Searching for the Sterile Wave:

A ν_μ-disappearance search using Kaon decay-at-rest

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Outline

- A proposal to look for signs of sterile neutrinos through a muon neutrino disappearance experiment, dubbed "KPipe"
- Briefly describe experimental anomalies that motivate sterile searches
- Describe KPipe: its design and sensitivity

The Puzzle

- A number of experiments see an unexpected deficit or excess of neutrino events

Experiment name	Type	Oscillation channel	Significance
LSND	Low energy accelerator	muon to electron (antineutrino)	3.8σ
MiniBooNE	High(er) energy accelerator	muon to electron (antineutrino)	2.8σ
MiniBooNE	High(er) energy accelerator	muon to electron (neutrino)	3.4σ
Reactors	Beta decay	electron disappearance (antineutrino)	1.4-3.0σ (varies)
GALLEX/SAGE	Source (electron capture)	electron disappearance (neutrino)	2.8σ

The Puzzle

- Interpretable as coming from sterile neutrino oscillation with Δm^2 around 0.1-10 eV^2

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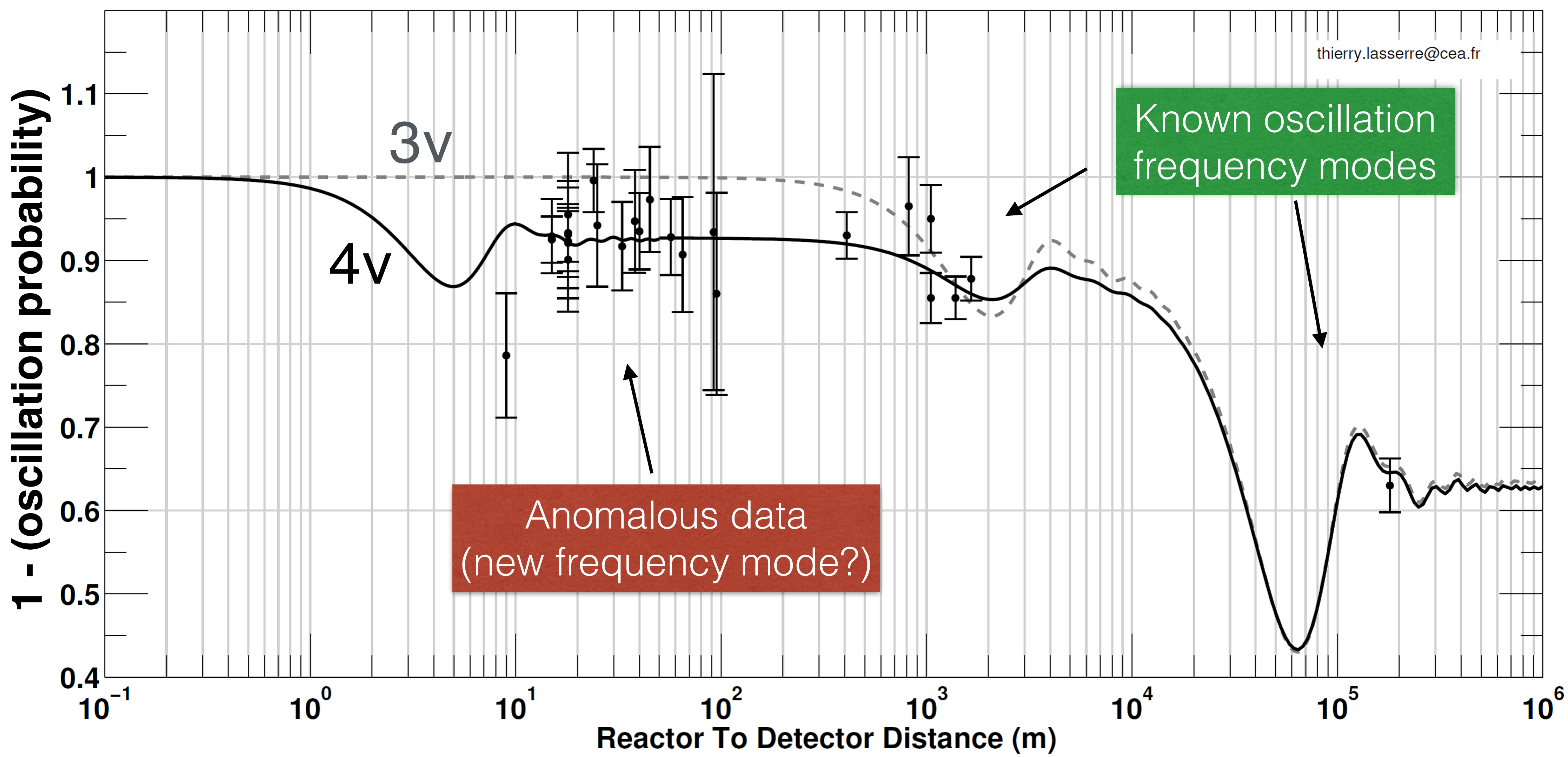
Ex. Reactor Anomaly

- Reanalysis of old reactor data sets show observed events is lower than expectation

$$P(\bar{\nu}_e \to \bar{\nu}_e)$$



Future Experiments

- Anomalies motivating experiments to verifying each type of anomaly directly

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Remeasuring reactor ν's, e.g. Nucifer, Prospect		electron disappearance (antineutrino)	1.4-3.0σ (varies)
High intensity ν sources, e.g. SOX, CeLAND, etc.		electron disappearance (neutrino)	2.8σ

Future Experiments

- Experiments probing (anti-)ν_e oscillations
- Is there a complimentary approach?

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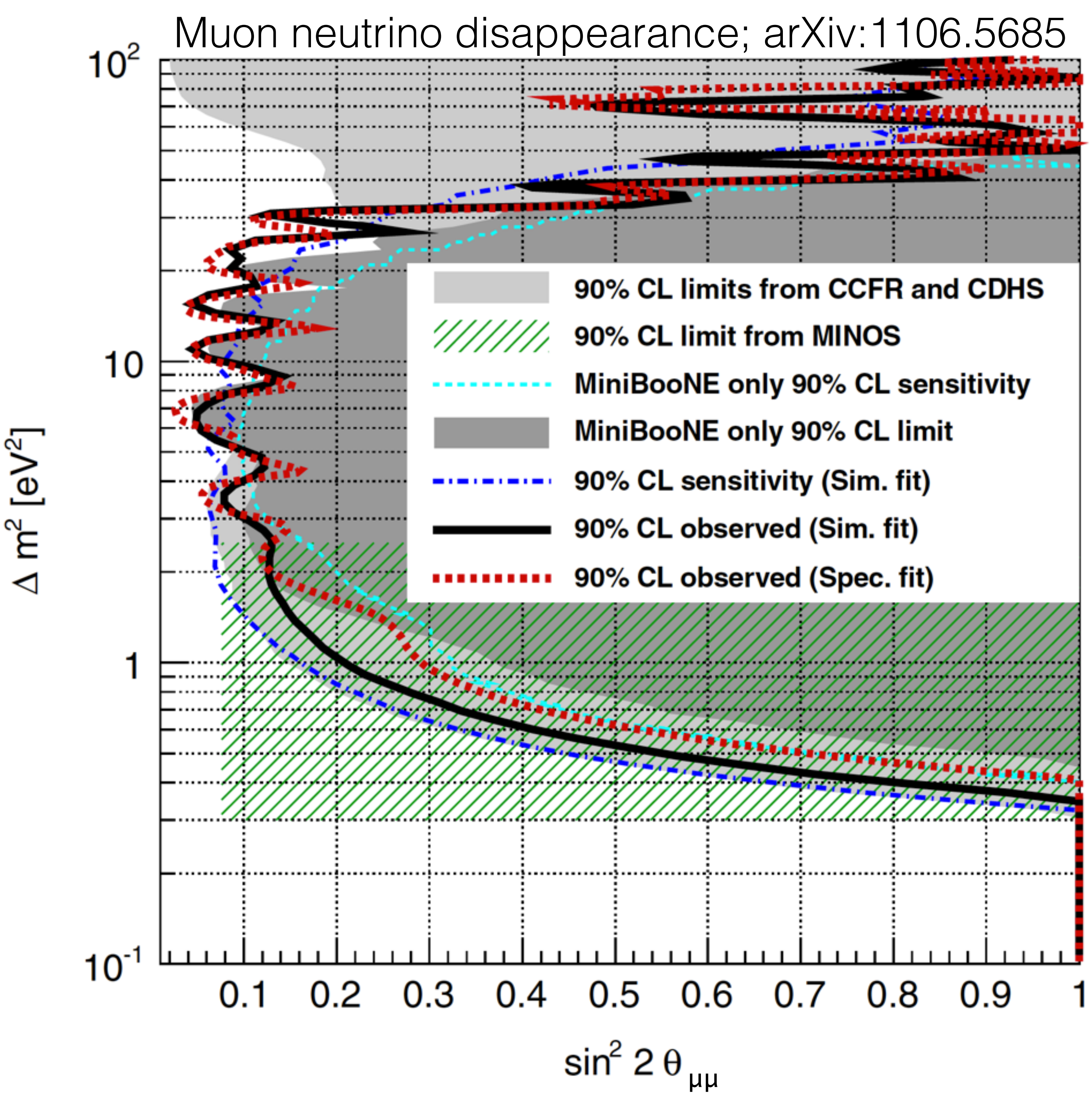
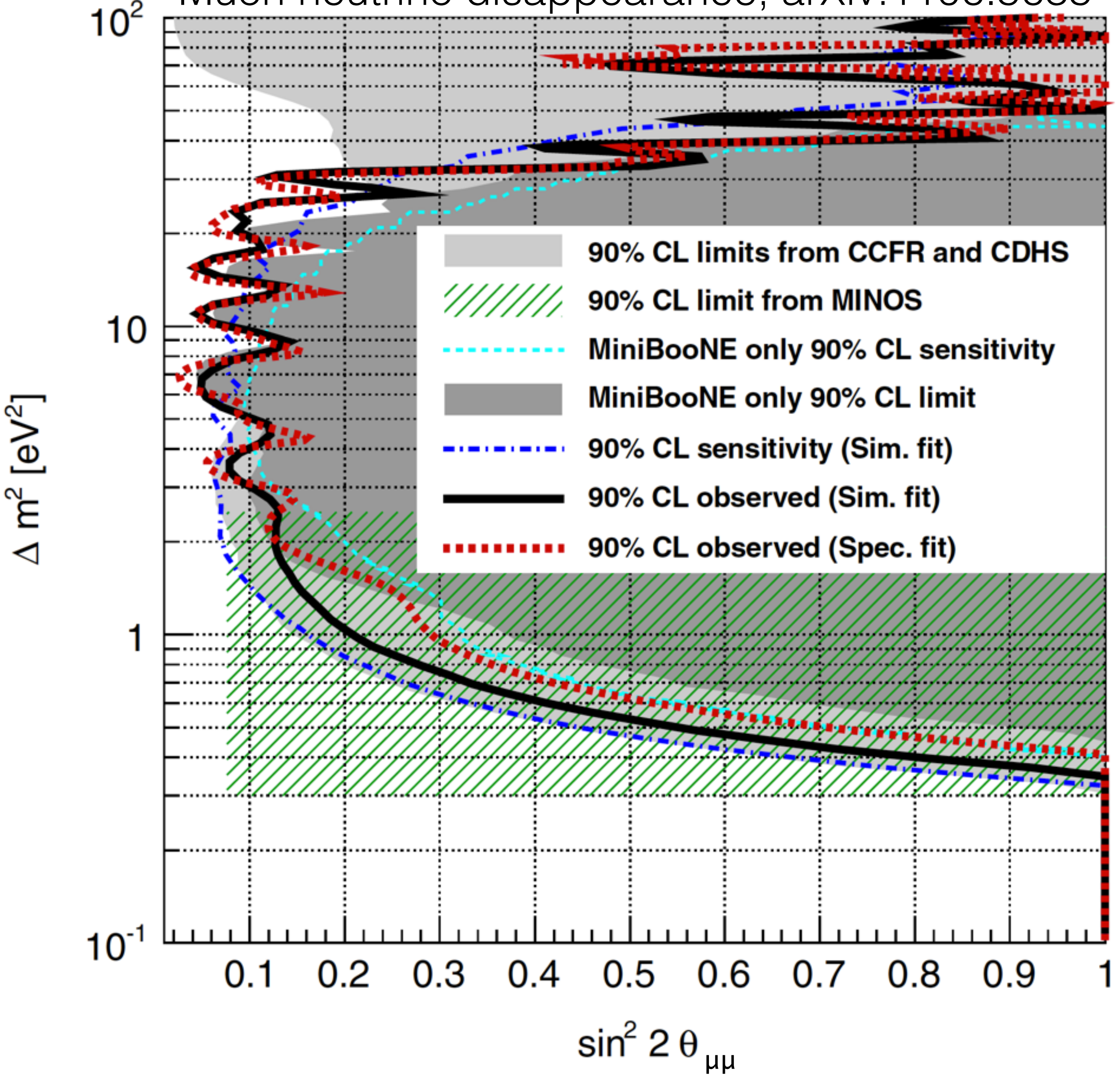
Muon Neutrino Disappearance



- Not all experiments see anomalies
- In fact, no experiment has seen muon neutrino disappearance
- An important constraint

Muon Neutrino Disappearance

Muon neutrino disappearance; arXiv:1106.5685



- If sterile neutrinos exist, there must be some amount of muon neutrino disappearance!

A proposal, with constraints

- A call for proposals from the DOE at the WINP workshop (Feb 2015)
- Must satisfy the following:

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    - be a fraction of 10 million dollars

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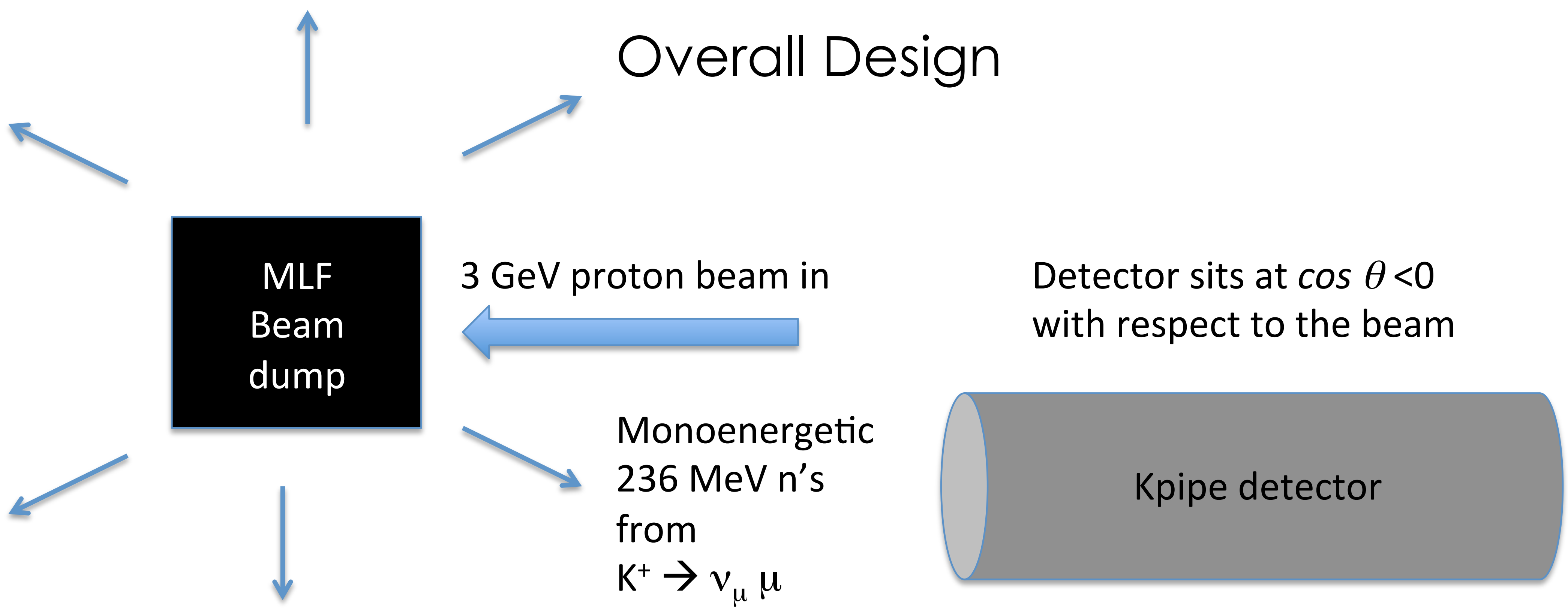
- Must satisfy the following:
  - Not associated with Fermilab program (e.g. SBN)
  - Decisive within 3 years of running
  - be a fraction of 10 million dollars
- Present such a proposal

