THE CERN NEUTRINO PLATFORM

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Wiν 2019, Bari, 2-7 June 2019

CERN | Neutrino PLATFORM

DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

The CERN Neutrino Platform mandate

- ESPP 2013: “CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments”
- Main goal : compact the European groups around the future Short and Long Baseline Neutrino programs taking place in US & Japan
- Part of the CERN Medium Term Plan (since 2015) – CERN acts as a hub for R&D on future technologies (HW and SW) and partner in several neutrino research programs
- Today: 146 institutions, active CERN partnership with external facilities in US/Japan

CENF Activities

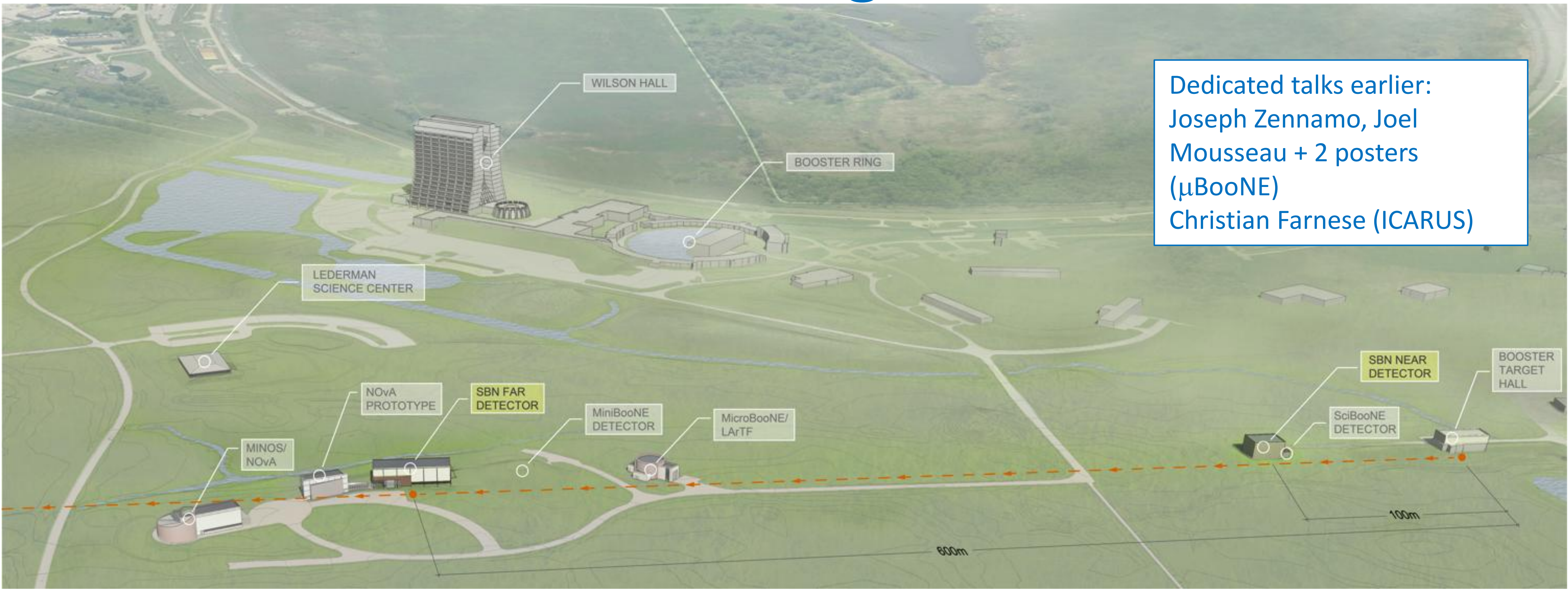
- *NP01: ICARUS refurbishing and far detector in the SBN FNAL facility (now at FNAL almost ready for operation)*
- *NP02: LAr double phase TPC demonstrator (ProtoDUNE DP)*
- *NP03: PLAFOND – generic detectors R&D*
- *NP04: LAr single phase TPC demonstrator (ProtoDUNE SP)*
- *NP05: Baby Mind muon detector for T2K near (operational)*
- *NP06: ENUBET project (new in the NP)*
- *NP07: ND280 T2K near detector upgrade (new)*

+ agreed active participation in the construction and exploitation of the LBNF/DUNE and SBN US programs

+ collaboration with DarkSide 20k experiment

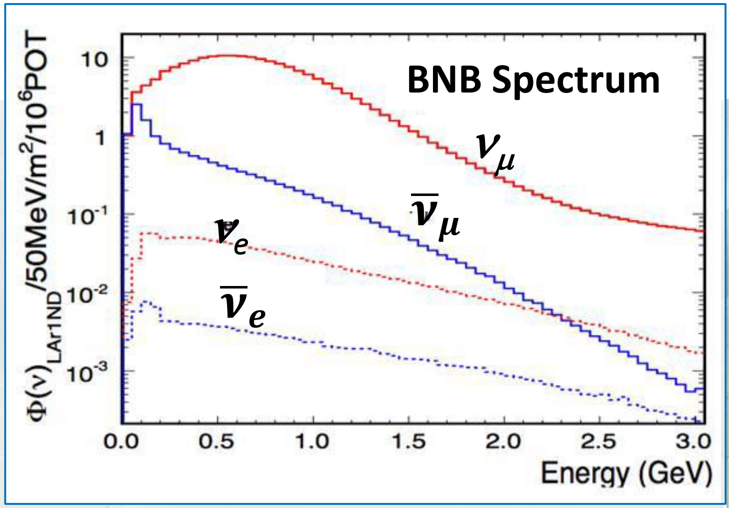
SBN Program

Dedicated talks earlier:
Joseph Zennamo, Joel Mousseau + 2 posters (μBooNE)
Christian Farnese (ICARUS)



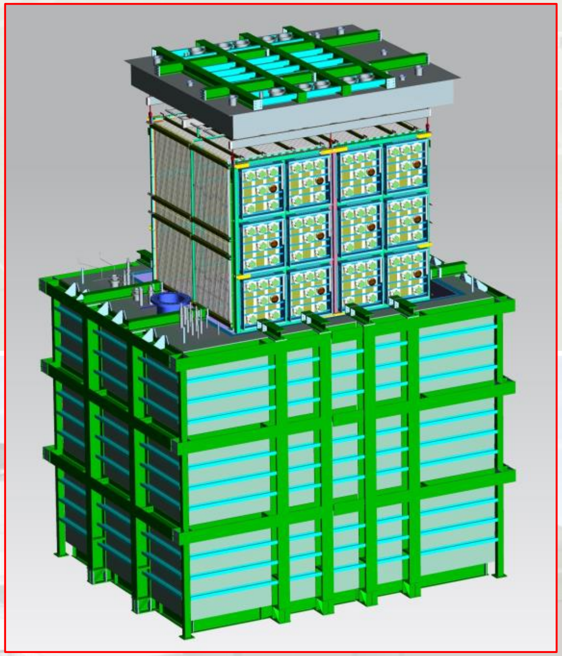
SBN Program

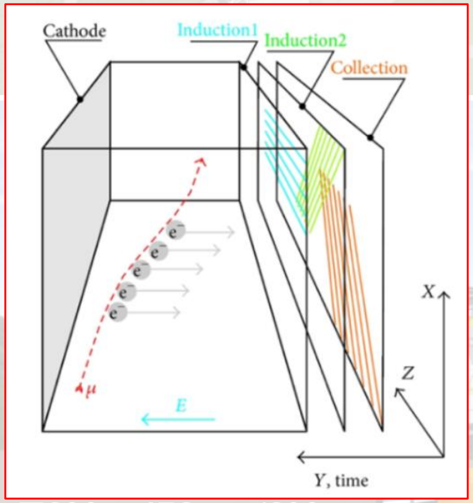
Short Baseline Neutrino program @ FNAL, dedicated to the search of sterile ν's, on the Booster Neutrino Beam.
Study of both ν_e appearance and ν_μ disappearance channels.
Direct comparison of ν spectra at near and far sites.
Same tech (LAr-TPC detectors), different implementations.

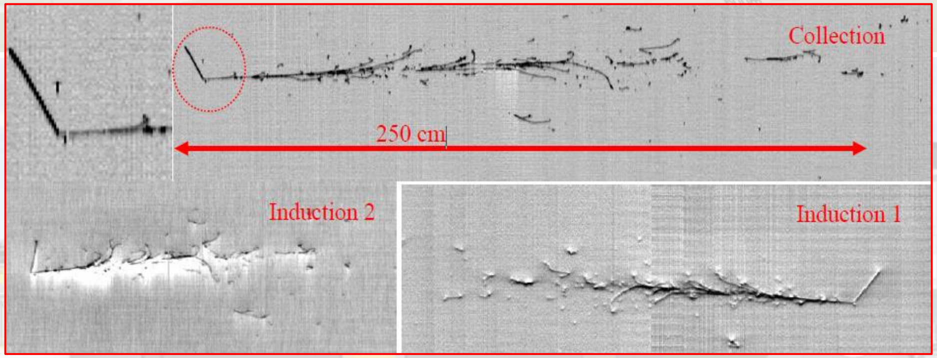


CENF roles:

- **ICARUS T600 refurbishment @ CERN and transport to FNAL**
- **Cryostats and cryogenics for both the T600 (NP01) and SBND**
- **Participation to the development of SBND (HV/field cage)**
- **Cryostat monitoring (strain gauges), commissioning**







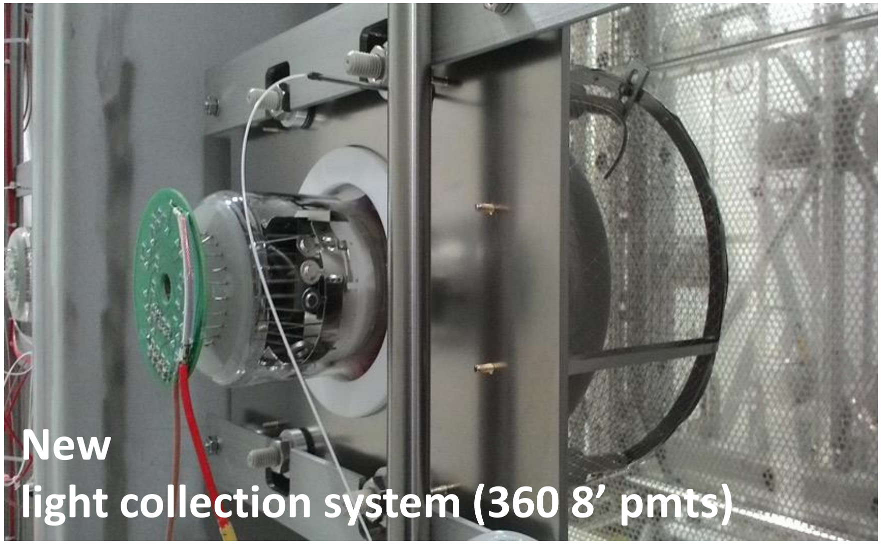
T600 – 476 ton/600 m

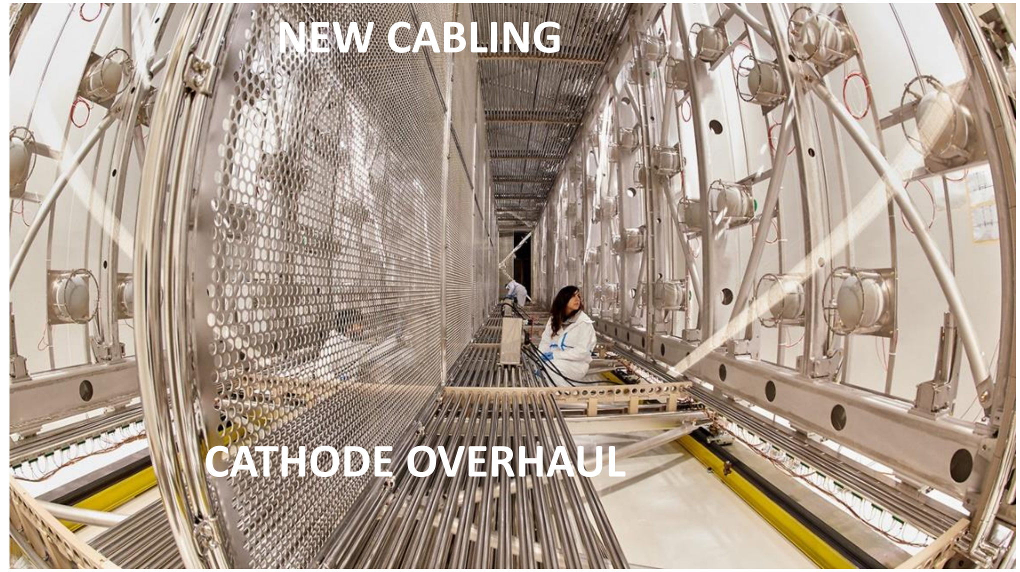
MicroBooNE
85 ton/470 m

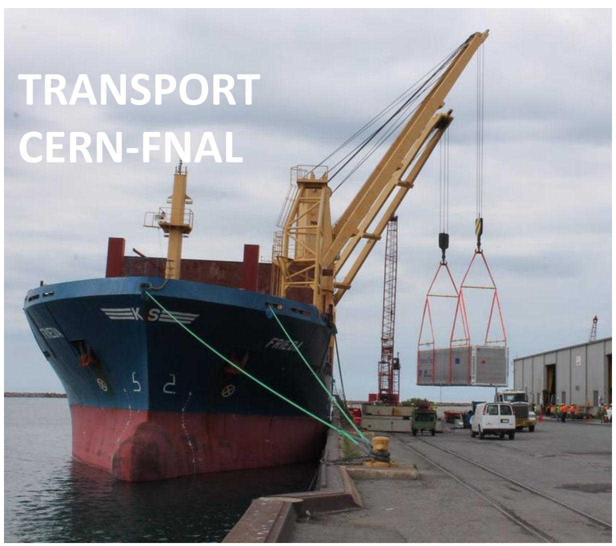
NEAR DETECTOR:
SBND – 112 ton/110 m

$L/E_\nu \sim 600$ m / 700 MeV $\sim \mathcal{O}$(1 m/MeV)

