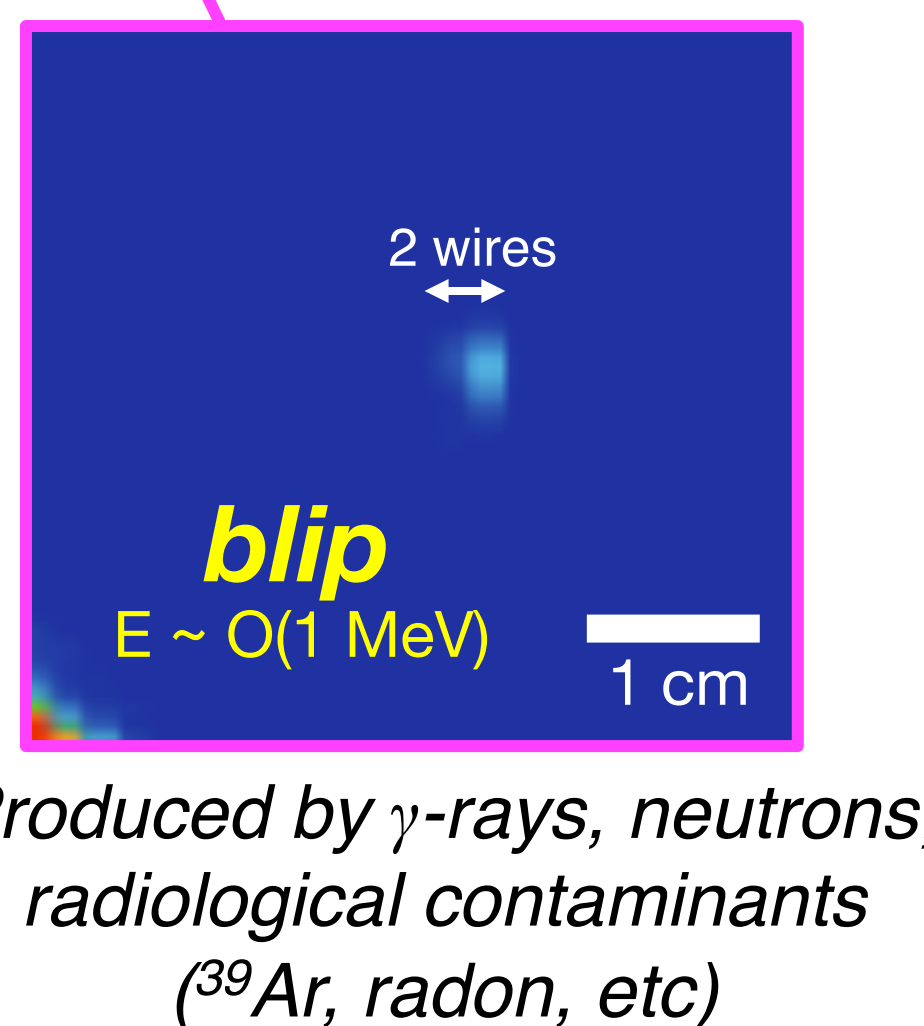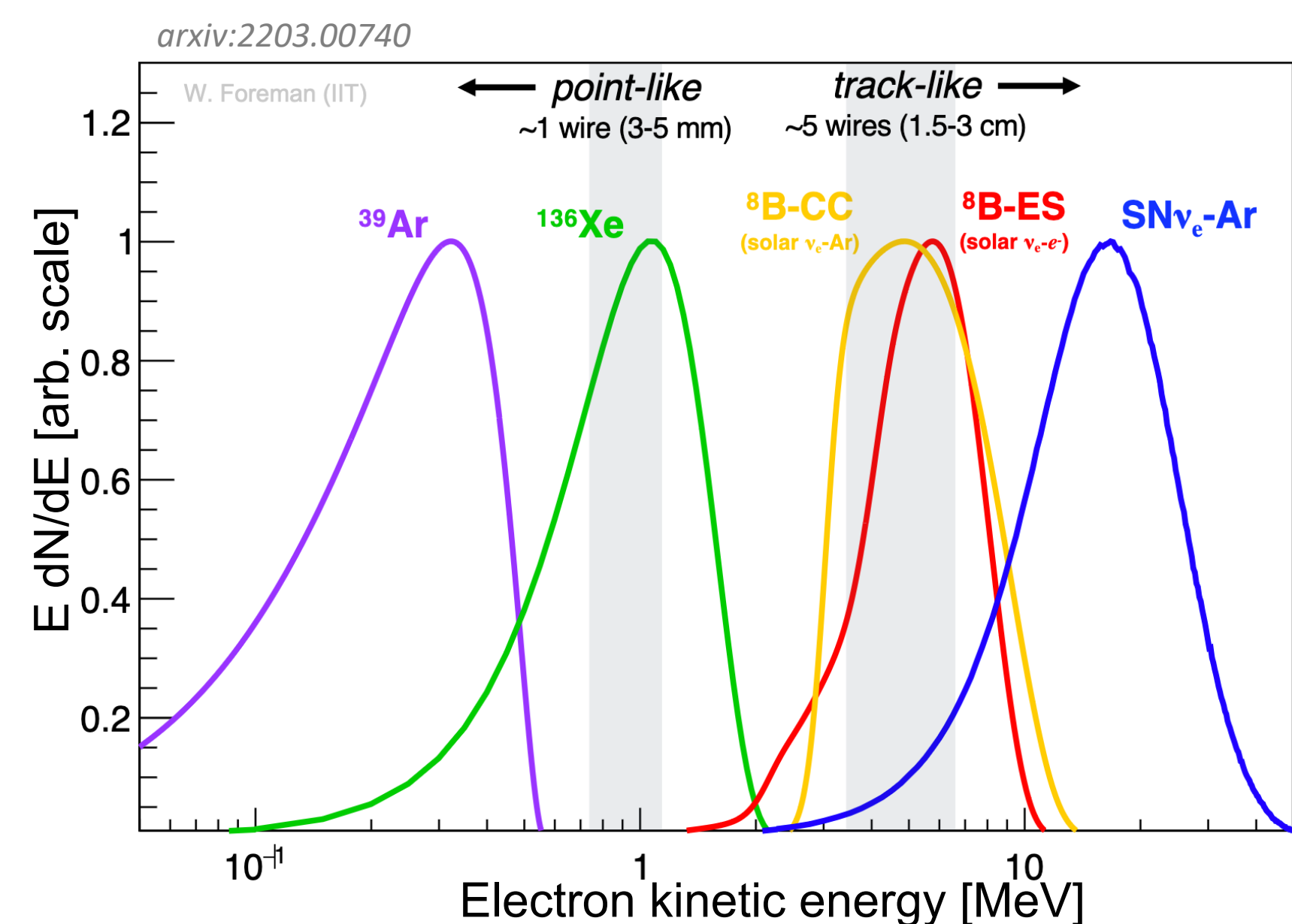# MeV-Scale Blip Reconstruction and Measurements of Radon Progeny in the MicroBooNE Liquid Argon TPC

