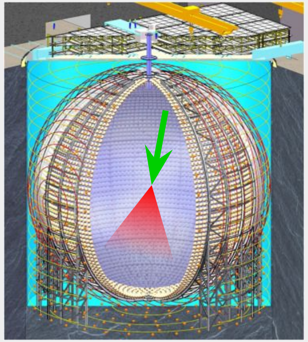


SHELDON:

Timing and optical properties of the JUNO liquid scintillator

Davide Basilico, Marco Beretta, Augusto Brigatti, Barbara Caccianiga,
Federico Ferraro, Cecilia Landini, Paolo Lombardi, Alessandra Re

Università degli Studi di Milano
INFN-Sezione di Milano

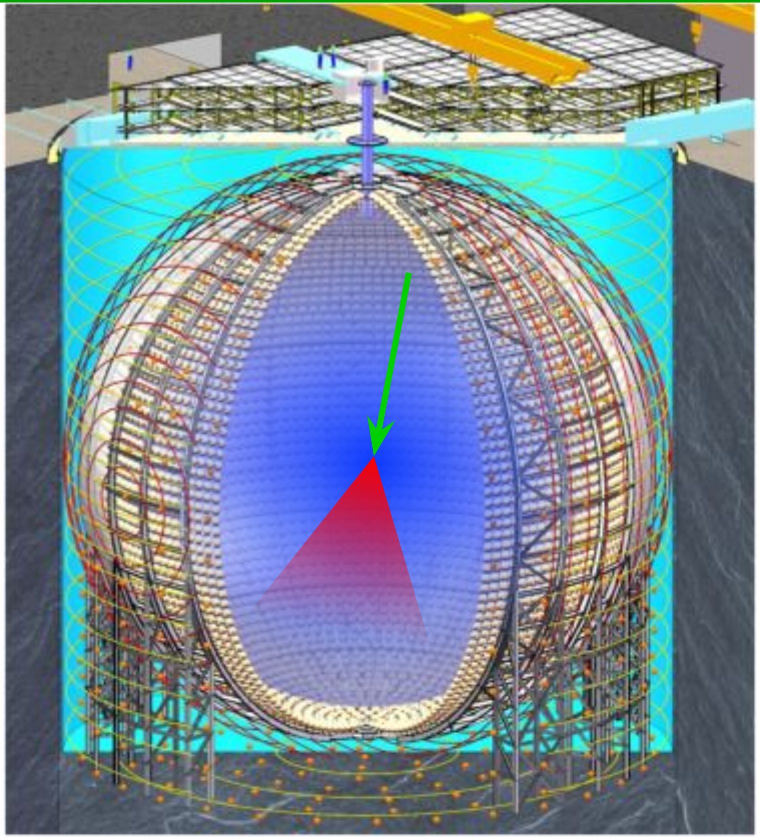
JUNO Italia meeting

Introduction

Since scintillation light is isotropic, any directional information is lost.

However, a few Cherenkov light is emitted and could potentially provide information on the neutrino direction.

SHELDON studies and characterizes the fluorescence and the Cherenkov emission in the scintillator mixture which is going to be used in JUNO.



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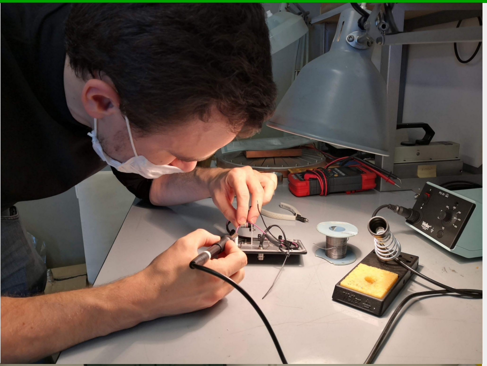
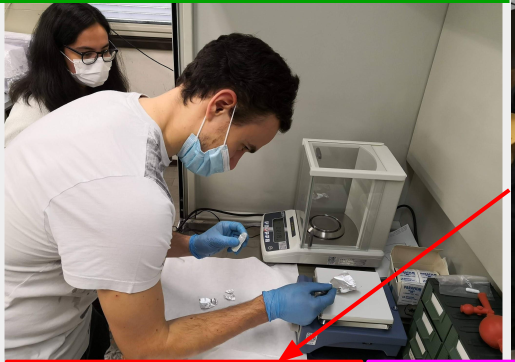
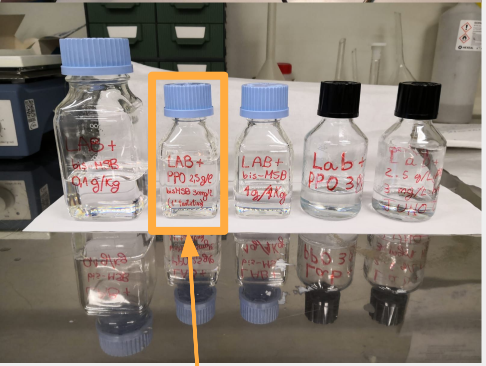
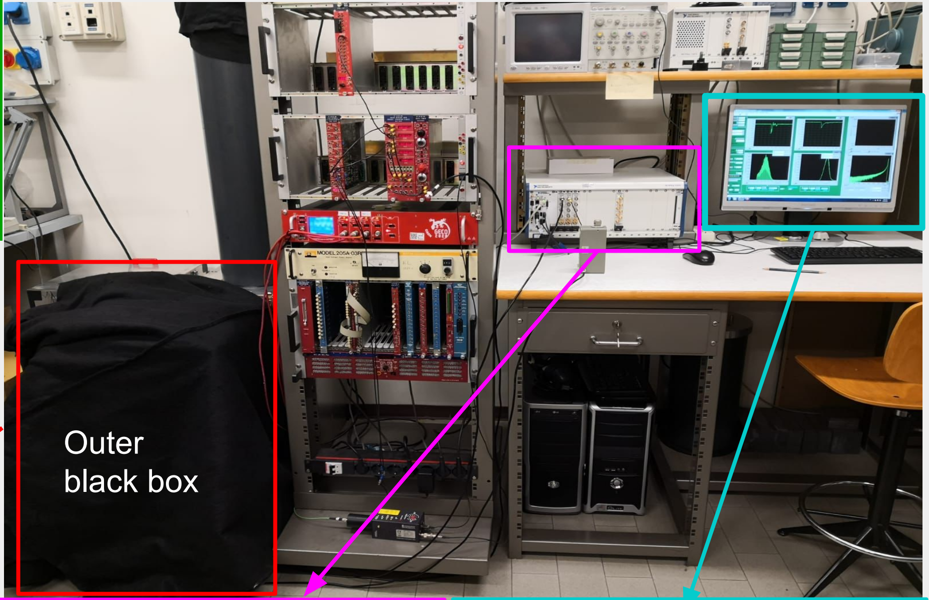
- **The SHELDON project**
- Measurement of fluorescence parameters
- Measurement of Cherenkov contribution
- Conclusions & future perspectives

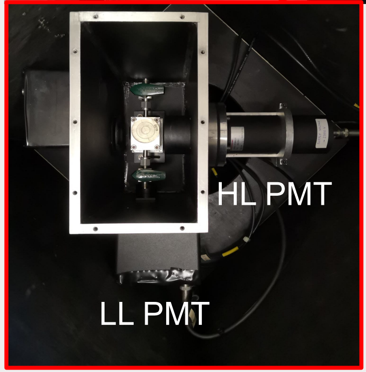
SHELDON’s laboratory

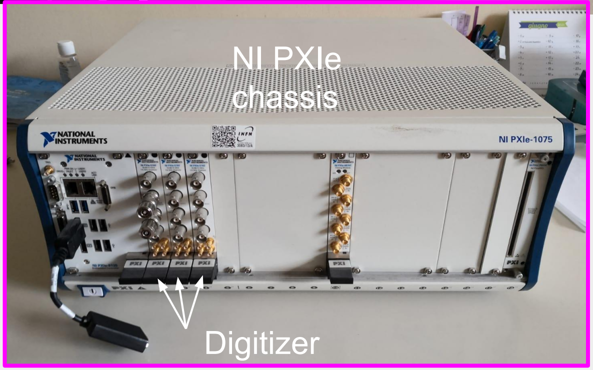


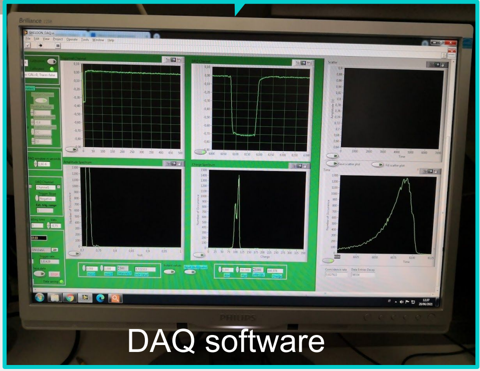






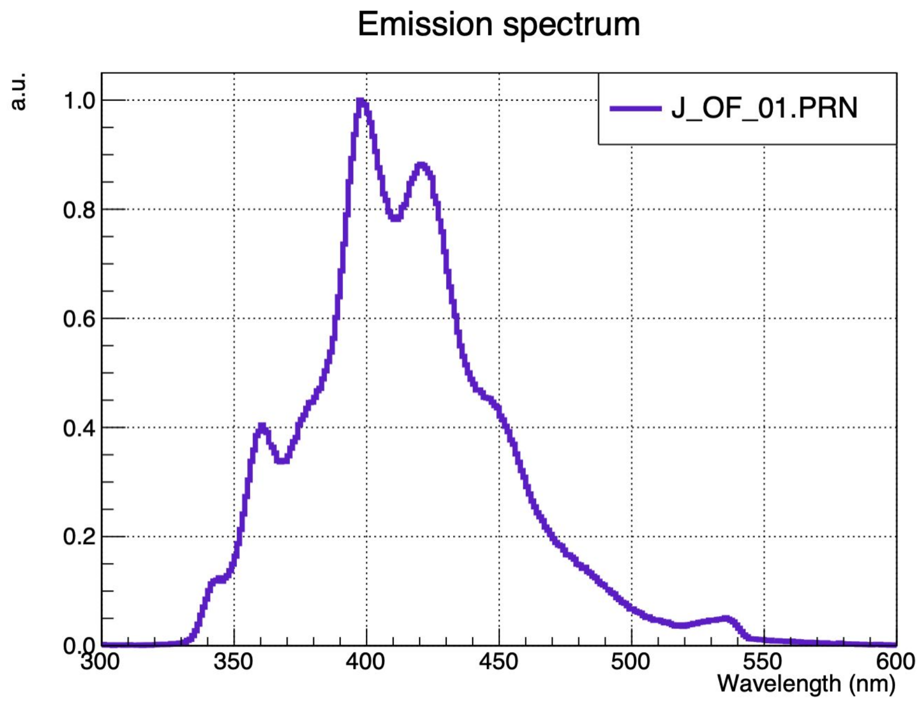






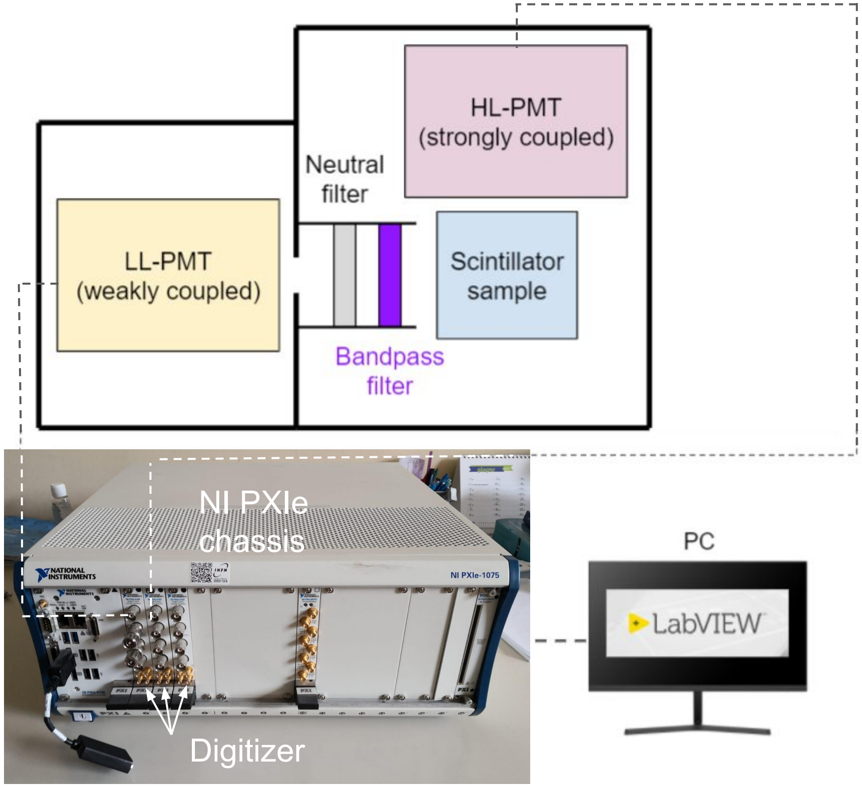
JUNO LS recipe: LAB + 2.5 g/L PPO + 3.0 mg/L bis-MSB

JUNO organic liquid scintillator



Measured @ Università degli Studi di Perugia
thanks to: Fausto, Aldo e Catia

The SHELDON project: experimental setup



Components of the setup:

JUNO LS sample

2 PMTs, one weakly coupled

Neutral filter

2 Digitizer (5 GS/s each)

LabVIEW DAQ software

Technique:

Time-**C**orrelated **S**ingle **P**hoton **C**ounting

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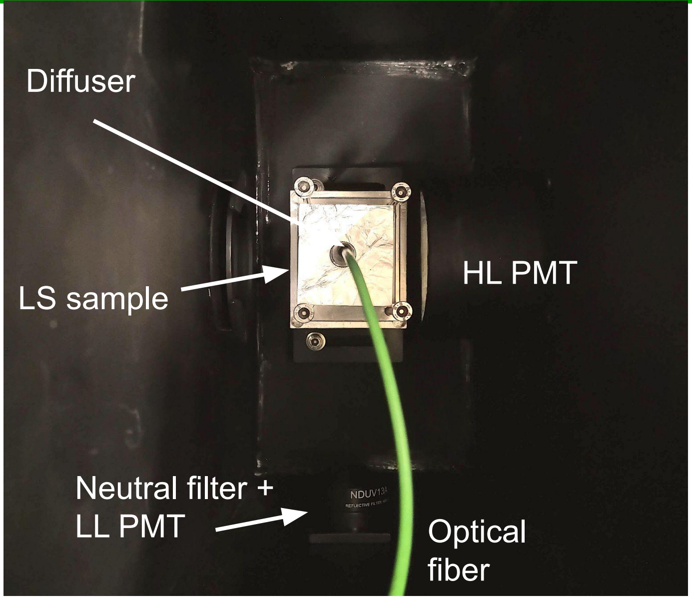
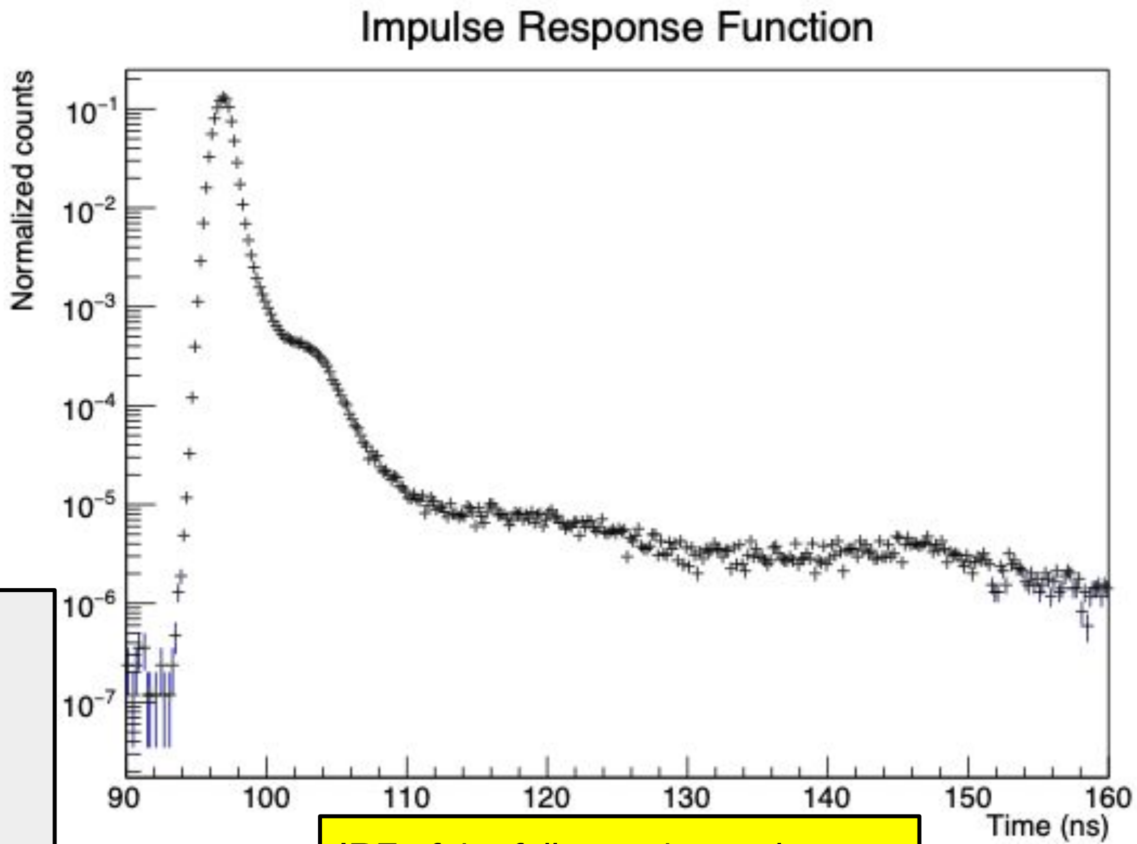
The SHELDON project: Impulse Response Function



The measurement of the Impulse Response Function is performed using a laser.

