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Modelling detector-specific reconstruction uncertainties in LAr-TPC

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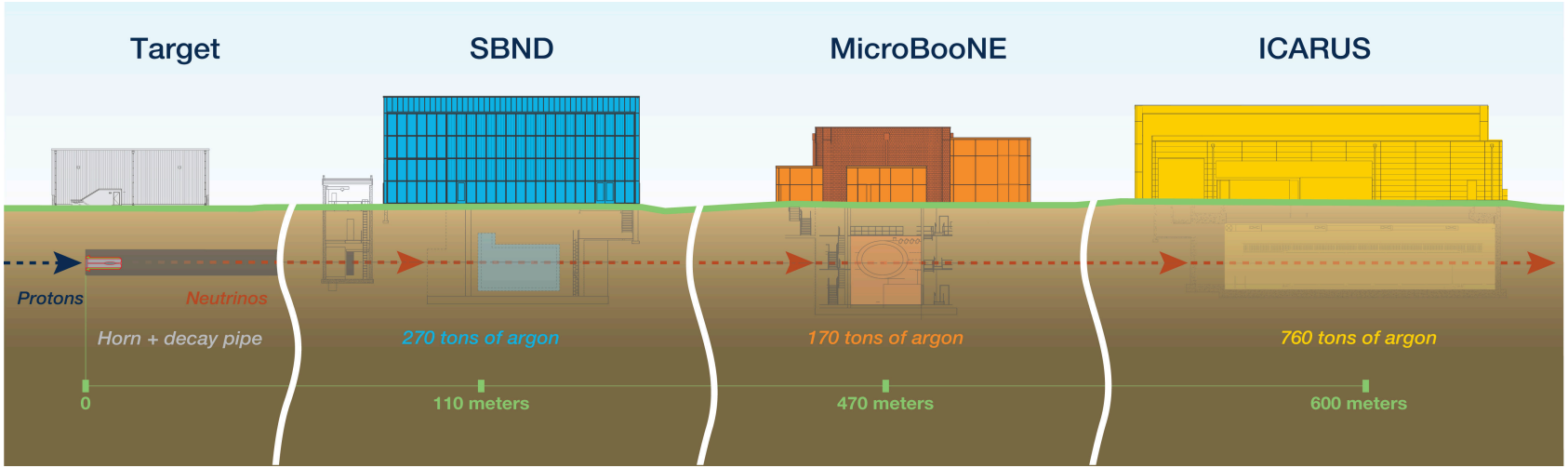
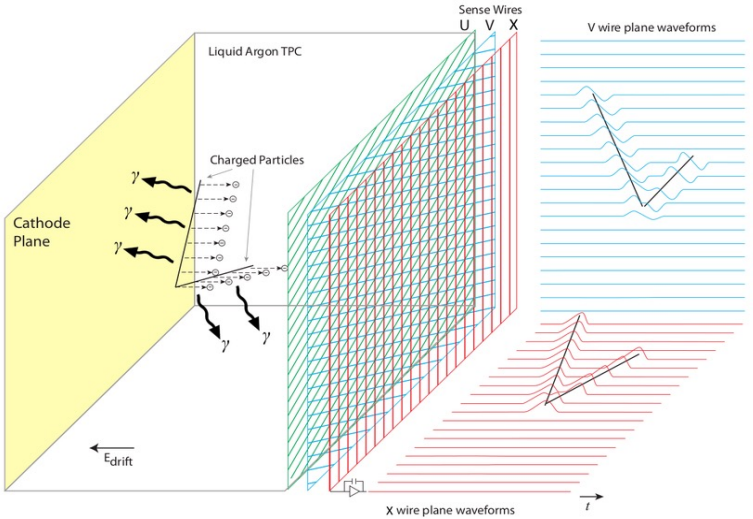
The SBN Program

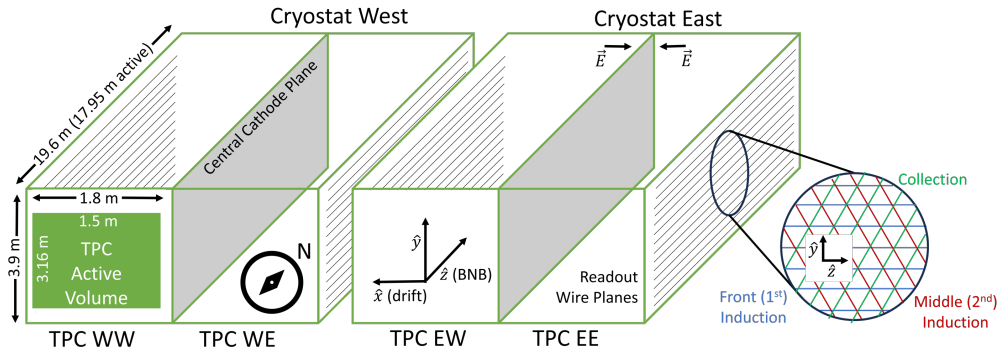
- Experimental observation of neutrino oscillations have established a picture consistent with **the mixing of three neutrino flavors** (ν_e, ν_μ, ν_τ) with three mass eigenstates (ν_1, ν_2, ν_3): however, in recent years, several experimental «anomalies» (**Reactor/Gallium** and **LSND/MiniBooNE anomalies**) have been reported which could be hinting at the presence of **additional neutrino states** with larger mass-squared differences participating in the mixing;
- 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 sterile neutrino hypothesis with the peculiarity of seeing the neutrino oscillation as the disappearance of ν_μ (SBND) and the appearance of ν_e (ICARUS).



LArTPC Working Principle in ICARUS

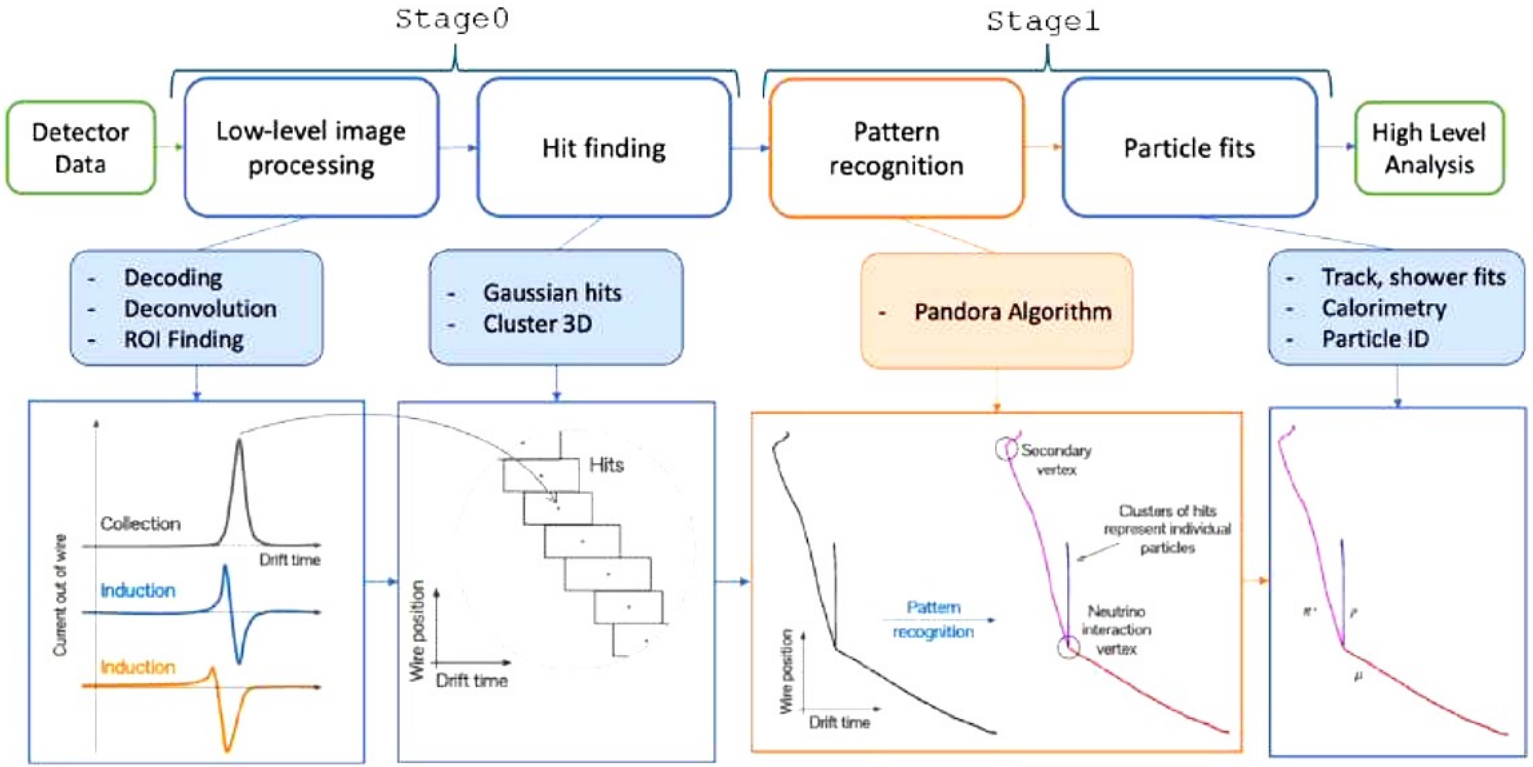
- Reconstruct tracks and showers with high level of **detail** and **efficiency**, as well as to provide a **precise measurement of ionization charge** necessary for good particle identification based on ionization energy loss;
- Operation based on subsequent steps:
  - **Ionization electrons production**;
  - **Drifting to the wires**;
  - **Creation of signals**.





