FD-VD X-ARAPUCA PDE Measurement @CIEMAT:

DF-XA & noDF-XA Comparison

Rodrigo Álvarez, Enrique Calvo, Aritz Canto, Clara Cuesta, Inés Gil, Ignacio López, Sergio Manthey, Iván Martín, Carmen Palomares, Laura Pérez, Antonio Verdugo

Goals

1. Measurement of the XA-VD **absolute PDE** (single-sided XA)

2. **Optimization** of the XA-VD **PDE**:

   Comparison between XA configurations (DF-XA vs noDF-XA)

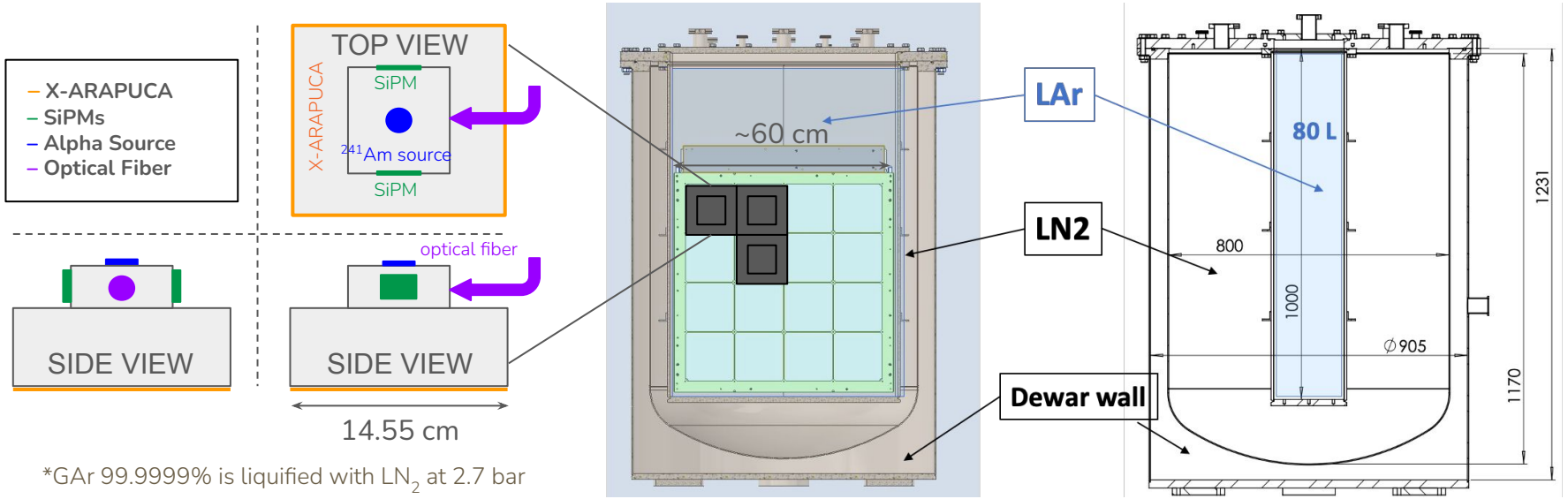
XA configurations under test at CIEMAT

VD-XA CONFIGURATIONS						
XA	**WLS Bar**		**SiPMs**	**Filter**	**Sided**	**Status**
1. DF-XA	G2P (80 mg/kg)	4.0 mm	FBK TT	ZAOT	Single	Tested
2. noDF-XA	G2P (80 mg/kg)	4.0 mm	FBK TT	*pTP PE-subs	Single	Tested
3. noDF-XA_24mg	G2P (24 mg/kg)	5.4 mm	FBK TT	*pTP PE-subs	Single	Being Tested
4. -	-	-	FBK TT	-	Double	To Be Tested

***pTP coated substrate (P.E.)** composed of fused silica JGS2

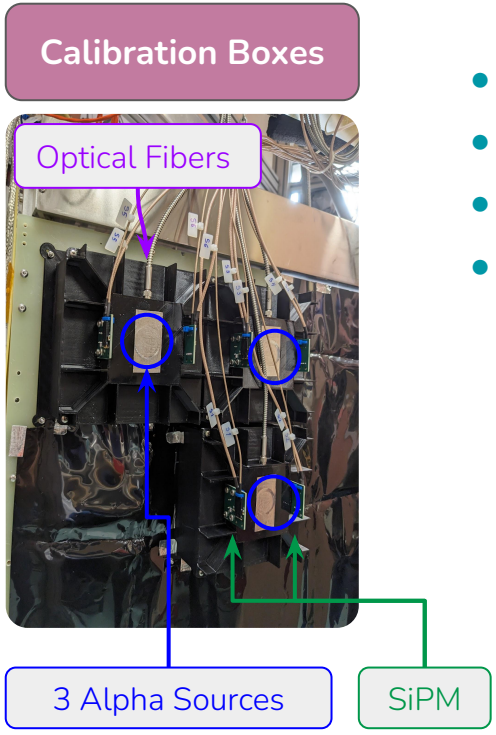
CIEMAT Setup Description

- **Measurement of the XA PDE in LAr** using 2 reference VUV SiPMs facing each other triggering on scintillation light from an ^{241}Am alpha source in 3 black calibration boxes (at the **only 3 not identical XA positions**)

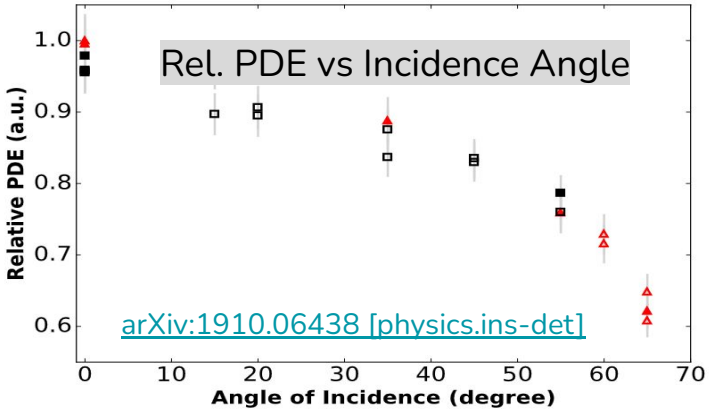


*GAr 99.9999% is liquified with LN_2 at 2.7 bar

Setup Description: Ref. Sensors



- Ref. SiPMs: HPK VUV4 SiPMs S13370 – 6075CN.
- Characterised at CIEMAT (L. Pérez et al.) (publication accepted by NIMA).
- Measured Xtalk at cryogenic temperature: (14.8 ± 0.3)% @ 3.5 OV
- SiPM efficiency @ CT VUV 127 nm: **12.69 ± 1.12 % at 4 OV**



