Supernova Neutrinos, Proton Decay and Atmospheric Neutrinos at DUNE

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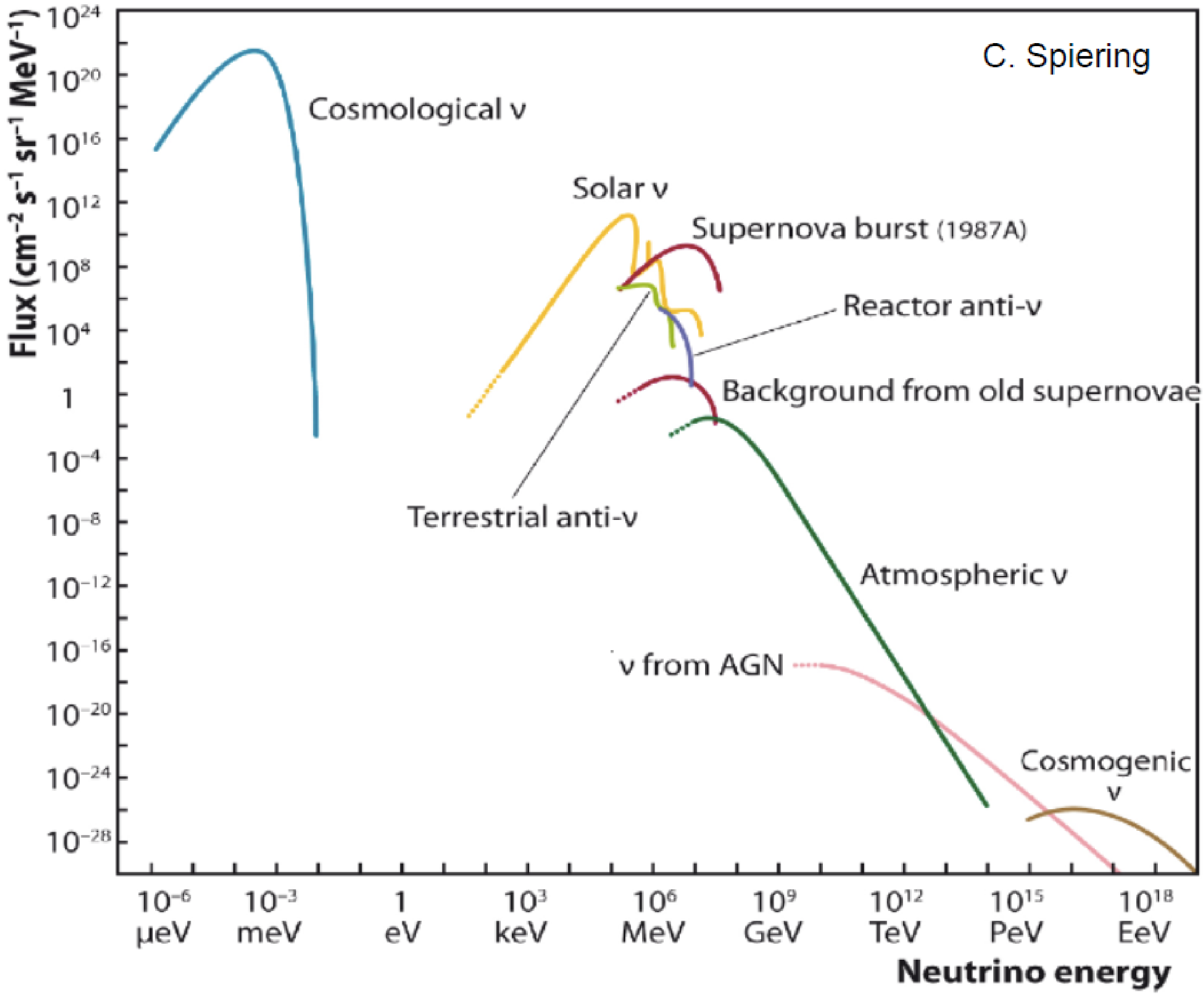
for the DUNE collaboration

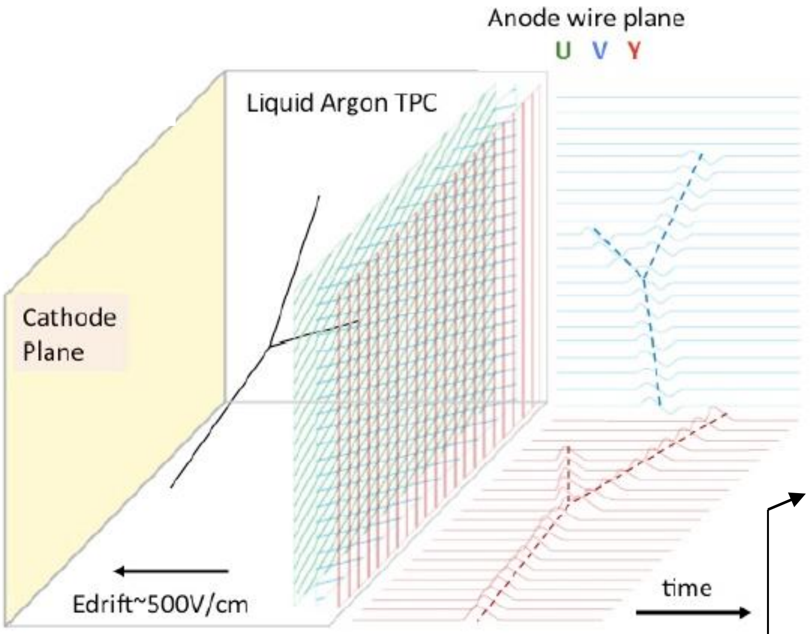
WIN 2017

UC Irvine, 21-June-2017

The supernova neutrino signal



Liquid argon time projection chambers



- fine-grained trackers
- no Cherenkov threshold
- high ν_e cross section

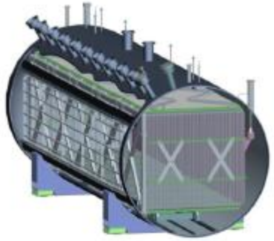
DUNE talk: Jianming Bian
Next Gen LBNEs & Tech: T. Kutter
July 21, 2017: groundbreaking @ SURF

