The Neutrino Platform and the neutrino programme at CERN

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J. Heyrovsky Institute of Physical Chemistry
Europe/Prague timezone

The CERN Neutrino Platform

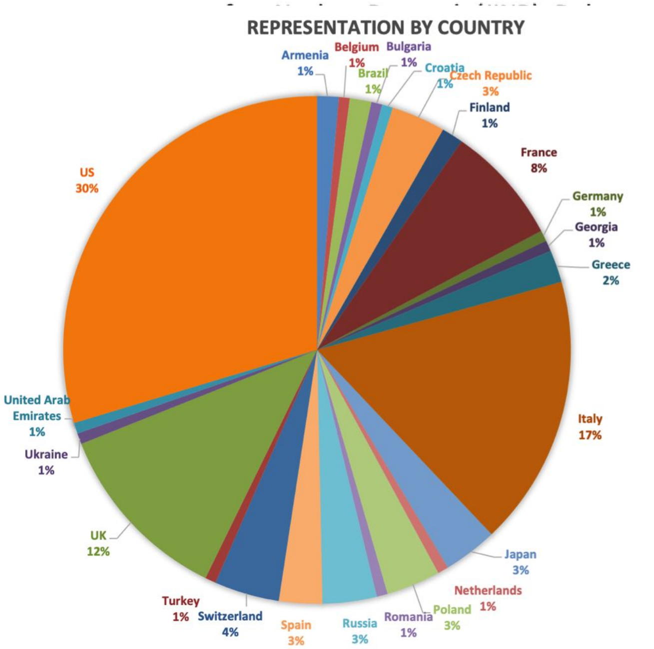
- We are following the mandate give by the EU strategy in 2013: “pave the way ….”
- Main goal : compact the European groups around the projects of the future short and long Neutrino baselines
- CERN as a facility for R&D on future technologies (HW and SW) and partner in several neutrino research programs

- A new phase of the Neutrino Platform has been recently approved
- including most notably a second campaign of test beam for ProtoDUNE detectors in2021.

CERN ν 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 Republic; University of Jyvaskyla - Department of Physics, Finland, Finland;
University of Oulu, Finland, Finland; CEA/IRFU,Centre d'etude de Saclay Gif-sur-Yvette - IRFU, France; Centre d'Etudes Nucléaires de Bordeaux-Gradignan, France; Centre
National de la Recherche Scientifique - LAPP-Laboratoire d'Annecy-le-Vieux de Physique des Particules, France; IN2P3 - LAL, France; Laboratoire de physique nucléaire et
de hautes énergies Paris (LPNHE), France; OMEGA Ecole Polytechnique IN2P3 / CNRS, France; Universite Clau ... yon I - Institut de Physique Nucleaire de Lyon,
France; Universite de Paris VII - Laboratoire APC - Astroparticules et Cosmologie, France; Université ... niversité Pierre et Marie Curie (UPMC) et Paris
Diderot, France; Université Savoie Mont Blanc, France; High Energy Physics Institute ... Justus-Liebig-Universität Gießen, Germany;
National Technical University of Athens, NTUA, Greece; The University of Ath ... ia, Universita di Roma, Italy; Dipartimento di
Fisica E. Pancini, Università di Napoli Federico II, Italy; Dipartiment ... Universita di Bologna, Italy; Dipartimento di
Matematica e Fisica, Universita del Salento, Lecce, Ital ... ; INAF - Osservatorio Astrofisico di Torino,
Italy; INFN e Laboratori Nazionali di Frascati ... zione di Lecce, Italy, Italy; INFN, Sezione di
Pavia, Italy, Italy; Laboratori Nazi ... & INFN, Milano-Bicocca, Italy; Università
degli Studi e INFN Milano - Sezi ... NFN, Catania - Sezione di Catania, Italy;
Universita e INFN, Napoli - Sezio ... adova, Italy; University of Genova, INFN,
Italy; High Energy Accelerator Res ... ty of Science and Technology, Krakow,
Poland, Poland; Institute of Nuclea ... National Centre for Nuclear Research,
Otwock, Poland, Poland; Warsaw U ...
Russia, Russia; Lebedev Physical Ins ...
Sciences - Institute for Nuclear R ... emical
Medioambientales y Tecnológicas (CIE ... (IFAE), Bellaterra, ...
Fisica Corpuscular (IFIC), Spain; Unive ... udy Abroad Program Geneva
Zuerich - ETH Zurich Institute for Par ... opean Organiz. for Nuclear Res. (CERN
Hochenergiephysik, Switzerland; Univer ... Dept. de Phys. Nucl. et Corpuscul., Switzerland; U
University (METU), Ankara,Turkey, Turke ... 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 Natior
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!



NP Projects – content of the talk

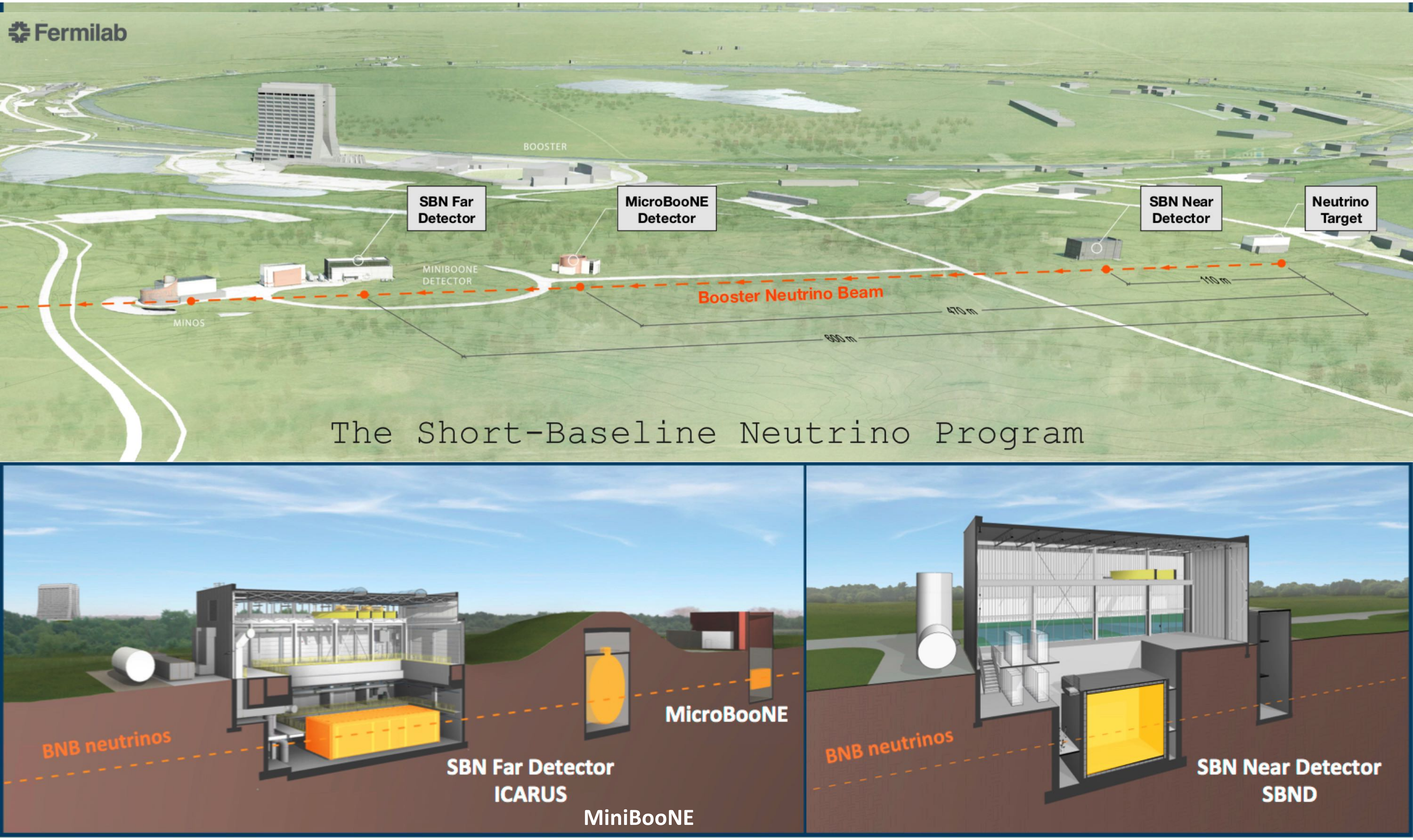
- *NP01: ICARUS refurbishing and far detector in the SBN FNAL facility (almost ready for operation)*
- *NP02: LAr double phase TPC demonstrator (ptotoDUNE)*
- *NP03: PLAFOND – generic detectors R&D*
- *NP04: LAr single phase TPC demonstrator (protoDUNE)*
- *NP05: BabyMind muon (near) detector for T2K (operational)*
- *NP06: ENUBET project*
- *NP07: ND280 T2K near detector upgrade*

Participation in the construction and exploitation in the SBN and LBNF/DUNE in US, and T2K(ND) in Japan programmes.

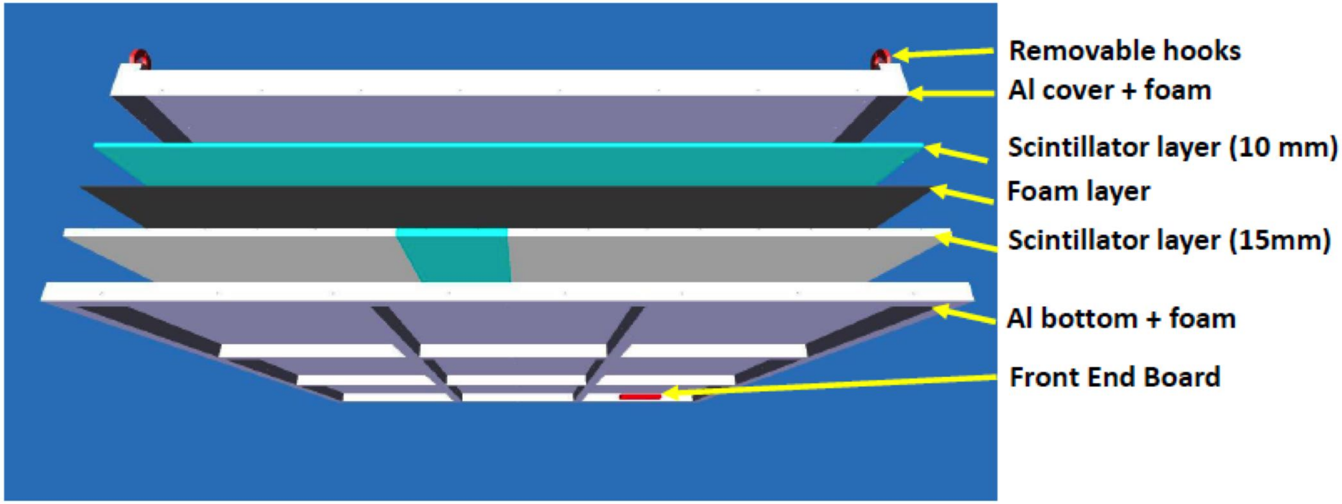
Few words also about the projects FASER and XSEN.

Acknowledgement/thanks: material in this talk (often preliminary) made available by members of the initiatives listed above.

NP01: SBN/ICARUS



ICARUS: 476 tons, 600 m MicroBooNE: 85 tons, 470 m SBND: 112 tons, 110 m

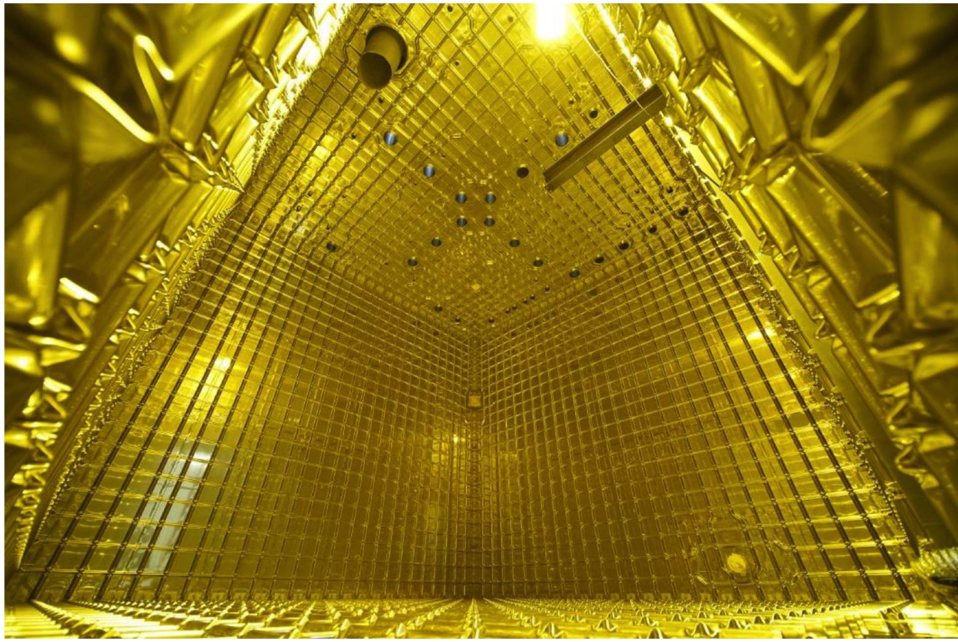


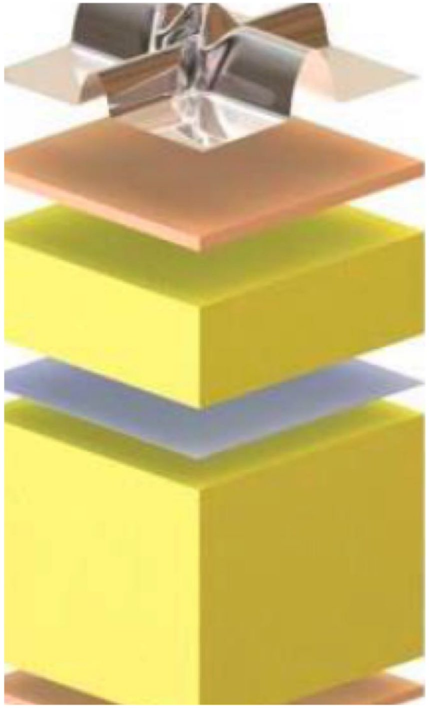
Cosmic Ray Tagger for position and time of charged tracks entering the TPC volume

