

Searches for dark sectors with the SBND experiment

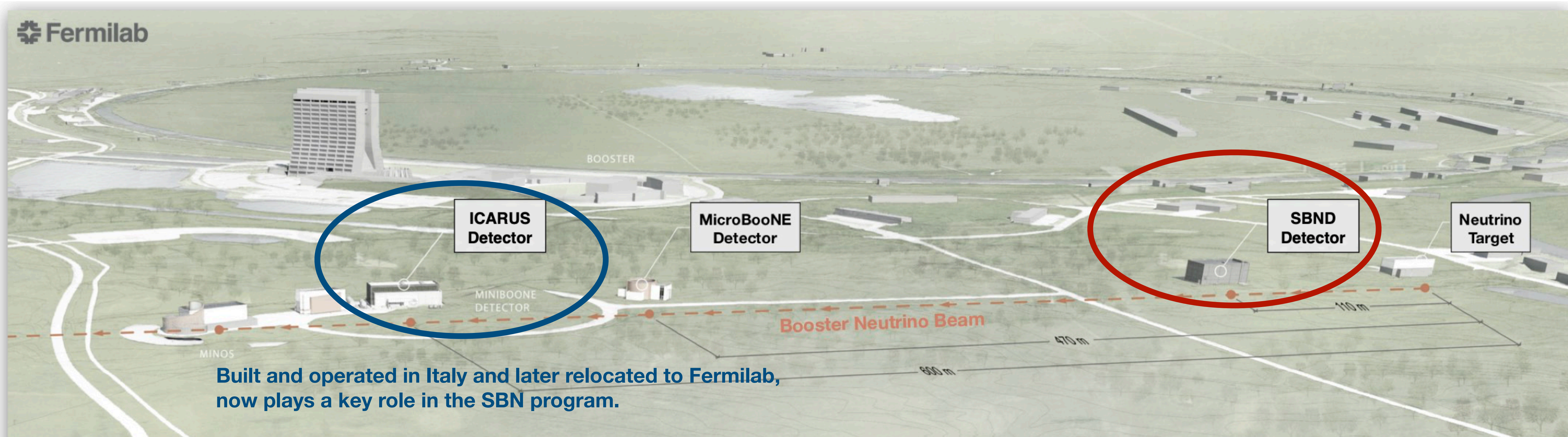


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On Behalf of the SBND Collaboration



- **The Short-Baseline Neutrino Program (SBN) at Fermilab**
- **The Short-Baseline Near Detector (SBND)**
- **Dark sector in SBND**

The Short-Baseline Neutrino Program



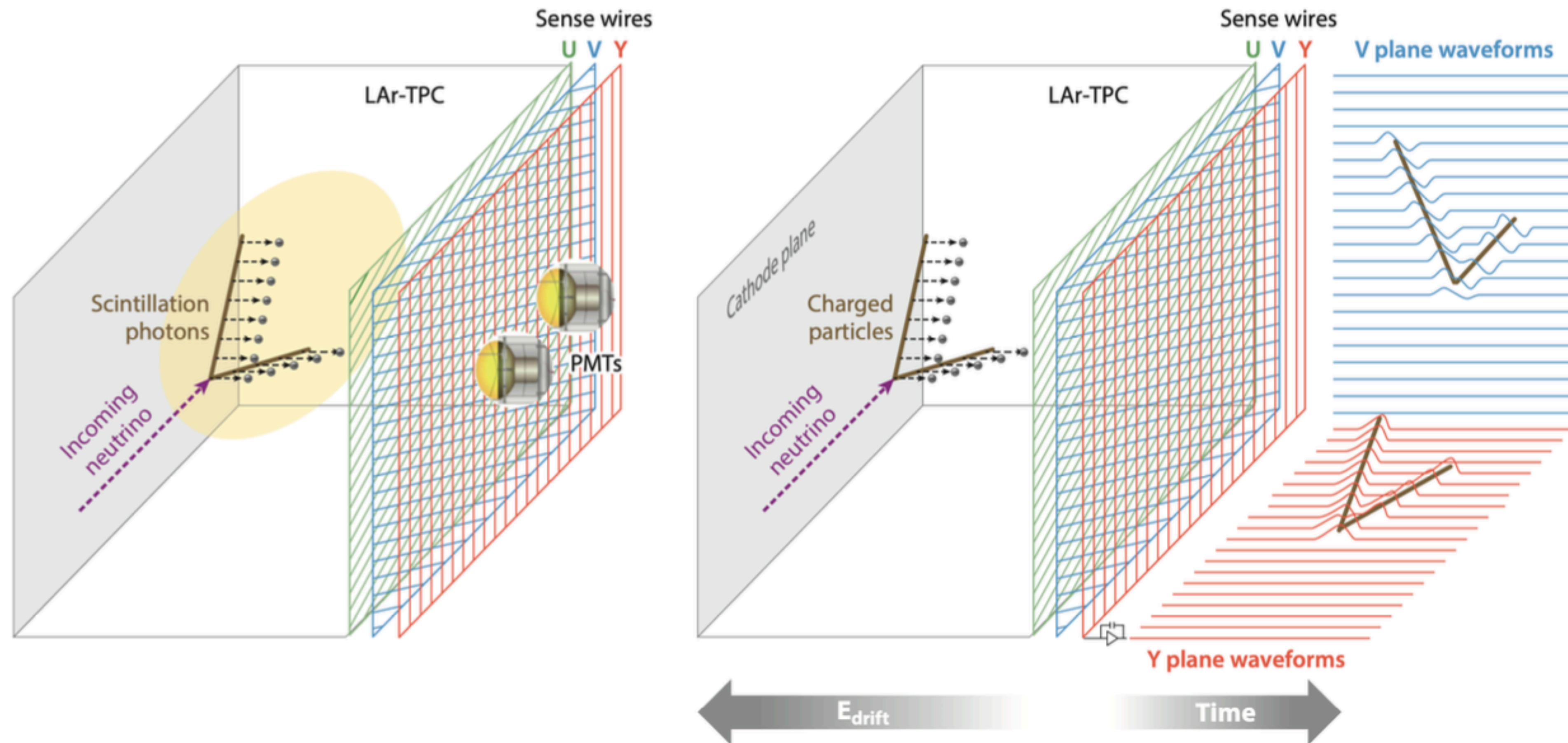
Two LArTPC detectors located along the Booster Neutrino Beam (BNB) at Fermilab : ICARUS, the far detector, located at 600 m from the target with an active mass of 476 tons, and SBND, the near detector, located at 110 m from the target with an Active mass of 112 tons

SBND



Topic of this talk!

Liquid Argon Time Projection Chamber



Digitized signals from the wire are collected [time of the wire pulse gives the drift coordinate and amplitude gives the deposited charge]

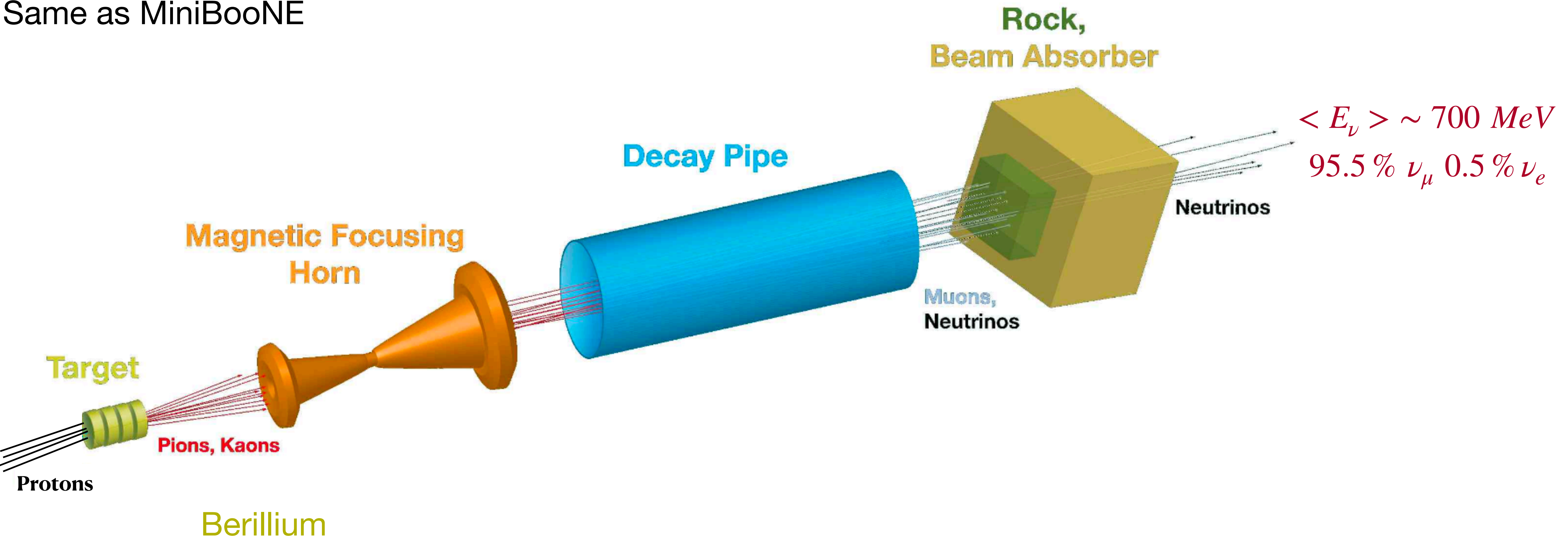
Charged particles produce **ionization** electrons and **scintillation** light (event time)

Ionization charges drift in a uniform electric field towards the readout wire planes.
Electron drift time $\sim$ ms

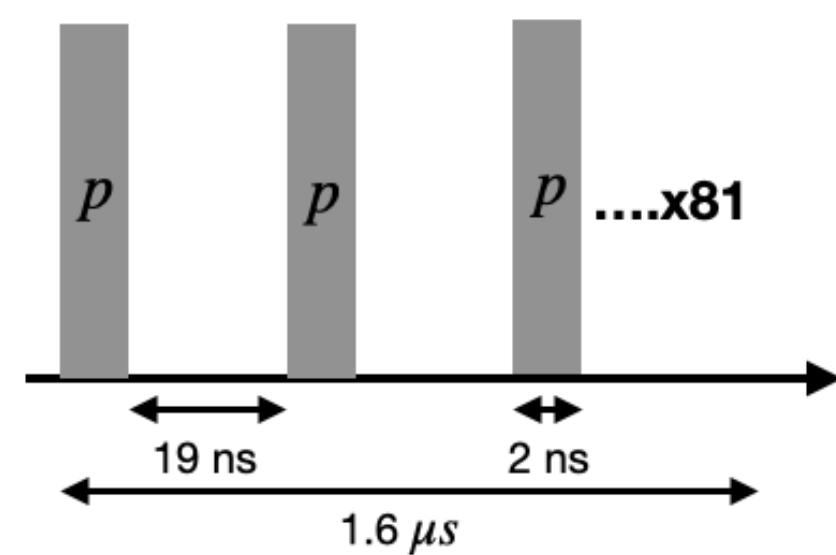
MIP at 500 V/cm:
 $\sim 60,000$ e/cm
 $\sim 50,000$ photons/cm

The Booster Neutrino Beam

Same as MiniBooNE



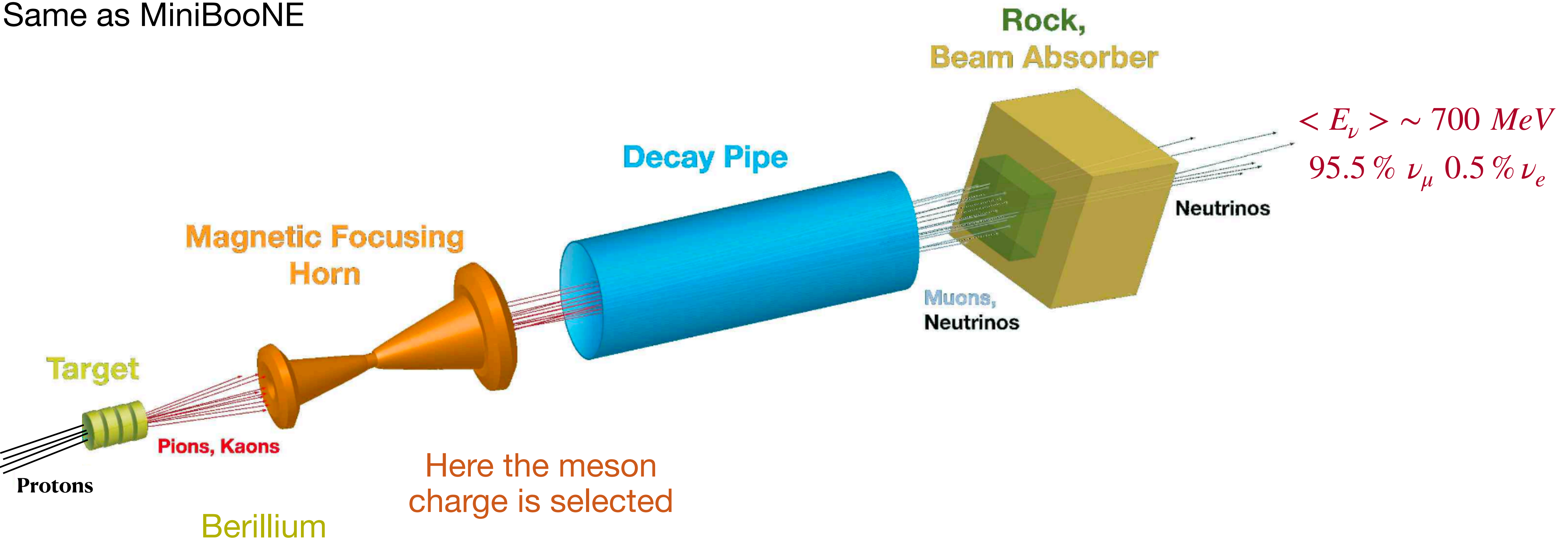
8 GeV protons delivered in $1.6 \mu\text{s}$ spills, each one with a structure of 81 bunches $\sim 2 \text{ ns}$ wide and $\sim 19 \text{ ns}$ apart



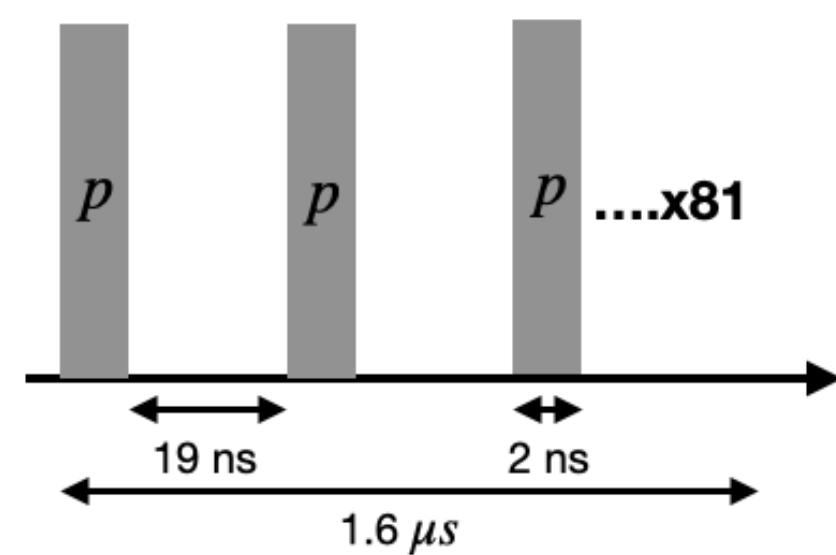
POT=Proton on target

The Booster Neutrino Beam

Same as MiniBooNE

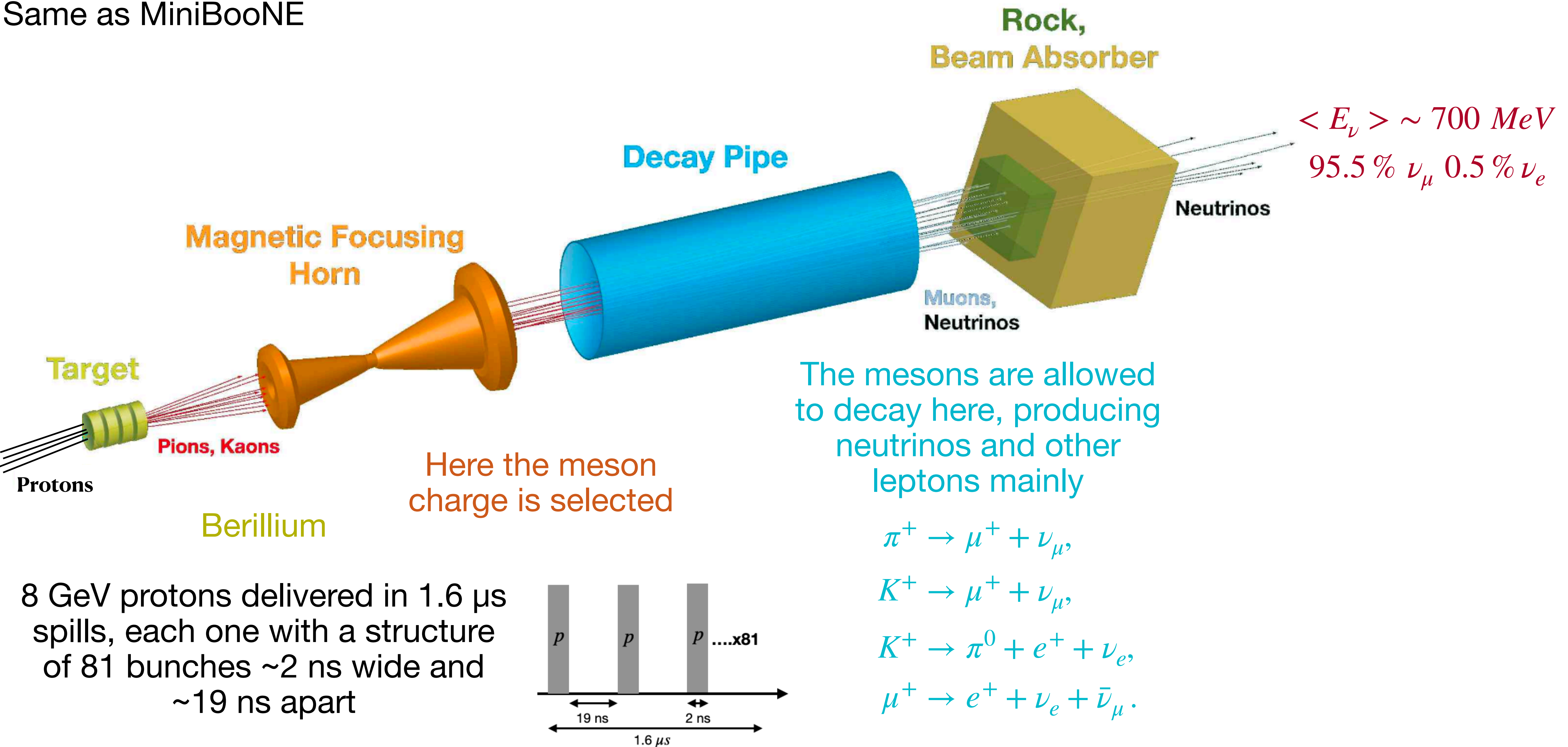


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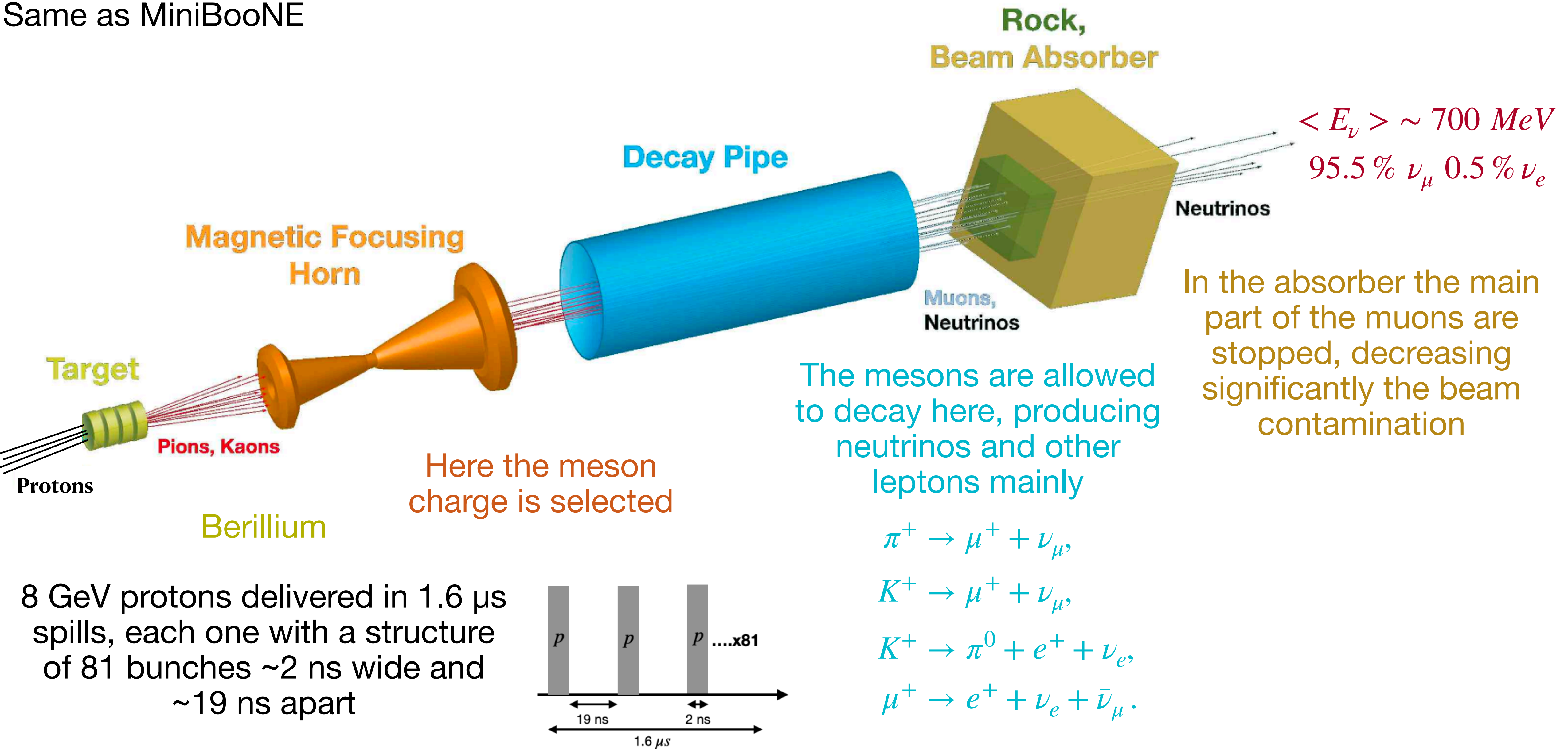
The Booster Neutrino Beam

