Searches for long-lived particle decays in MicroBooNE

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on behalf of the MicroBooNE Collaboration

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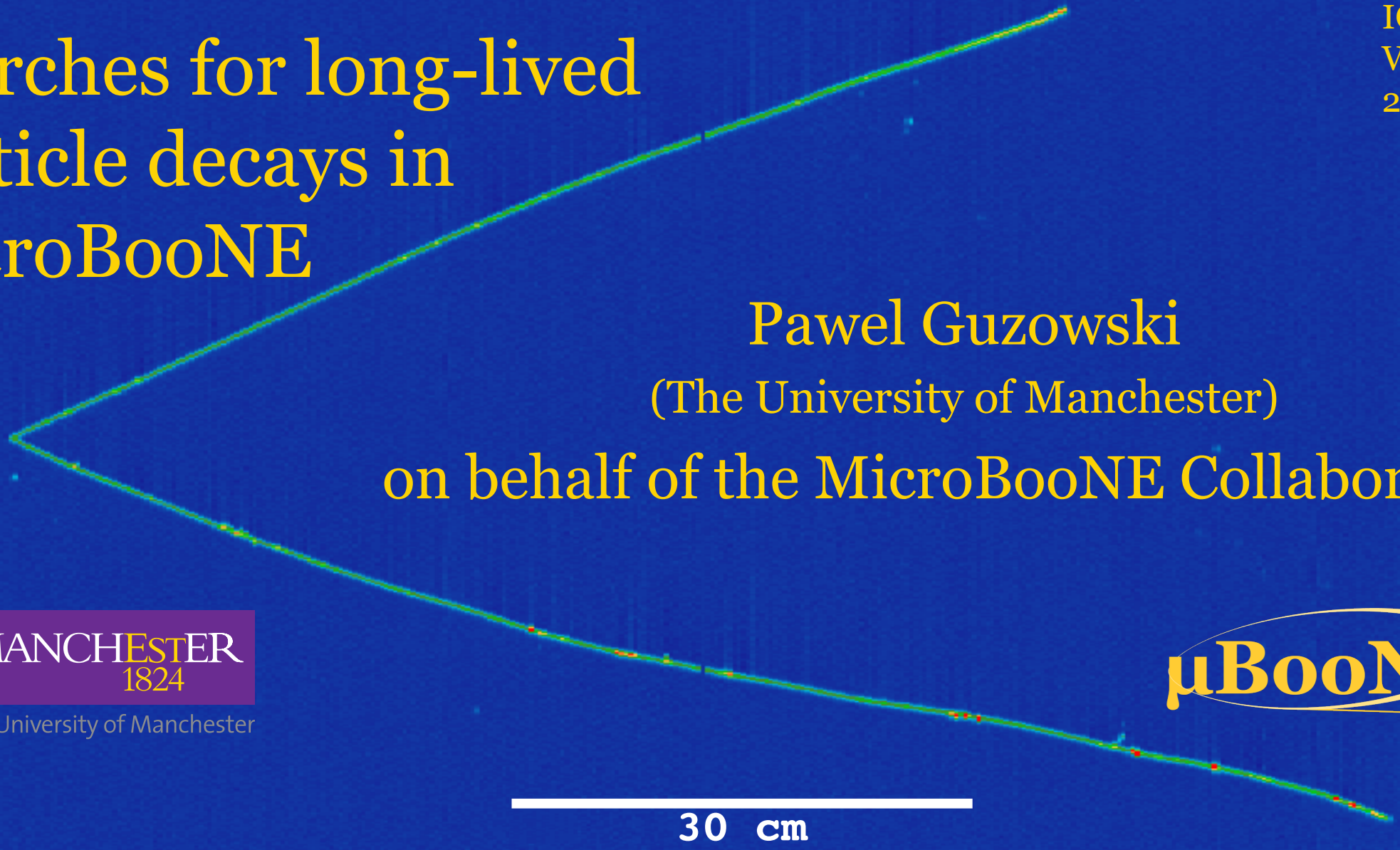
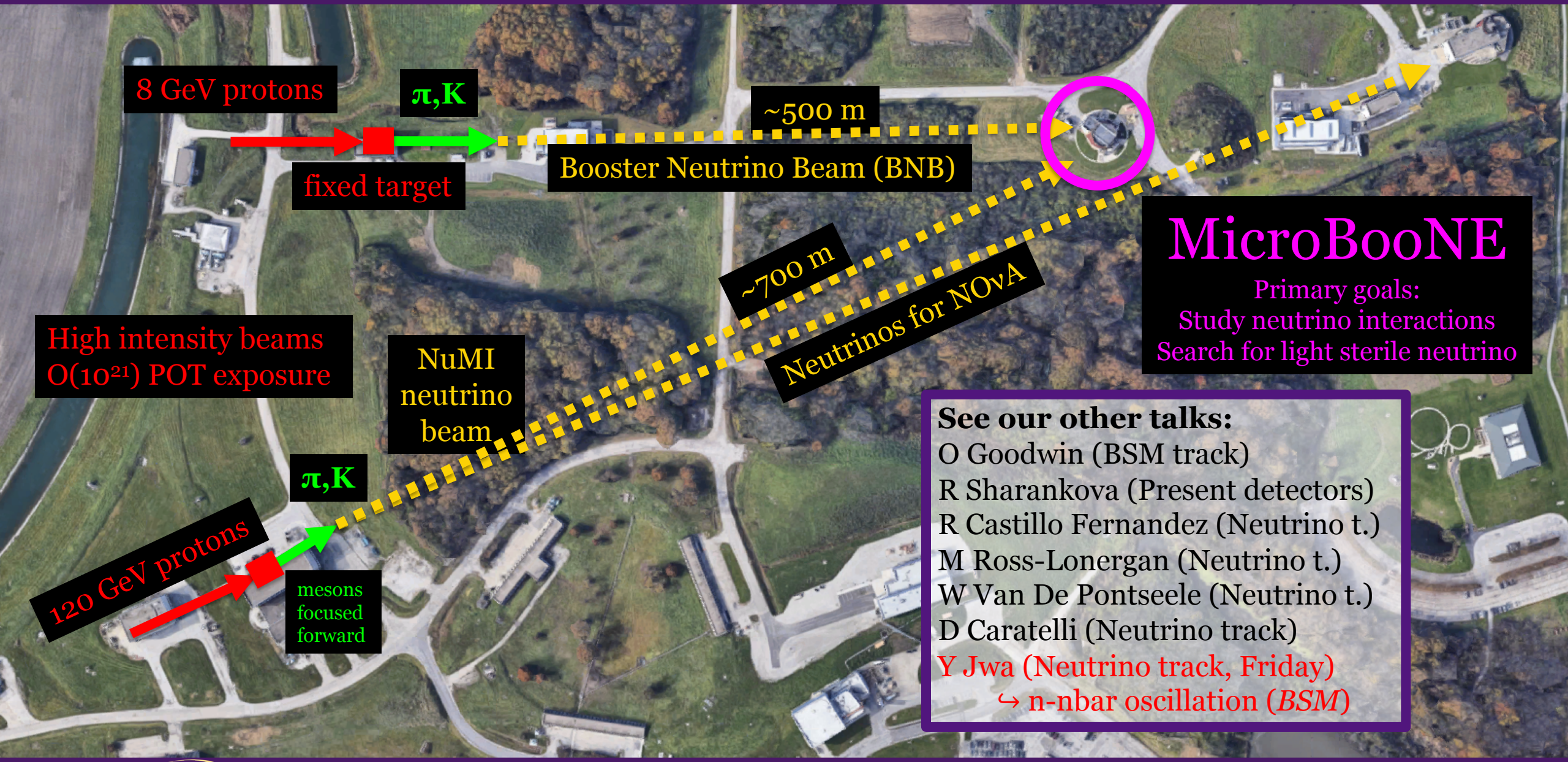
The University of Manchester

