# Status report of Italian activity on TOP

## Calibration studies with testbench system in Padova

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INFN - Padova

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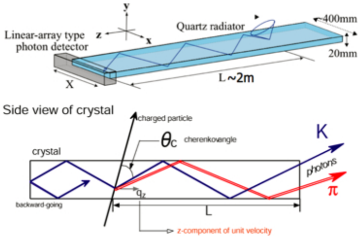
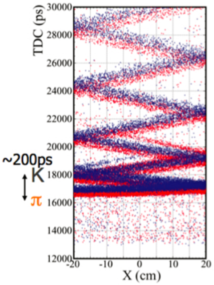
# Outlook

- Top provides PID in the barrel region of the detector
- Folding of the Cherenkov cone inside the quartz bar: $\rightarrow$ reconstruct using photon detection time information
- knowing the track direction & the intersection point with the bar is possible to predict the space-time pattern of produced photon
- the observed pattern is compared with the one predicted under different particle hypothesis and a likelihood is built



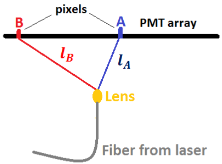



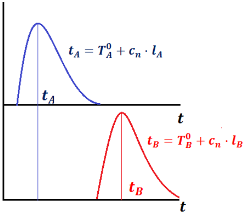

- **This talk**
  - calibration strategy
  - laser characterization
  - time spectra characterization
- **Focus on italian activities**

# Time alignment strategy - in principle

- Goal of the time alignment is the measurement of the time offset ($T^0$ henceforth) of each MCP-PMT pixel
- $T^0$ different for each pixel due to electronic & pixel properties
- a total of $512 \times 16$ channels must be calibrated

The simple case:




Now,

$$t_{(A,B)} = T^0_{(A,B)} + c_n \cdot \ell_{(A,B)}$$

or equivalently:

$$t_B - t_A = (T^0_B - T^0_A) + c_n \cdot (\ell_B - \ell_A)$$

being

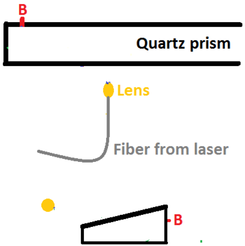
- $c_n$ the speed of light in the propagation medium
- $T^0_{(A,B)}$ the time off-set

**measured**, **known**, **what we want to measure**

- "all" what we need is to extract the position $t^i$ through a fit to the photon time-detection spectra
- **the time resolution upper limit of the photon path peak should (ideally) be $\sim$ 100 ps**

# Time alignment strategy - in quasi-practice

The almost-real case: one light source $\oplus$ quartz prism





- each pixel receives photons from 2, sometimes 3 (see later), light paths
- the fraction of each path depends on the properties of the lens (difficult to model with MC, need an excellent knowledge of lens properties)
- many detection times (j=1,2,..) ($t^i_j$) for a given channel $i$, **average separation $\sim$ 200-300 ps**
- need to understand which is the better path to be used to get the best $t^i$

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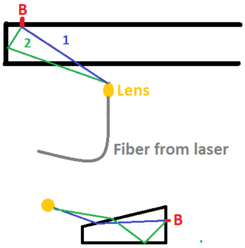


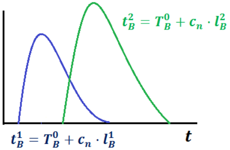


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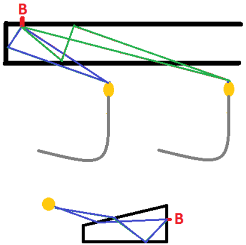
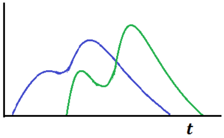
# Time alignment strategy - in practice

The real case:




- each pixel receives photons also from different fibers ($\sim 2$)
- in a given channel, the time distribution of detected photons could consist of up to $\sim 6$ signal peaks
- the relative position peaks is fixed by the geometry of the propagation
- ...but the electronic noise and laser resolution makes difficult to disentangle each single contribution $\Rightarrow$ worsening of resolution on the measured $t^i$ and, in turn, on the extracted $T^0$ for that channel

# Outlook of calibration

The following actions are mandatory to perform a reliable $T^0$ calibration:

- Laser characterization:
  - properties strongly depend on the attenuation value (**tune** henceforth)
  - the tune of the laser affects:
    - time resolution
    - position of the signal pulse
    - the appearance of secondary peaks in the detection time distribution (likely due to the attenuation mechanism)
  - the light yield hasn't a linear dependence on the laser tune
  - need to find the proper working point

- Time spectra analysis:
  - MC studies : understand what kind of inputs can be extracted from simulation
  - definition of the model
  - validation of the $T^0$ extraction procedure

- a test-bench system has been set up in Padova

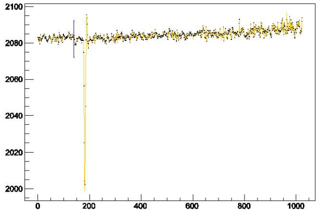
# Padova test bench system

- **Why a bench-test system?**
  - validate simulation
  - independent cross-check of T calibration operations
  - inspect the contribution due to each fiber to the time spectrum of each PMT

- **Padova equipment**
  - **1 MCP-PMT Hamamatsu**
  - **1 SiPM fbk**
  - **HV = 2500 V**
  - **digitizer CAEN V1742 @5 GHz**
  - **fibers + final bundle**
  - **nominal lens used in the experiment**

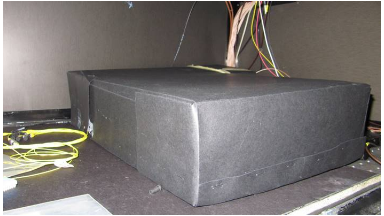
**Detection time computed with constant fraction method**

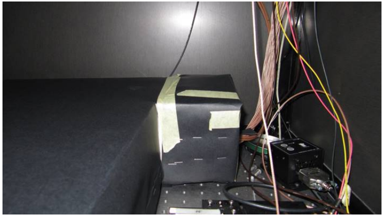
One photon event in MCP-PMT (ADC counts vs Digitizer bin [$\propto t$]), trigger signal:

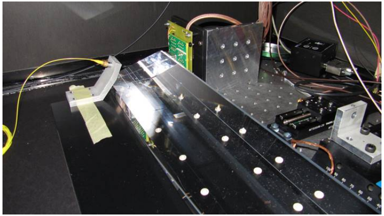


# Setup in Padova

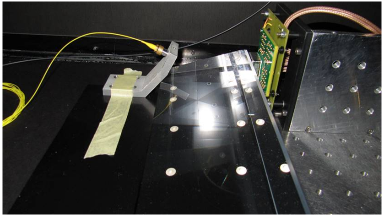
Quartz prism equal to those installed in KEK (rejected ‘cause of production damage on a corner)



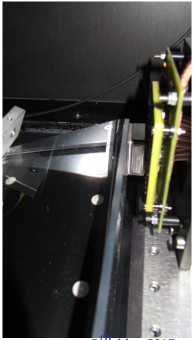




A dedicated support for fibers is in production



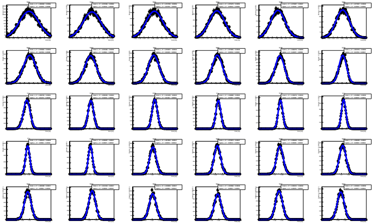
current precision on fiber position $\sim$ mm



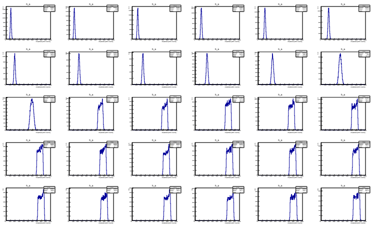
# Laser tune studies

Dependence of detection time shape & position vs attenuation (using SiPM)

**Detection time**

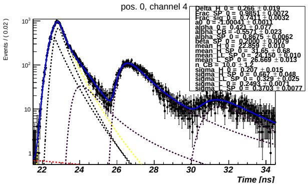


**Amplitude**

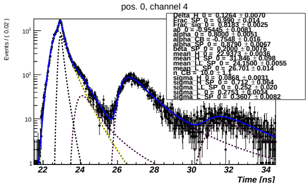


Appearance of secondary peaks (likely due to attenuation mechanism) (using MCP-PMT)

