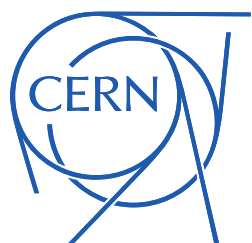


Physics Beyond the SM at the DUNE Near Detectors

Joachim Kopp (CERN & JGU Mainz)
Fermilab Neutrino Seminar Series | December 9, 2021

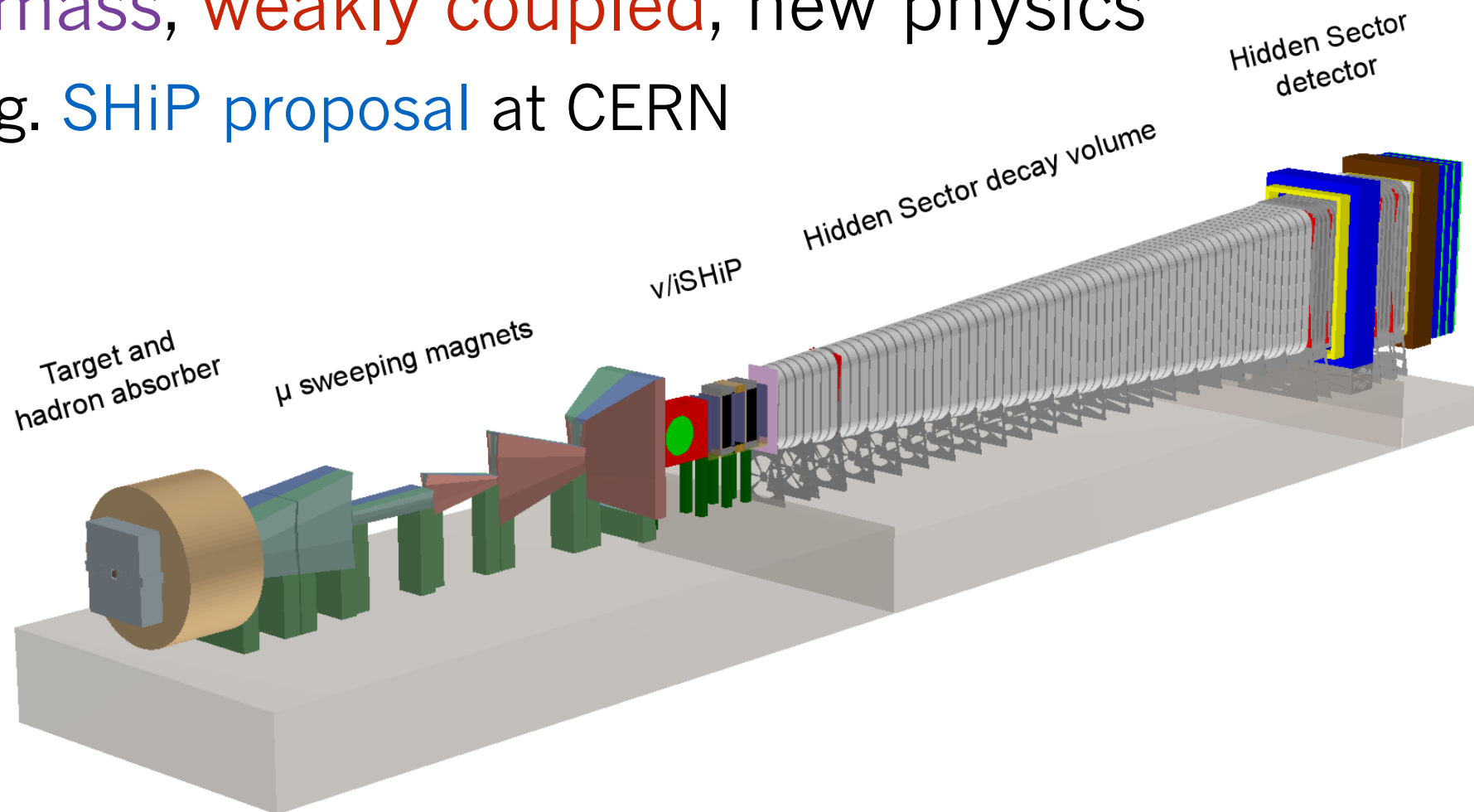
based on [arXiv:2102.03383](https://arxiv.org/abs/2102.03383)
with Moritz Breitbach, Luca Buonocore, Claudia Frugiuele, and Lukas Mitnacht



New Physics at Near Detectors

✓ Rich worldwide program searching for low-mass, weakly coupled, new physics

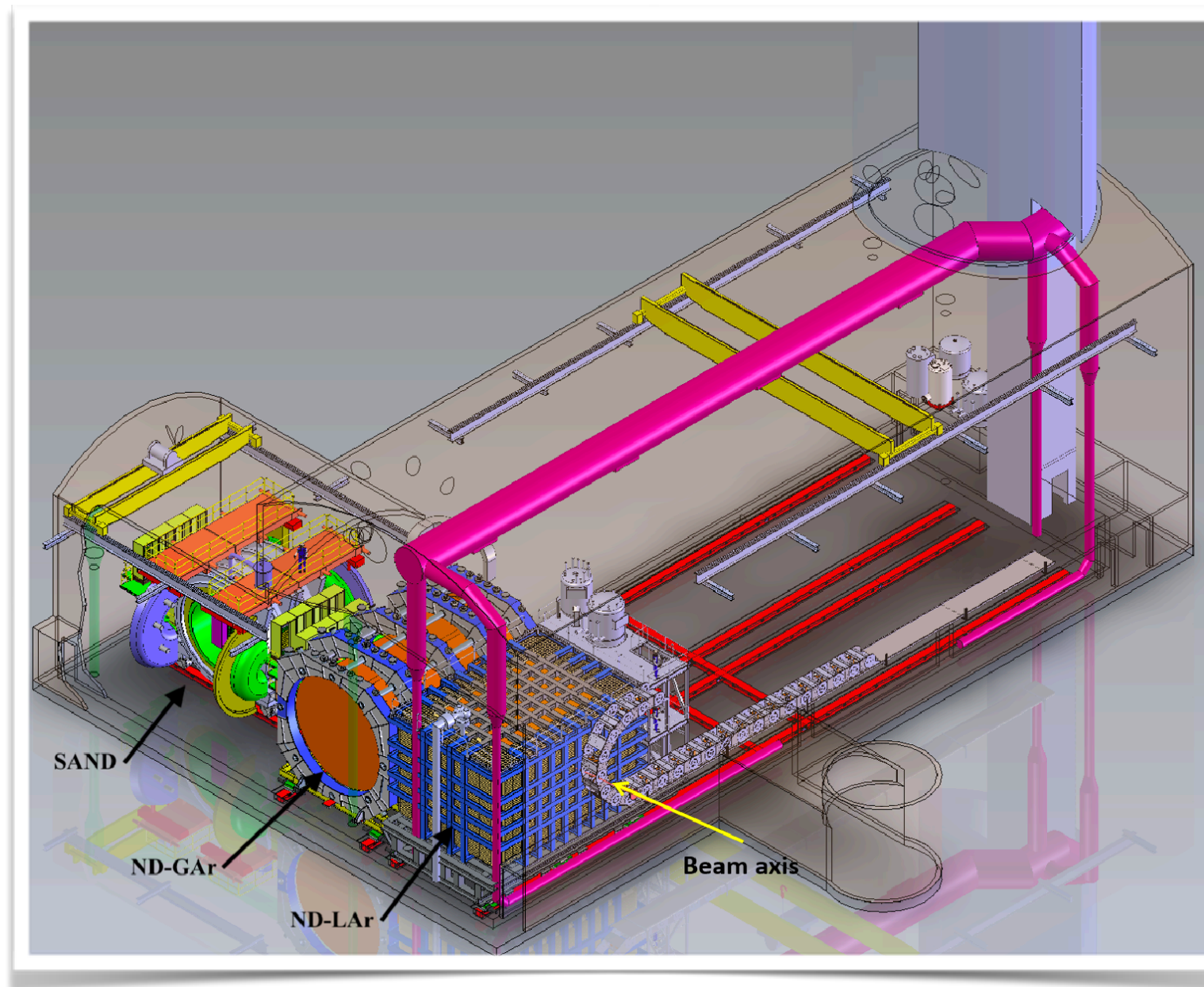
○ E.g. SHiP proposal at CERN



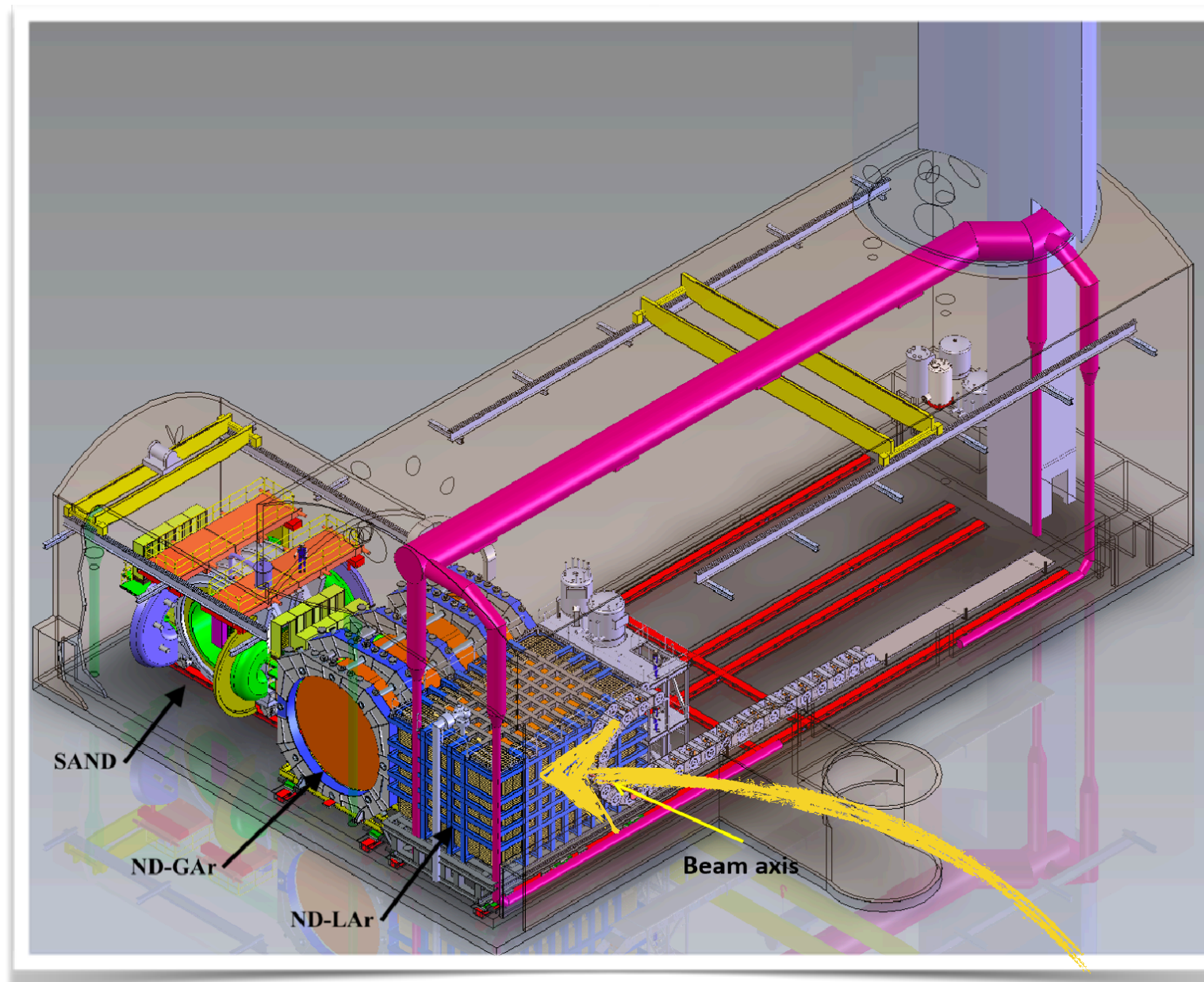
○ Search for displaced decays of new particles

✓ DUNE / T2HK Near Detectors have similar configuration

New Physics at Near Detectors

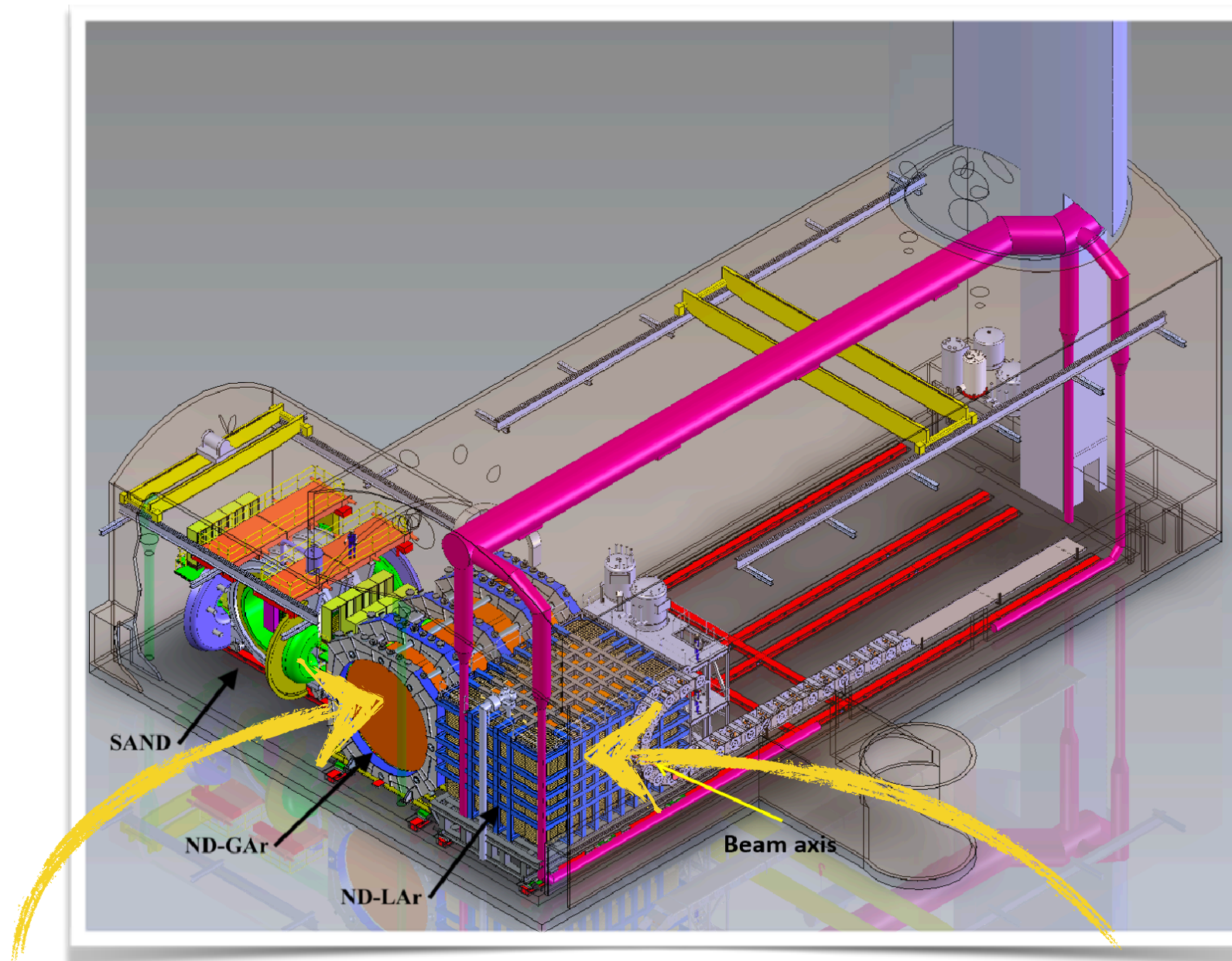


New Physics at Near Detectors



Liquid Argon TPC (“ND-LAr”)

New Physics at Near Detectors

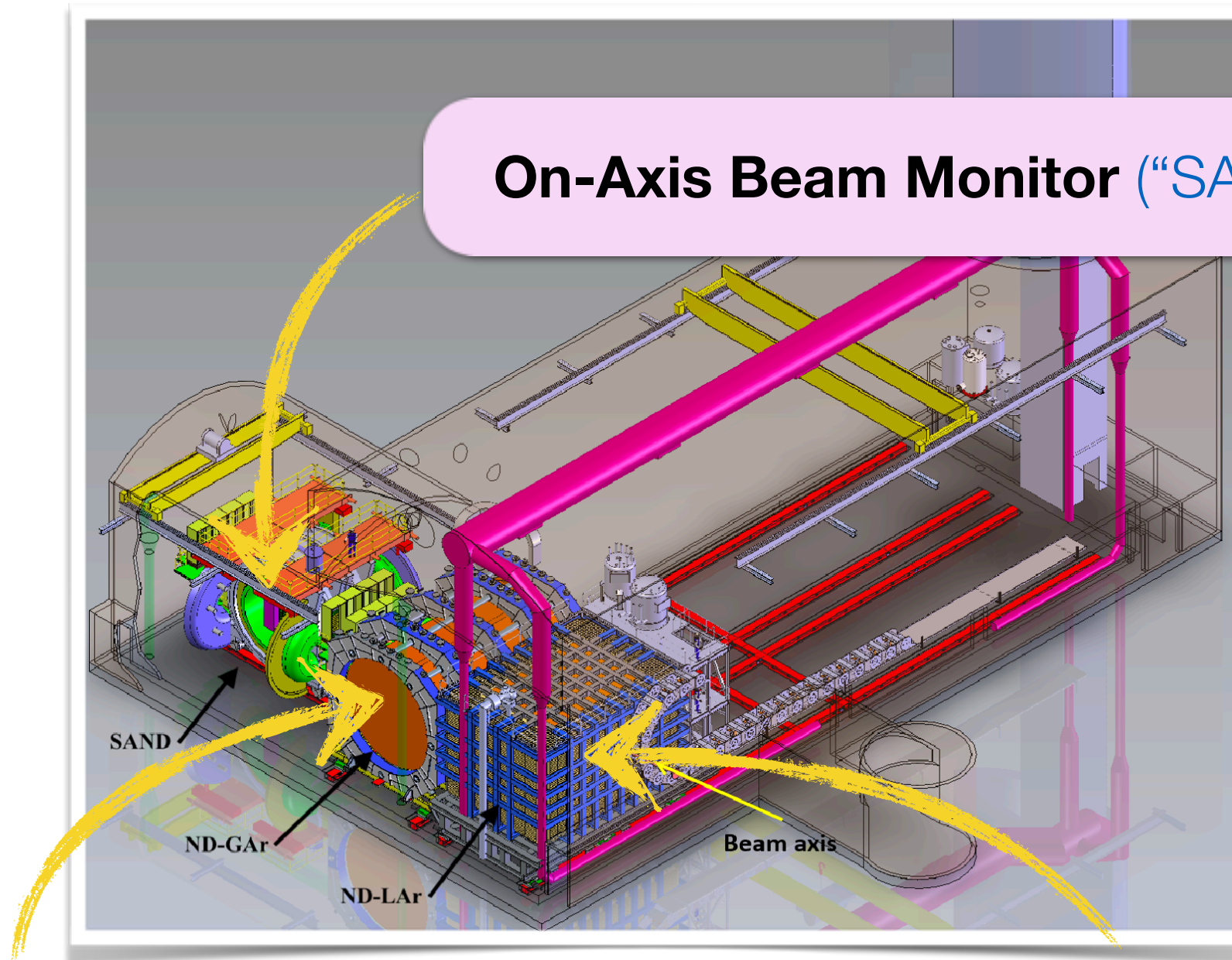


HP Gas TPC + ECal (“ND-GAr”)

