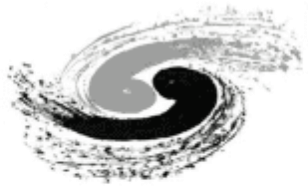

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FinalPIDSvc: tutorials and updates

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Introduction

- **FinalPIDSvc: a compact service to perform PID**
  - Link: https://code.ihep.ac.cn/glliu/FinalPIDSvc
- **Five flavors of charged particles** are considered: e / μ / π / K / p
- **ID variables:**
  - μ: TOF, TPC, E_ECAL, E_HCAL, E_HCAL, r_HCAL, minimum ΔR(trk, muon hits)
  - e: TOF, TPC, E_ECAL/p, E_HCAL, E_HCAL, r_HCAL
  - hadrons: TOF, TPC
- **Discriminant: total χ^2**
  - μ ID:

$$\chi^2(\mu) = (\frac{\mathrm{tof} - \mu_{\mathrm{tof}}}{\sigma_{\mathrm{tof}}})^2 + (\frac{\mathrm{dNdx} - \mu_{\mathrm{dNdx}}}{\sigma_{\mathrm{dNdx}}})^2 + (\frac{\mathrm{ee} - \mu_{\mathrm{ee}}}{\sigma_{\mathrm{ee}}})^2 + (\frac{\mathrm{eh} - \mu_{\mathrm{eh}}}{\sigma_{\mathrm{eh}}})^2 + (\frac{\mathrm{rh} - \mu_{\mathrm{rh}}}{\sigma_{\mathrm{rh}}})^2 + (\frac{\mathrm{dr}}{\sigma_{\mathrm{dr}}})^2 + 2\lambda_{\mathrm{dr}}\mathrm{dr} - 2\mathrm{ln} \cdot \mathrm{dr}.$$

  - e ID:

$$\chi^2(e) = (\frac{\mathrm{tof} - \mu_{\mathrm{tof}}}{\sigma_{\mathrm{tof}}})^2 + (\frac{\mathrm{dNdx} - \mu_{\mathrm{dNdx}}}{\sigma_{\mathrm{dNdx}}})^2 + (\frac{\mathrm{ee\_p} - \mu_{\mathrm{ee\_p}}}{\sigma_{\mathrm{ee\_p}}})^2 + (\frac{\mathrm{eh} - \mu_{\mathrm{eh}}}{\sigma_{\mathrm{eh}}})^2 + (\frac{\mathrm{rh} - \mu_{\mathrm{rh}}}{\sigma_{\mathrm{rh}}})^2.$$

  - π, K, p ID:

$$\chi^2(\mathrm{hadron}) = (\frac{\mathrm{tof} - \mu_{\mathrm{tof}}}{\sigma_{\mathrm{tof}}})^2 + (\frac{\mathrm{dNdx} - \mu_{\mathrm{dNdx}}}{\sigma_{\mathrm{dNdx}}})^2.$$

Introduction

- **Finalized PID procedure**
  - If the PFO is charged, return photon.
  - Otherwise, perform muon ID:
    - Given the muon ID WP, if the PFO passes it, return muon.
  - Otherwise, perform electron ID:
    - Given the electron ID WP, if the PFO passes it, return electron.
  - Otherwise, perform hadron ID:
    - Given the hypotheses of π / K / p, return the one with the smallest χ^2.

Installation

- Enter the CEPCSW environment:
  - cd Service
  - git clone git@code.ihep.ac.cn:glliu/FinalPIDSvc.git
- Modify CMakeLists.txt:
  - **Add** add_subdirectory(FinalPIDSvc)
- Compile:
  - cd ..
  - source setup.sh
  - ./build.sh
  - source setup.sh

Structure of FinalPIDSvc

Program level

- **initialize() / finalize():**
  - Standard functions to obtain the input data (parameters in χ^2 computation) or release them.

