Large-scale Neutrino Detectors Within and Surrounding Lake Geneva

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In collaboration with…

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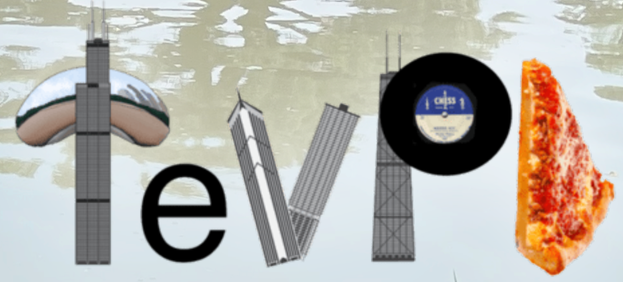
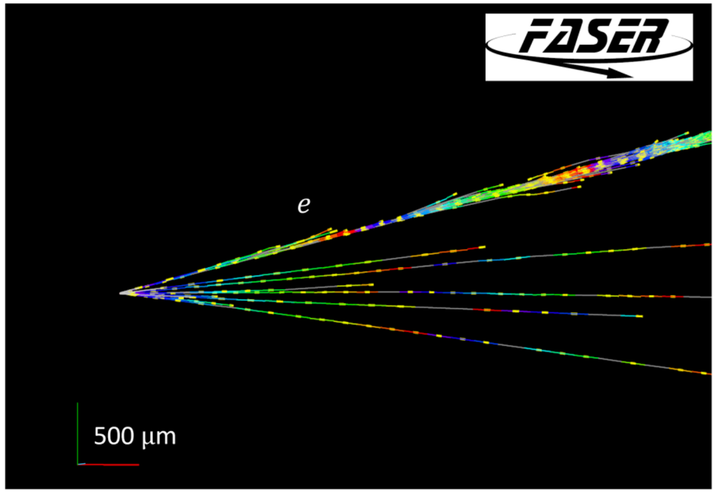
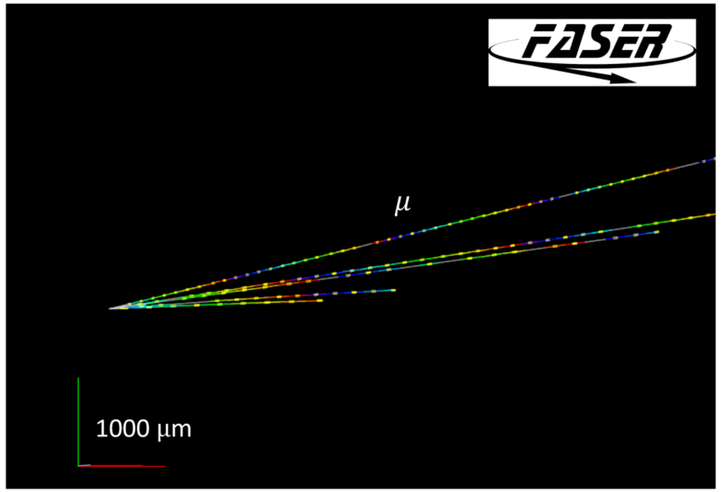
T. Yuan



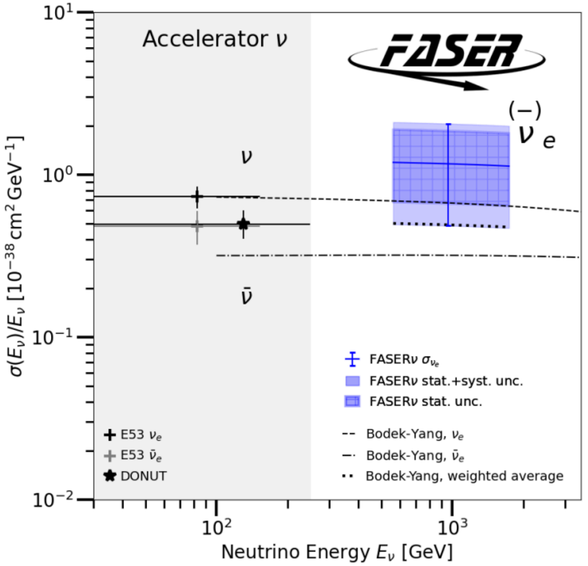
Chicago 2024

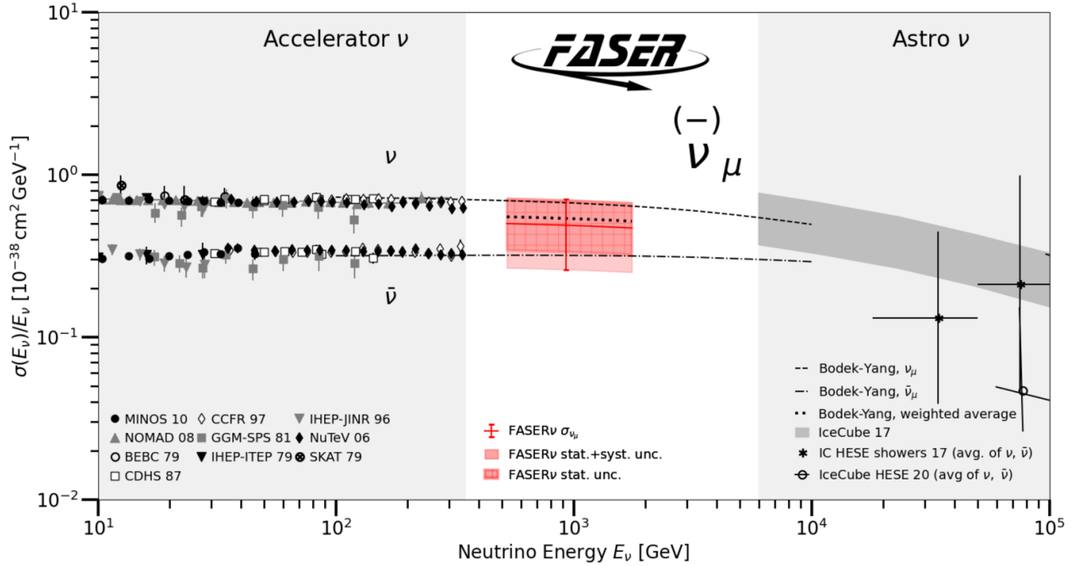
The Dawn of Collider Neutrino Physics

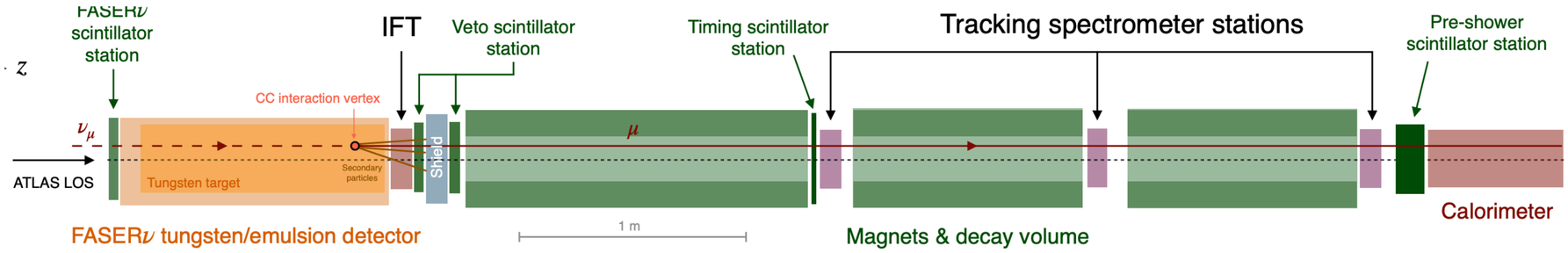




Unique sensitivity to TeV-scale neutrinos and long-lived particles produced in the forward direction at the LHC



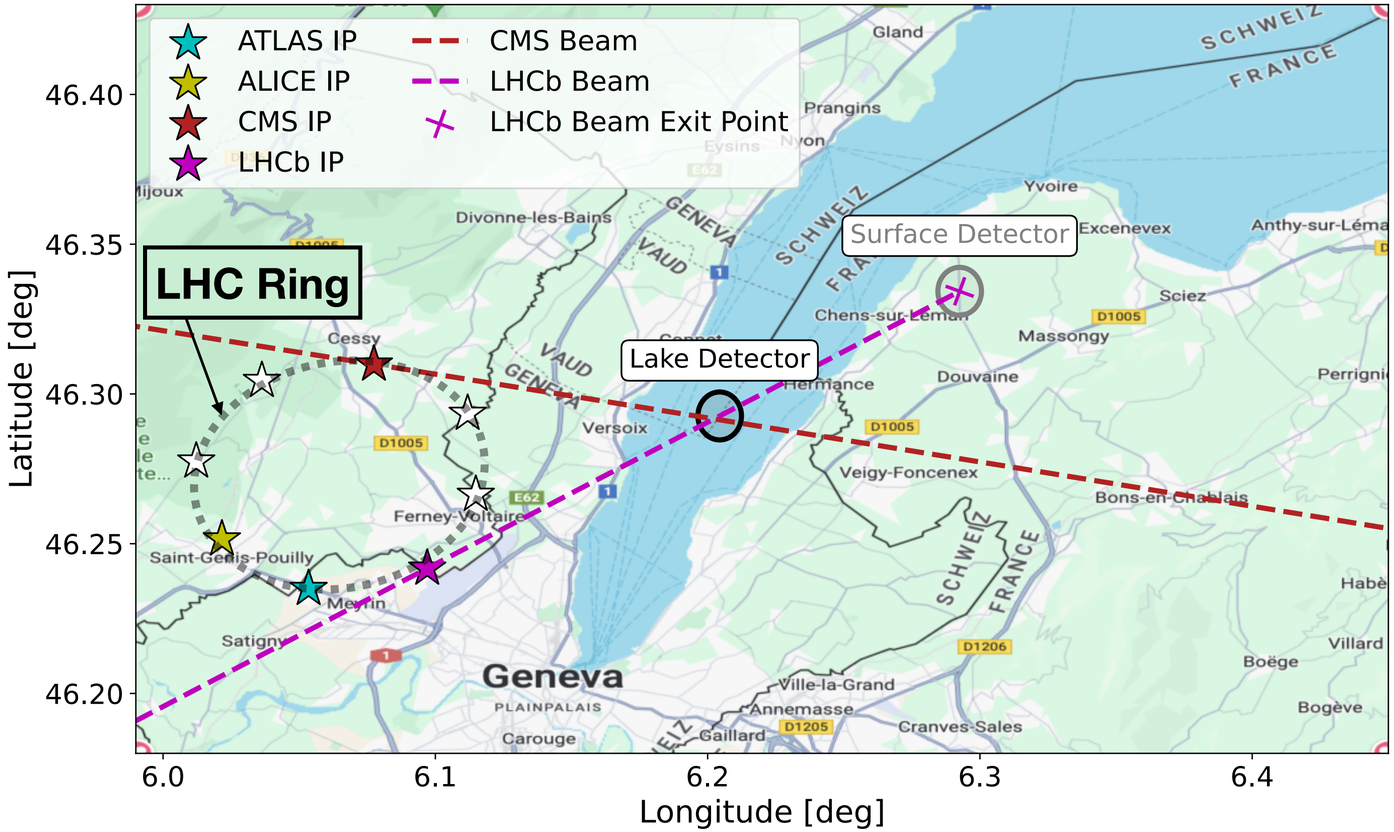




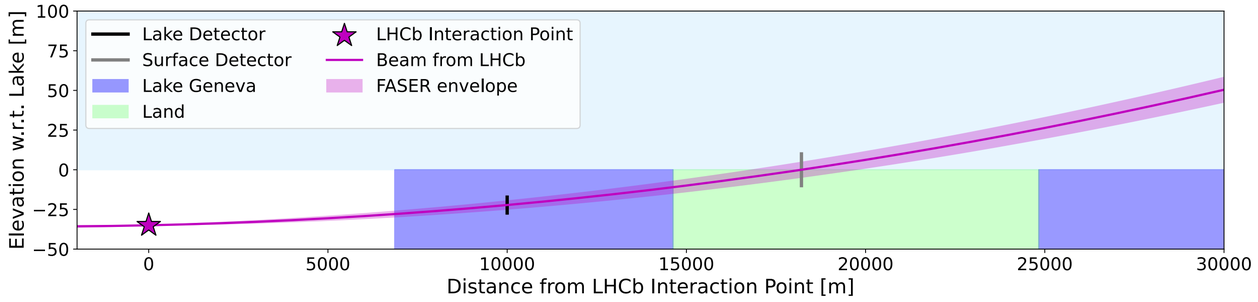
FASER Collab. 2023

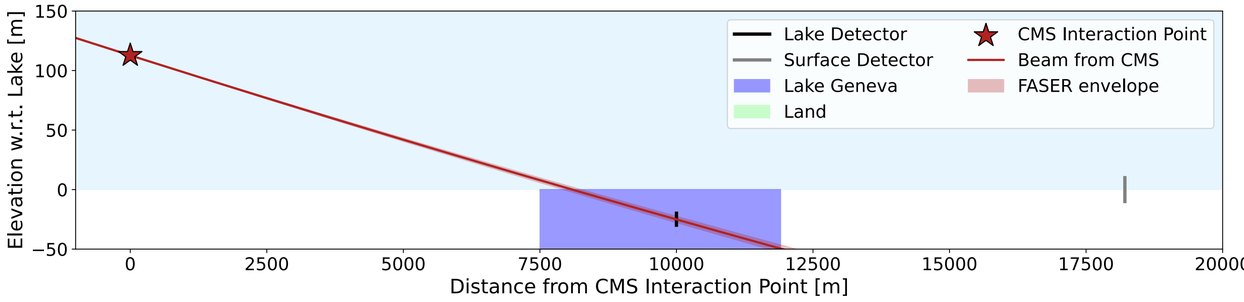
FASER Collab. 2024

LHC Neutrinos pass through Lake Geneva

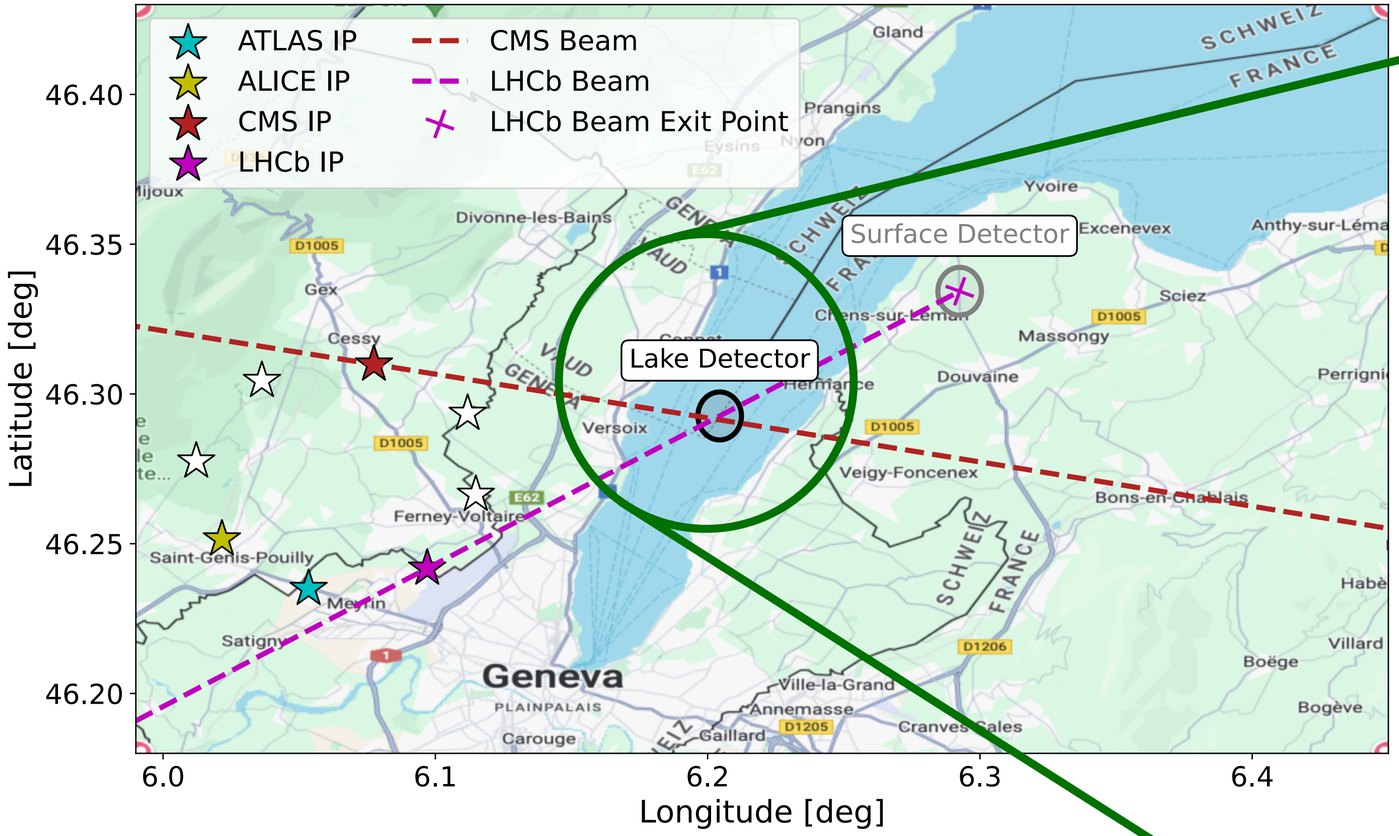


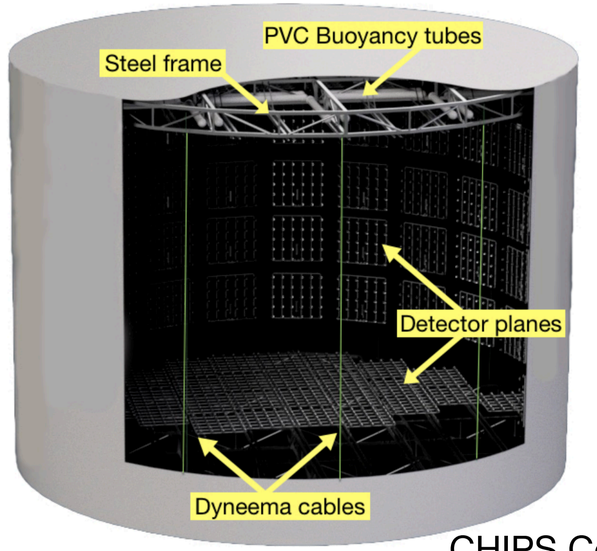
- This enables the construction of kiloton-scale lake-and-surface-based detectors that evade muon backgrounds from the p-p collision
- We focus on the neutrinos from LHCb, though sensitivity to other interaction points is also possible





