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Columbia University

(For the MicroBooNE Collaboration)

NOW 2012
Conca Specchiulla
9-16 September 2012

Collaboration

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- *Yale University*: C. Brasco, E. Church, B. T. Fleming, R. Guenette, K. Partyka, J. Spitz, A. Szelc, E. Klein

17 institutions
91 collaborators

Spokespersons: Bonnie Fleming, Sam Zeller

The Genealogy of MicroBooNE….

LSND

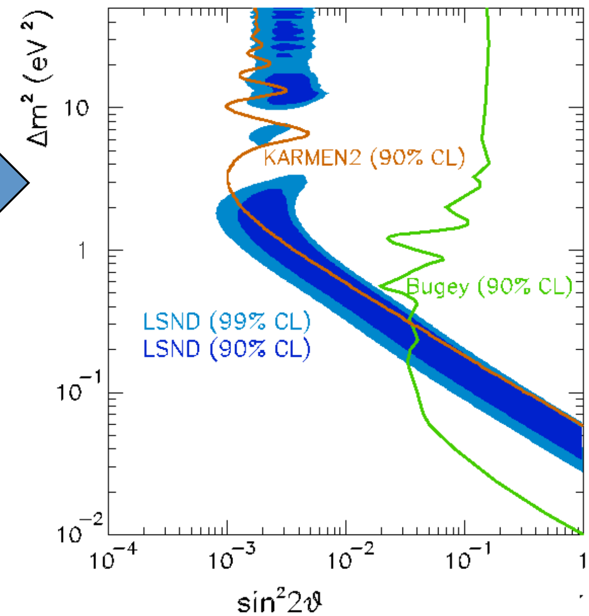
Interesting effect!

LSND observed a (~3.8σ) excess of $\bar{\nu}_e$ events in a pure $\bar{\nu}_\mu$ beam

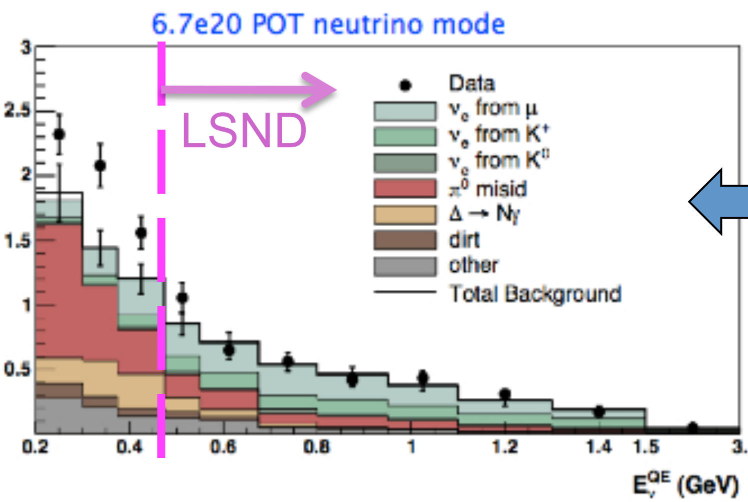
If due to oscillations:

L/E → High $\Delta m^2 \sim 1\ eV^2$

Can only be accomodated by a new STERILE neutrino



MiniBooNE Booster Neutrino Beam at Fermilab



MiniBooNE

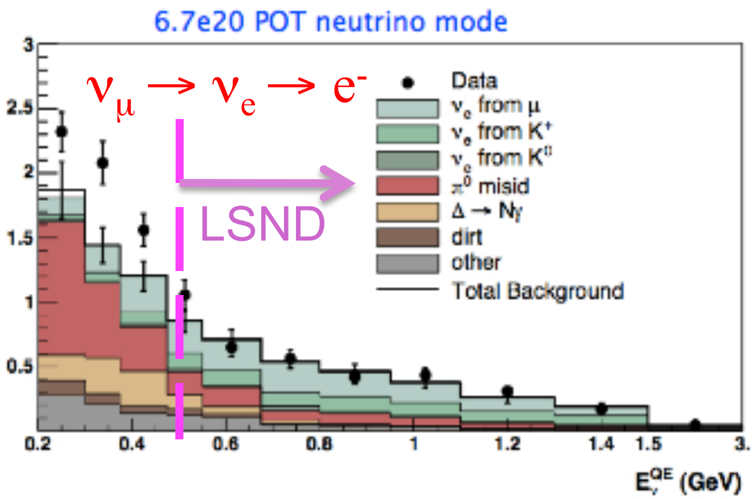
Interesting effect

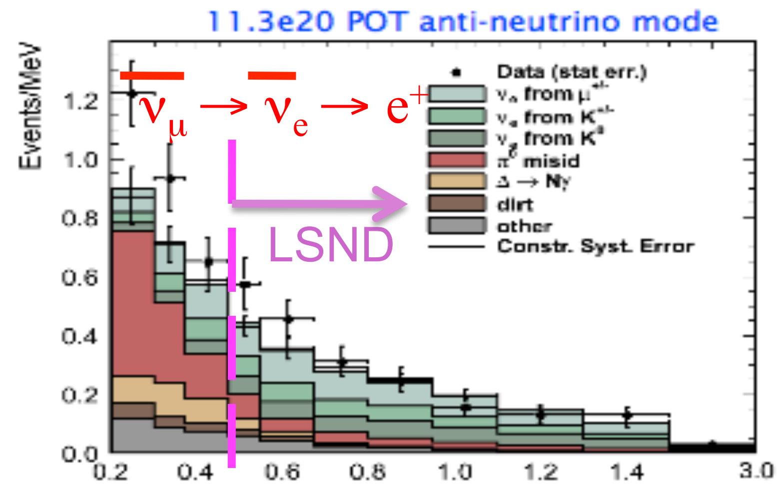
But a different one!

Excess but mostly at **Lower** energy than expected from LSND:

MicroBooNE

e/γ identification in MiniBooNE based on Cerenkov Rings





ν_e X → e + …

Single fuzzy ring of PMT's

For a converting γ the two rings from e^+ and e^- overlap.

Cannot distinguish an electron from a single γ to e+e-

From the MiniBooNE presentation at Neutrino 2012

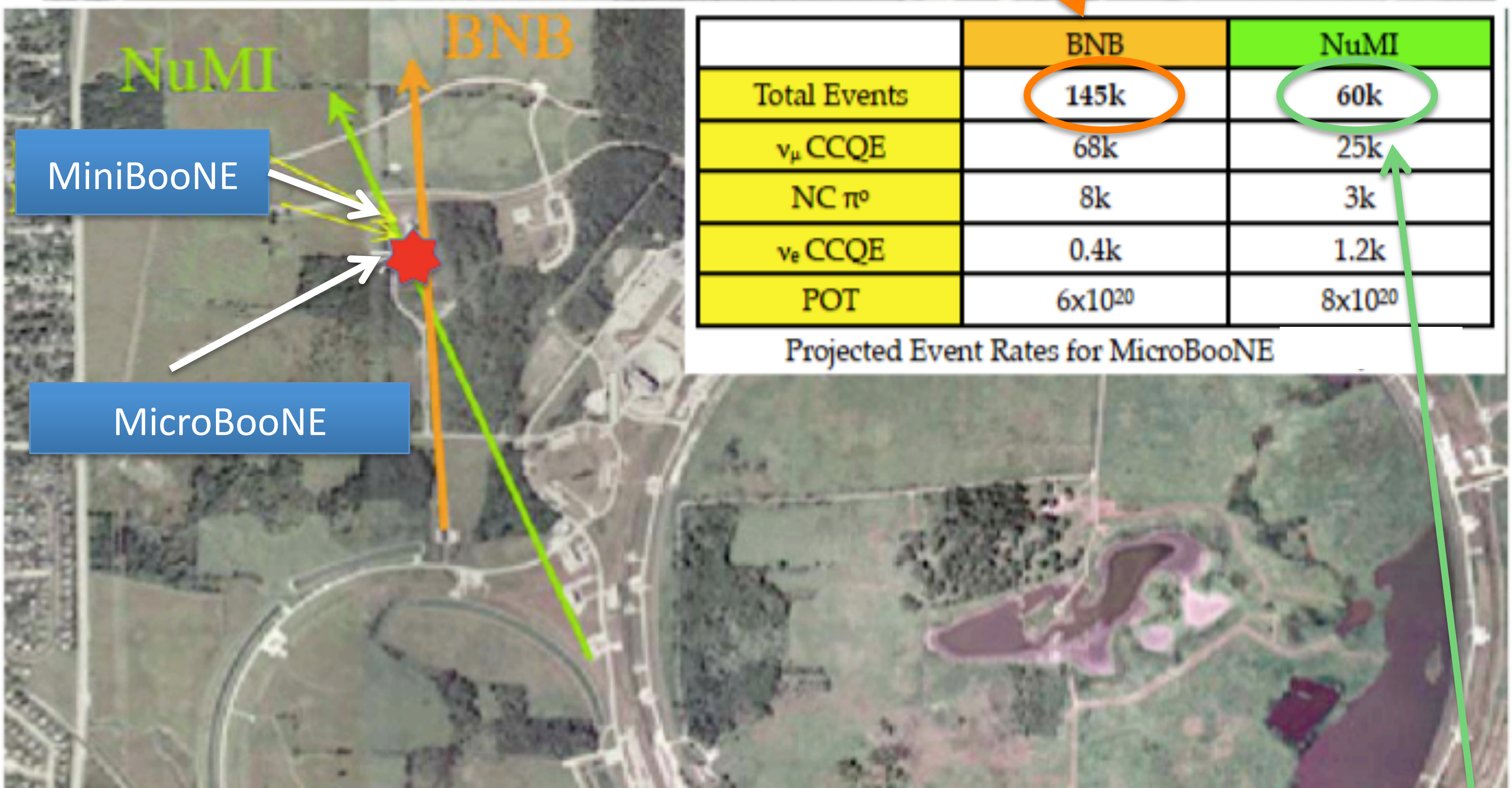
- It is not yet known whether the MiniBooNE excesses are due to oscillations, → e^+, e^- some unrecognized NC γ background, or something else

MicroBooNE: Liquid Argon TPC for good e/γ discrimination

Dual Purpose

- **Physics:**
  I. The MiniBooNE low energy Excess and the LSND anomaly .
  II. Cross sections
  III. SuperNova neutrinos
- **R&D**
  I. Argon fill without first evacuation. (Evacuation capability exists)
  II. Long Drift spaces (2.5m up from 1.5m).
  III. Cold Front end electronics (up to and including shaper) in Liquid Argon
  IV. Continuous readout for SuperNova events and storage for several hours, awaiting trigger from SuperNova Alert Network
  V. Measurement of Background to Proton decay searches in Large Underground LAr detectors.
  VI. Development of Reconstruction and Particle Identification techniques.

