DUNE detector design and low-energy reconstruction capabilities

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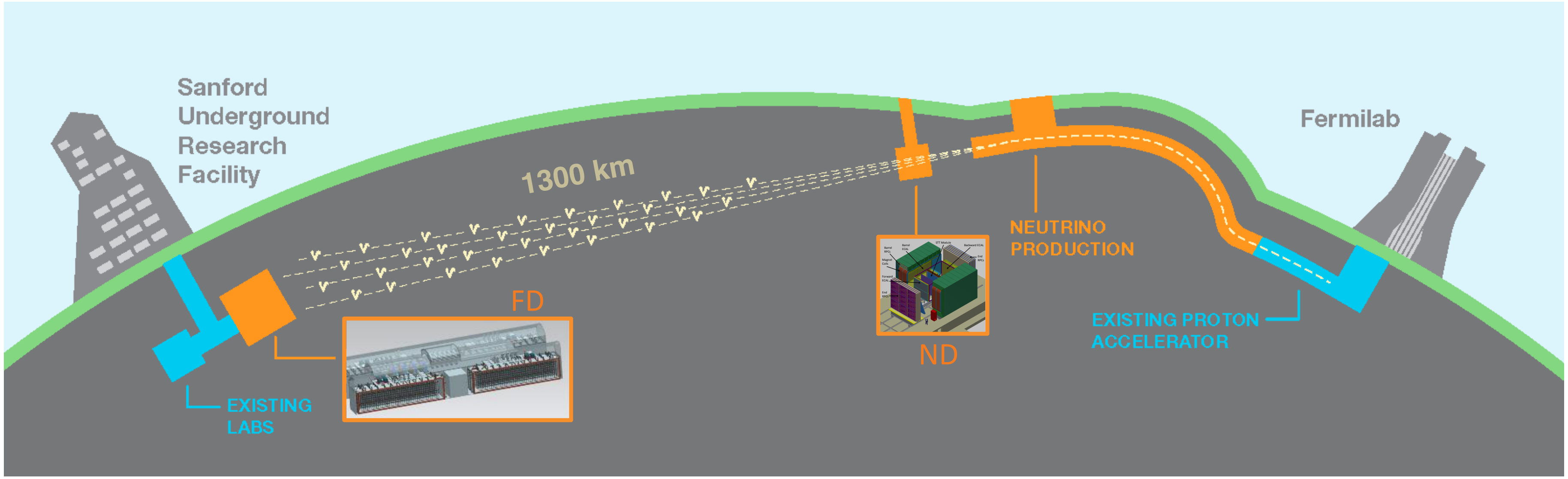
Outline

- The DUNE detector design
    - Single-phase option
    - Dual-phase option
- Current DUNE prototypes
    - 35-ton detector
    - protoDUNE SP
    - protoDUNE DP
- Other LAr TPC detectors
- Low-energy reconstruction capabilities
    - Scientific motivation: SN neutrino burst events, solar neutrino events, low-energy backgrounds
    - Low-energy neutrino interactions
    - Experimental challenges and detector requirements

DUNE Design

The DUNE Project

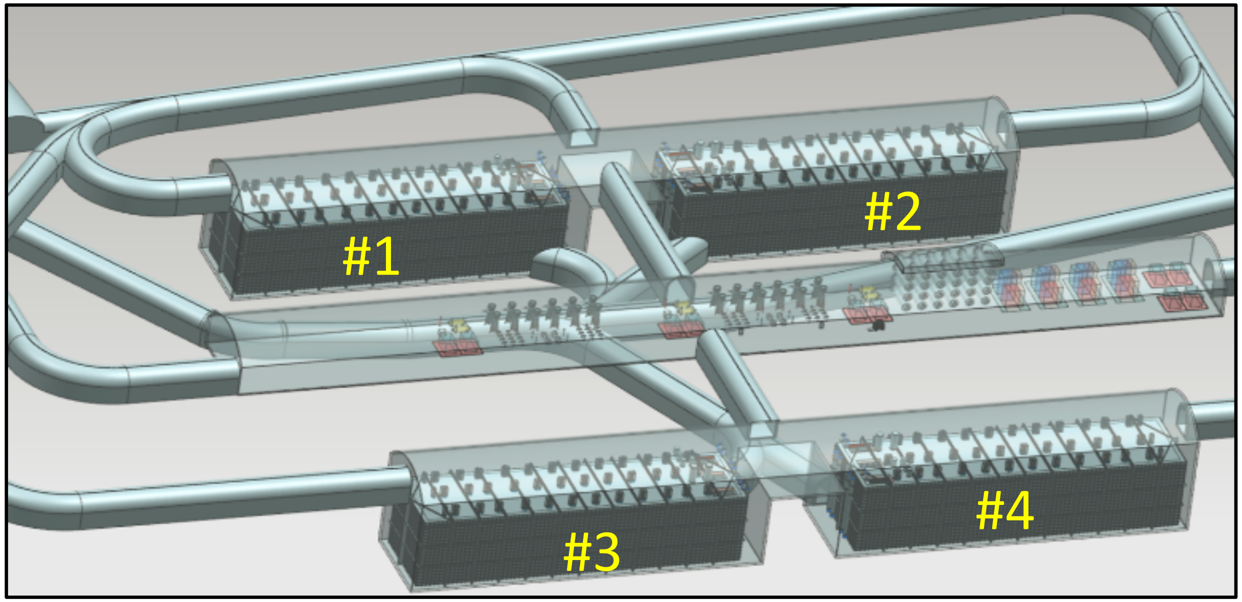


- Deep Underground Neutrino Experiment: **40 kton LAr TPC** far detector **at 1480 m depth** (4300 mwe) at SURF measuring neutrino spectra at 1300 km in a wide-band high purity ν_μ beam with peak flux at 2.5 GeV operating at ~1.2 MW and upgradeable to 2.4 MW
- 4 x 10 kton (fiducial) modules (**single and/or dual-phase**) with ability to detect SN burst neutrinos (+ nucleon decay, LBL oscillations, atmospheric νs)

Staged approach to 40 kton

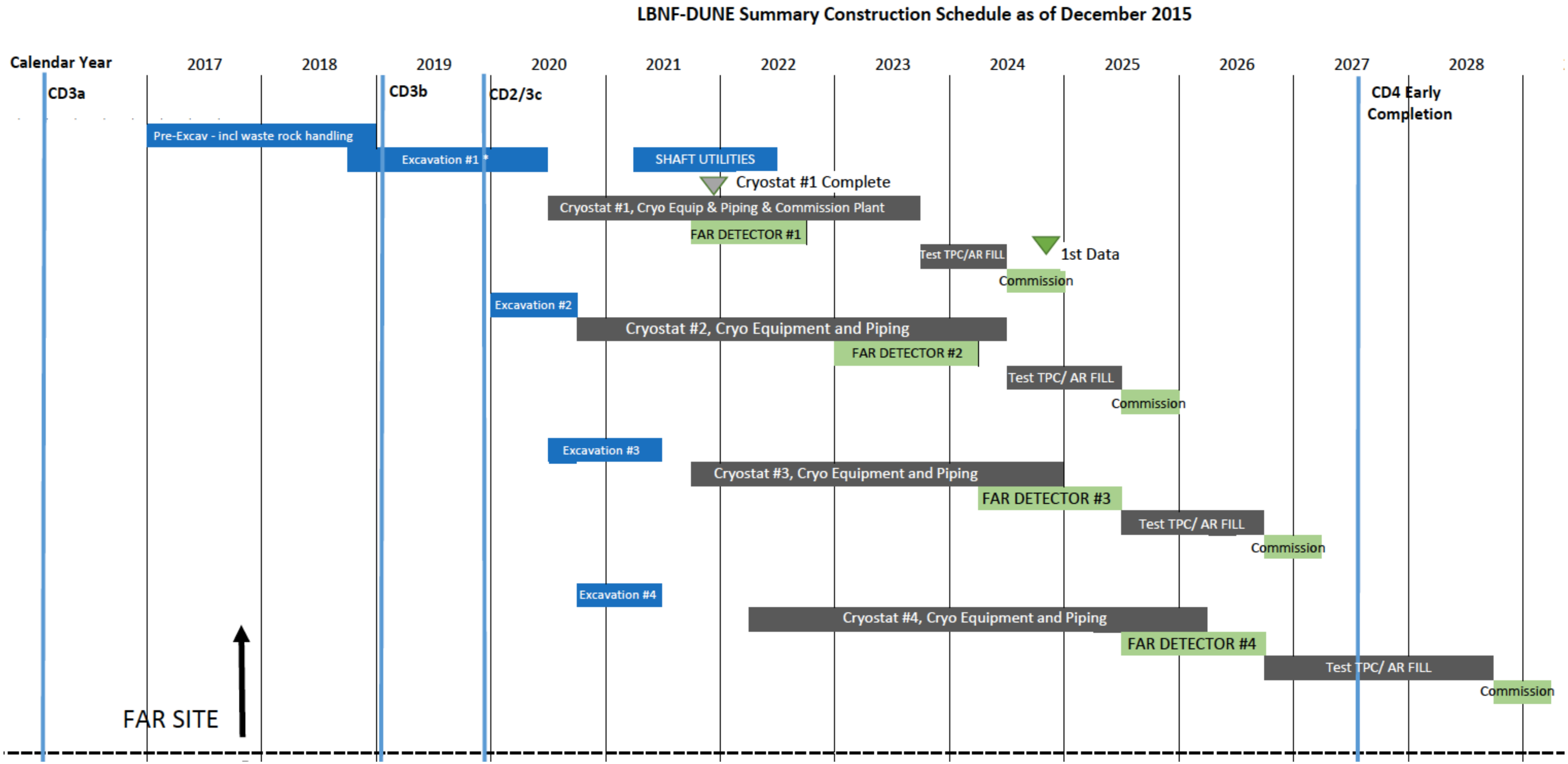
- Four caverns hosting **four independent 10 kton (fiducial mass) FD modules**
  - Assumed four identical cryostats 15.1 (W) x 14.0 (H) x 62 (L) m^3
  - Phase-in approach
  - Allows alternate designs (single vs dual-phase LAr TPCs)
- Installation of #1 module starts in 2022
- Complete TDR should be ready for 2019

DUNE Far Detector at SURF



LBNF and DUNE CDR Volume 4: The DUNE Detectors at LBNF (arXiv:1601.02984)

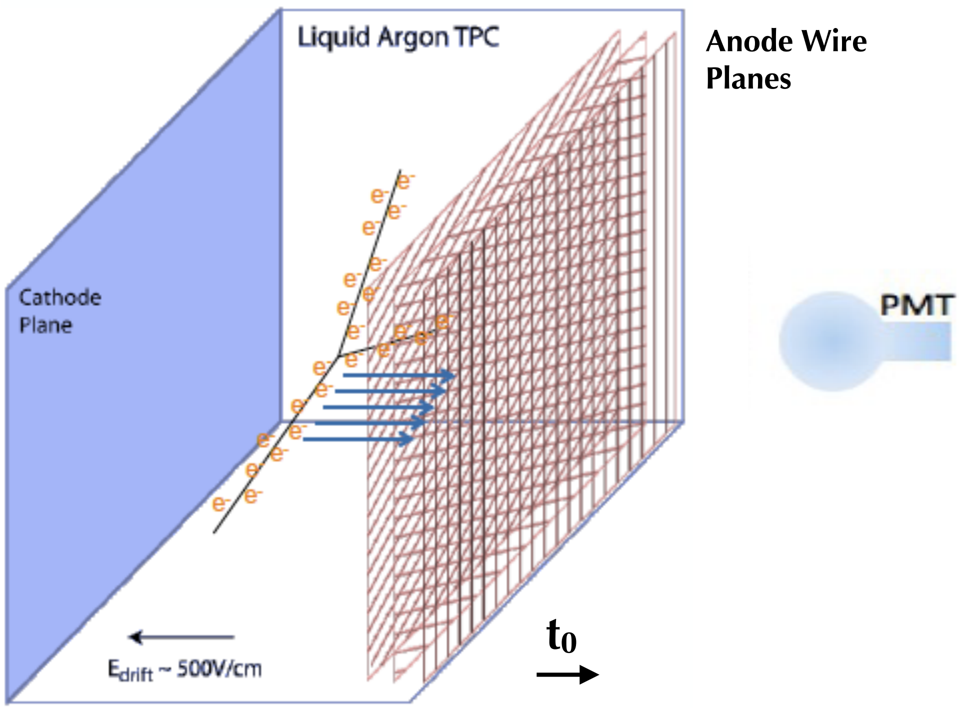
LBNF-DUNE Construction Schedule



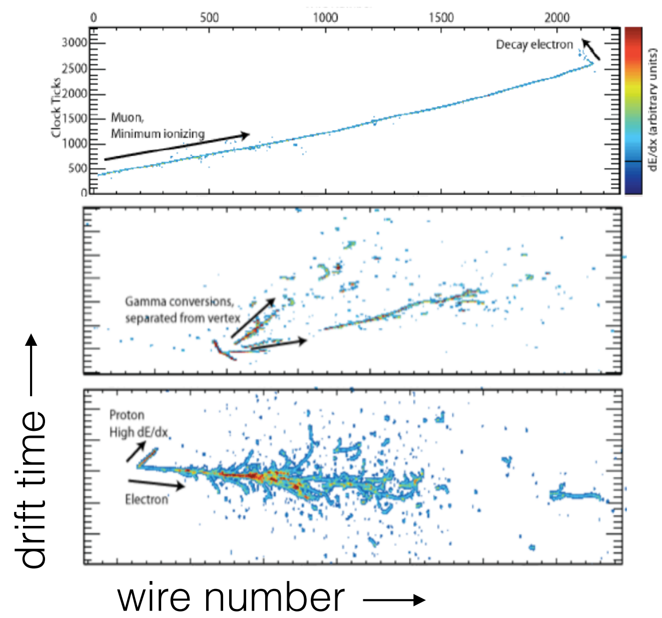
- First data in 2024!
- Beam ready in 2026
- DUNE construction finished in 2028

Single-phase LAr TPC detection principle

- Neutrino interactions in Ar produce charged particles that cause ionization and excitation of Argon
  - High electric field drifts electrons towards finely segmented anode wire planes
  - Excitation of Ar produces prompt scintillation light giving t_0 of the interaction
- Technology pioneered and **demonstrated by the ICARUS experiment** (the largest LAr TPC ever operated - 600 ton)

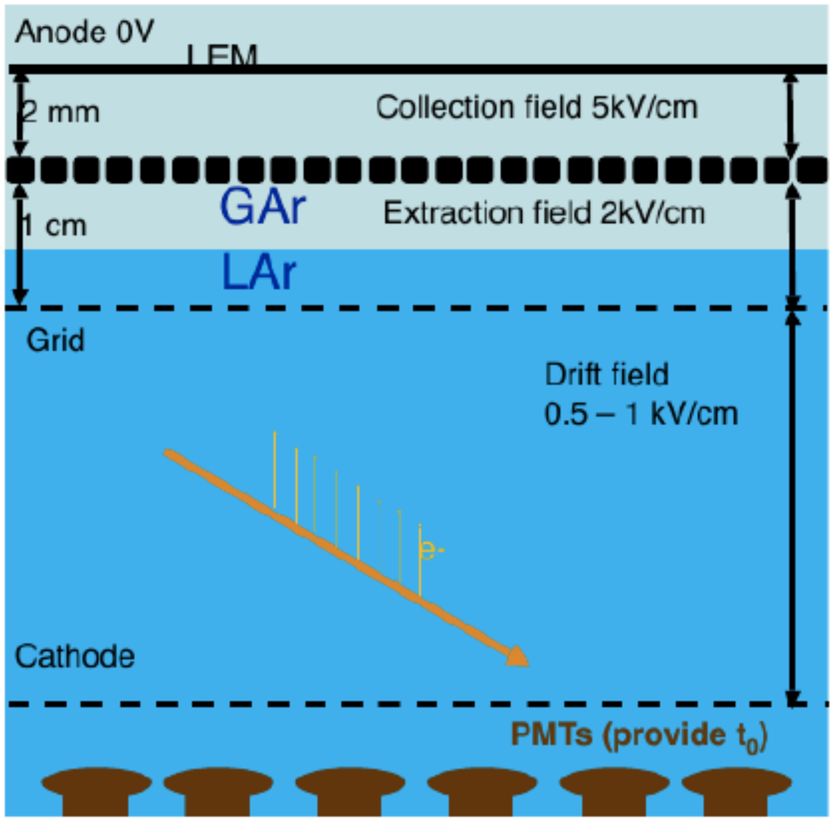


- Independent views provided by multiple wire orientations (2D position information)
- PMTs detect the light produced providing timing information
- 3D reconstruction of tracks and showers
- Time Projection Chamber