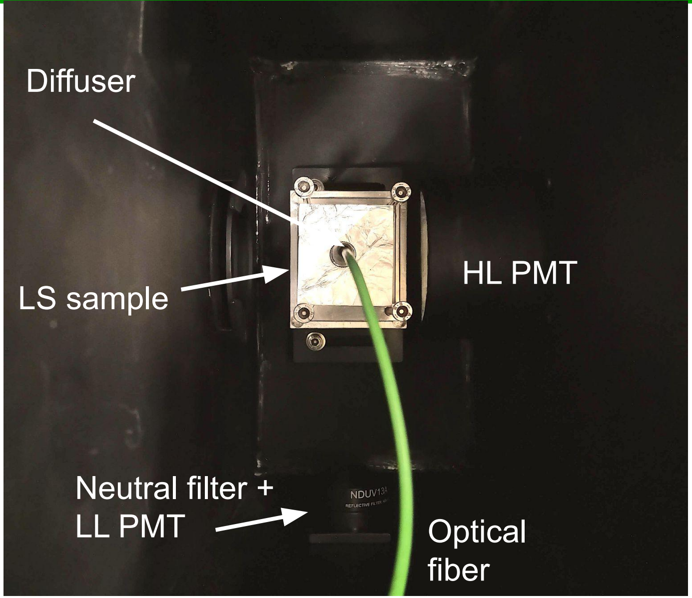
The laser has a pulse duration 75 ps.

A diffuser is placed at the end of the optic fibre to mimic a point like emission



IRF of the full experimental setup:
LS + PMT + ADC + CFD

The SHELDON project: Impulse Response Function



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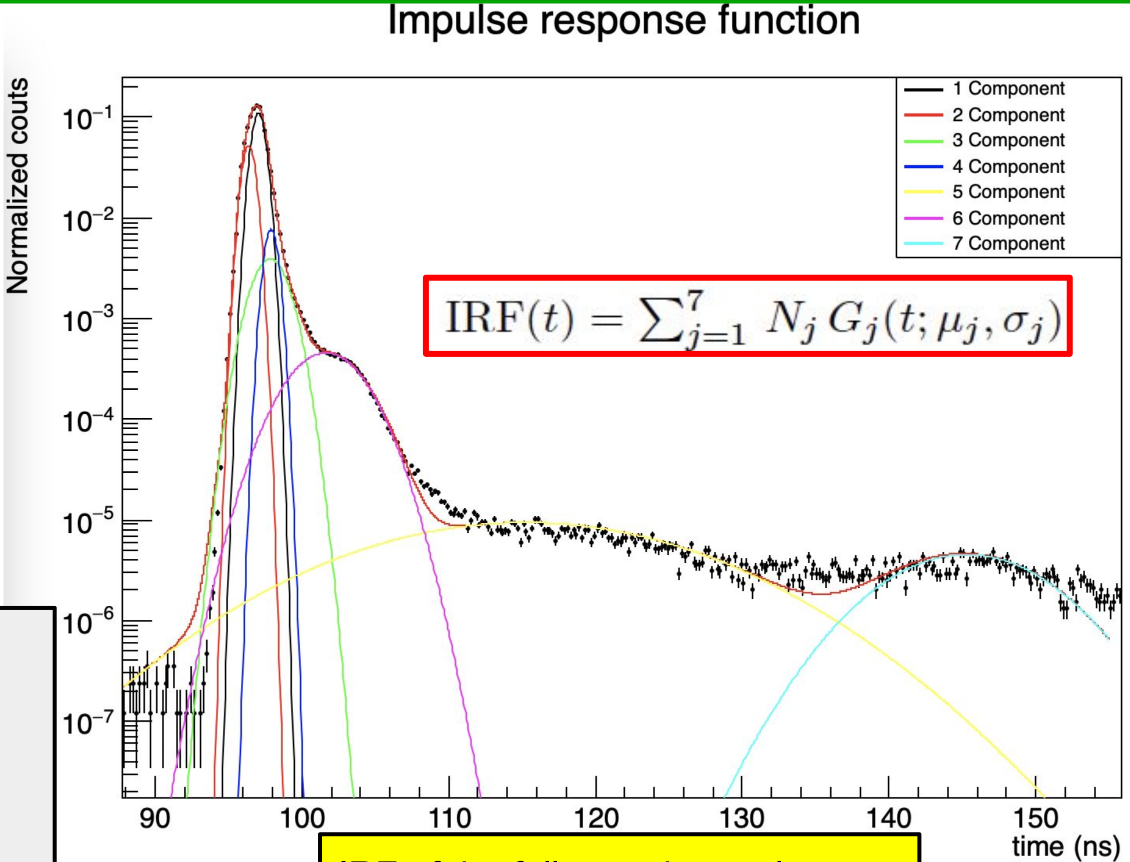

IRF of the full experimental setup:
LS + PMT + ADC + CFD

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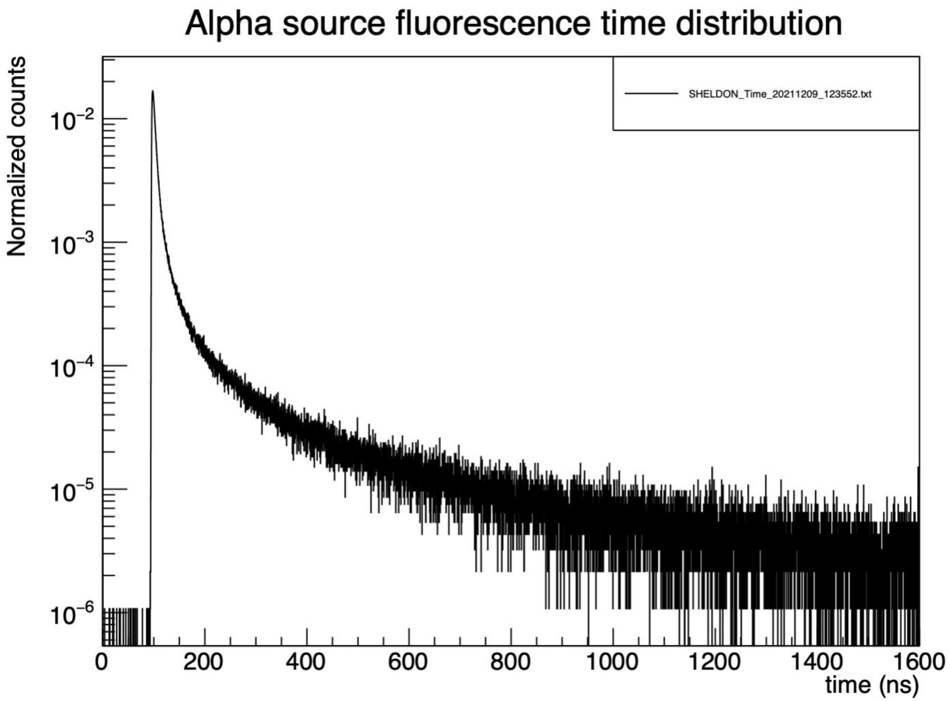
Measurement of fluorescence



Fluorescence time distribution obtain using an alpha source

Same experimental setup of the IRF one

The duration of the data acquisition is 10 days to obtain 10^6 events

The light emission is **not** a prompt emission

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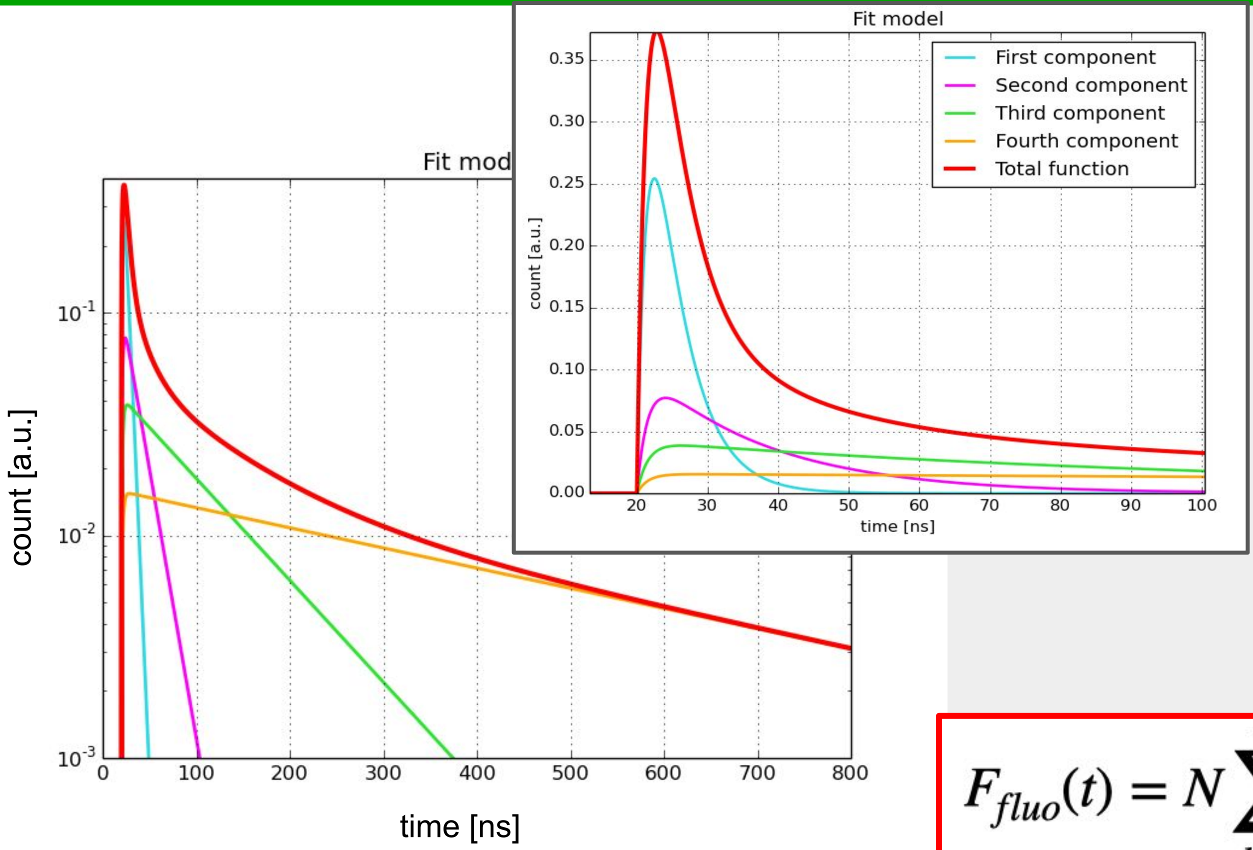
Fit model: four exponential decay



To describe the fluorescence time profile **4 components** are needed

The fourth becomes dominant starting from **~300 ns**

Our DAQ time window is **1600 ns**

$$F_{fluo}(t) = N \sum_{d=1}^{4} \frac{q_d}{\tau_d - \tau_r} \left(e^{-t/\tau_d} - e^{-t/\tau_r} \right)$$

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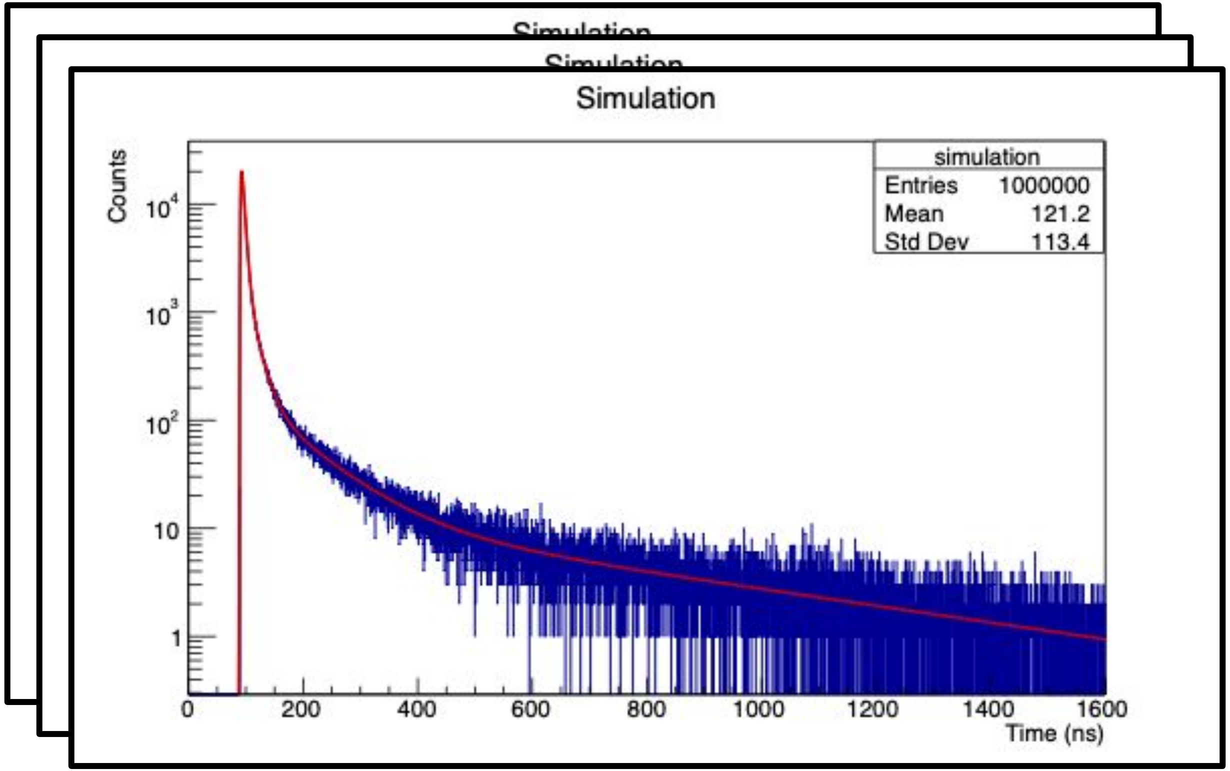
Monte Carlo study

Method validation

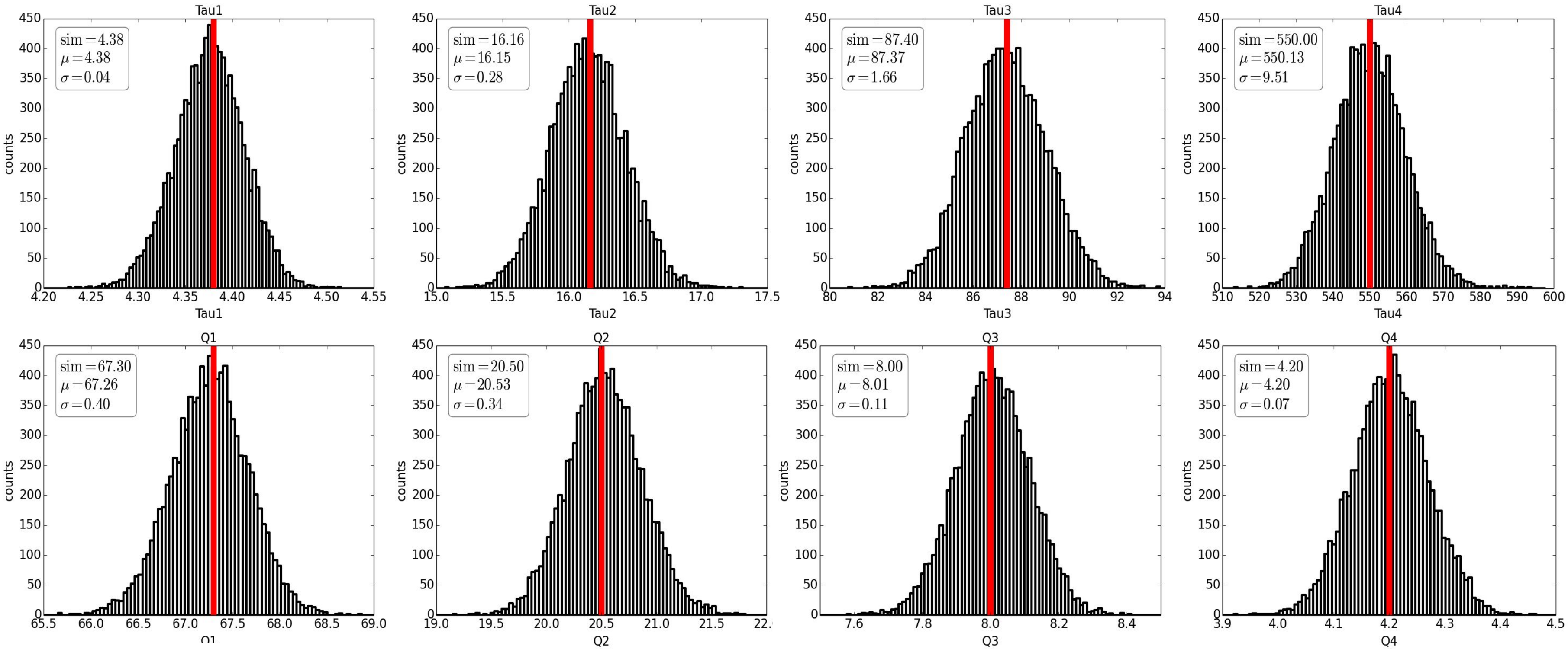
Monte Carlo simulation to produce **10^4 fake dataset**
used to evaluate the **possible fit sistematics** on fluorescence parameters