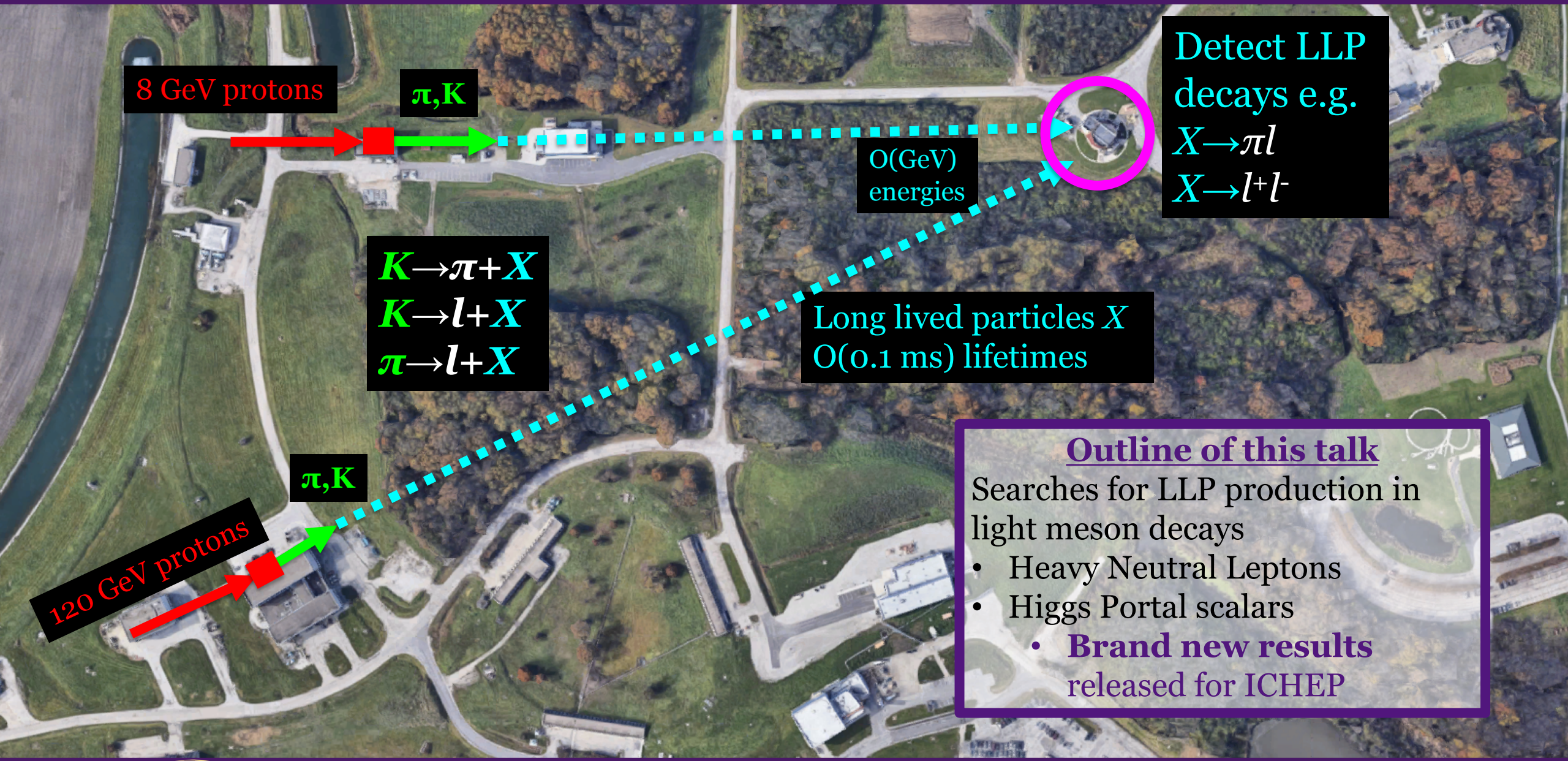
μBooNE



MicroBooNE and the Fermilab neutrino beamlines



MicroBooNE and the Fermilab LLP beamlines

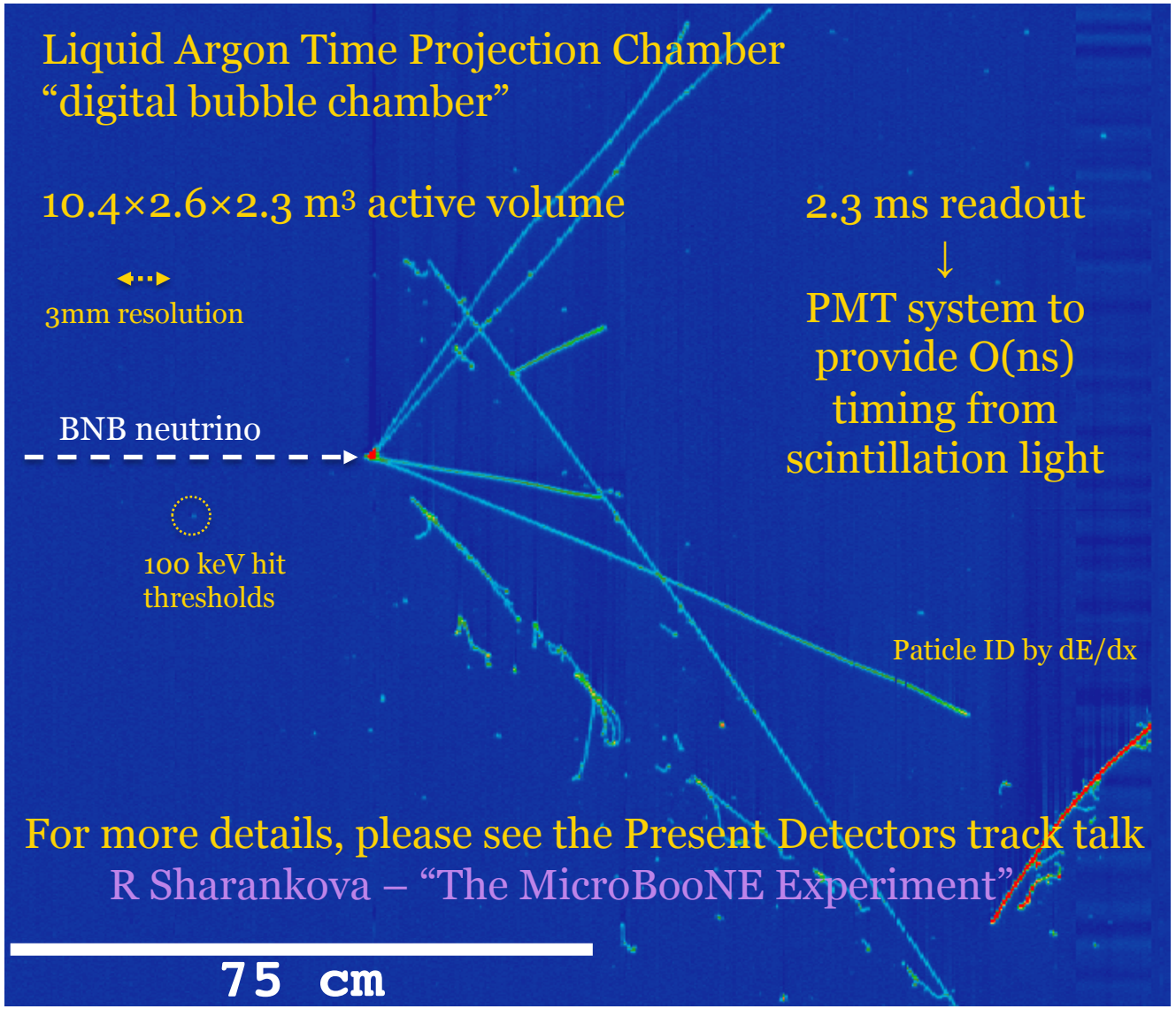


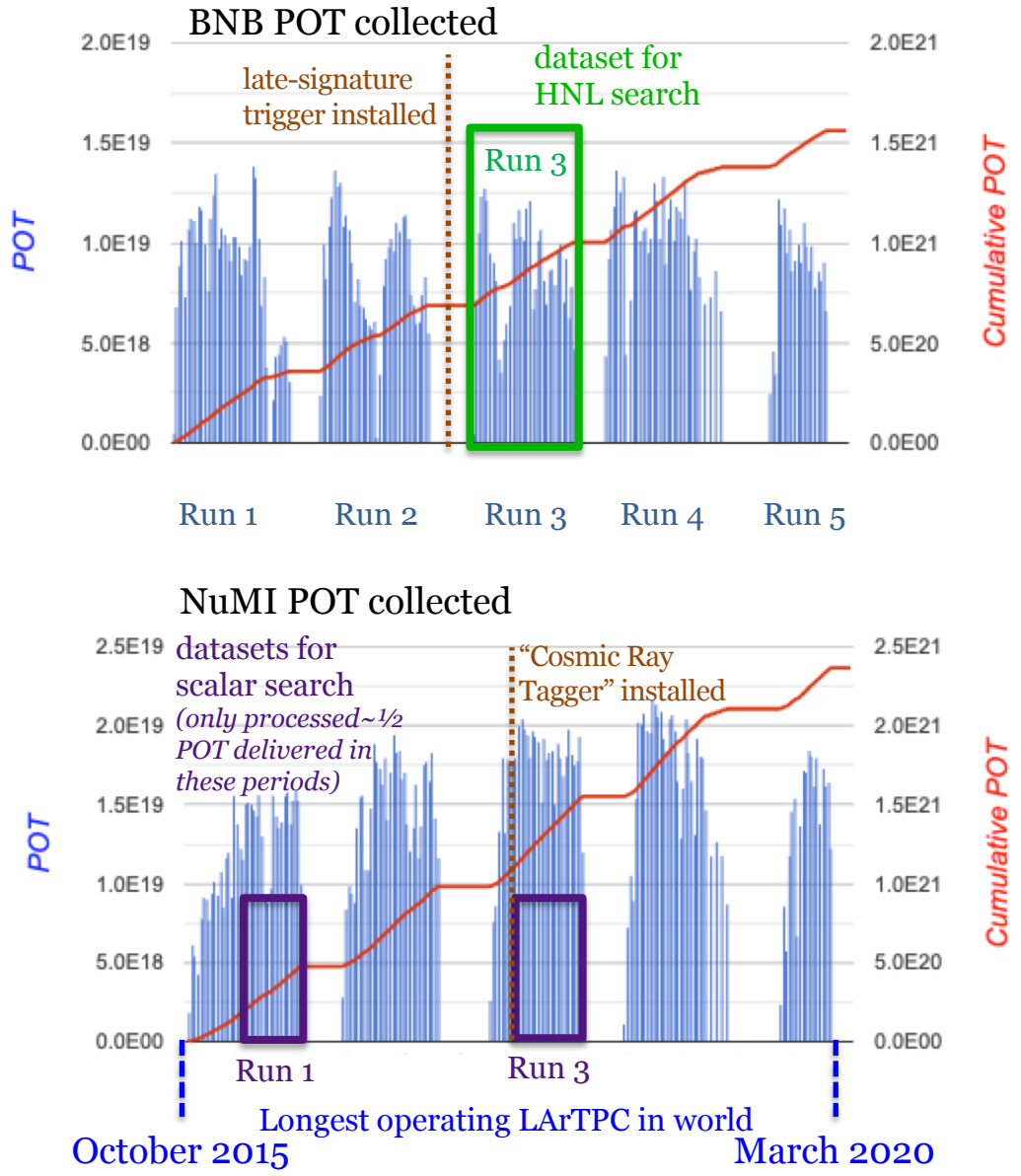
Outline of this talk

Searches for LLP production in light meson decays

- Heavy Neutral Leptons
- Higgs Portal scalars
  - **Brand new results** released for ICHEP

