Study of high time-resolution calorimeter using ILD detector simulation
(Preliminary results)

M. Kuhara[A],

T. Suehara[A], K. Kawagoe[A],

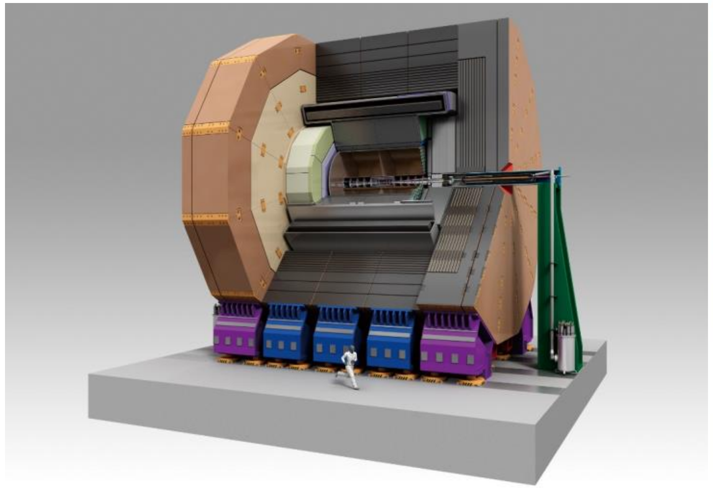
T. Yoshioka[B], D. Jeans[C]

(Kyushu Univ.[A], RCAPP[B], KEK IPNS[C])

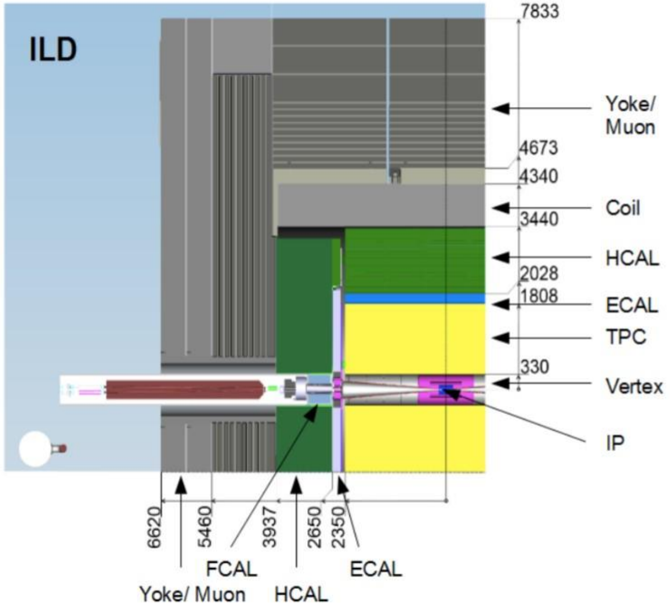
ILD and ECAL

ILD (International Large Detector)

- Tracking detector : TPC + sillicon
- Particle ID @TPC
  - → energy loss (dE/dx) and momentum

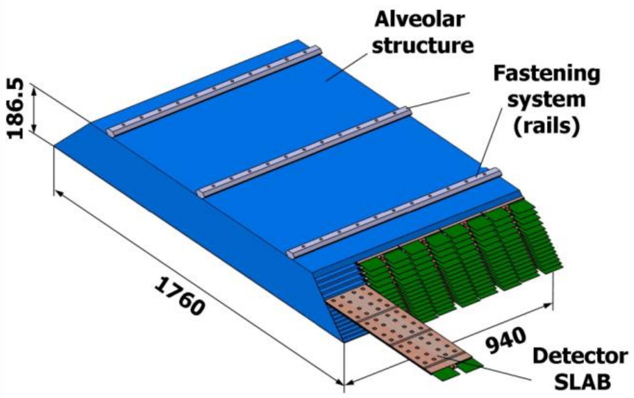


ILD



SiW-ECAL

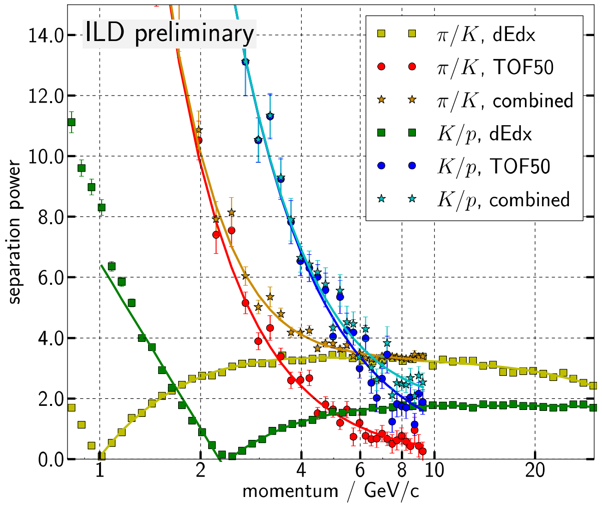
- Sandwich calorimeter (30 layers)
- Detection layers: Si (Pixel size : $5 \times 5\ mm^2$)
- Absorption layers: Tungsten (inner: 2.1 mm thick, outer: 4.2 mm thick)
- 24 radiation length in total



Particle ID / Time resolution of LGAD

Particle ID of hadrons

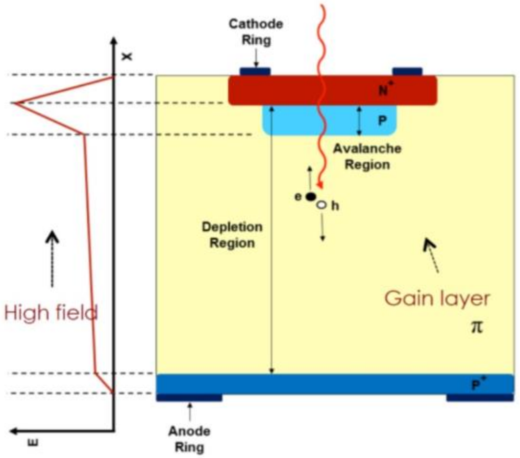
- ➢ Region where we can't identify particle by only measurement of dE/dx and momentum.
- ➢ Better separation power can be obtained by adding ToF than only dE/dx .
- ➢ Possible to separate π/K/p up to $3\sim5$ GeV by 50 ps ToF with dE/dx at TPC



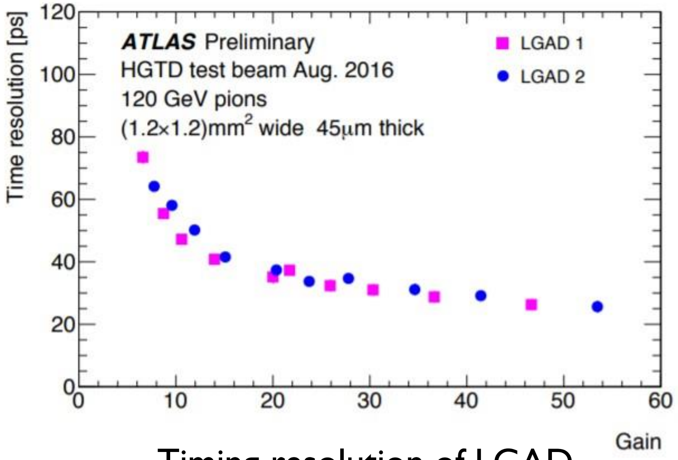
LGAD (Low Gain Avalanche Detector)

- ➢ A silicon sensor with avalanche amplification mechanism
- ➢ Higher timing resolution
  - ➢ 26 ps timing resolution achieved (study of ATLAS group)

- How LGAD contributes to time resolution and particle identification when it is used as part of ECAL
- Optimization of layer structure with LGAD in ECAL



Structure of LGAD



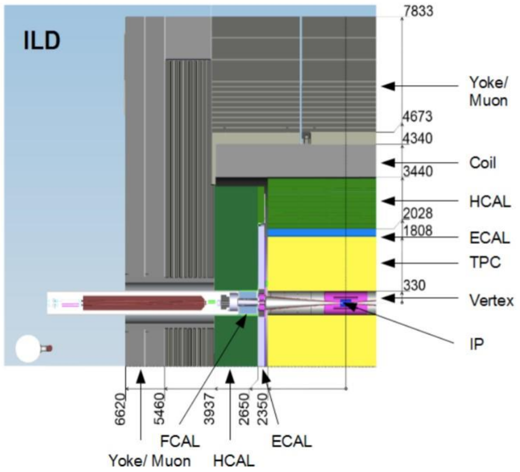
Timing resolution of LGAD
(ATLAS group)

