Consuntivi Scientifici
Esperimenti di Gruppo 2

Alessandro Menegolli
Dipartimento di Fisica e INFN, Sezione di Pavia

CdS INFN Pavia
5 maggio 2019

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.

Bilancio 2018

Distribuzione delle risorse per linea di ricerca.

	N. esp.	Budget 2018
1-Fisica del neutrino. BOREX, CUORE, CUPID, ENUBET_2, GERDA, ICARUS, JUNO, NU_AT_FNAL, T2K.	9	39.6%
2-Radiazione dall'Universo AMS2, AUGER, CTA, DAMPE, FERMI, GAMMAMEV, GAPS, IXPE_INFN, KM3, LSPE, QUBIC.	12	20.1%
3-L'Universo Oscuro CRESST, DAMA, DARKSIDE, EUCLID, NEWS, QUAX, SABRE, XENON	8	18.0%
4-Onde gravitazionali, fisica generale e quantistica *ARCHIMEDES2**, FISH, G-GRANSASSO-RD, HUMOR, LARASE, LIMADOU_CSN2, LISA, MAGIA-ADV, MOONLIGHT-2, SUPREMO, VIRGO	11	12.5%
Dotazioni di gruppo + esperimenti sotto DTZ (HOLMES_2, JEM-EUSO-RD, LVD, MOSCAB)	4	9.8%
Totale FTE Persone	44	14630.5 k€ 770 1174

Bilancio: 2013-2018

	2013	2014	2015	2016	2017	2018
Budget (k€)	11367.5	11482.5	12875	12143.5	14641.5	14630.5
FTE	550	605	660	717	752	770
Persone	856	865	931	1052	1092	1174

CSN2 è la commissione che è cresciuta di più in termini di FTE/persone negli ultimi anni:

- FTE cresciuti del 29% dal 2013;
- Numero persone cresciuto del 27% dal 2013;
- Numero sigle circa costante.
- Budget in crescita (del 22% rispetto al 2013, stabile rispetto al 2017).

Anagrafica PV 2018

Linea	Esperimento	FTE/persona
1. F, Boffelli, T. Cervi, A. Falcone, A. Menegolli, C. Montanari, P. Picchi, A. Rappoldi, G.L. Raselli, M. Rossella, A. Scaramelli, M. Spanu	ICARUS	7.3/11
2. P.W. Cattaneo, M. Manghisoni, A. Rappoldi, V. Re, E. Riceputi, M. Sonzogni	GAPS	3.0/6
3.		
4.		
Totale	**2**	**10.3/17**

GAPS

- GAPS (General AntiParticle Spectrometer) è stato progettato per studiare la componente di antiparticelle nei raggi cosmici con un focus specifico su antiprotoni ed antideuterio (ed antielio) di bassa energia (< 0.25 GeV/n). L'identificazione per la prima volta di antideuterio nei raggi cosmici sarebbe un segnale quasi certo di nuova fisica esplorando tutta una gamma di modelli teorici di materia oscura.

- GAPS verrà condotto con un volo di lunga durata (>30 giorni) su pallone stratosferico dall'Antartide. Altri voli successivi saranno probabilmente finanziati.

- I gruppi italiani coinvolti sono afferenti a: INFN di Firenze, INFN di Pavia ed Università di Bergamo, INFN di Napoli, INFN ed Università di Torino, INFN ed Università di Roma Tor Vergata, INFN di Trieste.

- La Collaborazione Internazionale oltre alla componente italiana consta di gruppi americani: Columbia University, MIT, UC Berkeley, UCLA, UC San Diego, University of Hawaii at Manoa, Oak Ridge National Laboratory; gruppi giapponesi: ISAS (JAXA).

- E’ stato recentemente concordato con la NASA di posticipare la finestra di lancio di un anno: adesso la finestra di lancio è prevista tra dicembre 2021 e febbraio 2022.

- D’accordo con la NASA, la collaborazione GAPS ha deciso di realizzare un prototipo dello strumento (GFP = GAPS Functional Prototype) entro la primavera 2020. L’obiettivo è dimostrare alla NASA che si sono compiuti progressi molto rilevanti verso la realizzazione dello strumento di volo, giustificando il prolungato finanziamento che NASA darà ai gruppi americani.

- Il cofinanziamento (circa 900 kEuro) da parte di ASI è attualmente disponibile alla collaborazione GAPS Italia (è stata creata una sigla GAPS_ASI), per coprire spese di personale (assegni di ricerca , cofinanziamento RTD A, et al) e la fabbricazione di parte dell’hardware (elettronica di front-end e back-end del tracciatore, high voltage system).

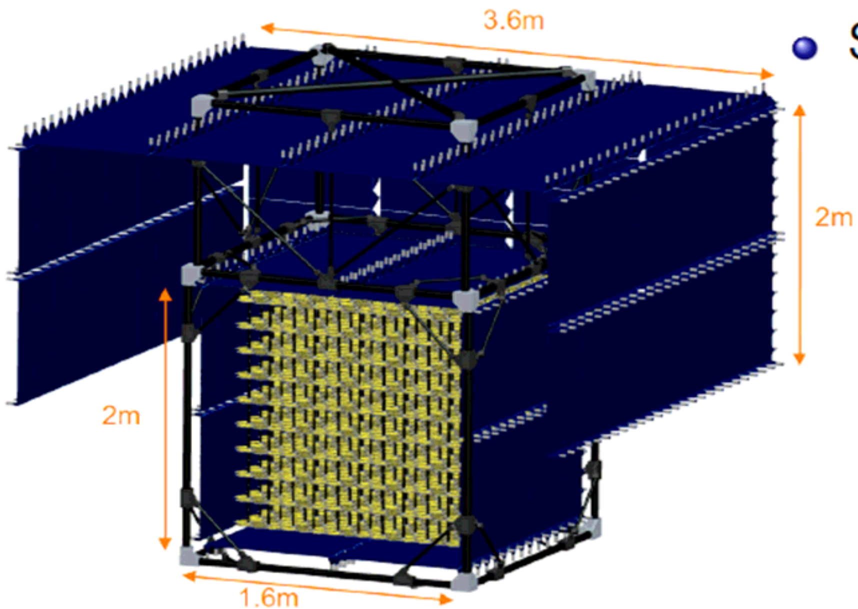
- Il gruppo di Pavia ha lavorato nel 2018 allo sviluppo dell'elettronica di lettura per il rivelatore a strisce in Si-Li per la tracciatura delle particelle, in collaborazione con INFN Trieste.

- Sono stati fabbricati 2 prototipi (4 e 8 canali) dell'ASIC di lettura dei rivelatori Si-Li, ed è stato quasi completato i progetto del prototipo a 32 canali dell'ASIC di volo.

- E' iniziato il lavoro sulla scheda di front-end su cui verrà montato 1 ASIC che leggerà 4 rivelatori a 8 strip ciascuno, e componenti elettronici ausiliari.

GAPS

spettrometro dedicato allo studio delle antiparticelle



- TOF plastic scintillator:
  - 500 ps time resolution
  - 16.5 cm wide plastic scintillators paddles
- Si(Li) detectors:
  - 10 layers (1.6m x 1.6m, layer space 20 cm)
  - Si(Li) 1350 wafer (10 cm diameter, 2.5mm thick)
  - timing resolution 100 ns
  - energy resolution 4 keV
  - operation temperature -35 C
  - readout with different resolution for high and low energy depositions:
    - X ray: 20 - 80 keV
    - charged particles: 0.1 - 100 MeV
- Weight: 1700kg
- Power: Si(Li) → 600W, TOF → 400W
- An effective trigger for stopping particles is being designed.

volo su pallone previsto per il 2020

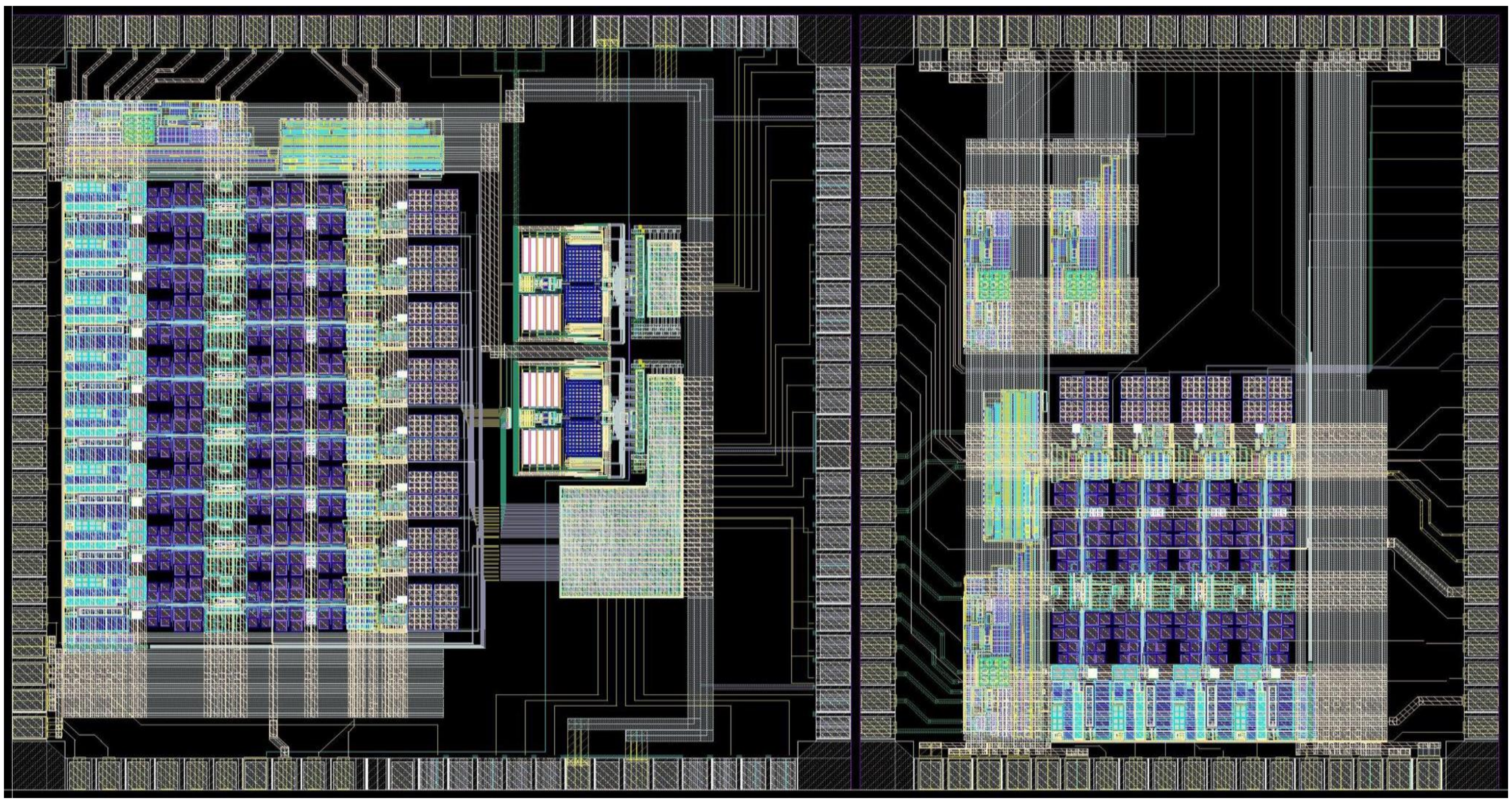
Analog Front-end in the ASIC for the GAPS Si(Li) Tracker

- The readout channel includes a low-noise Charge Sensitive Amplifier featuring an active signal compression implemented at feedback level by exploiting the non-linear features of an inversion-mode MOS capacitor.