Liquid Argon TPC (“ND-LAr”)

New Physics at Near Detectors

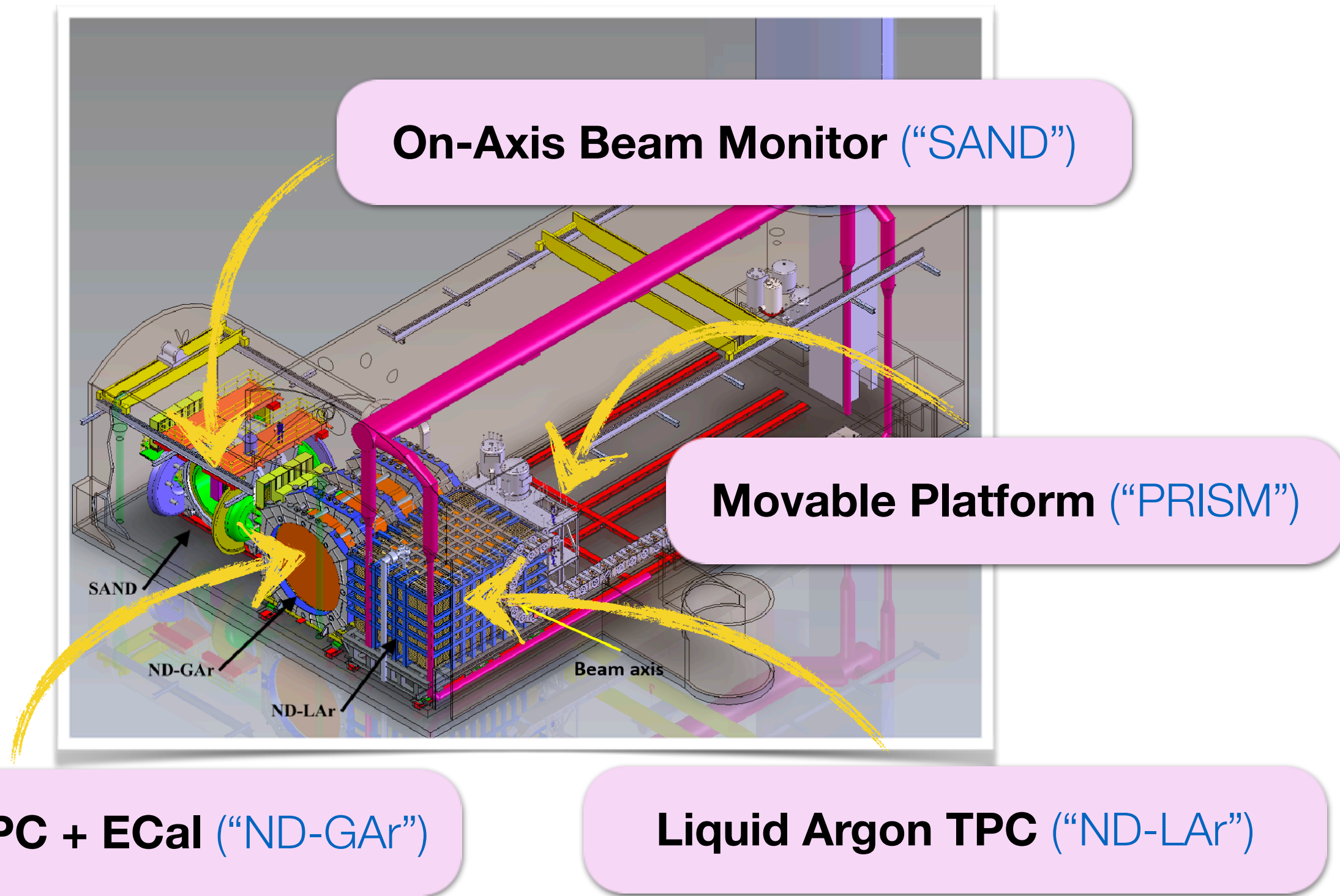
On-Axis Beam Monitor (“SAND”)



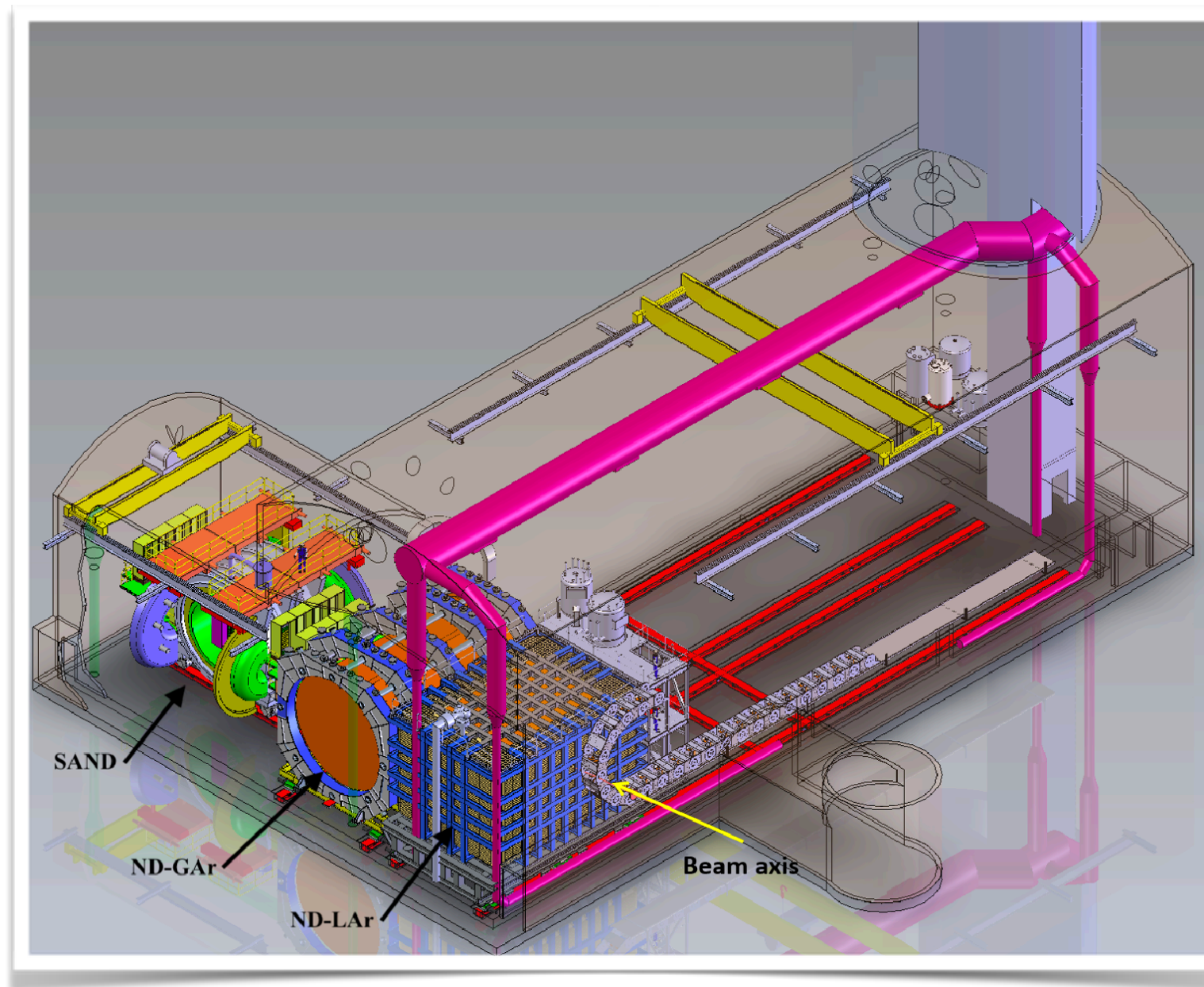
HP Gas TPC + ECal (“ND-GAr”)

Liquid Argon TPC (“ND-LAr”)

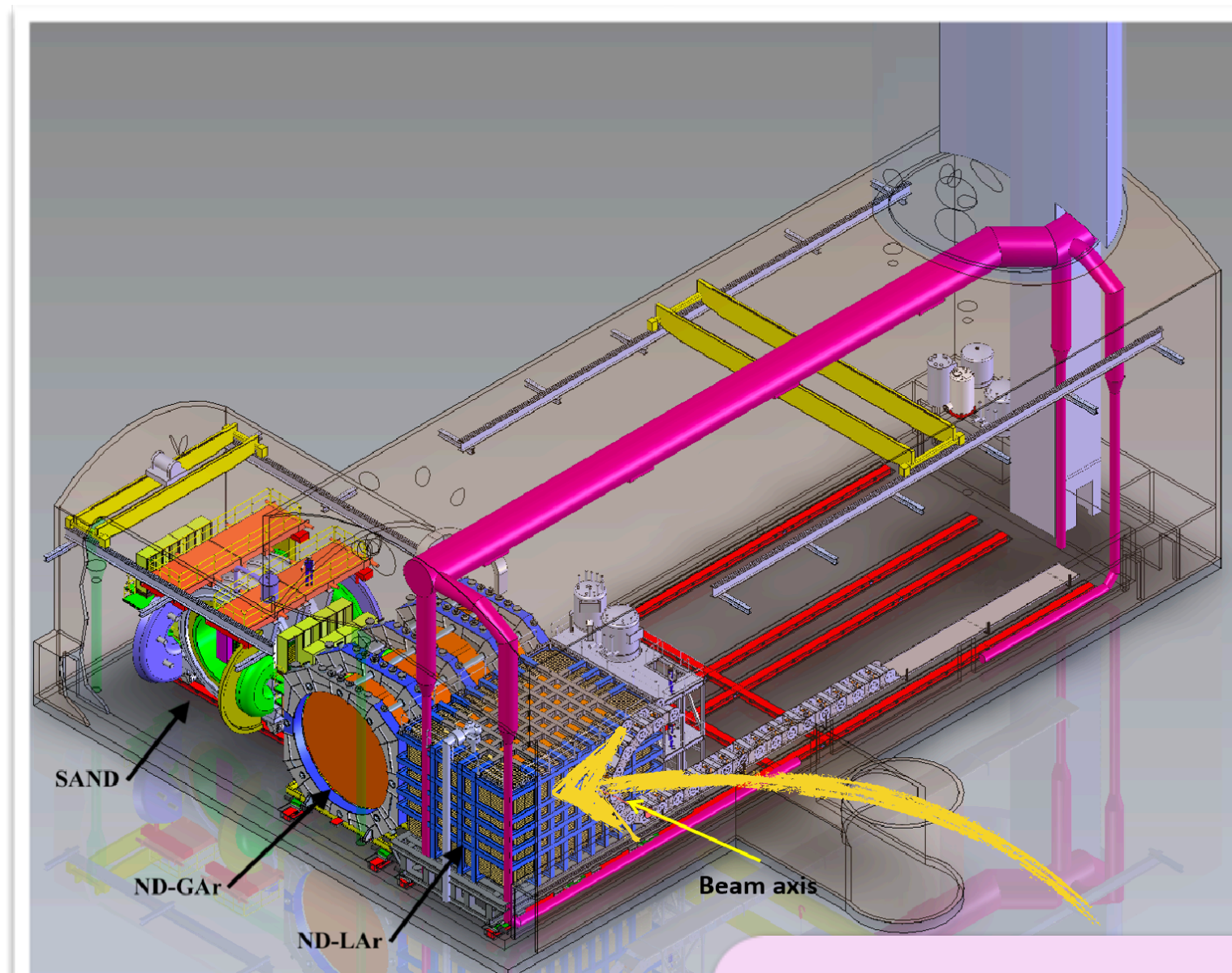
New Physics at Near Detectors



New Physics at Near Detectors



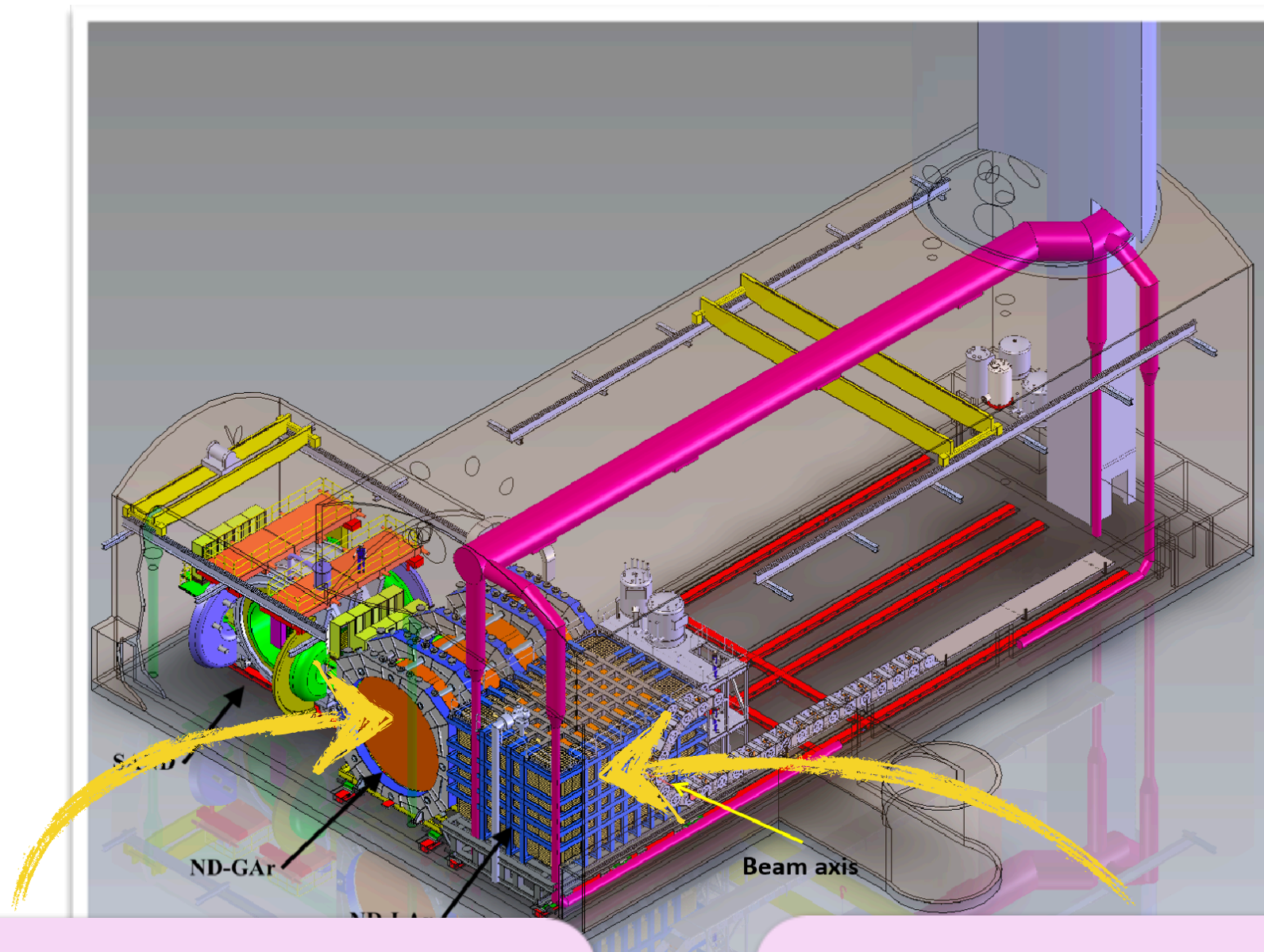
New Physics at Near Detectors



Liquid Argon TPC (“ND-LAr”)

- similar to far detector
(cancel systematic uncertainties)

New Physics at Near Detectors



HP Gas TPC + ECal (“ND-GAr”)

