Liquid Argon TPCs as Neutrino Detectors

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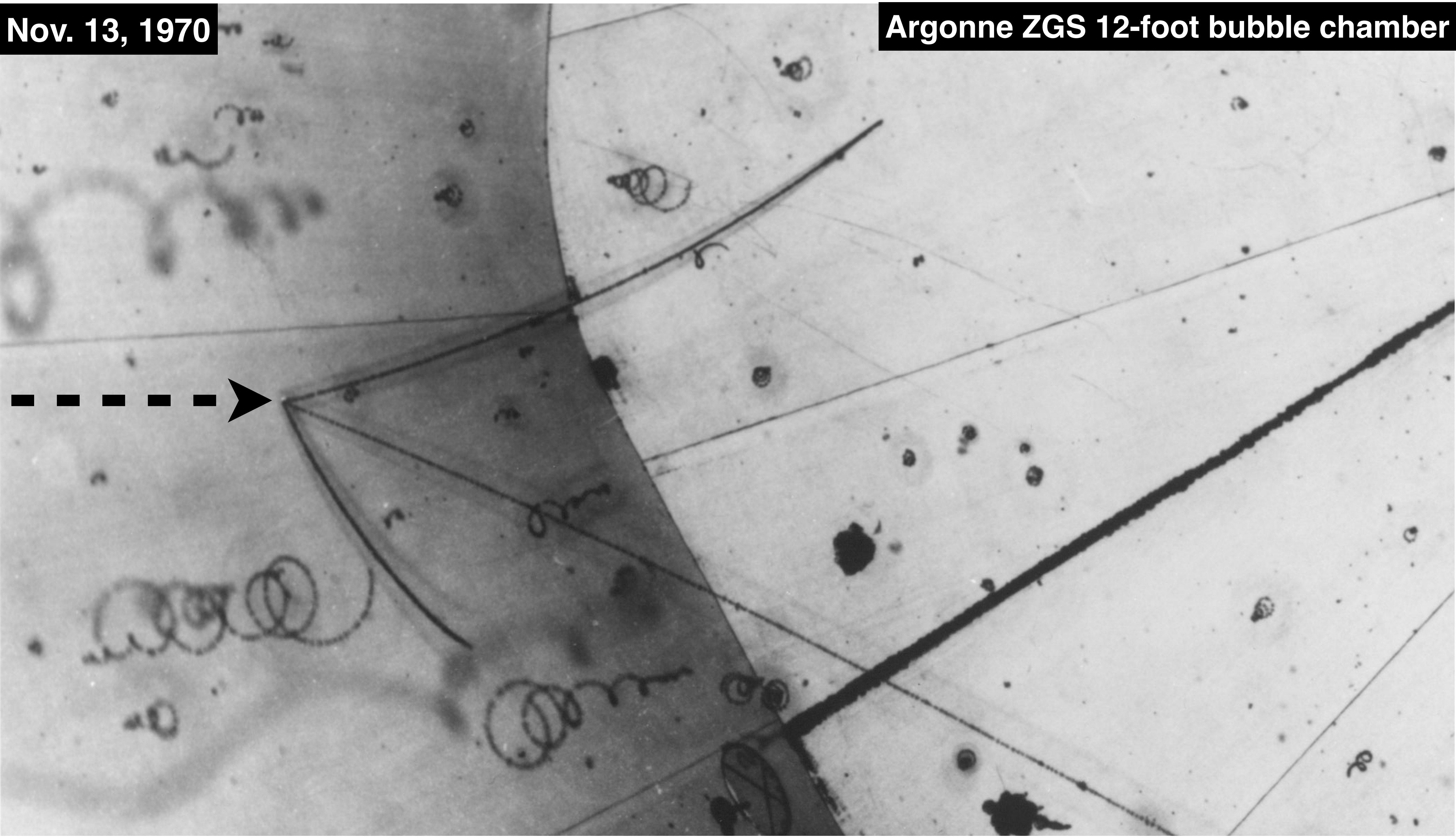
Enrico Fermi Institute, University of Chicago

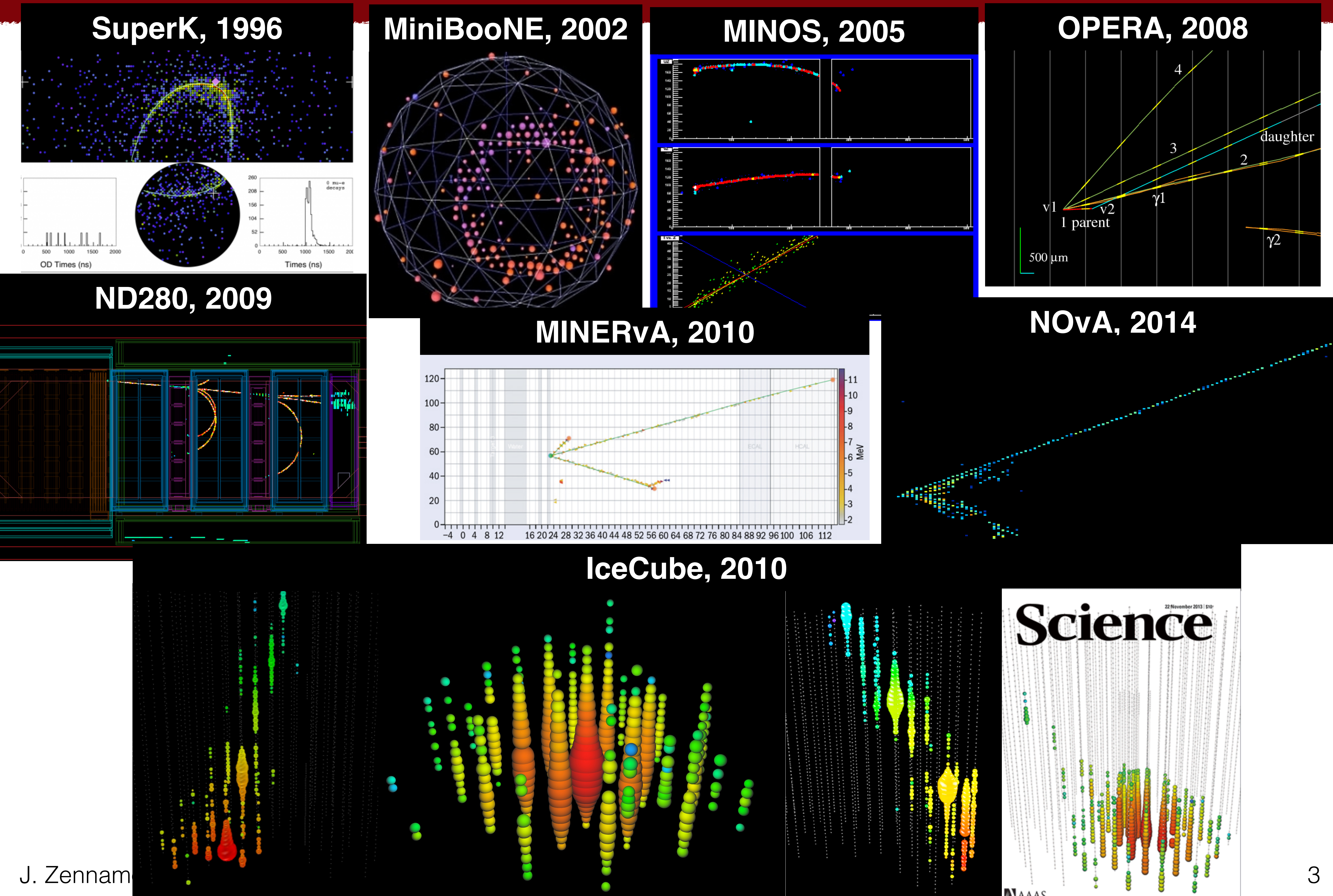
The IceCube Particle Astrophysics Symposium
May 6th, 2015

THE UNIVERSITY OF CHICAGO

In the beginning…



Neutrino Detectors



Enter the LArTPC…

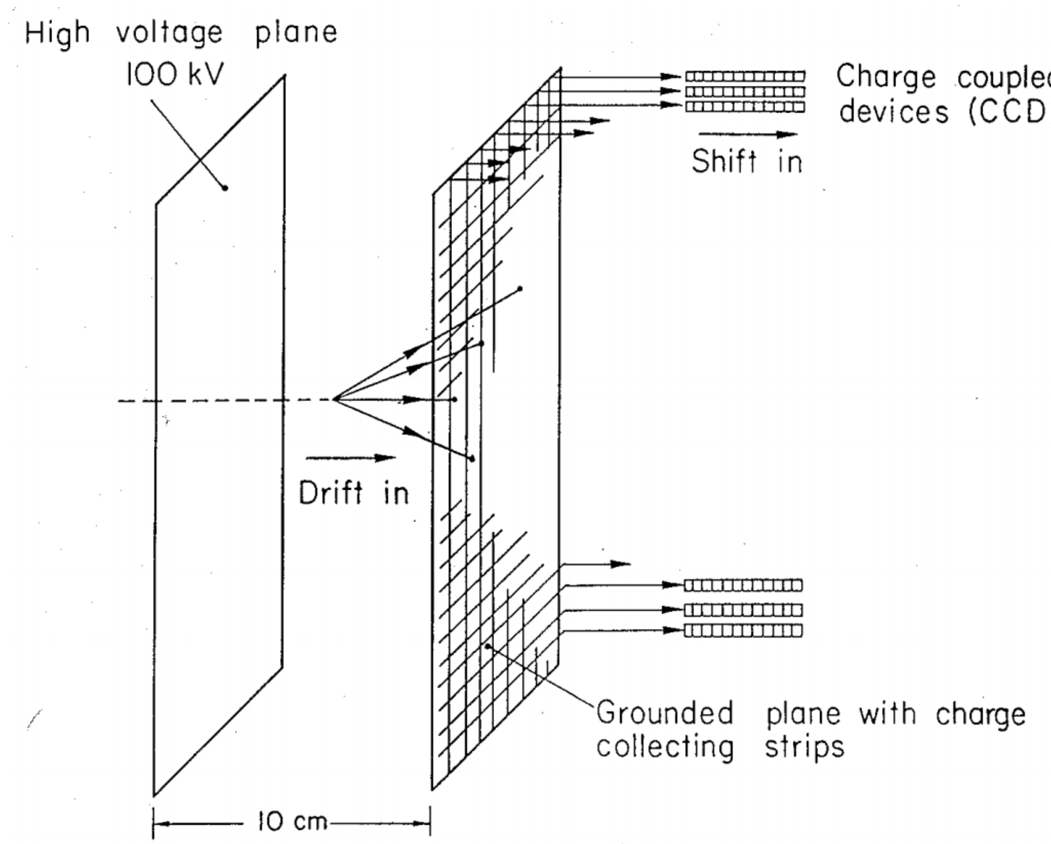
- 1950s - Liquid argon ionization chambers were in use
- 1968 - Alvarez proposed using liquid noble gas devices for particle physics
- 1970s - Liquid noble calorimeters were in use
- 1977 - Carlo Rubbia proposed using Liquid Argon Time Projection chamber for detecting neutrinos

EP Internal Report 77-8
16 May 1977

THE LIQUID-ARGON TIME PROJECTION CHAMBER:

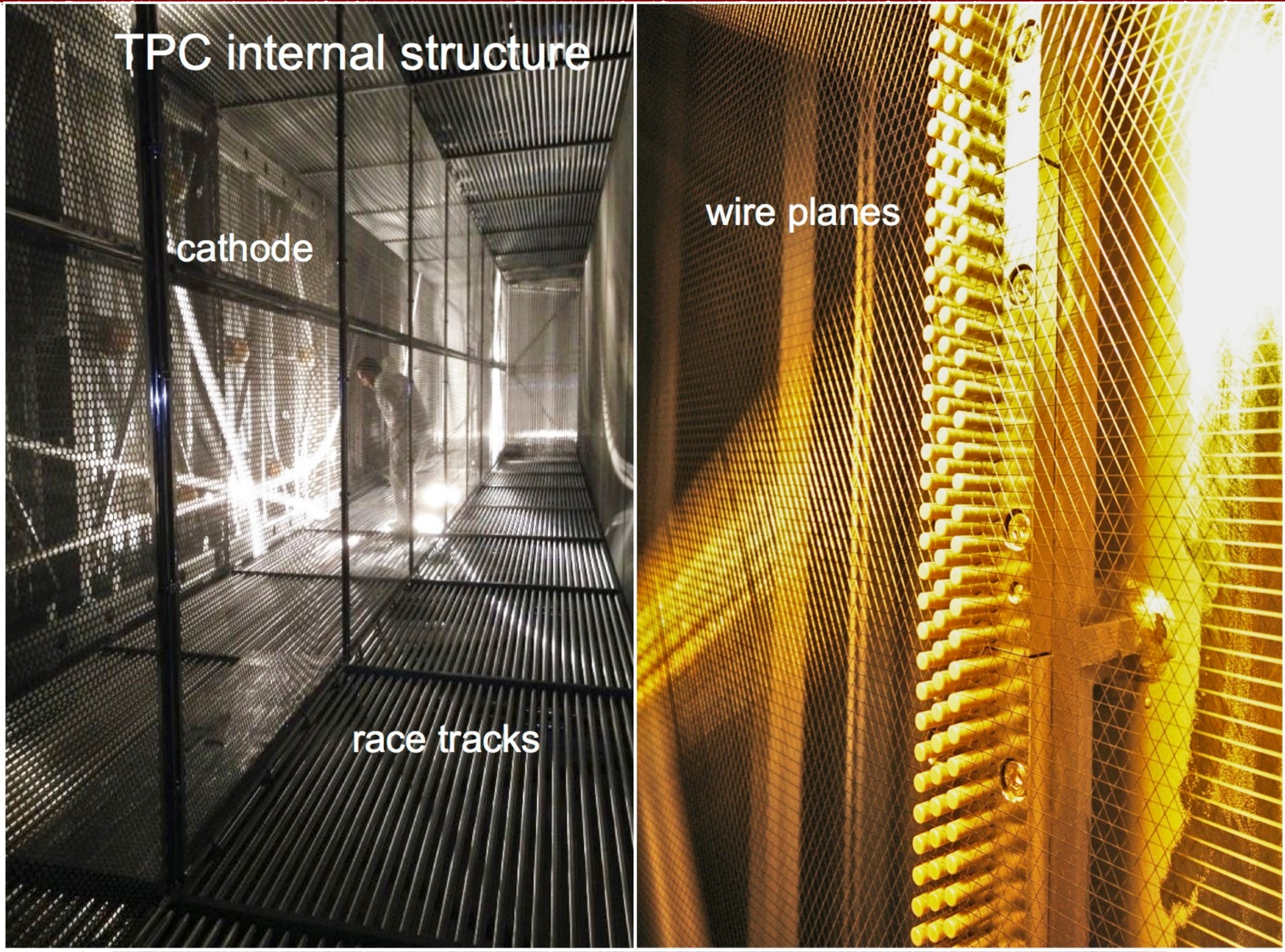
A NEW CONCEPT FOR NEUTRINO DETECTORS

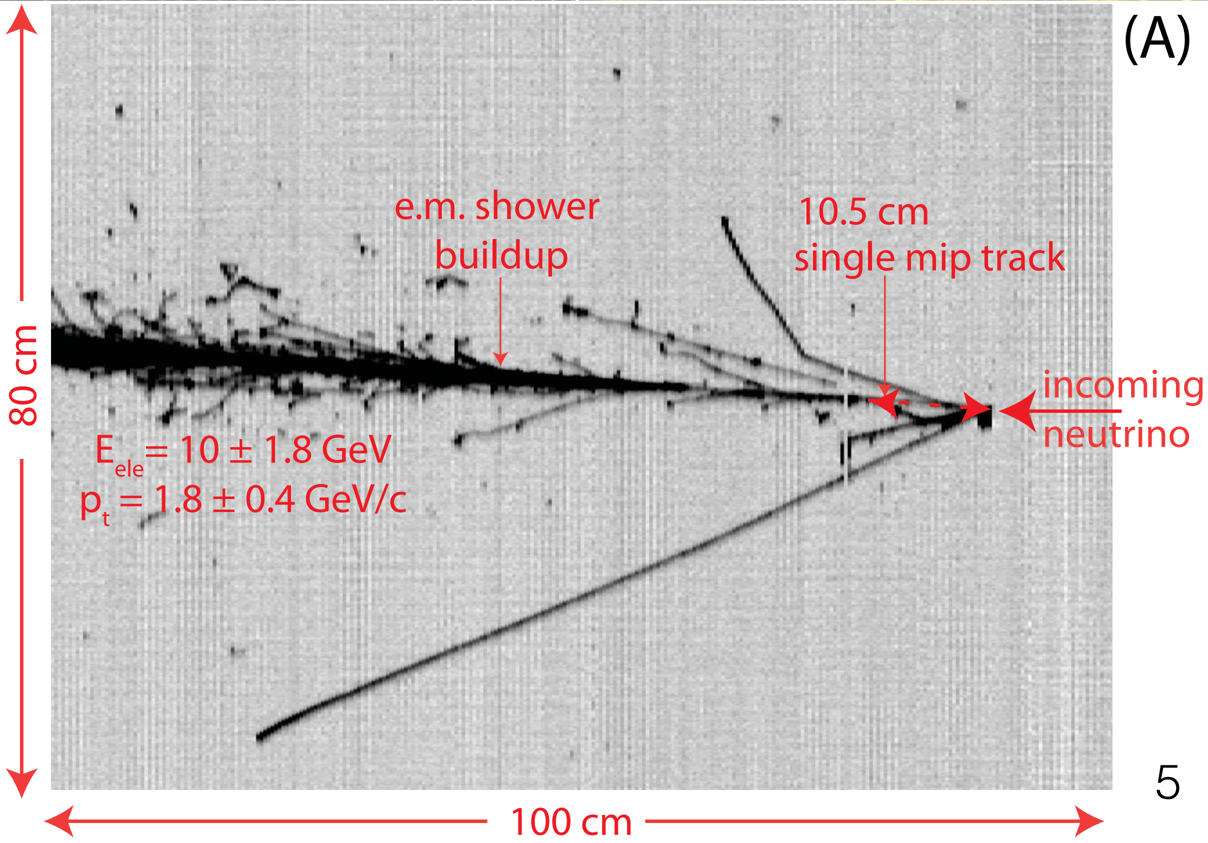
C. Rubbia



ICARUS

- 1985 - Proposal for ICARUS T600 in Gran Sasso, starting the ICARUS R&D program
  - This program addressed many of the technical challenges of developing LAr TPCs as viable neutrino detectors
- 2010-2012 - The T600 took data from the CNGS beam
- 2014+ - T600 is at CERN for refurbishment before it is moved to Fermilab as part of the Short Baseline Neutrino (SBN) program





The US Program

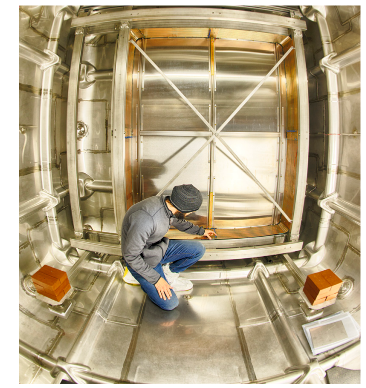
Building upon the ICARUS program a rich R&D and physics program based around LArTPCs has blossomed

R&D

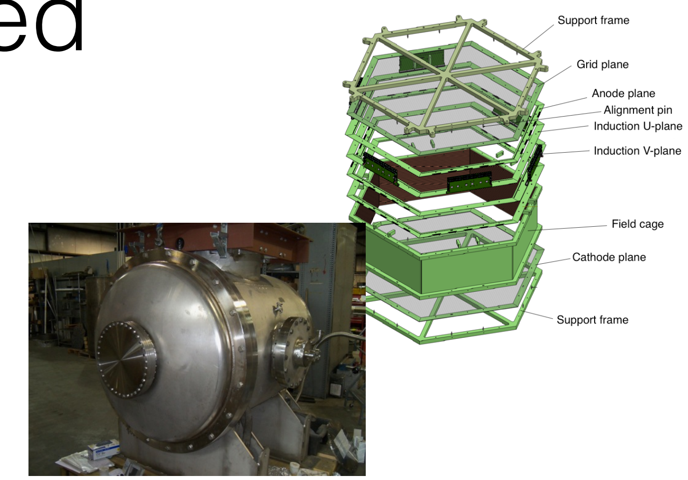
Yale TPC and Bo
(2008 and 2009)
Proof of Concept

LUKE
(2008)
Material Teststand

LAPD
(2011)
LAr Purity

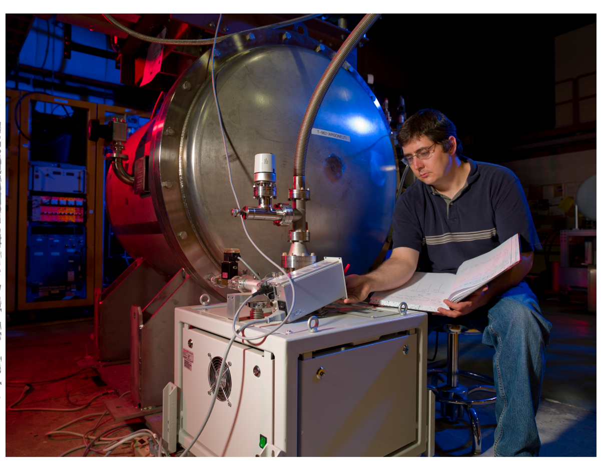


35Ton
(2013)
Cryostat Purity



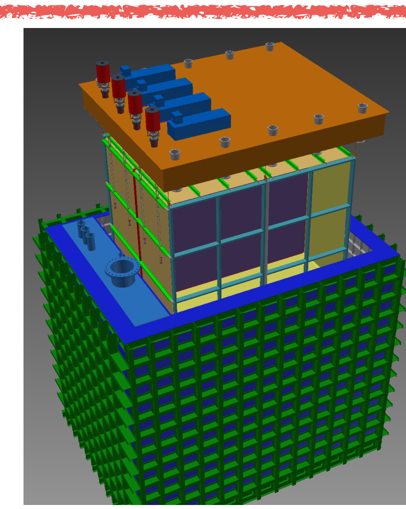
LArIAT and CAPTAIN
(2015)
LArTPC Calibration