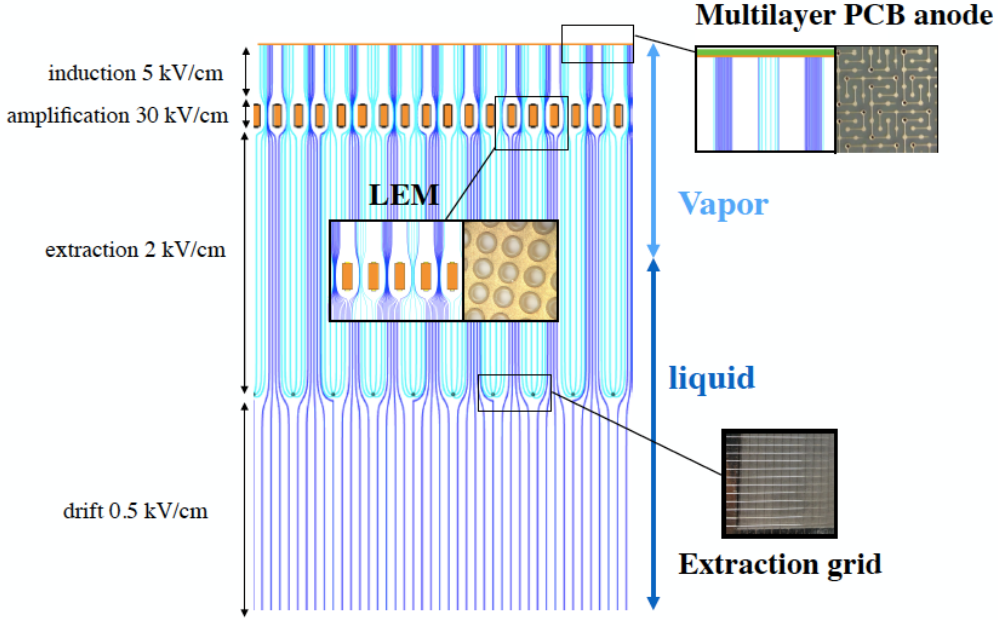


Dual-phase LAr TPC principle

Concept of double-phase LAr TPC (Not to scale)



Ionization signals amplified and detected in gaseous argon above the liquid surface

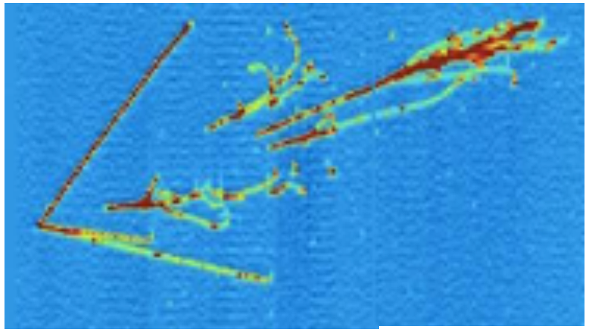


- Ionizing particle in LAr (2.12 MeV/cm for mip)
- Two measurements:
  - **Charge from ionization**: tracking and calorimetry

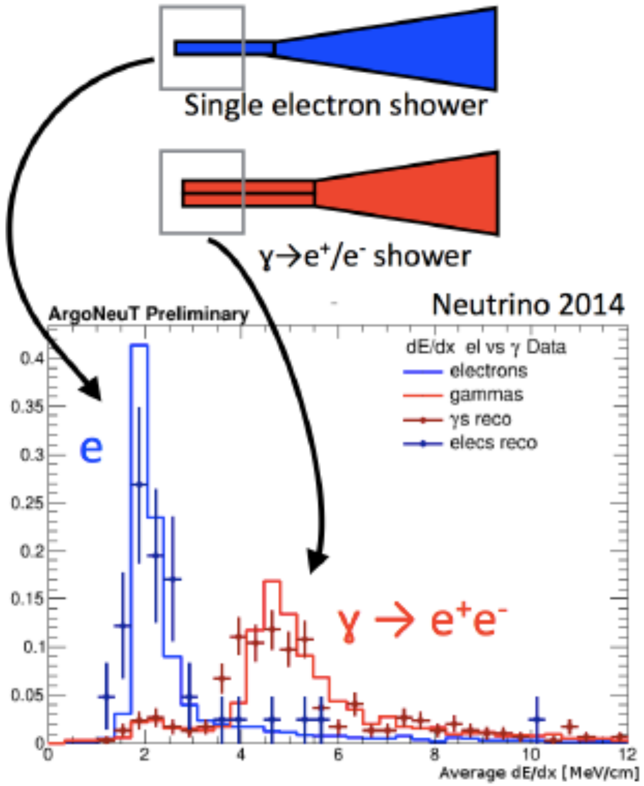
    Double-phase: multiplication in gas to increase gain and allow for long drift distances (> 5m) and low energy thresholds
  - **Scintillation light**: primary scintillation (trigger and t0) & secondary scintillation in gas
- Large surface instrumented with PMTs in LAr
- WArP, ArDM, DarkSide, …

DUNE Far Detector

- The **FD detector design is optimized** (in the energy range of few MeV to few GeV) **for**:
  - pattern recognition
  - energy measurement
  - particle ID



- The LAr TPC technology provides:
  - excellent 3D imaging capabilities
    - few mm scale over large volume detector
  - excellent energy measurement capability
    - totally active calorimeter
  - particle ID by dE/dx, range, event topology, …



Two proposed technologies

Single-phase

reference design for the CDR

Table 1: Parameters of the DUNE Far Detector LArTPC.

Parameter	Value
Module height	12.0 m
Module width	14.5 m
Module length	58.0 m
channels per APA	2,560
APAs per module	150
Active height (APA)	6.0 m
Active width (APA)	2.3 m
Drift distance in Liquid Argon	3.6m
Drift velocity	1.6 mm/μs
Drift time	2.25 ms
# drifts/readout factor	2.4
readout time	5.4 ms
bytes/sample	1.5
sample rate	2.0 MHz
samples/readout	10,800
# of detector modules	4
Total # of channels	1,536,000

Dual-phase

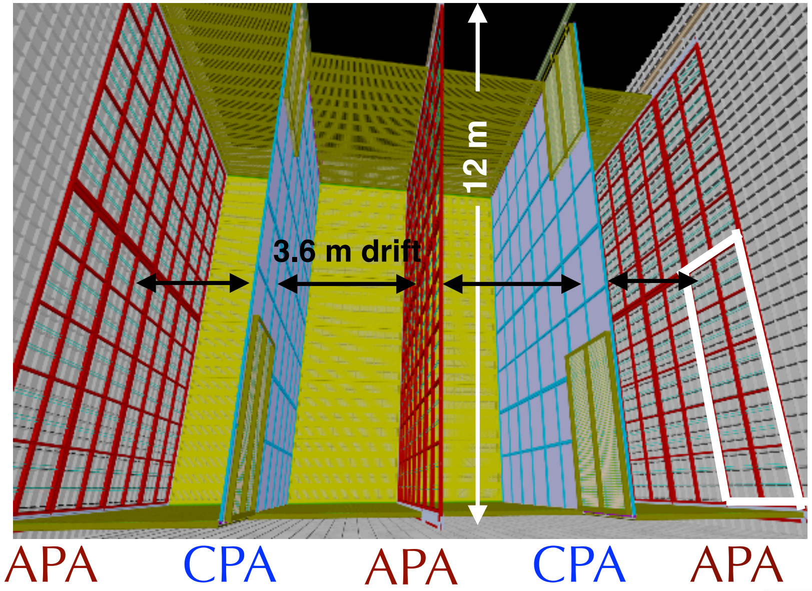
alternative design for the CDR

Parameter	Value
Full length	60.0 m
Detectors	4.0
channel/CRP	1,920
CRP/detector	80
Active height	12.0 m
Active width	12.0 m
Drift distance	12.0 m
Drift velocity	1.6 mm/μs
Drift time	7.5 ms
bytes/sample	1.5
sample rate	2.5 MHz
# drifts/readout	1.0
Readout time	7.5 ms
Samples/readout	18,750
Total # of channels	614,400

2: Basic parameters of the alternative Far Detector design.

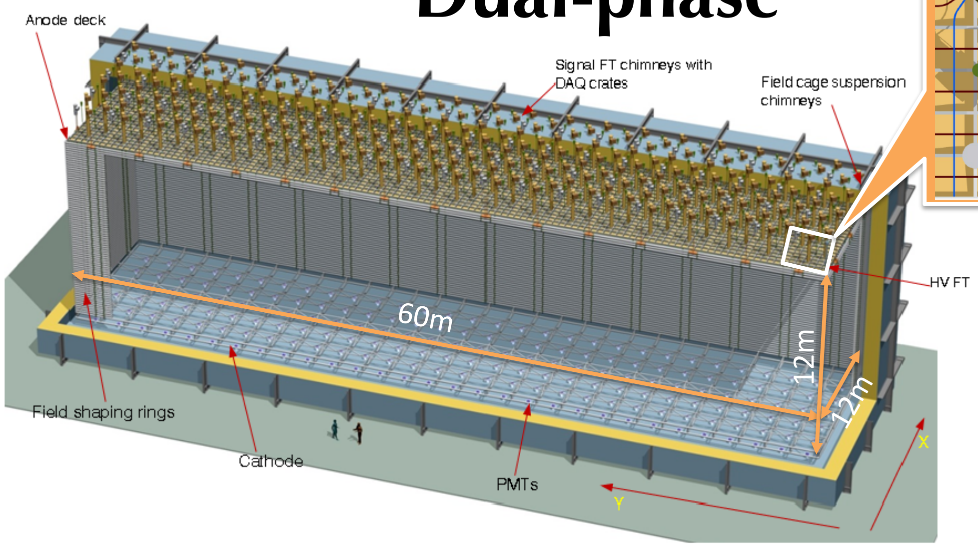
Two detector designs

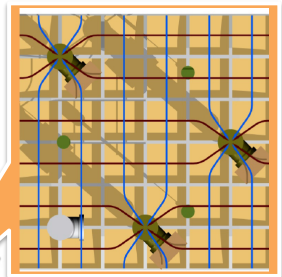
Single-phase



- 150 Anode Plane Assemblies (APAs)
  - 6 m high x 2.3 m wide
  - embedded photon detection system
  - wrapped wires read out both sides
  - 1 collection & 2 induction wire planes (wire pitch 5 mm)
- 200 Cathode Plane Assemblies (CPAs)
  - 3 m high x 2.3 m wide
- Cathode at -180 kV for 3.6 m drift
- Cold electronics (384,000 channels)

Dual-phase





- 80 3 x 3 m^2 CRP modules at the gas-liquid interface (2D charge collection)
- Hanging field cage and cathode at 600 kV (12 m drift)
- Decoupled PD system (PMTs)
- Finer readout pitch (3 mm), high S/N ratio, lower energy threshold, better pattern recognition, fewer readout channels (153,600), absence of dead material

Expected detector capabilities

Parameter	Requirement	Achieved Elsewhere	Expected Performance
Signal/Noise Ratio[1]	$9:1$	$10:1$ [11, 12][2]	$9:1$
Electron Lifetime	3 ms	>15 ms [12]	>3 ms
Uncertainty on Charge Loss due to Lifetime	$<5\%$	$<1\%$ [12]	$<1\%$
Dynamic Range of Hit Charge Measurement	15 MIP		15 MIP
Vertex Position Resolution[3]	(2.5,2.5,2.5) cm		(1.1,1.4,1.7) cm [13, 14]
$e-\gamma$ separation ϵ_e	>0.9		0.9
$e-\gamma$ separation γ rejection	>0.9		0.99
Multiple Scattering Resolution on muon momentum[4]	$\sim 18\%$	$\sim 18\%$ [15, 16]	$\sim 18\%$
Electron Energy Scale Uncertainty	$\sim 5\%$	$\sim 2.2\%$[17]	From LArIAT and CERN Prototype
Electron Energy Resolution	$0.15/\sqrt{E(\mathrm{MeV})}$ $\oplus 1\%$	$0.33/\sqrt{E(\mathrm{MeV})}$ [17] $+1\%$	From LArIAT and CERN Prototype
Energy Resolution for Stopping Hadrons	$<10\%$		From LArIAT and CERN Prototype
Stub-Finding Efficiency[5]	$>90\%$		$>90\%$

For $E_e < 50$ MeV,
11%/√E(MeV) + 2%
ICARUS

Table 5.1: Performance parameters specific to the dual-phase far detector design

Parameter	Requirement	Achieved Elsewhere	Expected Performance
Gas phase gain	20	200	20-100
Electron Lifetime	3 ms	>3 ms 35-t prototype	>5 ms
Minimal S/N after 12 m drift	9:1	$>100{:}1$	12:1-60:1

Advantage for low energy measurement

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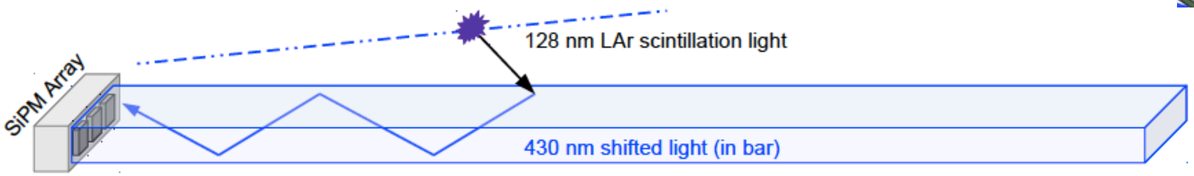
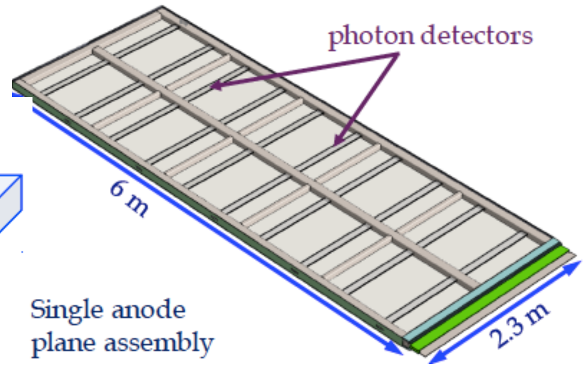
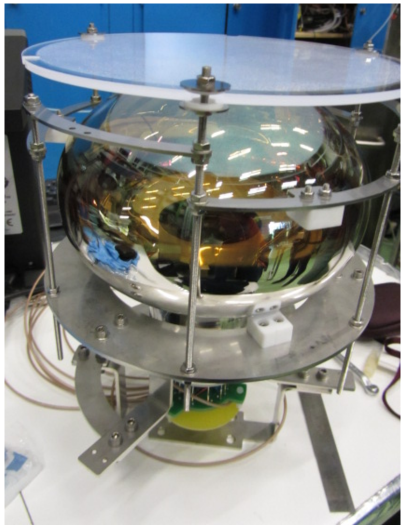
DUNE Photon Detection Systems