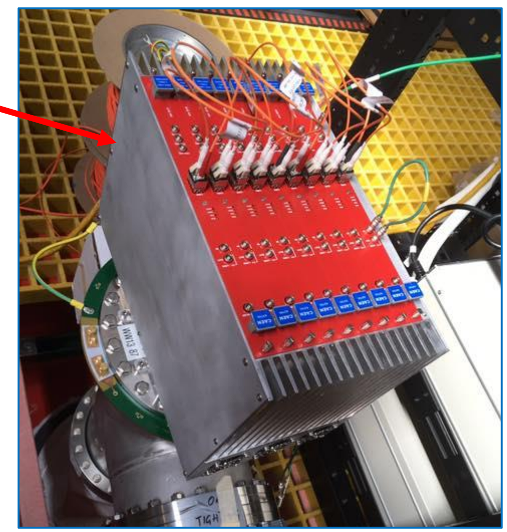
ICARUS refurbishment @ CERN

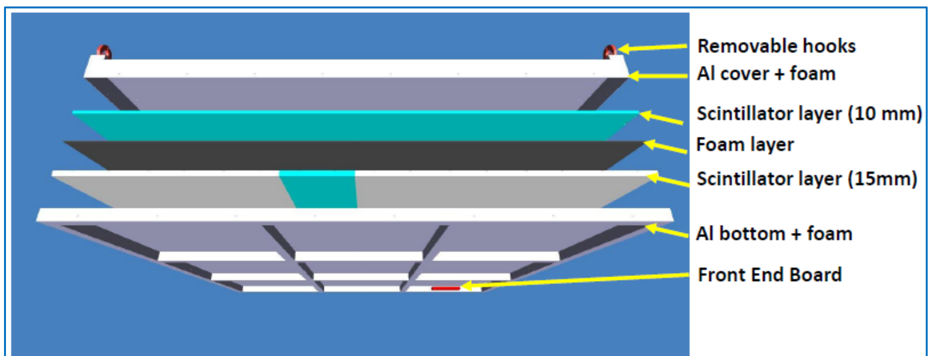






New warm electronics chain, Tested extensively @ CERN in a 50l set-up with cosmic muons





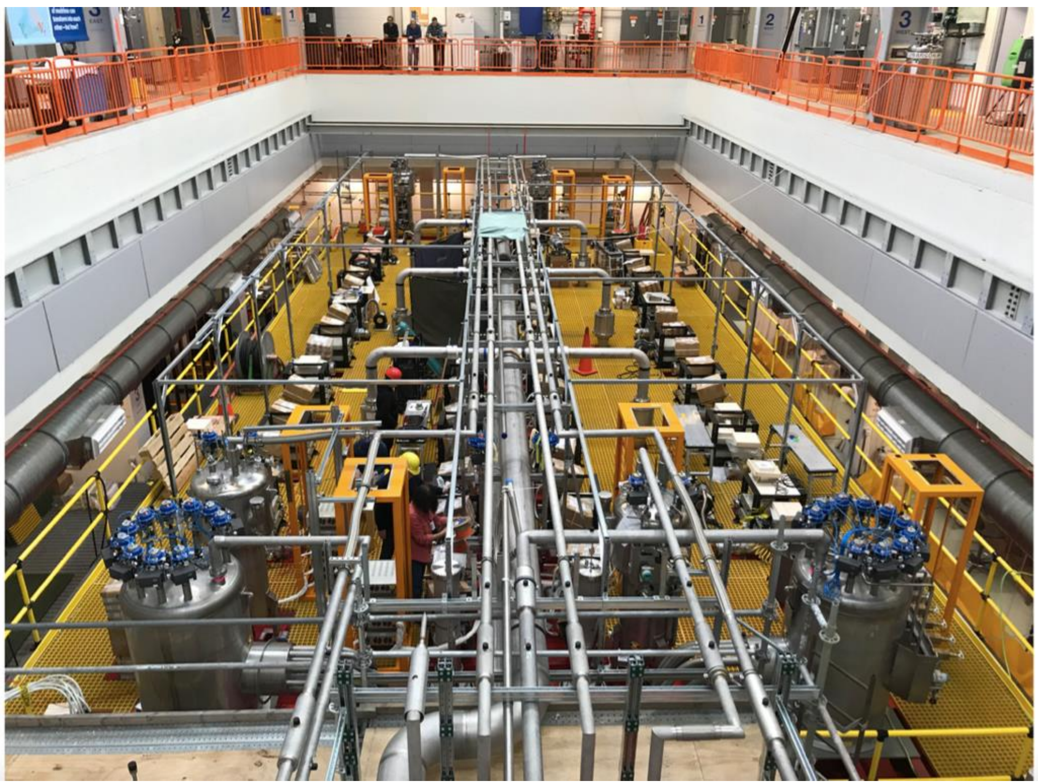
Cosmic Ray Tagger capable of measuring the position and time of entering charged tracks to the TPC volume.

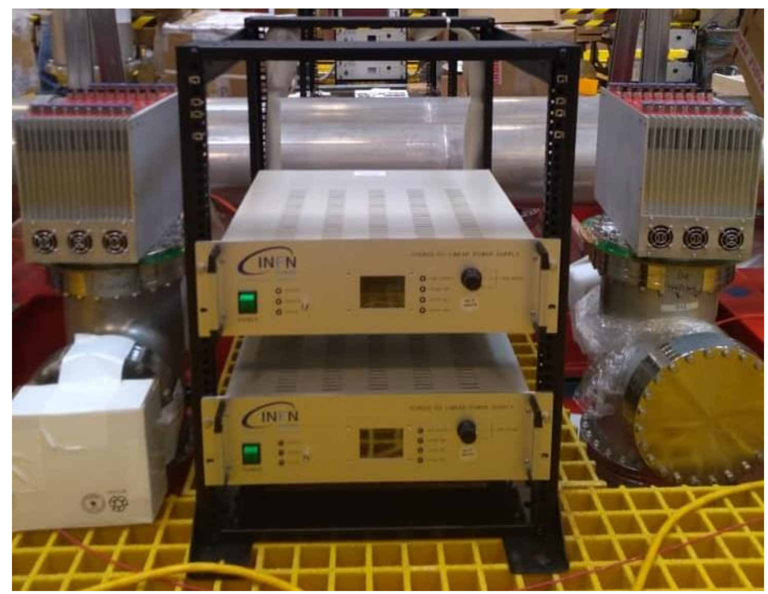
ICARUS talk
C. Farnese

ICARUS @ FNAL

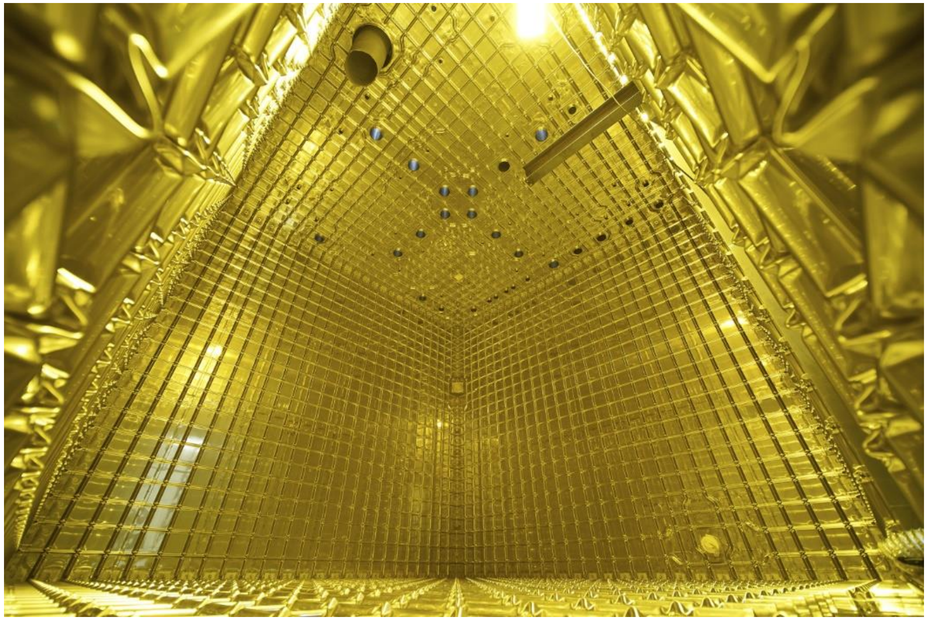
- ✓ Installation of Warm Vessel (2016-2017)
- ✓ Transport and insertion of the T600 (fall 2018)
- ✓ Installation activities, 2018 – ongoing (INFN/CERN/FNAL)
- ✓ Cryogenics installation (2019)

- Cryostat underwent pressure test. **Vacuum to start next week – cool-down in September.**



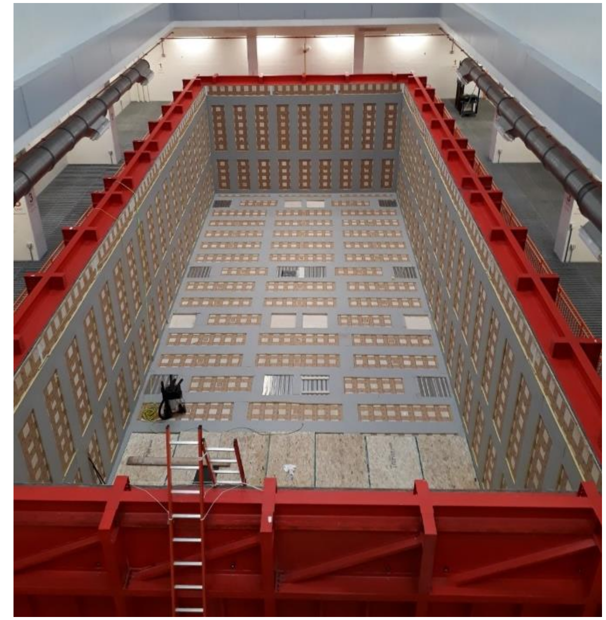


Membrane cryostat technology

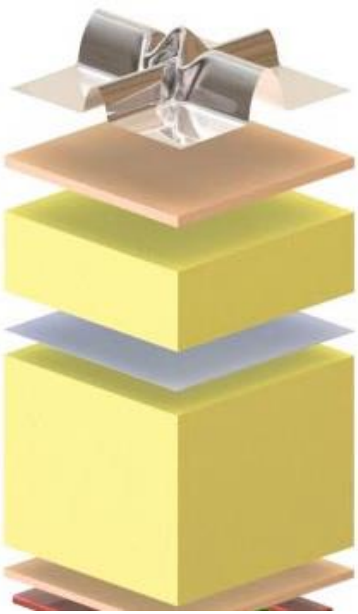


Close collaboration with industry (GTT). Membrane cryostat tech. developed for LNG transport ships

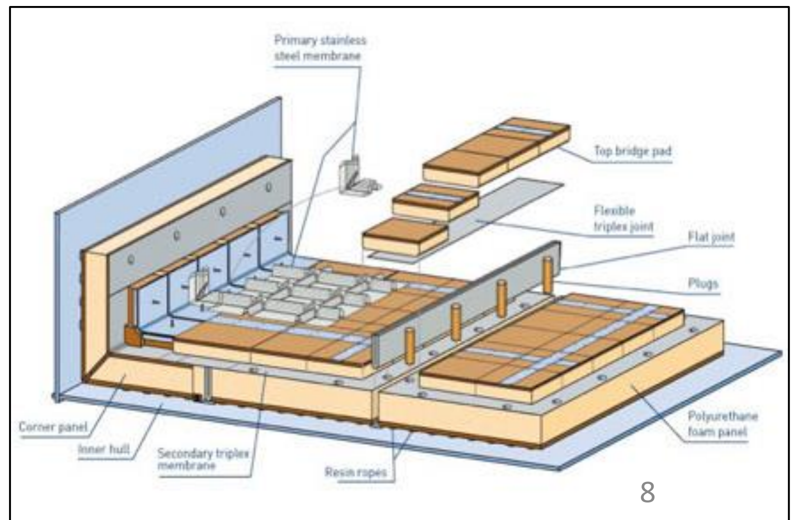
Re-engineered for LAr-TPC detectors



ICARUS: no membrane
Vacuum-pumped cryostats

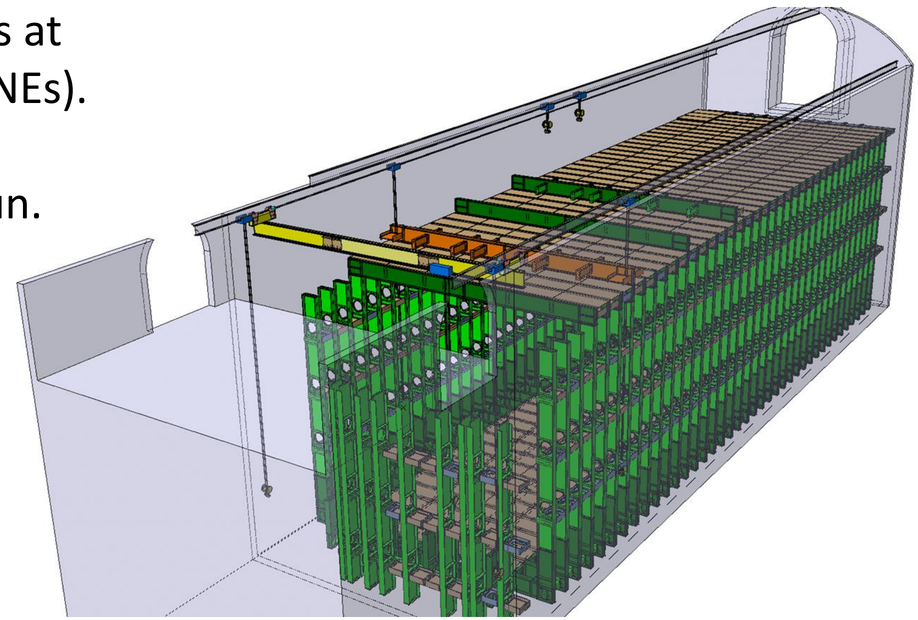


Membrane Cryostats:
No vacuum – Argon purge

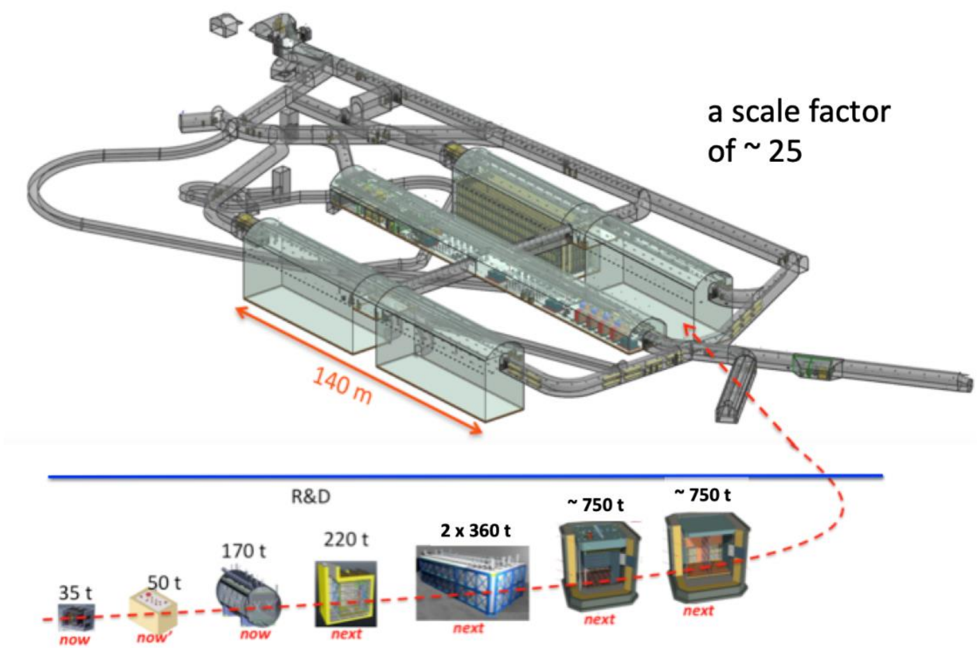


Towards US – LBNF – DUNE FD & ND

- Strong design effort on the cryostats and cryogenics.
- Construction and operation of large scale prototypes at CERN, exposed to charged particle beams (ProtoDUNEs).
- Single-Phase: updated design will be tested in ProtoDUNE-SP starting in 2021 with second beam run.
- Continuous R&D, e.g.:
  - Xe-doping (under test);
  - New wavelength-shifting (wls) materials (test);
  - Long drift (7.2 m SP - taskforce).



