Status report on cosmic muon event tagging with light signal

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Introduction

- WA105 SB Meeting, 14 April 2017:
  - ~30% of cosmic muons can't be detected (S1 photons don't reach the PMT array)
  - A peak search algorithm has been developed: tagging of ~65% of detectable muons

- Outline:
  - **Undetectable** muons **characteristics**
  - Algorithm **efficiency** for λ_{Abs}=30m
  - Algorithm **efficiency** for λ_{Abs}=4m
  - Use of the S1 peak **exponential shapes** to improve the efficiency (very preliminary)

- Study done with:
  - **PMT quantum efficiency**: 0.20
  - Electroluminescence gain **G=300**
  - **PMT** and **electronics response** not taken into account
  - **Sum** of the **36 PMT** signals
  - **400ns** sampling
  - PMTs **non-uniformly** spaced

Fraction of muons depositing photons on PMT array

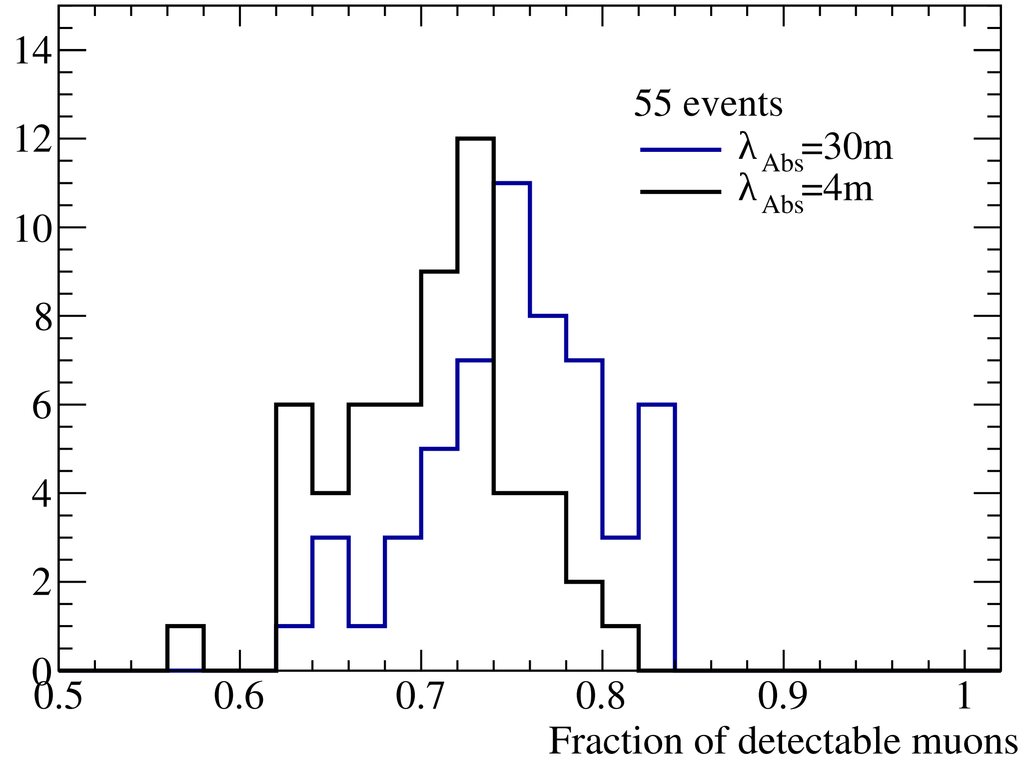
Detectable **muon:** muon inducing **S1 signal**
Undetectable **muon:** muon which **doesn't** induce a S1 signal

- A lot of photons **don't reach the PMT array (mostly** due to the **absorption** in LAr and **absorption** on stainless-steel **components)**
- If all the photons produced by a muon are absorbed, this muon can't be detected using the **light signal**

Study done with 55 cosmic events:

- λ_{Abs}=30m
  → **75.1%** of muons are detectable
- λ_{Abs}=4m
  → **70.4%** of muons are detectable

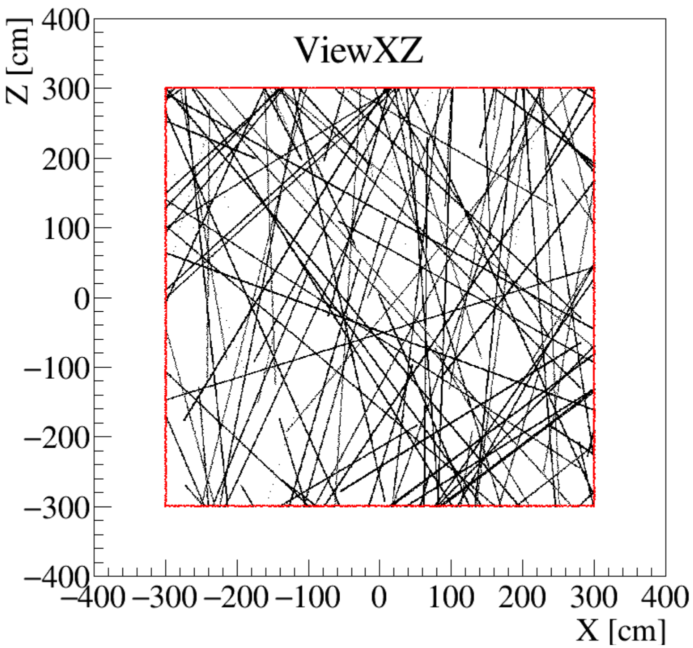
→ The **difference** between the two λ_{Abs} is **small**: most of the photons impacted by the LAr absorption are **already lost** at λ_{Abs}=30m

