SP PHOTON DETECTION SYSTEM

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University of Campinas - UNICAMP - Brazil

SP-PD Preliminary Design Review
18-19 June 2020

UNICAMP

FAPESP CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

Consortium Membership

Consortium Membership status on April 2020

Brazil	Federal University of ABC
Brazil	University Estadual de Feira de Santana
Brazil	Federal University of Alfenas Poços de Caldas
Brazil	Centro Brasileiro de Pesquisas Físicas
Brazil	University Federal de Goias
Brazil	Brazilian Synchotron Light Laboratory LNLS/CNPEM
Brazil	University of Campinas
Brazil	CTI Renato Archer
Brazil	Federal University of São Carlos
Brazil	Technological University of Paraná
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Colombia	Universidad del Atlantico
Colombia	Universidad Sergio Arboleda
Colombia	University Antonio Nariño

Czech Republic	Institute of Physics CAS, v.v.i.
Czech Republic	Czech Technical University in Prague
Paraguay	National University of Assuncion
Peru	PUCP
Peru	Universidad Nacional de Ingineria (UNI)
UK	Univ. of Warwick
UK	University of Sussex
UK	University of Manchester
UK	Edinburgh University
USA	Argonne National Lab

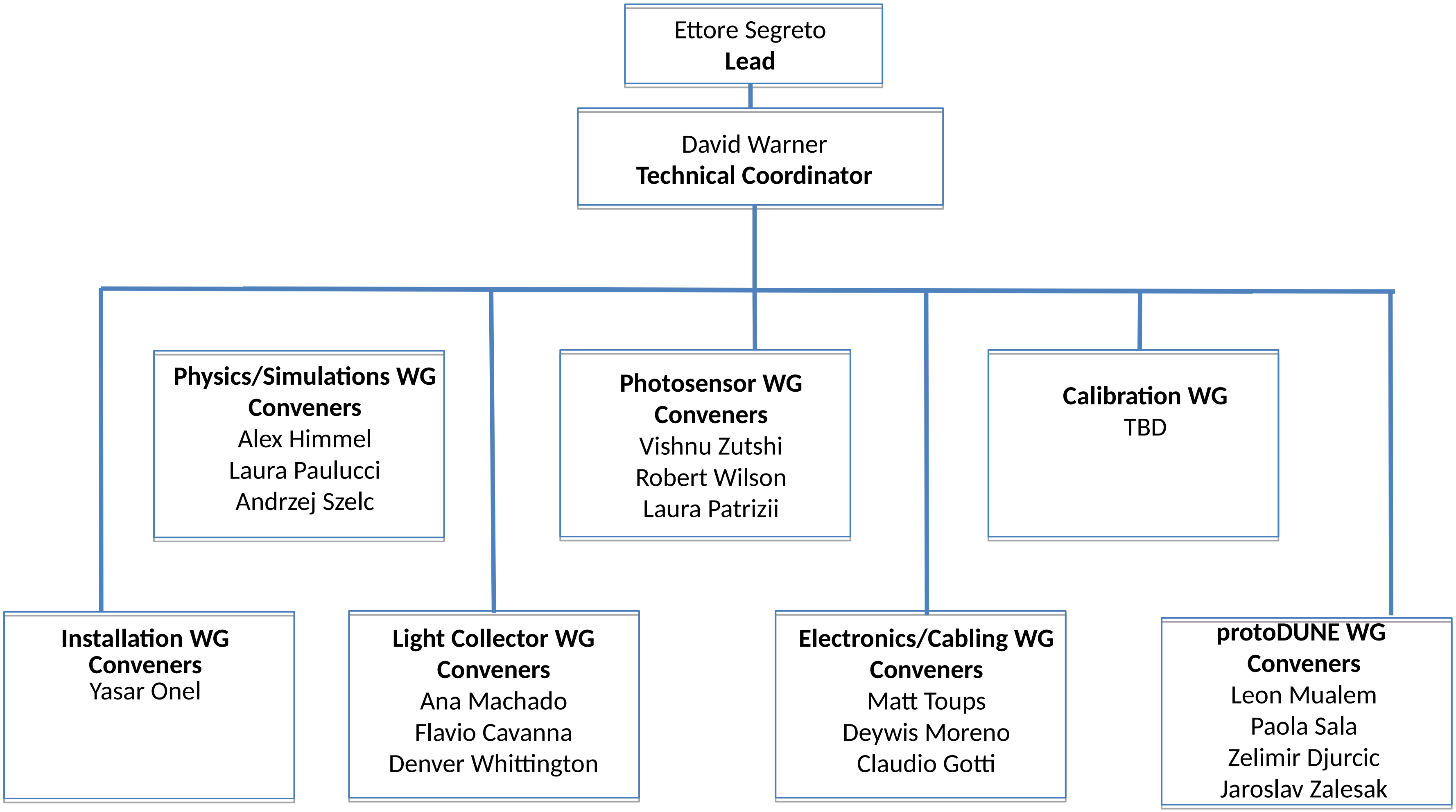
Consortium Membership

Pretty International Consortium

46 Participating Institutions ***equally distributed among Latin America (17) , North America (12) and Europe (17) as in the spirit of DUNE Colllaboration***

USA	California Institute of Technology
USA	Colorado State University
USA	Duke University
USA	Fermi National Accelerator Lab
USA	Idaho State University
USA	Indiana University
USA	University of Iowa
USA	University of Michigan
USA	Northern Illinois University
USA	South Dakota School of Mines and Technology
USA	Syracuse University
Italy	University of Bologna and INFN
Italy	University of Milano Bicocca and INFN
Italy	University of Genova and INFN
Italy	LNS Catania
Italy	University of Lecce and INFN
Italy	INFN Milano
Italy	INFN Padova
Italy	University of Ferrara and INFN
Spain	CIEMAT Madrid
Spain	Granada University
Spain	IFIC Valencia

PD Consortium Management Table of Organization



SP PD Scope

The scope of the photon detector (PD) system for the DUNE far detector reference design includes design, procurement, fabrication, testing, delivery and installation of the following components:

- ***Light collection system***
  - ✓ Collects photons from a large area and drives them towards the active sensors (SiPMs/MPPCs). **X-ARAPUCA** – an evolution of the ARAPUCA - is the baseline design.
- ***Silicon photomultipliers***
  - ✓ Two vendors with a proven experience in developing cyogenic sensors engaged by the Consortium: Hamamatsu and FBK. Both sensors will be tested in protoDUNE Run-II.
- ***Readout electronics***
  - ✓ Cold Summing board: acrively gangs the signals from the photosensors
  - ✓ DAPHNE: warm read-out board for digitization of the signals and communication with DAQ
- ***Monitoring system***
  - ✓ Led pulser, fibers and light diffusers
- ***Related infrastructure (***APA mounting, cabling, cryostat flanges, etc.)

Why do we need a PD system?

- ***Determination of T_0 for nucleon decay events:*** spatial localization of candidates fundamental to determine if its fully contained or associated with objects entering the detector from the outside. Correction for electron capture along the drift.

- ***For SNB neutrino events***, the PDS allows for proper location of the event vertex and improves **energy resolution** and gives possibly **greater sensitivity** to underlying supernova dynamical models.

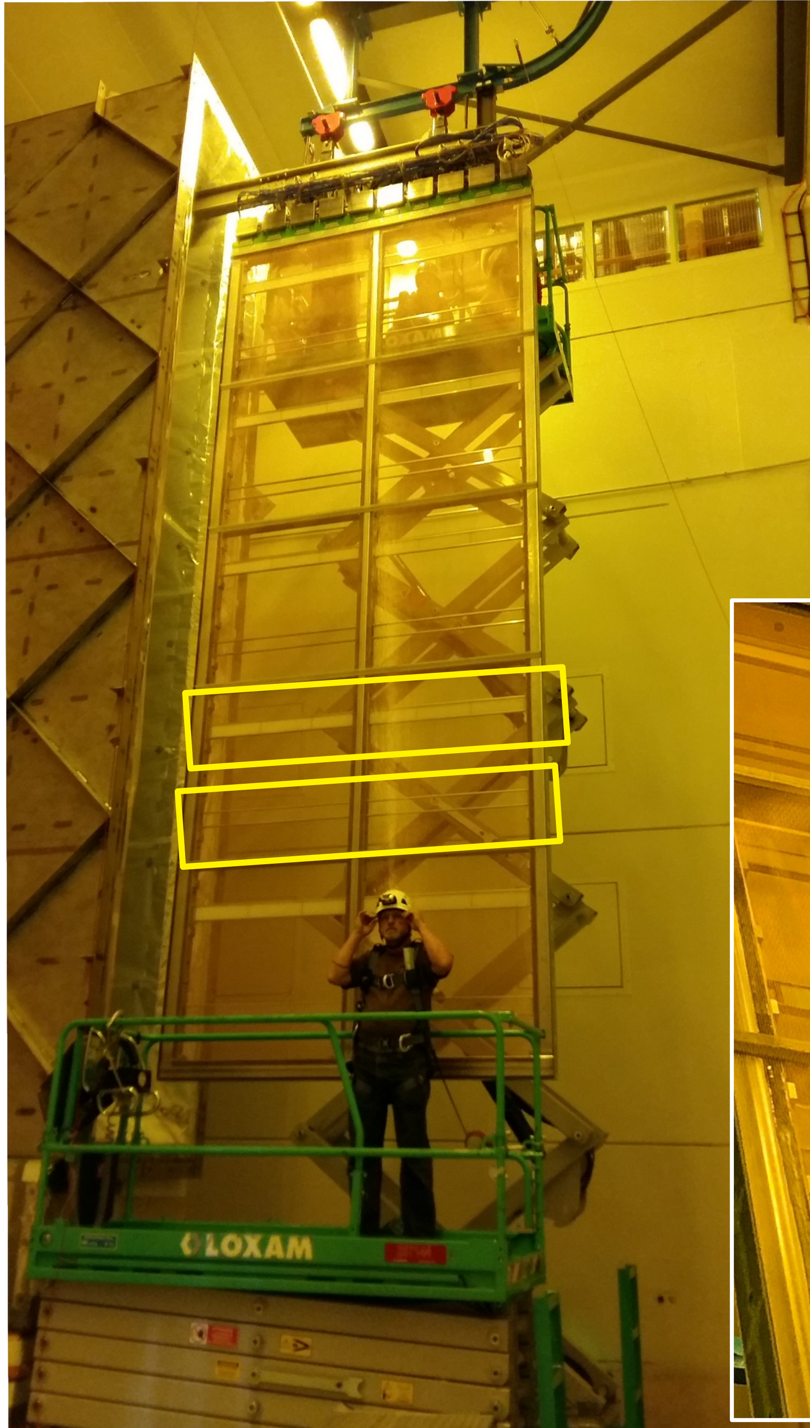
- The PDS also enables a **complementary triggering** scheme for the burst itself, increasing reliability, reducing dead time, and extending the sensitivity further out to nearby dwarf galaxies

- The PDS can also be used to directly measure ***energy calorimetrically*** for all classes of events working as a cross-check to the energy measured by the TPC or improving the resolution when both measurements are used together and exploiting the anti-correlation of light and charge

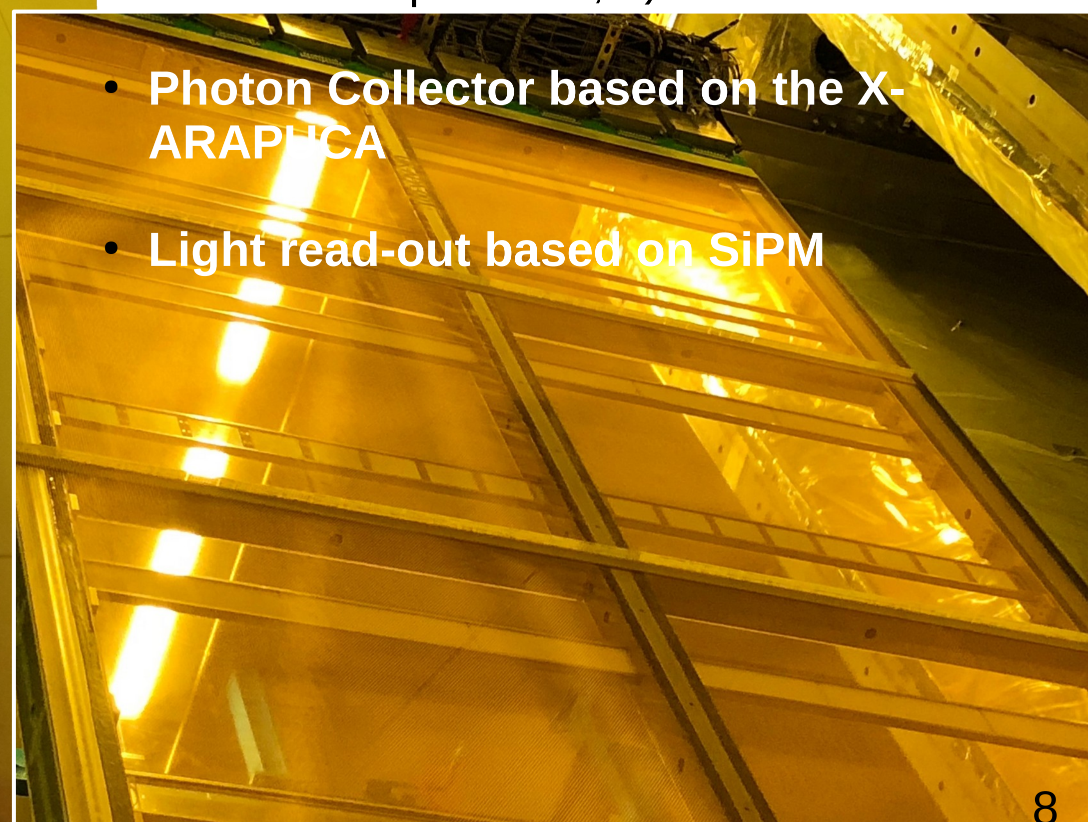
SPPD – High Level Requirements

Label	Description	Specification (Goal)	Rationale	Validation
SP-FD-3	Light yield	$>$ 20 PE/MeV (avg), $>$ 0.5 PE/MeV (min)	Gives PDS energy resolution comparable to that of the TPC for 5-7 MeV SN νs, and allows tagging of $>$ 99 % of nucleon decay backgrounds with light at all points in detector.	Supernova and nucleon decay events in the FD with full simulation and reconstruction.
SP-FD-4	Time resolution	$< 1\,\mu s$ ($< 100\,ns$)	Enables 1 mm position resolution for 10 MeV SNB candidate events for instantaneous rate $< 1\,m^{-3}ms^{-1}$.	
SP-FD-15	LAr nitrogen contamination	$< 25\,ppm$	Maintain 0.5 PE/MeV PDS sensitivity required for triggering proton decay near cathode.	In situ measurement