ICARUS detector preparation nearly complete

Cool-down and filling planned for November 2019 – January 2020

NP02, NP04: Membrane cryostat technology





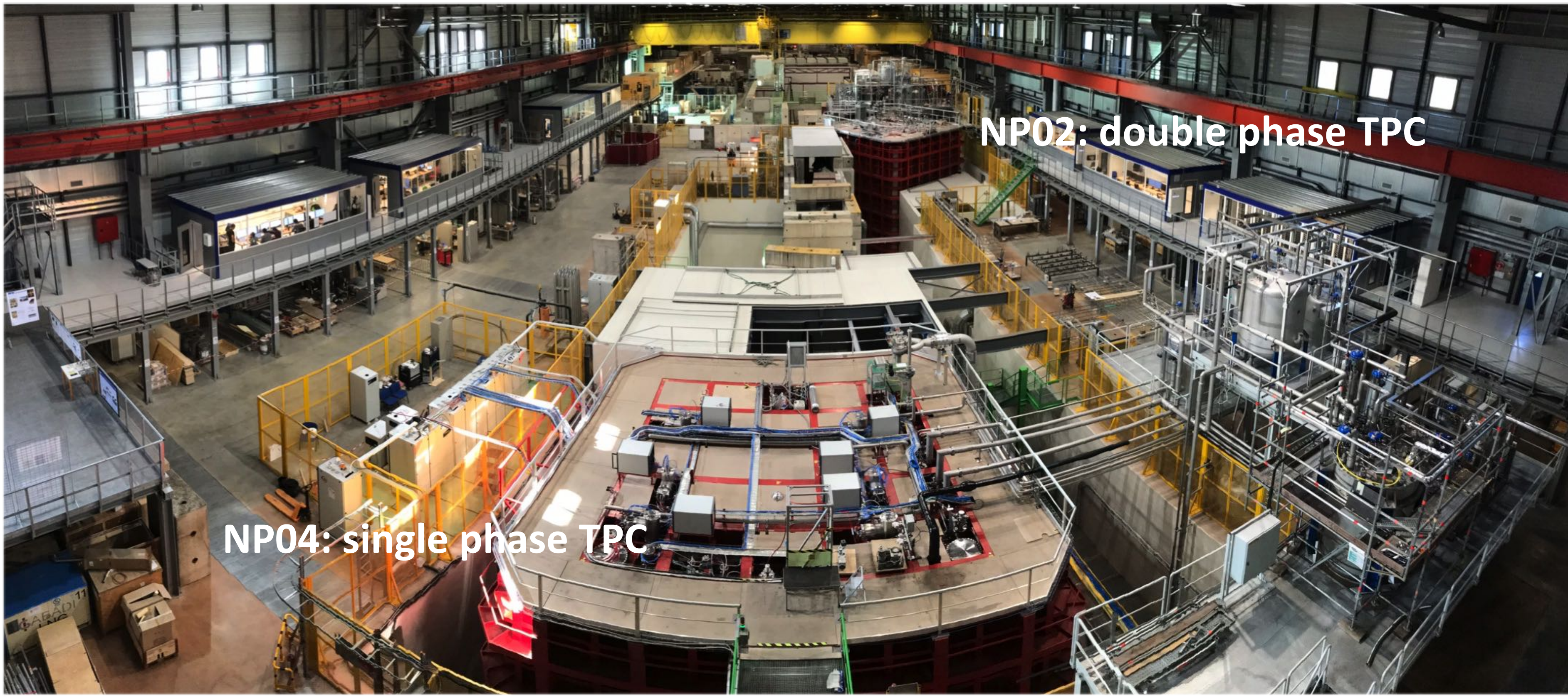
- Corrugated SS primary membrane in contact with LAr
- Plywood
- Insulation: reinforced polyurethane foam
- Secondary membrane for gas containment
- Insulation
- Plywood
- Outer vessel

No vacuum, insulation purged with Ar

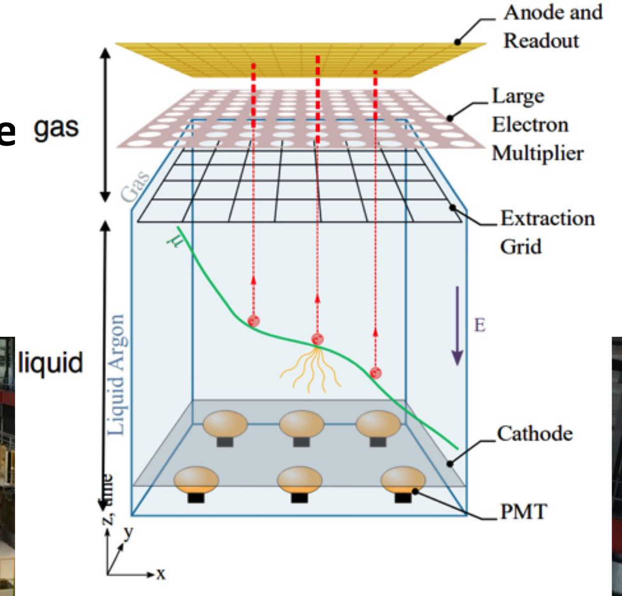
Concept developed for carrier ships. Developed for LAr in collaboration with industry (GTT)

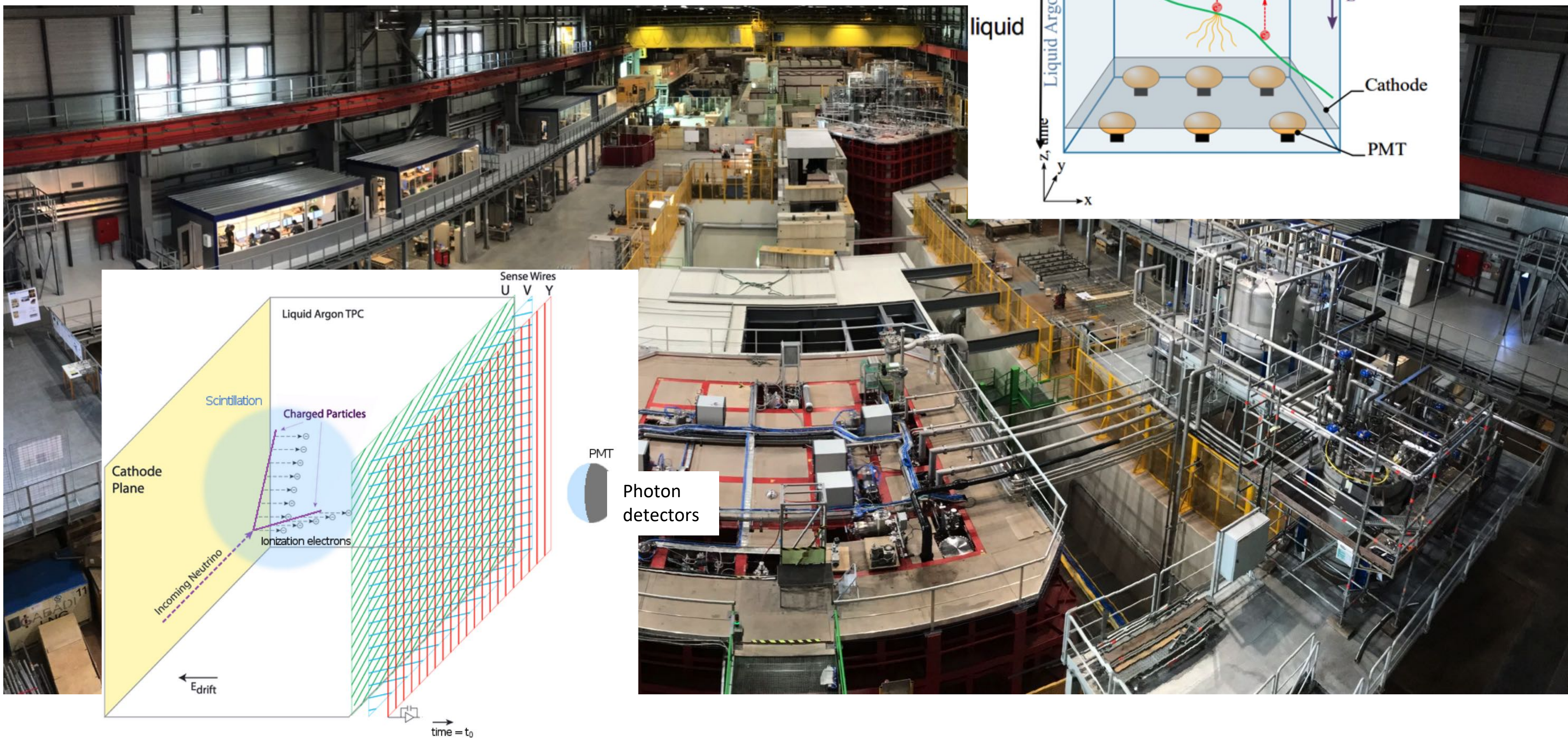
Used for ProDUNEs, SBND, DUNE, DarkSide …

EHN1 layout



NP02: double phase
760 tons of liquid





NP04: single phase
760 tons of liquid

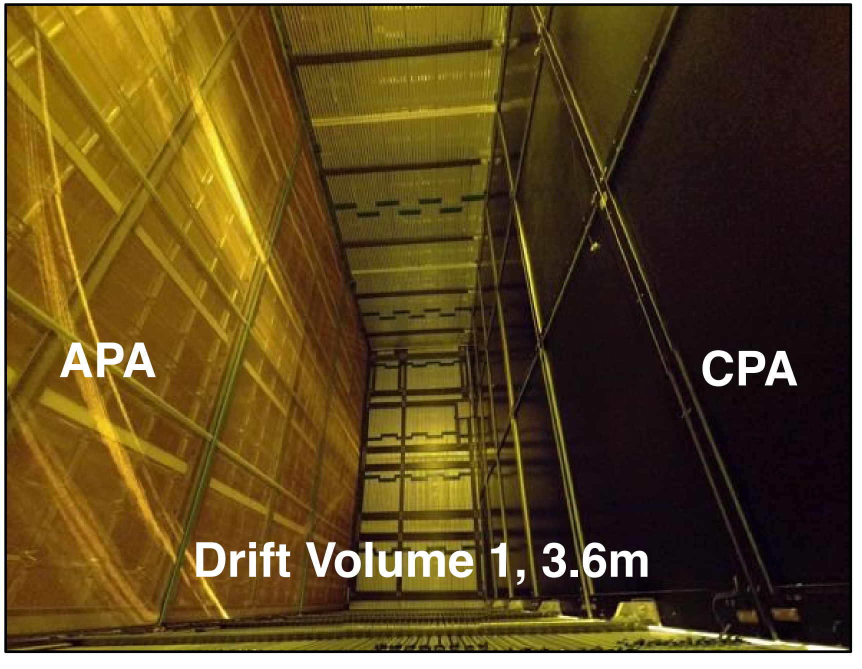
NP04: single phase LAr TPC

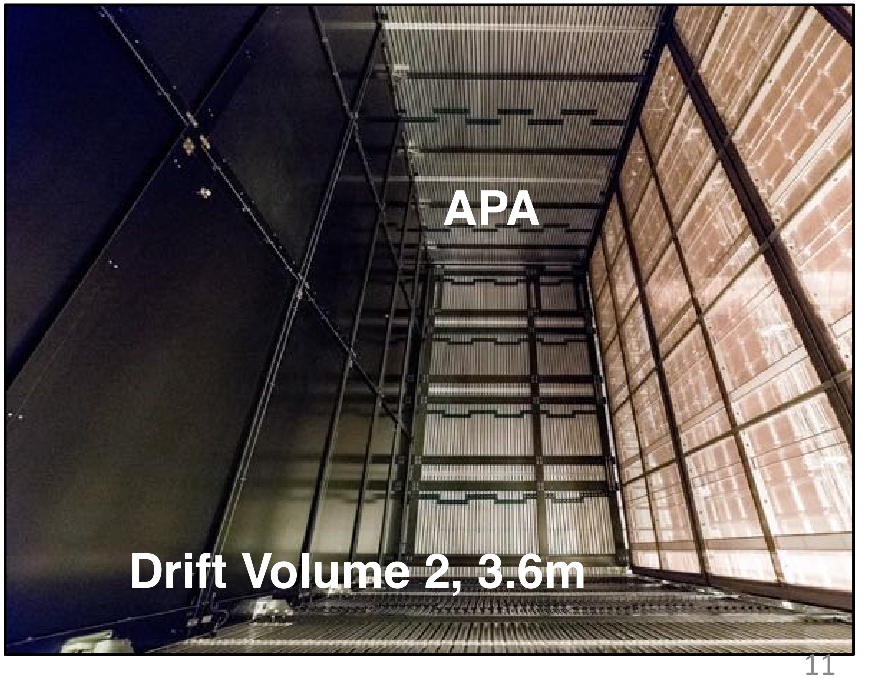
- *Assembled and cold tested by May 2018*
- *From May to August 2018 cooling and filling*
- *Ready for beam in Fall 2018*

