Common ground for 0nbb electronics

from a NEXT perspective

Curro Toledo – jtoledo@upv.es, the NEXT Collaboration

Neutrinoless double beta decay search in Xe - Next-generation experiment workshop in Montreal 12-14 November

First, the conclusion

We all have well defined, even ready to use in some cases, readout electronics for our future detectores/upgrades.

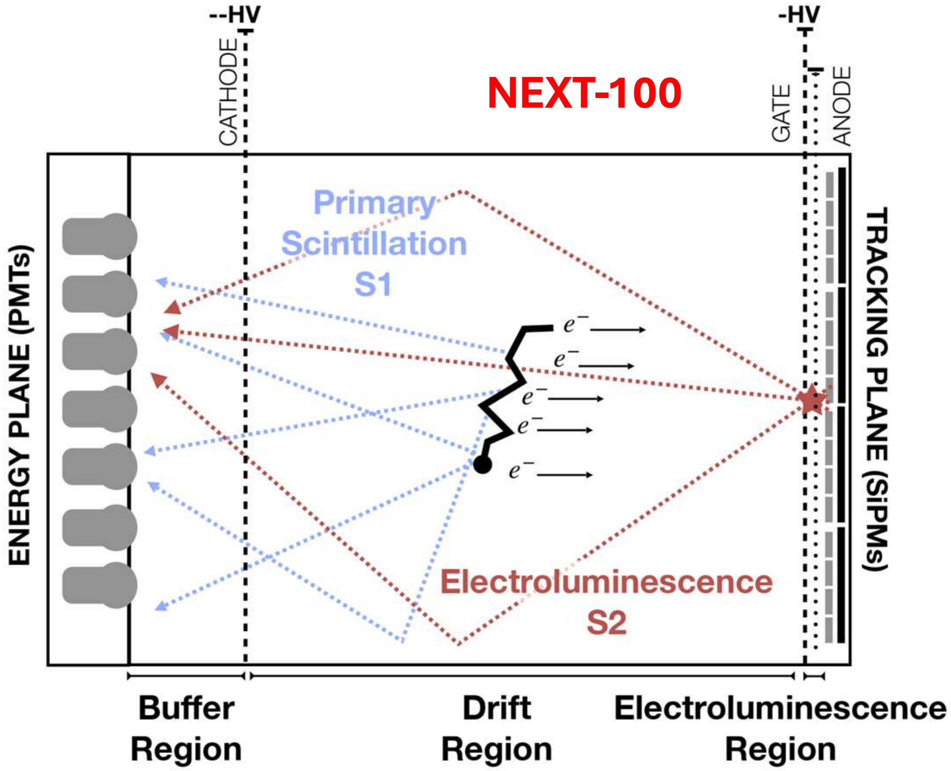
Still, there's enough common ground to justify a collaboration where we can all (hopefully) exchange expertise and reduce suffering.

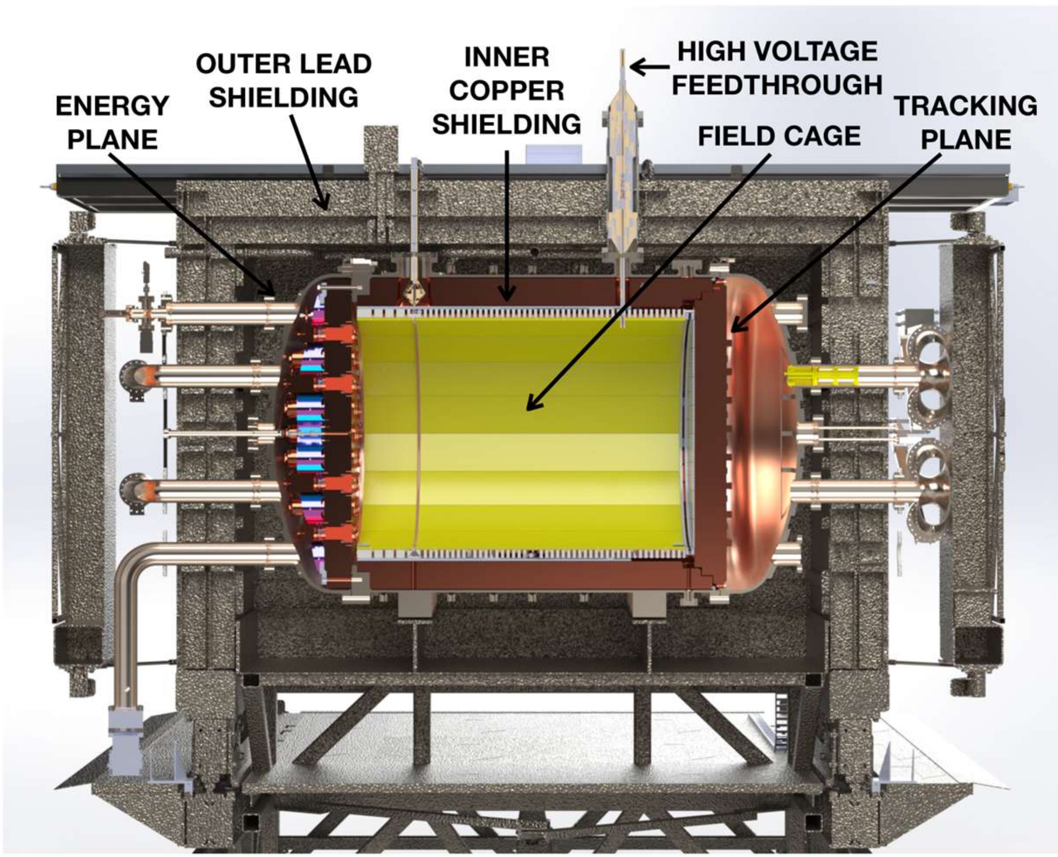
NEXT’s plans

"**The NEXT-100 Detector**" https://arxiv.org/html/2505.17848v1

Running since summer 2024

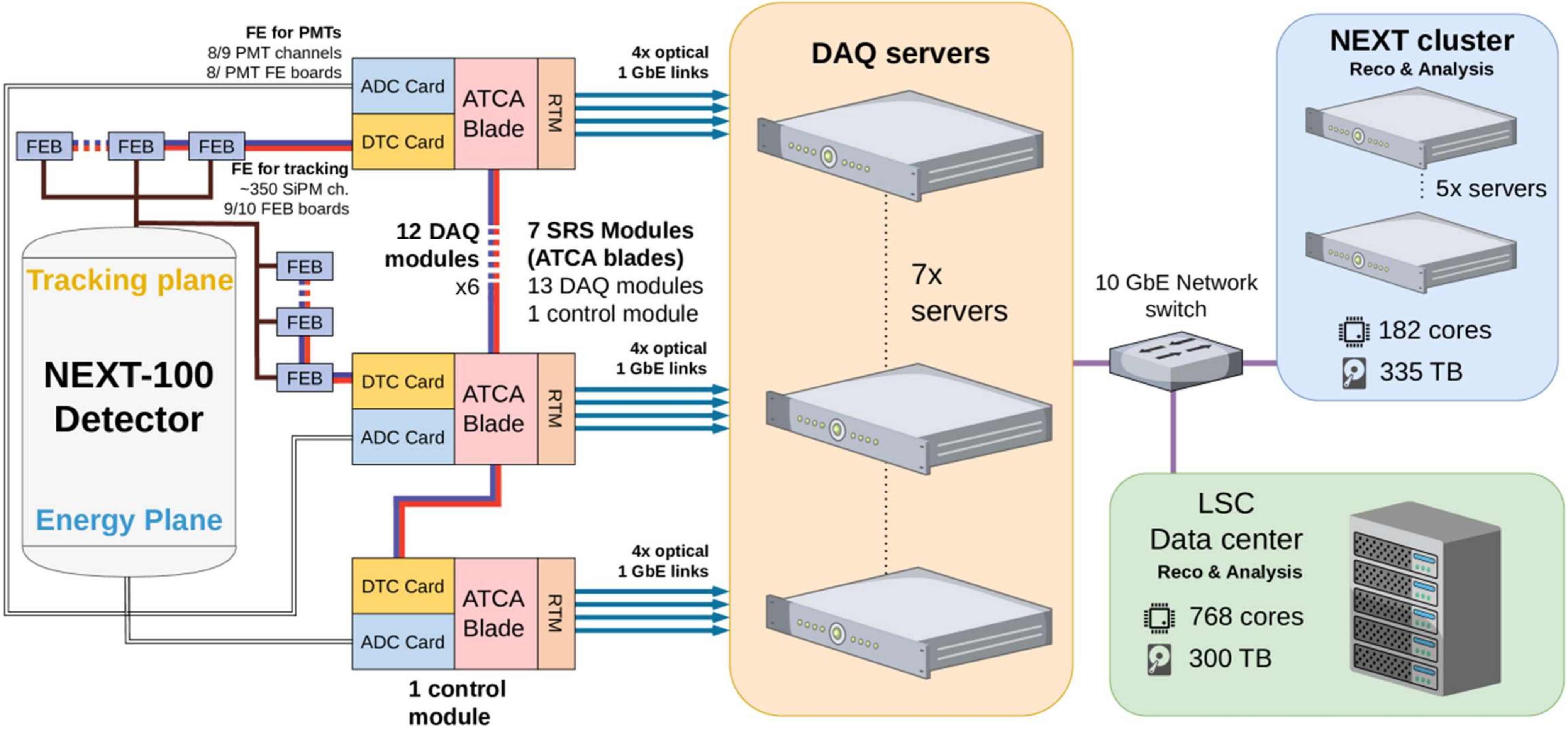
- Energy plane: 60 PMTs for S1 detection and energy measurement (S2)
- Tracking plane: 3.5k SiPM tracking plane for topological reconstruction & event filtering
- 12 cm copper shield
- Off-detector readout electronics