Lake Detector Proposal

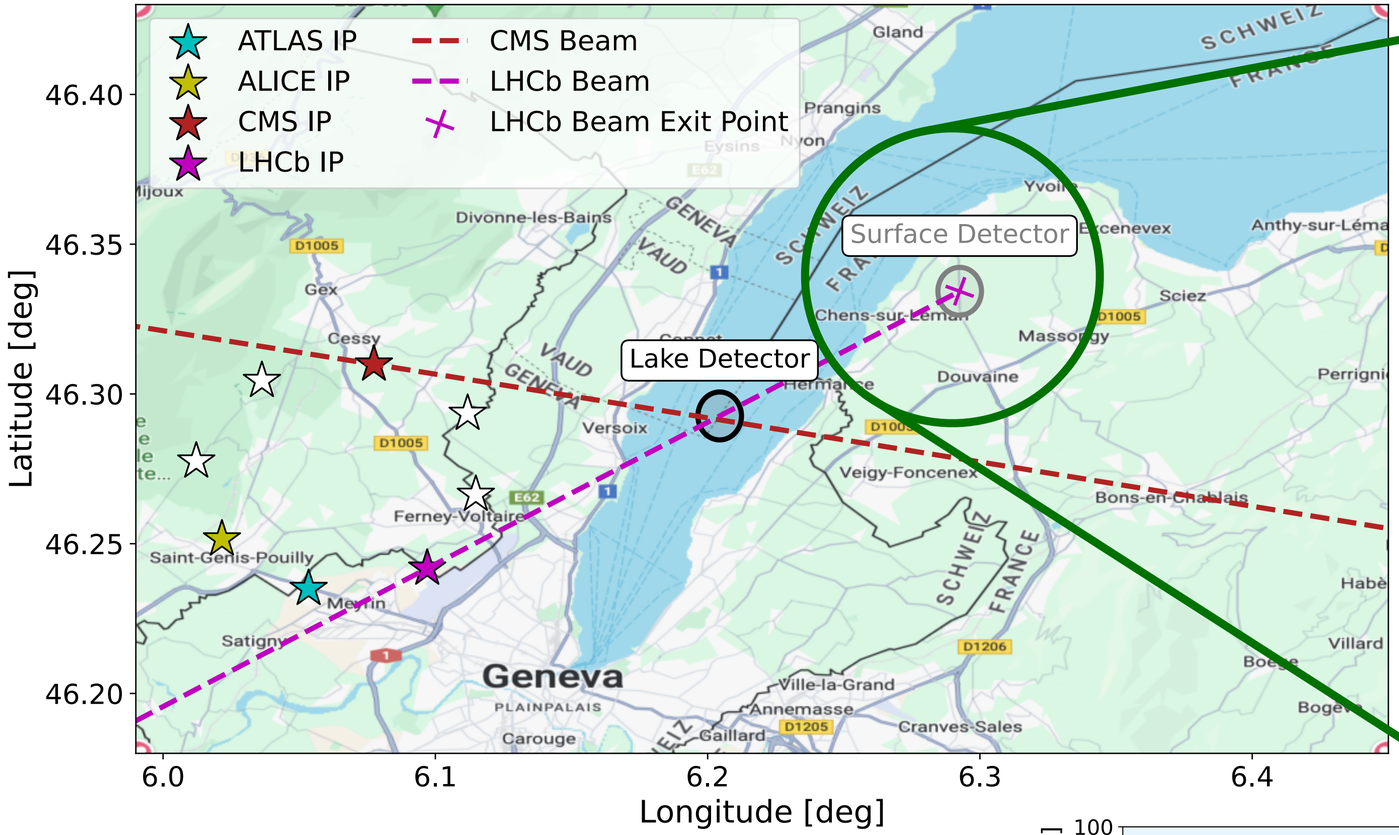


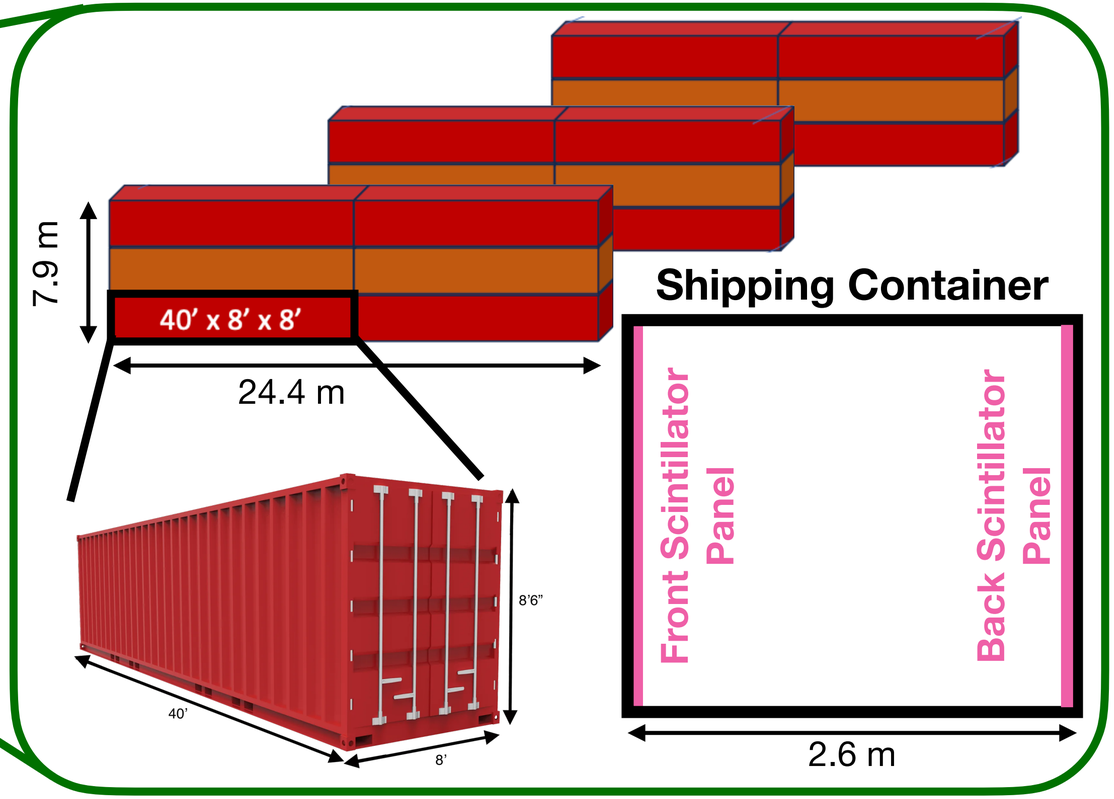


CHIPS Collab. 2024

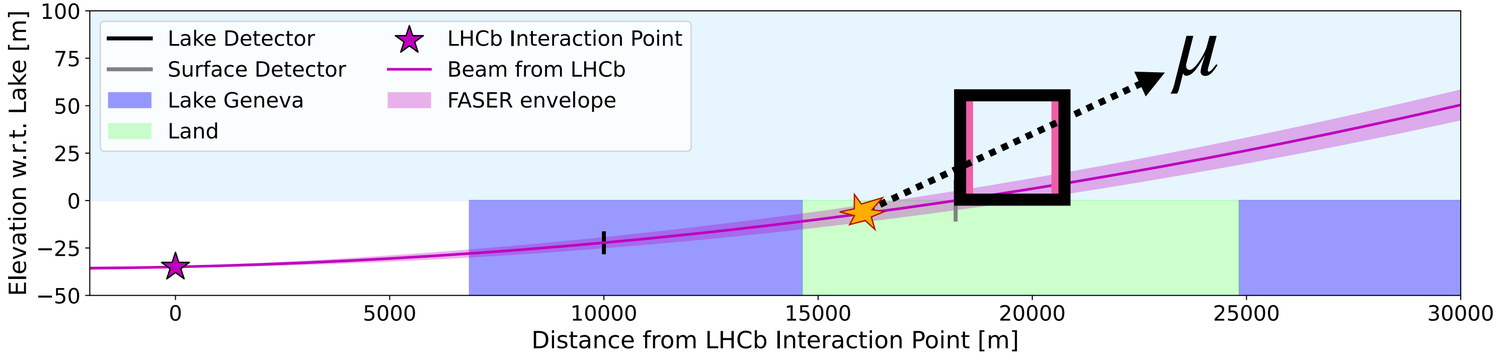
- A suite of CHIPS-style water Cherenkov detectors deployed in a modular fashion
- Benchmark lake detector: cylinder with radius of 5 m and length of 100 m (~4 CHIPS modules)

Surface Detector Proposal



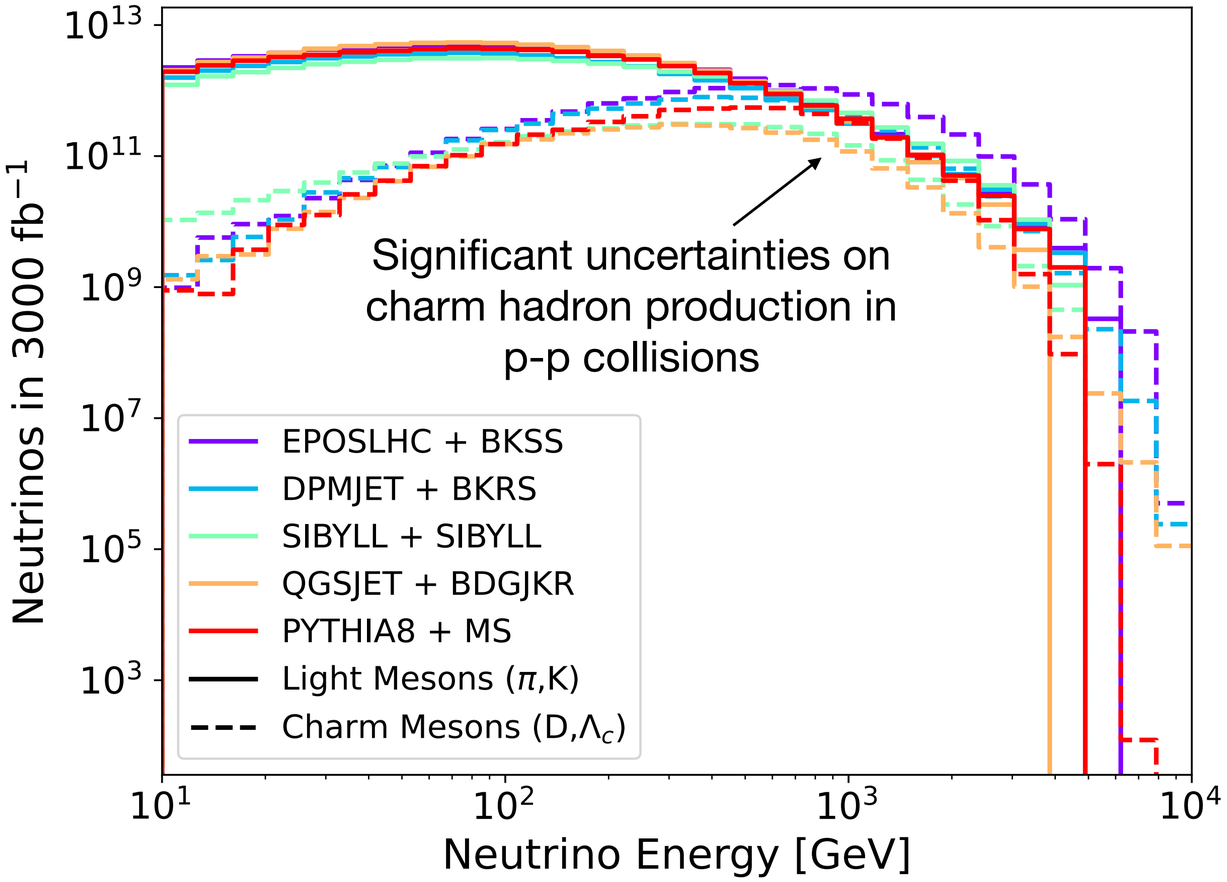


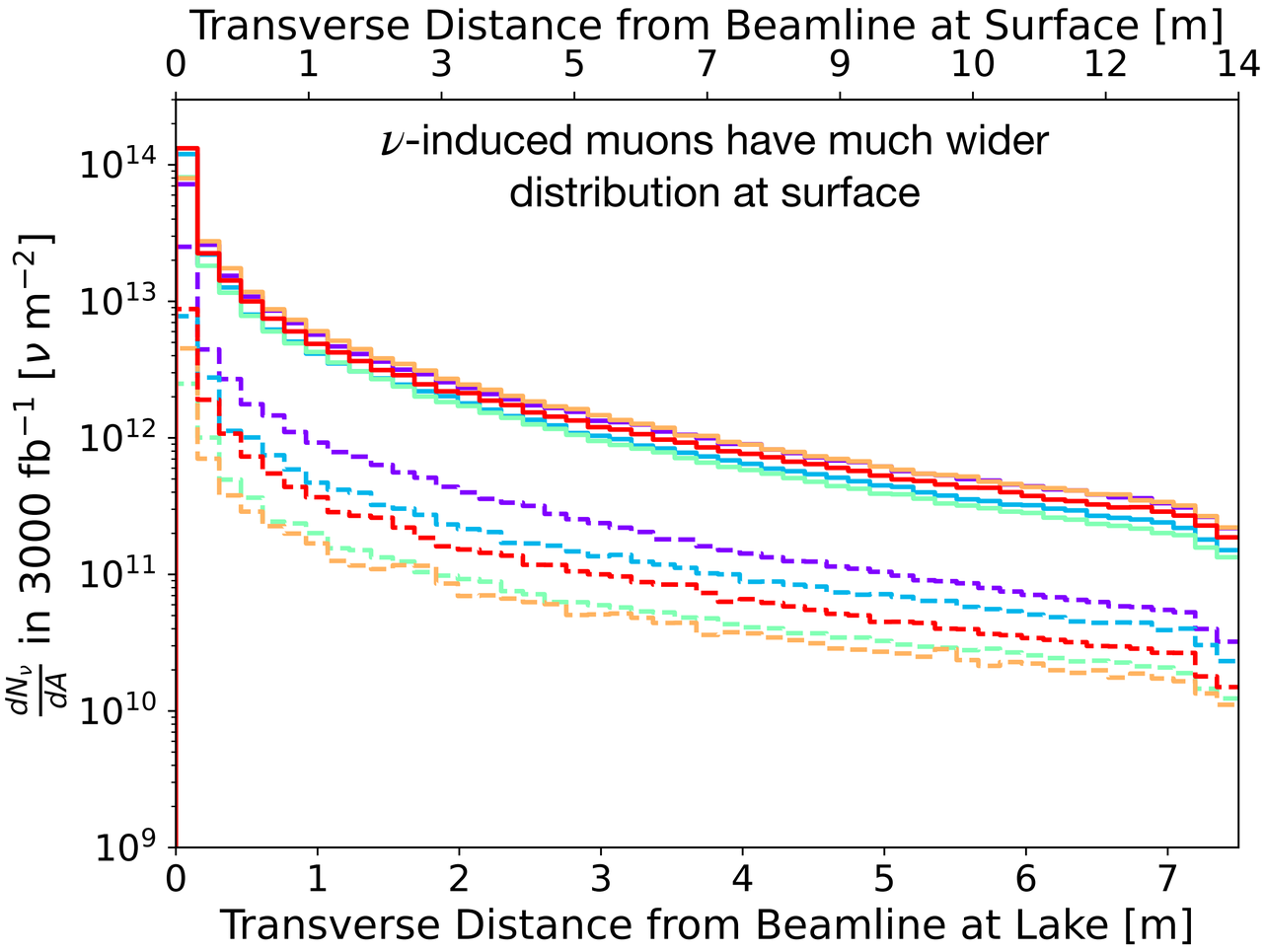
- Scintillator panels situated inside shipping crates
- Arranged in three sets of 3x2 crates



