



WYDZIAŁ FIZYKI I INFORMATYKI STOSOWANEJ  
AKADEMIA GÓRNICZO-HUTNICZA IM. STANISŁAWA STASZICA W KRAKOWIE

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# Multiplicity dependence of primary strange hadrons ( $K_s^0$ , $\Lambda$ ) in pp Collisions at LHC Energies

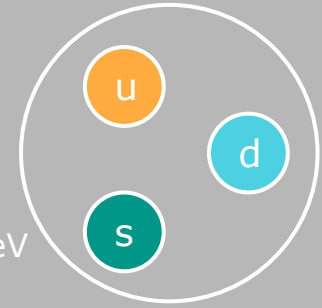


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# What are we looking for? ' $V^0$ ' particles

$V^0$ : Neutral, unstable particles that decay into pairs of particles

$\Lambda$



	mass → $\approx 2.3 \text{ MeV}/c^2$ charge → $2/3$ spin → $1/2$ <b>u</b> up	mass → $\approx 1.275 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$ <b>c</b> charm	mass → $\approx 173.07 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$ <b>t</b> top	mass → $0$ charge → $0$ spin → $1$ <b>g</b> gluon	mass → $\approx 126 \text{ GeV}/c^2$ charge → $0$ spin → $0$ <b>H</b> Higgs boson
QUARKS	mass → $\approx 4.8 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$ <b>d</b> down	mass → $\approx 95 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$ <b>s</b> strange	mass → $\approx 4.18 \text{ GeV}/c^2$ charge → $-1/3$ spin → $1/2$ <b>b</b> bottom	mass → $0$ charge → $0$ spin → $1$ <b><math>\gamma</math></b> photon	
	mass → $0.511 \text{ MeV}/c^2$ charge → $-1$ spin → $1/2$ <b>e</b> electron	mass → $105.7 \text{ MeV}/c^2$ charge → $-1$ spin → $1/2$ <b><math>\mu</math></b> muon	mass → $1.777 \text{ GeV}/c^2$ charge → $-1$ spin → $1/2$ <b><math>\tau</math></b> tau	mass → $91.2 \text{ GeV}/c^2$ charge → $0$ spin → $1$ <b>Z</b> Z boson	GAUGE BOSONS
LEPTONS	mass → $<2.2 \text{ eV}/c^2$ charge → $0$ spin → $1/2$ <b><math>\nu_e</math></b> electron neutrino	mass → $<0.17 \text{ MeV}/c^2$ charge → $0$ spin → $1/2$ <b><math>\nu_\mu</math></b> muon neutrino	mass → $<15.5 \text{ MeV}/c^2$ charge → $0$ spin → $1/2$ <b><math>\nu_\tau</math></b> tau neutrino	mass → $80.4 \text{ GeV}/c^2$ charge → $\pm 1$ spin → $1$ <b>W</b> W boson	

- Baryon
- Up, down and strange quark
- Has an antiparticle
- mass =  $(1115.683 \pm 0.006) \text{ MeV}$  (PDG)

$$\frac{d\bar{s} - s\bar{d}}{\sqrt{2}}$$

$K^0_s$

- Meson
- Superposition of  $K^0$  and  $\bar{K}^0$
- Is its own antiparticle
- s stands for 'short-lived'
  - $(0.8954 \pm 0.0004) \times 10^{-10} \text{ s}$  (PDG)
- mass =  $497.611 \pm 0.013 \text{ MeV}$  (PDG)

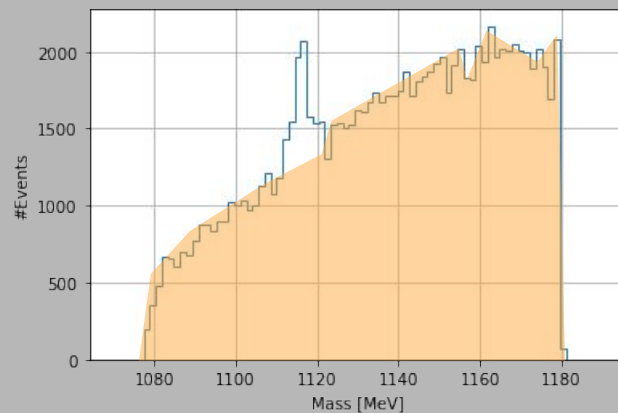
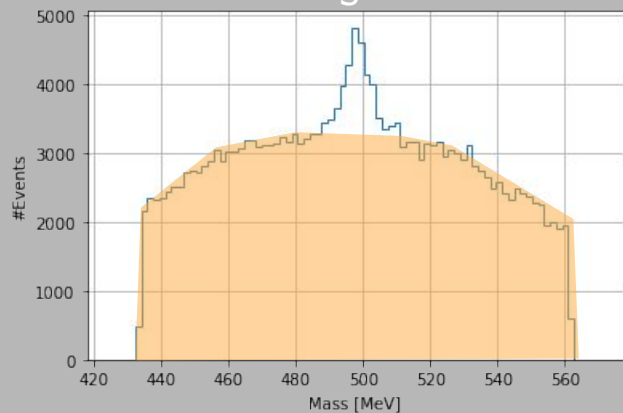
<https://www.quantumdiaries.org/2014/03/14/the-standard-model-a-beautiful-but-flawed-theory/>

Charged, stable particles ( $\pi^+$ ,  $K^+$ , p) were also investigated (we'll get to this later)

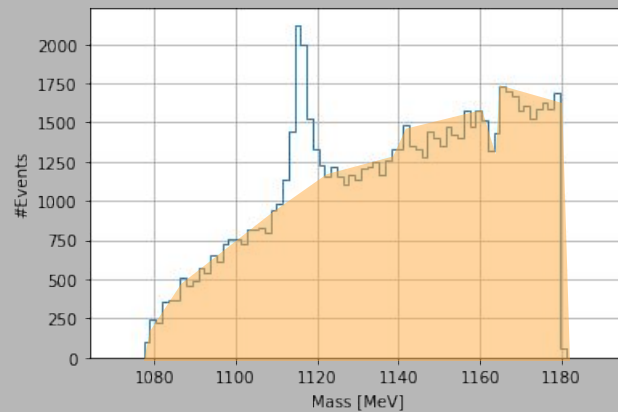
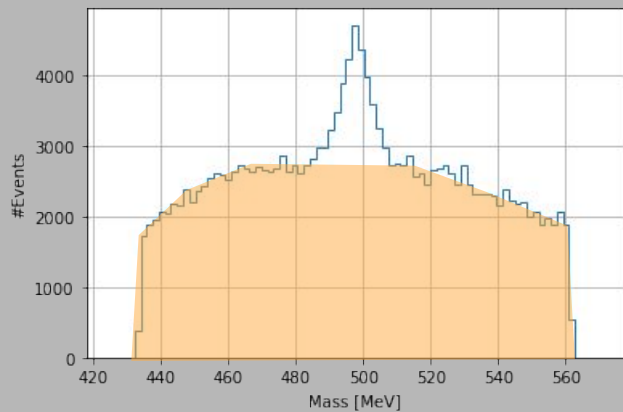
# Mass plots

