MicroBooNE - a not-so-micro LArTPC

Anne Schukraft
Fermilab
IPA, Madison, May 4-6, 2015

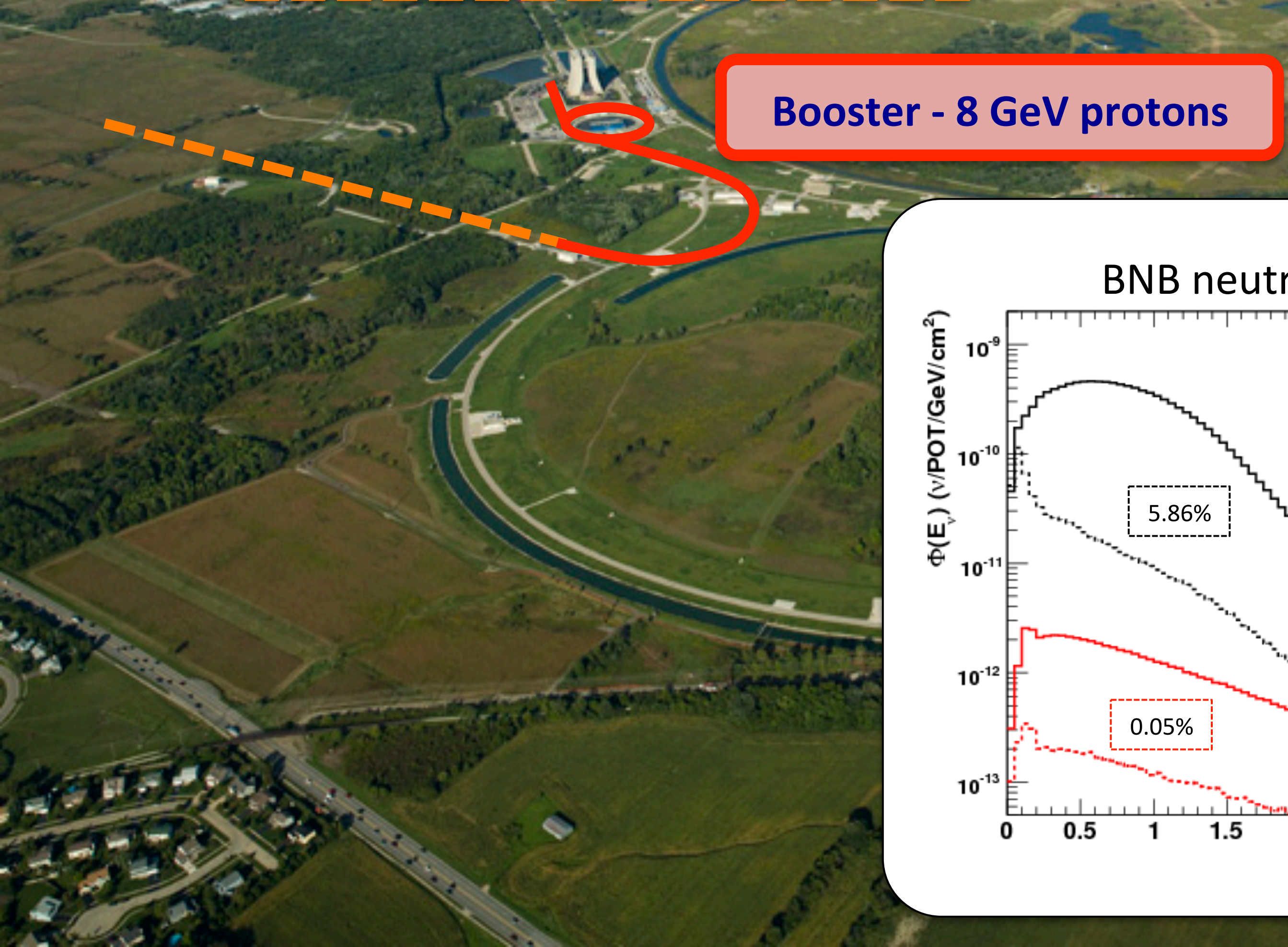

Fermilab

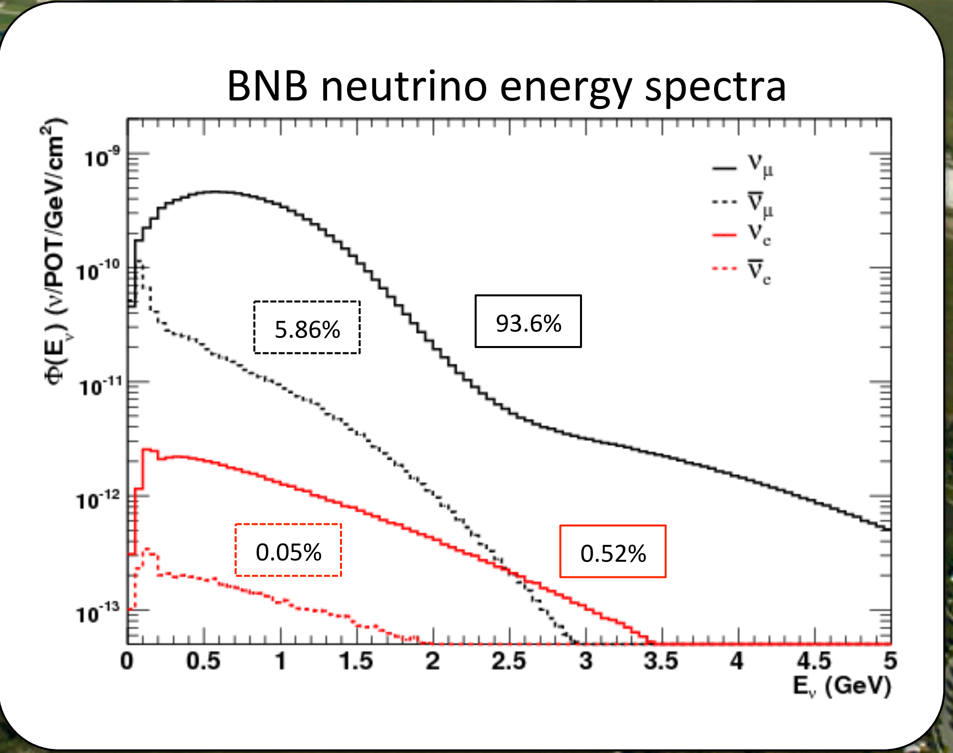
Neutrino beams at Fermilab

BNB

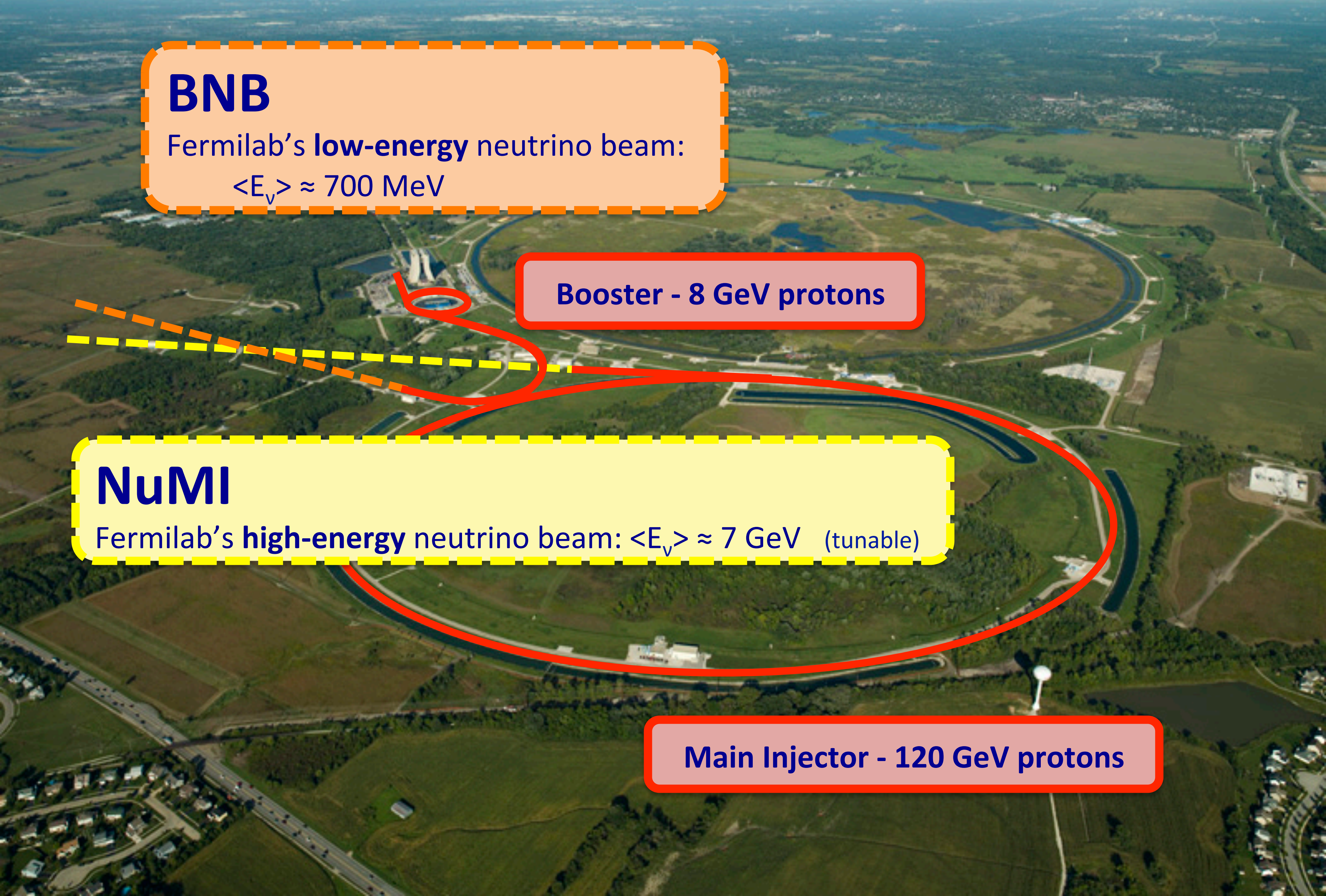
Fermilab's **low-energy** neutrino beam:

$\langle E_\nu \rangle \approx 700$ MeV

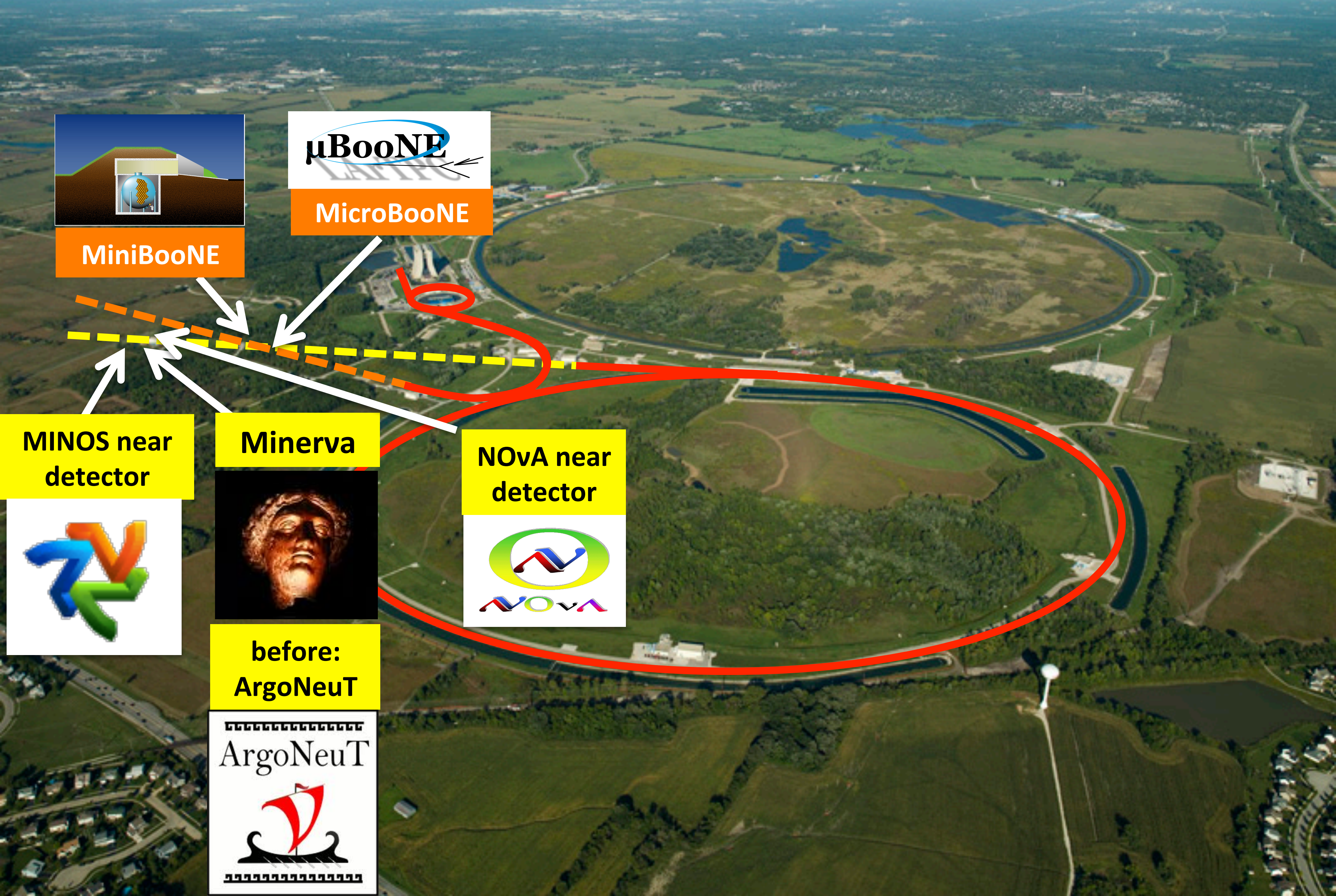




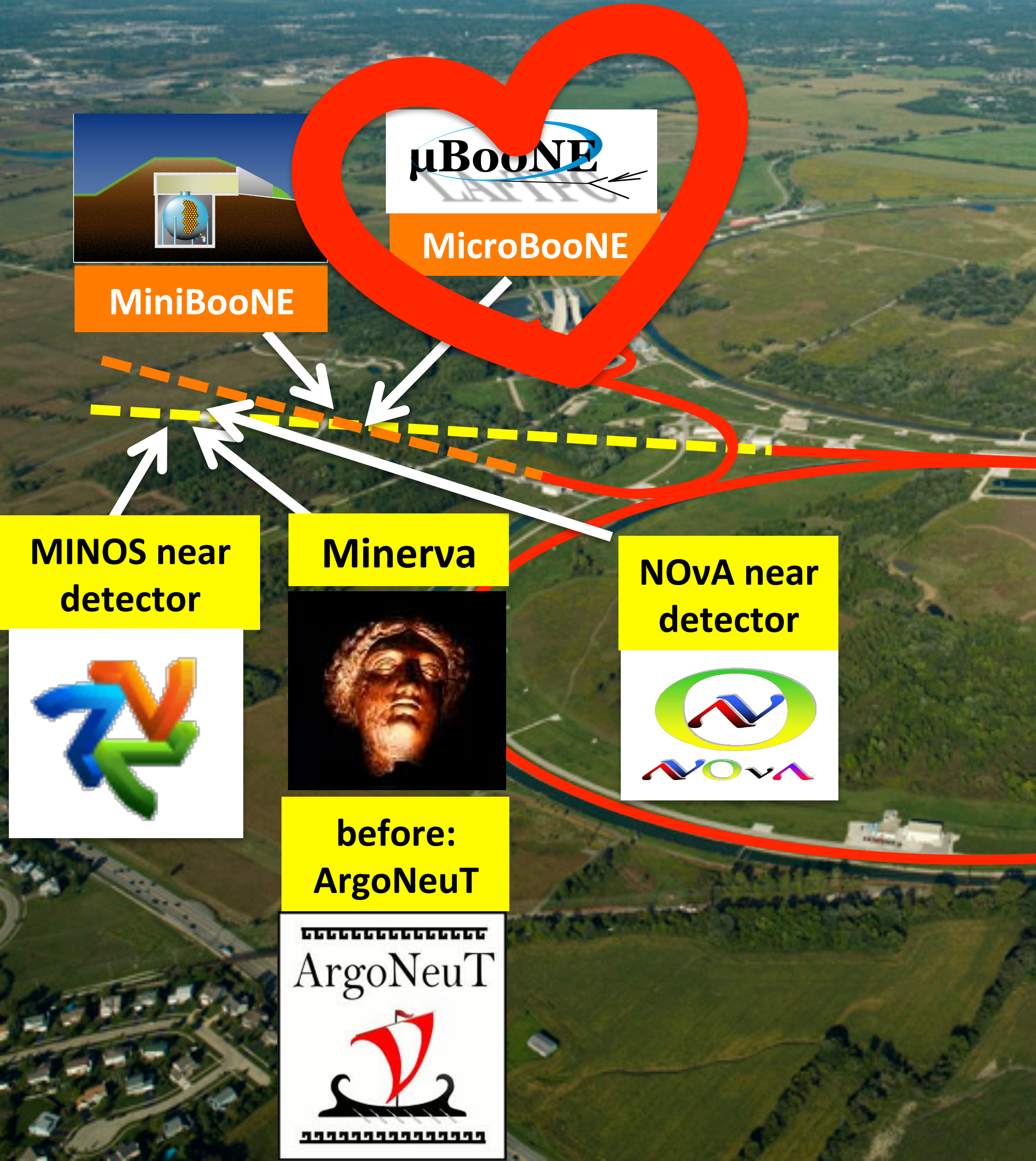
Neutrino beams at Fermilab



Neutrino experiments at Fermilab



Neutrino experiments at Fermilab



MicroBooNE

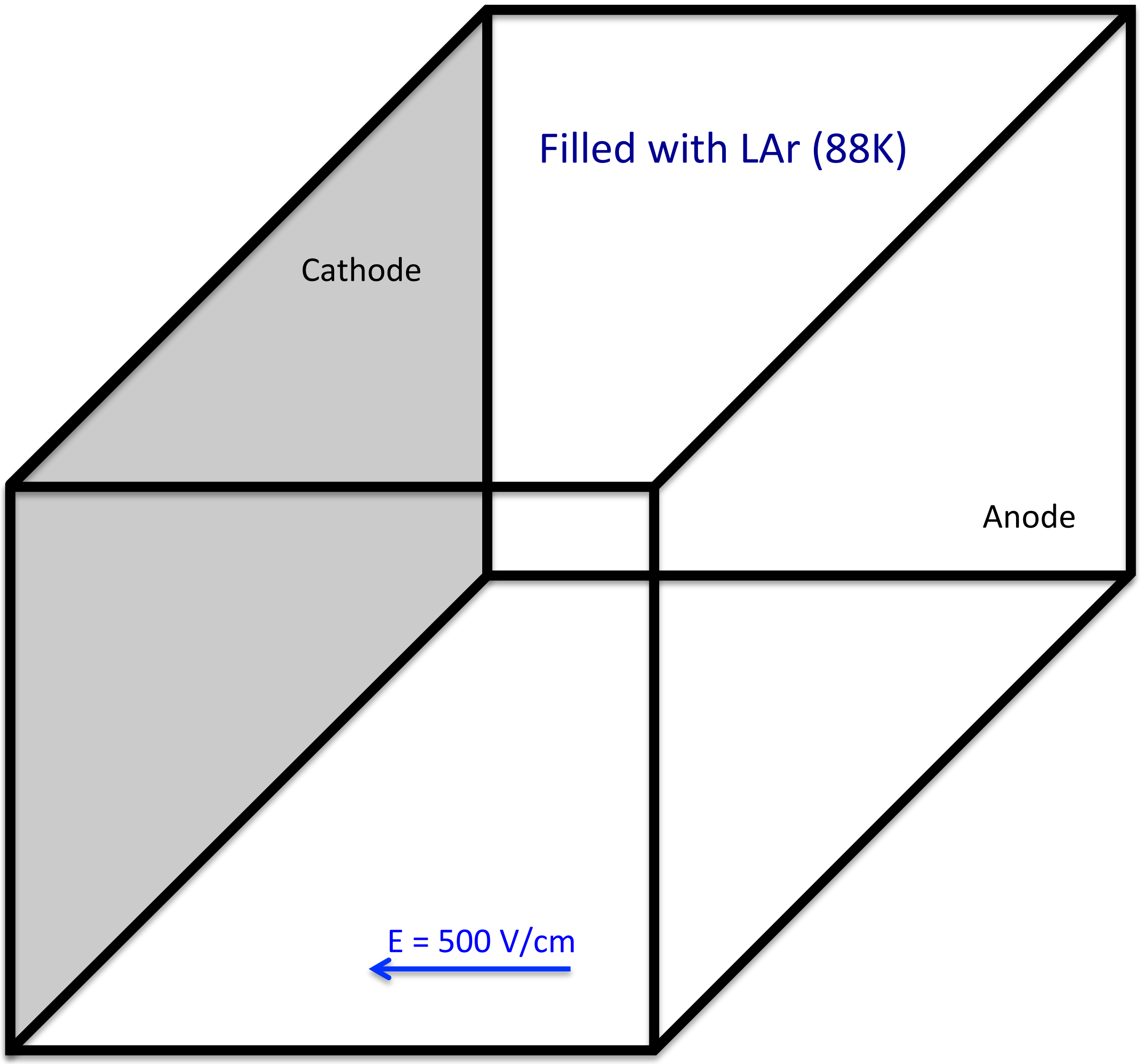
Short baseline experiment:
L = 470m

Technology:
LArTPC
170 t

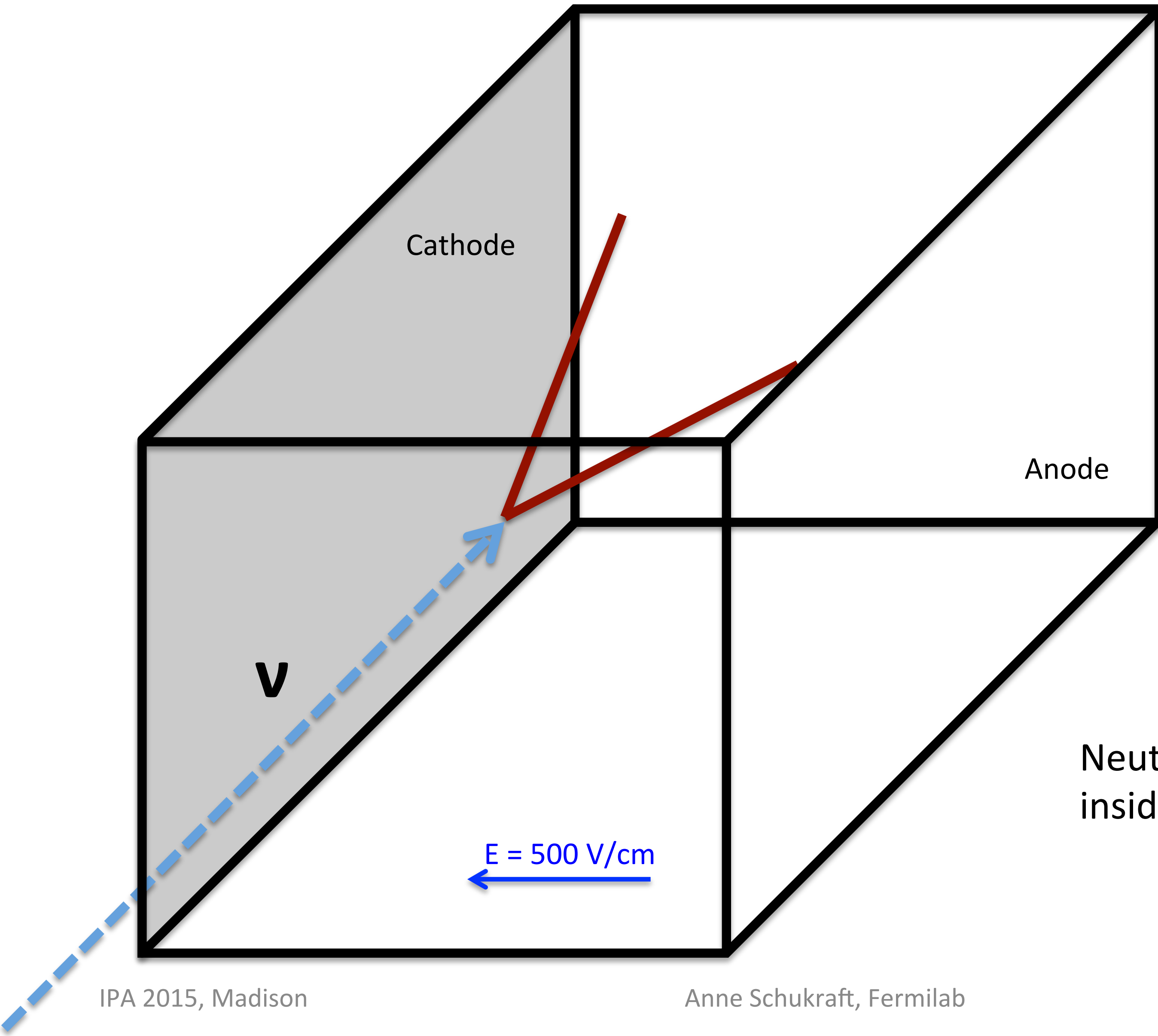
Physics goals:
MiniBooNE low-energy excess,
neutrino-argon cross sections,
LAr R&D

Status:
Right now in Cool Down phase!
Will start data taking this summer.

