Consuntivi Scientifici 2021
Esperimenti di Gruppo 2

Alessandro Menegolli

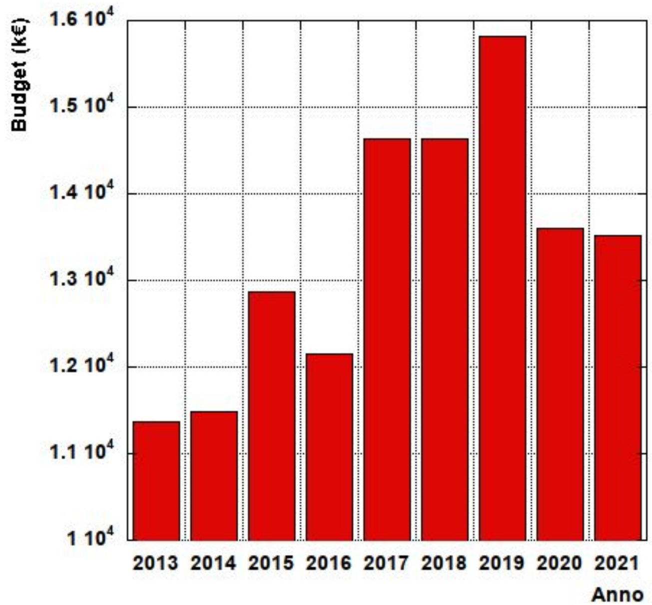
Dipartimento di Fisica e INFN, Sezione di Pavia

Grazie a P.W. Cattaneo, P. Malcovati, G.L. Raselli e V. Re per il materiale fornito

CdS INFN Pavia

15 giugno 2022

Bilancio: 2013-2021



*2020 e 2021: restituzioni COVID e riassegnazioni nel bilancio dell’anno successivo.

- CSN2 è la commissione che è cresciuta di più in termini di FTE/persone negli ultimi anni - per lo più da EPR (INAF) e Università:
- Numero sigle (~ 50) e FTE/pers (0.6-0.7) circa costanti negli ultimi anni

Attività: 4 settori di ricerca

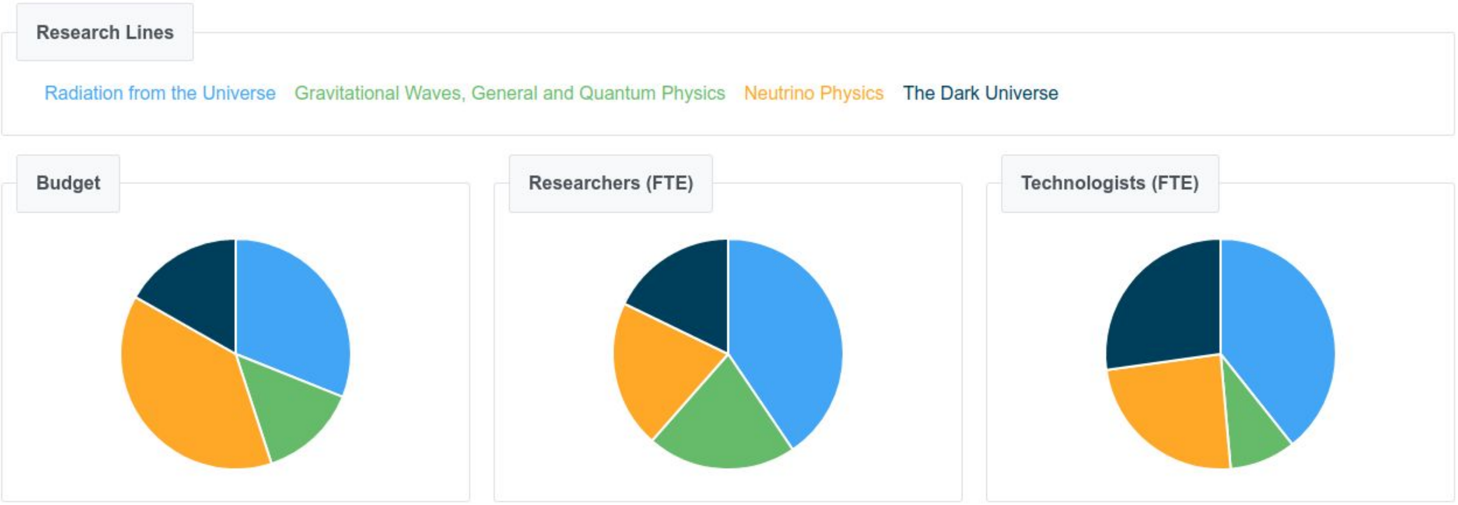
Le attività di CSN2 sono raggruppate in quattro settori:

Linea 1: Fisica del neutrino.
Oscillazioni di neutrino, decadimento doppio beta.

Linea 2: Radiazione dall'Universo
Raggi cosmici, raggi gamma, neutrini cosmici, antimateria.

Linea 3: L'Universo Oscuro
Materia Oscura, Energia Oscura, Assioni.

Linea 4: Onde gravitazionali, fisica generale e quantistica.
Onde gravitazionali, misure di g, effetti relativistici, proprietà quantistiche del vuoto.



Sigle 2021

Distribuzione delle sigle per linea di ricerca.

	N. esp.
1-Fisica del neutrino. CUORE-CUPID, CYGNO, ENUBET_2, GERDA, HOLMES_2, ICARUS, JUNO, NU_AT_FNAL, NUCLEUS, PTOLEMY, T2K, TRISTAN.	12
2-Radiazione dall'Universo AMS2, AUGER, CTA, FERMI, GAPS, HERD_DMP, KM3, LITEBIRD, LSPE, QUBIC, SPB2, XRO.	12
3-L'Universo Oscuro COSINUS_CSN2, CRESST, DAMA, DARKSIDE, EUCLID, NEWS, QUAX, SABRE, XENON	9
4-Onde gravitazionali, fisica generale e quantistica ARCHIMEDES2, ET_ITALIA, FISH, G-GRANSASSO-RD, HUMOR, LIMADOU_CSN2, LISA, MEGANTE_2, MOONLIGHT-2, SATOR_G, SUPREMO, VIRGO, VMBCERN	13
Totale	**46**

Sigle chiuse (a parte code di analisi): BOREX, LVD, MOSCAB

Anagrafica PV 2021

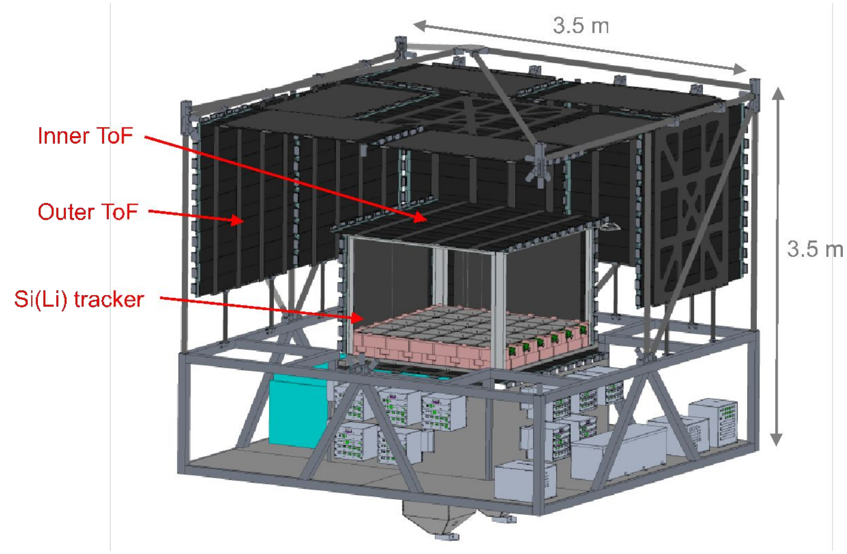
Linea	Esperimento	FTE/persona
1. F, Boffelli, A. Menegolli, C. Montanari, A. Rappoldi, G.L. Raselli, M. Rossella, A. Scaramelli	ICARUS	3.4/7
2. A. Agnesi, P.W. Cattaneo, C. De Vecchi, M. Grassi, F. Leporati, P. Malcovati, M. Manghisoni, M. Oddone, F. Pirzio, A. Rappoldi, G.L. Raselli,K.M. Rashid, V. Re, E. Riceputi, M. Sonzogni, E. Torti	GAPS, HERD, XRO	5.9/16
3.		
4.		
Totale	**4**	**9.3/21**

- *+1.2 FTE rispetto al 2020*
- *+ 6 persone rispetto al 2020*
- *Ma da 0.54 a 0.44 FTE/persona … basso!*

GAPS

General AntiParticle Spectrometer

The General Antiparticle Spectrometer (GAPS) is an Antarctic balloon experiment designed to detect low-energy cosmic antinuclei as an indirect signature of dark matter



The Instrument

Time-of-Flight System (TOF)

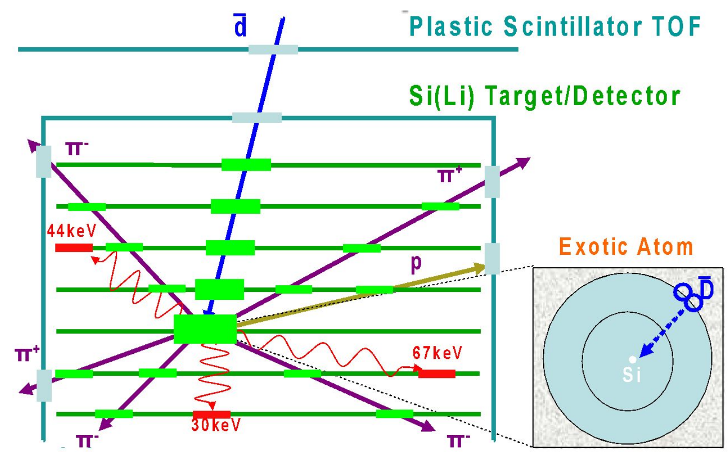
- 220 plastic scintillator paddles with Si-PM readout

Si(Li) Tracker

- About 1000 lithium-drifted silicon (Si(Li)) detectors
- 10 layers with 10 cm spacing
- 12x12 Si(Li) detectors per layer
- Modular structure (360 modules)

Particle identification

Time-of-flight system measures velocity and dE/dx



Si(Li) Tracker functions as

- target to slow an incoming antiparticle and capture it into an exotic atom in an excited state
- spectrometer for de-excitation X-rays
- tracker to measure antinucleus dE/dx and stopping depth, and annihilation products from nuclear decay

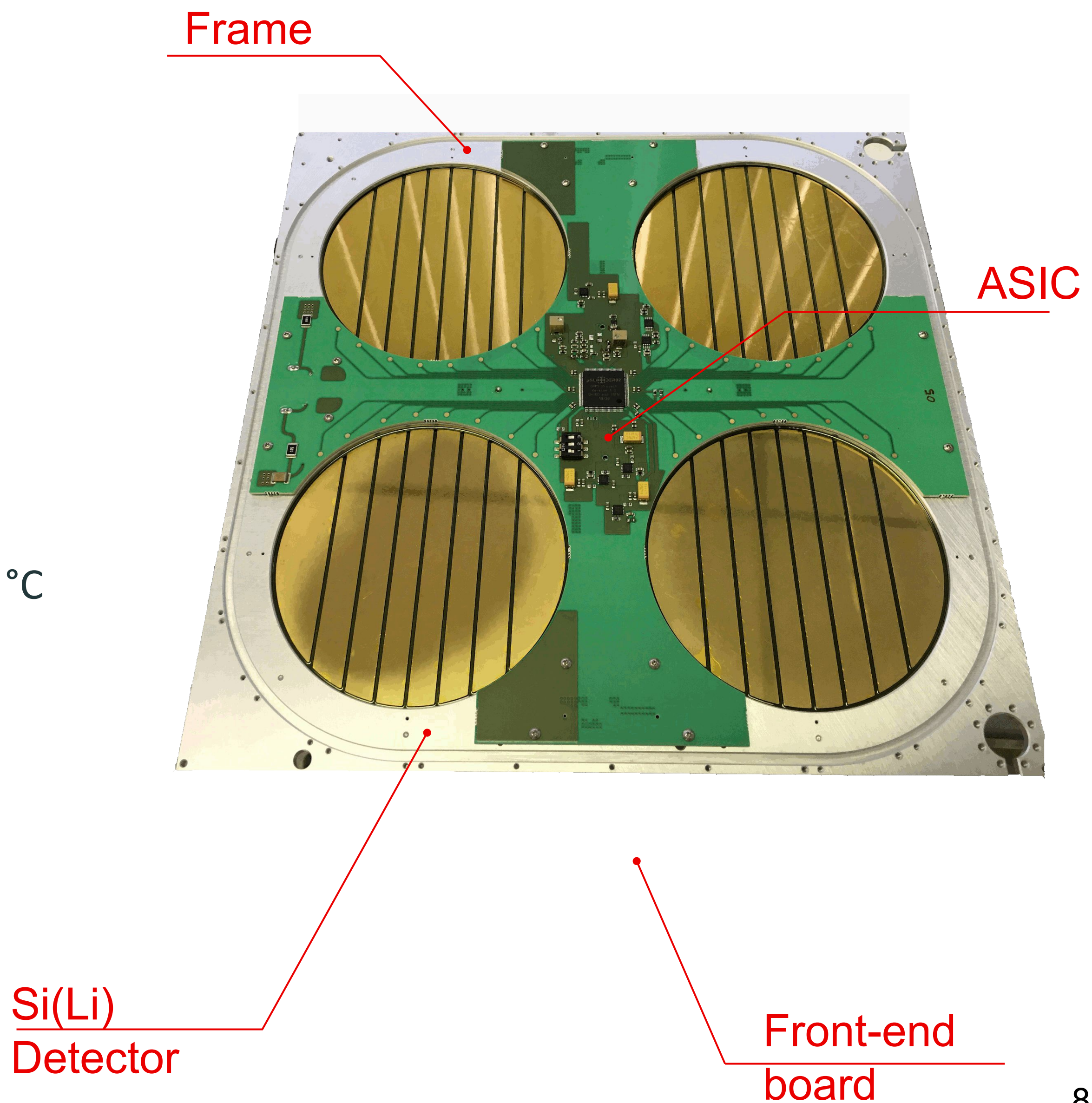
Si(Li) Tracker

Module

- 4 Si(Li) detectors (8 strips each)
- 1 readout ASIC
- 1 front end board
- Frame
- Top and bottom windows (not shown)

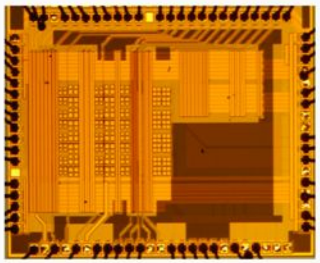
Front-end electronics requirements

- Channels per ASIC: 32
- Nominal operating temperature: -43 °C
- Power dissipation: ≤10 mW/ch
- Signal polarity: electrons
- Dynamic range: 10 keV-100 MeV
- Analog Resolution: 4 keV (FWHM)
  detector capacitance 40 pF
- Threshold: 10 keV
- Detector leakage current: 5 nA
- Event rate: 100 Hz



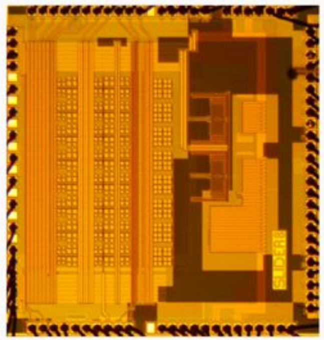
Front-end Electronics

SLIDER: SiLI DEtector Readout



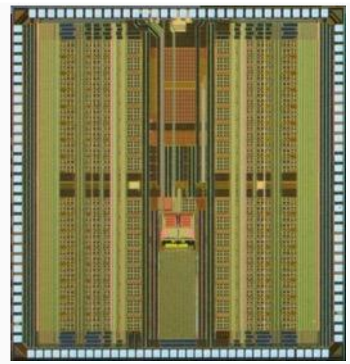
SLIDER4 (2018)