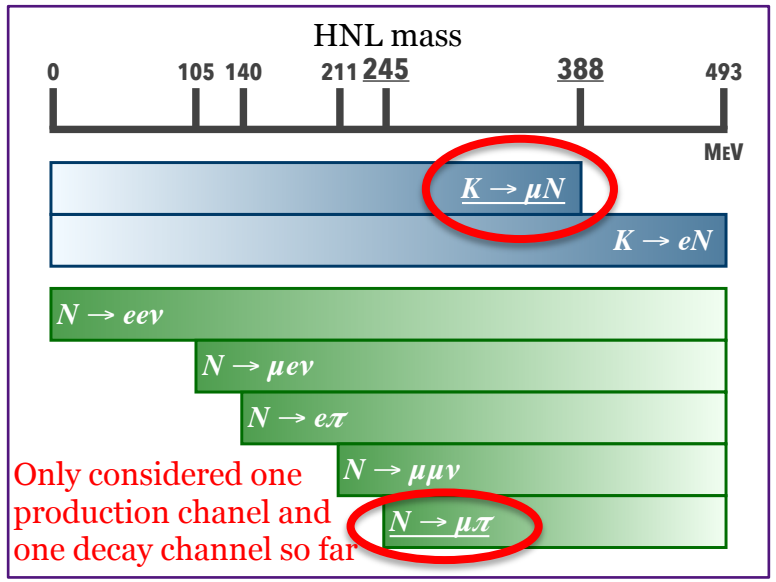
The MicroBooNE detector & data

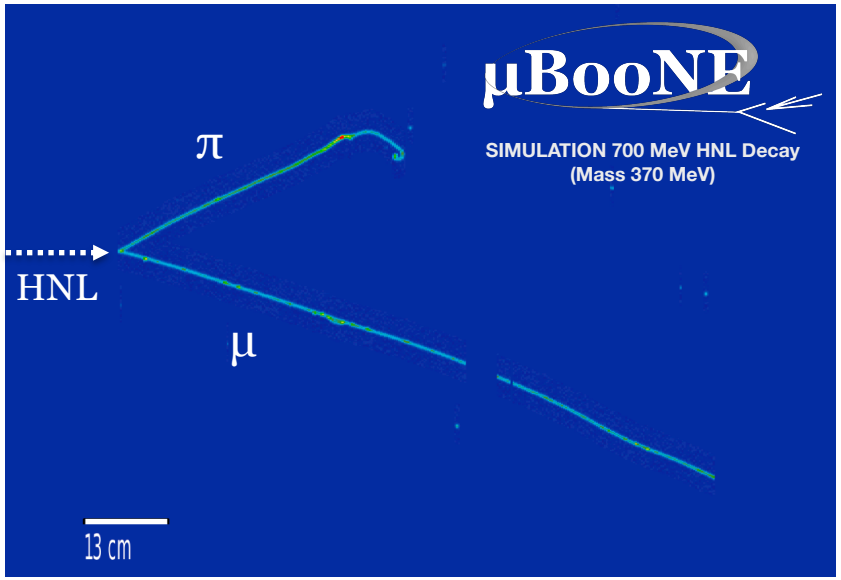


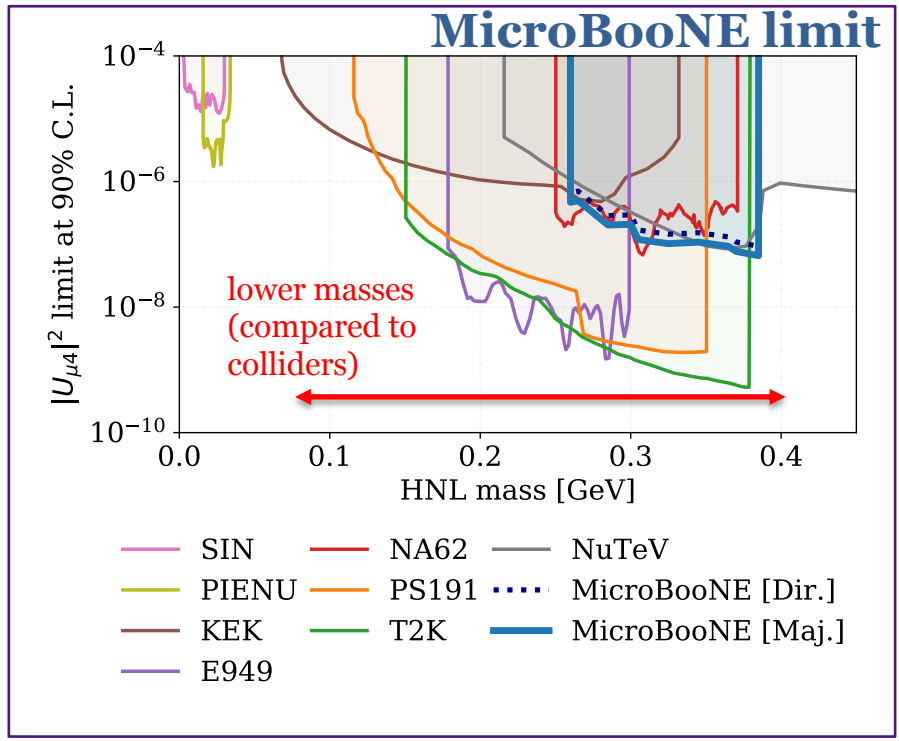


Heavy Neutral Leptons

From K decays in **BNB** (late-signature trigger)



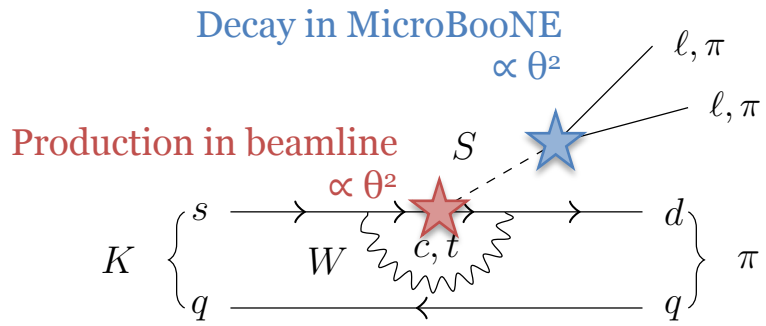


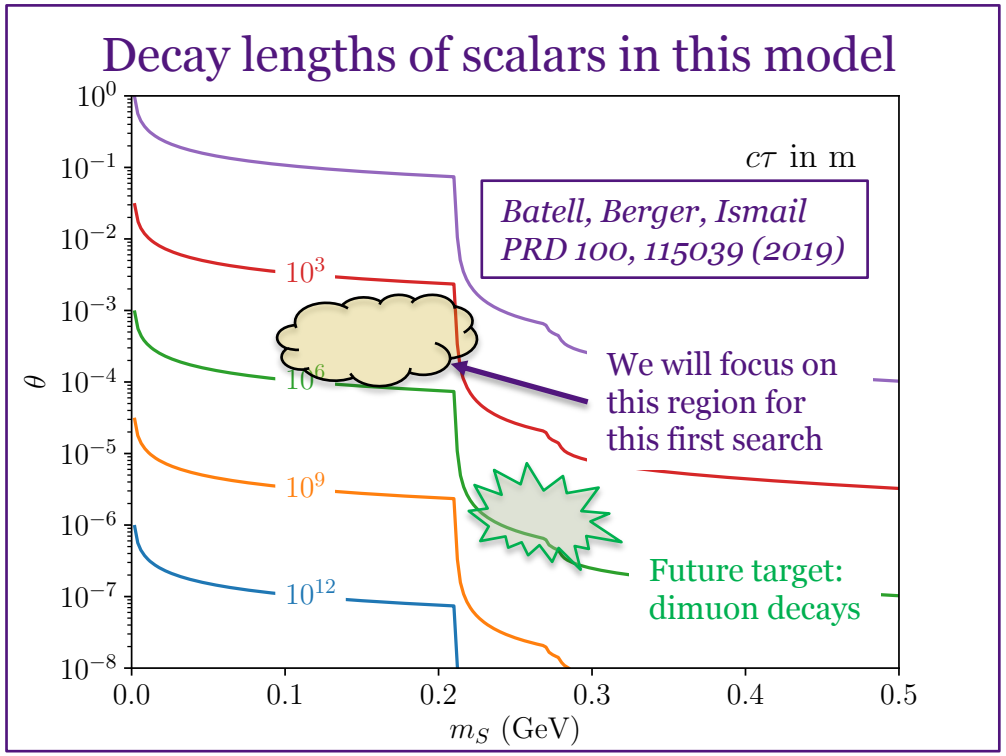


- First search for HNLs in a LArTPC
  - Published in Phys. Rev.D 101, 052001 (2020)
- More details presented in our other talk in the BSM session:
  - O Goodwin – "Search for heavy neutral leptons decaying into muon-pion pairs in the MicroBooNE detector"