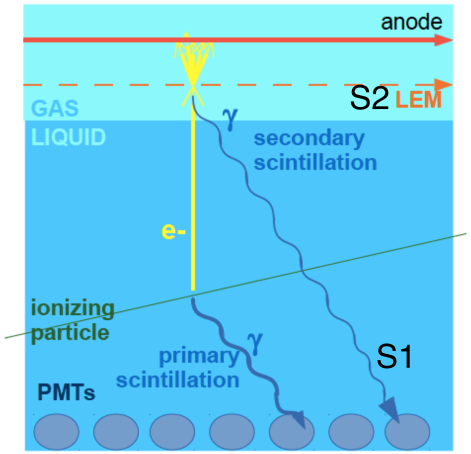
- FD **single-phase** optical detectors: WLS bars + SiPM
  - *Technique under development*

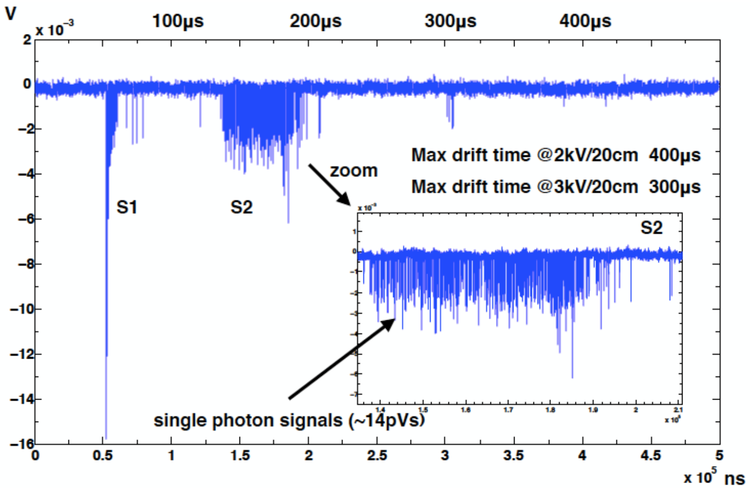




- FD **dual-phase** optical detectors: PMTs with TPB
  - *System well understood*



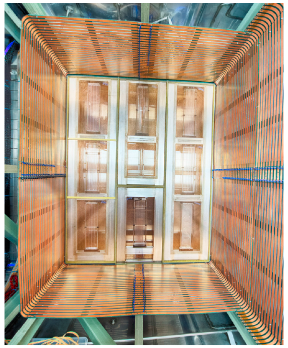




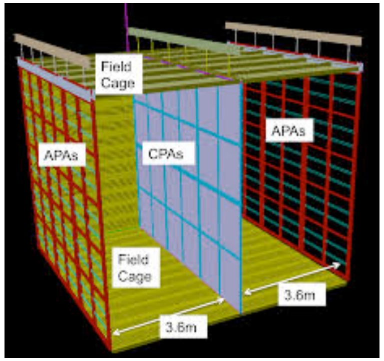
DUNE Prototypes

The DUNE strategy

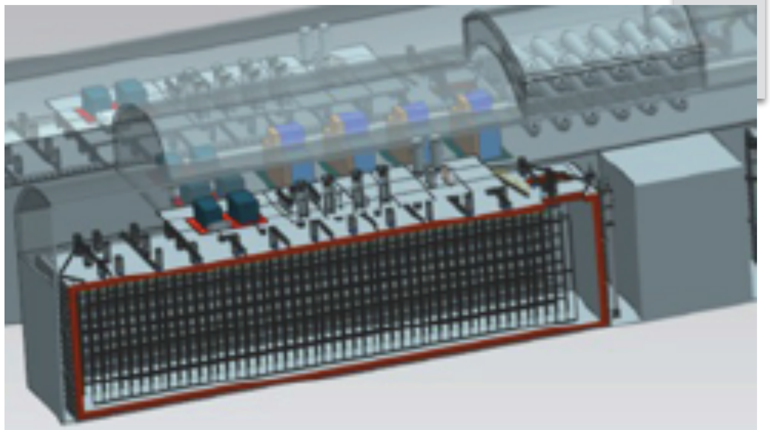
Single-phase



DUNE **35-t** @Fermilab (2015)

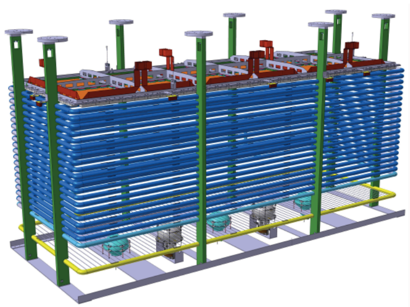


protoDUNE SP
@CERN: 300 ton
(2016-2019)

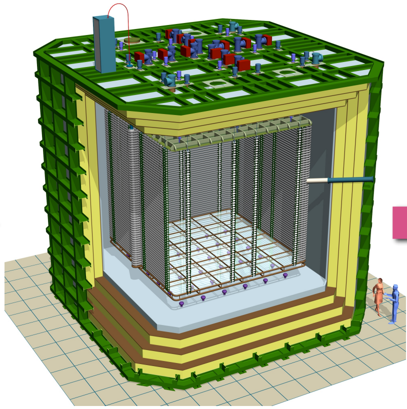


DUNE SP @SURF: 10 kton

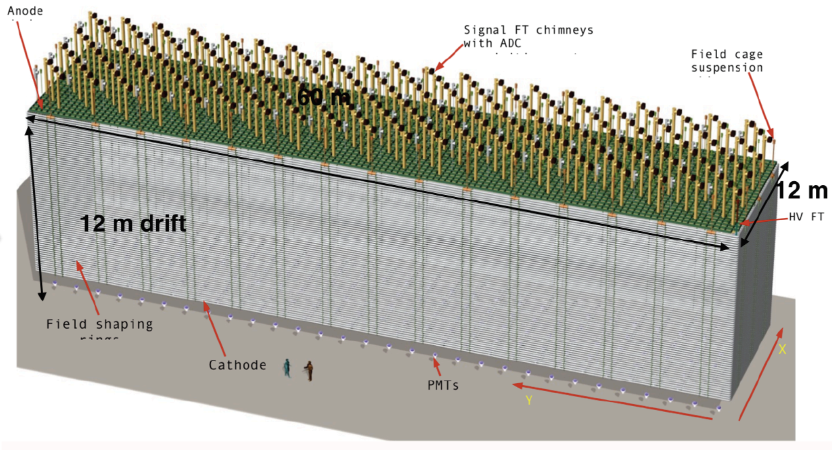
Dual-phase



WA105 **3x1x1 m³** @CERN:
4.2 ton (2016)



protoDUNE DP
@CERN: 300 ton
(2016-2019)



DUNE DP @SURF: 10 kton

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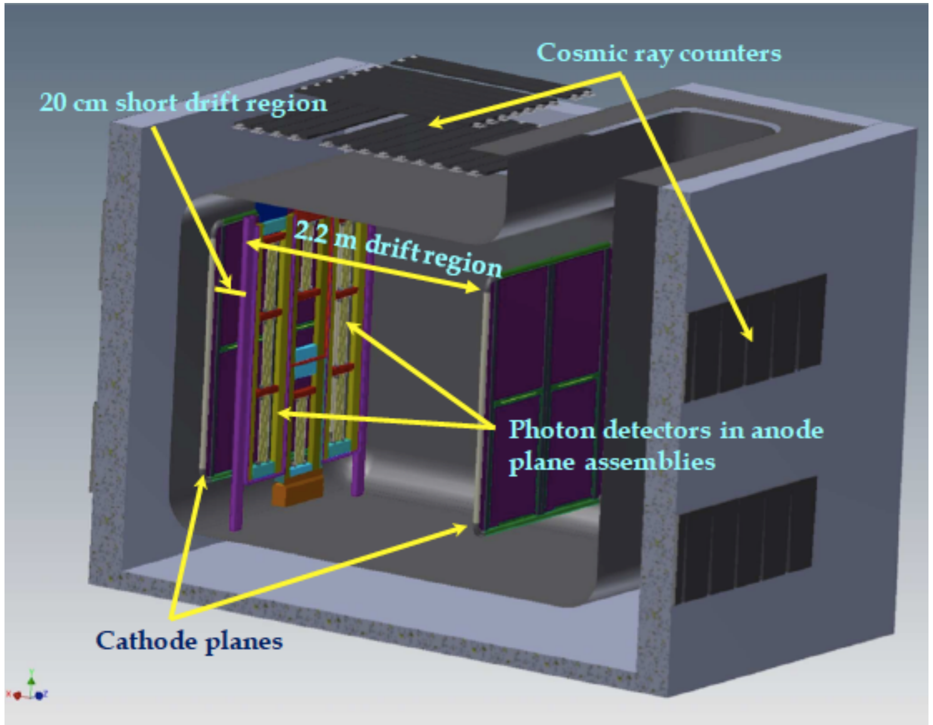
35-ton prototype @FNAL

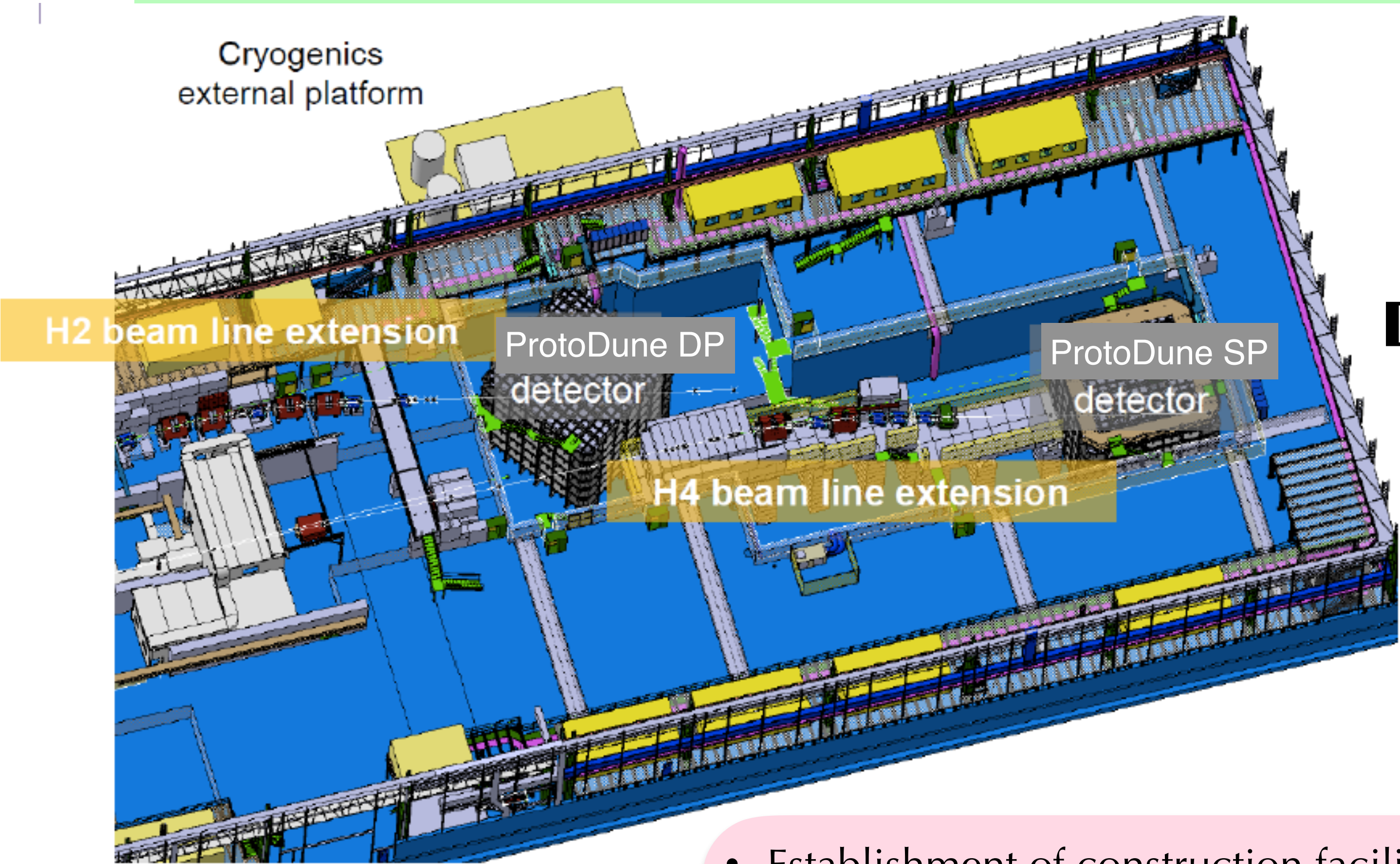
- First complete system test of DUNE single-phase TPC
- Characteristics
  - 2.5 m x 1.5 m x 2 m active volume
  - 2 drift volumes (long/short)
  - 8 sets of wire planes



- Will test
  - FR4 printed circuit board field cage
  - Wrapped wire planes
  - Cold electronics
  - Light-guide + SiPM photon detectors
  - Triggerless DAQ (continuous readout)
  - Reconstruction code
- Status
  - **Filled with LAr (Feb 2nd, 2016)**
  - Commissioning

ProtoDUNEs @CERN

Construction, installation and operation of **single**- and **dual-phase** large scale prototypes
➤ input to final DUNE FD designs

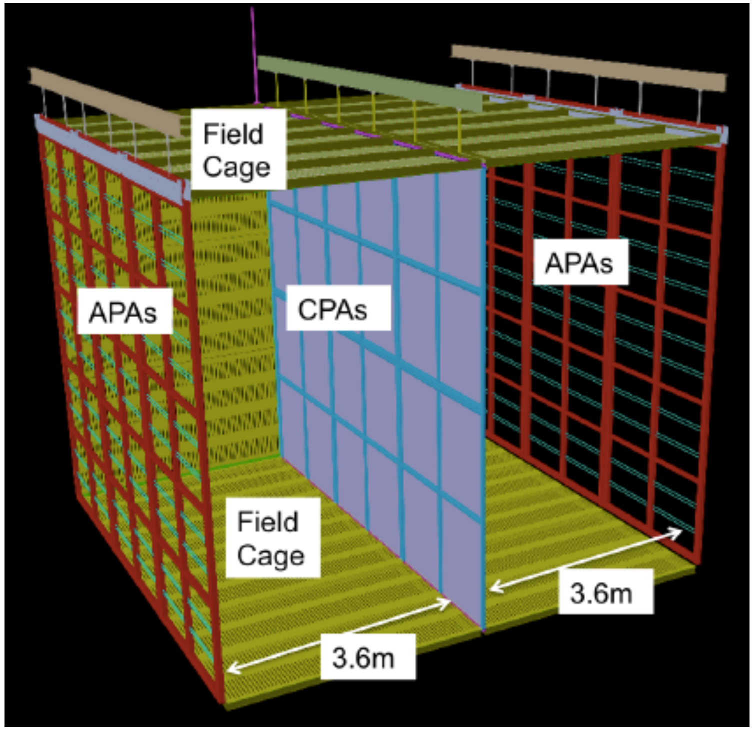


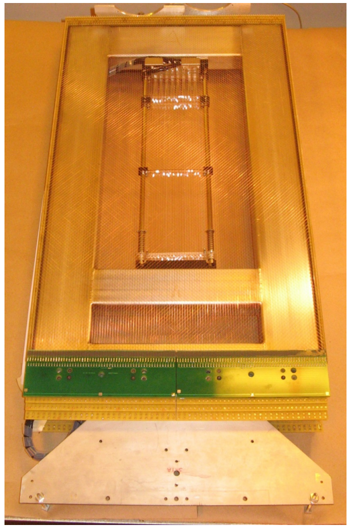
Data taking in 2018

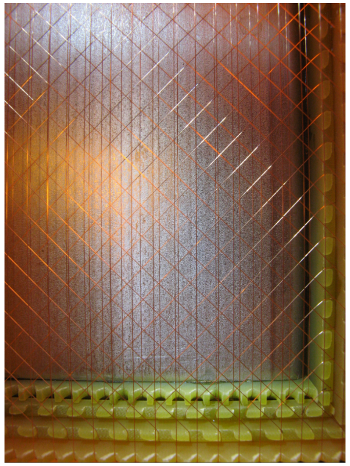
- Establishment of construction facilities
- Early detection of potential issues with construction methods and detector performance according to current designs
- Calibration of detector response to particle interactions in test beam

