HD Supercell efficiency measurements in Liquid Argon @ Milano-Bicocca: updated results

C. Massari, on behalf of the MiB working group

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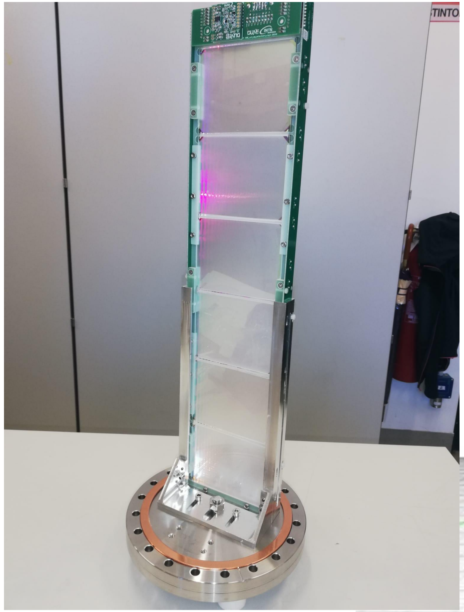
INFN Istituto Nazionale di Fisica Nucleare
SEZIONE DI MILANO BICOCCA

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

Setup to measure the XA-HD-SC PDE in LAr

The XA-HD-SC w. Cold FE circuit (top)



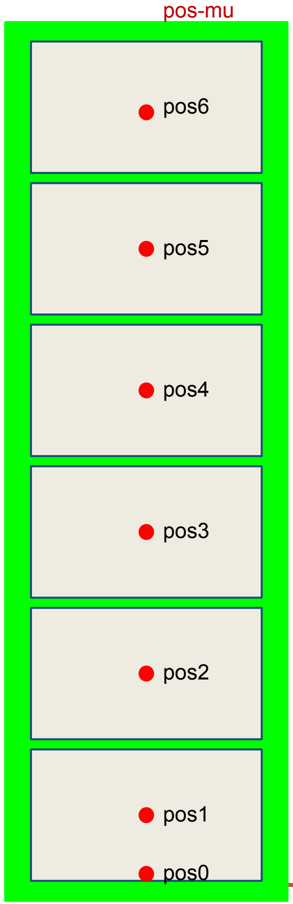
The XA-SC installed in the test chamber to measure the PDE along its z-axis.

Supercell equipped with:

- PMMA WLS (ELJ&G2P)
- dichroic filters

Method as published in JINST 16 (2021) 09027: z-scanning with an ^{241}Am exposed α source

Method & Data taking



z-scanning of the SC with the ^{241}Am α (5.480 MeV) source at the following positions:

1. **pos0**: (the lowest possible): ~2 cm above the flange.
2. **pos1, 2, 3, 4, 5, 6**: the center of each dichroic filter.
   Acquired: 10^4 x 4 wfms; 20 μs length; ~5 μs pretrigger.

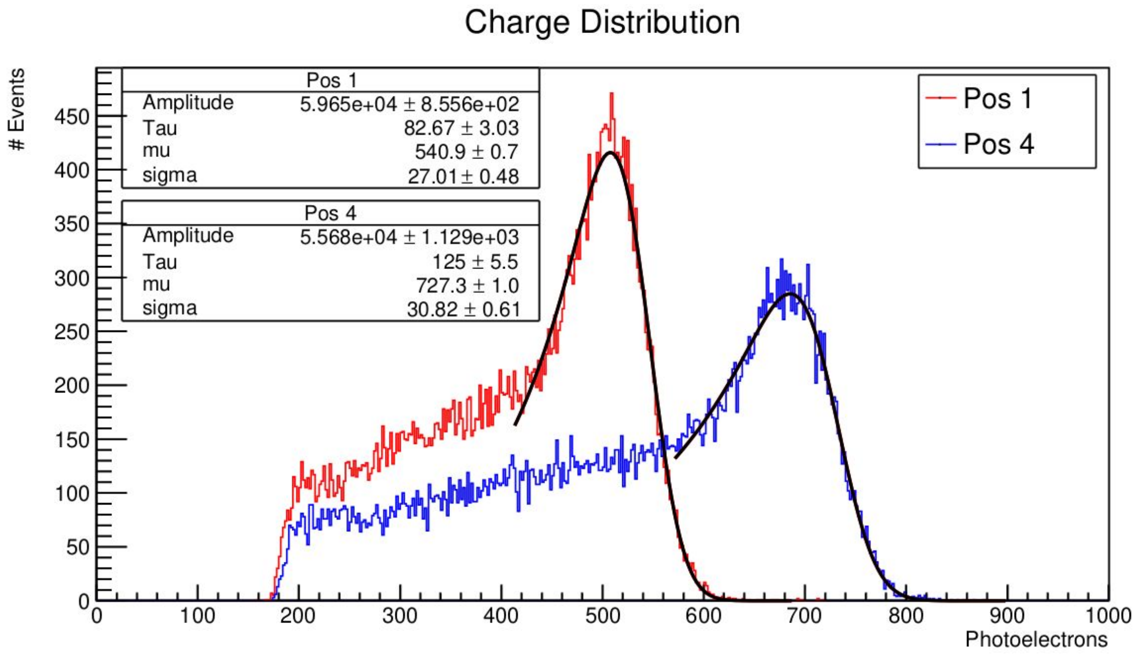
3. Source at the topmost position (~49 cm from the flange) and ~ out of LAr:
   - one **μ run** (10^4 x 4 events; 20 μs, 5 μs pretrigger)
   - one **s.ph.e. run** (10^4 x 8 events; 20 μs length; 1.6 μs pretrigger)

Source-to-dichroic filter distance: (55 +/- 1) mm.

What we updated

- Corrected the evaluation of the source position
- Improved evaluation of statistical errors
- New analysis of F_{int} and LAr purity correction using a new template
- Introduction of a systematic error for the non-uniformity of the PDE

