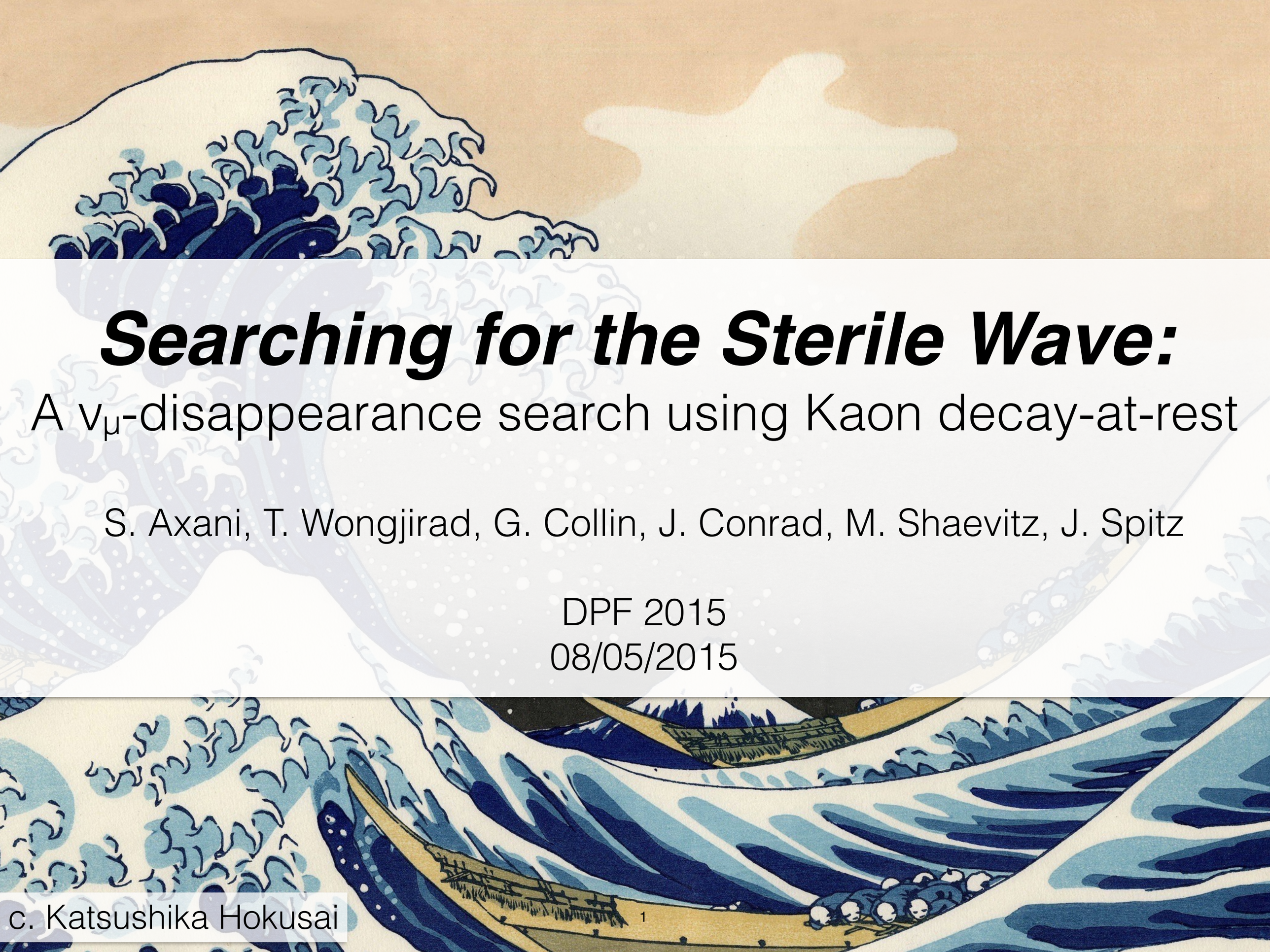

Searching for the Sterile Wave:

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

S. Axani, T. Wongjirad, G. Collin, J. Conrad, M. Shaevitz, J. Spitz

DPF 2015
08/05/2015

c. Katsushika Hokusai

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 a 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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Future Experiments

- Anomalies motivating future experiments to verify each type of anomaly directly

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Future Experiments

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Experiment name	Type	Oscillation channel	Significance
Accelerator experiments, e.g. MicroBooNE, Short Baseline Neutrino (SBN) program at Fermilab		muon to electron (antineutrino)	3.8σ
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		muon to electron (neutrino)	3.4σ
Remeasuring reactor ν's, e.g. Nucifer, Prospect		electron disappearance (antineutrino)	1.4-3.0σ (varies)
High intensity ν sources, e.g. SOX, IsoDAR, etc.		electron disappearance (neutrino)	2.8σ

Future Experiments

- Experiments probing oscillations to/from ν_e ($\bar{\nu}_e$)
- Is there a complementary approach?

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Accelerator experiments, e.g. MicroBooNE, Short Baseline Neutrino (SBN) program at Fermilab		muon to electron (antineutrino)	3.8σ
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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

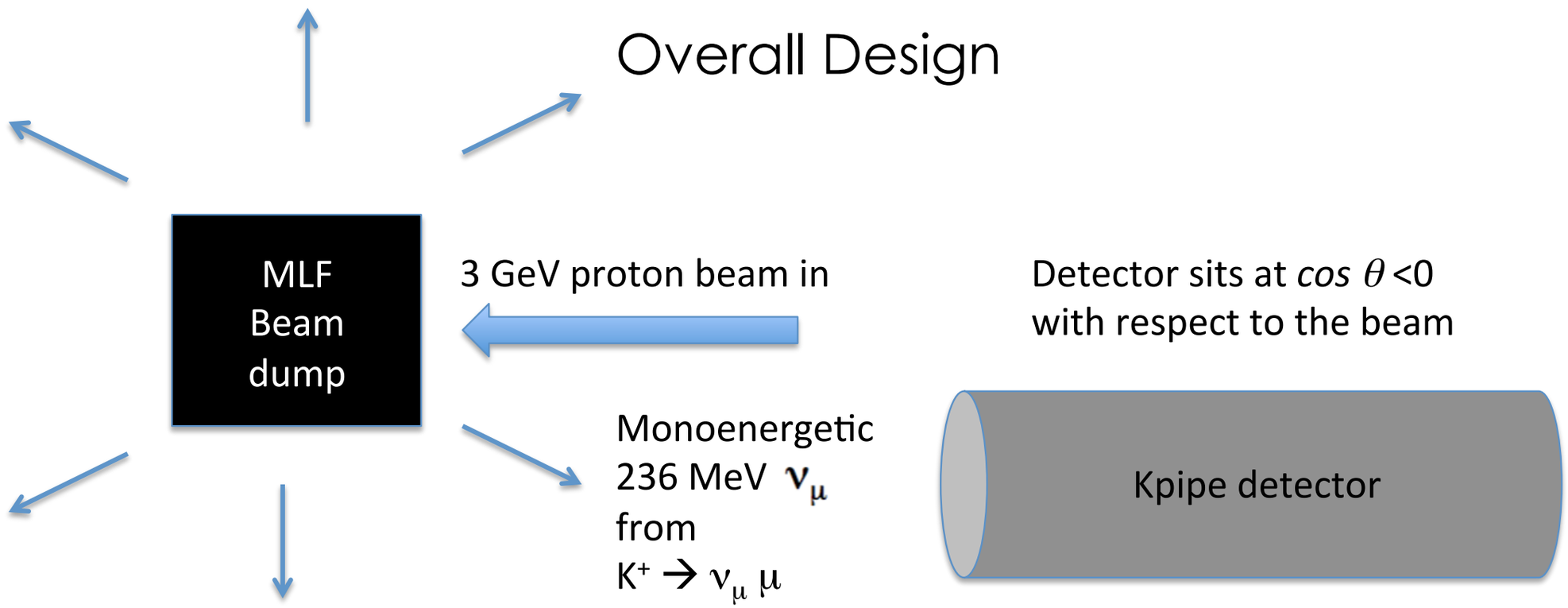
What about ν_μ disappearance?

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

$$P(\nu_\mu \rightarrow \nu_\mu) \simeq 1 - \underbrace{\boxed{4(1-|U_{\mu 4}|^2)|U_{\mu 4}|^2}}_{\text{Amplitude}} \sin^2(\underbrace{\boxed{1.27\Delta m^2_{41} L/E}}_{\text{Frequency}})$$

