The Higgs Portal Scalar

Samuel Homiller

Harvard University

For Section 2.1: Robinson, Knapen, Brod, Gori, Meade, Egana-Ugrinovic

January 22, 2021

The Higgs Portal

The *minimal* extension to the SM:

$$\mathcal{L}_{SM} + \frac{1}{2}\partial_\mu S \partial^\mu S - \underbrace{V(H, S)}$$

mixing between *H* and *S*

$\sin\theta$

Mass eigenstates:

h — the 125 GeV Higgs

φ — the new scalar

Coupling of phi to all other SM fields fixed by one, universal mixing angle:

$$\lambda_\varphi^f = -\sin\theta \frac{m_f}{v}$$

$$\frac{m_t}{v} \sim 0.7$$

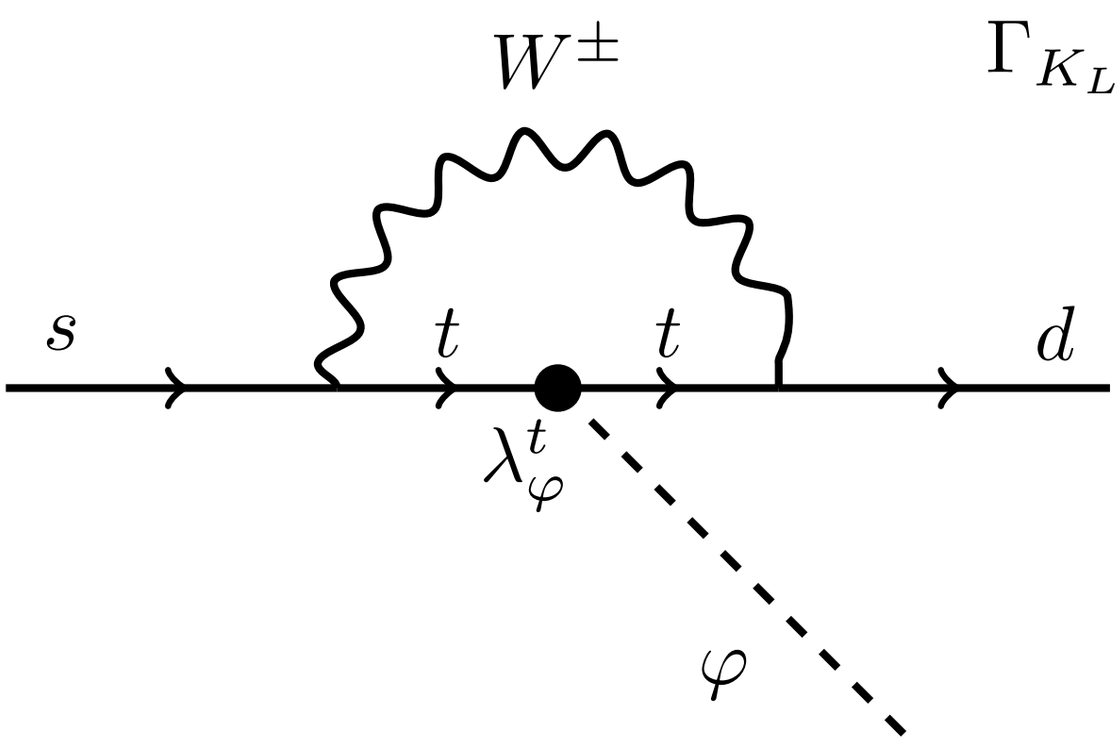
$$\frac{m_e}{v} \sim 2 \times 10^{-6}$$

Production and Decay

Decay governed by *small* coupling to electrons

→ For parameters of interest to us, $c\tau \sim 10 - 10^3\,\mathrm{km}$

Production on the other hand, arises at one loop via *large* coupling to the top!



$$\Gamma_{K_L\to\pi^0\varphi} = \frac{\left(\mathrm{Re}\, g_{\varphi K\pi}\right)^2}{16\pi m_K^3}\lambda^{1/2}(m_K^2, m_\pi^2, m_\varphi^2)$$

$$g_{\varphi K\pi} = \frac{3m_K^2}{32\pi^2 v^2}\sum_{f=u,c,t}\lambda_\varphi^f m_f V_{fd}^* V_{fs}$$

Signature at Kaon Factories

Scalar escapes undetected, so the signature is the two-body decay $K^+ \to \pi^+ X$ or $K_L \to \pi^0 X$, with X observed as missing energy.