 $K_S^0$  $\Lambda$  $V^0$ 

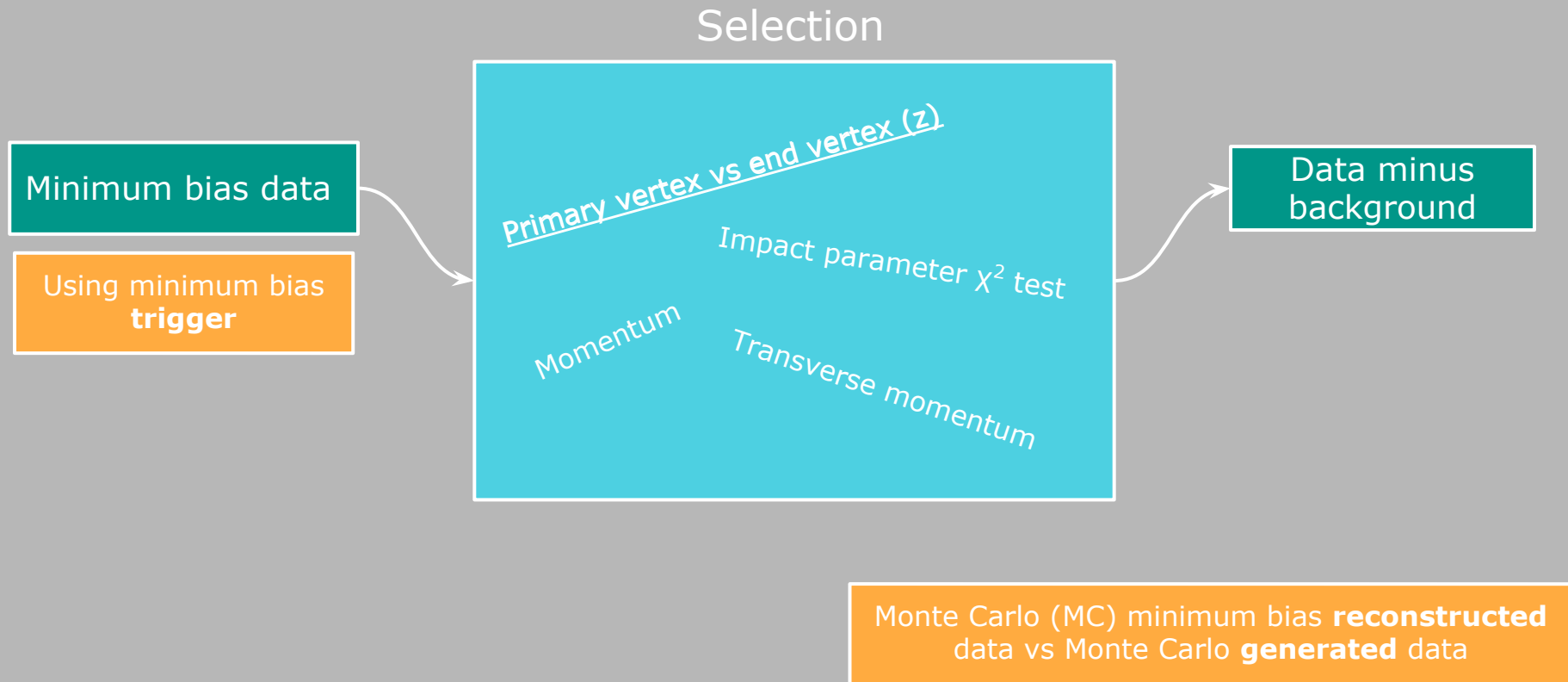
MAGNET UP



MAGNET DOWN



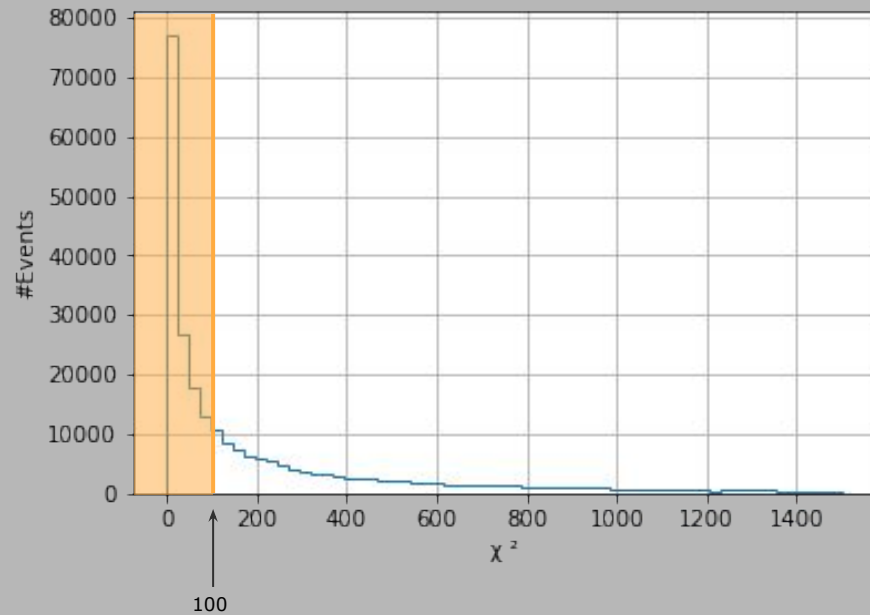
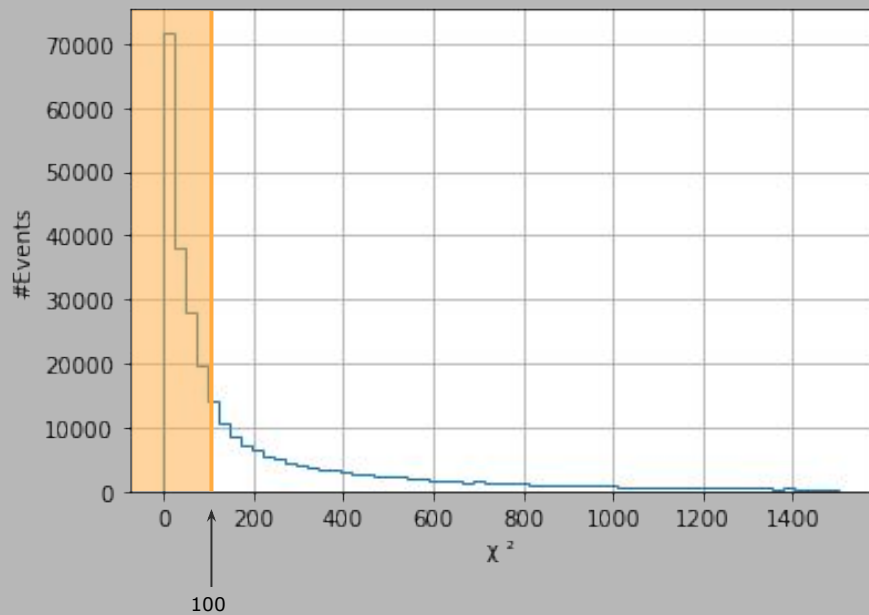
# Removing background\*