More in A. Himmel talk



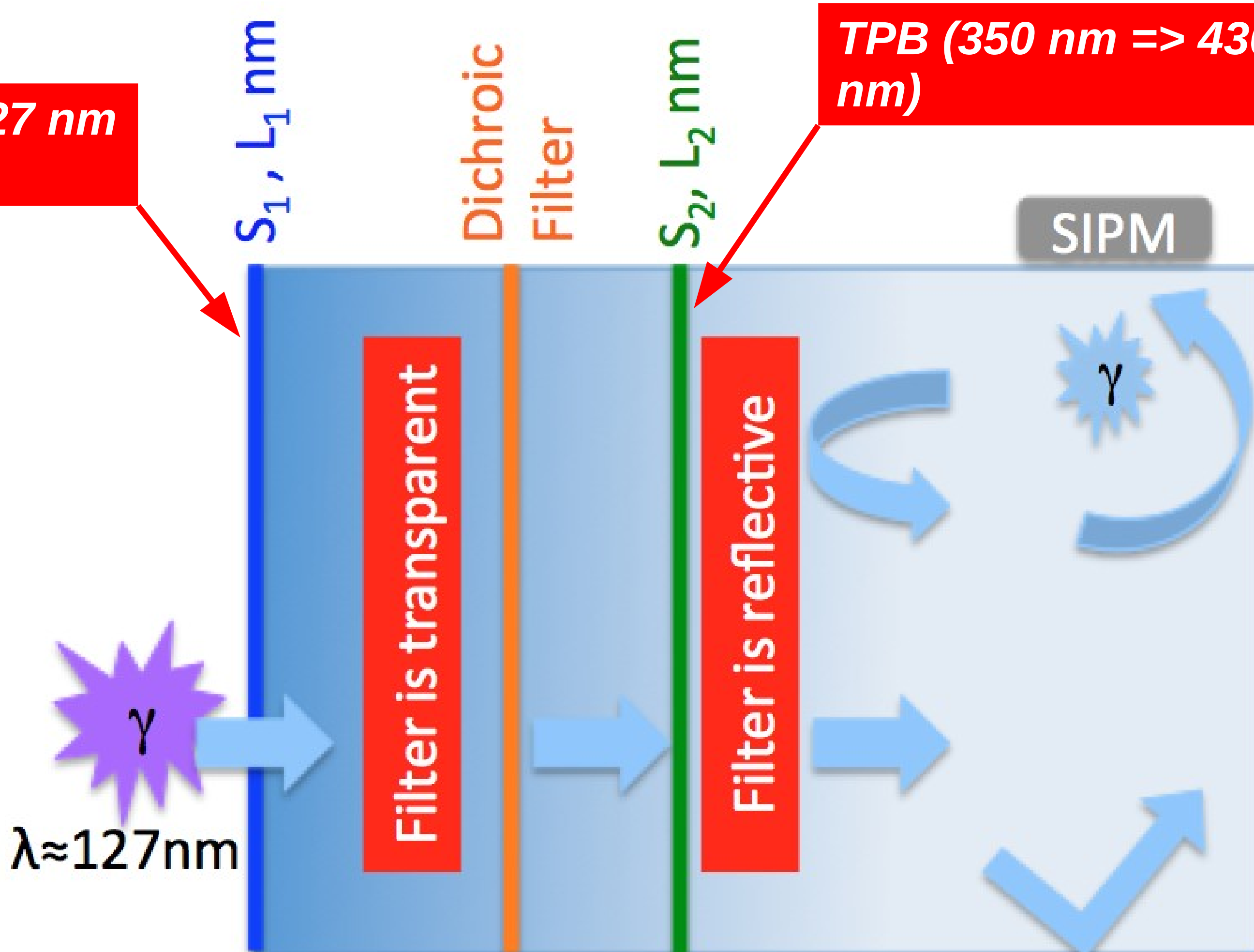
- **The final design of the SP PD will appear very similar to the protoDUNE one:**
- **Bar shaped modules** slided inside the APA frame between wire planes
- Each photon collector module will have approximate linear dimensions of 210 cm x 12 cm
- 10 modules per APA , ***1,500 modules in total***
- **Photon Collector based on the X-ARAPUCA**
- **Light read-out based on SiPM**



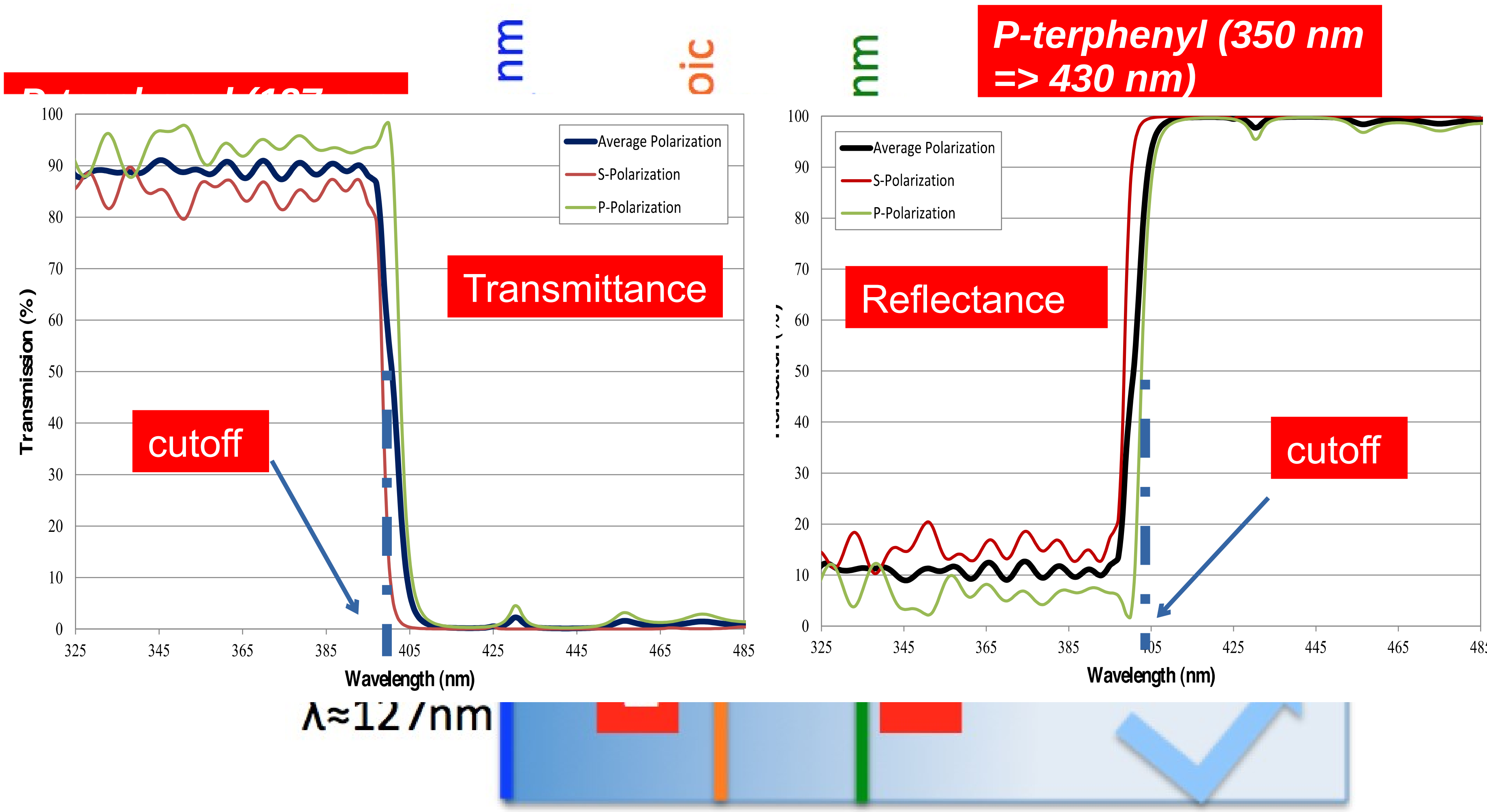
ARAPUCA concept – working principle

P-terphenyl (127 nm => 350 nm)

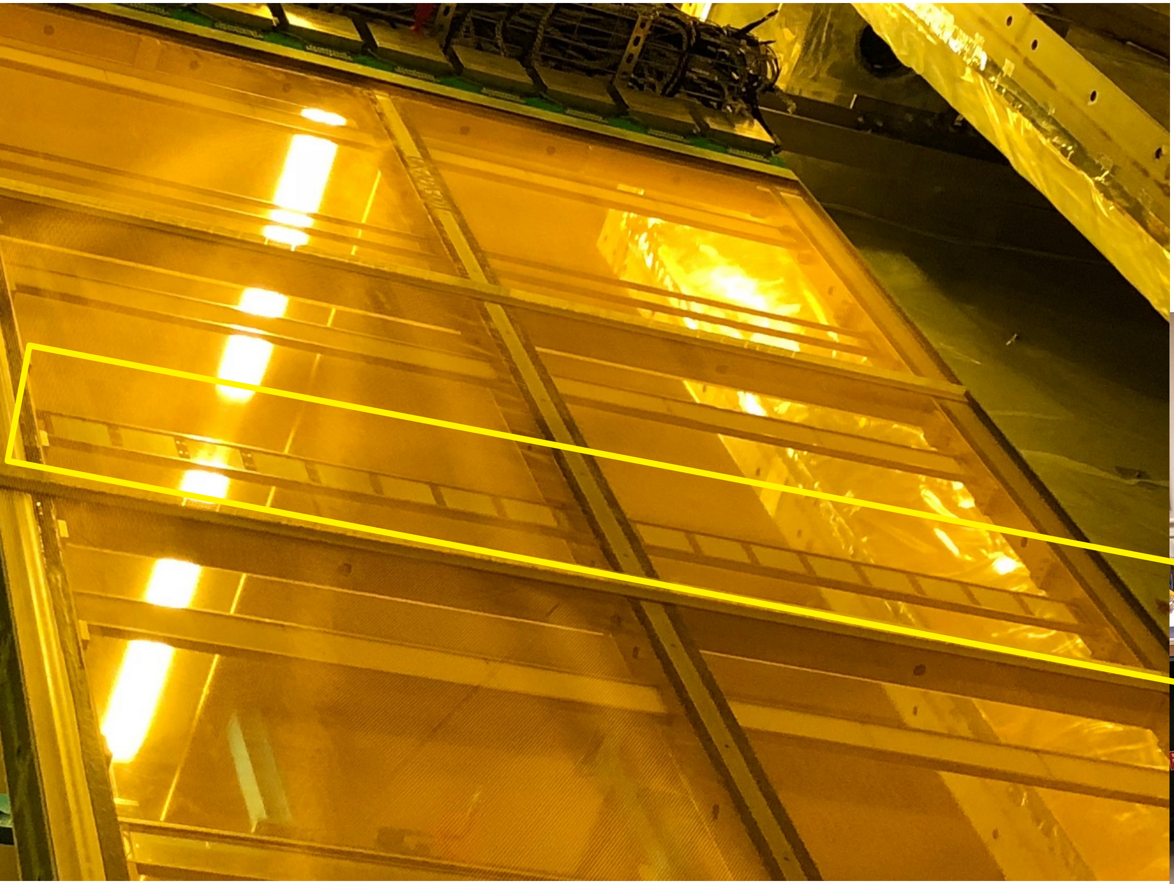
TPB (350 nm => 430 nm)



ARAPUCA concept – working principle



ARAPUCA modules in protoDUNE

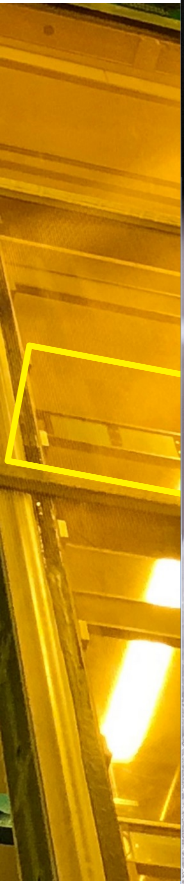


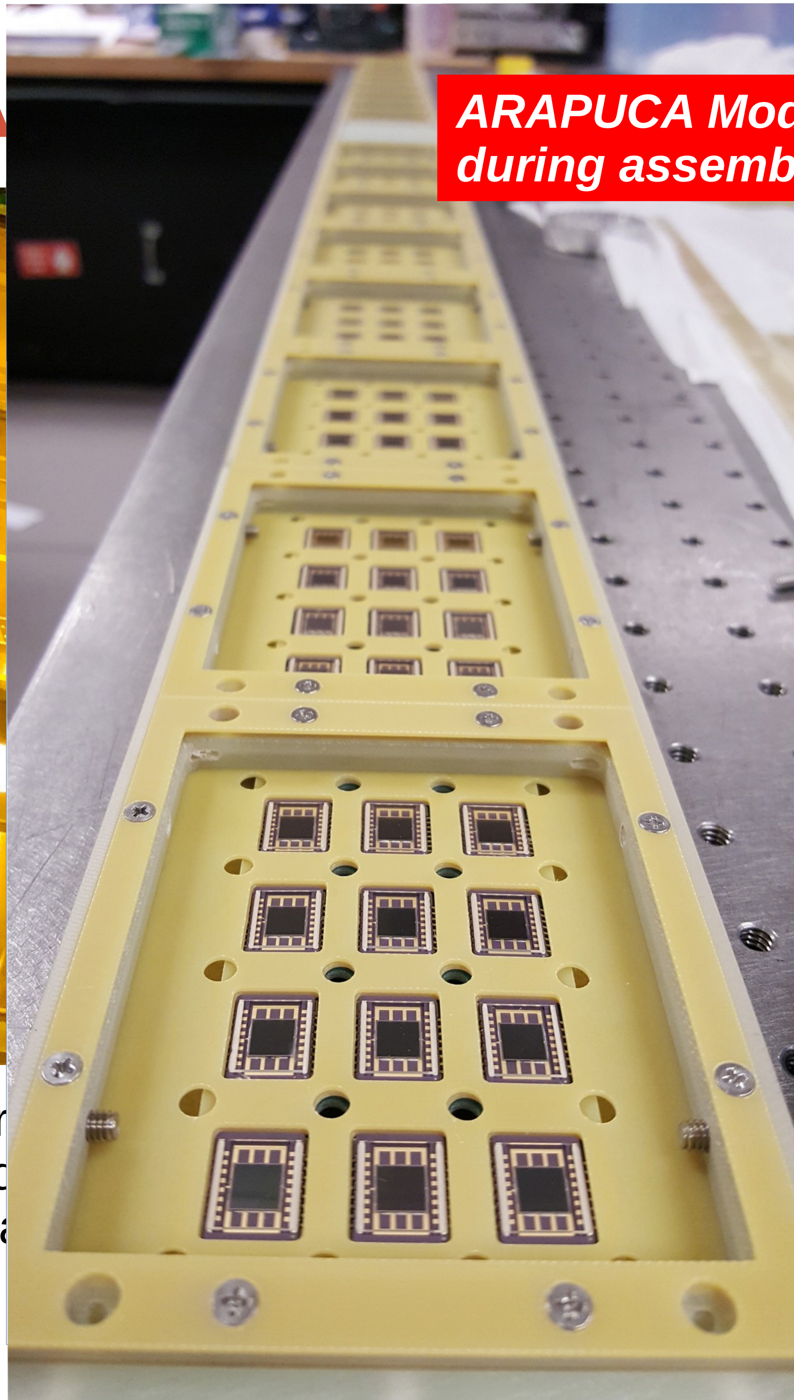
Two ARAPUCA arrays installed in protoDUNE (**APA#3** – close to the beam and **APA#4** -opposite side)

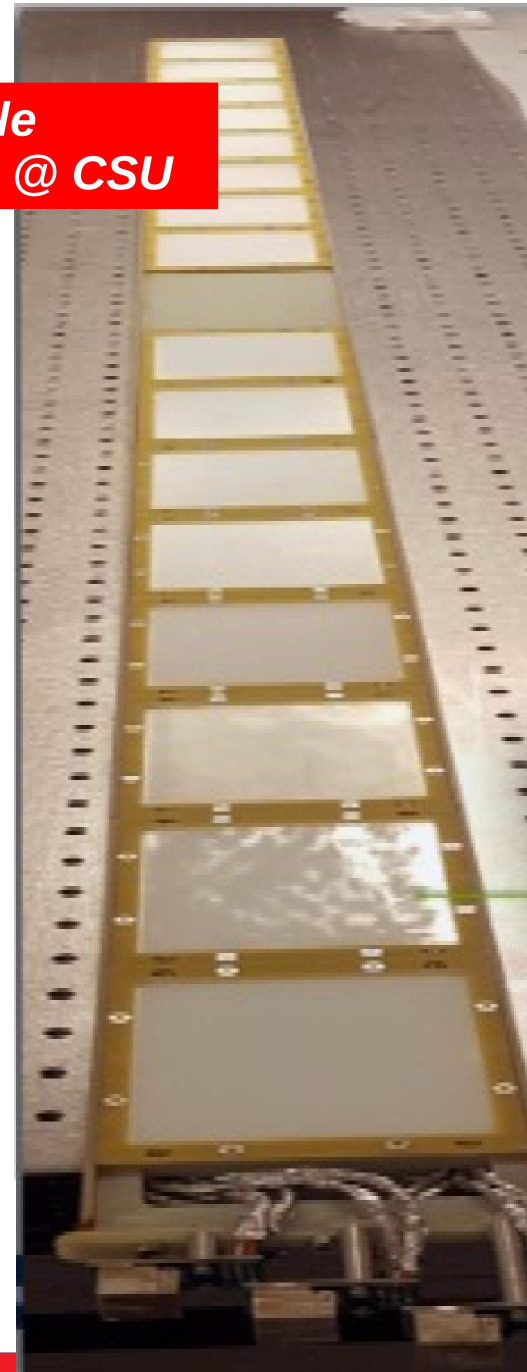
Each array hosts ***16 ARAPUCA cells*** (10 cm x 8 cm) and each cell is *read-out by 12* (*6*) Hamamatsu SiPM passively ganged together.

