PID: Electrons, Hadrons, and Light Nuclei

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O² Analysis Tutorial v5.0
https://indico.cern.ch/event/1574136/
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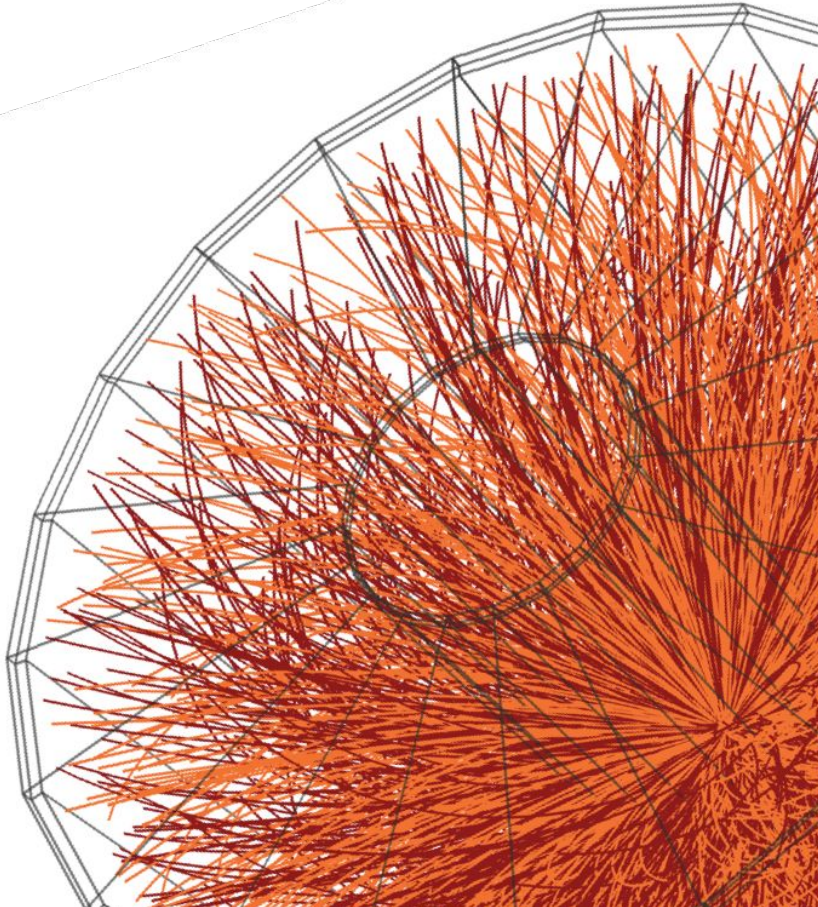
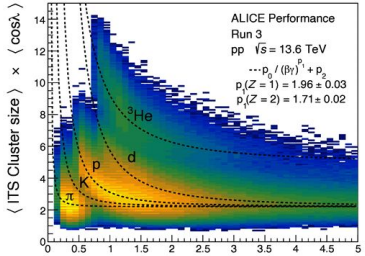


Goal of this session

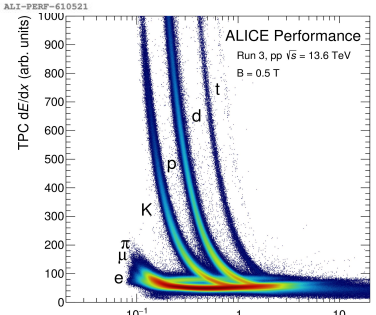
Get you **acquainted with**:

- What is **P**article **ID**entification (**PID**) ?
- **Detectors** that can be used 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/35308

ITS



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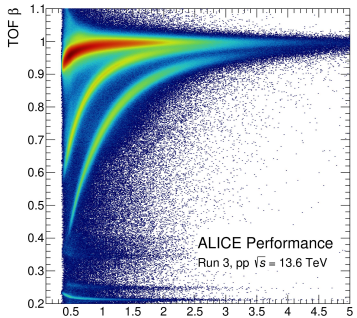
TPC

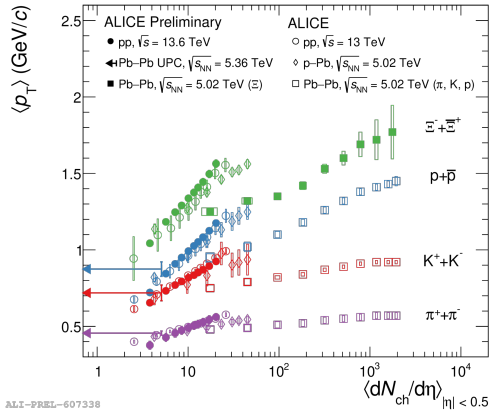


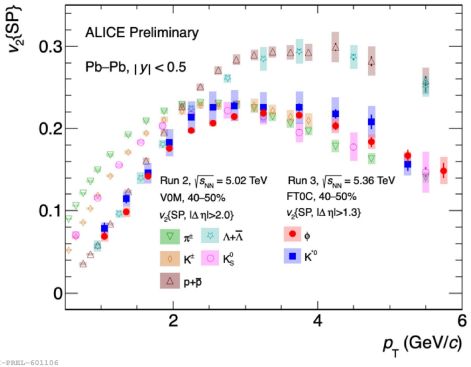
https://alice-figure.web.cern.ch/node/24363

TOF

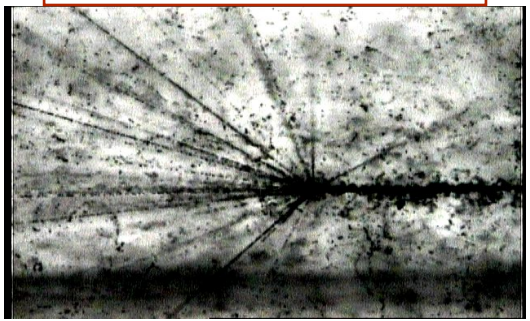
Particle Identification

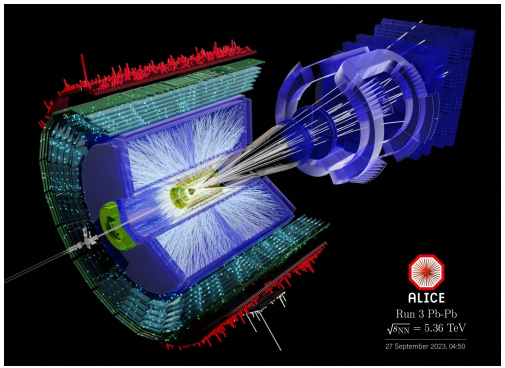
- From the thousands of particle crowd, we need to identify particles
- Introducing **PID**, we get wealth of information and new insights i.e. more information towards our goal





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

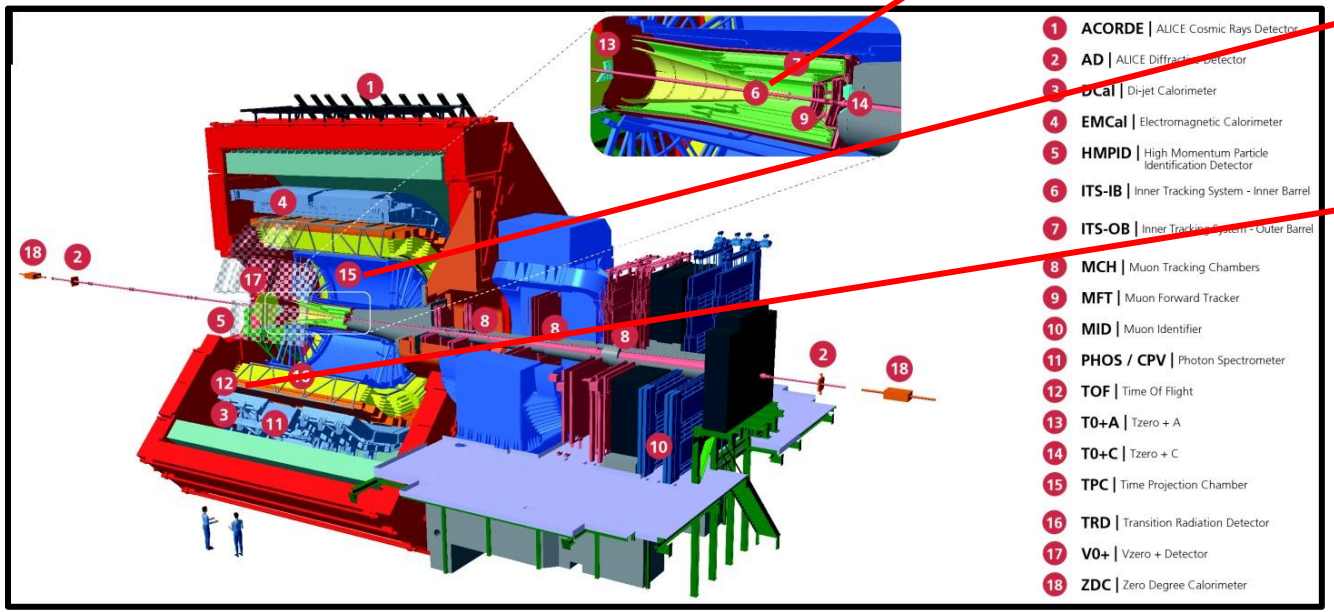




Few particles only

Thousands of particles

ALICE PID in Run 3



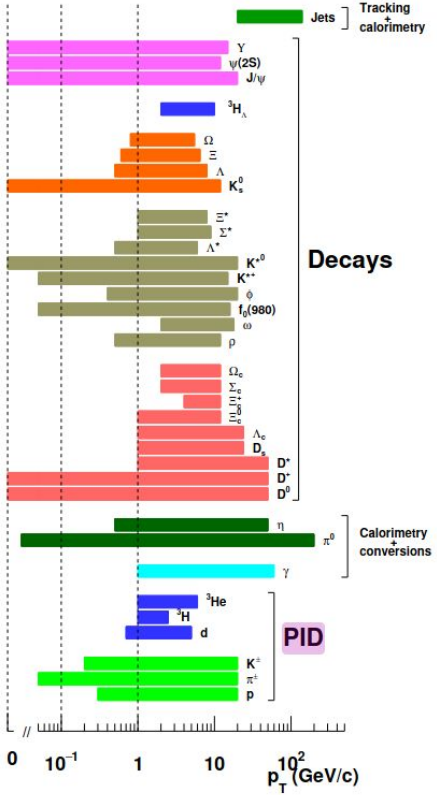
ITS: energy loss proportional to **Cluster size**

