Modelling detector-specific reconstruction uncertainties in LAr-TPC

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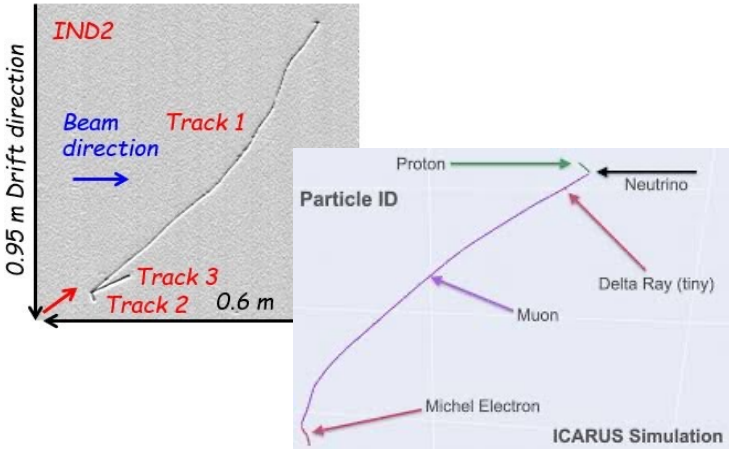
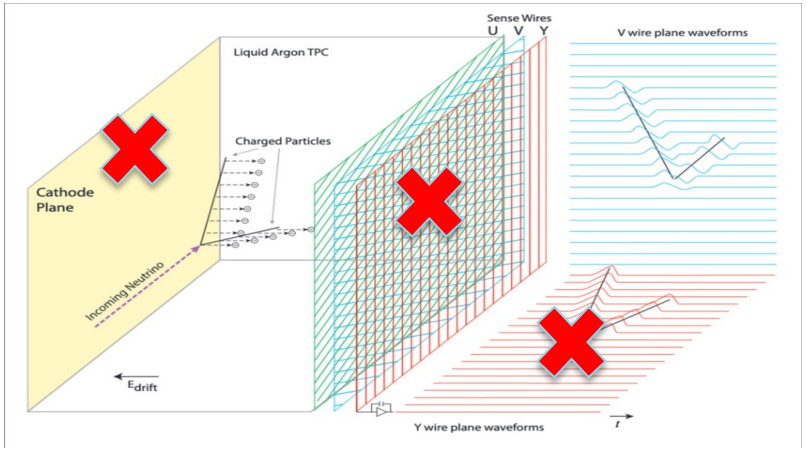
Introduction

Why is correct track reconstruction important in LAr-TPCs?

- Particle identification and classification;
- Energy determination;
- Study of neutrino interactions;





When does a split track manifest?

- Presence of unresponsive channels in the wire readout;
- Hit finding inefficiencies in one or more wire planes;
- A track crosses the cathode;

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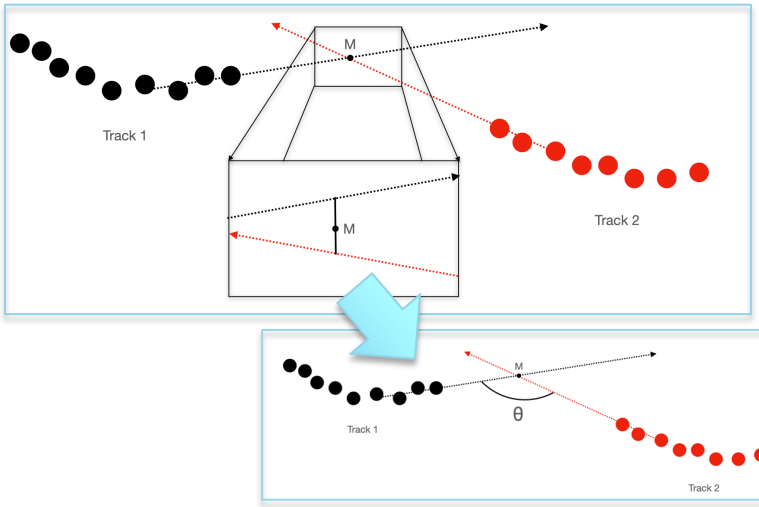
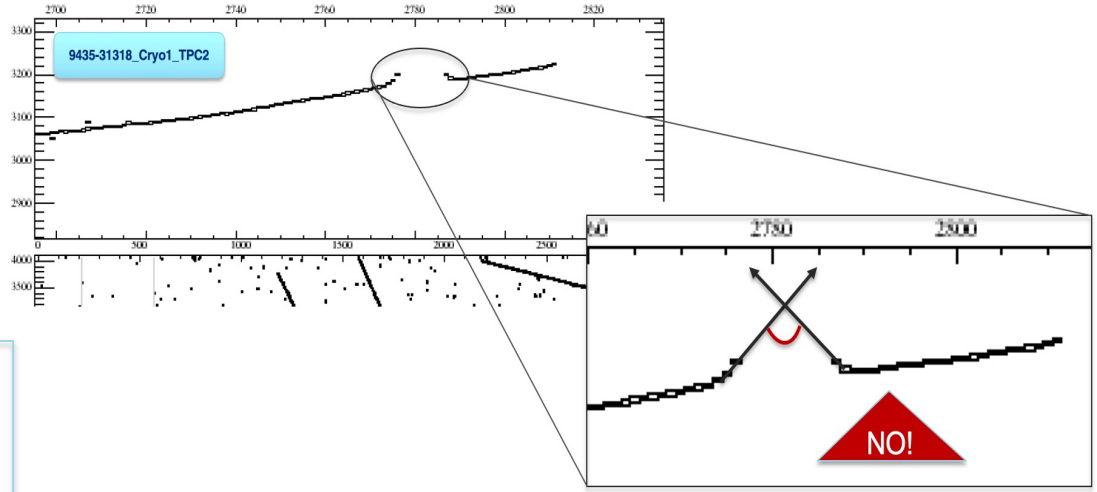
General idea