MicroBooNE in front of MiniBooNE: Same Booster Neutrino Beam (BNB)

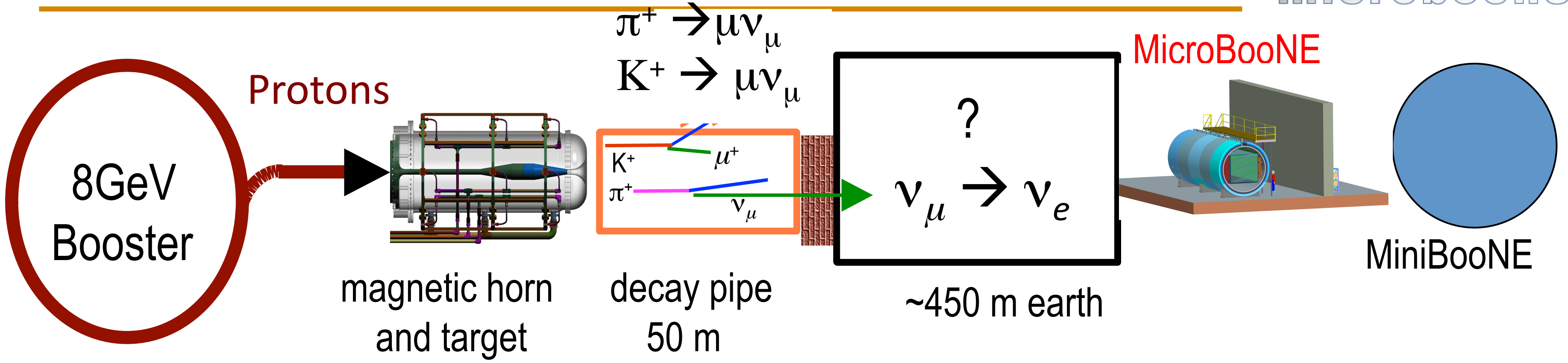


	BNB	NuMI
Total Events	145k	60k
ν_μ CCQE	68k	25k
NC π^0	8k	3k
ν_e CCQE	0.4k	1.2k
POT	6×10^{20}	8×10^{20}

Projected Event Rates for MicroBooNE

Bonus: NUMI beam: 110 mrad off-axis
4×10^{20} POT/year

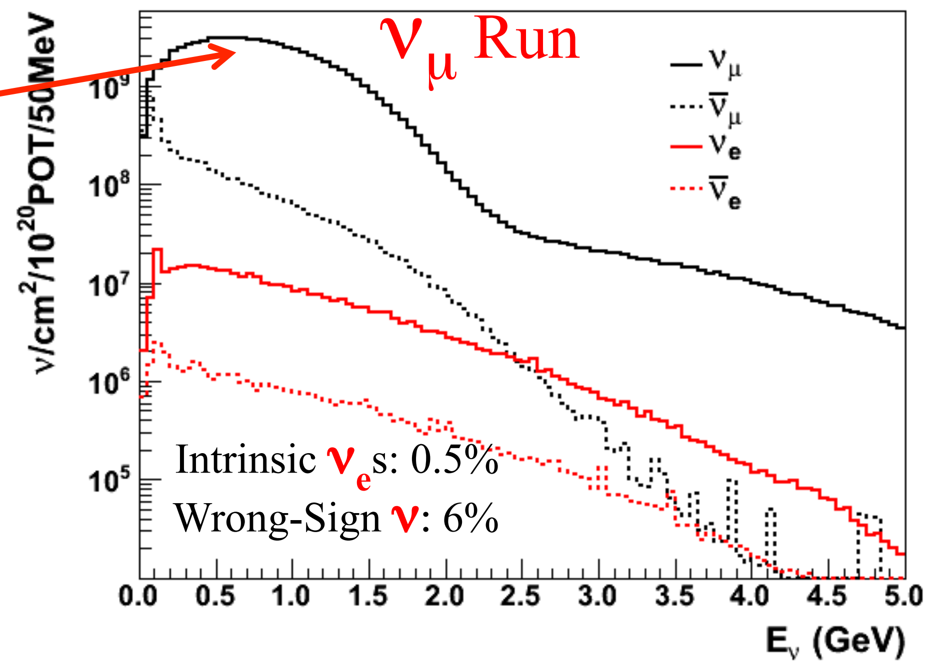
MicroBooNE at Fermilab



- **Similar L/E as LSND**
- **30m/40MeV ~ 475m/600MeV**
- **→ Same oscillation Prob → ν_e Excess**

- **Similar to MiniBooNE → Low energy Excess**

- **Different systematics**
  - **Event signatures**
  - **Backgrounds**

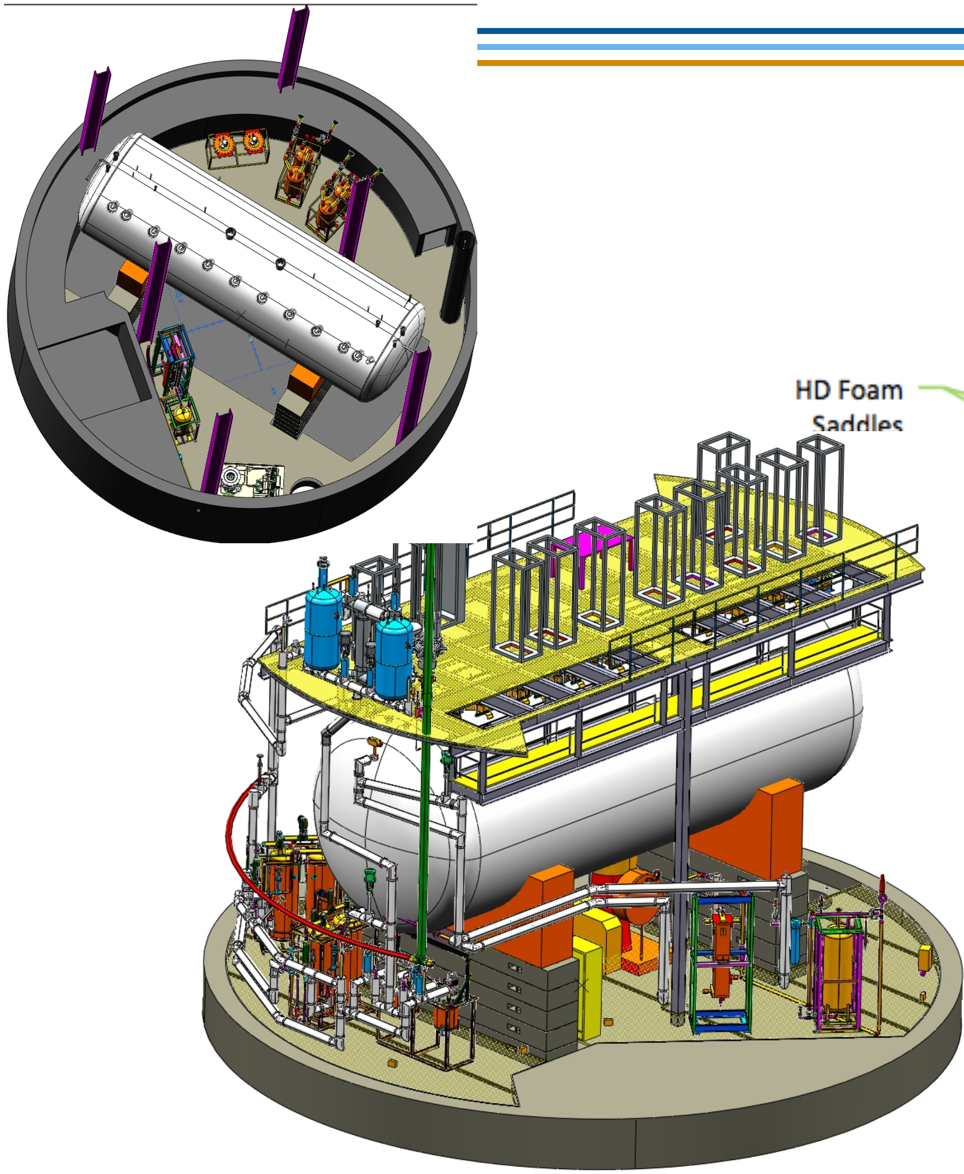


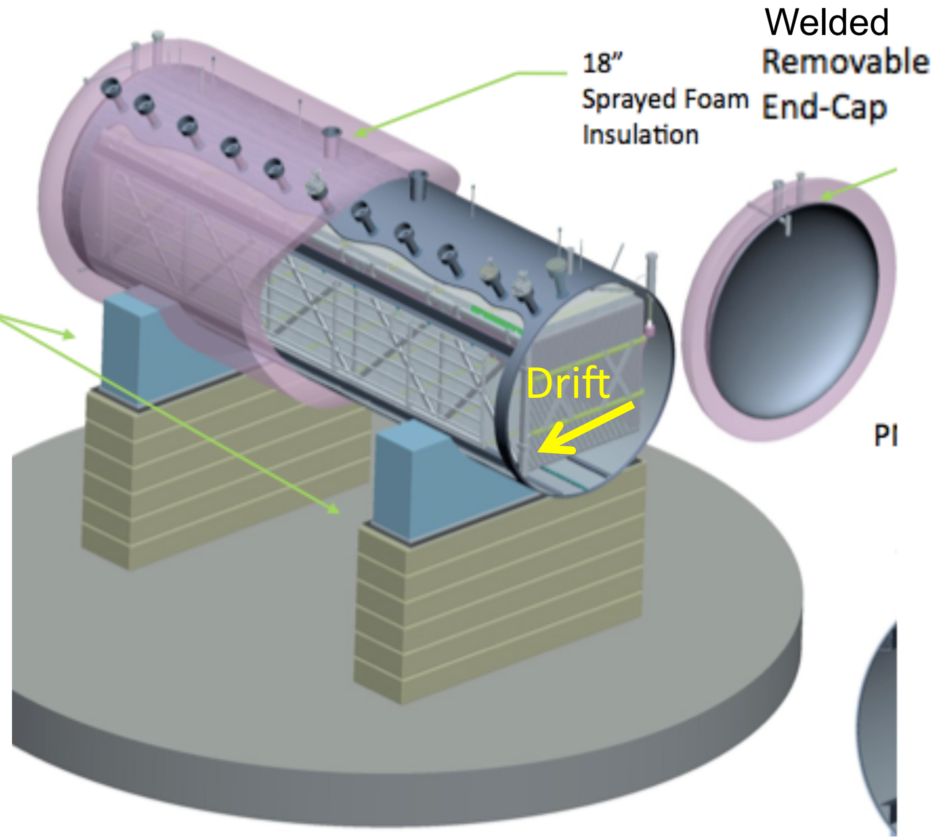
Site description

Start of construction

Today

Detector description





TPC: 100 tons of LAr
60 tons Fiducial volume

30 PMT's

MicroBooNE TPC

- Electric field: 500 V/cm
- Ionization electrons drift to
  3 recording planes (1.6mm/μsec)
  1.6 msec full 2.5m drift

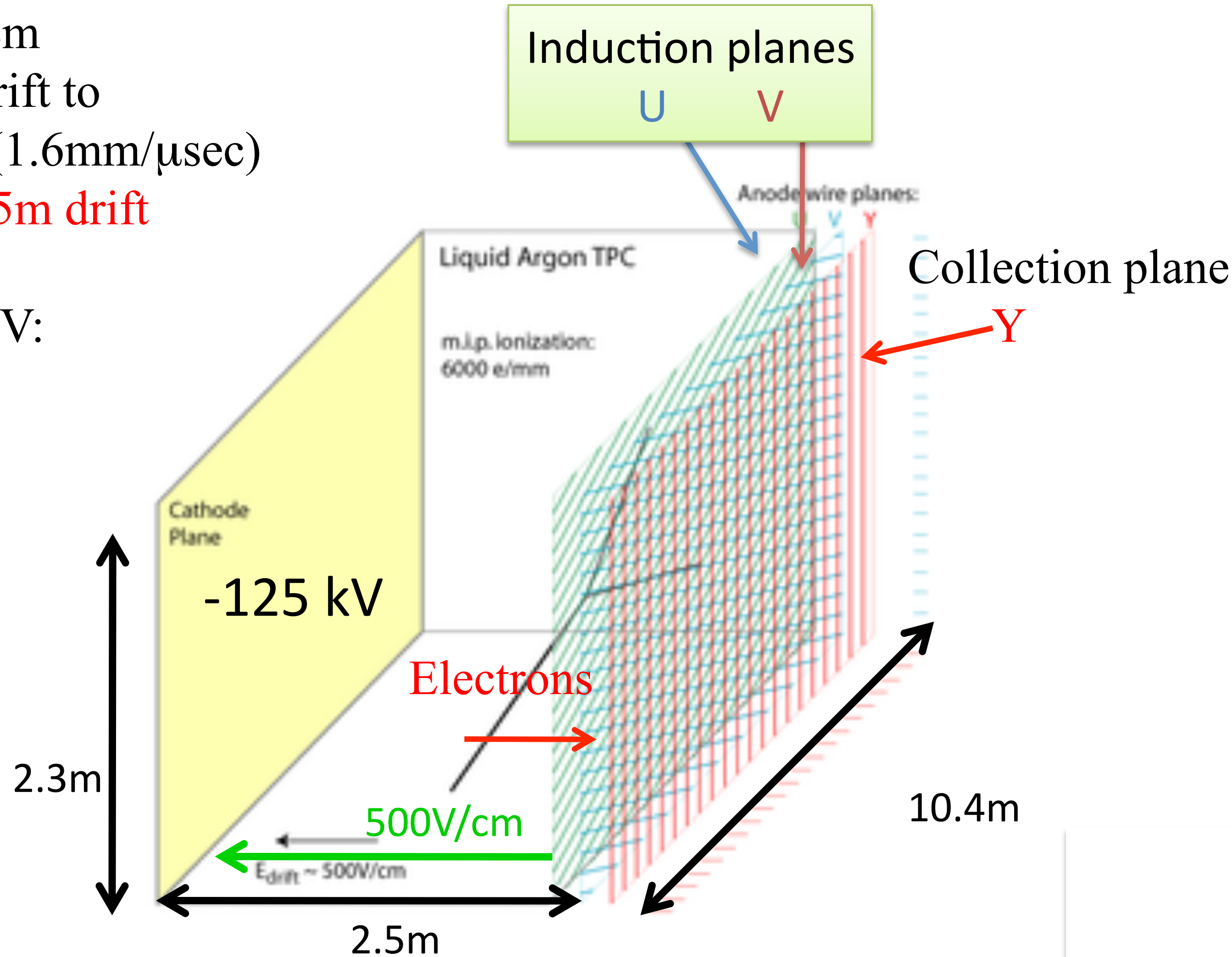
- 2 Induction planes U, V:
  +- 60^{o} to vertical

