1     0     0     0    -1      0     0  None
product2         e-  -1.0     0     1     0     0     0      0     0  None
product3         e+   1.0     0    -1     0     0     0      0     0  None
checking   checking  True  True  True  True  True  True  False  True  None

              G
reactant1  None
product1   None
product2   None
product3   None
checking   None

                                reaction Possibility       Strong   EM Weak
0  $\Sigma^0 \to \Lambda^0 + e^- + e^+$         Yes  I violation  Yes  Yes
```

20

$$K^+ \to \mu^+ + \nu_\mu$$

[ ]:
```
reactant = ['K+']
product = ['mu+','nu_mu']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1        K+   1.0     0     0     0     0      1    1/2    1/2  None
product1        mu+   1.0     0     0    -1     0      0      0      0  None
product2      nu_mu   0.0     0     0     1     0      0      0      0  None
checking   checking  True  True  True  True  True  False  False  False  None

              G
reactant1  None
product1   None
product2   None
checking   None
```

```
                    reaction Possibility            Strong              EM  \
0  $K^+ \to \mu^+ + \nu_\mu$         Yes  S,I,I3 violation  S,I3 violation

  Weak
0  Yes
```

21

$$K^- \to \mu^- + \bar{\nu}_\mu$$

[ ]:
```
reactant = ['K-']
product = ['mu-','-nu_mu']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1        K-  -1.0     0     0     0     0     -1    1/2   -1/2  None
product1         mu-  -1.0     0     0     1     0      0      0      0  None
product2     -nu_mu  -0.0     0     0    -1     0      0      0      0  None
checking   checking  True  True  True  True  True  False  False  False  None

               G
reactant1  None
product1   None
product2   None
checking   None

                         reaction Possibility            Strong  \
0  $K^- \to \mu^- + \bar \nu_\mu$         Yes  S,I,I3 violation

               EM Weak
0  S,I3 violation  Yes
```

22

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

[ ]:
```
reactant = ['K0']
product = ['pi+','pi-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1        K0   0.0     0     0     0     0      1    1/2   -1/2  None
product1         pi+   1.0     0     0     0     0      0      1      1  None
product2         pi-  -1.0     0     0     0     0      0      1     -1  None
checking   checking  True  True  True  True  True  False  False  False  None
```

```
                G
reactant1    None
product1        -
product2        -
checking     None
```

```
                    reaction Possibility              Strong               EM Weak
0  $K^0 \to \pi^+ + \pi^-$         Yes  S,I,I3 violation  S,I3 violation  Yes
```

23

$$K^0 \to \mu^+ + \mu^-$$

[ ]:
```
reactant = ['K0']
product = ['mu+','mu-']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
                name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1         K0   0.0     0     0     0     0      1    1/2   -1/2  None
product1         mu+   1.0     0     0    -1     0      0      0      0  None
product2         mu-  -1.0     0     0     1     0      0      0      0  None
checking    checking  True  True  True  True  True  False  False  False  None
```

```
                G
reactant1    None
product1     None
product2     None
checking     None
```

```
                    reaction Possibility              Strong               EM Weak
0  $K^0 \to \mu^+ + \mu^-$         Yes  S,I,I3 violation  S,I3 violation  Yes
```

24

$$K^+ \to \pi^0 + e^+ + \nu_e$$

[ ]:
```
reactant = ['K+']
product = ['pi0','e+','nu_e']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
                name     Q     B   L_e  L_mu L_tau      S      I     I3     C  \
reactant1         K+   1.0     0     0     0     0      1    1/2    1/2  None
product1         pi0   0.0     0     0     0     0      0      1      0     +
product2          e+   1.0     0    -1     0     0      0      0      0  None
product3       nu_e   0.0     0     1     0     0      0      0      0  None
checking    checking  True  True  True  True  True  False  False  False  None
```

```
                G
reactant1  None
product1      -
product2   None
product3   None
checking   None

                         reaction Possibility            Strong  \
0  $K^+ \to \pi^0 + e^+ + \nu_e$         Yes  S,I,I3 violation

