Geant4 simulation study in particle identification capability with silicon detector

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Heavy Ion Physics Experiment

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물리학과

Motivation

Particle IDentification (PID) is very important in nuclear physics experiments. In ALICE (A Large Ion Collider Experiments)@CERN, silicon detector (ITS) is mainly used for tracking and vertex, and TPC(Time Projection Chamber) is used for PID by seeing differences of dE/dx.

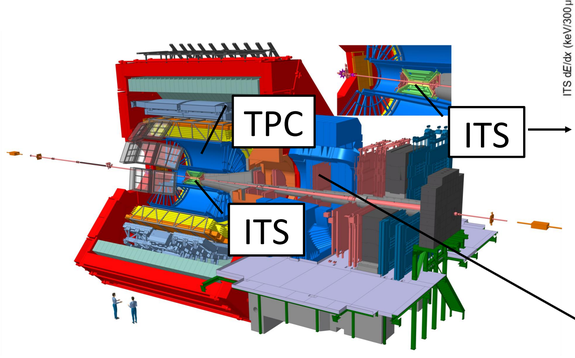


Figure 1. ALICE-ITS RUN3

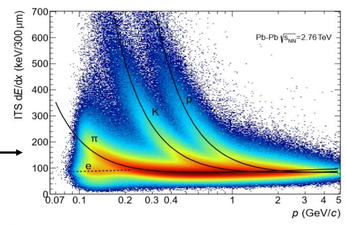


Figure 2. dE/dx distribution measured in the ITS

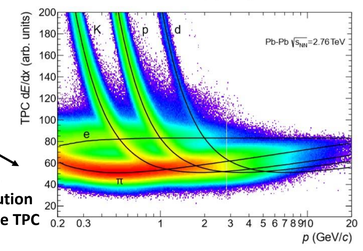


Figure 3. dE/dx distribution measured in the TPC

In future experiments, silicon detectors of better precision and faster readout than TPC can be used more extensively for particle tracking.
In this research, we have studied a PID capability of silicon material with Geant4 simulation framework.

Detail procedure

```
/run/initialize
/gun/particle e-
/tracking/verbose 0
/run/beamOn 500000
```

Figure 5. Geant4 macro example

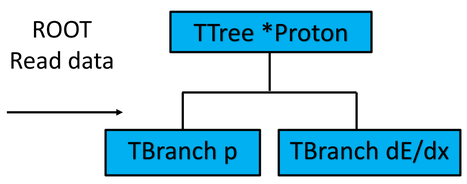
Geant4 simulation →

```
1 8.5735
0 9.24125
1 10.036
0 8.03235
1 2.70611
0 7.33781
1 10.5159
0 10.8967
1 16.4197
0 6.66633
1 5.33578
0 8.07467
1 11.9207
0 19.7484
```

Figure 6. Output example

(1-dE/dx, 0-momentum)

ROOT
Read data →




```
******************************************************************************
*Tree    :T         : Electron                                               *
*Entries :   500000 : Total =         4020885 bytes  File  Size =          0 *
*        :          : Tree compression factor =   1.00                       *
******************************************************************************
*Br    0 :p         : p/F                                                    *
*Entries :   500000 : Total  Size=    2010231 bytes  All baskets in memory   *
*Baskets :       62 : Basket Size=      32000 bytes  Compression=   1.00      *
*............................................................................*
*Br    1 :dE        : dE/F                                                   *
*Entries :   500000 : Total  Size=    2010361 bytes  All baskets in memory   *
*Baskets :       62 : Basket Size=      32000 bytes  Compression=   1.00      *
*............................................................................*
```

Figure 7. Tree example on ROOT

ROOT
Plot Histogram →

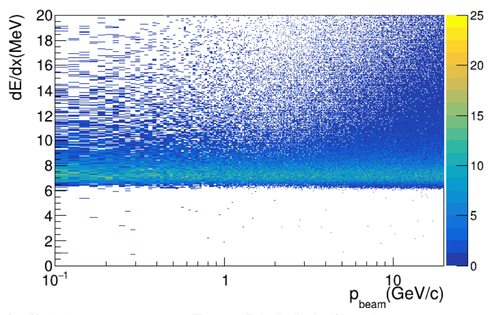


Figure 7. Histogram example on ROOT (dE/dx distribution of electron, Si=1 cm)