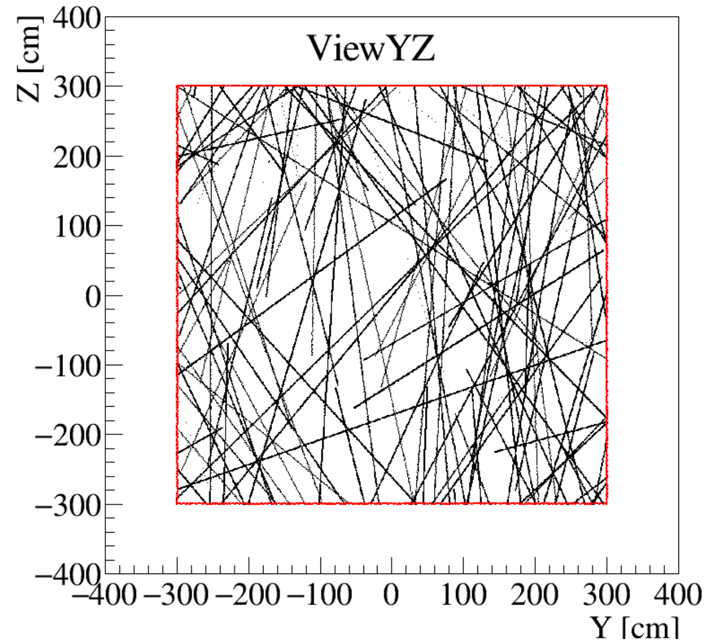


Undetectable muon trajectories

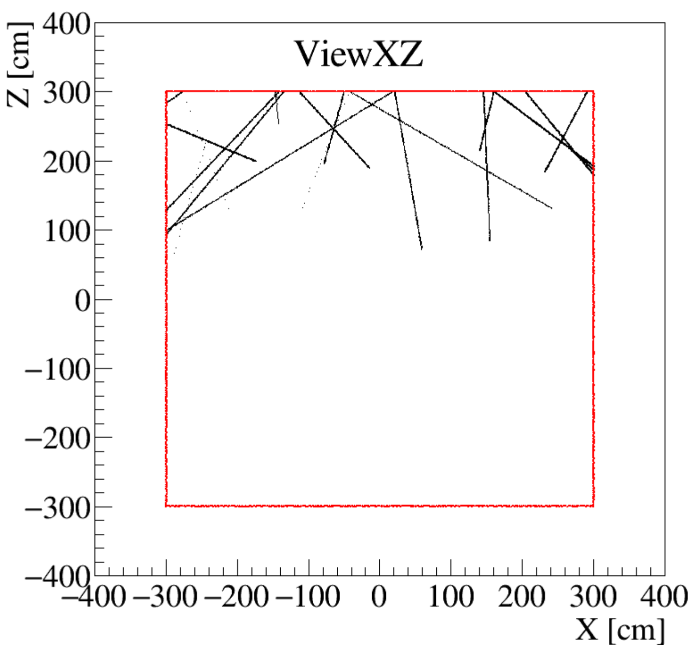
Cosmic muon trajectories for **1 event**

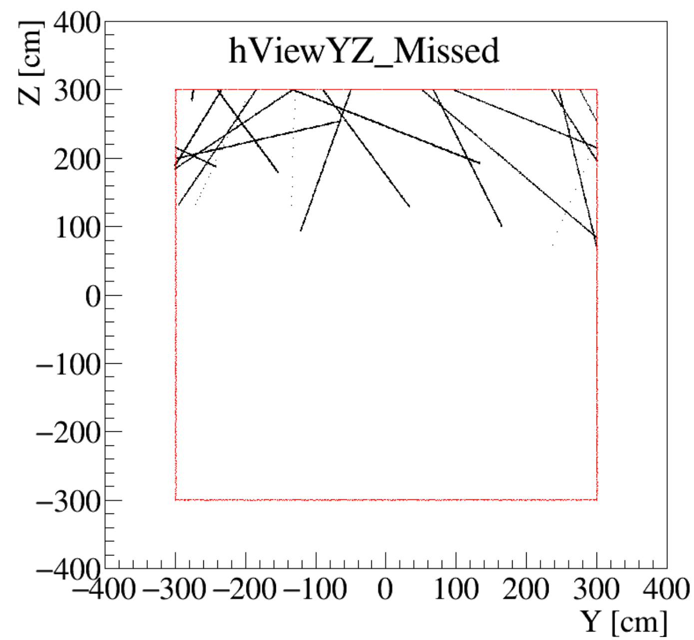
All comic muons entering the fiducial volume within the **(-4ms , +4ms)** time window