- 4 analog channels
- No digital back end
- 2 channels with analog output



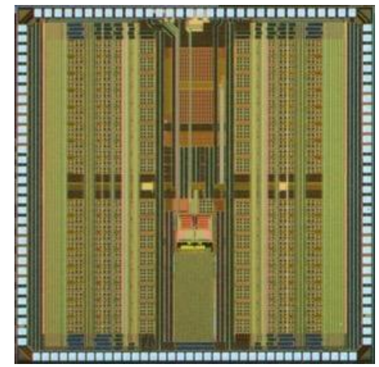
SLIDER8 (2018)

- 8 analog channels
- digital back end
- 11 bit ADC
- No access to analog blocks



pSLIDER32 (2019)

- 32 analog channels
- digital back end
- 11 bit ADC
- 2 channels with access to analog blocks

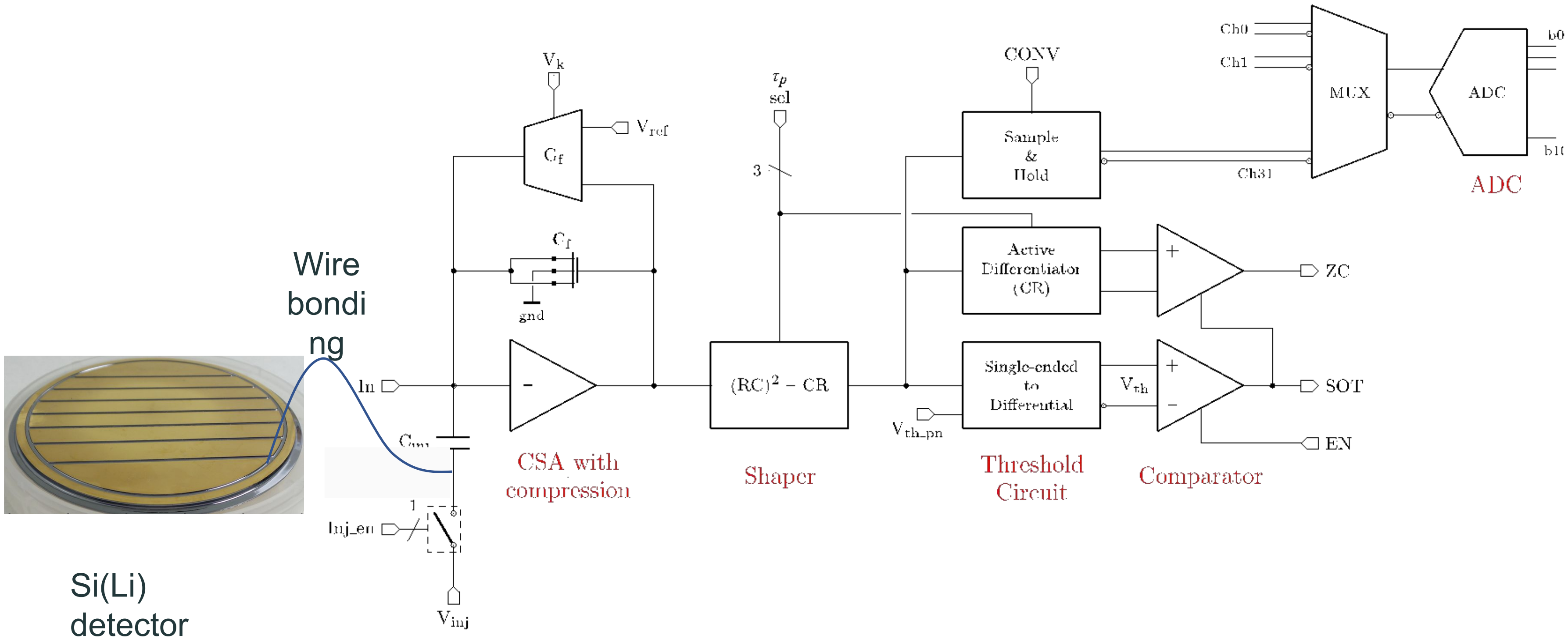


SLIDER32 (2021)

- 32 analog channels
- Digital back end
- 11 bit ADC
- 1 channel with analog outputs
- Additional tests points

The production of the final chip SLIDER32 in 2021 was successful, and front-end boards with ASICs are currently being tested and selected for the flight instrument.

Analog readout channel and ADC



- Charge sensitive amplifier with dynamic signal compression
- CR-(RC)2 filter with 8 selectable peaking times (from 250 ns to 1.8 µs)

- SOT comparator
  Signal Over Threshold identification
- Active CR and ZC comparator
  Shaper signal peak detection
- Single-ended to differential S&H
  Shaper signal peak storage

- Injection capacitance C_{inj}
  Calibration
- 11-bit hybrid SAR ADC
  One per ASIC with 32:1 MUX

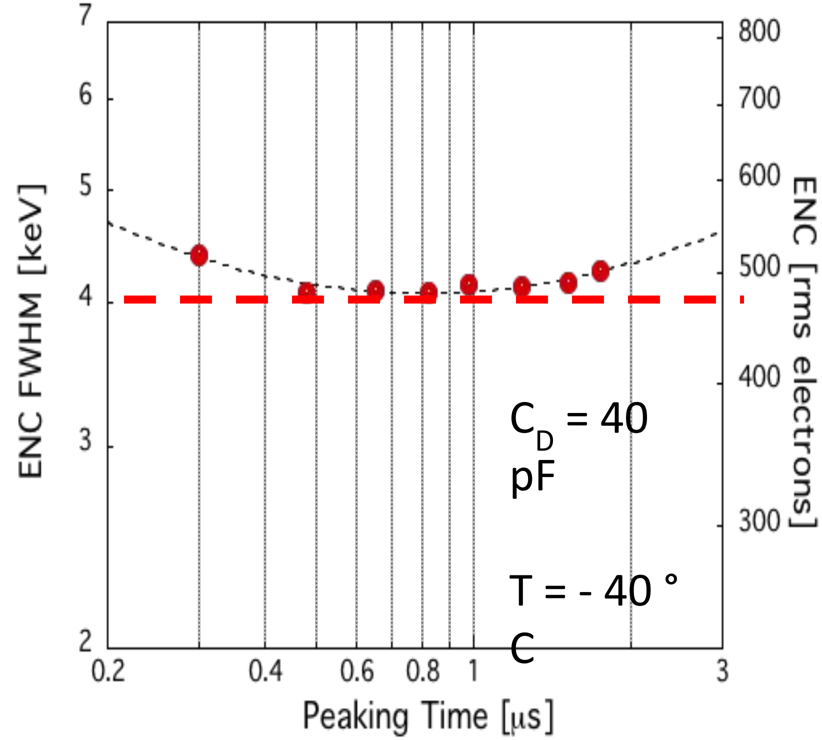
Tests on the readout ASIC

- The SLIDER32 chip (flight ASIC) was successfully tested in 2021.

- The chip is fully functional, achieving the 4 keV FWHM resolution necessary to detect characteristic X-rays that are emitted when an antinucleus is captured into an exotic atom.

- Front-end boards with readout ASICs were fabricated and are currently being tested. A validation procedure and the relevant documentation were defined

- The measured yield of the fabricated front-end boards is > 90%



Noise measured at the output of the ADC (ENC extracted from the variance of the distribution of output values)

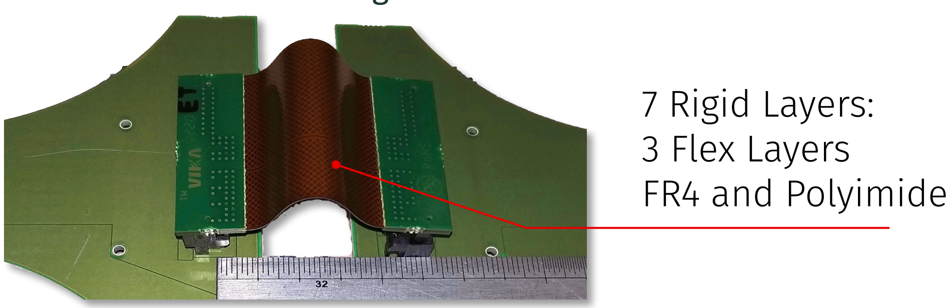
Front-end and Flex-rigid boards

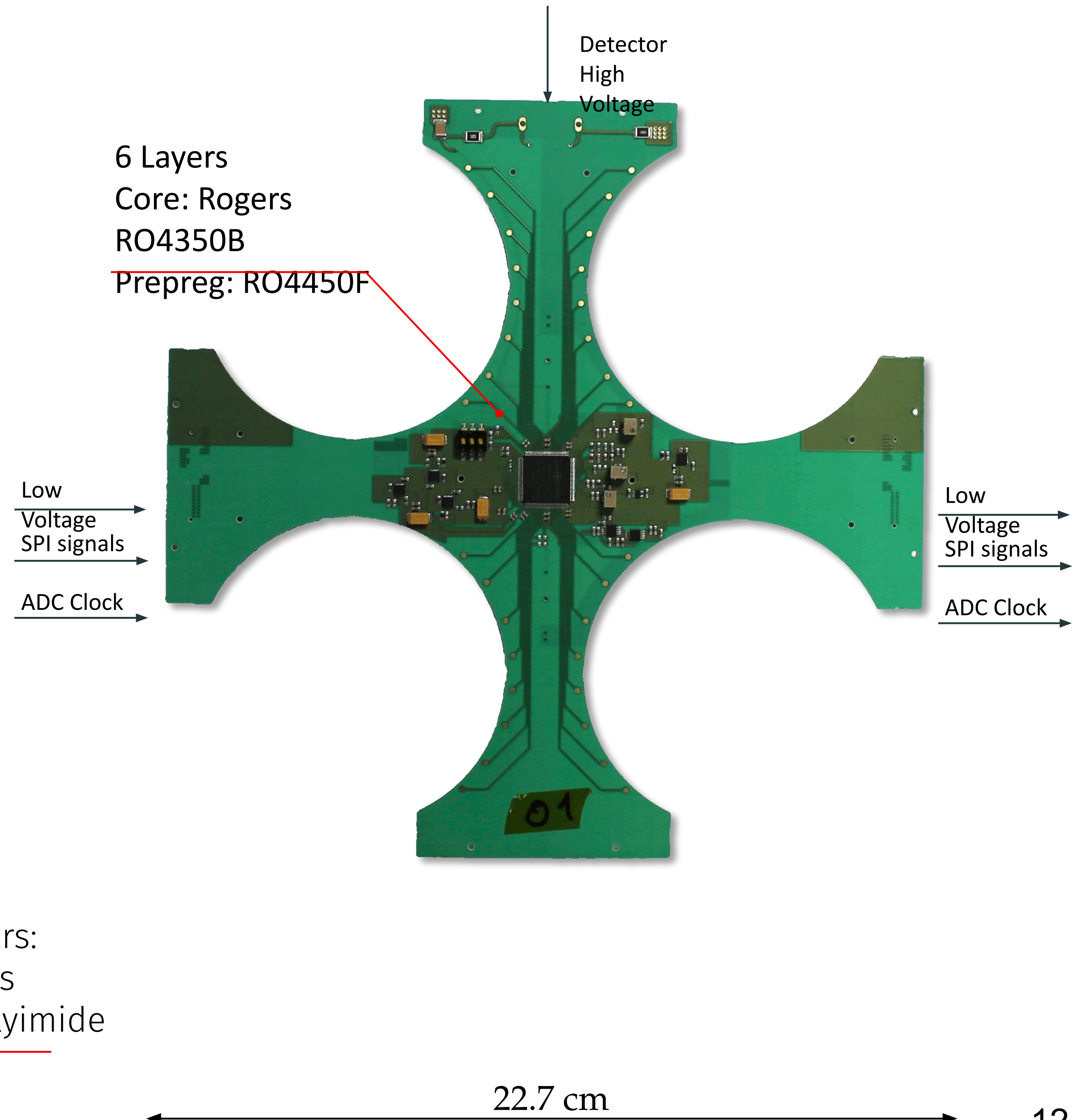
Front-end Board

- One ASIC connected to 4 Si-Li detectors
- voltage regulators and filtering for
  - Si(Li) detector High Voltage Power Supply
  - ASIC Low Voltage Power Supply (AVDD, DVDD)
- ASIC SPI control signals
- ADC clock
- Temperature sensor
- ASIC calibration system (16 bit DAC)

Flex-rigid Board

- Connects Front-end boards in series
- Propagates
  - ASIC Low Voltage Power Supply
  - SPI control signals and ADC clock





Validation procedure

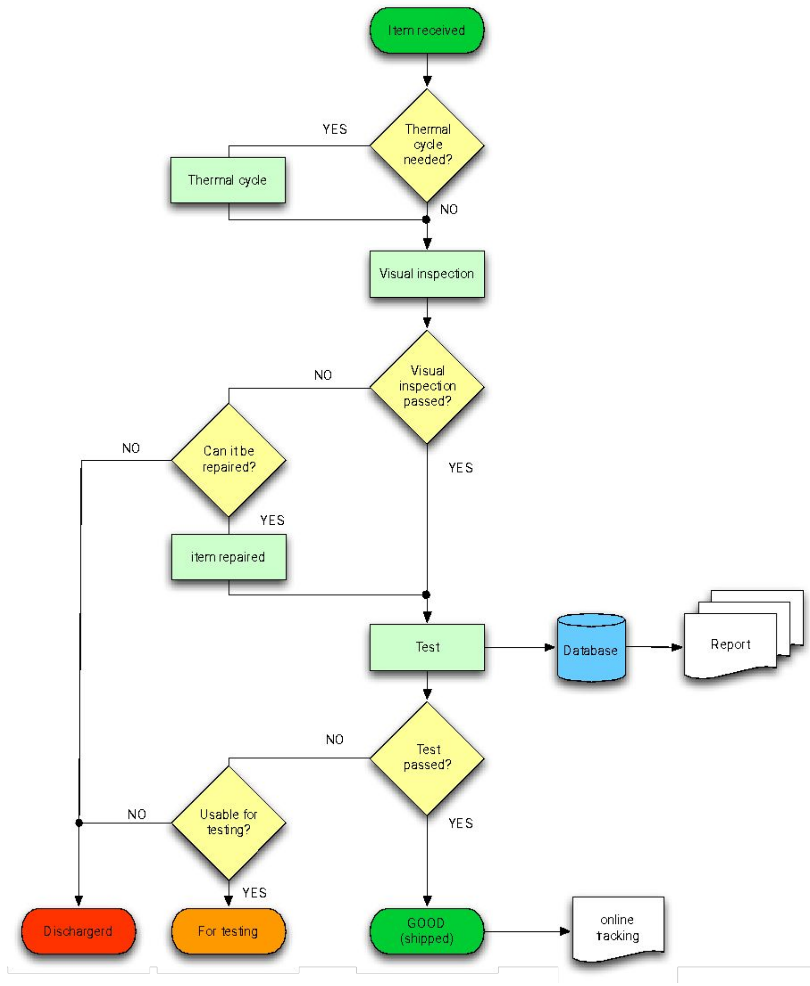
Each item undergoes a validation procedure that includes:

- **Thermal cycle** (if not already performed)
- **Visual inspection** (to search for defect, missing or bad soldered components...)
- **Test** (type of test depends on the item)