Physics

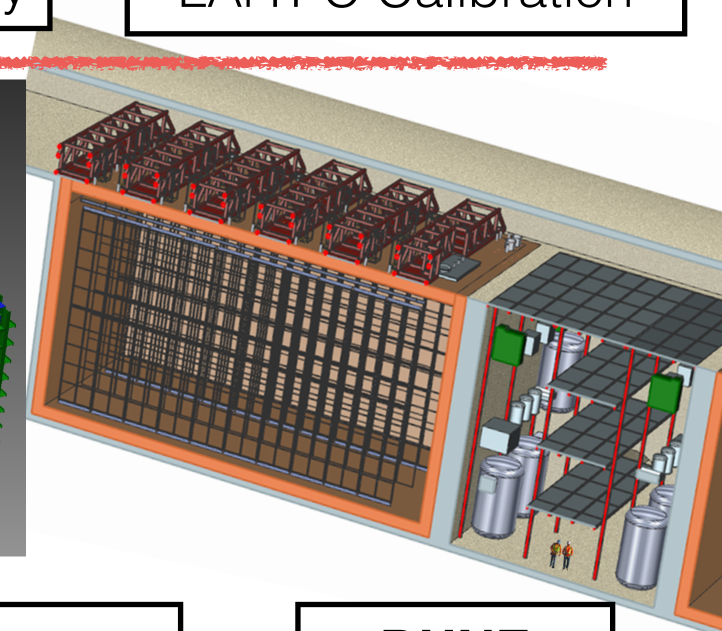


ArgoNeuT
(2009 - 2010)
ν-Ar Cross Sections

MicroBooNE
(2015 - 2018)
MiniBooNE
Low Energy Excess



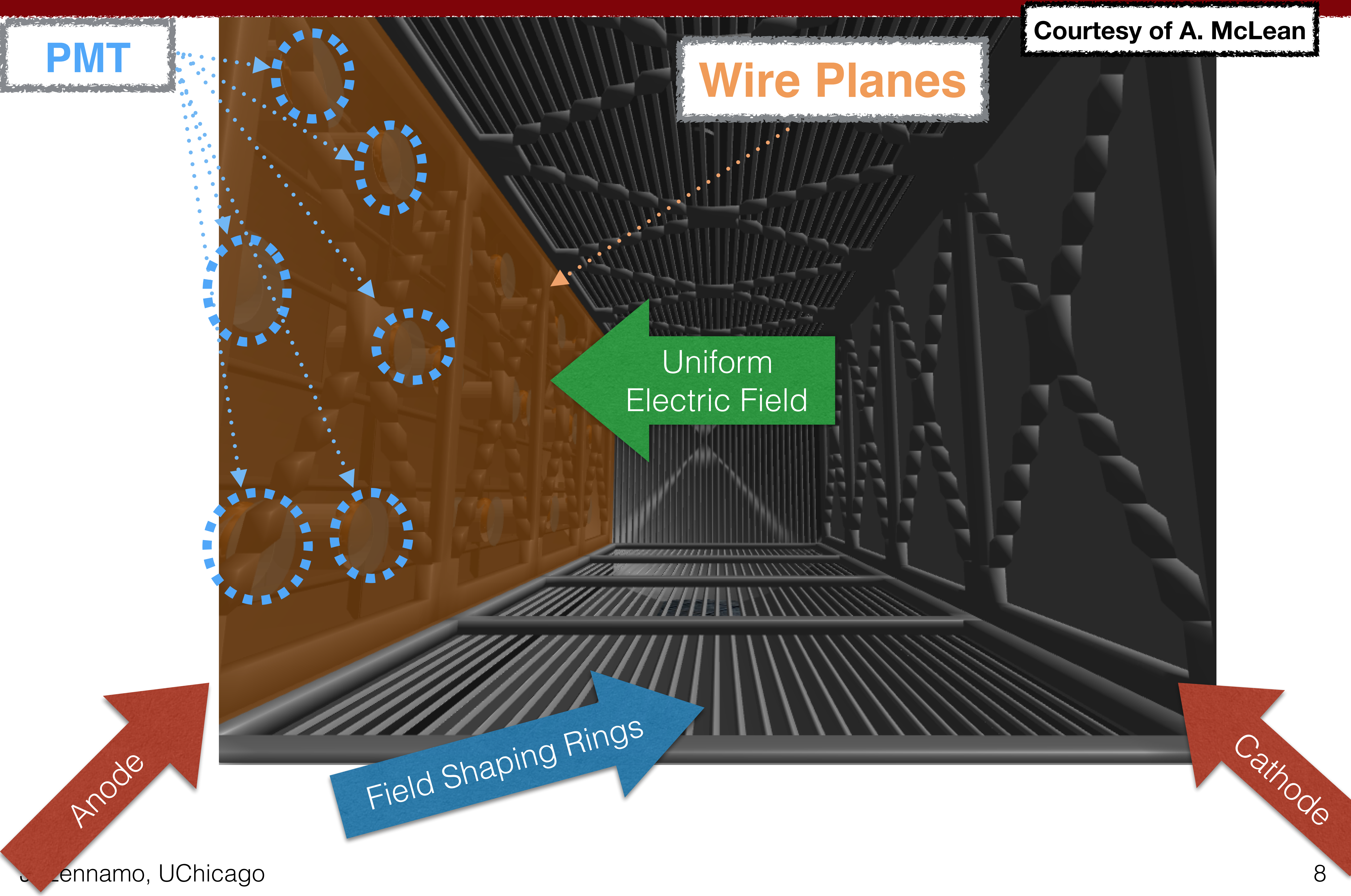
SBND
(2018 - 2021)
Searches for
Sterile Neutrino Oscillations



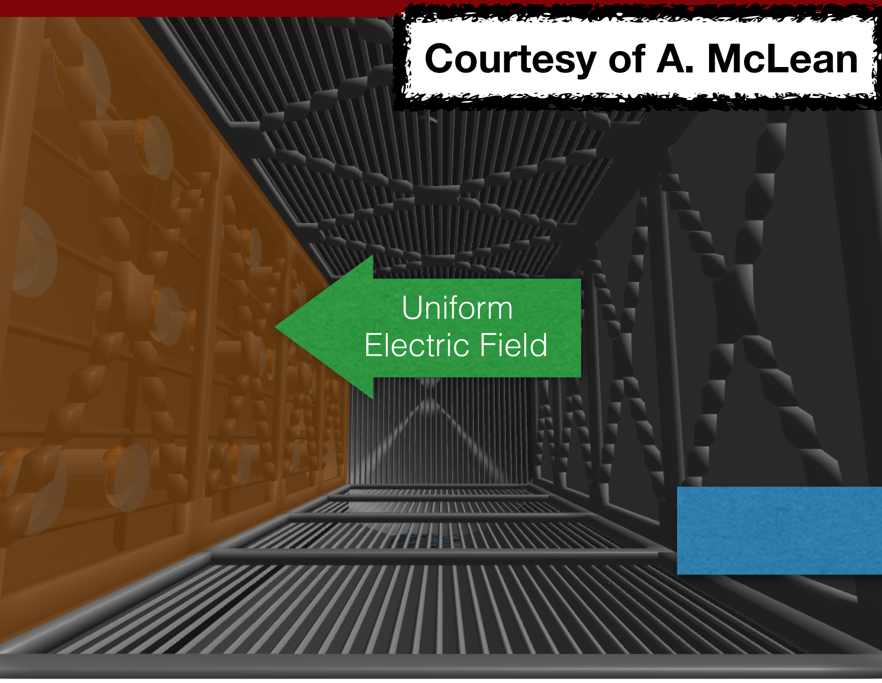
DUNE
(2025+)
CP Violation

The US Program

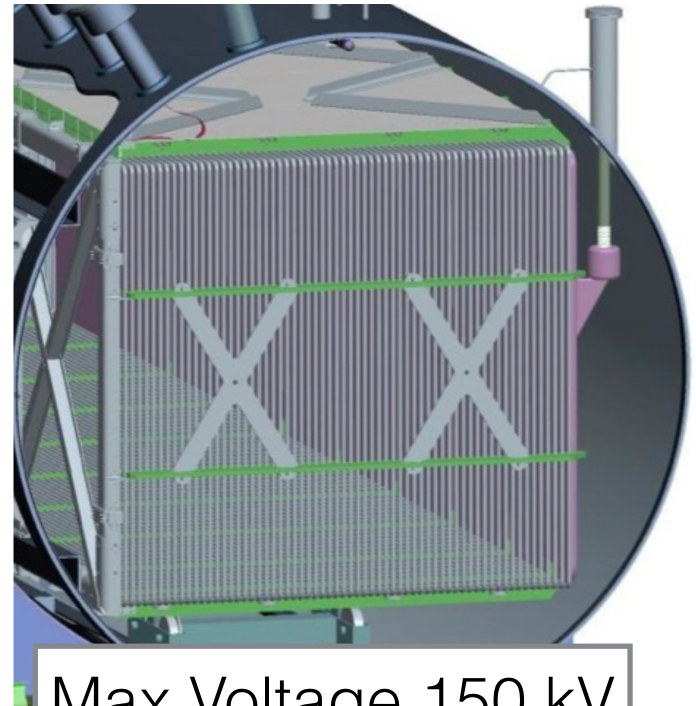
How Does a TPC Work?



High Voltage



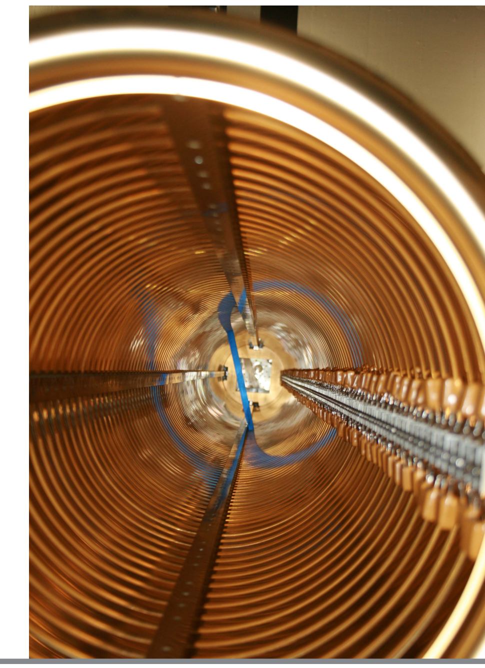
Externally Supplied



Max Voltage 150 kV

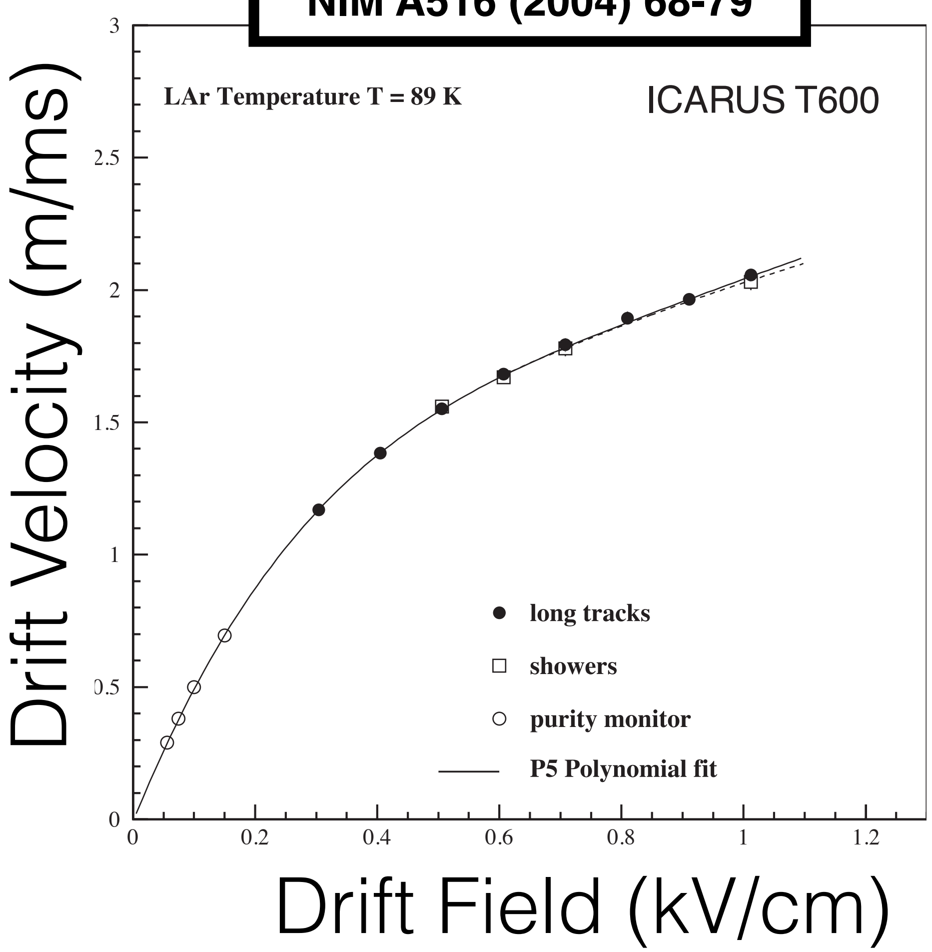
OR

Internally Produced



Max Voltage >500 kV

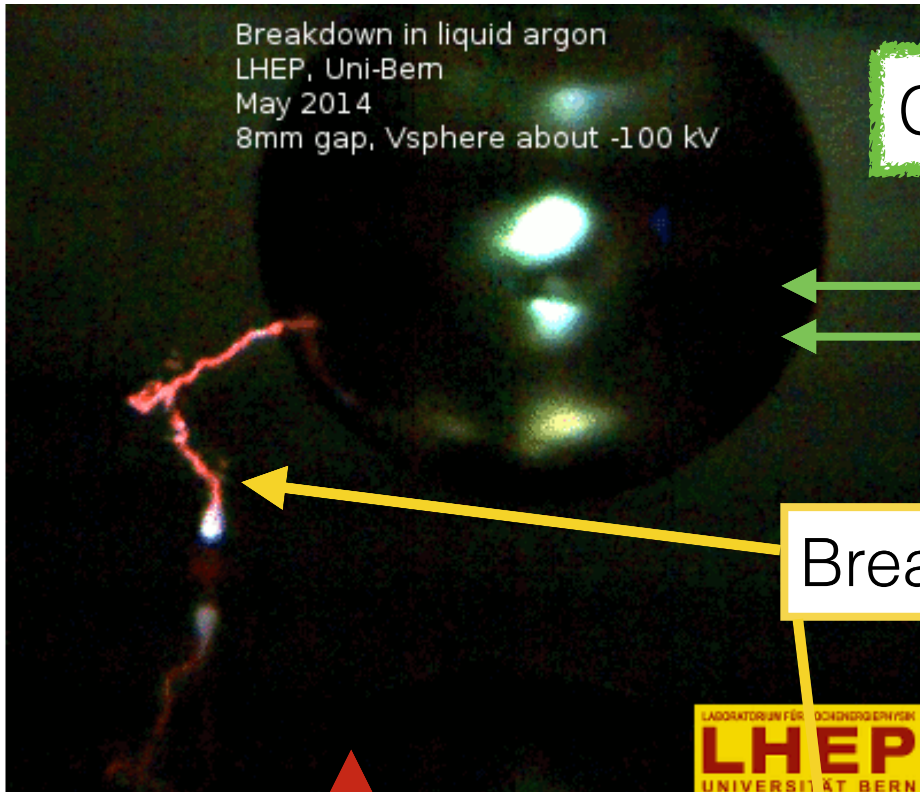
NIM A516 (2004) 68-79



Higher Field

- Shorter drift time
- Less electron attenuation
- Lower recombination
- Less electron diffusion

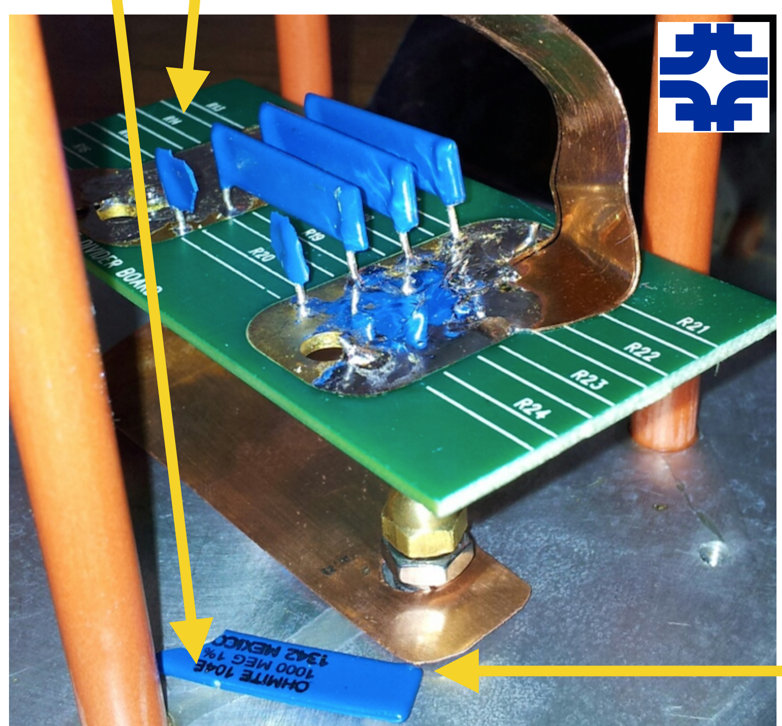
High Voltage Breakdowns In LAr



Cathode (-100 kV)

Breakdown

Anode (Ground)



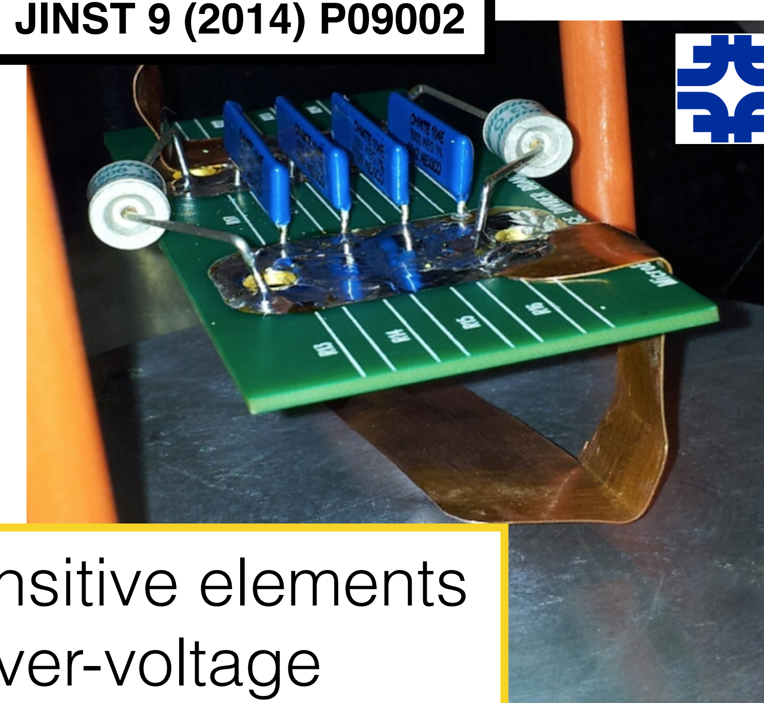
Protection Methods

Effectively halts breakdowns at field strengths >3x these

JINST 9 (2014) P07023

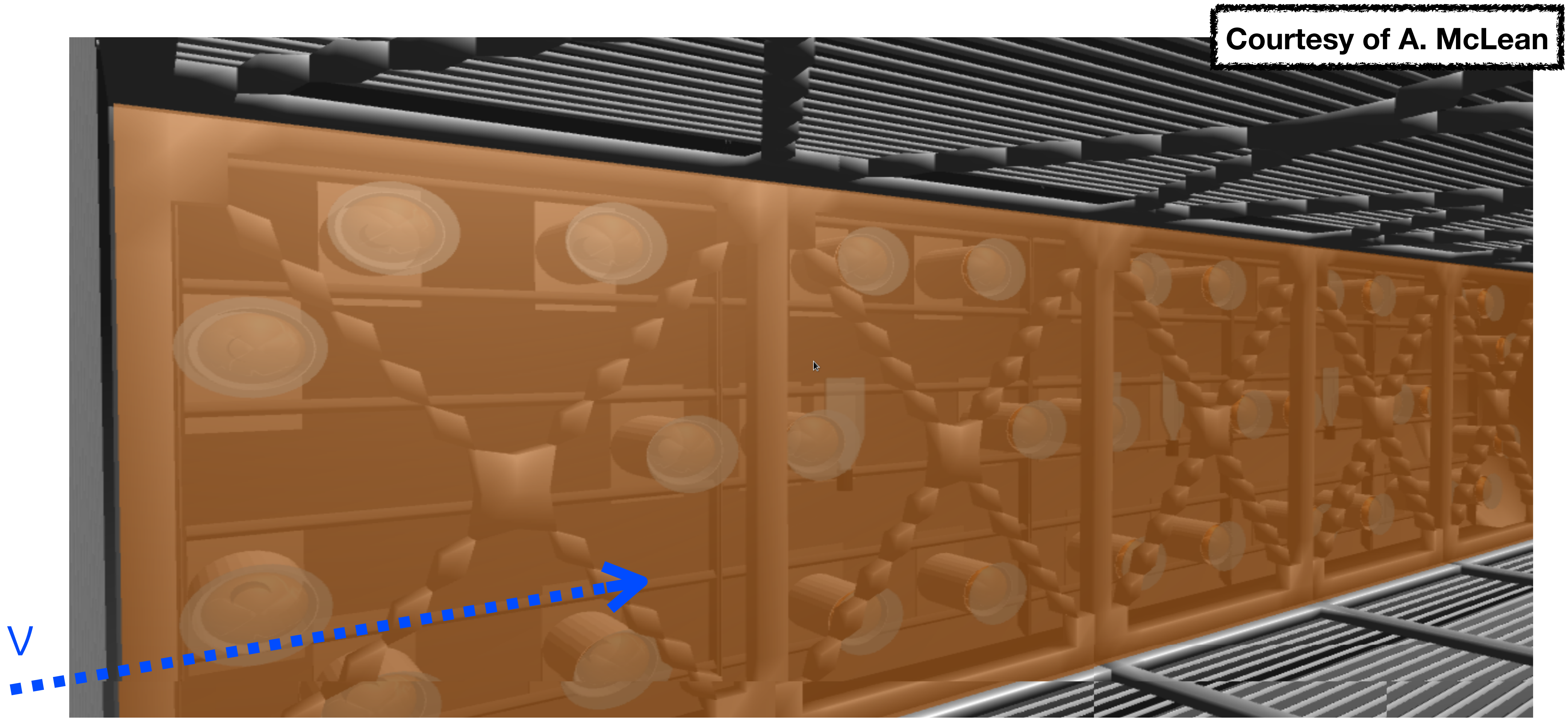
OR

JINST 9 (2014) P09002



Protects sensitive elements from over-voltage

How Does a TPC Work?



