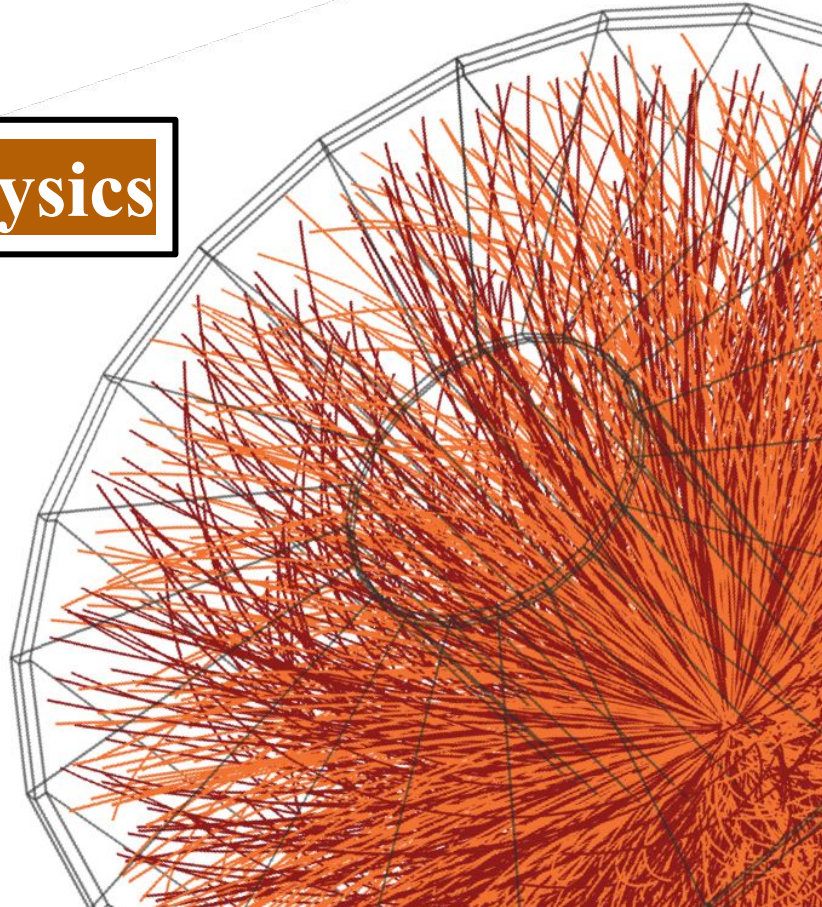
Particle Identification in O^2Physics

Hirak Kumar Koley
(hirak.koley@cern.ch)
Jadavpur University

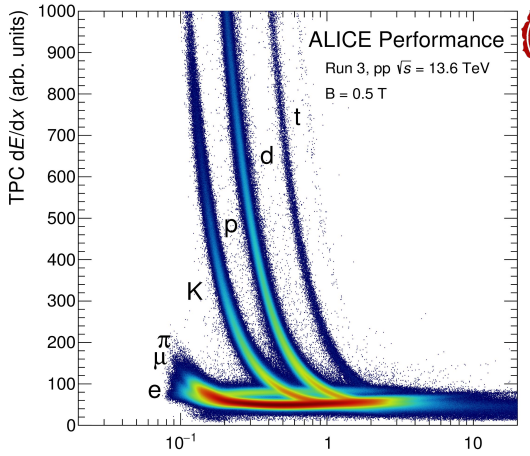
O^2 Analysis Tutorial v4.0
https://indico.cern.ch/event/1425820/
15th October 2024



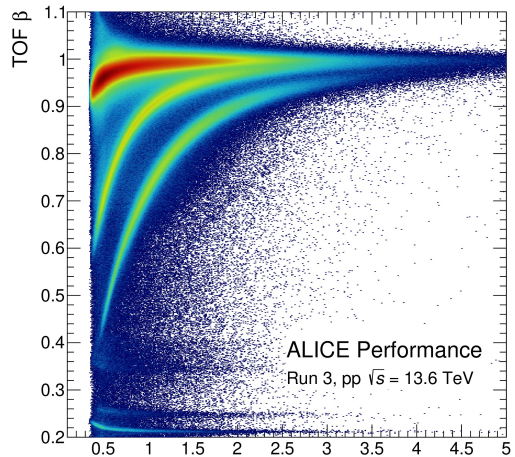
Goal of this session

Get you **acquainted with**:

- What is **Particle IDentification** (PID) ?
- **Detectors** for PID
- **Software tools** for PID in **O^{2}Physics**
- Work with **additional helper tasks**
- Use detector responses to perform **PID in analysis**
- **Assess quality** of particle identification with helper tasks
- Produce **beautiful plots** for PID performance
- Get help if things don't work as expected



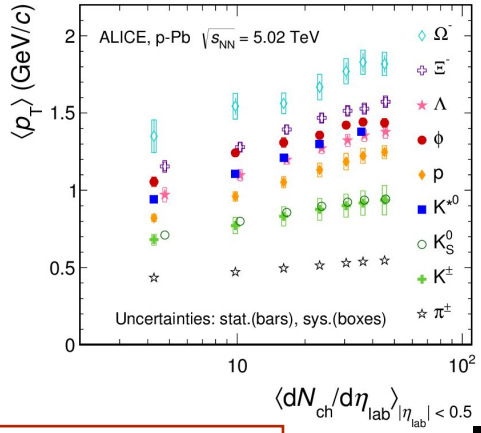
https://alice-figure.web.cern.ch/node/24364

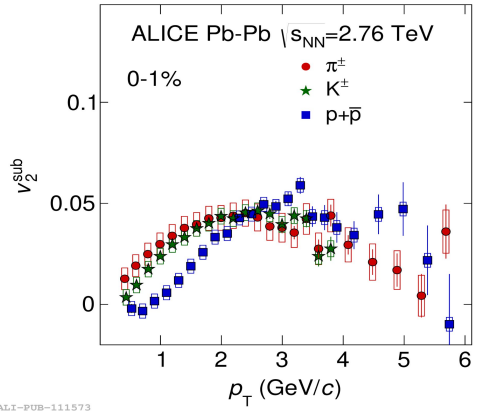


https://alice-figure.web.cern.ch/node/24363

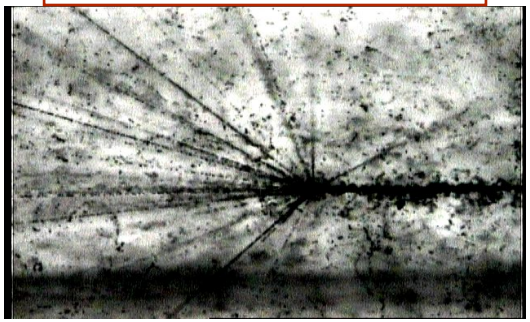
Particle Identification

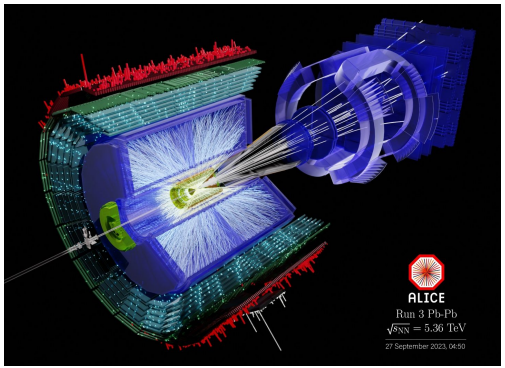
- From the thousands of particle crowd, we need to identify concerned particles
- Introducing PID, we get wealth of information and new insights i.e. more information towards our goal





Central Kr-Ag/Br event at 950 MeV/A





Few particles only

Thousands of particles

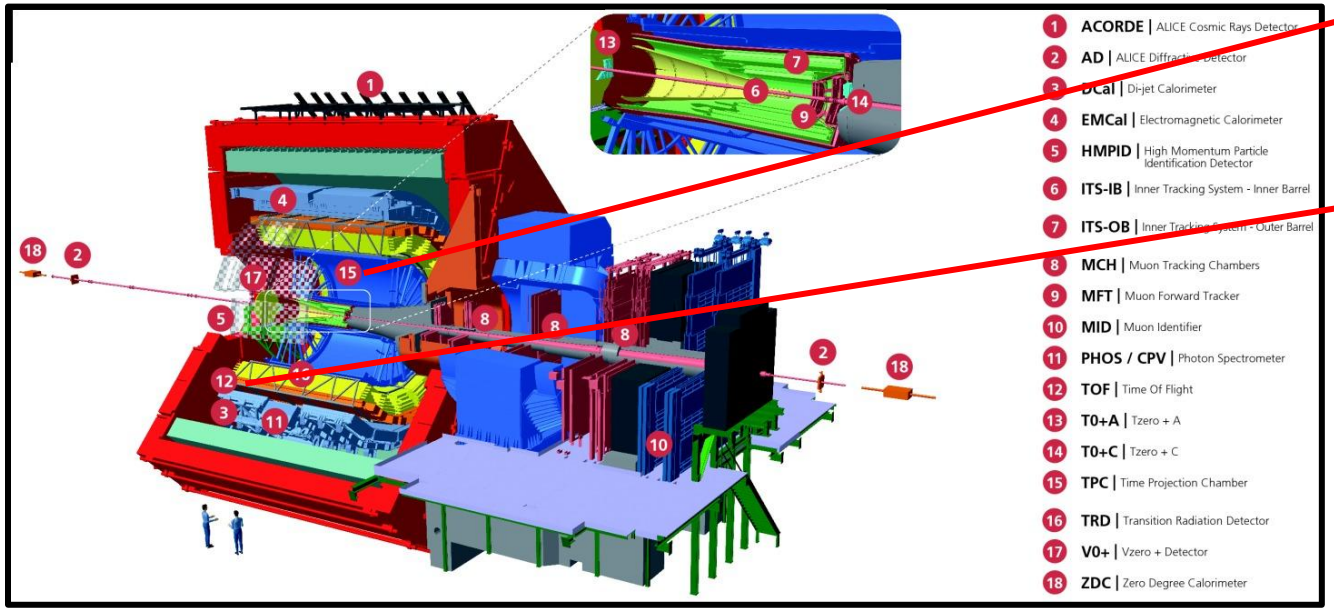
How to do PID:

- **Stable Particles:** Detector response that depends on particle velocity
  - Energy loss via Ionization (dE/dx) ~ $1/\boldsymbol{\beta}^2$
  - Time-of-flight, $\tau \sim 1/\boldsymbol{\beta}$
  - Emitted transition radiation ~ $1/\boldsymbol{\gamma}$
  - Cherenkov emission, $\cos(\boldsymbol{\theta}) = 1/n\boldsymbol{\beta}$