The Higgs Portal model

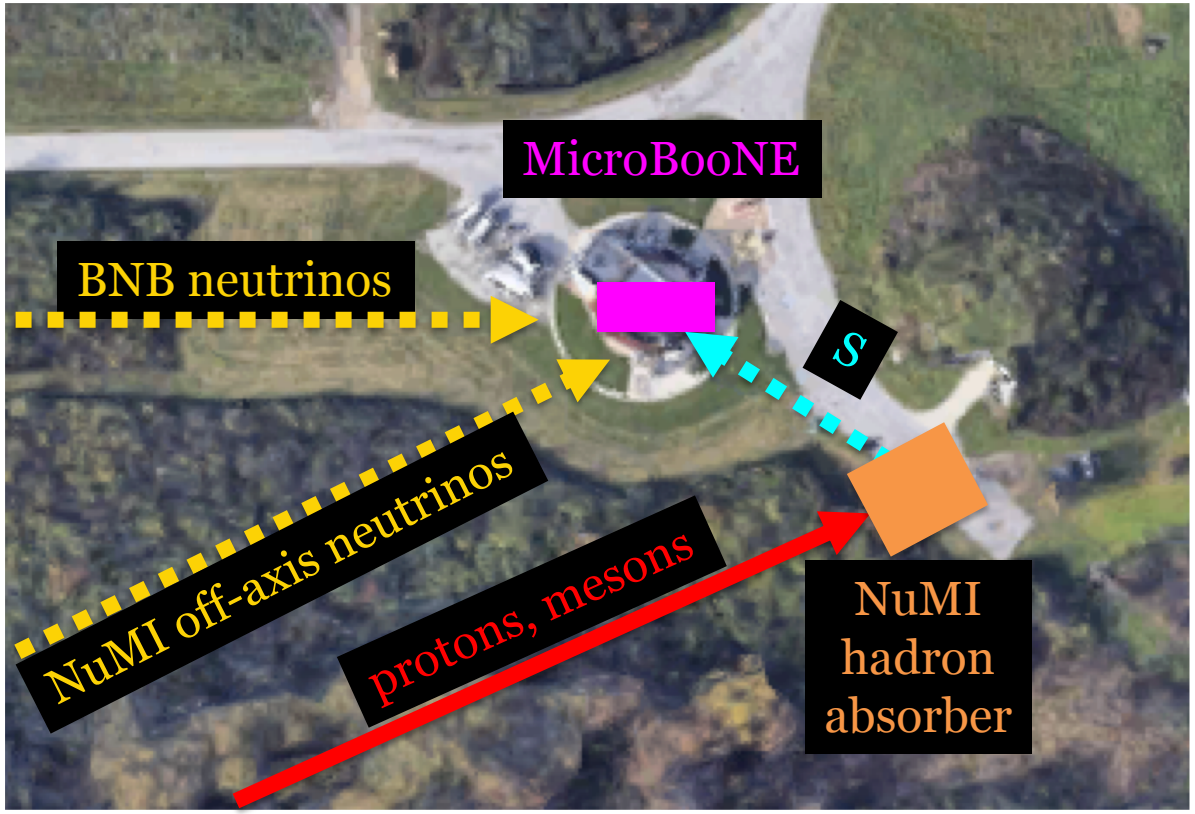
- Higgs boson mixes with a dark sector scalar S, with mixing angle θ
  - The Higgs is a "portal" to the dark sector
  - S acquires Yukawa couplings to fermions via this mixing
- Production in kaon decays
  - top-loop penguin diagram
  - for scalar masses < 360 MeV
- Decays to di-leptons or di-pions

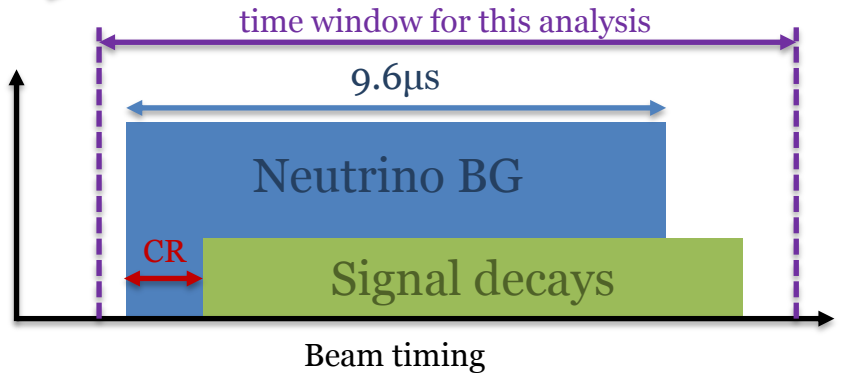




Search strategy

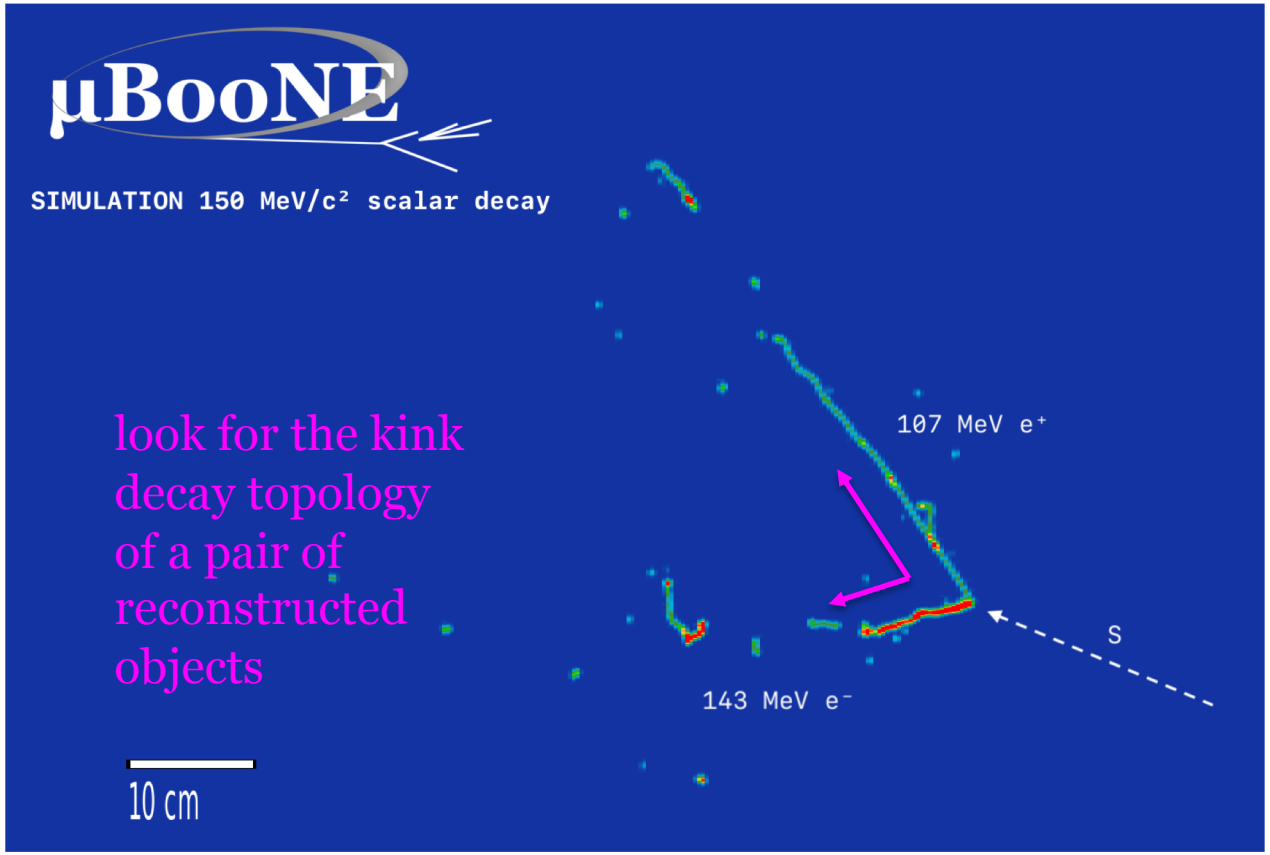
- Strategy proposed in recent phenomenological paper
  - Batell, Berger, & Ismail; Phys Rev D 100, 115039 (2019)
- Search for scalars produced from kaons decaying at rest in the NuMI hadron absorber
- Monoenergetic scalars
  - strongly peaked opening angle
- Incoming direction very different to typical interactions
- ~600ns delay w.r.t. neutrinos
  - not explicitly used in this current analysis, except as a control region





Signal reconstruction

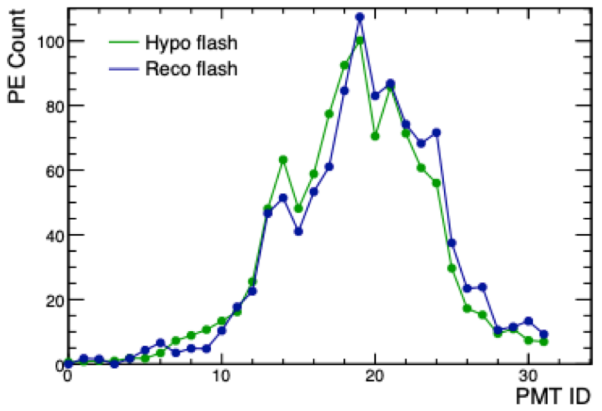
- For this search, we are targeting 100—200 MeV scalar masses
  - Decays only to electron positron pairs
- Reconstruction based on *Pandora*[*] algorithms
- Search for:
  - characteristic kink
  - opening angle
  - direction to hadron absorber