ProtoDUNE ARAPUCA array assembled by CSU group

A NE

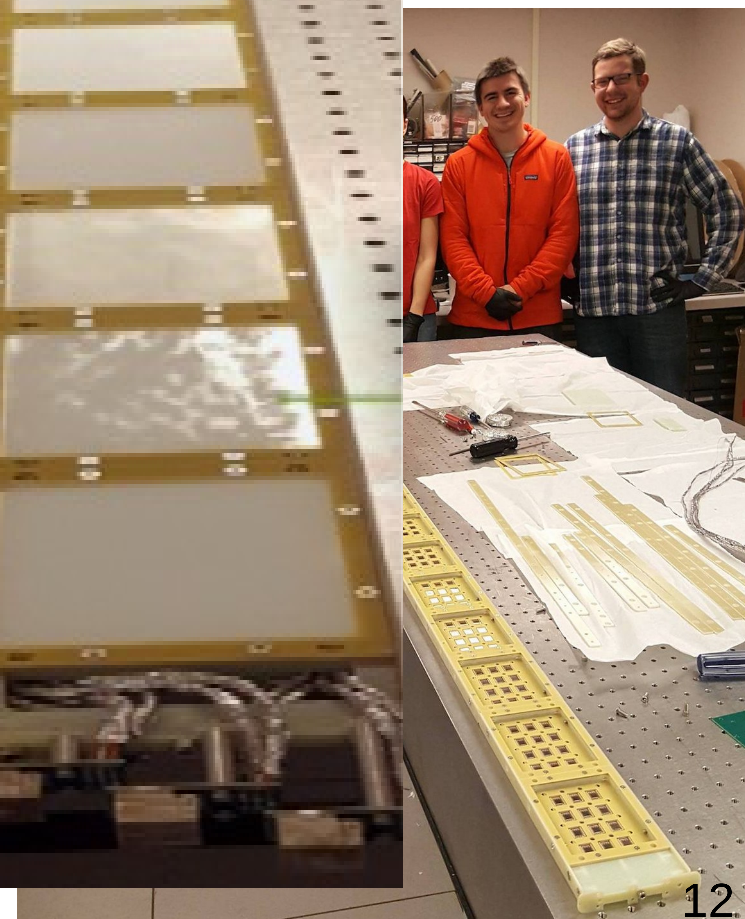






ARAPUCA Module
during assembly @ CSU

arrays installed
PA#3 – close to
A#4 -opposite

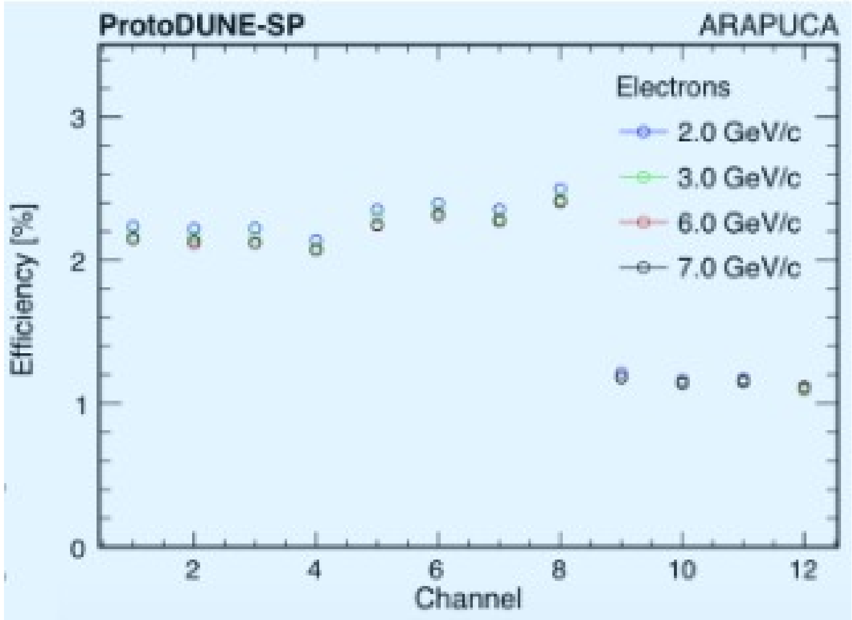


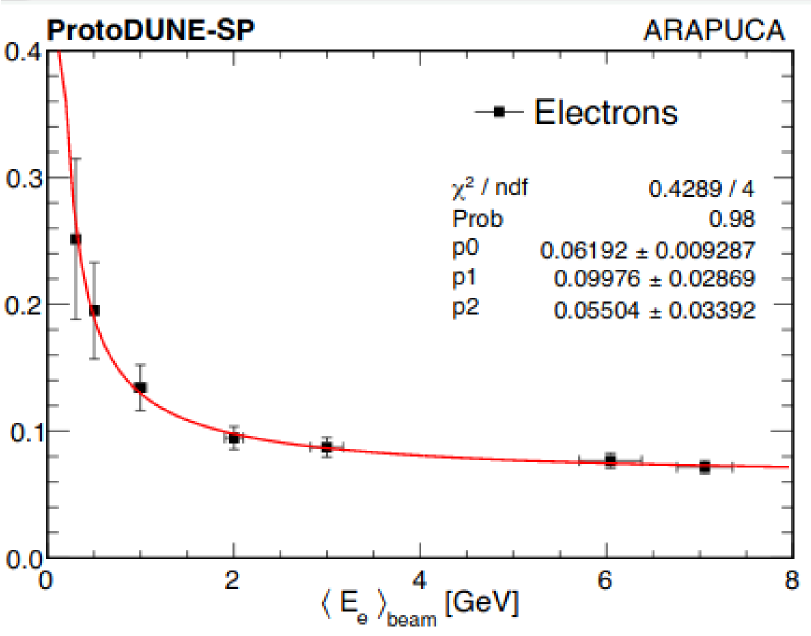
Each ar
cm) and
SiPM pa

ARAPUCA in protoDUNE

- ARAPUCAs showed good performances => 2% overall detection efficiency (12 MPPCs/cell)
- Detection efficiency stable along the run
- Good performances in energy reconstruction of beam events with light

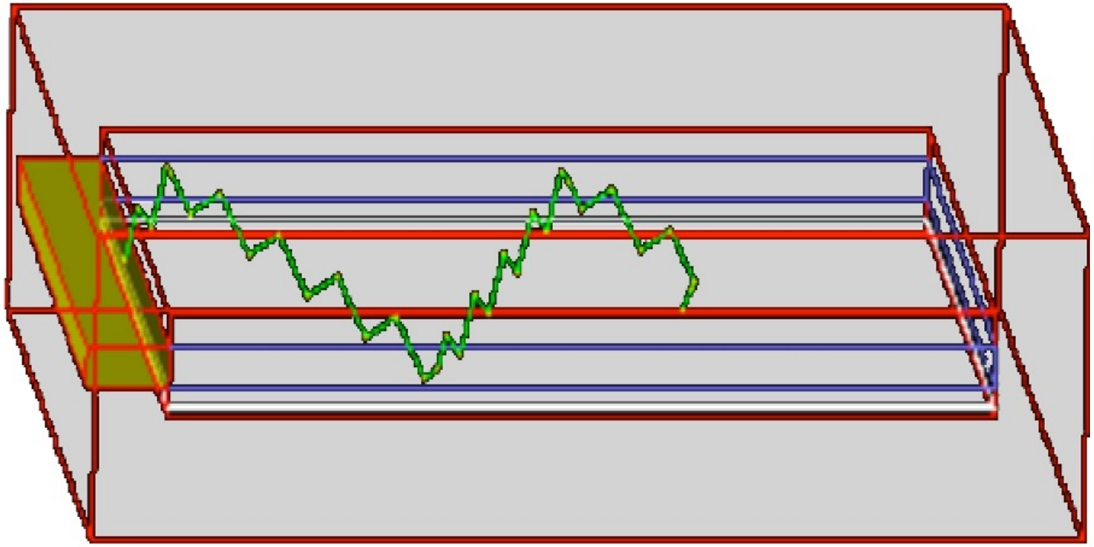
More in F. Cavanna talk

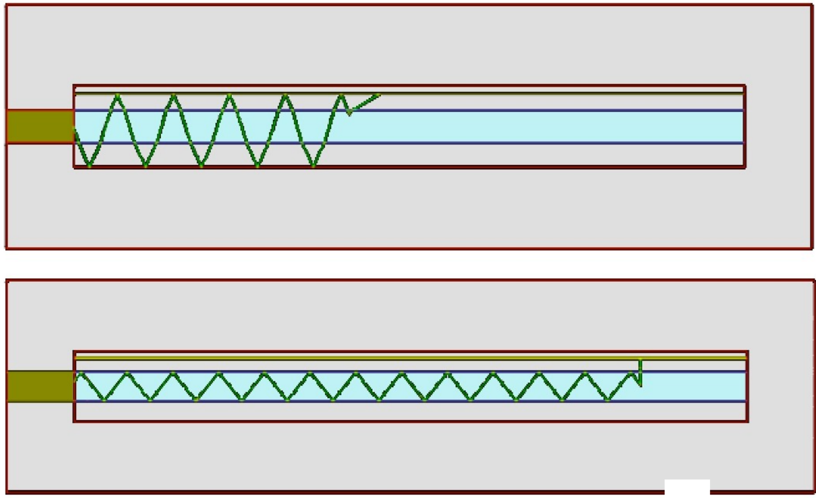




X-ARAPUCA concept

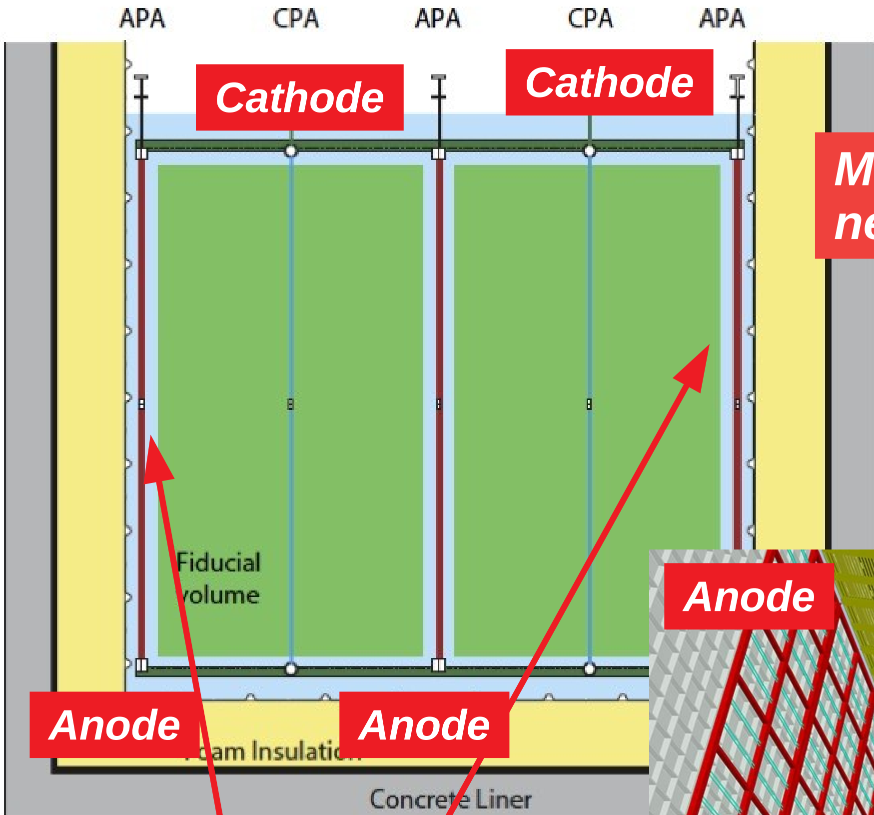
- The ***X-ARAPUCA*** represents a development and an optimization of the traditional *ARAPUCA*
- X-ARAPUCA is a *hybrid solution* between an ARAPUCA and a ***light guide***
- In an X-ARAPUCA the inner shifter is substituted by a ***polystyrene plate*** which has the *WLS compound embedded inside*. The active photo-sensors are optically coupled to one or more ends of the slab itself





X-ARAPUCA vs ARAPUCA

- In the X-ARAPUCA the standard ARAPUCA trapping mechanisms is untouched
- Additional trapping thanks to the WLS plates which increases the overall efficiency
- Simpler design → No need of evaporating the internal surfaces
- More robust → Reduces the risks of shifter detaching
- The same design can be easily adapted to a single sided (accepting light only from one side) or to double sided version (accepting light from both sides)

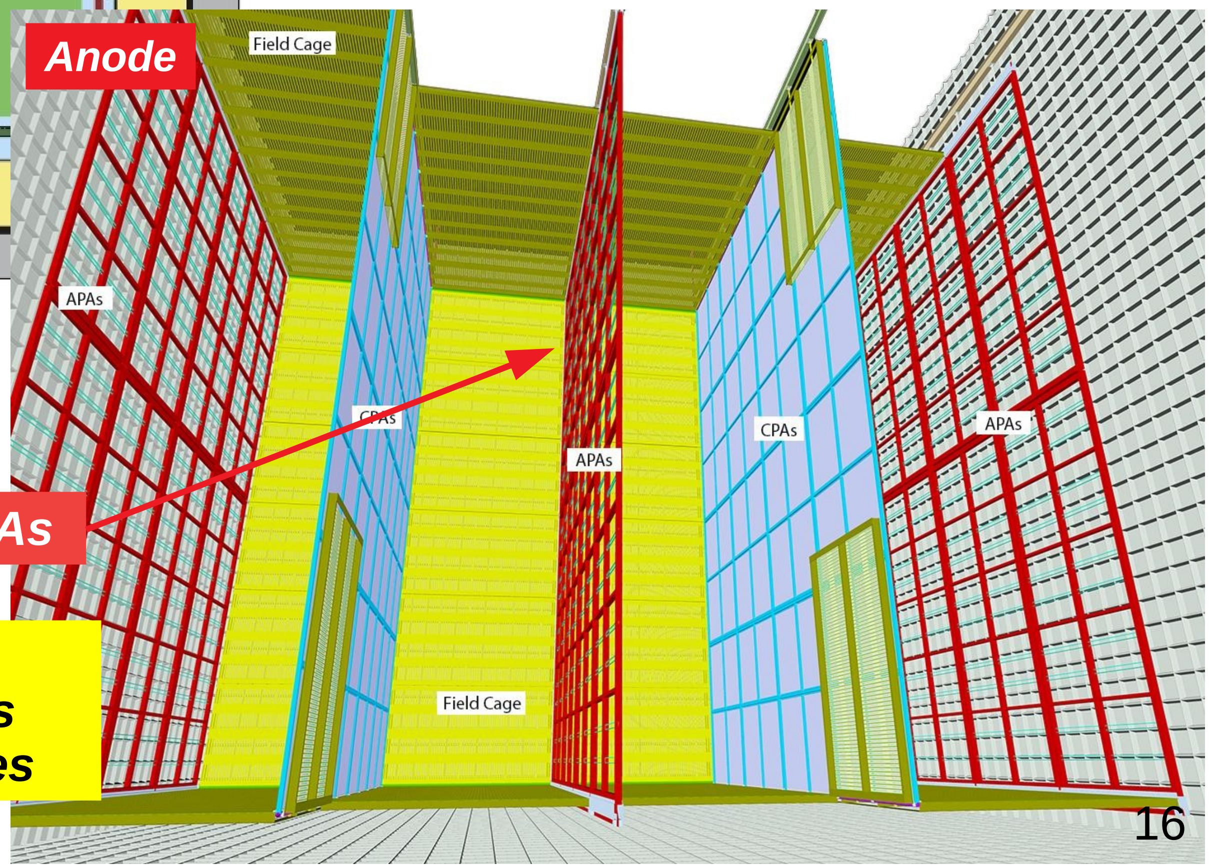


Cathode

Cathode

Anode

Anode



Anode

Modules installed on the central APAs need to be sensitive on two sides

Single sided X-ARAPUCAs

Double sided X-ARAPUCAs

In the first FD SP module:
- ***1,000 single sided modules***
- ***500 double sided modules***