6 x Anode **P**lane **A**ssembly

Cathode **P**lane **A**ssembly

Photon **D**etection





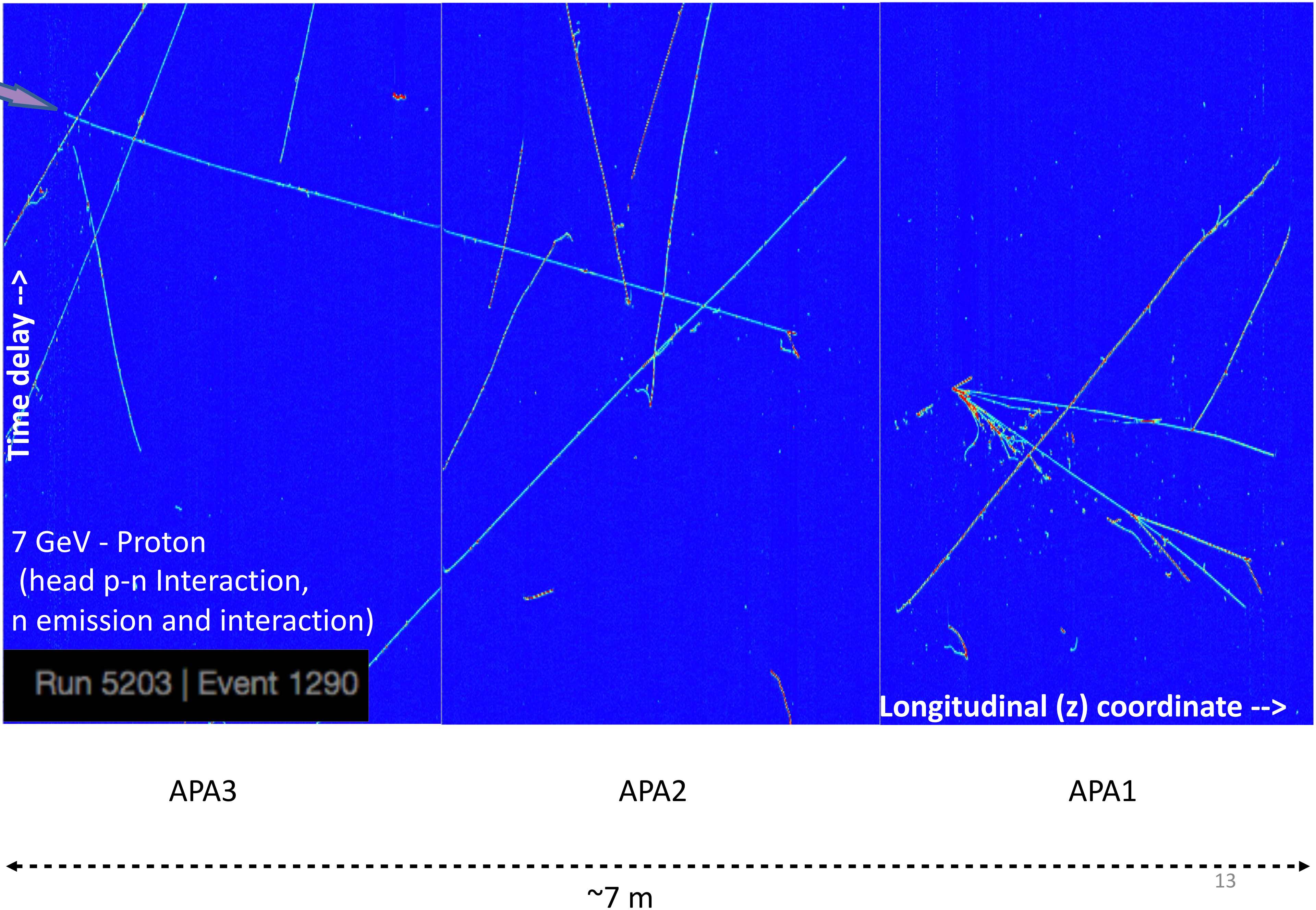
Data – Collected beam events

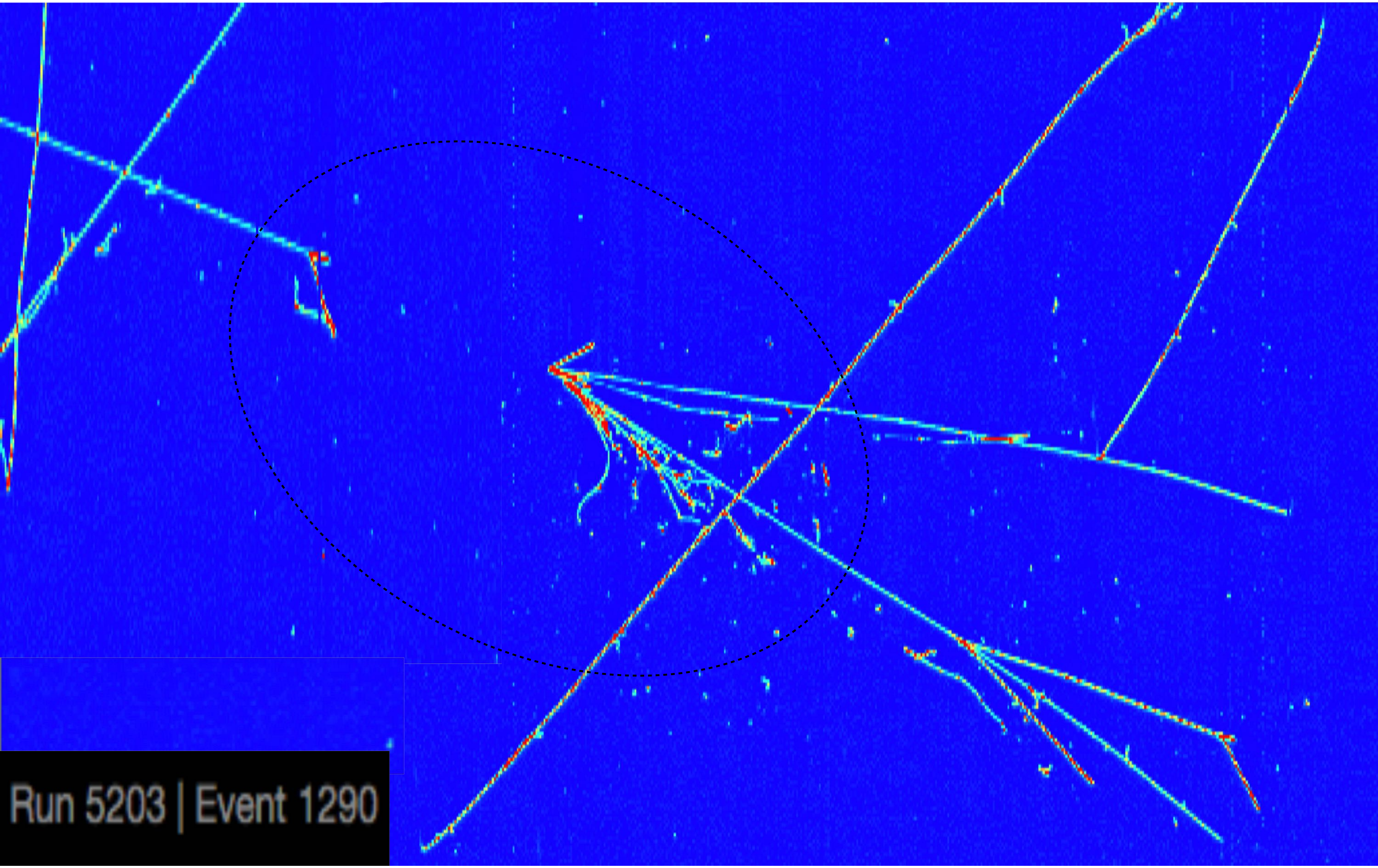
Momentum	Total Triggers	Expected Pi trig.	Expected Proton trig.	Expected Electr. trig.	Expected Kaon trig.
0.3 GeV/c	269K	0	0	242K	0
0.5 GeV/c	340K	1.5K	1.5K	296K	0
1 GeV/c	1089K	382K	420K	262K	0
2 GeV/c	728K	333K	128K	173K	5K
3 GeV/c	568K	284K	107K	113K	15K
6 GeV/c	702K	394K	70K	197K	28K
7 GeV/c	477K	299K	51K	98K	24K
All momenta	**4175K**	**1694K**	**779K**	**1384K**	**73K**

** Numbers based on beam simulation only*

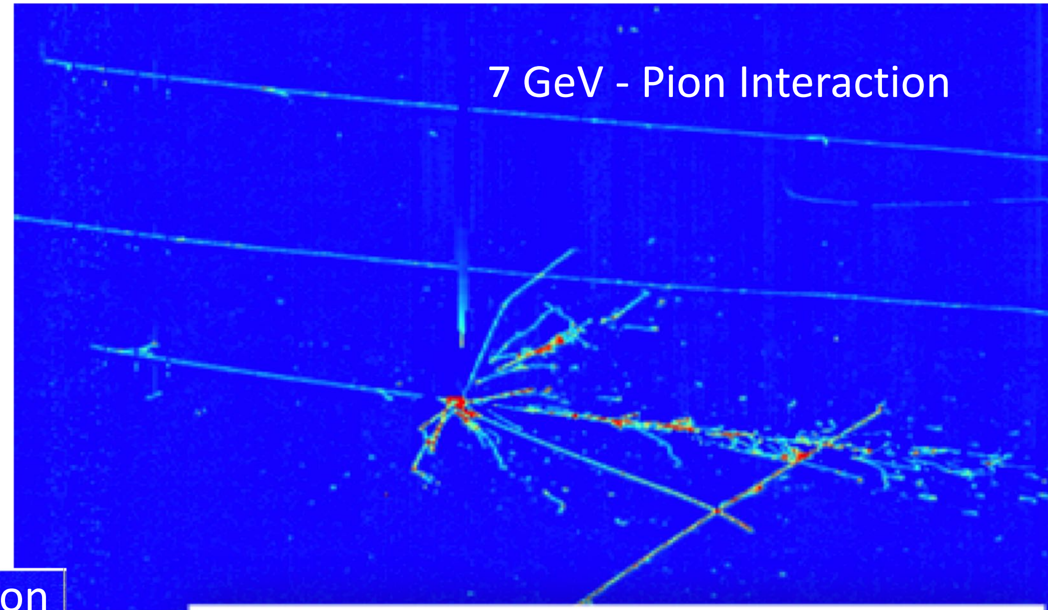
Over 4 million beam events!

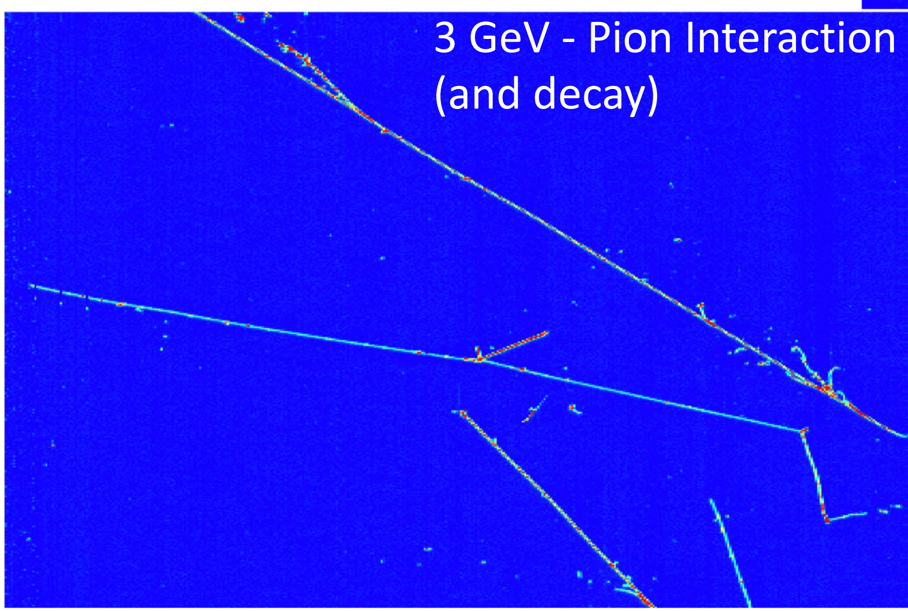
Over 20 million cosmics events!


Time delay -->
7 GeV - Proton
(head p-n Interaction,
n emission and interaction)
Run 5203 | Event 1290
Longitudinal (z) coordinate -->
APA3
APA2
APA1
~7 m

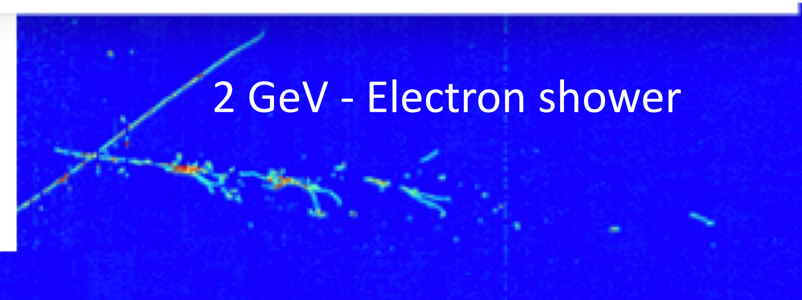

Run 5203 | Event 1290

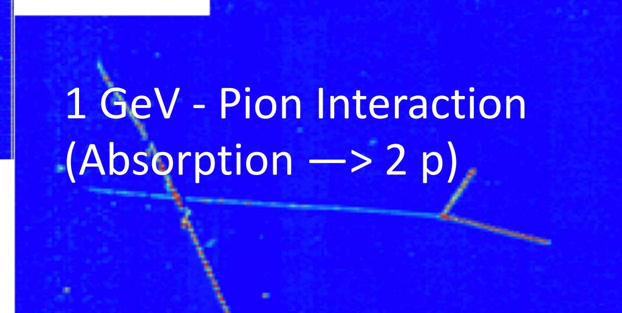
LAr TPC data of unprecedented quality





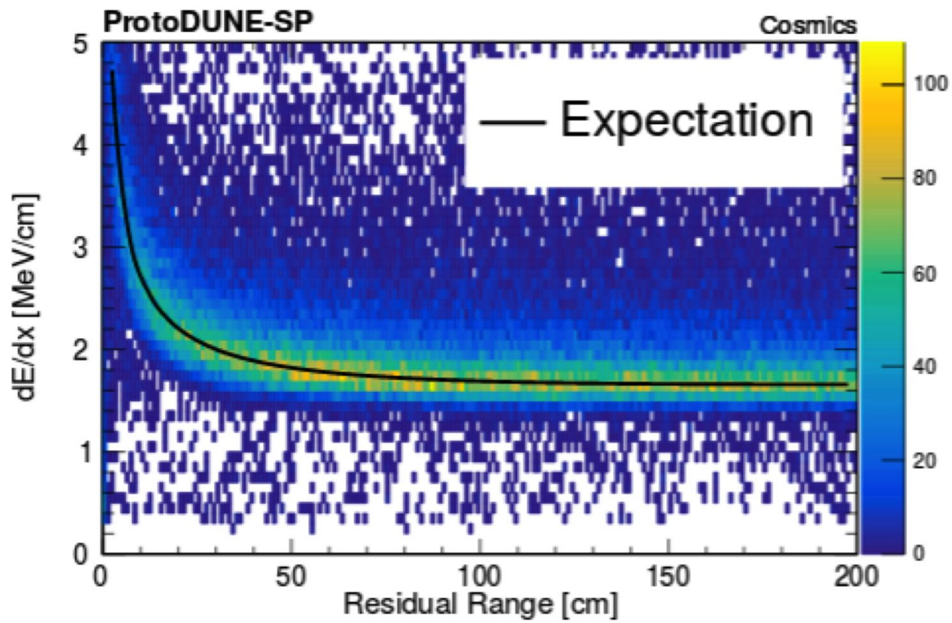
PROTO DUNE SP

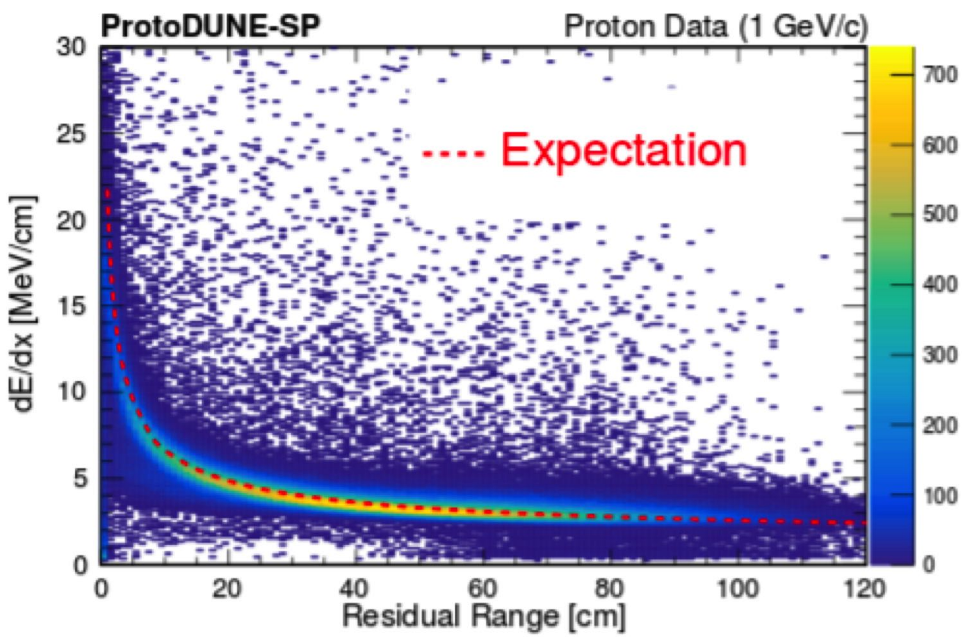




Detector Parameter	Minimal Requirement	Goal	ProtoDUNE Performance
Electric Drift Field	> 250 V/cm	500 V/cm	500 V/cm
Electron Lifetime	> 3 ms	10 ms	> 7 ms *
Electronics Noise	< 1000 enc	ALARA	450-750 enc s/n = 40--50

* Saturation limit of the internal purity monitor,
real value probably ~ 12-13 ms