Same as MiniBooNE



The Booster Neutrino Beam

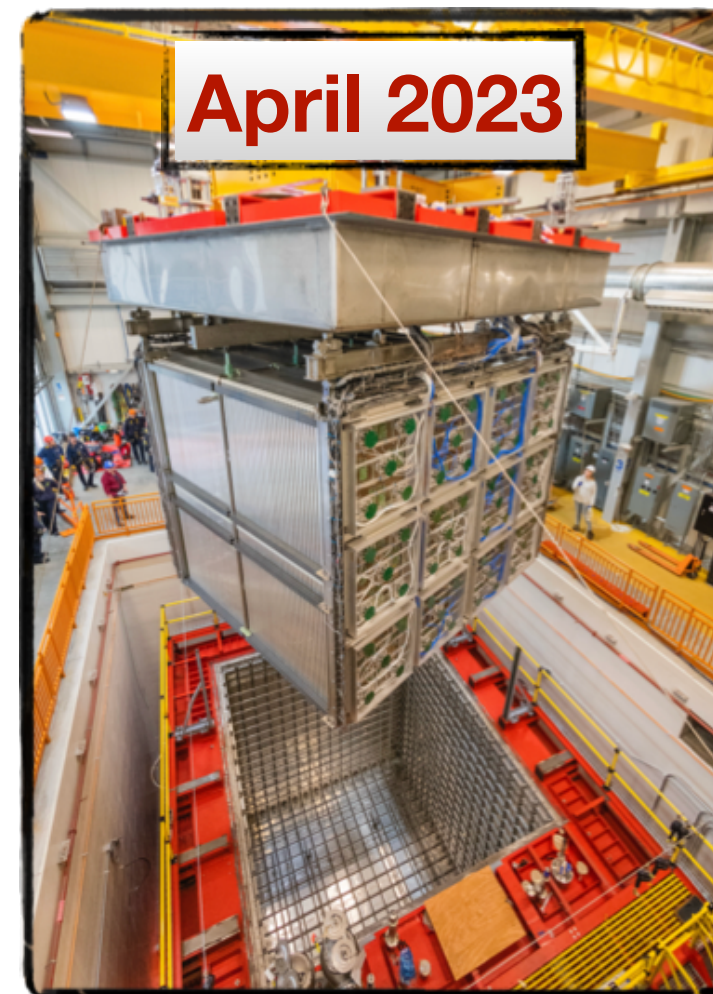
Same as MiniBooNE



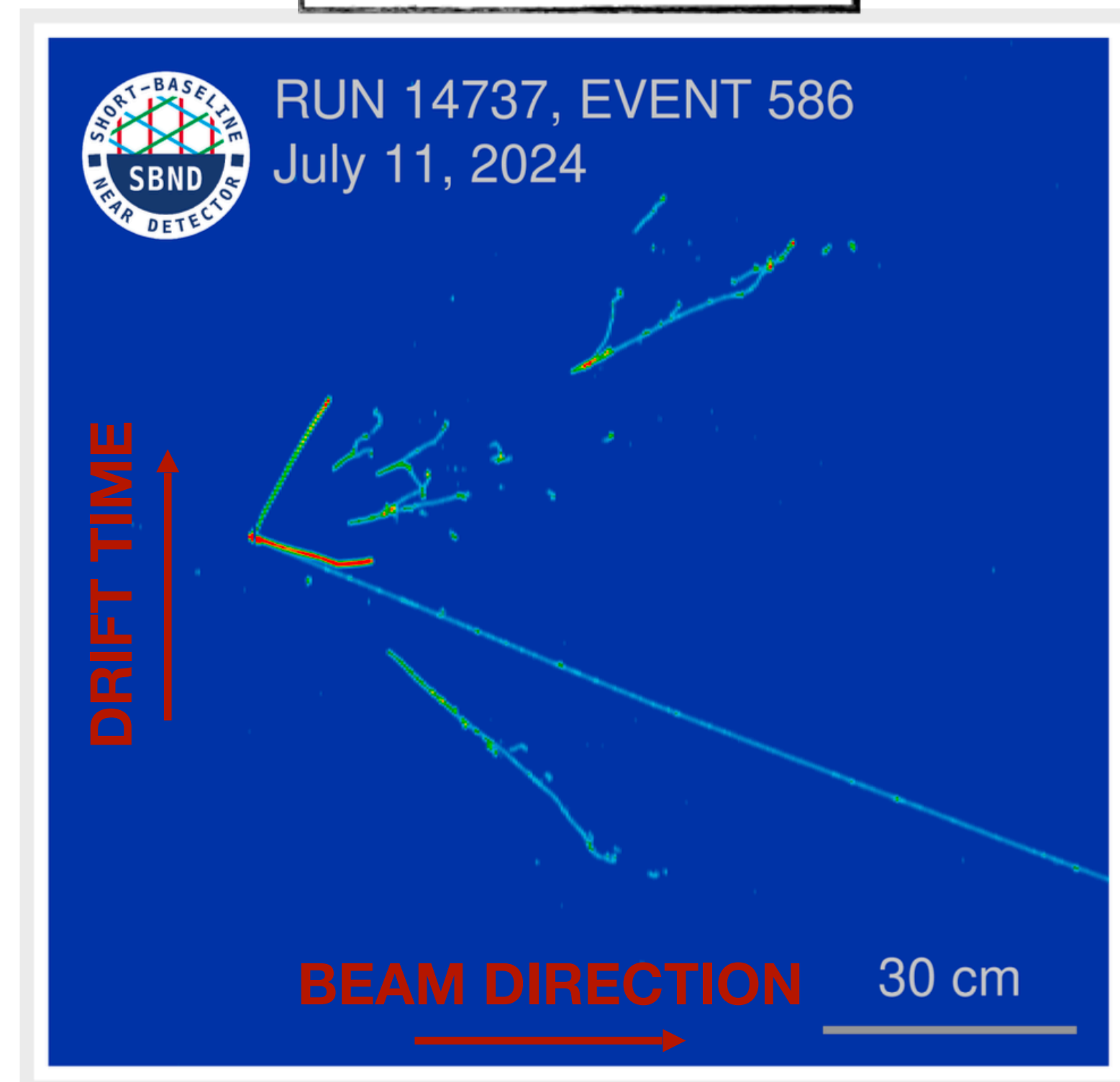
Short-Baseline Near Detector



Some of the SBND history!



SBND comes alive

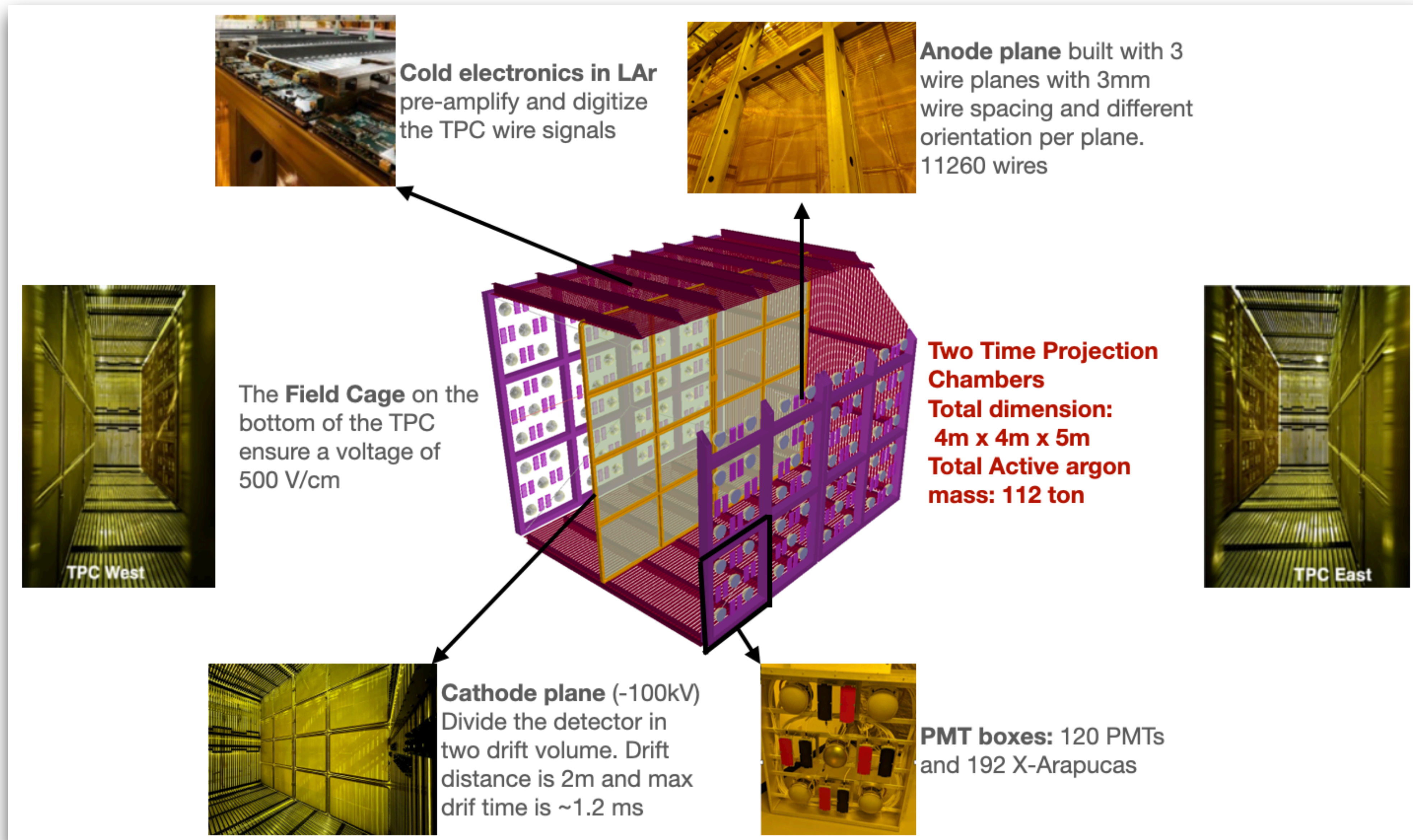


RUN 1: December 2024 - July 2025

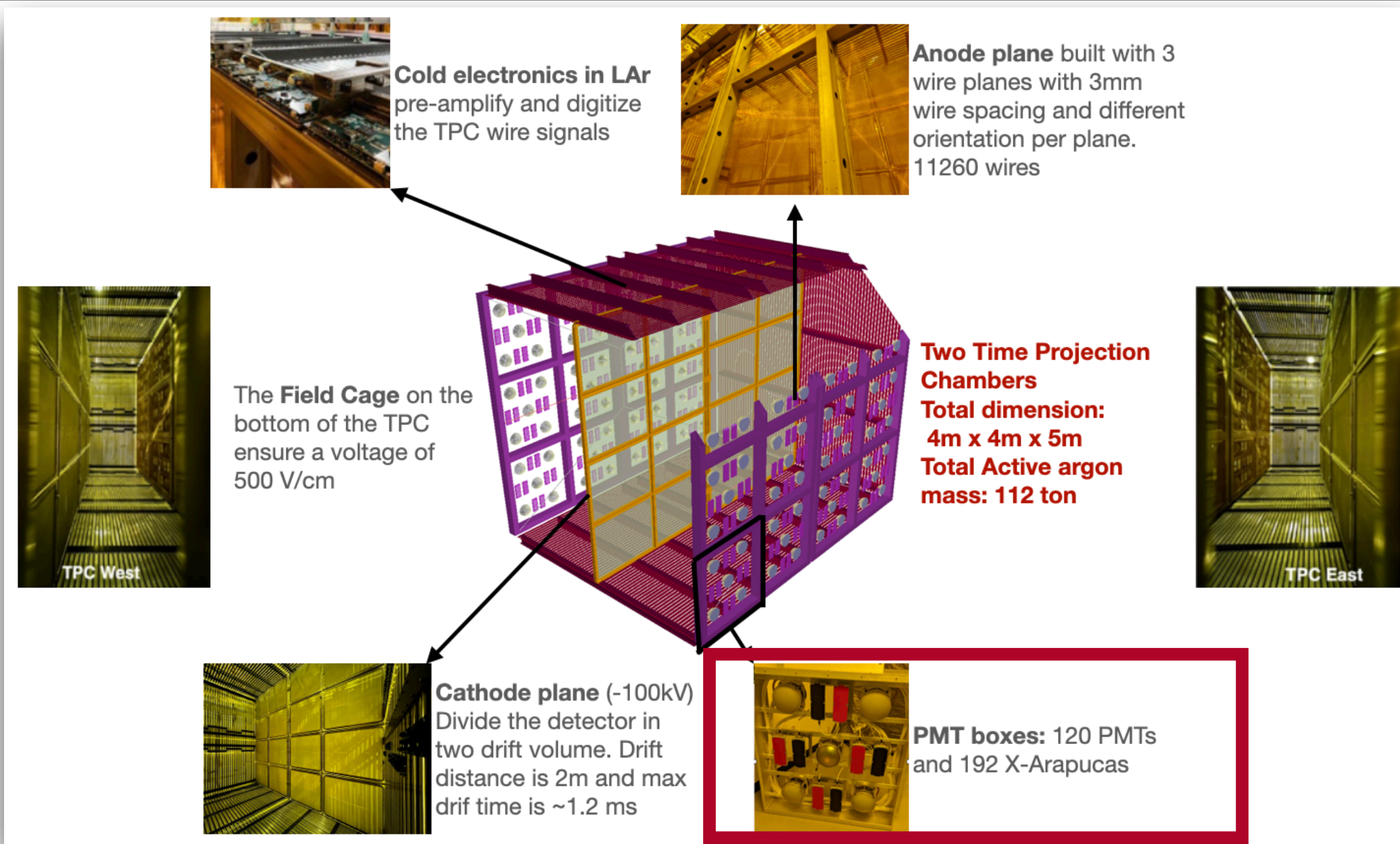
RUN 2: October 2025 -

Already collected 6.73×10^{20} POT, the largest neutrino-Argon dataset in the world, with more than 6 millions interactions.