Fit of alpha spectra: an example



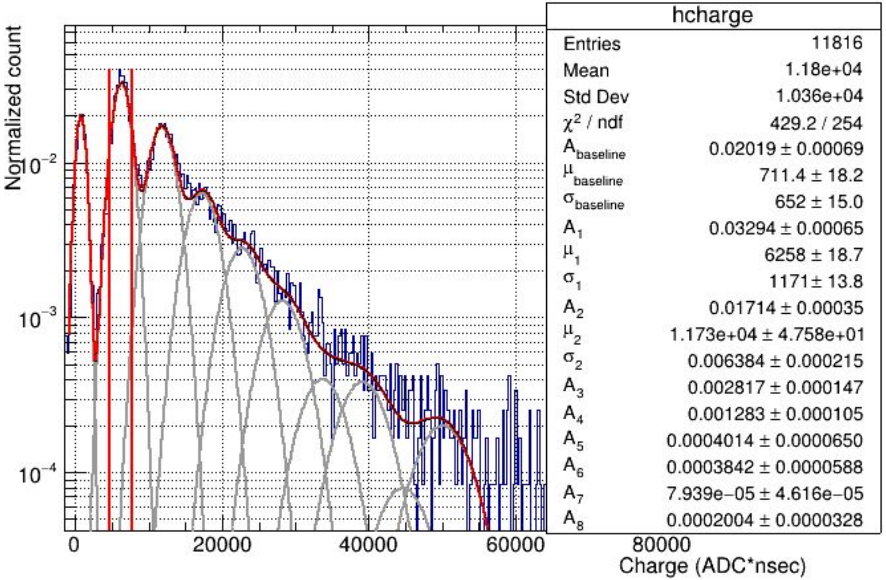
pos.1: σ/μ = 4.9 %

pos.4: σ/μ = 4.2 %

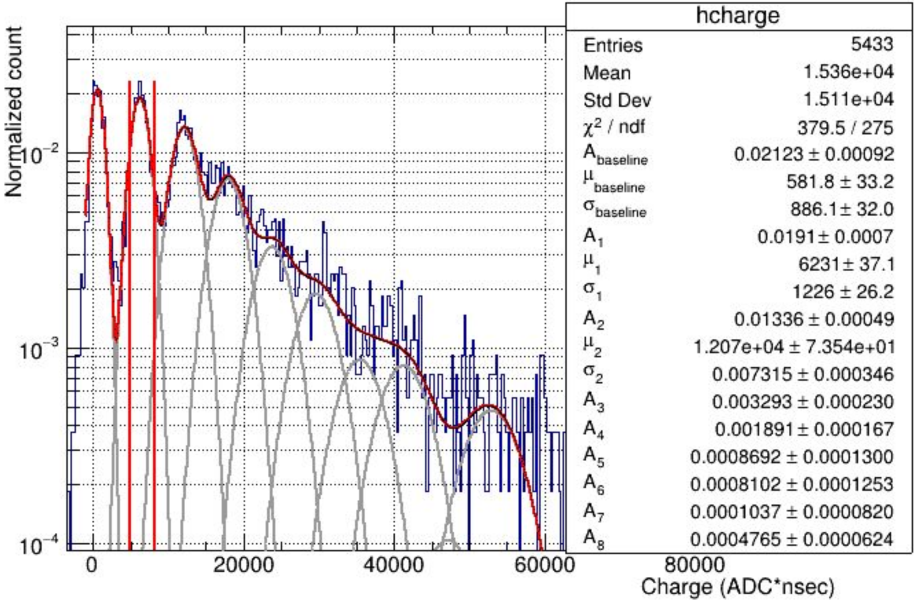
SC equipped with FBK & G2P

Single Photoelectrons spectrum

HPK S/N = 4.7



FBK S/N = 4.1



Solid angle evaluation

- Analytically computed as the solid angle of a pyramid with rectangular base (the SC):

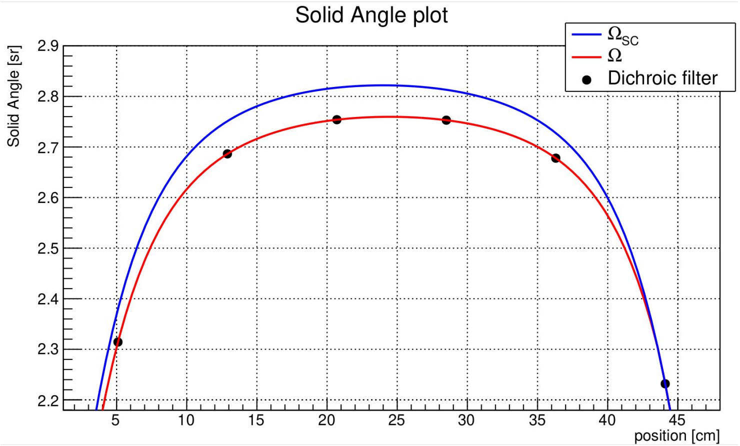
$$\Omega_{SC}(x) = 2\arctan\left(\frac{abh}{2R_1(x^2+h^2)+2R_2[x(x-b)+h^2]}\right) + 2\arctan\left(\frac{abh}{2R_1(x(x-b)+h^2)+2R_2[(x-b)^2+h^2]}\right)$$

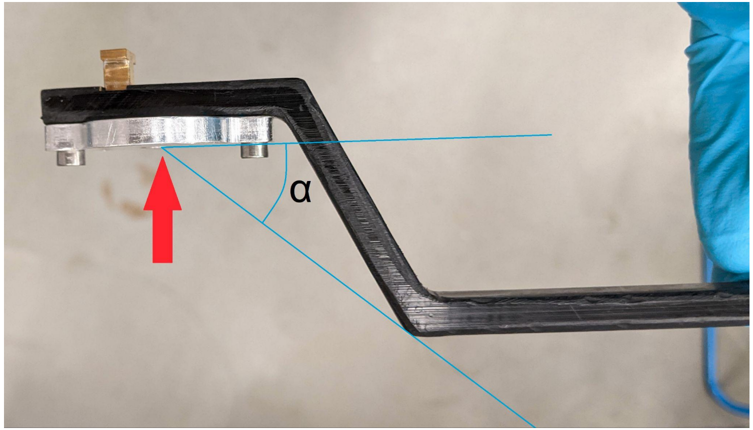
- The plastic frame that holds the alpha source shadow a fraction of the solid angle:

$$\Omega_s(x) = 2\arctan\left(\frac{wh(b-x-h\cot\alpha)}{2R_3[h\cot\alpha(b-x)+h^2]+2R_4[(h\cot\alpha)^2+h^2]}\right) + 2\arctan\left(\frac{wh(b-x-h\cot\alpha)}{2R_3[(b-x)^2+h^2]+2R_4[h\cot\alpha(b-x)+h^2]}\right)$$

- The total solid angle is:

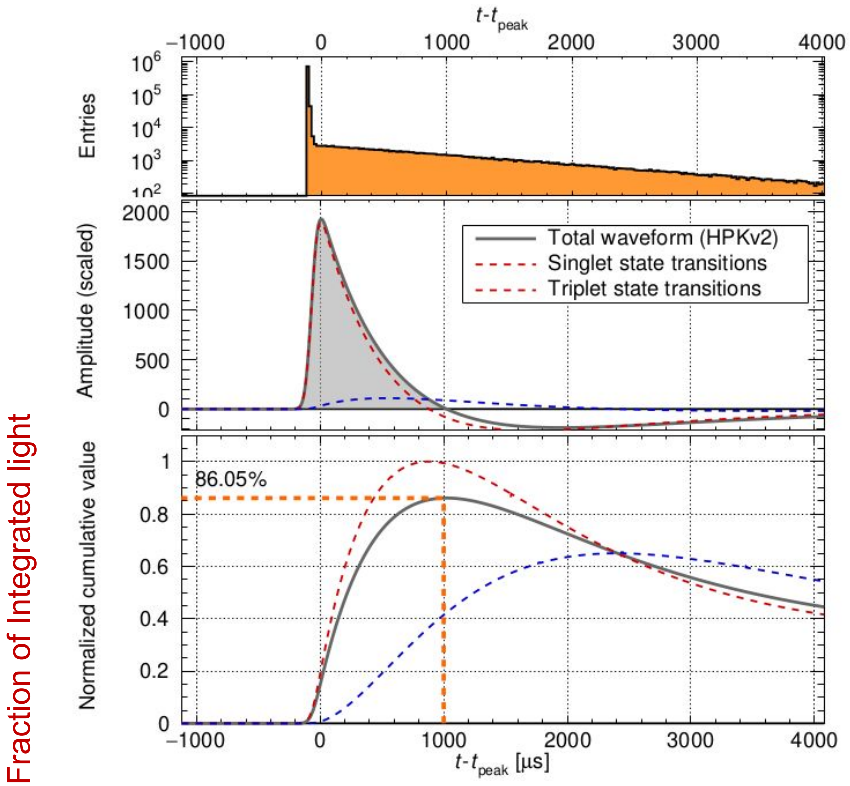
$$\Omega(x) = \begin{cases} \Omega_{SC}(x) - \Omega_s(x) & \text{if } x < b - h\cot\alpha \\ \Omega_{SC}(x) & \text{if } x \geq b - h\cot\alpha \end{cases}$$



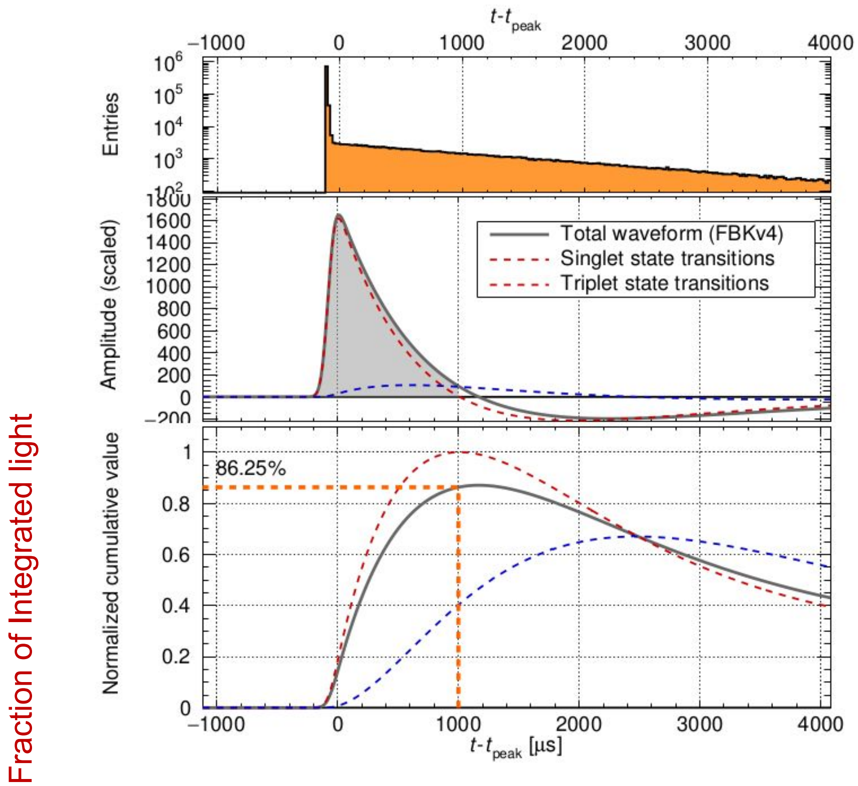


Fraction of integrated light

Synthetic wfms: SPHE ⊛ LAr profile (A_s=0.77; τ_s=7ns A_t=0.23; τ_t=1400 ns)