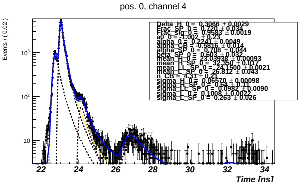
**T86**




**T80**




**T77**



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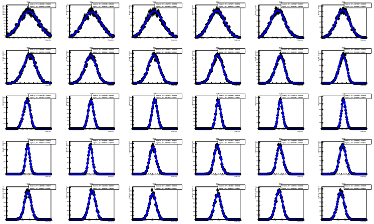

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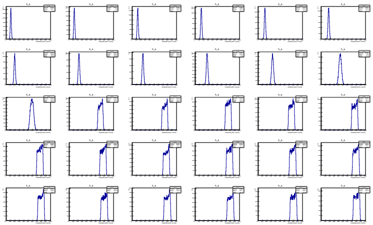

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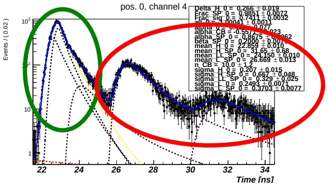


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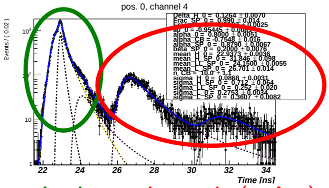


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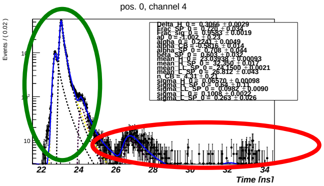
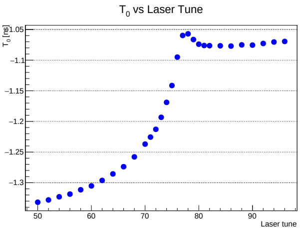


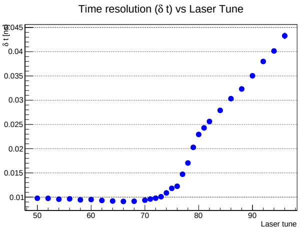

**true signal**, **secondary peaks ($\sim$ 4 ns)**

# Laser tune studies - $T^0$, $\delta t$, secondary peaks

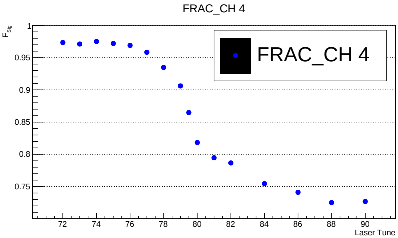
**$T^0$**




**Laser time resolution**




**Fraction of good-signal**




A strong dependence between $T^0$, $\delta T$, and the fraction of good-signal and laser attenuation is observed

- at tune values $\lesssim 76$ the single photon regime is lost
- in this region laser time resolution and good-signal fraction saturates
- current values are $\sim 80$

# Time spectra analysis

The goal is to extract, for each PMT channel, the position of the arrival time of a (properly) chosen photon path:

- this needs to perform a fit to the detection time spectrum
- due to the large number of photon paths ($\sim 6$) we need to fix some quantities
- the time separation between peaks can be fixed (looking at MC), depending only by the geometry
- this require our confidence in simulation being strong $\rightarrow$ studies to understand the best use of simulation

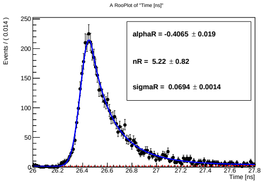
With the test-bench system in Padova we validated the $T^0$ computation procedure using data:

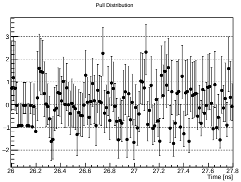
- fix the time separation looking at the spectrum from one single fiber
- extract a $T^0$ through the fit to the many fiber spectra

# Study of single path detection time shape

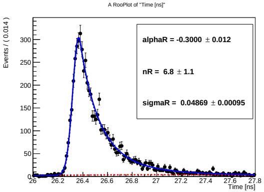
Time detection spectrum acquired by directly illuminating the MCP-PMT with the laser photons, without quartz prism

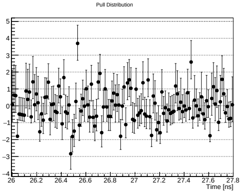
**ch 2**




**ch 5**




- signal shapes are non-gaussian, highly asymmetric 'cause of a tail at large times
- modeled by a **Crystal Ball** (**CB** henceforth)