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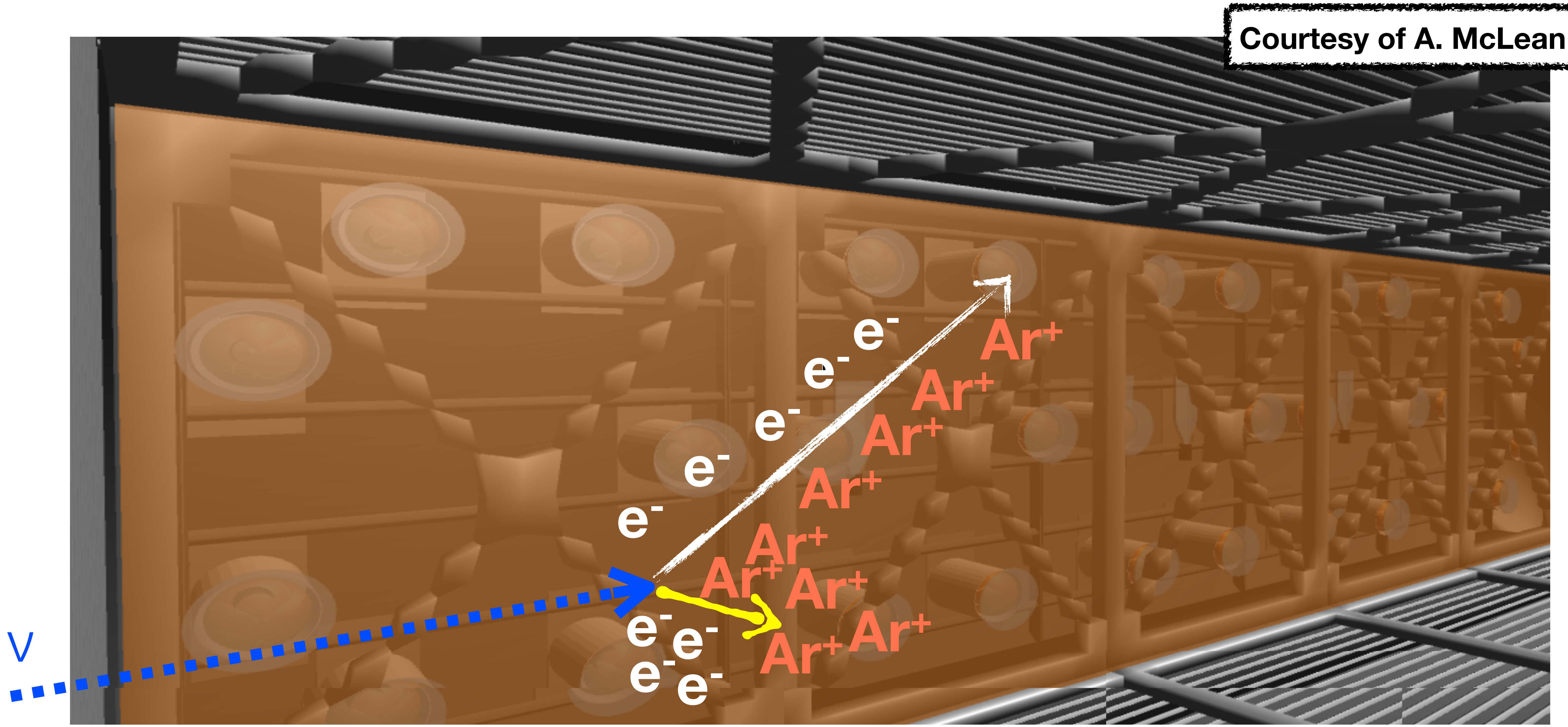

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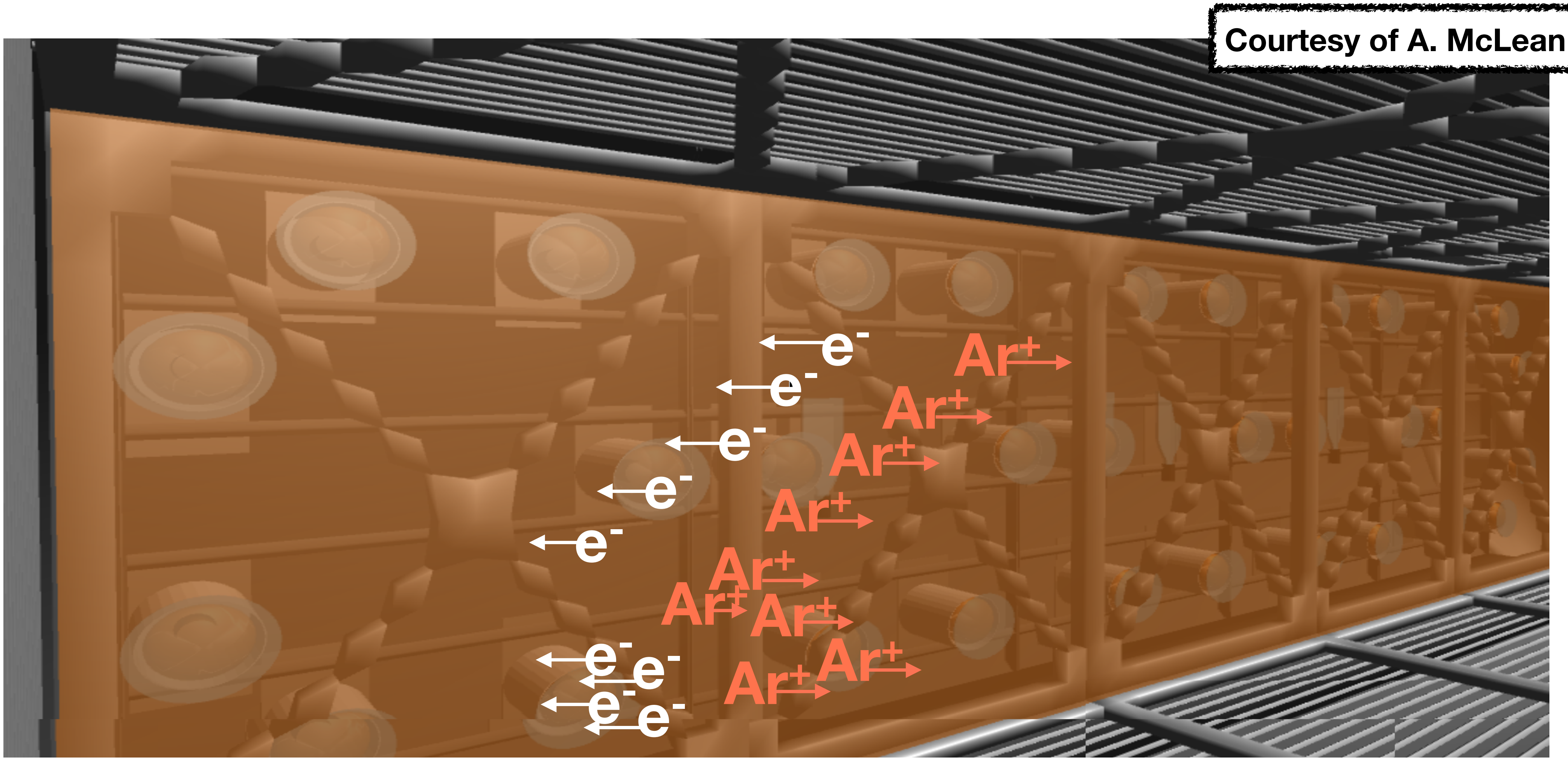

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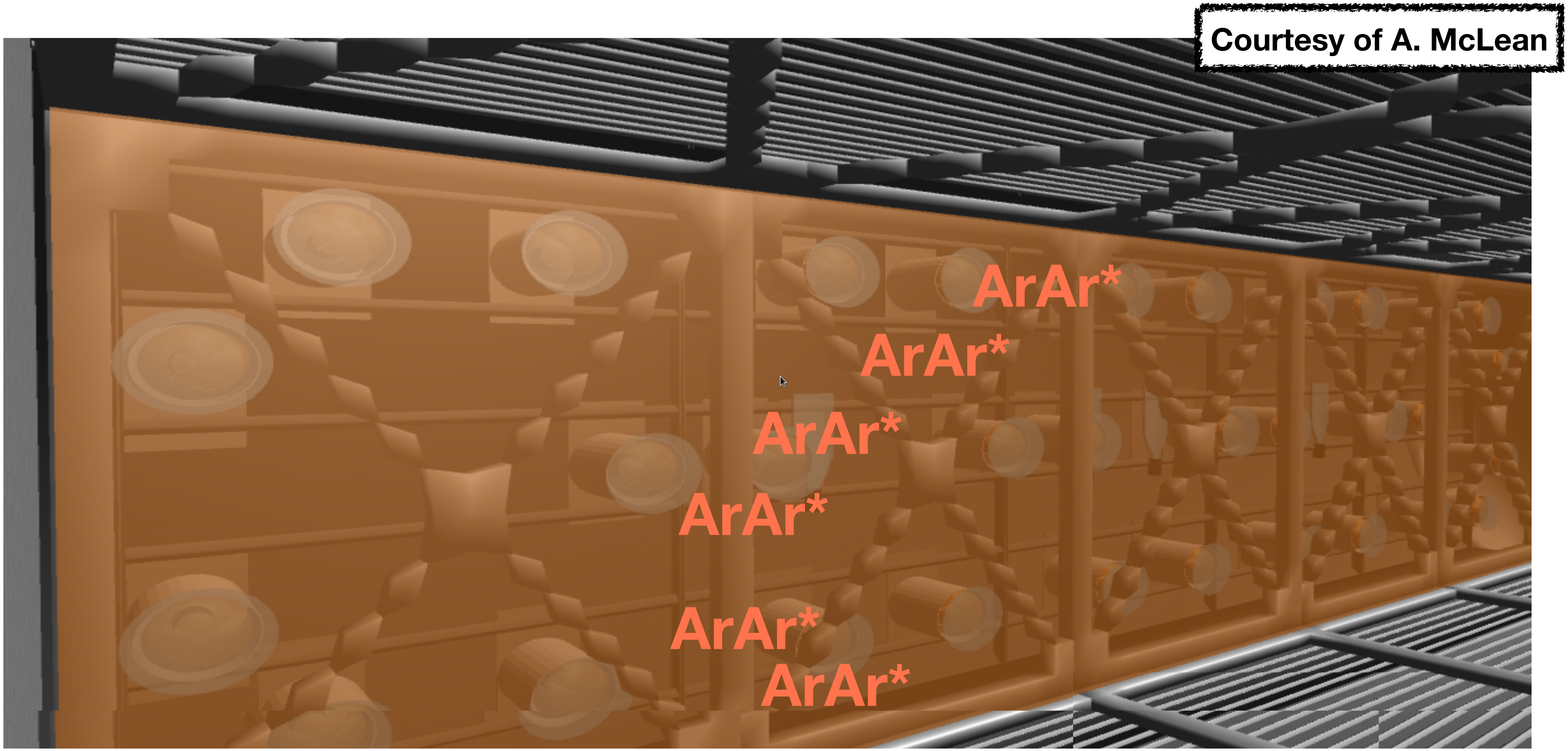

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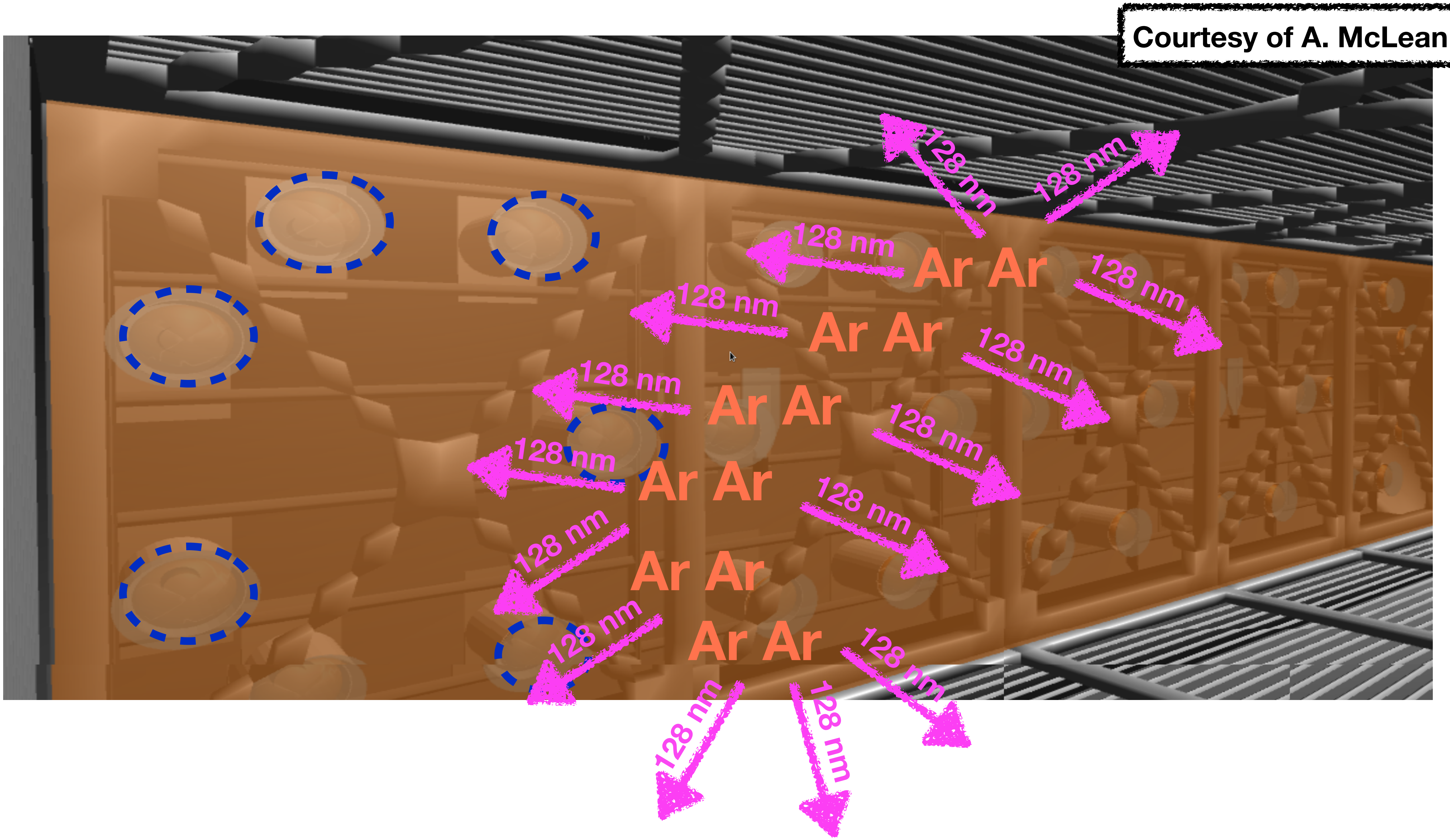
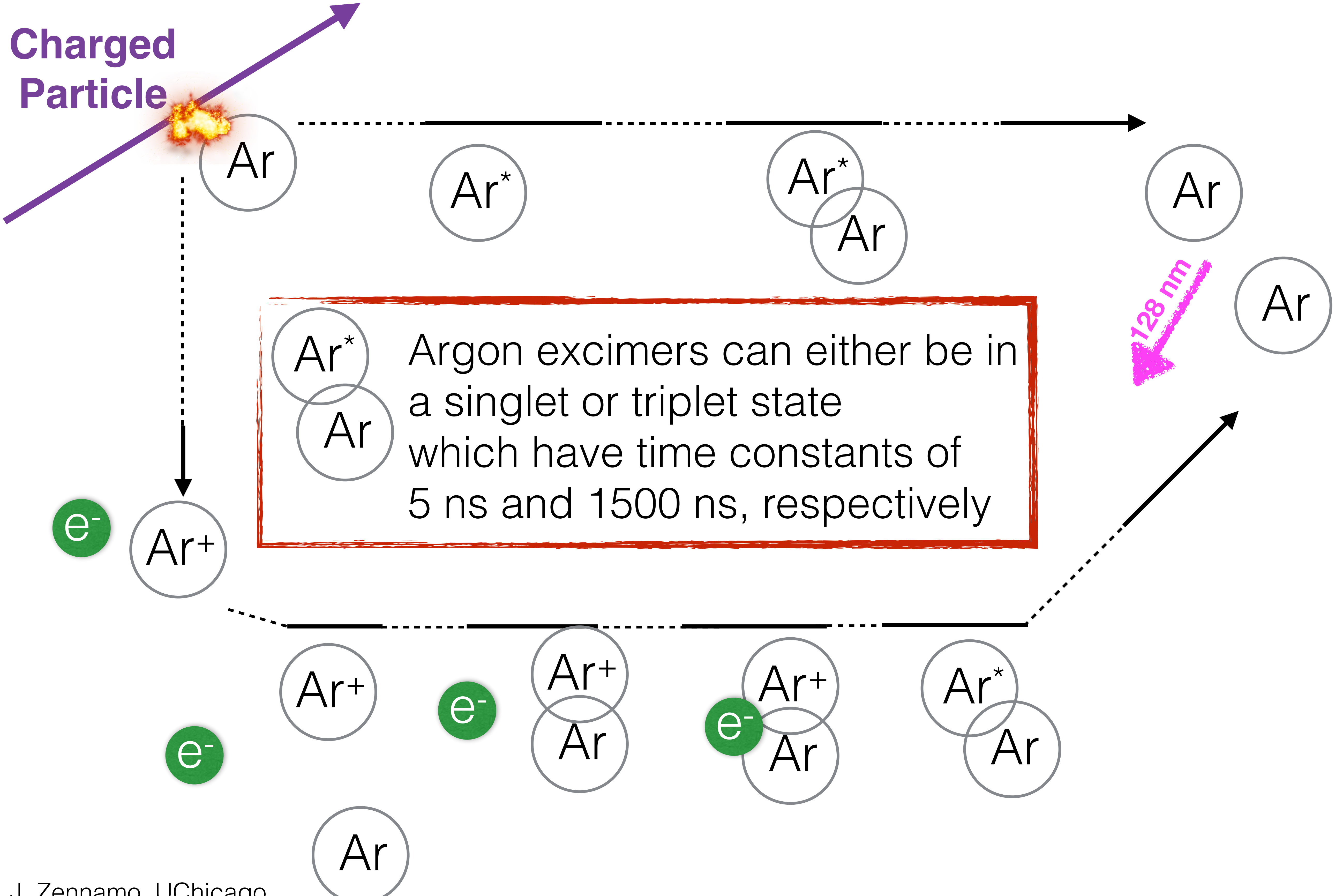
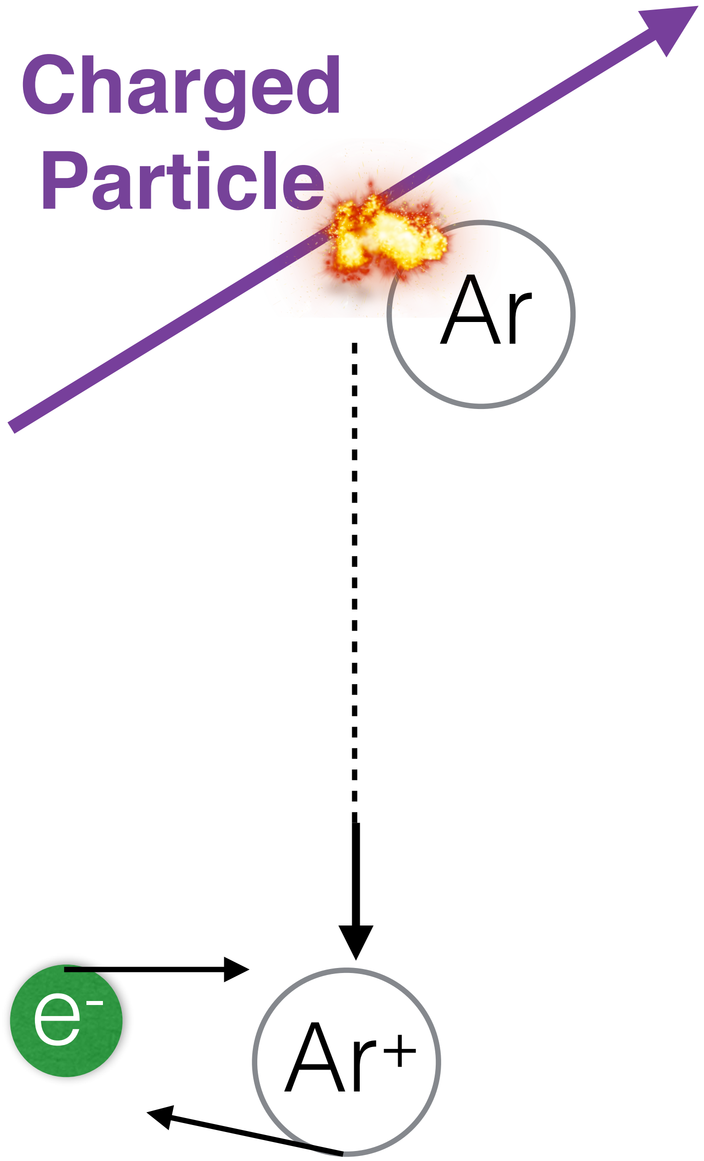


How Does Argon Scintillation Work?