- excellent event reconstruction
- magnetic field

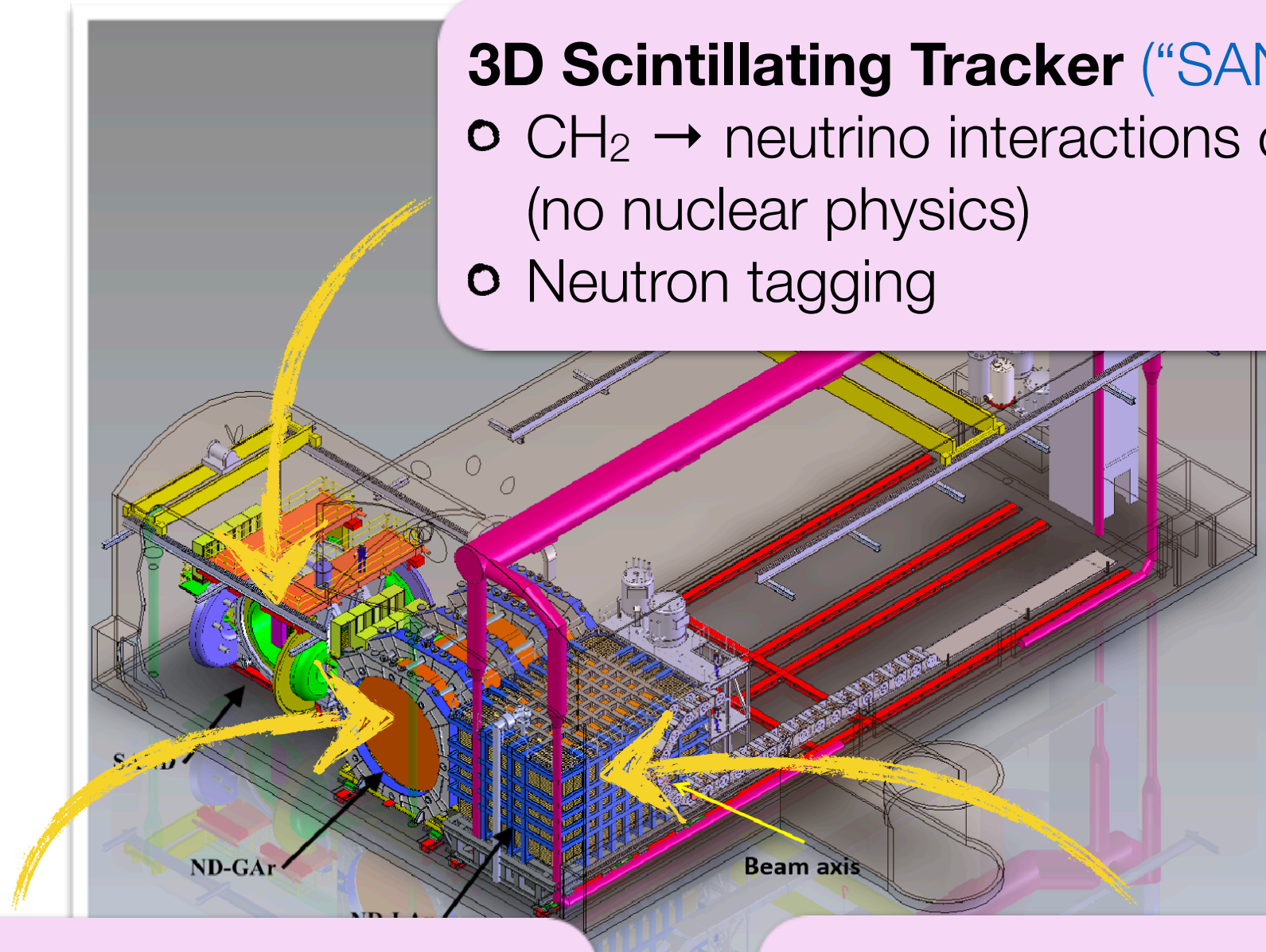
Liquid Argon TPC (“ND-LAr”)

- similar to far detector
- (cancel systematic uncertainties)

New Physics at Near Detectors

3D Scintillating Tracker (“SAND”)

- $\text{CH}_2 \rightarrow$ neutrino interactions on free protons (no nuclear physics)
- Neutron tagging



HP Gas TPC + ECal (“ND-GAr”)

- excellent event reconstruction
- magnetic field

Liquid Argon TPC (“ND-LAr”)

- similar to far detector (cancel systematic uncertainties)

New Physics at Near Detectors

3D Scintillating Tracker (“SAND”)

- $\text{CH}_2 \rightarrow$ neutrino interactions on free protons (no nuclear physics)
- Neutron tagging

Movable Platform (“PRISM”)

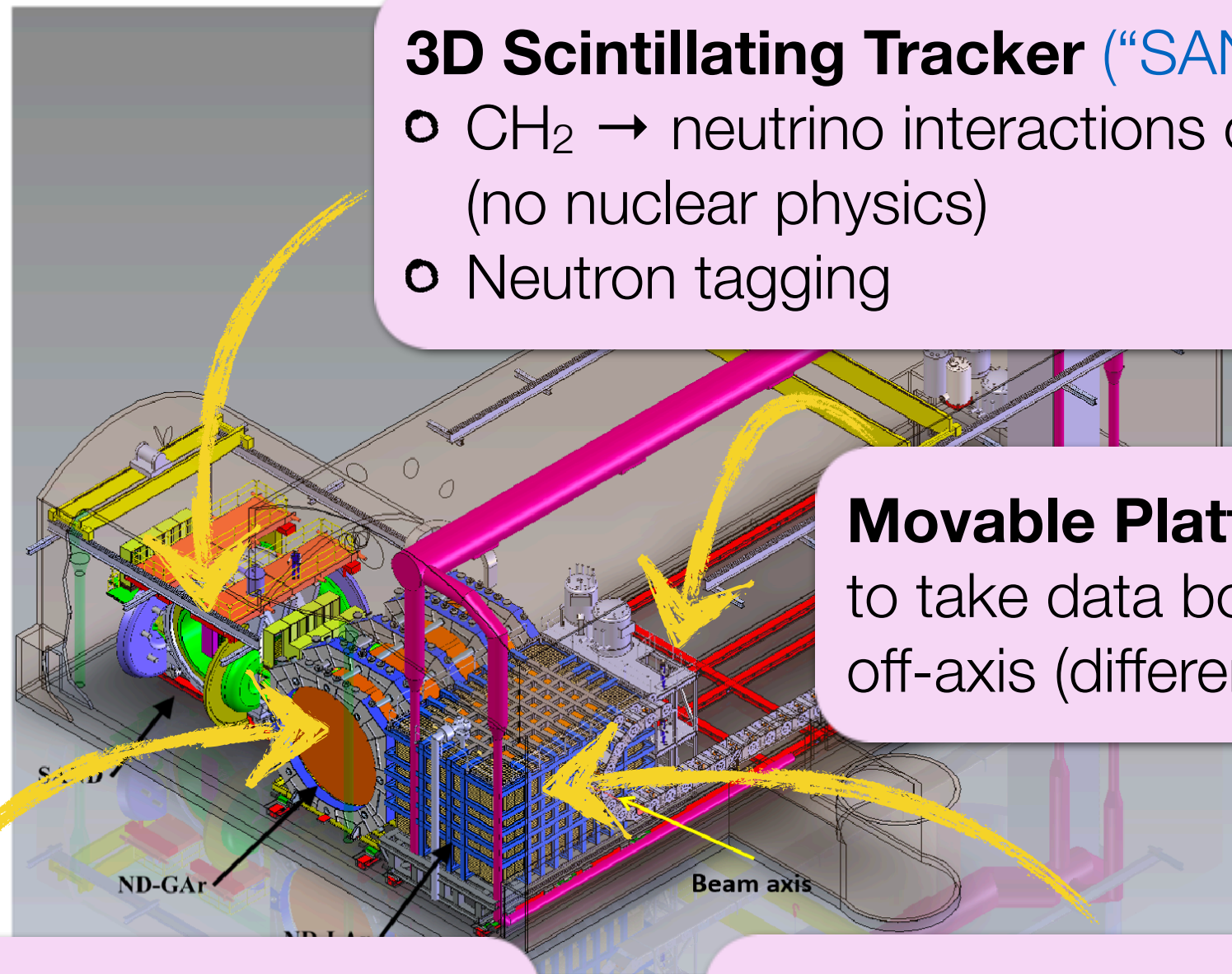
to take data both on-axis and off-axis (different beam spectra)

HP Gas TPC + ECal (“ND-GAr”)

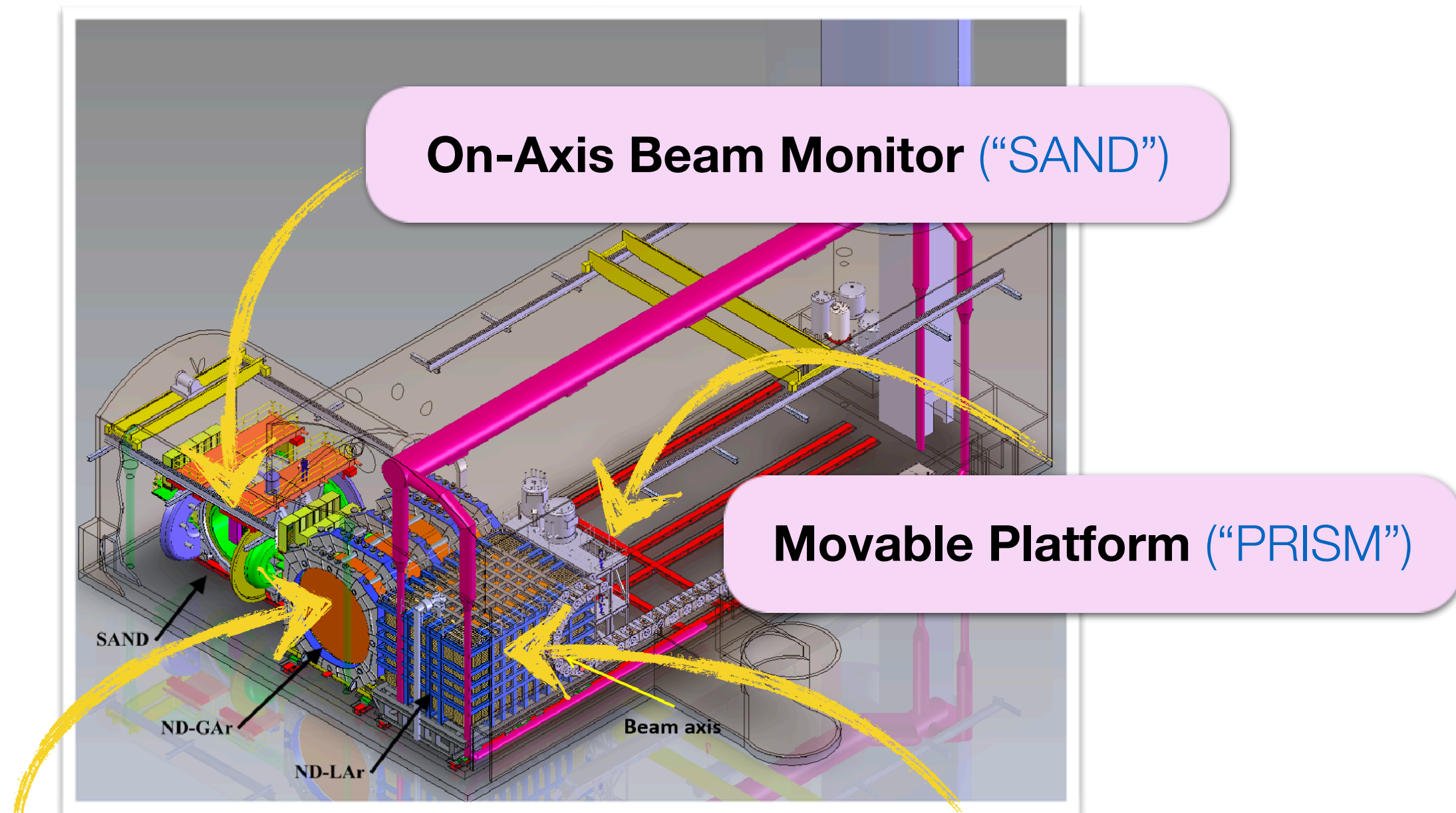
- excellent event reconstruction
- magnetic field

Liquid Argon TPC (“ND-LAr”)

- similar to far detector (cancel systematic uncertainties)



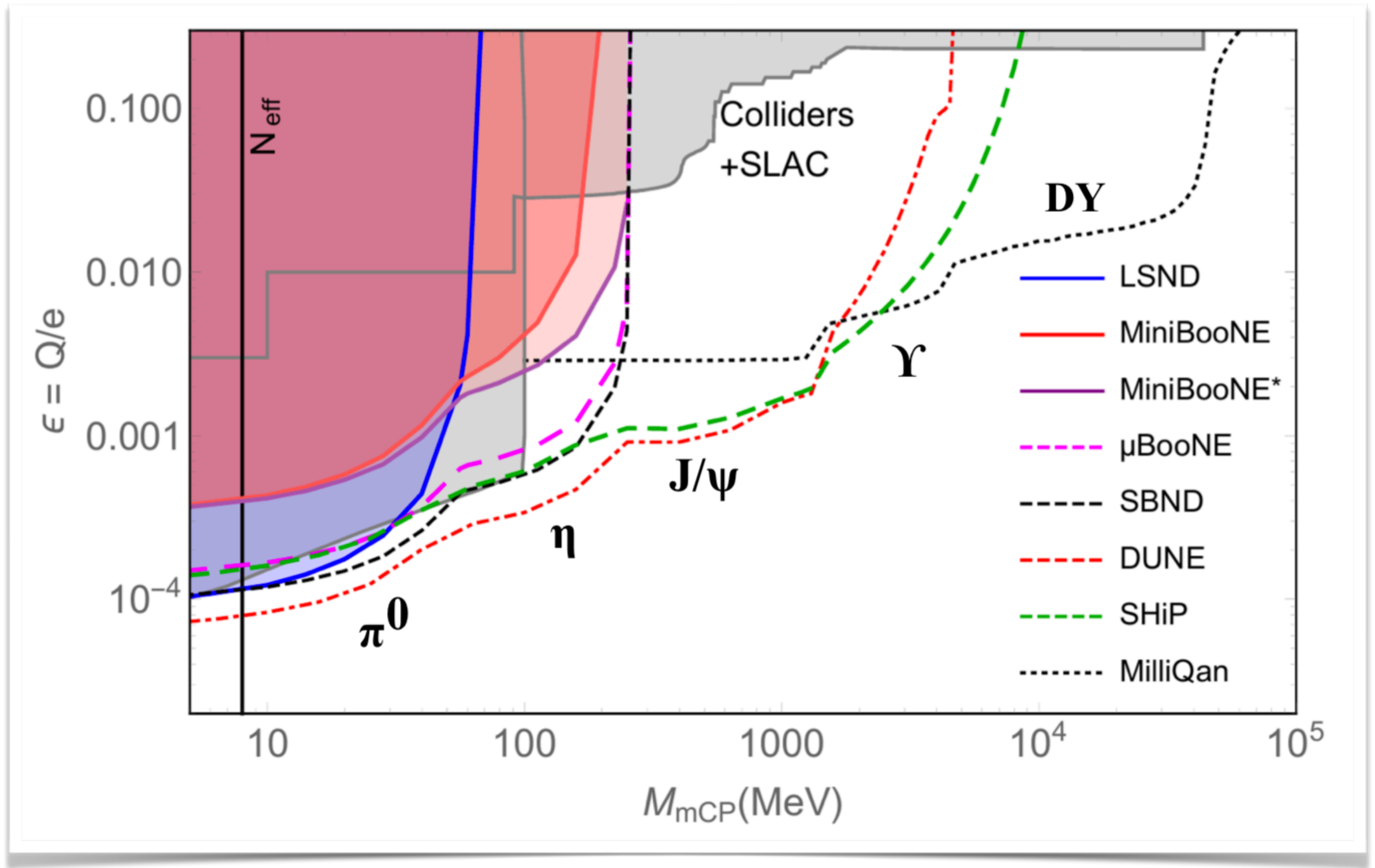
New Physics at Near Detectors



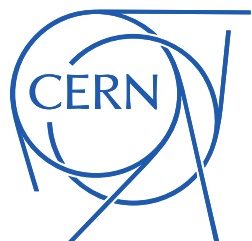
HP Gas TPC + ECal (“SEASIDE”)
(**S**ystem of **E**vaporated **A**rgon for **S**ystematics,
Interactions, and **D**etailed **E**vent Topologies)

Liquid Argon TPC (“LAGOON”)
(**L**iquid **A**rgon **G**adget for
On-axis and **O**ff-axis **N**eutrinos)

Example: Millicharged Particles



Light Dark Matter



Light Dark Matter

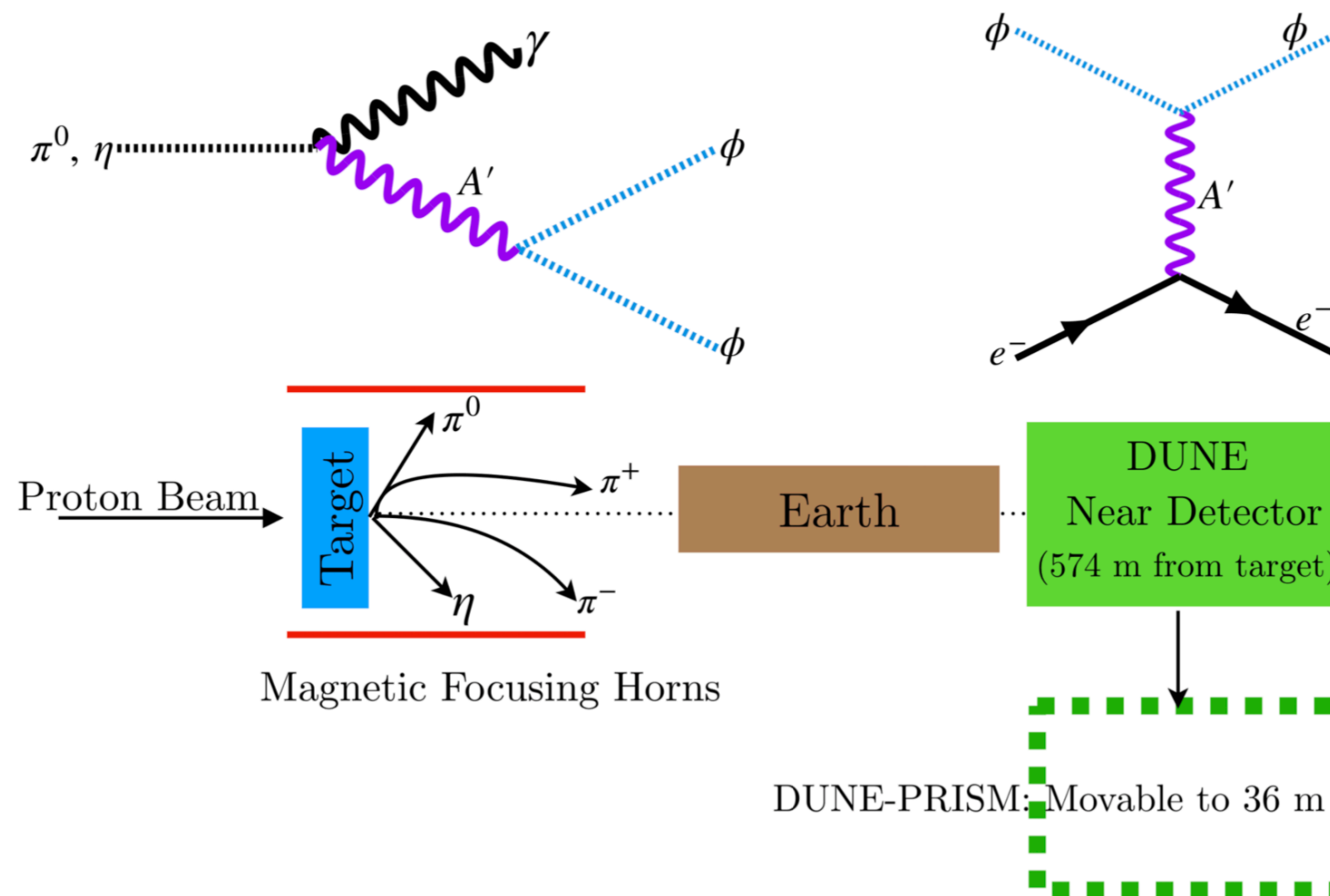


figure from de Romeri Kelly, Machado [arXiv:1903.10505](#)
see also Breitbach Buonocore Frugieue JK Mittnacht [arXiv:2102.03383](#)
see also Dobrescu Frugieue [arXiv:1410.1566](#); Coloma Dobrescu Frugieue Harnik [arXiv:1512.03852](#)
MiniBooNE-DM collaboration [arXiv:1807.06137](#); de Niverville Frugieue [arXiv:1807.06501](#)
Buonocore de Niverville Frugieue [arXiv:1912.09346](#)

$$\mathcal{L}_{\text{DM}} = \mathcal{L}_{A'} + \mathcal{L}_{\phi},$$

$$\mathcal{L}_{A'} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m_{A'}^2}{2}A'^{\mu}A'_{\mu} - \frac{1}{2}\epsilon F'_{\mu\nu}F^{\mu\nu},$$

$$\mathcal{L}_{\phi} = ig' A'^{\mu} J_{\mu}^{\phi} + (\partial_{\mu}\phi^{\dagger})(\partial^{\mu}\phi) - m_{\phi}^2\phi^{\dagger}\phi,$$

