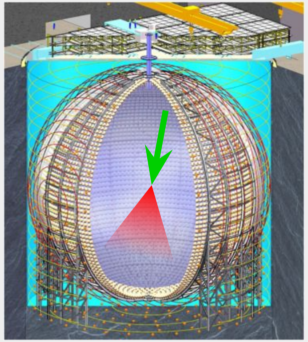

Timing and optical properties of the JUNO liquid scintillator

Meeting JUNO-Italia
28-29 Marzo 2023

INFN-Milano:
Davide Basilico, **Marco Beretta**, Augusto Brigatti, Barbara Caccianiga,
Federico Ferraro, Cecilia Landini, Paolo Lombardi, Alessandra Re, Gioele Reina

INFN-Perugia:
Catia Clementi, Aldo, Fausto Ortica, Aldo Romani

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Introduction

- **Optical properties of the liquid scintillator** are of crucial importance to JUNO

  → this talk

- We developed an experimental setup (SHELDON) to measure the **time distribution** of light and the **Cherenkov contribution** in the JUNO liquid scintillator

  → this talk

- We developed another experimental setup (SHELDON-REWIND) to measure the **refractive index** and the **group velocity** at different wavelengths

  → next talk by Gioele Reina

- We are also working on the impact of our experimental result on JUNO SNiPER

  → next to next talk by Marco Malabarba

Index

- Introduction
- **SHELDON: time distribution**
- Emission spectrum
- Absorbance
- Conclusions

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)

Impact on the JUNO experiment:

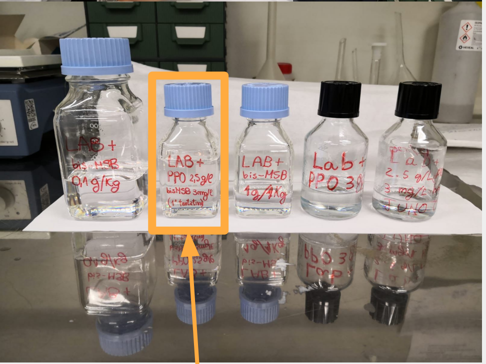
- event reconstruction
- particle identification via PSD
- improved description of fluorescence parameters in the JUNO MC

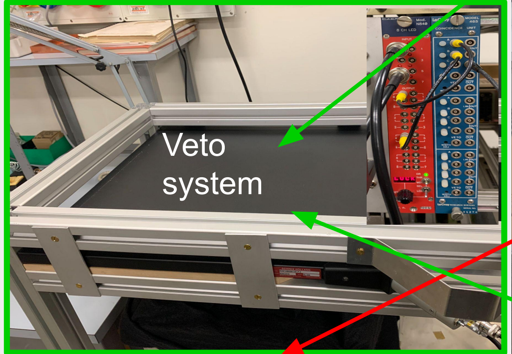
Study of the Cherenkov radiation in the JUNO LS (relative contribution)

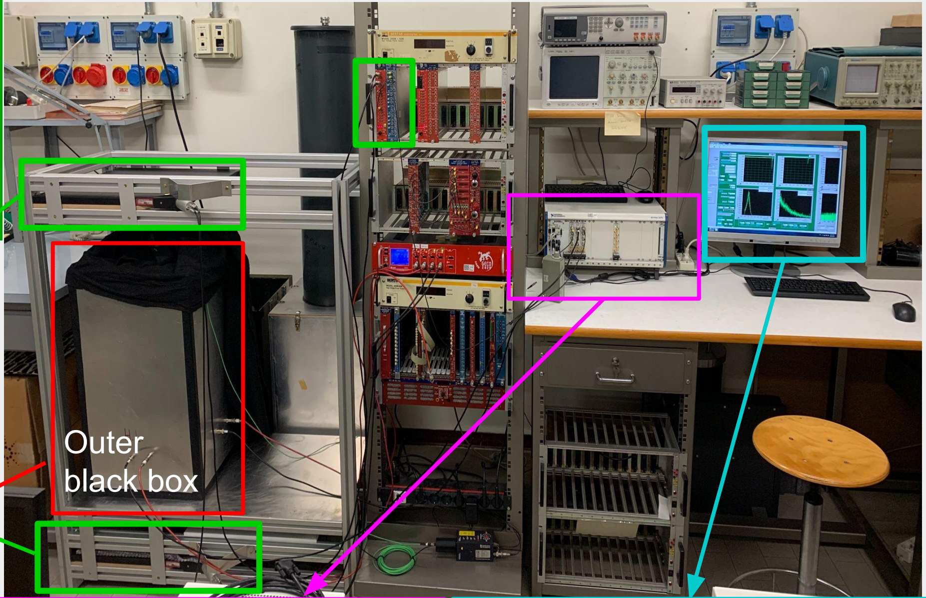
Impact on the JUNO experiment:

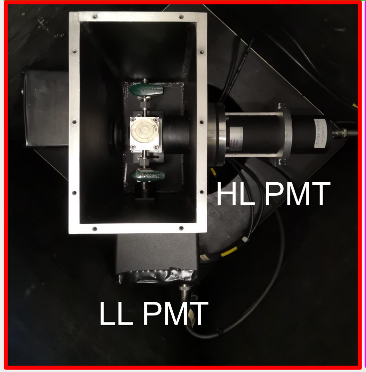
- Improved understanding of energy response
- Possible reconstruction of the direction of incident neutrino

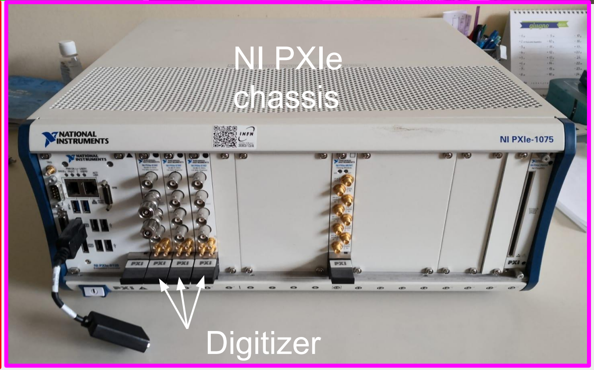
SHELDON's laboratory @ UNIMI

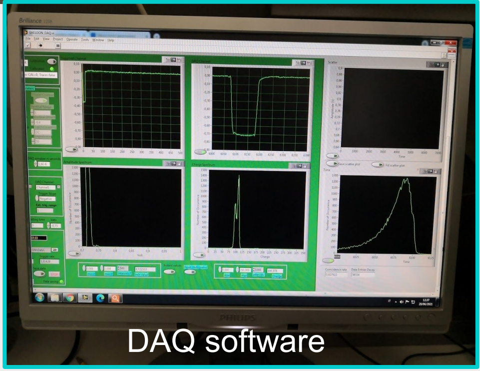






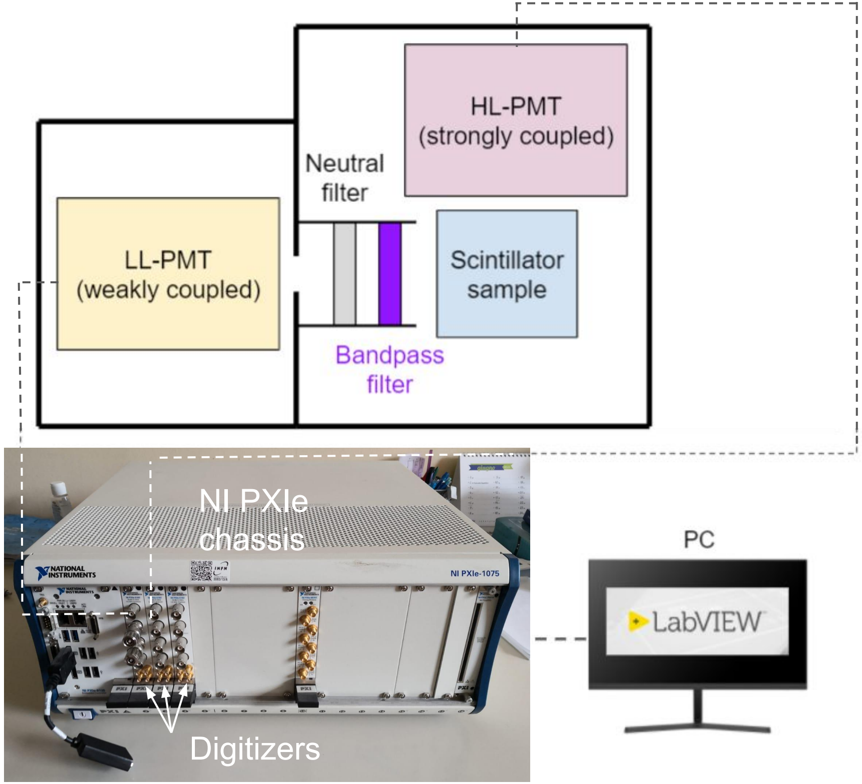






JUNO LS recipe: LAB + 2.5 g/L PPO + 3.0 mg/L bis-MSB

SHELDON: overview of the setup



Components of the setup:

JUNO LS sample

2 PMTs, one weakly coupled

Neutral filter

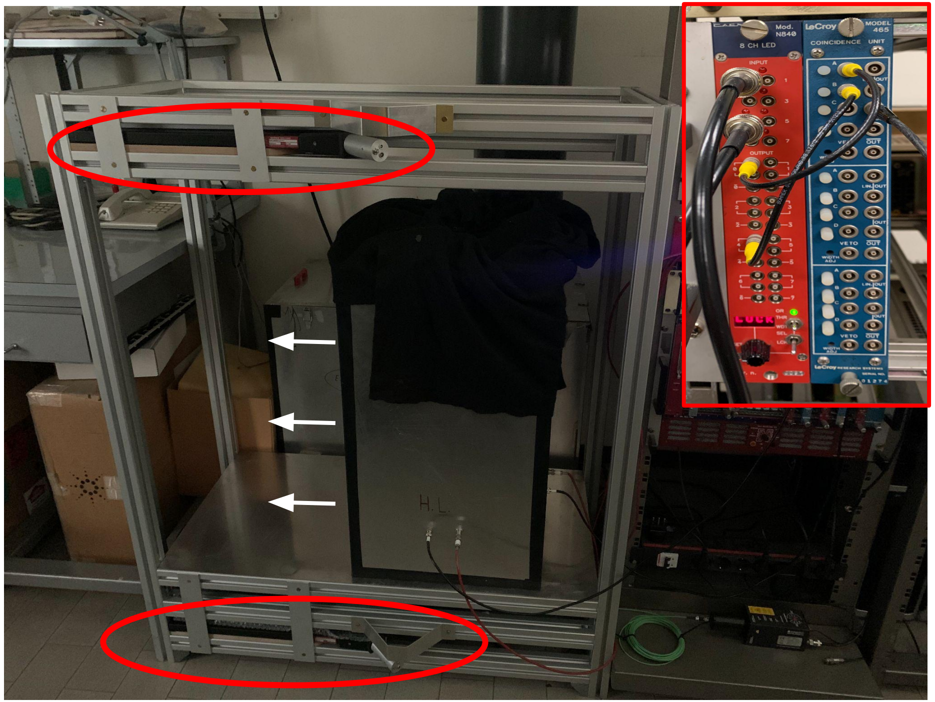
2 Digitizers (5 GS/s each)

LabVIEW DAQ software

Technique:

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

SHELDON: implementation of veto system



Components of the setup:

