Measurements and enhancement of the X-Arapuca light detection efficiency

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In this work, we present the first characterization of the photon detection efficiency of an X-Arapuca prototype sizing 20 x 7.5 cm² using an [241]Am source and the enhancement of the device efficiency of about +50% by replacing the baseline WLS with a newly developed WLS material. The resulting efficiency found is comparable with the first X-Arapuca single cell test performed in Brazil 2019-2020 with a natural uranium, ^{60}Co source and cosmic muons.
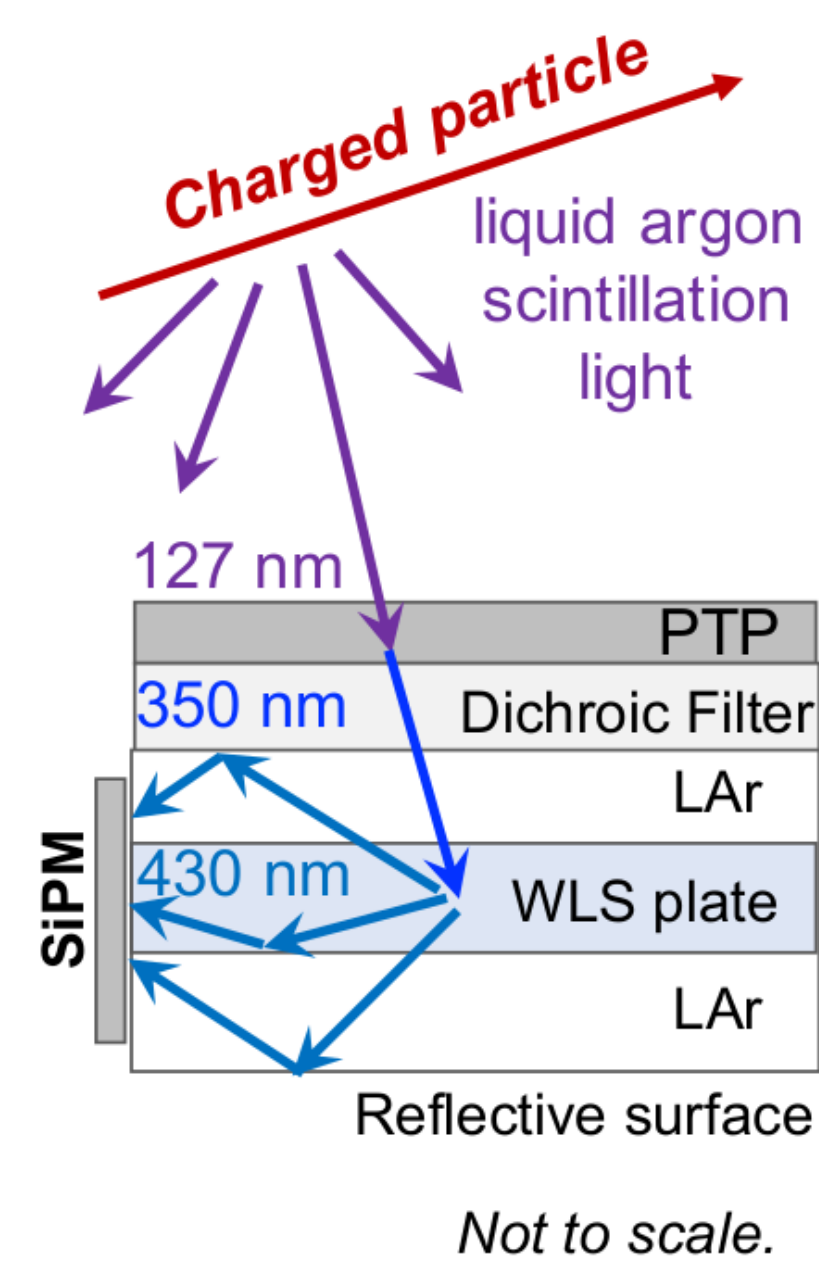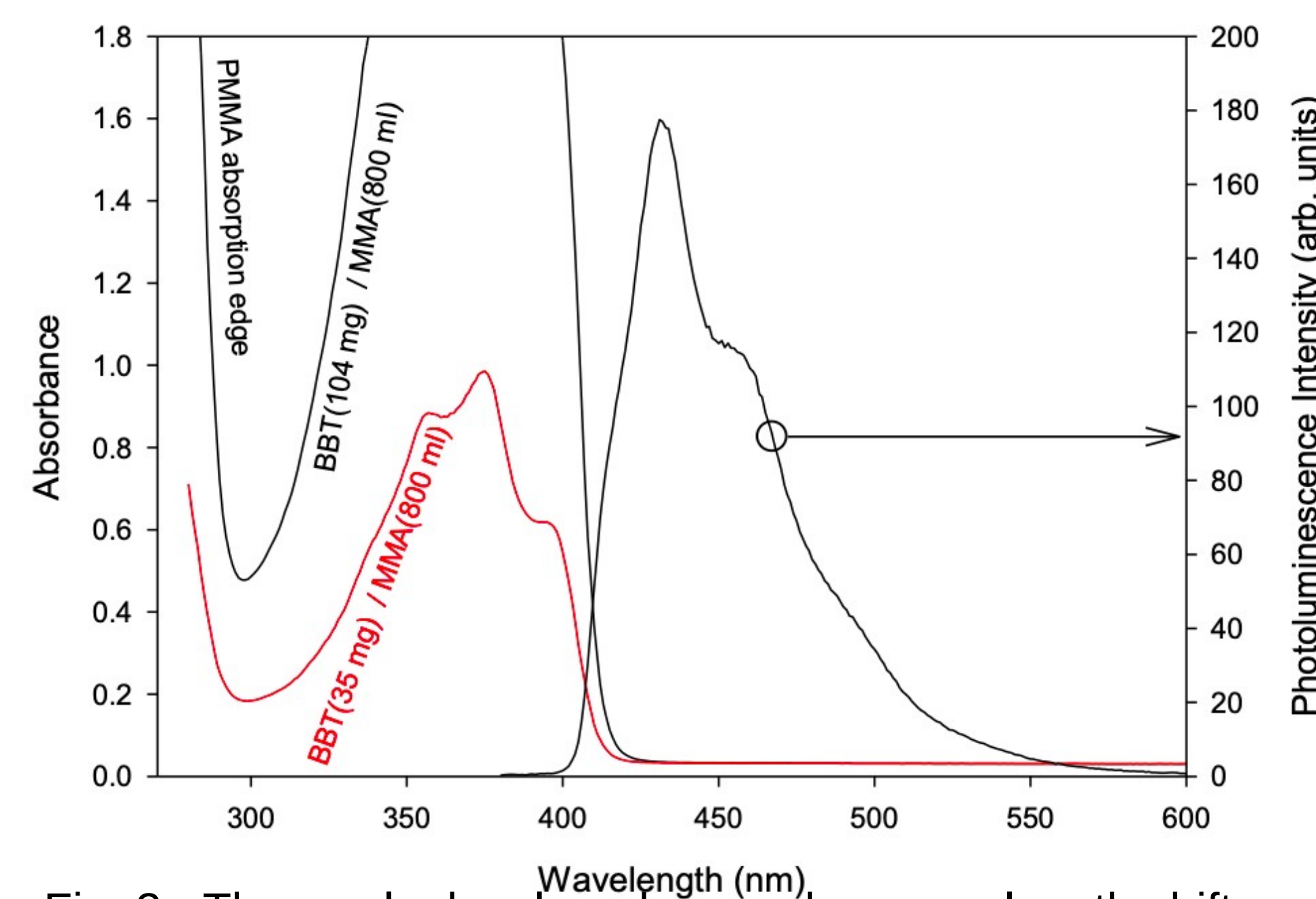
Motivation