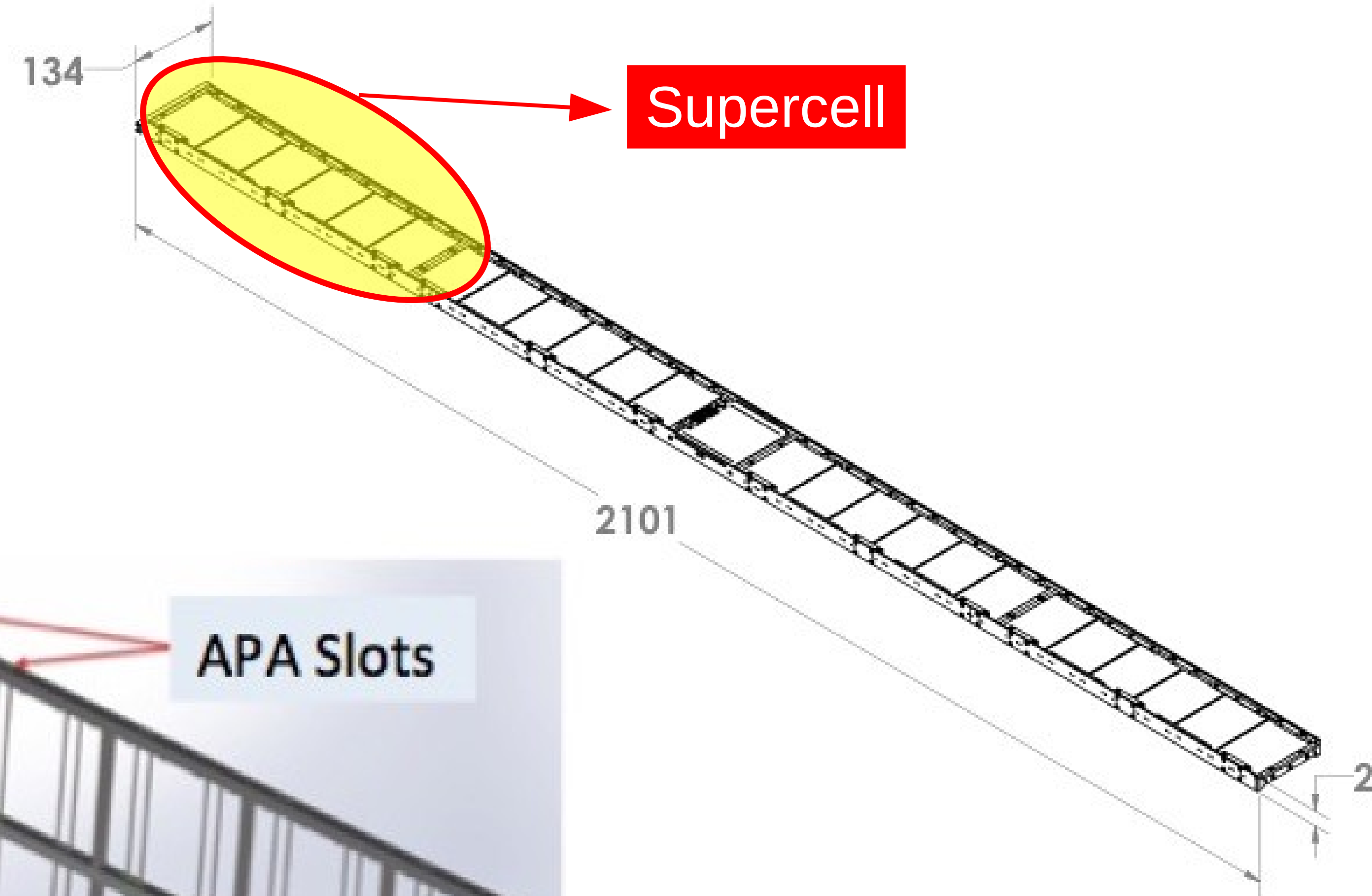
X-ARAPUCA modules

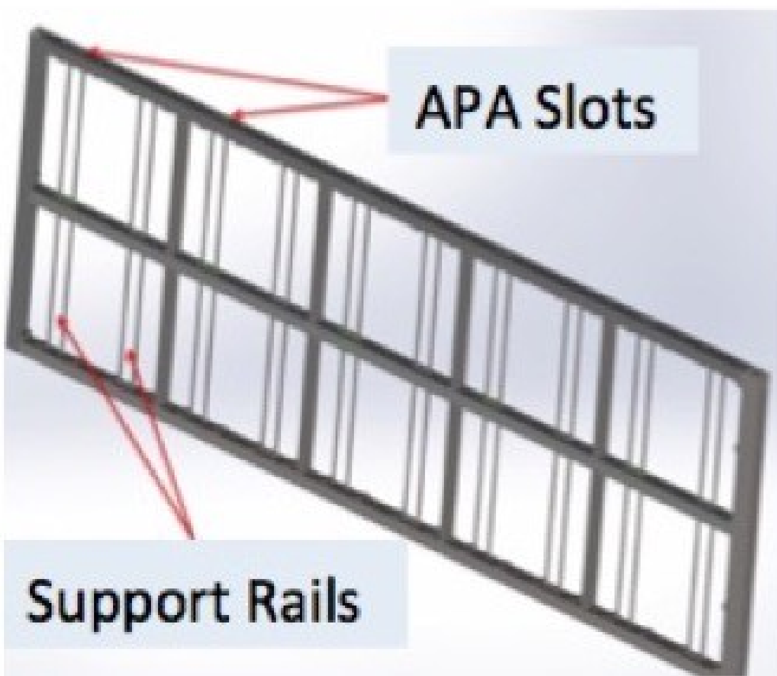
- An **X-ARAPUCA module** for DUNE will have dimensions of approximately 210 cm x 12 cm, segmented into *four cells* **(supercells)**. Each supercell is an X-ARAPUCA and will host **48 SiPMs** read-out by one single electronic channel

- Each supercell hosts
  - ✓ *6 dichroic filters (~10 cm x 8 cm Area) => Produced by OPTO eletronica (São Carlos – SP – Brazil). First version of the filters tested in the single cell and tested in a spectrophotomer → Showed good performance. Working on the optimization of the cut-off and in reducing its dependence from angle of incidence*
  - ✓ *1 lightguide plate (~ 48 cm x 10 cm x 0,35 cm) => Baseline is Eljen EJ286 → blue fluor (peak emission @ 425 nm) in a polystyrene matrix. Investigating a different matrix (PVT) which is cheaper. Investigating different manufacturers*
  - ✓ *Refective foil on the internal surfaces → 3M ESR*
  - ✓ *48 actively ganged SiPM (6 mm x 6mm) => Two open options → Hamamatsu cryogenic MPPC specifically developed for DUNE and FBK cryogenic SiPM → Optimization of SiPM developed for the DarkSide experiment on the basis of the DUNE specifications*

- Each module hosts a Cold electronic summing boards. MPPC/SiPM are passively ganged in groups of 6 → 8 groups of 6 MPPC/SiPM are actively ganged by the cold summing board

X-ARAPUCA: Supercell





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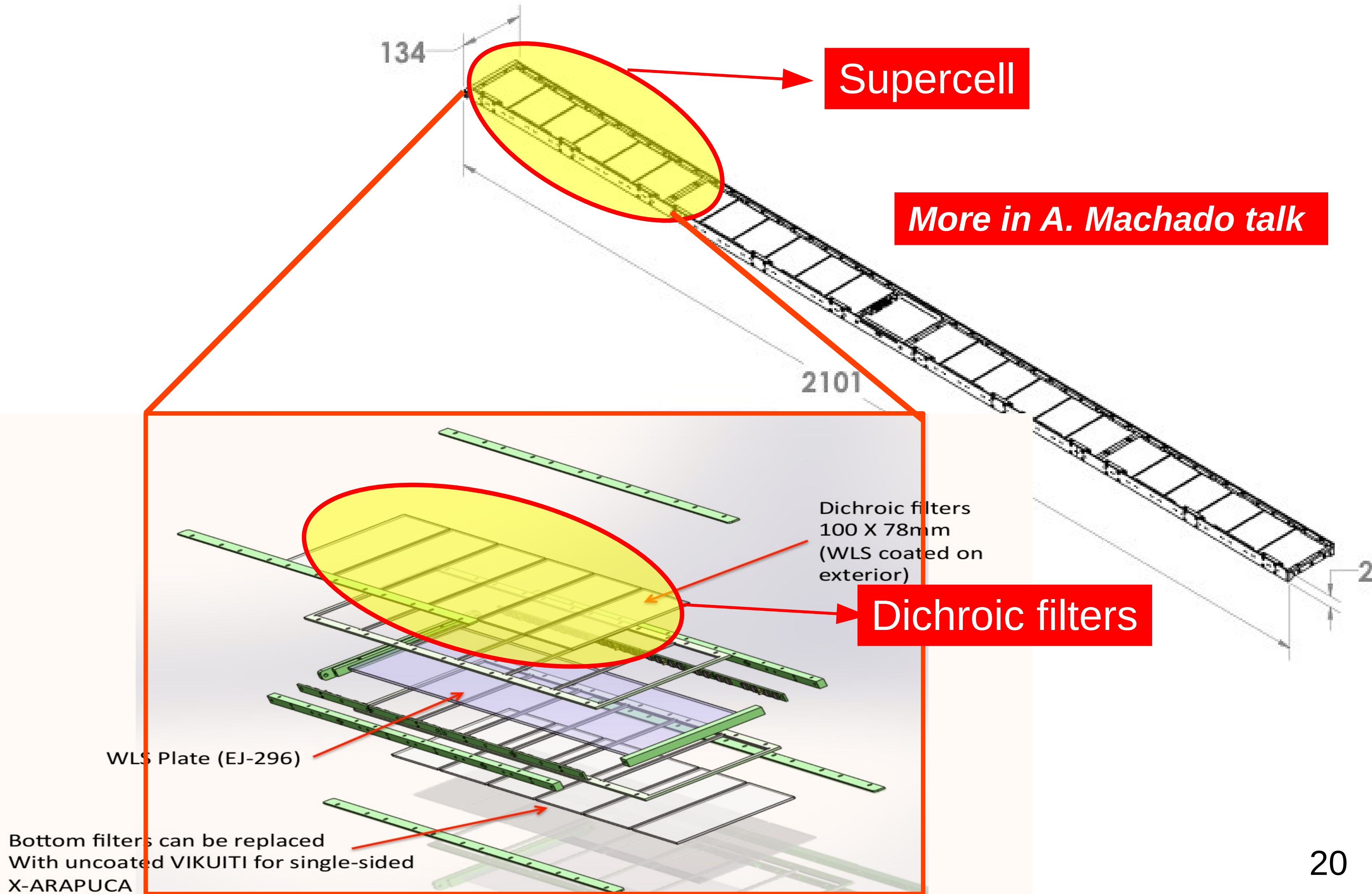
X-ARAPUCA: Dichroic filters