- **Calorimetry:** full energy deposition, e-photon-hadron discrimination from shower profile

- **Unstable particles:** Invariant mass reconstruction / topological decay

ALICE In Run 3



TPC use energy loss value given by **Bethe-Bloch**

TOF Use particle **flight time** from collision vertex to TOF

PID using TPC-TOF: "nσ-cut" method

Specific energy loss (dE/dx) of the track compared with the expected energy loss (Bethe-Bloch formula) for different particle species.

$$n\sigma = \frac{\mathrm{d}E/\mathrm{d}x_{measured} - \mathrm{d}E/\mathrm{d}x_{expected}}{\sigma_{PID(TPC)}}$$

- $\mathrm{dE/dx}_{measured}$: measured energy loss in the TPC gas
- $\mathrm{dE/dx}_{expected}$: expected energy loss for particular particle hypothesis
- $\boldsymbol{\sigma}_{PID(TPC)}$: TPC dE/dx resolution on the measurement which depends on detector performance

Time of flight of the particle compared with the expected arrival time of flight for a given particle species hypothesis.

$$n\sigma = \frac{t_{measured} - t_{expected}}{\sigma_{PID(TOF)}}$$

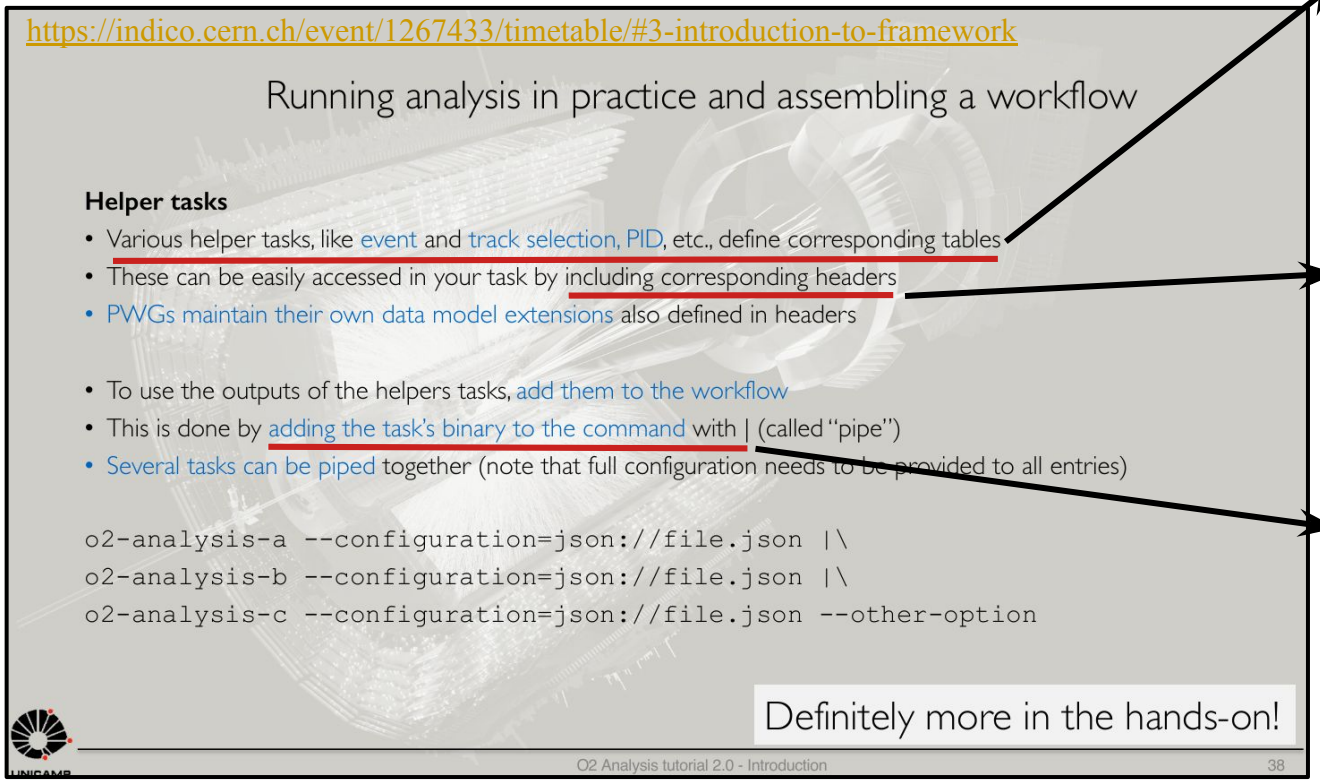
$t_{measured} = t_{hit} - start_{Time}$

- t_{hit}: particle arrival time measured in the TOF detector
- $start_{Time}$: event collisions time (namely the particle start time)
- $t_{expected}$ is computed by the ALICE reconstruction taking into account track length, momentum and energy loss in the material
- $\boldsymbol{\sigma}_{PID(TOF)}$ depends on
  - intrinsic resolution of the TOF detector
  - tracking capabilities of the ALICE
  - the precision in the determination of the collision time of the events → depends on the "T0" detector resolution, number of tracks reaching the TOF and the spread of the vertex.

$$\sigma_{PID(TOF)} = \sqrt{\sigma^2_{TOF} + \sigma^2_{starttime} + \sigma^2_{tracking}}$$

Data model and helper tasks

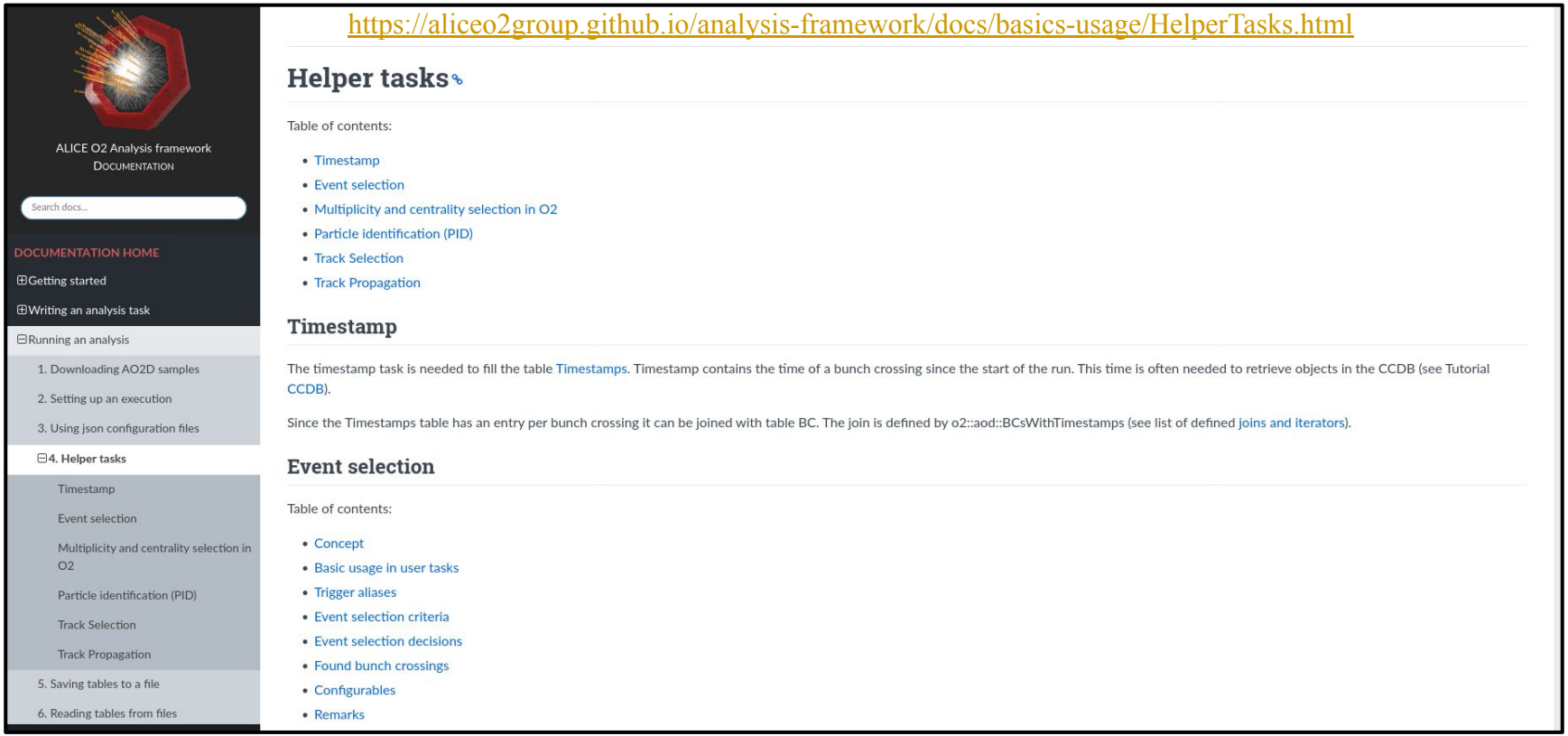
– Adding pieces to the data model



- Extended info (e.g. Nσ) is not directly available in the AO2D
  → **computed on the fly**
  How?
- New headers will need to be included to extend the subscribed data model
- New PID tasks will be needed in pipe to compute additional information