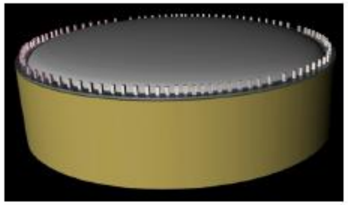
ICARUS
(Italy...)
0.6 kton

MicroBooNE
(USA)
0.2 kton

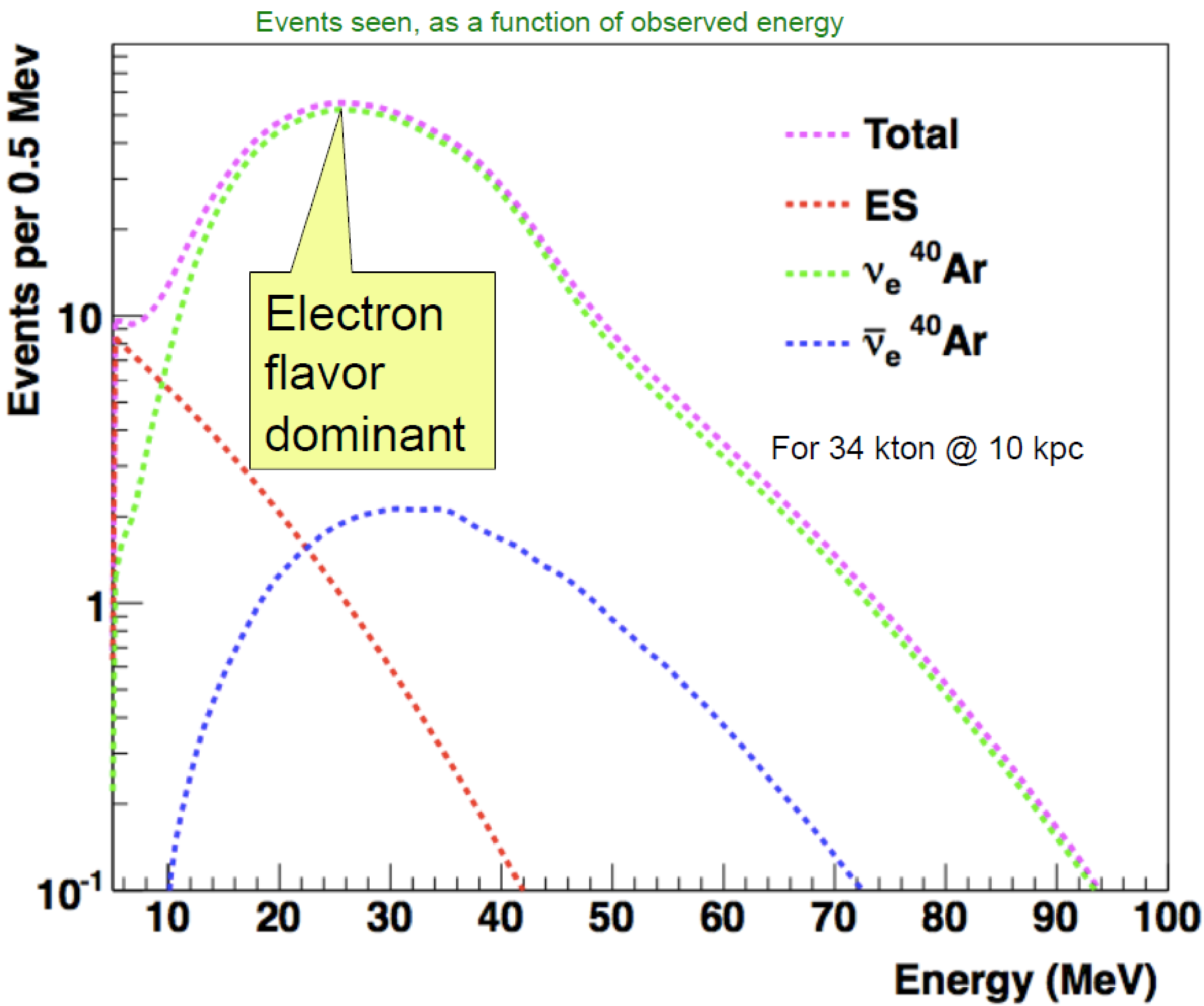
DUNE
(USA)
40 kton

GLACIER
(Europe)
100 kton

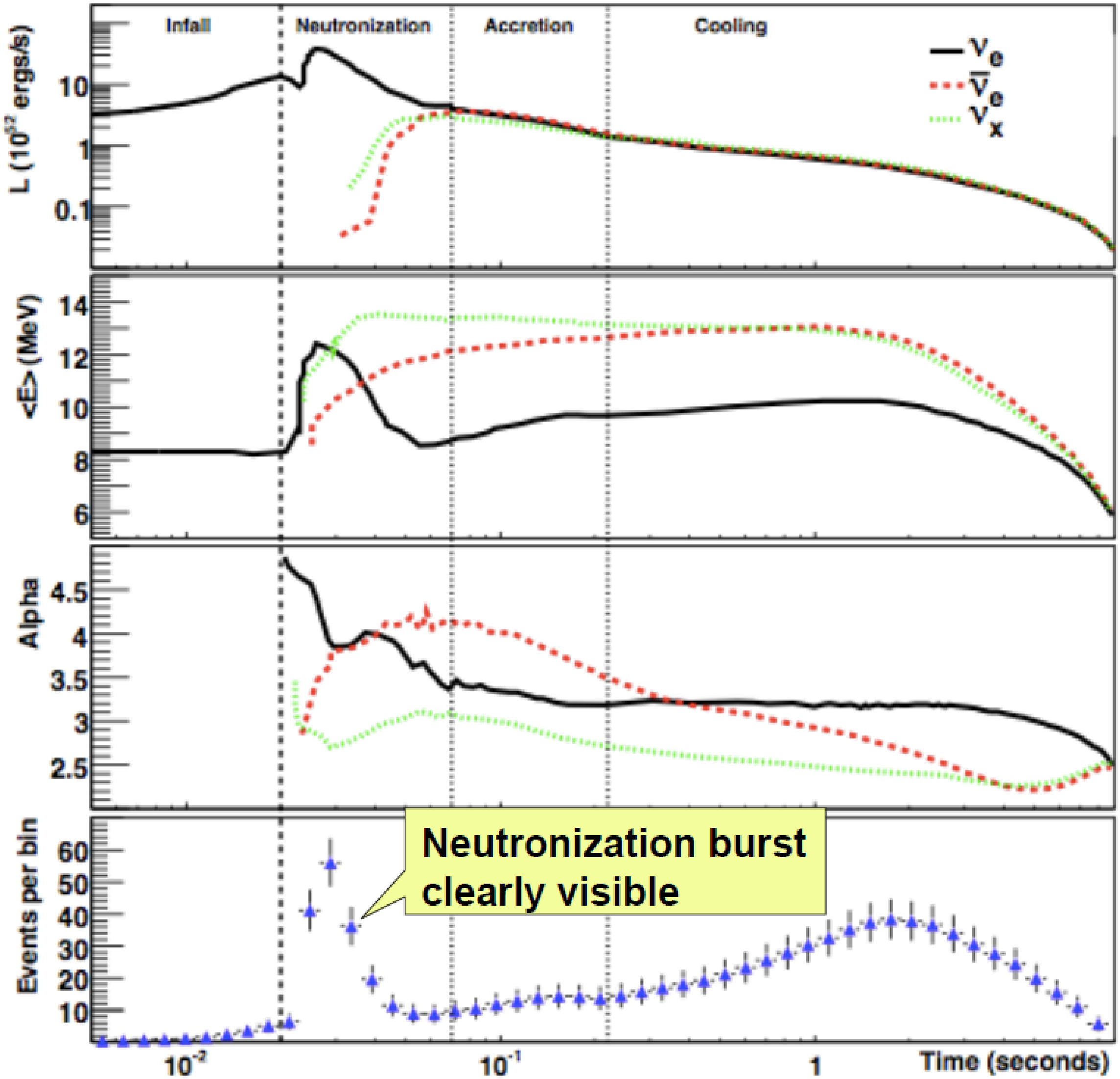




Supernova signal in a liquid argon detector



Example of supernova burst signal in 34 kton of LAr

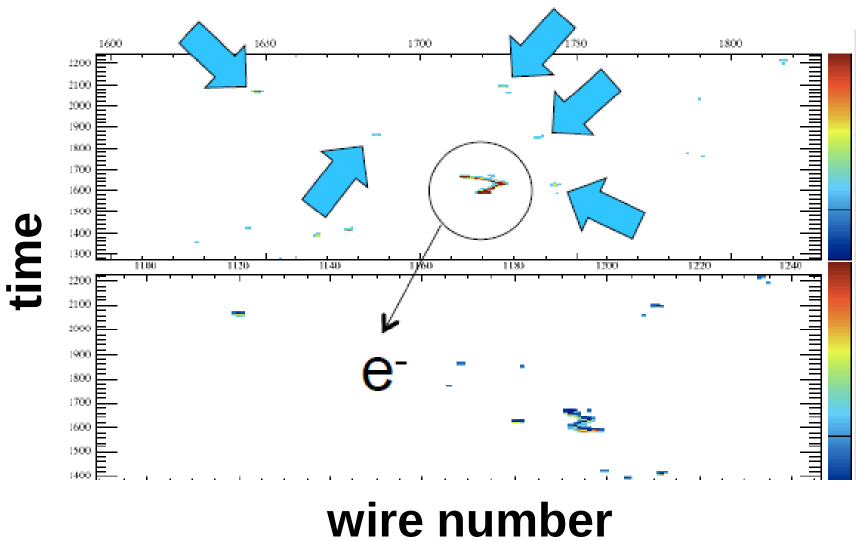


Flux from Huedepohl et. al, PRL 104 (2010) 251101 @ 10 kpc

arXiv:1307.7335

-> plenary talks: M. Nakahata & B. Dasgupta

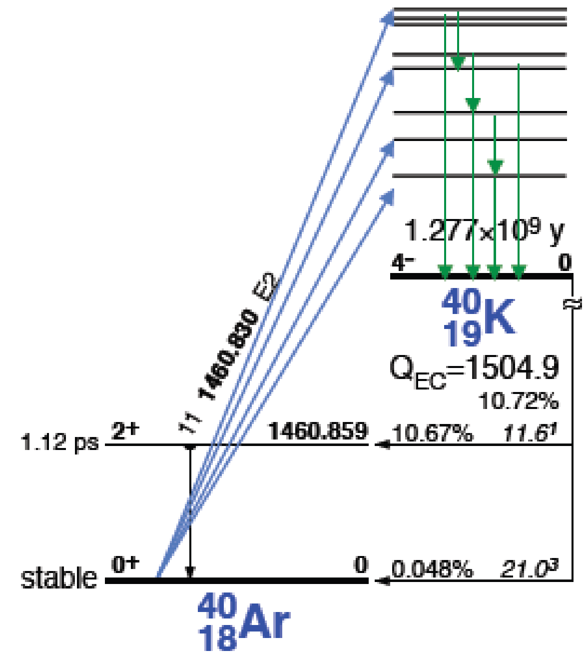
Can we tag ν_e CC interactions in argon using nuclear deexcitation γ's?