VUV SiPM PDE used in our setup (corrected by the effective angle of incidence):

OV 3.5 (V):

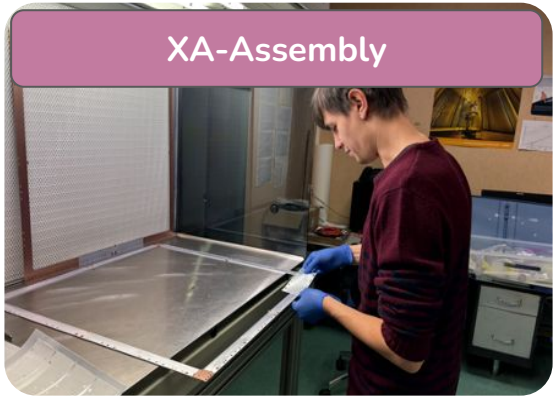
$$\epsilon_{\text{Ref.}} = (11.70 \pm 1.04)\%$$

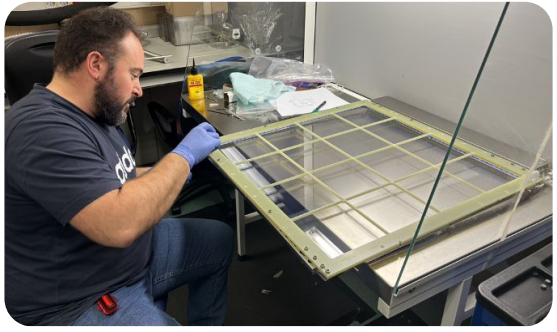
OV 4.0 (V):

$$\epsilon_{\text{Ref.}} = (12.06 \pm 1.07)\%$$

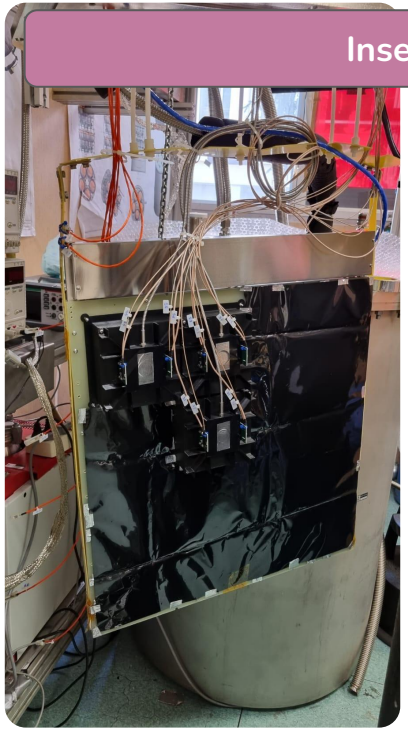
Setup @ CIEMAT: X-ARAPUCA Assembly & Insertion

XA-Assembly



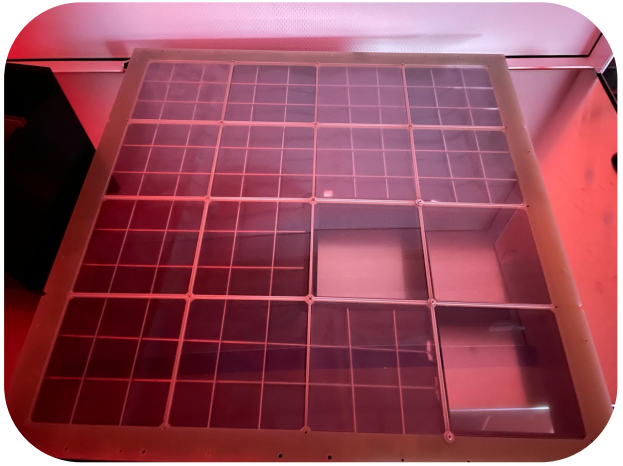


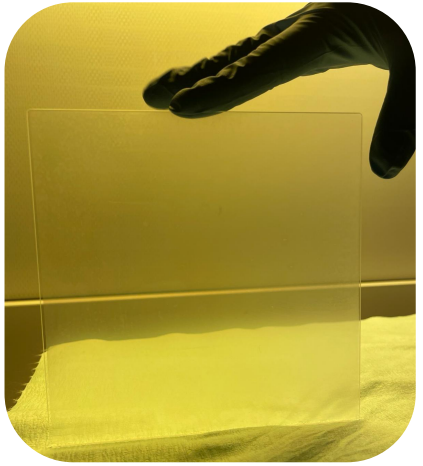
Inserting the VD-XA in the vessel



Setup @ CIEMAT: X-ARAPUCA Substrate w/o filter.

- **New configuration tested** with **pTP coated substrate (fused silica JGS2)** windows w/o dichroic filter (from PhotonExport).