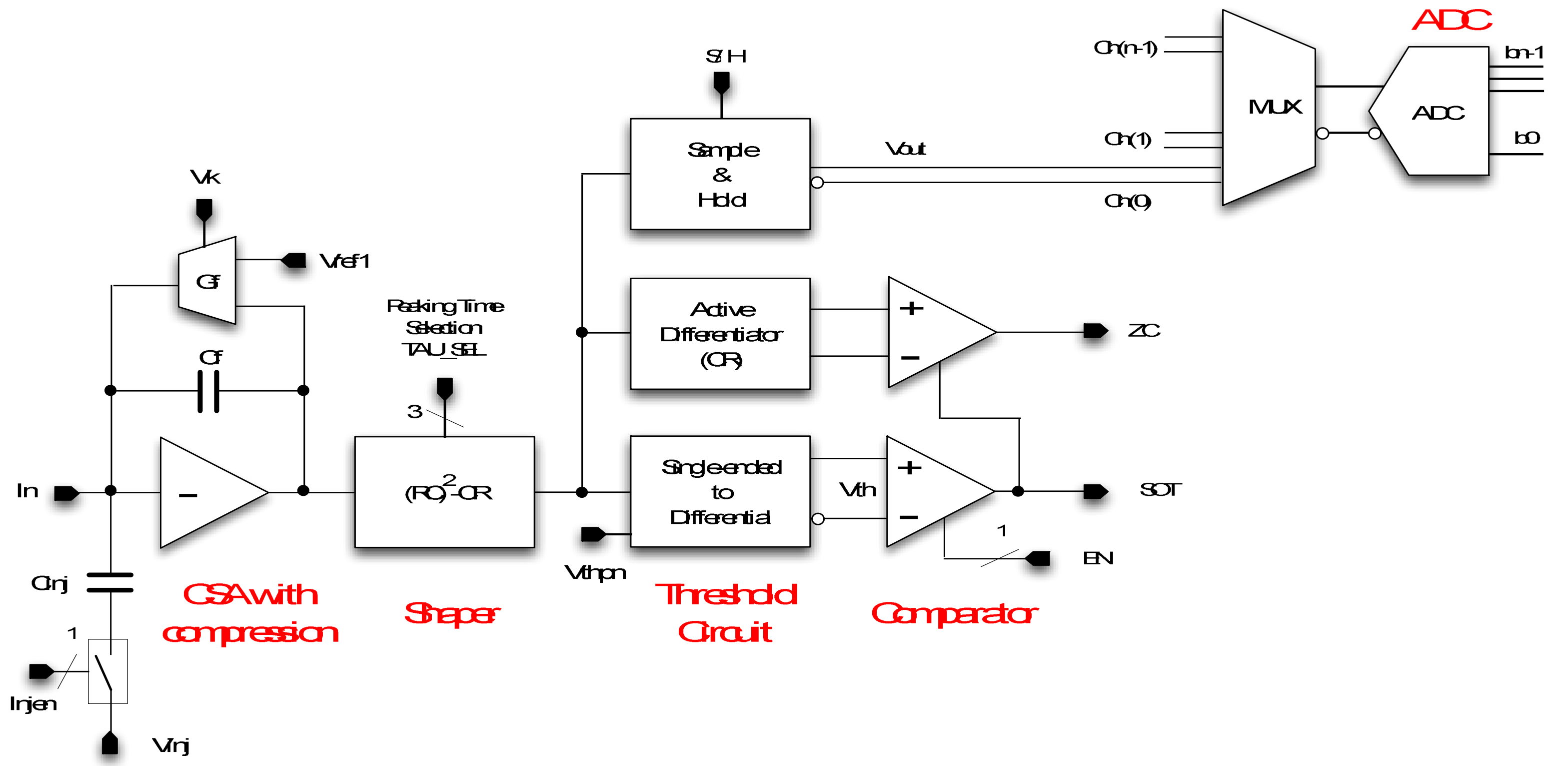
- Further stages designed by the Pavia/Bergamo group include a shaper, a discriminator and a Sample&Hold (interfacing with the ADC designed by Trieste).

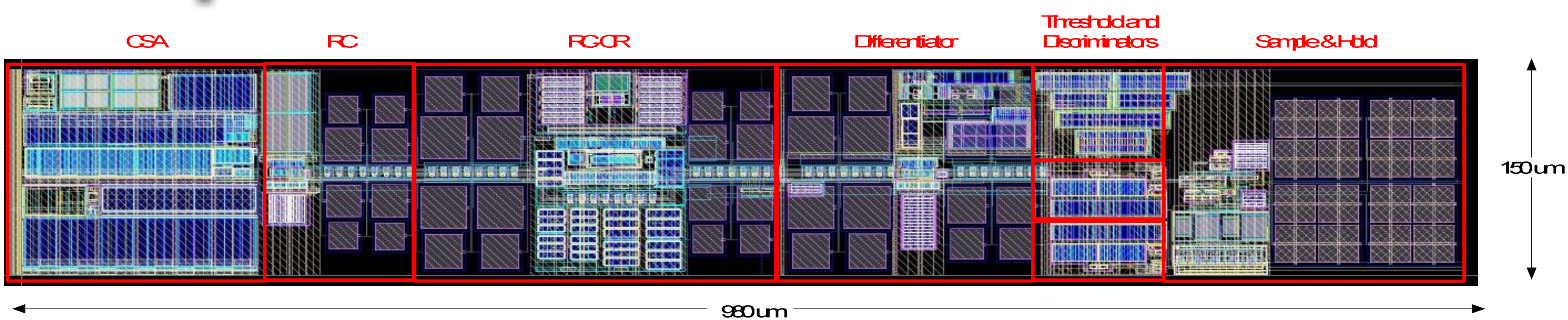
- The channel was designed in the TSMC 180 nm CMOS technology and was integrated in the first prototype ASICs submitted in August 2018 (delivered in December).