2 plastic scintillators EJ 200

Linear Edge Discriminator

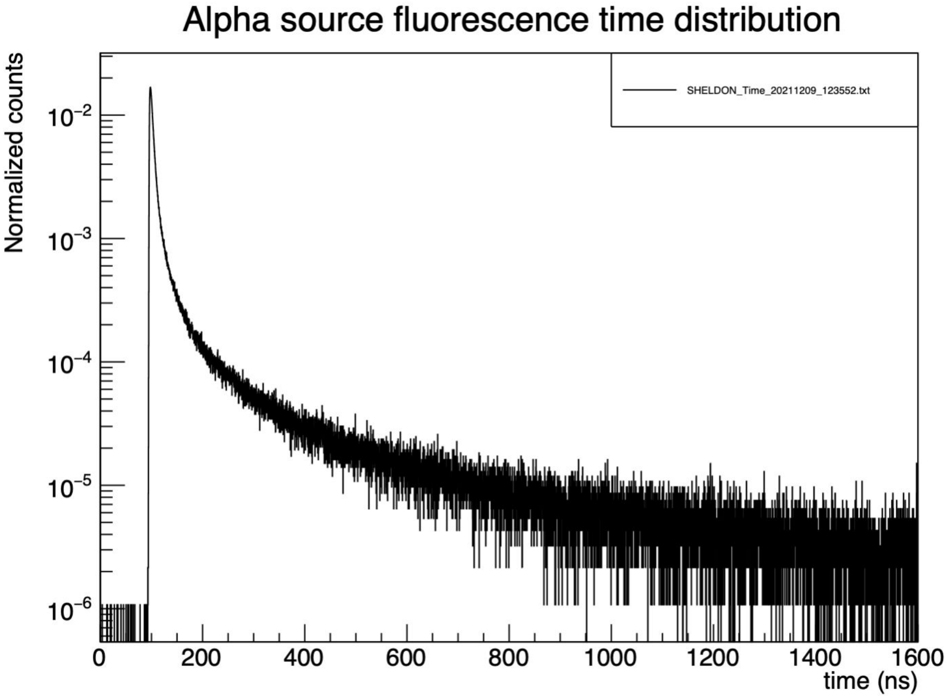
Coincidence Unit

3rd Digitizer (5 GS/s)

Improved LabVIEW DAQ software

INSTALLED

SHELDON: fluorescence time distribution

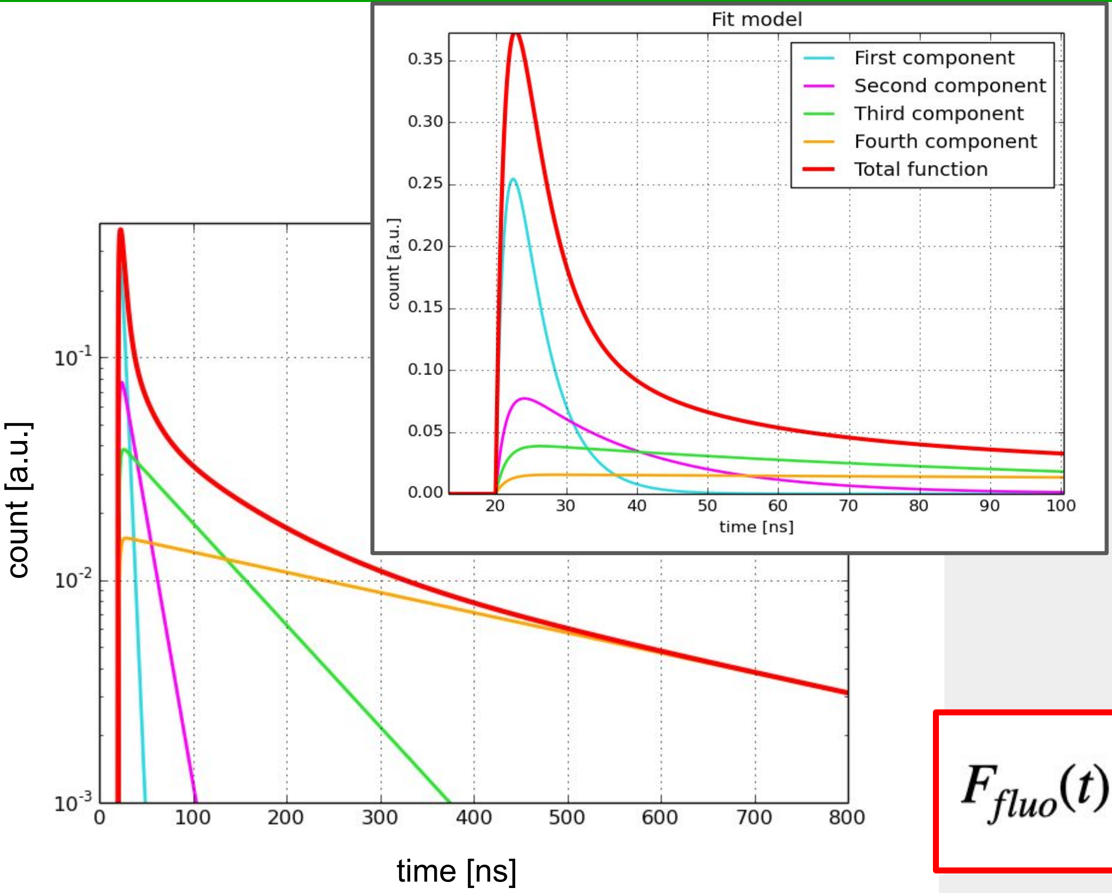


Normalized **fluorescence** time distribution obtained using an alpha source

10^6 events (obtained in 10 days)

Light emission is **not** prompt

SHELDON: fit model



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

The fourth component becomes dominant after **~300 ns**

DAQ time window: **1600 ns**

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

SHELDON: preliminary results

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

The two curves have different tails

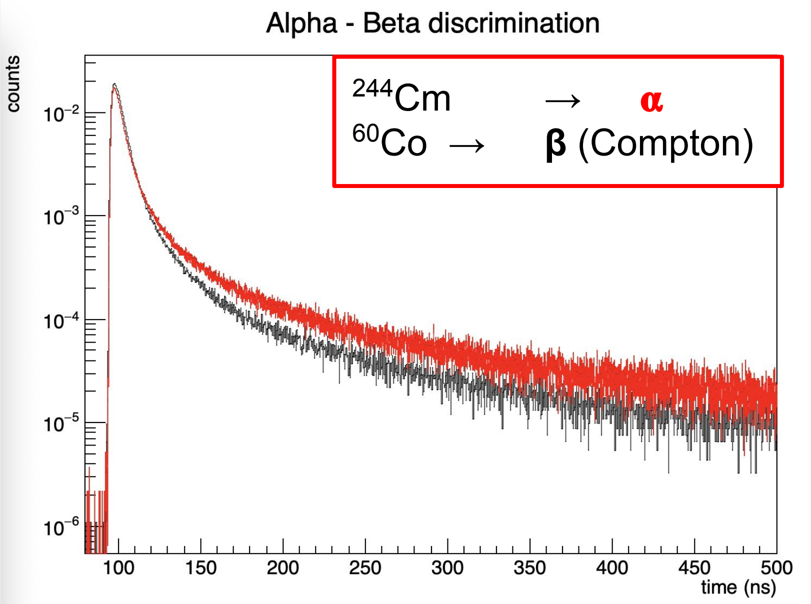
We have measured this using the muon veto

We have to measure the proton time profile using an AmBe source

	τ_1 [ns]	τ_2 [ns]	τ_3 [ns]	τ_4 [ns]
α	4.52 ± 0.02	19.22 ± 0.32	96.5 ± 1.9	619 ± 11
e^-	4.51 ± 0.01	17.37 ± 0.21	82.2 ± 1.9	503 ± 8
	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
e^-	66.81 ± 0.50	21.67 ± 0.40	7.45 ± 0.14	4.44 ± 0.65

PRELIMINARY RESULTS

statistical uncertainties only



We have measured the time profile for alpha and beta sources with veto

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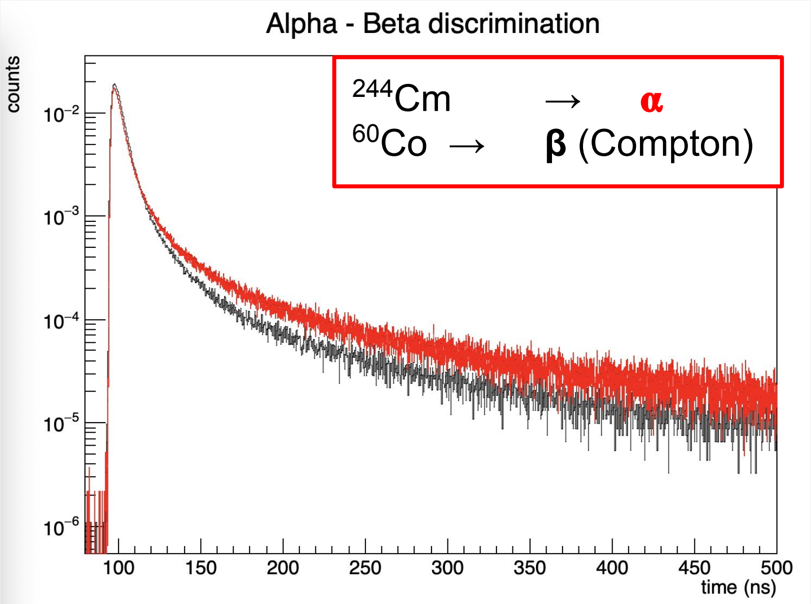

We have measured the time profile for alpha and beta sources with veto

Fluorescence time in SNiPER

Particles	Fast(ns)/ Ratio	Slow(ns)/ Ratio	Slower(ns)/ Ratio	Slowest(ns)/ Ratio
γ, e^+, e^-	4.6/70.7%	15.1/20.5%	76.1/6.0%	397/2.8%
n, p^+	4.5/61.4%	15.7/23.2%	76.2/9.0%	367/6.4%
α	4.345/49.82%	17.64/27.39%	89.045/14.67%	544.48/8.12%

Talk of Yaoguang Wang “Detector simulation status” 18/07/2022

Fluorescence time in SNiPER

Provided by the Munich group as preliminary results

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Talk of Yaoguang Wang “Detector simulation status” 18/07/2022

We still don’t know the source of this parameters

Fluorescence time in SNiPER: comparison

Particles	Fast(ns)/ Ratio	Slow(ns)/ Ratio	Slower(ns)/ Ratio	Slowest(ns)/ Ratio
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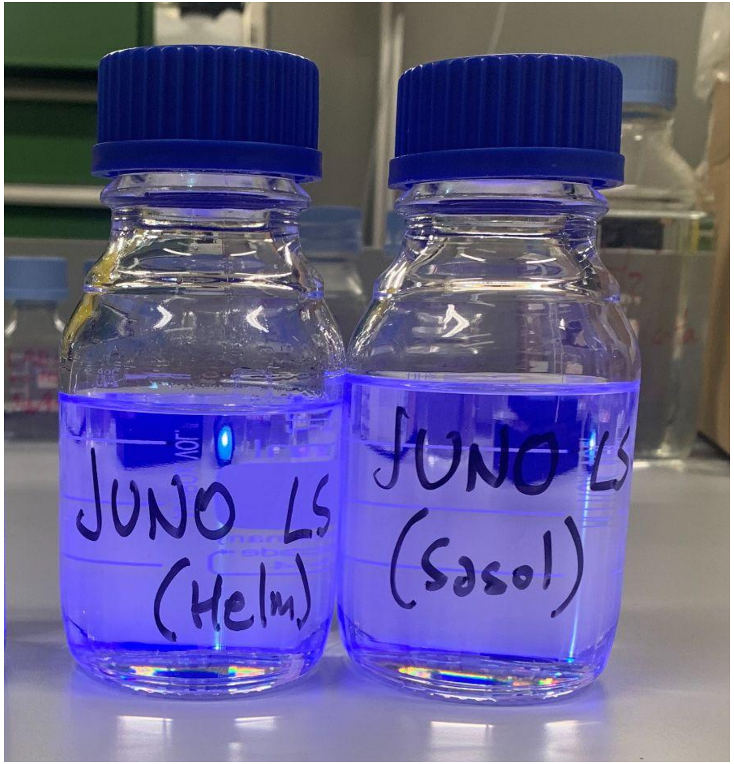
SHELDON PRELIMINARY RESULTS