Simulation and time information

Data

- single particle PDG=211 (π^+) and PDG=321(K^+)
- ILD detector simulation
- ILCSoft : v01-19-04
- Energy : 1 , 2 , 5 , 10 GeV
- 10000 events each
- Hits at the ECAL barrel are studied
- Ignore hits with arrival time > 12 ns

  (to remove slow component)

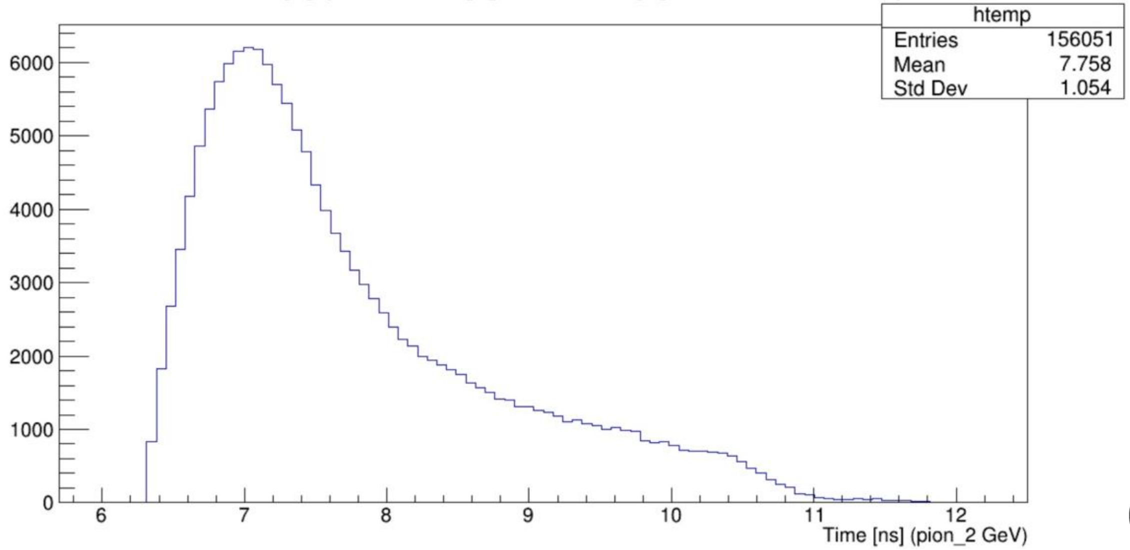


Time

- Investigate arrival time of each hit
- Errors due to sensor time resolution are not considered
- The distance from the IP to ECAL is about 1.8 m

  → The time from IP to ECAL is about 6.1 ns
- The time distribution is reasonable

Time from collision to hit π^+(2 GeV)

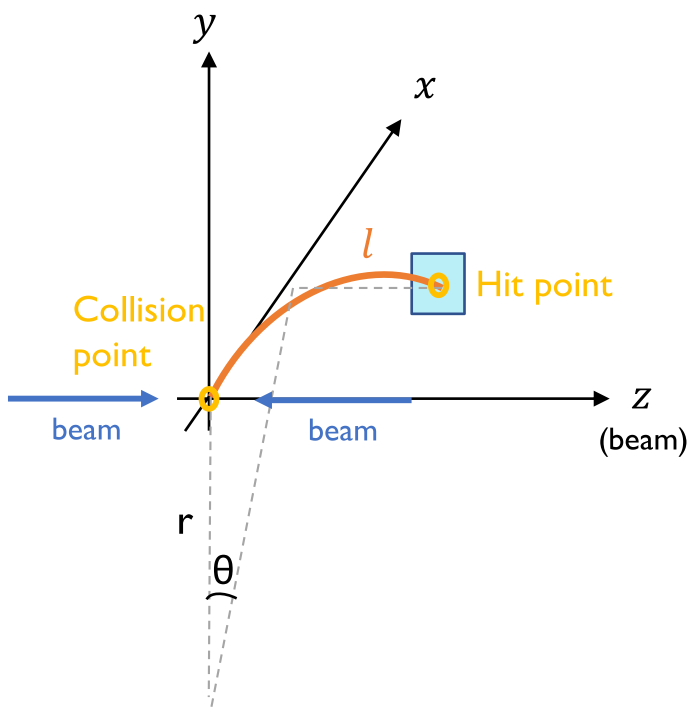


Calculation method of mass

- **Path length l (Spiral movement)**
  Orbital radius r
  Magnetic field $B = 3.5\ \mathrm{T}$
  Momentum $\boldsymbol{p} = (p_x, p_y, p_z)$
  →Initial momentum of MC truth

$$l = \sqrt{(\theta r)^2 + z^2}$$

$$\theta r = 2r Arcsin\left(\frac{\sqrt{x^2+y^2}}{2r}\right), \quad r = \frac{p}{0.3B} = \frac{\sqrt{{p_x}^2+{p_y}^2}}{0.3B}$$



- **Mass of particle m**
  Energy E
  Time from IP to ECAL hit t

$$m = E\sqrt{1-\beta^2} = E\sqrt{1-\frac{(\theta r)^2 + z^2}{(ct)^2}}$$

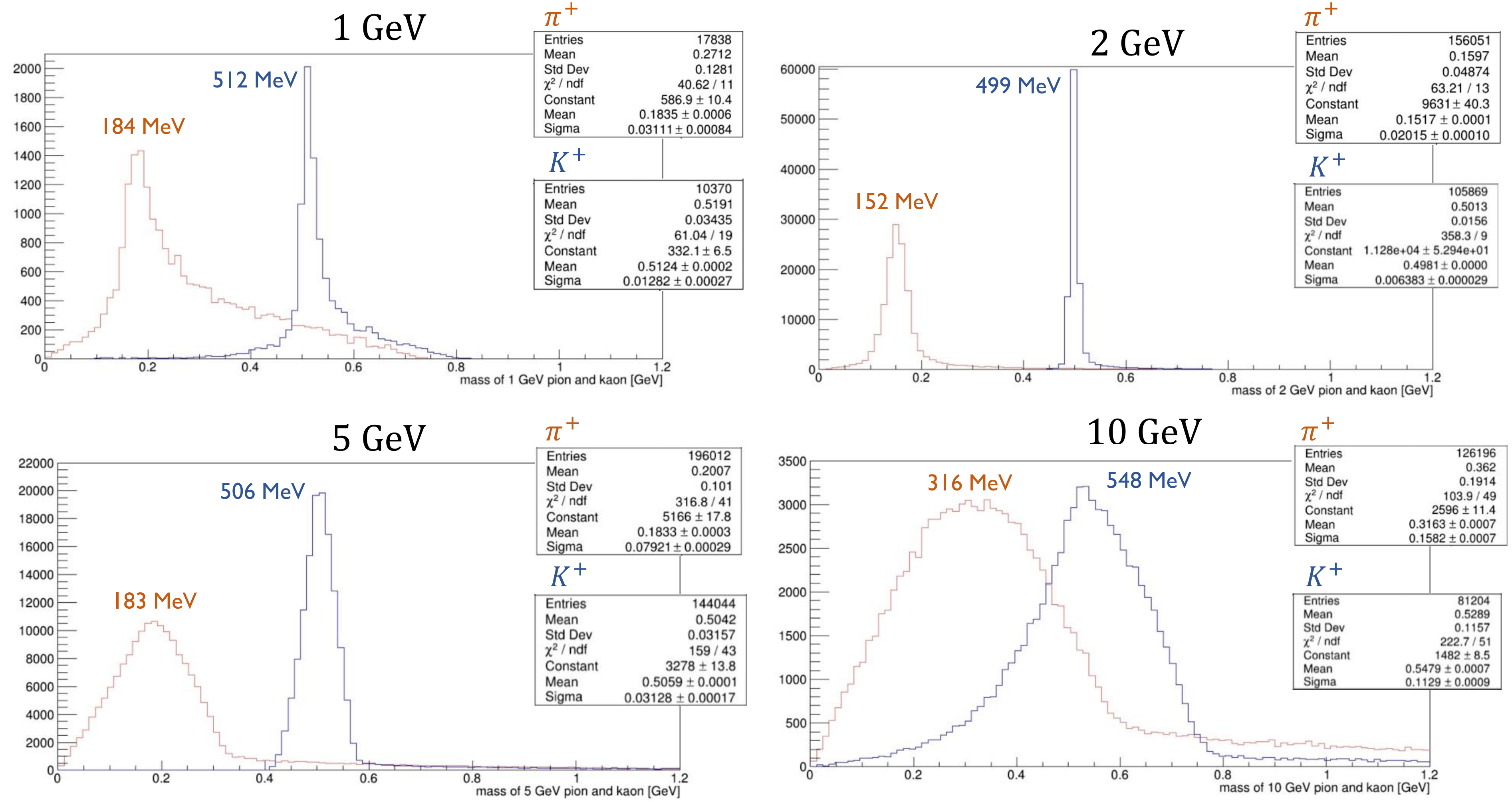
$$\beta = \frac{v}{c} = \frac{l}{ct}$$

Result : mass of π^+ and K^+ [each hit]