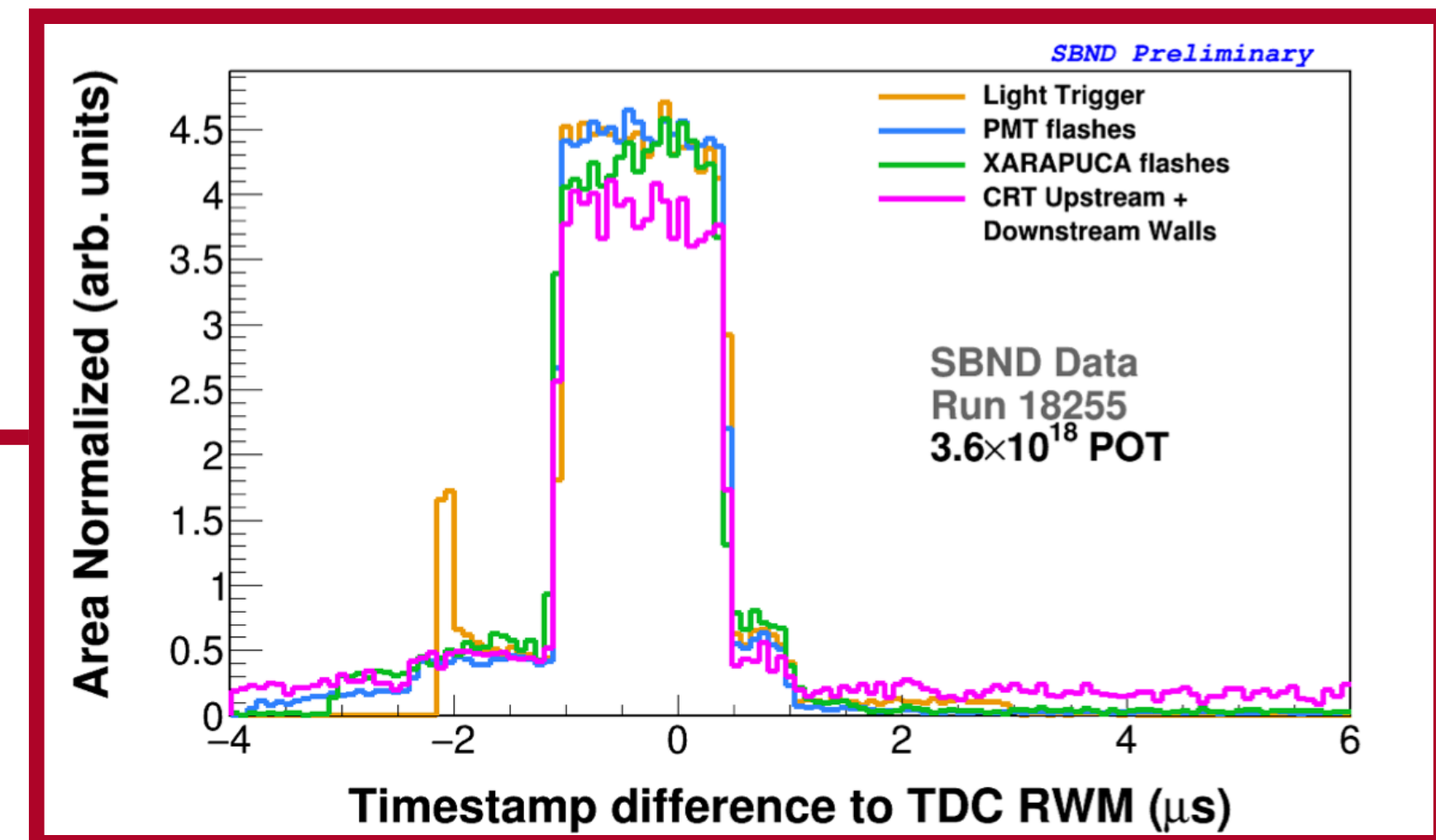
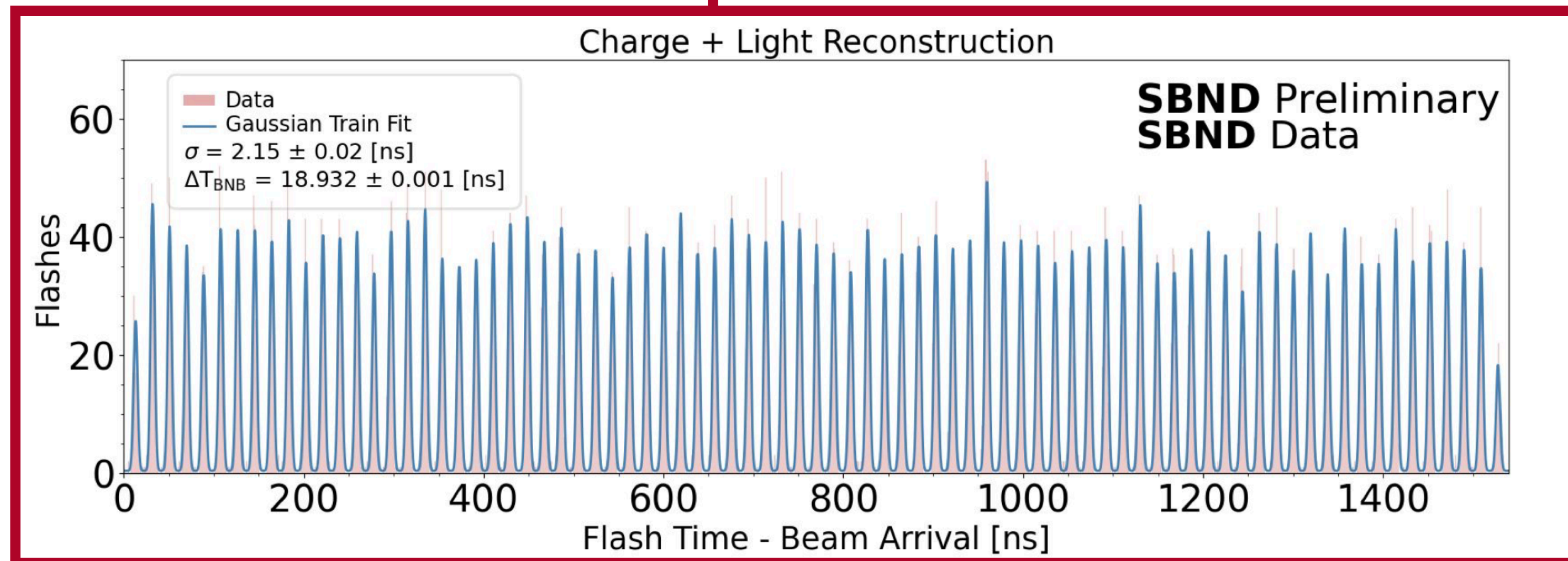
The Short-Baseline Near Detector



The Short-Baseline Near Detector

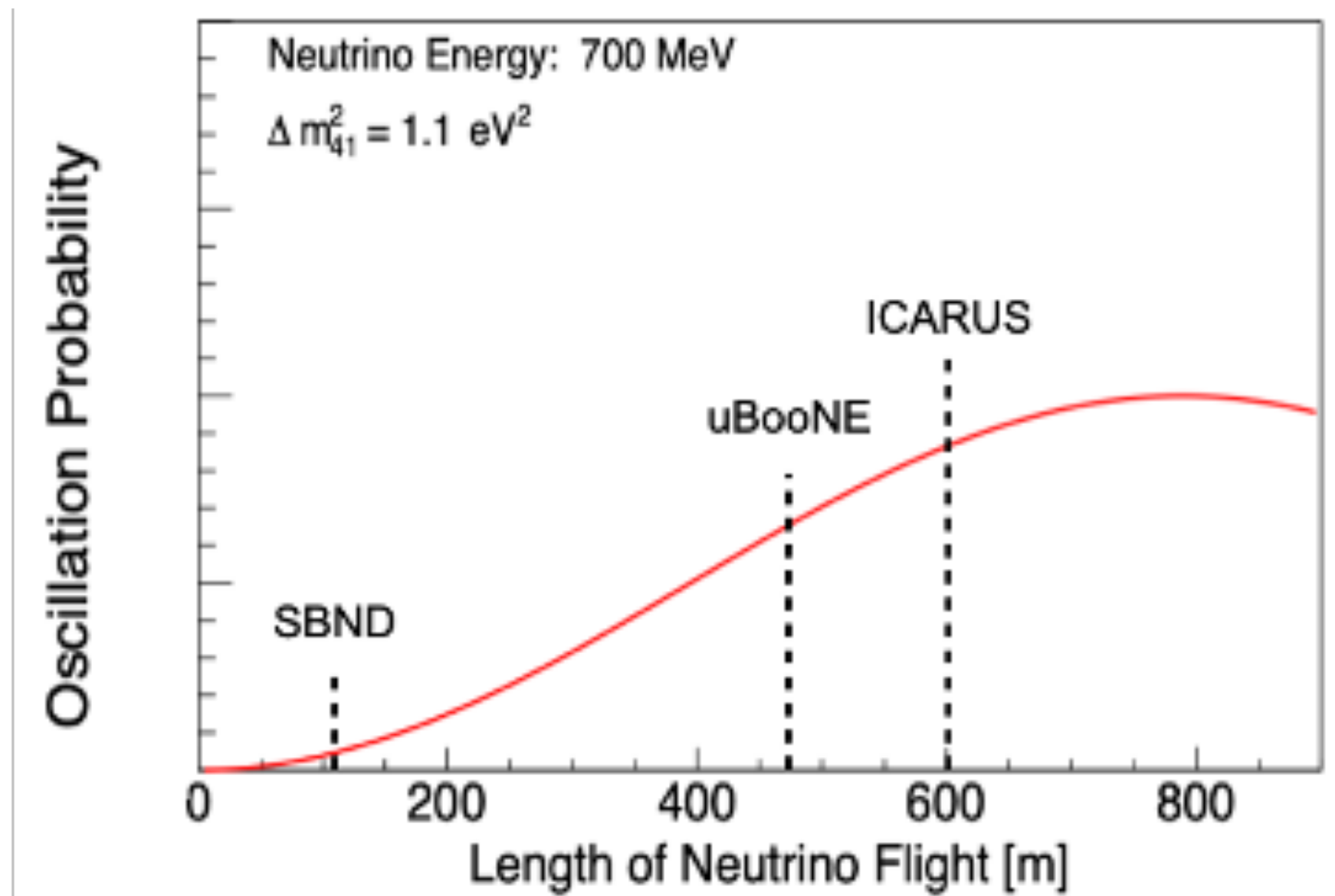


O(1ns) temporal resolution



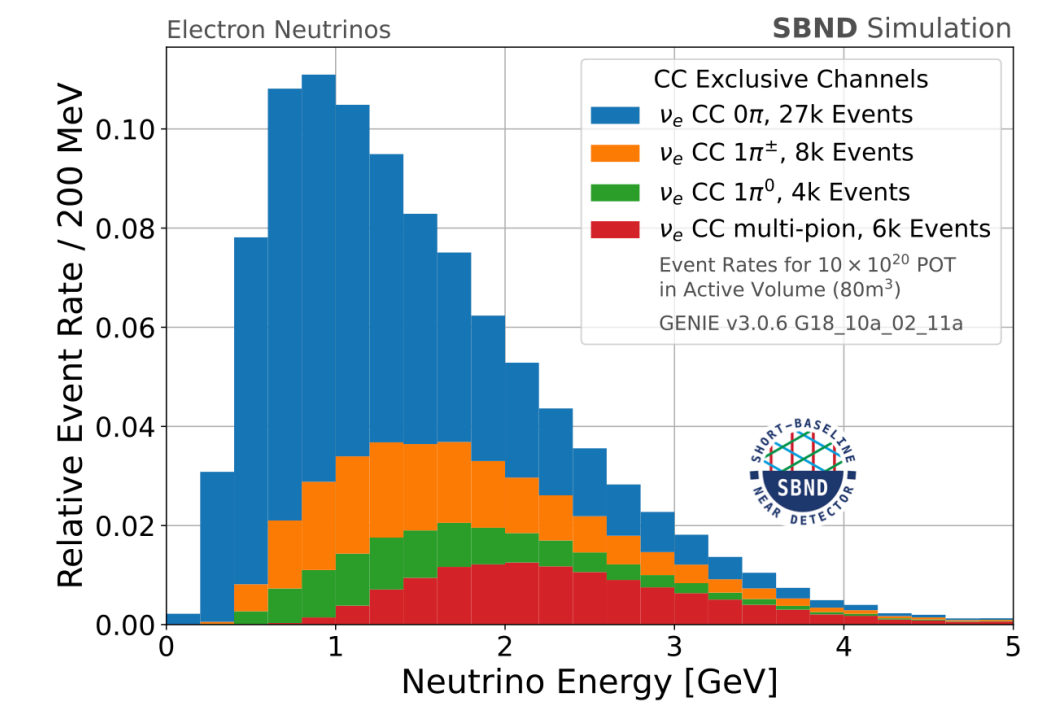
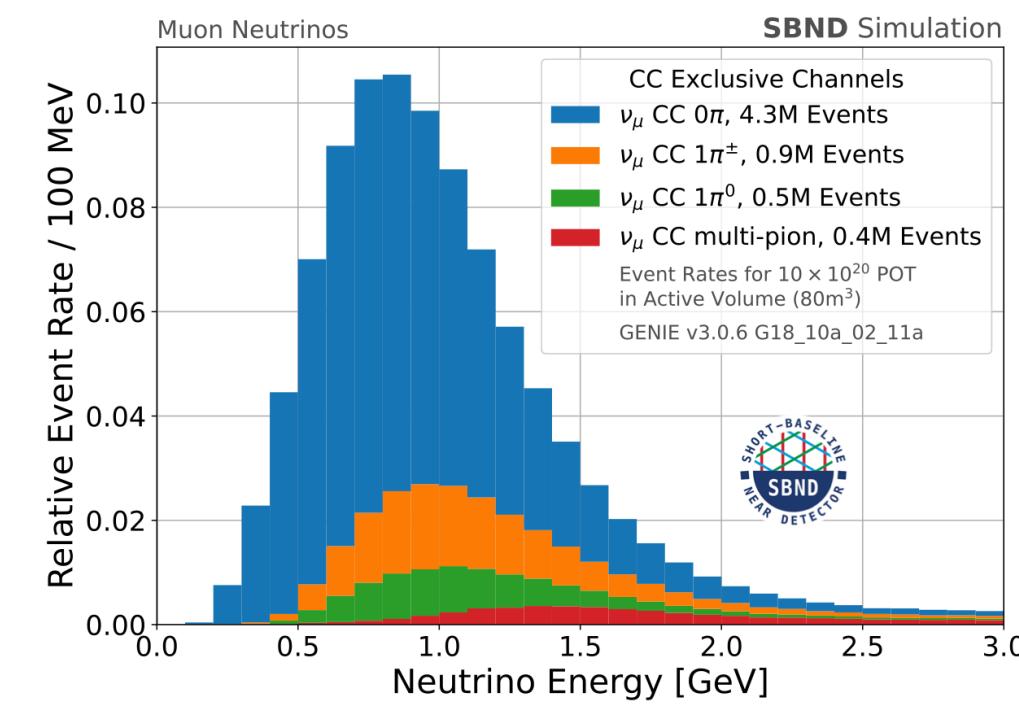
SBND physics goals: Oscillation and Cross-section

Sterile neutrino oscillations. The multiple detectors in the SBN program enables searches both in appearance and disappearance

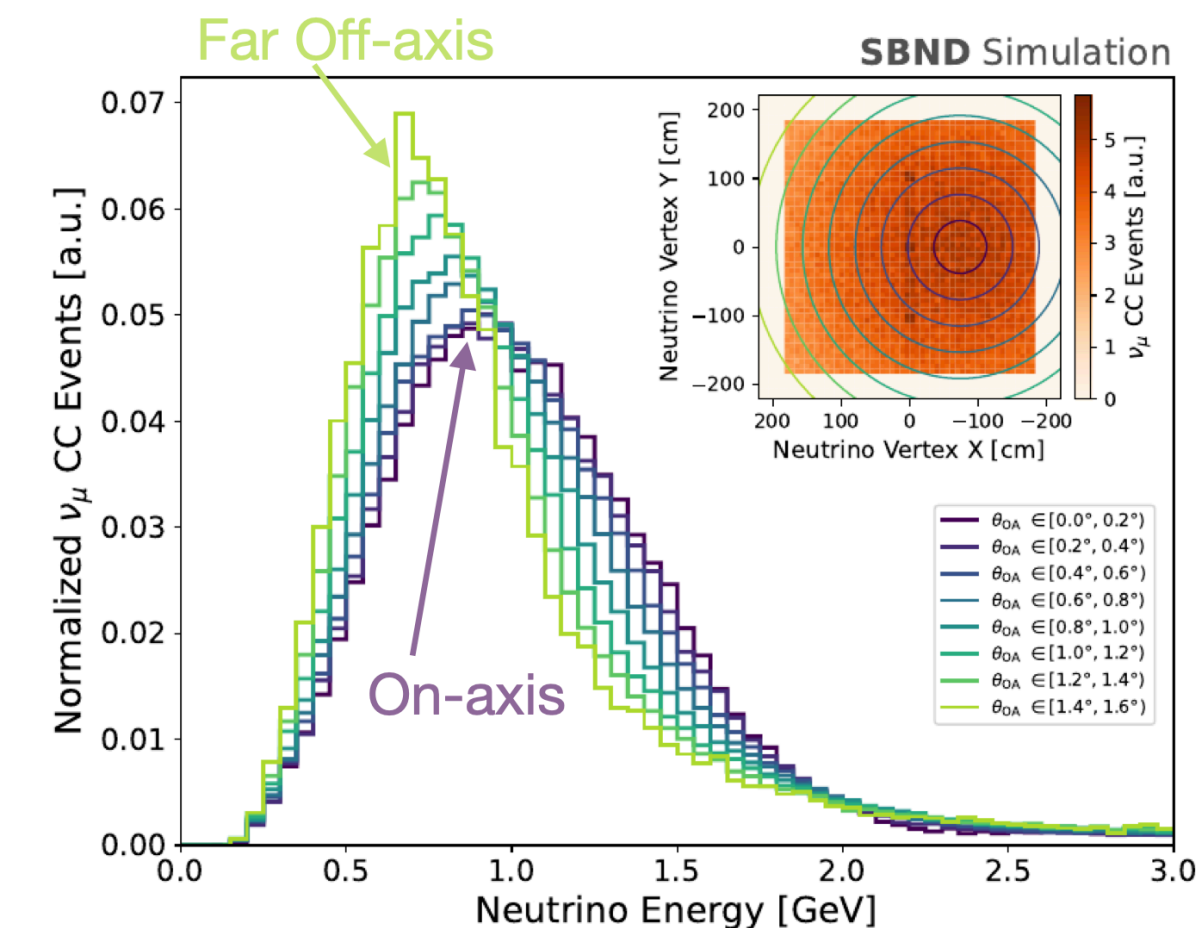


SBND is the key to mitigate the large neutrino flux and cross-section uncertainties

Neutrino cross sections on LAr



$6 \times 10^6 \text{ CC}\nu_\mu$ and $45 \times 10^3 \text{ CC}\nu_e$ in 3 years



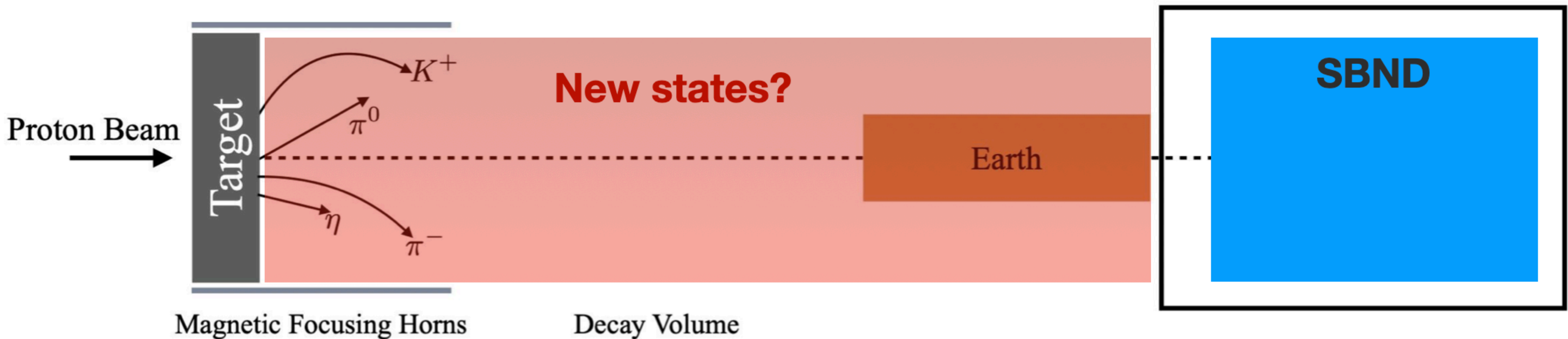
SBND PRISM
Flux characterization
and background
rejection

Phys.Rev.D 113 (2026) 7, 072007

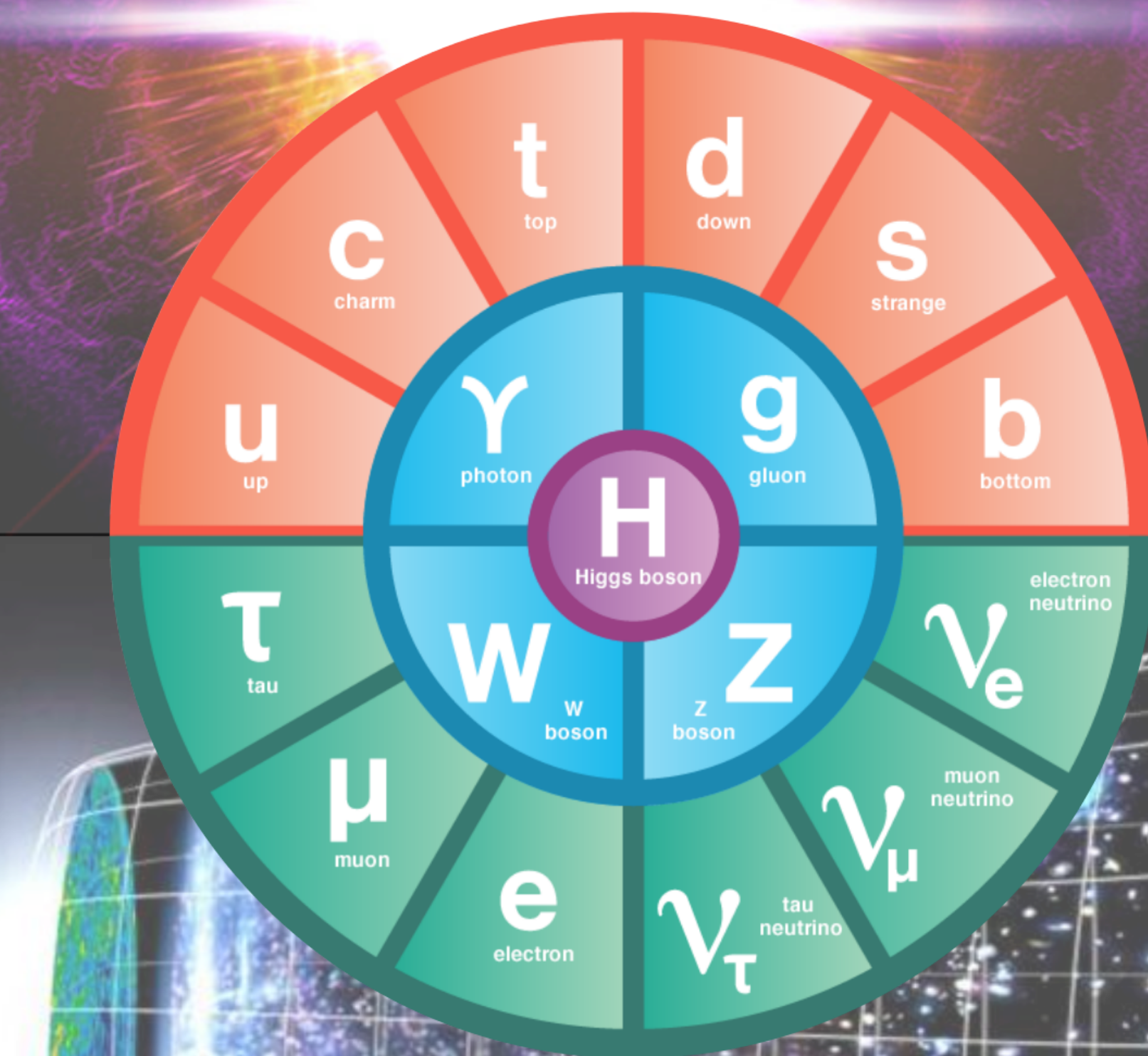
First cross-section measurements will be shown in three weeks at Neutrino '26 conference