- ICARUS consists of **two** identical adjacent modules (**cryostats**); in each there are **two TPCs** separated by a central, vertical, common **cathode;**
- Each TPC has **three parallel read-out planes**: **induction-1** has horizontal parallel wires, while **induction-2** and **collection** are oriented $\pm 60^{o}$ with respect to it;
- ICARUS consists of a total of **55,295 readout channels.**

Event Reconstruction in ICARUS



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Split Tracks

- The purpose of this work is to **analyze and model detector-specific reconstruction uncertainties in Lar-TPC**. Such reconstruction inefficiencies are identified during the «Patter Recognition» phase and significantly affect the subsequent steps of Particle Fits and High Level Analysis.

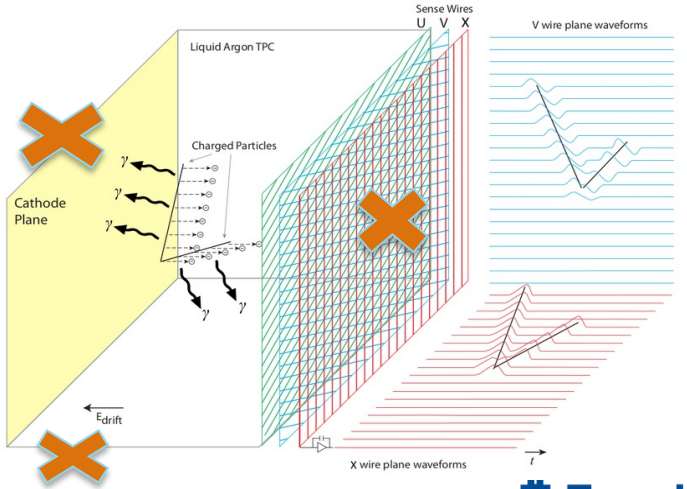
Erroneous estimation of particle energies

Poor Particle Identification

Substantial reduction in the efficiency of characterizing events associated with neutrino interactions

- An important class of detector-specific reconstruction uncertainties is represented by **«Splittig Tracks» :** these are caused by missing hits that were not accounted for at the reconstruction level or that PANDORA was not able to account for when stiching the divided tracks segments. At the detector level, the **most common known reason for track splitting** are:

  - ✓ Malfuctioning channels;
  - ✓ Presence of the cathode Plane;
  - ✓ Electric field distortions.



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Goal of the internship

- The goal of my internship is moving on sequential steps:

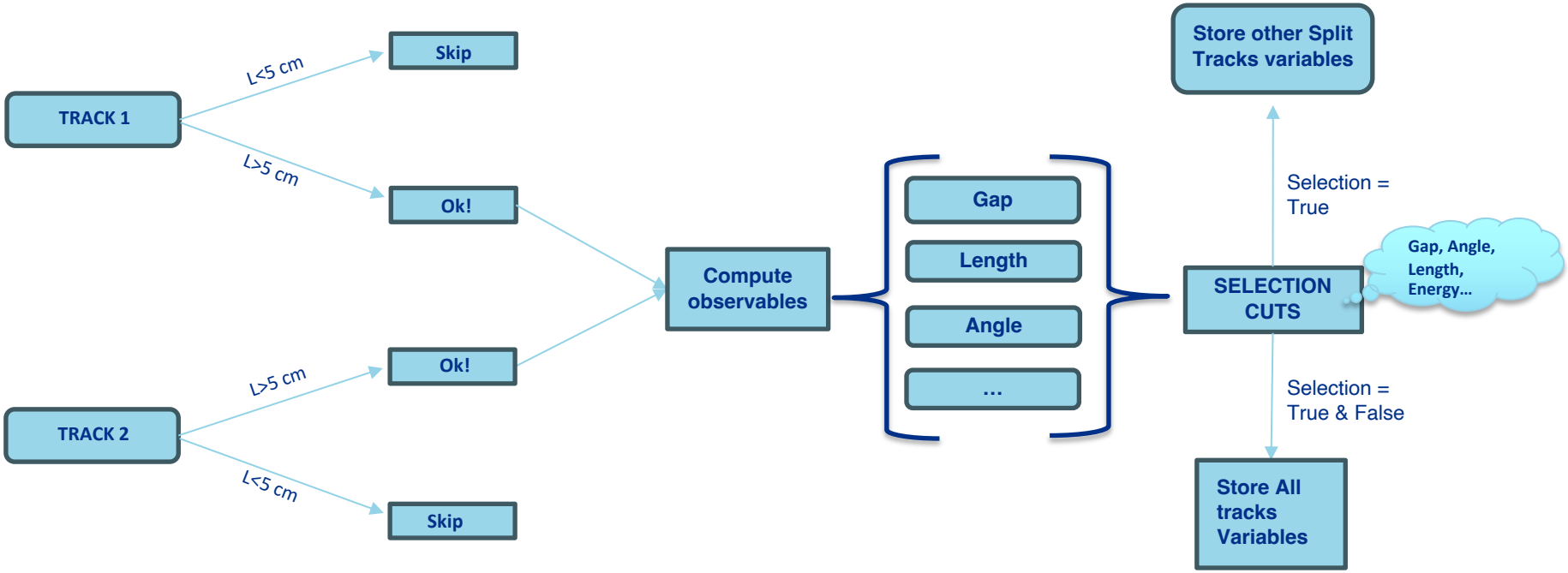
  1. The first step consists in writing a plug-in, based on LArSoft's ART framework, whose purpose is to **identify the presence of split tracks** based on their geometric characteristics (length, gap and angle between them);
  2. Use the plug-in on various runs in order to **validate its selection performance**, **reconstruction of the quantities of interest** and study the distribution of the observables in order to select the **most favorable cuts**;
  3. Study the **distribution of lost channels** due to split track phenomena on different wire planes, understand their behavior and **quantify the coherent noise component** to which the different planes are subject. Implement the distribution of lost channels to the **HARPS tool** in order to generate a data sample enriched by the presence of multiple split tracks.

  In particular, this discussion will be divided into four parts

  1. Presentation of the Plug-in form and focus on the calculation of the observables of interest;
  2. Determining the cuts by applying the plug-in to run 9435 and validating the plug-in capabilities by applying it to runs 7xxx;
  3. Study of the distribution of lost channels and HARPS tool;
  4. Conclusion.

1. Plug-in logic and calculation of variables of interest

1. Logical structure of the Plug-in used – general scheme



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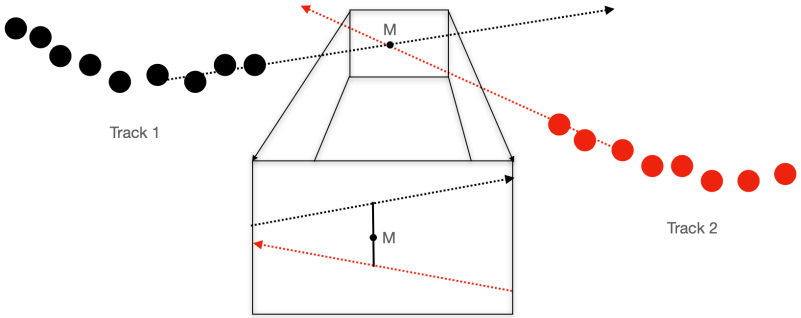
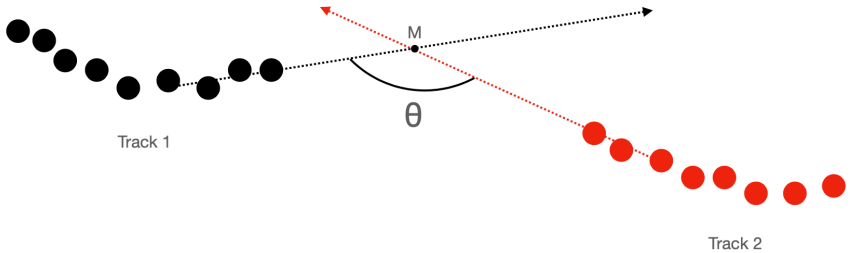
1. Logical structure of the Plug-in used – Angle between tracks (1)