KPipe

Overall Design

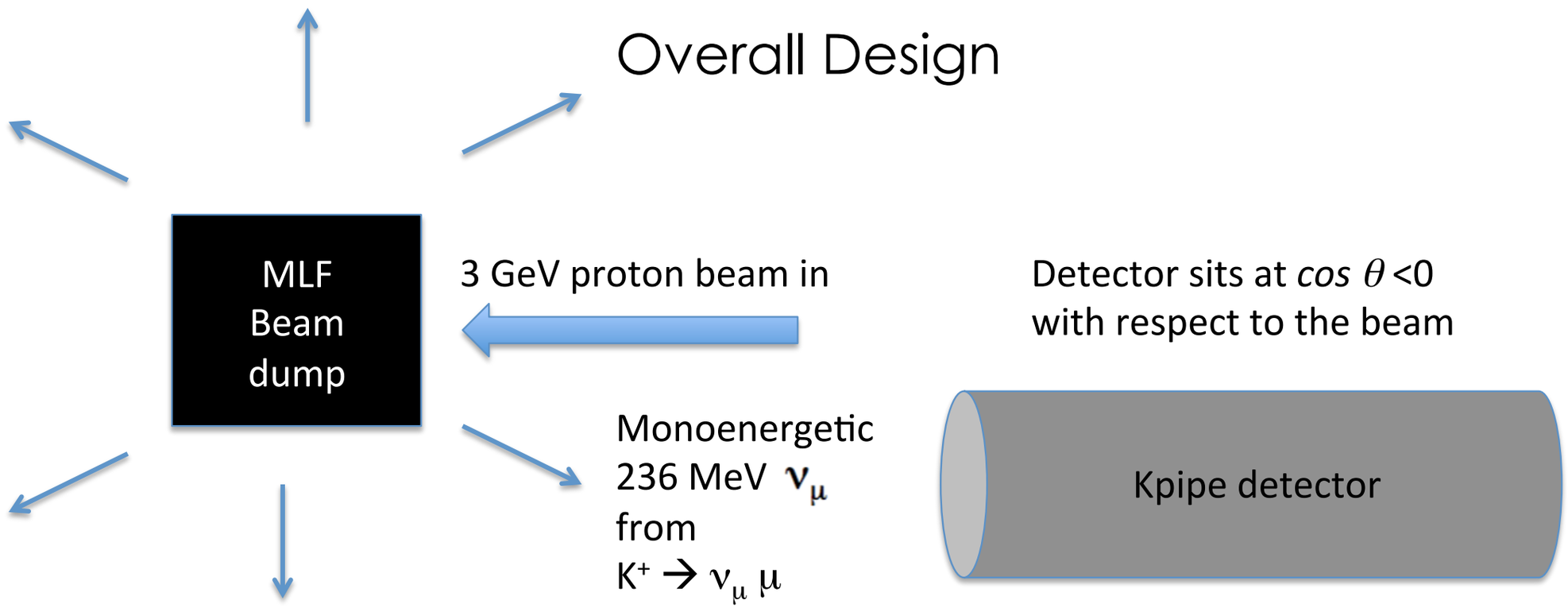


(1) pure, mono-energetic flux of muon neutrinos

(2) long detector to measure the oscillation wave

KPipe

Overall Design



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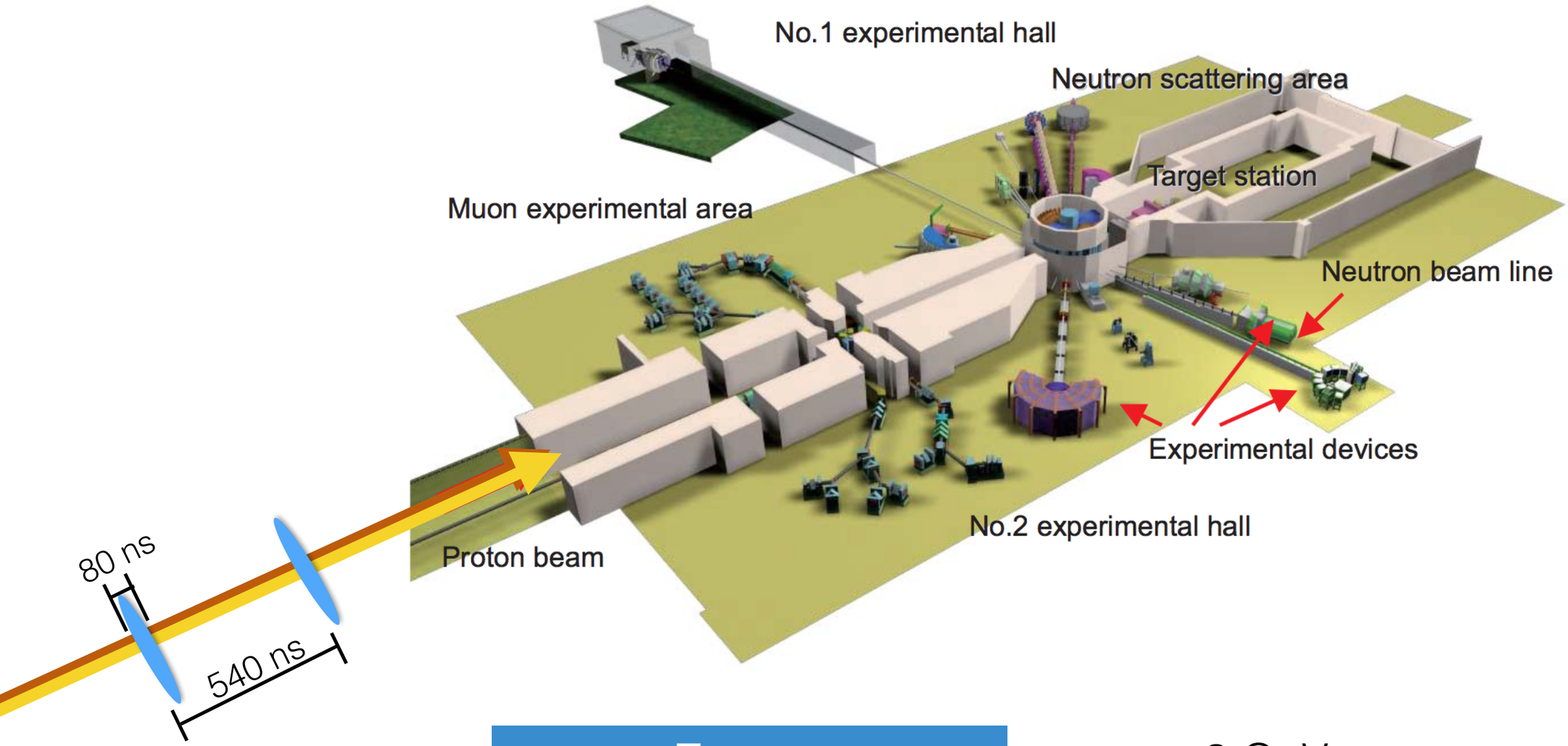
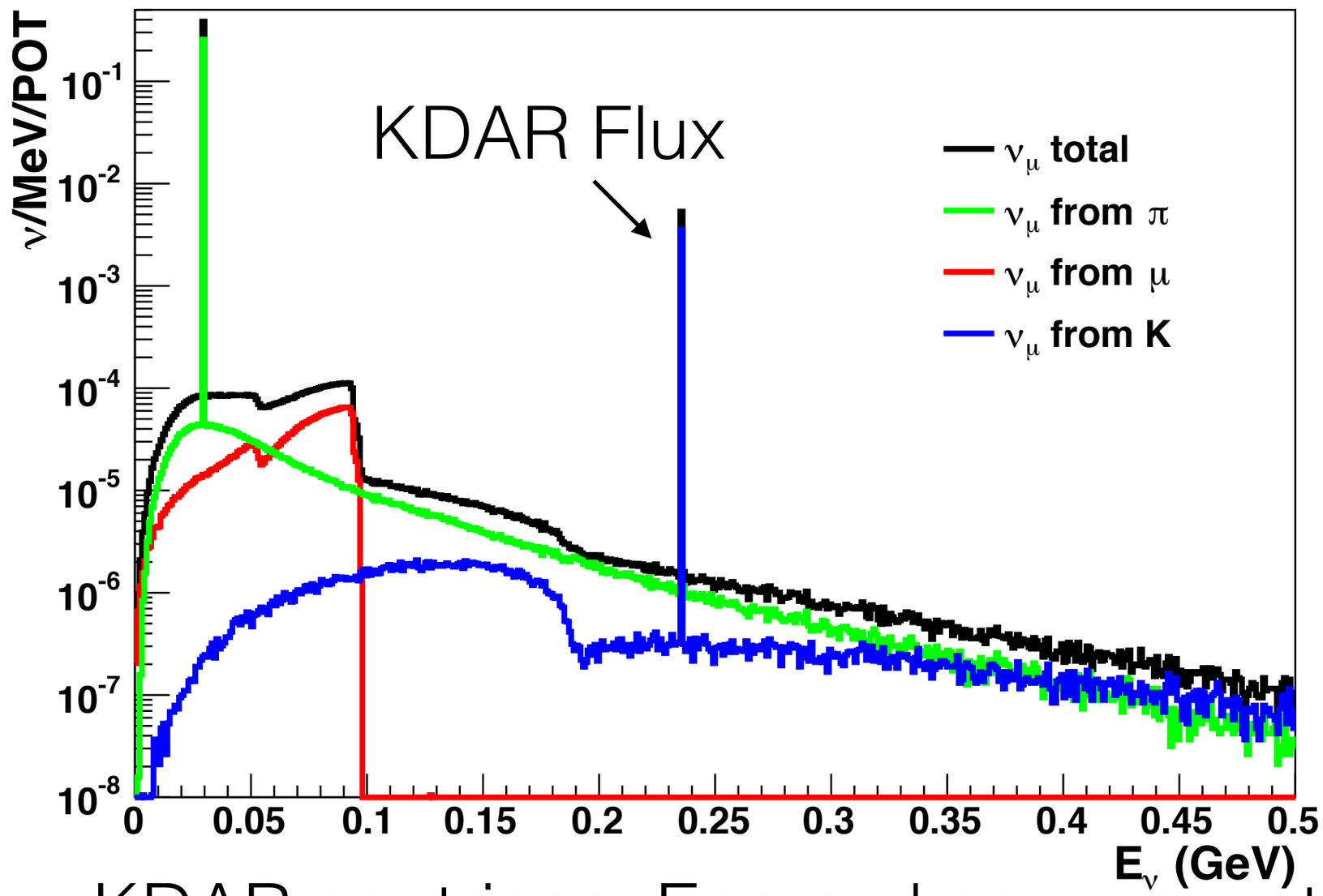
JPARC MLF



Energy	3 GeV
Electrical Current	0.333 uA
Power	1 MW
Frequency	25 Hz

Neutrino Fluxes

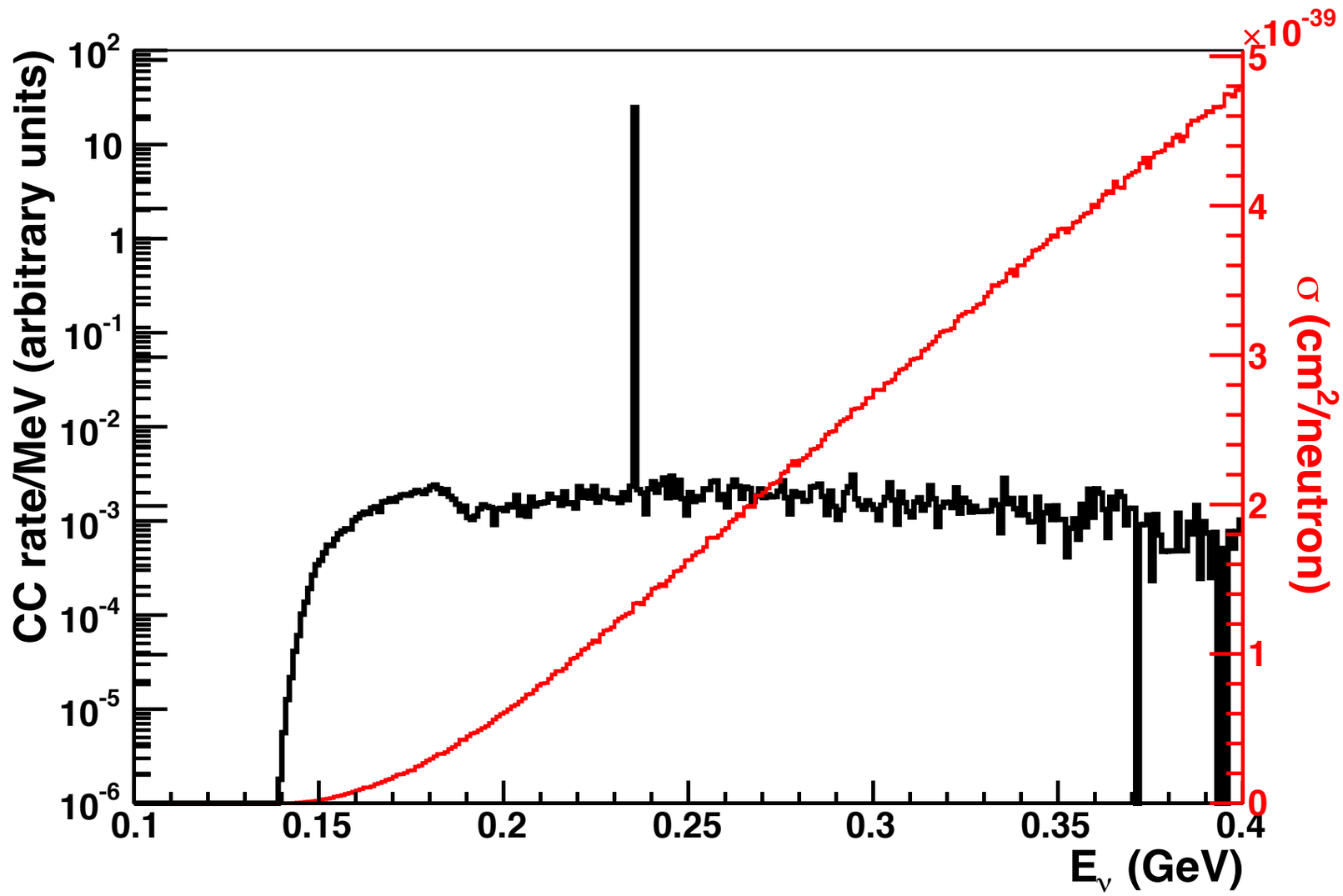
- Our flux simulation: 3 GeV protons hitting Hg target