Monte Carlo study

Method validation

The uncertainties on the fluorescence parameters are at the percentage level



No relevant bias is shown on all parameters

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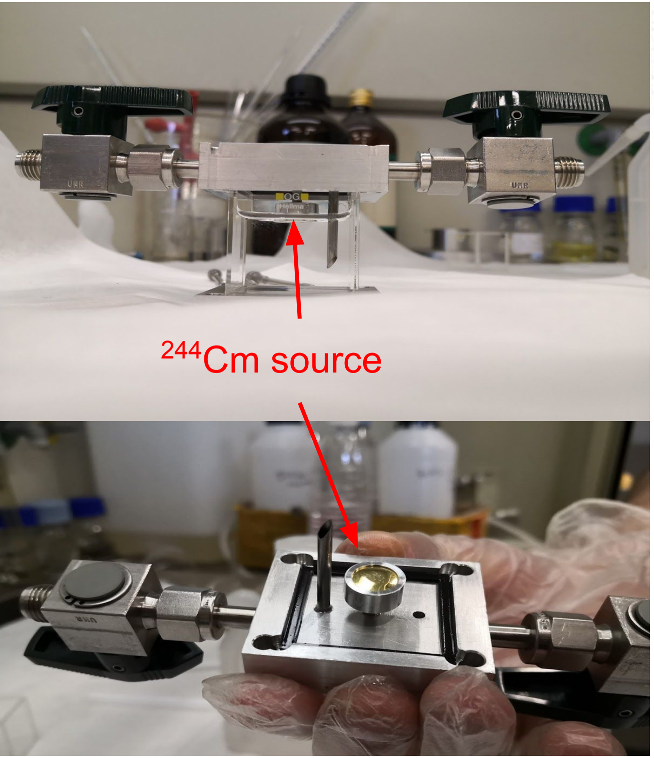
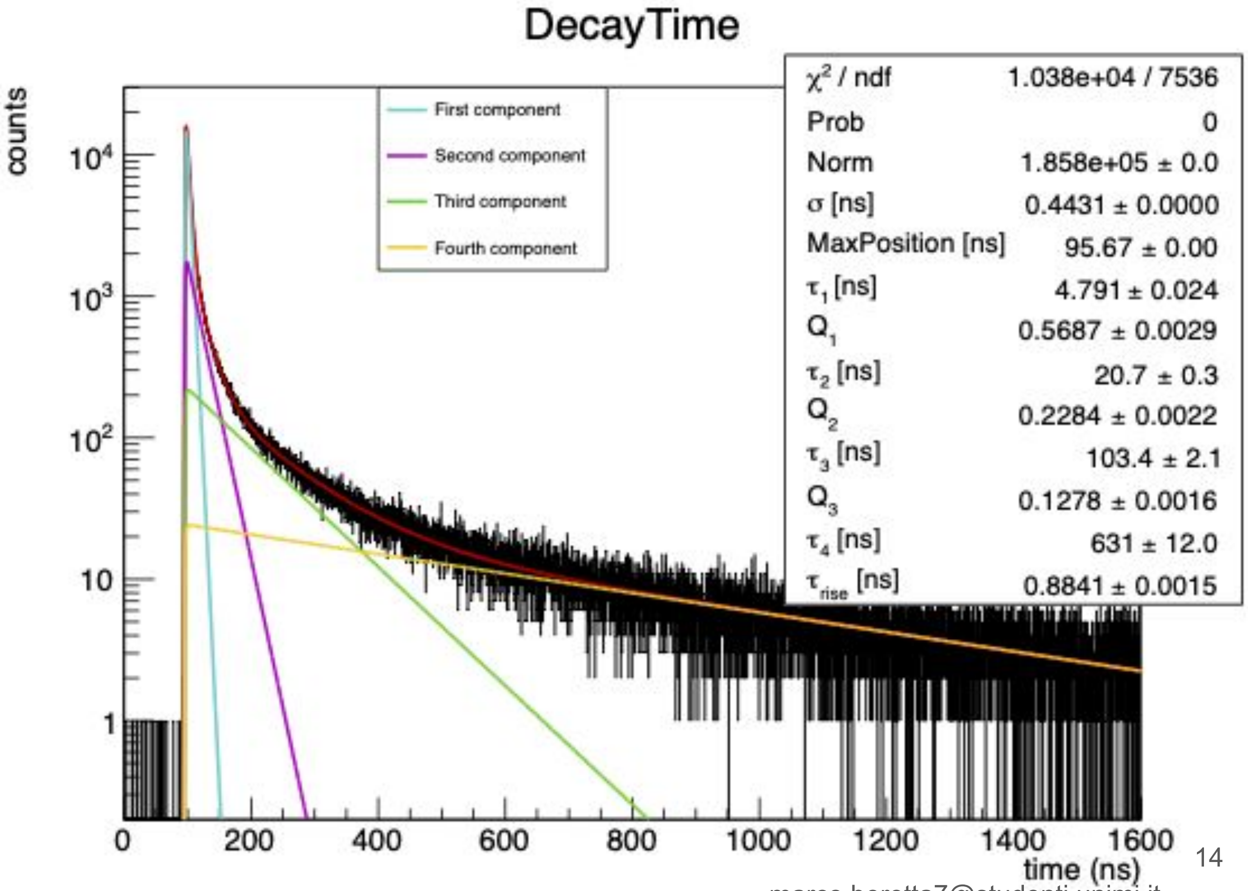
Measurement of fluorescence parameters: α-source





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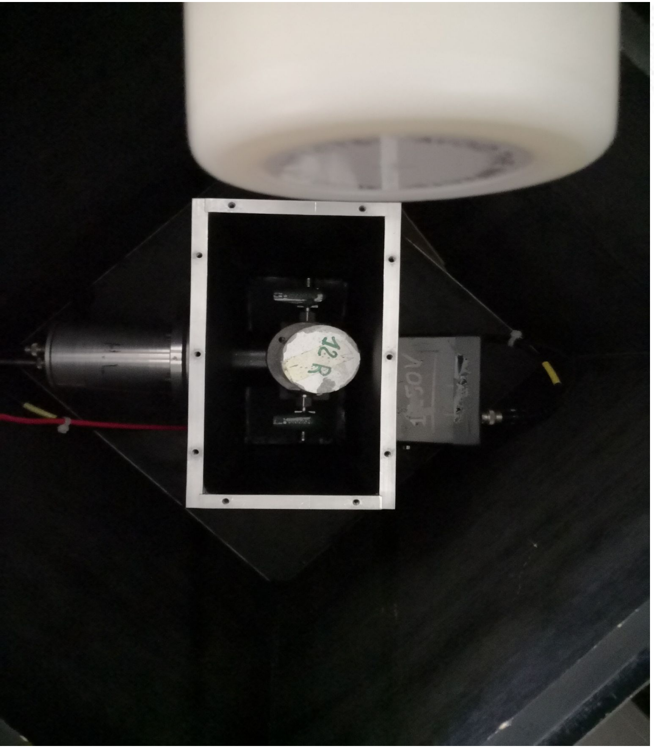
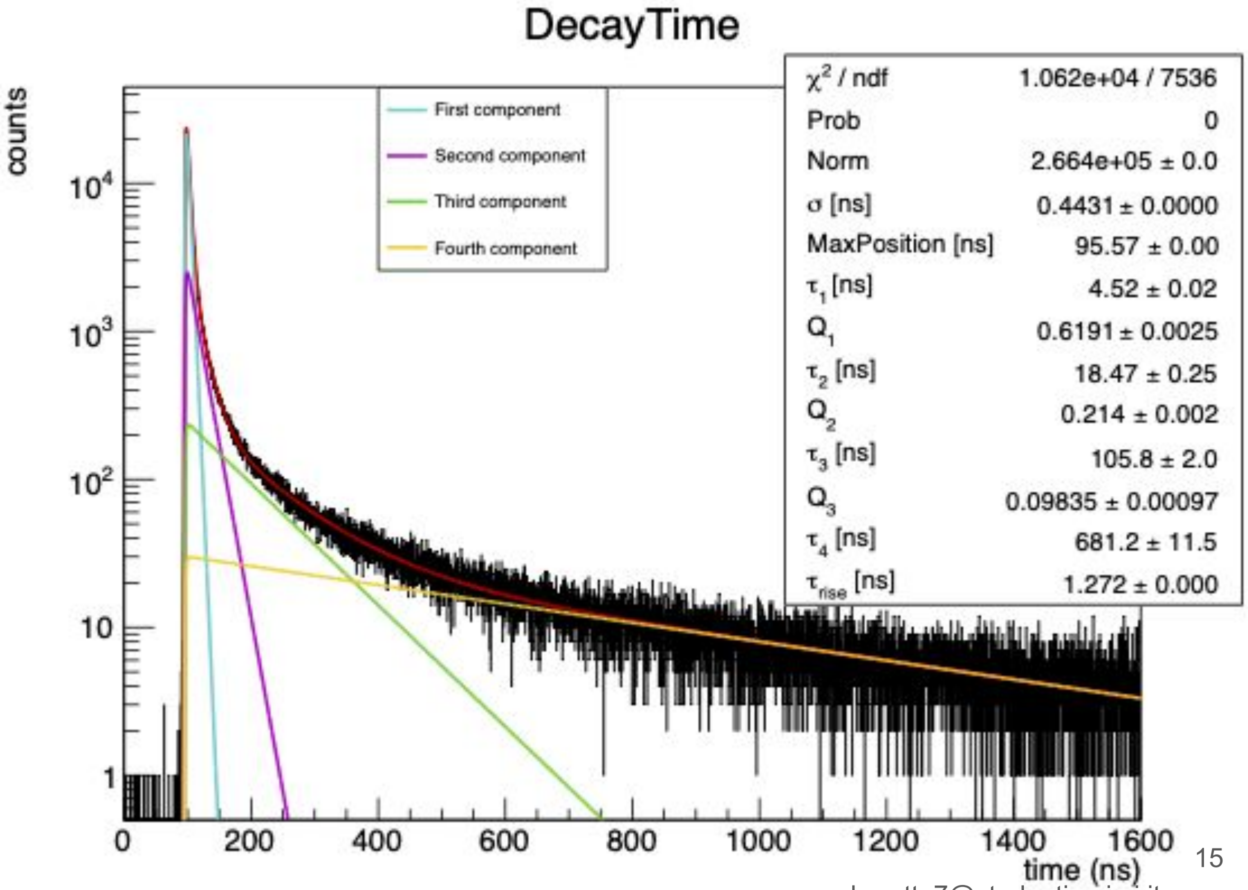
Measurement of fluorescence parameters: *protons*





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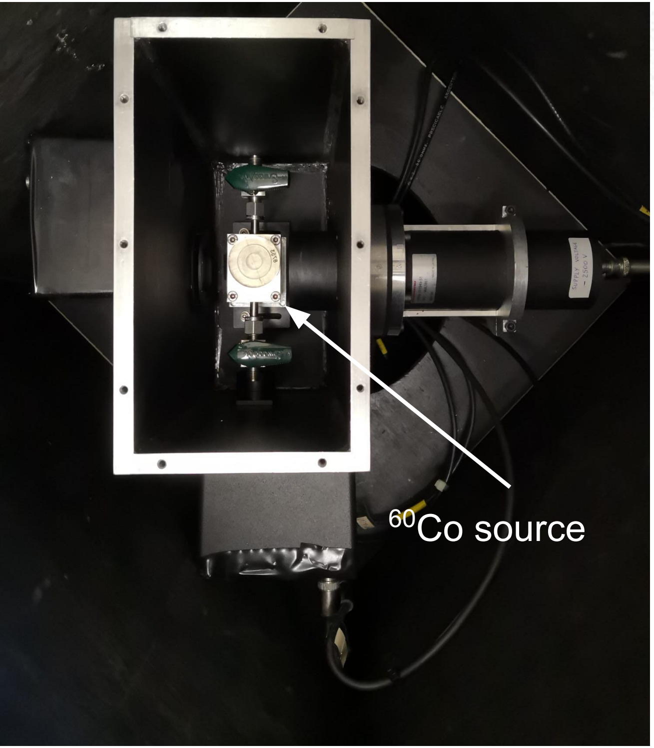
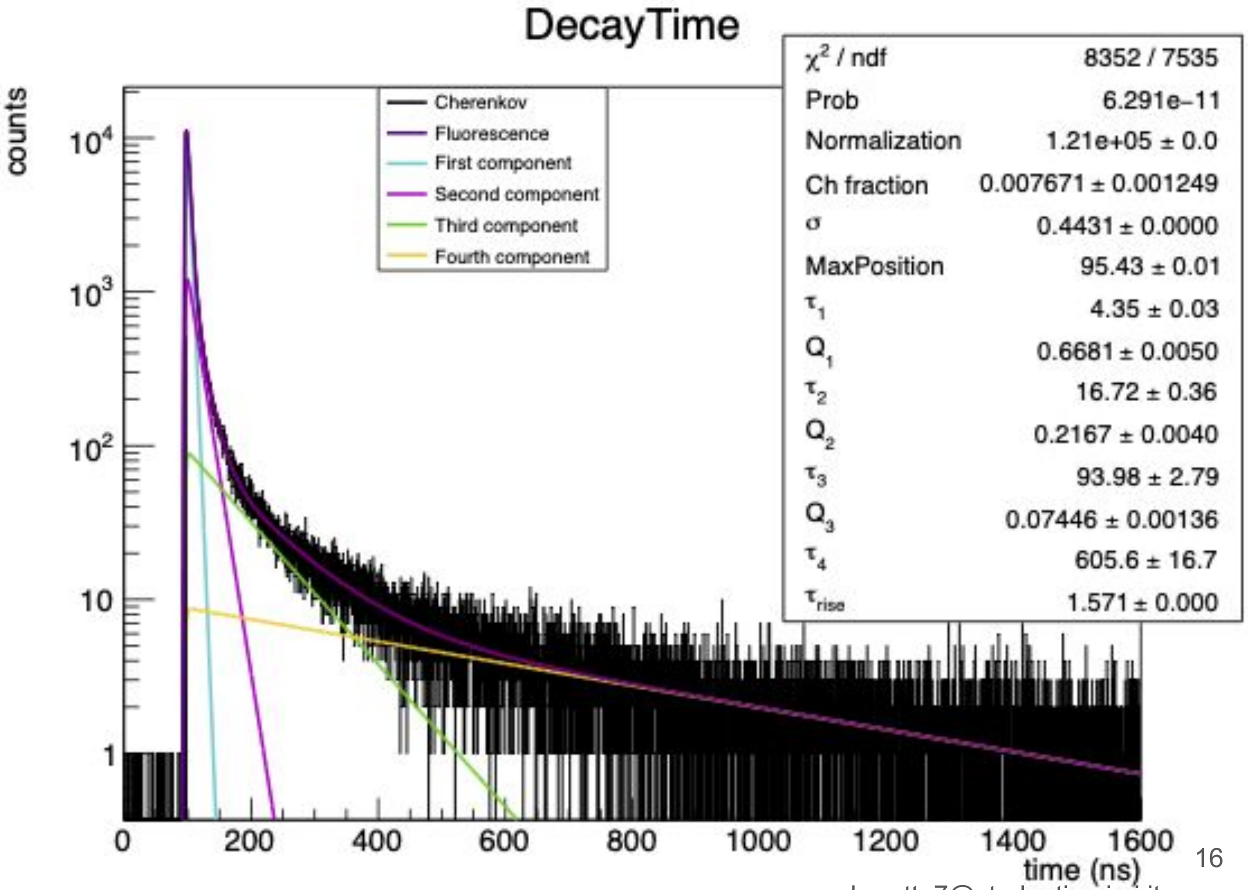
Measurement of fluorescence: β-source





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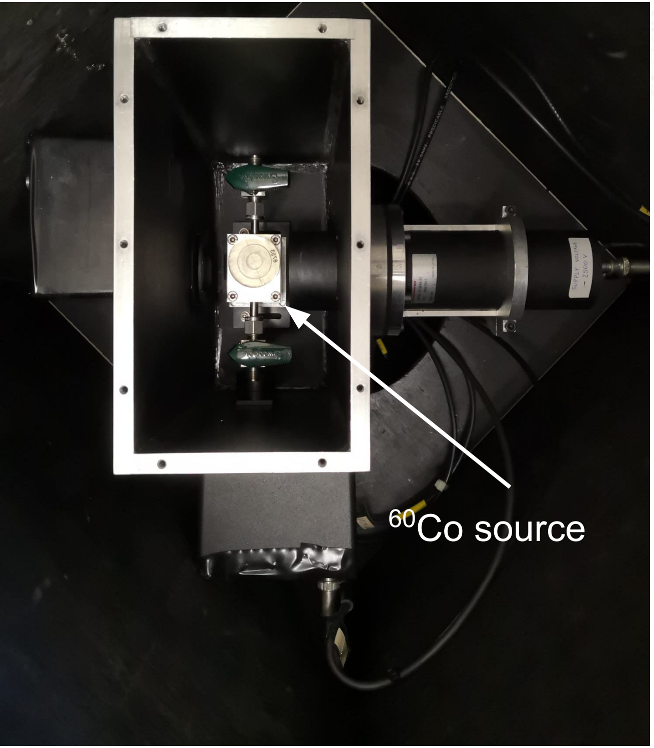
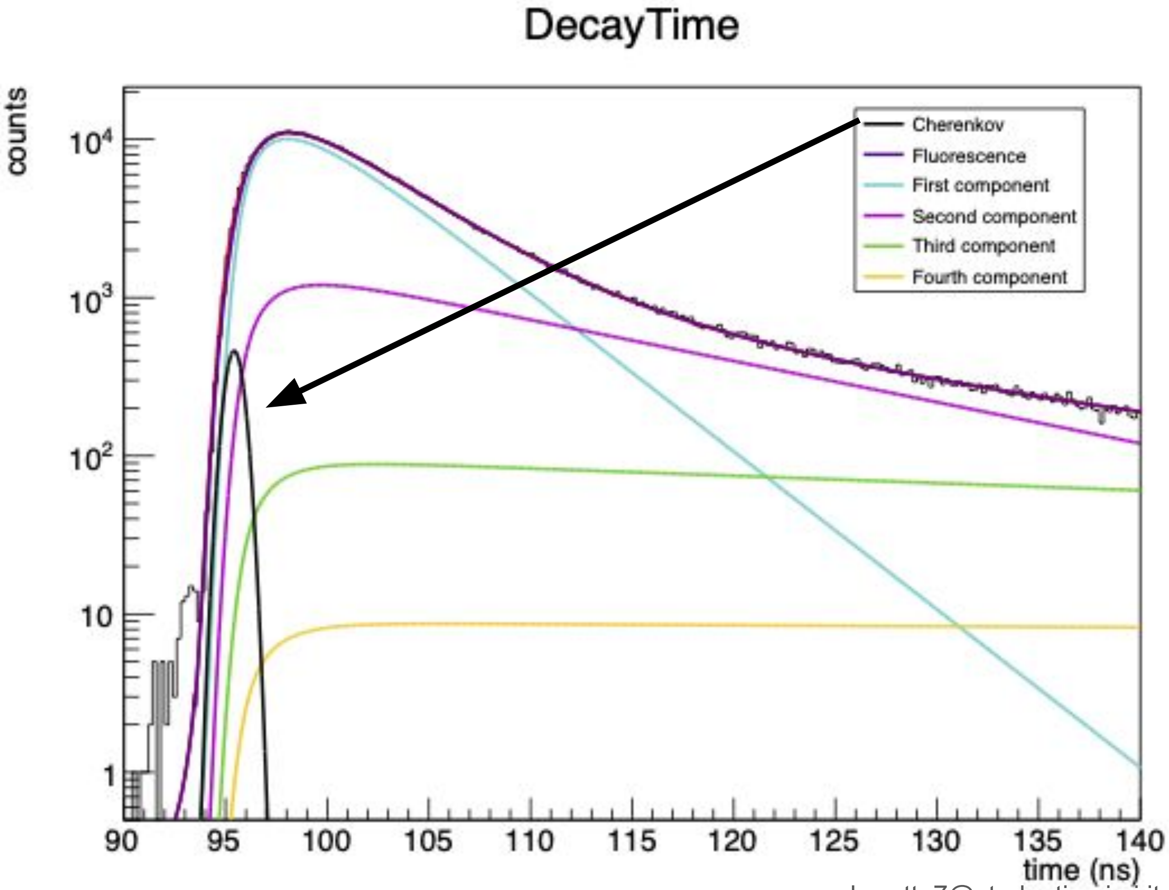
Measurement of fluorescence: β-source





