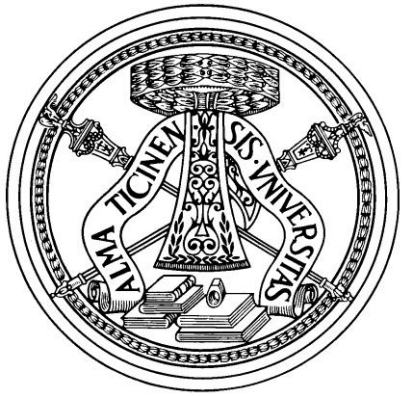

Analysis of Monte Carlo events for ICARUS trigger studies

ICARUS Collaboration meeting

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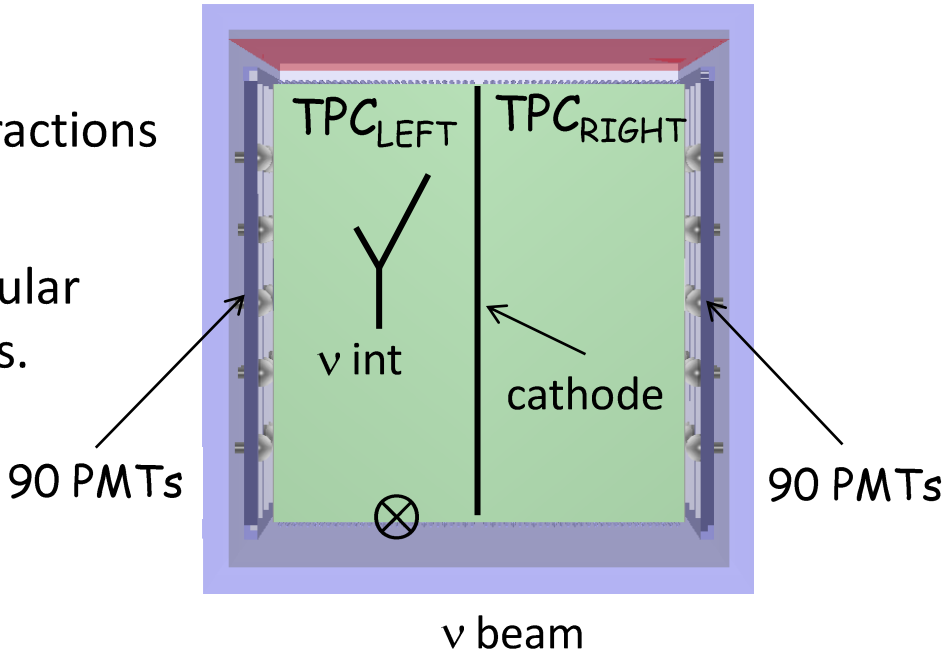
Outline

- Introduction.
- Number of PMTs fired as a function of threshold and energy.
- Detection efficiency as a function of thresholds and majorities.
- Possibility of exploit the analogue sum of the signal of 15 adjacent PMTs for trigger logics.
- First attempt to evaluate the timing resolution for neutrino vertex reconstruction with PMT signals.

Introduction

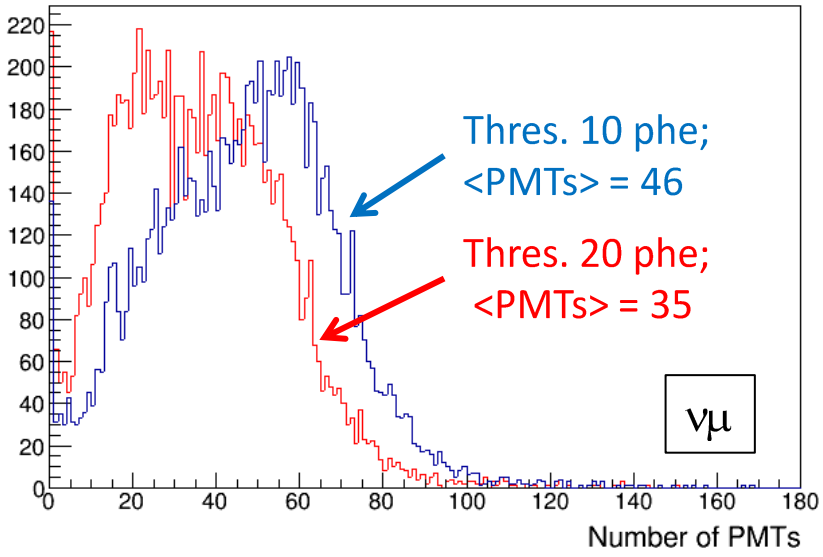
First study dedicated to the ICARUS trigger performance was carried out by analyzing events simulated with LArsoft:

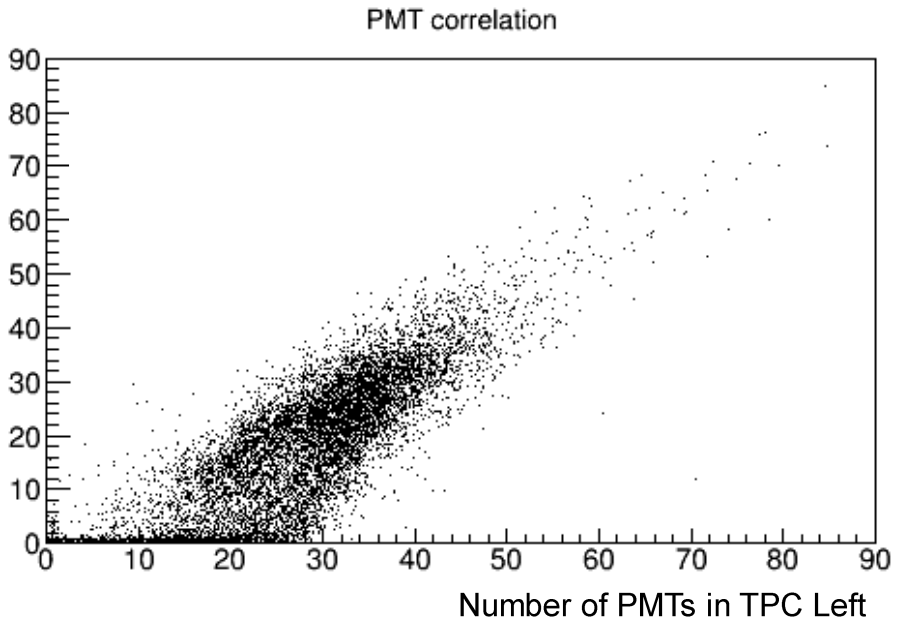
- BNB $\nu\mu$ and νe: both CC and NC interactions occurring in the TPC_{LEFT}
- crossing muons with energy and angular distribution similar to the cosmic rays.