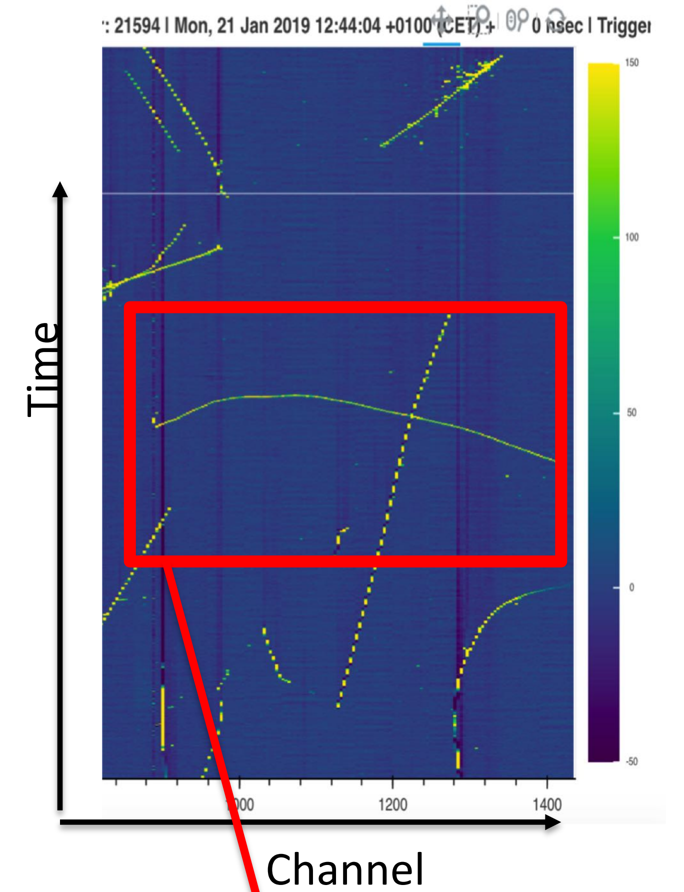




dE/dx vs. residual track length for cosmic muons and beam protons, after detector calibration (mainly corrections of space-charge effects)

Space Charge Effect (SCE) in large LAr TPC operated on surface

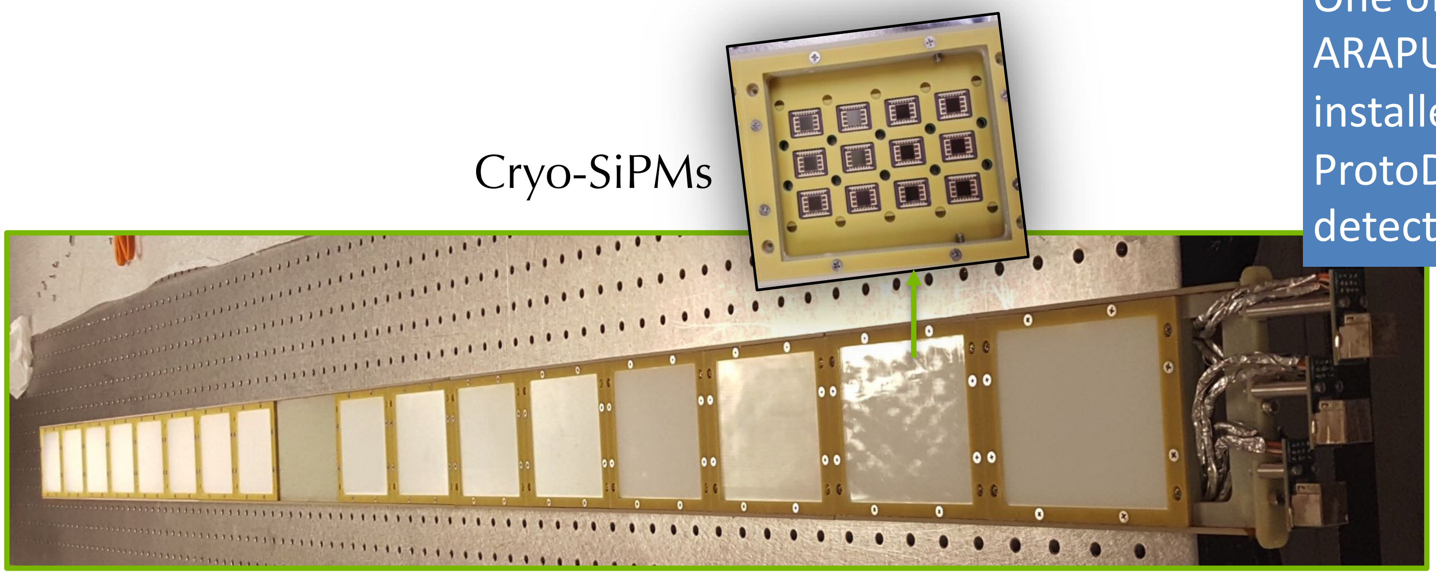
- Positive Ions accumulate in the drift volume, affecting the electric field
- SCE depend on cosmic ray flux, ions mobility, **E-field and drift distance** in the LAr TPC
  - Drift field larger (lower) at cathode (anode)
  - **x(t) distorted** (partially compensated, larger effect near center of drift region)
  - Mismatch between V(x) induced by space charge and V(x) defined on field cage generates **transverse field components near the detector side surfaces**
  - This effect is cumulative and largest for electron drifting from the cathode: the apparent y, z coordinates are moved inside the detector (as much as 35 cm in ProtoDUNE/SP)
  - The drift velocity of is slower than the **convective flow of LAr** (due to thermal gradients and LAr recirculation) – additional complexity
- **Need a 3D correction map**, use tracks with geometrical constraints:
  - Side walls crossing
  - Cathode crossing
  - Anode piercing
  - CRT tagged (cosmic ray tagger, beam tagger)
- SCE corrections are needed for track reconstruction and dE/dX calibration



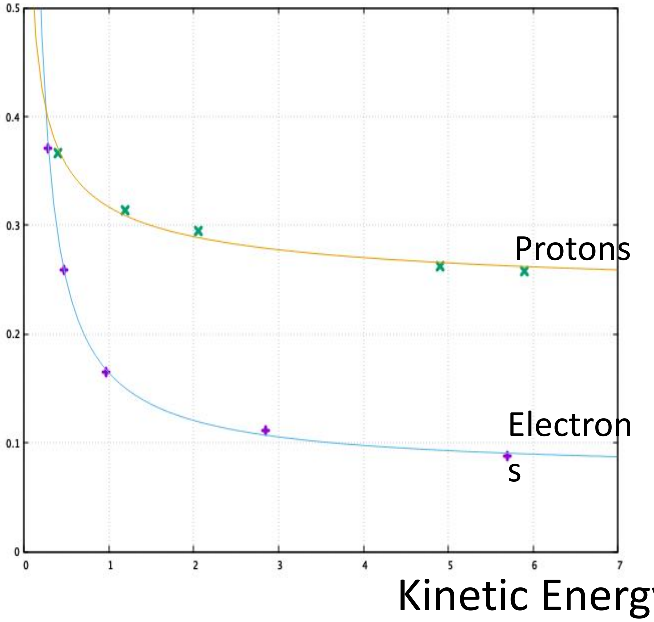
Raw Data
Cosmic muon should be a straight line.
→distorted because of SCE

ARAPUCA Photon Detector design

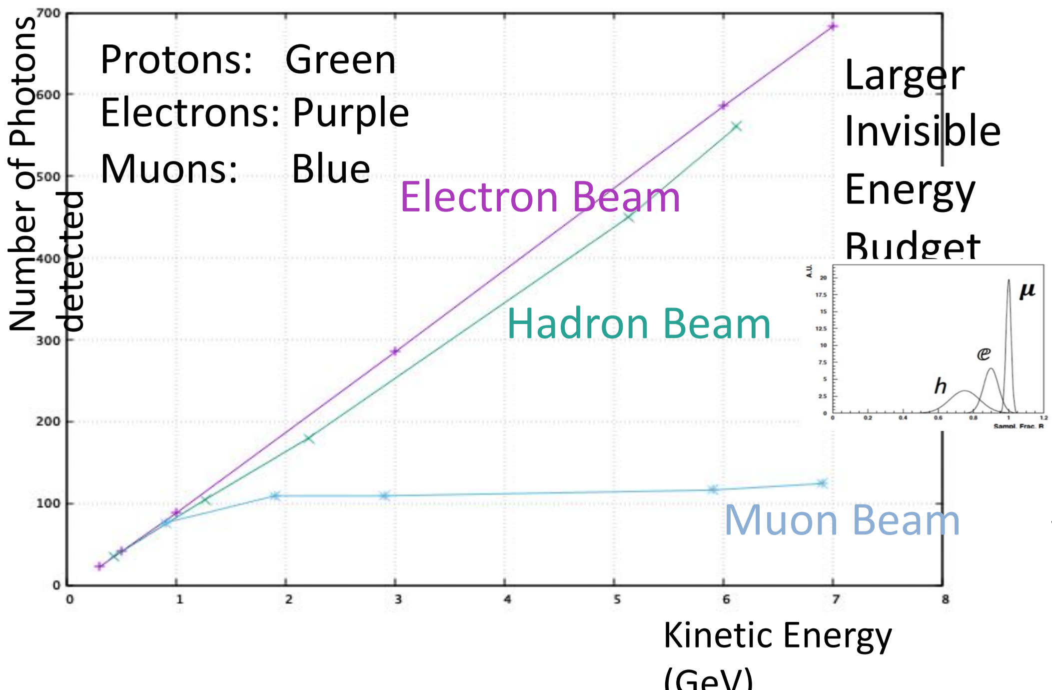
- 12 (or 6) cryo-SiPMs per Cell - passively ganged
- Dichroic (short-pass) filter - optical window: 9.8 x 7.8 cm^2
- p-TP deposited on outer surface of Dichroic glass, TPB on inner surfaces deposited on VIKUITI Reflective Foil



One of the two ARAPUCA arrays installed with ProtoDUNE photon-detection system



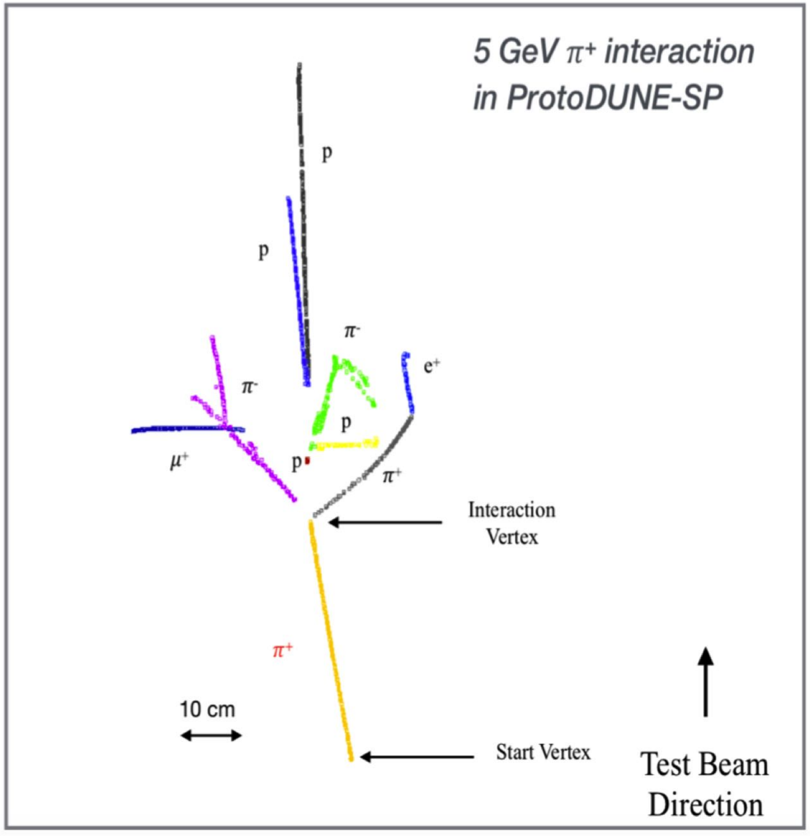
Calorimetric energy reconstruction from detection of LAr scintillation light by ARAPUCA Bar



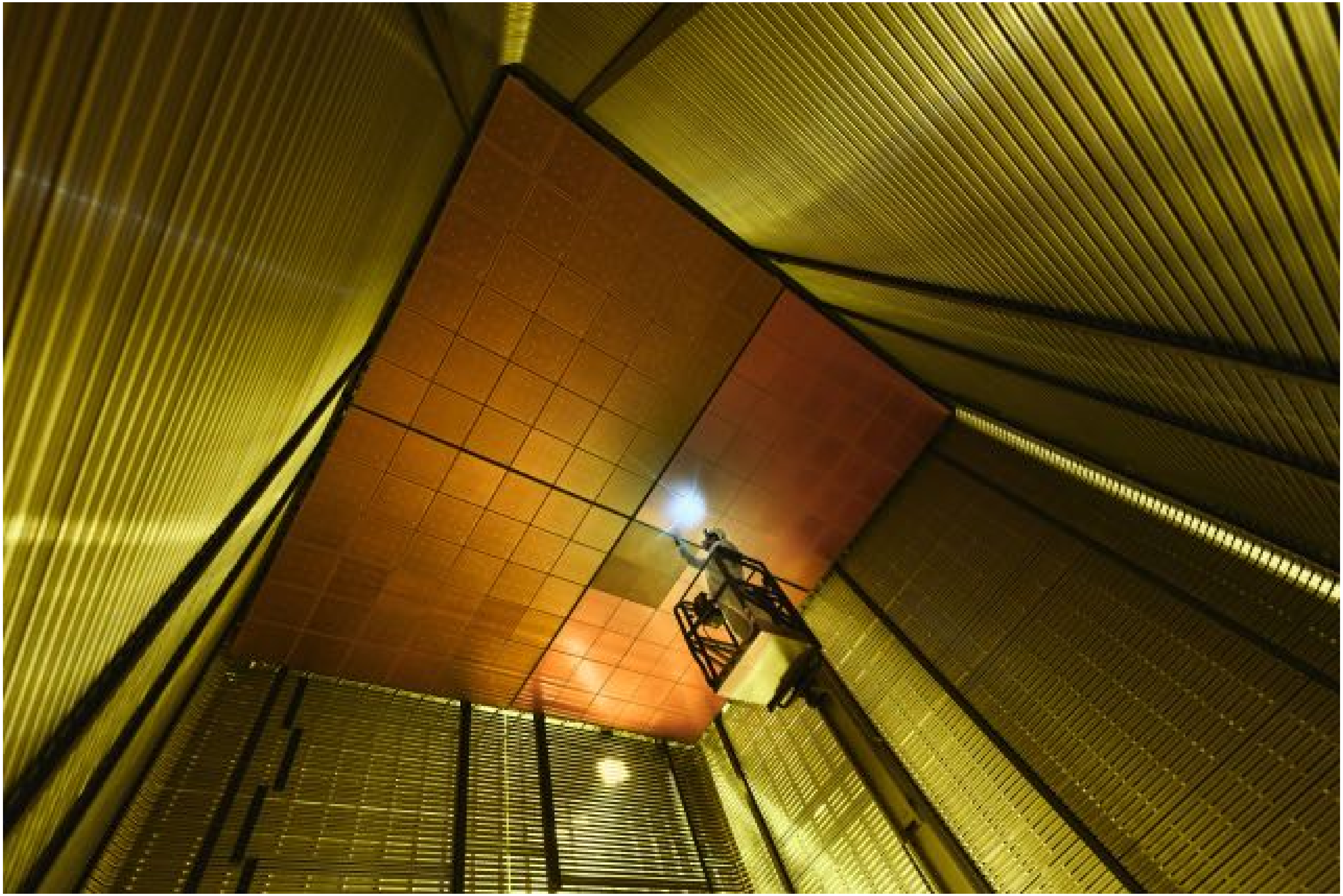
Light yield: about 0.1 ph/MeV with single ARAPUCA bar at 3m distance

Automated pattern recognition and reconstruction software

- Pandora progress to improve reconstruction specifically for ProtoDUNE.
- Adaptive Boost Decision Tree based Beam Particle ID:
  - Efficiencies: 72.3% for beam and 94.5% for cosmic muons