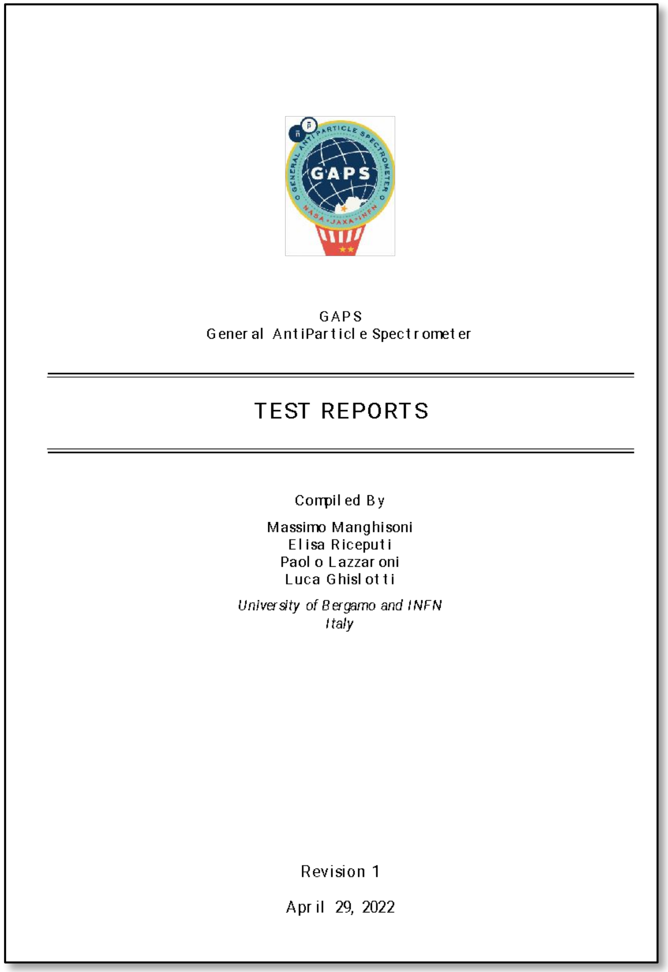
At the end of the procedure

- Test results are saved in a database
- An item report with test results is generated
- The item is classified as
  - **GOOD**
  - **USABLE for testing activity only**
  - **DISCHARGED**
- GOOD and USABLE items are delivered to Columbia (the online tracking file is updated)

In addition a **Test Report Document** is generated and delivered to ASI



Test Report Document


GAPS
General AntiParticle Spectrometer

TEST REPORTS

Compiled By
Massimo Manghisoni
Elisa Riceputi
Paolo Lazzaroni
Luca Ghislotti

University of Bergamo and INFN
Italy

Revision 1

April 29, 2022

It includes

- **A detailed description of the type of tests**
- **The validation criteria**
- **A Statistical analysis of some parameters**
- **The report generated for each item**
- **The list of the shipment to Columbia**

1 Front-End Board

The test of the Front-End Board (FEB) is performed at ambient temperature in a twofold way:

- by measuring the DC bias conditions of the circuit with a Fluke 79 III digital multimeter and a Keysight N6705C DC Power analyzer (with N6762A and N6733B modules);
- by running a purposely developed Automated validation test controlled by a *terasIC* OpenVino Toolkit based on an ALTERA Cyclone V FPGA; this procedure performs several type of tests summarised in the following list:
  1. Noise (ENC)
  2. Pedestal
  3. Self trigger
  4. Threshold scan
  5. Channel input-output characteristic
  6. Waveform scan

  The results provided by these tests will be made available online.

A detailed description of the setup used for the tests is reported in Fig. 1 and 2. At first, the setup described in Fig. 1 as been used. After having realized that with this configuration the proper soldering of the ERNI output connector is not verified, the setup has been improved as shown in Fig. 2.

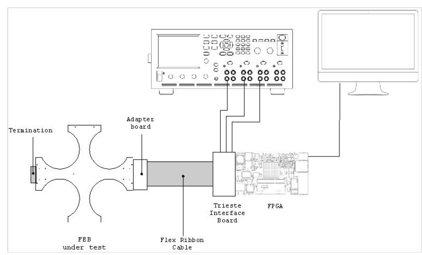


Figure 1: Detailed description of the setup adopted for the tests on the first set of FEB boards.

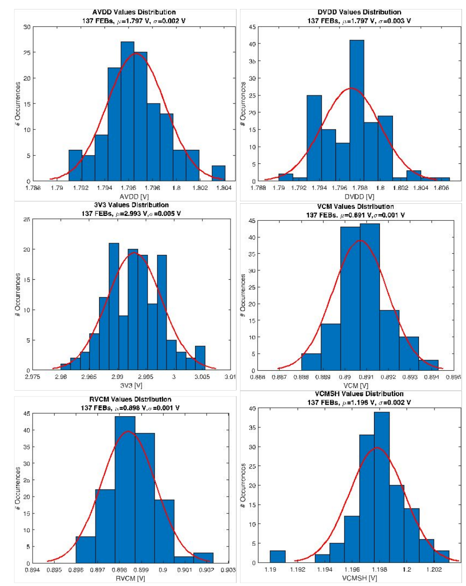
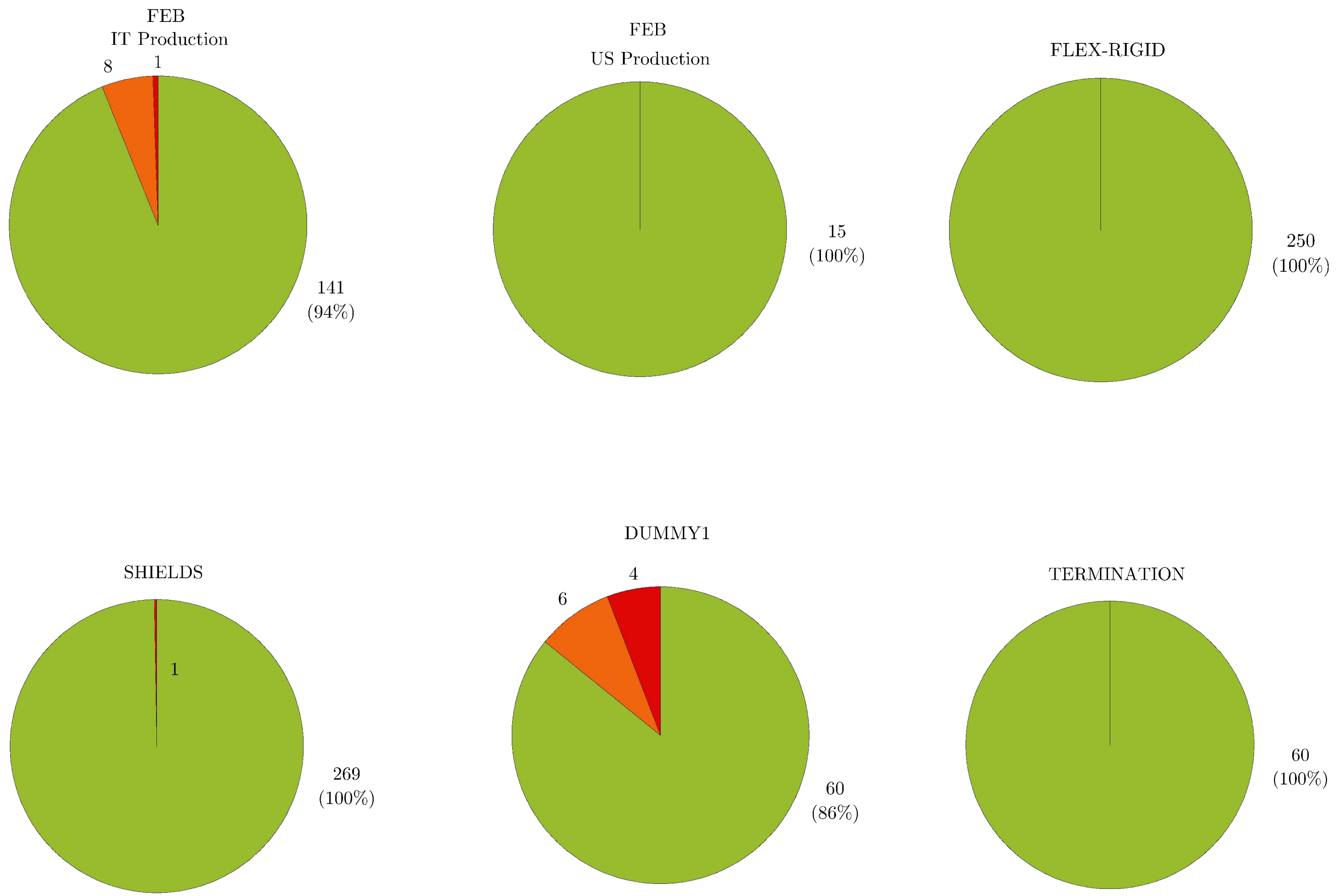


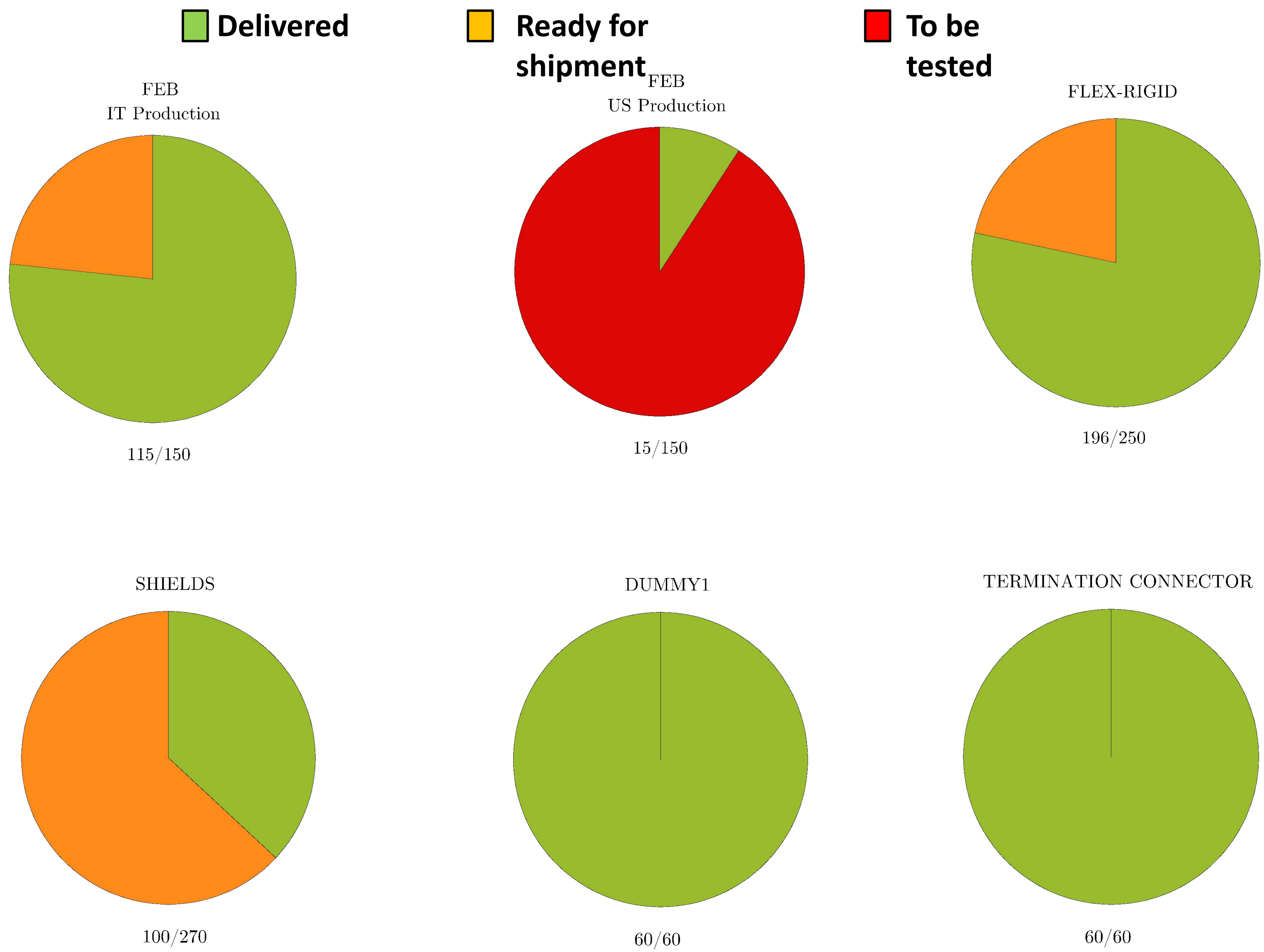
Figure 3: Statistical distribution of measured DC voltages.

Yield



(*) 135 still to be tested

Status of flight items delivered to US for tracker assembly



Summary of 2021 activity

- All the items needed for Si(Li) tracker assembly have been procured
- All the items, but 135 FEBs, have been successfully tested and validated
- The test of the remaining 135 FEBs will be completed within about 2-3 weeks

Presentazioni

Massimo Manghisoni, **pSLIDER32 a 32 channels mixed-signal Processor for the GAPS Si(Li) tracker. TIPP2021** - May 27, 2021 (virtual)

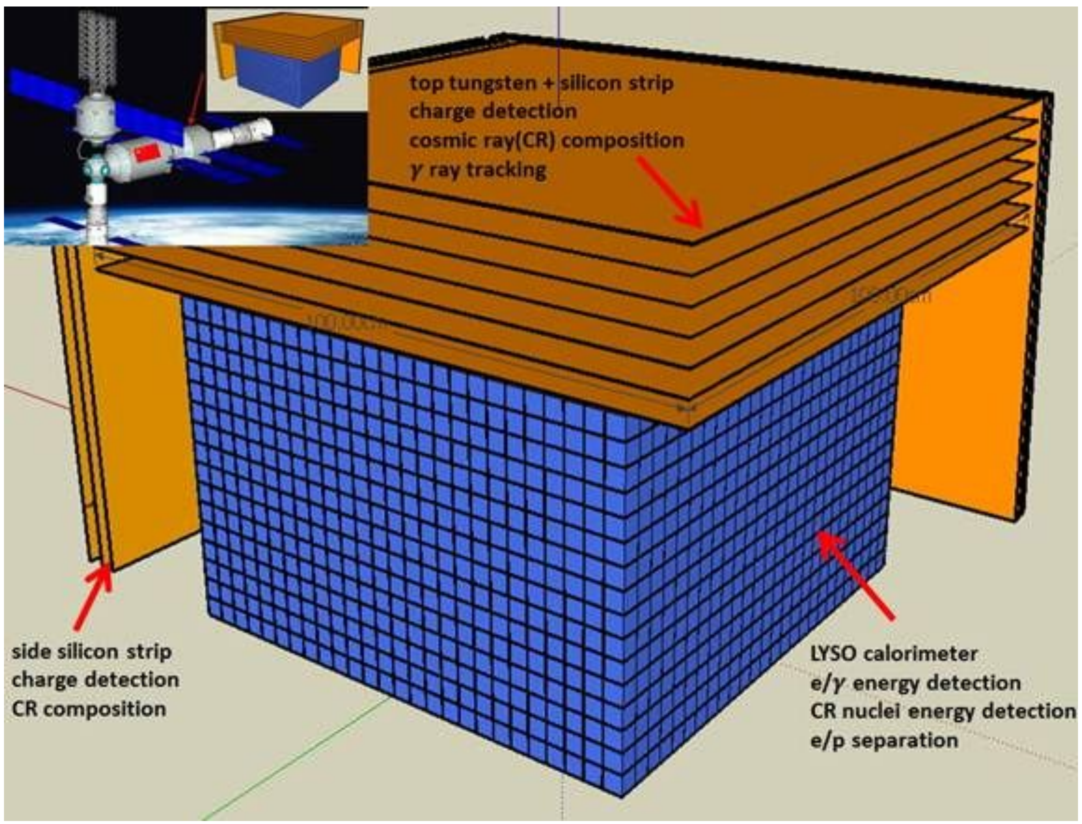
Personale INFN Pavia - 2021

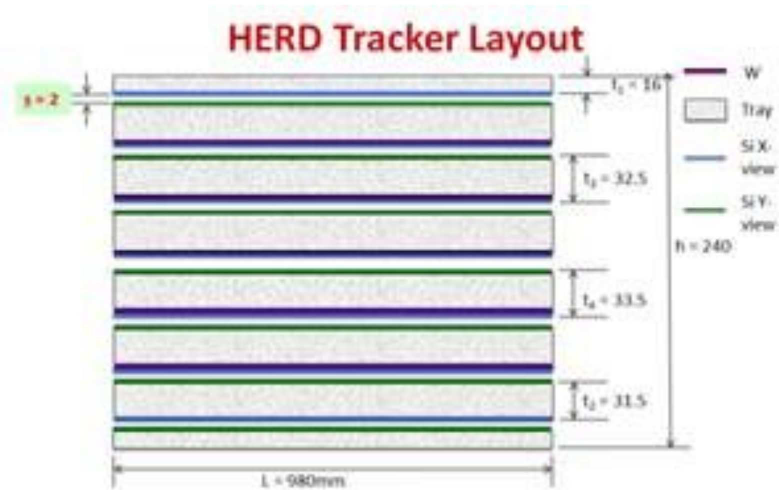
- Valerio Re (PO) 20%
- Massimo Manghisoni (PA) 50%
- Elisa Riceputi (Assegnista) 50%
- Mauro Sonzogni (Dottorando) 100%