The principle of a LArTPC

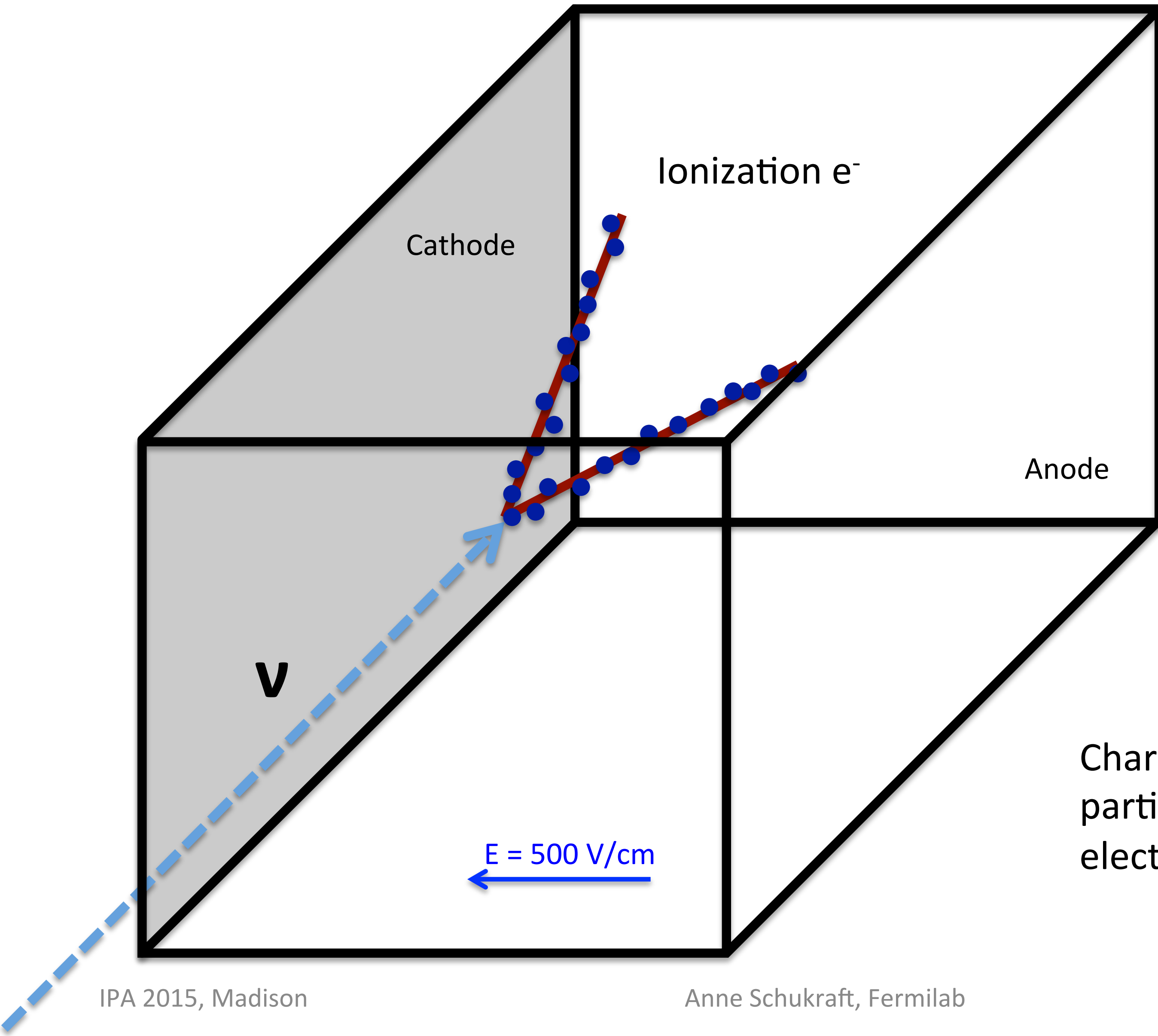


The principle of a LArTPC



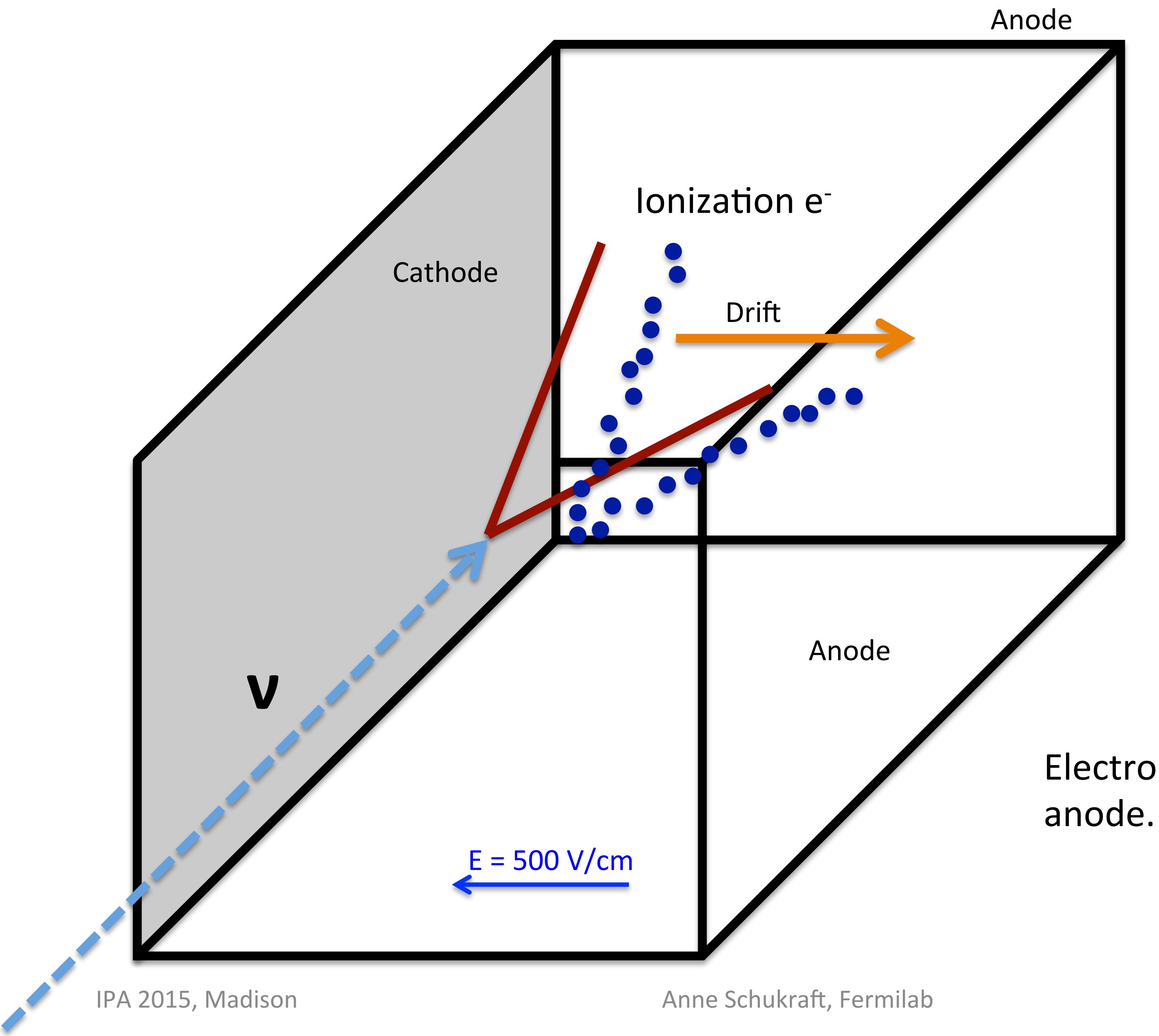
Neutrino interacting with inside the TPC volume

The principle of a LArTPC



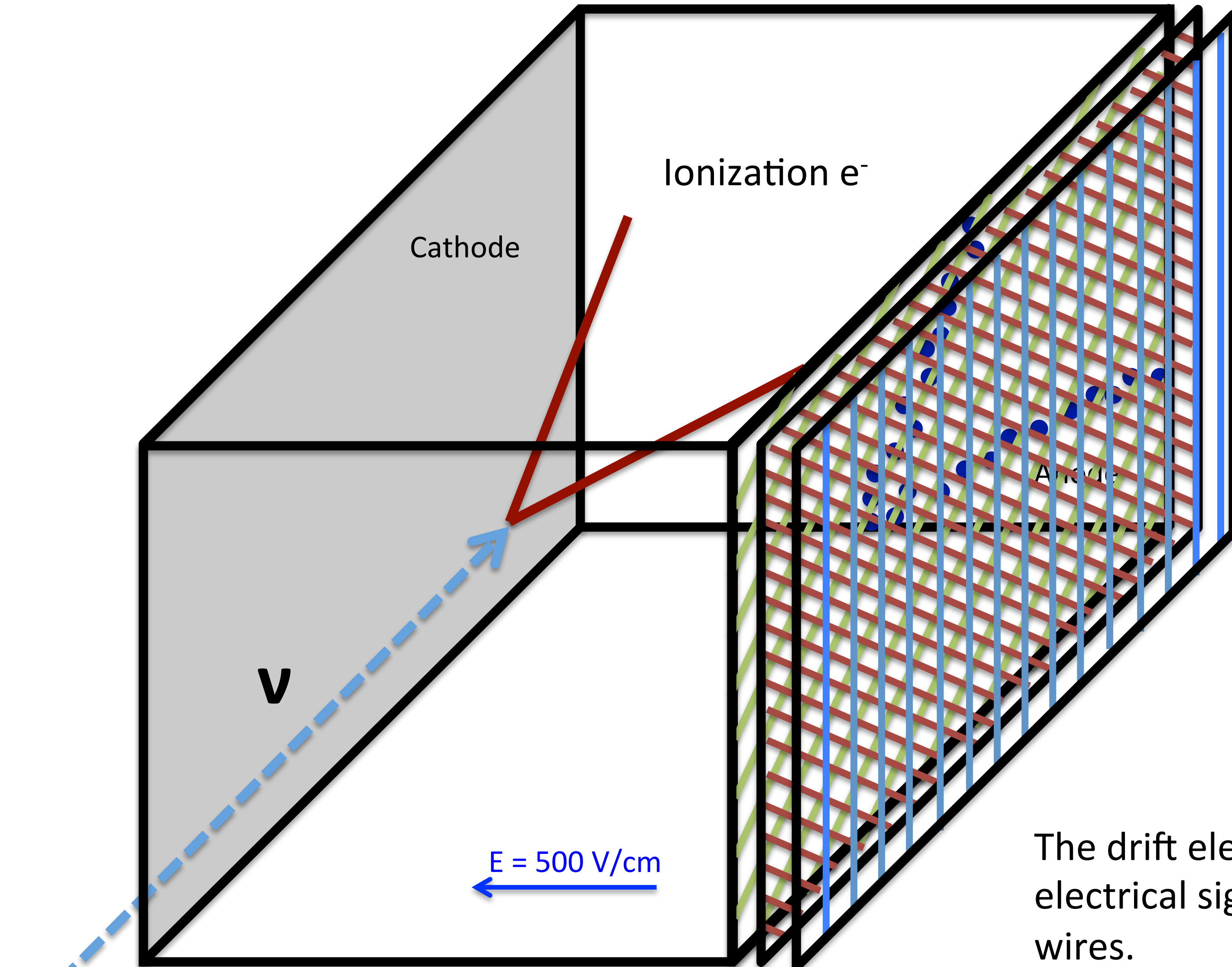
Charged secondary particles produce ionization electrons

The principle of a LArTPC



Electrons drift towards anode.

The principle of a LArTPC

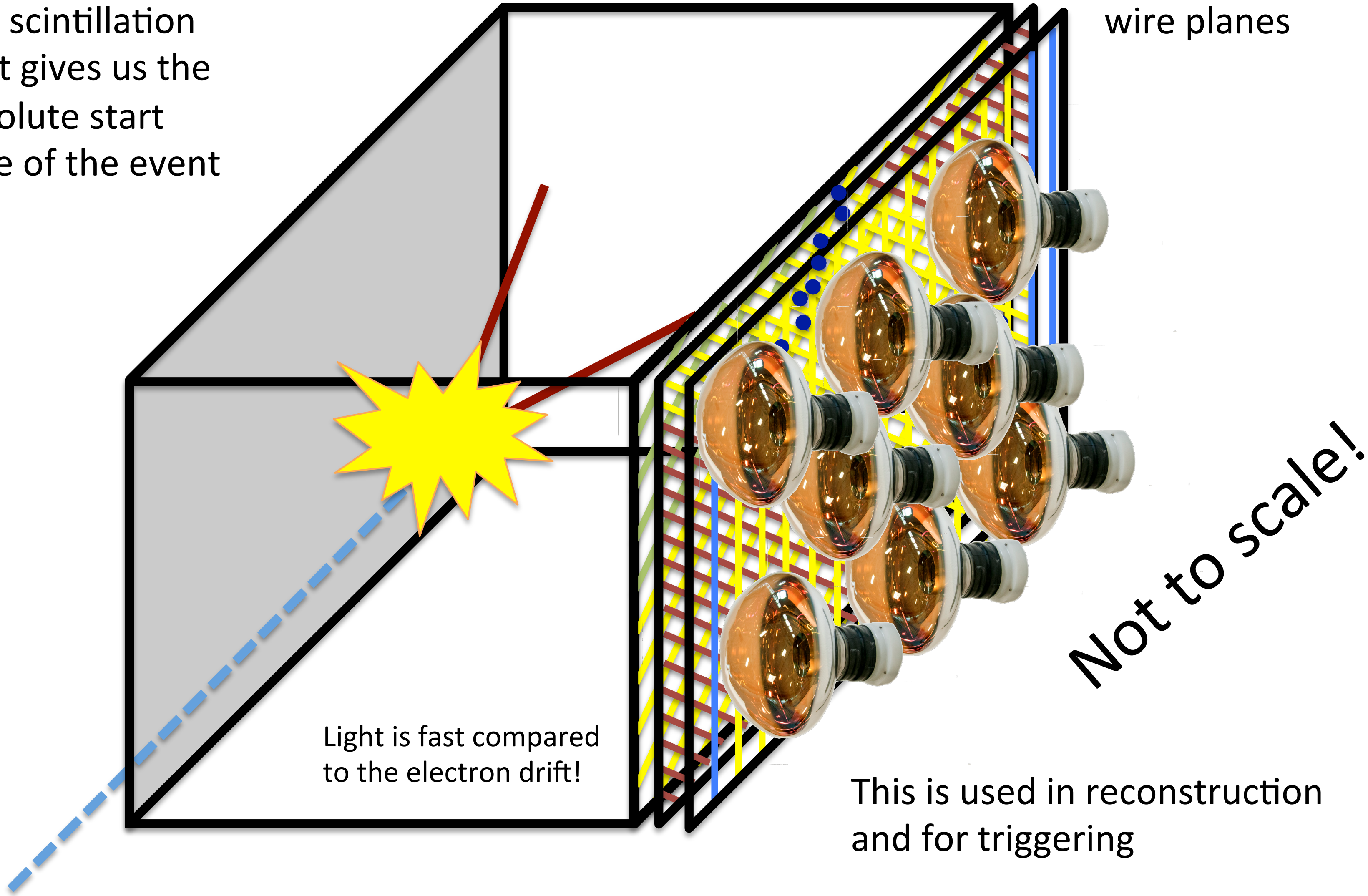


The drift electrons cause an electrical signal on the anode wires.

Scintillation light in a TPC

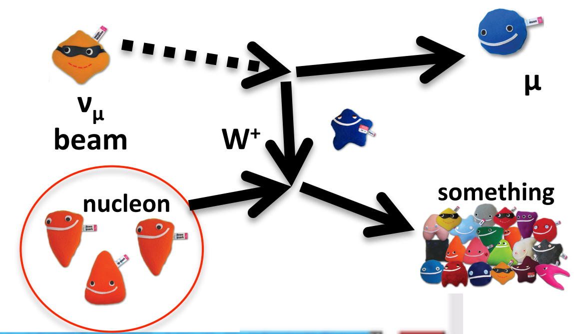
The scintillation light gives us the absolute start time of the event

Light collection system behind wire planes

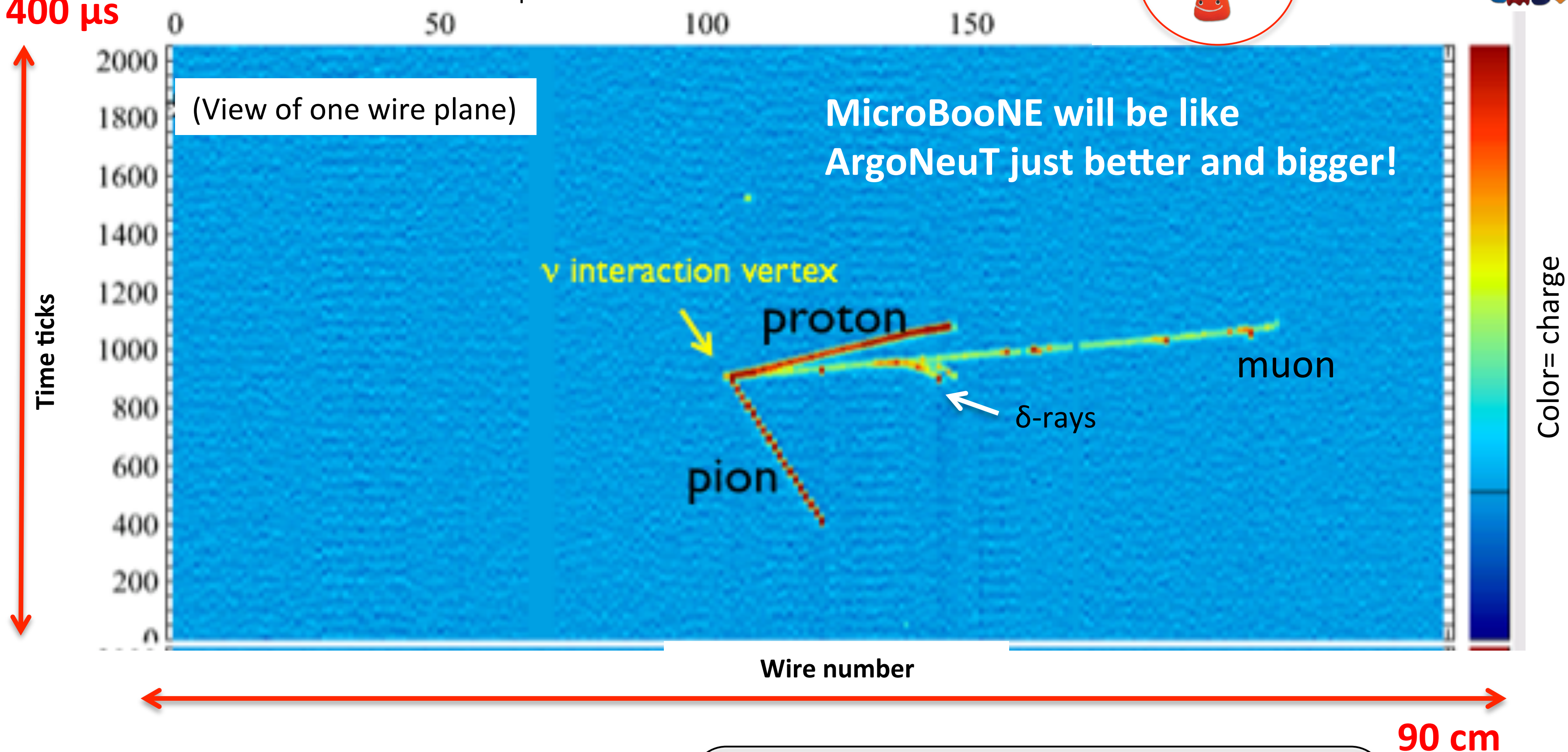


This is used in reconstruction and for triggering

Neutrino events in LAr



A charged-current ν_μ interaction in ArgoNeuT

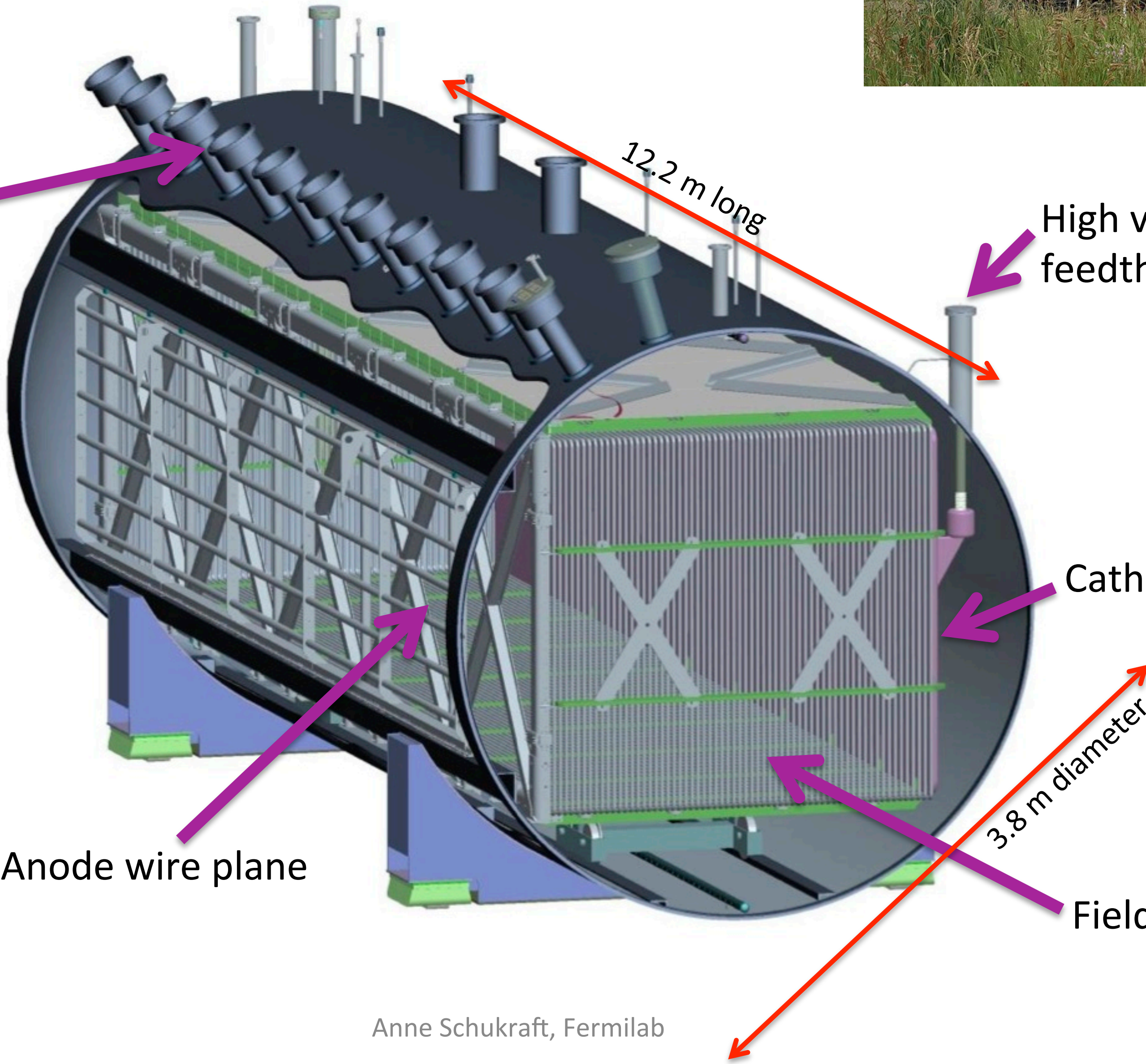


Back to bubble chamber quality, but fully automated!!!

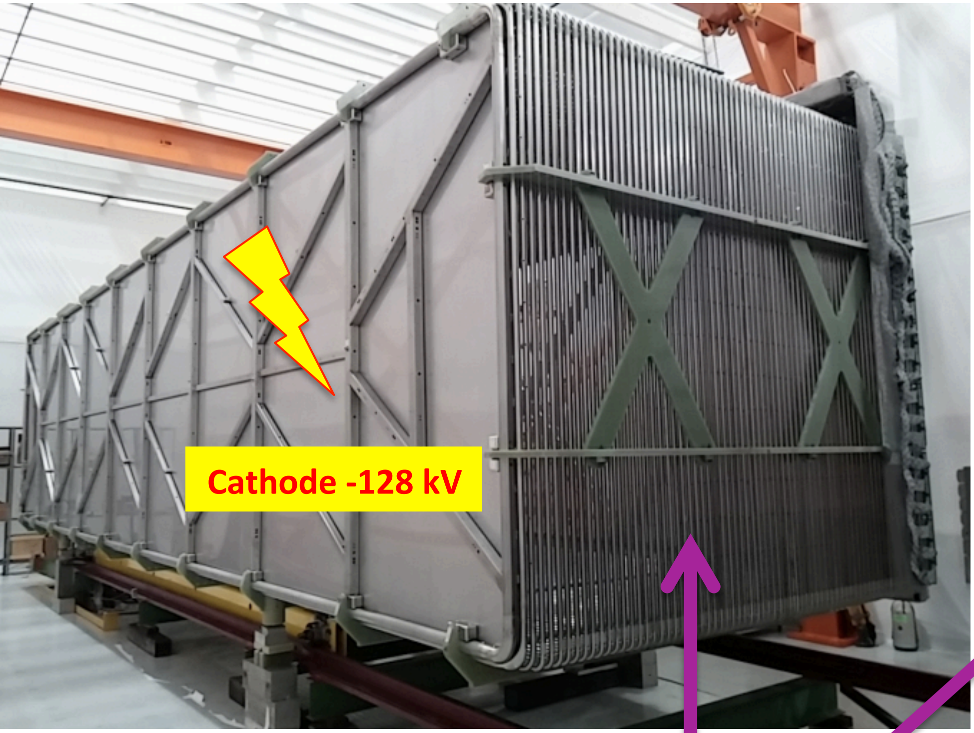
From ArgoNeuT to MicroBooNE

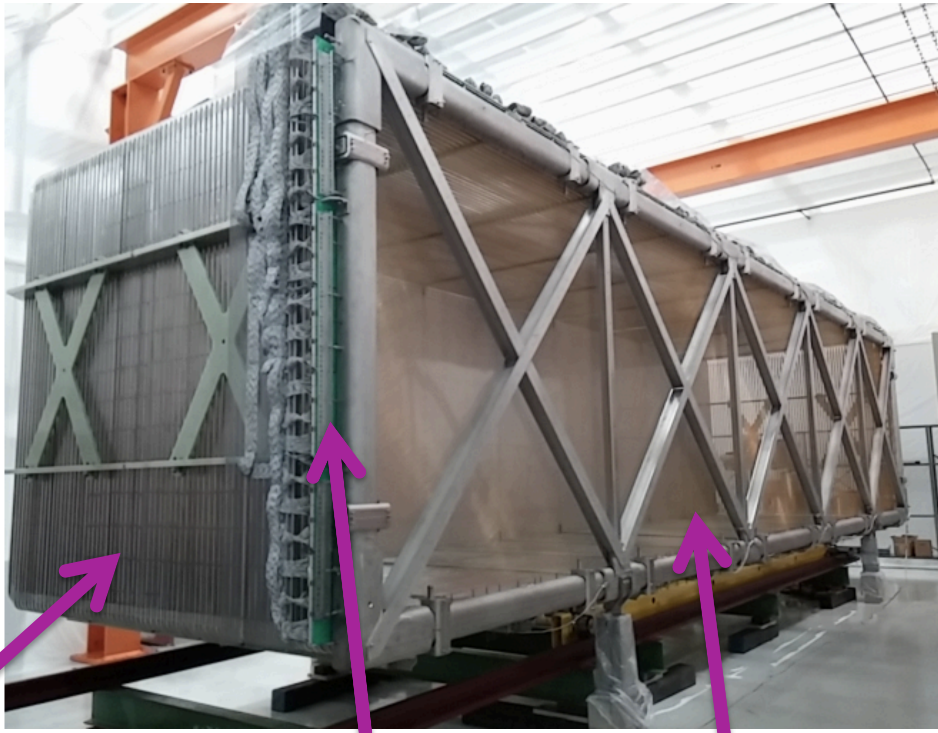
ArgoNeuT — Scale volume by factor 220 → μBooNE

The MicroBooNE detector



The TPC – cathode and field cage





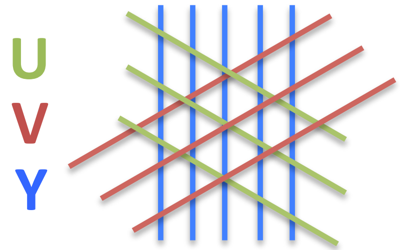
Anode wire plane

Field cage:
64 stainless steel tubes at different potential to create a uniform electric field inside
“loops around the TPC volume”

