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

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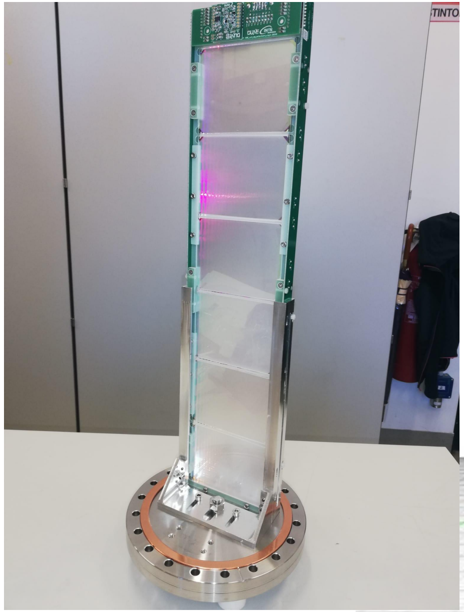
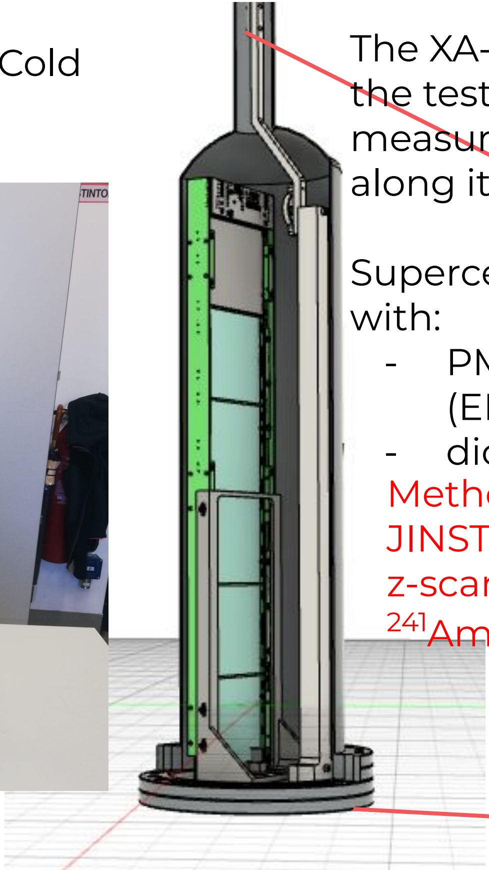
Setup to measure the XA-HD-SC PDE in LAr

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:

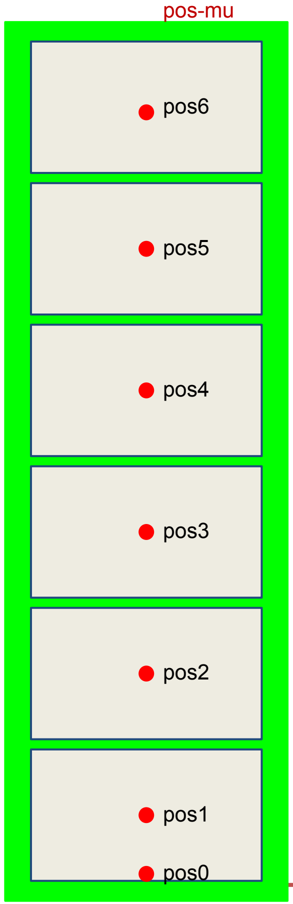
- PMMA WLS (ELJ&G2P)
- dichroic filters

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

What we updated:

- Fixed a bug in the code for the efficiency computation.
- Changed sphe integration interval:
  - this update:
    - HPK: from 120 ns before the peak to 800 ns after the peak;
    - FBK: from 170 ns before the peak to 800 ns after the peak;
  - first release: HPK & FBK: from 60 ns before the peak to 800 ns after the peak;
- Changed alpha wfm integration interval
  - this update: HPK & FBK: from 400 ns before the peak to 1000 ns after the peak;
  - first release: HPK & FBK: from 300 ns before the peak to 600 ns after the peak;
- New measurements of SC efficiency w. FBK & Eljen lightguide: New
- Resolution vs $\sqrt{N_{phe}}$: New
- gain of detector vs V_{OV}: New
- Muon wfm deconvolution: New
- muon analysis: New

Method & Data taking



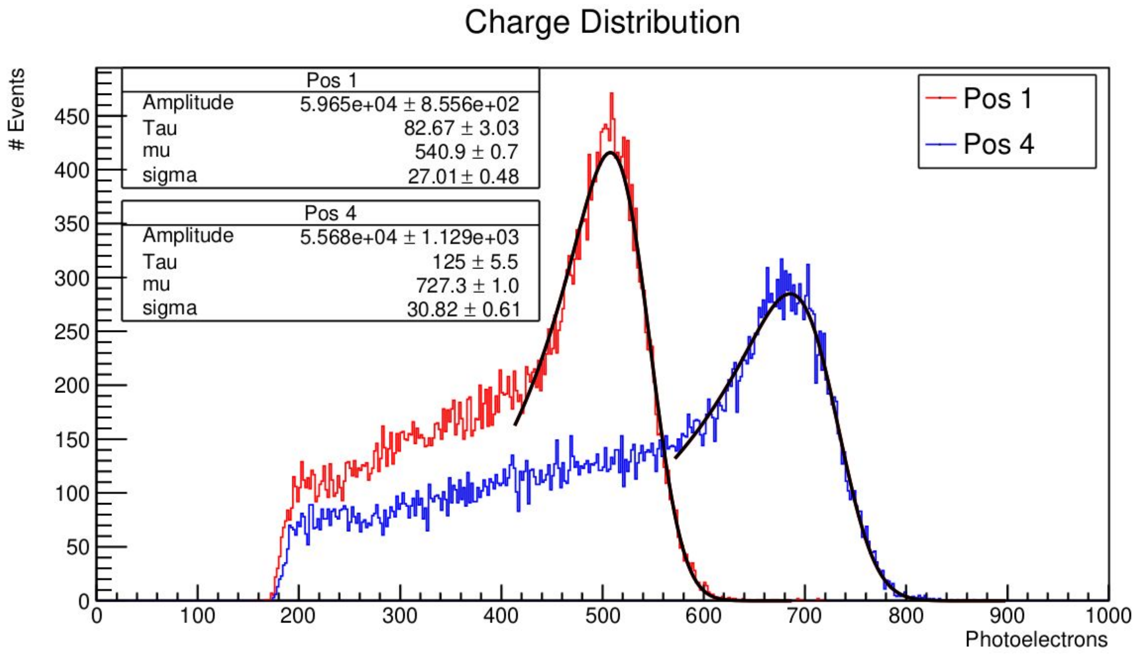
z-scanning of the SC with the ^{241}Am α (5.480 MeV) source at the following positions:

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.