KPipe

Overall Design

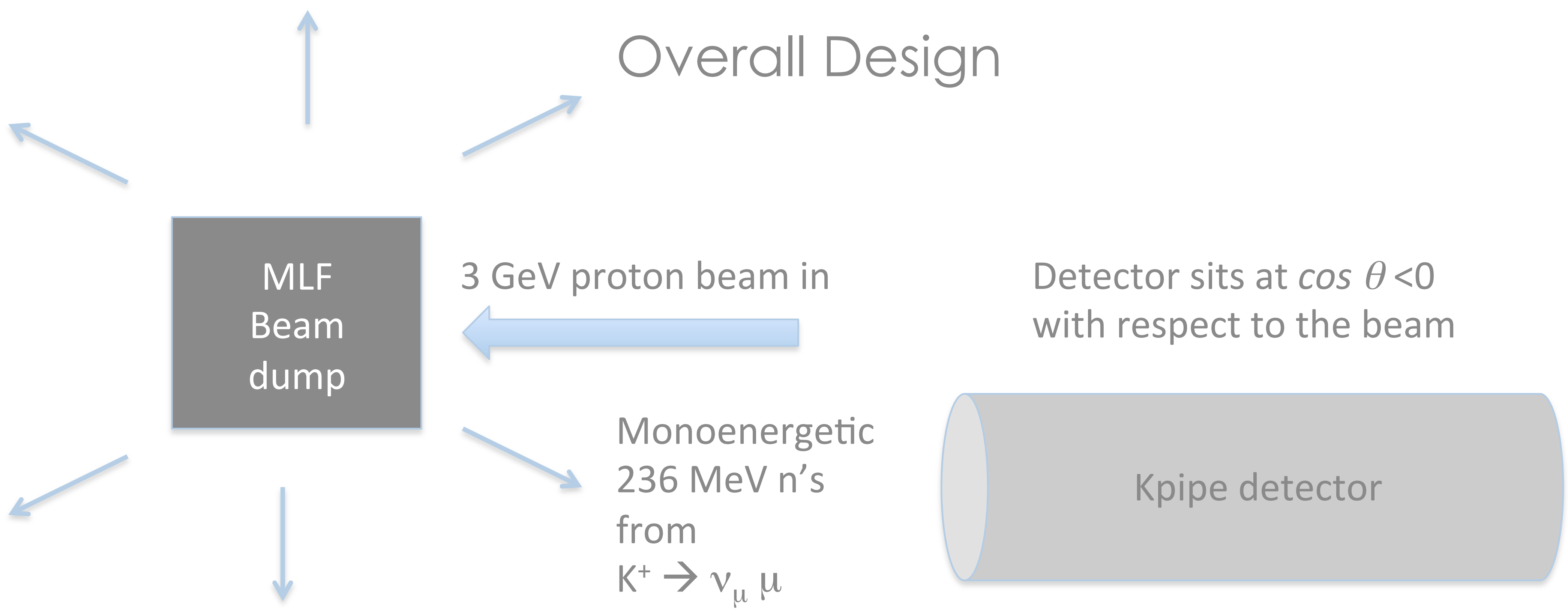


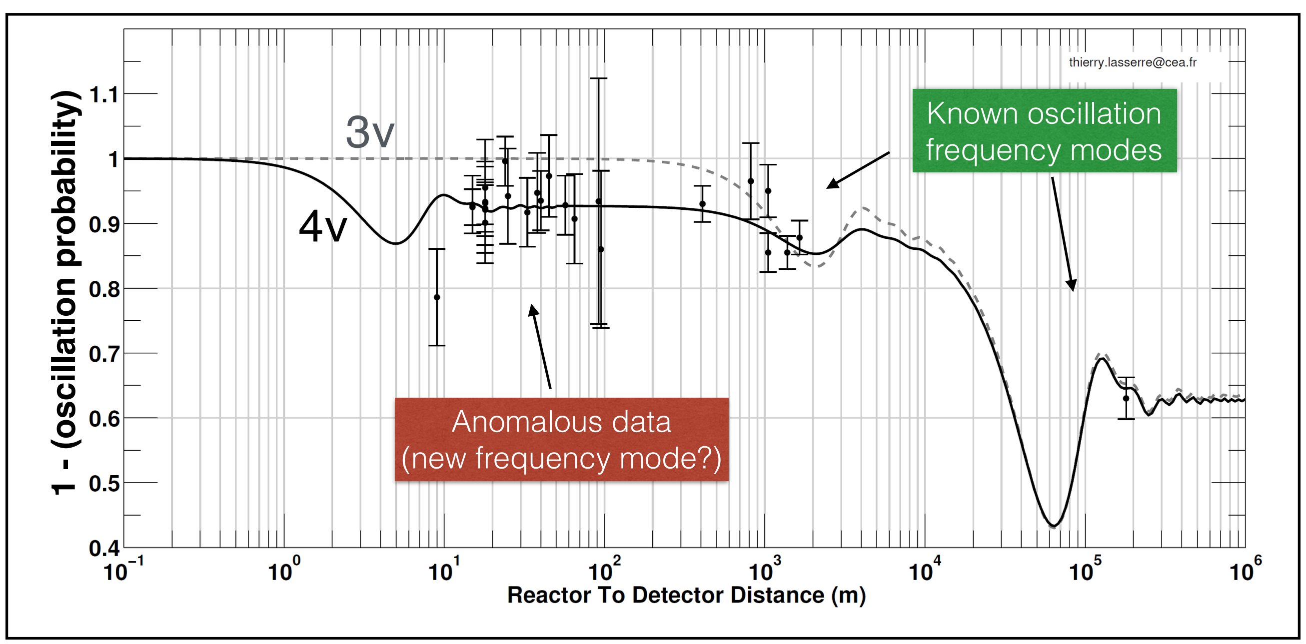
(1) pure, mono-energetic flux of muon neutrinos

(2) long detector to measure the oscillation wave

KPipe

Overall Design

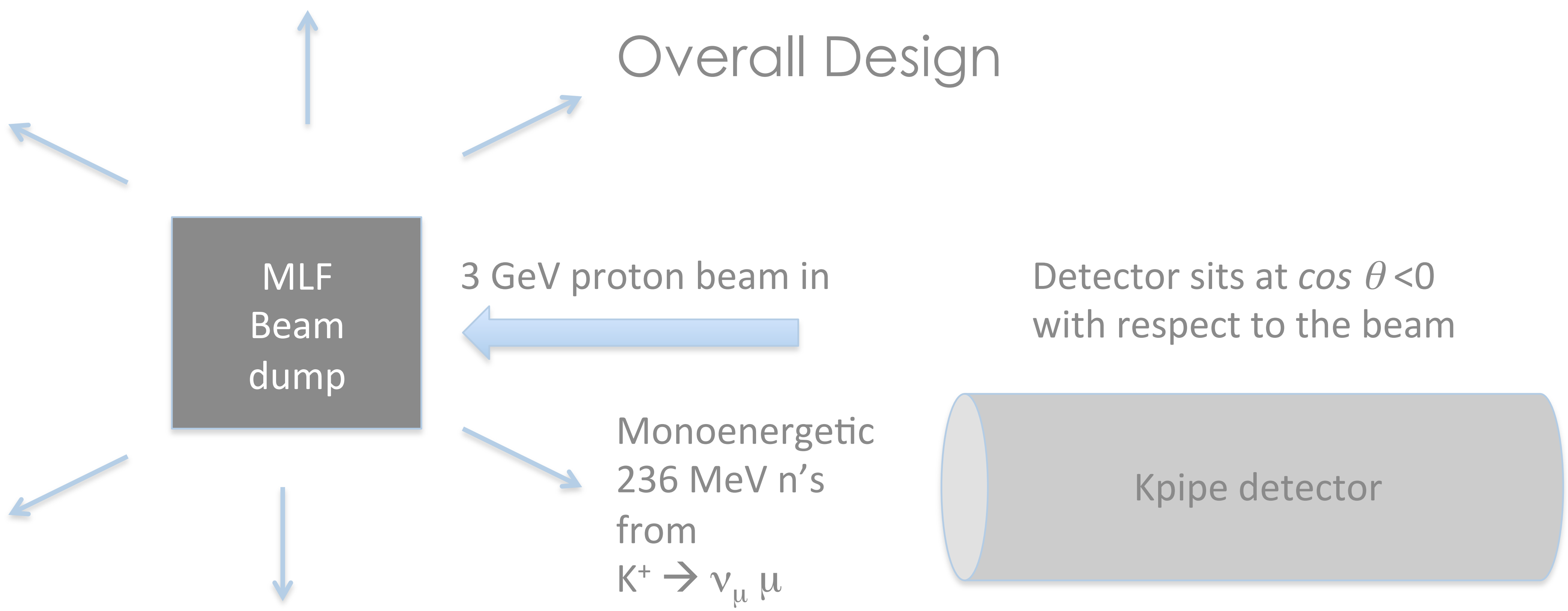


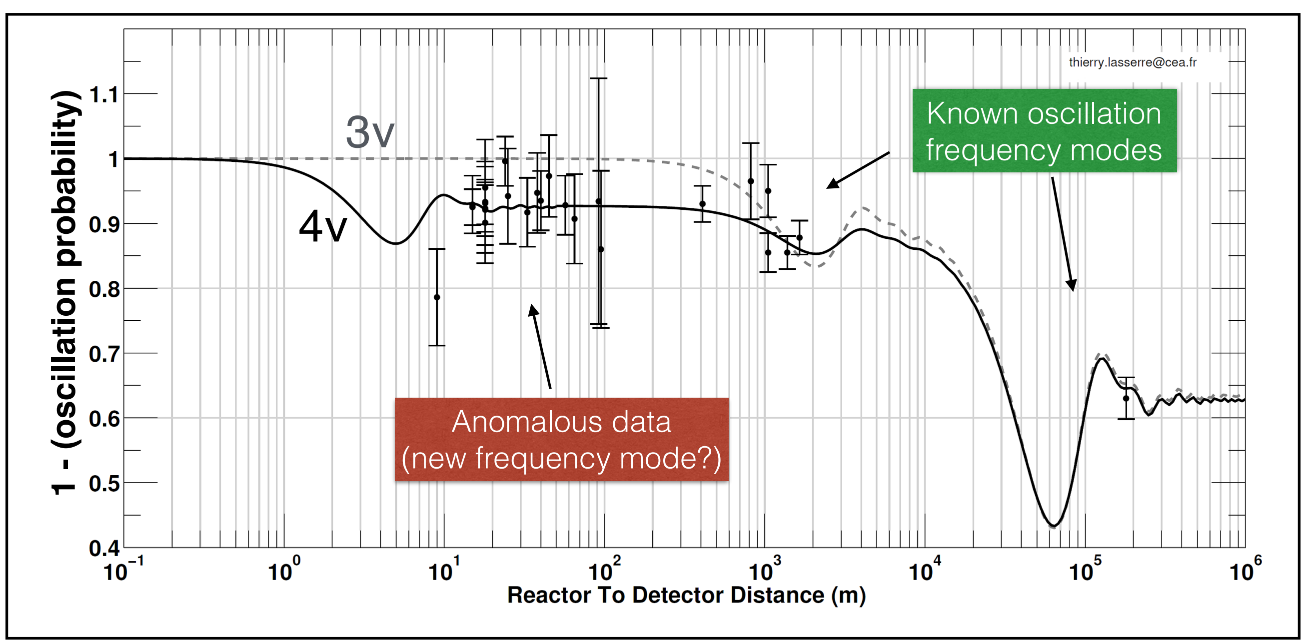


- The aim is to produce data analogous to the reactor anomaly plot — except all in one detector

KPipe

Overall Design

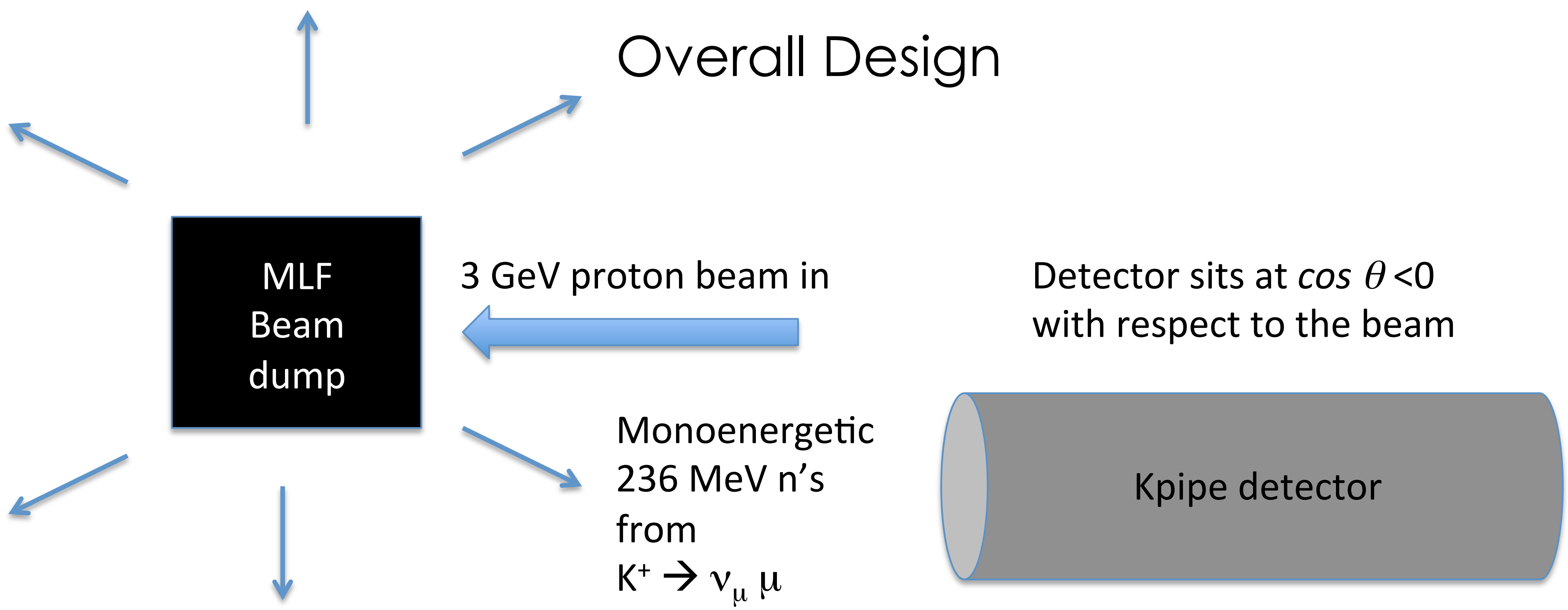




- If signs of steriles are seen, would also have info. about different frequency modes - thus number of steriles

