The 30th International Symposium on Particles, Strings and Cosmology
PASCOS 2025
21 – 25 July 2025
Durham, UK

# New physics searches at the NA62 experiment

On behalf of the NA62 collaboration

Artur Shaikhiev (artur.shaikhiev@cern.ch)
Lancaster University

# NA62 experiment (decay-in-flight)

- Main goal is measure ultra rare kaon decay $K^+ \to \pi^+ \nu\nu$ with 10% precision

- SM prediction:

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.60 \pm 0.42) \times 10^{-11}$$

[Buras et al., EPJC 82 (2022) 7, 615]

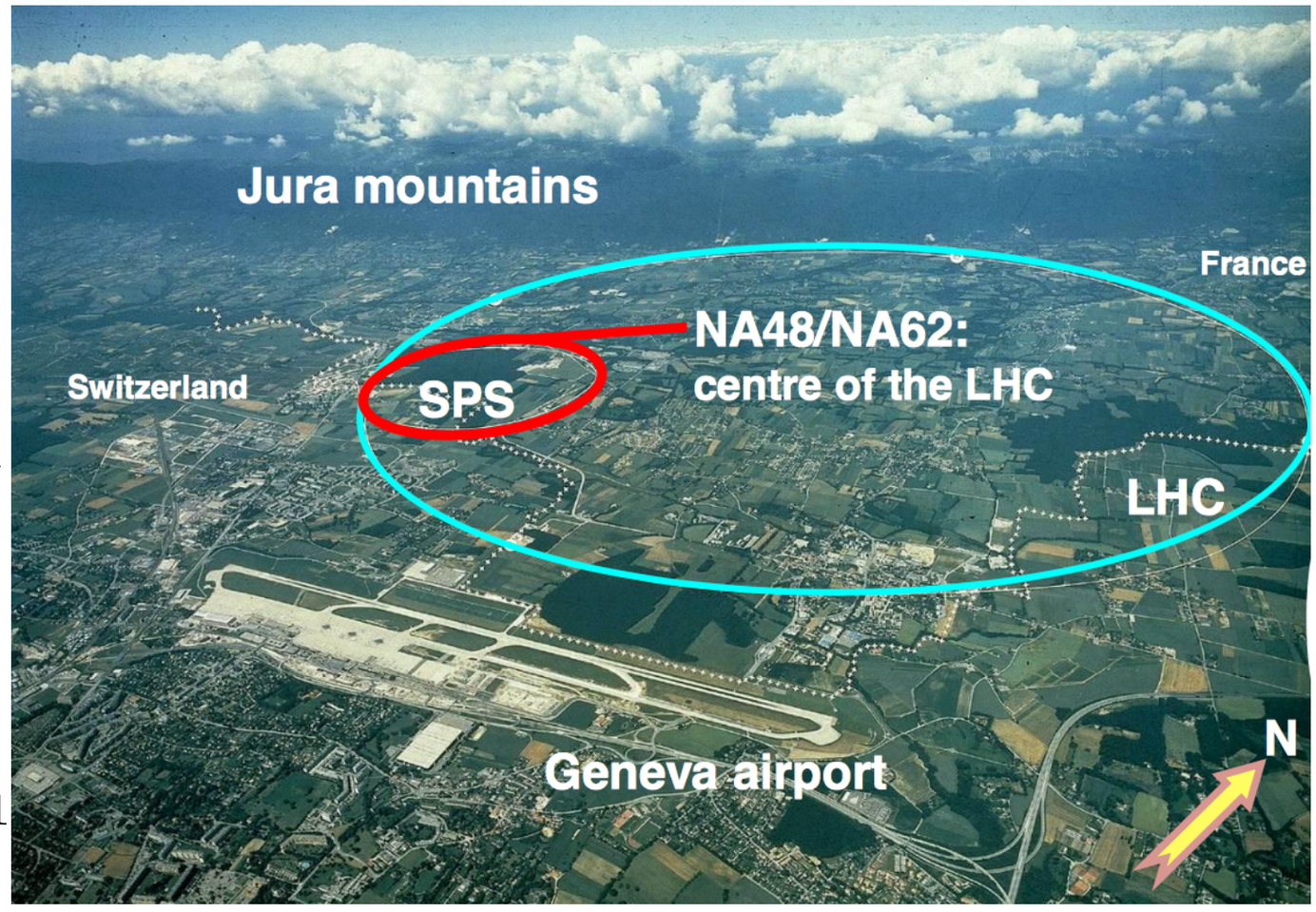
- Experimental measurements

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$

[E949/E787 PRL 101 (2008) 191802]

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (13.0^{+3.3}_{-3.0}) \times 10^{-11}$$

[NA62, JHEP02 (2025) 191]
see M.Mirra talk for details




Run1, Physics Run
2016 — 45 days
2017 — 160 days
2018 — 217 days

Run2, Physics Run
2021 — 85 days
2022 — 215 days
2023 — 150 days
2024 — 204 days
2025 — ongoing now
2026 — end of data taking

