

# ProtoDUNE-HD PDS: SuperCell PDE values

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ProtoDUNE PDS Sim/Reco - 28 OCT 2024

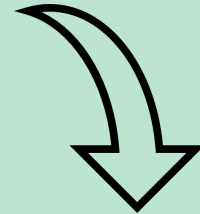
DEEP UNDERGROUND  
NEUTRINO EXPERIMENT



# Simulation PDE values from LAr measurements

SEE PUBLICATION FOR MORE INFO:

[Eur. Phys. J. C 84, 1004 \(2024\)](#)



EVENT GENERATOR



GEANT4



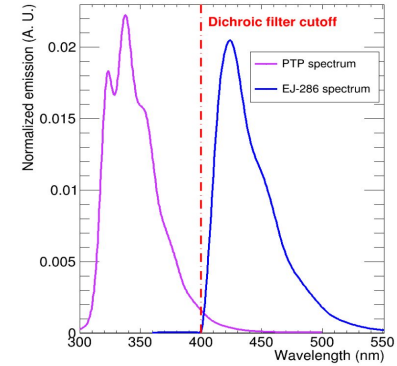
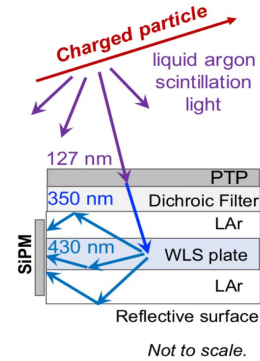
DETECTOR SIMULATION



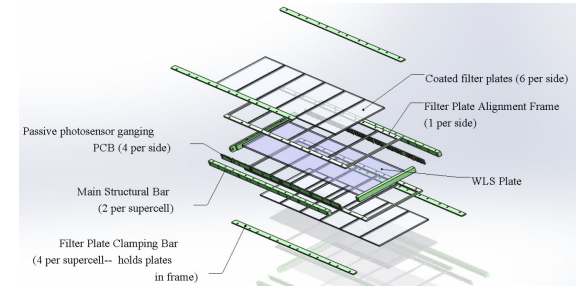
RECONSTRUCTION

# FD-HD configuration characterization

- The XAs' configurations installed in ProtoDUNE-HD (NP04) were tested in **LAr** at CIEMAT and Milano Bicocca.
- Common electronics ( see [C. Brizzolari et al 2022 JINST 17 P11017](#) )



SiPMs	WLS bar	Testing Site
(A) <a href="#">FBK TT</a>	<a href="#">EJ-286PS-1</a>	CIEMAT + MiB
(B) <a href="#">FBK TT</a>	<a href="#">G2P-FB165A</a>	MiB
(C) <a href="#">HPK 75HQ</a>	<a href="#">EJ-286PS-1</a>	CIEMAT
(D) <a href="#">HPK 75HQ</a>	<a href="#">G2P-FB165A</a>	CIEMAT+MiB



# Data Analysis

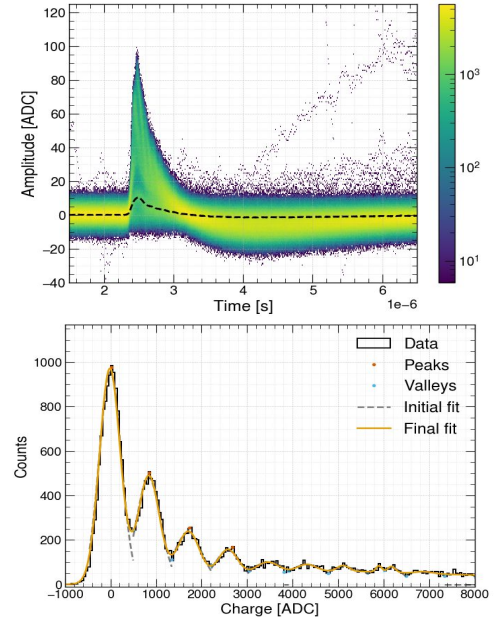
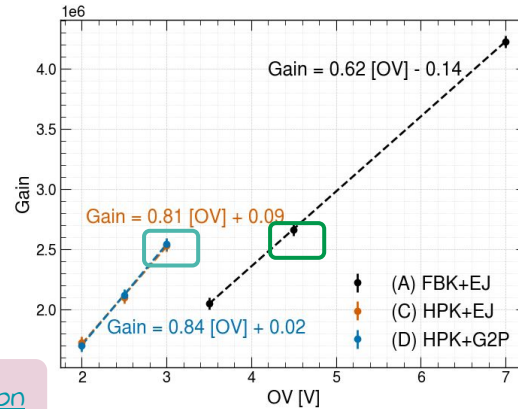
- Calibration (*common procedure*)
  - Calibrations at low light levels with a 405 nm laser in both sites
  - $SNR = (\mu_1 - \mu_0) / \sqrt{(\sigma_1^2 + \sigma_0^2)} > 2$
  - Cross-talk (CT)