Totale FTE: 2.2

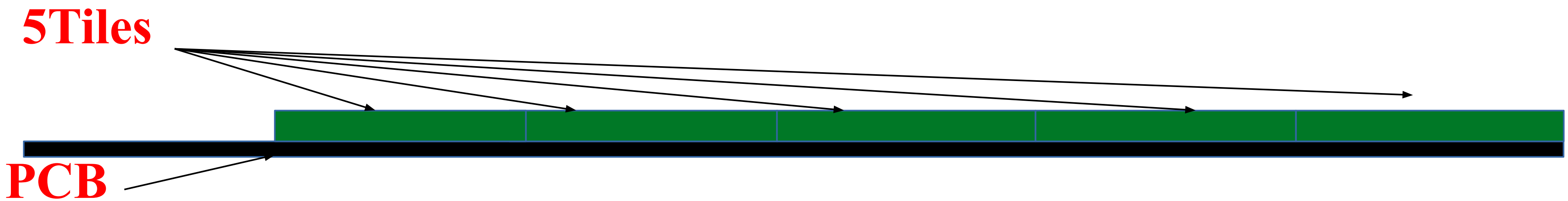
HERD

- HERD(High Energy Cosmic Radiation Detection) facility is one of the Cosmic Lighthouse Program onboard China’s Space Station, planned to be launched and assembled in 2020.
- The main science objectives of HERD onboard China’s space station are detecting dark matter particle, study of cosmic ray composition and high energy gamma-ray observations.
- The main constraints imposed on HERD are: total weight less than around 2 tons and total power consumption less than around 2 kilowatts.

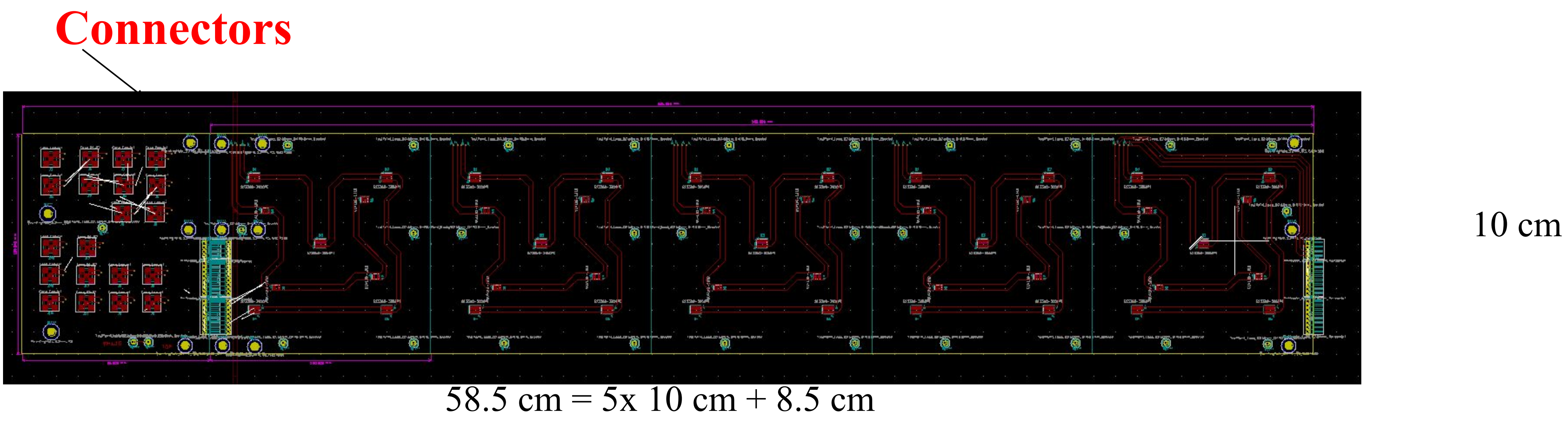




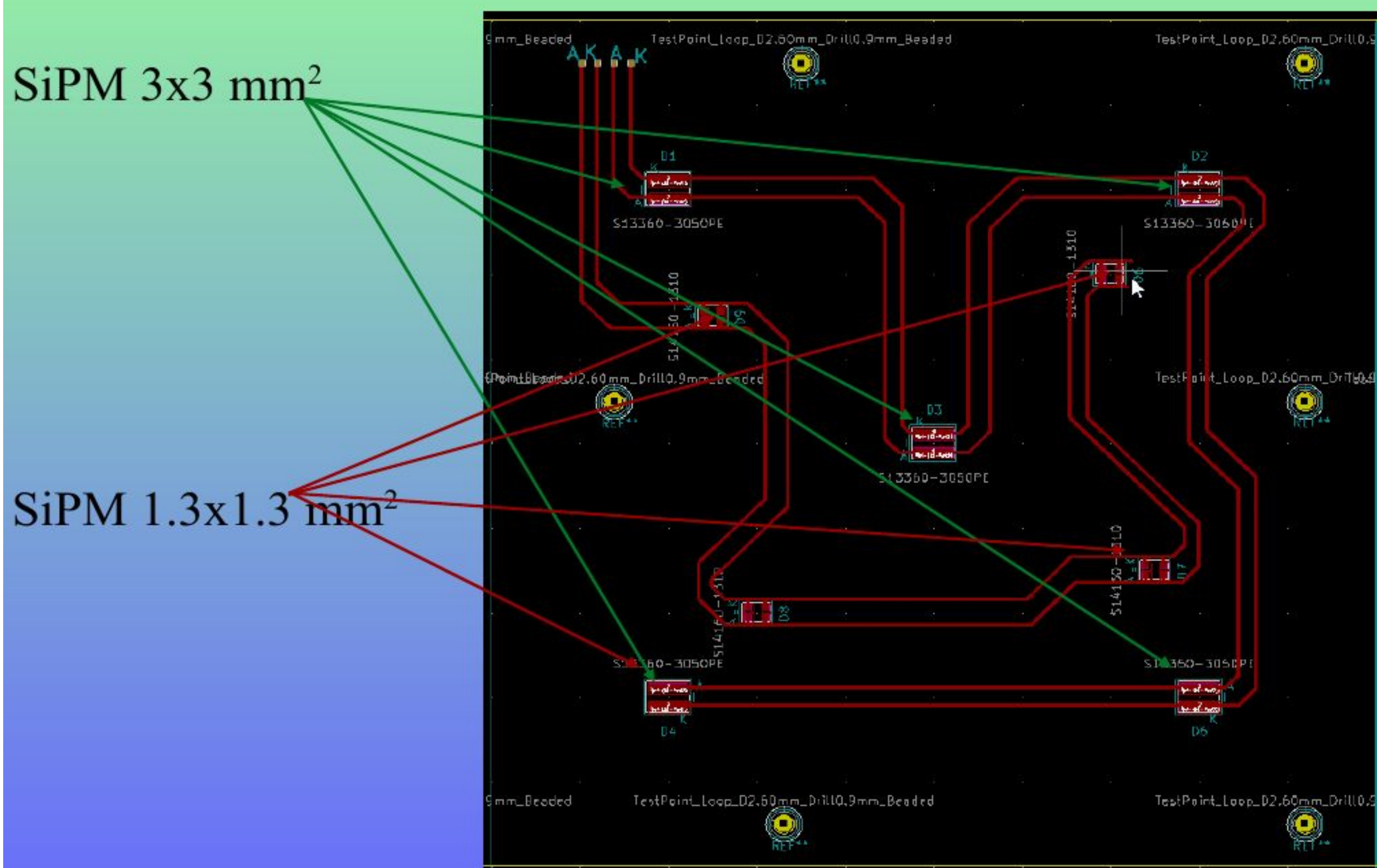
Long PCB for tile beam test



5 SiPM 3x3 mm^2 model S13360-3050PE (Hamamatsu)
4 SiPM 1.3x1.3 mm^2 model S14160-1310PS (Hamamatsu)
Inner paths connecting tiles and the MCX connector are matched 50 Ω in the second layer between two ground layers for shielding.

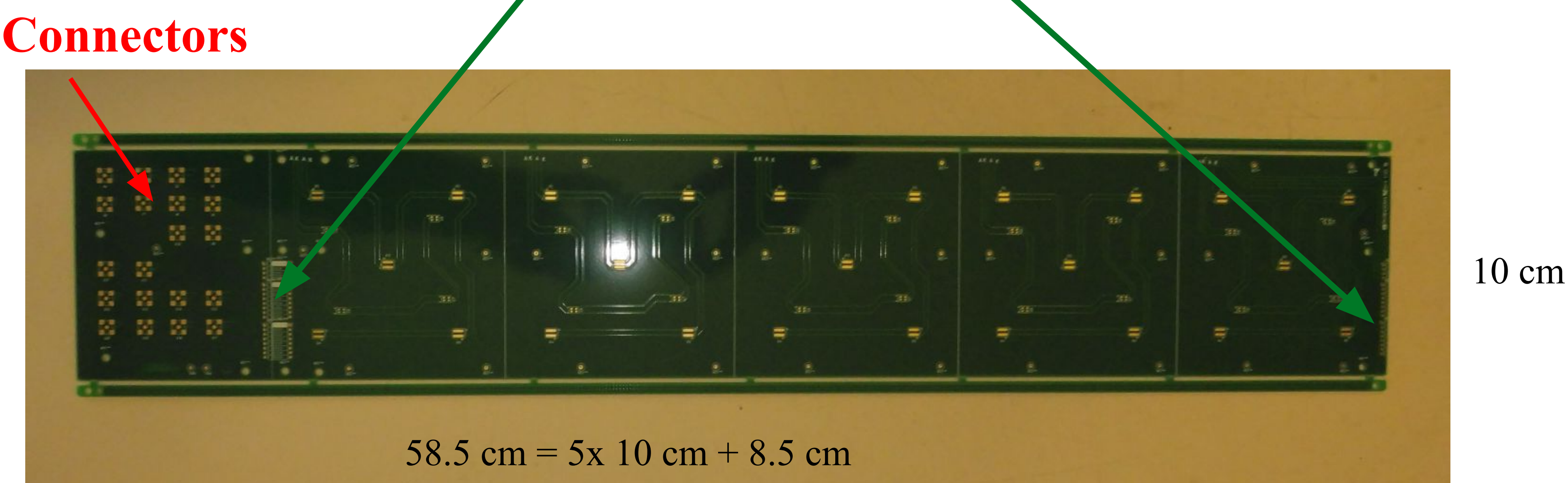


Layout for single tile



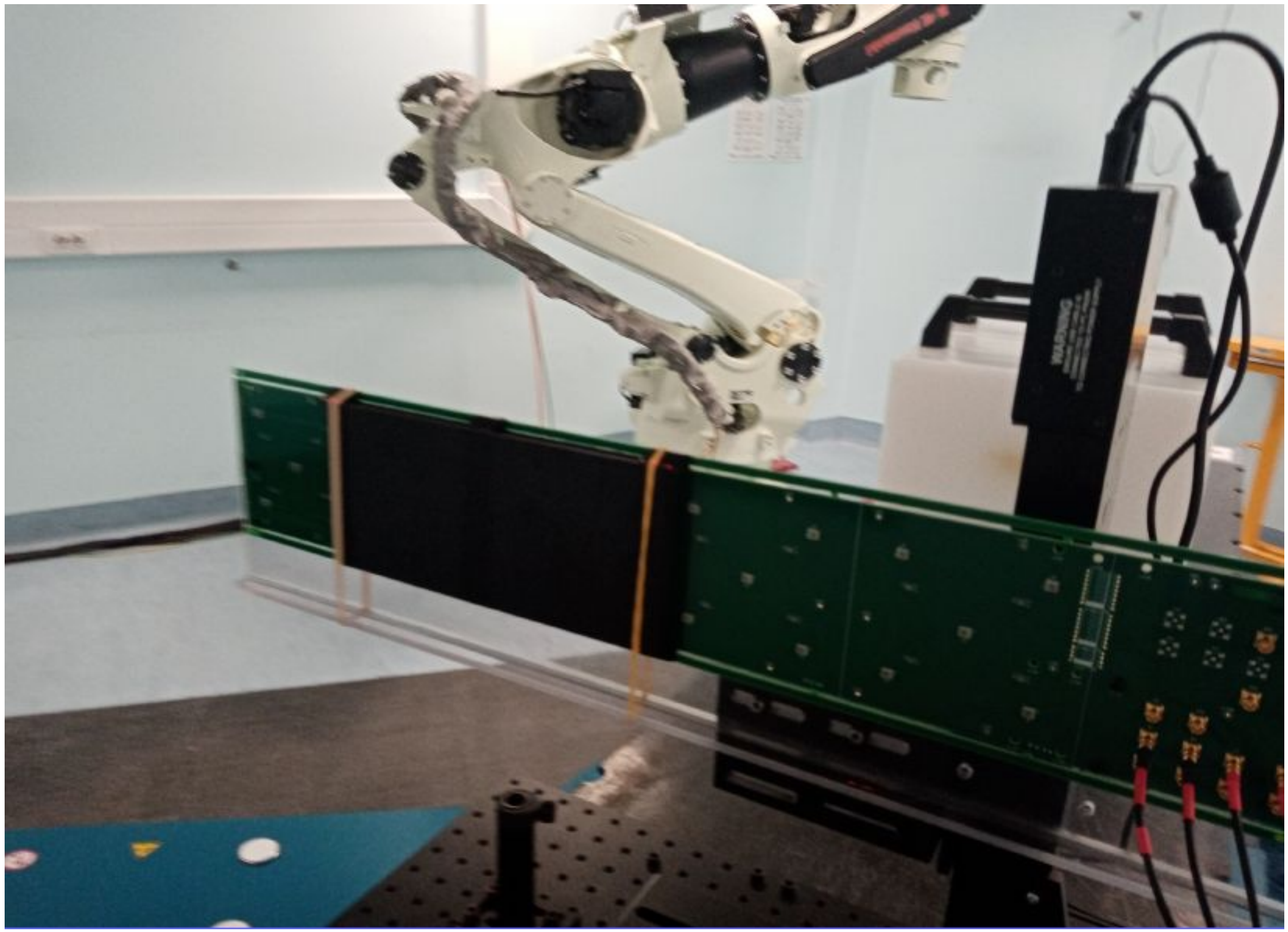
Long PCB for 10 tiles

- Building 1m long PCB is technically challenging.
- 2 PCBs 50 cm long can be ganged together with connectors.
- For testing purpose in the laboratory (non for beam test) connectors
- on both sides of the long PCB are available.
- That will allow testing tile mounted 1 m away from the output: signal attenuation and cross talk.