Wire readout electronics boards

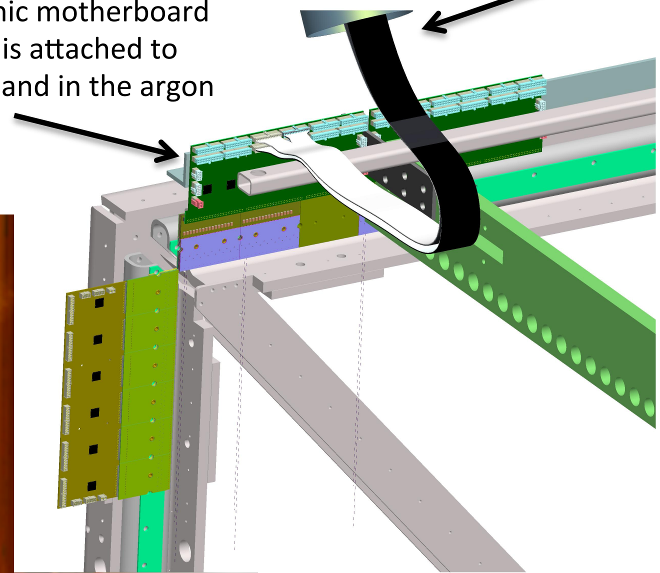
The TPC – anode wire plane

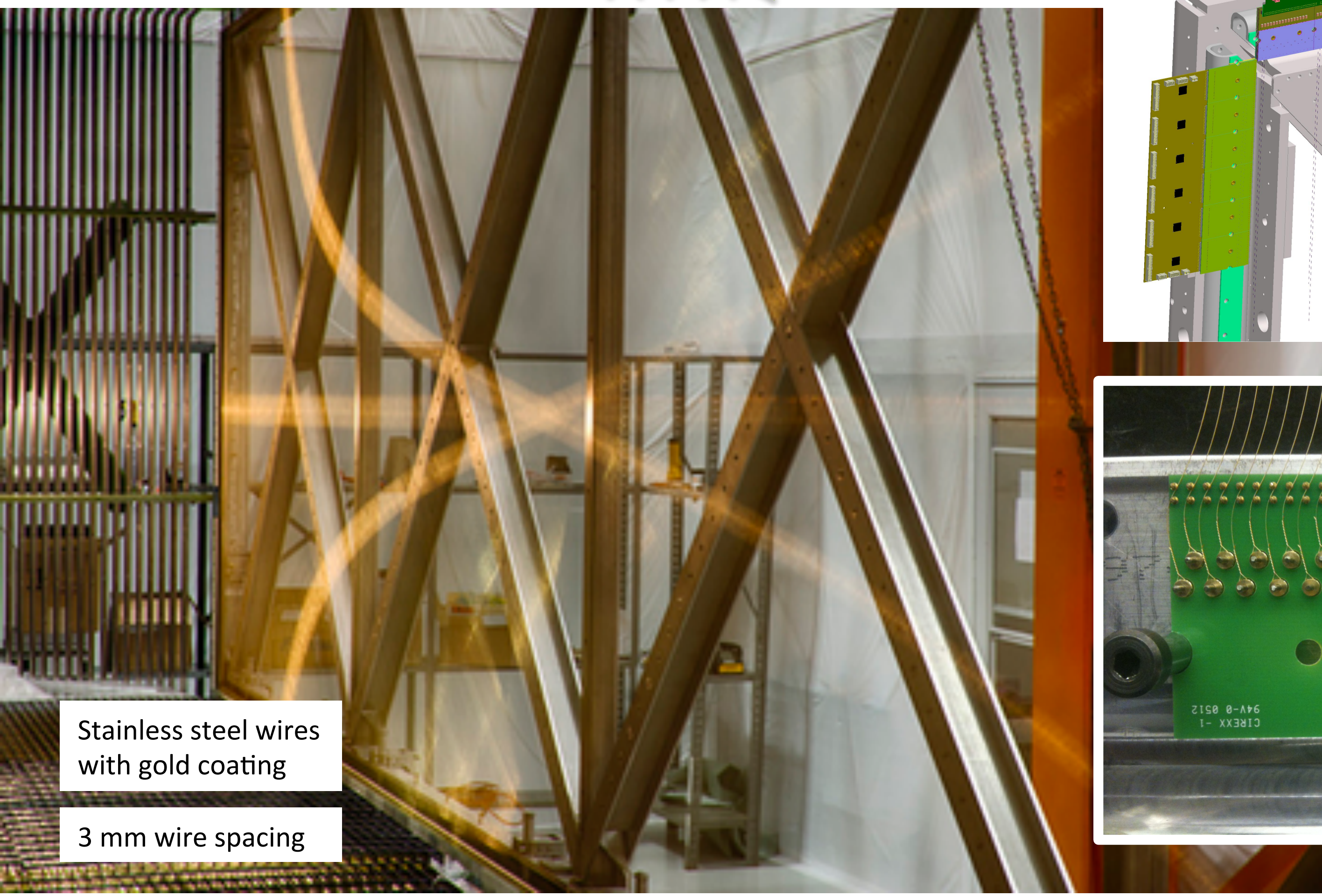
3 wire planes
8256 wires total



Low-noise electronic motherboard with pre-amplifier is attached to wire carrier board and in the argon

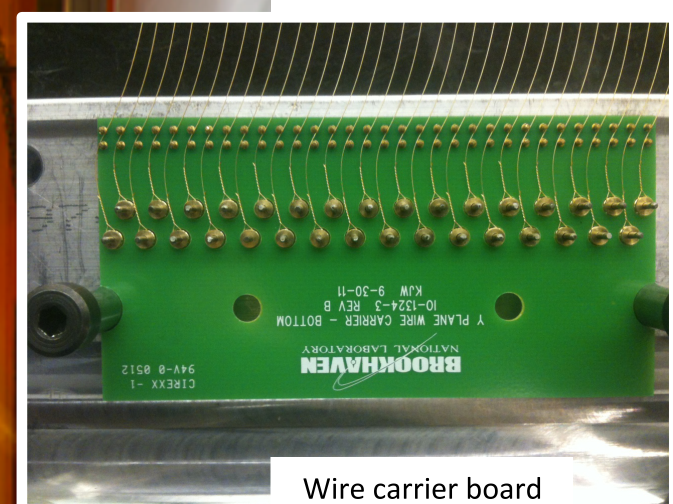
Cold cables bring signal out to the feedthrough





Stainless steel wires with gold coating

3 mm wire spacing



Wire carrier board

The high voltage (HV) system

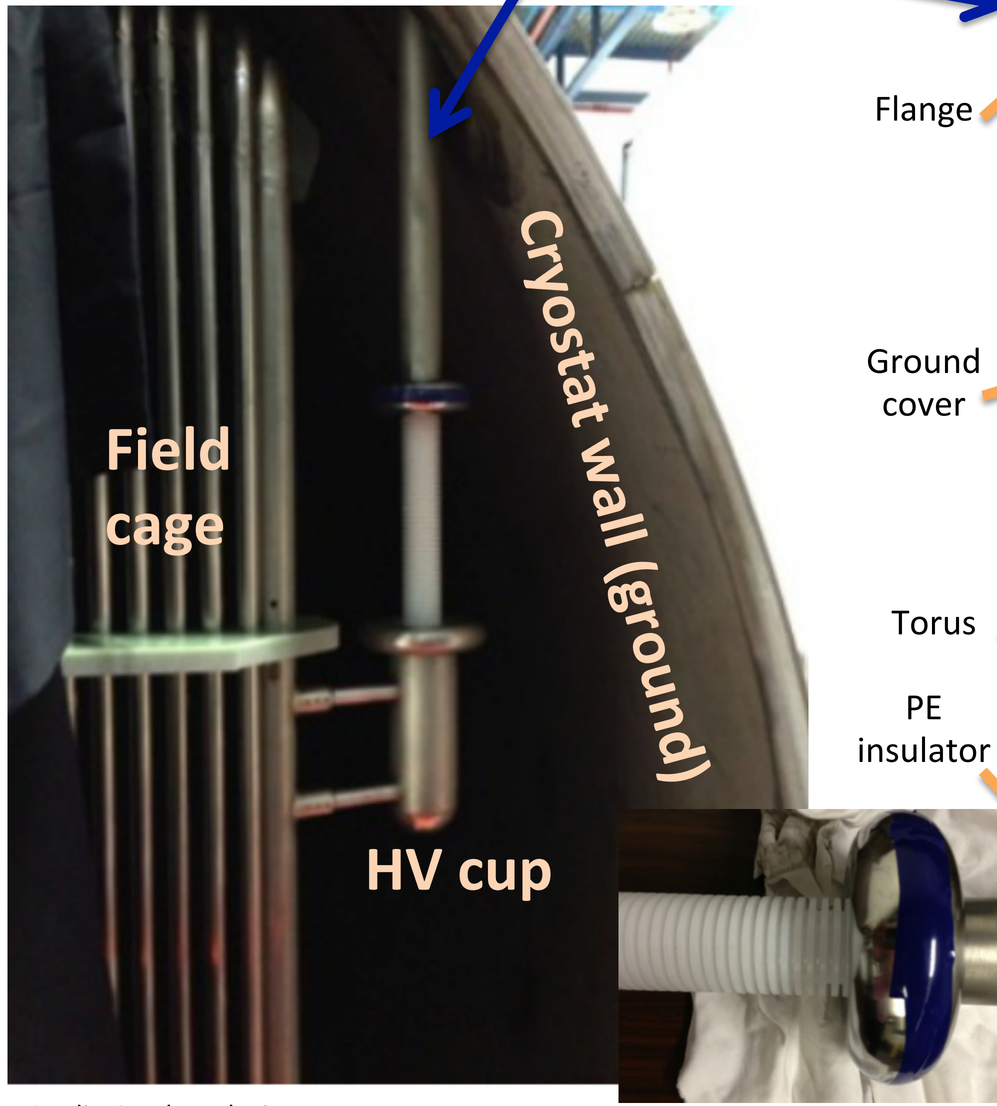
MicroBooNE has a longer drift distance than previous detectors

-> needs a high cathode voltage to supply electrical field **(-128 kV)**

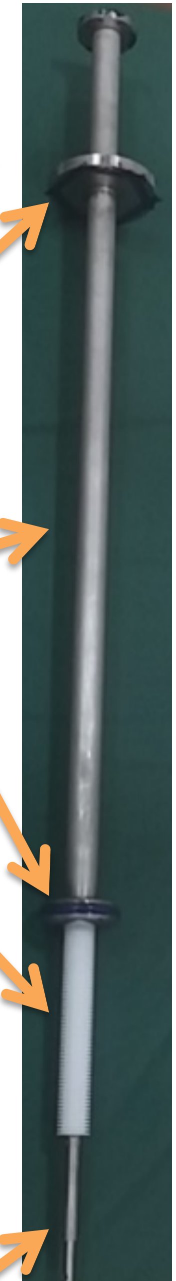
The challenge:

Avoid electrical breakdown between components on different electrical potential

See also: breakdown studies in LAr:
JINST 9, P11001 (2014)
JINST 9, P04006 (2014); JINST 9, P07023 (2014)



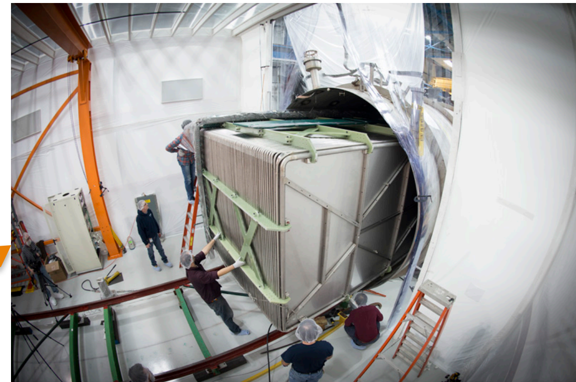
Credit: Sarah Lockwitz



Installation – a picture series

PMT system installation: Dec 2013

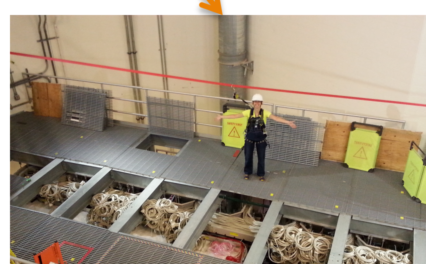
TPC insertion: Dec 23rd, 2013



Moving day! June 23rd, 2014

MicroBooNE's home in the beam line: The LAr Test Facility

Foamed in! July 2014



Cabled up! Sept. 2014

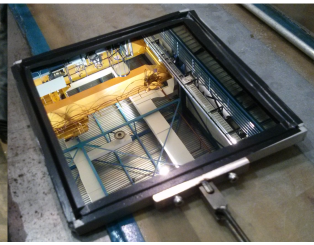
All electronics in! Dec. 10, 2014

Final health check

Looking through a 10’ vacuum port with

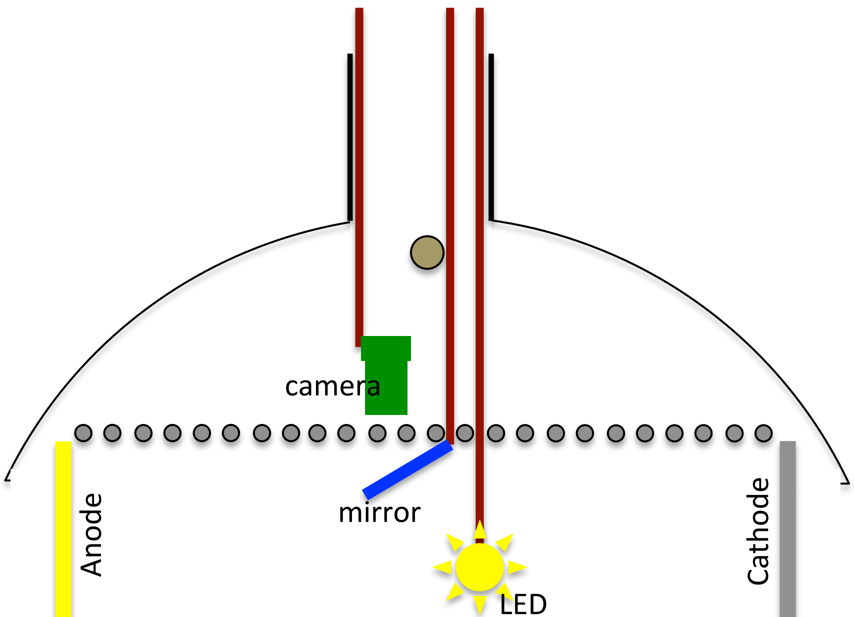
a camera,

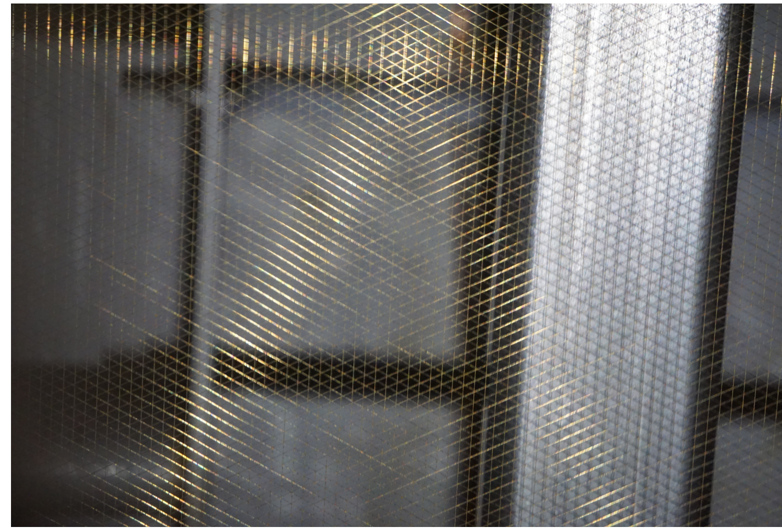
a mirror,



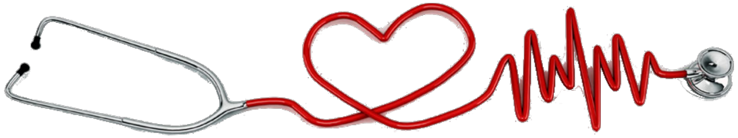
an LED lamp

… and viewing wires from up to 5m distance.



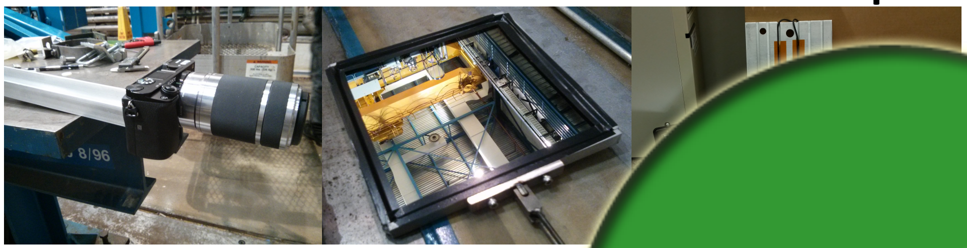


Final health check

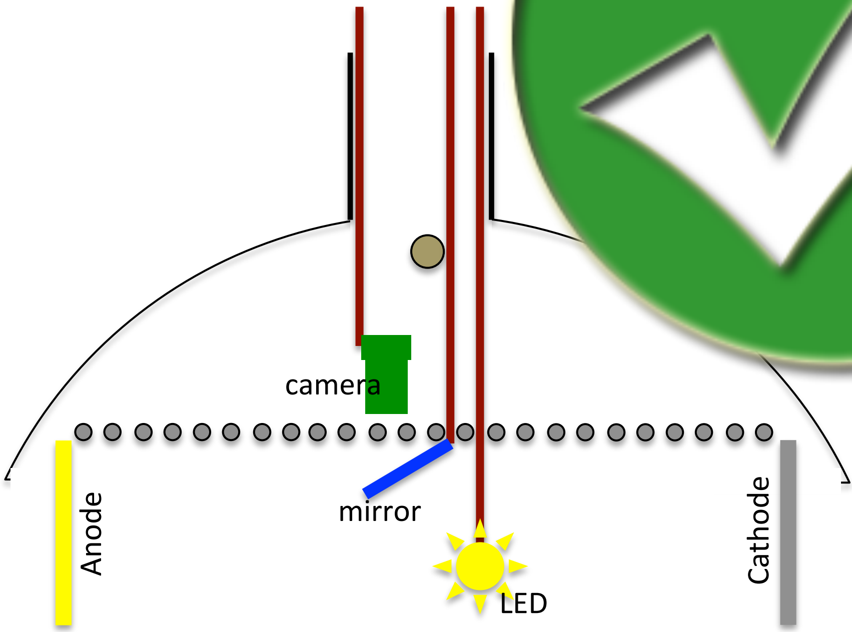


Looking through a 10' vacuum port with

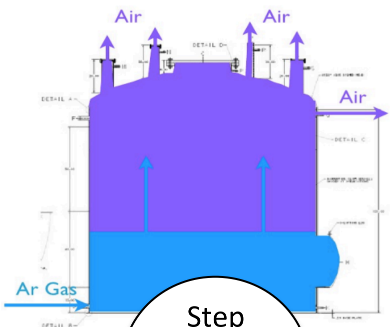
a camera, **a mirror,** **an LED lamp**



... and viewing wires from u



MicroBooNE live



Step
1

Purge
with argon gas to get air out.

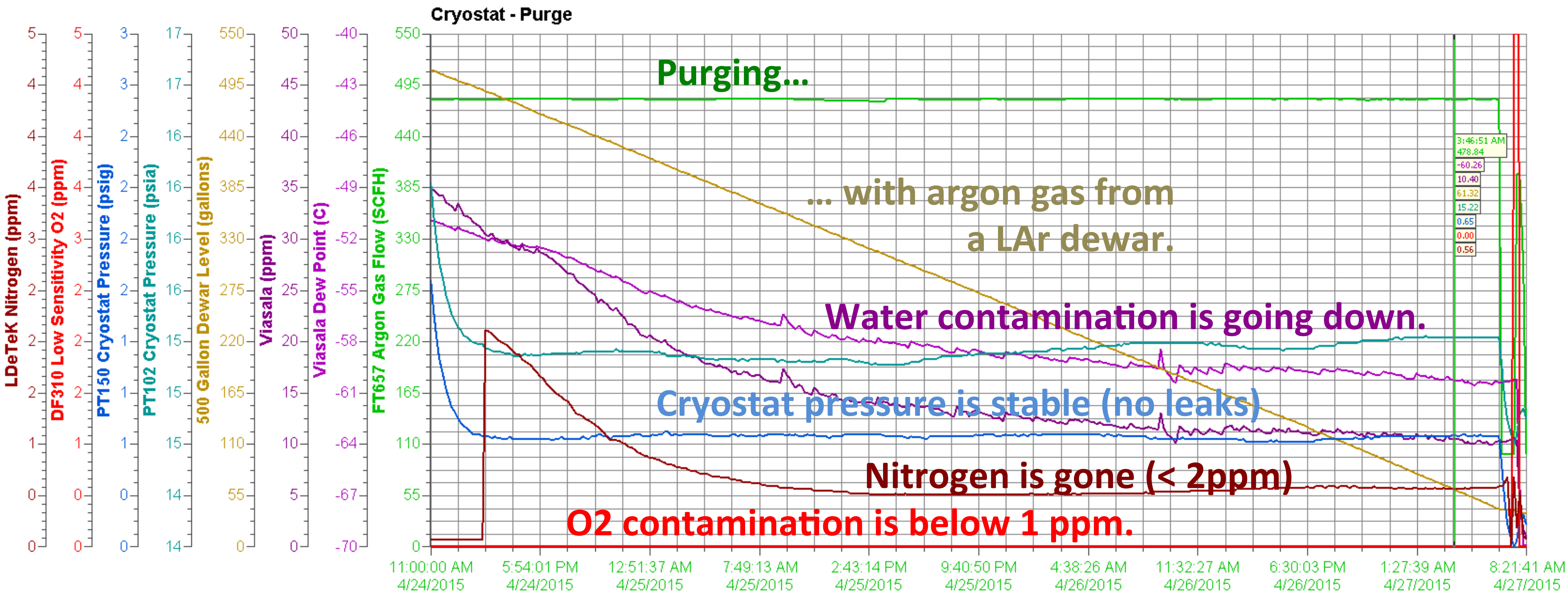
Step
2

Cool-down
with argon gas slowly to avoid mechanical stress of detector components

Step
3

Fill with 10 truck loads of liquid argon.

MicroBooNE live

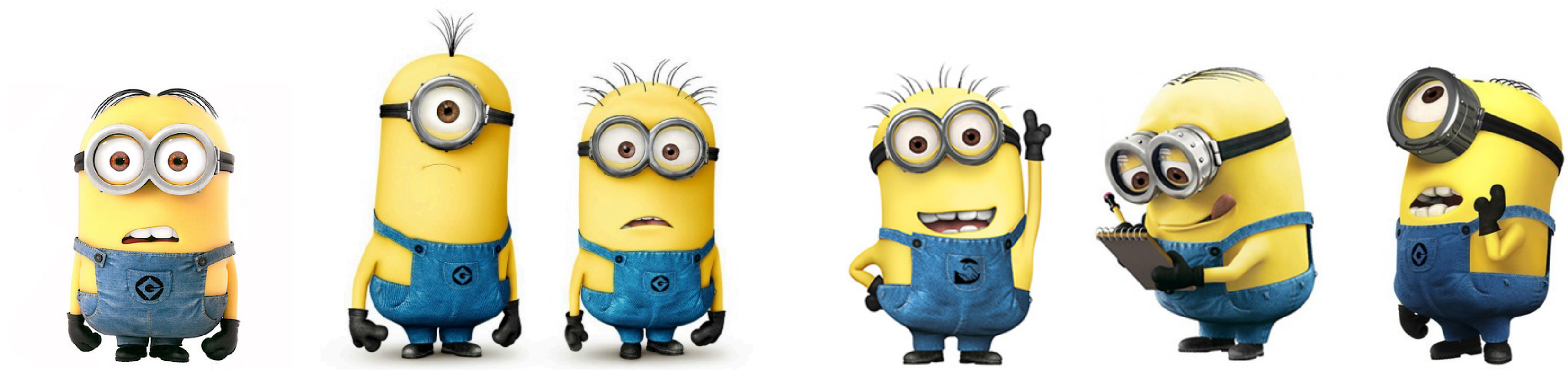


Value	Pen Name	Description
479	FT657 Argon Gas Flow (SCFH)	Ar flow readback (F_CV)
-60	Viasala Dew Point (C)	Low sensitivity H2O (F_CV)
10	Viasala (ppm)	Low sensitivity H2O (F_CV)
61	500 Gallon Dewar Level (gallons)	500 Gal Ar Dewar level in gallons (F_CV)
15.22	PT102 Cryostat Pressure (psia)	Cryostat - absolute (F_CV)
0.65	PT150 Cryostat Pressure (psig)	Cryostat - gauge (F_CV)
0.00	DF310 Low Sensitivity O2 (ppm)	Low sensitivity O2 (F_CV)
0.56	LDeTeK Nitrogen (ppm)	High sensitivity N2 (F_CV)

11:00:00 AM 4/24/2015 8:21:41 AM 4/27/2015

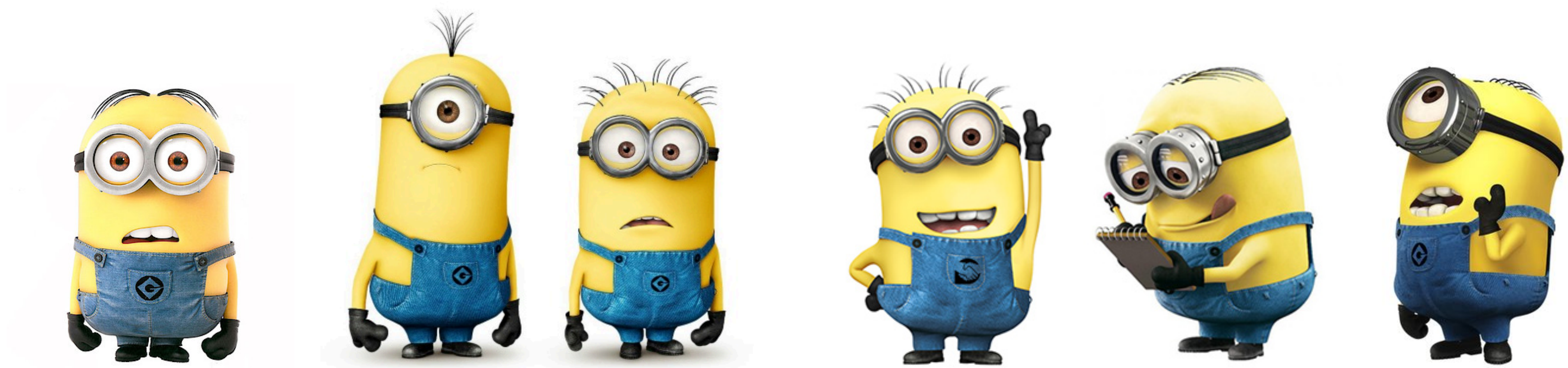
MicroBooNE's contribution to open questions in neutrino physics

- Resolving the nature of the MiniBooNE low-E excess.
- Understanding of neutrino scattering on argon.
- Detector physics: study diffusion, recombination and purity in LAr.
- Detection of supernova neutrinos.
- Explore backgrounds for future proton decay searches.



MicroBooNE's contribution
to open questions in neutrino physics

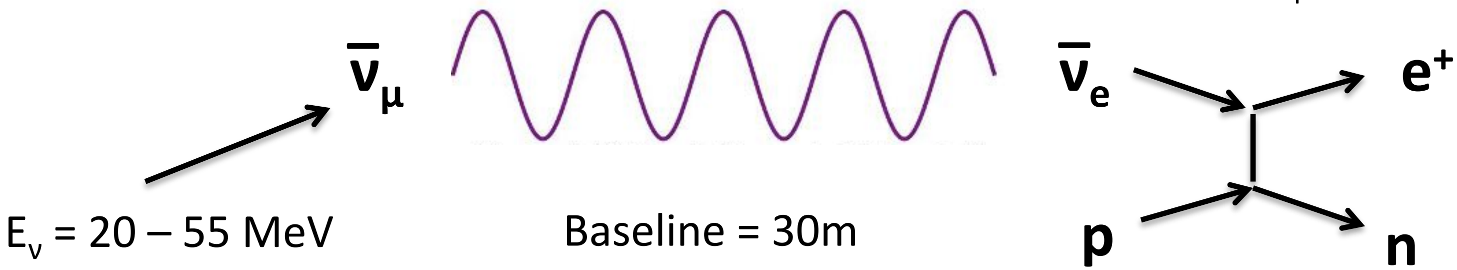
- **Resolving the nature of the MiniBooNE low-E excess.**
- Understanding of neutrino scattering on argon.
- Detector physics: study diffusion, recombination and purity in LAr.
- Detection of supernova neutrinos.
- Explore backgrounds for future proton decay searches.