Fig. 1 - The X-Arapuca concept scheme.

Fig. 2 - The newly developed secondary wavelength shifters absorption and emission spectra, and the PMMA absorption.

Confront between **EJ-286** (PVT based) and the WLS from G2P (PMMA based), **FB118-2**.

PVT – Polivyniltoluene, PMMA – Poly(methyl methacrylate), BBT – 2,5-Bis(5-tert-butyl-benzoxazol-2-yl)thiophene
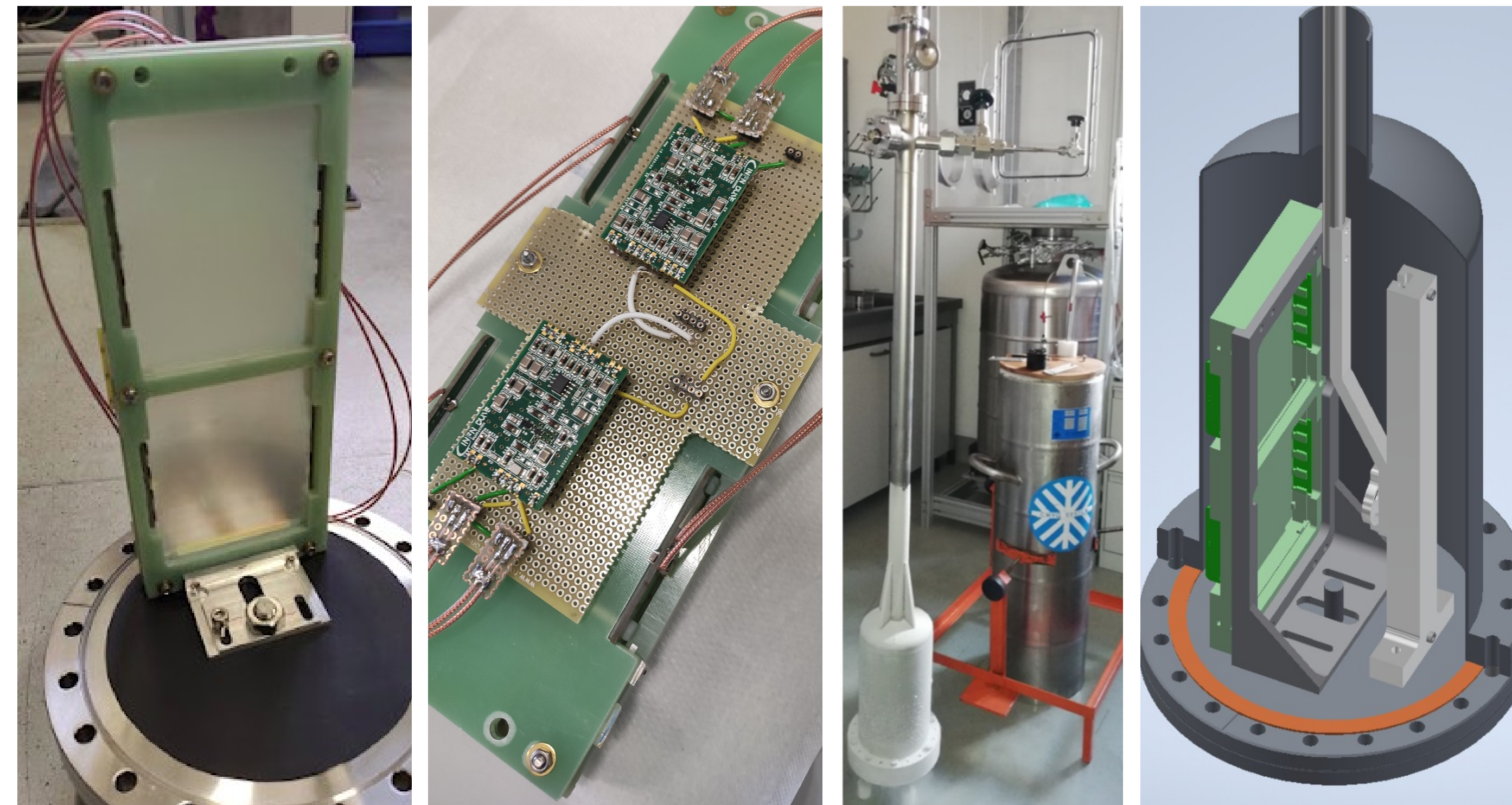
Procedures