ProtoDUNE Single-Phase

- Engineering prototype of DUNE SP TPC using full-scale detector components
- Active volume: 6 m x 7 m x 7 m
- 6 Anode Plane Assemblies (6 m high x 2.3 m wide)
  - Photon detectors integrated into the APAs
  - 10 PD paddles per APA
- 6 Cathode Plane Assemblies (3 m high x 2.3 m wide)
- Cathode at -180 kV for 3.6 m drift (same drift length as in FD)
- Drift field: 500 V/cm
- 15360 total readout wires in TPC
- Wire spacing: 4.79 mm X plane, 4.67 mm U plane, 4.67 mm V plane, 4.5 mm
- Test-beam with charged particles at CERN

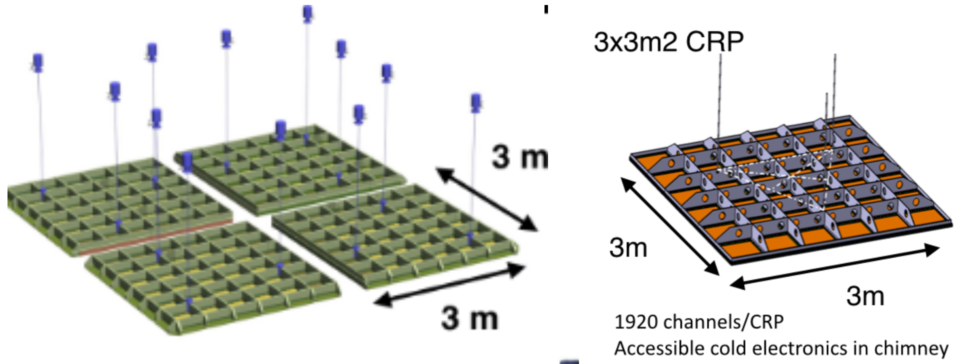


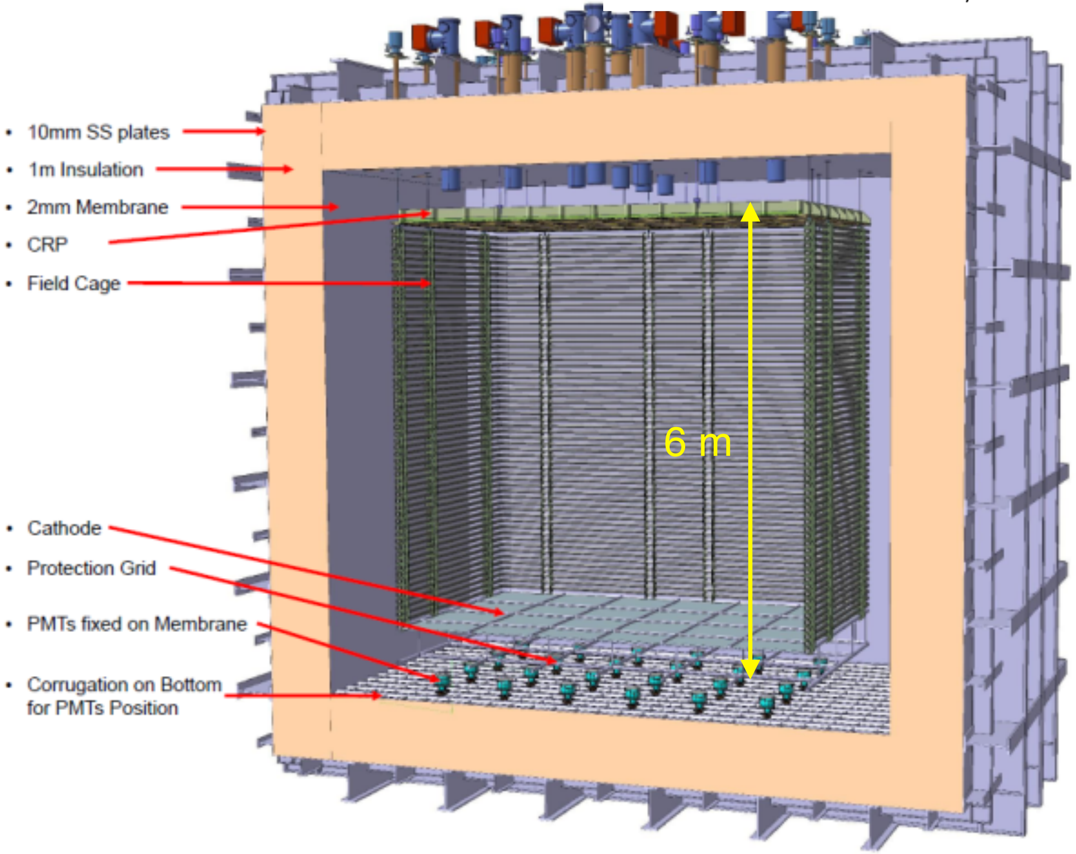




ProtoDUNE Dual-Phase

- Engineering prototype of DUNE DP TPC
  - 1/20 number of channels of 10 kton DUNE (1/40 volume & data size)
- Active volume: 6 x 6 x 6 m^3
- 6 m x 6 m anode plane made of four 3m x 3m independent readout units
- 6 m vertical drift -> -300 kV cathode voltage
- Drift field: 500 V/cm (extraction field: 2 kV/cm)
- 7680 readout channels
- Validation of construction techniques and operational performance of full-scale DP TPC prototype modules
- Exposure to charged hadrons, muons and electrons beams at CERN (0.5-20 GeV)

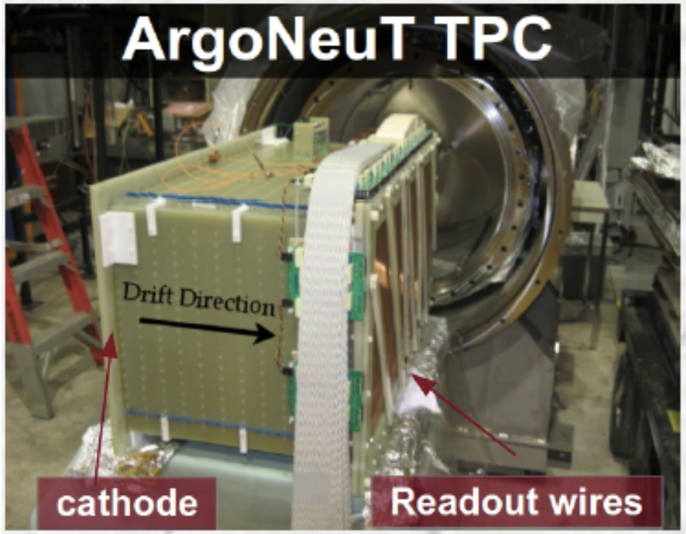


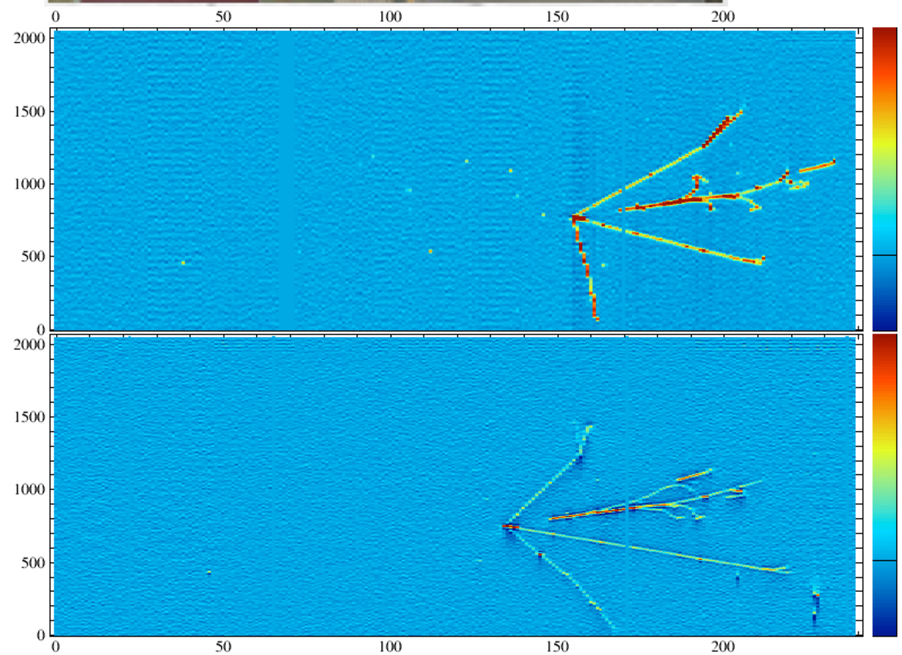


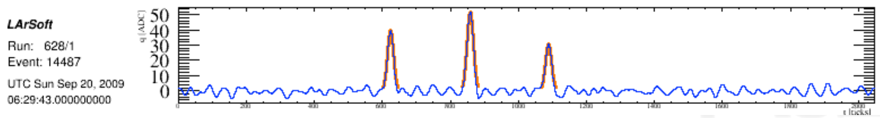
Other LAr TPC detectors

ArgoNEUT @NuMI (➜ LArIAT)

- 90 cm long x 40 cm tall x 47 cm drift
  - Active volume: 175 litres
  - 3 wire planes: induction, collection and shield (4 mm wires spacing)
  - No light detection system
- Took **data from 09/2009 to 02/2010 at the NuMI beam**
  - 2 weeks in neutrino mode & 4 months in antineutrino mode
  - 0.1 - 20 GeV energy of neutrino beam
- Goals:
  - Measure ν-Ar cross-sections
  - Calibration of LAr detectors
  - Study nuclear effects
  - Reconstruction techniques
- **Main results**:
  - Muon neutrino and antineutrino cross sections
  - Crossing muon analysis
  - Charge recombination
  - Back to back protons
  - Coherent pion production

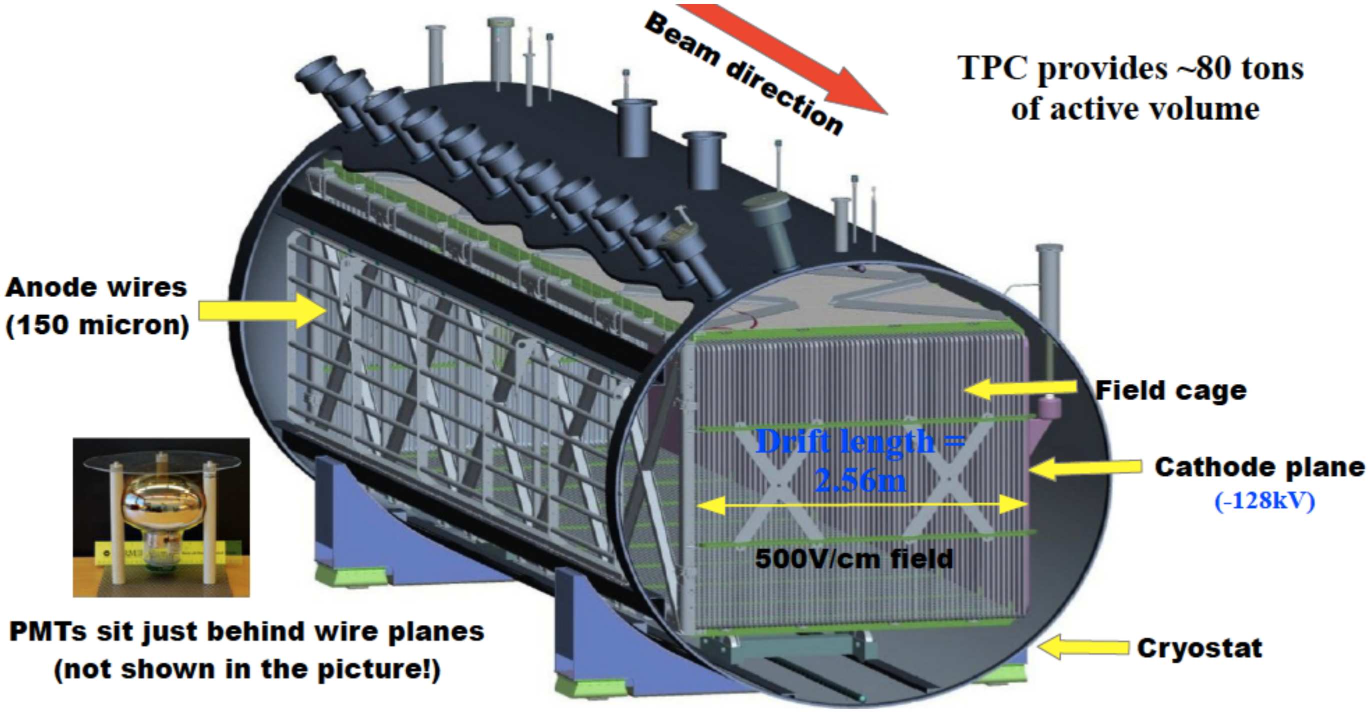






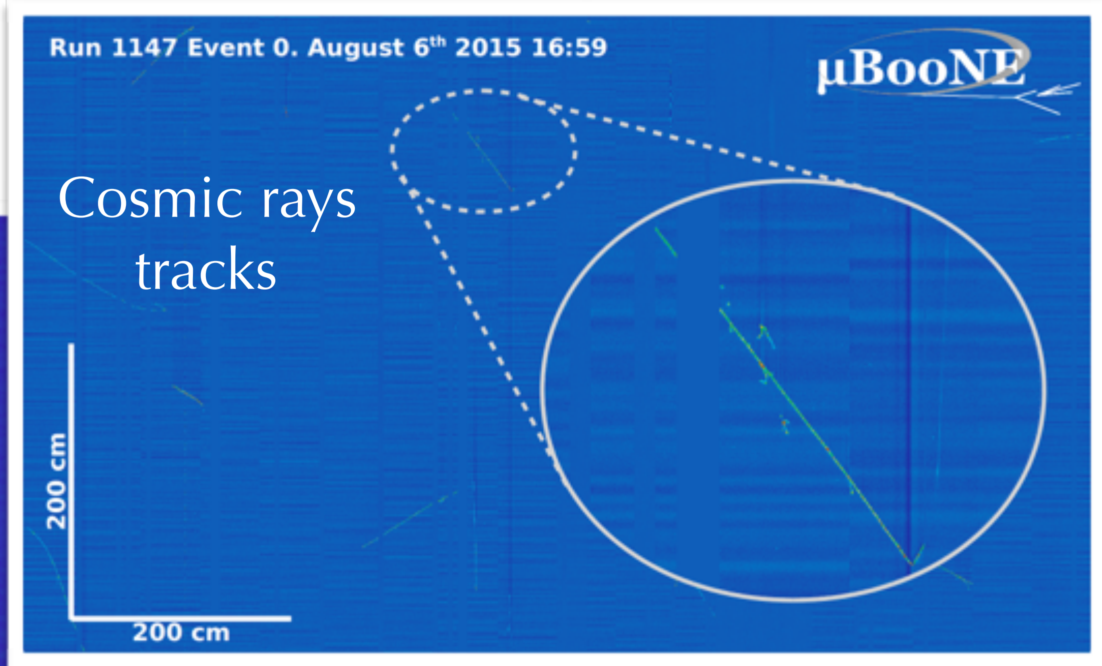
MicroBooNE @BNB

- 170 ton (80 ton active) LAr TPC neutrino experiment in the Fermilab Booster Neutrino Beam line (at 470 m from start of the BNB)
  - 10.3 m long x 2.3 m tall x 2.5 m drift, 3 mm wire pitch, -128 kV cathode voltage
  - 32 8″ cryogenic PMTs
- Physics **goals**:
  - Address the low-energy electron-like excess observed by MiniBooNE
  - Make high statistics measurements of ~1 GeV neutrino interactions in Ar and study nuclear effects