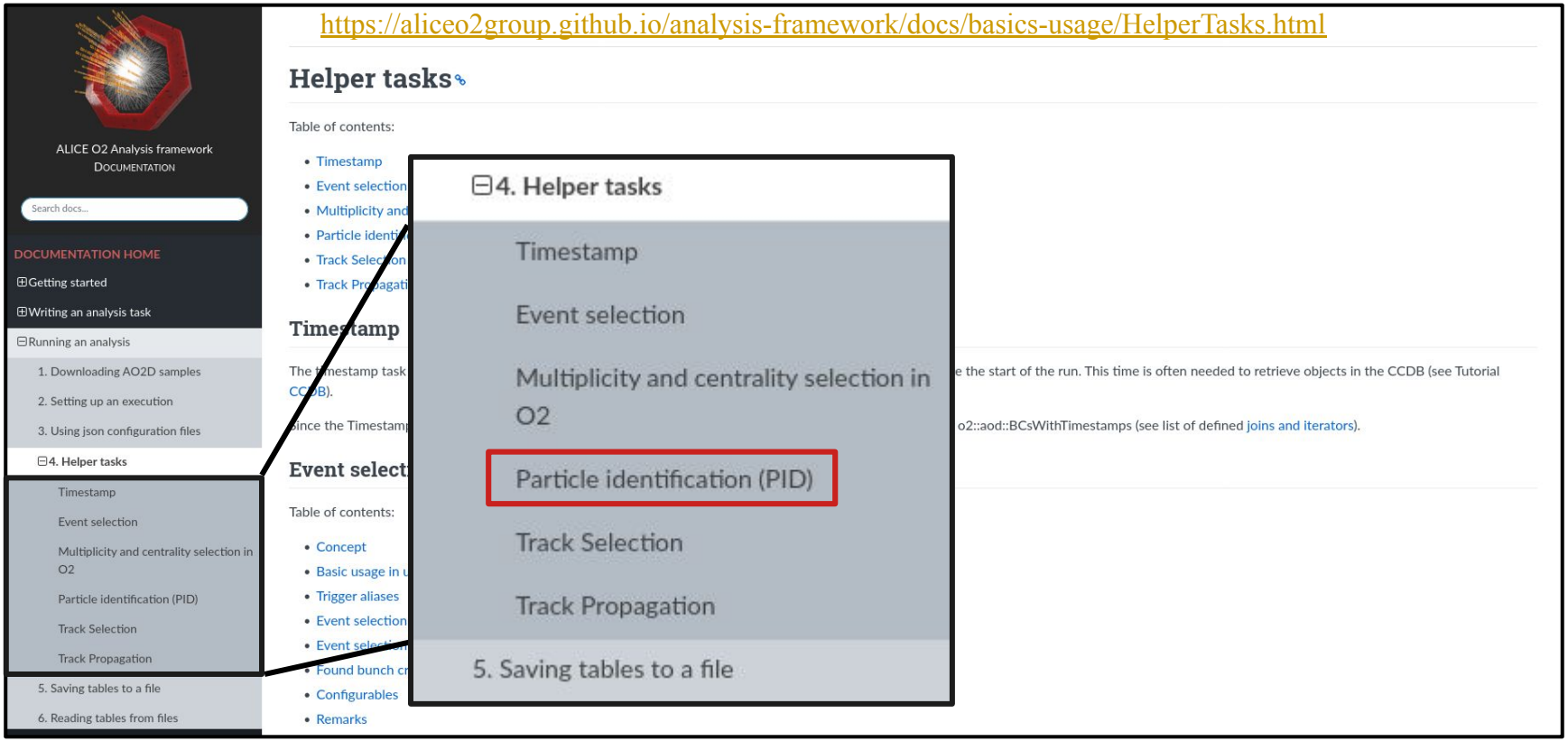
A guide to the helper tasks

– Advanced analyses need more helper tasks



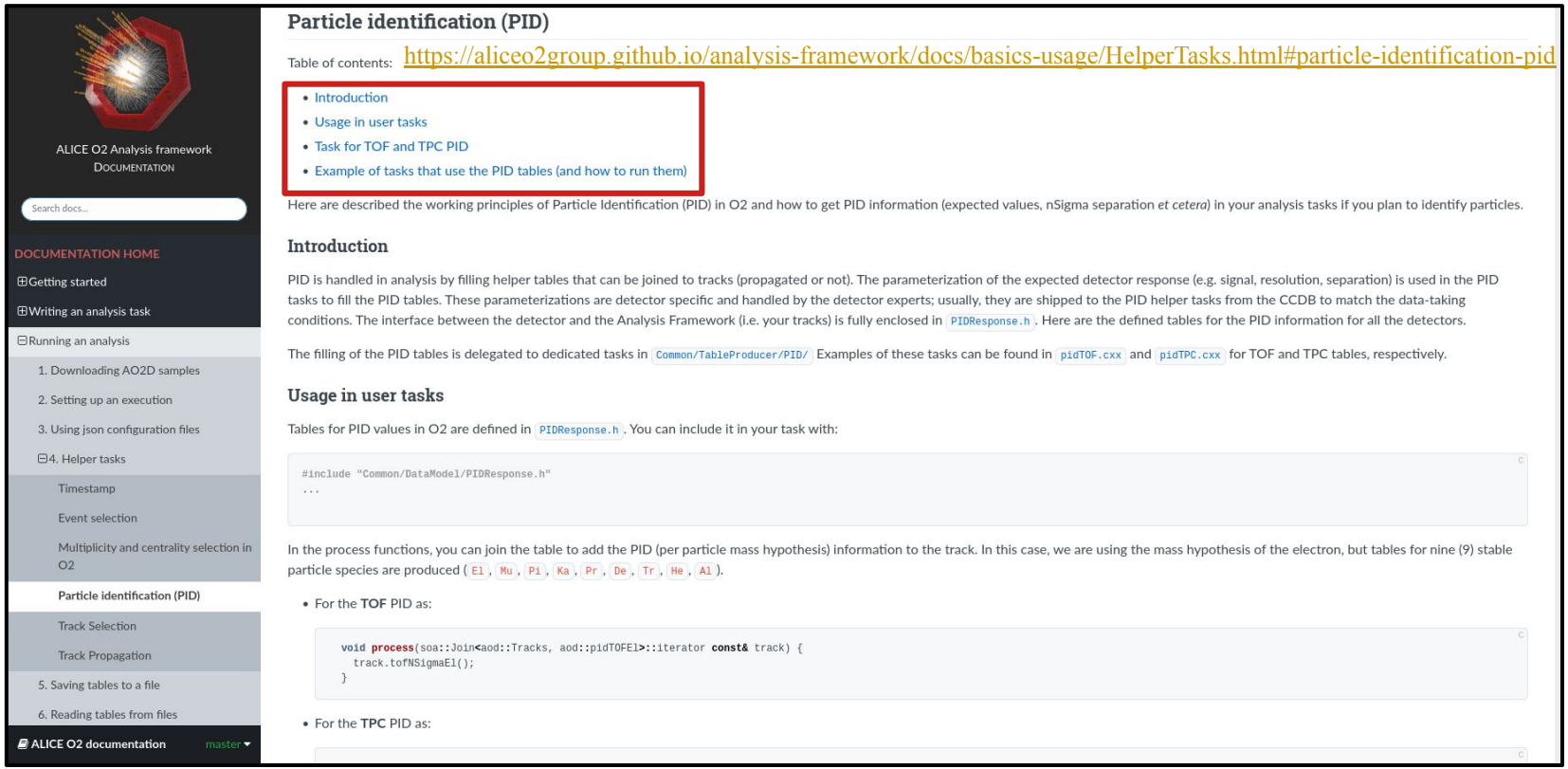
A guide to the helper tasks

– Advanced analyses need more helper tasks



A guide to the PID helper tasks

– Guide to use the PID information, should cover all cases



ALICE O2 Analysis framework
Documentation

Search docs...

DOCUMENTATION HOME
⊞Getting started
⊞Writing an analysis task
⊟Running an analysis
1. Downloading AO2D samples
2. Setting up an execution
3. Using json configuration files
⊟4. Helper tasks
Timestamp
Event selection
Multiplicity and centrality selection in O2
Particle identification (PID)
Track Selection
Track Propagation
5. Saving tables to a file
6. Reading tables from files
ALICE O2 documentation master

Particle identification (PID)

Table of contents: https://aliceo2group.github.io/analysis-framework/docs/basics-usage/HelperTasks.html#particle-identification-pid

- Introduction
- Usage in user tasks
- Task for TOF and TPC PID
- Example of tasks that use the PID tables (and how to run them)

Here are described the working principles of Particle Identification (PID) in O2 and how to get PID information (expected values, nSigma separation *et cetera*) in your analysis tasks if you plan to identify particles.

Introduction

PID is handled in analysis by filling helper tables that can be joined to tracks (propagated or not). The parameterization of the expected detector response (e.g. signal, resolution, separation) is used in the PID tasks to fill the PID tables. These parameterizations are detector specific and handled by the detector experts; usually, they are shipped to the PID helper tasks from the CCDB to match the data-taking conditions. The interface between the detector and the Analysis Framework (i.e. your tracks) is fully enclosed in `PIDResponse.h`. Here are the defined tables for the PID information for all the detectors.

The filling of the PID tables is delegated to dedicated tasks in `Common/TableProducer/PID/` Examples of these tasks can be found in `pidTOF.cxx` and `pidTPC.cxx` for TOF and TPC tables, respectively.

Usage in user tasks

Tables for PID values in O2 are defined in `PIDResponse.h`. You can include it in your task with:

```
#include "Common/DataModel/PIDResponse.h"
...
```

In the process functions, you can join the table to add the PID (per particle mass hypothesis) information to the track. In this case, we are using the mass hypothesis of the electron, but tables for nine (9) stable particle species are produced (`El` , `Mu` , `Pi` , `Ka` , `Pr` , `De` , `Tr` , `He` , `Al`).