“The NEXT-100 Detector” https://arxiv.org/html/2505.17848v1

DAQ: ALICE’s DATE replaced with a custom framework: Duck (https://github.com/next-exp/duck)

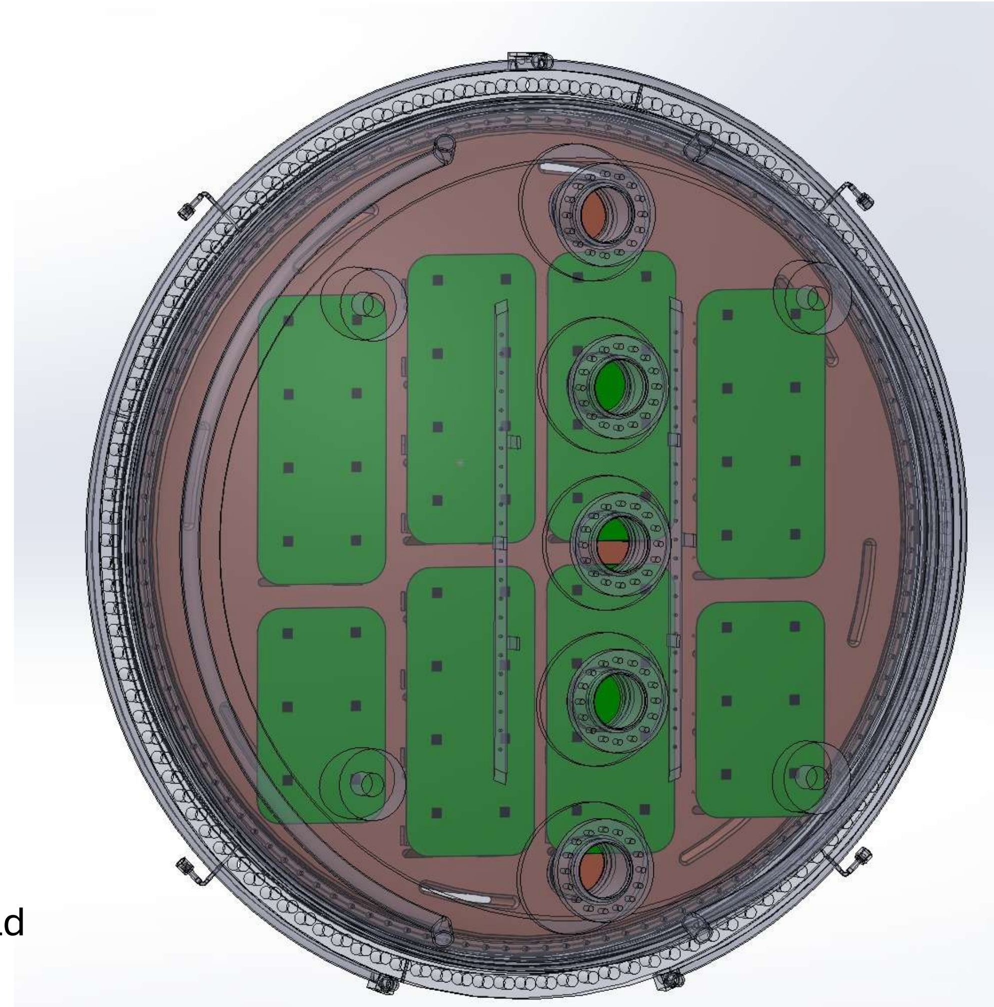


NEXT 100 upgrade

Tracking Plane with 15 mm pitch (3584 SiPMs – 56 DBs):

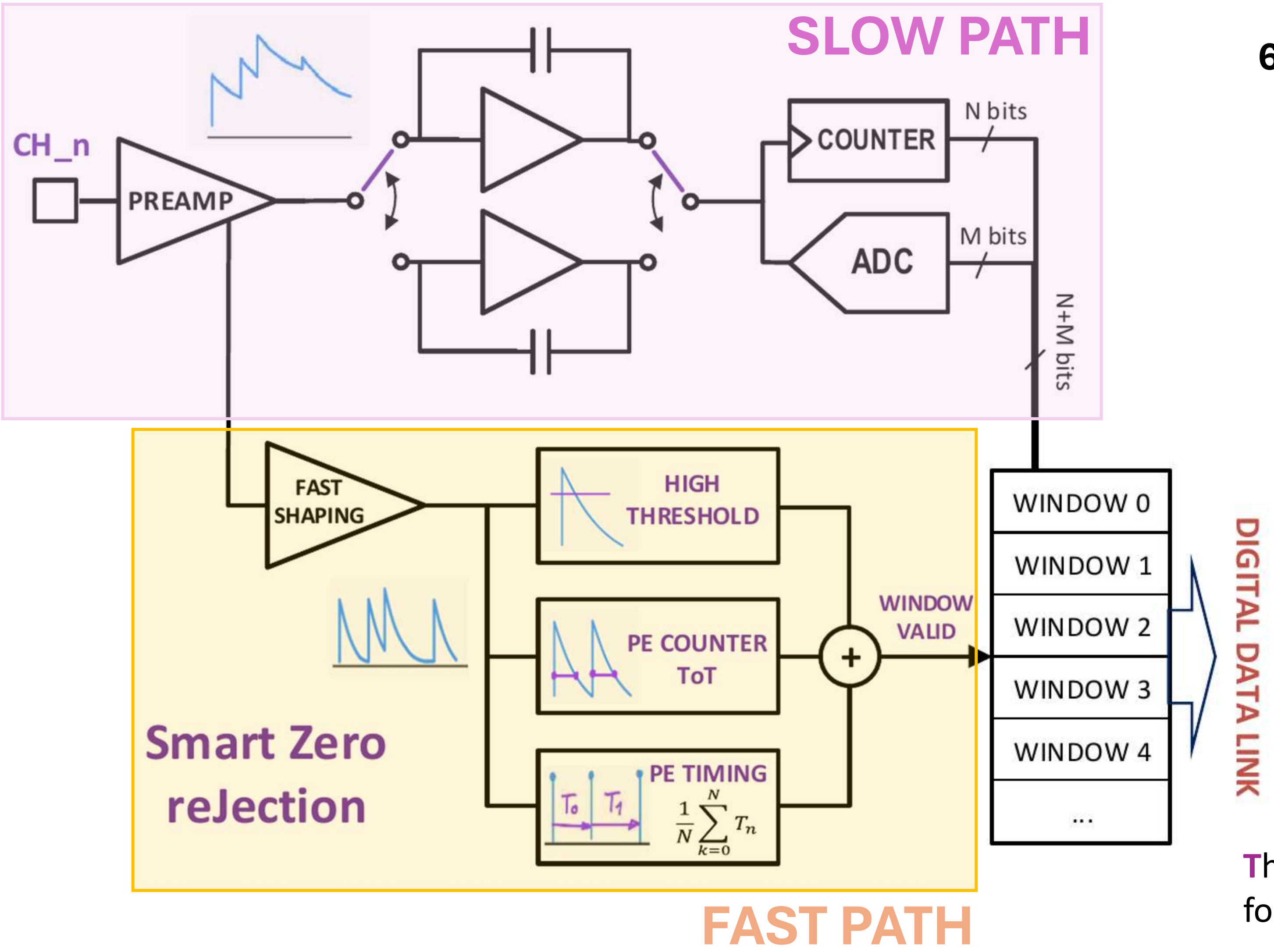
- 8 Readout Tiles, with:
  - 6-8 mixed-signal 64-ch ASICs each
  - 2x optical transceivers
  - Bare-die FPGA (comms hub)
  - SRAM (double event buffer)
  - Voltage regulators, auxiliar logic
  - 8x conns to SIPM array cables
- Total:
  - 56 ASICs
  - 16x 220 Mb/s fibers (DAQ and timing/control)

- No need for a second concentrator stage
- Power Consumption: 14x8 W = **112 W**
- Use low-background components despite the 12-cm Cu shield