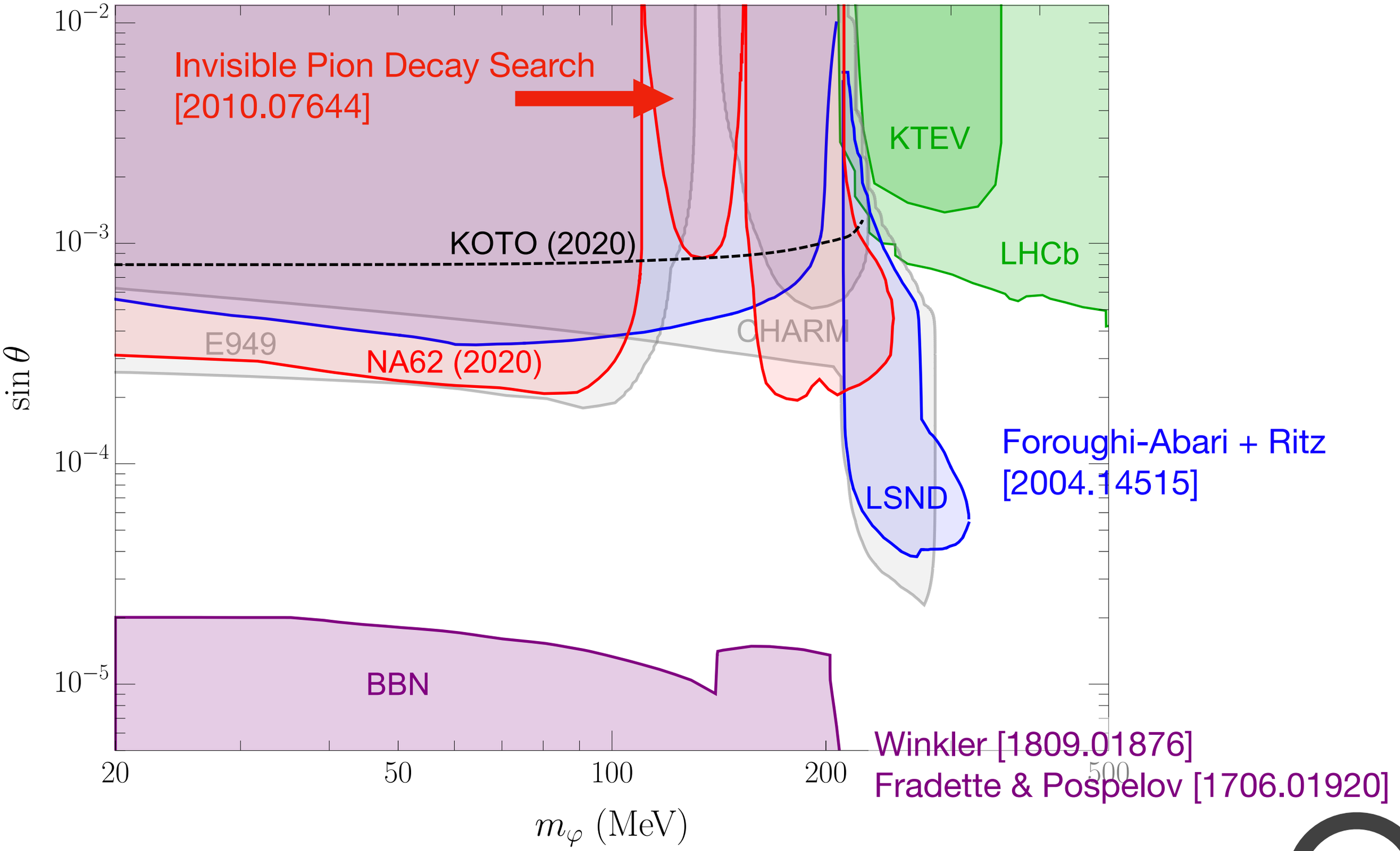
Already limits from NA62 & KOTO:

- NA62 (2017 data): 2011.11329
  2010.07644 (near pion mass)

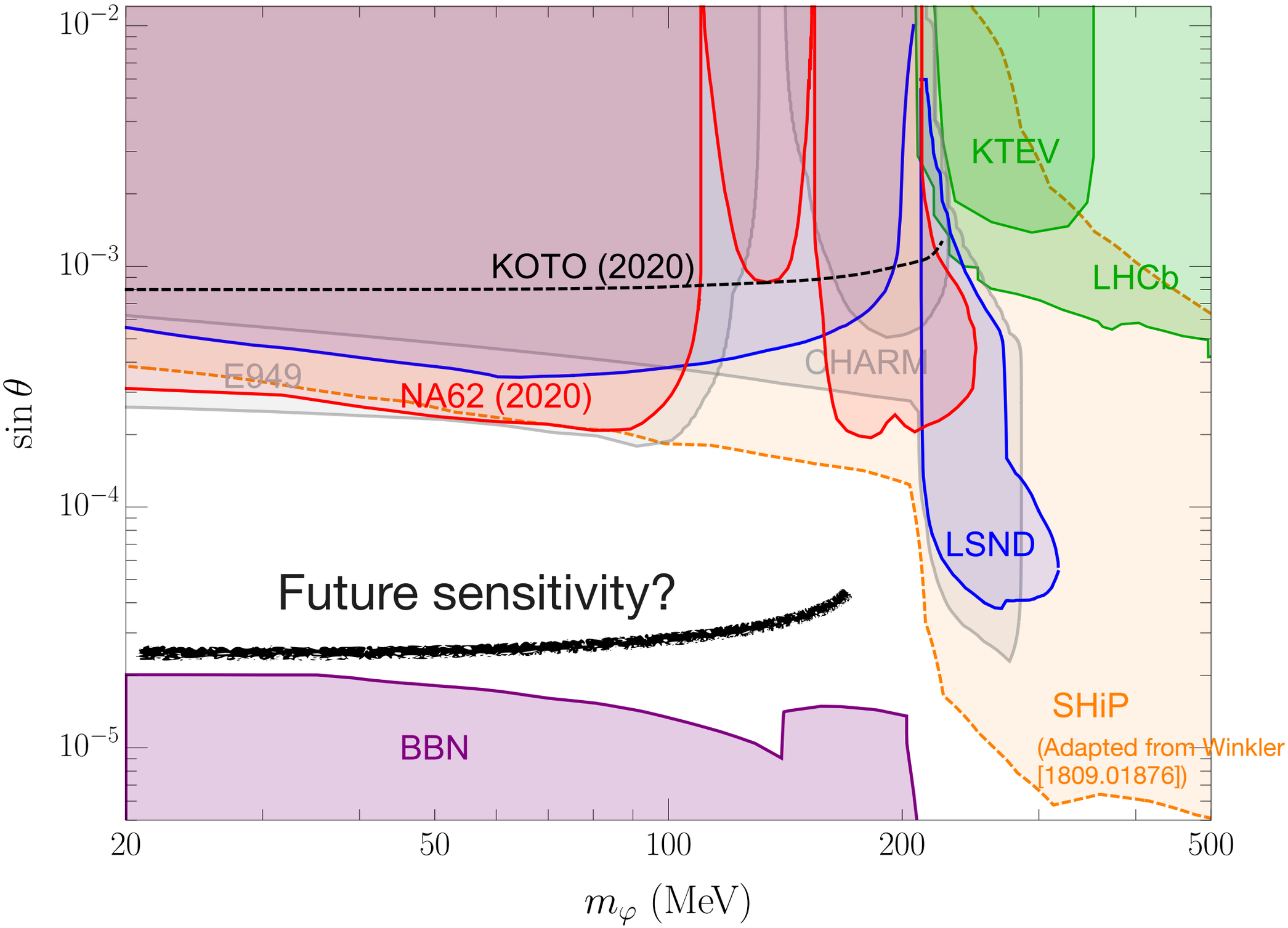
- KOTO (2015 data): 1810.09655

How far can these be pushed with future data?