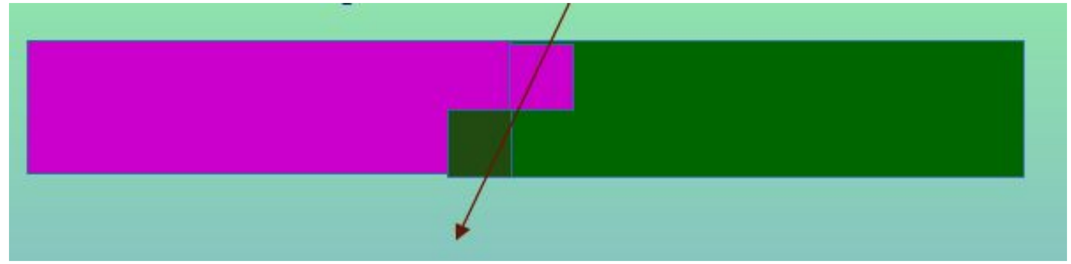
CNAO beam test 2021

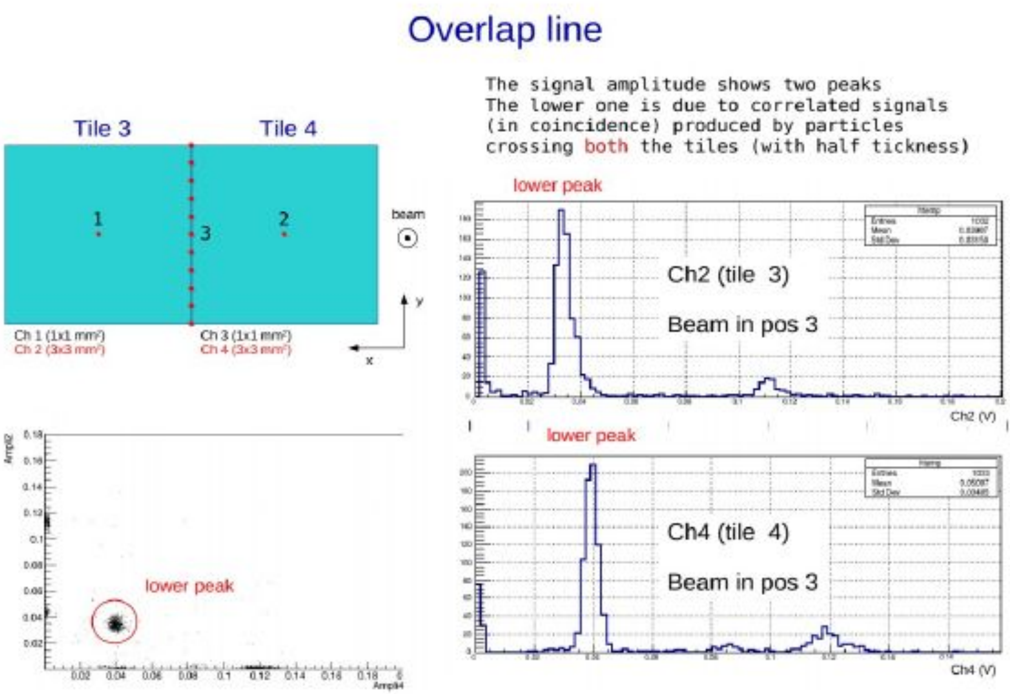
Beam tests 31-08-2021 and 01-12-2021.

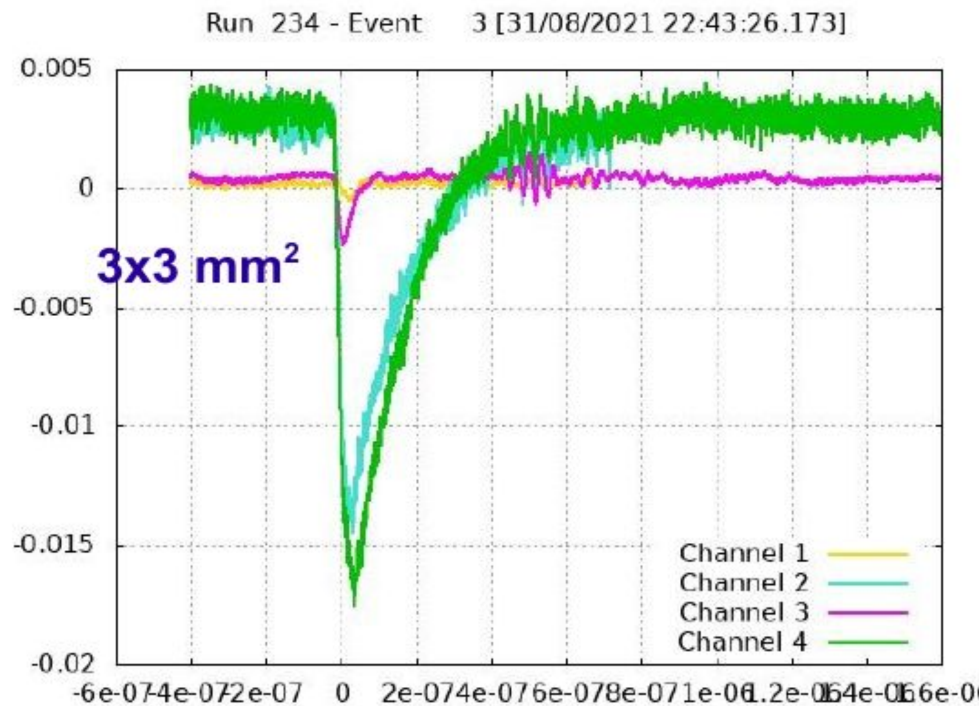


Tiles with edge

- To get full hermeticity tiles are step shaped on edge.
- Smaller signals are expected on both tiles.
- Test at CNAO with C ions

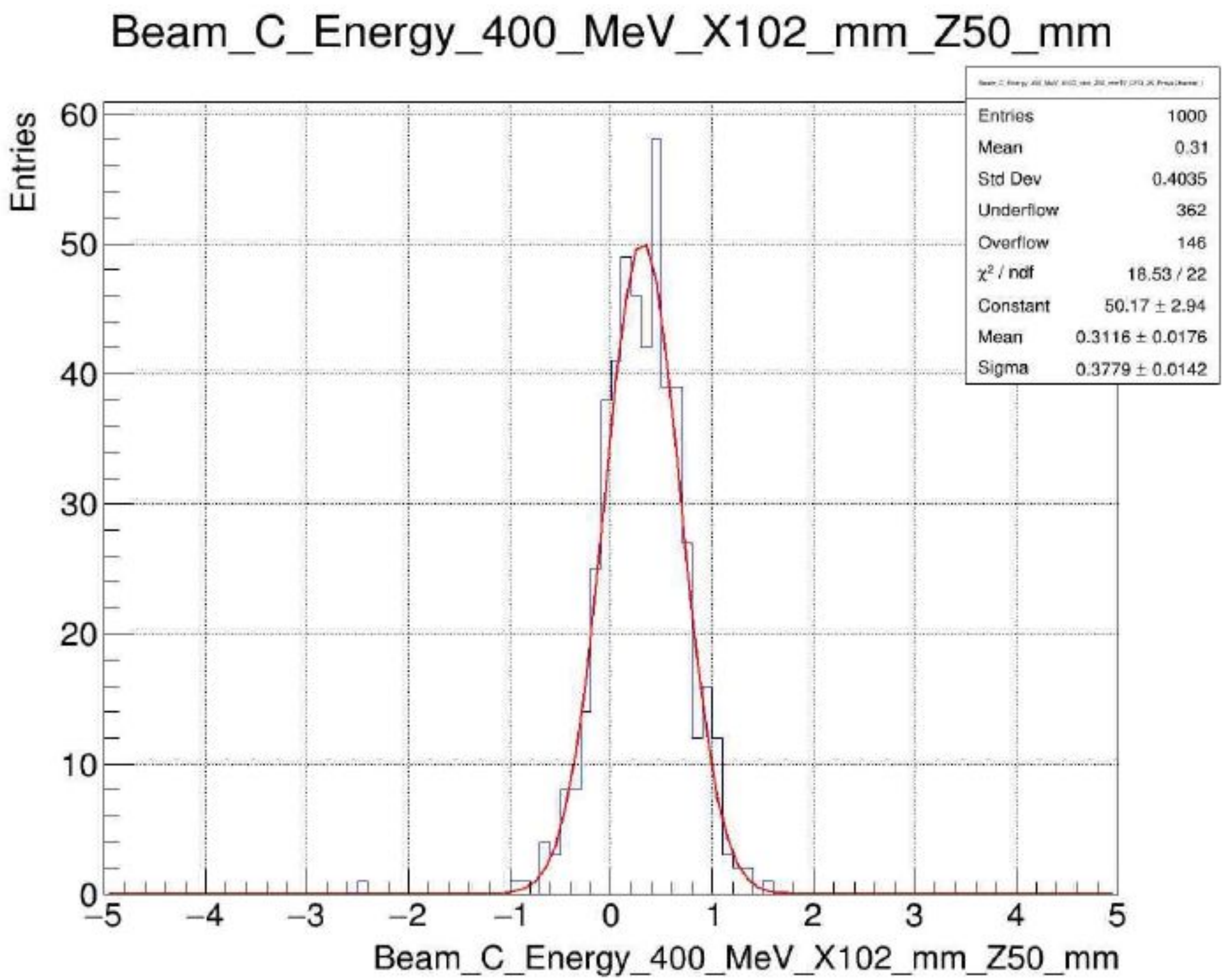




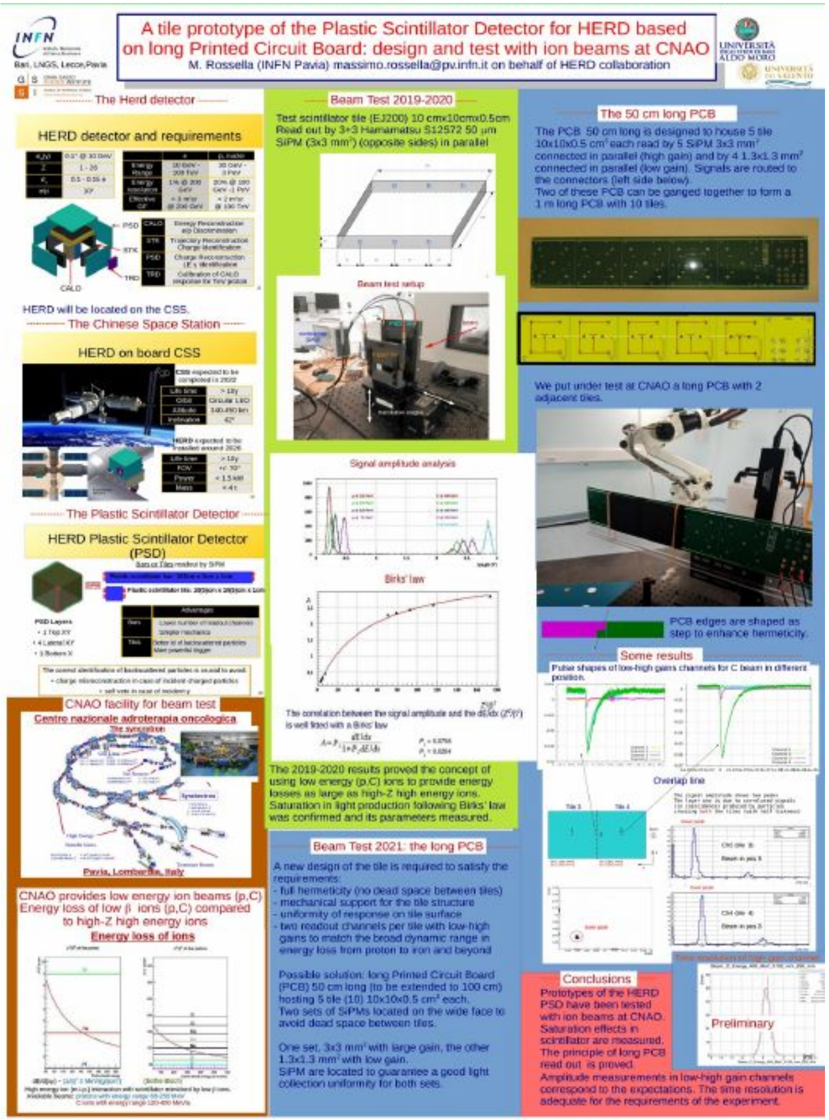


Timing with PSD

Timing resolution ~300 ps obtained with C ions.

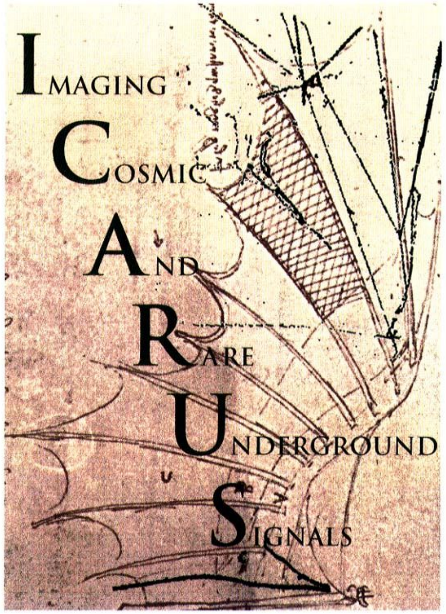


Presentation at Elba conference



FTE 2021

P.W. Cattaneo	0.4
C. De Vecchi	0.3
F. Leporati	0.2
M. Oddone	0.1
A. Rappoldi	0.4
G.L. Raselli	0.1
E. Torti	0.2
Totale FTE	**1.7**



ICARUS

An overview of ICARUS at FNAL

- RUN 0: May 31st - June 26th 2021. ICARUS took data regularly with an initial trigger with BNB and NuMI beams collecting a relevant sample of neutrino events.
- Several upgrades have been carried out since the summer shutdown, involving the cryogenic plant, PMTs, TPCs, Trigger, DAQ, slow controls, networking and servers.
- ICARUS detector and cryogenic plants are then steadily operating:
  - LAr purity allows an e-lifetime ~3 ms in WEST module and ~5 ms in EAST one;
  - All the detector components are operating without significant issues;
  - DAQ and Trigger allow a smooth data taking with both BNB and NuMI ν beams.
  - The collected neutrino and cosmic events are used to calibrate the T600 sub-systems and tune the event reconstruction software.
- Top CRT installation and activation have been recently completed. The commissioning and integration activities of the full CRT are progressing well.
- Concrete blocks for the three layers of overburden (~ 6 m w.e.) installed at the end of May 22.
- RUN 1: first for physics, now ongoing until the beam shutdown (July 11). Restart in mid-October.