Fit of alpha spectra: an example

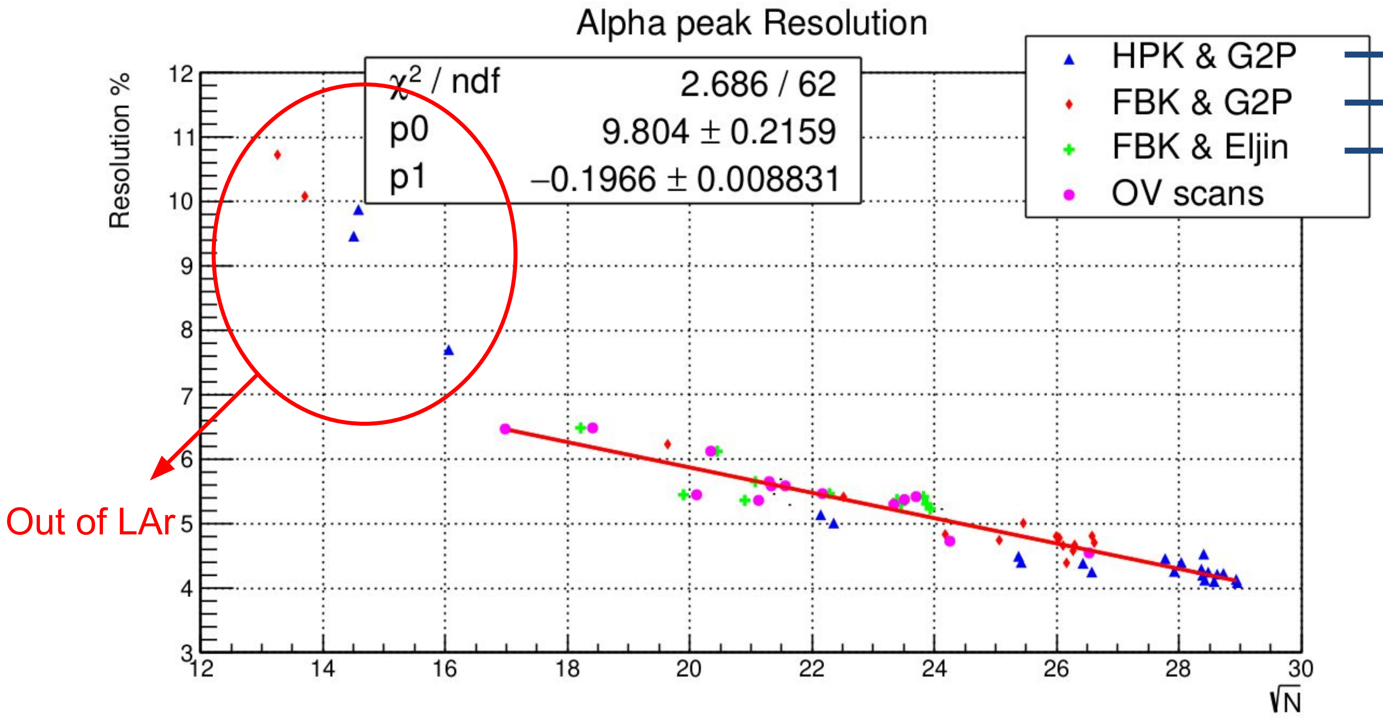


pos.1: σ/μ = 4.9 %

pos.4: σ/μ = 4.2 %

SC equipped with FBK & G2P

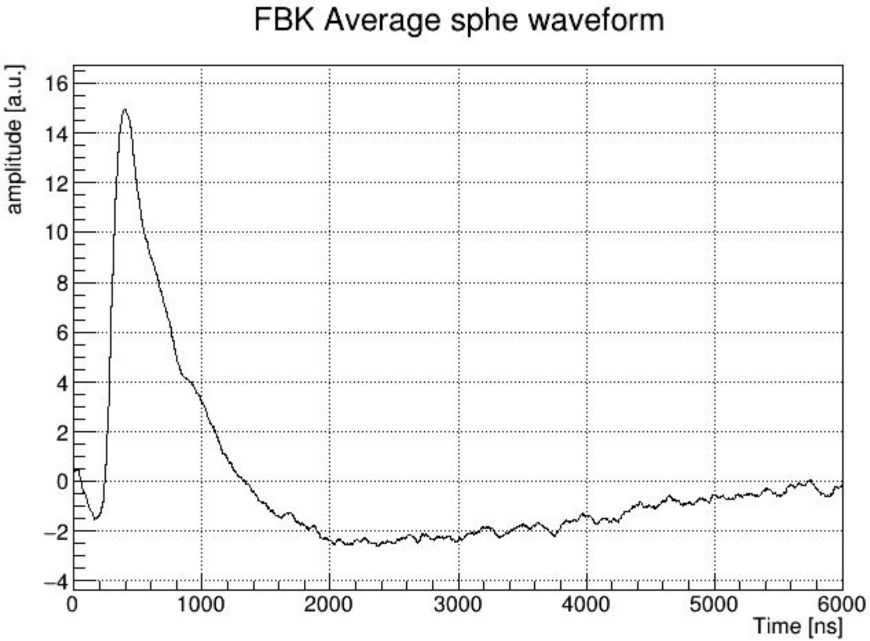
Resolution vs sqrt(n photoelectrons)

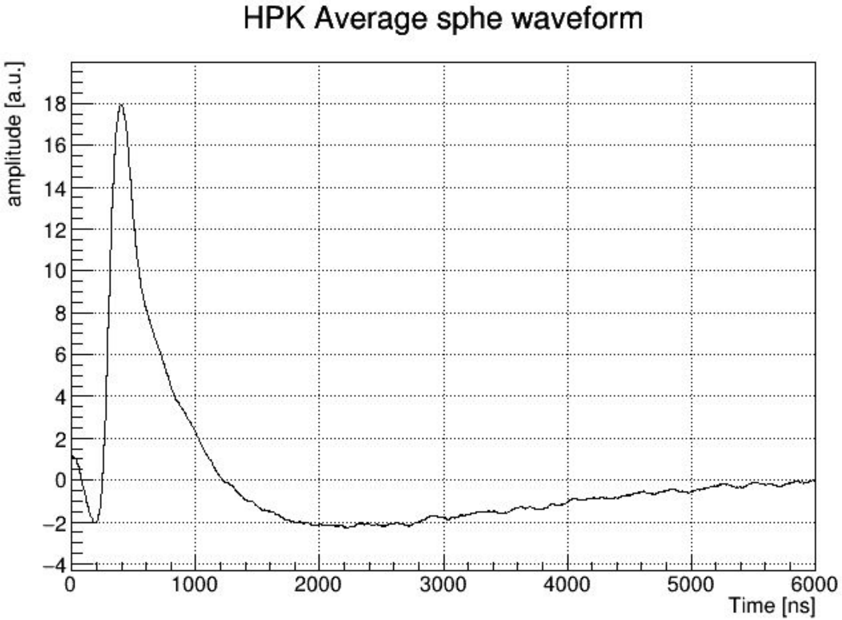


50% P.D.E.
45% P.D.E.
45% P.D.E.