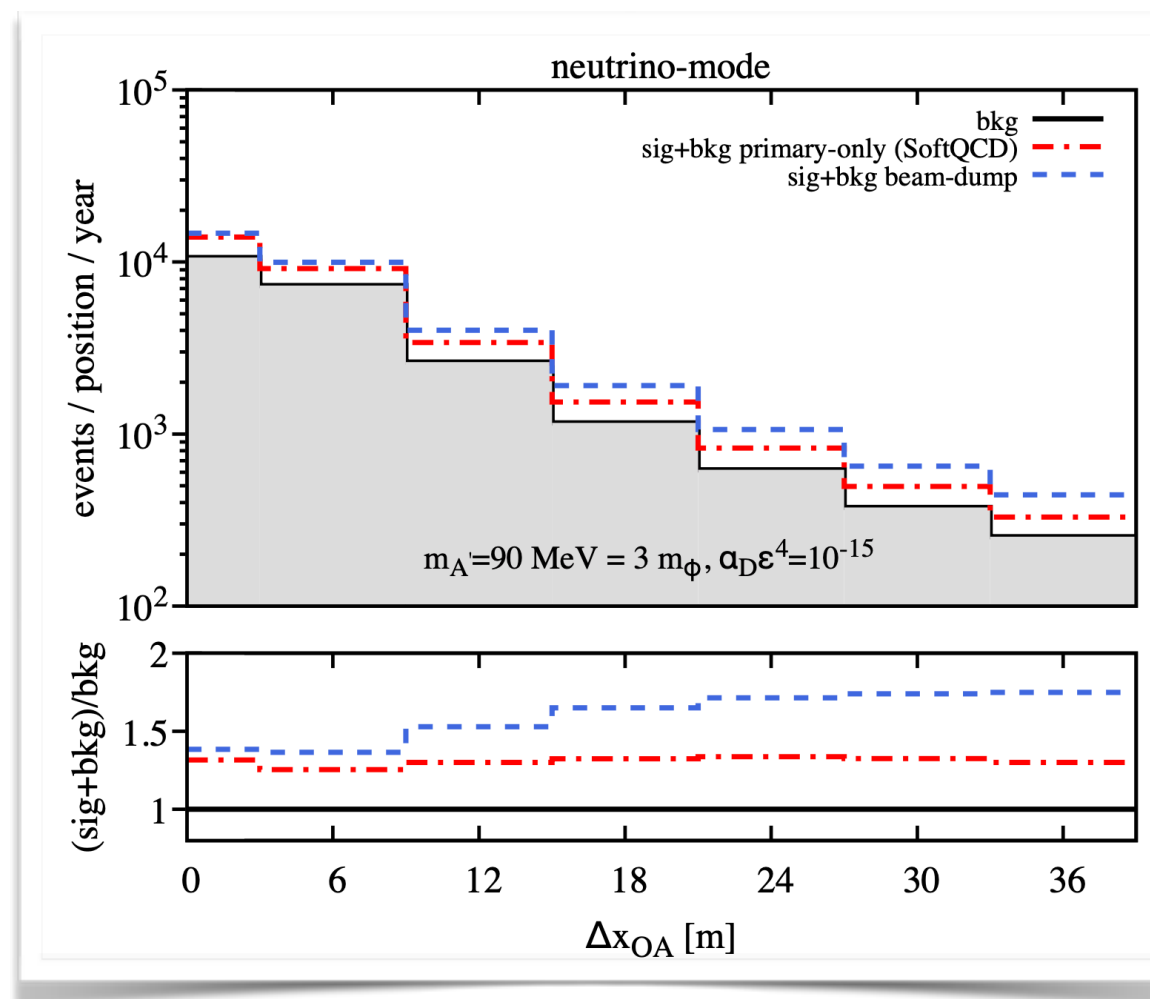
Breitbach Buonocore Fruguele JK Mittnacht [arXiv:2102.03383](https://arxiv.org/abs/2102.03383)
see also Dobrescu Fruguele [arXiv:1410.1566](https://arxiv.org/abs/1410.1566); Coloma Dobrescu Fruguele Harnik [arXiv:1512.03852](https://arxiv.org/abs/1512.03852)
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de Romeri Kelly, Machado [arXiv:1903.10505](https://arxiv.org/abs/1903.10505); Buonocore de Niverville Fruguele [arXiv:1912.09346](https://arxiv.org/abs/1912.09346)

Light Dark Matter

- ☑ Production predominantly in meson decays

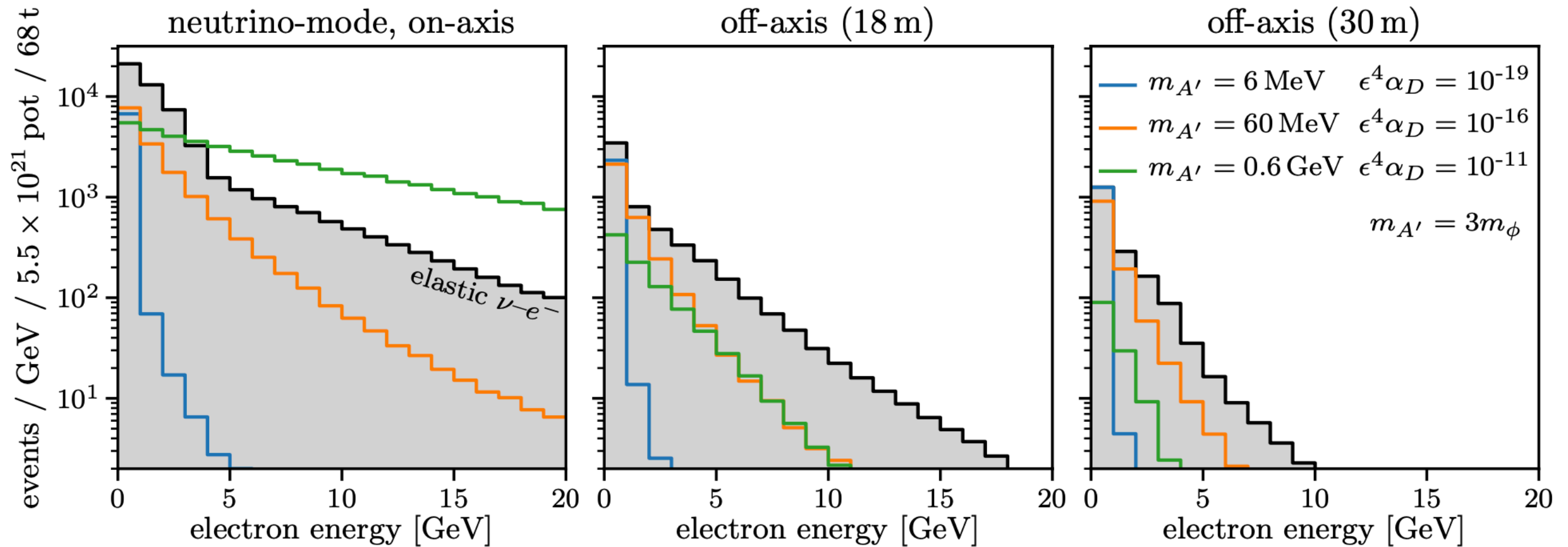
$$X \rightarrow \gamma A' \rightarrow \gamma \phi \phi^\dagger$$

- ☑ important to include interactions of secondary particles



Celentano Darmé Marsicano Nardi
[arXiv:2006.09419](https://arxiv.org/abs/2006.09419)

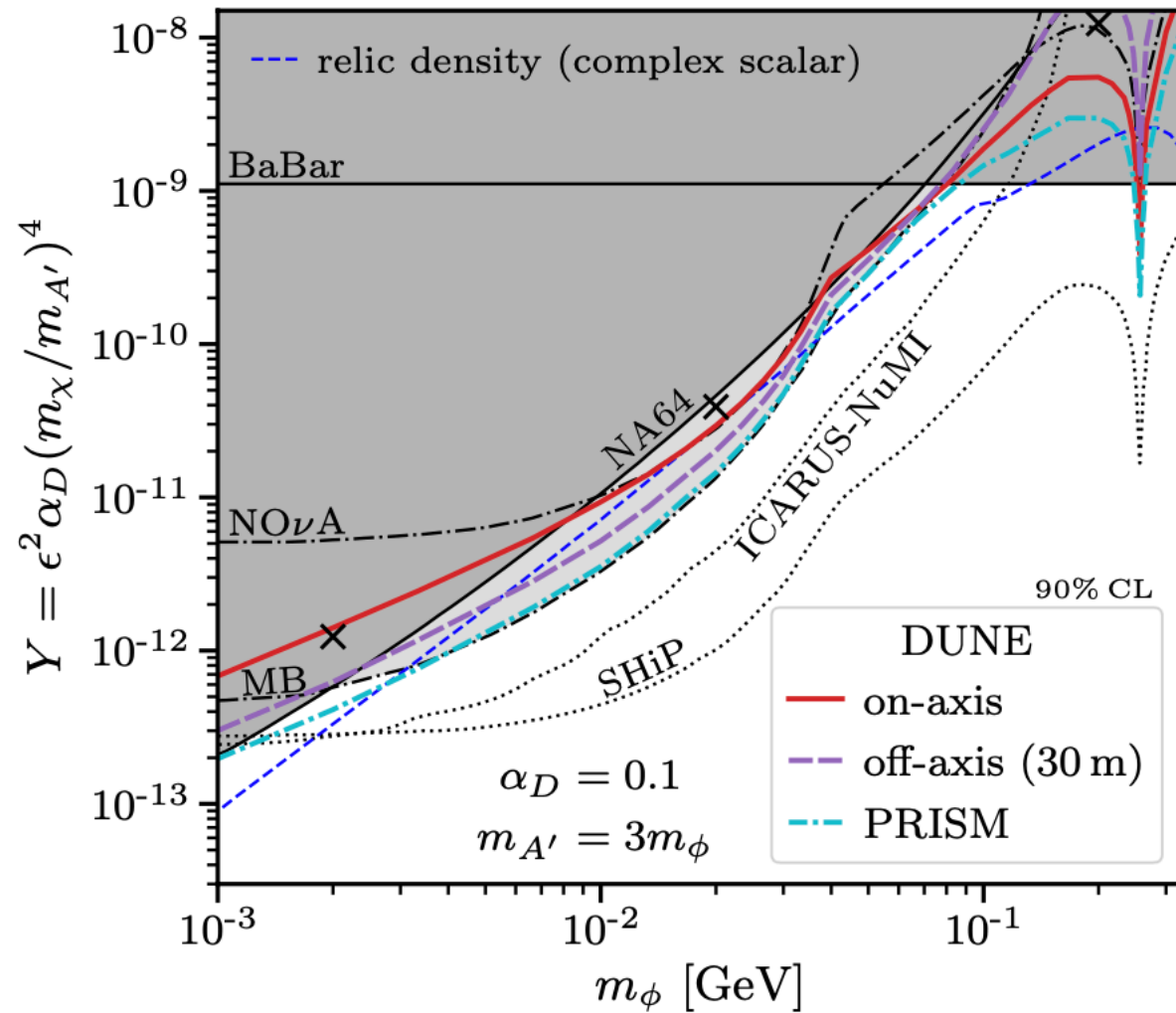
Benefits of Going Off-Axis



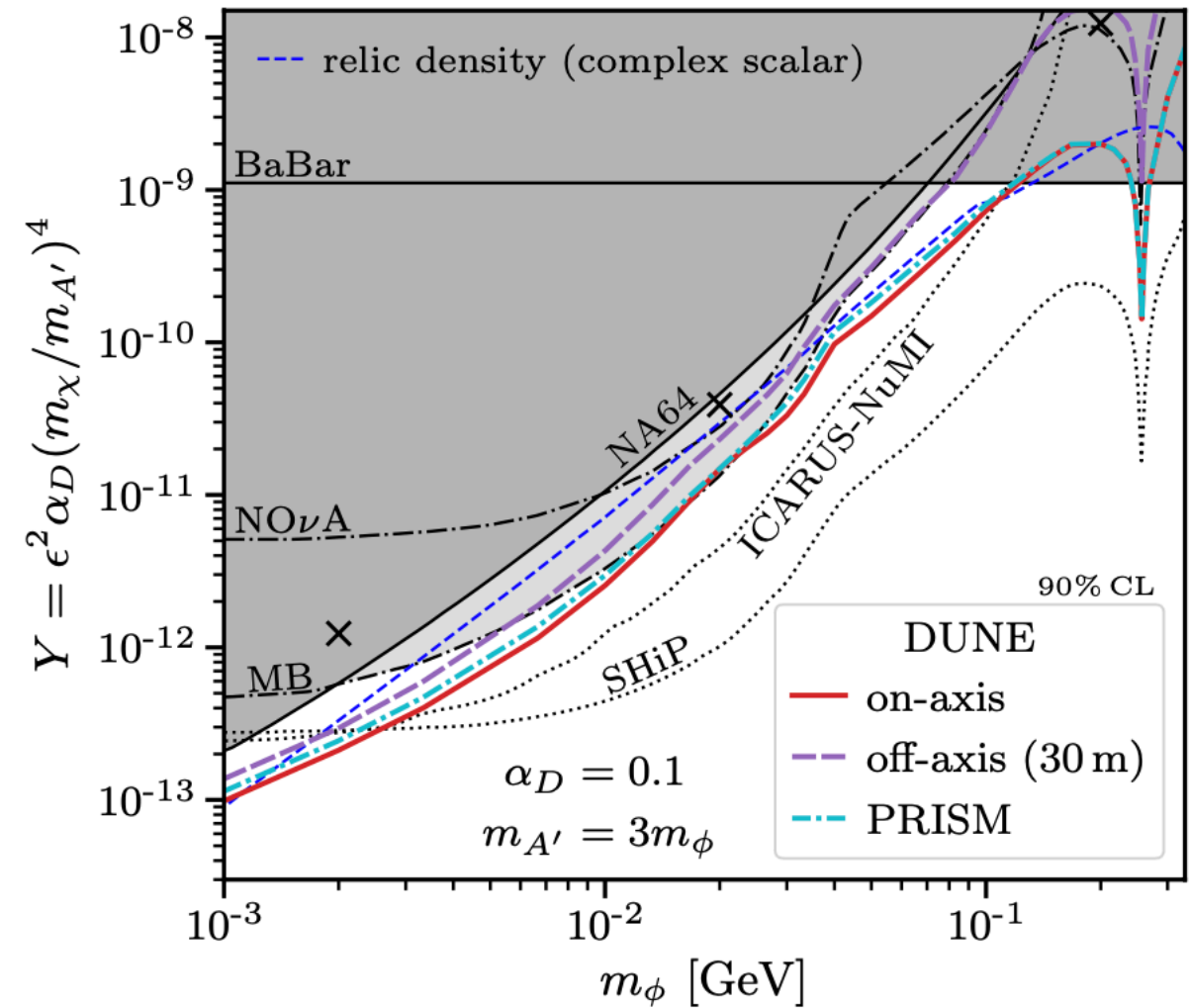
☑ off-axis: improved signal-to-background ratio

Light Dark Matter: Results

total rates analysis

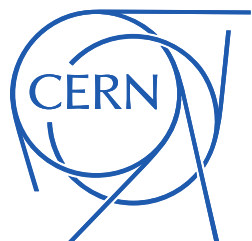


spectral analysis ($\Delta E = 250$ MeV)



Heavy Neutral Leptons

(Heavy Sterile Neutrinos)

