Search for Heavy Neutral Lepton at MicroBooNE

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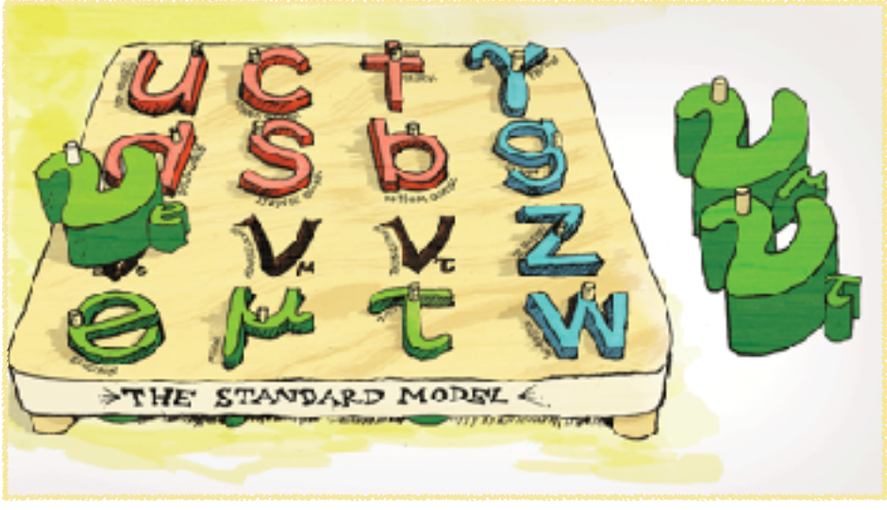
PONDD Workshop
December 7th 2018

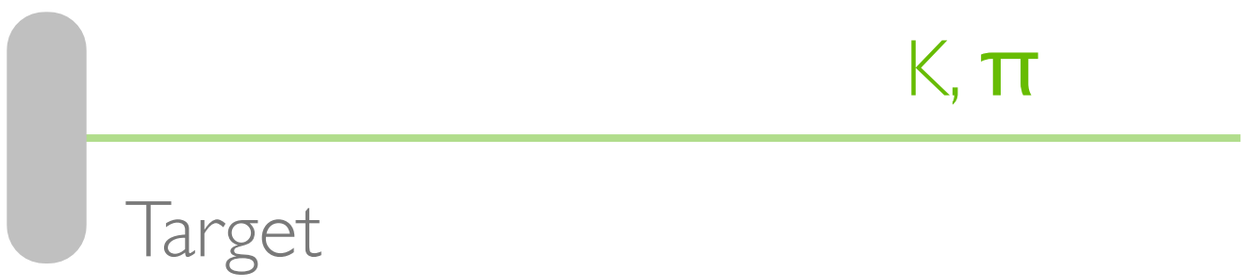
Heavy Neutral Lepton

- Search for MeV-scale heavy neutral lepton (HNL or N) at Short Baseline Neutrino program (SBN)
- May help understand neutrino mass generation and distinguish potential models
- Not oscillatory owing to the large mass
- Complementary to the oscillation analyses in SBN for eV-scale sterile neutrinos



Production

Accelerator neutrino beam or
fixed target facility produce
charged mesons, such kaons, pions



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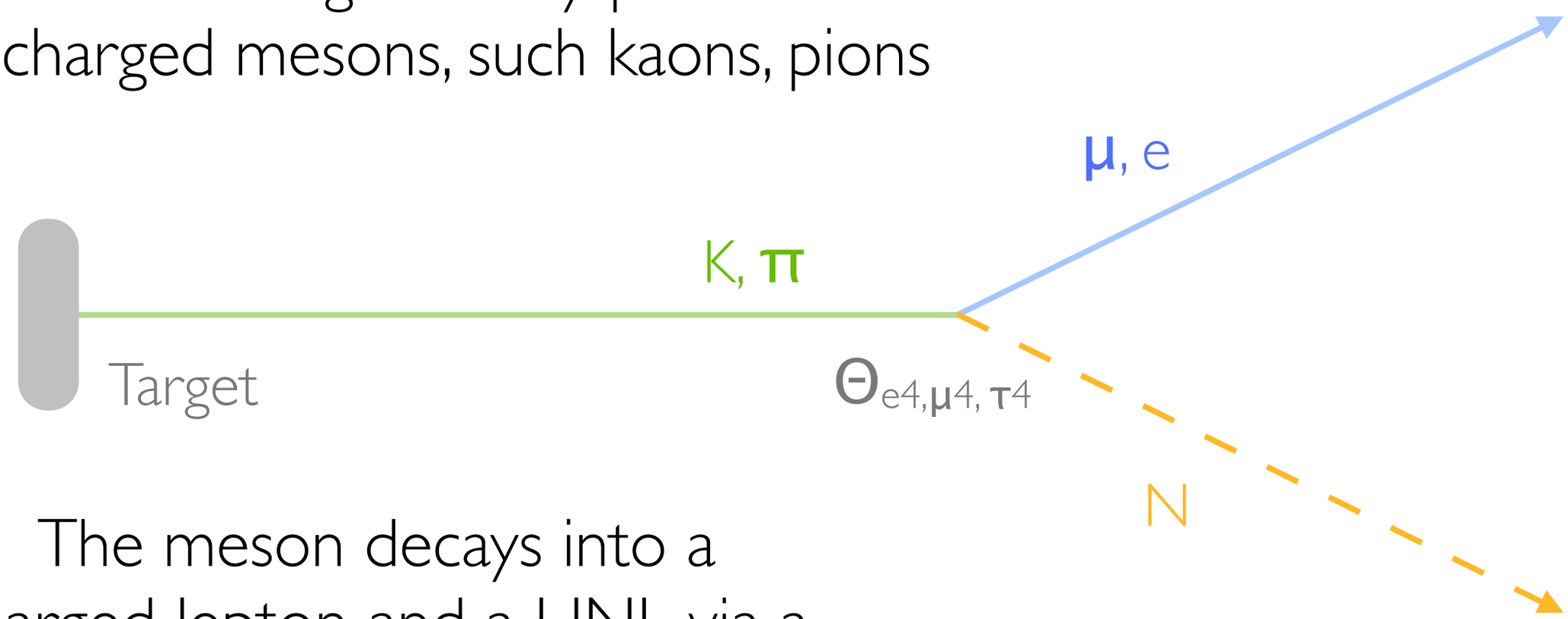
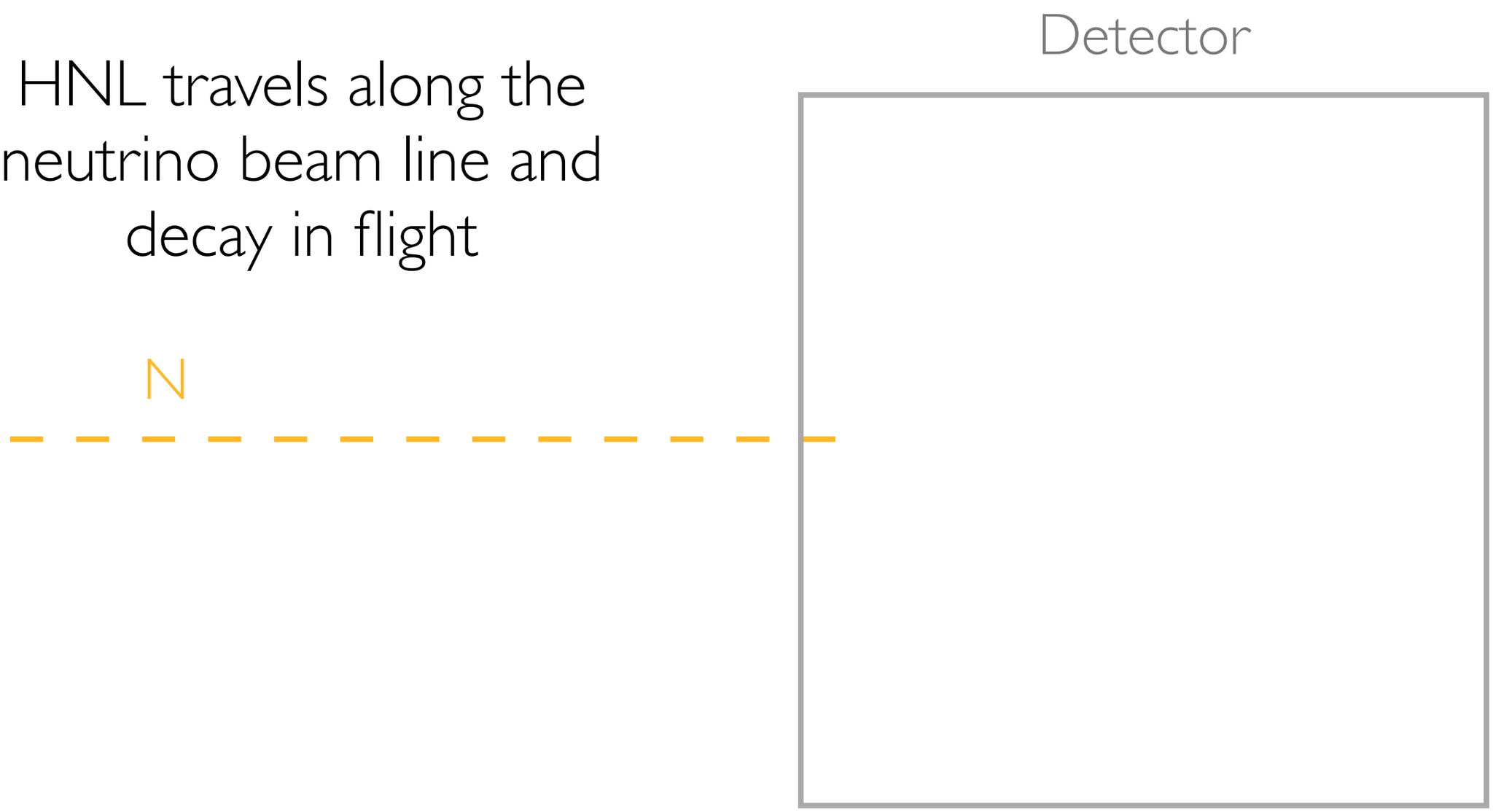


The meson decays into a charged lepton and a HNL via a mixing angle, $\Theta_{e4,\mu4,\tau4}$, between the SM neutrino and the HNL

Consider Majorana particles
No helicity suppression

Decay

HNL travels along the neutrino beam line and decay in flight



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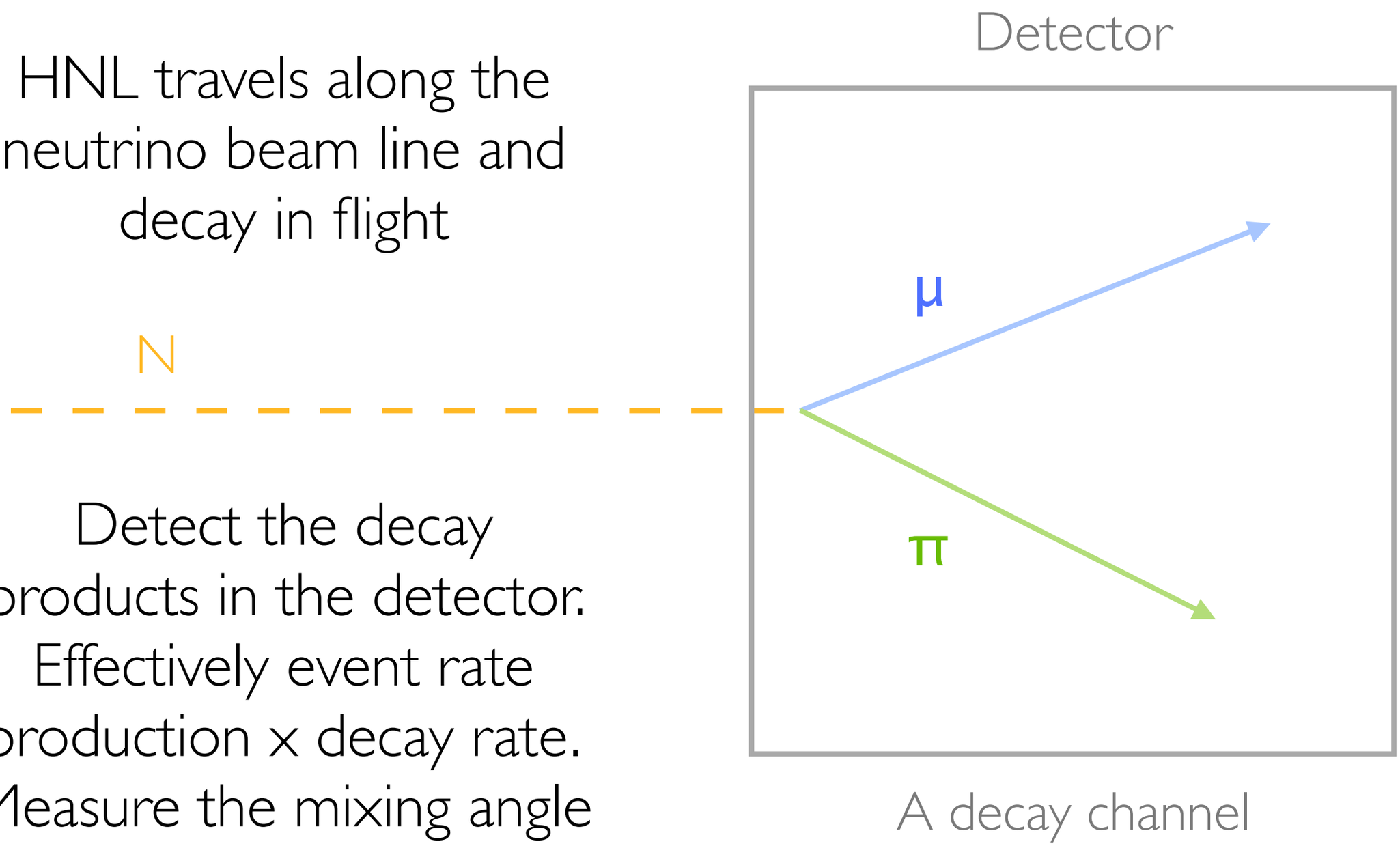

Detect the decay products in the detector. Effectively event rate production x decay rate. Measure the mixing angle $\Theta_{\mu 4, e4, \tau 4}$ with each M_N

Decay Channels

- 2 or 3-body decays
- Charged current:
  $N \rightarrow \gamma\nu$, $N \rightarrow \mu e \nu$,
  $N \rightarrow e\pi$, $N \rightarrow \mu\pi$
- Charged and neutral current:
  $N \rightarrow 3\nu$, $N \rightarrow ee\nu$,
  $N \rightarrow \nu\pi^0$, $N \rightarrow \mu\mu\nu$
- This analysis: $N \rightarrow \mu^{\pm}\pi^{\mp}$
  - Dominant channel in $M_N > 250$ MeV/c^2

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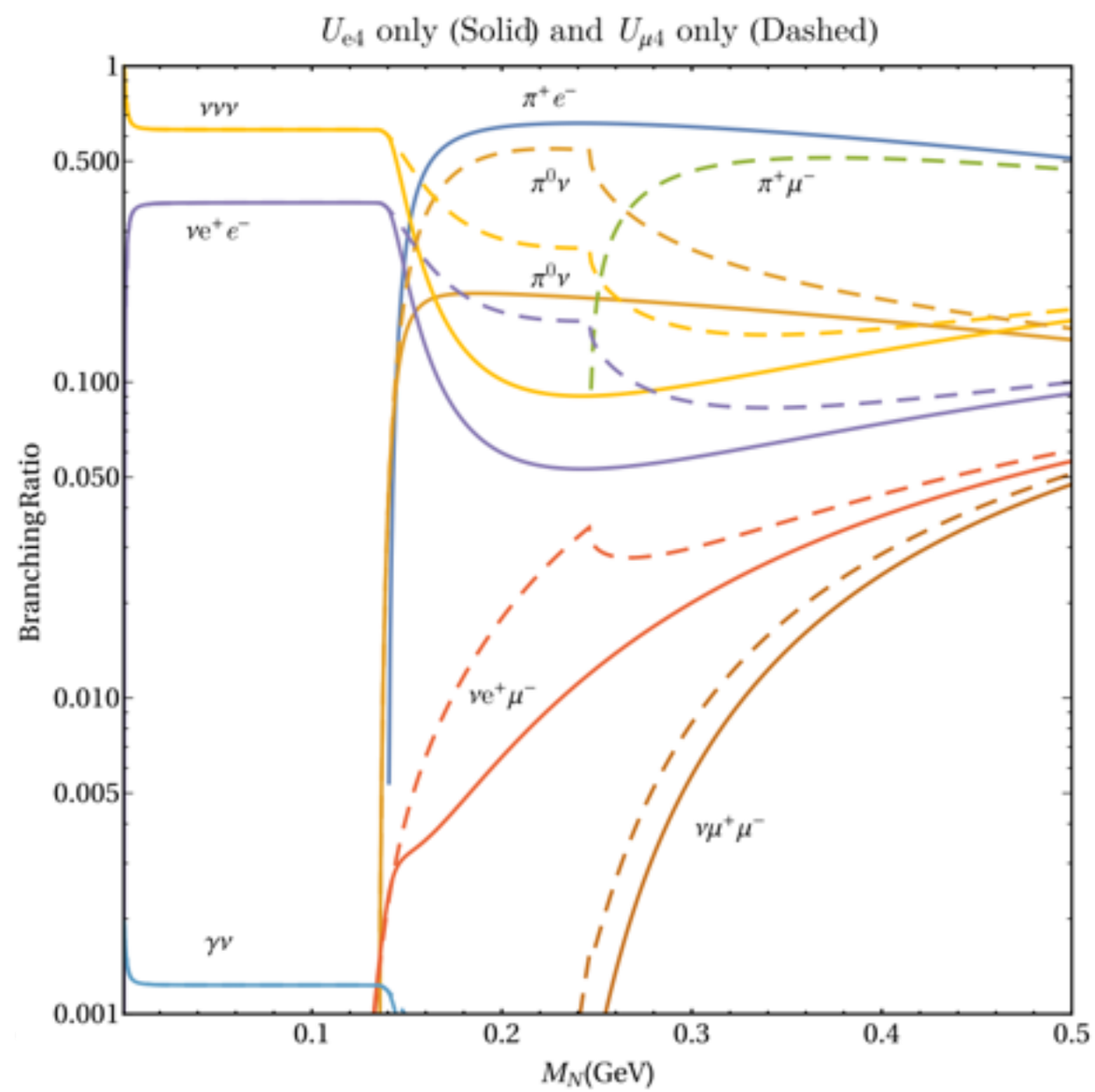
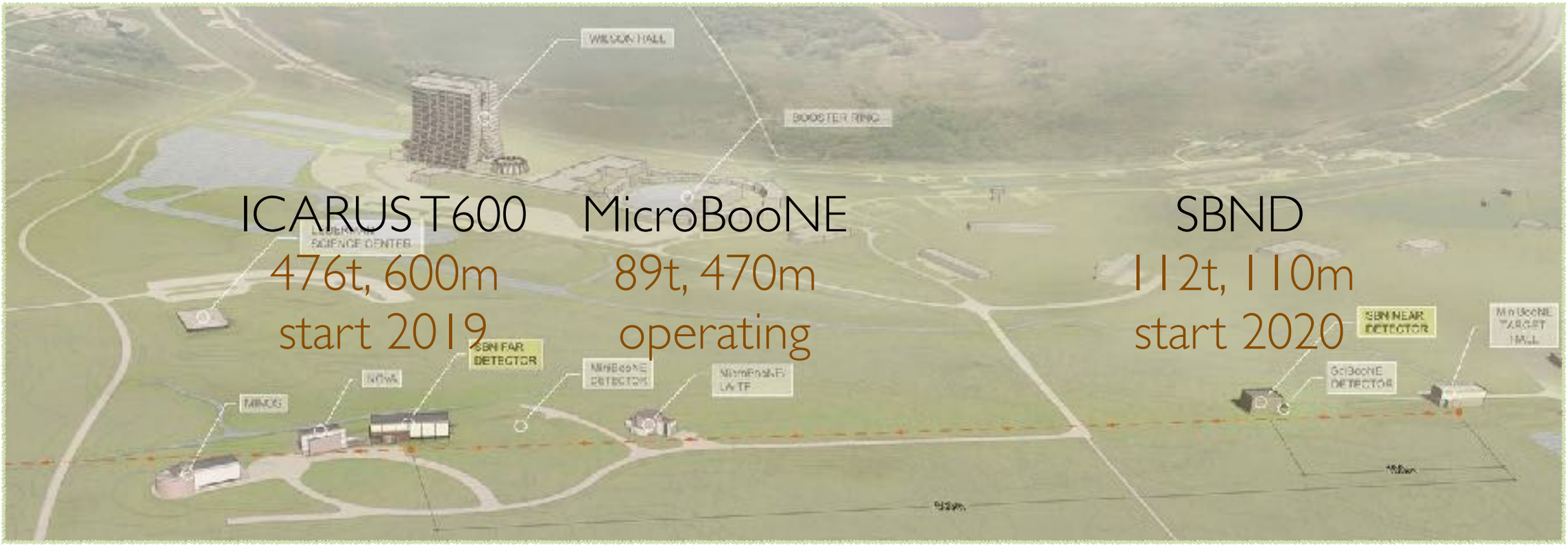