Layout of the first prototype of the Front-end ASIC for the Si(Li) Tracker

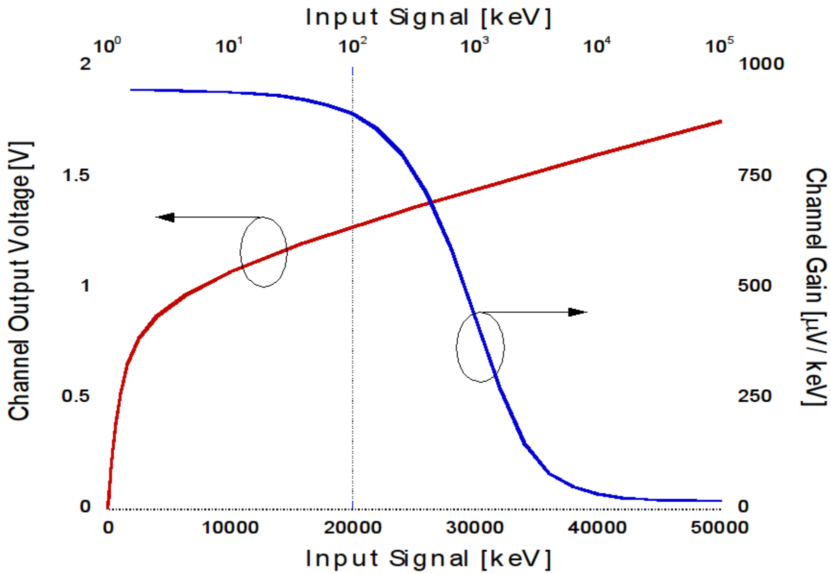


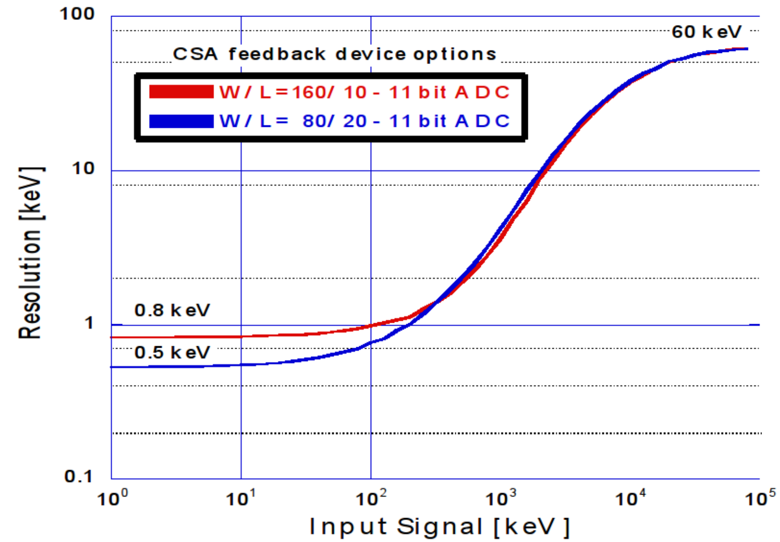
Analog Readout Channel





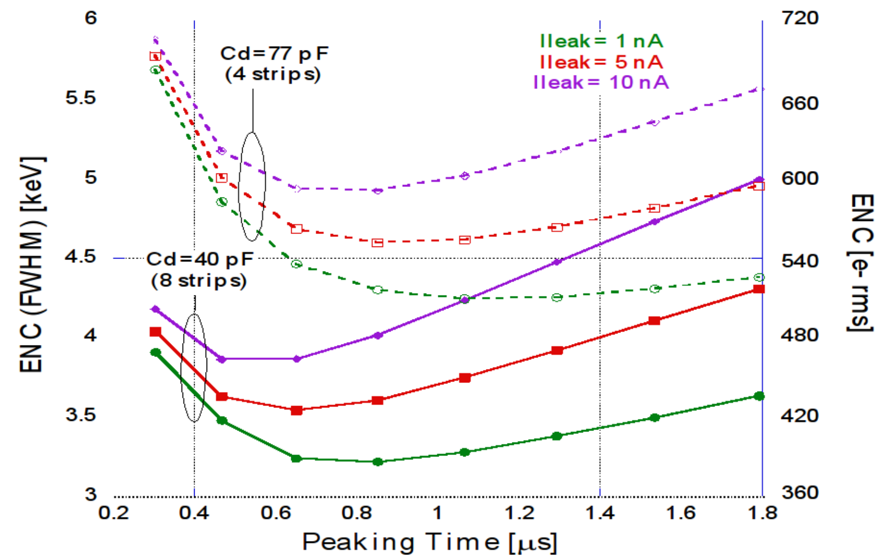
Overall Channel Performance



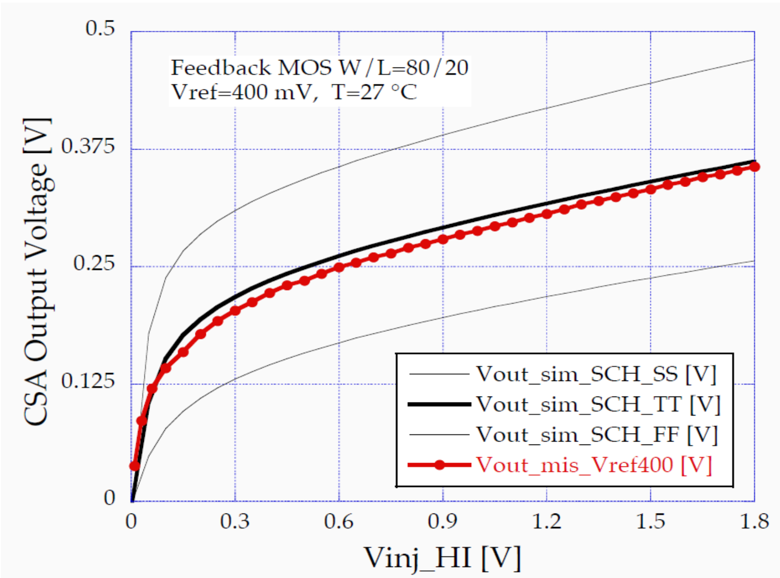


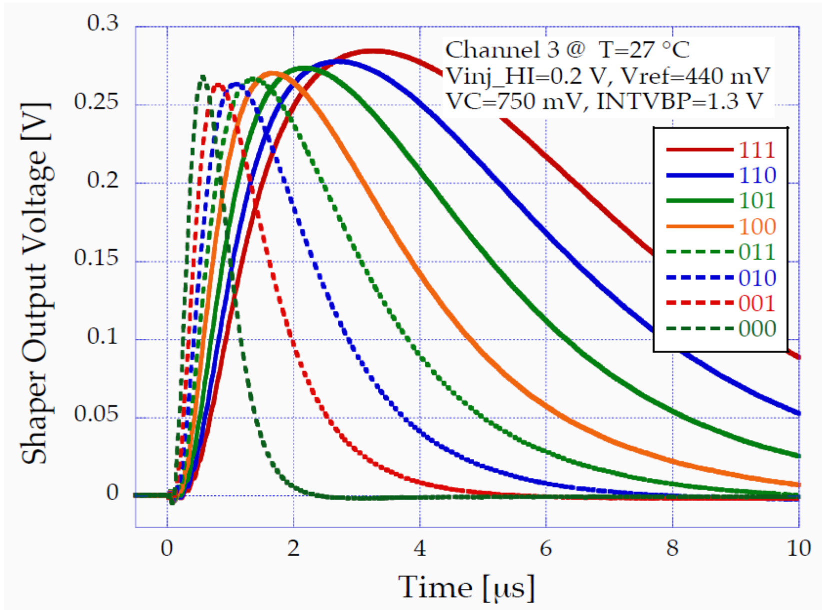
Two main critical requirements:

- Very wide dynamic range (10 keV – 100 MeV): bilinear gain characteristic with dynamic signal compression.
- Very good resolution (FWHM ≤ 4 keV at -30 °C) at low energies for X-ray detection: low-noise preamplifier design, tuning of the signal peaking time.

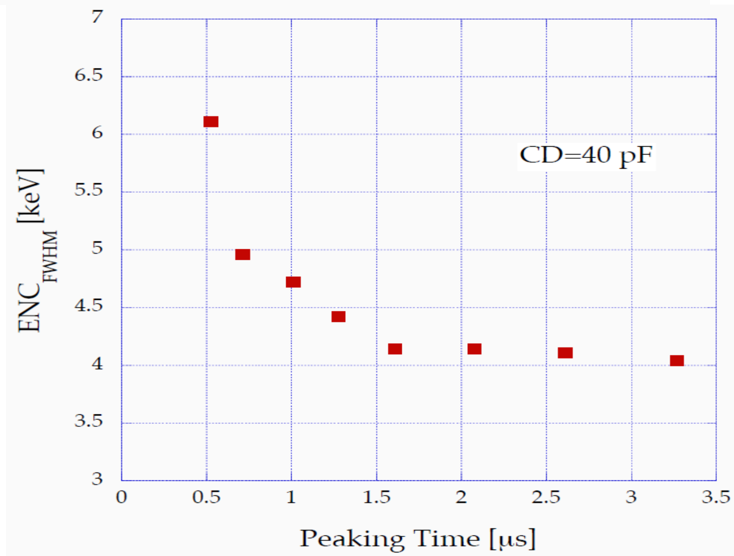


SLIDER4 preliminary test results

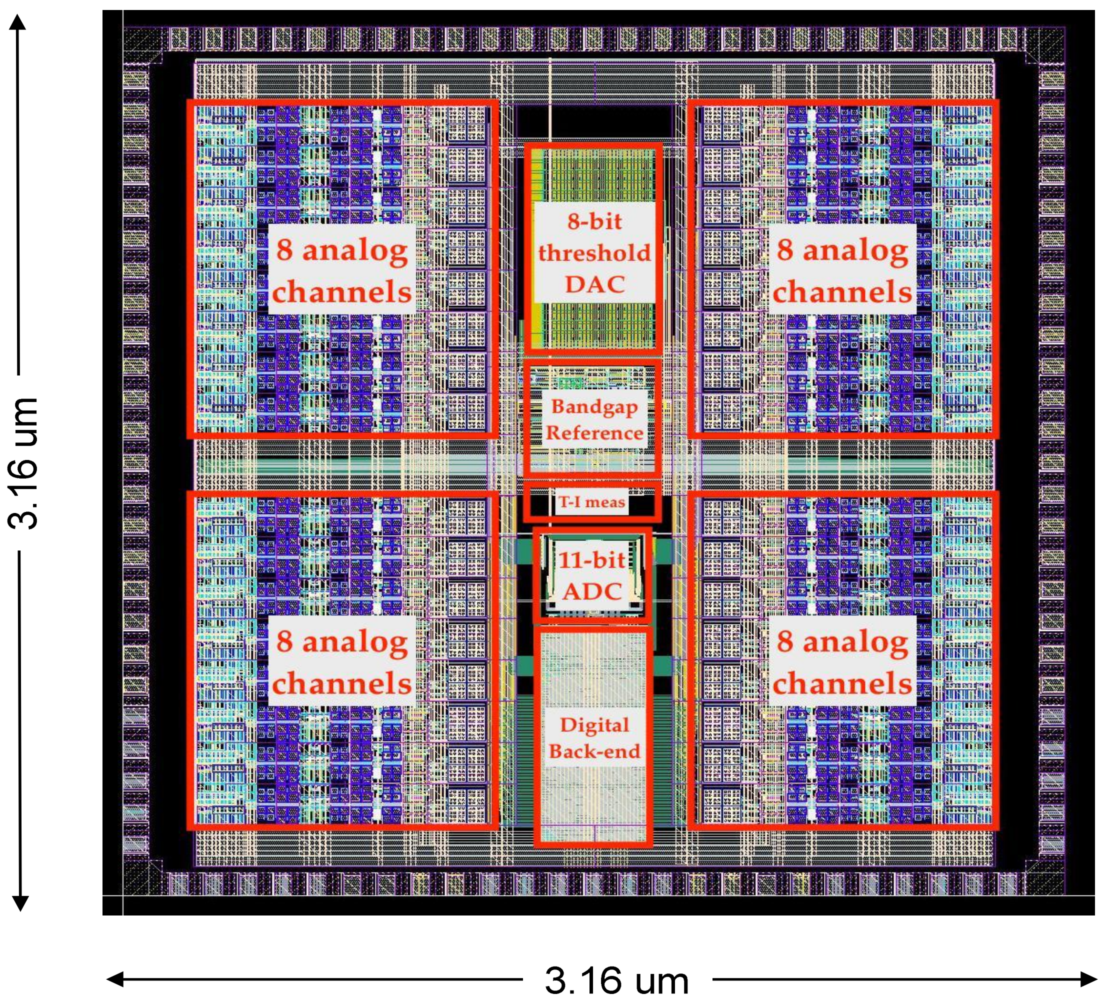




- Good test results, very promising in view of the submission of 32-channel prototype.
- Correct behavior of the dynamic signal compression.
- Very good resolution (FWHM close to 4 keV), excess noise contributions detected and understood.



ASIC Goal: SLIDER32



32 channels

Silicon-LIthium DEtector Readout ASIC

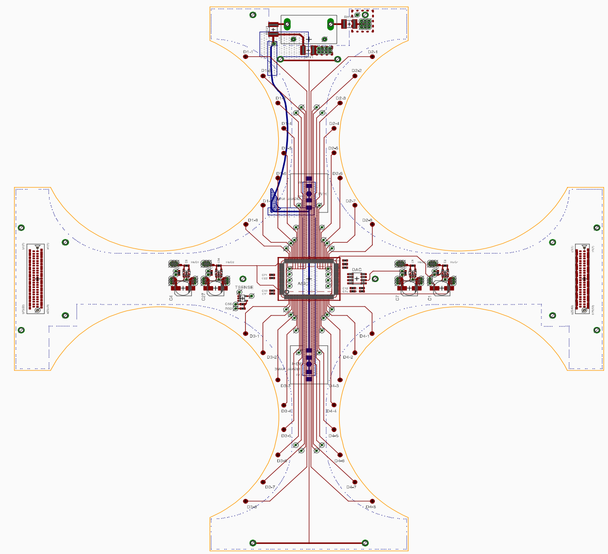
- 32 analog readout channels
- 11 bits ADC
- Digital Back End
- Bandgap reference with 3-bit DAC regulation
- 8-bit DAC for threshold setting
- 3-bit DAC for threshold fine trimming
- Detector leakage current readout
- Temperature sensor readout