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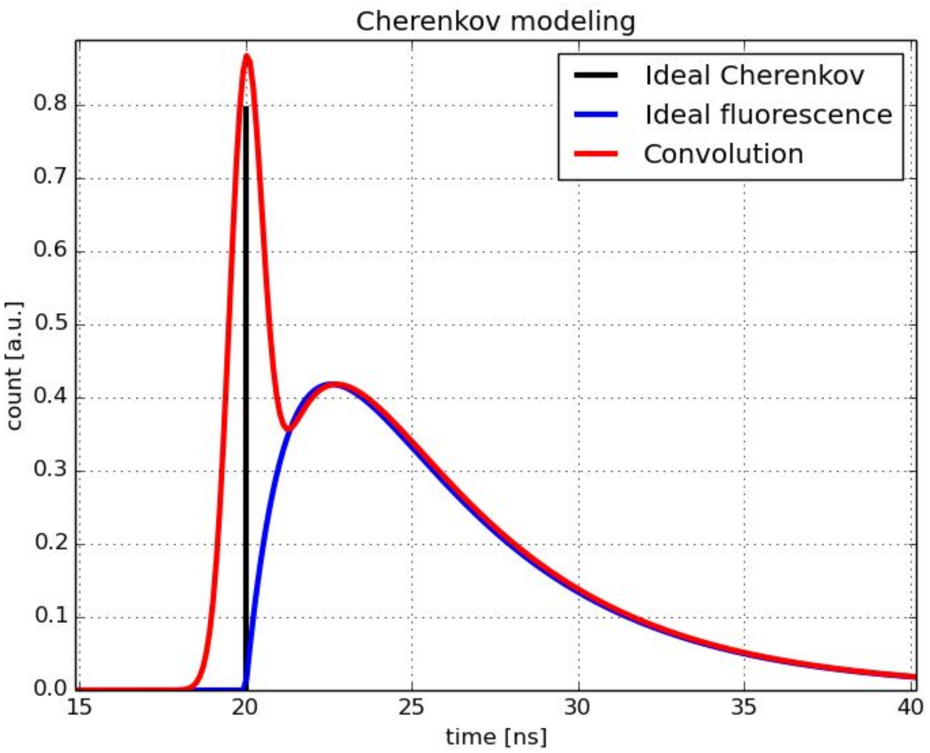
Fit model: Cherenkov contribution



The Cherenkov contribution is modeled as a **delta function**

It is summed to the **fluorescence** model

The **sum** is convolved with the detector response

$$\mathrm{IRF}(t) = \sum_{j=1}^{7} N_j\, G_j(t; \mu_j, \sigma_j)$$

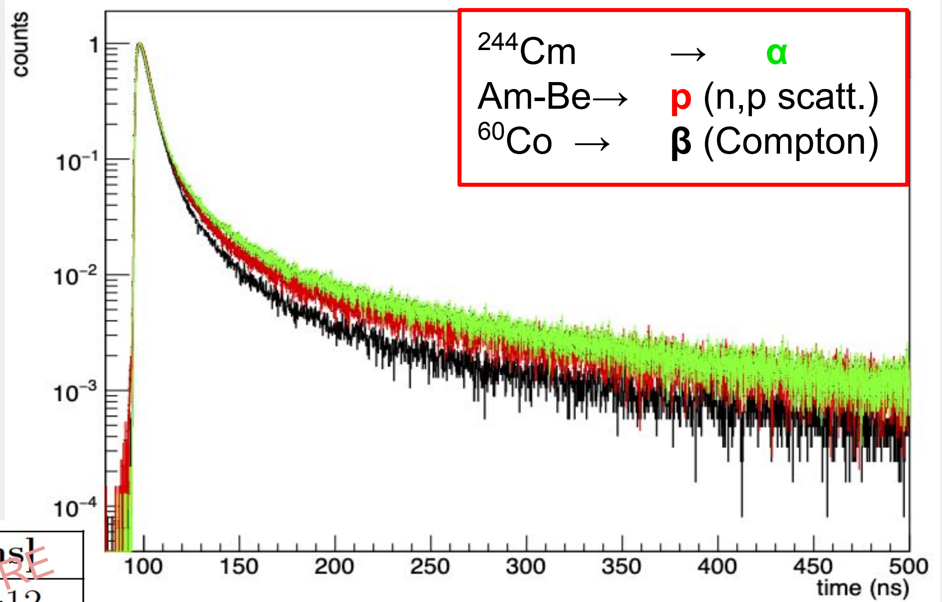
$$F_{Total}(t) = [N_{Ch}\, \delta(t, t_0) + (1 - N_{Ch})\, F_{Fluo}(t)] * \mathrm{IRF}(t)$$

Measurement of fluorescence: preliminary results

Measurement of **fluorescence** **time distribution** using three different radioactive sources

The three curves have different tails

The distribution on the incident radiation and gives the possibility to do **P**ulse **S**hape **D**iscimination



	τ_1 [ns]	τ_2 [ns]	τ_3 [ns]	τ_4 [ns]
α	4.79±0.04	20.69±0.34	103.4±2.1	631±12
p	4.52±0.02	18.47±0.25	105.8±2.0	681±11
e^-	4.35±0.03	16.72±0.36	94.0±2.8	607±17
	q_1 [%]	q_2 [%]	q_3 [%]	q_4 [%]
α	56.87±0.29	22.84±0.22	12.78±0.16	8.27±0.62
p	61.91±0.25	21.40±0.20	9.83±0.10	7.70±0.55
e^-	66.81±0.50	21.67±0.40	7.45±0.14	4.44±0.65

PRELIMINARY RESULTS ON THE JUNO MIXTURE

PRELIMINARY RESULTS

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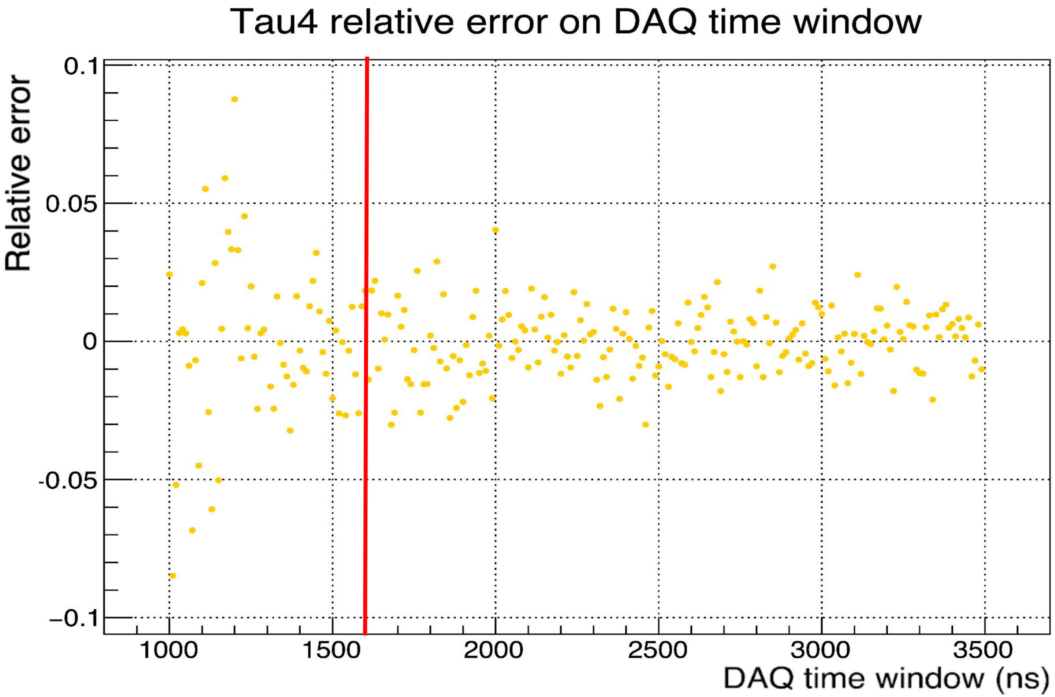
Monte-Carlo study

Systematic error introduced by the choice the DAQ time window

The relative uncertainty on slow component decreases as the upper end of the DAQ time window increases.



The red line represent our DAQ time window

The number of events is fixed (similar to a measurement lasting **one week**)

As the statistic increases the uncertainty decreases

The trend does not change with increasing statistics

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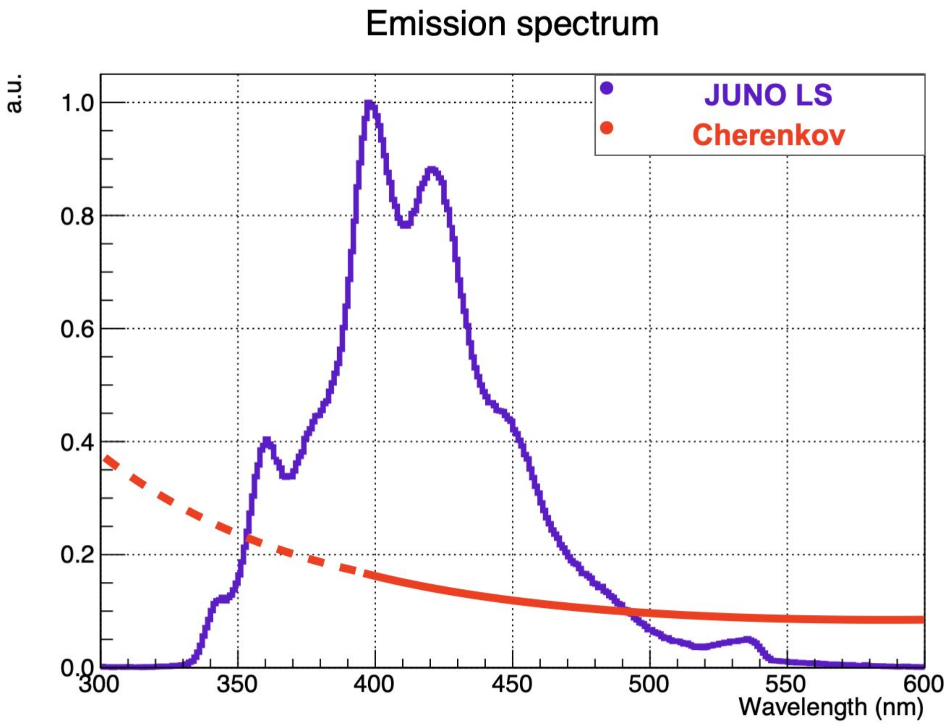
Cherenkov contribution at different wavelength



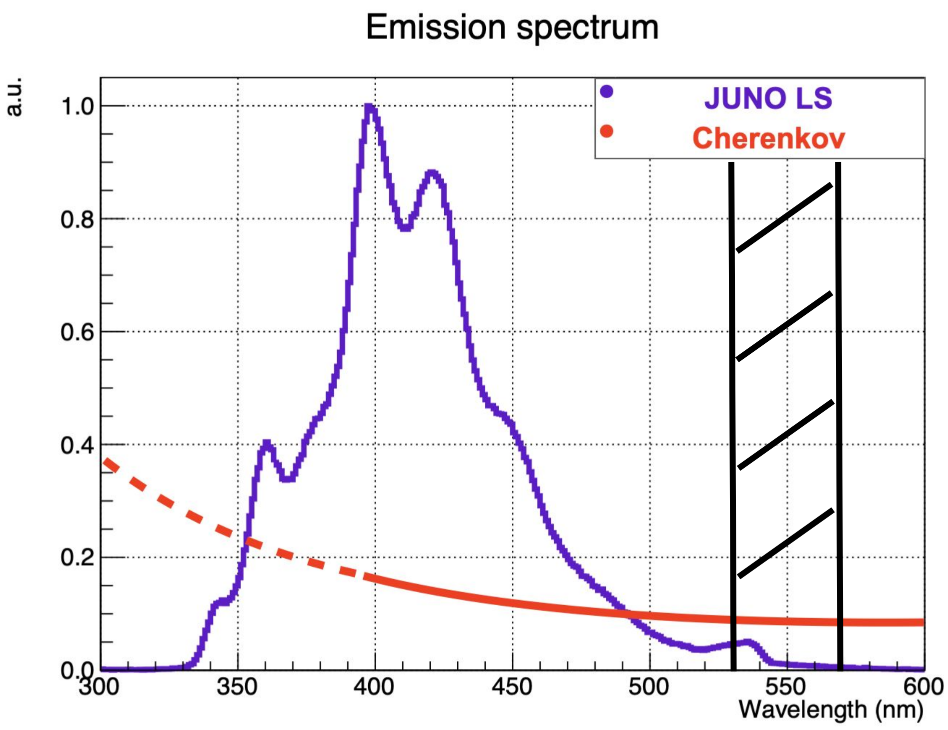
Cherenkov light can be separated from scintillation light thanks to its spectral features.

The JUNO LS emission spectrum has a maximum at 400 nm

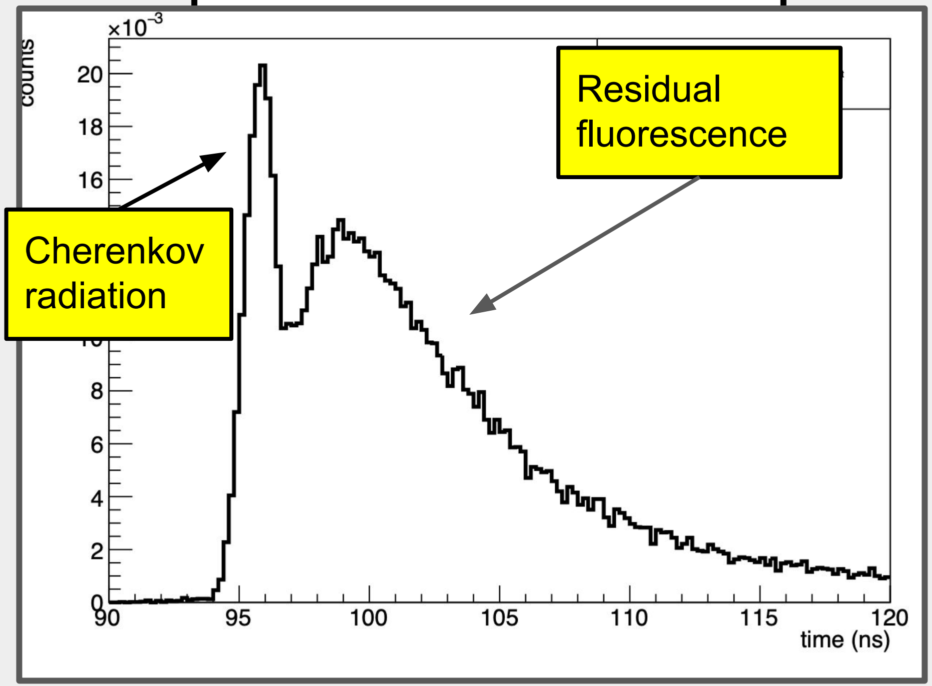
The Cherenkov spectrum (not to scale) decreases as $1/\lambda^2$ and extends above the scintillation spectrum.

Using appropriate optical filters it is possible to select the light in a **desired wavelength interval,** separating scintillation and Cherenkov light.

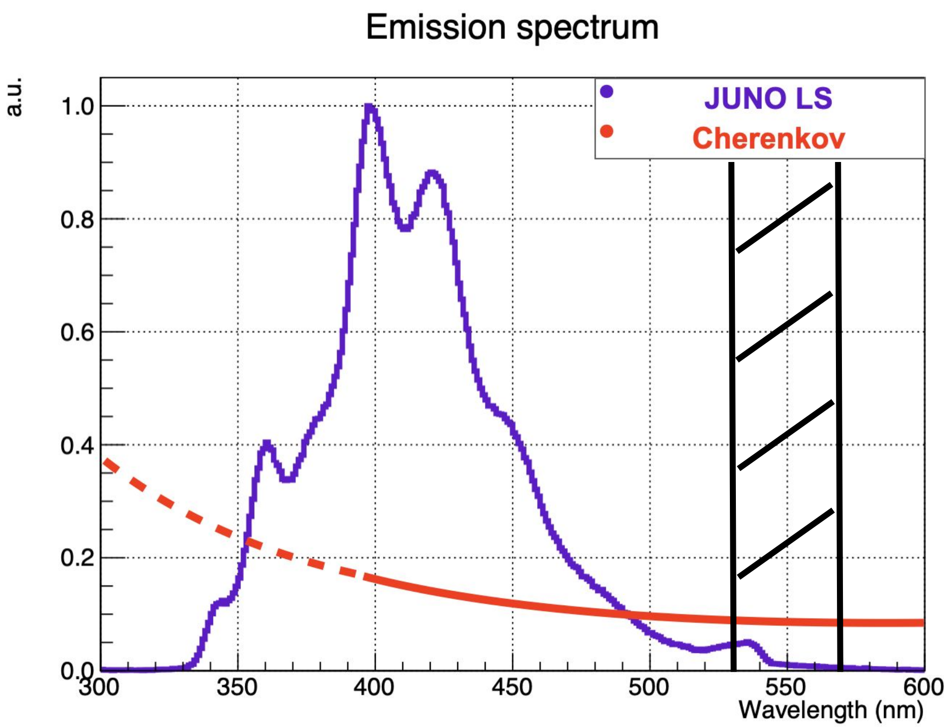
Cherenkov contribution at different wavelength