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  - ✓ *1 WLS plate (~ 48 cm x 10 cm x 0,35 cm) => Baseline is Eljen EJ286 → blue fluor (peak emission @ 425 nm) in a polystyrene matrix. Investigating a different matrix (PVT) which is cheaper. Investigating different manufacturers*
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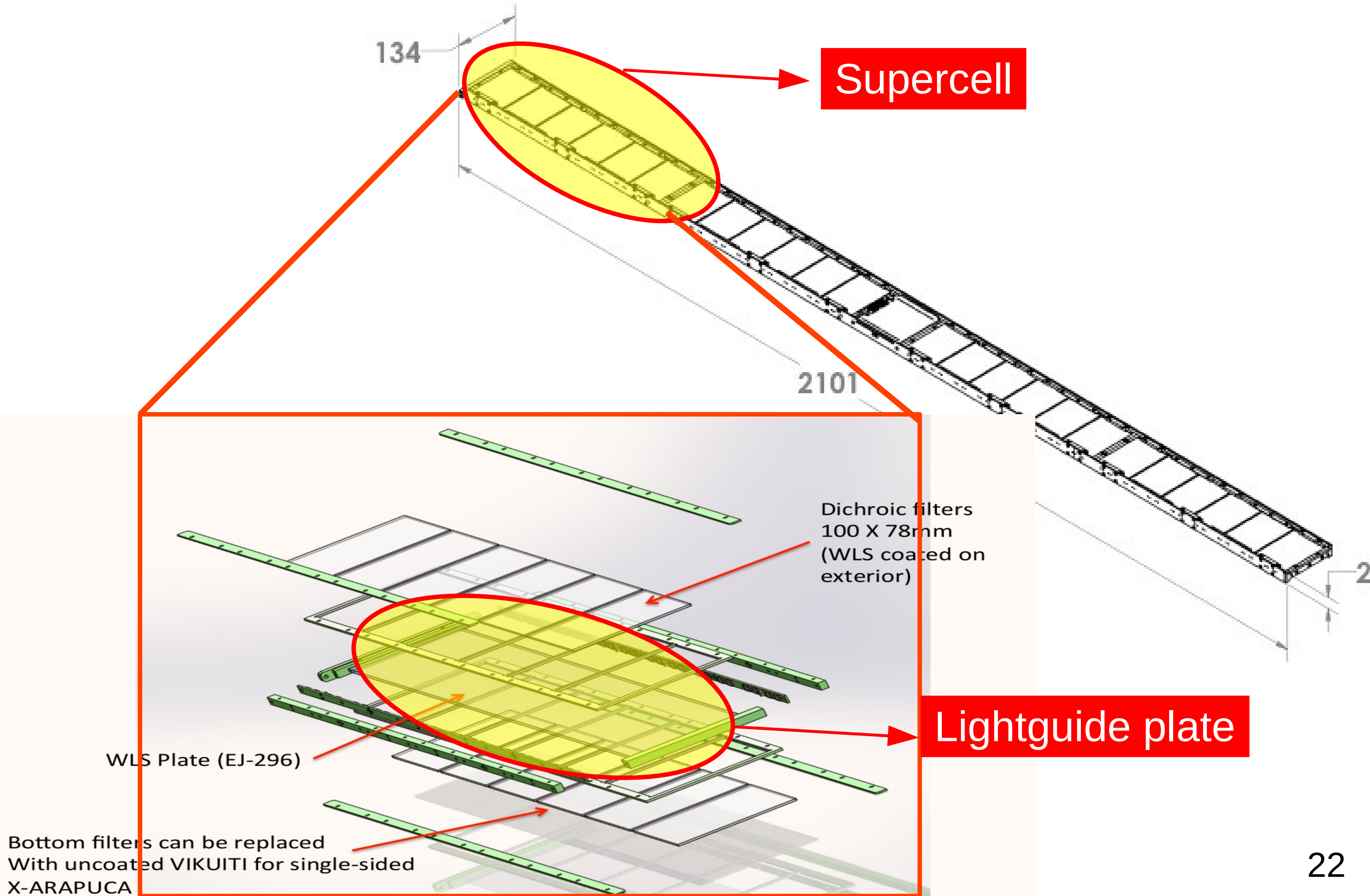
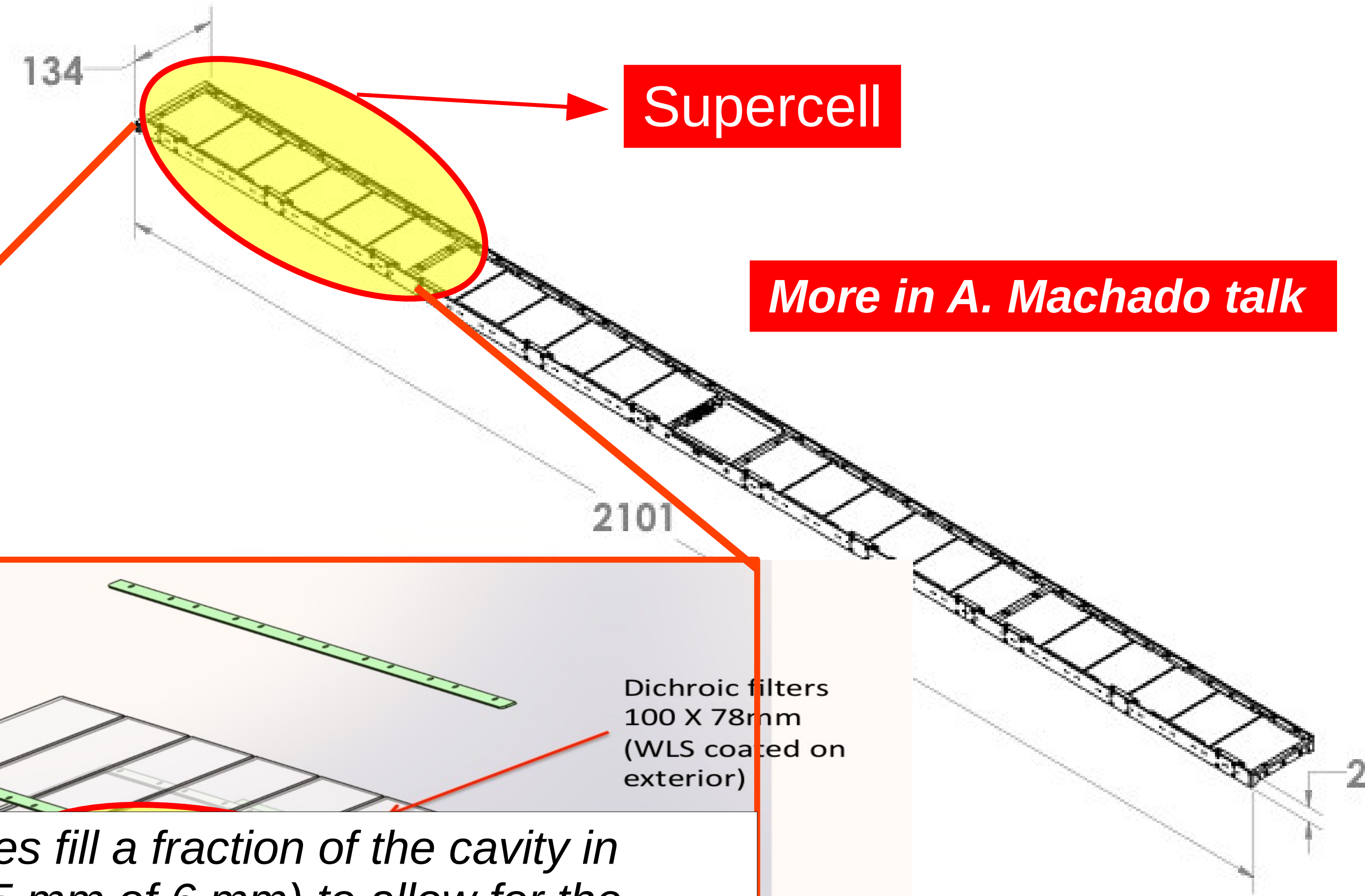
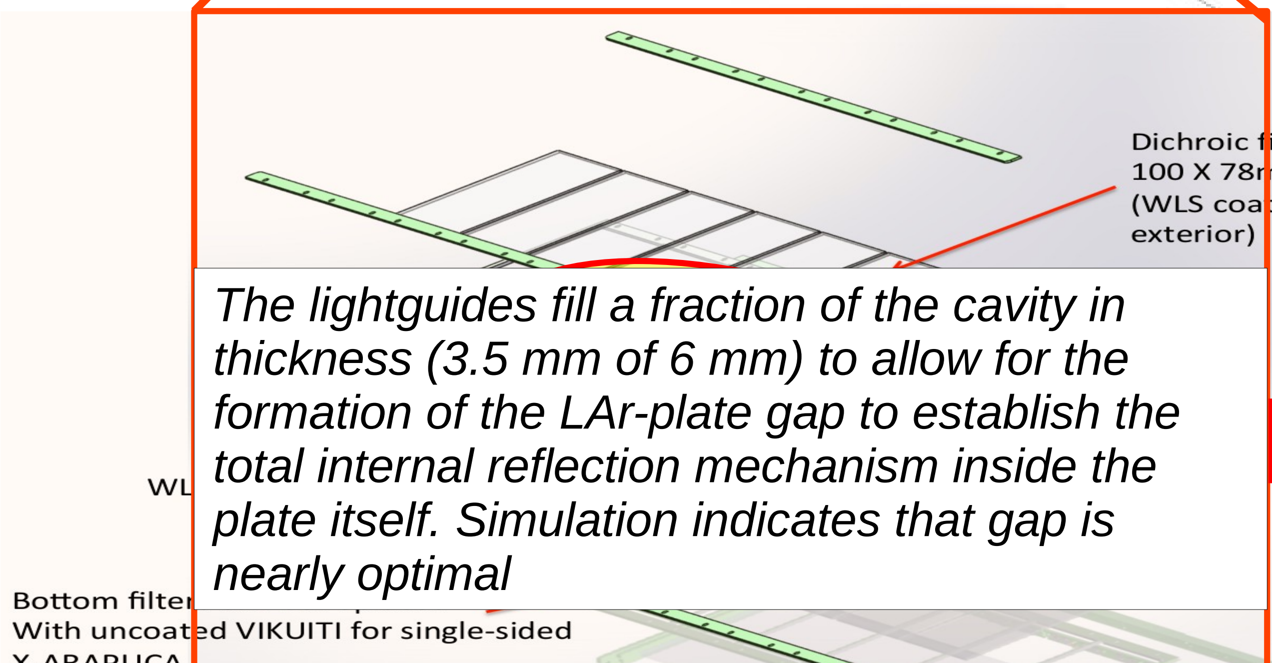
X-ARAPUCA: WLS plate



X-ARAPUCA: WLS plate



More in A. Machado talk



The lightguides fill a fraction of the cavity in thickness (3.5 mm of 6 mm) to allow for the formation of the LAr-plate gap to establish the total internal reflection mechanism inside the plate itself. Simulation indicates that gap is nearly optimal

Lightguide plate

X-ARAPUCA modules

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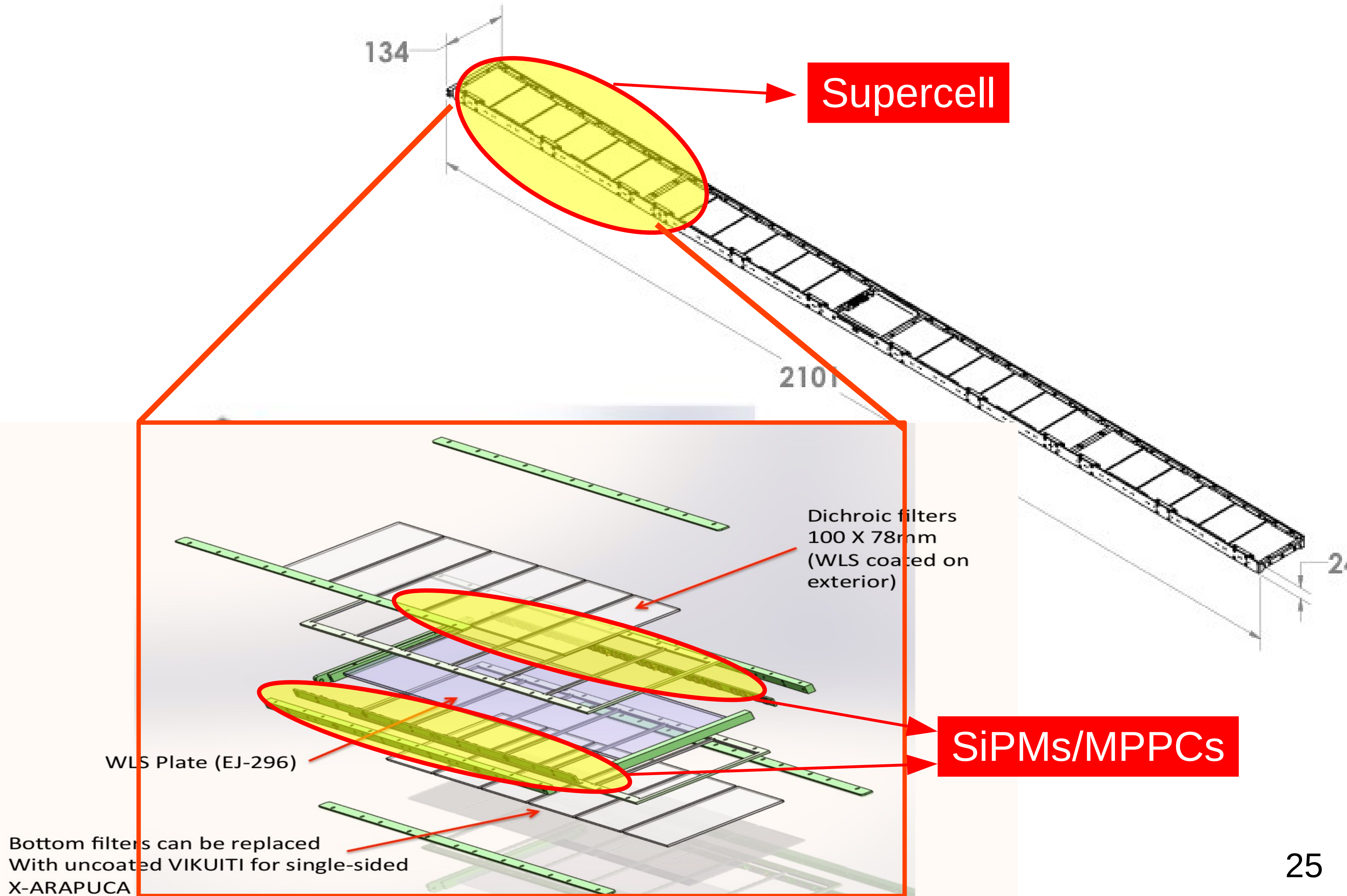
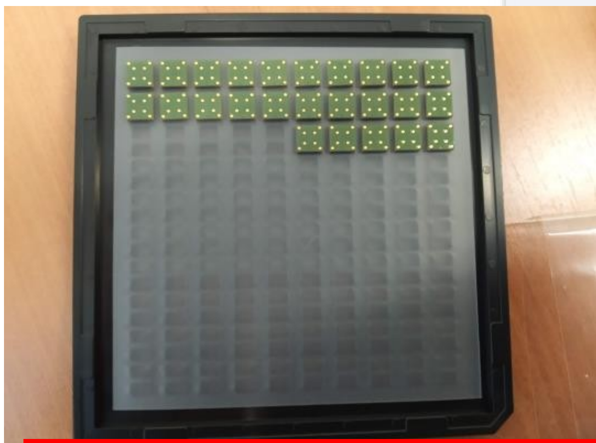
X-ARAPUCA: SIPMs/MPPCs



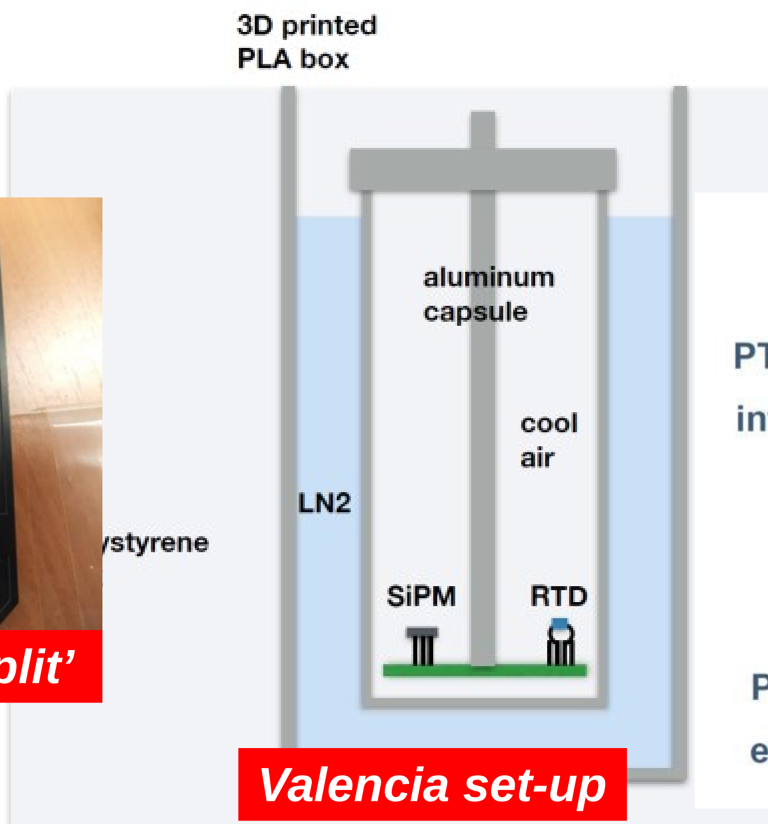
X-ARAPUCA: SIPMs/MPPCs

- Sensors tested in different laboratories according to a common procedure: *Milano-Bicocca*, *Bologna*, *Madrid*, *Valencia*, *Prague*, *NIU*

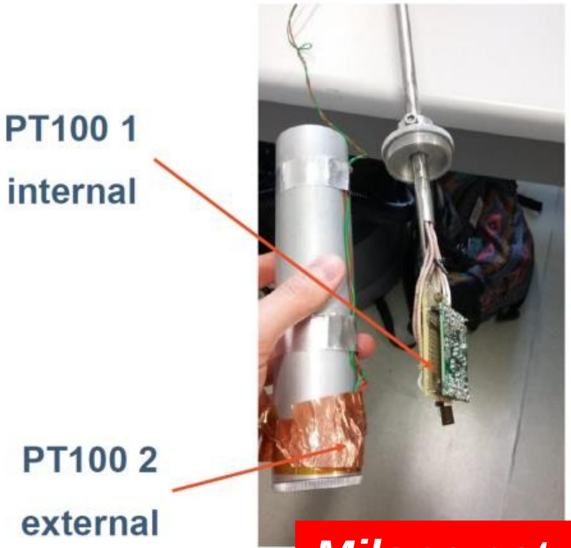
More in F. Terranova talk



First Hamamatsu 'split'