- KDAR neutrinos: Energy known exactly

Neutrino Rates

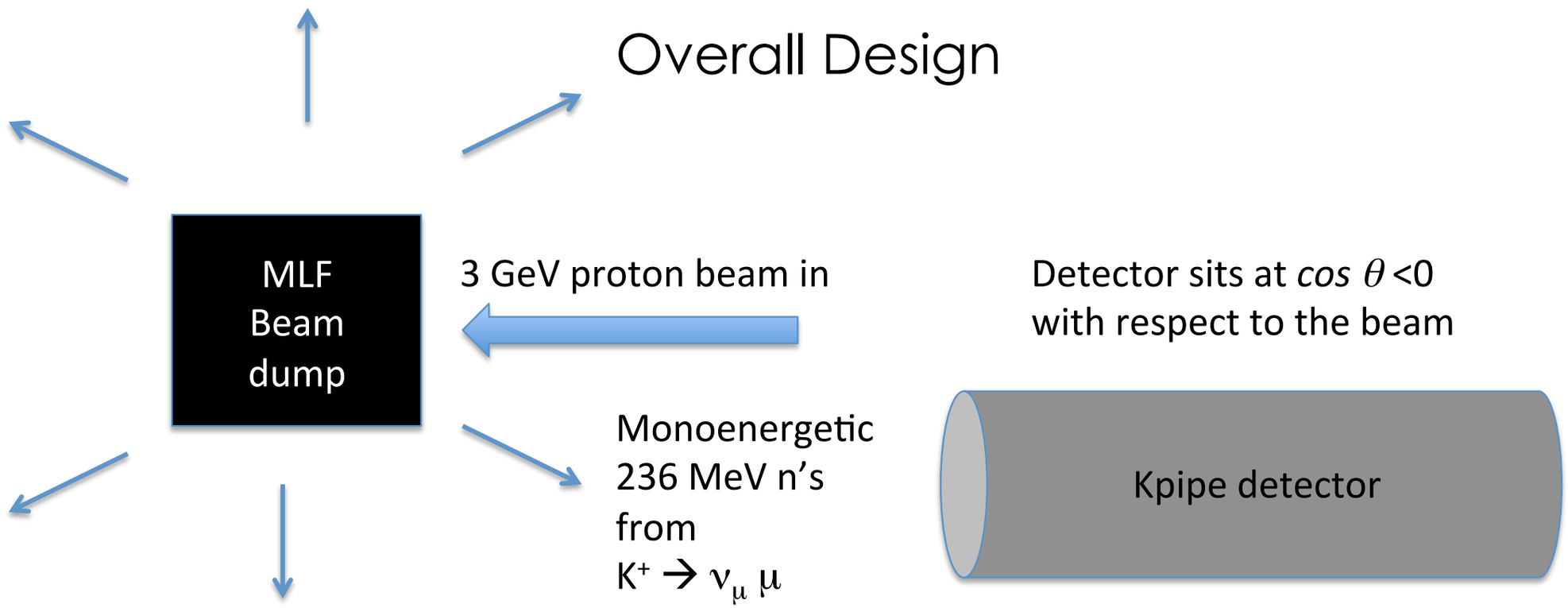
- CCQE cross-section and muon production threshold suppresses much of the non-KDAR neutrino flux



- 98.5% of interactions will be KDAR neutrinos

KPipe

Overall Design



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

(2) long detector to measure the oscillation wave

Detector

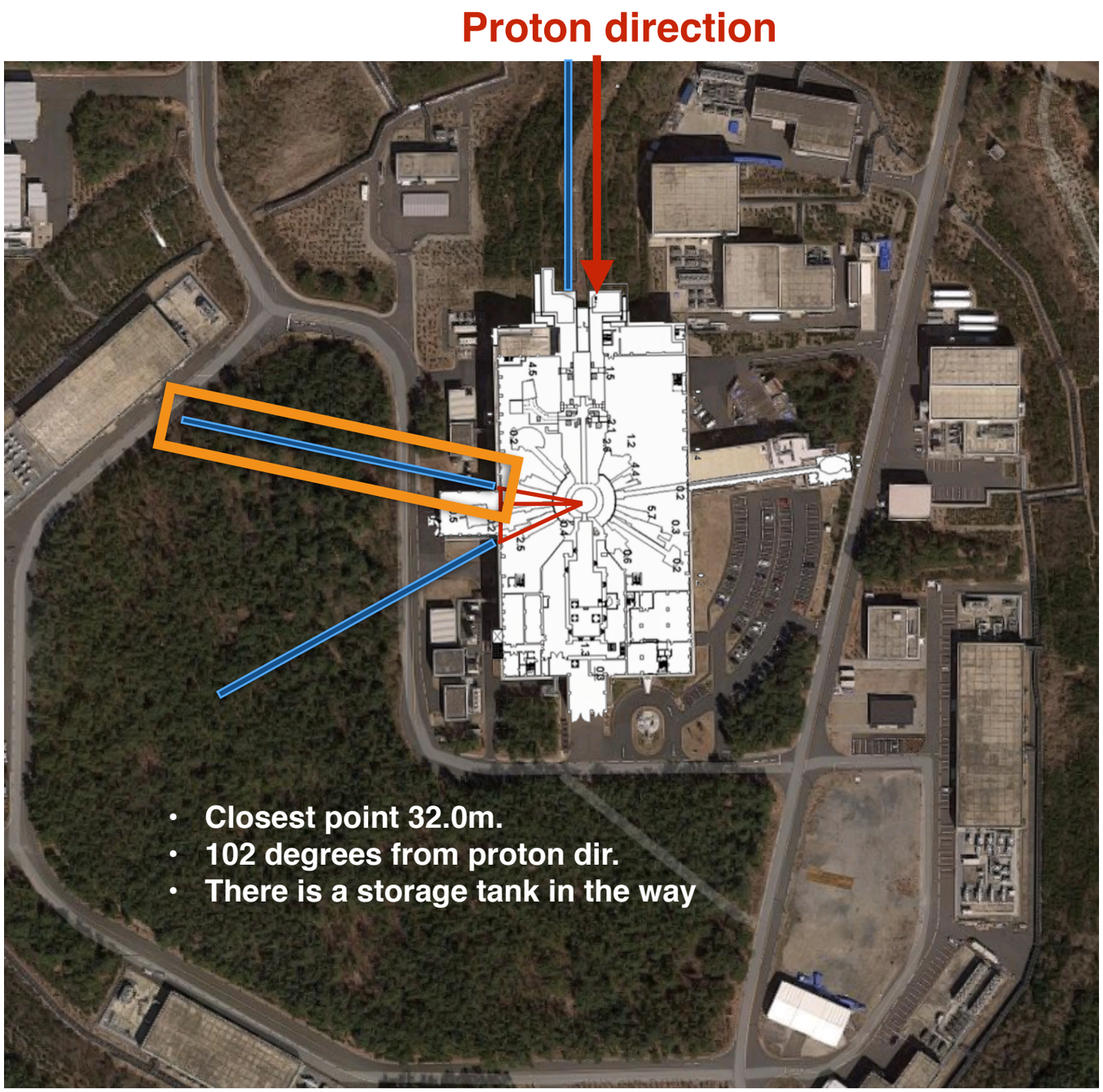
- A (BIG) high density polyethylene pipe, 3 m diameter and 120 m long, filled with liquid scintillator

Detector Location

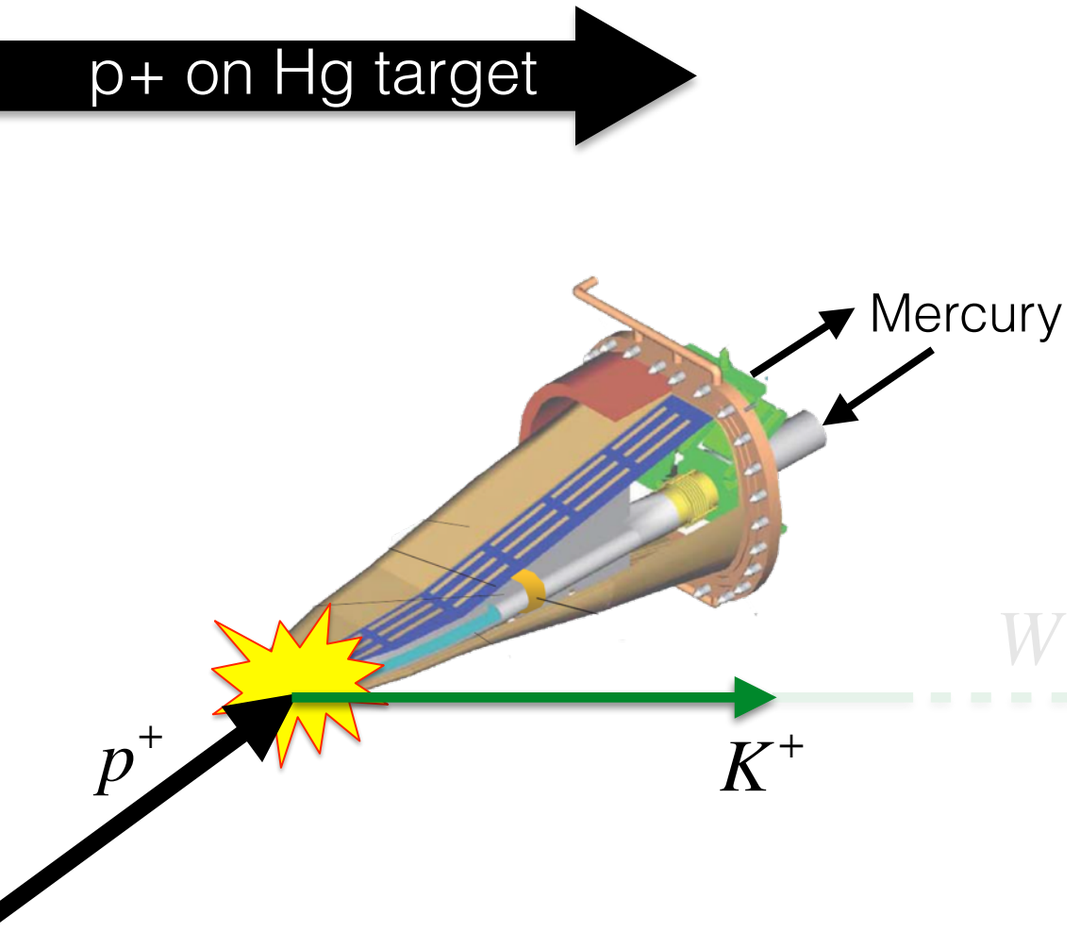
Studied possible locations of pipe around MLF building