(Gaussian core $\oplus$ power-law tail at high times):

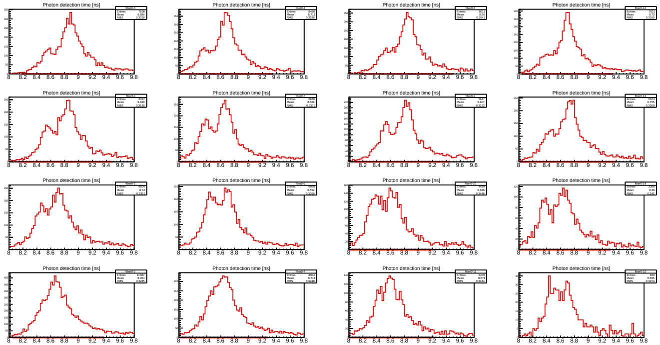
  - the width $\boldsymbol{\sigma}$ indicates the best case scenario for time resolution (*i.e.* the better we can do)

- $\sigma \sim 50 - 80ps$, depends on acquisition chain
- the prism will cause an increase in the time spread

**x-axis range [26-27.8] ns**

**Full model**, **background**

# Time spectra from data (for illustration!! - x-axis range [8,9.8] ns)



Data acquired with PMT in **same position** (top-left) and with two fibers in two positions:

- **pos.0 : 9 mm** from the left border
- **pos.1 : 57 mm** from the left border

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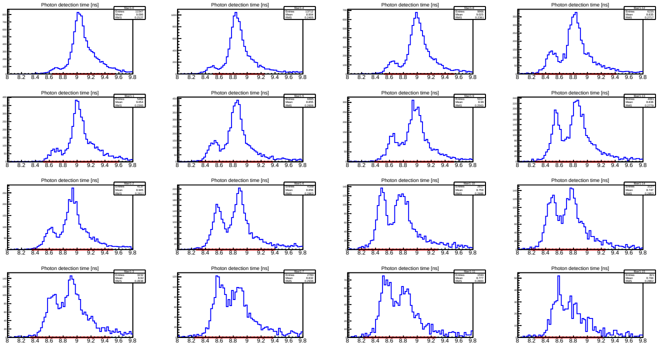


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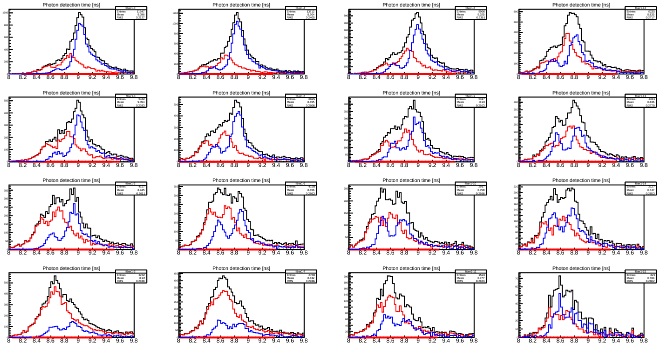


# Time distribution model

2 signal CB/fiber $\oplus$ 1 polynomial background:

- $\mathcal{P}_{Sig}^{pos.i}(T|t) = f_L \mathcal{CB}(t - \Delta_H^i, \delta t_L) + (1 - f_L)\mathcal{CB}(t, \delta t_H)$

where

- $\mu$ is the mean detection time of the reflected photon path (*i.e* $T^0$), which has the higher stat
- $\Delta_H$ is the time interval between the reflected and the direct photon path
- $\delta_{L,H}$ are the time resolutions
- $f_L$ are the fraction of direct and reflected paths

- $\mathcal{P}_{bkg}(T)$ : $2^{nd}$ degree Chebychev polynomial
- $\mathcal{P}(T) = f_{sig}\mathcal{P}_{Sig}(T|t) + (1 - f_{sig})\mathcal{P}_{bkg}(T)$

For each PMT channel, the $T^0$ (i.e. $t$) is extracted in two conditions:

- fitting the spectra acquired with the each fiber separately
- fitting the spectrum obtained by merging the previous 2 spectra, using the PDF :

$$\mathcal{P}(T|t) = F_{sig}(f_0\mathcal{P}_{Sig}^0(T|t) + (1 - f_0)\mathcal{P}_{Sig}^1(T|t + \Delta)) + (1 - F_{sig})\mathcal{P}_{bkg}(T)$$

and fixing, $\Delta_H^{(0,1)}$ and $\Delta$ extracted with the previous fits

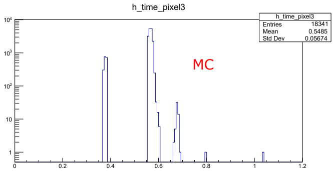
**N.B At present the same fit model is used for all PMT channels, for all fiber configurations**

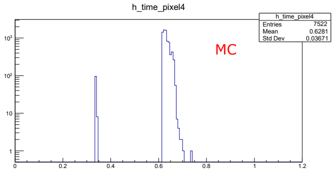
# Time distribution model

**N.B** **At present the same fit model is used for all PMT channels, for all fiber configurations**

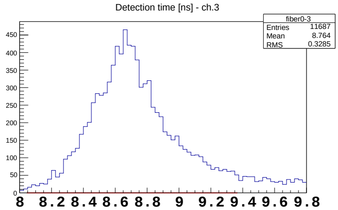
**This is still a rough approximation** *e.g.*:

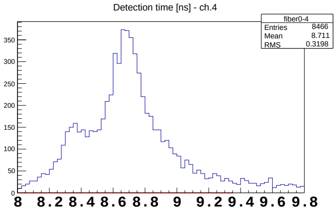
**Simulation** **(x-axis range [0,1.2] ns)** **N.B. without detector effect!**




**Data**

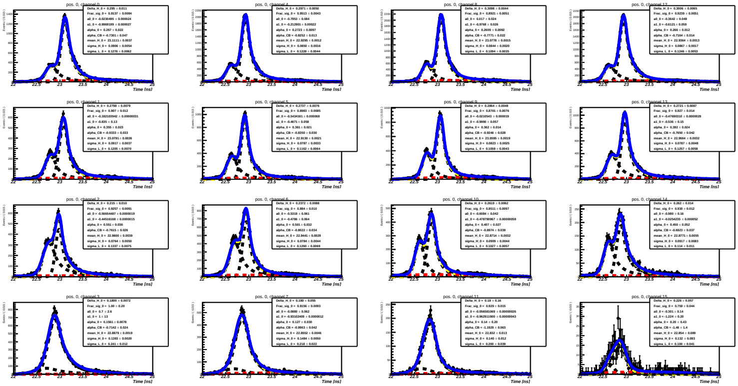



**We need a specific model for each PMT pixel, for each fiber position!**

# Example of time spectra analysis from single fiber - pos 0

$$\mathcal{P}^{pos.0}_{Sig}(T|t) = f_L\mathcal{CB}(t-\Delta^0_H, \delta t_L) + (1-f_L)\mathcal{CB}(t, \delta t_H)$$

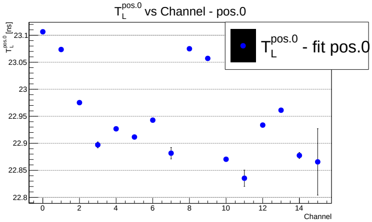


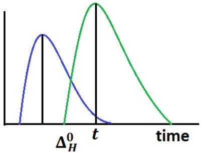
clearly evident the two main paths in the first three rows

in the last row the two photon paths get too close and are not resolved

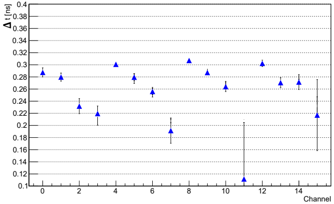
# Example of time spectra analysis from single fiber - pos 0