Charged-current absorption:

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

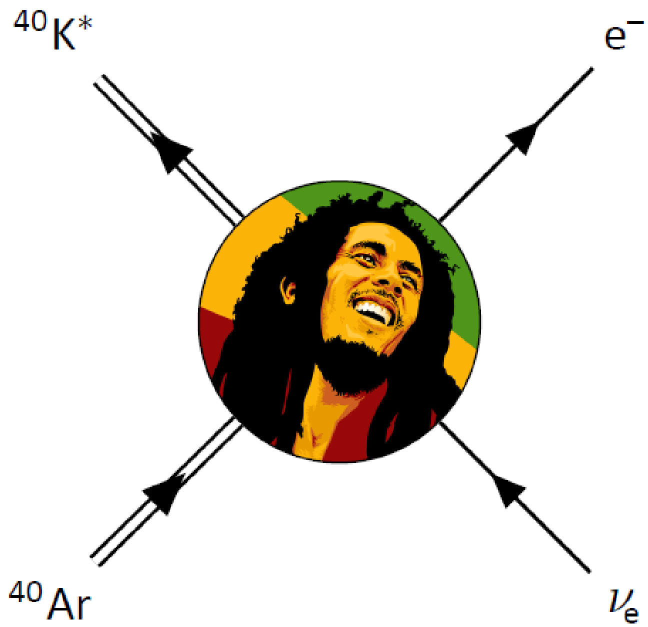
(g.s. to g.s. is 3rd forbidden transition)



20 MeV ν_e , 14.1 MeV e^-, simple model based on R. Raghavan, PRD 34 (1986) 2088
Improved modeling based on ^{40}Ti (^{40}K mirror) β decay measurements in progress
Direct measurements (and theory) needed!

MARLEY: **M**odel of **A**rgon **R**eaction **L**ow-**E**nergy **Y**ields

- **Goal:** determine whether "every little thing gonna be all right" for SN neutrino physics in LArTPCs
- Event generator for SN ν on ^{40}Ar
- Current version focuses on generating ν_eArCC events



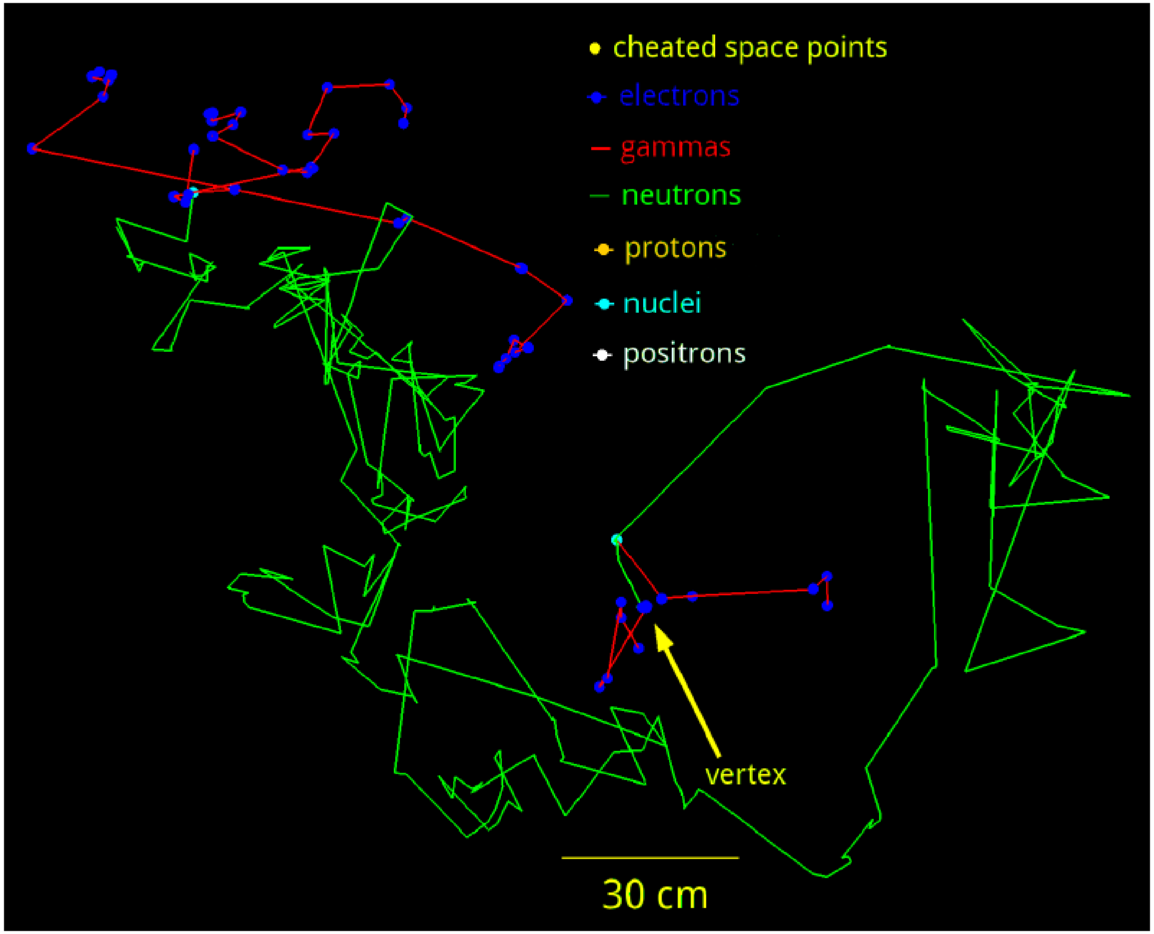
R. Svoboda,
S. Gardiner (-> talk),
C. Grant & E. Pantic

Example neutron event (true trajectories)

- E_ν = 16.3 MeV
- e^- deposited 4.5 MeV
- No primary γs from vertex
- ^{39}K deposited 68 keV
- n deposited 7.6 MeV (mostly from capture γs)
- Total visible energy:

  12.2 MeV
- Visible energy sphere radius:

  1.44 m
- Neutrons bounce around for a long time!



-> need to control u/g neutron background!

1.) Important: Radiological Model and Inputs from Screening

⇒ ***Requirements on Radiopurity driven by intrinsic Ar-39 level in LAr (1.01 Bq / kg)***

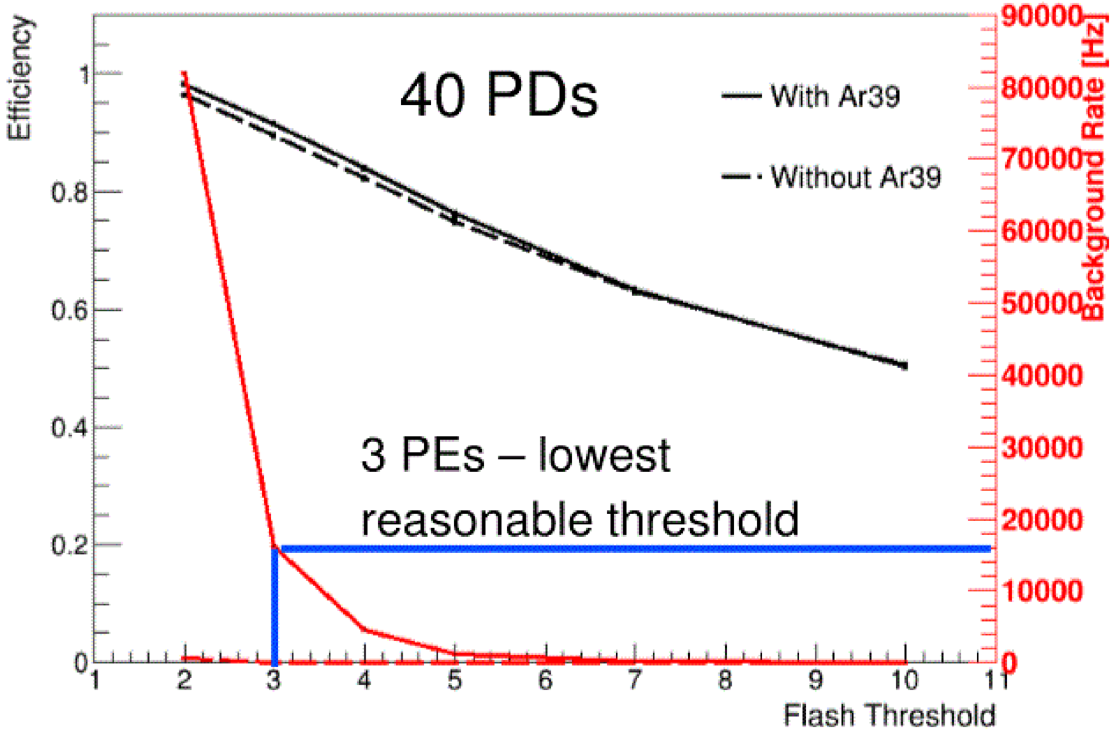
(would require Manhattan-Project style effort to mitigate for DUNE)