High Voltage: Charge Vs. Light



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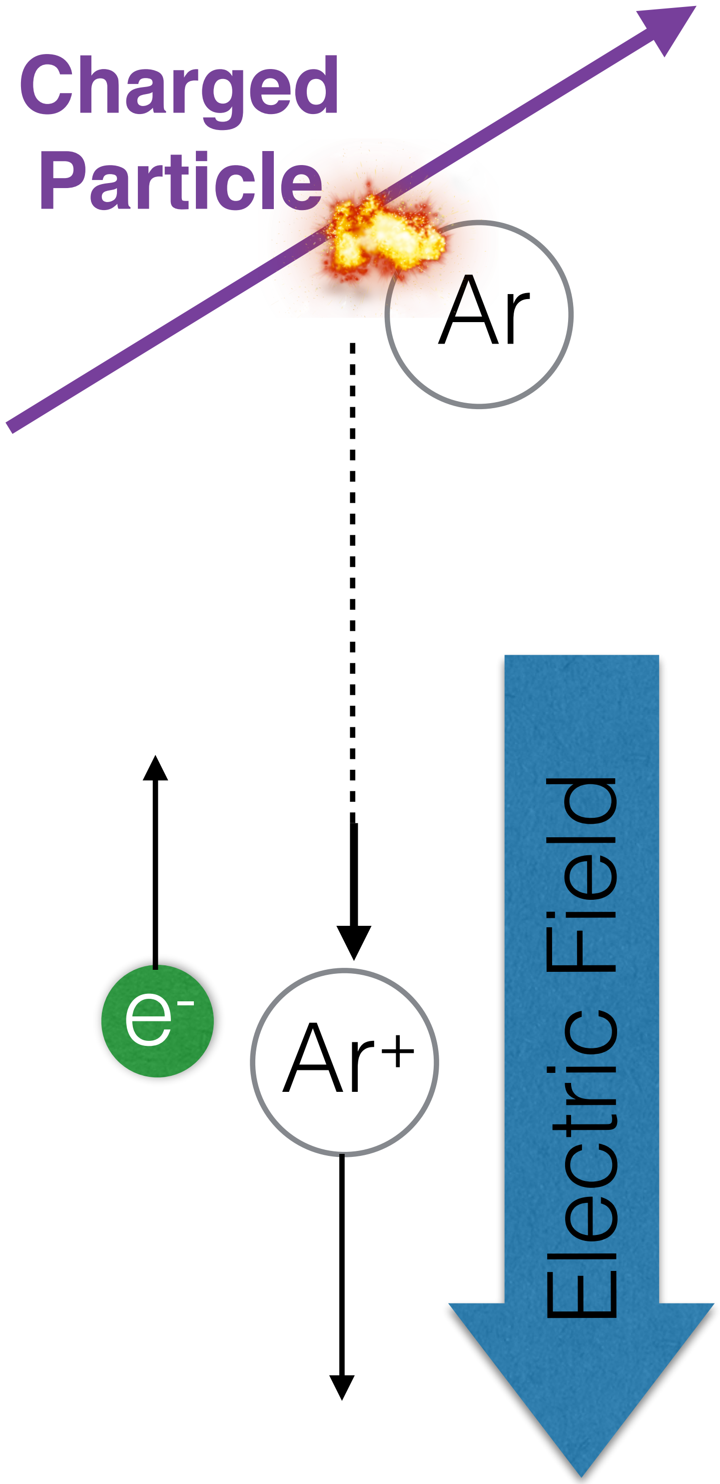
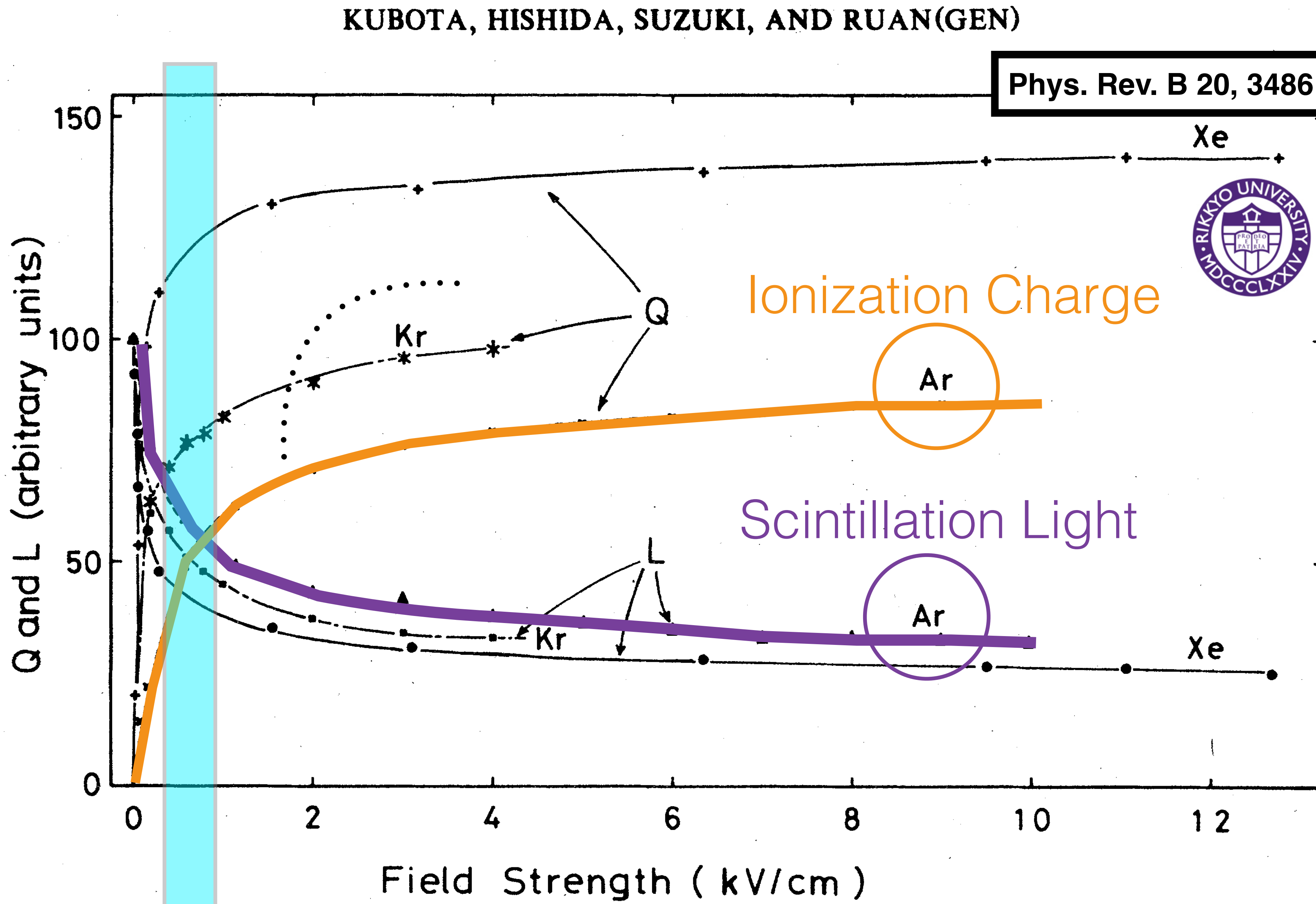
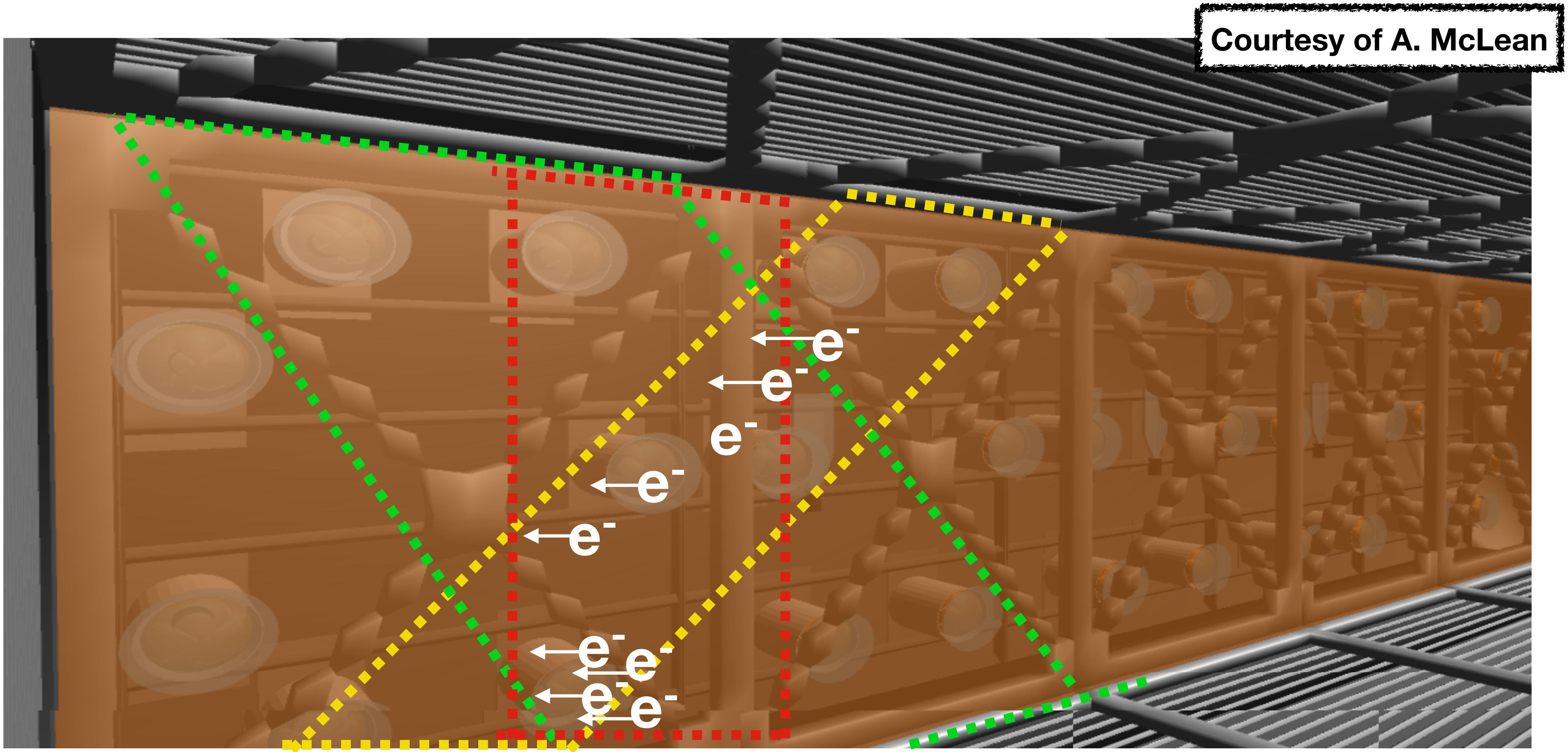


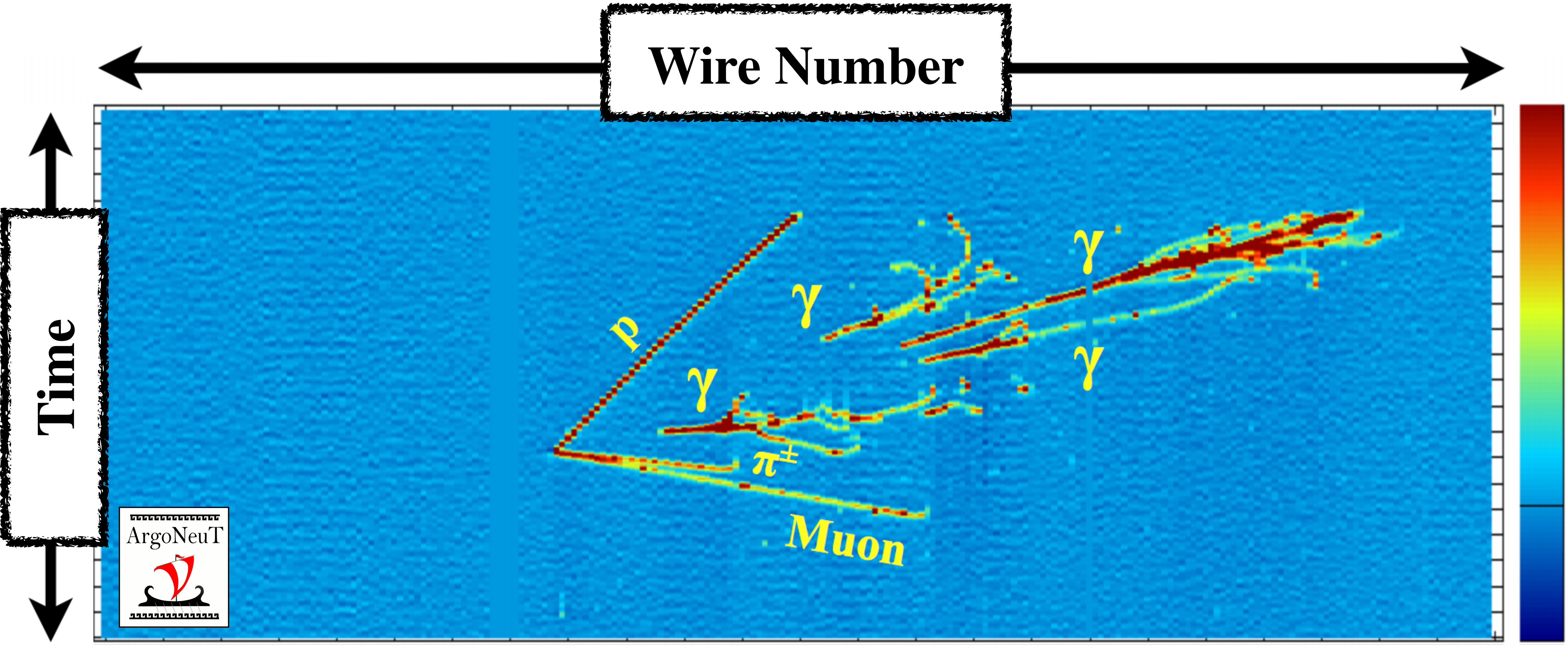


Typical LAr TPC Field Strength

How Does a TPC Work?



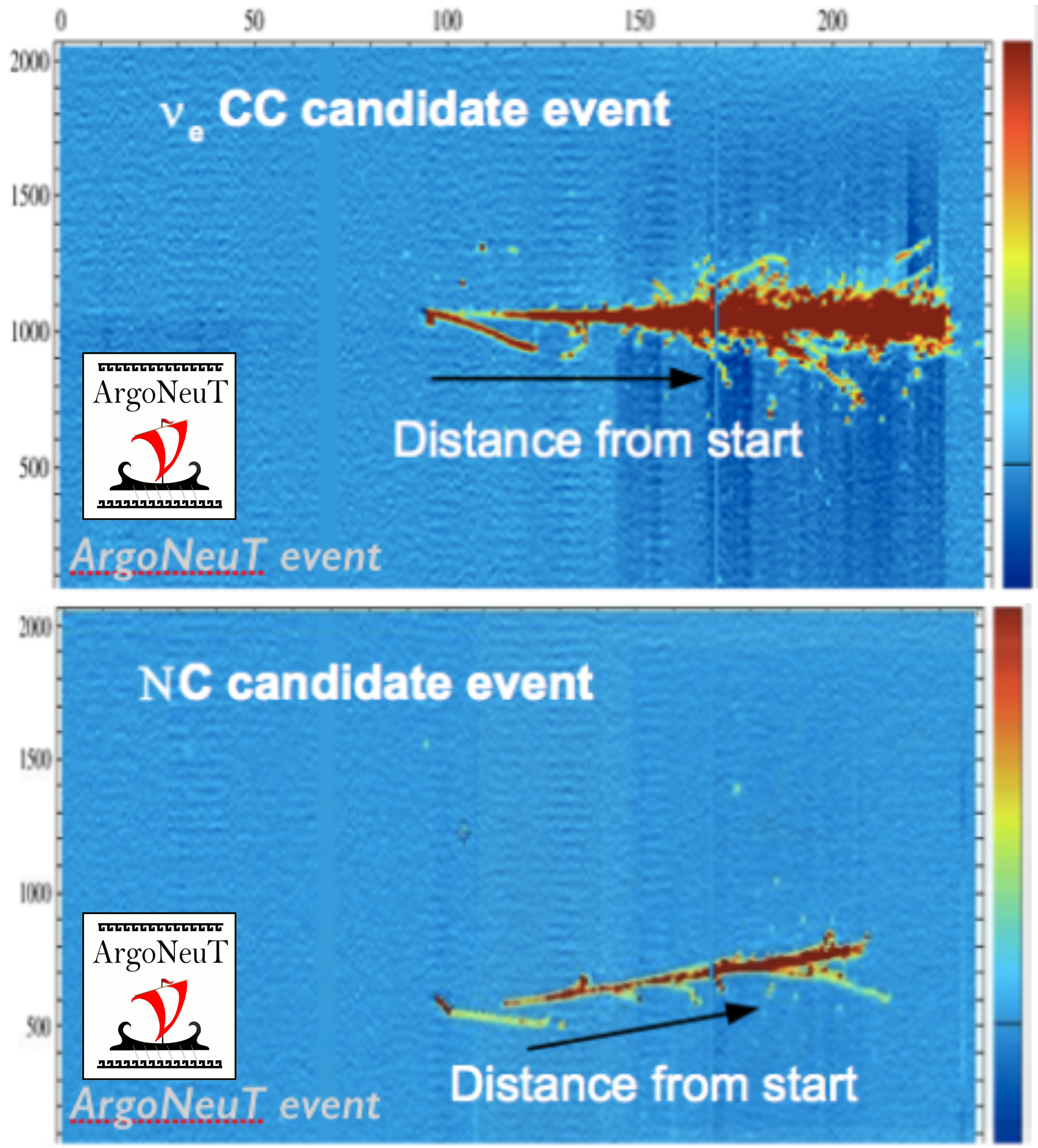
Liquid Argon Time Projection Chambers

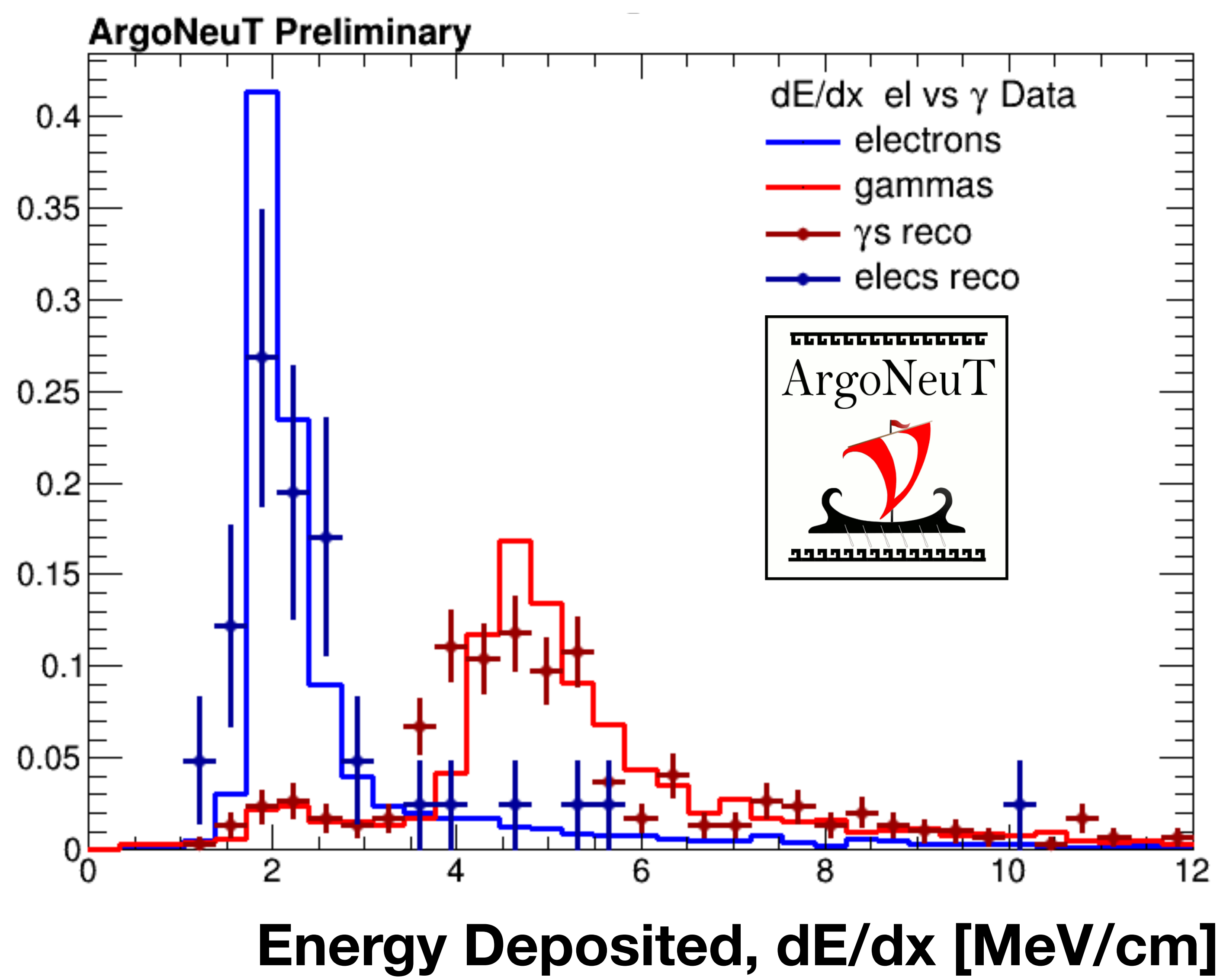


Example DIS event
(courtesy of ArgoNeuT collaboration)

Charge deposited

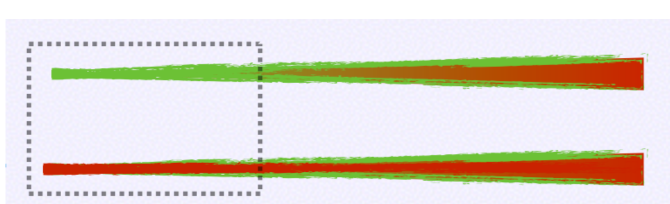
Liquid Argon Time Projection Chambers





Electron

$\gamma \rightarrow e^{+} + e^{-}$



Why Argon?