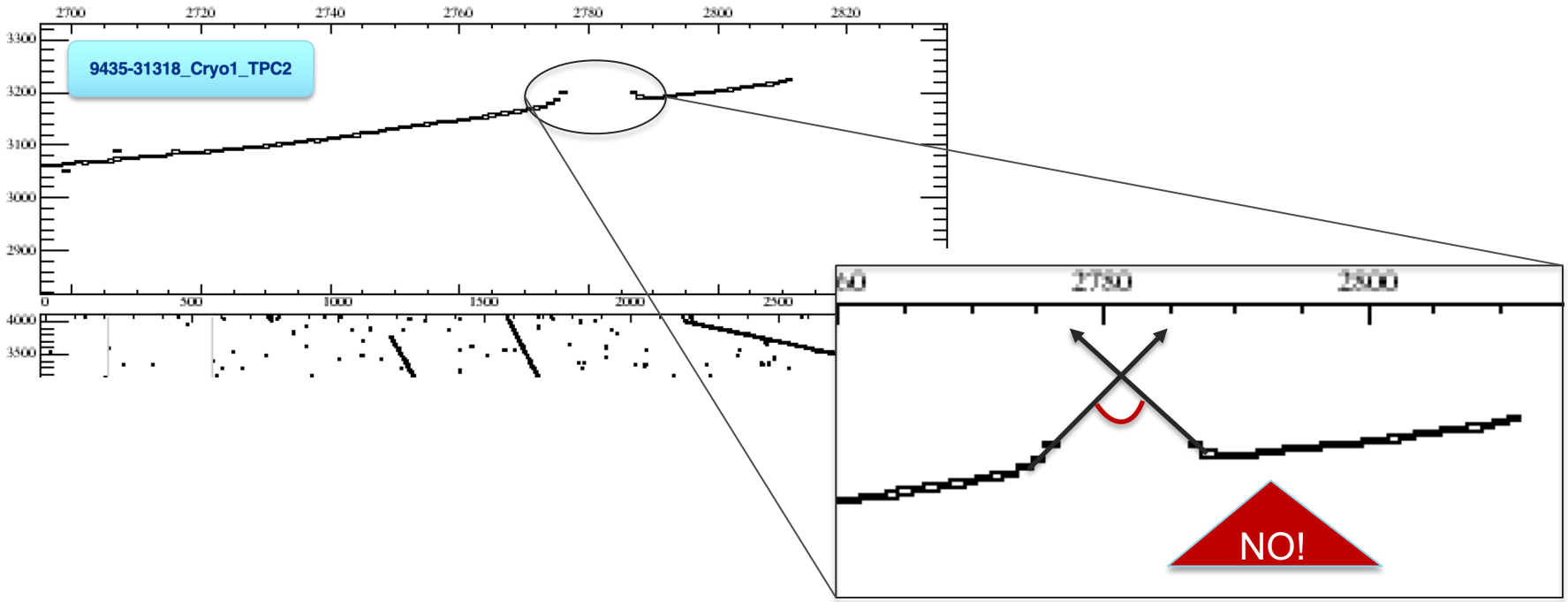
- For the angle, two cases are possible:
  - **Parallel Case:** Take the angle between the common direction and the line connecting the start and end subtracks this from π to approximate a difflection angle.
  - **Not parallel case:** In this case we proceed in steps
    1. Based on the last_1 and first_2 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.





1. Logical structure of the Plug-in used – Angle between tracks (2)

- The situation is never that easy…



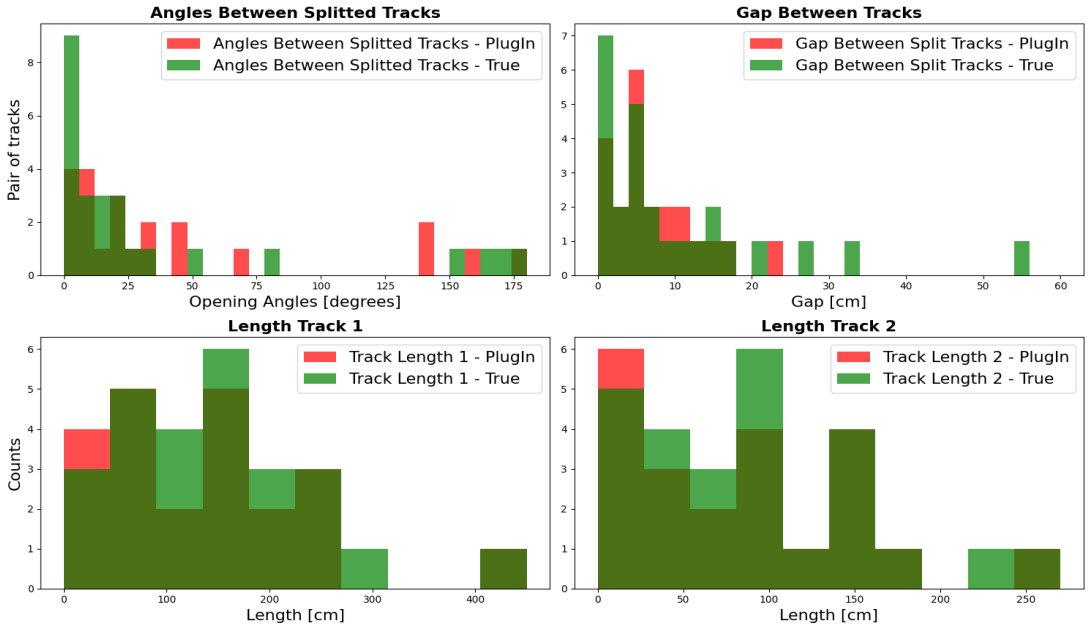
2. Determining the cuts by applying the plug-in to run 9435 and validating the plug-in capabilities by applying it to runs 7xxx

(7152, 7190, 7230, 7244, 7262, 7334, 7339 , 7418, 7428, 7471, 7504)

2.1 Run9435: Comparison between selected and true variables

- To validate the plug-in's ability to reconstruct the variables of interest run 9435 was used, of which the presence of 26 pairs of split tracks is known.
- The search was limited exclusively to anomalous events and a selection was made in the search for pairs of tracks with a **length greater than 5cm** and with a **gap less than 25cm**.
- The table shows a quantitative comparison to confirm the **accuracy** of the reconstruction of the variables of interest.

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



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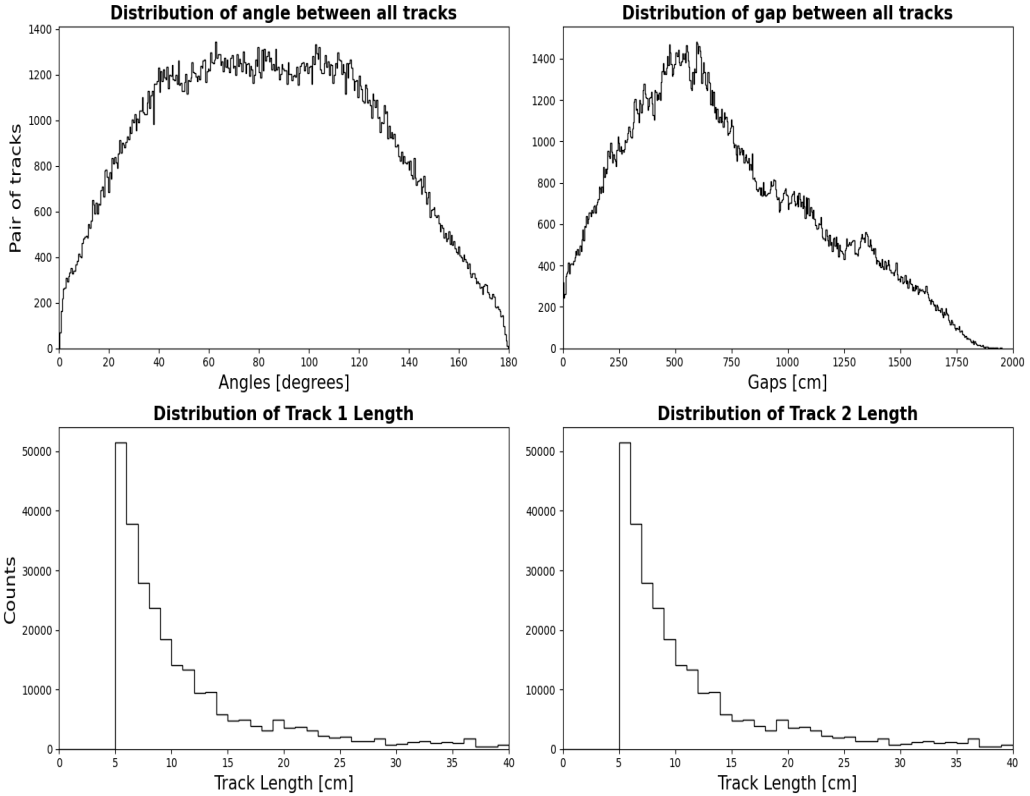
2.1 Run9435: Distribution of variables of all tracks and cuts selection

- By comparing the trends of the observables for split track phenomena with the totality of the pairs (see right), **three simultaneous cuts** were obtained to be performed to identify split track events on a generic sample:
  - Length of the tracks

    L1, L2 > 40 cm
  - Gap between the tracks

    Gap < 25cm
  - Angle between tracks

    $\boldsymbol{\theta} \in \{ [\mathbf{0}, \mathbf{25}]^{o} \cup [\mathbf{155}, \mathbf{180}]^{o} \}$
- The number of tracks that pass the three simultaneous selections is approximately **0.007%.**