→ Bipolar pulse

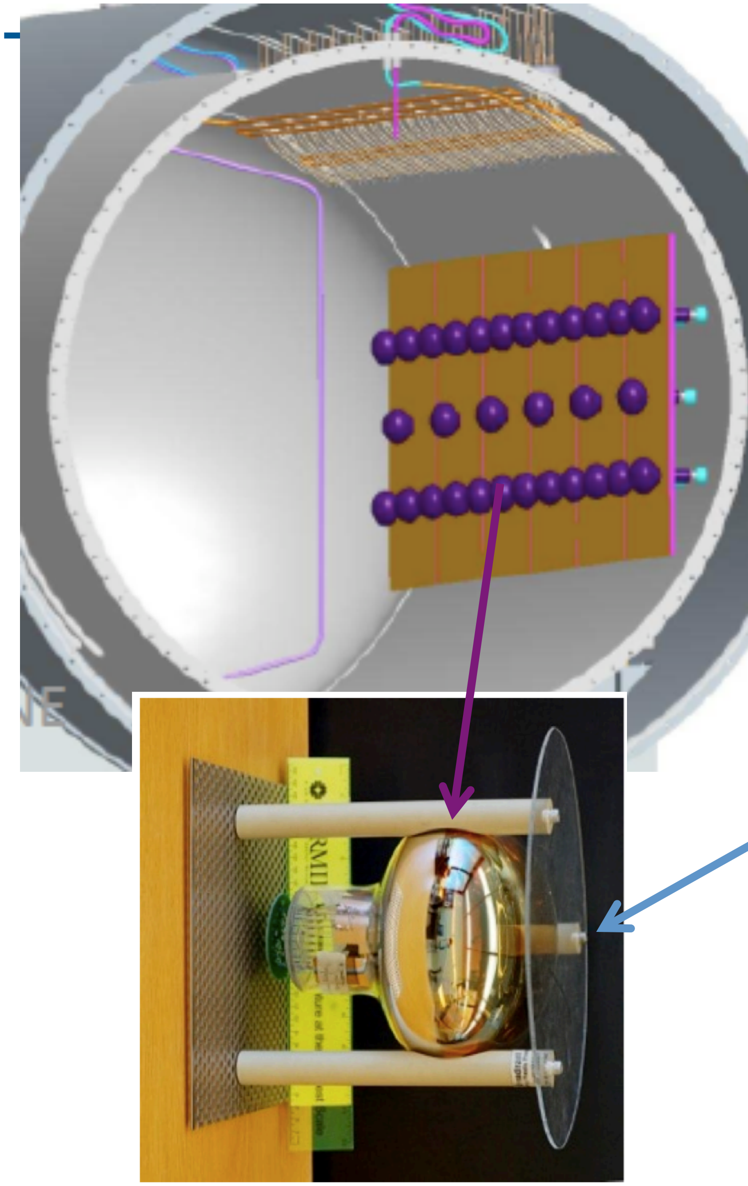
- 1 collection plane Y:
  vertical

→ Unipolar pulses

- Together: 3D stereo



MicroBooNE Photodetectors

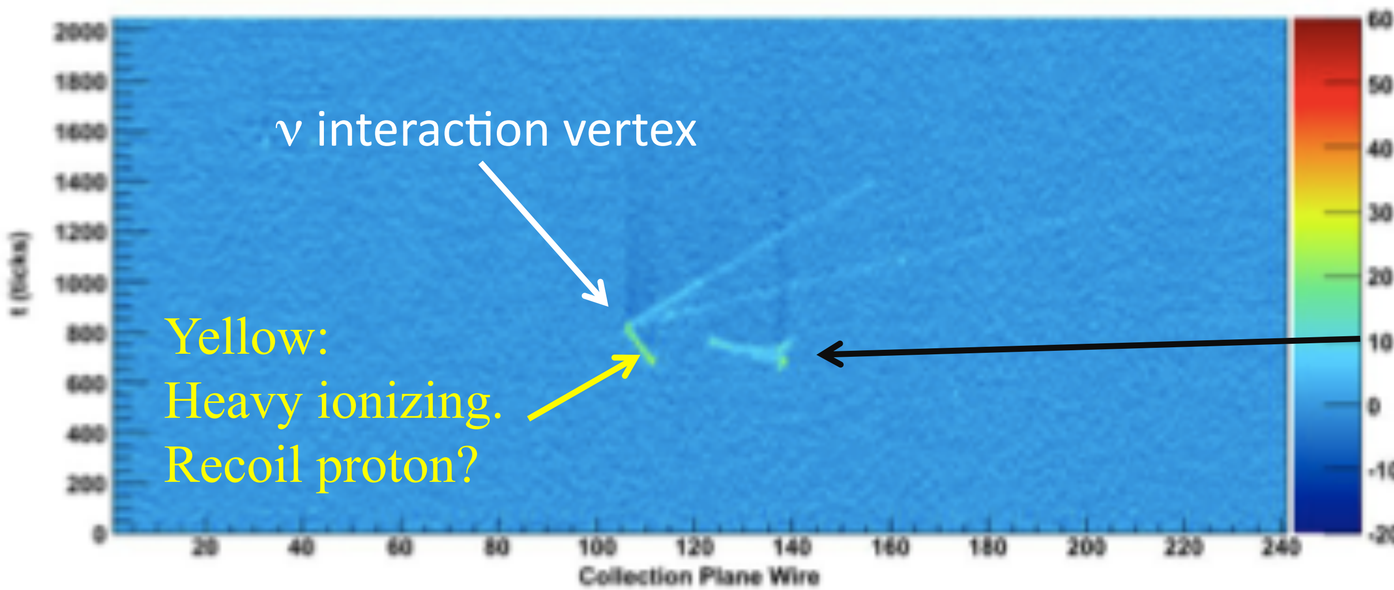


LAr scintillates in the UV at 128nm:
Use it

- To determine time of event
- To trigger on events in time with beam

- 30 Hamamatsu R5912-02 14 stage 8 inch pmt's.
- Located behind collection plane
- Plate coated with Tetraphenyl-butadiene (TPB) to shift UV light to visible in front of each pmt.
- 6ns fast component: yields 6000 photons/MeV
- 4 photo-electrons/MeV **recorded**

Very detailed information: Event observed in ArgoNeut



Colour denotes Pulse height

Photon conversion
$\gamma \rightarrow e^+ e^-$

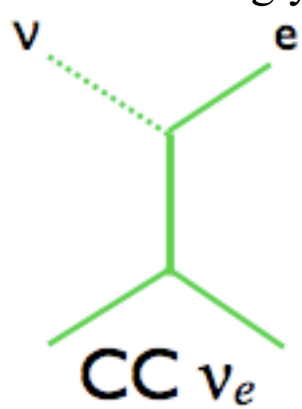
Advantages over MiniBooNE

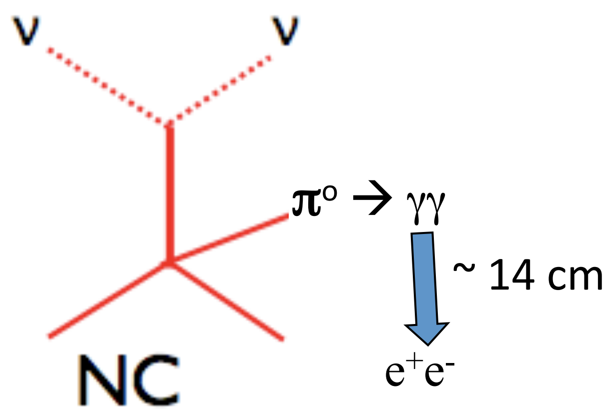
- Detailed knowledge of topology of events
- All charged particles seen (no Cerenkov threshold)→ Purer CCQE sample
- dE/dx and range allow particle identification
- Photons distinguishable through displaced conversion vertex

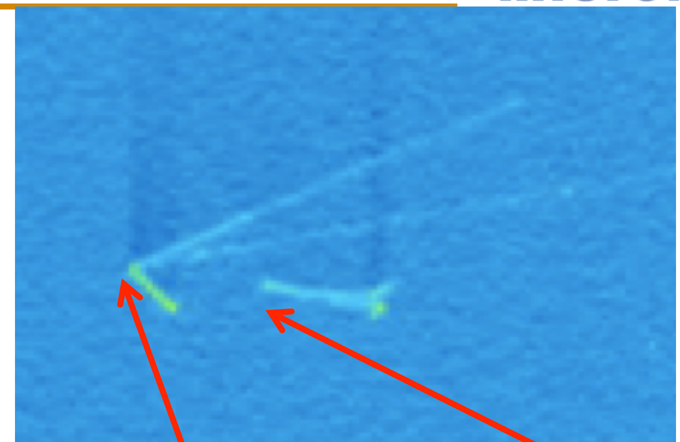
- Fid. Volume : MiniBooNE **450t** → MicroBooNE **60t** but better **e/γ** efficiency

What is the MiniBooNE excess due to? Electrons or Photons?

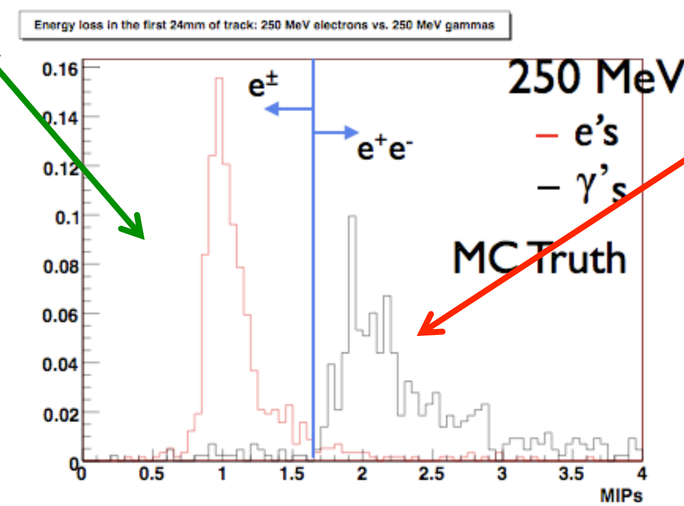
Electron : Connected to
primary vertex
And singly ionizing track







Photon: Gap between primary vertex and conversion point
and doubly ionizing

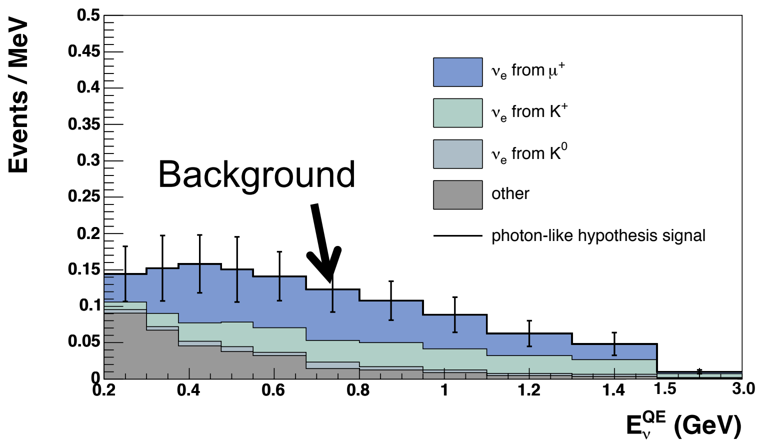


dE/dx for electrons and gammas in first 2.4 cm of track

Physics Motivation I. Excess due to Electrons.