Res = σ/μ

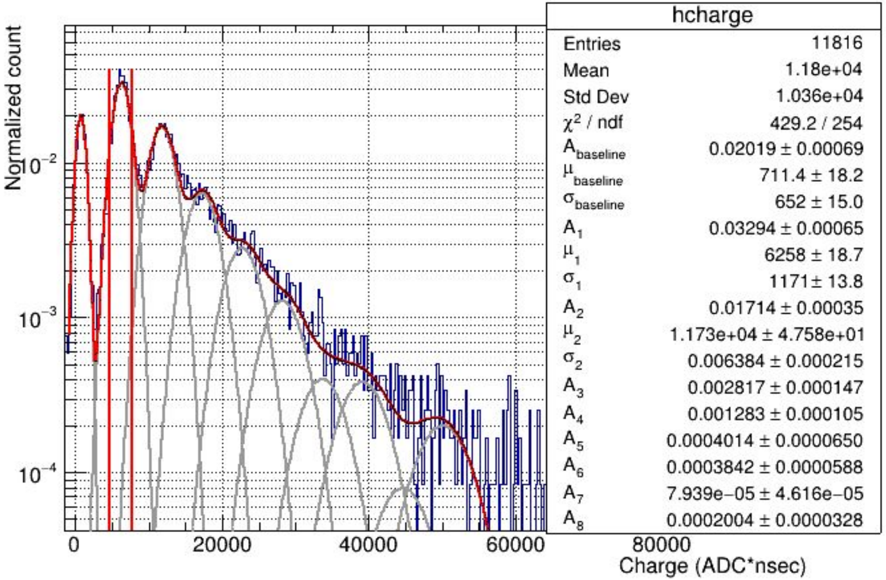
Single Photoelectrons mean waveform



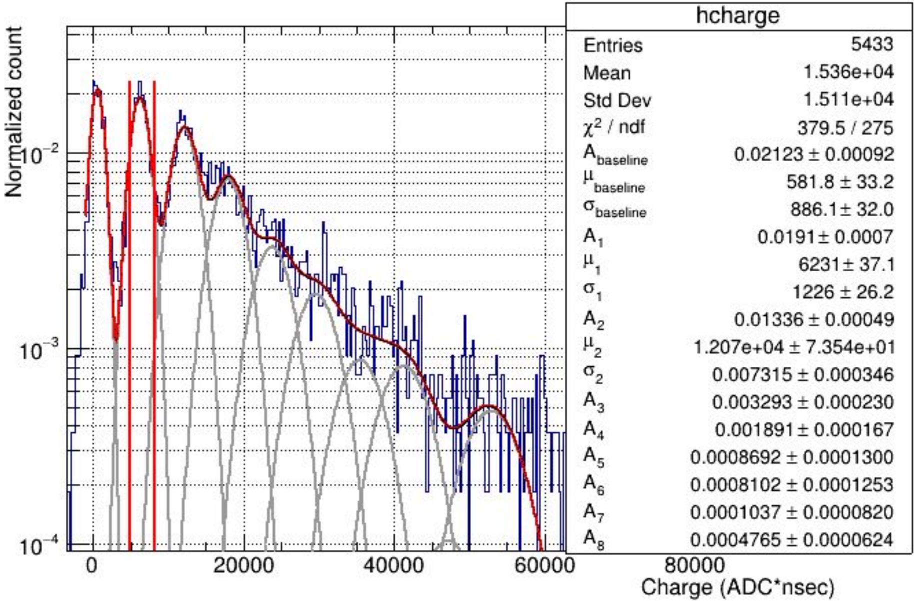


Single Photoelectrons spectrum

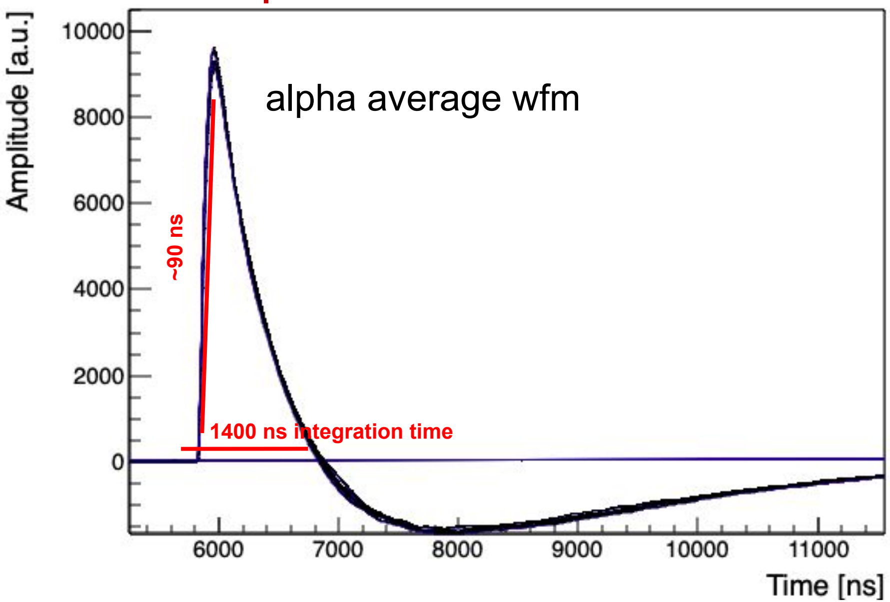
HPK S/N = 4.7



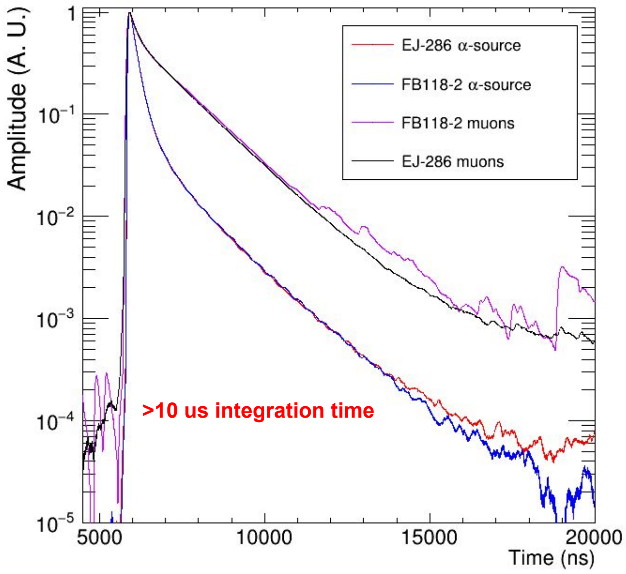
FBK S/N = 4.1



Pulse shape

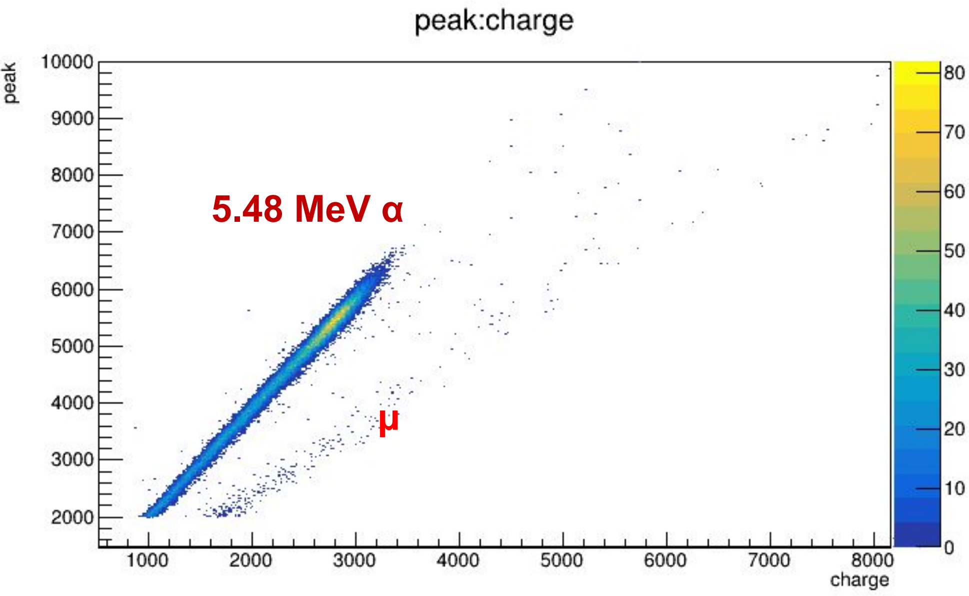


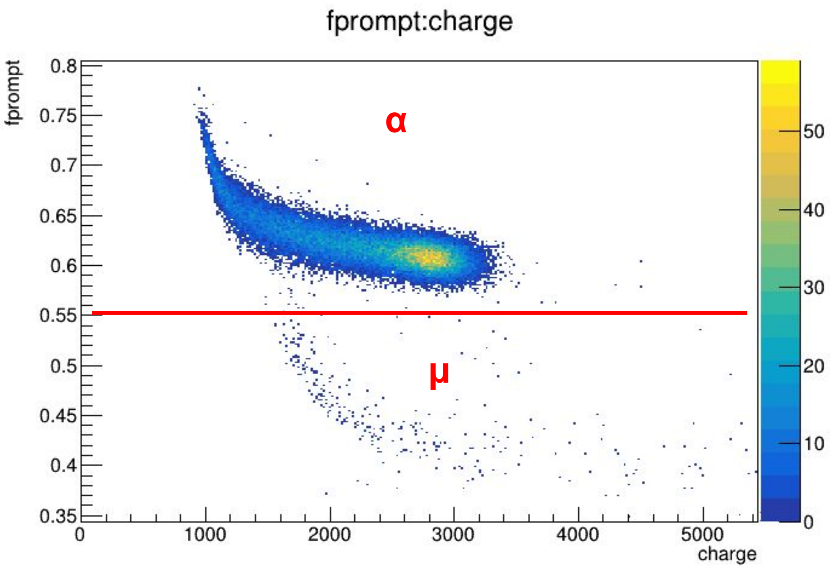
JINST ave. wfms



- The wfm shows a long undershoot due to 1) the SiPMs AC and 2) cold-to-warm stage couplings. Due to undershoot we implemented different analysis than in JINST work
- No s.ph.e. deconvolution: selection of long s.ph.e. pulses in our data not yet ready → Integrate for 900 nsec (600 ns from peak), to avoid the negative lobe
- Produce synthetic wfms by [LAr scnt. light time profile * s.ph.e. response function from SiPMs studies @ CIEMAT]
- Determine the integrated (within 900 ns) fraction of singlet/triplet light on the synthetic wfm

Linearity and F_{prompt}





F_{prompt} vs charge:
cut at 0.55

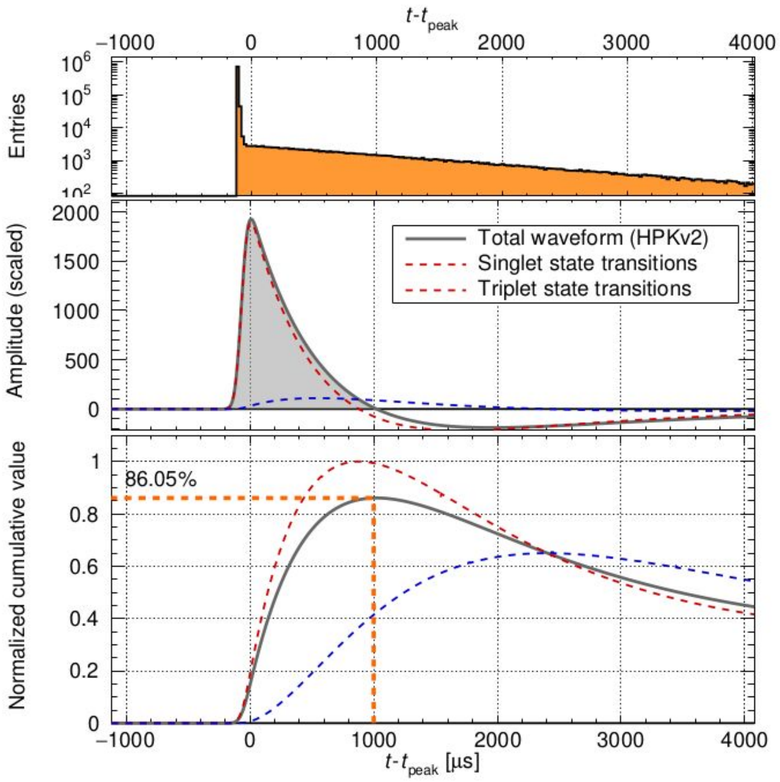
Linearity verified over > 1 decade

- **α vs μ discrimination well achievable by F_{prompt}**
- due to negative lobe in the present analysis **we are missing a large fraction of the slow component**

Fraction of integrated light

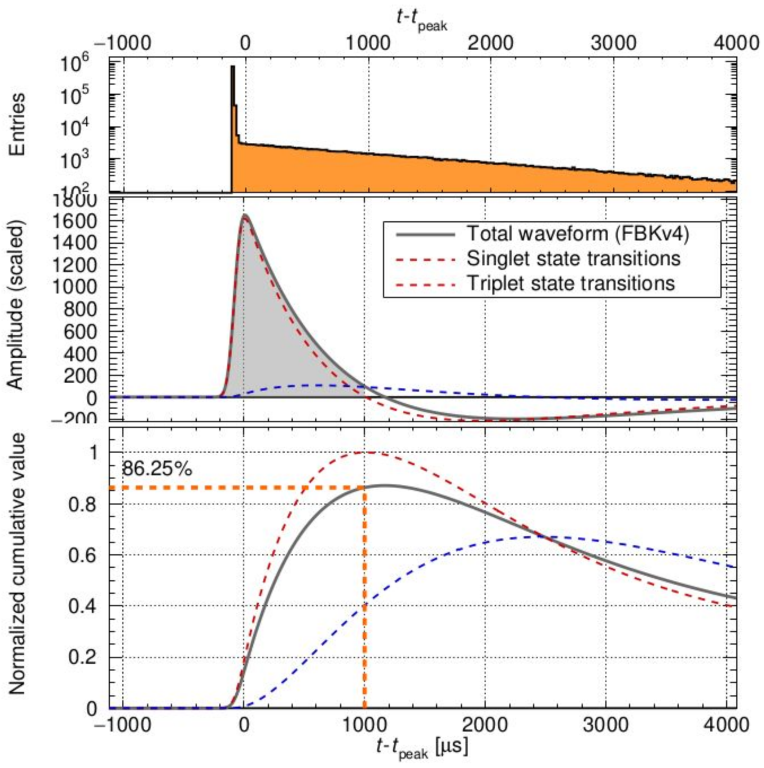
Synthetic wfms: SPHE ⊛ LAr profile (A_s=0.77; τ_s=7ns A_t=0.23; τ_t=1400 ns)