μBooNE

Bryce Littlejohn, Will Foreman (Illinois Institute of Technology) representing the MicroBooNE Collaboration
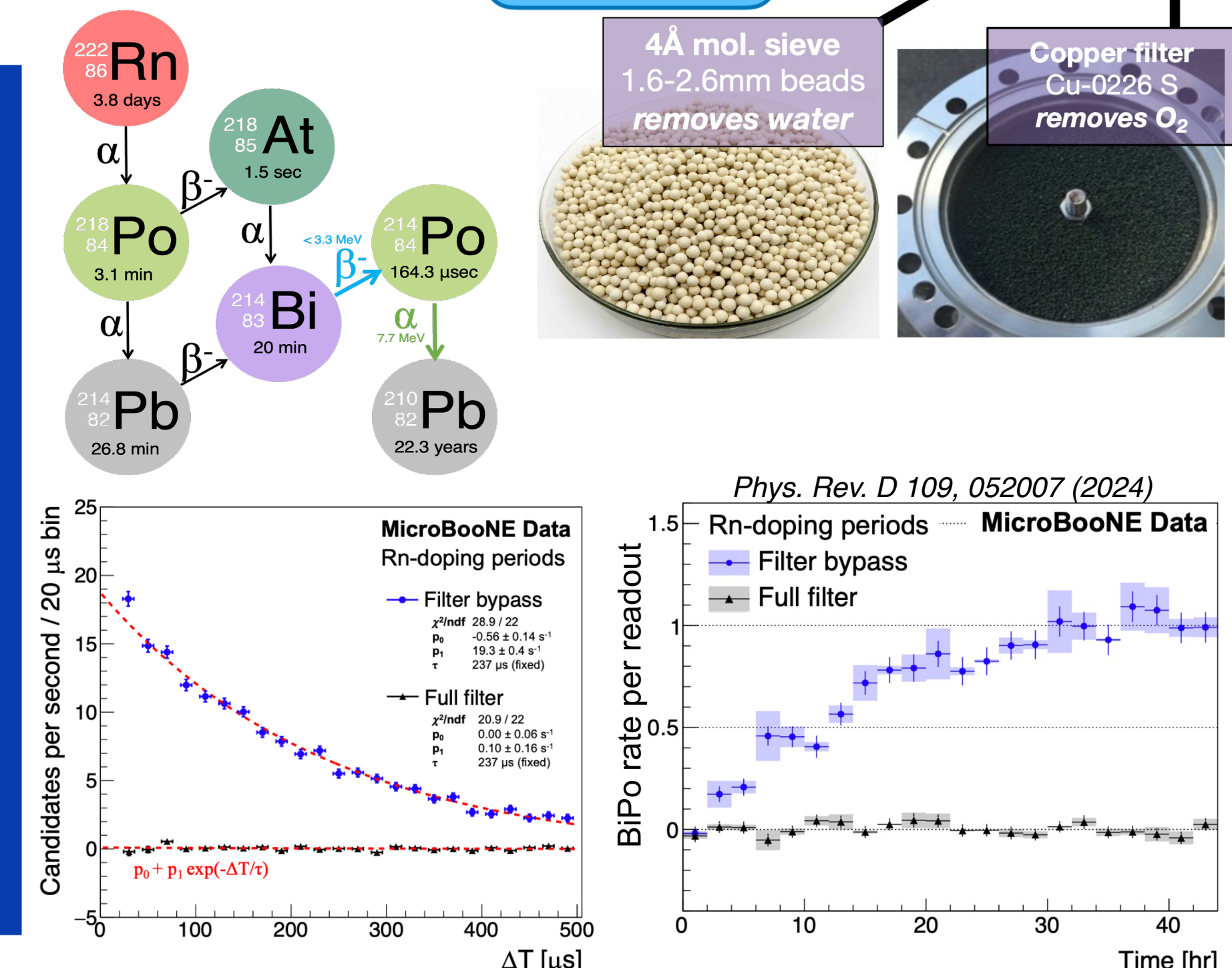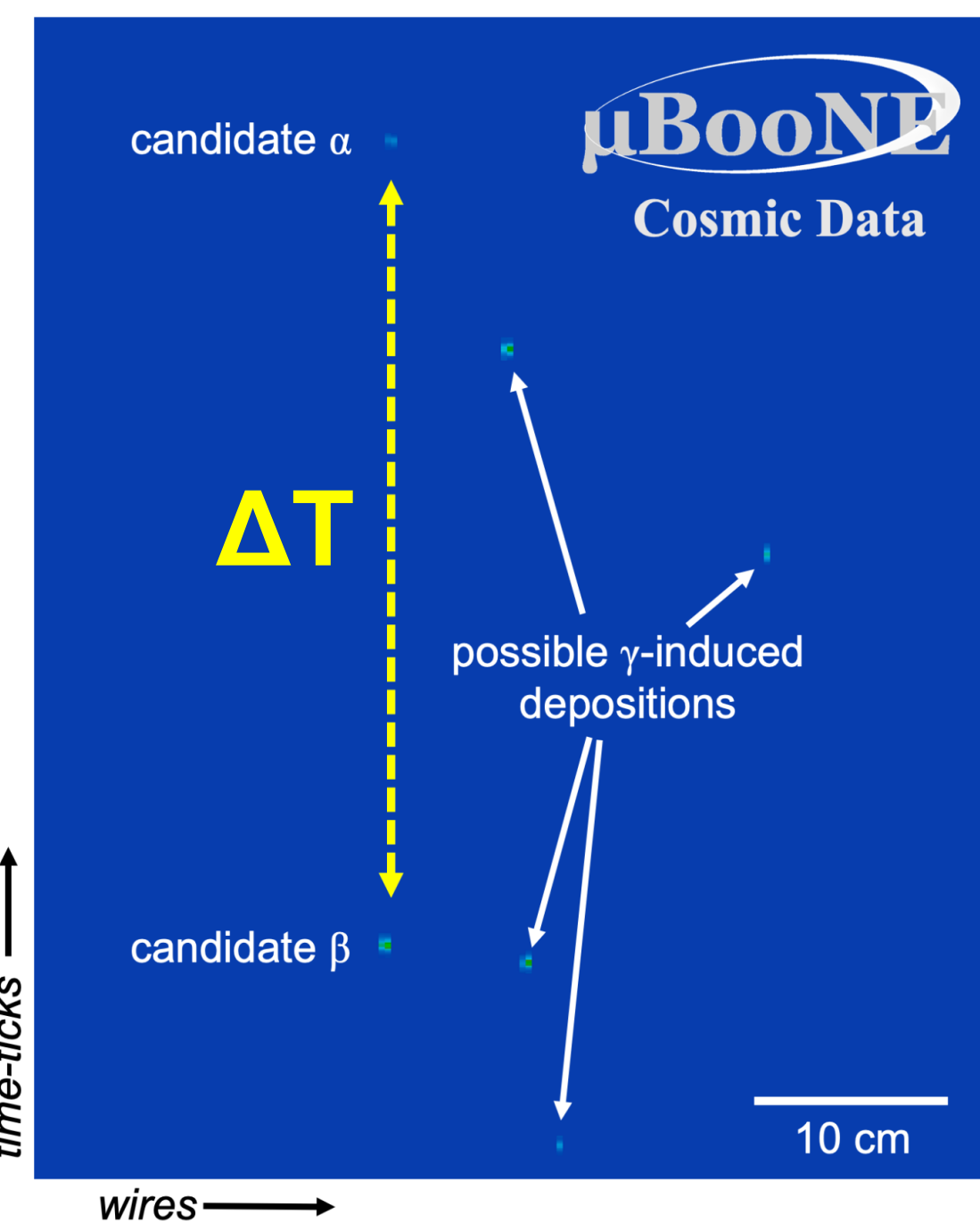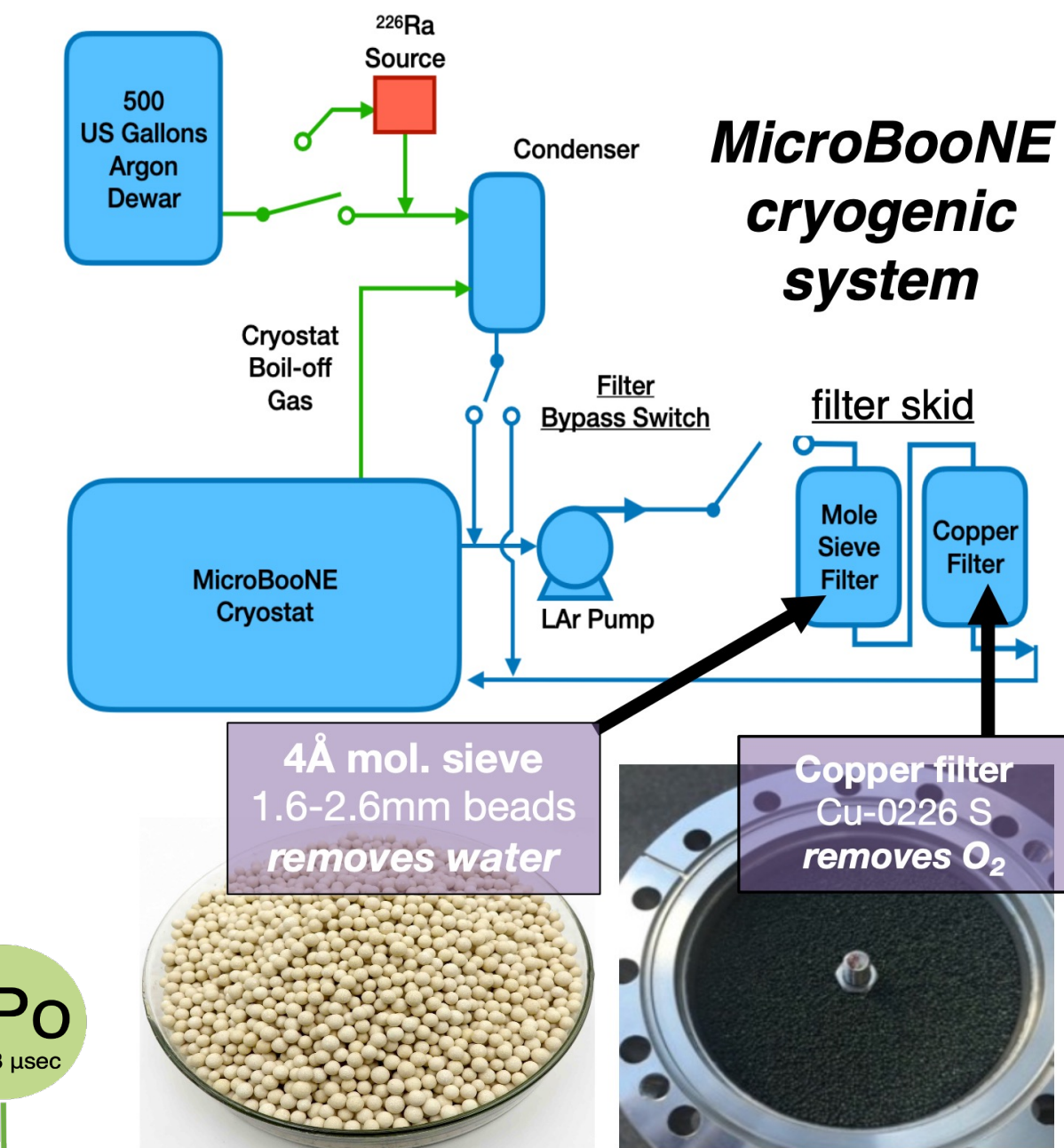
1) Energy Scales in LArTPCs