               EM Weak
0  S,I3 violation  Yes
```

25

$$\mu^+ \to e^+ + \nu_e$$

[ ]:
```
reactant = ['mu+']
product = ['e+','nu_e']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e   L_mu L_tau     S     I    I3     C  \
reactant1       mu+   1.0     0     0    -1     0     0     0     0  None
product1         e+   1.0     0    -1     0     0     0     0     0  None
product2       nu_e   0.0     0     1     0     0     0     0     0  None
checking   checking  True  True  True  False  True  True  True  True  None

                G
reactant1  None
product1   None
product2   None
checking   None

                  reaction     Possibility Strong  EM Weak
0  $\mu^+ \to e^+ + \nu_e$  L_mu violation     No  No    No
```

26

$$\pi^+ \to \mu^+ + \bar{\nu}_\mu$$

[ ]:
```
reactant = ['pi+']
product = ['mu+','-nu_mu']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e   L_mu L_tau     S     I    I3     C  \
reactant1       pi+   1.0     0     0     0     0     0     1     1  None
product1        mu+   1.0     0     0    -1     0     0     0     0  None
```

```
product2     -nu_mu  -0.0     0     0     -1     0     0      0      0  None
checking   checking  True  True  True  False  True  True  False  False  None

              G
reactant1     -
product1   None
product2   None
checking   None

                           reaction     Possibility Strong  EM Weak
0  $\pi^+ \to \mu^+ + \bar \nu_\mu$  L_mu violation     No  No   No
```

27

$$\pi^- \to \mu^- + \bar{\nu}_\mu$$

[ ]:
```
reactant = ['pi-']
product = ['mu-','-nu_mu']
reaction,result=reaction_checker(reactant,product)
display(reaction,result)
total_result = pd.concat([total_result, result], ignore_index=True)
```

```
               name     Q     B   L_e  L_mu L_tau     S      I     I3     C  \
reactant1       pi-  -1.0     0     0     0     0     0      1     -1  None
product1        mu-  -1.0     0     0     1     0     0      0      0  None
product2     -nu_mu  -0.0     0     0    -1     0     0      0      0  None
checking   checking  True  True  True  True  True  True  False  False  None

              G
reactant1     -
product1   None
product2   None
checking   None

                           reaction Possibility          Strong            EM  \
0  $\pi^- \to \mu^- + \bar \nu_\mu$         Yes  I,I3 violation  I3 violation

  Weak
0  Yes
```

[ ]:
```
total_result.index+=1
total_result
```

[ ]:
```
                                      reaction     Possibility  \
1                    $p + p \to n + \pi^+ + p$             Yes
2        $p + p \to \bar n + \pi^+ + p + \pi^0$     B violation
3                  $\pi^+ + p \to \Sigma^+ + p$     B violation
4                $\pi^+ + p \to \Sigma^+ + K^+$             Yes
5          $\pi^+ + p \to \Sigma^+ + p + \pi^0$     B violation
6                        $\pi^+ + p \to \Xi^0$     Q violation
```

7	$\Sigma^+ + p \to \Lambda^0 + \pi^+ + p$	Yes
8	$\Sigma^- + p \to \Xi^- + p$	Yes
9	$\Xi^0 \to e^- + p + \bar \nu_e$	Yes
10	$\Xi^0 \to \Lambda^0 + \pi^0$	Yes
11	$\Xi^- \to \Lambda^0 + \pi^-$	Yes
12	$\Omega^- \to \Lambda^0 + \pi^-$	Yes
13	$\Omega^- \to \Lambda^0 + K^-$	Yes
14	$\Omega^- \to \Xi^0 + \pi^-$	Yes
15	$\Omega^- \to \Xi^0 + K^-$	Yes
16	$\Xi^- \to \Sigma^0 + \mu^- + \bar \nu_\mu$	Yes
17	$\Xi^- \to e^- + p + \bar \nu_e + \pi^-$	Yes
18	$\Sigma^0 \to \Lambda^0 + \gamma + \gamma$	Yes
19	$\Sigma^0 \to \Lambda^0 + e^- + e^+$	Yes
20	$K^+ \to \mu^+ + \nu_\mu$	Yes
21	$K^- \to \mu^- + \bar \nu_\mu$	Yes
22	$K^0 \to \pi^+ + \pi^-$	Yes
23	$K^0 \to \mu^+ + \mu^-$	Yes
24	$K^+ \to \pi^0 + e^+ + \nu_e$	Yes
25	$\mu^+ \to e^+ + \nu_e$	L_mu violation
26	$\pi^+ \to \mu^+ + \bar \nu_\mu$	L_mu violation
27	$\pi^- \to \mu^- + \bar \nu_\mu$	Yes

	Strong	EM	Weak
1	Yes	Yes	Yes
2	No	No	No
3	No	No	No
4	Yes	Yes	Yes
5	No	No	No
6	No	No	No
7	Yes	Yes	Yes
8	S,I,I3 violation	S,I3 violation	Yes
9	S violation	S violation	Yes
10	S,I,I3 violation	S,I3 violation	Yes
11	S,I,I3 violation	S,I3 violation	Yes
12	S,I,I3 violation	S,I3 violation	Yes
13	S,I,I3 violation	S,I3 violation	Yes
14	S,I,I3 violation	S,I3 violation	Yes
15	Yes	Yes	Yes
16	S,I,I3 violation	S,I3 violation	Yes
17	S violation	S violation	Yes
18	I violation	Yes	Yes
19	I violation	Yes	Yes
20	S,I,I3 violation	S,I3 violation	Yes
21	S,I,I3 violation	S,I3 violation	Yes
22	S,I,I3 violation	S,I3 violation	Yes
23	S,I,I3 violation	S,I3 violation	Yes
24	S,I,I3 violation	S,I3 violation	Yes