- The first part of my work consists in **writing a plug-in**, based on LArSoft's ART framework, **to identify split track events** and built on a selection algorithm based on constraints imposed on certain observables (e.g. angles and gaps between tracks, length of tracks);
- In this preliminary phase, the main goal was to implement in the Plug-In the **calculation of the observables of interest** and subsequently **validate its reconstruction capacity** by comparing it with a sample of 26 pairs of split tracks (collected in drive) previously analyzed with the event scanner;



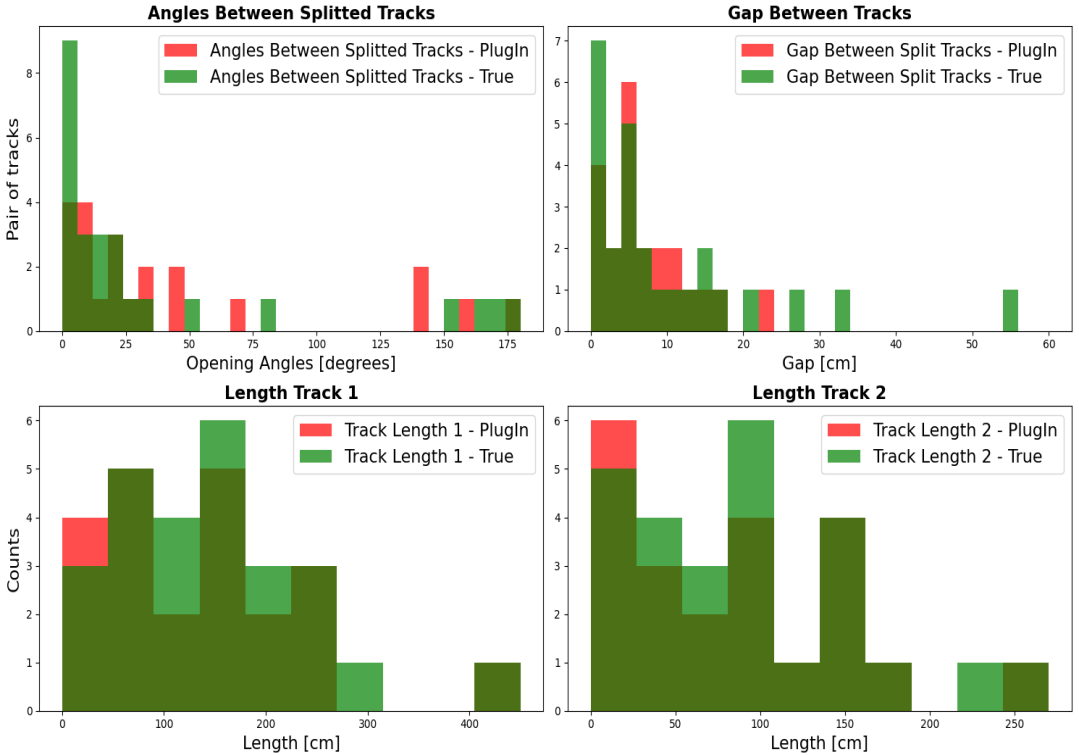


Comparison between selected and true variables

- The selection algorithm is based on the search for pairs of tracks with a **length greater than 5cm** and with a **gap less than 25cm**. Furthermore, the search is limited to only those events in which a split track is known to be present;
- The results obtained show a satisfactory degree of selection of split track events. An overview of results is presented in the table:

Variable	True-Positive	False-Positive	False-Negative
Angles	14	8	12
Gap	18	4	8
Length1	21	1	5
Length2	21	1	5

- From the distribution of the variables it is possible to obtain information regarding the cuts to be performed to correctly select split track events on samples whose presence is not known.