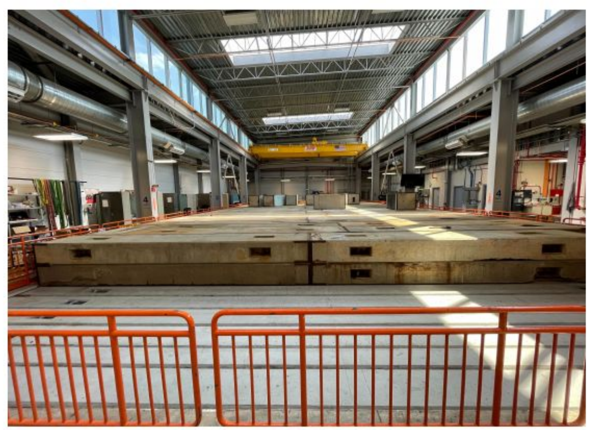
Timeline of ICARUS commissioning and operation

2020 | **2021** | **2022**

- Aug 28, 2020
  Detector activation
- Dec 9-11, 2020
  ORR
- Mar 2021
  First neutrinos
- June 2021
  RUN-0
- June - Oct 2021
  Beam shutdown
- Nov 5, 2021
  Beginning of second beam
- Dec 10, 2021
  CRT installation complete
- Feb 17, 2021
  CRT components in data

Sept 2020

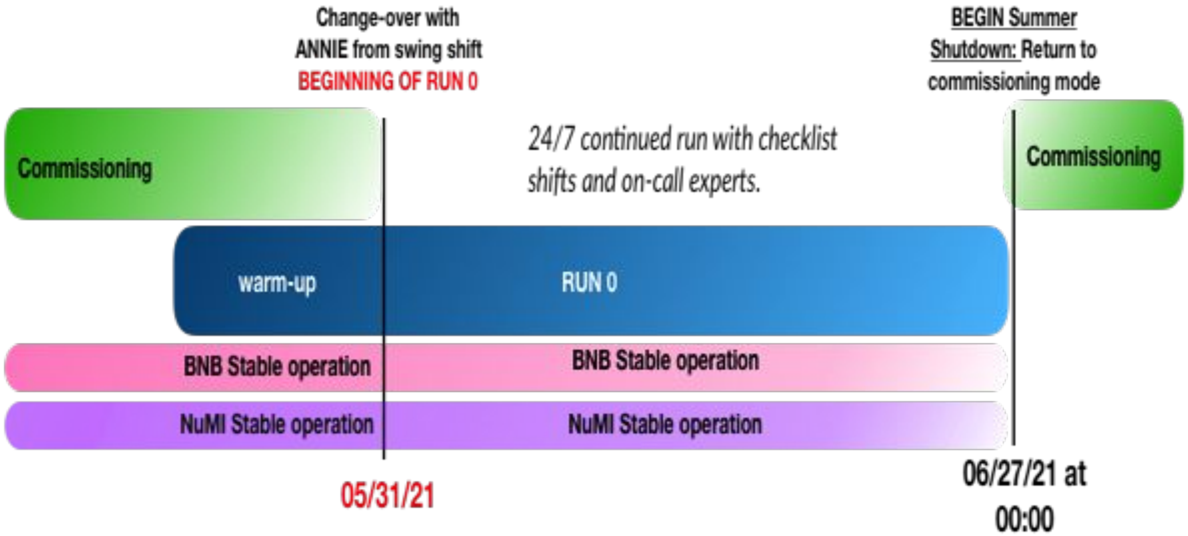
Dec 2021

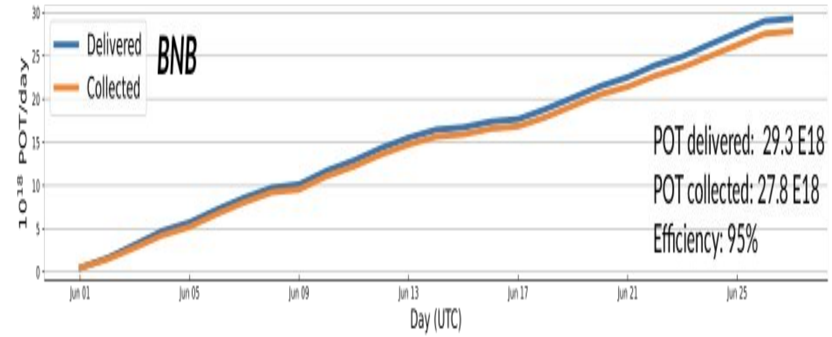


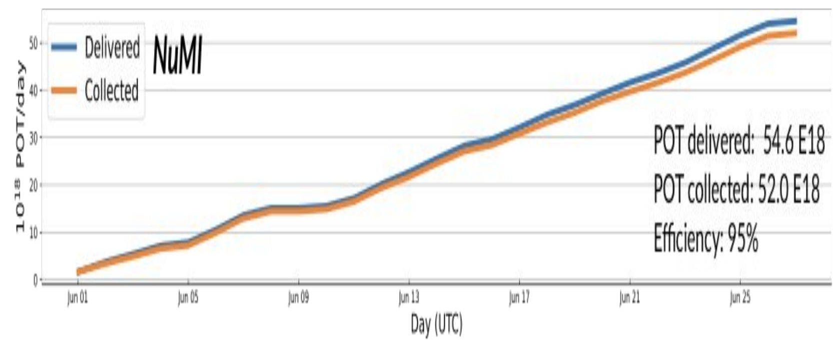
May 2022

First ICARUS data taking: RUN 0

- RUN 0 goals: certify the detector readiness for physics quality data with TPC and PMT operating as primary BNB user in stable mode.







- Data taking efficiency was >90%, the downtime related to occasional DAQ crashes.

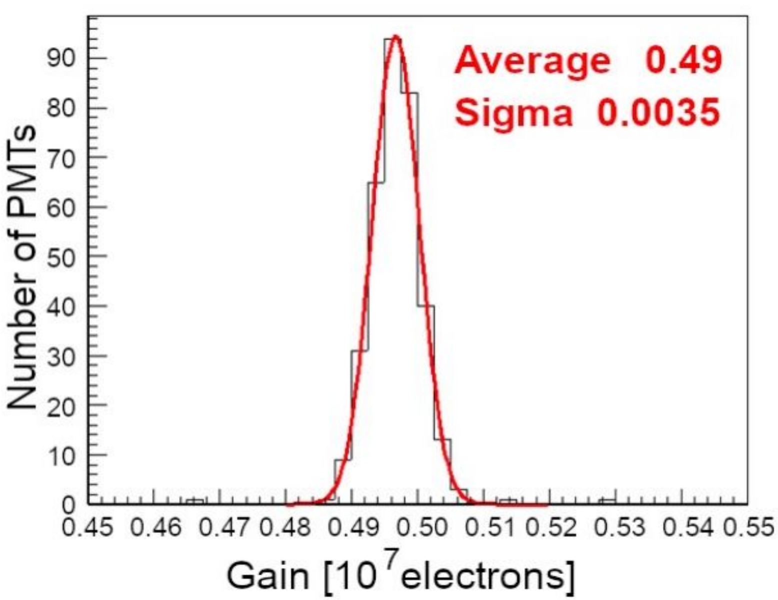
- Data was collected using mainly two types of trigger:
  - *"PMT Majority":* coincidence of beam signal with > 10 fired PMTs (8 phe threshold);
  - *"Spill-only" or MinBias trigger*, collecting every beam spill without any PMTs signal requirement (for control of the detector).

A part of collected runs was filtered and visually scanned identifying 254 νμCC and 15 νeCC gold event sample used for tuning the event reconstruction software.

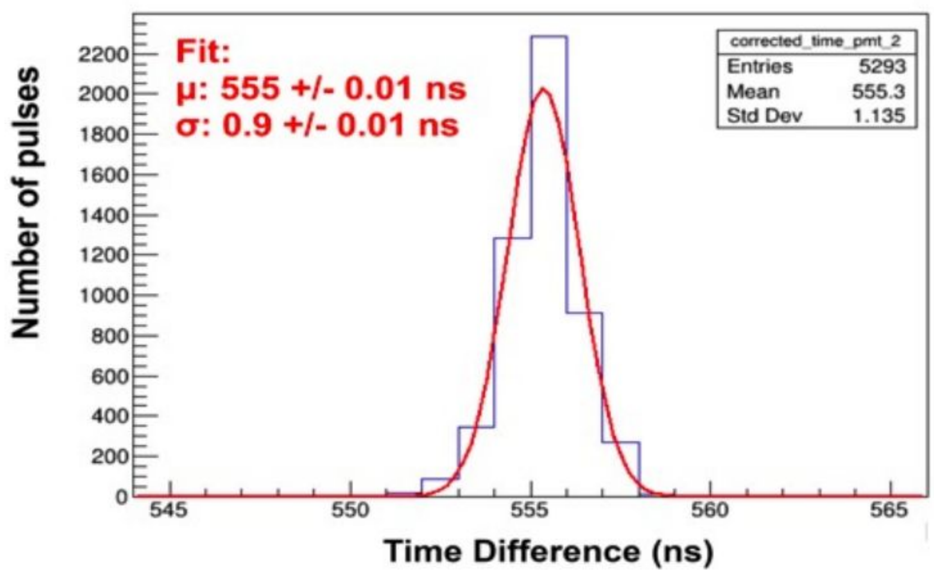
Scintillation light detection system (Pavia lead)

- The PMT light detection system is working smoothly since its activation.
- The PMT gains are equalized to G = 0.5×10^7 with a spread <1%. Set point takes into account unexpected decrease of the gain with time measured after filling with LAr, possibly caused by fatigue of the dynodes due to the high current value induced by the ~250 kHz photon rates produced by cosmic rays at shallow depth and 39Ar.
- PMT transit time and signal timing can be measured with ~ 1 ns precision.

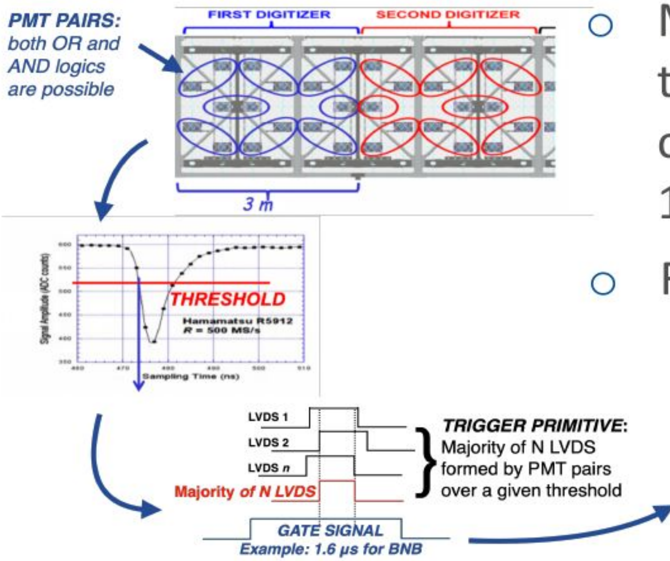
Distribution of the gain of the 360 PMTs



Distribution of time difference between PMT signals and trigger time



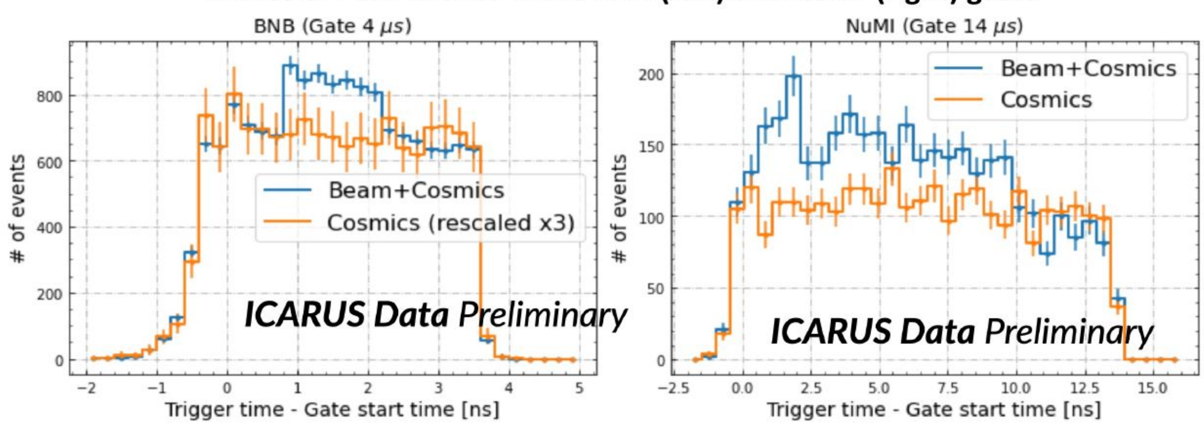
Trigger (Pavia contribution)



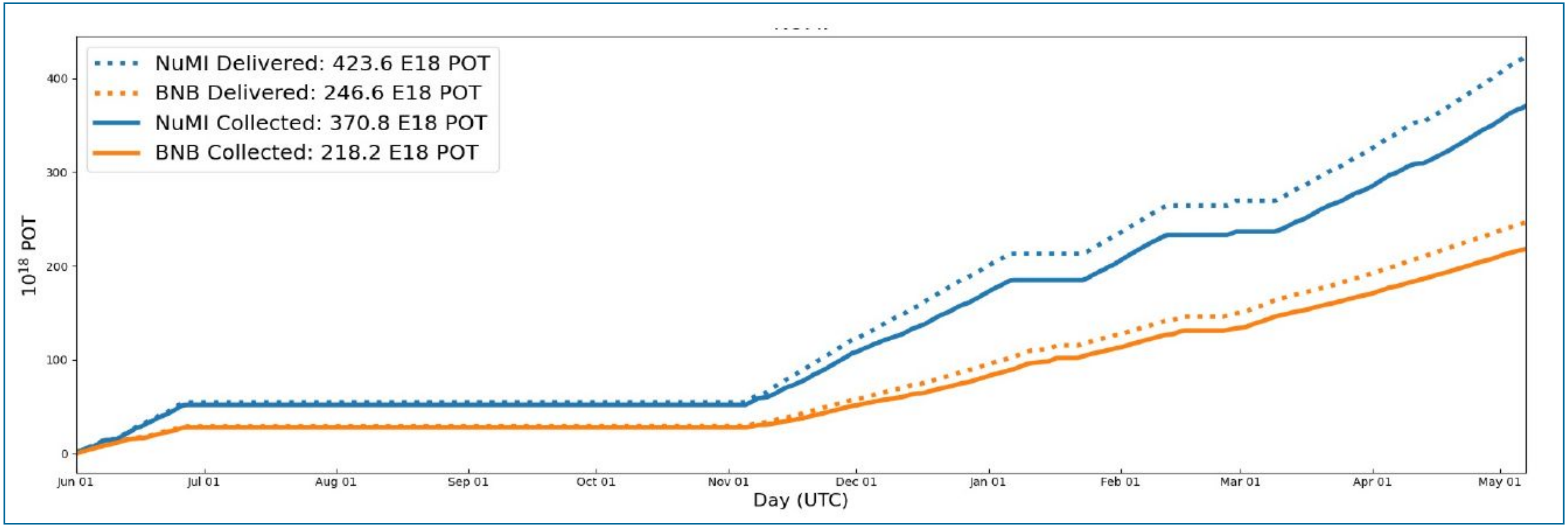
- Main ICARUS trigger signal generated by majority of the discriminated pairs of PMT signals (LVDS) in coincidence with the BNB and NuMI beam spill gates, 1.6 and 9.5 µs respectively.
- For every global trigger, light and CRT activity occurring for 2 ms around the trigger time are also recorded, to recognize and tag cosmics crossing the detector during the 1 ms e^- drift time.

- Verification of correct timing of beam signals by looking for excess of PMT light flashes over the cosmic background rate in minimum-bias runs.