OV	PDE	Crosstalk (%)	OV	PDE	Crosstalk (%)
3.5	40	$12.68 \pm 0.27$	2.0	40	$6.6 \pm 0.7$
4.5	45	$16.05 \pm 0.32$	2.5	45	$9.0 \pm 1.0$
7.0	50	$32.47 \pm 0.47$	3.0	50	$11.0 \pm 1.0$

(a) FBK TT

(b) HPK HQR75

see [HPK MPPCs Characterization](#)



SiPMs biased at 4.5 OV (FBK TT) and 3.0 OV (HPK HQR75) → similar gain + CT < 20% in both models

# PDE vs OV

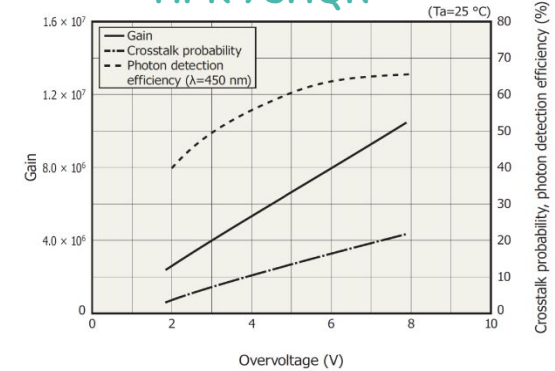
- **Not linear** dependency + depends on  $T^a$  and **wavelength**
- SiPM PDE percentage not measured at out conditions (just nomenclature)
- Computing the ratios for different configurations results:

	$\lambda$ ?? nm - T ?? K	$\lambda$ 128 nm - T 83 K	
(FBK)	Manufacturer	HD-XA	VD-XA
$PDE_{45\%}/PDE_{40\%}$	1.13	1.16	1.15
$PDE_{50\%}/PDE_{45\%}$	1.11	1.24	1.27

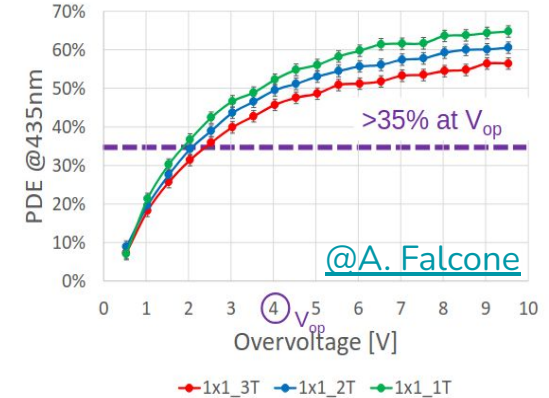
DUNE CM VD-XA

- Trusted SiPM OV-PDE progression corresponding to 40%, 45% and 50% **cannot be reproduced in DUNE's OP-conditions.**

## HPK 75HQR



## FBK NUV-HD-Cryo



# Paper results

- PDE has been measured to be **about 2%** at 4.5 OV (FBK) & 3.0 OV (HPK)

	FBK + EJ (A)	FBK + G2P (B)	HPK + EJ (C)	HPK + G2P (D)
MiB [ $\epsilon_{\text{MIB}}$ ]	$1.80 \pm 0.15$	$2.22 \pm 0.19$	-	$2.40 \pm 0.20$
CIEMAT [ $\epsilon_{\text{MAD}}$ ]	$1.34 \pm 0.24$	-	$1.59 \pm 0.29$	$2.13 \pm 0.38$
CIEMAT [ $\epsilon'_{\text{MAD}}$ ]	$1.61 \pm 0.12$	-	$1.86 \pm 0.15$	$2.50 \pm 0.21$

- 10% higher for HPK and the same WLS bar + increases between (24-35)% with the G2P

→ Four configurations installed in ProtoDUNE-HD

→ Operated this summer at 4.5 OV (FBK) & 2.5 OV (HPK) [**45% PDE**]