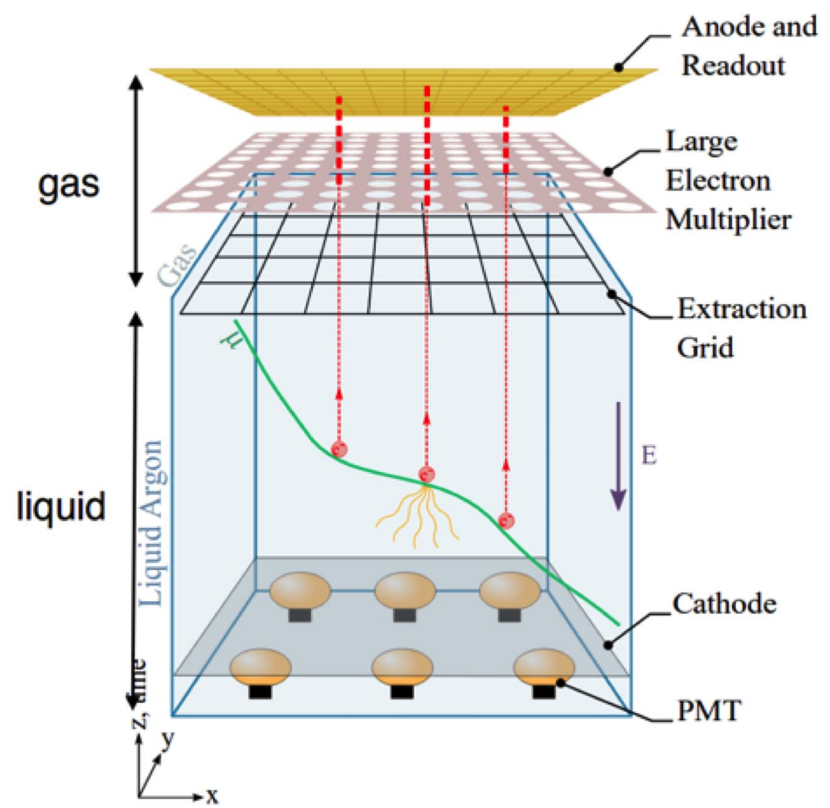


NP02: double phase LAr TPC



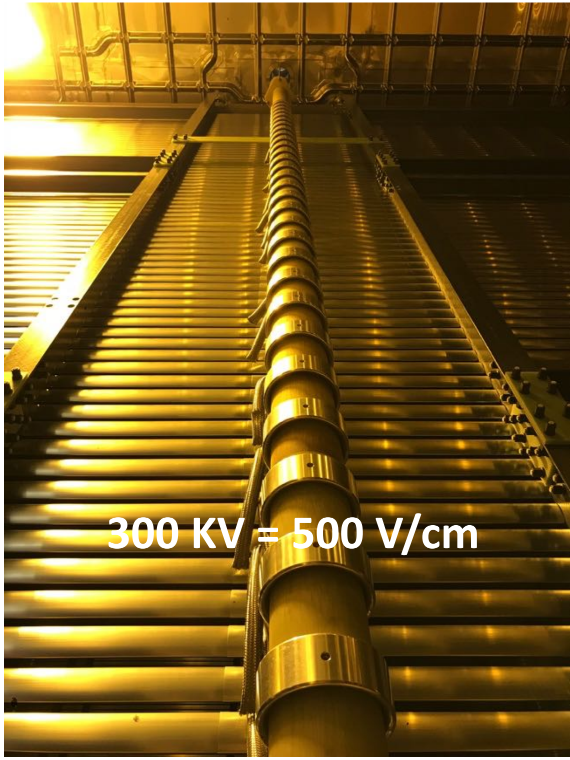
NP02: double phase LAr TPC

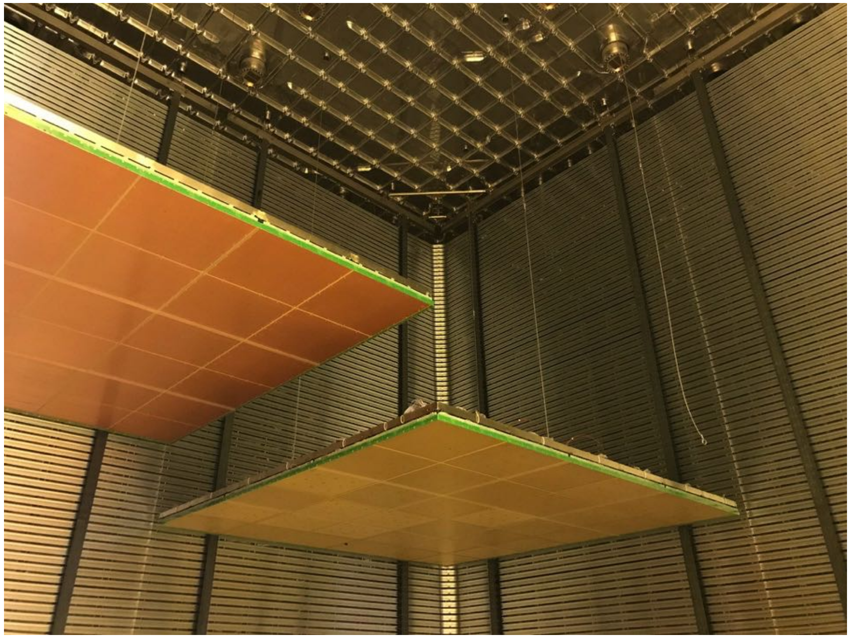
- ✓ ProtoDUNE/DP as a real first large scale demonstrator (6 m max. drift)
- ✓ More critical technology (LEM amplifiers stability, high HV system=600KV) which needs more R&D in the future to be ready for a final DUNE detector.
- ✓ Environmental conditions (liquid stability and purity, space charge effects, positive ions back drift into the liquid …) are the critical points to first experimentally address and understand.

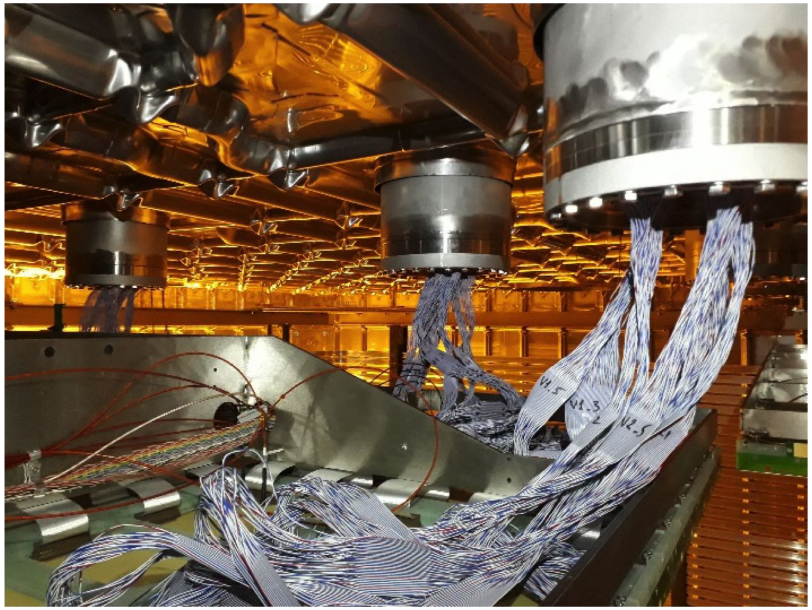


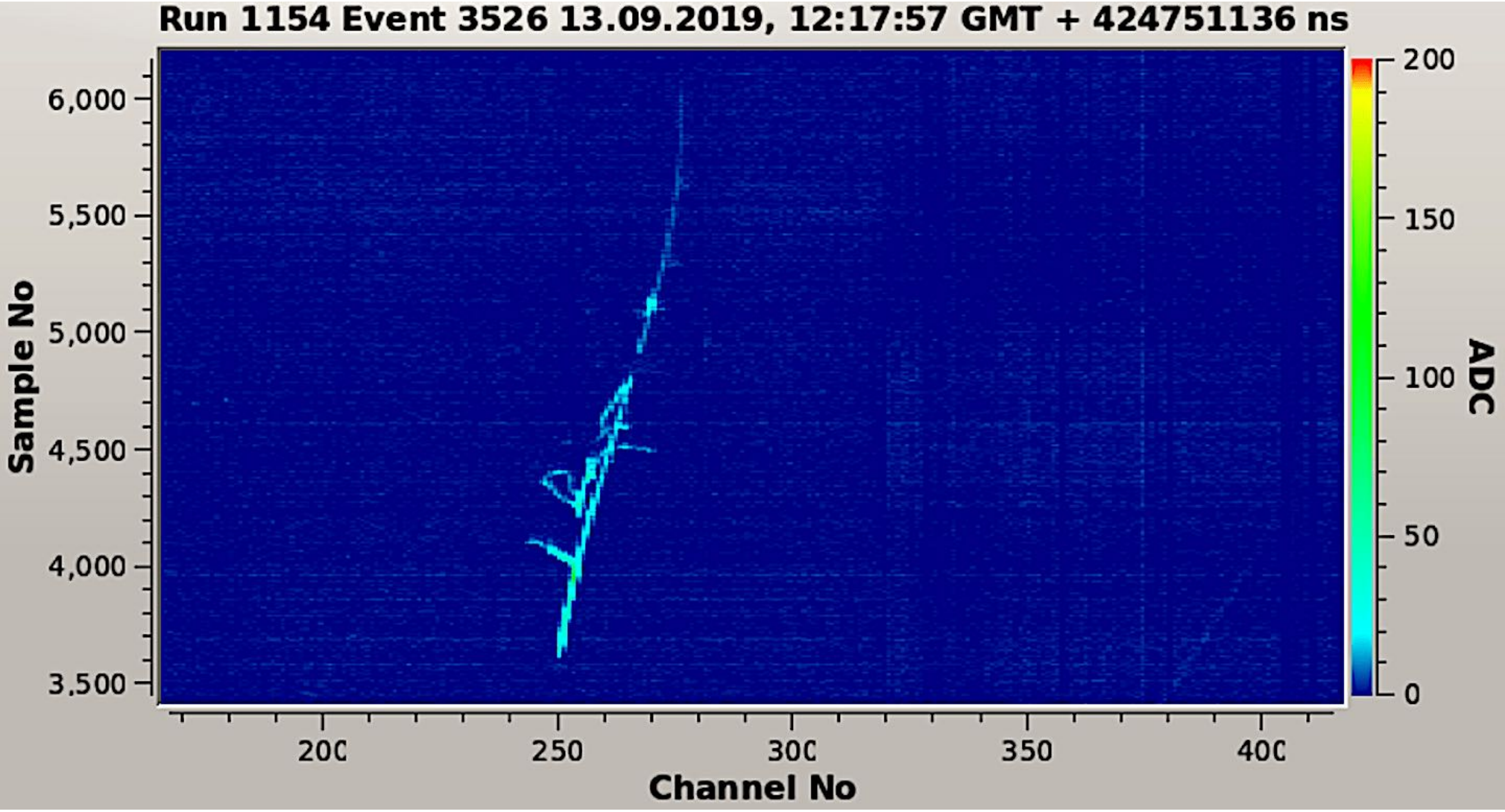
NP02: double phase

- Final readout units assembled and cold tested by end of 2018
- Installation completed in spring 2019
- Purging, cooling and filling in summer



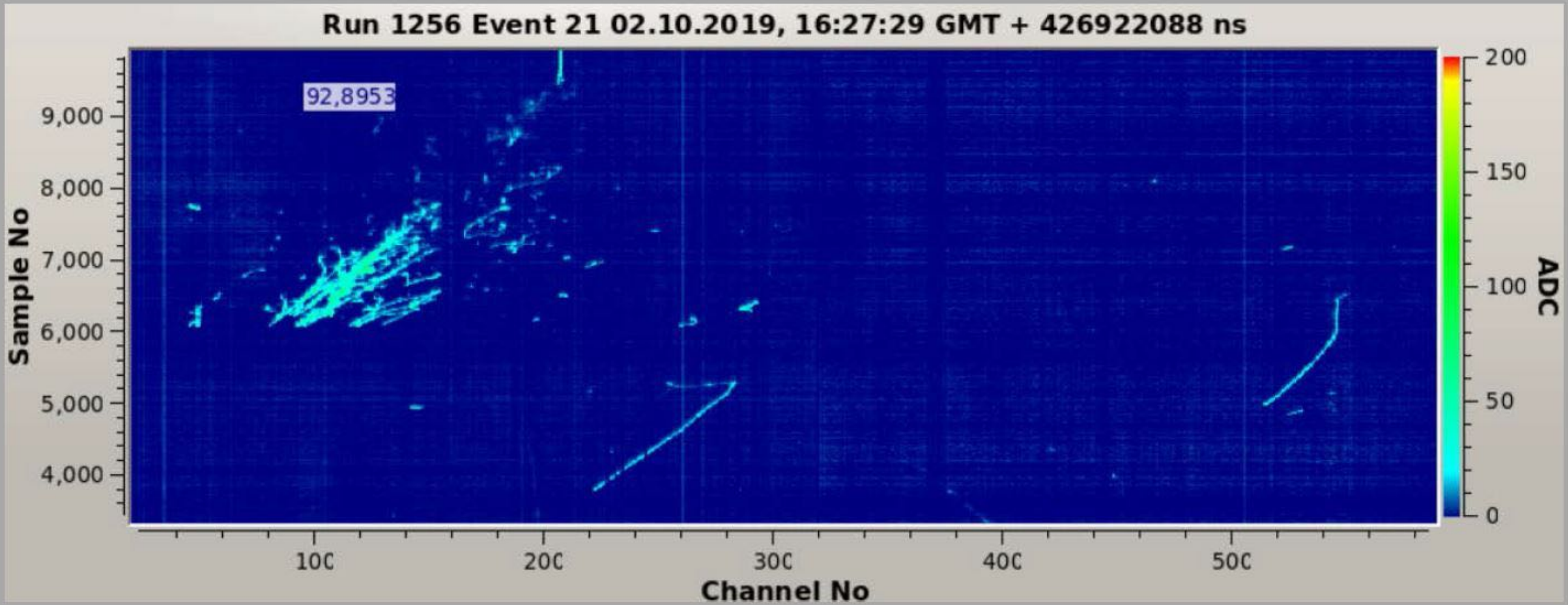






One of the first tracks observed in ProtoDUNE/DP
[Fermilab News and CERN News, Oct. 9, 2019]

Event with electromagnetic showers and two muon decays,
LEMs at 3.1 kV at 1010 mbar, grid at 6100 V