\*Not necessarily all, but as much as possible!

# Reconstructed vs generated MC data

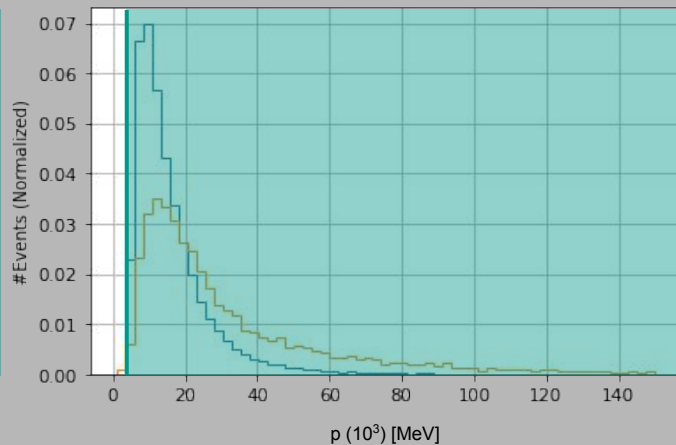
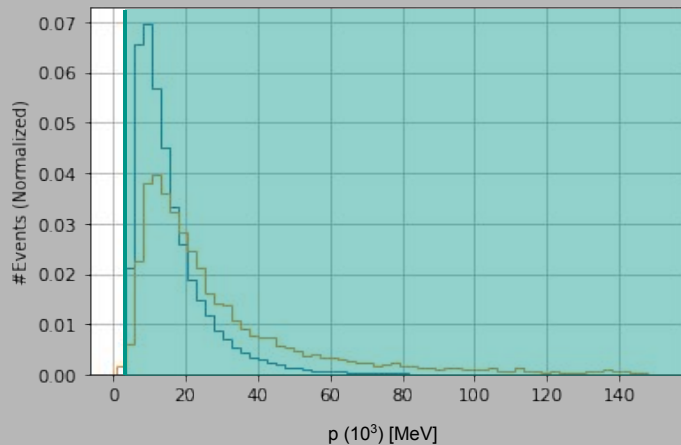
Impact parameter  $\chi^2$  test



$$\chi^2 = \frac{\sum (\text{Value} - \text{Value}_{\text{true}})^2}{\text{Value}_{\text{true}}}$$

# Reconstructed vs generated MC data

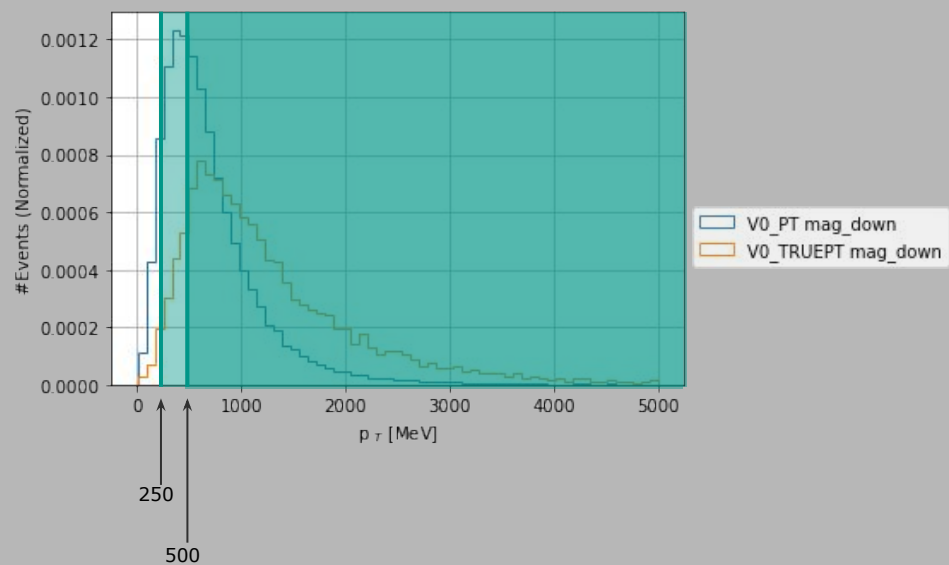
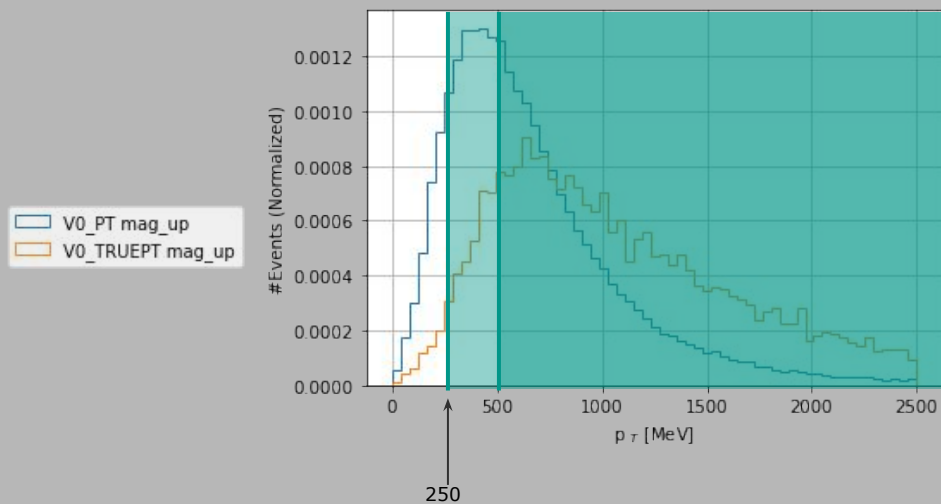
## Momentum



Threshold at 3000 MeV (notice x-axis scale!)