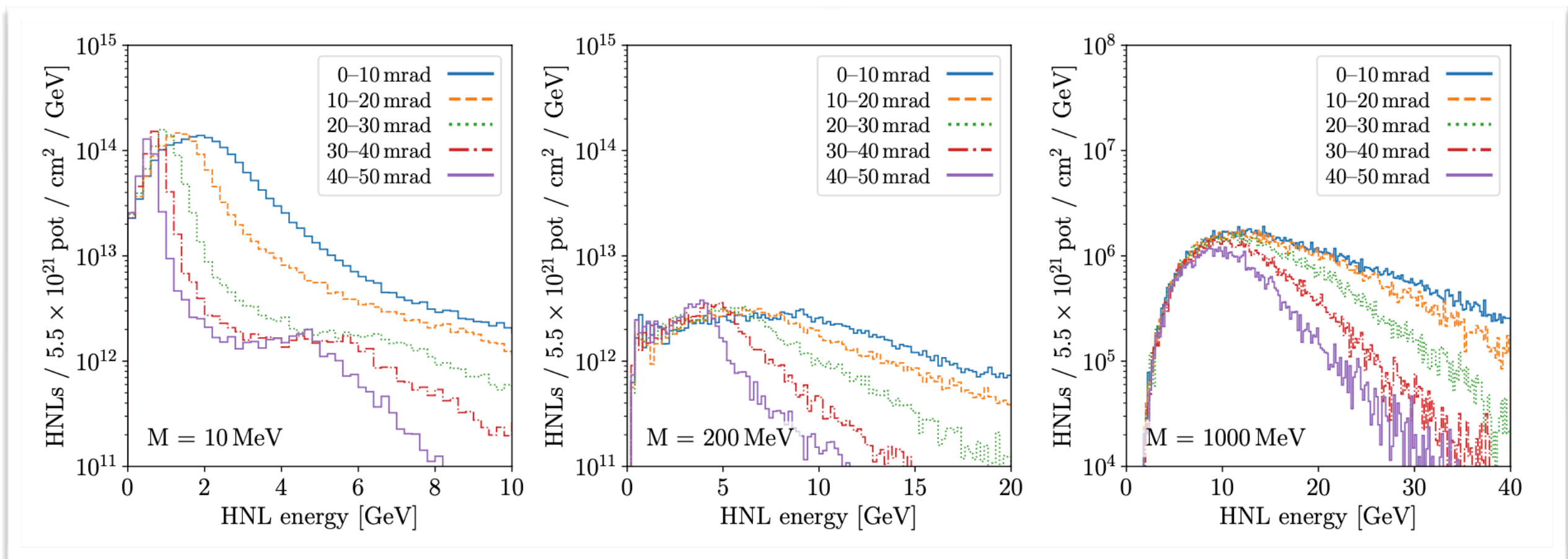


Heavy Neutral Leptons

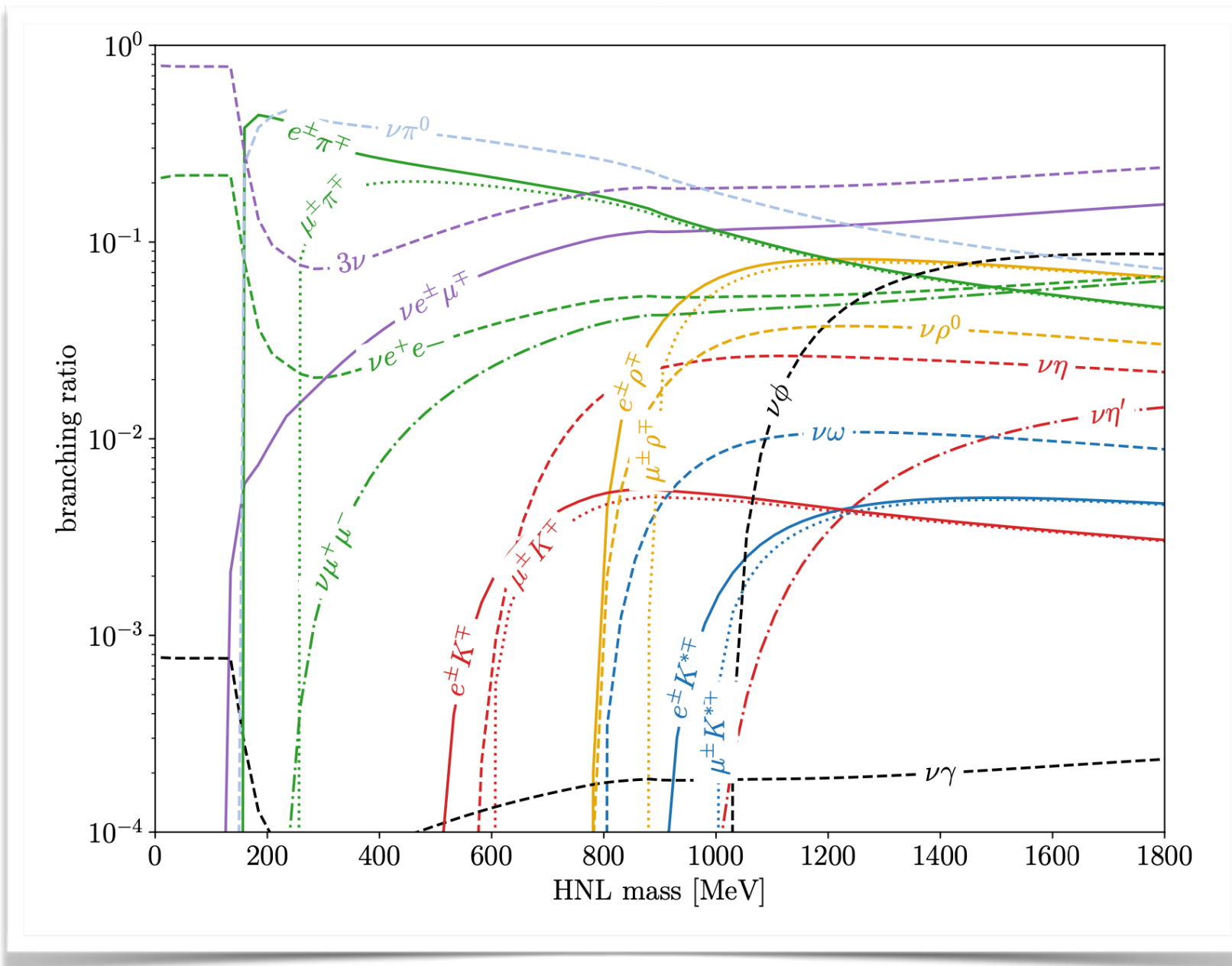
- ☑ SM singlet fermions, coupled only through ν mixing

$$\mathcal{L}_{\text{HNL}} \supset y \bar{L} \tilde{H} N$$

- ☑ Production in meson decays
(same as SM ν , but different kinematics)



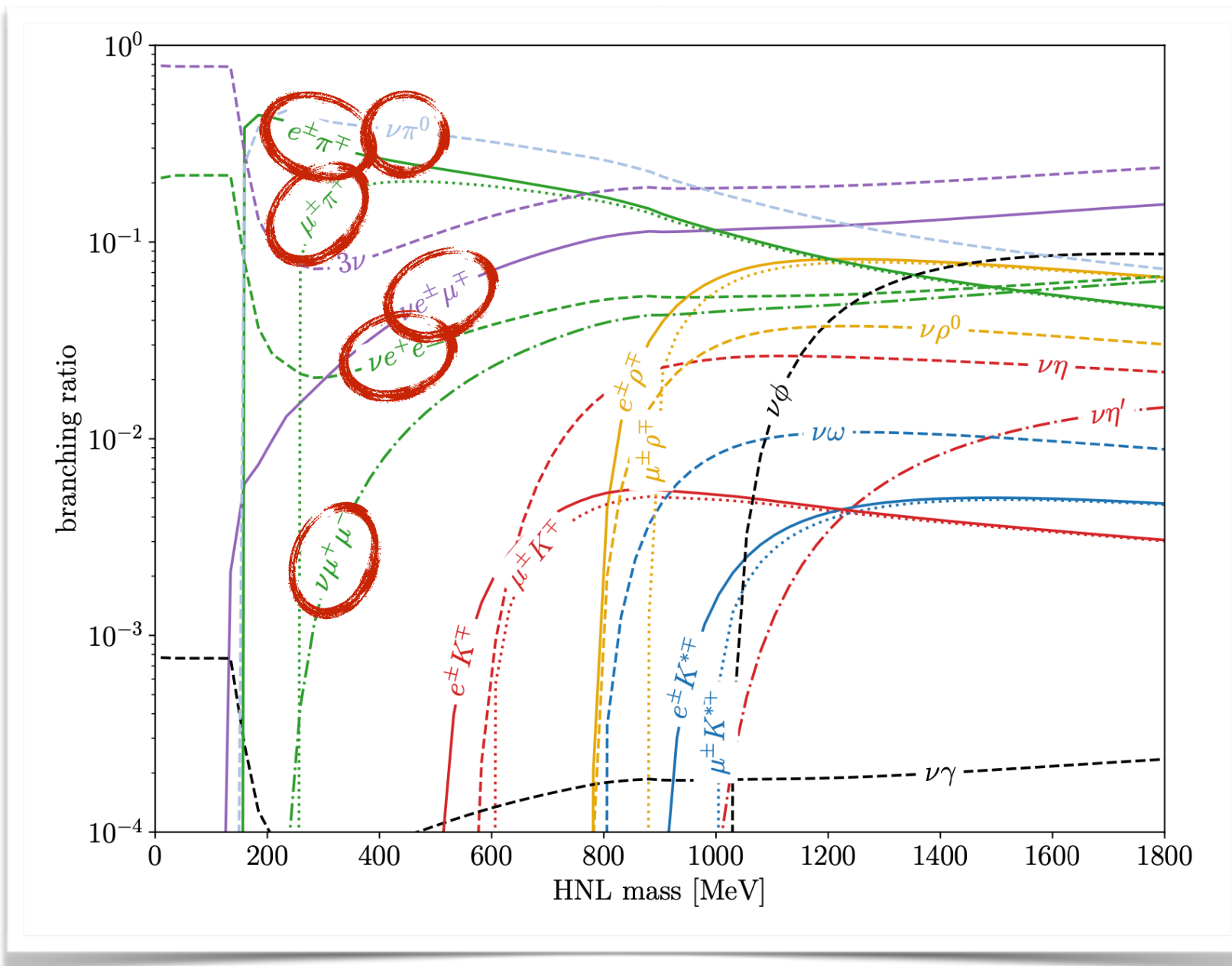
HNL Decay



- ☑ some disagreement in the literature
- ☑ we use NuShock code by Tommaso Boschi

Ballett Boschi Pascoli
arXiv:1905.00284

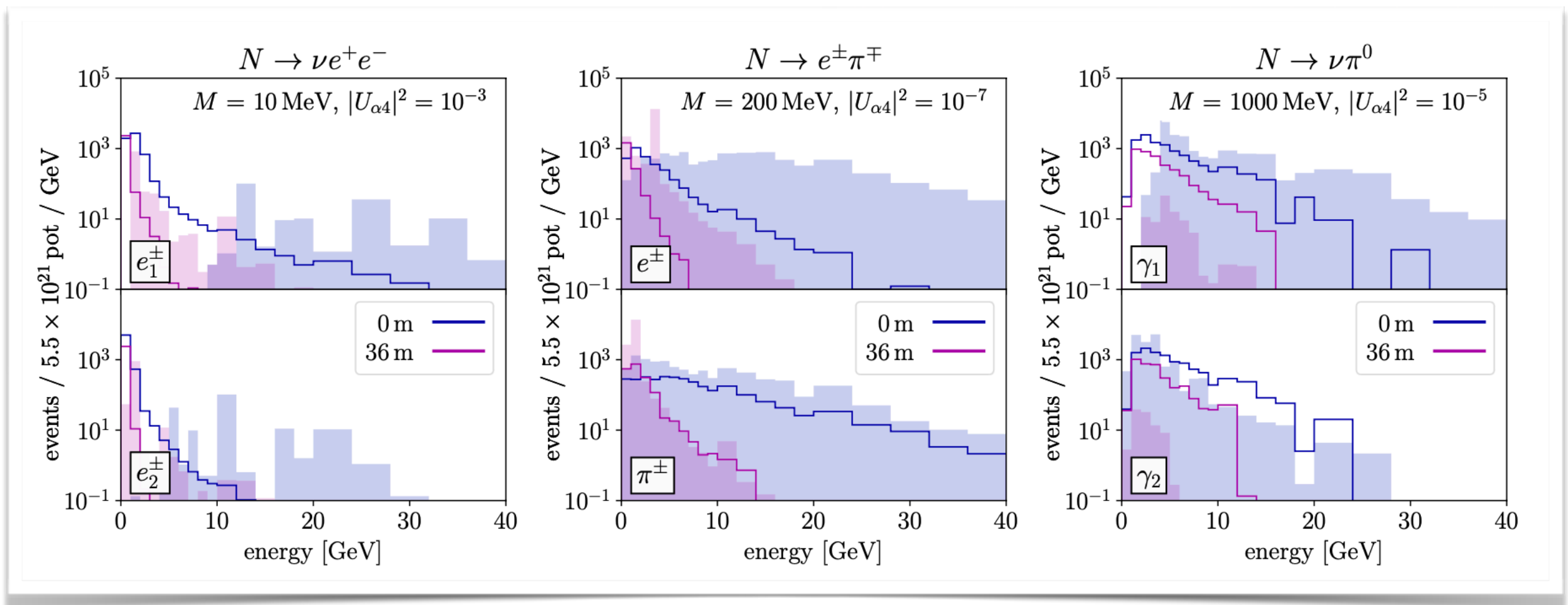
HNL Decay



- ☑ some disagreement in the literature
- ☑ we use NuShock code by Tommaso Boschi

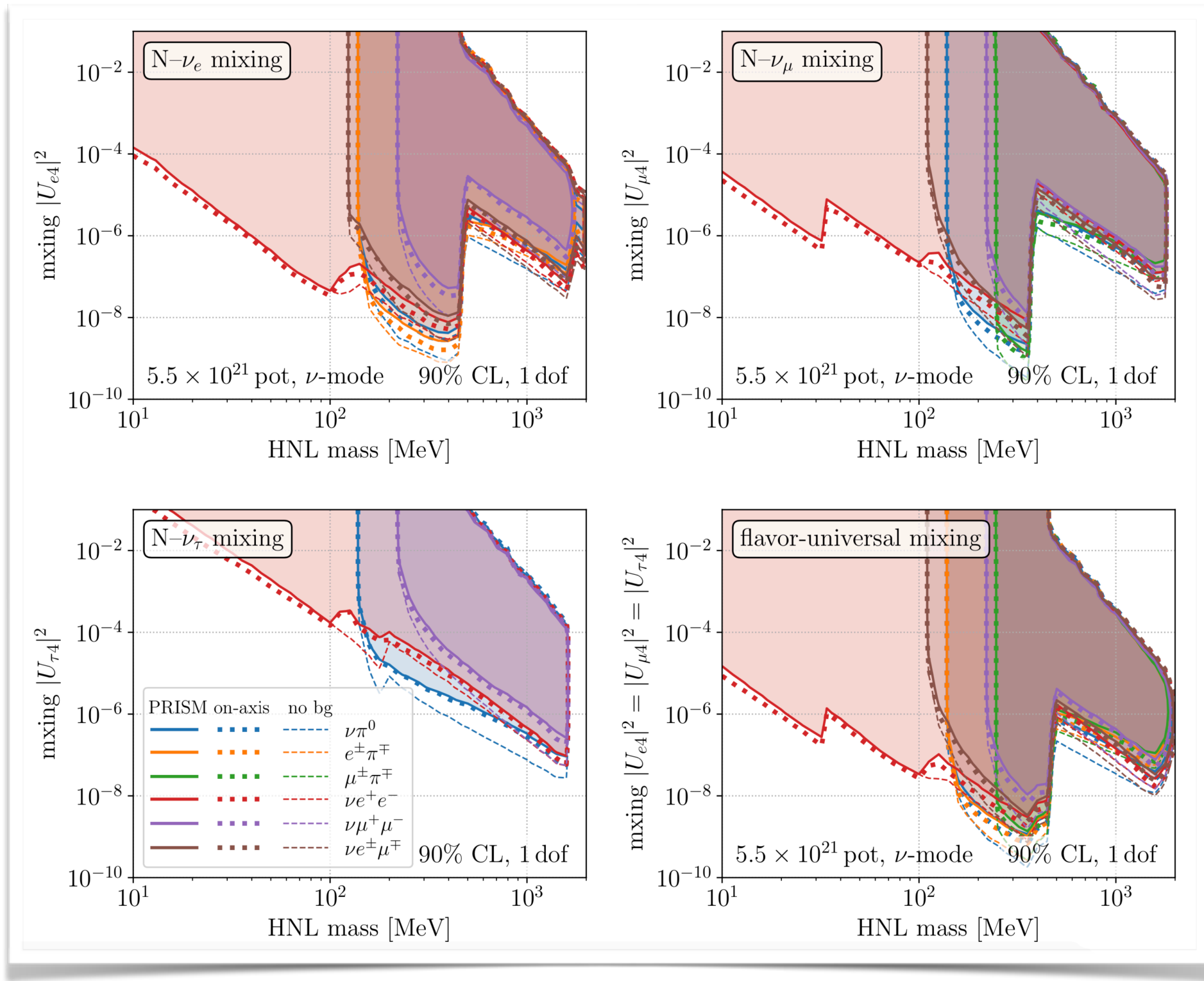
Ballett Boschi Pascoli
arXiv:1905.00284

HNL Decay

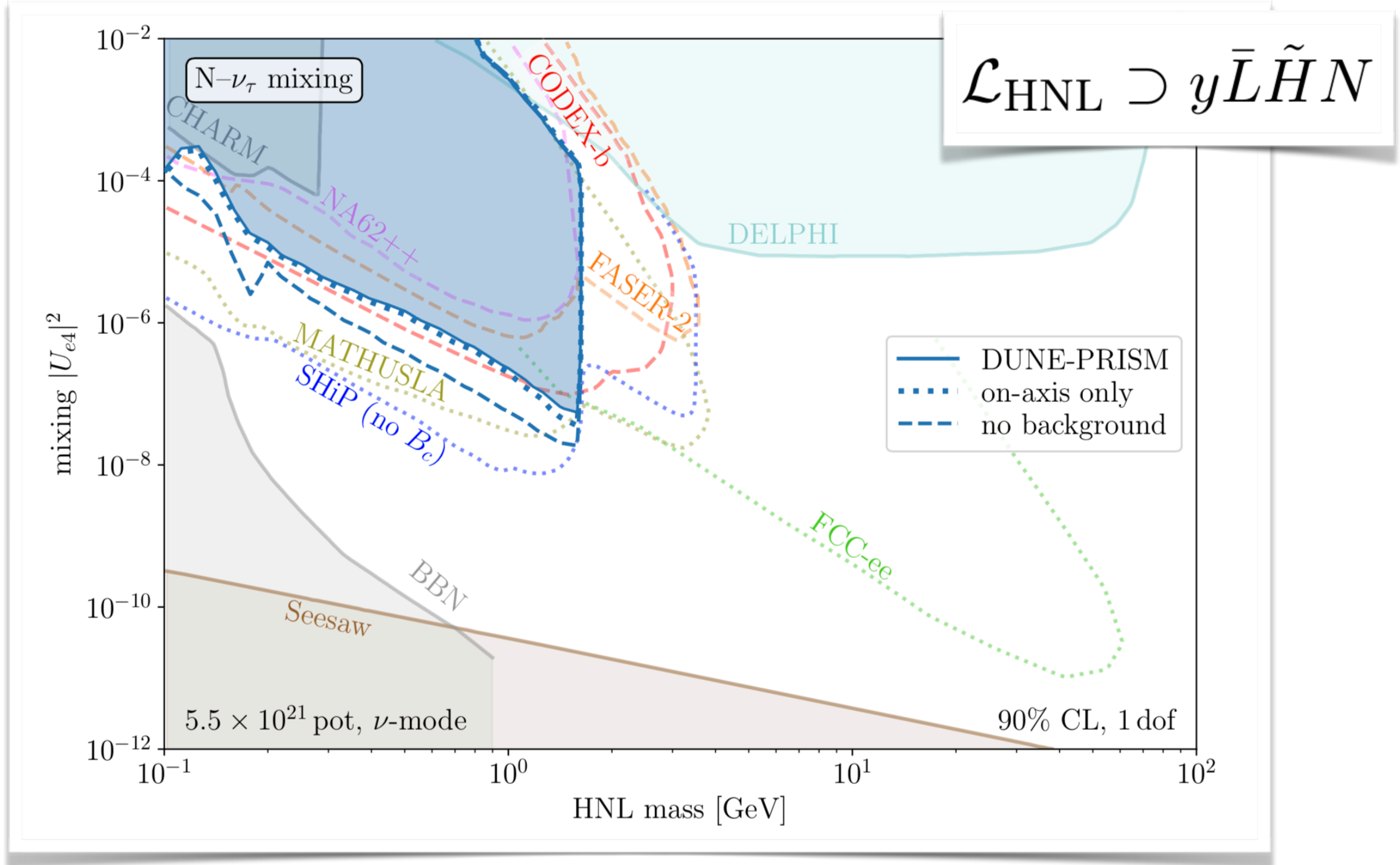


- ✓ off-axis: improved signal-to-background ratio, especially in 2D plane
- ✓ but cuts (especially on angle w.r.t. beam axis) very efficient at suppressing backgrounds, too.