LHC Forward Neutrino Flux

We use github.com/makelat/forward-nu-flux-fit for simulated samples of forward neutrinos produced in ATLAS

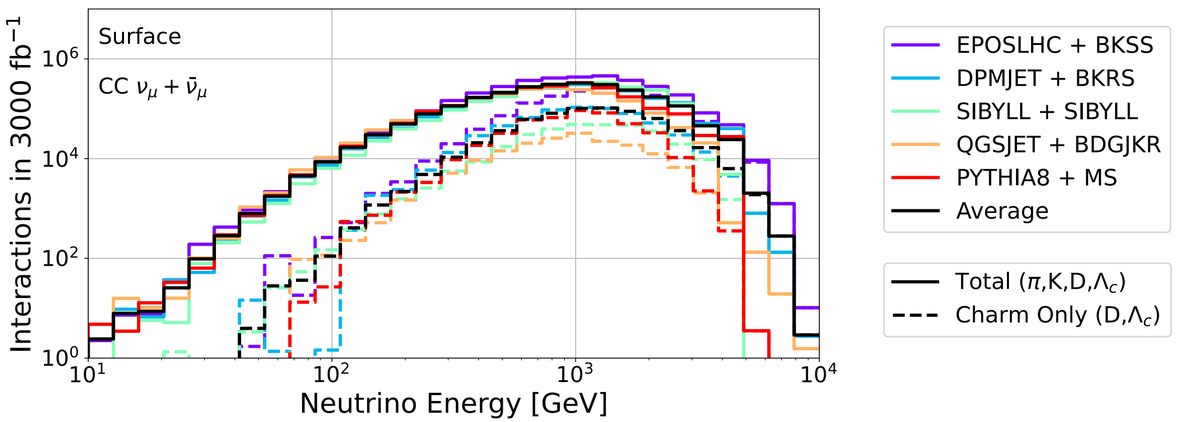


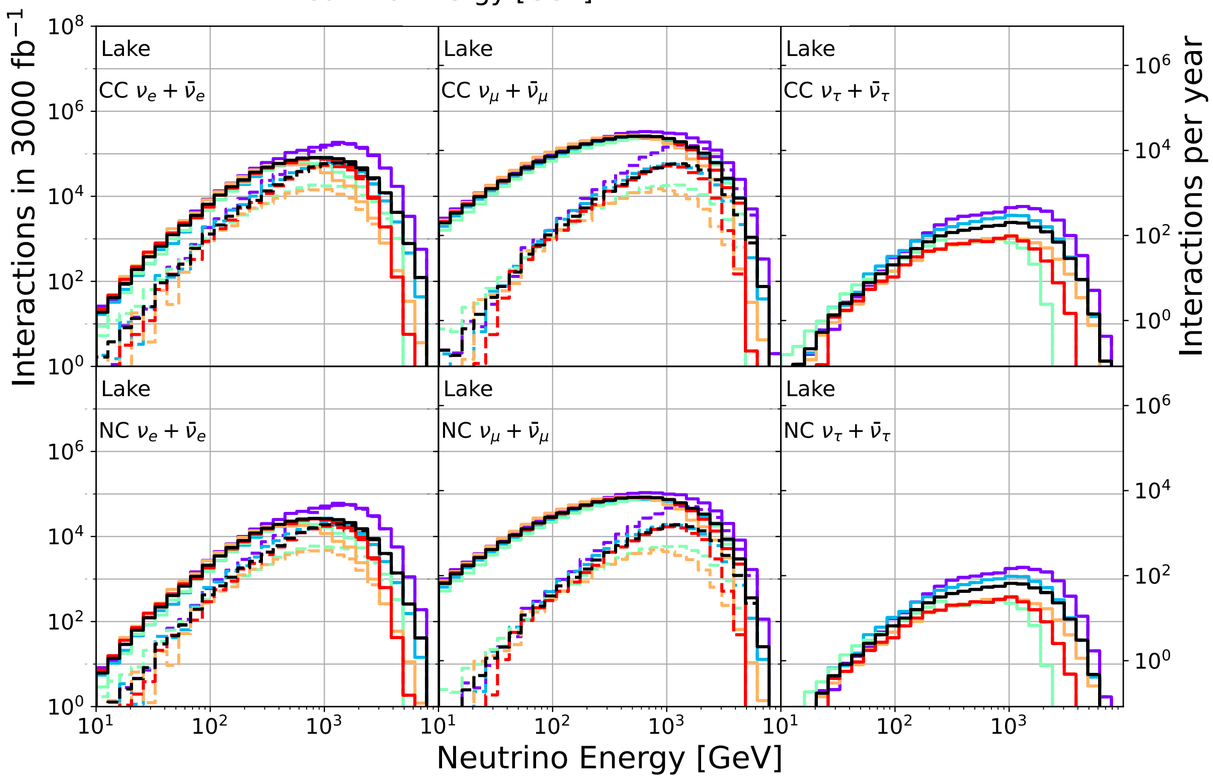


Event Rates

- We simulate DIS neutrino interactions along the LHCb beamline using the SIREN simulation toolkit [1]
- >1M interactions per detector in 3000 fb^{-1} (corresponding to High Luminosity LHC)
- Some flavor identification possible in the lake detector using topology of Cherenkov rings

These detectors offer a cost-effective opportunity to collect large samples of TeV-scale collider neutrino interactions



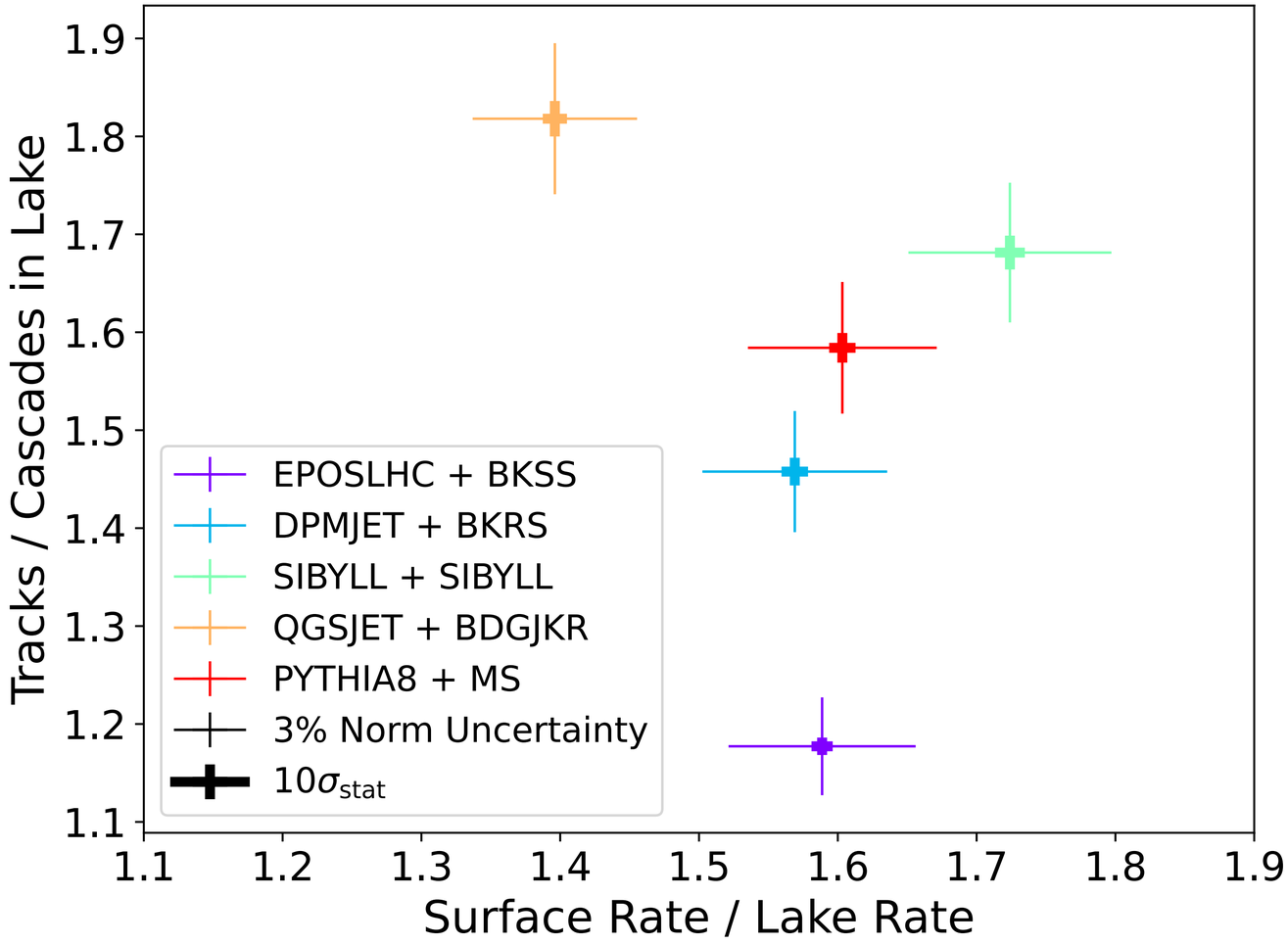


[1] A. Schneider, NK, A. Wen 2024

What can we do with over a million collider neutrinos?

Charm Production in p-p Collisions

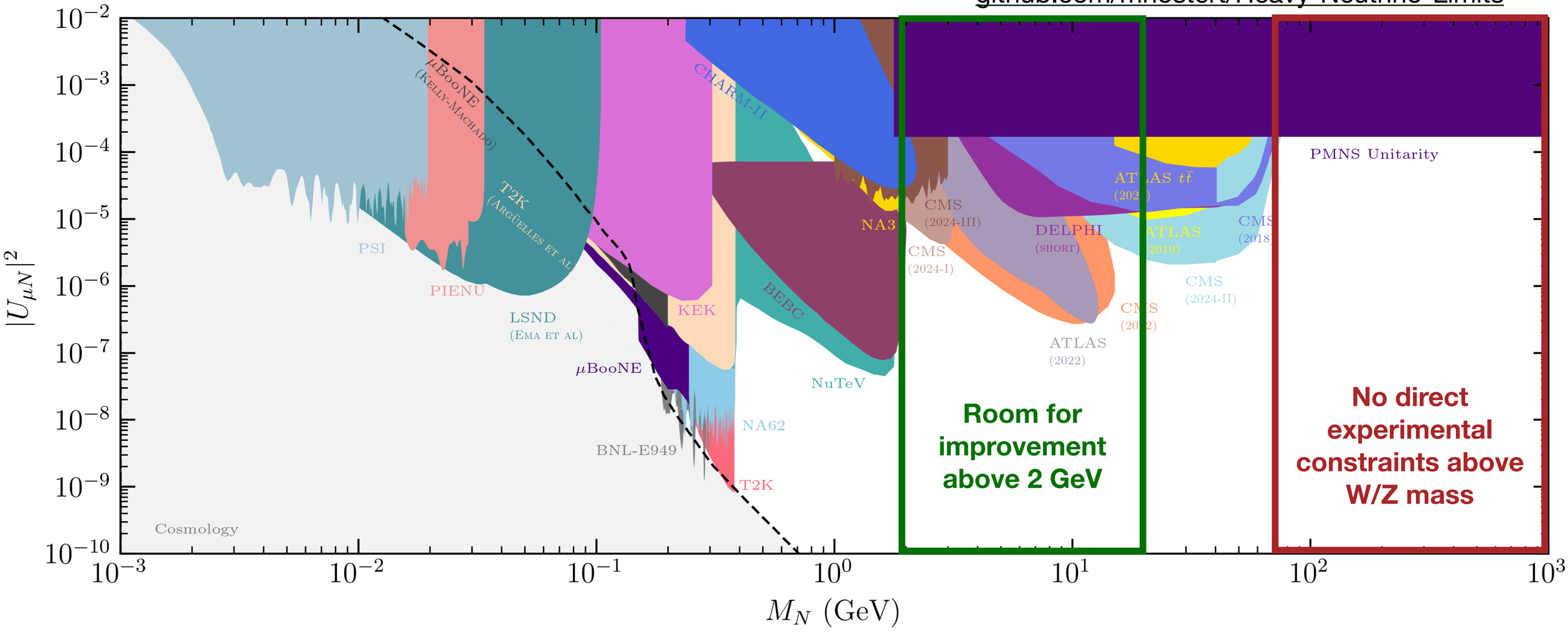
- Order-of-magnitude uncertainties on forward charm production in p-p collisions
- Increasing forward charm production rates corresponds to…
  1. **More high-energy muon neutrinos**
  2. **More electron and tau neutrinos**
- Ratio measurements can distinguish between charm production models
- Important implications for **intrinsic charm content of the proton [1]** and the **prompt atmospheric neutrino flux [2]**



[1] Maciula+ 2022 [2] Jeong+ 2023

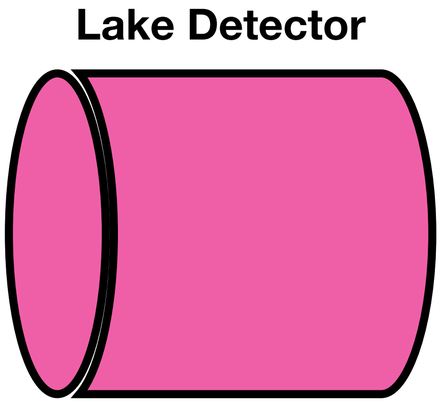
Heavy Neutral Leptons

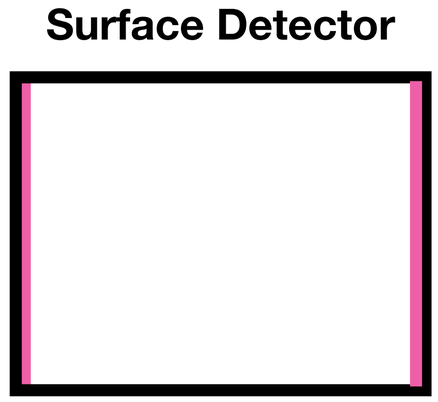
github.com/mhostert/Heavy-Neutrino-Limits



Heavy Neutral Lepton Searches

- Two ideas to look for HNLs in our proposed detectors





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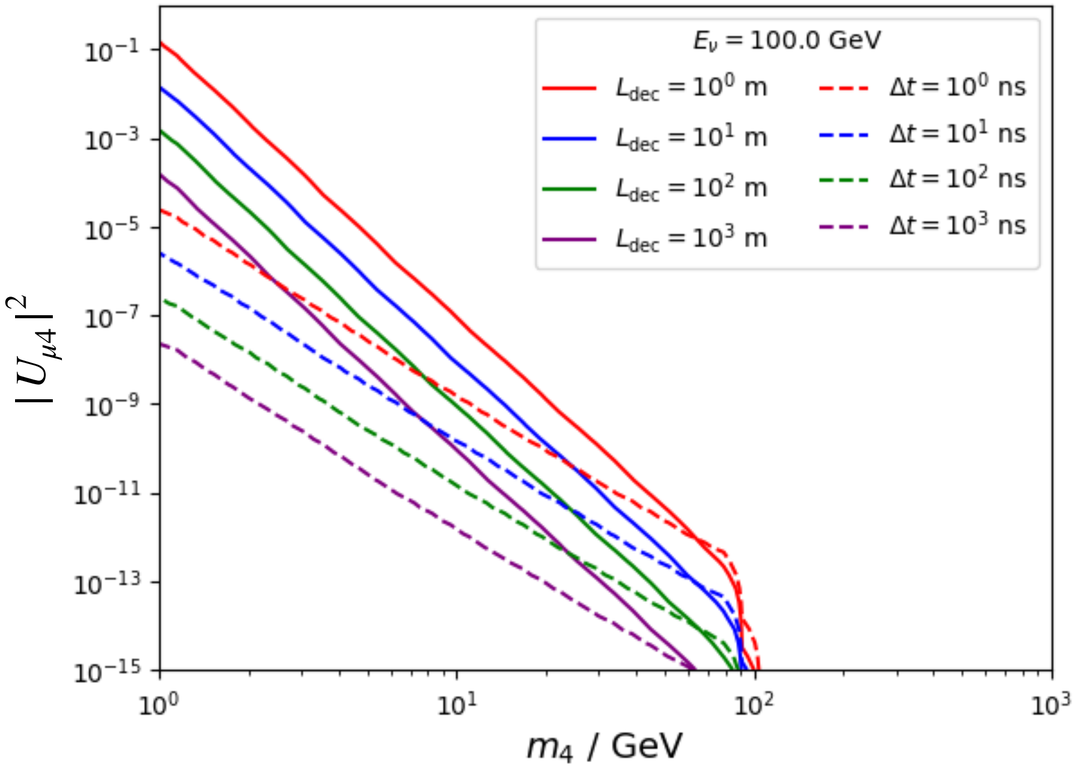