Valencia set-up



Milano set-up

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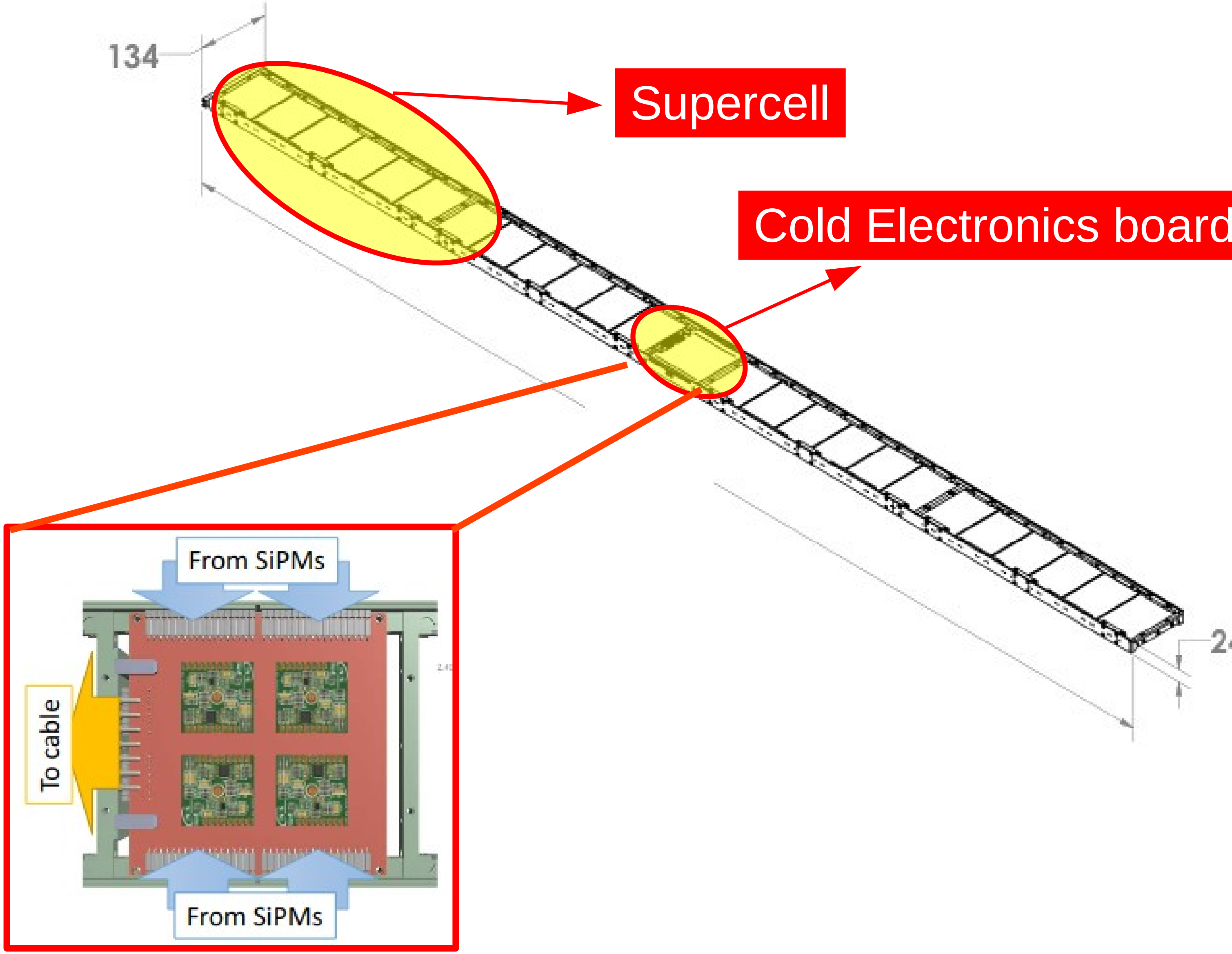
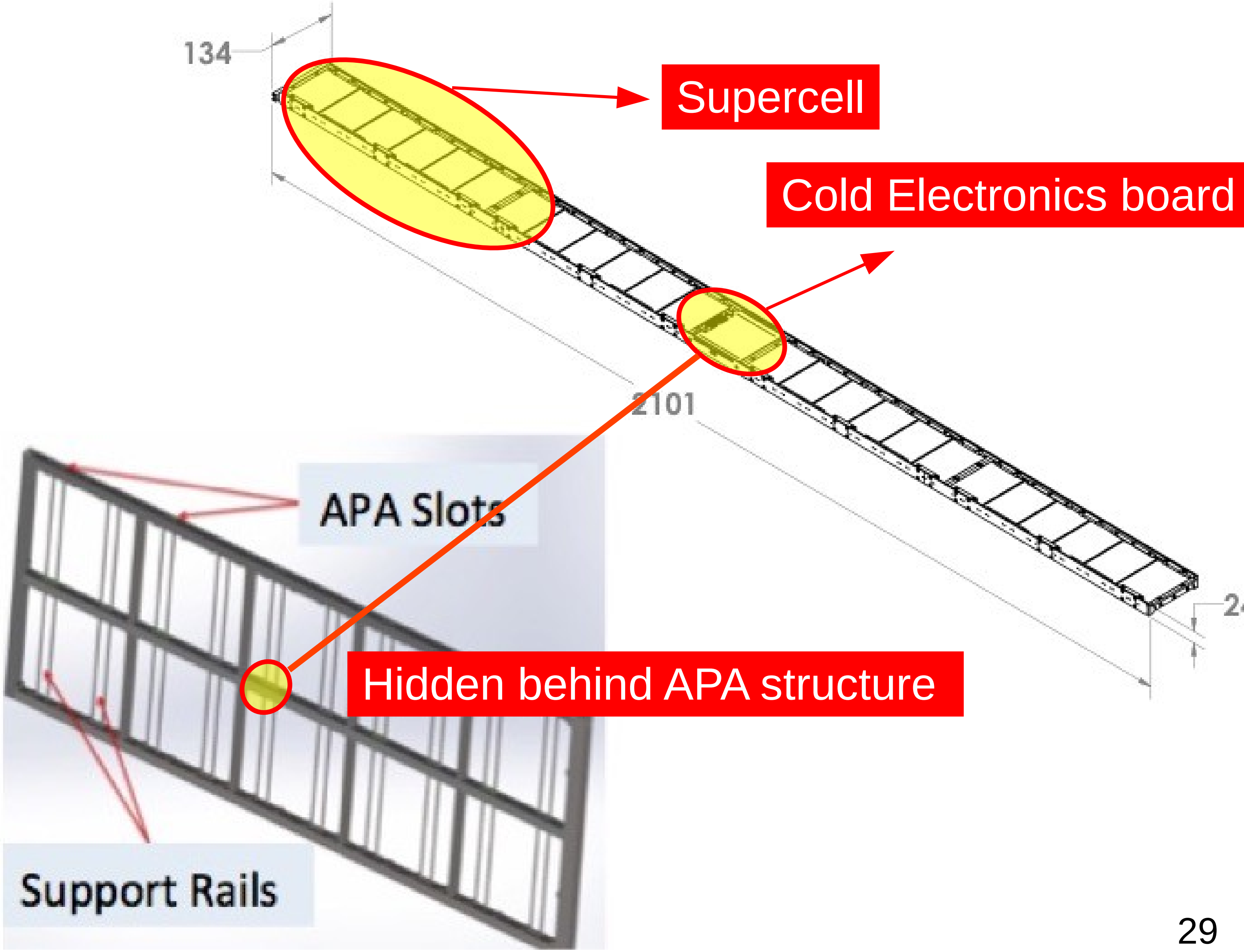
X-ARAPUCA Cold Electronics



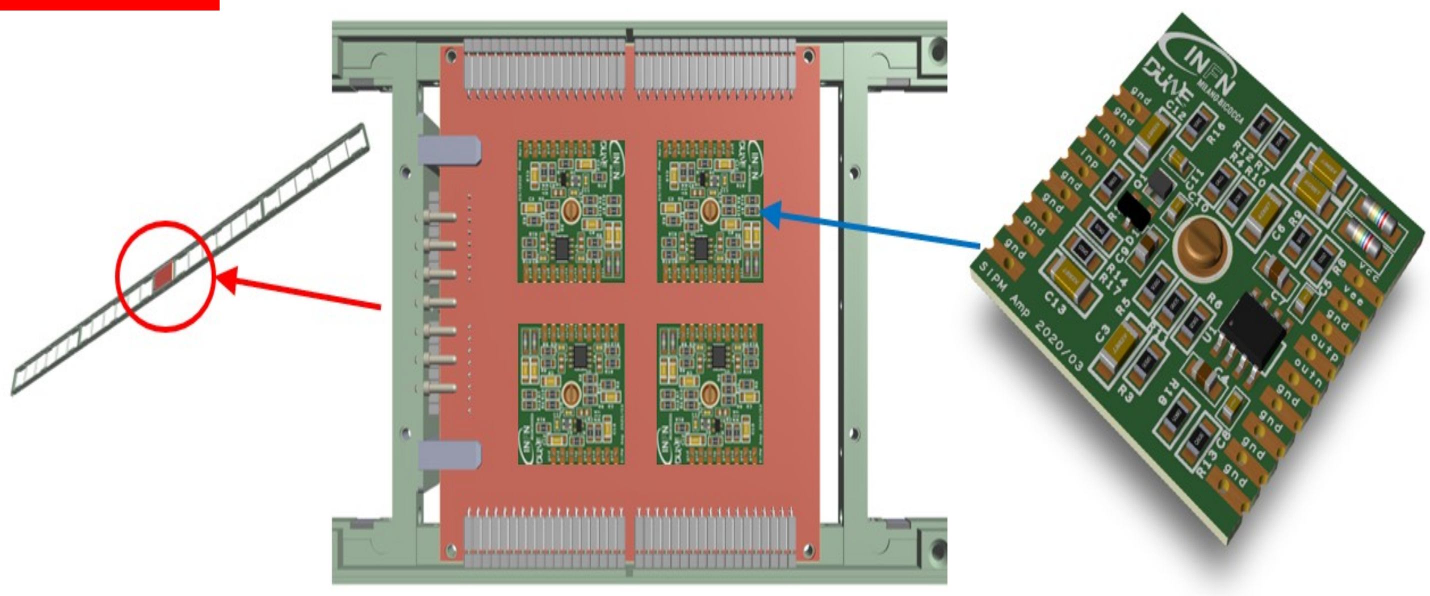
X-ARAPUCA modules



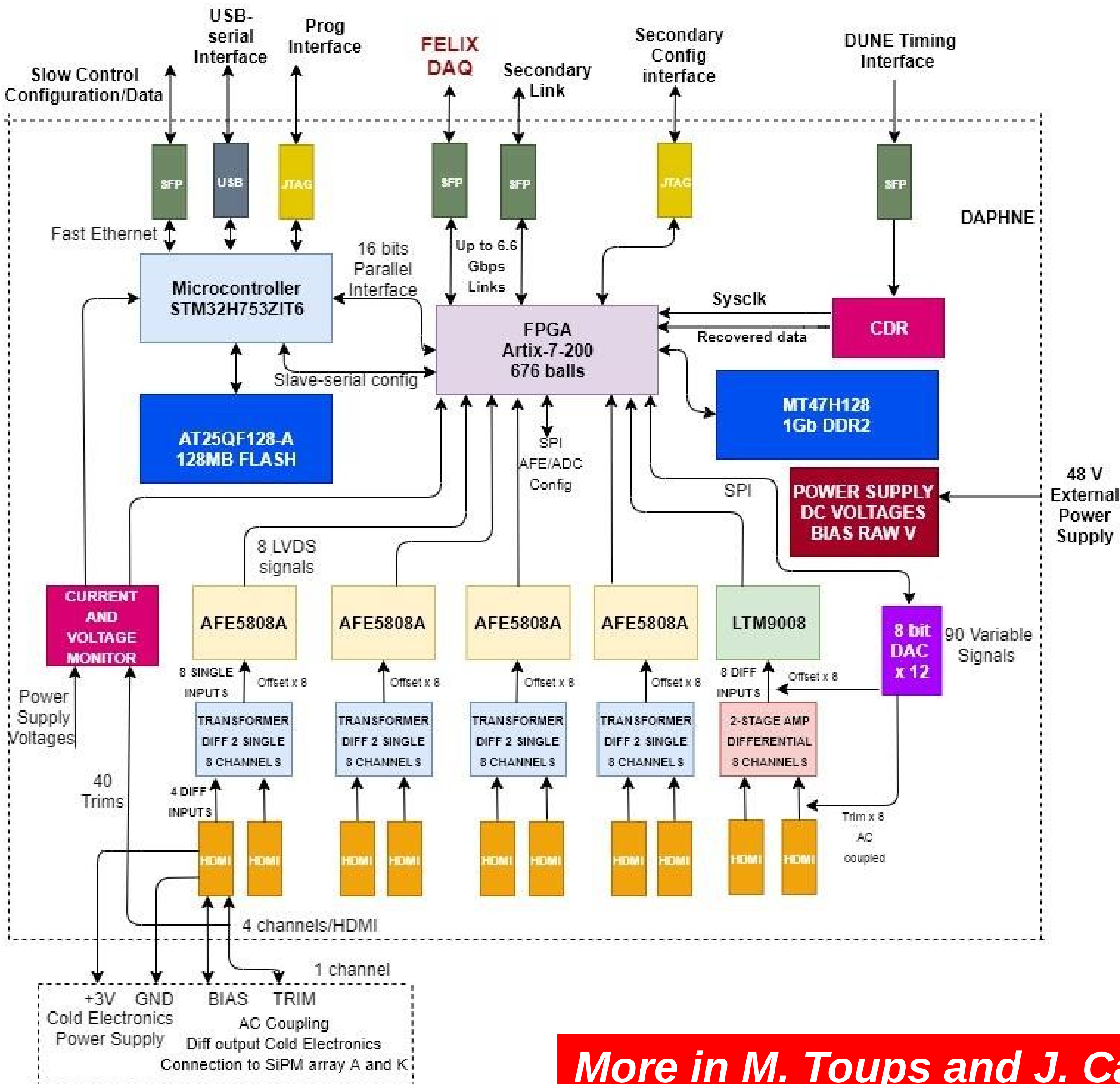
Cold amplifier

- *Evolution of the TDR design*
- Now a ***two-stage amplifier***: *SiGe bipolar transistor + fully differential opamp (lower noise, lower power consumption, higher flexibility in setting the loop gain, higher dynamic range with respect to previous design)*
- First tests with ***SiPM + added capacitance*** to *simulate ganging* show promising results for signal to noise ratio
- ***Design of PCBs to fit the PD mechanics is progressing***
- Further tests of the entire module are ***planned for next autumn***

More in C. Gotti talk



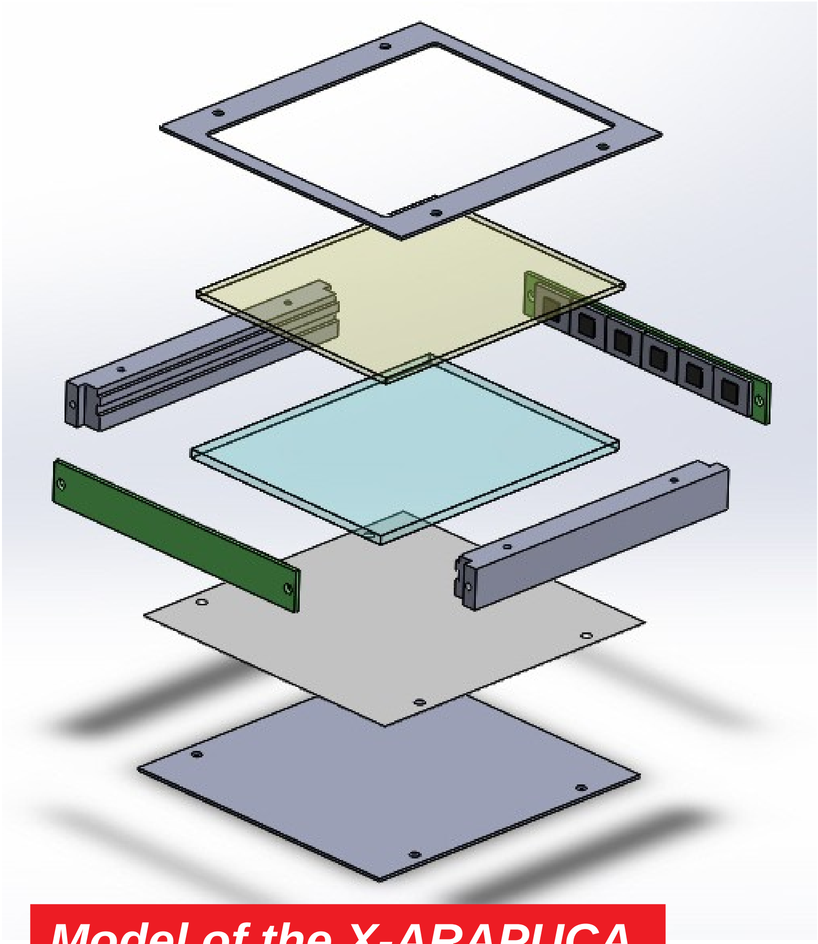
Warm Read-out Electronics (DAPHNE)



- ***40 channels/65 Msps/ 14 bits***
- Bias-Trim Voltage supply
- Cold Electronics power supply + 3V
- Gigabit link up to 6.6 Gb/s to FELIX DAQ/full-mode protocol
- DUNE Timing interface
- *Firmware and Gateware being developed*