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

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

How to do PID:

- **Unstable particles:** Invariant mass reconstruction / topological decay
- **Calorimetry:** full energy deposition, e-photon-hadron discrimination from shower profile
- **Stable Particles:** Detector response that depends on particle velocity
  - Energy loss via Ionization (dE/dx) ~ $1/\beta^2$
  - Time-of-flight, $\tau \sim 1/\beta$
  - Emitted transition radiation ~ $1/\gamma$
  - Cherenkov emission, $\cos(\theta) = 1/n\beta$



https://arxiv.org/abs/2211.04384

PID using "nσ-cut" method

ITS/TPC

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

$$n\sigma = \frac{dE/dx_{measured} - dE/dx_{expected}}{\sigma_{PID(TPC)}}$$

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

TOF

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

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

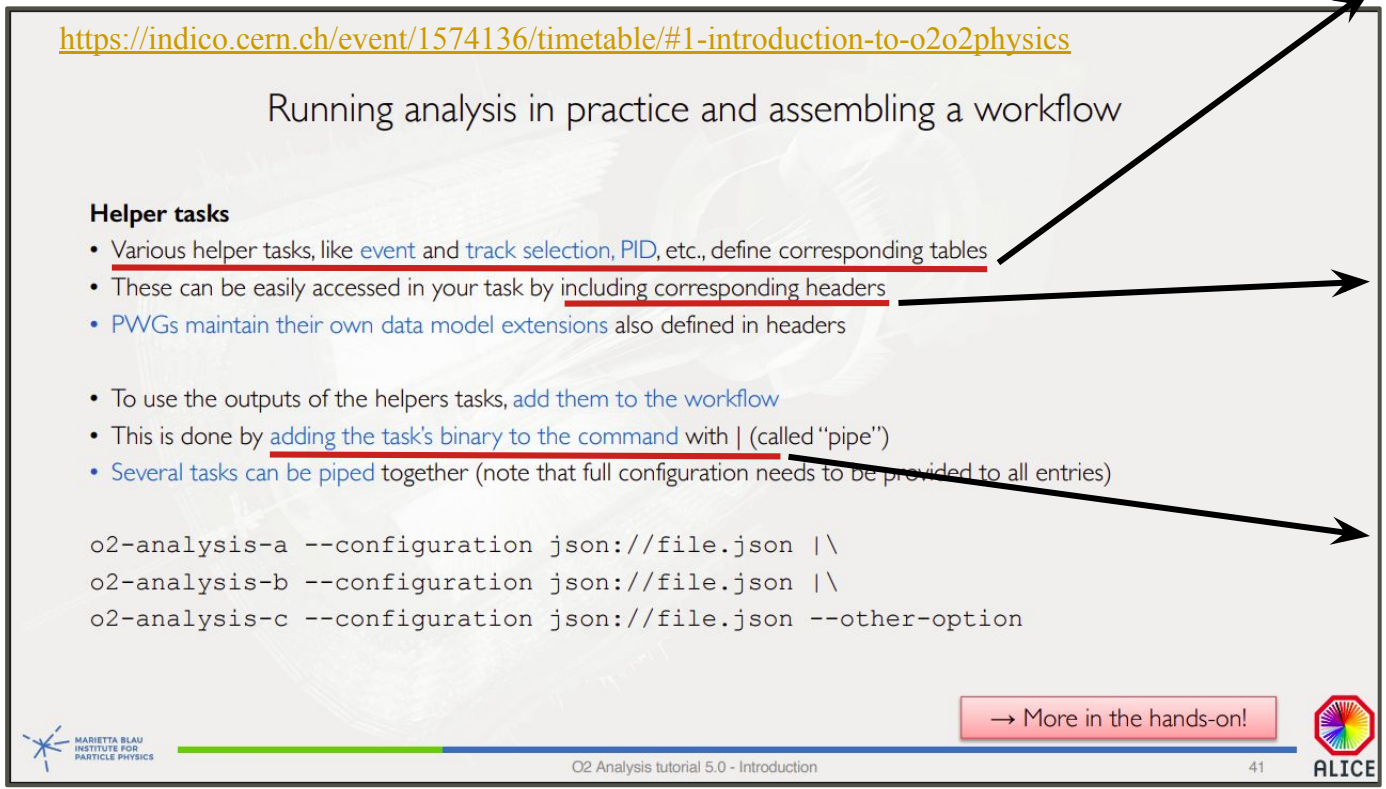
$t_{measured} = t_{hit} - start_{Time}$

- 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

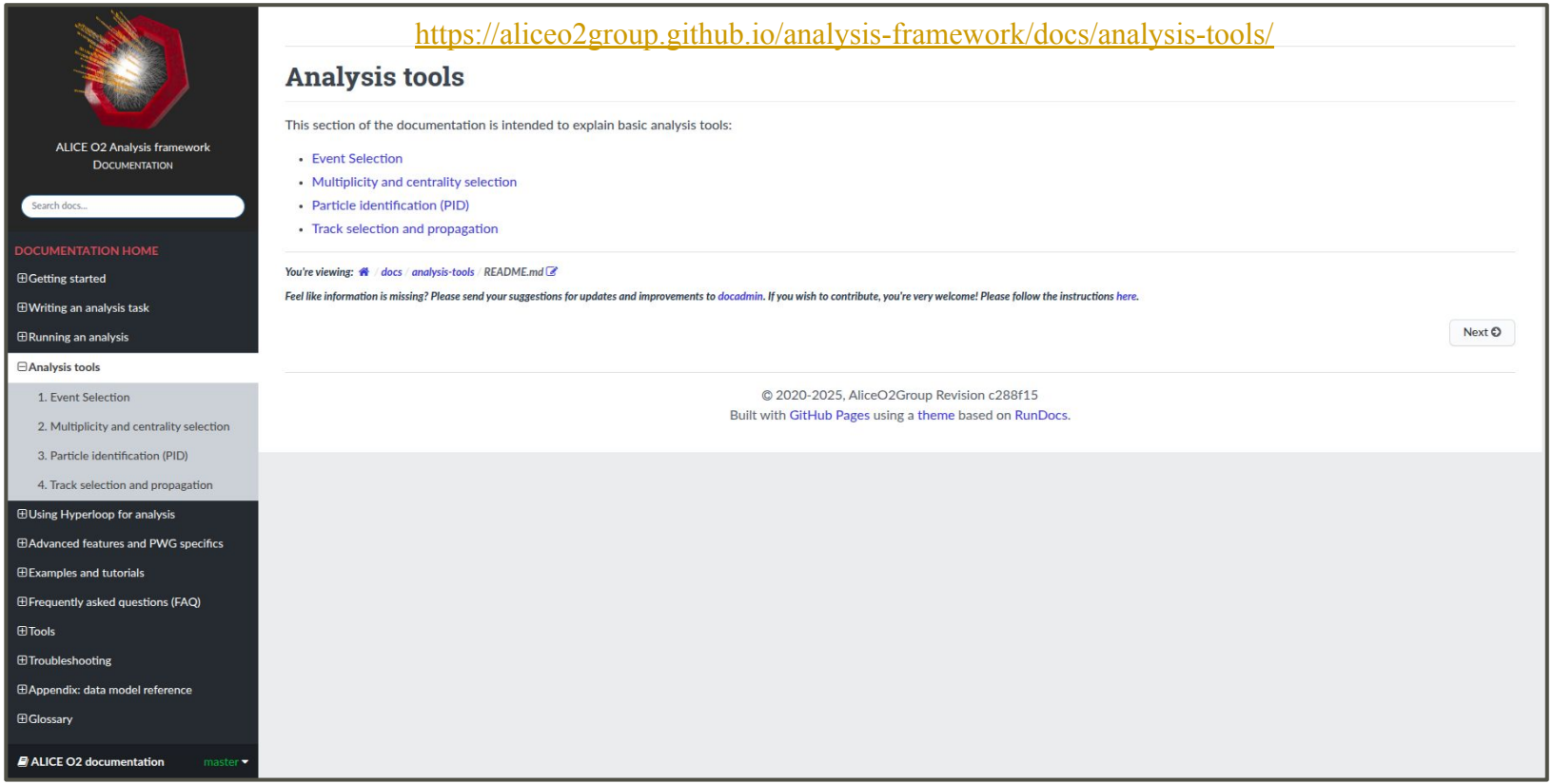
– Adding pieces to the data model



- 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

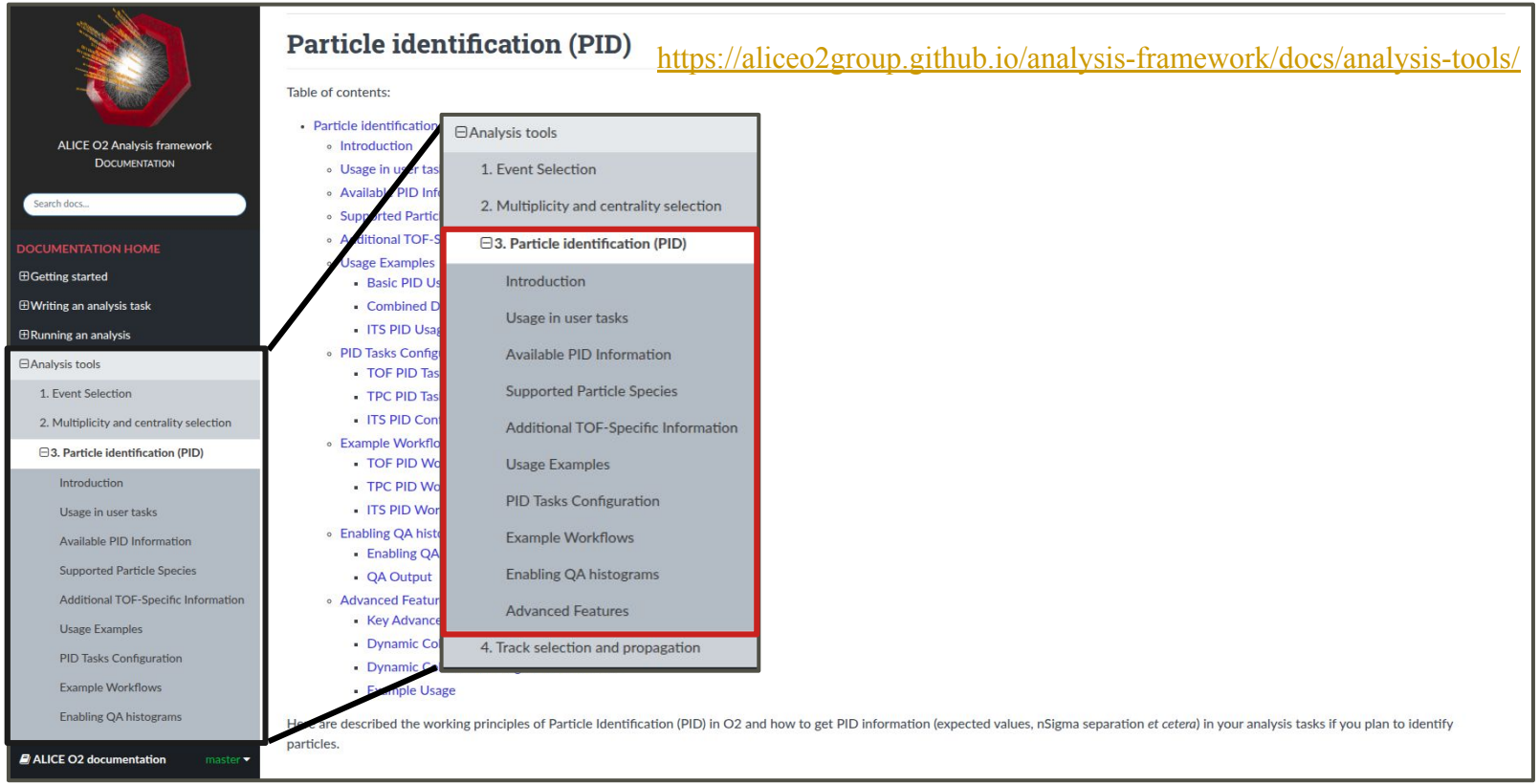
A guide to the helper tasks

– Advanced analyses need more helper tasks



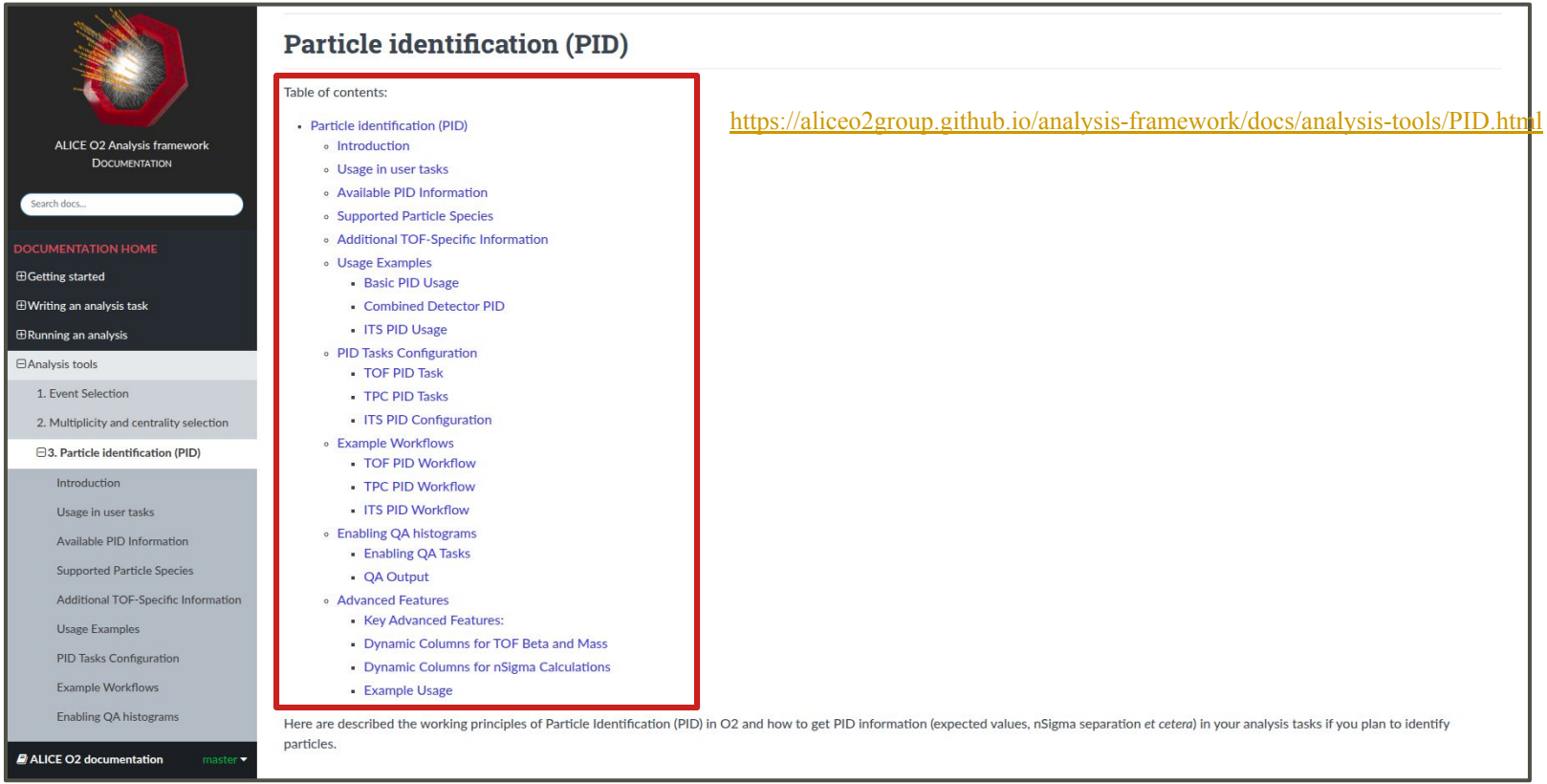
A guide to the helper tasks