- The scintillation light signal reaching each PMT is computed as a function of the track position inside the detector.
- In the conversion to photoelectrons a 7% photocathode quantum efficiency is applied together with a random smearing according to Poisson statistics. To mime the saturation, the signal is limited to 400 phe.
- Time propagation of the scintillation light is determined as a function of the PMT distance from the position where photons are generated.
- Only **fast component** of the light is considered for a first prompt level trigger.

Total number of PMT vs threshold

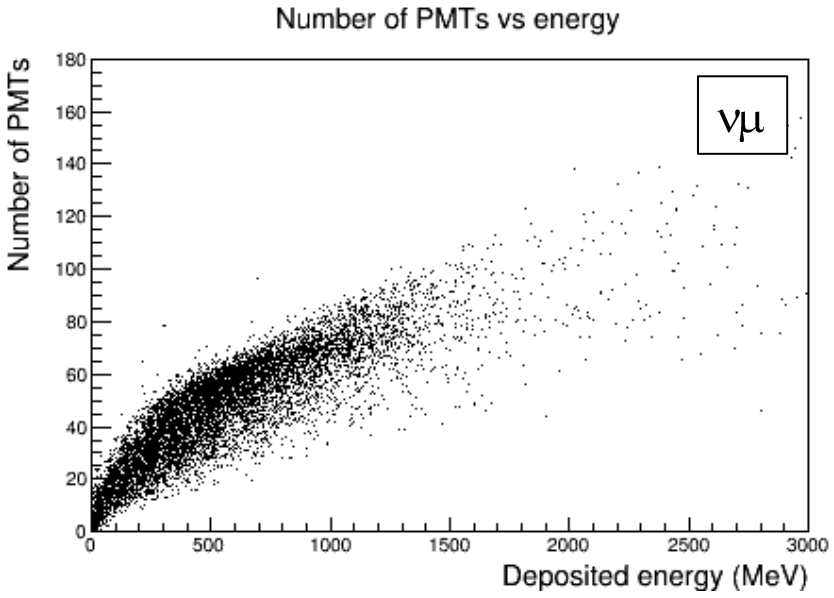




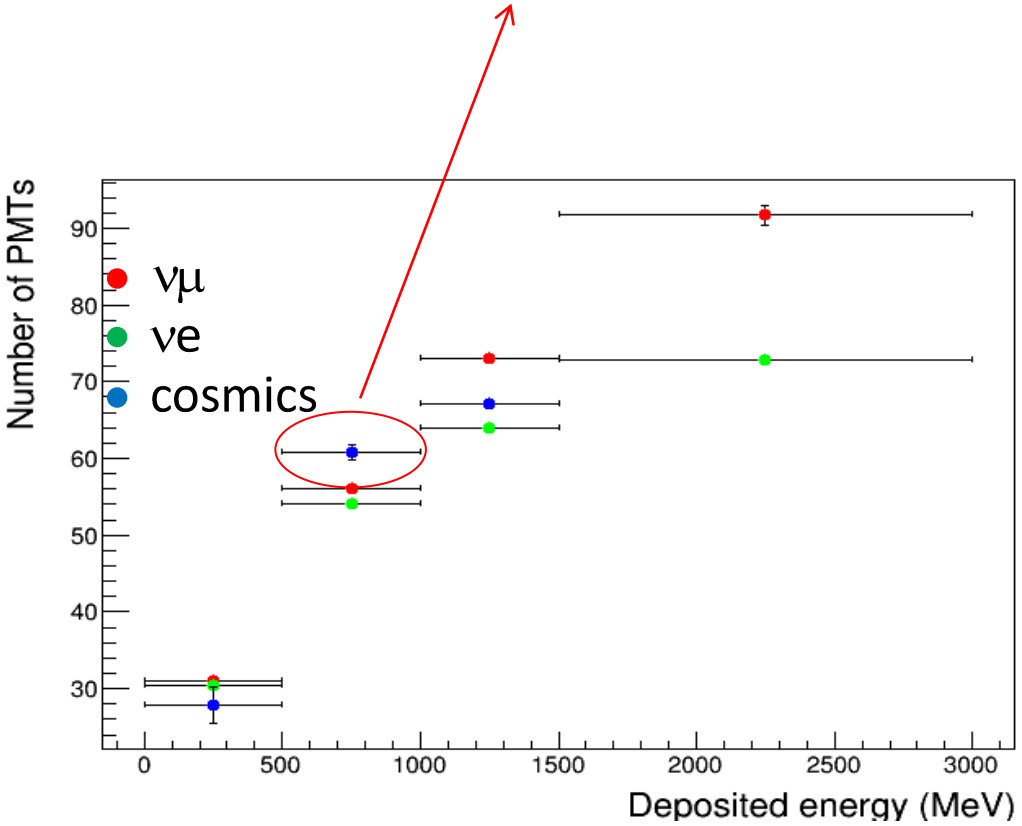
- On average, for BNB νμ interactions, ≈46 PMTs out of the total 180 inside a T300 are fired above a 10 phe threshold:
  - 28 in the chamber where interaction occurs (TPC_{LEFT});
  - 20 on the adjacent one (TPC_{RIGHT}), behind the semi-transparent cathode.

- Similar results hold also for νe interactions, with a larger average PMT multiplicity (<PMTs> = 52 for 10 phe threshold).

Total number of PMTs vs energy



- Most cosmics events are concentrated in this energy bin.

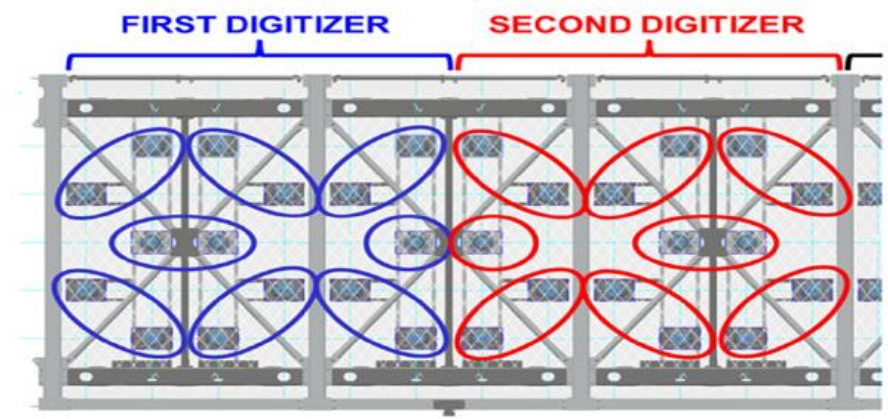


- νμ sample as an example in the scatter plot.
- A threshold of 10 phe is set on each PMT.