One **difference** in our measurements is the different **LAB** used as solvent: **Sasol** (Milano) vs **Helm** (Munich)

Another difference is the in the **analysis**: analytical vs numerical **convolution**, IRF, …

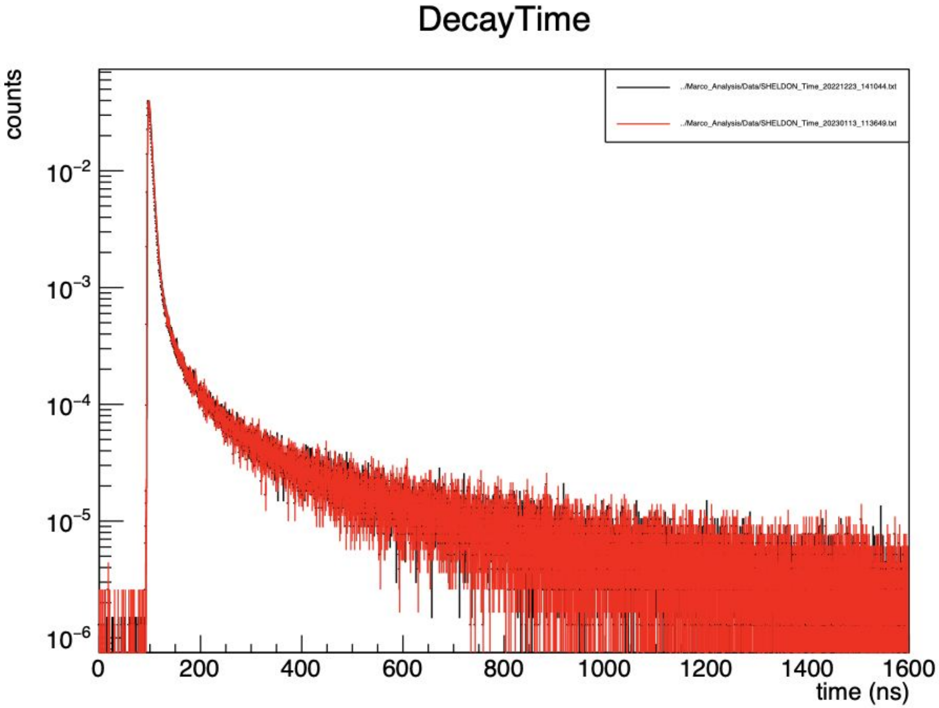
Fluorescence time distribution: SASOL vs HELM



The LAB that we used (SASOL) is different from the LAB used by the Munich group (HELM) whose results are in SNiPER

2 LS samples produced in Perugia, **SASOL** and **HELM,** distributed both to Milan and Munich

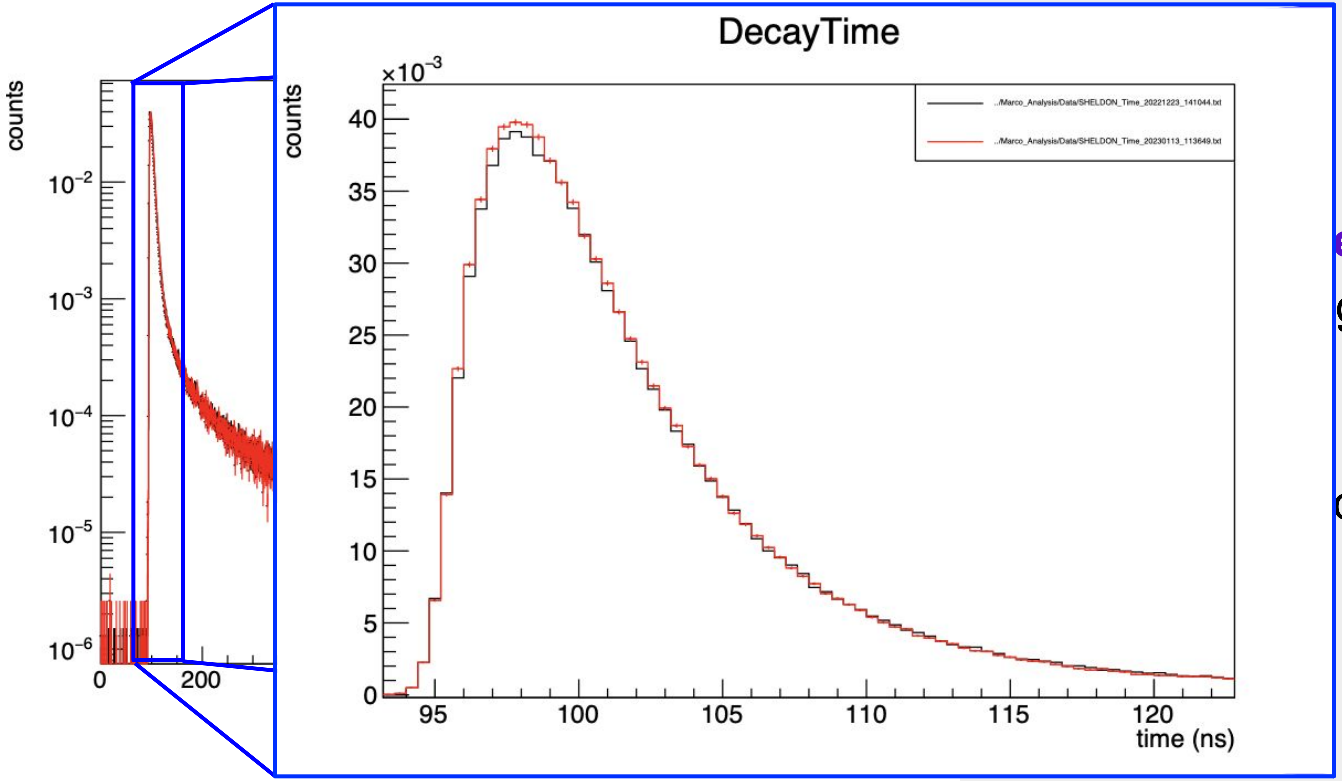
Fluorescence time distribution: SASOL vs HELM



Fluorescence time distribution obtained using a ^{60}Co source

The measured time distribution is very similar

Fluorescence time distribution: SASOL vs HELM



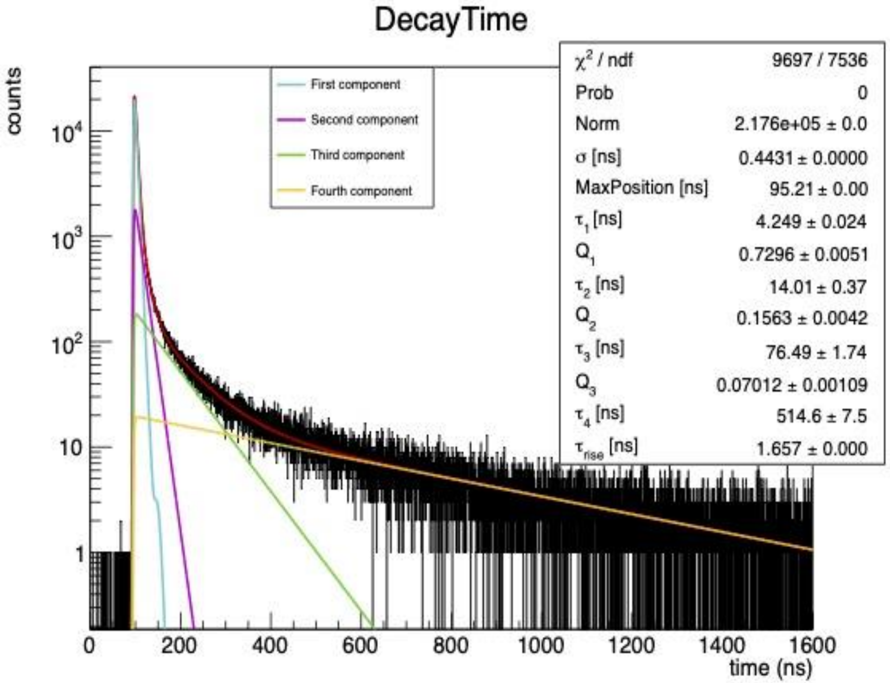
e time distribution

g a ^{60}Co source

d time distribution is

Fluorescence time distribution: SASOL vs HELM

Example of fit on the Sasol based LS mixture



Measurements with same statistics with **beta source**

	τ_1 [ns]	τ_2 [ns]	τ_3 [ns]	τ_4 [ns]
Sasol based	4.25 ± 0.02	14.01 ± 0.37	76.5 ± 1.7	514.6 ± 7.5
Helm based	4.29 ± 0.02	14.45 ± 0.47	77.3 ± 2.1	515.6 ± 8.6
	q_1 [%]	q_2 [%]	q_3 [%]	q_4 [%]
Sasol based	72.96 ± 0.51	15.62 ± 0.46	7.01 ± 0.11	4.65 ± 0.69
Helm based	75.61 ± 0.51	13.56 ± 0.39	6.67 ± 0.13	4.39 ± 0.65

statistical uncertainties only

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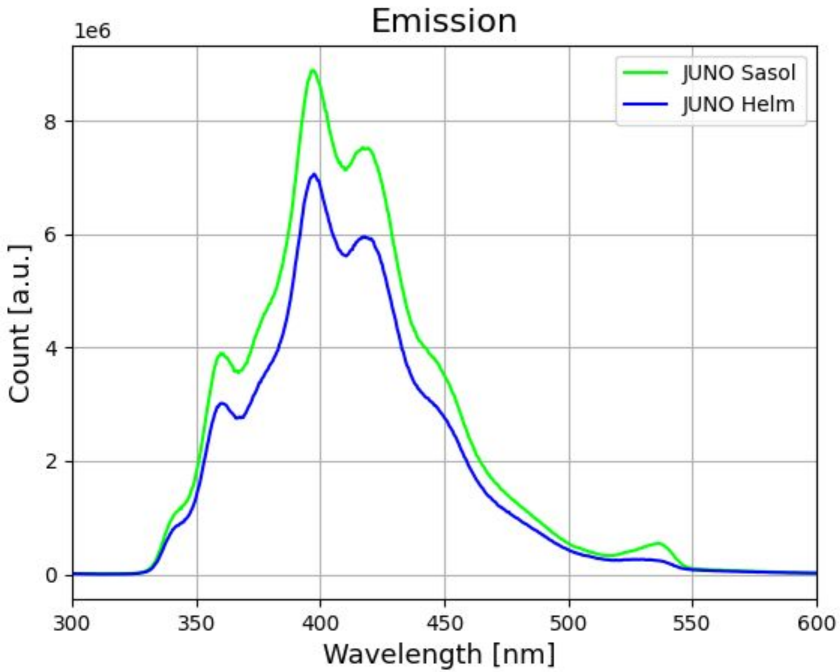
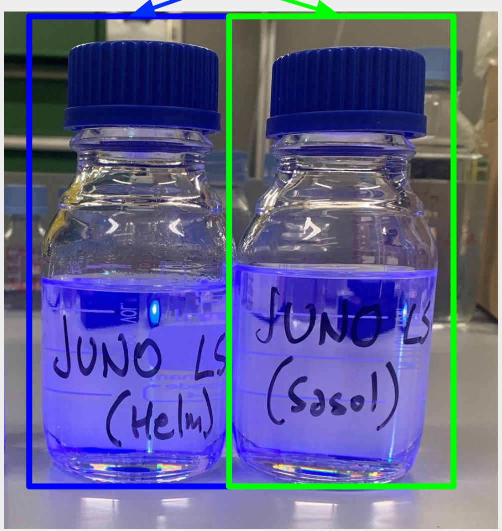
- SHELDON: time distribution
- **Emission spectrum**
- Absorbance
- Conclusions