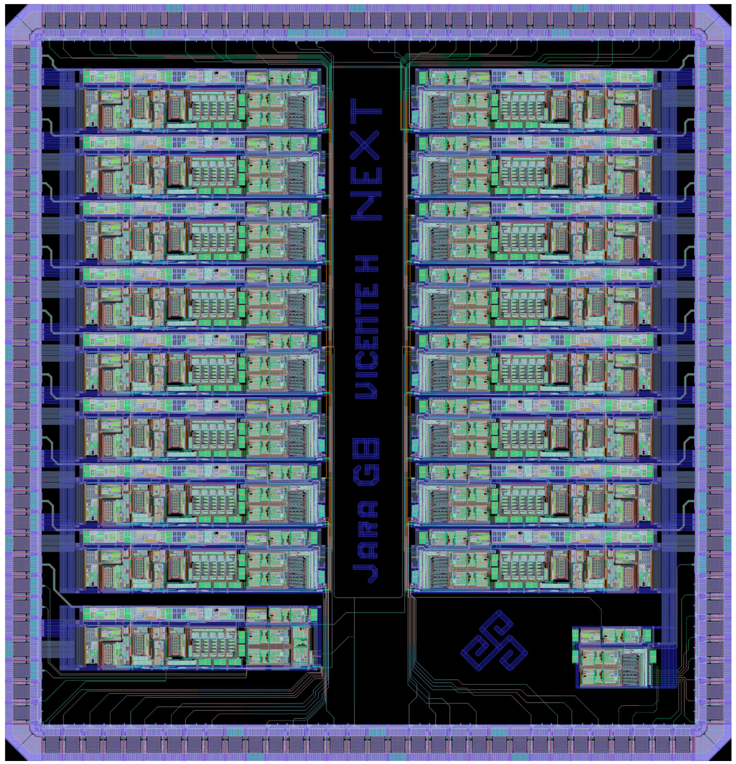


V. Herrero, J. García-Barrena, "**ASIC Development for NEXT**", available upon request

Readout ASIC



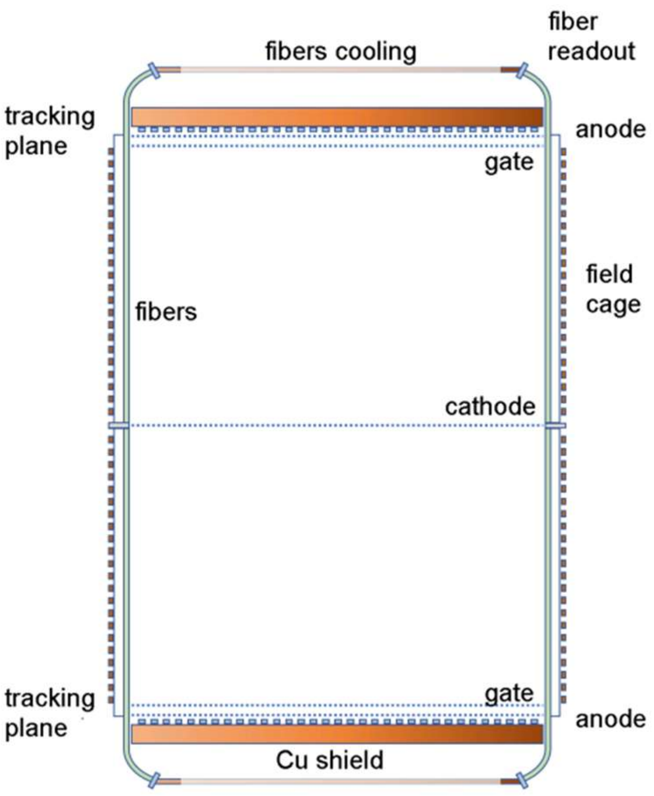
6-ch NEXT ASIC prototype: TRISKJ

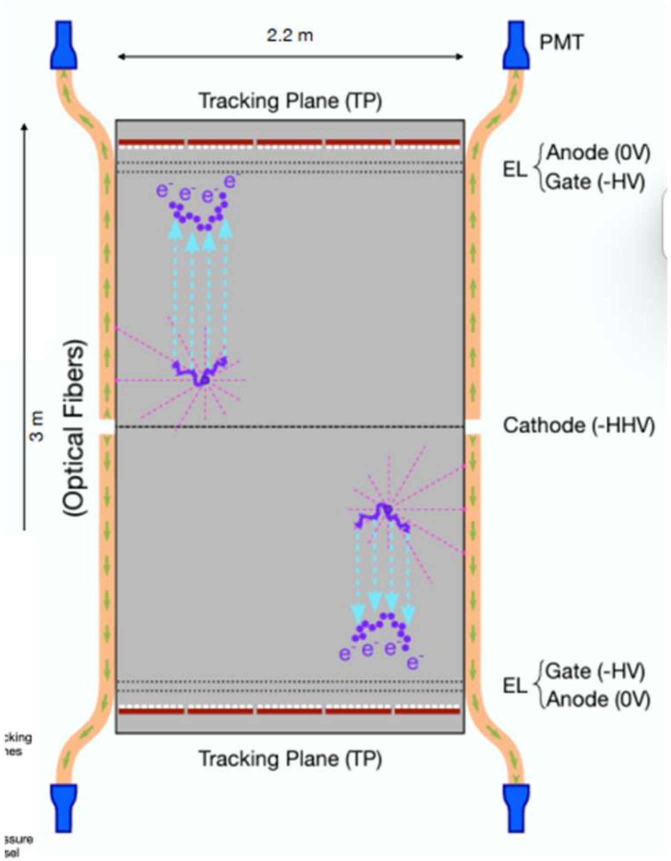


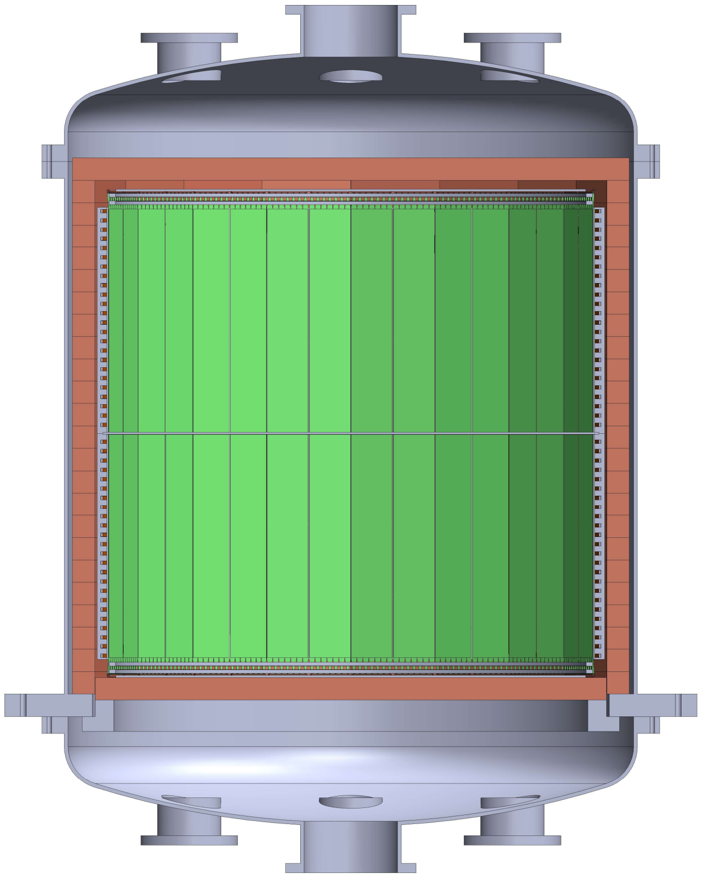
Threshold signal Recovery and Improvement for Statistical darK count reJection

NEXT HD

- Ton-scale gas Xe **symmetric TPC**, reflective cathode in the middle, 12-cm inner copper + 3m of water shielding
- **Dense SiPM planes (ca. 50k SiPM/plane)** on both ends, pitch reduced to 10 mm
- **WLS fiber barrel** for energy measurement