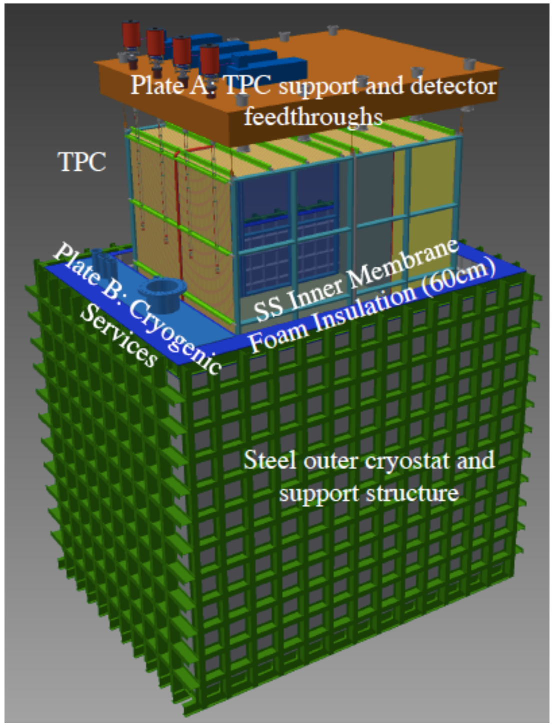
MicroBooNE status

- Assembly and installation complete
- Detector filled with ultra pure LAr
- First neutrino beam from the Fermilab Booster accelerator on October 15, 2015
- Taking data…

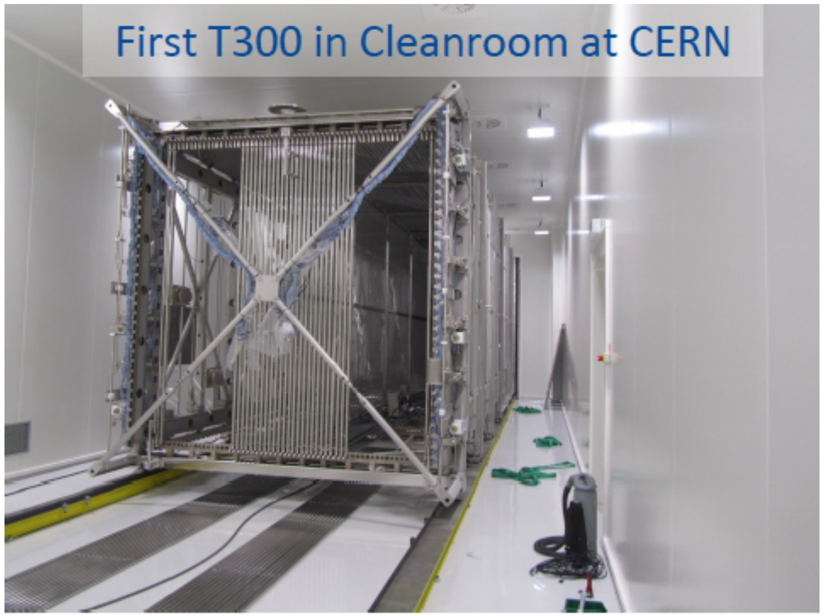


SBND & ICARUS at SBN program

- Another 2 LAr detectors being constructed and operated soon



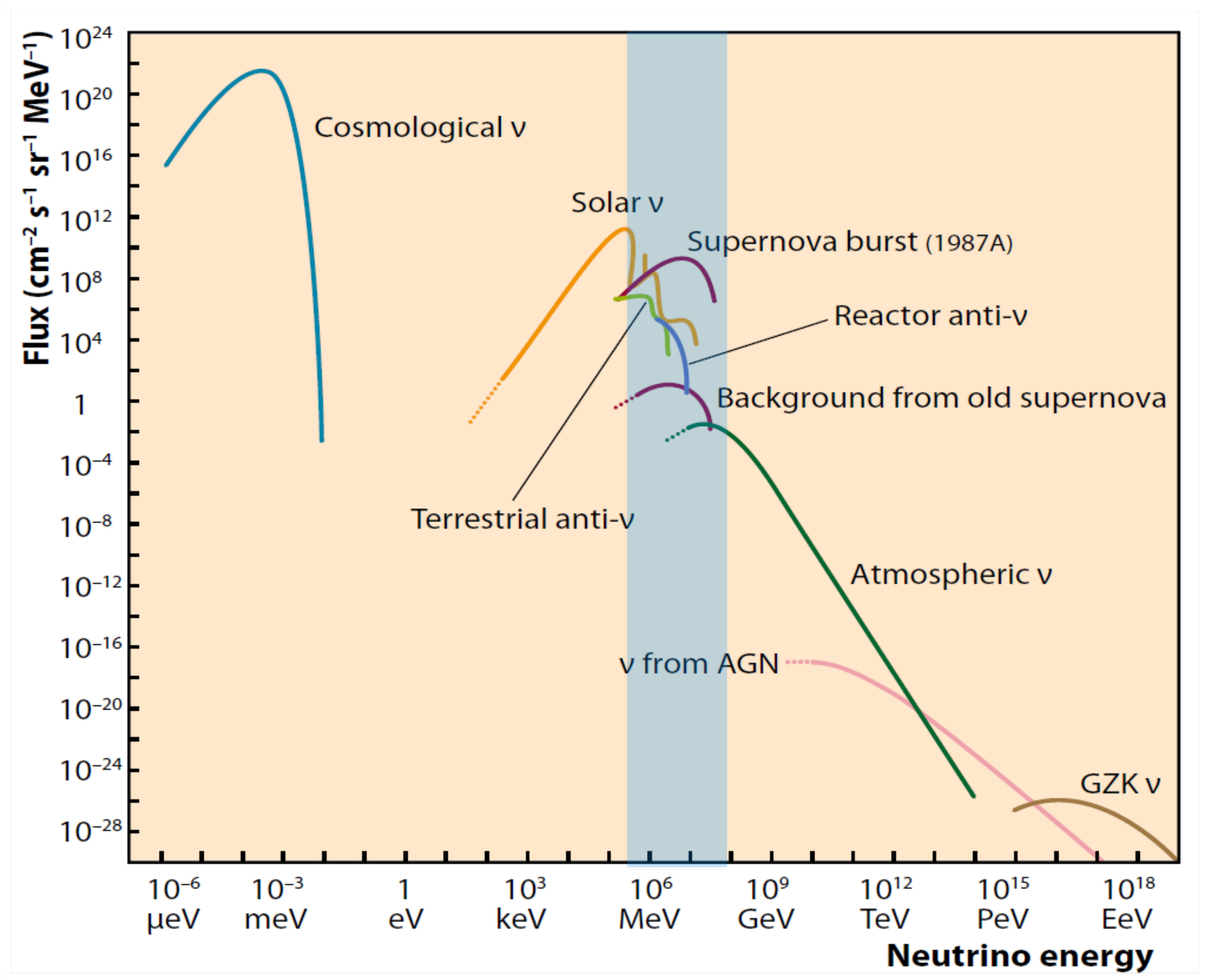
- **SBND**: under design phase
  - 112 ton active volume (4 x 4 x 5 m^3)
  - To be located 110 m from the BNB neutrino source
  - To be operational in 2018
  - Large data sample for neutrino-argon interaction studies in the GeV energy range



- **ICARUS**: under refurbishment at CERN
  - Was the first large scale LAr TPC to run in a neutrino beam line (CNGS from 2010 to 2013)
  - Will be shipped to Fermilab in 2017

Low-energy reconstruction capabilities

Low-energy neutrino spectrum



Energy deposited in the TPC <100 MeV

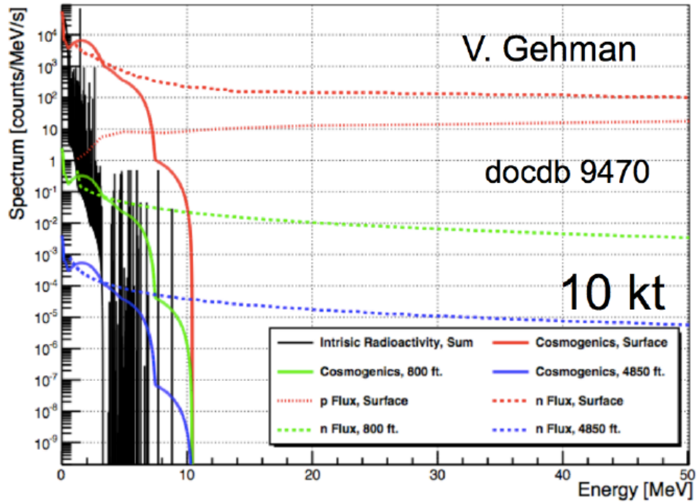
Low-energy neutrino physics @DUNE

- **SN neutrino burst** detection (primary DUNE goal)
  - Burst of events with known background

Channel	Events "Livermore" model	Events "GKVM" model
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	2720	3350
$\overline{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	230	160
$\nu_x + e^- \rightarrow \nu_x + e^-$	350	260
Total	3300	3770

no oscillations *collective effects*

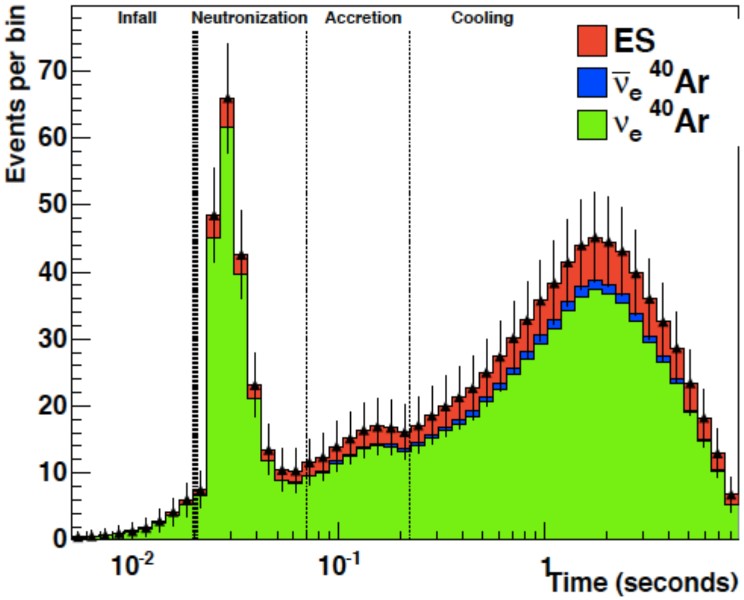
- **Solar neutrinos**
  - High rate but background is an issue
  - ~100 solar ν's per day (limited to ^{8}B physics)
- **DSNB**
  - Low rate and high background (challenging)
  - ~4 DSNB neutrino interactions per year



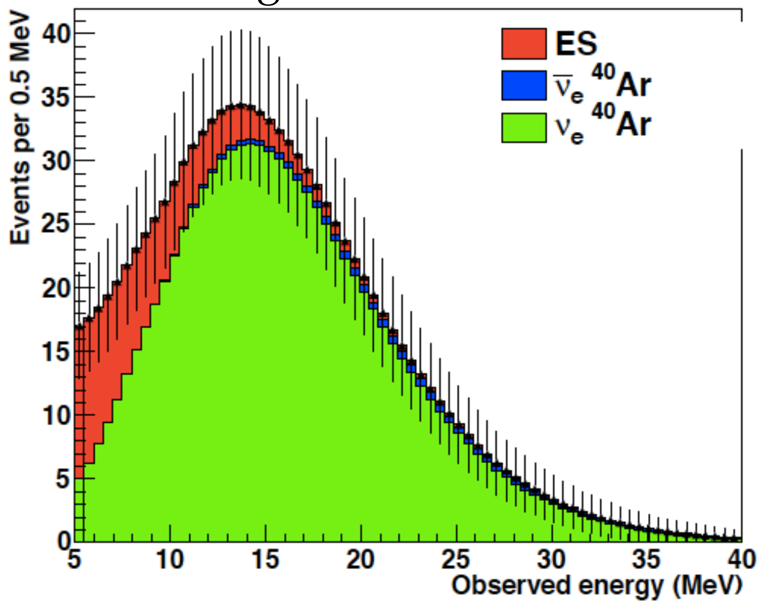
LBNF and DUNE CDR Volume 2: The Physics Program for DUNE at LBNF (arXiv:1512.06148)

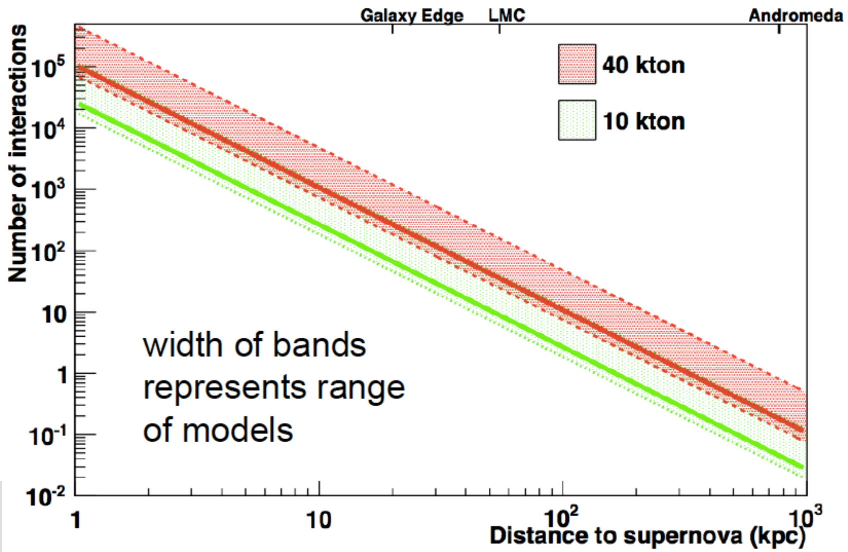
DUNE: 40 kton LAr (SN @10 kpc)

Time-dependent signal



Expected event spectrum
integrated over time



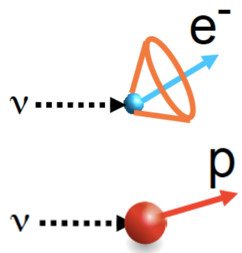


Low-energy ν detection channels

- **Elastic scattering (ES)**
  - Pointing information (e-)
  - Proton recoil (difficult)