Experimental Constraints



Experimental Constraints



Conclusions

- The Higgs portal is the simplest model of BSM physics, and is also ubiquitous in highly motivated scenarios
  (see e.g., [2012.07864] for a nice discussion)

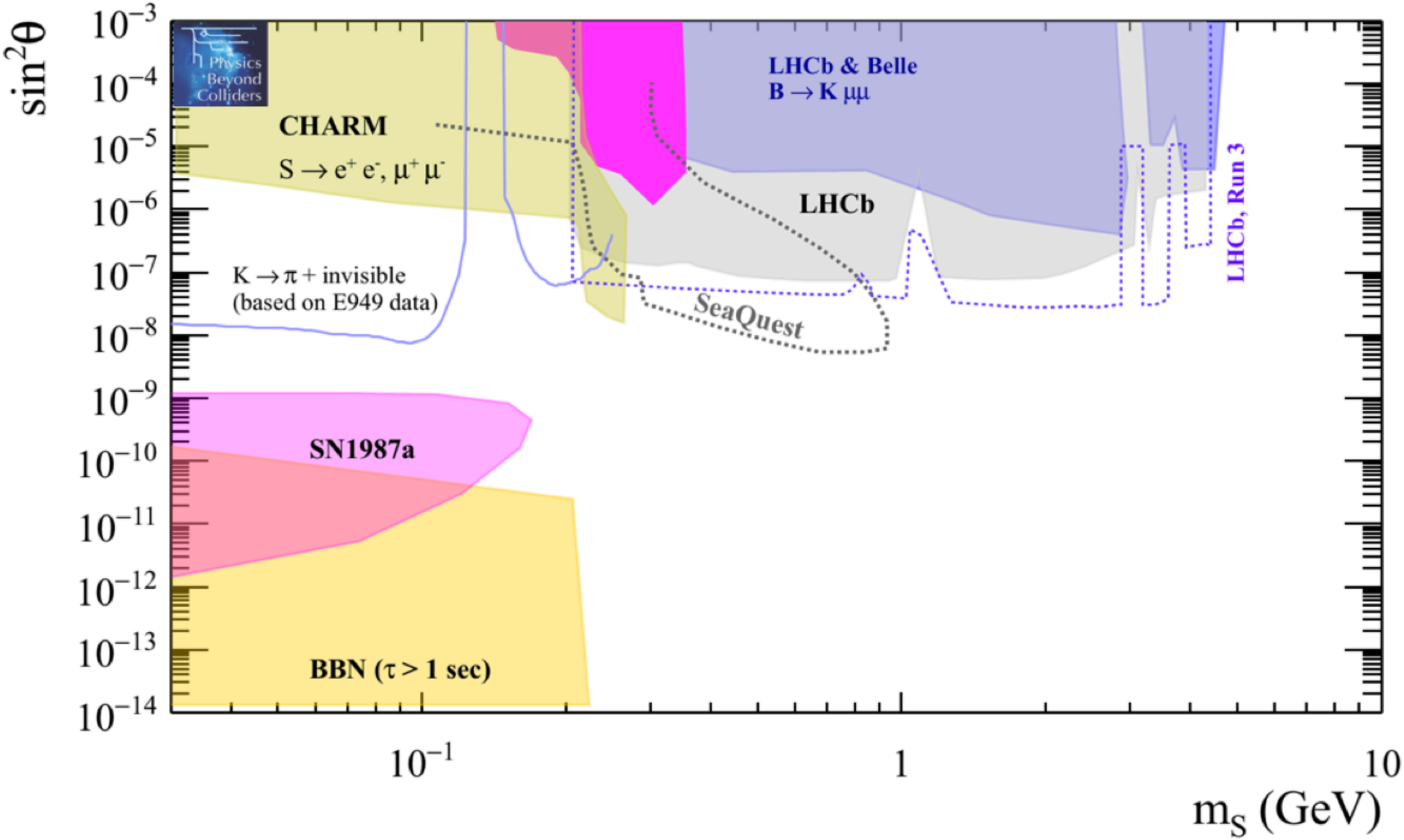
- Kaon factories are the *only* way to test these theories in the ~(0, 250 MeV) mass range — and there is a well-defined window to try and close!