→ NP04 Database

FBK + EJ (A)	FBK + G2P (B)	HPK + EJ (C)	HPK + G2P (D)
1.58	2.22	1.59	2.17

→ Values included in the fcl file: [duneopdet/OpticalDetector/opticaldetectormodules\\_dune.fcl](https://duneopdet/OpticalDetector/opticaldetectormodules_dune.fcl)

# PDE from NP04 data



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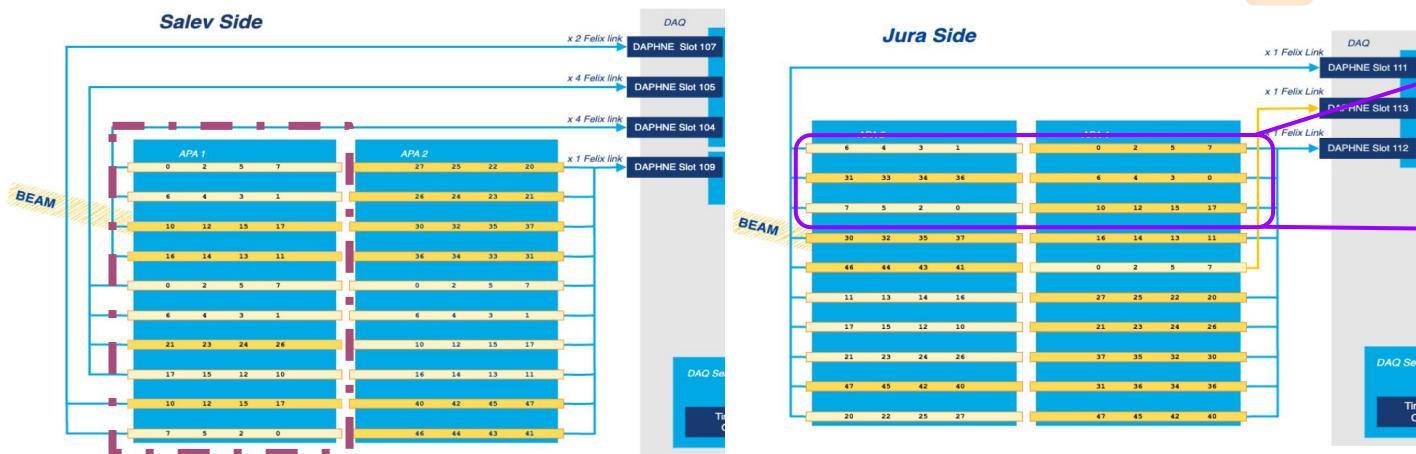
# NP04 overview

- 160 channels, with 4 X-ARAPUCA per PDS module
- 7 DAPHNE boards with 40 channels each
- **APA 1** in full streaming (3 DAPHNE) + **APAs 2, 3, 4** in self-trigger (4 DAPHNE)
- Two different SiPM vendors, **HPK (orange)** and **FBK (light yellow)**
- Breakdown voltage needs to be computed for each X-ARAPUCA ( $V_{OP} = V_{BD} + OV$ )

## Overvoltages (OV) [V]

	HPK	FBK
40% SiPMs PDE	2.0	3.5
45% SiPMs PDE	2.5	4.5
50% SiPMs PDE	3.0	7.0

Before 9<sup>th</sup> July  
After 9<sup>th</sup> July





# Roadmap to XA PDE

Similar procedure as followed with [ProtoDUNE-SP](#) beam data:

- Beam data from particles of known type
- $\epsilon_{XA} = \text{detected photons (data)} / \text{impinging photons (montecarlo)}$