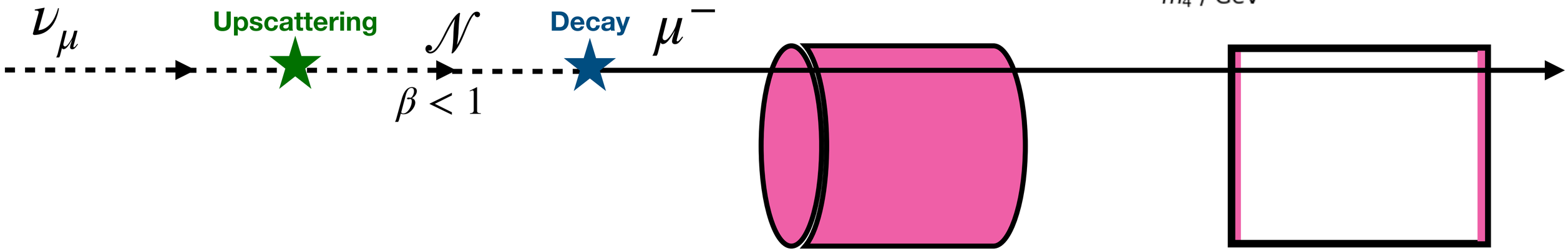

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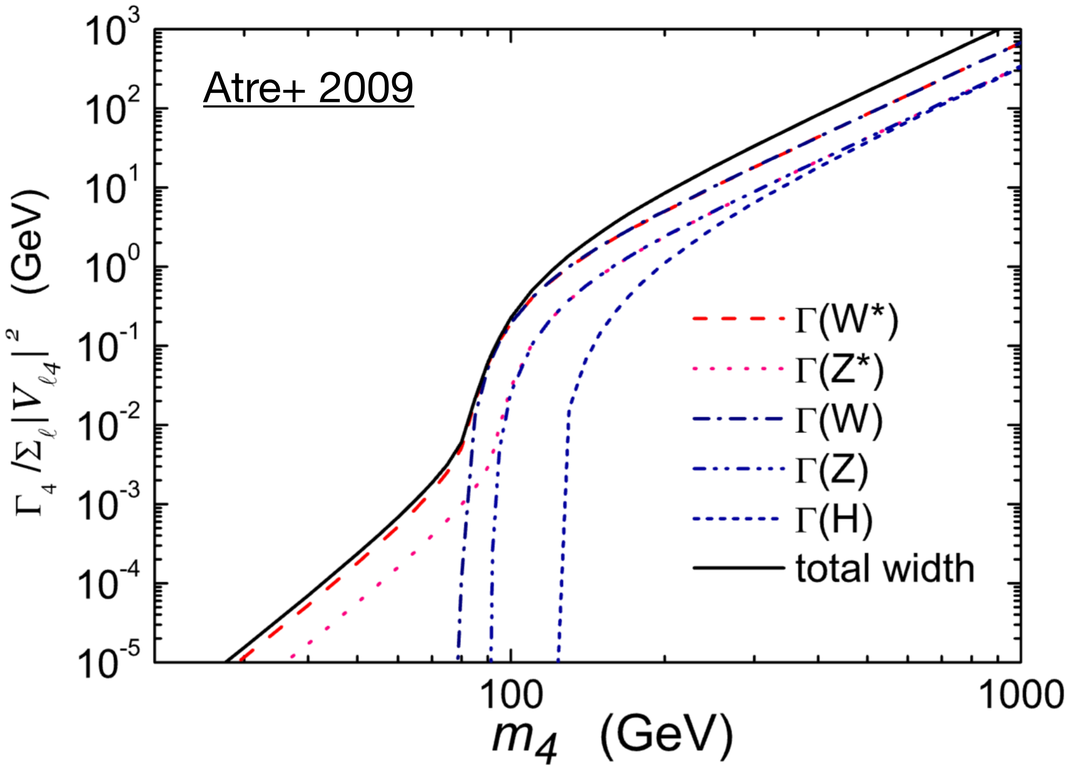

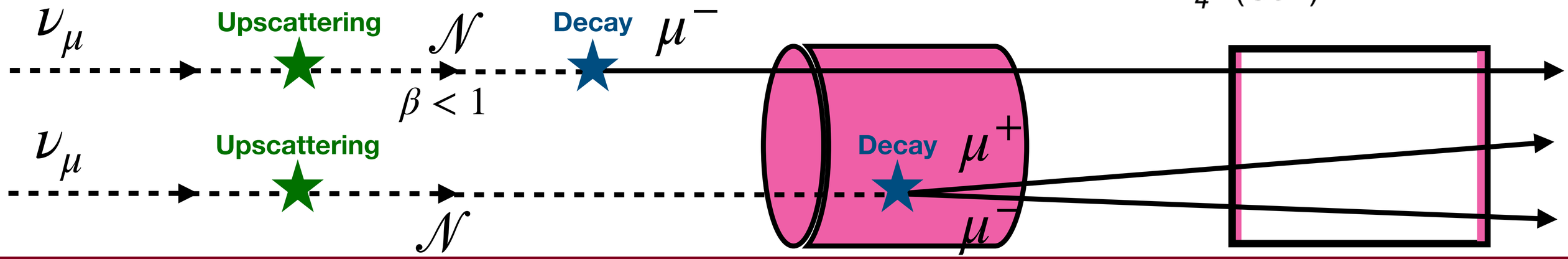

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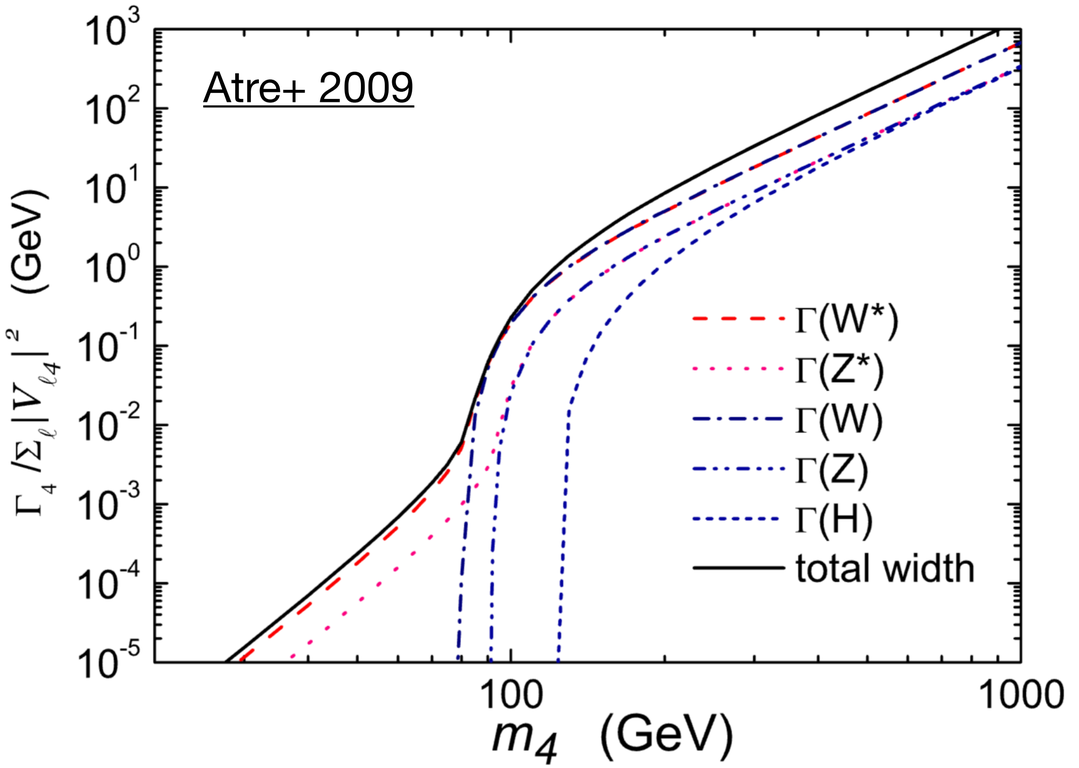
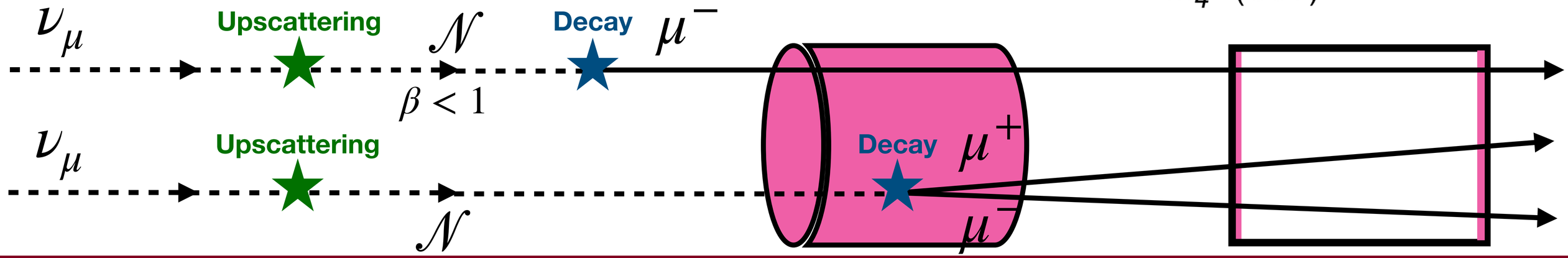
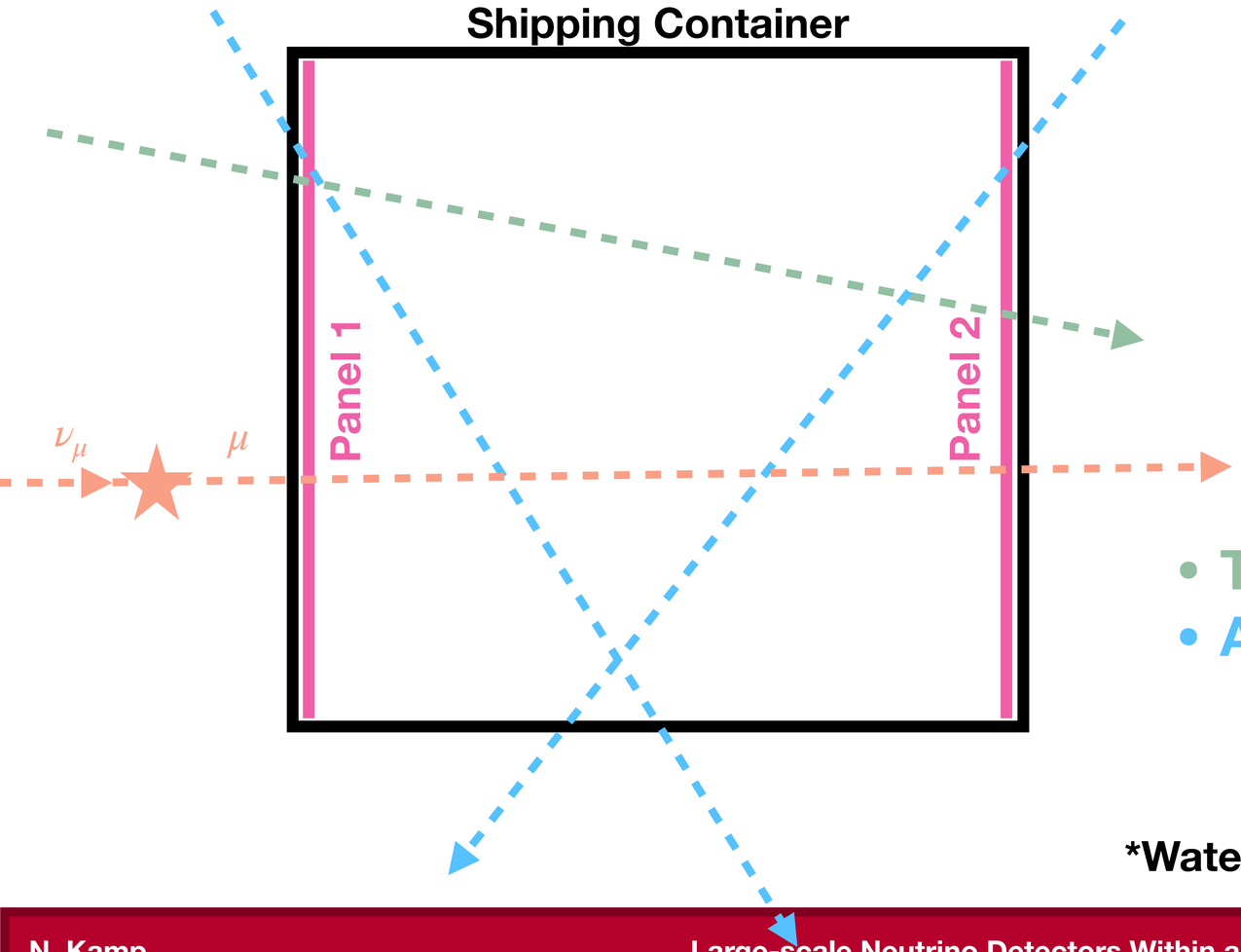


Sensitivity studies in progress



Surface Detector Background



Signal

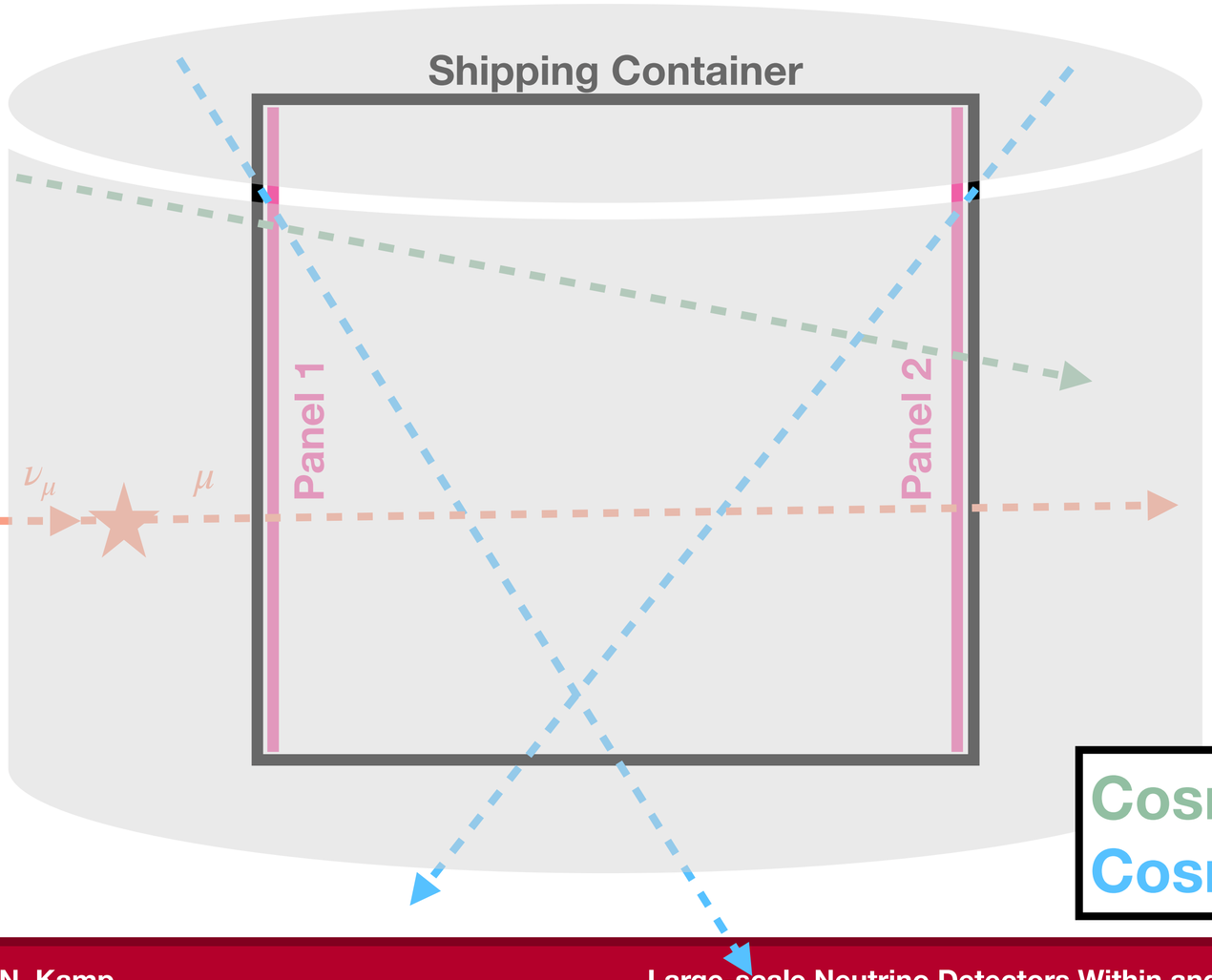
- True coincidence from a ν-induced muon
  ~11 mHz per surface detector