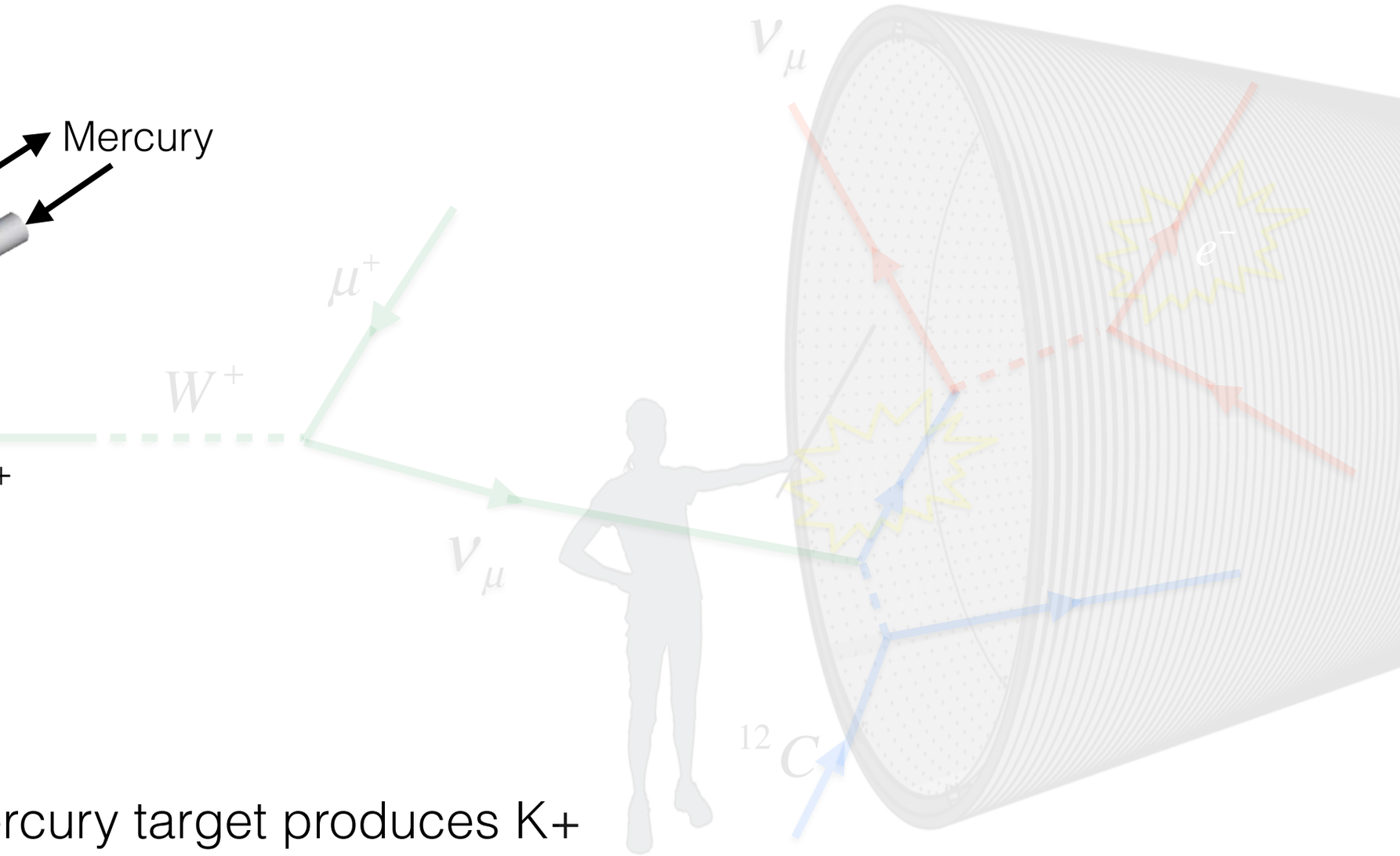
Chose location (highlighted in orange) based on sensitivity and available space

Want to be as close as possible to maximize rate



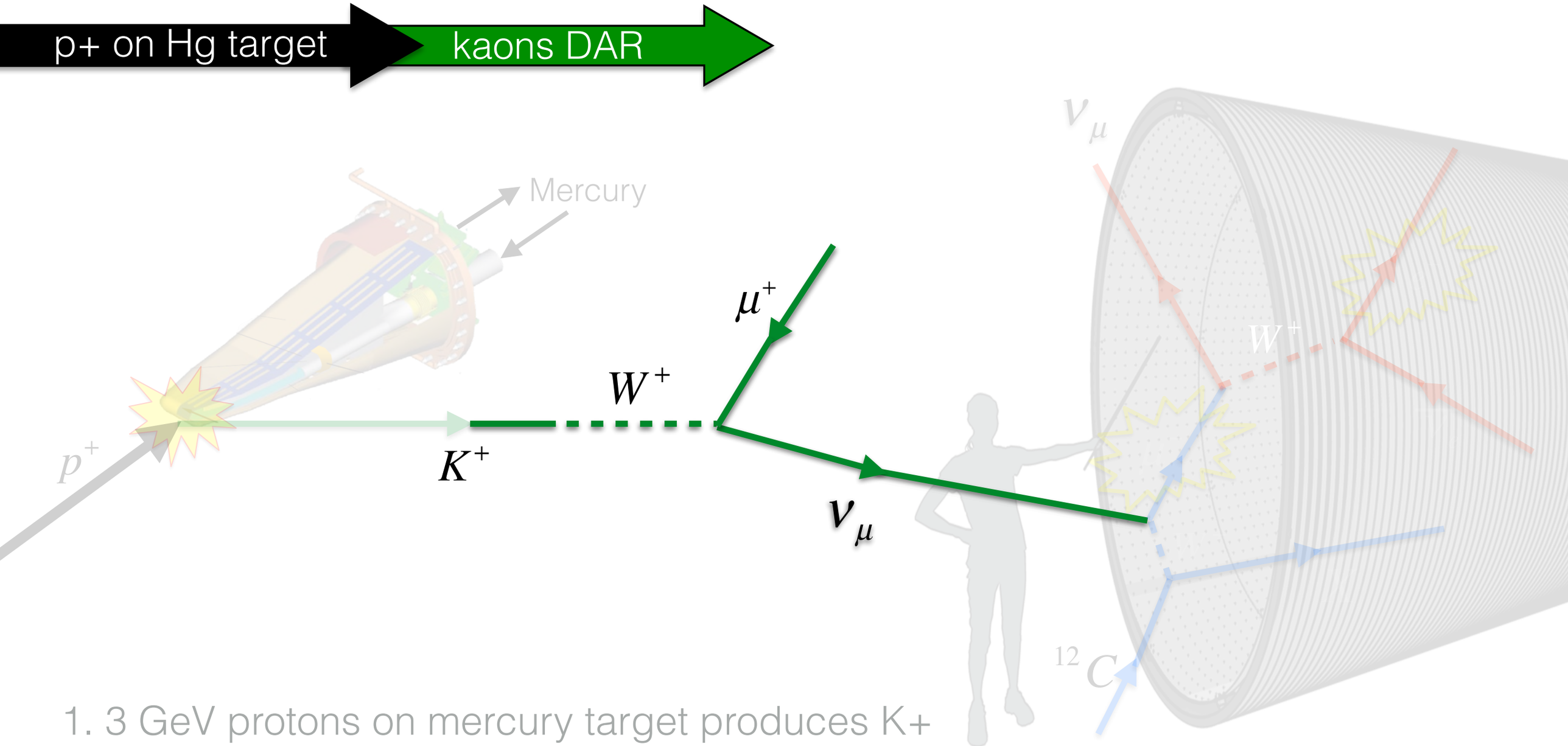
Signal





1. 3 GeV protons on mercury target produces K+
2. K+ decay at rest (DAR) producing mono-energetic muon neutrinos (235.5 MeV)
3. Prompt signal from muon produced in the CCQE interaction
4. Delayed signal from the Michel electron

Signal



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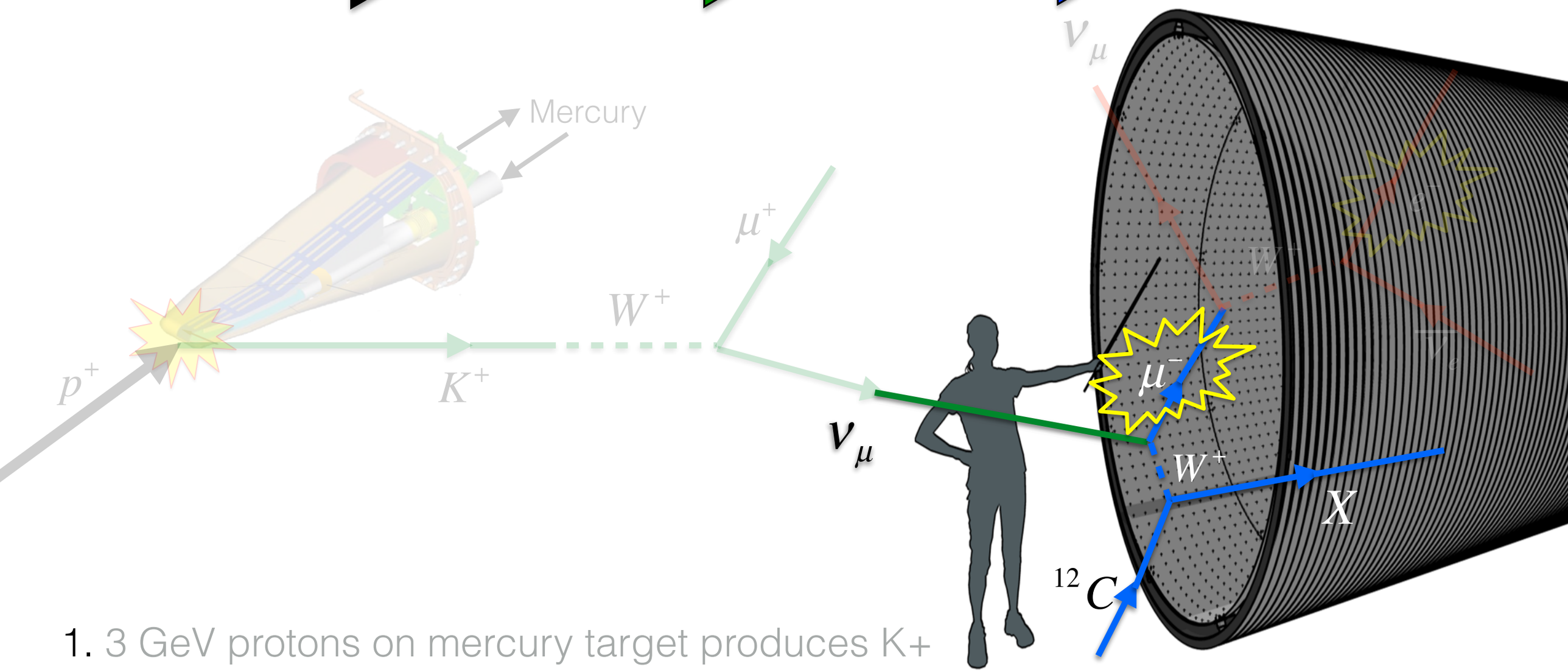
Signal

p+ on Hg target → kaons DAR → prompt CC signal



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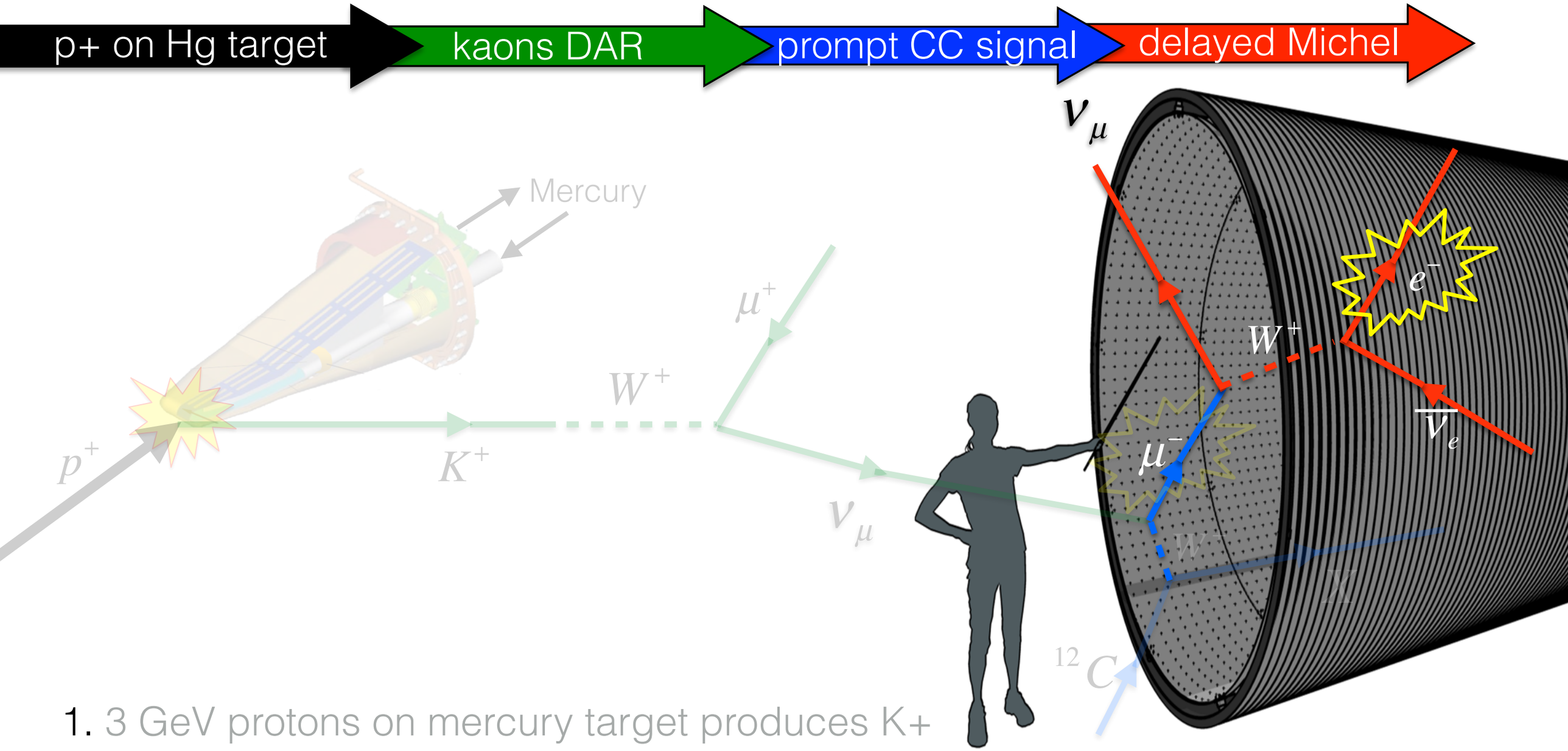