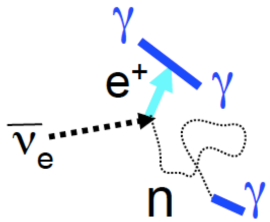
$$\nu_x + e^- \rightarrow \nu_x + e^-$$

$$\nu_x + p \rightarrow \nu_x + p$$



- **Inverse beta-decay (IBD)**
  - High cross section
  - Neutron tagging

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

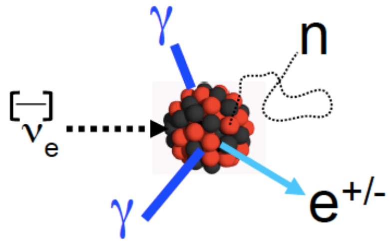


- **Charged-currents (CC)**
  - Different products

    (de-excitation gammas, leptons, neutrons…)

$$\nu_e + (N,Z) \rightarrow e^- + (N-1, Z+1)$$

$$\bar{\nu}_e + (N,Z) \rightarrow e^+ + (N+1, Z-1)$$

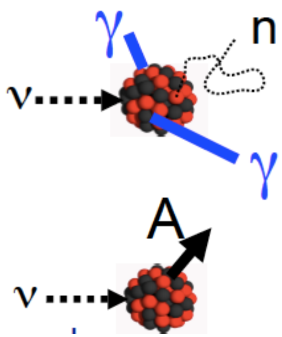


- **Neutral-currents (NC)**
  - De-excitation gammas

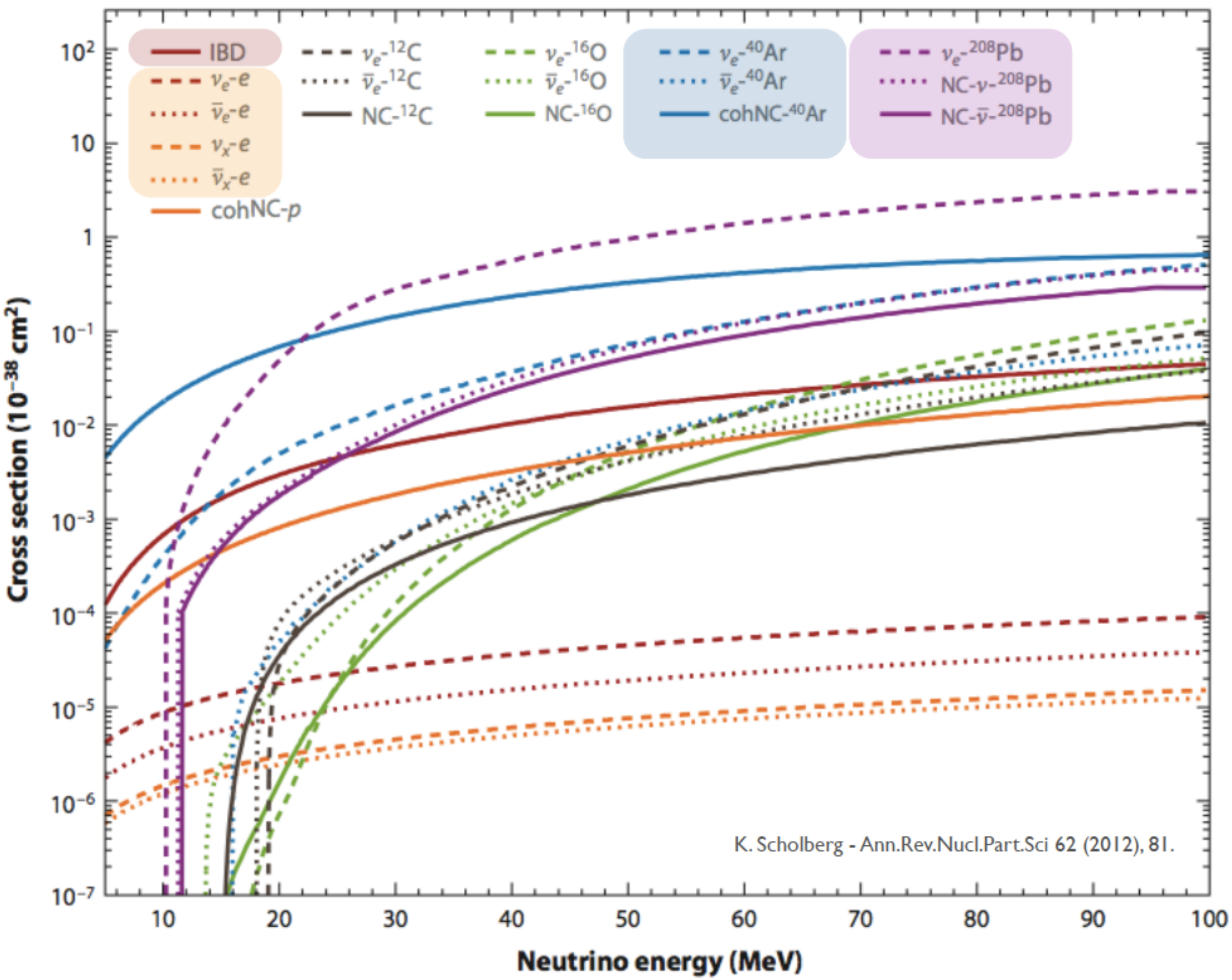
    or neutrons

$$\nu + A \rightarrow \nu + A^*$$

$$\nu_x + A \rightarrow \nu_x + A$$



Neutrino interactions at < 100 MeV



Interactions with nuclei very poorly understood

Low-energy neutrino signal in LAr

- Elastic scattering (ES) on electrons

$\nu + e^- \rightarrow \nu + e^-$

- Charged-current (CC) interactions on Ar

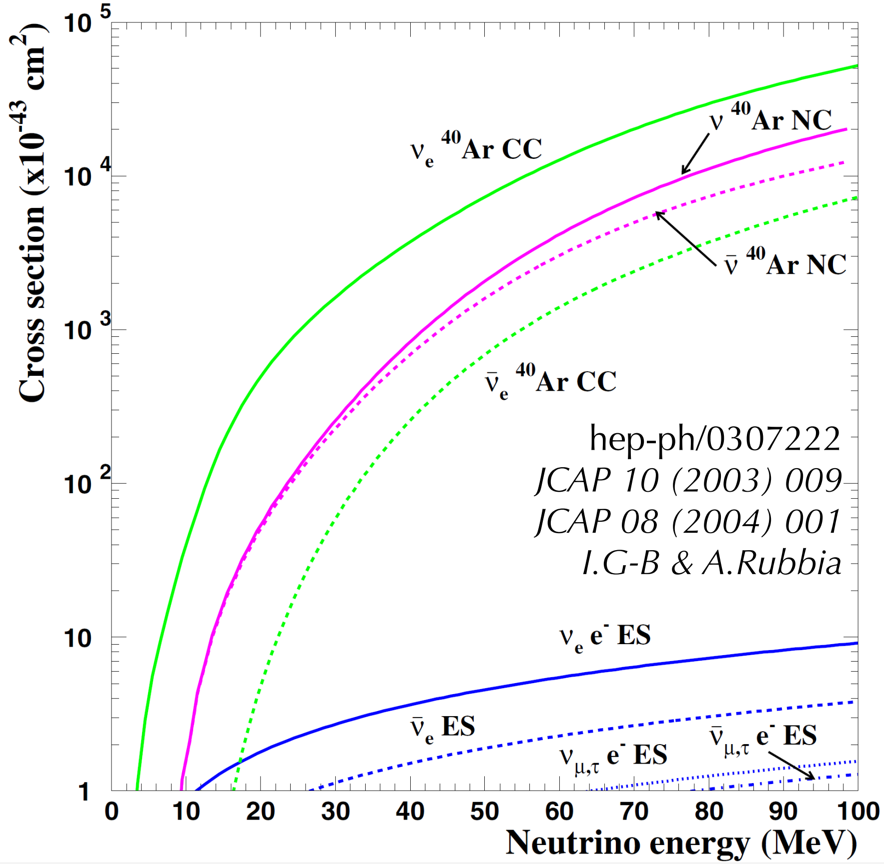
$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$ $E\nu_e > 1.5$ MeV

$\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+$ $E\bar{\nu}_e > 7.48$ MeV

- Neutral current (NC) interactions on Ar

$\nu + {}^{40}Ar \rightarrow \nu + {}^{40}Ar^*$ $E\nu > 1.46$ MeV

SN ν cross sections on Ar



Possibility to separate the different channels by a classification of the associated photons from the K, Cl or Ar de-excitation (specific spectral lines for CC and NC) or by the absence of photons (ES)

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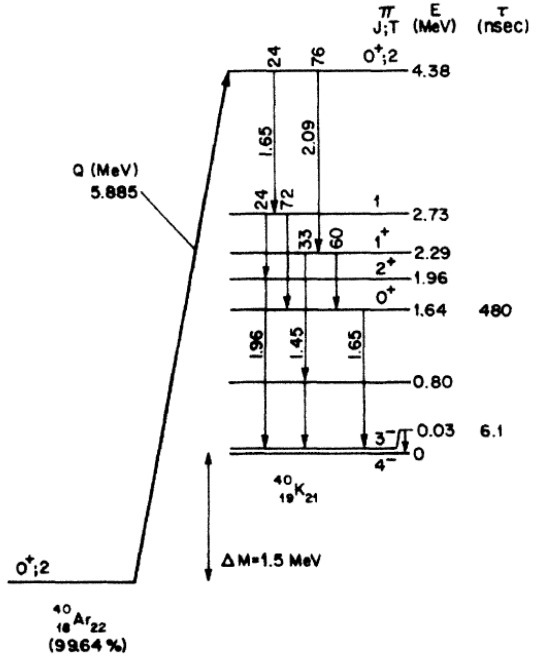
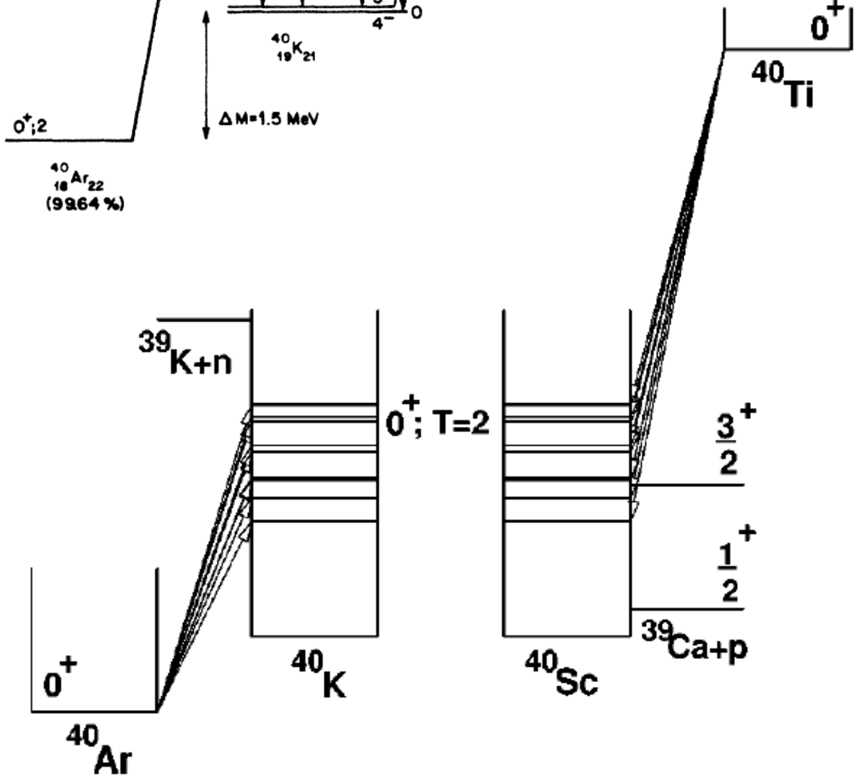
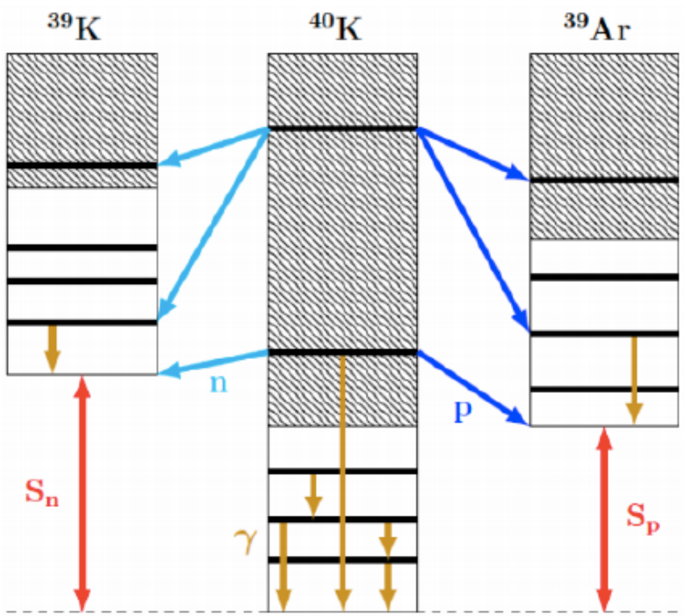
ν_eCC final states: de-excitation γs

- **Lack of precision models of low energy neutrino argon reactions**
  - No measurements are available
  - Some efforts to study this problem with indirect beam sources and small-scale experiments
- **Fermi transition to 4.38 MeV IAS ^{40}K**
  - σ precisely known < 1%
  - Raghavan, PRD 34 (1986) 2088
- **GT transitions of various ^{40}K**:
  Experimental data of β-decay of the mirror nucleus ^{40}Ti
  - Ormand et al., Rhys. Lett. B 345 (1995) 343-350
  - Trinder et al., Phys. Lett. B 415 (1997) 211-216
  - Bhattacharya et al., Phys. Rev. C 58 3677 (1998)





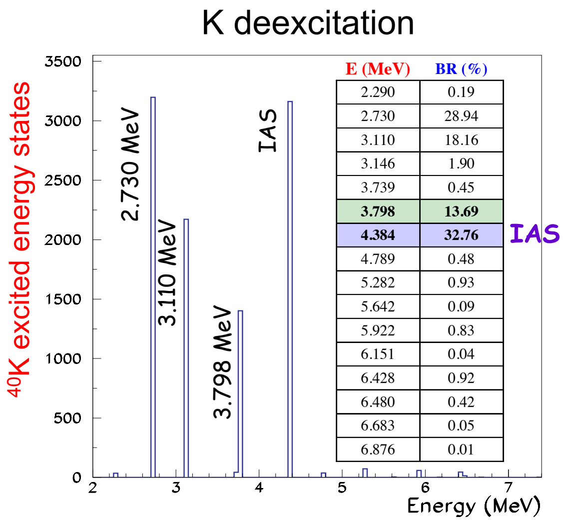
Low energy neutrino interactions



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

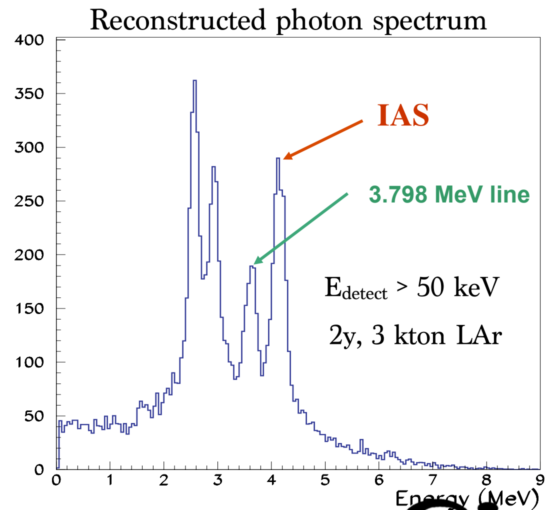
MARLEY MC event generator is being integrated in the DUNE software

- Relative feeding of nuclear states is not precisely known
- Subsequent de-excitation γs are uncertain
  - Critical for energy reconstruction
- Highly excited ^{40}K can de-excite via n or p emission
  - Further complication of energy reconstruction



E (MeV)	BR (%)
2.290	0.19
2.730	28.94
3.110	18.16
3.146	1.90
3.739	0.45
3.798	13.69
4.384	32.76
4.789	0.48
5.282	0.93
5.642	0.09
5.922	0.83
6.151	0.04
6.428	0.92
6.480	0.42
6.683	0.05
6.876	0.01