– Advanced analyses need more helper tasks



A guide to the PID helper tasks

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



https://aliceo2group.github.io/analysis-framework/docs/analysis-tools/PID.html

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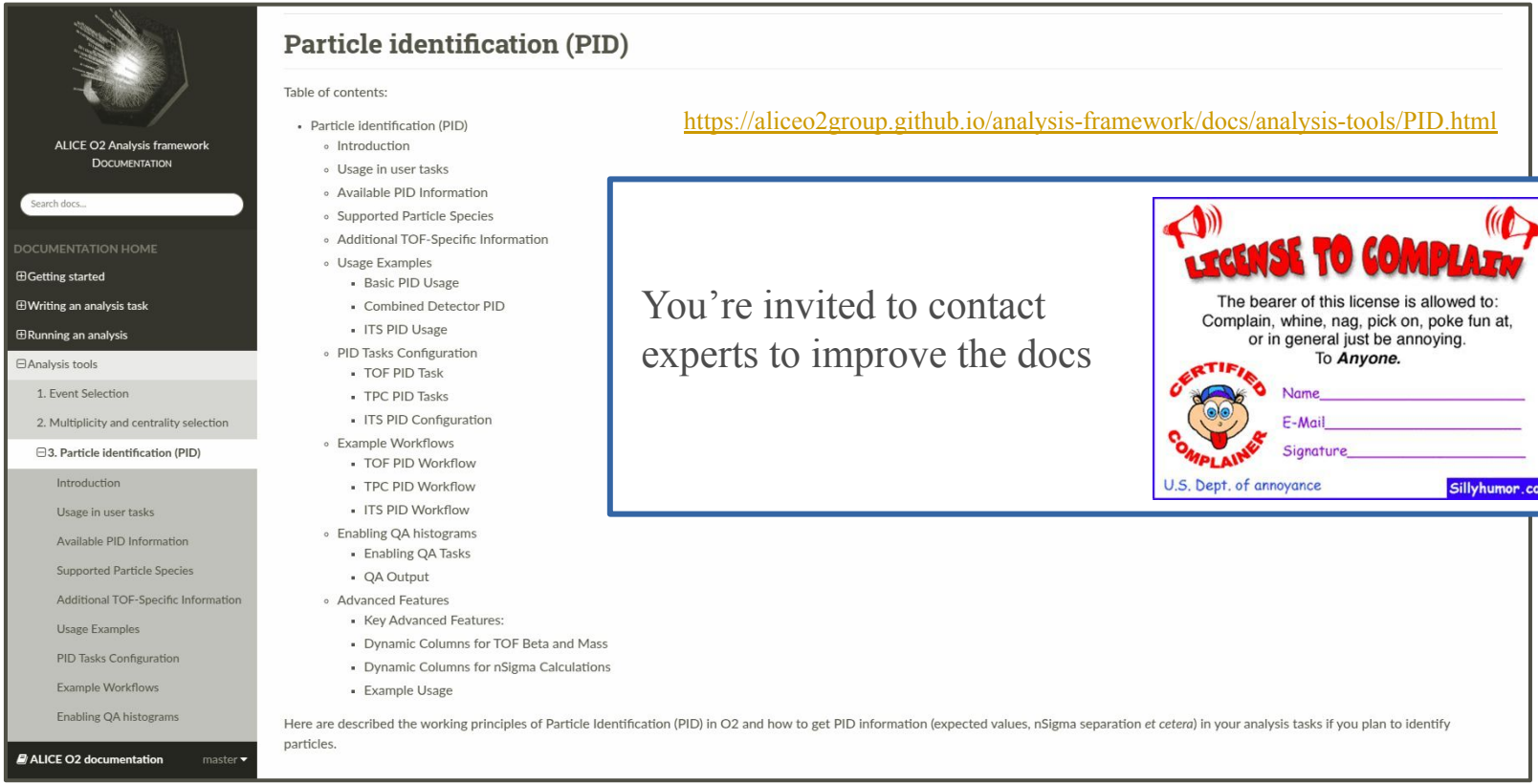
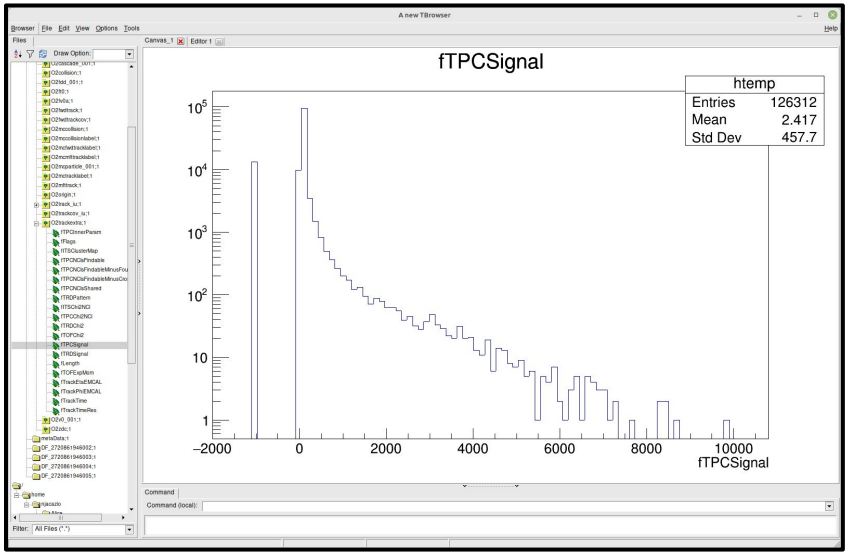
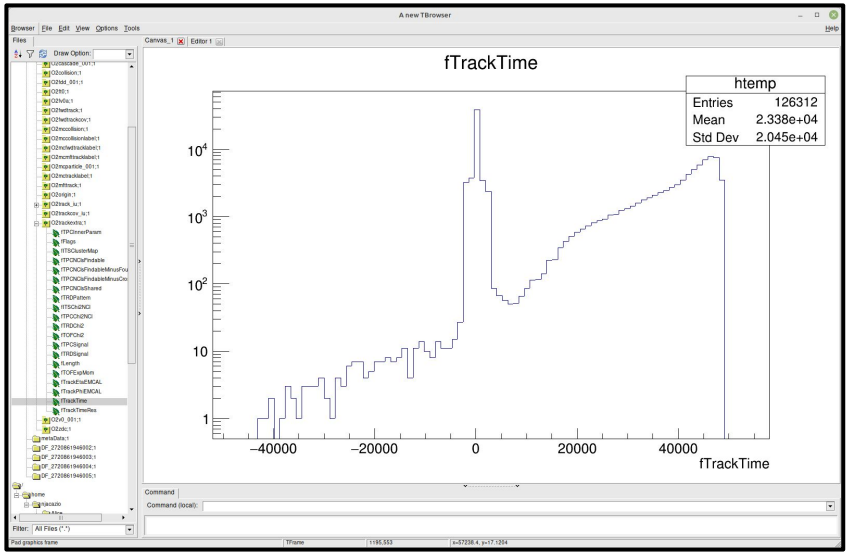


Example: select pions

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





AnalysisResults.root

Example: select pions

AO2D.root

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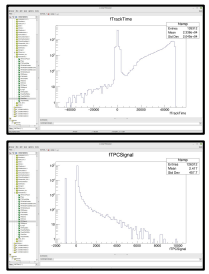
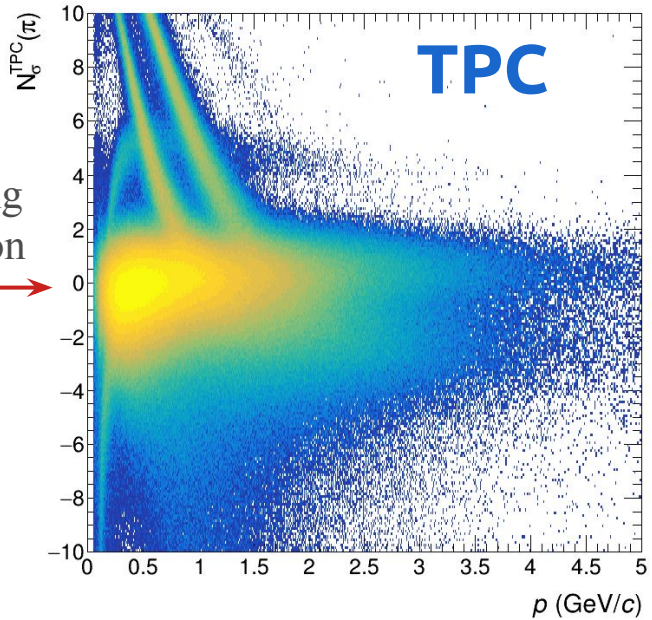
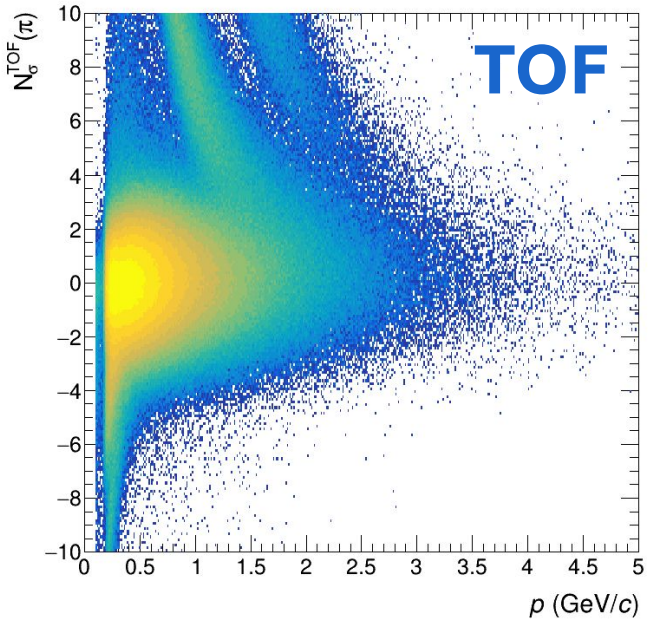