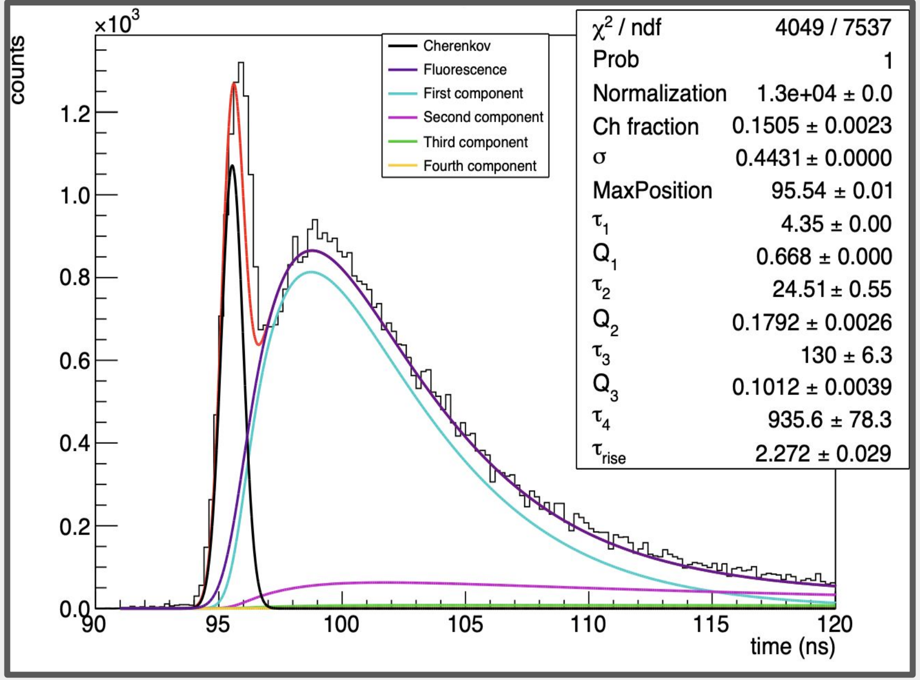
550 - 40 nm



Cherenkov contribution at different wavelength



550 - 40 nm



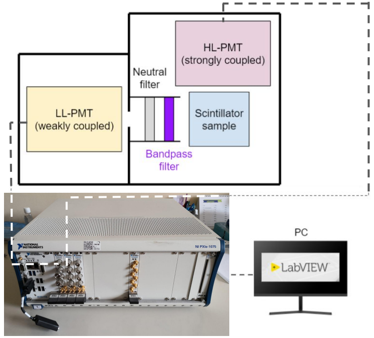
Cherenkov = 15.1 ± 0.2 %

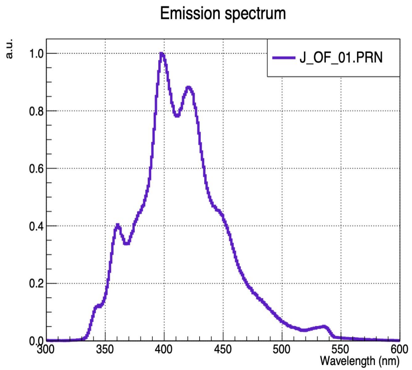
Index

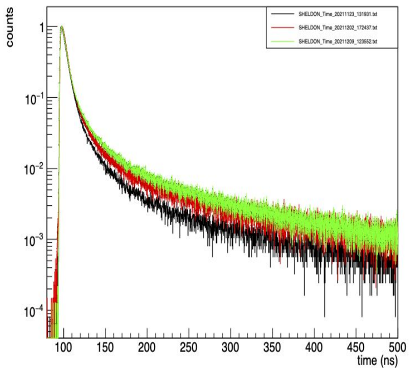
- The SHELDON project
- Measurement of fluorescence parameters
- Measurement of Cherenkov contribution
- **Conclusions & future perspectives**

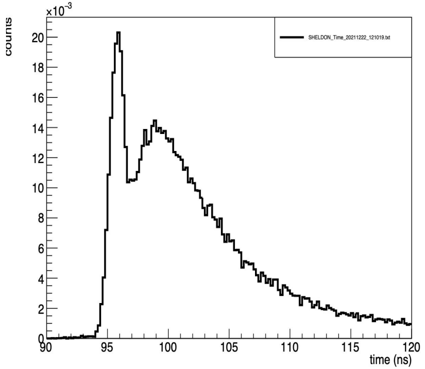
Conclusions

- We developed an experimental setup for the fluorescence time measurement
- We produced the JUNO liquid scintillator and measured the emission spectrum
- We measured the fluorescence distribution from three different source
- We are going to conclude the analysis
- We measure the Cherenkov contribution at different wavelength









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Conclusions: future prospective

- Consider the muon flux in SHELDON measurements

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Conclusions: future prospective

- Consider the muon flux in SHELDON measurements → **Muon veto**

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Conclusions: future prospective

- Consider the muon flux in SHELDON measurements → **Muon veto**
- Measurement of the refractive index of the liquid scintillator
- Measurement of the group velocity in the liquid scintillator

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Conclusions: future prospective

- Consider the muon flux in SHELDON measurements → **Muon veto**
- Measurement of the refractive index of the liquid scintillator
- Measurement of the group velocity in the liquid scintillator

SHELDON-REWIND

Conclusions: future prospective

- Consider the muon flux in SHELDON measurements → **Muon veto**
- Measurement of the refractive index of the liquid scintillator
- Measurement of the group velocity in the liquid scintillator

SHELDON-REWIND

- Development of a Monte Carlo using Geant4 to evaluate the Cherenkov emission in our setup to by compared to the Cherenkov separation measurement

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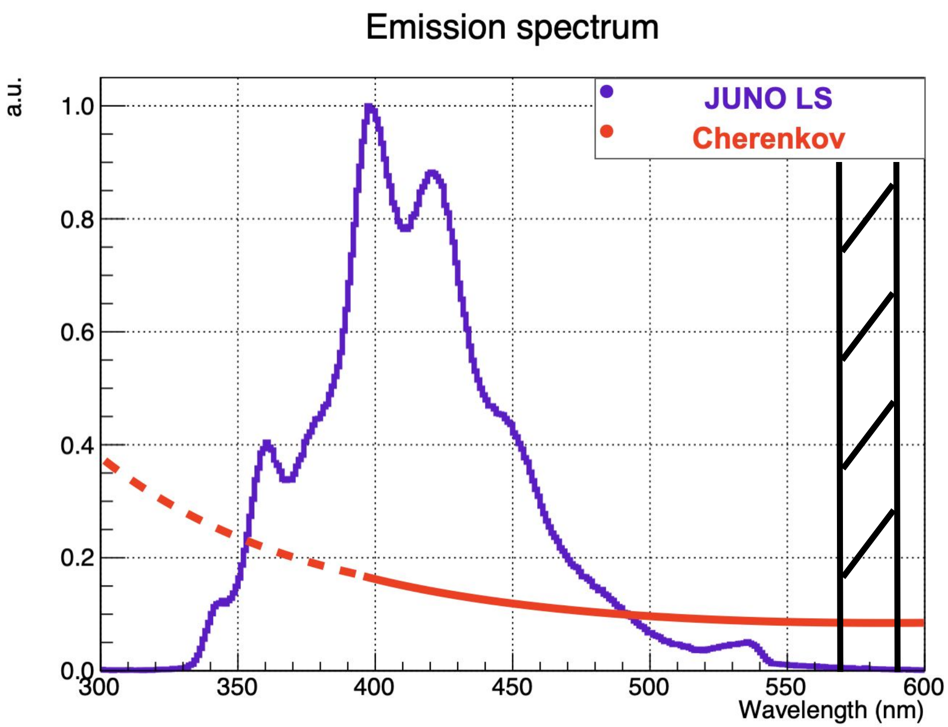
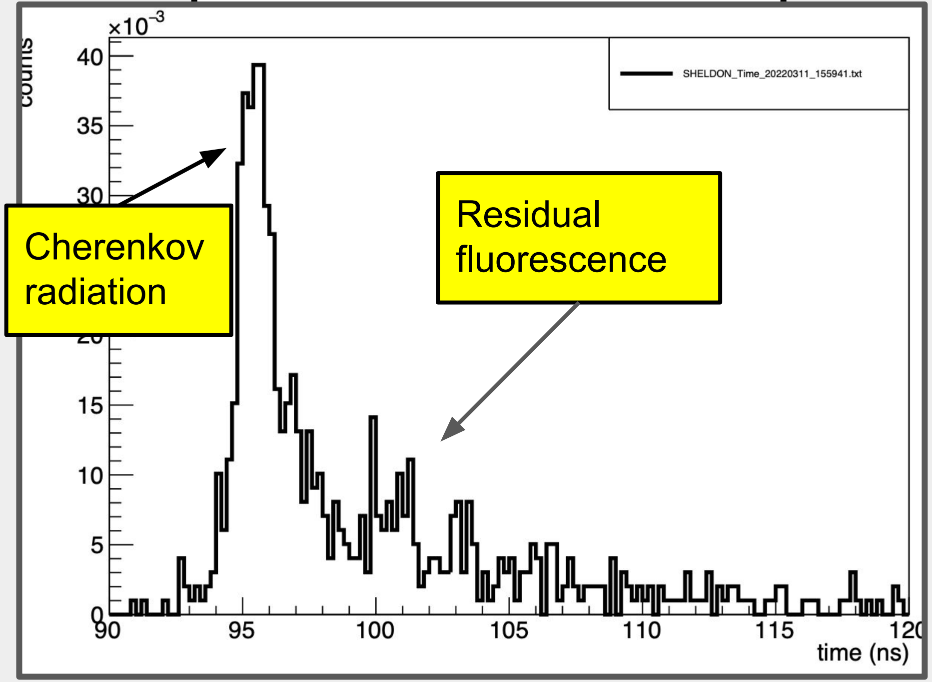
Grazie per l’attenzione

Backup

Cherenkov contribution at different wavelength

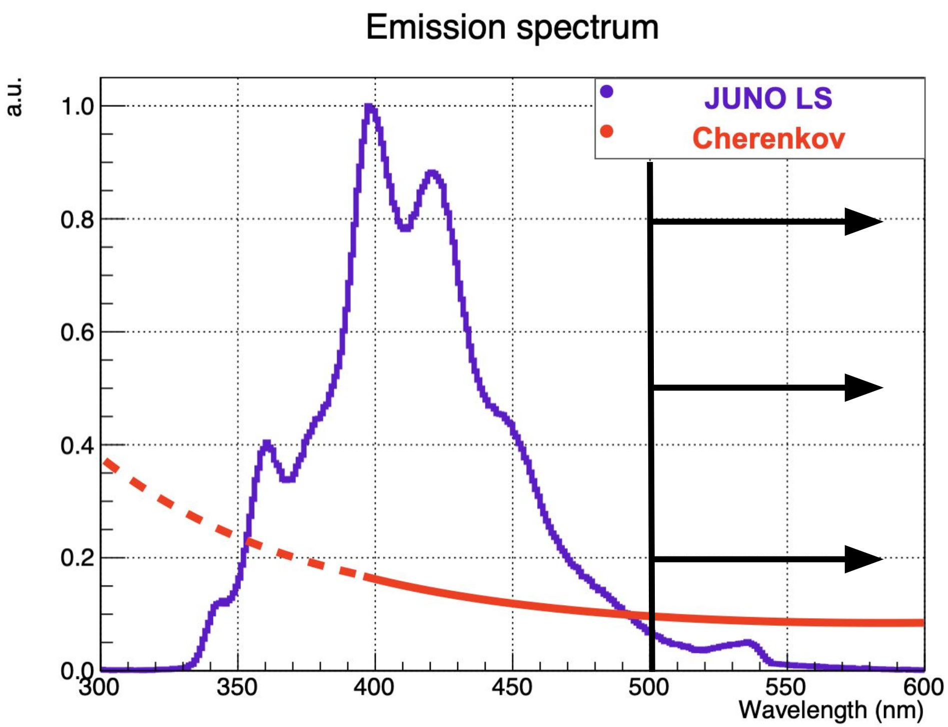


580 - 10 nm

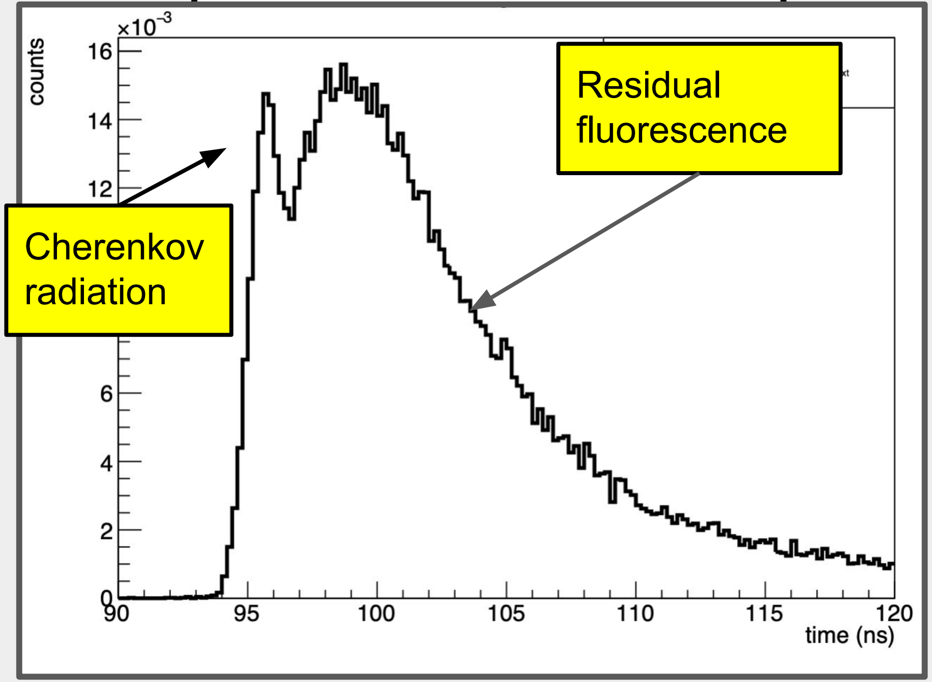


Cherenkov ≥ 25 %

Cherenkov contribution at different wavelength



500 nm pass long filter

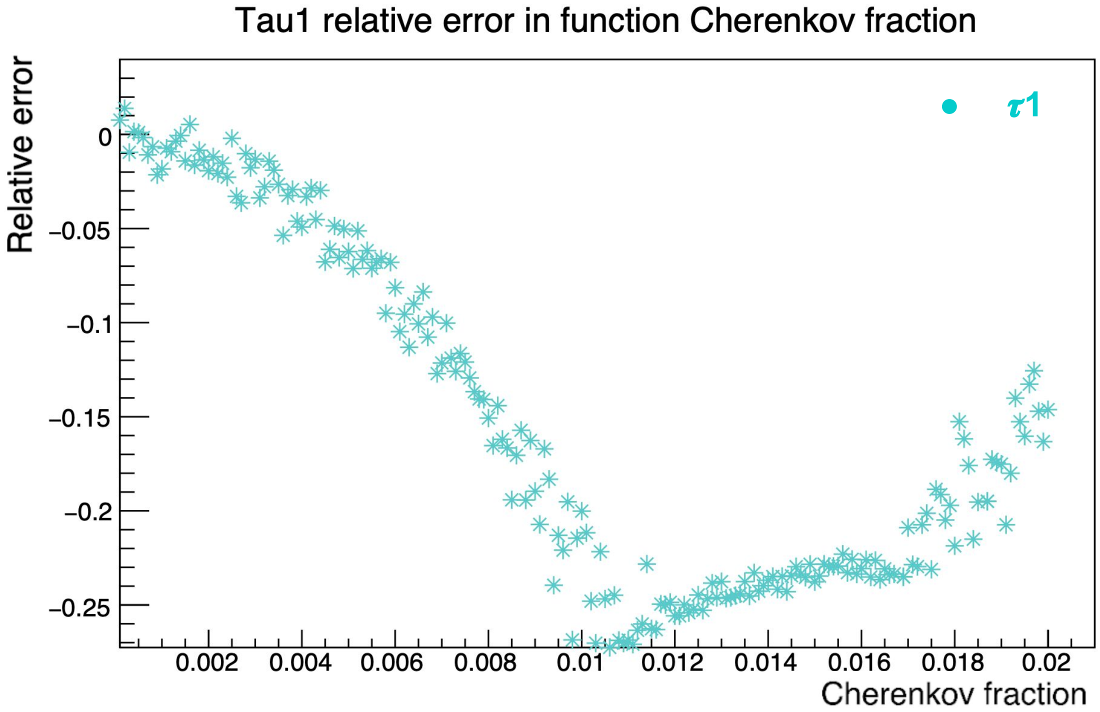


Cherenkov = 8.56 ± 0.16 %

Monte-Carlo study

Systematic error due to the exclusion of the Cherenkov contribution in the fit ⟶ Cherenkov **not** included

The exclusion of Cherenkov light on the fit mostly affects on the fast component



Monte-Carlo simulates different contribution of Cherenkov light

The fit does not consider the Cherenkov light

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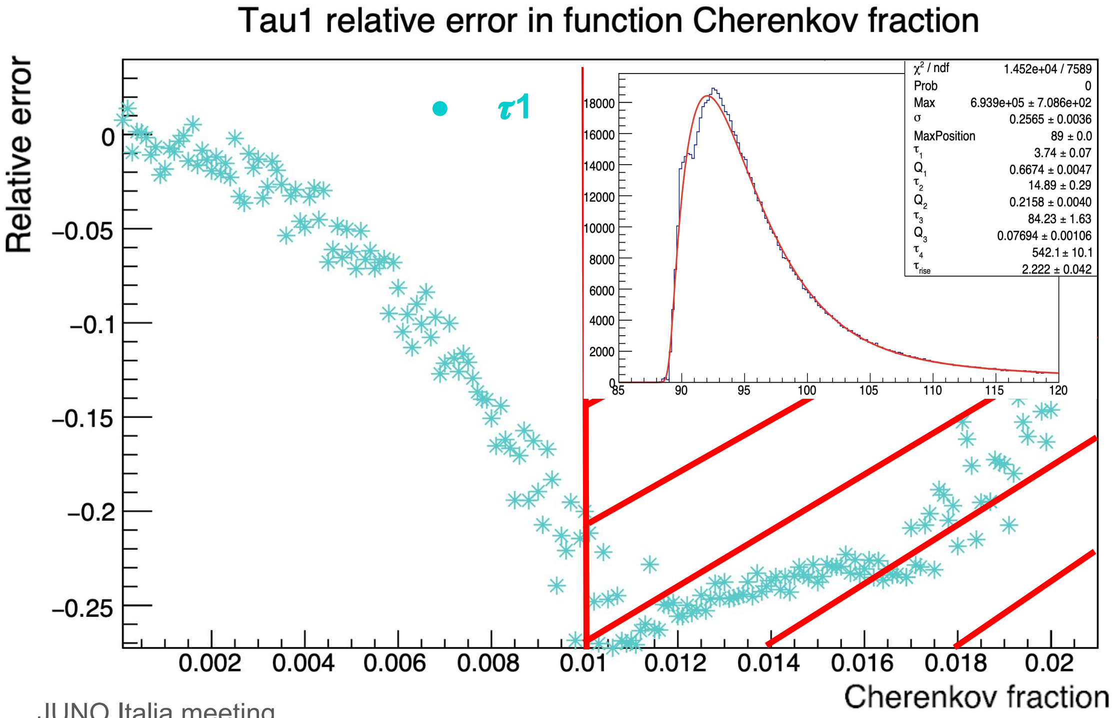
Monte-Carlo study

Systematic error due to the exclusion of the Cherenkov contribution in the fit ⟶ Cherenkov **not** included

The exclusion of Cherenkov light on the fit mostly affects on the fast component



The part of the graph above 0.01 fraction makes no sense. In that case Cherenkov light becomes important and the fit doesn't work.