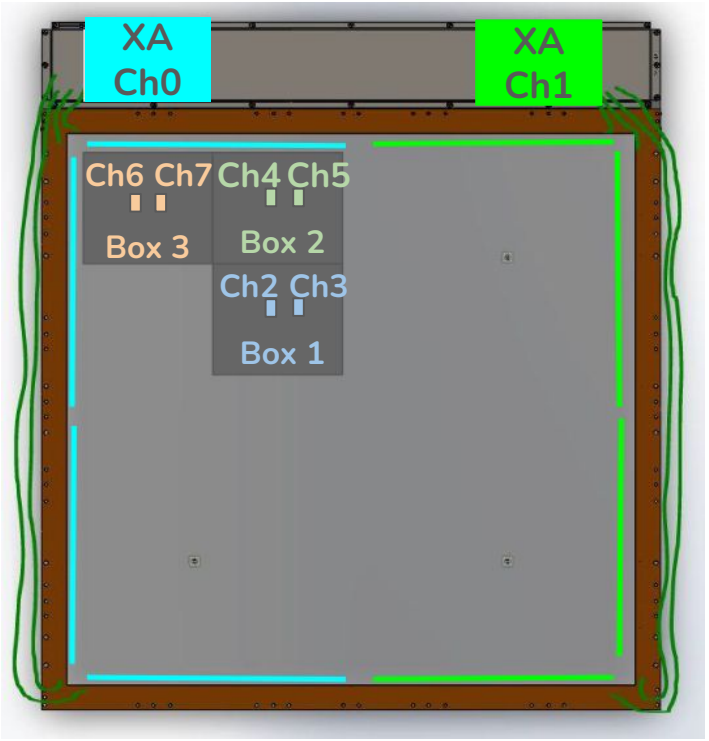




Timeline

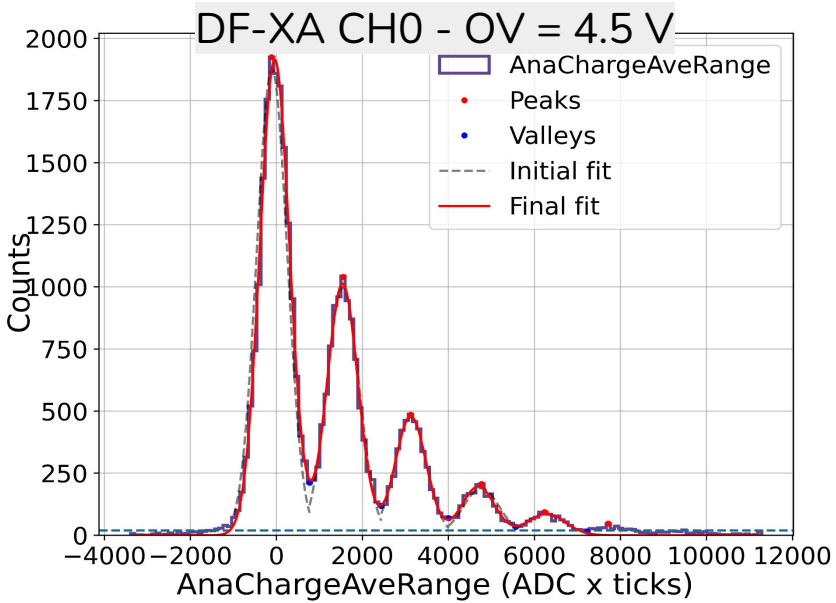
Configuration	Setup Timeline	
1. DF-XA	Membrane XA assembly	Jul. 23
1. DF-XA	LAr setup commissioning	Aug. 23
1. DF-XA	Gain and noise characterization LN_2	Sep. 23
1. DF-XA	LAr PDE Data taking	(13^{th} - 15^{th}) Dec. 23
2. noDF-XA	Noise characterization LN_2	Mar. 24
2. noDF-XA	LAr PDE Data taking	(13^{th} - 14^{th}) Mar. 24
3. noDF-XA_24mg	LAr PDE Data taking	(16^{th} - 17^{th}) Apr. 24

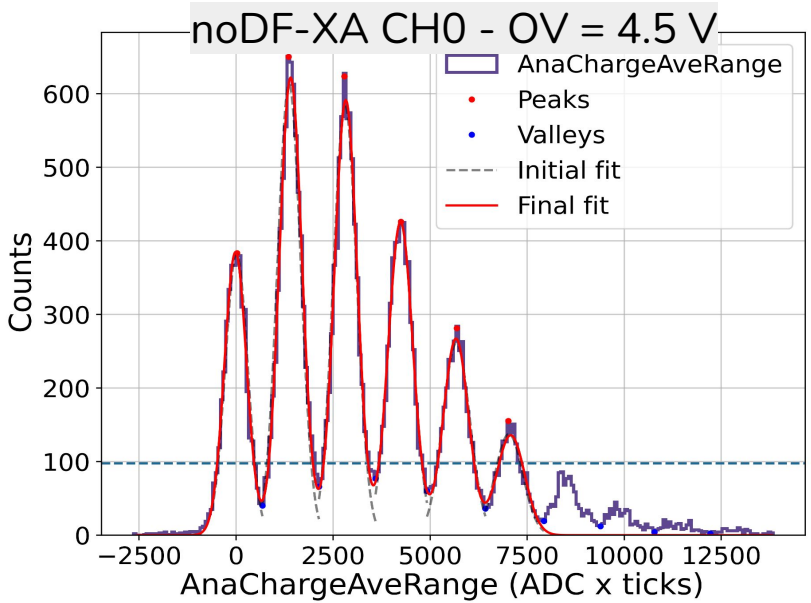
Setup Channel Arrangement



XA Calibration: Gain and S/N

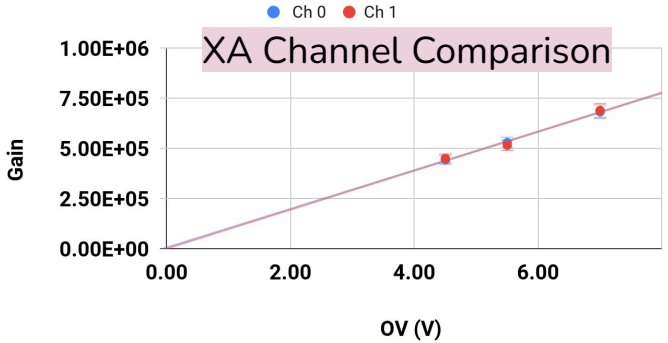
- Example calibration finger plots for the different setups.





XA Calibration: Gain and S/N

- Both XA-channels successfully calibrated.
- Compatible results between XA configs.



- DF-XA:

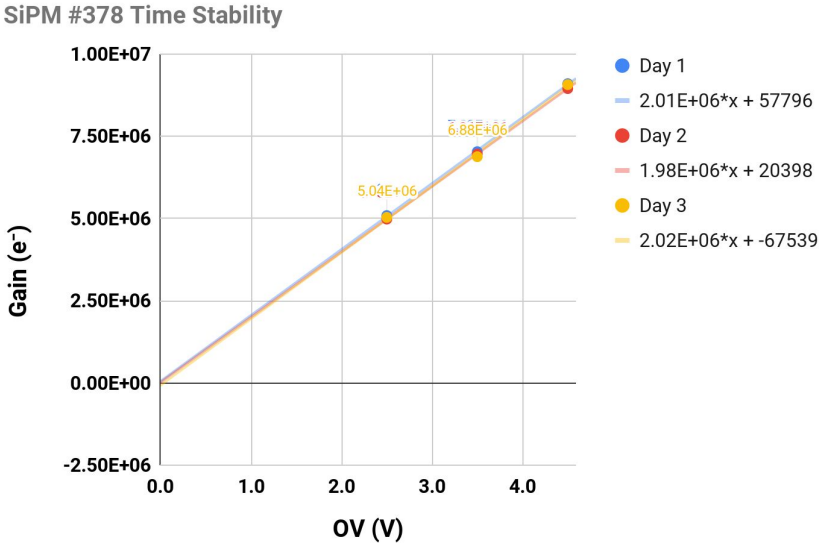
	XA0				XA1			
OV	Gain (e^-)	ERROR	S/N	ERROR	Gain (e^-)	ERROR	S/N	ERROR
7.0	**6.82E+05**	9E+03	**4.63**	0.27	**6.83E+05**	7E+03	**5.27**	0.14
5.5	**5.37E+05**	9E+03	**5.94**	0.08	**5.37E+05**	1.3E+04	**6.77**	0.21
4.5	**4.41E+05**	3E+03	**4.48**	0.10	**4.40E+05**	2E+03	**4.63**	0.04