SBN at Fermilab



- Address LSND and MiniBooNE anomalies: sterile ν?
- Measure ν-Ar cross section
- BNB ν_μ from Fermilab accelerator
- 3 LArTPC detectors in different baselines

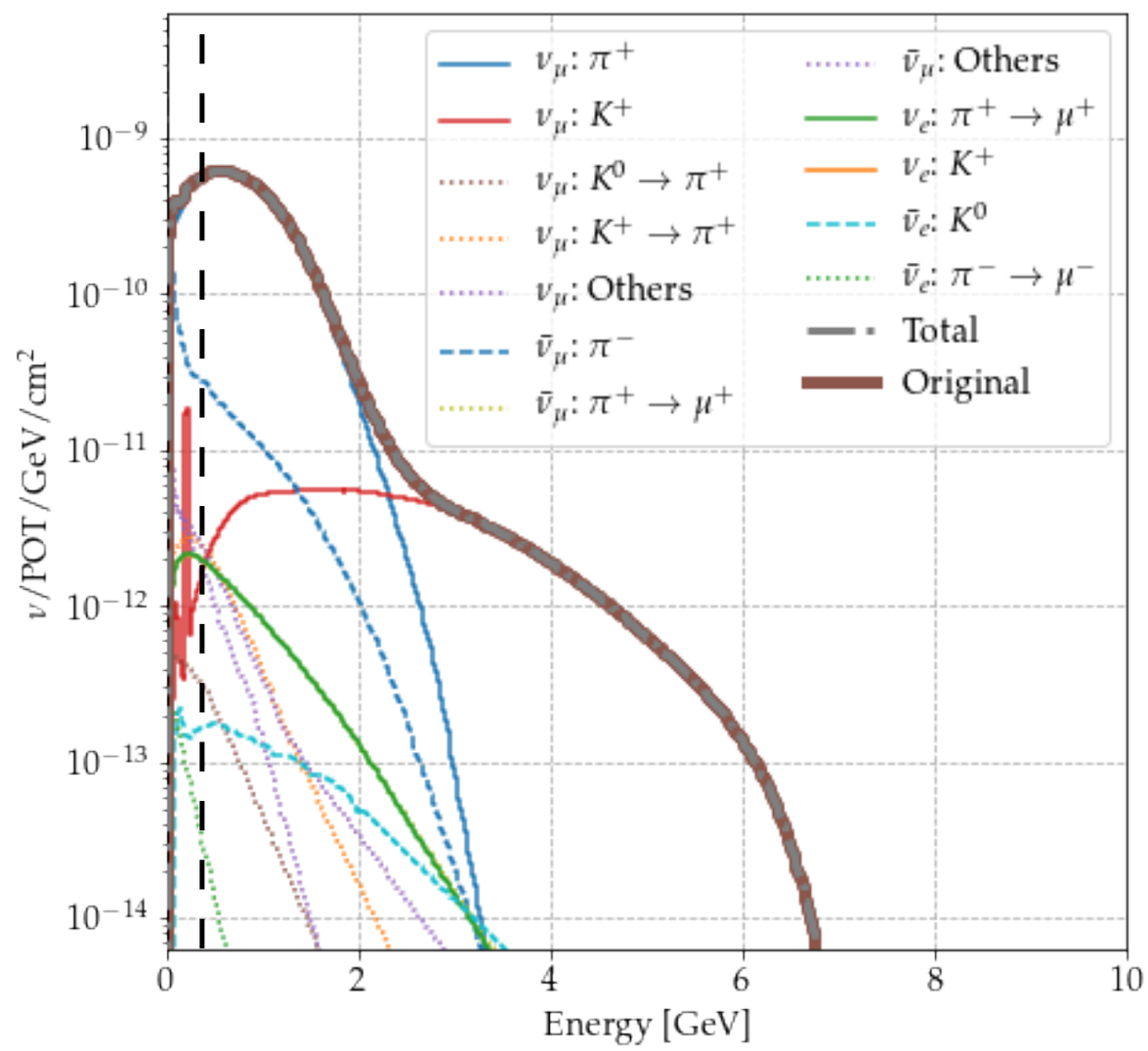
HNL Flux from BNB

- Scale the SM neutrino flux spectrum by the mixing angle

$$\phi_N(E_N) = \phi_{\nu_\alpha}(E_{\nu_\alpha})|\Theta_{\alpha 4}|^2$$

- Consider nonzero $\Theta_{\mu 4}$
- HNL produced by K→N**μ**
- Remove the unphysical HNL (E_N<M_N) and re-scale
- Obtain a lower bound of the HNL flux estimation

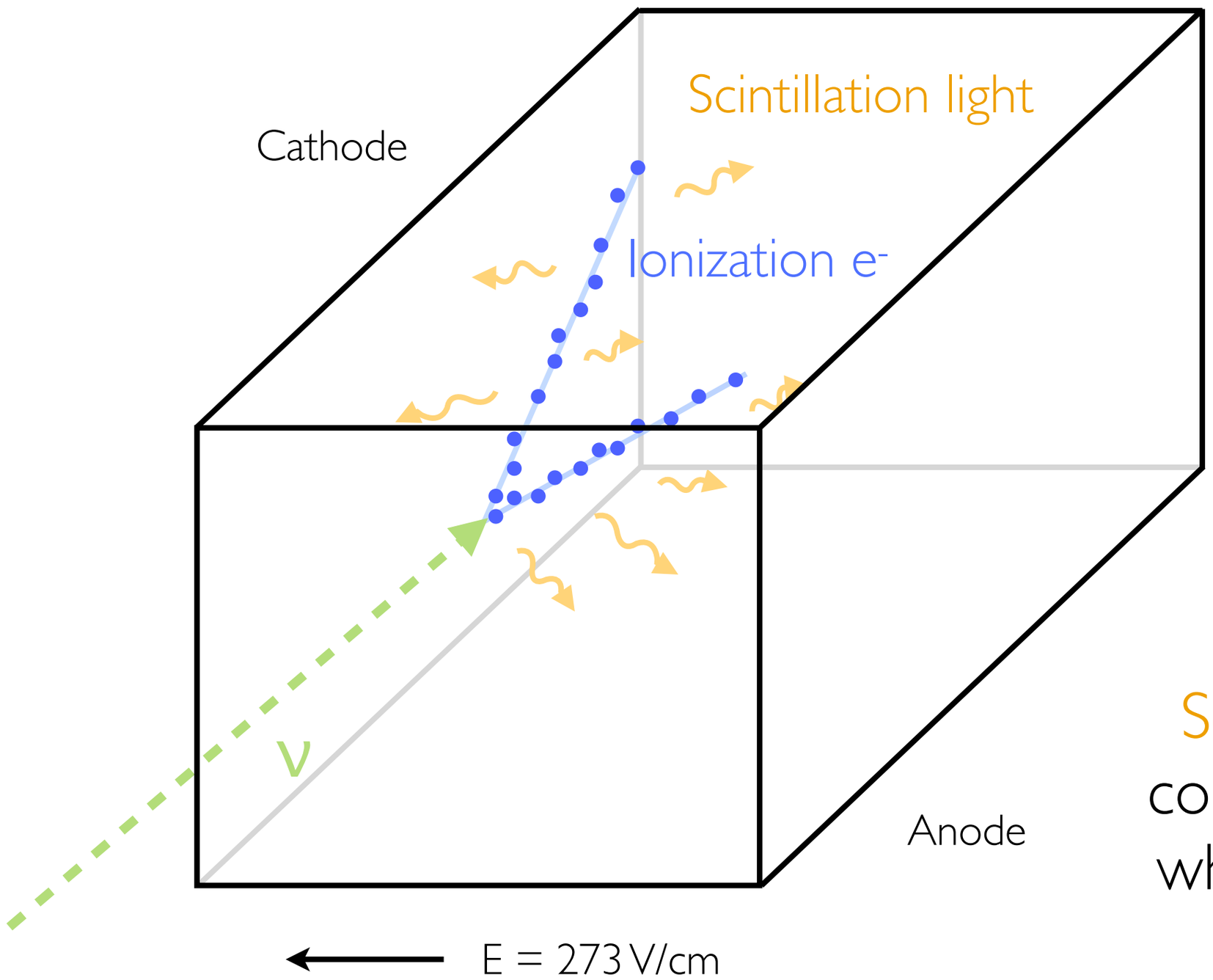
Courtesy of Davide Porzio
Based on JHEP04(2017)102



MicroBooNE Analysis: First Search in LArTPCs

Analysis Team: Owen Goodwin, Davide Porzio, Stefan Söldner-Rembold, Y.-T. Tsai

LArTPC Feature

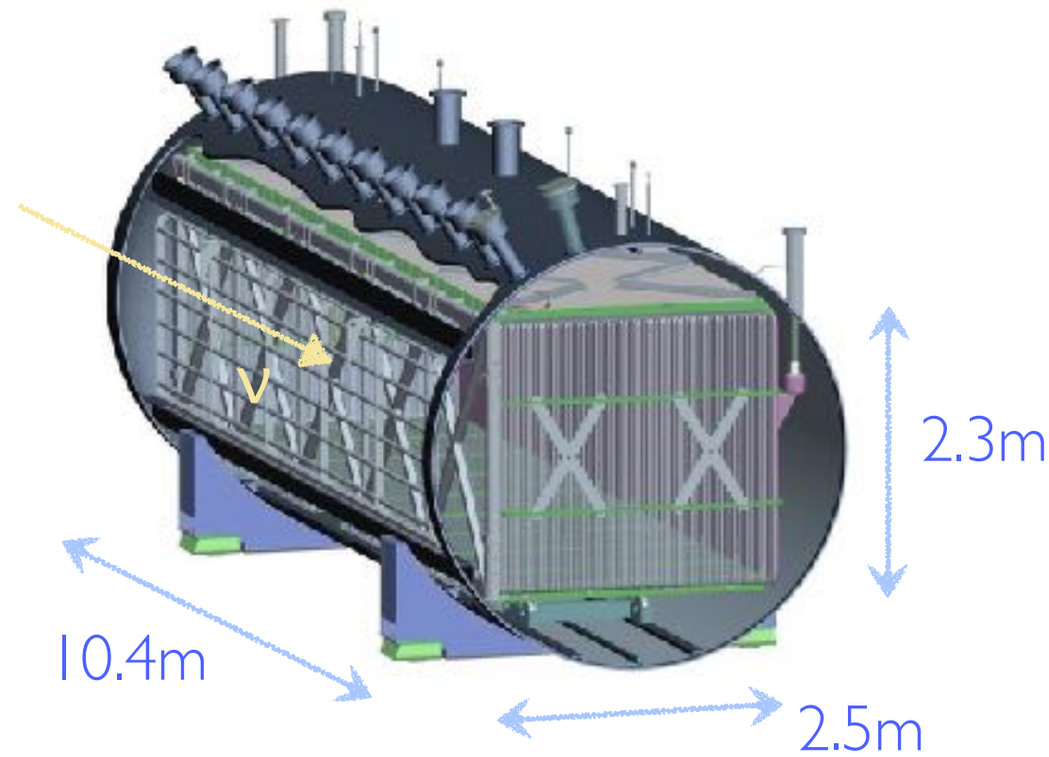


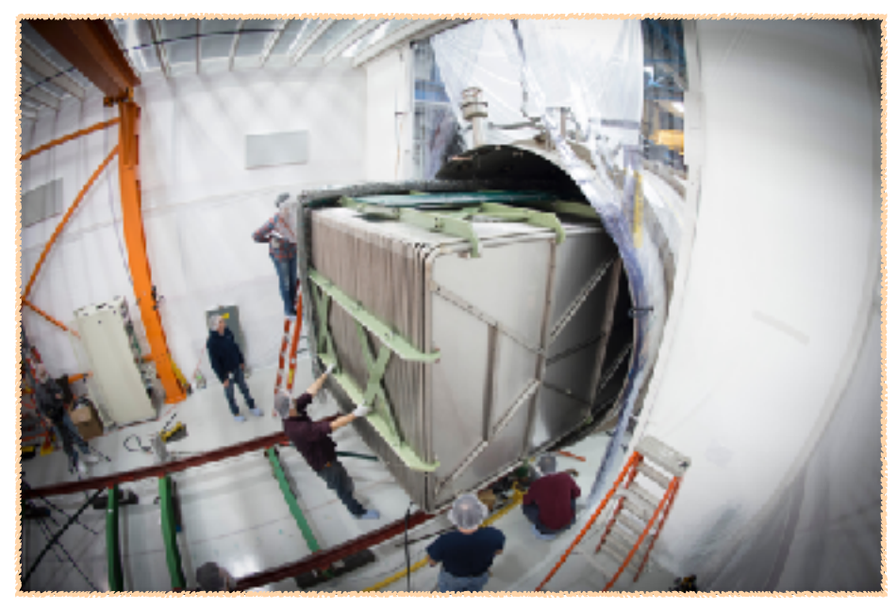
Charged particles ionize LAr, producing electrons and scintillation light

Scintillation light is collected in a few ns, while drift electrons in a few ms

MicroBooNE

- First large LArTPC in the US
- LAr: 89 tons (active)
- 1 TPC: 2.3mx2.5mx10.4m
  - 8192 wires, 3-mm pitch
  - 2MHz sampling rate
- Light collection
  - 32 PMTs+4 paddle PMTs
  - 64MHz sampling rate
- Cosmic ray tagger
- Located on surface





Event Generation

- The timing of HNL production uniformly distributed within a BNB spill
- HNL energy provided by the flux spectrum
- HNL collinear with beam axis
- Decay points uniformly distributed in the detector
- Isotropic decay in HNL rest frame
- Event rate scaled by decay probability