A step by step approach : *"large prototypes as demonstrators"*



Near Detector: action of uniting/steering the community towards:

- Definition of physics requirements
- Technology/design selection

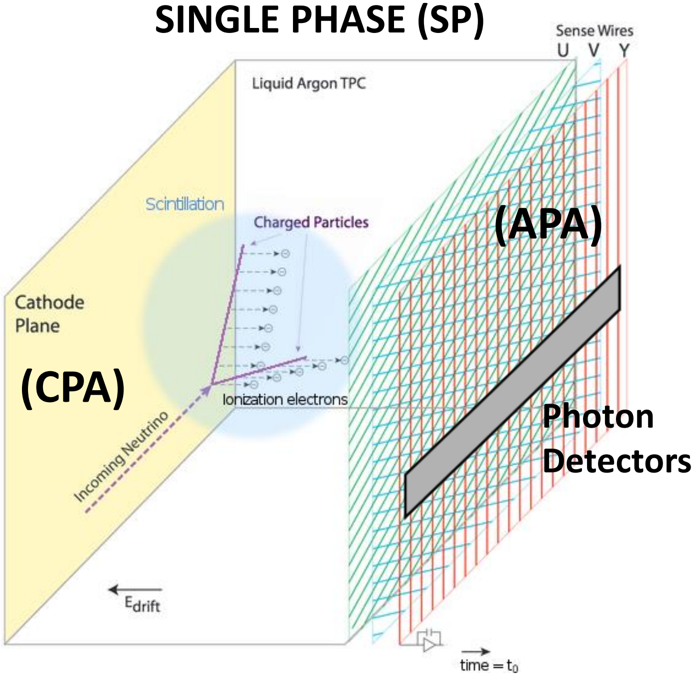
DUNE talk by: Thomas Kutter (Tuesday)

DUNE prototypes - ProtoDUNEs

- The most impressive accomplishment of the Platform.
- Two large scale prototypes for the DUNE Far Detector (760 tons of LAr).
- Designed and constructed to perfectly reproduce the elements of the final DUNE FD.
- Aim: operate them on charged particles beams at CERN (H2, H4 tertiary beams from SPS, 0.5-7 GeV momentum)
  - Full characterization of detector performance;
  - training of reconstruction algorithms;
  - development of electronics read-out;
  - study of nuclear effects (e.g. Ar-π interactions)

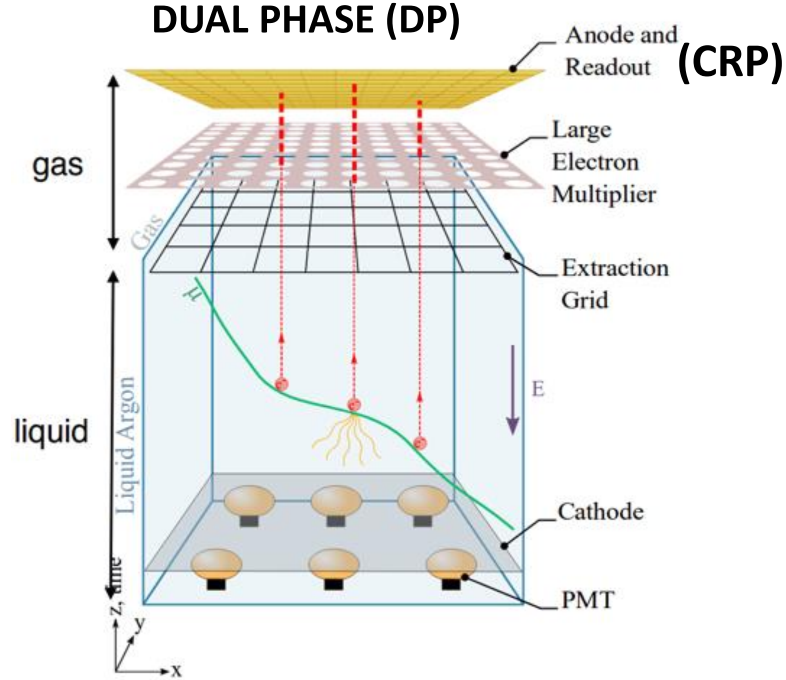
Synergies between the 2 technologies:
- HV feedthrough and field cage tech.
- Cryogenics/Argon monitoring (purity)
- Computing/storage infrastructure
- Monitoring and slow control (T, p, σ)

SINGLE PHASE (SP)

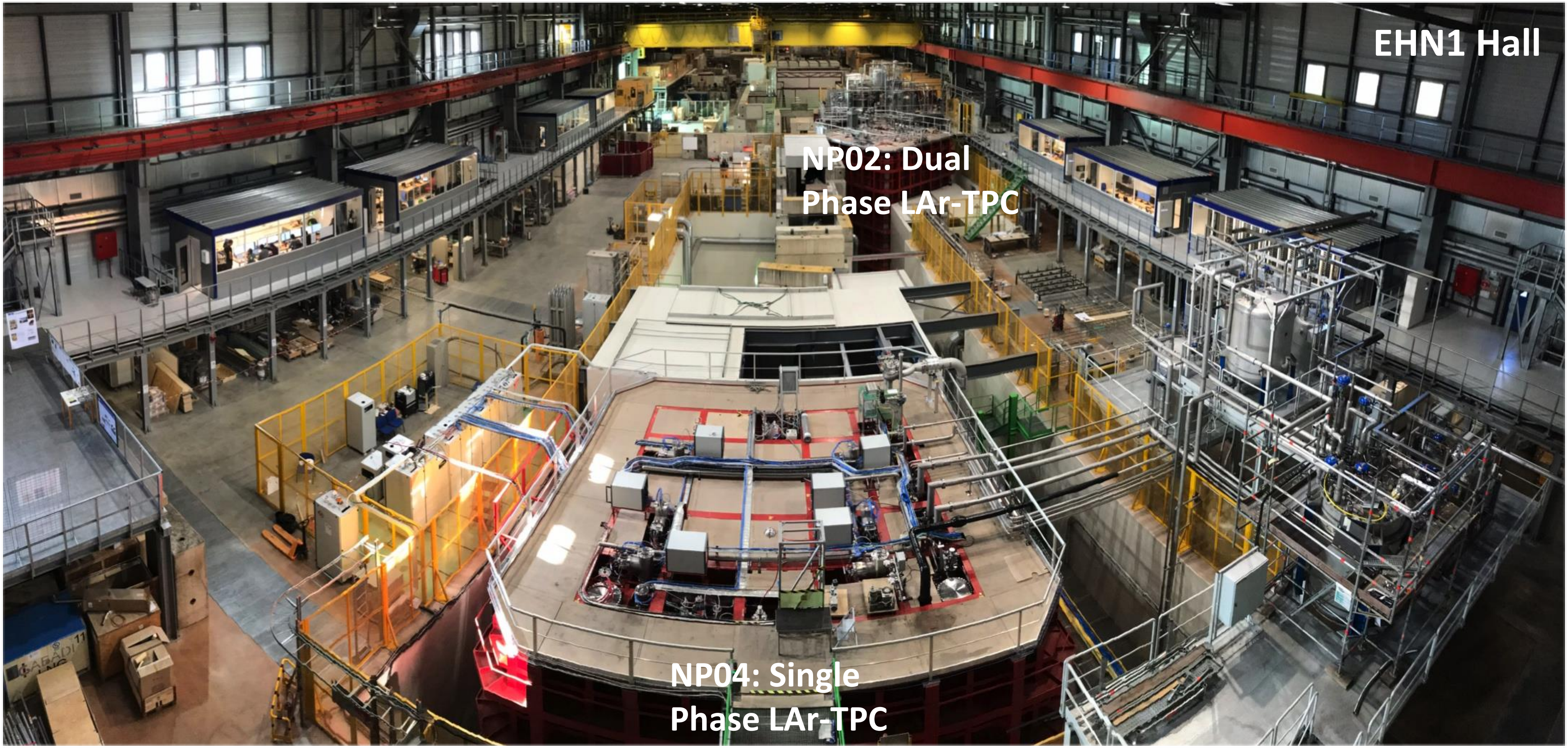


DUNE talk by: Thomas Kutter (Tuesday)

DUAL PHASE (DP)



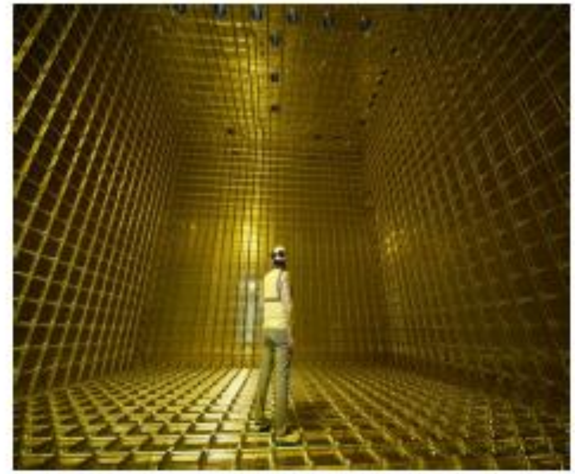
DUNE prototypes - ProtoDUNEs



Path to ProtoDUNE SP completion in EHN1

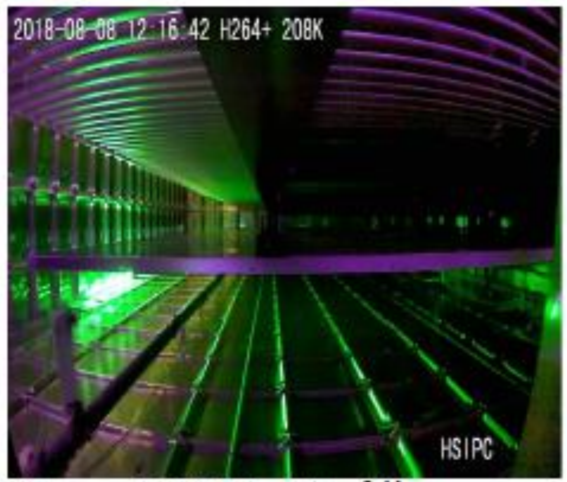
March 2016, construction of EHN1 extension

November 2016, cryostat structure assembly



September 2017, cryostat completion

February 2018, detector assembly and installation

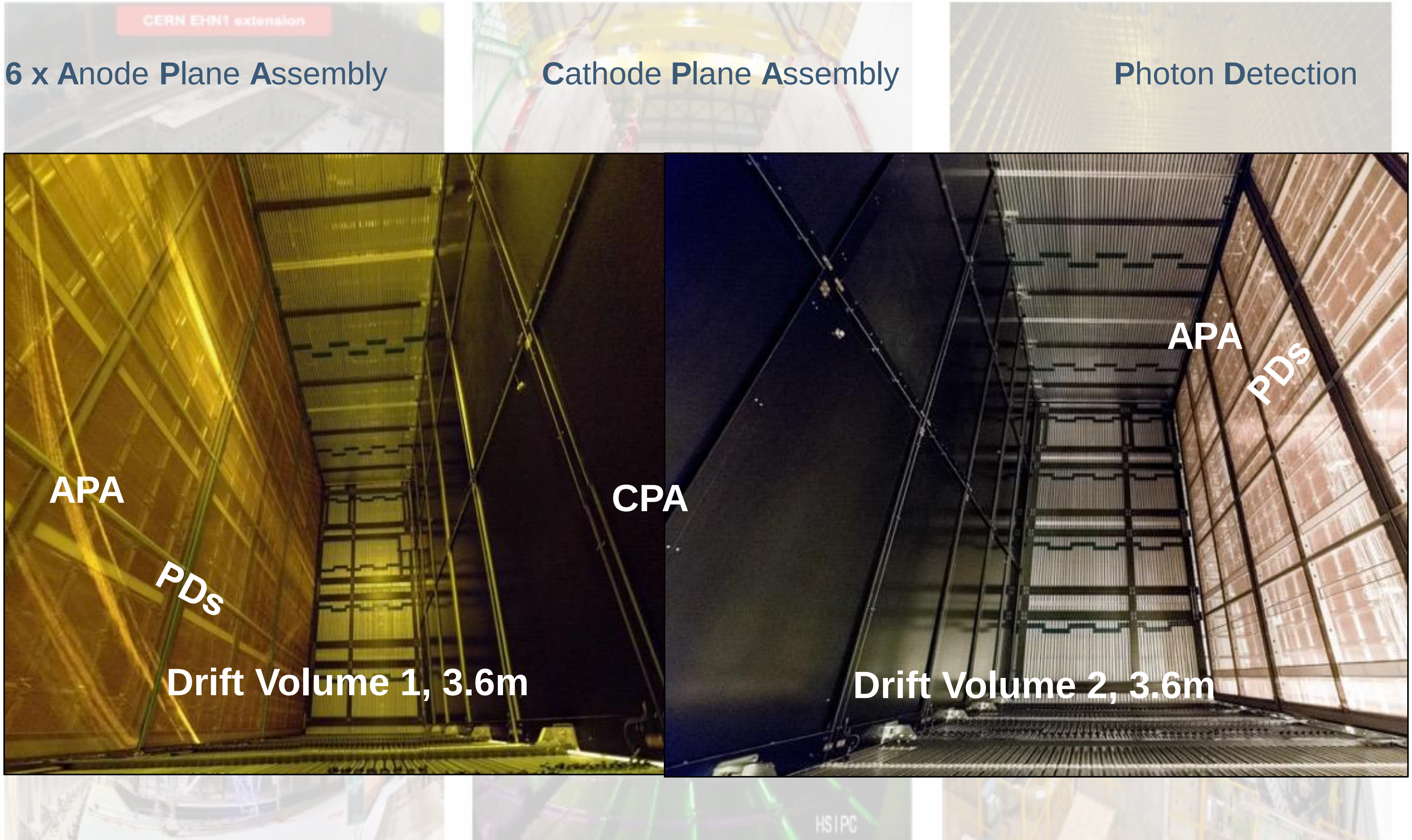


August 2018, LAr filling and purification

September 2018, beam ready & detector ready for beam!