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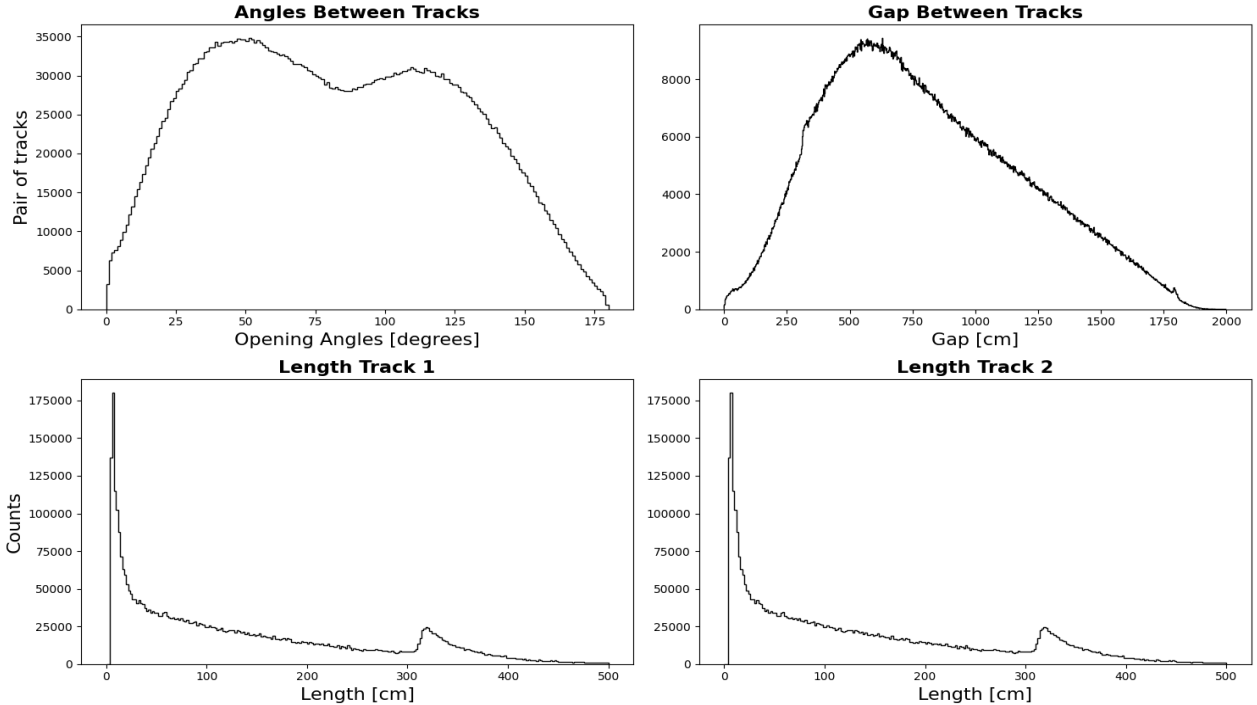
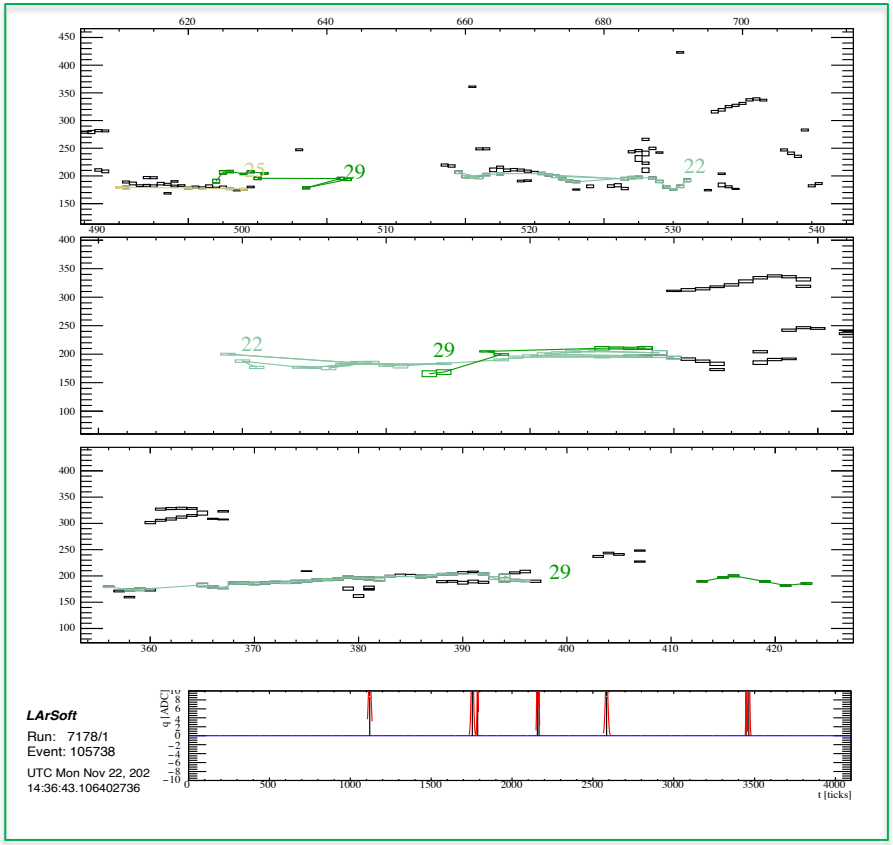
2.2 Run7xxx: All tracks

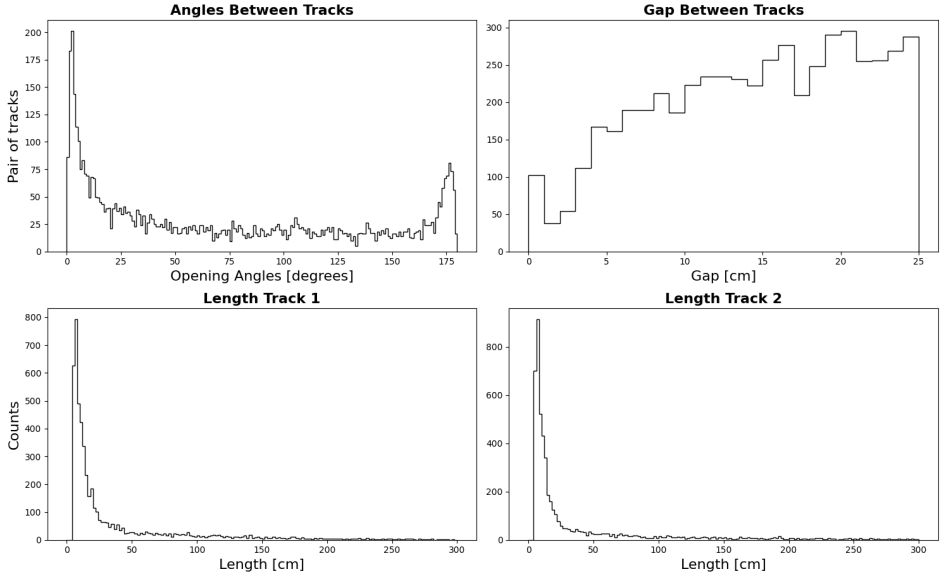
- In runs 7xxx a trend **similar to that of run 9435** is observed (although with greater statistics), except for the length of the tracks which has a **peak around L=320cm** (probably referred to tracks associated with muons);



- The total number of track pairs found before selections is **N=4,362,526**.
- The next slides will show the **cuts performed sequentially** in order to highlight the need for increasingly precise selections for the identification of split track events.