HNL: Results

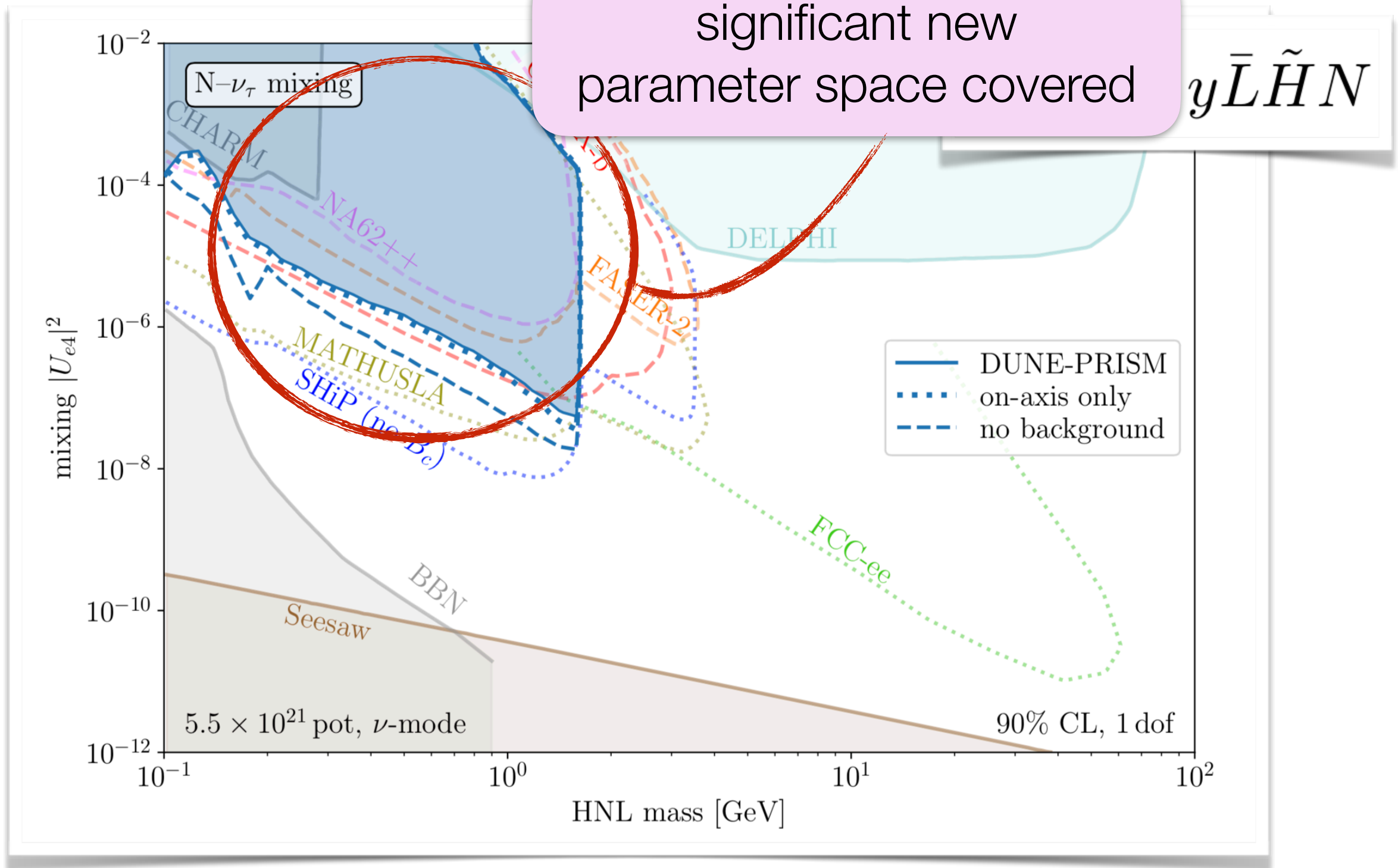


Example: Heavy Neutral Leptons



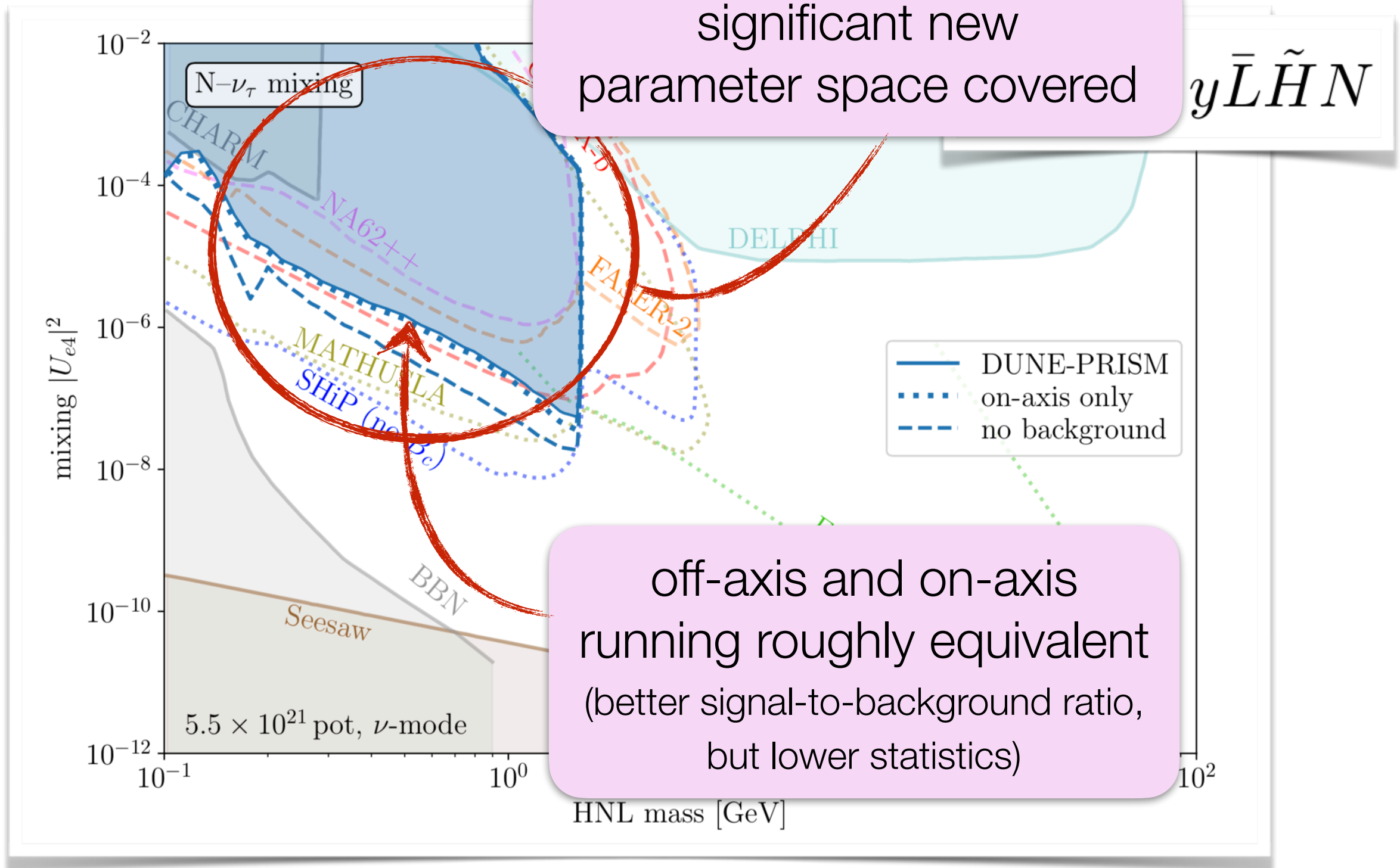
Breitbach Buonocore Frugieue JK Mitnacht [arXiv:2102.03383](https://arxiv.org/abs/2102.03383)
 see also works by Ballett Boschi Coloma Dobrescu Fernandez-Martinez Gonzalez-Lopez
 Harnik Hernandez-Martinez Pascoli Pavlovic

Example: Heavy Neutral Leptons



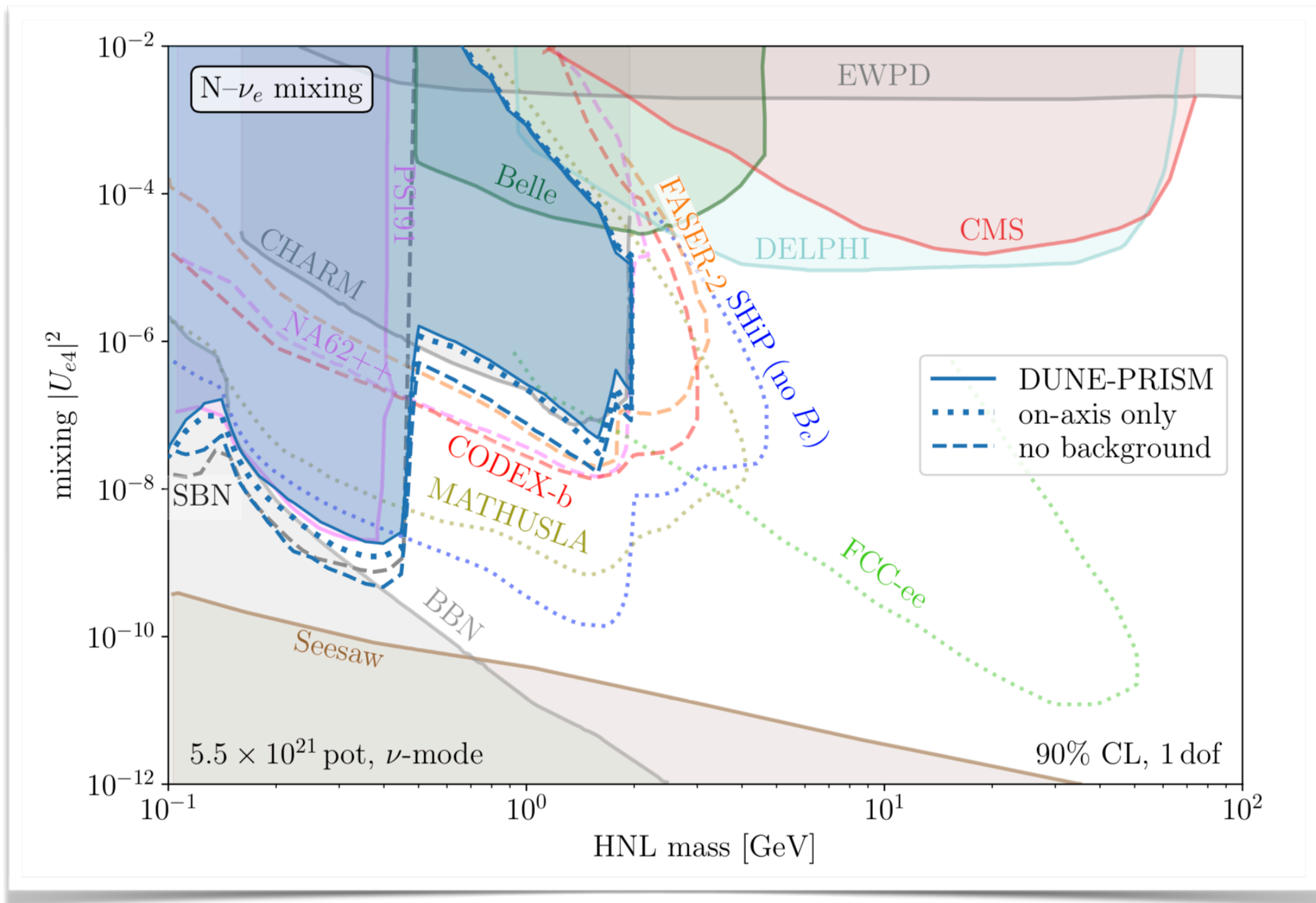
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Example: Heavy Neutral Leptons

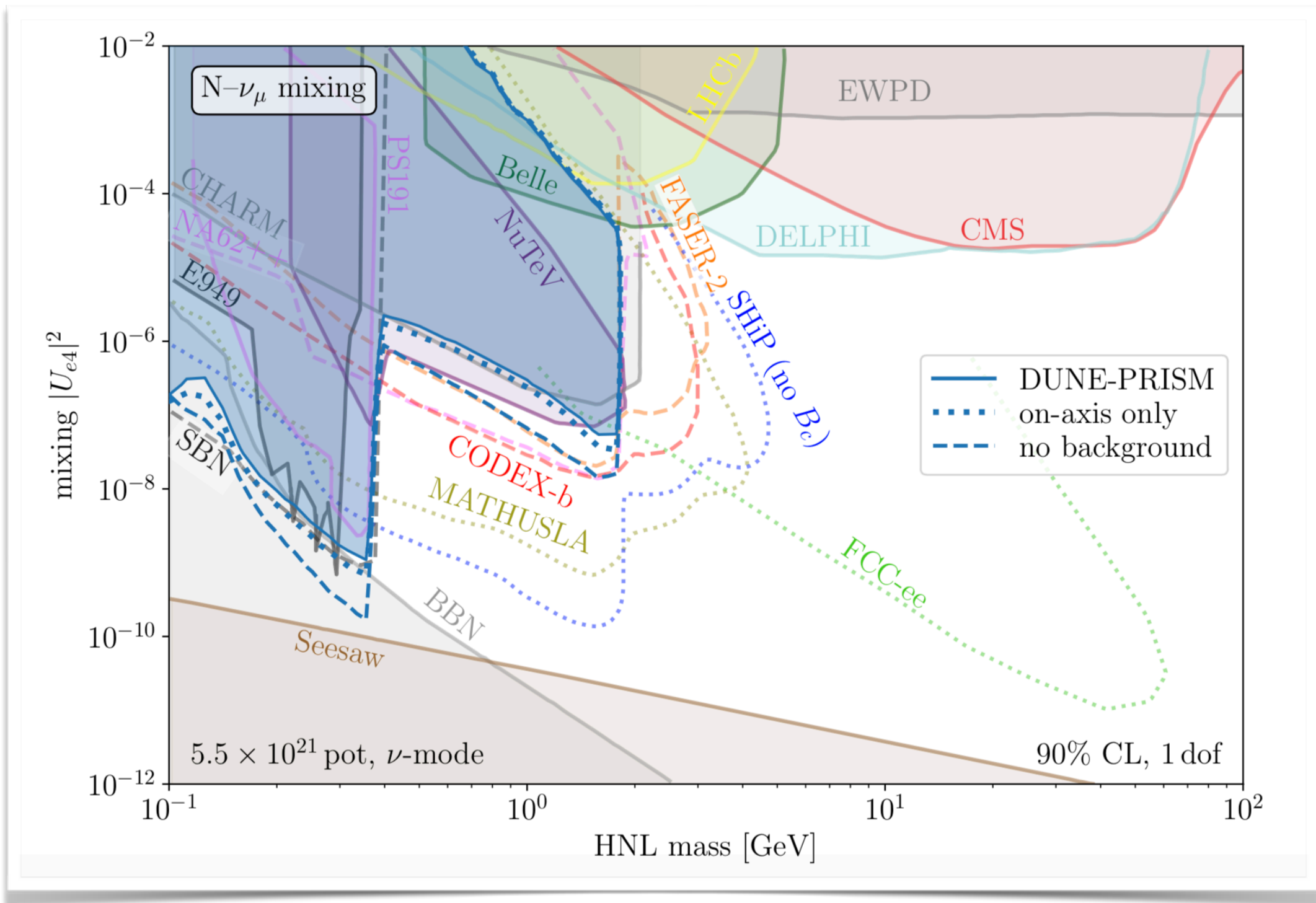


Breitbach Buonocore Frugieue JK Mitnacht [arXiv:2102.03383](https://arxiv.org/abs/2102.03383)
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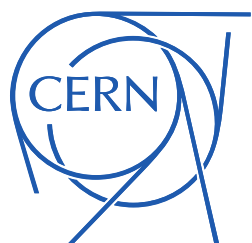
HNL: Results