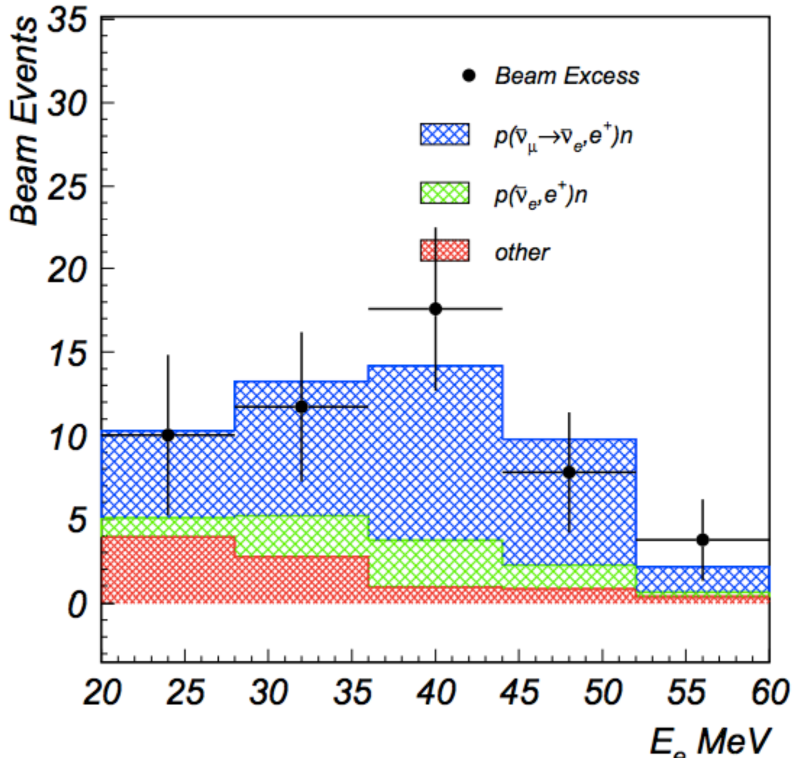


ν_e appearance signals: LSND

167 ton liquid scintillator detector
@ Los Alamos

Looking for an anti electron neutrino appearance signal in a $\bar{\nu}_\mu$ beam.





The measured electron spectrum shows an excess over background expectations

Phys. Rev. D 64, 112007 (2001)

$$P_{\alpha\to\beta,\alpha\neq\beta} = \sin^2(2\theta)\,\sin^2\left(1.267\frac{\Delta m^2 L}{E}\frac{\mathrm{GeV}}{\mathrm{eV}^2\,\mathrm{km}}\right)$$

Best fit:

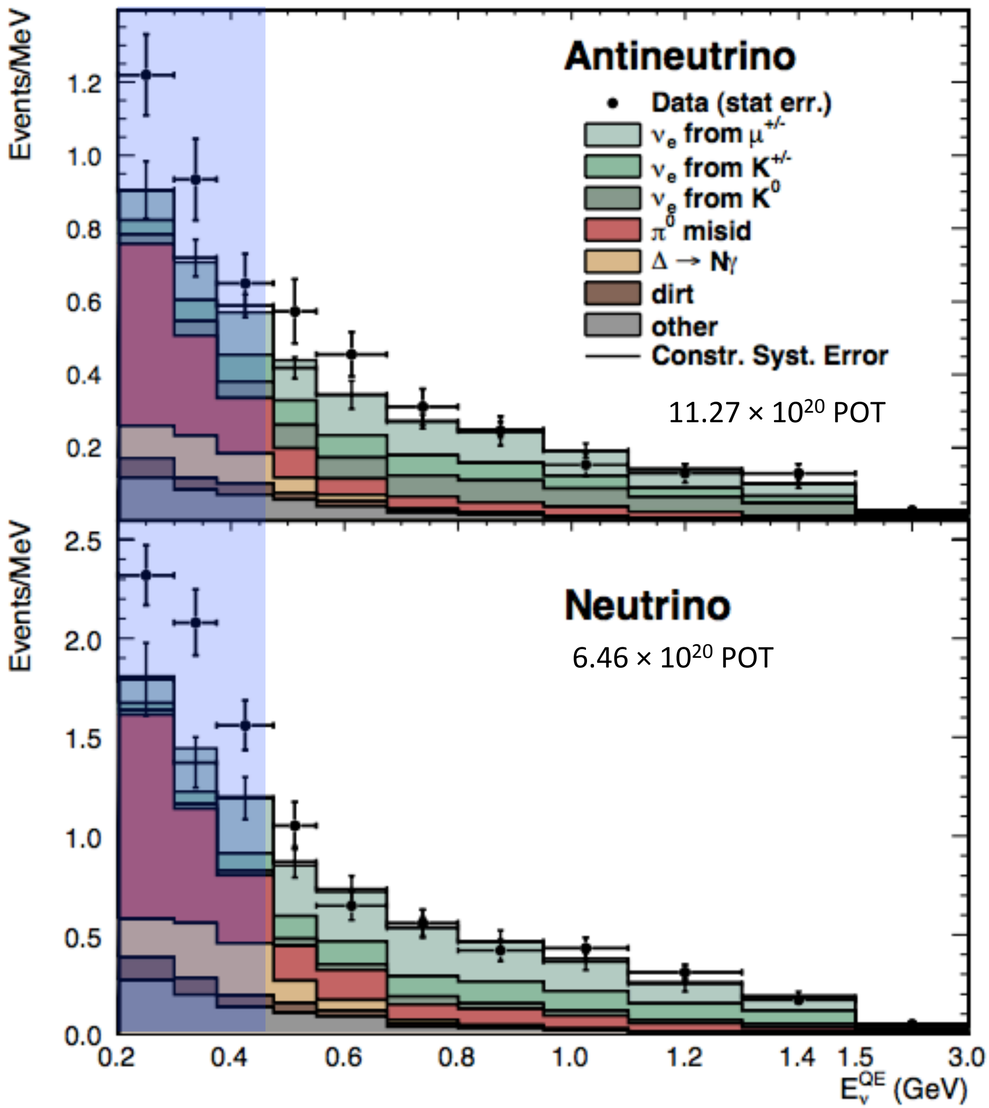
$\Delta m^2 = 1.2\ \mathrm{eV}^2 \qquad \sin^2\theta = 0.003$

The best fit is not in agreement with standard oscillations.

ν_e appearance signals: MiniBooNE

800t mineral oil Cherenkov detector @ Fermilab

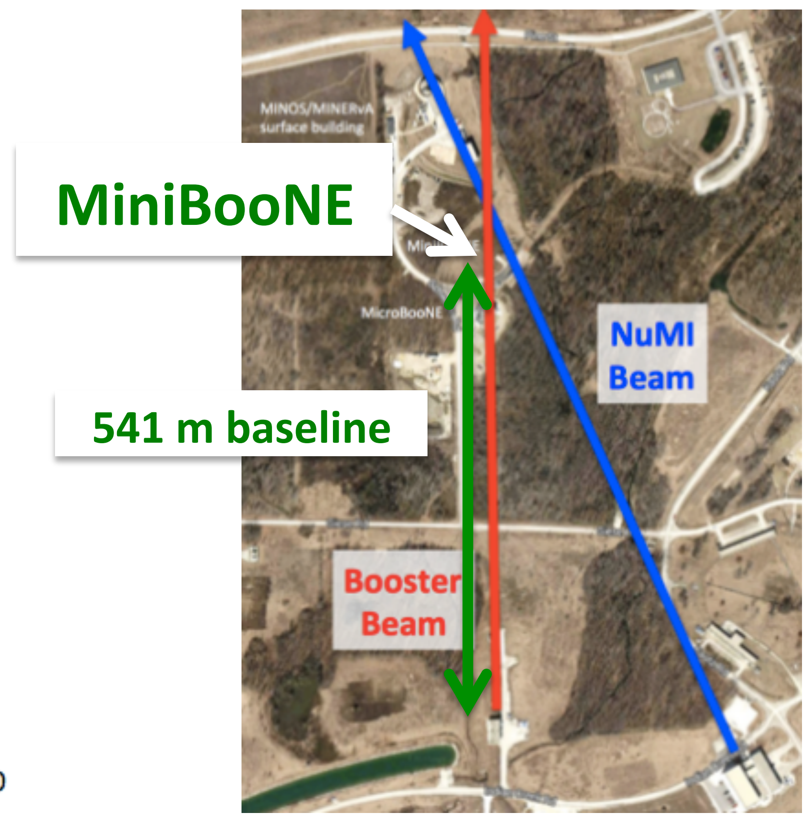
The MiniBooNE low-energy excess



Phys. Rev. Lett. 110, 161801 (2013)

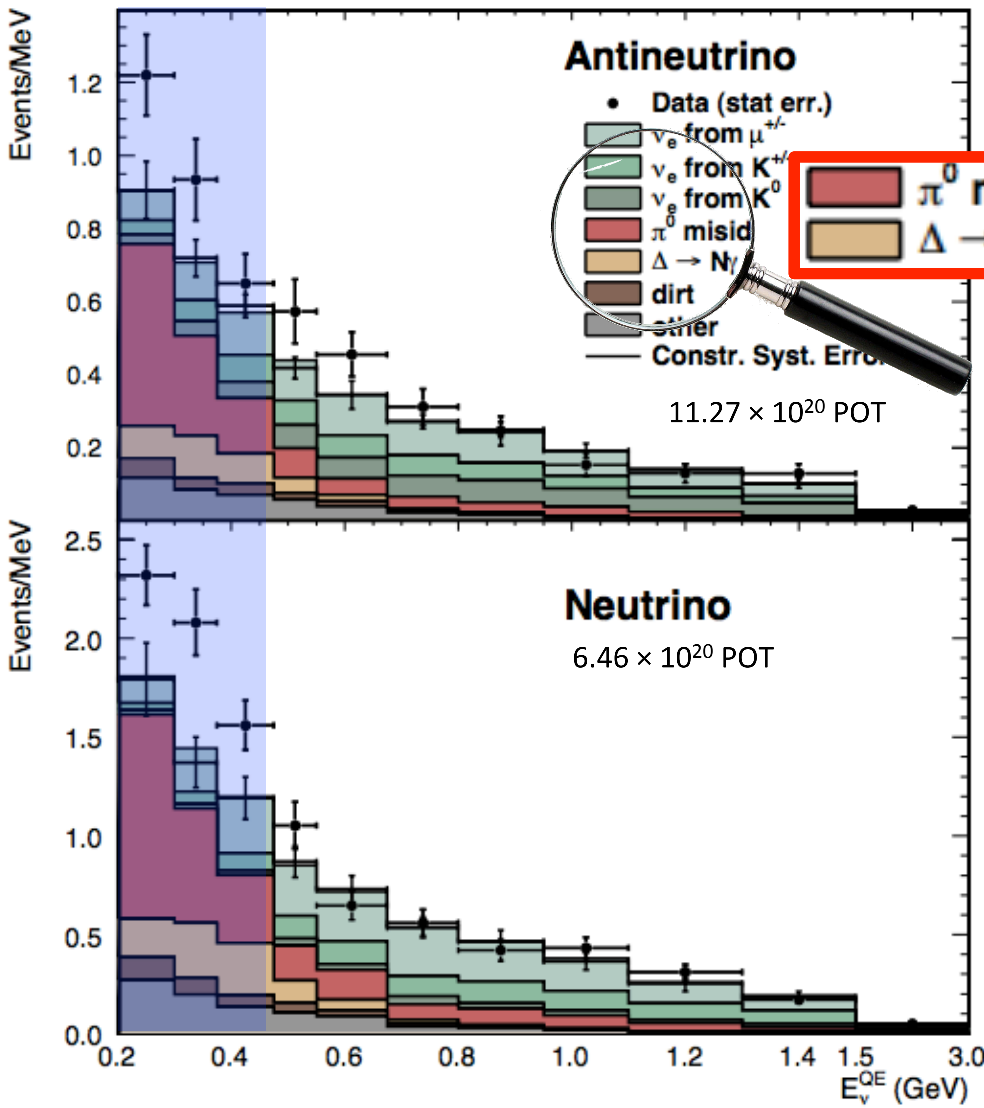
MiniBooNE compared to LSND:

- Longer baseline: 541 m
- Higher energy beam: ≈ 700 MeV
- -> Same L/E!



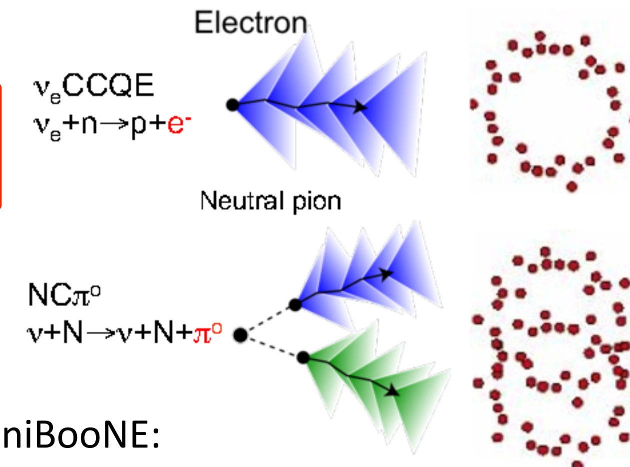
The MiniBooNE low-E excess: e or γ?

The MiniBooNE low-energy excess



Phys. Rev. Lett. 110, 161801 (2013)

The shape of the excess resembles the spectrum of γ background.



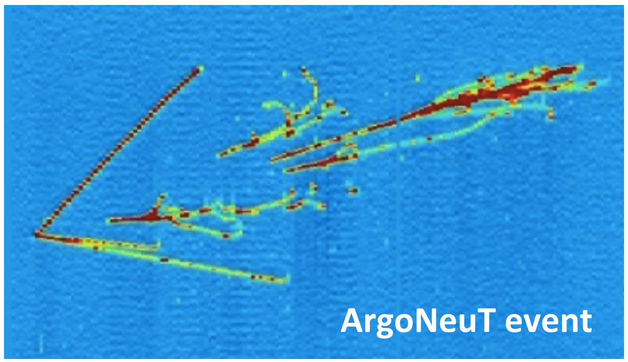
For MiniBooNE:
e and single γ look the same.

μBooNE LArTPC

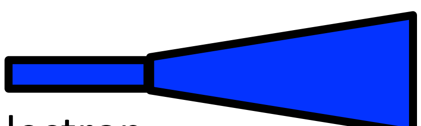
- Same beam
- Same baseline
- Can distinguish e and γ

Proof of principle with ArgoNeuT data!

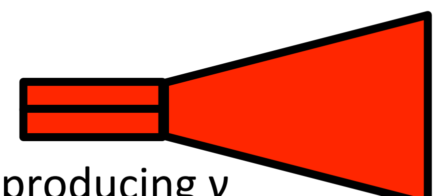
Case 1: The neutral γ (π^0) is observed as gap between vertex and EM shower:



Case 2: If the gap is too small to be observed, the charge at the start of the shower can be reconstructed through a measurement of dE/dx



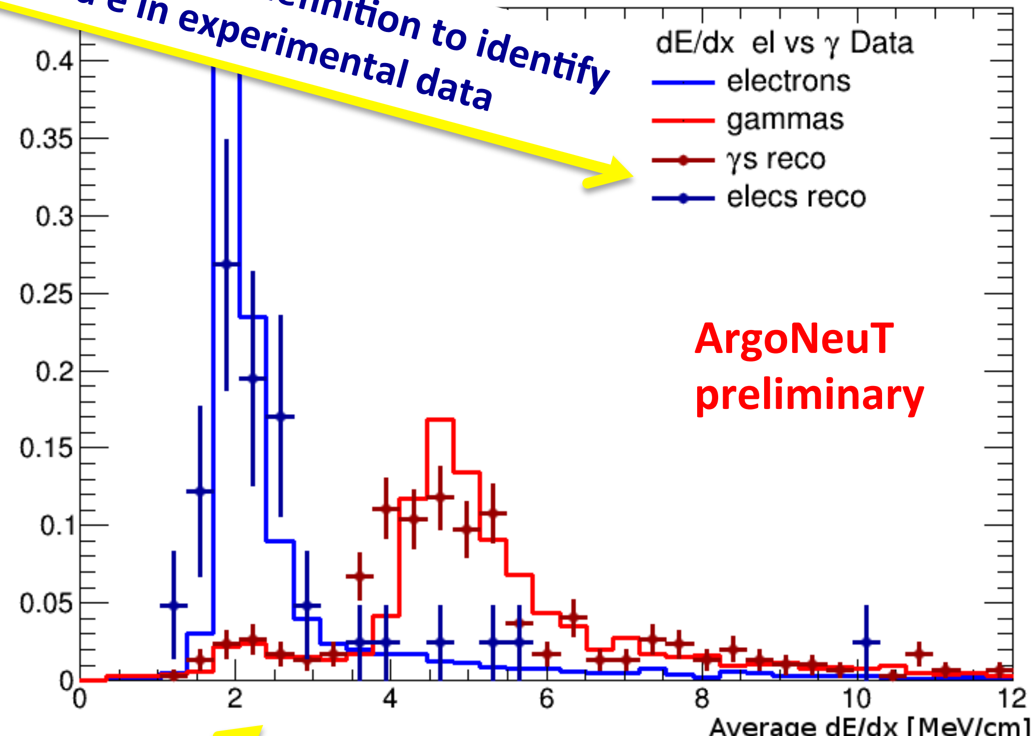
Single electron



e^+/e^- pair producing γ

Use the topological definition to identify γ and e in experimental data

First presented @ NEUTRINO2014
by A. Szelc for ArgoNeuT



Plot the dE/dx distribution for these events

MicroBooNE will be able to resolve the nature of the MiniBooNE low-energy excess!

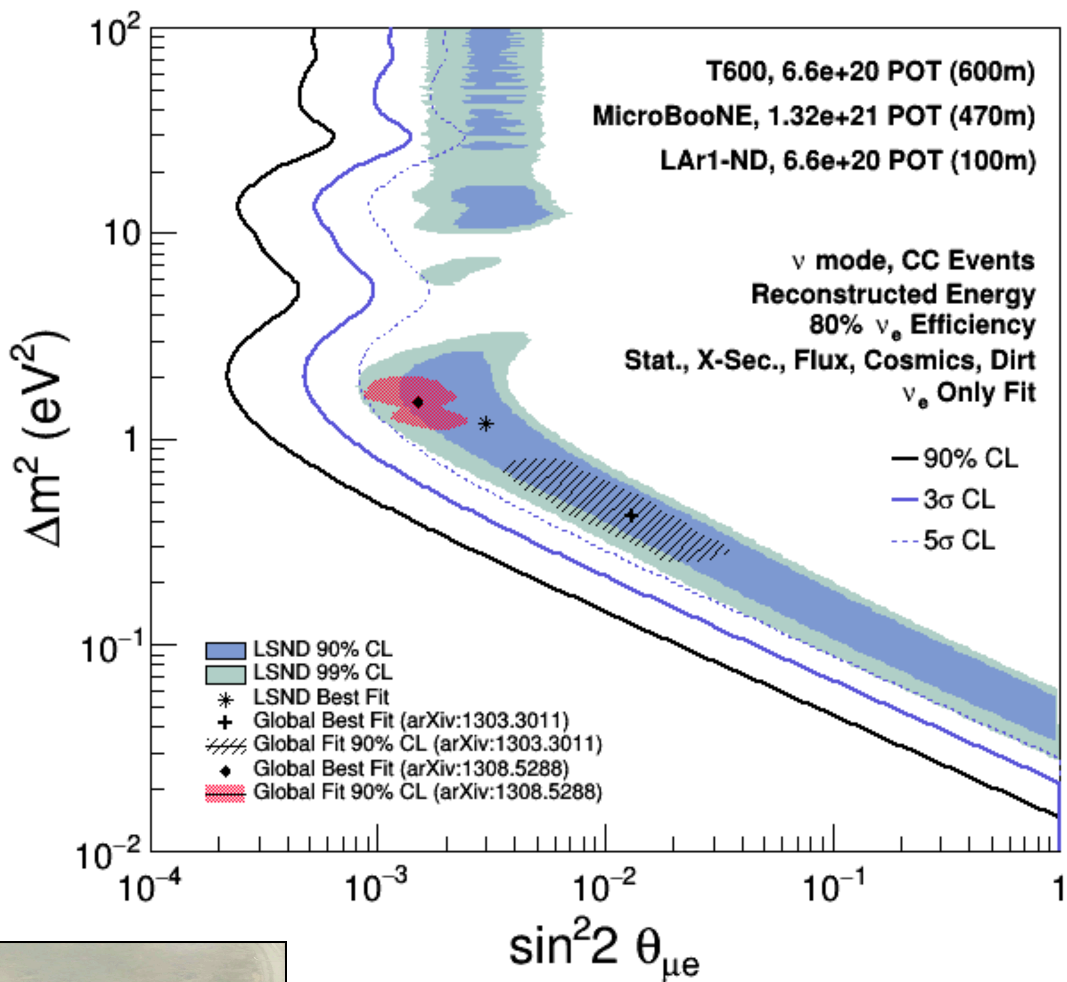
The SBN program

MicroBooNE alone is not sensitive to a sterile neutrino signal (LSND excess) due to limitations in size and flux understanding.

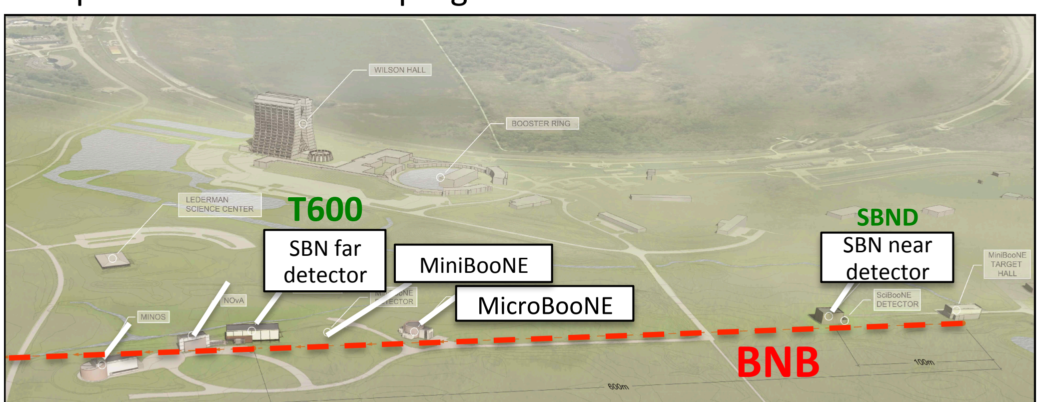
Solution: SBN program

Build LAr near and far detectors around MicroBooNE

-> 3 LArTPCs in the Booster Neutrino Beam will sample the neutrino spectrum as a function of energy and distance



Proposed short baseline program at Fermilab

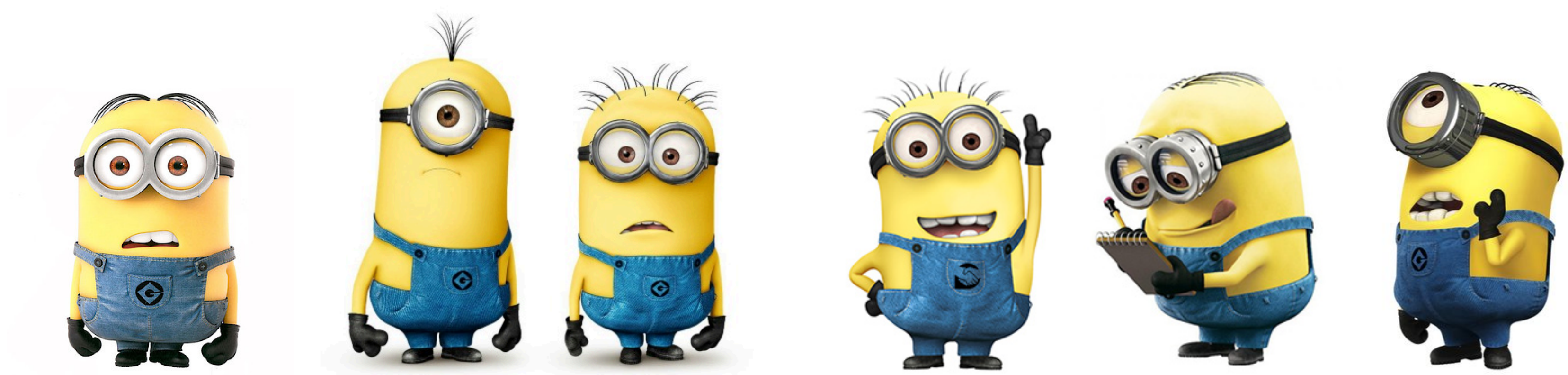


With SBN we can make a definitive statement on the LSND and MiniBooNE anomalies!

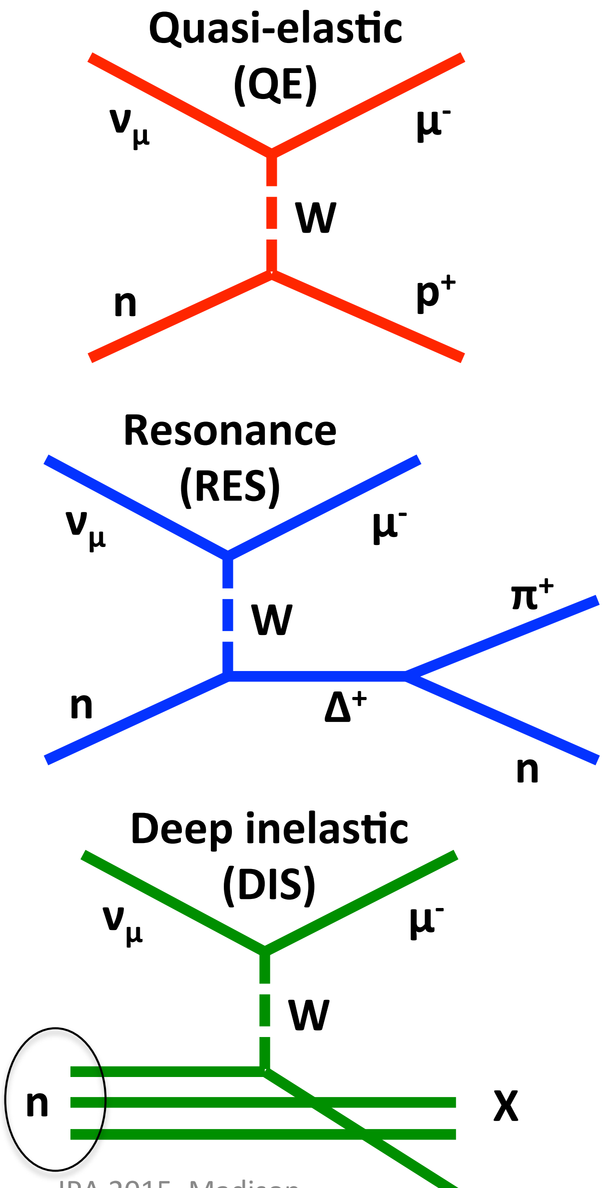
arXiv: 1503.01520

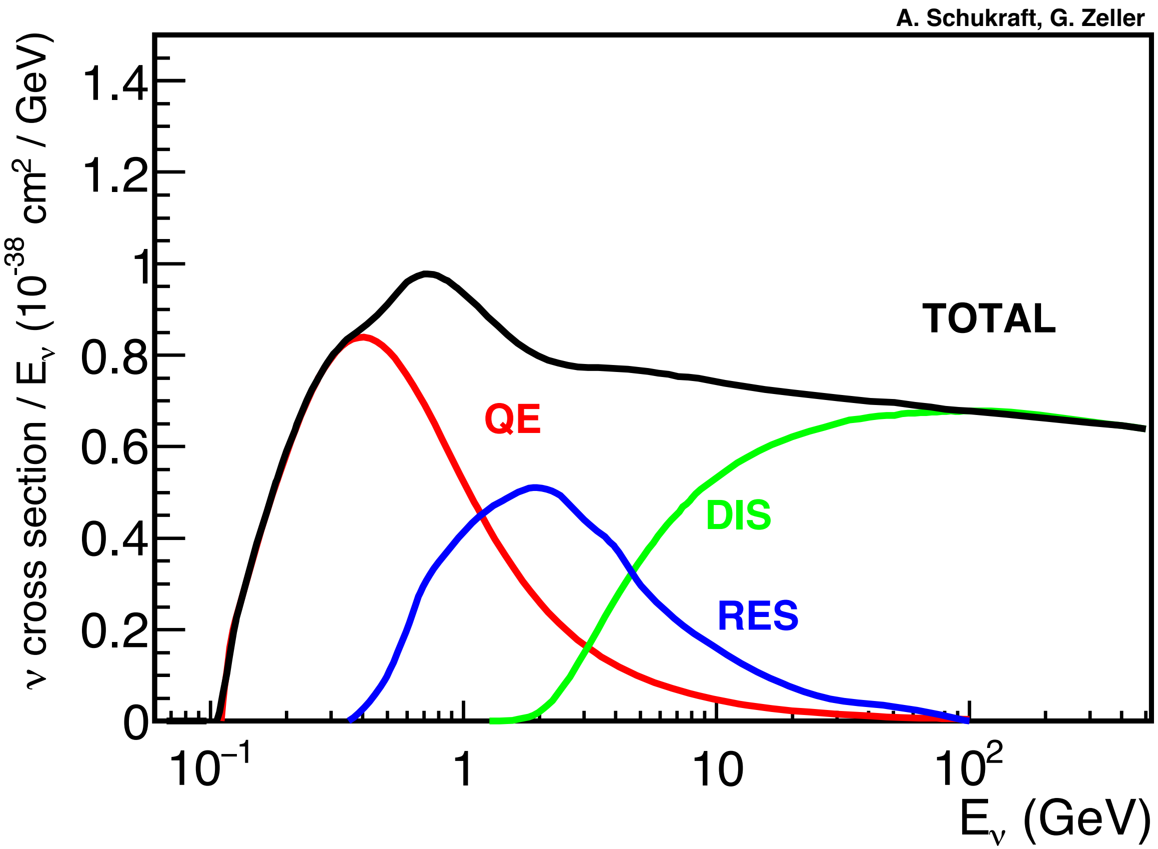
MicroBooNE's contribution
to open questions in neutrino physics

- Resolving the nature of the MiniBooNE low-E excess.
- **Understanding of neutrino scattering on argon.**
- Detector physics: study diffusion, recombination and purity in LAr.
- Detection of supernova neutrinos.
- Explore backgrounds for future proton decay searches.