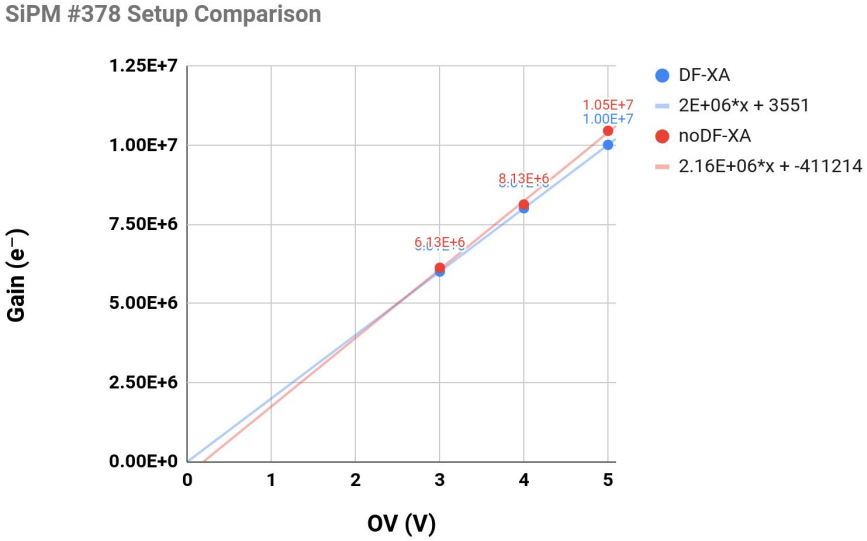
- noDF-XA:

	XA0				XA1			
OV	Gain (e^-)	ERROR	S/N	ERROR	Gain (e^-)	ERROR	S/N	ERROR
7.0	**6.63E+05**	7E+03	**6.47**	0.05	**6.91E+05**	4E+03	**5.95**	0.09
5.5	**5.24E+05**	1.2E+04	**5.37**	0.03	**5.33E+05**	6E+03	**5.45**	0.03
4.5	**4.32E+05**	1.9E+04	**4.56**	0.02	**4.28E+05**	3E+03	**4.57**	0.01

SiPM Calibration

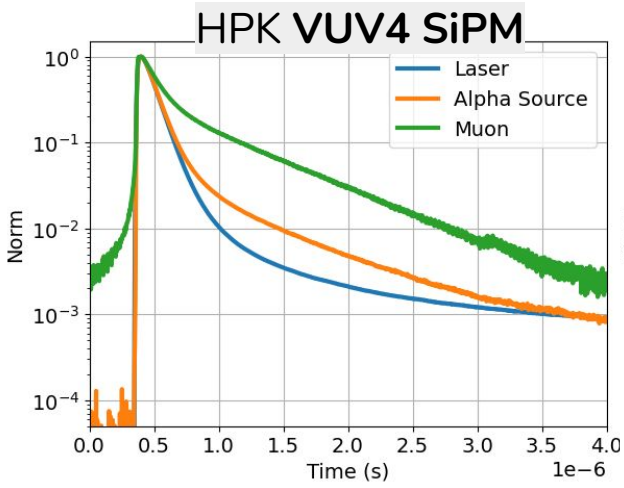
- Showing stability of SiPM calibration curve between different measurements, setups and days

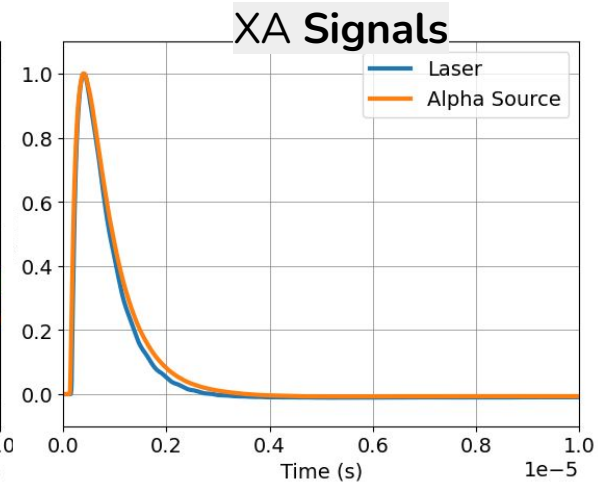


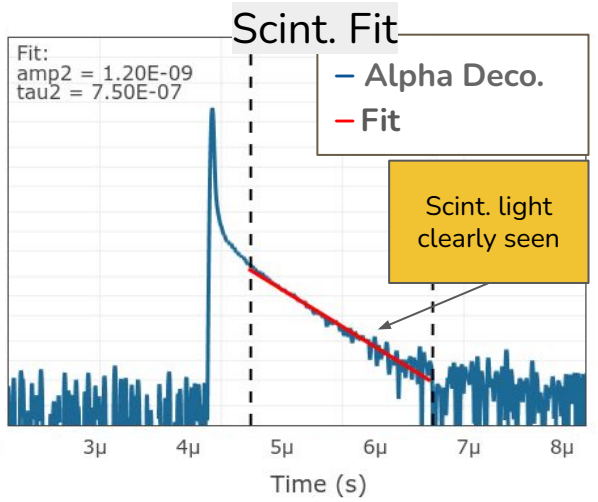


Scintillation Light Waveforms

- Scintillation light seen by ref. SiPM sensors and XA.
- From deco. wvf fit can be performed to extract scintillation parameters.