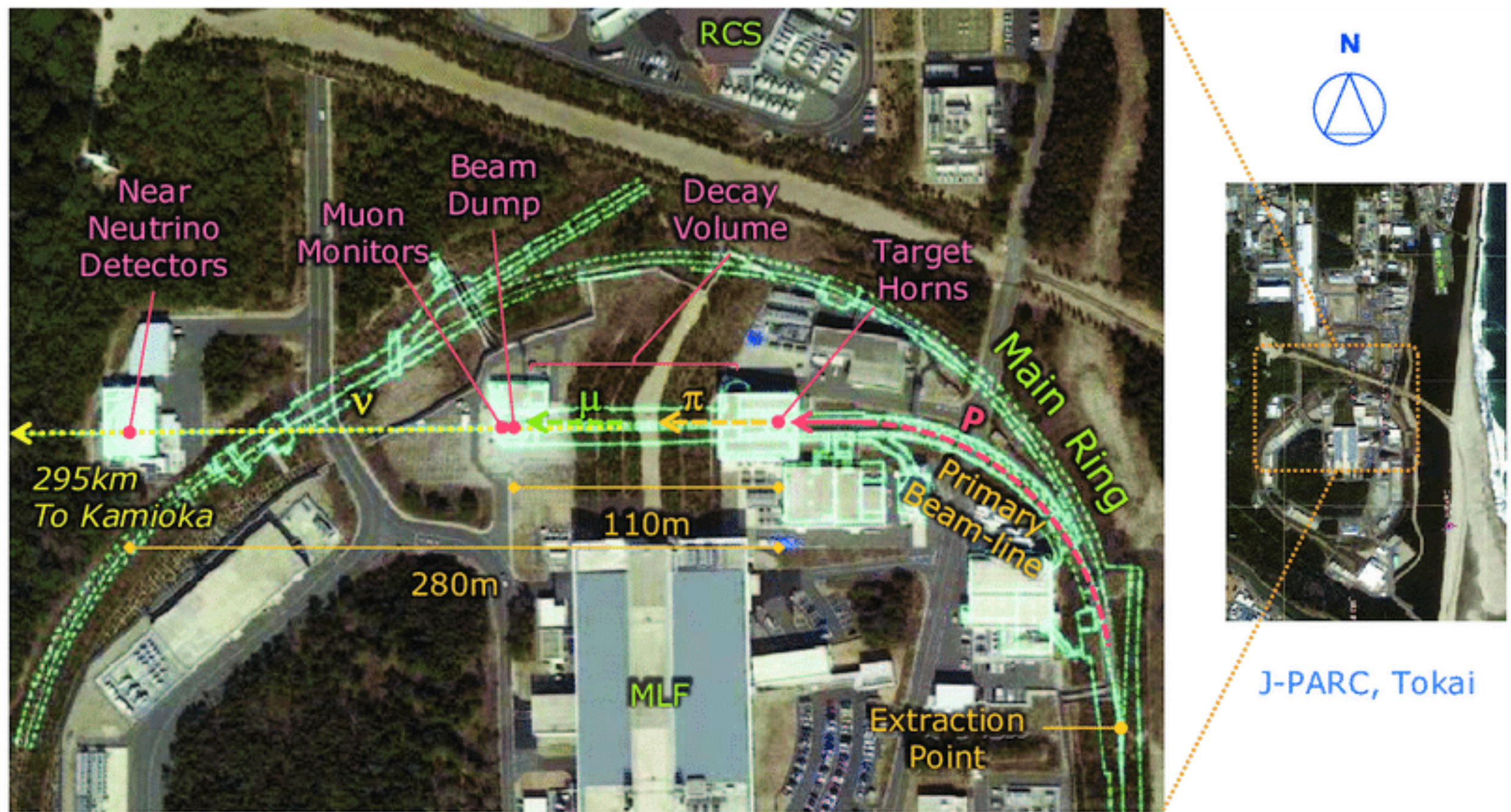
HNL: Results



Comparison to T2HK



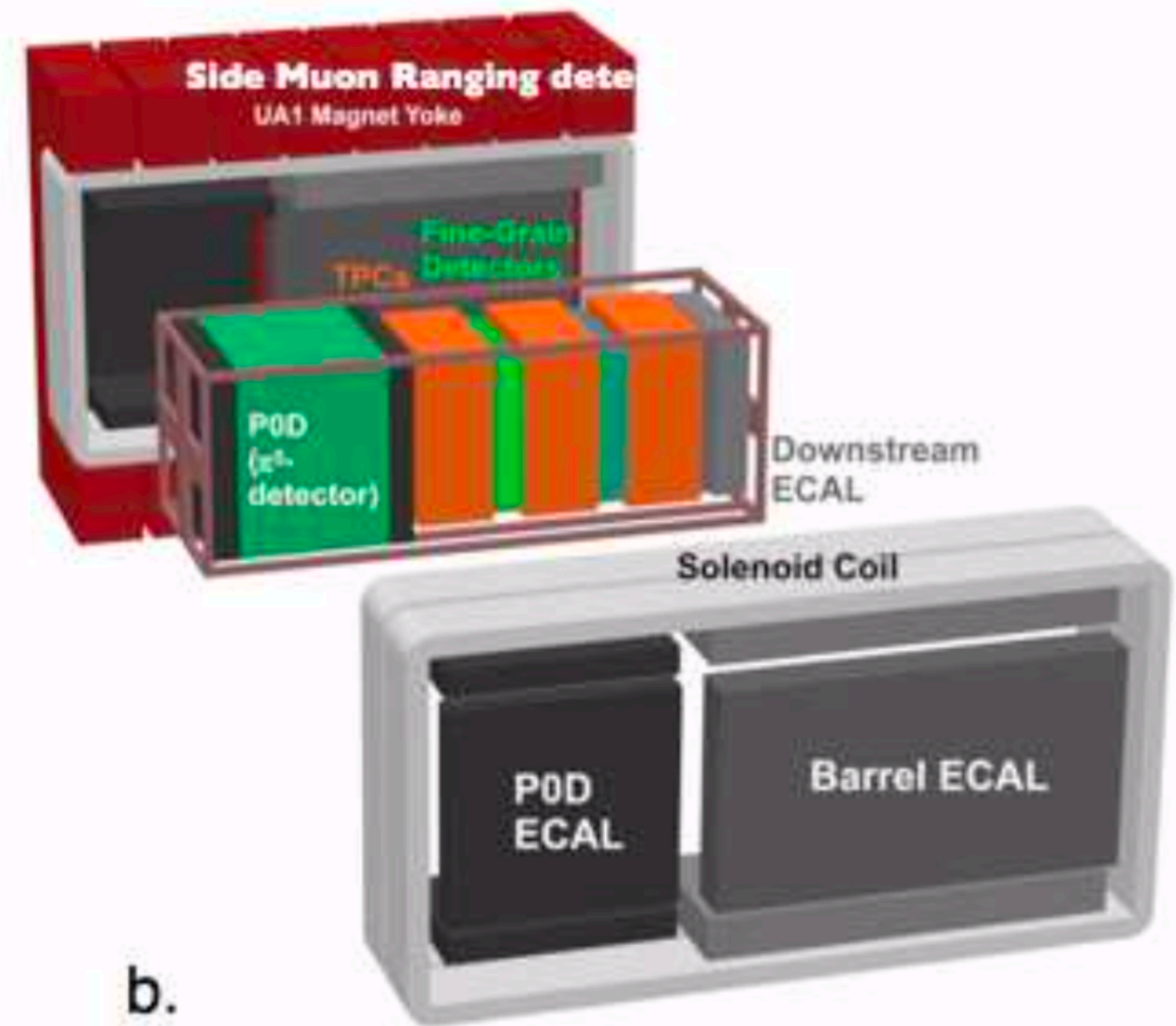
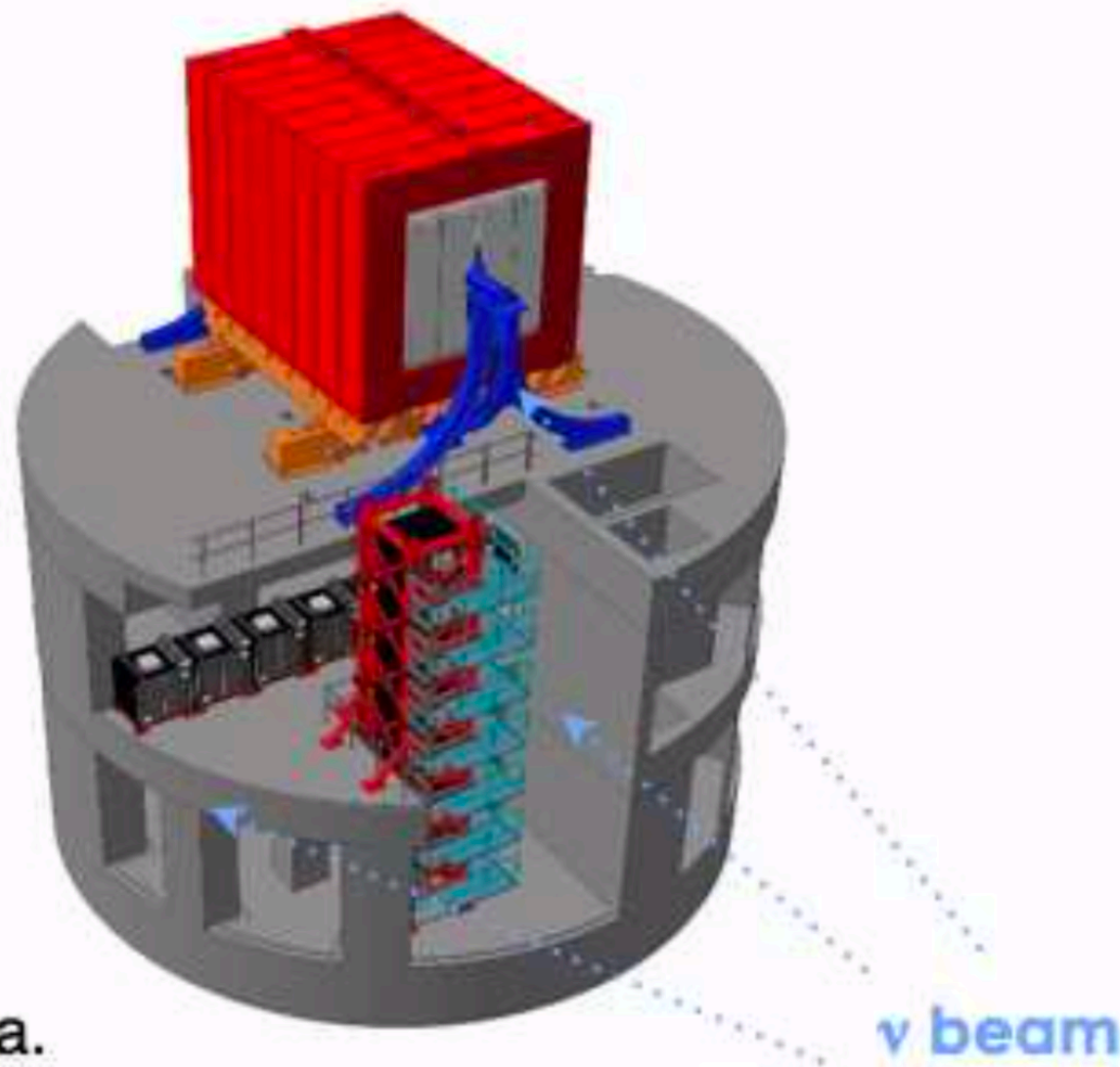
The J-PARC Neutrino Beam



J-PARC, Tokai

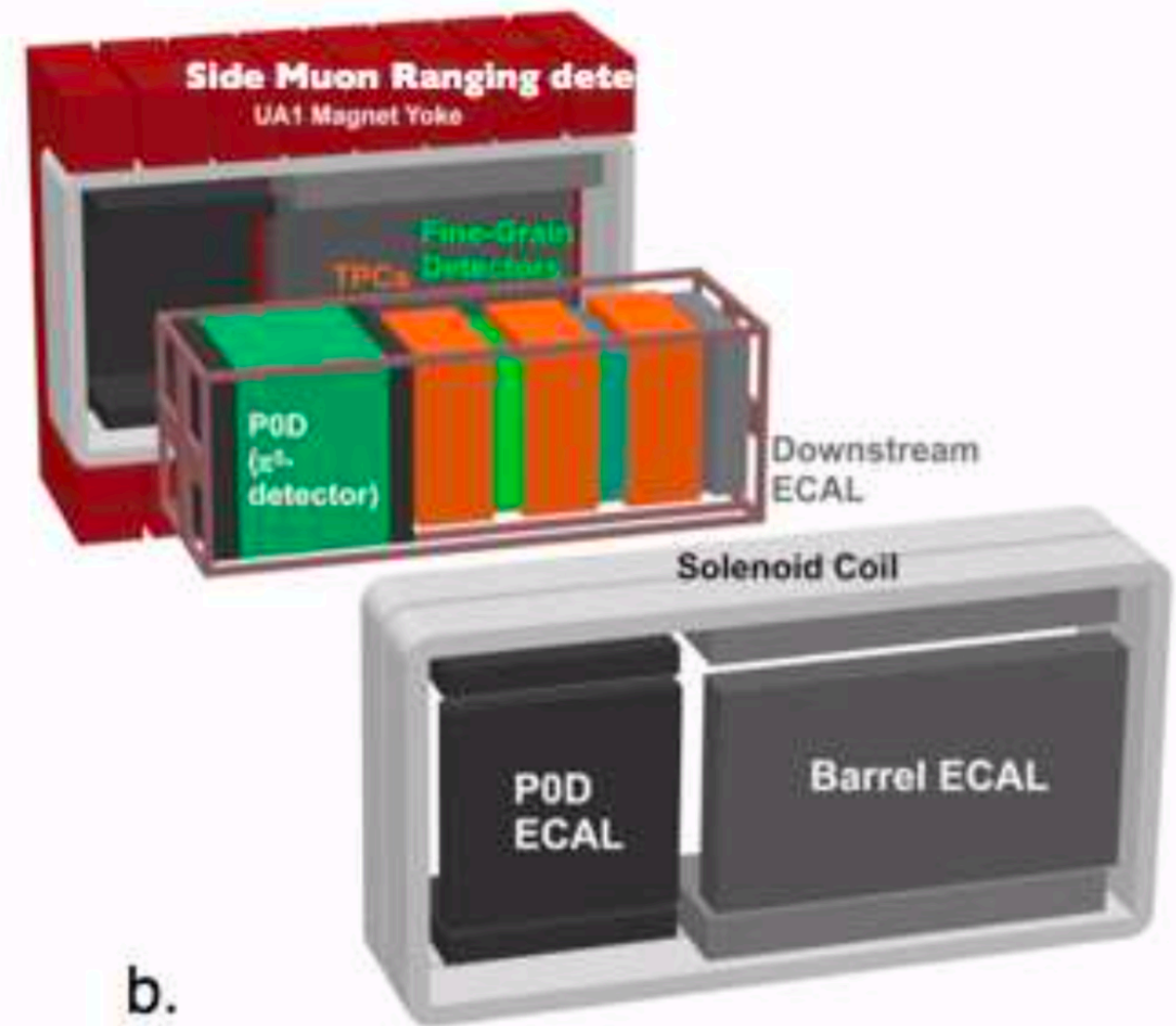
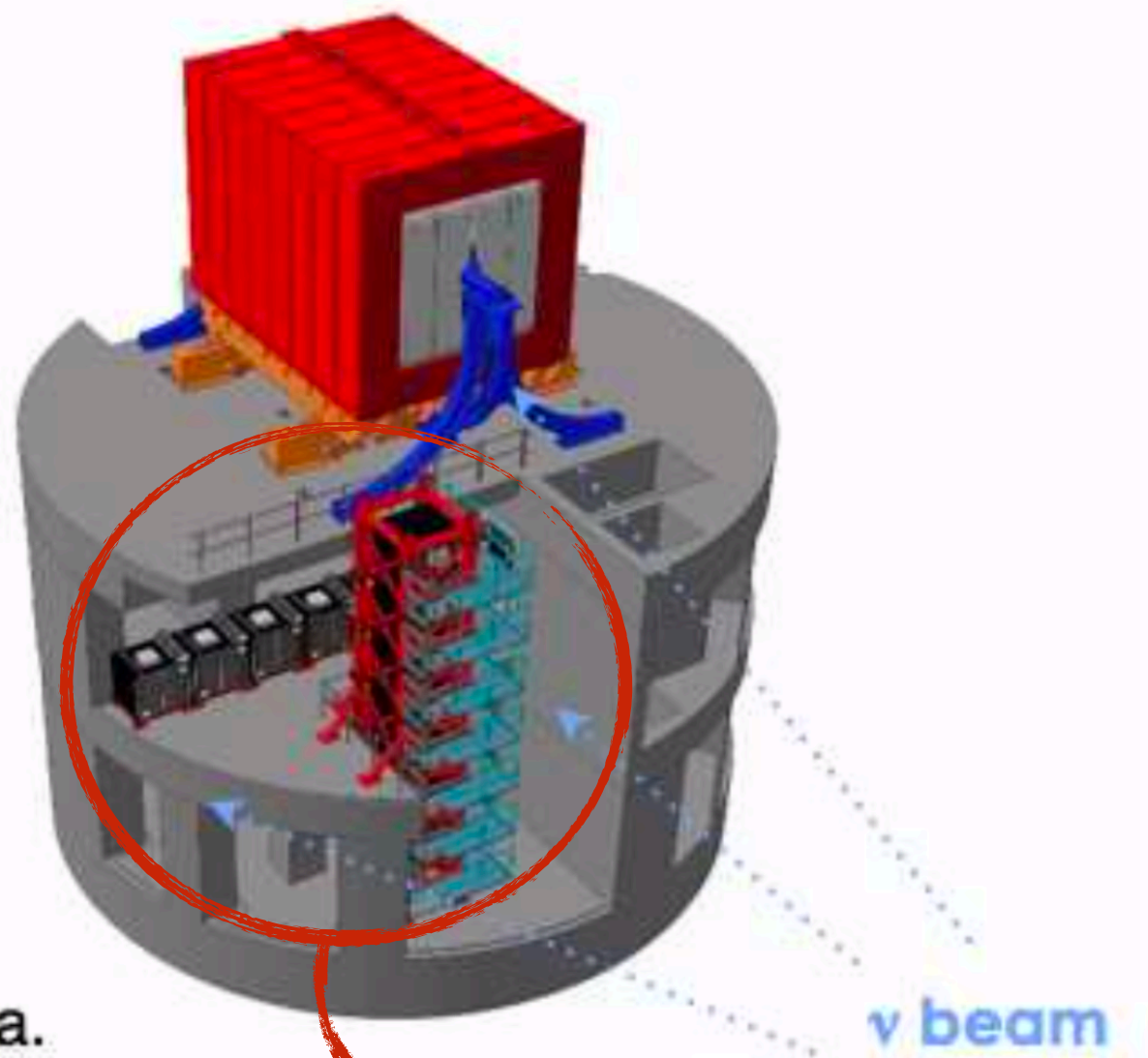
Ishida arXiv:1411.5540