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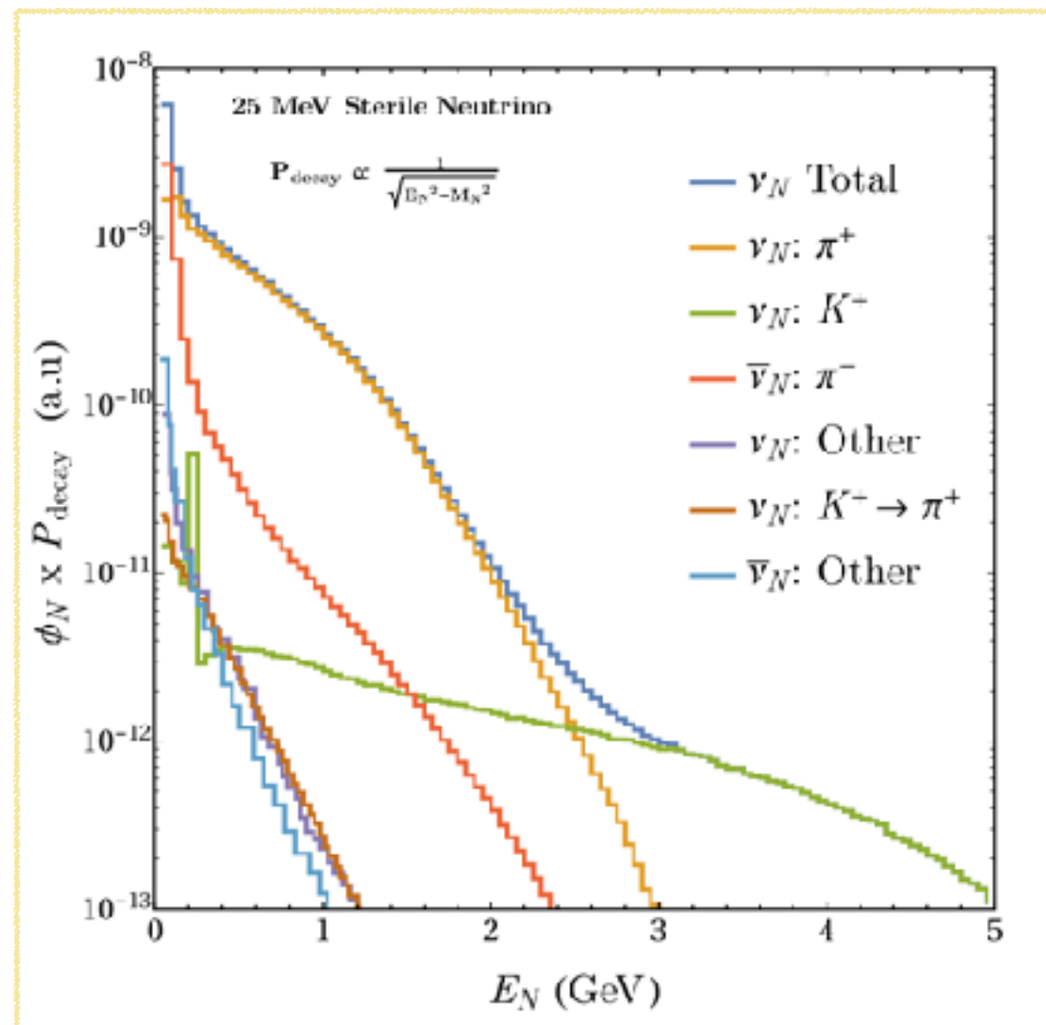
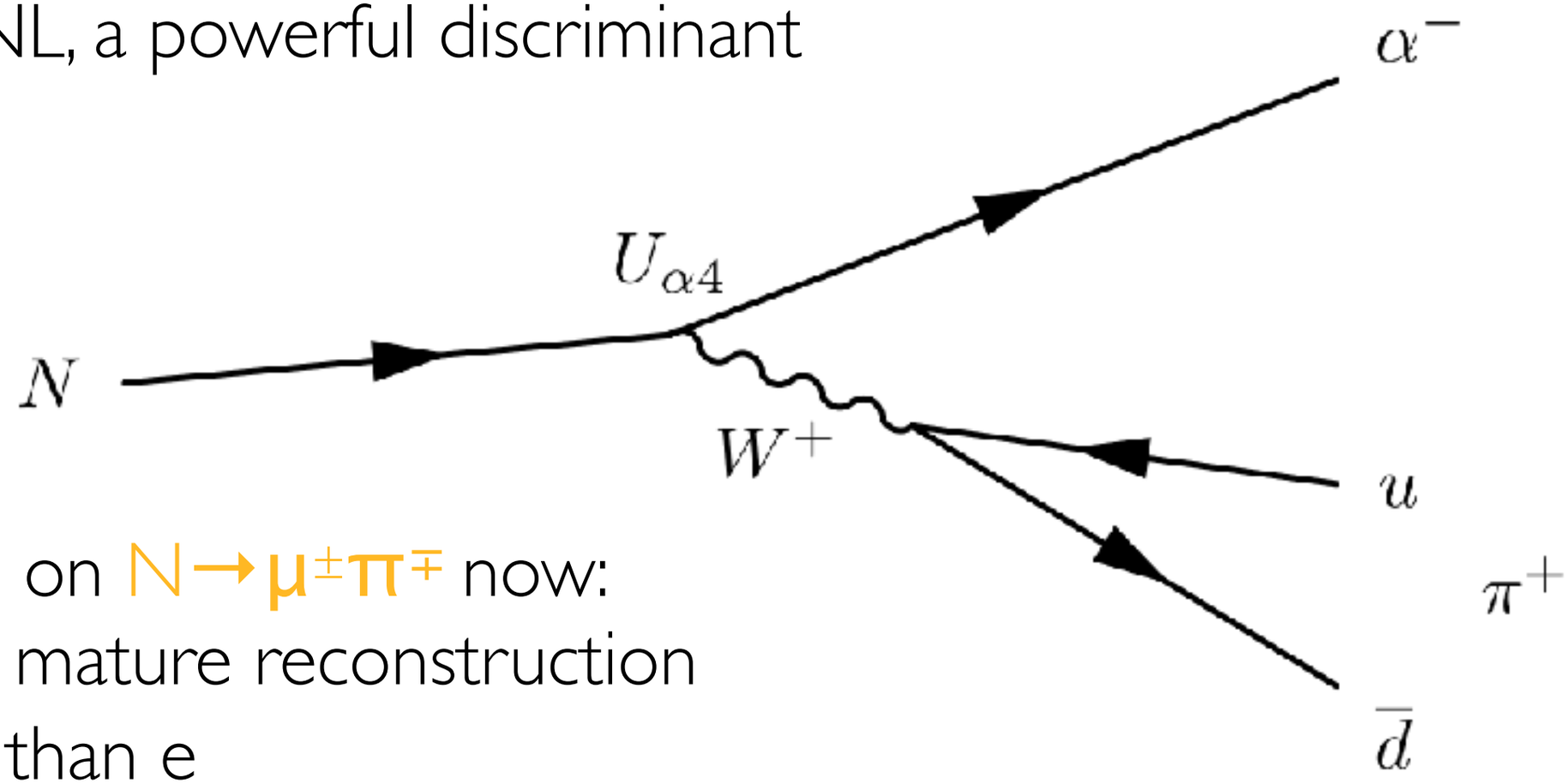
for M_N = 25 MeV/c^2



2-body Decay

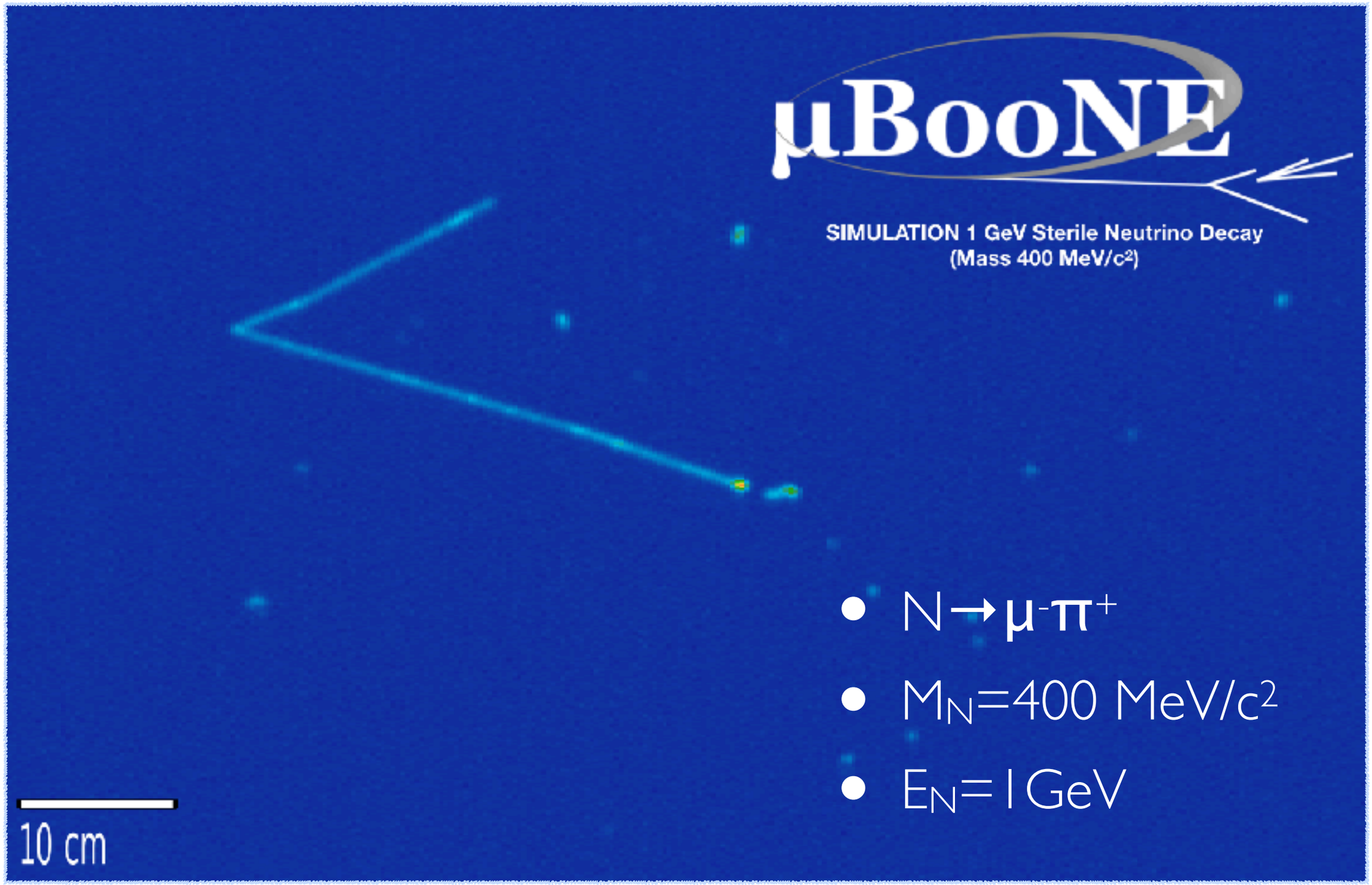
$N \rightarrow l^{\pm}\pi^{\mp}$

- Fully reconstructed final states
- Able to reconstruct the invariant mass of HNL, a powerful discriminant



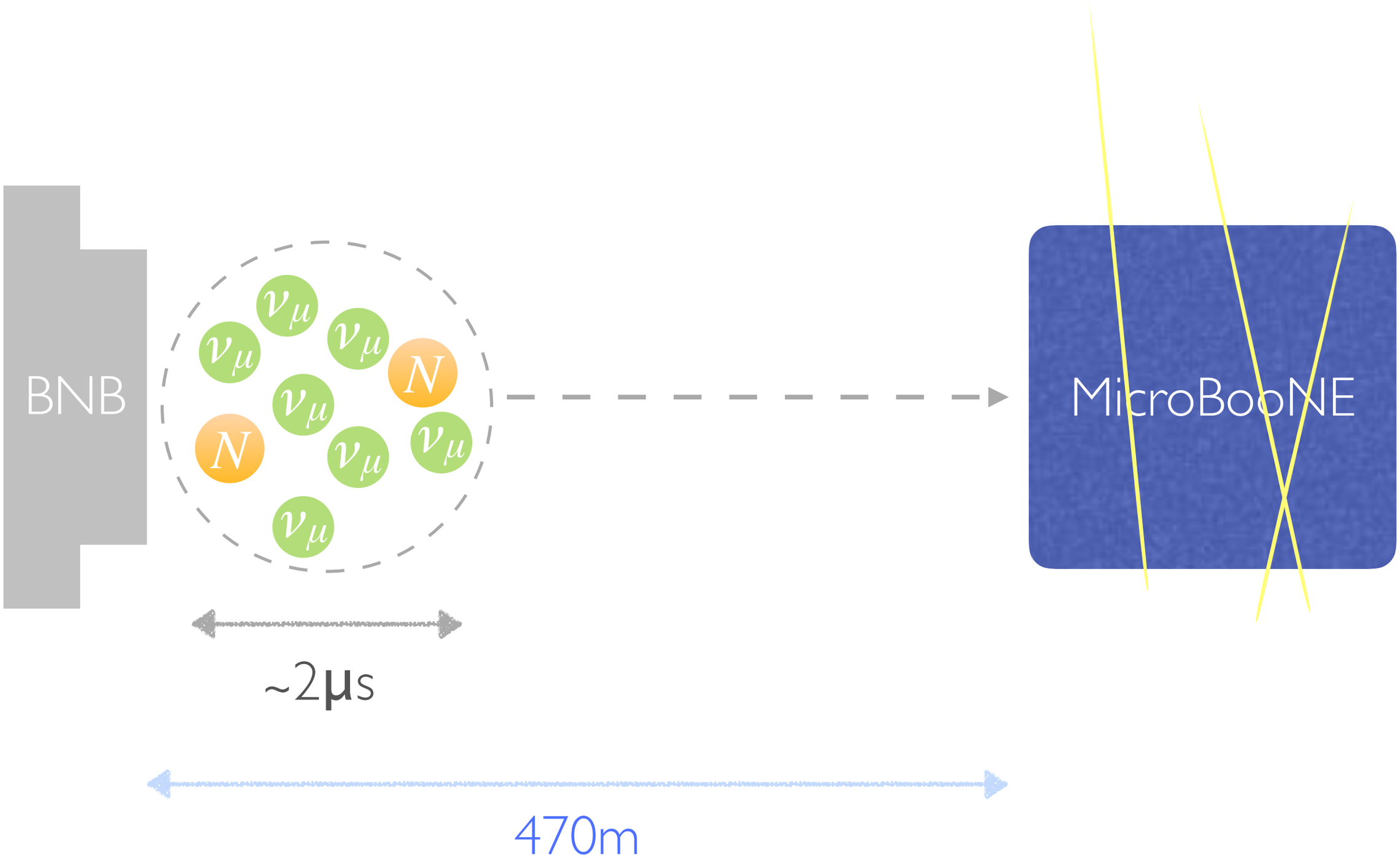
Focus on $N \rightarrow \mu^{\pm}\pi^{\mp}$ now: more mature reconstruction for **μ** than e

HNL Event



- $N \rightarrow \mu^- \pi^+$
- M_N=400 MeV/c^2
- E_N=1 GeV

Time of Flight



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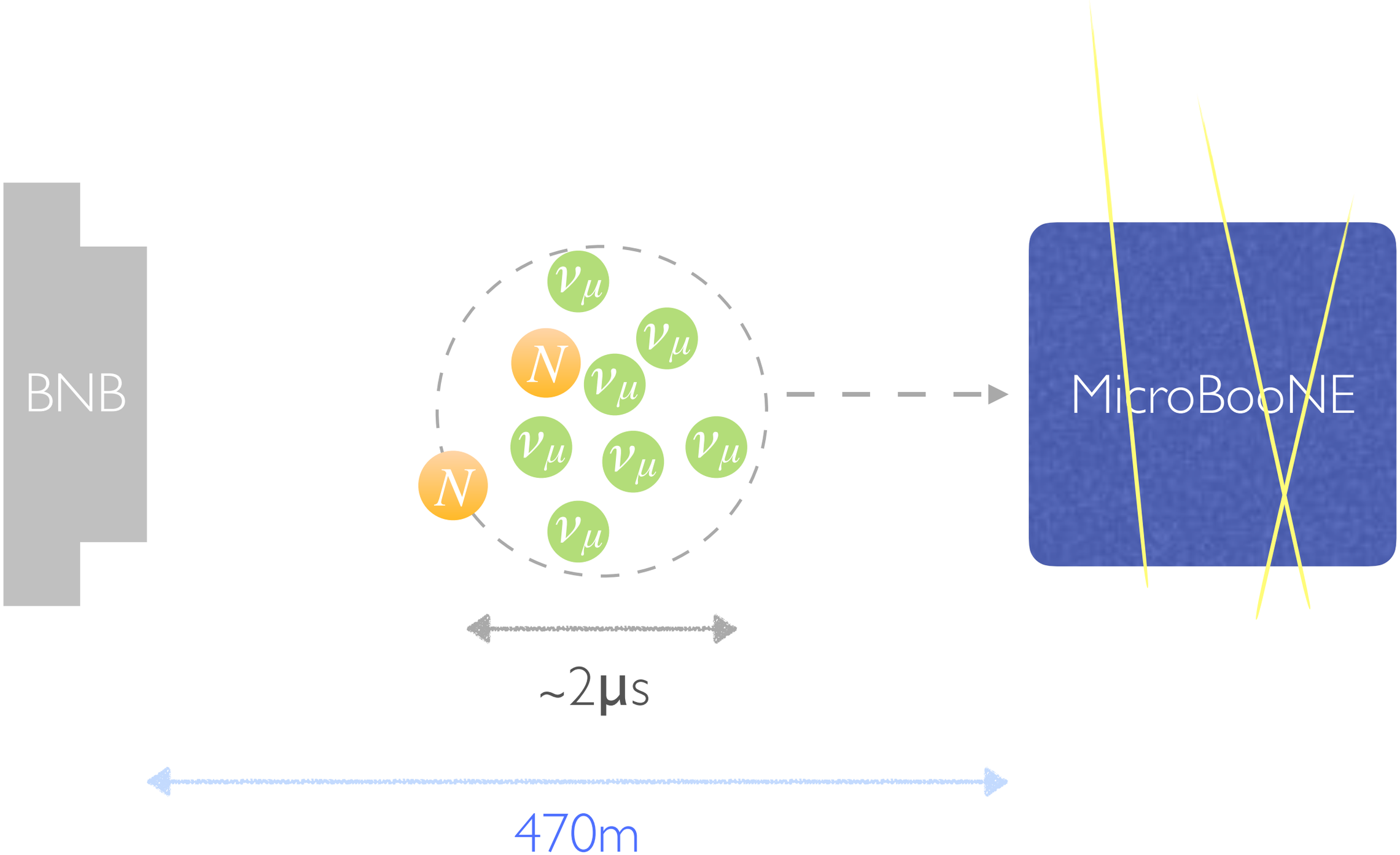