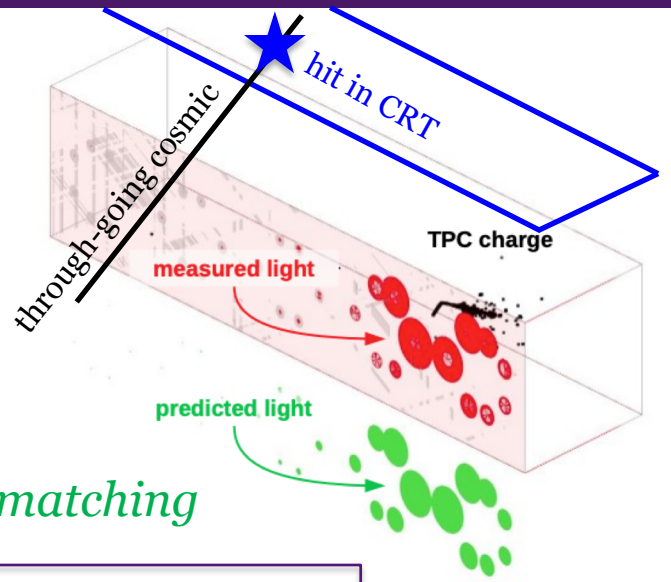


** EPJC 78, 82 (2018); https://github.com/PandoraPFA*

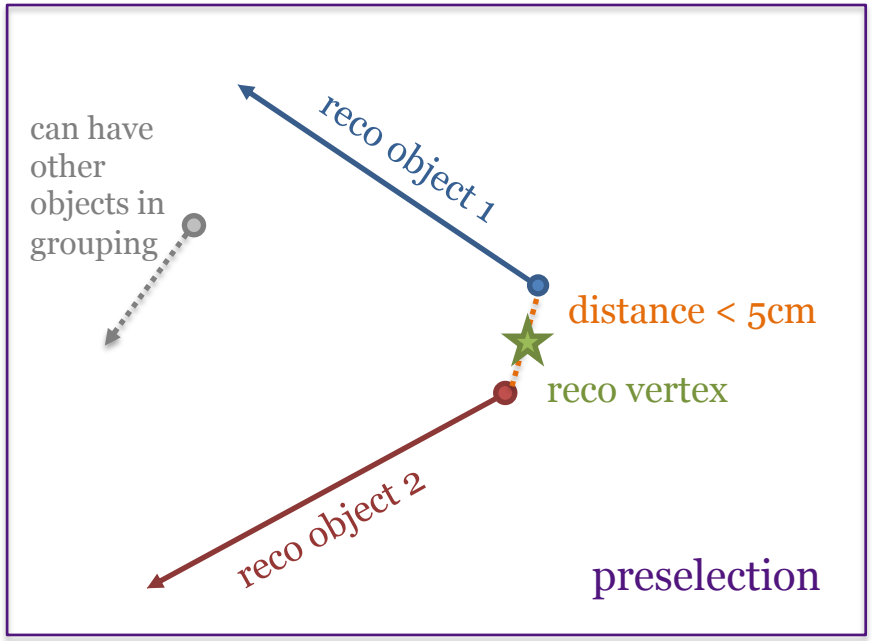
Signal preselection

- *Pandora* groups reconstructed objects together
  - matching to PMT signals, for event timing
  - Cosmic ray tagger veto in Run 3
- Take all pairs of objects in the grouping
  - Require distance between object ends less than 5 cm
  - Reconstructed vertex inside TPC active volume
- Consider all possible passing pairs of objects at this stage
  - Boosted Decision Tree to filter out backgrounds…



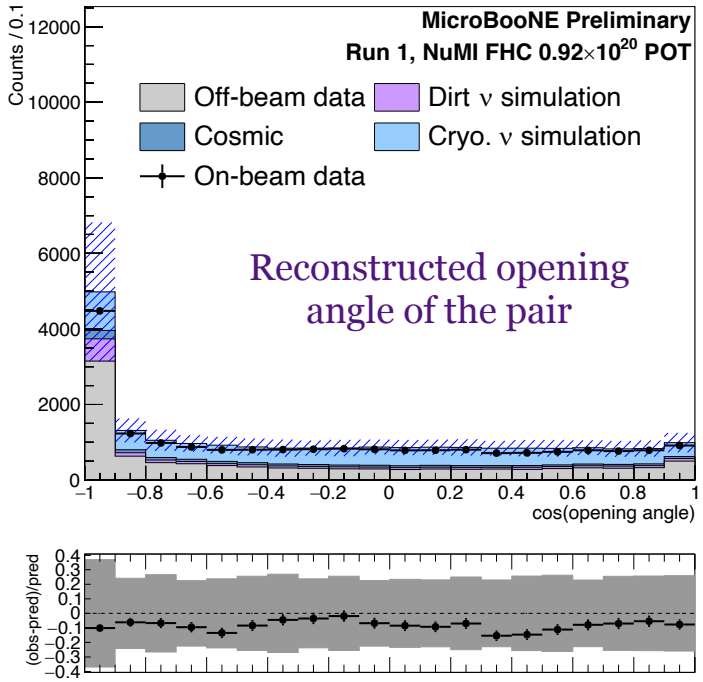


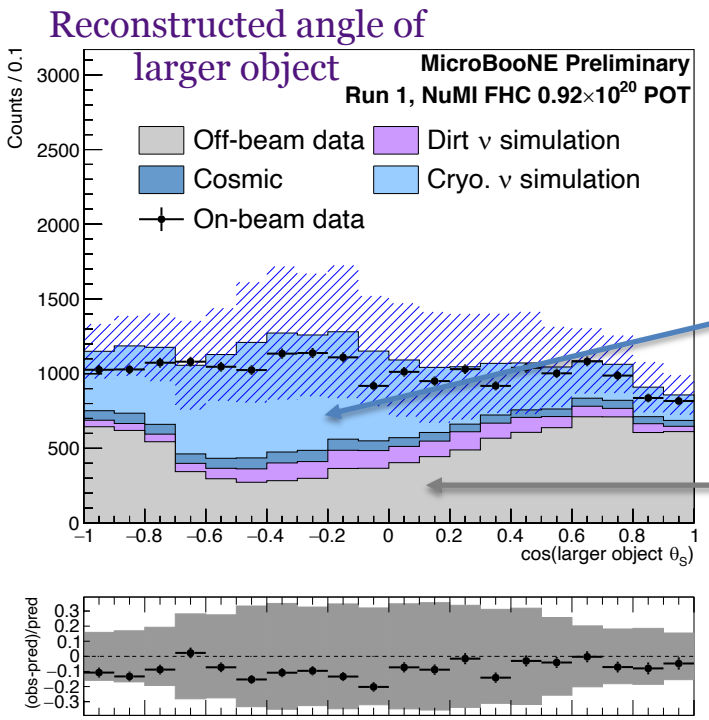
PMT matching



Boosted Decision Tree selection

- Trained BDTs against two types of background
  - Against pure cosmics, and against neutrinos
- Approximately mass-agnostic BDTs
  - uniform 100—200 MeV signal training sample
- Performance of simulation verified using 600ns 'prompt' control region





Some BDT input distributions for preselected events (full time window)

Neutrino interaction background

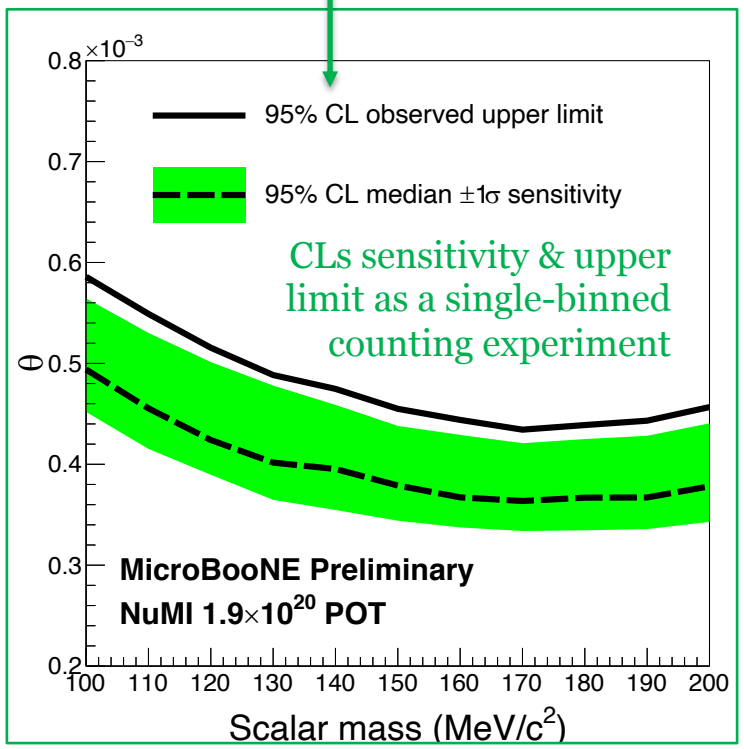
Pure cosmic background (data driven)

Results

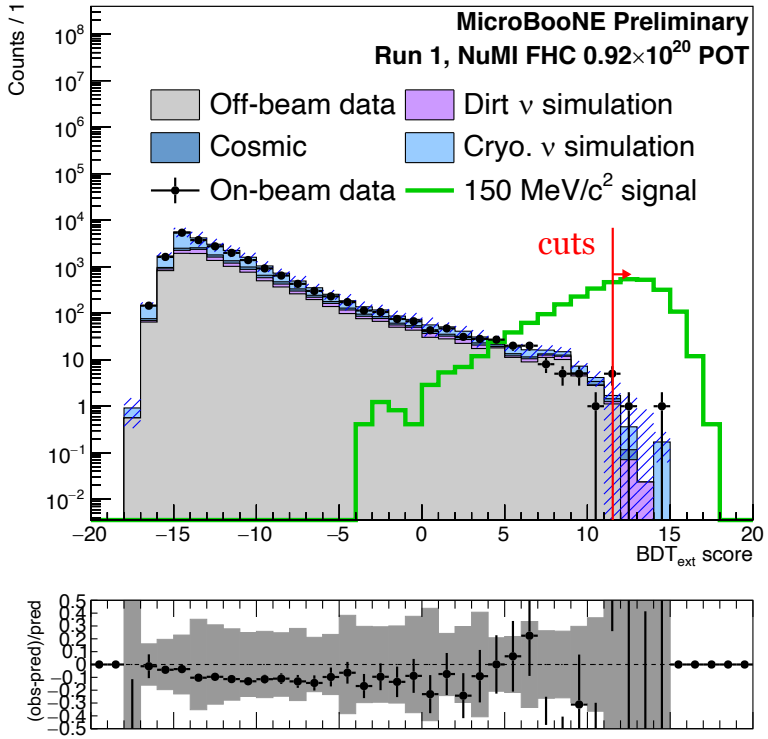
- BDT cuts chosen to maximise sensitivity
- After unblinding, we observe 6 events
  - 1 is rejected as an obvious cosmic
    - PMT timing is before the beam spill window
  - After hand-scanning, all are consistent with being background
- 5 events, with background expectation of 2.0±0.8