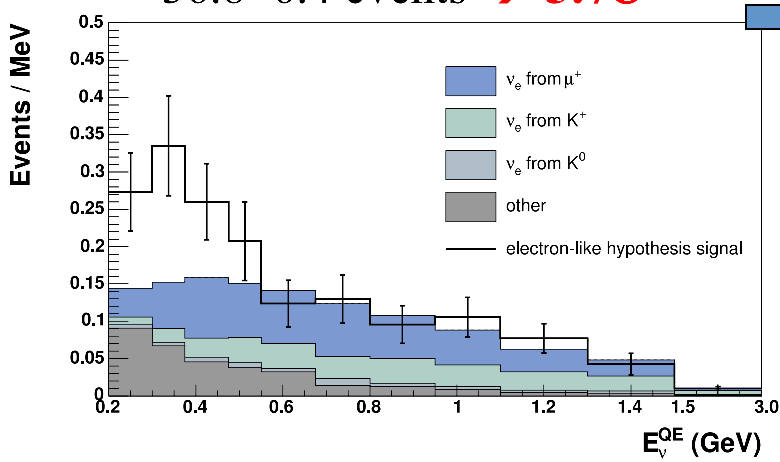
Cuts to Select Electrons, Reject γ's

Excess NOT due to electrons



Excess IS due to electrons

36.8±6.4 events → **5.7σ**



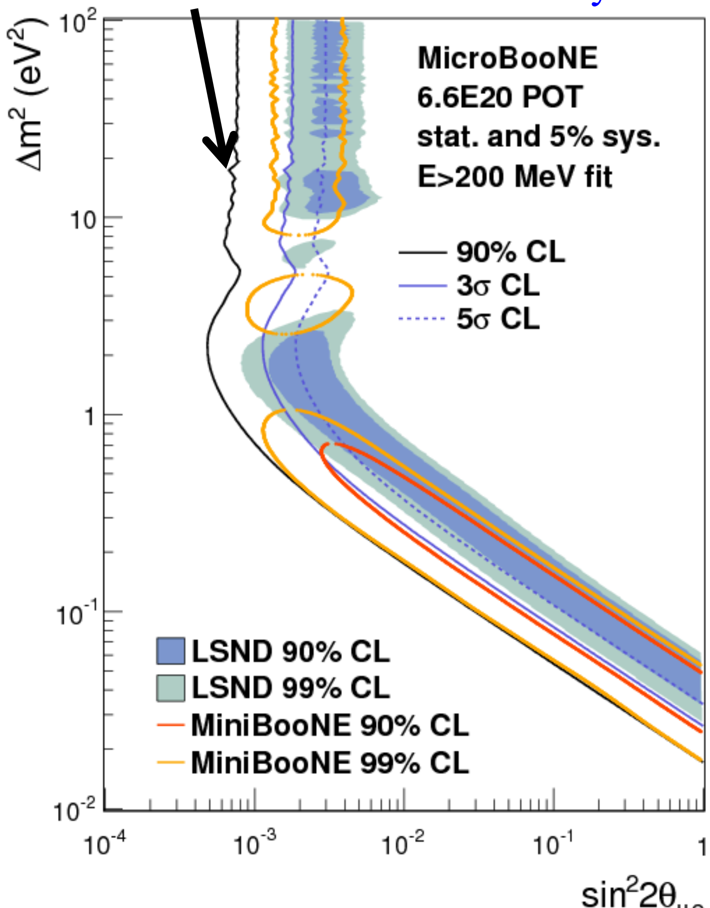
(Estimated from MiniBooNE rates)

◆If there is any electron excess

In the context of $\nu_\mu \rightarrow \nu_s \rightarrow \nu_e$ oscillations

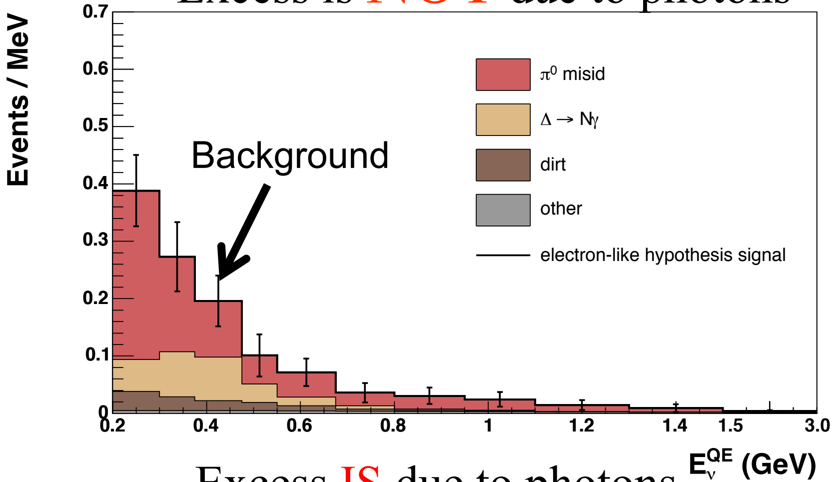
(3+1 oscillations)

MicroBooNE 90% CL Sensitivity



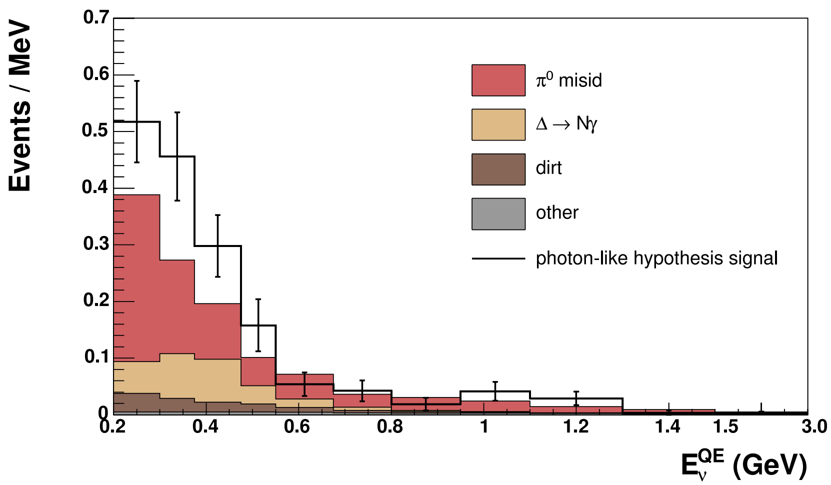
Physics Motivation. Excess due to: Photons.
Cuts to Select Photons, Reject e's

Excess is NOT due to photons



Excess IS due to photons

36.8±8.9 events → 4.1σ



(Estimated from MiniBooNE rates)

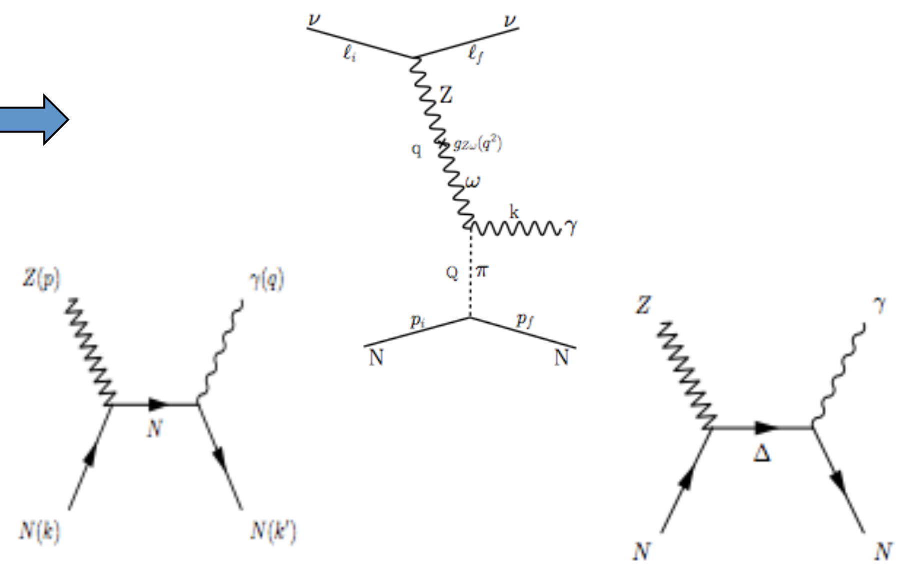
- Background: γ or π^0

OR

- Radiative ν interaction

Examples:

- R. Hill arXiv: 0905.0291
- Jenkins et al arXiv:0906.0984
- Serot et al arXiv: 1011.5913



Physics Motivation II: Measurement of Cross sections

Argon nucleus, High Statistics, High spatial resolution

Expected event rates for 6.6 x 10^{20} POT

production mode	# events
CC QE ($\nu_\mu n \to \mu^- p$)	60,161
NC elastic ($\nu_\mu N \to \nu_\mu N$)	19,409
CC resonant π^+ ($\nu_\mu N \to \mu^- N \pi^+$)	25,149
CC resonant π^0 ($\nu_\mu n \to \mu^- p \pi^0$)	6,994
NC resonant π^0 ($\nu_\mu N \to \nu_\mu N \pi^0$)	7,388
NC resonant $\pi^\pm$ ($\nu_\mu N \to \nu_\mu N' \pi^\pm$)	4,796
CC DIS ($\nu_\mu N \to \mu^- X$, $W > 2$ GeV)	1,229
NC DIS ($\nu_\mu N \to \nu_\mu X$, $W > 2$ GeV)	456
NC coherent π^0 ($\nu_\mu A \to \nu_\mu A \pi^0$)	1,694
CC coherent π^+ ($\nu_\mu A \to \mu^- A \pi^+$)	2,626
NC kaon ($\nu_\mu N \to \nu_\mu K X$)	39
CC kaon ($\nu_\mu N \to \mu^- K X$)	117
other ν_μ	3,678
total ν_μ CC	98,849
total ν_μ NC+CC	133,580
ν_e QE	326
ν_e CC	657

Suite of low energy cross section measurements

- Measurement of Δs through NC elastic scattering at very low Q^2
- Pion production: Coherent vs. resonant
- K production: cross sections and proton decay studies
- Electron neutrino cross sections

Physics Motivation III: SuperNovae neutrino's

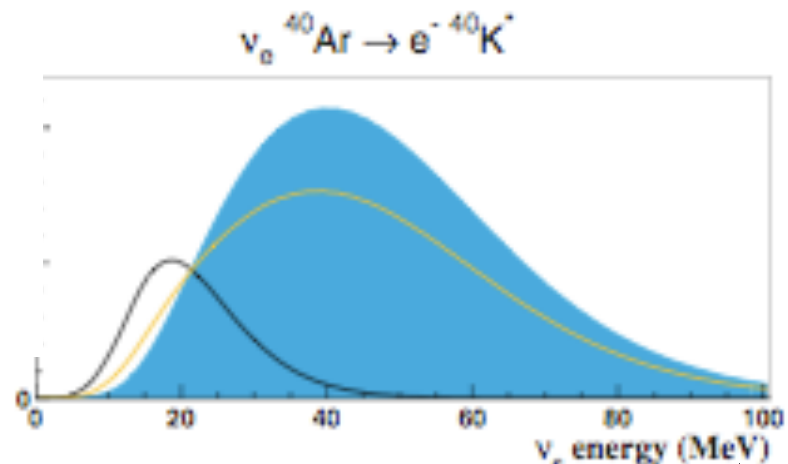
About 29 neutrino events observed for SN1987a

