Physics Analysis Software Framework for Belle II

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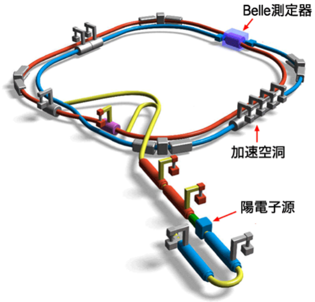
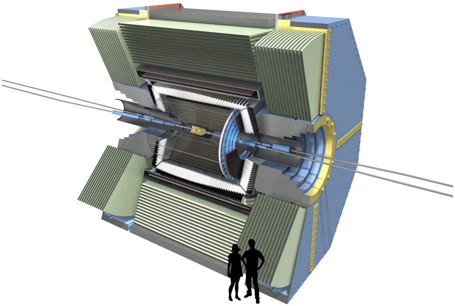
Belle II experiment





SuperKEKB accelerator

- asymmetric e^+e^- collider (4 GeV / 7 GeV)
- nano-beam optics
- luminosity 40 $\times$ KEKB ($8 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$)

Belle II detector

- tracking and vertexing
- hadron and lepton ID
- γ and K_L detection

Belle II experiment

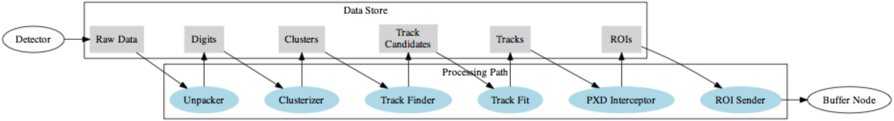
Broad physics program including

- B physics (rare decays, CPV)
- Charm physics (mixing, CPV, new resonances)
- Tau physics (LFV)

Physics analysis software must provide

- Exclusive and inclusive decay reconstructions
- Reconstruction of recoil particles
- Flavor tag
- Continuous background suppression
- Event pre-selection (skim) / output to micro dst

Belle II software framework (Basf2)



- Flexible framework build of
  - modules, which process data
  - data store, to share data between modules
- Modules are organized in a user-defined chain using python script
- Data store consists of a Root-storable objects
  - StoreArrays and StoreObjPtrs
  - relations between elements of different data objects
- The content of the data store (or its part) can be read from or written to a Root file at any point in the chain using dedicated modules

Basf2 ingredients

Modules

- A module can be put into path many times; each time a new instance is created.
- Data processing of a module can be steered by module parameters; parameters can be of types
  - int, float, std::string
  - std::tuple constructed of above types
  - std::vector of all above types

Data store objects

- template classes representing single object (StoreObjPtr) or an array of objects (StoreArray)
- multiple data store objects of a given type can be created
- distinguished by their names

Basf2 provides all ingredients to build a framework for the physics analysis.

Physics Analysis Framework

Data model

- class Particle: a common representation of a reconstructed particle
  - final state particle $(e, \mu, \pi, K, p, \gamma, K_L)$
  - pre-reconstructed V0 particle (K_S, Λ)
  - reconstructed in decay (via combinations)
  - internally holds Lorentz vector, vertex, error matrix, relation to daughter particles, PDG code, and some other informations.
- StoreArray<Particle>: array of all reconstructed particles
  - a work space
  - modules can append particles to this array
  - modules can modify particles in this array (vertex fit!)
  - modules can select particles from this array
- class ParticleList: list of particles of a given type (PDG code)
  - internally holds a vector of pointers (indices) to appropriate elements of StoreArray<Particle>
  - particle lists: single Data store objects distinguished by their names
  - name composed of a standard particle name and a label: `pi+:slow`

Modules

The basic modules

- ParticleLoader
  - appends particles constructed from mdst objects (reconstructed tracks, ECL clusters K_L, V0) to the work space
- ParticleSelector
  - selects particles from the work space (makes particle list) or
  - applies selection criteria to the list (by removing unselected)
  - selection criteria (Boolean expression) are given via module parameter
- ParticleCombiner
  - makes combinations from any number of input particle lists
  - appends combined particles to a work-space
  - creates particle list of combined particles
- VertexFitter
  - performs all kinds of vertex fits on particles from a given list
  - updates successfully fitted particles (on the work space) and connects (via framework relations) the vertex object or
  - removes badly fitted from the list

Modules and additional data objects

Other modules

- a module for best candidate selection
- a module for MC truth matching
- a module for continuum suppression
- TMVA teacher and expert modules
- a module for flavor tagging
- a module which builds and connects the rest-of-event to a particle
- a ntuple maker module (flat ntuple)
- ...