Systematic uncertainties

Uncertainty	Background	Signal
Flux (hadron production)	34.0%	30.0%
Cross-section model	3.2%	–
Off-beam statistics	67.4%	–
Simulated statistics	24.3%	< 2.2%

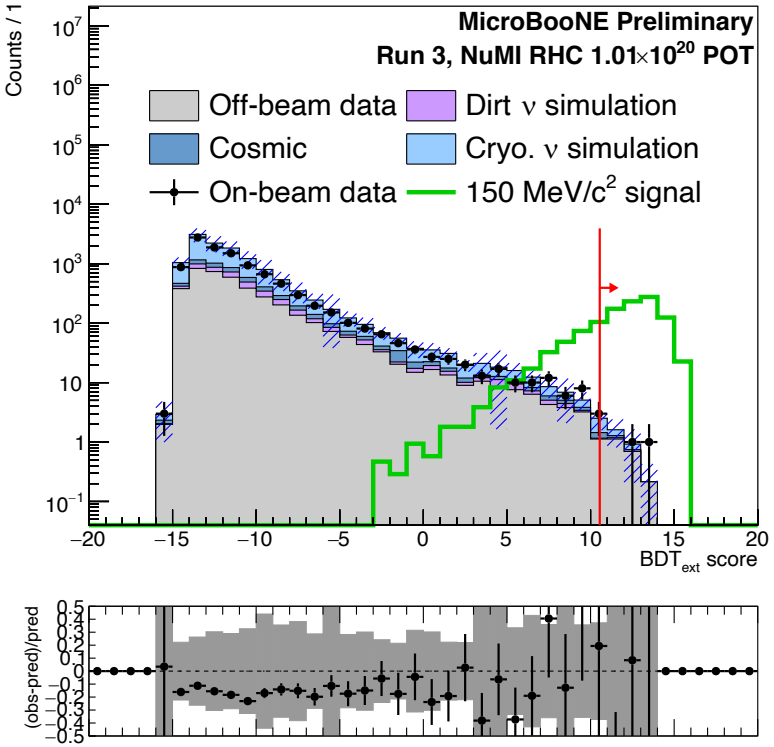


Run 1



BDT scores *vs* cosmics

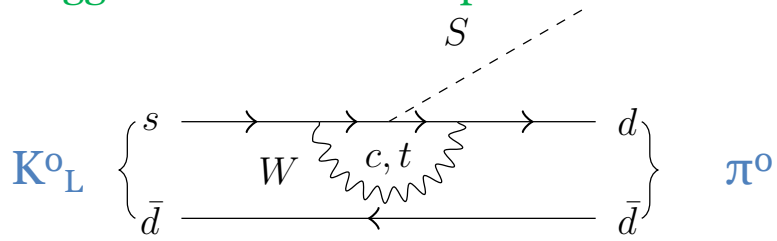
Run 3

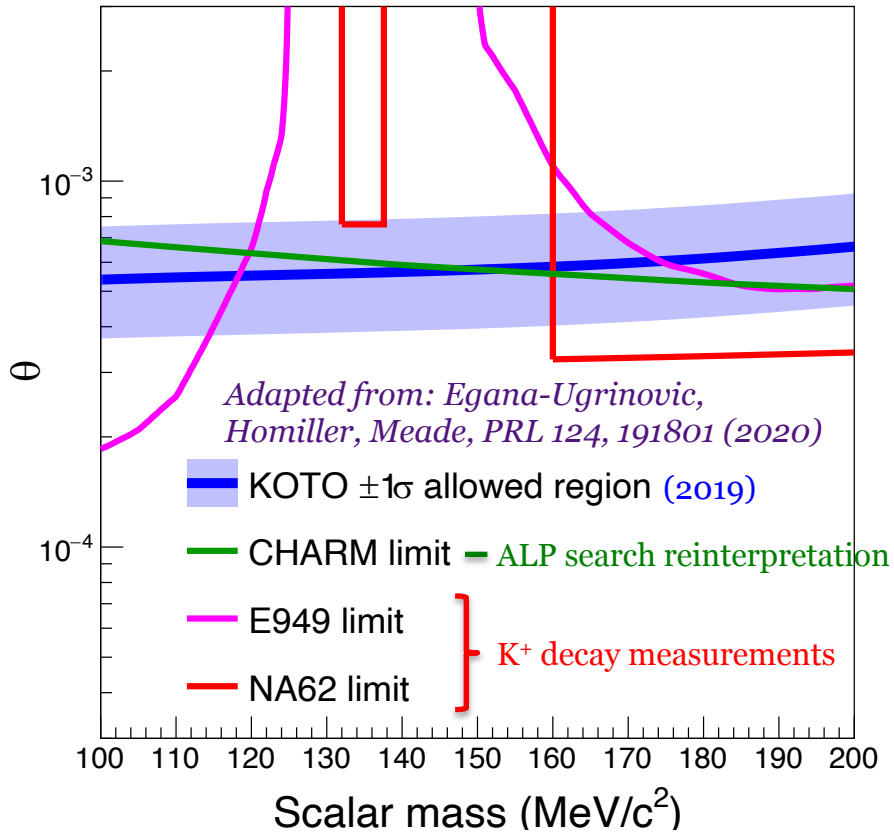


The KOTO anomaly

- KOTO experiment is searching for $K^0_L \to \pi^0 \nu\nu$
  - Anomalous excess reported at KAON2019, O(100) × SM
  - See talk yesterday from N Shimizu (Flavour track)
    - Updated results, this is out of date
- Missing energy *might be* a Higgs Portal scalar
  - Only small range of masses remains allowed

Higgs Portal scalar escapes the KOTO detector



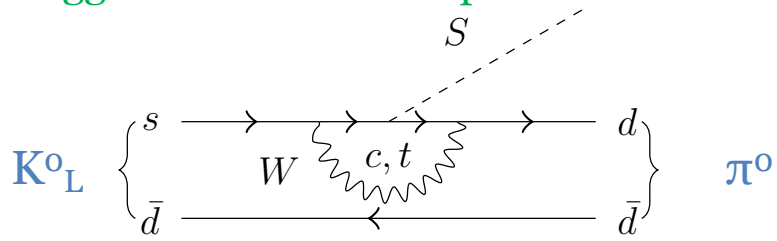


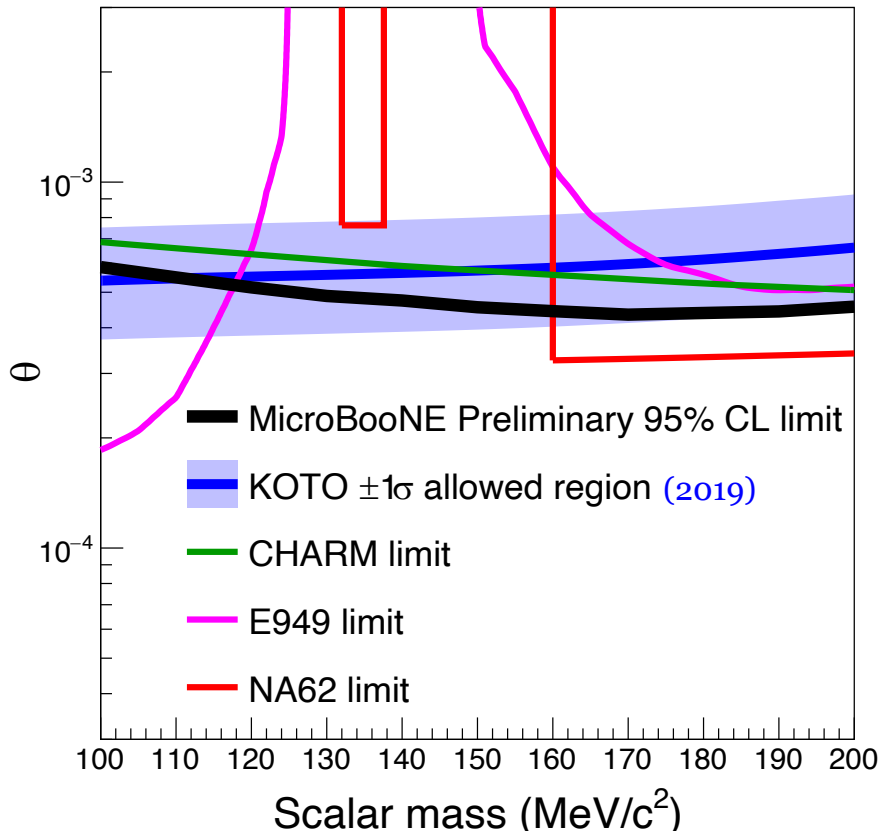
The KOTO anomaly: MicroBooNE limit

- KOTO experiment is searching for $K^0_L \to \pi^0 \nu\nu$
  - Anomalous excess reported at KAON2019, O(100) × SM
  - See talk yesterday from N Shimizu (Flavour track)
    - Updated results, this is out of date
- MicroBooNE is sensitive to the remaining parameter space
  - **Excludes central value at 95% CL**