From Francesco Pietropaolo – ProtoDUNE SP timeline – Beam run: September-November 2018
Continuous data taking with cosmic rays since end of beam run

Path to ProtoDUNE SP completion in EHN1



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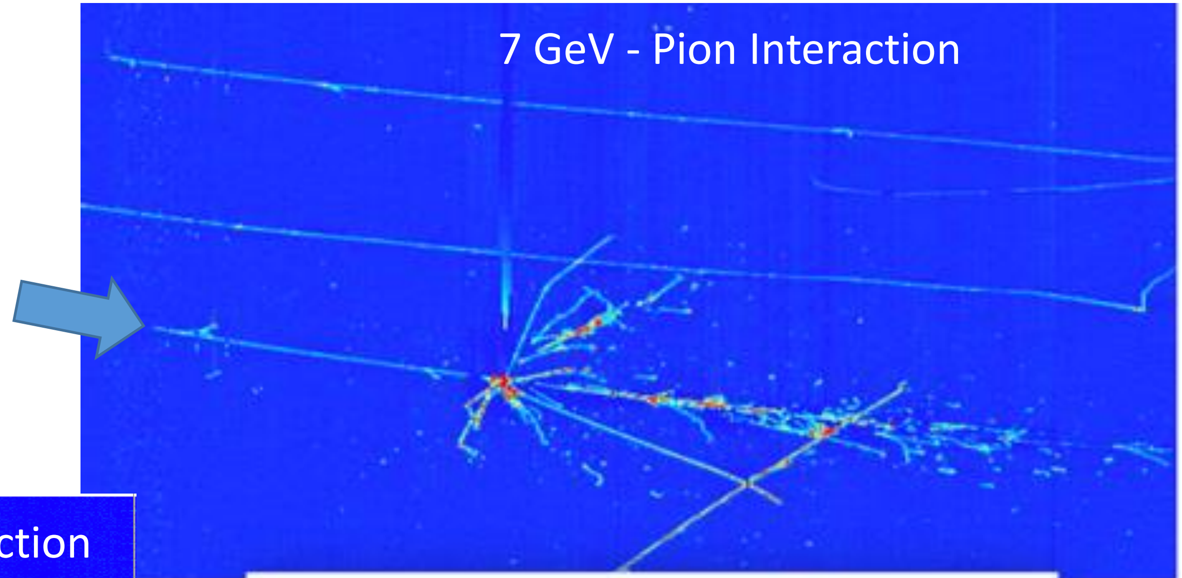
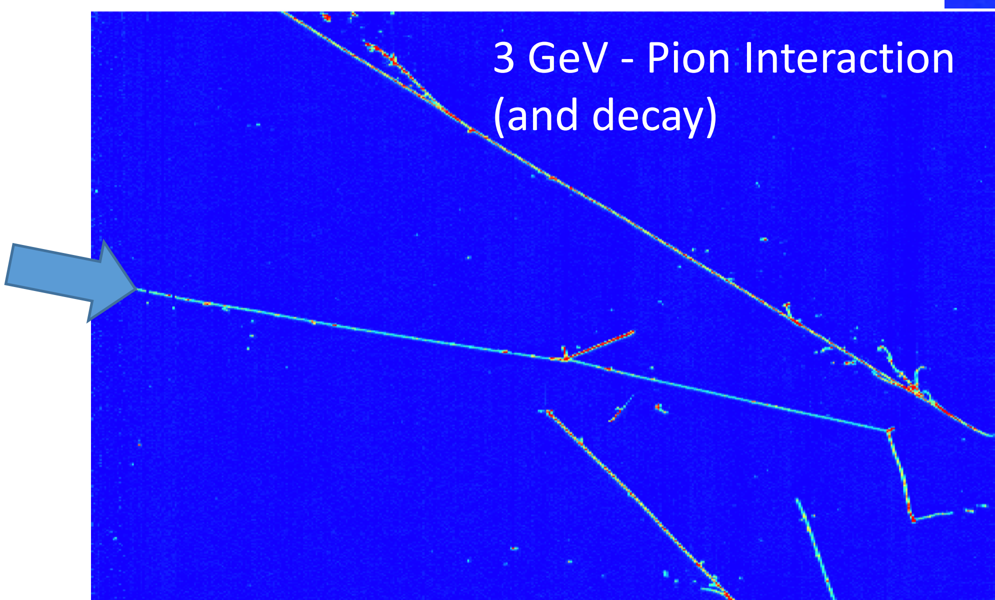
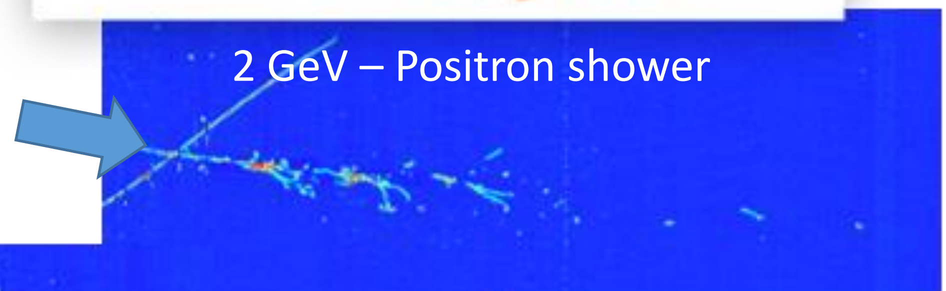
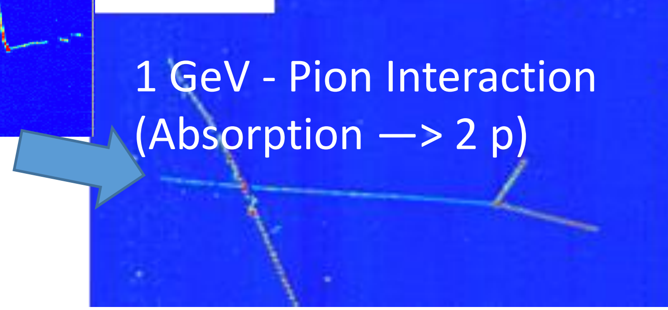
The ProtoDUNEs – Single Phase

LAr TPC data of unprecedented quality





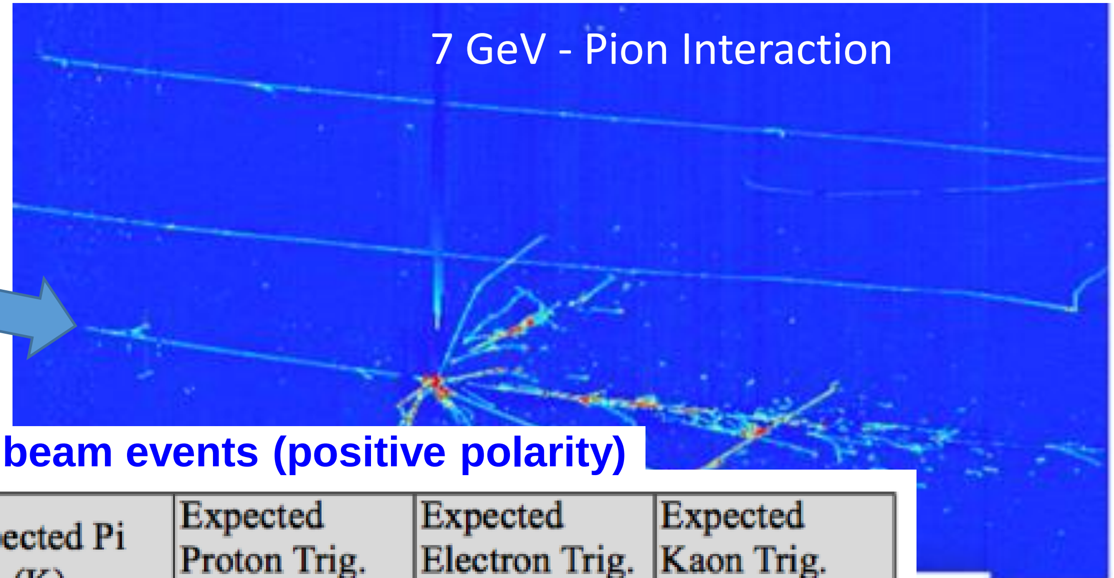




Over 4 million beam events collected!
(Positive polarity only)
Over 20 million cosmic rays events!

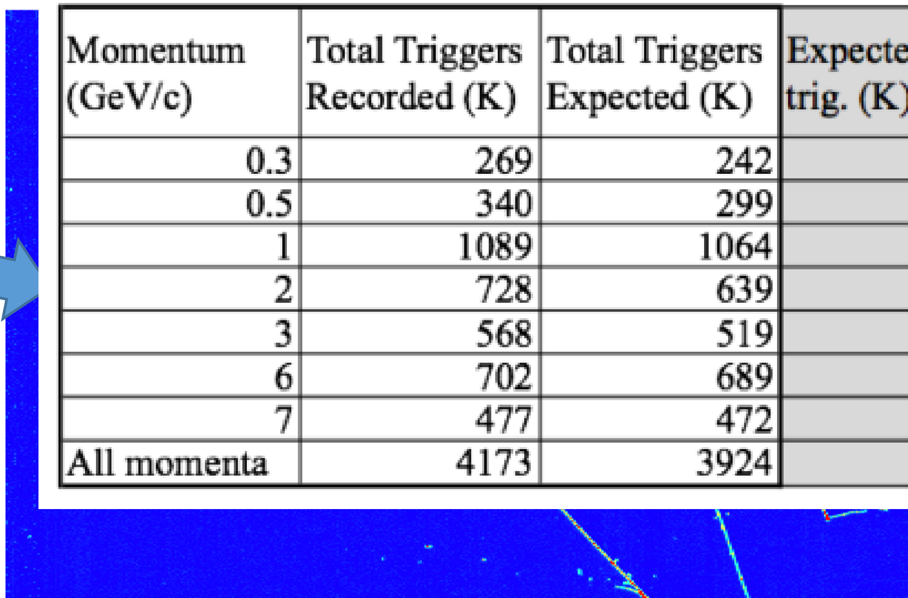
ProtoDUNE – Single Phase

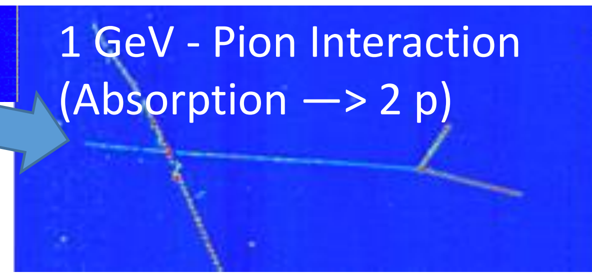
LAr TPC data of unprecedented quality



Summary of collected beam events (positive polarity)

Momentum (GeV/c)	Total Triggers Recorded (K)	Total Triggers Expected (K)	Expected Pi trig. (K)	Expected Proton Trig. (K)	Expected Electron Trig. (K)	Expected Kaon Trig. (K)
0.3	269	242	0	0	242	0
0.5	340	299	1.5	1.5	296	0
1	1089	1064	382	420	262	0
2	728	639	333	128	173	5
3	568	519	284	107	113	15
6	702	689	394	70	197	28
7	477	472	299	51	98	24
All momenta	4173	3924	1693.5	777.5	1381	72



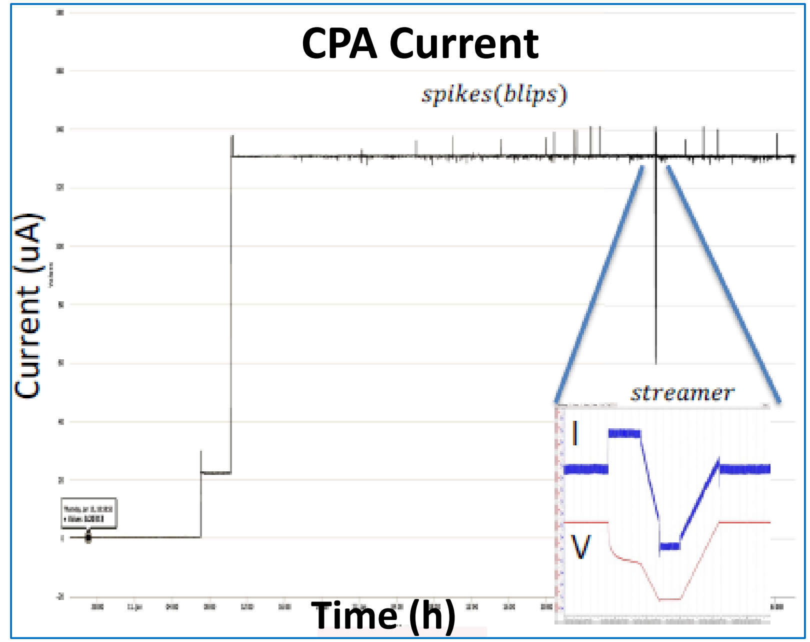


Over 4 million beam events collected!
(Positive polarity only)
Over 20 million cosmic rays events!