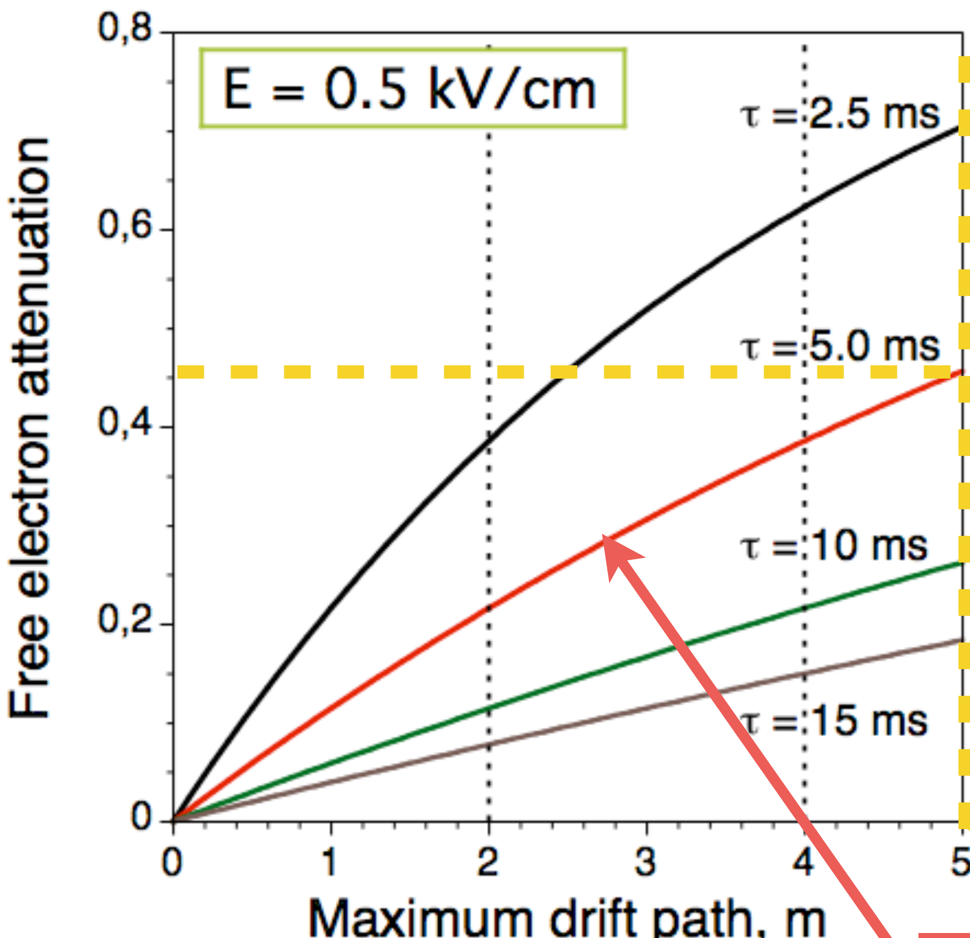
Courtesy of
M. Soderberg

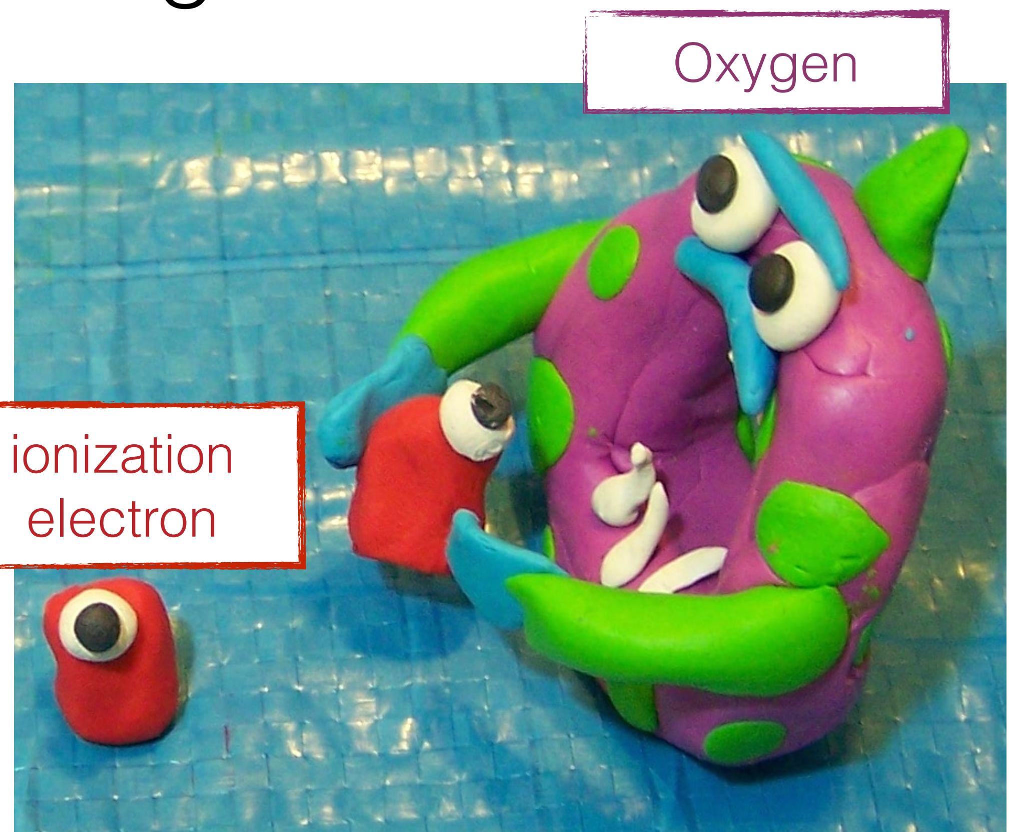
	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120	165	373
Density [g/cm	0.125	1.2	1.4	2.4	3	1
Radiation Length [cm]	755.2	24	14	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3	3.8	1.9
Scintillation [γ/MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	
Approx. Cost [$/kg]	52	330	5	330	1200	

- Argon is transparent to drifting electrons and its own scintillation light
- Impurities in the argon can capture electrons and quench scintillation light, originally these argon purity was viewed as the largest technical challenge of LAr TPCs

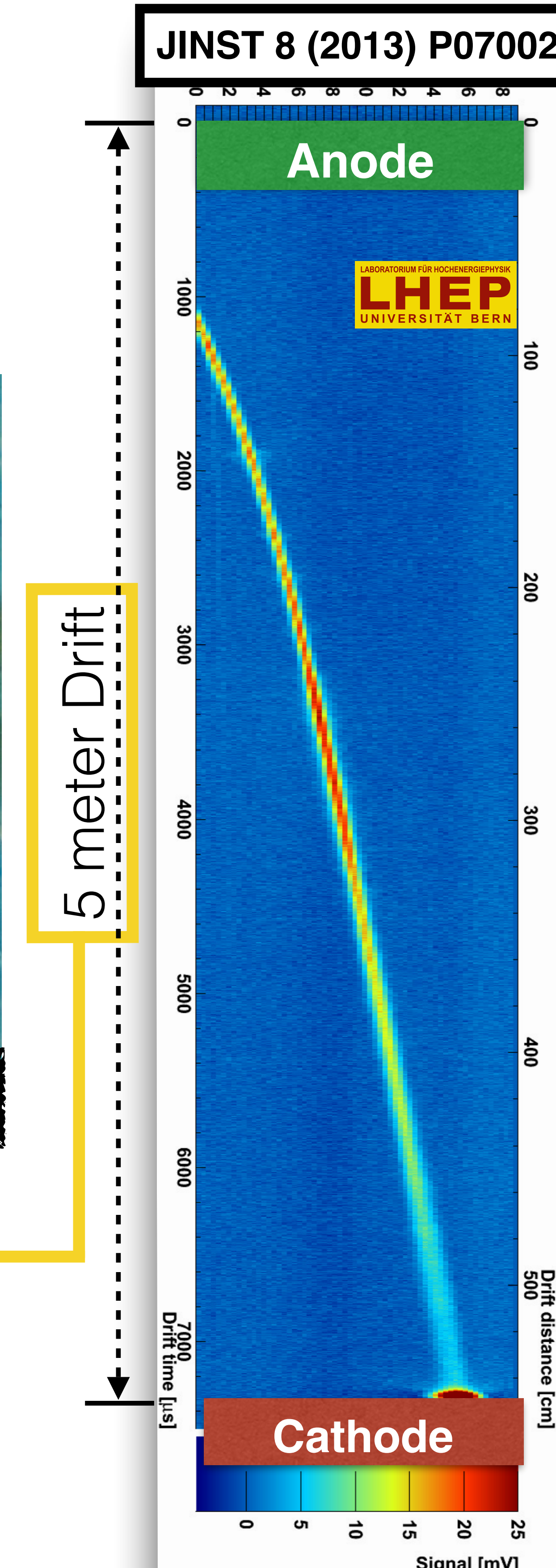
Purity and Drifting Electrons

When electronegative contaminants are introduced to the liquid they can capture drifting electrons, reducing their number exponentially in time





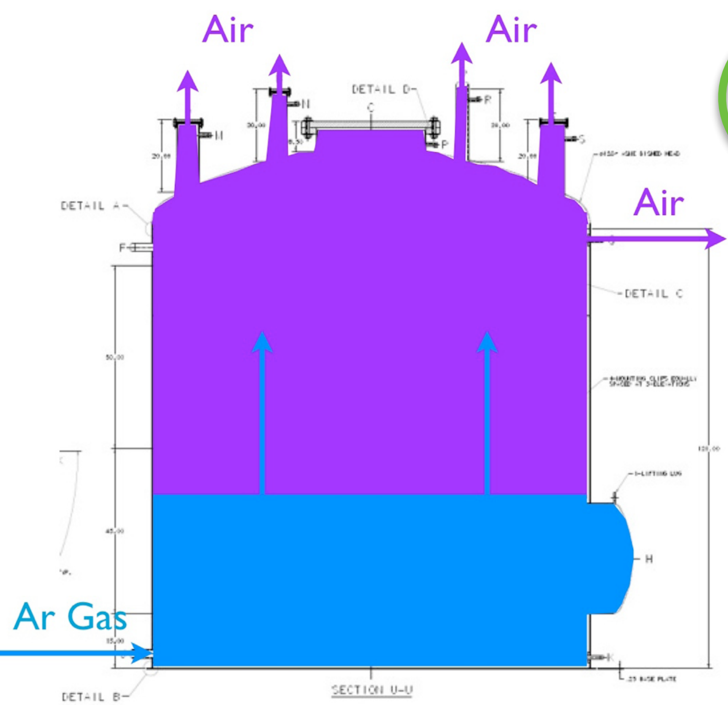
Courtesy of W. and E. Ketchum

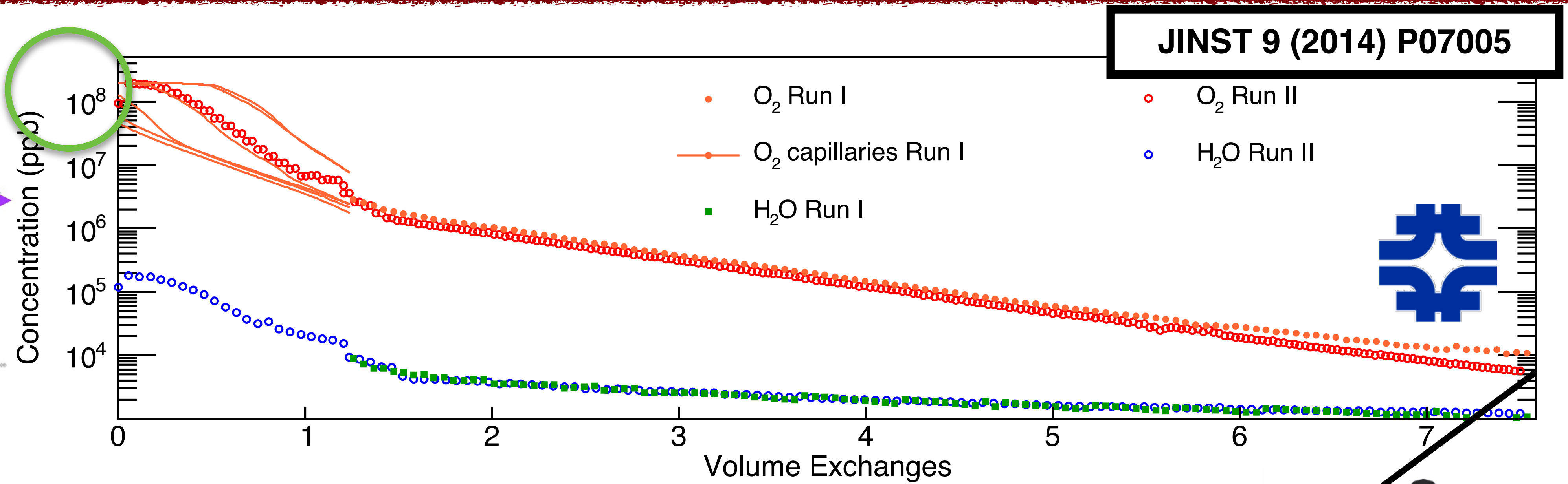


τ = 5 ms is equivalent to ~60 ppt O_2

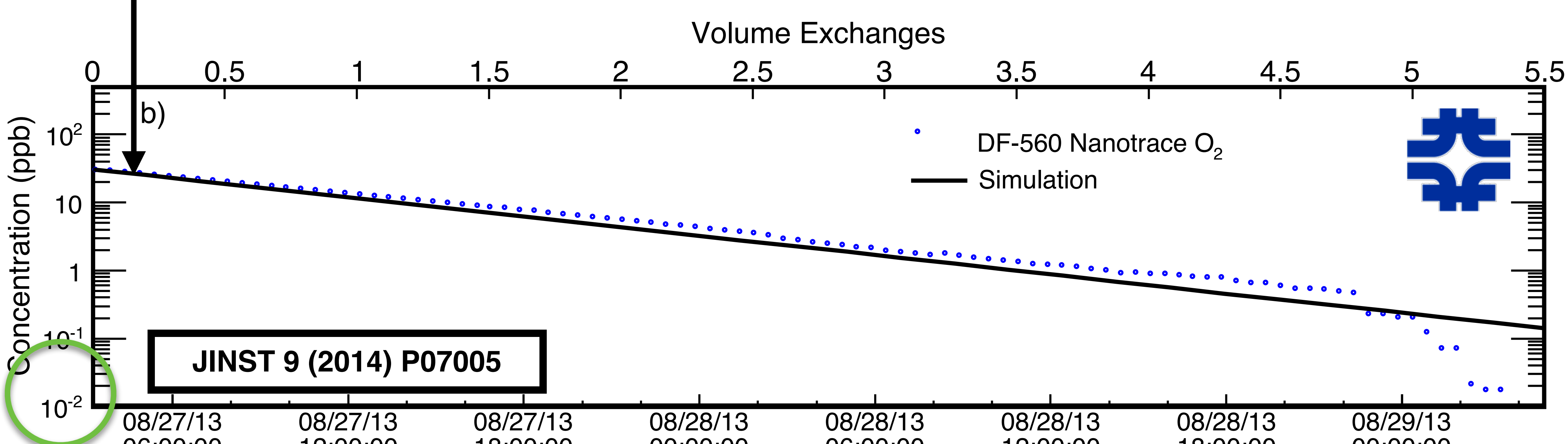
J. Zennamo, UChicago

Argon Purity



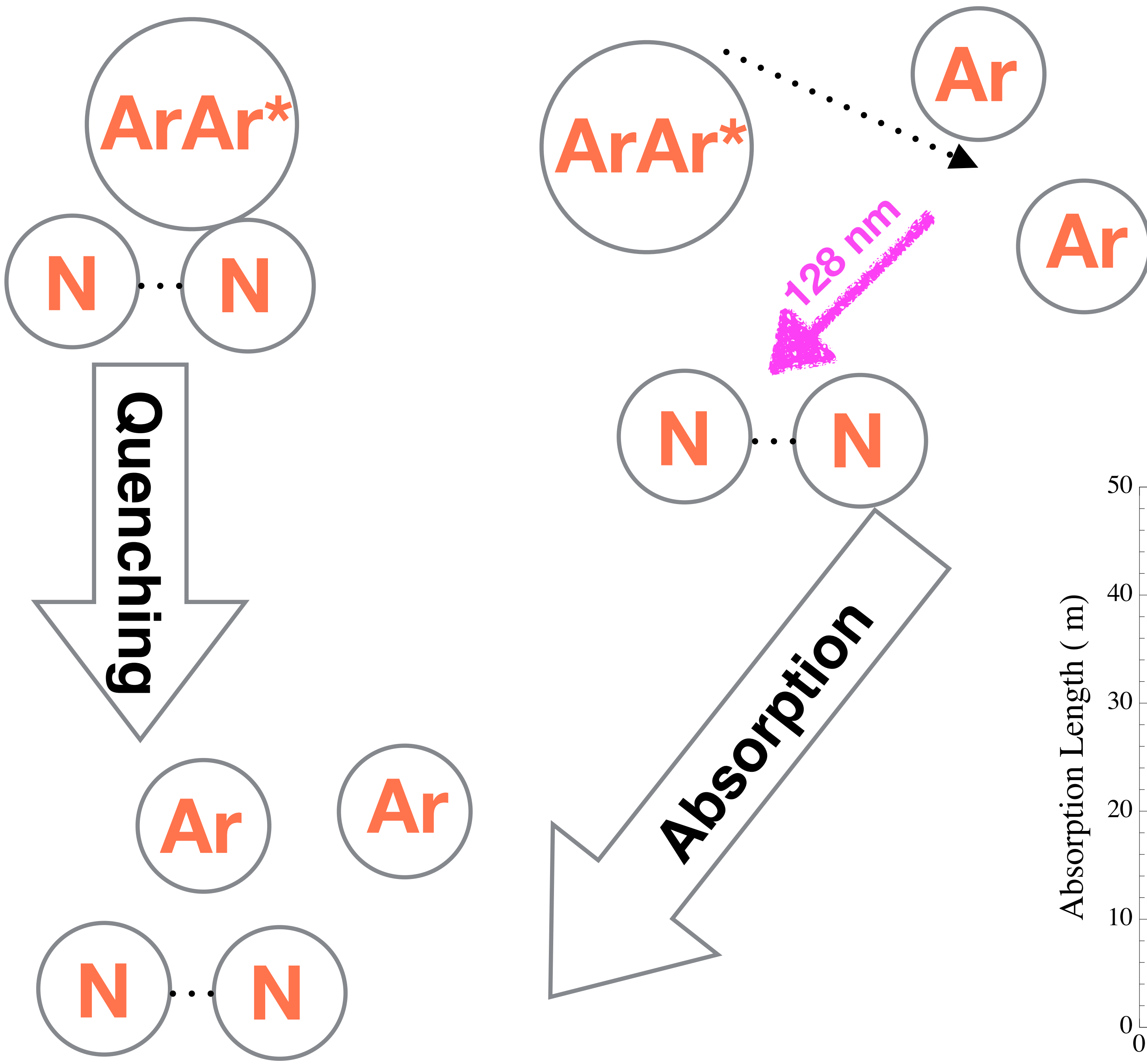


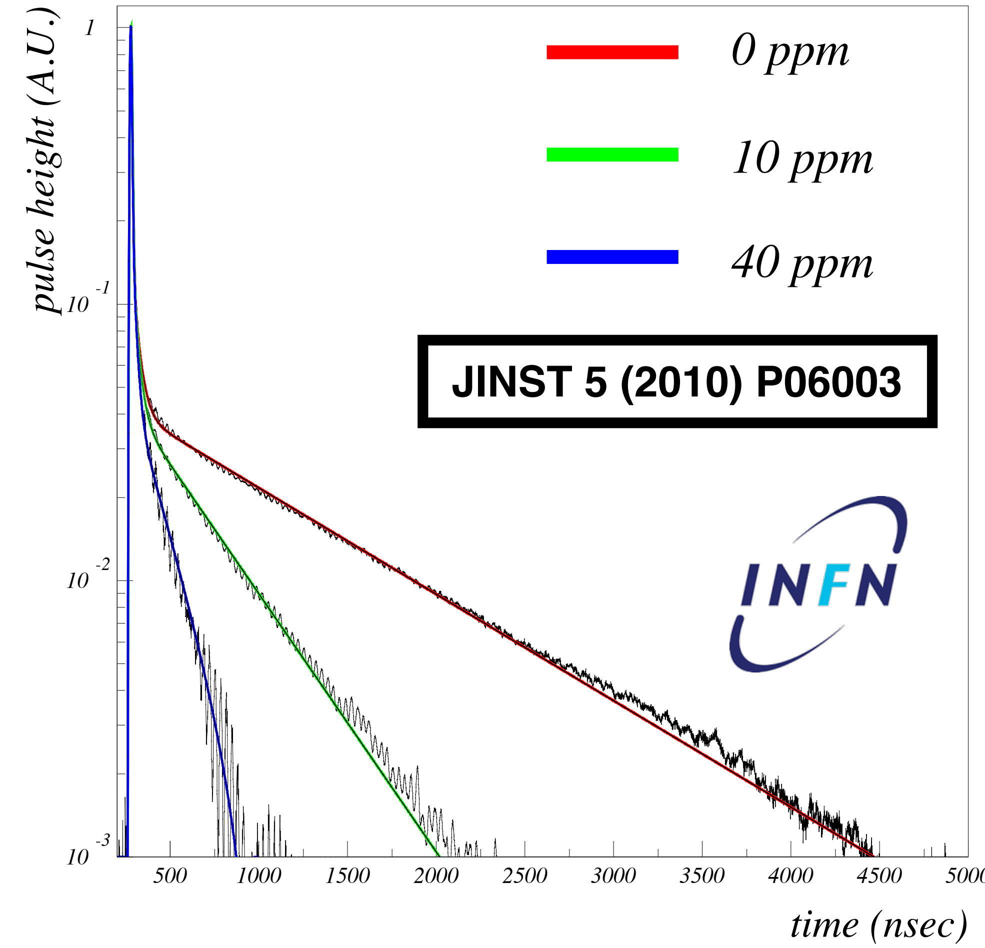
O_2 Drops from 21% to 10 ppt!