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Distribution of variables of all tracks

- Once the ability to reconstruct the variables of interest was validated, from the trends just presented it was possible to derive three simultaneous cuts to be performed to identify split track events on a generic sample:
  - Length of the tracks

    L1, L2 > 30 cm

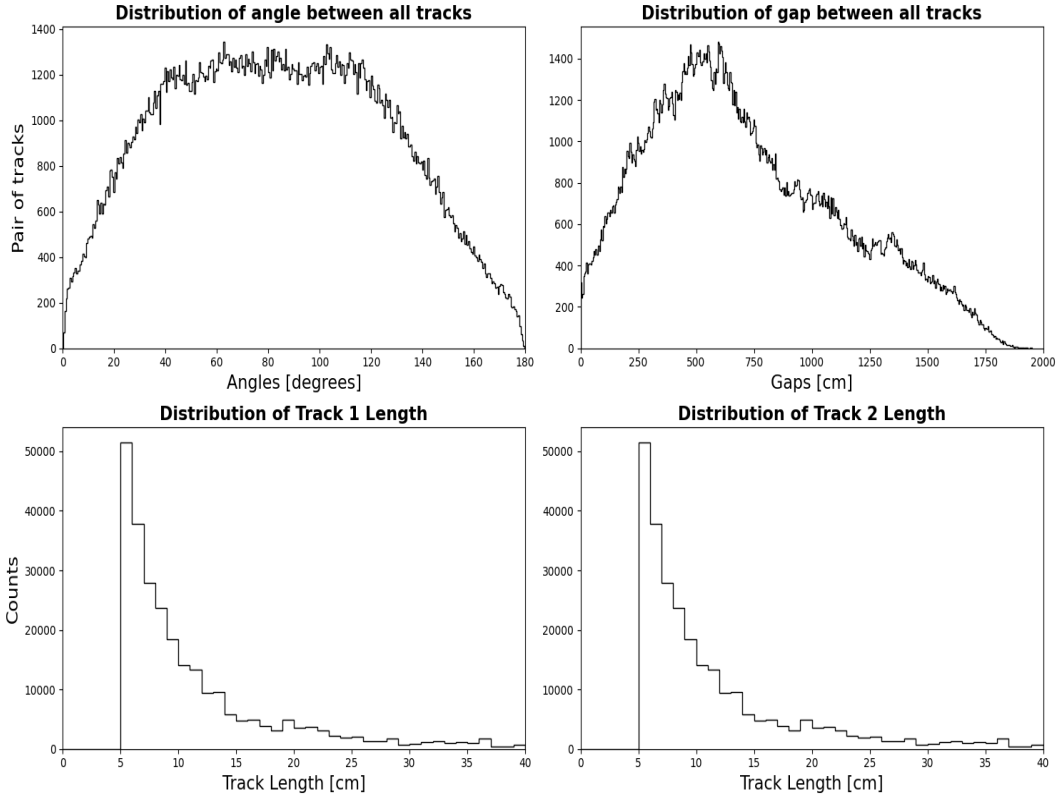
  - Gap between the tracks

    Gap < 25cm

  - Angle between tracks

    $$\boldsymbol{\theta} \in \{\, [\mathbf{0}, \mathbf{30}]^{\boldsymbol{o}} \cup [\mathbf{150}, \mathbf{180}]^{\boldsymbol{o}} \,\}$$

- In the figure it is possible to appreciate the distribution of angles, gaps and lengths of **all the pairs of tracks** present in the analyzed data sample;



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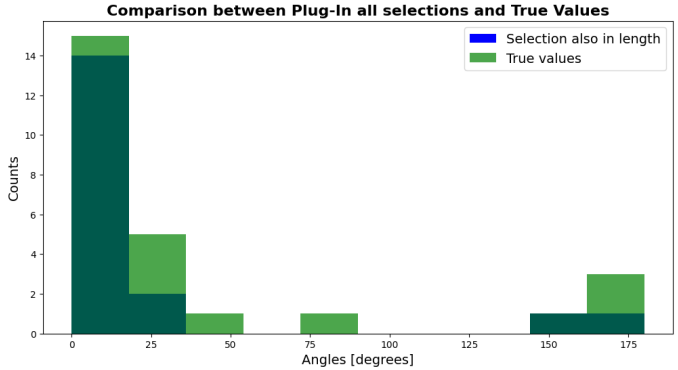
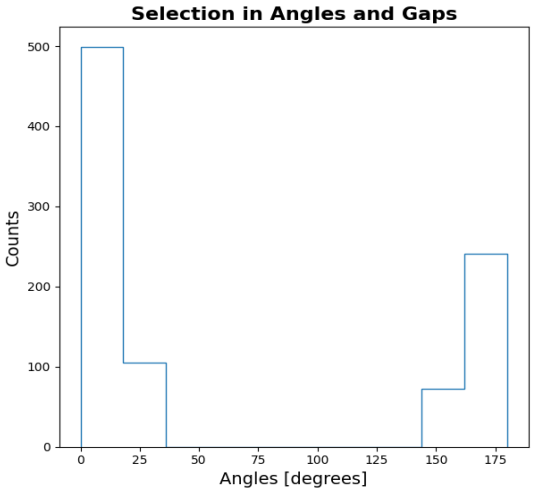
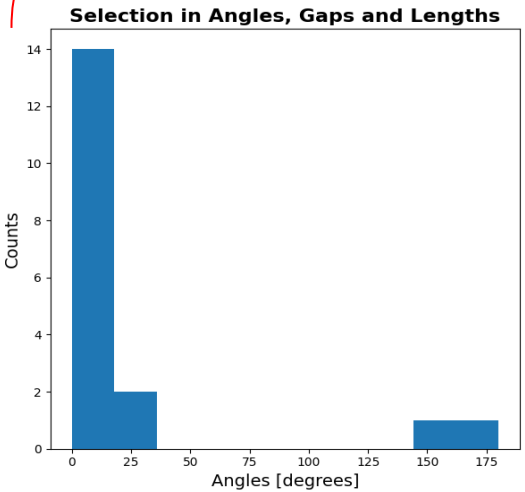
Results of Selections