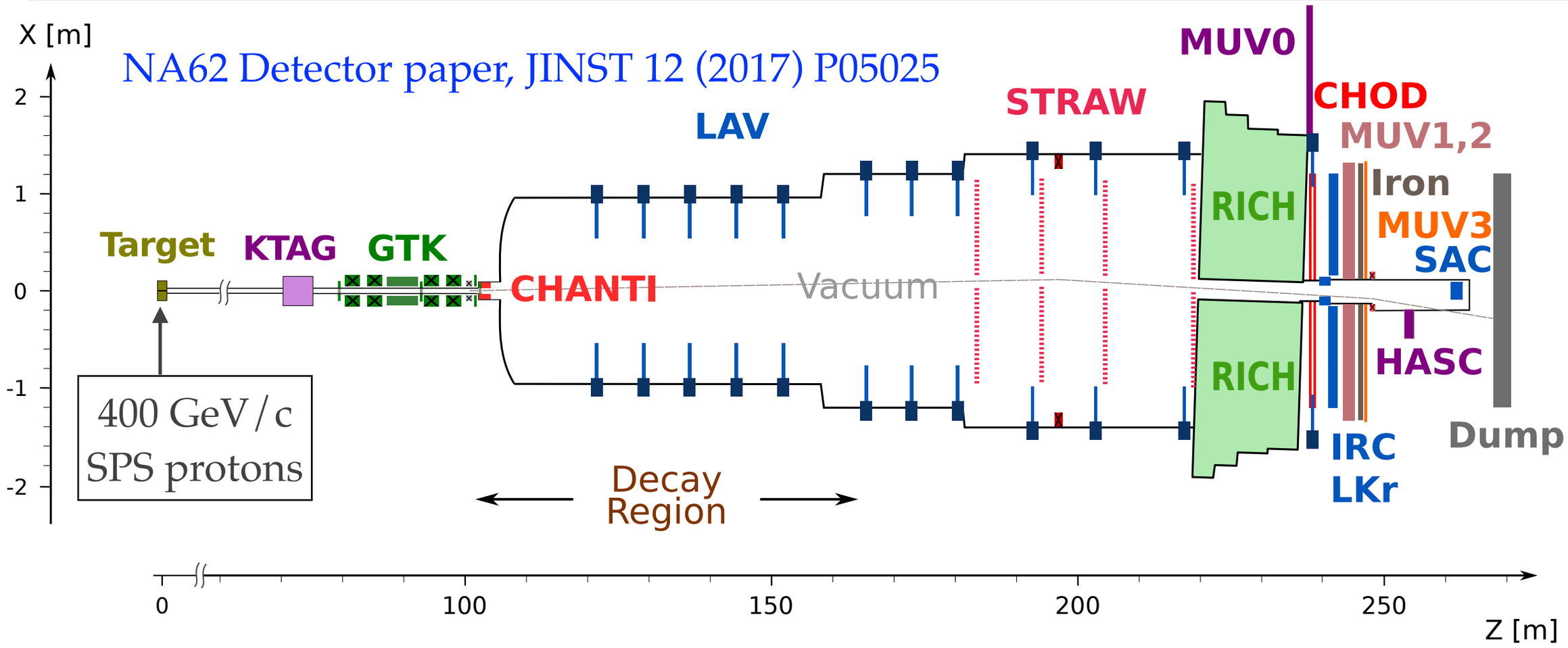
# NA62 broad physics program

- Precision measurements: $K^+ \to \pi^+ \gamma\gamma$, $K^+ \to \pi^+ \mu^+ \mu^-$, $K^+ \to \pi^0 e^+ \nu\gamma$
- Lepton flavour/number violation decays: $K^+ \to \pi^- l^+ l^+$, $K^+ \to \pi^\pm \mu^\mp e^+$, $K^+ \to \pi^- \pi^0 e^+ e^+$, …
- Exotic particles searches
  - $K^+ \to l^+ N$, $\pi^0 \to \gamma A'$
  - NA62 dump mode (decays into SM particles) — This talk
  - $K^+ \to \pi^+ X$ (arXiv:2507.17286 — published yesterday!)
    - X is invisible: decays into dark matter particles or neutrinos or lifetime is long enough to escape the detector
    - X decays into SM particles
  - $\pi^+ \to e^+ N$ (arXiv:2507.07345v1 — recent publication)

# The NA62 detector

**Unseparated secondary beam:**

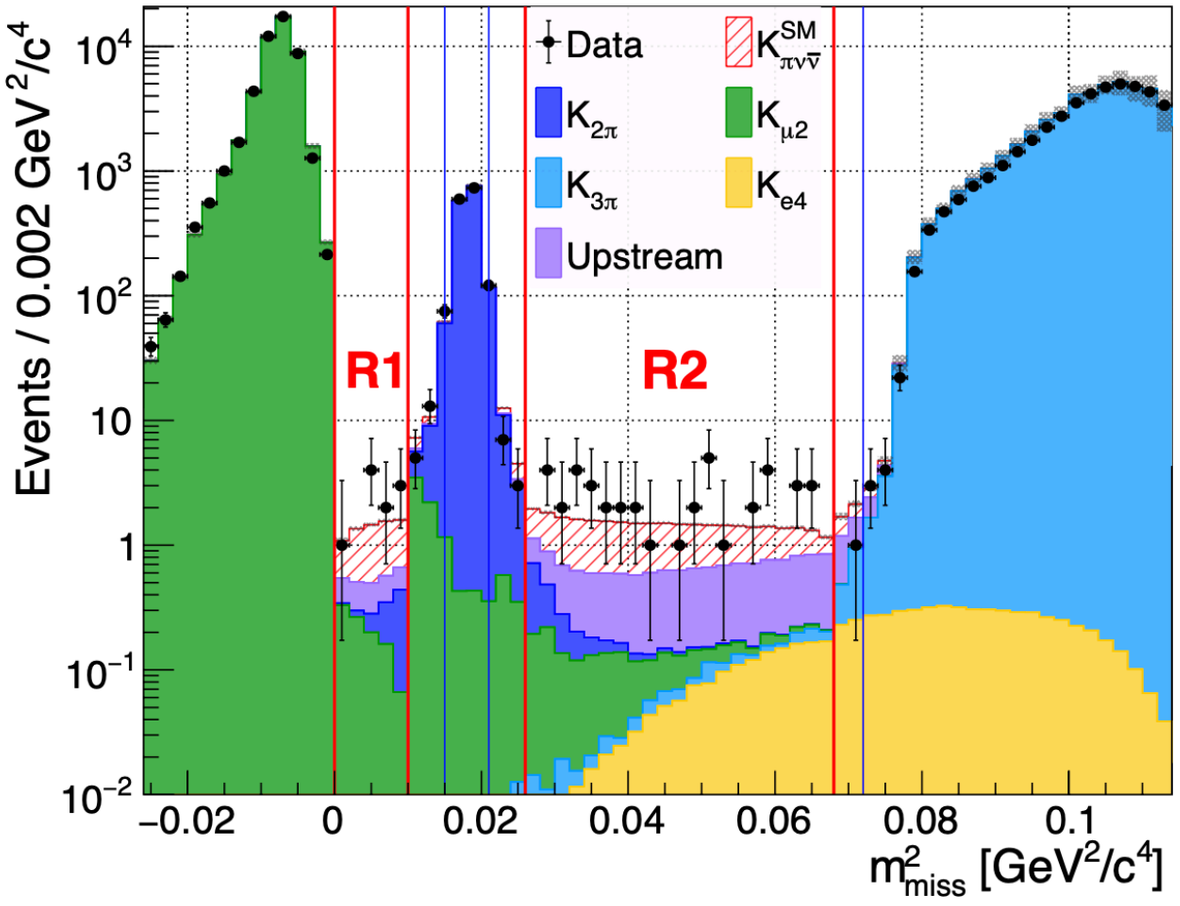
- $K^+$(6%), $\pi^+$(70%), p(24%)
- Nominal beam particle rate at GTK3: 750 MHz;
- Average beam particle rate during 2018: 450 — 500 MHz
- Momentum: 75 GeV/c