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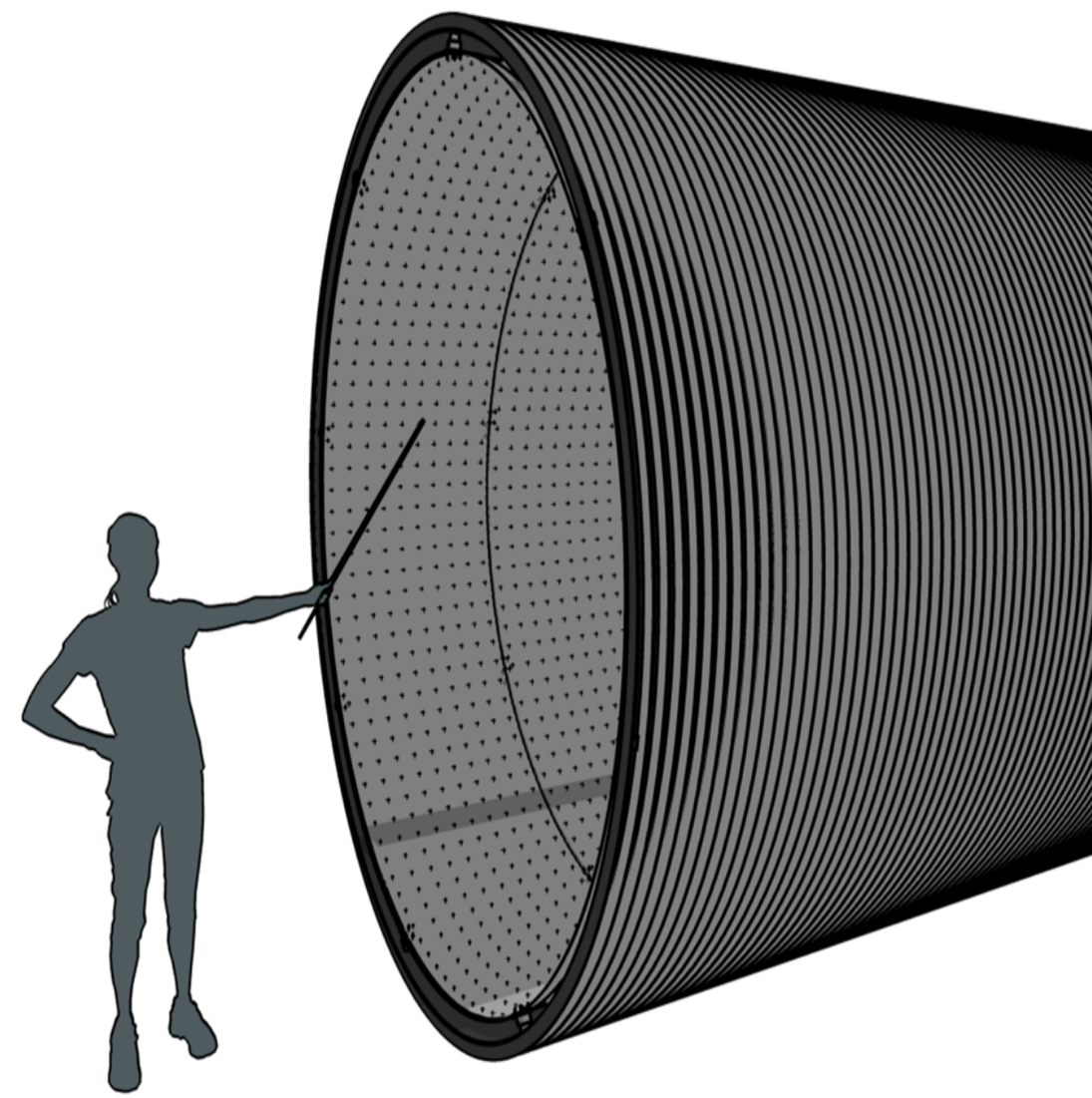
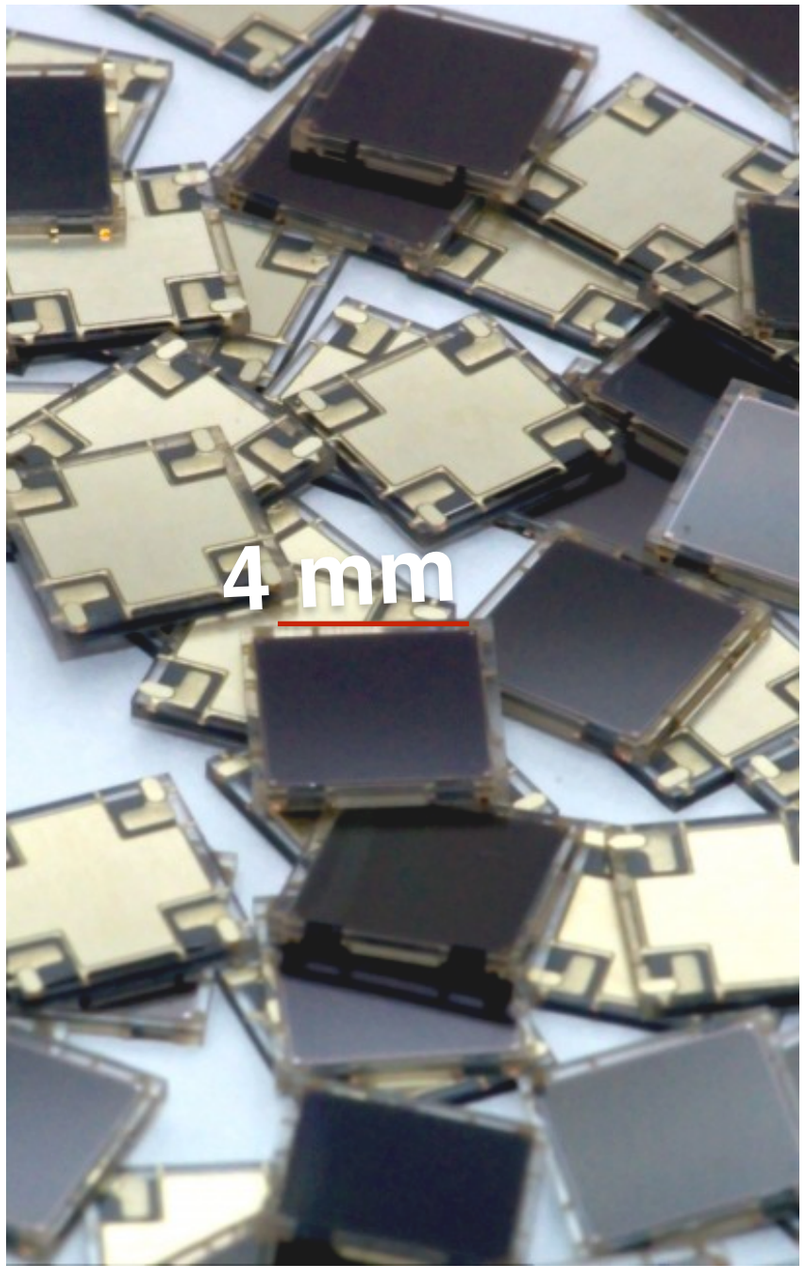
Instrumentation

- Divide volume into target and veto region
- Target region has 1200 hoops containing 100 silicon photomultipliers (SiPM) each
- Veto region has 122 hoops with 100 SiPMs each