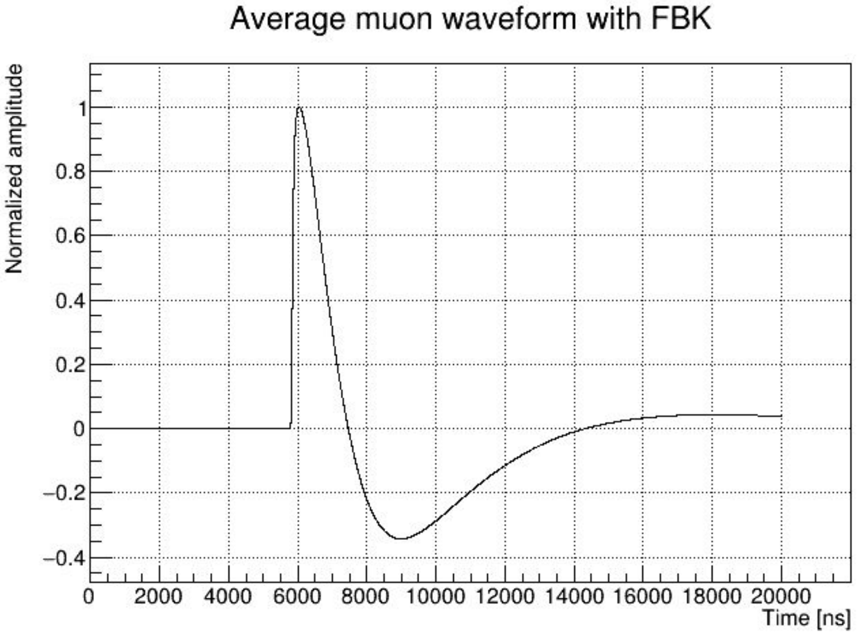


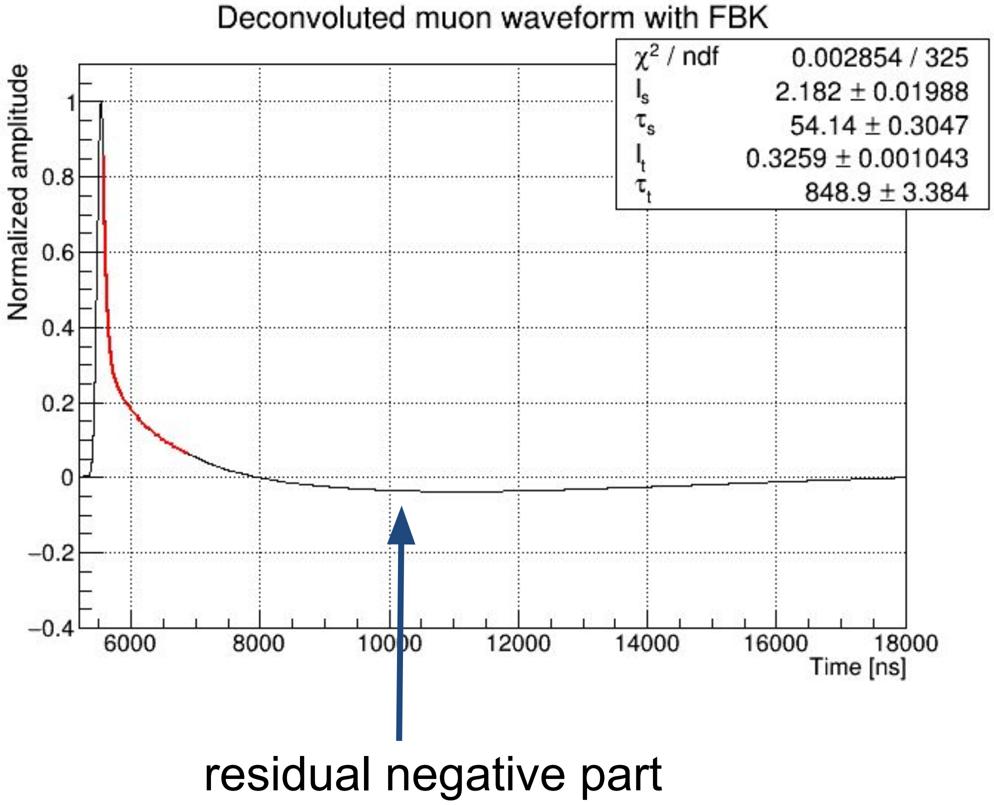
HPK SPHE wfm



FBK SPHE wfm

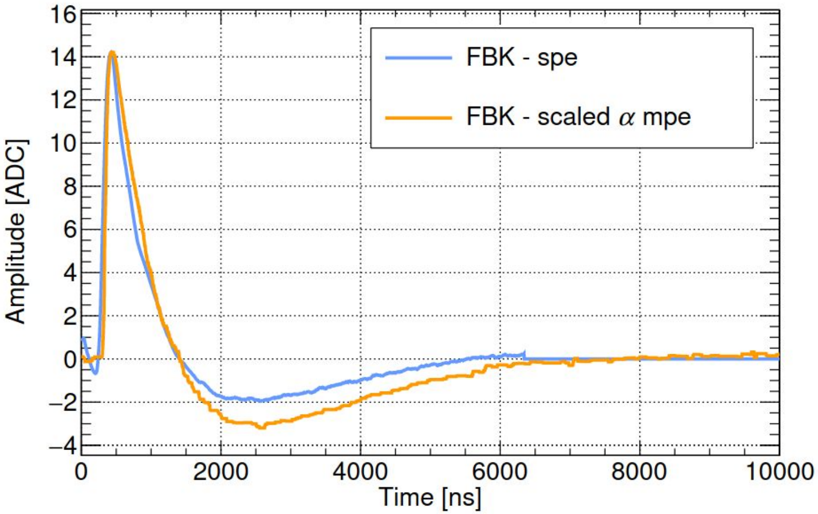
Previous deconvoluted muon waveform



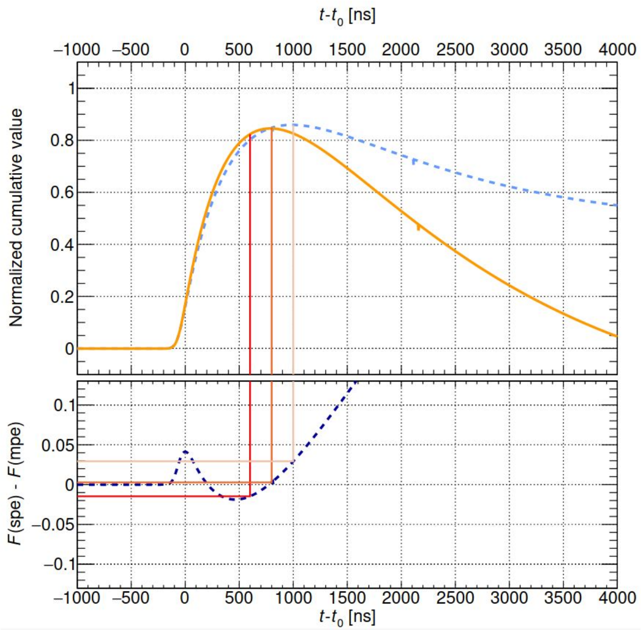


Multi-photoelectron template

- Since the deconvolution of the muon average waveform using the sphe mean waveform failed, we tried using a different "template"
- Selected an alpha event with few photoelectrons (~70pe), with a high F_{prompt} (F_{prompt} > 0.9) and normalized its amplitude
- Used this new template for the determination of F_{int} and the LAr purity correction