***t***

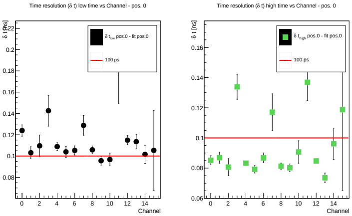


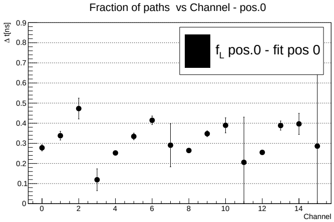

$\Delta_H^0$




Time resolution of the two paths: **low**, **high** time



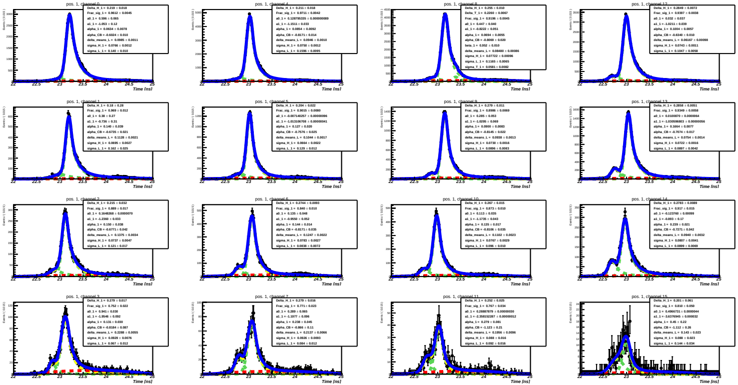

Fraction of low time component



# Example of time spectra analysis from single fiber - pos 1

$$\mathcal{P}^{pos.1}_{Sig}(T|\Delta) = f_L\mathcal{CB}(t+\Delta-\Delta^1_H,\delta t_L) + (1-f_L)\mathcal{CB}(t+\Delta,\delta t_H)$$

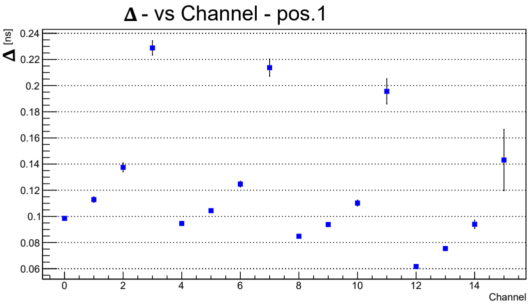
**$t$ fixed with fit of pos.0 spectrum**



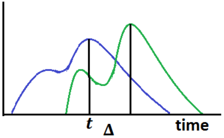
There's one main path (the reflected one)

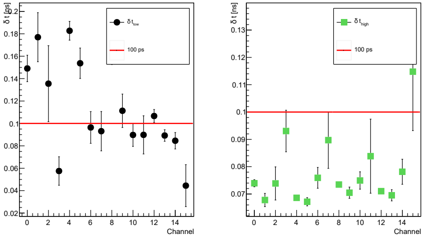
Tails are not well modeled: hint of another high time path(?)

# Example of time spectra analysis from single fiber - pos 1




Time difference between the main photon paths from the two fibers, *i.e.*




Time resolution of the two paths: **low**, **high** time

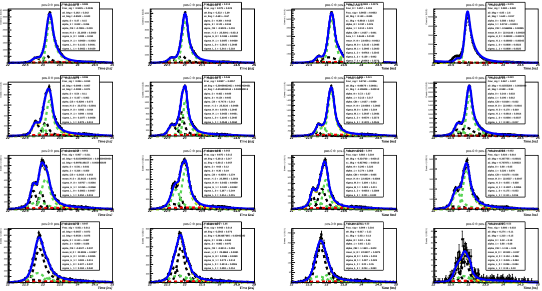
The **high** time peak has a resolution $\sim$ 70 ps

# Full time spectra comparison - pos.0 $\cup/\oplus$ pos.1

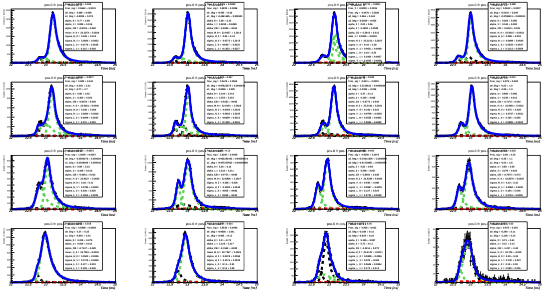
It is now possible to compare the full spectra obtained in two ways:

- simple merging of the pos 0 & 1 spectra (**pos.0 $\cup$ pos.1**)
- true data acquisition with both fibers illuminating the PMT (**pos.0 $\oplus$ pos.1**)