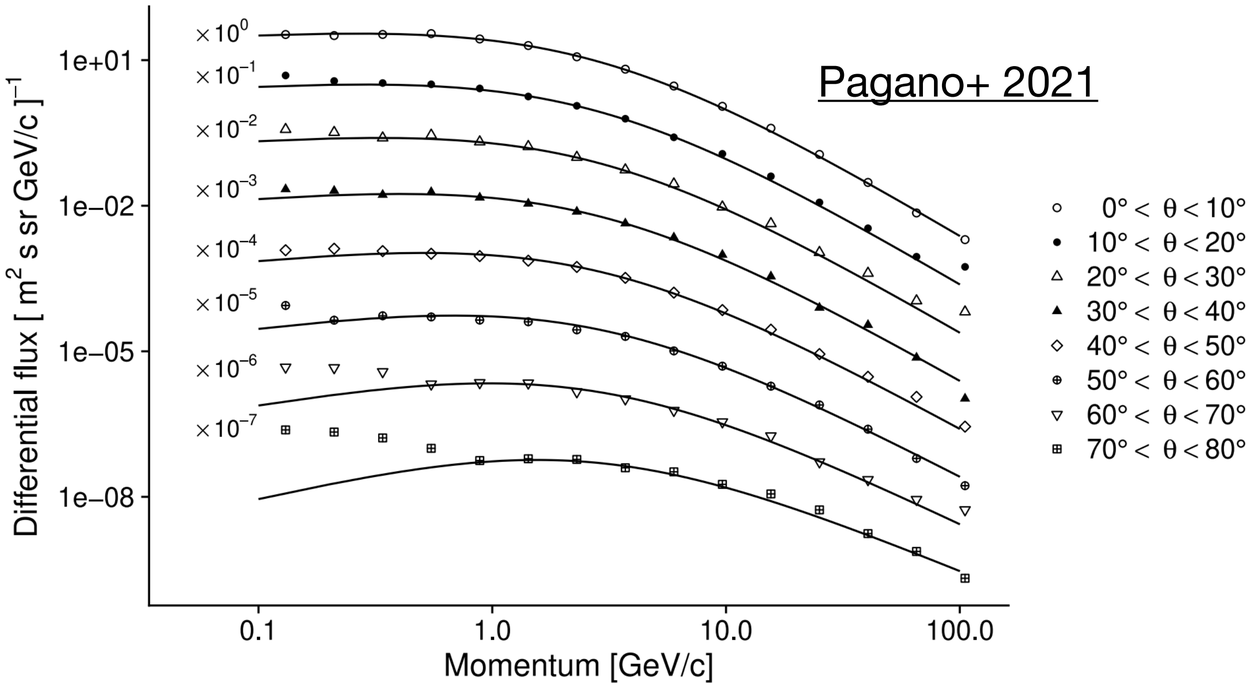
Background

- True coincidence from a single cosmic muon
- Accidental coincidence from two cosmic muons

*Water overburden reduces cosmic backgrounds in lake detector

Surface Detector Background





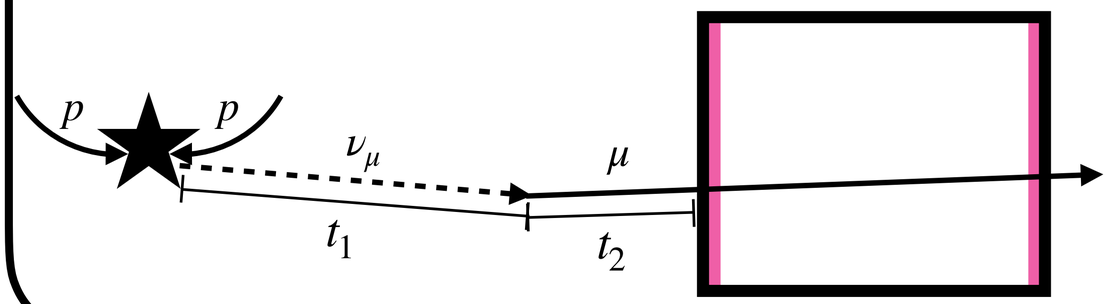
We use EcoMug to generate cosmic muons in a cylinder surrounding one of the shipping containers

Cosmic muon true coincidence rate: 1.67 kHz

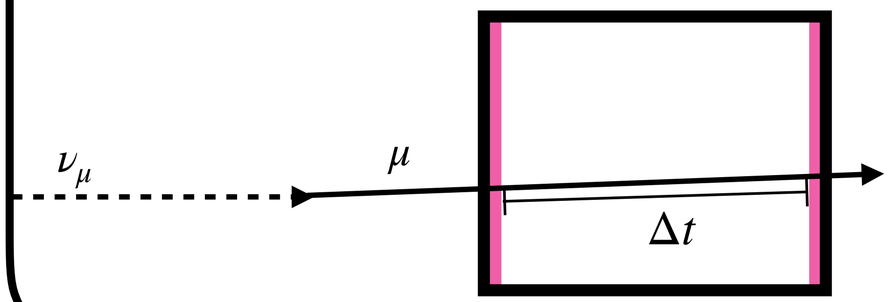
Cosmic muon single panel rate: 1.62 kHz

Four Strategies for Background Rejection

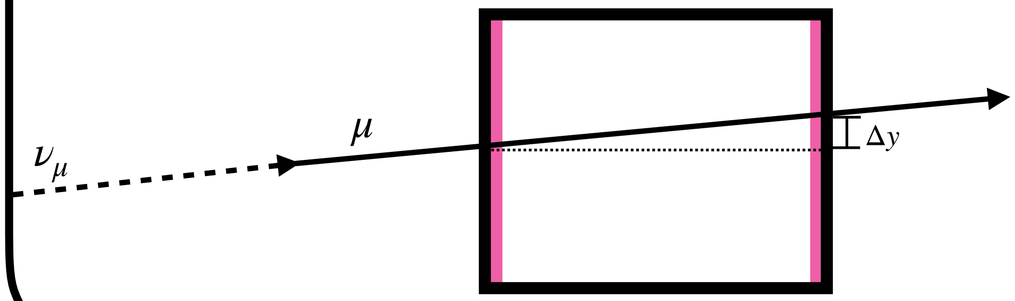
1. Timing with respect to proton collision



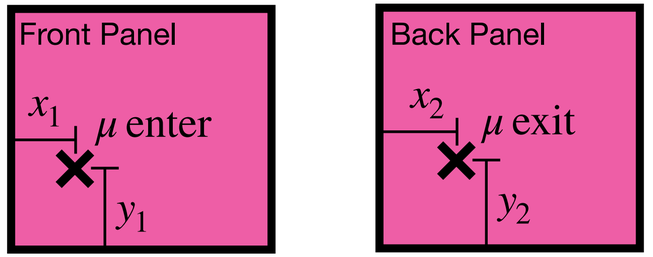
2. Time difference between scintillator panels



3a. Up-going spatial information



3b. Two-dimensional spatial information



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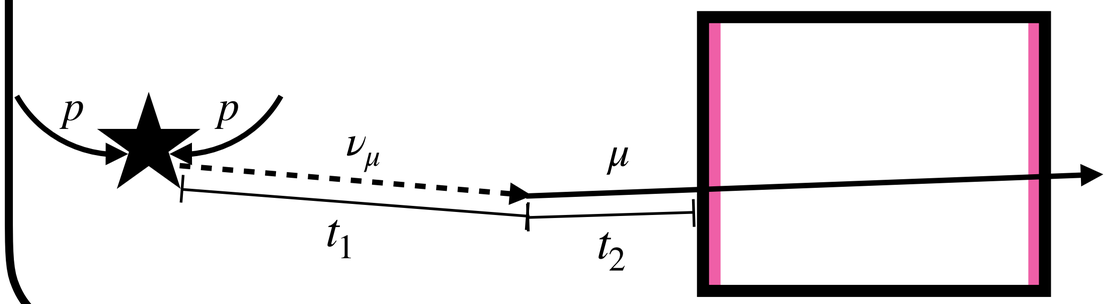

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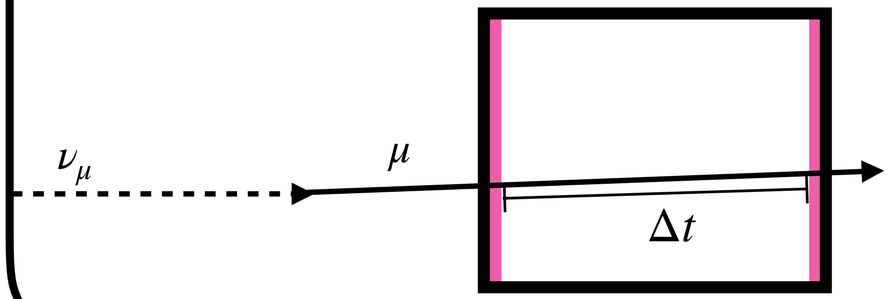

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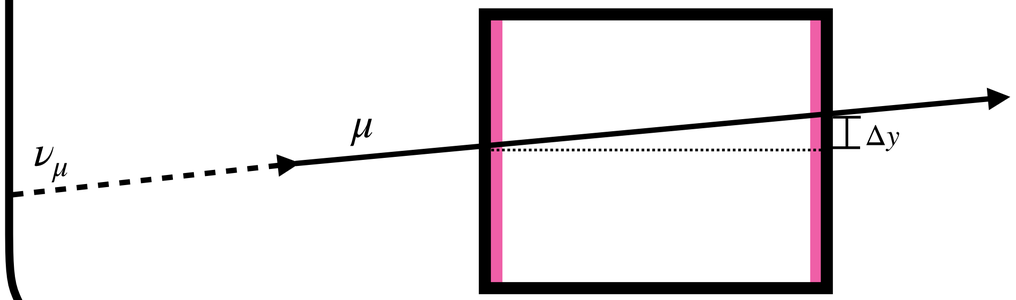
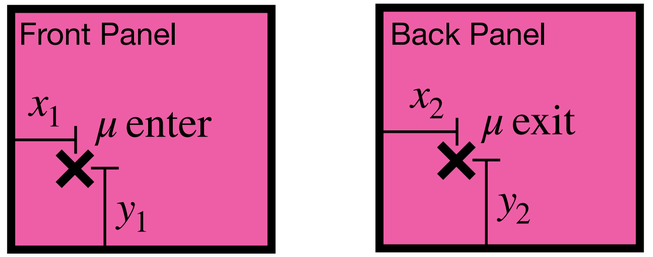
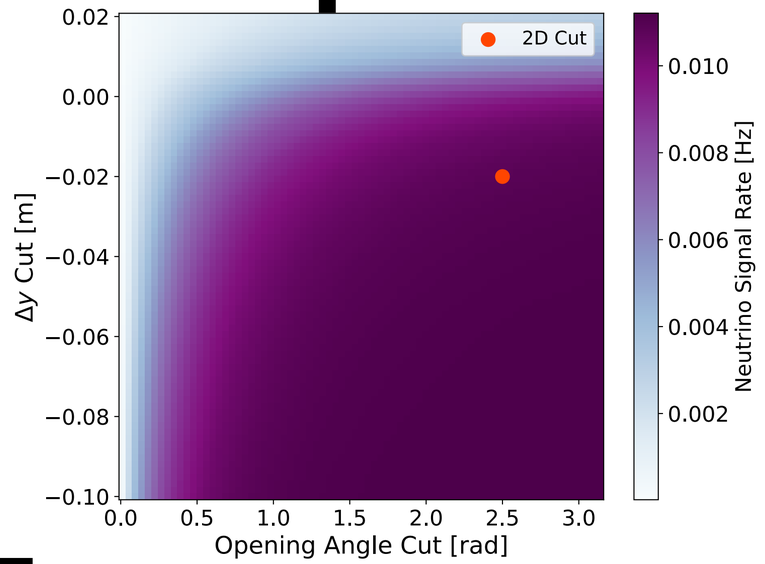


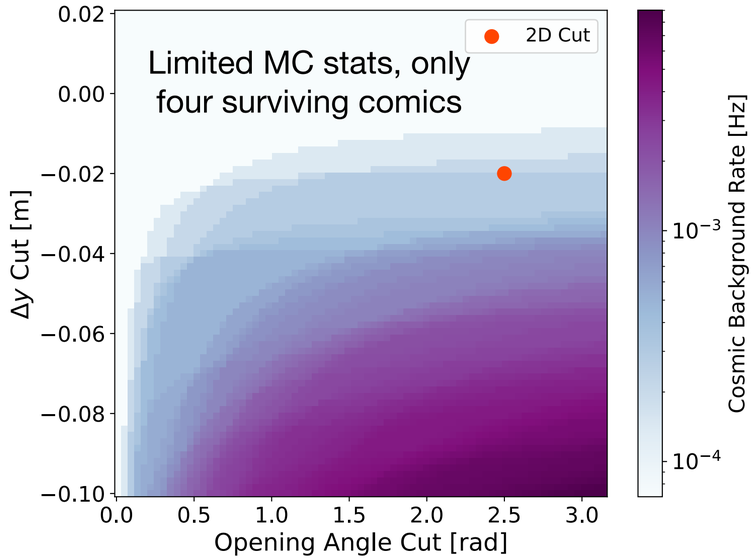
3b. Two-dimensional spatial information

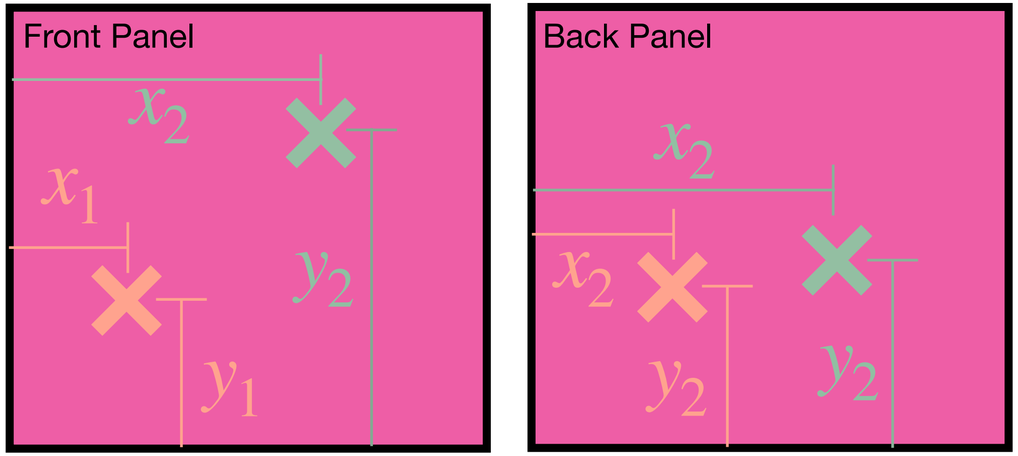


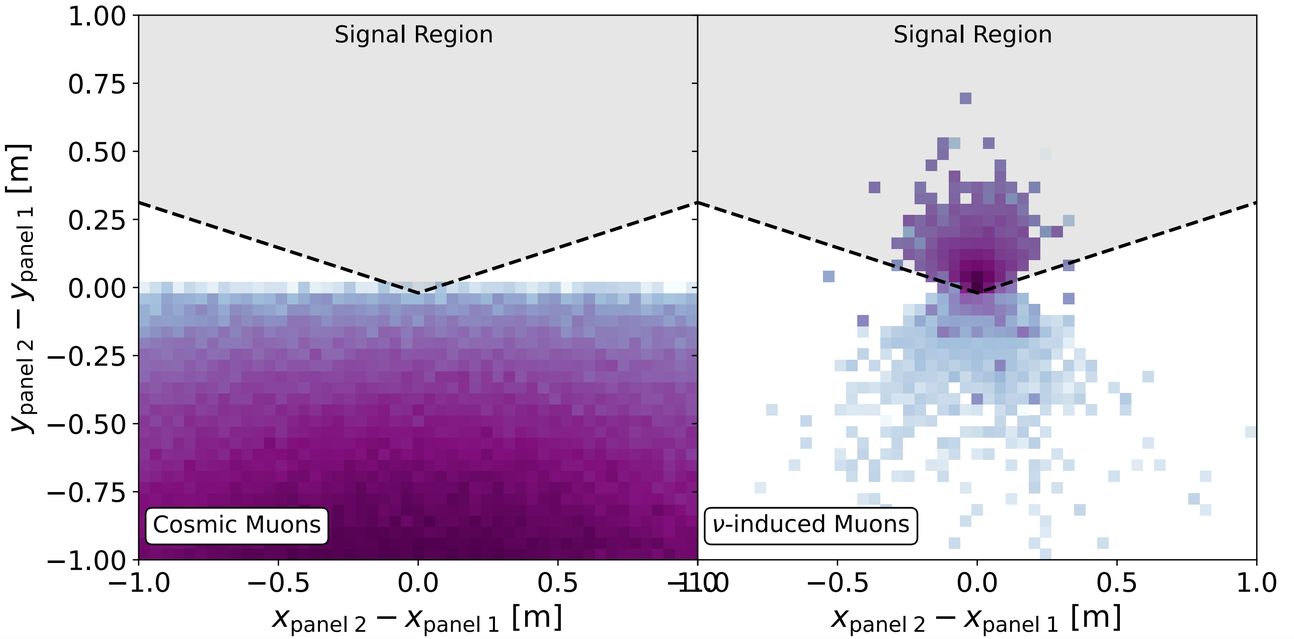
Two-dimensional spatial information

- Neutrino-induced muons travel ~orthogonal to the scintillation panels
- **Strategy: make a triangle-based cut on Δx and Δy**