# Reconstructed vs generated MC data

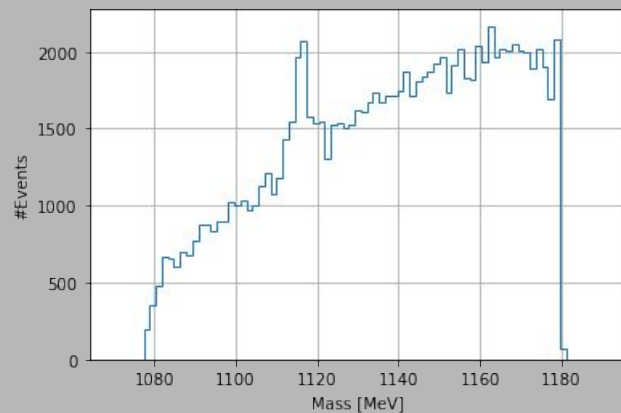
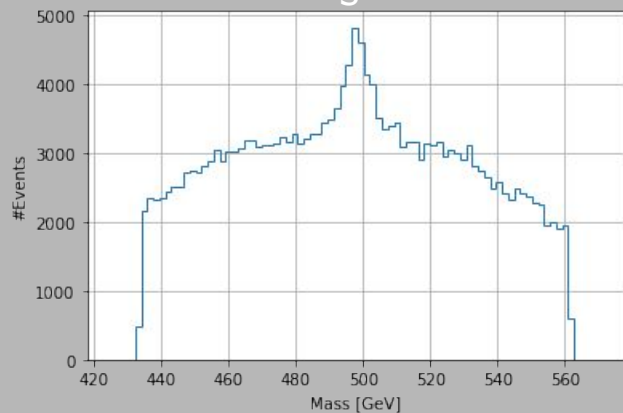
$p_T$  (transverse momentum)



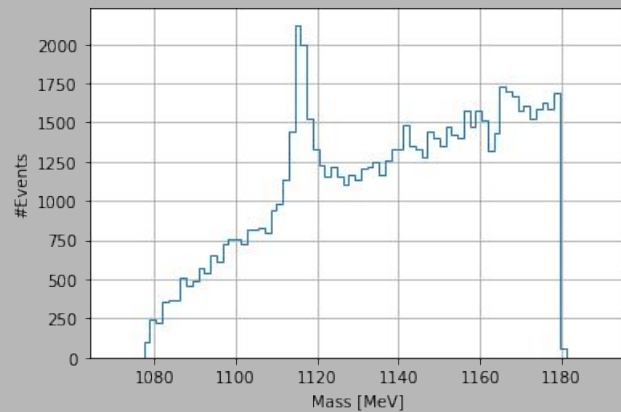
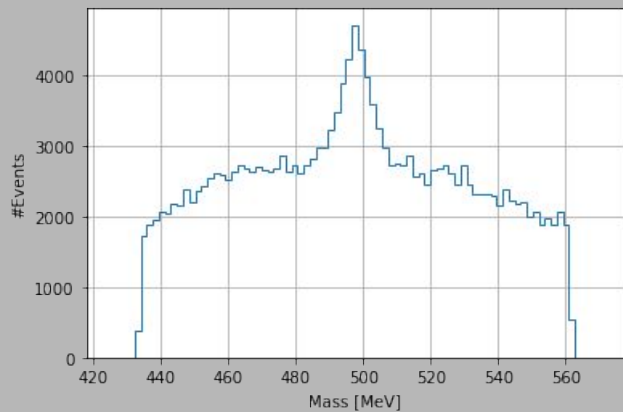
# Mass plots

 $K_S^0$  $\Lambda$  $V^0$ 

MAGNET UP



MAGNET DOWN





250 MeV  $\leq p_T$

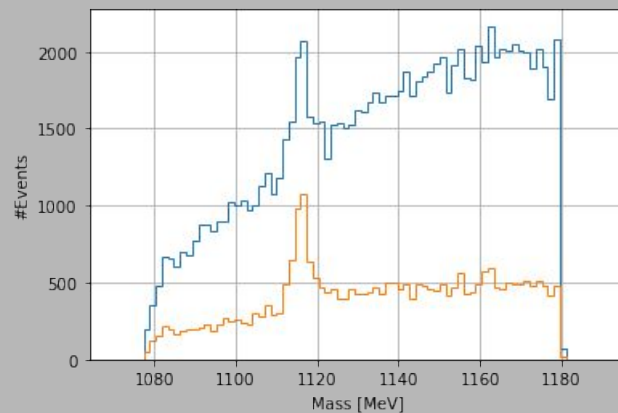
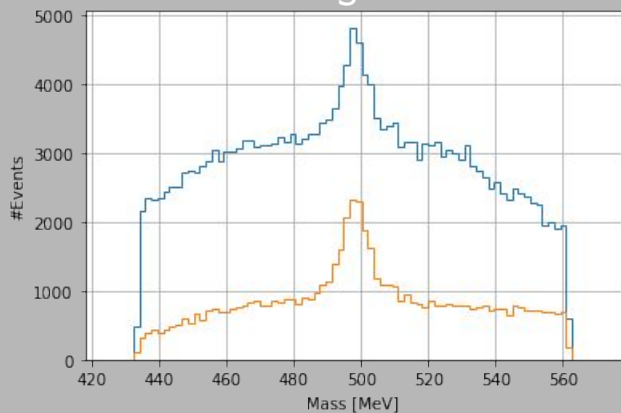
$K_S^0$