- **Radiological control is crucial for far detector!**

⇒ **alpha- and gamma-screening of radiologically critical detector components for far detector used as inputs for radiological model**

- **Full-blown radiological model is condensed into one LArSoft producer file and provides input for SNB, DAQ simulations, cosmogenics, atmospheric ν's, ndk etc.**

^{39}Ar background



~3 kHz/PD

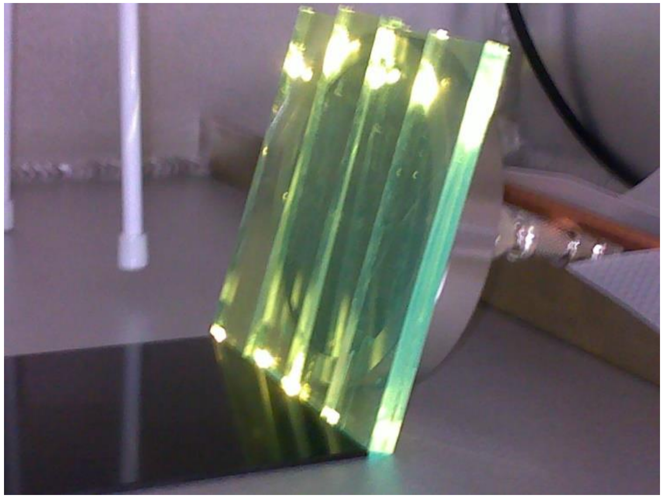
We want the threshold to be as low as possible, but then background is overwhelming

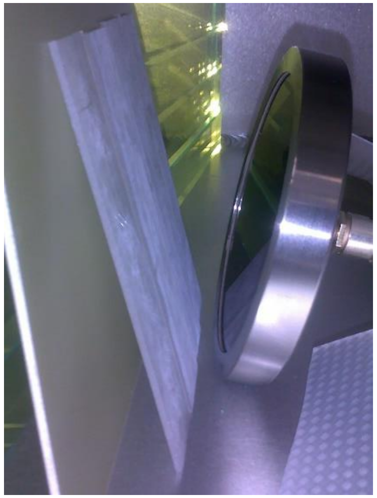
Thresh.	SN ε	Bkgd
2 PE	98%	81 kHz
5 PE	76%	1.3 kHz
10 PE	50%	20 Hz

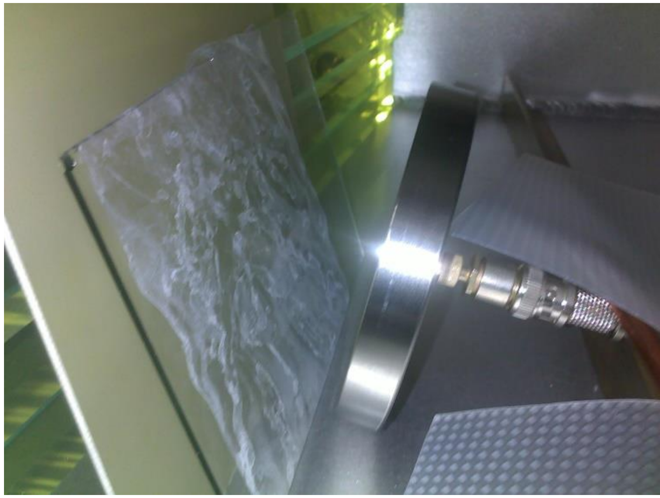
Ar-39 + Rn-222 background study

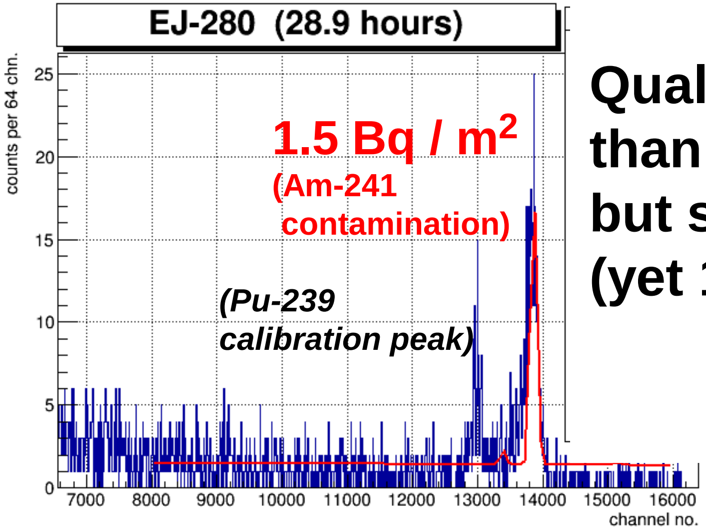
-> Rn-222 ~ Ar-39

Quality control (QC) by α/β–screening with AlphaBACH at SDSMT:





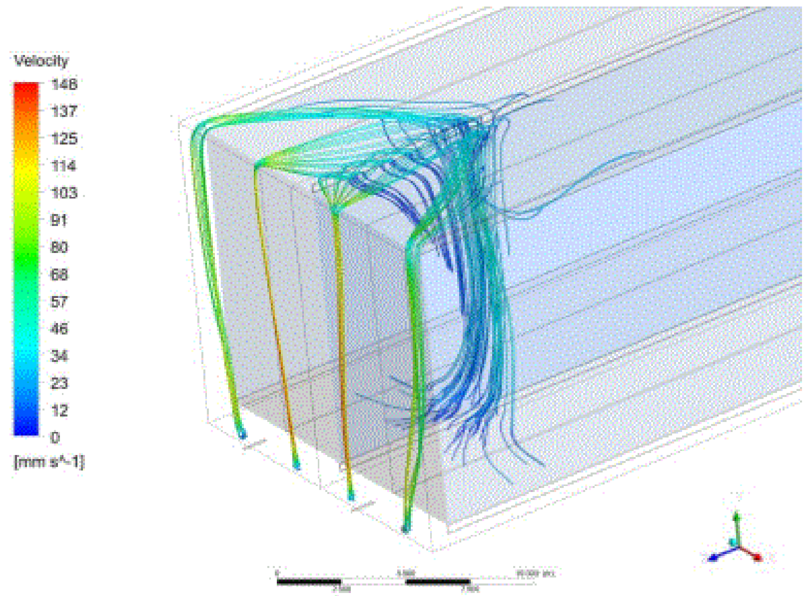




Quality Assurance (QA) much less stringent than for dark matter experiments, but still 1000x below NRC swipe sample sensitivity (yet 1000x above AlphaBACH sensitivity)

1) Detector Uniformity

DUNE/LBNF far detector single-phase
Distribute flow to 4 locations
(one injection pump at one end + manifold



⇒ **ensure uniform detector response: purity and electron lifetime (employ purity monitors)**