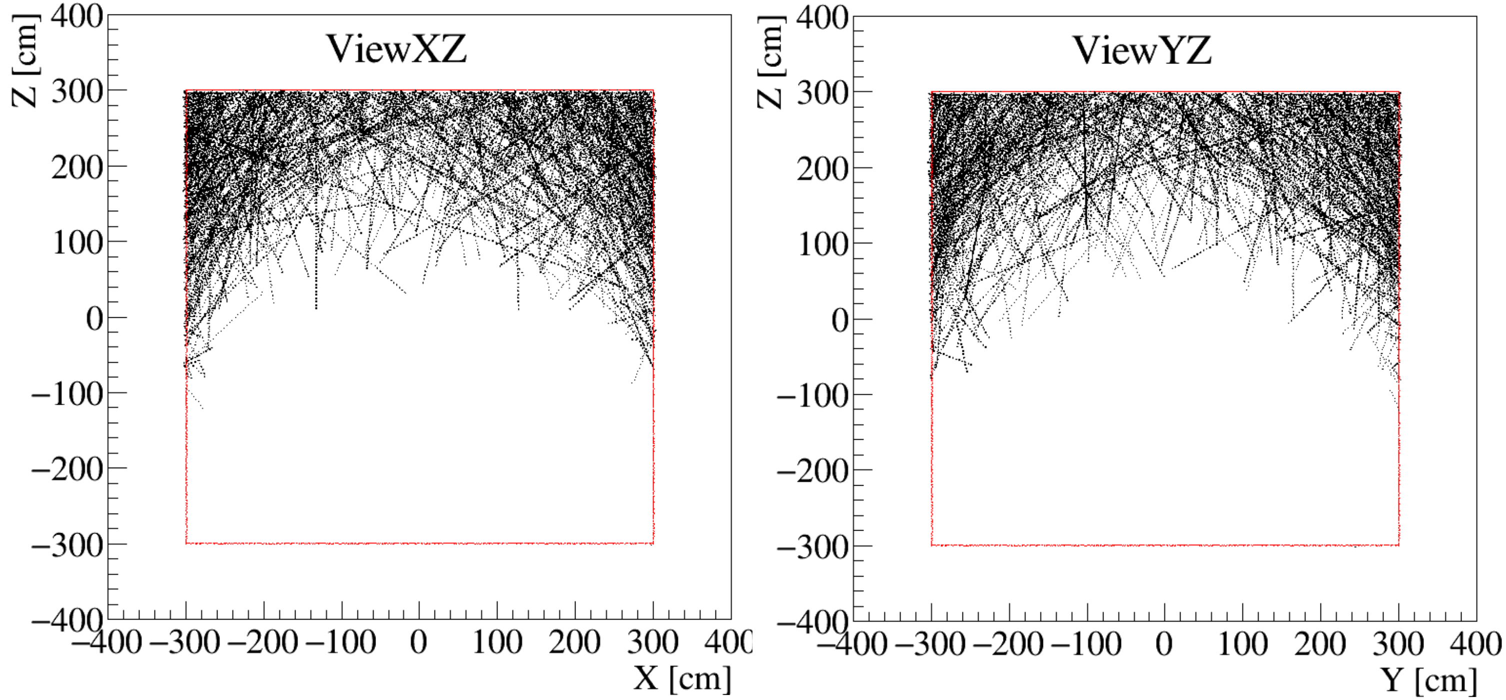
Undetectable muons





Undetectable muon trajectories

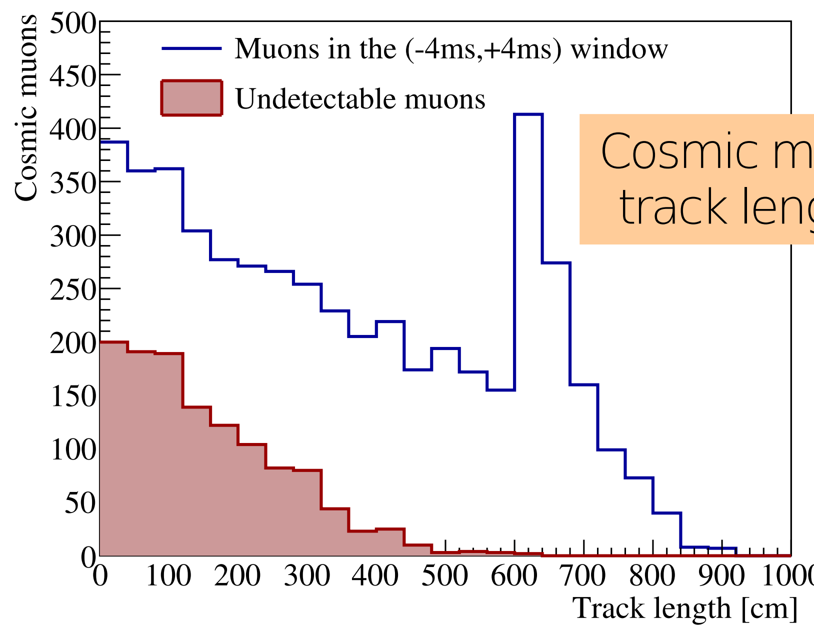
Trajectories of **undetectable muon** for 55 events



Undetectable muons:

- Muons traveling at the top **of the detector**, especially in the corners
- Muons with short **track length**