- Mass of each hit
- The peak positions are larger than the true masses
  (true value π^+: 139 MeV
  K^+: 494 MeV)

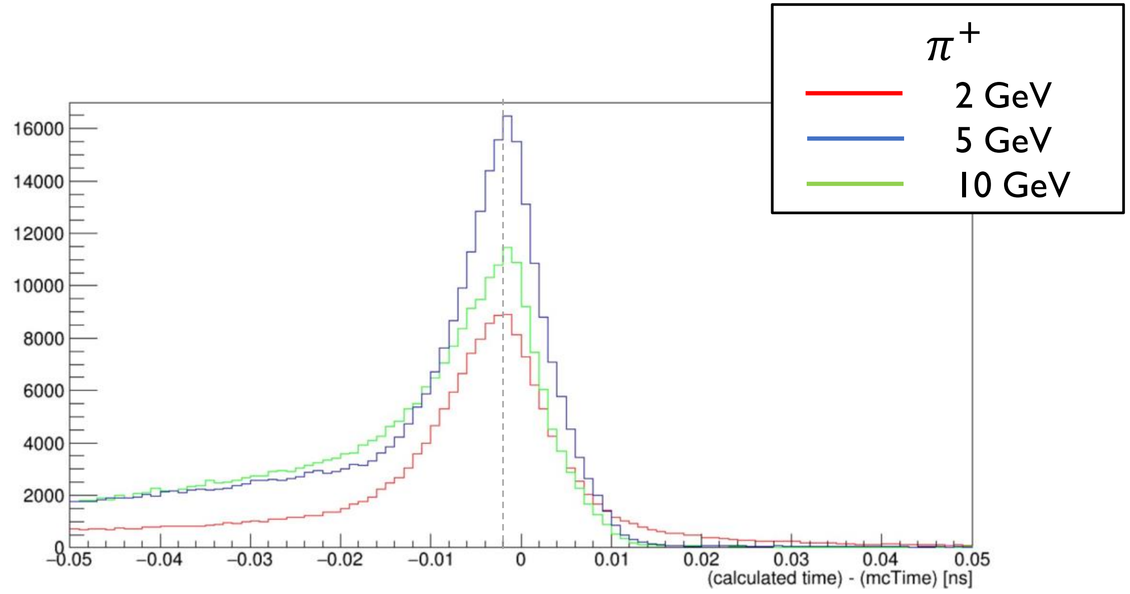
- 1 GeV : Large tail
  → Particle stops in the ECAL
- 5,10 GeV : Wide peak width

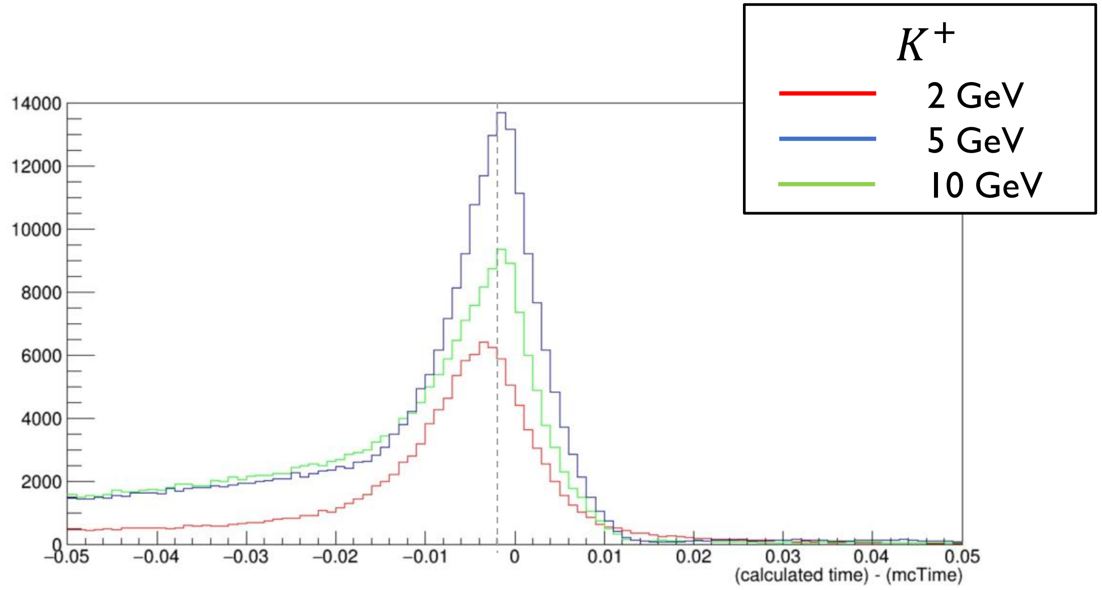
- π^+ and K^+ can be identified up to 5 GeV (if no detector timing smearing.)



Comparison of the hit time and the propagation time

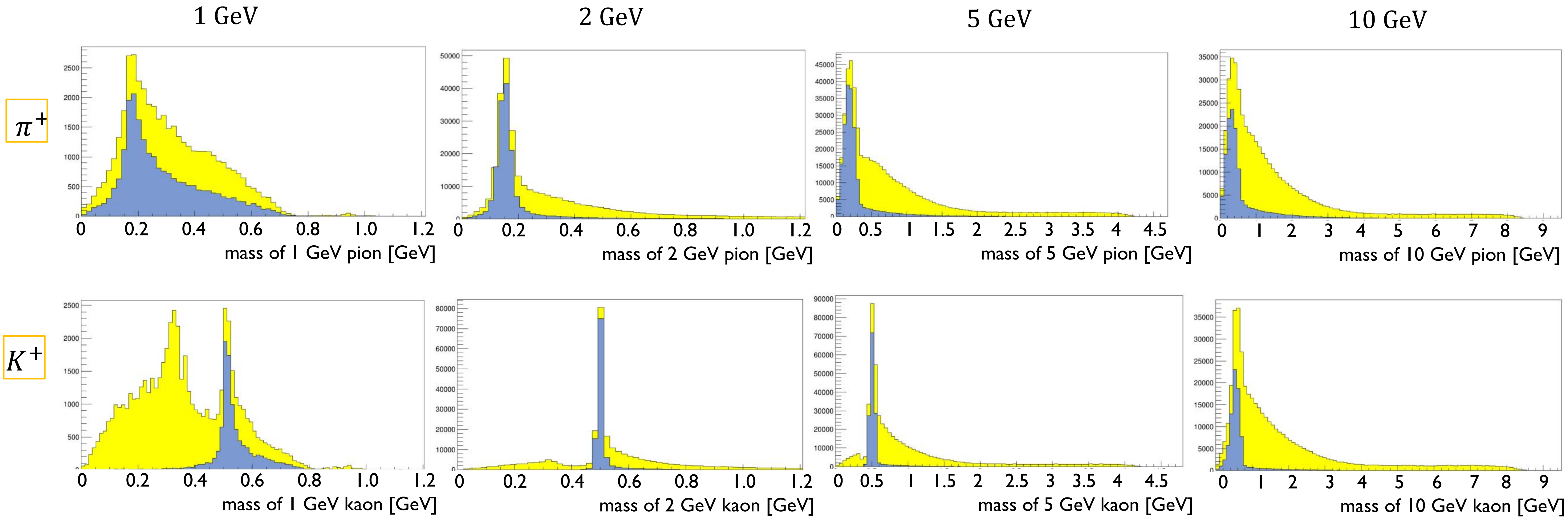
- Comparison of the hit time and the propagation time calculated from the path length and the true mass
- Distribution obtained by (propagation time) – (hit time)





- The value of peak is 2 ps smaller than true value.
- Width of time difference : about -20 ps to 10 ps
- This time deviation can be a possible source of the bad separation of π^+ and K^+ mass at higher energies.