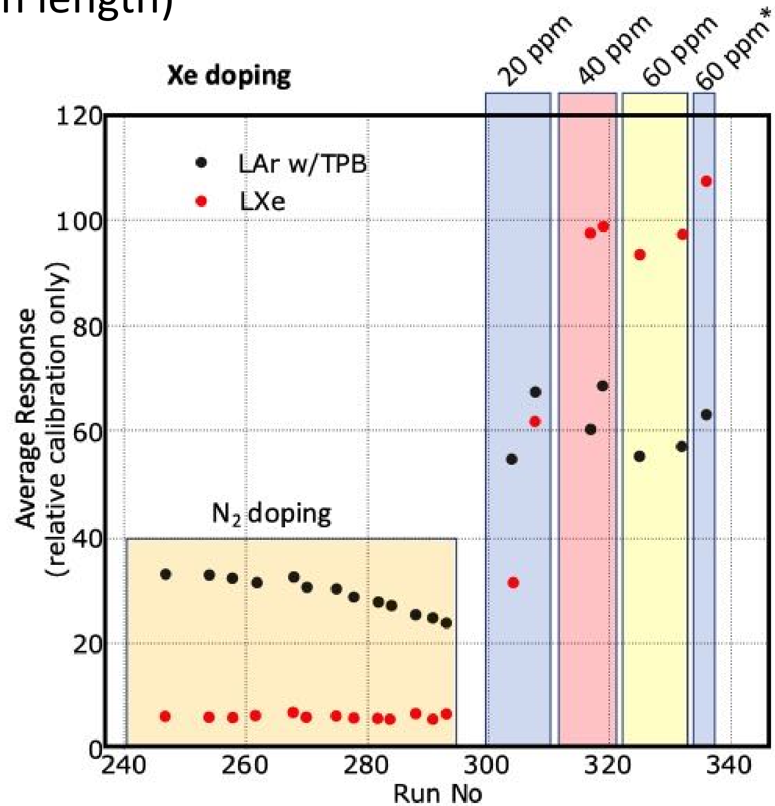
A more recent event form ProtoDUNE/DP

R&D activity on LAr detectors

- Other technologies for TPC sensors are considered for the 4^{th} module of DUNE

- R&D also on **photon detection** for LAr scintillation light:
- Besides the wave-length-shifters used e.g. in ARAPUCA (p-terphenyl and TPB) and PMTs (TPB most frequently), the use of diffused **Xenon in LAr** is of particular interest (higher light collection, longer Rayleigh length)

- The **stability of the Xe-Ar** mixture is being tested in a small prototype – and being considered as the last test of the first run of ProtoDUNE/SP.
- **Nitrogen pollution** affects the light emission in LAr, and it is relevant to know how Xenon competes with it.
  - (very) **preliminary** results are encouraging:



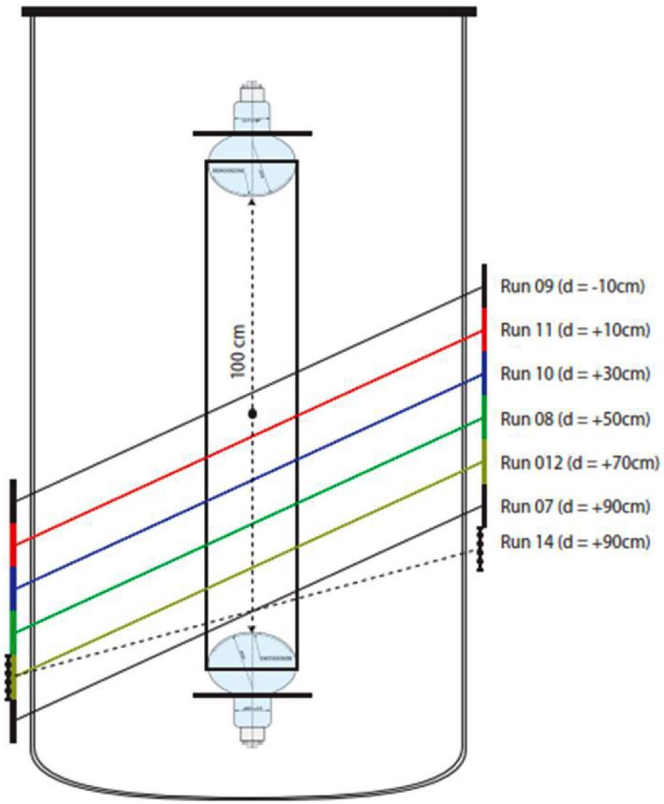
LAr w/TPB response drops to ~ 70 % with N_2 doping to 5.2 ppm

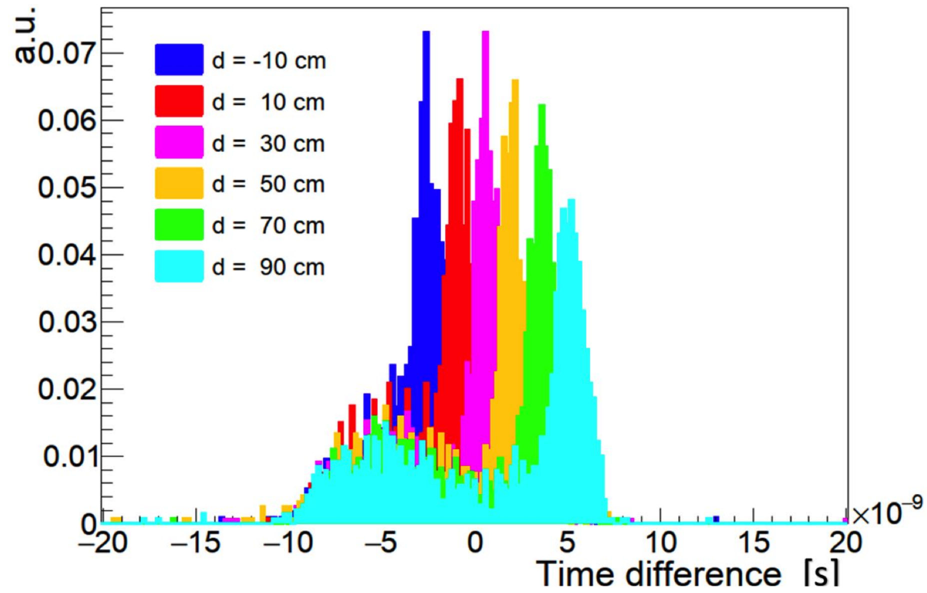
All PMTs see an increase in the level of light

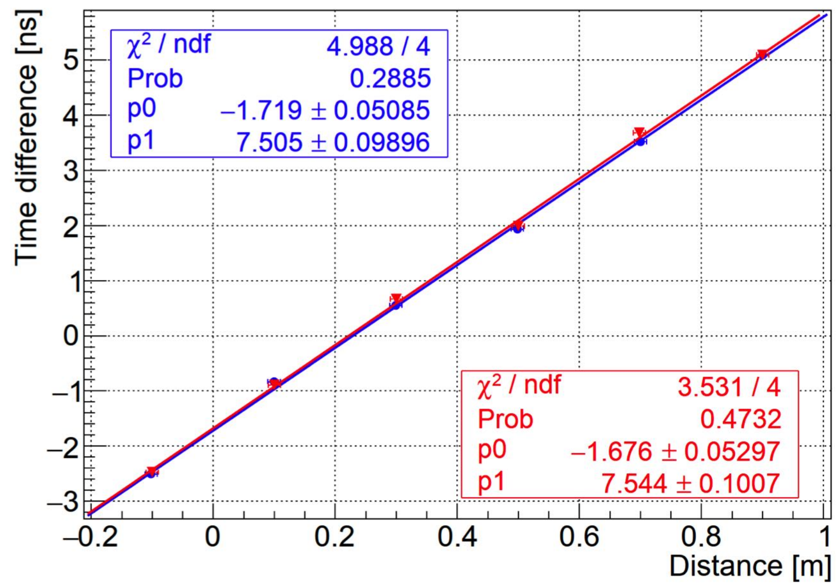
The amount of light seen is larger than the pure LAr response with the first Xe doping

* HV=0

A recent result of R&D on scintillation light in LAr: the propagation velocity







The scintillation light velocity (inverse)

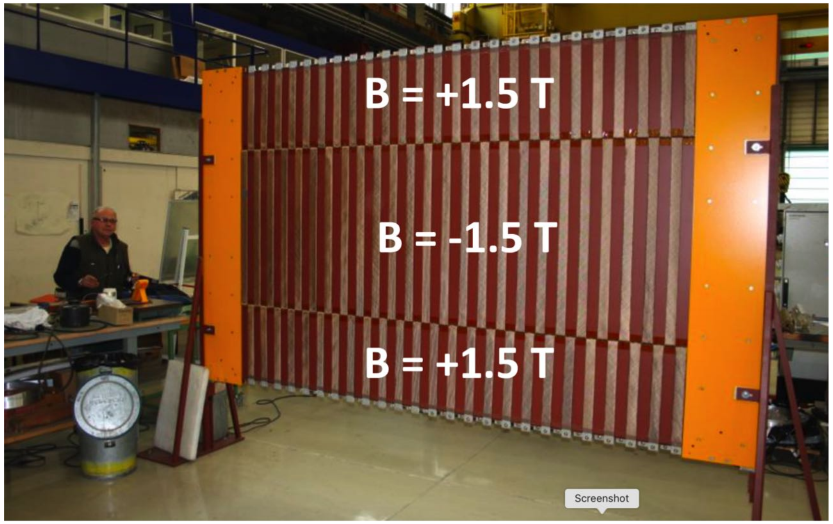
$\mathbf{1/v_g = 7.50 \pm 0.07\,\mathit{stat} \pm 0.05(\mathit{syst})\ \mathit{ns/m}}$

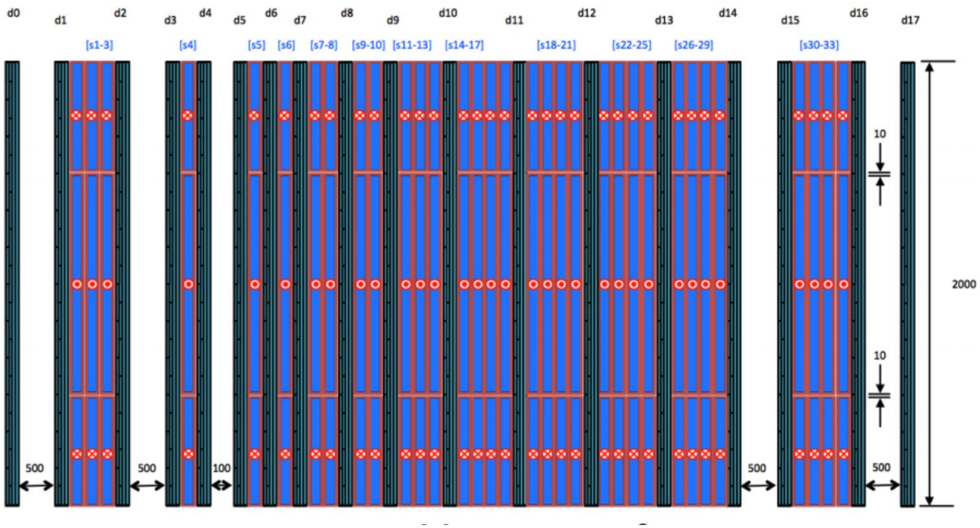
[Nucl.Instrum.Meth. A936 (2019) 178-179]

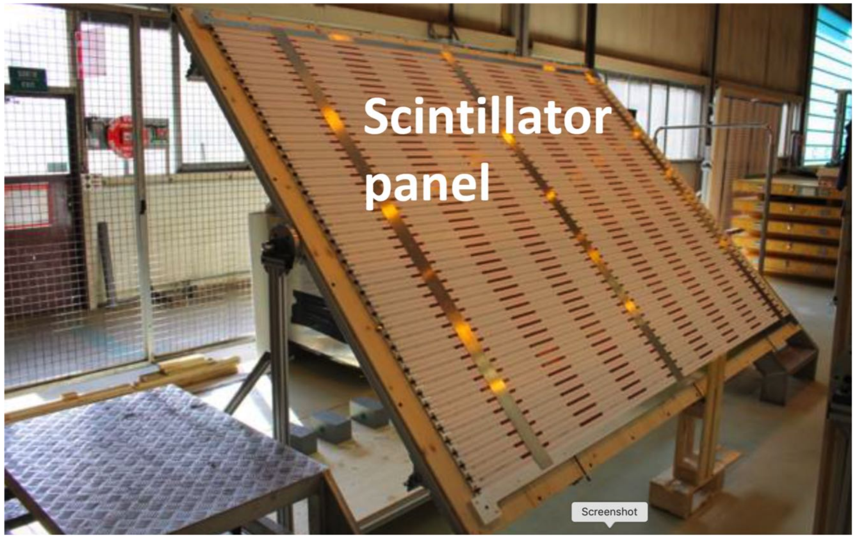
NP05: BabyMind muon (near) detector for T2K

Muon spectrometer for the WAGASCI experiment (T2K beam line)

- Sandwich of 33 magnets and 18 scintillator modules
- 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



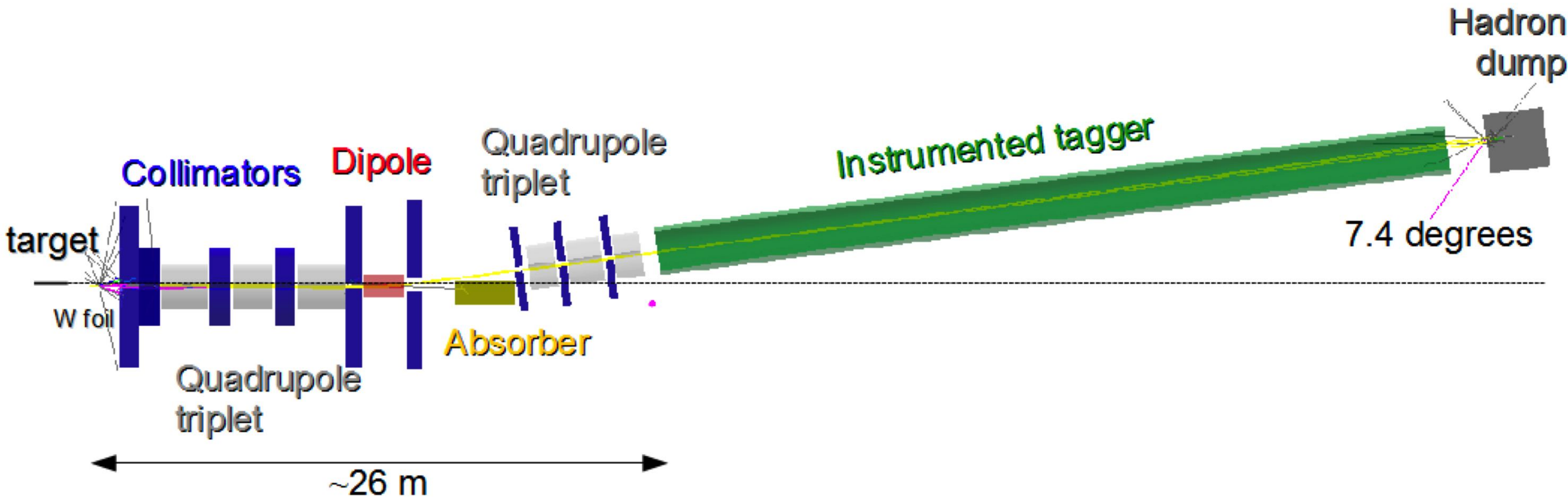




NP06: ENUBET

instrumented decay tunnel for calibration of neutrino beam

[CERN-SPSC-2018-034/SPSC-1-248]



The wall of the decay tunnel is equipped with a calorimeter that can tag Ke3 decays ($K^+ \rightarrow \pi^0 e^+ \nu_e$), and provide accurate measurements of ν_e and K^+ fluxes.

CERN is providing support from accelerator experts.