Emulation of CAEN board logic outputs for trigger efficiency

- A trigger study has been carried out to emulate the PMT granularity of discriminated signals provided by the available electronics.

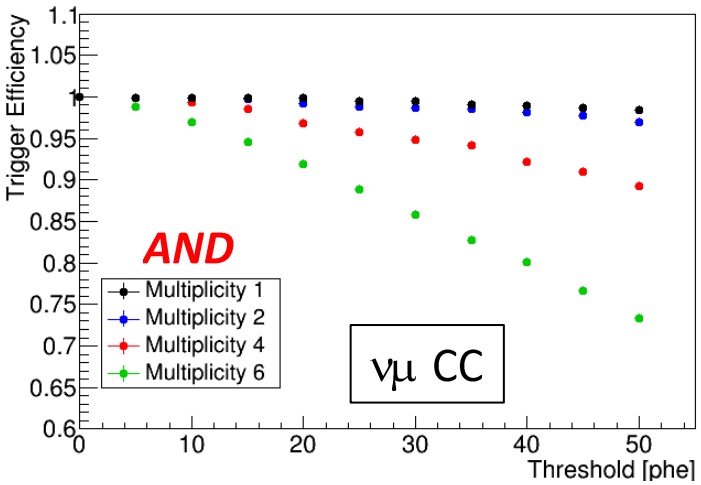
- The CAEN boards indeed do not provide the discriminated signal of each input channel but instead generate either the OR or the AND of the discriminated signals for each pair of adjacent channels.

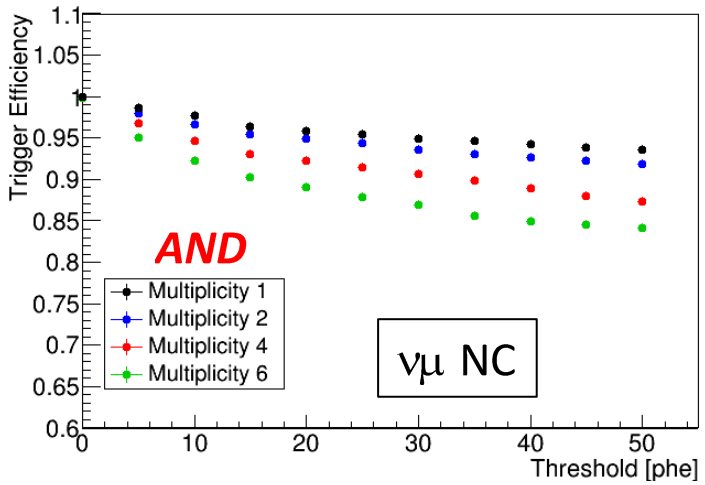


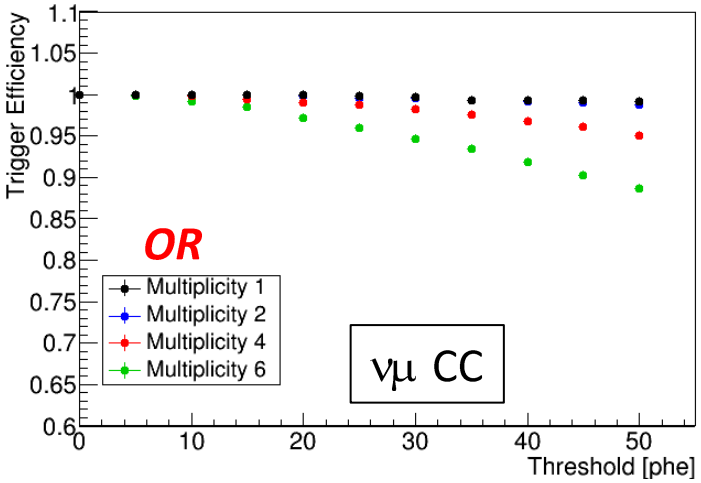
Coupling scheme of adjacent PMTs

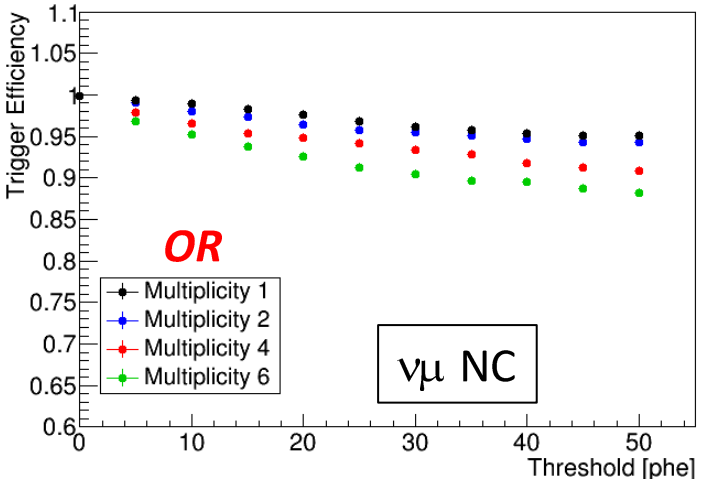
In the following plots, a majority of AND (and OR) of adjacent PMTs is defined rather than a majority of single PMTs.

Trigger efficiency: AND/OR of 2 adjacent PMTs





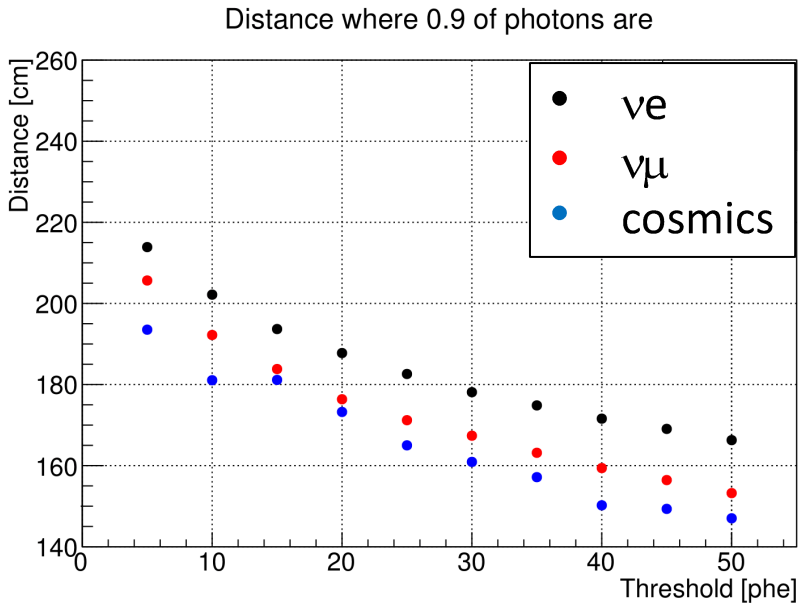




- As expected, the efficiency is slightly larger for CC than for NC events. A proper combination of threshold and multiplicity would allow optimizing the detection efficiency.