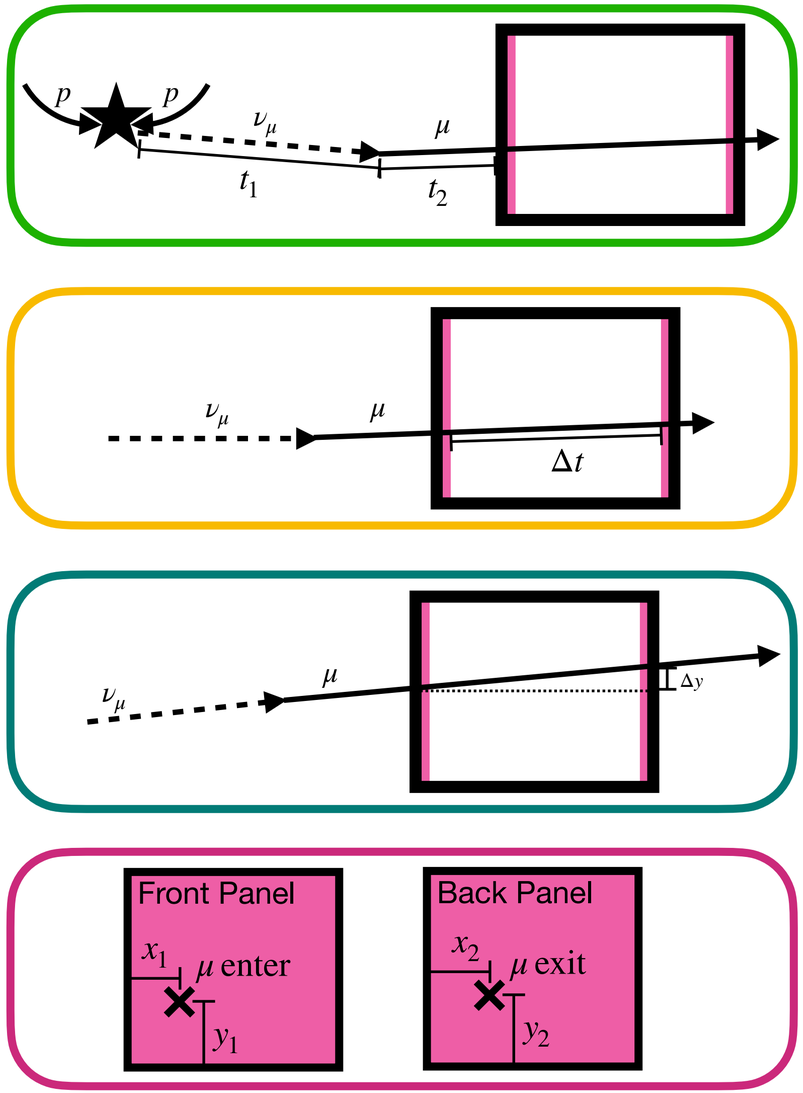


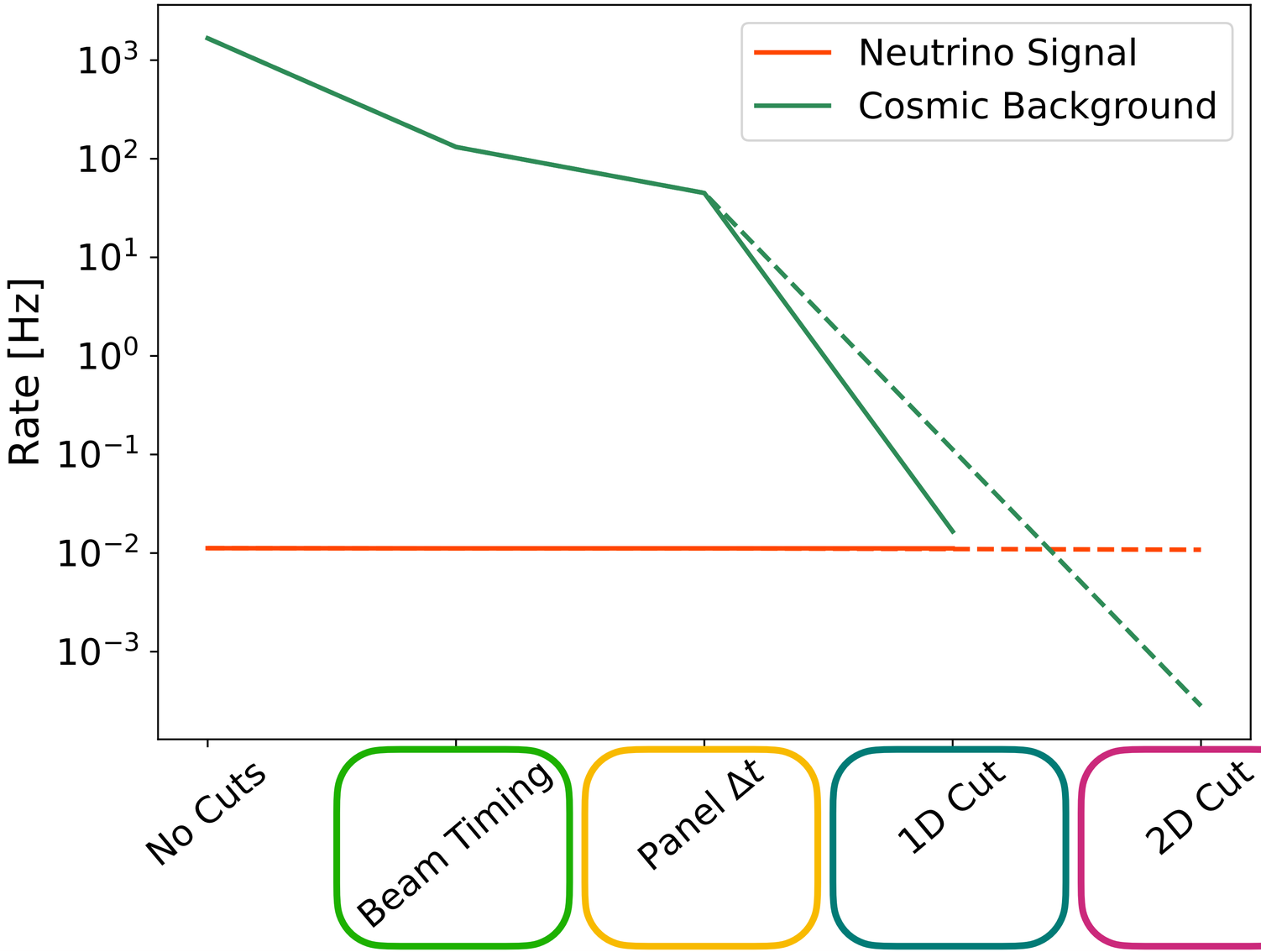


ν-induced muon rate: 11 mHz

Cosmic muon true coincidence rate: ~0.3 mHz

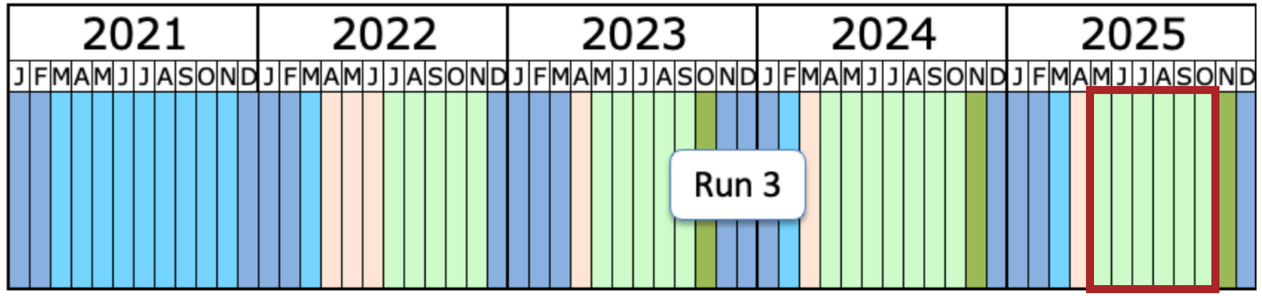
Surface Background Overview





Prototype Surface Detector

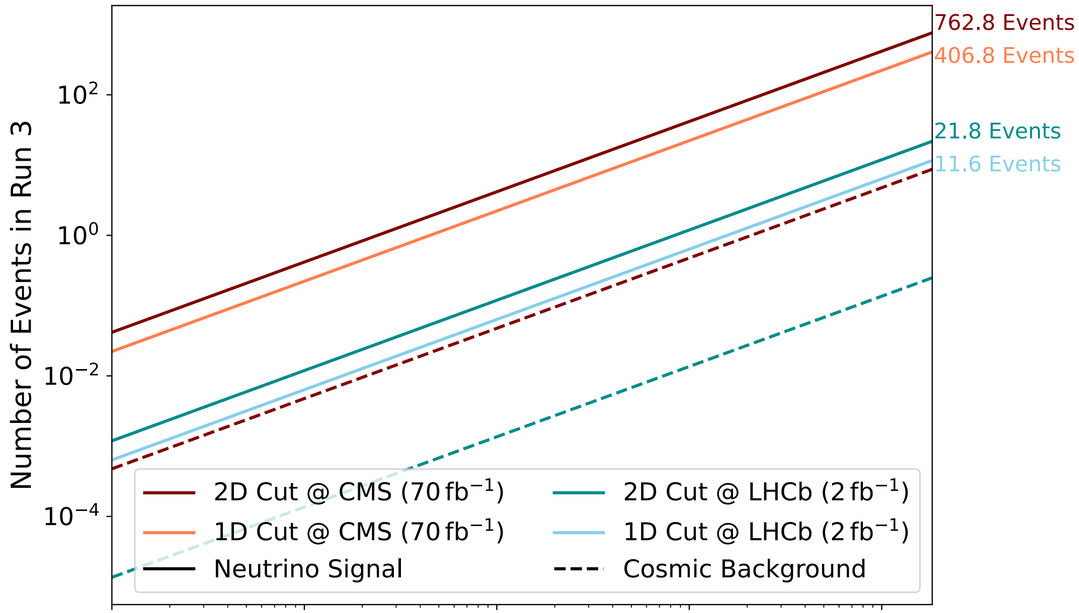
lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm

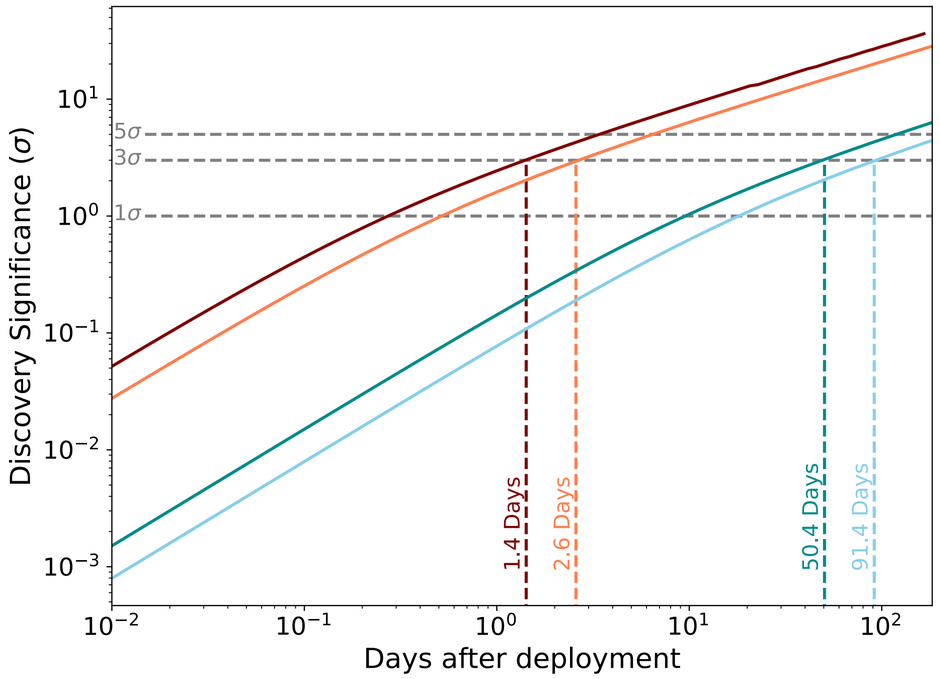


Shutdown/Technical stop
Protons physics
Ions (tbc after LS4)
Commissioning with beam
Hardware commissioning

What can we do here with one shipping crate detector?

Shipping Container





Takeaways

Neutrinos from LHCb and CMS pass through Lake Geneva and exit the Earth's surface

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These datasets would be sensitive to forward charm production in p-p collisions and GeV-to-TeV-scale heavy neutral leptons

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Cosmic muon backgrounds are manageable

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These datasets would be sensitive to forward charm production in p-p collisions and GeV-to-TeV-scale heavy neutral leptons

Cosmic muon backgrounds are manageable

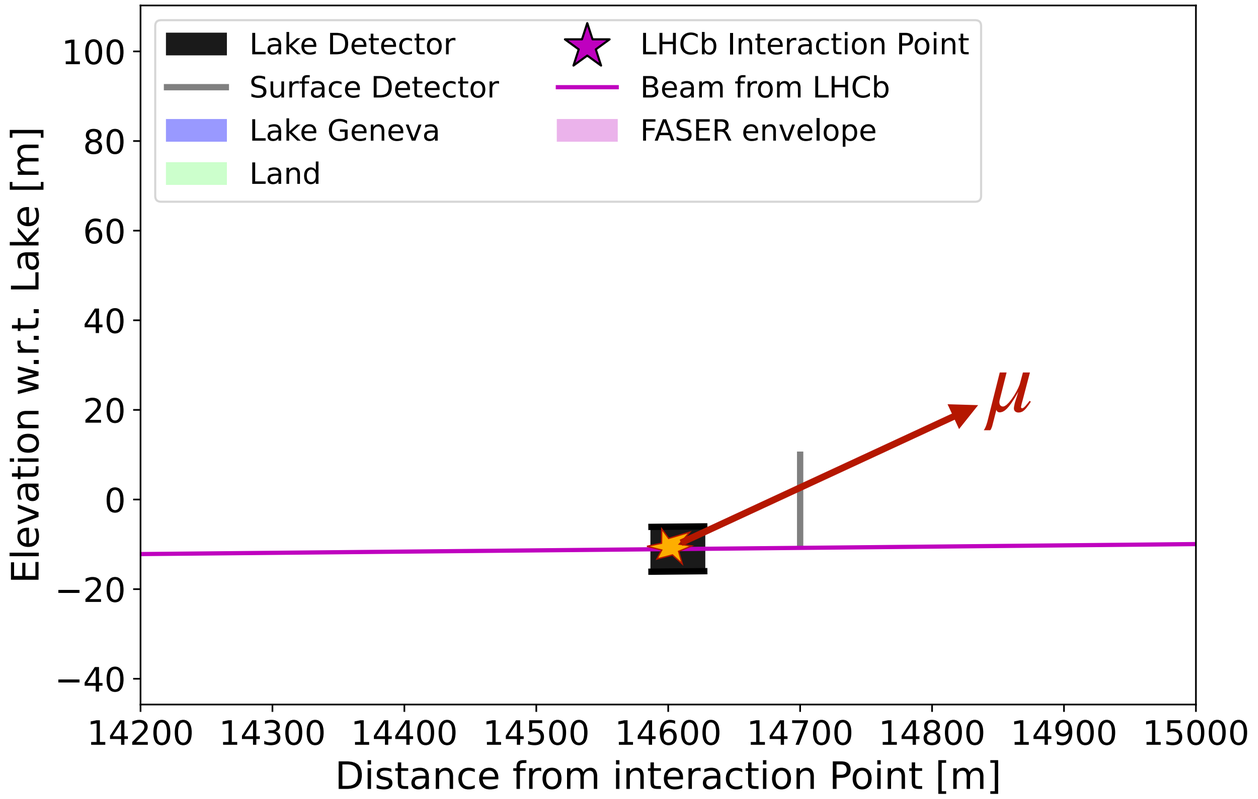
A prototype surface detector can be deployed at the end of LHC Run 3