The relative error gets worse as the Cherenkov fraction increases

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Monte-Carlo study

Systematic error due to the exclusion of the Cherenkov contribution in the fit ⟶ Cherenkov **not** included

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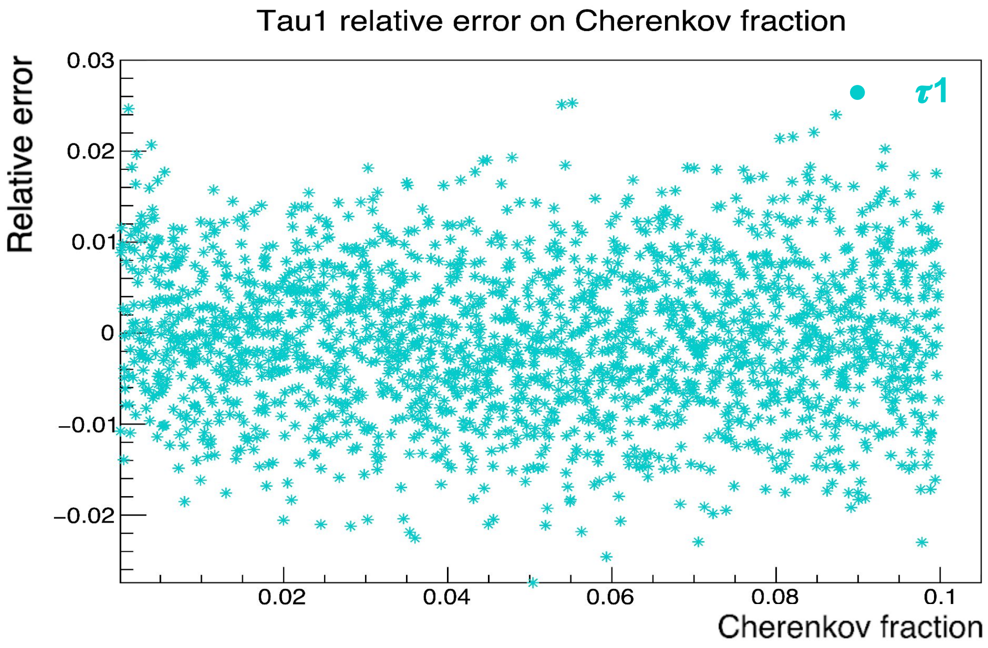
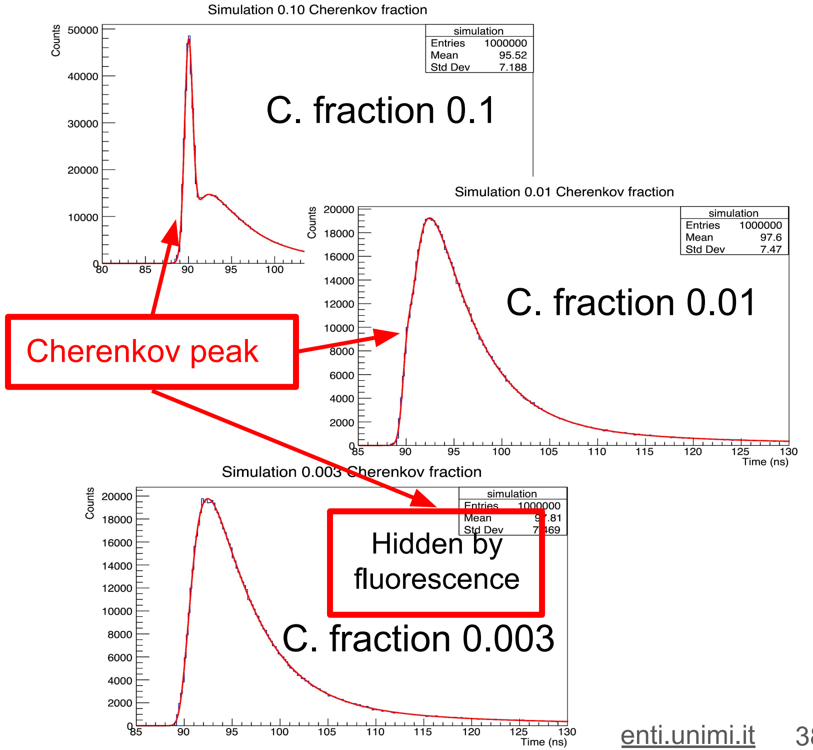


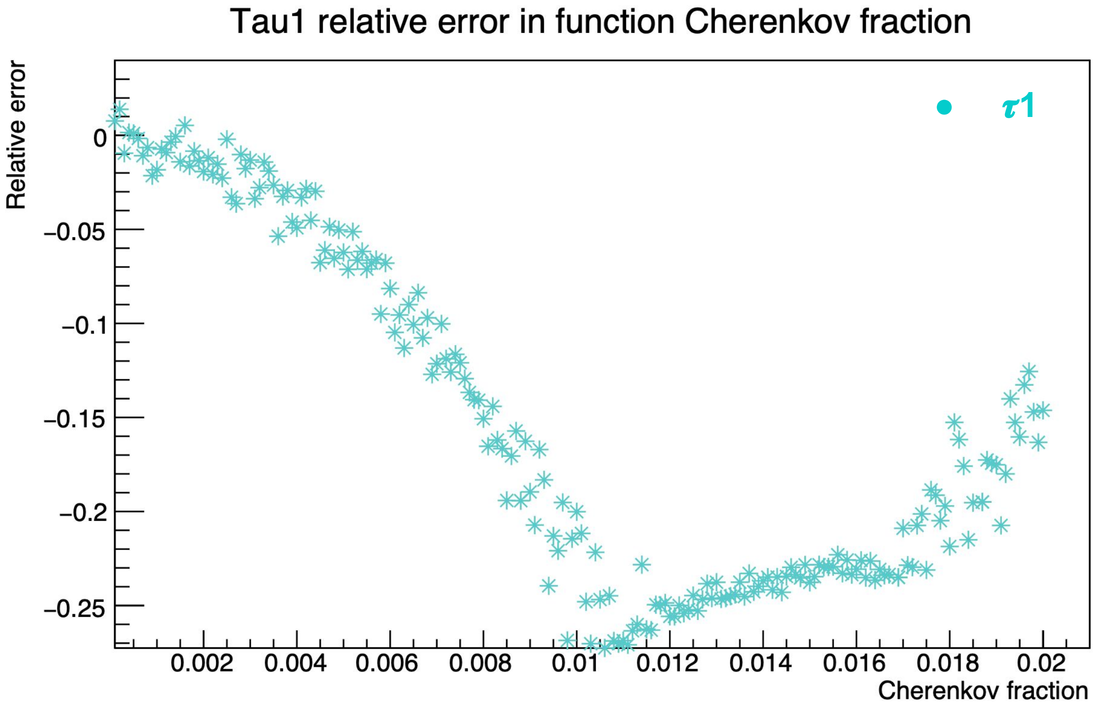


Monte Carlo study

Systematics studies: Cherenkov neglect

Same **Monte Carlo simulation** of the sensitivity studies

Cherenkov **simulated** in the time distribution, but **neglected in the fit**



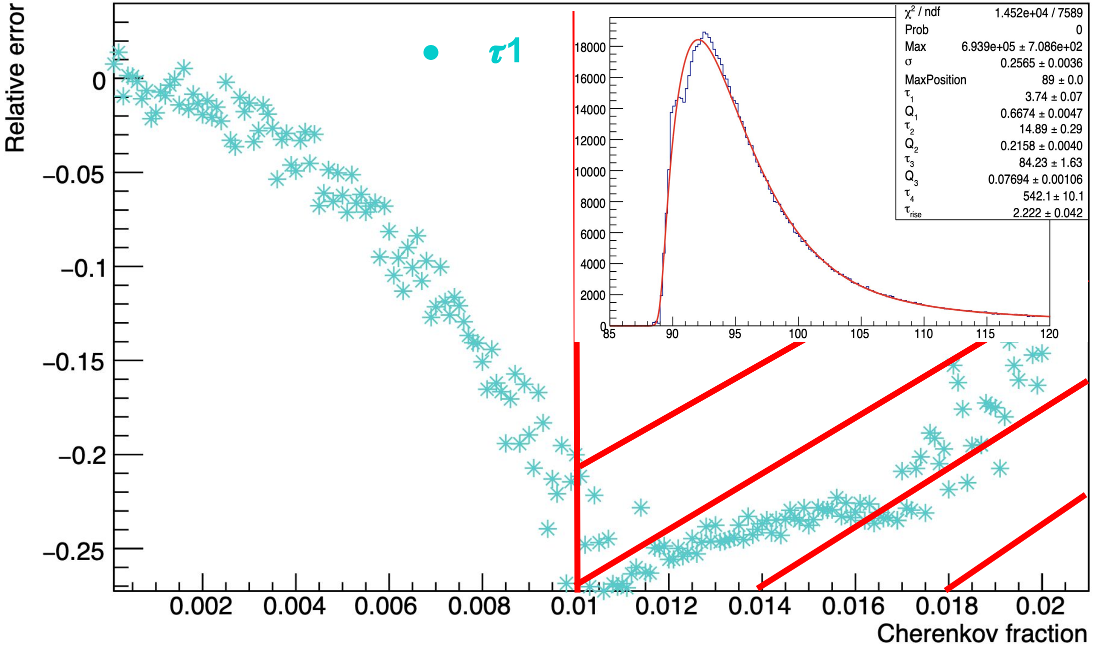
Monte Carlo study

Systematics studies: Cherenkov neglect

Same **Monte Carlo simulation** of the sensitivity studies

Cherenkov **simulated** in the time distribution, but **neglected in the fit**

Tau1 relative error in function Cherenkov fraction



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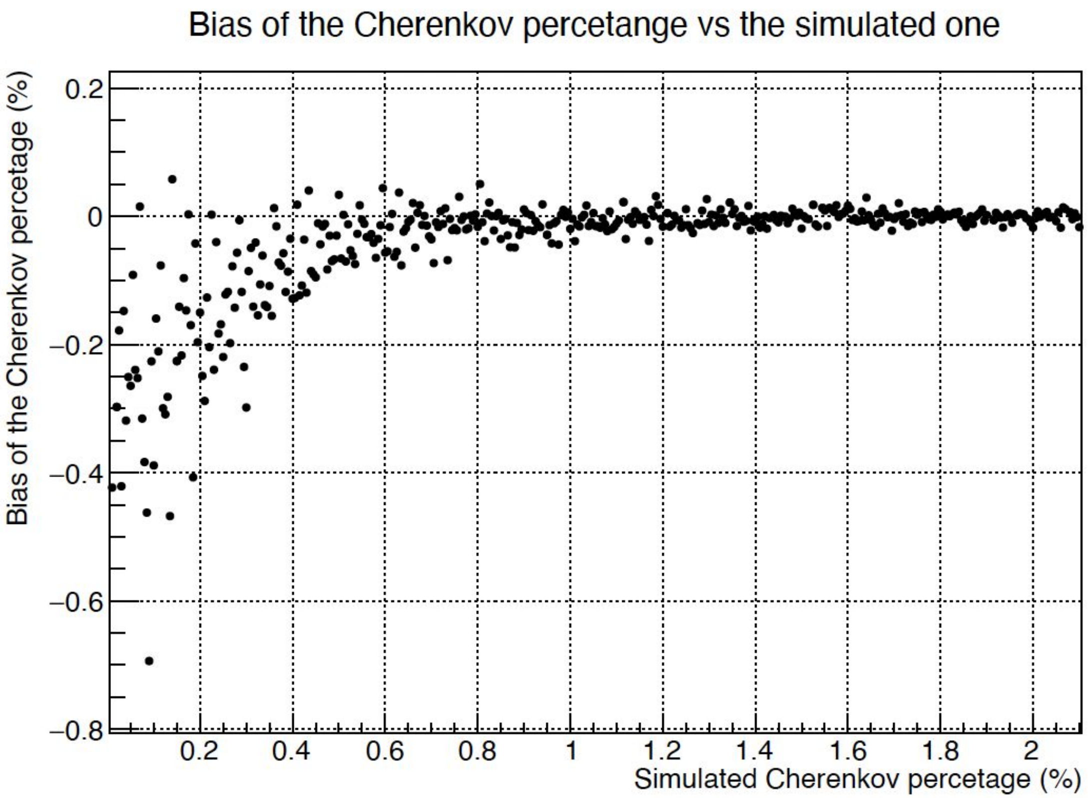
The relative error gets worse as the Cherenkov fraction increases

Cherenkov sensitivity study



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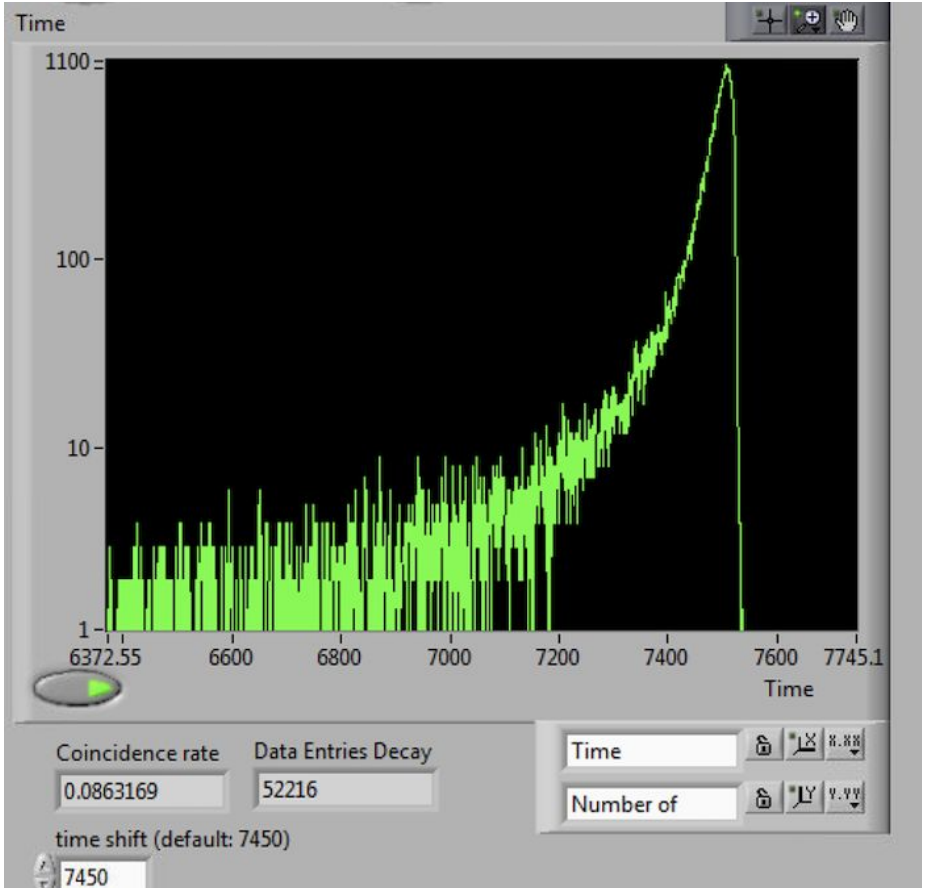
Measurement of cosmic background



Measurement of fluorescence: Results

	τ_1 [ns]	τ_2 [ns]	τ_3 [ns]	τ_4 [ns]
α	4.79±0.04	20.69±0.34	103.4±2.1	631±12
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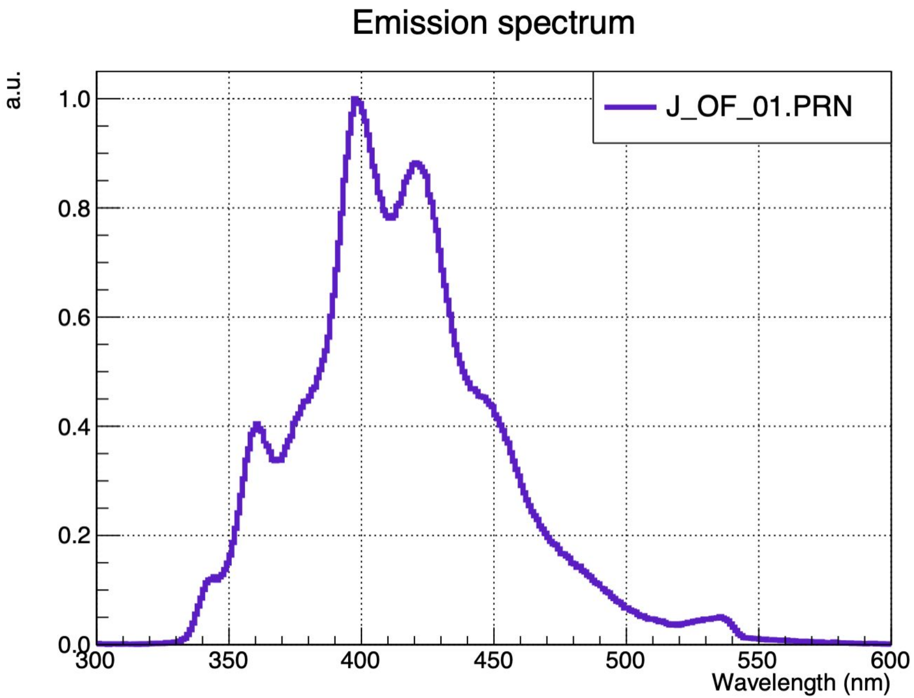
e^-	4.35±0.03	16.72±0.36	94.0±2.8	607±17
	q_1 [%]	q_2 [%]	q_3 [%]	q_4 [%]
α	56.87±0.29	22.84±0.22	12.78±0.16	8.27±0.62
p	61.91±0.25	21.40±0.20	9.83±0.10	7.70±0.55
e^-	66.81±0.50	21.67±0.40	7.45±0.14	4.44±0.65
	τ_r [ns]	Cherenkov [%]	χ^2_r	
α	0.88±0.00	/	1.4	
p	1.27±0.00	/	1.4	
e^-	1.57±0.00	0.76±0.12	1.1	

JUNO organic liquid scintillator

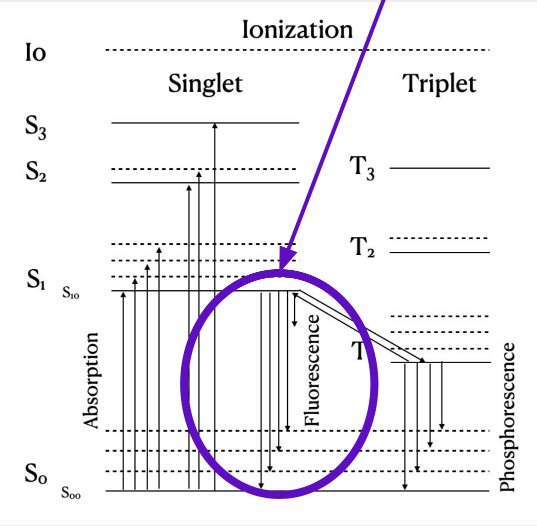
JUNO LS recipe:
LAB + 2.5 g/L PPO + 3 mg/L bis-MSB