## DATA

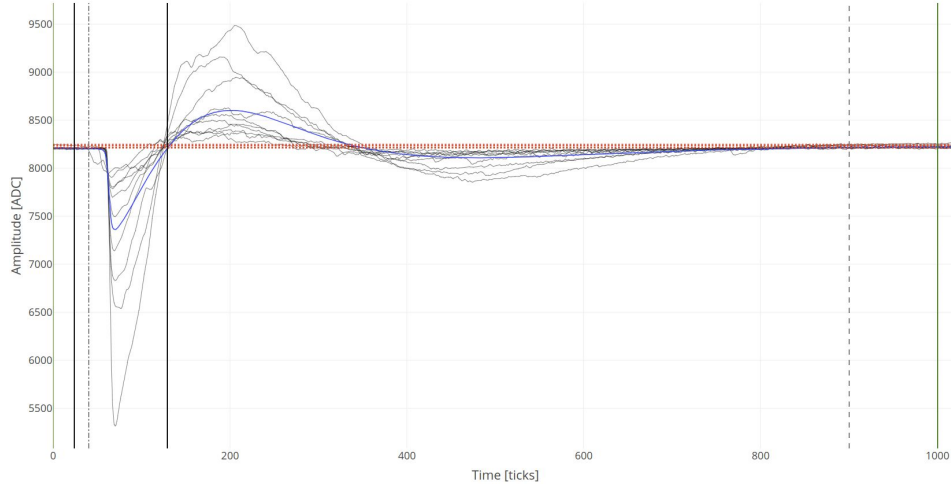
- Runs 27374 (7 GeV), 27378 (-7 GeV) → select electrons (to do: muons)
- Compute average waveform for each channel
- Set the integration ranges as the crossing points with baseline (only positive lobe)
- To do: APA 1 + other energies

## MC

- Beam + cosmics MC with LArSoft standard fcl for ProtoDUNE-HD (50 evts → low statistics!)
- To do: Increase statistics (official production?)

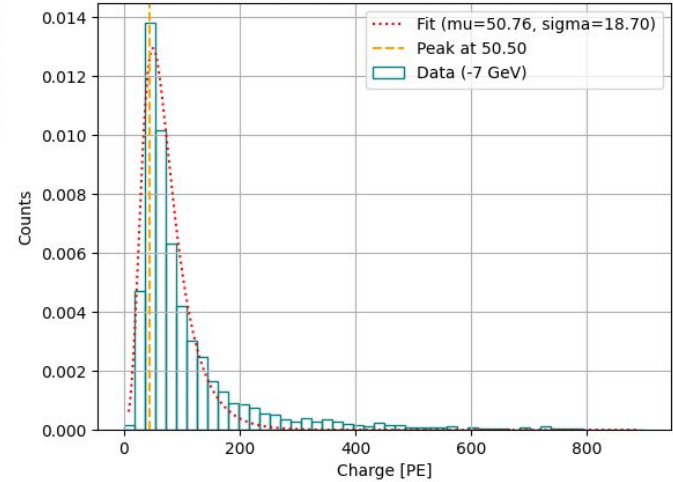
# NP04 Data

## 10 wvf + Average (example for ep 109 ch 0)



- (1,1) - Wf 0
- (1,1) - Wf 1
- (1,1) - Wf 2
- (1,1) - Wf 3
- (1,1) - Wf 4
- (1,1) - Wf 5
- (1,1) - Wf 6
- (1,1) - Wf 7
- (1,1) - Wf 8
- (1,1) - Wf 9
- Average