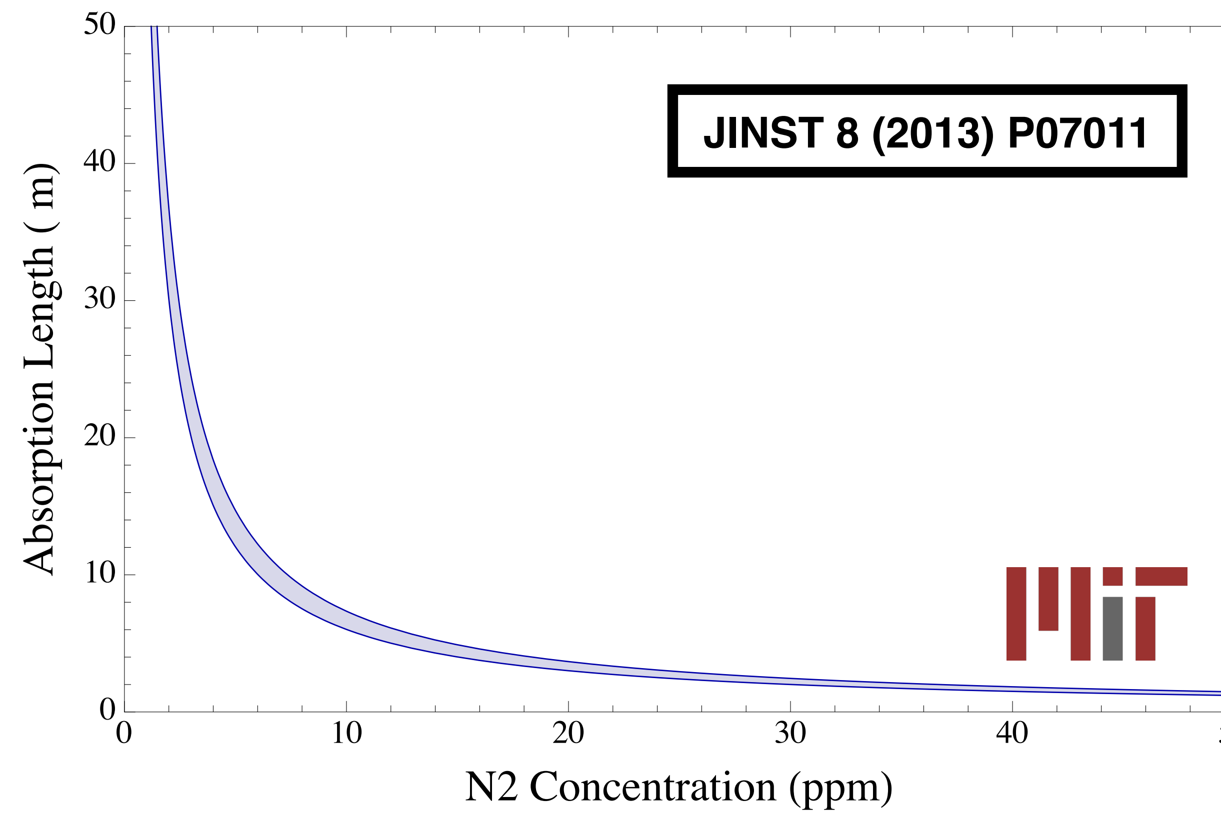


Purity and Scintillation Light

- Harder to remove from argon is nitrogen, which does not affect the drifting electrons



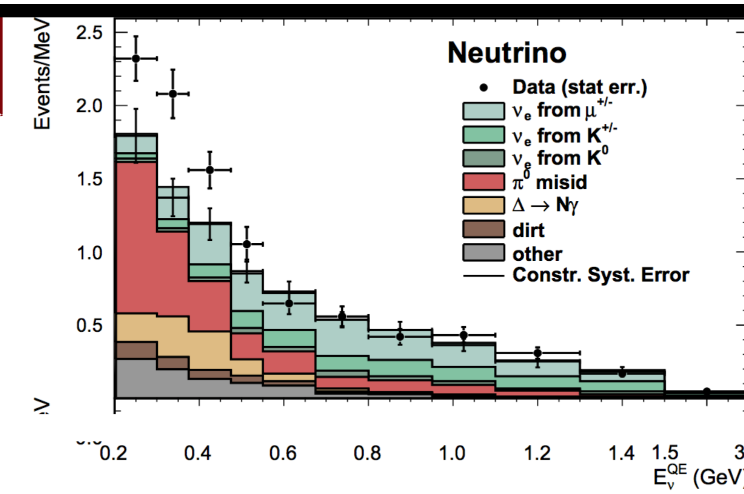




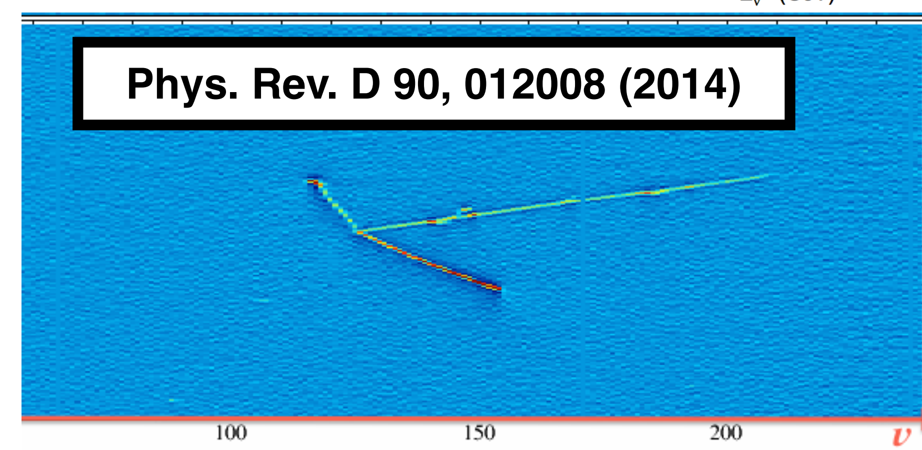
Physics Enabled by LArTPCs

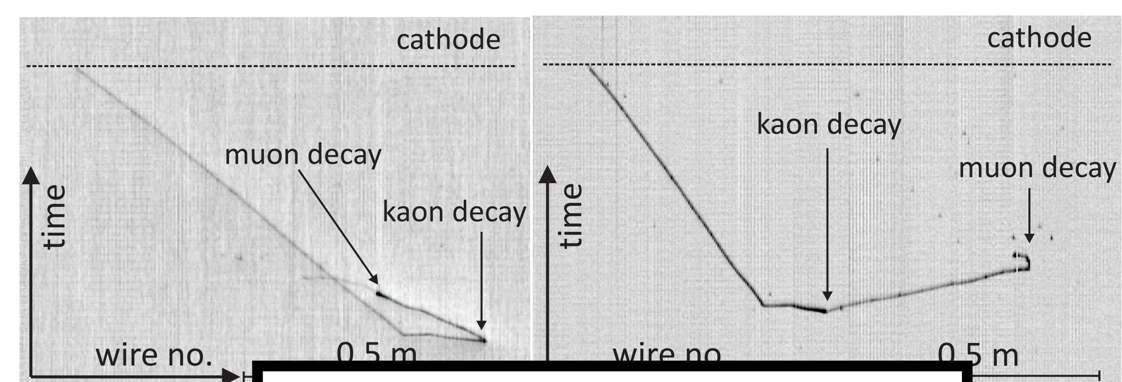
- Investigating Short Baseline Anomalies
- Careful measurements of ν-Ar cross sections
  - With full characterization of the vertex
- Supernova Neutrinos
- Proton decay (p→Kμν̄)
- Searches for long baseline oscillations (mass hierarchy and CP Violation)

Phys.Rev.Lett. 110 (2013) 161801

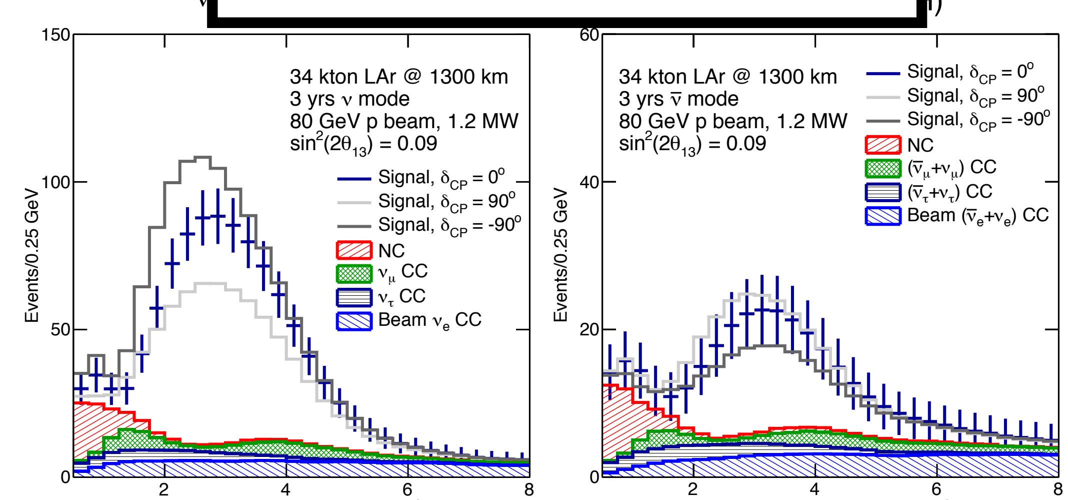


Phys. Rev. D 90, 012008 (2014)





arXiv:1307.7335



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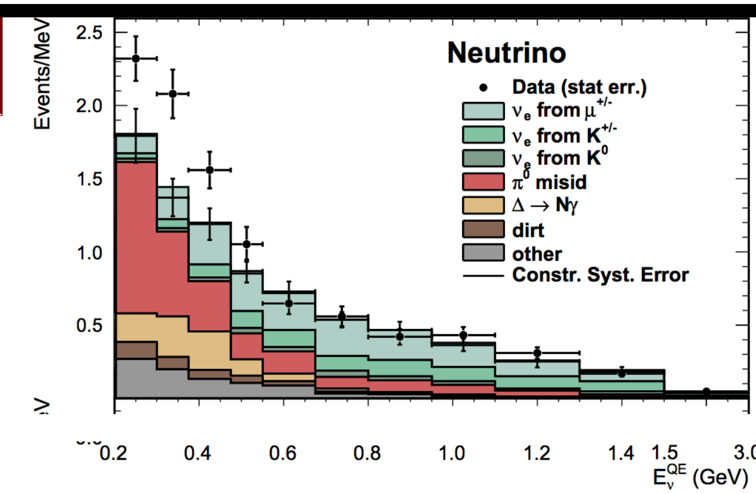
Anne Will Cover This Next Session

Alex Will Cover This Next Session

Phys.Rev.Lett. 110 (2013) 161801



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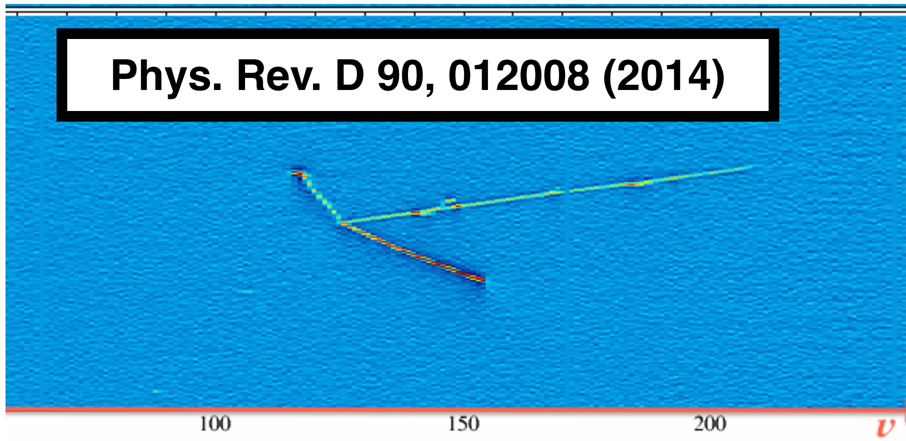

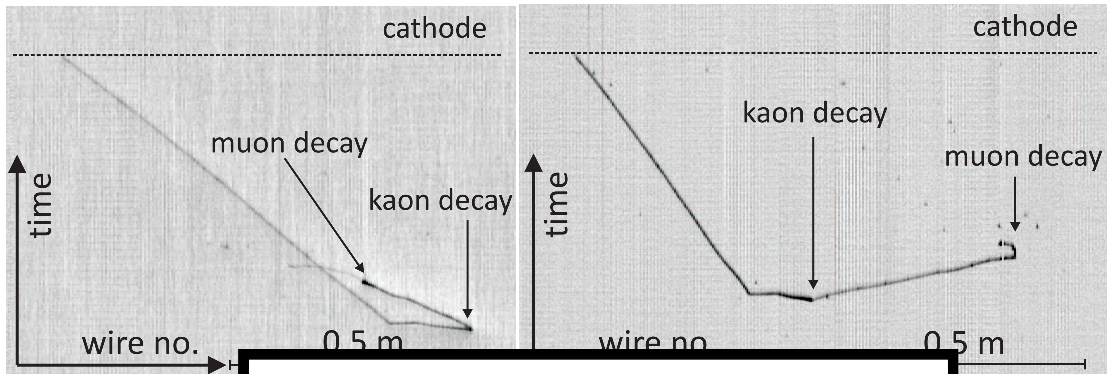

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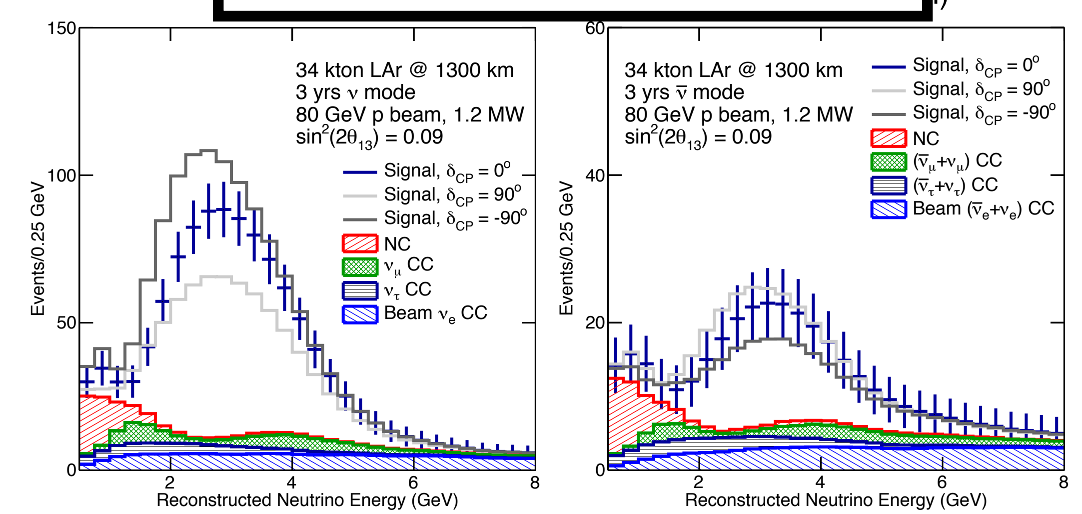
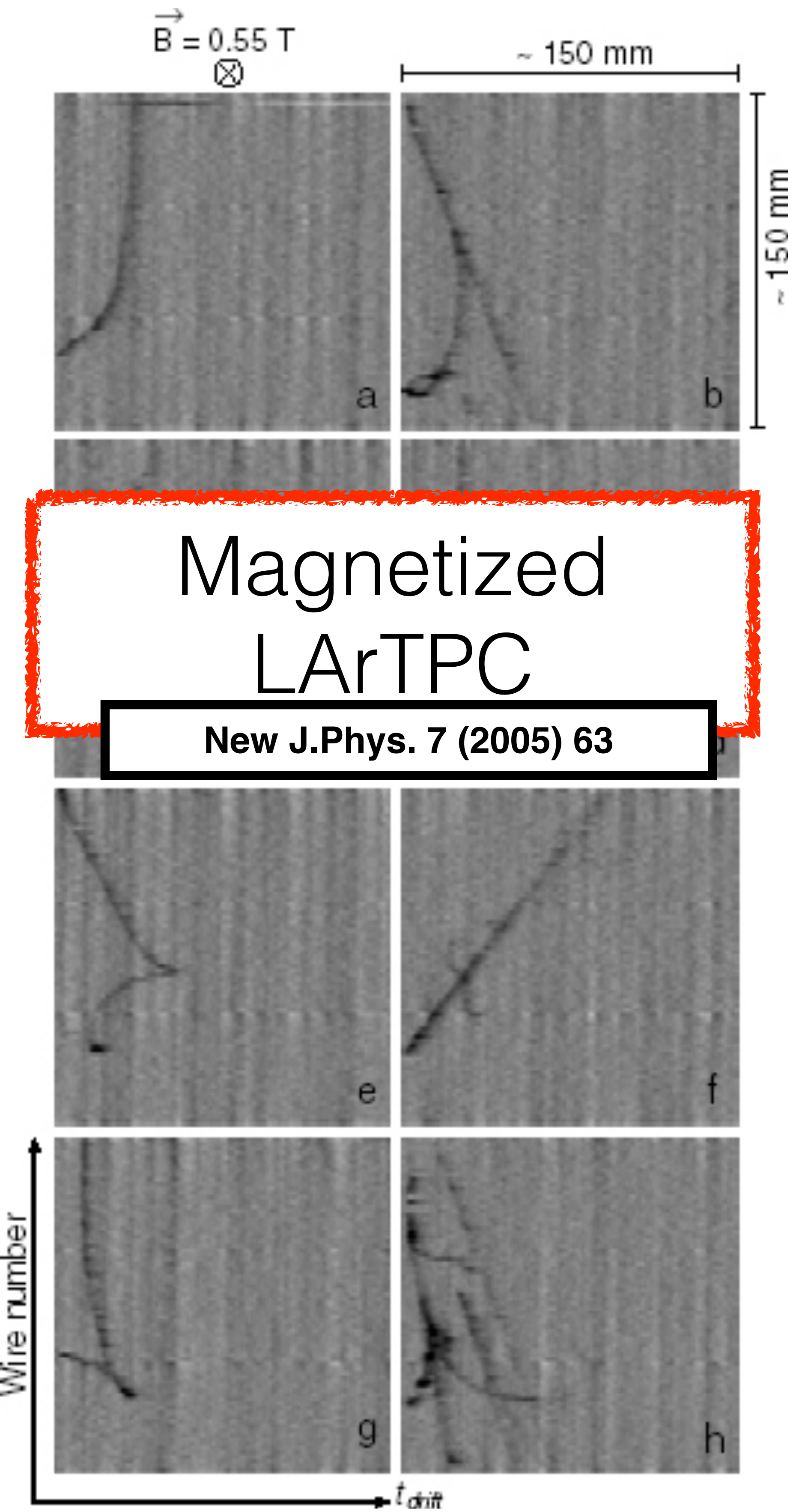
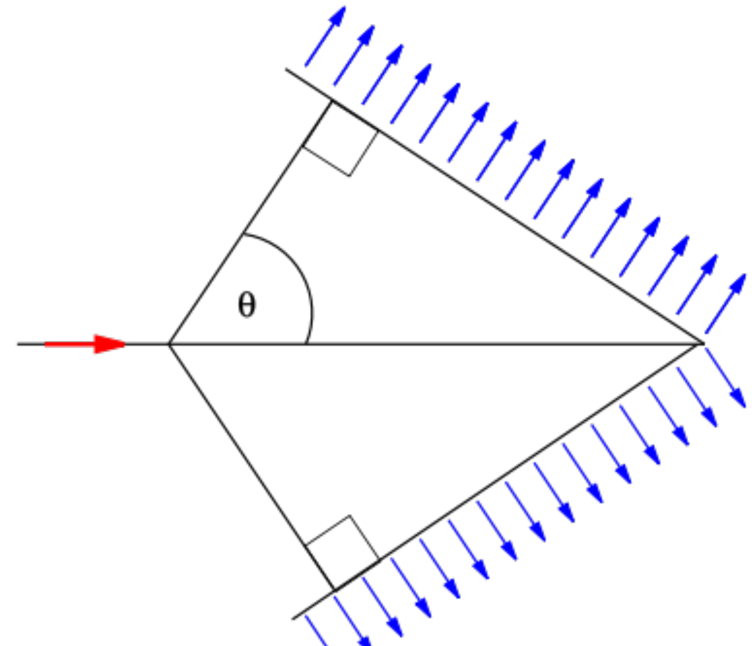


