The CERN Neutrino Platform and ProtoDUNEs

XVIII International Workshop on Neutrino Telescopes - Venezia, 2019

Marzio Nessi, 21-03-2019

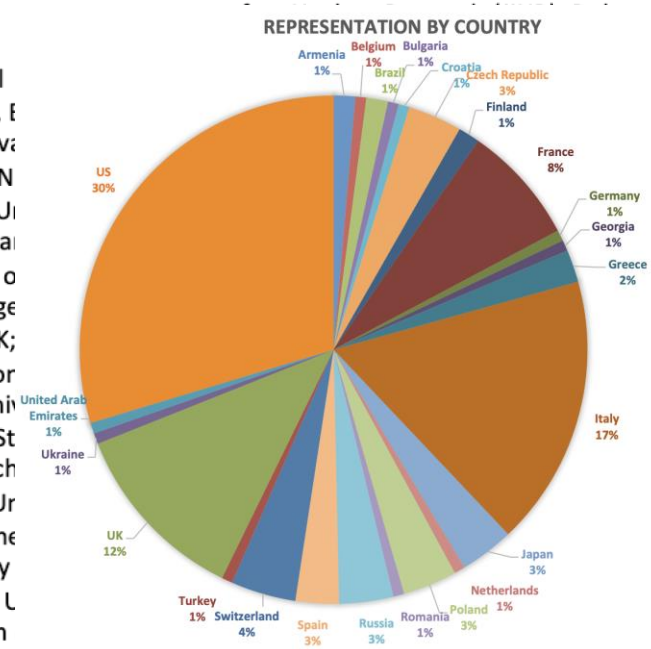
The CERN Neutrino Platform

- 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

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; Dipartimen Universita di Bologna, Italy; Dipartimento di Matematica e Fisica, Universita del Salento, Lecce, Italy ; INAF - Osservatorio Astrofisico di Torino, Italy; INFN e Laboratori Nazionali di Frascati ione 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 dova, 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 (IRAE), Bellaterra, E Fisica Corpuscular (IFIC), Spain; Unive udy Abroad Program Geneva Zuerich - ETH Zurich Institute for Par pean Organiz. for Nuclear Res. (CERN Hochenergiephysik, Switzerland; Univer Dept. de Phys. Nucl. et Corpuscul., Switzerland; U University (METU), Ankara,Turkey, Turke al 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 Uni 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!



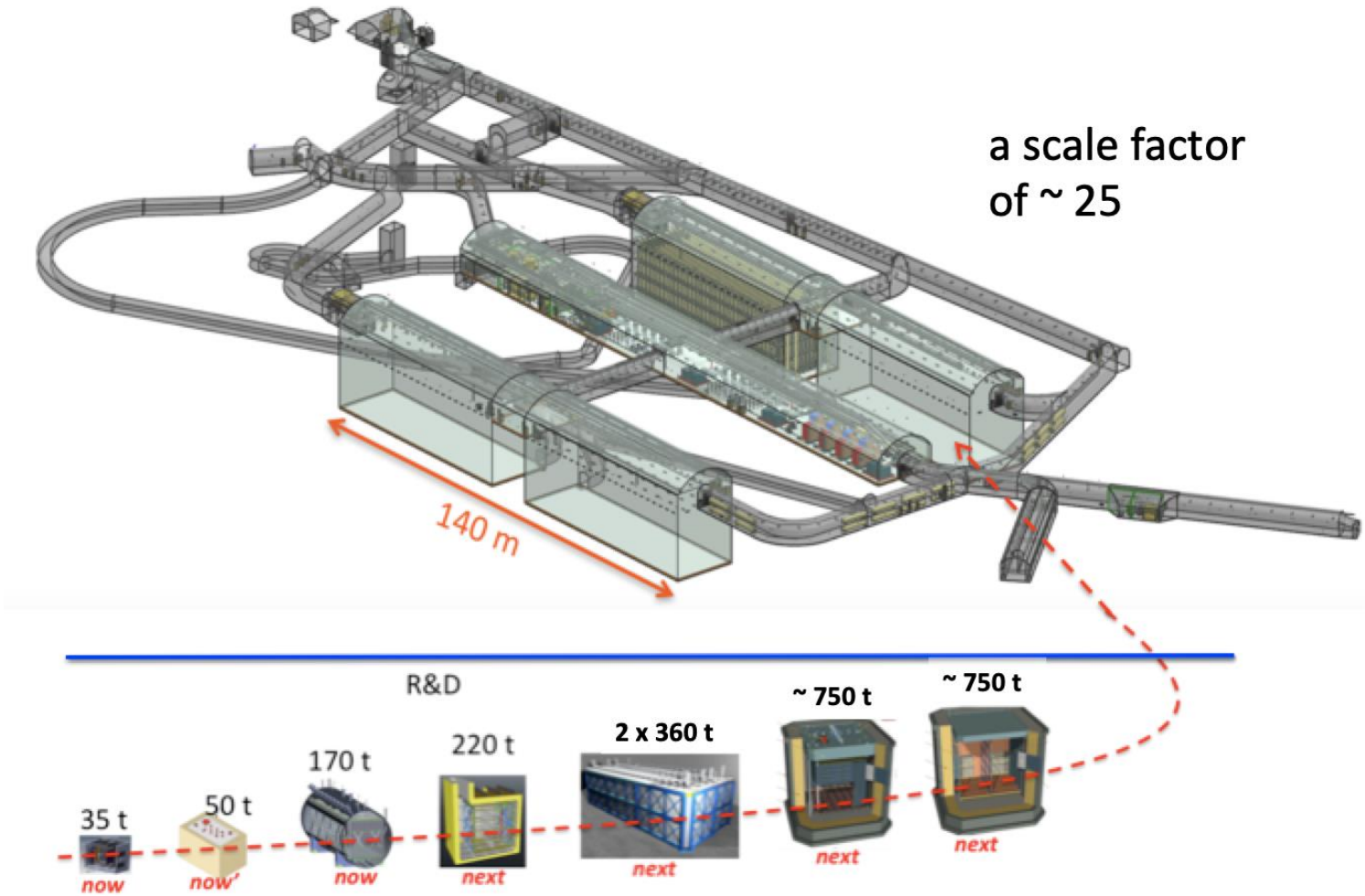
NP Projects

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

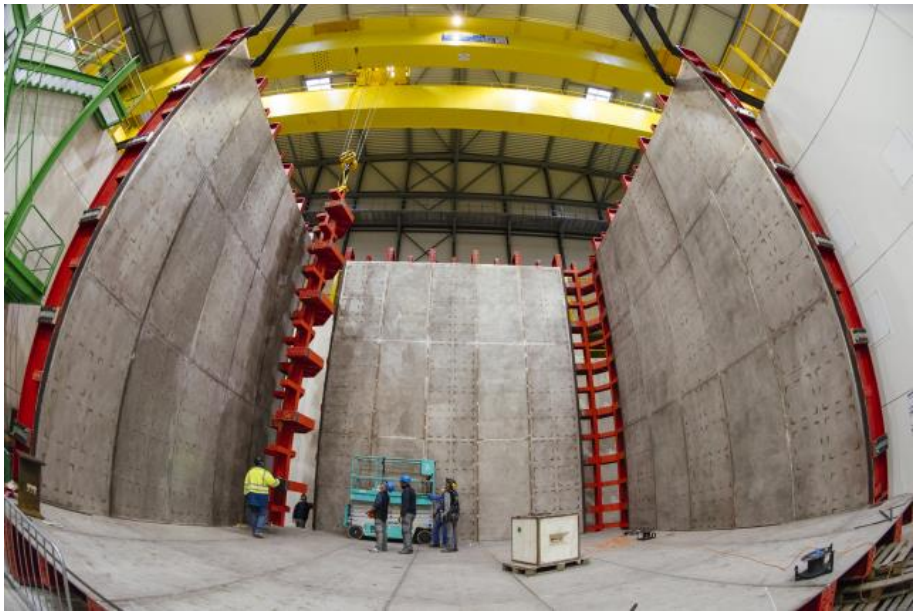
+ agreed active participation in the construction and exploitation of the LBNF/DUNE and SBN US programs

ProtoDUNEs

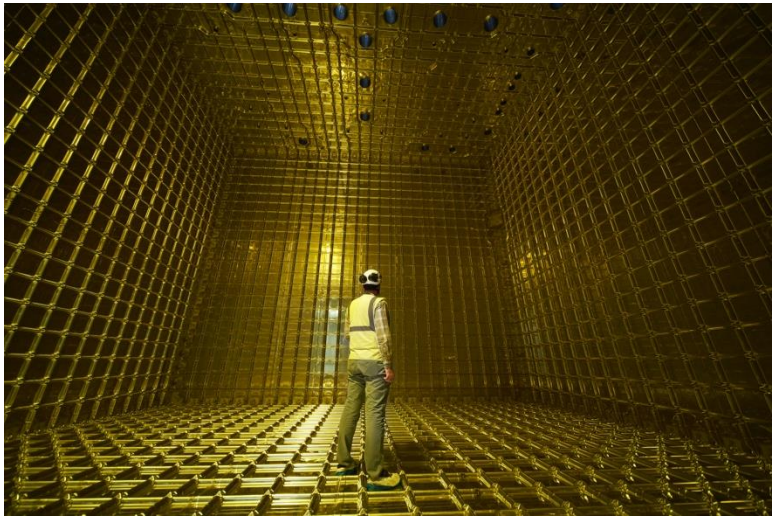
A step by step approach : ***"large prototypes as demonstrators"***



March 2016



November 2016

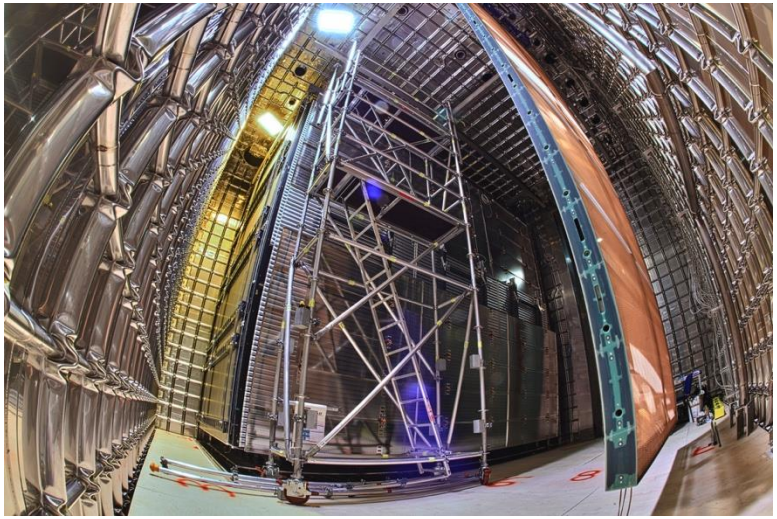


September 2017

September 2018, ready for beam!

March 2016

November 2016

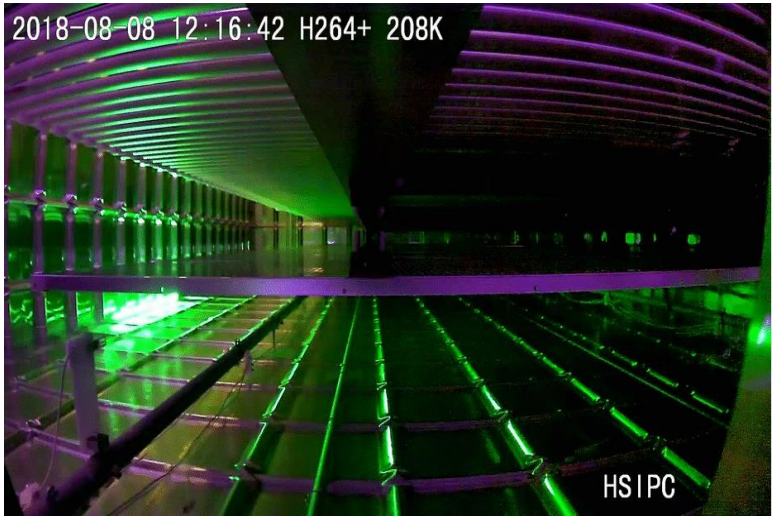


February 2018

September 2018, ready for beam!

March 2016

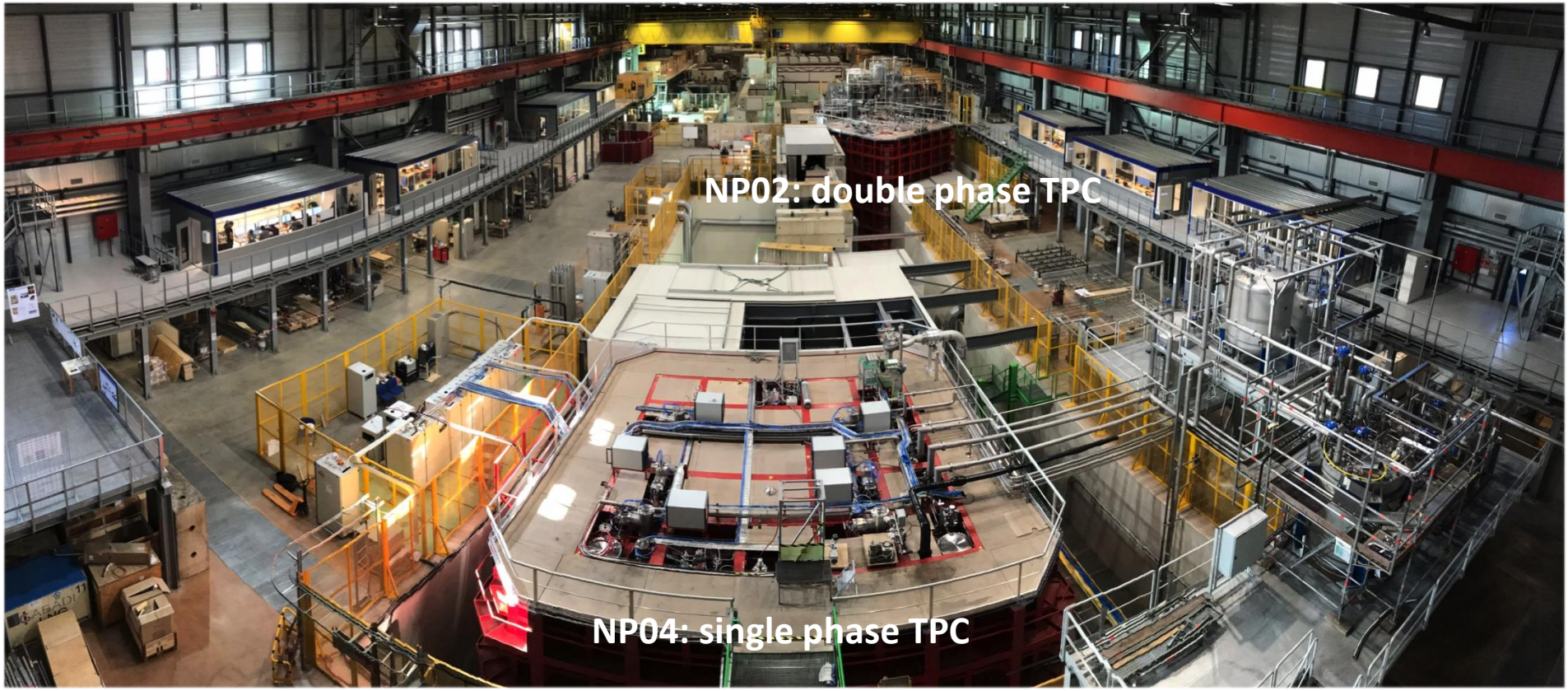
November 2016



August 2018

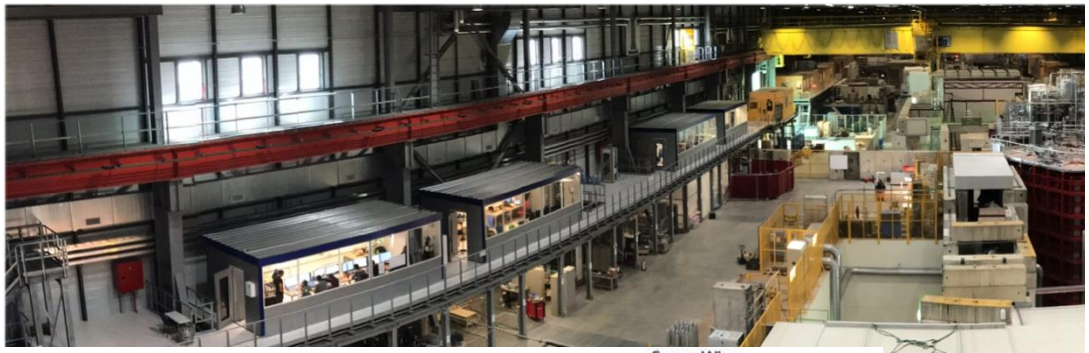
September 2018, ready for beam!