KPipe

Overall Design



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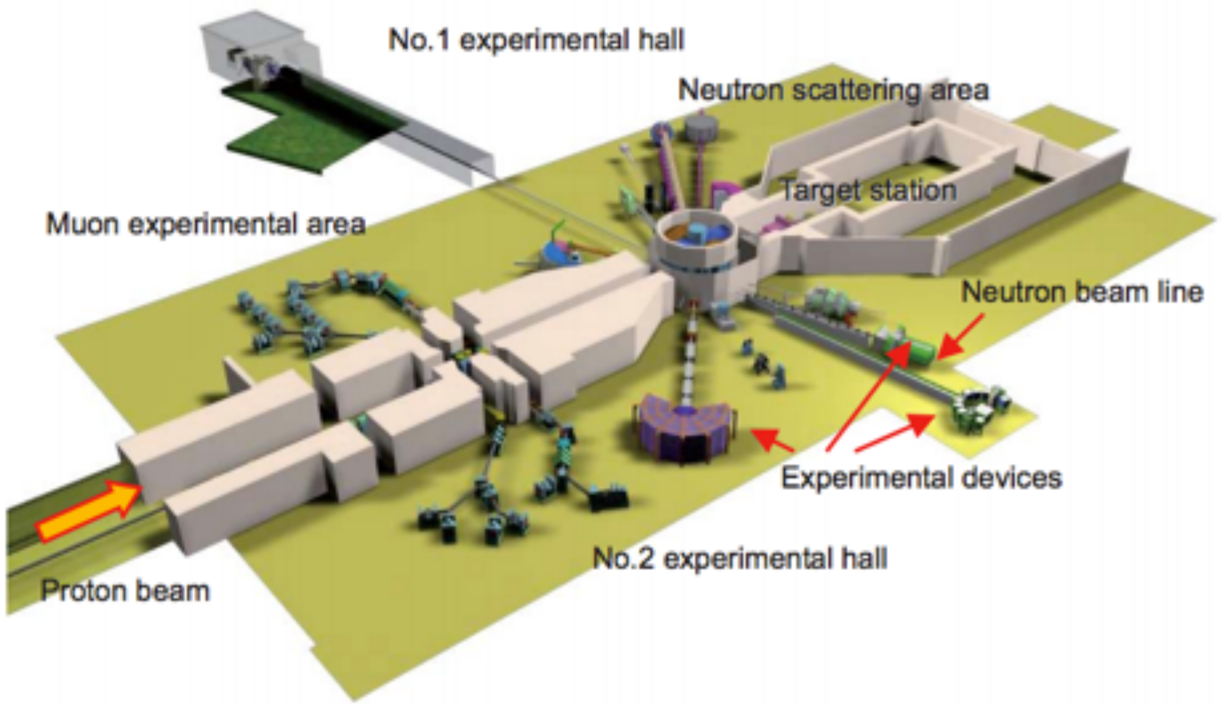
(2) long detector to measure the oscillation wave

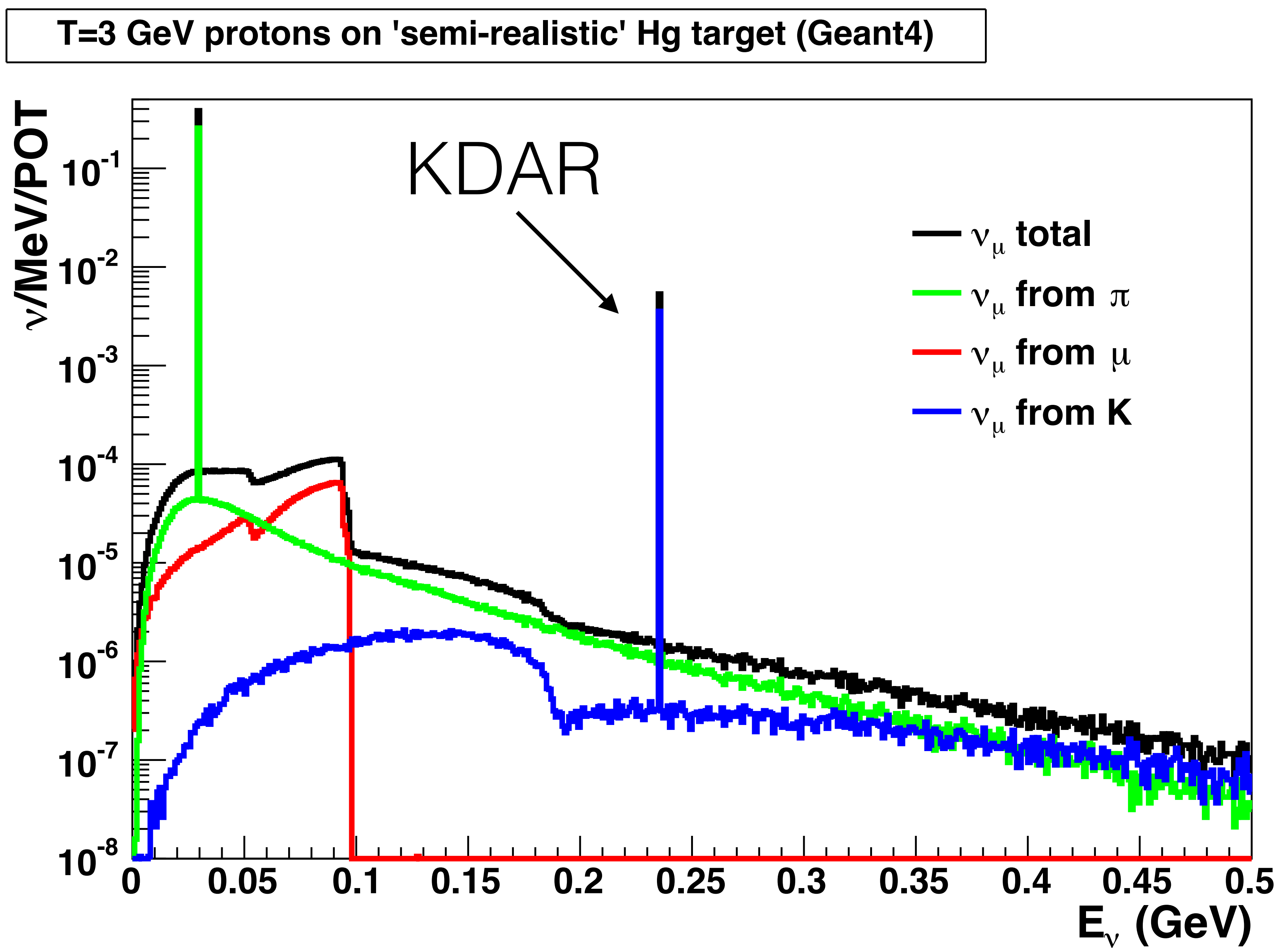
JPARC MLF



- Beam at Materials and Life Science Facility at JPARC
- 3 GeV protons on Hg
- target power: 1 MW
- pulsed with tight beam windows:
  2 pulses with 80 ns width, 540 ns apart at 25 Hz

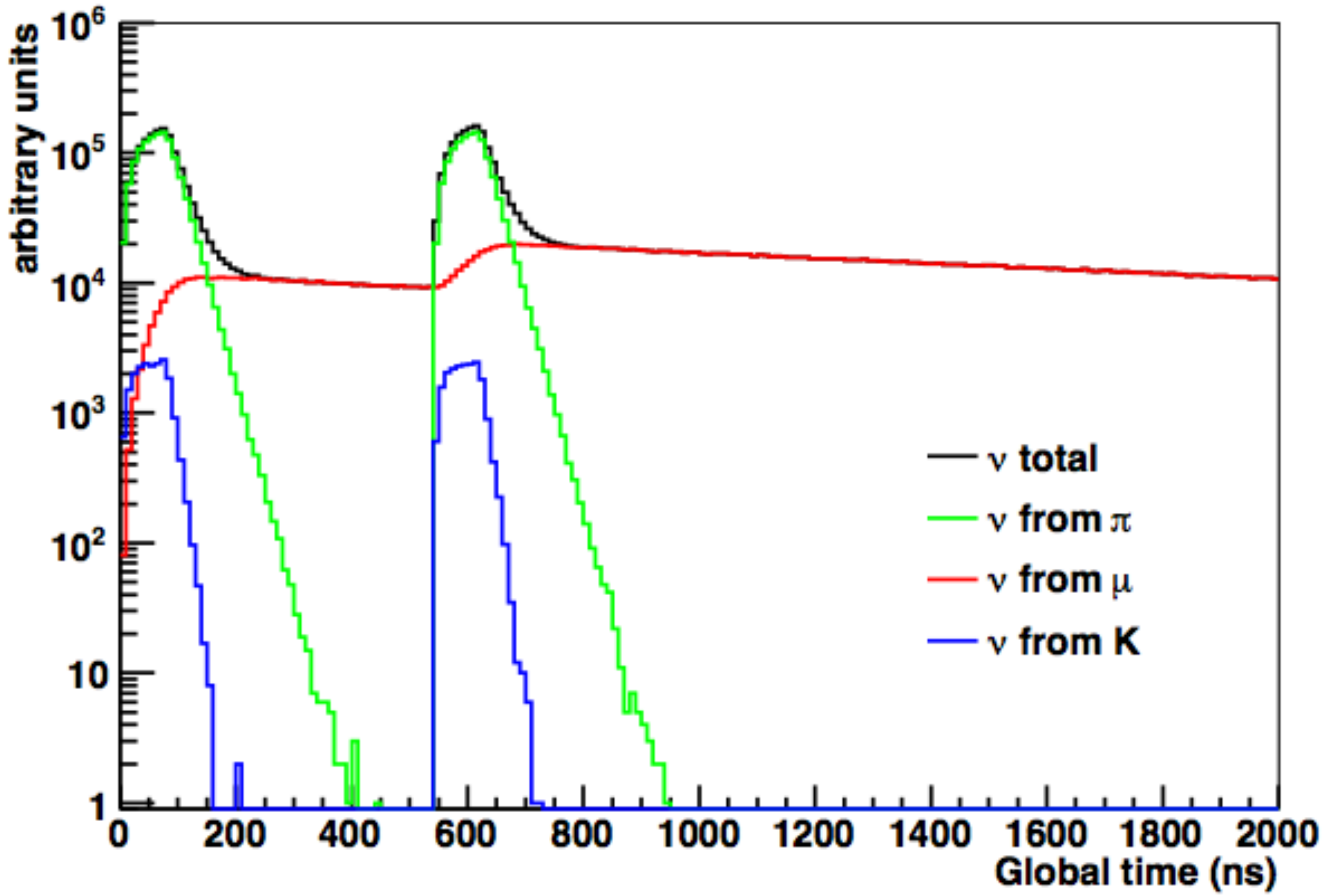
JPARC MLF

- Our flux simulation: 3 GeV protons hitting Hg target

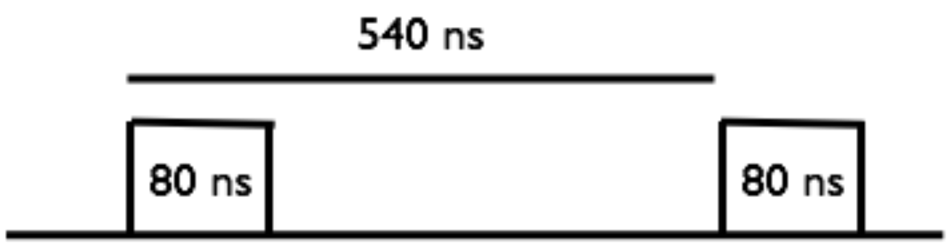


KDAR neutrinos: Energy known exactly

Beam Timing



- Timing of neutrinos should be well-known
- Look for interactions coming from neutrinos in the two windows