It is possible to highlight how the selection on angle and gap (keeping the cut on the lengths at 5cm) is **not yet completely sufficient** to select the split tracks (low purity); however, by implementing the **cut on the length** of the two traces at 30cm the **result improves significantly**!







Outline and next goals

- To conclude, in these first weeks of work:
  - Several events were viewed using the event scanner in order to **become familiar with recognizing split tracks** and their importance in reconstructing events in LAr-TPCs was understood;
  - A **valid method of calculating the angle between two tracks** that led to plausible results even for pathological events (e.g., split tracks near the cathode) was found;
  - A plug-in was written that implemented the **search for split tracks** based on known cuts and calculated observables of physical interest by saving them in a TTree. This plug-in is written in a versatile form so that it can be easily adapted for use with other data samples;
- Next goals:
  - **Short term:** Find the optimal selection parameters based on the studied variables (e.g., angles and gaps between tracks, length of tracks). Improve the discrimination ability of split tracks by implementing additional selections based on variables other than the observed ones (e.g., energy loss). Special attention will also be paid to the distribution of missed channels.
  - **Long term:** Use the HARPS tool (Hit Activity Removal from Particles for Systematics, developed by Bruce Howard), based on throw gaps in tracks based on gap probability, to an MC samples to generate a systematic sample with additional split tracks. This sample will then be analyzed using the plug-in with the optimized cuts. Finally, the expected effect of track splitting on neutrino reconstruction efficiency will be evaluated.

THANKS FOR YOUR ATTENTION!