Blue: minimum bias  
Orange: selection

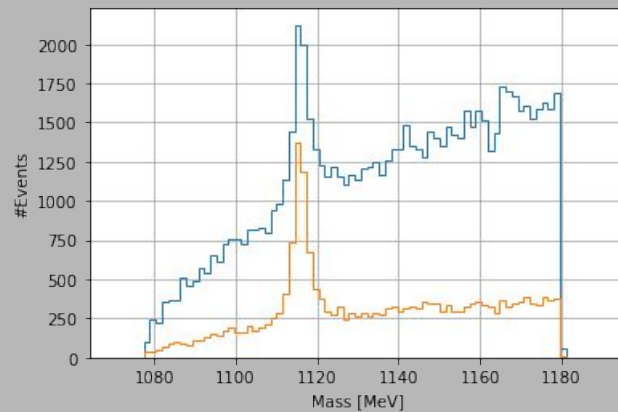
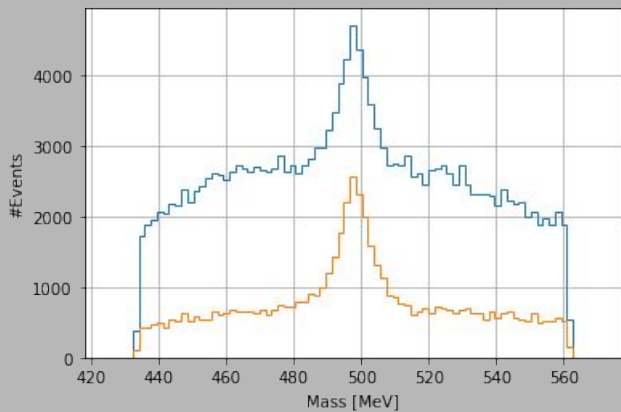
$\Lambda$

$V^0$

MAGNET UP



MAGNET DOWN



500 MeV  $\leq p_T$

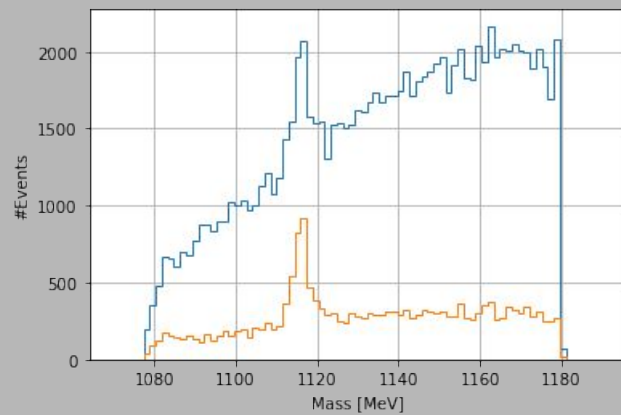
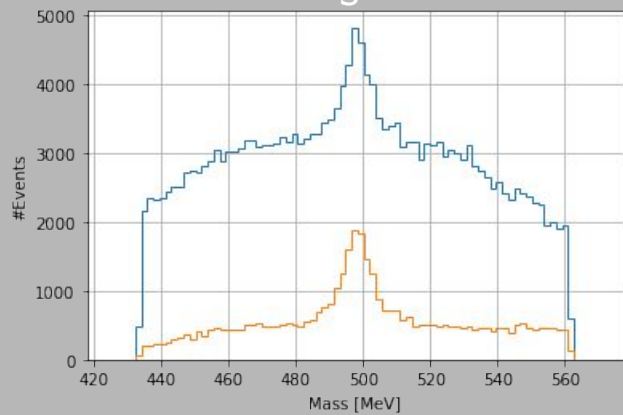
$K_S^0$

Blue: minimum bias  
Orange: selection

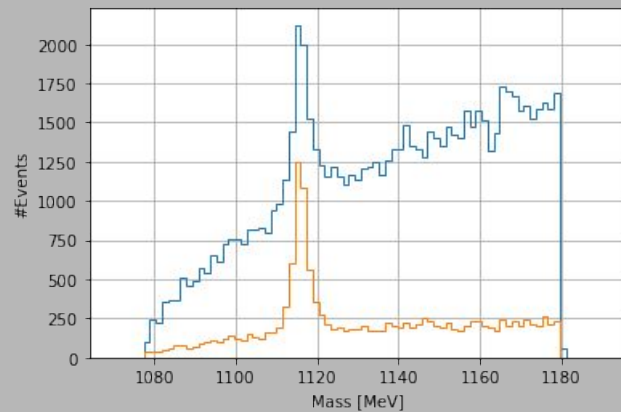
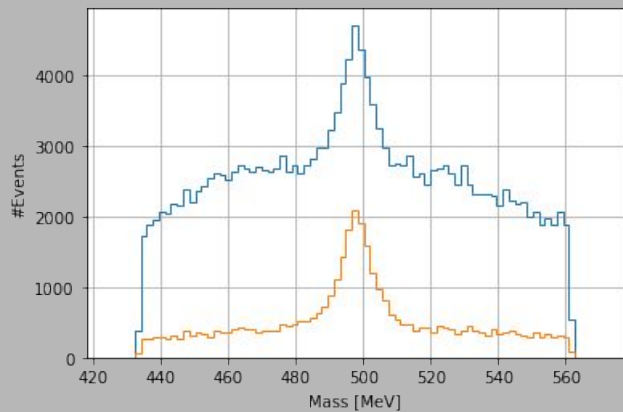
$\Lambda$

$V^0$

MAGNET UP



MAGNET DOWN





FROM THIS MOMENT ON, ONLY DATA FROM THE  
'UP' POLARITY IS CONSIDERED

No unusual differences between the polarities can be seen on the mass plots of  
the strange particles

# What is multiplicity?

Number of candidates per event

Here we will look at multiplicity per unit  $\eta$

$V^0$

## Method used

Apply mass cut to single out mass peak:

PDG mass - 15 MeV < m < PDG mass + 15 MeV

Data passing selection

Enquiry into  $p_T$ :