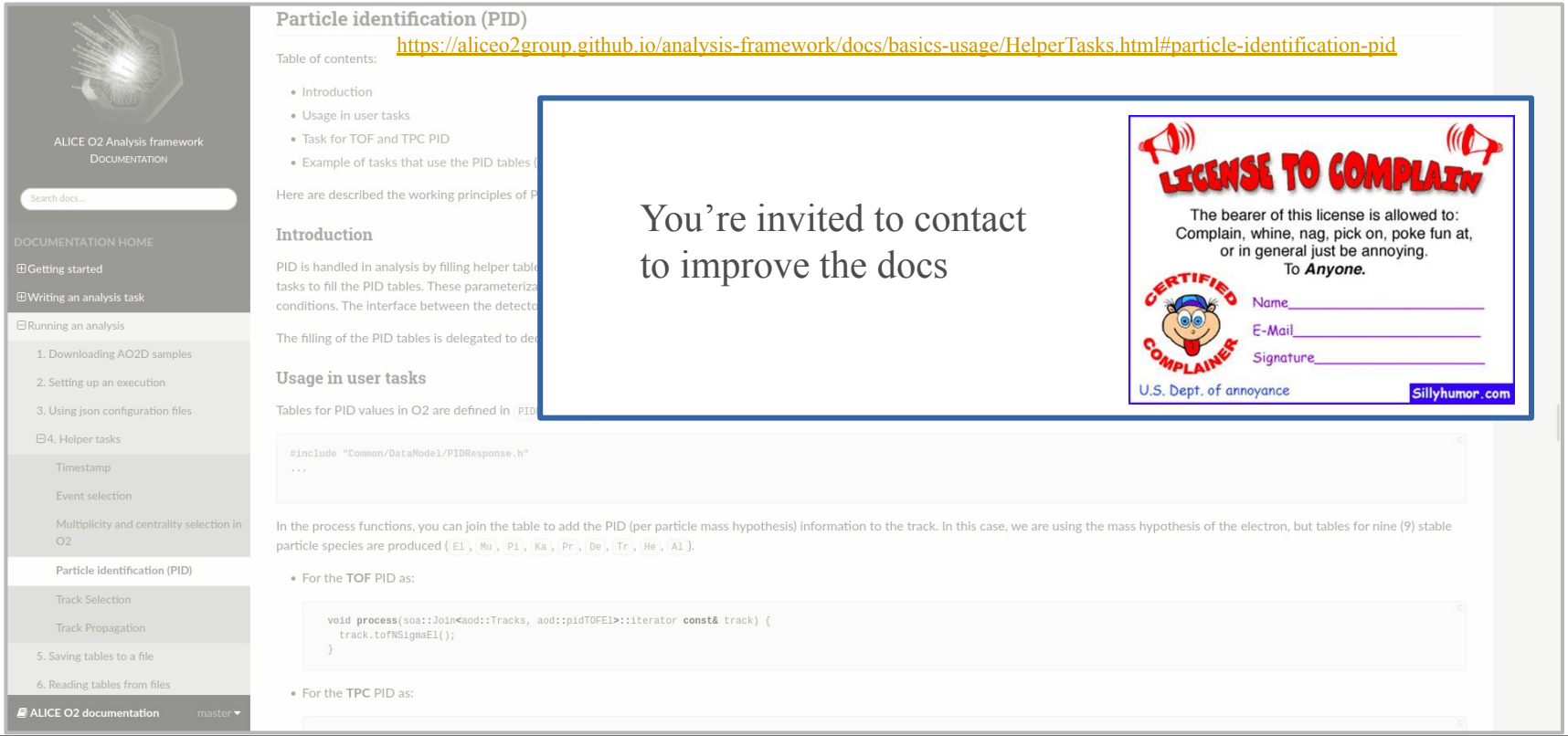
- For the **TOF** PID as:

```
void process(soa::Join<aod::Tracks, aod::pidTOFEl>::iterator const& track) {
  track.tofNSigmaEl();
}
```

- For the **TPC** PID as:

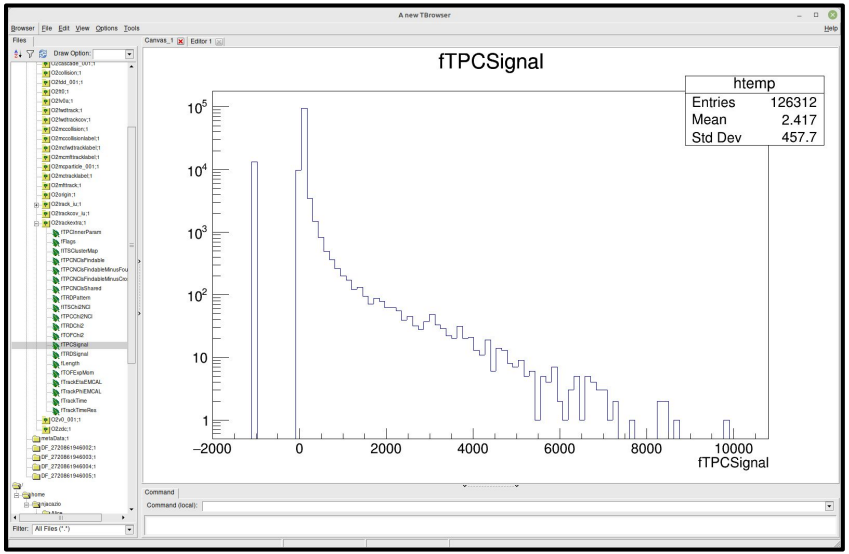
A guide to the PID helper tasks

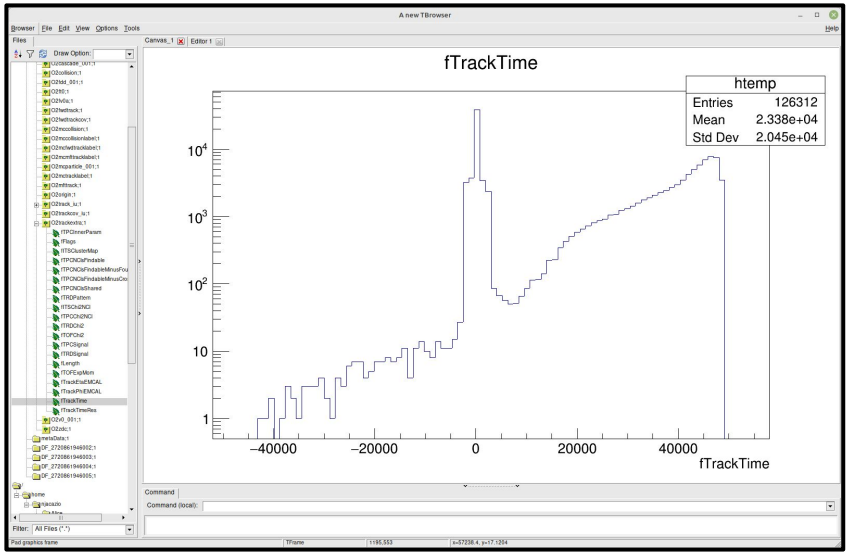
– Guide to use the PID information, should cover all cases



Example: select pions

AO2D.root → "Raw" detector data: $1/p_T$, TPCSignal, TrackTime, …



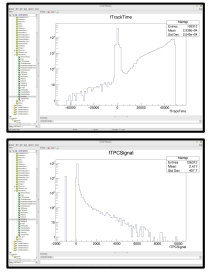


AnalysisResults.root

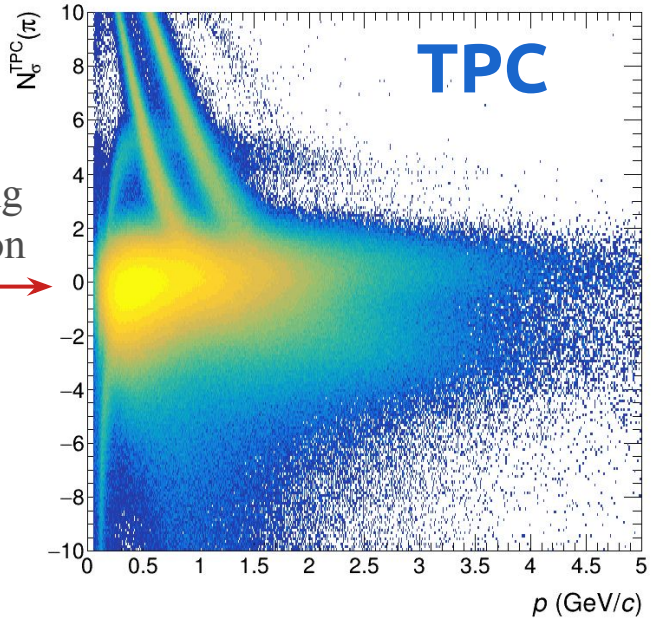
Example: select pions

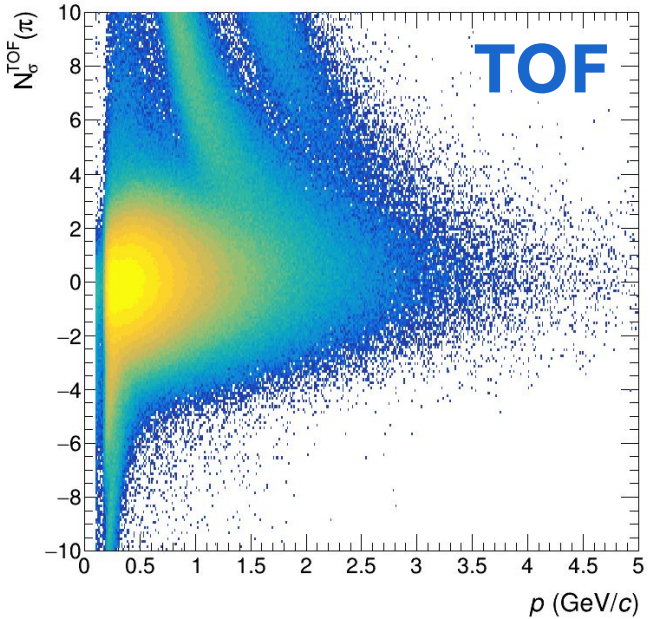
AO2D.root

"Raw" detector data: $1/p_T$, TPCSignal, trackTime, …



Processing: building pion Nσ information



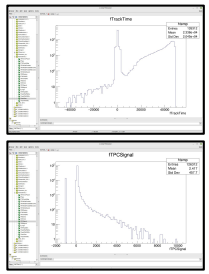


AnalysisResults.root

Example: select pions

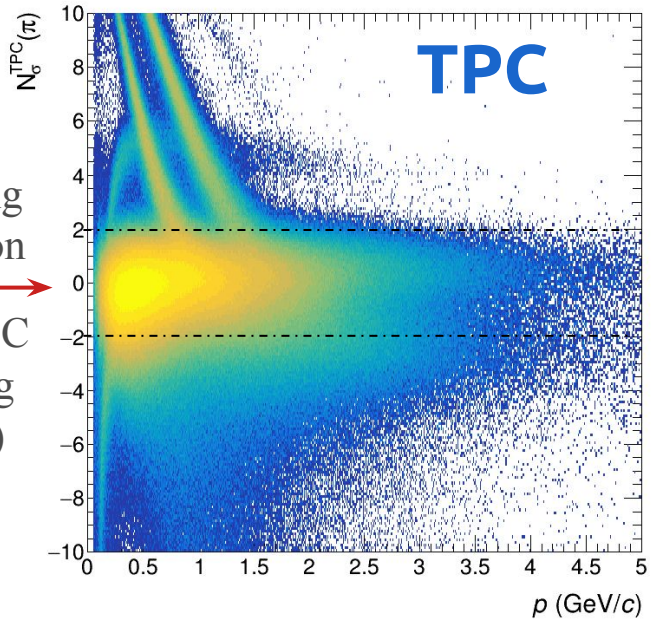
AO2D.root

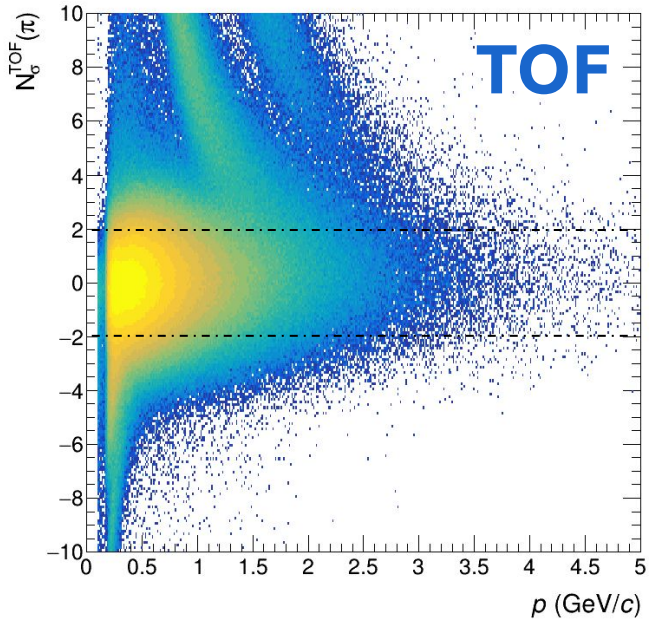
"Raw" detector data: $1/p_T$, TPCSignal, trackTime, …