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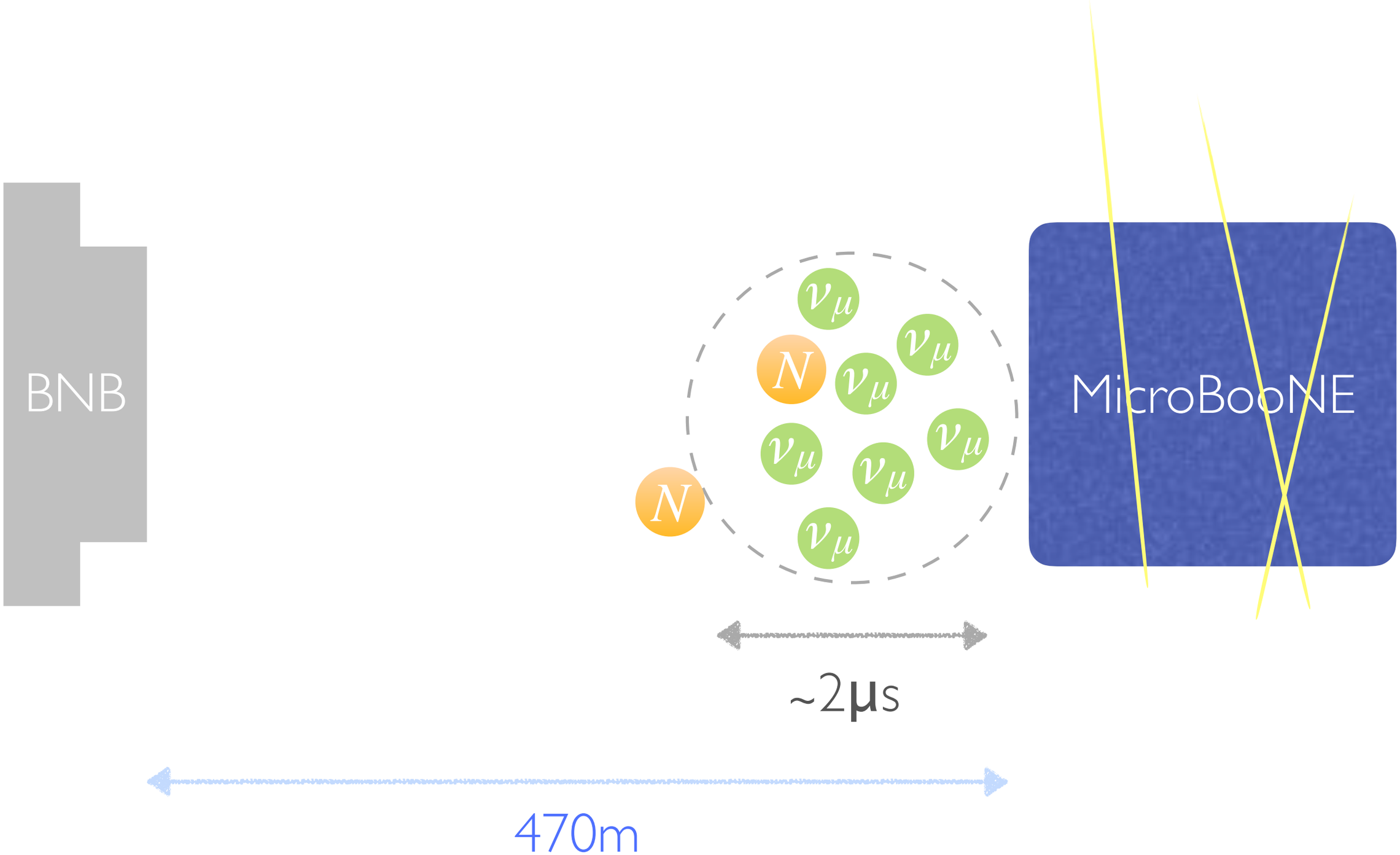

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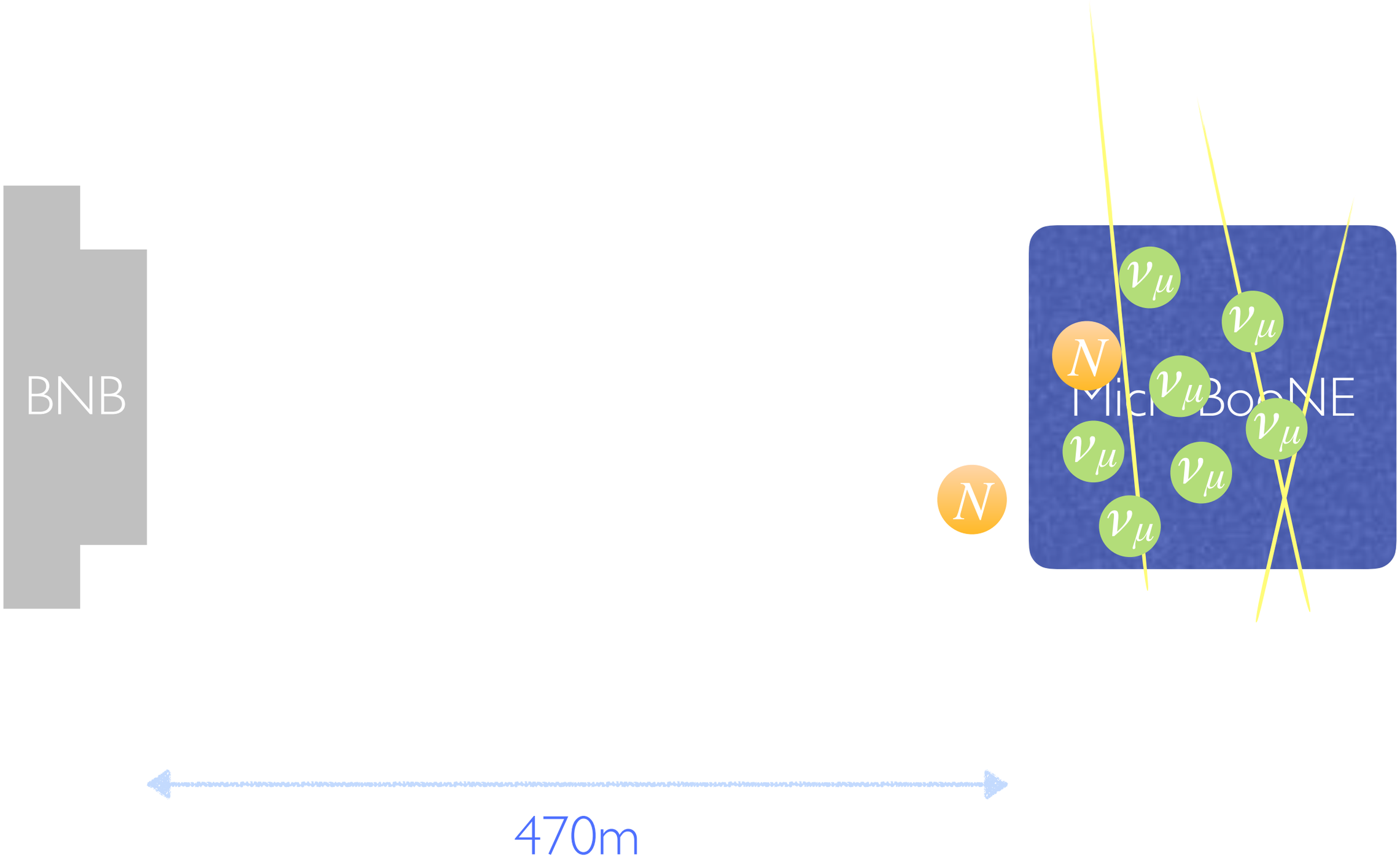

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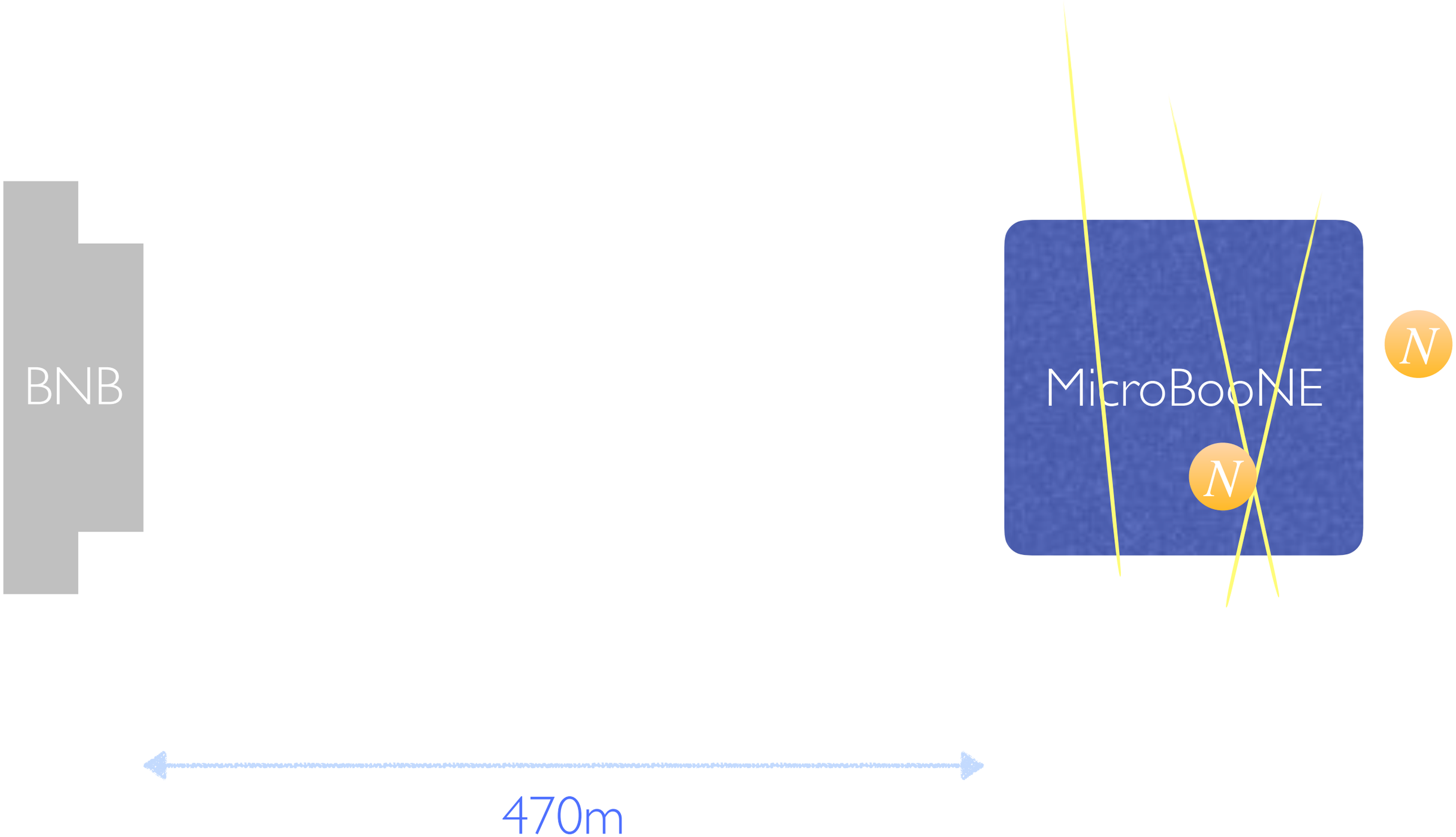
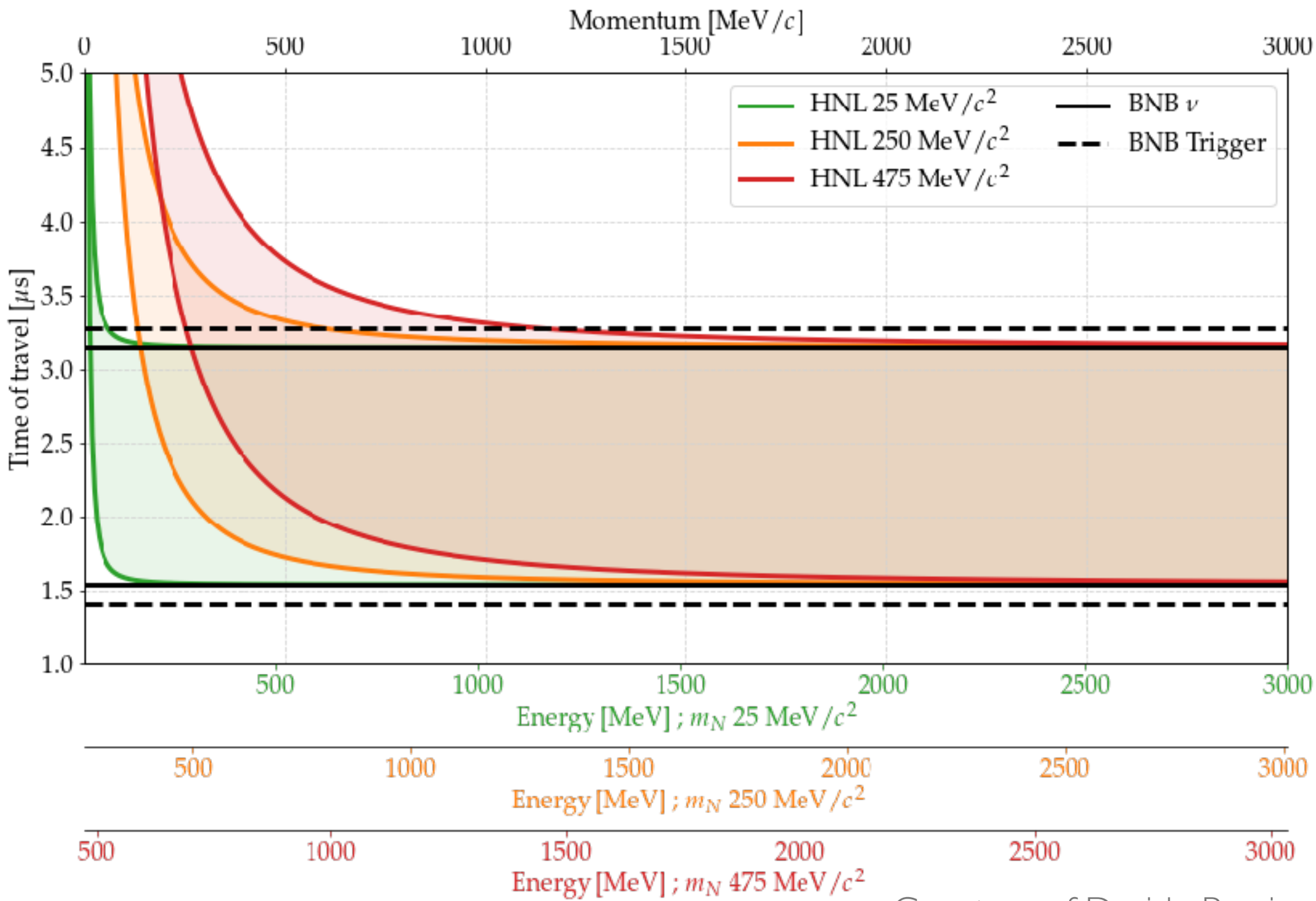
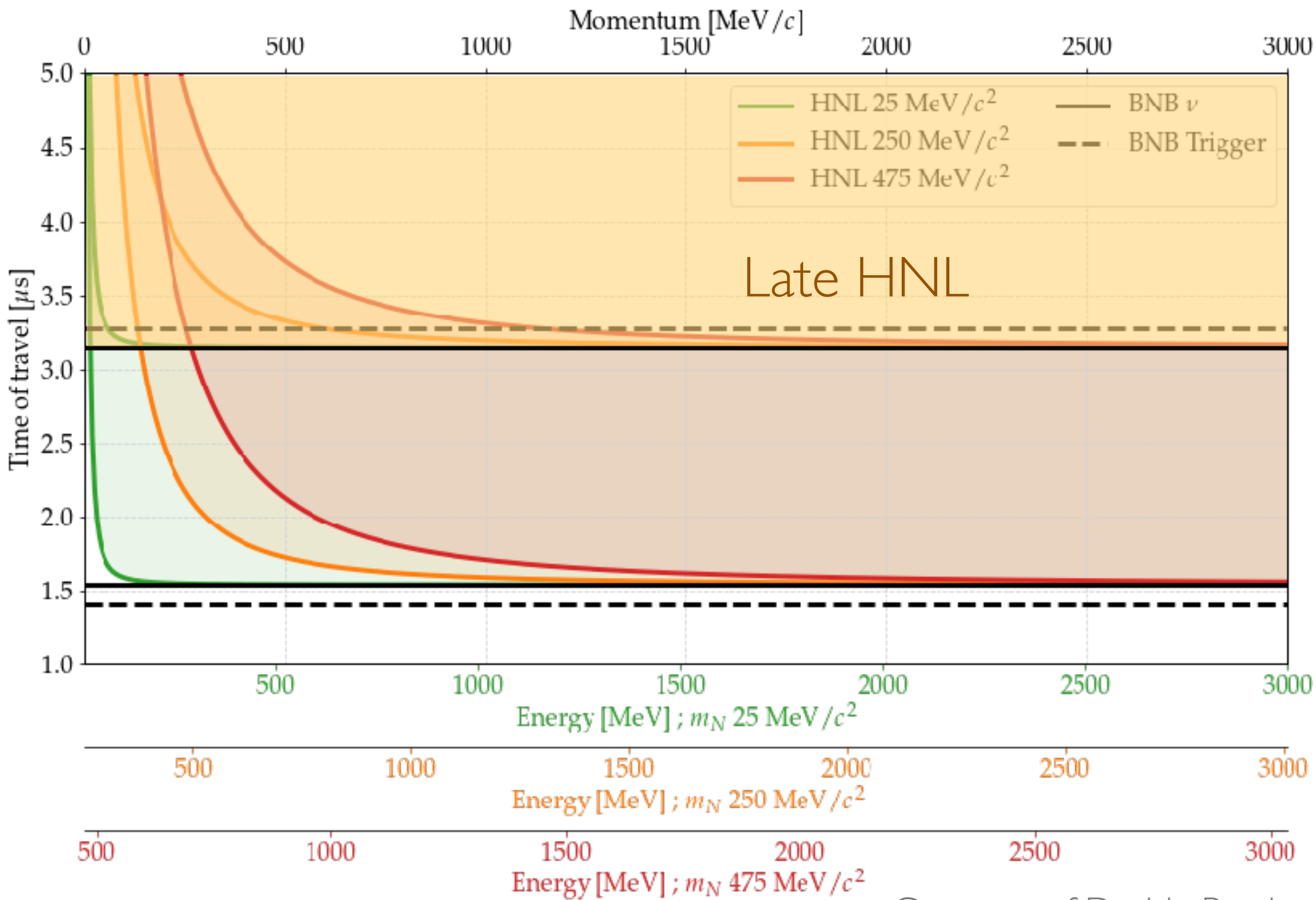