IAS



Challenges for low-E neutrino detection

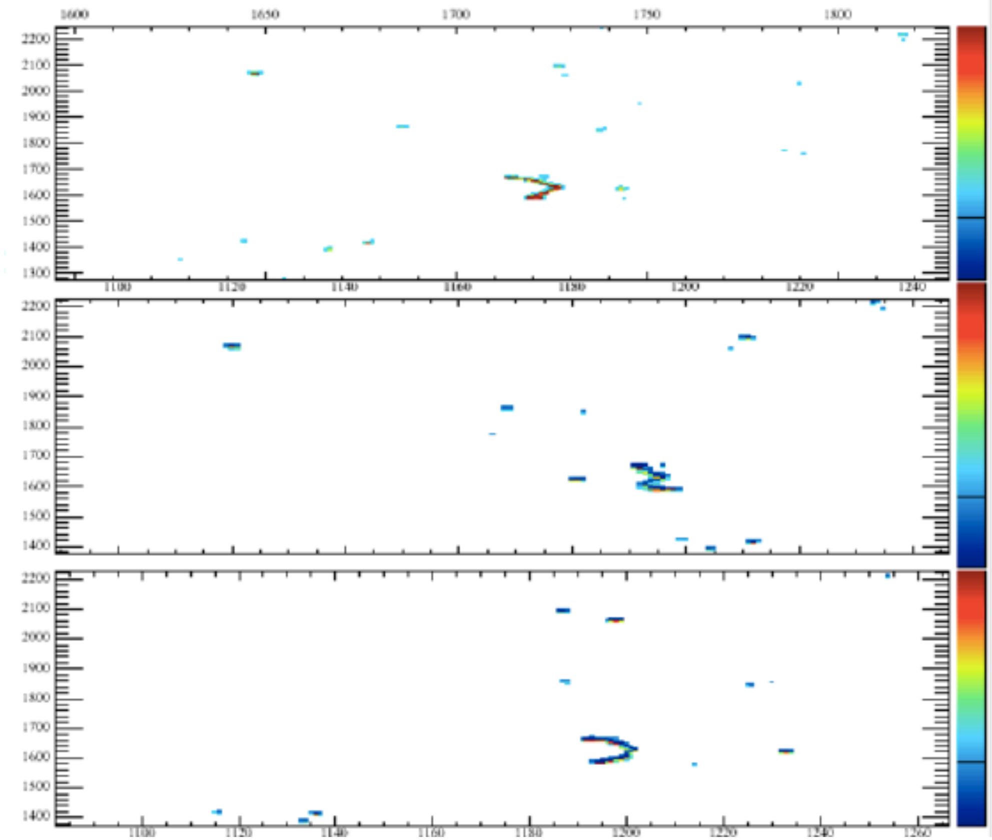
Determination of low-energy ν-Ar cross-sections

Knowledge of neutrino interactions (γ's de-excitation)

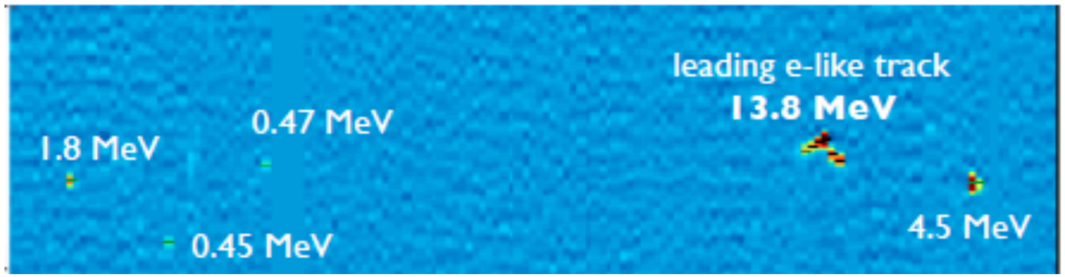
Lack of knowledge

Low energy neutrino interactions

- **Simulation** of 20 MeV ν_e (14.1 MeV e-), MicroBooNE geometry
- De-excitation gammas produce diffuse compton-scatters
- Energetic electron has significant probability of bremsstrahlung (gammas are present even in absence of nuclear de-excitations)



How to reconstruct these small number of hits?



(simulated low-energy electron and gamma data from C. Adams)

Main low-energy backgrounds

- The main issue to understand
- They will constrain our capabilities for signal
- **Neutron capture processes** in detector materials
- **Radioactive backgrounds** in Ar and detector materials
- **Cosmogenics** by cosmic rays interaction with Ar
- **Electronic noise**

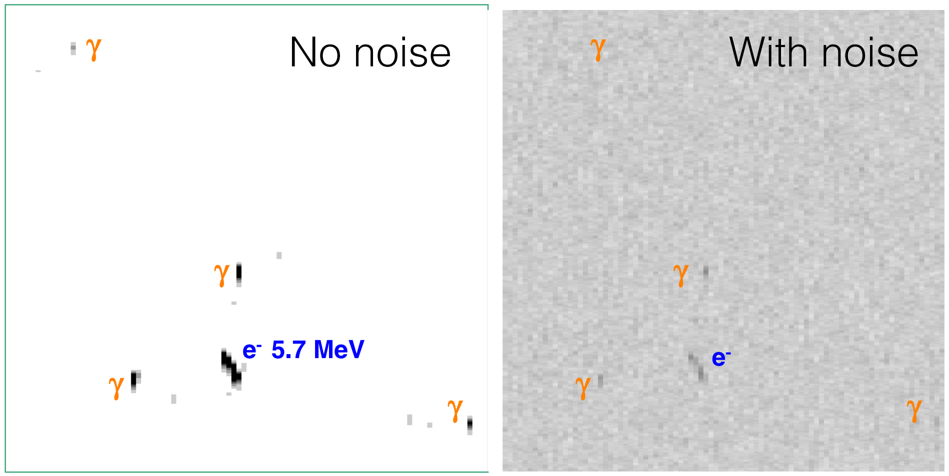
$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$$

Neutron background sources:

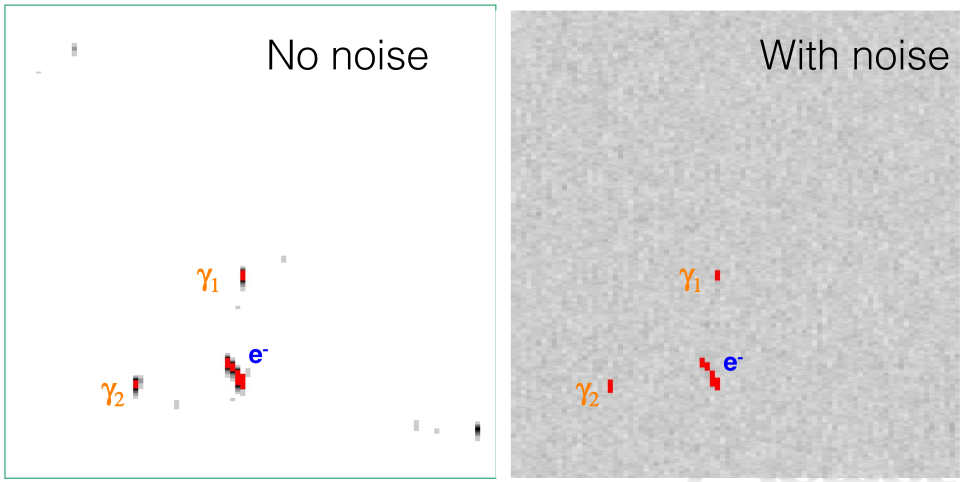
- External source: natural radioactivity of the rock
- Internal source: radioactive contamination of the detector materials
- High energy muons

Stable isotope	Abundance (%)	Process	σ (barns)	Q-value (MeV)
^{40}Ar	99.6	$n + {}^{40}Ar \rightarrow {}^{41}Ar^* \rightarrow {}^{41}Ar + \gamma$'s	0.66	6.099
^{36}Ar	0.337	$n + {}^{36}Ar \rightarrow {}^{37}Ar^* \rightarrow {}^{37}Ar + \gamma$'s	5.2	8.788
^{38}Ar	0.063	$n + {}^{38}Ar \rightarrow {}^{39}Ar^* \rightarrow {}^{39}Ar + \gamma$'s	0.8	6.598
^{27}Al	100	$n + {}^{27}Al \rightarrow {}^{28}Al^* \rightarrow {}^{28}Al + \gamma$'s	0.23	7.725
^{56}Fe	91.72	$n + {}^{56}Fe \rightarrow {}^{57}Fe^* \rightarrow {}^{57}Fe + \gamma$'s	2.59	7.646
^{54}Fe	5.8	$n + {}^{54}Fe \rightarrow {}^{55}Fe^* \rightarrow {}^{55}Fe + \gamma$'s	2.25	9.298
^{57}Fe	2.2	$n + {}^{57}Fe \rightarrow {}^{58}Fe^* \rightarrow {}^{58}Fe + \gamma$'s	2.48	10.045
^{58}Fe	0.28	$n + {}^{58}Fe \rightarrow {}^{59}Fe^* \rightarrow {}^{59}Fe + \gamma$'s	1.28	6.581

ν_eCC MC event



Hit reconstruction (E_{detect_th} = 200 keV)



Challenges for low-E neutrino detection

Determination of low-energy ν-Ar cross-sections

Knowledge of neutrino interactions (γ's de-excitation)

Lack of knowledge

Detector performance

Triggering / DAQ

- Good time resolution
- Large data acquisition in a few seconds

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

$\hookrightarrow \gamma$'s

compton $\hookrightarrow e^-$

Low-energy event reconstruction and identification

- Ability to **tag** electrons and de-excitation gammas from nuclear transitions
- Measurement of **energy**, **time** and **direction** of events

Extraction from background

- Good vertex resolution
- Low cosmic background
- Low radioactive background

Detector requirements for low-E ν's

Detector requirement/goal	Value	Main detector systems involved	Purpose
Trigger efficiency for interactions between 5-100 MeV	>90%	Trigger/DAQ & PD System	SN burst
Data acceptance without loss and buffer for at least 2 minutes	Non-zero suppression	DAQ	SN burst
Vertex resolution able to distinguish between SN ν from entering or cosmogenic backg	~cm	Photon Detection System & TPC	Background rejection
Reconstruction of cosmic muons and associated radiation		TPC & PD System	Background rejection
Reconstruction efficiency for 5 MeV events	~80%	Photon Detection System	Flavor-energy features of the SN spectrum
Particle Identification		TPC & PD System	Identification of gamma cascades from low-E ν int. / Flavor tagging
Energy resolution for events of energy 5-100 MeV	< 10%	TPC & PD System	Features on the SN neutrino spectrum
Absolute time resolution	< 1 ms	DAQ & PD system	SN burst / Energy resolution
Angular resolution	< 20º (T_e > 5 MeV)	TPC	Event direction

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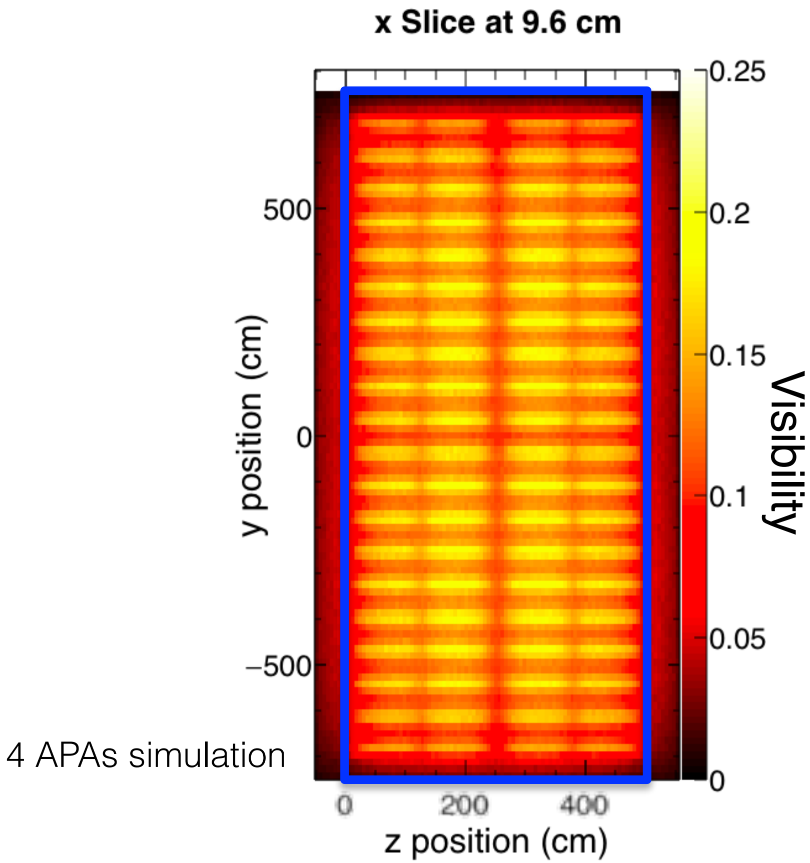
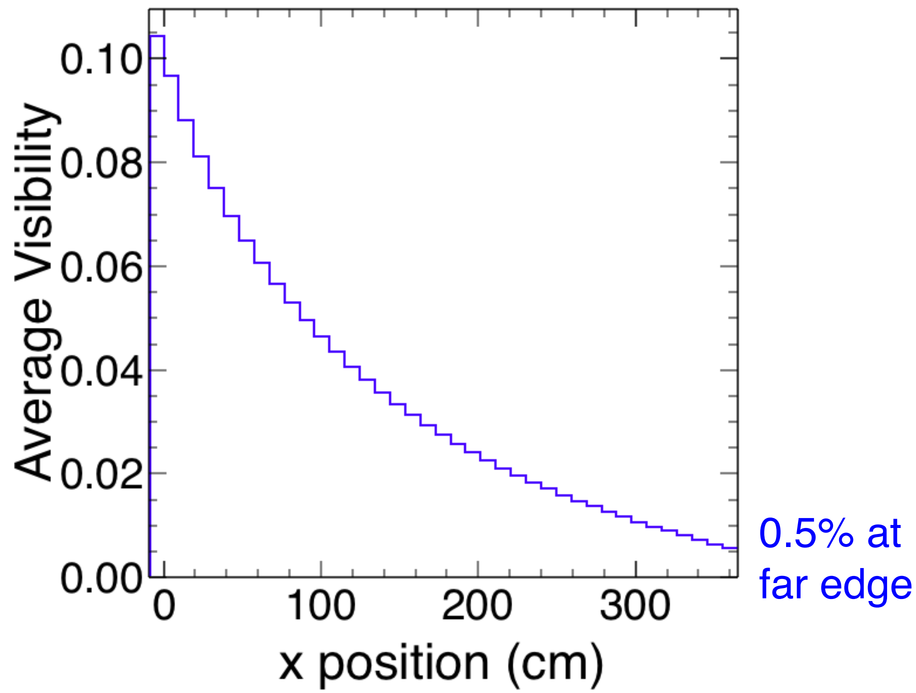
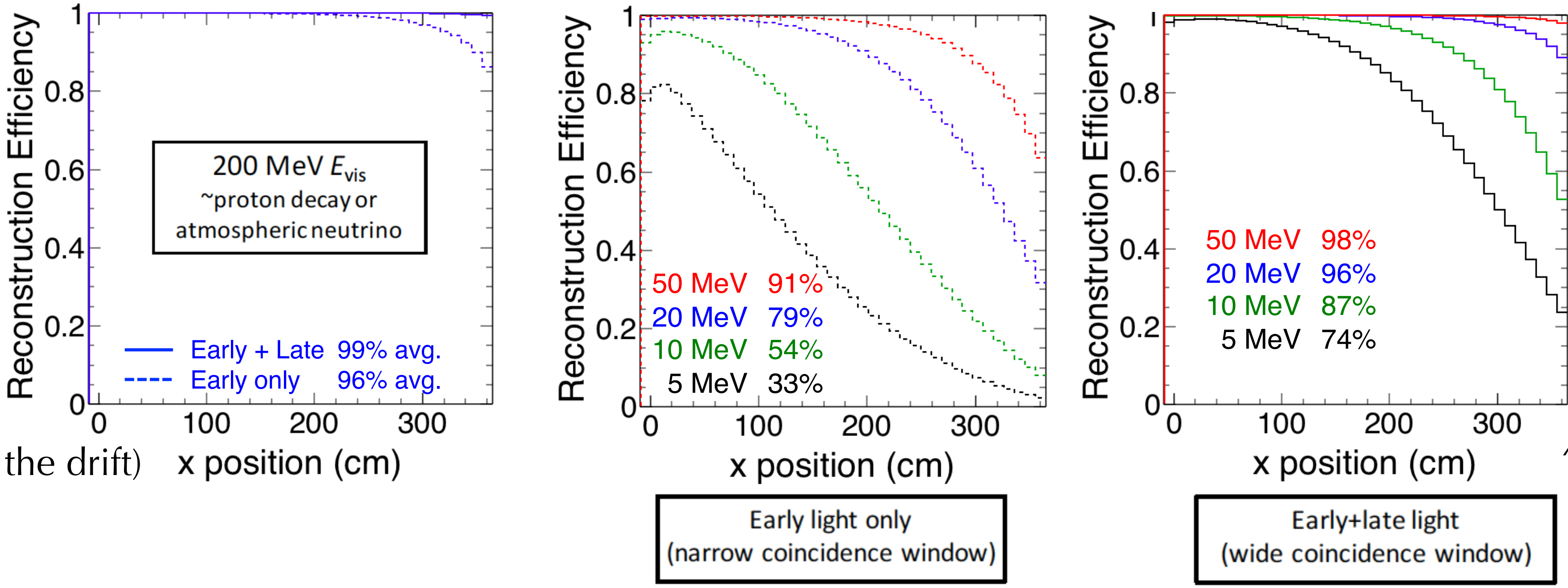
Photons reaching optical detectors