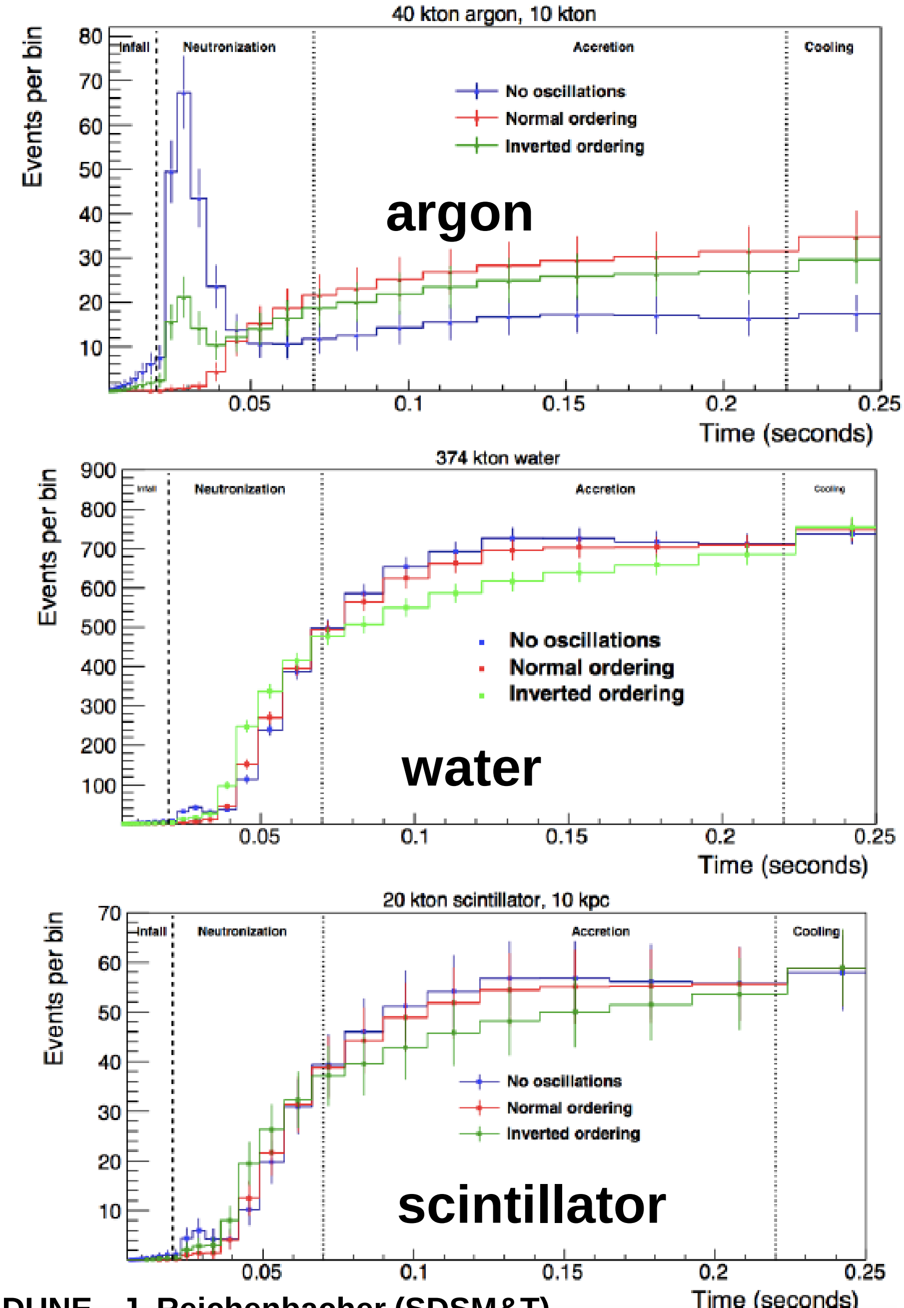
⇒ **impact of complicated flow pattern checked with fluid dynamic simulation (employ RTDs)**

1.) Supernova Neutrinos with DUNE

Same supernova model, other future large detectors

- neutronization burst much more visible in LAr
- time profile varies by hierarchy, differently for different detectors

$\Rightarrow$ ***We need LAr SNB detector!***



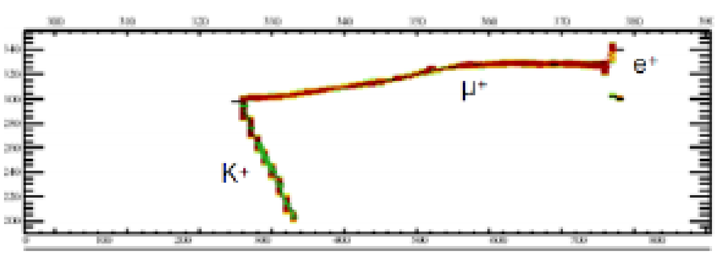
ν_e

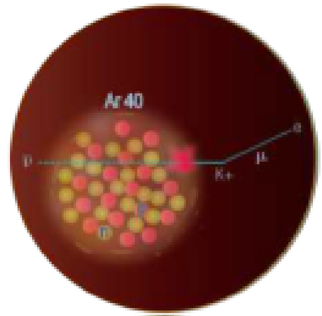
$\bar{\nu}_e$

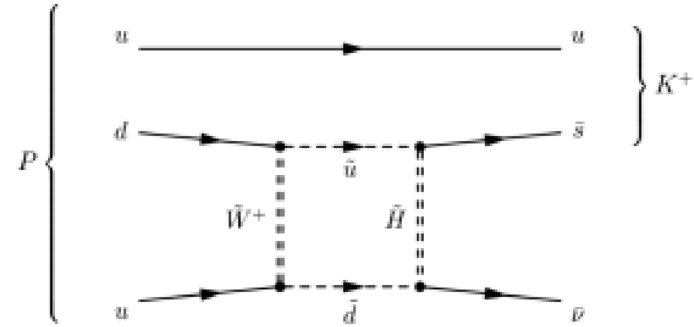
$\bar{\nu}_e$

2.) Nucleon Decay in DUNE

Grand Unified Theories predict the decay of protons and bound neutrons. The dominant proton decay mode in most supersymmetric GUTs is $p \to \overline{\nu} K^{+}$.







DUNE's golden proton decay mode!

-> see talk: K.S. Babu (proton decay theory)

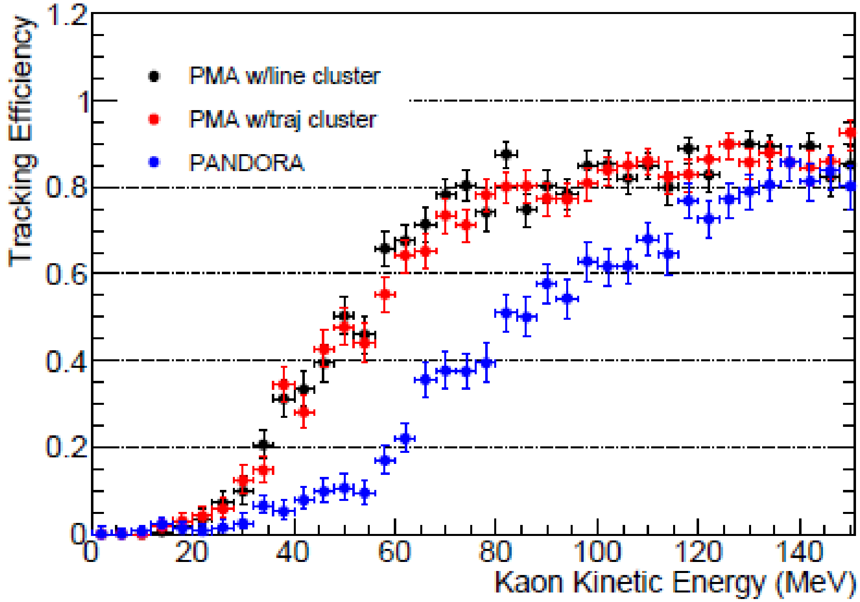
-> see talk: M. Miura (proton decay searches)

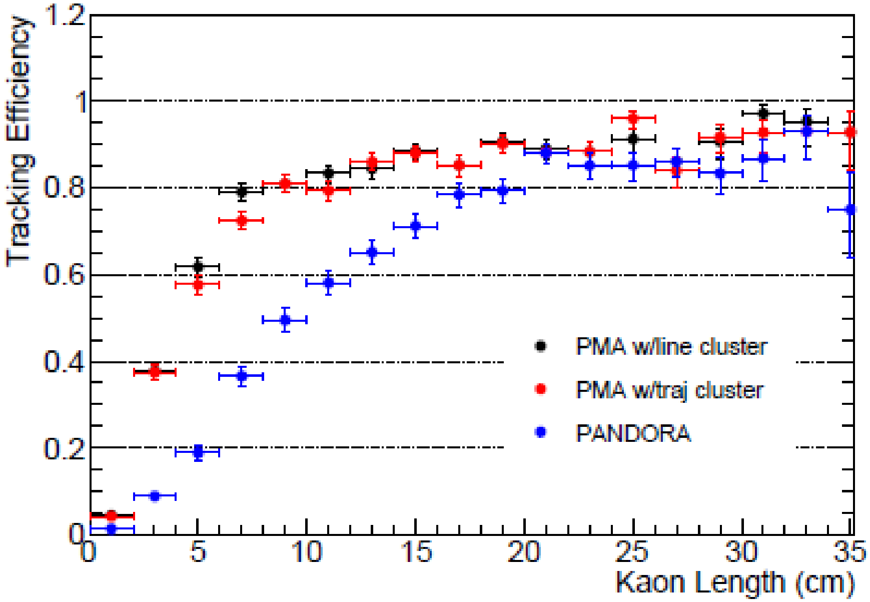
-> see talk: R. N. Mohapatra (GUTs, Neutrinos and Flavor Symmetries)

p -> $\overline{\nu}$ K^{+} in SUSY models connected to neutrino mixings and hence can test seesaw!