→ It amounts to about 25% of all cosmic muons



Cosmic muons track lengths

Peak search algorithm

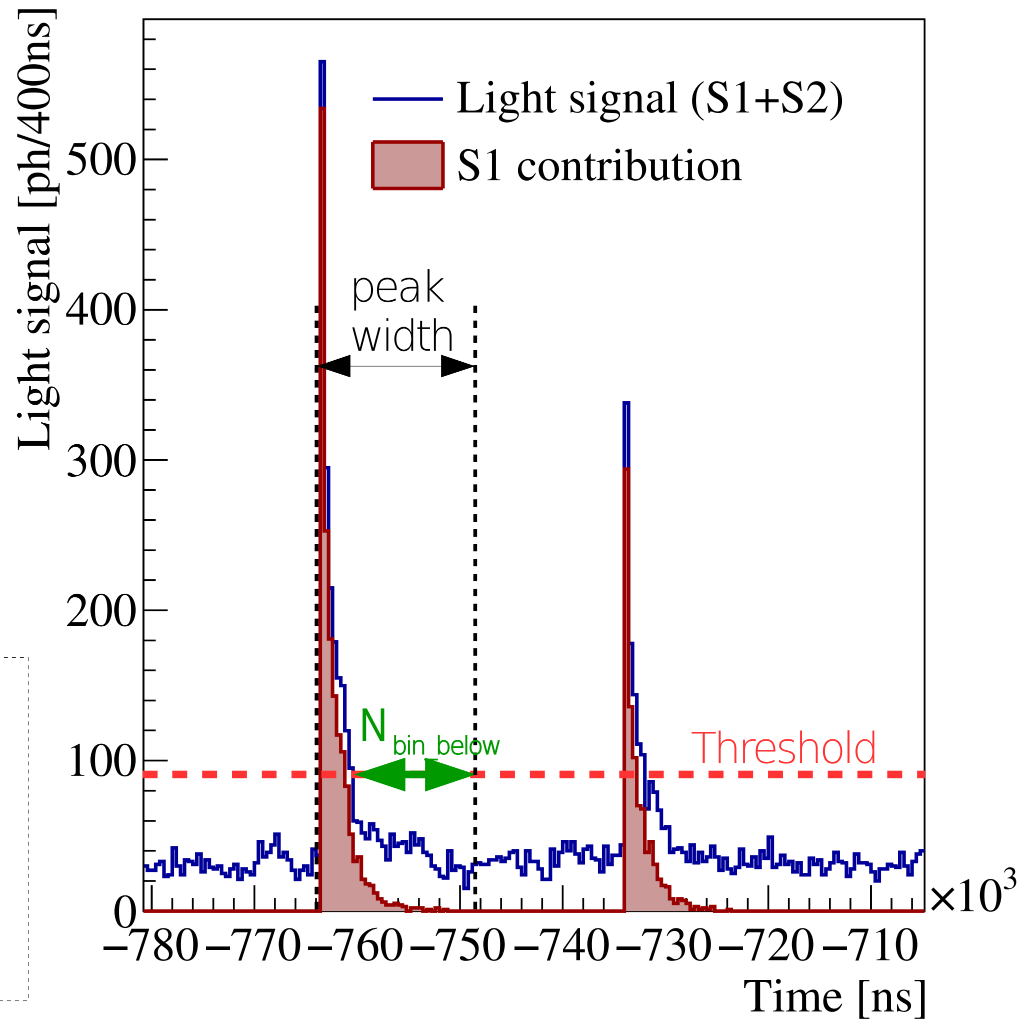
The aim is to tag the S1 peaks

1. Look for **bins** with a number of photons **above** a given **threshold**

2. Does **not** search a new peak until finding at least N_{bin_below} **consecutive** bins **below** the threshold

2 parameters:

- Threshold
- N_{bin_below}



Note: At **last** talk, use of a **temporary cut** on the **ratio** between the **peak maximum** and **the peak width**

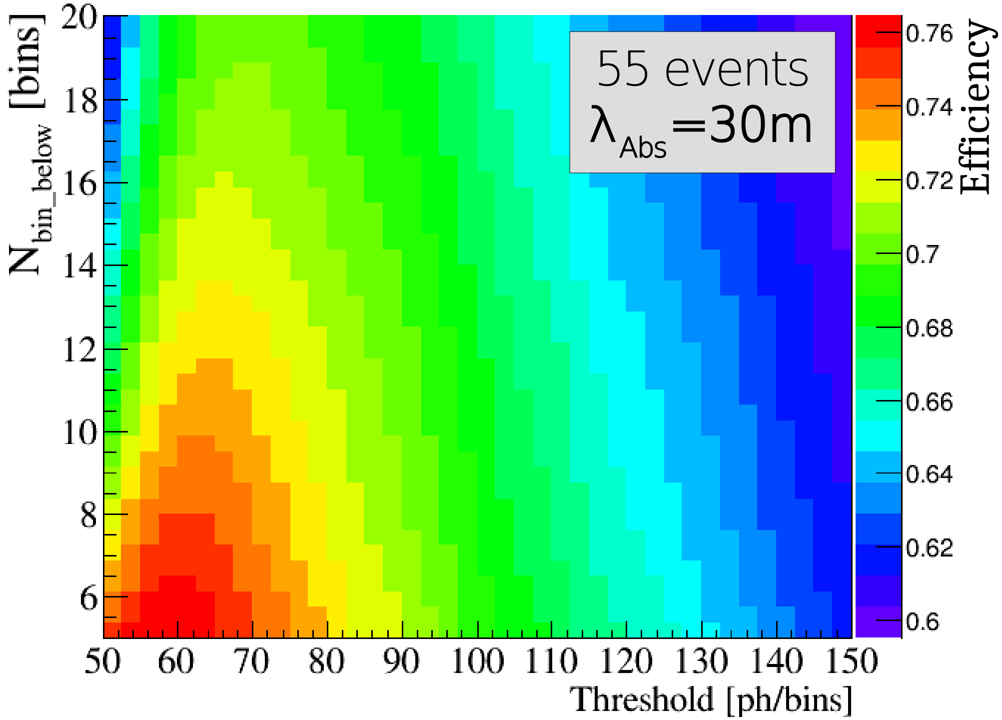
→ An **improvement** of this cut is **under study** (see end of the talk)

Peak search algorithm efficiency (λ_{Abs}=30m)