Emission spectrum

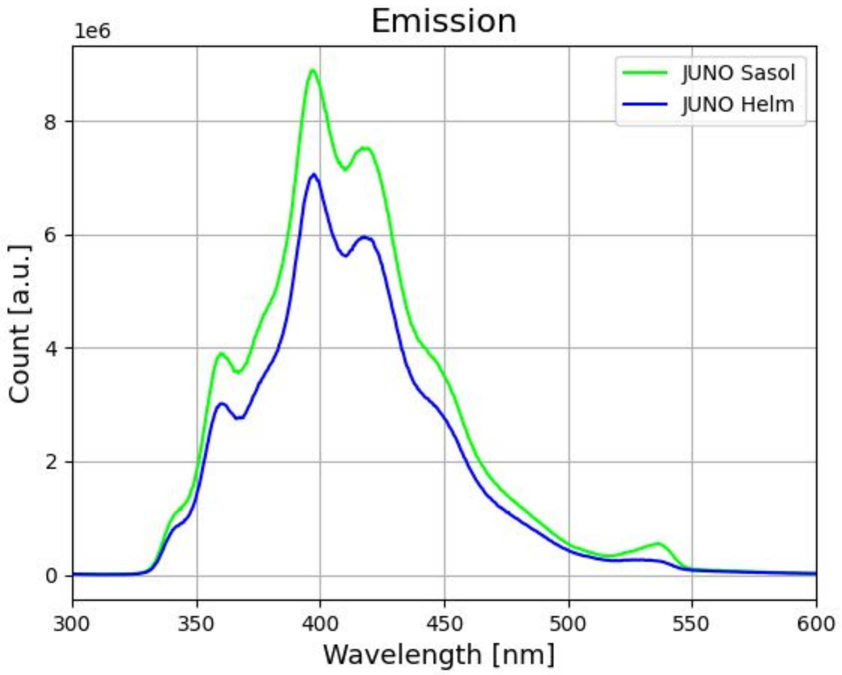


Produced both for Milano and Munich groups



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

Emission spectrum



JUNO LS mixtures produced, in Perugia, using Sasol LAB and Helm LAB have:

- **Different light yield**

Measured @ Università degli Studi di Perugia
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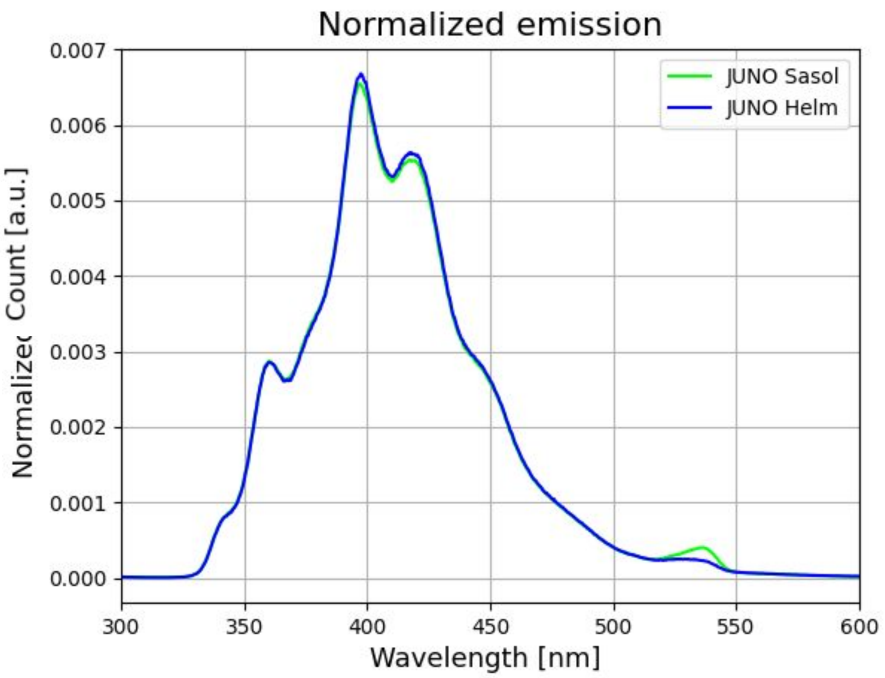
Emission spectrum

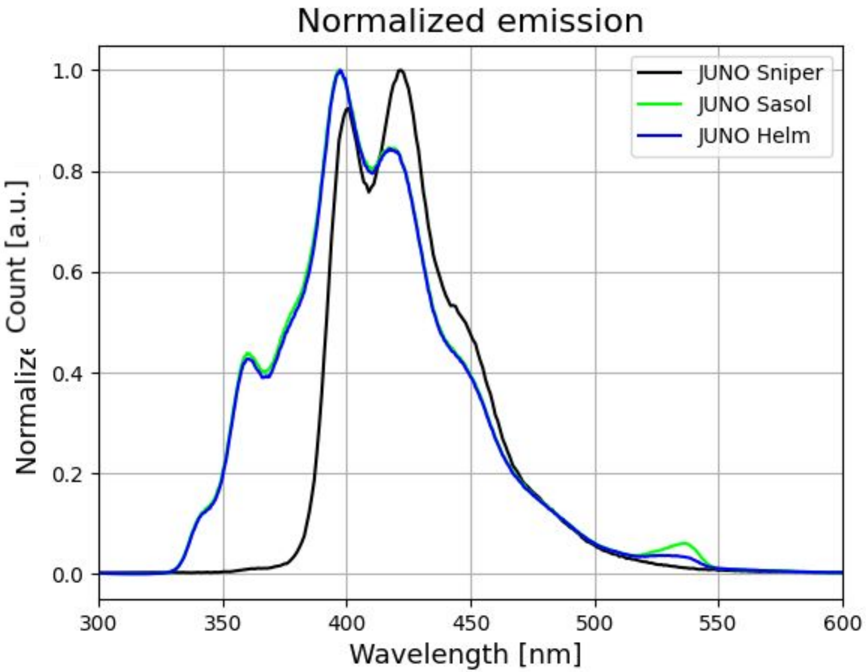


JUNO LS recipe: LAB + 2.5 g/L PPO + 3.0 mg/L bis-MSB

JUNO LS mixtures produced, in Perugia, using Sasol LAB and Helm LAB have:

- **Different light yield**
- **Similar spectrum**

Emission spectrum



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JUNO LS mixtures produced, in Perugia, using Sasol LAB and Helm LAB have:

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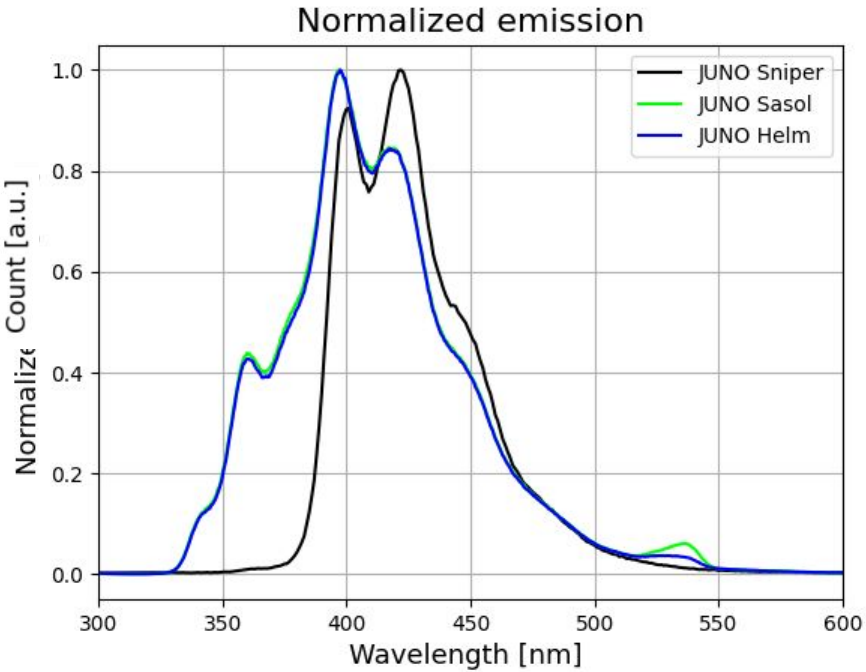
- **Similar spectrum**

The spectrum implemented in SNiPER is different!

Emission spectrum



JUNO LS recipe:	LAB + 2.5 g/L PPO + 3.0 mg/L bis-MSB
DB LS recipe:	LAB + 3.0 g/L PPO + 15 mg/L bis-MSB

JUNO LS mixtures produced, in Perugia, using Sasol LAB and Helm LAB have:

- **Different light yield**
- **Similar spectrum**

The spectrum implemented in SNiPER is different!