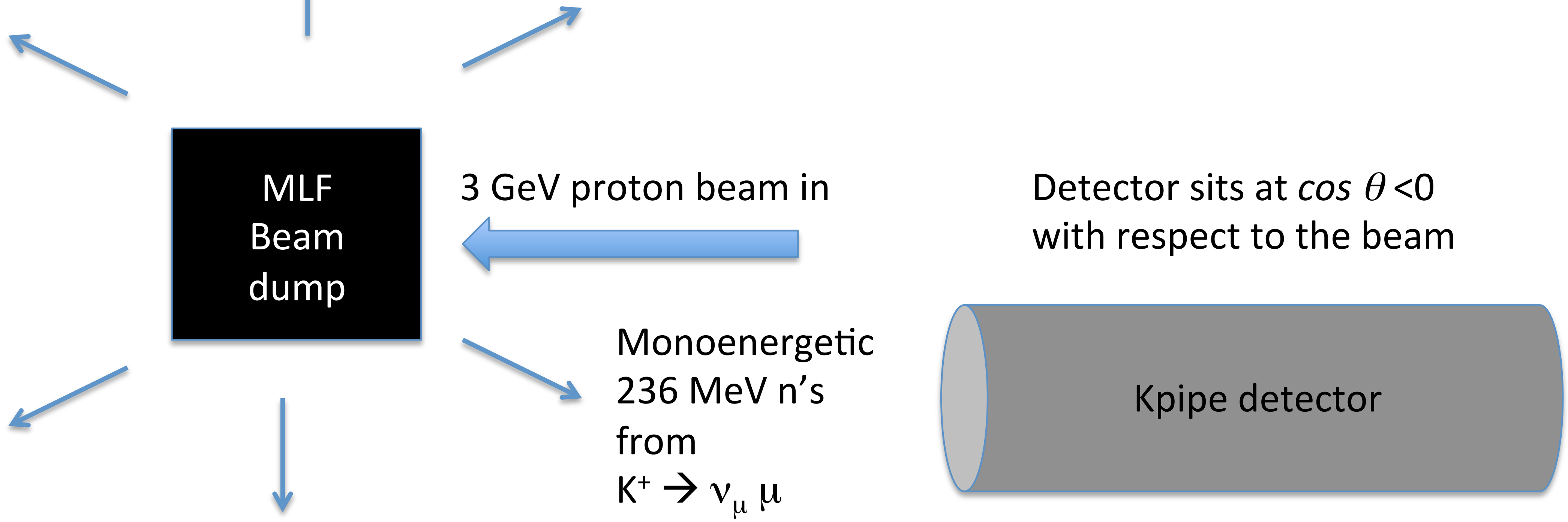


Beam structure

25 Hz

KPipe

Overall Design

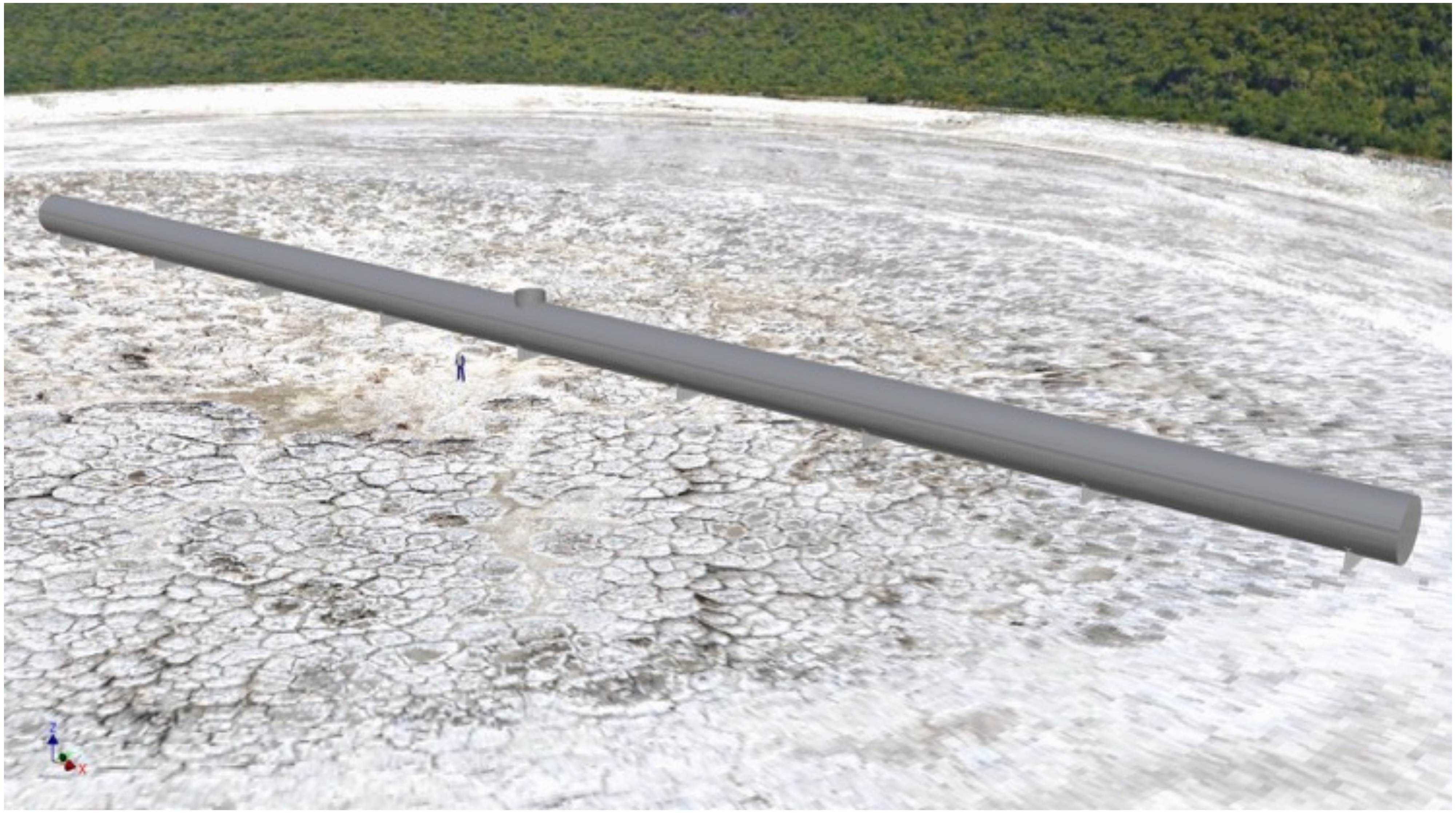


(1) pure, mono-energetic flux of muon neutrinos

(2) long detector to measure the oscillation wave

Detector

- A (BIG) pipe, 3 m diameter and 120 m long, filled with liquid scintillator

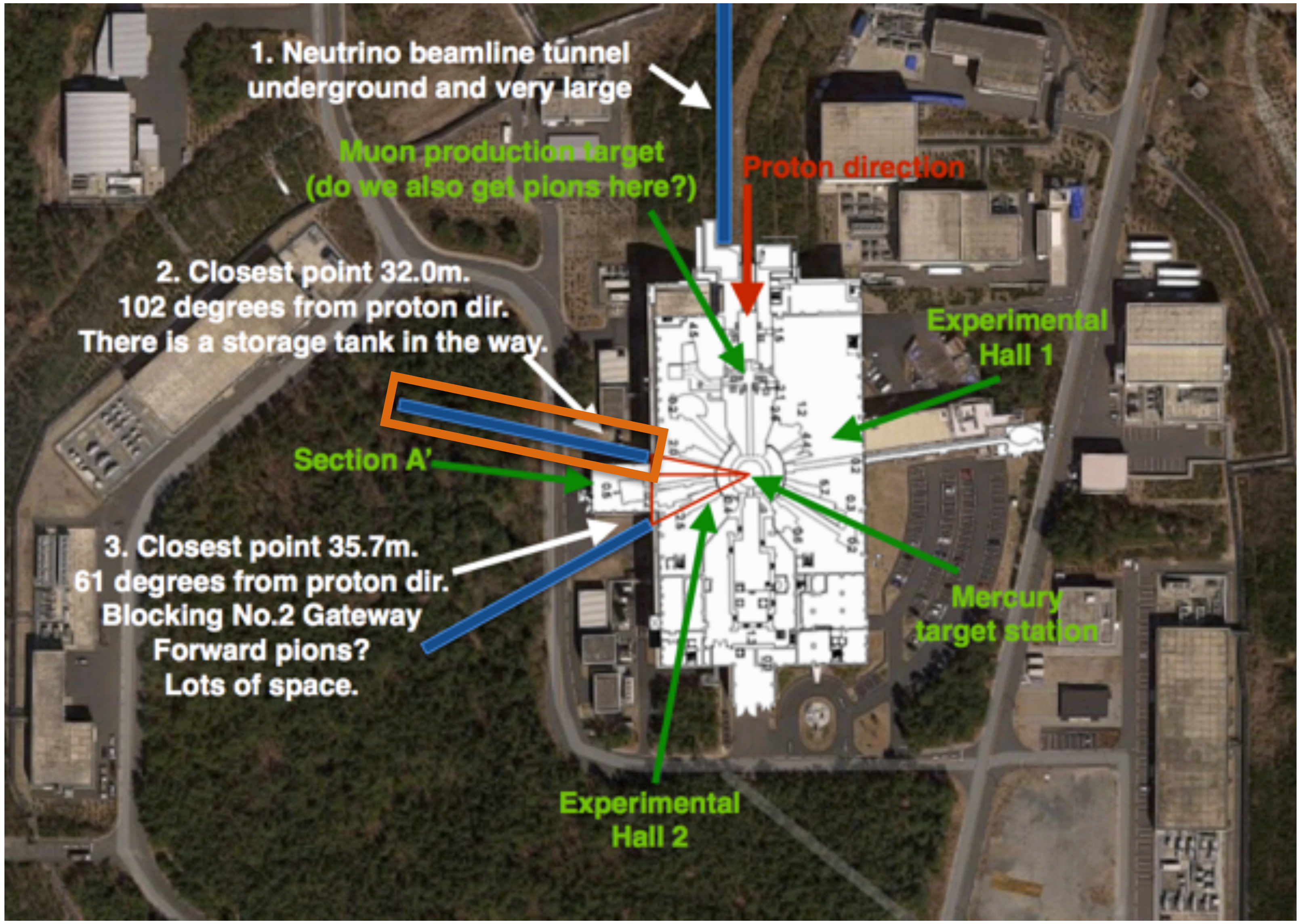


Detector Location

Studied possible locations of pipe around MLF building

Chose location (highlighted in orange) based on sensitivity and available space

Want to be as close as possible to maximize rate



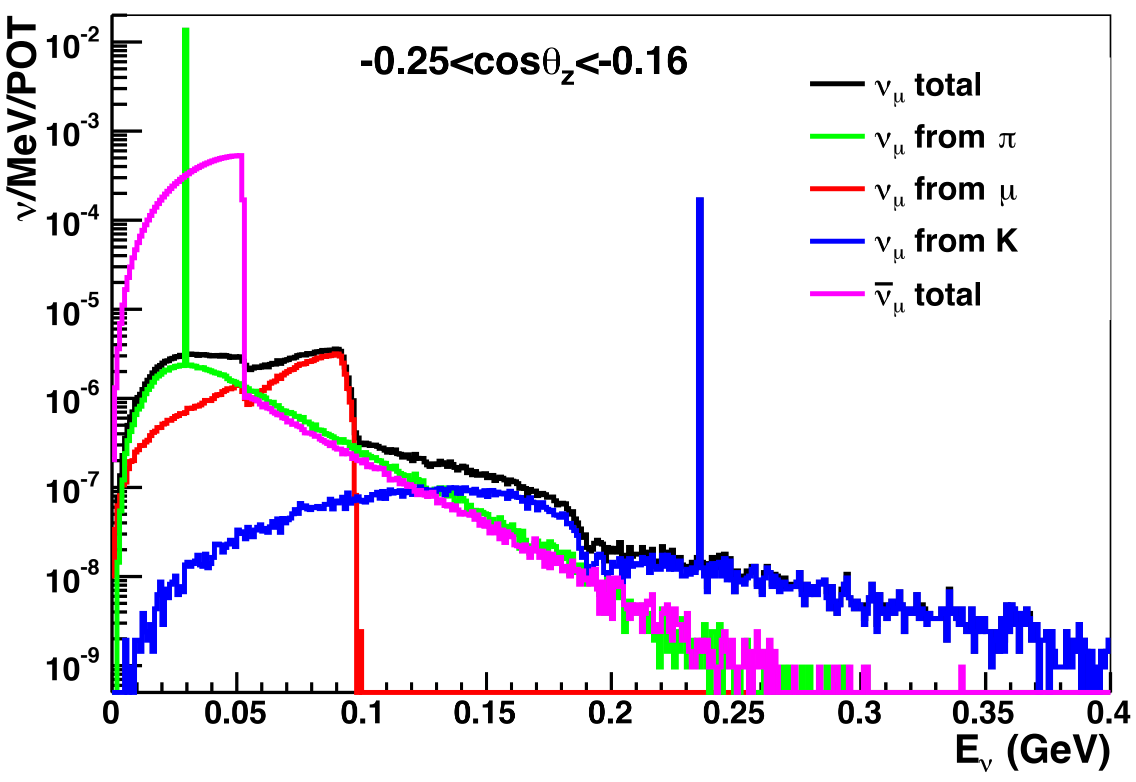
Detector Vessel

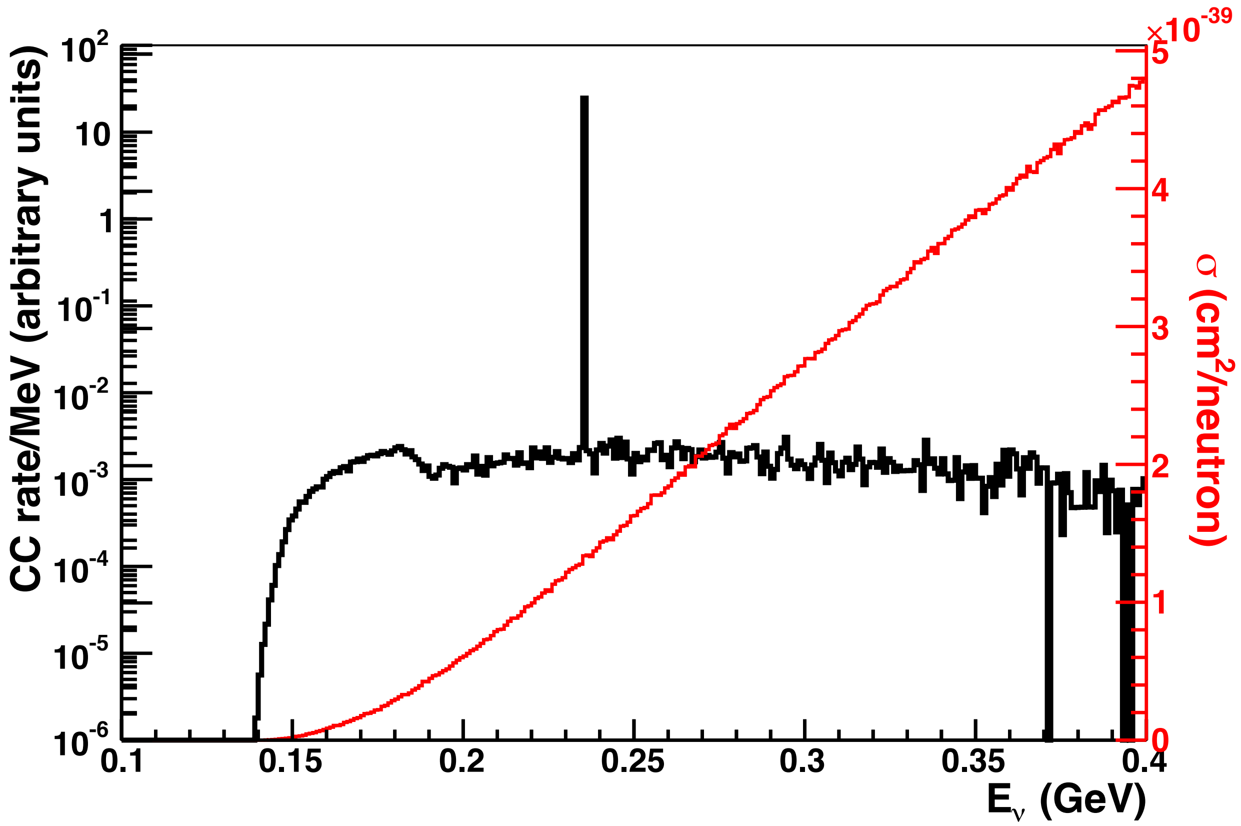
- Such a big stainless pipe is likely very expensive
- Idea: try and use high density polyethylene vessel
- used for sanitation, irrigation, wastewater

DuroMaxx® – Steel Reinforced Polyethylene Technology

Event Rate

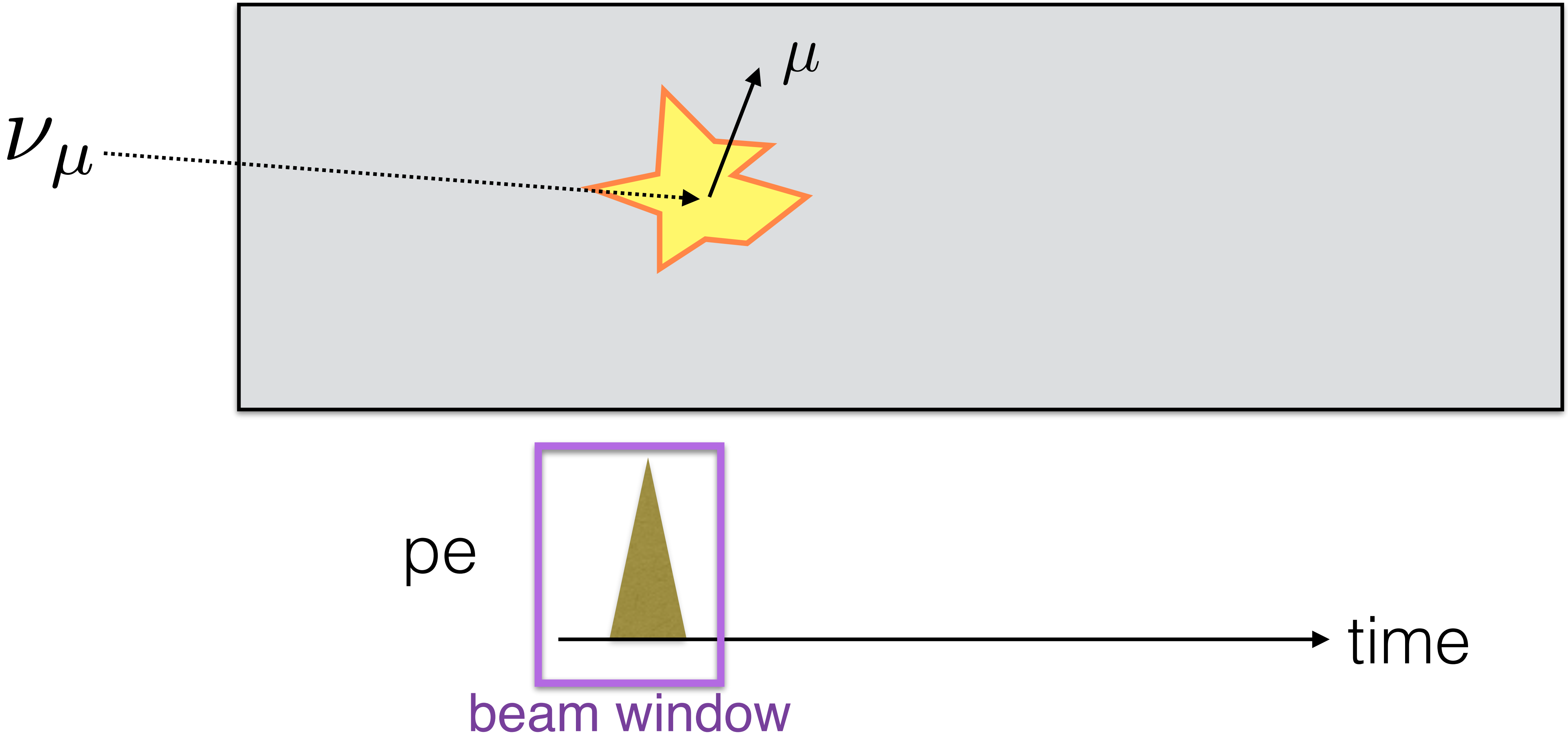
- Looking for numu CCQE interactions
- CCQE cross-section and muon production threshold suppresses much of the non-KDAR neutrino flux
- 98% of interactions will be KDAR neutrinos





Detector Signal

- What we are after:



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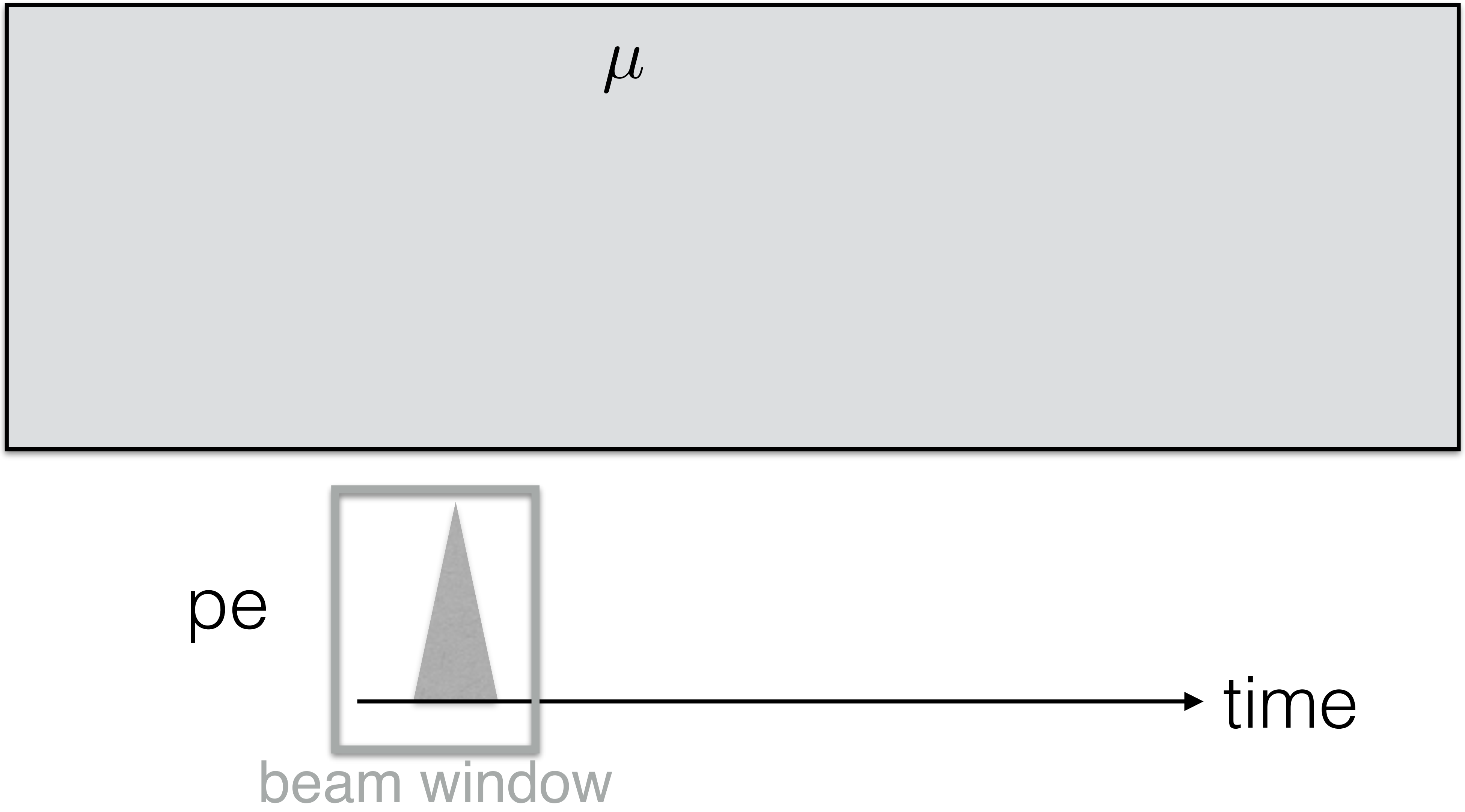

Detector Signal

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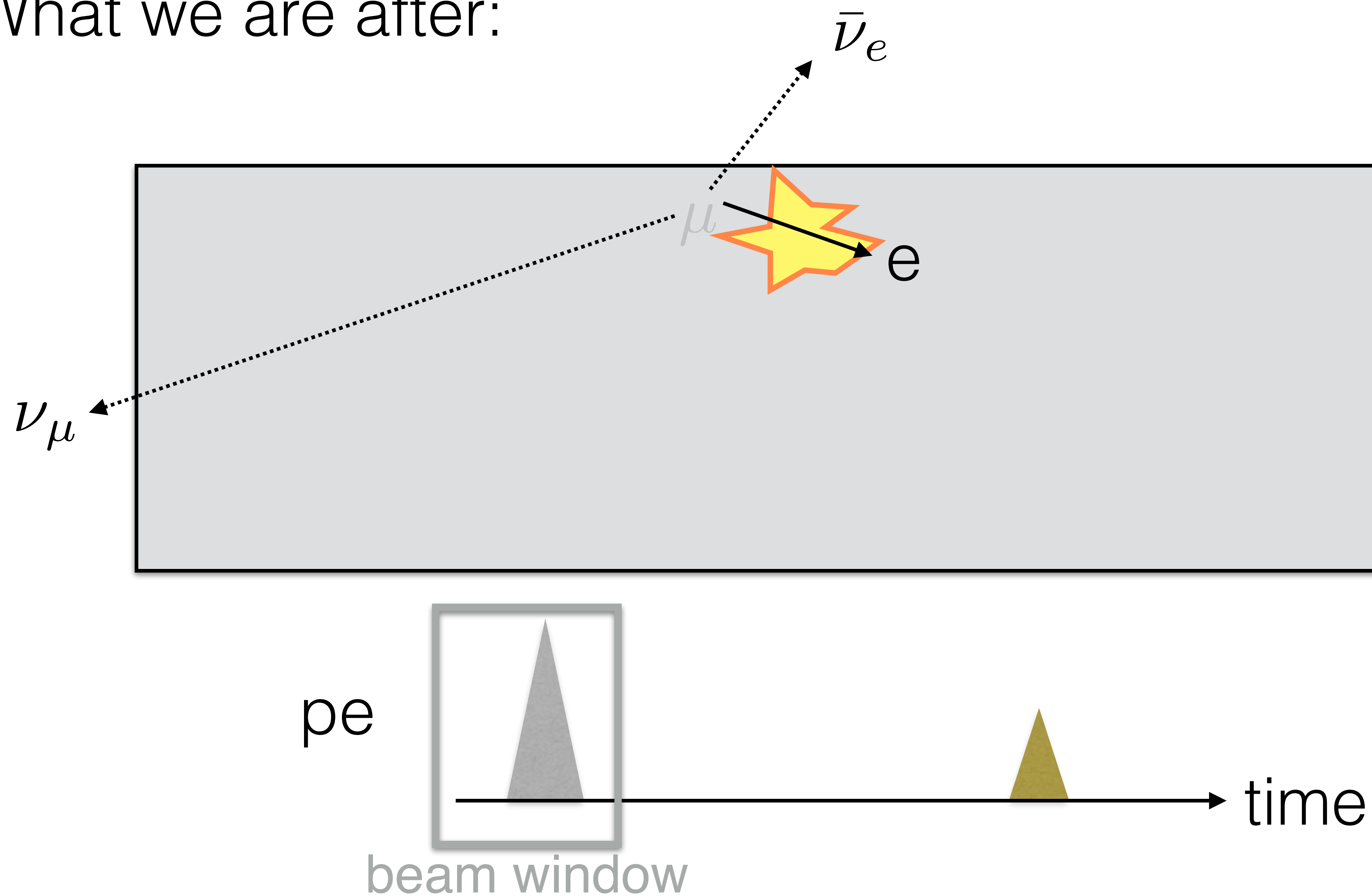
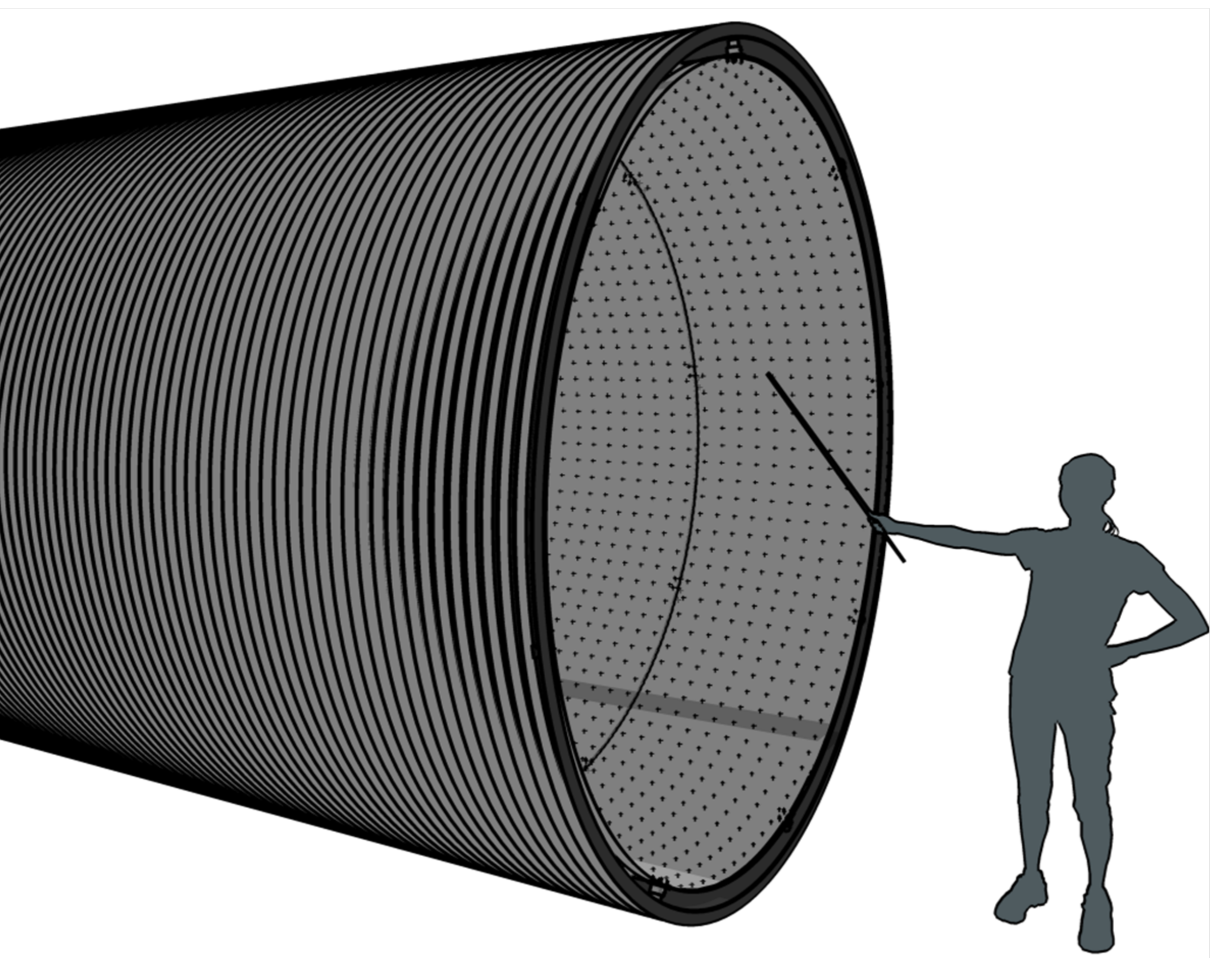
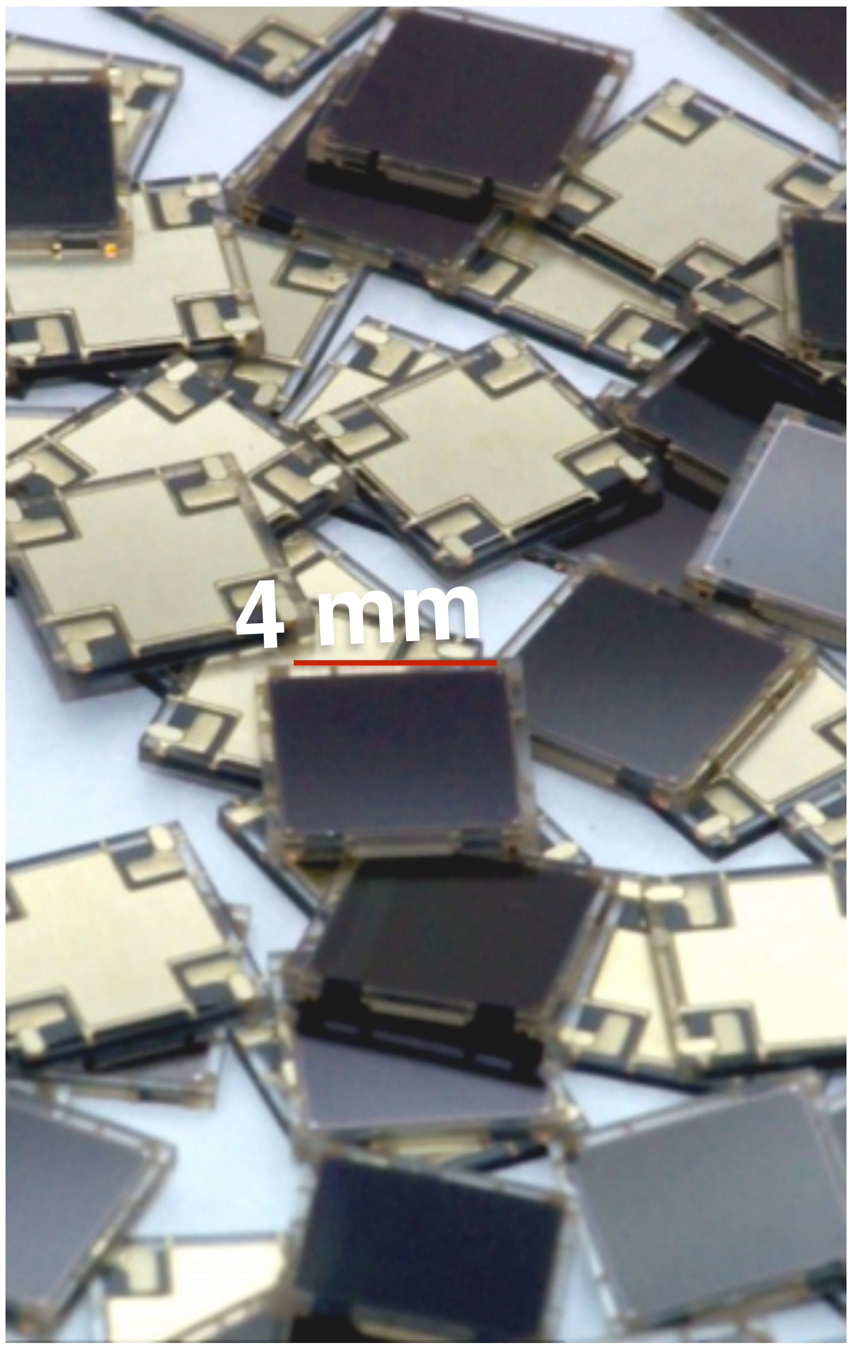


Instrumentation



- Divide volume into target and veto region
- target region has 1200 hoops containing 100 SiPMs each
- veto region has 122 hoops with 100 SiPMs each

Photon Detector: SiPMs



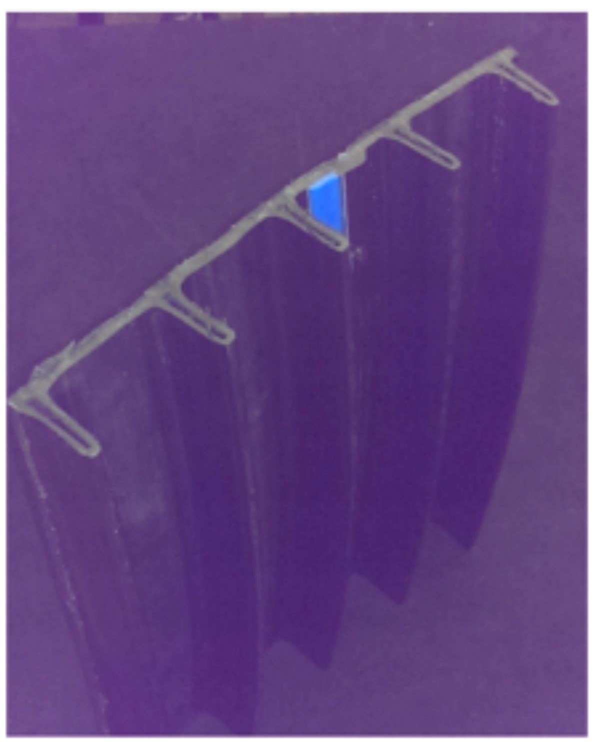
- Silicon photomultipliers
  - compact
  - low voltage ~ 27 V bias needed
  - inexpensive when ordered in bulk: ~$20/SiPM
- Small: 121K SiPMs only 0.4% photocoverage — need lots of light

Scintillator

- Fill vessel with liquid scintillator — medium great for detecting low energy events
- options:
  - Mineral oil + pseudocumeme
    - pros: used by another neutrino experiment, NOVA, supposedly inexpensive, about 4500 photons/MeV
    - cons: pseudocumeme can be aggressive solvent
  - LAB: linear alkyl benzene
    - pros: higher light yield ~10,000 photons/MeV, non-toxic
    - con: potentially more expensive
- Relying on high light yield of liquid scintillators to overcome sparse instrumentation — is it enough?