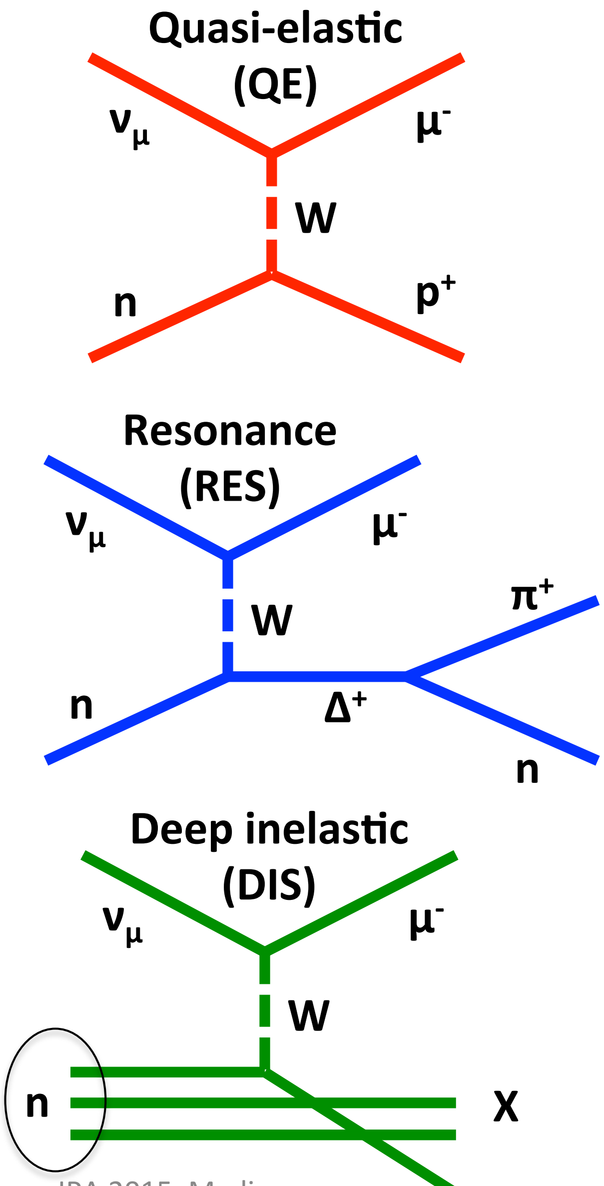
Neutrinos interacting with nucleons



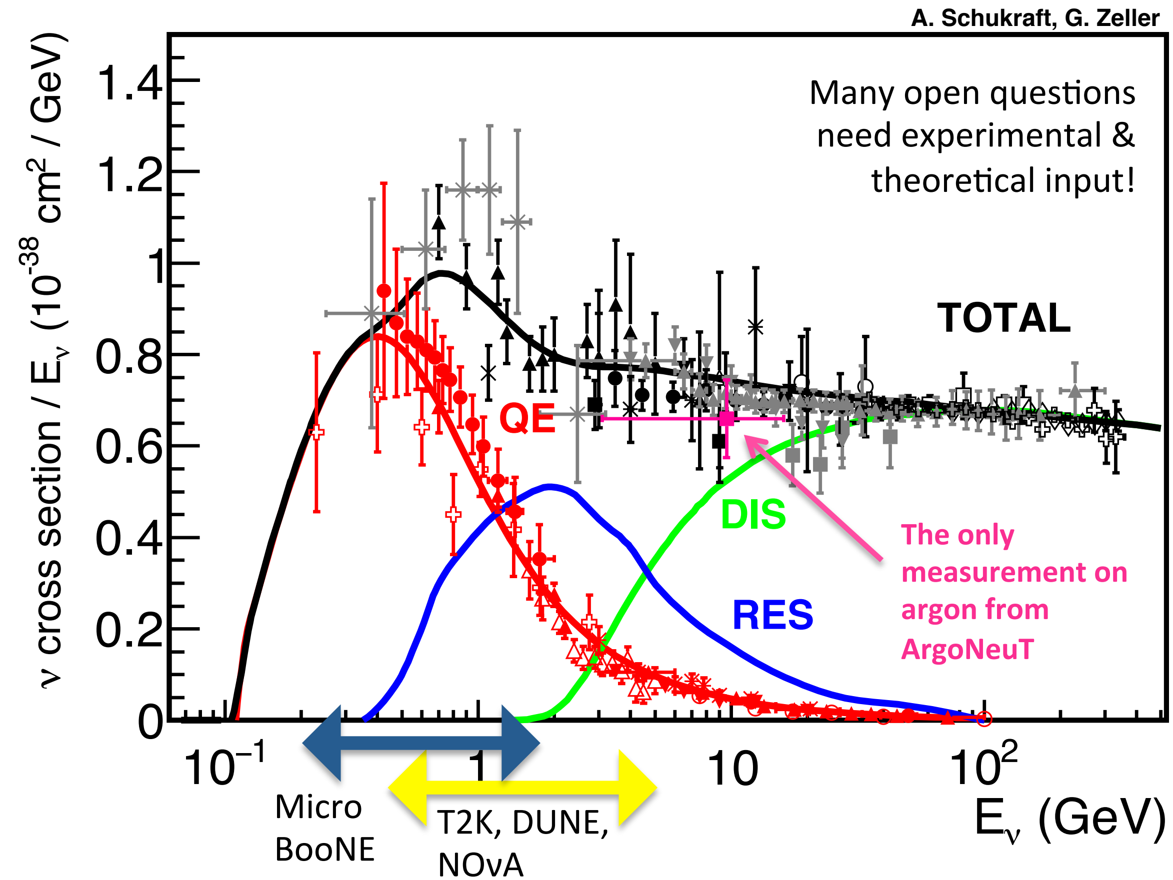


(also neutral current diagrams)

Neutrinos interacting with nucleons



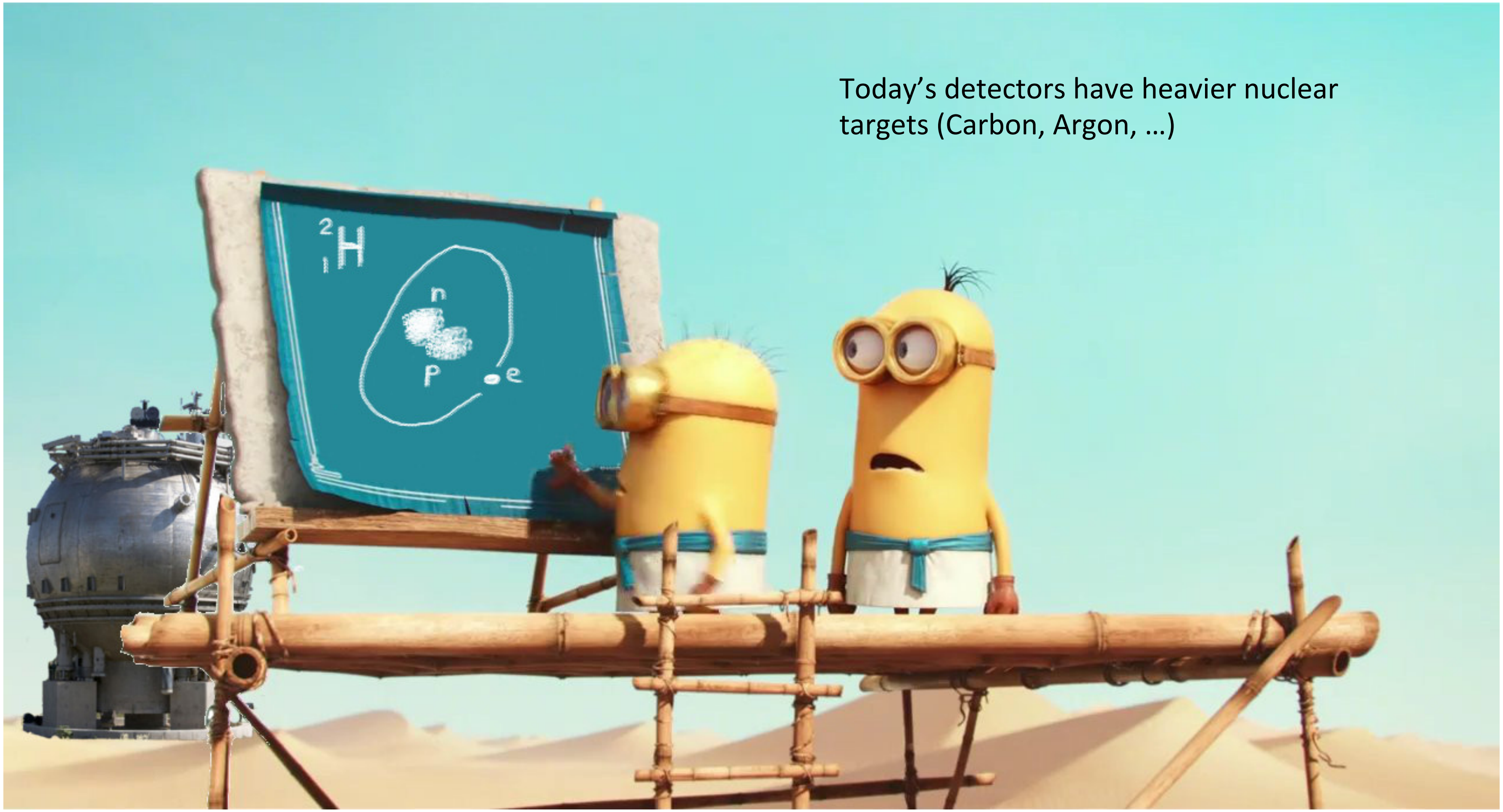
Lots of interesting (nuclear) physics over all energy ranges.



We need to understand neutrino-nucleon scattering to understand event rates, final states and neutrino energy estimation in oscillation experiments

From bubble chambers to modern experiments

Historic data is bubble chamber data, i.e. hydrogen or deuterium target.

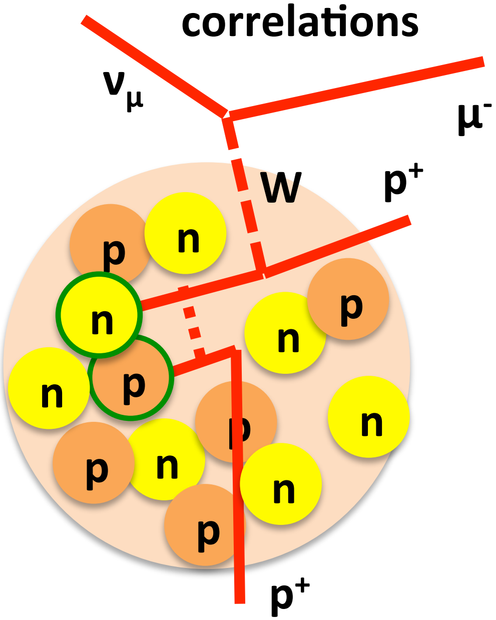


Today's detectors have heavier nuclear targets (Carbon, Argon, …)

The next level: scattering off a nuclear target

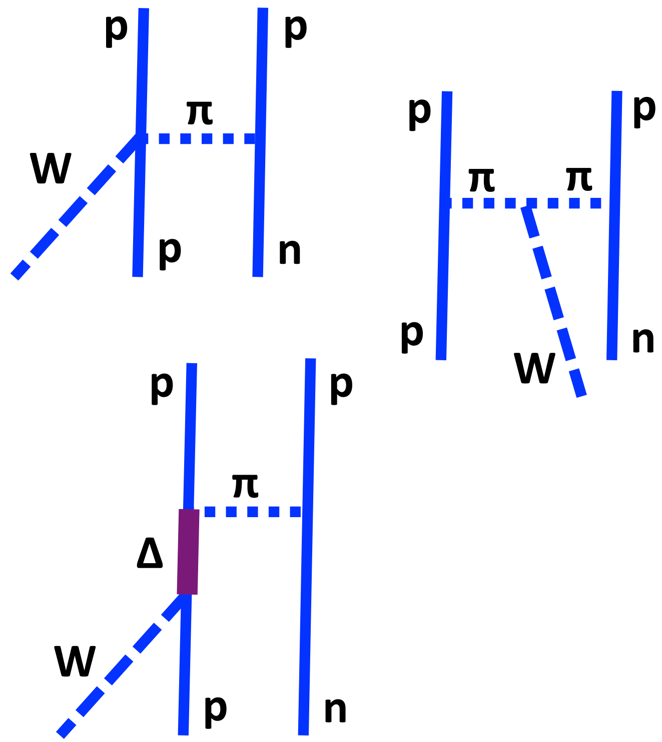
When scattering off nuclei instead of free nucleons the observed topology can be more complex:

Nucleon-nucleon correlations



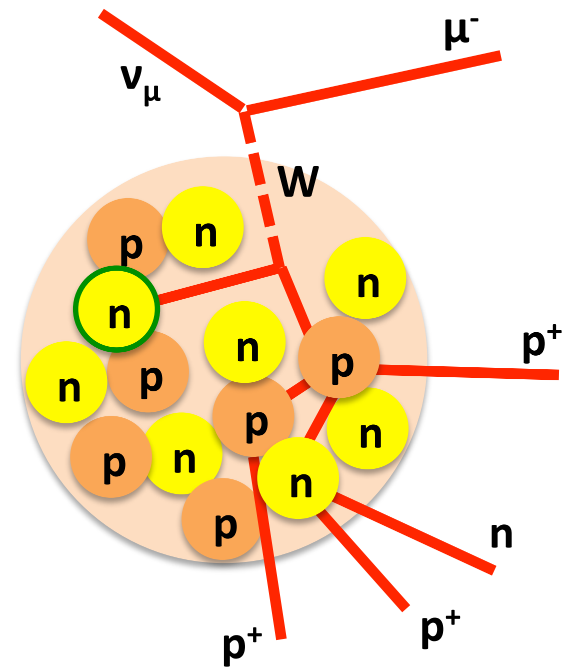
Two nucleons in correlation
Means for the experimentalist:
Multi-nucleon knockout!
The pair inside the nucleus has:
large relative momentum,
small total momentum

Meson exchange currents



The observed state looks like QE but it was not!

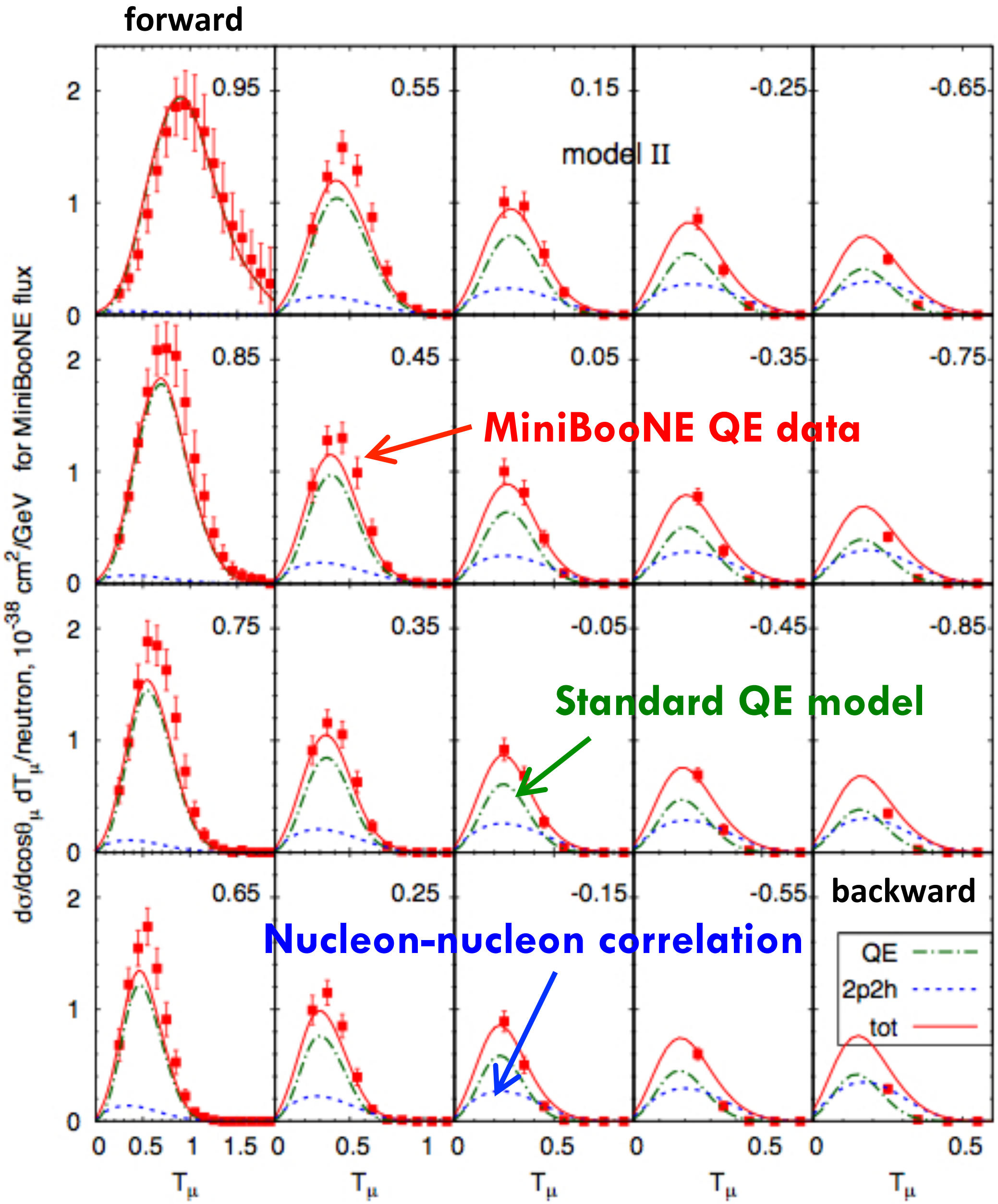
Final state interactions



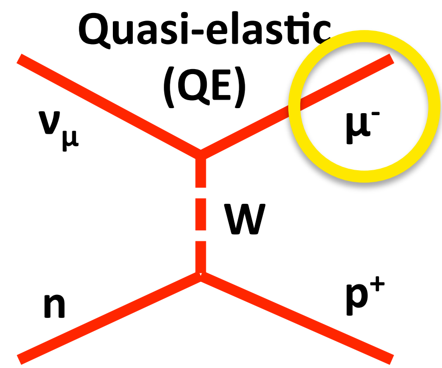
Multi-nucleon knockout through re-interaction of the outgoing nucleon

Nuclear effects in recent data

- seen in MiniBooNE



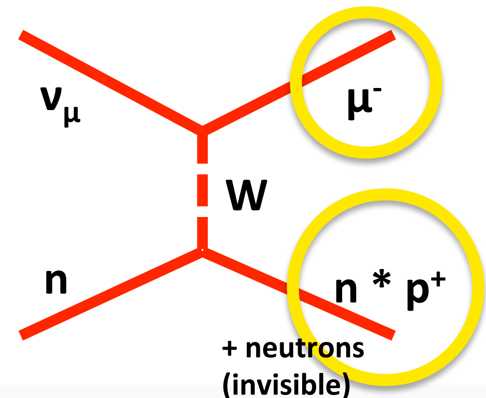
Lalakulich, Gallmeister, Mosel, arXiv:1203.2935



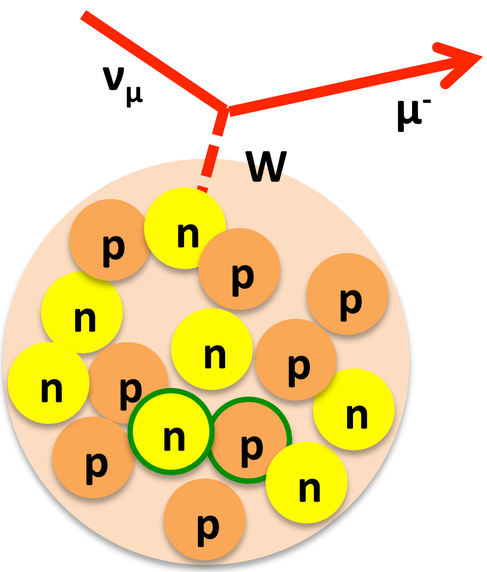
Lessons learned from MiniBooNE:

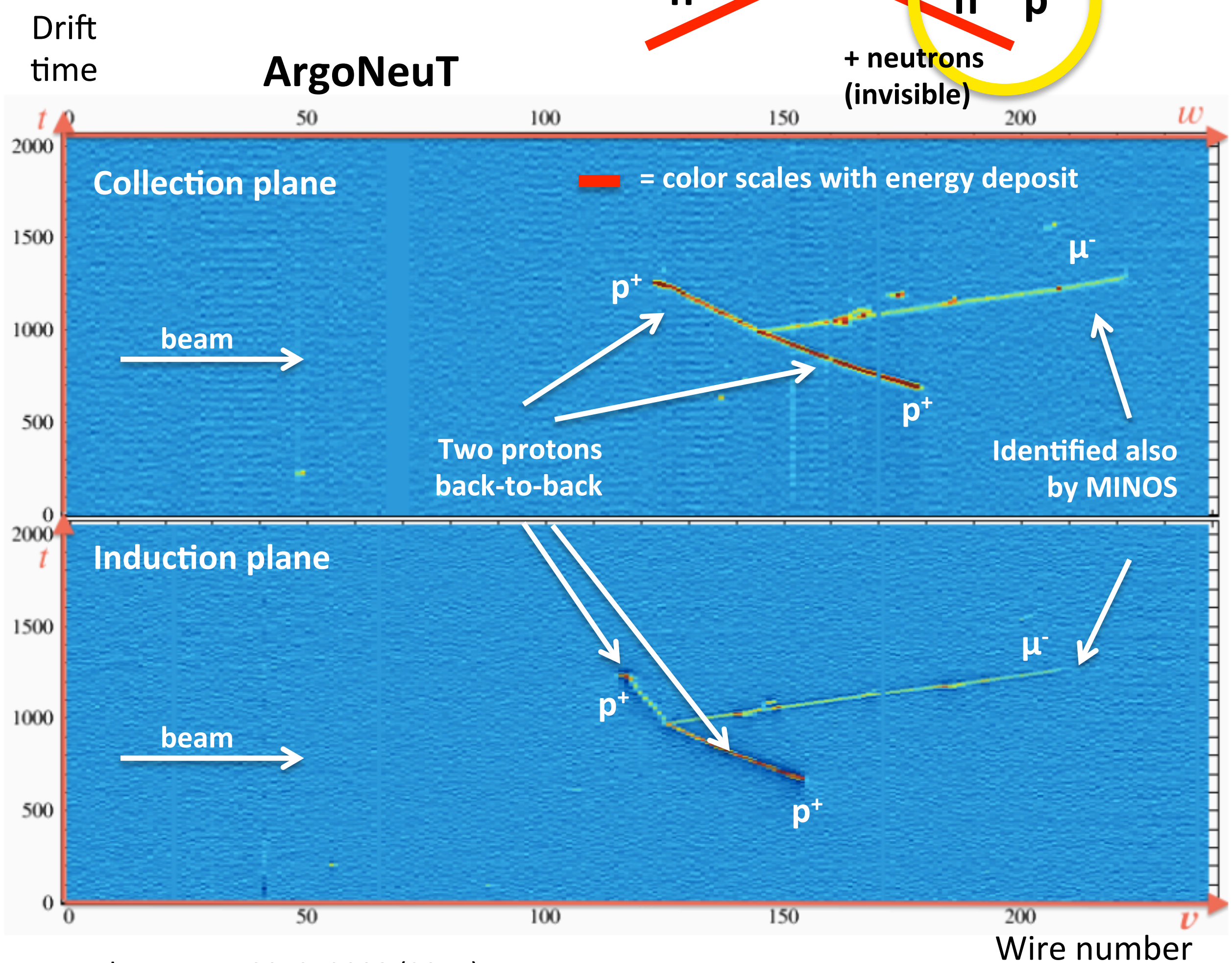
- Nuclear effects play an important role, especially for backward scattering
- For the understanding, it is important to also investigate the hadronic side of the interaction

Nuclear effects in recent data
– seen in ArgoNeuT



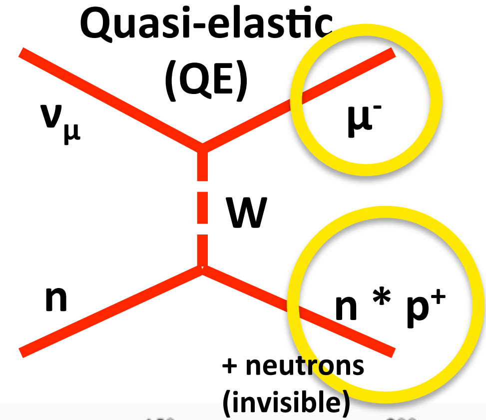
Nucleon-nucleon correlations



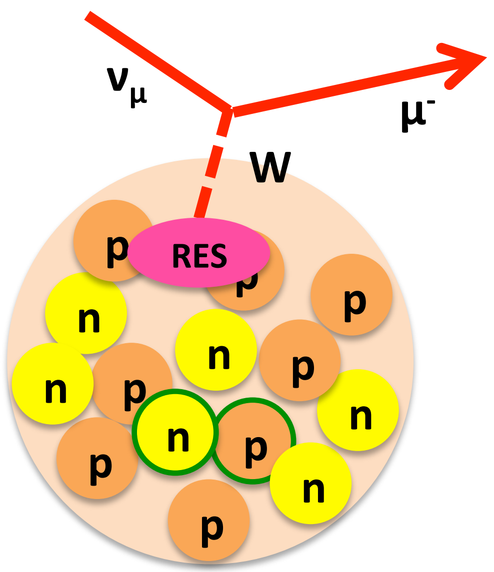


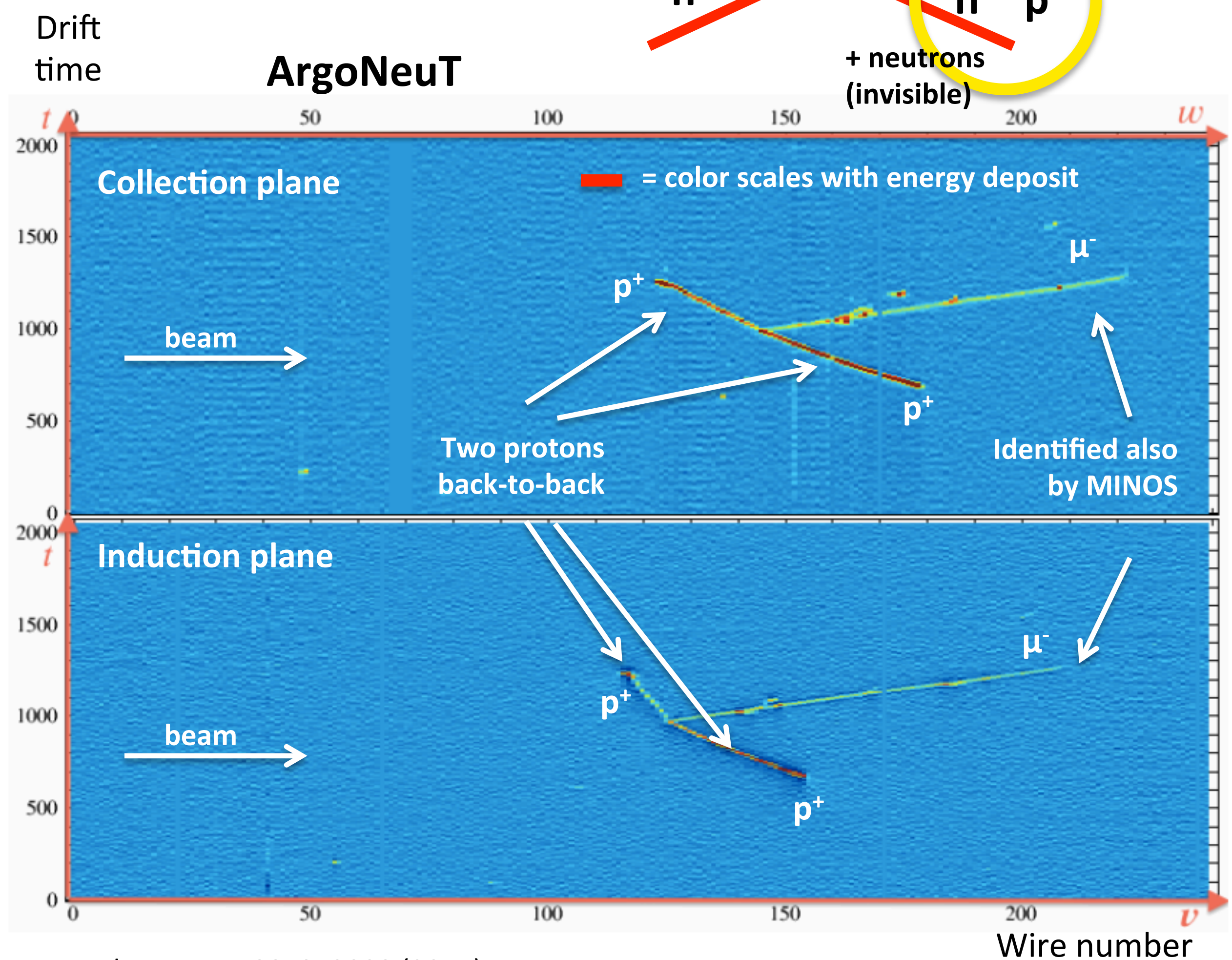
Phys. Rev. D90, 012008 (2014)