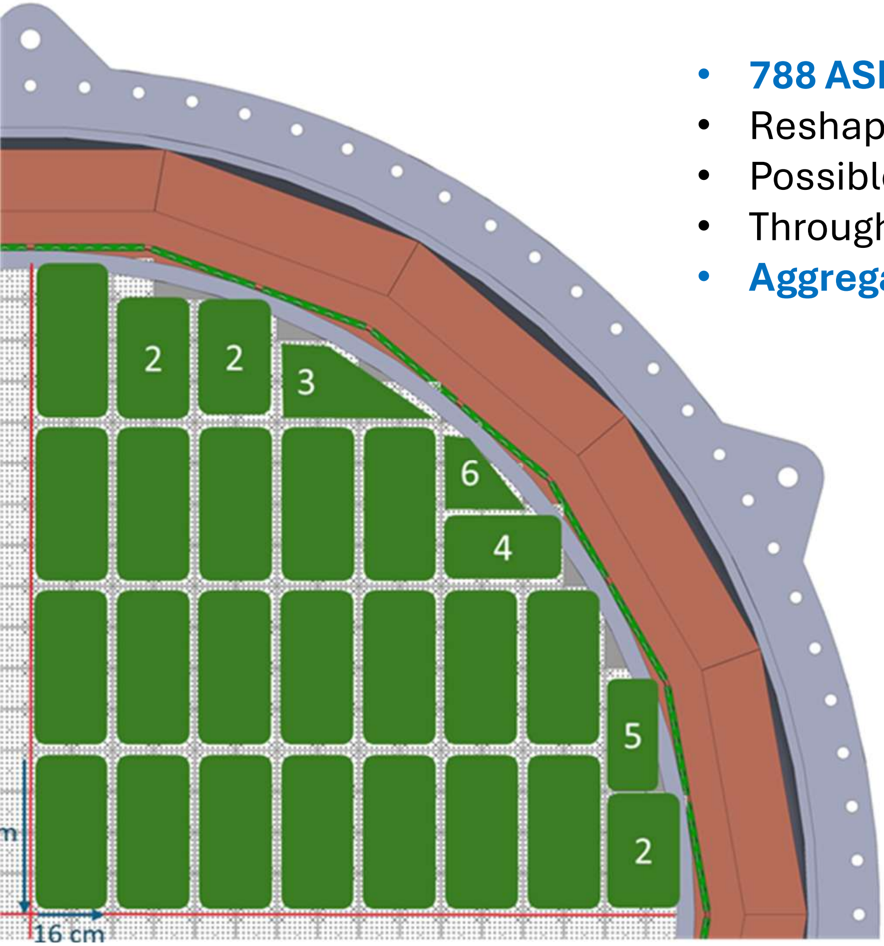




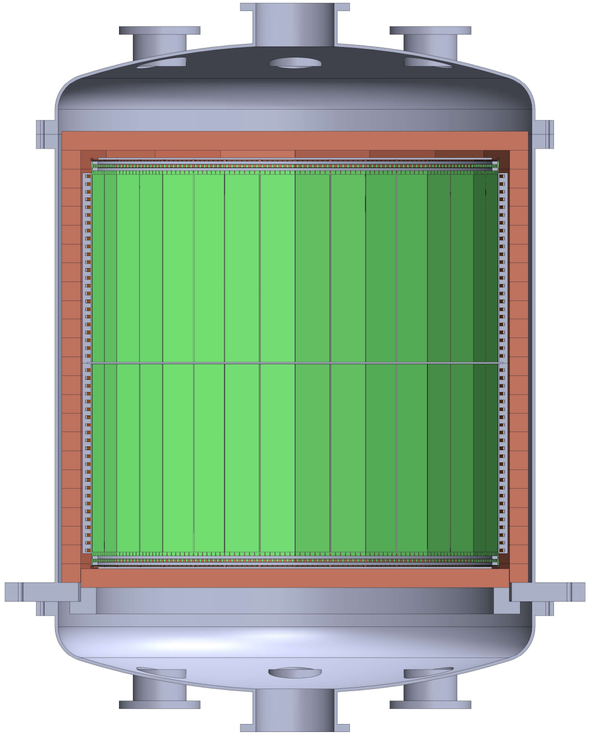


NEXT HD tracking plane

- Dense SiPM planes (ca. 50k SiPM/plane) on both ends, pitch reduced to 10 mm

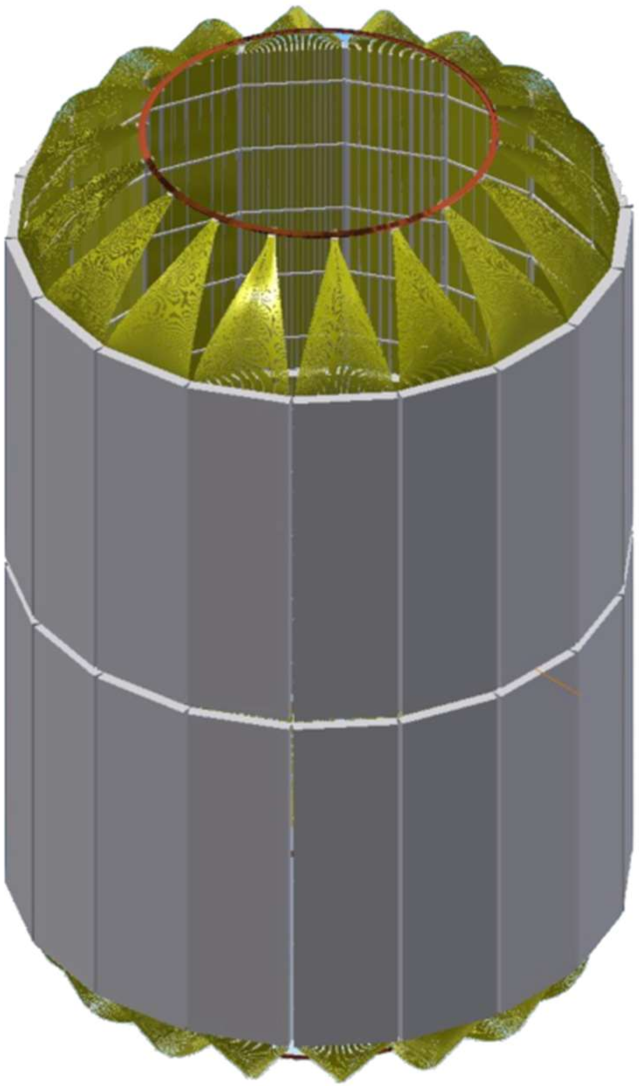


- **788 ASICs in 216 tiles**
- Reshape NEXT100-upgrade tiles to 6 geometries
- Possible ASIC upgrade from 12 to 14-bit ADCs?
- Throughput per tile: 256 Mb/s
- **Aggregated throughput excedes 50 Gb/s**



- In-detector mux stage to reduce number of fibers accross the FT
- Ca. **2800 W power dissipation**

NEXT HD fiber barrel



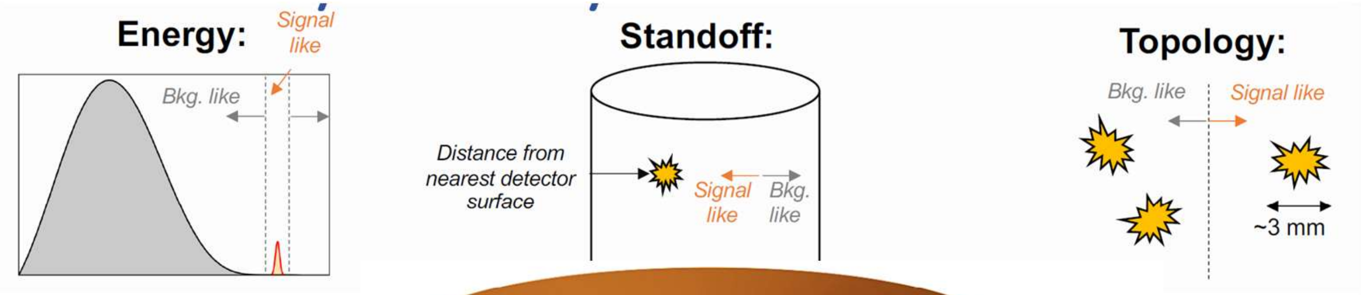
- Fiber barrel for energy measurement (504 cooled SiPMs)
- No PMTs: improved background budget
- TPC walls covered by double-clad wavelength shifting fibers read out with cooled SiPMs
- Readout electronics: custom external FE + SRS-ATCA digitizer+ DAQ

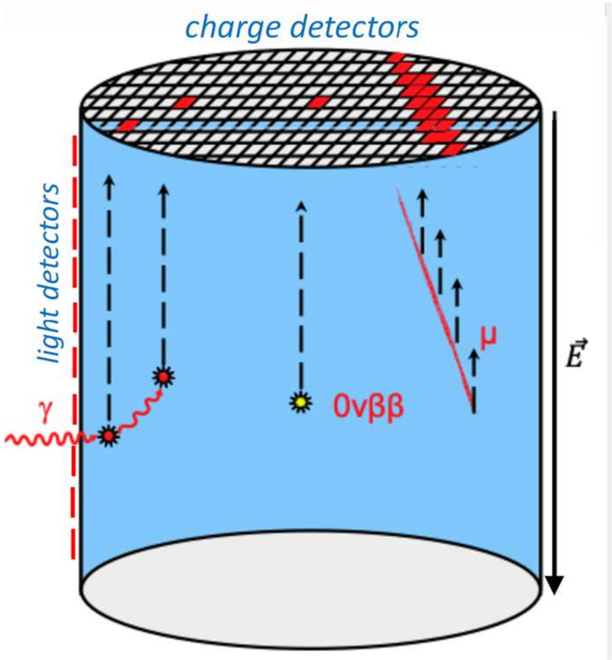
R. Soletti, “**Towards a fiber barrel detector for next-generation high pressure gaseous xenon TPCs**” LIDINE 2023