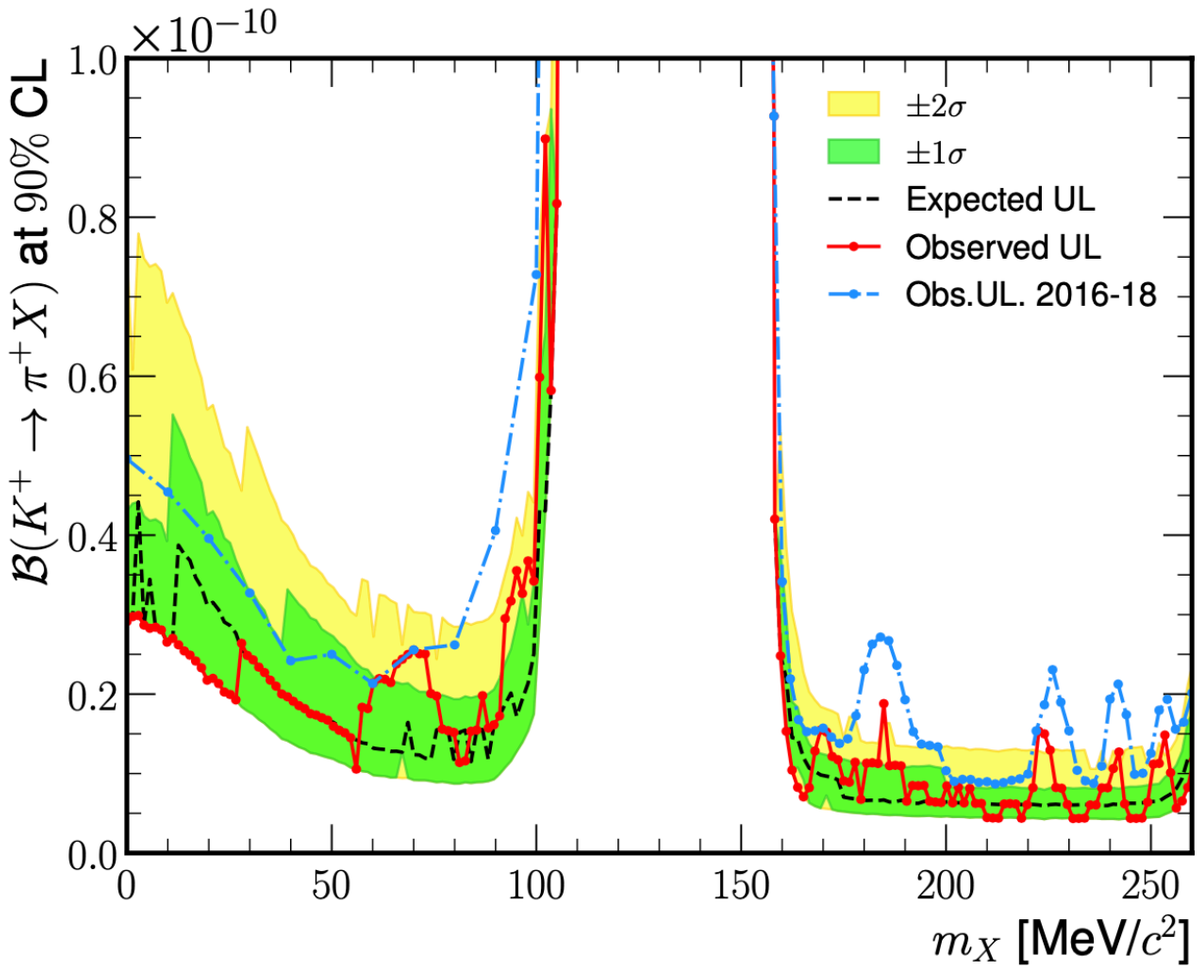



- Timing between sub detectors O(100 ps)
- Kaon ID and direction (KTAG, GTK)
- Particle ID and direction (STRAW, RICH, LKr, HASC, MUV): $\mu^+$ rejection O($10^7$)
- Photon veto (LAV, LKr, IRC, SAC): $\pi^0 \to \boldsymbol{\gamma\gamma}$ rejection O($10^7$)

# $K^+ \to \pi^+ X$, X is invisible

Interpretation (arXiv:2507.17286) of $K^+ \to \pi^+ \nu\nu$ result, 2016–2022 data [JHEP02 (2025) 191].
Peak search: $K^+ \to \pi^+ \nu\nu$ is the main background and number of background events is estimated using SM branching ratio.