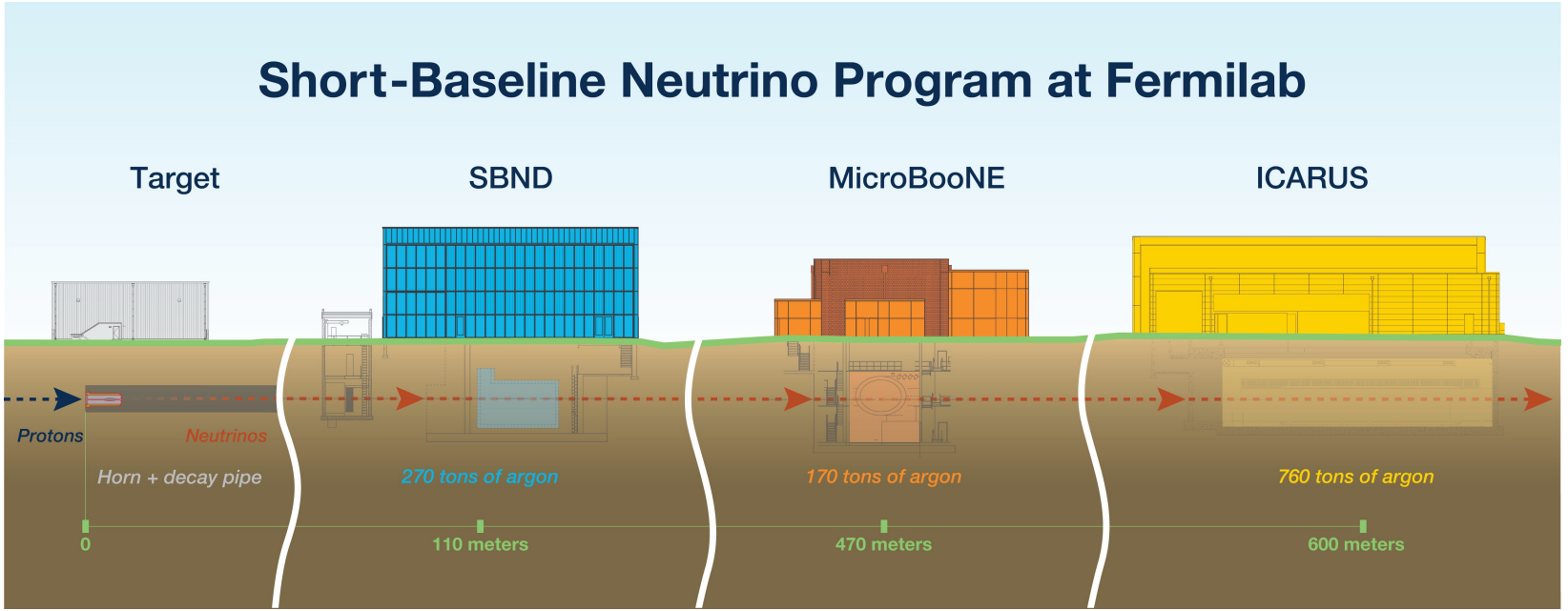
BACKUP SLIDES

Physics Program

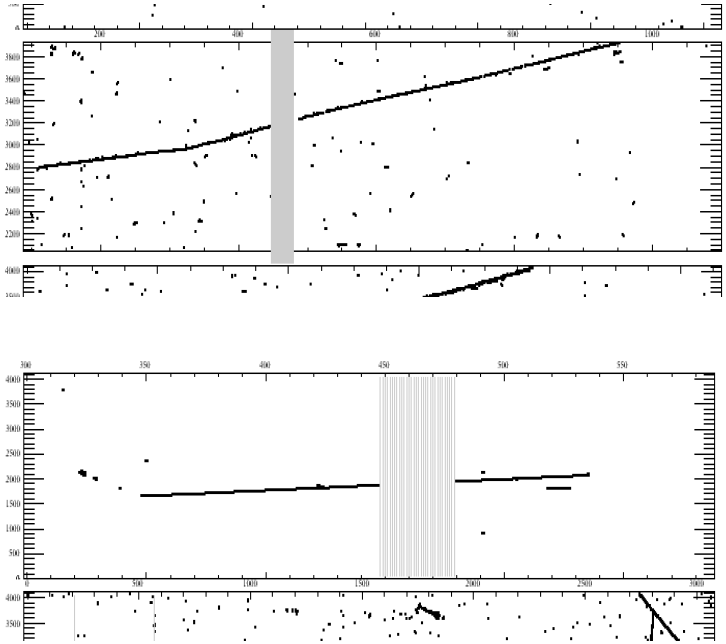
- Experimental observation of neutrino oscillations have established a picture consistent with the mixing of three neutrino flavors (ν_e, ν_μ, ν_τ) with three mass eigenstates (ν_1, ν_2, ν_3): however, in recent years, several experimental «anomalies» have been reported which could be hinting at the presence of additional neutrino states with larger mass-squared differences participating in the mixing;
- Mainly two distinct classes of anomalies pointing at additional physics beyond the SM, namely:
  - **Reactor and Gallium Anomaly**
  - **LSND/MiniBooNE anomaly**
- The most common interpretation of this collection of data is evidence for the existence of one or more additional, mostly **«sterile» neutrino states** with masses at or belowe the few eV range;
- The SBN physics program fits in this framework, testing the Neutrino-4 oscillation hypotesis with SBND and **ICARUS**;

Short Baseline Neutrino (SBN) Program

- SBN program includes three Liquid Argon Time Projection Chamber (LAr-TPC) detectors located on axis in the Booster Neutrino Beam (BNB), as shown in picture.