Excess of PMT flashes in the BNB (left) and NuMI (right) gates



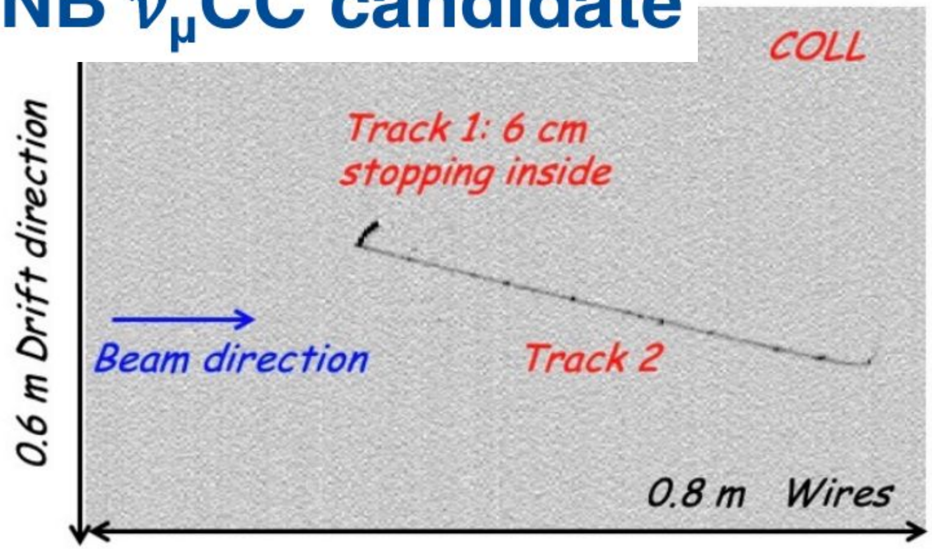
Data taking with BNB and NuMI beams

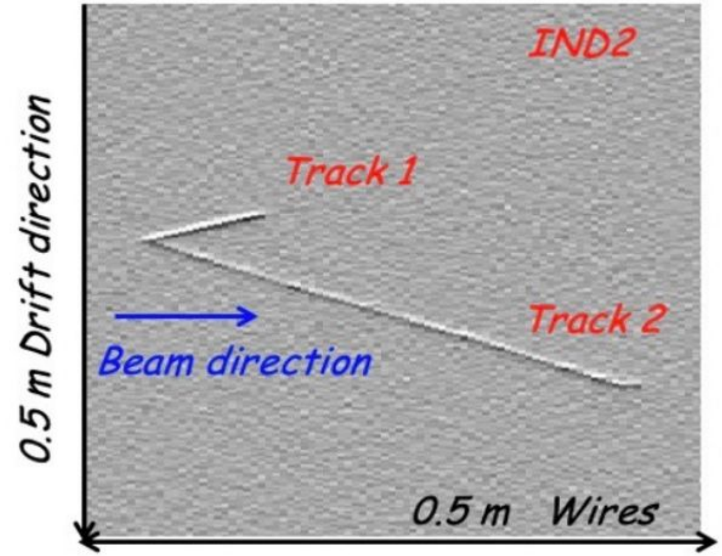


- Full time (24/7) neutrino beam run May 31st - June 27th 2021: "RUN-0".
- Part time (at least weeknights & full weekends) neutrino beam run since Nov 5th. Average intensity 4E12/50E12 protons per pulse for BNB/NuMI.
- Overall 88% efficiency of beam data collection, despite several installation and commissioning activities.
- Data collected so far used for detector calibration/commissioning. From June 2022 data good for physics.

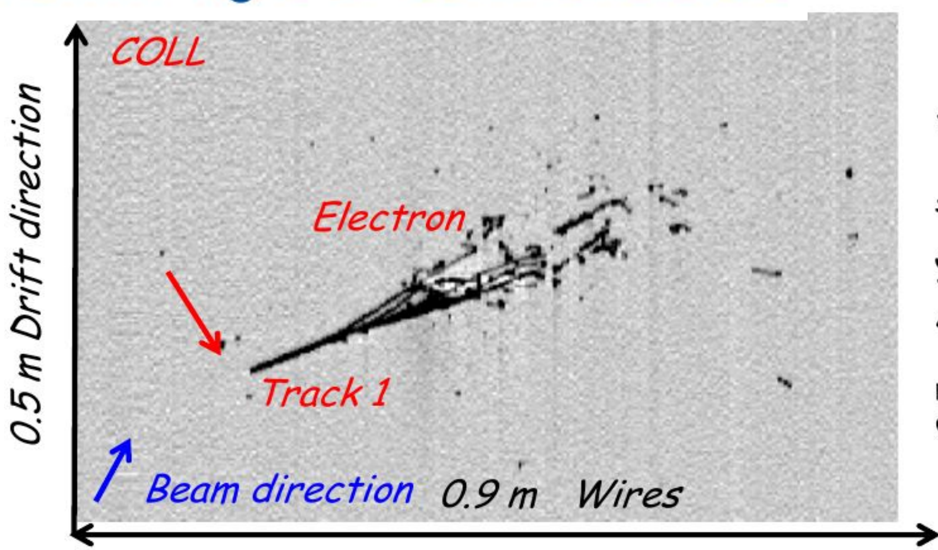
Example of neutrino events

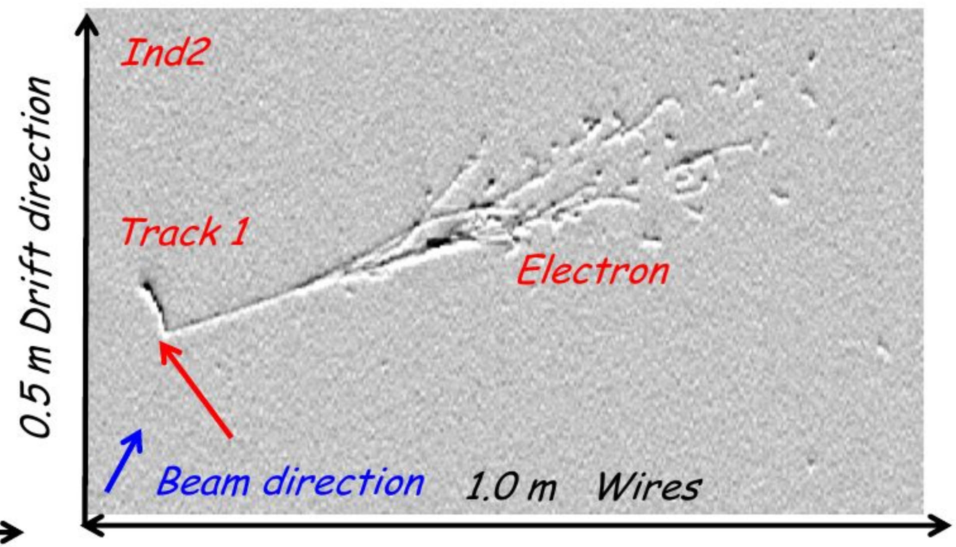
BNB ν_μCC candidate



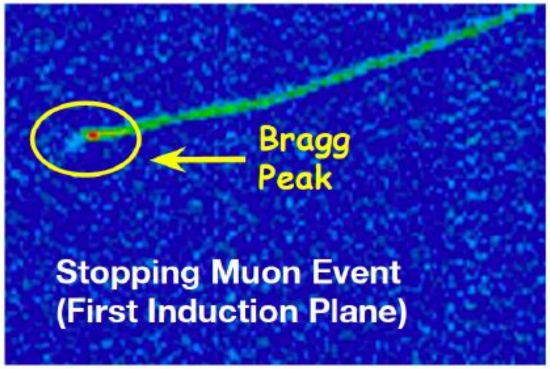


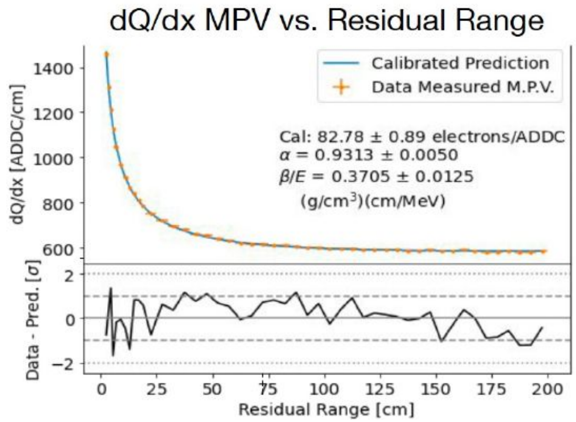
NuMI ν_eCC candidate





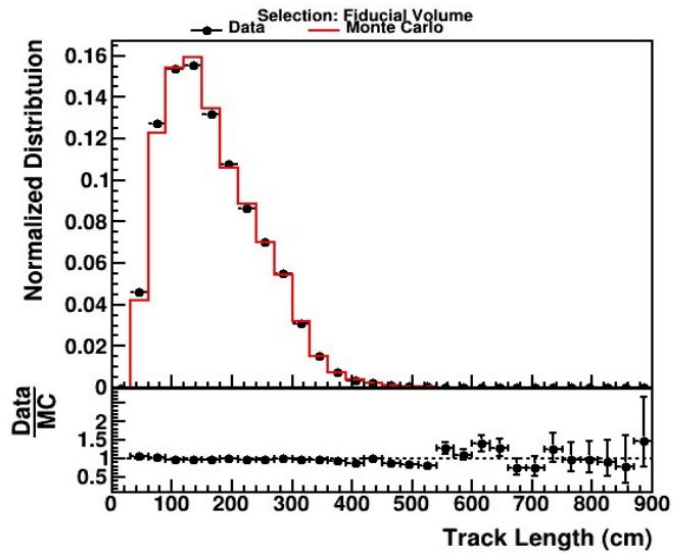
Event reconstruction



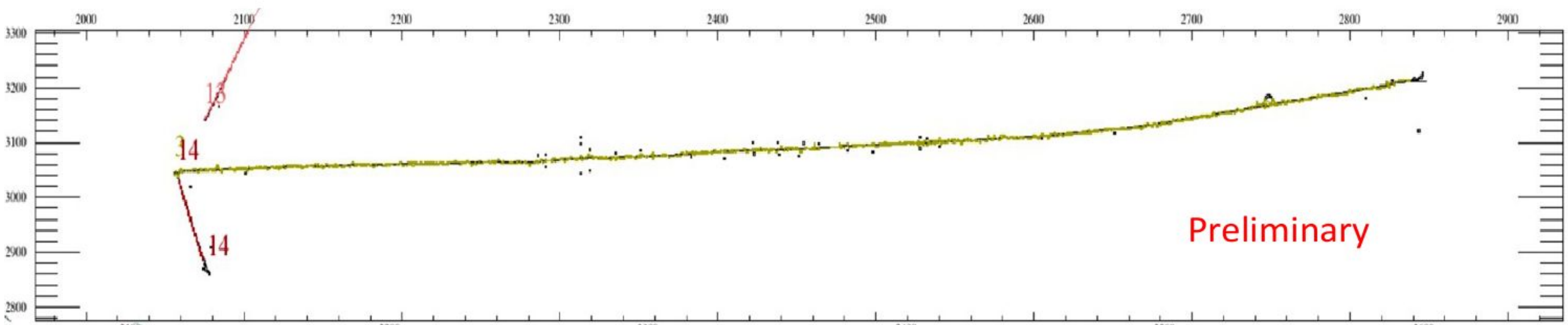


Useful for TPC wire calibration

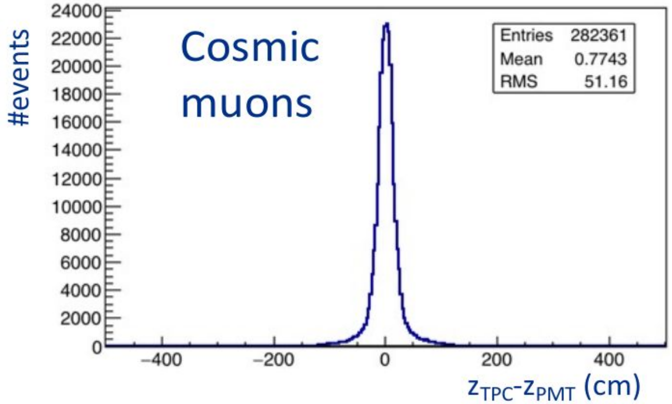
Cosmic track reconstruction: data/MC comparison

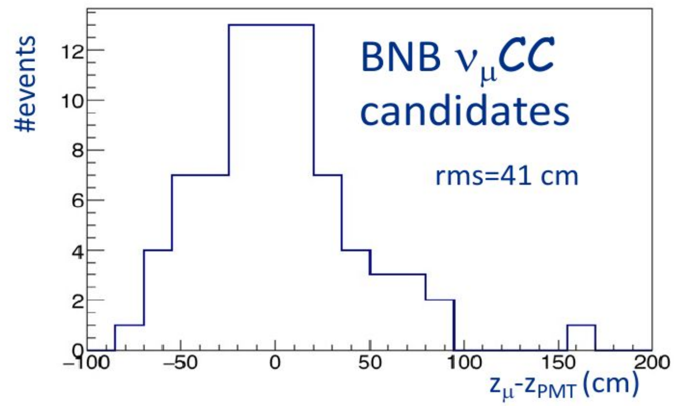


Sample data event selected by visual scanning with reconstruction overlaid



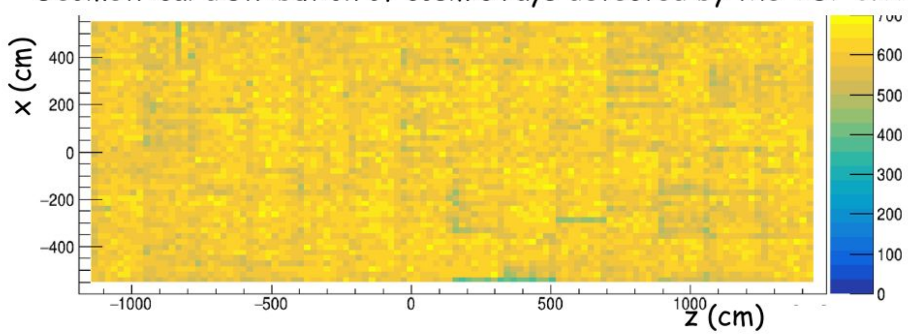
TPC-PMT-CRT matching

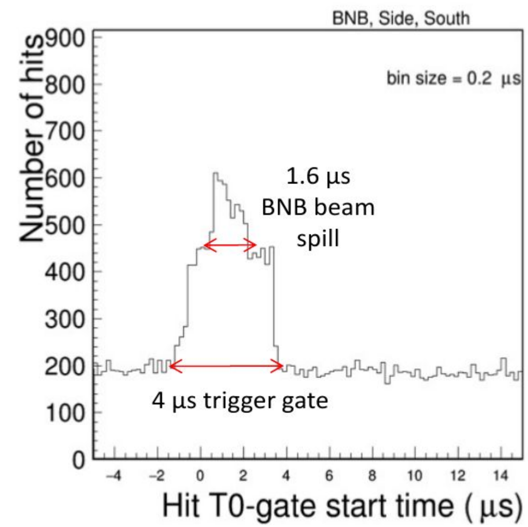




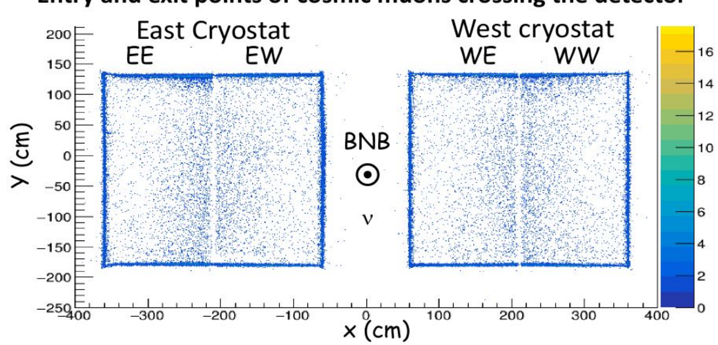
Comparing the track (TPC) and the light (PMT) barycenter

Geometrical distribution of cosmic rays detected by the TOP CRT





Entry and exit points of cosmic muons crossing the detector



Beam activity is visible on side CRT

ICARUS PV: attività 2021

FTE 2021

F. Boffelli	0.3
A.Menegolli	0.6
C. Montanari	1
A. Rappoldi	0.3
G.L. Raselli	0.9
M. Rossella	0.3
A. Scaramelli	0
Totale FTE	**3.4**

Attività ICARUS 2021:

- Calibrazione e test dei PMT a freddo.
- Sviluppo del sistema di trigger che utilizza i segnali dei PMT.
- Sviluppo del sistema di acquisizione dati dei PMT e integrazione nel software di acquisizione del rivelatore.
- Sviluppo software e programmazione FPGA per il trigger.
- Sviluppo software/Monte Carlo per analisi dati FNAL.