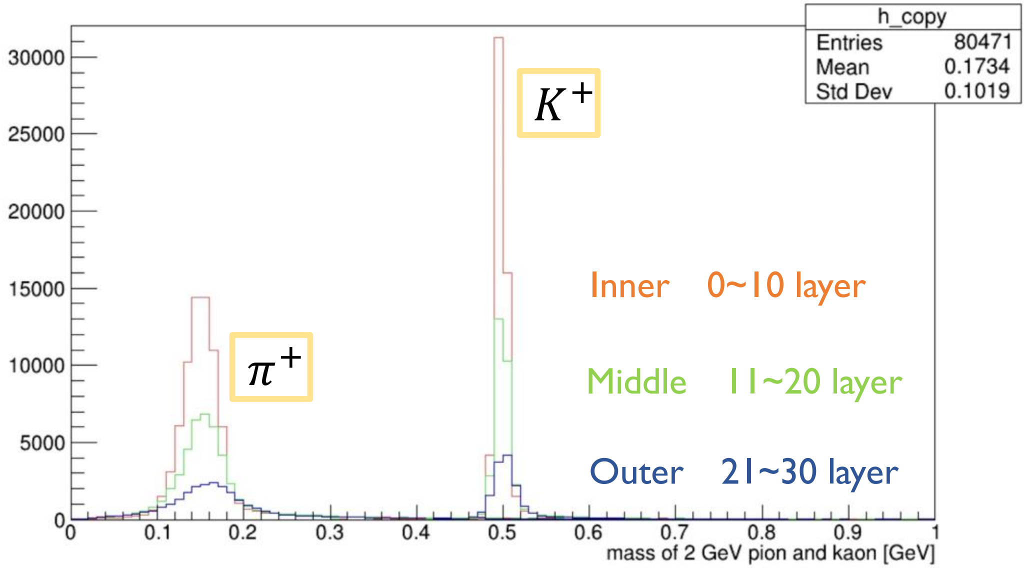
Contamination of secondary particles



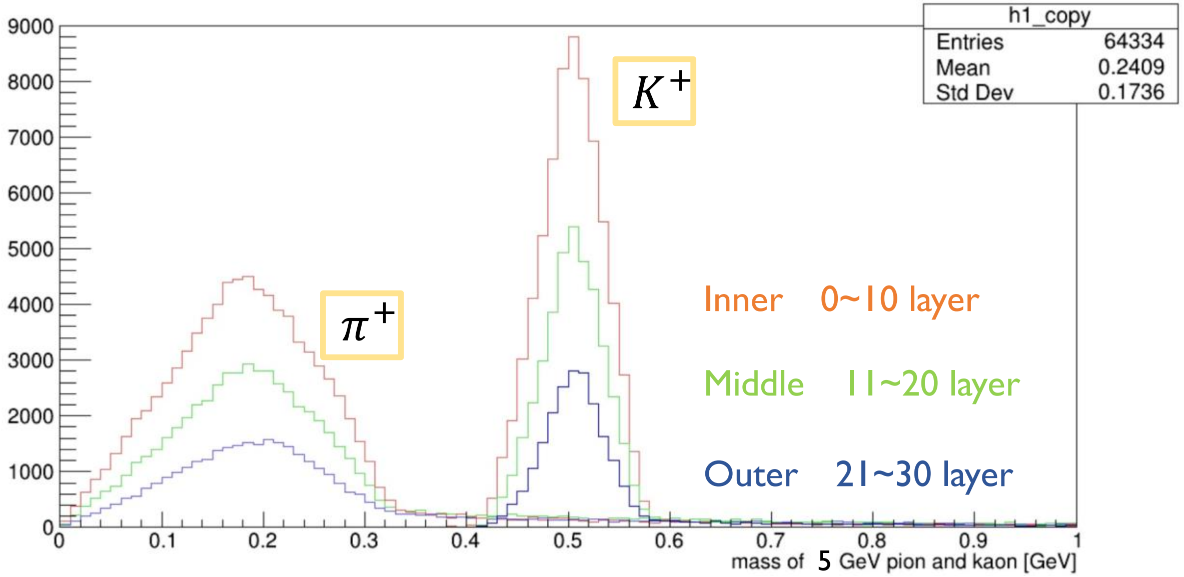
- Select hits directly induced by π^+ and K^+ with MC information (blue) / all hits (yellow)
- Need to think of ways to separate hits of secondary particles.

Mass and layer : $\pi^{+} and\ K^{+}$ 2 GeV /5 GeV

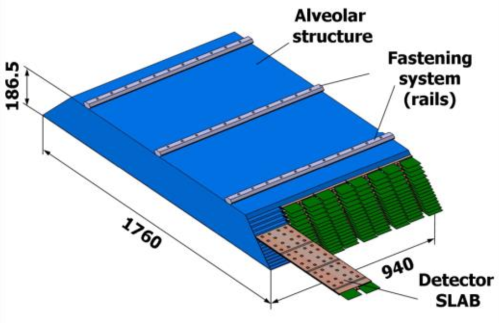
2 GeV

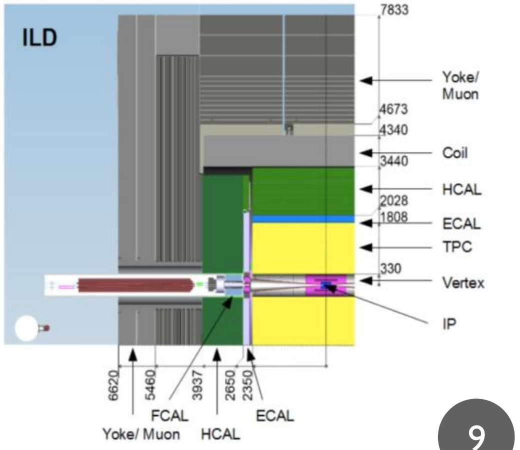


5 GeV



- Mass distribution of all hits
- Data : single particle PDG=211 (π^{+}) 2 GeV / single particle PDG=321 (K^{+}) 2 GeV
- Mass widths of the outer layers are bigger in 2 GeV





Averaged mass of each cluster

- Smaller 80% of masses of hits contained in one event are extracted,
  and average masses to obtain a distribution as the mass of the event (without cut of secondary particle)
- Threshold : 0.4 GeV → Calculated the rate of events that could be correctly identified
- π^+ (true value about 0.139 GeV) mass smaller than 0.4 GeV,
  K^+ (true value about 0.494 GeV) mass larger than 0.4 GeV is considered to be correctly identified.

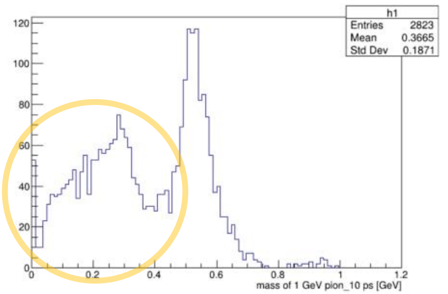
π^+	1ps	10ps	20ps	50ps
1 GeV	86.95	86.99	86.99	87.03
2 GeV	97.16	97.18	97.28	97.35
5 GeV	79.27	80.38	81.86	86.49
10 GeV	65.62	74.77	87.59	99.74

[%]

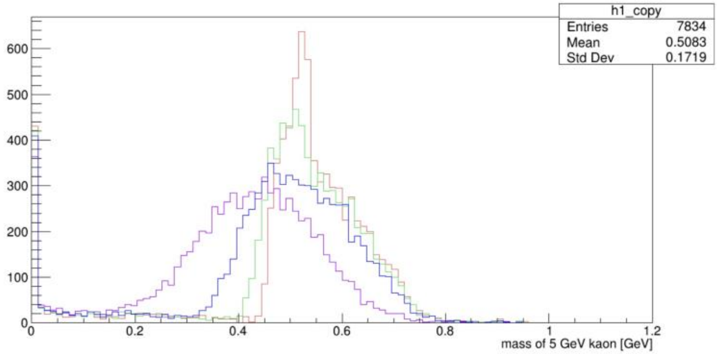
K^+	1ps	10ps	20ps	50ps
1 GeV	46.29	46.29	46.29	46.25
2 GeV	79.68	79.65	79.59	79.46
5 GeV	88.14	87.79	79.65	54.57
10 GeV	83.45	68.12	40.56	1.15

[%]

1 GeV K^+ (10 ps)



5,10 GeV (Figure : 5 GeV K^+)



1 ps, 10 ps, 20 ps, 50 ps

Mass distribution is shifted to smaller with worse time resolution.

- π^+ and K^+ can be identified with good precision
  10 ps ~ 20 ps : up to 5 GeV
  50 ps : up to 2 GeV
- Threshold optimization is needed

Summary

- LGAD can improve the timing resolution of ECAL.
- Particle ID by ToF with single π^+ and K^+ is investigated.
- Mass of each particle is obtained by averaging masses calculated with individual hits.
- π^+ and K^+ can be identified by ToF up to 5 GeV with 10-20 ps timing resolution of hits and up to 2 GeV with 50 ps resolution.