- Benefits to MeV-scale blip reconstruction:
  - Tagging neutrons & γ-rays from ν-Ar hadronic final-states for calorimetry
  - PID for μ/π capture-at-rest
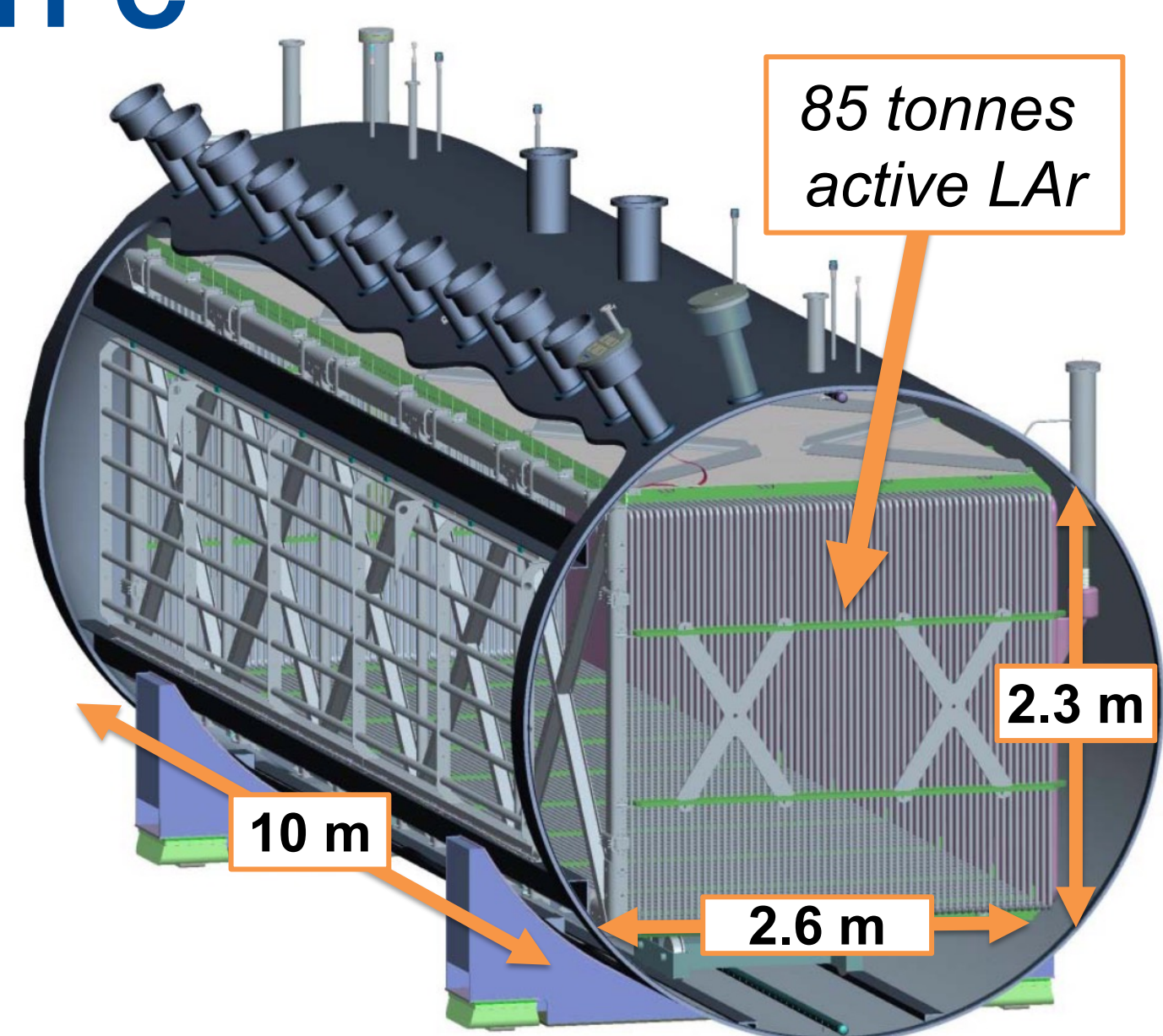 - Supernovae & solar ν detection
  - 'Beyond Standard Model' searches