2.) Nucleon Decay in DUNE

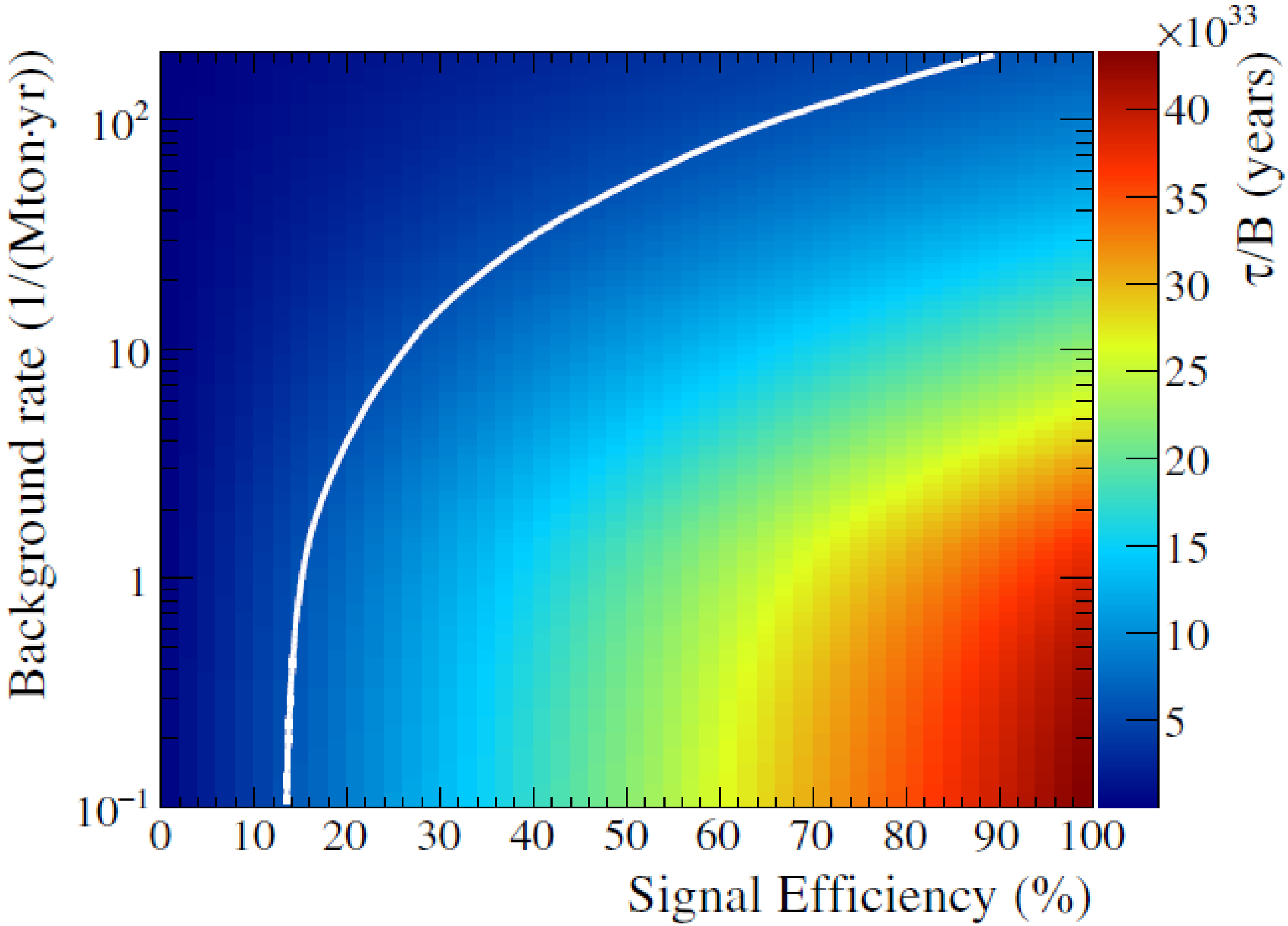
Proton Decay – DUNE Golden Mode





-> already doing a good job on K+ tracking efficiency (keep improving)

2.) Nucleon Decay in DUNE

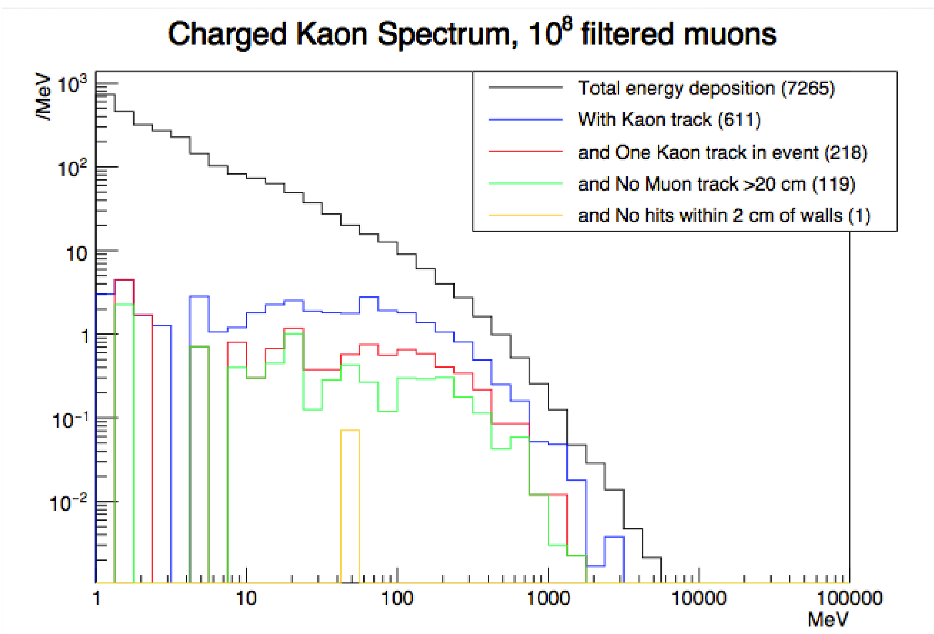


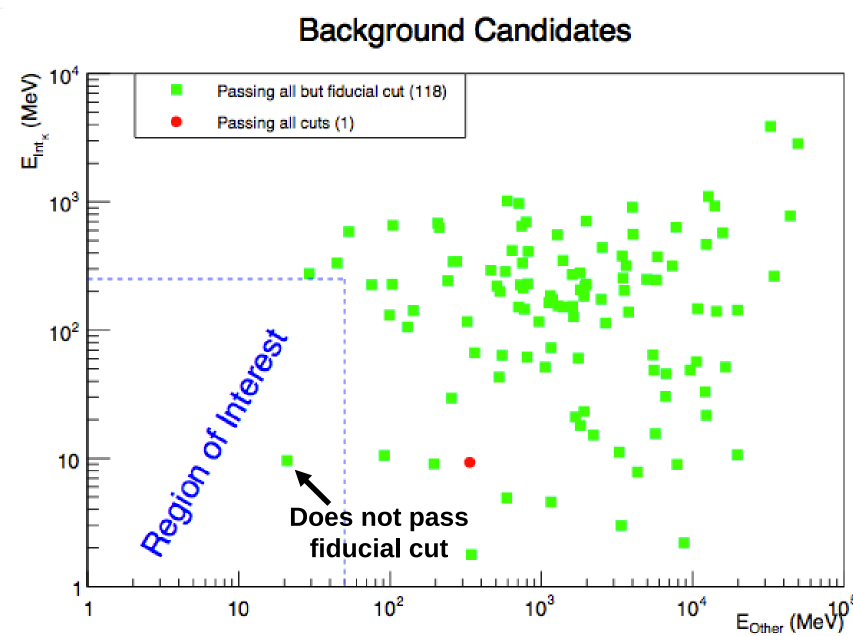
Partial lifetime sensitivity p -> $\bar{\nu}$ K$^+$ at DUNE, for a 400 kton year exposure and at 90% confidence level, as a function of background rate and signal efficiency (*compared to SK limit*)

Muon-Induced Backgrounds to Nucleon Decay

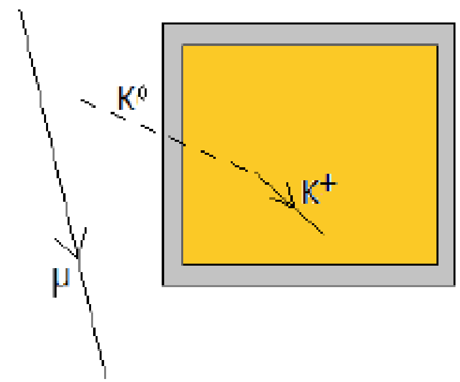
Goal: Simulate primary muons in rock above Far Detector, reconstruct particles that deposit energy in detector active volume, classify and quantify events.