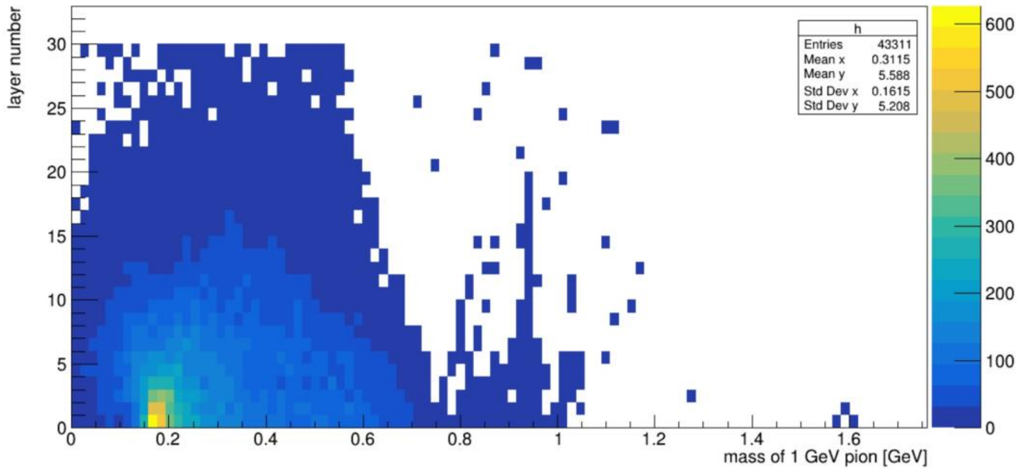
Next step

- Optimize averaging method over hits
- Calculate mass with reconstructed momentum
- Investigate effect to the resolution and particle ID by combining LGAD with ECAL
- Study LGAD prototype