Electron shower $E \sim O(300\ MeV)$
Proton track $E \sim O(100\ MeV)$
μBooNE
RUN 8617 SUBRUN 46 EVENT 2328

2 wires

blip $E \sim O(1\ MeV)$ 1 cm

arxiv:2203.00740
W. Foreman (IIT)

point-like ~1 wire (3-5 mm)   track-like ~5 wires (1.5-3 cm)

^{39}Ar ^{136}Xe ^8B-CC (solar ν_e-Ar) ^8B-ES (solar ν-e) $SN\nu_e$-Ar

Electron kinetic energy [MeV]

Produced by γ-rays, neutrons, radiological contaminants (^{39}Ar, radon, etc)

2) The MicroBooNE LArTPC

- Ran from 2015-2021
- Exposed to Booster & NuMI ν beamlines at FNAL, $E_\nu \sim O(1\ GeV)$
- E-field: 274 V/cm
- 2.3 ms charge drift time *(3.2 ms saved per triggered readout event)*
- 3 wire planes
- 3 mm wire spacing
- Sampling: 0.5μs per time-tick

85 tonnes active LAr
2.3 m   10 m   2.6 m

3) MeV-Scale Reconstruction in MicroBooNE

- Tools adapted from techniques pioneered by the ArgoNeuT [1] and MicroBooNE [2] collaborations, and described in [4] → `BlipReco` algorithm in LArSoft
- Wire signals processed with low-threshold settings to enhance sensitivity at electron energies ≲ 1 MeV.
- Energy resolution for electrons: $\sigma_E \sim 10\%$ at 1 MeV, $< 8\%$ at 5 MeV

^{214}Bi decay
γ's produce nearby blips via Compton scattering & photoelectric effect

Drifting ionization
E-field
cathode
LAr

U-plane (induction)
V-plane (induction)
Y-plane (collection)

3 anode wire planes
Intersection of hit wires determines blip YZ coordinate

Phys. Rev. D 109, 052007 (2024)
Low-threshold
Standard

MicroBooNE Simulation
Hit on collection plane
3D blip (2-3 planes)

Energy deposited by electron [MeV]

MicroBooNE Simulation
Electrons with cosmic overlay
Low-threshold reconstruction

$$\frac{\delta E}{E} = \frac{a_0}{E} \oplus \frac{a_1}{\sqrt{E}} \oplus b$$

a_0 [%]	3.1 ± 0.2
a_1 [%]	6.4 ± 0.2
b [%]	7.30 ± 0.05

Phys. Rev. D 109, 052007 (2024)
Energy deposited by electron [MeV]

References
[1] R. Acciarri et al. (ArgoNeuT), Phys. Rev. D 99, 012002 (2019)
[2] A. Bhat, PhD Thesis, Syracuse Univ., FERMILAB-THESIS-2021-14
[3] P. Abratenko et al. (MicroBooNE), J. Instrum. 17 1044 (11), P11022 (2024)
[4] P. Abratenko et al. (MicroBooNE), Phys. Rev. D 109, 052007 (2024)
[5] A. Avasthi et al., Snowmass 2022, arXiv:2203.08821

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Fermilab   U.S. DEPARTMENT OF ENERGY Office of Science   NSF   FN NF   Science and Technology Facilities Council   THE ROYAL SOCIETY   UK Research and Innovation   SWISS NATIONAL SCIENCE FOUNDATION