Fraction of Integrated light



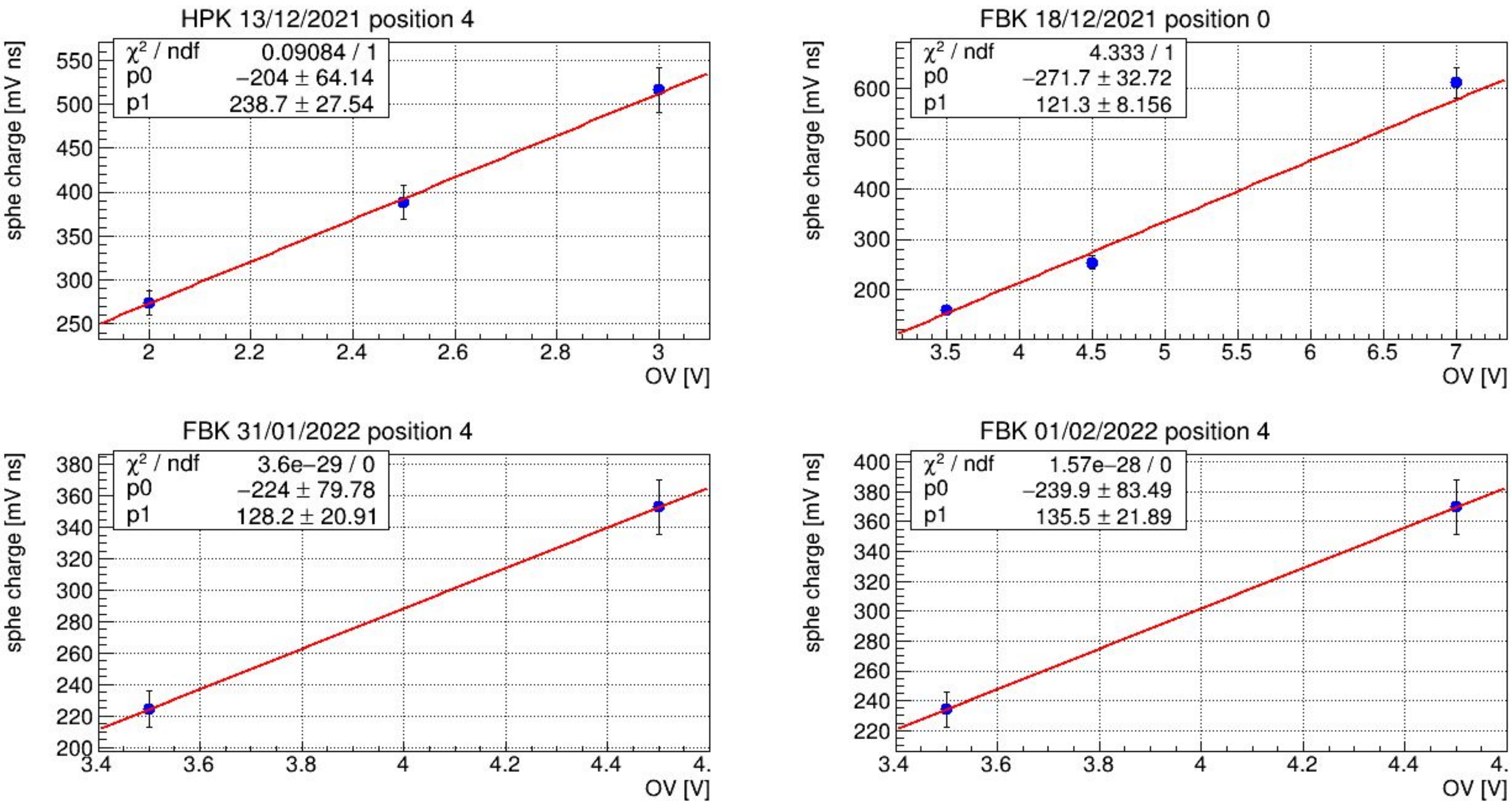
HPK SPHE wfm

Fraction of Integrated light

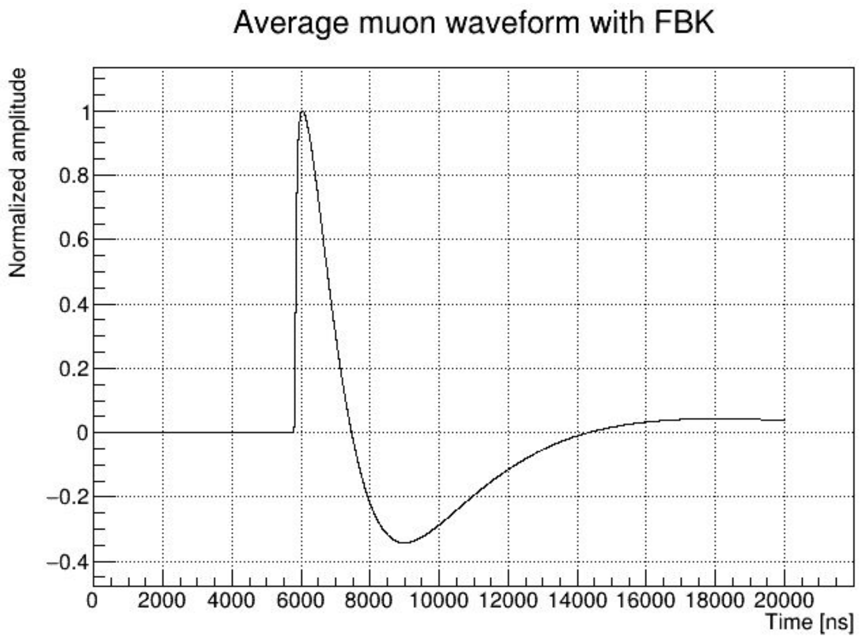


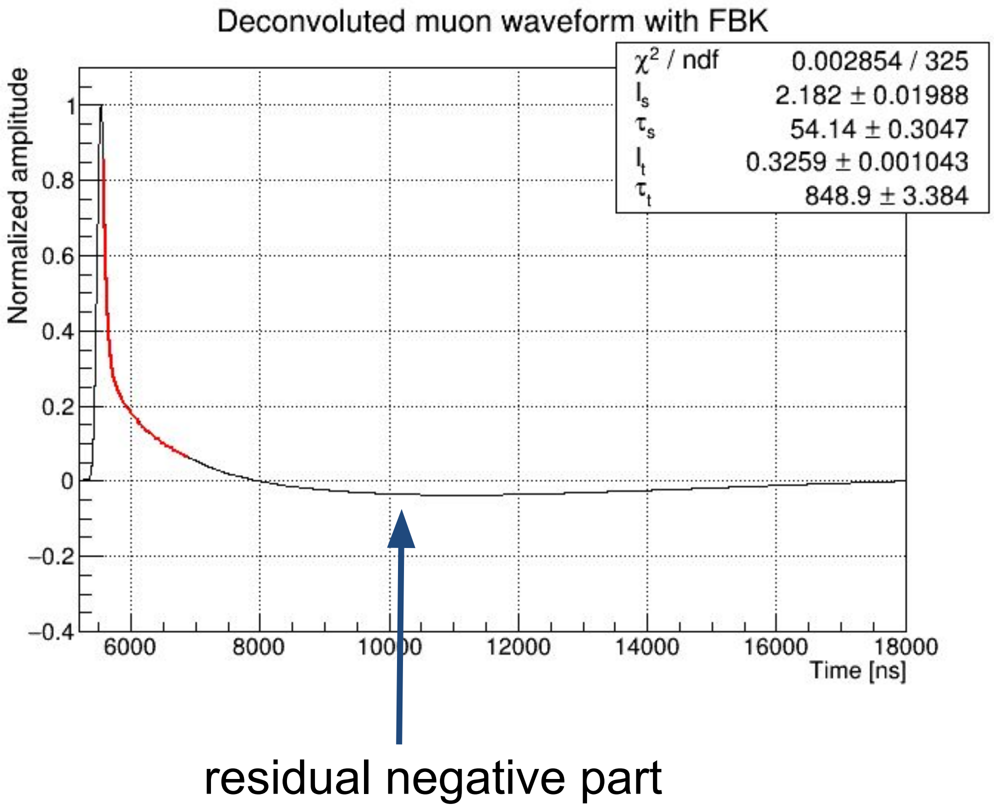
FBK SPHE wfm

Gain vs V_{OV}

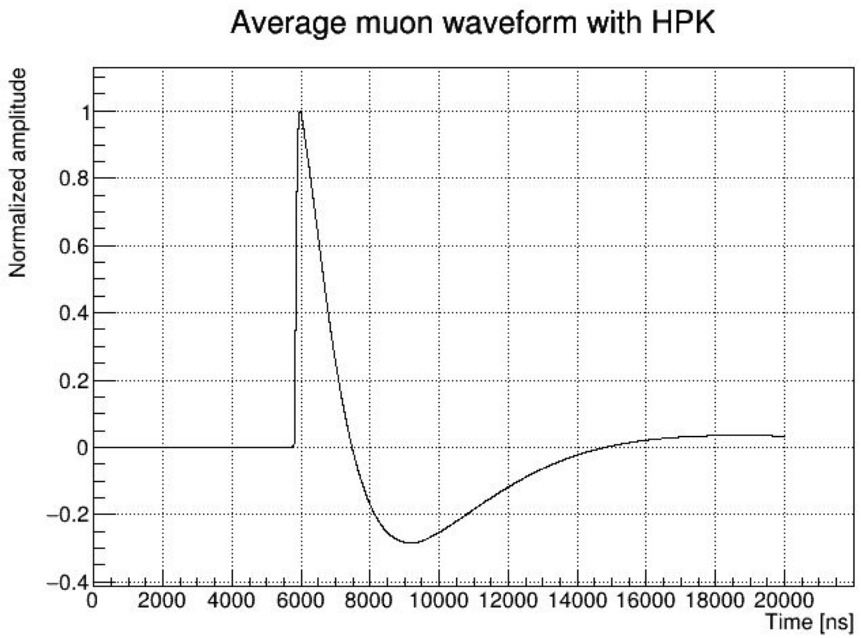

HPK 13/12/2021 position 4
χ² / ndf 0.09084 / 1
p0 −204 ± 64.14
p1 238.7 ± 27.54
sphe charge [mV ns]
OV [V]
FBK 18/12/2021 position 0
χ² / ndf 4.333 / 1
p0 −271.7 ± 32.72
p1 121.3 ± 8.156
sphe charge [mV ns]
OV [V]
FBK 31/01/2022 position 4
χ² / ndf 3.6e−29 / 0
p0 −224 ± 79.78
p1 128.2 ± 20.91
sphe charge [mV ns]
OV [V]
FBK 01/02/2022 position 4
χ² / ndf 1.57e−28 / 0
p0 −239.9 ± 83.49
p1 135.5 ± 21.89
sphe charge [mV ns]
OV [V]