2.2 Run7xxx: Selection on Gap





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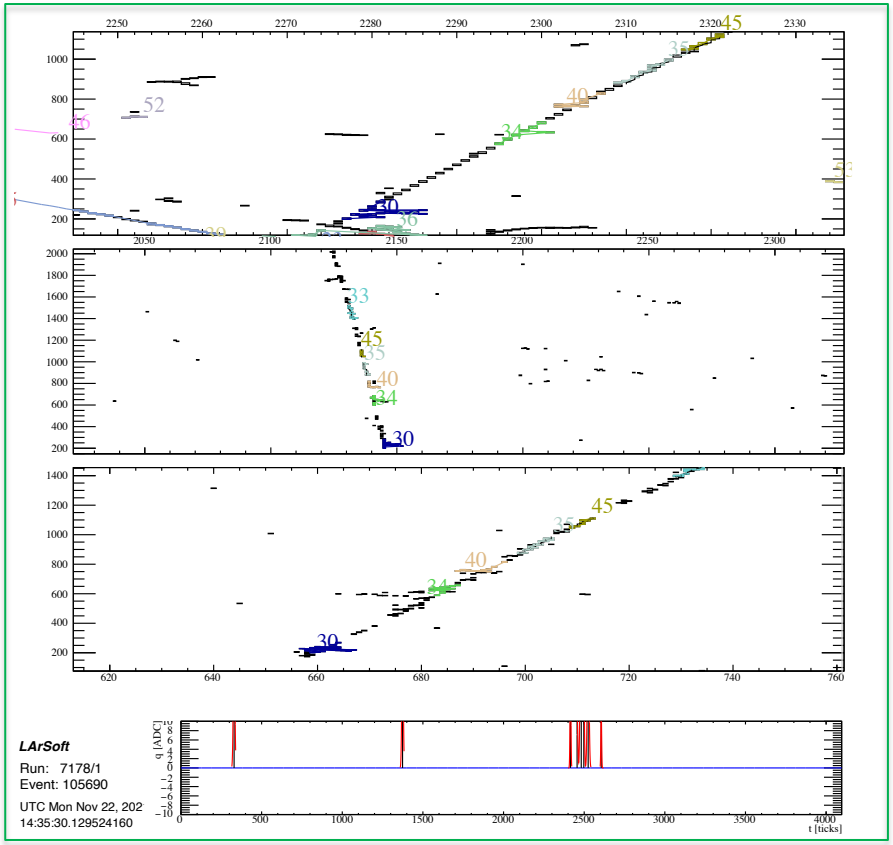
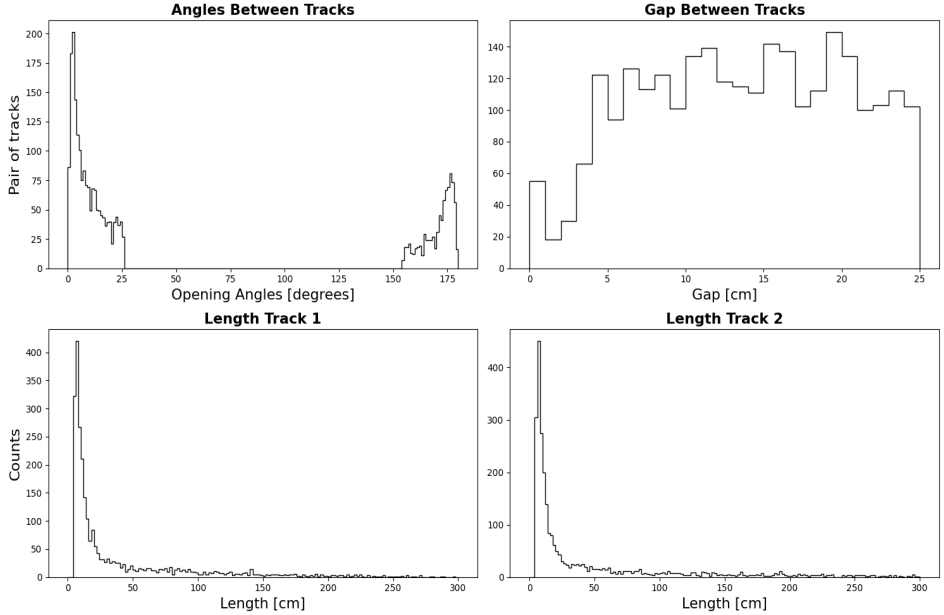
2.2 Run7xxx: Selection on Gap and Angle





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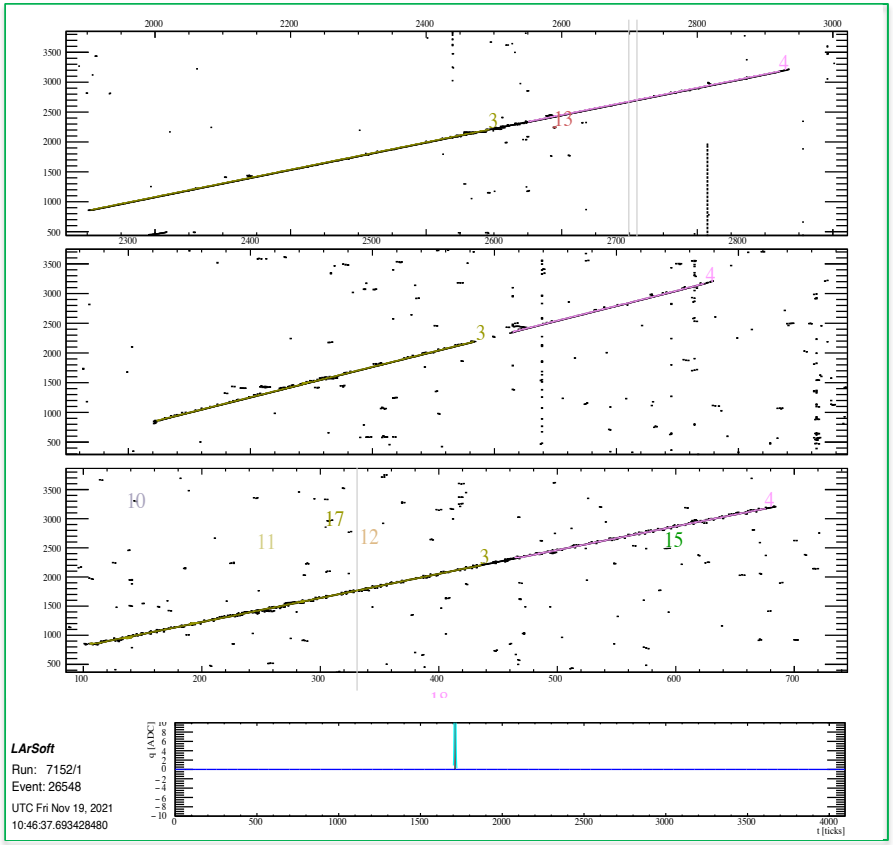
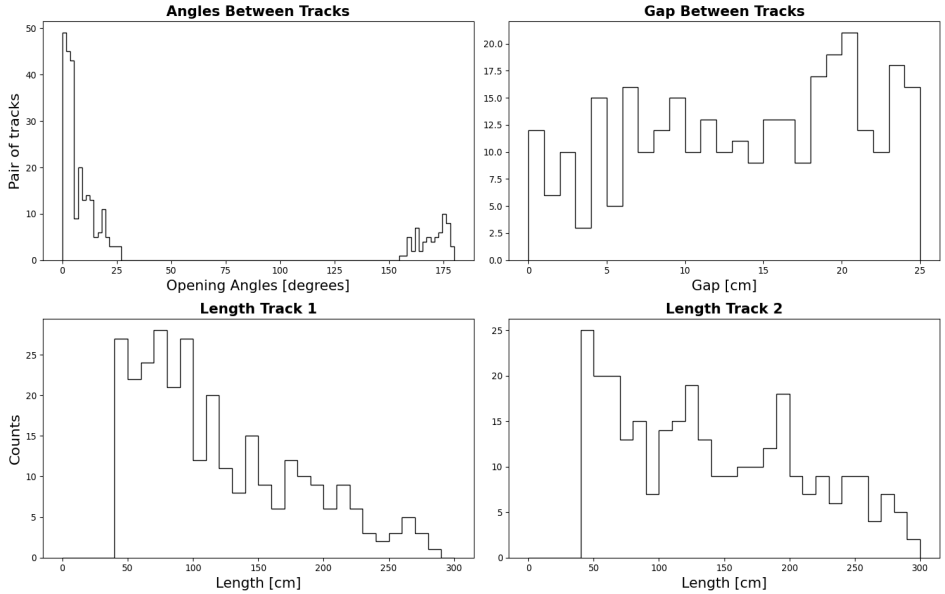
2.2 Run7xxx: Selection on Gap, Angle and Length





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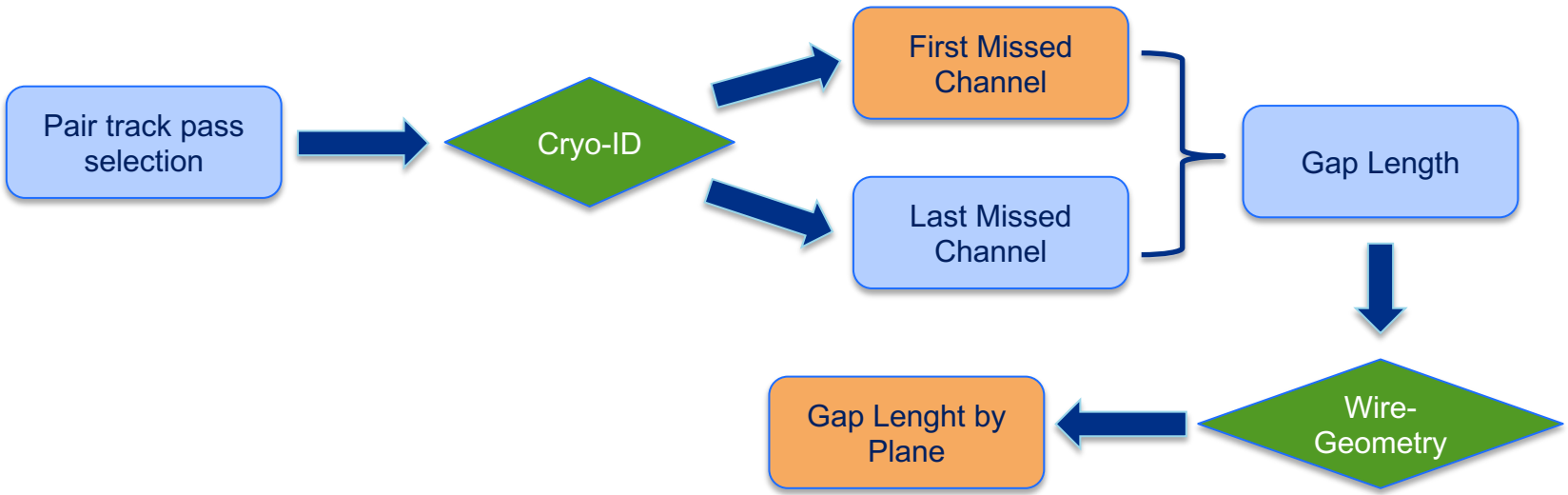
3. Study of the distribution of lost channels