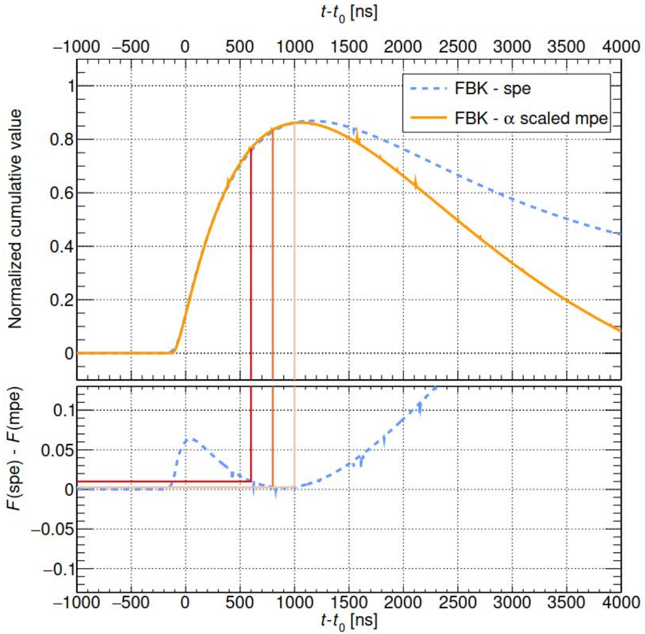


Mpe F_{int} evaluation



HPK

~3% difference from spe template

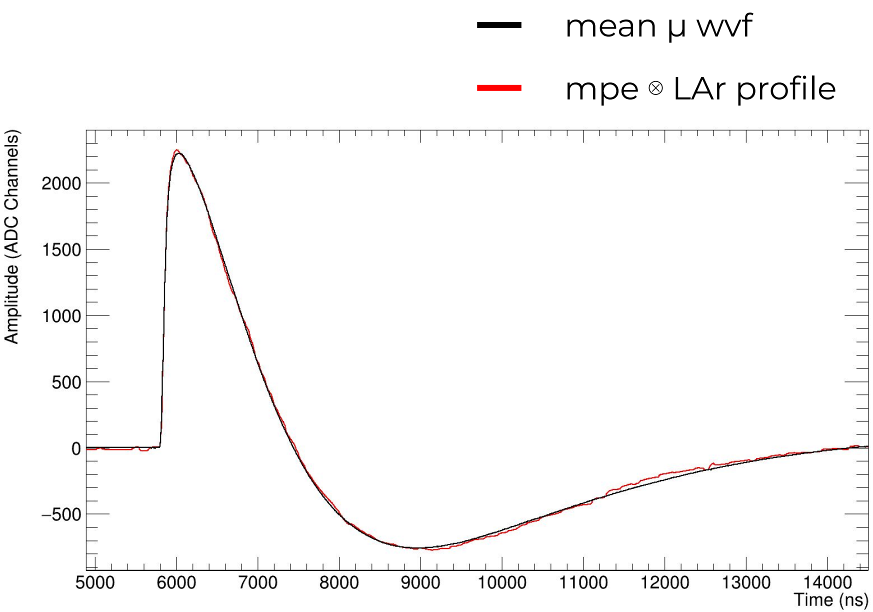


FBK

< 1% difference from spe template

Mpe muon convolution

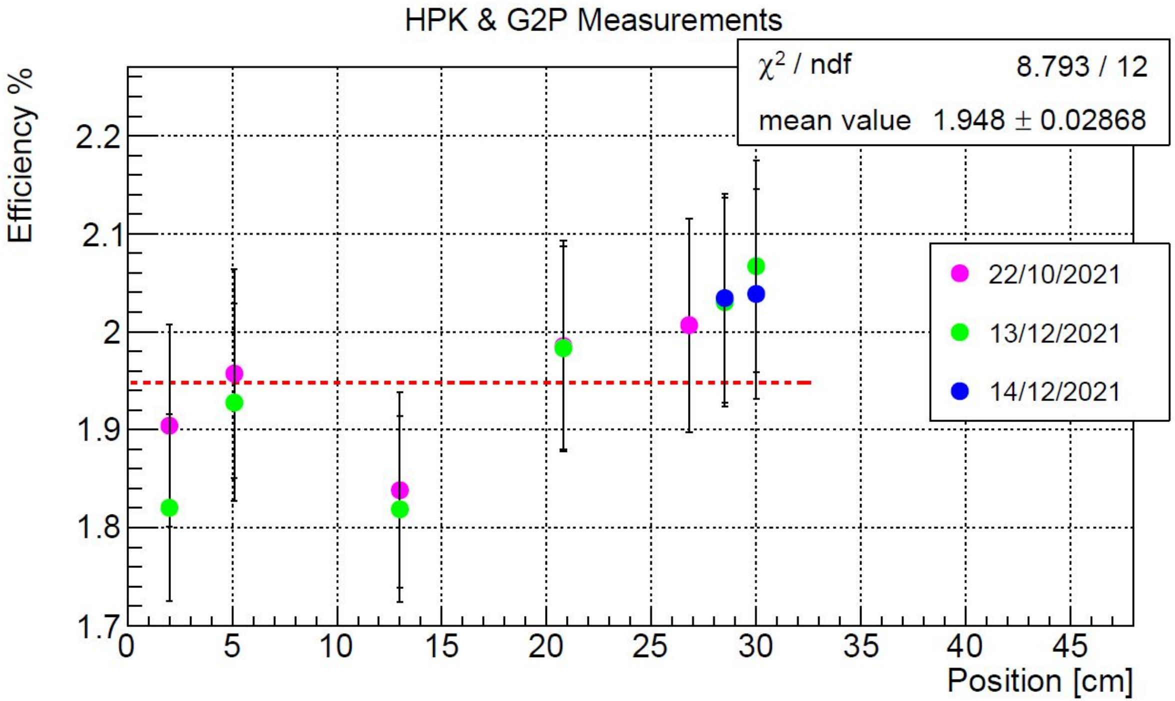
- Convolution of the mpe template with LAr scintillation profile
- Fit the function with the average muon waveform and extract τ_T
- Achieved a good fit and a reliable value of τ_T
- We did it only for the FBK&G2P data



τ_T = 1069 ns

Efficiency results: HPK & G2P

$$\epsilon = \frac{4\pi \cdot \alpha\ \text{peak(ADC)}}{\text{s.ph.e.(ADC)} \cdot f_{int} \cdot \text{LY}_{\text{LAr}} \cdot \text{En}_\alpha \cdot \text{q}_\alpha \cdot \Omega}$$