HNL Arriving Time



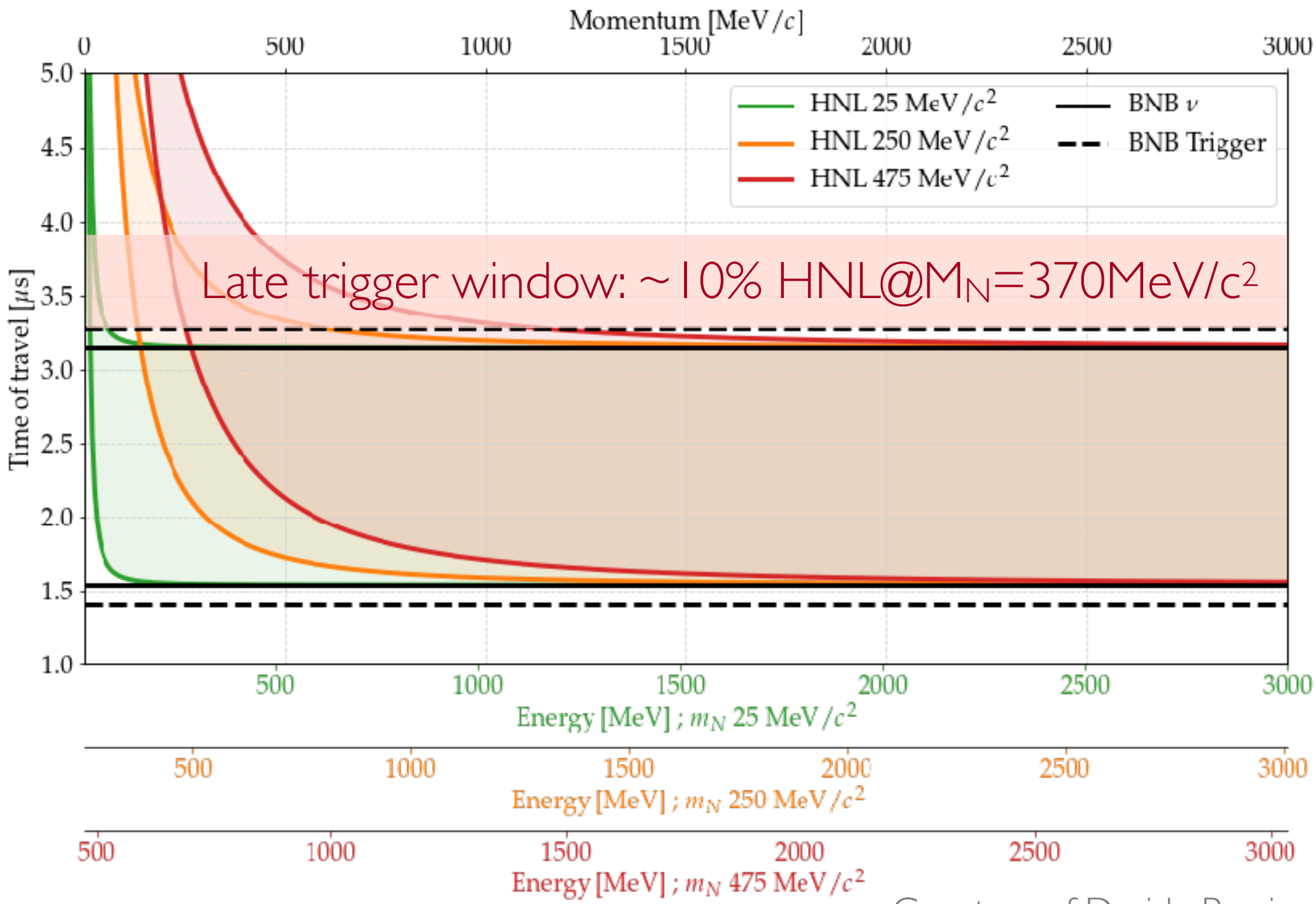
Courtesy of Davide Porzio

HNL Arriving Time



Courtesy of Davide Porzio

HNL Late Trigger Window



Courtesy of Davide Porzio

Expected Background

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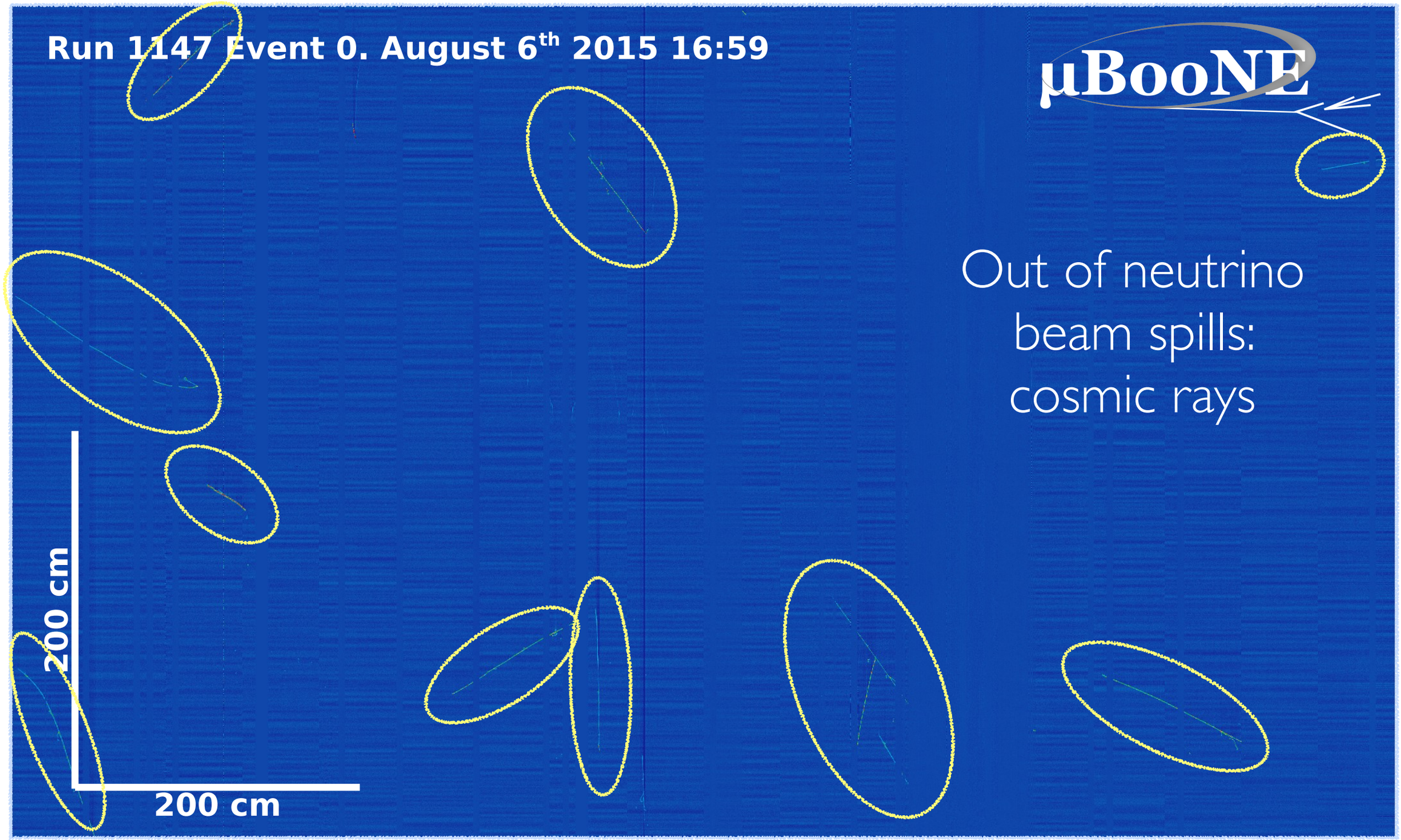
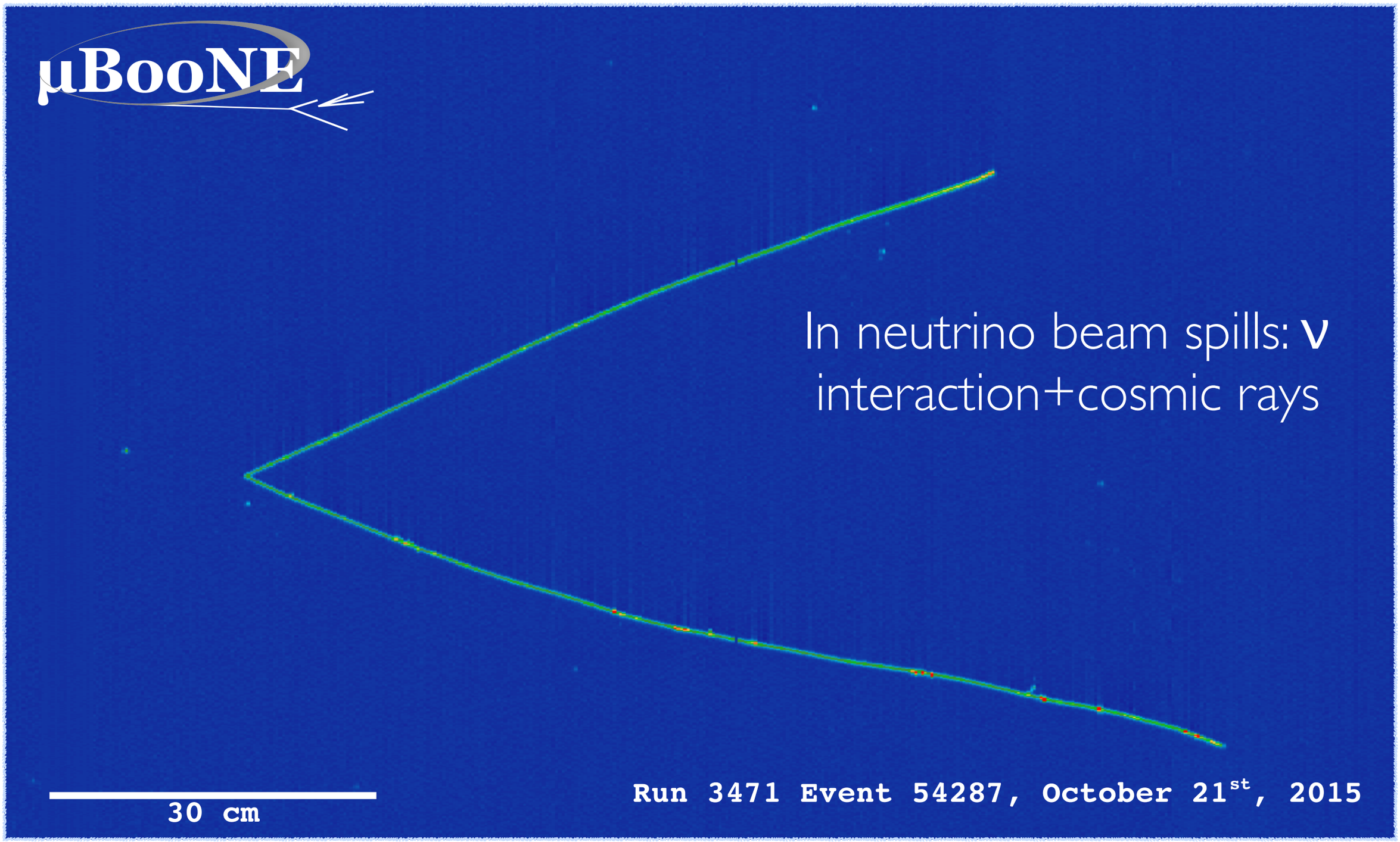


Out of neutrino beam spills: cosmic rays

Expected Background



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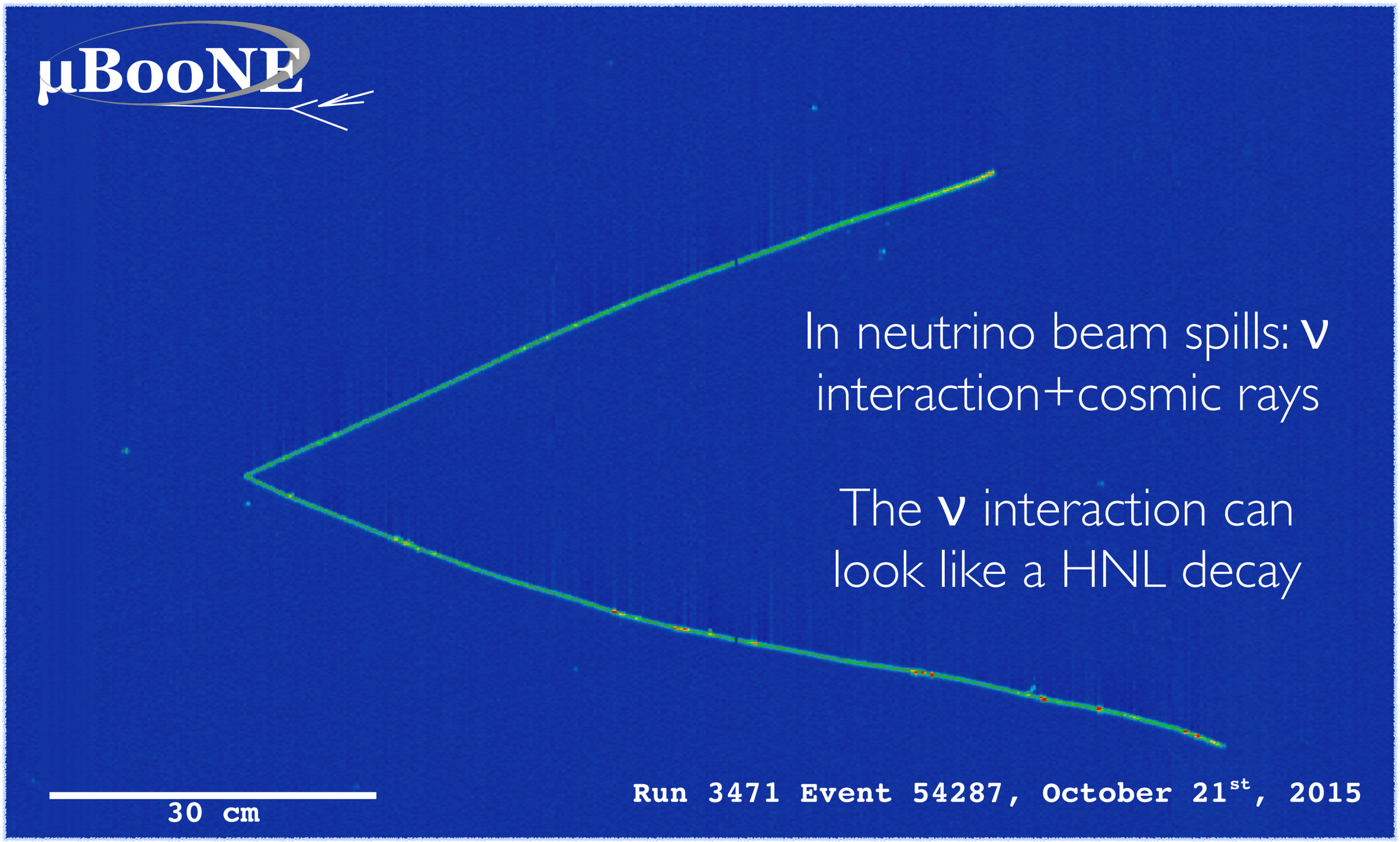
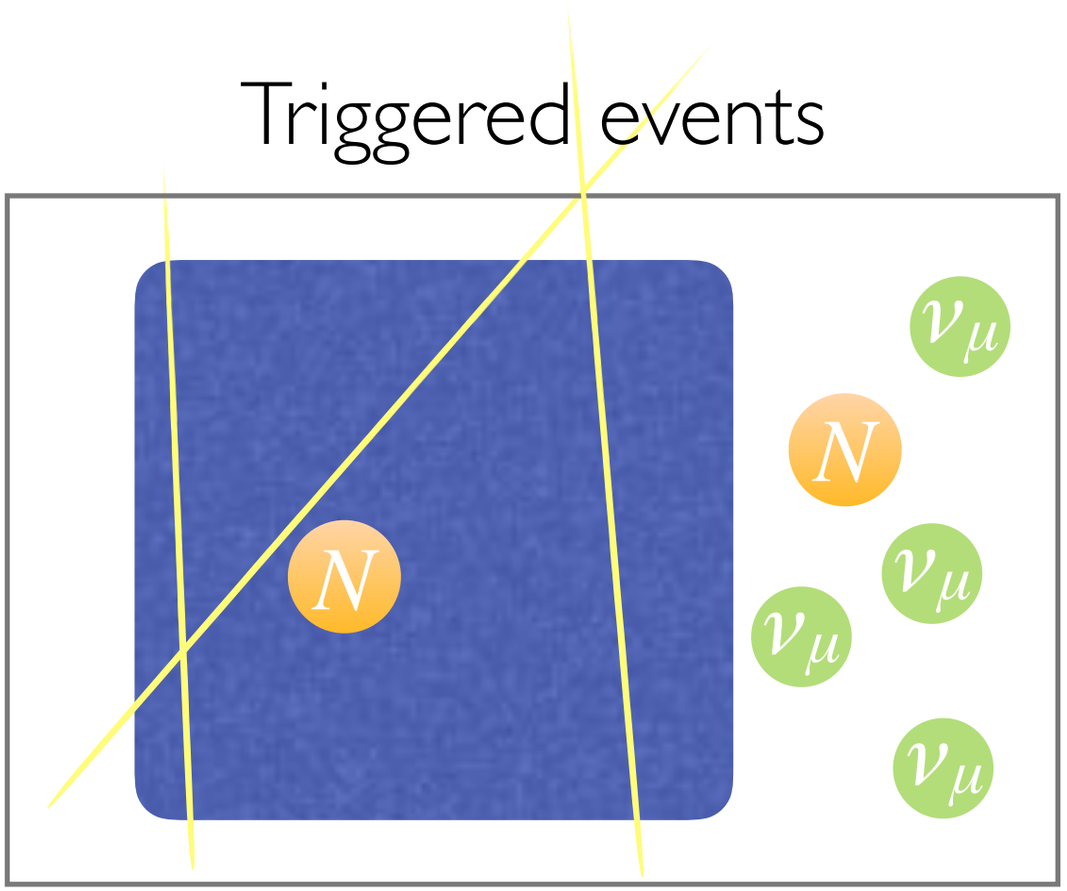
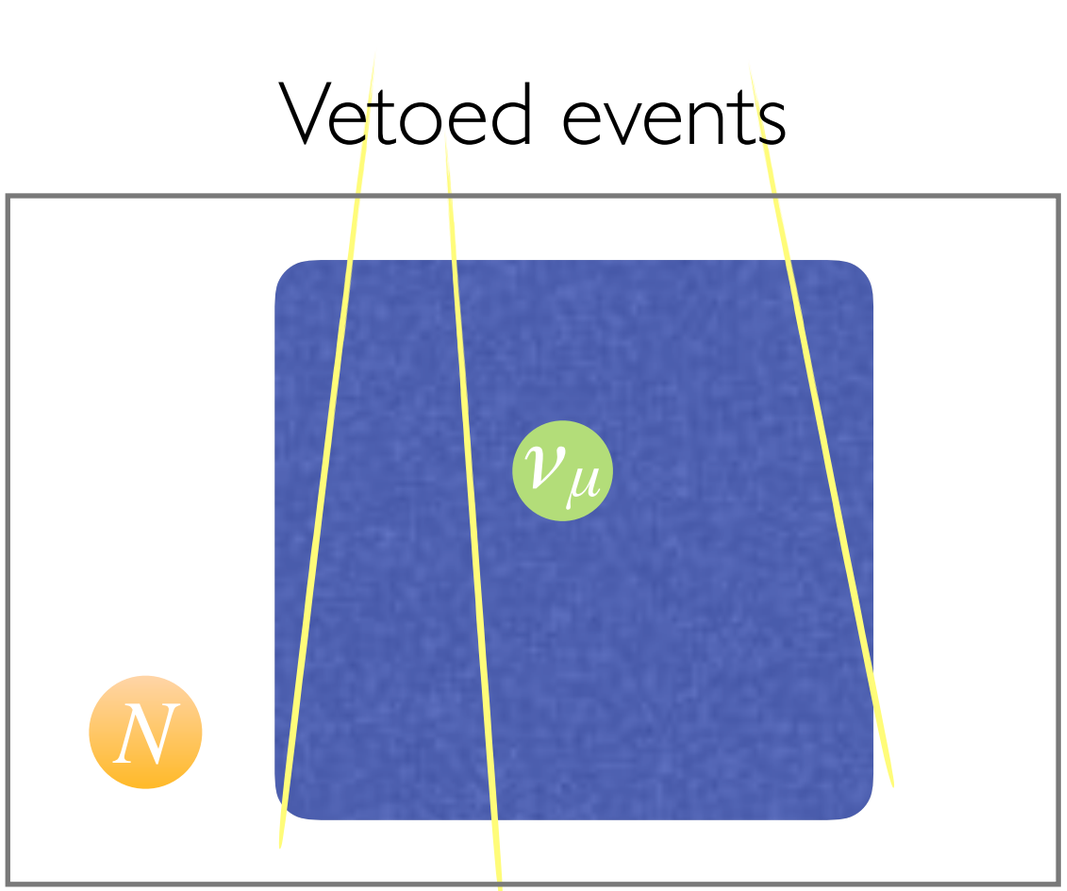