```
25                No              No   No
26                No              No   No
27    I,I3 violation    I3 violation  Yes
```

[ ]:
```
print(total_result.to_markdown())
```

```
|    | reaction                                    | Possibility    | Strong
| EM             | Weak   |
|---:|:--------------------------------------------|:---------------|:----------
-------|:---------------|:-------|
|  1 | $p + p \to n + \pi^+ + p$                   | Yes            | Yes
| Yes            | Yes    |
|  2 | $p + p \to \bar n + \pi^+ + p + \pi^0$      | B violation    | No
| No             | No     |
|  3 | $\pi^+ + p \to \Sigma^+ + p$                | B violation    | No
| No             | No     |
|  4 | $\pi^+ + p \to \Sigma^+ + K^+$              | Yes            | Yes
| Yes            | Yes    |
|  5 | $\pi^+ + p \to \Sigma^+ + p + \pi^0$        | B violation    | No
| No             | No     |
|  6 | $\pi^+ + p \to \Xi^0$                       | Q violation    | No
| No             | No     |
|  7 | $\Sigma^+ + p \to \Lambda^0 + \pi^+ + p$    | Yes            | Yes
| Yes            | Yes    |
|  8 | $\Sigma^- + p \to \Xi^- + p$                | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
|  9 | $\Xi^0 \to e^- + p + \bar \nu_e$            | Yes            | S
violation      | S violation    | Yes    |
| 10 | $\Xi^0 \to \Lambda^0 + \pi^0$               | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 11 | $\Xi^- \to \Lambda^0 + \pi^-$               | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 12 | $\Omega^- \to \Lambda^0 + \pi^-$            | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 13 | $\Omega^- \to \Lambda^0 + K^-$              | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 14 | $\Omega^- \to \Xi^0 + \pi^-$                | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 15 | $\Omega^- \to \Xi^0 + K^-$                  | Yes            | Yes
| Yes            | Yes    |
| 16 | $\Xi^- \to \Sigma^0 + \mu^- + \bar \nu_\mu$ | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 17 | $\Xi^- \to e^- + p + \bar \nu_e + \pi^-$    | Yes            | S
violation      | S violation    | Yes    |
| 18 | $\Sigma^0 \to \Lambda^0 + \gamma + \gamma$  | Yes            | I
violation      | Yes            | Yes    |
| 19 | $\Sigma^0 \to \Lambda^0 + e^- + e^+$        | Yes            | I
violation      | Yes            | Yes    |