- Simulated 10^8 muons (~20 years exposure)
- Applied basic selection cuts for νK^+
  - *No events pass all selection cuts in 20-yr sample*
  - Study BG events that pass all-but-one cut (fiducial or ROI)





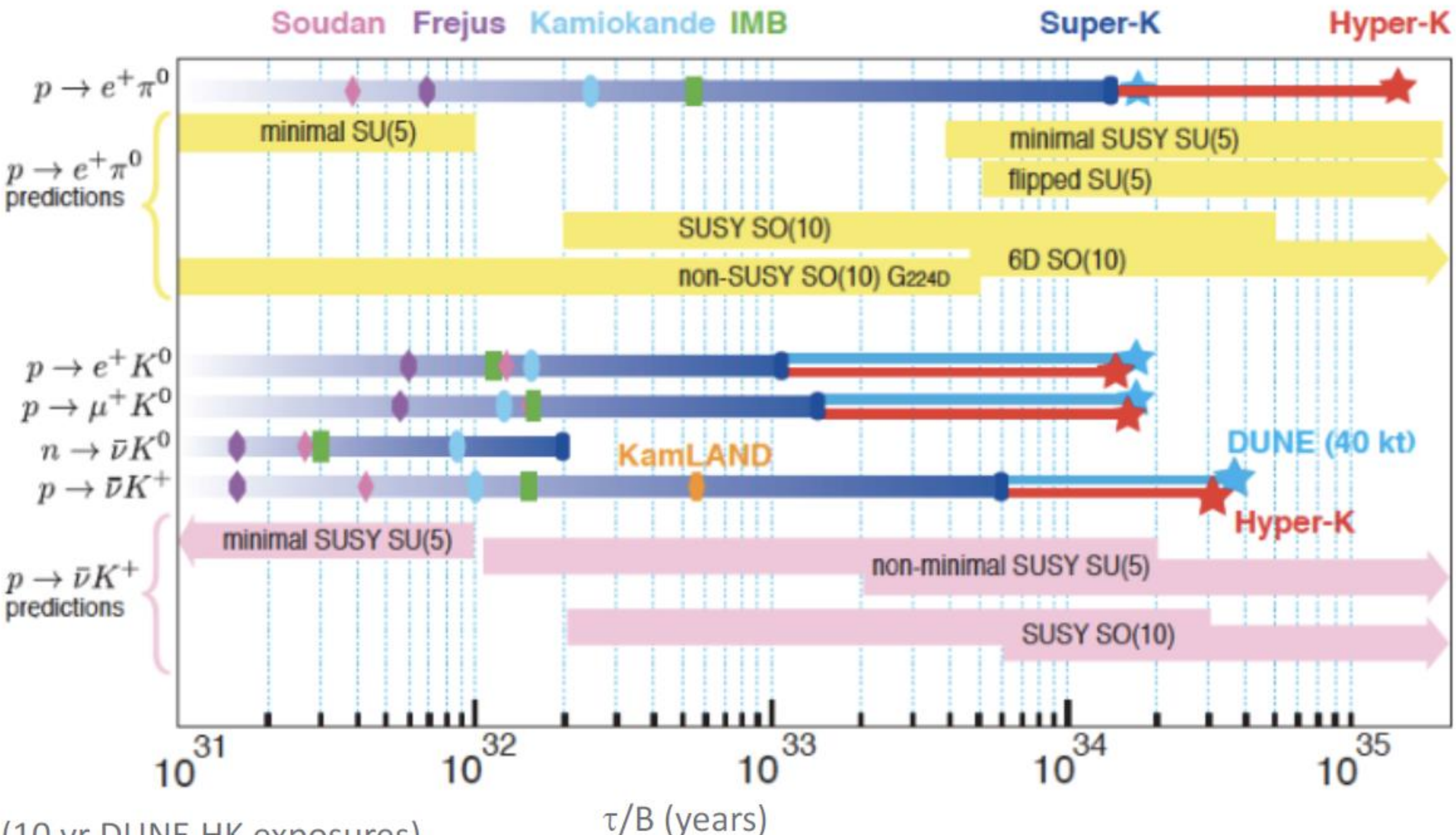
Muon-induced K^0_L passing all cuts (but not in ROI)



An example of a muon induced K^+ background event.

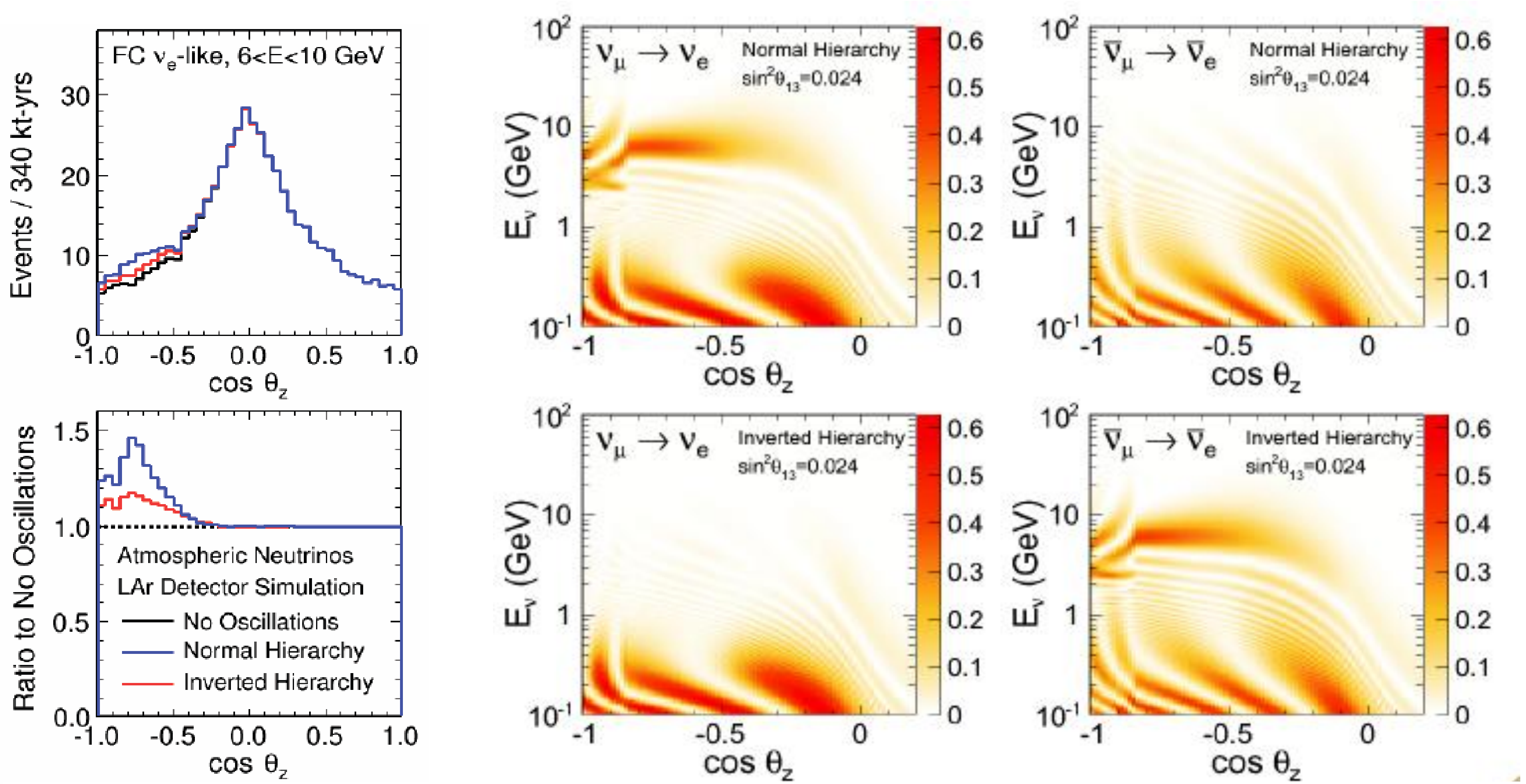
- cosmogenic backgrounds
- atmospheric ν NC and CC bck

2.) Nucleon Decay in DUNE



(10 yr DUNE,HK exposures)