LY_{LAr} = 5.0 E+4
q_α = 0.7
En_α = 5.480 MeV
f_{int} = 0.862

No X-talk and LAr purity corrections

Efficiency results: FBK & G2P

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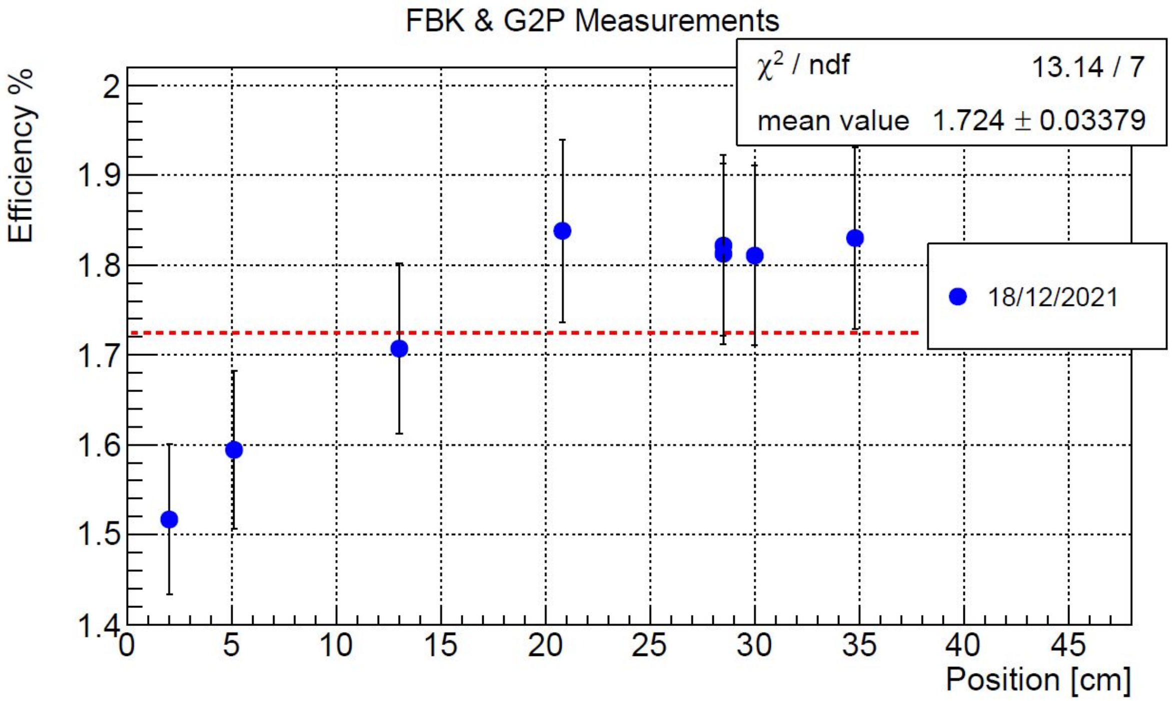
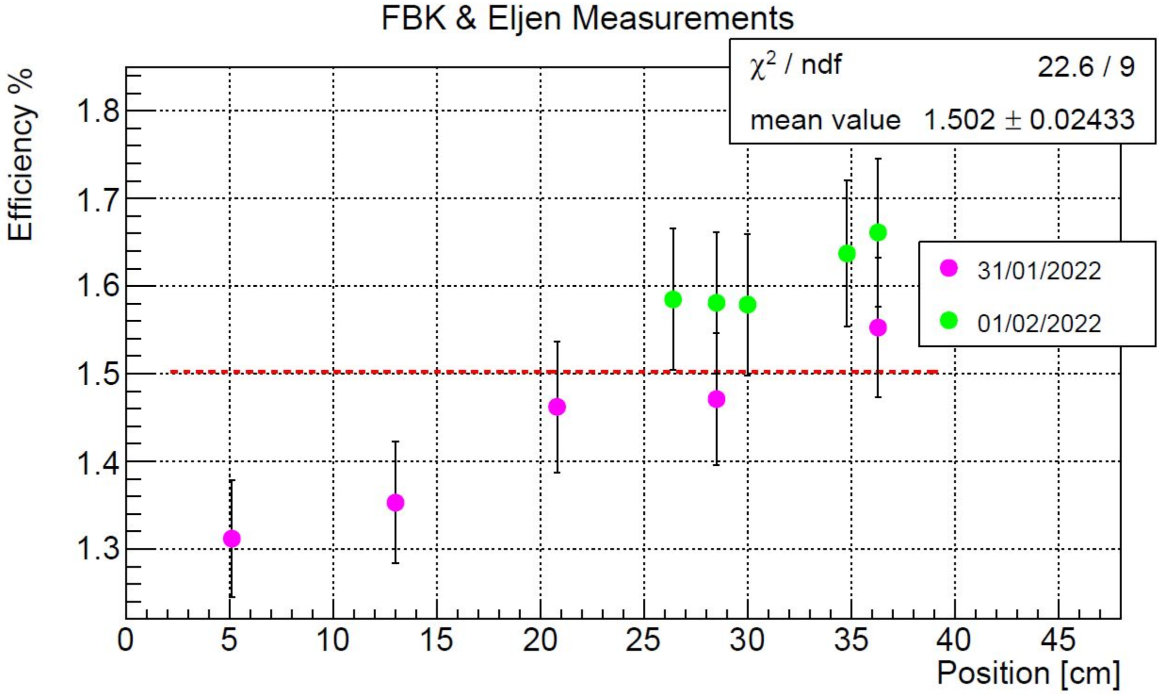


LY_{LAr} = 5.0 E+4
q_α = 0.7
En_α = 5.480 MeV
f_{int} = 0.86

No X-talk and LAr purity corrections

Efficiency results: FBK & Eljen

$$\epsilon = \frac{4\pi \cdot \alpha \text{ peak(ADC)}}{\text{s.ph.e.(ADC)} \cdot f_{int} \cdot \text{LY}_{\text{LAr}} \cdot \text{En}_{\alpha} \cdot \text{q}_{\alpha} \cdot \Omega}$$



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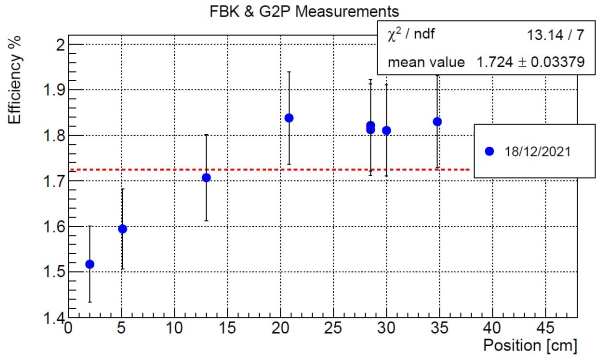
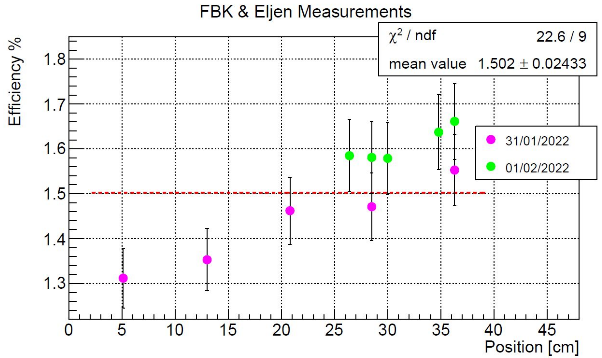
Systematic uncertainty

- Lowest positions (x < 15cm) with FBK show a worse PDE
  - May be caused by one (or more) SiPM board with a higher V_{bkd} or by dichroic filters with worse performances in the lowest positions
  - Systematic error as the difference between the average PDE with all position ε_{all} and average PDE with higher positions (x>15cm) ε_c





Efficiency: X-talk and P_{LAr} corrections

		OV	PDE	Uncorrected ε_{XA}	Measured Xtalk	P_{LAr}	Position systematic	Corrected $\varepsilon_{XA\ x\ talk\ only}$	Corrected $\varepsilon_{XA\ x\ talk\ and\ P\_LAr}$
this work	HPK** & G2P	3.0V	50%	1.94 (0.03)	6.62%	TBD	0.08	1.82 (0.08)	
	FBK*** & G2P	4.5V	45%	1.72 (0.03)	15.7%	1.06	0.10	1.49 (0.10)	1.58 (0.10)
	FBK*** & Eljen	4.5V	45%	1.50 (0.02)	15.7%	TBD	0.06	1.29 (0.07)	
JINST work	HPK commercial*	2.7V	45%	3.5 (0.1)	22%			2.9 (0.1)	

* S14160-6050HS (6 × 6) mm^2, 50 μm
** 75um-HQR
*** Triple Trench

$$P_{\mathrm{LAr}} = \left(0.77 + 0.23 \times \frac{\tau_T}{1414\ \mathrm{ns}}\right)^{-1}$$