- Example (AND logic): efficiency >95% for ν_μCC can be reached either with a 15 phe thres. and a 6 PMT couple multiplicity or with a 25 phe thres. and a 4 PMT couple multiplicity.

Analysis of PMT wall slices



- Distance from the geometrical barycenter of the PMTs within which at least the 90% of the total fast light is collected.
- For a threshold of 10 phe this distance is roughly 2 meters.

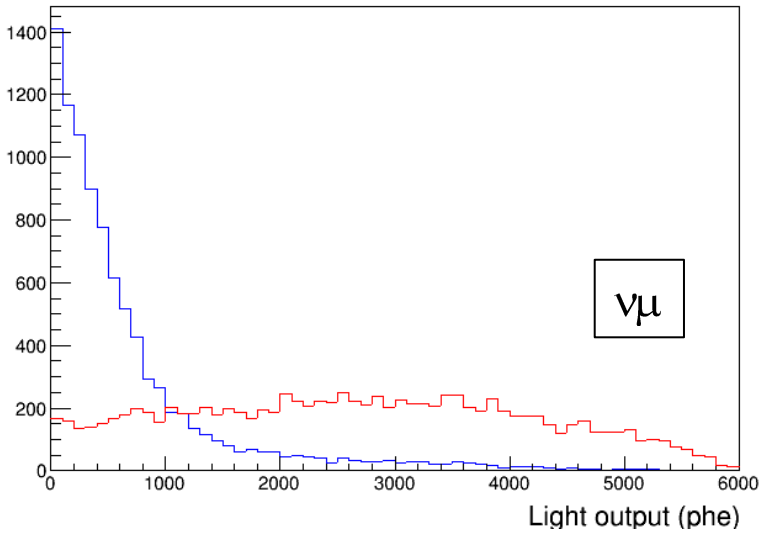
- Most of light collected within ≈3 meters from the geometrical barycenter of PMTs → refined analysis carried out to exploit the possibility to perform an analogue sum of the PMT signals in six slices per TPC, 3 meters each, containing 15 PMTs.

- For each slice, the total number of fast photons collected was evaluated without applying any threshold on the PMTs.

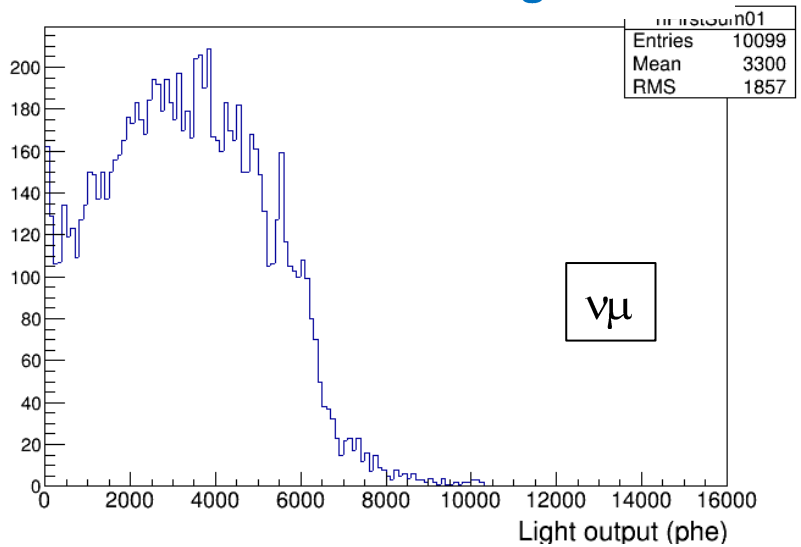
- For each event, the slice with the largest number of collected photons in both TPCs has been identified ("first" slice).

Light distribution on the «first» slice

Light output (phe) from TPC Left and TPC Right



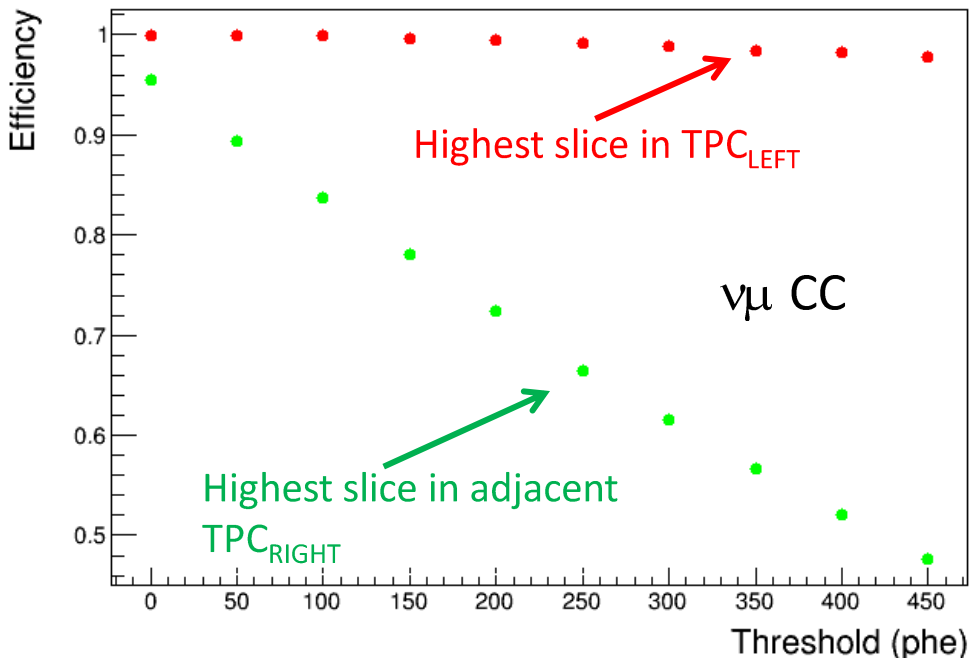
Overall light output (phe) from TPC Left + TPC Right



- The two slices with most collected photons in either the chamber TPC_{LEFT} where ν interacts and in the adjacent TPC_{RIGHT} have been considered.