Processing: building pion Nσ information

Cutting at 2σ in TPC and TOF (e.g. using partitions or filters)





AnalysisResults.root

Filter & Partitions: https://indico.cern.ch/event/1425820/timetable/#1-introduction-to-o2o2physics

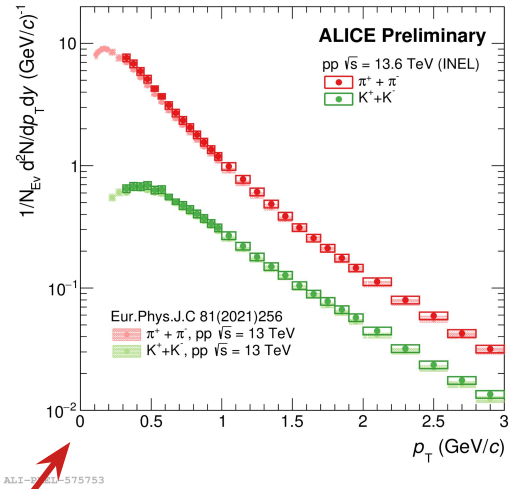
Example: select pions

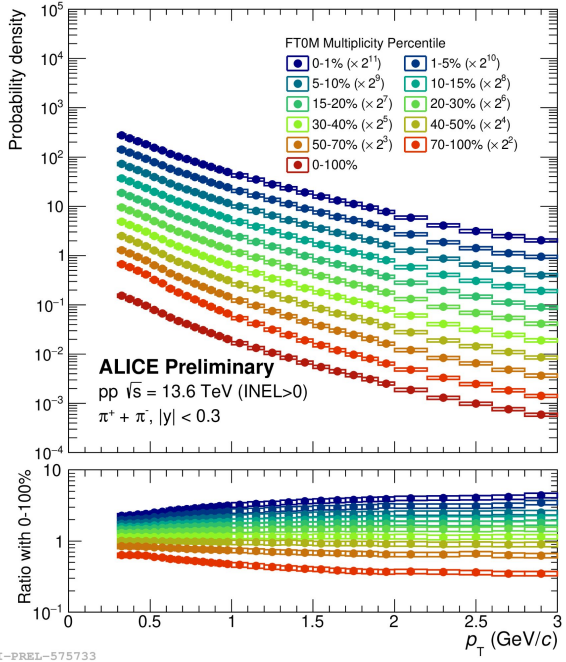
AO2D.root

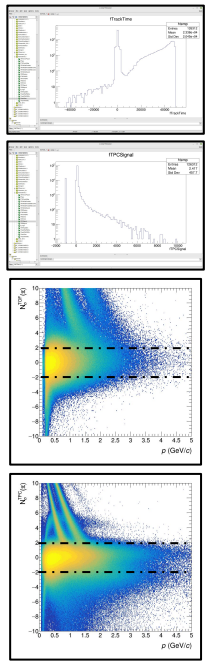
"Raw" detector data: $1/p_T$, TPCSignal, trackTime, …

Processing: building pion Nσ information

Cutting at 2σ in TPC and TOF (e.g. using partitions or filters)







Your physics results, *OK but how?*

AnalysisResults.root

Filter & Partitions: https://indico.cern.ch/event/1425820/timetable/#1-introduction-to-o2o2physics

Including PID data formats

- How to access PID data formats, include **PIDResponse.h** header!

```
#include "Common/DataModel/PIDResponse.h"
...
```

El, Mu, Pi, Ka, Pr, De, Tr, He(^{3}He), Al(^{4}He)

- Tables available for PID
  - Expected values (e.g. Bethe Bloch, expected TOF)
  - Expected resolutions
  - Separation
  - Nσ
  - Extra PID information e.g. TOF mass, TOF beta, …

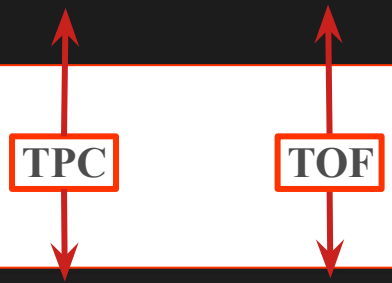
} Available for all particle mass hypotheses from electrons to α

Documentation → https://aliceo2group.github.io/analysis-framework/docs/basics-usage/HelperTasks.html#usage-in-user-tasks

Subscribing to PID tables

```
void process(soa::Join<aod::Tracks, aod::pidTPCPi, aod::pidTOFPi> const& tracks)
{ ... }
```

Pion PID




```
void process(soa::Join<aod::Tracks, aod::pidTPCKa, aod::pidTOFKa> const& tracks)
{ ... }
```

Kaon PID

- For more than one particle - join the table for each particle.

```
void process(soa::Join<aod::Tracks, aod::pidTPCPi, aod::pidTPCKa,
                       aod::pidTOFPi, aod::pidTOFKa> const& tracks) { ... }
```

Pion and Kaon PID

NB: El, Mu, Pi, Ka, Pr, De, Tr, He(^{3}He), Al(^{4}He) → are the 9 PID tables available per detector

Documentation → https://aliceo2group.github.io/analysis-framework/docs/basics-usage/HelperTasks.html#usage-in-user-tasks

Accessing PID info

- Accessing to table content

```
void process(soa::Join<aod::Tracks, aod::pidTPCPi, aod::pidTPCKa,
                       aod::pidTOFPi, aod::pidTOFKa> const& tracks)
{
 for (auto& track : tracks) {
   track.tpcNSigmaPi(); // TPC Nsigma of pions
   track.tofNSigmaPi(); // TOF Nsigma of pions
   track.tpcNSigmaKa(); // TPC Nsigma of kaons
   track.tofNSigmaKa(); // TOF Nsigma of kaons
 }
}
```

- Can be done by using helper functions

```
void process(soa::Join<aod::Tracks, aod::pidTPCPi, aod::pidTPCKa,
                       aod::pidTOFPi, aod::pidTOFKa> const& tracks)
{
 for (auto& track : tracks) {
   o2::aod::pidutils::tpcNSigma<2>(track); // for pions, index = 2 & index runs from 0 to 8
   o2::aod::pidutils::tofNSigma<2>(track); // for pions, index = 2 & index runs from 0 to 8
 }
}
```

Documentation → https://aliceo2group.github.io/analysis-framework/docs/basics-usage/HelperTasks.html#usage-in-user-tasks

PID tasks in the workflow

- Tasks to include in the workflow

```
o2-analysis-pid-tpc | o2-analysis-pid-tpc-base | o2-analysis-track-propagation|
o2-analysis-timestamp --aod-file AO2D.root
```

Task

Dependencies

- Here, we compute the N-Sigmas for each particle.
- Need to subscribe for specific particle in your task.

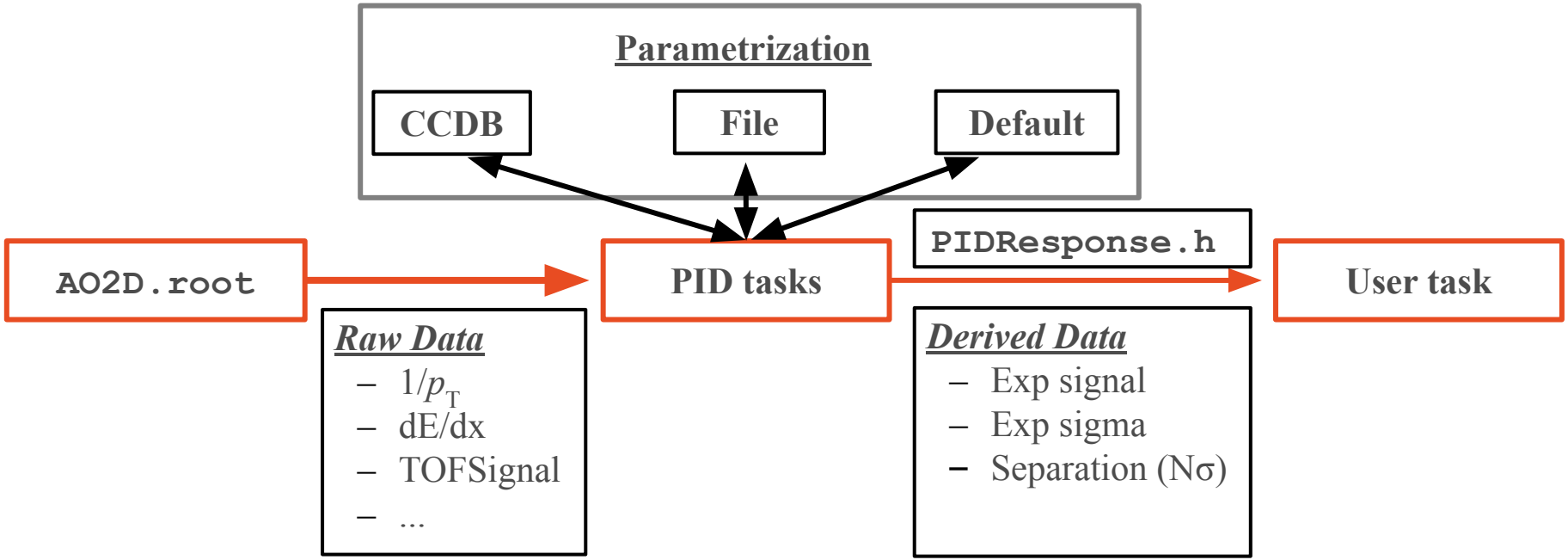
```
o2-analysis-pid-tof | o2-analysis-pid-tof-base | o2-analysis-track-propagation |
o2-analysis-event-selection | o2-analysis-timestamp | o2-analysis-ft0-corrected-table
--aod-file AO2D.root
```

- These tasks produce tables for all particles
- Only tables that are subscribed to are produced
- Configuration is flexible

Documentation → https://aliceo2group.github.io/analysis-framework/docs/basics-usage/HelperTasks.html#task-for-tof-and-tpc-pid

Advanced features

The complete PID workflow



NB: access to CCDB is needed for the PID calibration
→ timestamp task is a dependency of the PID tasks

Include PID QA output!