4) Radon-doping R&D Run

- ^{222}Rn doped into LAr for 2021 R&D run
- Observable increase of $^{214}Bi \to ^{214}Po$ (BiPo) candidates seen when filters were bypassed
  - Filters remove > 97% of radon! [3]
- In follow-up study, ΔT 'decay time' distribution background-subtracted & fit to exponential function to measure BiPo rate [4]
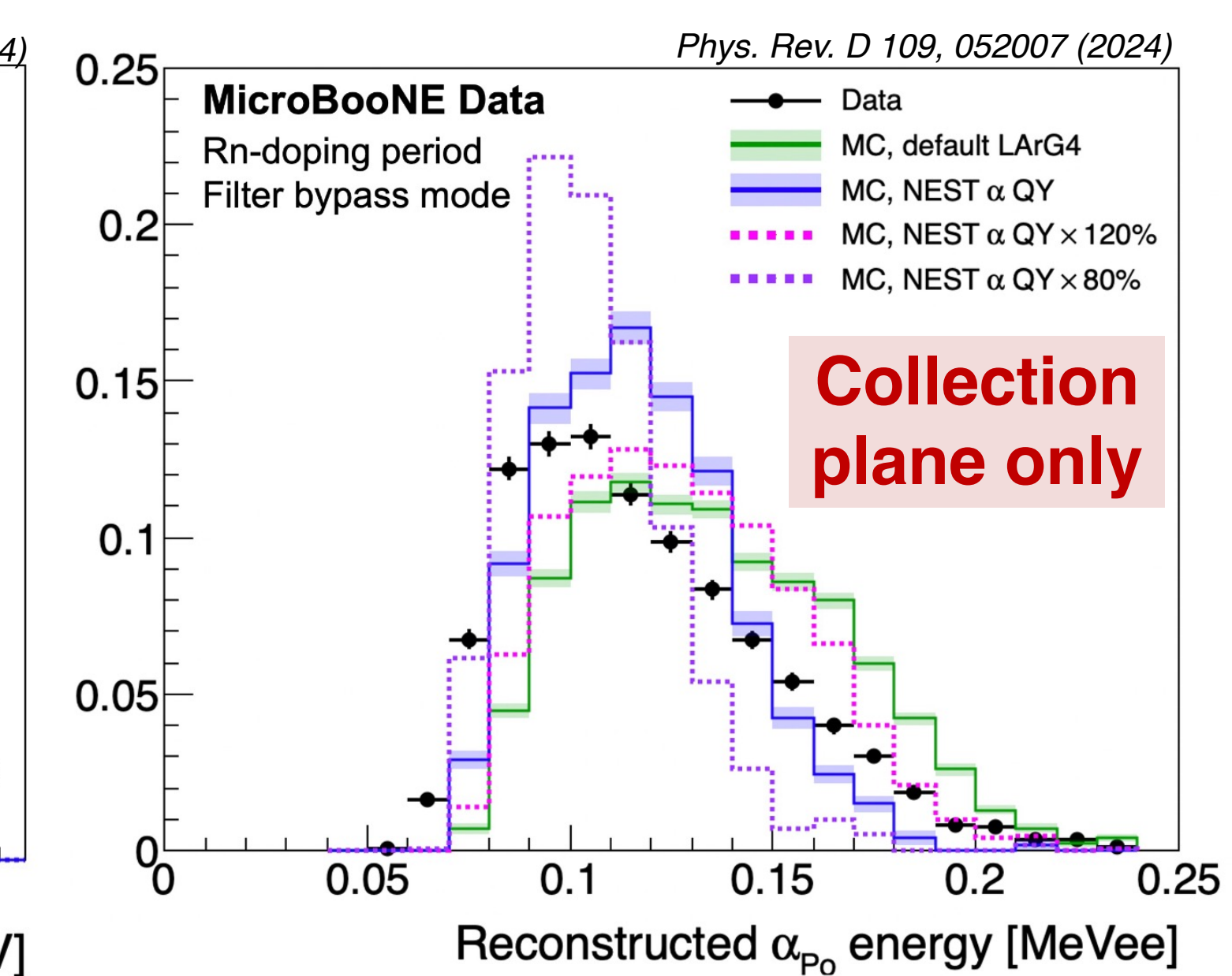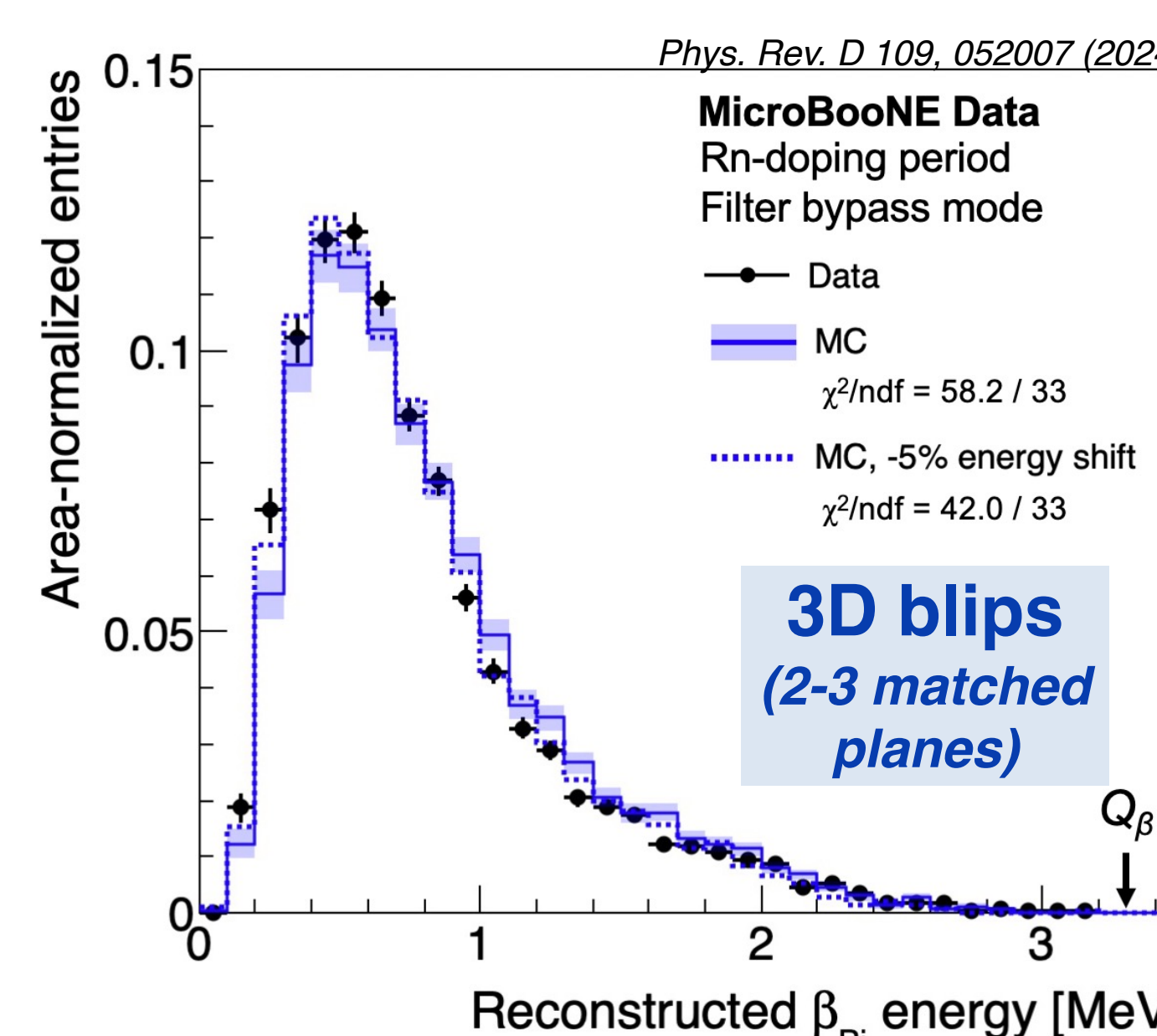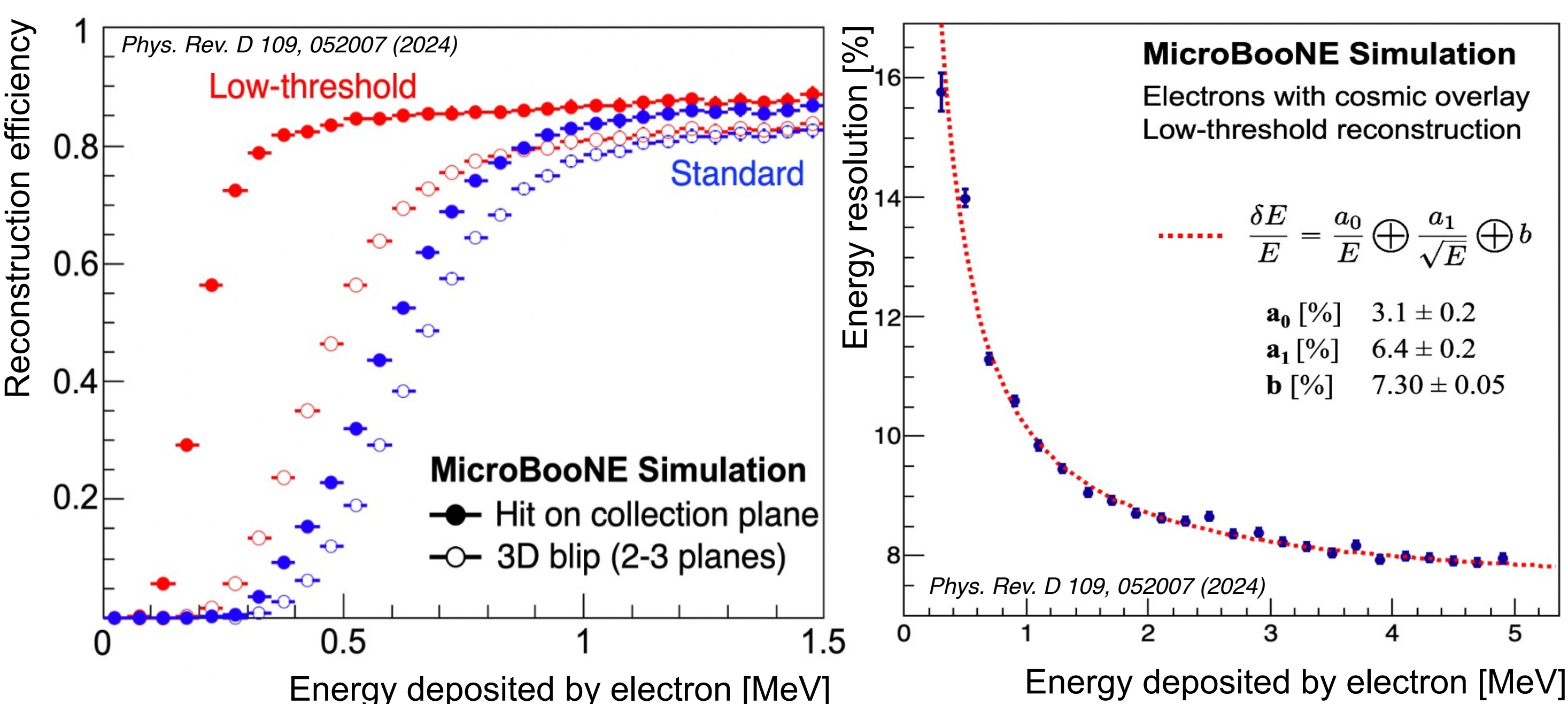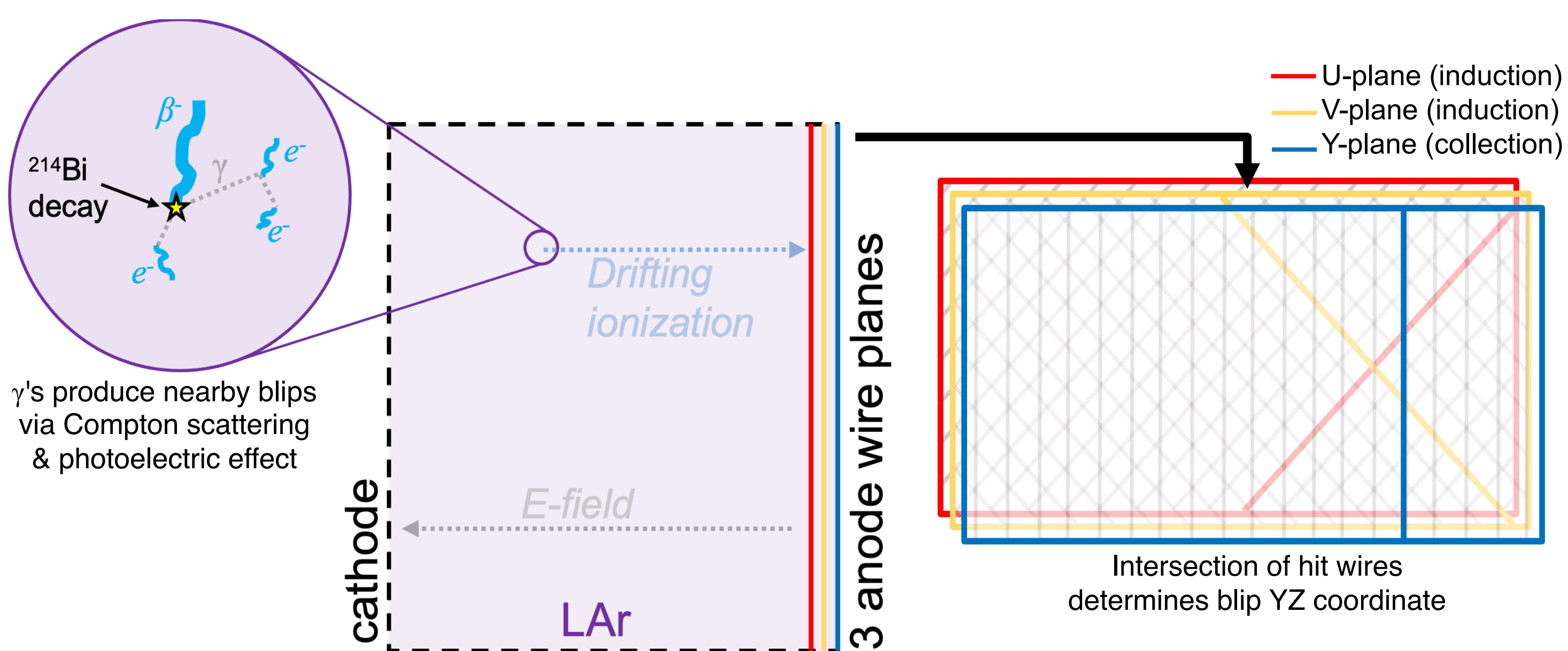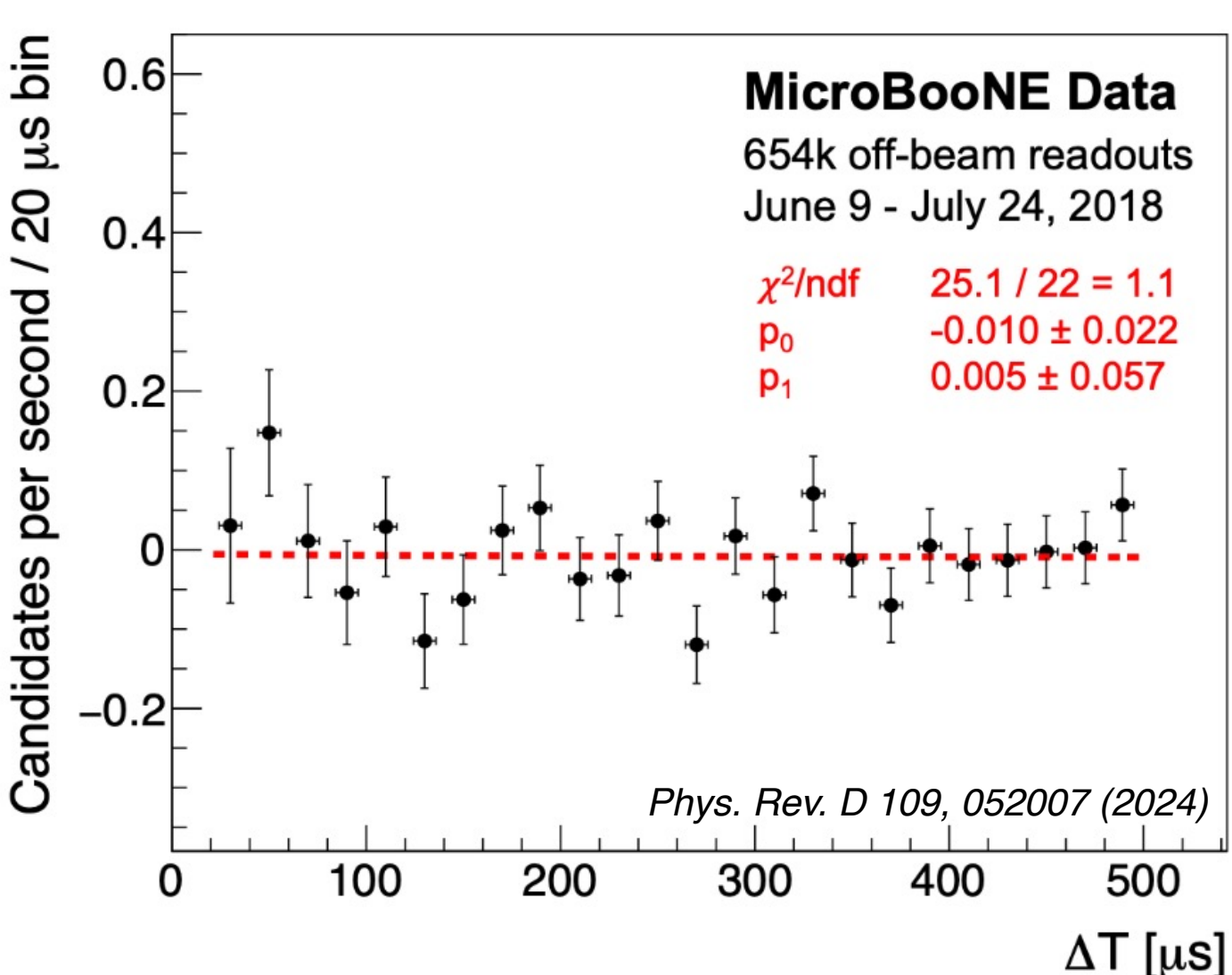