Processing: building pion Nσ information





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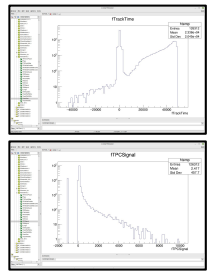
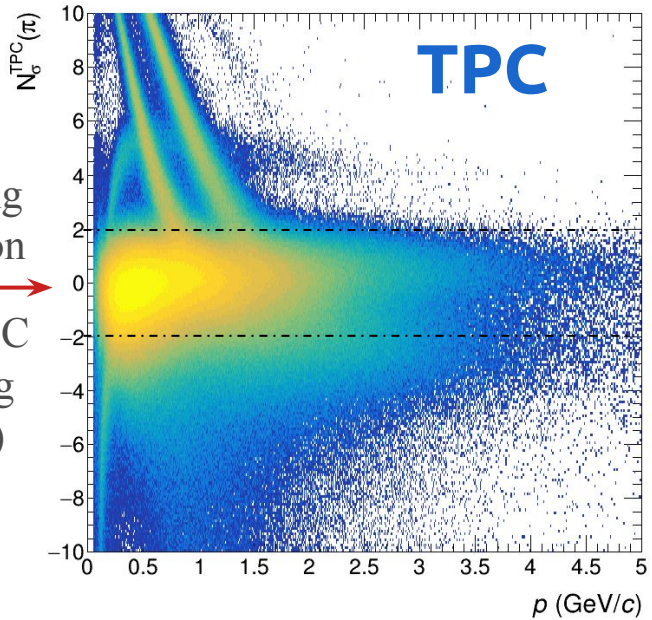
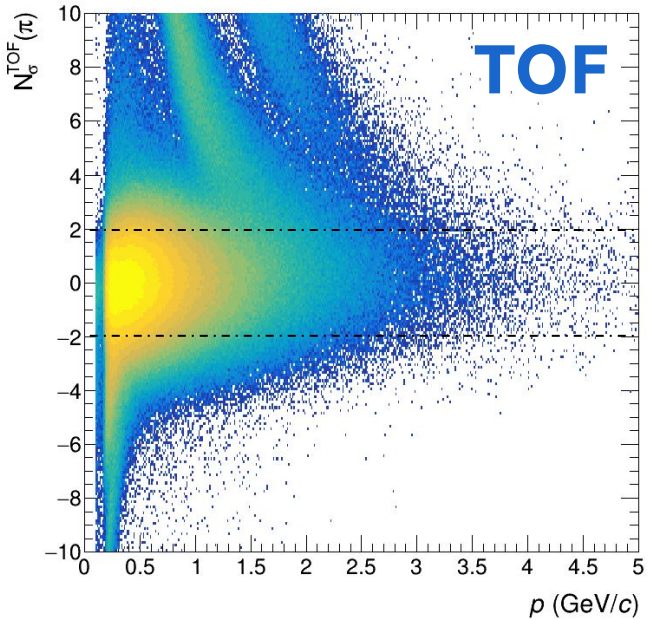


Processing: building pion Nσ information

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





AnalysisResults.root

Filter & Partitions: https://indico.cern.ch/event/1574136/timetable/#1-introduction-to-o2o2physics

Example: select pions

AO2D.root

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Processing: building pion Nσ information

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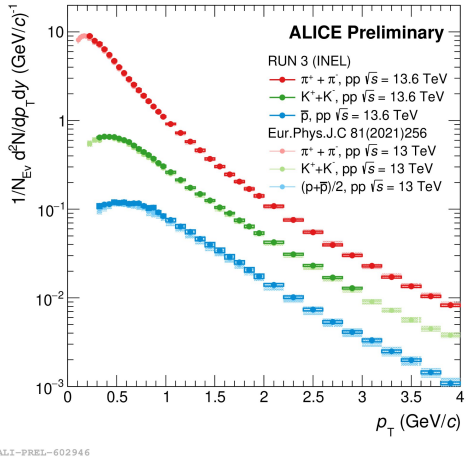
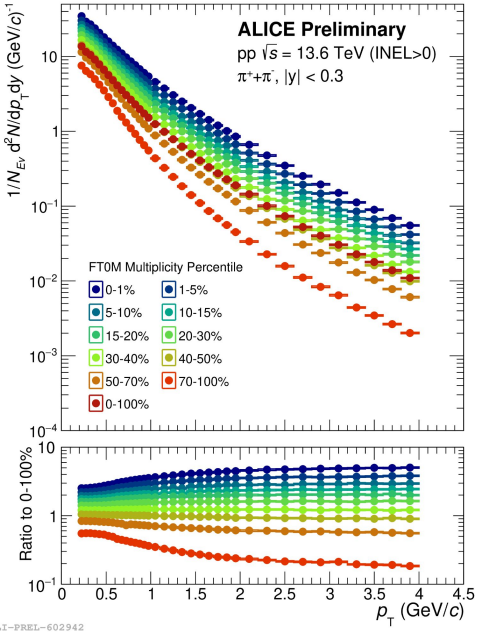
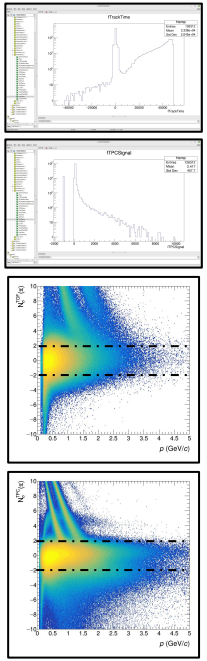






Your physics results, *OK but how?*

AnalysisResults.root

Filter & Partitions: https://indico.cern.ch/event/1574136/timetable/#1-introduction-to-o2o2physics

Example: select pions

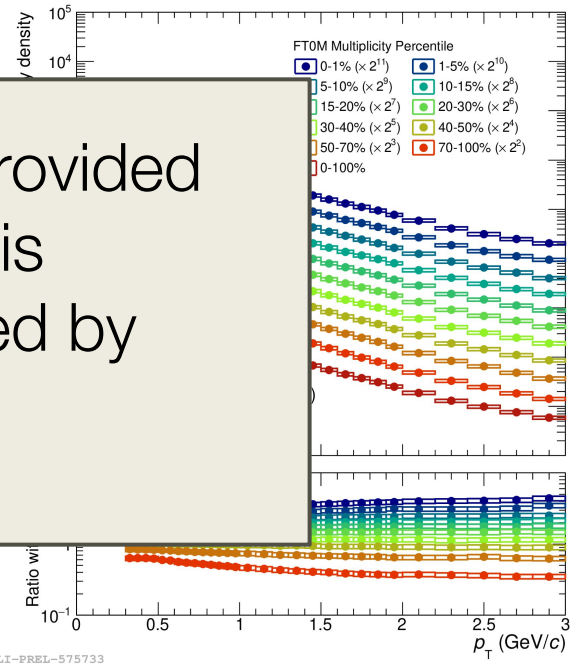
AO2D.root

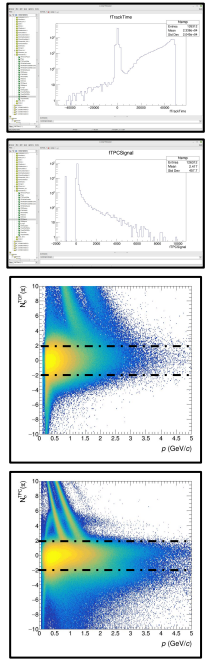
"Raw" detector data: $1/p_T$, TPCSignal, trackTime, …

Processing: building pion Nσ information

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

PID performance provided by central systems is constantly monitored by DPG experts!





Your physics results, *OK but how?*

AnalysisResults.root

Filter & Partitions: https://indico.cern.ch/event/1574136/timetable/#1-introduction-to-o2o2physics

Including PID data formats

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

```
#include "Common/DataModel/PIDResponseITS.h"
#include "Common/DataModel/PIDResponseTPC.h"
#include "Common/DataModel/PIDResponseTOF.h"
```

  - ITS nSigma values
  - TPC nSigma values
  - TOF nSigma values

- Tables available for PID

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

- Expected values (e.g. Bethe Bloch, expected TOF)
- Expected resolutions
- Separation (i.e. measured signal - expected signal)
- Nσ separation
- 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/analysis-tools/PID.html#usage-in-user-tasks

Subscribing to PID tables

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

Pion PID

TPC

TOF

```
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/analysis-tools/PID.html#usage-in-user-tasks

Accessing PID info for TPC and TOF

- 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/analysis-tools/PID.html#usage-in-user-tasks

TPC/TOF PID tasks in the workflow

- Tasks to include in the workflow

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

PID Tasks

Dependencies

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

```
o2-analysis-pid-tof-merge | 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/analysis-tools/PID.html#example-workflows

Accessing PID info for ITS

- ITS information is only dynamic (computed on the fly).
- Parametrization is taken from the **pidITS.cxx** task with the workflow *o2-analysis-pid-its*