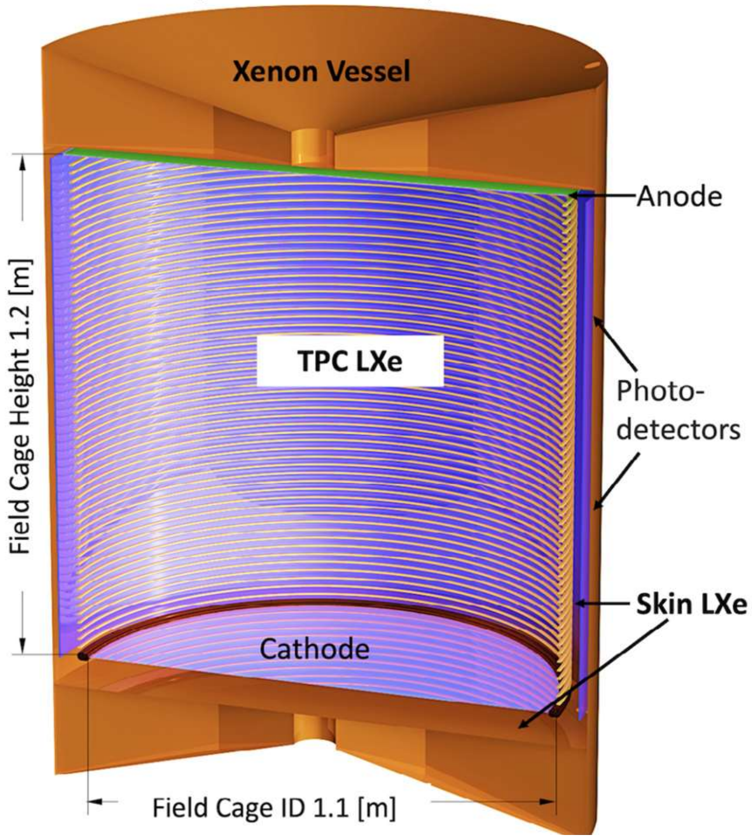
nEXO

E. Angelico, “**Searching for neutrinoless double beta decay using the nEXO detector**” LIDINE 2023, Madrid

T. Stiegler et al., “**Event reconstruction in a liquid xenon Time Projection Chamber with an optically-open field cage**” NIM A 1000 (2021) 165239



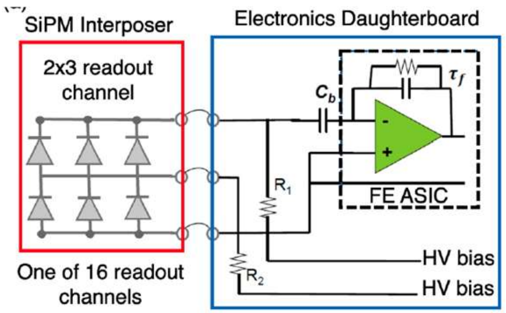


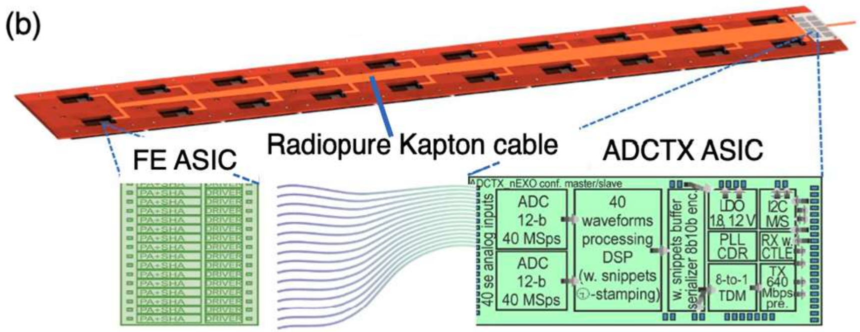


5-ton LXe TPC, aims at ca.1% energy resolution at Qbb
Single-photon resolution at 175 nm UV scintillation
In-detector read-out electronics (in cold, 163 K)

M.P. Watts, “**nEXO photon detection system and read-out electronics**” 2025 JINST 20 C06009

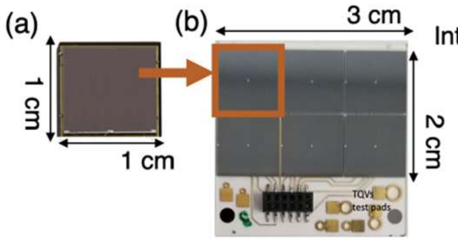
- 20-ns CRT between tiles required for event rejection
- 0.6-mm fused silica tile substrates (kapton, Cirlex considered too dirty)

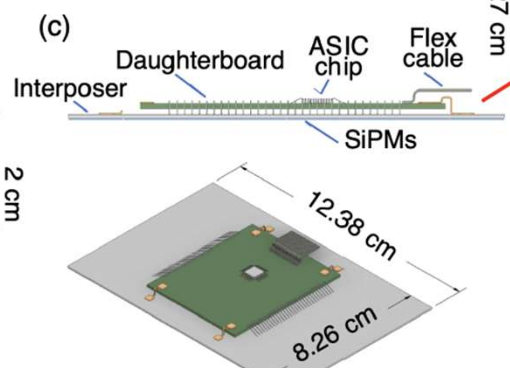


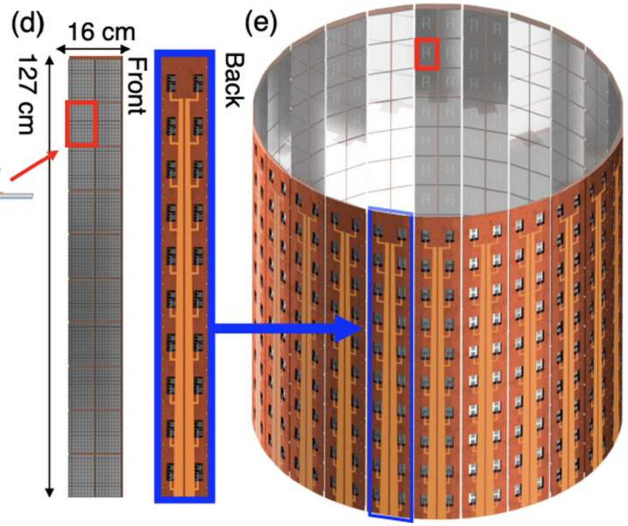


20-tile kapton stave (1920 SiPMs)

24 staves for 7680 channels (46k SiPMs)







4,6 m^2 VUV-sensitive SiPM area
>2% light-collection efficiency

6 SiPM = 1 channel
Fused silica board

16-channel tile with a
16-ch analog ASIC

XENONnT

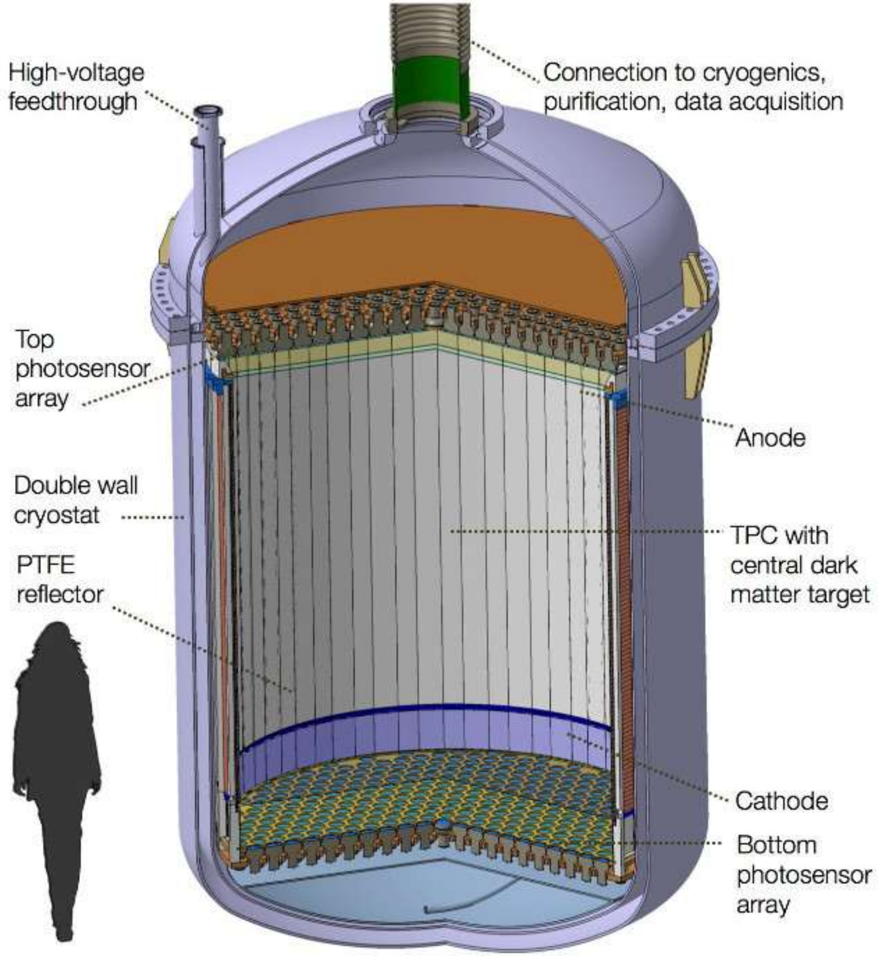
E. Aprile et al., "**The triggerless data acquisition system of the XENONnT experiment**" 2023 JINST 18 P07054