- Average yield vs. position in the detector
  - Central region only to avoid over-emphasizing loss at walls
- Average ε_{geo} = 4.7%
- Plot also includes 30% wire shadowing
- Total light: 24,600 x ε_{geo} = 1,200 γ/MeV





Reconstruction efficiency



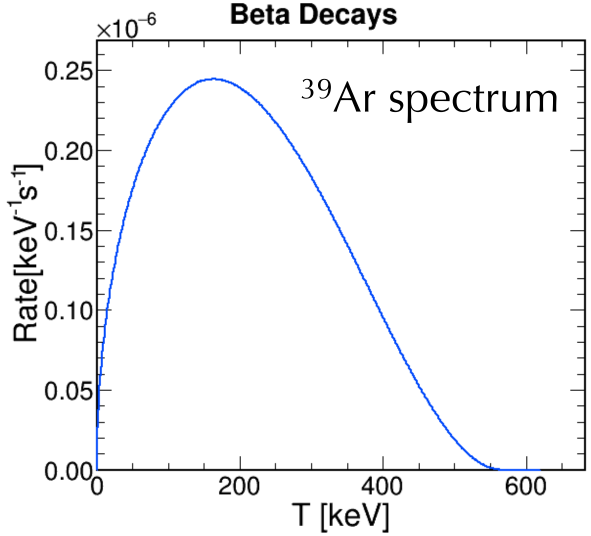
(along the drift)

A. Himmel

- **Proton decay** reconstruction efficiency:
  - Assuming 200 MeV visible energy (conservative estimate)
  - With late light (the late light gives 4x increase in photons, but need electronics capable of 1 PE signals, which increases cost) >99% efficiency
- **Supernova** reconstruction efficiency
  - Only early light and requiring 2 coincident PEs -> For 5 MeV events, only 33% efficiency
  - Early + late light and requiring 2 coincident PEs (optimistic!) -> For 5 MeV events, 74% efficiency

Low-energy backgrounds: ^{39}Ar

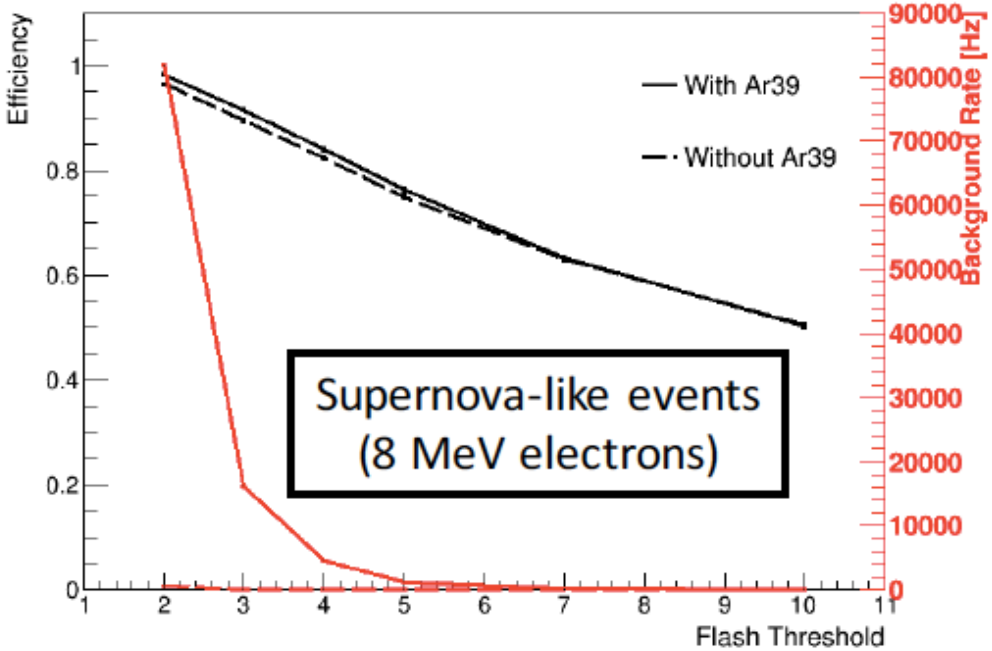
- ^{39}Ar β-decays, ~500 keV endpoint (~12,000 photons)
- Energy is low but visible if close to the photodetectors
  - 3.5 γ´s if decay is close to the PDs
- Expected background rate: ~1.01 Bq/kg
- Photocoverage improvement increases sensitivity to background
- Algorithms to suppress ^{39}Ar in PDs are needed



Only 4 APAs
FD will have 150 APAs

^{39}Ar photon background (in 2.7% of far detector)

Thresh.	SN ε	Bkgd
2 PE	98%	81 kHz
5 PE	76%	1.3 kHz
10 PE	50%	20 Hz



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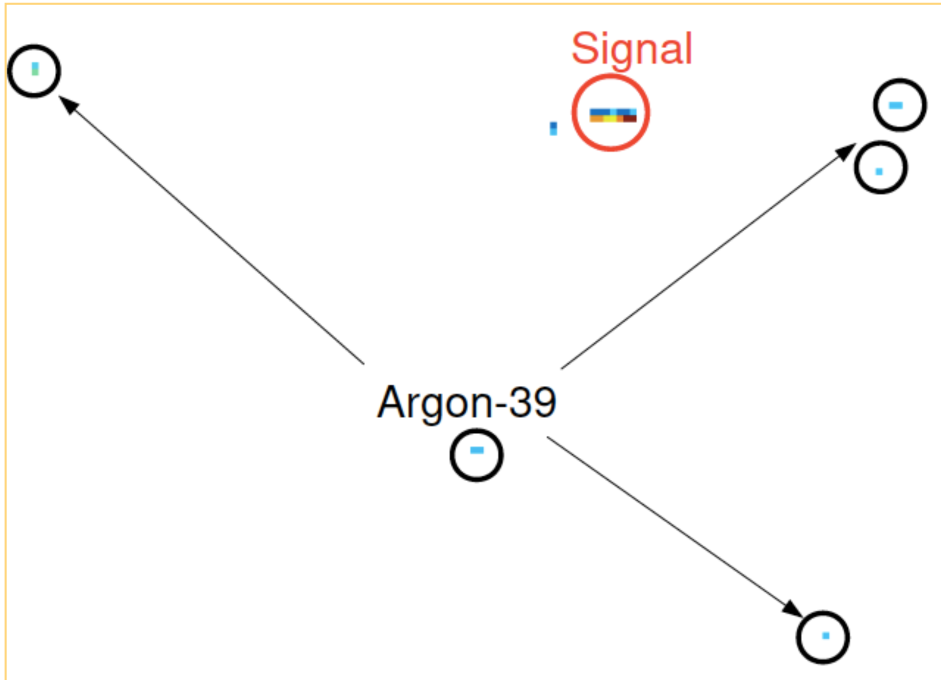
Background reduction

- It does not look impossible to separate ^{39}Ar from signal events (good **spatial resolution**)
- ^{39}Ar is a serious background issue for photodetectors
  - Rate depends on **flash threshold**
- ^{39}Ar can mimic low energy events so we need to use the photon detection information for trigger

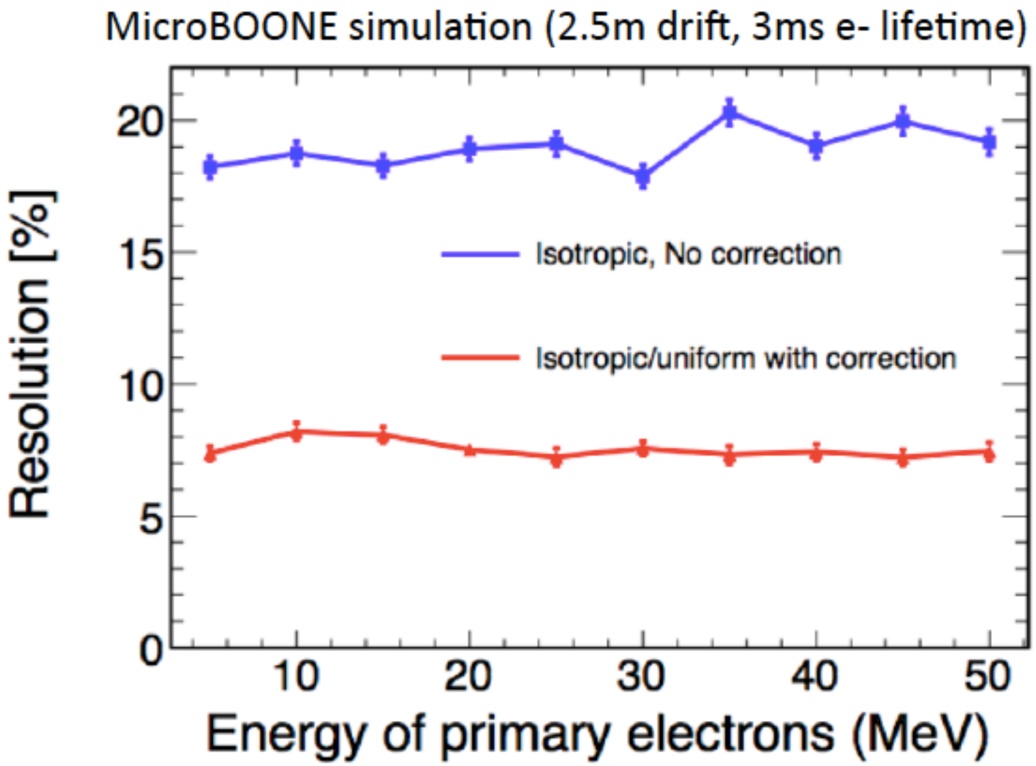
Signal
(10 MeV γ)



Energy resolution

- Energy resolution depends on **drift distance** and **electron lifetime**
- The t_0 correction improves the energy resolution

$$Q_{correction} = Q \times e^{Drifttime/Lifetime}$$



~20% w/o t_0 correction

~10% with t_0 correction

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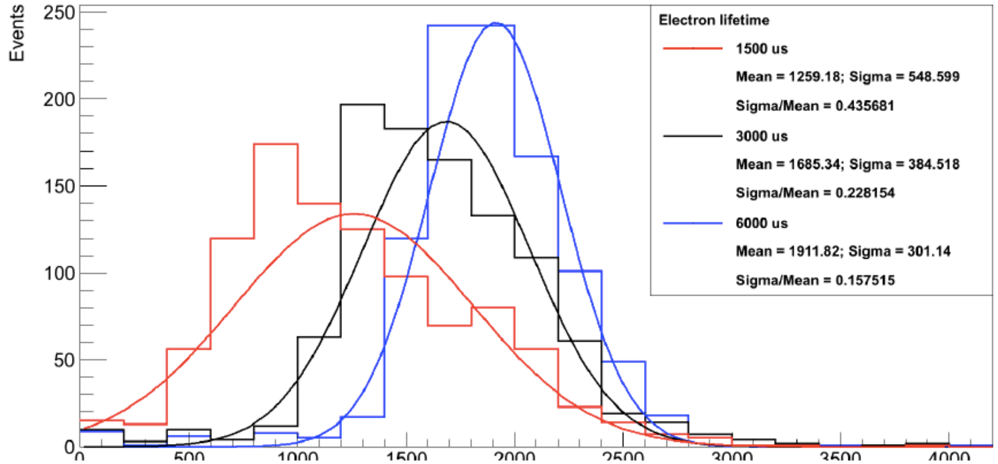
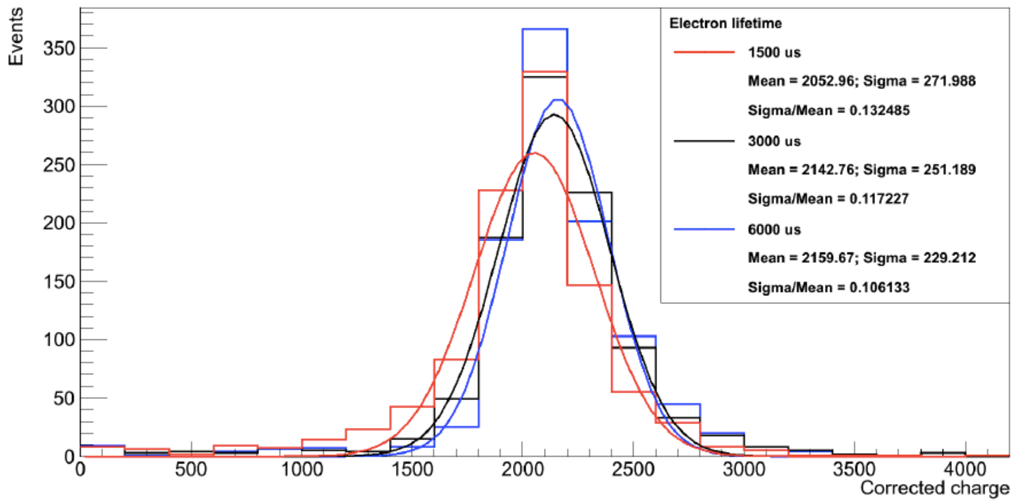
Energy resolution

- If electron lifetime is worse (1.5 ms), the energy resolution is significantly degraded (~20%)



- With drift correction (from t_0 from photons), we get ~13% resolution



G. Sinev

Information from prototypes

- Low-energy data information from LAr prototypes
  - Response from Michel electrons
  - Radioactive backgrounds / ^{39}Ar
  - Cosmogenics
  - Calibration with sources
  - Trigger/DAQ
  - Photons
  - Directionality
- Comparison between single- and dual-phase technologies

Conclusions

- Detection of SN neutrino events is one of the main goals of future large underground detectors (primary scientific goal for DUNE)
  - Other low energy events can be detected with DUNE (solar νs, DSNB, …)
- Important to understand the different low-energy ν detection channels (cross-sections, signatures, directionality, reconstruction, timing, etc.) and the detector response
- Dedicated studies are needed to understand the low energy background sources and intensity (^{39}Ar and radiological backgs) and their separation from the low energy signals
- Many studies to be done to improve the low-energy event detection performance of future large underground detectors