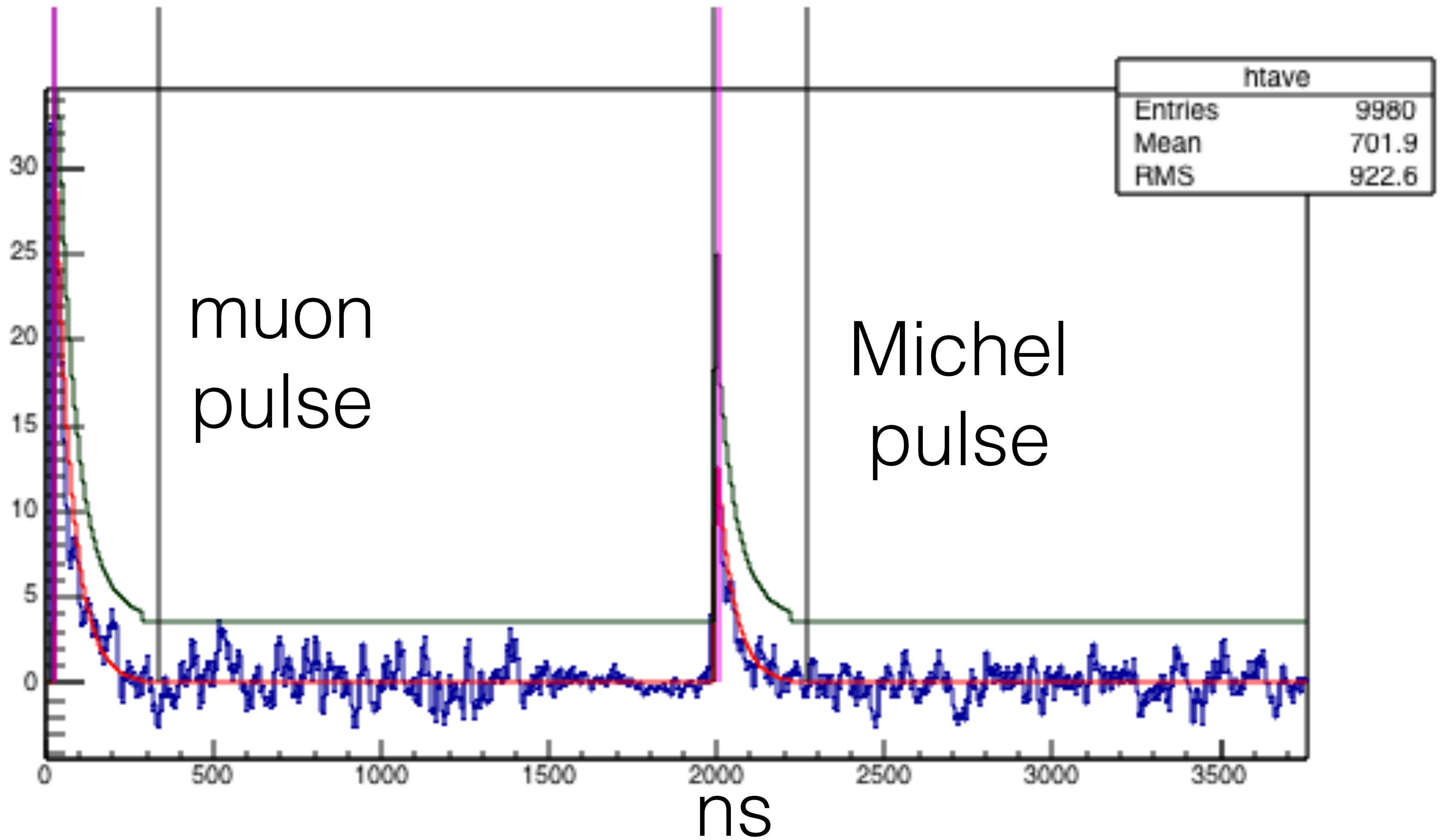
Scintillator

- received test piece of HDPE
- testing to see if material withstands attack from pseudocumene
- in the process of trying to get some LAB



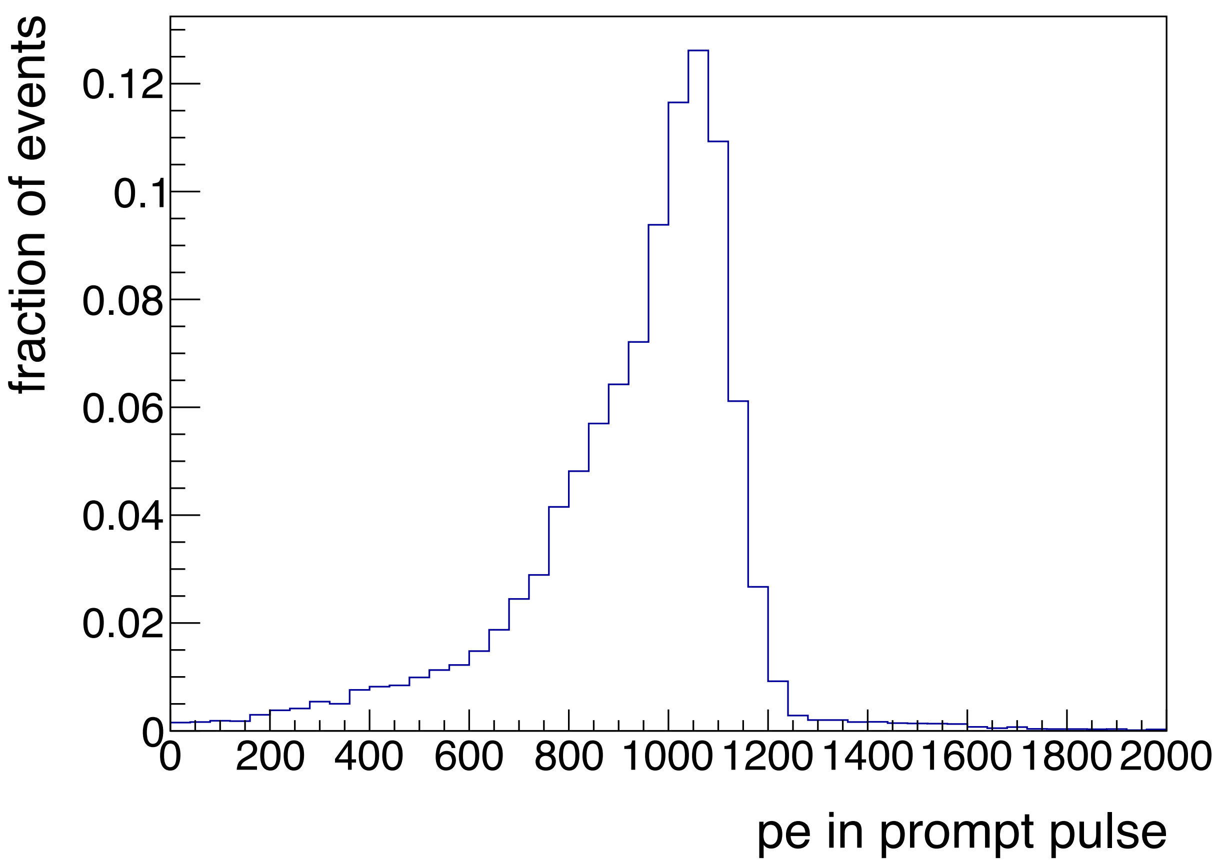
Signal Simulation

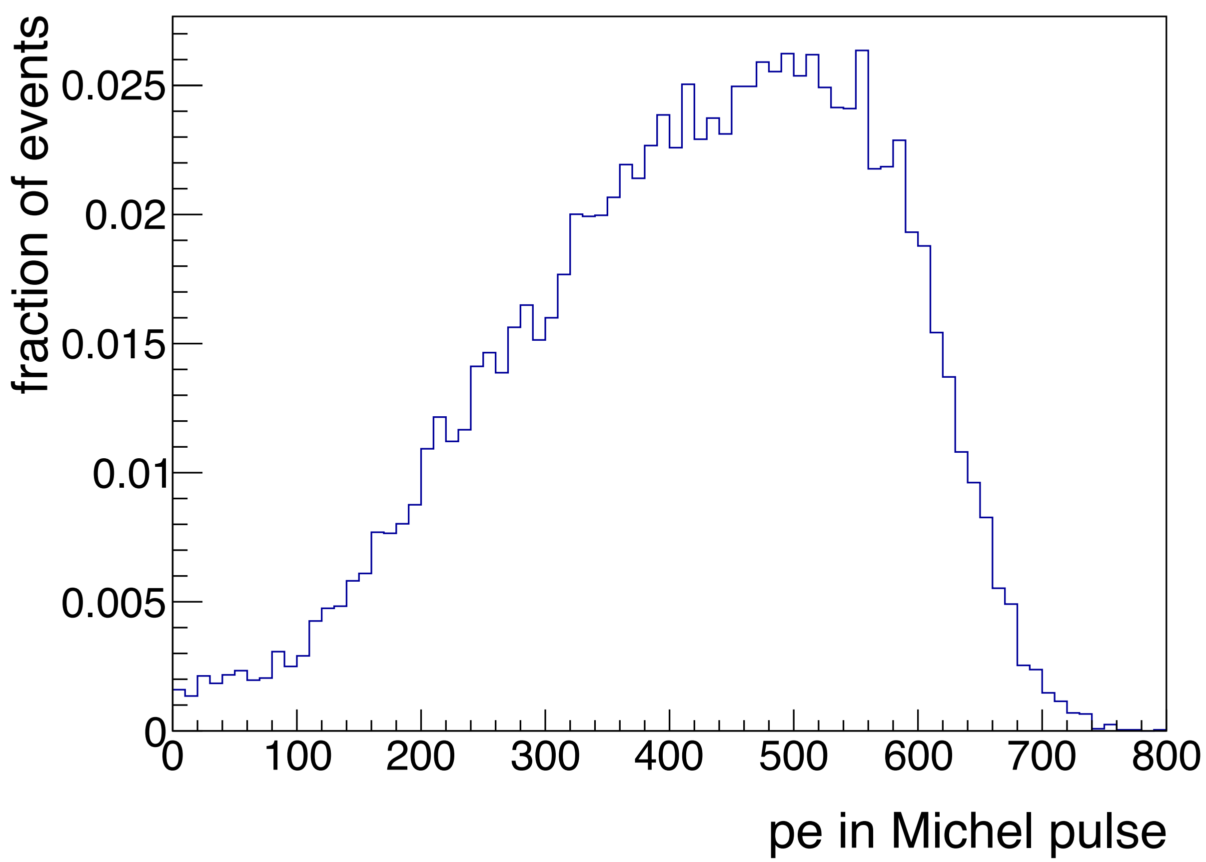
- Include photon hits from interactions and 1.6 MHz dark rate
- Implemented pulse finding algorithm to pull out “double flash” signal from all the SiPM dark noise



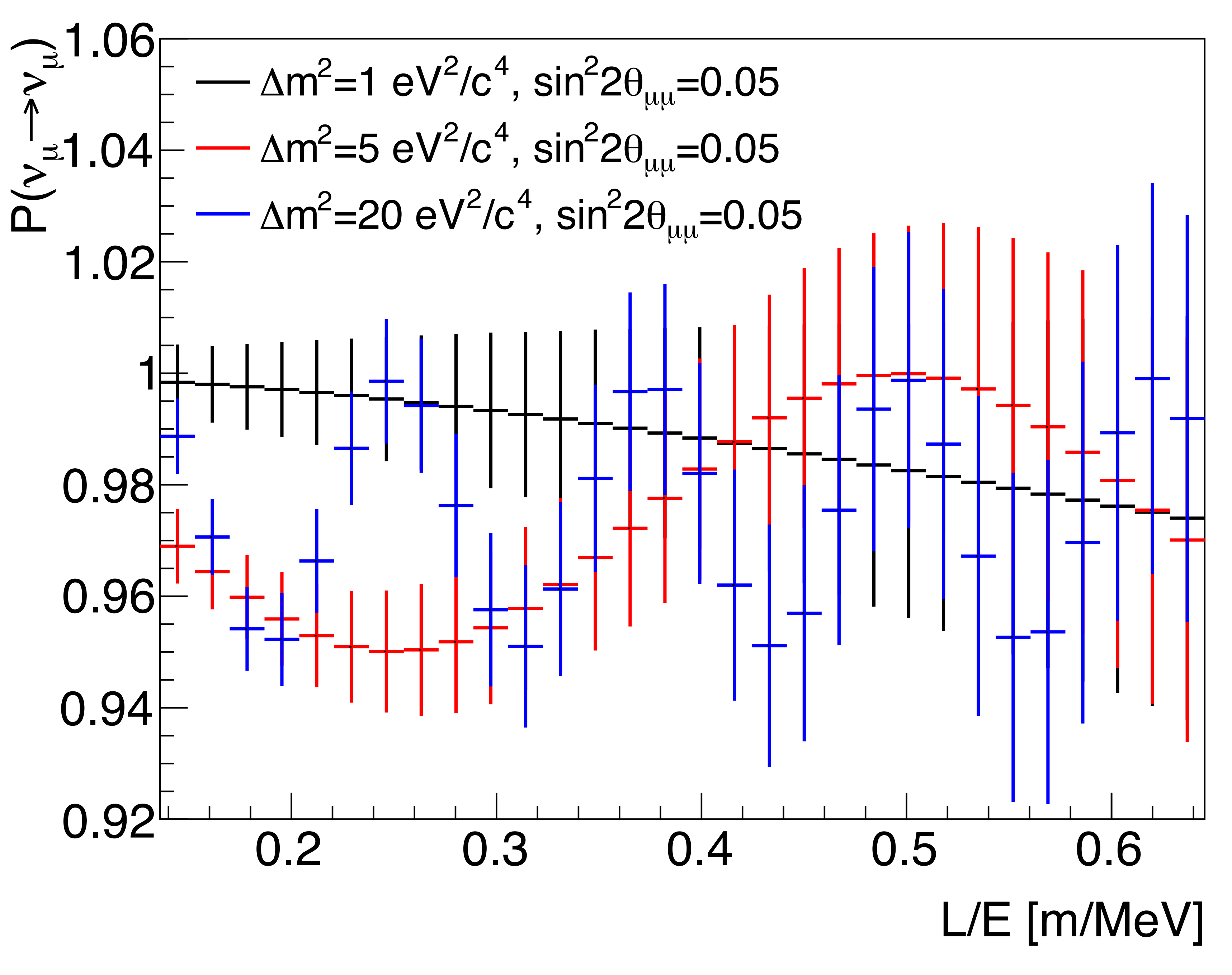
Signal Simulation

- Estimated photons collected
- MC scintillator produces ~4500 photons/MeV
- With current coverage, seems to be enough light