In neutrino beam spills: ν interaction+cosmic rays

The ν interaction can look like a HNL decay

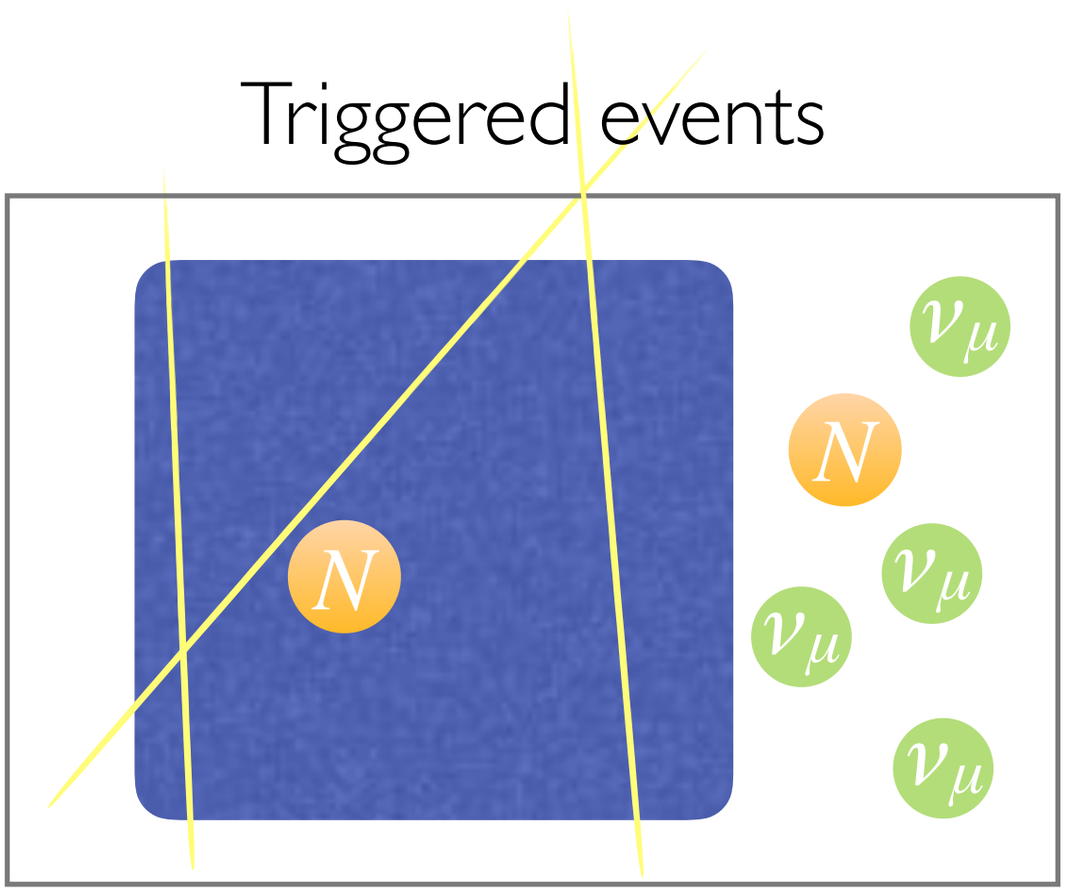
Data-Driven Analysis

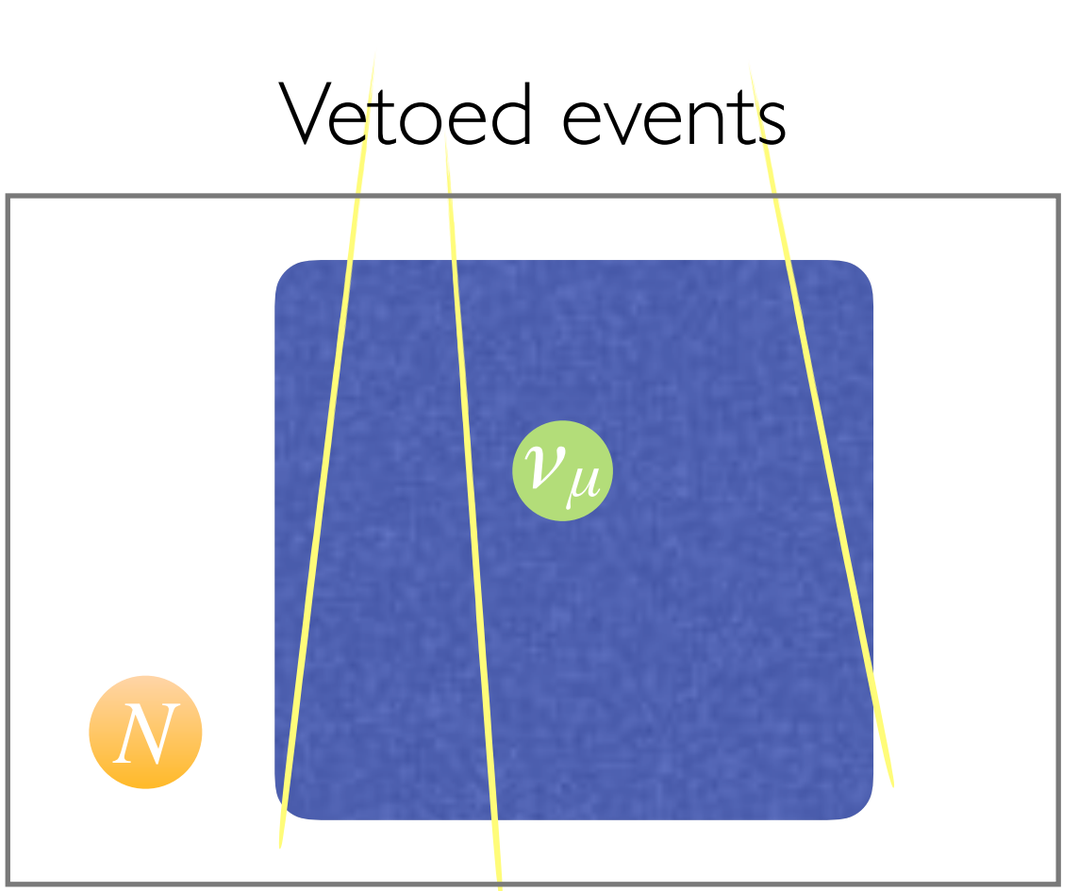




- Use the events triggered in late trigger window, but vetoed those triggered in the BNB trigger window
- Only ~10% HNL (M_N=370MeV/c^2), but no SM neutrino background

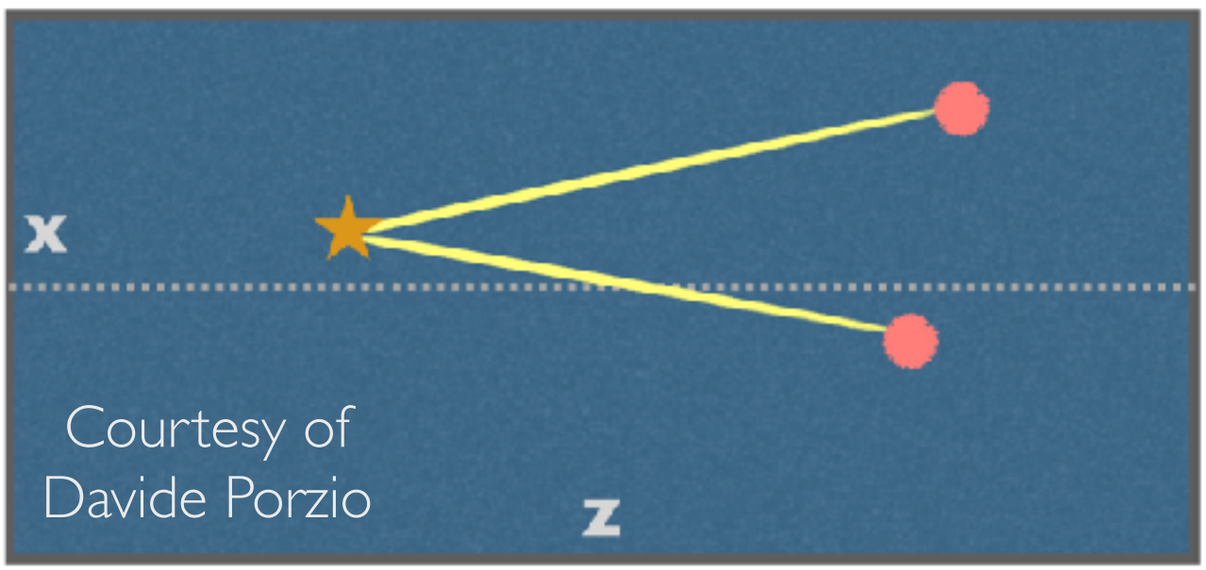
Data-Driven Analysis





- Measure an excess of events in a data sample containing only cosmic rays
- Allow us to use cosmic ray data collected out of neutrino beam spills to model background

Preselection & Discriminant



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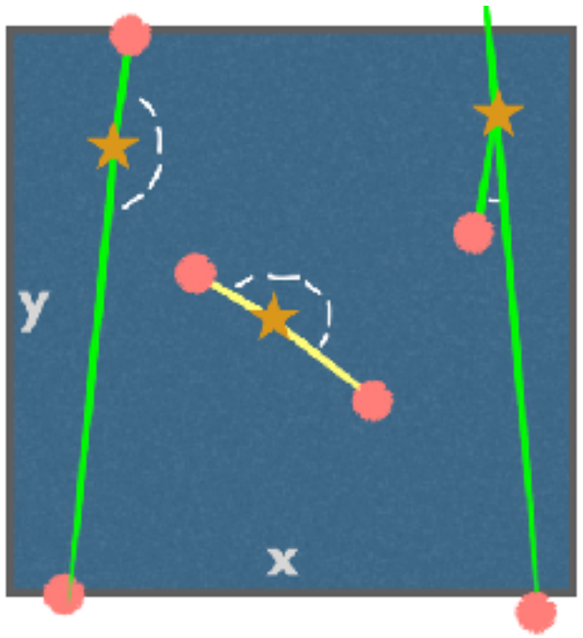
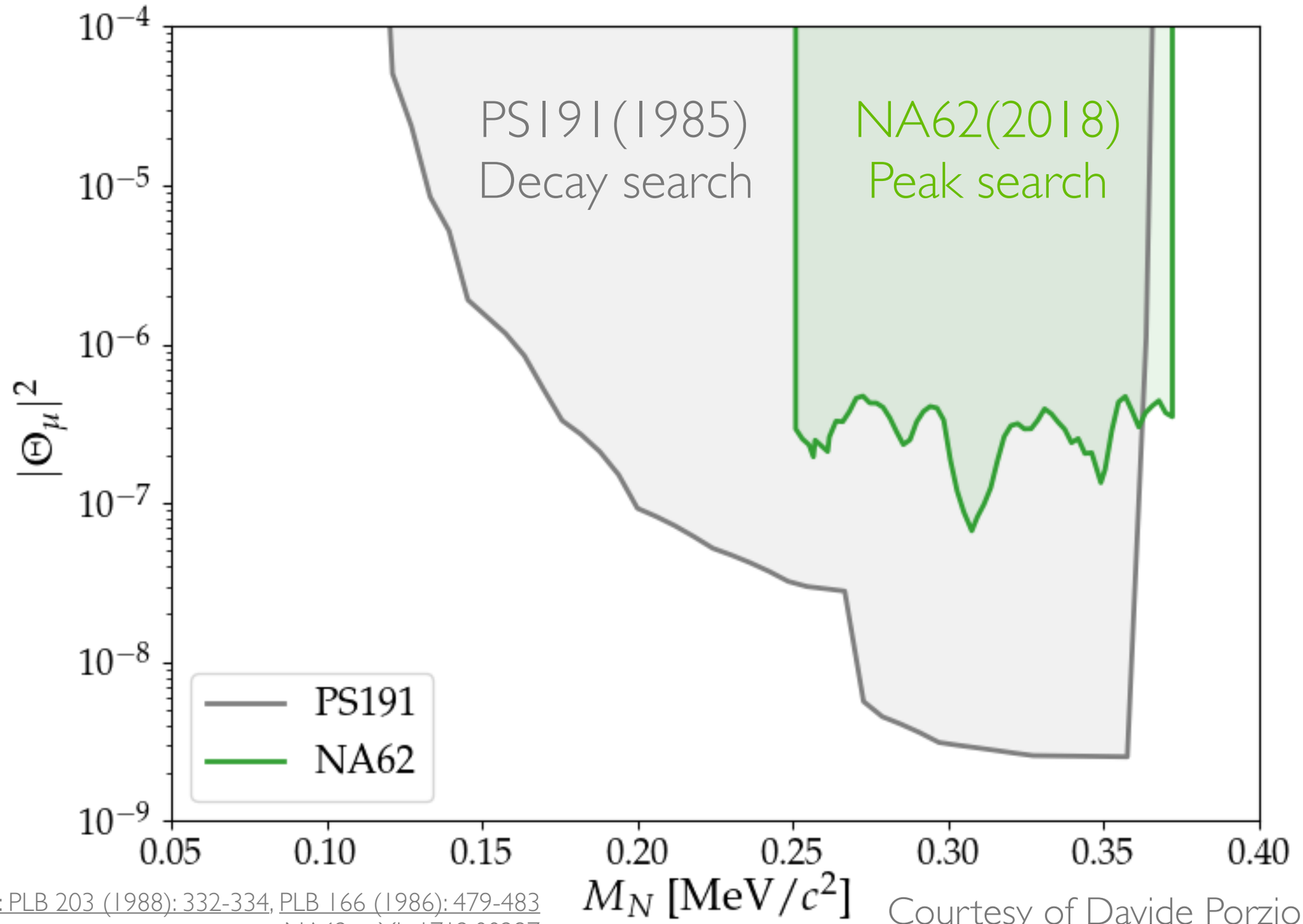
Davide Porzio



- Select candidates with exactly two tracks associated to a decay vertex
- Eliminate the candidates with exiting tracks
- Cosmic background comes from broken tracks and sometimes delta rays
- Form a BDT discriminant based on the HNL invariant mass, opening angle, etc.