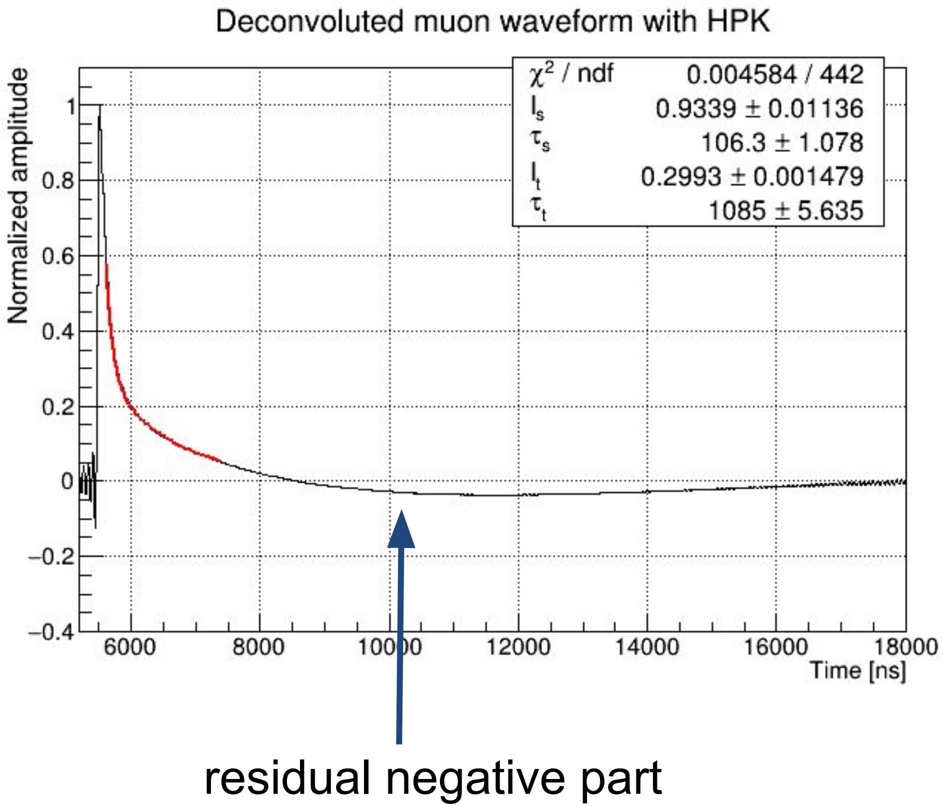
Deconvoluted muon waveform



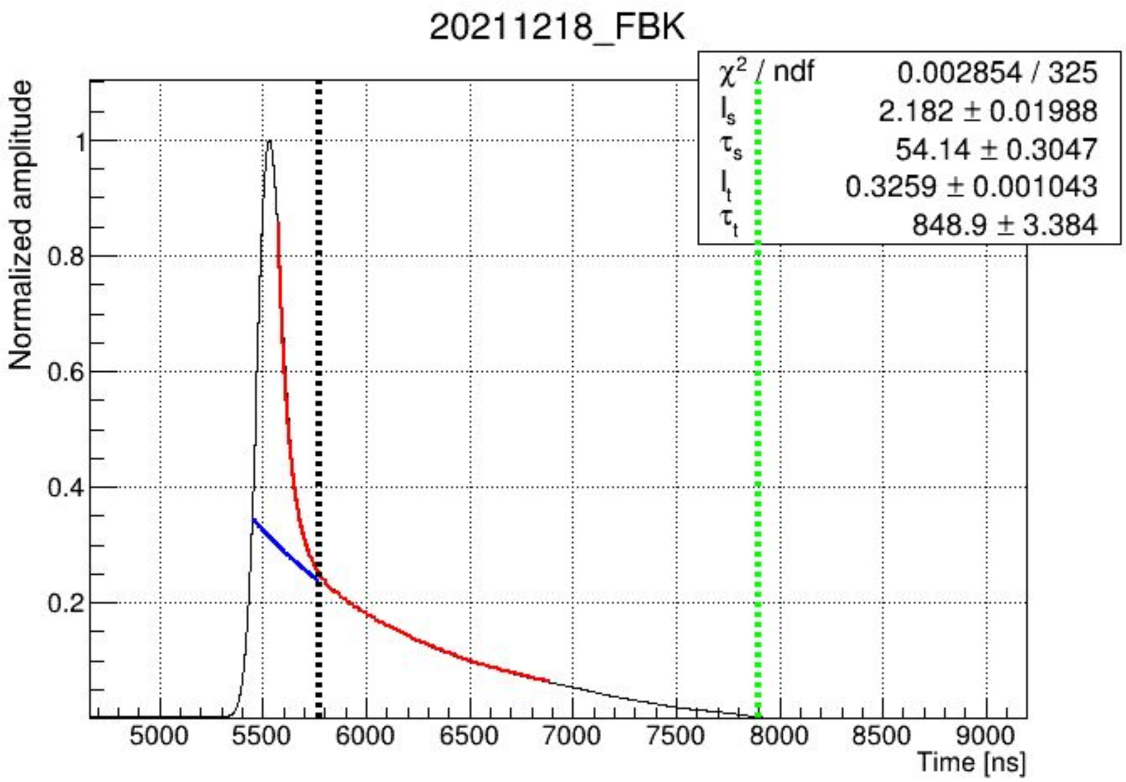


Deconvoluted muon waveform



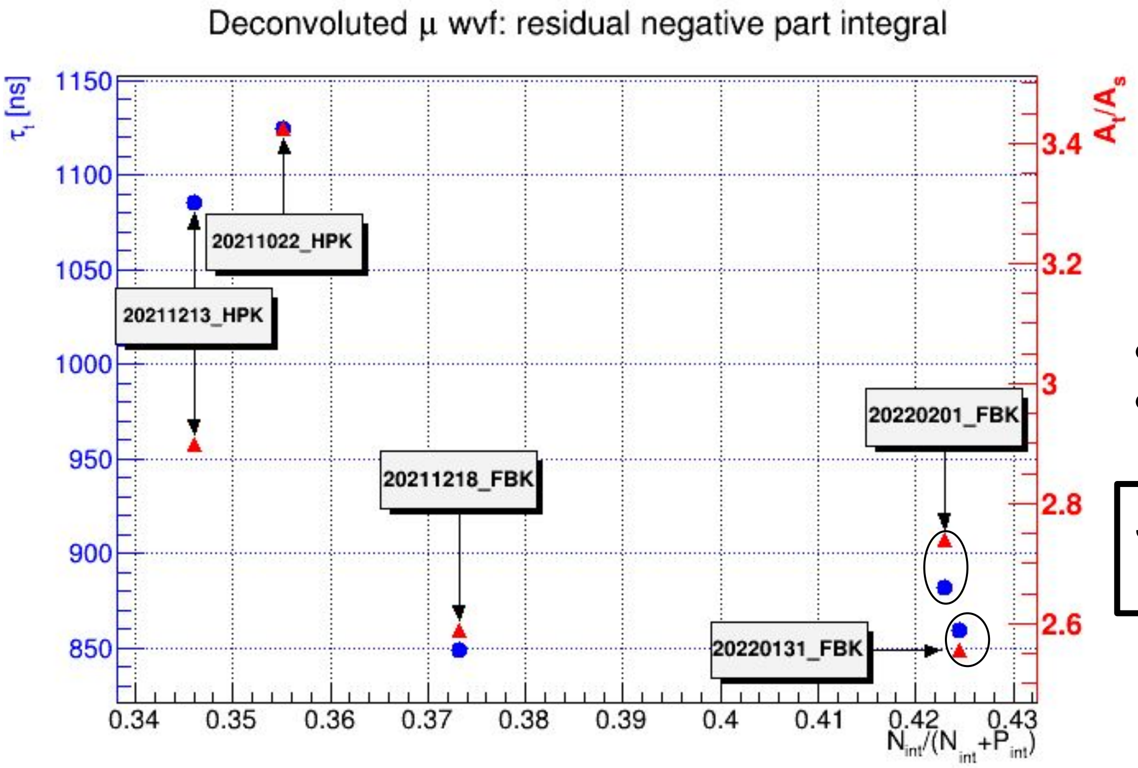


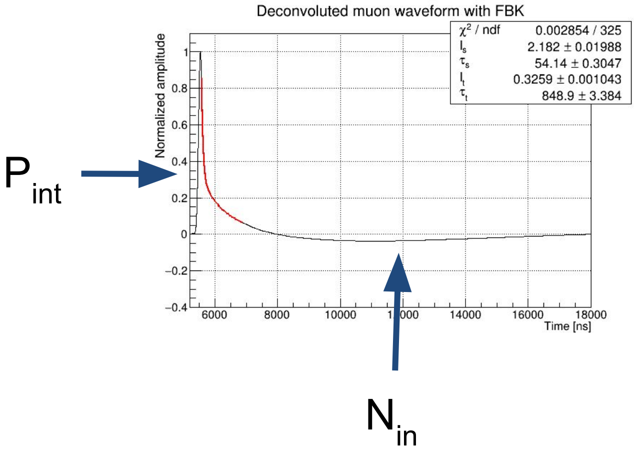
Numerical evaluation of A_t/A_s



- Fit does not well represent I_s
- Numerical integration of singlet+triplet component (black dashed line)
- Analytic evaluation of triplet component (blue line) to obtain A_s (singlet component integral)

Residual negative part integral





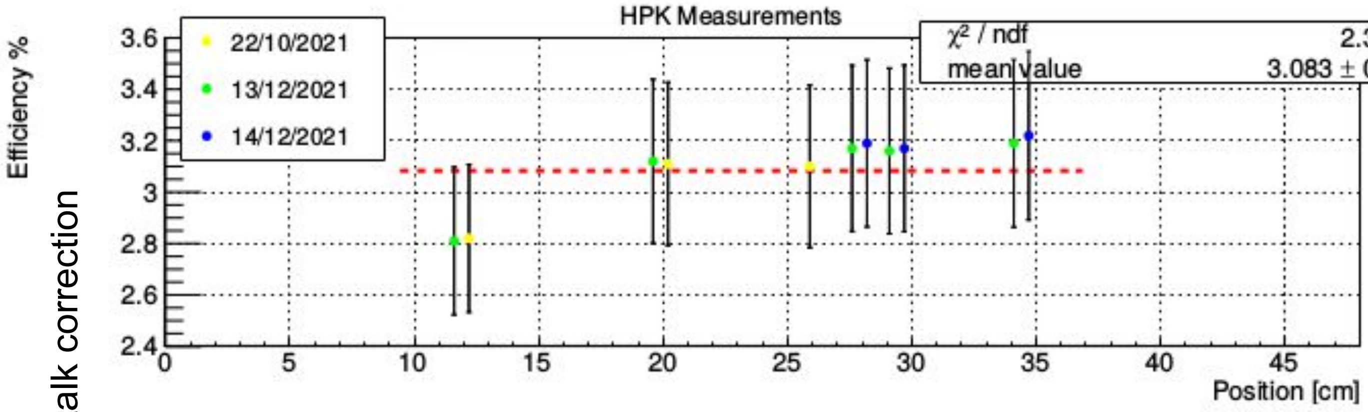
- Correlation between τ_t and A_t/A_s
- Dependence of N_{int} from SiPM type