Between 10 and 20 Absorption events

$\nu_e\ {}^{40}Ar \rightarrow e^-\ {}^{40}K^*$

expected for a **galactic** supernova

Electron Energy: tens of MeV

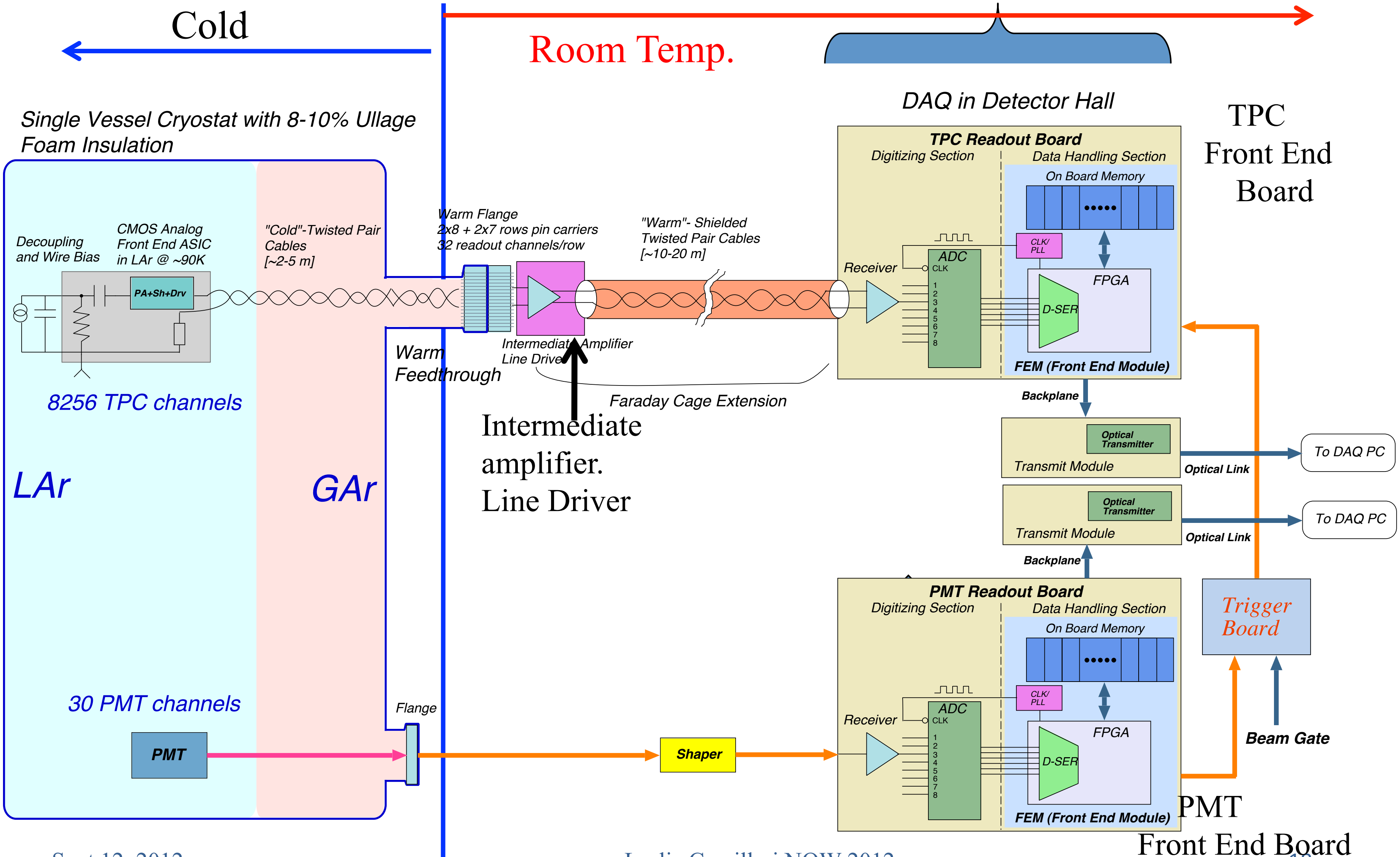


0 20 40 60 80 E_ν (MeV)

0 20 40 60 80 E_e

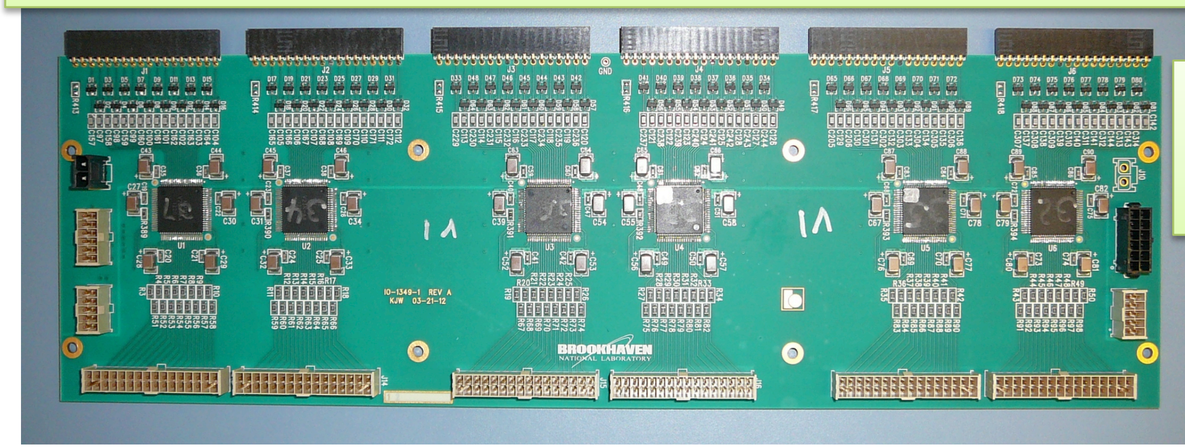
I. Gil-Botella and A. Rubbia JCAP 10(2003)009

R&D III: Cold Electronics



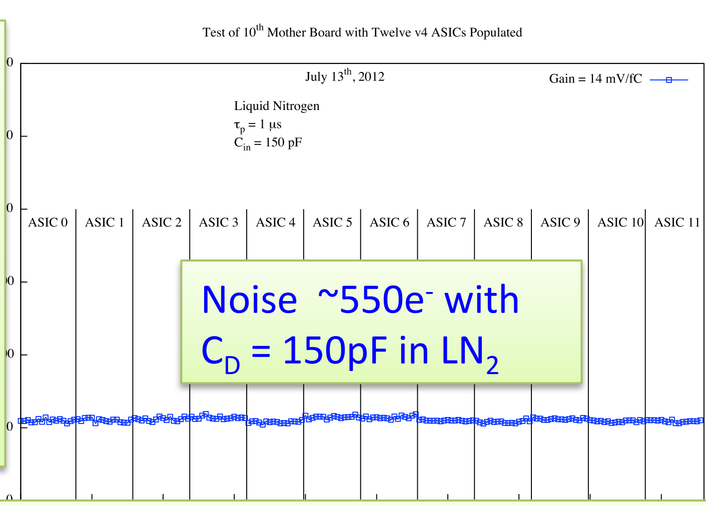
Cold Electronics : CMOS Analog Front End ASIC

16 channel/chip charge amplifier: Adjustable Gain 4.7, 6.8, 14.0, 25.0 mV/fC
Adjustable peaking time 0.5,1,2,3 μs, 5.5 mW/channel