The T2K Near Detectors



Vasheret *et al.* arXiv:1101.1996

The T2K Near Detectors

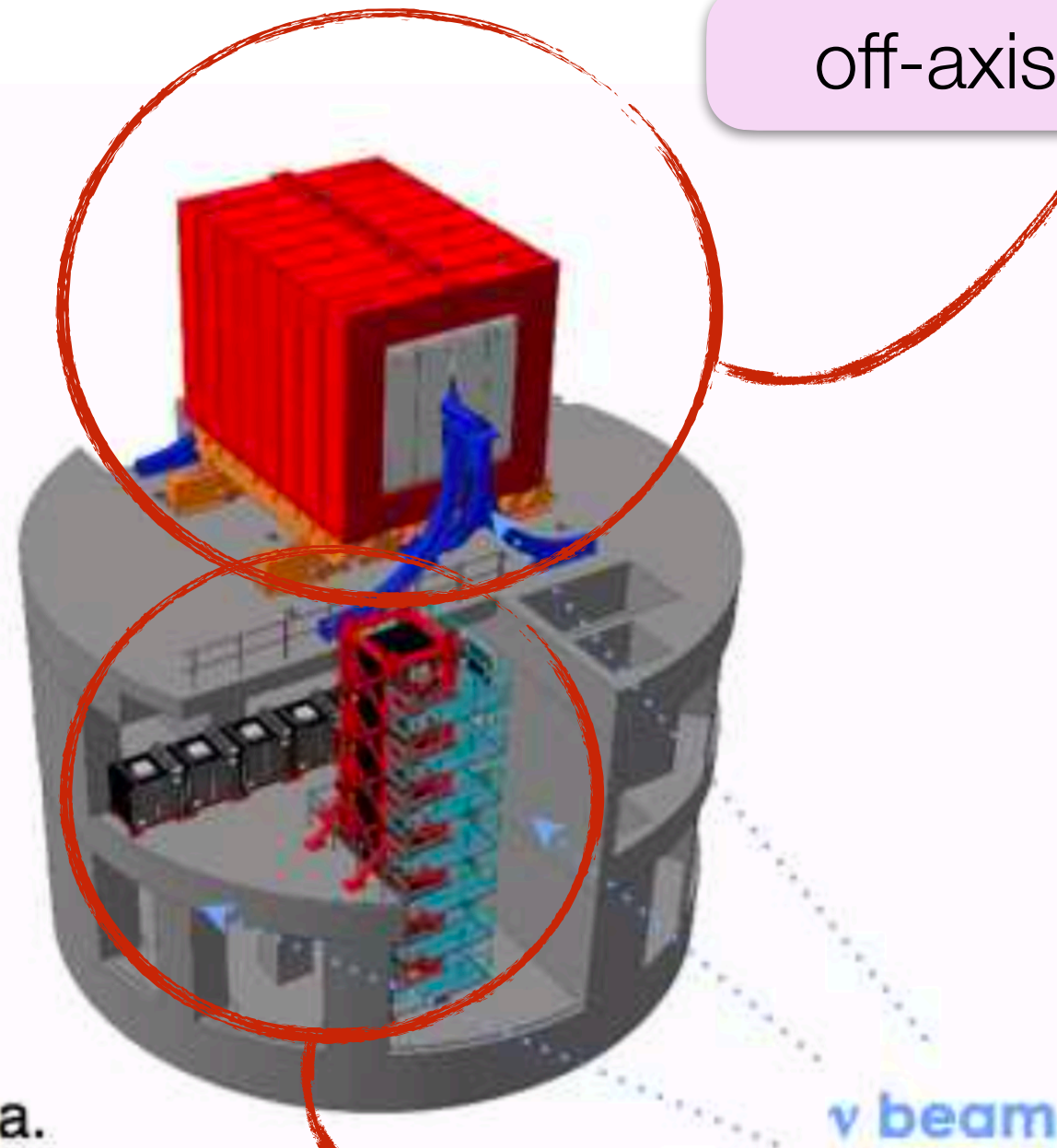


on-axis beam monitors

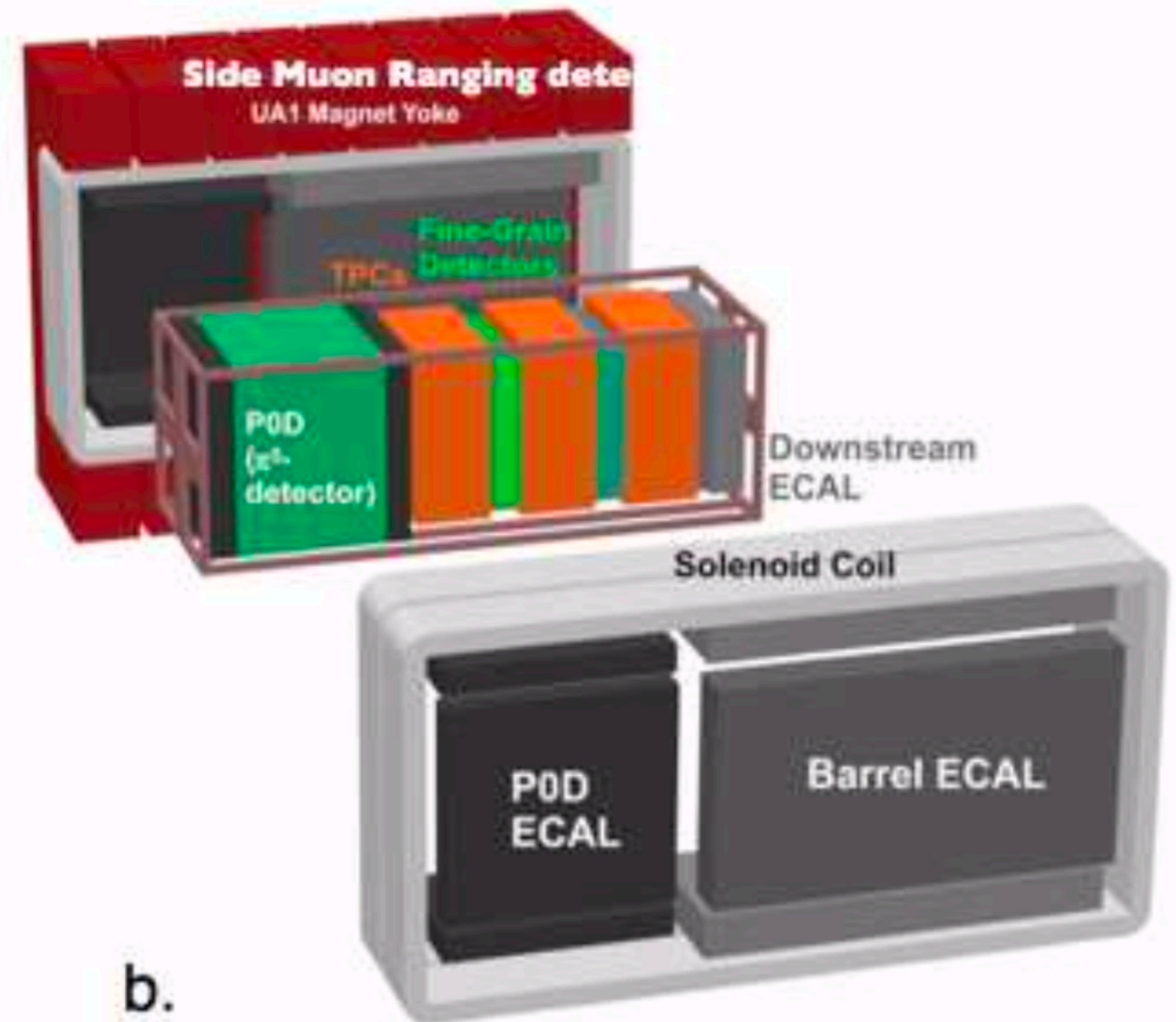
Vasheret *et al.* arXiv:1101.1996

The T2K Near Detectors

off-axis “ND-280”



a.



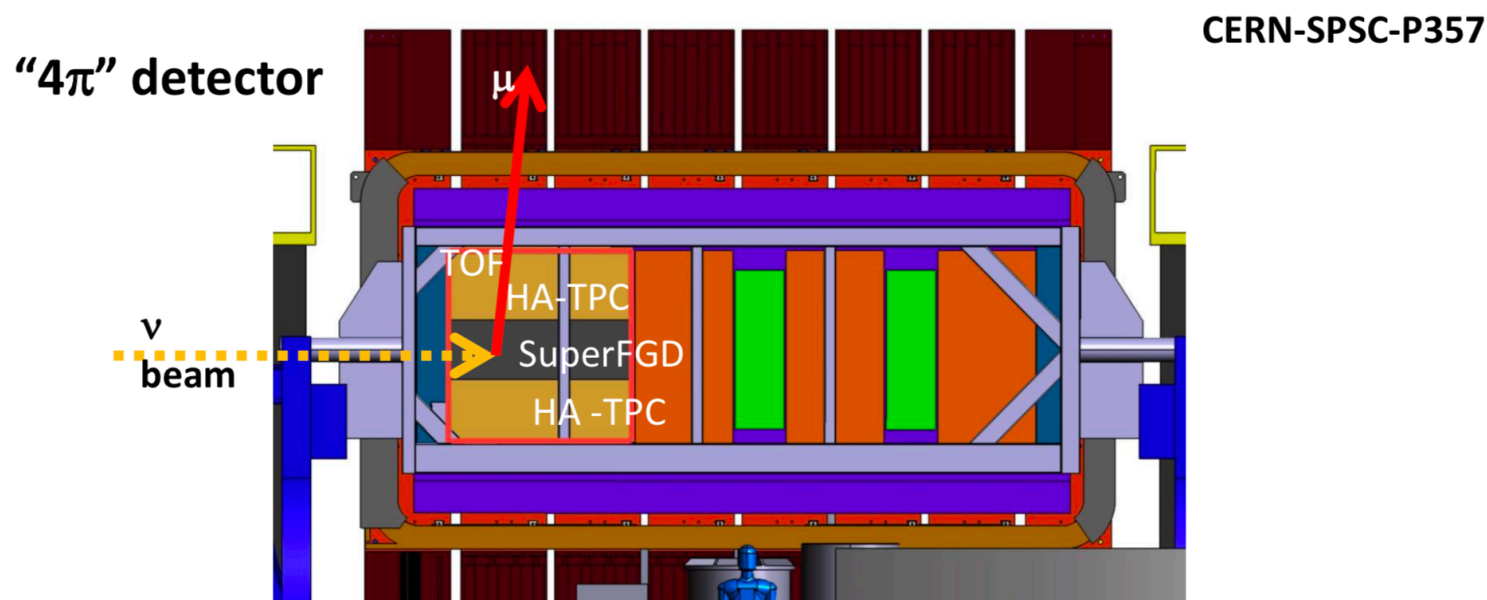
b.

on-axis beam monitors

Vasharet *et al.* arXiv:1101.1996

Towards T2HK

Upgraded ND-280
(2.2 tons \rightarrow 4.2 tons)

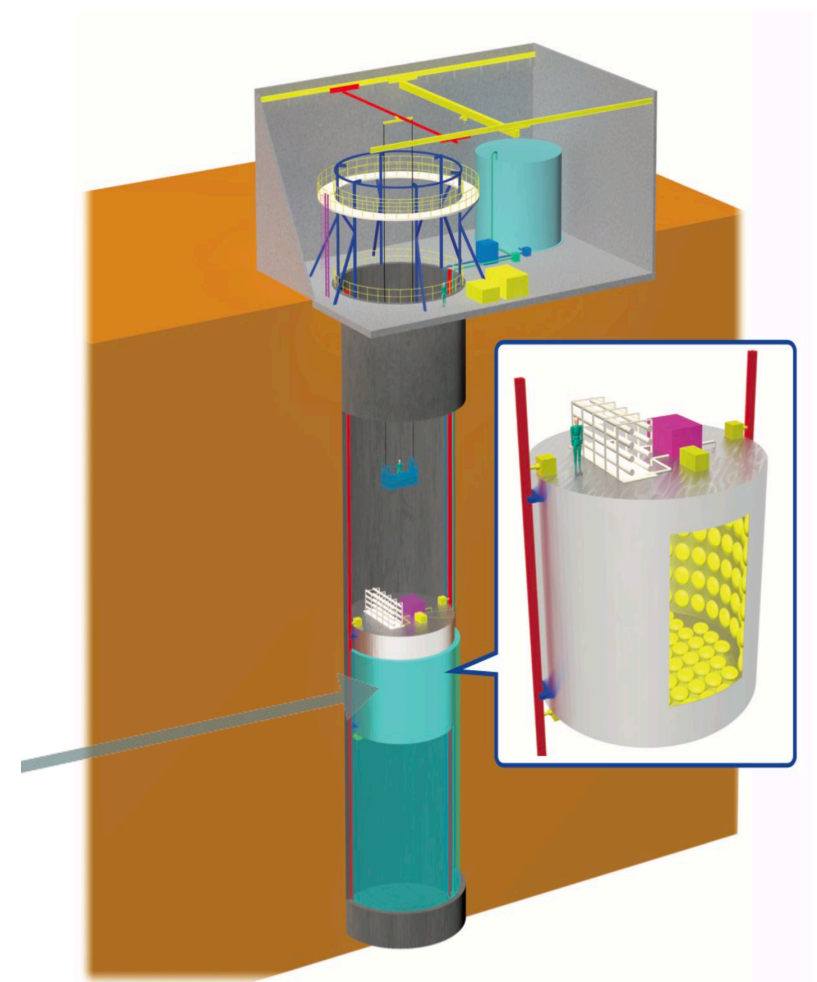


cf. DUNE: 0–3.5° off-axis

ND-LAr: 67 tons, $\sim 100 \text{ m}^3$ – liquid, large BG for HNLs

ND-GAr: 1 ton, $\sim 100 \text{ m}^3$ – gaseous, low BG for HNLs

Movable WC Detector
(sub-kton, 1–4° off-axis)

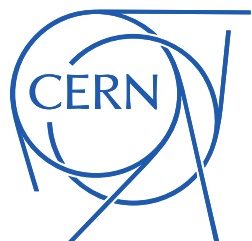


from a talk by Thorsten Lux

Thoughts about DUNE and T2HK

- ☑ Assume same number of POT
- ☑ Light DM Scattering
 - T2HK will benefit from larger detector mass if WC detector is built
 - to be seen if CC ν_e background can be as efficiently suppressed (based on angular cut)
 - and how many muons are mis-reconstructed as electrons
- ☑ Heavy Neutral Leptons
 - detector volumes similar
 - DUNE benefits from ND-GAr (when it is built) due to very low background

Summary

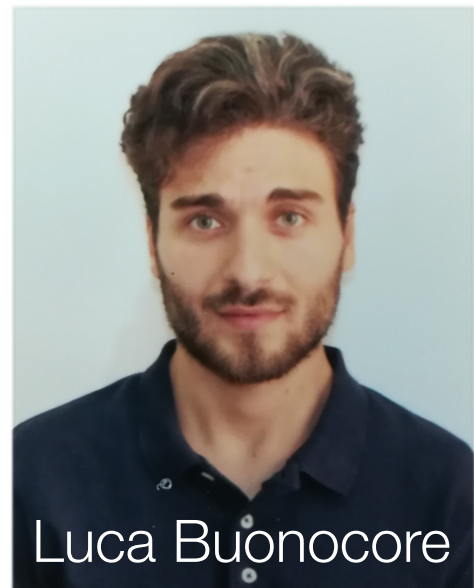


Summary

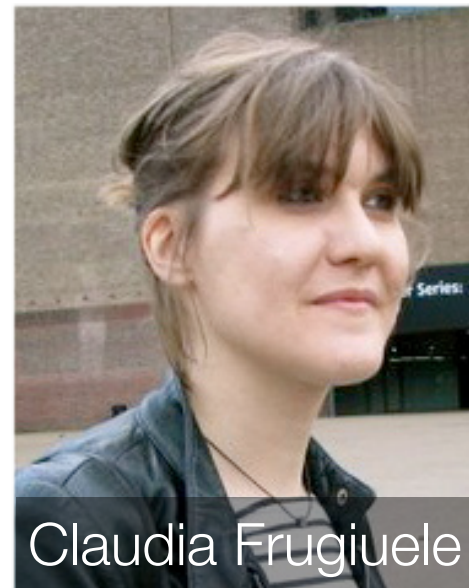
- ☑ Exciting Physics at the DUNE ND complex:
 - Millicharged Particles
 - Light Dark Matter
 - Leptophobic DM (not in this talk)
 - Heavy Neutral Leptons
 - ...
- ☑ off-axis measurements useful also for BSM physics



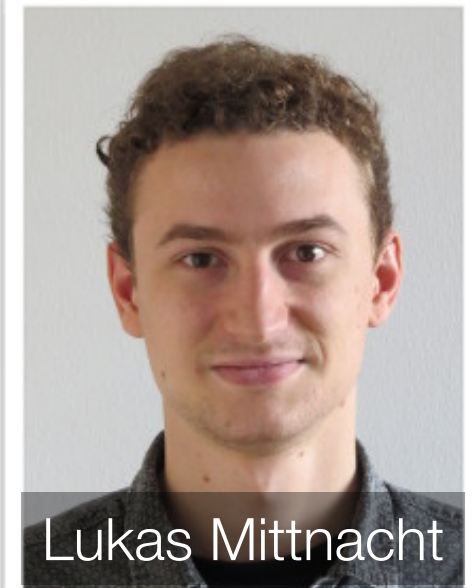
Moritz Breitbach



Luca Buonocore



Claudia Frugiuele



Lukas Mittnacht