→ **it was inherited from DayaBay**

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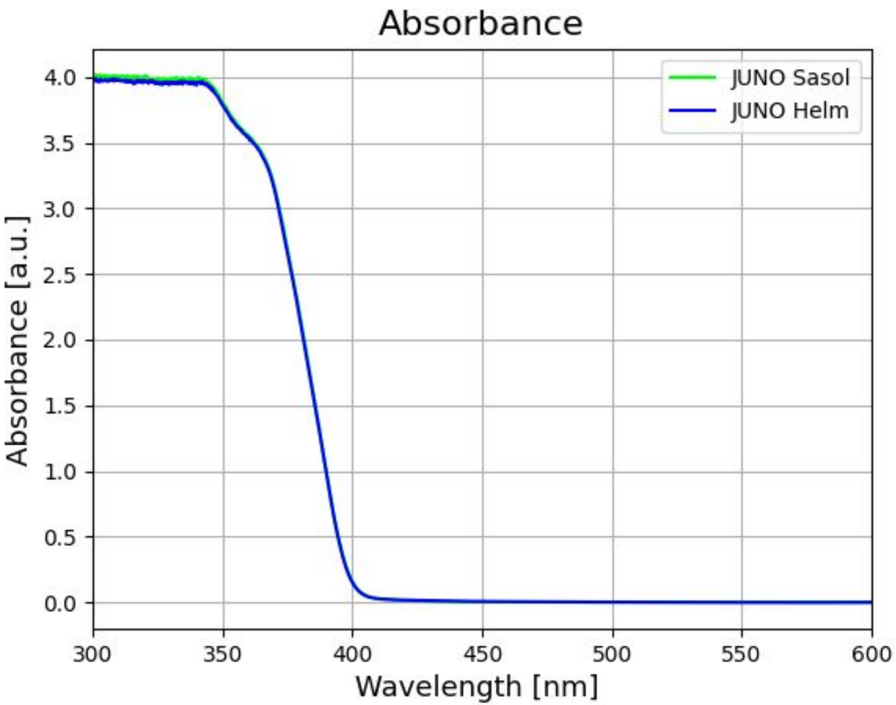
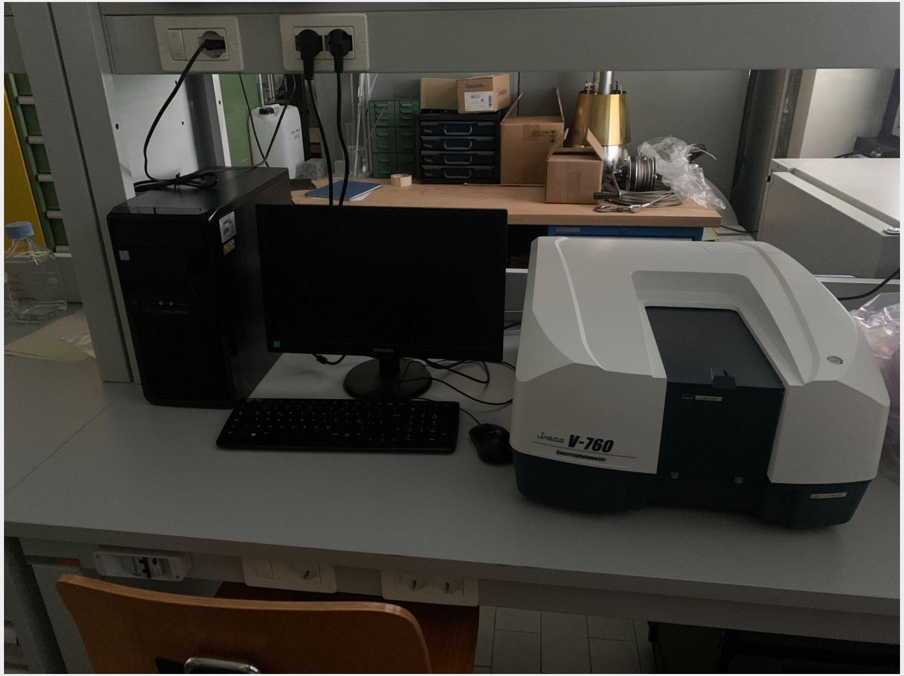
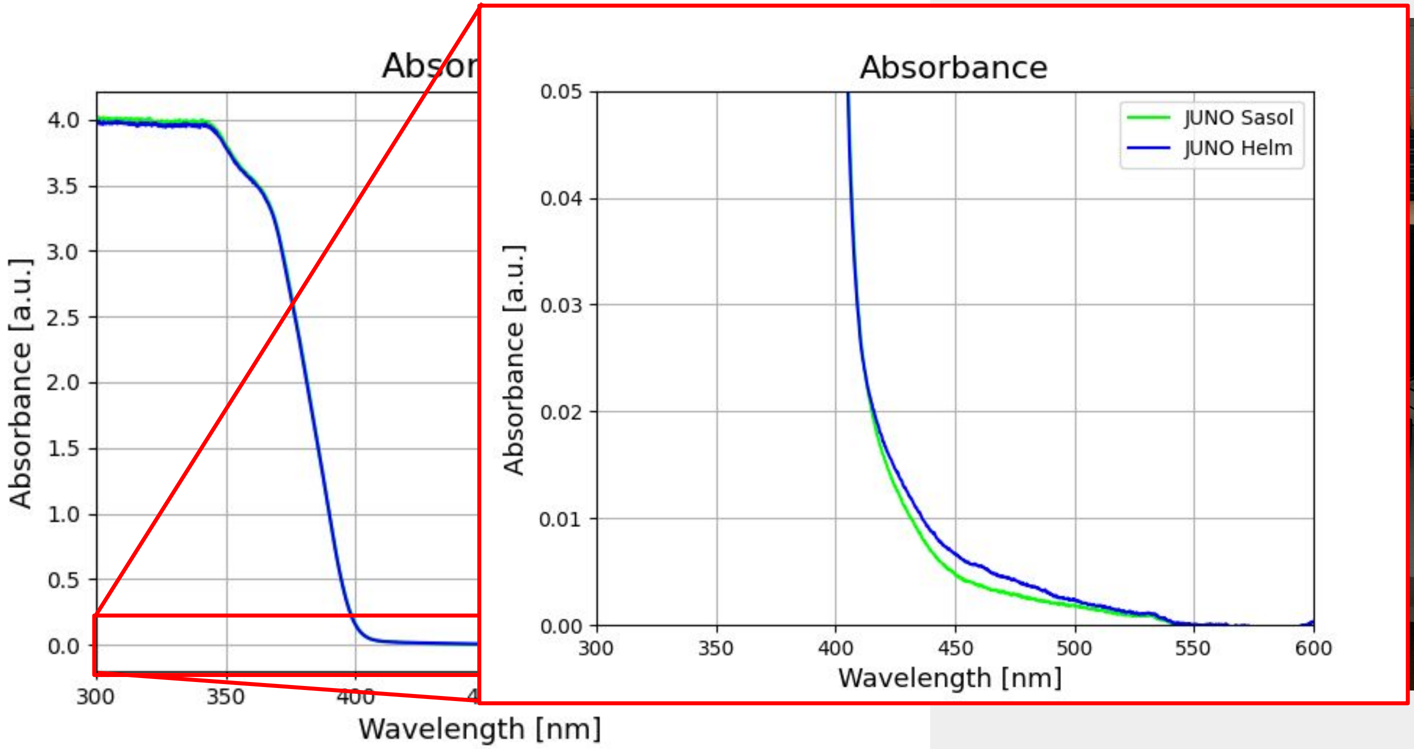
Absorbance





Measured using a Jasco V-760 spectrophotometer in Milan

Absorbance



This parameter is expected to be much different after on-site purification

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- Introduction
- SHELDON: Time profile measurement
- Emission spectrum
- Absorbance
- **Conclusions**

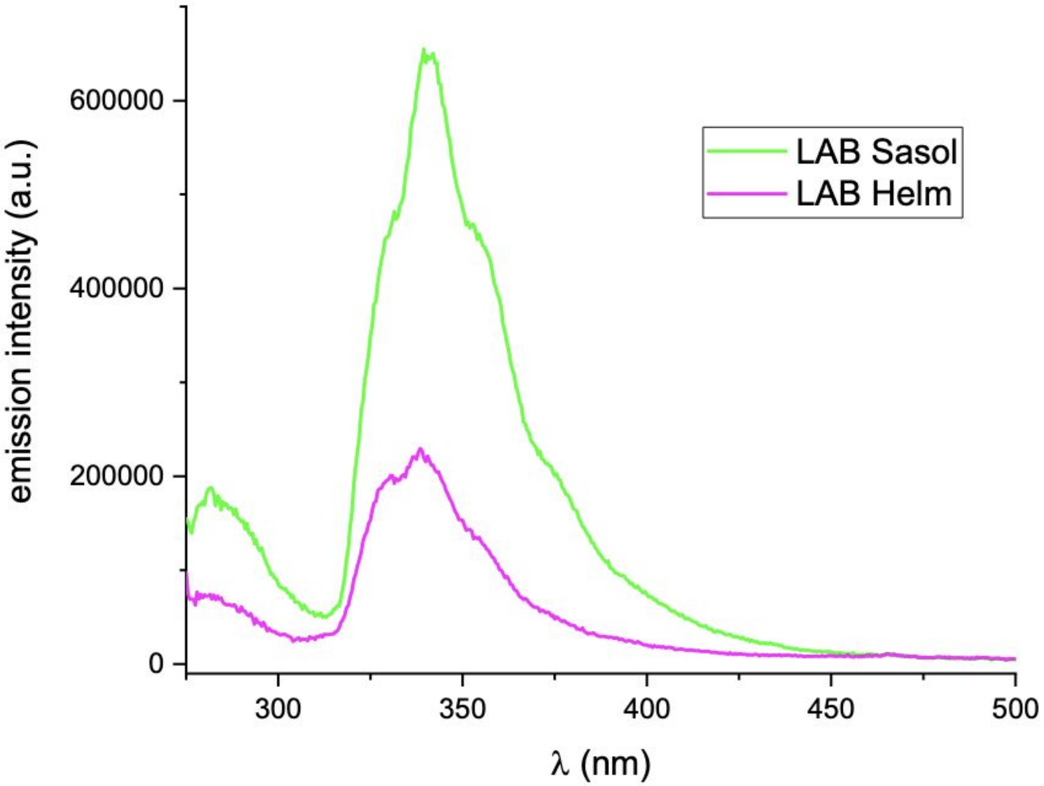
Conclusions

- We proved that observed **differences** with respect to other existing measurements on fluorescence parameters are **not due to different producers**
- The emission spectra of **LAB from different producers** show **different yield** but **the overall shape is the same**
- We observe **very small differences in the absorbance**, but we expect it to be much different after on-site purification
- **Our results on the fluorescence parameters can be inserted in SNiPER** to evaluate their impact on event reconstruction and Pulse-Shape Discrimination
- We are still improving our analysis on the **fluorescence time distribution** to achieve solid, accurate results