- Ton-scale LXe TPC, upgrade from XENON1T with TPC, muon veto + (new) neutron veto (120 PMTs)
- Only light sensors (S1 + S2 from electroluminiscence)
- Trigerless DAQ (only a per-channel threshold is applied) based on COTS modules

494 PMTs:
- 253 PMTs in the TPC's top array (low + high gain channels, custom FE by U. Zurich)
- 241 PMTs in the bottom array (low-gain are summed for a HE veto)

Read-out:
- CAEN digitizers (100, 500 MHz), scalers and clock generators.
- GPS timestamp (15 ns accuracy) to all digitizers

DAQ:
- Based on Strax, a Python framework



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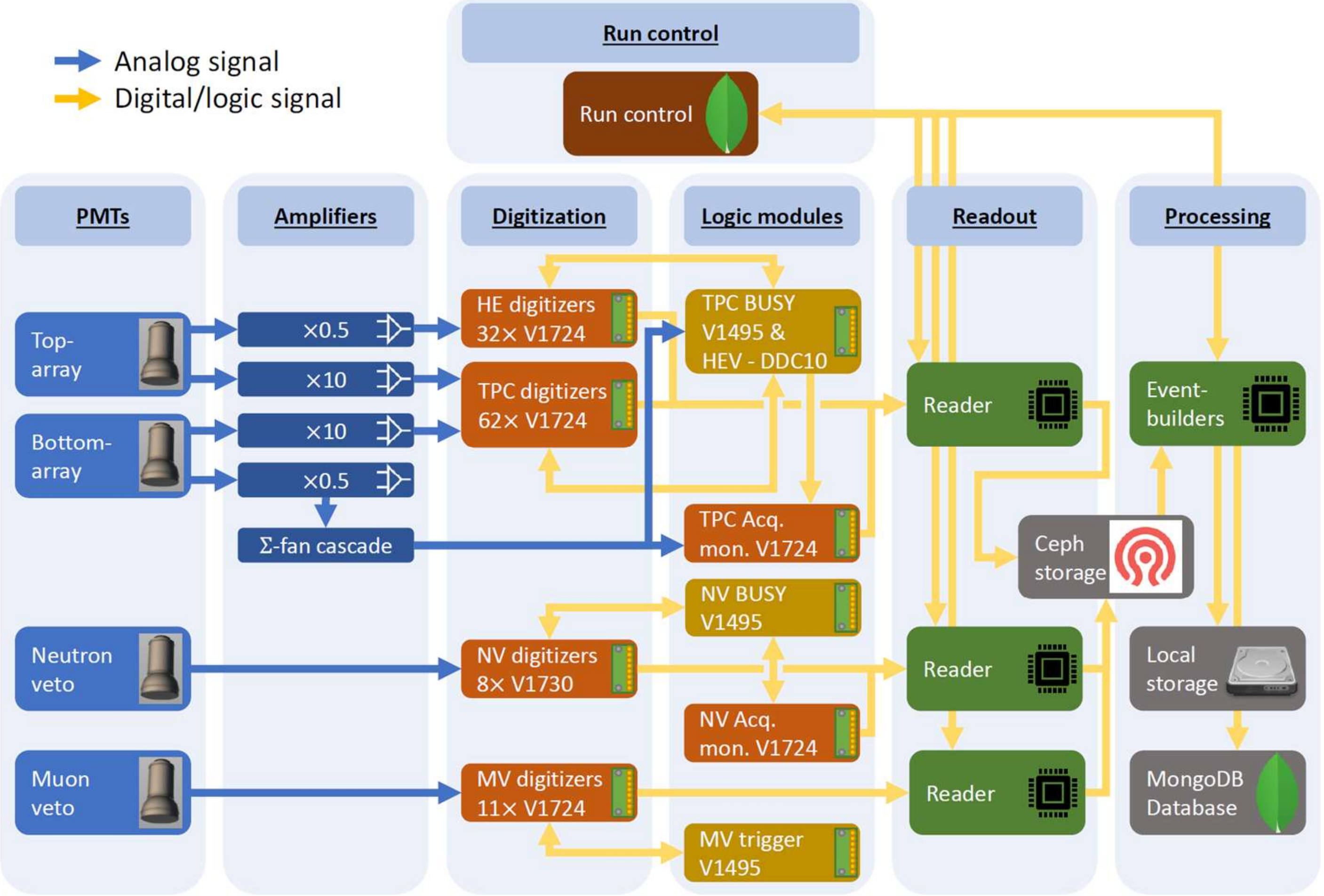
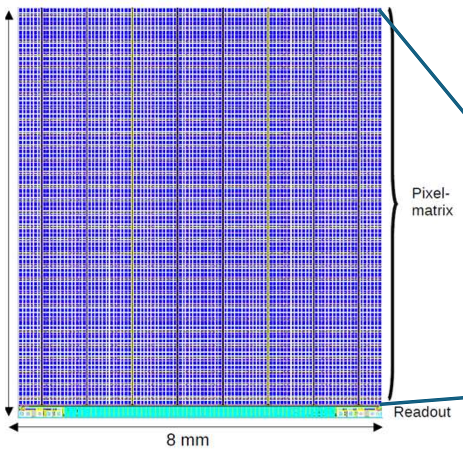


XLZD

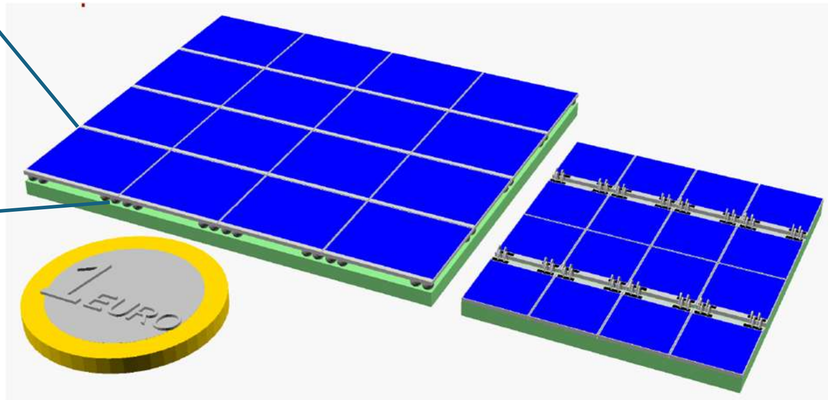
A. Bismarck., “**Xenoscope and Photosensor R&D for DARWIN at UZH**” LIDINE 2023

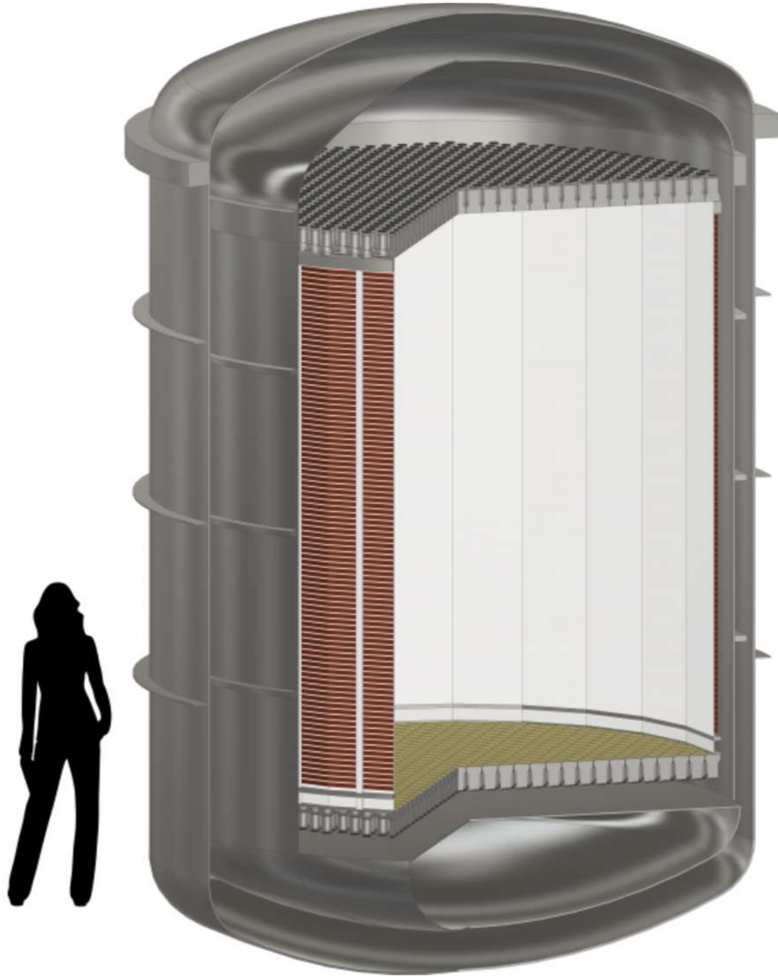
M. Keller et al., “**Digital SiPM array with high fill factor and data driven readout for photo detection in liquid noble gas experiments**” LIDINE 2023