Fig. 3 - Front and back pictures of the X-Arapuca device (200 x 75 mm2), SiPMs two channels of 4 SiPMs Hamamatsu model S14160-6050HS (6 x 6 mm2), 50 μm pitch, peak sensitivity wavelength (λ) 450 nm, photon detection probability at λ~50%, terminal capacitance of 2.0 nF and operated at +2.7 overvoltage over the breakdown voltage. The device was submersed in Lar facing an 241Am source that can slide in the trail.
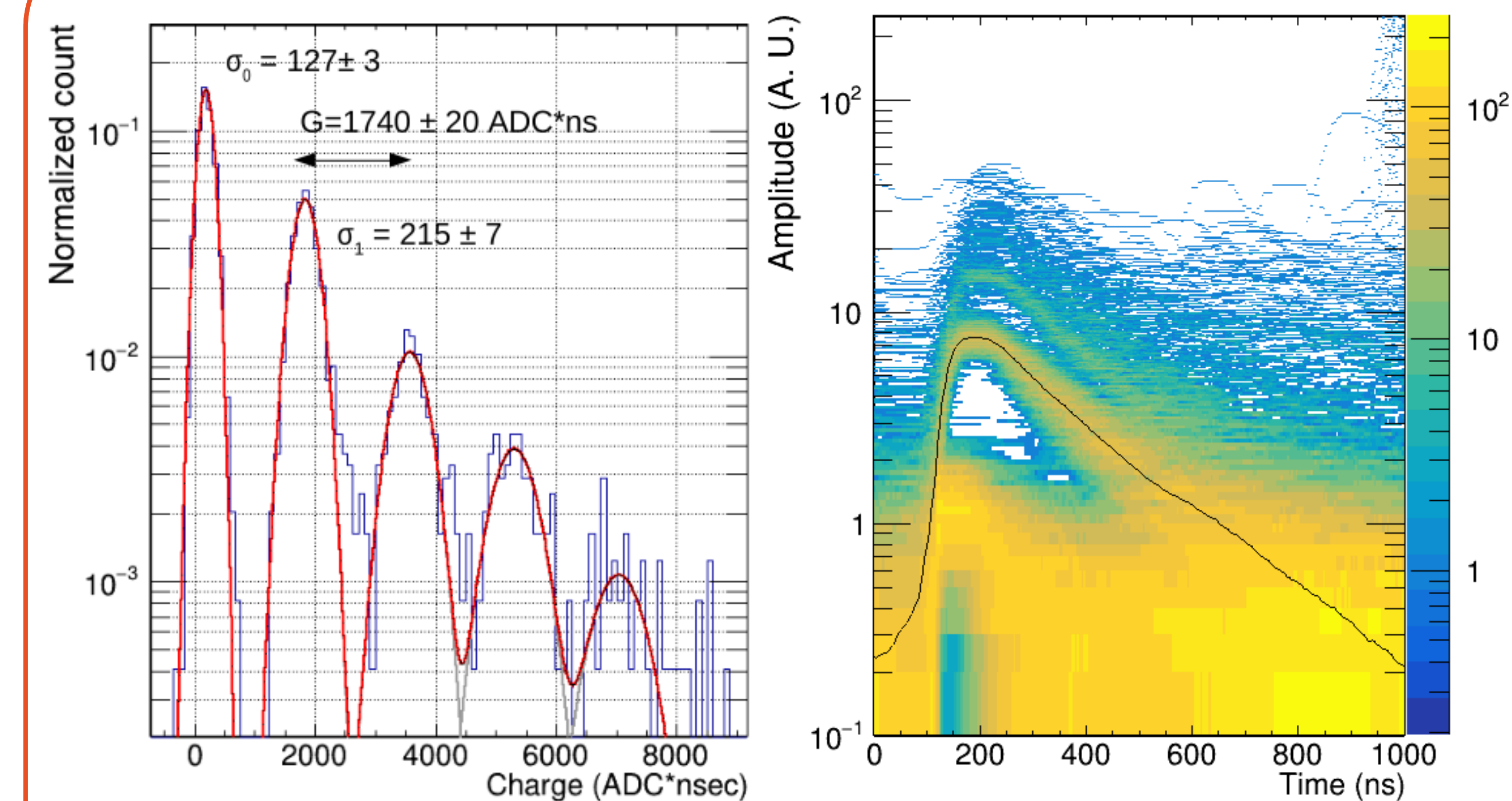
Calibration

Fig. 4 - Single photo-electron spectrum extracted. The fit function is the sum of five Gaussians. The pedestal (n=0) and the fist peak (n=1) have three free parameters, the n=2 peak the standard deviation fixed at √n · σ1. For n>2 peaks both means and standard deviations are fixed at n · G and √n · σ1, respectively.