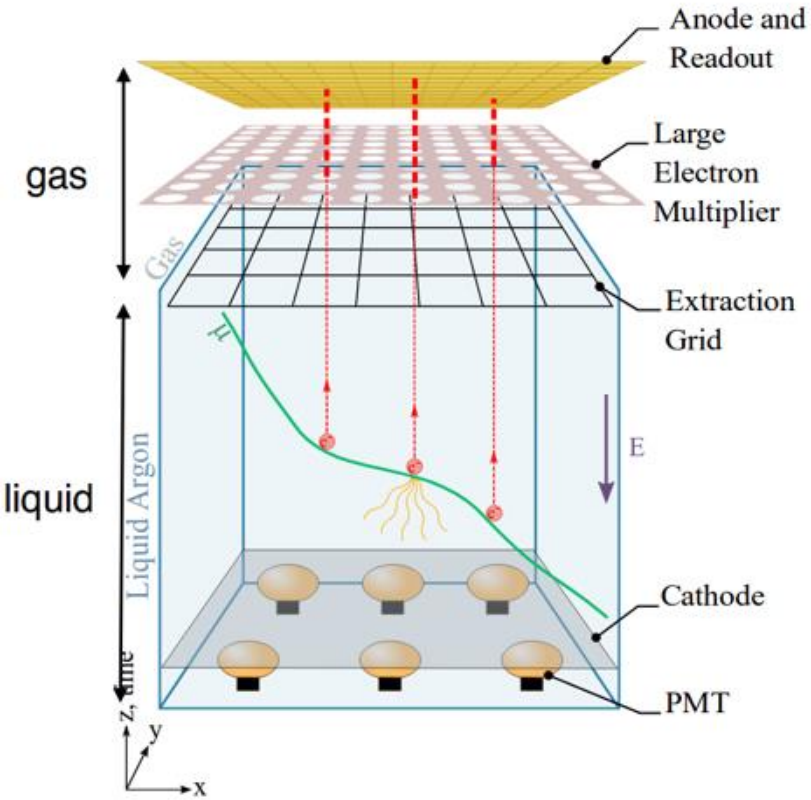
EHN1 layout

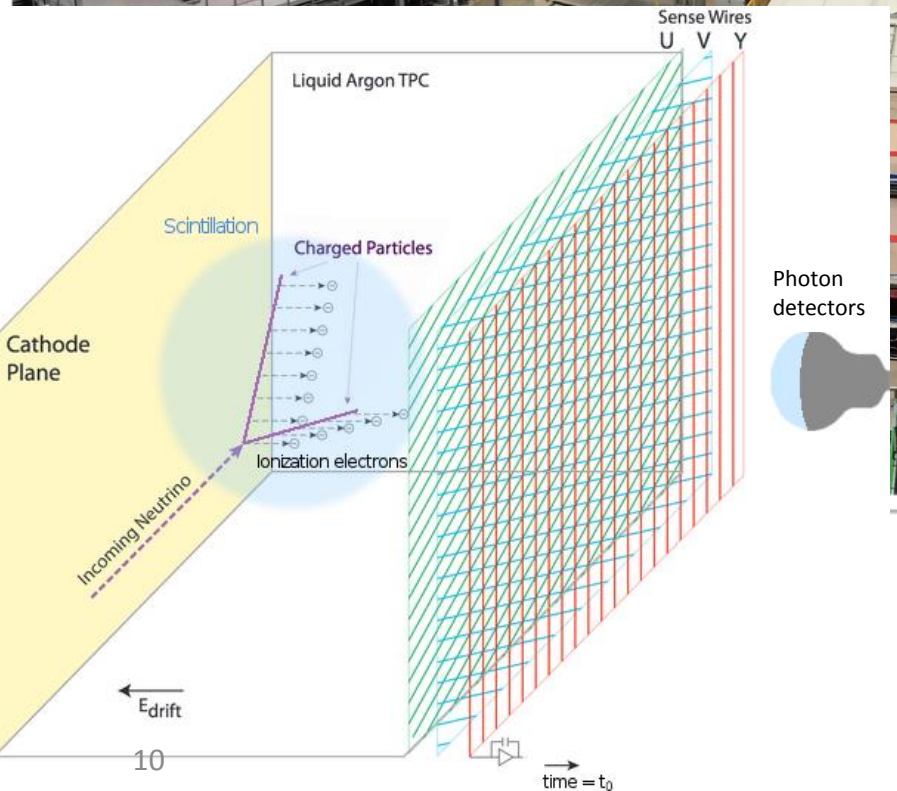


NP02: double phase

~ 760 tons of liquid







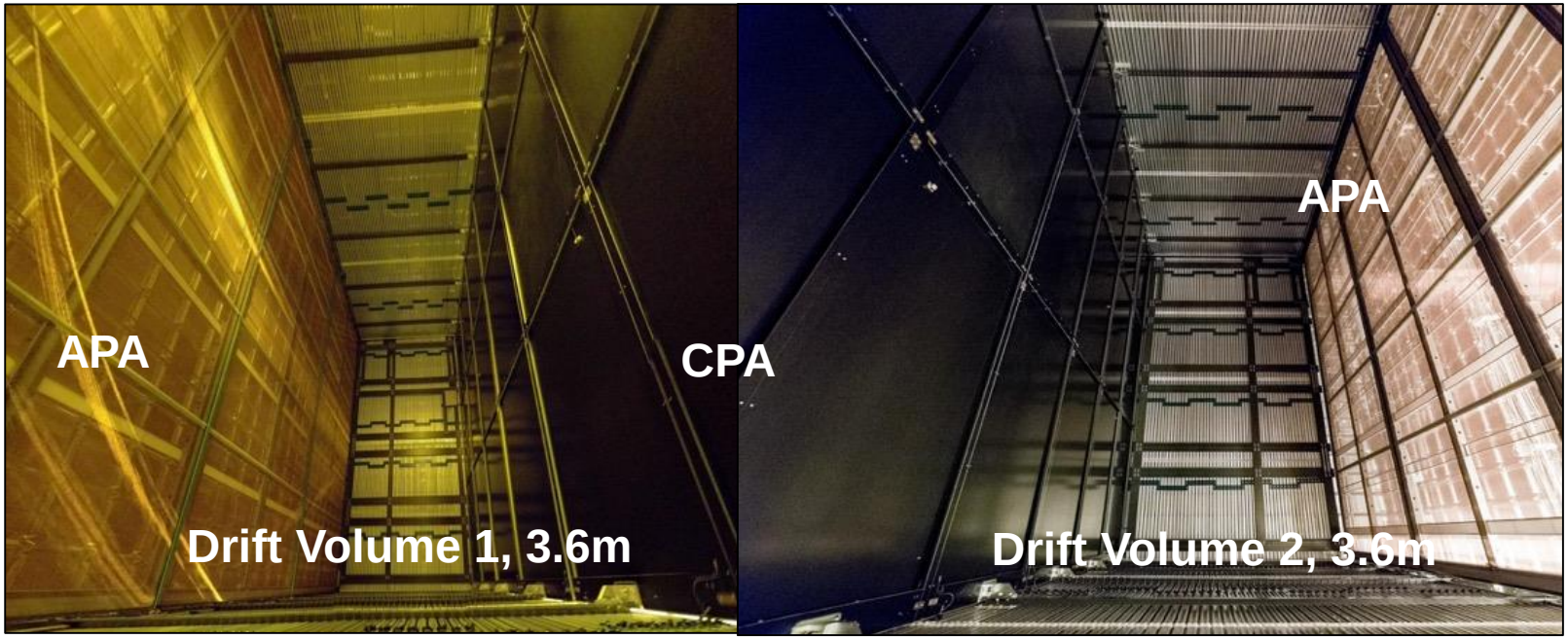
NP04: single phase

~760 tons of liquid

NP04: single phase LAr TPC

- *Assembled and cold tested by May 2018*
- *From May to August 2018, cooling and filling*
- *End August 2018 HV on and ready for beam*

6 x Anode **P**lane **A**ssembly **C**athode **P**lane **A**ssembly **P**hoton **D**etection



Data – Collected beam events

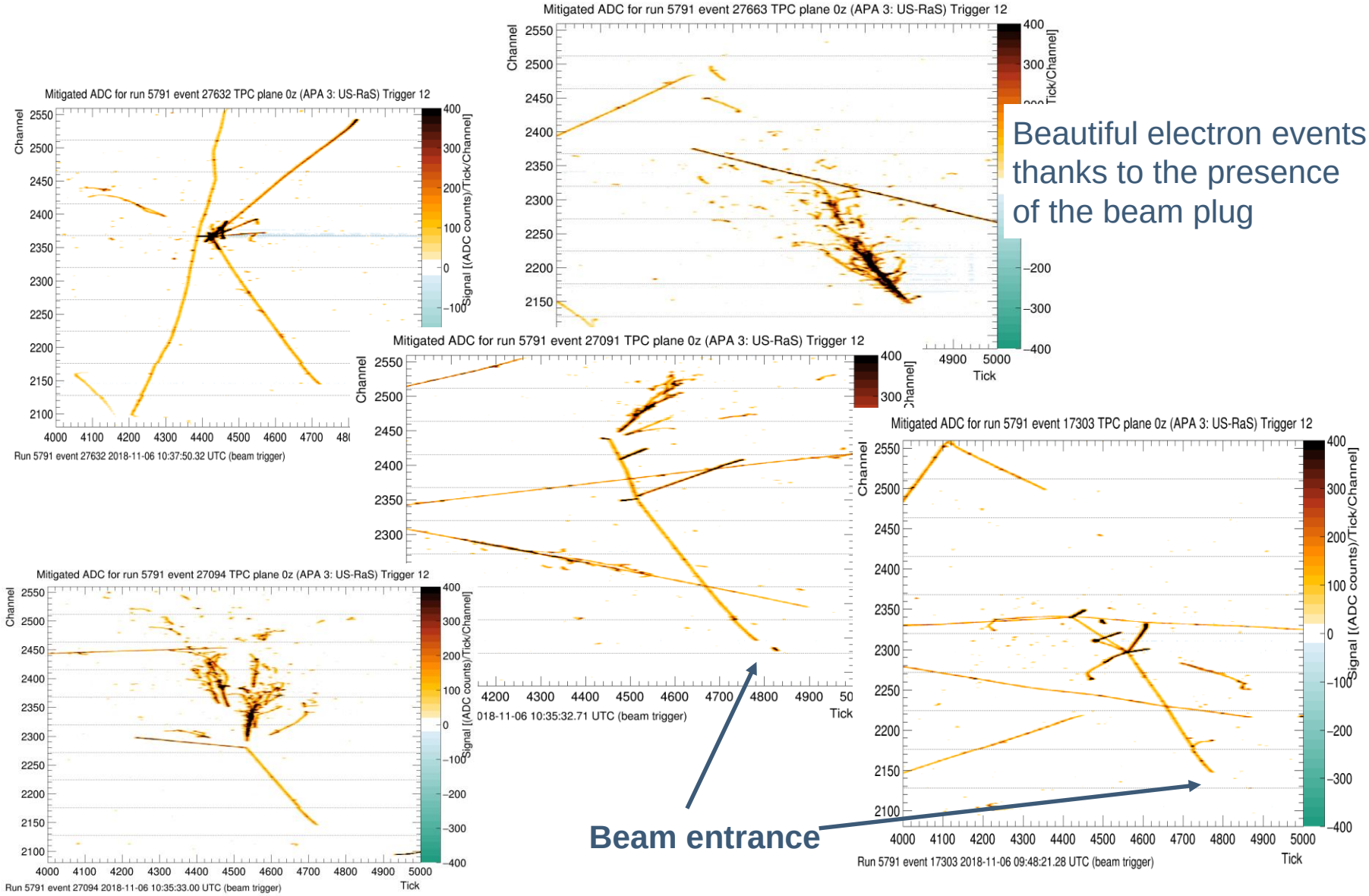
Momentum	Total Triggers	Expected Pi trig.	Expected Proton trig.	Expected Electr. trig.	Expected Kaon trig.
0.3 GeV/c	269K	0	0	242K	0
0.5 GeV/c	340K	1.5K	1.5K	296K	0
1 GeV/c	1089K	382K	420K	262K	0
2 GeV/c	728K	333K	128K	173K	5K
3 GeV/c	568K	284K	107K	113K	15K
6 GeV/c	702K	394K	70K	197K	28K
7 GeV/c	477K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