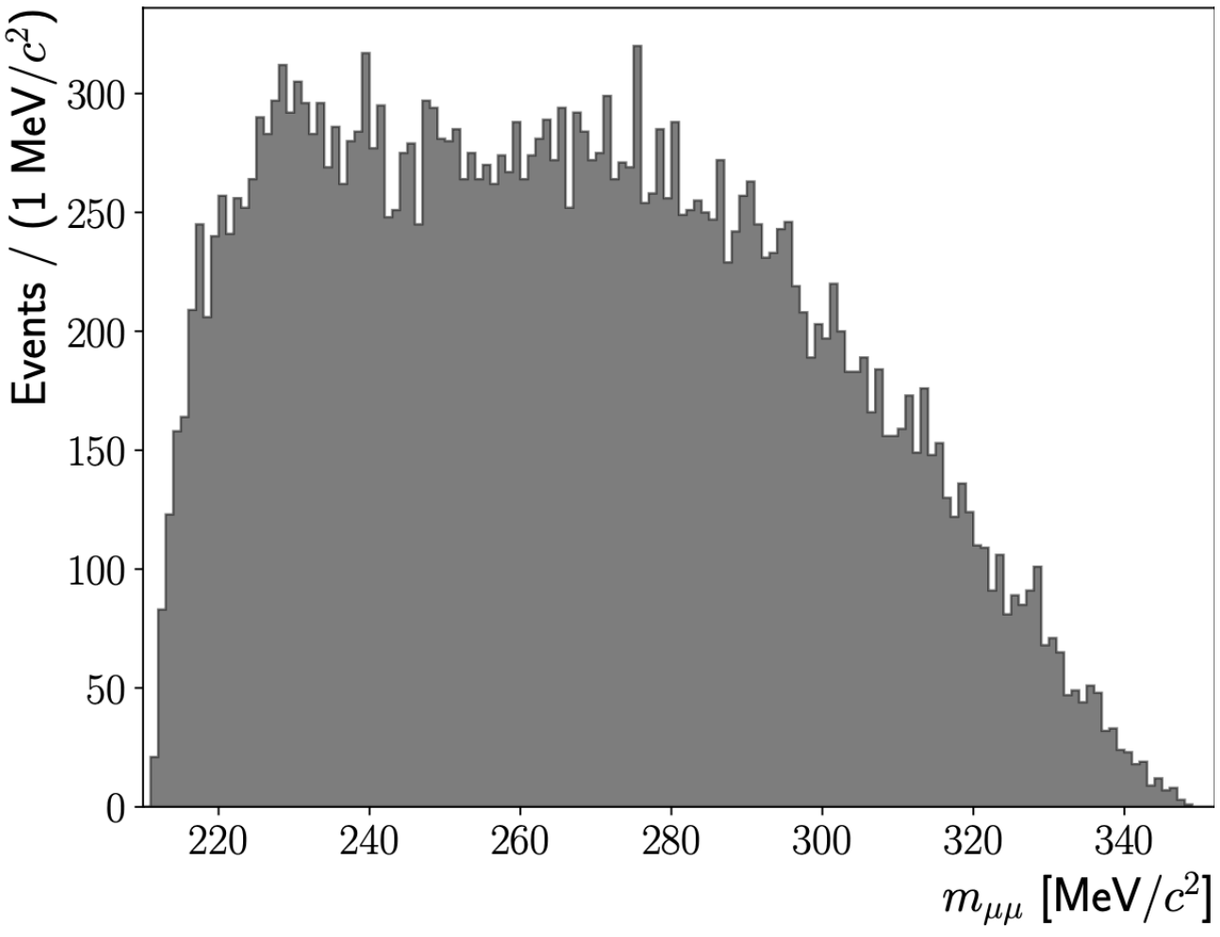


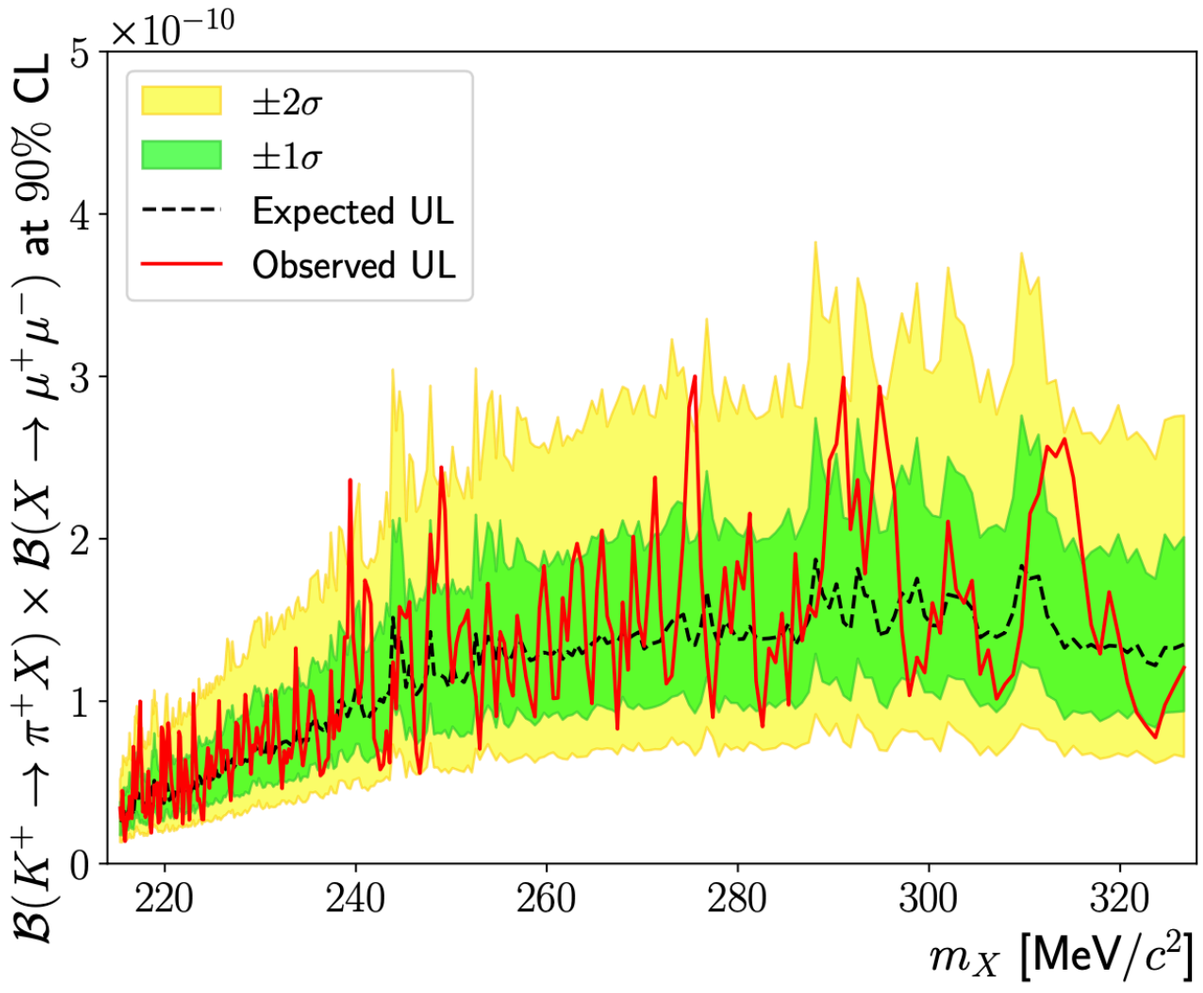




Model-independent constraints

# $K^+ \to \pi^+ X, X \to \mu^+\mu^-$

Interpretation (arXiv:2507.17286) of $K^+ \to \pi^+\mu^+\mu^-$ result, 2017–2018 data [JHEP 11 (2022) 011]. Peak search: data driven background estimation — sideband fits with masked signal region for each mass hypothesis.