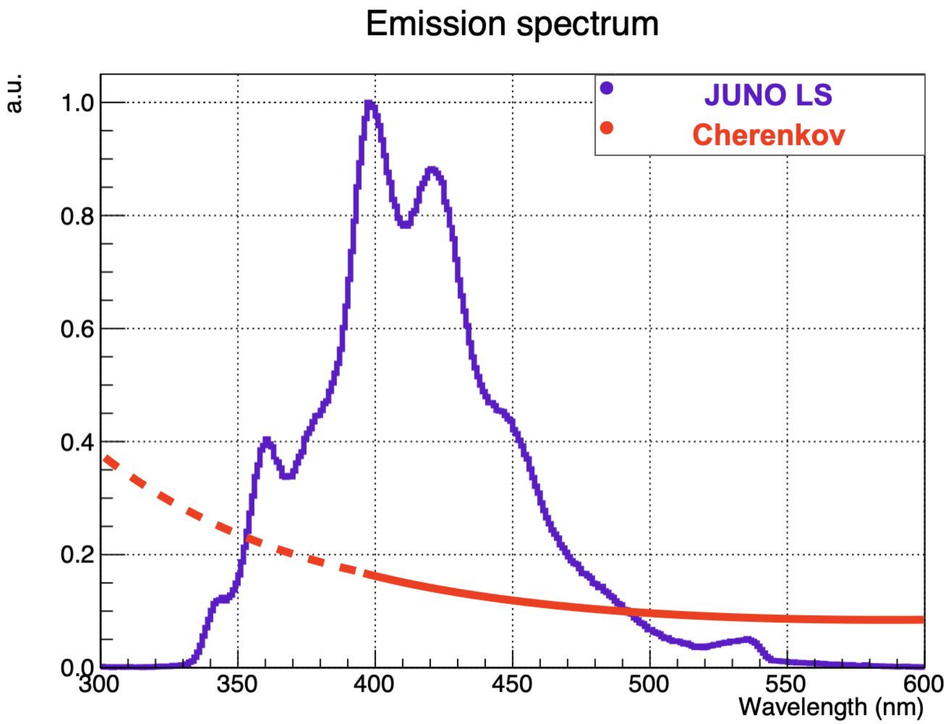
Measured @ Università degli Studi di Perugia

Isotropic emission:
~**99%** of the total light emission

Light emission:
LS emits light through **fluorescence**
with a characteristic time profile (ns)



JUNO organic liquid scintillator: light emission

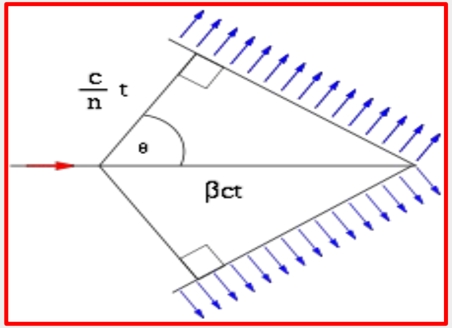


Cherenkov radiation:
it depends on the particle speed and the refractive index of the medium

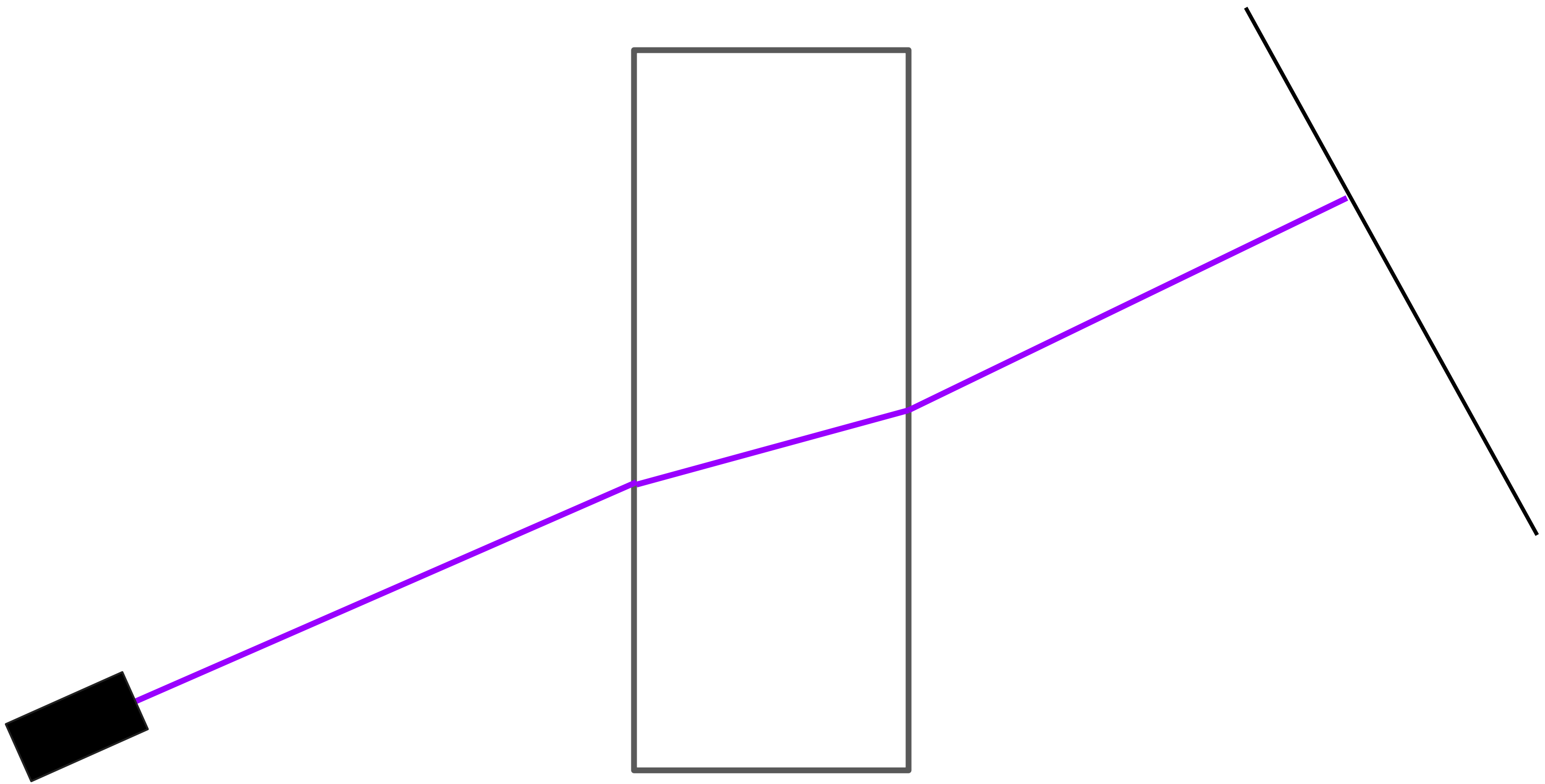
Directional emission:
~**1%** of the total light emission

Light emission:
instantaneous (for our purposes)

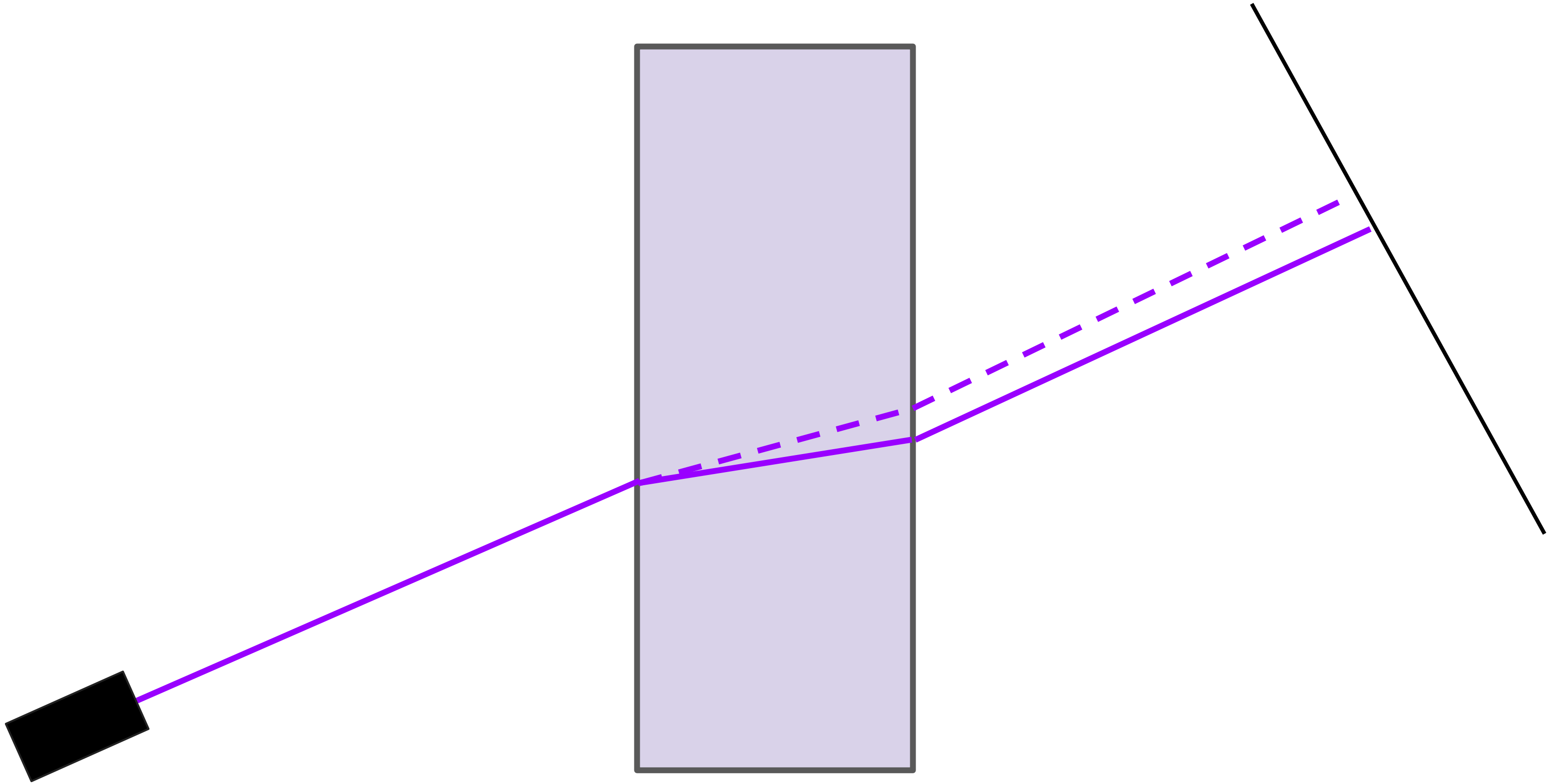
Spectrum:
~λ^{-2}



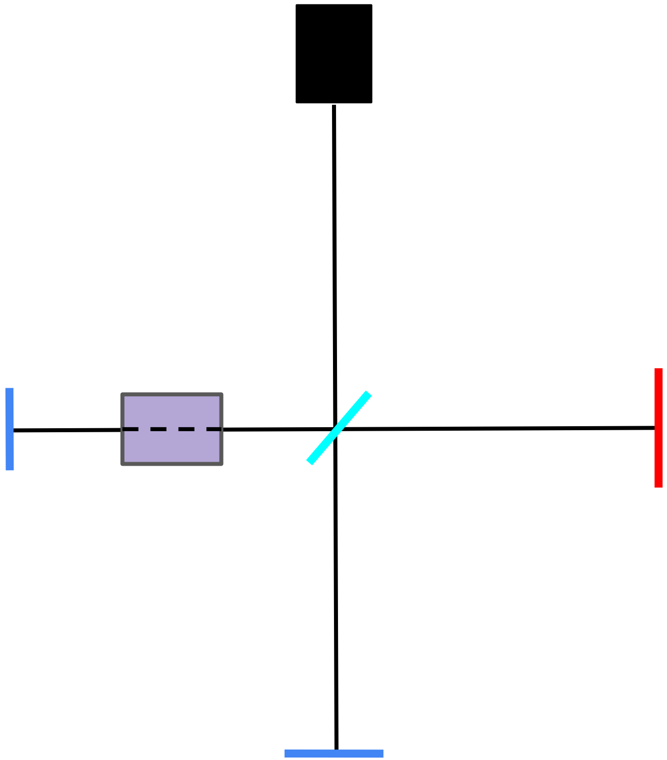
Measurement of the refraction index



Measurement of the refraction index

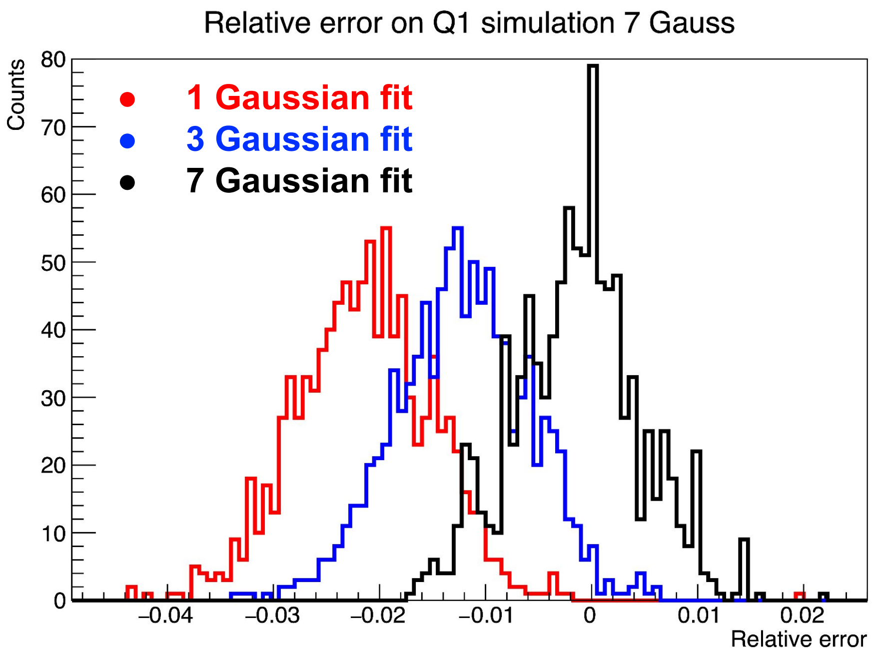


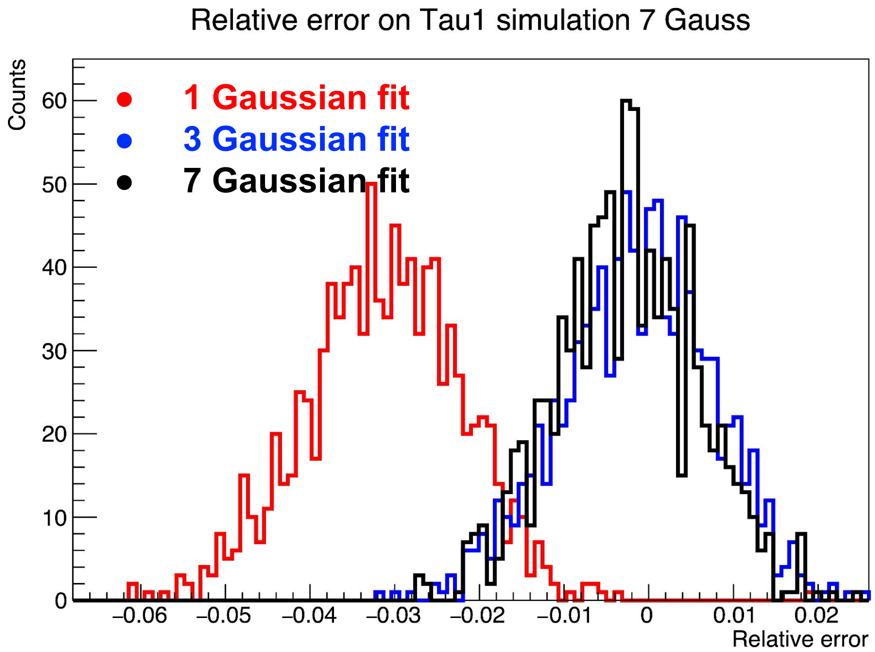
Measurement of the group velocity



Systematic error introduced by fit ⟶ 7 Gaussians

The modeling of the time rensonse affects more on the 1nd and the 2nd component





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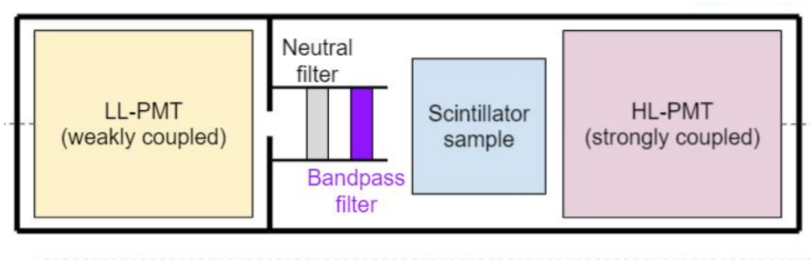
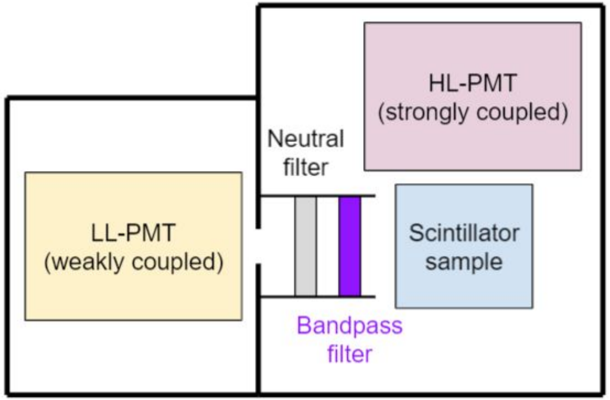

Neutral filter
LL-PMT (weakly coupled)
Scintillator sample
HL-PMT (strongly coupled)
Bandpass filter