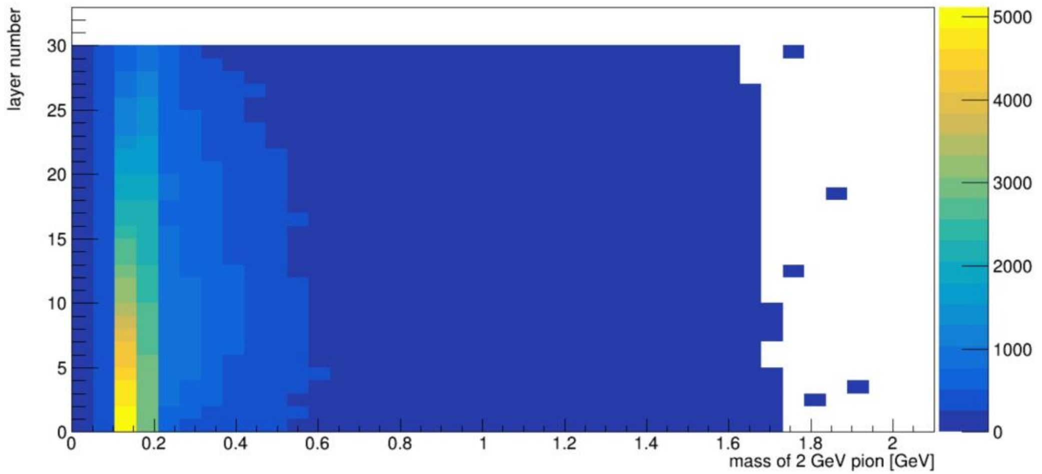
BACKUP

π^+ : mass vs layer number

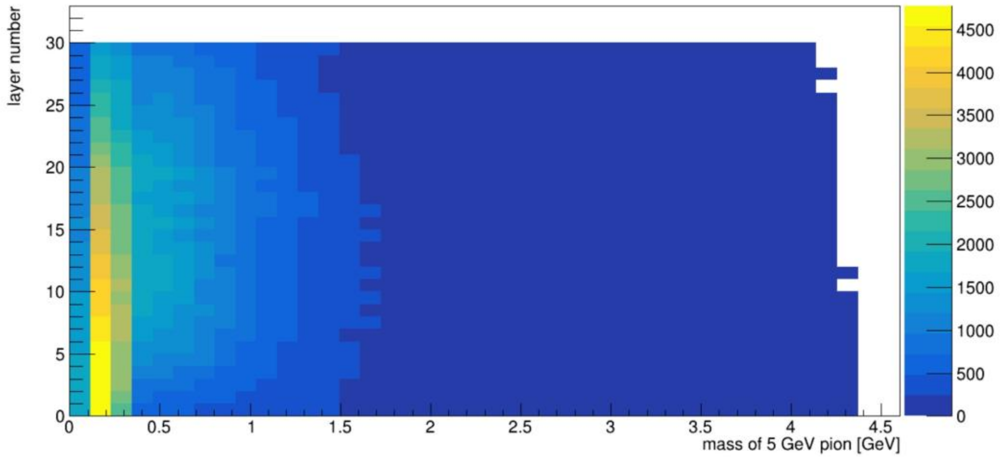
1 GeV



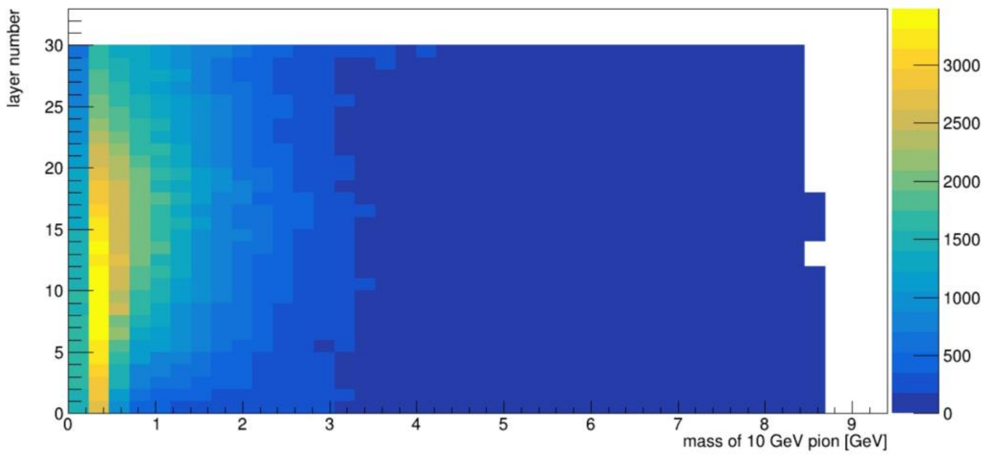
2 GeV



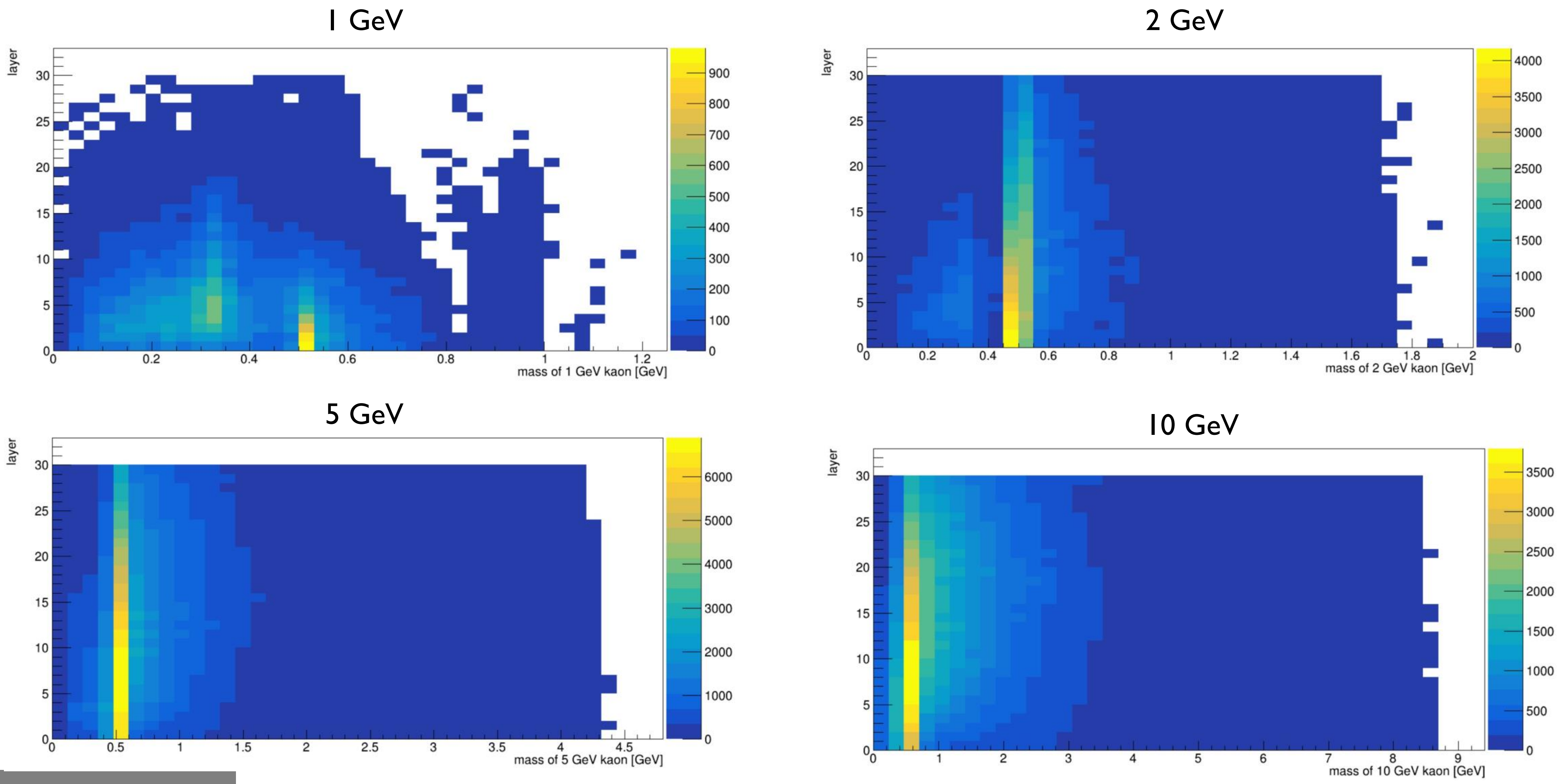
5 GeV



10 GeV

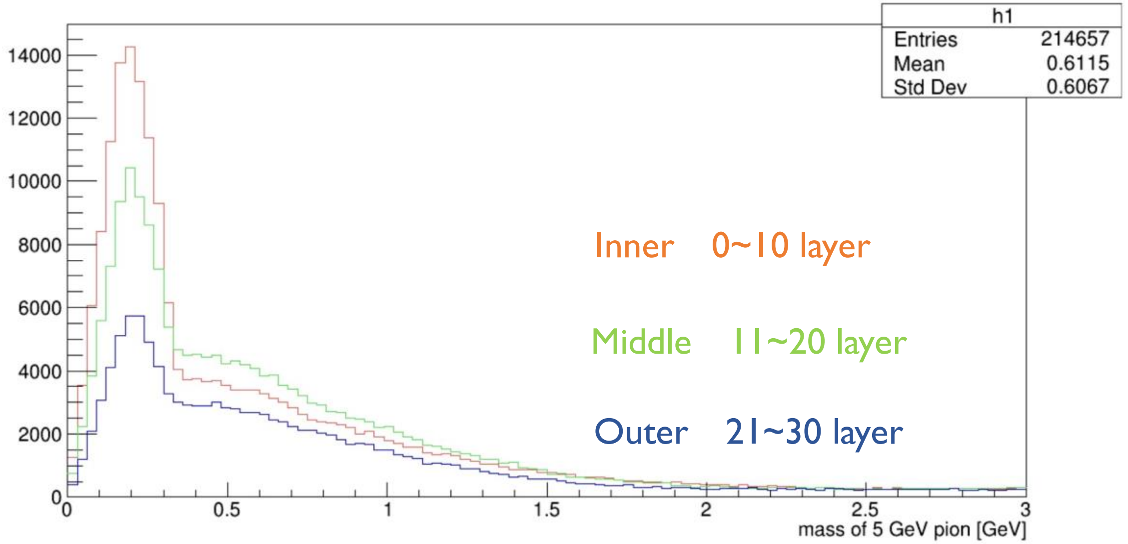


K^+ : mass vs layer number

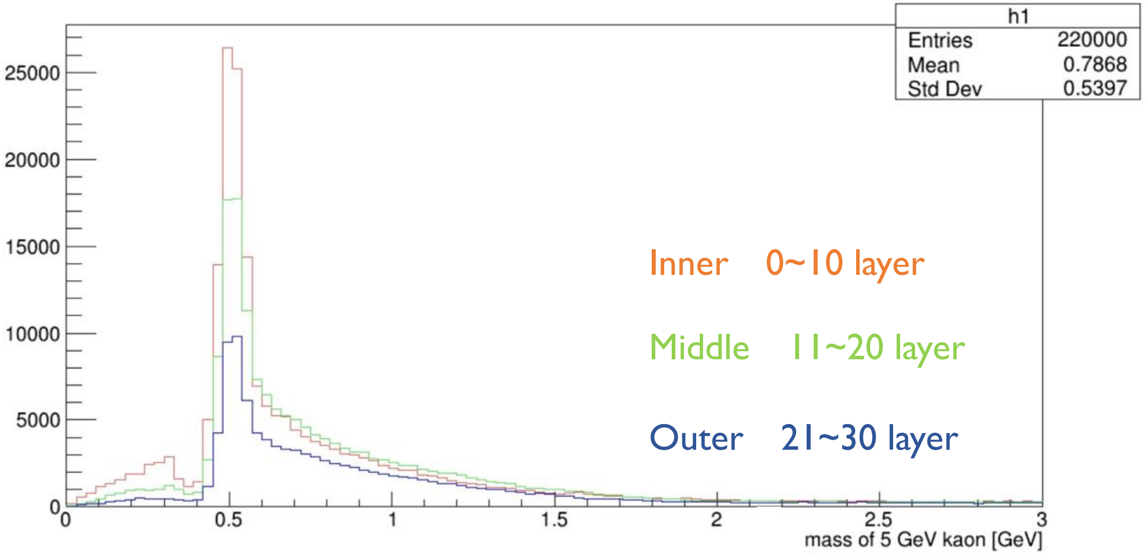


Mass and layer : $\pi^{+} and\ K^{+}$ 5 GeV

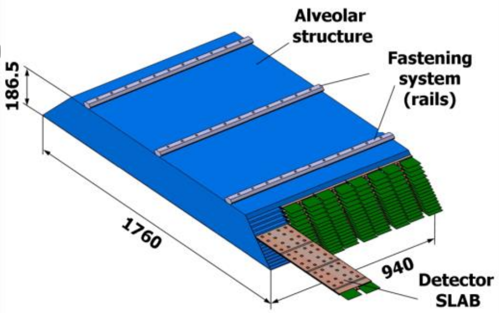
π^{+}

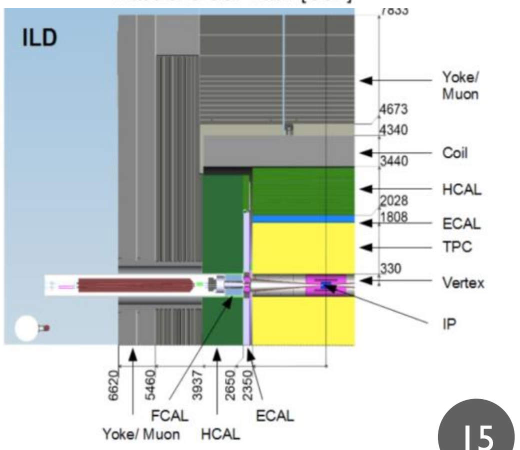


K^{+}



- Without cut of secondly particle
- Mass distribution of all hits
- Data : single particle PDG=211 (π^{+}) 2 GeV / single particle PDG=321 (K^{+})
- Mass widths of the outer layers are bigger