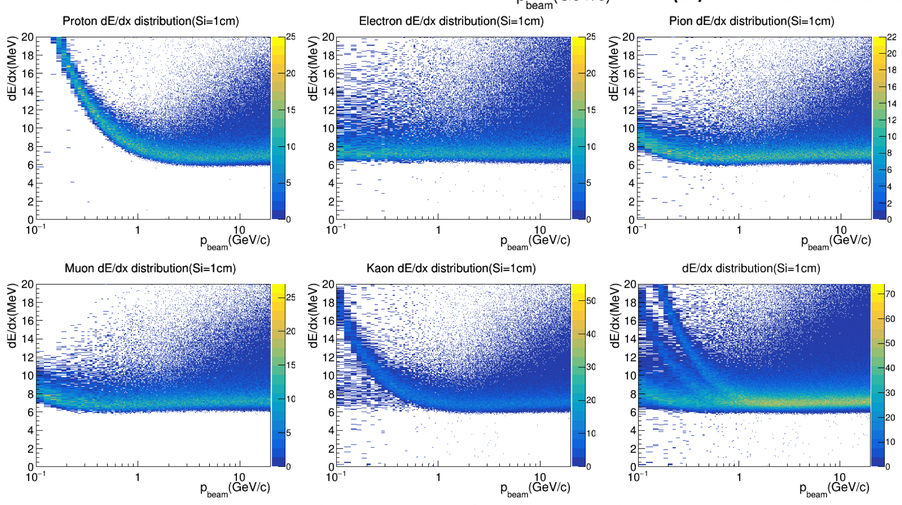


Figure 8. dE/dx distributions from Geant4 Simulation (Silicon thickness = 1cm)

Figure 8. shows dE/dx distributions from Geant4 simulation in case of 1 cm thickness silicon for 5 particles(p, e^-, π, μ, K) in 0-20 GeV/c momentum. Lower right plot is the sum of 5 particles.

Method & Set-up

Used Geant4 simulation for getting data (energy deposition)

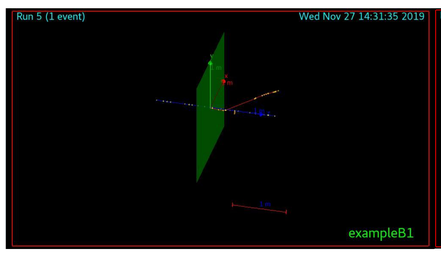


Figure 4-1. Made Geant4 Detector model (Detector 300μm-Si, Beam proton)

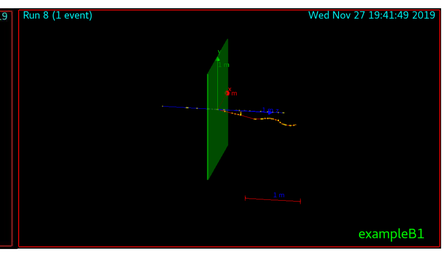


Figure 4-2. Made Geant4 Detector model (Detector-1cm Si, Beam-proton)

Detector Material – Silicon (Si)
Thickness – 300 μm, 1 cm, 10 cm
Beam Particle – p, e^-, π, μ, K
Momentum – Uniform distribution(0-20 GeV/c)
Number of particles – 500,000/run
Output – Beam momentum, Energy deposition inside the silicon material
Used ROOT to analyze data and plot histograms/graphs

Results

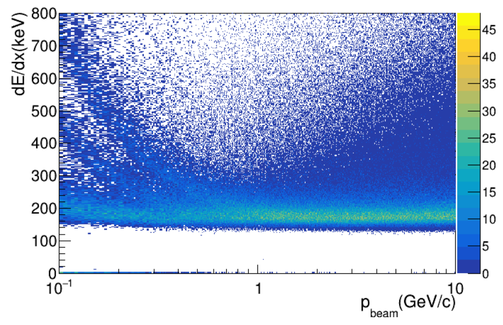


Figure 9. dE/dx distribution(Si=300 μm)