SBND physics goals: **Beyond the Standard Model Physics**

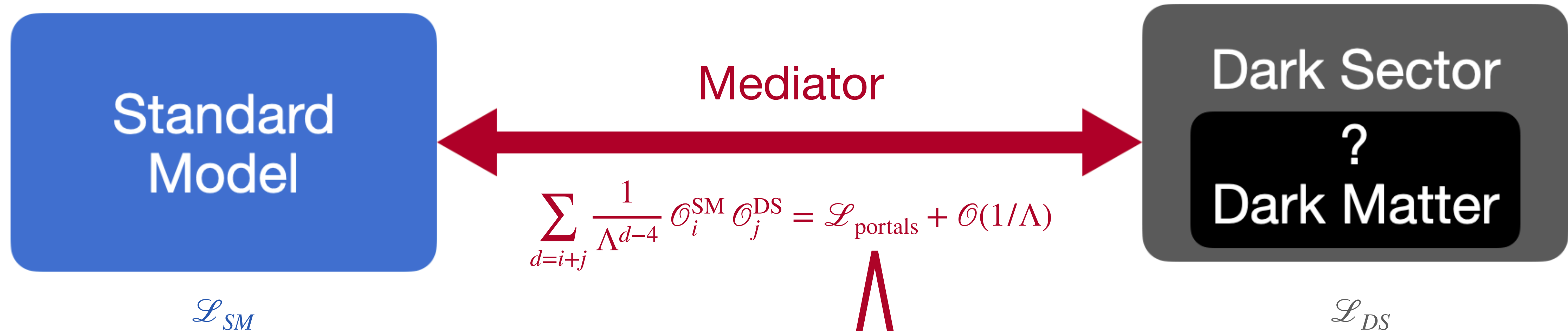
Given its proximity to the target and its excellent spatial, temporal, and energy resolution, **SBND** provides ideal conditions to search for new states produced in the BNB that decay inside its volume, thereby opening the door to dark sector investigations.



Dark Sector



Portals to the Dark Sector



$$\mathcal{L}_{\text{neutrino portal}}^{d=4} = - \sum_{\alpha, I} y_{\nu}^{\alpha I} (\bar{L}_{\alpha} H) N_I \rightarrow - \frac{1}{\sqrt{2}} \sum_{\alpha, I} v y_{\nu}^{\alpha I} \bar{\nu}_{\alpha} N_I + \dots$$

$$\mathcal{L}_{\text{Higgs portal}}^{d=3,4} = - (\mu S + \lambda S^2) H^{\dagger} H \rightarrow - \frac{\mu v}{m_h^2 - m_S^2} S J_h + \dots$$

$$\mathcal{L}_{\text{vector portal}}^{d=4} = - \frac{\epsilon}{2 \cos \theta_W} B_{\mu\nu} F'^{\mu\nu} \rightarrow \epsilon e A'_{\mu} J_{\text{EM}}^{\mu} + \dots$$

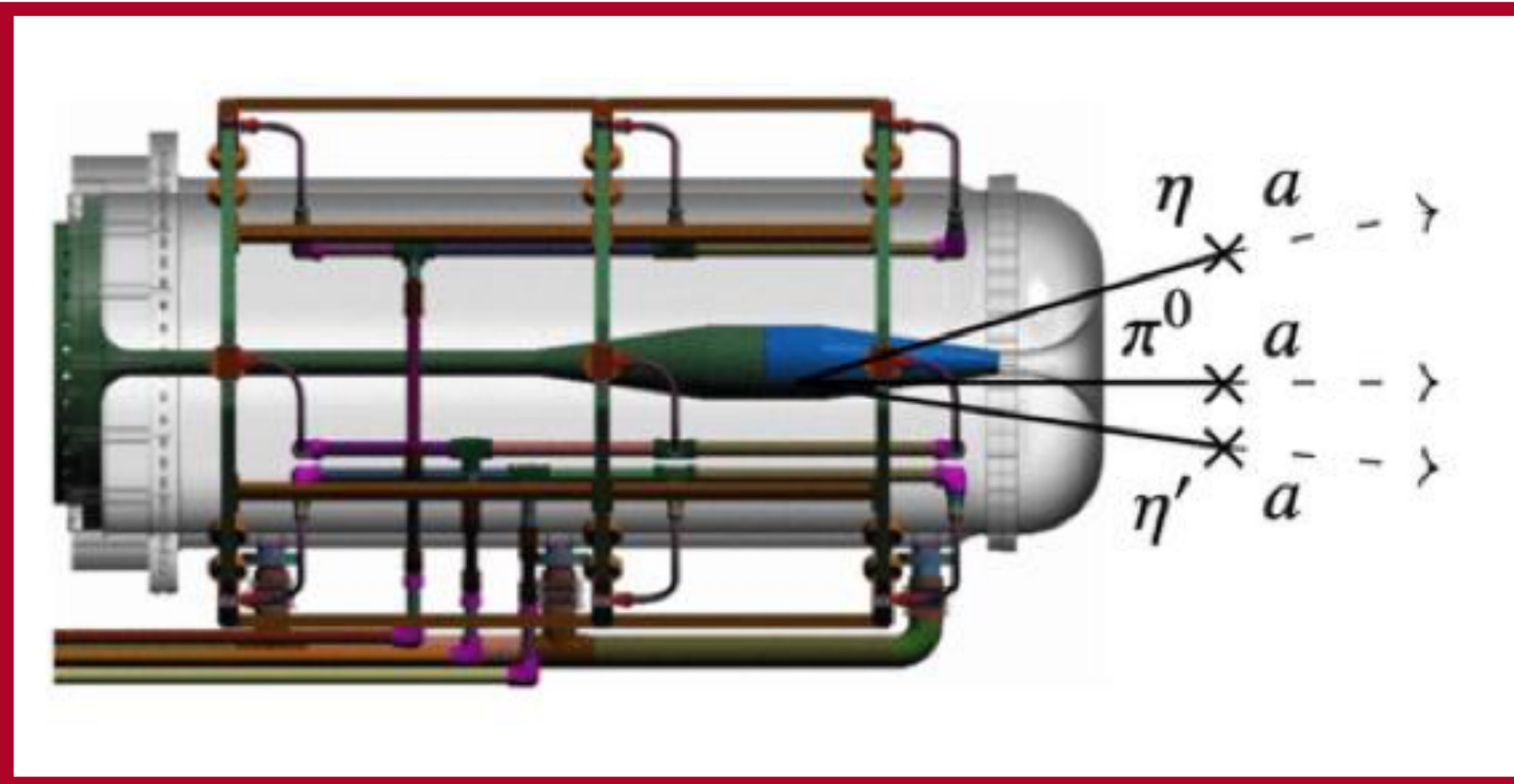
$$\mathcal{L}_{\text{axion portal}} = \frac{a}{4f_G} \text{Tr}(G^{\mu\nu} \tilde{G}_{\mu\nu}) + \frac{a}{4f_{\gamma}} F^{\mu\nu} \tilde{F}_{\mu\nu} + \frac{1}{f_q} \partial_{\mu} a \sum_q \bar{q} \gamma^{\mu} \gamma^5 q + \frac{1}{f_l} \partial_{\mu} a \sum_l \bar{l} \gamma^{\mu} \gamma^5 l$$

The general Lagrangian will be

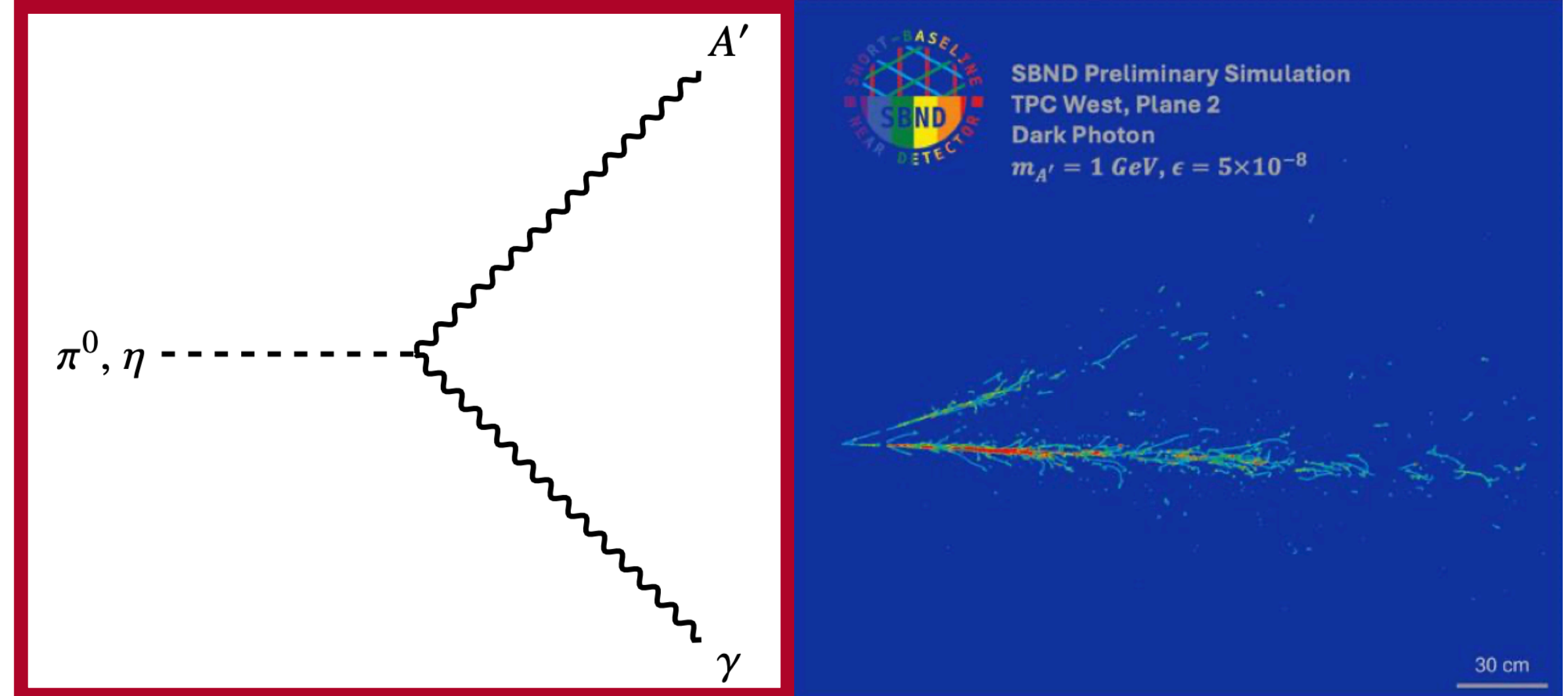
$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{DS}} + \mathcal{L}_{\text{Portals}}$$

Portal mediators in SBND

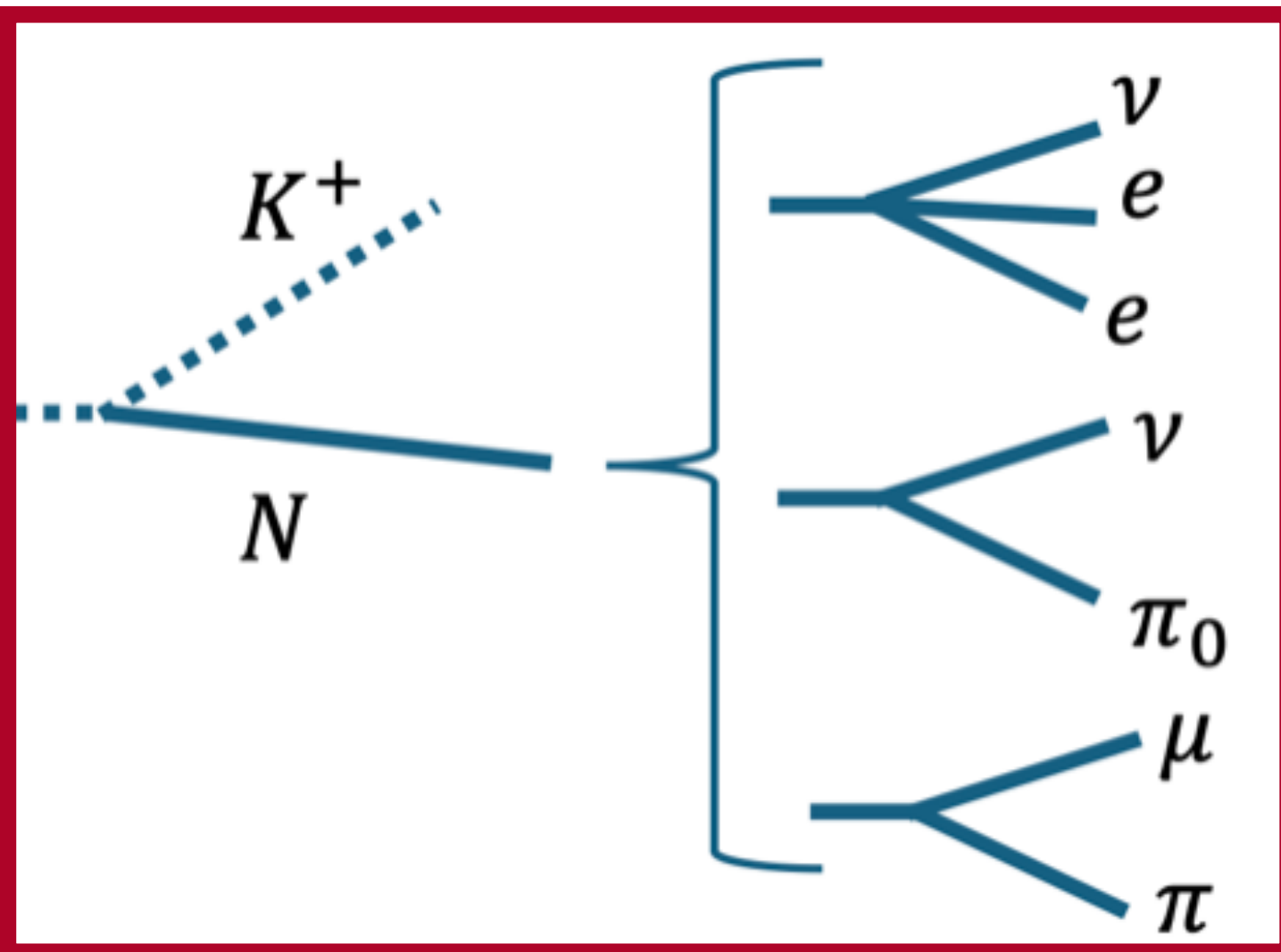
Heavy QCD Axions



Dark Photons



Heavy Neutral Lepton



Long-Lived Particles

...To be continued!

SBND's first BSM search, using data collected with the Cosmic Ray Tagger operating as a standalone detector and targeting long-lived particles, is in the final stage of review and will be submitted for publication soon.

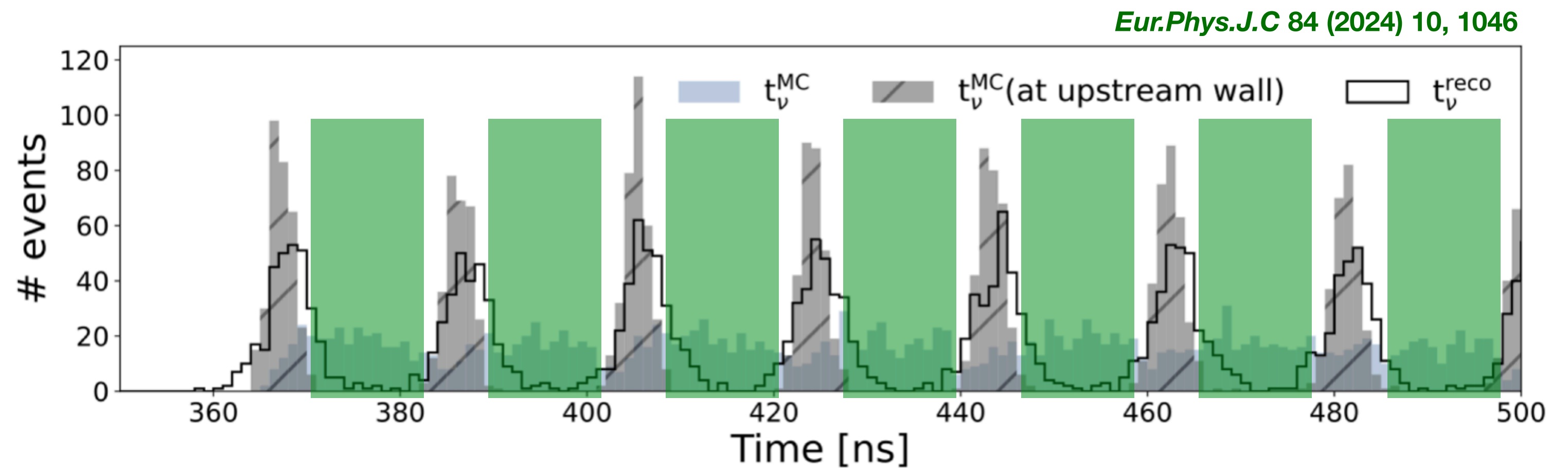
How to look for portal mediators

Kinematic analyses

Energy, momentum, invariant mass, and angular distributions — are essential to separate BSM signals from background

Timing analyses

Neutrinos arriving at SBND reproduce the same temporal profile of the proton striking the target. Due to the higher masses of the portal mediators, we in general expect to observe a delay in their temporal profile