JINST: $A_t/A_s = 3.45 \pm 0.36$
$\tau_t = 1414 \pm 21$ ns

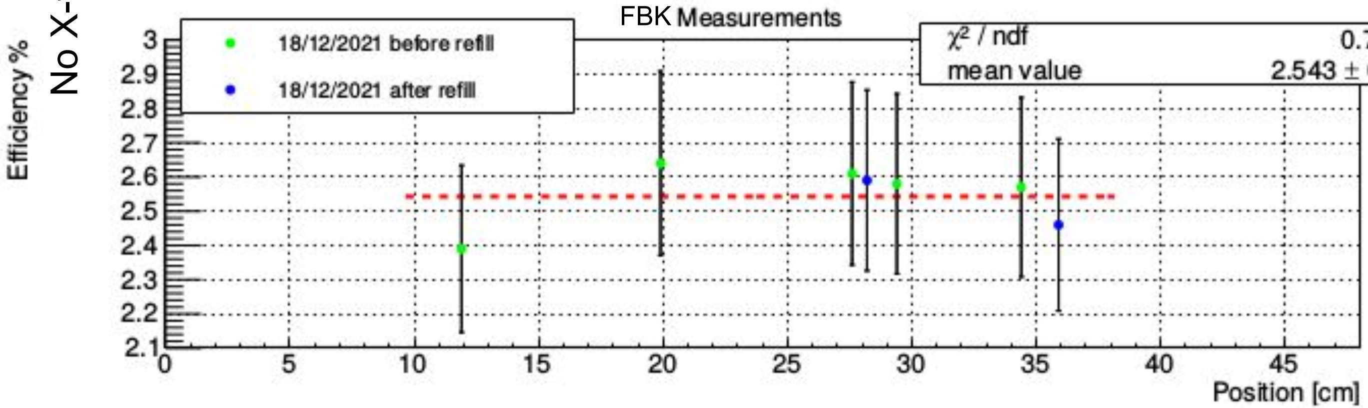
Efficiency: previous presentation

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

No X-talk correction



LY_{LAr} = 5.1 E+4
q_{α} = 0.72
En_{α} = 4.480 MeV
f_{int} = 0.7-**0.8** (TBC, ~10% uncertainty)



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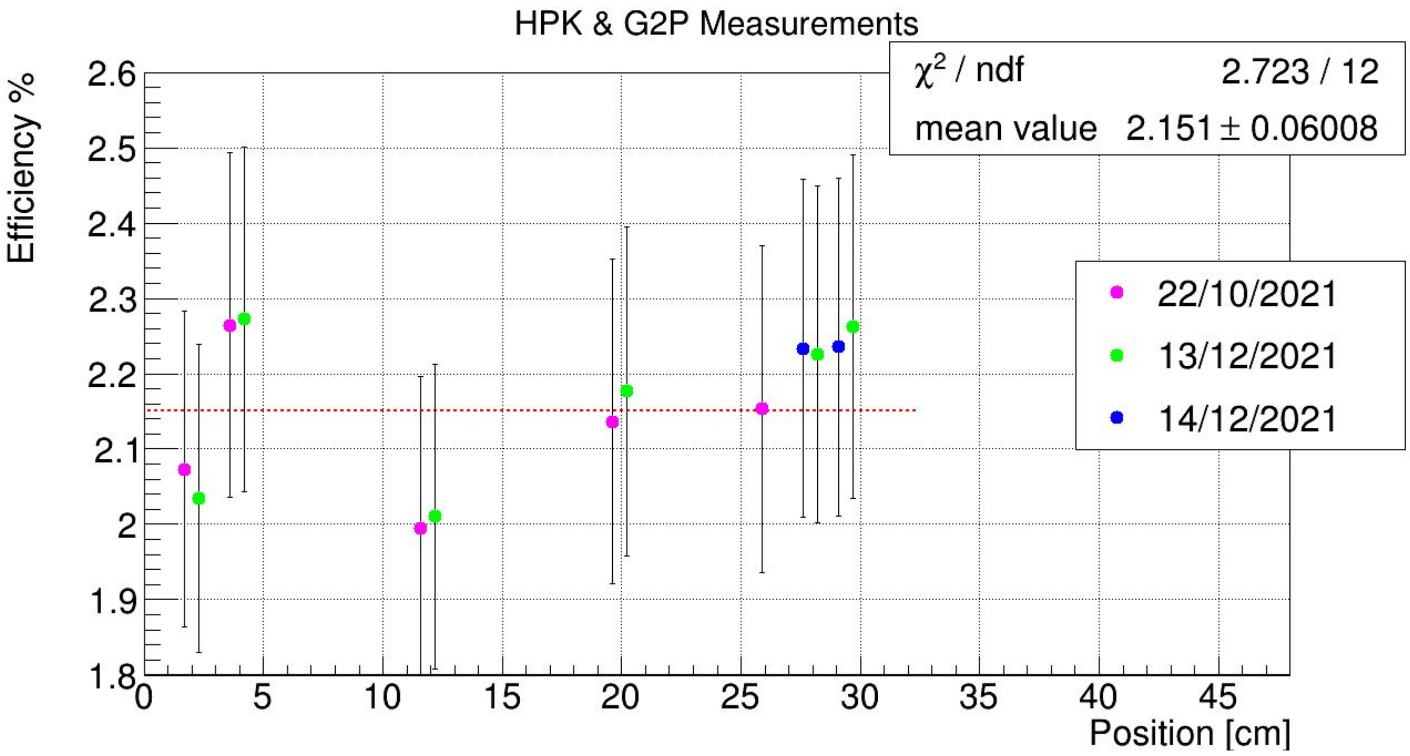
Efficiency: Updated results
HPK & G2P