Fig. 5 - The events from an alpha in the plane Fprompt versus number of p.e..

Conclusions

	EJ-286	FB118-2
En. res. (σ/μ)	6.0 ± 0.2 %	3.6 ± 0.1 %
ϵ_{raw}	2.3 ± 0.1 %	3.5 ± 0.1 %
τ_T	1294 ± 35 ns	
LAr purity corr.	+ (1.4 to 2.6) %	
Cross-talk corr.	- (18 ± 1) %	
ϵ	1.9 ± 0.1%	2.9 ± 0.1%

Tables 1 - Summary of the results achieved. Energy resolution of the α pea, Efficiency Prior (raw) and post correction, measured Triplet half-life. Efficiency found at Campinas was 2.20 ± 0.44 % for the X-Arapuca single-cell.

Positions	G_ϵ
2,3,4	55 ± 5 %
5	50 ± 5 %
1	63 ± 6 %

Tables 2 - The PDE increase (Gε) when replacing the EJ-286 in the X-Arapuca with the FB118, for the five source positions.
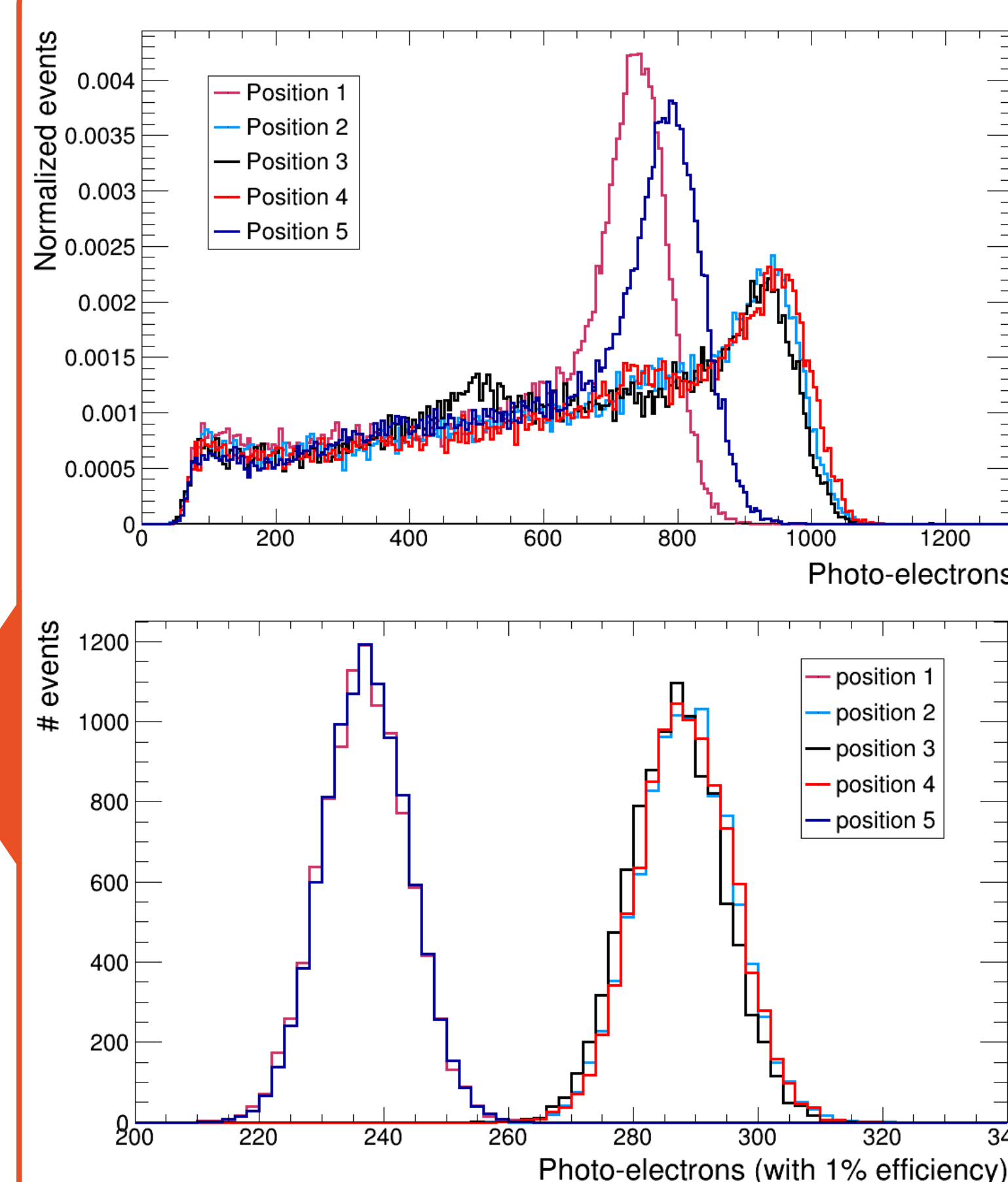
Efficiency