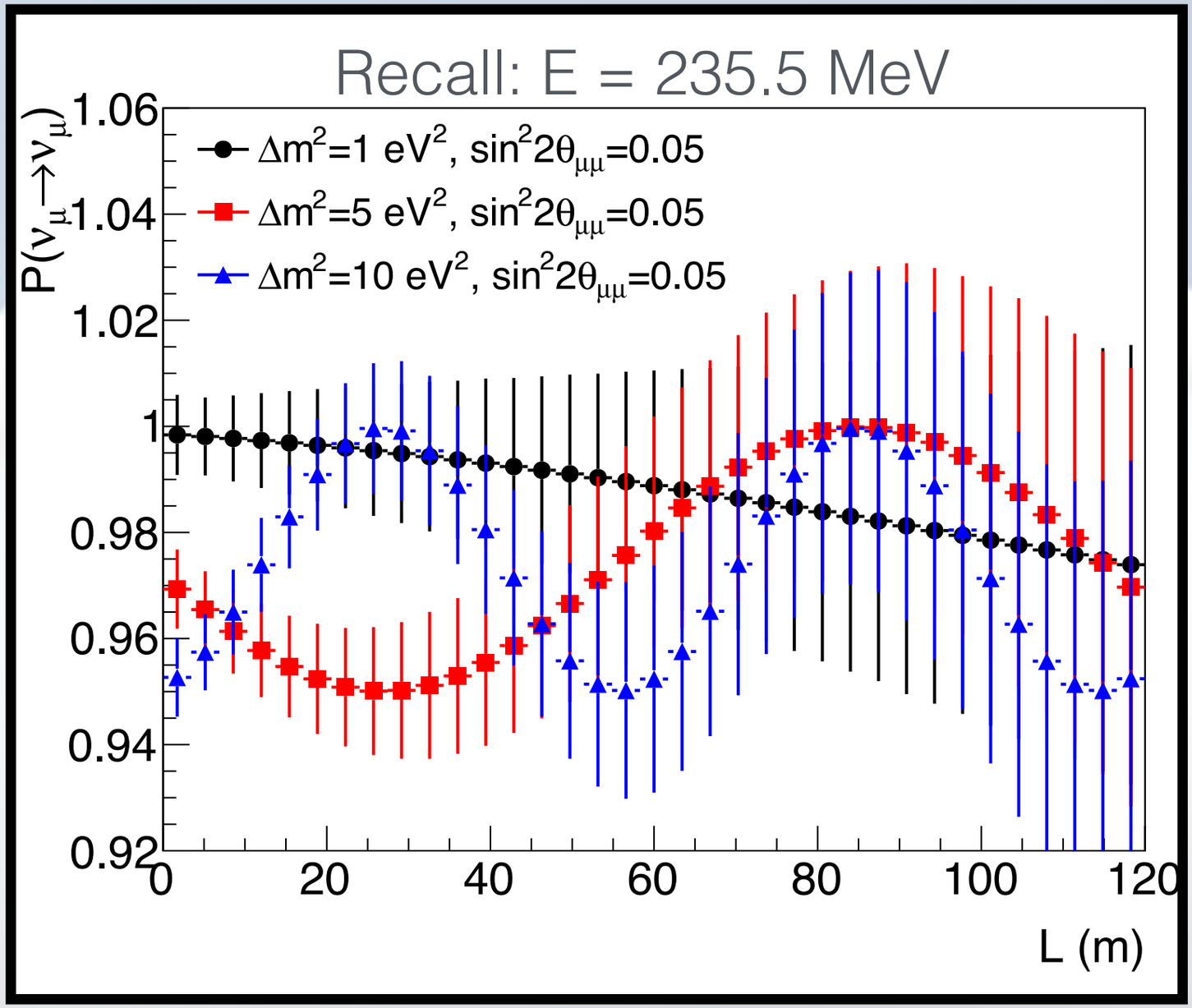


Photon Detector: SiPMs



- 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

What we want to measure



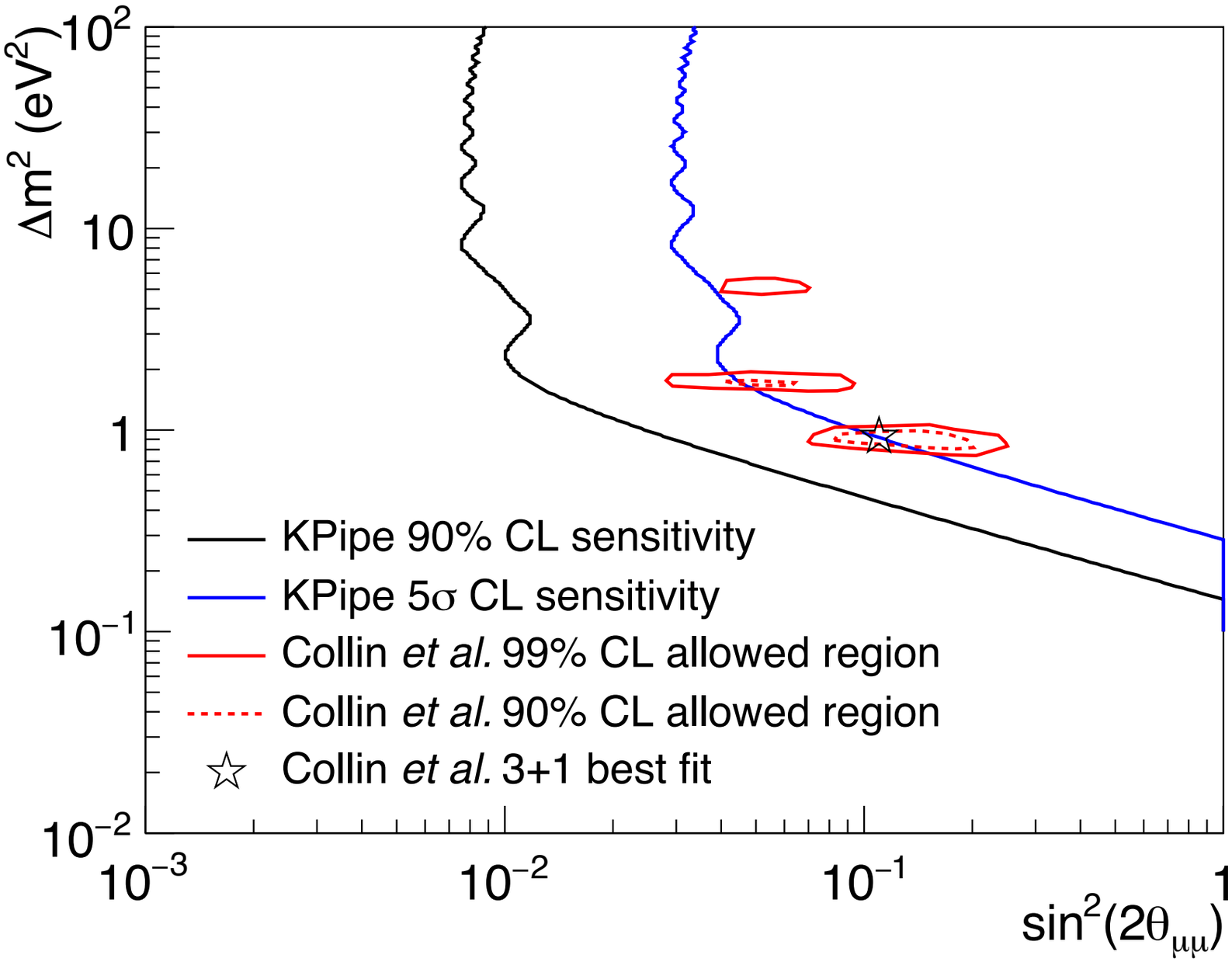
- **Seeing the osc. wave would be definitive evidence for sterile ν's**

Sensitivity

Kaon production uncertainty	+/- 0.2 m
Baseline reconstruction uncertainty	0.8 m
Event generator model	NuWro
Kaon production models	MARS15 = 0.0073 K+/POT
Selection efficiency	75%
CR background rate	27 Hz

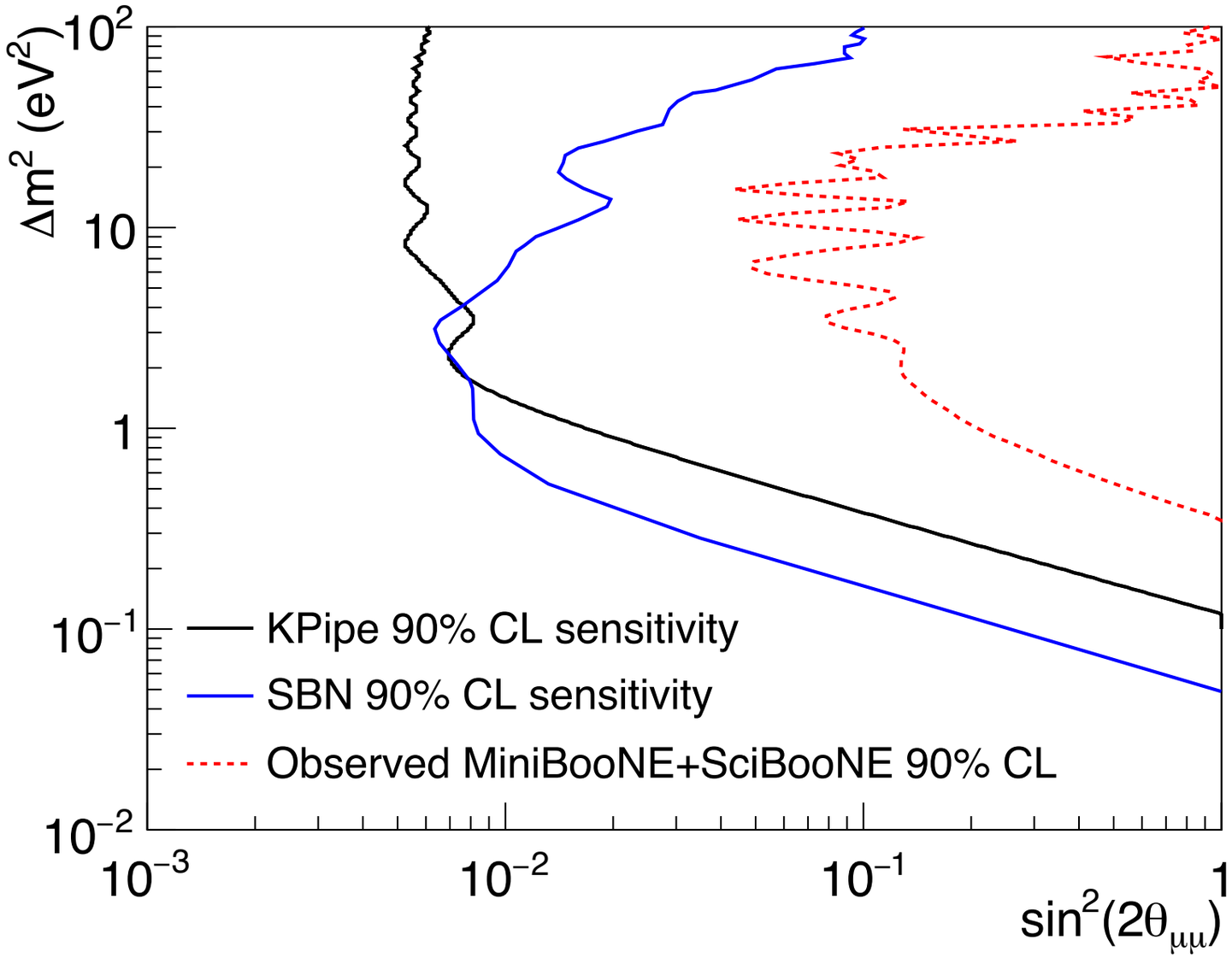
Sensitivity Study

- Three years of running
- Exclude sizable portion of allowed regions at 5 sigma
- This is statistics limited.



Sensitivity Study

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



Costs

	Quantity	Unit Price	Total Price
Scintillator (using NoVA) price	732 metric tonne	1.5k$/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

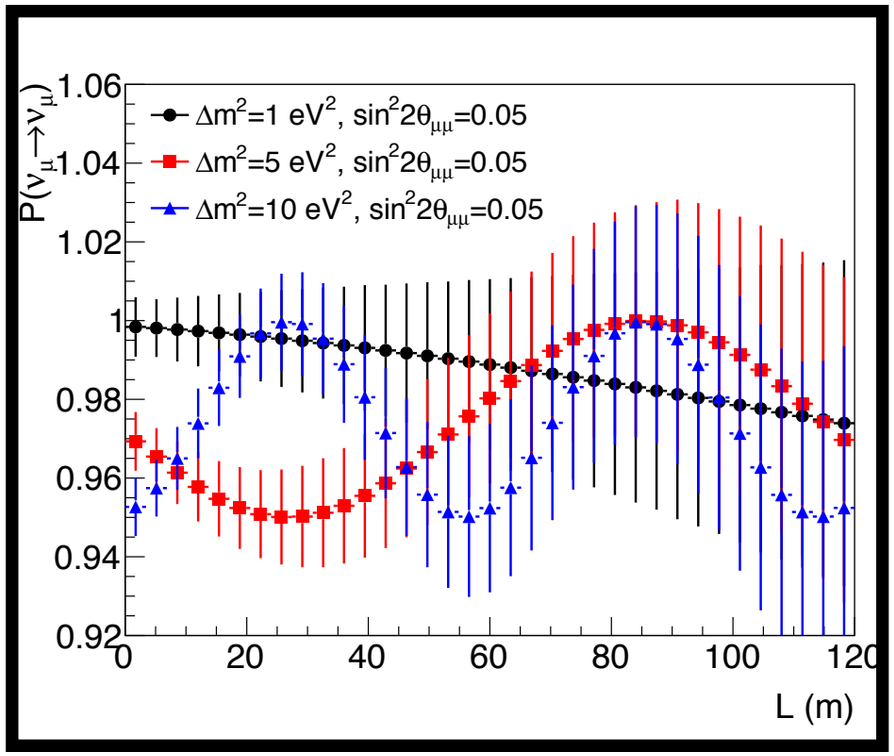
Total	4.6 M$

Summary

- Observation (or lack thereof) 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

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

- Presenting to JPARC today!

Thanks!