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

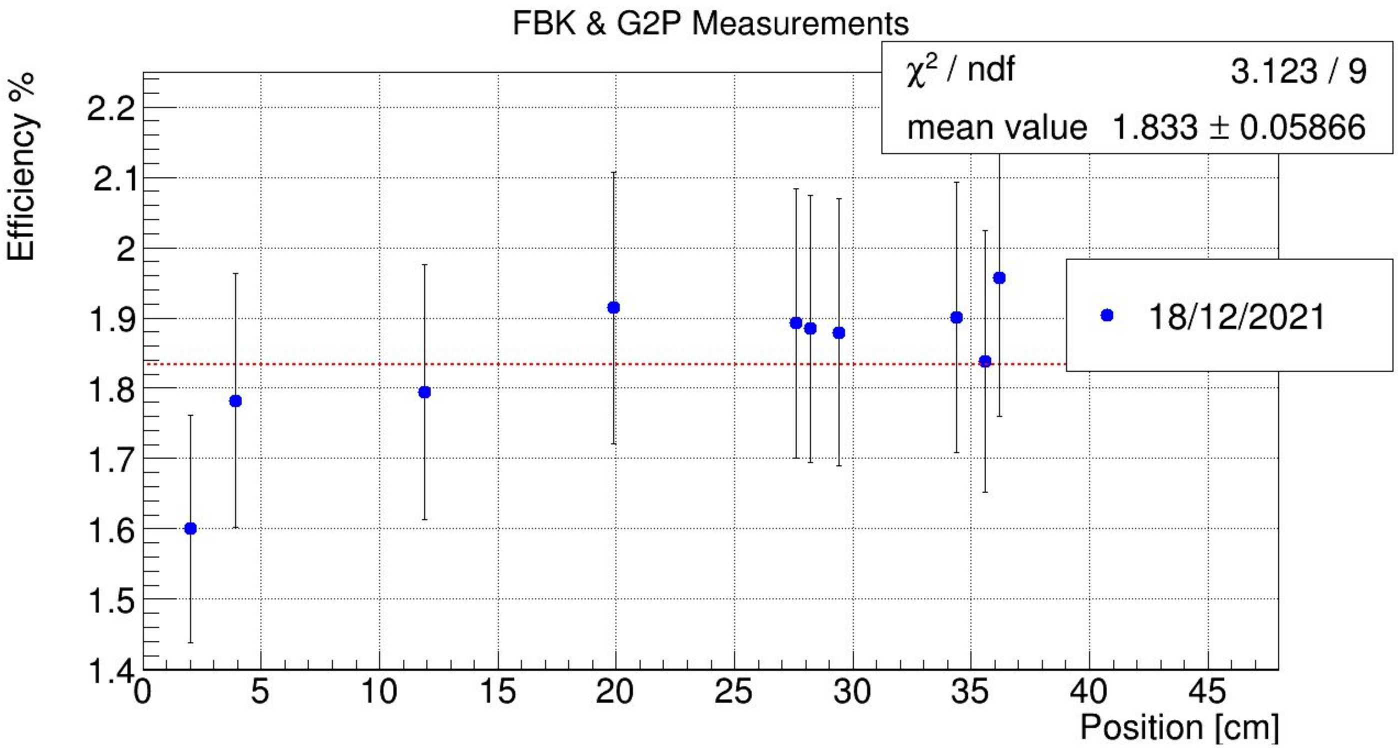


LY_{LAr} = 5.0 E+4
q_{α} = 0.7
En_{α} = 5.480 MeV
f_{int} = 0.862

No X-talk and LAr purity corrections

Efficiency: Updated results
FBK & G2P

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

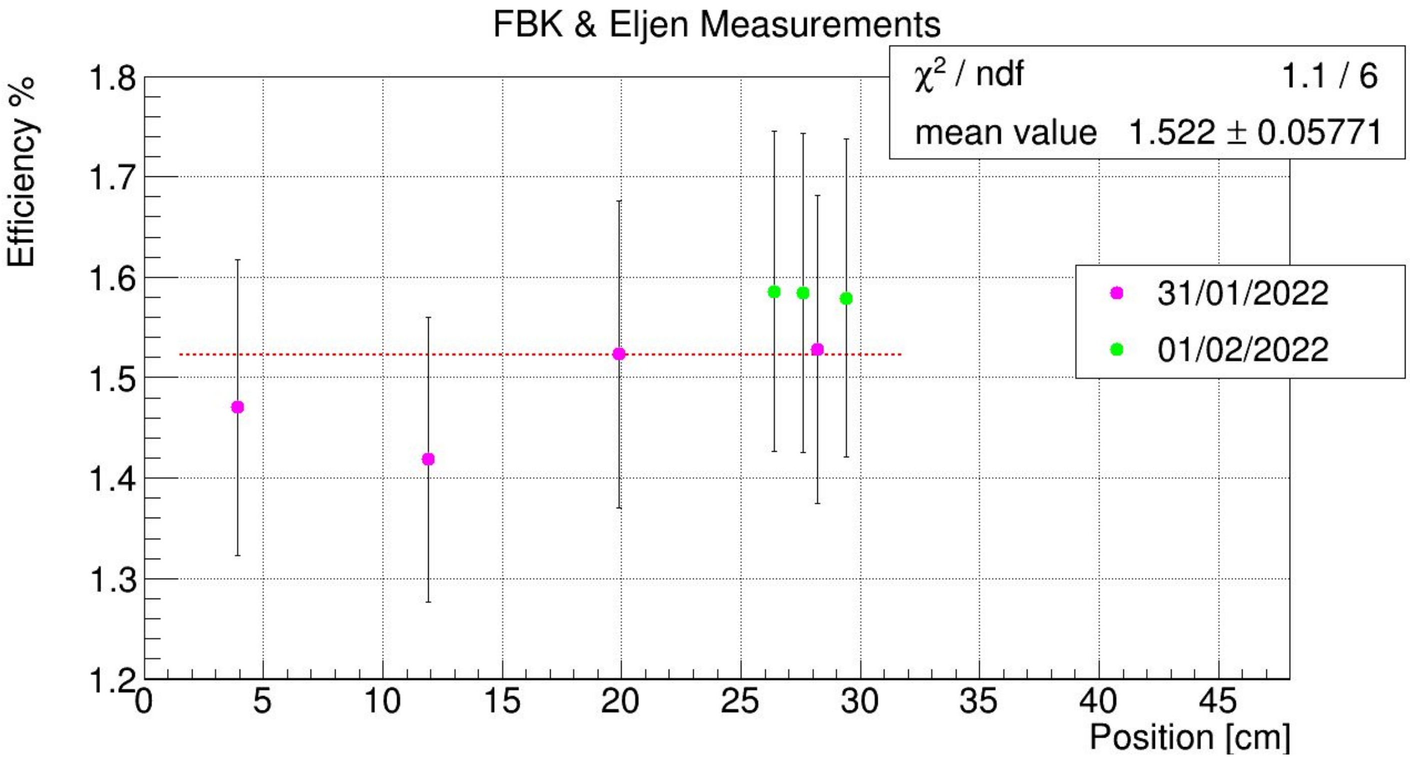


LY_{LAr} = 5.0 E+4
q_{α} = 0.7
En_{α} = 5.480 MeV
f_{int} = 0.86

No X-talk and LAr purity corrections

Efficiency: Updated results
FBK & Eljen

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



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

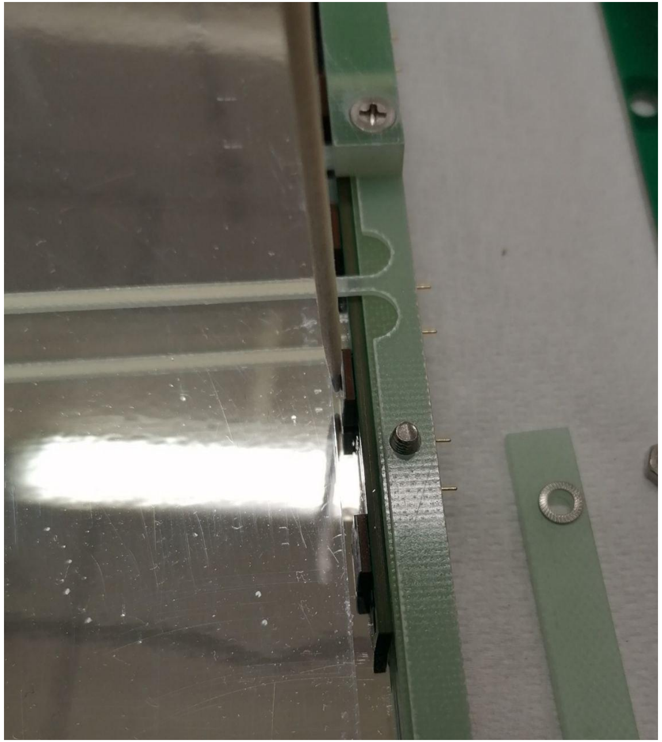
Efficiency: X-talk and P_{LAr} corrections

		OV	PDE	Uncorrected ε_{XA}	Measured Xtalk	P_{LAr} correction	Corrected $\varepsilon_{XA\ x\ talk\ only}$	Corrected $\varepsilon_{XA\ x\ talk\ and\ P\_LAr}$
this work	HPK** & G2P	3.0V	50%	2.15 (0.06)	6.62%	0.95	2.02 (0.05)	2.13
	FBK*** & G2P	4.5V	45%	1.83 (0.06)	15.7%	0.91	1.58 (0.05)	1.74
	FBK*** & Eljen	4.5V	45%	1.52 (0.06)	15.7%	0.91	1.31 (0.05)	1.44
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

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

Possible cause for lower efficiencies



Gap between the WLS bar and the SiPMs. At room temperature, for G2P and HPK: ~1/1.5 mm overall.

At cyro temp probably: ~2 mm or more

Shrinking of G2P WLS bar: 8.3‰ (lower limit)

Shrinking of the frame: we tried to estimate the shrinking of the SiPM PCB (same material), with our method it wasn't observable/measurable.

Conclusions

- $S/N_{HPK} = 4.7$; $S/N_{FBK} = 4.1$, better than first release
- Verified linearity of resolution
- Verified linearity of gain vs V_{OV}
- Problems in deconvolution of muon average waveform
- Not sure about LAr purity correction.
- Supercell efficiency with cross talk (and LAr purity) correction:
  - HPK 2.02 (2.13) ± 0.05%
  - FBK & G2P 1.58 (1.74) ± 0.05%
  - FBK & Eljin 1.31 (1.44) ± 0.05%

To Do

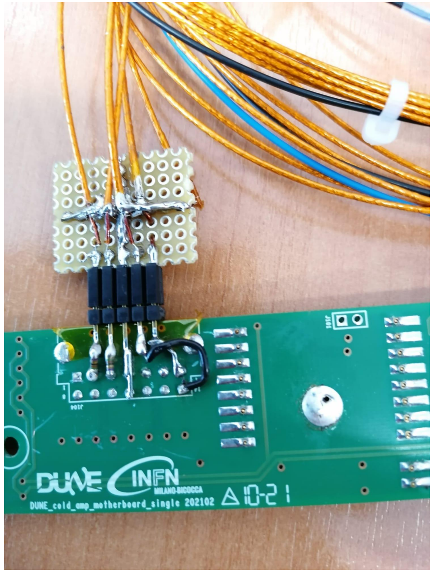
- Better estimation of LAr purity and muon analysis
- Deconvolution of alpha average waveforms
- Measurement of Eljen bar shrinking

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

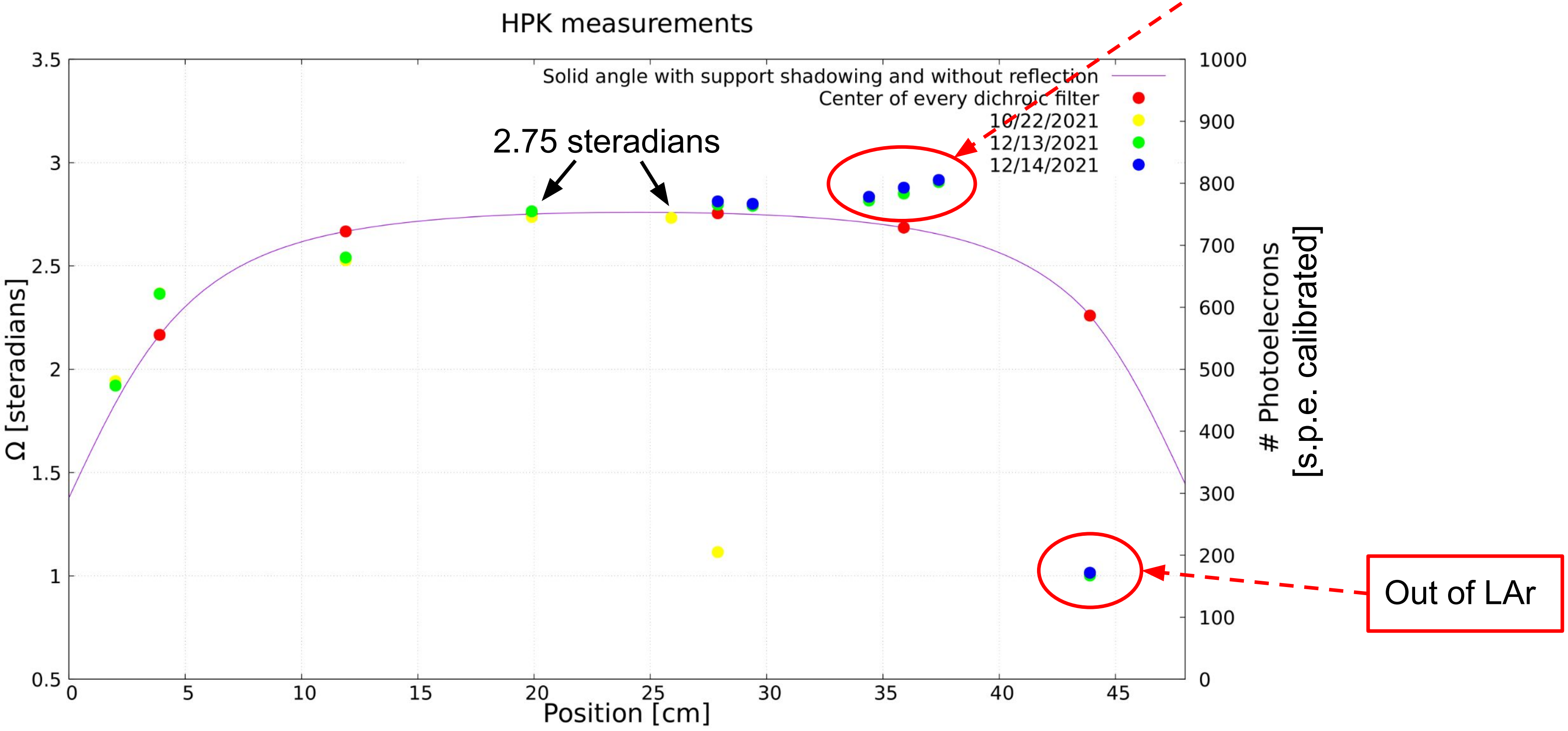


- Cold cables: a bundle of five Kapton RG178 coaxial cables. No DUNE blue cable & Hirose connector due to mechanical (dimension, stiffness) constraints of the setup