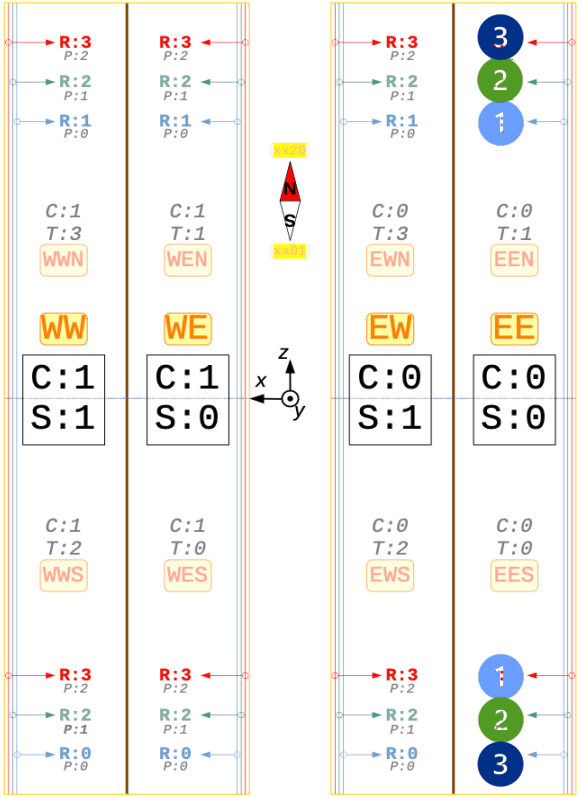
3. Lost Channel Storage Logic

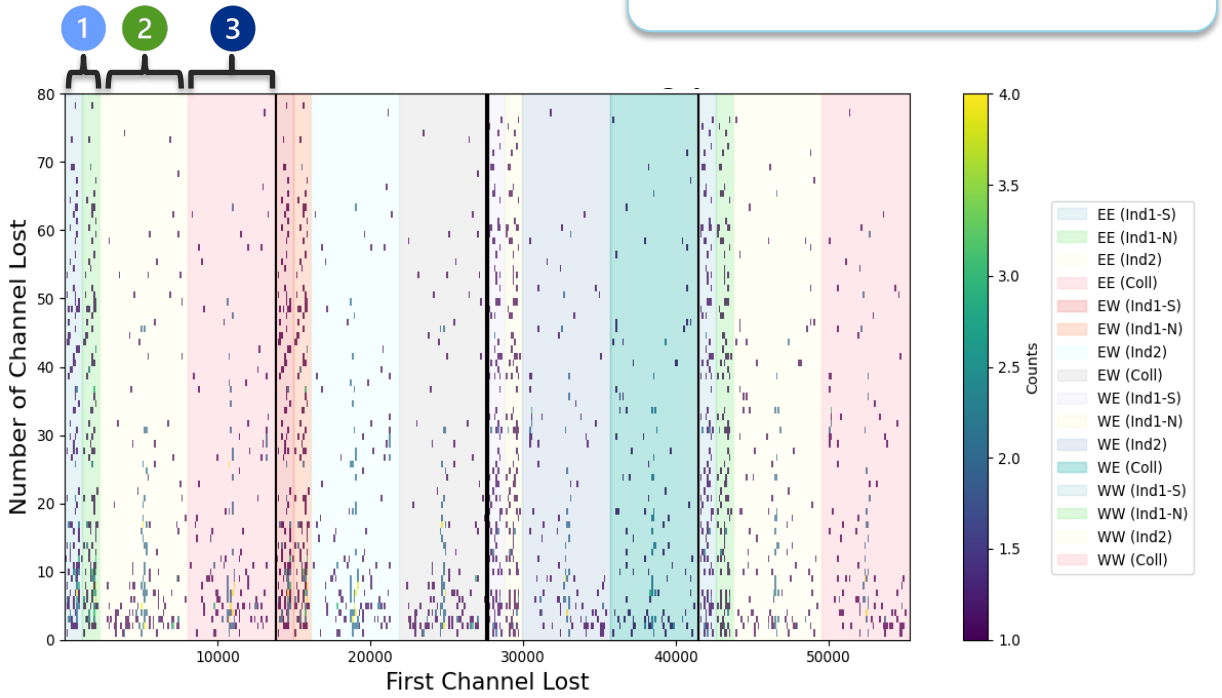
- Once the reconstruction and selection capabilities of the plug-in have been confirmed, the last study performed is associated with the **distribution of lost channels**: this study is useful to understand the portions of the detector most subject to split track phenomena and quantify their impact on the reconstruction of events;
- The study of lost channels will also be implemented in the **HARPS** (Hit Activity Removal from Particles for Systematics) tool: the goal of HARPS is to modify the events to remove certain hits (according to channel lost distribution) and thus generate modified samples and study how reconstruction changes depending on the applied change.