- On average they heap up ≈70% and ≈ 60% of the detected phe in the chamber respectively.

Efficiency of first slice vs threshold

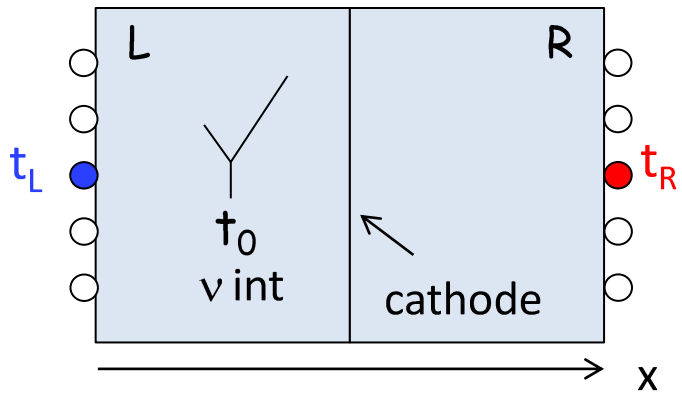


- A trigger based on the highest signal slices could reach almost full detection efficiency up to high thresholds for the TPC$_{LEFT}$ and a > 90% efficiency also in the adjacent TPC$_{RIGHT}$ for a 50 phe threshold.

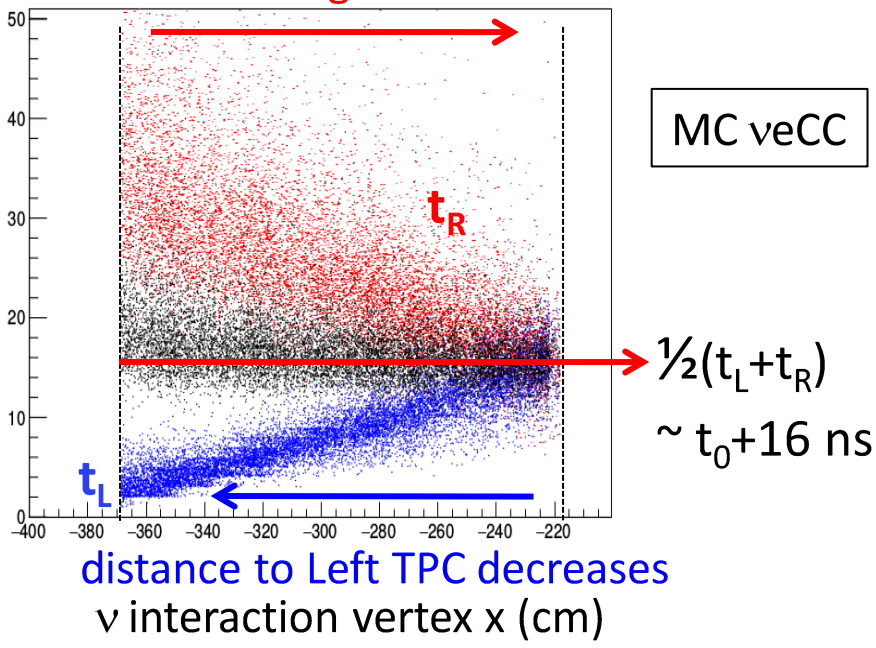
- Smaller efficiency are expected for the NC case: for example, for a 50 phe threshold the detection efficiency in TPC$_{LEFT}$ is 90%.

Event Filtering by PMT timing – transverse resolution

- In order to select genuine ν interactions the acquired events can be filtered out by reconstructing quasi-online the PMT signals, determining signal pulse height and timing at ns level.
- The precise timing of neutrino interaction will depend on position of the vertex interaction along both the transverse (drift) x and longitudinal z directions.
  - Light propagation from track to PMTs introduces a delay between t_0 time of ν interaction and the first hit PMT in Left, Right TPCs t_L, t_R which increases with track distance from PMTs:



ν interaction in Left TPC

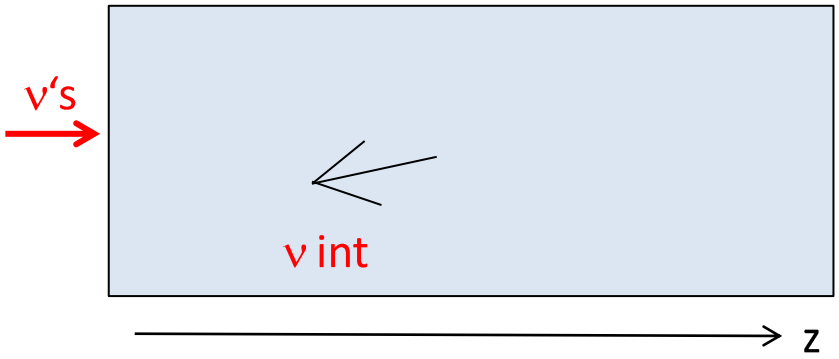


→ (t_L+t_R)/2 provides a 1st evaluation of t_0 ν interaction independent from ν vertex position with σ ~2.4 ns

Scint. light propagation delay

Event Filtering by PMT timing – longitudinal resolution

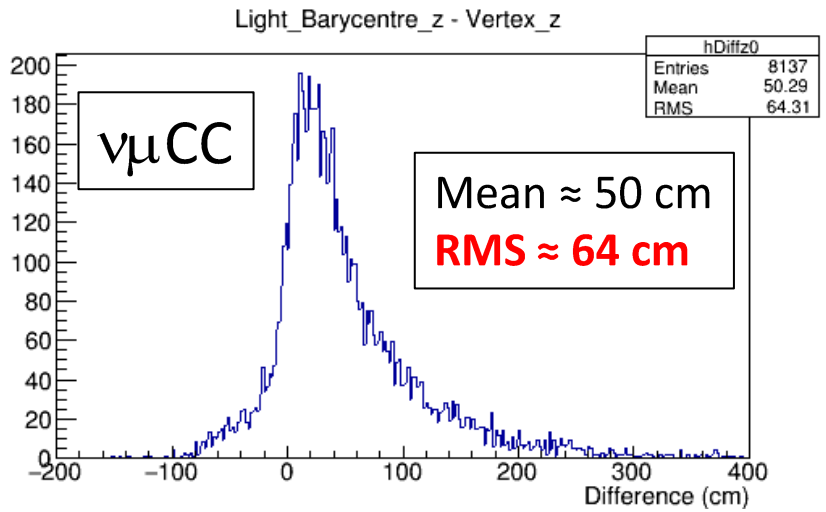
- First attempt to determine the position of ν interaction along the beam direction by using the hit PMT signals alone.