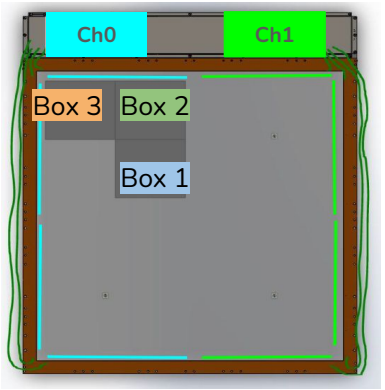




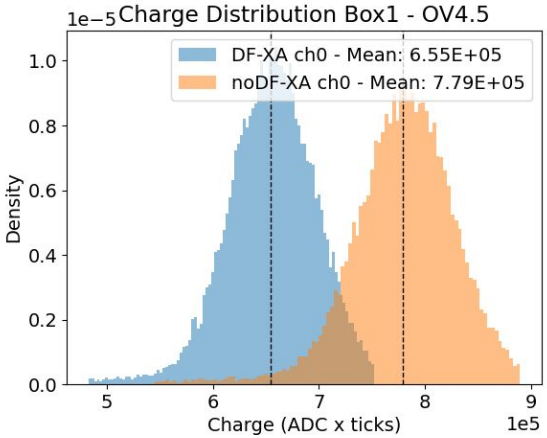


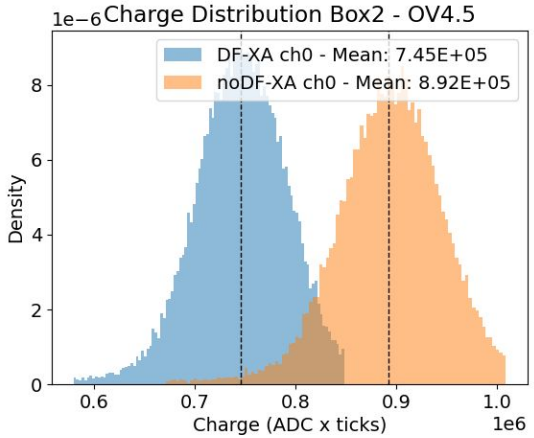
Comparison of XA-VD for config #1 & #2

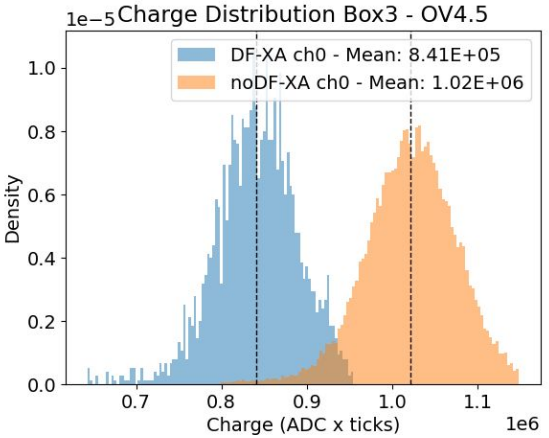
- Observed increase in collected charge for config #2!
- **noDF-XA** sees ~**29 - 26%** (for ch0 - ch1) **more charge** than **DF-XA** in every box (after correcting for absolute light diff.)



XA-VD Ch0 - OV 4.5 V - Config. Comparison







XA PDE computation

Direct Method (Comparison with ref. SiPM efficiency)

$$\epsilon(\mathrm{XA}) = \frac{\#PE_{\mathrm{XA}}}{\#PE_{\mathrm{Ref.SiPM}}} \cdot \epsilon(\mathrm{Ref.SiPM}) \cdot f_{corr}$$

#PE$_{XA}$: PEs detected by the XA

#PE$_{refSiPM}$: PEs detected by the reference SiPMs

ε(ref SiPM): absolute measurement at CT by CIEMAT

Correction factors ($f_{corr} = f_{geo} * f^{XA}_{XT} / f^{SiPM}_{XT}$):

- f_{geo}: Geometrical Factor → correction for different distance of sensor to alpha source.
- f_{XT}: XTalk Correction → from dedicated measurements of FBK/HPK SiPMs

Updated XTalk Computation!

- Using XTalk values (XT%) measured in the labs for FBK TT sensors.
- X-Check method from computation Vinogradov model (see backup): Fit composite poissonian to describes the effect of cross-talk.

XTalk Summary

XA	FBK TT
OV	XT %
7	32.5 ± 0.5
4.5	16.1 ± 0.3
3.5	12.7 ± 0.3

Correction Factor f_{XT}

XA	FBK TT
OV	f_{XT}
7	0.68 ± 0.02
4.5	0.840 ± 0.005
3.5	0.873 ± 0.004

$$f_{\mathrm{XT}} = \frac{1}{1 + K_{\mathrm{dup}}}$$

$$K_{\mathrm{dup}} = \frac{1}{1 - \mathrm{XT}\%}$$

Evaluation of uncertainties

Error computation takes into account uncertainties associated to the following variables:

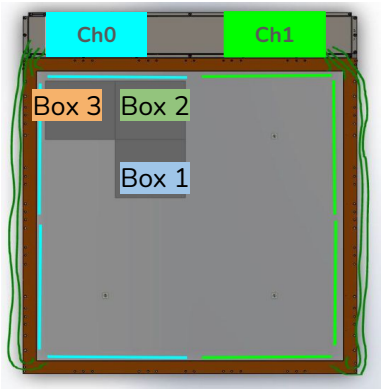
- Dominant
  - SiPM PDE **(8.9%)**: From ref. constrained from CIEMAT own measurements.

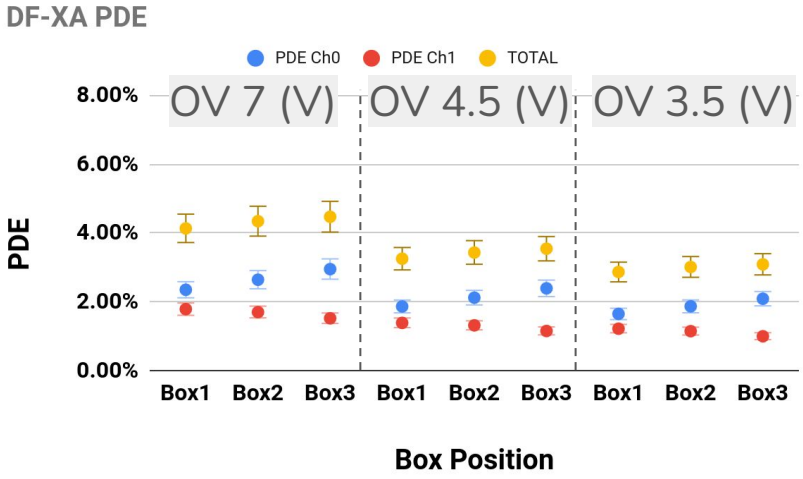
- Subdominat
  - XA #PE (~2%): From repeated gain measurement + gaussian fit of collected charge.
  - SiPM #PE (~2%): Gaussian fit of combined #PE collected per SiPM pair.
  - GEOMETRIC FACTOR (1.43%): From sim. + sensor deviation measurement.
  - XA XTALK (< 1%): From ref. (see prev slide - publication pending)
  - SiPM XTALK (< 1%): From ref. (L. Pérez et al.)