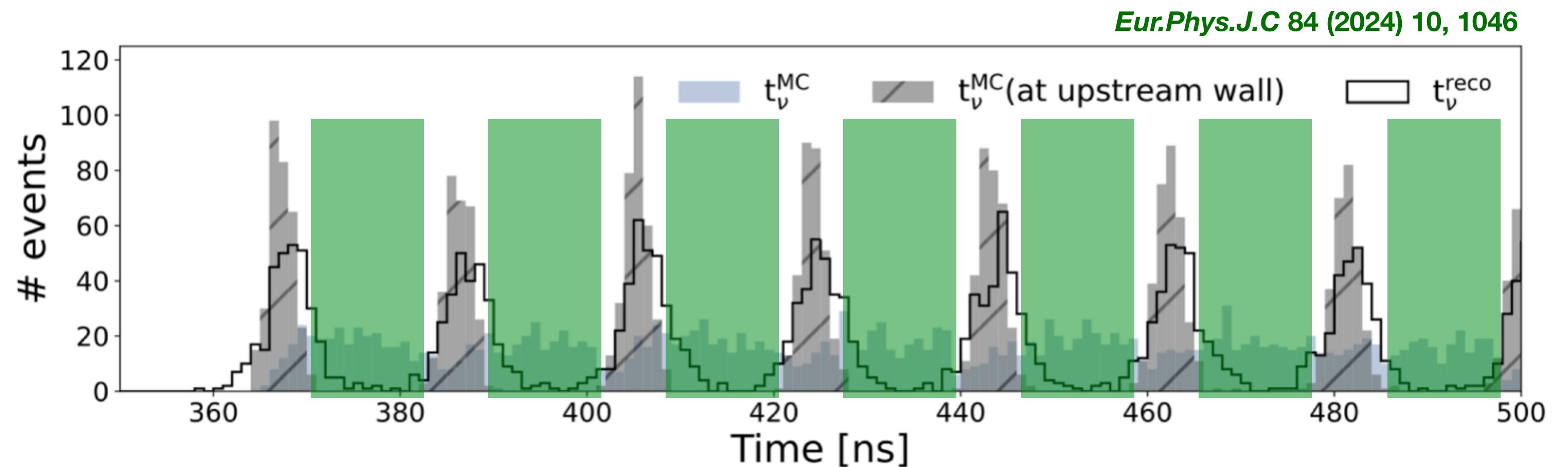
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Background

Beam-induced neutrinos events and cosmic-ray induced ones

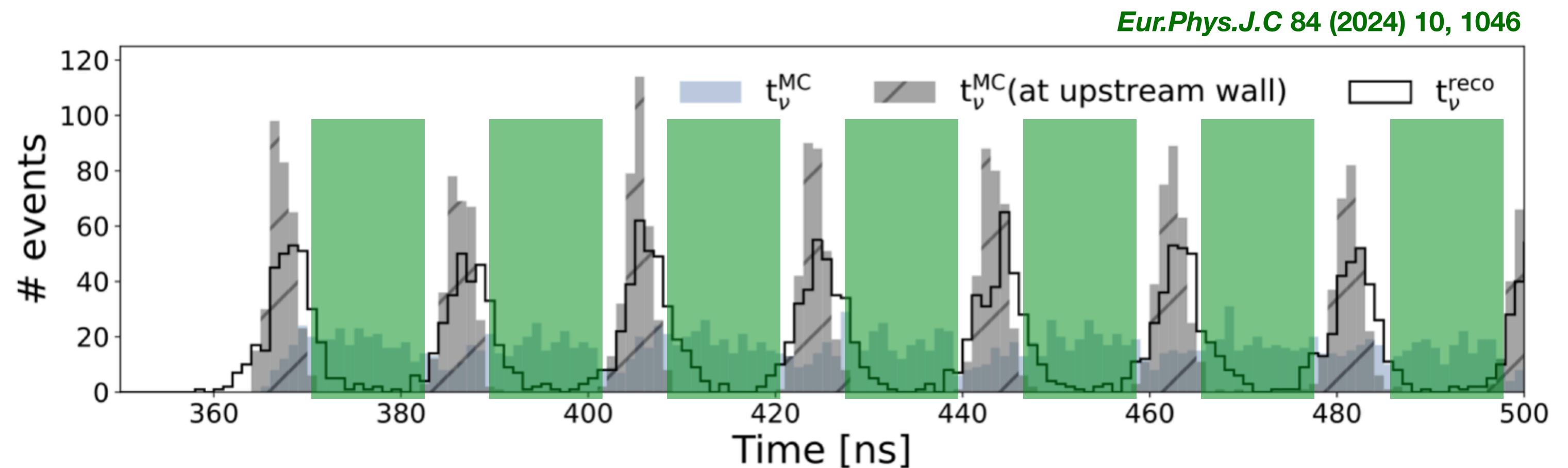
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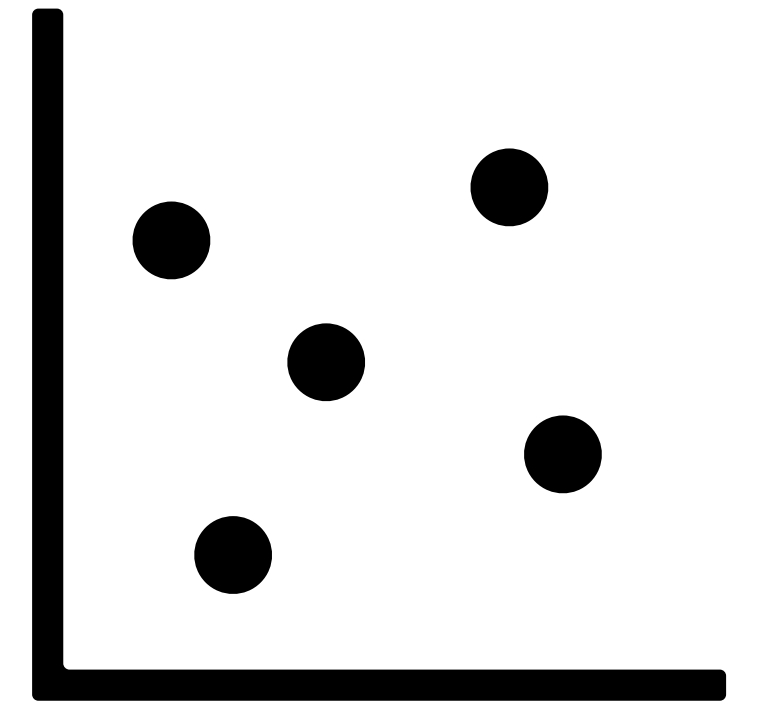
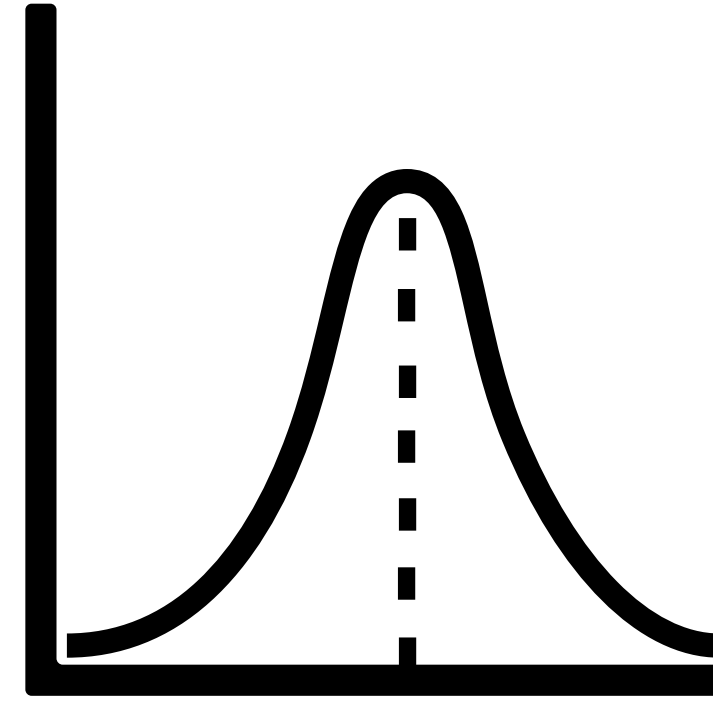


Background

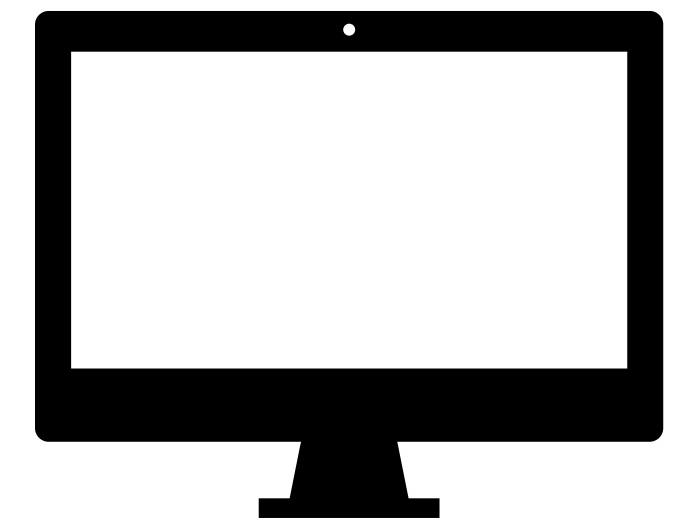
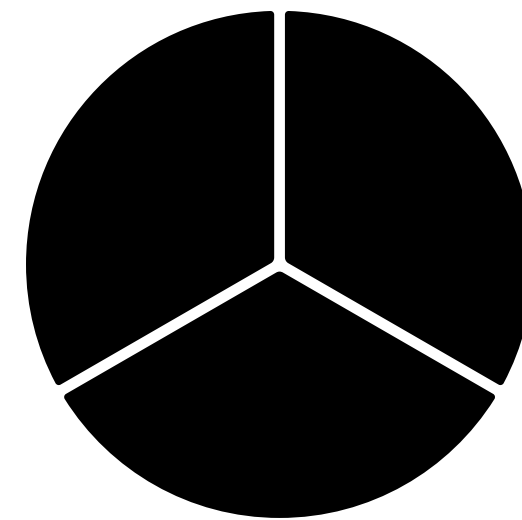
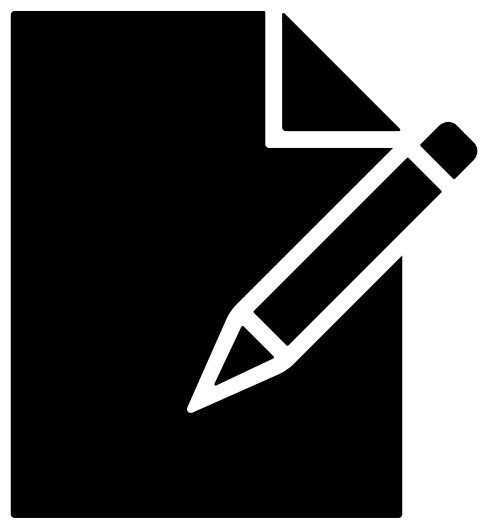
Beam-induced neutrinos events and cosmic-ray induced ones

Simulation framework

BSM signal simulation is performed using either standalone generators or the MeVPortal software. The MeVPortal framework has been developed by the SBN collaboration (arXiv:2605.11321) and will soon include all relevant models.



Searches Overview

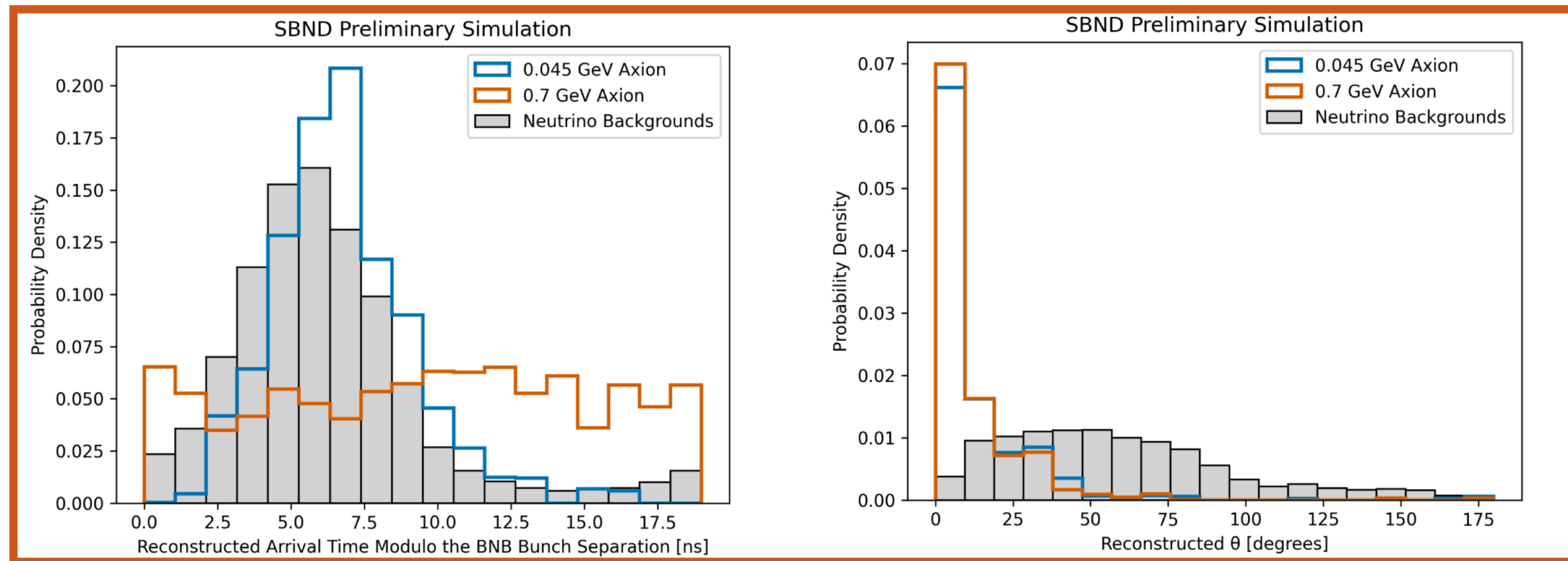


Heavy Axion QCD

Proposed solution to the Strong CP problem $\mathcal{L}_{\text{eff}} = \frac{a}{8\pi f_a} (c_3 \alpha_3 G\tilde{G} + c_2 \alpha_2 W\tilde{W} + c_1 \alpha_1 B\tilde{B})$

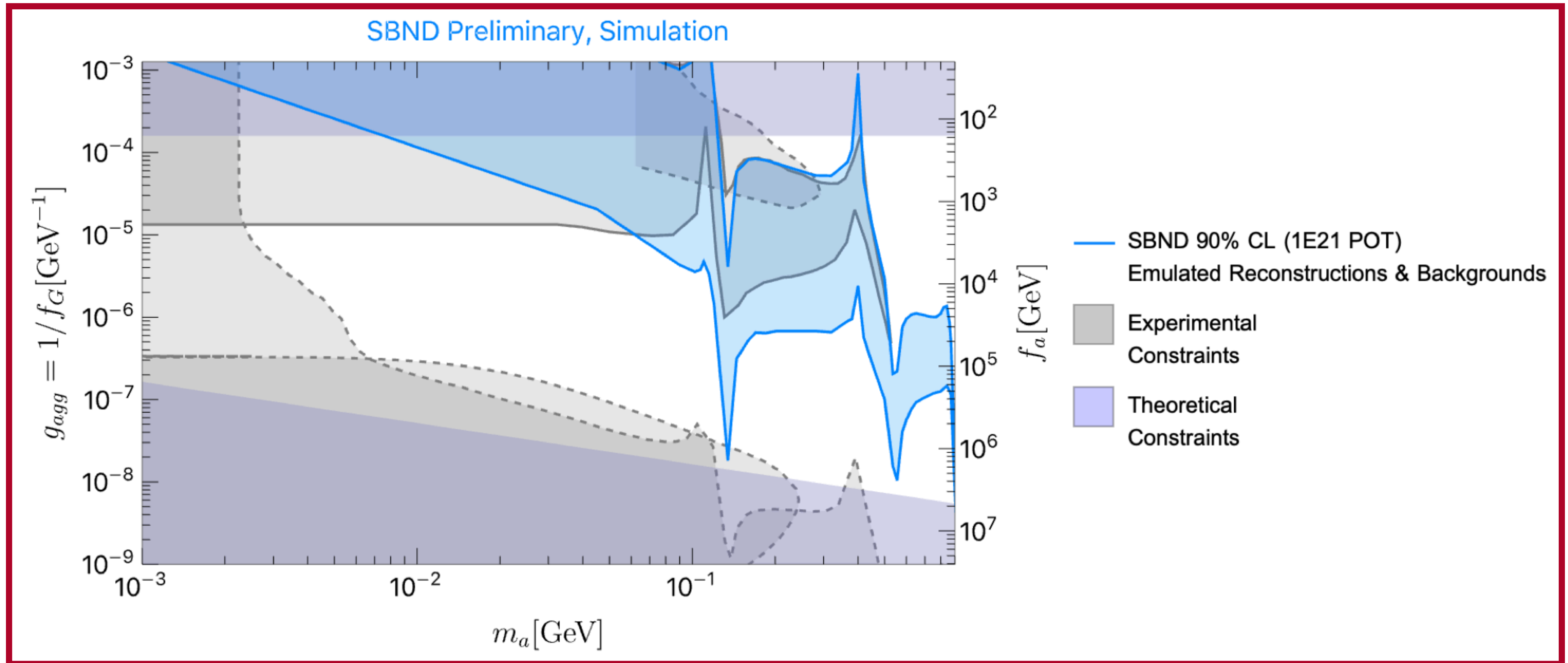
The axions can couple with gluons, leptons and hadrons with the Standard Model gauge coupling (α_i) and the different contributions are described by c_i . **Codominant scenario:** $c_1 = c_2 = c_3$

Produced by neutral mesons π^0, η, η' in the BNB while for decay channel we focus on $a \longrightarrow \gamma\gamma$ that result in SBND as **electromagnetic shower activity**.