- PID tasks come with QA output included!

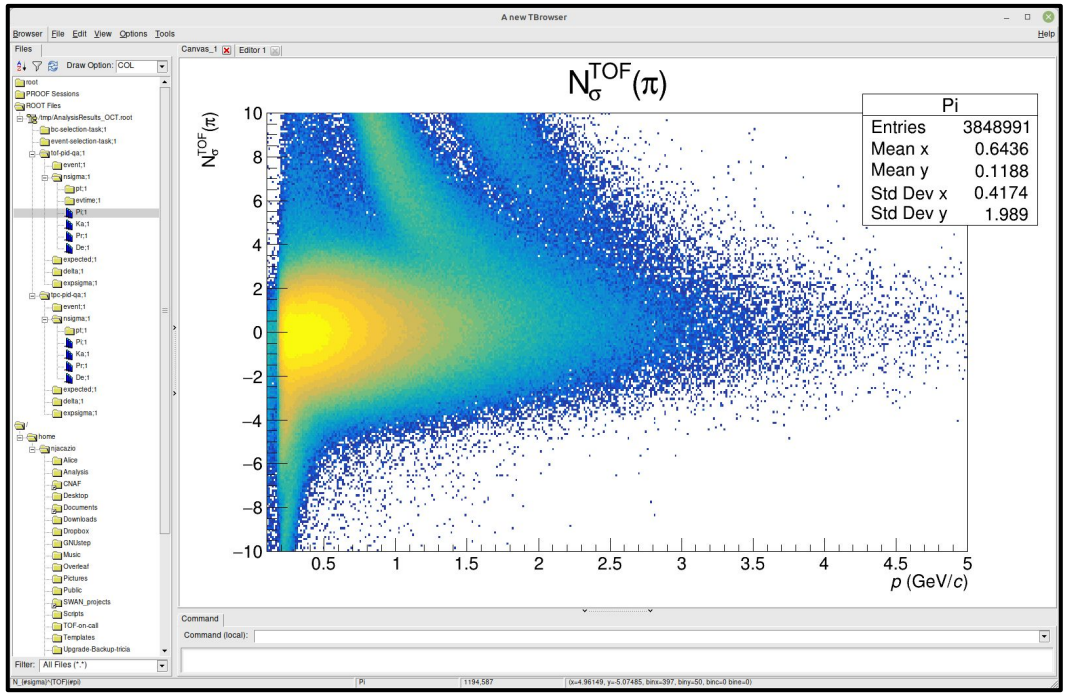
```
o2-analysis-pid-tpc-qa

o2-analysis-pid-tof-qa
```

- Monitor Nσ
- Produce nice performance plots e.g. TPC/TOF signals

```
o2-analysis-pid-tpc-qa-mc
o2-analysis-pid-tpc-qa-sig

o2-analysis-pid-tof-qa-evtime
o2-analysis-pid-tof-qa-beta
o2-analysis-pid-tof-qa-mc
```

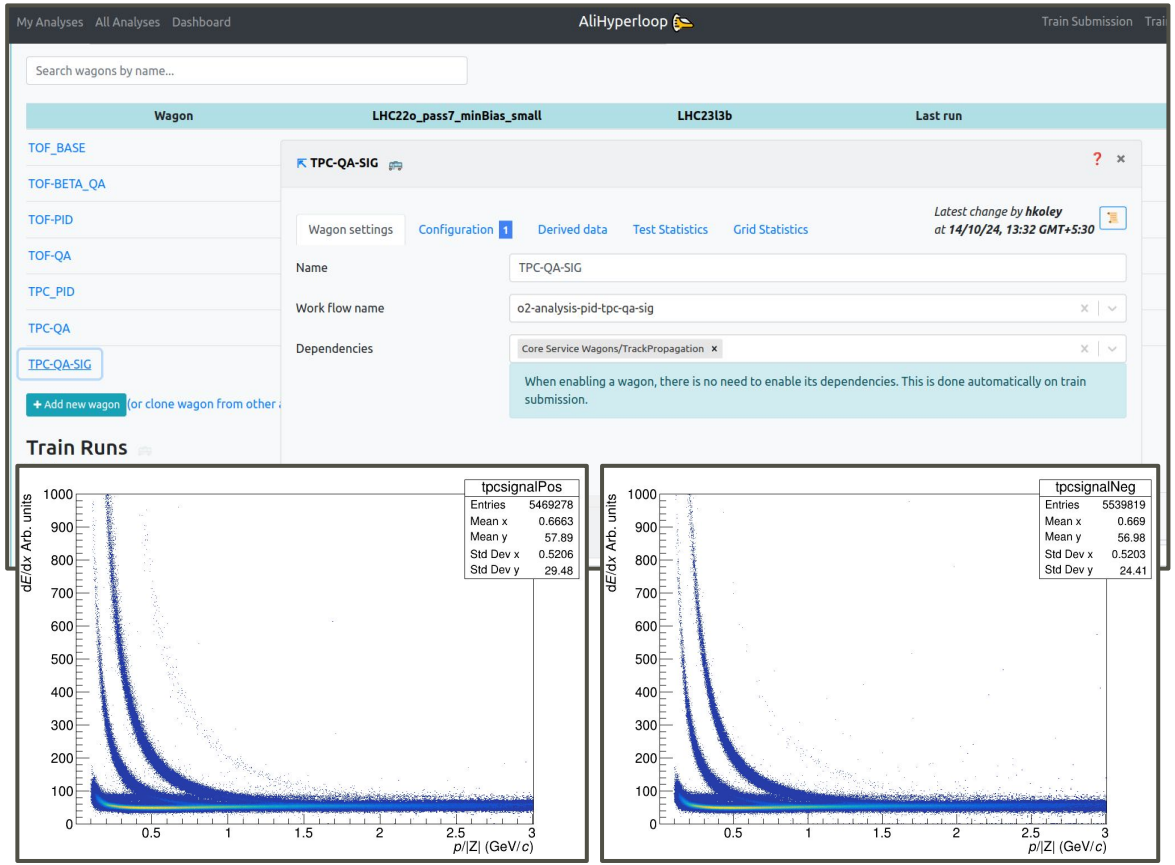


- QA for MC (e.g. purity) and more (e.g. mass)!

Documentation → https://aliceo2group.github.io/analysis-framework/docs/basics-usage/HelperTasks.html#enabling-qa-histograms

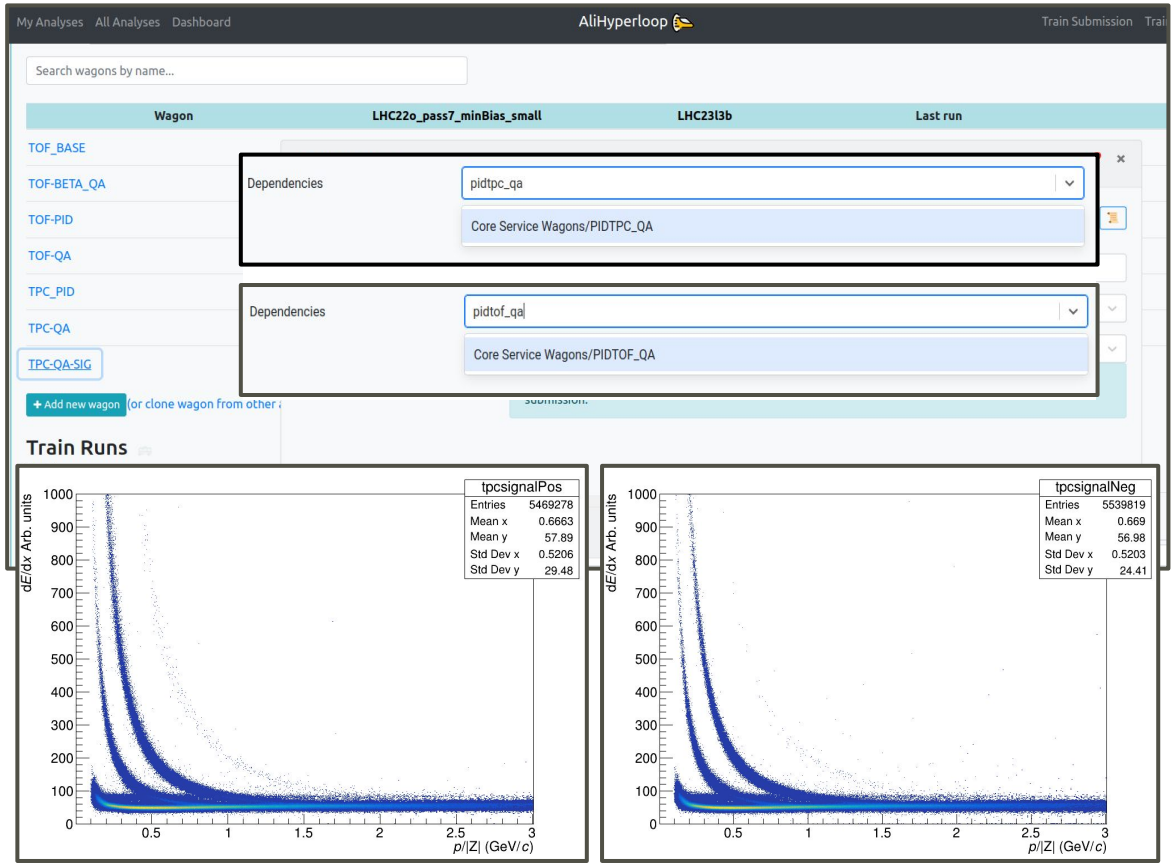
Setup wagons for PID QA in Hyperloop

- Monitor Nσ
- Include nice performance plots e.g. TPC/TOF signals



Setup wagons for PID QA in Hyperloop

- Monitor Nσ
- Include nice performance plots e.g. TPC/TOF signals
- QA wagons are also available centrally to be subscribed to instead of duplicated