General idea

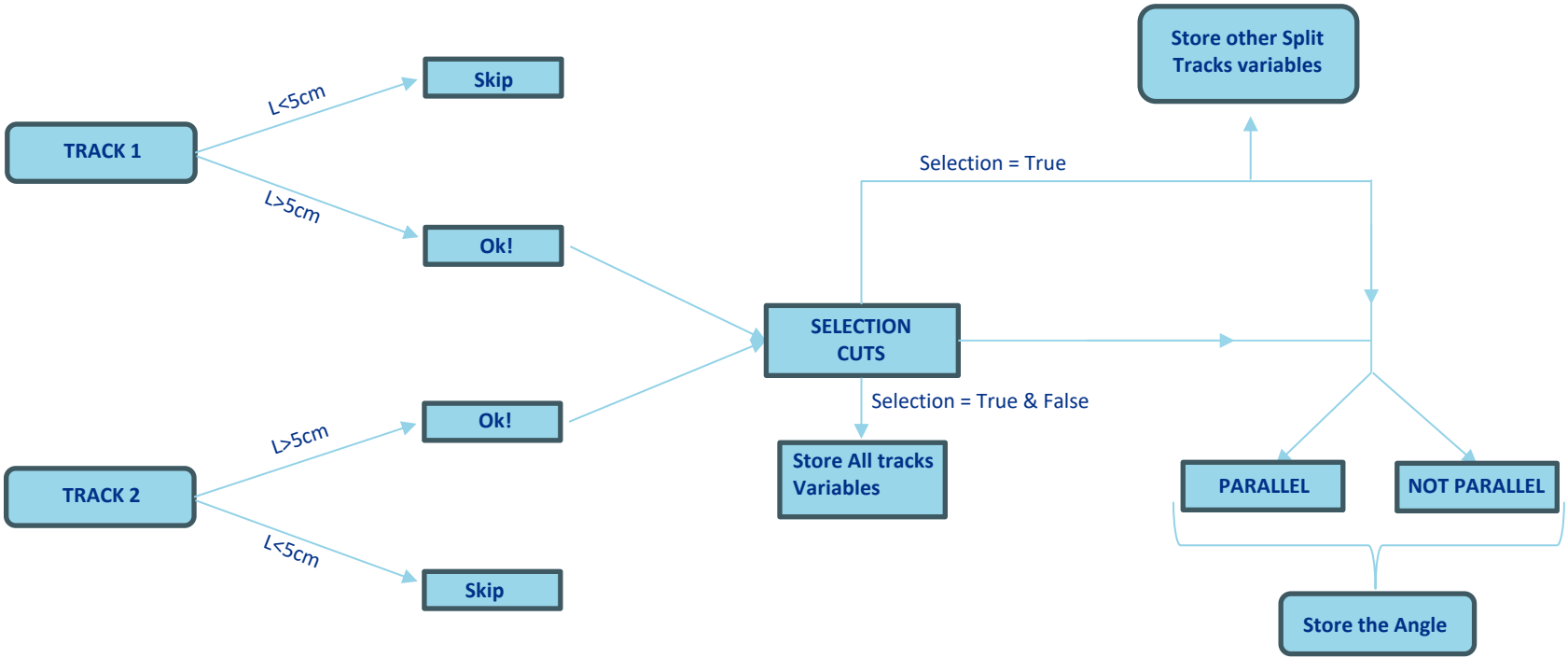


Examples of Splitted tracks from: 9435_1869_Cryo1_ TPC0 (up) & TPC2 (down)

- At this preliminary stage, the main objective was to identify and characterise the split tracks present in Run 9435 of ICARUS in order to determine useful variables for discriminating them;
- The results presented here originate from the use of a plug-in, written specifically for this specific analysis and developed further in the coming weeks, based on LArSoft's ART framework;
- This discussion will be divided into three main sections:

1. Plug-in logic used for the selection of split tracks
2. Analysis of the distribution of:
   - Angle and Gaps between tracks
   - Length of tracks
   - Lost channels
3. Conclusion and next goals

Logical structure of the Plug-in used – general scheme



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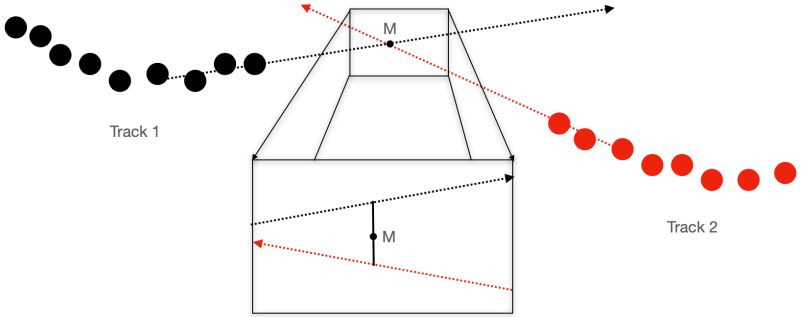
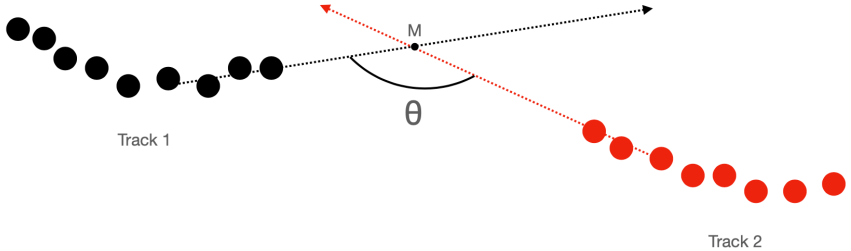
Logical structure of the Plug-in used – Angle between tracks (1)

- As just presented, two cases are possible:
  - **Parallel Case:** Subtract from π the angle between the common direction and the vector connecting the end of the first track to the start of the second track;
  - **Not parallel case:** In this case we proceed in steps
    1. Based on the last_1 and first_2 points -> Project towards track 1 and forwards track 2;
    2. Search midpoint M of perpendicular line that minimize distance between them;
    3. Store the angle formed by the end of Track 1, M and the start of Track 2.