pSLIDER32
First full ASIC prototype

32-channel prototype will be submitted by the end of June

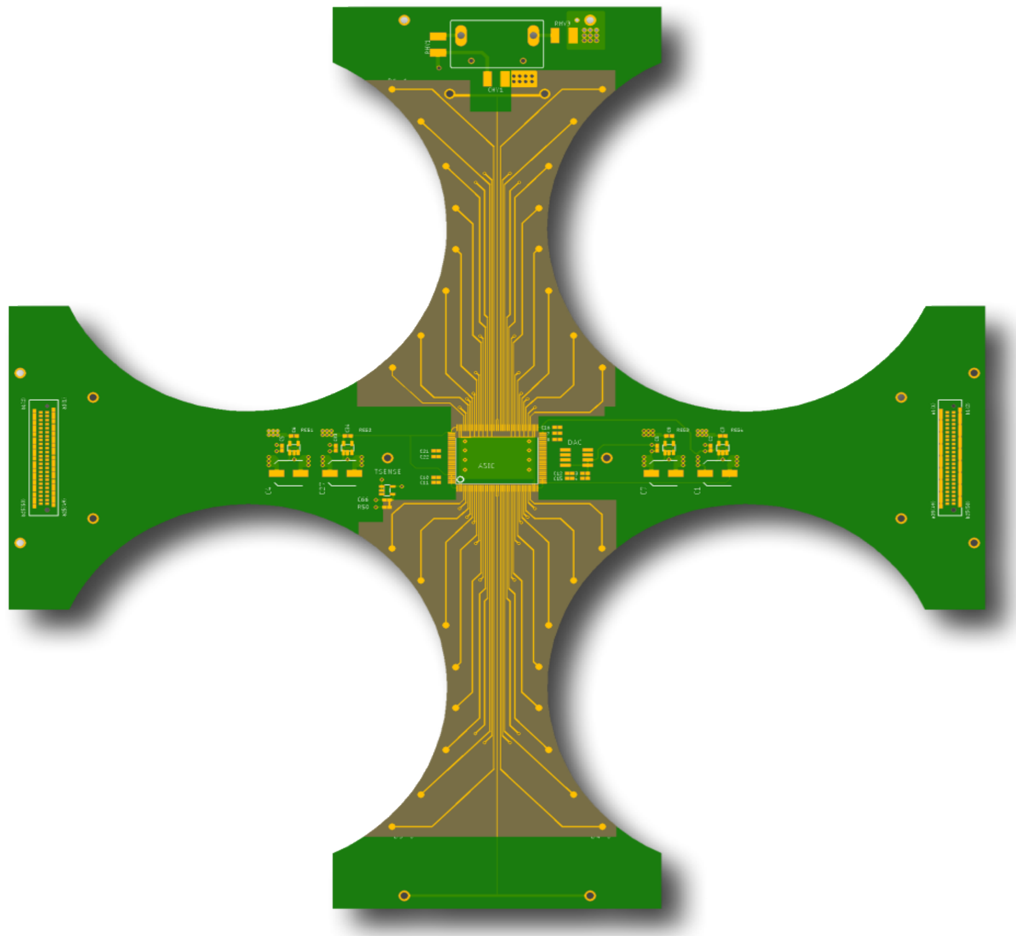
Front-end Board

- Work on the analog Front-End Board started with a technical meeting taking place in Bergamo with U.S. collaborators on October 2, 2018.
- Besides the bias voltage system (voltage regulators and filtering), the FEB also houses auxiliary circuits monitoring the operating conditions of the front-end ASIC and of the detector.
- This includes a temperature sensor to monitor the detector cooling system, an electronic calibration system to monitor the gain stability and calibrate the nonlinear response of the charge-sensitive preamplifier.

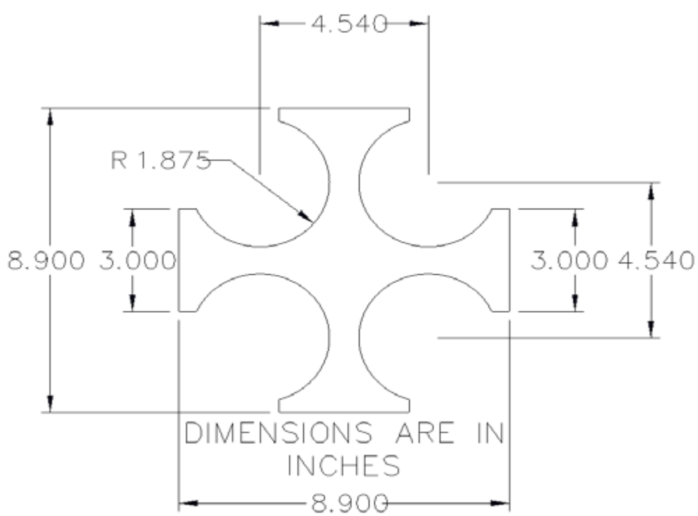


FE board overview

- 32 channels ASIC for 4 detectors readout
- Voltage regulators
- DAC for calibration
- Connectors for DAQ interface
- Temperature Sensor
- High voltage connector and filtering



6 layer PCB FR4



Personale INFN PV

Personale INFN 2018

➢ Paolo Cattaneo (Primo Ric.)	30%
➢ Andrea Rappoldi (Primo Tec.)	20%
➢ Valerio Re (Prof. Ordinario)	20%
➢ Massimo Manghisoni (Prof. Associato)	30%
➢ Elisa Riceputi (Dottorando)	100%
➢ Mauro Sonzogno (Dottorando)	100%

Totale FTE: 3.0

Consuntivo finanziario 2018

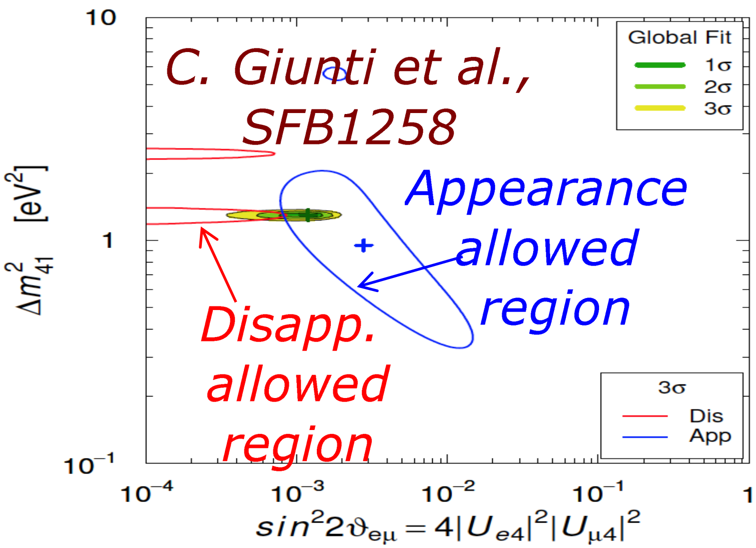
Descrizione	Stanziato	Variato	Subjudice e Cong.	Preimpegno	Impegni	Disponib.	Proposta in corso	Disp. Teorica
Rimborso per viaggio e trasloco	5.000,00	1.000,00	0	0	5.061,00	939	0	939
Strumenti tecnico-specialistici non sanitari	3.000,00	2.721,03	0	0	5.370,36	350,67	0	350,67
Pubblicazioni	0	1.035,55	0	0	1.035,55	0	0	0
Materiale bibliografico	0	250	0	0	196,02	53,98	0	53,98
	8.000,00	5.006,58	0	0	11.662,93	1.343,65	0	1.343,65

Avanzo di circa 1 kEuro sulle missioni dovuto al fatto che a metà dicembre
è stata annullata con scarso preavviso la prima riunione di avanzamento con ASI a Roma

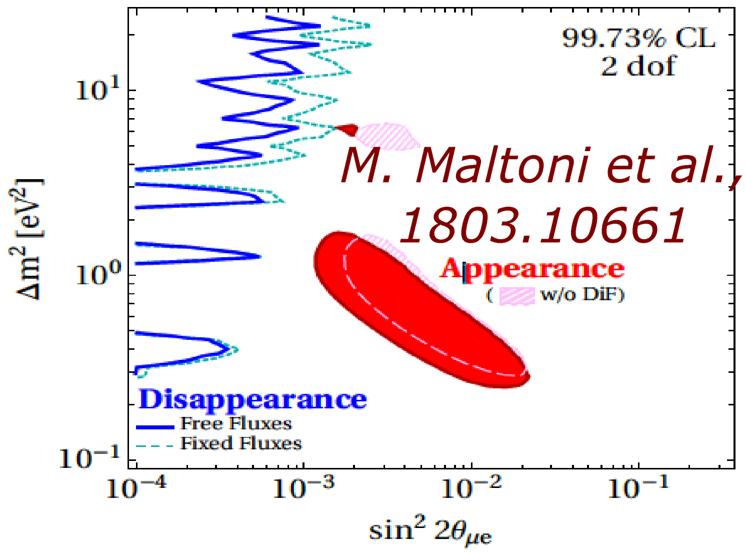
ICARUS

Perspective for sterile neutrino physics

- The sterile neutrino scenario is far from understood and needs a definitive clarification.
- Some "anomalies" from accelerators (LSND), reactor, neutrino sources, point out to flavour transitions in the $\Delta m^2 \sim 1\ eV^2$ range.
- However, no evidence of oscillations in $\nu\mu$ disappearance data (MINOS, IceCube).
- Tension between appearance and nm disappearance results. Measuring both channels with the same experiment will help disentangle the physics scenario.



Combined analyses



- A comparison between far/near detector is crucial for any accelerator experiment, with a better control of backgrounds and systematics

SBN satisfies these requirements: it could have a crucial role in solving the sterile neutrino puzzle!

La collaborazione ICARUS

The ICARUS Collaboration: O(100) scientists

Spokesman: C. Rubbia (GSSI)

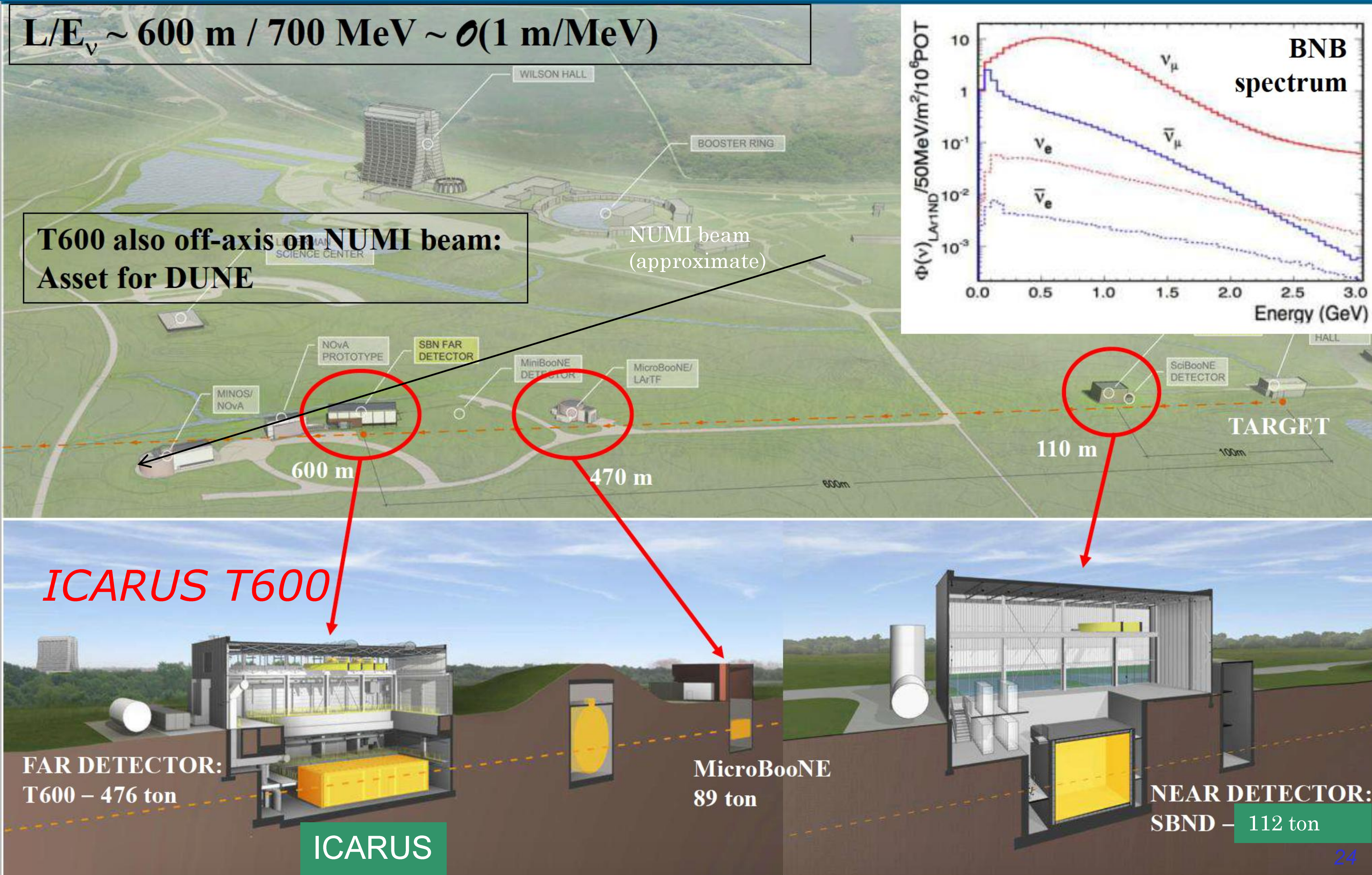
Catania (INFN and Univ.)
GSSI
LNGS
INFN Milano Bicocca
INFN Napoli
Padova (INFN and Univ.)
Pavia (INFN and Univ.)