** Numbers based on beam simulation only*

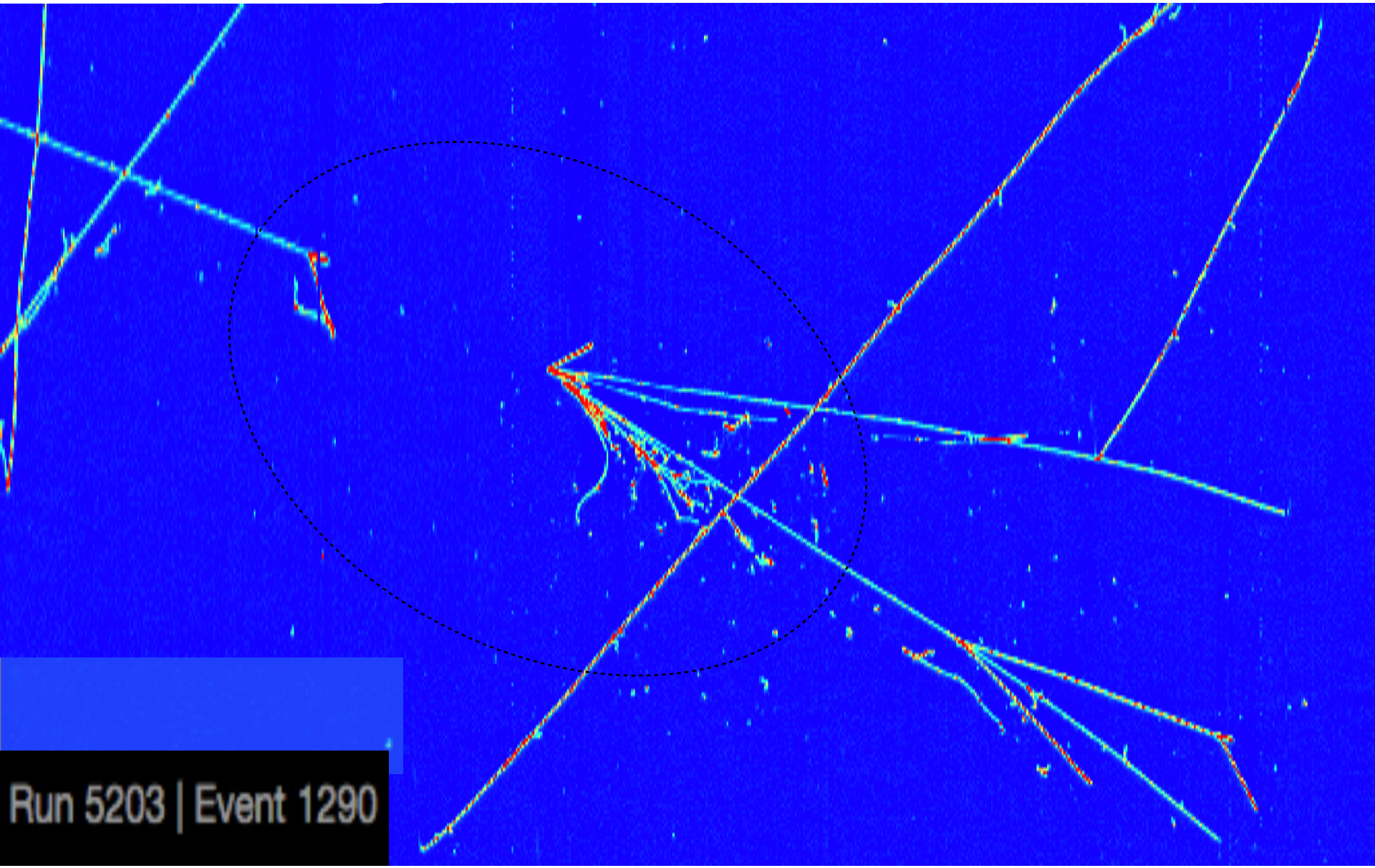
Over 4 million beam events!

Over 20 million cosmics events!

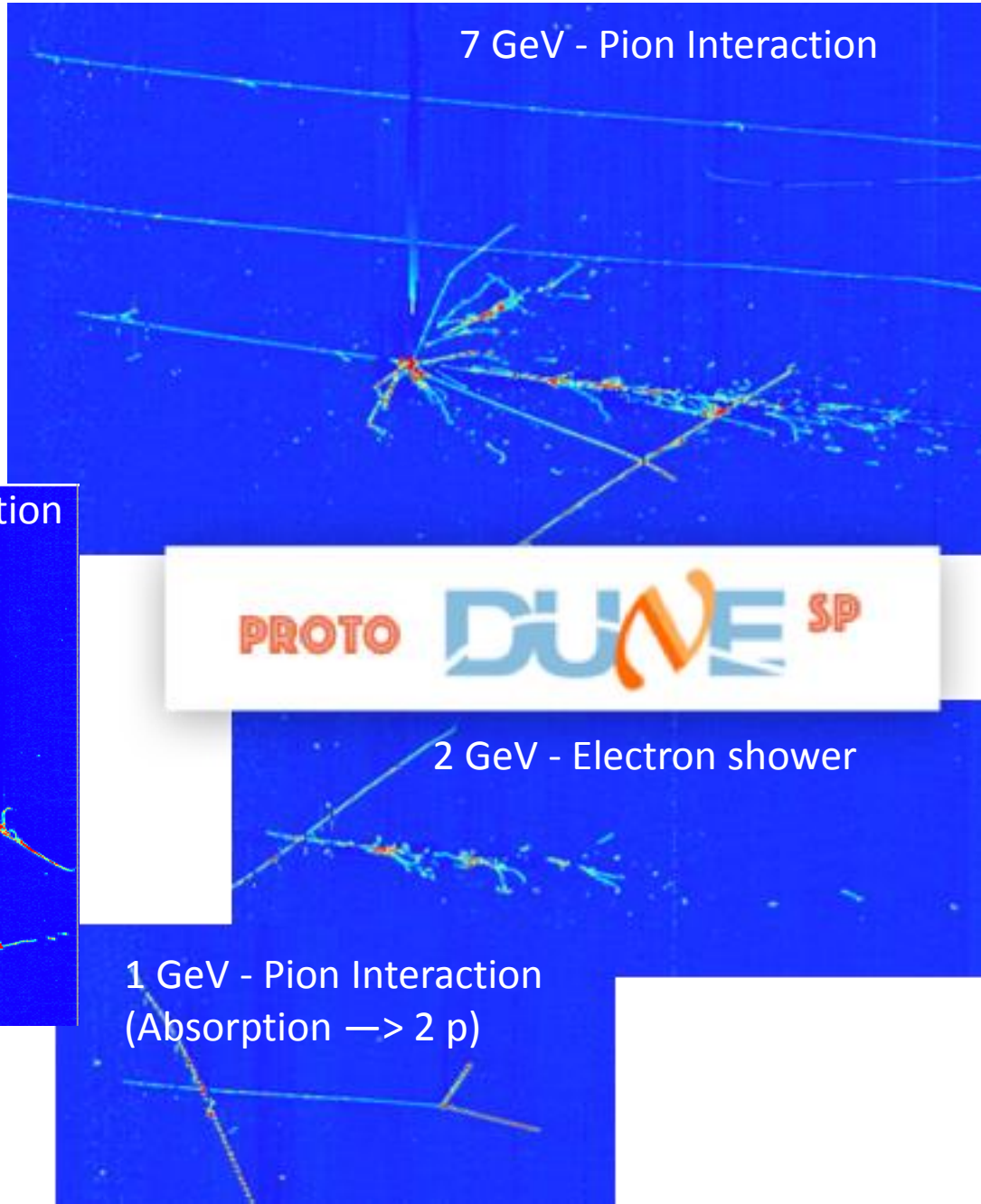
Event Gallery - Beam

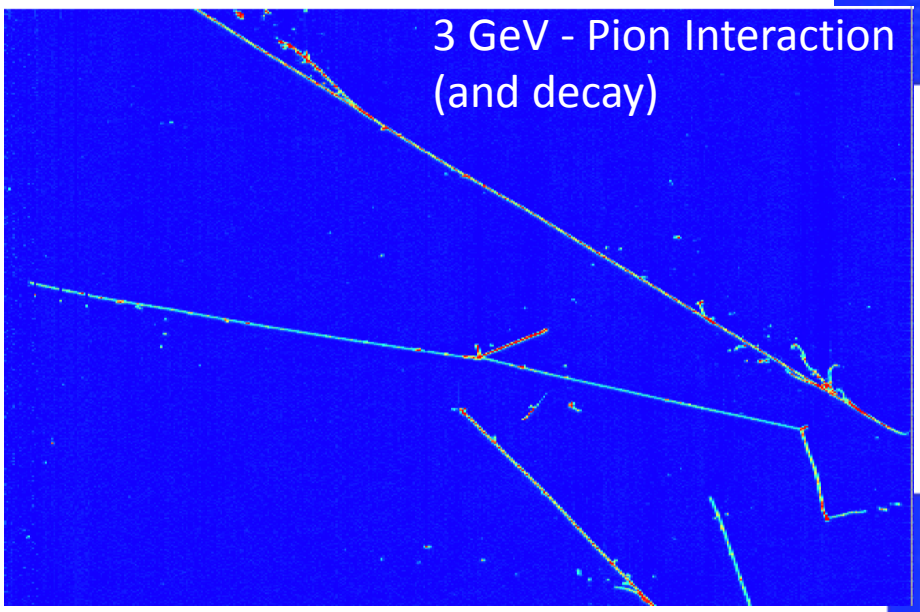


Beautiful electron events thanks to the presence of the beam plug


Run 5203 | Event 1290

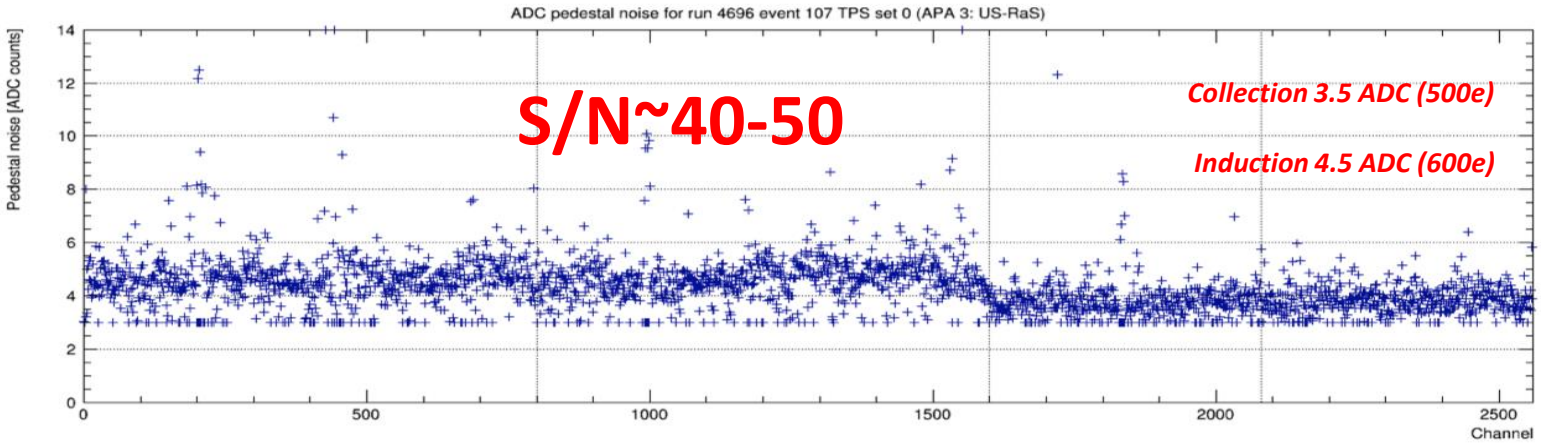
LAr TPC data of unprecedented quality





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 internal purity monitor,
real value probably ~ 12-13 ms