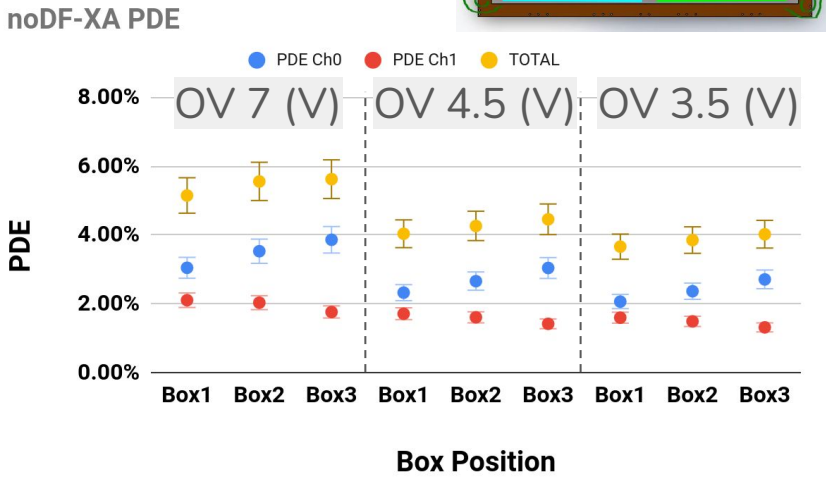
PDE stability

Showing PDE position dependence between:

- XA Setups (**DF-XA - noDF-XA**)
- XA Channels (Ch0 - Ch1)
- Box positions (see ref.)



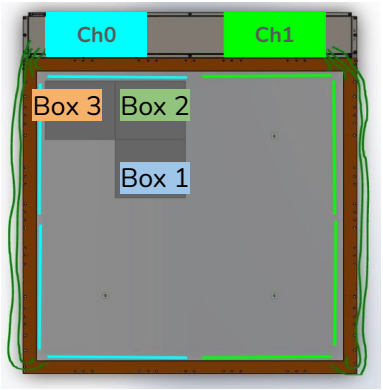


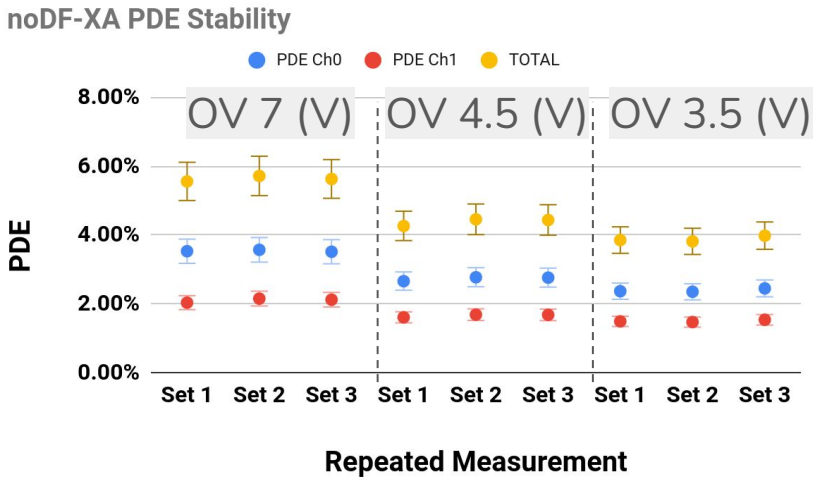


PDE stability

Showing PDE differences (**e.g. noDF-XA & Box2**) between:

- XA Channels (Ch0 - Ch1)
- Repeated measurements (Set 1, Set 2, Set 3)





Absolute XA-VD PDE Results (PRELIMINARY)

Compare measured XA-VD Configurations:

- **DF-XA**: G2P (4 mm) / FBK-TT / 80 mg*kg^{-1} / **ZAOT**
- **noDF-XA**: G2P (4 mm) / FBK-TT / 80 mg*kg^{-1} / **pTP substrate (PhotonExport)**

DF-XA

XA OV	PDE (%)
7	4.2 ± 0.4
4.5	**3.3 ± 0.3**
3.5	2.9 ± 0.3

noDF-XA

XA OV	PDE (%)
7	5.4 ± 0.5
4.5	**4.3 ± 0.4**
3.5	3.9 ± 0.4

COMPARISON	
OV	RELATIVE PDE INCREASE
7	31%
4.5	**30%**
3.5	32%

Conclusions

- Setup shows stable measurement conditions among different XA-VD configurations
- **Preliminary CIEMAT measurement** of the absolute XA-VD PDE @CT in LAr for the 3 different positions and for 2 different XA configurations
  - **noDF-XA PDE ~30% higher than DF-XA PDE**
  - Ongoing measurement: **noDF-XA_24mg** with WLS width 5.4 mm.
- **Next measurement** (expected ~mid May?): Double-sided XA
  - We will modify our current XA-VD module with mechanical parts from CSU or from a coldbox XA
  - **IMPORTANT**: we need one set of coated ZAOT DF and/or one set of pTP coated P.E. substrates

BACKUP

MegaCell Charge Difference

- Comparison of identical runs provides consistent increase in light collection.
- DF-XA charge has been corrected with a factor of 7.2% to account for absolute light differences measured at the SiPMs.

OV	Box	DF-XA	noDF-XA	Rel.	DF-XA	noDF-XA	Rel.	DF-XA	noDF-XA	Rel.
Config		Cannel 0			Channel 1			Combined		
7.0	1	1.48E+06	1.89E+06	28.21%	1.13E+06	1.43E+06	27.10%	1.07E+03	1.36E+03	27.73%
7.0	2	1.66E+06	2.19E+06	31.99%	1.07E+06	1.38E+06	28.84%	1.12E+03	1.47E+03	30.76%
7.0	3	1.86E+06	2.40E+06	29.31%	9.59E+05	1.20E+06	24.95%	1.16E+03	1.48E+03	27.83%
4.5	1	6.10E+05	7.83E+05	28.41%	4.53E+05	5.76E+05	26.94%	6.70E+02	8.56E+02	27.78%
4.5	2	6.94E+05	8.96E+05	29.22%	4.29E+05	5.40E+05	25.67%	7.08E+02	9.05E+02	27.86%
4.5	3	7.82E+05	1.02E+06	30.93%	3.76E+05	4.76E+05	26.51%	7.31E+02	9.46E+02	29.50%
3.5	1	4.05E+05	5.13E+05	26.65%	2.98E+05	3.74E+05	25.45%	5.76E+02	7.27E+02	26.14%
3.5	2	4.59E+05	5.87E+05	27.88%	2.81E+05	3.49E+05	24.40%	6.06E+02	7.67E+02	26.56%
3.5	3	5.14E+05	6.73E+05	30.89%	2.45E+05	3.08E+05	25.93%	6.21E+02	8.03E+02	29.28%
		MEAN	ERROR	% ERROR	MEAN	ERROR	% ERROR	MEAN	ERROR	% ERROR
		29%	1.7%	5.8%	26%	1.3%	5.1%	28%	1.5%	5.2%