500 US Gallons Argon Dewar ^{226}Ra Source   Condenser

MicroBooNE cryogenic system

Cryostat Boil-off Gas   Filter Bypass Switch   filter skid

MicroBooNE Cryostat   LAr Pump   Mole Sieve Filter   Copper Filter

4Å mol. sieve 1.6-2.6mm beads *removes water*   Copper filter Cu-0226 S *removes O₂*

μBooNE Cosmic Data

candidate α
ΔT
candidate β
possible γ-induced depositions
10 cm

^{222}Rn 3.8 days
α
^{218}At 1.5 sec
α
^{218}Po 3.1 min ^{214}Po 164.3 μsec
α
^{214}Bi 20 min ^{214}Pb 22.3 years
β
^{214}Pb 26.8 min ^{210}Pb 22.3 years

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MicroBooNE Data Rn-doping periods
Filter bypass
Full filter

ΔT [μs]

Rn-doping periods   **MicroBooNE Data**
Filter bypass
Full filter
Time [hr]

5) Calorimetric Data/MC Validation

- R&D data used to validate the MC at the MeV-scale by reconstructing background-subtracted energy spectra of β_{Bi} and α_{Po}
- BiPo rate efficiency from MC: $\varepsilon_{nom} = (8.3 \pm 4.2)\%$, with uncertainties in α_{Po} charge-quenching dominating the error

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MicroBooNE Data Rn-doping period Filter bypass mode
Data
MC $\chi^2/ndf = 58.2 / 33$
MC, -5% energy shift $\chi^2/ndf = 42.0 / 33$
3D blips (2-3 matched planes)
Q_β
Reconstructed β_{Bi} energy [MeV]

Phys. Rev. D 109, 052007 (2024)
MicroBooNE Data Rn-doping period Filter bypass mode
Data
MC, default LArG4
MC, NEST α QY
MC, NEST α QY × 120%
MC, NEST α QY × 80%
Collection plane only
Reconstructed α_{Po} energy [MeVee]

6) Ambient Rn Results & Conclusions

MicroBooNE Data 654k off-beam readouts June 9 - July 24, 2018

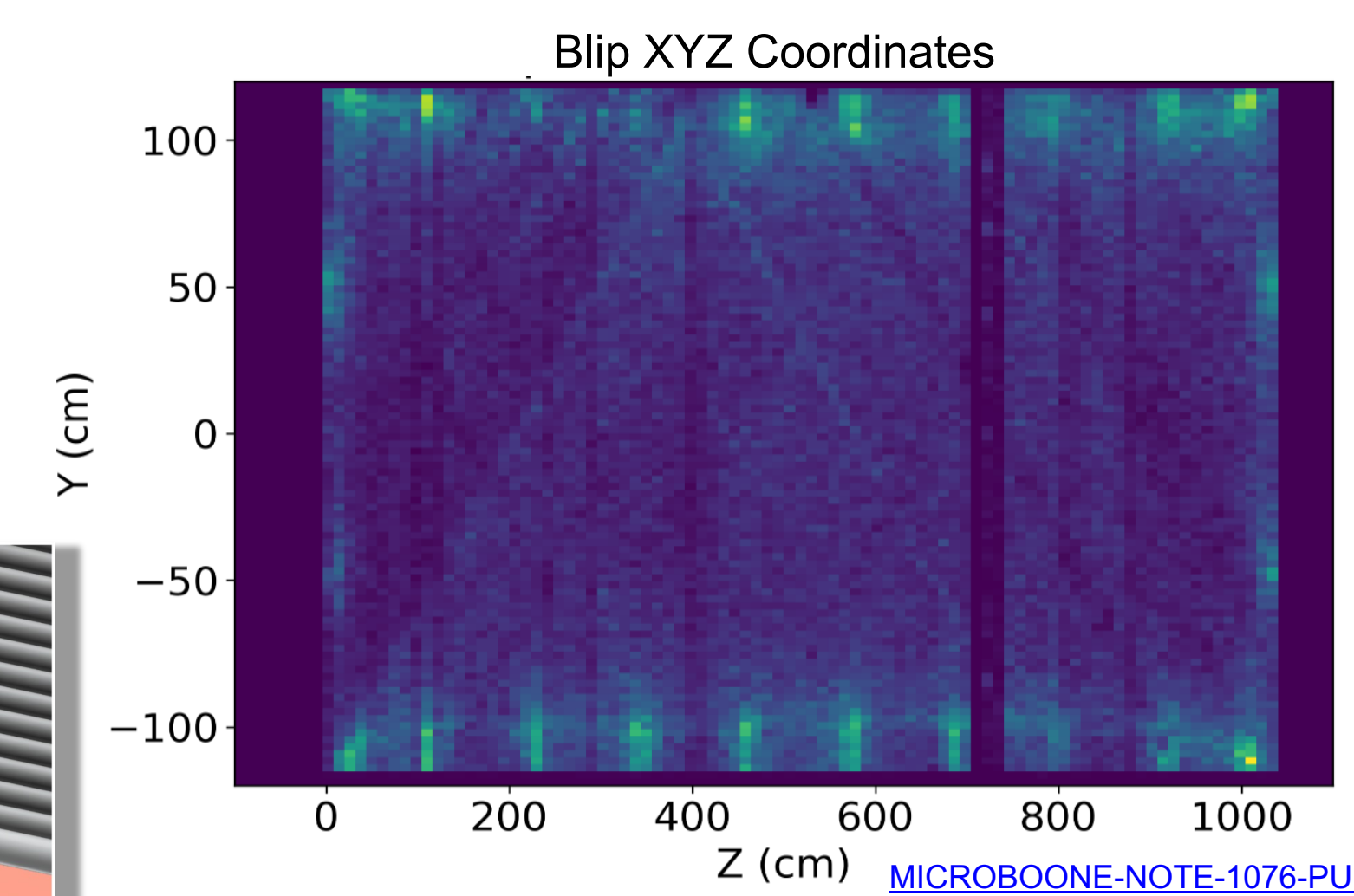|	
χ^2/ndf	25.1 / 22 = 1.1
p_0	-0.010 ± 0.022
p_1	0.005 ± 0.057

Phys. Rev. D 109, 052007 (2024)
ΔT [μs]

- No measurable BiPo rate in standard physics data-taking conditions:
  $$R_{Bi214} = (0.01 \pm 0.17)\ mBq/kg$$
  $R_{Bi214} < 0.35\ mBq/kg$ at 2σ C.L.
- Isotope plate-out effects estimated with toy MC: $R_{Rn222}/R_{Bi214} \sim 2.3 \pm 0.4$
- Estimated ^{222}Rn level below DUNE's target of ≲ 1 mBq/kg [5]

This in-situ radiopurity measurement is the first of its kind for a large single-phase LArTPC!

✓ calorimetric capabilities to *sub-MeV levels*
✓ achievement of DUNE-required ^{222}Rn levels through standard LAr liquid filtration system

7) Ongoing MeV-scale Work in MicroBooNE

- Calibrations with γ-rays from radioactive ^{208}Tl in support struts
- Electron/proton PID for blips
- Proton/neutron-like content in cosmic flux data

Stay tuned!

Blip XYZ Coordinates
Y (cm)
Z (cm)
G-10 Strut   Field Cage Tubes
MICROBOONE-NOTE-1076-PUB