Event level

- **SetCollections():**
  - Set the TPC, TOF, and muon hits collections. The full PFO collections are also set.
- **MatchMuonHitsToTracks():**
  - Match the muon hits to extrapolated tracks. More details later.
- **SetWP_mu() / SetWP_ele():**
  - Set WPs for muon and electron ID. Currently available WPs: WP::is60, is70, is80 and is90.
  - Default: is90.
- **AddVar() / RemoveVar():**
  - Add or remove variables used to build the total χ^2.
  - Default: all used.

PFO level

- **LoadPFO():**
  - Load the PFO (edm4hep::ReconstructedParticle) that you want to identify.
- **GetType():**
  - Return the abs(Pdgid) of the ID result.
- **ComputeChi2Total():**
  - Every time you AddVar() or RemoveVar(), you should run this to recompute the total χ^2.

Application: PIDDumpAlg

- **Use Alg to read the process the standard output of reconstruction**
- **In the header: PIDDumpAlg.h**
  - Add some includes:

```
#include "FinalPIDSvc/IFinalPIDSvc.h"
#include "DetInterface/IGeomSvc.h"
#include <GaudiKernel/Service.h>

#include <DDRec/DetectorData.h>
#include <DDRec/CellIDPositionConverter.h>
#include <DD4hep/Segmentations.h>
```

  - Define the FinalPIDSvc:

```
SmartIF<IFinalPIDSvc> m_pid_svc;
```

  - Define the TOF, TPC and muon hit collections

```
DataHandle<edm4hep::TrackerHitCollection> m_inputMuonBarrel{"MuonBarrelTrackerHits", Gaudi::DataHandle::Reader, this};
DataHandle<edm4hep::TrackerHitCollection> m_inputMuonEndcap{"MuonEndcapTrackerHits", Gaudi::DataHandle::Reader, this};
DataHandle<edm4hep::RecTofCollection> m_inTofCol{"RecTofCollection", Gaudi::DataHandle::Reader, this};
DataHandle<edm4hep::RecDqdxCollection> m_inDqdxCol{"DndxTracks", Gaudi::DataHandle::Reader, this};
```

Application: PIDDumpAlg

- **In the cpp: PIDDumpAlg.cpp**
  - Add some includes:

```
#include "DD4hep/DD4hepUnits.h"
#include "DD4hep/Detector.h"
#include <DD4hep/Objects.h>
#include <DDRec/CellIDPositionConverter.h>
```

  - Initialize the FinalPIDSvc:

```
m_pid_svc = service("FinalPIDSvc");
```

  - Read all the TOF, TPC and muon hit collections
  - Event level procedures

```
m_pid_svc->SetCollections(barrelhits, endcaphits, tofcol, dqdxcol, PFO);
m_pid_svc->MatchMuonHitsToTracks();

m_pid_svc->SetWP_mu(WP::is90);
m_pid_svc->SetWP_ele(WP::is90);

m_pid_svc->RemoveVar(WP::mindR); //Do this if you mean to do this
```

  - Get the result for a given PFO

```
auto outpfo = pfo.clone();
bool load=m_pid_svc->LoadPFO(outpfo);
if (!load) continue;
PID.push_back(m_pid_svc->GetType());
```

Application: PIDDumpAlg

- **In the python script: PIDDump.py**
  - Add the services

```
############ FinalPIDSvc ##################
from Configurables import FinalPIDSvc
pidsvc = FinalPIDSvc("FinalPIDSvc")
cepcswdatatop = "/cvmfs/cepcsw.ihep.ac.cn/prototype/releases/data/latest"
pidsvc.eleFile = "/cefs/higgs/liugeliang/CEPC/202503/CEPCSW/Service/FinalPIDSvc/data/eID_database_new.root"
pidsvc.muFile = "/cefs/higgs/liugeliang/CEPC/202503/CEPCSW/Service/FinalPIDSvc/data/muID_database_new.root"
##########################################

############ GeomSvc ##################
from Configurables import DetGeomSvc
geosvc = DetGeomSvc("GeomSvc")
geometry_option = "TDR_o1_v01/TDR_o1_v01.xml"
geometry_path = os.path.join(os.getenv("DETCRDROOT"), "compact", geometry_option)
if not os.path.exists(geometry_path):
    print("Can't find the compact geometry file: %s"%geometry_path)
    sys.exit(-1)
geosvc.compact = geometry_path
##########################################
```