3. Missed Channel vs Gap Lenght distribution

Memo: IND1 is split into IND1-S and IND1-N due to wire cutting at z=0





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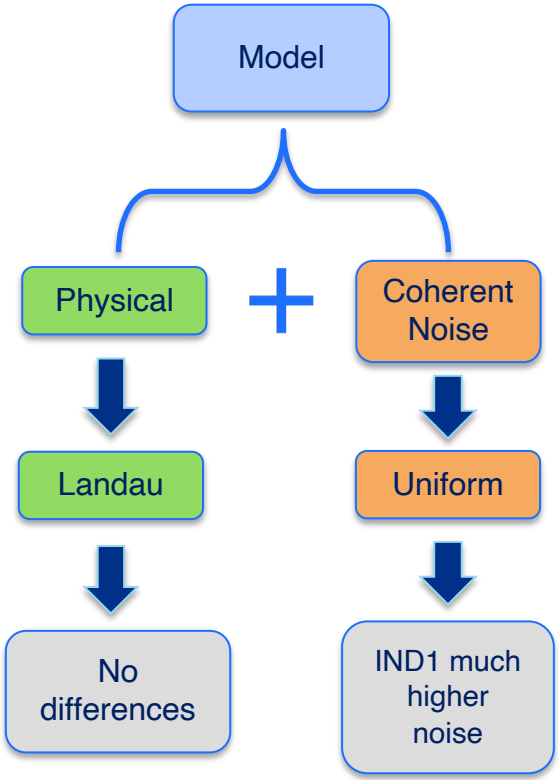
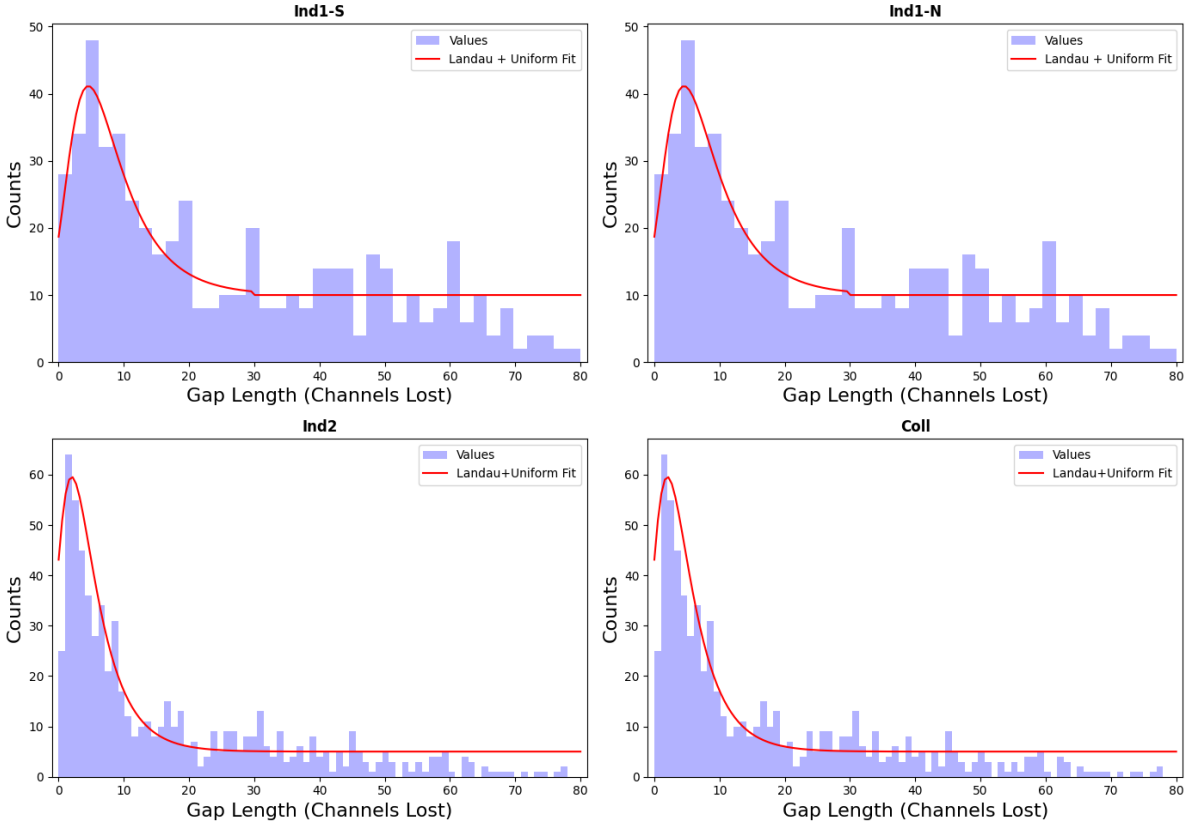
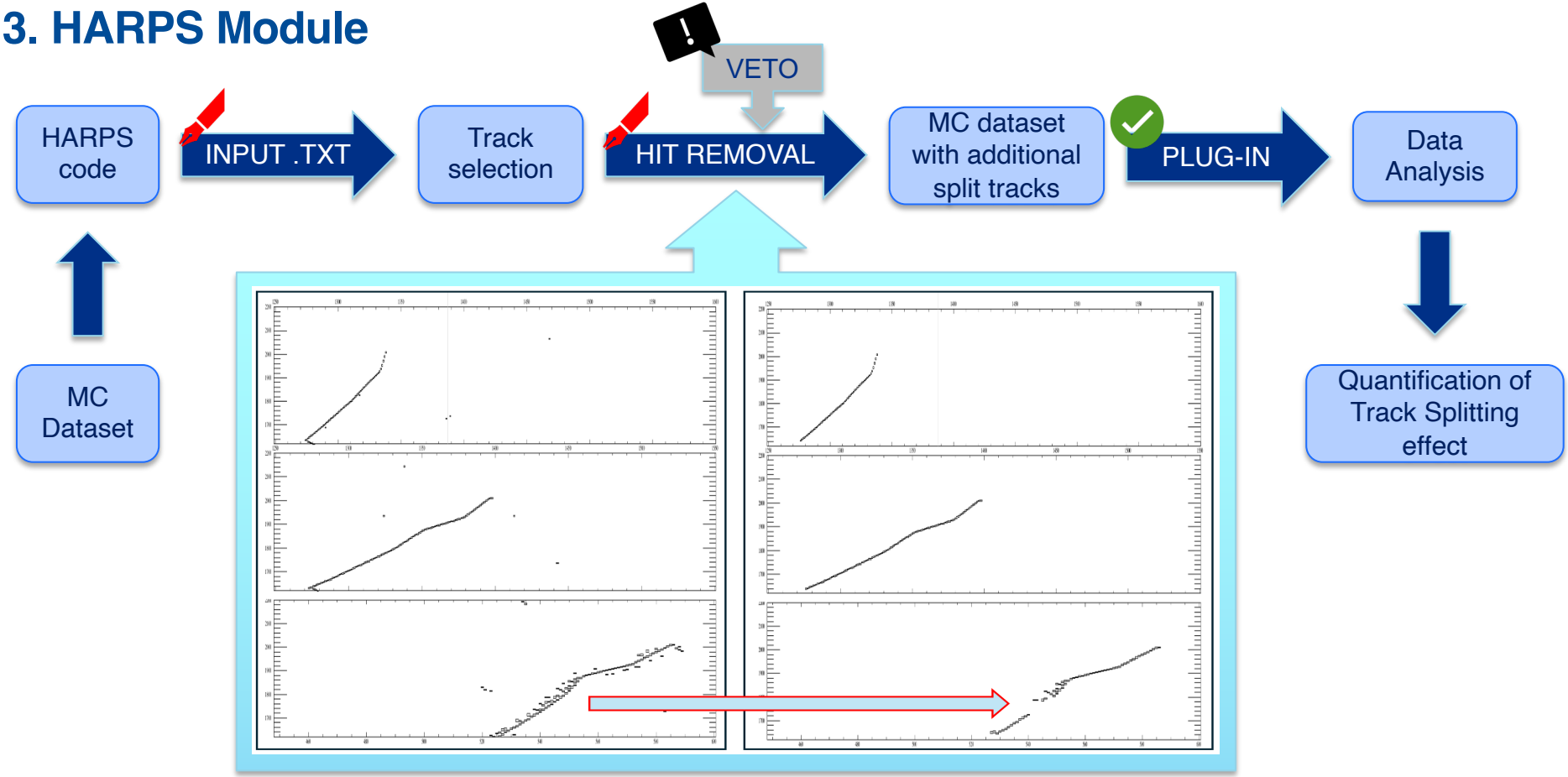
3. Channel lost - fit





3. HARPS Module



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4. Conclusion

4. Conclusion

What has been done?

- The importance of **accurate event reconstruction** was understood, and several potential issues were highlighted;
- A versatile and optimized **plug-in in ART was developed**, which can be applied to any dataset to **identify Split Tracks based on geometric characteristics** and **store their main observables**: angle between tracks, gap, missed channels and segment lengths;
- The **geometric distribution of Split Tracks** in the detector was studied, identifying the distribution followed by the number of missed channels. Using this, the result was implemented into the HARPS module.

What are the possible developments?

- Implementation of **additional methods for selecting split tracks event**s (e.g., energy-based selections);
- **Validation of the plug-in's performance** on further runs;
- More detailed study of the **coherent noise component** in the lost channel distribution.

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**
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- 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;
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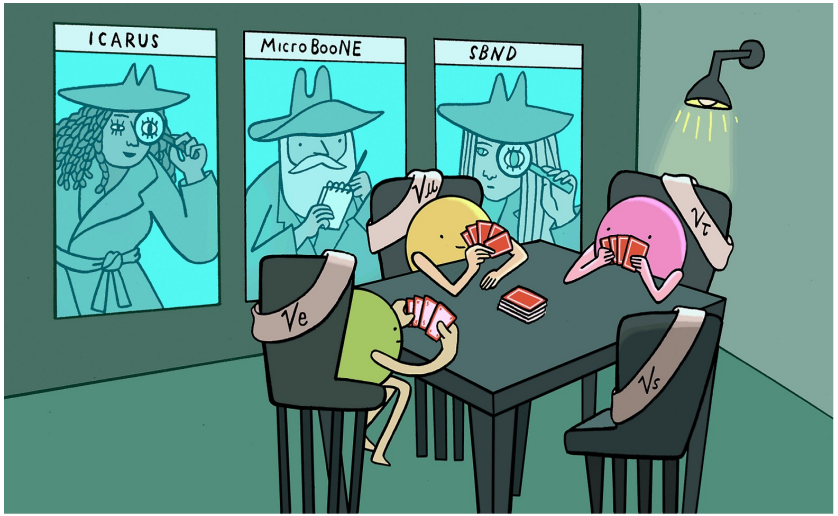

2.1 Run9435: Comparison between selected and true variables

- In this preliminary phase the main objective was to validate the plug-in's ability to reconstruct the variables of interest and to search for the optimal cuts to be performed to select split track events. For this purpose, run 9435 was used, of which the presence of 26 pairs of split tracks is known (whose characteristics are known and collected in drive).

- Therefore, knowing the anomalous events, the search was limited exclusively to these and a selection was made in the search for pairs of tracks with a **length greater than 5cm** and with a **gap less than 25cm**. The results obtained are presented in the figure, the quality of the selection is summarized in the table:

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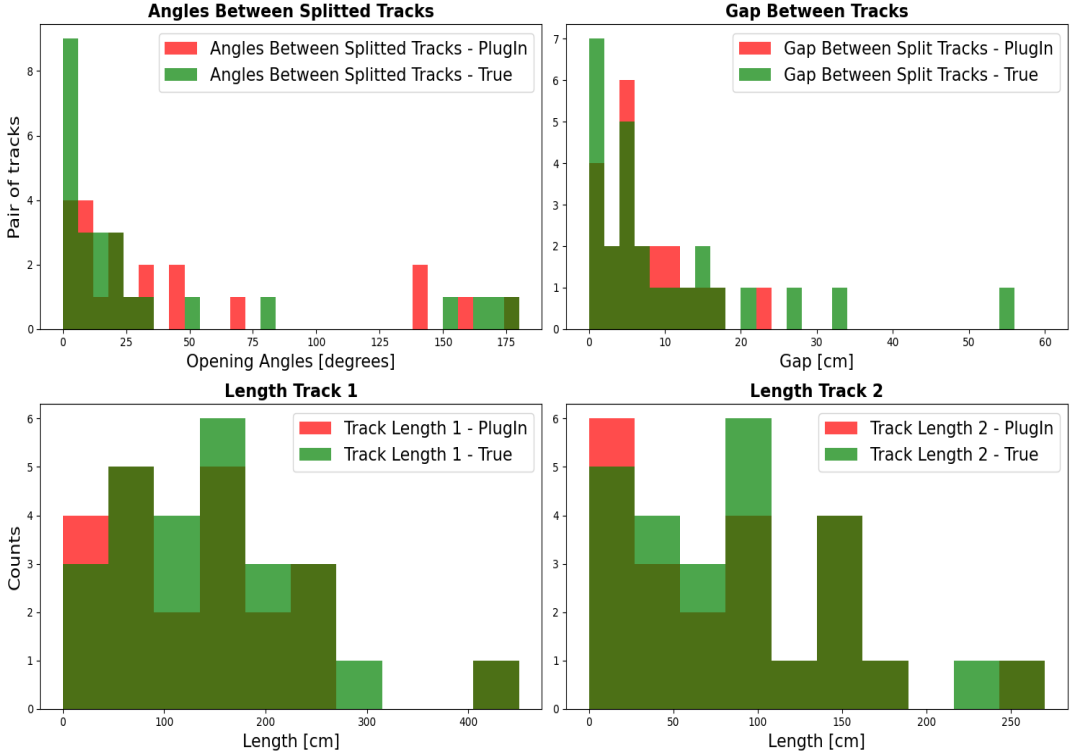
Gap	18	4	8
Length1	21	1	5
Length2	21	1	5