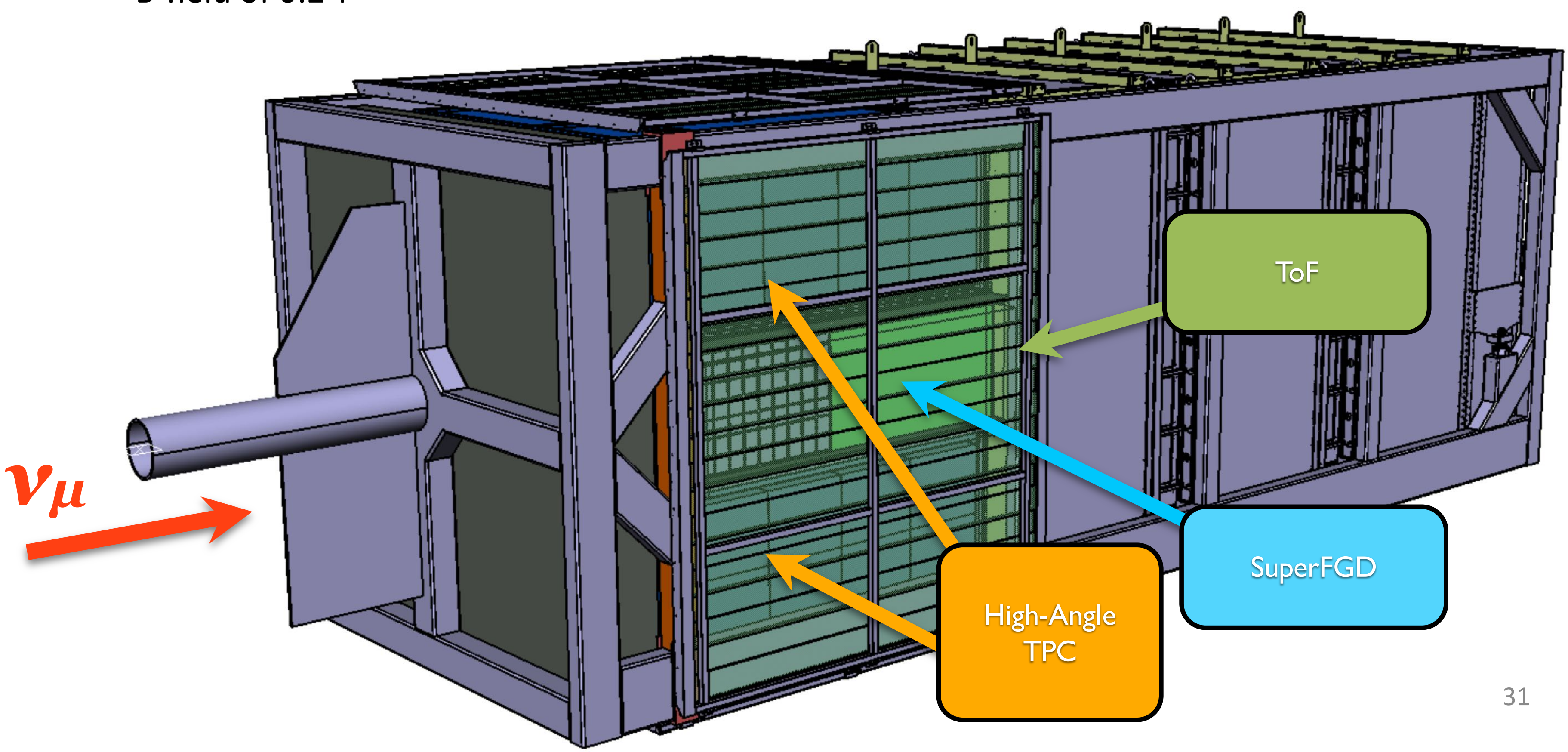
A demonstrator may come later.

T

NP07: The upgrade of the T2K Near Detector (ND280)

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

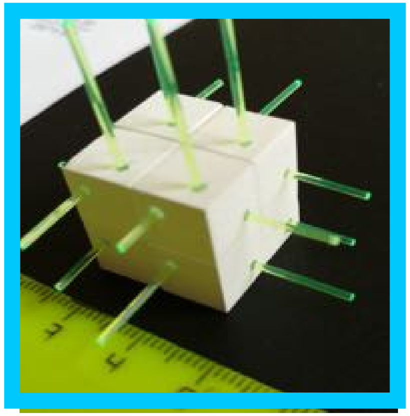
	Current	Upgrade
Target Mass (tons)	~2	~4

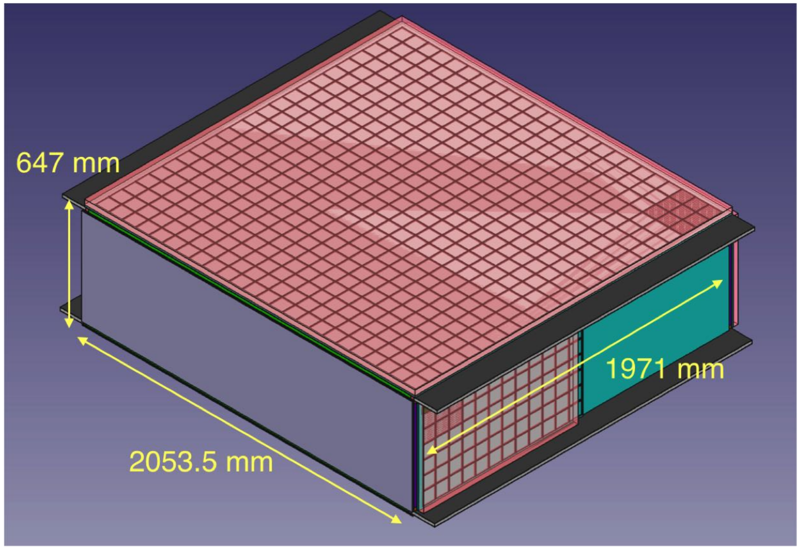


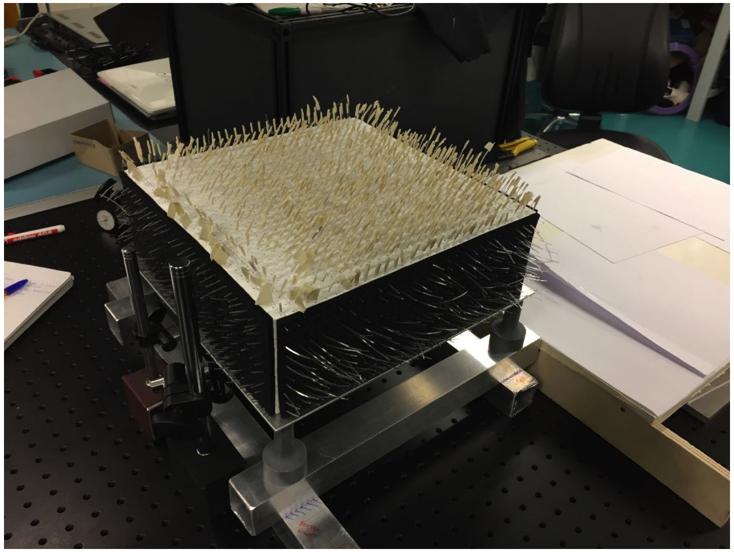
SuperFGD for ND280

2018 JINST 13 P02006

- CERN involved in the R&D of SuperFGD
- Design of the detector mechanics
- Scintillation light readout
- LED calibration system
- Building a small prototype (10k cubes)



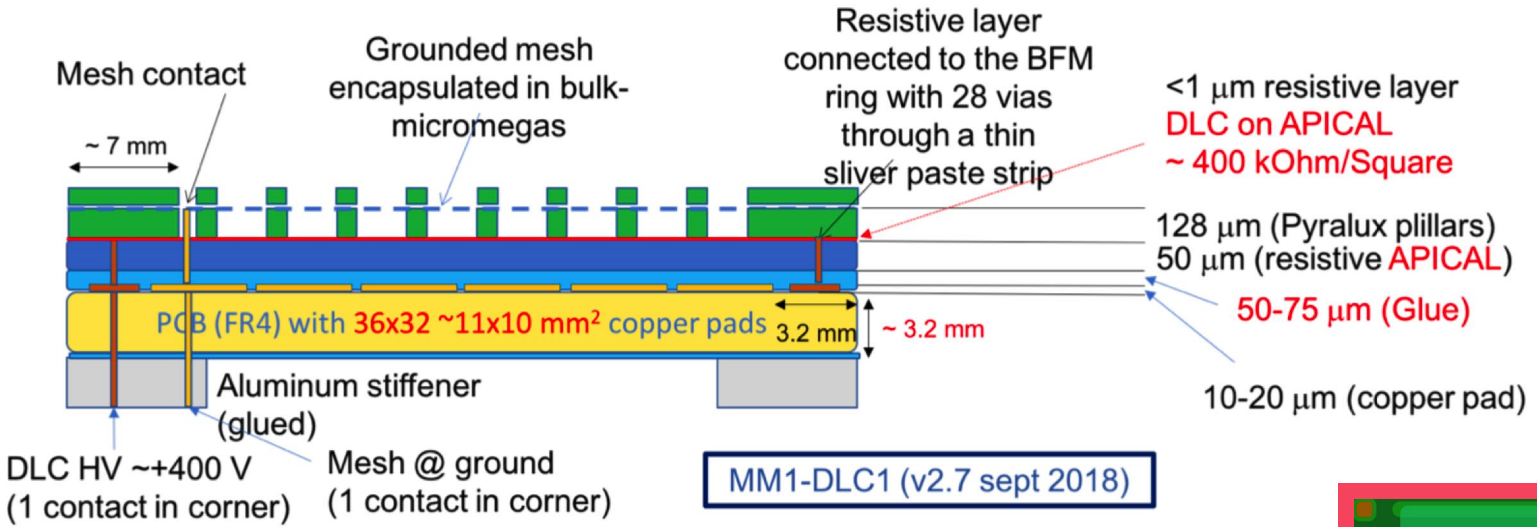


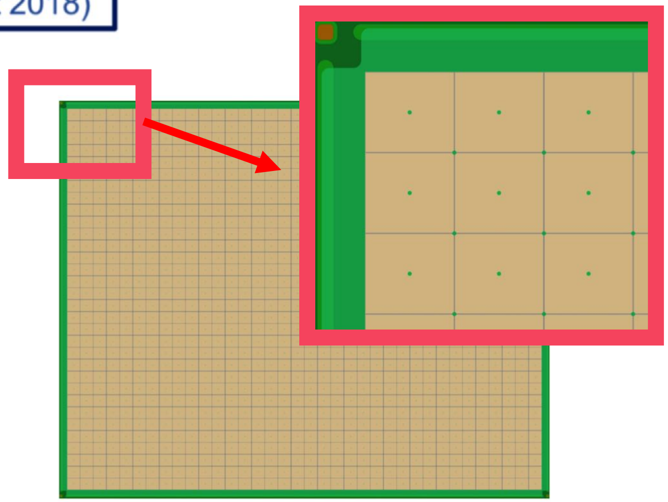


(Technology considered also for the Near Detector of DUNE)

Resistive Micromegas for the (gas) TPC of NP280

- Resistive MicroMegas production will be done at CERN

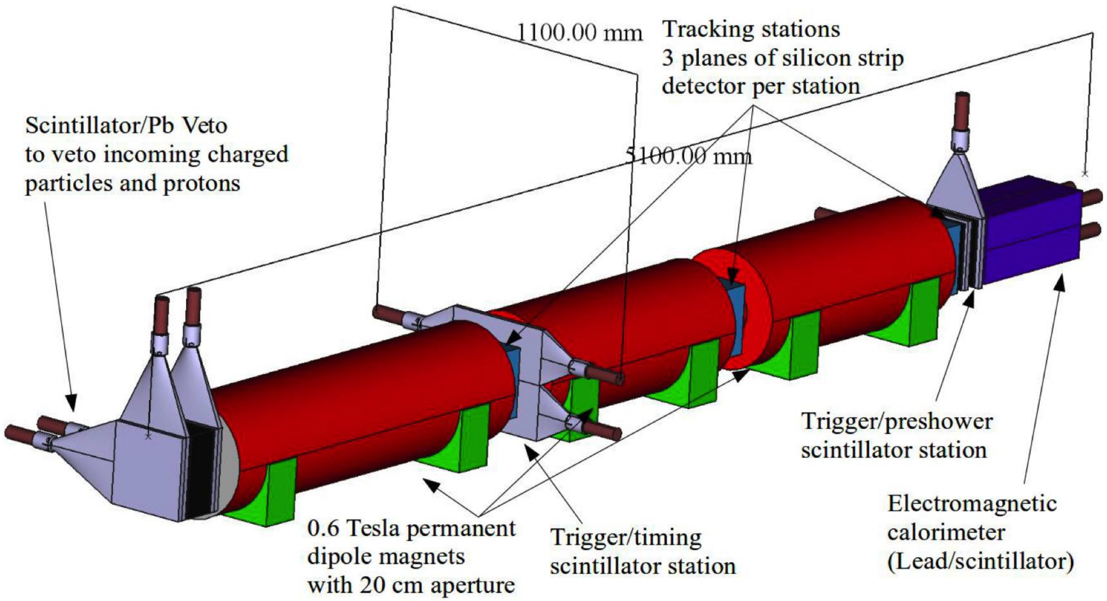




Gas system based on gas recirculation Ar-CF4-iC4H10 (95% - 3 % - 2%)

Total detector volume is 18.4 m^3 —> 3 V-TPCs + 2 HA-TPCs)

Neutrinos from LHC: Faser-ν and XSEN



FASER experiment baseline set-up

- On the LHC collision axis, at 480 m from the interaction point of ATLAS
- In an unused tunnel, shielded from LHC background
- Approved for a search of dark photon
- Preparing a proposal for an extension for the observation of neutrinos above 400 GeV, adding emulsion stacks and aiming at ν_τ interactions.

neutrino fluence from IP1 and IP5

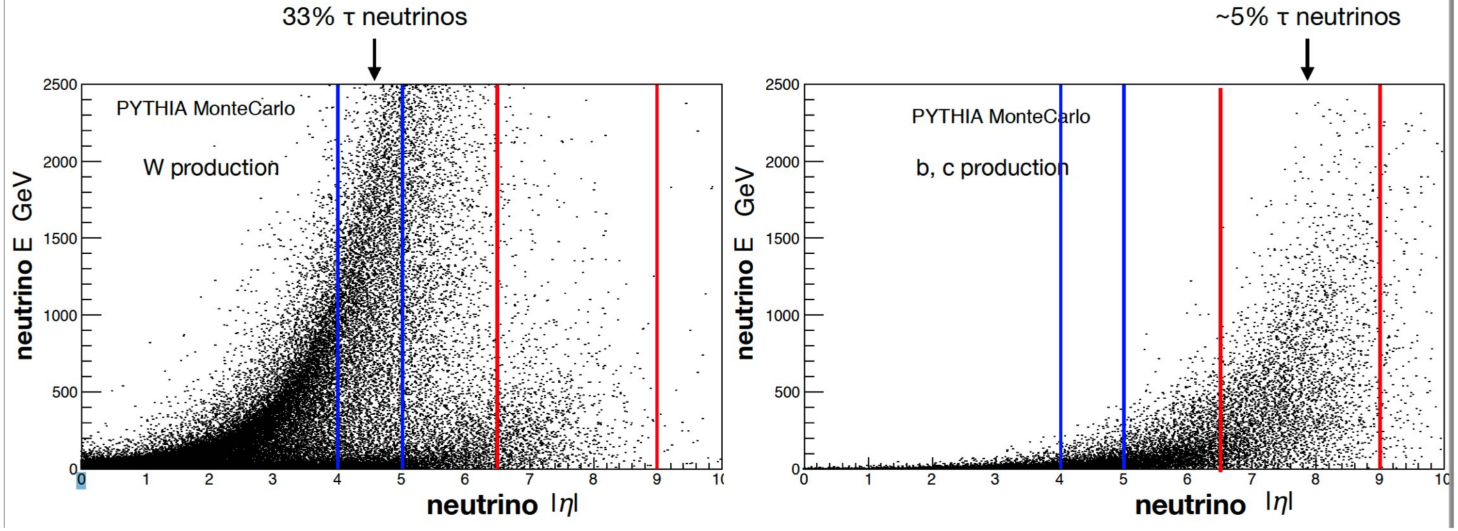


Table 1: Neutrino fluences in $4 < |\eta| < 5$, $|\eta| > 6.5$, for 3000 fb^{-1}.