What we want to measure



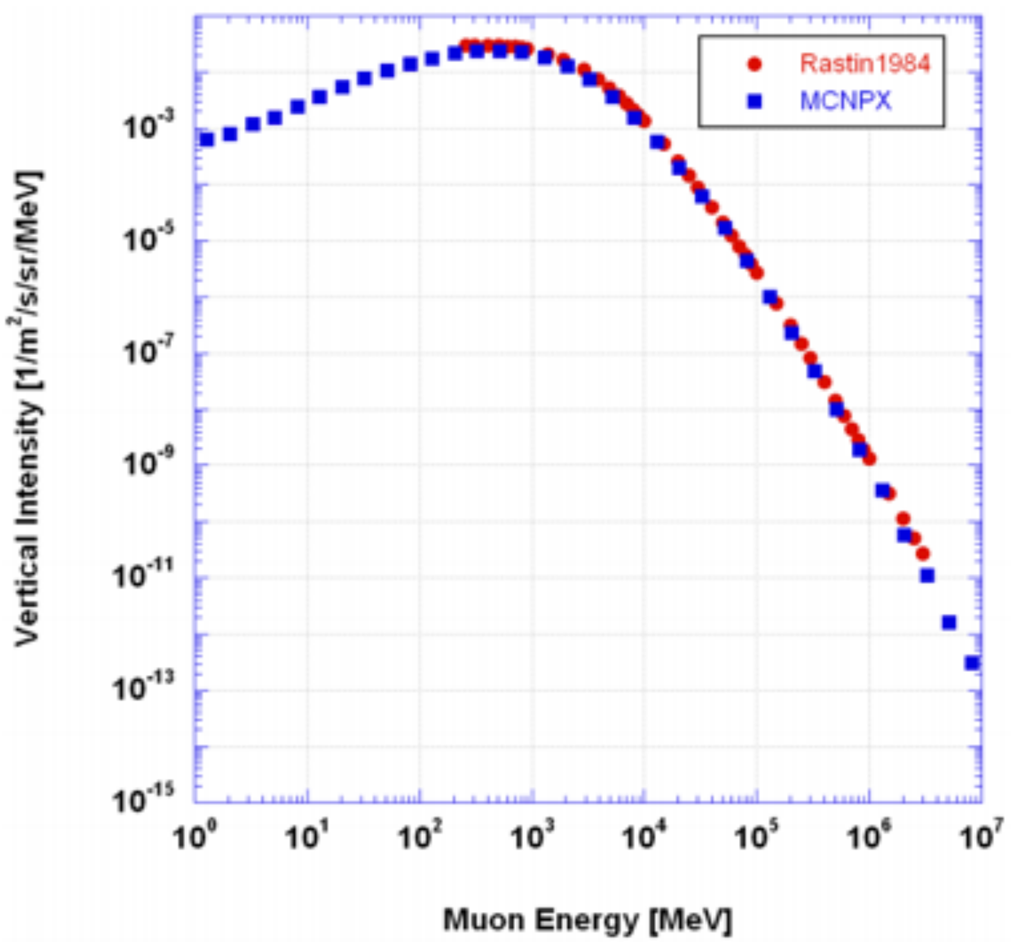
Seeing the osc. wave would be definitive evidence for sterile ν's

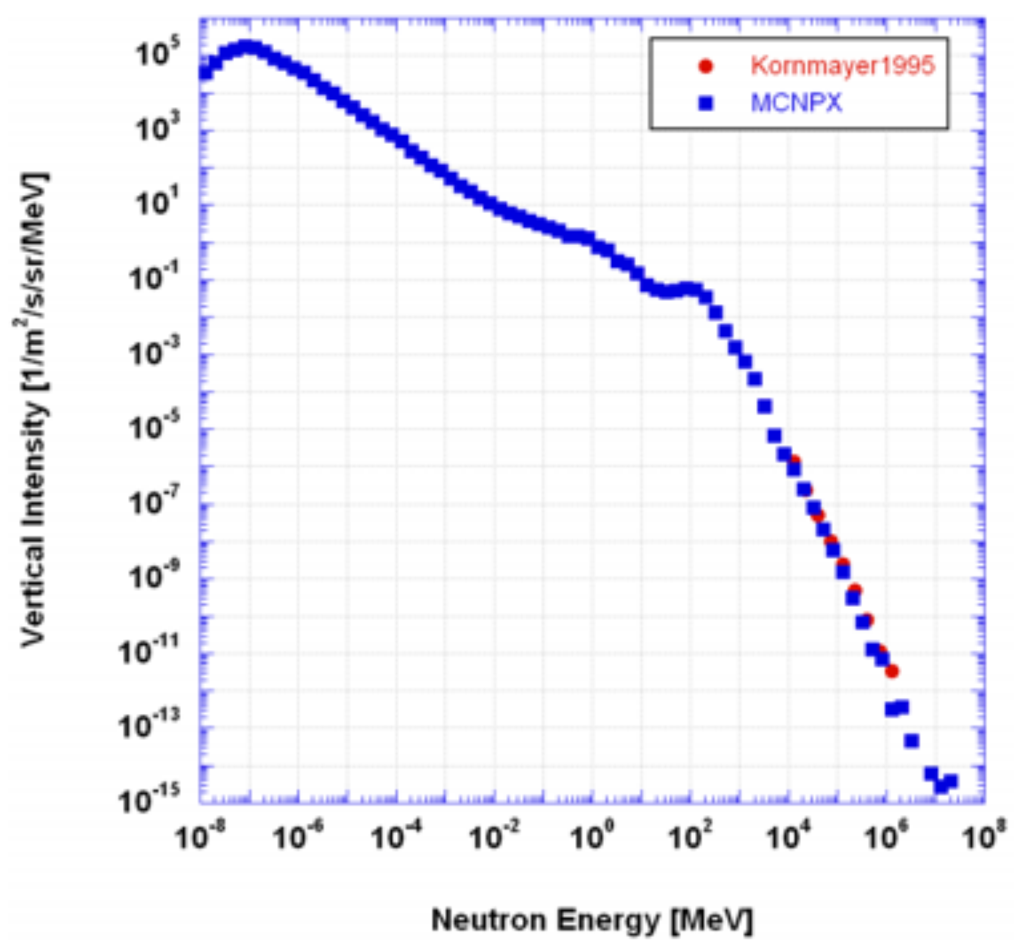
Backgrounds

- Cosmic rays are main background
- Timing and selection will bring event background down
- Studied via simulation

Cosmic Ray Simulation

- Cosmic ray simulation using package called CRY
- generates cosmic ray shower event at given latitude and altitude
- particles provided: muons, photons, pions, neutrons, protons, electrons





Signal Selection

- Signal events have neutrino-induced muon interactions. Remove backgrounds, which we expect will be mostly cosmic rays
  - 2 flashes: muon, then Michel electron
  - no veto hits
  - in time
  - 2 flashes close in Z
  - upper energy cut on both muon and Michel electron pulse, to remove high energy cosmic ray events
  - low energy threshold for noise
- Studied with detector MC

Selection Efficiency

- removing cosmics comes at some cost to signal
- mostly due to cuts around signal bounds

Events in target region	100%
contained muons (calculation)	87%
prompt pulse seen (above noise level)	87%
Michel seen	77%
Cuts for cosmic	75%

Backgrounds

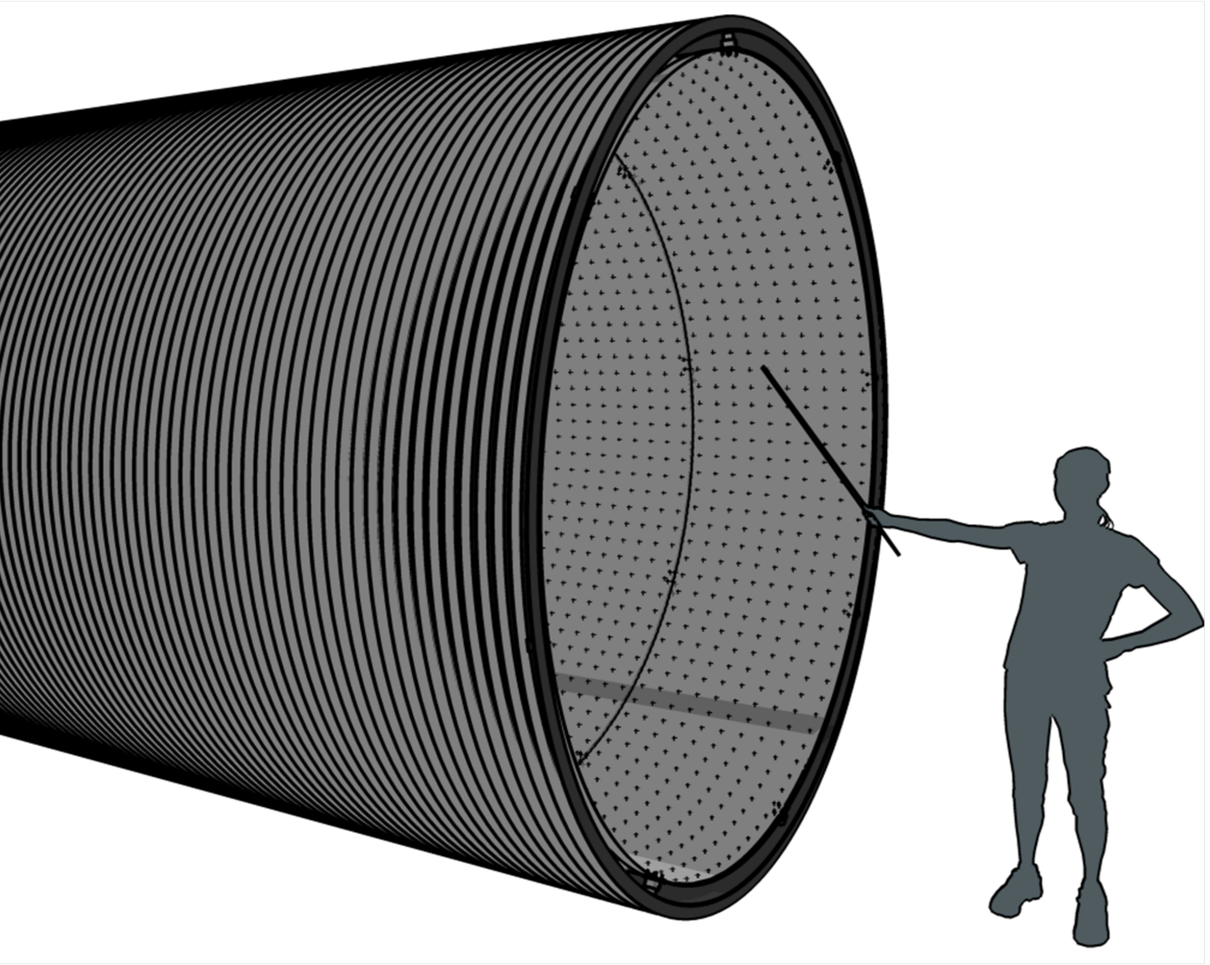
- Backgrounds mostly from stopping muons that pass undetected by veto
- Above ground
- Photon showers, neutrons, electrons would be reduced if pipe is buried/shielded

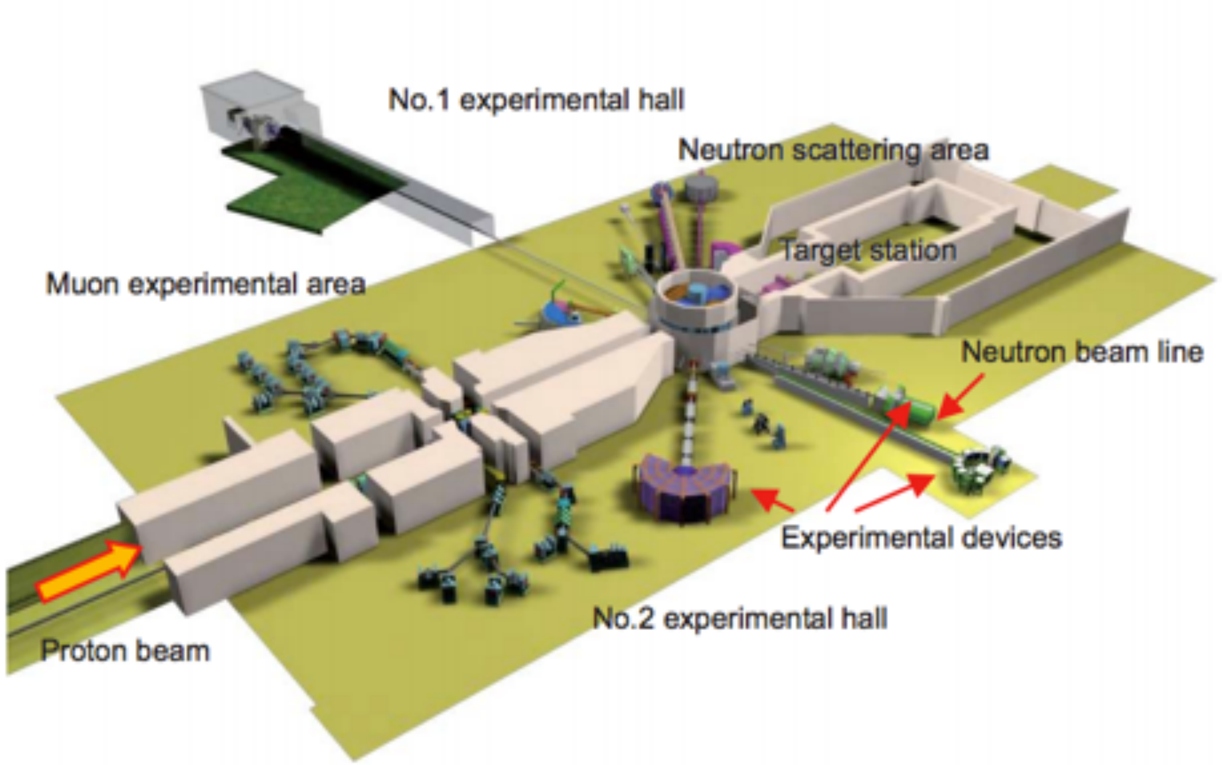
signal to background ratio:
60:1 at front
3:1 at back

Total Rate	27 Hz (100%)
photons	5%
neutrons	20%
muons only	60%
muons+others	15%

Sensitivity

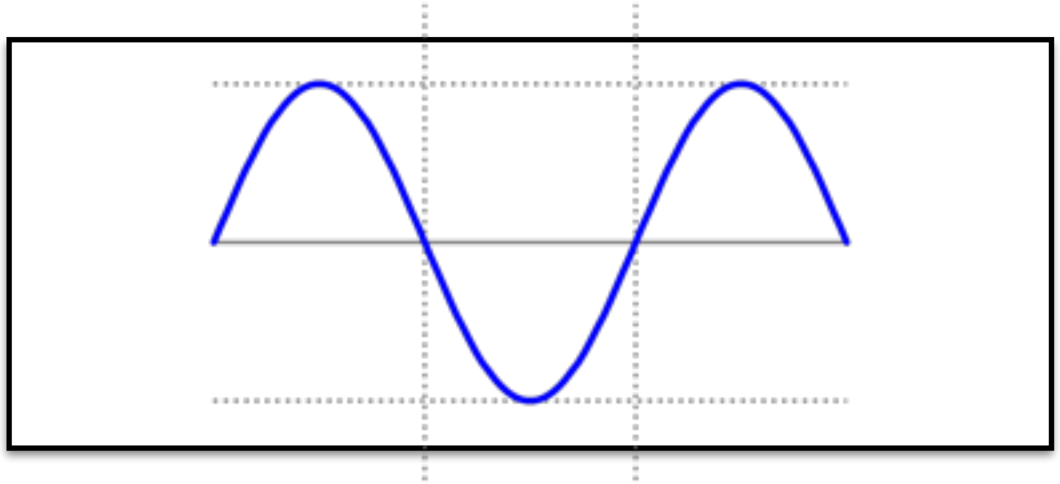
- Putting everything together, what is the sensitivity of KPipe?