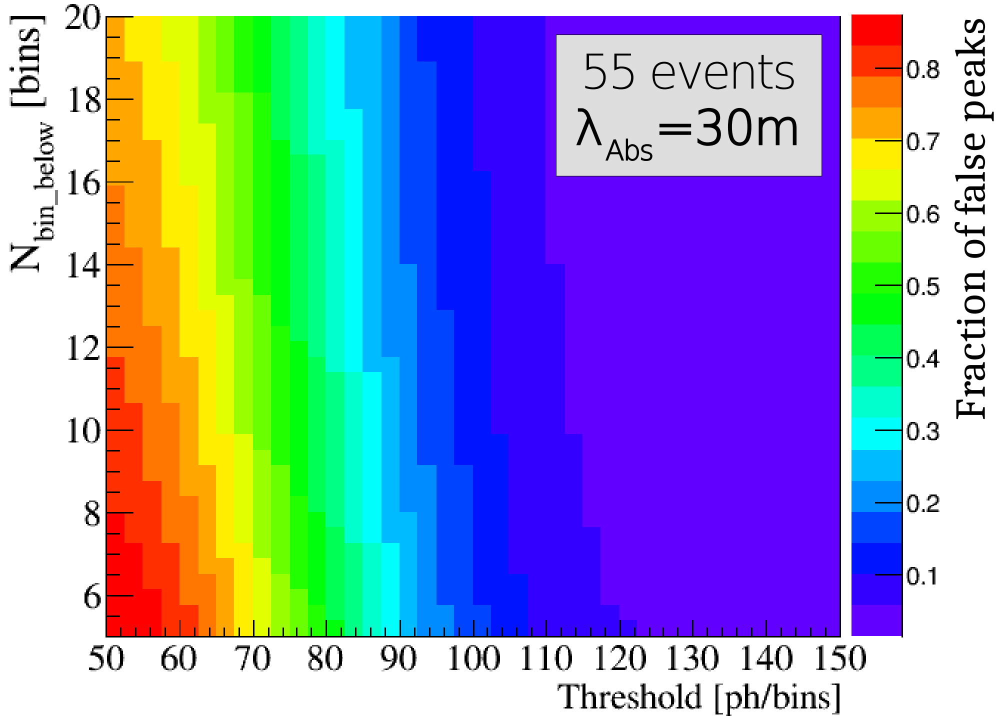
Efficiency = #peaks matching a muon / #detectable muons

Fraction of false peaks = #peaks that don't match a muon / #found peaks

Efficiency



Fraction of false peaks



For Thresholds > 100 ph/bins:

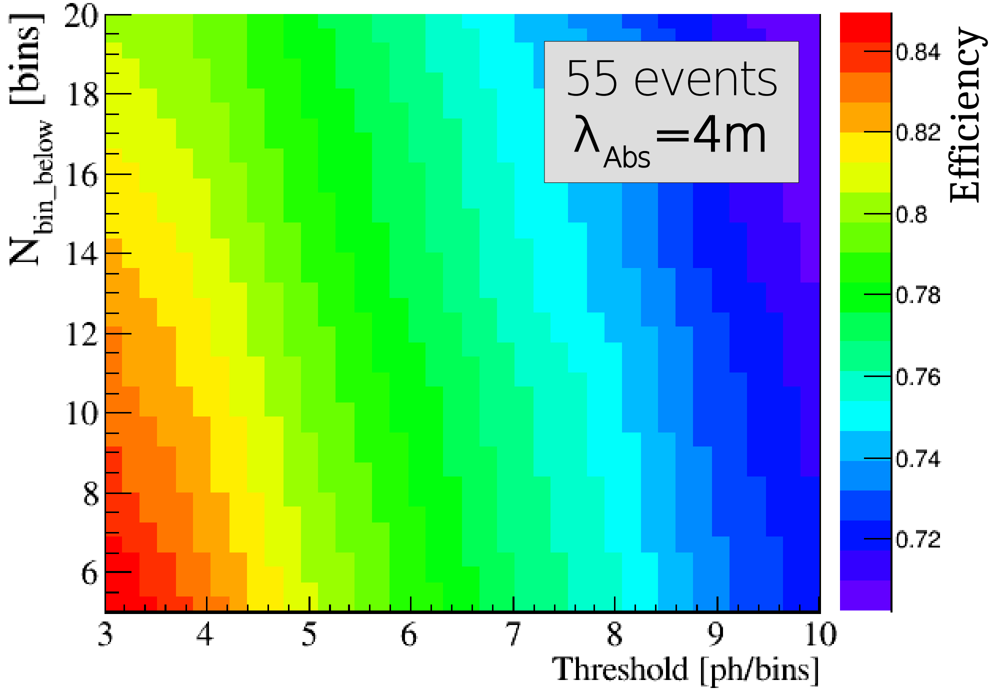
- Fraction of false peaks <15%
- Maximum efficiency ~68% for N_{bin_below} <12

Peak search algorithm efficiency (λ_{Abs}=4m)

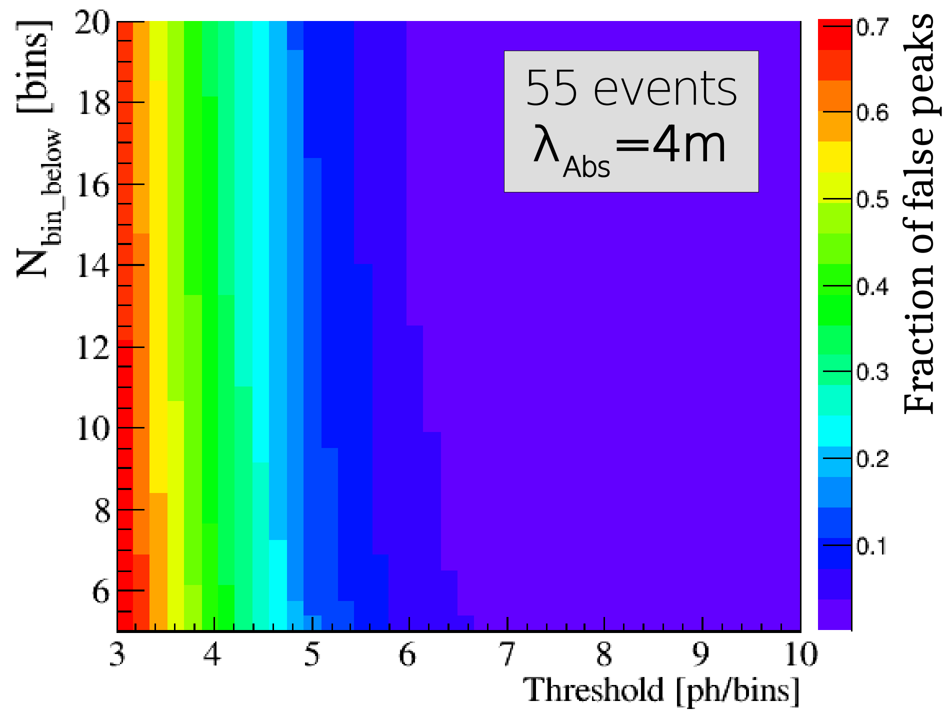
Efficiency = #peaks matching a muon / #detectable muons