- 50-ton scale two-phase Xe TPC inside a cryostat, with top and bottom 3” PMT planes (1800 in total)
- Alternative to PMTs: Digital SiPMs (lower cost, more radiopure)



- Based on U. Heidelberg (Fischer & Keller)
- High fill factor (77%)
- 8640 SPADs
- Pins/balls on bottom for higher fill factor



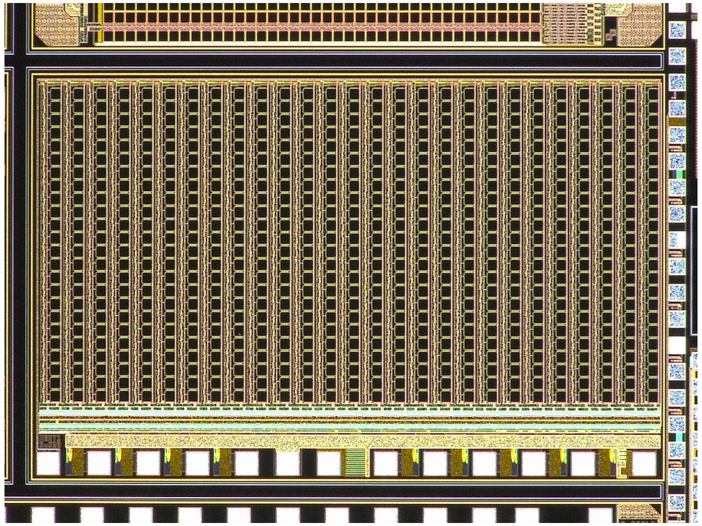


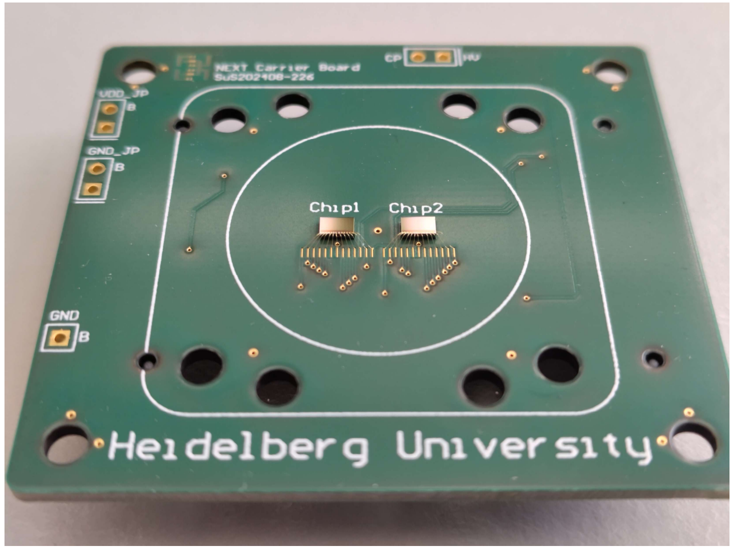
- **In 2025, an ASIC for DARWIN was produced, as well as a protype ASIC for NEXT, based on the same technology**

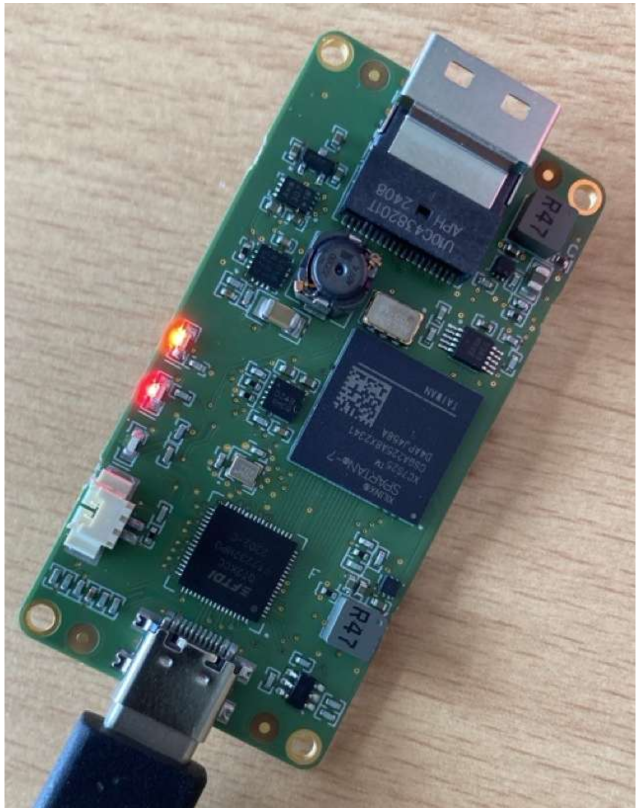
Readout ASIC alternative FOR NEXT

NEXT Digital SiPM prototype based on SPAD (Fischer & Keller): DPDNXT1

- 65 ASICs available
- Several ASICs glued and bonded to PCBs
- Test module (with USB interface) available and tested

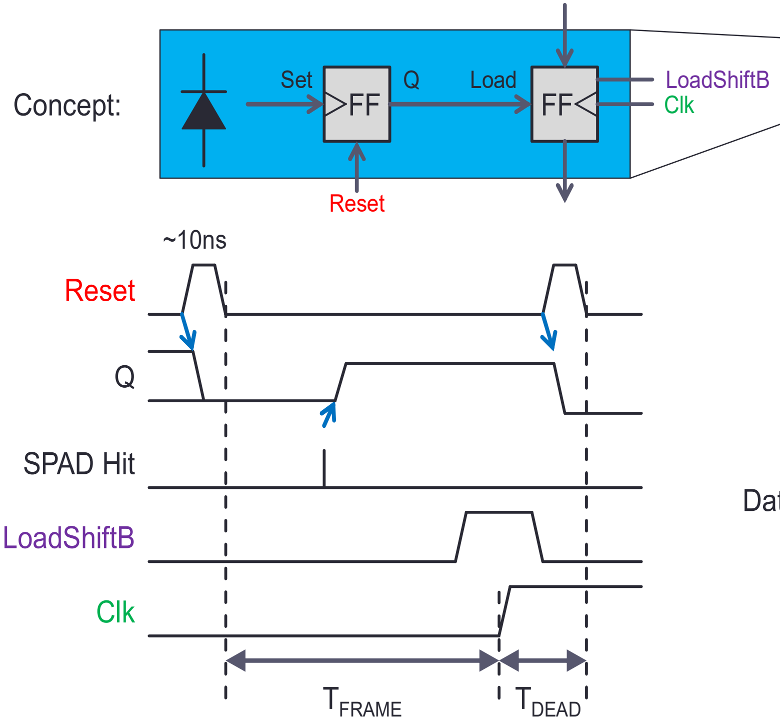


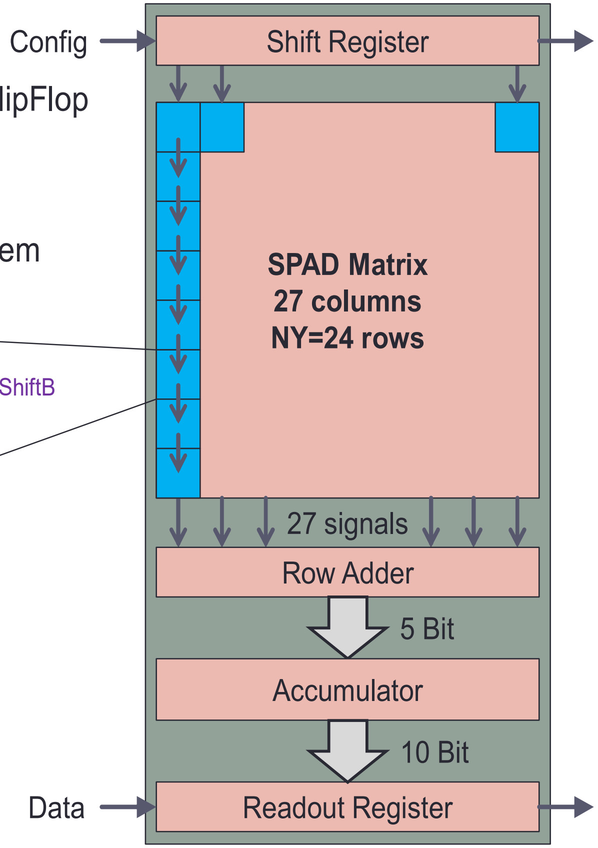




Readout: Principle

- Hits in Pixel are stored in a Hit Flipflop
- After T_{FRAME} they are transferred to a shift register FlipFlop
- Hit FF is cleared, new hits can be accepted
- Flipflop data is clocked down and added up digitally
- Small dead time (~20ns) from reset/load -> no problem