**Exploiting time delays
and angular distribution**

Heavy Axion QCD



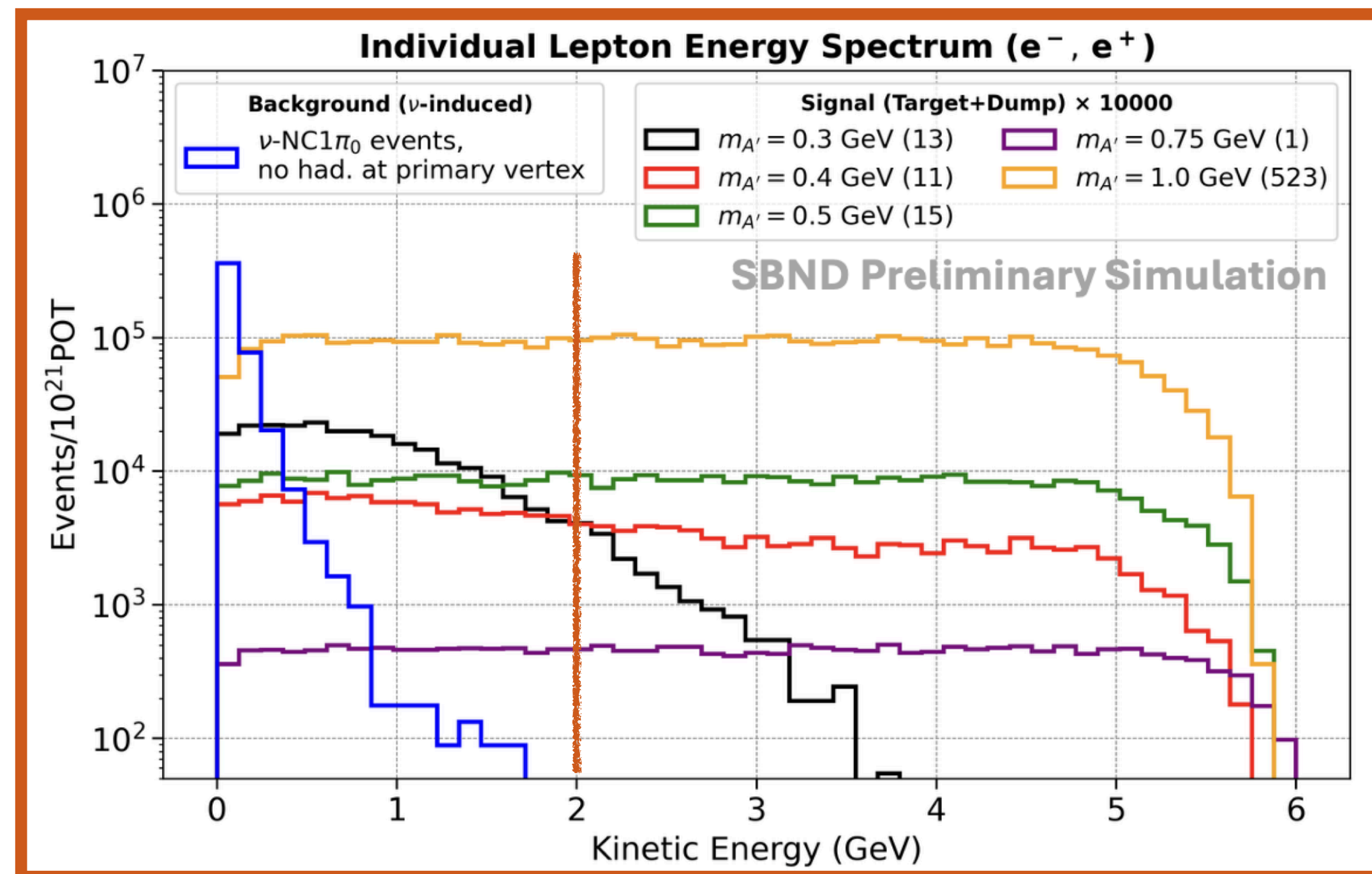
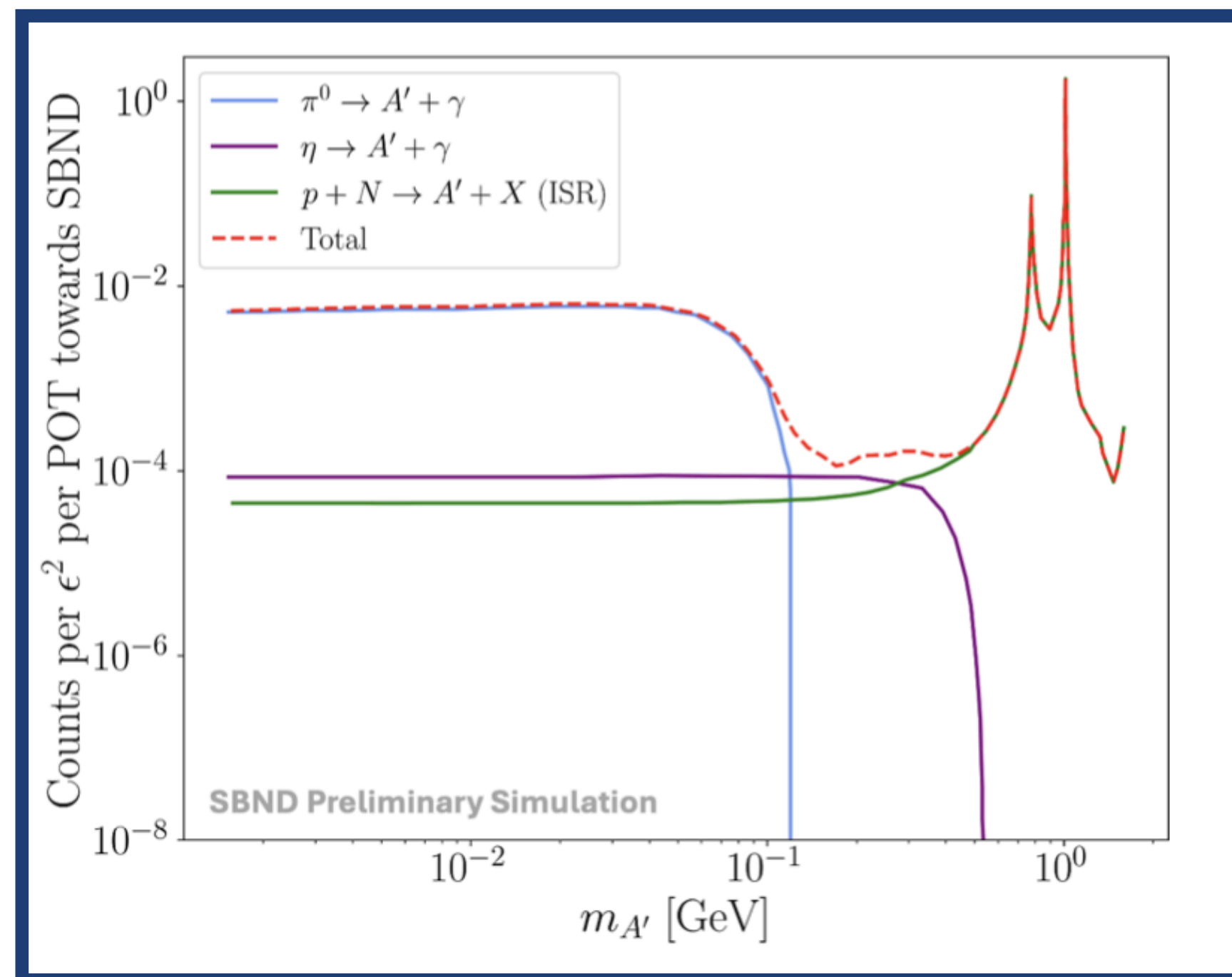
**Ability to explore new world-leading
Heavy QCD axions parameter space**

Dark Photon

U(1) gauge boson coupling to the SM via ϵ , kinetic mixing

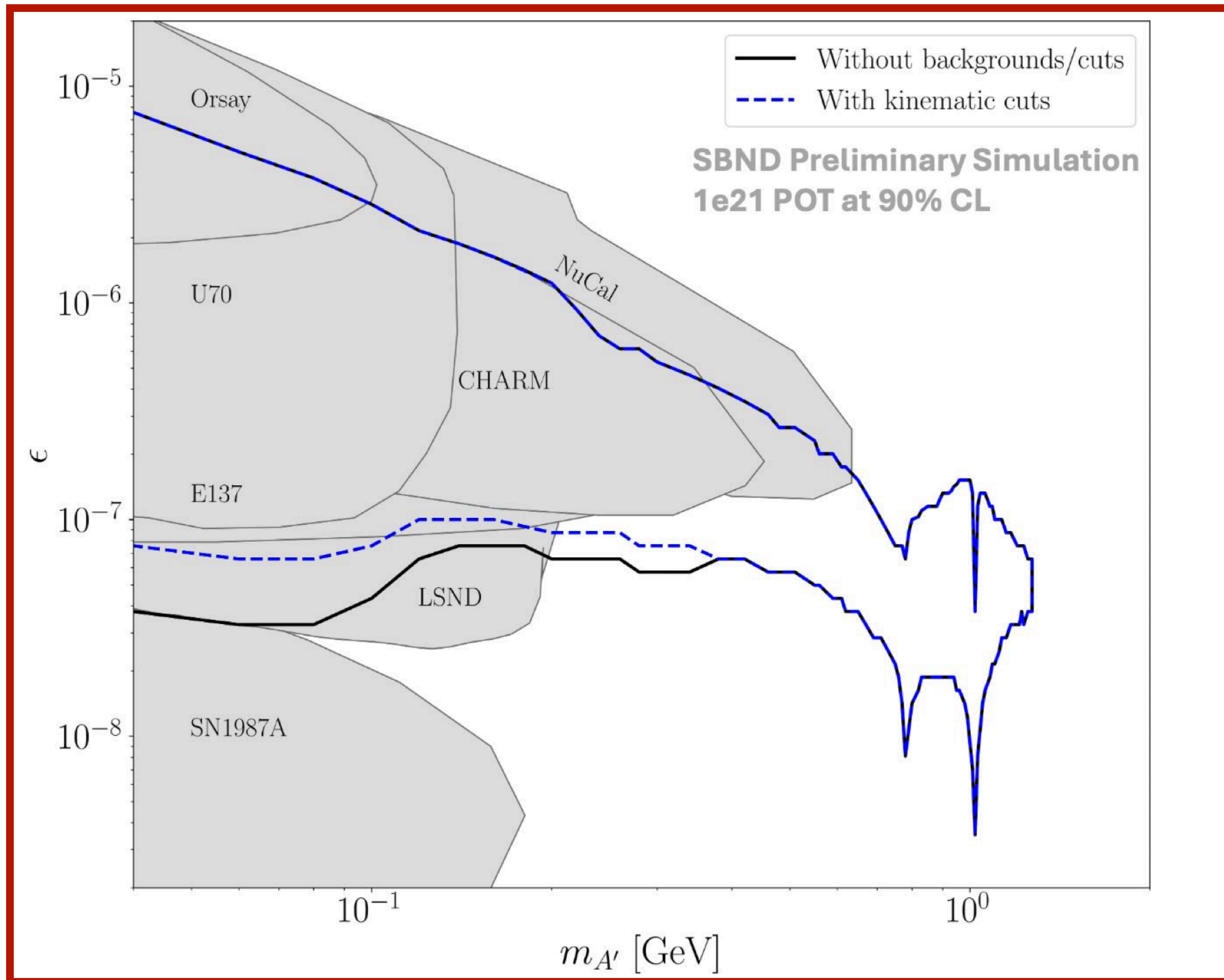
$$\mathcal{L} \supset -\frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{m_{A'}^2}{2} A'_\mu A'^\mu \longrightarrow \mathcal{L}_{eff} \supset \frac{m_{A'}^2}{2} A'_\mu A'^\mu + \epsilon e \sum_f q_f \bar{f} \gamma^\mu f A'_\mu$$

Produced by neutral mesons π^0, η 2-body decay in the BNB and by proton bremsstrahlung at the target, while for decay channel we focus on $A' \longrightarrow e^+ e^-$, that result in SBND as **electromagnetic shower activity**.



The higher kinetic energy of electromagnetic showers induced by Dark Photons can be exploited by applying a 2 GeV cut

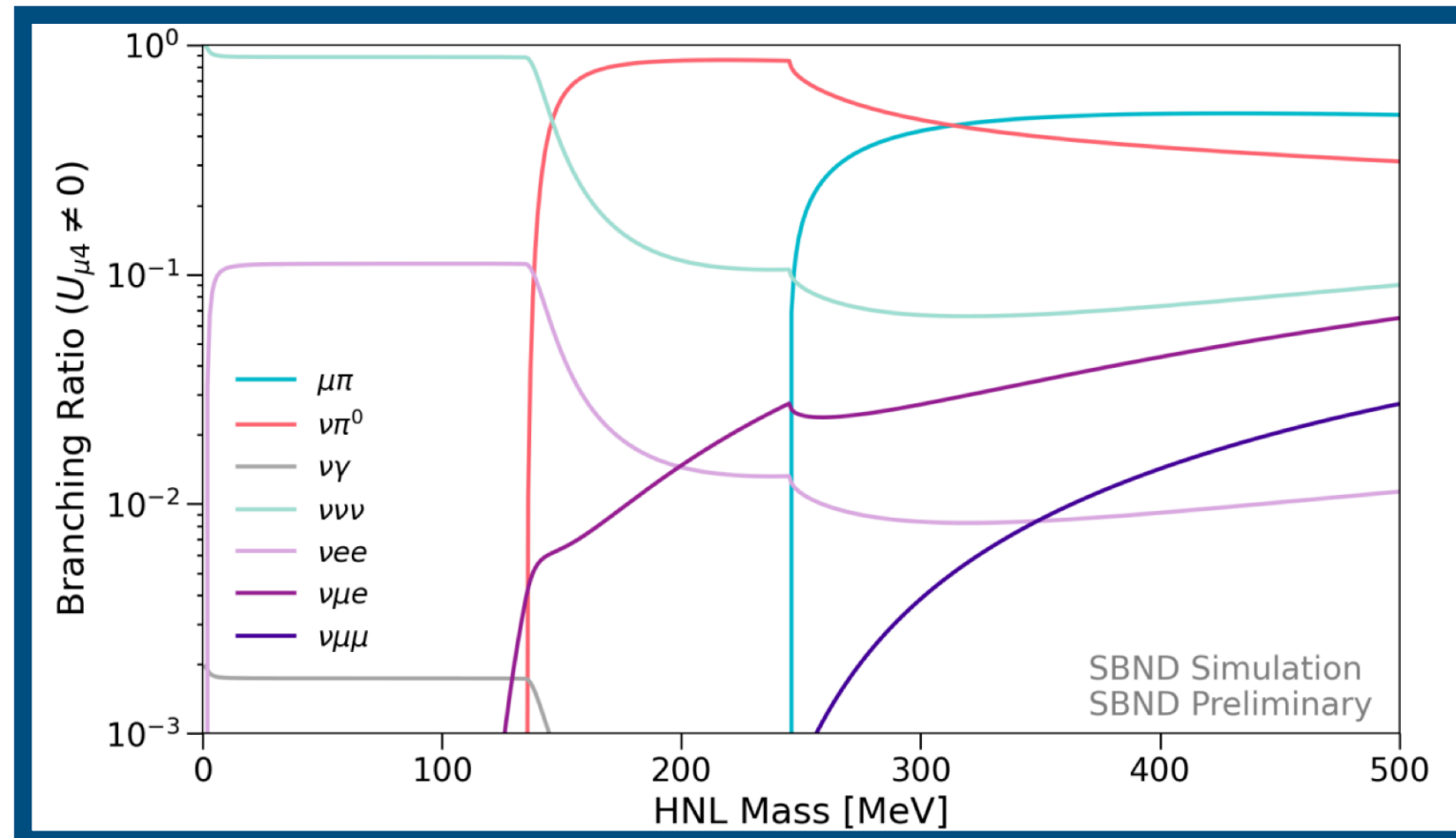
Dark Photon



**Ability to explore new world-leading
Dark Photon parameter space**

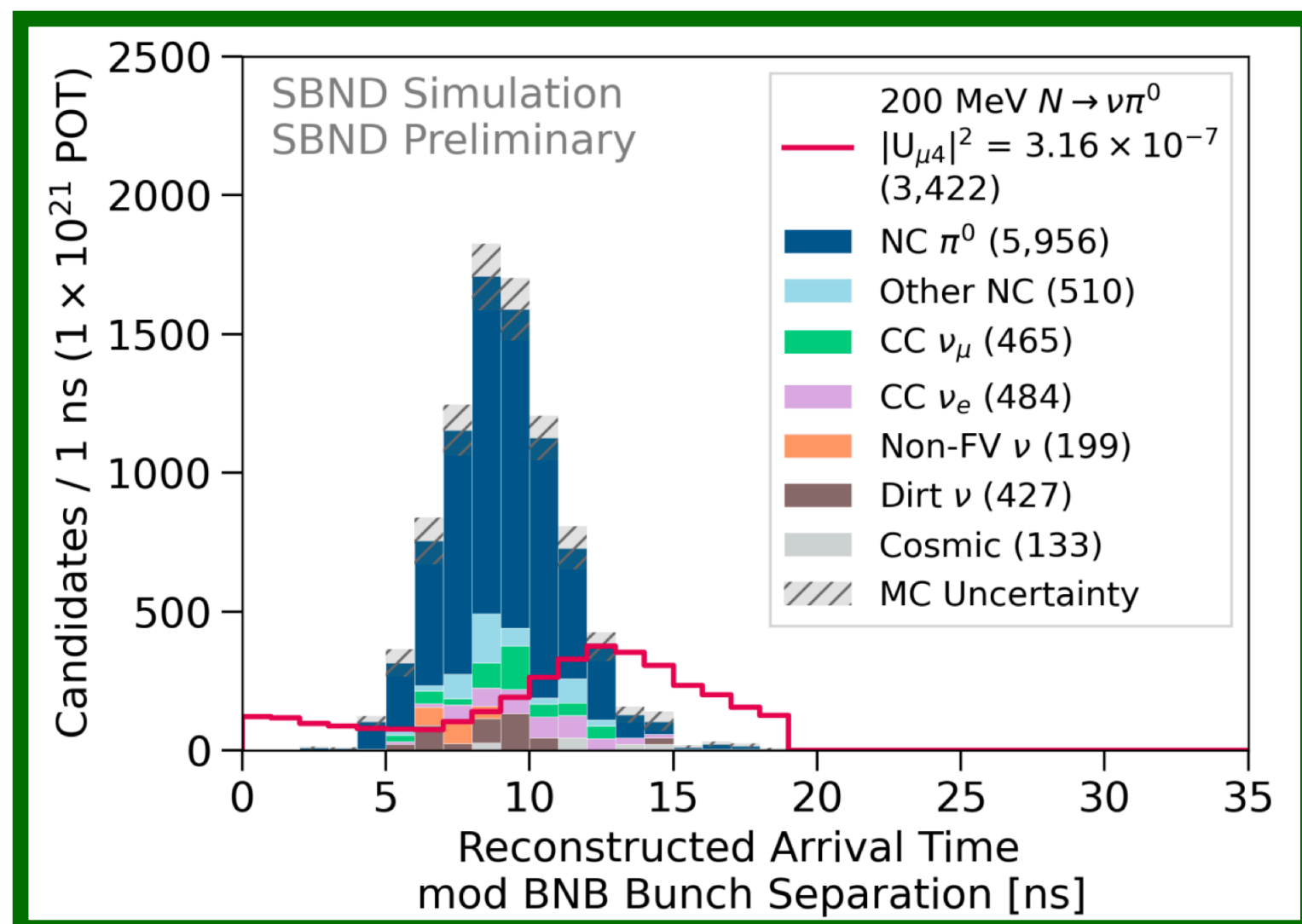
Heavy Neutral Lepton

Proposed as right-handed fermion coupled to the standard neutrinos via an extended PMNS matrix. Assumed as Majorana one for this analysis. **Complete SBND reconstruction chain is performed**



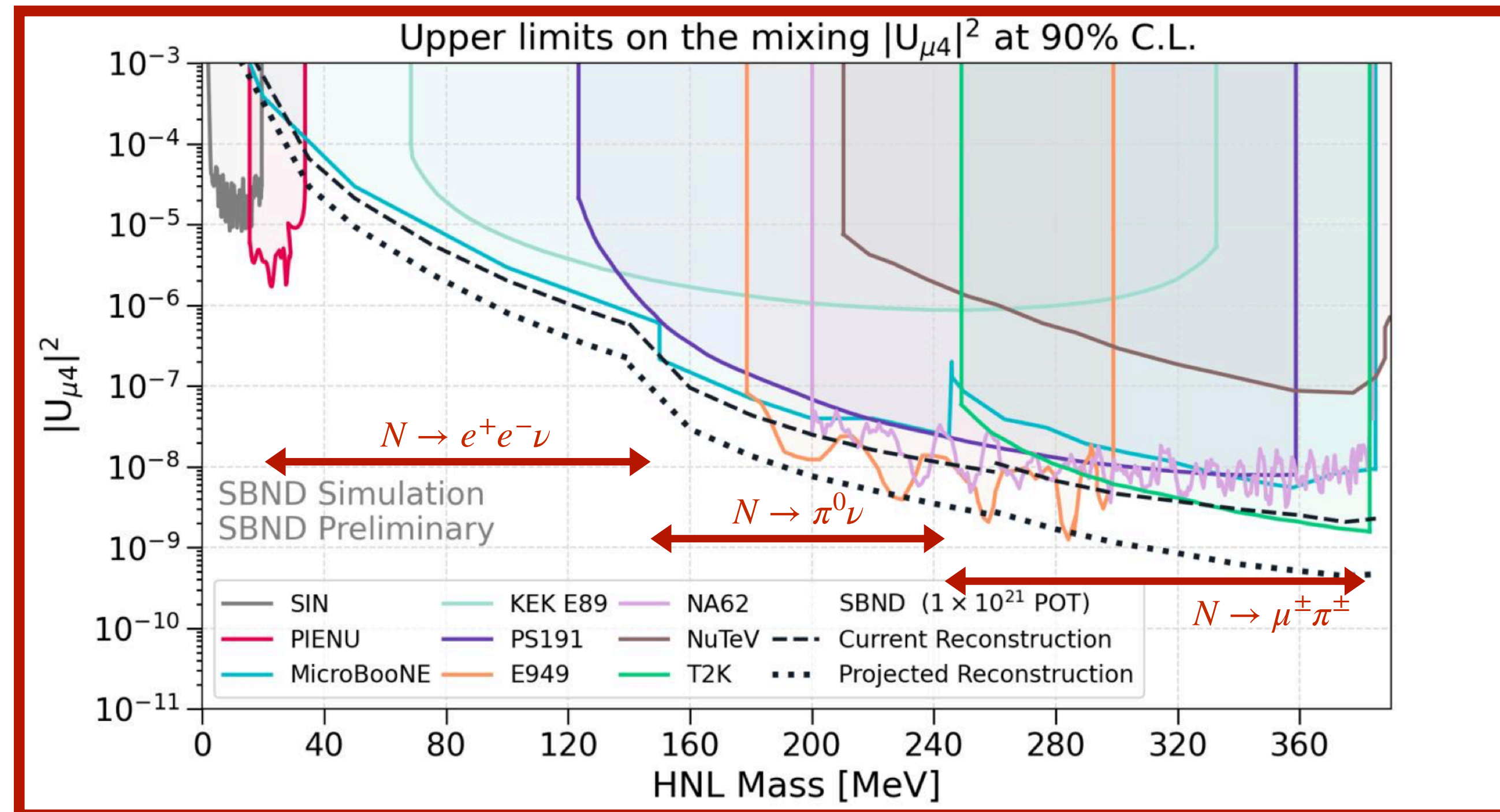
**MeVPrtl
simulation**

[arXiv:2605.11321](https://arxiv.org/abs/2605.11321)