- Signature is K → π + inv. with 2-body kinematics
  Can these searches be optimized for 2-body kinematics as opposed to 3-body?

Supplementary

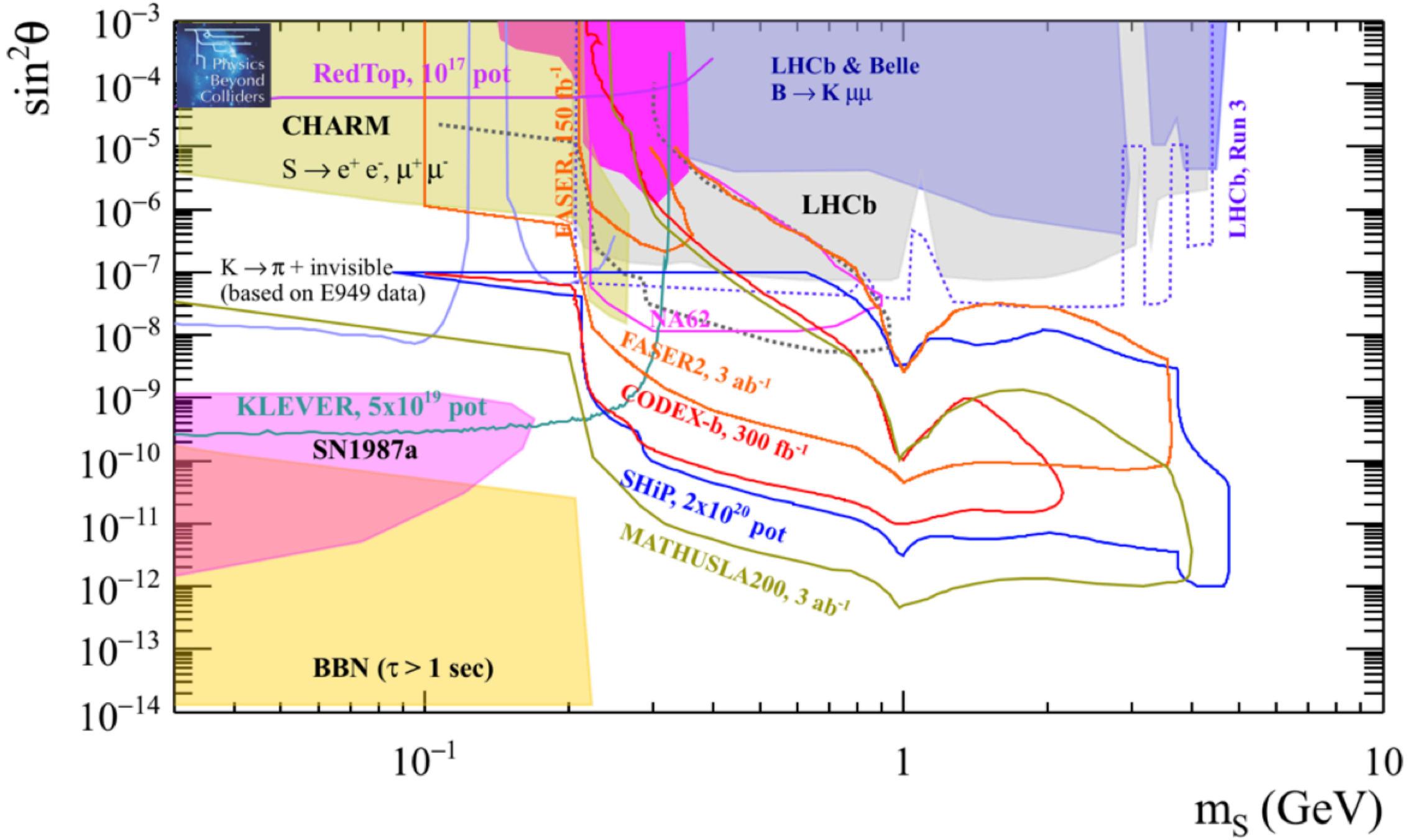
PBC Projections

1901.09966



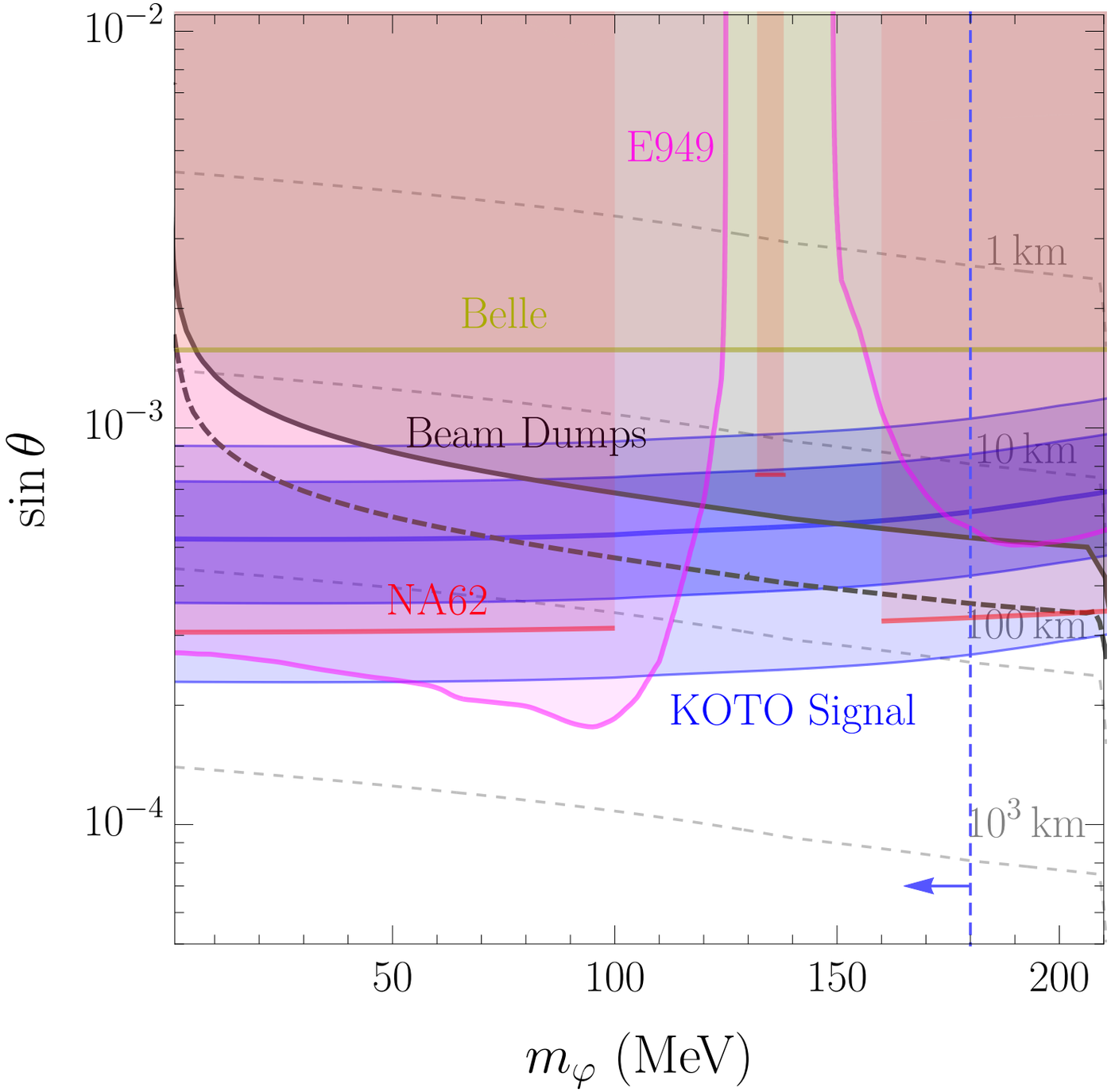
PBC Projections

1901.09966



KOTO Events