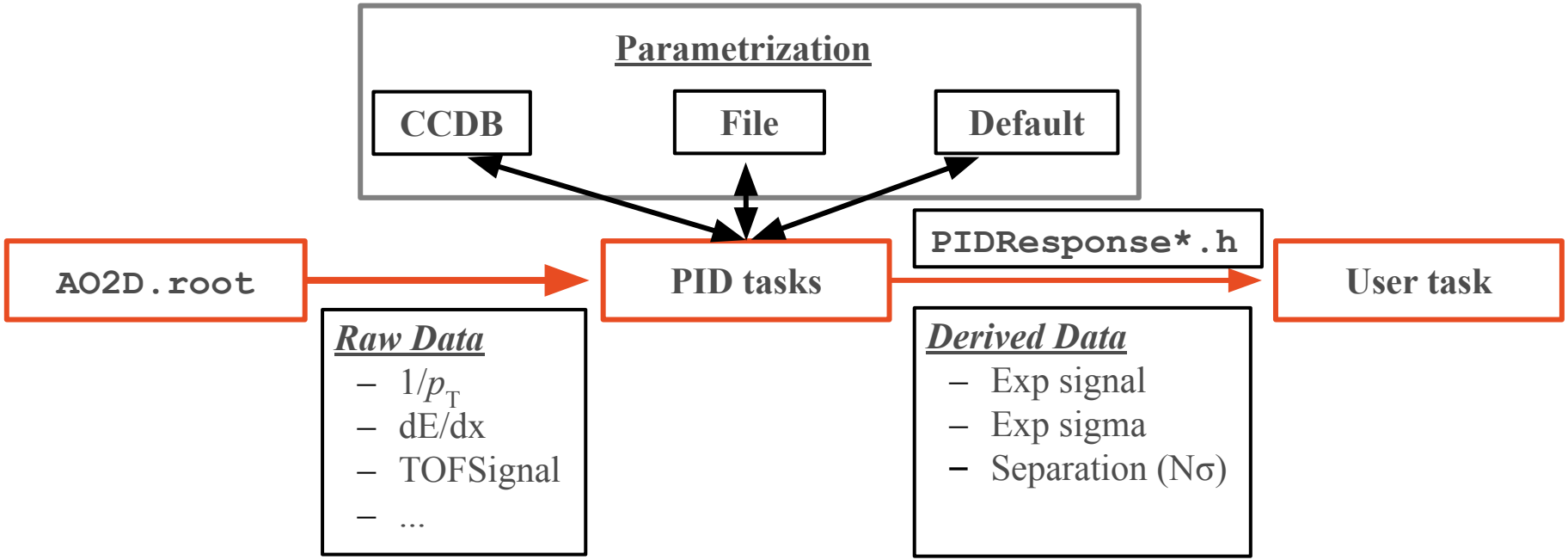
```
void init(o2::framework::InitContext& context)
{
 o2::aod::ITSResponse::setParameters(context); // Load Parameters from pidITS.cxx task
}

void process(aod::Tracks const& tracks)
{
 auto tracksWithPid = soa::Attach<aod::Tracks,
                                  aod::pidits::ITSNSigmaPi,
                                  aod::pidits::ITSNSigmaKa>(tracks);
 for (auto& track : tracksWithPid) {
   track.itsNSigmaPi(); // ITS Nsigma of pions
   track.itsNSigmaKa(); // ITS Nsigma of kaons
 }
}
```

Documentation → https://aliceo2group.github.io/analysis-framework/docs/analysis-tools/PID.html#its-pid-usage

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!

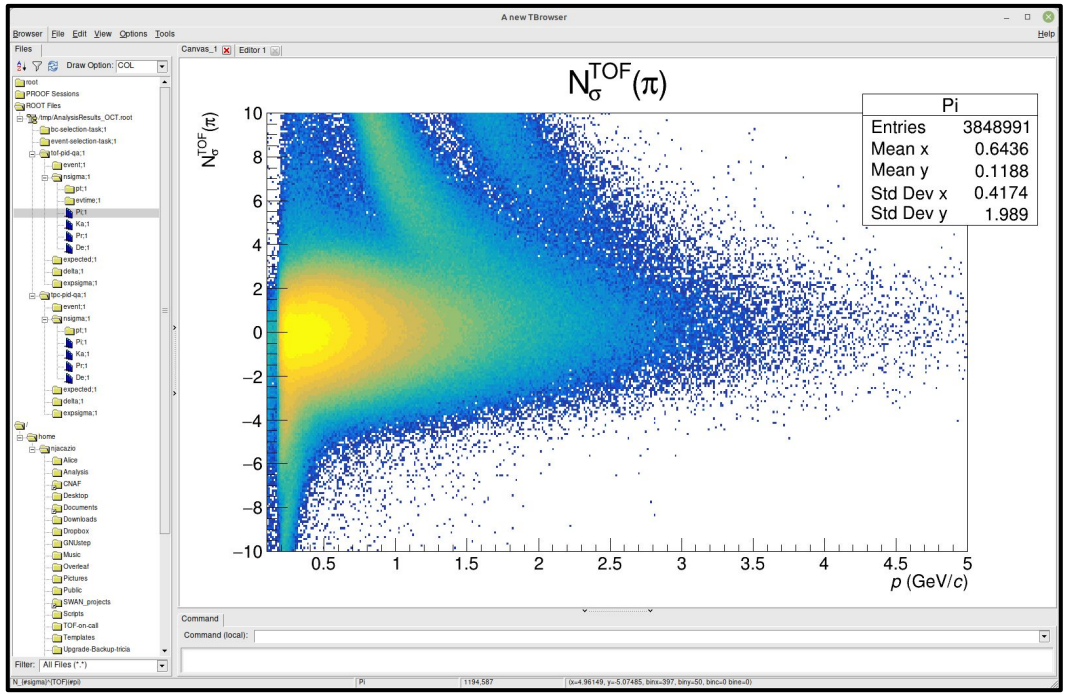
- PID tasks come with QA output included!

```
o2-analysis-pid-its-qa
o2-analysis-pid-tpc-qa
o2-analysis-pid-tof-qa
```

- Monitor Nσ
- Produce nice performance plots e.g. ITS/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
```

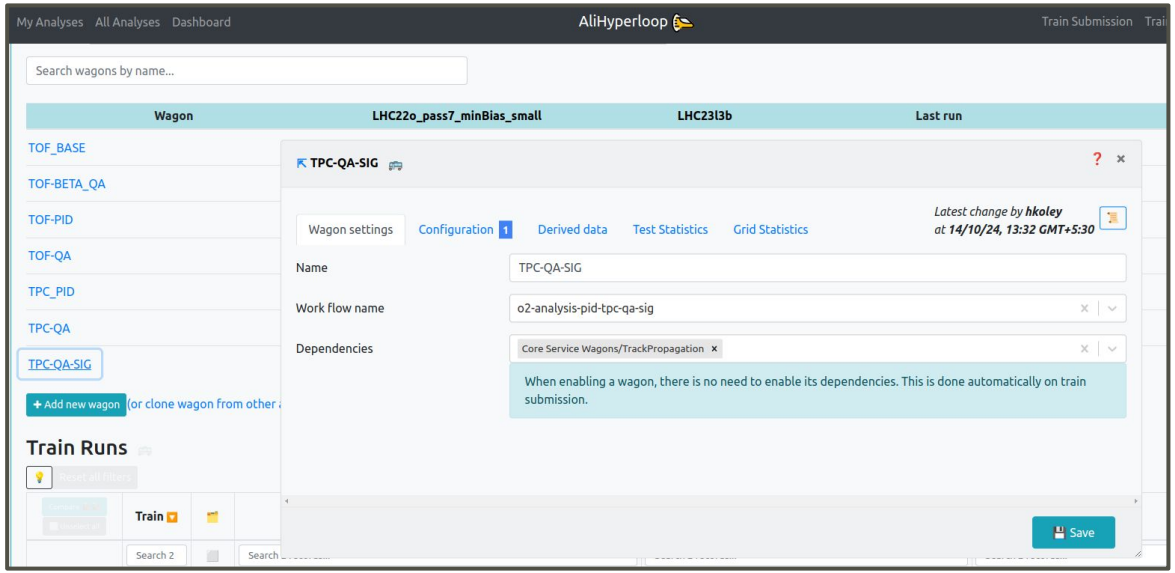


- QA for MC (e.g. purity) and more (e.g. mass)!

Documentation → https://aliceo2group.github.io/analysis-framework/docs/analysis-tools/PID.html#enabling-qa-histograms

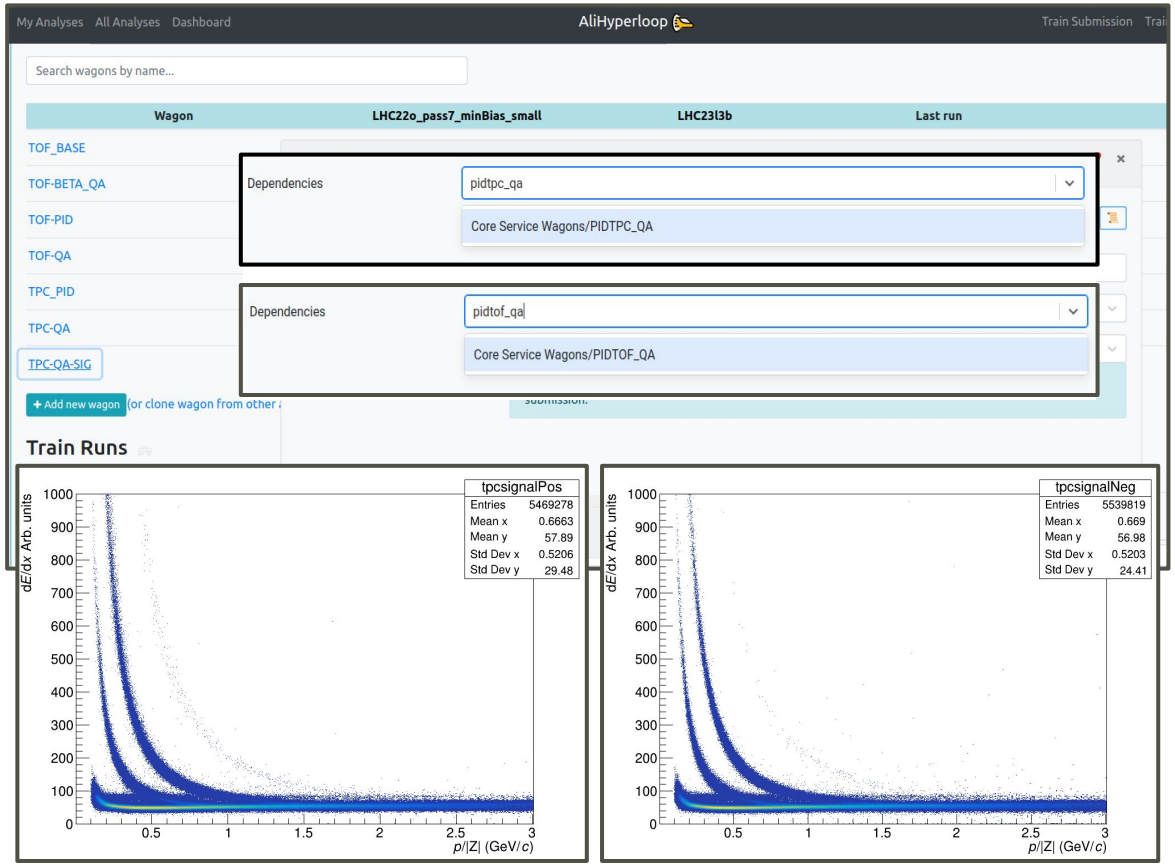
Setup wagons for PID QA in Hyperloop

- 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

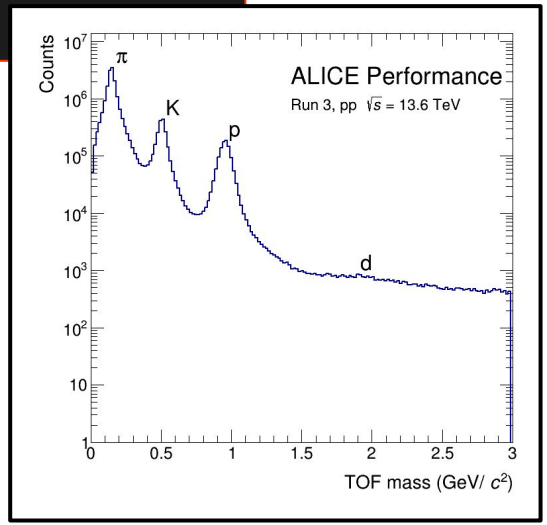
```
void process(soa::Join<aod::Tracks, aod::pidTOFmass, aod::pidTOFbeta> const& tracks)
{
 for (auto& track : tracks) {
   track.beta(); // TOF beta
   track.mass(); // TOF mass
 }
}
```

- Access by the following task: Executable