Public note: **MICROBOONE-NOTE-1092-PUB**

Higgs Portal scalar escapes the KOTO detector





Summary

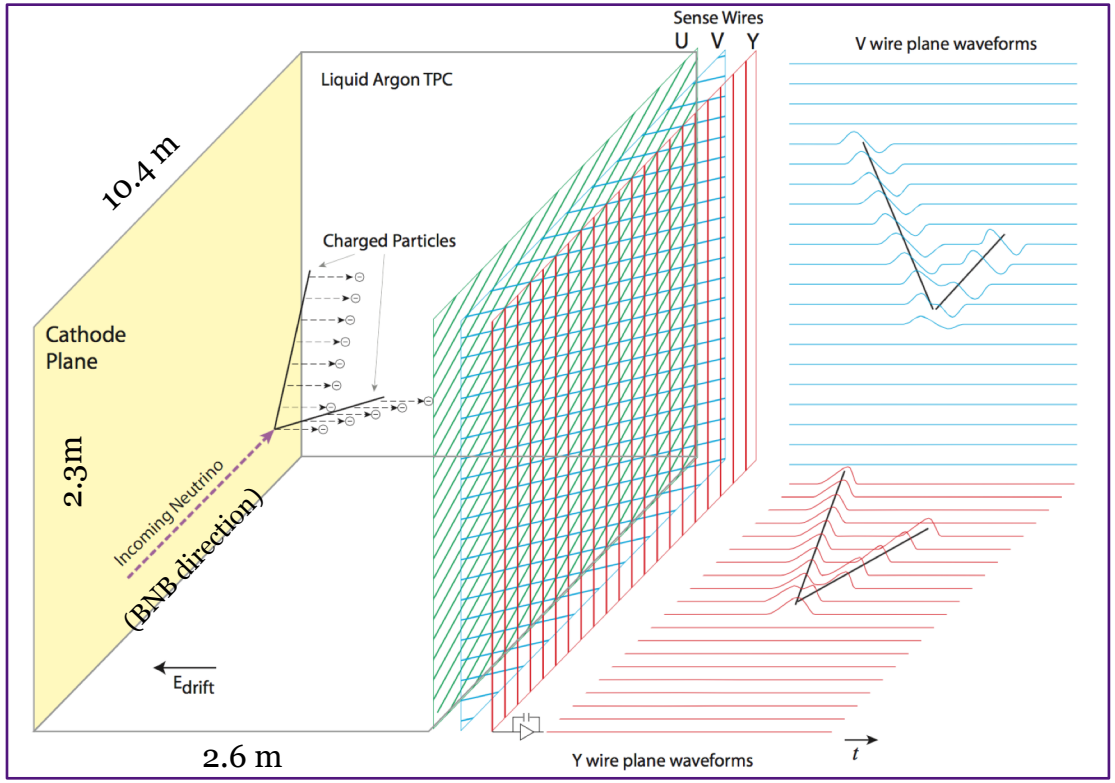
- Fermilab's neutrino beamlines are also potential high-intensity light LLP factories
- MicroBooNE can be a discovery experiment for decays of LLPs
- First search for sub-GeV Heavy Neutral Lepton decays in a LArTPC was recently published
- We have presented today new competitive results for O(100 MeV) scalars in the Higgs Portal model
  - This model excluded as cause of KOTO (2019) anomaly central value at 95% CL
- Stay tuned for more data and search channels
  - For HNLs and Higgs Portal Scalars
  - Other BSM models, including
    - dark photons, inelastic scattering of dark matter ("dark tridents"), millicharged particles, neutron-antineutron oscillation, ...
- **Lots more BSM opportunites and results over coming years with MicroBooNE**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 752309

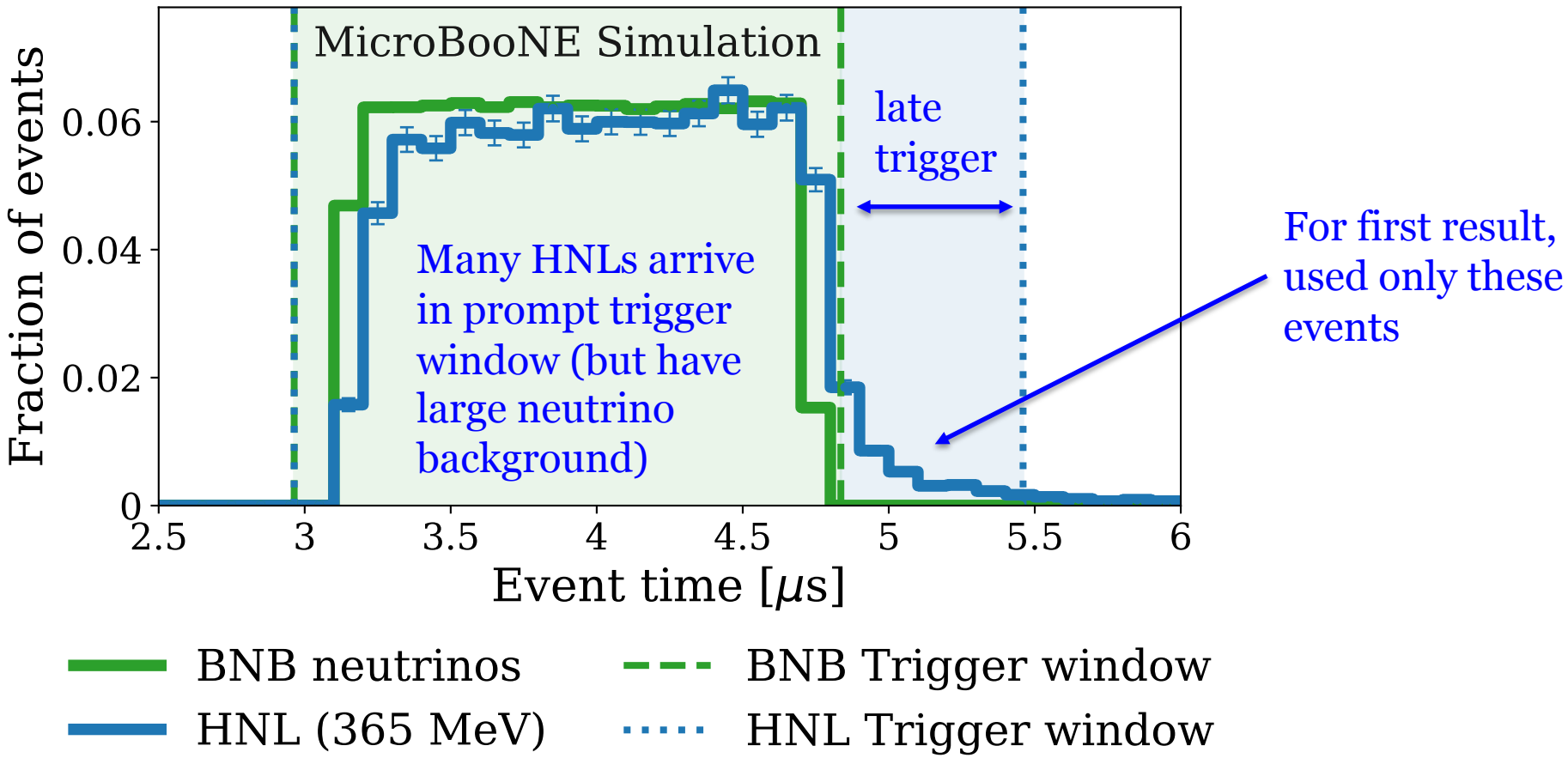
ADDITIONAL SLIDES

The MicroBooNE detector operation principle

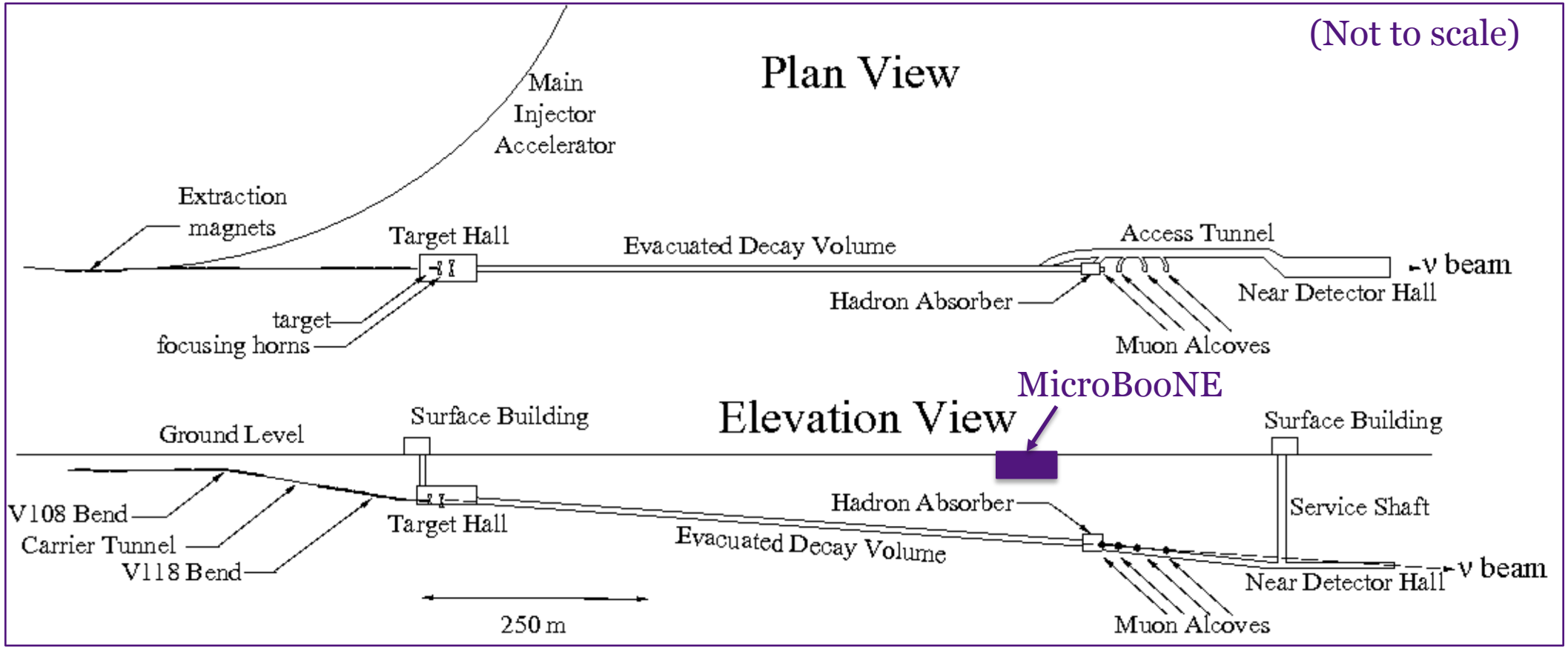
- MicroBooNE is a liquid argon time projection chamber (LArTPC)
  - Longest operating in world
  - Running since 2015
- Active volume: 10.4×2.6×2.3 m^3
- 3 mm wire pitch; 0.5 mm drift coordinate sampling resolution
- 2.3 ms drift time
- PMT system to provide O(ns) timing information
- Cosmic Ray Tagger installed around detector, from Run 3 onwards



