Particle decay reconstruction

P. Ronchese
Dipartimento di Fisica e Astronomia “G.Galilei”

Università di Padova

“Object oriented programming and C++” course

Simulated events

Data to read and analyze have been produced by simulating the decay of two strange particles

- $K_S^0 \rightarrow \pi^+\pi^-$
  two opposite charge particles in the final state, with the same mass
- $\Lambda^0 \rightarrow p\pi^-$
  two opposite charge particles in the final state, with different masses
- background events
  up to 10 particles, with random charges

Particles properties

- Unstable particles
  - K^0_S : $M_K = 0.497611\ \text{GeV}/c^2$, $\tau_K = 89.54$ ps
  - Λ^0 : $M_\Lambda = 1.115683\ \text{GeV}/c^2$, $\tau_\Lambda = 263.2$ ps
- Stable particles
  - $\pi^\pm$: $M_\pi = 0.1395706\ \text{GeV}/c^2$
  - p : $M_p = 0.938272\ \text{GeV}/c^2$

Stable particles (pions, protons) cannot be distinguished, unstable particles must be reconstructed by making hypotheses on the masses of the decay products

Invariant mass

The mass of a decaying particle can be determined by the masses and momenta of its decay products plus the light speed in vacuum c:

$$M = \frac{\sqrt{E_{\text{tot}}^2 - p_{\text{tot}}^2 c^2}}{c^2} \quad ; \quad E_{\text{tot}} = \Sigma_i E_i \quad ; \quad p_{\text{tot}} = |\Sigma_i \vec{p}_i|$$

The single particle energies can be computed in an analogous way:

$$E_i = \sqrt{p_i^2 c^2 + M_i^2 c^4}$$

Usually masses and momenta are measured with units GeV/c^2 and GeV/c respectively, so that in the previous formulas $c = 1$ can be assumed:

$$M = \sqrt{E_{\text{tot}}^2 - p_{\text{tot}}^2} \quad ; \quad E_i = \sqrt{p_i^2 + M_i^2}$$

Data format

The file `particle_events.txt` contains the data, written in text form

Each event contain:

- an event identifier (i.e. an `int`)
- the coordinates x, y, z of the decay point (3 `float`s)
- the number of particles (an `int`)
- for each particle 4 numbers:
  - the electric charge (an `int`)
  - the momentum components p_x, p_y, p_z (3 `float`s)

Particle data dump - version 1

Read the text file and produce a dump onto the screen
(use the “Energies data dump - version 1” example as reference)

- Create 4 arrays:
  - an array of `int` to contain particles charges,
  - an array of `float` to contain particles p_x ,
  - an array of `float` to contain particles p_y ,
  - an array of `float` to contain particles p_z.
- Create functions to:
  - read an event from file,
  - dump an event onto the screen,
- Create a `main` function to loop over the file and dump the events.

Particle data dump - version 2

Read the text file and produce a dump onto the screen
(use the “Energies data dump - version 2” example as reference)

- Create 2 `struct`s:
  - `Event` : to contain event data,
  - `Particle` : to contain particle data.
- Create functions to:
  - read an event from file,
  - dump an event onto the screen,
  - free the memory used by the event
    (including the memory used by all the particles).
- Create a `main` function to loop over the file and dump the events.

Particle mass mean - version 1

Read the text file and compute invariant mass mean and r.m.s. (use the “Energies data mean - version 1” example as reference)

- Create a function to compute the invariant mass of the decaying particle:
  - consider the two hypotheses $K^0_S \to \pi^+\pi^-$ and $\Lambda^0 \to p\pi^-$
  - choose the one being more consistent with the known M_K and M_Λ
  - select events with mass in the range $0.490 \div 0.505$ GeV$/c^2$
- Count the number of selected events
- Compute mass mean and r.m.s.

Particle mass mean - version 2

Read the text file and compute invariant mass mean and r.m.s. for K_S^0 and Λ^0
(use the “Energies data mean - version 2” example as reference)

- Modify the version 1 to use `class`es:
  - create a `class` to contain event data,
  - create a `class` to compute statistics.
  - select events with total energy in the following ranges:
    - between 0.490 and 0.505,
    - between 1.114 and 1.118.
- Modify the `main` function to use the new `class`es.

Particle mass mean - version 3

Read the text file and compute invariant mass mean and r.m.s. for K_S^0 and Λ^0
(use the "Energies data mean - version 3" example as reference)

- Modify the version 2 to use STL:
  - use a `std::string` to handle input file name,
  - use a `std::vector` to store particle pointers.