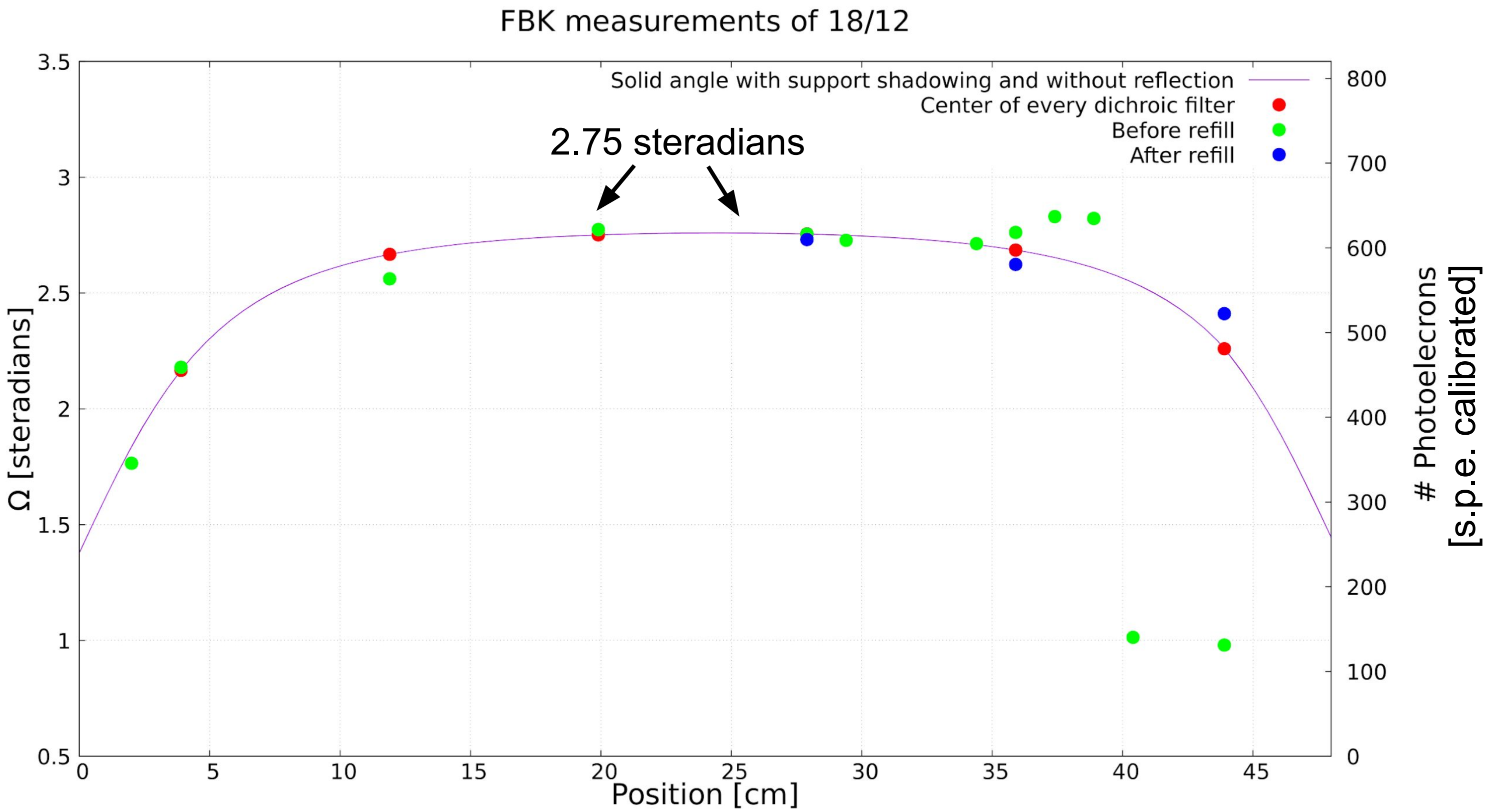
- Warm cables: 2.5 m, 50 Ω LEMO cables

- 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**

Measurements with HPK (aggiornare)



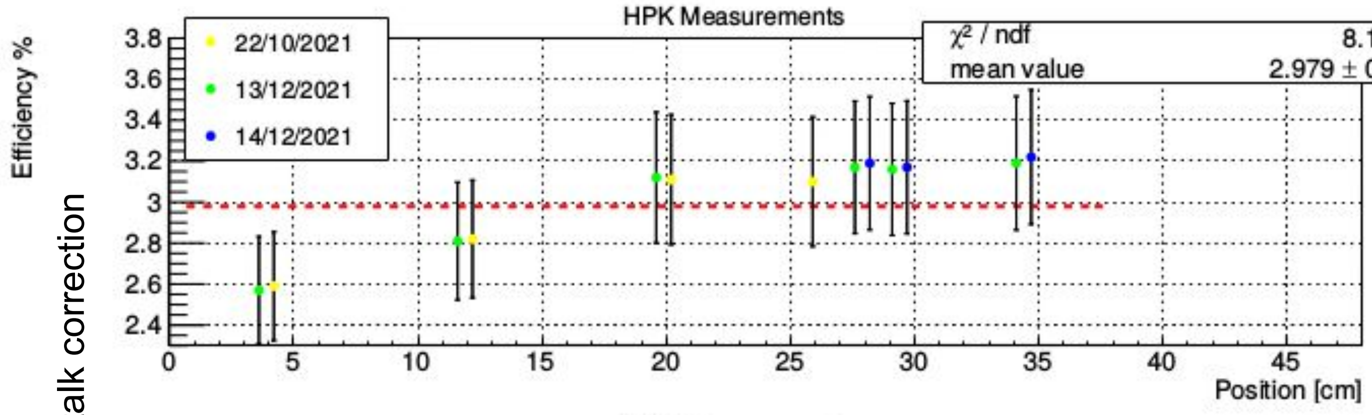
Measurements with FBK (aggiornare)



Efficiency: positions 1 to 5

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

No X-talk correction



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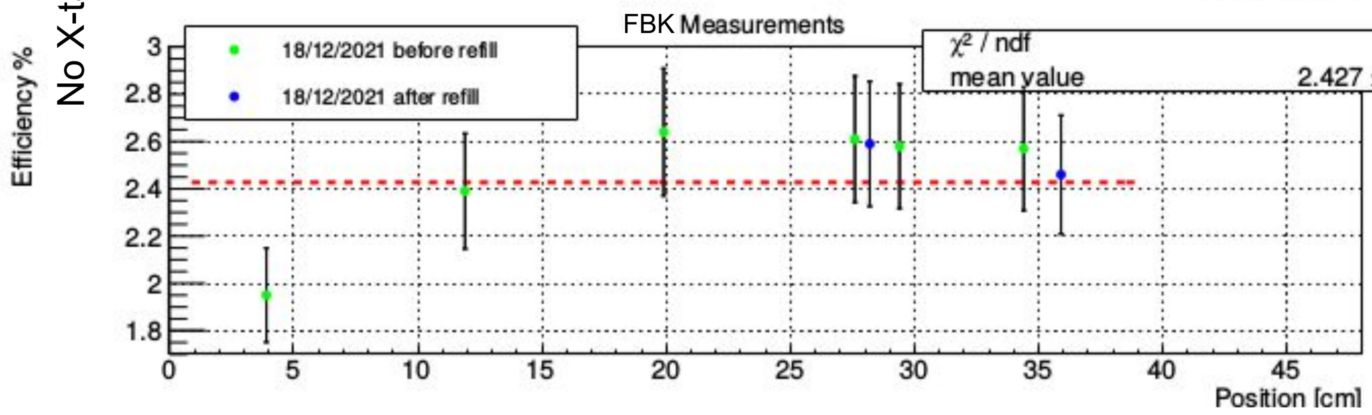

LY_{LAr} = 5.1 E+4
q_α = 0.72
En_α = 4.480 MeV
f_{int} = 0.7-**0.8** (TBC, ~10% uncertainty)

Cosa viene aggiornato in questo update

- //Corretto baco angolo solido disso al minimo valore (pos.1)
- Fixed a bug in the code for the efficiency computation.
- Changed sphe integration interval:
  - this update:
    - HPK: from 120 ns before the peak to 800 ns after the peak;
    - FBK: from 170 ns before the peak to 800 ns after the peak;
  - first release:
    - HPK & FBK: from 60 ns before the peak to 800 ns after the peak;
  - //S/N improved while gain unchanged
- integrazione alpha average wfm (selected at peak)
  - this update: (HPK&FBK: -400 ns to +1000 ns)
  - first release: (HPK&FBK: -300 ns to +600 ns)
- New measurements of SC efficicncy w. FBK & ELjin lightguide: New
- alpha & muon wfm deconvolution: New
- muon analysis: New
- gain of detector vs V_OV: New