ProtoDUNE SP - performance

Detector Parameter	Minimal Requirement	Goal	ProtoDUNE Performance
Electric Drift Field	> 250 V/cm	500 V/cm	500 V/cm
Electron Lifetime	> 3 ms	10 ms	> 7 ms *
Electronics Noise	< 1000 enc	ALARA	450-750 enc

*= Saturation limit of the Purity Monitors – real value estimated around 10 ms

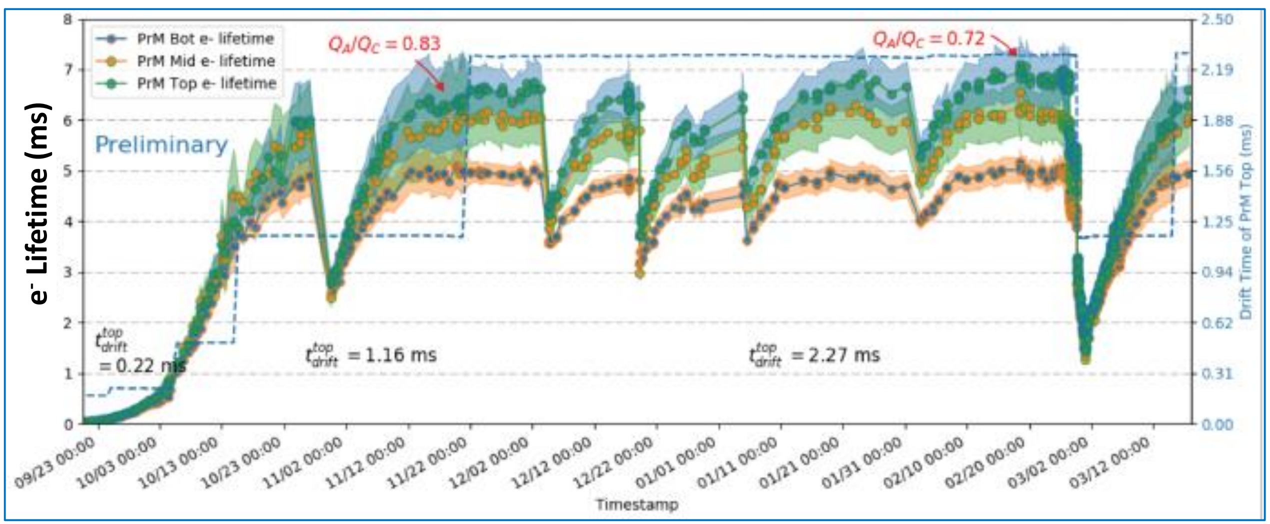


HV stable at 500 V/cm – 180 kV on cathode – 98% live-time

Two classes of instabilities: spikes and streamers

No correlation of HV stability vs LAr purity

Extensive lifetime studies – main sources of impurities is outgassing in warm phase



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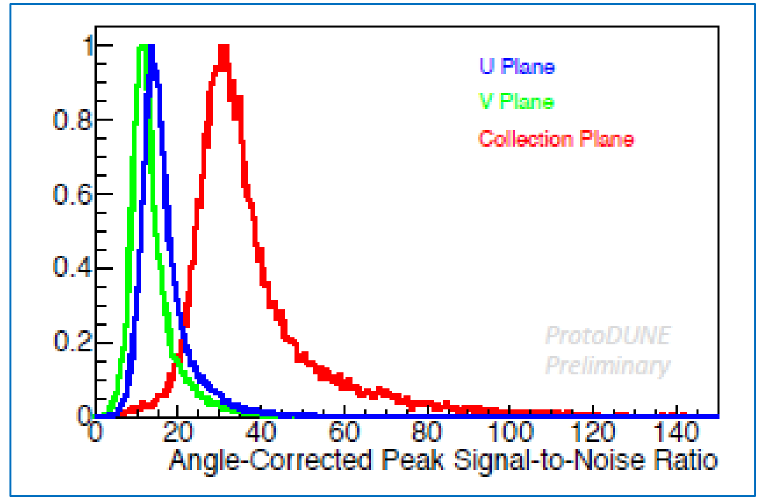
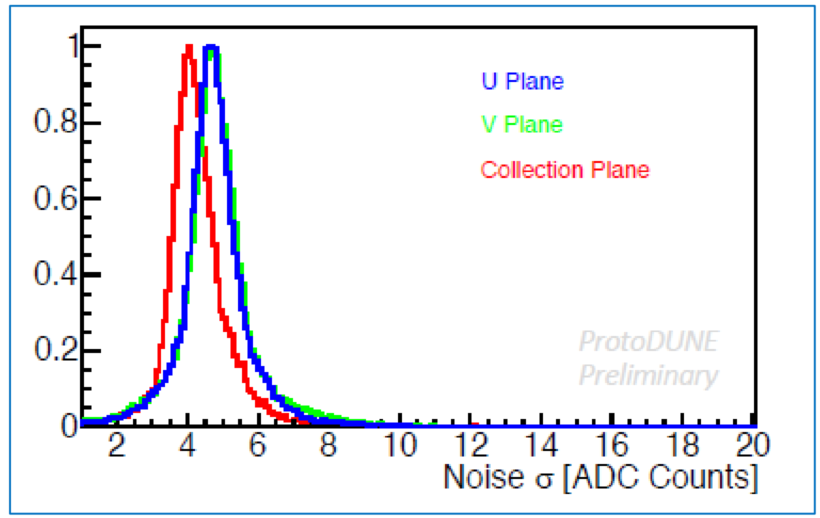


99.7% of the 15,360 channels are alive and responsive

APA Cold Electronics modules characterized with an extensive set of tests in different configurations:

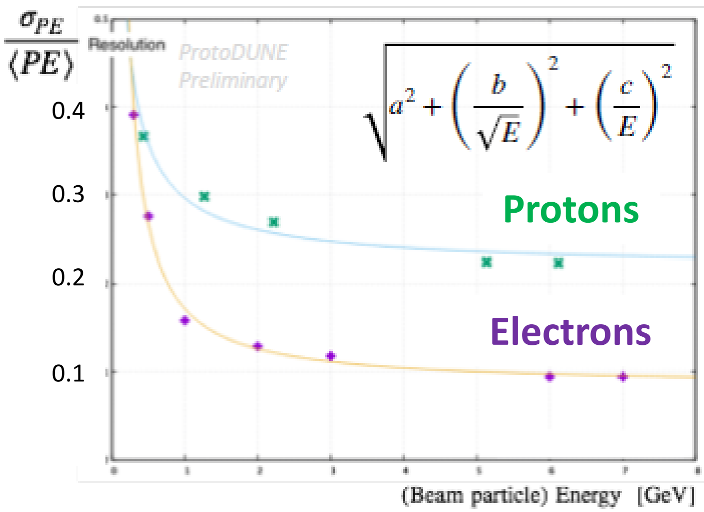
- subdetectors ON/OFF,
- HV ON/OFF,
- grounding,
- concurrent building activities.



DAQ development ever ongoing, along three main axes:

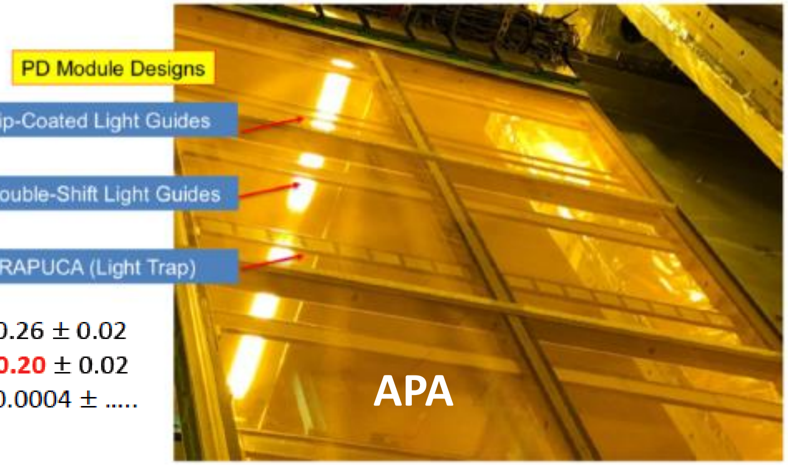
- intervention and improvements on both DAQ servers and ARTDAQ Software;
- detector operation:
  - continuous integration of subsystems in DCS;
  - high rate stable runs achieved (40 Hz).
- R&D towards DUNE.

ProtoDUNE SP – Photon Detectors



a = 0.26 ± 0.02
b = 0.20 ± 0.02
c = 0.0004 ± .....

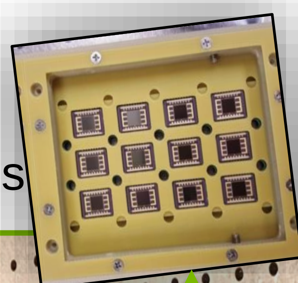
a = 0.12 ± 0.01
b = 0.11 ± 0.02
c = 0.082 ± 0.004

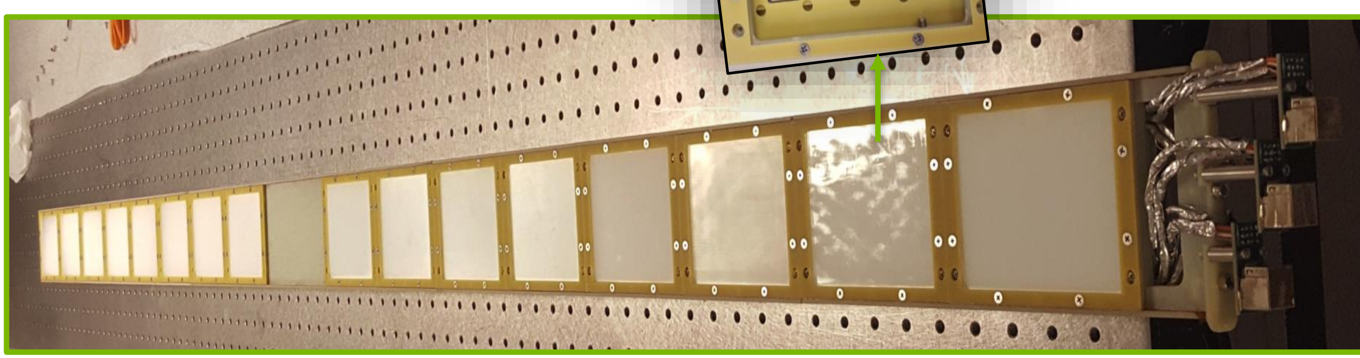


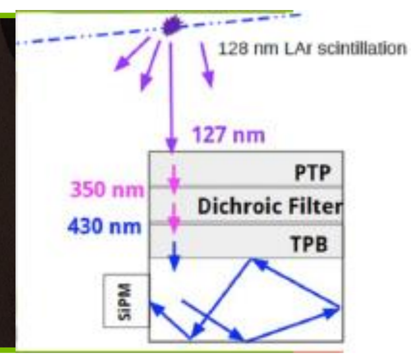
10/APA bars inserted in APA frame.
Three different techs.
Calibration/Stability/ Noise runs performed over 2019.
Calibration done with diffusers on CPA:

- ARAPUCA shows higher efficiency.
- LY $\simeq$ 0.1 phe/MeV (single ARAPUCA bar @~3m distance)
- Improved version of ARAPUCA is now the baseline for DUNE FD

Cryo-SiPMs



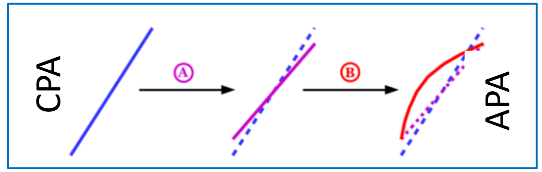


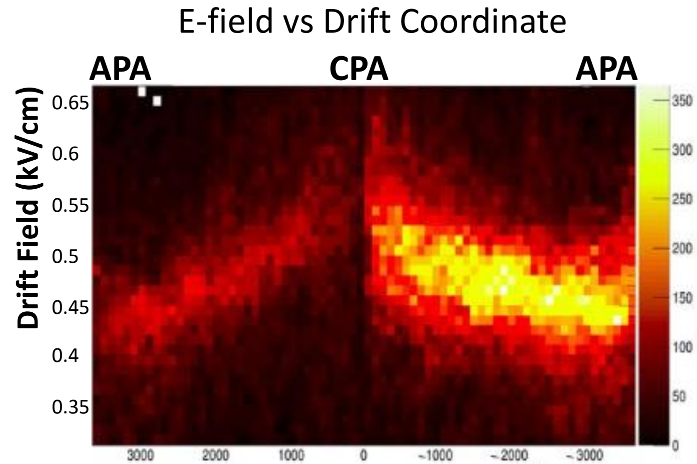


ProtoDUNE SP – calibration

Mis-calibration sources:

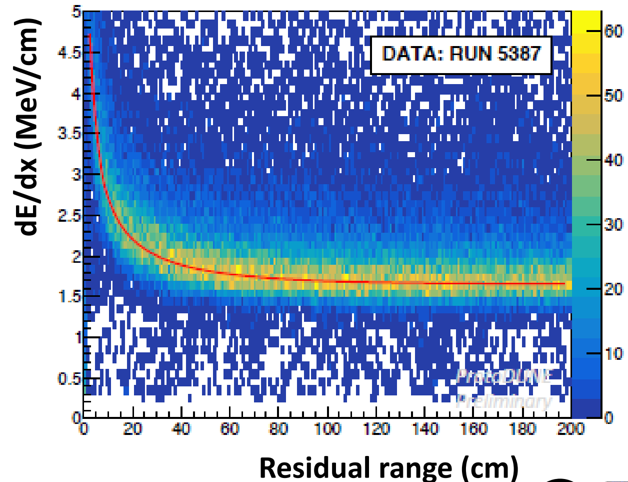
- Electron lifetime
- Space Charge Effect (SCE), due to high density of charge produced by cosmic rays.
- Hardware/geometrical sources (e.g. disconnected wires, TPC edges).