S. Axani, T. Wongjirad, G. Collin, J. Conrad, M. Shaevitz, J. Spitz

Massachusetts Institute of Technology
Columbia University
University of Michigan

Back-up

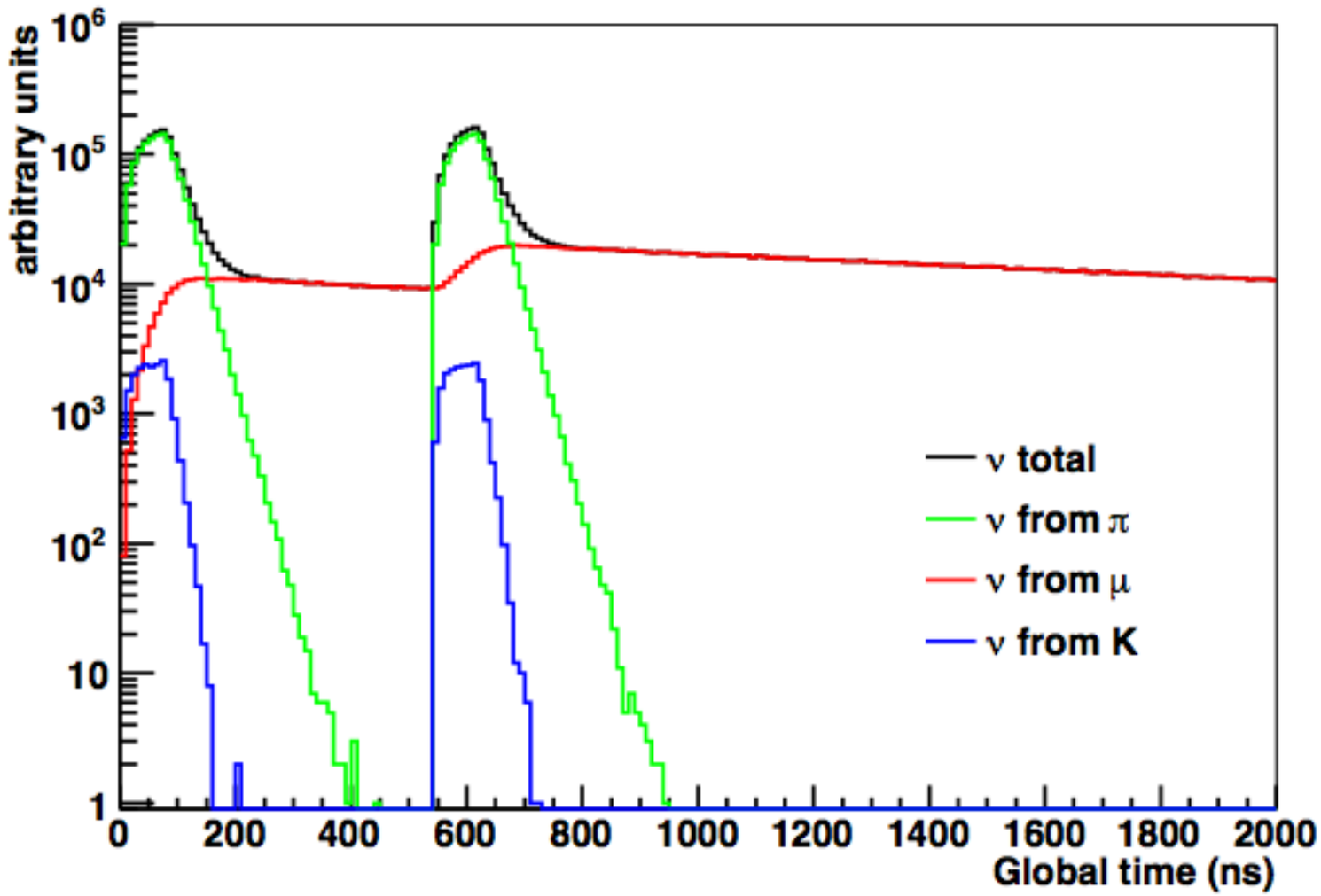
Backgrounds

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

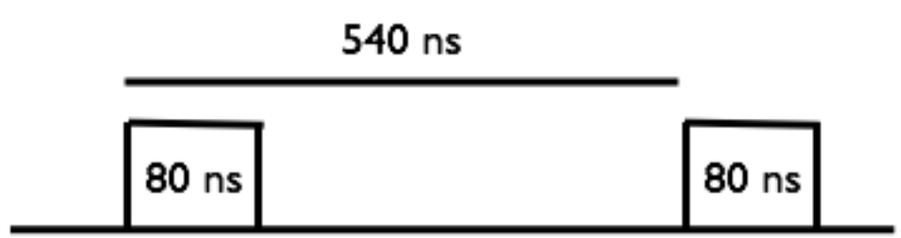
signal to background ratio:
60:1 at front
3:1 at back

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

Beam Timing



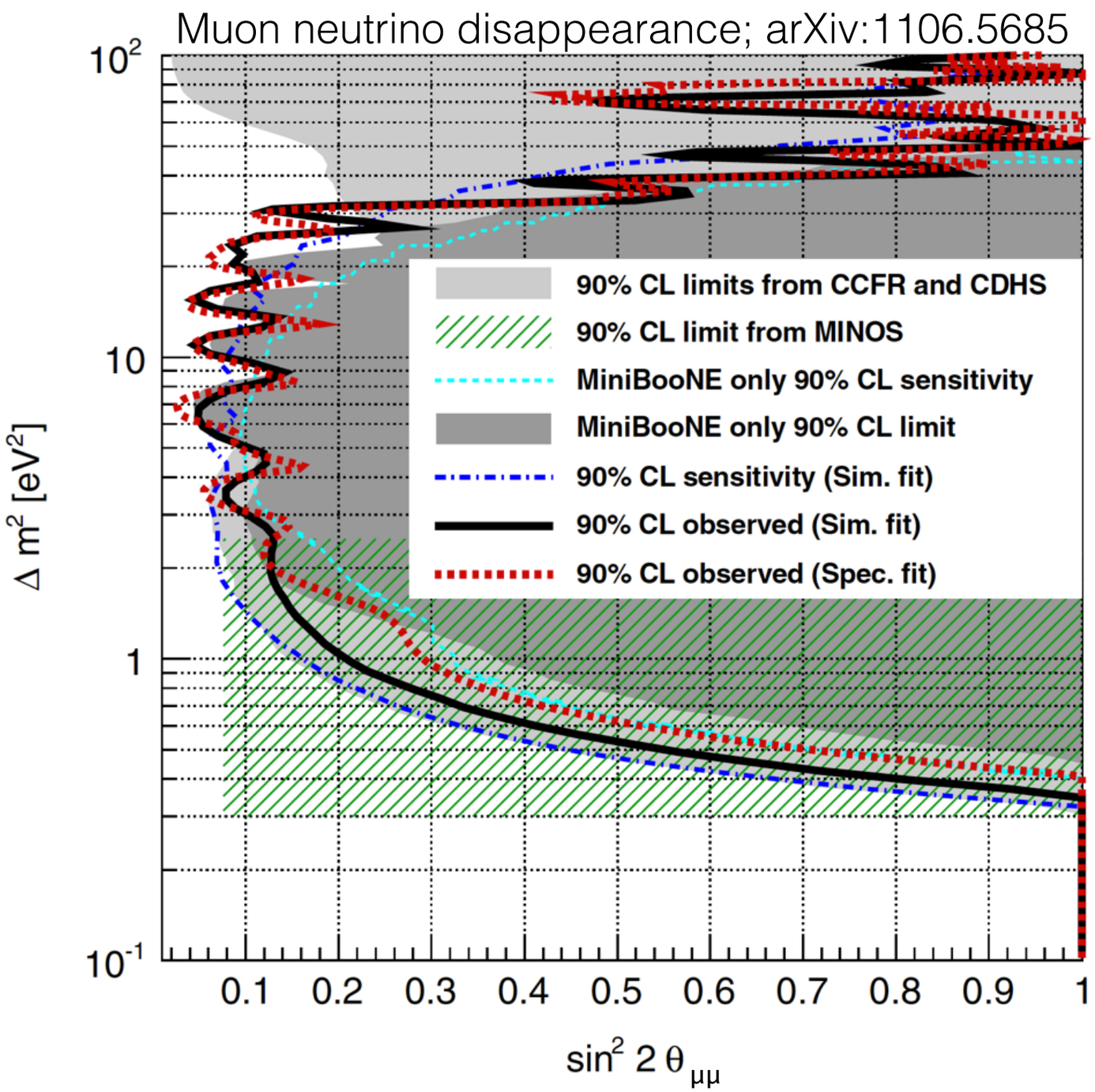
- Timing of neutrinos should be well-known
- Look for interactions coming from neutrinos in the two windows