More in M. Toups and J. Castaño talks

X-ARAPUCA validation program

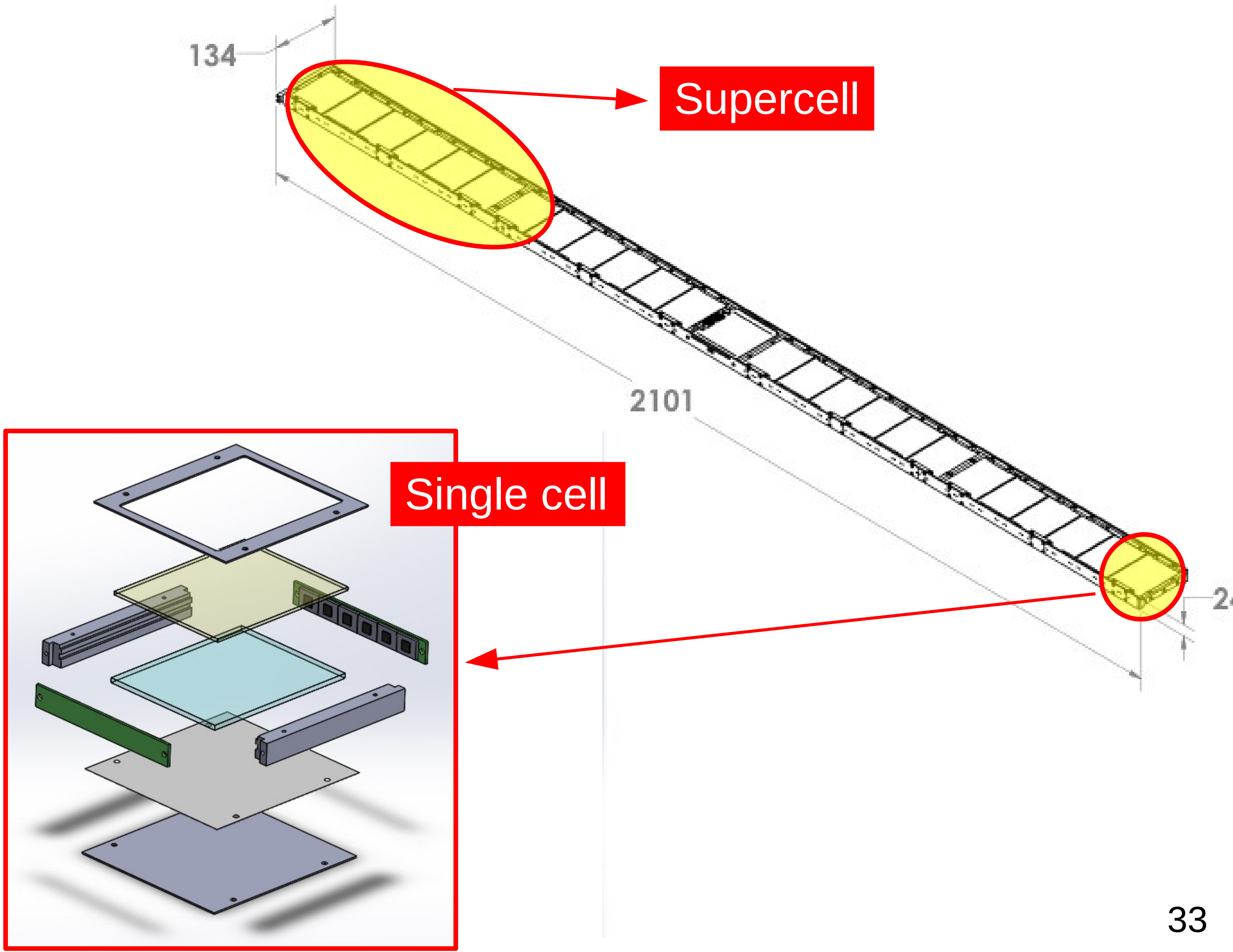


Model of the X-ARAPUCA tested at UNICAMP

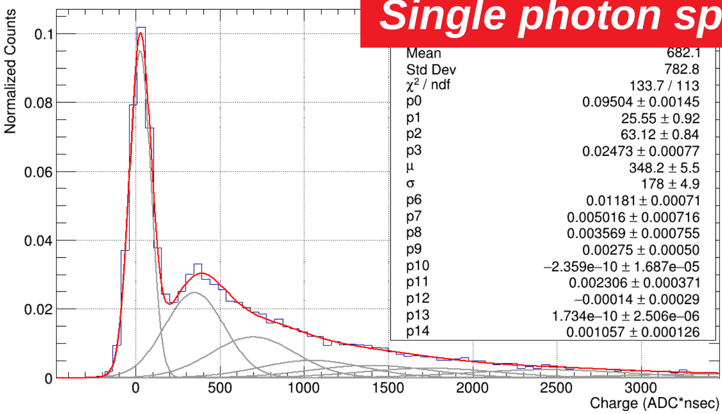
Several tests performed with the single cell prototype

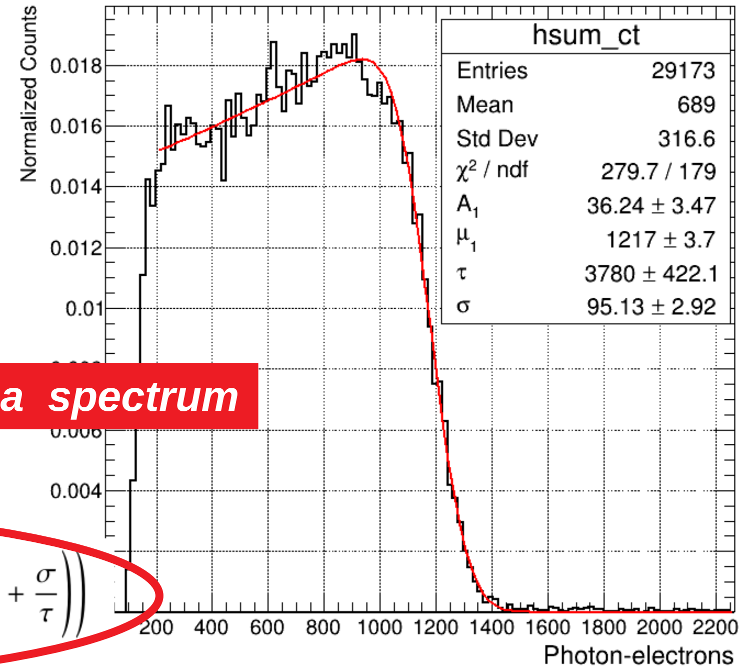
- A small ***10 cm x 8 c***m X-ARAPUCA tested in LAr at **UNICAMP.** See F. Cavanna talk
- **Two arrays of 4 SiPM** (Hamamatsu S13360-6050VE), passively ganged and read-out with two separate electronic channels
- Both Single sided version and double sided tested with radioactive sources
- Filters by OPTO Eletronica (São Carlos – Brazil). ***See A. Machado talk***
- Lightguide plate => Eljen-286 with a PVT matrix

X-ARAPUCA validation program



X-ARAPUCA test result





Fit function

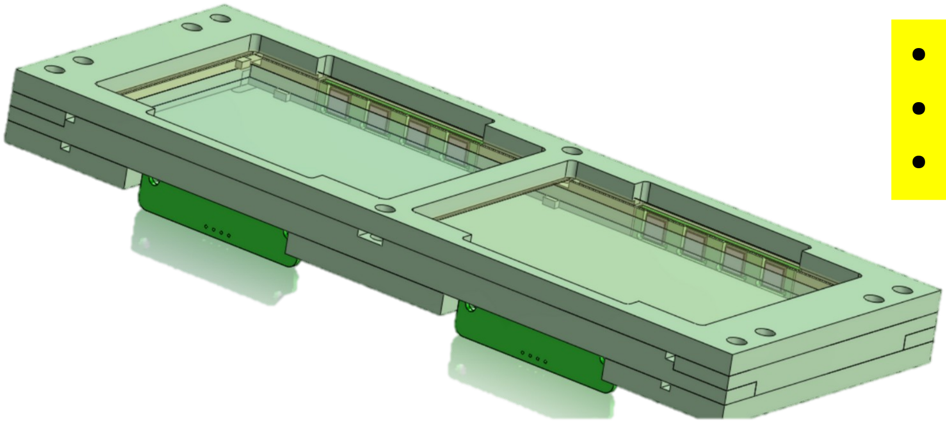
$$F(E) = \sum_{i=1}^{3} f(E-\mu_i;\sigma,\tau) = \sum_{i=1}^{3} \frac{A_i}{2\tau} \exp\left(\frac{E-\mu_i}{\tau} + \frac{\sigma^2}{2\tau^2}\right) \operatorname{erfc}\left(\frac{1}{\sqrt{2}}\left(\frac{E-\mu_i}{\sigma} + \frac{\sigma}{\tau}\right)\right)$$

- The source is an ***alloy of aluminum and natural uranium***
- The fit returns the *number of detected photons for each line* => Comparison with number of photons impinging on X-ARAPUCA window gives the efficiency
- ***An efficiency around 3.0% was found for single sided and double sided modules***

More in F. Cavanna talk

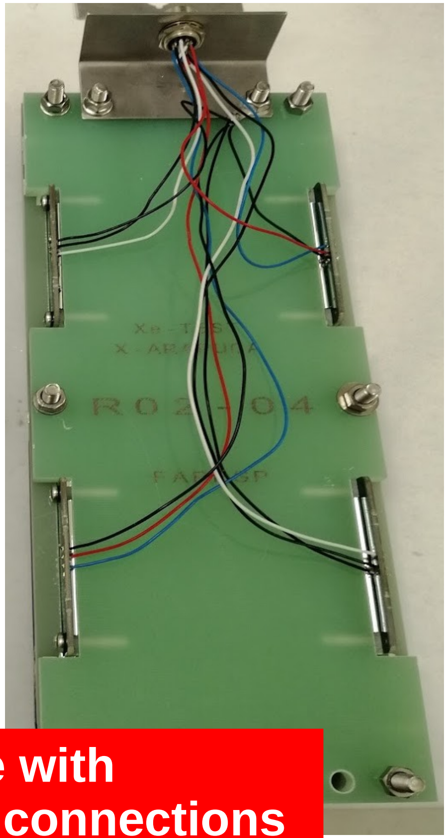
α energy (MeV)	relative intensity	parent nucleus
4.187	48.9%	^{238}U
4.464	2.2%	^{235}U
4.759	48.9%	^{234}U

X-ARAPUCA validation: *two cells*



- *Two dichroic windows (10 cm x 8 cm)*
- *One lightguide plate (20 cm x 8 cm)*
- *16 Photosensors*

- Consortium is currently testing two cells modules designed for the SBND experiment (200 of these modlues will be installed)
- Two modules sent to CERN for the Xe doping test
- One will be tested @ Milano Bicocca other one @ UNICAMP
- This step is important to organize the assembly facility and train the assembly team



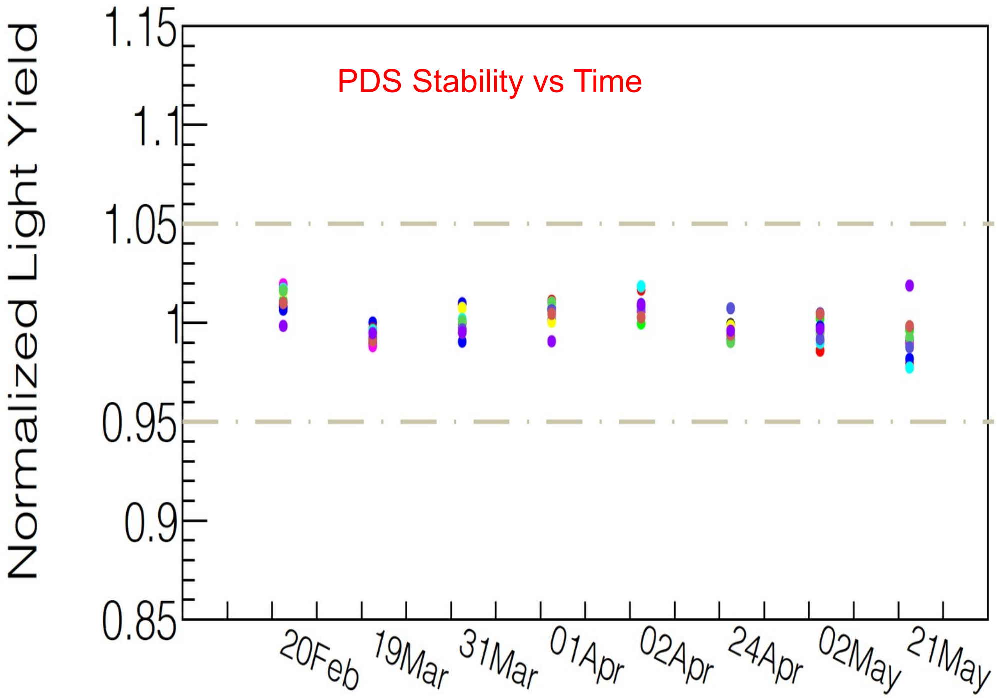
Back side with electrical connections

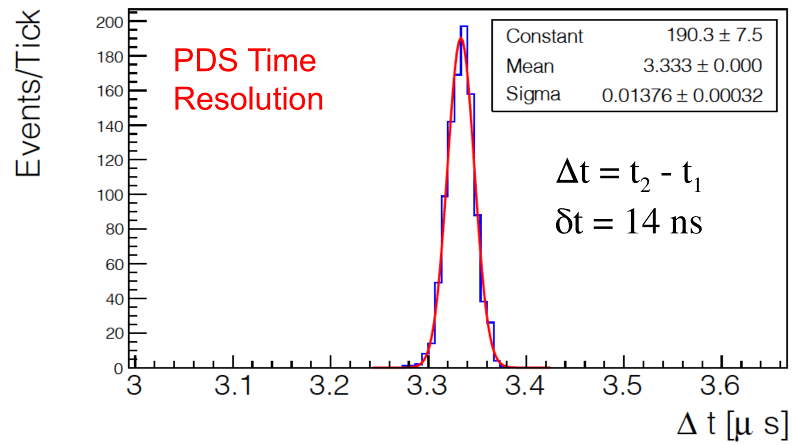
X-ARAPUCA validation: next phase

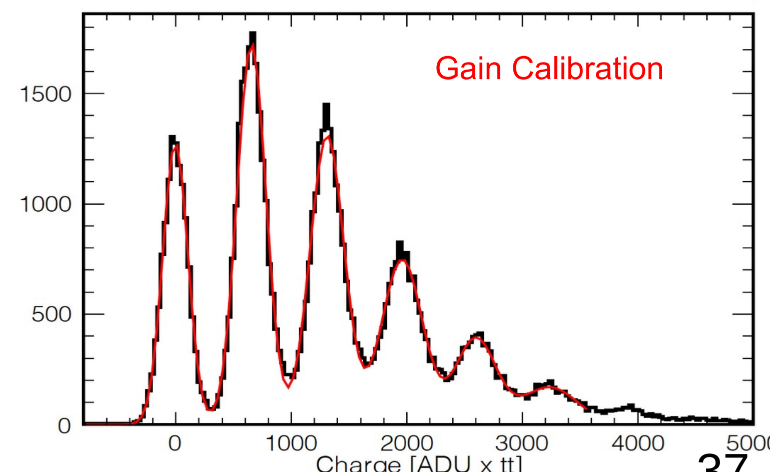
- Next fundamental phase will consist of the testing of a supercell with cold electronics in LAr. Delayed due to Covid emergency
- Read-out with the first prototypes of the new read-out board => DAPHNE
- Candidate laboratories: Milano Bicocca, Madrid, UNICAMP
- First vertical slice tests of the PD System: DAPHNE + Cold Electronics + X-ARAPUCA Supercell

Monitoring System

- Monitoring system will be ***largely inspired by the protoDUNE design***
- The system is constituted by an ***external UV led pulser*** (275 nm), ***quartz optical fibers, optical feed through*** and ***light diffusers*** installed on the *cathode plane*
- Allowed for characterization and calibration: **gain, cross-talk, time-resolution, channel-to-channel timing, and PDS stability**







Xenon Option

- Xenon doping allows to shift the wavelength of LAr scintillation photons from 128 nm to 174 nm.
- Two clear advantages
  - Increasing the Rayleigh scattering length => more uniform light collection from tracks passing at different distances along the drift direction.
  - Risk mitigation against N_2 contaminations: N_2 filtering is not viable in the far detector. ***N_2 efficiently suppresses the formation of the 128 nm argon scintillation light, while the xenon doping acts to prevent the N_2 quenching process.*** Tested with success in protoDUNE
- Additional improvement in detection efficiency possible with slight modification to the dichroic filter design
- Test performed in ProtoDUNE-SP from February 2020 discussed in S. Tufanli talk
- Xenon option discussed in EDMS 2382770

Xenon Option: next steps

- R&D program to optimize the X-ARAPUCA design started @ UNICAMP (Dichroic filter and WLS plate)
- First test will be at room temperature, followed by small scale tests @ CERN
- Though xenon doping is not currently part of the baseline design for the PDS, it will likely be included as a component of the ProtoDUNE-2 run and will be evaluated for inclusion in the baseline prior to the Production Readiness Review.