```
o2-analysis-pid-tof-merge
```

- Comes with QA as well

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



Event time for TOF

- Multiple event times can be used for TOF measurement
- With respect to Run2, we now ask the track which event time 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
   track.tofEvTime(); // Event Collision time used for the track
 }
}
```

- Executable that handles event time

```
o2-analysis-pid-tof-merge
```

- 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) - recommended

```
Configurable<bool> useNetworkCorrection{"useNetworkCorrection", 0, "(bool) Weather 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));
```

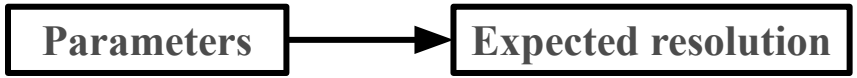
- Fine-tuned pass dependent calibration of the charge bias on momentum + resolution

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

- Refer to the Hyperloop configurations (explained later)

How these values are computed: ITS

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




```
DECLARE_SOA_DYNAMIC_COLUMN(ITSNSigmaElImp, itsNSigmaEl, //! Nsigma separation with the ITS detector for electrons
                           [](uint32_t itsClusterSizes, float momentum, float eta) -> float {
                             return ITSResponse::nSigmaITS<o2::track::PID::Electron>(itsClusterSizes, momentum,
eta);
                           });
```

- ITS PID is provided with dynamic columns only. Parametrization for MC and Data is slightly different and has to be provided to the dynamic column before being able to provide a calibrated signal. Resolution parametrization is taken from *o2-analysis-pid-its*
- **N.B.** it is fundamental to perform the `o2::aod::ITSResponse::setParameters(context);` call in your init function!

ITS PID helper tasks on Hyperloop

- Dependencies on Hyperloop
  - **Run 3**
- in doubt ? ask!!
- Take them as reference for local running!!

TPC PID helper tasks on Hyperloop

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

AliHyperloop

Core wagons

PIDTPCService	* *		
PIDTPCService-MonteCarloTuneOnData	* *		*
PIDTPCService-NeuralNetwork	*	*	
PIDTPCService-NeuralNetwork-MonteCarloTuneOnData	*	*	*
PIDTPCService-NeuralNetwork-MonteCarloTuneOnData-Run2	*	*	*
PIDTPCService-NeuralNetwork-Run2	*	*	

Description on the specific tasks

Neural network corrections:

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

- BB curve is not precise enough for a "real life" detector
- Difference between the Bethe-Bloch fits, and real function is done as a correction using neural networks
- Network learns correction factor (in 7D) to the Bethe-Bloch Parameterization
- **Input to the network:** p, tan(λ), sign(q)/p_T, mass hypothesis, normalized multiplicity, normalized number of clusters, FT0 Occupancy
- **Output:** dE/dx of identified particles as a ratio to the Bethe-Bloch Parameterization

MCTuneOnData:

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

TOF PID helper tasks on Hyperloop

- Dependencies on Hyperloop
  - **Run 2**
  - **Run 3**
  - **Data**
  - **MC**
- Include the one according to your needs and in doubt ask the experts!!

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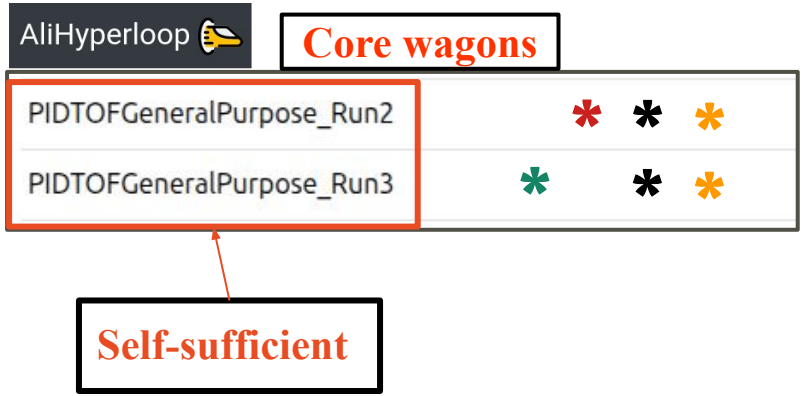
Core wagons

PIDTOFGeneralPurpose_Run2	*	*	*
PIDTOFGeneralPurpose_Run3	*	*	*

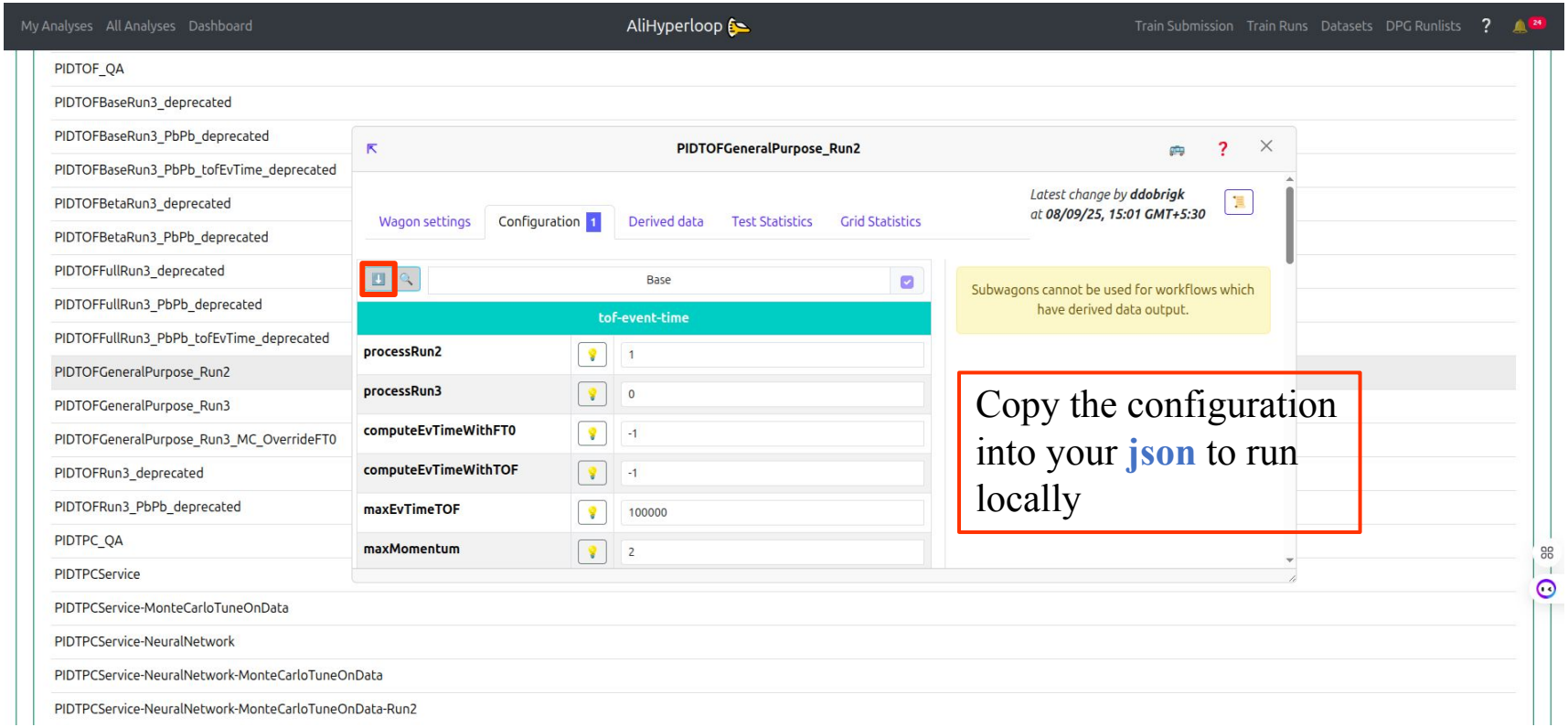
TOF PID helper tasks on Hyperloop

- Dependencies on Hyperloop
  - **Run 2**
  - **Run 3**
  - **Data**
  - **MC**
- Include the one according to your needs and in doubt ask the experts!!
- Only general purpose tasks are needed (no other TOF dependencies). Setup of collision system/MC is automatic.
- Take them as reference for local running!!