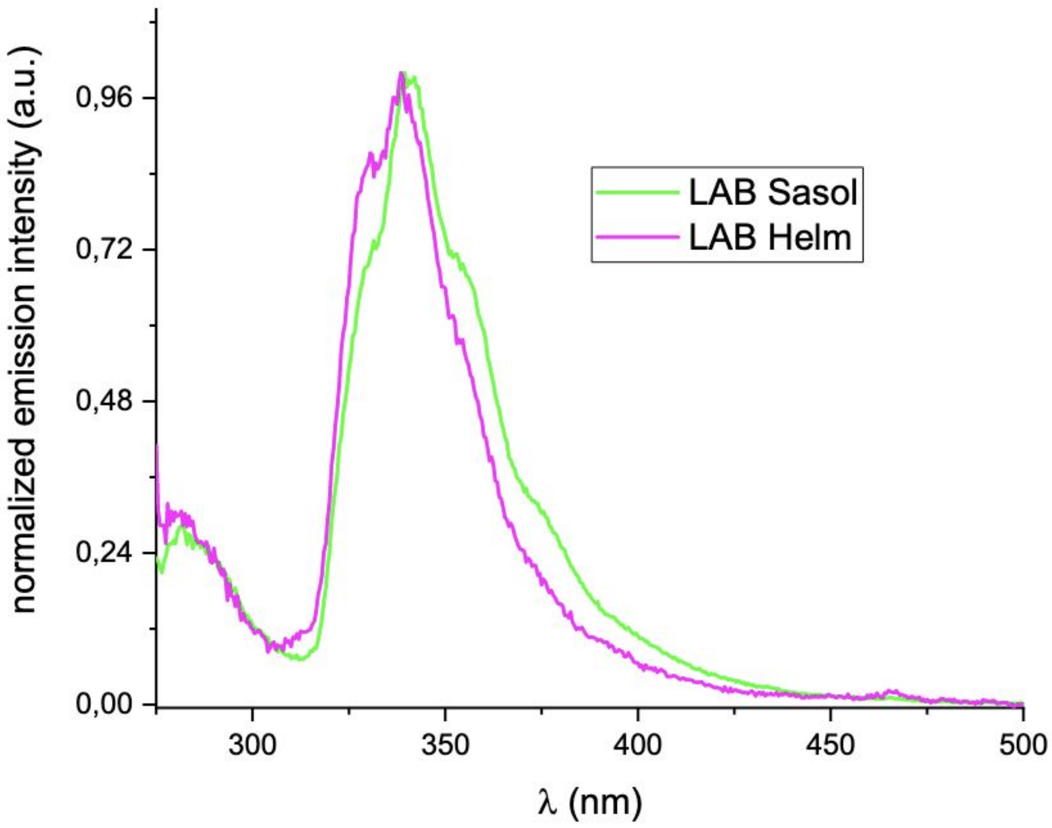
Thank you for your attention

Backup

Sasol and Helm LAB differences

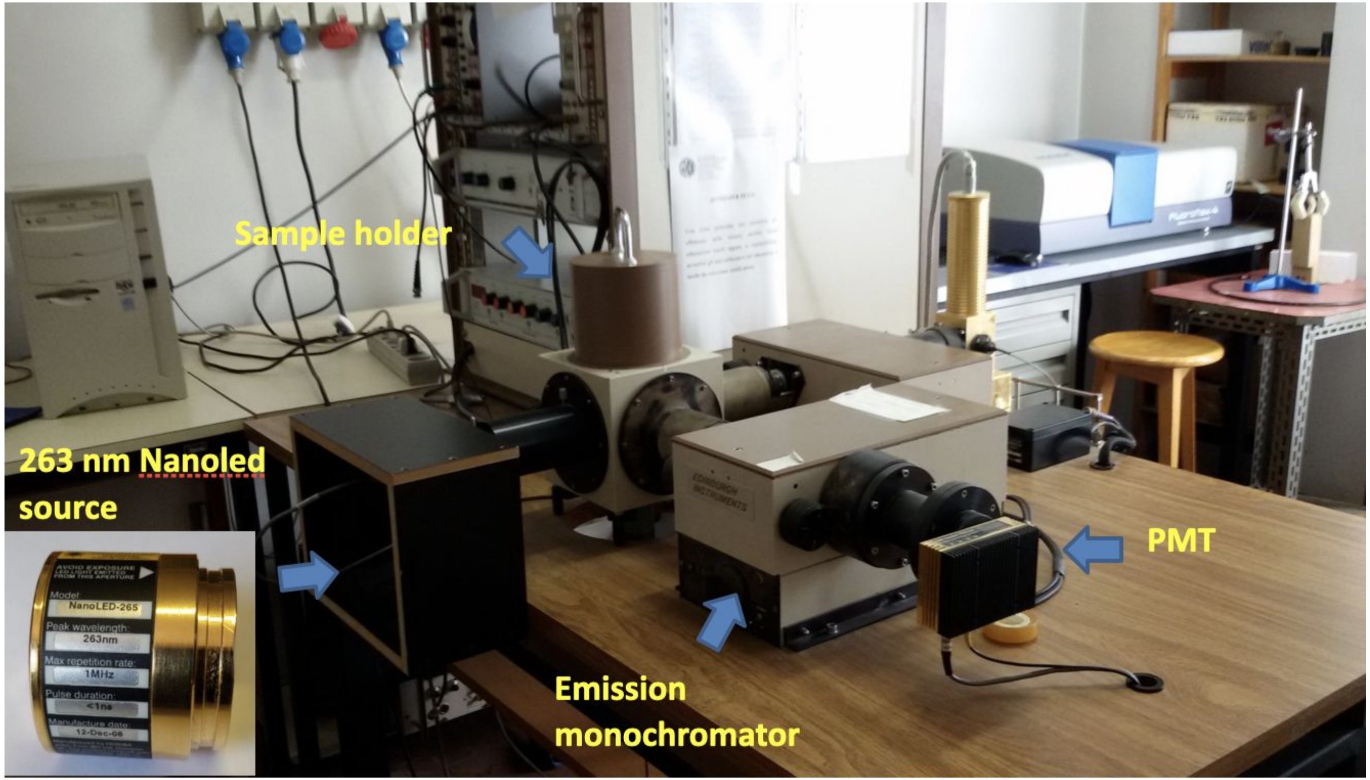


Sasol and Helm LAB differences



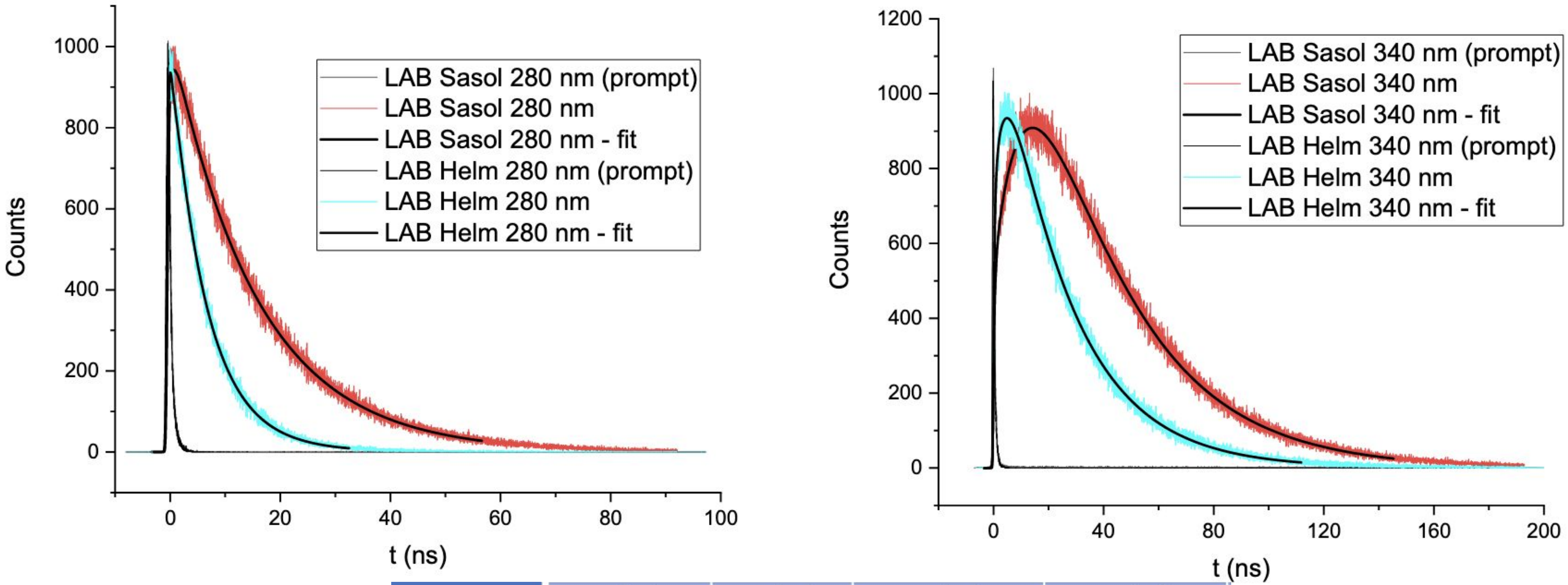
Sasol and Helm LAB differences

single-photon counting set -up



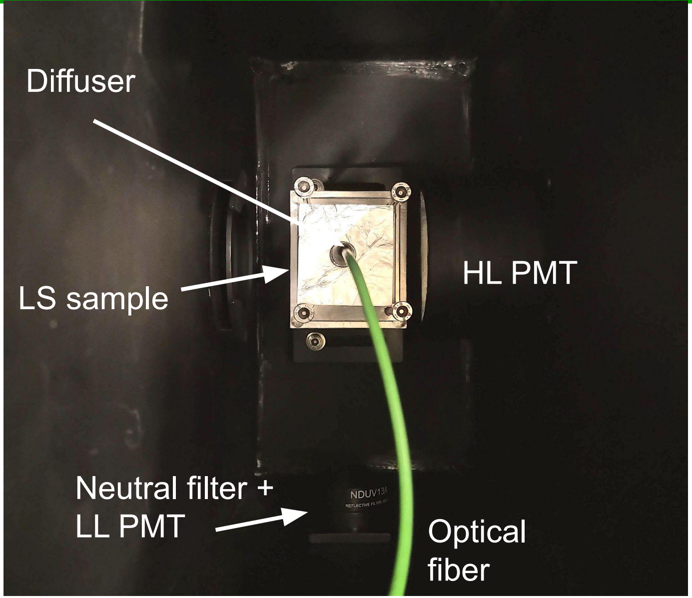
Sasol and Helm LAB differences

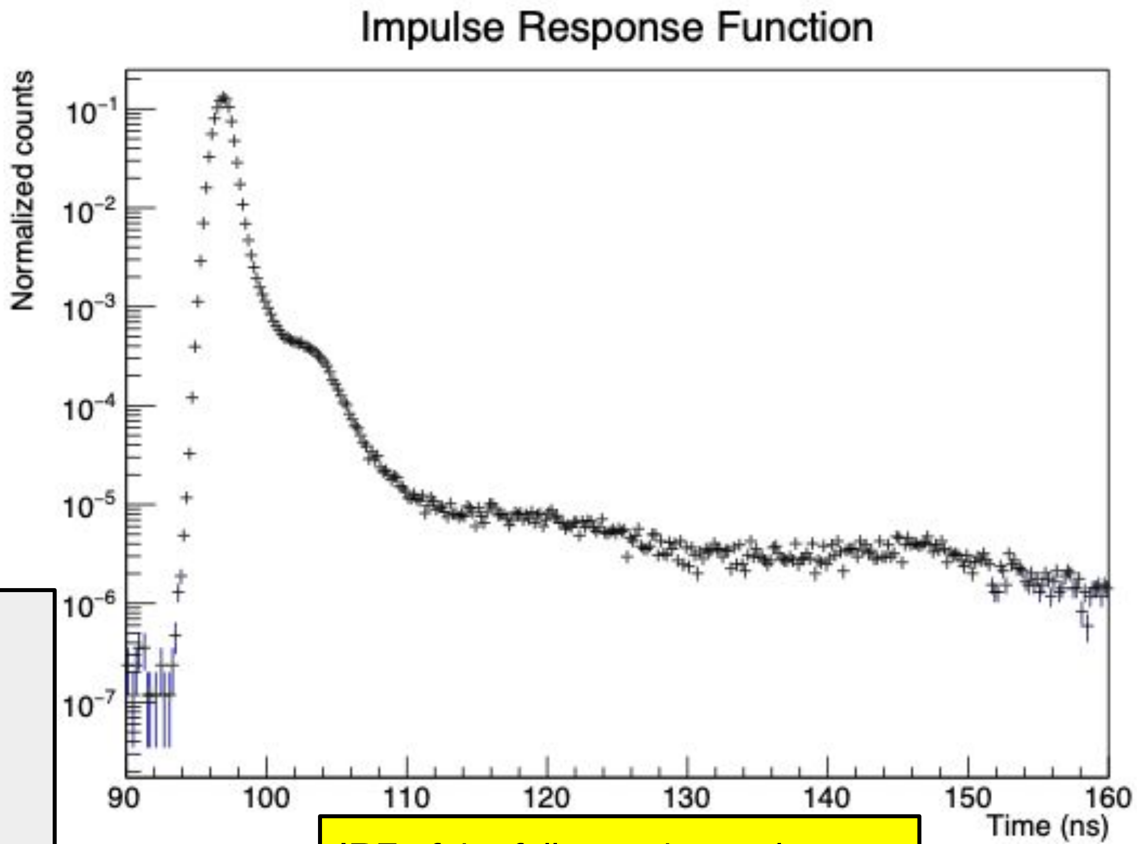
Fluorescence decay of LAB samples



	τ_1 (ns) 280 nm	τ_2 (ns) 280 nm	τ_1 (ns) 340 nm	τ_2 (ns) 340 nm
SASOL	15.6 ± 0.5	-	13.1 ± 0.4	30.3 ± 0.9
HELM	5.7 ± 0.2	8.6 ± 0.3	4.3 ± 0.1	24.5 ± 0.7

SHELDON: Impulse Response Function





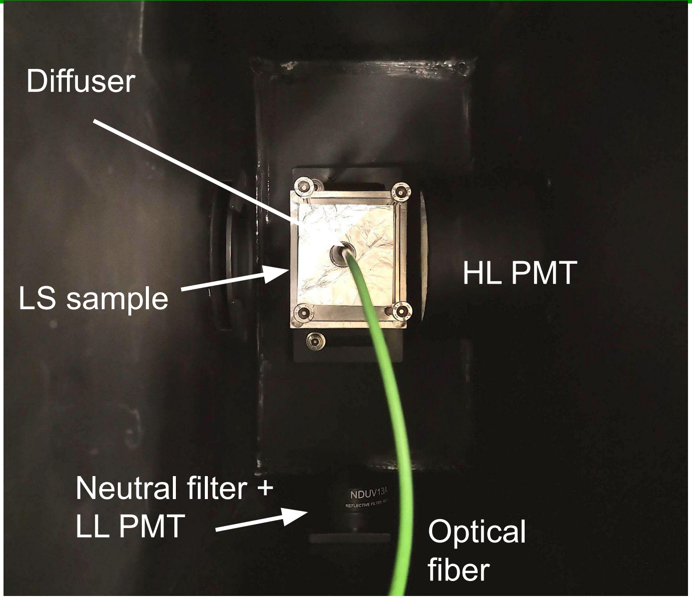
The measurement of the Impulse Response Function (IRF) is performed using a laser.