Prototype Vertical
Cold Mother Board
with prototype ASICs

Crosstalk < 0.3%



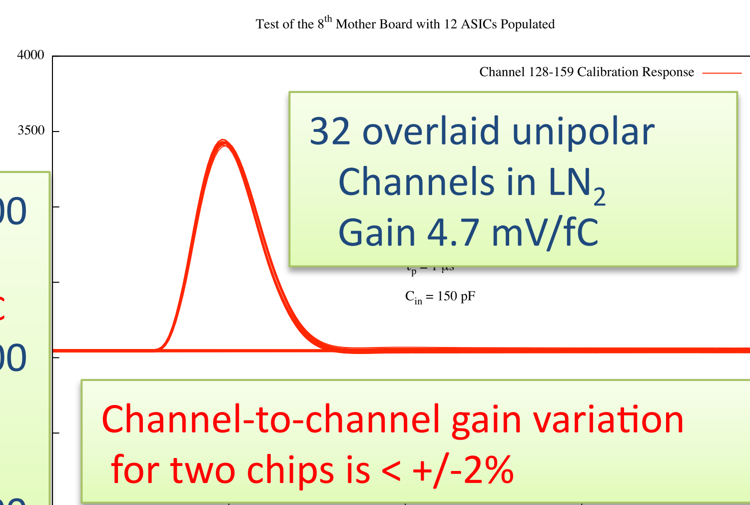
2500 e^-

1500

500

Noise ~550e^- with
C_D = 150pF in LN_2

0 100 channel



32 overlaid unipolar
Channels in LN_2
Gain 4.7 mV/fC

3000

ADC

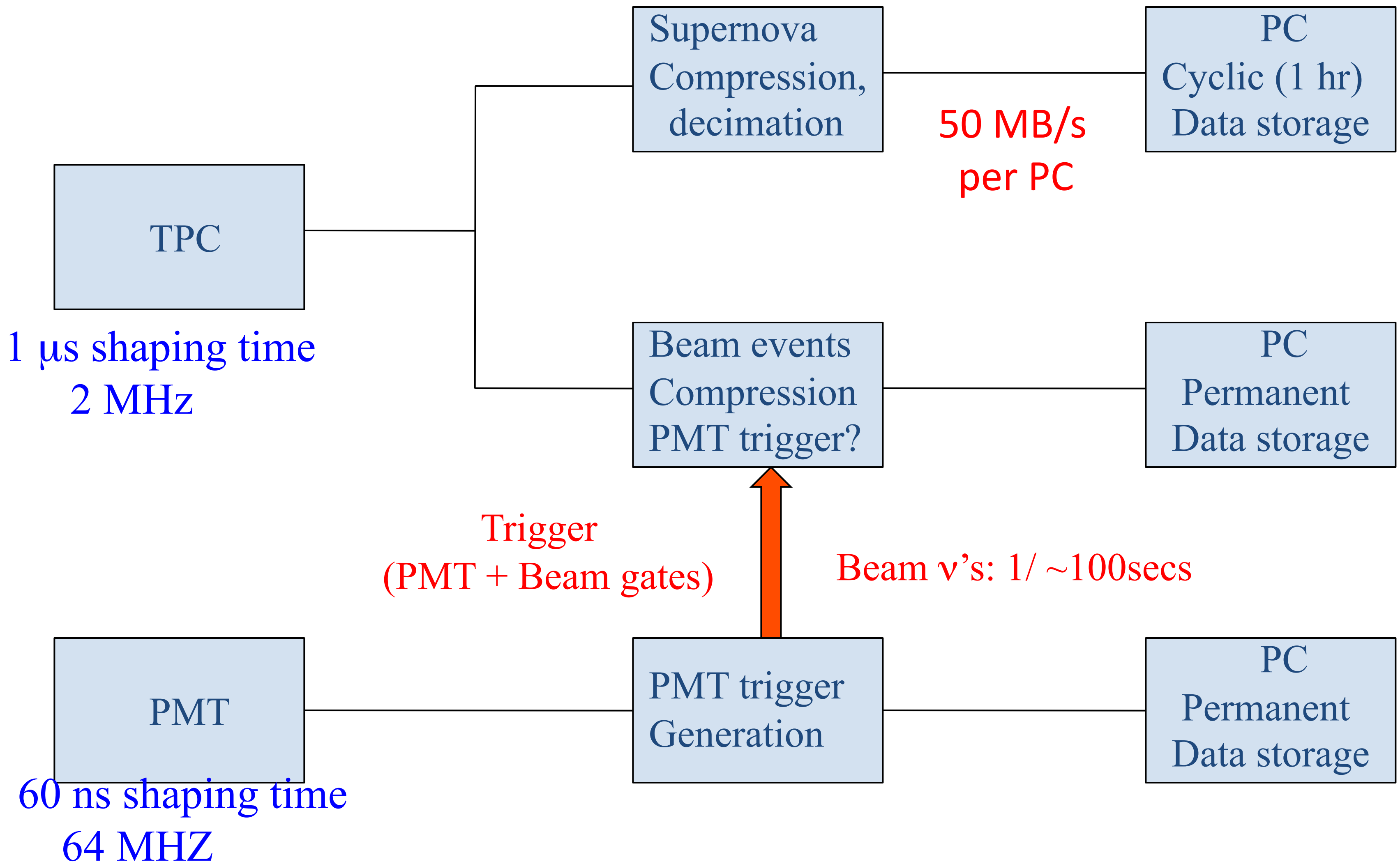
2000

1000

Channel-to-channel gain variation
for two chips is < +/-2%

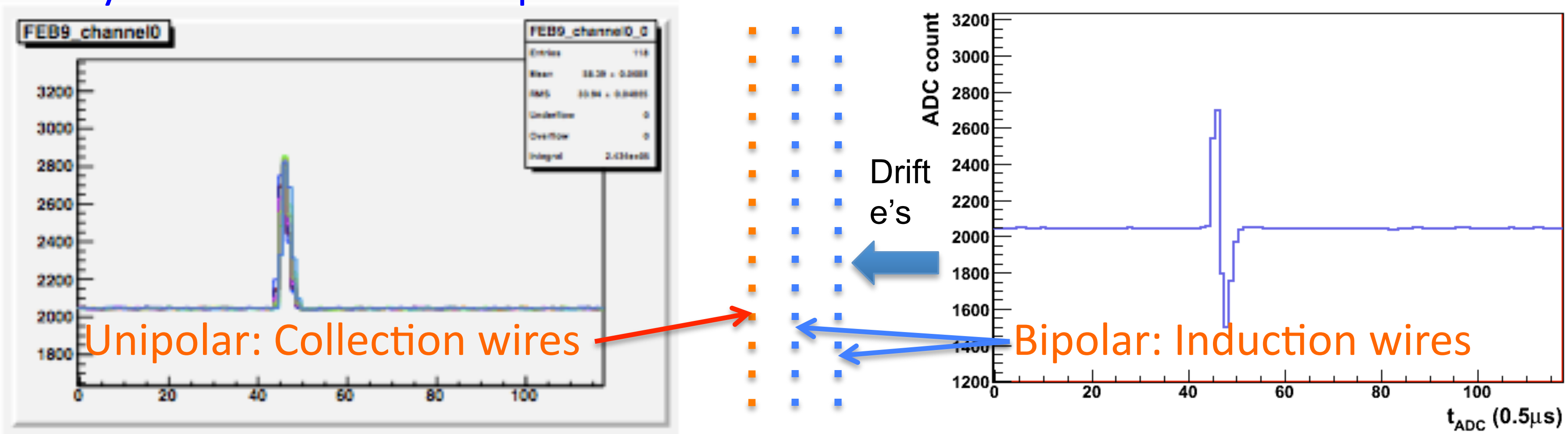
0 100 sample (time)

R&D IV Continuous readout for SN: TPC data read by 9 PC's each covering ~ 1.1 m along the beam

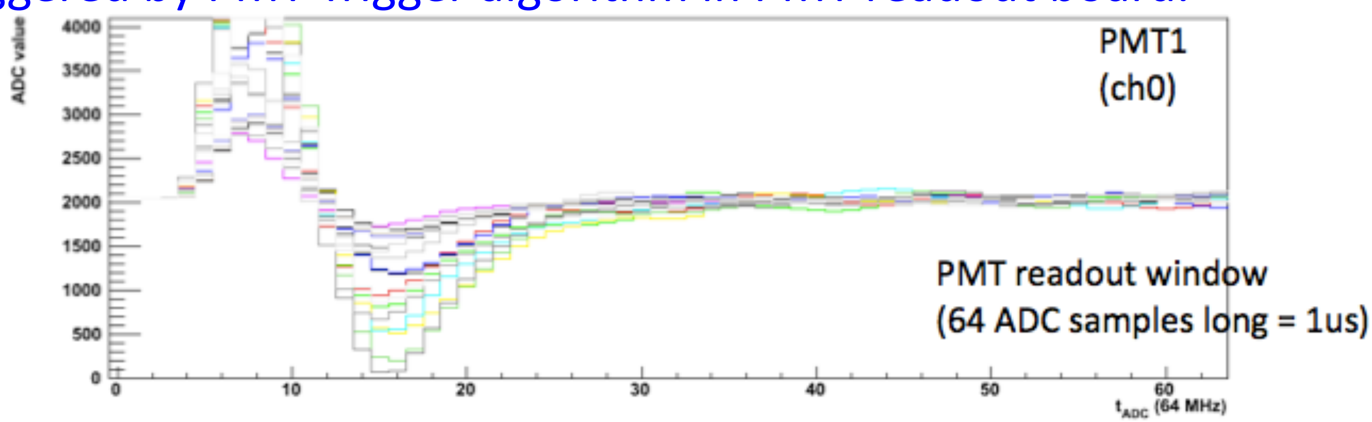


Trigger and Readout Tests

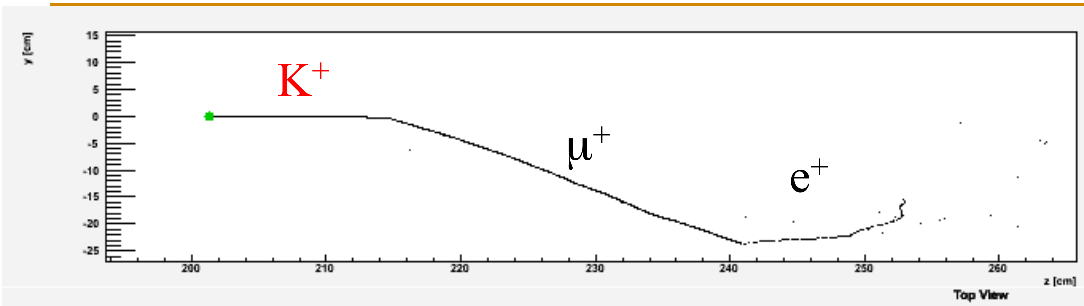
TPC CALIBRATION pulses readout through TPC readout chain
Triggered by External calibration pulse.



Readout of cosmic rays PMT pulses through whole PMT readout chain
Triggered by PMT Trigger algorithm in PMT readout board.



R&D V: Background to Proton Decay → $K^+ \bar{\nu}_\mu$



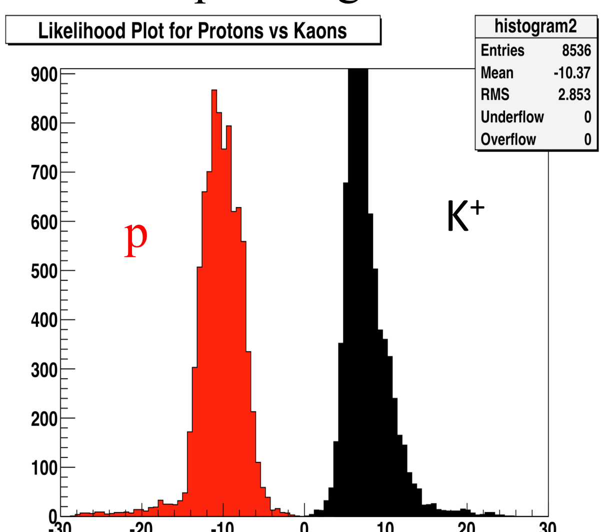
2. Measure background from cosmic rays

1. Identify K^+

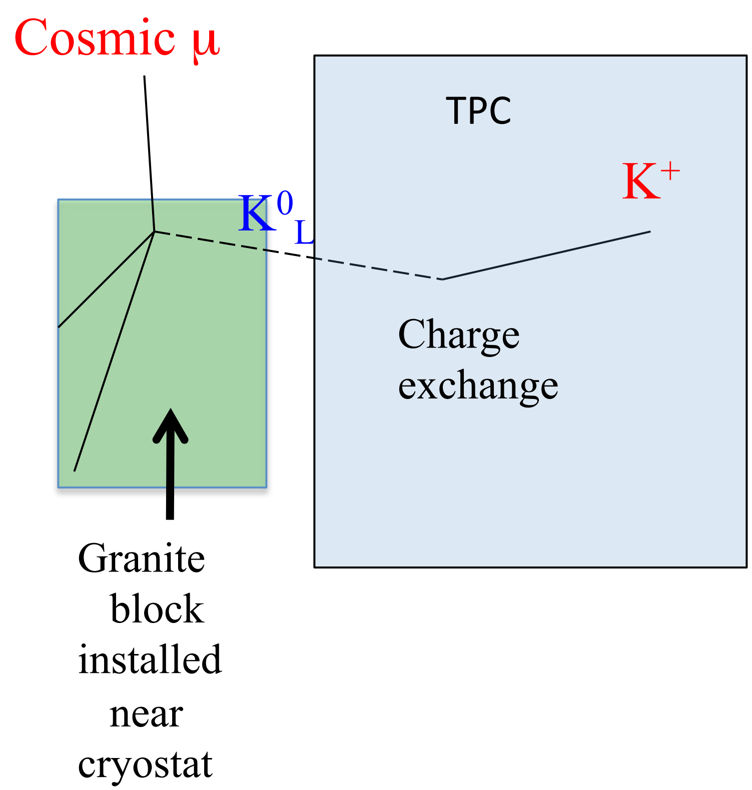
Example: Simulation Studies → Measurements

Separating 339 MeV/c K^+

from protons of equal range: 15 cm

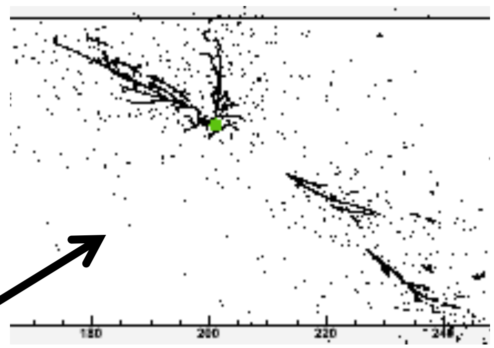


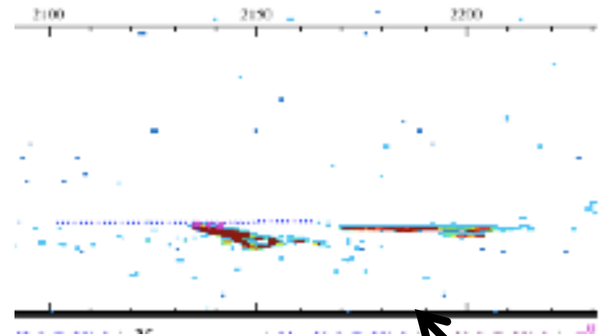
Likelihood: 4 dE/dx measurements along track



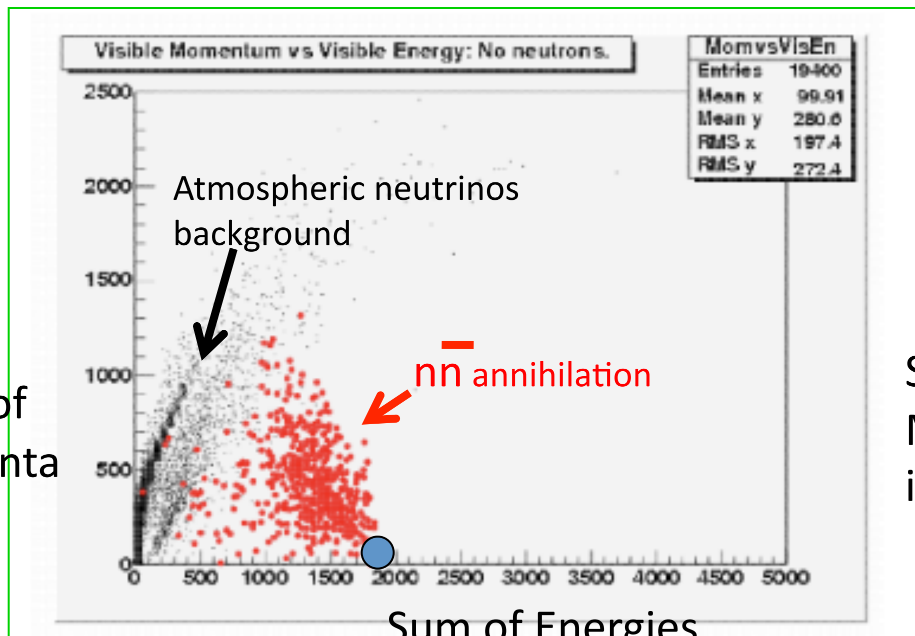
R&D V: Background to Proton Decay: $n\bar{n}$ oscillations → annihilation

Oscillation of neutron to antineutron followed by **annihilation** of antineutron with an Argon nucleus nucleon.