Nuclear effects in recent data
– seen in ArgoNeuT



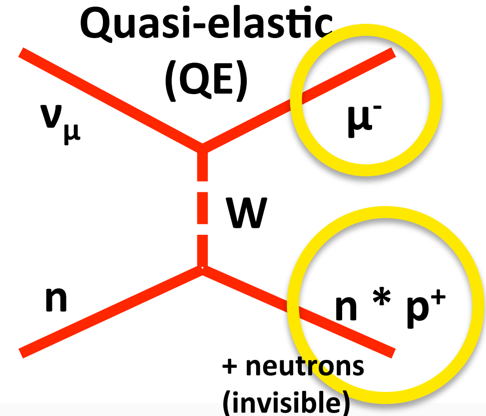
Nucleon-nucleon correlations



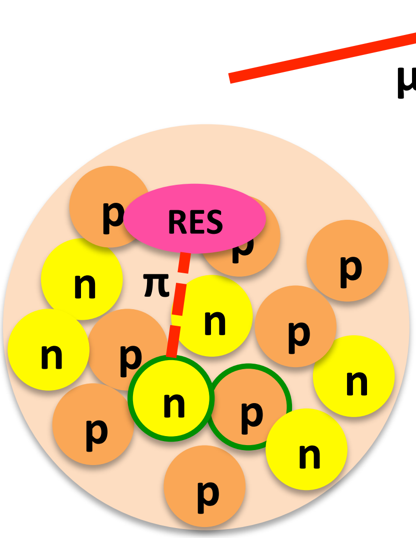


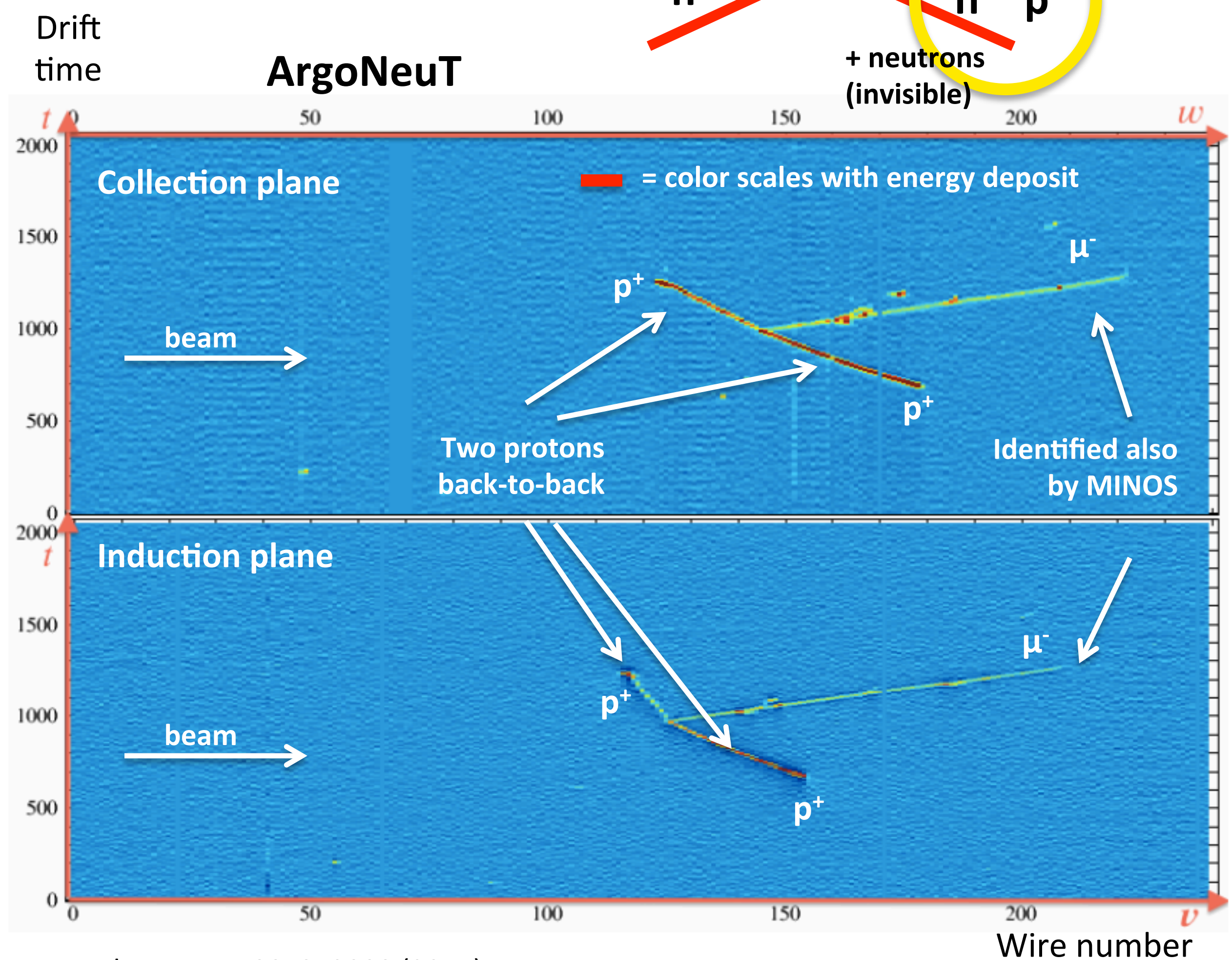
Phys. Rev. D90, 012008 (2014)

Nuclear effects in recent data
– seen in ArgoNeuT



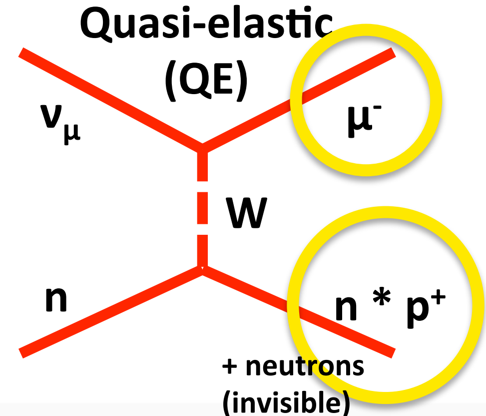
Nucleon-nucleon correlations



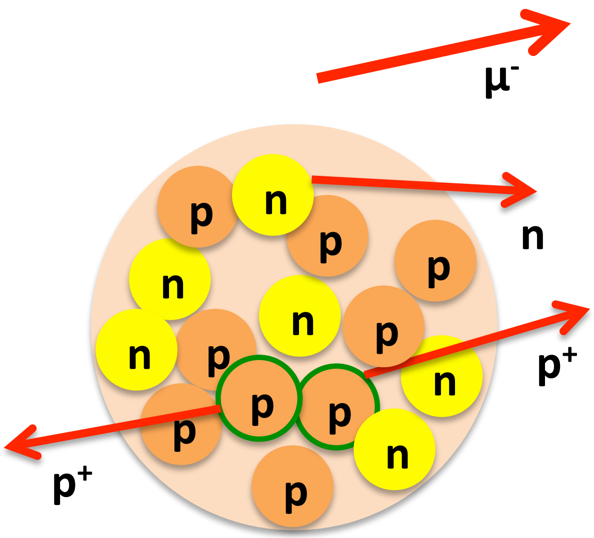


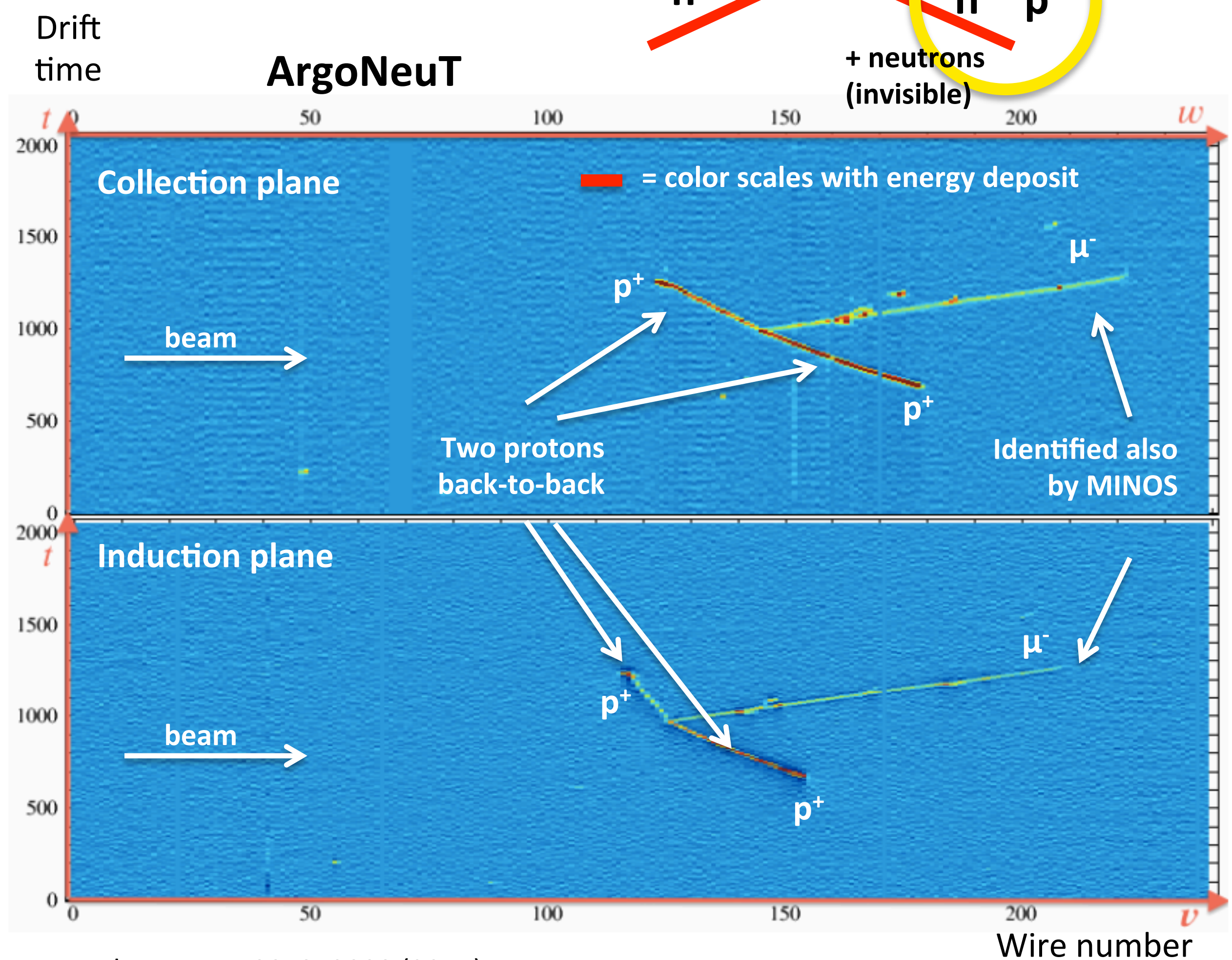
Phys. Rev. D90, 012008 (2014)

Nuclear effects in recent data
– seen in ArgoNeuT



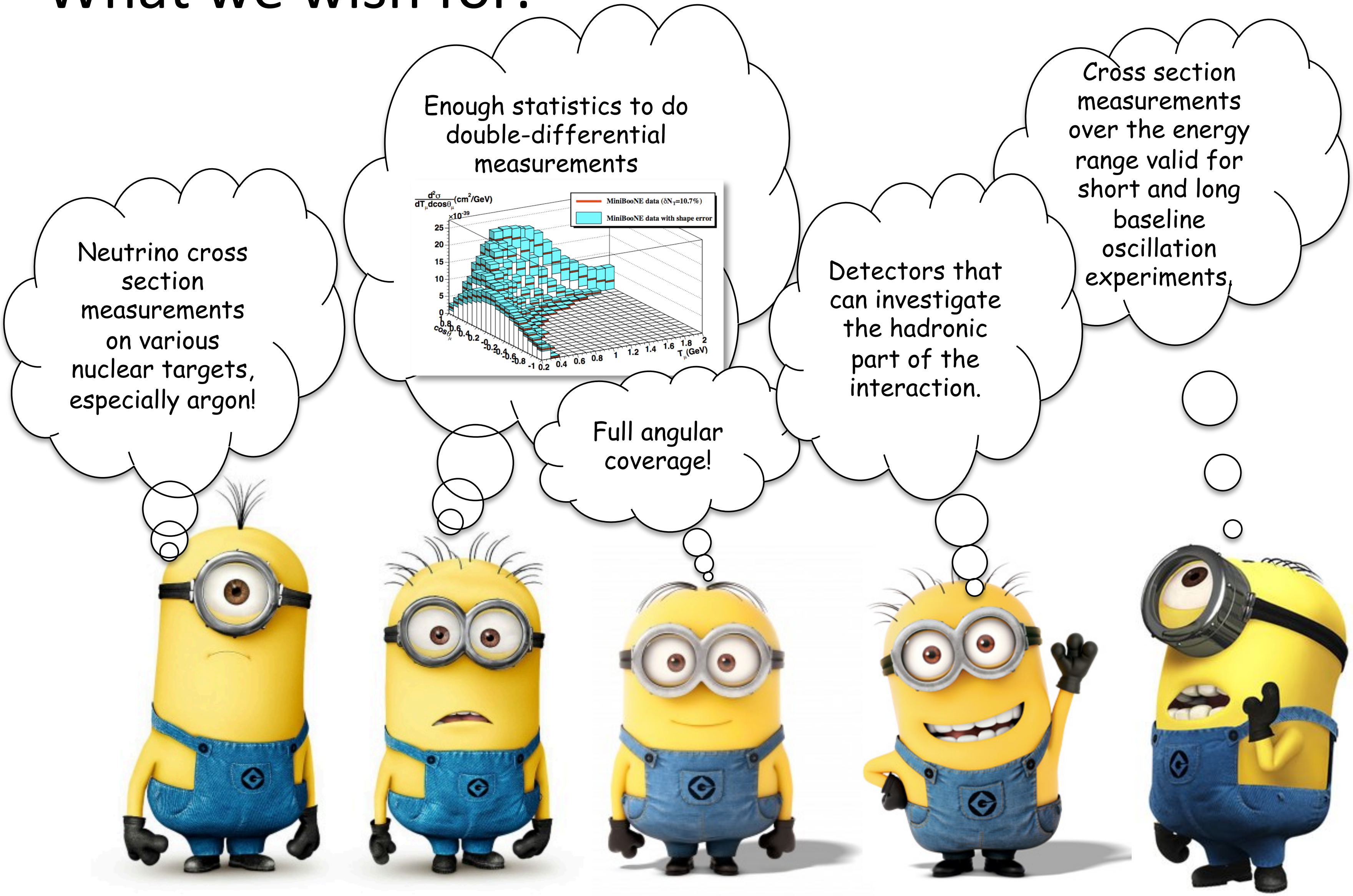
Nucleon-nucleon correlations





Phys. Rev. D90, 012008 (2014)

What we wish for:



What we wish for:

Different targets:
Minerva, T2K

Argon:
ArgoNeuT,
MicroBooNE, SBN,
(CAPTAIN)

High statistics:
Lots of MiniBooNE
measurements!

Will be followed by
MicroBooNE, SBN, …

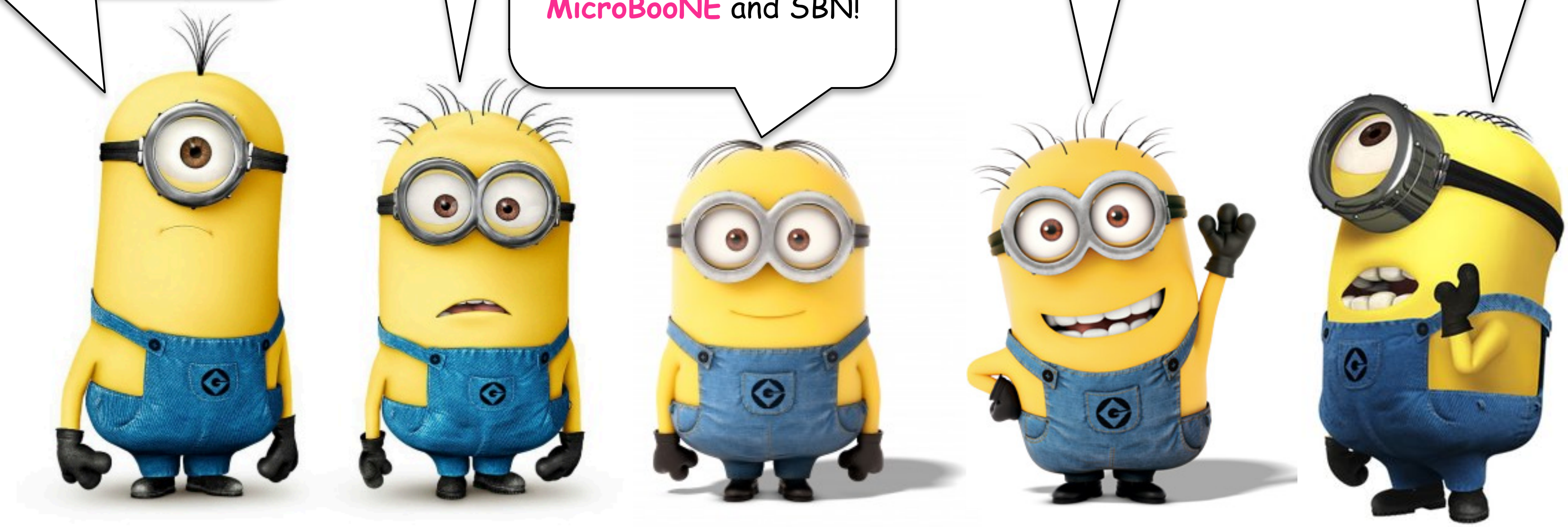
Full angular coverage:
Yes, with
MicroBooNE and SBN!

Studying the hadronic side of the interaction
with Minerva,
MicroBooNE
and SBN

Energy range:

NuMI
Minerva, (CAPTAIN):
1^{st} LB oscillation max

BNB
Mini/MicroBooNE
2^{nd} LB oscillation max

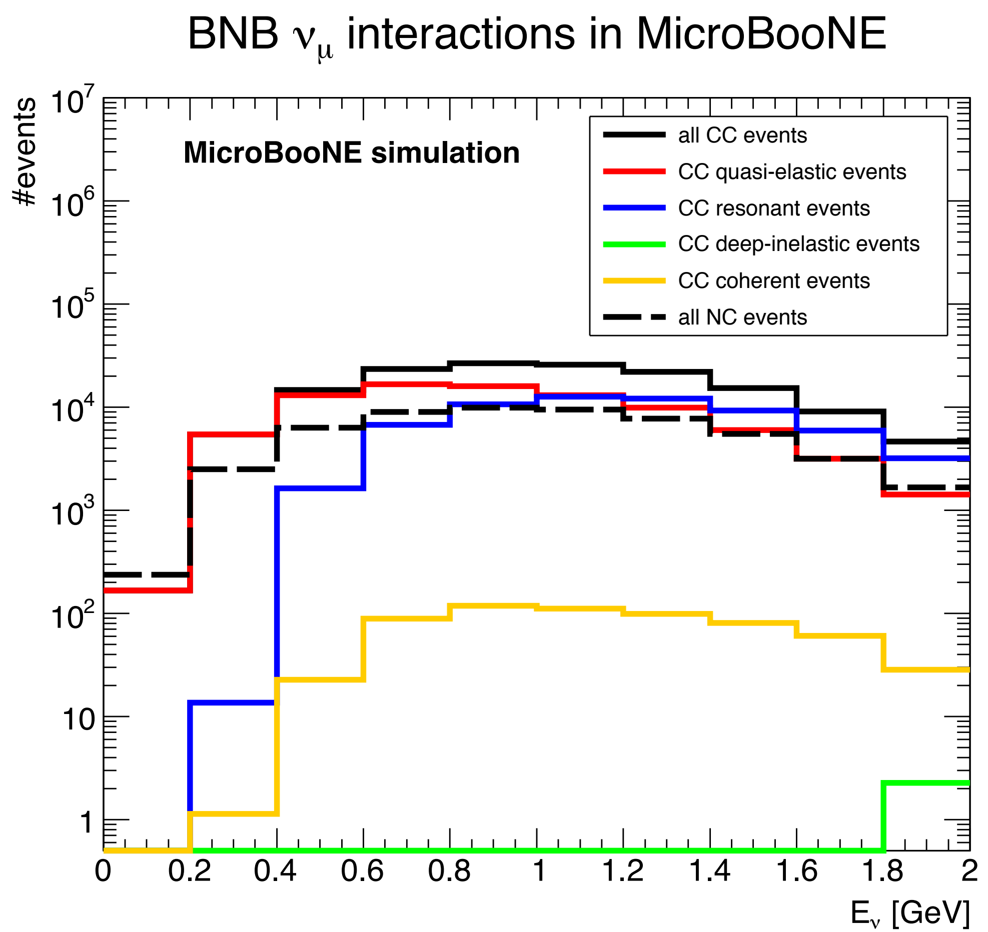


Cross sections in MicroBooNE – interaction channels

1e20 POT
(6 months, 87 tons, no efficiencies)

	numu	numubar	nue	nuebar
CC Total	26646	250	238	9.8
CC - QE	14630	128	114	5.8
CC – RES	8631	91	93	< 1
CC – DIS	3271	29	29	3.9
NC Total	9860	101	81	3.9

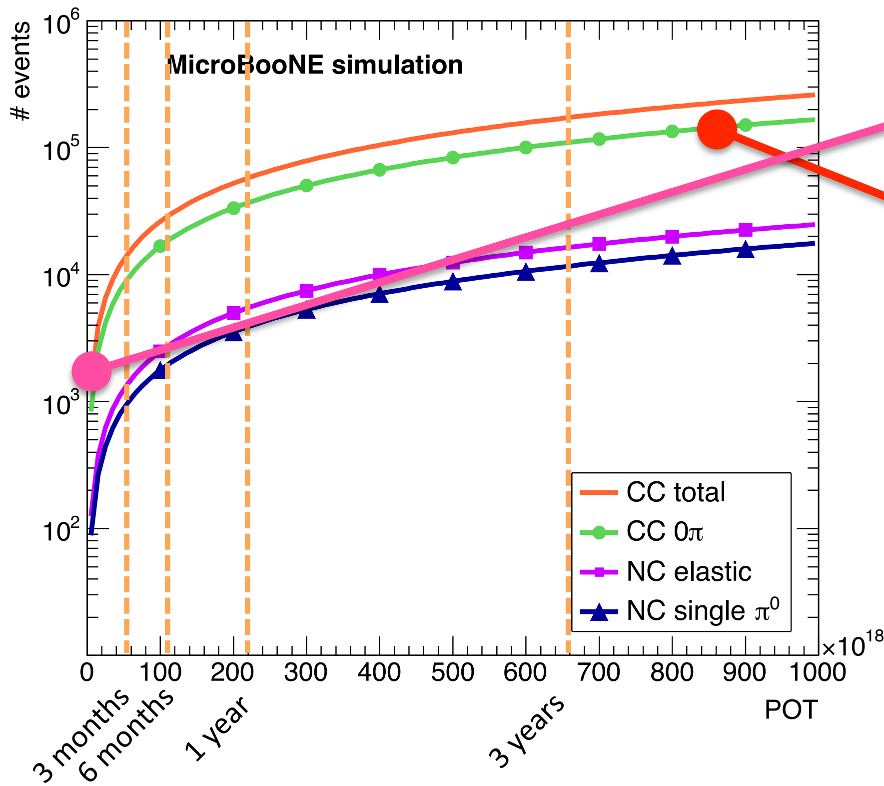
MicroBooNE in the BNB will deliver unprecedented statistics in the energy range of 200 MeV – 2 GeV on Argon (quasi-elastic and resonant processes).