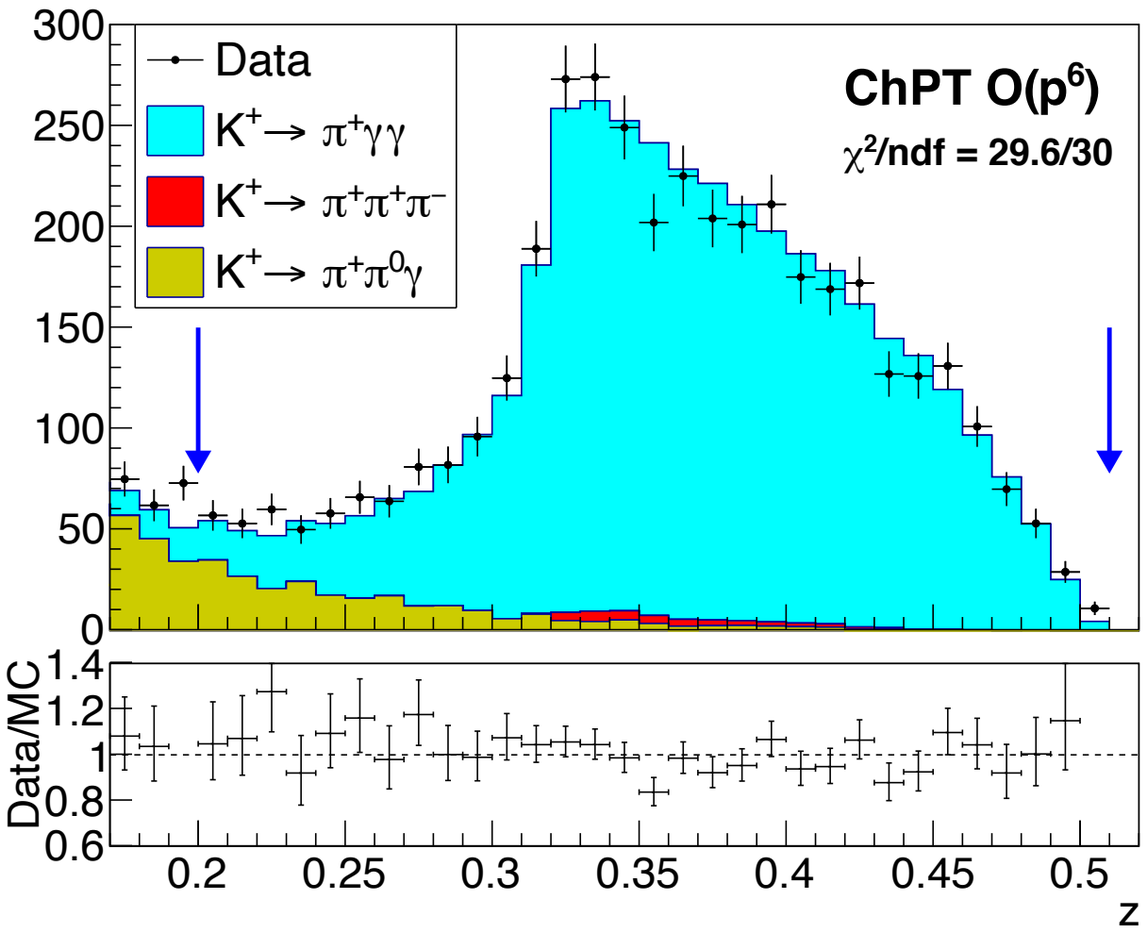


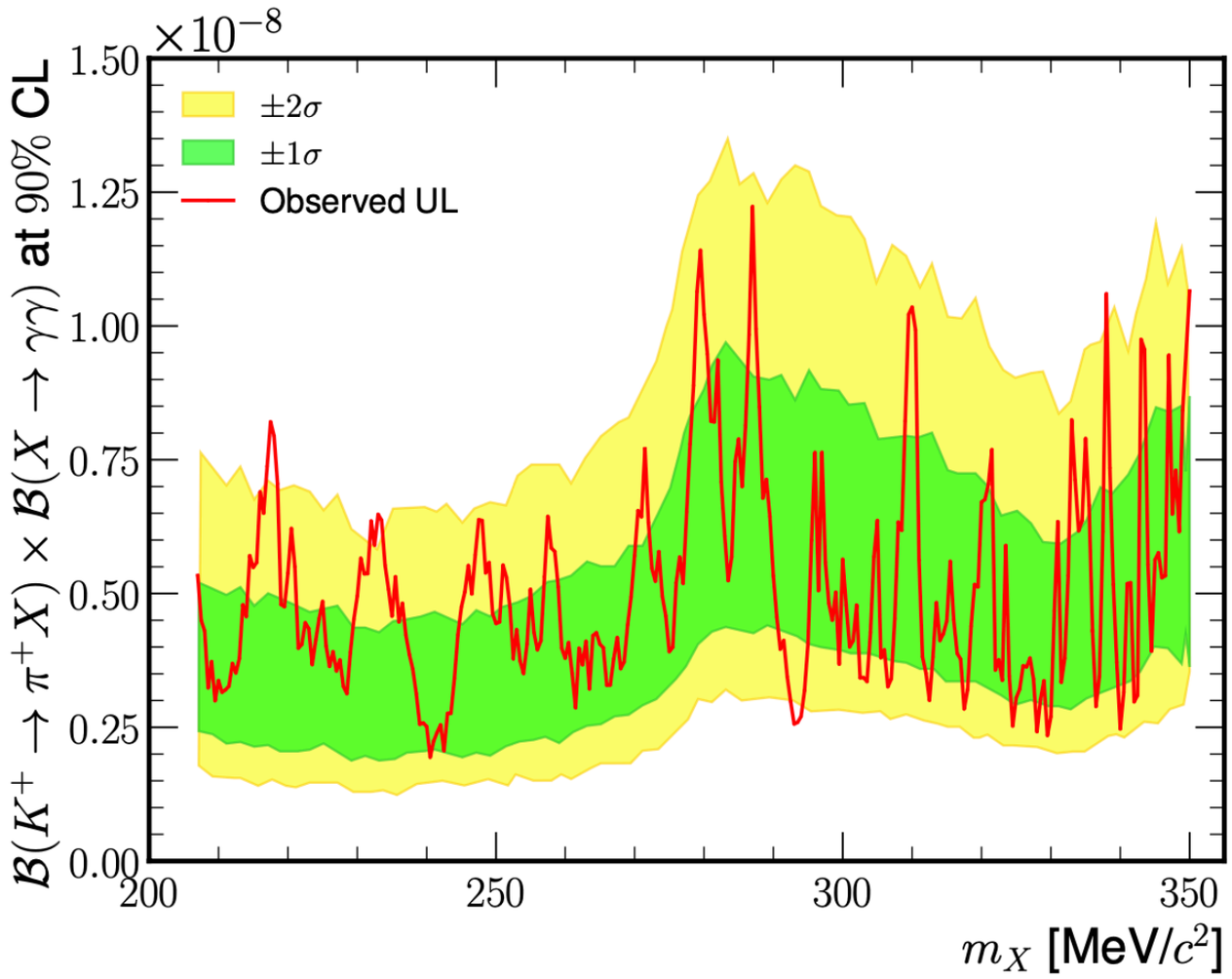

Model-independent constraints for prompt X decay

# $K^+ \to \pi^+ X,\ X \to \gamma\gamma$

Interpretation of $K^+ \to \pi^+ \gamma\gamma$ result, 2017–2018 data set [PLB 850 (2024) 138513].
Peak search: $K^+ \to \pi^+ \gamma\gamma$ is the main background and number of background events is estimated using MC simulations.




$z = (P_K\text{-}P_\pi)^2 / (m_K)^2 = (m_{\gamma\gamma} / m_K)^2$




Model-independent constraints for prompt X decay

# $K^+ \to \pi^+ X$ models

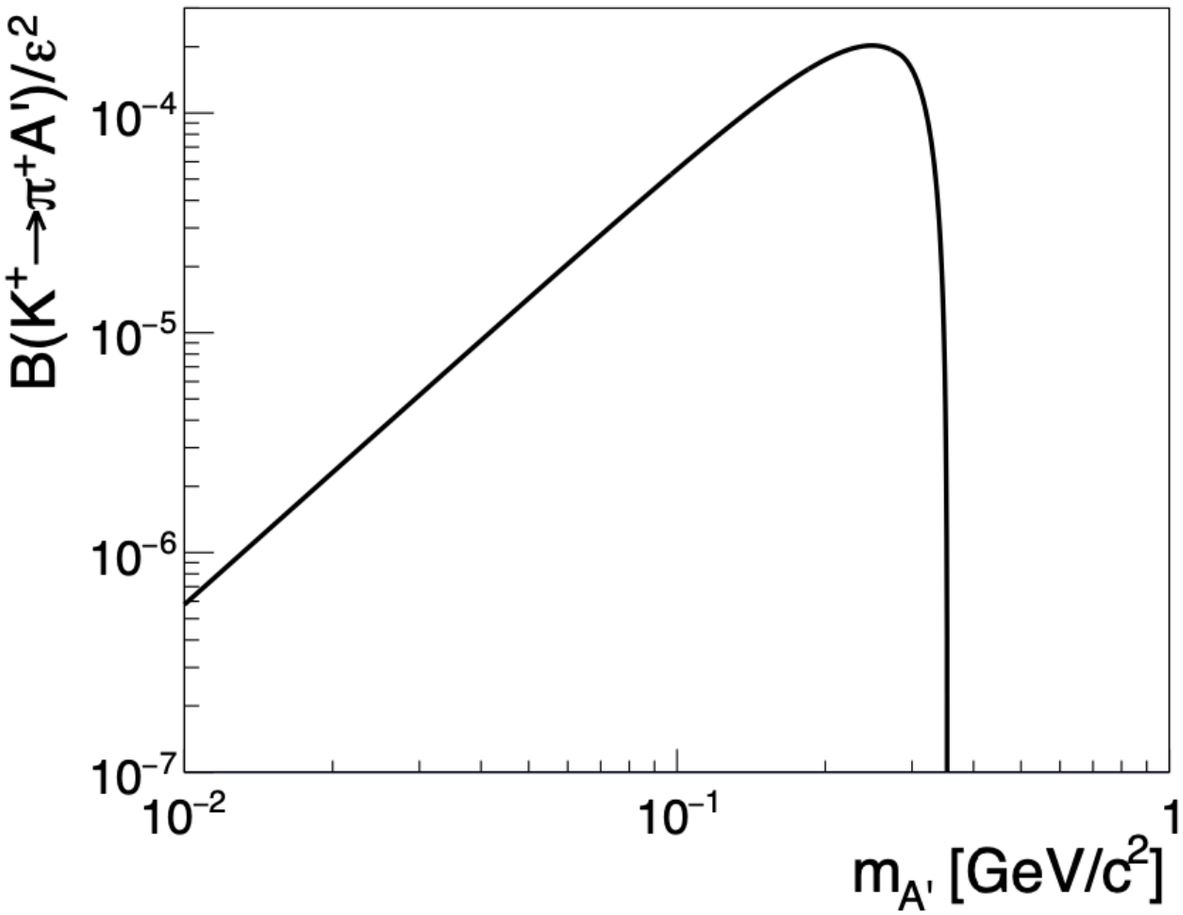
| Benchmark | BSM particle ($X$) | Type | Coupling to SM | Search |
|---|---|---|---|---|
| BC1 | dark photon ($A'$) | vector | $\varepsilon$ | $\mu^+\mu^-$ |
| BC2 | dark photon ($A'$) | vector | $\varepsilon$ | invisible |
| BC4 | dark scalar ($S$) | scalar | $\theta$ | invisible, $\mu^+\mu^-$ |
| BC4-inv | dark scalar ($S$) | scalar | $\theta$ | invisible |
| BC10 | axion-like particle ($a$) | pseudoscalar | $C_{ff}$ (to fermions) | invisible, $\mu^+\mu^-$ |
| BC10-inv | axion-like particle ($a$) | pseudoscalar | $C_{ff}$ (to fermions) | invisible |
| BC11 | axion-like particle ($a$) | pseudoscalar | $C_{GG}$ (to gluons) | invisible, $\gamma\gamma$ |