Fraction of false peaks = #peaks that don't match a muon / #found peaks

Effiency



Fraction of false peaks

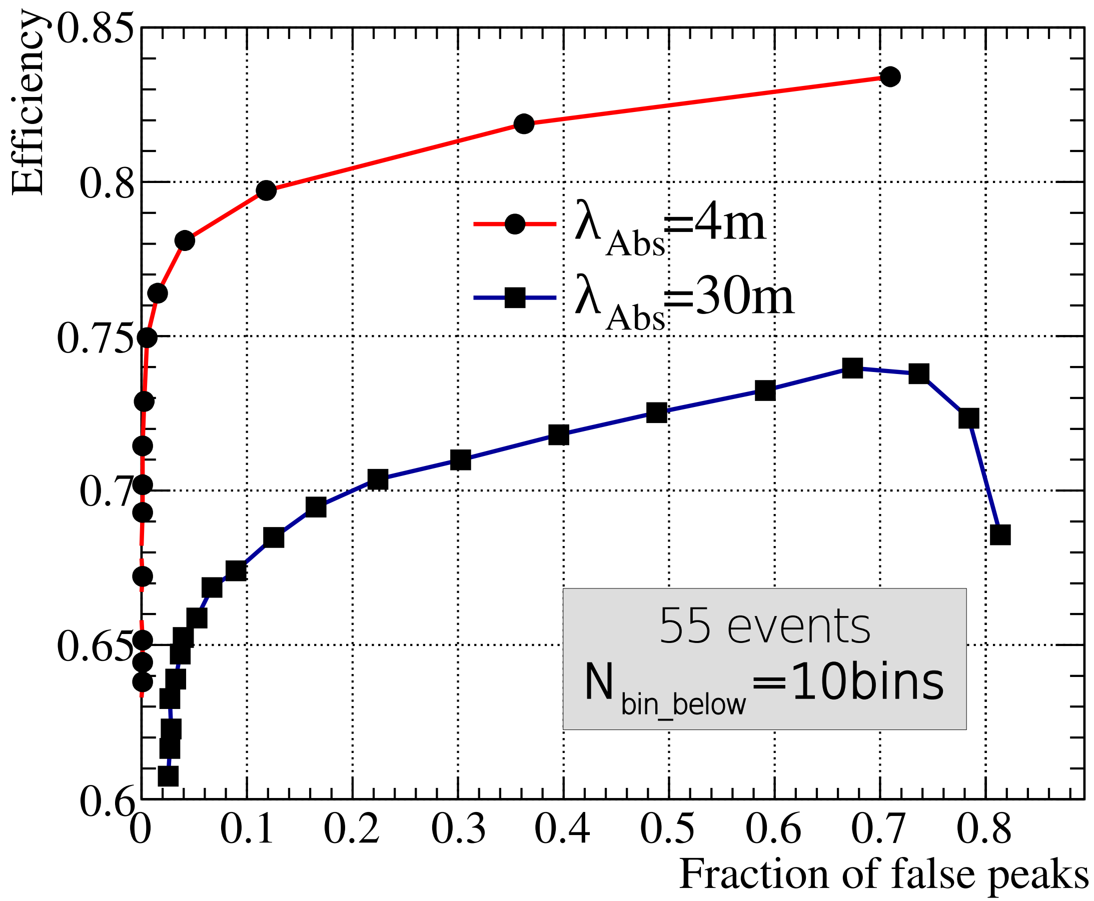


For Thresholds > 6ph/bins: Very low fraction of false peaks with a maximum efficiency ~78%

Peak search algorithm efficiency

Efficiency = #peaks matching a muon / #detectable muons

Fraction of false peaks = #peaks that don't match a muon / #found peaks



Efficiency and fraction of false peaks for different Threshold

→ S2 signal is more affected by the LAr absorption: S1 signal is more visible

→ The tagging is more efficient for λ_{Abs}=4m (but important reduction of the light signal)

S1 peak exponential shapes

Preliminary study

Most of false peaks = S2 **fluctuations** tagged as S1 peaks

→ Can we use the S1 peak exponential shapes to reject false peaks ?