Beam structure

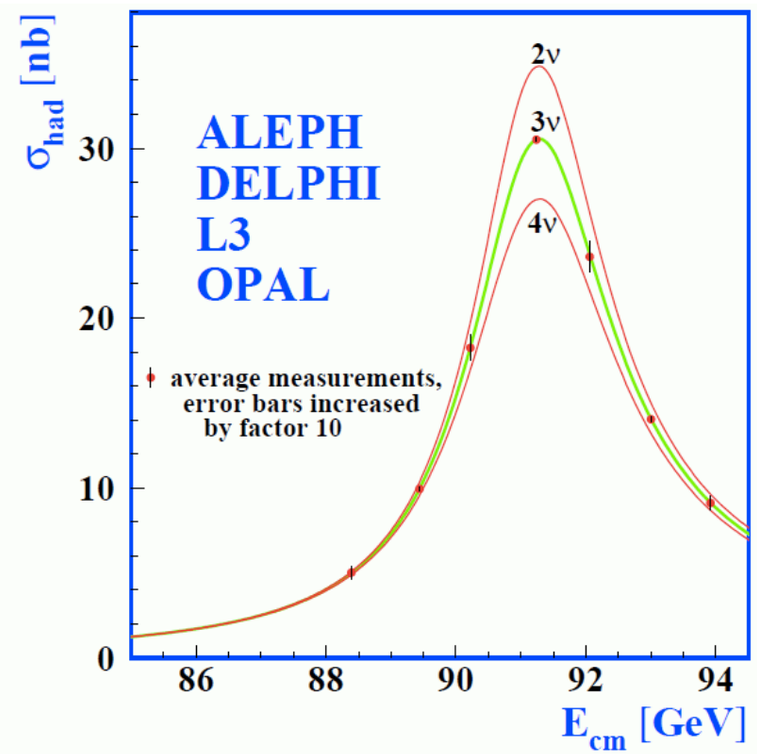
25 Hz

Muon Neutrino Disappearance

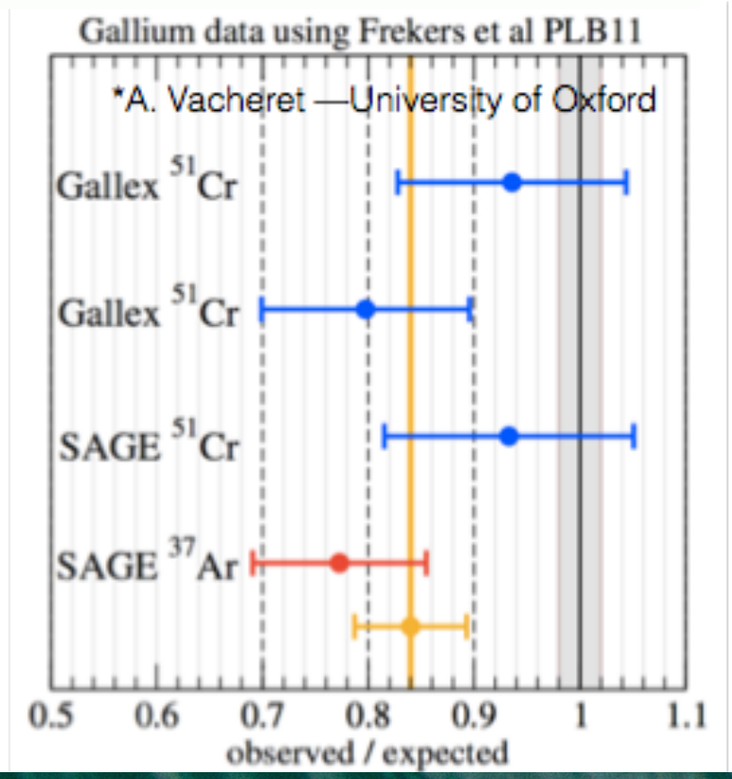


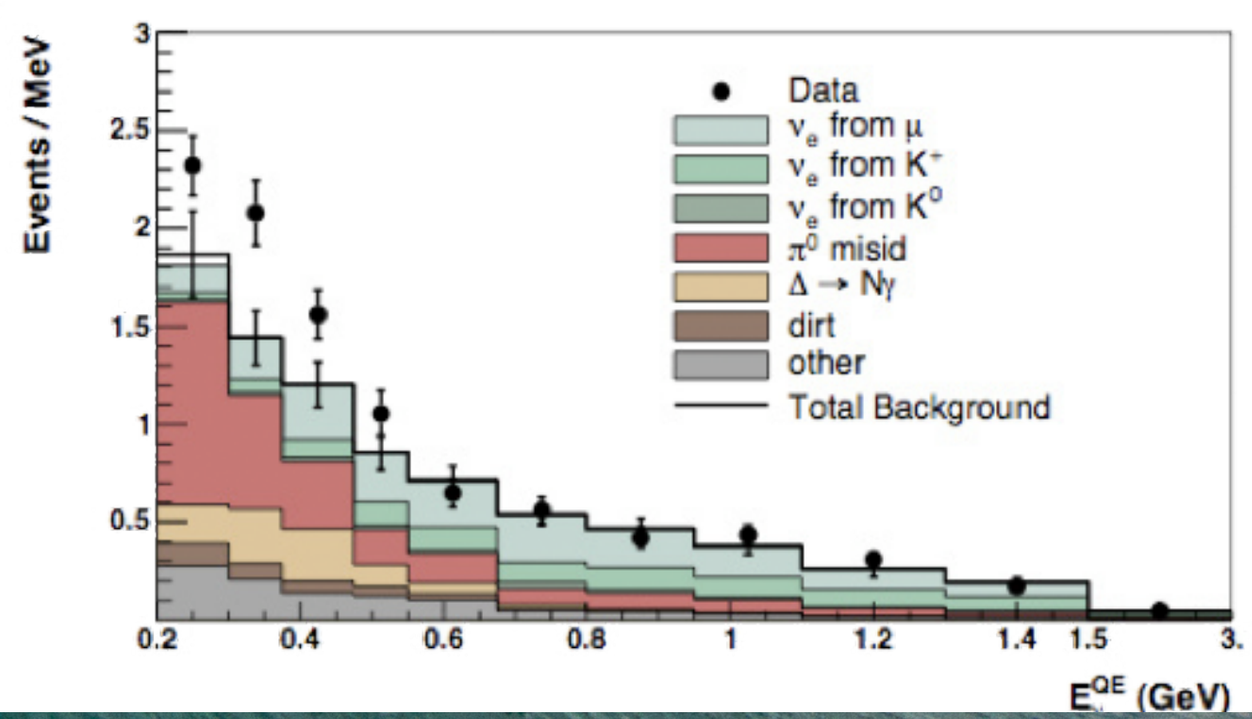
- Not all experiments see anomalies
- In fact, no experiment has seen muon neutrino disappearance
- An important constraint

(backup) Sterile Hypothesis



- The width of the Z boson shows us that there are only 3 flavors of neutrinos that interact via the weak force
- Reactor experiments indicate that there is a deficit in the electron flavored neutrinos
- Calibration source experiments confirm this
- Data from low L/E oscillation experiments observe ~3 sigma excess in nue and nuebar.



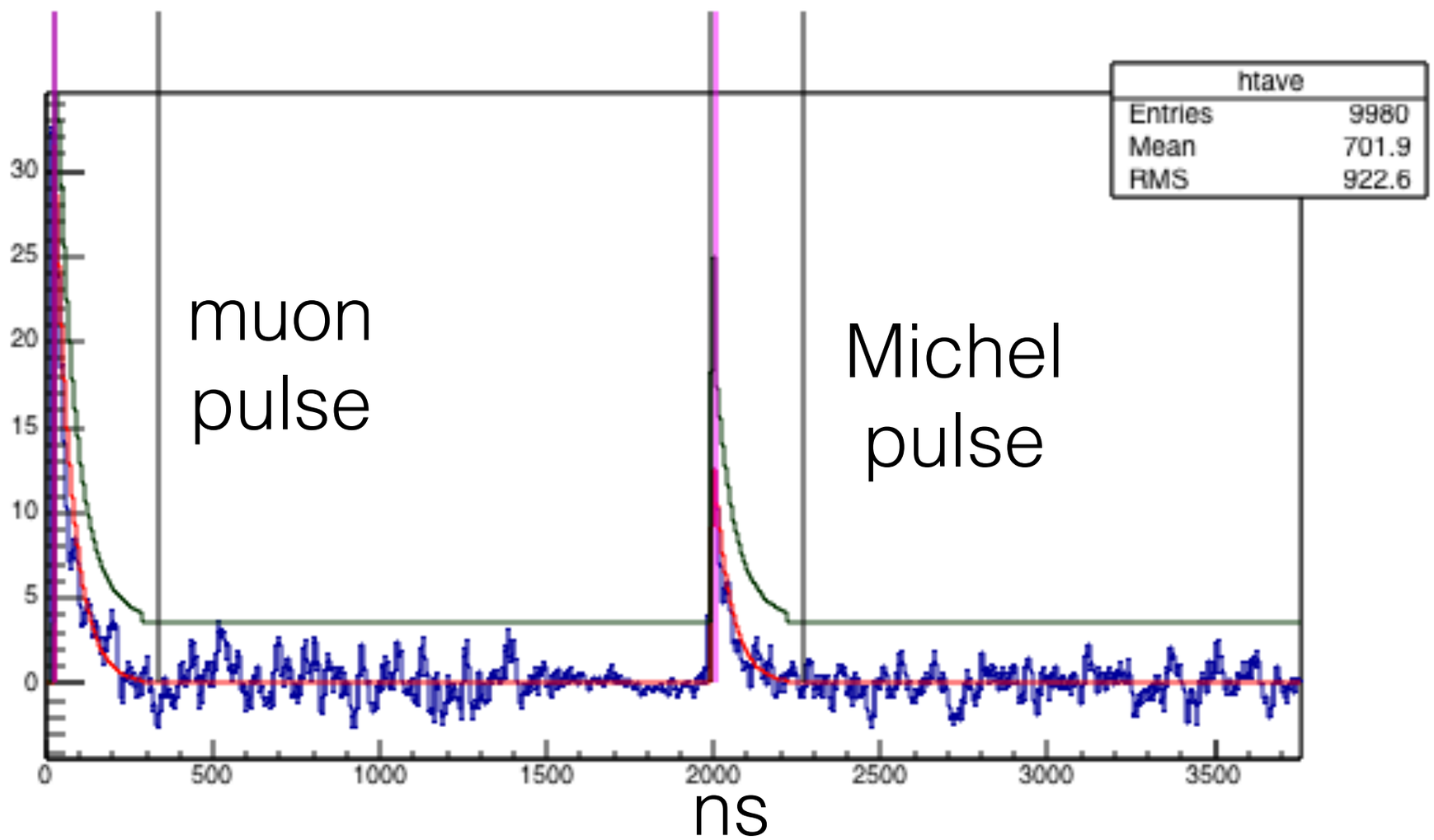


Signal Selection

- 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

Signal Simulation

- Include photon hits from interactions and 1.6 MHz dark rate



Selection Efficiency

- removing cosmics comes at some cost to signal

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%
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muons only	60%
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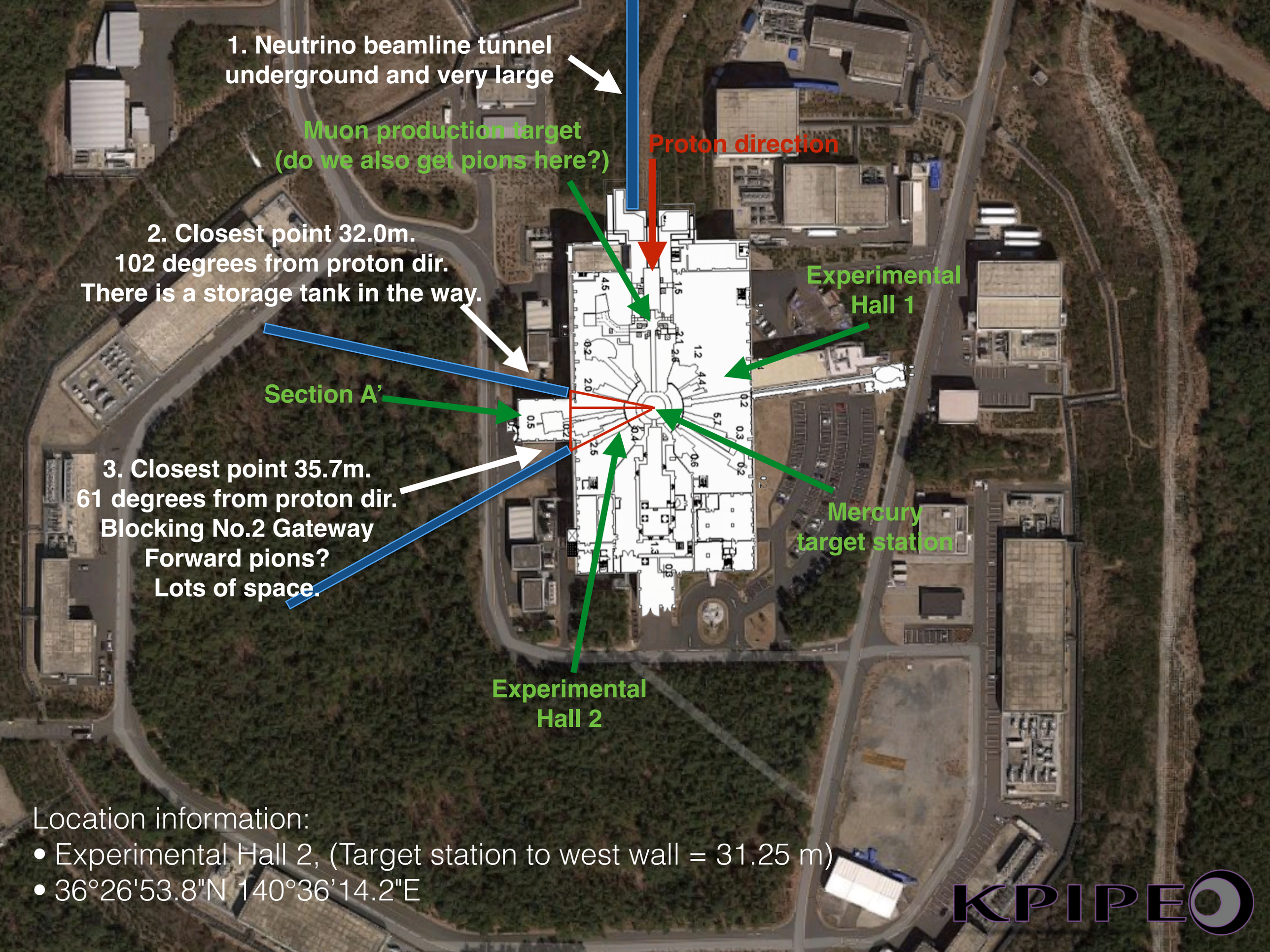
1. Neutrino beamline tunnel
underground and very large
Muon production target
(do we also get pions here?)
Proton direction
2. Closest point 32.0m.
102 degrees from proton dir.
There is a storage tank in the way.
Experimental
Hall 1
Section A'
3. Closest point 35.7m.
61 degrees from proton dir.
Blocking No.2 Gateway
Forward pions?
Lots of space.
Mercury
target station
Experimental
Hall 2
Location information:
• Experimental Hall 2, (Target station to west wall = 31.25 m)
• 36°26'53.8"N 140°36'14.2"E
KPIPEO