Sensitivity Study

- Shape only analysis
  - ignore normalization of sin wave



- Note: systematic uncertainty primarily from statistics of signal and cosmic ray events
  - Uncertainty from flux and cross section only affect normalization which is not used in the analysis
  - Decoupling from these systematics is one of the attractive features of this setup

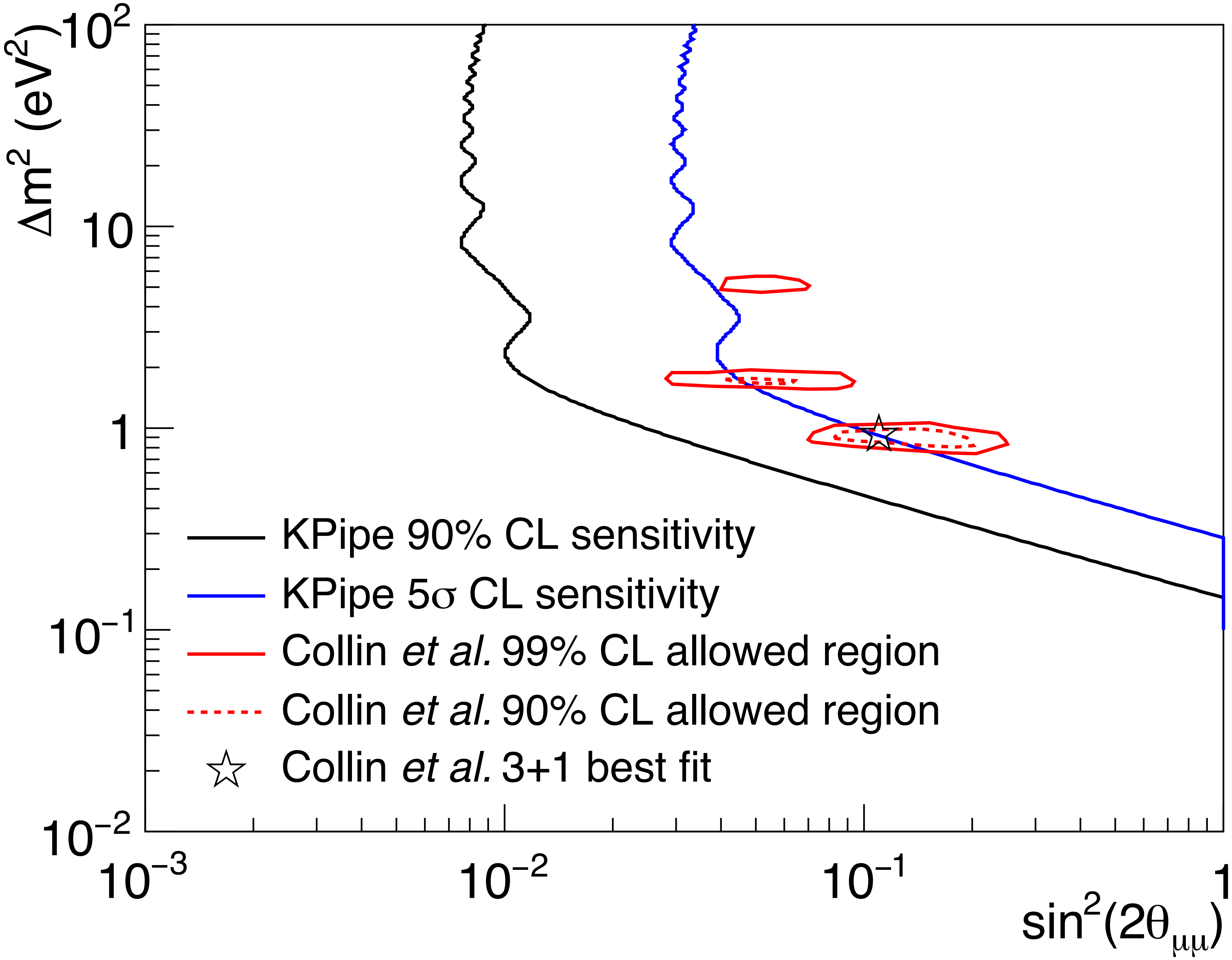
Sensitivity

- Parameters for sensitivity calculation

Kaon production uncertainty	+/- 0.2 m
baseline reconstruction unceratinty	0.8 m
Event generator model	NuWro
Kaon production models	GEANT4 = 0.0038 K+/POT MARS15 = 0.00725 K+/POT
Selection efficiency	75%
CR background rate	27 Hz

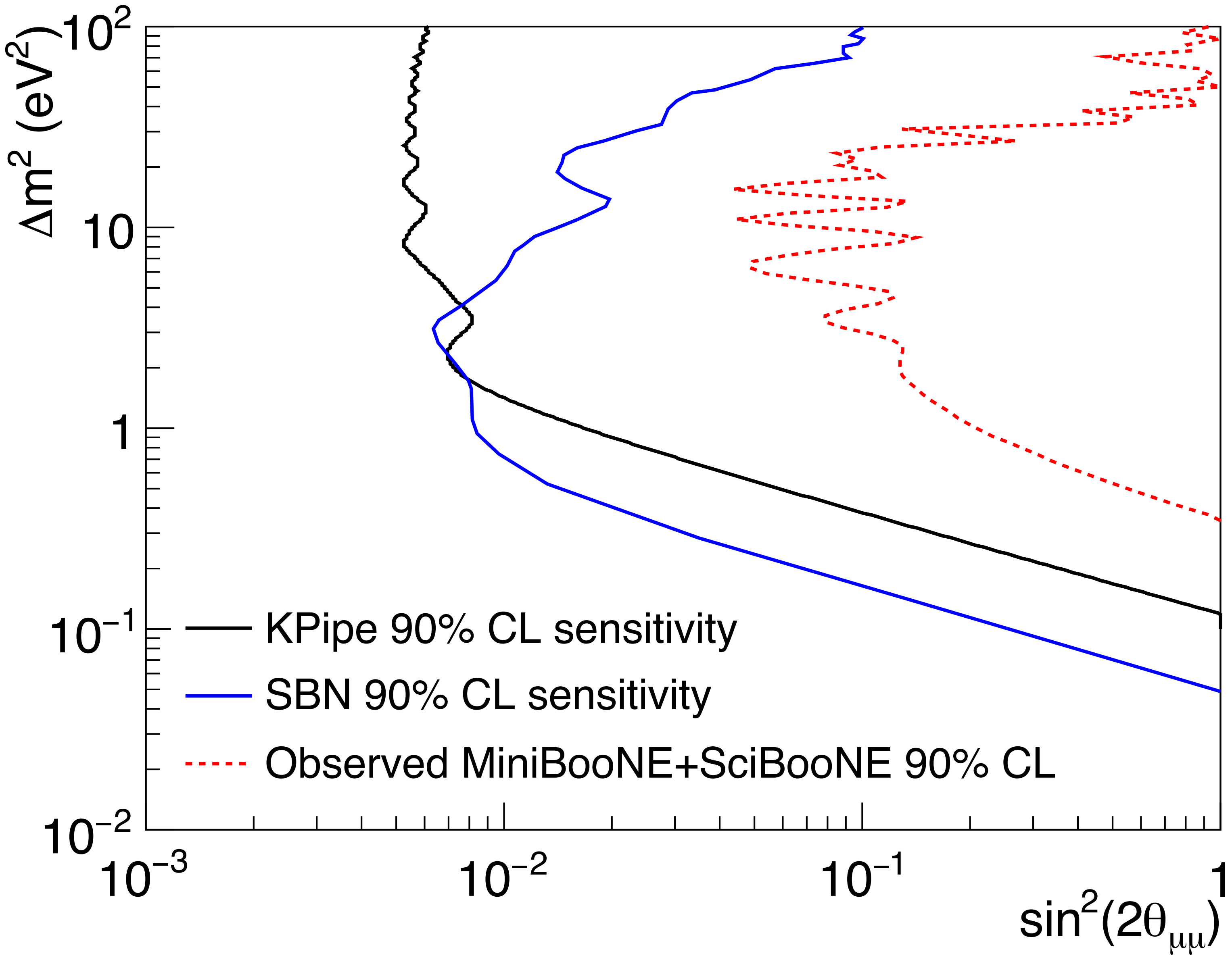
Sensitivity Study

- Three years of running
- Exclude sizable portion of allowed regions at 5 sigma



Sensitivity Study

- Six years of running
- Extends limit at high mass splitting by an order
- Complements SBN program
    - 6 years uBooNE
    - 3 years SBND
    - 3 years T600



Costs

	Quantity	Unit Price	Total Price
Scintillator (using NoVA) price	732 tonnes	1.5 $/tonne	1.1 M$
SiPMs	121,200	$20	2.4 M$
Readout	1212 channels	$300	0.36 M$
Vessel	120 m	2400 $/m	0.29 M$
Vessel Installation	1	$22k	0.022 M$
SiPM panels	1056 m^2	150 $/$m^2$	0.16 M$

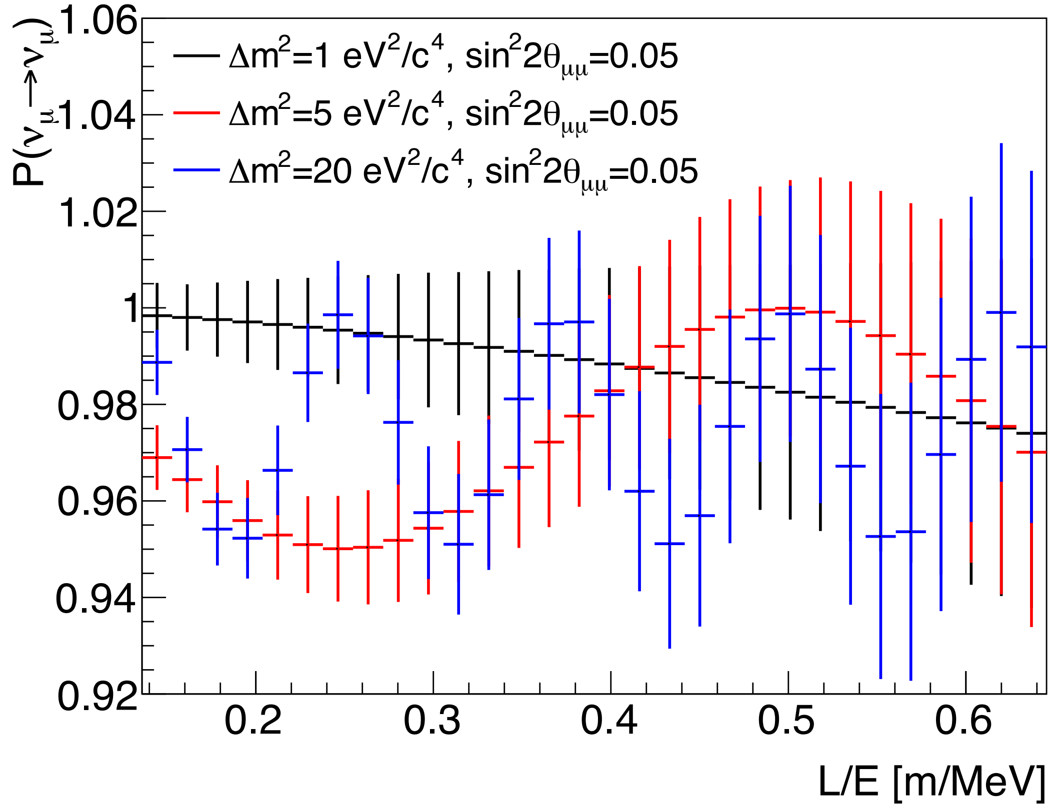
Total	4.6 M$

Summary

- Observation (or lack there of) of muon neutrino disappearance is important in understanding sterile anomaly

- KPipe is a proposal to look for muon neutrino disappearance at around 1-10 eV^2 given the WINP constraints

KPipe traces out the oscillation wave



- Lots of power for less than 5 million dollars

- A paper with more details: http://arxiv.org/abs/1506.05811

Backup Slides

Signal Simulation

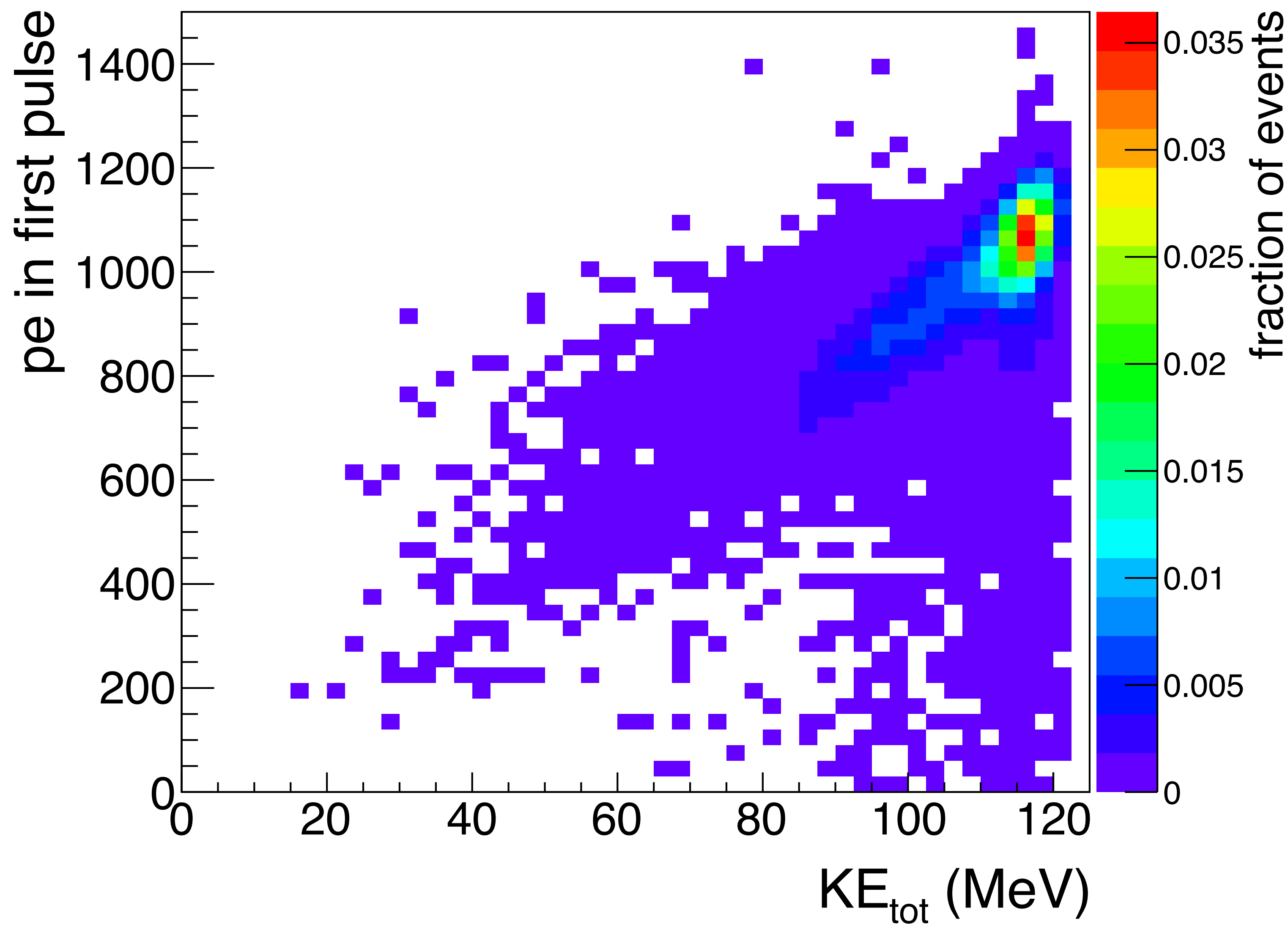


FIG. 6: The number of photoelectrons in a 236 MeV ν_μ CC event's first pulse versus the total kinetic energy ($KE_{tot} = KE_\mu + \sum KE_p$).