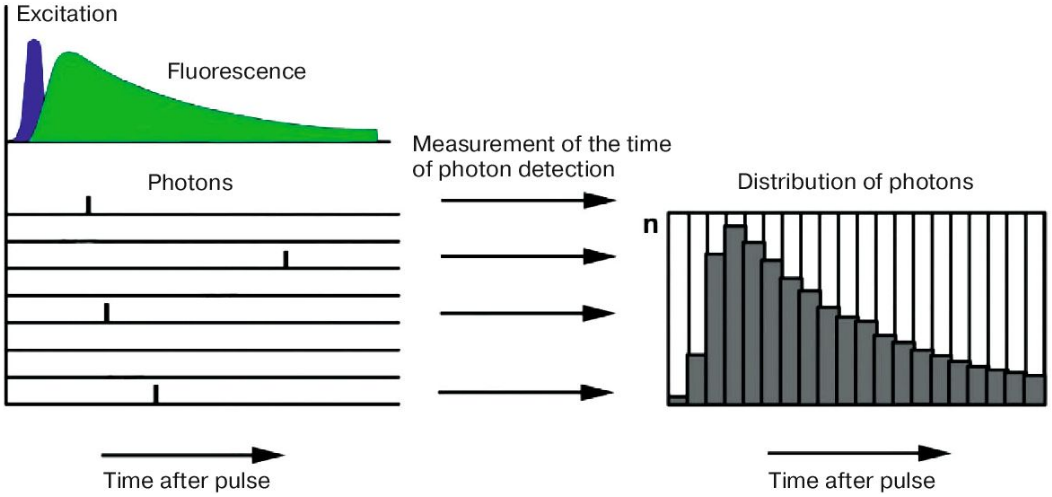

HL-PMT (strongly coupled)
Neutral filter
LL-PMT (weakly coupled)
Scintillator sample
Bandpass filter

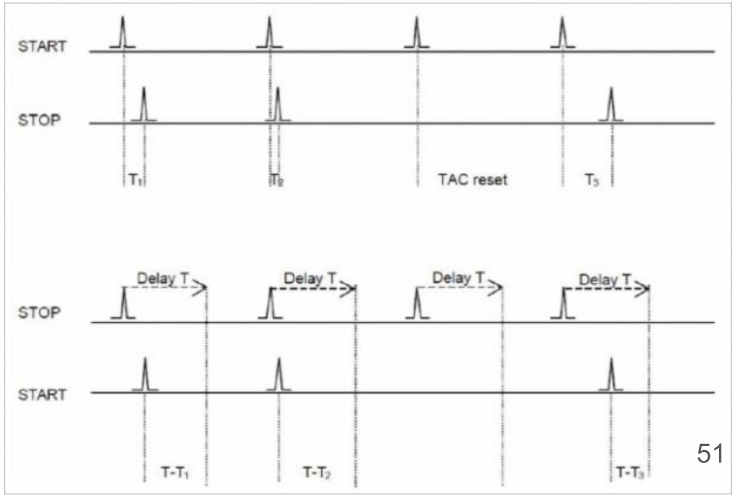
Measurement of fluorescence time profile with the single photon counting technique

Time-correlated single photon counting (TCSPC) is a technique to measure the fluorescence decay time.

Under certain hypothesis ($R_{sp} << R_{tr}$), the time of arrival of the photons w.r.t. to the trigger reproduces the fluorescence time distribution.

In our application, one PMT provides the START signal (trigger) and the other PMT gives the STOP signal.





The SHELDON project: scientific goals

Separation of c**HE**renkov **L**ight for **D**irectionality **O**f **N**eutrino

Two main goals:

Accurate measurement of fluorescence time distribution (fluorescence parameters)

Study of the Cherenkov radiation in the JUNO LS

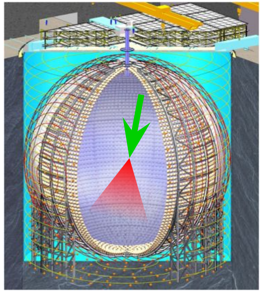
Impact on the JUNO experiment:

- event reconstruction
- particle identification via PSD
- improved description of fluorescence parameters in the JUNO MC

Impact on the JUNO experiment:

- Improved understanding of energy response
- Possible reconstruction of the direction of incident neutrino

JUNO Italia meeting



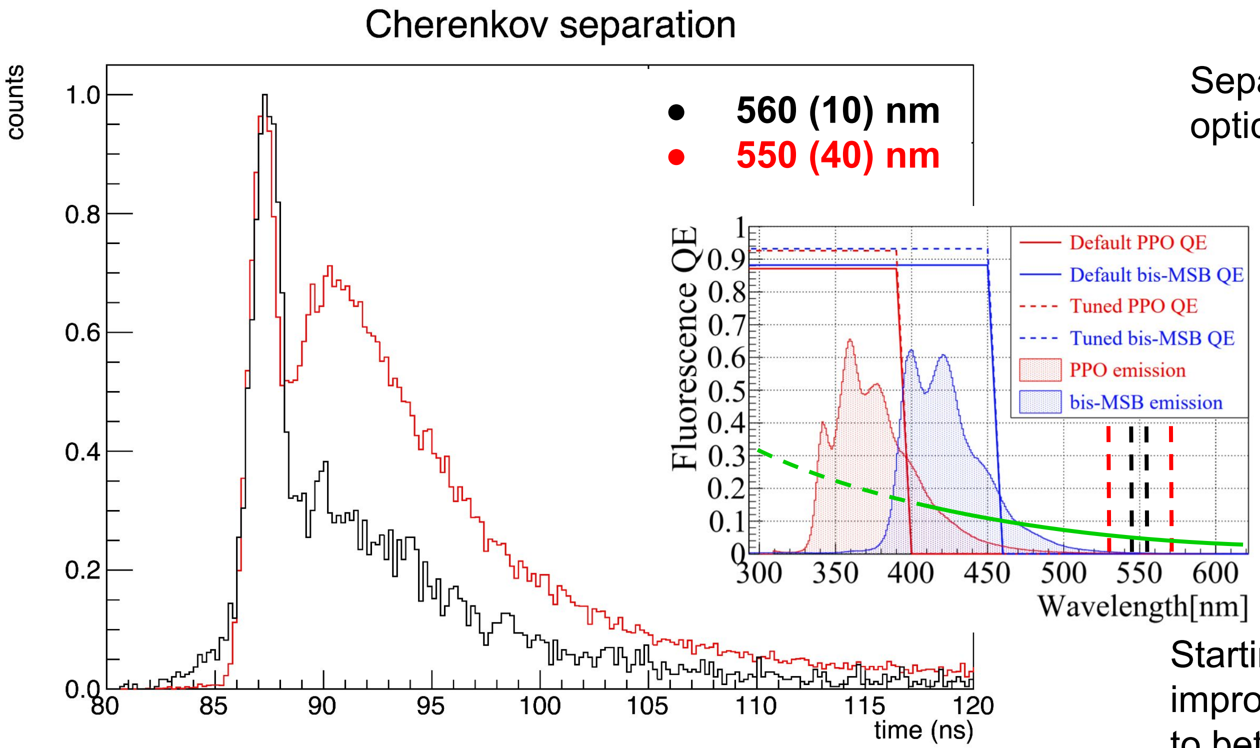
SHELDON

Separation of cHErenkov Light for Directionality Of Neutrinos

Davide Basilico, **Marco Beretta**, Augusto Brigatti, Barbara Caccianiga,
Federico Ferraro, Cecilia Landini, Paolo Lombardi, Alessandra Re

Università degli Studi di Milano
INFN-Sezione di Milano

Separation of Cherenkov light - first results with JUNO mixture



Separation of **Cherenkov light** using optical filters

Actually we use only two bandpass filters:

- **560 ± 5** nm
- **550 ± 20** nm

The first measurements has low statistics due to the small rate

Starting from next week we will improve statistic and use other filters to better sampling the spectrum

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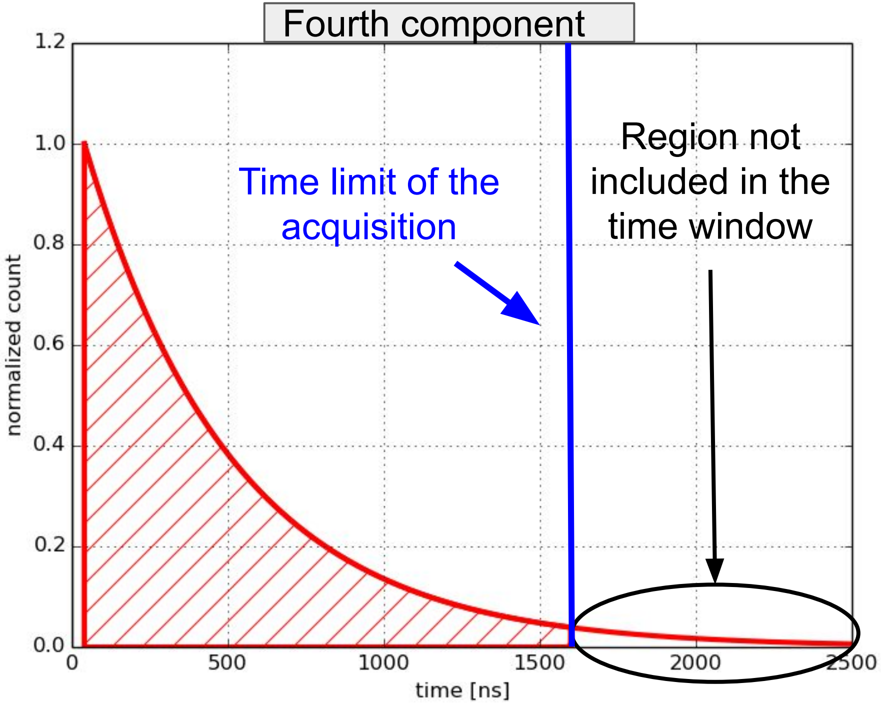
Normalization of the fourth component



The fit model uses four components to describe the de-excitation time of the L.S.

These components are normalized to the integral of the exponential

For the fourth component this introduces an error

We improve the implementation of this normalization to consider this error

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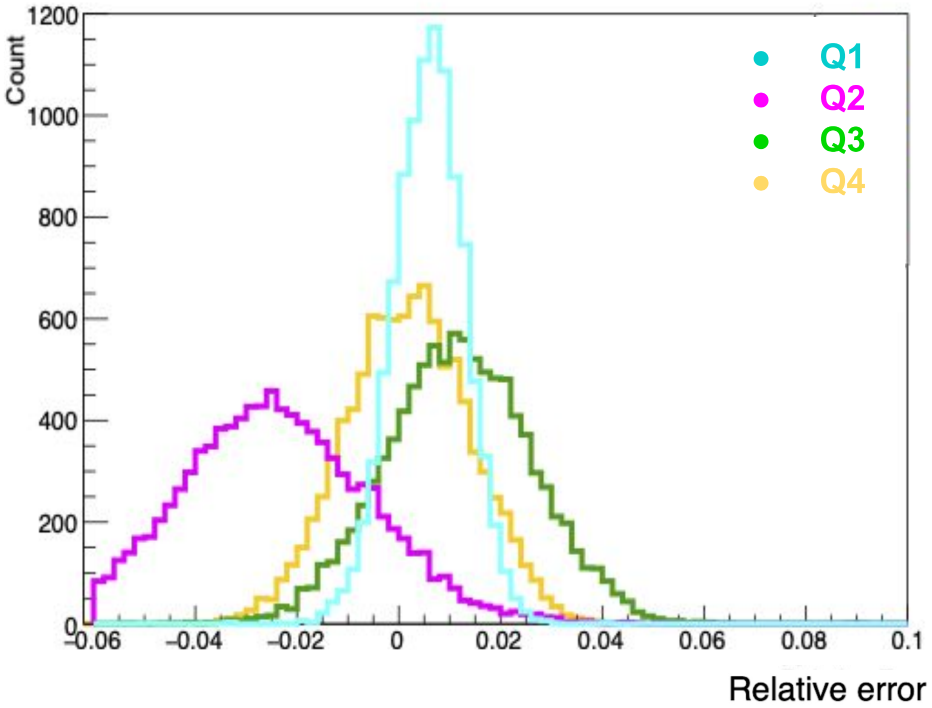
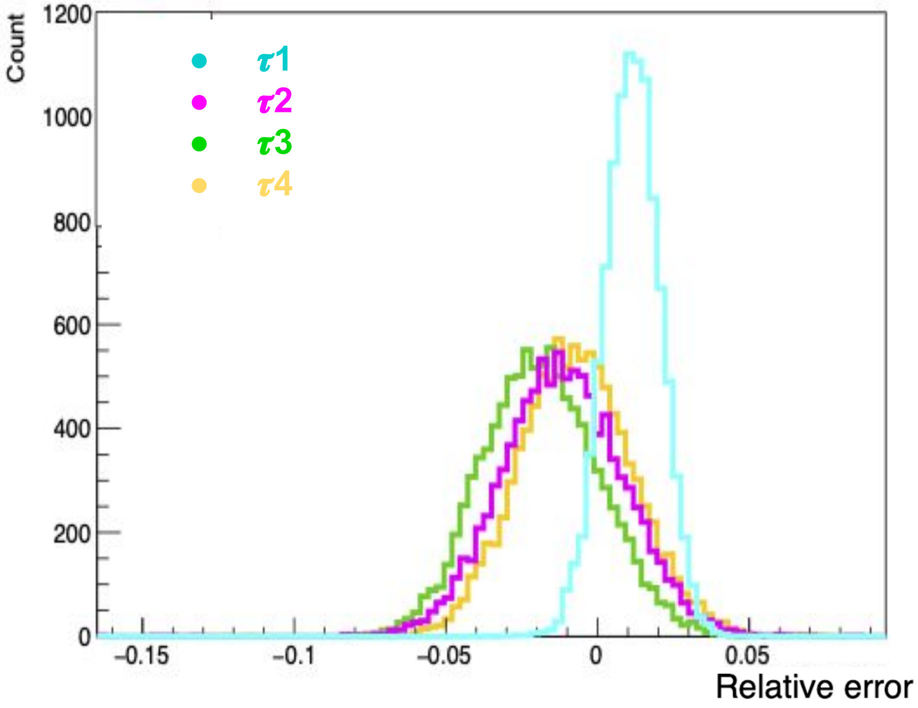
Monte-Carlo study

Systematic error introduced by fit ⟶ On 10^5 simulations

A simple Monte Carlo was realized to study the fit systematics.

The percentage uncertainty introduced by the fit is less than 5% on τ_i and q_i.





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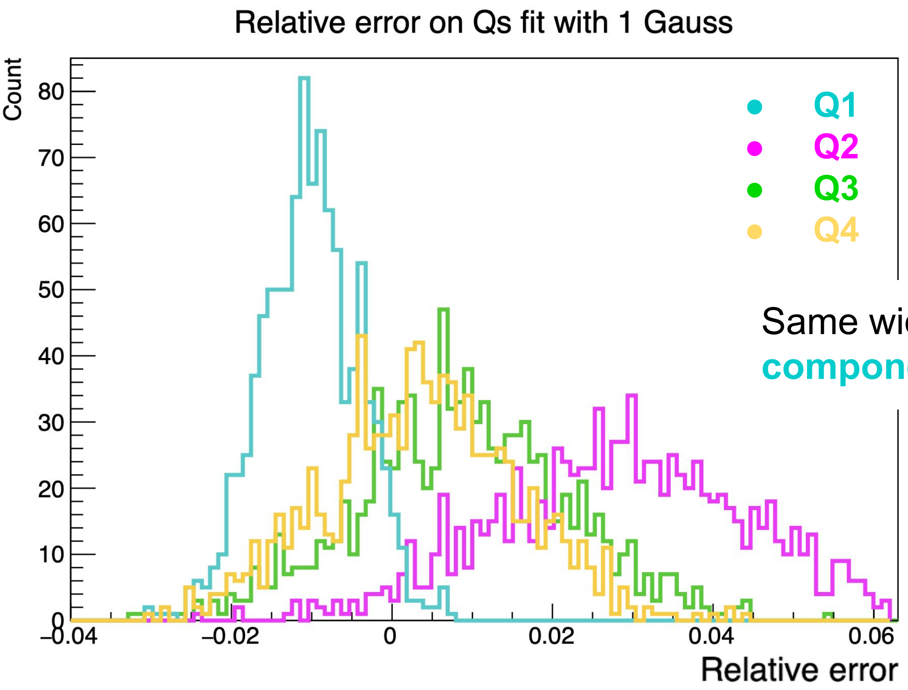
Monte-Carlo study

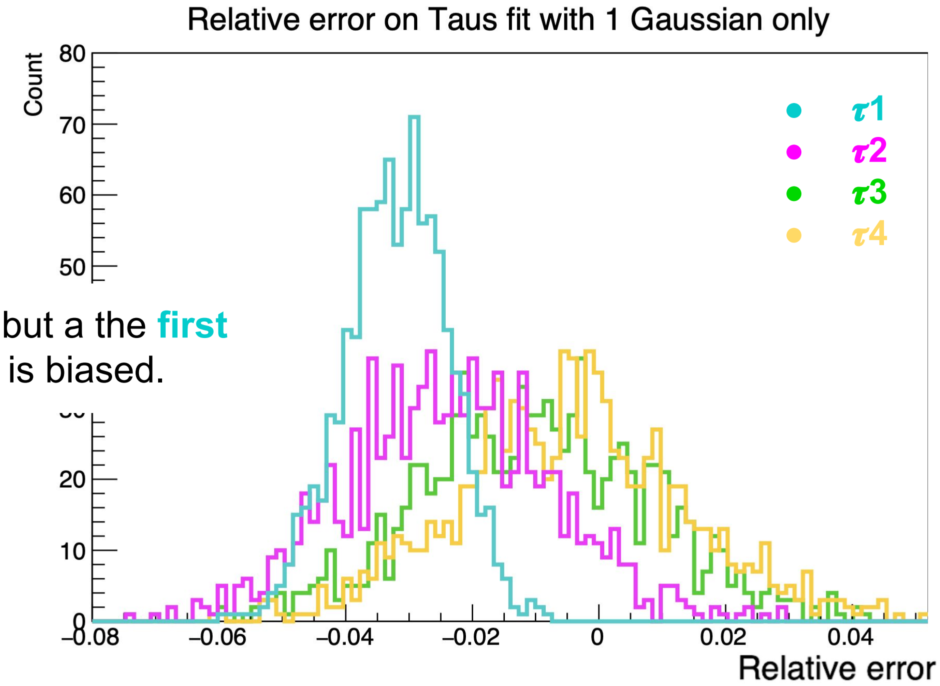
Systematic error introduced by a different description of the detector response

Only 1 Gaussian was used instead of 3 to describe the system response

In this case the percentage uncertainty gets worse for the fast component



Same width but a the **first component** is biased.



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