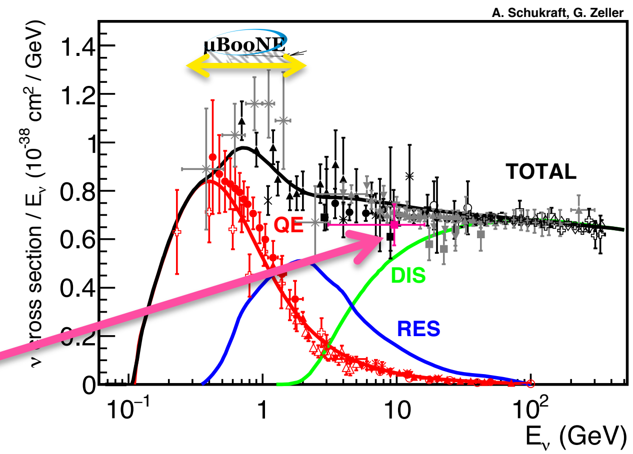
Cross sections in MicroBooNE – final states

First analyses

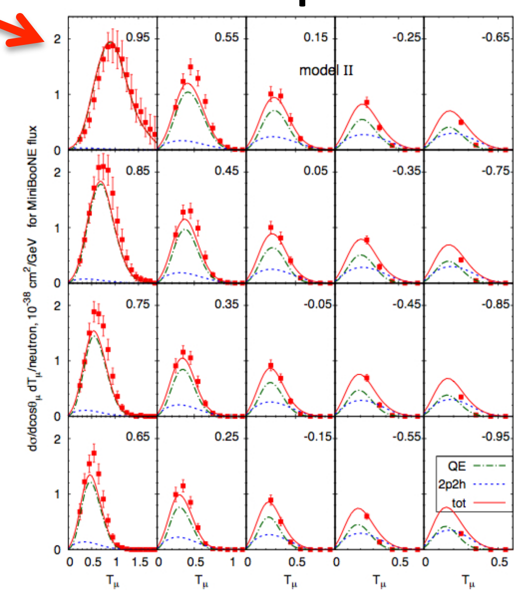
1e20 POT (6 months, 87 tons, no efficiencies)			
numu			
CC inclusive	CC 0 pi	NC elastic	NC single pi0
26553	16997	2596	1719



CC inclusive



CC 0 pion

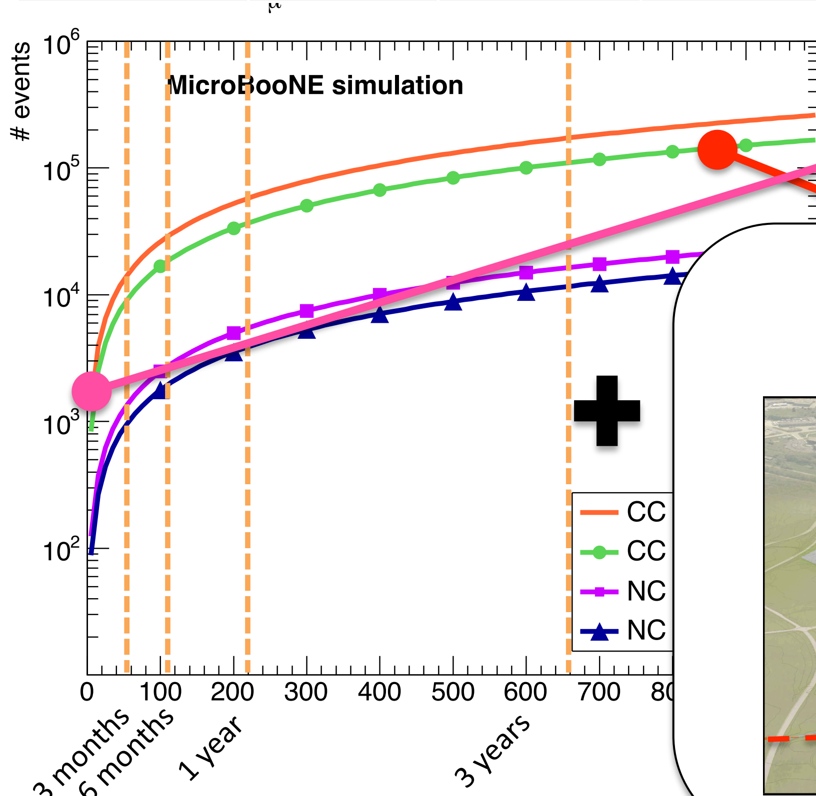


Cross sections in MicroBooNE – for the experimentalist

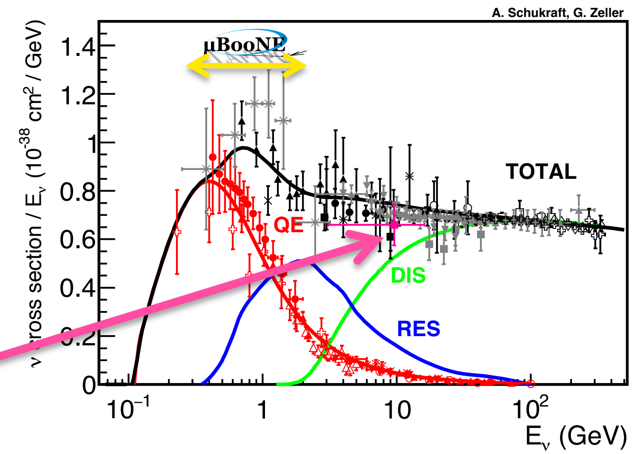
First analyses

1e20 POT (6 months, 87 tons, no efficiencies)

	numu			
	CC inclusive	CC 0 pi	NC elastic	NC single pi0
	26553	16997	2596	1719

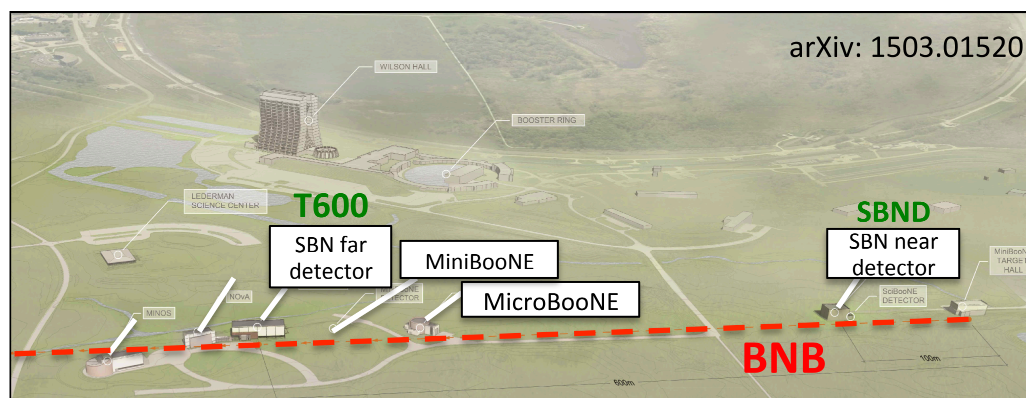


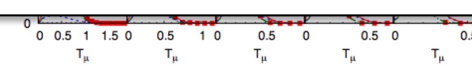
CC inclusive



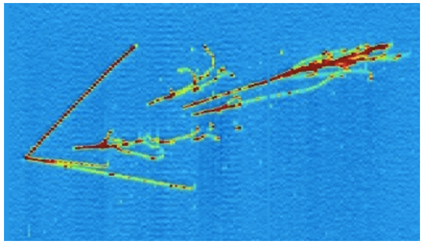
SBND in 2018

Closer to target: 30x higher rate!

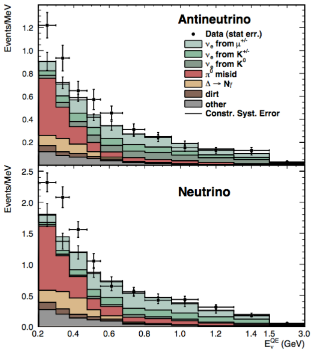




Summary

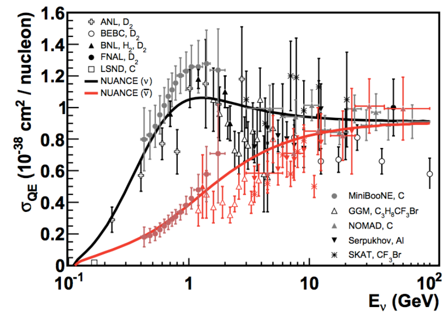


- MicroBooNE will deliver awesome neutrino event views!



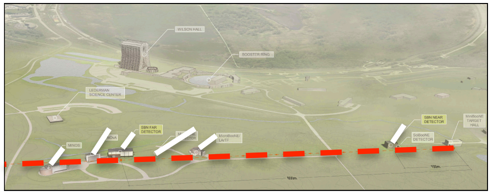
- MicroBooNE will examine the nature of the MiniBooNE low-E excess

- MicroBooNE will deliver high statistics of neutrino-argon interactions, which we need a better understanding of (also in view of future experiments)



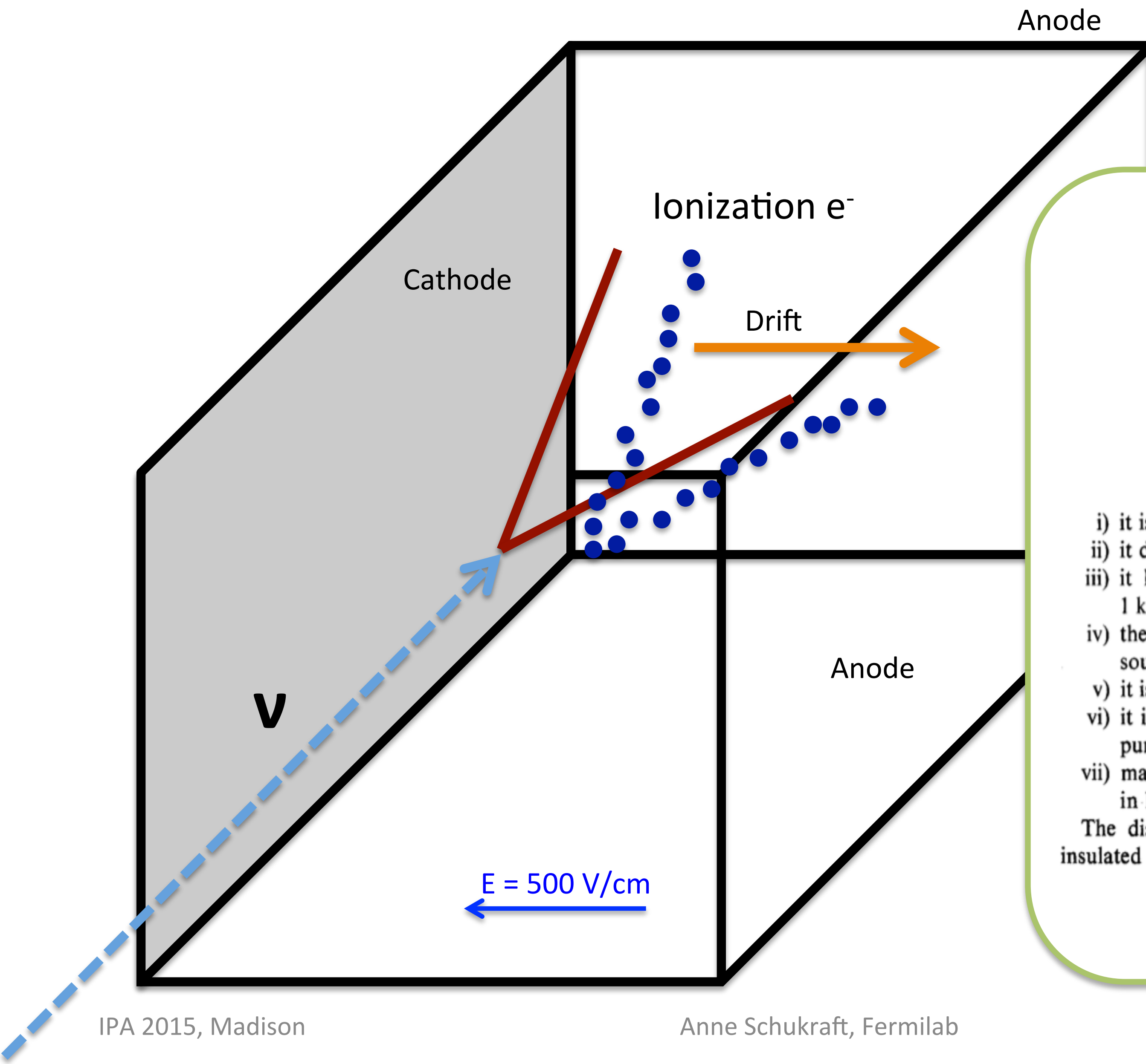
- MicroBooNE is about to start data taking – stay tuned!

- In the future, the Short Baseline Neutrino Program (SBN) will be provide much more statistics and sensitivity to the LSND excess/sterile neutrino signature



- Backup -

The principle of a LArTPC



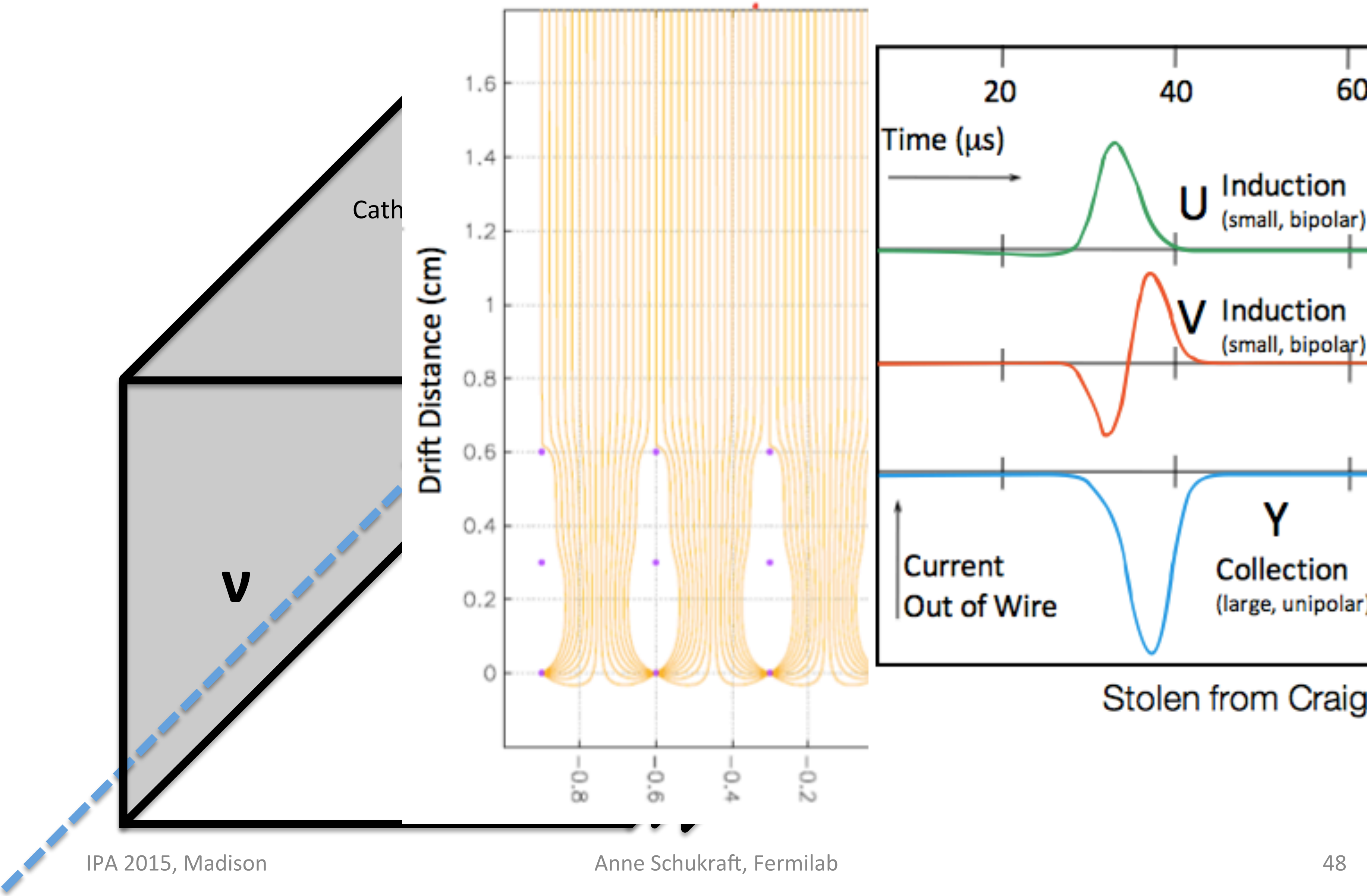
Why liquid argon?

i) it is dense (1.4 g/cm^3);
ii) it does not attach electrons;
iii) it has a high electron mobility ($\sim$5 mm/μs at 1 kV/mm);
iv) the cost is low (\$0.14$\rightarrow$0.50/kg, depending on source and quantity);
v) it is inert, in contrast to flammable scintillators;
vi) it is easy to obtain in a pure form and easy to purify;
vii) many electronegative impurities are frozen out in liquid argon.

The disadvantage is that the container must be insulated for liquid-argon temperature (86 K).

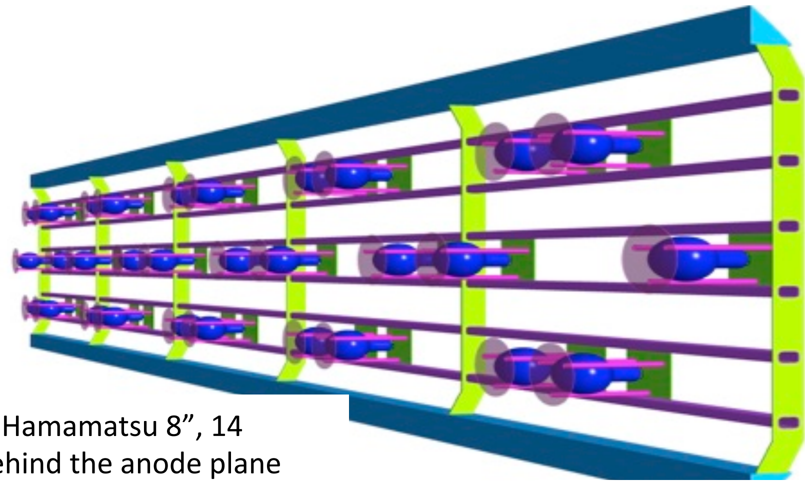
Willis & Radeka, NIM 120 (1974)

The principle of a LArTPC



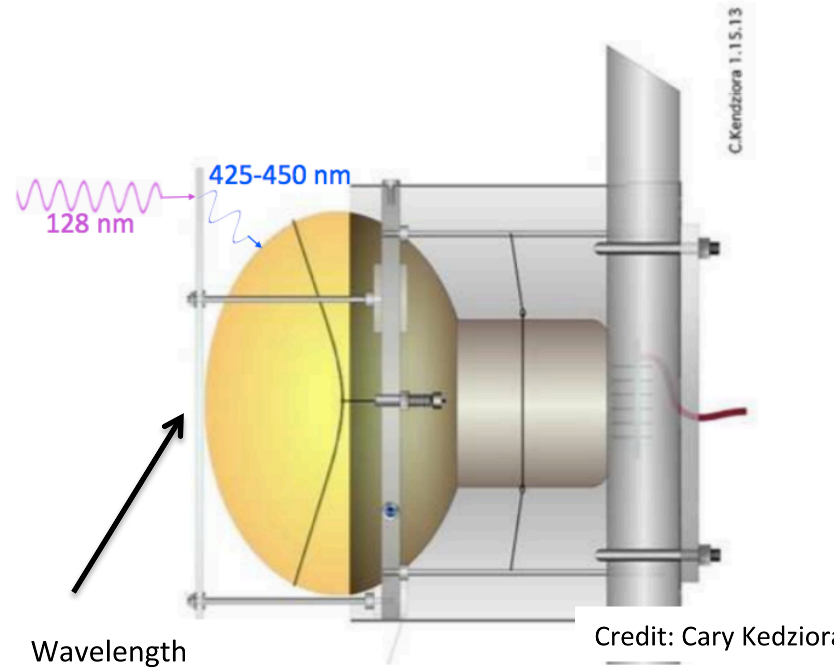
Stolen from Craig

The light collection system



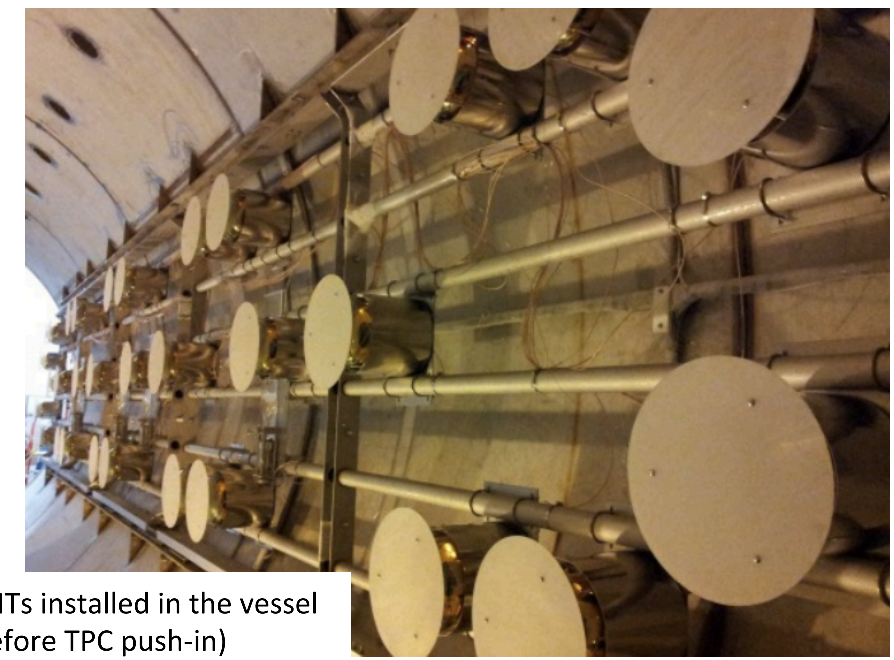
32 PMTs (Hamamatsu 8”, 14 stages) behind the anode plane

Credit: Tess Schmidt

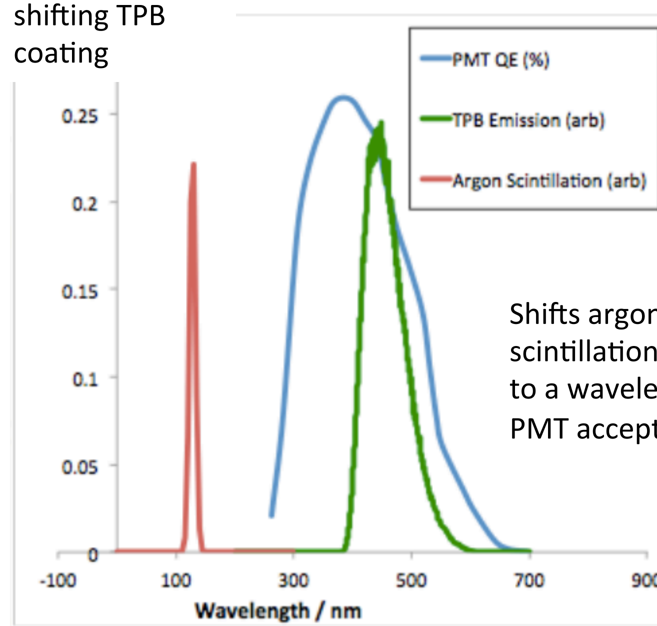


Wavelength shifting TPB coating

Credit: Cary Kedziora



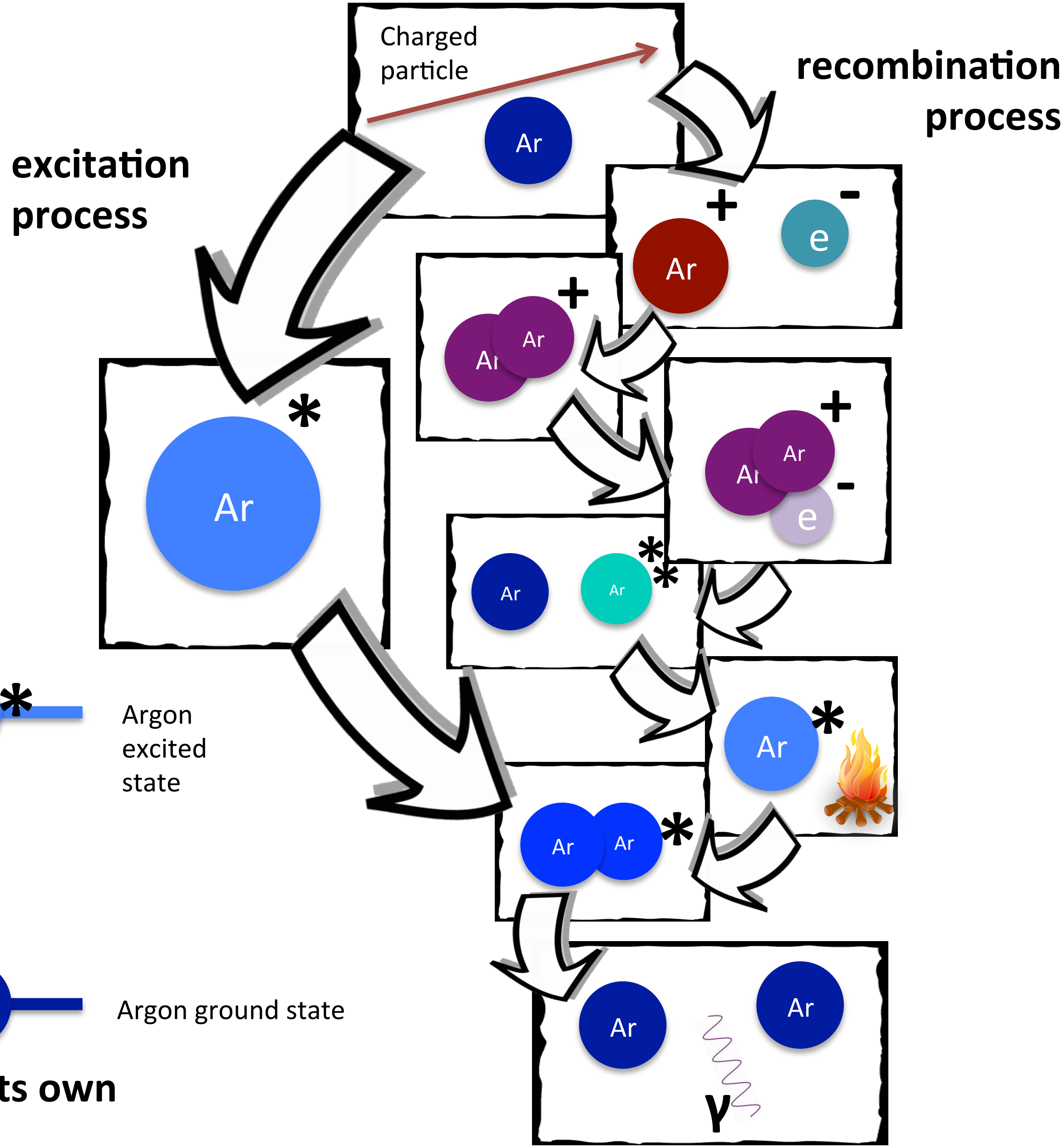
PMTs installed in the vessel (before TPC push-in)



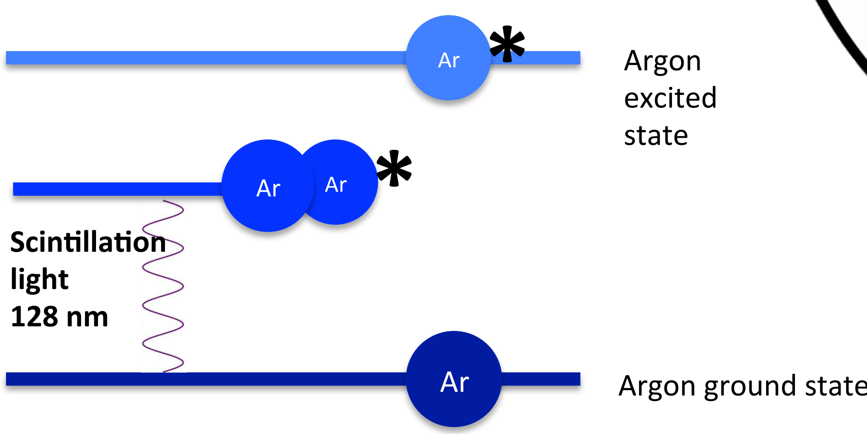
B.J.P. Jones, et al JINST 8 (2013) P01013

Shifts argon scintillation light (VUV) to a wavelength in the PMT acceptance region

Scintillation light in LAr



The important conclusion:



Argon is transparent to its own scintillation light!