**Exploiting
time delays
relative to
neutrinos
(arrival time)**

Sensitivity

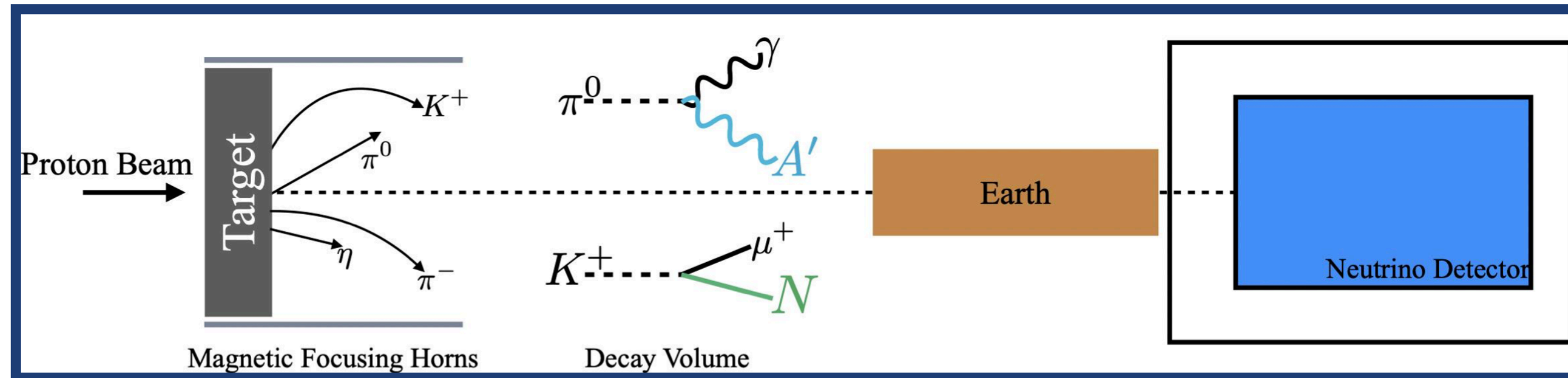


**Ability to explore new world-leading
HNL parameter space**

Long-Lived Particle

Model-independent search for exotic particles produced in the BNB and decaying in SBND

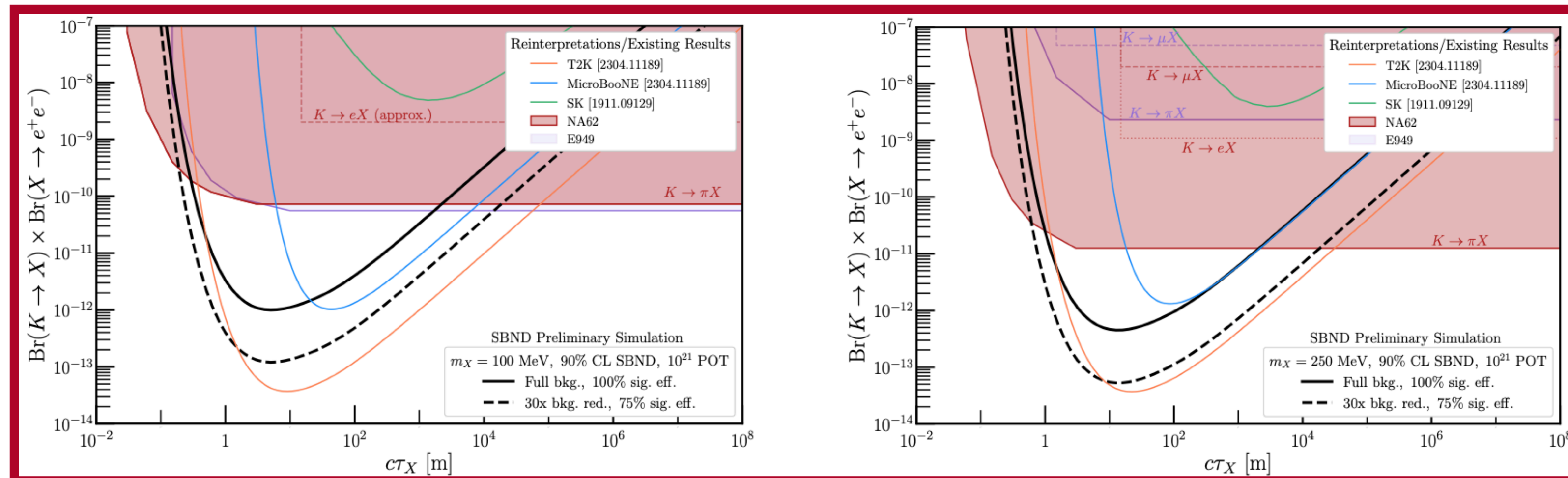
Production



For this analysis we consider the production channels

$$K^+ \rightarrow \pi^+ + X$$
$$K^+ \rightarrow \mu^+ + X$$

Sensitivity



A model-independent search also has the potential to explore new world-leading parameter space

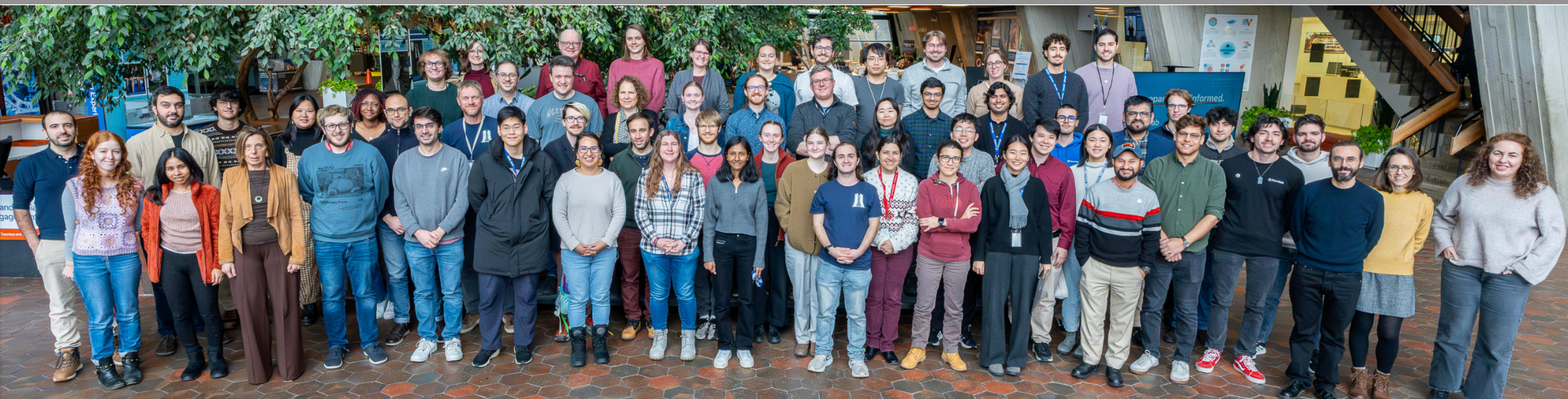
Simplified framework approach [arXiv:2304.11189](https://arxiv.org/abs/2304.11189)

Summary and Outlook

SBND has capability to probe many BSM models — a publication is in preparation!

- **LArTPC and PDS provide excellent spatial and timing resolution**
- **Timing and kinematic analyses offer the potential for world-leading searches**
- **With its large data sample, SBND is sensitive to dark matter and dark sector models, as well as neutrino mass models, and enables model-independent analyses for broader investigations.**

Ongoing SBND data analyses are expected to produce exciting new insights — stay tuned!

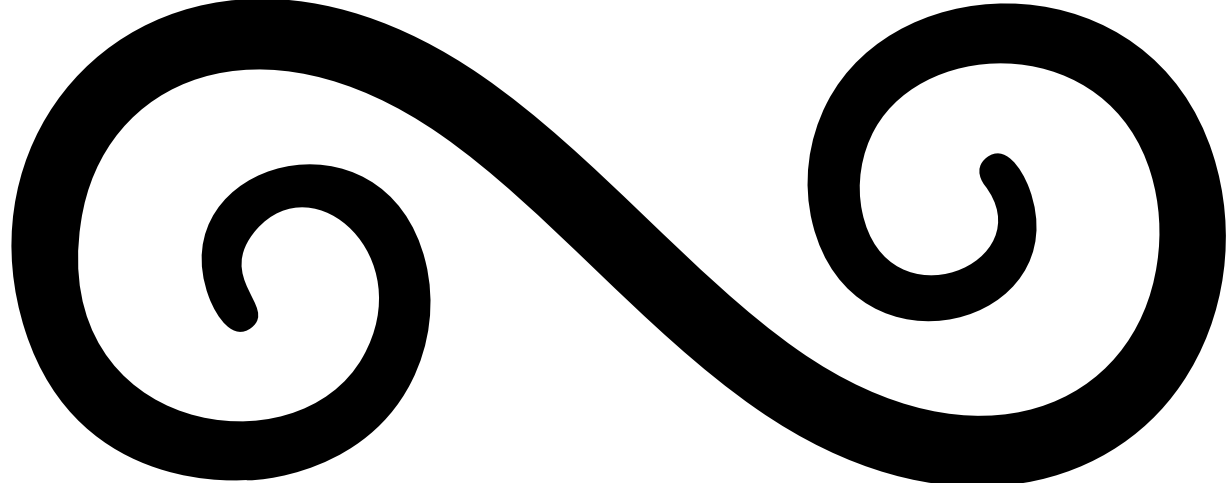


SBND Collaboration

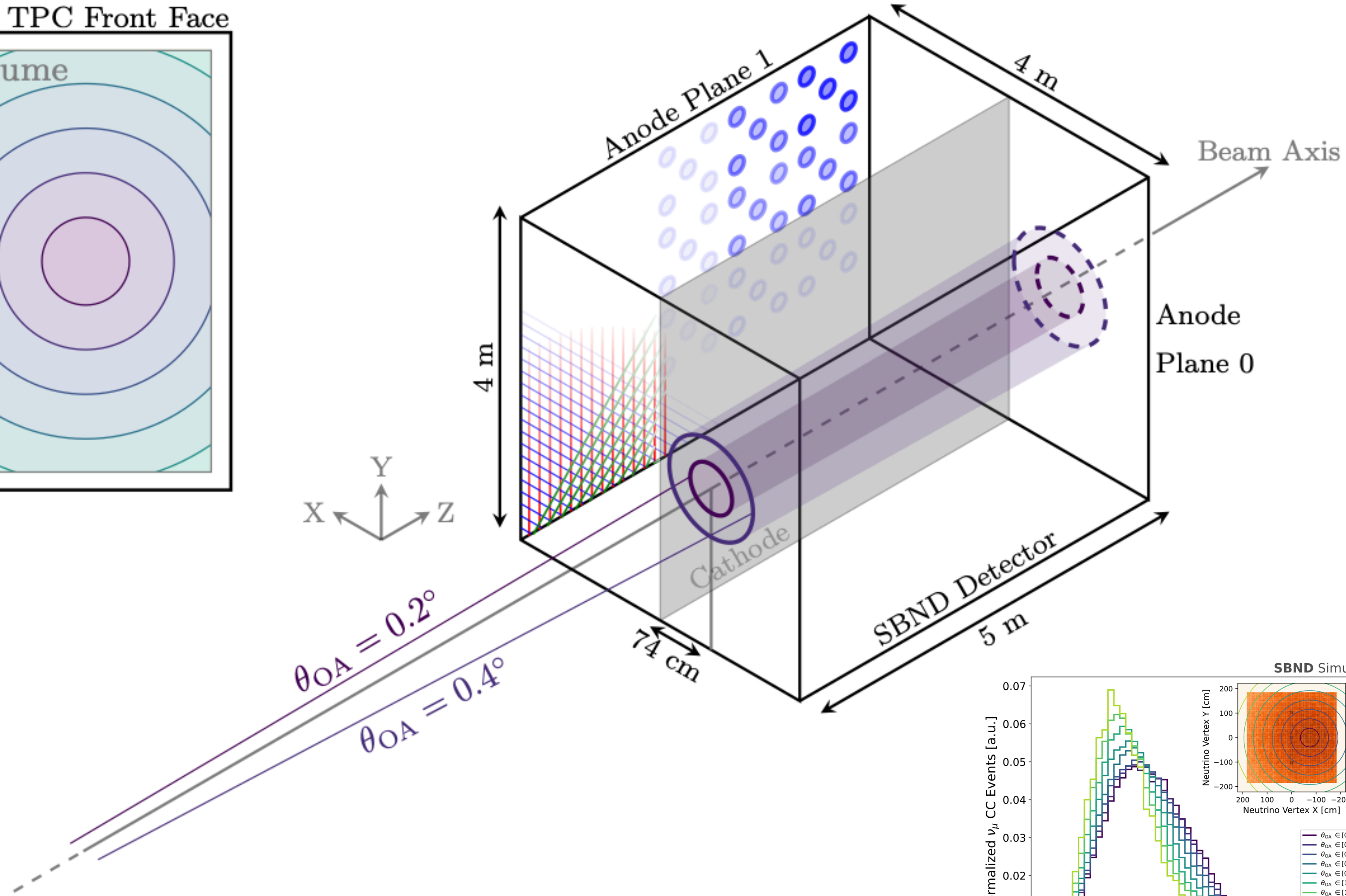
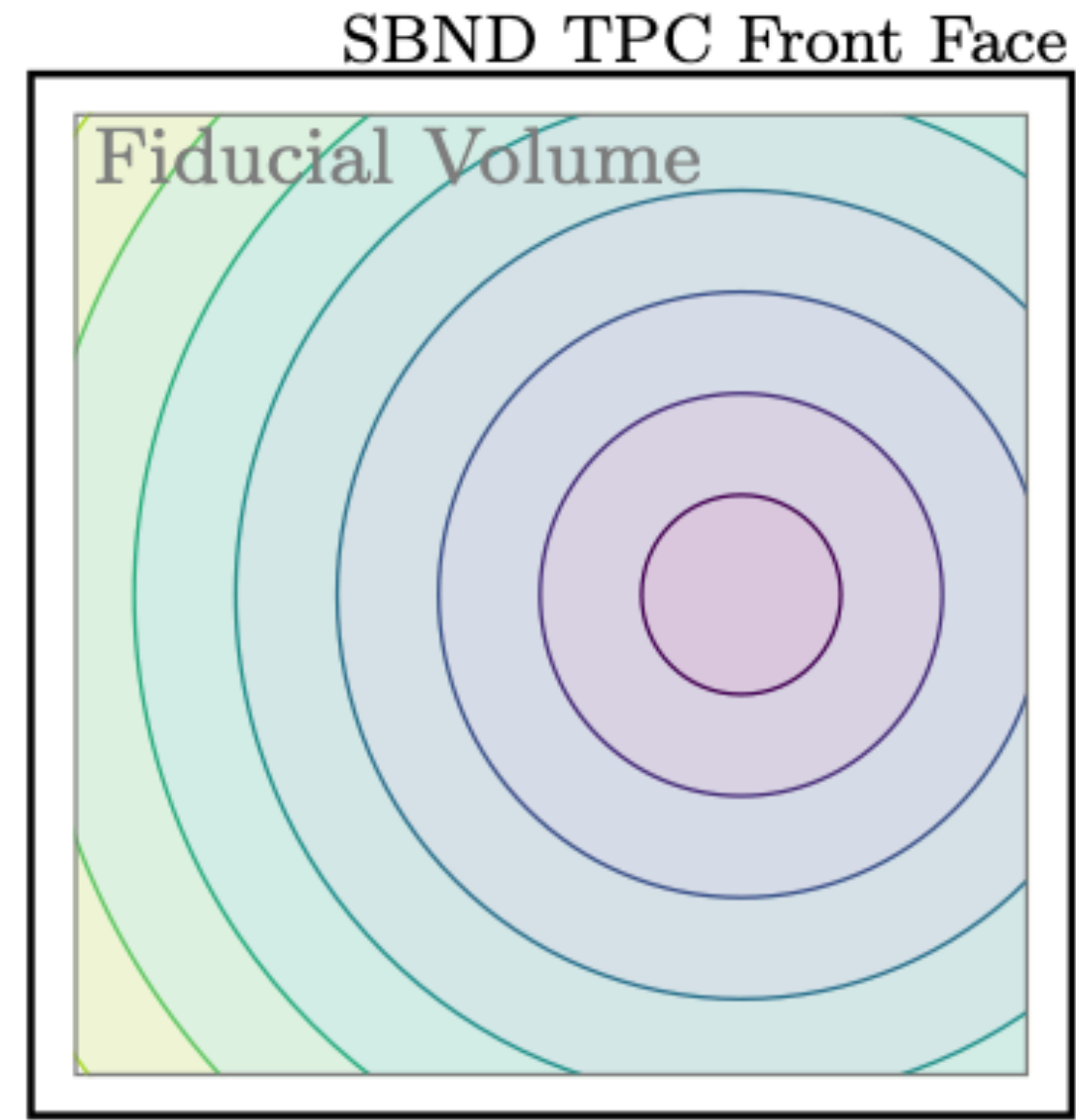
December 2025 Collaboration Meeting, Fermilab

Thank you!