Bin 1: 150-650 MeV  
Bin 2: 650-1000 MeV  
Bin 3: 1000-3000 MeV

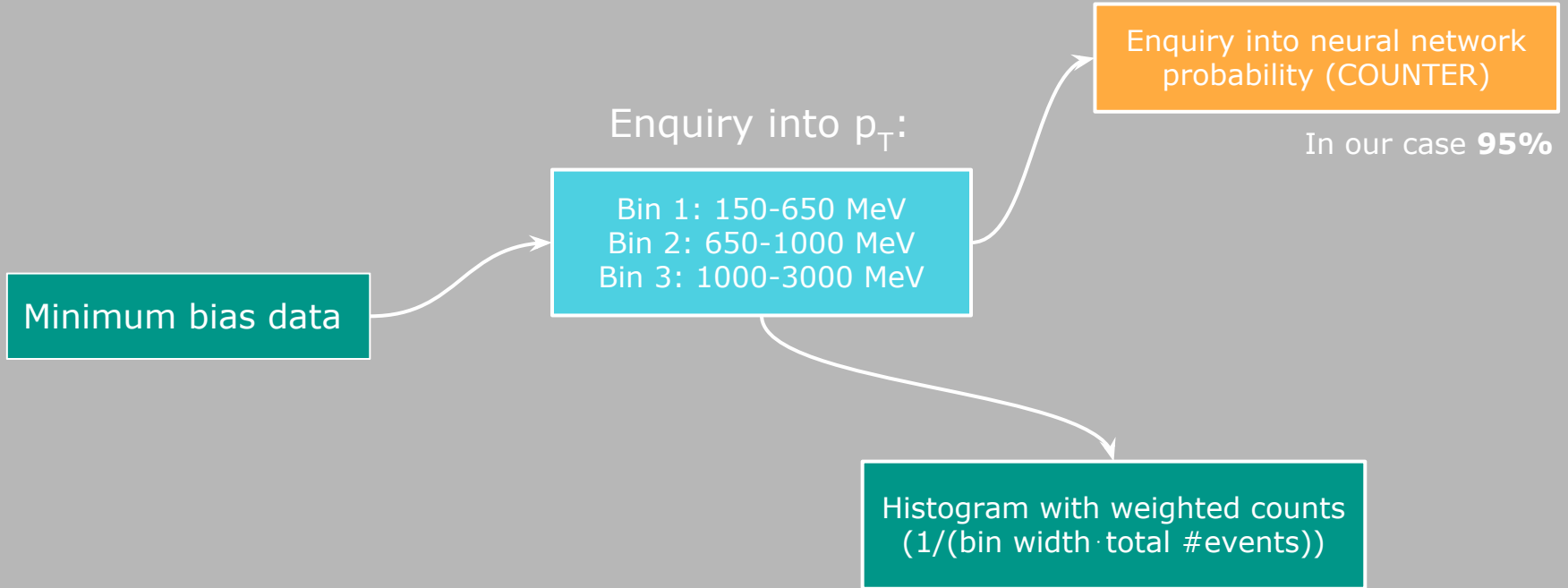
TRUE-MATCHING:  
Enquiry into PDG particle ID  
(COUNTER)

Counter will be  
useful later!

Histograms with weighted counts  
( $1/(\text{bin width} \cdot \text{total \#events})$ ) for  
different IDs

# Comparison with stable particles

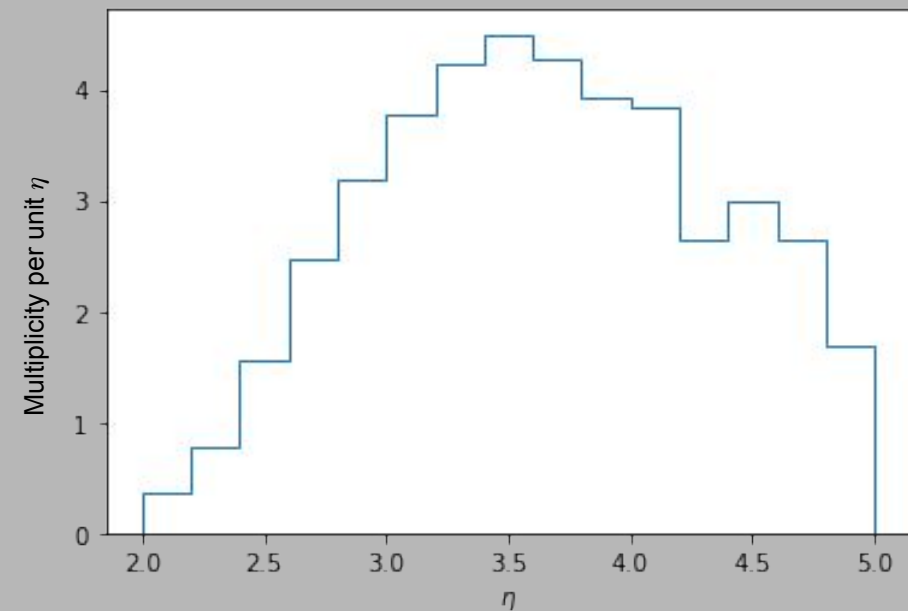
Pions, kaons, protons



We need reference multiplicities to determine how common the strange particles are in pp collisions...

# Multiplicity as a function of $\eta$

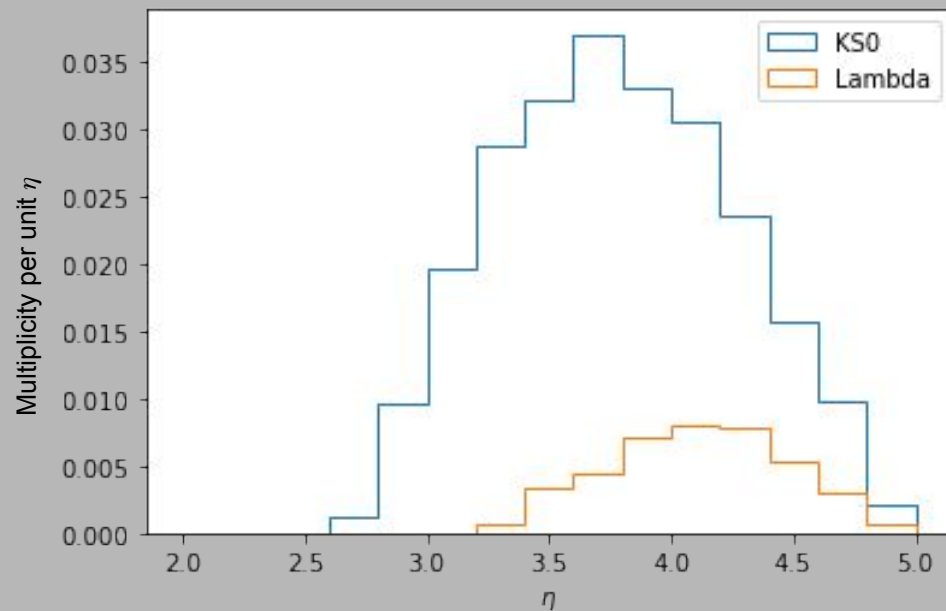
$150 \text{ MeV} \leq p_T < 650 \text{ MeV}$