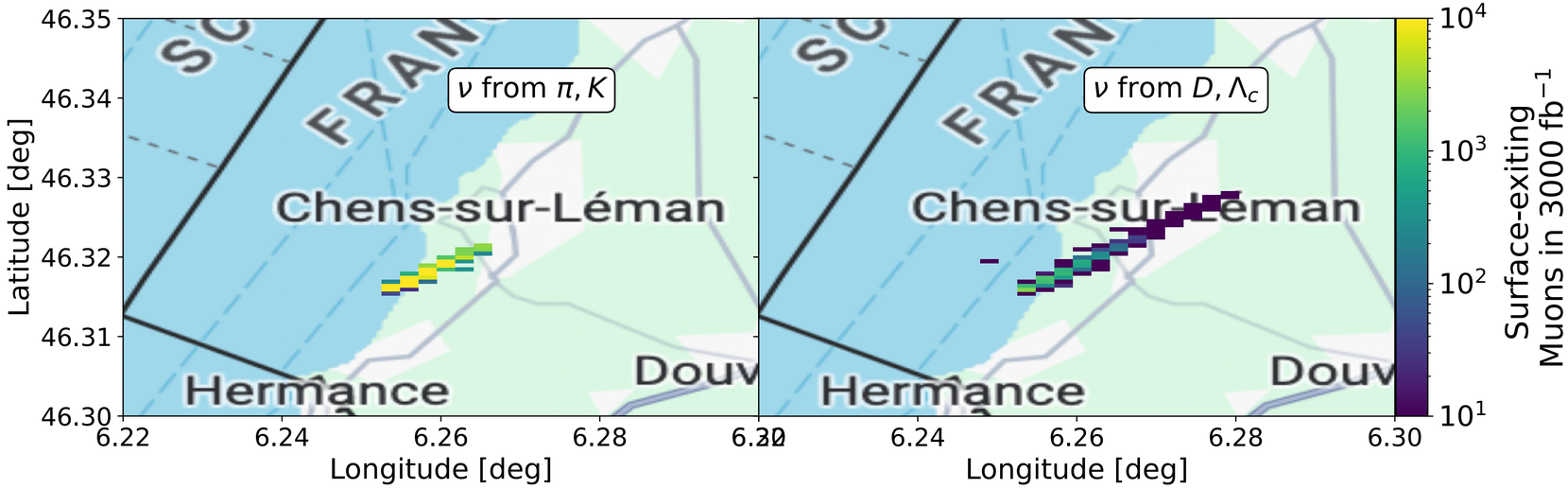
Thanks!

Please feel free to reach out if you have ideas for these detectors
nkamp@g.harvard.edu

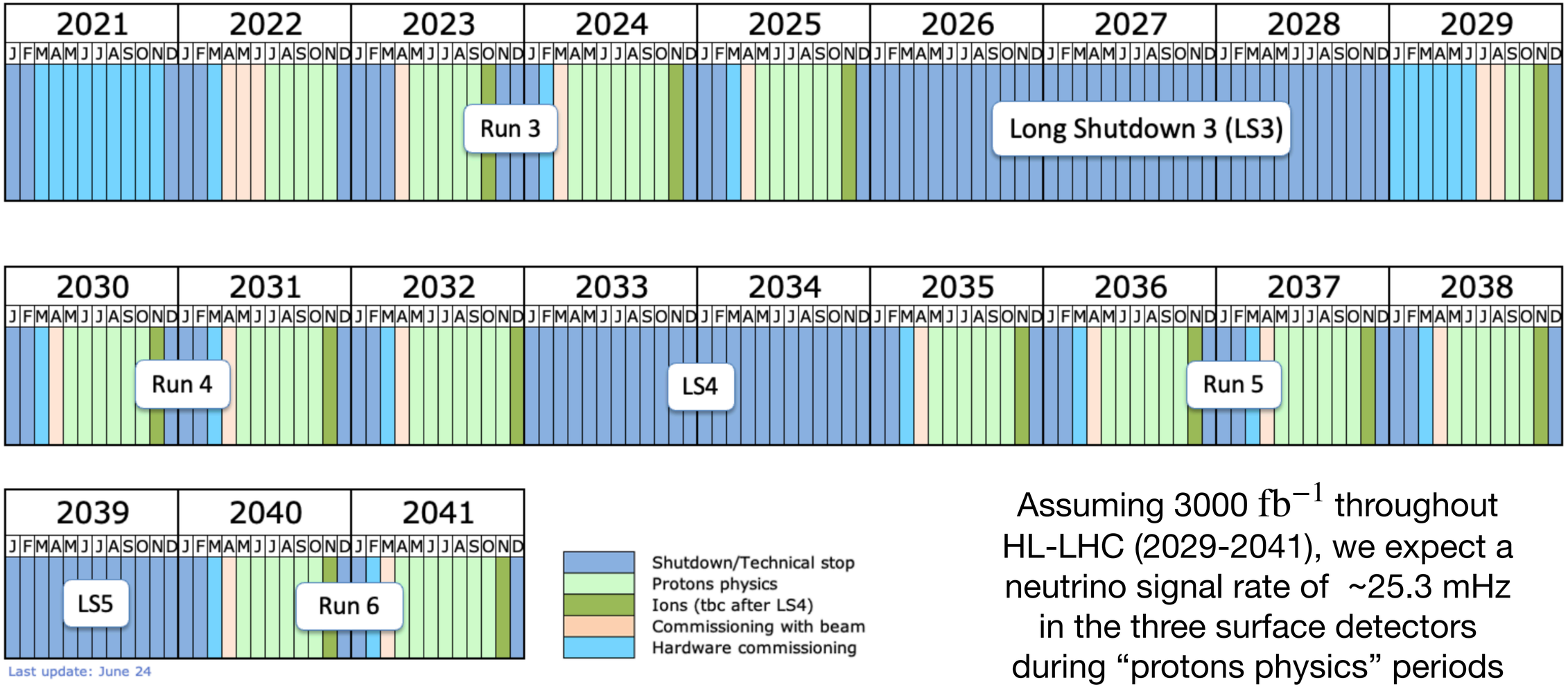
Backup

Correlated Lake + Surface Measurement





Neutrino Event Rate

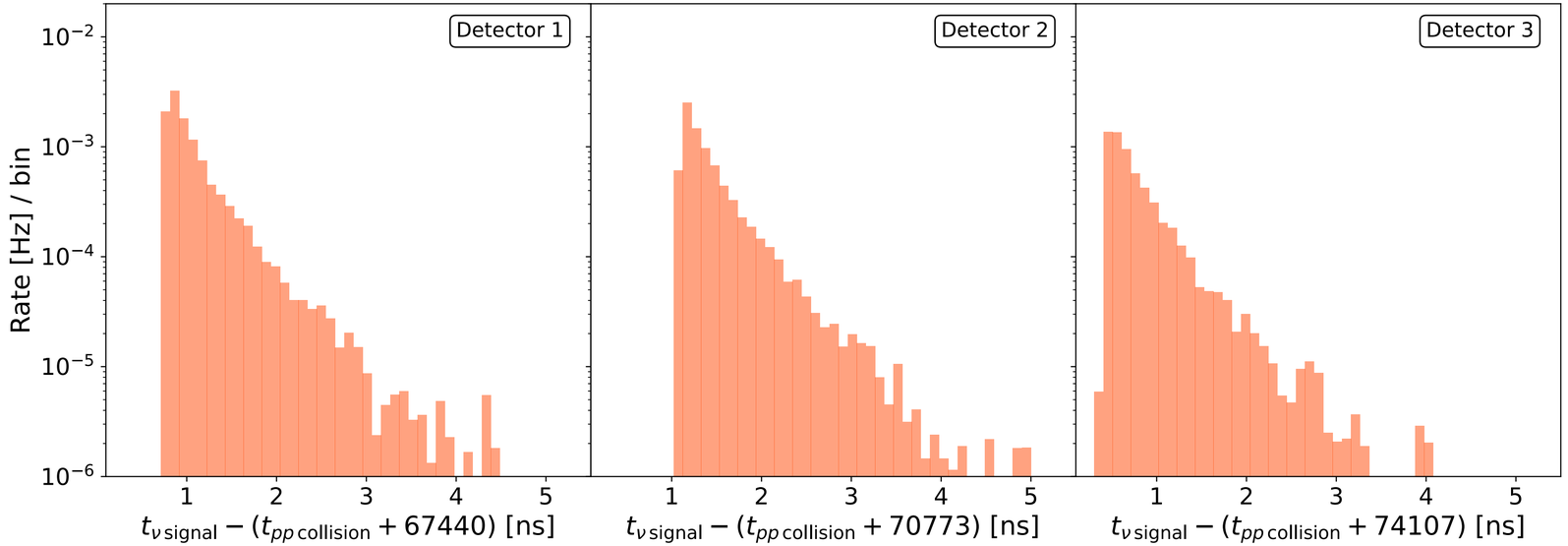


Assuming 3000 fb^{-1} throughout HL-LHC (2029-2041), we expect a neutrino signal rate of ~25.3 mHz in the three surface detectors during “protons physics” periods

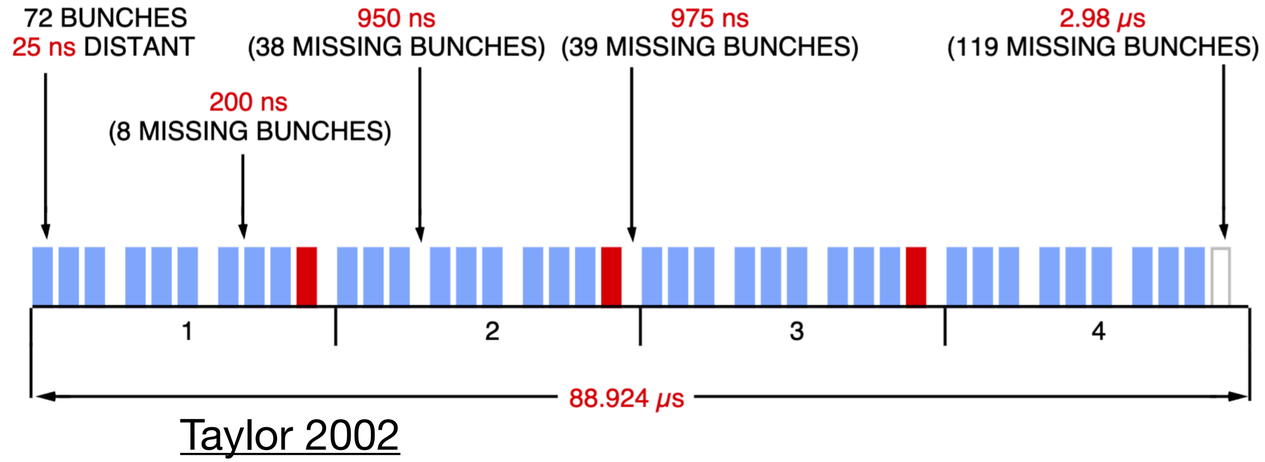
lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm

1. Timing with respect to proton collision

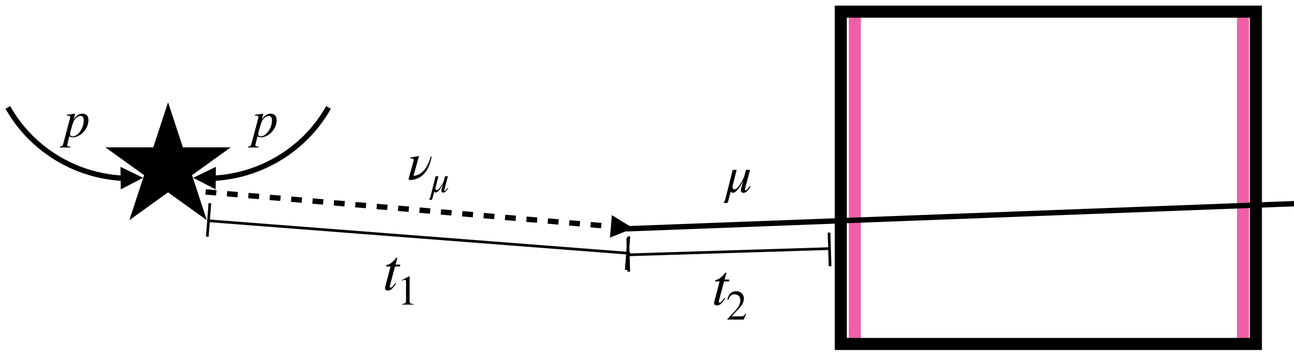
- The LHC has an inherent duty factor of 78.9%
- Within each 25 ns bunch, >99% of neutrino signal events arrive within a 2.5 ns window



Effective duty factor: 7.9%



Taylor 2002



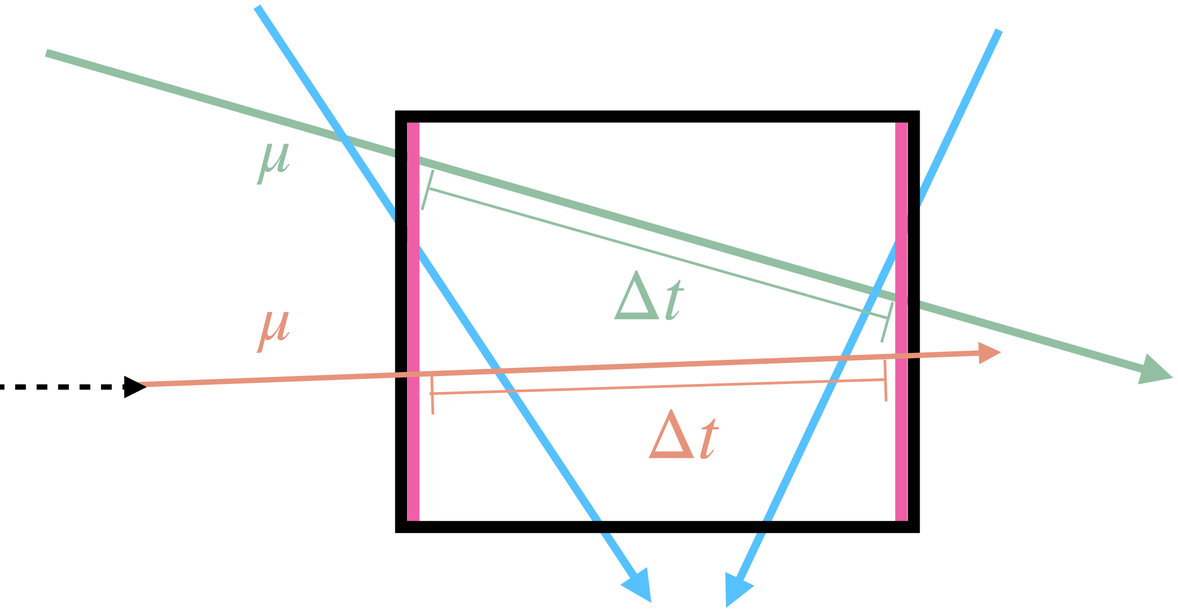
ν-induced muon rate: 11 mHz

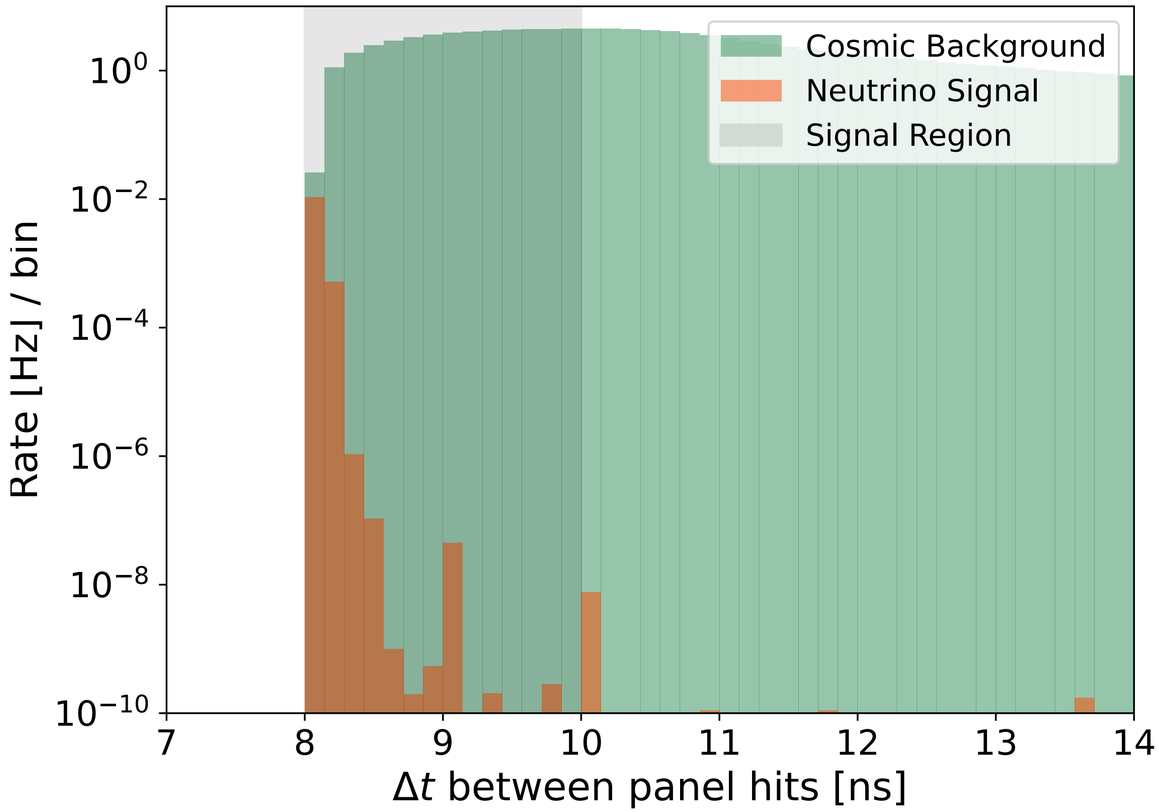
Cosmic muon true coincidence rate: 132 Hz