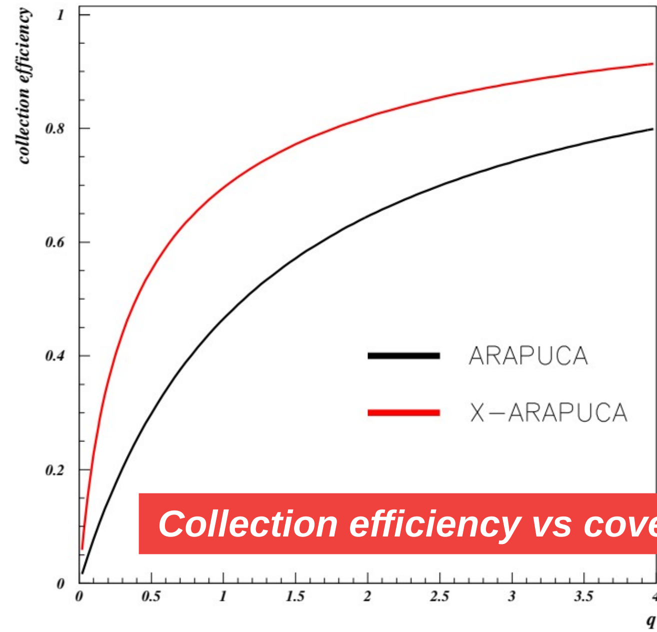
Summary

- SP-PD System made great progresses since the Conceptual Design Review at the end of 2018
- X-ARAPUCA design validated on small scale prototypes
- Consortium is ready to start the validation of the supercell design
- Substantial advance in the SiPM procurement and testing
- Warm electronic read-out board design completed. Now in the prototyping phase
- Xenon doping is an attractive option to improve uniformity of light collection, increasing light collection efficiency and making the PDS resistant to nitrogen contaminations
- Solid baseline design which meets all[requirements

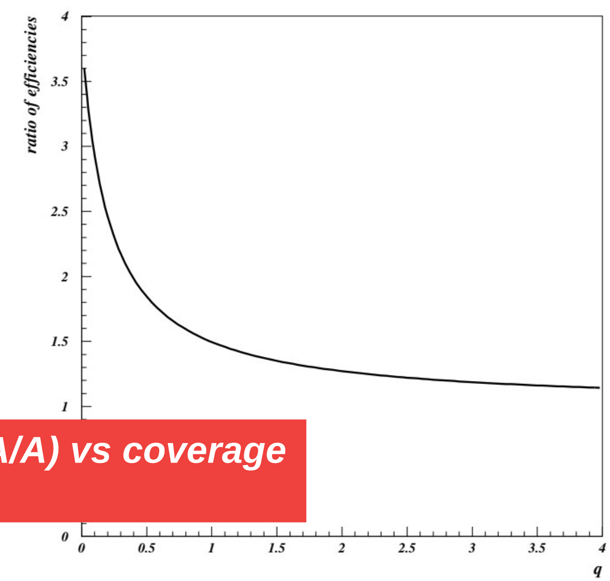
Back - up

X-ARAPUCA vs. ARAPUCA

- **X-ARAPUCA is more efficient in trapping photons**:
  - Analytical calculations and MC simulations appoint to an enhancement *between 40% and 70%* wrt ARAPUCA
- **Simpler design:**
  - **No need of evaporating** the internal side of the filter or internal surfaces
  - Great advantage especially for double sided X-ARAPUCAs
  - Faster production
- **Risk reduction:**
  - Reduced adhesion issues → limited to the external shifter



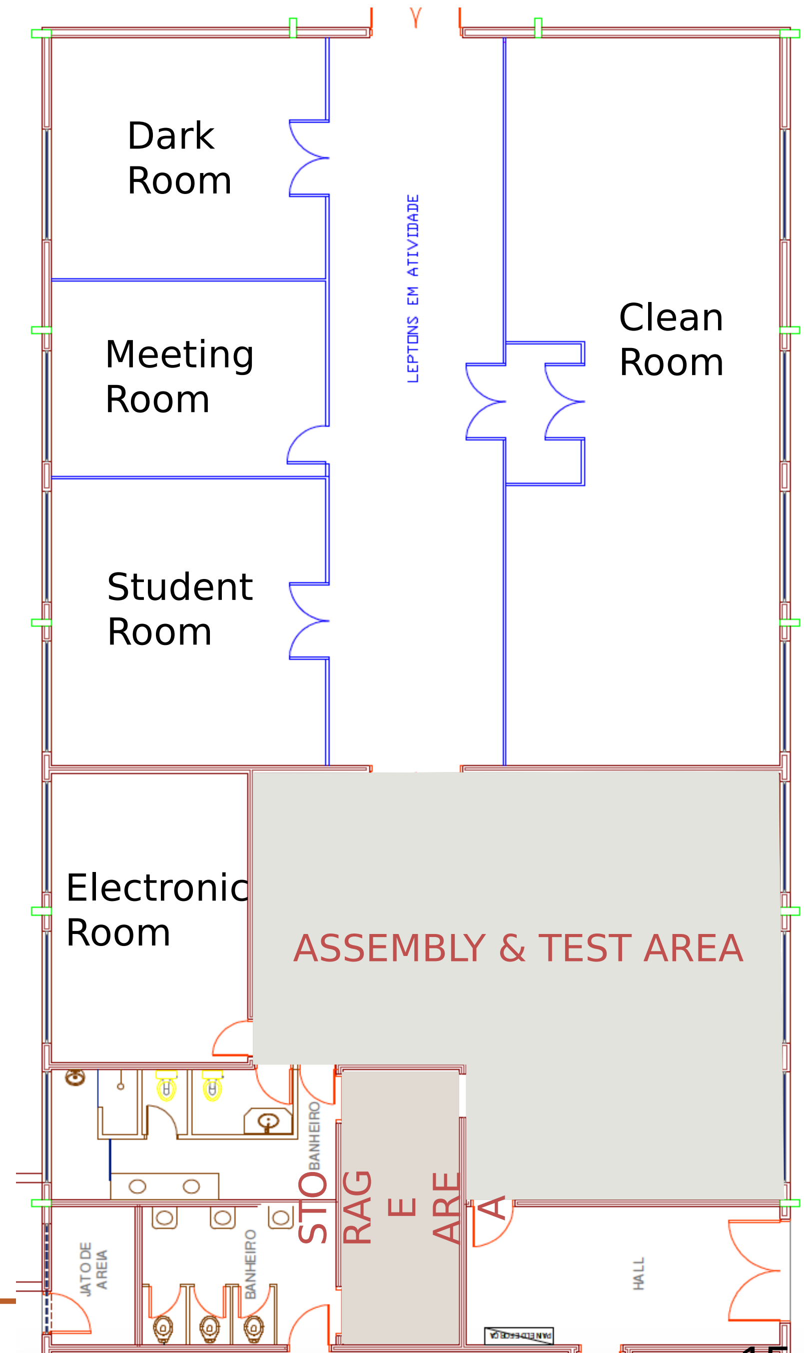
Collection efficiency vs coverage

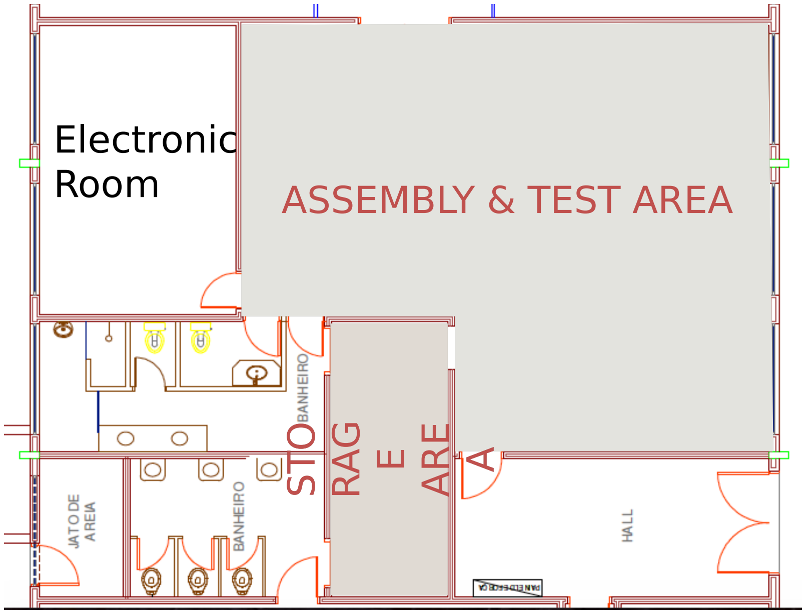


Ratio of efficiencies (XA/A) vs coverage

LAB. LEPTONS

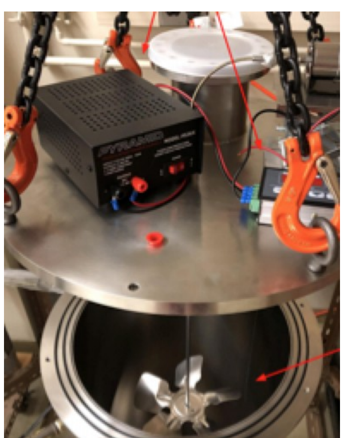
- A new area with 100m² was added to the laboratory which will be dedicated to assembly, testing and storage.
- The total area of LabLepton is now around 350m².

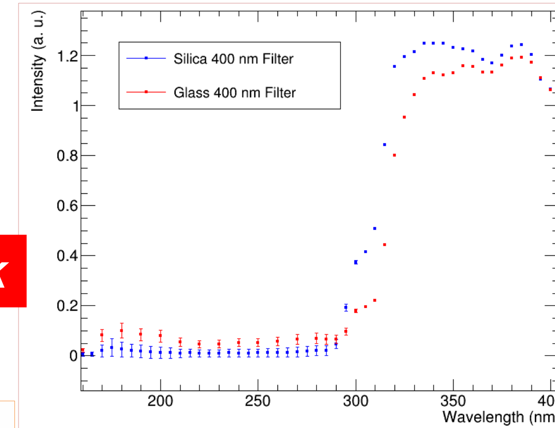



Electronic Room
ASSEMBLY & TEST AREA
STO
RAG
E
ARE
A
BANHEIRO
BANHEIRO
JATO DE AREIA
HALL

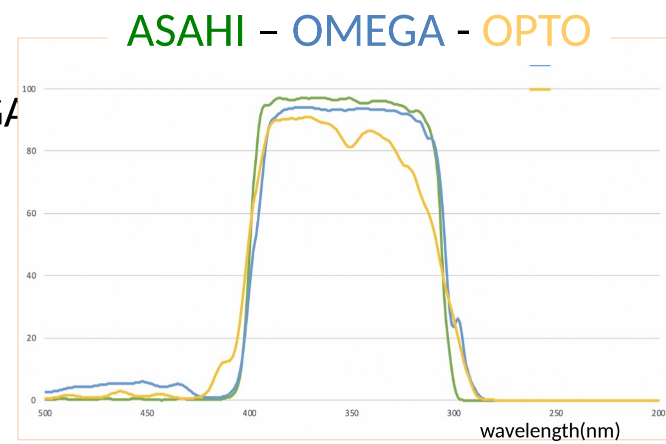
Dichroic filters

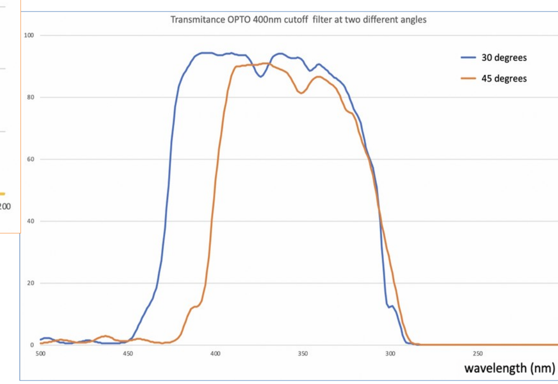
- ***Substrate tests***
  - Fused silica X Optical Glass (B270)
  - Coated Adhesion
- ***Transmittance***
  - Comparison (ASAHI, OMEGA, OPTO)
  - Spectrum at 2 diff angles – OPTO
- ***Scanning***
  - Coated Filter
- ***Next tests***
  - Long term LAr Tests

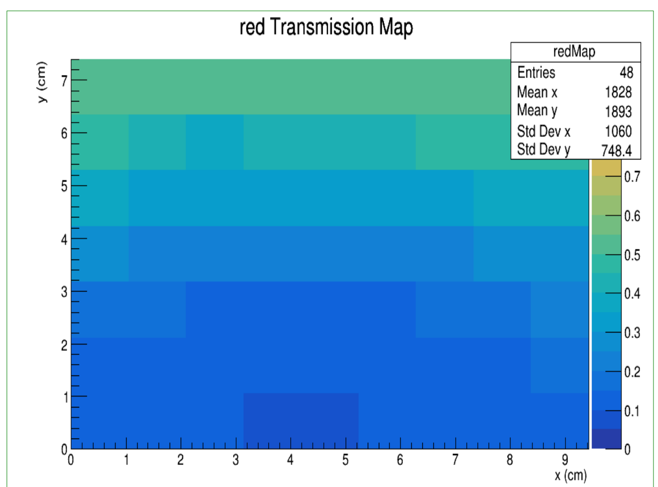




More in A. Machado talk





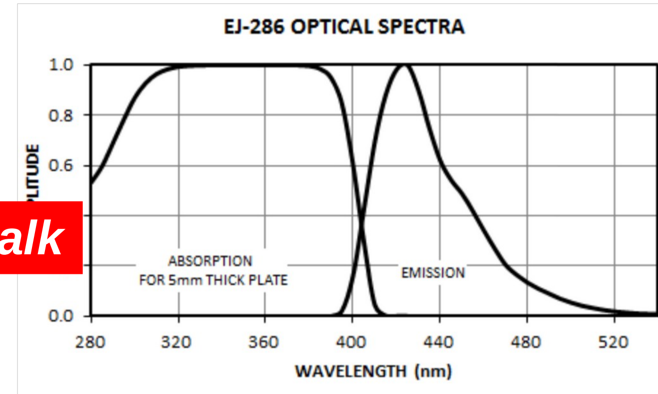


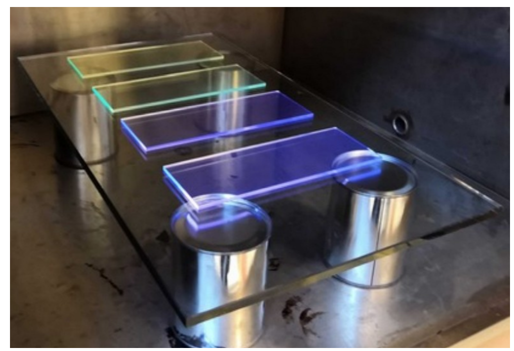
Baseline for DUNE:
Filter produced by OPTO 400nm, with a optical glass B270 substrate.

WLS Plates

- Tests on ELJEN light bars
  - Immersion in LN2
    - Fast : quick dunk
    - Slow: 2cm/sec
  - Annealing (only for PVT)
  - Results from ICEBERG
  - Comparisons among different matrixes: PVT, Polystyrene and PMMA

More in A. Machado talk





Baseline for DUNE
- ***ELJEN (EJ286) comercial Blue emmiting WLS plate***
- ***Peak wavelength 425nm***
- ***Matrix polystyrene***