TOF beta and TOF mass

- TOF specific are the beta and mass

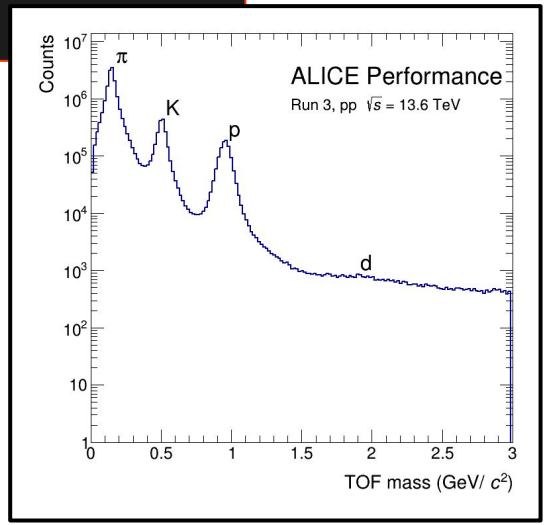
```
void process(soa::Join<aod::Tracks, aod::pidTOFmass, aod::pidTOFbeta> const& tracks)
{
 for (auto& track : tracks) {
   track.beta(); // TOF beta
   track.mass(); // TOF mass
 }
}
```

- Access by the following task: Executable

```
o2-analysis-pid-tof-beta
```

- Comes with QA as well

```
o2-analysis-pid-tof-beta-qa
```



Event time for TOF

- Multiple event times can be used for TOF measurement
- With respect to Run2 we now ask the track which event it used

```
void process(soa::Join<aod::Tracks, aod::pidEvTimeFlags> const& tracks)
{
 for (auto& track : tracks) {
   track.isEvTimeTOF();  // TOF Event time
   track.isEvTimeT0AC(); // T0AC Event time
 }
}
```

- Executable that handles event time

```
o2-analysis-pid-tof-base
```

- Comes with QA as well

```
o2-analysis-pid-tof-qa-evtime
```

How these values are computed: TPC

- The expected values and expected resolution are computed from the Aleph Bethe Bloch (5 parameters)


```
table(response.GetExpectedSigma(collisions.iteratorAt(trk.collisionId()), trk, pid),
      response.GetNumberOfSigma(collisions.iteratorAt(trk.collisionId()), trk, pid));
```

- Fine-tuned neural-network based calibration can be used (see with experts)

```
Configurable<bool> useNetworkCorrection{"useNetworkCorrection", 0, "(bool) Wether or not to use the
network correction for the TPC dE/dx signal"};
```

- Refer to the Hyperloop configurations (explained later)

How these values are computed: TOF

- The ingredients for the expected values are already in the AO2D
- Need to compute the expected resolution + corrections


```
table(responsePID.GetExpectedSigma(mRespParamsV2, track),
      responsePID.GetSeparation(mRespParamsV2, track));
```

- Fine-tuned pass dependent calibration of the charge bias on momentum + resolution

```
Configurable<bool> loadResponseFromCCDB{"loadResponseFromCCDB", false, "Flag to load the response
from the CCDB"};
```

- Refer to the Hyperloop configurations (explained later)

TPC PID helper tasks on Hyperloop

- Dependencies on Hyperloop
  - **Internal dependency**
  - **Run 2**
  - **Run 3**
  - **Neural network corrections**
  - **MC tune on Data**
  - **keep TPC only tracks**
- Include the one according to your needs and in doubt ask!!
- Take them as reference for local running!!

AliHyperloop

Core wagons

PIDTPC	*				
PIDTPC_keepTPCOnlyTracks	*				*
PIDTPC_MCTuneOnData	*			*	
PIDTPC_MCTuneOnData_keepTPCOnlyTracks	*			*	*
PIDTPC_NN	*	*			
PIDTPC_NN_keepTPCOnlyTracks	*	*			*
PIDTPC_NN_MCTuneOnData	*	*		*	
PIDTPC_NN_MCTuneOnData_keepTPCOnlyTracks	*	*		*	*
PIDTPC_Run2	*				
PIDTPC_Run2_MCTuneOnData	*			*	
PIDTPC_Run2_NN	*	*			
PIDTPC_Run2_NN_MCTuneOnData	*	*		*	
PIDTPCBase		*	*		
PIDTPCBase_Run2	*		*		

Description on the specific tasks

For the training, samples of electrons, pions and protons are obtained from a V0 sample, Kaons from TPC+TOF

Neural network corrections:

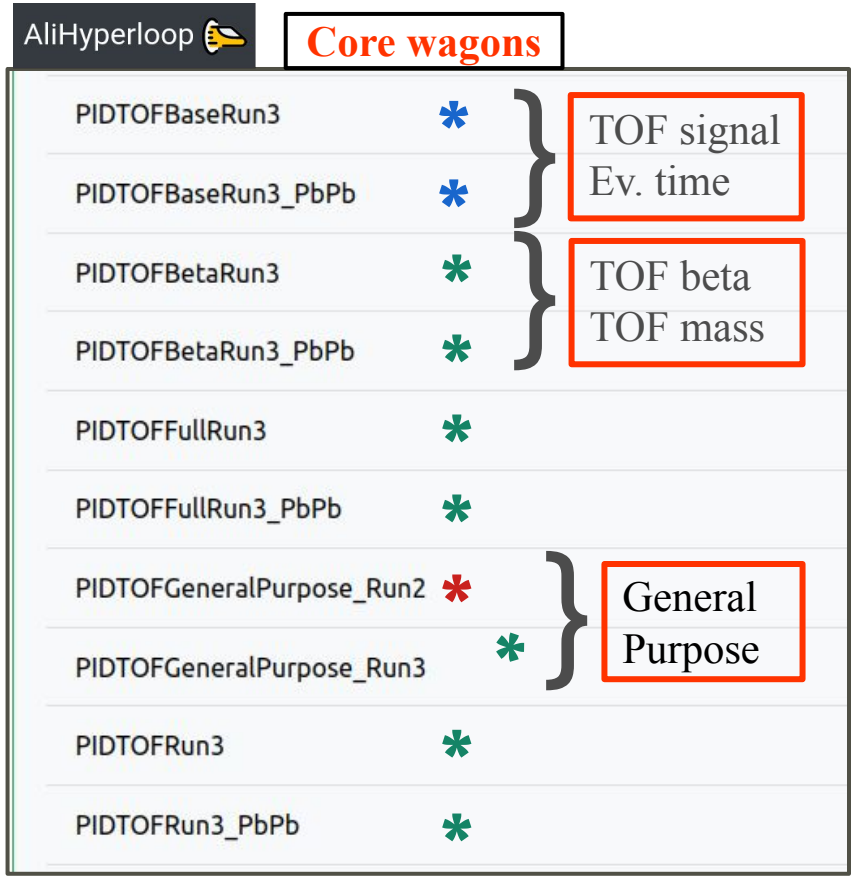
- BB curve is not precise enough for a "real life" detector
- Difference between the BB fits and real function is done as a correction using neural networks
- Input to the network: p, tan(λ), sign(q)/p_T, mass hypothesis, normalized multiplicity, normalized number of clusters
- Network learns correction factor (in 6D) to the Bethe-Bloch Parameterization
- Output: dE/dx of identified particles as a ratio to the Bethe-Bloch Parameterization

MCTuneOnData:

- Expected BB fits and sigmas are used to sample the dE/dx signal in MC

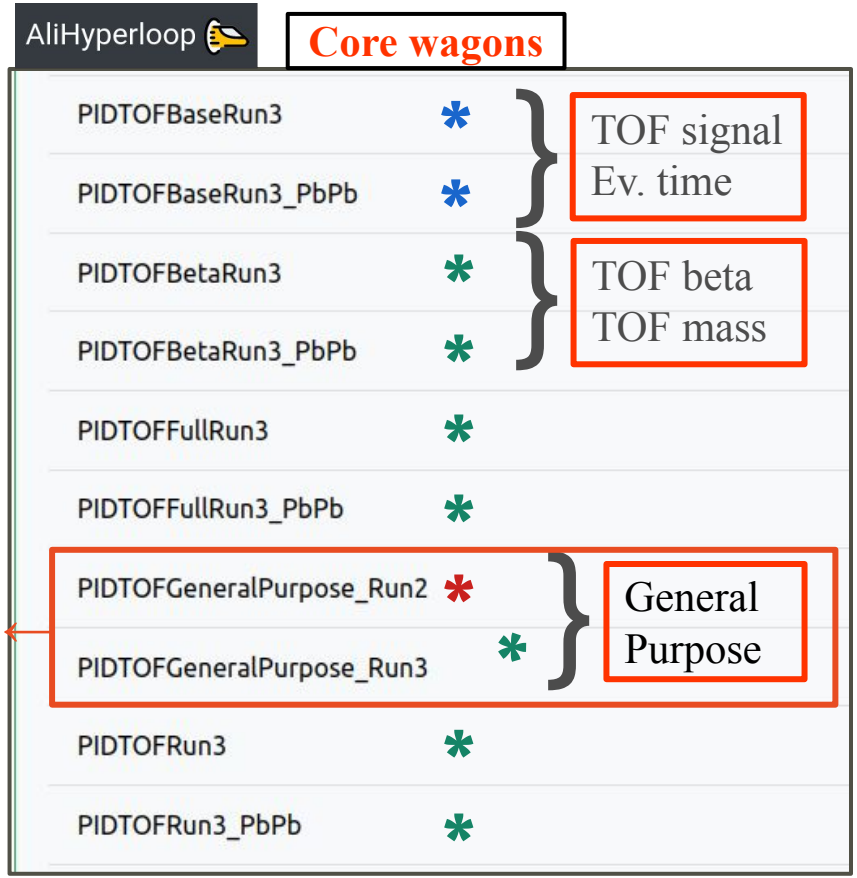
TOF PID helper tasks on Hyperloop

- Dependencies on Hyperloop
  - **Internal dependency (not to be included)**
  - **Run 2**
  - **Run 3**
- Include the one according to your needs and in doubt ask the experts!!
- Take them as reference for local running!!