Fig. 8 - Alpha spectrum for the 5 positions and the MC toy-model output.
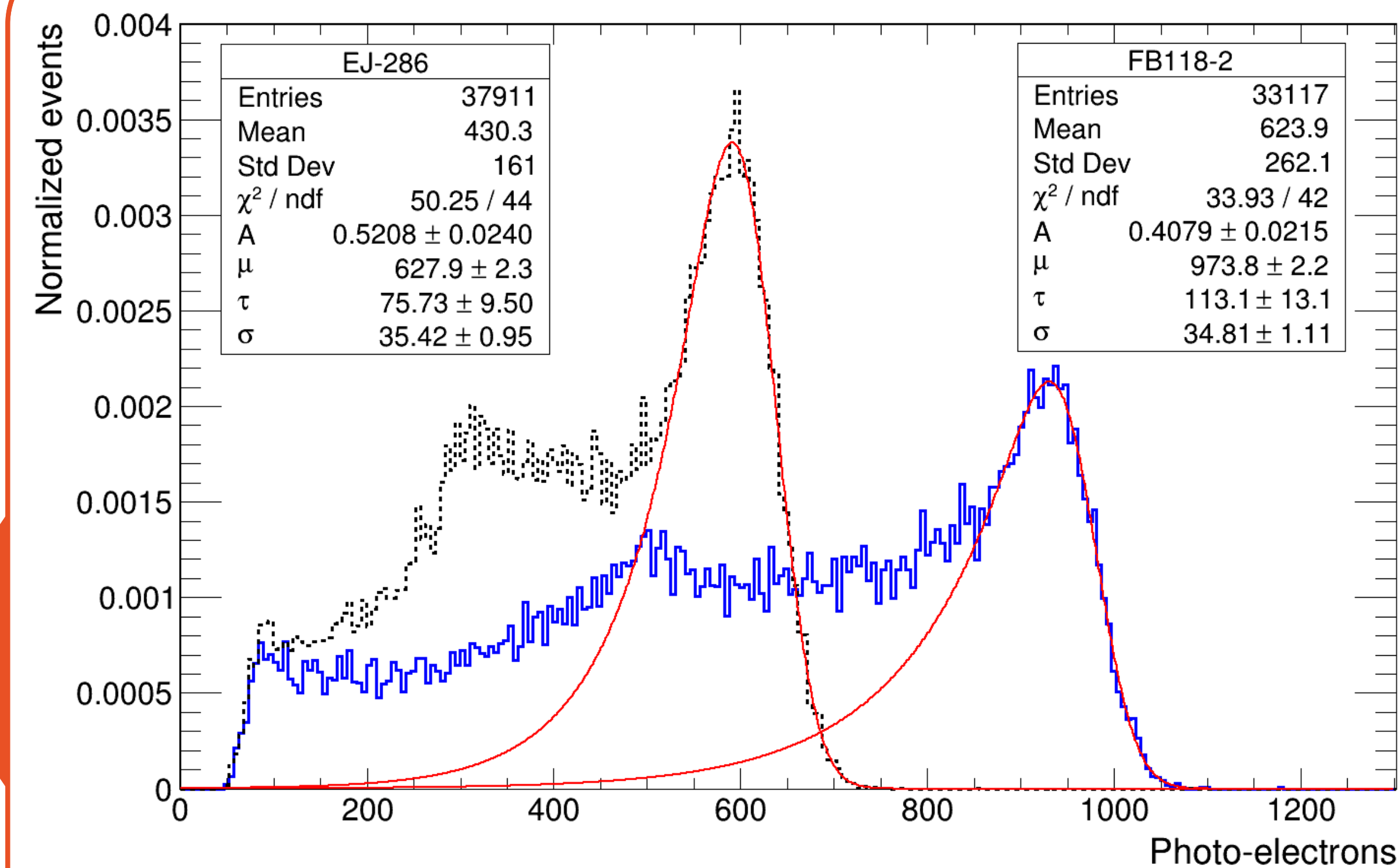
Enhancement