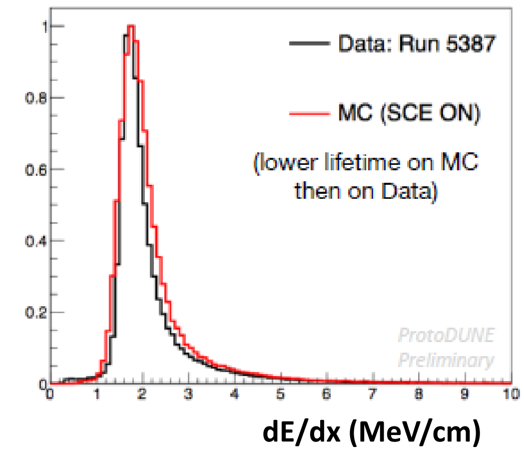




Energy scale tuning with stopping muons sample.

- Apply detector uniformity and average recombination corrections.
- Tune calorimetry constant such that calibrated dE/dx matches expectation:

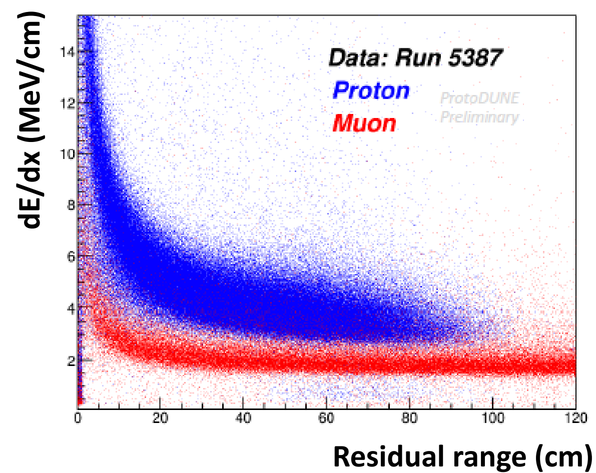




Calibration samples:

- Pulser data for electronics calibration
- t0-tagged cosmic ray muons dQ/dx
- ^{39}Ar

dE/dx of beam p/π/e^+ extracted after correcting for recombination, lifetime, SCE, energy tuning. Residual differences from expectations are ascribed to residual non-corrected SCE (mapping still underway).

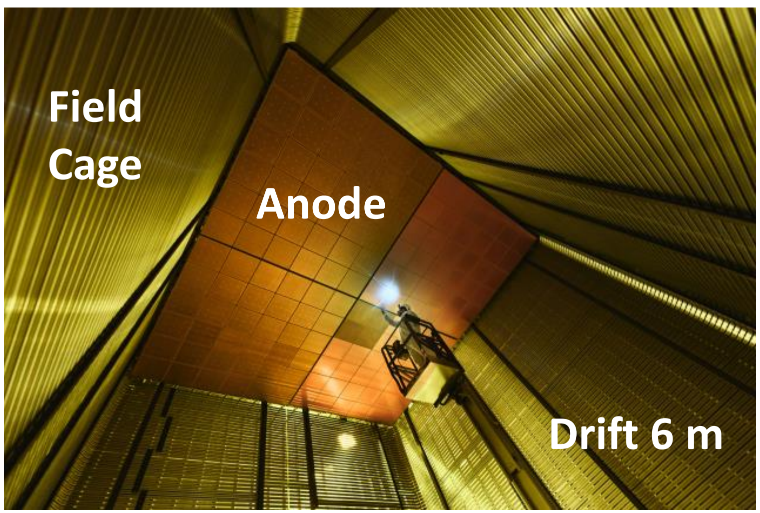


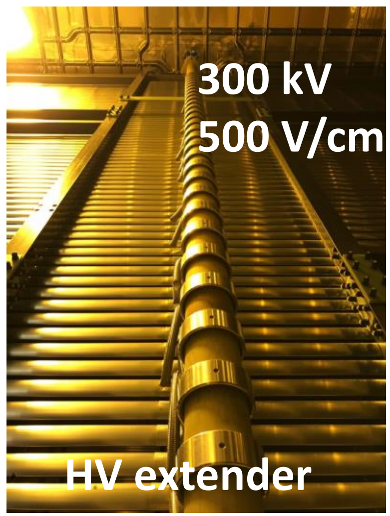
ProtoDUNE Dual Phase

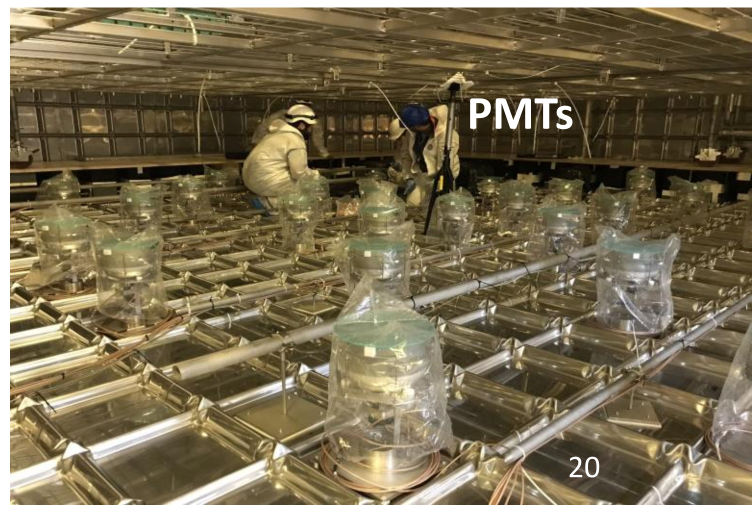
- Demonstrator constructed and operated in 2017.
- ProtoDUNE DP Installation being completed in these days. ***Commissioning (purge, cooldown) starts in 2 weeks. HV on by mid August 2019.***
- Final readout planes assembled and cold tested by end of 2018. Field Cage/Cathode/PMTs installed in 2018.
- Monitoring systems recently installed (Cameras, Purity Monitors, Temperature sensors).

✓ More critical technology (LEM amplifiers stability, very ***HV=600 kV***) which needs more R&D in the future to be ready for a final DUNE detector.

✓ Environmental conditions (liquid purity, space charge effects, positive ions back drift into the liquid ,….) are the critical points to first experimentally address and understand.





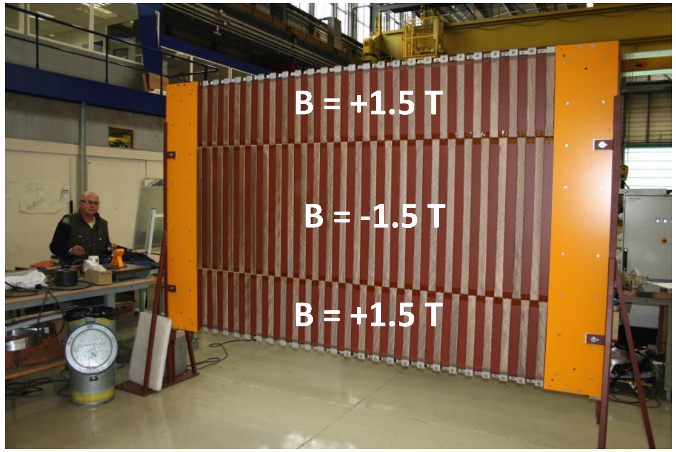


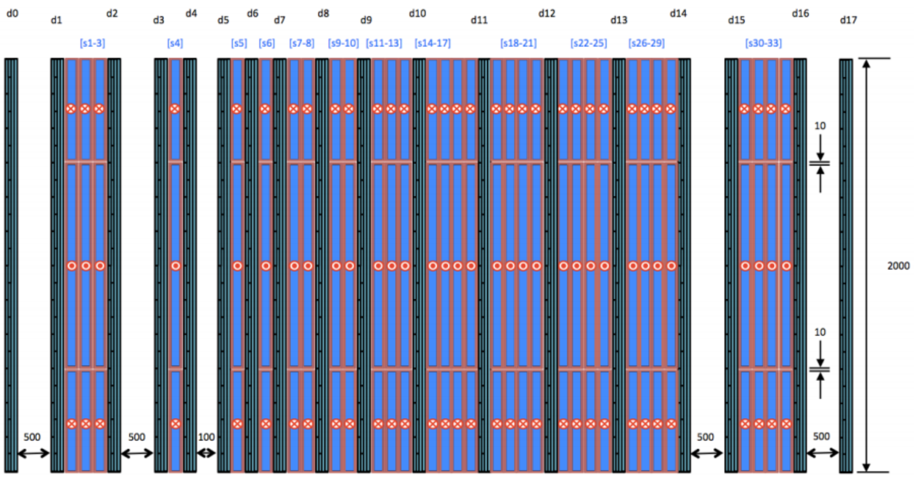
Towards Japan - BabyMIND

Sandwich of 33 magnets and 18 scintillator modules:

- Well defined B-field in the central zone, thanks to two-slit magnet design.
- Precise identification of muon momentum and charge.
- **Construction @ CERN and test beam on the PS line in summer 2017. Shipped soon after to Japan.**
- Commissioning run in 2018 at J-PARC. Physics run in 2019
- First muon tracks in 2018!

Magnetised muon spectrometer for the WAGASCI experiment (T2K beam line)





Gaps: increased lever arm for better angular resolution

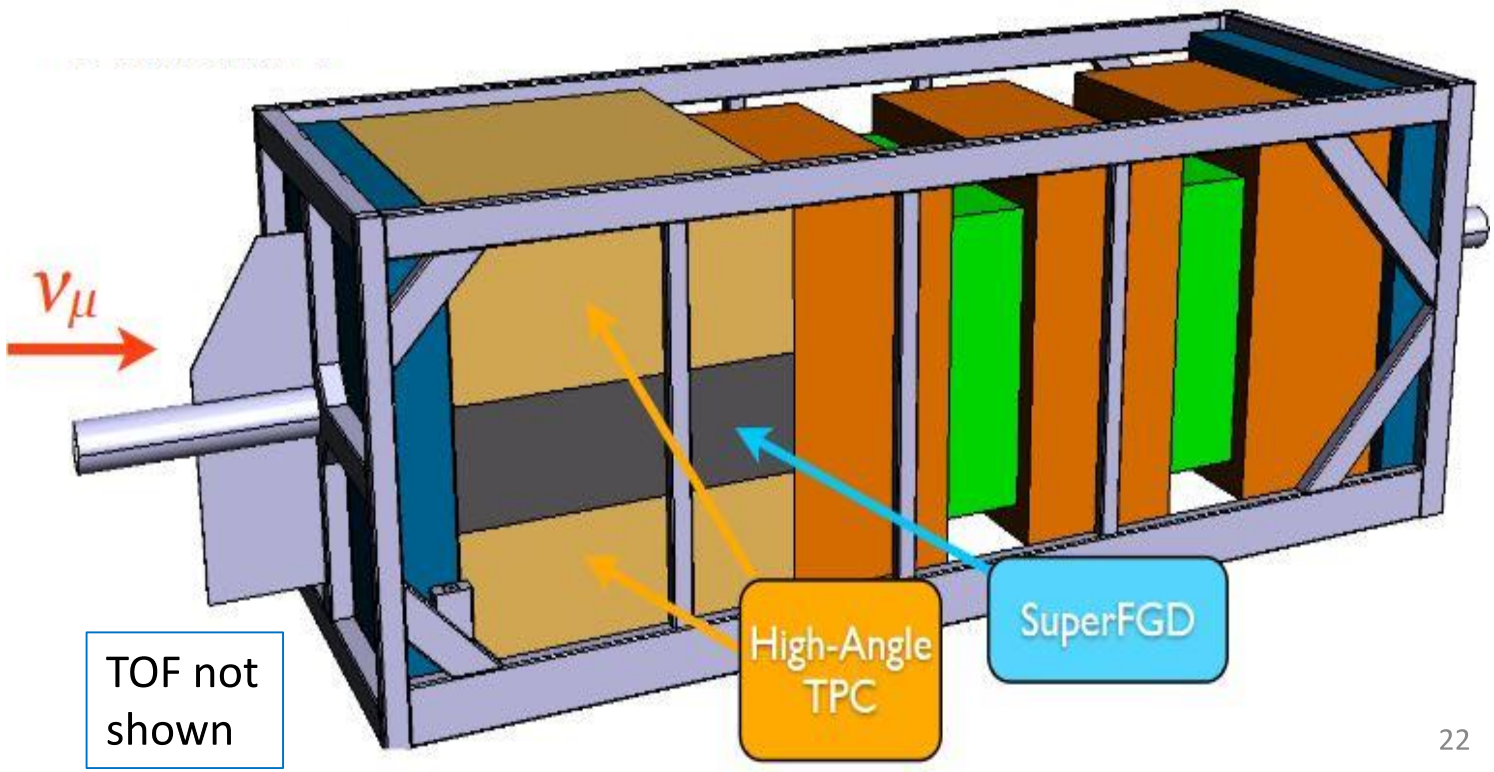
Participating in the ND280 upgrade

ND280: T2K off-axis Near Detector

Present detector has good efficiency mainly for forward tracks:

- Keep the electromagnetic calorimeter
- **Horizontal active target (Fine-Grain) detector: SuperFGD**
- Two High-Angle TPCs
- Time-of-Flight detector around new tracker
- B-field of 0.2 T

	Current	Upgrade
Target Mass (tons)	~2	~4



TOF not shown

Talk by: Yury Kudenko (this morning)

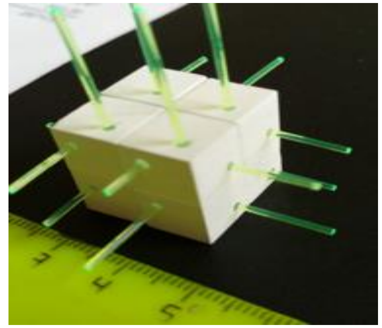
ND280 upgrade

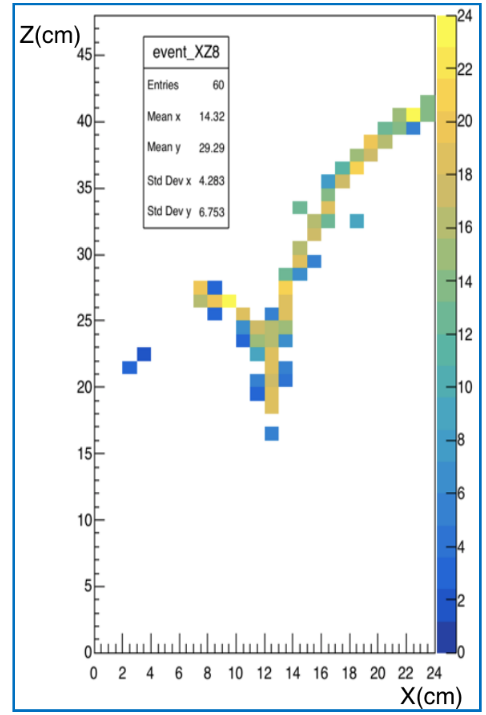
CENF Activities

Main involvement in SuperFGD:

- Design of the detector mechanics
- Scintillation light readout
- LED calibration system

2018 JINST 13 P02006

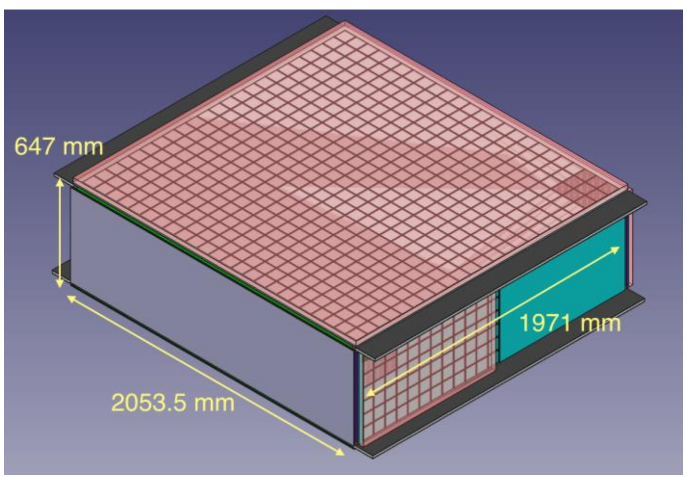


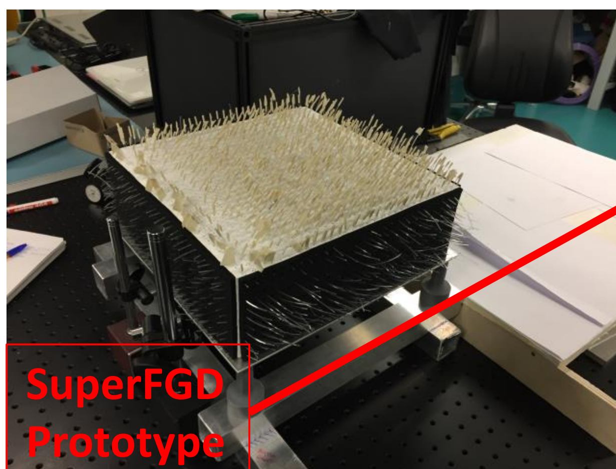


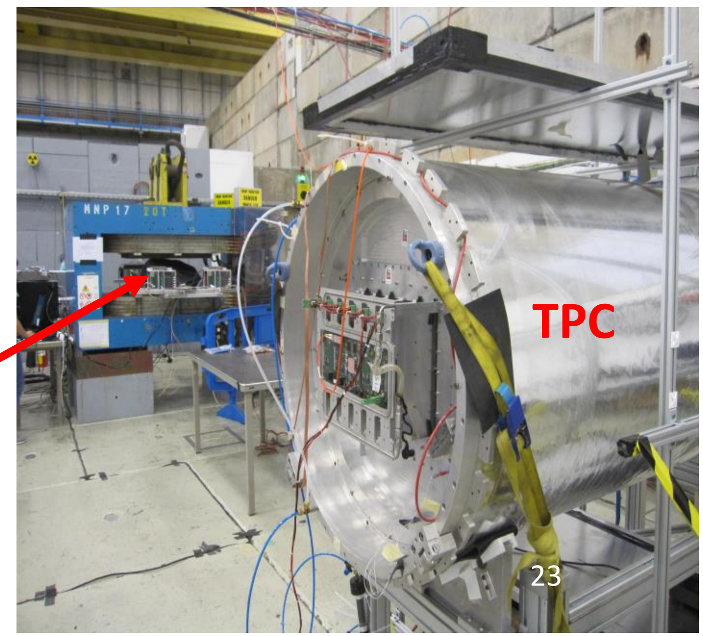
TPC component production at CERN (Resistive MicroMegas)

Test Beams at PS-T9 area in Summer 2018:

- prototype SuperFGD (10k cubes constructed at CERN) in B-field from 0.2T to 0.7T -> characterization
- Atmospheric gas TPC with RMM (improved resolution)

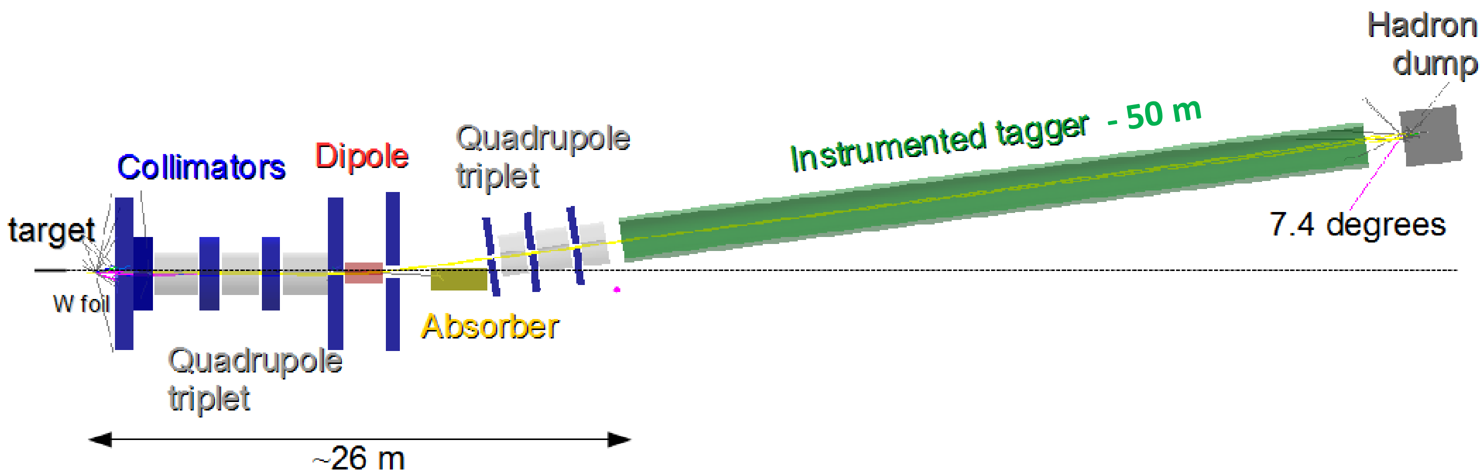






Attracting new partners - ENUBET

Talk by: Andrea Longhin (Tuesday)
Poster by: Laura Pasqualini



ERC winning project.
Beamline with enhanced precision monitoring on ν-beam fluxes, by performing detection of leptons produced at large angle from beam hadrons decay.

Started in 2016, multiple test beam campaigns at CERN.
Now a partner of the Neutrino Platform (NP06)

- CERN will provide support/guidance from accelerator experts.
- Goal to build and validate a demonstrator to be tested after LS2.

Ideal deployment:
~500 ton neutrino detector @ 100 m from the target

ICARUS @ FNAL or pDUNE-SP/DP @ CERN

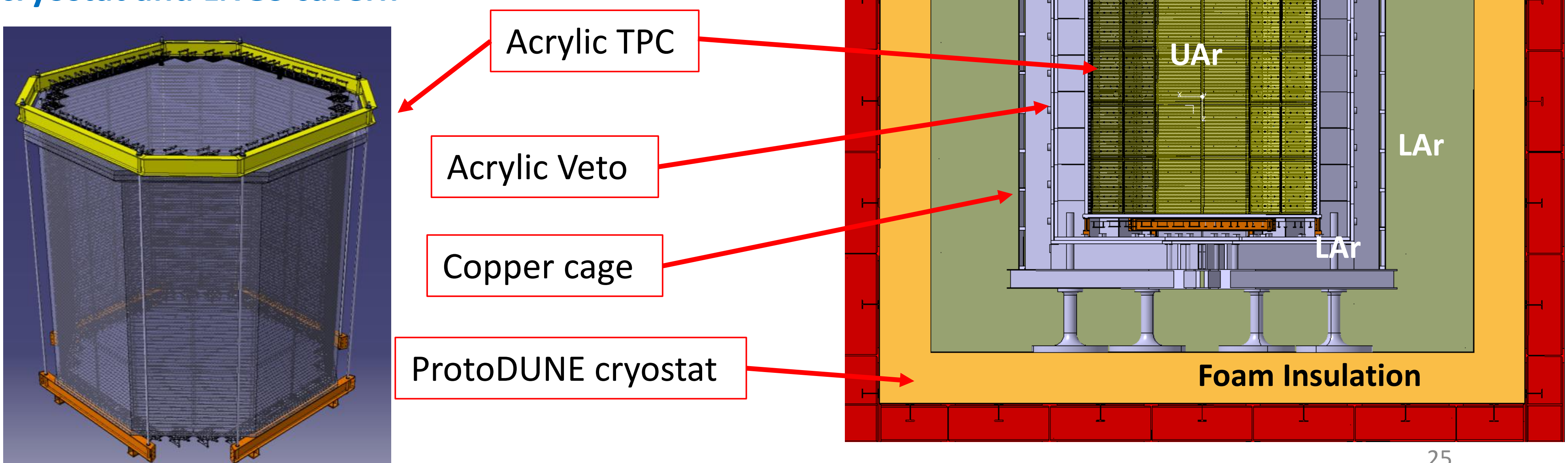
Going Dark – DarkSide 20k

New challenge: exporting the tech to Dark Matter. **Common ground: LAr-TPC tech**

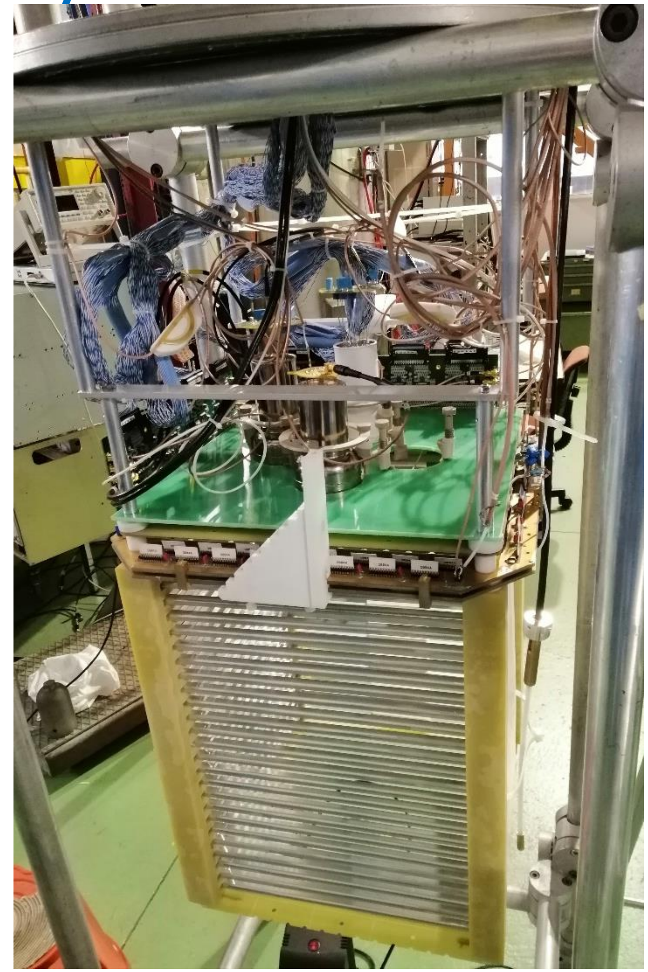
- Next step in DM searches with dual-phase LAr-TPC (50 tons active mass).
- Major advantage: use of Underground Argon (UAr), depleted in β-decaying ^{39}Ar isotope: eliminate largest Ar-bkg source. Successfully demonstrated in DarkSide 50 experiment.
- Active Veto exploits standard Argon, inside cryostat *à la ProtoDUNE*.
- Acrylic vessels read by Photon Detector units (SiPM-based)

DS50 talk by Luca Pagani (Friday)

- **New R&D on cryostat, to export the technology to a much more demanding environment, in terms of radio-purity and cleanliness .**
- **Strong design integration effort, involving detector, cryostat and LNGS cavern**



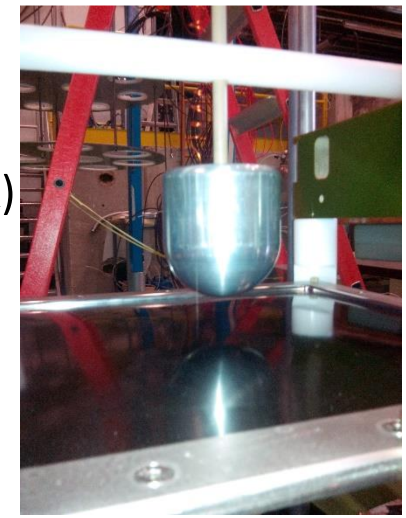
Leaning towards discovery – R&D

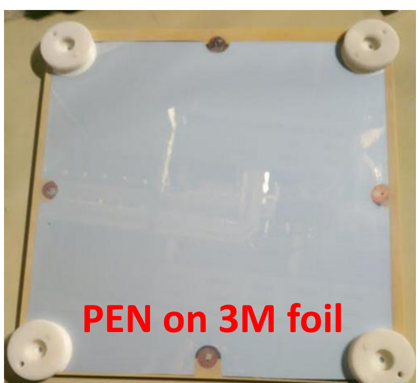


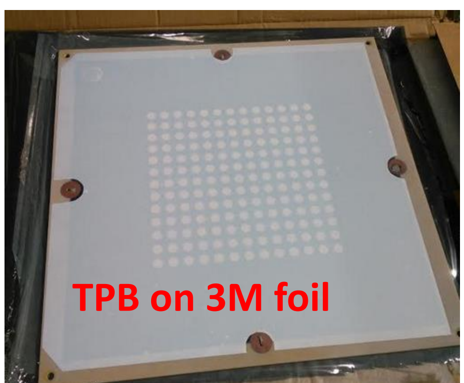
Continuous R&D with the 50 liters Icarus Chamber (FLIC)