Annihilation
- Spherical
- Zero NET momentum
- Total energy = 2 M_n



Sum of Momenta

Atmos. ν
(Main background)
- Linear
- Non-zero momentum
- No constraint on energy

Simulation using Truth
Measure cosmic background in MicroBooNE.

Status

- Approval granted by Fermilab Director upon recommendation by the Program Advisory Committee.
- Approved for construction by funding agencies National Science Foundation (NSF) and Department of Energy (DOE).
- Cost: ~ $20M
- Installation: **2013**
- Data Taking: Late **2013** / Early **2014**
- Looking forward to some interesting measurements with this most precise detector

Back Up

Physics Motivation I: Low energy excess due to Electrons

Extra check in MicroBooNE

- Neutrino energy calculated assuming events are Quasi-Elastic
  Additional particles in event, not seen by MiniBooNE
  (below Cerenkov threshold)

↓

Underestimate Neutrino Energy

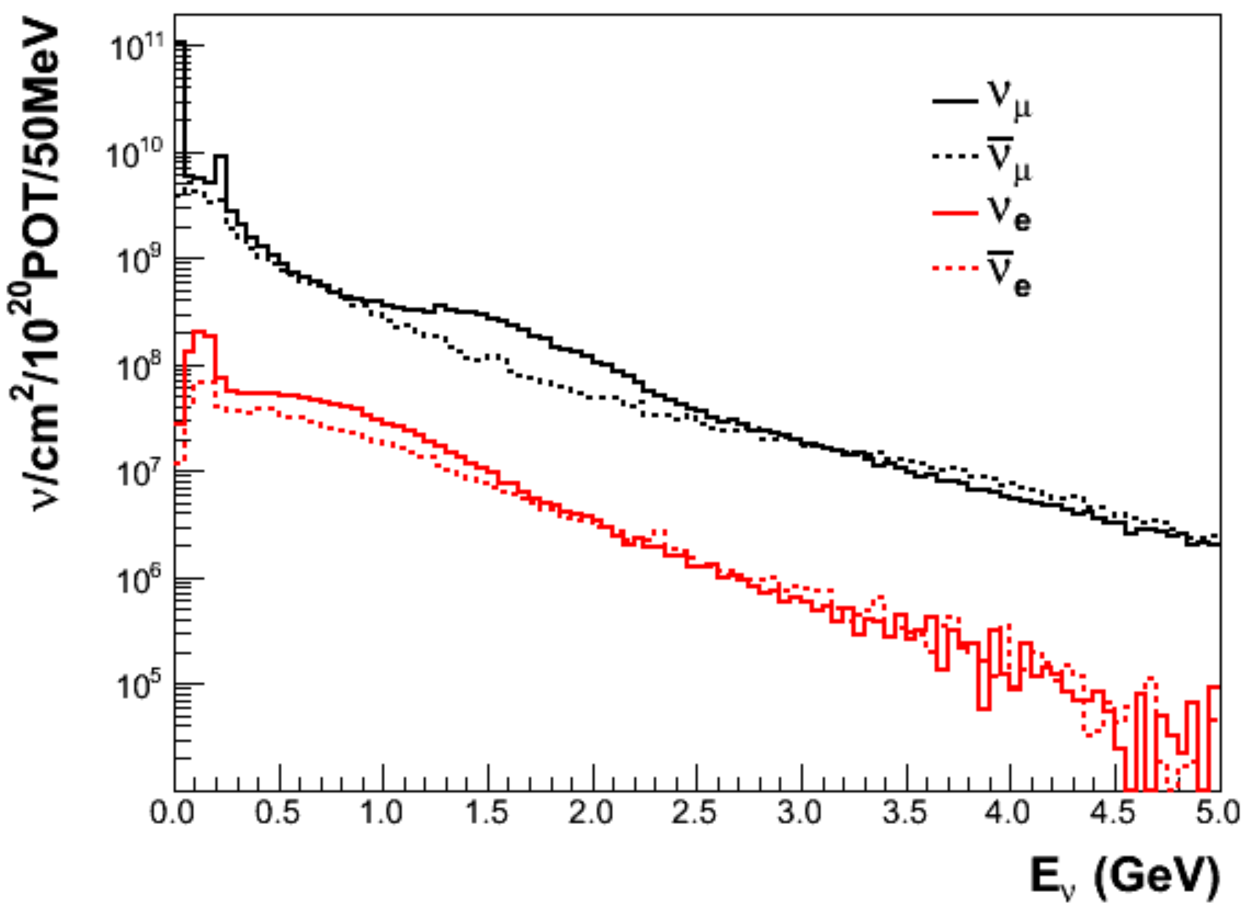
↓

Low energy Excess

M. Martini, et al Phys. Rev. D85 (2012) 093012

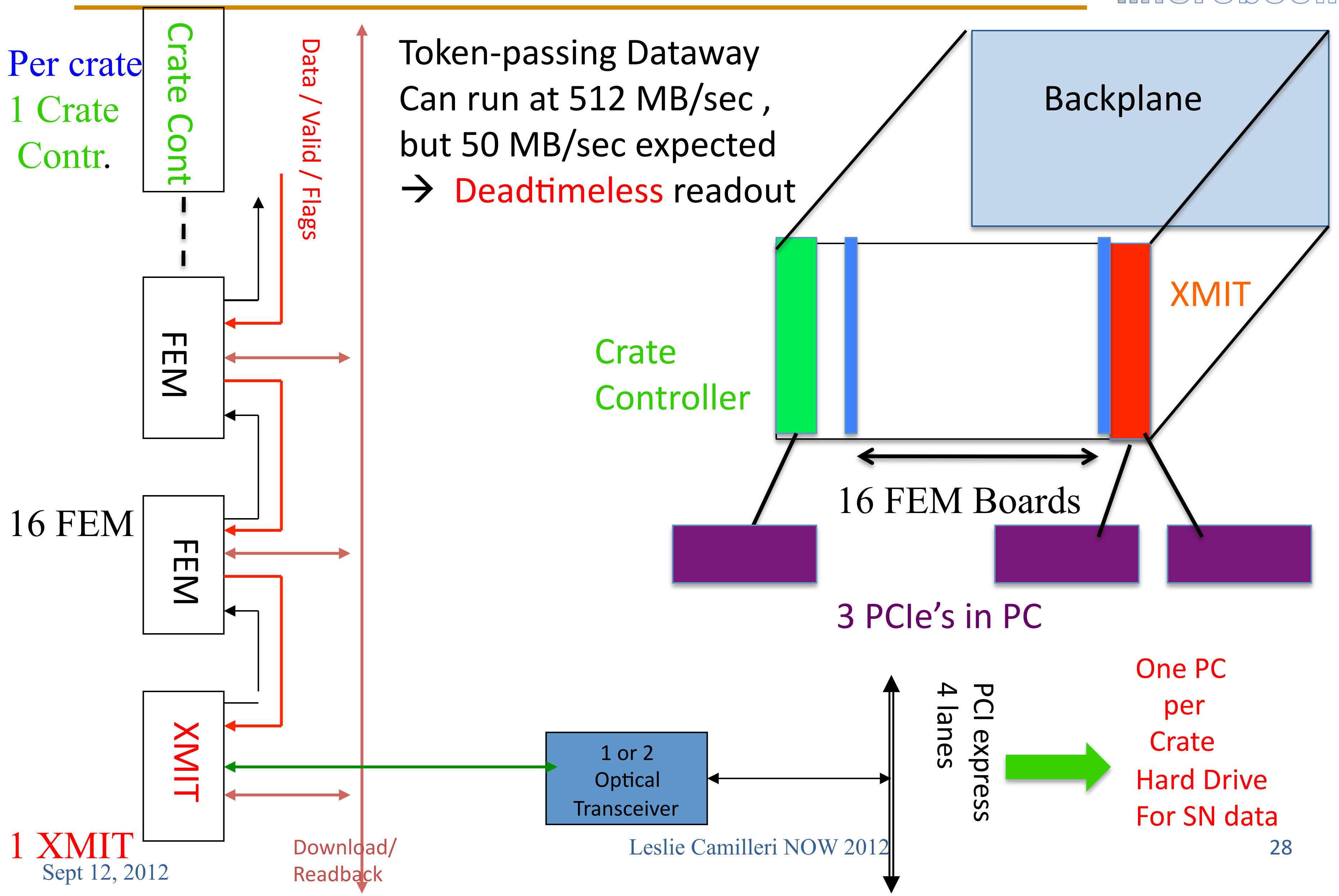
MicroBooNE reconstructs all particles: can avoid this problem.

NUMI FLUX



$\nu/cm^2/10^{20}POT/50MeV$
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
E_ν (GeV)
ν_μ
$\bar{\nu}_\mu$
ν_e
$\bar{\nu}_e$

Digitization components: 9 TPC + 1 PMT crates



Event rates

- Booster Neutrino Beam: The booster runs at a maximum of **15Hz**.

  So the electronics must be able to run at that rate.

- Although the beam neutrino event rate is much lower: **1/600 secs.**
- **To avoid recording unnecessary "empty spill data" the photodetectors will provide a trigger for neutrino beam events.**
- **Will be recorded WITHOUT loss of information: Compression only.**

- Supernova events are spread over ~ 20 secs and are low energy.

  Impossible to recognize amidst radioactivity and cosmic rays background.

  Must rely on "external alert" from the supernova alert watch: ~ 1 hour.