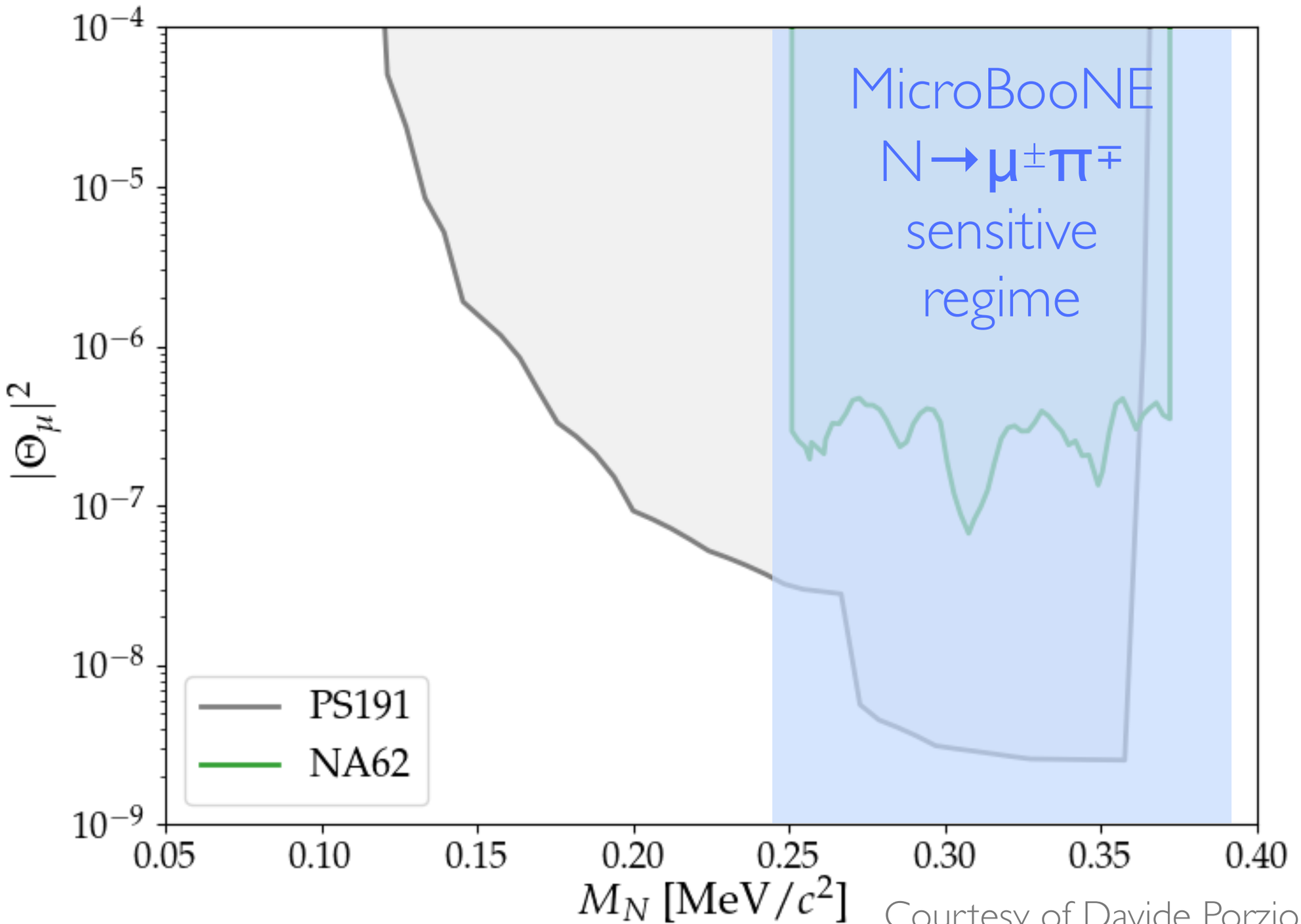
Sensitivity



PS191: PLB 203 (1988): 332-334, PLB 166 (1986): 479-483
NA62: arXiv:1712.00297

Courtesy of Davide Porzio

Sensitivity



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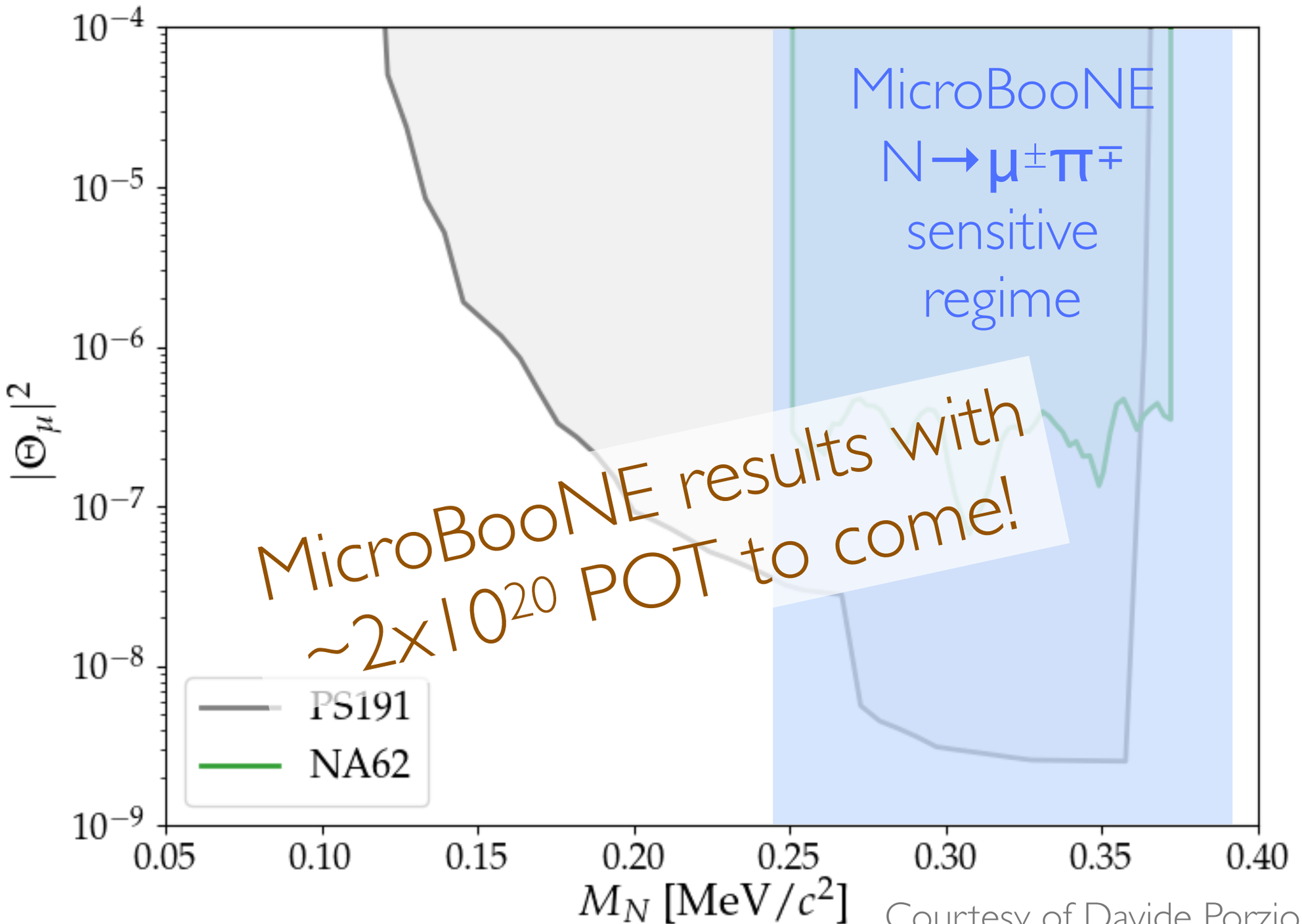
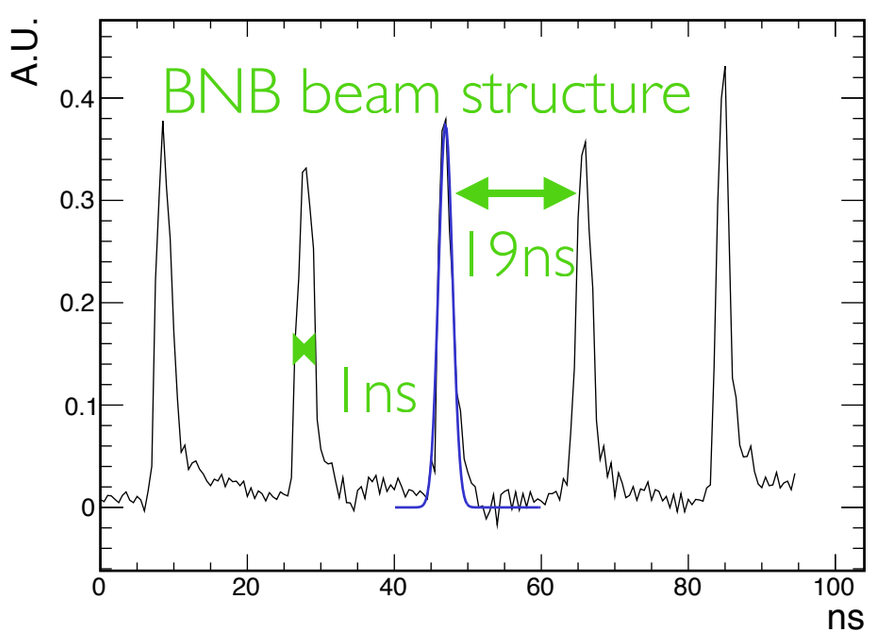


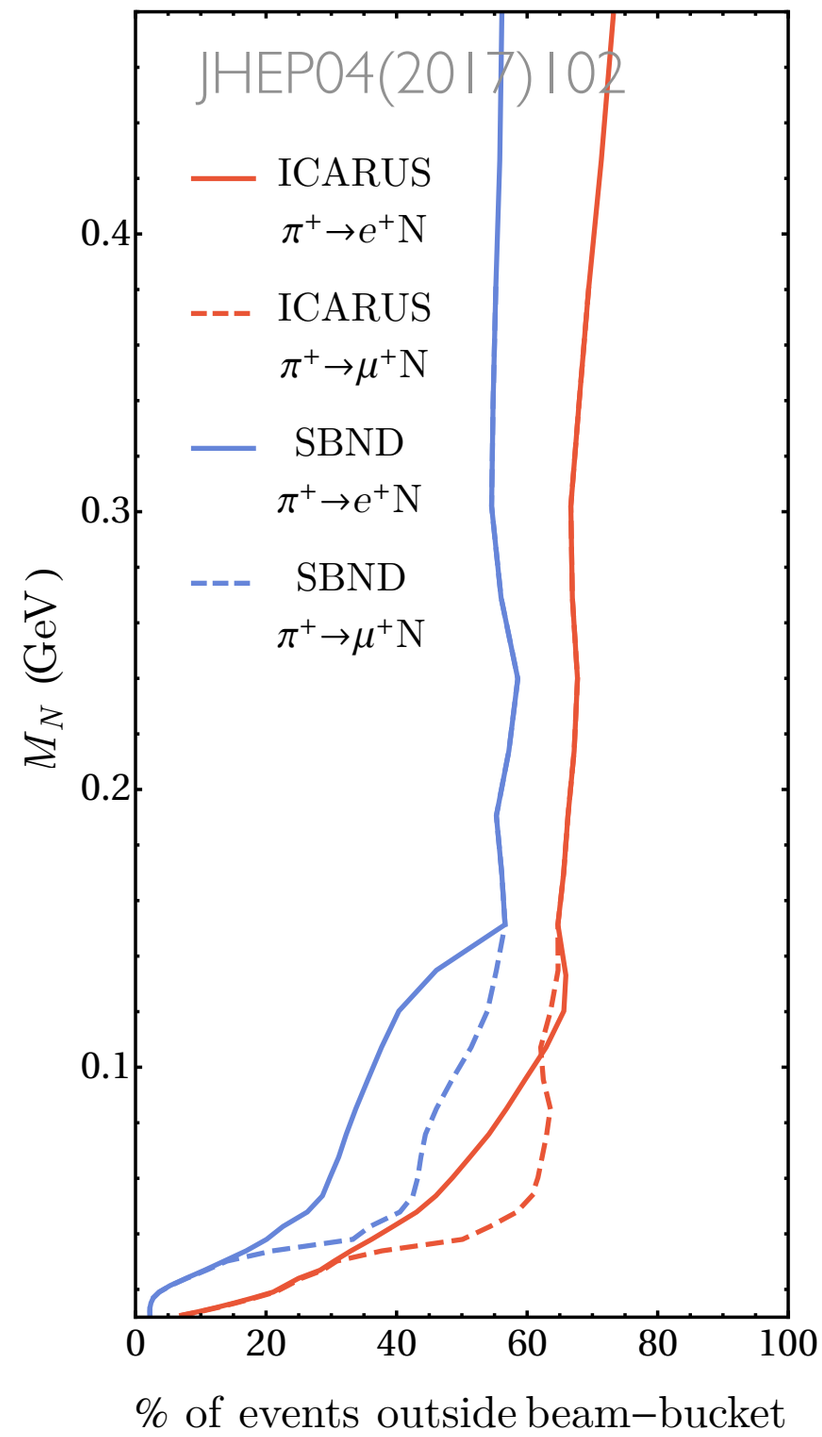
Courtesy of Davide Porzio

Outlook at SBN

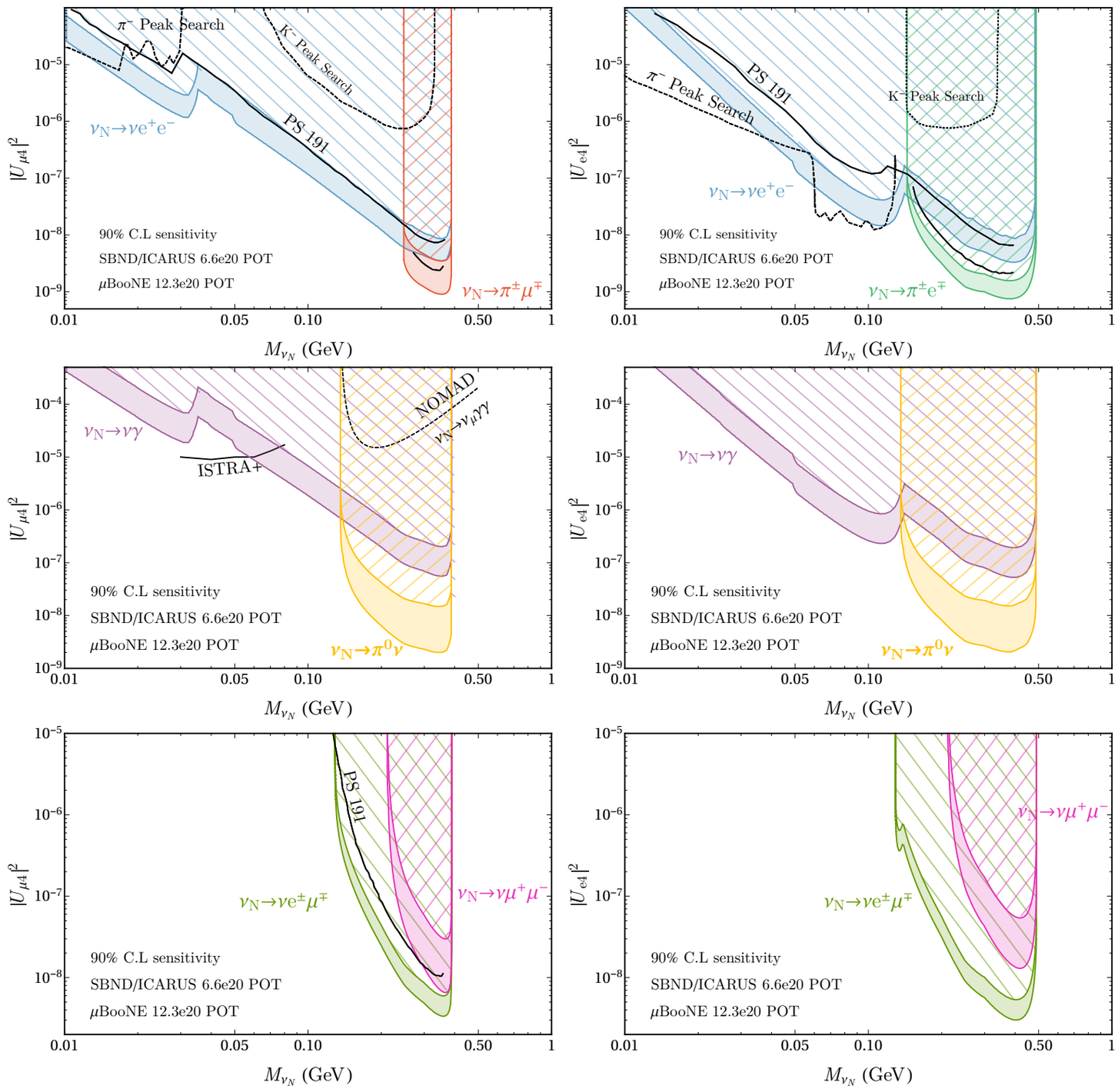
- $N \rightarrow e^{\pm}\pi^{\mp}$ larger parameter space
- Higher sampling rate of light systems in ICARUS and SBND
  - Events outside beam buckets
- Better sensitivity & cross check