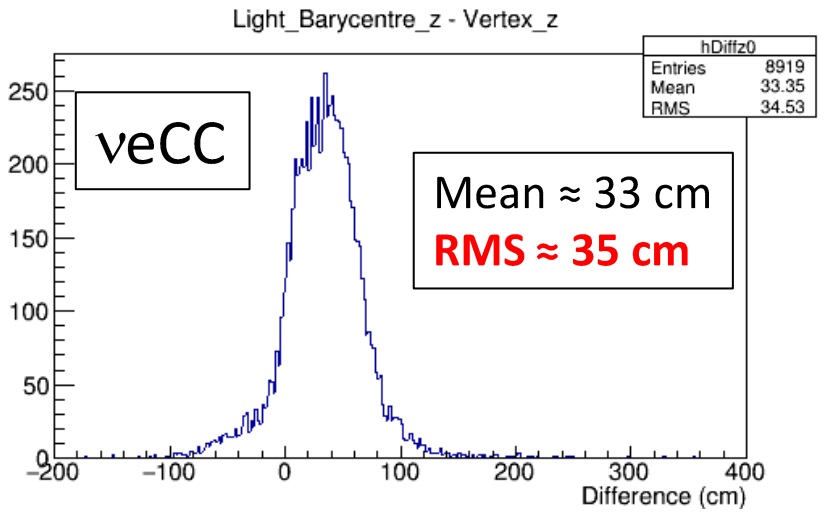


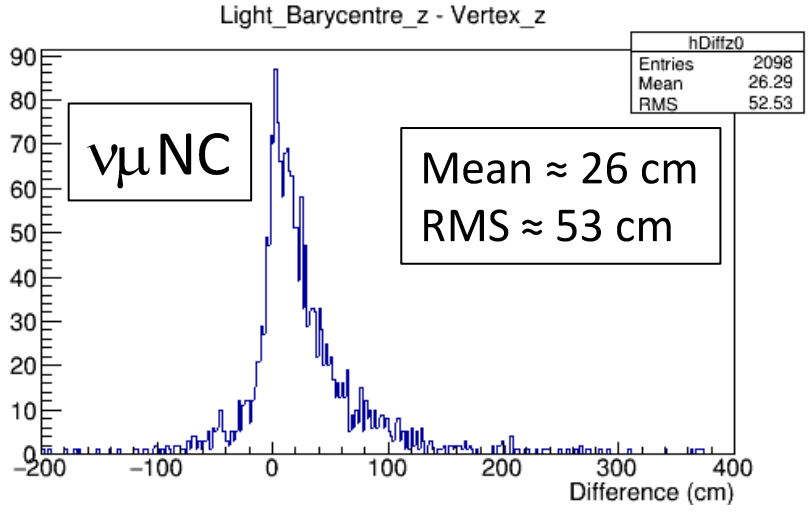
- The analysis was performed on the usual MC νμ and νe samples (≈10.000 events each), separately for CC and NC.

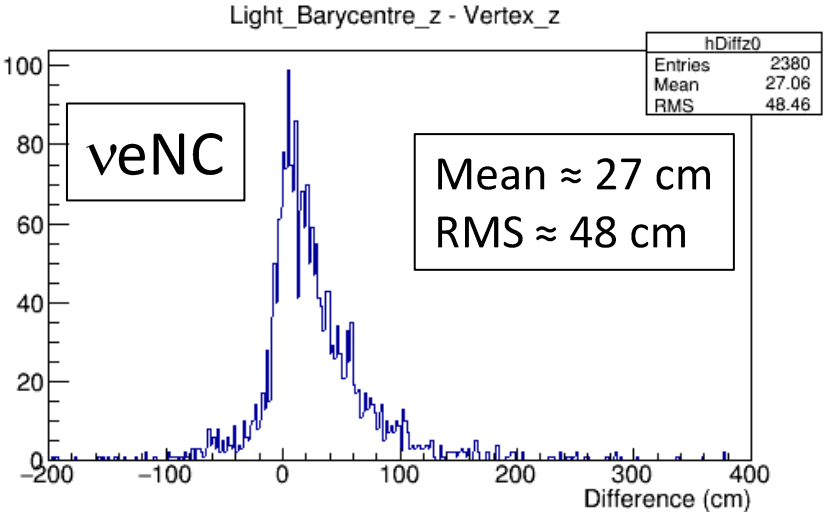
- The following slides are showing the distribution of the difference between the true neutrino vertex position along the beam direction and:
  1. the barycentre of hit PMTs.
  2. the position of first hit PMT.