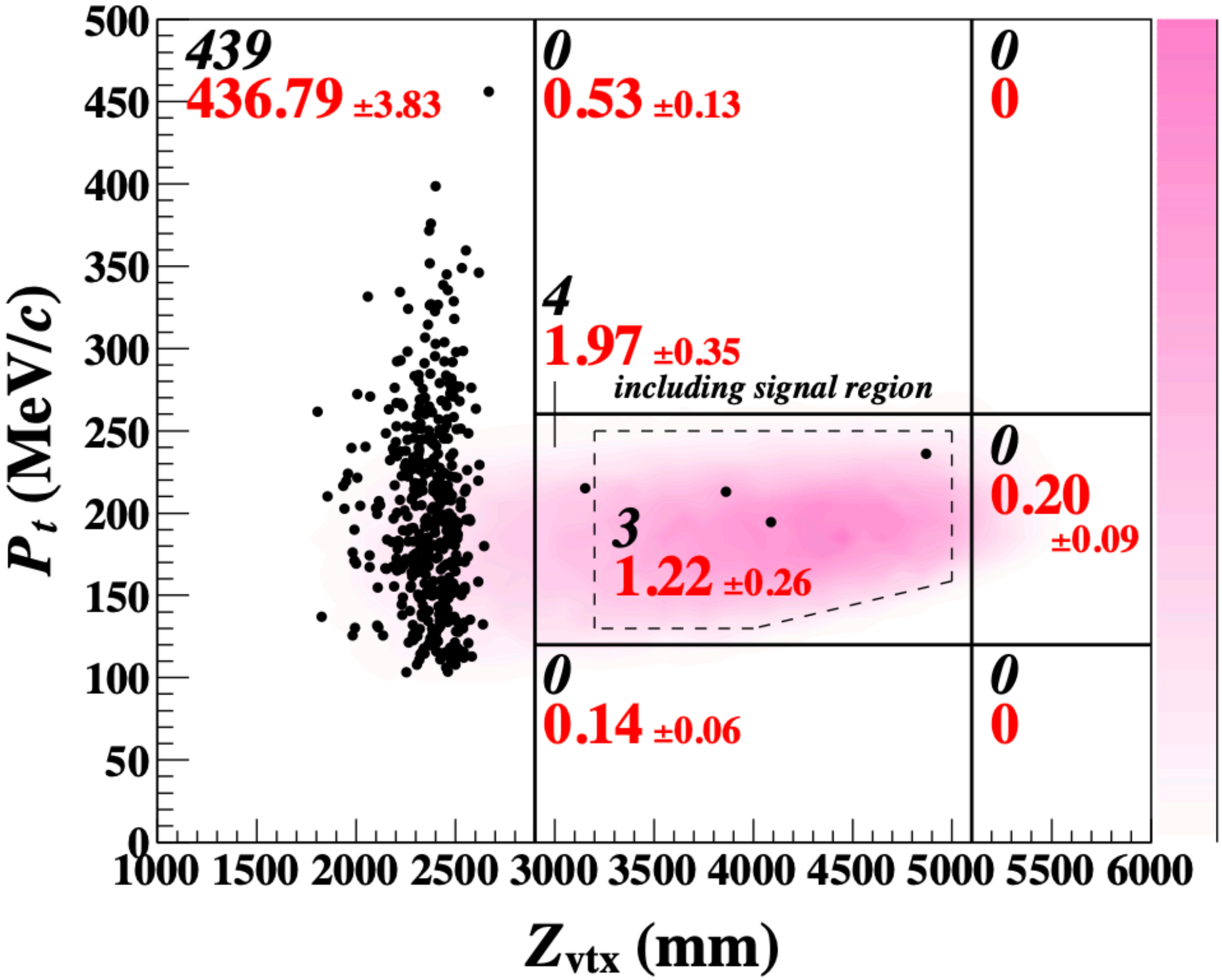
1911.10203 — Egana-Ugrinovic, SH, Meade



Preferred region for 3 events (2 event region is similar)