- N.B. legacy wagons are marked as Deprecated are not actively maintained and will be removed
- Test the new TOF dynamic columns for PID (similar to ITS approach) for better performance. See backup for example.

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

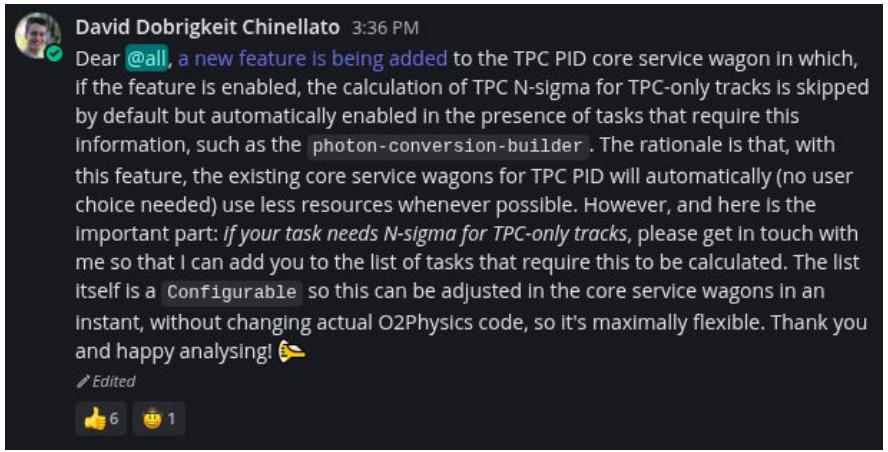
- Async QC Weekly meeting (Tuesdays 15h00) → https://indico.cern.ch/event/1607965/
- DPG AOT-track (Thursdays 9h30) → https://indico.cern.ch/event/1568266/
- Detector and QA experts
- **ITS** → francesco.mazzaschi@cern.ch
- **TPC** → ana.marin@cern.ch
- **TOF** → nicolo.jacazio@cern.ch
- **PID QA** →DPG-AOT coord.

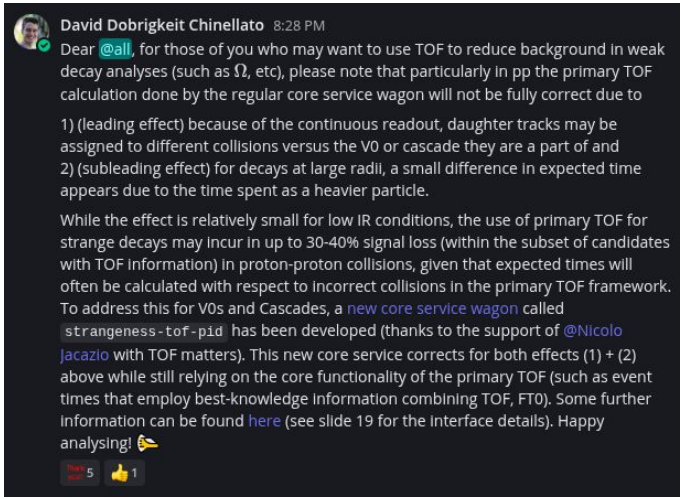
Suggestions are welcome, eager to improve!

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





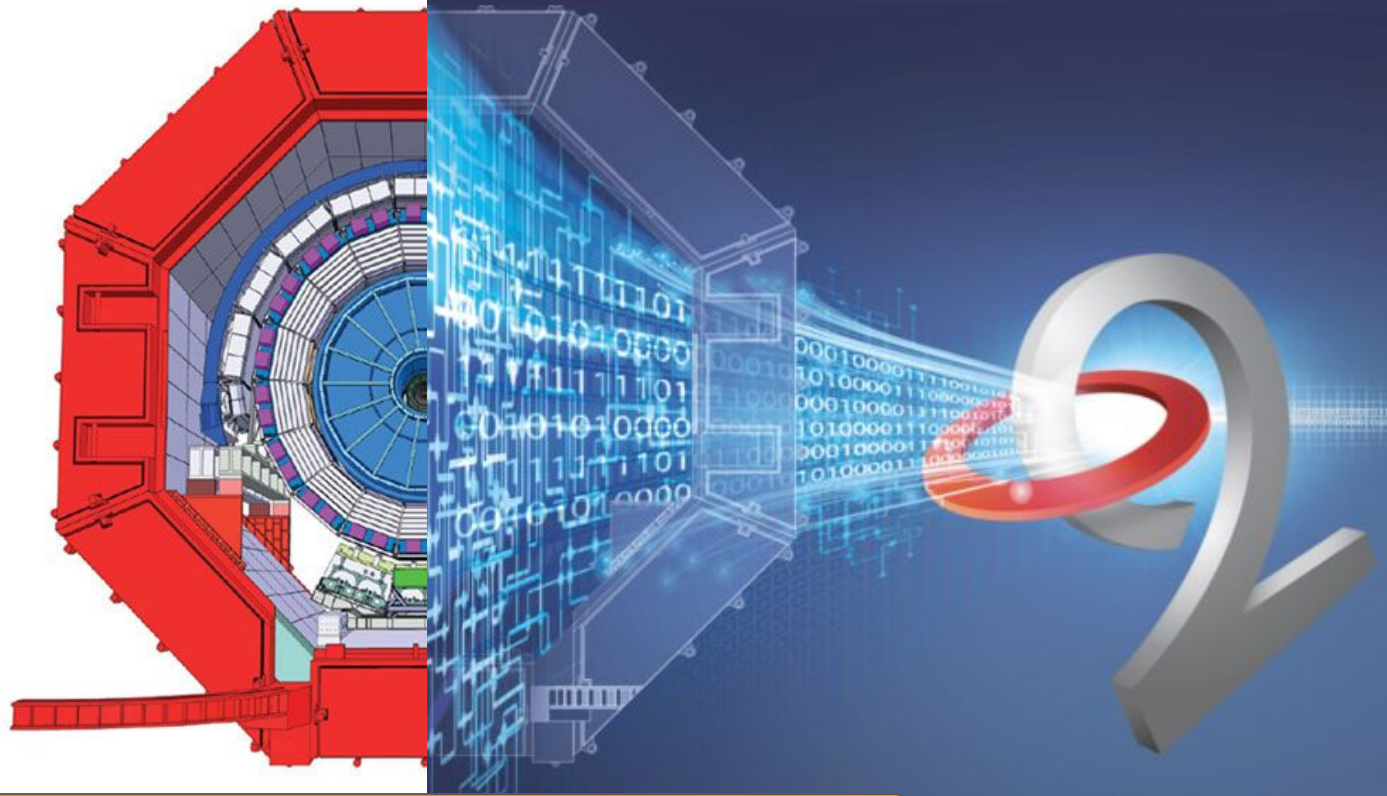
Issues, developments, and calibration releases are announced here (for PID but not only!)

Take home message

- PID will be likely useful in your analysis
  - Provided by central tasks, calibrated and checked by DPG
- Refer to the documentation for usage
- In case of doubts or unexpected features ask away!
- Test it yourself right now!

TRUG
TEST READY TO USE


```
wget -L --content-disposition "https://cernbox.cern.ch/s/rZTWHWSGHRHz8iB/download" -O /tmp/setup.sh
bash /tmp/setup.sh
```



Thank you for your attention

TOF dynamic columns PID response

```
struct tofPidQaImp {
 Service<o2::pid::tof::TOFResponse> tofResponse;
 Service<o2::ccdb::BasicCCDBManager> ccdb;
 void init(o2::framework::InitContext& context)
 {
   tofResponse->initSetup(ccdb, context);
 }

 using TrackCandidates = soa::Join<aod::Tracks, aod::TracksExtra, aod::TrackSelection,
                                   aod::pidEvTimeFlags, aod::TOFSignal, aod::TOFEvTime,
                                   aod::pidTOFFlags>;
 void process(CollisionCandidate const& collision,
              TrackCandidates const& tracks,
              o2::aod::BCsWithTimestamps const&)
 {
   tofResponse->processSetup(collision.bc_as<o2::aod::BCsWithTimestamps>());
   auto tracksWithPid = soa::Attach<TrackCandidates, o2::aod::TOFNSigmaDynEl>;
   for (const auto& t : tracksWithPid) {
     t.tofNSigmaDynEl();
   }
 }
```