Particle mass mean - version 4

Read the text file and compute invariant mass mean and r.m.s. for K_S^0 and Λ^0
(use the "Energies data mean - version 4" example as reference)

- Modify the version 3 to use `class`es in place of global functions:
  - create a `class` to read or simulate events,
  - create a `class` to dump events,
  - create a `class` to compute statistics.
- Create the `class`es as derivations of interfaces to get events and process them.
- Create a `class` to simulate events.
- Modify the `main` function to use the new `class`es.

Particle histograms - version 1

Histogram invariant mass for K_S^0 and Λ^0
(use the “Energies data plot - version 1” example as reference)

- Modify the mean-version 4 to include graphic histograms and allow multiple histograms handling:
  - inside the general analysis steering `class` pair each object computing mean and rms mass with a `TH1F` object,
  - create, set and save histograms in the same `class` , too.
- All other `class`es and the main function stay unchanged.

Particle histograms - version 2

Histogram invariant mass for K_S^0 and Λ^0
(use the “Energies data plot - version 2” example as reference)

- Take `AnalysisInfo` and `SourceFactory` from the particle analysis example.
- Modify the main function to use the new `class`es .

Particle histograms - version 3

Histogram invariant mass for K_S^0 and Λ^0
(use the “Energies data plot - version 3” example as reference)

- Modify the version 2 to use a “factory” to create analyzer objects:
  - take the new versions of `AnalysisSteering` and `AnalysisFactory` from the particle analysis example,
  - modify `EventDump` and `ParticleMass` to be handled by `AnalysisFactory`.
- Modify the main function to use the new `class`.

Particle histograms - version 4

Histogram invariant mass and decay time for K_S^0 and Λ^0 (use the "Energies data plot - version 3" example as reference)

- Modify the version 3 to use a "dispatcher" to loop over events:
  - declare `EventDump` and `ParticleMass` as `ActiveObserver`s, and remove the calls to `update` functions,
  - remove the `process` function from `AnalysisSteering` and rename it to `update` in all analyzers,
  - reconstruct decays in a `class ParticleReco` declared as `LazyObserver` and `Singleton`,
  - create `ParticleLifetime` , `ProperTime` and `LifetimeFit class`es for decay time histograms,
  - add a `run` function to `EventSource` .
- Move the event loop from the `main` function to the `run` function in `EventSource` .

Particle histograms - version 5

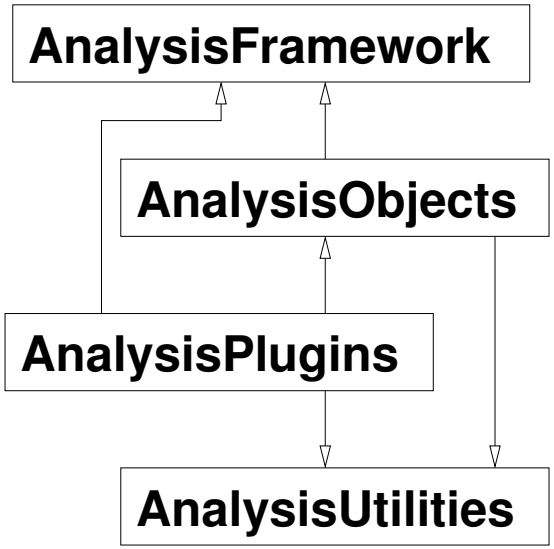
Histogram invariant mass and decay time for K^0_S and Λ^0 (use the "Energies data plot - version 5" example as reference). Add mean lifetime fit.

- Modify the version 4 to use a "dispatcher" to handle begin/end of analysis:
  - declare in `AnalysisInfo` an `enum AnalysisStatus` with values `begin` and `end`,
  - declare `AnalysisSteering` as an `ActiveObserver` of `AnalysisInfo::AnalysisStatus`,
  - in `AnalysisSteering` implement a function `update` calling in its turn `beginJob` or `endJob`.
- Replace in `main` the analyzers loop calls to `beginJob` and `endJob` with notifications of `AnalysisInfo::begin` or `AnalysisInfo::end`.
- In `LifetimeFit` add a maximum likelihood fit to estimate the mean lifetime and the corresponding error

Particle histograms - version 6

Histogram invariant mass and decay time for K_S^0 and Λ^0 (use the "Energies data plot - version 6" example as reference).

- Modify the version 5 to organize the code in packages:
  - create 4 packages: `AnalysisFramework`, `AnalysisPlugins`, `AnalysisObjects`, `AnalysisUtilities`,
  - move all source files, including `main.cc`, into those packages, avoiding circular dependencies,
  - compile each package into a library but `AnalysisPlugins`, where each analyzer is to be compiled to a distinct library.



- Produce the executable by using a dummy source code.