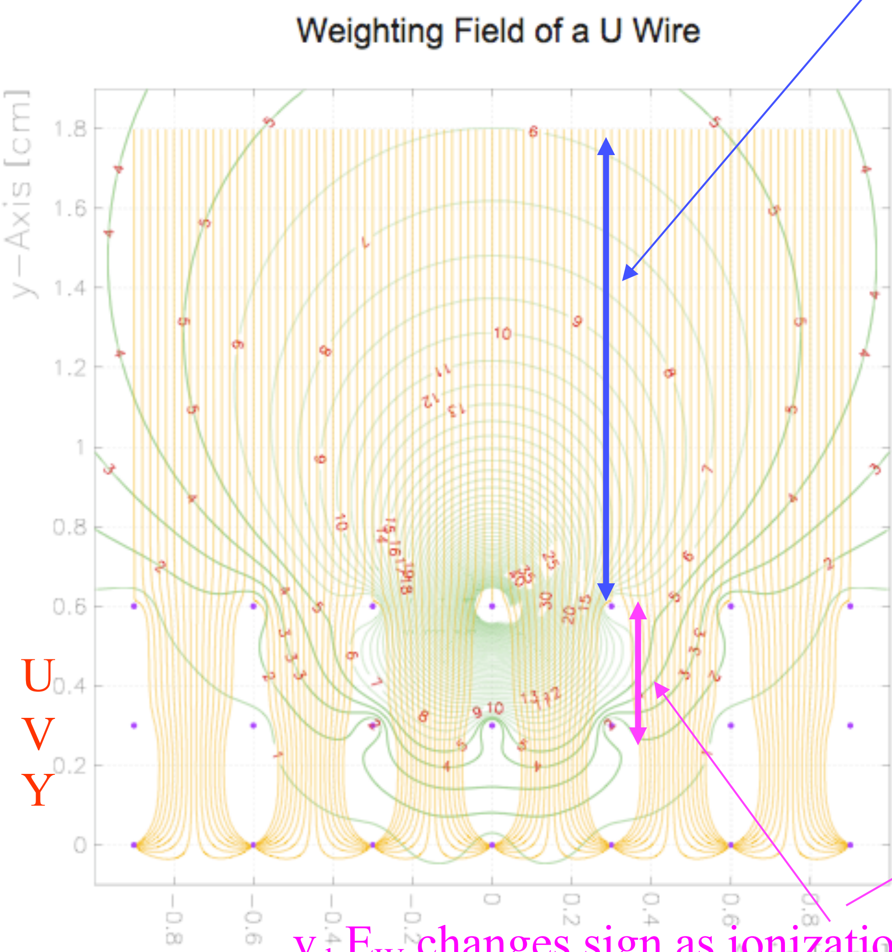
→ **The last hour of supernova data must be always available in case…**

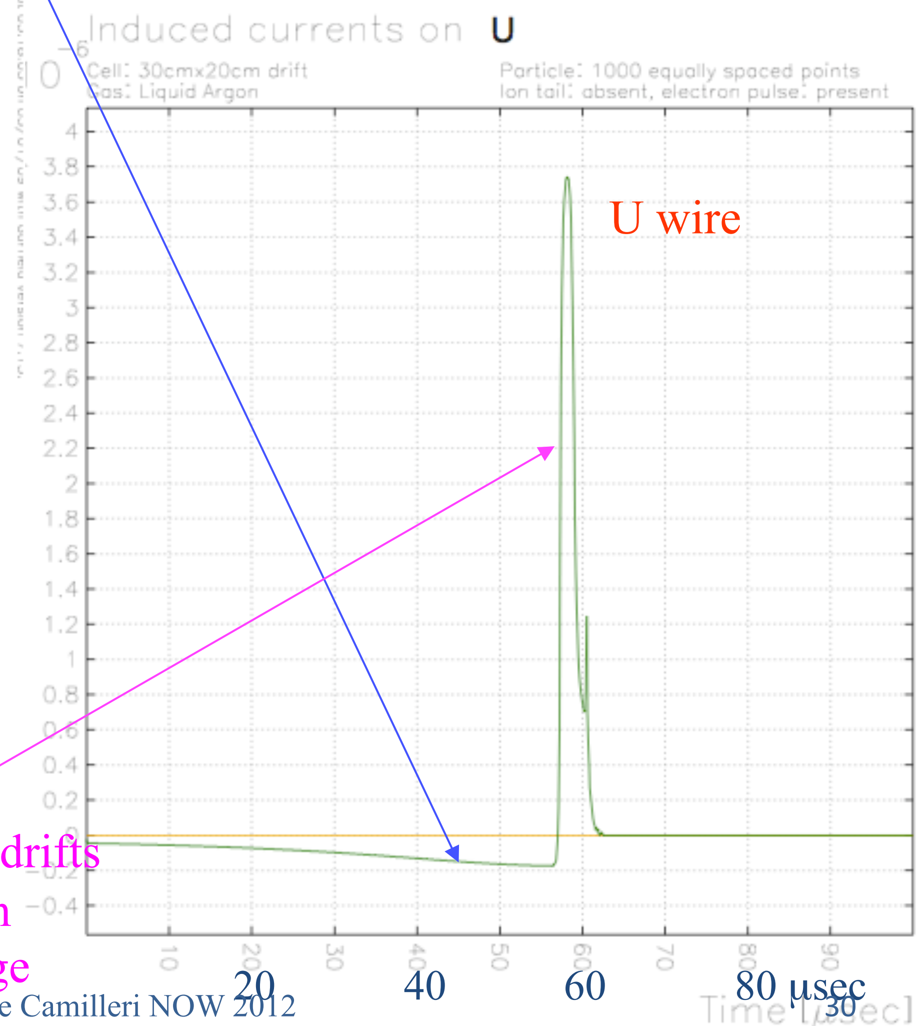
Will be Compressed AND reduced in volume by

throwing out "ZERO's" (decimation).

Pulse shapes

Long negative pulse seen on U until charge drifts passed U:

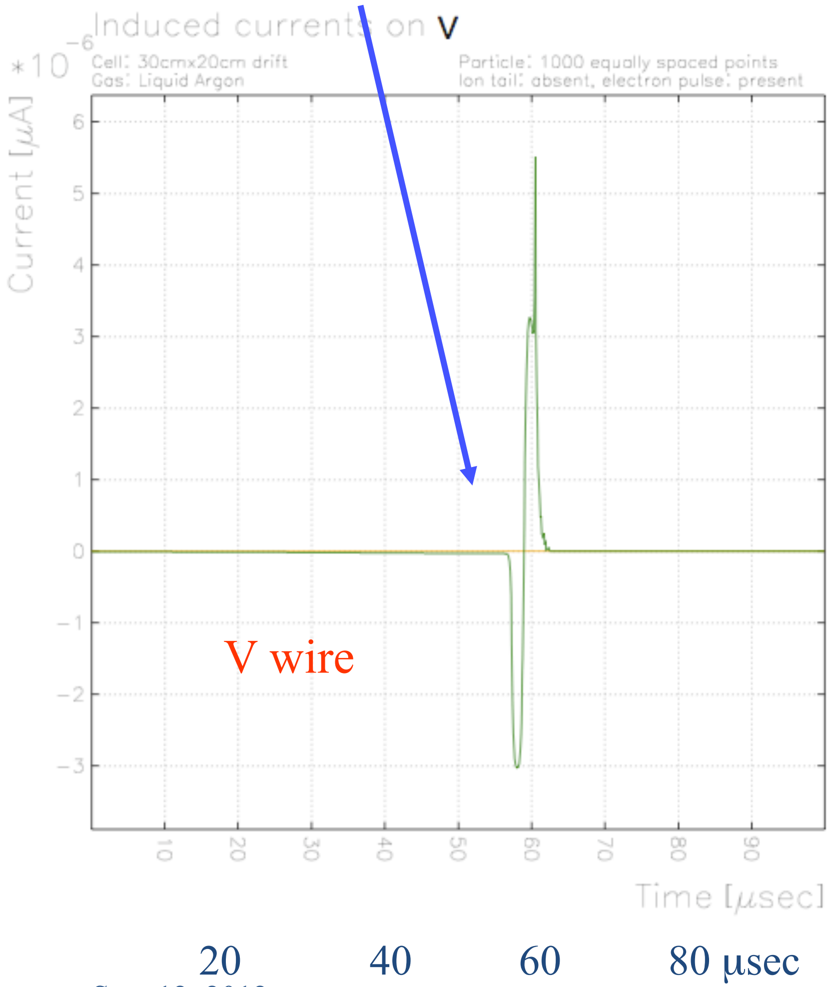


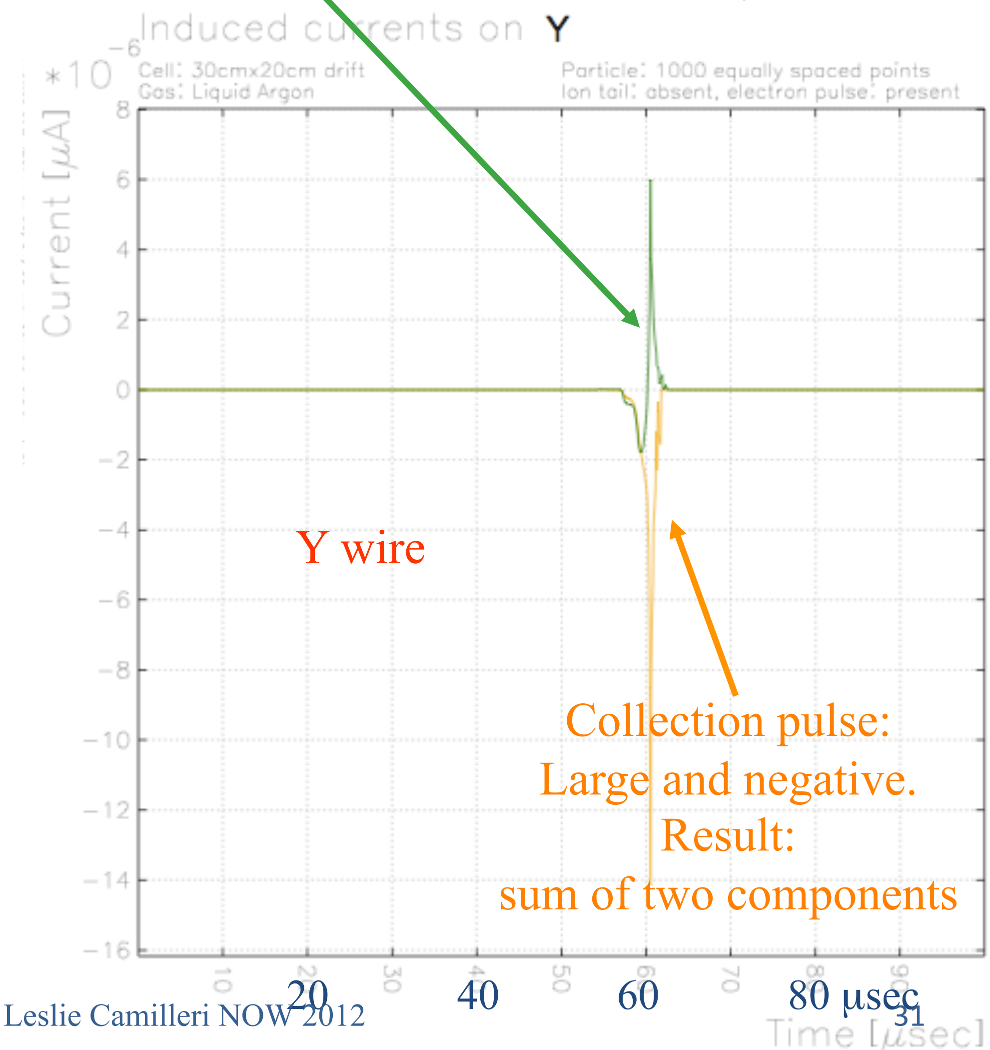


$v_d.E_W$ changes sign as ionization drifts passed U: pulse changes sign
Continues positive until charge collected at Y

Not much charge seen on V until charge drifts passed U.
Negative pulse while the charge drifts between U and V
Positive pulse while ionization drifts between V and Y

Induced pulse:
starts when ionization crosses U plane,
increases when it crosses V
Goes positive when
ionization reaches nearby wires





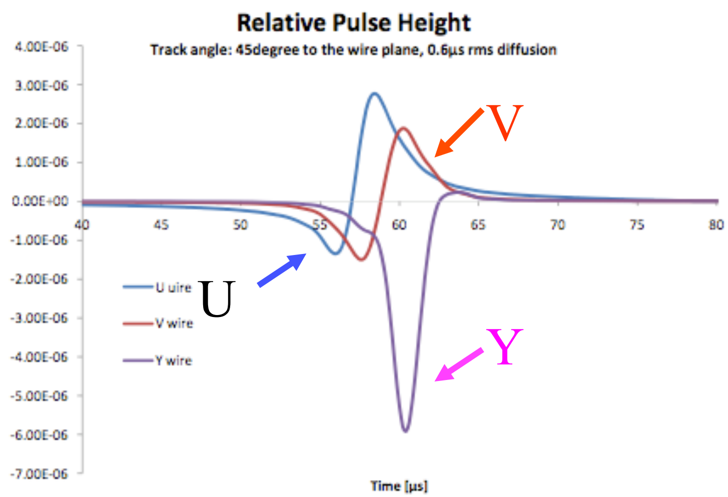
Collection pulse:
Large and negative.
Result:
sum of two components

ADC dynamic range

➢For a 45° track:

The U,V pulse heights are 25% - 30% of those on the Y plane

➢The pulse heights for large drift distances is reduced due to electron lifetime



The smallness of these pulses determines the low end of the ADC dynamic range

High end: A stopping proton depositing the last 3mm of ionization in a single wire, will deposit the equivalent of 14 mips in that wire.