Courtesy of En-Chuan Huang



Predicted Sensitivity



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HNL Flux from NuMI

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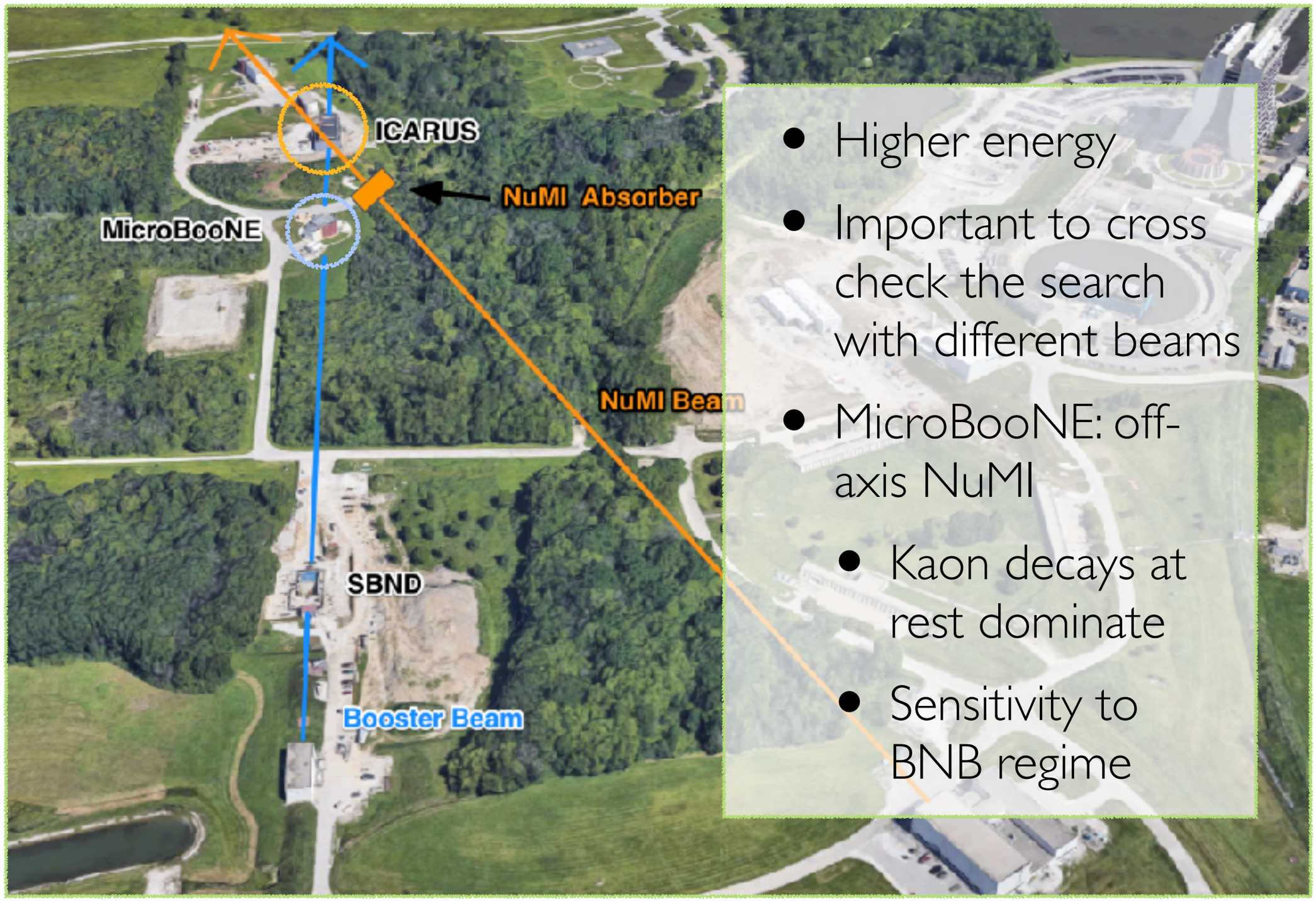
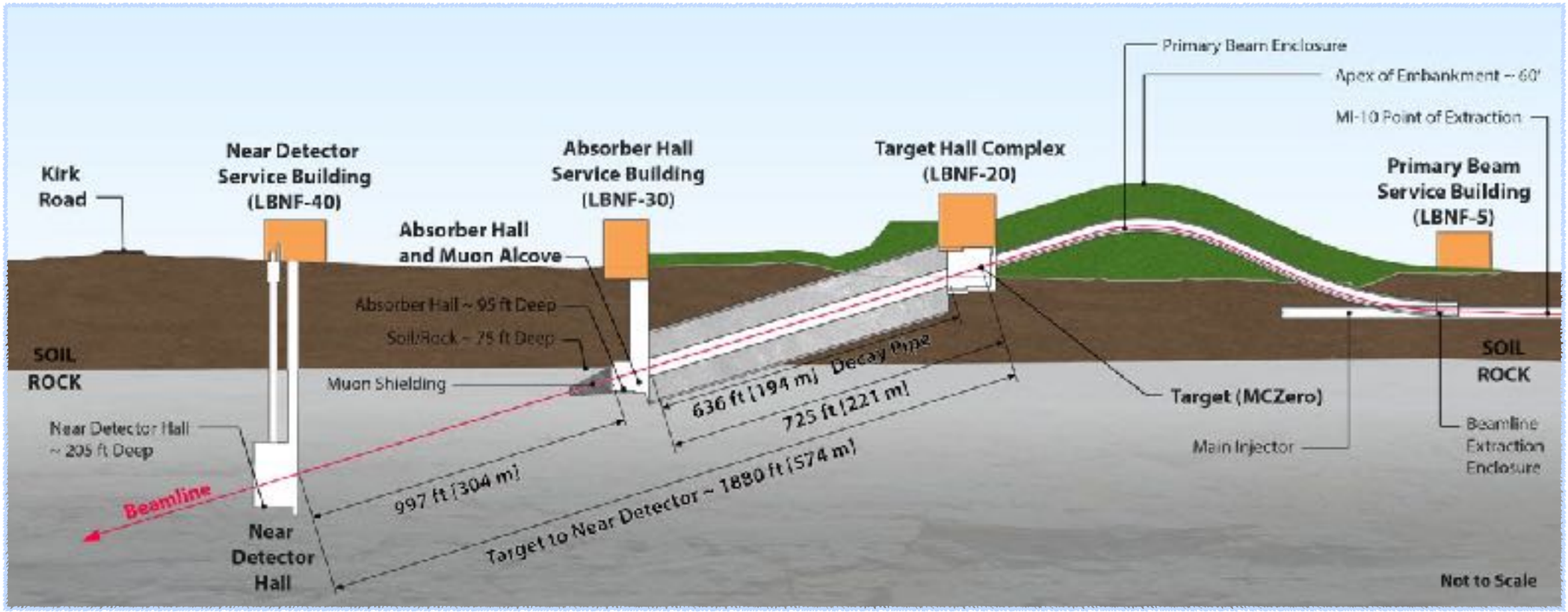


- Higher energy
- Important to cross check the search with different beams
- MicroBooNE: off-axis NuMI
  - Kaon decays at rest dominate
  - Sensitivity to BNB regime

DUNE Near Detector



- Beam produced HNL: ND or SBL experiments
- LBNF: Higher energy, more intense
  - Probe wider and higher HNL mass range
  - Beam for ν_τ appearance probes more parameter space

SBN to DUNE LArTPC ND

- Probe complementary parameter space
- Confirm the results in overlapping parameter space
- Develop reconstruction algorithms and analyses with data taken at SBN in short terms
- Inform the design of DUNE ND
- Advantages of DUNE ND
  - Little cosmic ray background
  - Advanced technology
- Possible challenge of DUNE ND
  - Pile-up of the SM neutrino-argon interactions

Summary

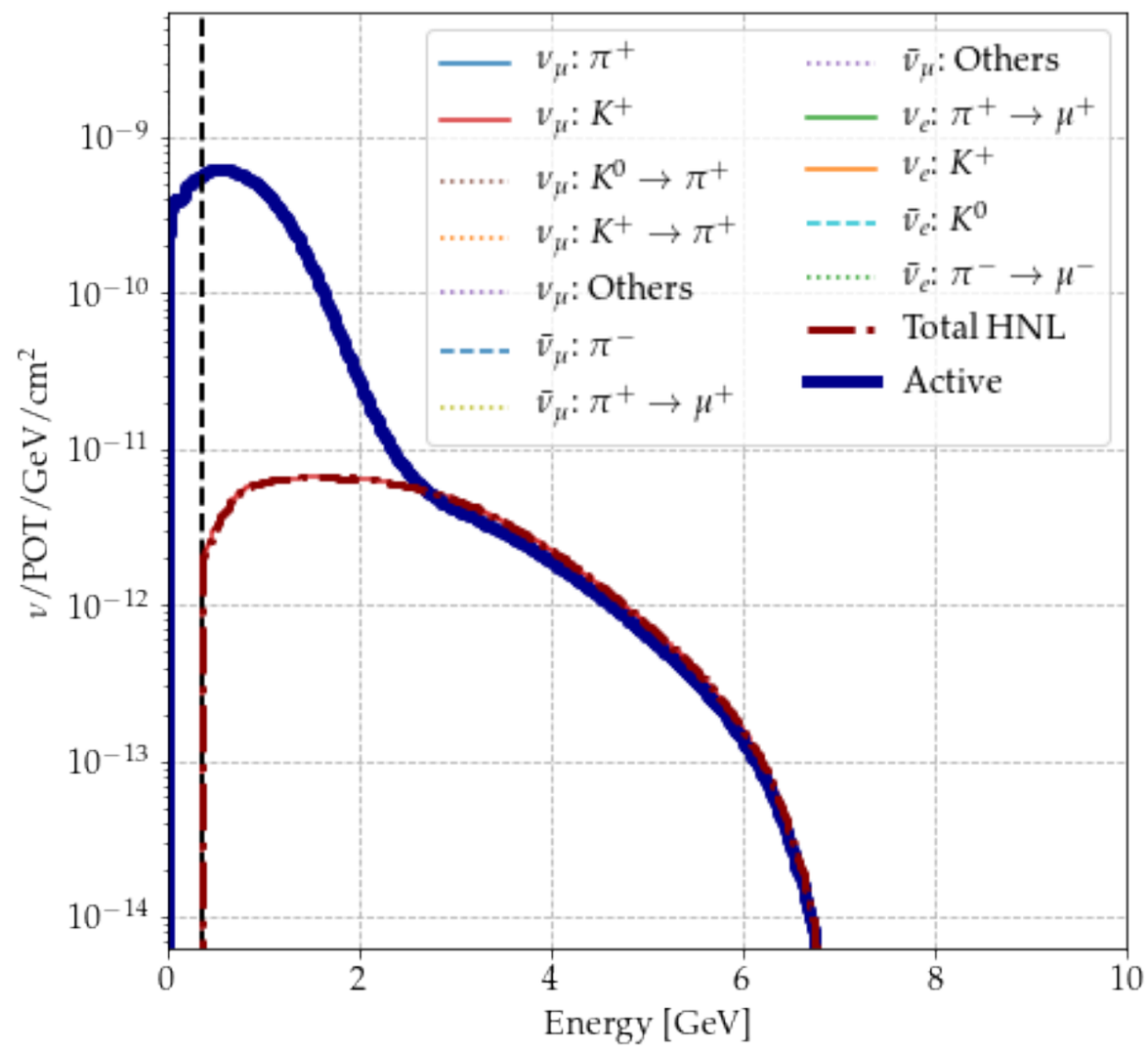
- Heavy neutral lepton search: a novel and motivated idea of physics beyond the SM
- Beam produced HNL well suited for DUNE ND and SBN experiments
- MicroBooNE analysis: the first HNL search in LArTPCs
  - Result with ~2×10^{20} POT coming soon!
- DUNE ND and SBN have complementary sensitivity and competitive to other experiments

Backup

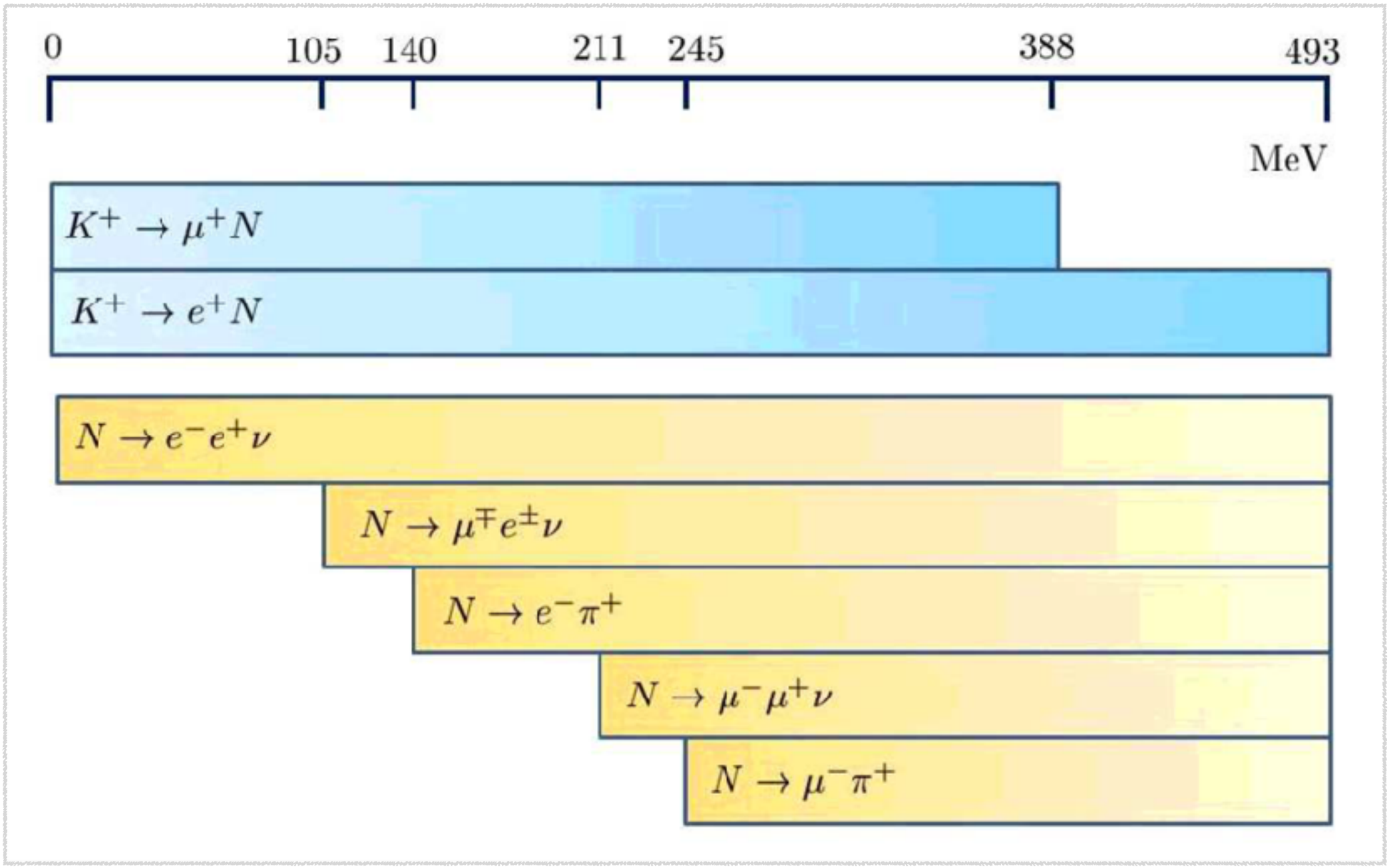
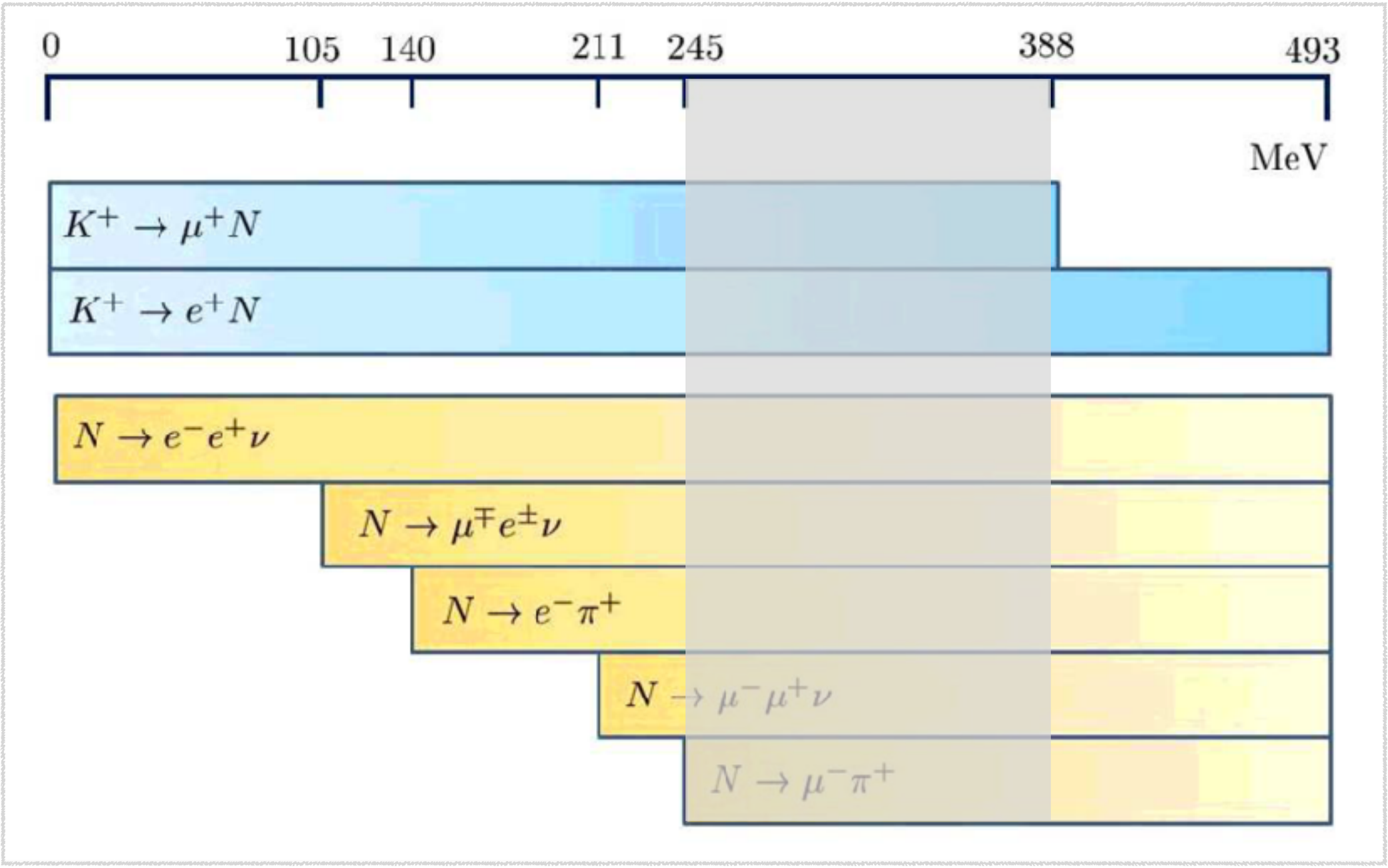
Expected Flux Spectrum

- For $N \rightarrow \mu^{\pm}\pi^{\mp}$ channel, $M_N > 245$MeV
- Consider nonzero $\Theta_{\mu 4}$
- HNL produced by $K \rightarrow N\mu$
- Assume the angular distribution of HNL similar to SM neutrinos
- In practice, HNL has more forward momenta than SM neutrinos
- Obtain a lower bound of the HNL flux estimation

Courtesy of Davide Porzio



Sensitivity on HNL Mass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