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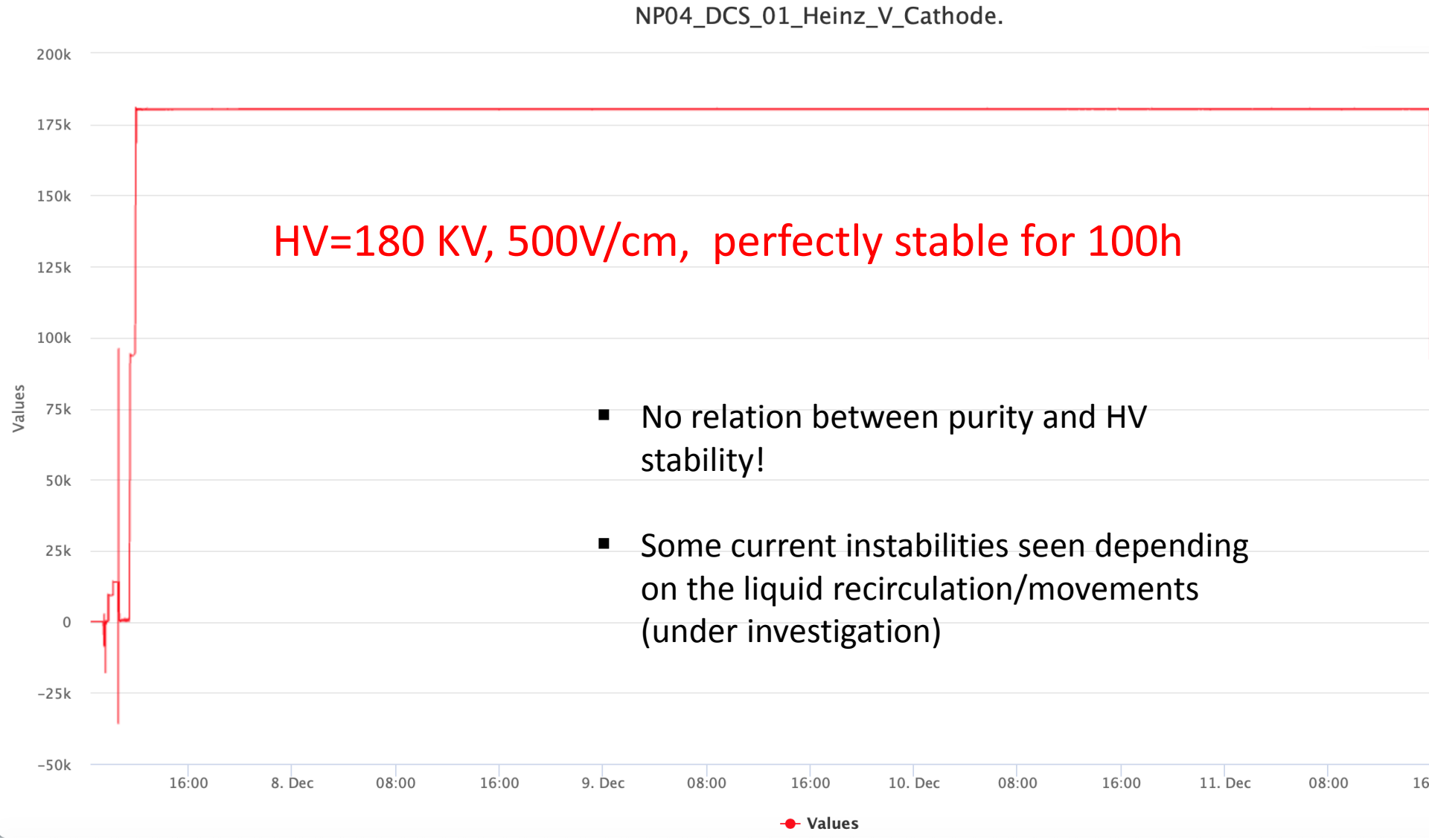
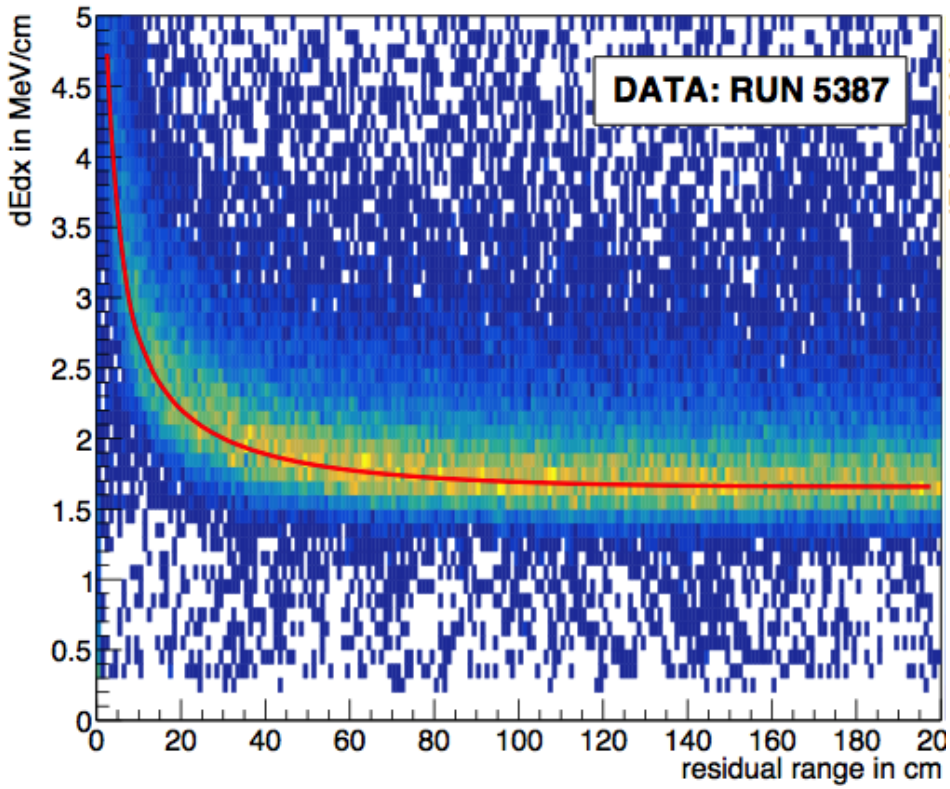
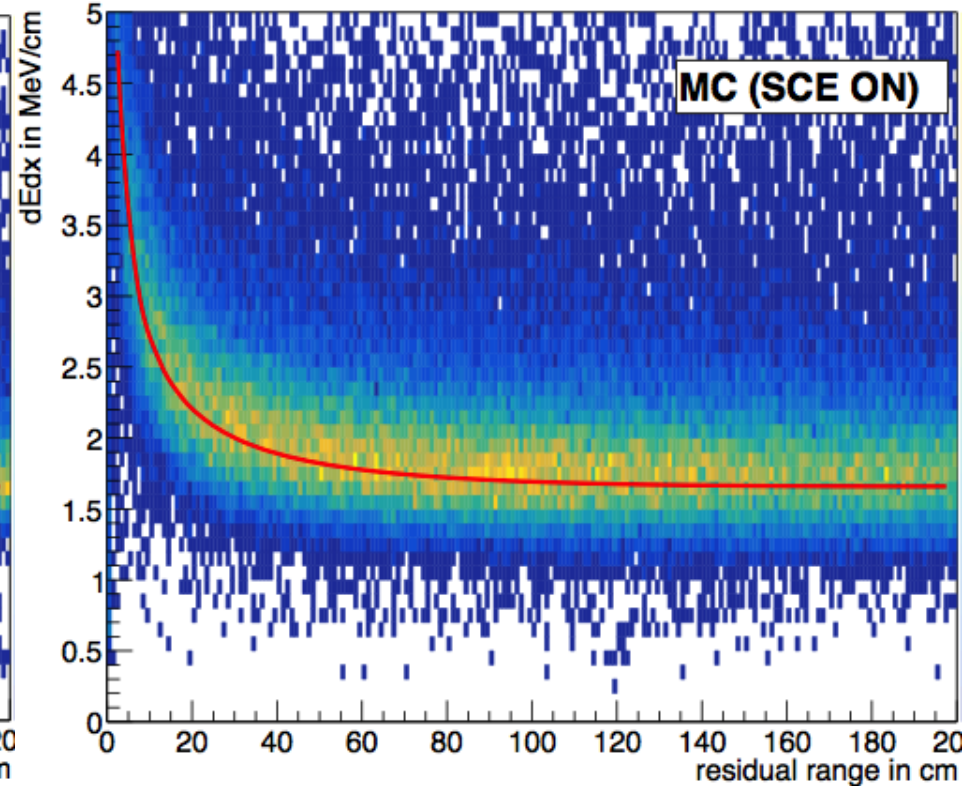
ProtoDUNE lesson



HV=180 KV, 500V/cm, perfectly stable for 100h

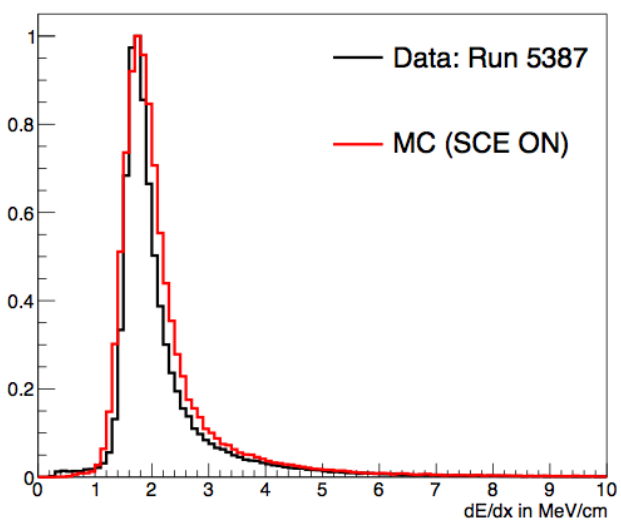
- No relation between purity and HV stability!
- Some current instabilities seen depending on the liquid recirculation/movements (under investigation)





Charge Signal Calibration: from ADC to Charge to Energy

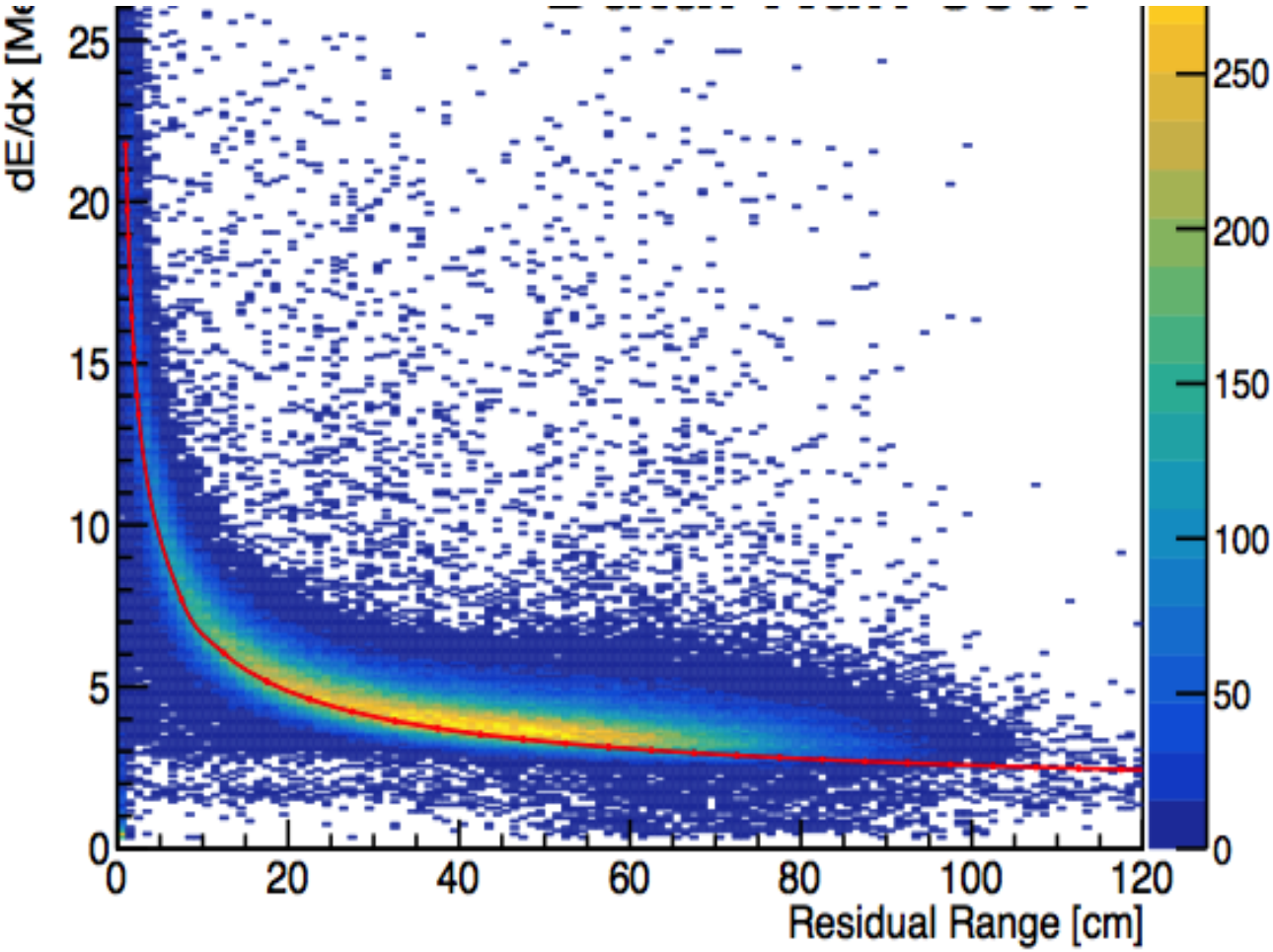
(after e-Lifetime and SpCharge correction)

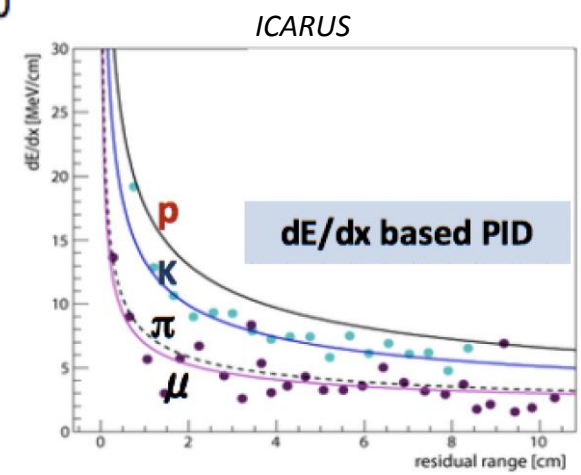


Cosmic Stopping Muon dE/dx distributions: **data** & **MC**.

Red curve: Bethe-Bloch most probable value of dE/dx versus residual range

protoDUNE preliminary

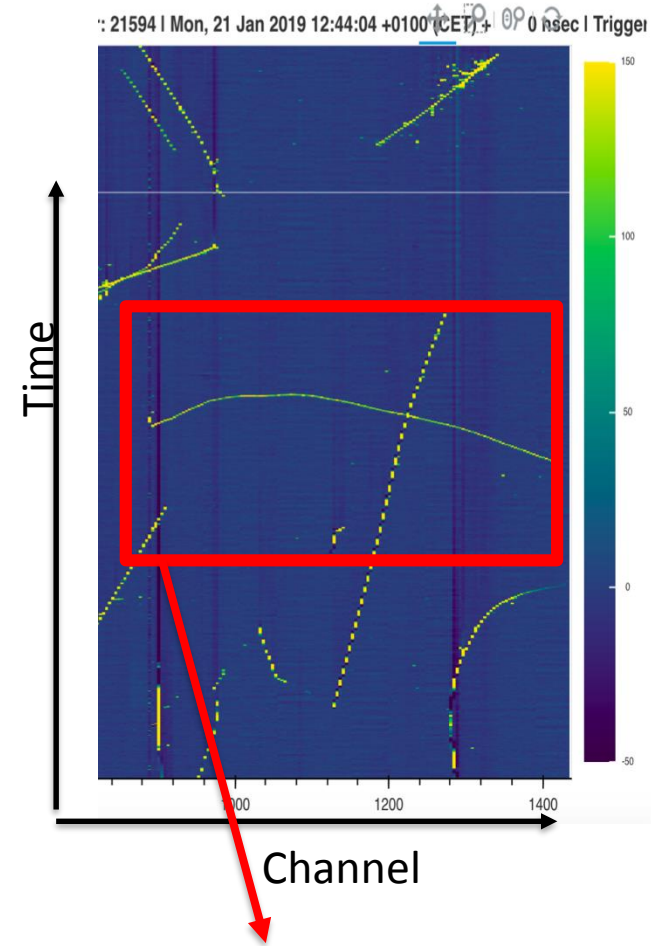




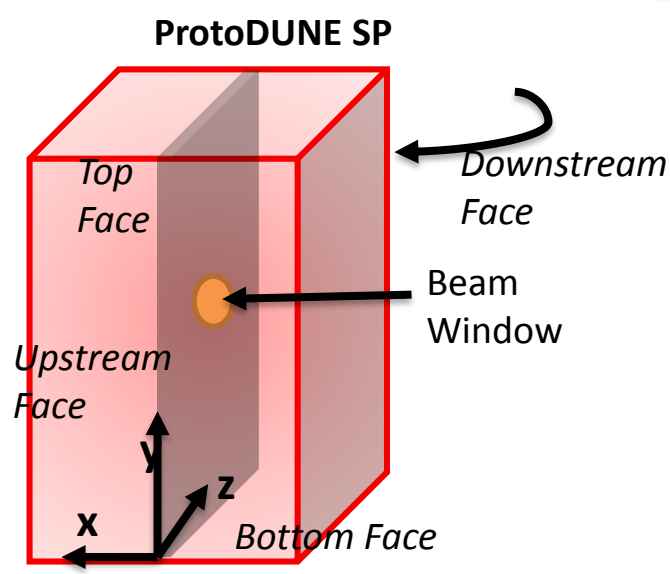
Proton dE/dx distribution for 1 GeV beam data after applying the calibration derived using cosmic ray muons. Red curve: expected (theoretical prediction) most probable value of dE/dx vs residual range.