STABLE PARTICLES

total #events = 31400

#bins = 15



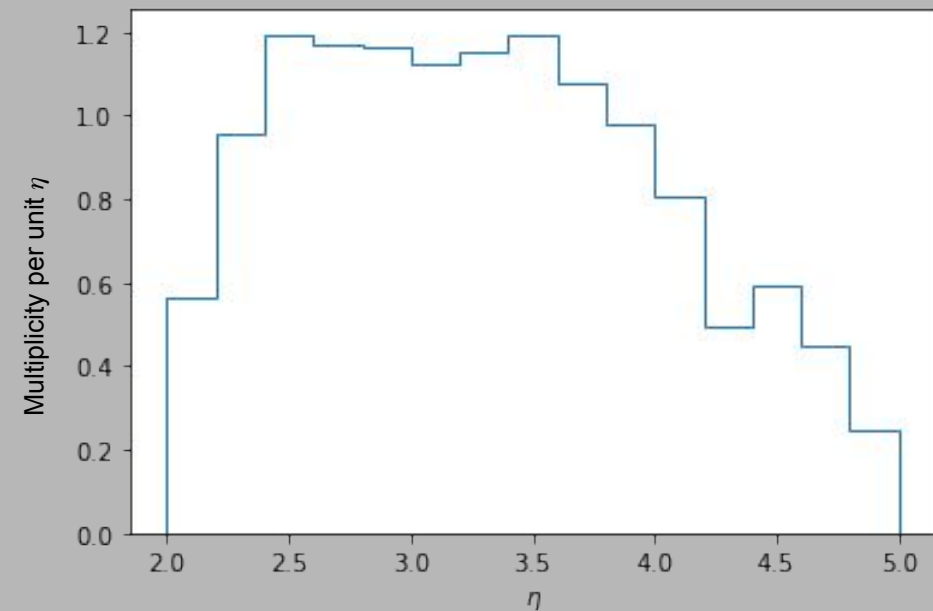
STRANGE PARTICLES

total #events = 77786

#bins = 15

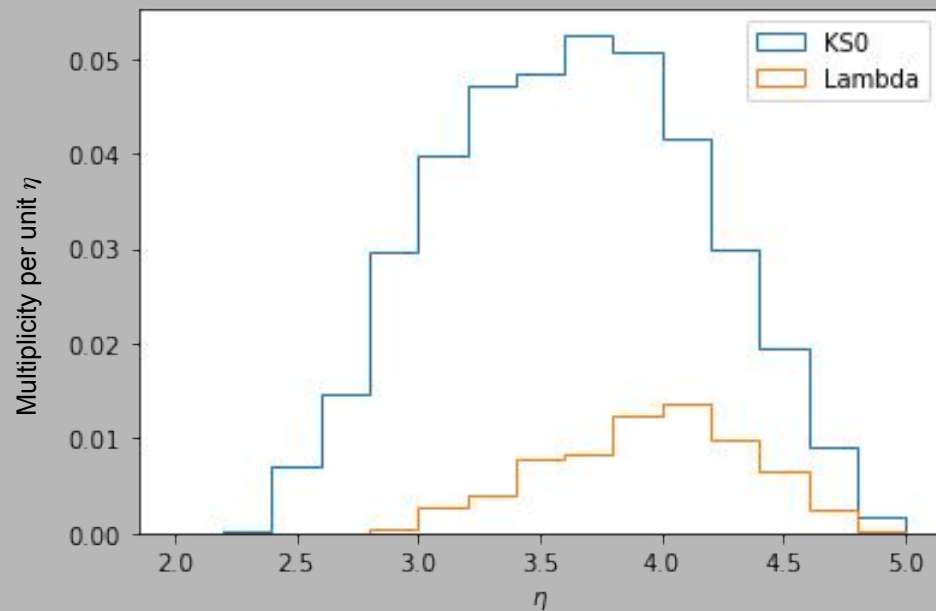
# Multiplicity as a function of $\eta$

$650 \text{ MeV} \leq p_T < 1000 \text{ MeV}$



STABLE PARTICLES

total #events = 31400  
#bins = 15

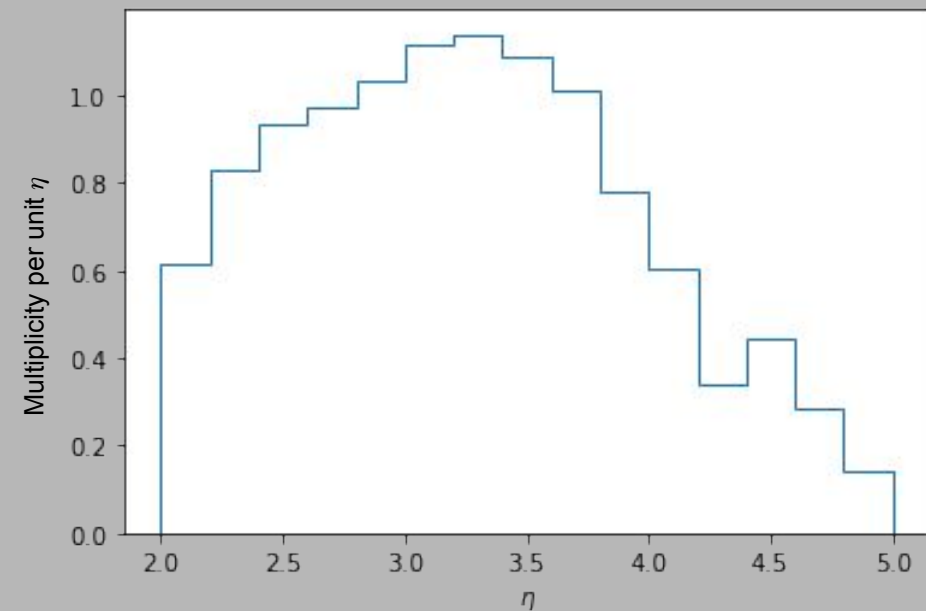


STRANGE PARTICLES

total #events = 77786  
#bins = 15

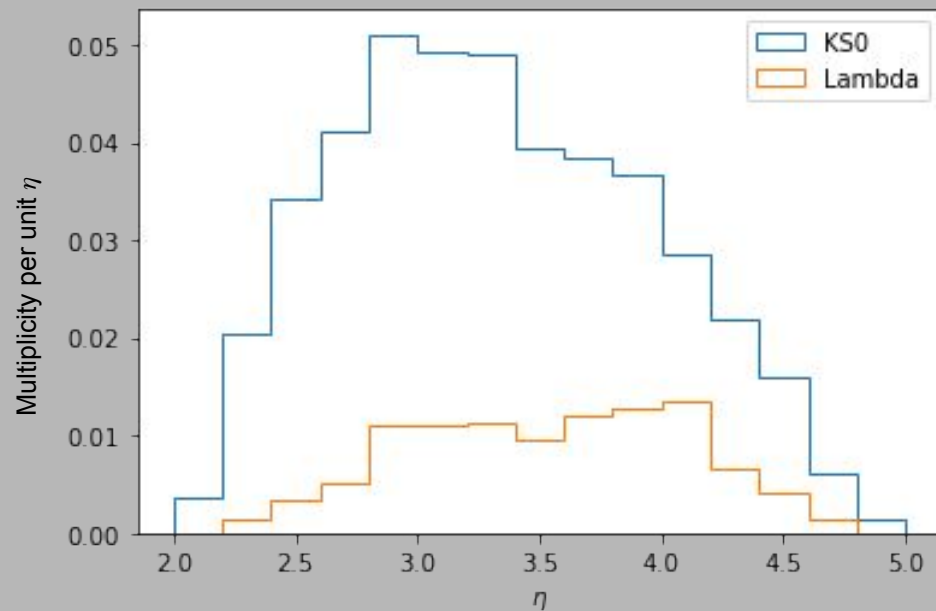
# Multiplicity as a function of $\eta$

$1000 \text{ MeV} \leq p_T < 3000 \text{ MeV}$



STABLE PARTICLES

total #events = 31400  