Brookhaven (BNL)
Colorado State
FNAL
Houston
Pittsburgh
Rochester
SLAC
Texas (Arlington)
Southern Methodist Univ.

CINVESTAV

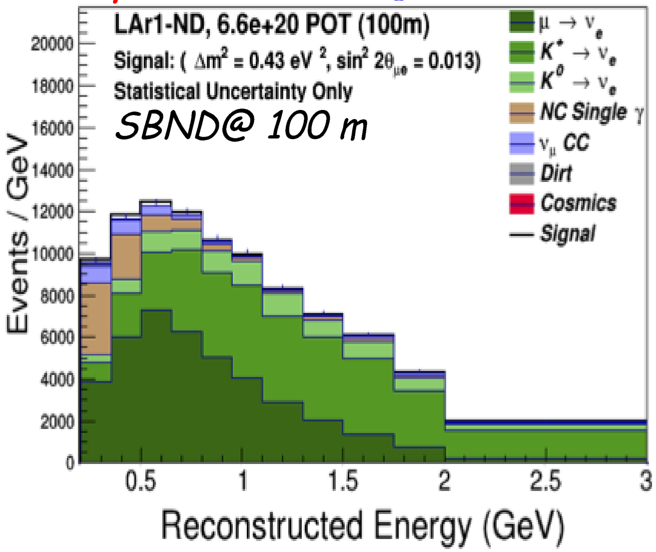
This work was supported by the EU *Horizon 2020* Research and Innovation Programme under the Marie Sklodowska-Curie Grant Agreement No. 822185

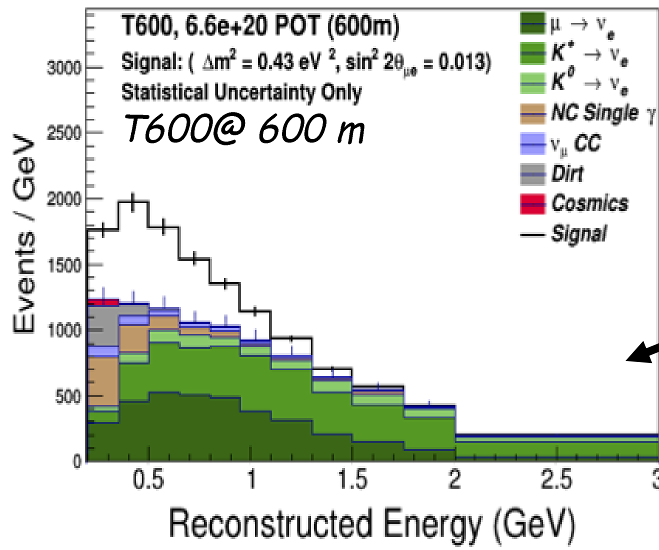
The SBN project



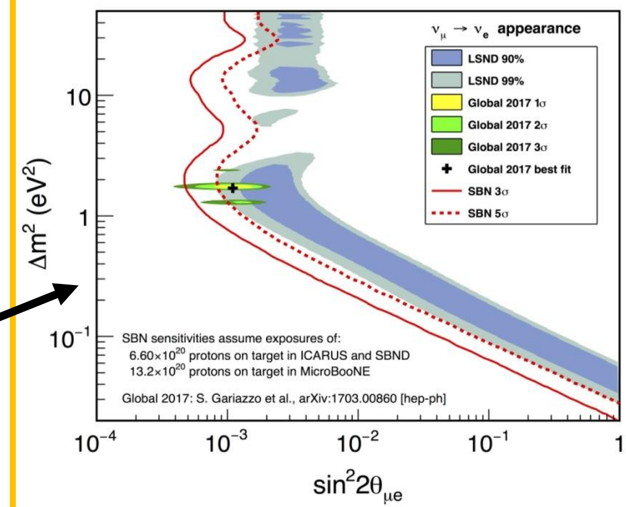
Spectra and sensitivity

νe spectra (oscillation signal + backgrounds),
Example for $\sin^2 2\theta = 0.013$ $\Delta m^2 = 0.43$ eV^2





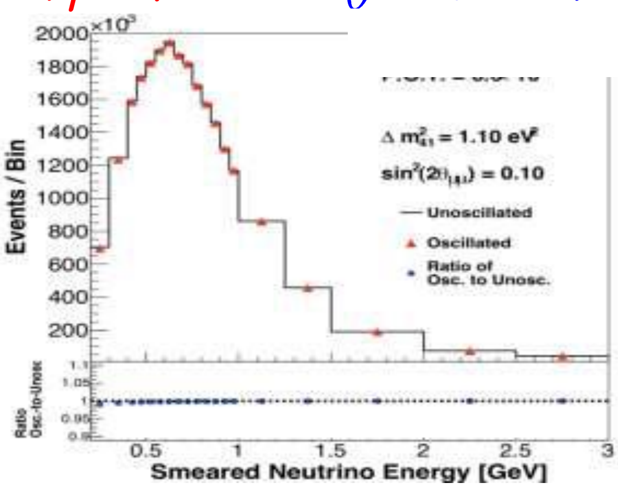
νe appearance: LSND 99% CL region covered at 5 σ level

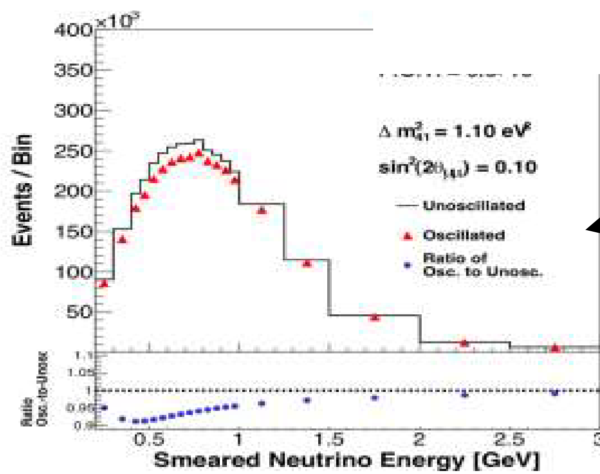


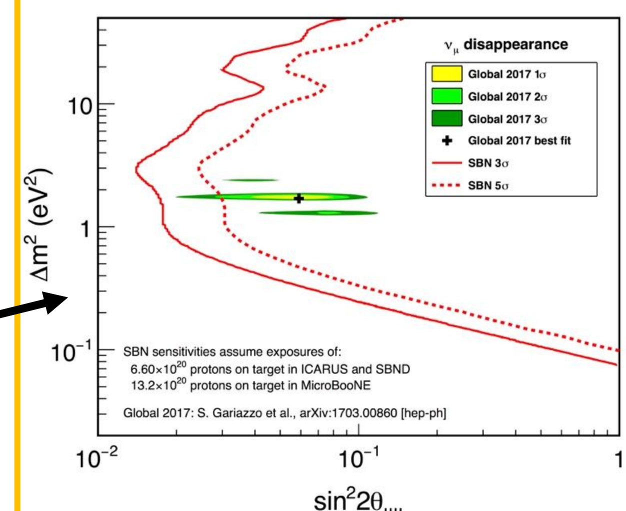
In absence of oscillations, spectra should be ~identical

3-5 σ νμ disapp. SBN sensitiv.

νμ spectra (oscillation modulation) for 3 years (6.6 10^{20} pot)
Example for $\sin^2 2\theta = 0.01$ $\Delta m^2 = 1.10$ eV^2



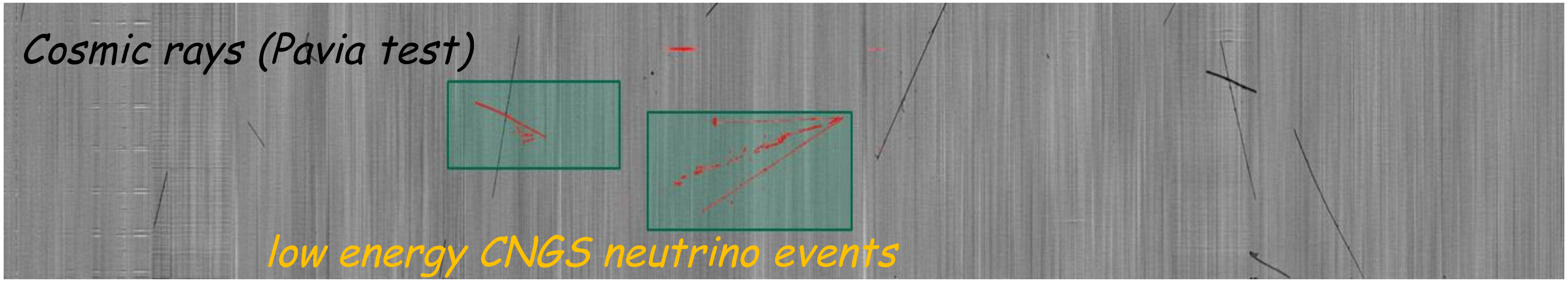




A new experimental challenge: LAr-TPC on surface

ICARUS at FNAL is facing a more challenging experimental condition than at LNGS, requiring the recognition of $O(10^6)$ ν interactions amongst 11 kHz of cosmic rays.

- A 3 m concrete overburden will remove contribution from charged hadrons/γ's.
- ~11 m tracks will hit the T600 in 1 ms TPC drift window: associated γ's represent a serious background source for ne search since e's produced via Compton scatt./ pair prod. can mimic a genuine νe CC.