Additional data objects

- Vertex, RestOfEvent, FlavorTagInfo, EventExtraInfo, ...
- can be linked to particles via framework relations

Python steering

- Commands that represent dedicated actions are defined using python functions. Example:

```
def reconstructDecay(decayString, cut, path=analysis_main):

    combiner = register_module('ParticleCombiner')
    combiner.param('decayString', decayString)
    combiner.param('cut', cut)
    path.add_module(combiner)

reconstructDecay('D0 -> K- pi+', '1.8 < M < 1.9')
```

- Decay string in this example defines input and output particle lists
  - charge conjugate states are implicitly included
- Selection criteria given as the second argument is parsed to a C++ representation during module initialization
  - variable names are replaced during parsing with function pointers
  - Boolean expression is per event evaluated using recursion
- Additional variables can be easily defined by user

Steering example: reconstruction of $D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+$

```
#!/usr/bin/env python
# -*- coding: utf-8 -*-

from basf2 import *
from modularAnalysis import *
from stdLooseFSParticles import *

inputMdst('DstarSignalMC.mdst.root') # define mdst input file

stdVeryLoosePi() # make lists of very loosely selected pions (pi+:all, pi-:all)
stdLoosePi()     # make lists of loosely selected pions (pi+:loose, pi-:loose)
stdLooseK()      # make lists of loosely selected kaons (K+:loose, K-:loose)

# reconstruct D0 -> K- pi+ + cc
reconstructDecay('D0 -> K-:loose pi+:loose', '1.7 < M < 2.0 and p_CMS > 2.2')
vertexKFit('D0', 0.001)
applyCuts('D0', '1.81 < M < 1.91')

# reconstruct D*+ -> D0 pi+ + cc
reconstructDecay('D*+ -> D0 pi+:all', 'Q < 0.05')
vertexKFit('D*+', 0.001)
applyCuts('D*+', 'Q < 0.02 and p_CMS > 2.5')

outputUdst('recDstar.udst.root', ['D*+']) # write selected events to micro dst

process(analysis_main) # process events
```

Conclusions

- An overview of the physics analysis software framework at Belle II has been given
- The framework utilizes the Basf2 software framework, and uses python for steering
- Although the framework is still under development, a user can already perform most of the physics analysis steps like decay reconstructions, vertex fits, tag the flavor of a B meson and perform TMVA-based continuum suppression.

Backup: cpu usage

running steering example from slide 10 for 1000 events

Name	Calls	Time(s)	Time(ms)/Call
RootInput	1001	0.25	0.25 +- 0.36
Progress	1000	0.01	0.01 +- 0.01
Gearbox	1000	0.01	0.01 +- 0.00
ParticleLoader_pi+:all	1000	0.17	0.17 +- 0.04
ParticleLoader_pi+:loose	1000	0.16	0.16 +- 0.04
ParticleLoader_K+:loose	1000	0.15	0.15 +- 0.04
ParticleCombiner_D0 -> K-:loose pi+:loose	1000	0.03	0.03 +- 0.03
Geometry	1000	0.01	0.01 +- 0.00
ParticleVertexFitter_D0	1000	0.14	0.14 +- 0.15
ParticleSelector_applyCuts_D0	1000	0.01	0.01 +- 0.00
ParticleCombiner_D*+ -> D0 pi+:all	1000	0.02	0.02 +- 0.01
ParticleVertexFitter_D*+	1000	0.11	0.11 +- 0.14
ParticleSelector_applyCuts_D*+	1000	0.01	0.01 +- 0.00
RootOutput	1000	0.70	0.70 +- 1.69
Total	1001	2.00	2.00 +- 1.77