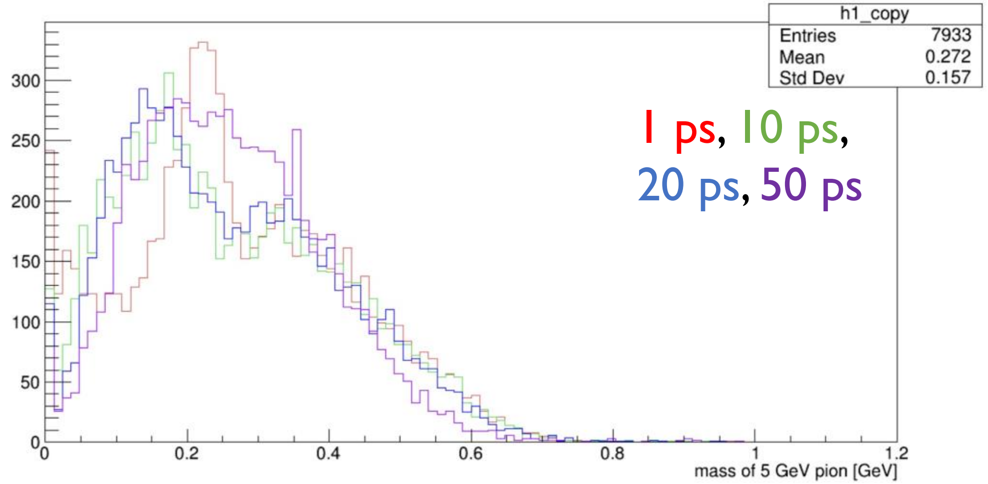




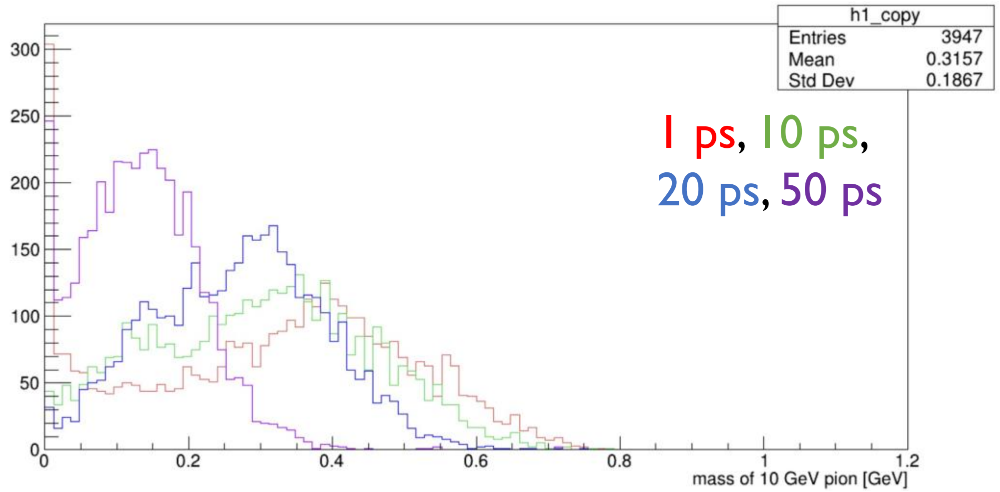
イベントごとの質量

1 ps, 10 ps, 20 ps, 50 ps

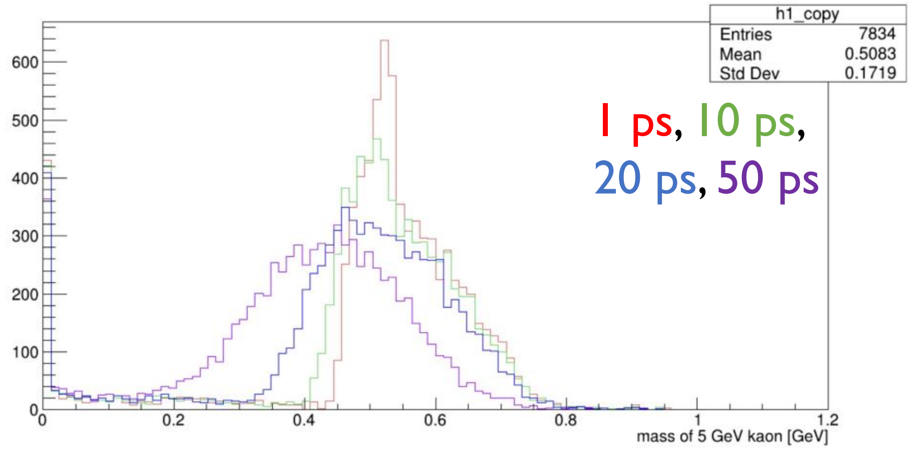
5 GeV pion



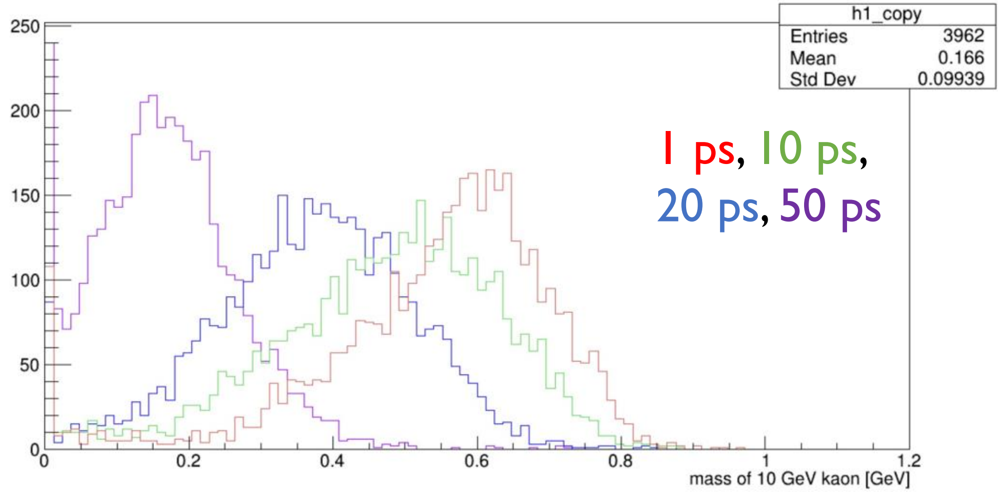
10 GeV pion



5 GeV kaon



10 GeV kaon



ヒットごとの質量分布：π^+(139 MeV)

- ヒットごとの質量
- 使用したデータ

  single particle PDG=211 (π^+)