Fig. 7 - The α spectrum fit with equation below for EJ-286 (black, dashed line) and FB118 (blue, solid line).

$$F(E) = \frac{A}{2\tau} \exp\left(\frac{E-\mu}{\tau} + \frac{\sigma^2}{2\tau^2}\right) \mathrm{erfc}\left(\frac{1}{\sqrt{2}}\left(\frac{E-\mu}{\sigma} + \frac{\sigma}{\tau}\right)\right)$$
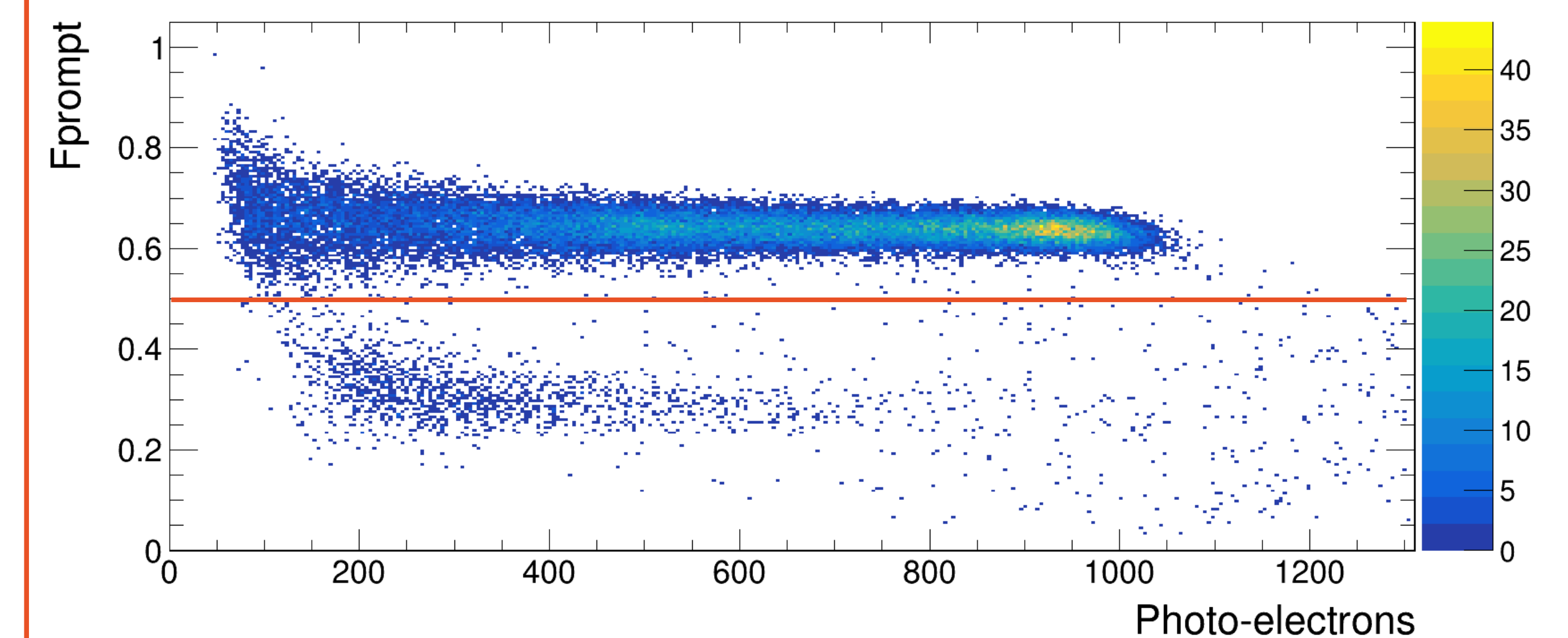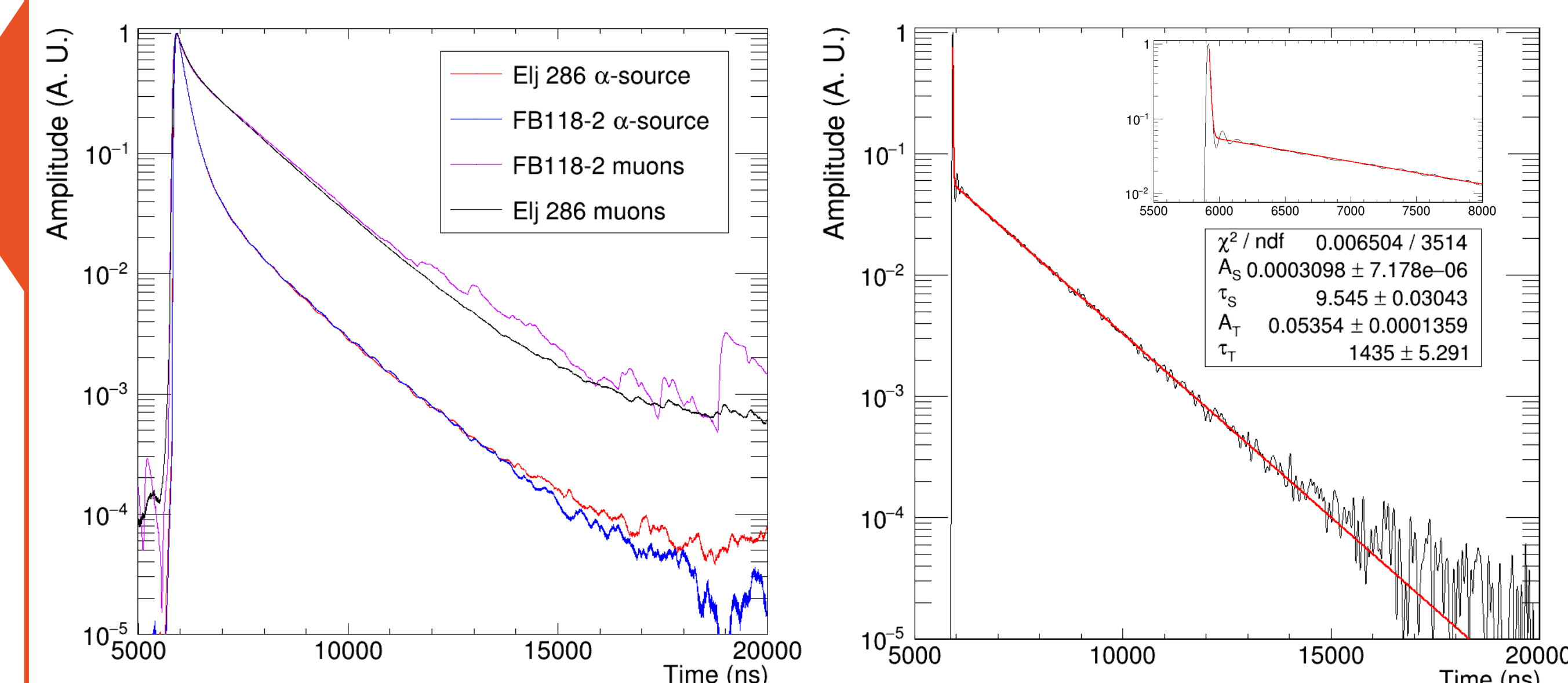

Fig. 6 - The normalized average waveforms of the events, selected on the Fprompt classifier. The deconvolved averaged waveforms of muons.

Acknowledge