  - Input collections
    - inp.collections = ["MuonBarrelTrackerHits", "MuonEndcapTrackerHits" , "CyberPFO", "CompleteTracksParticleAssociation","RecTofCollection", "DndxTracks"]
  - In ApplicationMgr

```
ExtSvc=[podioevent, geosvc],
```

Application: PIDDumpAlg

- **In the python script: PIDDump.py**
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```

  - Input collections
    - inp.collections = ["MuonBarrelTrackerHits", "MuonEndcapTrackerHits" , "CyberPFO", "CompleteTracksParticleAssociation","RecTofCollection", "DndxTracks"]
  - In ApplicationMgr

```
ExtSvc=[podioevent, geosvc],
```

Application: PIDDumpAlg

- In CMakeLists.txt
  - Add the services

```
gaudi_add_module(PIDDump
                 SOURCES src/PIDDumpAlg.cpp
                 LINK DataHelperLib
                     k4FWCore::k4FWCore
                     Gaudi::GaudiKernel
                     EDM4HEP::edm4hep
                     EDM4CEPC::edm4cepc EDM4CEPC::edm4cepcDict
                     k4FWCore::k4FWCore
                     FinalPIDSvc
                     FinalPIDSvcLib
                     DetInterface
                     DetSegmentation
                     TrackSystemSvcLib
                     ${LCIO_LIBRARIES}
                     ${ROOT_LIBRARIES}
                     ${CLHEP_LIBRARIES}
)
```

Updates regarding Muon ID

- **More muon hits information is saved**

- **Procedures before**
  - Extrapolation: extrapolate the inner tracks to the muon detector
  - Correction: perform angular corrections regarding the energy loss
  - Track-hit match: match each muon hit to the extrapolated track with the smallest ΔR
  - Min ΔR: for each track, pick up the smallest ΔR among all muon hits matched to it, as the discriminant.

- **New procedures**
  - Ideas from Hengne Li
  - After Track-hit match, choose the min ΔR as before.
  - Second Min ΔR: Loop the matched muon hits again, and choose the min ΔR, with the muon hits that is not in the same layer as the first chosen muon hit.
  - Third Min ΔR: Loop the matched muon hits again, and choose the min ΔR, with the muon hits that is not in the same layer as the first and second chosen muon hits.

Updates regarding Muon ID

- **Distance information**
  - For the three chosen muon hits for each track, the distance in the corresponding layers are also computed.
  - For barrel: the track is extrapolated to the same radius as the hit, and the distance is computed as $\mathrm{d} = \sqrt{\mathrm{r}^2\Delta\phi^2 + \Delta\mathrm{z}^2}$
  - For endcap: the track is extrapolated to the same z as the hit, and the distance is computed as $\mathrm{d} = \sqrt{\Delta\mathrm{x}^2 + \Delta\mathrm{y}^2}$

- **Possible muon ID methods**
  - Build χ^2 for the three min $\Delta\mathrm{R}$ and combine all of them.
  - Require to find all such three muon hits in three different layers, possibly require the distance to be small enough (< 5cm?)

Ongoing studies

- Weiqi Meng is performing the mentioned studies on **muon hits ID**, to check the performances or improvements of different methods.

- Changhua Hao is checking the **original distributions** of E_ECAL/p, E_ECAL, E_HCAL, r_HCAL, and **optimize the parameters** used to build χ^2

- I am producing the **efficiency plots** produced from the new services, and check irregular behaviors.
  - Performances seem too good.