Responsabilità/Incarichi (solo ICARUS -> diversi incarichi come joint SBN program):

- Coordinamento tecnico ICARUS @FNAL (C. Montanari).
- Coordinamento sistema di rivelazione della luce di scintillazione: (G.L. Raselli).
- Rappresentante del gruppo Icarus-Pavia nell'Istitution Board SBN e ICARUS (G.L. Raselli).
- Chair Editorial and Speakers’ Board (A. Menegolli).

XRO

X RAY OBSERVATORIES

XRO – X-RAY OBSERVATORIES

- Riunisce le attività sulle missioni

  IXPE : Imaging X-Ray Polarimetry Explorer (già in CSN2)

  eXTP: enhanced X-Ray Timing and Polarimetry (nuova)

- Responsabili nazionali

  L. Baldini (PI) e V. Bonvicini (TS)

- Strutture partecipanti:

  TS, PI, TO, MI, PV, BO, TIFPA, PG, RM2

- Man power

  > 20 FTE complessivi

eXTP enhanced X-ray Timing and Polarimetry Mission

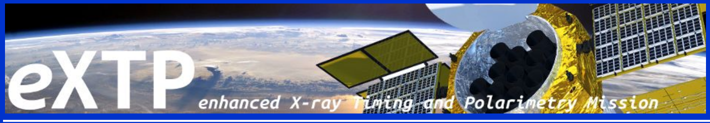
eXTP Consortium

PI – China: Prof. Shuang-Nan Zhang IHEP/CAS – Beijing

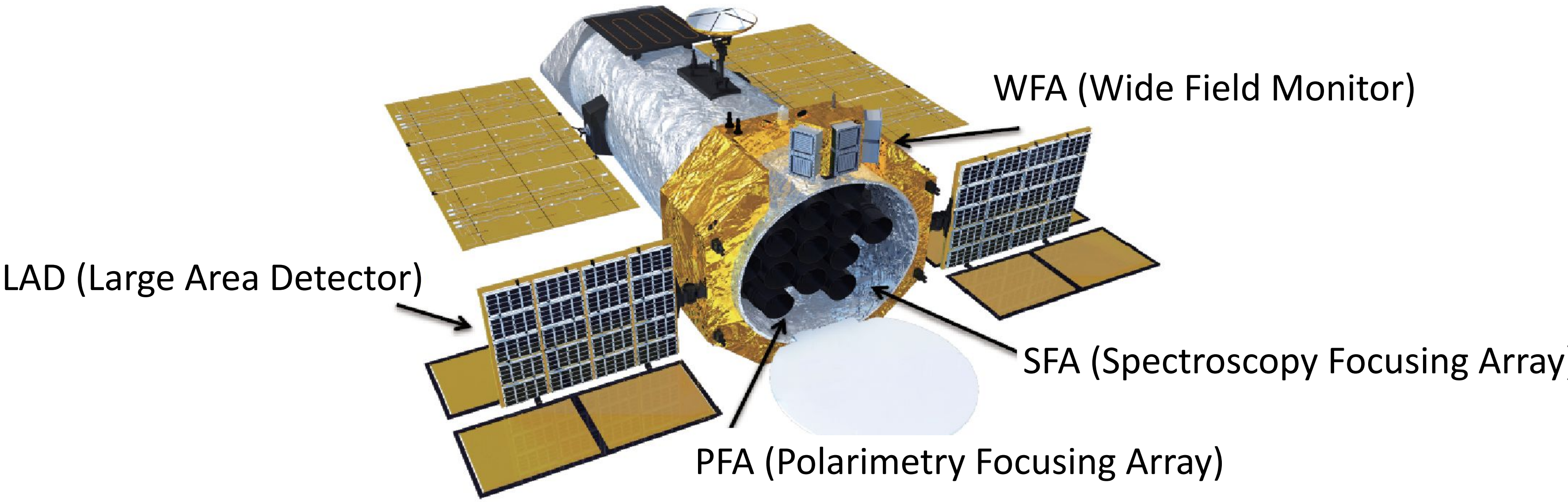
PI – Europe: Dr. Marco Feroci – INAF IAPS Roma

CAS	中国科学院 CHINESE ACADEMY OF SCIENCES
CNSA	CNSA
IHEP	Institute of High Energy Physics, Chinese Academy of Sciences
Tsinghua University	清华大学 Tsinghua University
Tongji University	同济大学 TONGJI UNIVERSITY
CAST Beijing	中国航天 中国空间技术研究院 China Academy of Space Technology
Microsat Shanghai	microsat

Italy	INAF, INFN
Spain	CSIC, IEEC Institut d'Estudis Espacials de Catalunya
Germany	Eberhard Karls Universität Tübingen, MPE, FAU Friedrich-Alexander Universität Erlangen-Nürnberg
France	cea
Switzerland	Université de Genève
Czech Republic	asu Astronomical Institute of the Czech Academy of Sciences
Poland	CBK PAN, CAMK PAN
Denmark	DTU
The Netherlands	NOVA, SRON

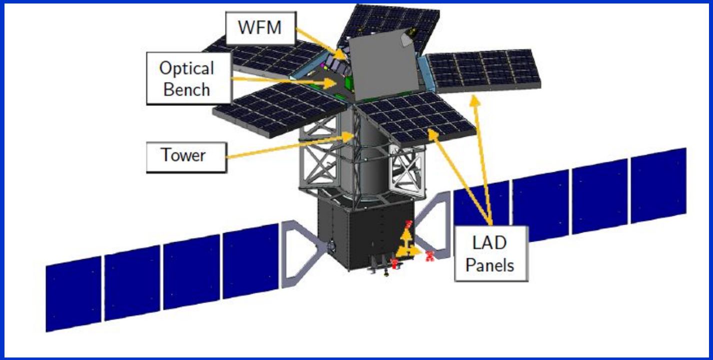


eXTP Concept

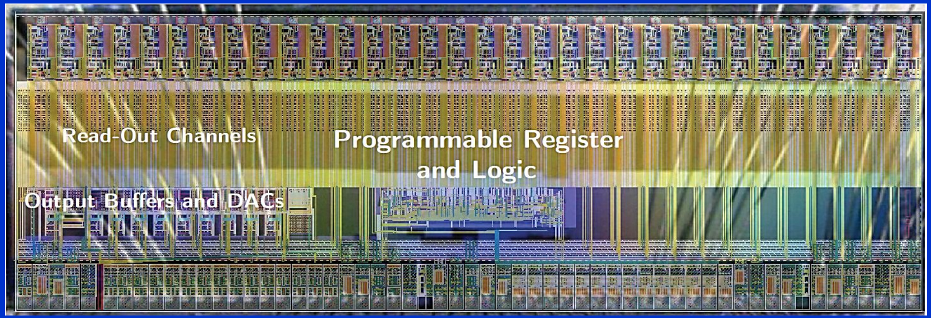


Payload	Configuration	Optics	Detector	Eff. Area (cm^2)	Energy Range (keV)
SFA	9 Telescopes	Nickel Replica	SDD	5000 – 7000	0.5 - 10
LAD	40 Modules	MCP Collimator	SDD	34000	2 - 30
PFA	4 Telescopes	Nickel Replica	GPD	900	2 - 10
WFM	6 Cameras	1.5 Coded Mask	SDD	FOV > 4sr	2 - 50

VEGA ASIC



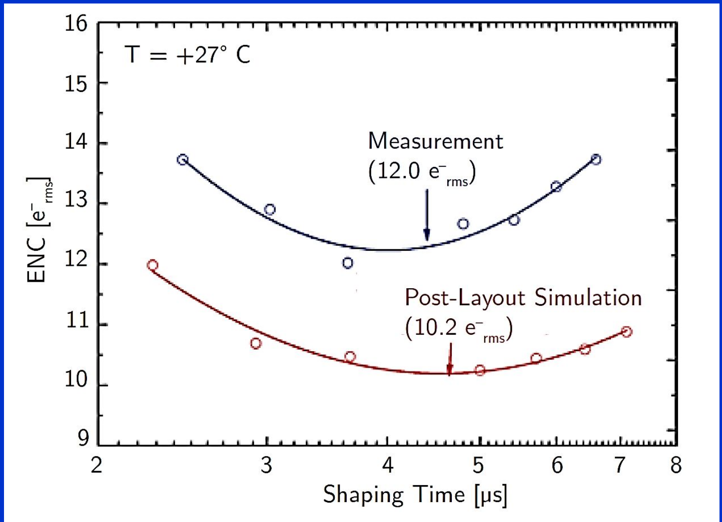
VEGA ASIC (32 Channels)



Originally designed for LOFT

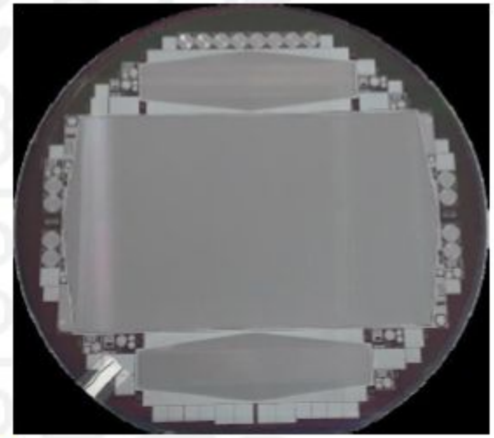
Baseline ASIC for eXTP

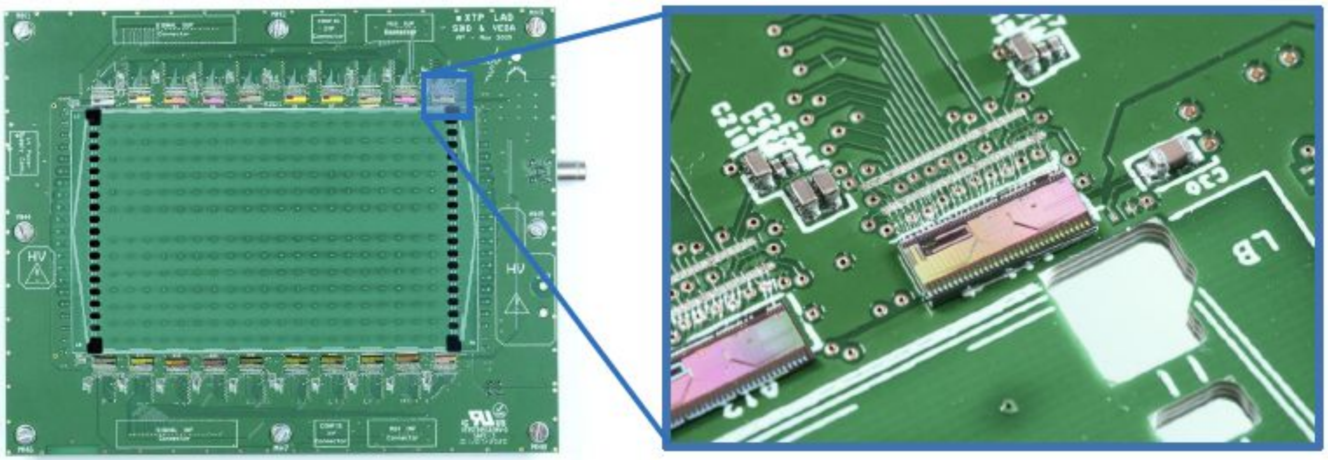
LAD and WFM detector tests



SDD+VEGA ASIC

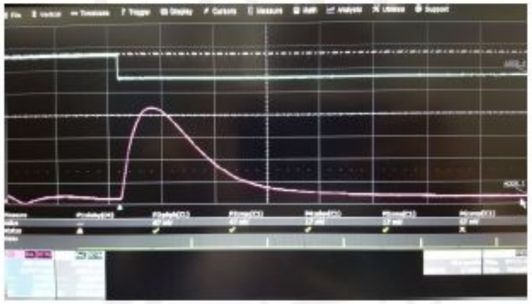
- First setup to test full-scale LAD detector
  - 1 full-scale LAD SDD to be integrated after ASIC characterization
  - 2×10 VEGA ASICs already integrated
    - ASIC can be programmed independently (daisy chain + skip option)
    - 2×10 single analog output + 2 multiplexed analog output



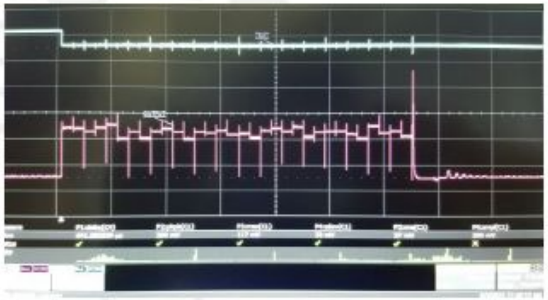


SDD+VEGA ASIC

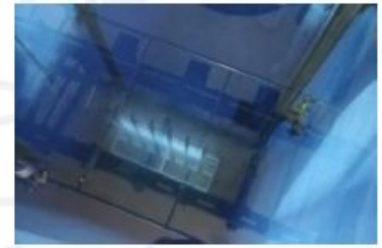
- All 20 ASICs tested
  - SUP side (10 ASICs)
    - 10 fully functional (analog and trigger logic)
  - INF side (10 ASICs)
    - 9 fully functional (analog and trigger logic)
    - 1 half-functional (analog but not trigger logic)



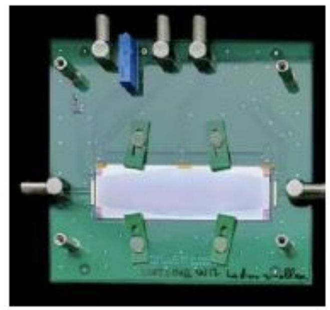
- Parallel output tested
  - All functional ASICs on same side operated at the same time with no issues
  - Parallel ASIC-wise analog multiplexing verified



SDD+VEGA ASIC Radiation Test



- Total Ionising Dose (TID) study to be performed at ENEA/Casaccia (RM)
  - 1 week (99 hours) of ^{60}Co irradiation to cumulate $\approx$ 20 krad(Si) at $<$ 4 rad(Si)/min
  - Leakage current vs TID



- Setup is ready
  - 3 × LADino
    - 1 reference anode on one side
    - All anodes on other side
  - Pico-ammeter
  - Acquisition and monitoring interface

- Test planned for winter-spring 2022

Budget

- INFN Pavia:
  - Piero Malcovati – Responsabile locale (0.5 FTE)
  - Marco Grassi – Postdoc (0.5 FTE)
  - Rashid Karim – PhD student (1.0 FTE)
- Budget:
  - Run ASIC: 13 k€ (interamente utilizzati)

Grazie per questi 7 lunghi anni e in bocca al lupo a Massimo!