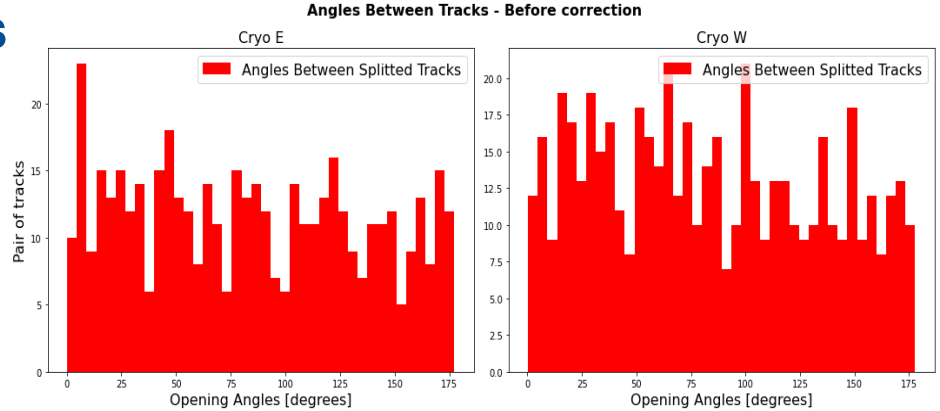


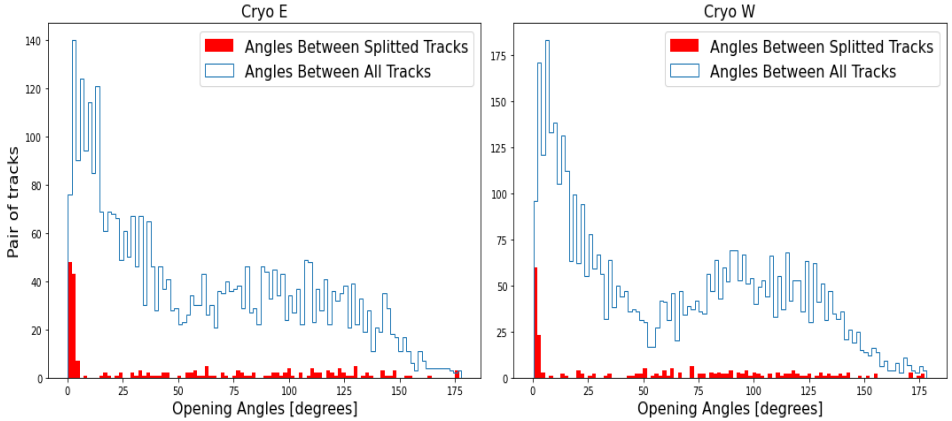


Distributions – Angle between tracks

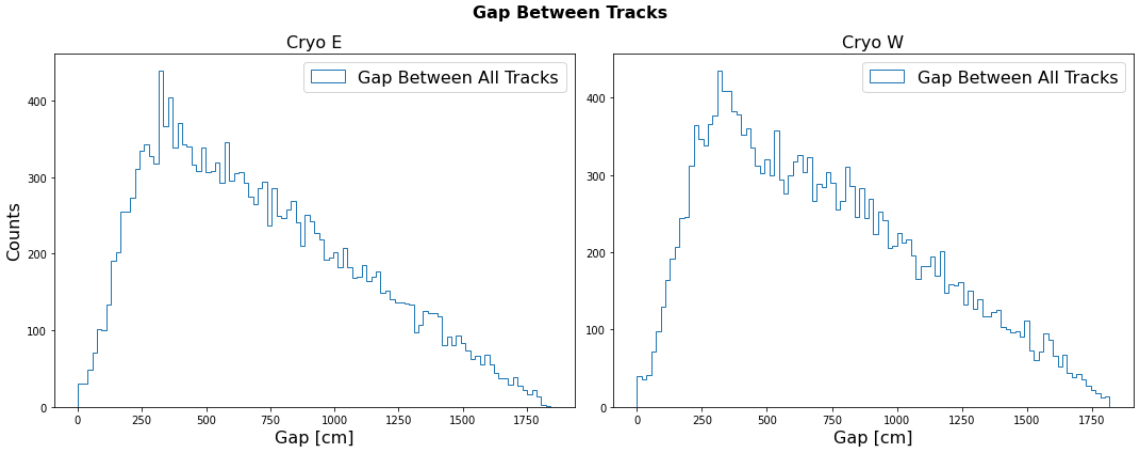
- It is possible to observe that after the correction obtaining the direction on the last N=20 hits, the distribution goes from uniform to peaked in $\theta \in [0,10^o]$.
- It is possible to observe how the cut on the gap (the only one carried out in this analysis phase) is still not sufficient to discriminate the split tracks.

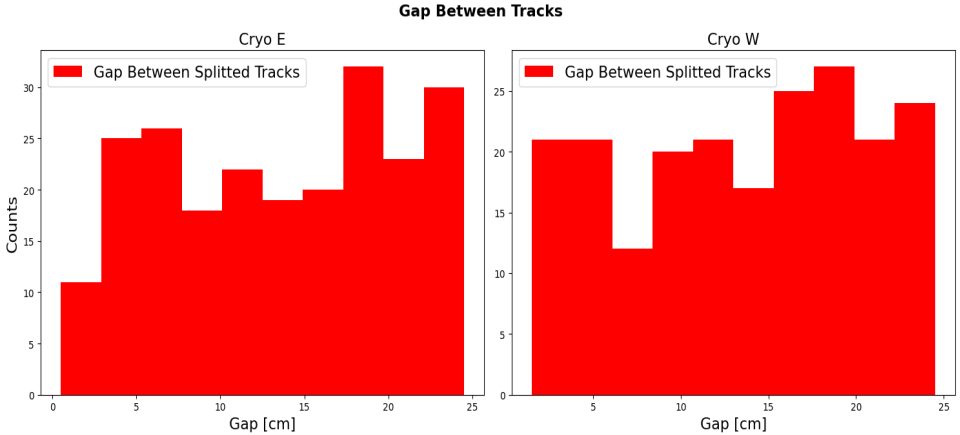
```
std::vector<recob::Track::Point_t> points1;
for (size_t i = std::max(0, int(trackHits1.size()) - N); i < trackHits1.size(); ++i) {
    points1.push_back(track1->LocationAtPoint(i));
}
recob::Track::Vector_t avgDir1(0, 0, 0);
for (size_t i = 1; i < points1.size(); ++i) {
    avgDir1 += (points1[i] - points1[i-1]);
}
avgDir1 = avgDir1.Unit();
```