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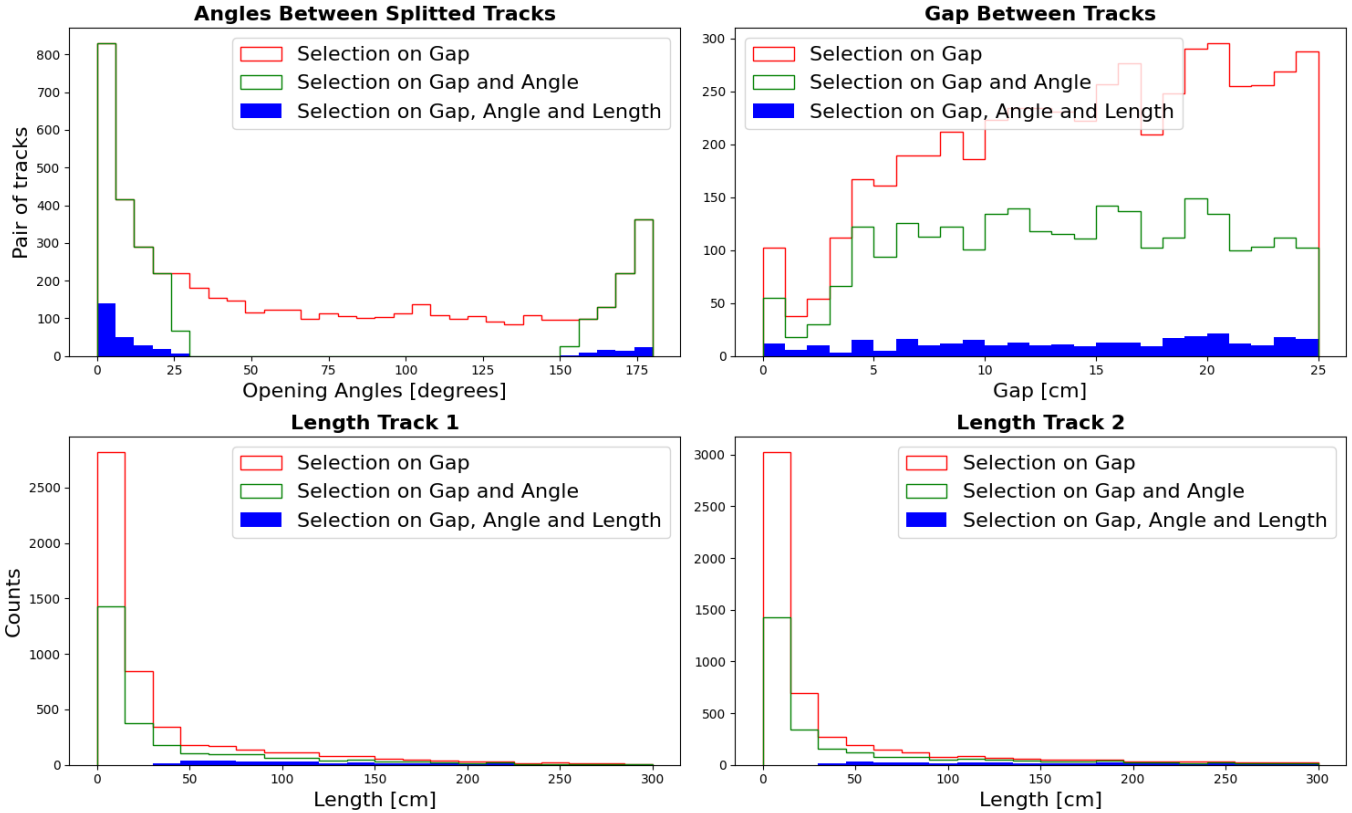
3. RUN7xxx: Comparison between different selection steps



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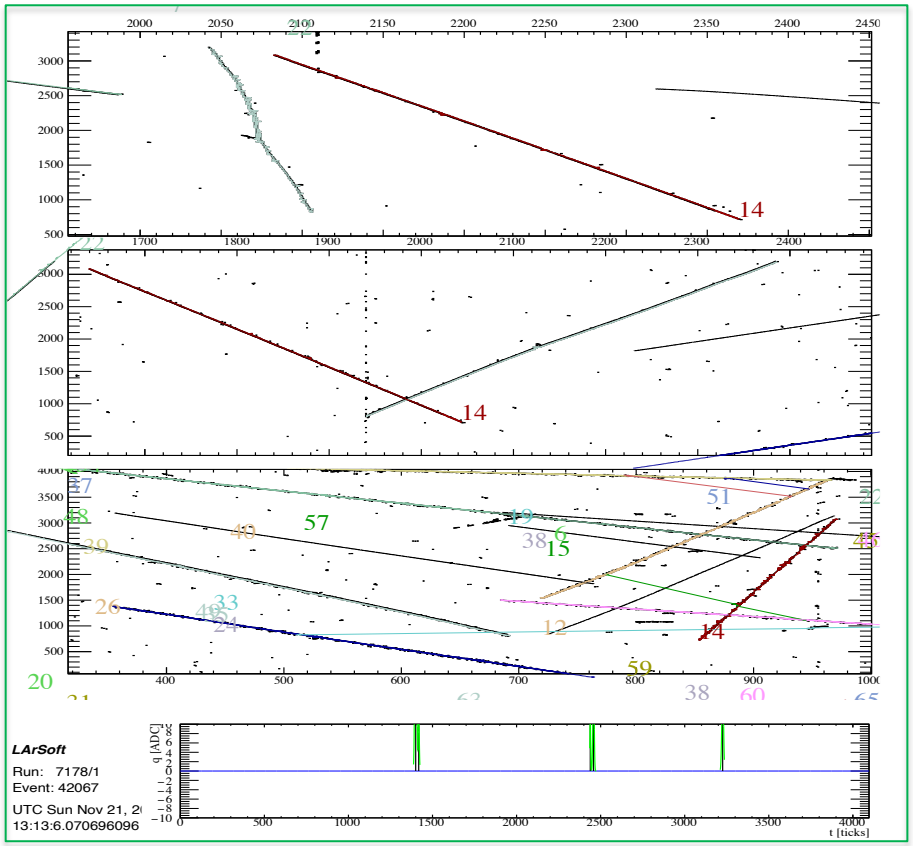
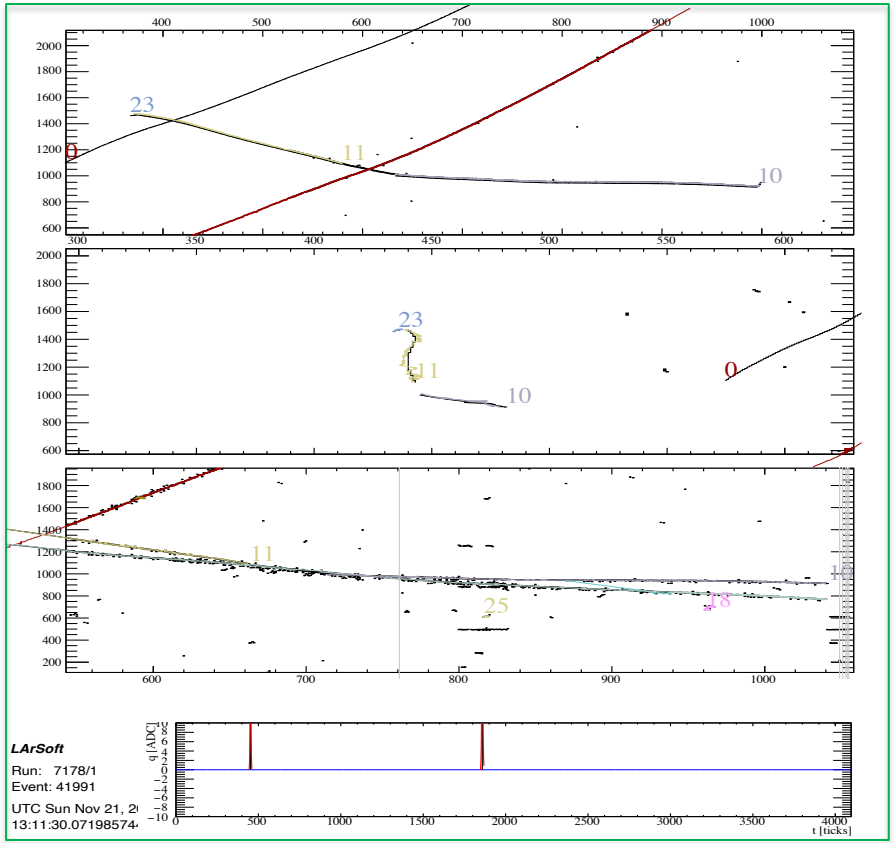
3. RUN7xxx: Abnormal Examples





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