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| 20 | $K^+ \to \mu^+ + \nu_\mu$                    | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 21 | $K^- \to \mu^- + \bar \nu_\mu$               | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 22 | $K^0 \to \pi^+ + \pi^-$                      | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 23 | $K^0 \to \mu^+ + \mu^-$                      | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 24 | $K^+ \to \pi^0 + e^+ + \nu_e$                | Yes            | S,I,I3
violation | S,I3 violation | Yes    |
| 25 | $\mu^+ \to e^+ + \nu_e$                      | L_mu violation | No
| No             | No     |
| 26 | $\pi^+ \to \mu^+ + \bar \nu_\mu$             | L_mu violation | No
| No             | No     |
| 27 | $\pi^- \to \mu^- + \bar \nu_\mu$             | Yes            | I,I3
violation   | I3 violation   | Yes    |
```

0.5.1 So I get the whole answer

	reaction	Possibility	Strong	EM	Weak
1	$p + p \to n + \pi^+ + p$	Yes	Yes	Yes	Yes
2	$p + p \to \bar{n} + \pi^+ + p + \pi^0$	B violation	No	No	No
3	$\pi^+ + p \to \Sigma^+ + p$	B violation	No	No	No
4	$\pi^+ + p \to \Sigma^+ + K^+$	Yes	Yes	Yes	Yes
5	$\pi^+ + p \to \Sigma^+ + p + \pi^0$	B violation	No	No	No
6	$\pi^+ + p \to \Xi^0$	Q violation	No	No	No
7	$\Sigma^+ + p \to \Lambda^0 + \pi^+ + p$	Yes	Yes	Yes	Yes
8	$\Sigma^- + p \to \Xi^- + p$	Yes	S,I,I3 violation	S,I3 violation	Yes
9	$\Xi^0 \to e^- + p + \bar{\nu}_e$	Yes	S violation	S violation	Yes
10	$\Xi^0 \to \Lambda^0 + \pi^0$	Yes	S,I,I3 violation	S,I3 violation	Yes
11	$\Xi^- \to \Lambda^0 + \pi^-$	Yes	S,I,I3 violation	S,I3 violation	Yes
12	$\Omega^- \to \Lambda^0 + \pi^-$	Yes	S,I,I3 violation	S,I3 violation	Yes
13	$\Omega^- \to \Lambda^0 + K^-$	Yes	S,I,I3 violation	S,I3 violation	Yes
14	$\Omega^- \to \Xi^0 + \pi^-$	Yes	S,I,I3 violation	S,I3 violation	Yes
15	$\Omega^- \to \Xi^0 + K^-$	Yes	Yes	Yes	Yes
16	$\Xi^- \to \Sigma^0 + \mu^- + \bar{\nu}_\mu$	Yes	S,I,I3 violation	S,I3 violation	Yes
17	$\Xi^- \to e^- + p + \bar{\nu}_e + \pi^-$	Yes	S violation	S violation	Yes
18	$\Sigma^0 \to \Lambda^0 + \gamma + \gamma$	Yes	I violation	Yes	Yes
19	$\Sigma^0 \to \Lambda^0 + e^- + e^+$	Yes	I violation	Yes	Yes

	reaction	Possibility	Strong	EM	Weak
20	$K^+ \to \mu^+ + \nu_\mu$	Yes	S,I,I3 violation	S,I3 violation	Yes
21	$K^- \to \mu^- + \bar{\nu}_\mu$	Yes	S,I,I3 violation	S,I3 violation	Yes
22	$K^0 \to \pi^+ + \pi^-$	Yes	S,I,I3 violation	S,I3 violation	Yes
23	$K^0 \to \mu^+ + \mu^-$	Yes	S,I,I3 violation	S,I3 violation	Yes
24	$K^+ \to \pi^0 + e^+ + \nu_e$	Yes	S,I,I3 violation	S,I3 violation	Yes
25	$\mu^+ \to e^+ + \nu_e$	L_mu violation	No	No	No
26	$\pi^+ \to \mu^+ + \bar{\nu}_\mu$	L_mu violation	No	No	No
27	$\pi^- \to \mu^- + \bar{\nu}_\mu$	Yes	I,I3 violation	I3 violation	Yes