Ref. XTalk values

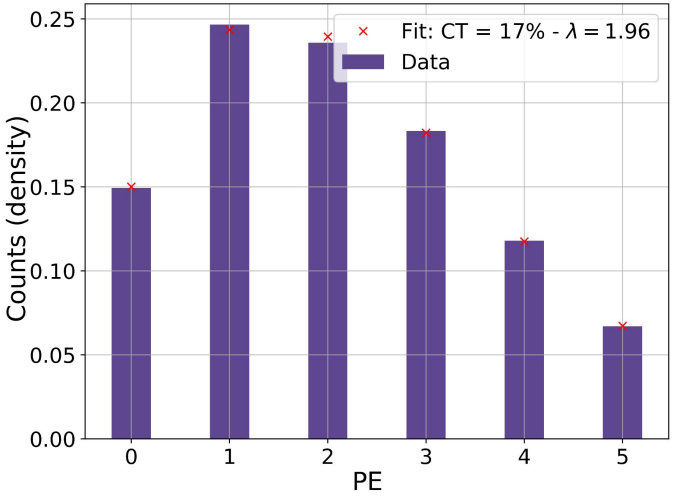
	FBK TT		
OV	XT	DXT	%
7	**32,5**	0,5	1,4%
4,5	**16,1**	0,3	2,0%
3,5	**12,7**	0,3	2,1%
	Used in HD-XA & VD-XA		2,1%

	SiPM#289				SiPM#290			
OV		XT	DXT	%		XT	DXT	%
4,5		23,7	0,92	3,9		23,9	0,98	4,1
3,5		**15,1**	0,43	2,9		**14,7**	0,29	2,0
2,5		10,1	0,54	5,3		10,0	0,08	0,8

Updated XTalk Computation!

- Selected method for computation **Vinogradov model:** Fit composite poissonian to describes the effect of cross-talk.

e.g. OV 4.5 - Ch0 - XTalk Estimation Fit



XTalk Summary

XA	Ch 0	Ch 1
OV	XT %	XT %
7	33±6.6	34±2.4
4.5	19±3.8	19±1.3
3.5	14±2.7	13±0.9

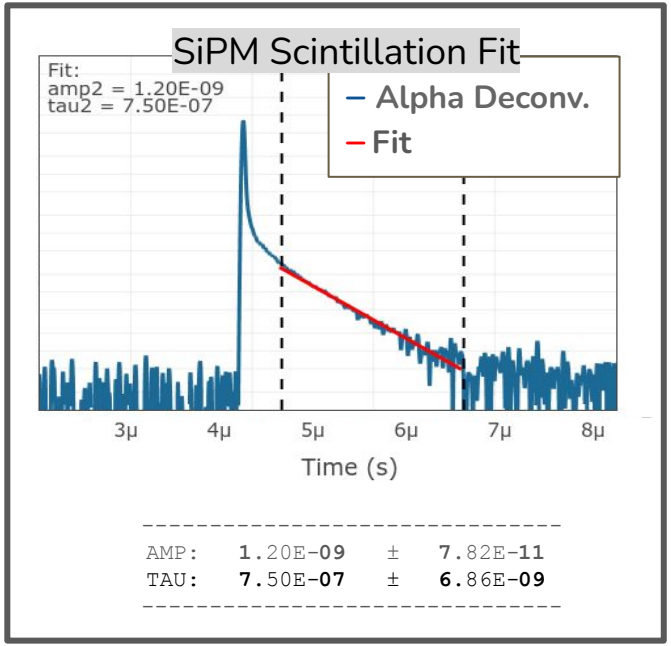
Duplication Factor

XA	Ch 0	Ch 1
OV	KDUP	KDUP
7	0.67±0.07	0.66±0.03
4.5	0.81±0.05	0.81±0.02
3.5	0.86±0.04	0.87±0.01

Setup Purity

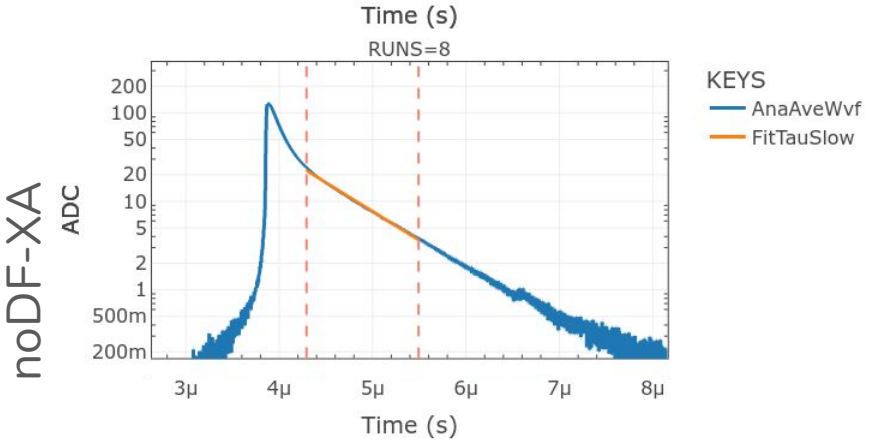
- Purity change corresponds to measured light **decrease of ~7.2%**.

Presented @ CM



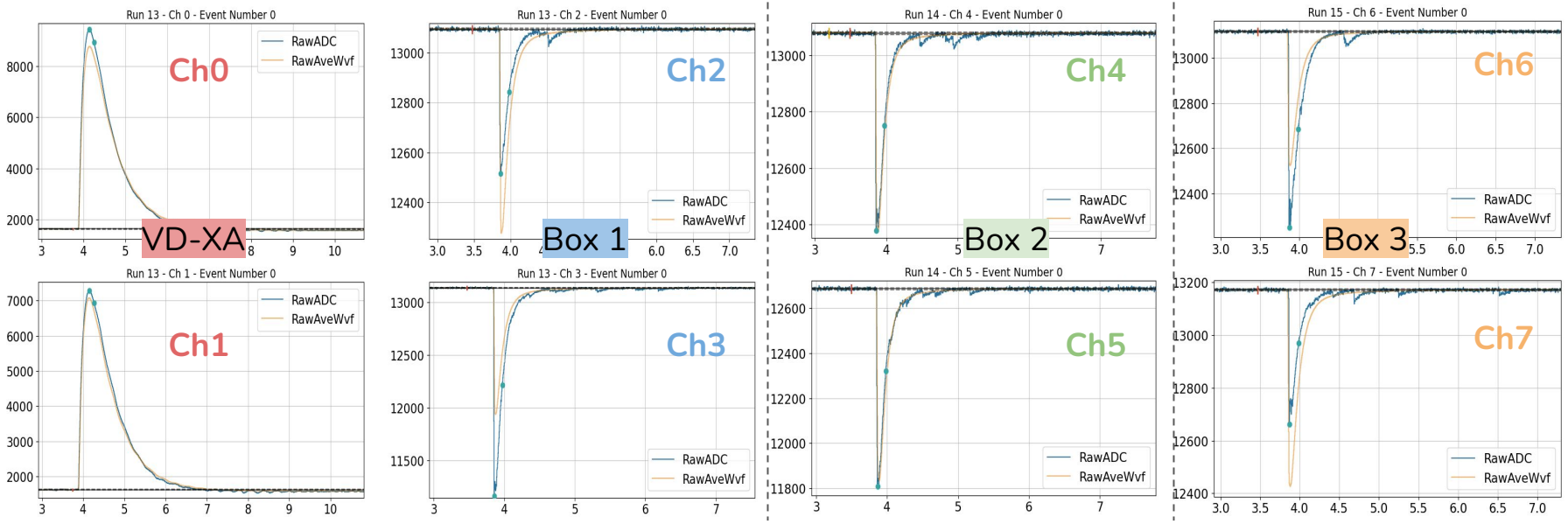
AMP:	1.20E-09	±	7.82E-11
TAU:	7.50E-07	±	6.86E-09