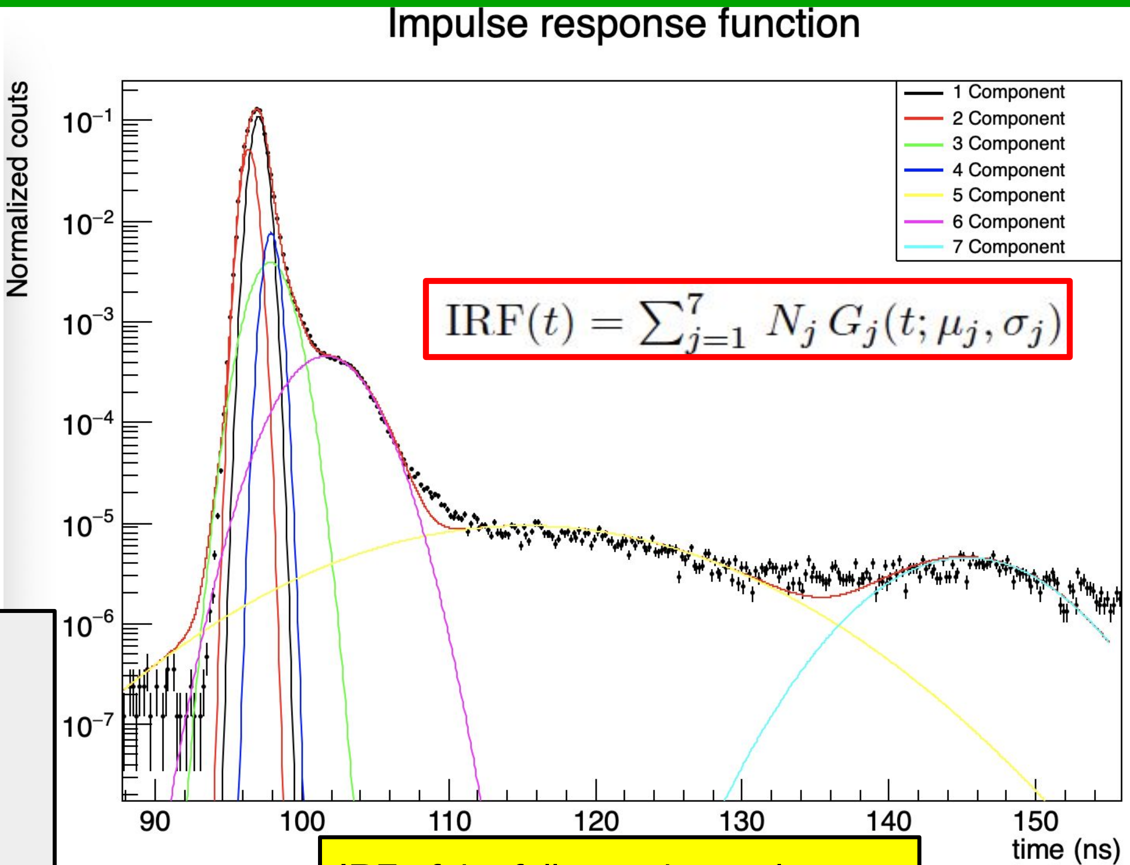
The laser has a pulse duration of 75 ps.

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

SHELDON: Impulse Response Function





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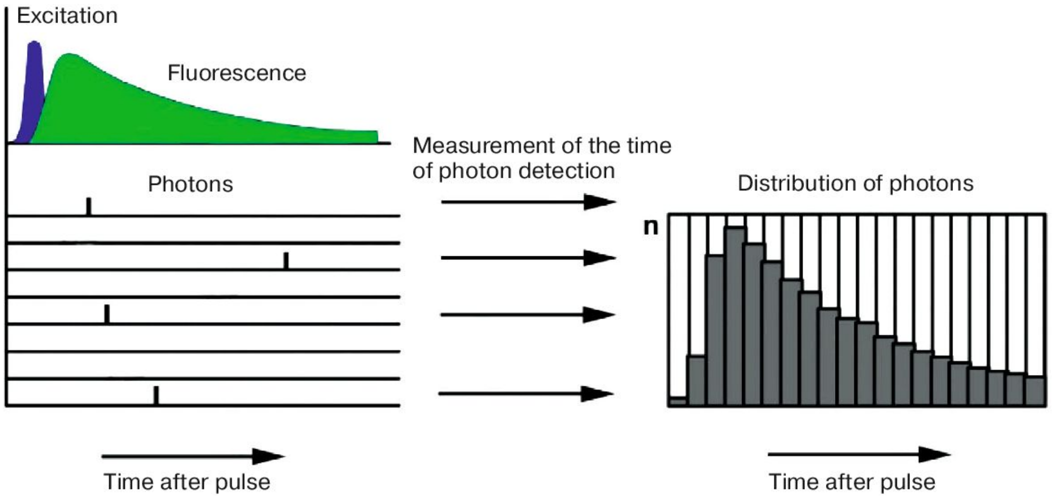
IRF of the full experimental setup:
LS + PMT + ADC + CFD

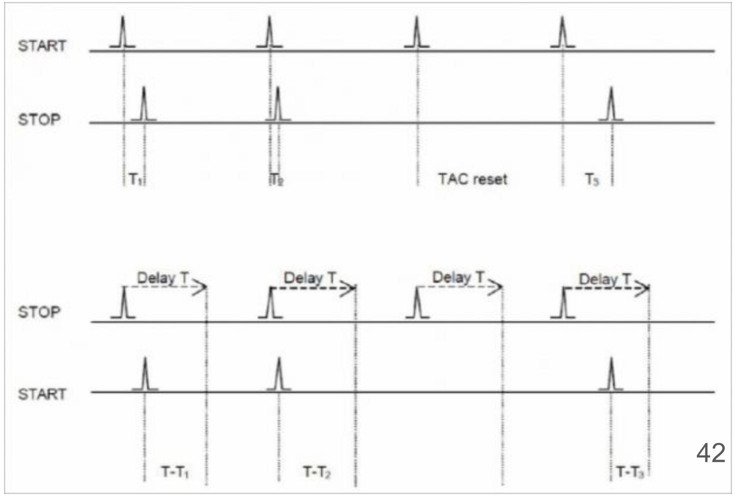
Measurement of fluorescence time profile with the single photon counting technique

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.





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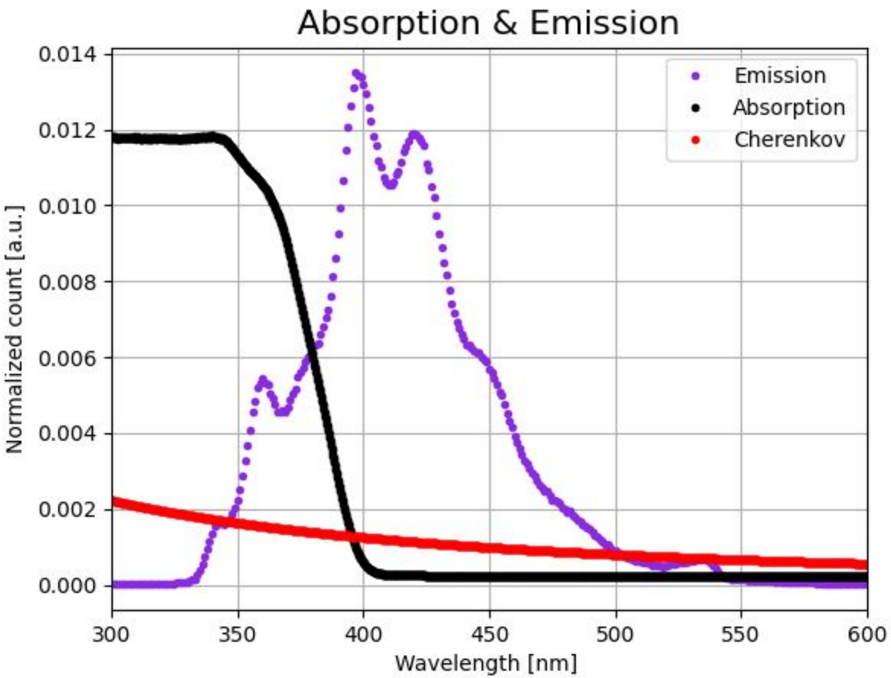
- The SHELDON project
- Measurement of fluorescence parameters
- **Separation of the Cherenkov contribution**
- Evaluation of the Cherenkov contribution
- Conclusion

Cherenkov contribution at different wavelengths



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

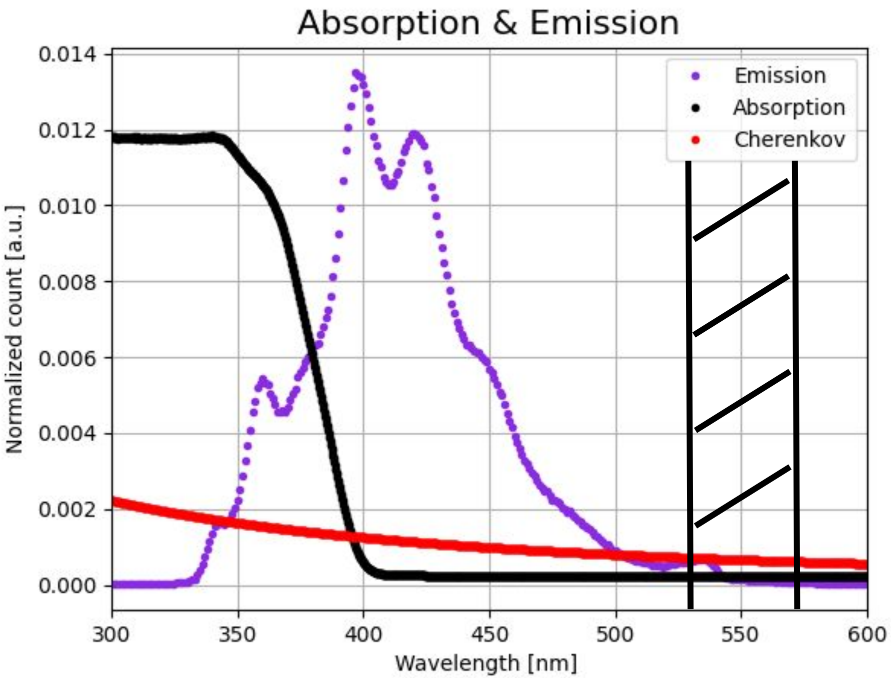
The JUNO LS emission spectrum has a maximum at 400 nm

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

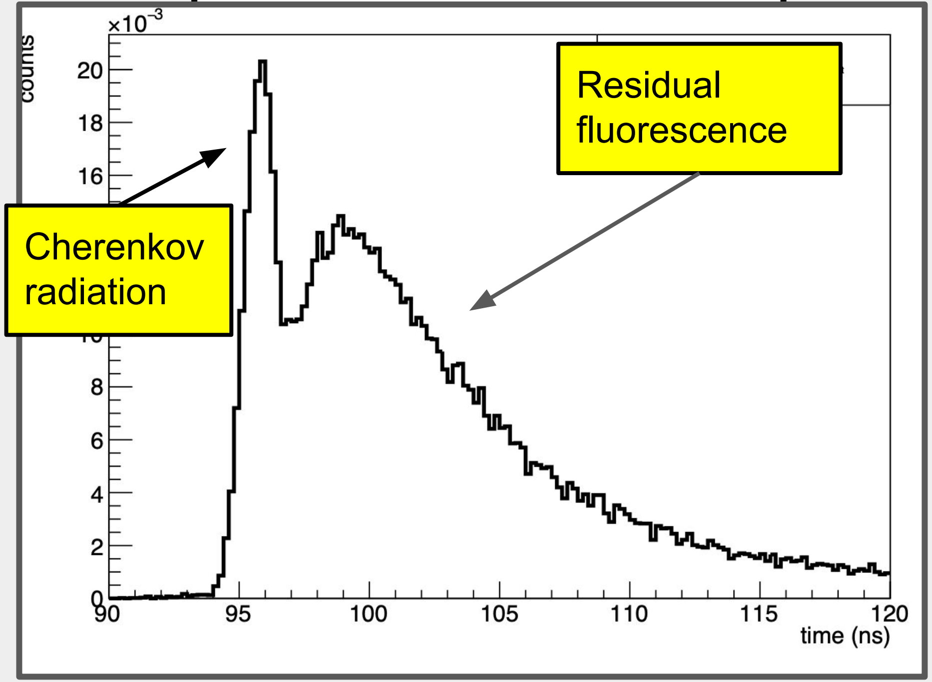
Using appropriate optical filters it is possible to select the light in a **desired wavelength interval**, separating scintillation and Cherenkov light.