HNL late-signature trigger



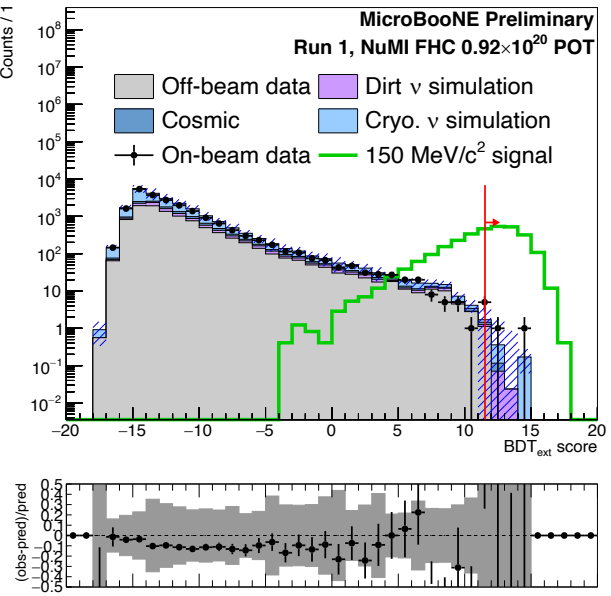
NuMI beamline



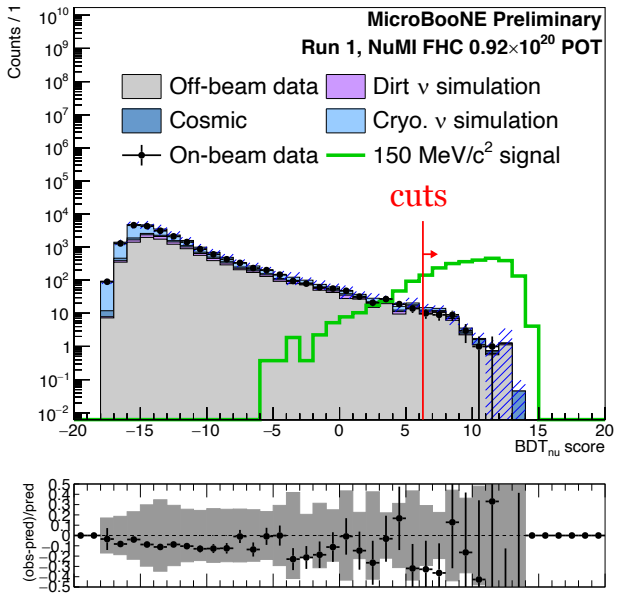
Nucl. Instrum. Meth. A 806, 279 (2016)

BDT Results

Run 1

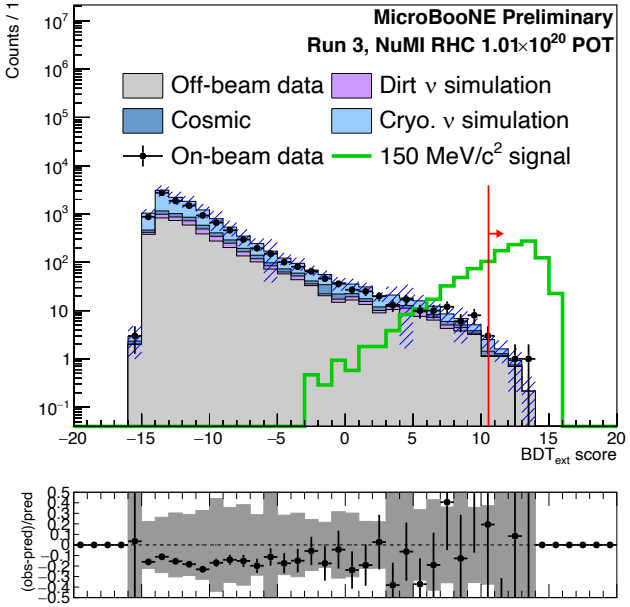


BDT vs cosmics

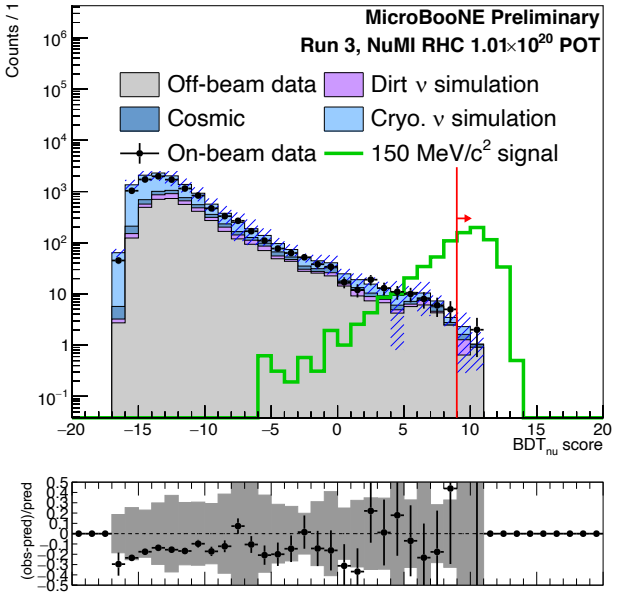


BDT vs neutrinos

Run 3



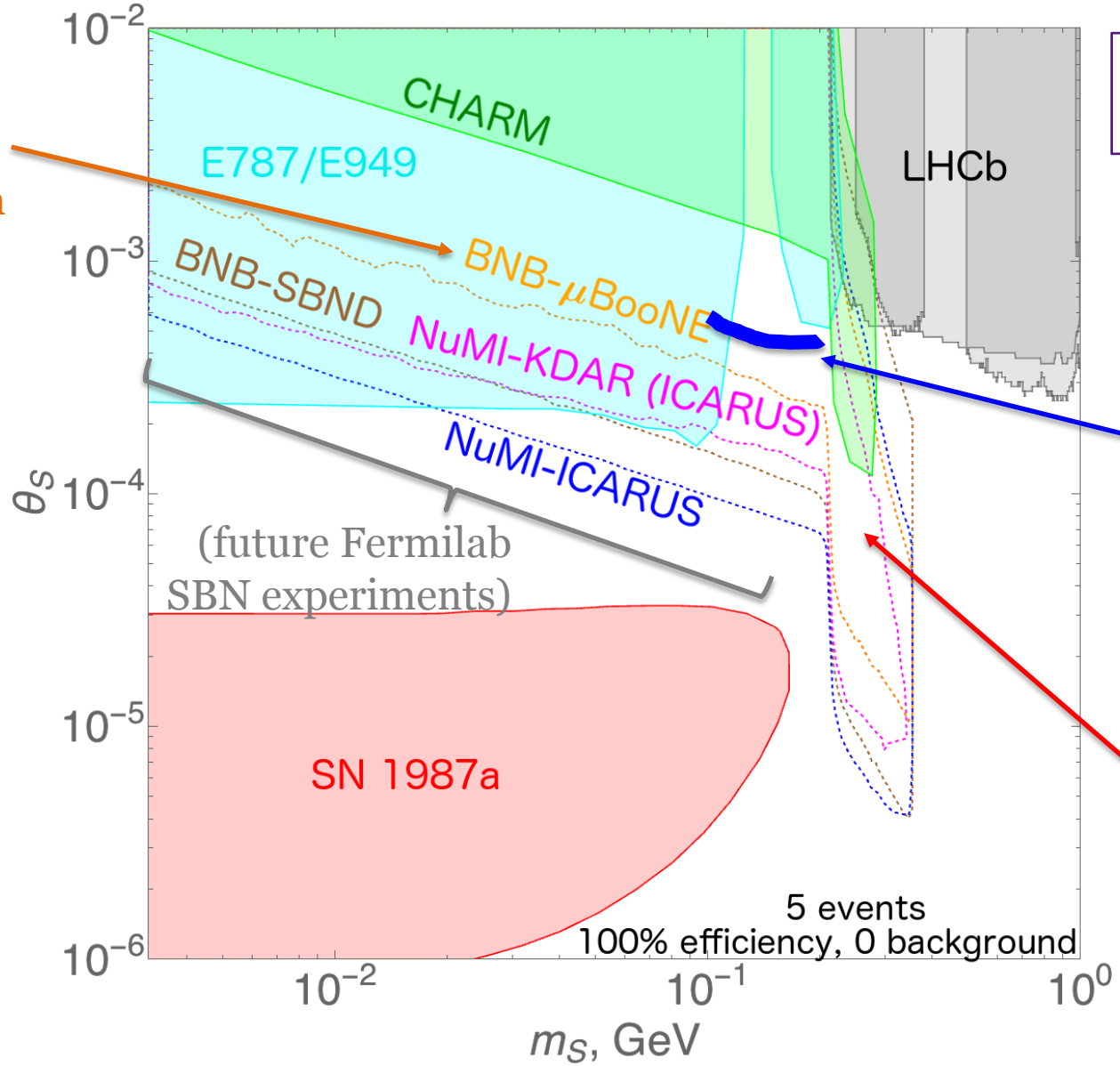
BDT vs cosmics



BDT vs neutrinos

Projected sensitivity (by phenomenologists)

MicroBooNE, using Booster Neutrino Beam



Batell, Berger, Ismail
PRD 100, 115039 (2019)

Today's result (roughly drawn)

Di-muon, di-pion decay channels