- To face new experimental conditions, T600 underwent an intensive overhauling at CERN in the Neutrino Platform framework from 2015 to 2017, before shipping to US.
- Several technology developments were introduced *while maintaining the already achieved performance at LNGS run:*
  - new cold vessels, with a purely passive insulation;
  - renovated LAr cryogenics/purification equipment;
  - improvement of the cathode planarity
  - upgrade of the PMT system: higher granularity and ns time resolution
  - new faster, higher-performance read-out electronics;

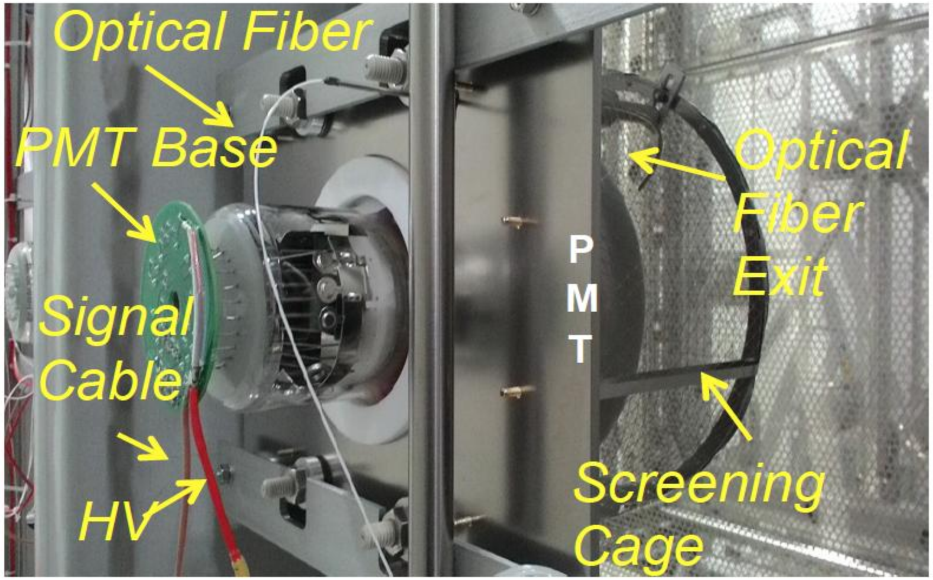
Upgrade of the light collection system (almost all PV item!)

In shallow depth operation, the light collection system will allow to:

- Precisely identify the time of occurrence (t0) of any ionizing event in the TPC
- Determine the event rough topology for selection purposes
- Generate a trigger signal for read-out

ICARUS@SBN exploits 90 PMTs per TPC (5% coverage, 15 phe/MeV) that provides:

- Sensitivity to low energy events (~ 100 MeV)
- Good spatial resolution (≤ 50 cm)
- ≈ ns timing resolution
- Possible cosmics identification by PMT space/time pattern



Timing/gain equalization will be performed with laser pulses

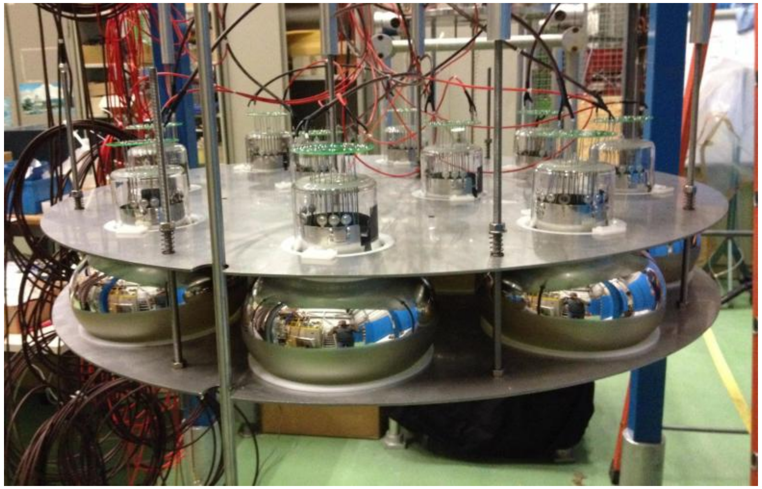
λ = 405 nm

FWHM < 100 ps

peak power ~ 400 mW

PMT tests at CERN (almost all PV item!)

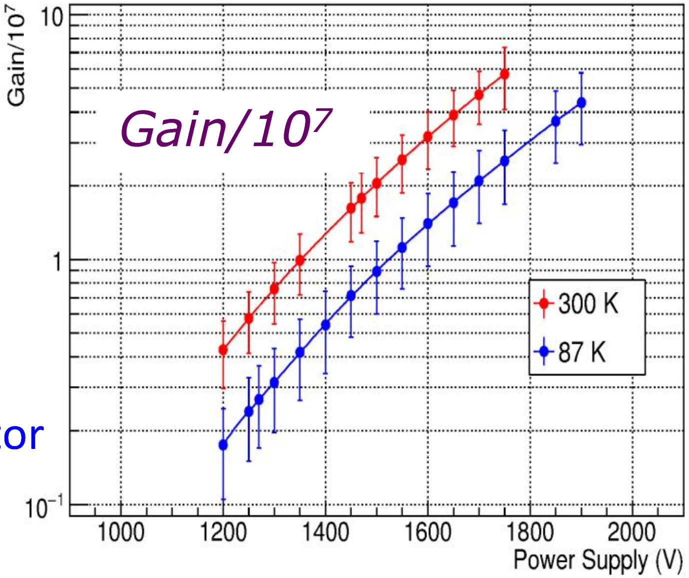
- All PMTs tested at room temperature in a dedicated dark room at CERN
- A subset of 60 PMTs tested immersed in LAr to compare the PMT performance in cryogenic environment to room temperature
- All PMTs illuminated with laser light pulses

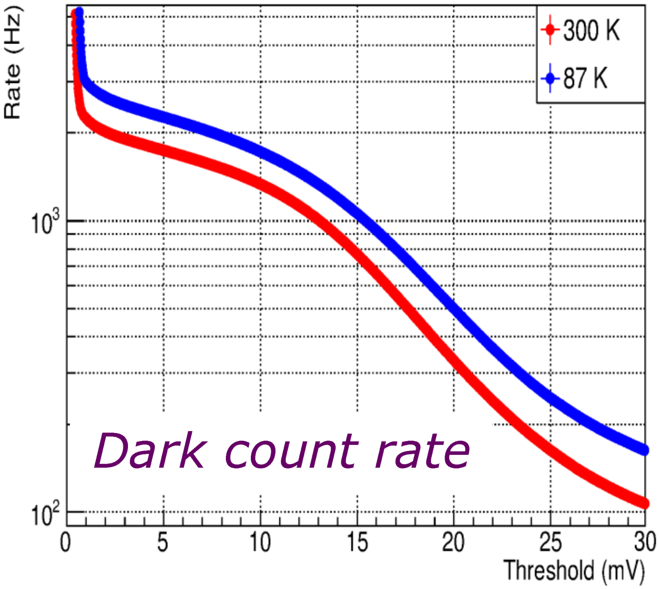


PMTs were characterized individually at 300K and 87K:

- Gain
- Dark count rate
- Peak/valley ratio
- Uniformity of photocathode response

The gain reduction in LAr w.r.t. room temperature (up to a factor 10) will be compensated by a ~ 100 V increase in power supply voltage





JINST 13 (2018) P10030

Upgrade of TPC read-out electronics

ICARUS electronics at LNGS was based on:

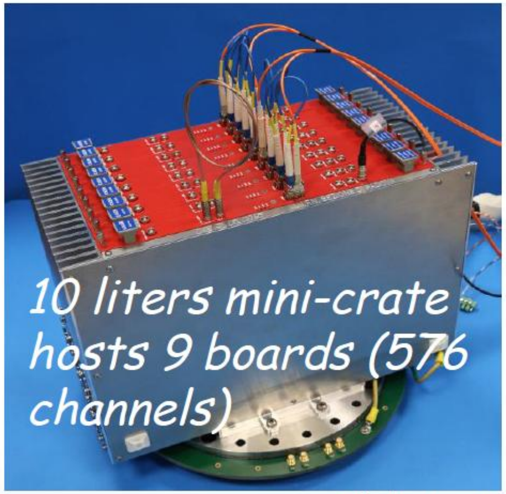
- "warm" low-noise front-end amplifier
- Multiplexed 10-bit ADC
- Digital VME module for local storage, data compression, trigger information

Performances proved adequate for track reconstruction and muon momentum measurement (Multiple Coulomb Scattering)

(S/N)m.i.p. ~ 7 in Collection, resolution sy ~ 0.7 mm along drift

However, in view of the SBN program, some components were modernized and improved:

- Serial 12-bit ADC, fully synchronous in the whole detector -> ~20% improvement in muon momentum resolution via MCS
- Serial bus architecture increases transmission rate to Gbit/s
- More compact layout: both analog+digital electronics hosted on a single flange



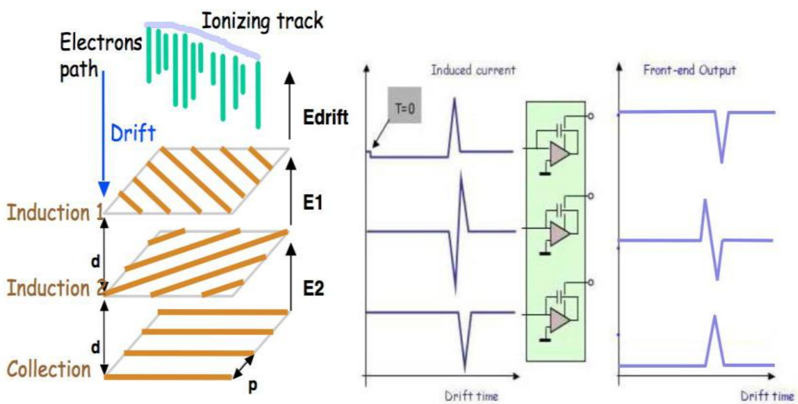
New electronics extensively tested on a 50-liter TPC@CERN

JINST 13 (2018) P12007

Front-end electronics

The analog front-end shaping was also modified:

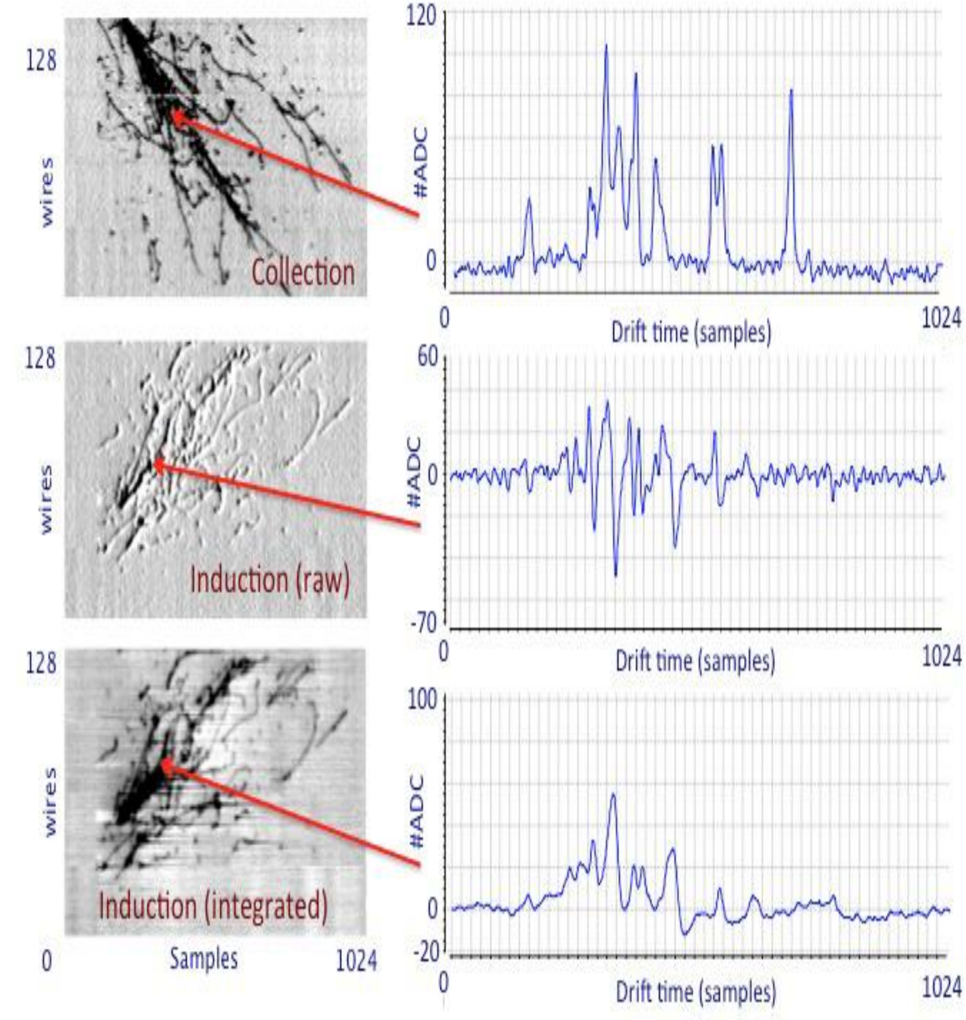
- Lower noise ~ 1200 e- equivalent (~20% S/N improvement w.r.t. LNGS electronics)
- Shorter shaping time (~ 1.5 ms for all planes) matc electron transit time between planes
- Drastic reduction of undershoot after large signals description of crowded vertex region



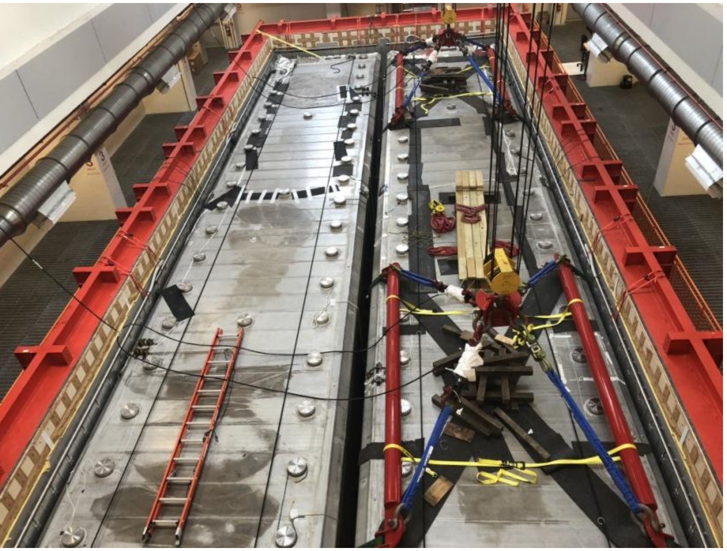
In particular, Induction 2 signal keeps bipolar (unlike in old front-end):

- Possible off-line integration with suitable LF filterir
- Allows calorimetric measurement in this plane to ~2 worse resolution than Collection)
- May improve ne identification efficiency by ~20%

Tests on 50-liter TPC at CERN:



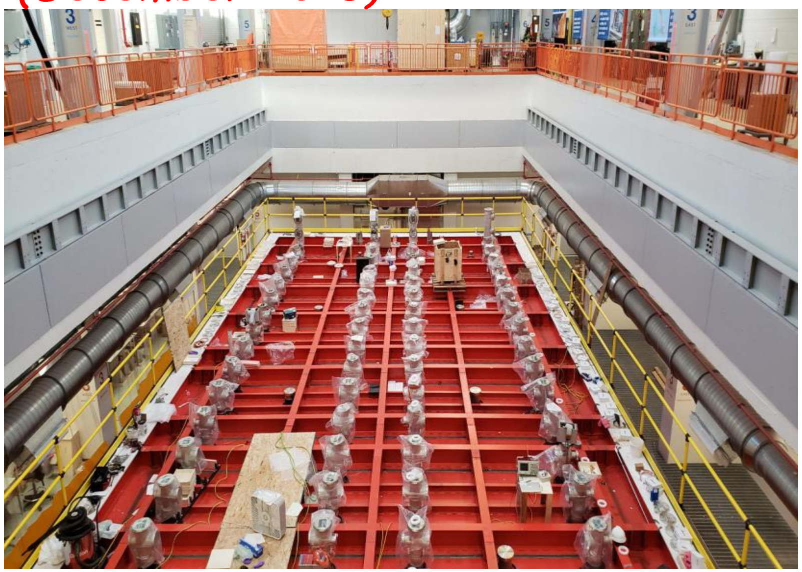
ICARUS installation at FNAL

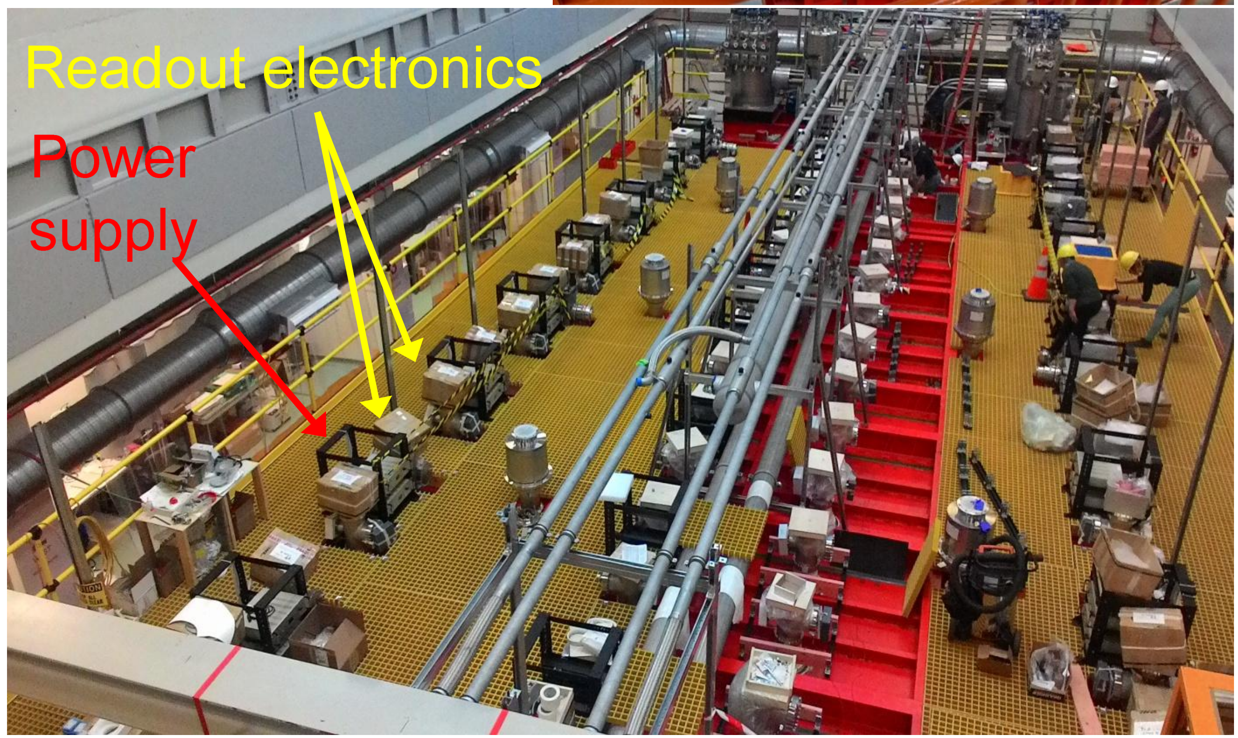


Placement of ICARUS (August 2018)

Chimneys installation (October 2018)

Feedthrough installation (December 2018)





Positioning the readout electronics (May 2019)

ICARUS installation at FNAL: status

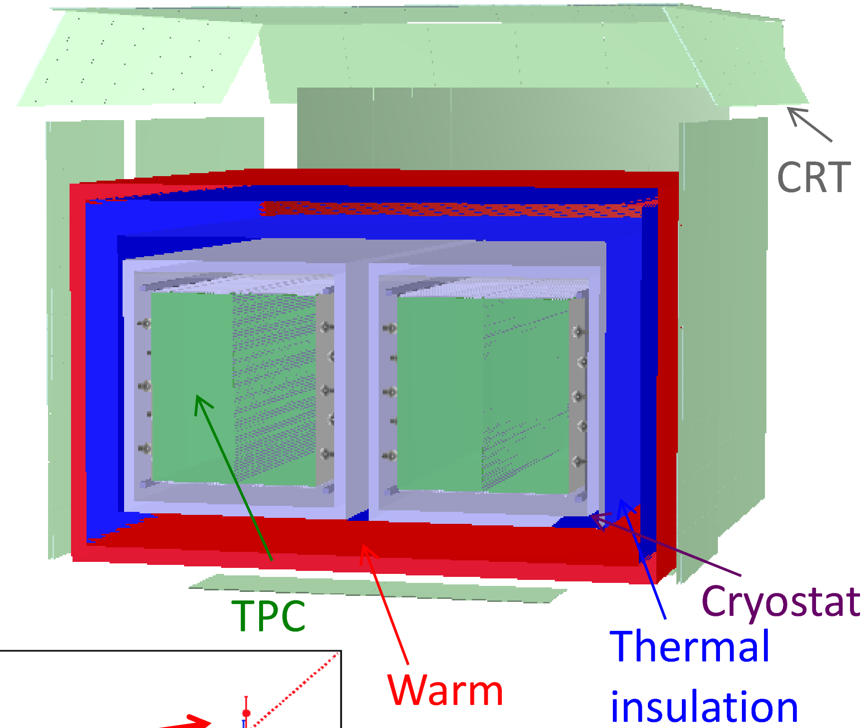
- T600 installed inside warm vessel in August 2018
- Installation of TPC/PMT feedthrough flanges and connectivity tests, completed by February 2019
- Leak tightness tests completed
- Top cold shields and top CRT support installed