Backup



PRISM



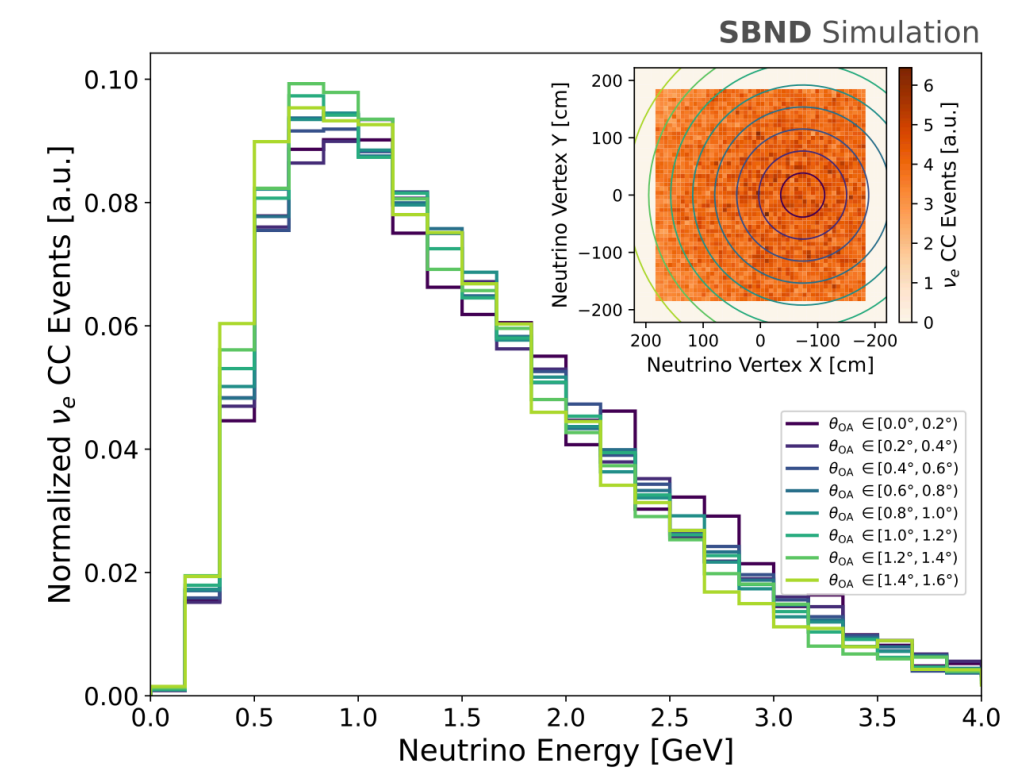
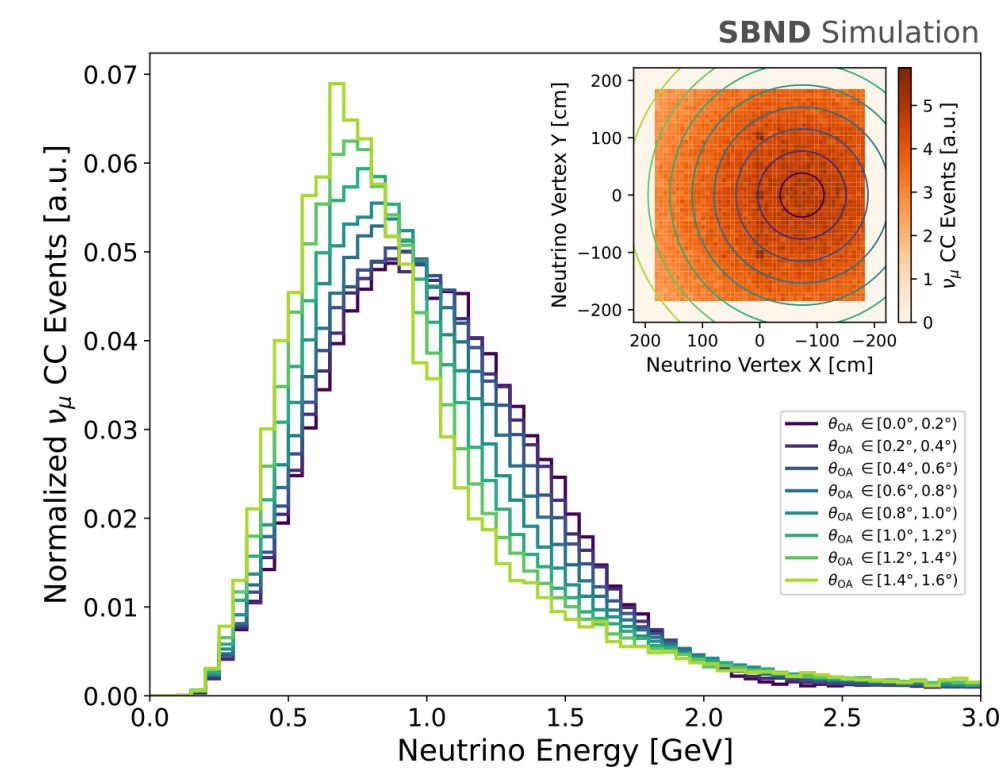
$$N(E) = \Phi(E) \sigma(E) \epsilon(E)$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu,$$

$$K^+ \rightarrow \mu^+ + \nu_\mu,$$

$$K^+ \rightarrow \pi^0 + e^+ + \nu_e,$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu.$$



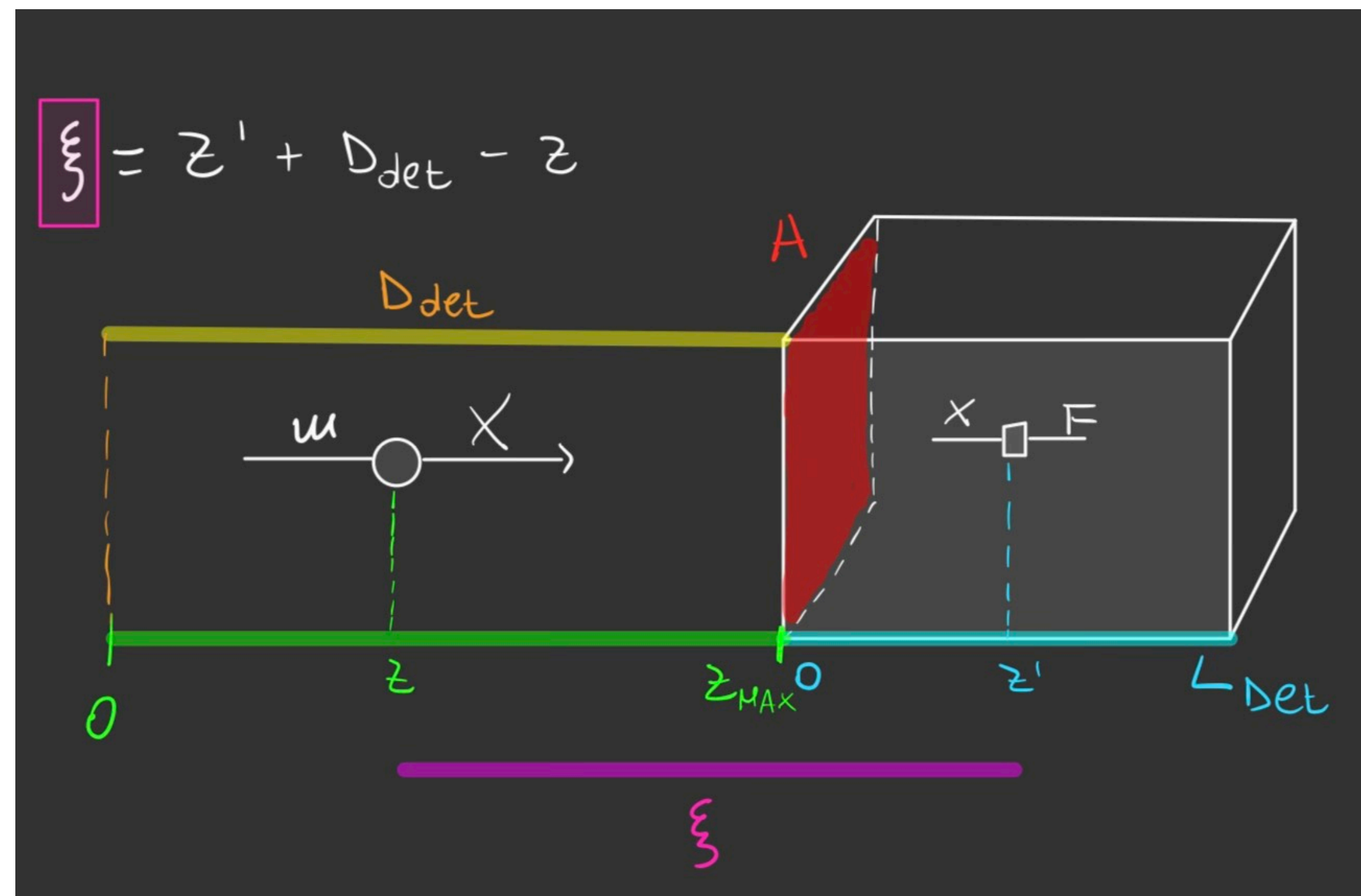
Simplified framework

$$\Phi_X = \frac{c_m N_{\text{POT}}}{A_{\text{Det.}}} \varepsilon(m; m_X, \dots) \text{Br}(m \rightarrow X)$$

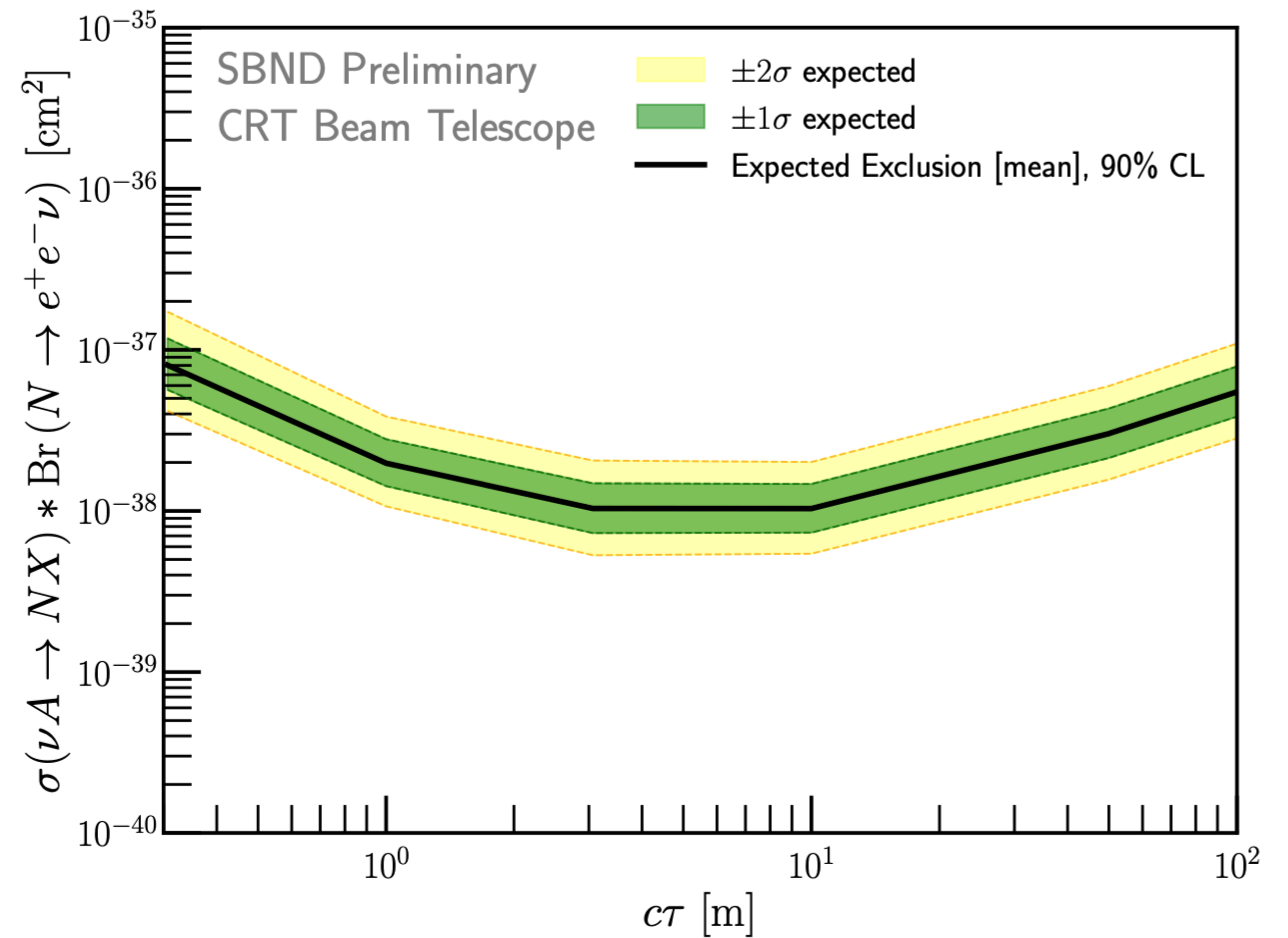
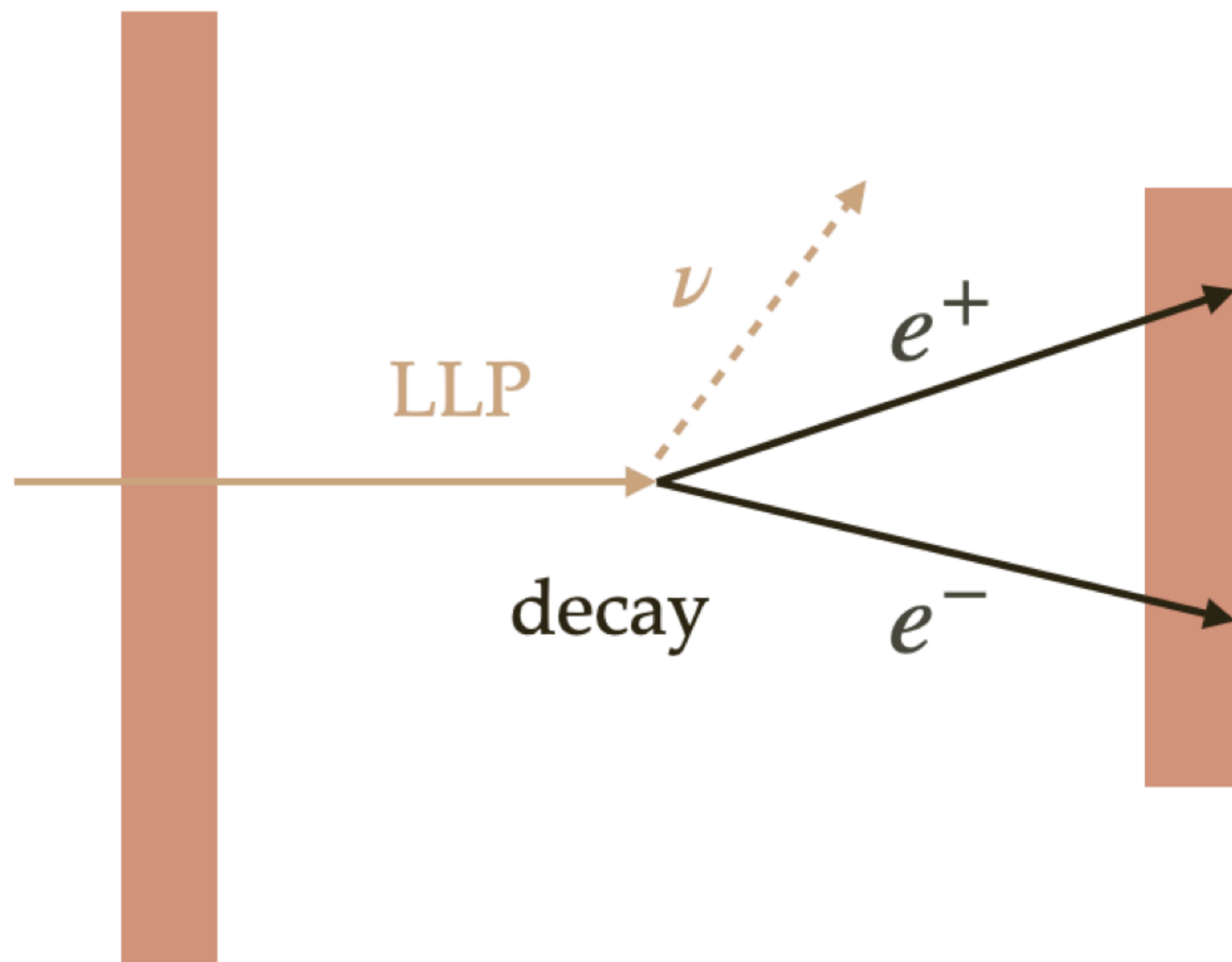
$$N_{\text{sig}}^F = \int dE_X \int_{A_{\text{Det.}}} dA \int_0^{z_{\text{max}}} dz \int_0^{L_{\text{Det.}}} \left(\frac{d^2 \Phi_X}{dE_X dz} P_{\text{Decay}}(E_X, z' + D_{\text{Det.}} - z) \text{Br}(X \rightarrow F) \right) dz'$$

$$N_{\text{sig}}^F = f(c\tau_{LLP}, m_{LLP}, \text{Br}(K \rightarrow \pi + LLP) \times \text{Br}(LLP \rightarrow F))$$

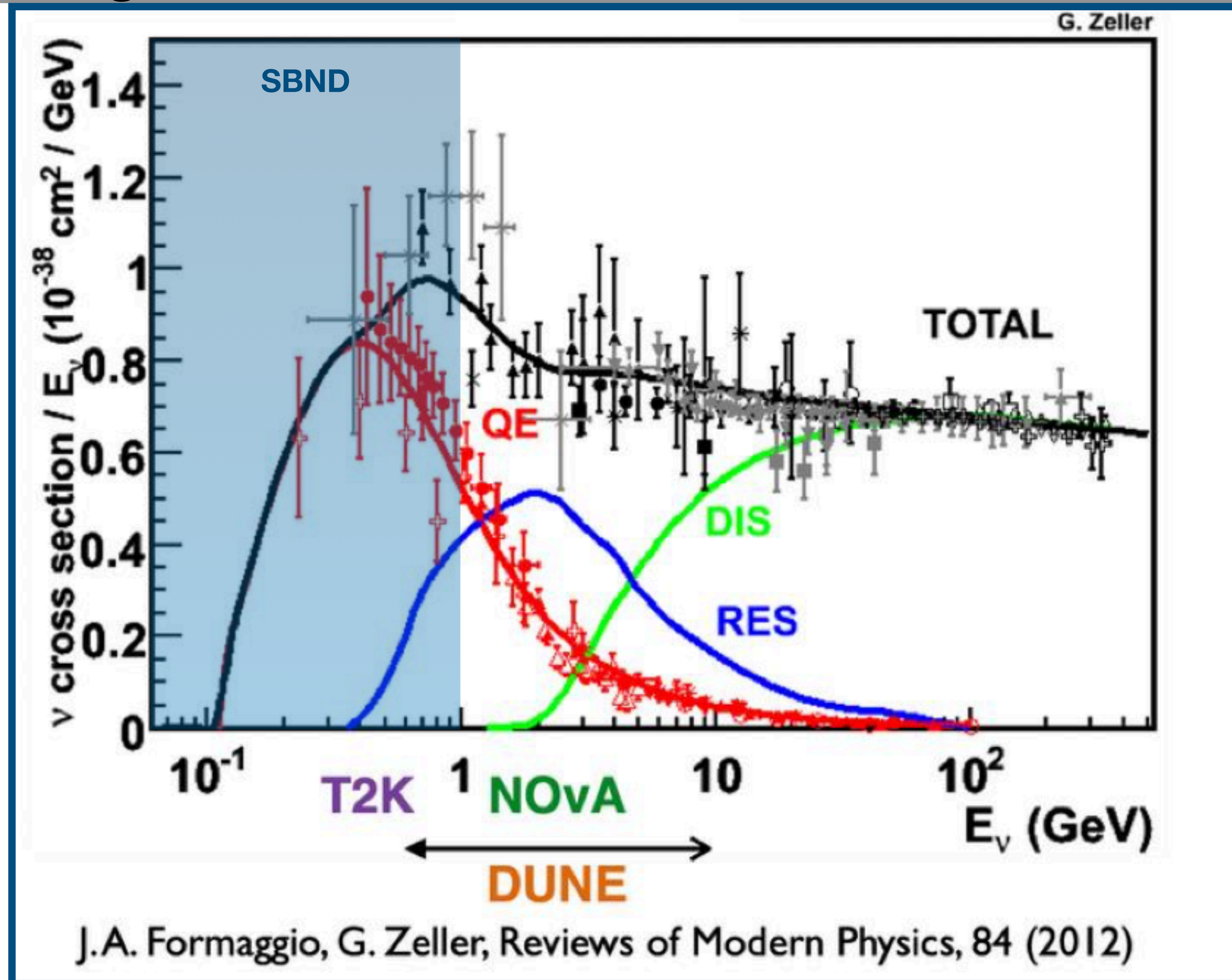
$$P_{\text{Decay}}(E_X, \zeta) = \frac{1}{\gamma_X \beta_X c \tau_X} e^{-\frac{\zeta}{\gamma_X \beta_X c \tau_X}}; \quad \gamma_X = \frac{E_X}{m_X}$$



Long-lived Particles in the SBND CRT Beam Telescope



Cross-section region



Dark photon time