Conclusions

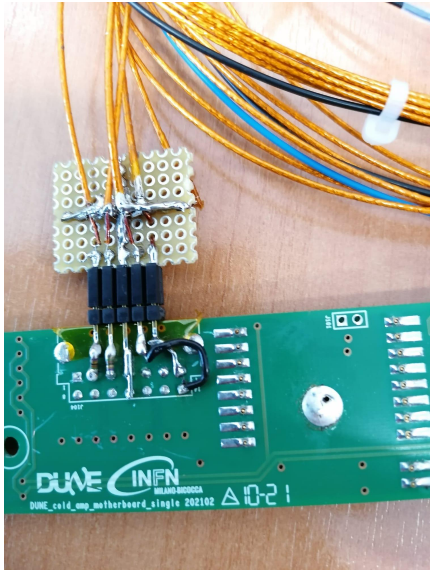
- A non-linearity of the system response affected the determination of τ_T
    - Using a new mpe template we achieved a reliable better estimation of τ_T and the LAr purity correction
    - We also re-computed F_{int} showing a significant difference in the HPK data
- We observed a non-uniformity in the PDE along the SC dimension
    - There are several effects that may cause a disuniformity in the SC PDE (different V_{bkd} , dichroic filters, gap between SiPMs and WLS bar…)
    - The “real” PDE of the SC average all those effects

Backup

Features of the XA HD Supercell under tests

Size/type of the WLS slab Dichoics (sipm/WLS) area	**G2P** 480 x 93 mm^2, NO Vikuiti on short edges 6 x dichroics (Opto-Campinas) 3.9%
SIPMs	HPK DUNE-75um-HQR, +3V OV (50% PDE) FBK TT, +4.5V OV (45% PDE)
Ganging	x 48 SiPMs by MiB cold Amplifier
# electronic channels	1
SiPMs -Cold Amp. Cold Amp dyn. range	AC 2000 ph.e.
s.ph.e. (50 Ω, 45 V)	~ 2.0 mV on 50 Ω for both HPK and FBK
Chamber volume	~ 10 l
Digitizer	CAEN 14-bit 250 MS/sec, 4 ns/sample

Hardware



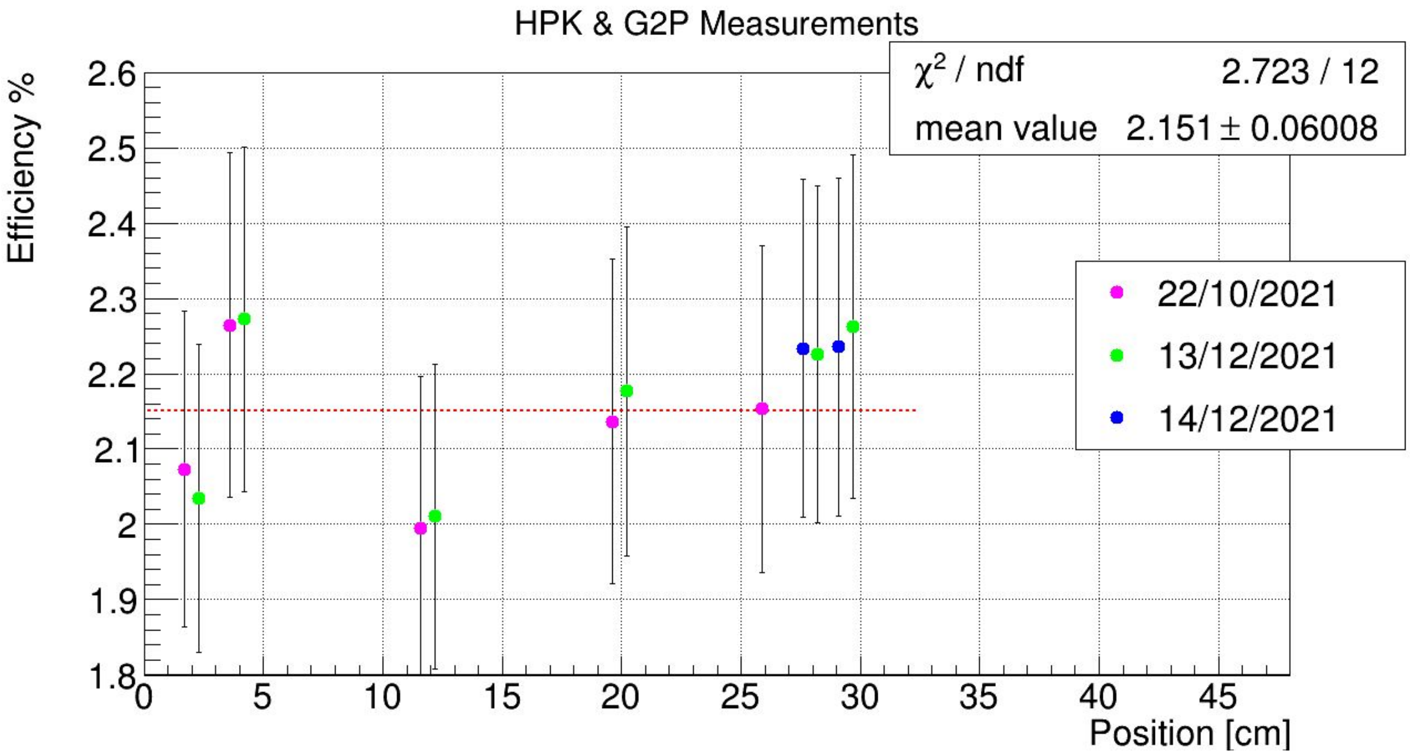
- Cold cables: a bundle of five Kapton RG178 coaxial cables. No DUNE blue cable & Hirose connector due to mechanical (dimension, stiffness) constraints of the setup

- Warm cables: 2.5 m, 50 Ω LEMO cables

- Cold-to-warm flange: 10 contacts vacuum/pressure connector mounted on a CF40 flange - No Hirose:
  - **the chamber and its payload are pumped down to 10^{-4} mbar prior filling →**
  - **high LAr purity achieved with high reproducibility**
  - **the purity is maintained w.o. any recirculation along several days from filling**

Efficiency: Updated results
HPK & G2P

$$\epsilon = \frac{4\pi \cdot \alpha \text{ peak(ADC)}}{\text{s.ph.e.(ADC)} \cdot f_{int} \cdot \text{LY}_{\text{LAr}} \cdot \text{En}_\alpha \cdot \text{q}_\alpha \cdot \Omega}$$