Quantity	Value
Chip Dimensions	$2887 \times 1852\,\mu m^2$
Number of pixels	$NX \times NY = 27 \times 24 = 648$
Pixel pitch	$105 \times 60\,\mu m^2$
Sensitive SPAD area per pixel	$2414\,\mu m^2$
Matrix fill factor	38%
Total SPAD area on chip	$1.56\,mm^2$
Number of pads	13
Minimal frame time	$\approx 100\,ns \times N_{CHIP}$

COMMON GROUND

IDENTIFIED INTERESTS

Isaac J. Arnquist et al., “**Ultra-low radioactivity flexible printed cables**” 2023 EPJTI (link)

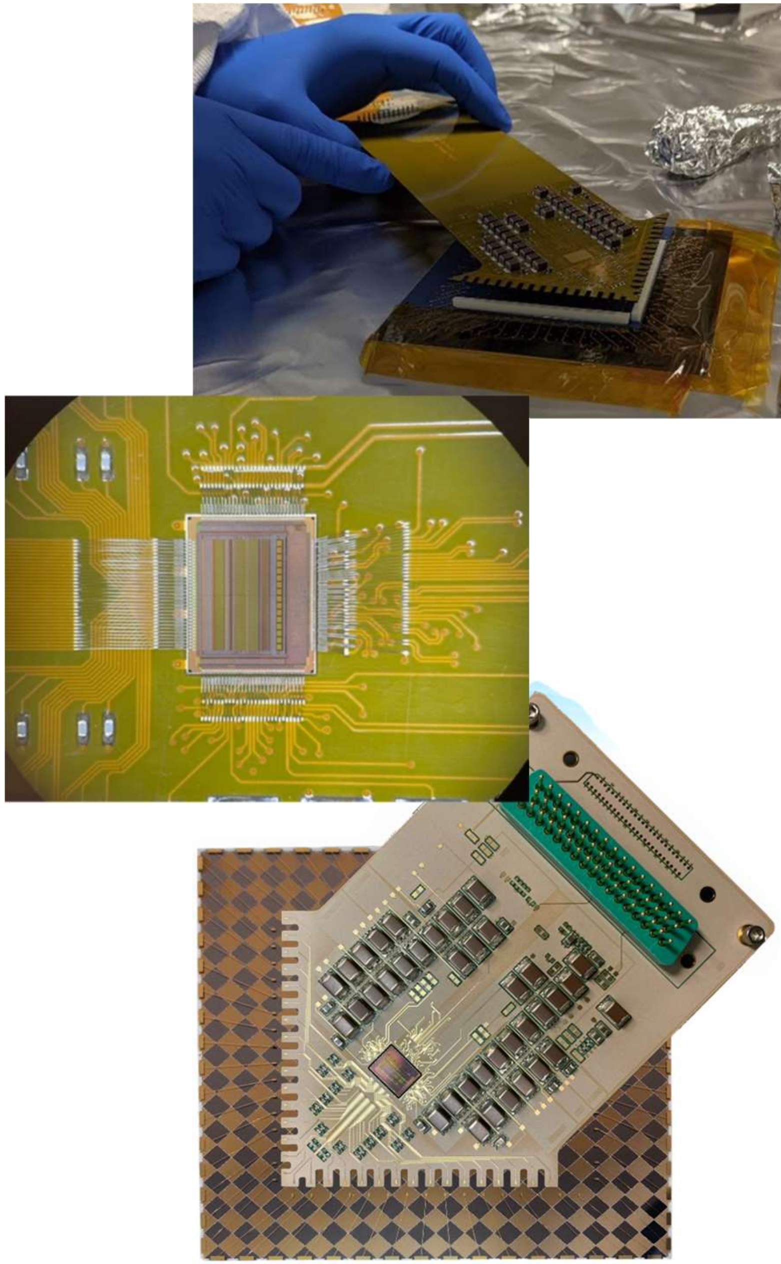
- Cu-clad polyimide cables with 10x activity reduction wrt EXO-200

E. Angelico, “**nEXO charge-readout module with built-in, cryogenic ASIC readouts**” LIDINE 21, 9-16-2021

- COB & wire bonding
- Fast digital I/O ASIC interface (ca. 1 Gbps)
- Low-activity capacitors & other passives (nEXO, NEXT, AXEL databases)
- Bias voltage distribution (electronics and SiPMs) and power efficiency for large in-vessel planes and sensor readout

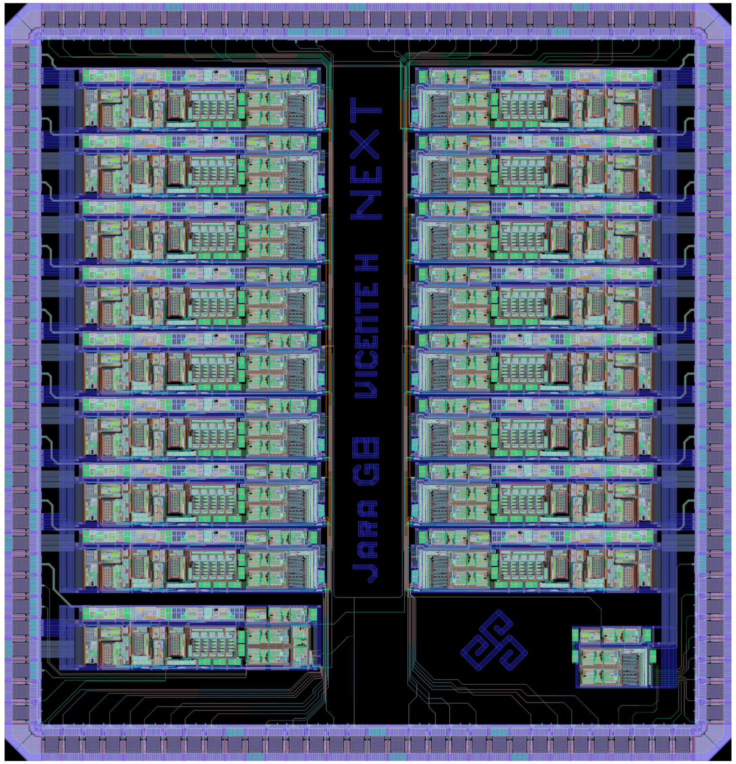
M. Keller et al., “**Digital SiPM array with high fill factor and data driven readout for photo detection in liquid noble gas experiments**” LIDINE 2023

- SPAD-based Digital SiPM technology from U. Heidelberg



IDENTIFIED INTERESTS

- Optical fiber across feedthroughs
- IN-vessel low-power low-background optical transceivers



Ge screening results

Category	Material	mass for Ge [g]	time for Ge [day]	middle-U (214Bi) [mBq/kg]	lower-Th (208Tl) [mBq/kg]	mass for 1000L [kg]	middle-U (214Bi) [mBq]	lower-Th (208Tl) [mBq]	comment
Chamber	SUS (Morimatsu)	4349.7	4.9	<0.88	<1.21	~1000	<880	<1210	need Ge sensitivity
Chamber	welding wire	250.5	4.8	84900+-177	14300+-104	6.2	526380	88660	very sad
Feedthrough	epoxy (tecsam)	29.5	12.4	179+-19	188+-31	~1	179	188	
Feedthrough	Cable FPC 2.5m	31.4	3.0	<1.12	<1.56	3.7	<4.1	<5.8	
ELCC	MPPC (ceramic) x7	1.37	3.0	44400+-1310	6610+-936	1.5	66600	9915	to be reduced
ELCC	Unit FPC x2	9.0	9.8	<54.6	<93.4	0.53	<28.7	<49.2	
ELCC	PTFE	3368.1	4.6	<1.29	<1.46	6.1	<7.9	<8.9	
ELCC	PEEK	3042.5	7.0	21.7+-8.0	15.4+-10.8	1.0	21.7	15.4	
ELCC	connector (hirose) x10	2.17	1.9	6880+-673	9670+-1170	0.05	344	484	to be reduced
ELCC	mesh (welded)	50.71	6.3	107+-17	<31.2	2.0	214	<62.4	
ELCC	mesh (sintered) x1	0.22	6.8	<4060	<4220	0.026	<106	<110	
PMT	PMT x2	65.6	6.0	14.8+-9.8	<20.9	3.28	48.5	<68.6	to be replaced
PMT	breeder circuit x1	6.0	15.6	10500+-170	11700+-269	0.6	6300	7020	to be replaced
PMT	PMT cable x1	65.1	13.1	<12.6	<23.9	6.51	<63.7	<126	to be replaced
TPC	CW capacitor x20	12.7	3.1	1130+-85	327+-87	0.2	226	65.4	to be reduced
TPC	HDPE	1476.3	3.0	3.8+-2.0	<4.6	86	327	<396	
Electronics	AXELBOARD56 x1	316.9	15.9	6360+-24	10700+-43	37	235320	395900	outside

The conclusion, again

We all have well defined, even ready to use in some cases, readout electronics for our future detectores.

Still, there’s enough common ground to justify a collaboration where we can all (hopefully) Exchange expertise and reduce suffering.