	$4 < \|\eta\| < 5$	$\|\eta\| > 6.5$
Neutrinos from pp collisions at $\sqrt{s}$=14 TeV with c and b production		
neutrino fluence in acceptance /3000 fb^{-1}	$3.9\ 10^{14}$	$1.7\ 10^{14}$
τ neutrino fluence in acceptance /3000 fb^{-1}	$2.7\ 10^{13}$	$9.3\ 10^{12}$
neutrino average energy (RMS) (GeV)	30(30)	400(350)
Neutrinos from pp collisions at $\sqrt{s}$=14 TeV with W production		
neutrino fluence in acceptance /3000 fb^{-1}	$1.7\ 10^{10}$	$1.1\ 10^{9}$
τ neutrino fluence in acceptance /3000 fb^{-1}	$4.7\ 10^{9}$	$1.1\ 10^{8}$
neutrino average energy (RMS) (GeV)	600(600)	400(400)

Screenshot

In a similar location, but somewhat off-axis, the **XSEN proposal** aims at neutrinos of higher energy, with a few tons of nuclear emulsions.
[http://arxiv.org/abs/1903.06564]

Conclusion

- Very intense 4 years of activities over many fronts, in line with the EU strategy recommendation (pave the way....)
- Community compact behind the project (more than 100 institutions collaborating)
- Important CERN effort as host lab (the buildings, the infrastructure, cryostats, cryogenics, DAQ, DCS, detectors components and assembly). A model of host lab interplay with the scientific collaborations for the future facilities.
- Results are very positive, with a large visibility in the international community (even outside Neutrino physics)

Technology implications

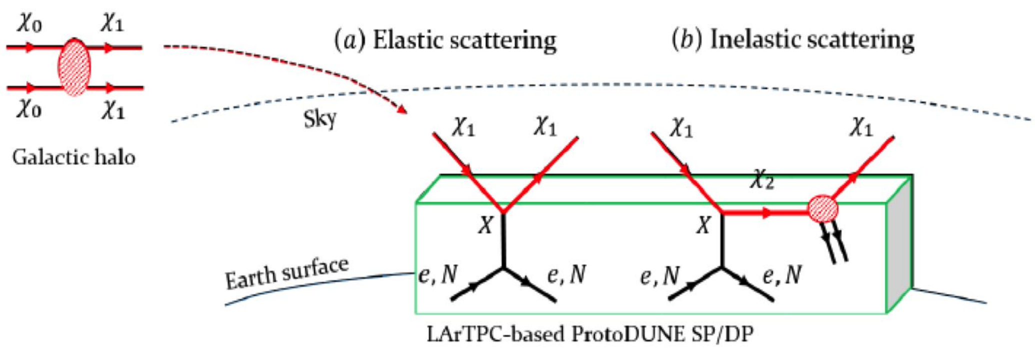
- We have now a strong and solid proposal for DUNE (basis of DUNE TDRs).
- *Next phase is to apply the lessons learned and test a real DUNE module zero, before starting mass production (project submitted and approved by CERN RB).*
- We have already one of our detectors taking regular data in T2K (Baby Mind). We are now opening to other activities within T2K (new T2K near detector).
- *The developed LAr technology, in particular for all what concerns cryostats, cryogenics and cold electronics is opening new possibilities and interests in other fields of application …… like dark matter search (example DARKSIDE-20k).*
- In parallel we have developed many R&D applications, which will impact the future of these type of detector technologies.

Physics research possibilities with protoDUNE

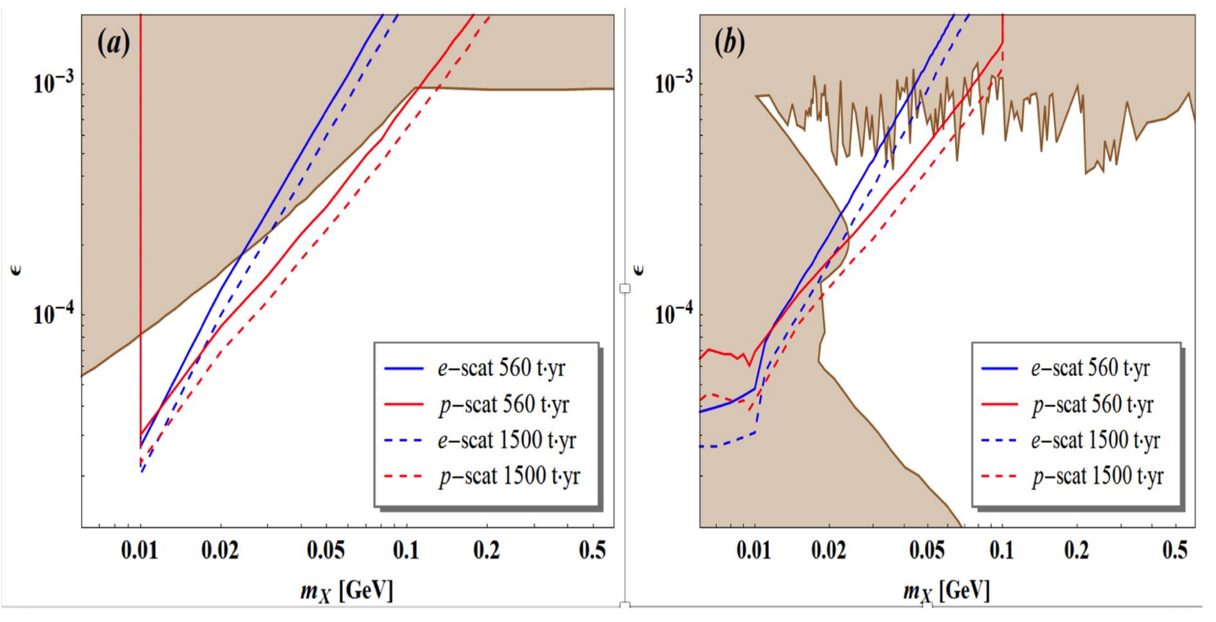
We start exploring several ideas on physics which can be done with the existing protoDUNEs (even with cosmics).

- *Hadronic –Argon cross section measurements (inclusive and semi-exclusive)*
- *Searches for boosted dark matter in cosmic rays*
- *Searches for fractional/mini/millicharged particles in cosmic rays*
- *Searches for monopoles in cosmic rays*

Boosted Dark Matter



arXiv:1803.03264

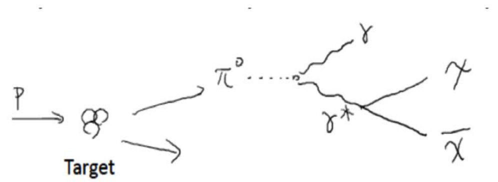


Dark matter with multiple components in order to be compatible with present DM limits

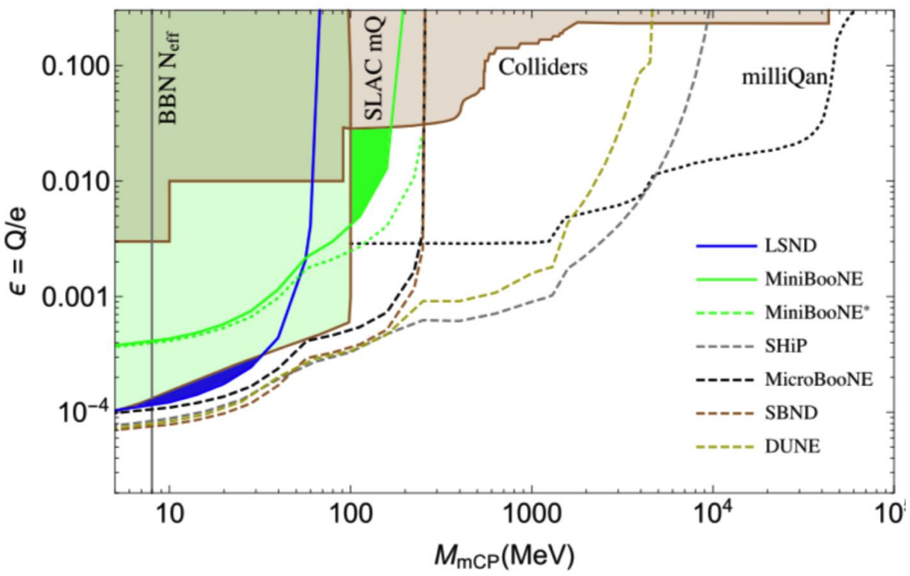
Can be searched for in the Near detector (beam Induced) and in ProtoDUNE (cosmic ray induced)

Millicharge Searches

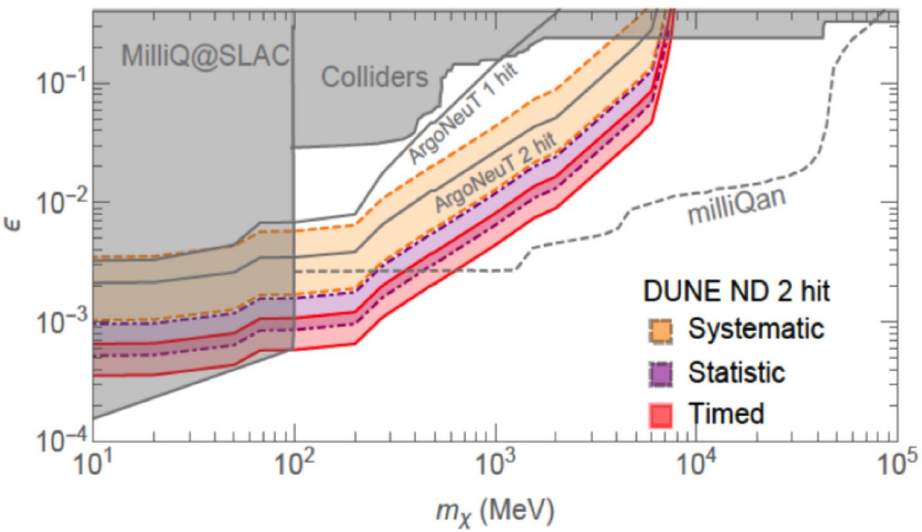
Recently there is a lot of revived interest to look for millicharged particles, ie particles with a charge much smaller than the electron. Signatures are elastic electron scattering and particles crossing the detector with small de/dx ionization losses



arXiv:1806.03310



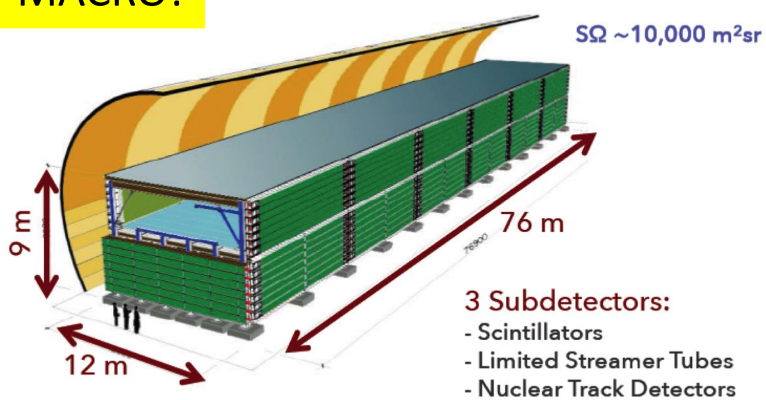
arXiv:1902.03246



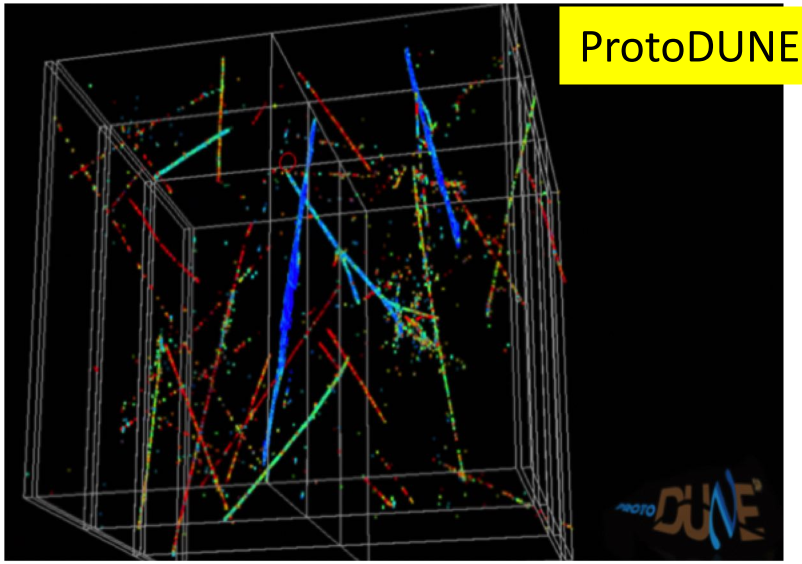
Sensitivity for DUNE ND and ProtoDUNEs under study

Monopole Searches

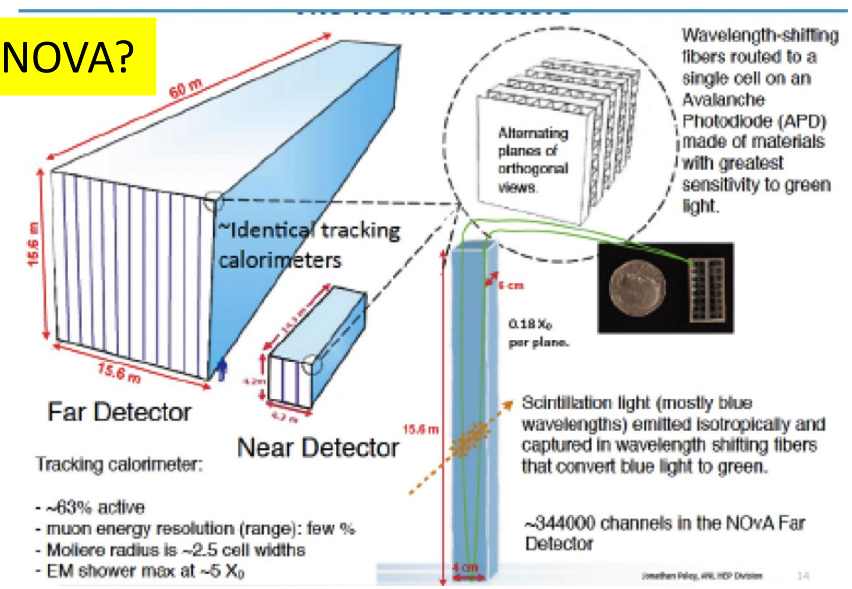
MACRO!



ProtoDUNE??



NOVA?



Ionization saturation?
Backgrounds?
Triggers?

-Searching for highly Ionizing particles
-Study of sensitivity with ProtoDUNE and the DUNE far detector launched