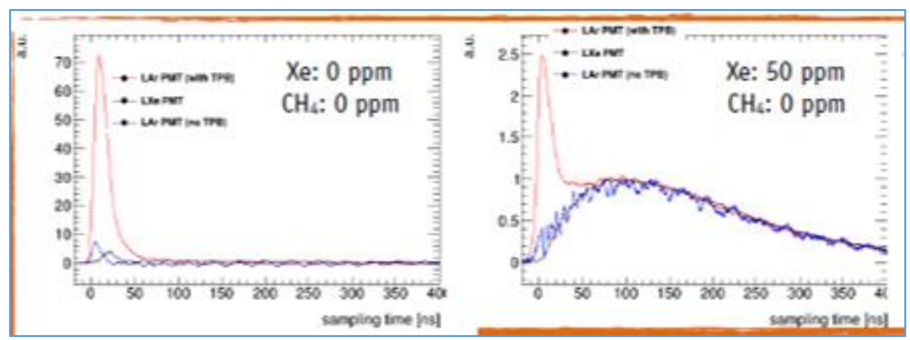
Small LAr-TPC with its own recirculation system, used to test new technologies and materials. **Almost 30 year old set-up.**

- ✓ Cold / hybrid electronics solutions for LAr-TPCs (ICARUS)
- ✓ Tests of Very High Voltage (VHV) power supplies/cables/feedthroughs for DUNE program (300 kV)
- ✓ Selection and tests of new materials for ProtoDUNE/DUNE design.
  - Aluminum/G10 field cage
  - Resistive cathodes (kapton)
- ✓ New wls materials: PEN vs TPB (DUNE, DS20k)
- ✓ Effects of dielectric reflector+wls on pDUNE SP cathode, concerning space charge
- ✓ Xe doping in Liquid Argon (DUNE, DS20k)







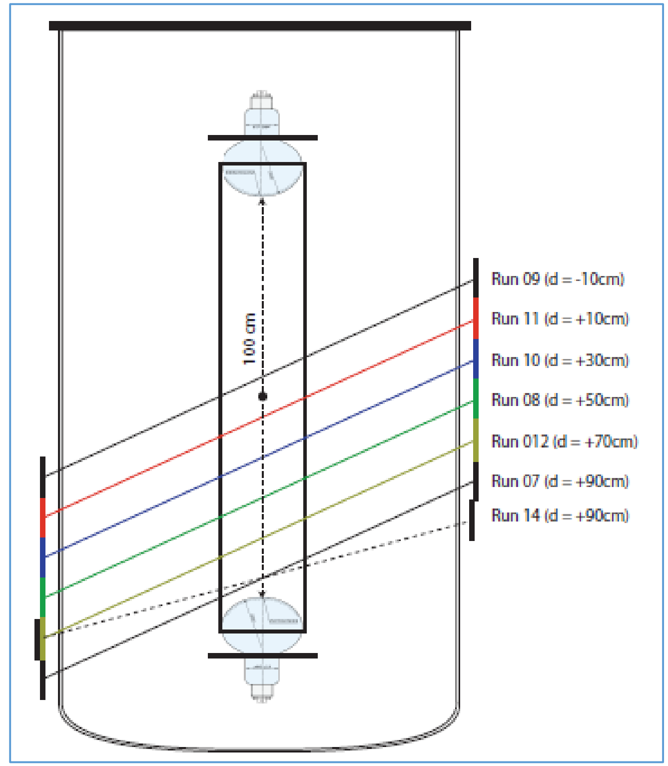


Leaning towards discovery – R&D

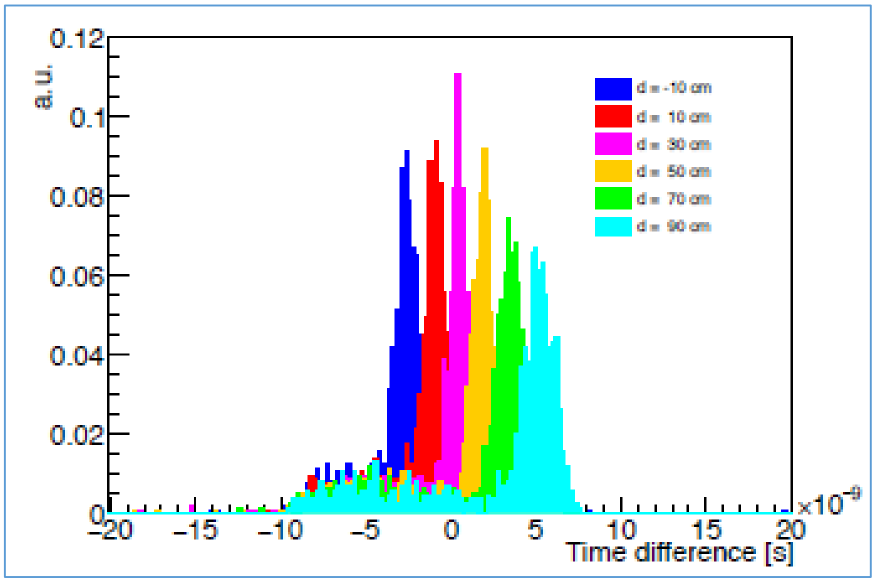
First measurement of group velocity of 128 nm photons in LAr

- Setup made of 2 PMTs facing each other in LAr bath.
- Trigger with cosmic rays, detected by external scintillators: different heights and track slopes.
- Relative measurement (Δs vs Δt)

- $1/v_g$ = 7.50 ± 0.07 (stat) ns/m.
- Combination with existing measurements @ higher λ allows deriving:
  - n = 1.369 ± 0.004
  - l_{Ray} = 91.0 ± 2.8 cm



https://doi.org/10.1016/j.nima.2018.10.082



In conclusion…

CENF Main goal : compact the European groups around the future Short and Long Baseline Neutrino programs taking place in US & Japan

After 6 years: **huge success**

- Continuous, strong R&D program
- ICARUS/BabyMIND/ProtoDUNE SP successfully concluded important milestones
- ICARUS/ProtoDUNE DP commissioning starting now.
- New projects ever going on / upcoming
- **Longer term ProtoDUNE SP program**
  - † Cryostat emptying and opening in 2020
  - † Detector dismantling/new upgraded installation in 2020-2021
  - † New filling within 2021: ready for beam after CERN LS2
    - ✓ Goal: complete beam events data set, with negative polarity particles
    - ✓ Goal: test module-0 of DUNE Single-Phase Far detector.

- There is much more I didn't have time to discuss: DAQ/slow control system development; computing and big data stream/management (FELIX); beam simulation and implementation, …

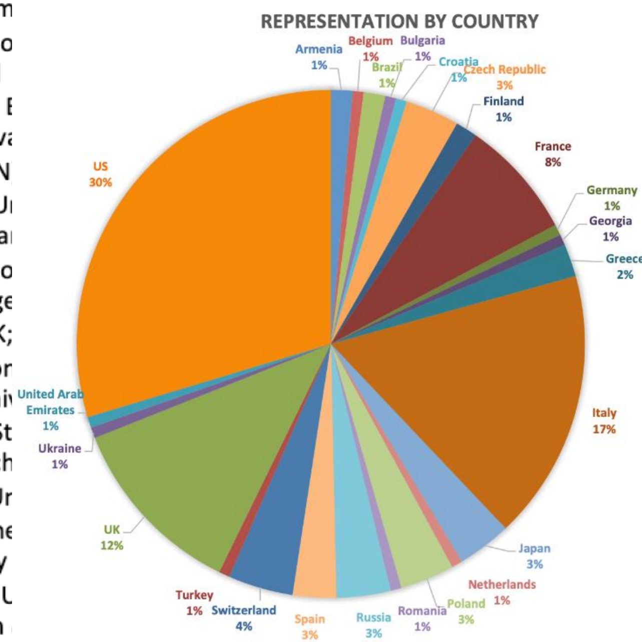
Thank you

Back Up

The Platform today, 146 institutions

Alikhanian National Science Laboratory (YerPhi), Armenia; Institute of Theoritical Physics and Modeling, Armenia, Armenia; Theoretical Nuclear Physics Research Group, Department of Physics and Astronomy, Ghent University, Belgium; Campinas University, Brazil, Brazil; Federal University of ABC, Brazil, Brazil; University of Sofia, Department of Physics, Bulgaria, Bulgaria; Ruder Boskovic Institute, Zagreb, Croatia, Croatia; Acad. of Sciences of the Czech Rep., Czech Republic; Charles University, Faculty of Mathematics and Physics, Czech Republic; Czech Technical University, Czech Republic; Institute of Experimnetal and Applied Physics, Czech Technical University in Prague, Czech Republic; Institute of Physics, Acad. of Sciences of the Czech Rep., Czech Republi... niversity of Jyvaskyla - Department of Physics, Finland, Finland;
University of Oulu, Finland, Finland; CEA/IRFU,Centre d'etude de Saclay Gif-sur-Yvette - IRF... ntre d'Etudes Nucléaires de Bordeaux-Gradignan, France; Centre
National de la Recherche Scientifique - LAPP-Laboratoire d'Annecy-le-Vieux de P... ance; IN2P3 - LAL, France; Laboratoire de physique nucléaire et
de hautes énergies Paris (LPNHE), France; OMEGA Ecole Polytechni... laude Bernard-Lyon I - Institut de Physique Nucleaire de Lyon,
France; Universite de Paris VII - Laboratoire APC - Astron... derot, France; Université Pierre et Marie Curie (UPMC) et Paris
Diderot, France; Université Savoie Mont Bla... ersity, Georgia; Justus-Liebig-Universität Gießen, Germany;
National Technical University of At... sica e Astronomia, Universita di Roma, Italy; Dipartimento di
Fisica E. Pancini, Univers... nento di Fisica, Universita di Bologna, Italy; Dipartimento di
Matematica e... Roma Tre, Italy; INAF - Osservatorio Astrofisico di Torino,
Italy; INFN e La... Italy; INFN, Sezione di Lecce, Italy, Italy; INFN, Sezione di
Pavia, Italy, Ital... Italy; Universita & INFN, Milano-Bicocca, Italy; Università
degli Studi e IN... y; Universita e INFN, Catania - Sezione di Catania, Italy;
Universita e INFN... N, Sezione di Padova, Italy; University of Genova, INFN,
Italy; High Energy... kyo, Japan; AGH University of Science and Technology, Krakow,
Poland, Poland; In... eoretical Physics, Wroclaw, Poland; National Centre for Nuclear Research,
Otwock, Poland, Po... niversity of Bucharest, Rom...
Russia, Russia; Lebe... e, Moscow, Russia, Russia; Lomonoso...
Sciences - Institute... Academy of Sciences - Institute of Chemical
Medioambientales y T... a, Spain; Institut de Fisica d'Altes Energies (IFAE), Bellaterra, E...
Fisica Corpuscular (IFI... ty of Seville, Spain; Boston University Study Abroad Program Geneva...
Zuerich - ETH Zurich ... te for Particle Physics, Switzerland; European Organiz. for Nuclear Res. (CERN...
Hochenergiephysik, Switzerland; Universite de Geneve - Dept. de Phys. Nucl. et Corpuscul., Switzerland; U...
University (METU), Ankara,Turkey, Turkey; Imperial College London, UK; Lancaster University, UK; Queen Ma...
Rutherford Appleton Lab. - Rutherford Appleton Laboratory, UK; University of Birmingham, UK; University o...
Edinburgh, UK; University of Glasgow, UK; University of Liverpool, UK; University of London - University College...
Oxford - Particle Physics, UK; University of Sheffield, UK; University of Sussex, UK; University of Warwick, UK;
New York University Abu Dhabi, United Arab Emirates; Argonne National Laboratory, US; Brookhaven Nation...
University, US; Drexel University, US; Duke University, US; Fermi National Accelerator Lab., US; Harvard Univ...
University, US; Lawrence Berkeley National Lab., Berkeley, US; Los Alamos National Laboratory, US; Louisiana St...
State University, US; Princeton University, US; SLAC National Accelerator Laboratory, US; South Dakota Sch...
Methodist University, Dallas, US; State University of New York (Stonybrook), US; University of Boston, US; Ur...
University of California Los Angeles, US; University of California, Berkeley, US; University of California, Irvine...
Honolulu, US; University of Houston, US; University of Iowa, US; University of Minnesota, US; University...
Philadelphia, US; University of Pittsburgh, US; University of Rochester - Department of Physics and Astronomy, U...
Arlington, US; University of Texas at Austin, US; University of Wisconsin, Madison, US; Virginia Tech, US; William...

- ✓ Very intense R&D in various domains on new technologies
- ✓ Active partnership of CERN on external experiments/facilities in the US, Japan
- ✓ Effort to bring to new communities the organization model of the LHC project and collaborations!

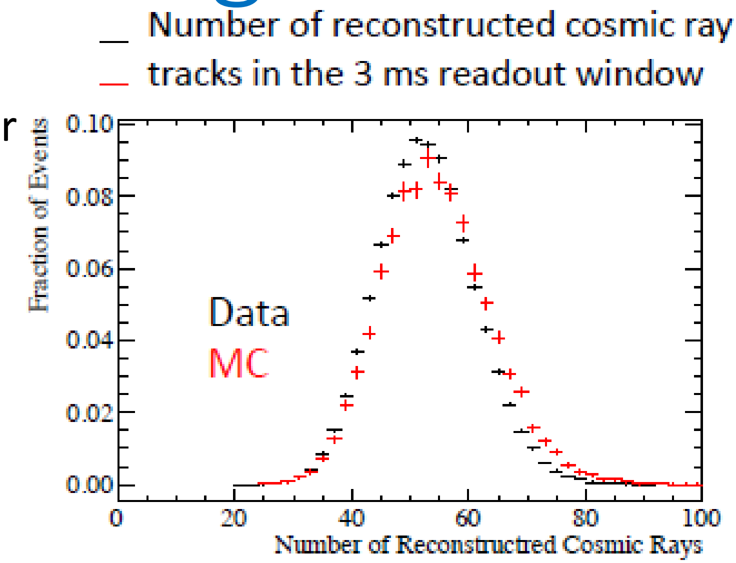


ProtoDUNE SP – signal processing

Automated pattern recognition and reconstruction software: Pandora package progress to improve reconstruction specifically for ProtoDUNE.

Adaptive Boost Decision Tree based Beam Particle ID. Efficiencies:

- 72.3% for beam
- 94.5% for cosmic muons



The precision hadron cross section measurements will help DUNE physics in many ways:

- Providing input to the neutrino generators to improve the final state interaction models. E.g.: the charge exchange process π^++Ar->Ar*+p+π^0 is an important background to the ν_e signals
- Validating the GEANT simulation of hadron interactions in LAr.