Next Steps For LArTPCs



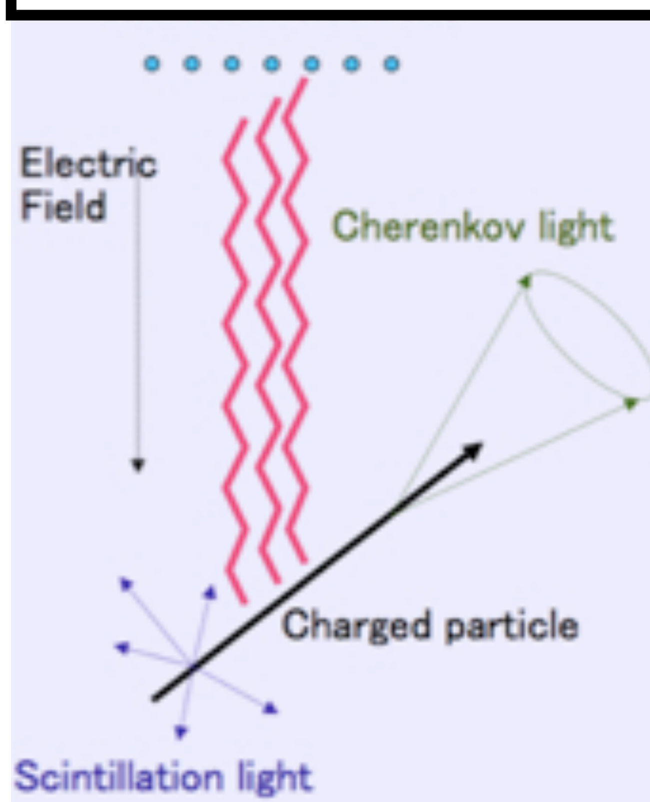
Magnetized LArTPC

New J.Phys. 7 (2005) 63

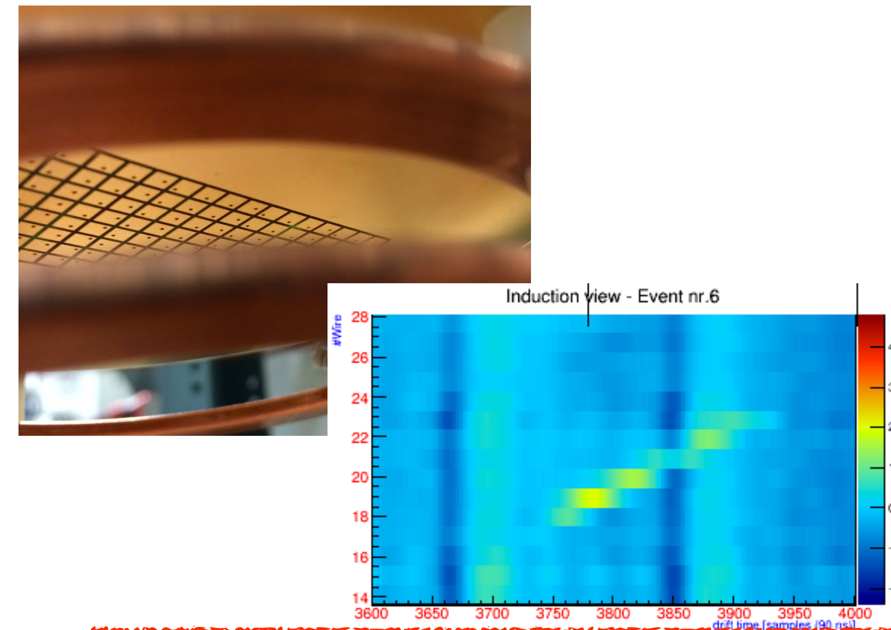


Cherenkov Light Detection

NIM A516 (2004) 348-363

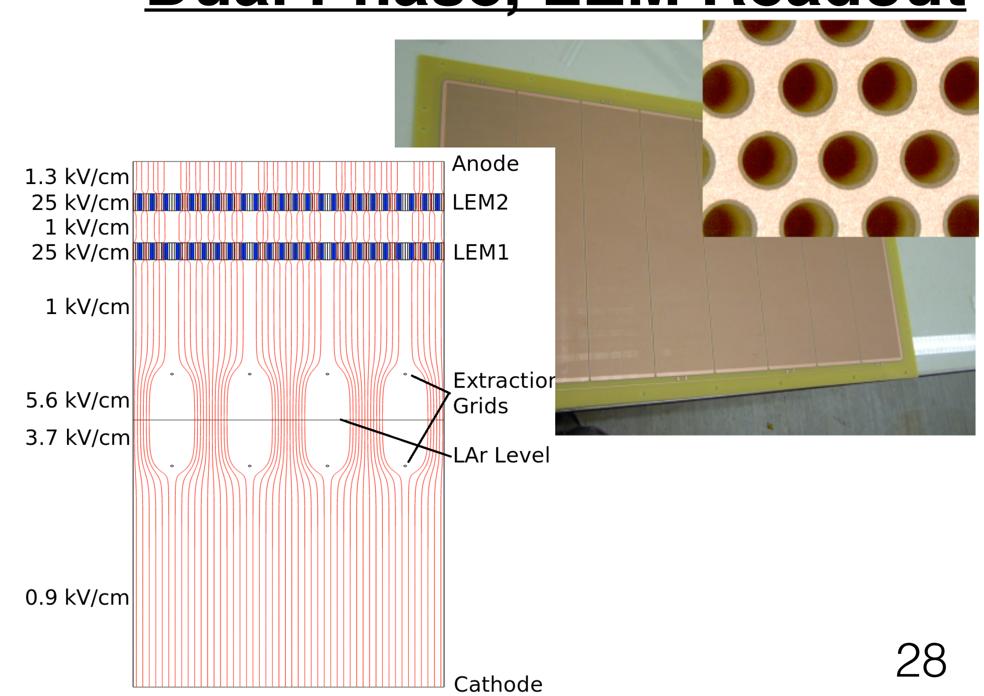


Single Phase, Pad Readout



New Readout Methods

Dual Phase, LEM Readout



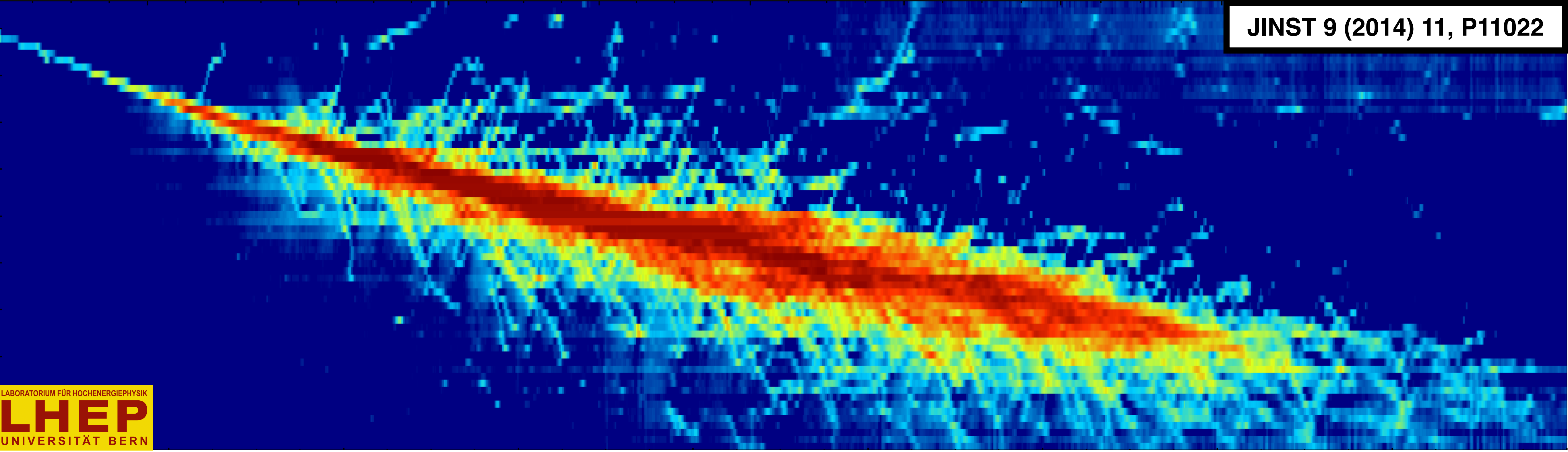
Conclusions

- With a totally electronic readout and bubble chamber quality resolution the liquid argon TPC allows for precision neutrino physics

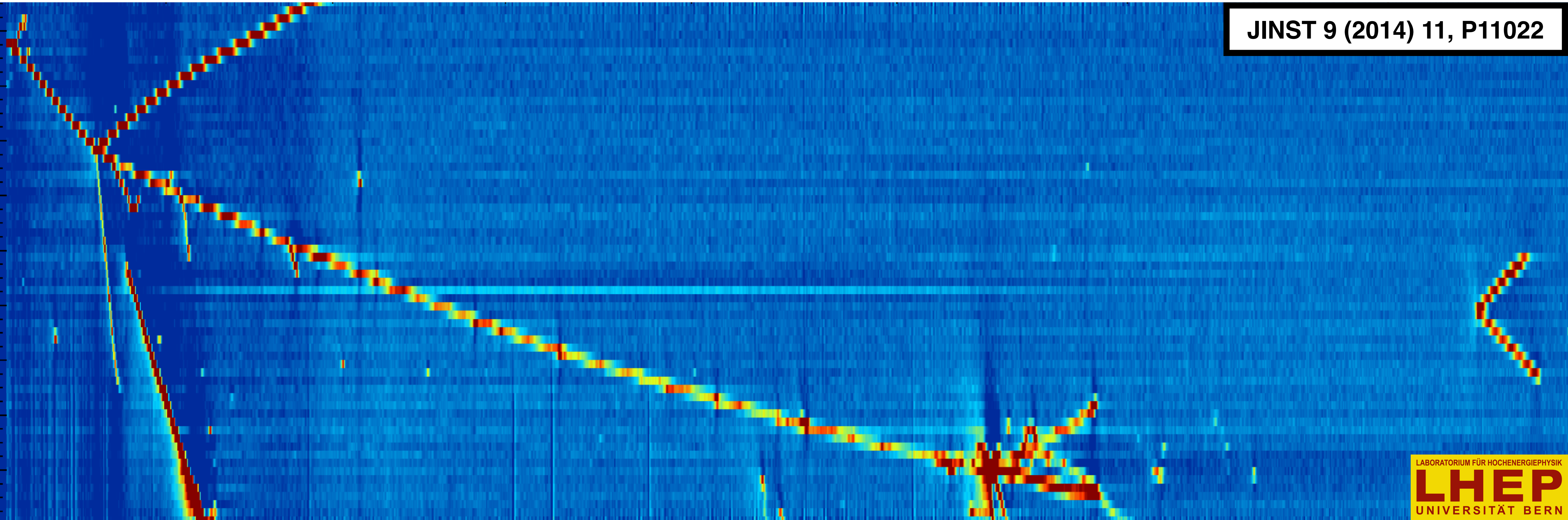
- Many of the technical challenges that we faced in past decades have been addressed

- These detectors are allowing us to start investigating details of nature that have so far escaped our understanding

There is a bright future ahead of us as we push to improve these detectors!


JINST 9 (2014) 11, P11022
LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

Thank you!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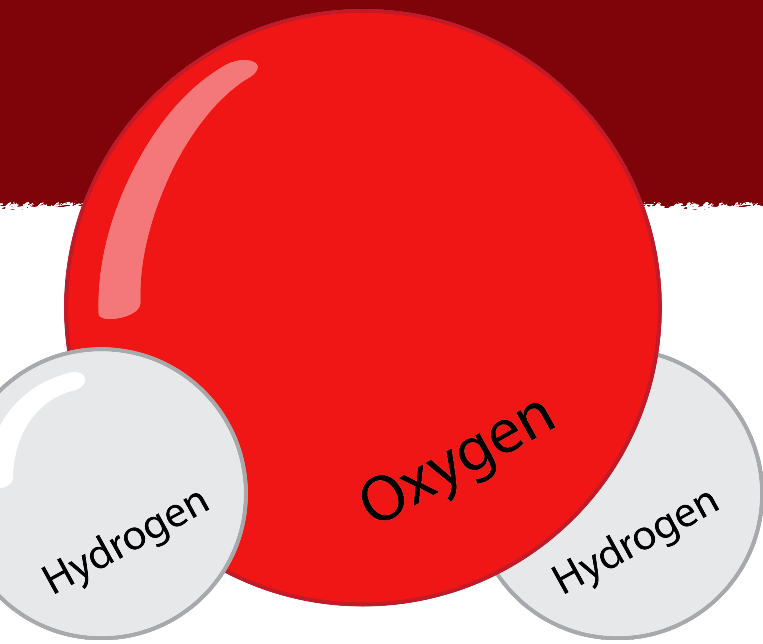
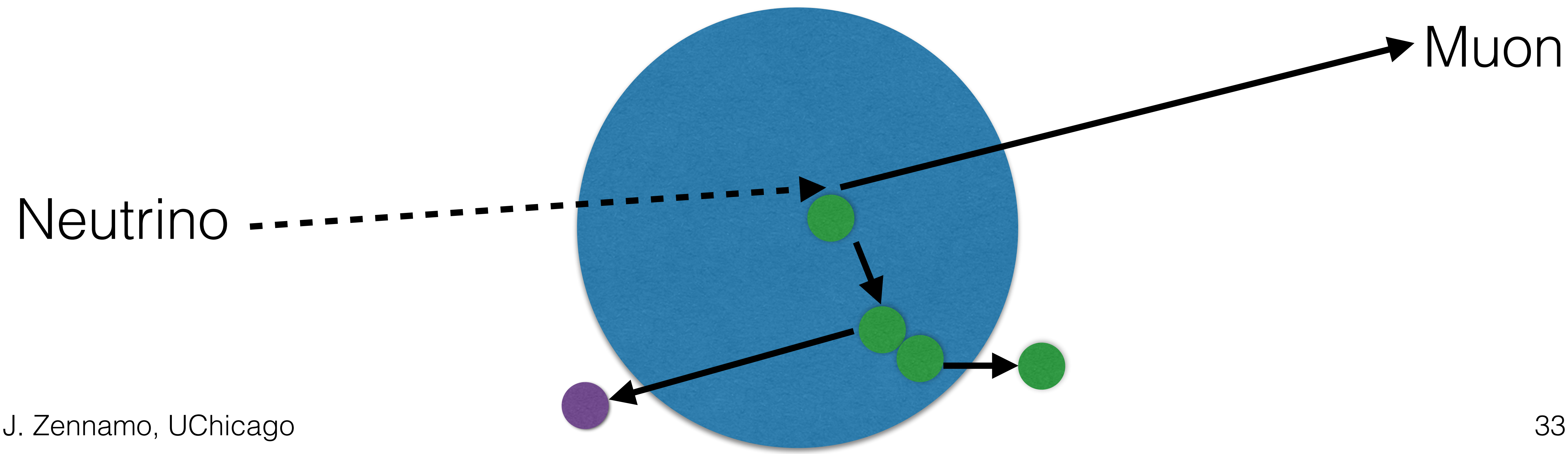
Backups

Two Phase

Nuclear Effects



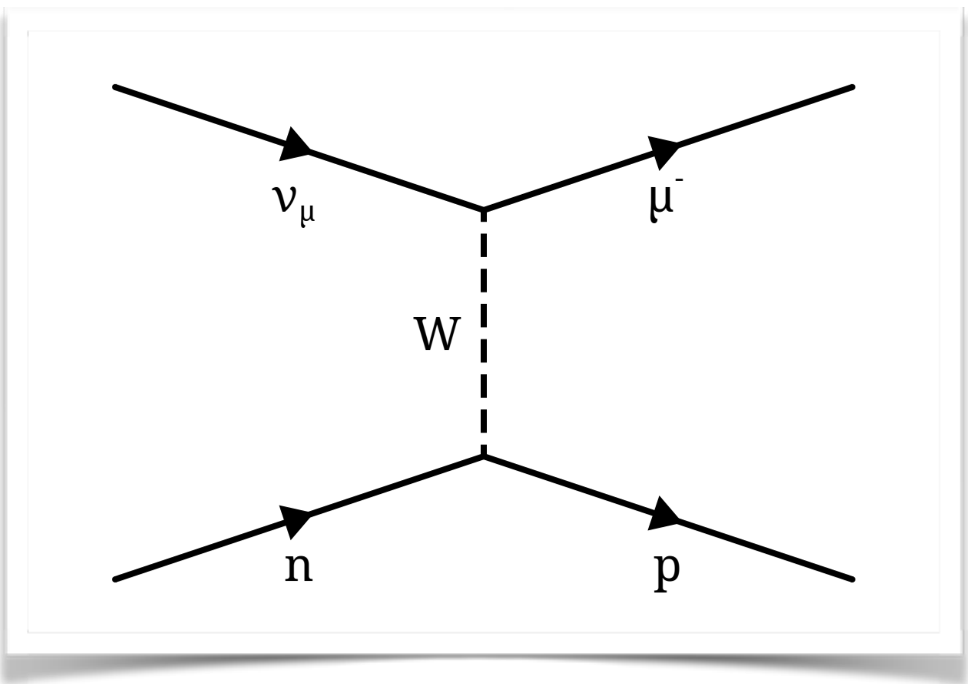
- While water and scintillator have free protons in the form of bound hydrogen atoms argon does not
- As baryons from neutrino interactions traverse the nuclear medium they can interact with the rest of the nucleus