noDF-XA



AMP2:	3.29E-08	±	5.56E-11
TAU2:	**7.00E-07**	±	**1.48E-09**

Event examples



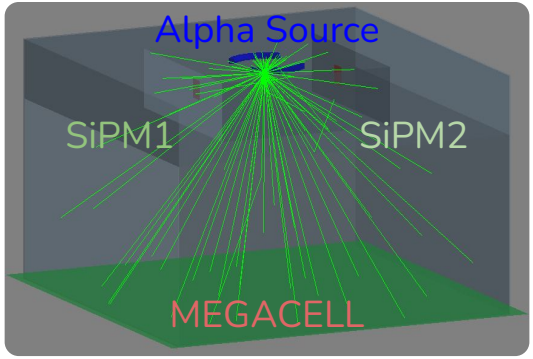
- **Ref. sensors in each Box** provide trigger conditions based on **threshold + coincidence**.
- → Clean sample of alpha scintillation signals.

Geometrical Factor

- Ratio of photons determined by **standalone GEANT4 simulation.**
- It accounts for the differences in sizes/positioning of ref. sensors.

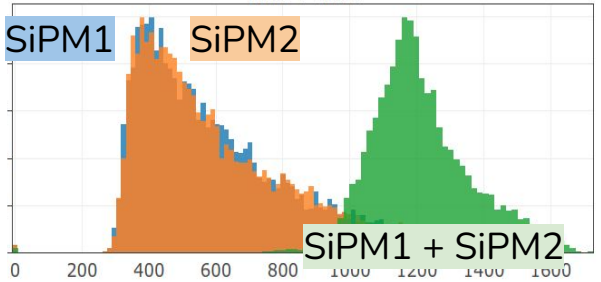
$$f_{\text{geom}} = \frac{\Omega(\text{Ref.})}{\Omega(\text{XA})} = 0.047 \pm 0.001$$

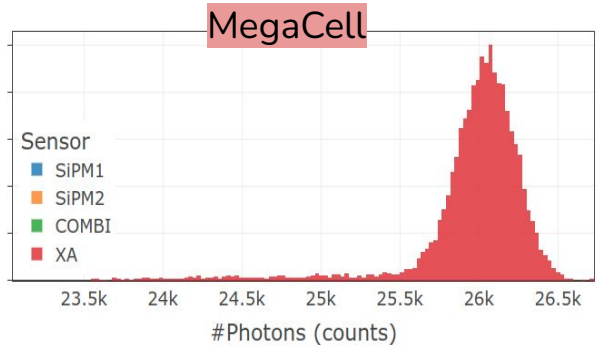
Sensor	MEAN Ph.	ERROR
XA-VD (21170 mm²)	25900	237
SiPM (12 mm²)	1210	13



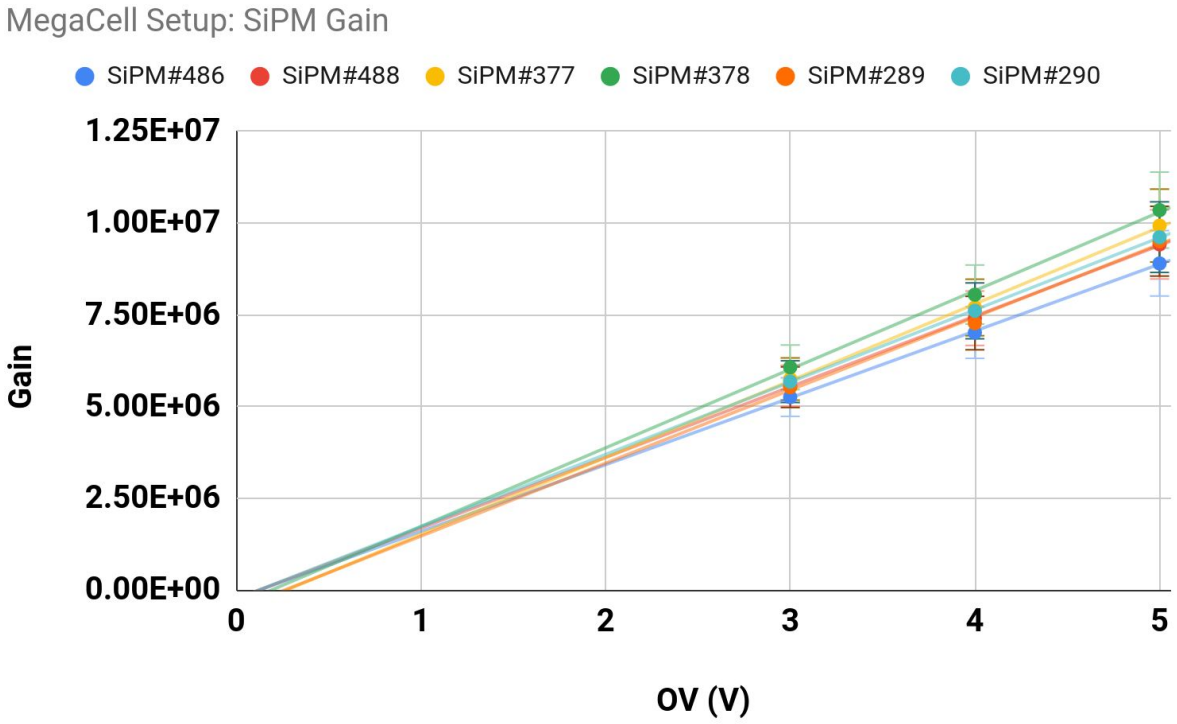
14.55 x 14.55 cm²

Photon distribution at sensors





SiPM Gain


MegaCell Setup: SiPM Gain
SiPM#486
SiPM#488
SiPM#377
SiPM#378
SiPM#289
SiPM#290
1.25E+07
1.00E+07
7.50E+06
5.00E+06
2.50E+06
0.00E+00
Gain
0
1
2
3
4
5
OV (V)