Cosmic muon single panel rate: 128 Hz

2. Time difference between scintillator panels

- Neutrino-induced muons tend to travel transverse to the scintillator plane, while cosmic muons pass through at larger angles on average
- **Strategy: only keep events any events for which $8 < \Delta t/\mathrm{ns} < 10$**

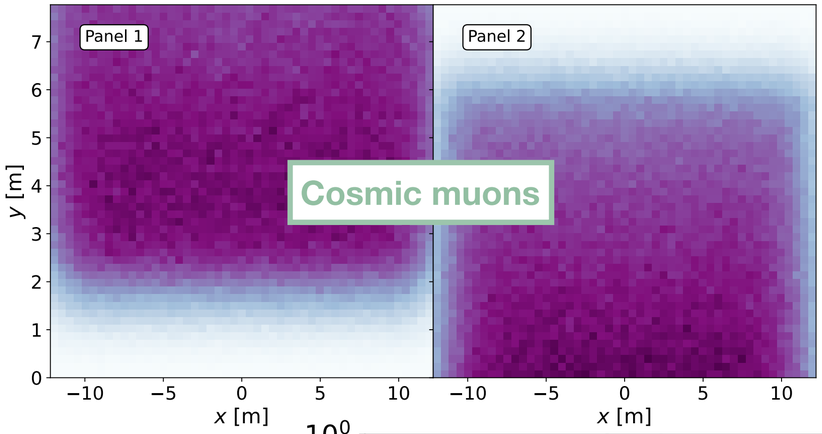


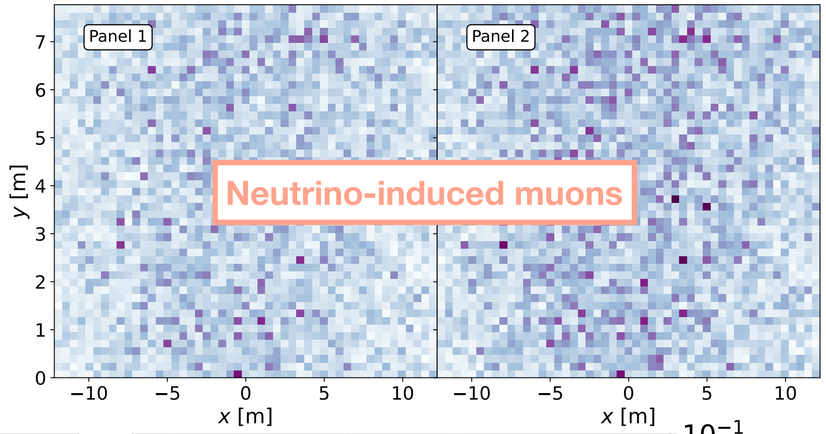


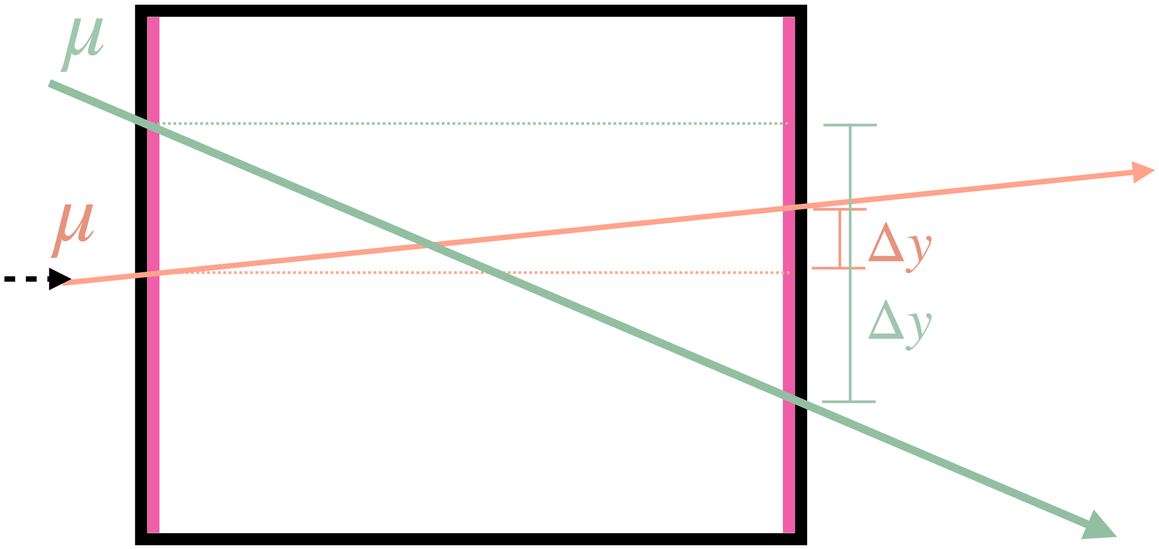
ν-induced muon rate: 11 mHz
Cosmic muon true coincidence rate: 45 Hz
Cosmic muon accidental coincidence rate:
128 Hz $\times$ (1.62 kHz $\times$ 2 ns) = 0.4 mHz

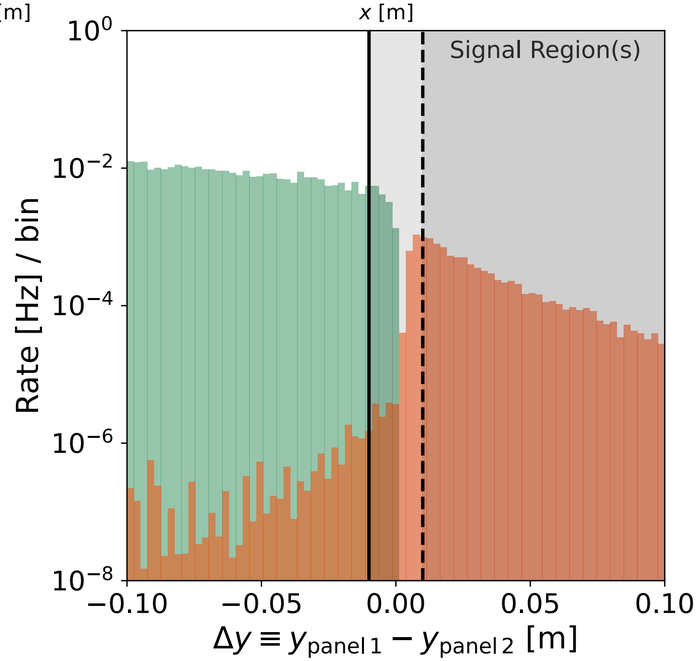
3a. Up-going spatial information

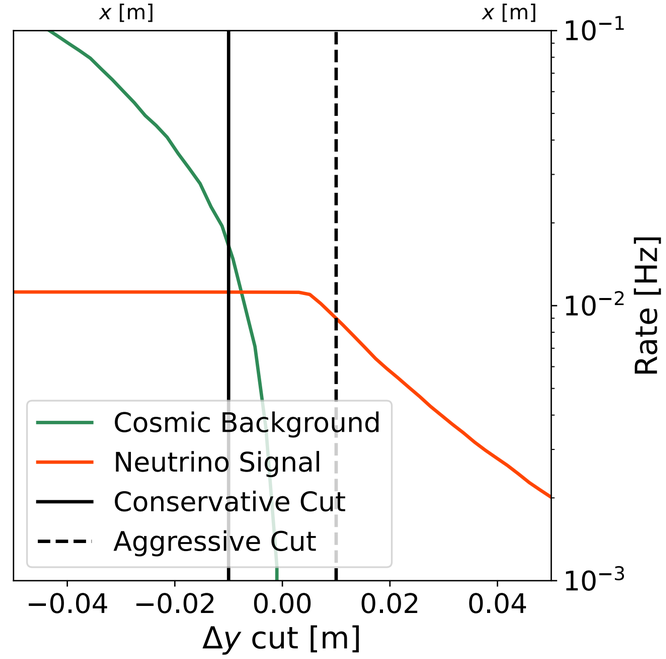
- Neutrino-induced (cosmic) muons tend to travel upward (downward)
- **Strategy: only keep events for which $\Delta y > -1$ cm**
- A more aggressive cut is possible but will reduce signal efficiency









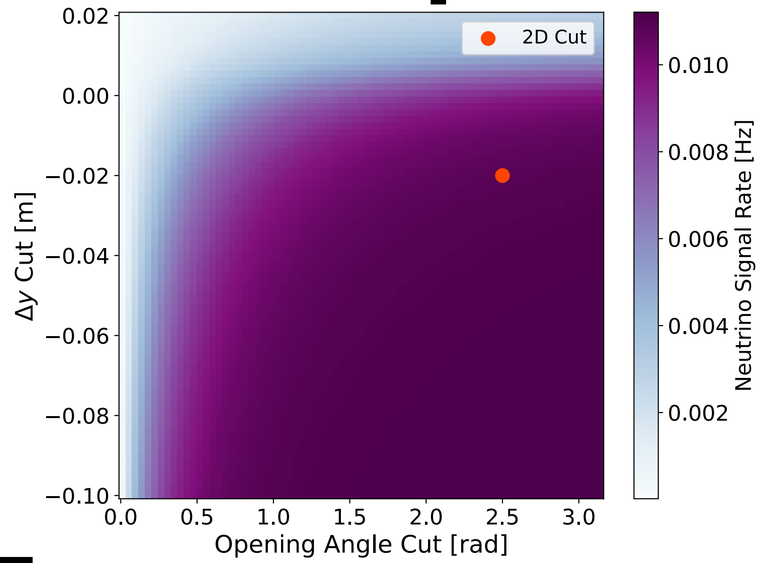


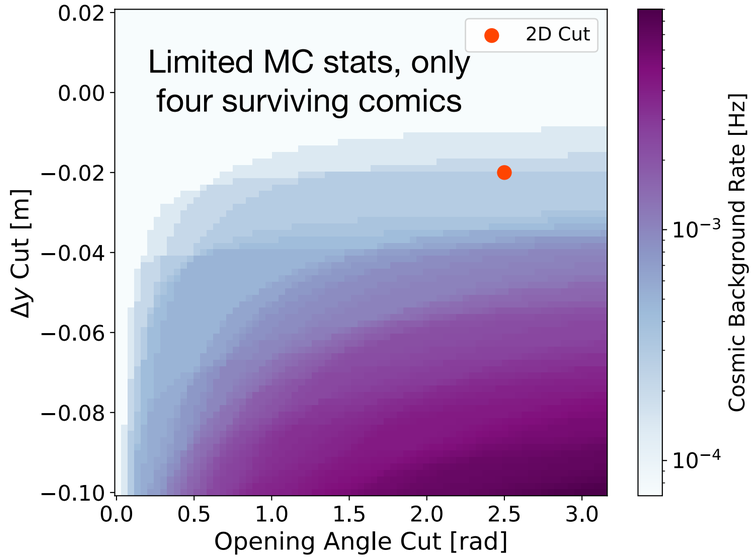
ν-induced muon rate: 11 mHz

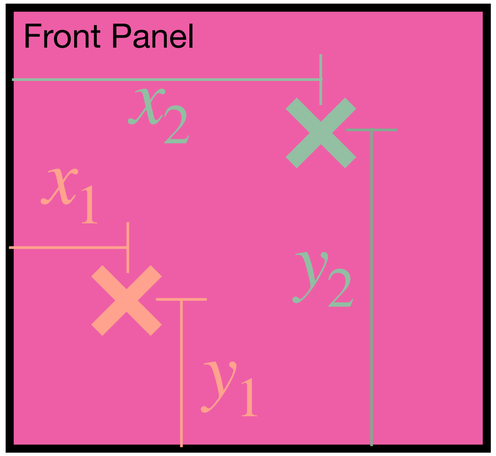
Cosmic muon true coincidence rate: 17 mHz

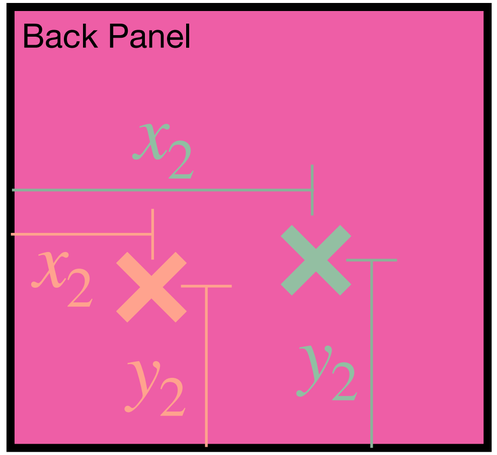
3b. Two-dimensional spatial information

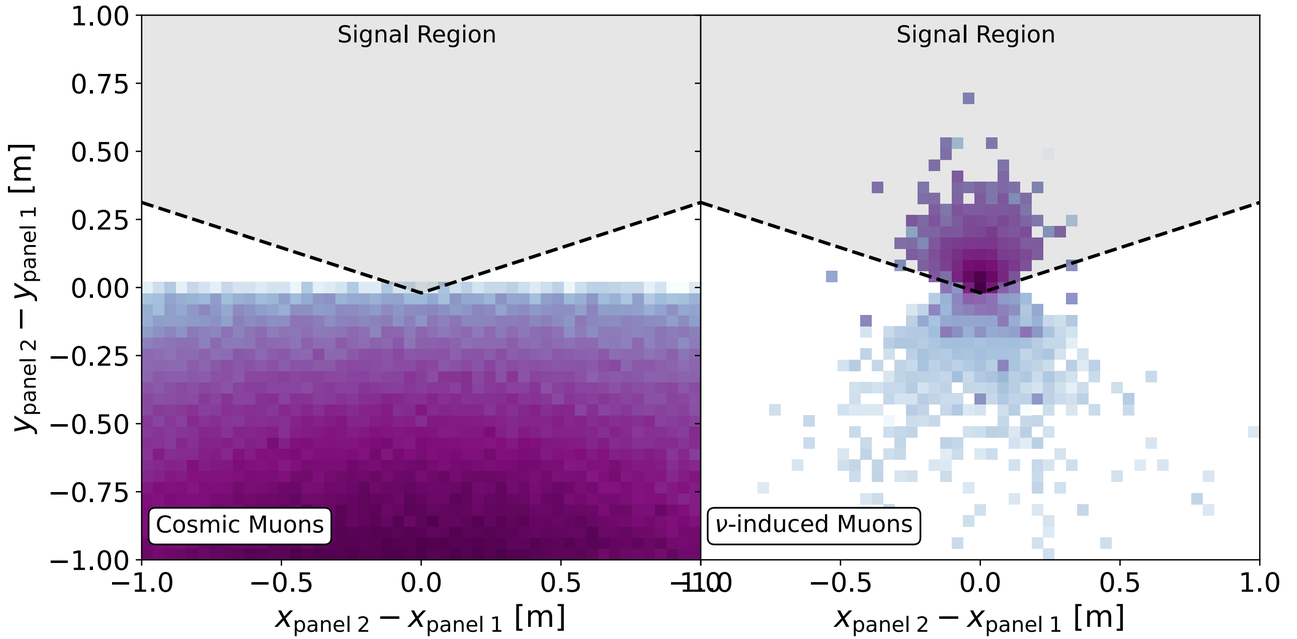
- Neutrino-induced muons also don't tend to deviate in the horizontal direction
- **Strategy: make a triangle-based cut on Δx and Δy**











ν-induced muon rate: 11 mHz

Cosmic muon true coincidence rate: ~0.3 mHz

Prototype Sensitivity Details