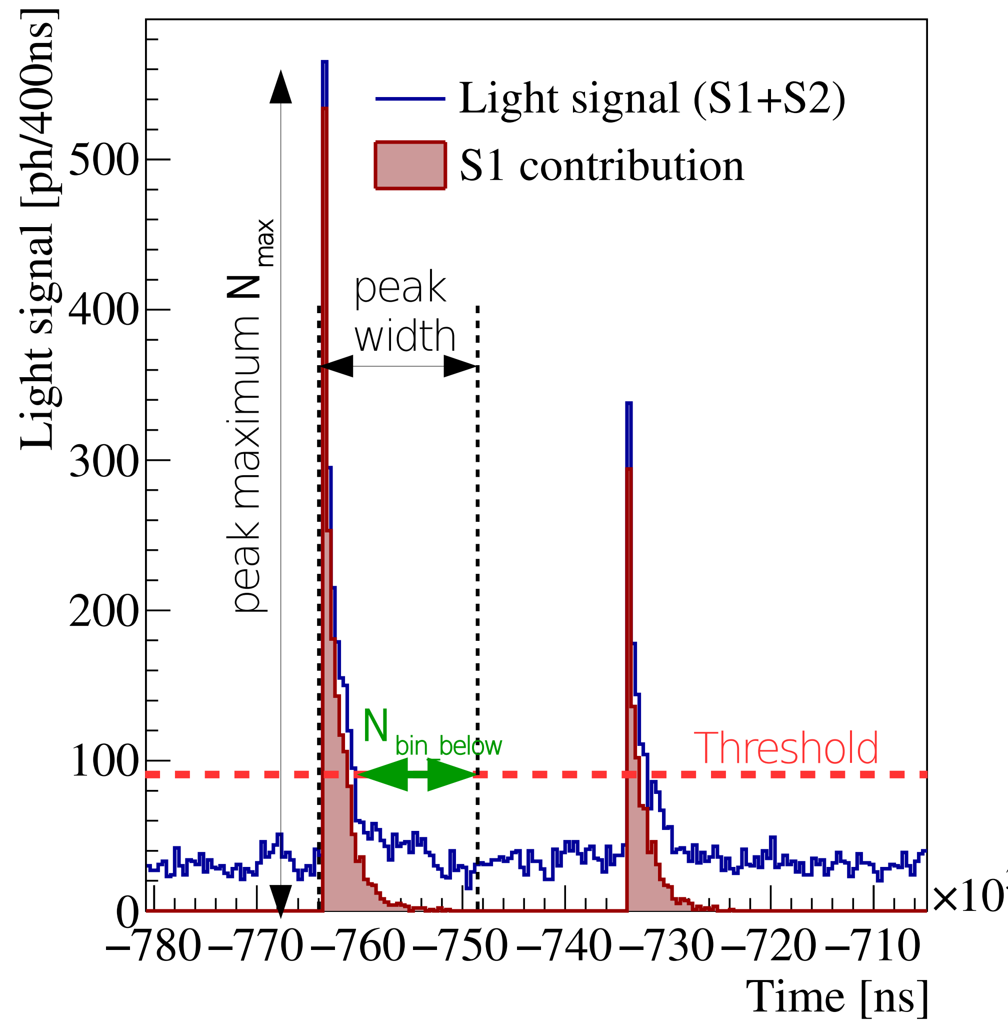
Computation of a "theoretical" peak width:

$\Delta t_{Threshold}$ = time to go back **below the threshold**

$$N(\Delta t_{Threshold}) = N_{max} \exp\left(\frac{-\Delta t_{Threshold}}{\tau_{slow}}\right) = Threshold$$

$$\Delta t_{Threshold} = \tau_{slow}(\ln(N_{max}) - \ln(Threshold))$$

↑ 1600ns



The **exponential shape** is **modified** by the photon travel in LAr:

→ We can't directly use $\Delta t_{Threshold}$ to **reject** false peaks.

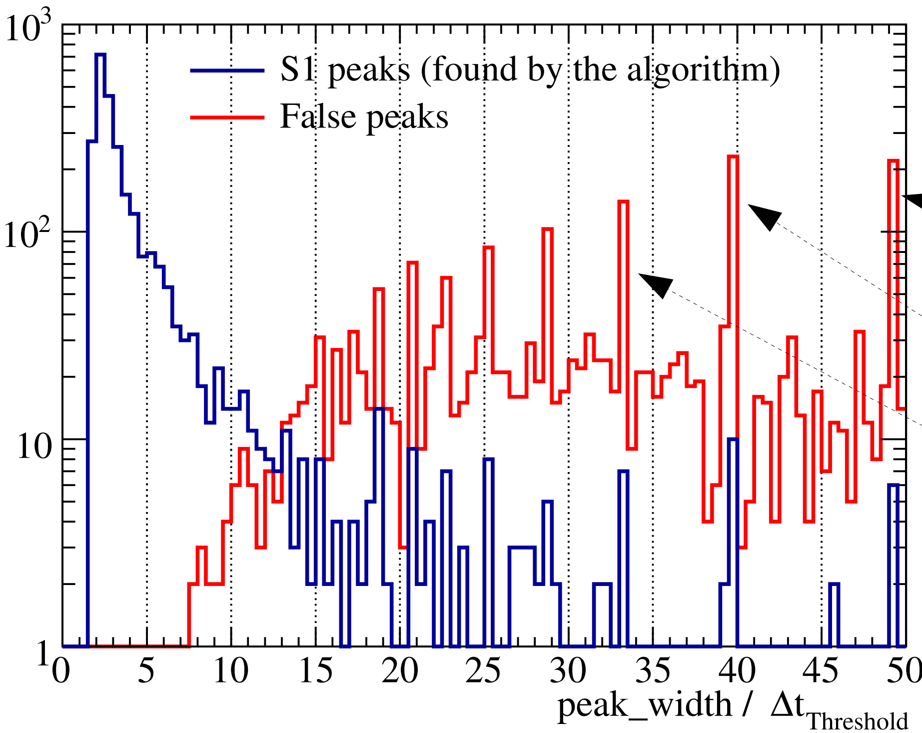
→ We look at the ratio between the width found by the algorithm and $\Delta t_{Threshold}$: $\frac{peak\_width}{\Delta t_{Threshold}}$

S1 peak exponential shapes

Distribution of $\frac{\text{peak\_width}}{\Delta t_{\text{Threshold}}}$ for all the found peaks

λ_{Abs}=30m

Threshold=70ph/bins
$N_{\text{bin\_below}}$=10bins
55 events



Most of the S2 background fluctuations correspond to peaks with only one bin above the threshold