#bins = 15



STRANGE PARTICLES

total #events = 77786  
#bins = 15

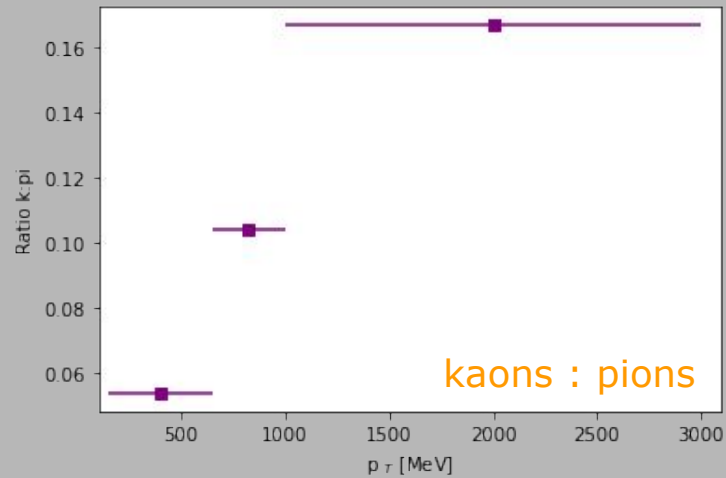
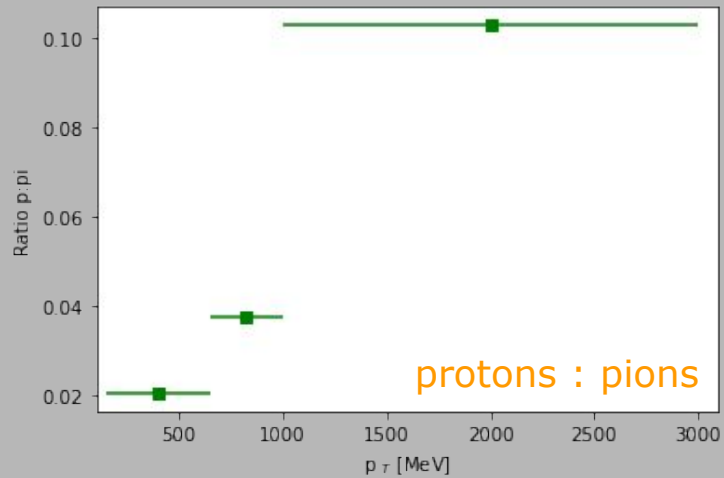
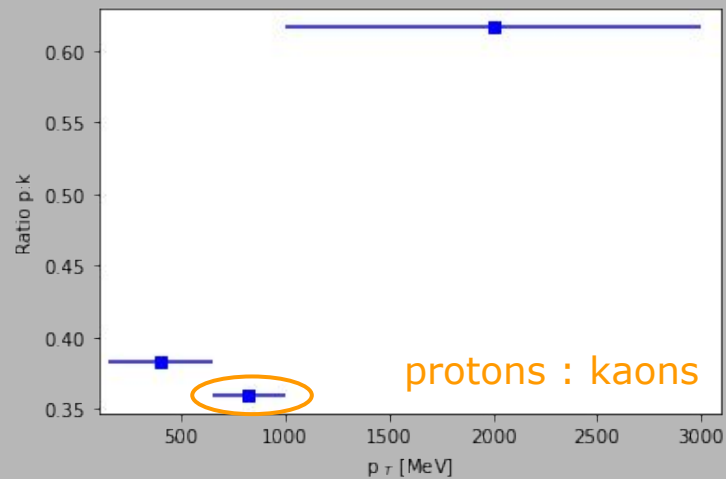
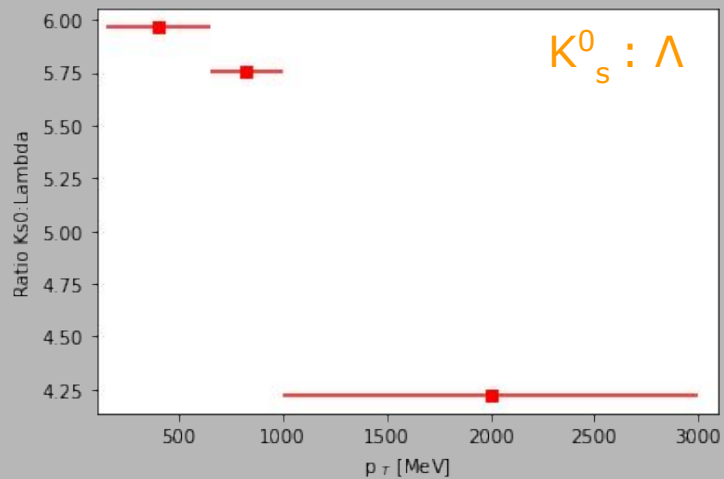


# Particle counters

These will be used to calculate particle ratios in different  $p_T$  ranges

Particle (ID)	150-650 [MeV]	650-1000 [MeV]	1000-3000 [MeV]
$K^+$ (321)	13579	7669	9570
$K_s^0$ (310)	3776	6137	6835
$\Lambda^0$ (3122)	633	1067	1619
$\pi^+$ (211)	253434	73643	57304
p (2212)	5200	2758	5901

# Particle ratios







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