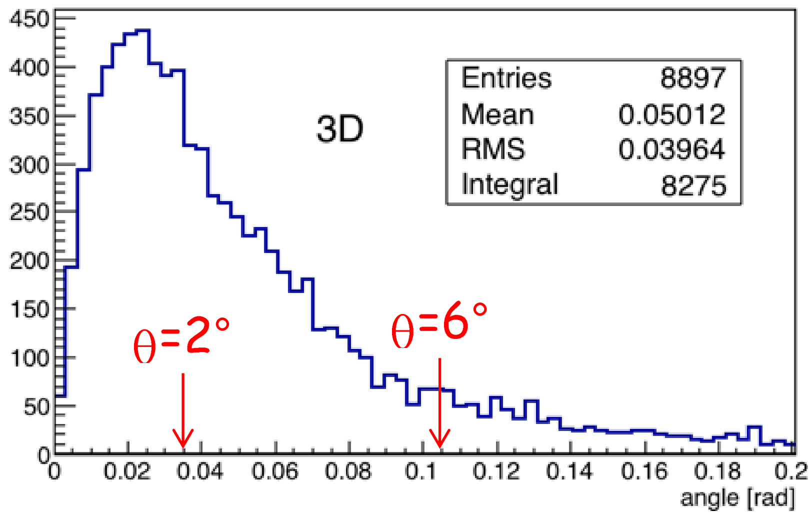
- PMT electronics and trigger being tested at cryogenic temperatures at CERN
- Installation of proximity cryogenics started in February
- Side CRT installation also ongoing
- Director’s Review in December 2018 recognized the great progress of SBN

Reconstruction and analysis

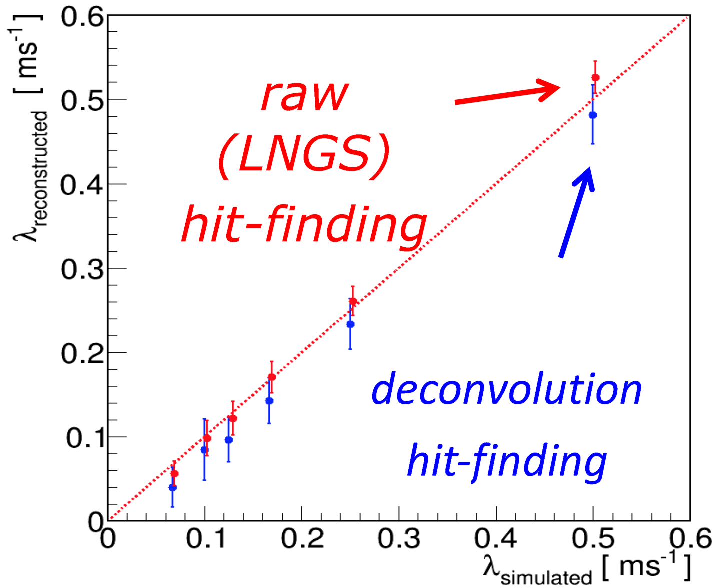
- A detailed understanding of detector-related systematics and their correlation across near/far detectors will be crucial to SBN physics
- Common reconstruction tools and oscillation analysis are therefore fundamental
- ICARUS joined the LArSoft framework: mutual sharing of algorithms and tools and cross-check between different reconstruction approaches
- Full simulation performed with realistic geometry and signals from all sub-detectors (TPC,PMT,CRT)

Scheme of detector geometry





angle between sim/reco direction for EM showers



electron lifetime (reco vs. sim)

ICARUS PV: anagrafica e consuntivi

Personale INFN 2018

- F. Boffelli 100%
- T. Cervi 100%
- A. Falcone, 100%
- A. Menegolli 60%
- C. Montanari 100%
- P. Picchi 0%
- A. Rappoldi 40%
- G.L. Raselli 100%
- M. Rossella 30%
- A. Scaramelli 0%
- M. Spanu 100%

Totale FTE: 7.3

Descrizione	Stanziato	Variato	Impegni	NOTE
Rimborso per viaggio e trasloco	68.000,00	18.000,00	82.901,66	
Strumenti tecnico-specialistici non sanitari	5.000,00	-1.160,45	3.839,55	
Licenze d'uso per software	4.000,00	-4.000,00	0	
Attrezzature scientifiche	6.000,00	4.512,83	10.509,97	
Altri servizi diversi n.a.c.	87.000,00	715.000,00	800.790,35	Rimborso MoU
Manutenzione ordinaria e riparazioni di attrezzature	6.000,00	-6.000,00	0	
Impianti	280.000,00	-280.000,00	0	
TOTALE	**456.000,00**	**446.352,38**	**898.041,53**	

ICARUS PV: attività 2018

Attività di test in corso 2018/2019:

- Studio del cablaggio esterno dei PMT e posizionamento dei racks.
- Sviluppo del sistema di trigger di ICARUS che utilizza i segnali dei PMT.
- Test sul sistema di calibrazione Laser dei PMT.

Queste attività sono condotte con l'ausilio di «test-bench» del rivelatore assemblati in varie sedi INFN (Pd, Pv) e al CERN.

Attività software:

- Sviluppo software/Monte Carlo per analisi dati FNAL.
- Sviluppo del sistema di acquisizione dati dei PMT e integrazione nel software di acquisizione del rivelatore.
- Sviluppo software e programmazione FPGA per il trigger.

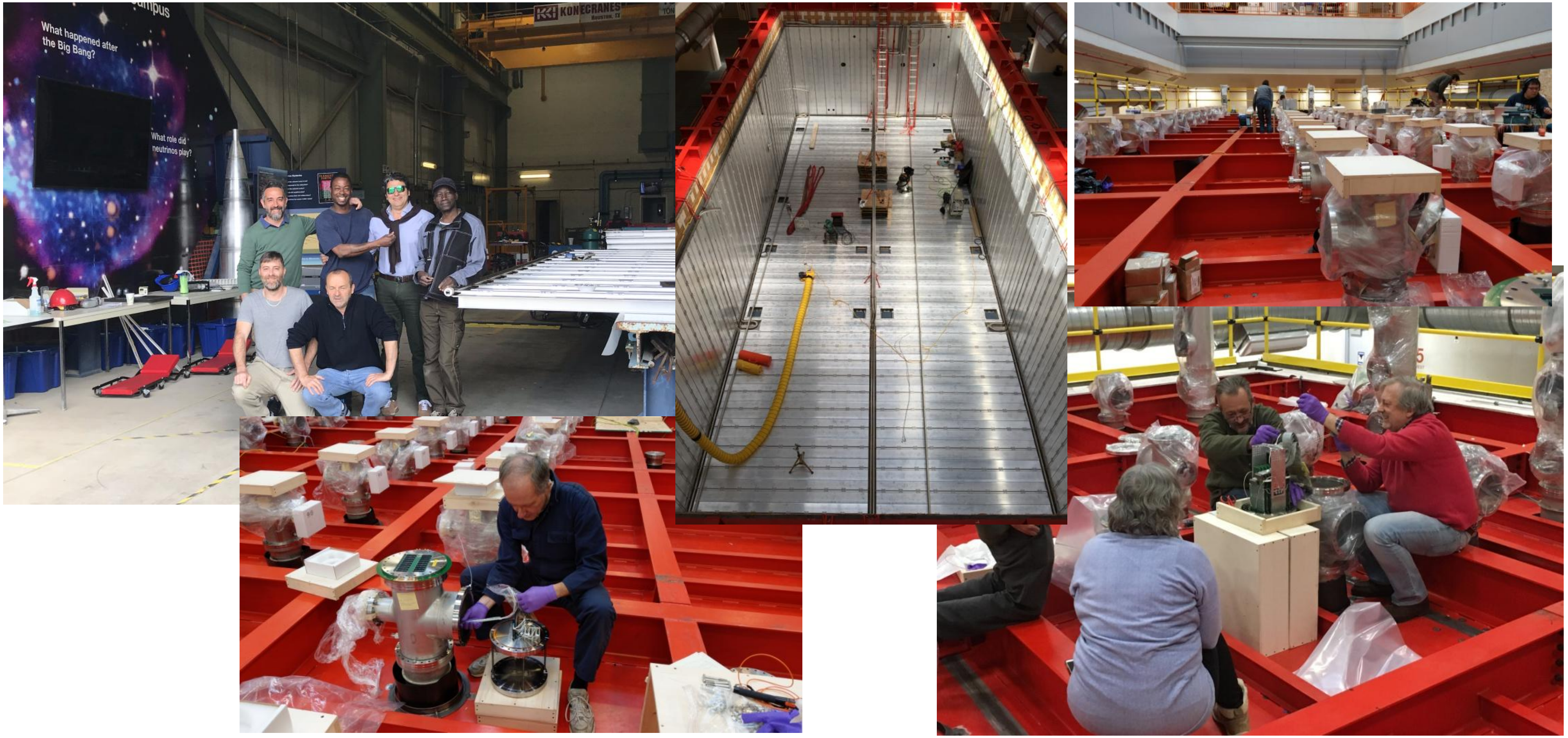
Attività di R&D:

- R&D nuovi tipi di foto-rivelatori a temperature criogeniche (SiPM arrays).

ICARUS PV: attività 2018

Attività hardware:

- Coordinamento tecnico di tutte le attività di montaggio a FNAL (C. Montanari).
- Montaggi relativi al sistema di rivelazione della luce di scintillazione: passanti PMT e fibre ottiche laser (G.L. Raselli, M. Rossella).
- Installazione pannelli LN2 prima della collocazione finale del rivelatore (F. Vercellati).



ICARUS PV: pubblicazioni, conferenze e tesi 2018

Pubblicazioni:

1. Bonesini M. et al., "*An innovative technique for TPB deposition on convex window photomultiplier tubes*", JINST vol. 13, p. 12020 (2018), doi: 10.1088/1748-0221/13/12/P12020
2. Bagby L. et al., "*New read-out electronics for ICARUS-T600 liquid argon TPC. Description, simulation and tests of the new front-end and ADC system*", JINST vol. 13, p. 12007 (2018), 10.1088/1748-0221/13/12/P12007
3. Babicz M. et al., "*Test and characterization of 400 Hamamatsu R5912-MOD photomultiplier tubes for the ICARUS T600 detector*", JINST vol. 13, p. 12030 (2018), 10.1088/1748-0221/13/10/P10030

+ 14 proceedings di conferenza.

Conferenze:

1. M. Rossella, "*Optical Properties of TetraPhenylButadiene as wavelength shifter for the detection of VUV scintillation light from liquefied noble gases* ", PM2018 - 14th Pisa Meeting on Advanced Detectors.
2. M. Rossella, "*Detection of Vacuum Ultra-Violet light by means of SiPMs with and without a wave-length shifter coating for High Energy Physics experiments* ", PM2018 - 14th Pisa Meeting on Advanced Detectors.
3. G.L. Raselli, "Sterile neutrino searches with the ICARUS detector ", Neutrino Oscillation Workshop (NOW 2018, Ostuni).
4. A. Menegolli, "*The deployment of ICARUS at SBN* ", European Neutrino "Town" meeting 2019 (CERN)

Tesi:

Tesi di dottorato di Tommaso Cervi: «*Development of an innovative photodetector for liquid argon applications: the SiPMs Single Channel Array*».

Uno sguardo al 2019...