- 1 bin with 4 photons above threshold:

$$\frac{\text{peak\_width}}{\Delta t_{\text{Threshold}}} = \frac{11 \cdot 400}{1600(\ln(74) - \ln(70))} = 49.5$$

- 1 bin with 5 photons above threshold: 39.9
- 1 bin with 6 photons above threshold: 33.4

Preliminary study

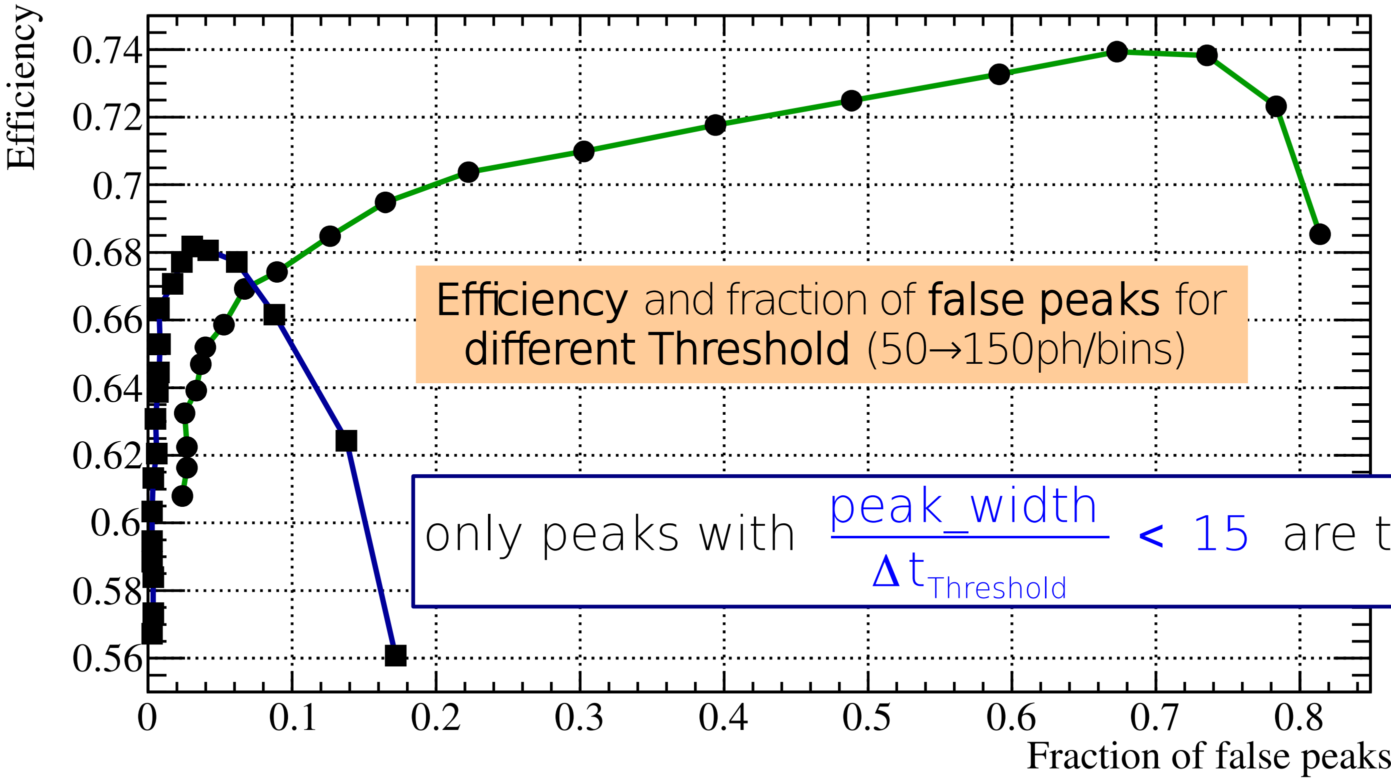
Note: for the time being, **peak_width** takes $N_{\text{bin\_below}}$ into account

→ Can be a good criteria to reject S2 fluctuations tagged as S1 peaks

S1 peak exponential shapes

Efficiency = #peaks matching a muon / #detectable muons

Fraction of false peaks = #peaks that don't match a muon / #found peaks



Efficiency and fraction of false peaks for different Threshold (50→150ph/bins)

only peaks with $\frac{\text{peak\_width}}{\Delta t_{Threshold}} < 15$ are tagged as S1 peaks

N_{bin_below}=10bins

λ_{Abs}=30m

- Reduction of the fraction of false peaks
  → Maximum fraction of false peaks of 18% instead of 80% (for Threshold=50ph/bins)
- Maximum efficiency of 68% with ~4% of false peaks
  → Without the cut: for the same efficiency, 12% of the found peaks are false

→ Ongoing study

Conclusion and next steps

- ~25% of cosmic muons can't be detected with the light signal

  → Muons traveling at the top of the detector and/or with short tracks

- Work on the peak search algorithm:
  - Using 2 parameters: Threshold and N_{bin_below}
    - For 400ns sampling, tagging of
      - 68% of detectable muons (λ_{Abs}=30m)
      - 80% of detectable muons (λ_{Abs}=4m)
  - Adding a 3rd parameter based on the peak width estimation: significant reduction of S2 background
    - Example: reduction of a factor 3 for λ_{Abs}=30m

- Next steps:
  - Take into account the PMT and electronics responses
  - Impact of the binning on the algorithm efficiency (400ns and 25ns sampling)
  - Use of the S1 peak shapes to reject false peaks
  - Impact of the LAr absorption length on the algorithm efficiency (λ_{Abs}=30m,4m and λ_{Abs}=89m)

Used in ProtoDUNE-SP simulations