Purity requirements

Electronegative impurities (O_2 and H_2O) absorb the drift electrons

$$N_e(t_{drift}) = N_e(t_0) \times \exp(-t_{drift} / \tau)$$

A calculation for MicroBooNE:

Electrical field: 500 V/cm
-> Drift velocity: 1.6 mm/us

Maximum drift distance: 2.5 m
-> Maximum drift time: 1.56 ms

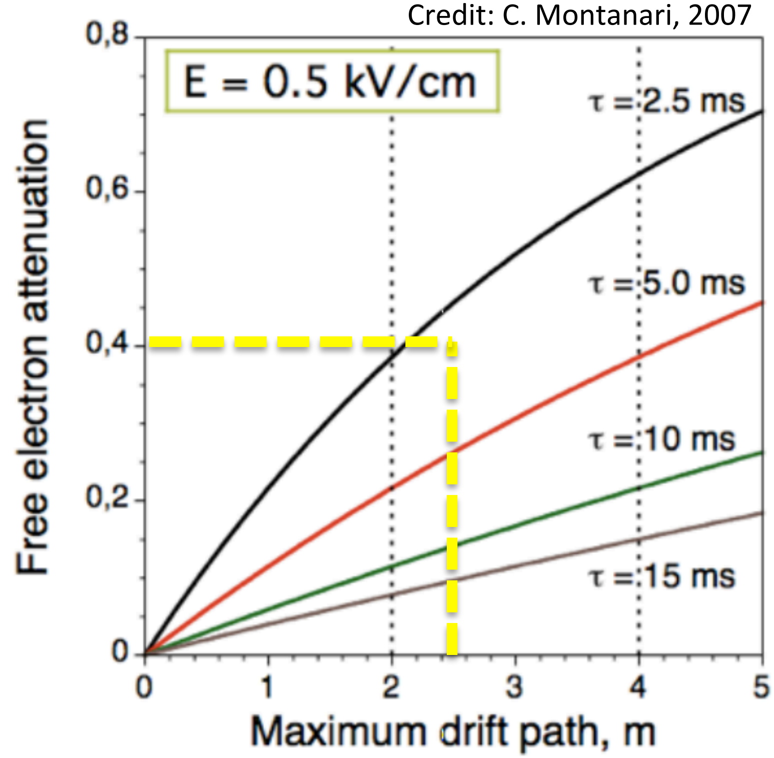
Want to lose at most 40% signal
-> need an electron lifetime of 3 ms

-> Corresponds to **100 ppt O_2**

In addition:

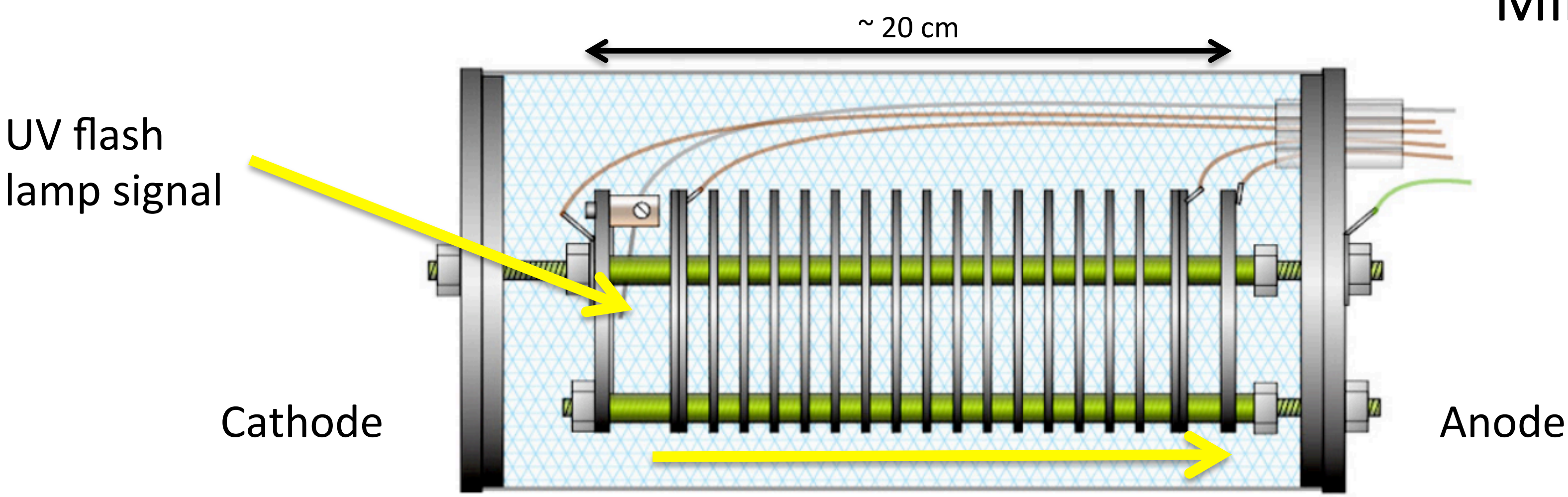
Need to avoid quenching and absorption of scintillation light by N_2
-> require < 2 ppm N_2

Credit: C. Montanari, 2007

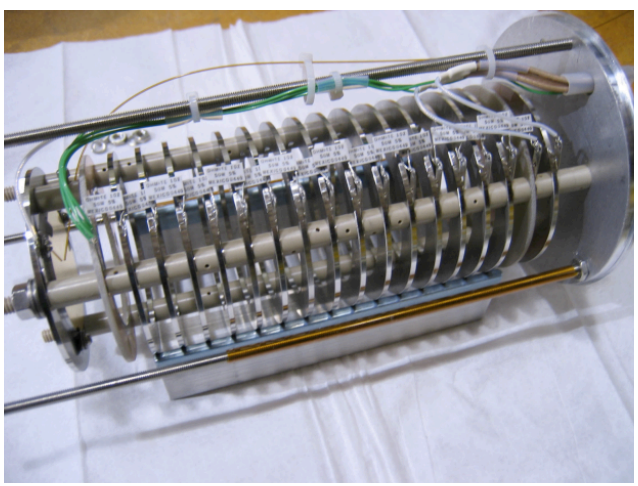


Purity monitoring

A purity monitor is a Mini-TPC



Measure electron drift time t_{drift}

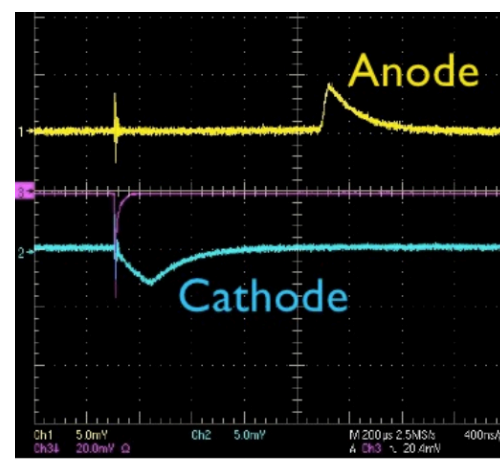


Based on the ICARUS design

$$Q_{anode} = Q_{cathode} \times \exp(-t_{drift} / \tau)$$

The electron lifetime τ is a measure for the purity

We have three of these: 2 inside the cryostat, 1 before the LAr enters



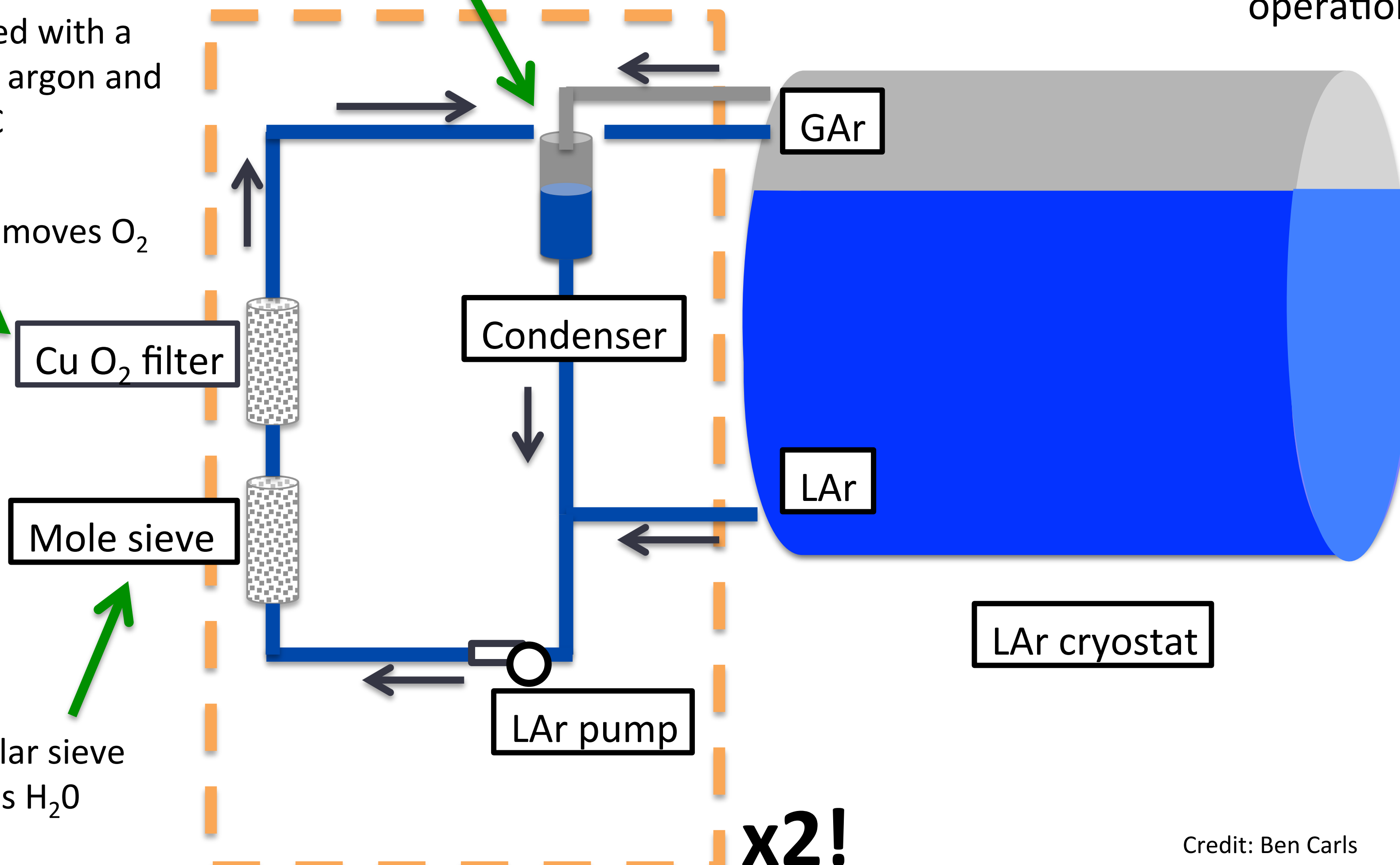
Cryogenics operational circle

Gaseous argon is recondensed using LN_2

One volume exchange per day during operation

Filters can be regenerated with a mixture of argon and H_2 @ 400C

Cu filter removes O_2



Molecular sieve removes H_20

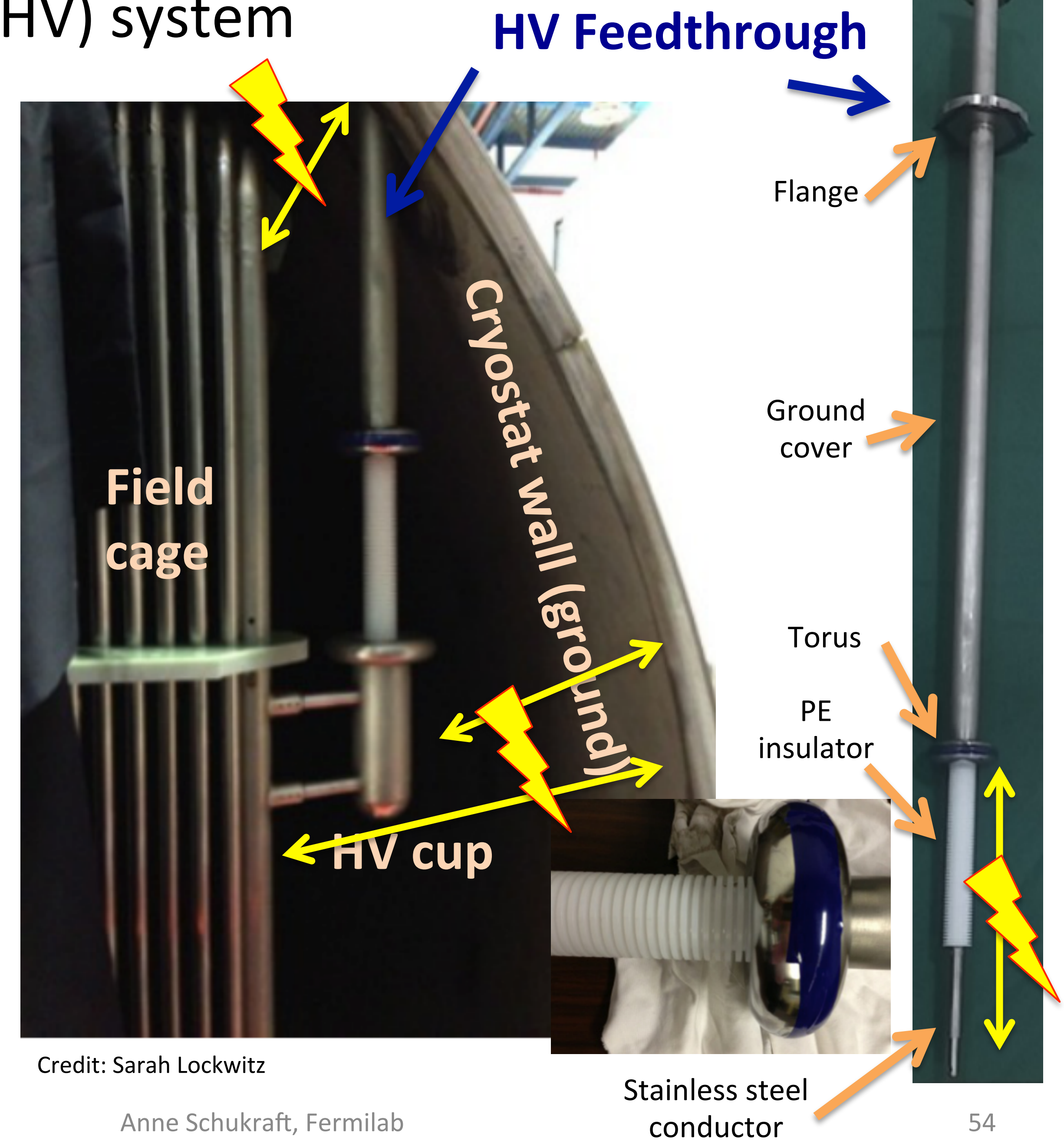
Credit: Ben Carls

The high voltage (HV) system

MicroBooNE has a longer drift distance than previous detectors
-> needs a high cathode voltage to supply electrical field **(-128 kV)**

The challenge:

Avoid electrical breakdown between components on different electrical potential



Credit: Sarah Lockwitz

Precautions against HV breakdown

All components have been tested before installation

Credit: Sarah Lockwitz

"Smushed elbows" near the cathode plane

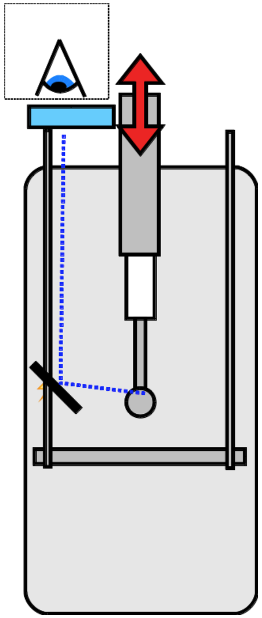
JINST 9, P09002 (2014)
JINST 9, T11004 (2014)

Credit: Jen Raaf

Field cage resistors have been replaced with a special version near the cathode

Varistor surge protection near the cathode

Dielectric strength of liquid argon

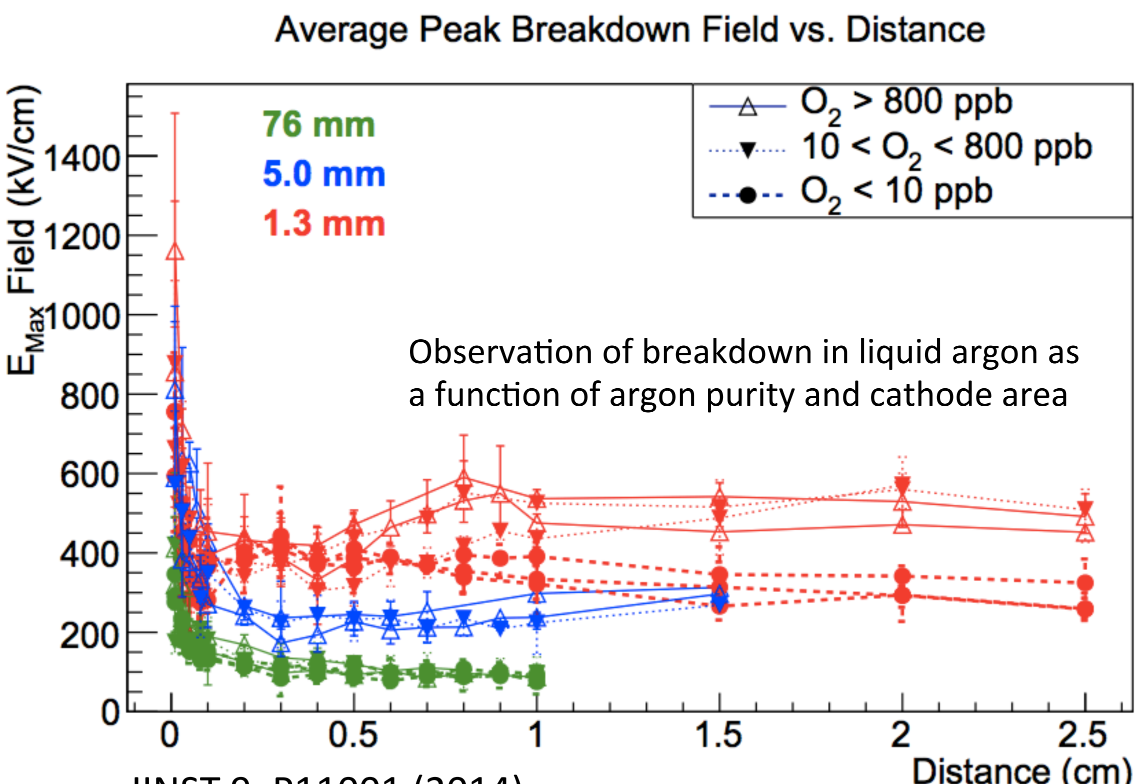


Credit: Sarah Lockwitz

Historically it was believed that the dielectric strength of argon is high (~ 1 MV/cm)

But breakdown has been observed recently at much lower electric fields

This needs to be taken into consideration for experiment designs



Observation of breakdown in liquid argon as a function of argon purity and cathode area

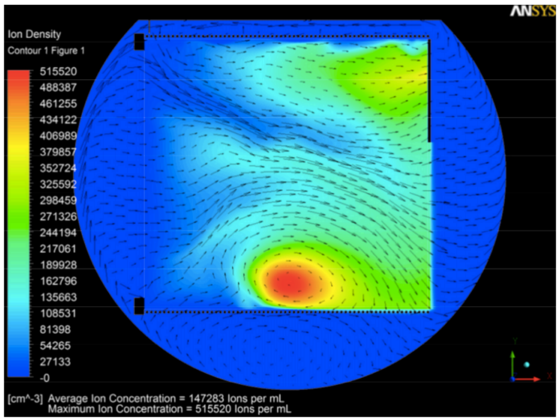
JINST 9, P11001 (2014)

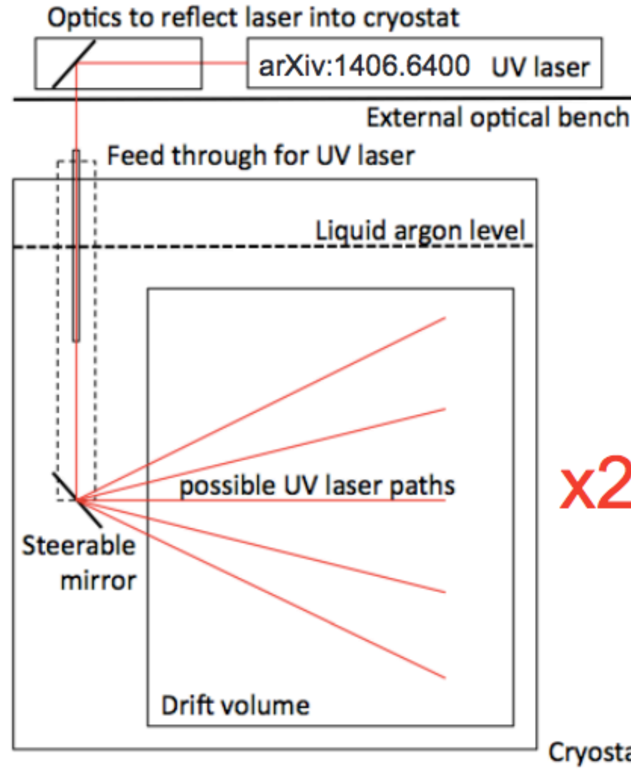
JINST 9, P04006 (2014); JINST 9, P07023 (2014)

The UV laser calibration system

Positive space charge will accumulate and distort the electrical field inside the TPC

Simulated space charge distribution

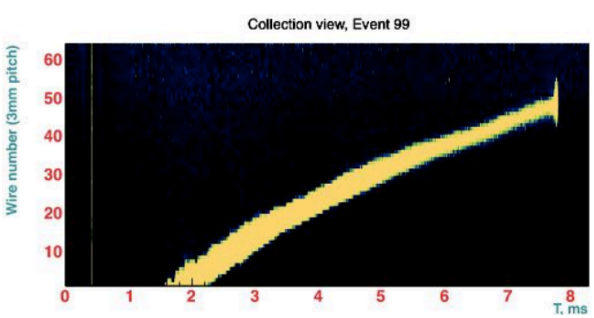




Credit: Thomas Strauss

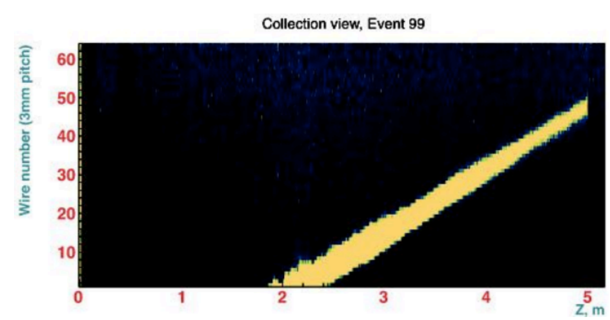
The electrical field can be calibrated with a 266 nm UV laser, that ionizes the argon

arXiv: 1406.6400



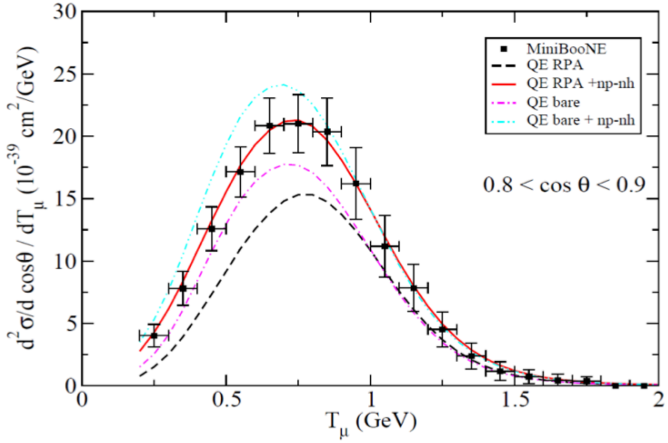
UV laser event

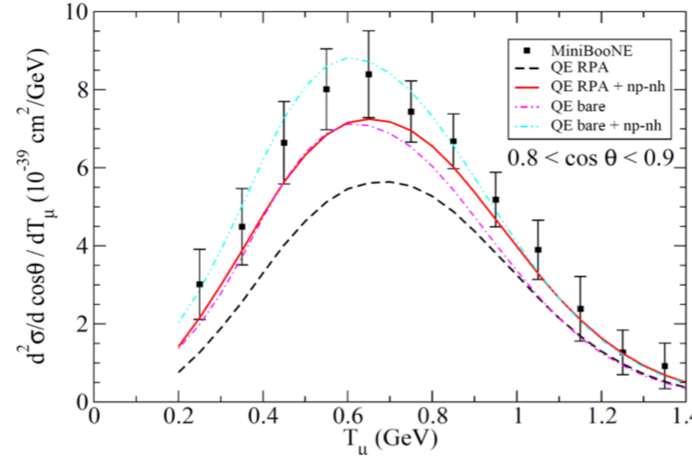
Field Correction



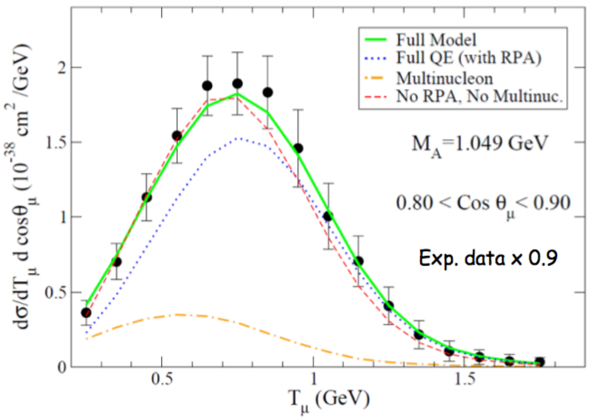
ν $\bar{\nu}$

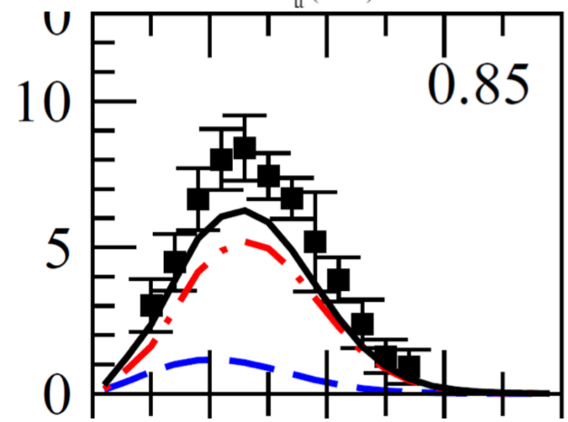
Martini et al.





Nieves et al.

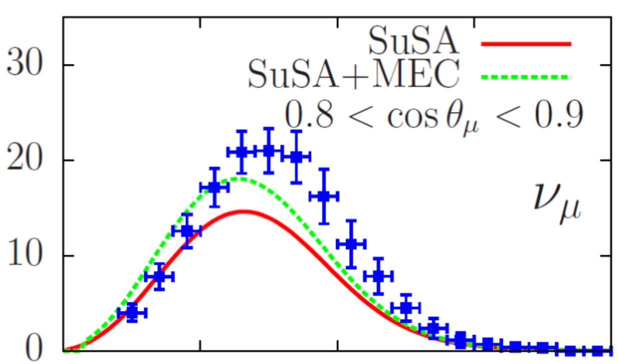


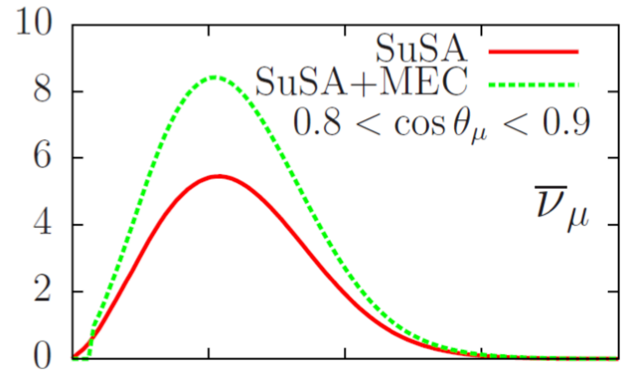


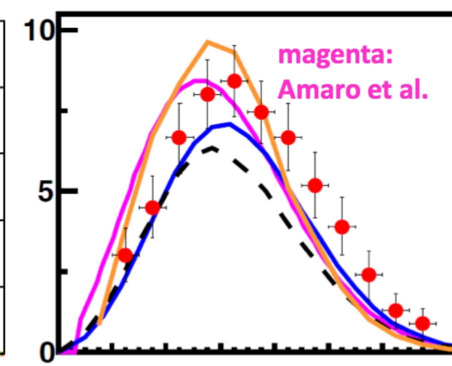
black: QE RPA+2p2h

red: QE RPA

Amaro et al.







M. Martini et al. @ INT Workshop 2013

LArTPCs in neutrino beams

Technology for the future!

… and there are many more LArTPCs in test stands, test beams and as dark matter detectors