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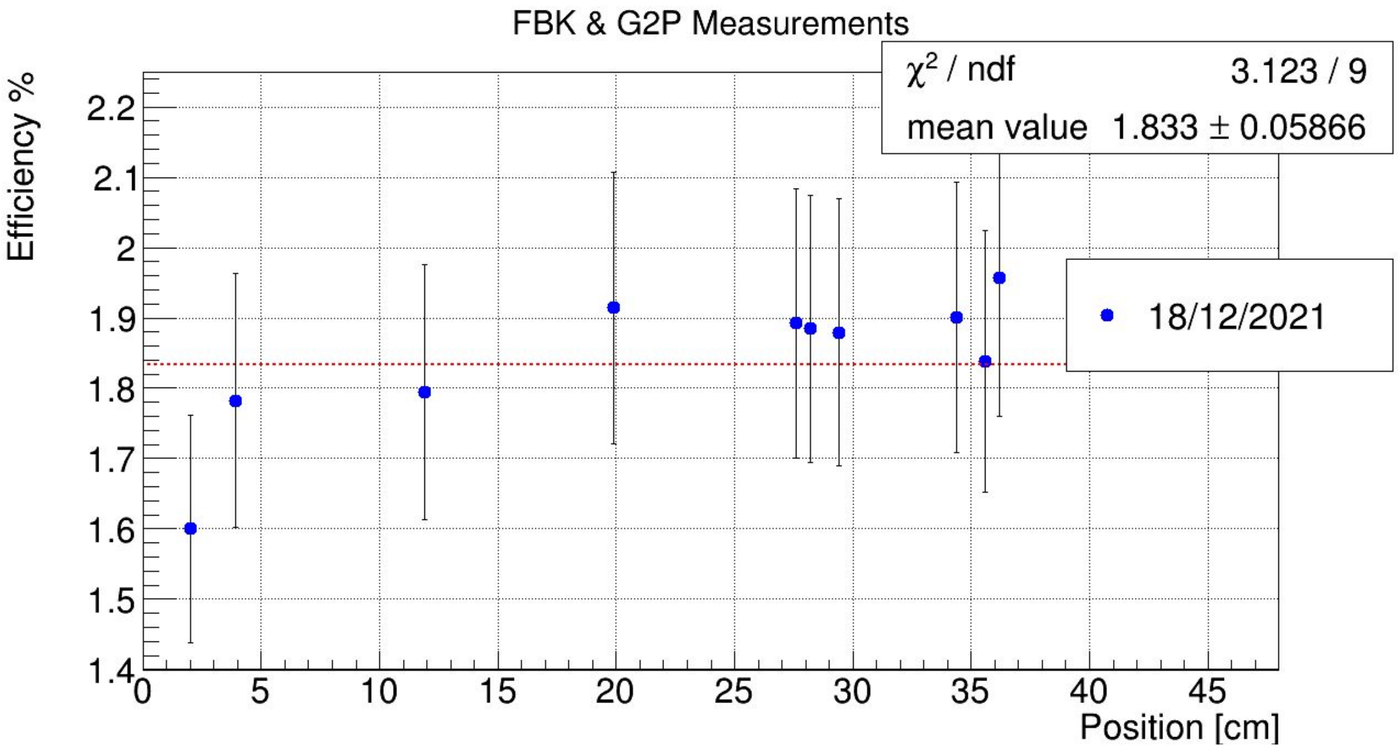

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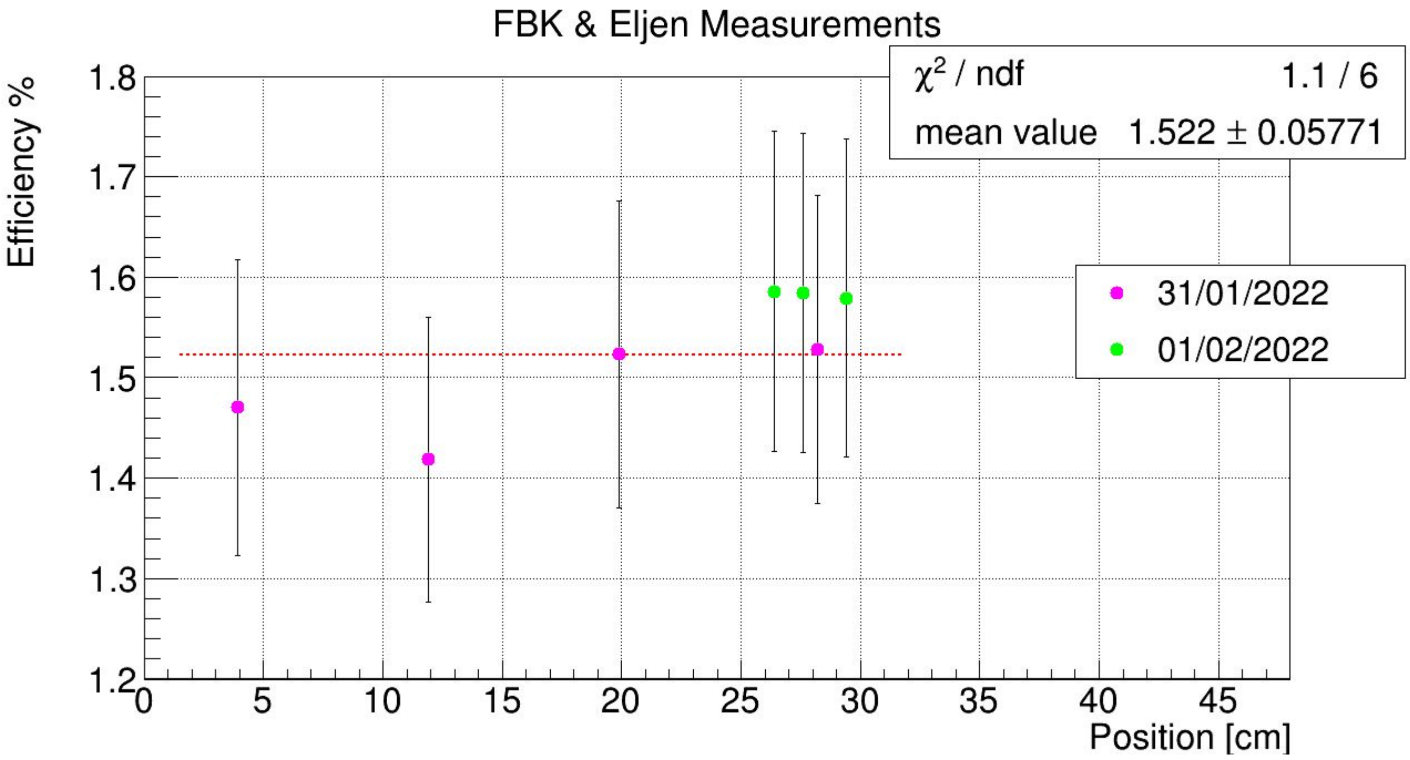

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