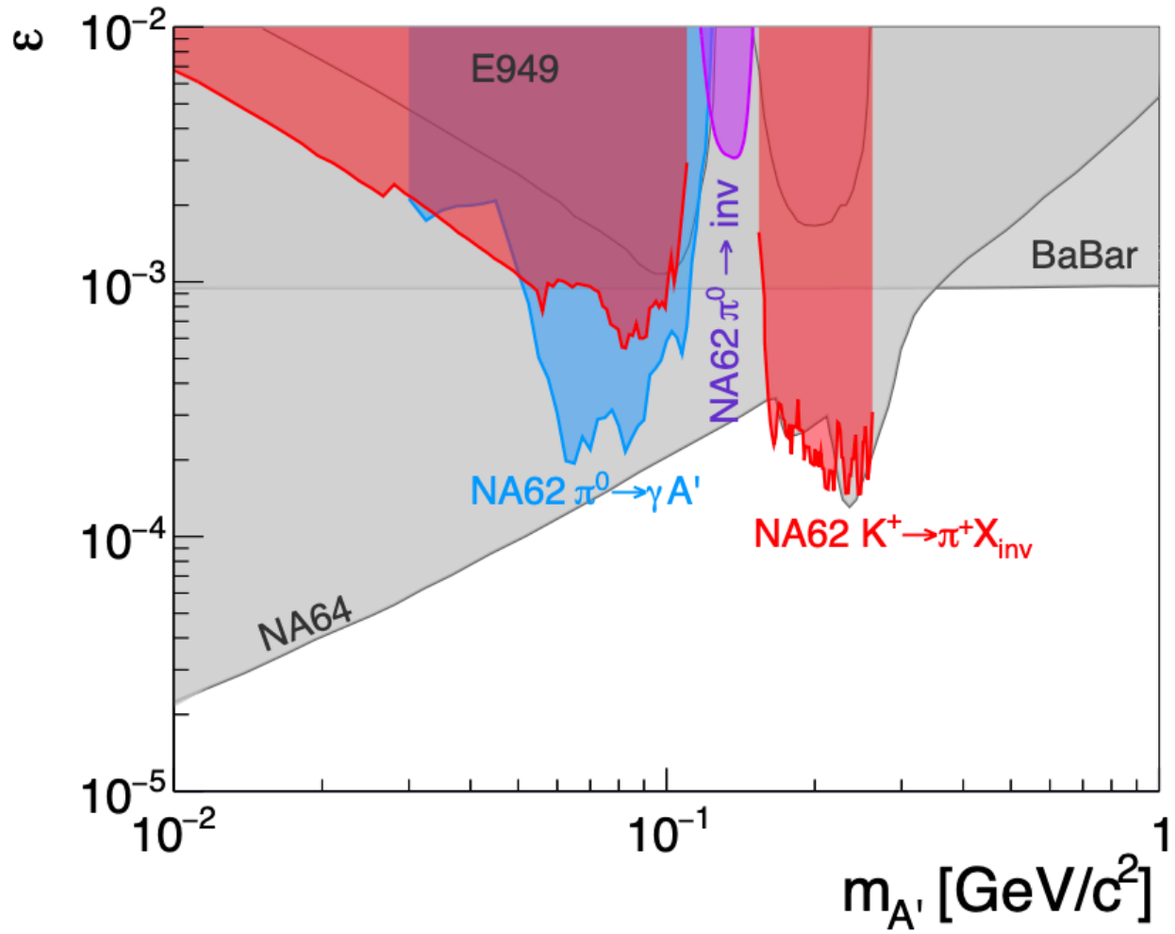
$$\mathcal{B}(K^+ \to \pi^+ X) = \frac{p_X}{8\pi\Gamma_K m_K^2}|\mathcal{M}|^2$$

where $\Gamma_K = 5.32 \times 10^{-14}\,\text{MeV}$ is the $K^+$ decay width, $p_X$ is the momentum of $X$ in the kaon rest frame, and $m_K$ is the $K^+$ mass . The matrix element $\mathcal{M}$ depends on the hidden-sector scenario and is proportional to the coupling strength.