Light Barycentre – Neutrino vertex position: TPC Left



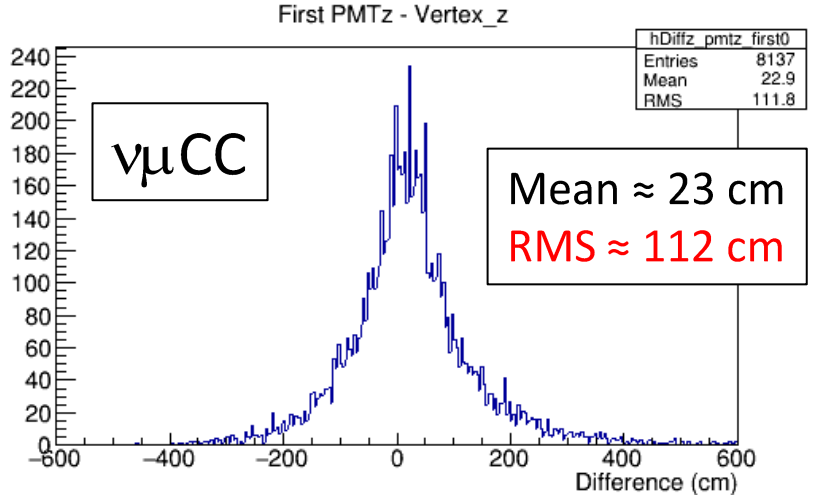


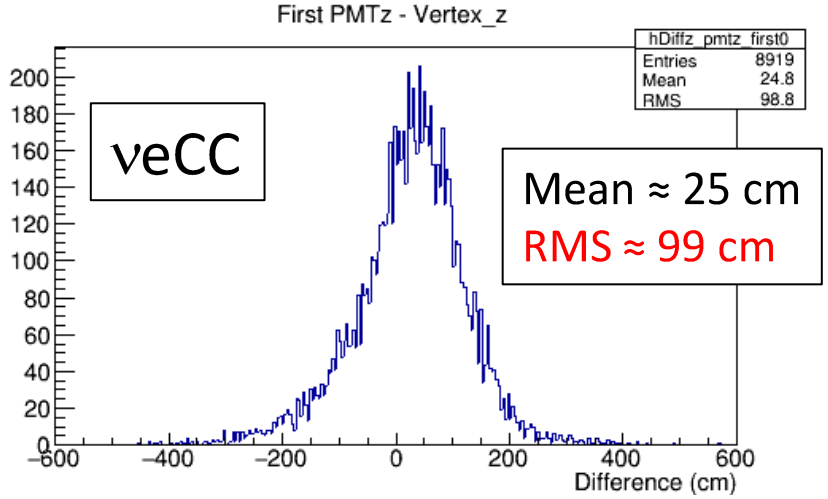


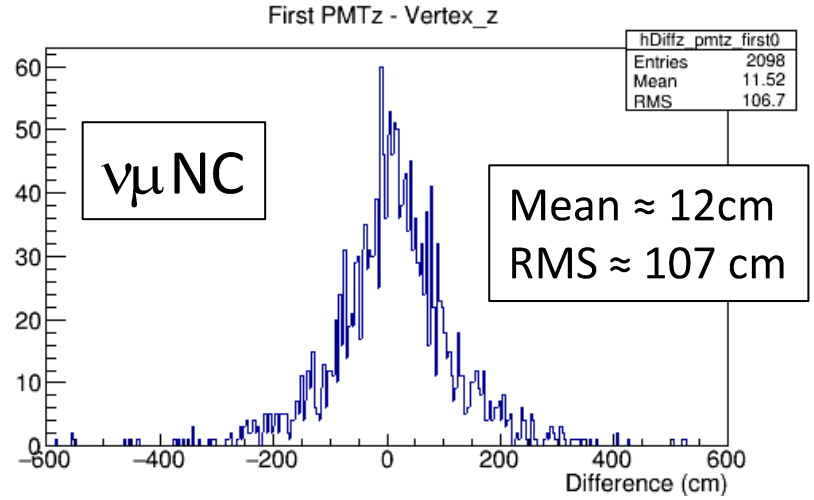


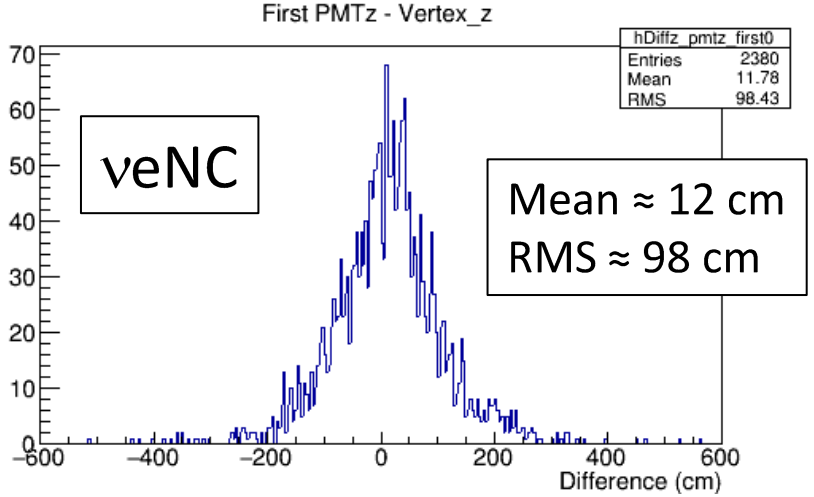
- Note the long tail of νμCC distribution due to the CC muon propagating forward, while νeCC distribution is more symmetric because of the compactness of the event.

First hit PMT – Neutrino vertex position: TPC Left





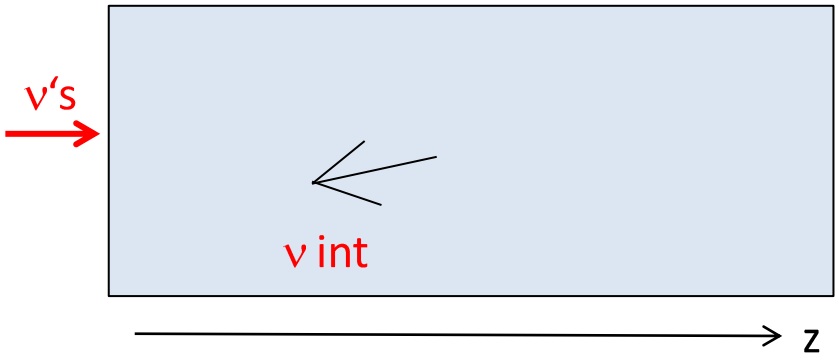




- Distributions are now more symmetric because the first hit PMT is on average close to the neutrino vertex, but RMS resolutions are worse with respect to the ones evaluated with the light barycentre.

Event Filtering by PMT timing – longitudinal resolution

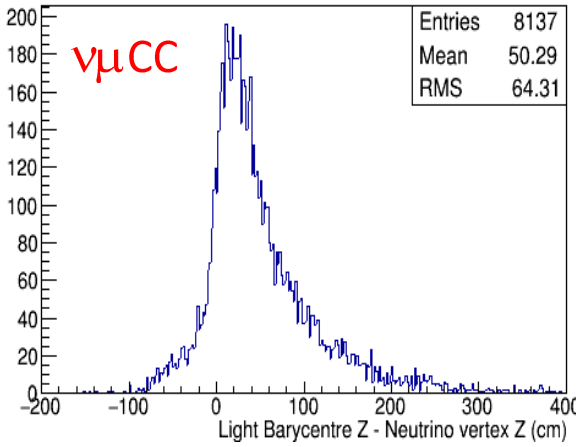
- First attempt to determine the position of ν interaction along the beam direction by using the hit PMT signals alone.

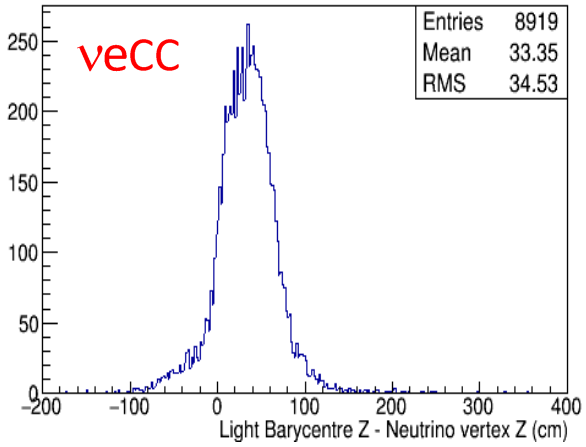


- Best RMS resolutions have been obtained for νμCC and νeCC by evaluating of the difference between the true neutrino vertex position along the beam direction and the barycentre of hit PMTs.