Space Charge Effect (SCE)

- Positive Ions accumulate at cathode, introduce their own electric field which distorts the detector E-field
  - Causing **offset** for cosmics entering and exiting the TPC faces and distortions (bowing)
  - Tracks are **"pushed inside"** from the borders of the detector
- SCE depends on cosmic ray flux, E-field and drift distance in the LAr TPC, ions mobility
- **Need a 3D correction map**, use cosmics with known position
  - Cathode crossing
  - Anode piercing
  - CRT tagged

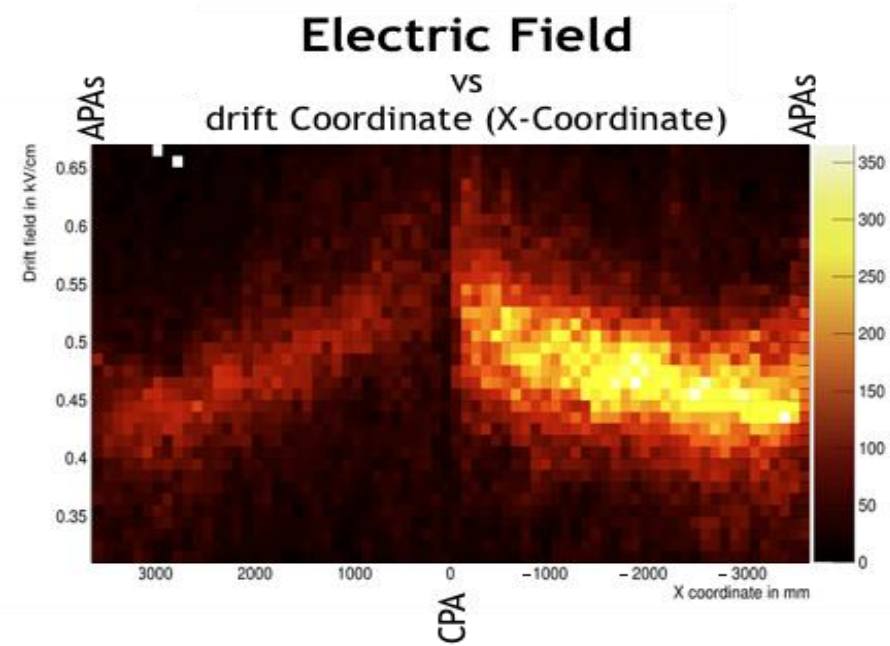


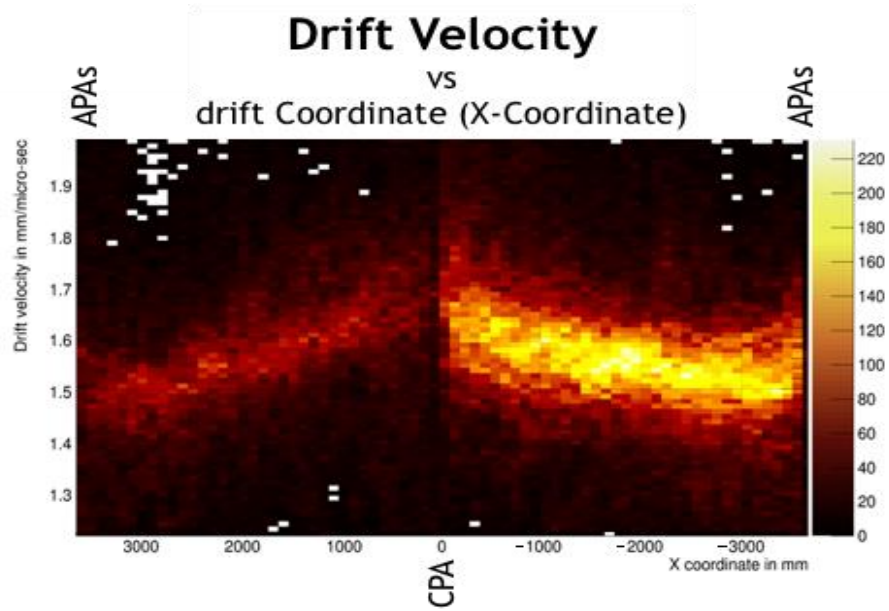
Raw Data
Cosmic muon should be a straight line.
→distorted because of SCE



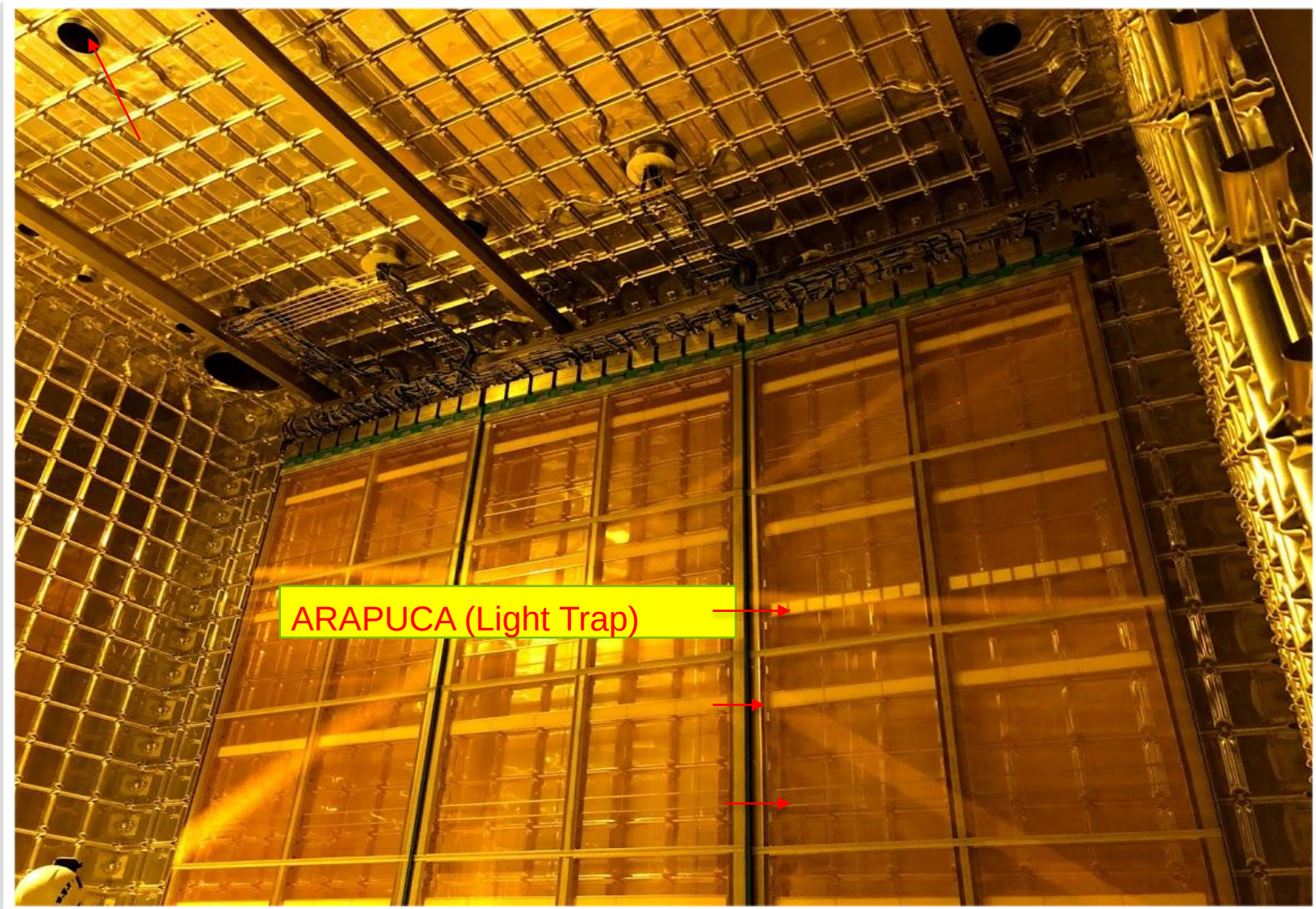
Space Charge Effect (SCE)

- **Maximum offset of ~35cm @ nominal field 500V/cm**
- Strongest displacements close to cathode (x=0)
- Asymmetry between two sides →caused by convection and liquid insertion + extraction, the detector is not in the middle of the cryostat