## Charge distribution (run027378\_ep109\_ch0)



APA 1

APA 2

APA 3

APA 4



APA 1

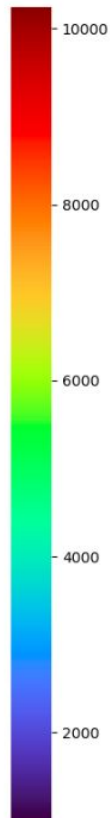
APA 2

APA 3

APA 4

(VERY) PRELIMINARY

FBK - G2P 1318.00	FBK - G2P 1958.00	FBK - G2P 2897.00	FBK - G2P 2877.50	HPK - EJ 721.00	HPK - EJ 3599.00	HPK - EJ 525.50	HPK - EJ 115.00	FBK - EJ 2333.00	FBK - EJ 518.00	FBK - EJ 104.50	FBK - EJ 311.00	HPK - G2P 257.50	HPK - G2P 3011.00	HPK - G2P 1607.50	HPK - G2P 1378.50
FBK - EJ 1878.00	FBK - EJ 2705.00	FBK - EJ 4086.50	FBK - EJ 3953.00	HPK - G2P 3732.50	HPK - G2P 4482.00	HPK - G2P 4532.00	HPK - G2P 4034.00	HPK - EJ 2765.00	HPK - EJ 3244.50	HPK - EJ 4129.00	HPK - EJ 4080.00	HPK - G2P 3266.00	HPK - G2P 3559.50	HPK - G2P 2273.50	HPK - G2P 2056.50
HPK - G2P 2380.50	HPK - G2P 3707.50	HPK - G2P 5729.50	HPK - G2P 5318.00	HPK - EJ 5174.00	HPK - EJ 5843.00	HPK - EJ 4690.00	HPK - EJ 3865.00	FBK - G2P 2643.00	FBK - G2P 4789.50	FBK - G2P 5098.50	FBK - G2P 3363.00	HPK - EJ 3349.00	HPK - EJ 4059.50	HPK - EJ 2853.50	HPK - EJ 2671.00
HPK - G2P 3071.50	HPK - G2P 6642.00	HPK - EJ 10246.00	HPK - EJ 7729.50	HPK - EJ 5663.50	HPK - EJ 5495.00	HPK - G2P 4727.00	HPK - G2P 4255.50	HPK - EJ 3245.00	HPK - EJ 7158.00	HPK - EJ 4488.50	HPK - EJ 2848.50	HPK - EJ 3181.00	HPK - EJ 4175.00	HPK - EJ 3435.00	HPK - EJ 3236.50
FBK - G2P 3367.00	FBK - G2P 5959.00	FBK - EJ 7966.00	FBK - EJ 5966.00	FBK - G2P 5458.50	FBK - G2P 5170.50	FBK - EJ 4560.50	FBK - EJ 3798.00	HPK - G2P 2279.00	HPK - G2P 4152.50	HPK - G2P 3005.50	HPK - G2P 2398.00	FBK - G2P 3025.50	FBK - G2P 4018.00	FBK - G2P 5020.00	FBK - G2P 4703.00
FBK - EJ 2825.50	FBK - G2P 4150.00	FBK - G2P 4895.00	FBK - G2P 5287.50	FBK - G2P 6984.50	FBK - G2P 5597.00	FBK - EJ 4633.00	FBK - EJ 3681.50	FBK - G2P 1667.50	FBK - G2P 2323.00	FBK - G2P 2301.00	FBK - G2P 2094.00	HPK - G2P 2954.00	HPK - G2P 4985.50	HPK - G2P 6109.00	HPK - G2P 3220.50
HPK - EJ 2750.50	HPK - EJ 3957.50	HPK - EJ 4593.50	HPK - EJ 5849.50	FBK - EJ 7022.00	FBK - EJ 8329.50	FBK - EJ 5602.50	FBK - EJ 4004.00	FBK - EJ 1401.50	FBK - EJ 1766.00	FBK - EJ 1825.50	FBK - EJ 1750.50	HPK - EJ 2577.00	HPK - EJ 4381.50	HPK - EJ 3308.00	HPK - EJ 2360.00
FBK - EJ 3079.00	FBK - EJ 4311.50	FBK - EJ 4663.50	FBK - EJ 5516.00	FBK - G2P 5979.50	FBK - G2P 7025.50	FBK - G2P 5639.50	FBK - G2P 4263.00	FBK - G2P 1390.50	FBK - G2P 1608.50	FBK - G2P 1583.50	FBK - G2P 1523.00	HPK - EJ 2002.00	HPK - EJ 3150.50	HPK - EJ 3423.50	HPK - EJ 3956.00
HPK - EJ 2410.00	HPK - EJ 3646.00	HPK - EJ 5114.00	HPK - EJ 4595.00	HPK - G2P 4700.00	HPK - G2P 5872.00	HPK - G2P 5000.00	HPK - G2P 3401.00	HPK - G2P 2879.00	HPK - G2P 2263.00	HPK - G2P 1414.00	HPK - G2P 1248.00	HPK - G2P 1792.00	HPK - G2P 3064.50	HPK - G2P 2848.50	HPK - G2P 1886.00
FBK - EJ 1686.50	FBK - EJ 2590.50	FBK - EJ 4152.50	FBK - EJ 3173.50	HPK - EJ 3065.50	HPK - EJ 3030.50	HPK - EJ 2618.50	HPK - EJ 2083.00	FBK - G2P 1574.50	FBK - G2P 2169.50	FBK - G2P 1285.50	FBK - G2P 983.50	HPK - G2P 1703.50	HPK - G2P 3137.50	HPK - G2P 1545.00	HPK - G2P 998.00



# PDE results (preliminary)

- Values ~1%
  - investigating some channels with very low values.
- MC with low statistics
  - to be improved.
- Expected **relative differences** ~ (24-35)% between **EJ** and **G2P** not seen in these preliminary results
- Working on more energies and APA1 (full streaming mode)