RMS resolution ≈ 30 (60) cm for νeCC (νμCC).

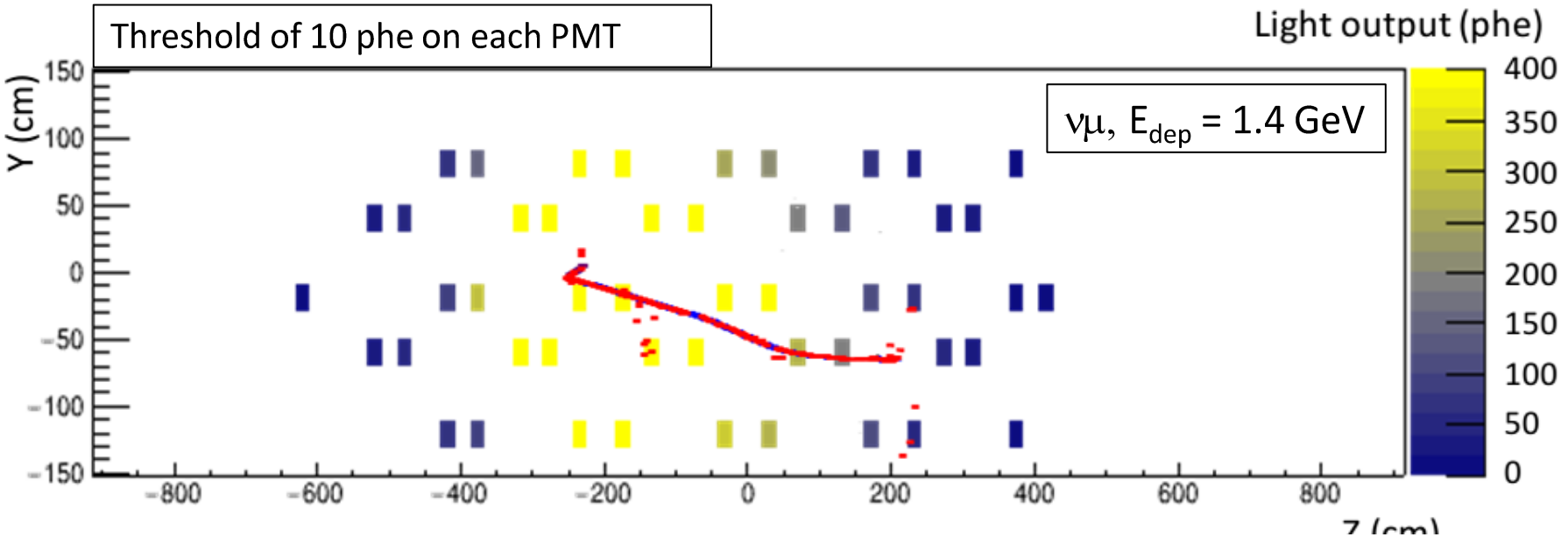
Corresponding to ≈ 1 (2) ns time resolution.

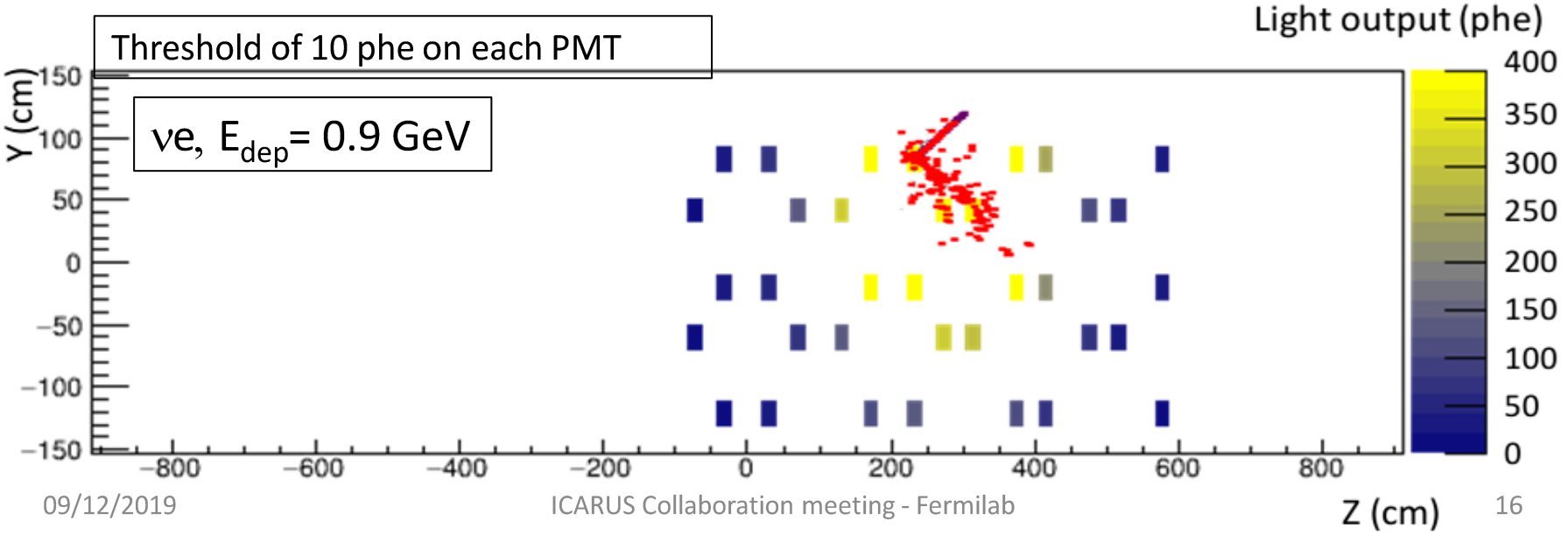




- Possible improvement of RMS resolution along the longitudinal direction by using the average of the light barycentre of the two TPCs.

First examples of Charge + PMT images





Conclusions

- The light output from a Monte Carlo sample of several types of events in ICARUS was analyzed to provide inputs for a trigger based on the PMTs.
- It has been shown how the majority of AND/OR of PMT couples can be exploited: depending the threshold applied on each PMT, the multiplicity of the PMTs may impact on the trigger efficiency.
- The analogue sum of 15 PMTs on a slice of 3 meters seems reasonable to perform a trigger, whose efficiency can be evaluated as a function of the threshold applied to a whole slice of 15 PMTs.
- First attempt to use the time information from PMTs to determine the time of ν interaction: $\sigma \approx 2.7 \div 3.1$ ns time resolution seems feasible (combining transverse and longitudinal contributions).