marco.beretta@unimi.it

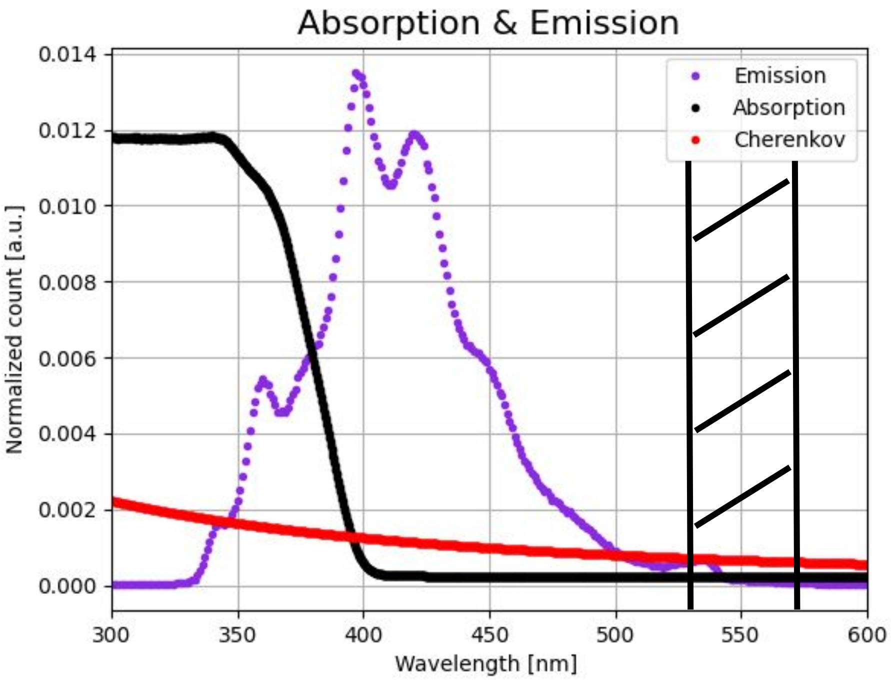
Cherenkov contribution at different wavelengths



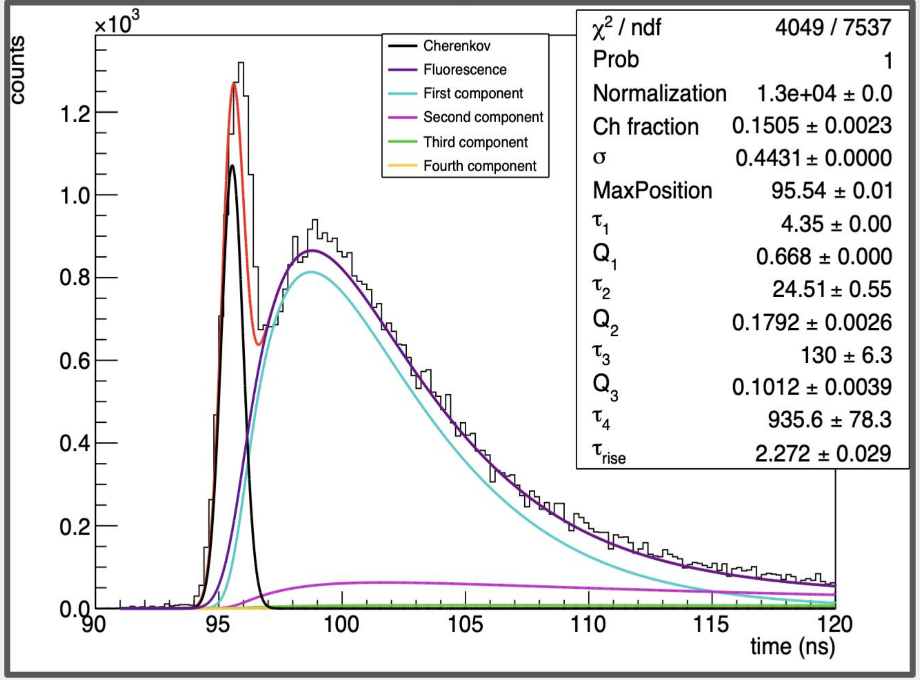
550 - 40 nm



Cherenkov contribution at different wavelengths



550 - 40 nm

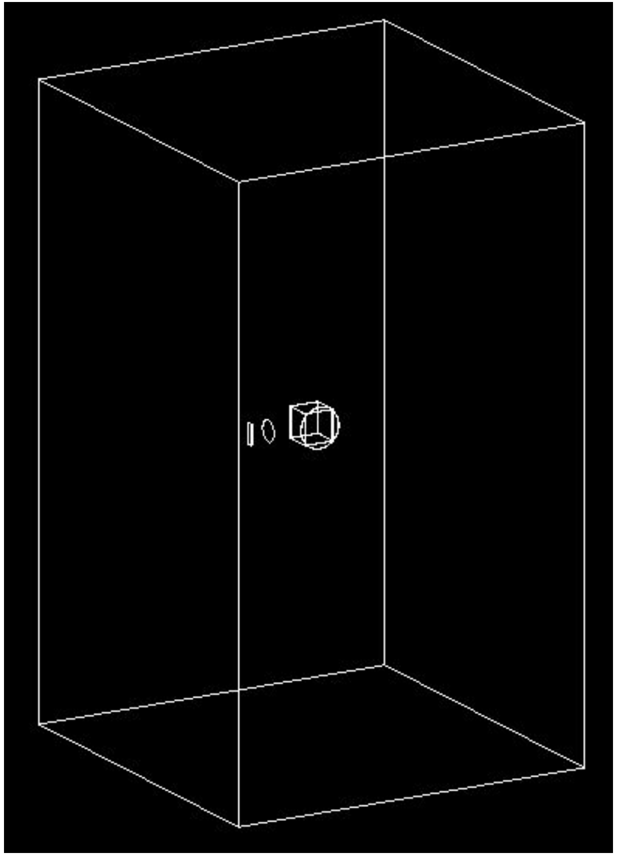


Cherenkov = 15.1 ± 0.2 %

Index

- The SHELDON project
- Measurement of fluorescence parameters
- Separation of the Cherenkov contribution
- **Evaluation of the Cherenkov contribution**
- Conclusion

Evaluation of the Cherenkov contribution



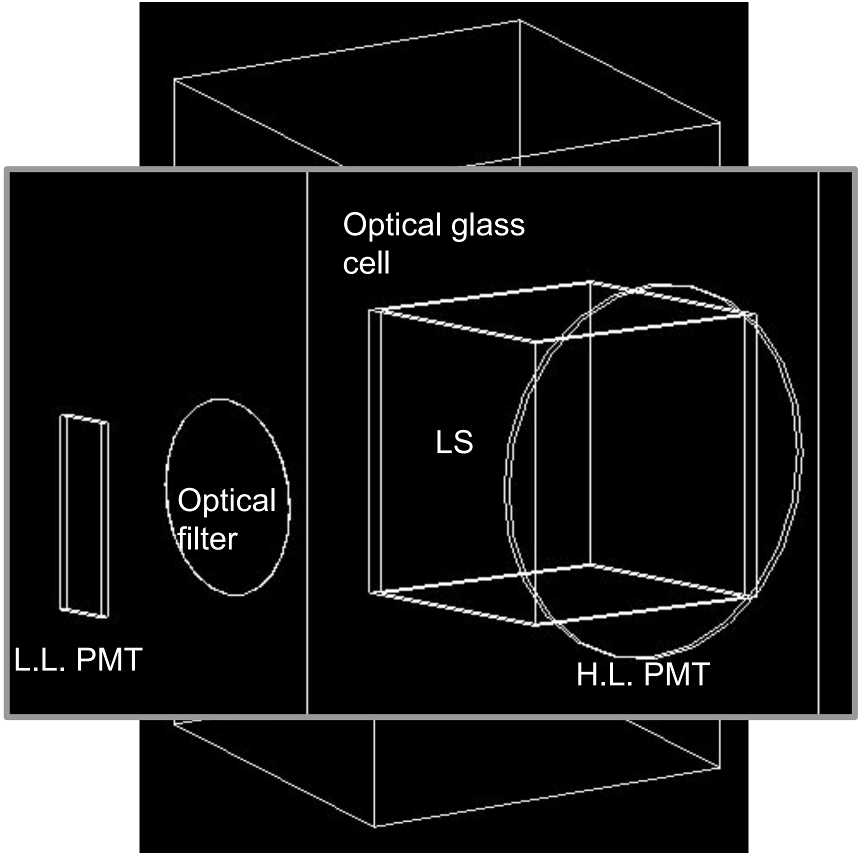
Using the new measurement of the **refractive index**

-> Gioele Reina's Talk

And a Geant4 simulation of our setup developed by Gioele Reina (master student @ UNIMI)

marco.beretta@unimi.it

Evaluation of the Cherenkov contribution



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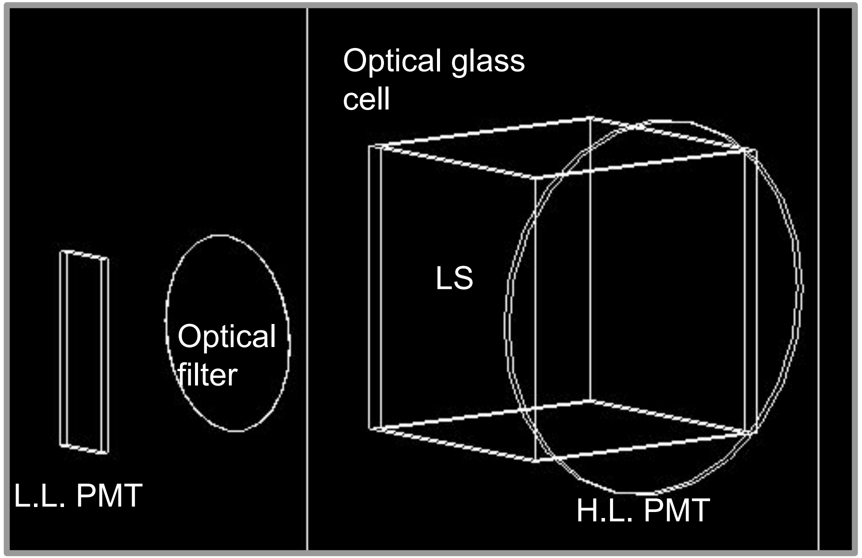

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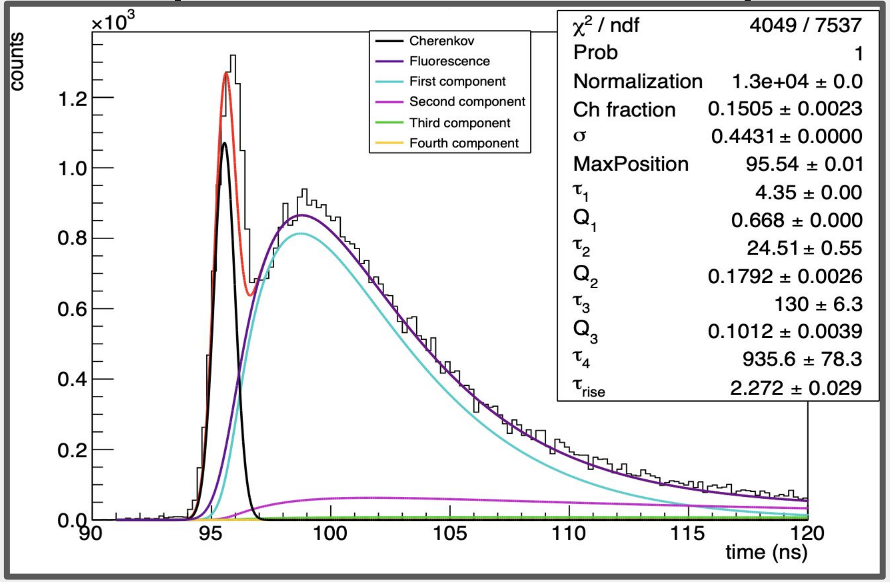

We will measure the Cherenkov contribution in the JUNO LS comparing real data with simulations

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