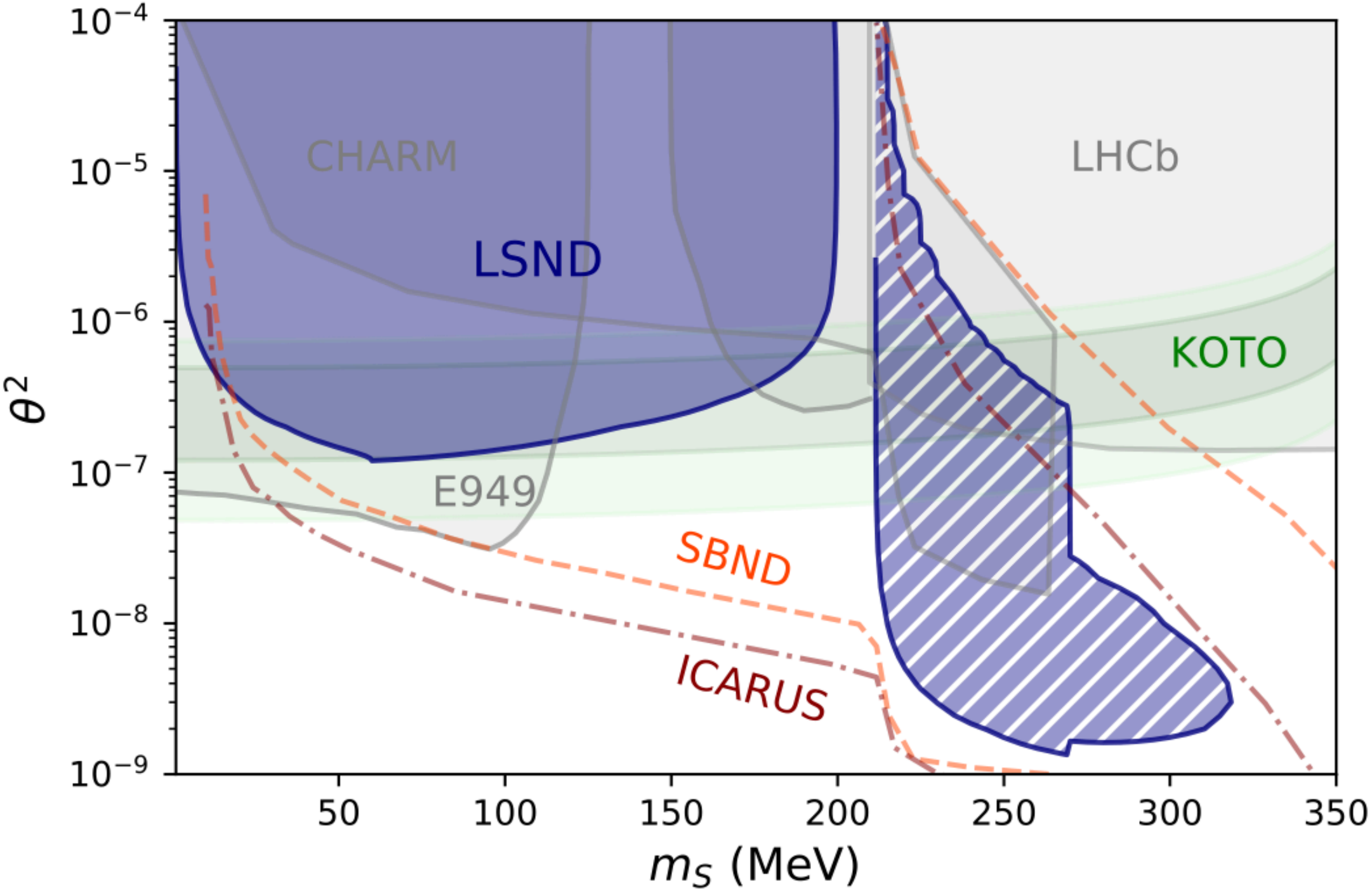
Aggressive vs. conservative CHARM bound (includes production via eta decays)

KOTO Events


439
436.79 ±3.83
0
0.53 ±0.13
0
0
4
1.97 ±0.35
including signal region
3
1.22 ±0.26
0
0.20
±0.09
0
0.14 ±0.06
0
0
P_t (MeV/c)
Z_{vtx} (mm)
500
450
400
350
300
250
200
150
100
50
0
1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000

LSND Constraints

2004.14515 — Foroughi-Abari, Ritz



FASER Projections

2006.10630 — Kling, Trojanowski