  1 , 2 , 5 , 10 GeV
- PDG=211でカット

➢ 分布のピークの値は、理論値よりわずかに大きい

➢ 2 GeVは最も理論値に近く、
  テールも小さい

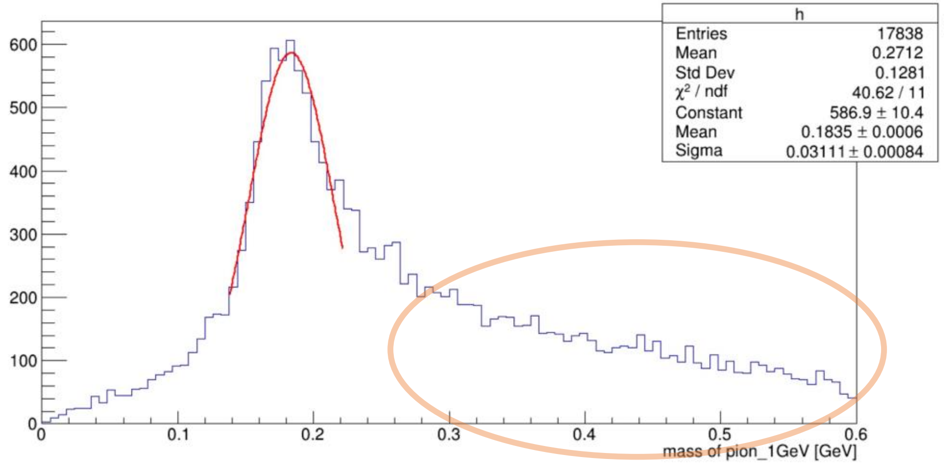
➢ 1 GeVではテールが目立つ

  →エネルギーが小さく、散乱して
  すぐに止まってしまう

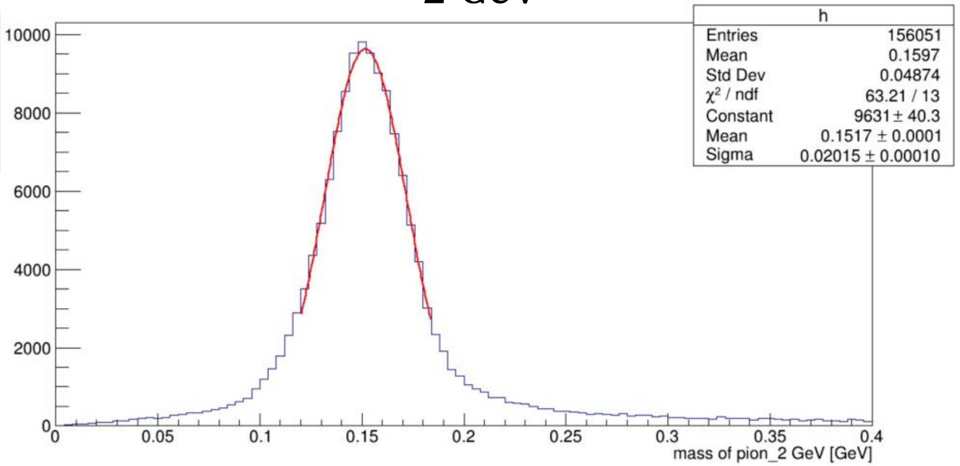
➢ 5 , 10 GeVではピーク幅が大きい

  →ピクセルサイズを考慮していないのが原因の一つではないか

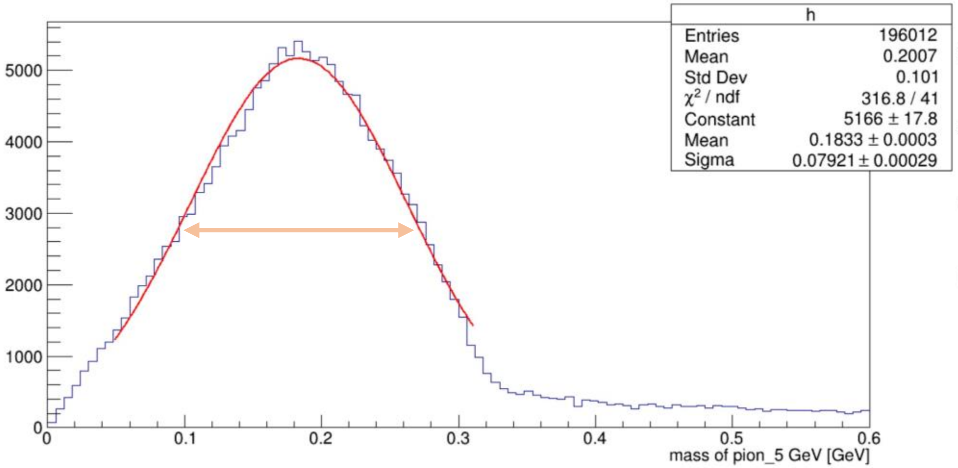
1 GeV



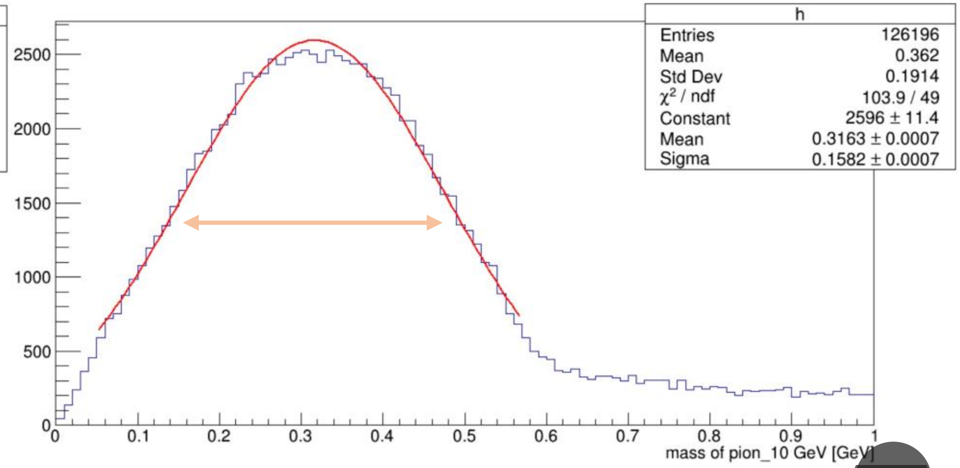
2 GeV



5 GeV



10 GeV



ヒットごとの質量分布: K^+(494 MeV)

- **ヒットごとの質量**
- **使用したデータ**

  single particle PDG=321 (K^+)

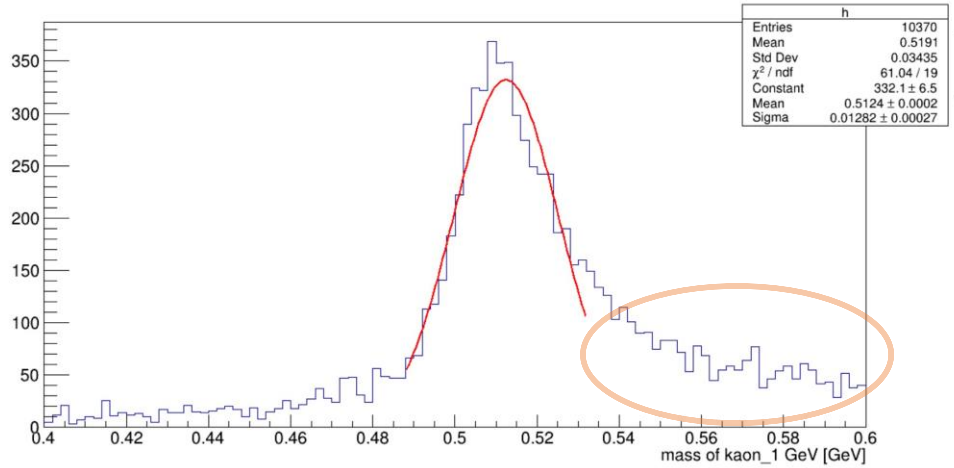
  1 , 2 , 5 , 10 GeV

- PDG=211でカット

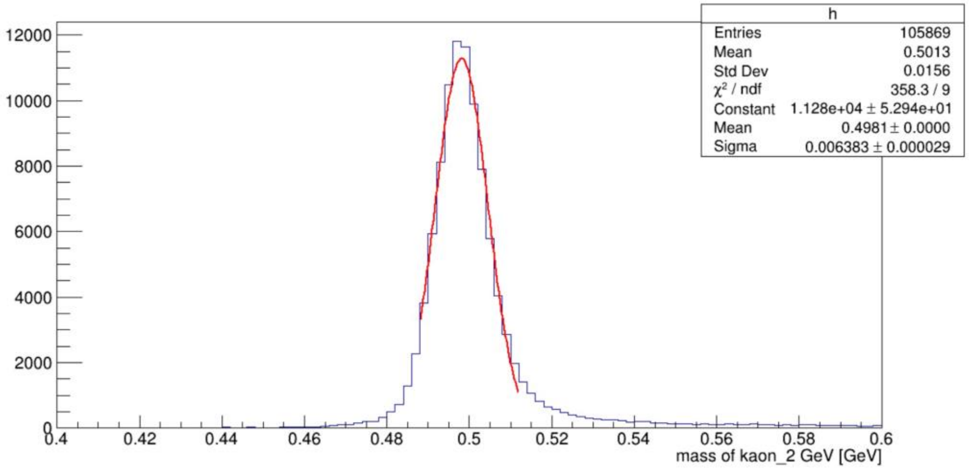
➢ **パイオンと同じく、分布のピークの値は、理論値よりわずかに大きい**

➢ **それぞれのエネルギーでの特徴も同様**

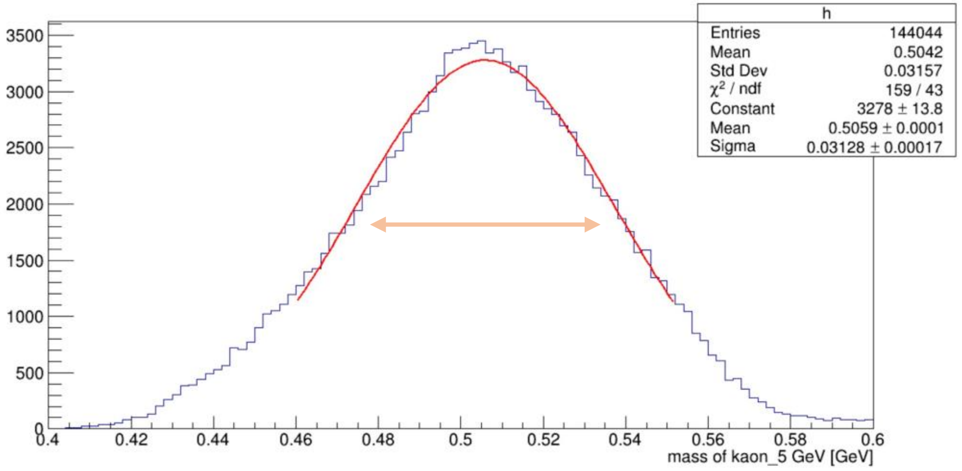
1 GeV



2 GeV



5 GeV



10 GeV