Distributions – Gap between tracks + Angular efficiency





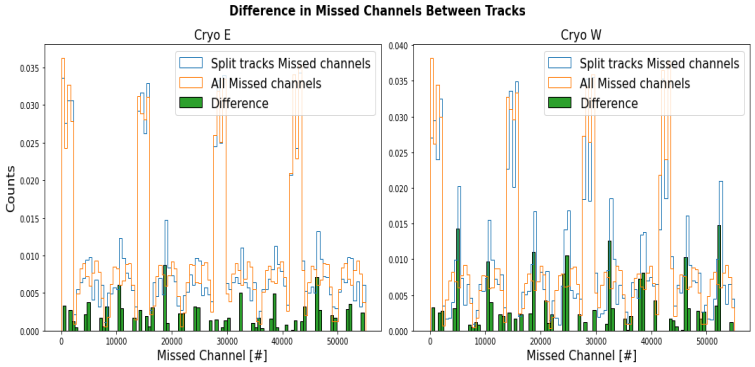
- The gap distribution between all the tracks has a peak near 250-300cm and then decreases linearly;
- Setting a maximum gap at 25cm could at this point be not exactly the best indicator of split tracks.

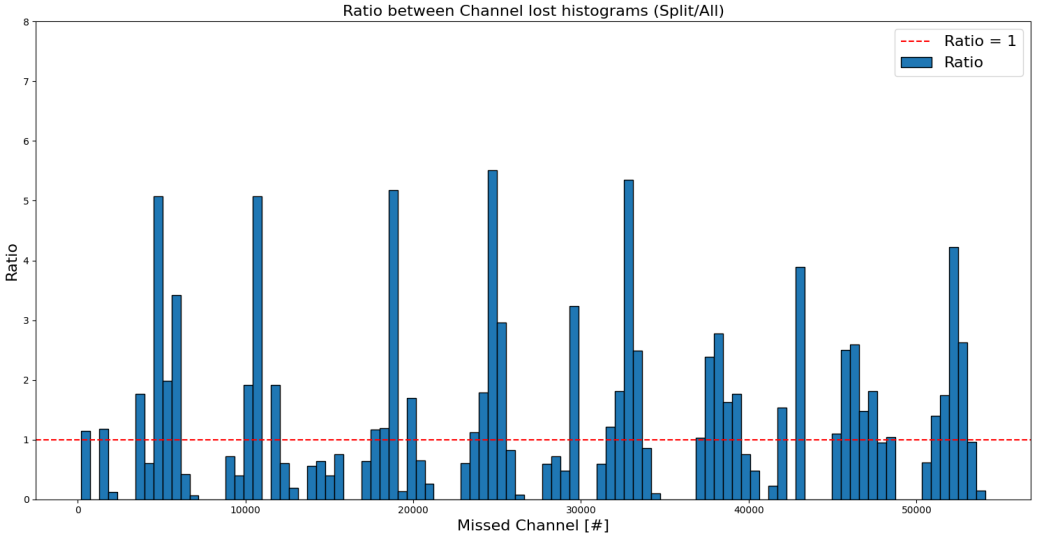
- The angular efficiency (resp. accuracy) of the cut (from gap cut) varies between 22% (66%) with a 2-degree cut and 50% (17%) with a 10-degree cut (over 10 degrees the accuracy worsens without improving the efficiency).

Missed Channel Ditribution

- As a further analysis, currently in preliminary form, we searched for lost channels, defined as the set of channels between the end of a track and the beginning of the next one
- The trend of the lost channels was obtained both for the total pairs of tracks and for the tracks identified as split tracks, and then the ratio was carried out
- The results of this preliminary analysis show how there are sporadically peaks with a number of channels lost due to split tracks greater than those lost randomly

```
for (auto const& planeGeom : fGeometry->Iterate<geo::PlaneGeo>())
{
  try {
    raw::ChannelID_t endChannel1 = fGeometry->NearestChannel(endPos1, planeGeom.ID());
    raw::ChannelID_t startChannel2 = fGeometry->NearestChannel(startPos2, planeGeom.ID());
    for (raw::ChannelID_t ch = endChannel1 + 1; ch < startChannel2; ++ch)
    {
      all_missed_channel->Fill(ch);
    }
  }
 catch (const std::exception& e)
 {
 }
}
```





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