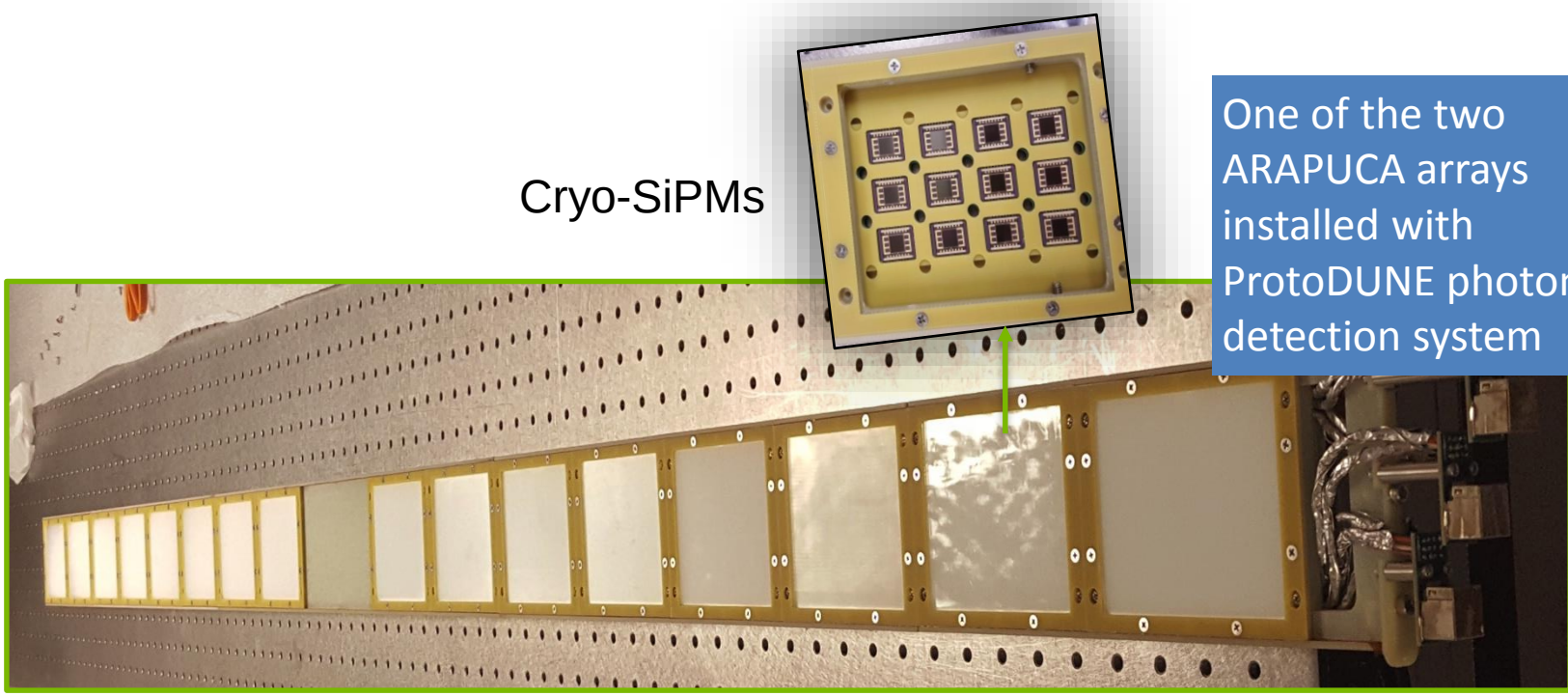


Photon-Detector



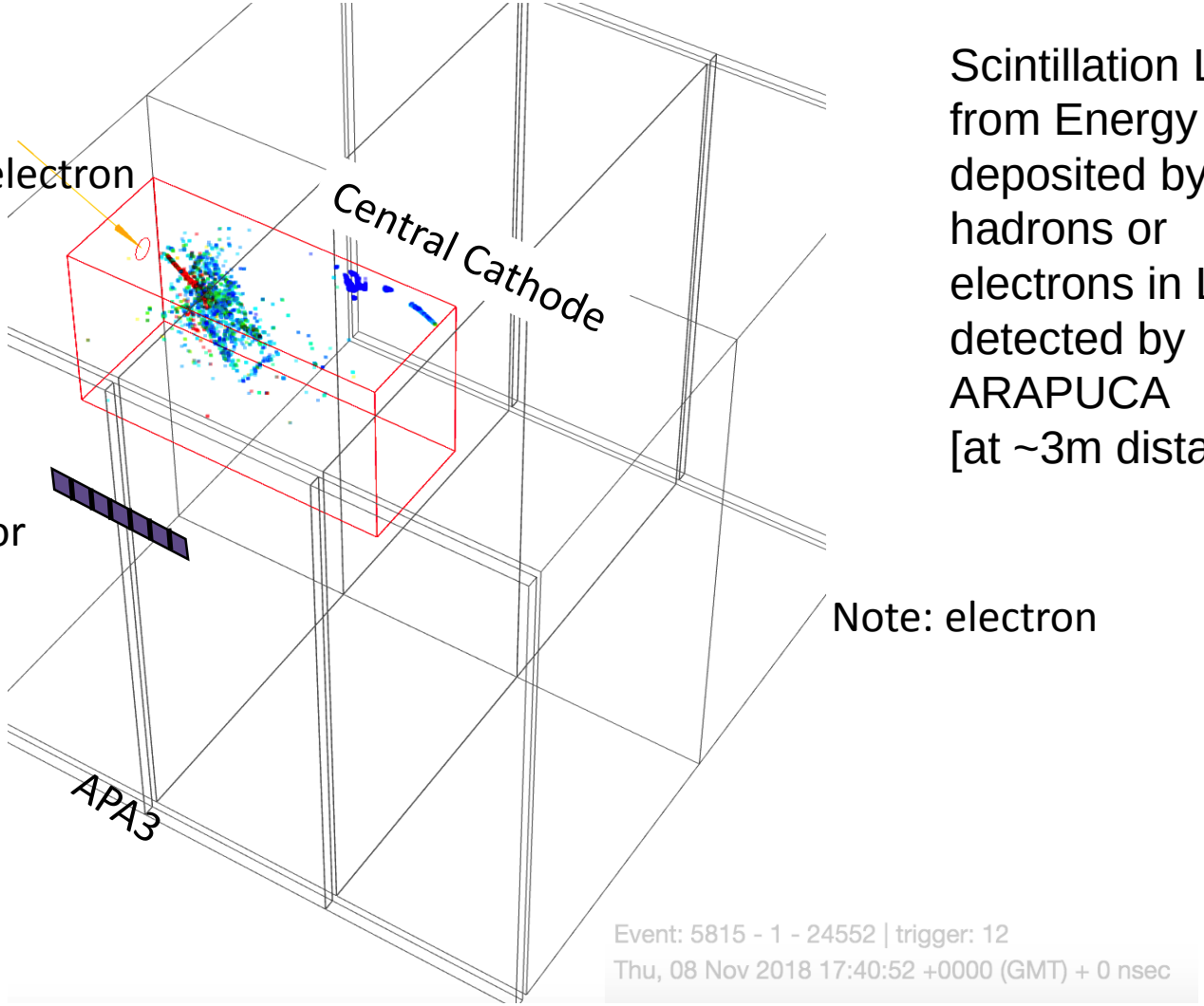
ARAPUCA PD design for protoDUNE

- 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

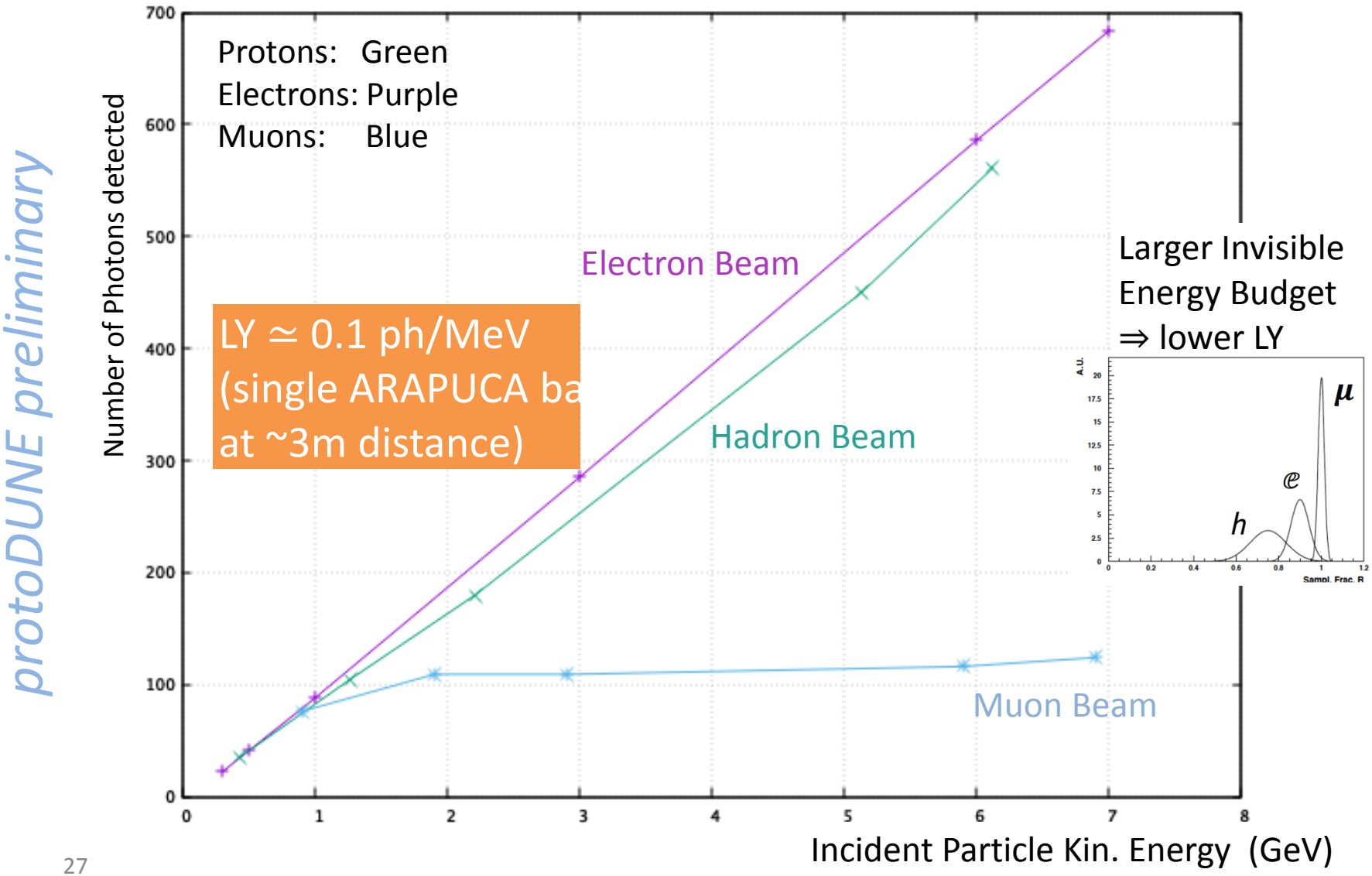
Test Beam Run:
1 - 7 GeV Momentum Charged Particle (e, had) Beams



Scintillation Light from Energy deposited by beam hadrons or electrons in LAr detected by ARAPUCA [at ~3m distance]

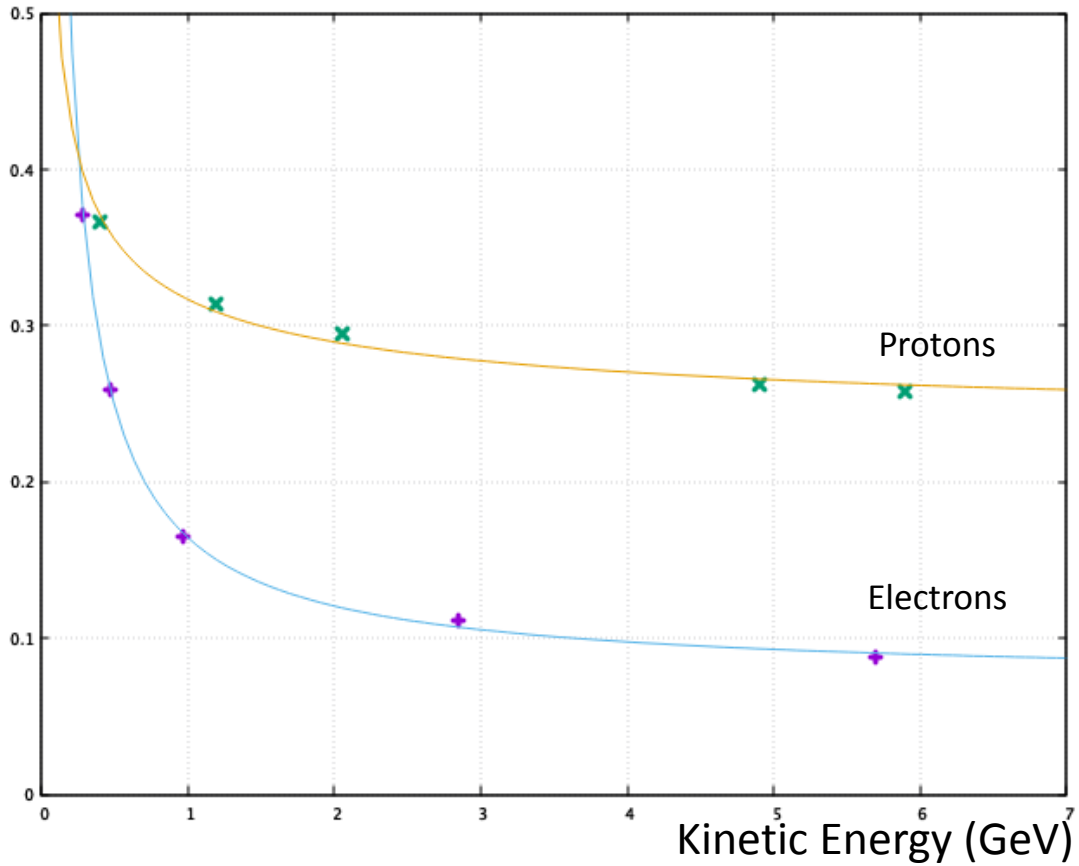
Note: electron

Calorimetric ENERGY reconstruction from detection of LAr Scintillation Light by ARAPUCA Bar



Calorimetric ENERGY reconstruction from detection of LAr Scintillation Light by ARAPUCA Bar

protoDUNE preliminary



$K_1 = 0.26 \pm 0.02$
$K_2 = \mathbf{0.17} \pm 0.07$
$K_3 = 0.0004 \pm .....$

$K_1 = 0.12 \pm 0.01$
$K_2 = \mathbf{0.073} \pm 0.006$
$K_3 = 0.082 \pm 0.004$

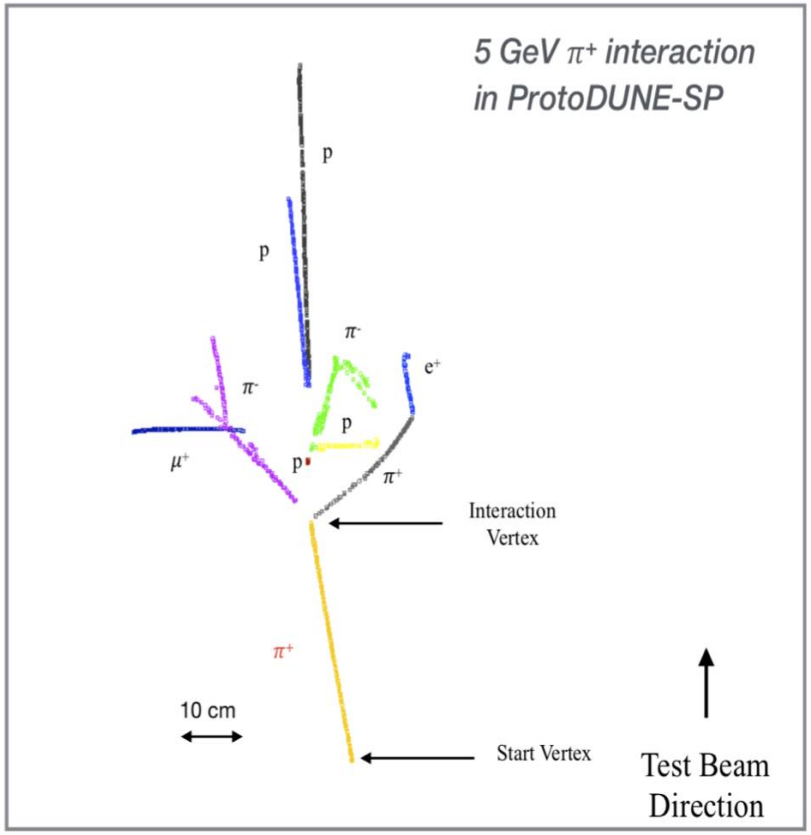
k1 (constant term) includes "longitudinal leakage" (energy deposited far from the PhDet - part of scintillation light not detected)

k2 (stochastic term) - detector resolution (in case of protons, it includes beam momentum spread)

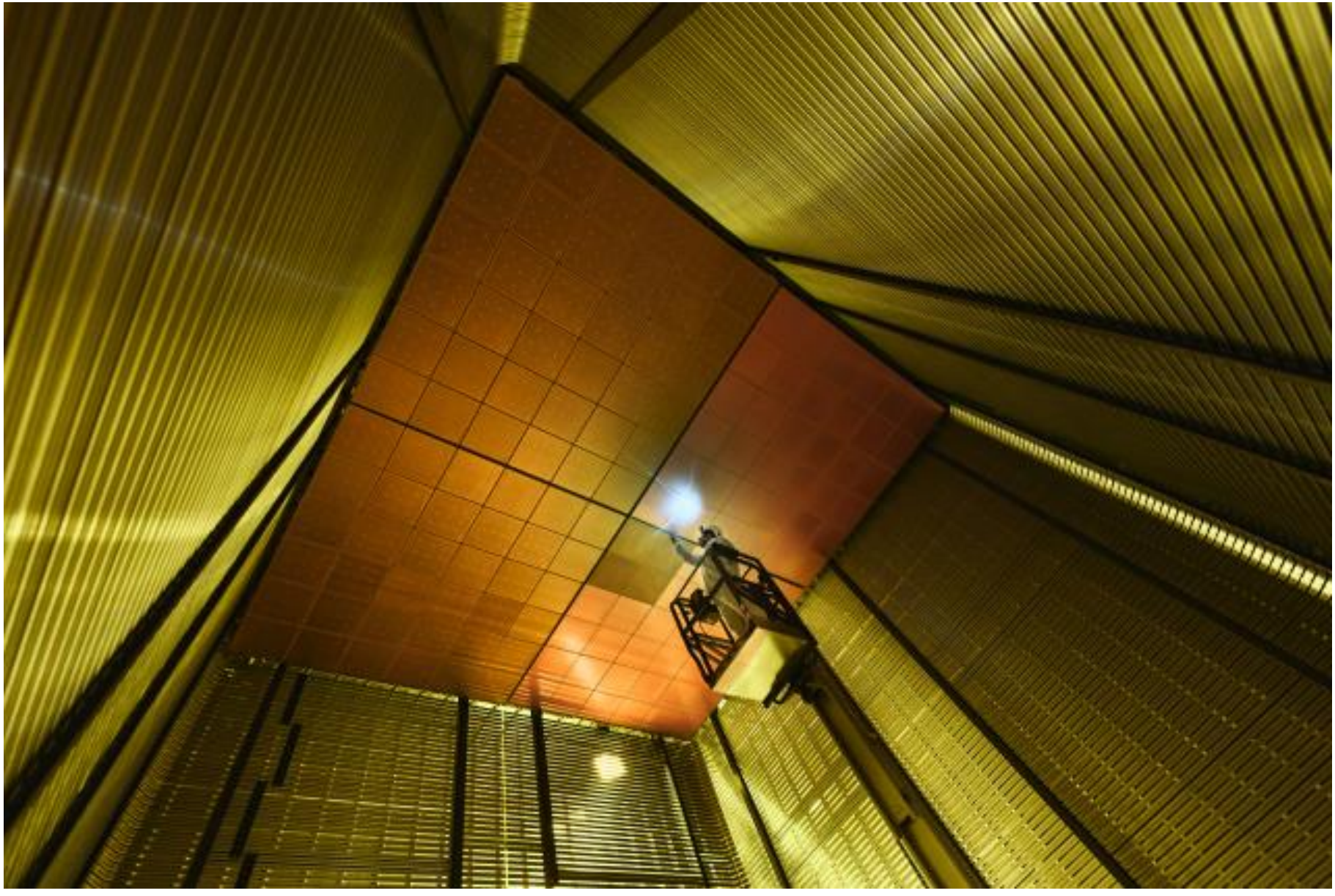
k3 account for the spread in the beam momentum in case of electrons