Measuring Nuclear Effects

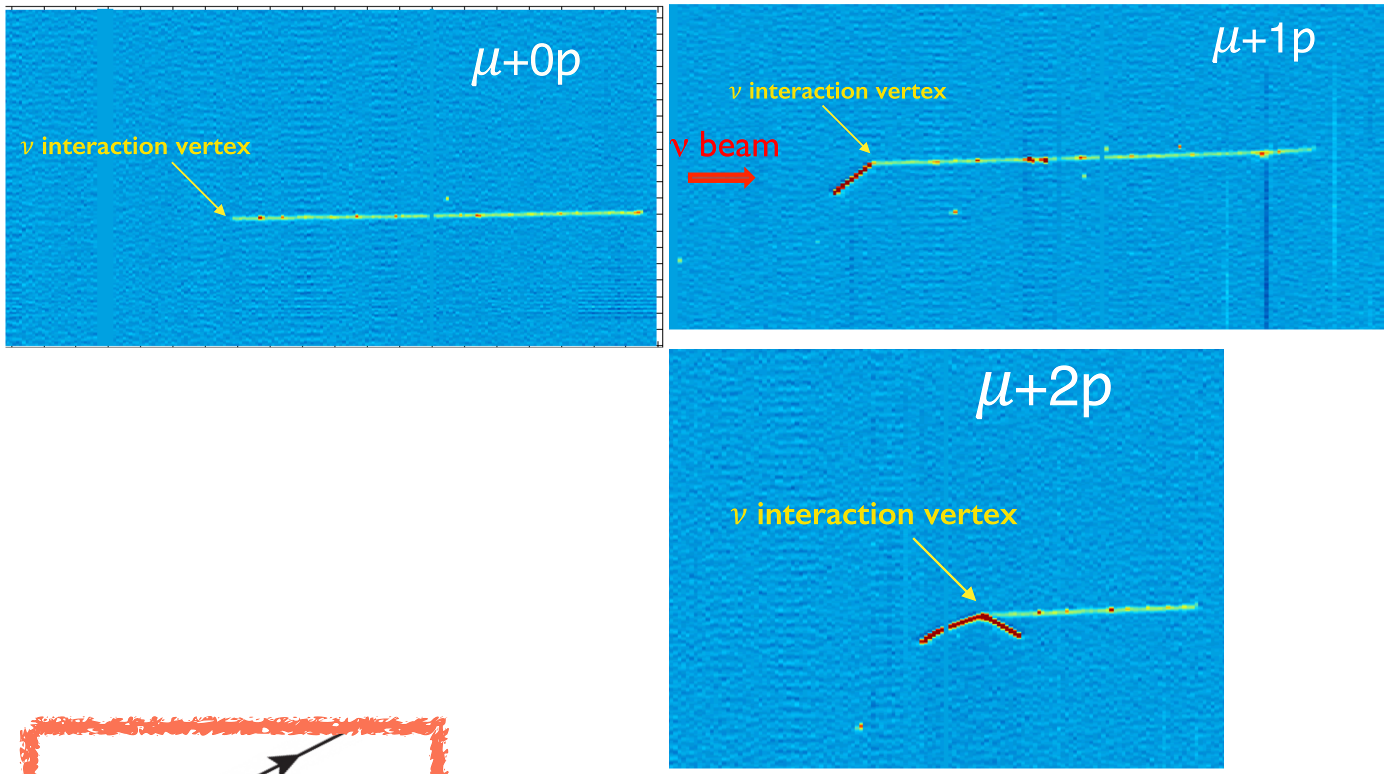
Results from ArgoNeuT

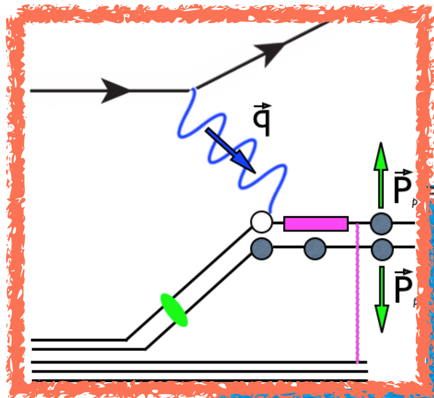
Charged Current Quasi-elastic

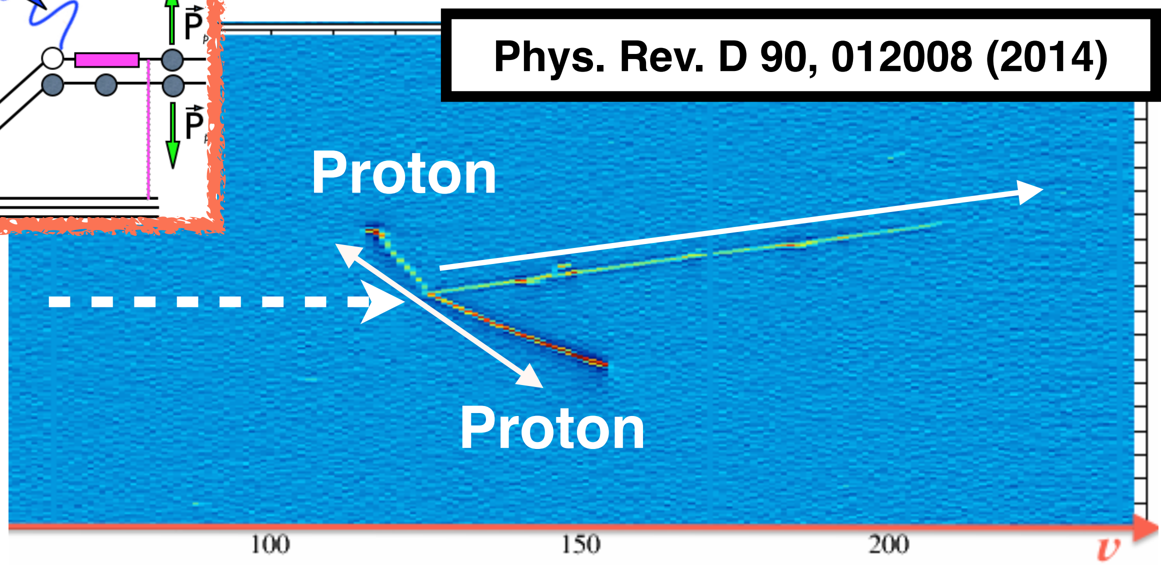


Nuclear Effects

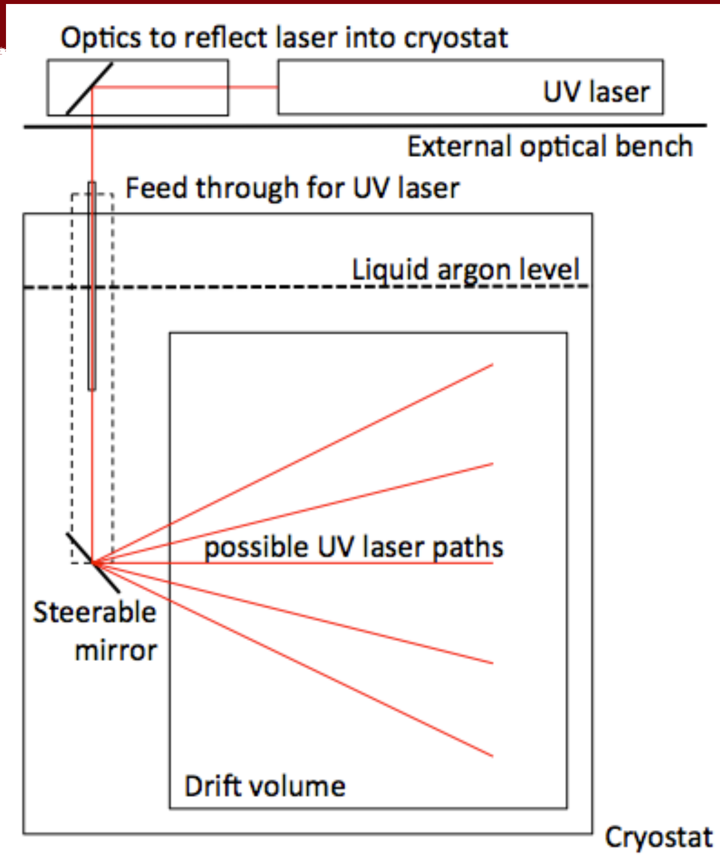
Classification Based on Topology

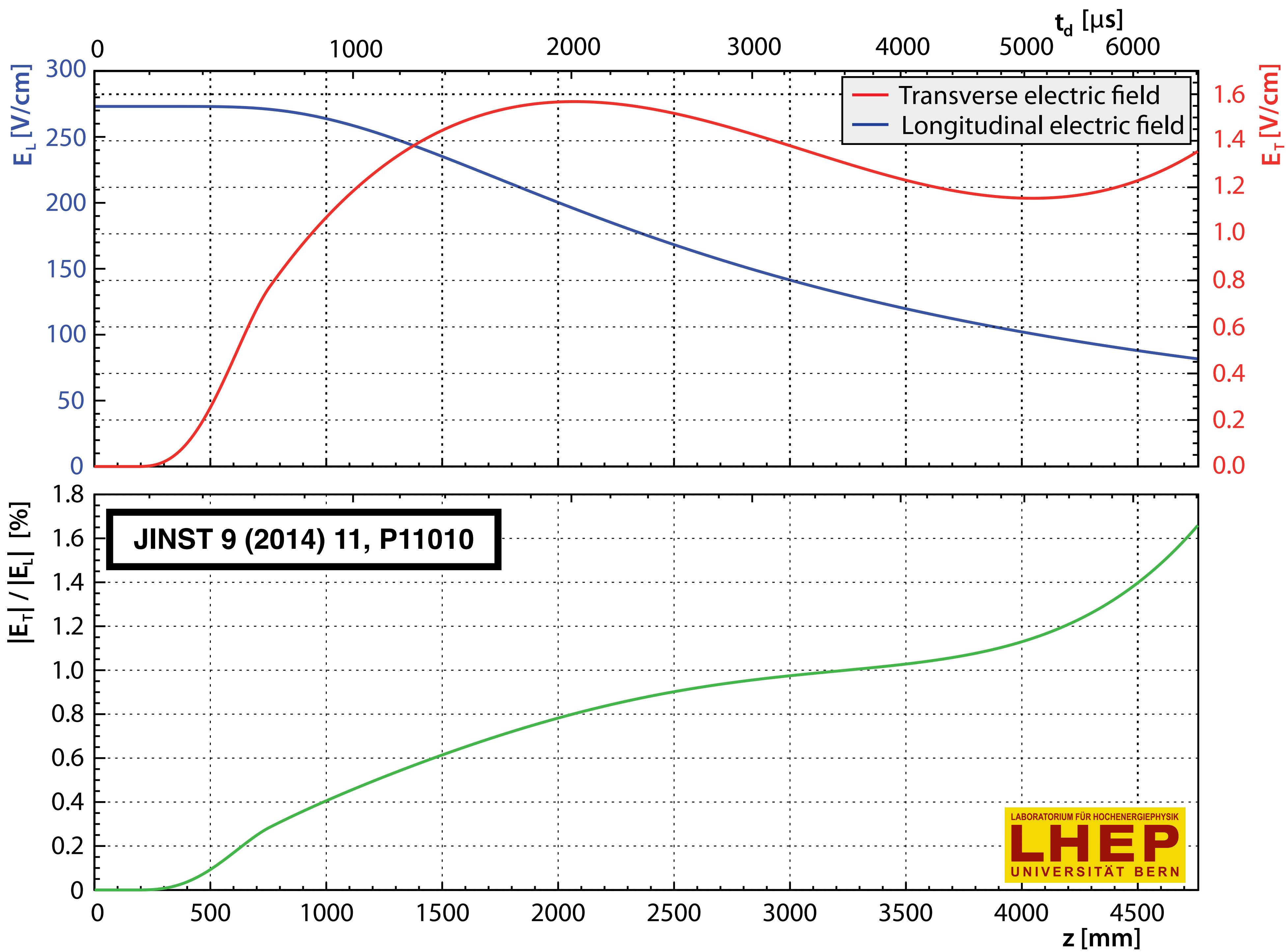




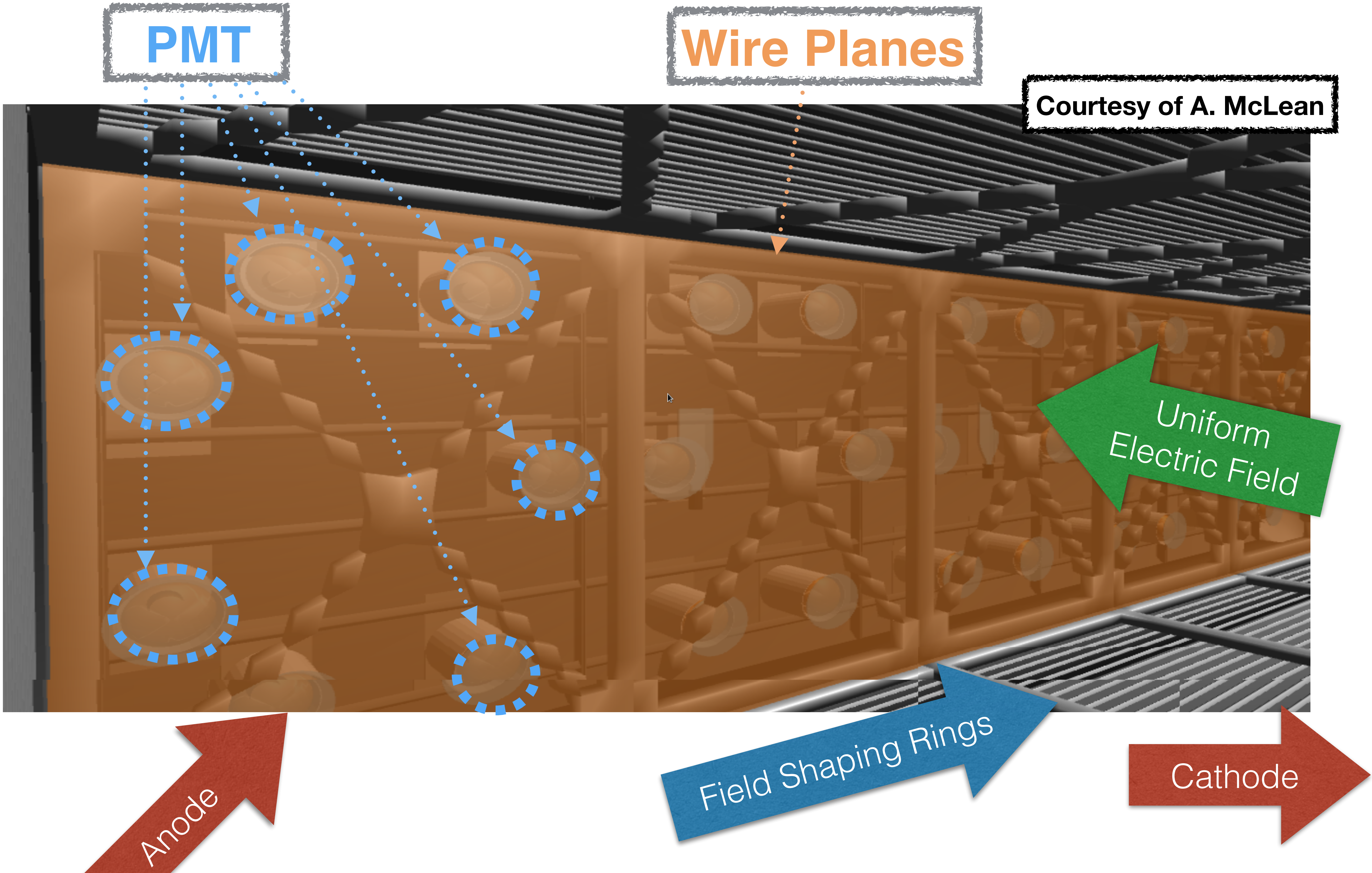


Laser Calibration

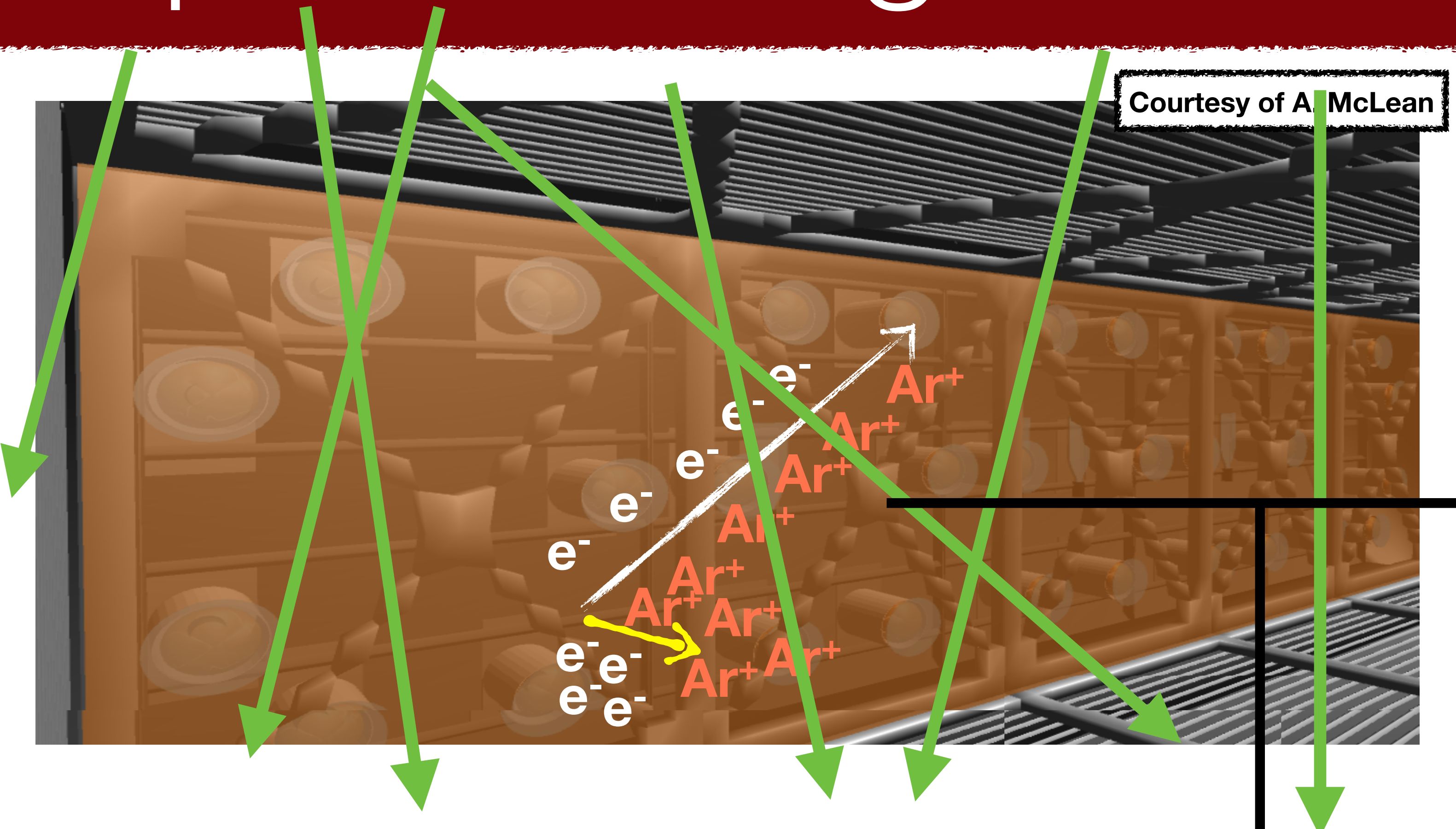


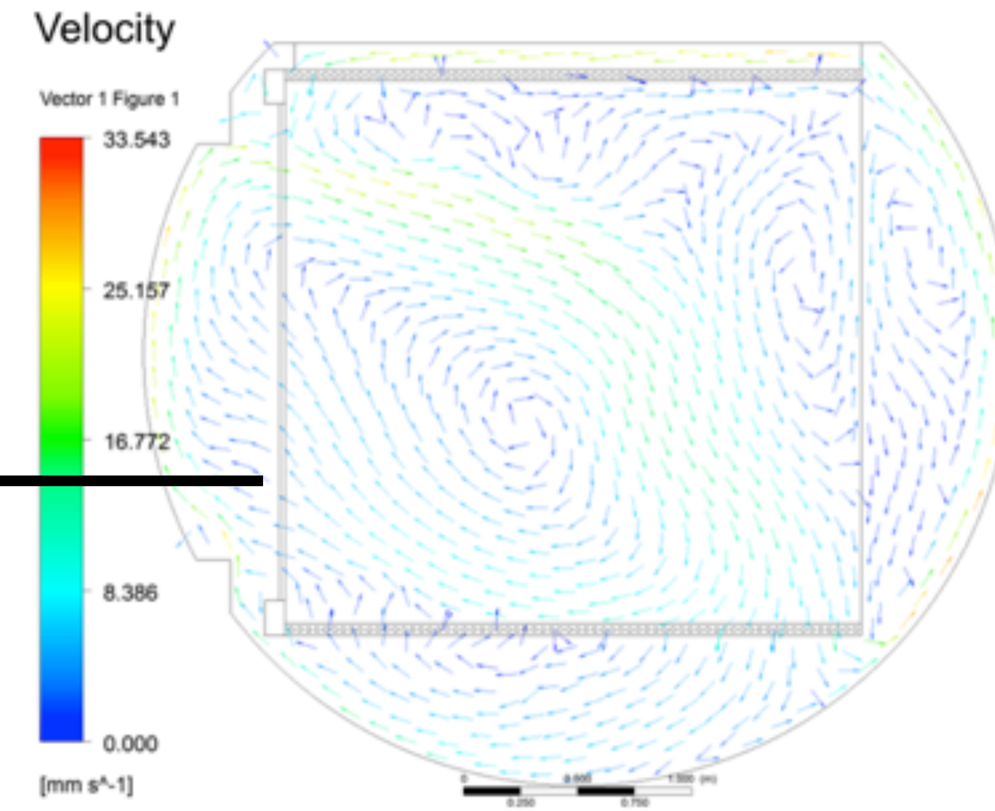


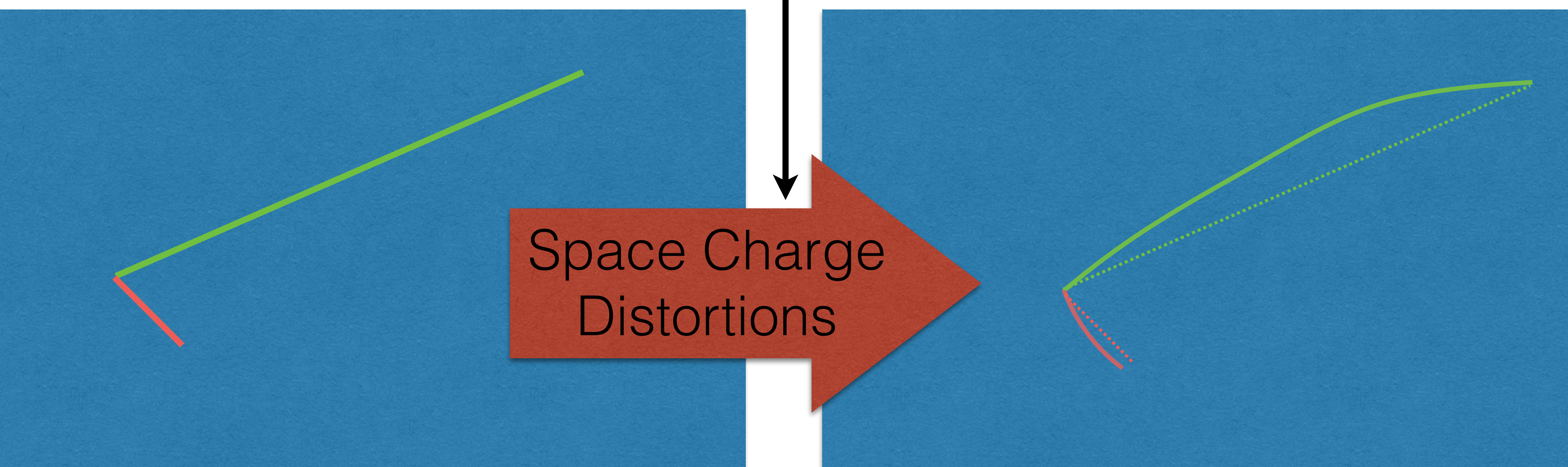
How Does a TPC Work?



Space Charge in Surface Detectors







Laser Calibration

JINST 9 (2014) 11, P11010