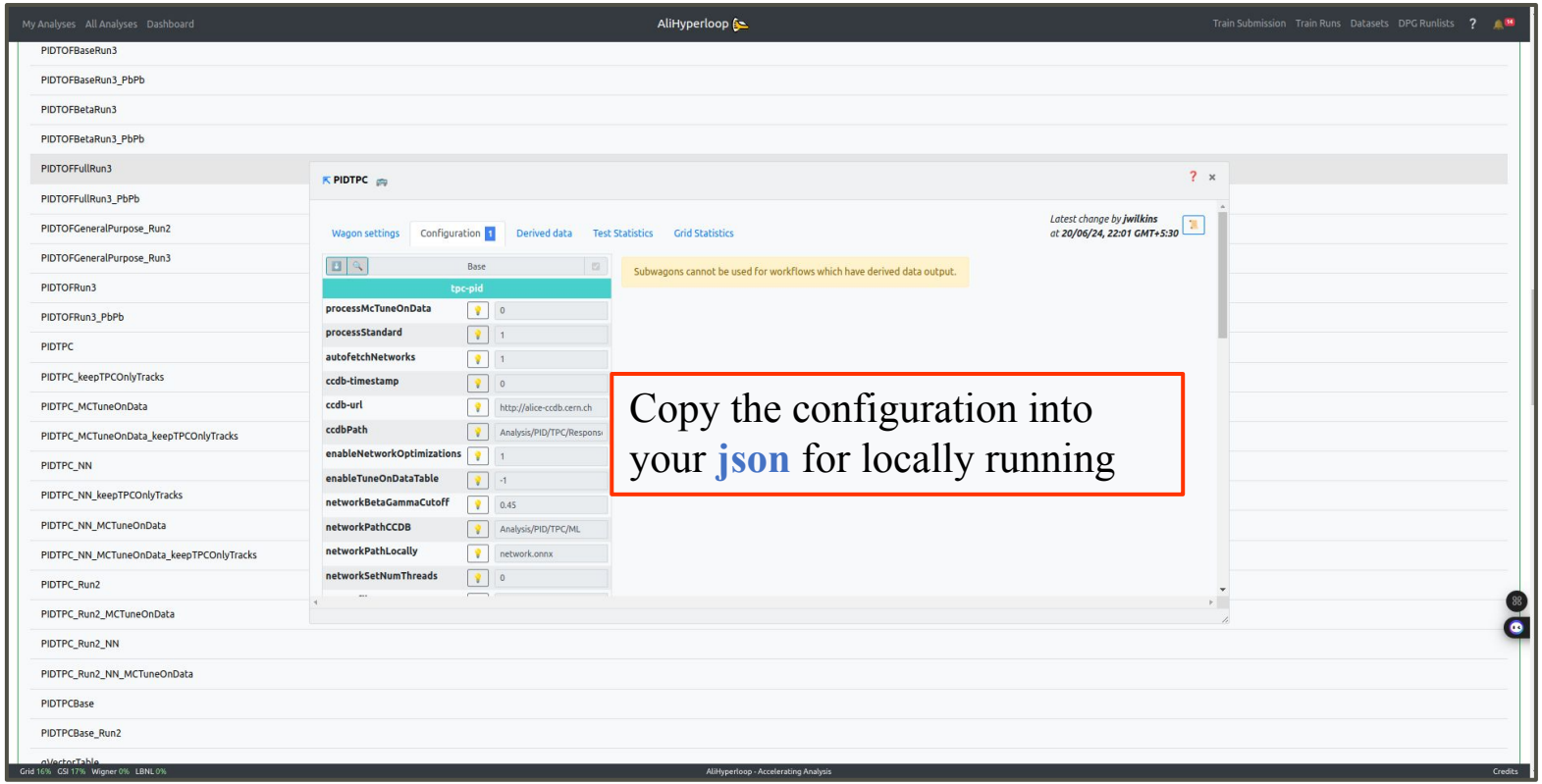


TOF PID helper tasks on Hyperloop

- Dependencies on Hyperloop
  - **Internal dependency (not to be included)**
  - **Run 2**
  - **Run 3**
- Include the one according to your needs and in doubt ask the experts!!
- Take them as reference for local running!!
- Only general purpose tasks are needed (no other TOF dependencies). Setup of collision system is automatic.
  Other tasks will be deprecated soon.



Taking Hyperloop as a reference



- Inspect the task configuration that suits your case, in case of doubt ask !!

Where to orient yourself and report your findings

Plethora of occasions to report your (good or bad) findings

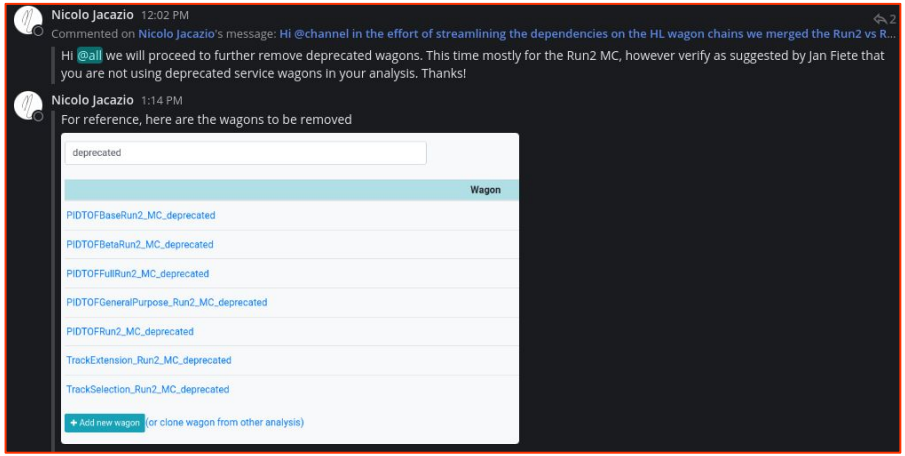
- Async QC Weekly meeting (Tuesdays 15h00) → https://indico.cern.ch/event/1464688/
- DPG AOT-track (Thursdays 9h30) → https://indico.cern.ch/event/1464946/
- Detector and QA experts
- **TPC** → ana.marin@cern.ch
- **TOF** → nicolo.jacazio@cern.ch
- **PID QA** → banajit.barman@cern.ch + DPG-AOT coord.

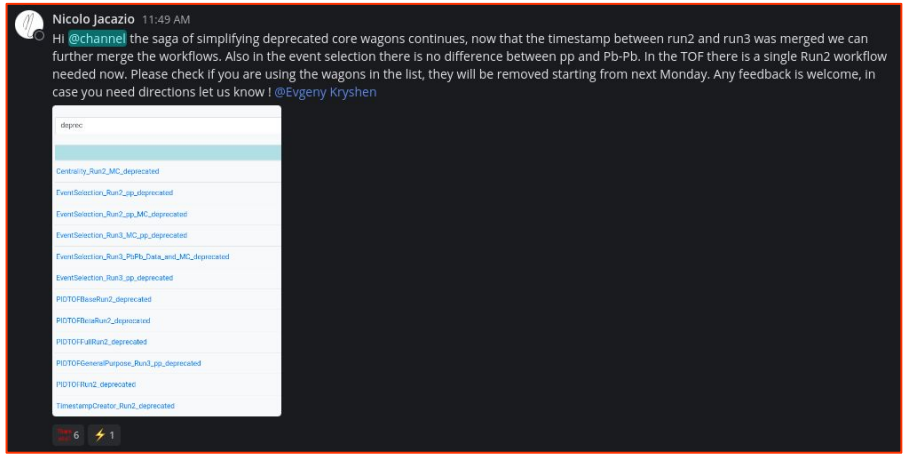
Suggestions are welcome, eager to improve!

Get updated

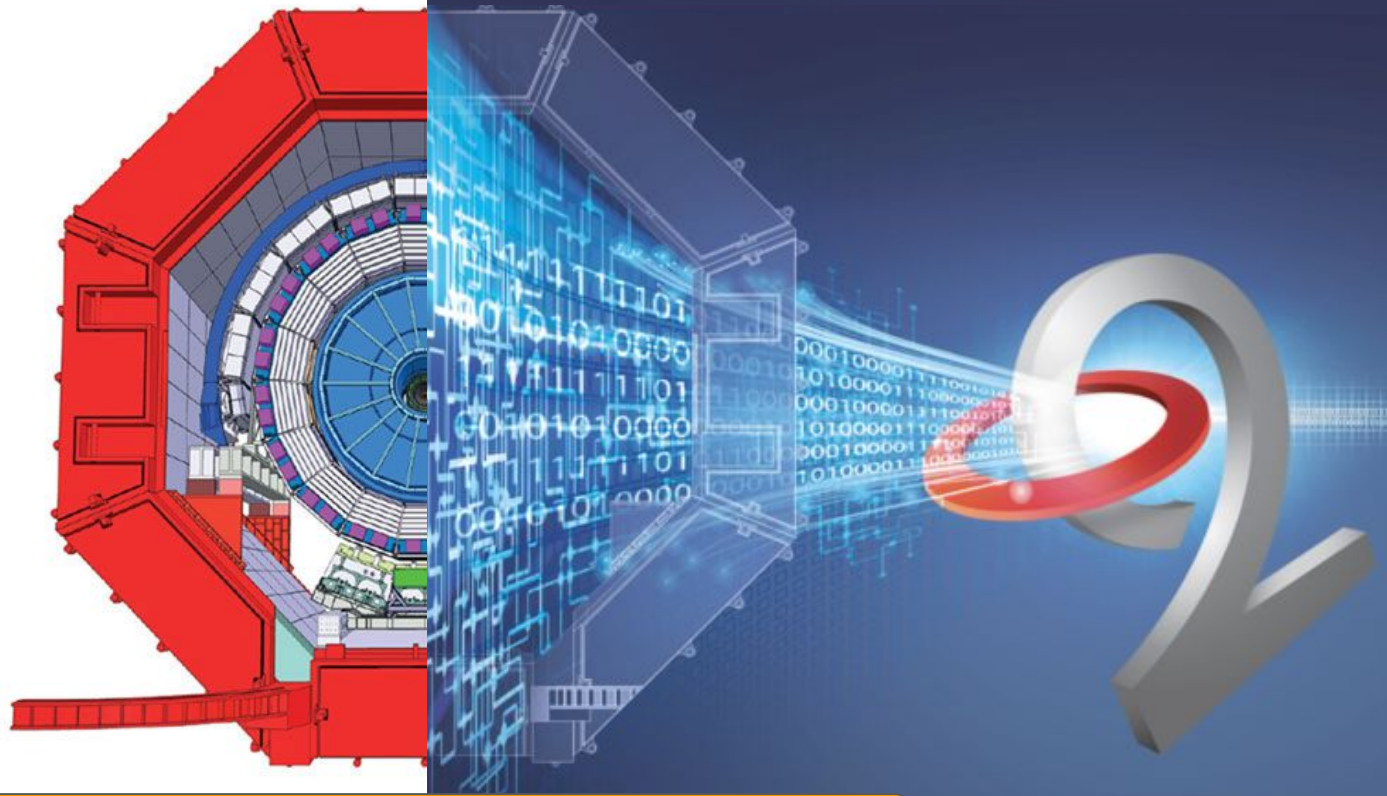
- Mattermost channel → https://mattermost.web.cern.ch/alice/channels/o2-analysis
- Subscribe to announcements:

  https://mattermost.web.cern.ch/alice/channels/o2-analysis-announcements





Issues, developments, and calibration releases are announced here (for PID but not only!)



Thank you for your attention