**pos.0 $\cup$ pos.1**



**pos.0 $\oplus$ pos.1**



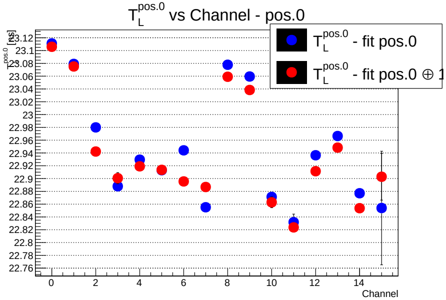
needs more work to understand the fit model

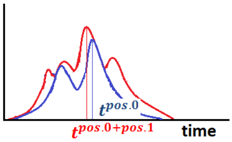
Crucial to understand which quantities can be fixed (in addition to time separations) from simulation (*e.g.* the relative weights)

# Full time spectra comparison - pos.0 $\cup/\oplus$ pos.1

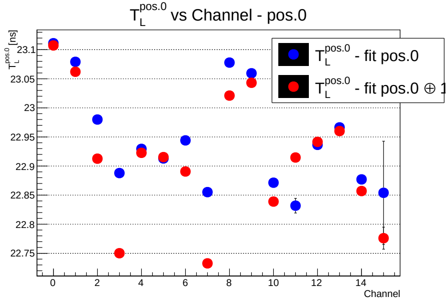
Comparison with absolute position obtained from fit pos.0 time spectrum

**pos.0 $\cup$ pos.1**




**pos.0 $\oplus$ pos.1**




Absolute position consistent for some channels, less for others

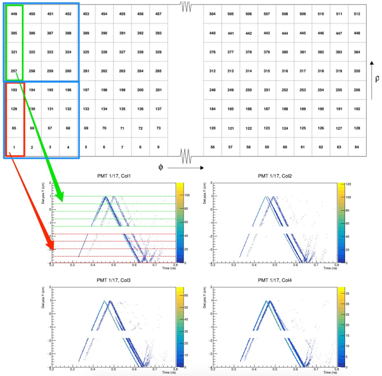
dependence on the statistics & the time separation between the various signals

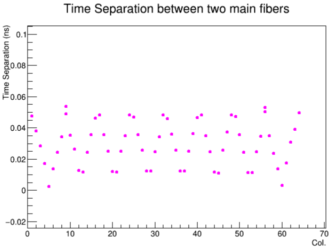
# MC studies

- Simulate the light emission from all the 9 fiber
- Study the detection time vs the pixel position
- Clear geometrical pattern but ...
- ... time separation is not constant within a pixel (due to its finite size $\sim$ 5 mm): in the worst case

$$\delta t|_{pixel} \sim 40ps$$

- strongly related with the relative yield

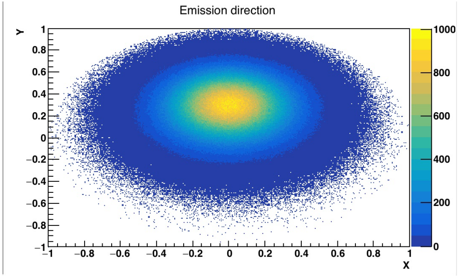


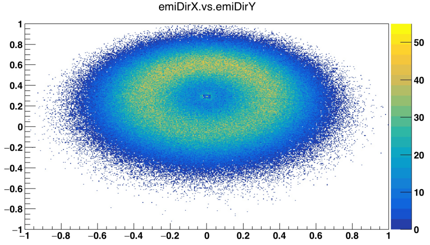



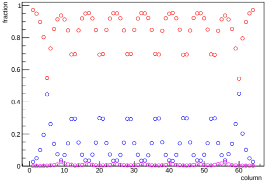

Time shift between adjacent fibers

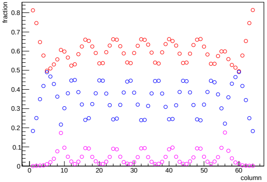
# MC studies

Check the effect of a different lens model on the path fractions




**Lens opening angle effect not negligible**

# Conclusions

- A large effort is being carried for the Time alignment of the MCP-PMT detectors
- Many tasks are required:
  - characterization of laser device
  - definition of a procedure to fit the time spectra
  - study and understanding of simulation
- A test-bench system has been set up in Padova
  - laser behavior understood $\rightarrow$ need to fix the working point
  - definition & cross-check of the time calibration procedure
- Next steps
  - repeat the laser characterization with the laser device installed in the experiment
  - apply, optimize, and tune the fit procedure to the true data collected in the experiment
  - plan to report the procedure in an internal note

# Backup