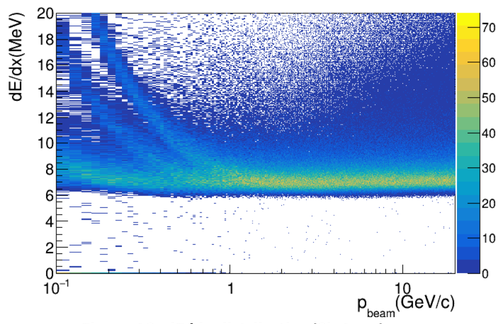


Figure 10. dE/dx distribution(Si=1 cm)

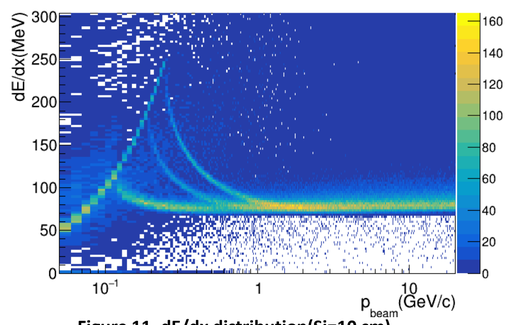


Figure 11. dE/dx distribution(Si=10 cm)

Figure 9 shows dE/dx distribution of 5 different particle beam with 0-10 GeV/c momentum while traversing 300 μm thickness silicon. When comparing Figure 9 (Geant4) to Figure 2 (ALICE data), two figures of the same silicon material thickness show very similar distributions (Bethe-Bloch distribution). Therefore, it is confirmed that the current Geant4 simulation setup and analysis procedure are correct.

Figure 10 shows dE/dx distribution while traversing 1 cm thickness silicon. When comparing Figure 10 to Figure 3, 1 cm Si detector's PID resolution seemed comparable with the current ALICE TPC.

Figure 11 shows dE/dx distribution while traversing 10 cm thickness silicon. In Figure 11, under 0.3 GeV/c, proton dE/dx distribution is quite different from the case with 1 cm silicon(Figure 10) and it's hard to distinguish particles in p < 0.1 GeV/c. Because particle lost all given energy when passing through the detector.

Summary & Outlook

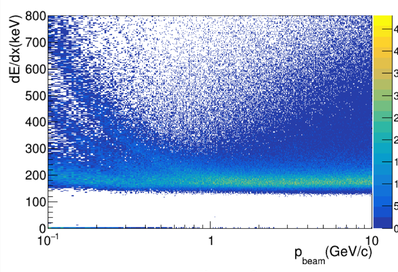


Figure 9

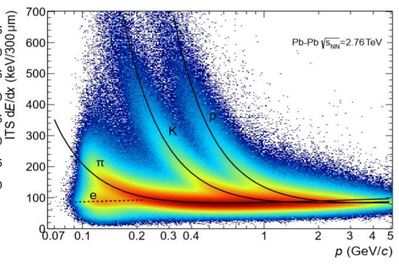


Figure 2

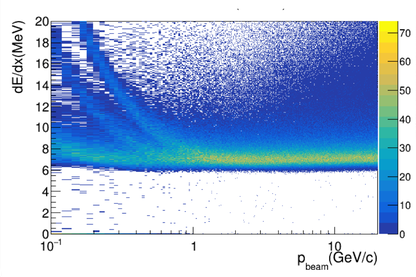


Figure 10

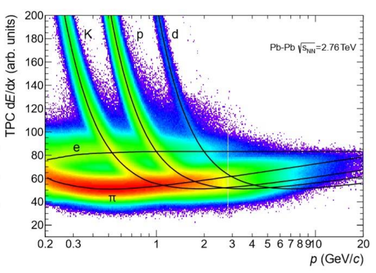


Figure 3

We made a Geant4 simulation and analysis setup to test PID capability with silicon material.
As a result, we confirmed the setup by comparing the results from the current ALICE ITS.
In the test with 1 cm silicon, the PID capability is comparable with the current TPC in ALICE
In order to find an optimized silicon thickness, more tests with various silicon thickness and detailed analysis need to be done to evaluate PID capability.

References

Christian Lippman, Particle identification, Nuclear Instruments and Methods in Physics Research A 666(2012) 148-172
ALICE collaboration, Performance of the ALICE Experiment at the CERN LHC." International Journal of Modern Physics A 29.24 (2014): 1430044. Crossref. Web.
CERN ROOT, https://root.cern.ch
Geant4, http://geant4.web.cern.ch/
ALICE, http://alice.cern.ch/