3.) Atmospheric Neutrinos with DUNE

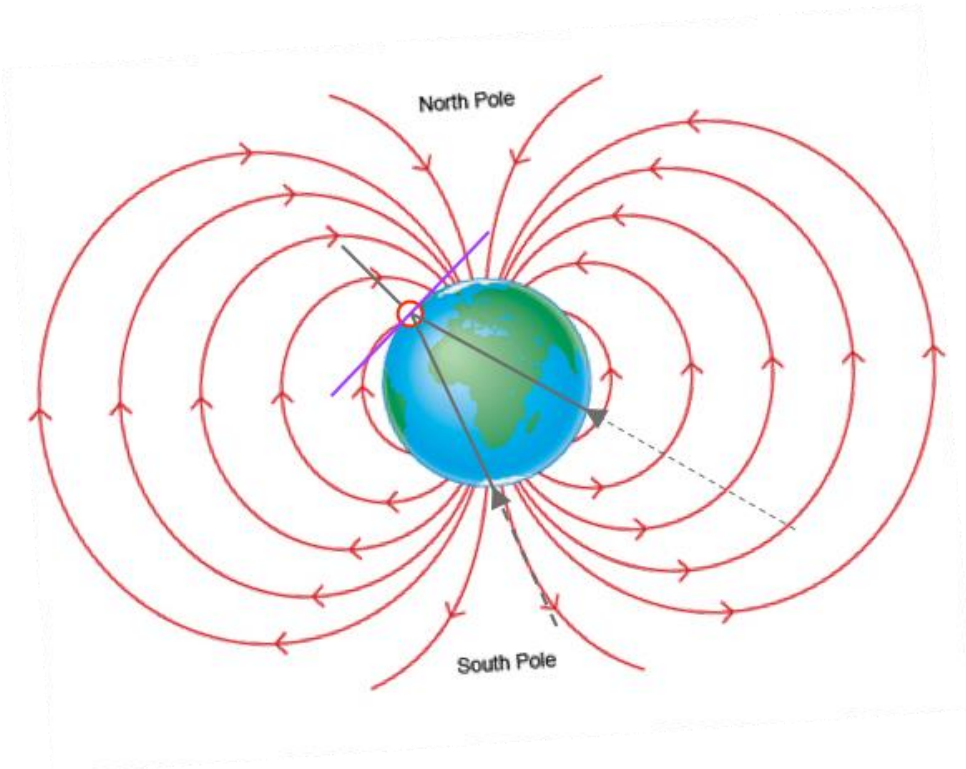


Upward-going multi-GeV neutrinos are sensitive to matter effects via MSW resonance:

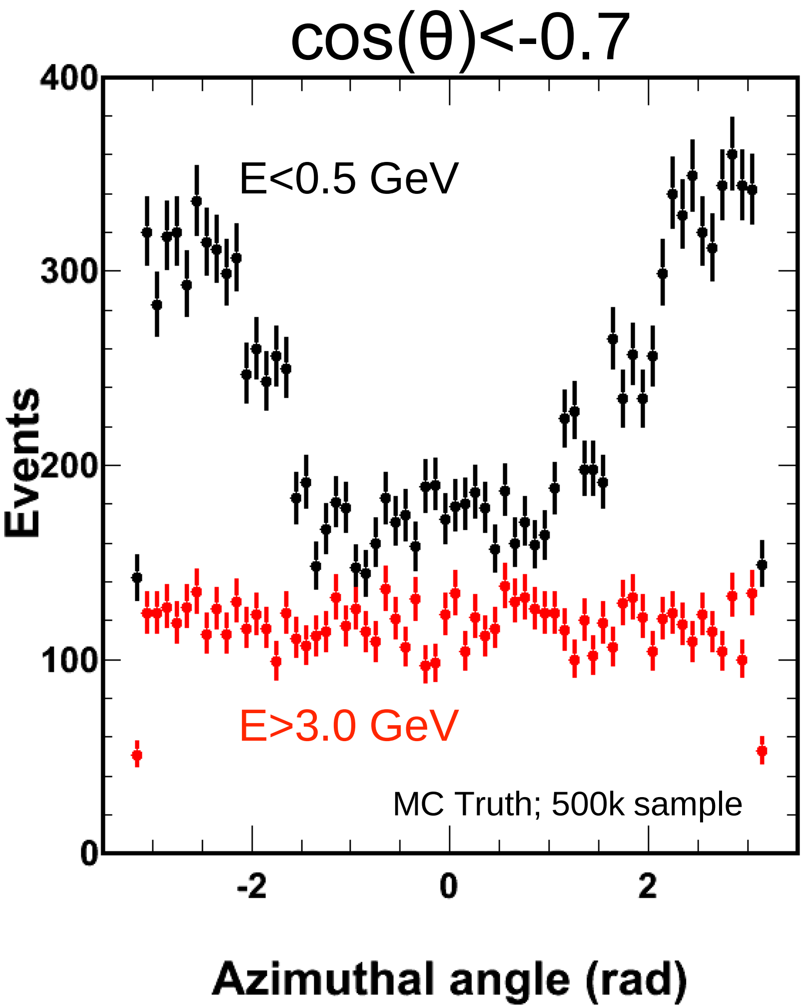
- Can probe neutrino mass hierarchy, θ_{23} octant and δ_{CP} phase
- Test standard oscillation model over multiple oscillation wavelengths
- Atmospheric neutrino data can help resolve ambiguities that arise in beam-only oscillation analyses

Atmospheric Neutrino Azimuthal Angle Distributions

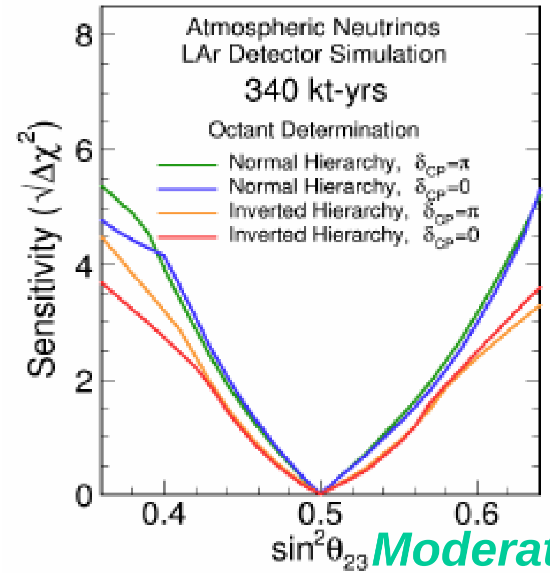
Goal: Provide an *in situ* measurement that demonstrates our ability to accurately determine neutrino direction.

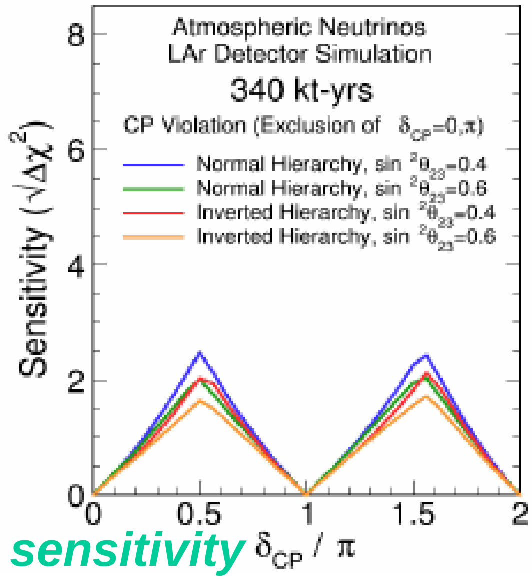


Less geomagnetic shielding
at the poles = more (low energy)
neutrinos from polar regions.



3.) Atmospheric Neutrinos with DUNE

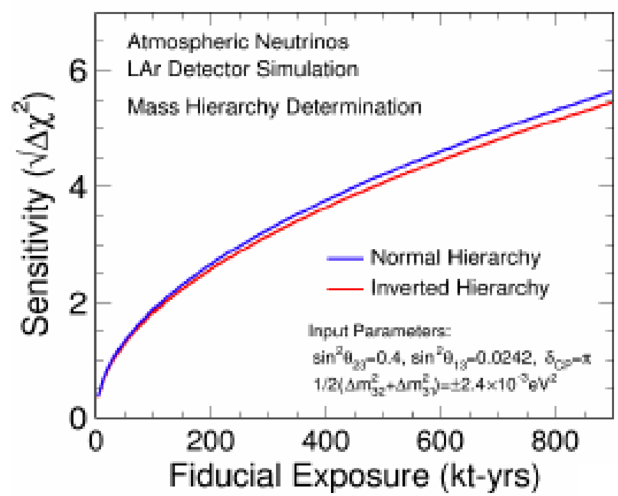




Sample	Events / 340 kt-yr
FC ν_e-like	13,651
FC ν_μ-like	20,257
PC ν_μ-like	6,675

Moderate sensitivity to octant and δ_{CP}

MSW resonance enables determination of MH:
- for ν MSW in case of NH
- for anti-ν MSW in case of IH
(nearly independent of δ_{CP}, unlike accelerator exp.)



DUNE MH sensitivity comparable to Hyper-K despite smaller mass
(better resolution of energy and angle)