Automated pattern recognition and reconstruction softwere

- 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



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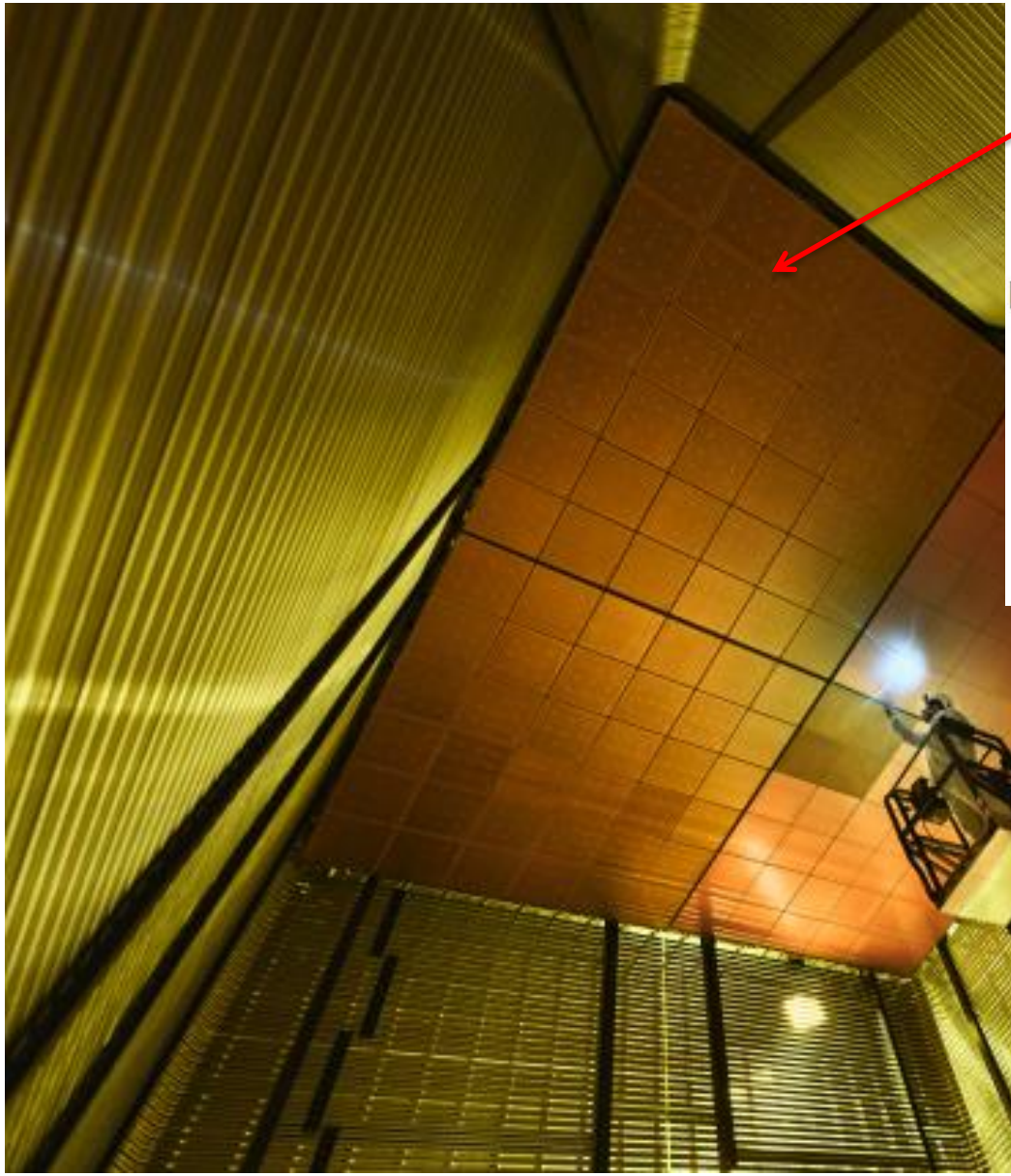
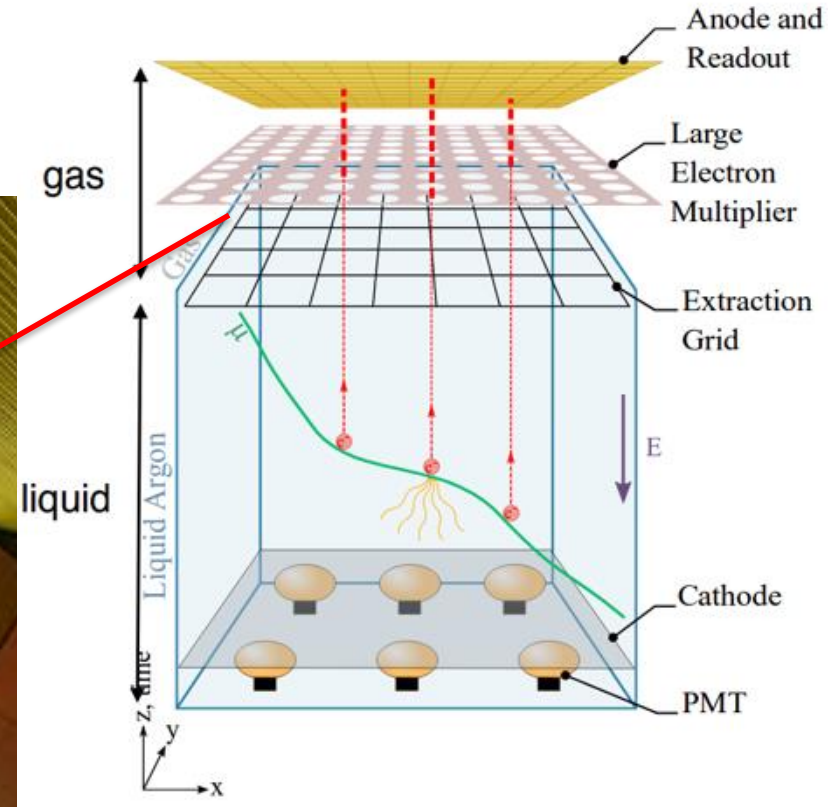
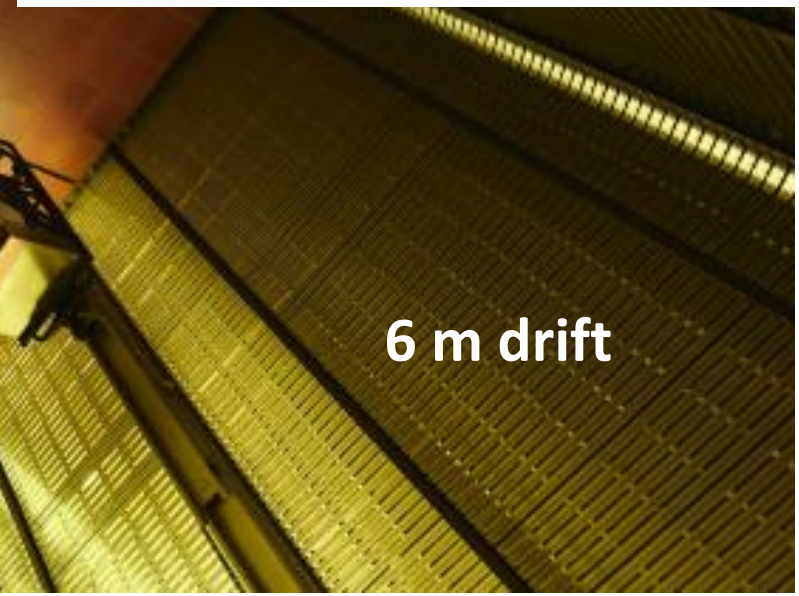
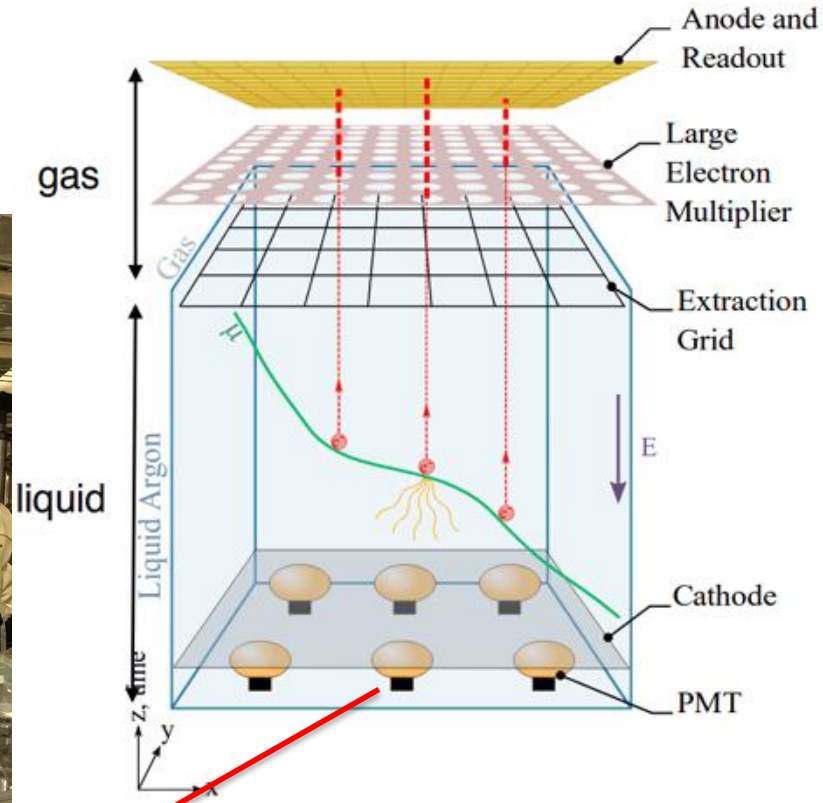




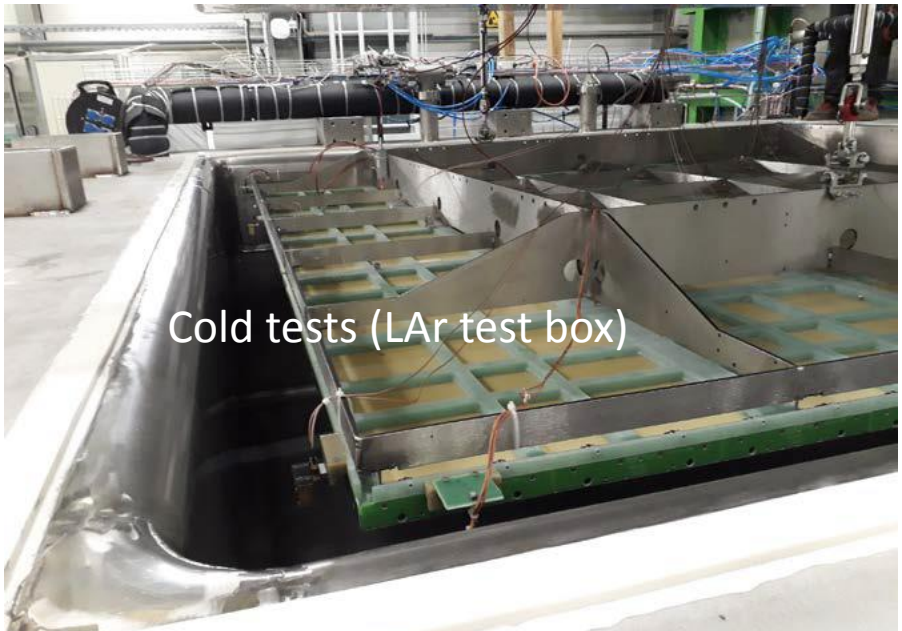


NP02: double phase



NP02: double phase

- *LEM amplifier technology more complex, needed more iterations (HV stability tuning)*
- Final readout units assembled and cold tested by end of 2018
- *Final installation ongoing, start closing the cryostat in the second half of April*
- Start purging, cooling and filling in June 2019
- *We expect the HV on by end July-August 2019*



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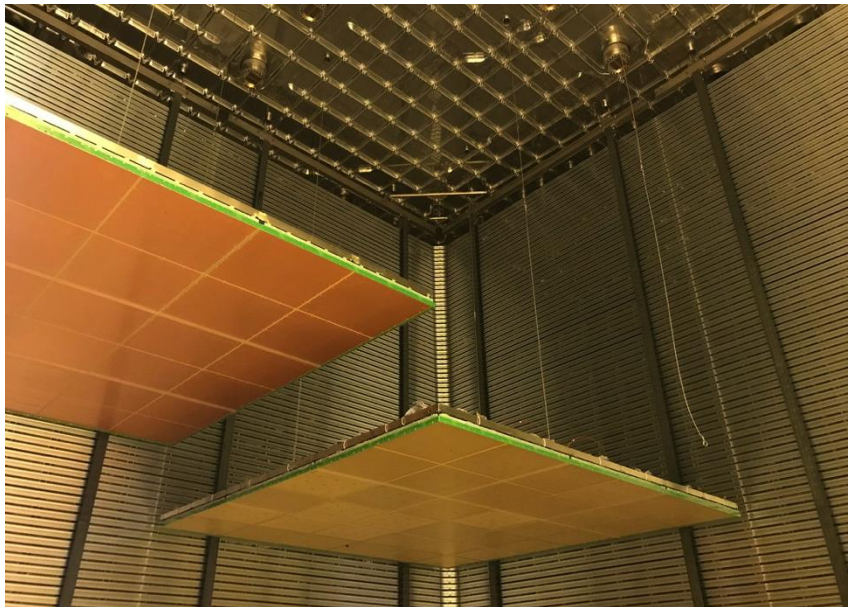

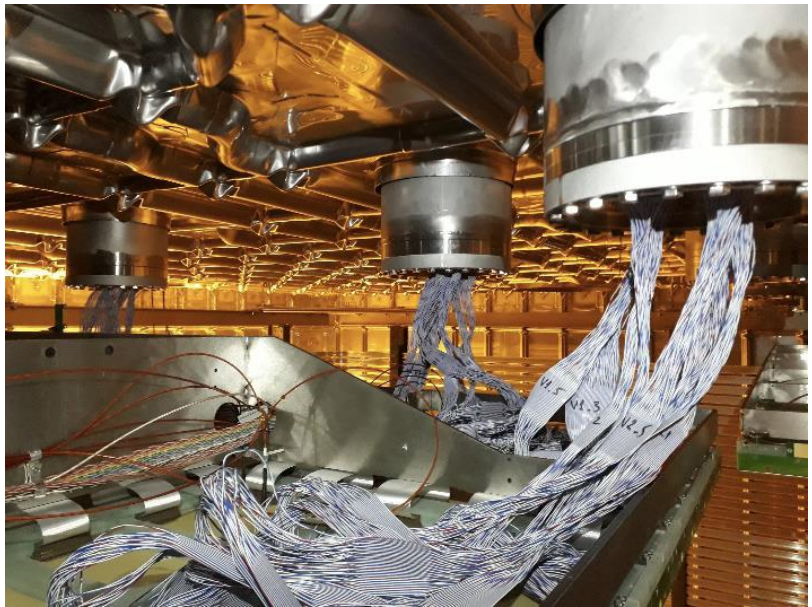

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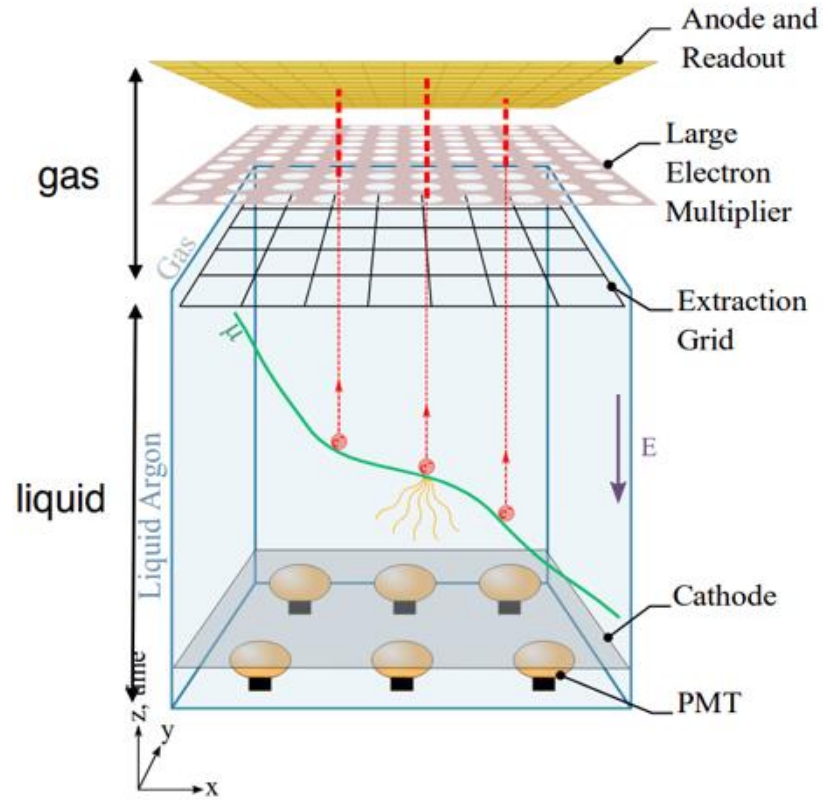


- ✓ ProtoDUNE DP as a real first large scale demonstrator.
- ✓ More critical technology (LEM amplifiers stability, high HV system=600KV) which needs more R&D in the future to be ready for a final DUNE detector.
- ✓ Environmental conditions (liquid purity, space charge effects, positive ions back drift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

Summary

- Very intense 3 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, I did not point it directly to avoid confusion)
- 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.

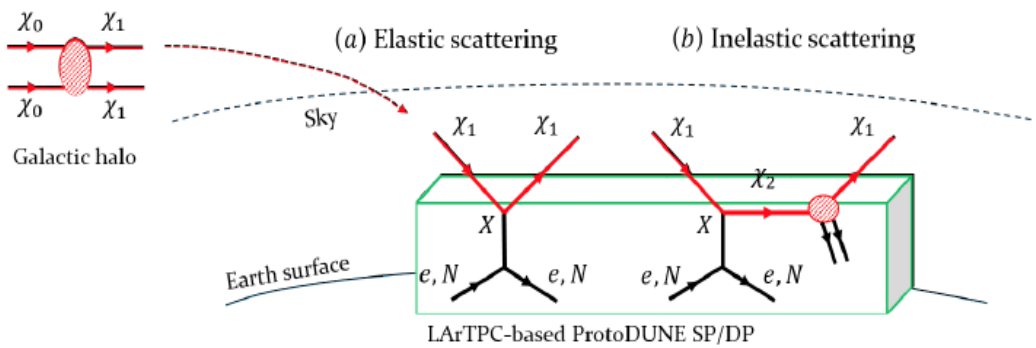
Physics research possibilities with protoDUNE

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

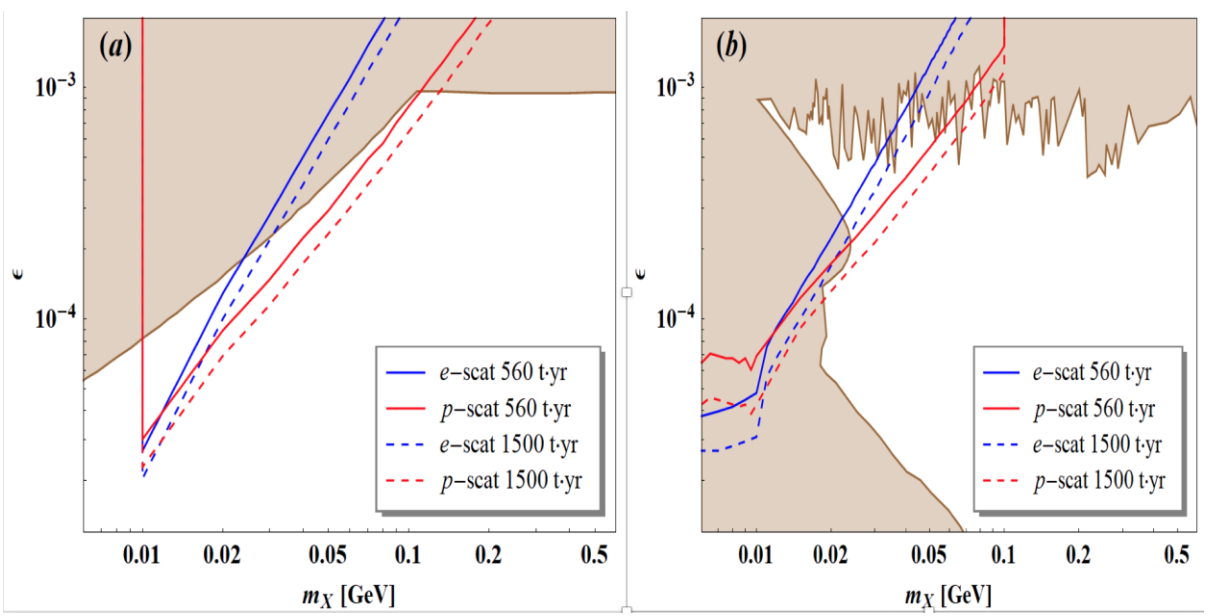
- *Hadronic –Argon cross section measurements (inclusive and semi-exclusive)*
- *Searches for boosted dark matter in cosmic rays*
- *Searches for fractional/mini/millicharged particles in cosmic rays*
- *Searches for monopoles in cosmic rays*

Grazie

Boosted Dark Matter



arXiv:1803.03264

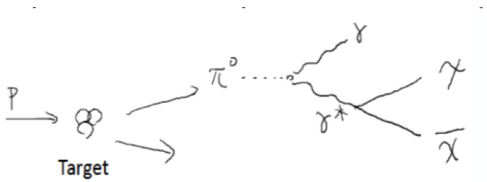


Dark matter with multiple components in order to be compatible with present DM limits

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



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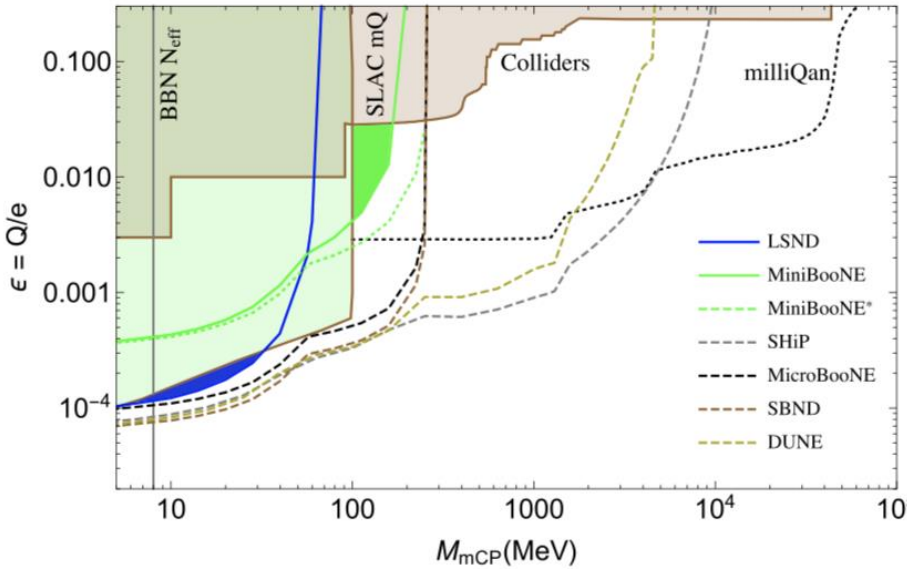
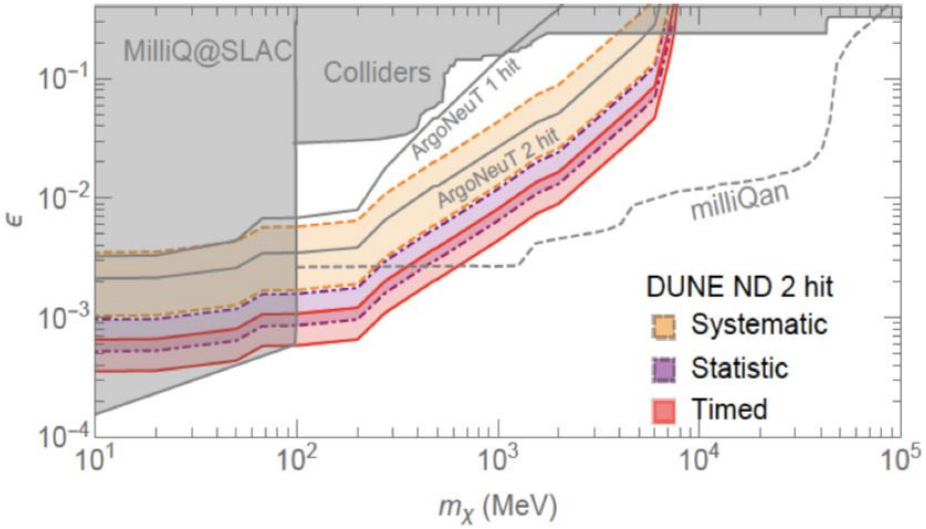


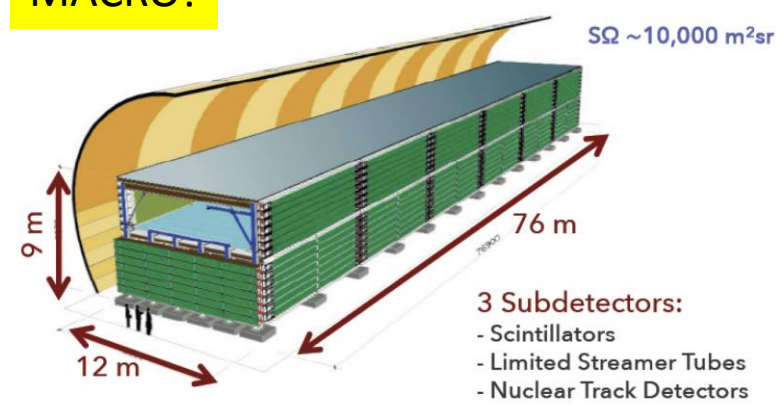
arXiv:1902.03246



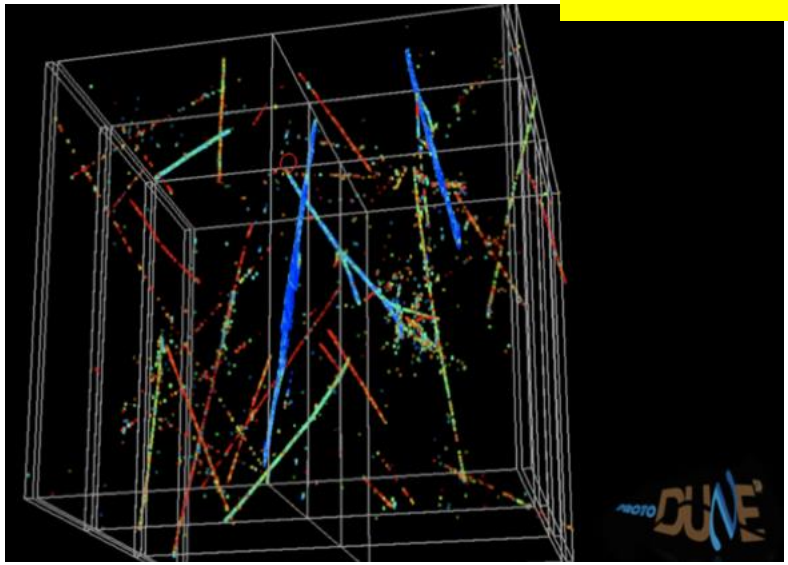
Sensitivity for DUNE ND and ProtoDUNEs under study

Monopole Searches

MACRO!

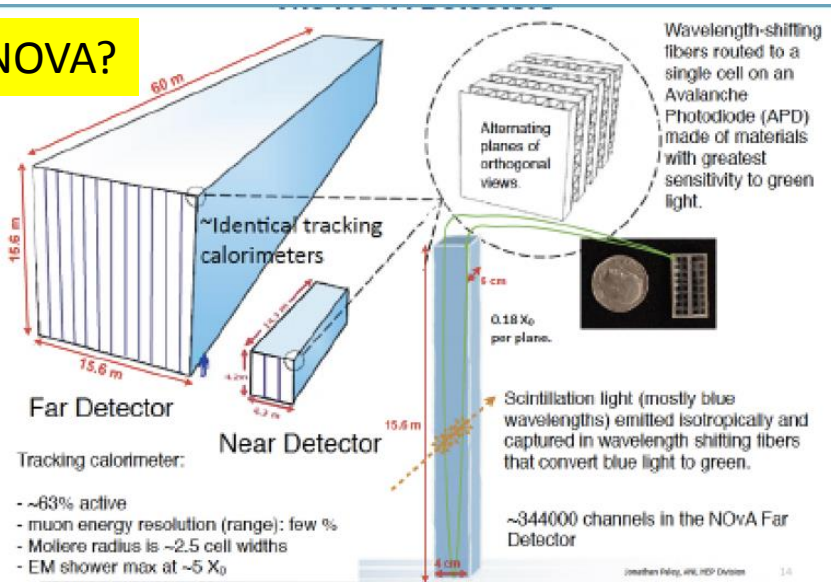


ProtoDUNE??



Ionization saturation?
Backgrounds?
Triggers?

NOVA?



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