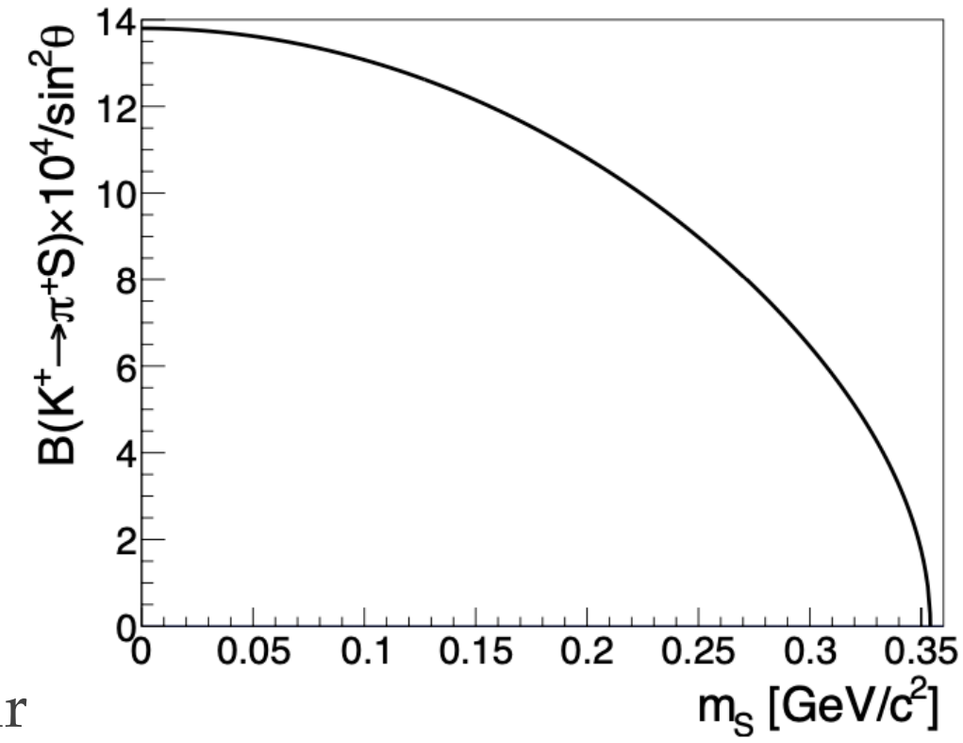
# $K^+ \to \pi^+ X$ models

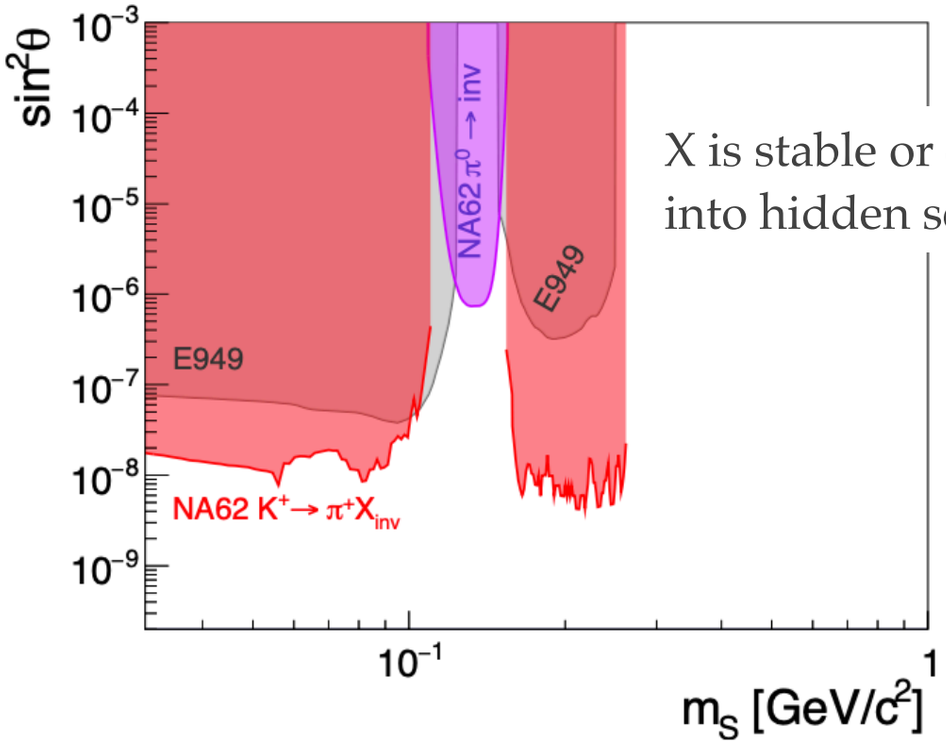
BC2



# $K^+ \to \pi^+ X$ models



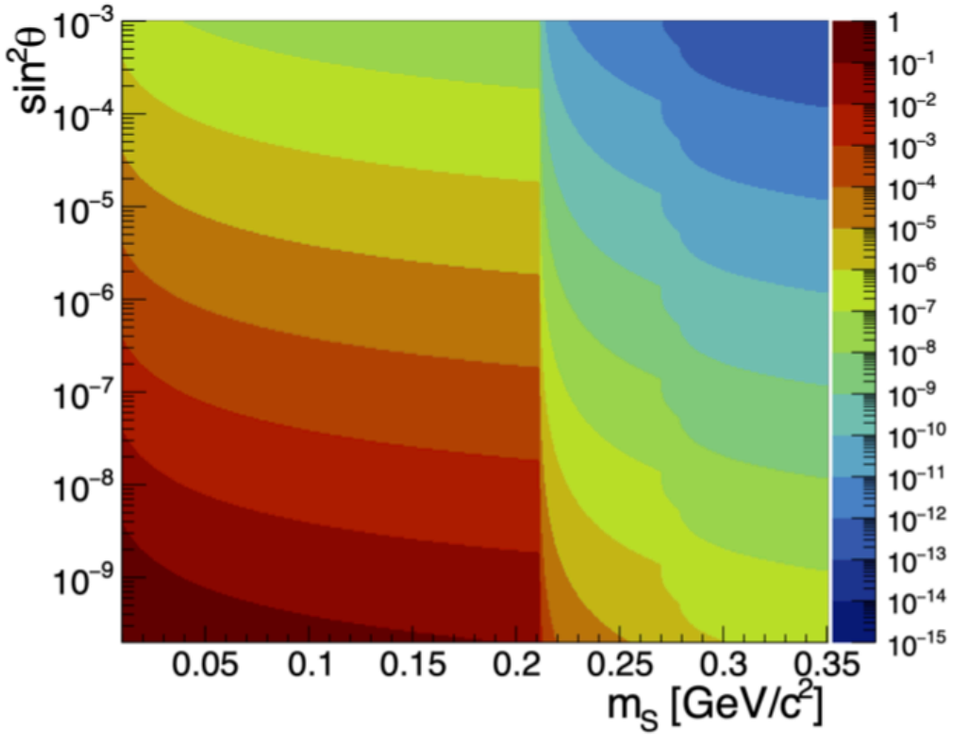



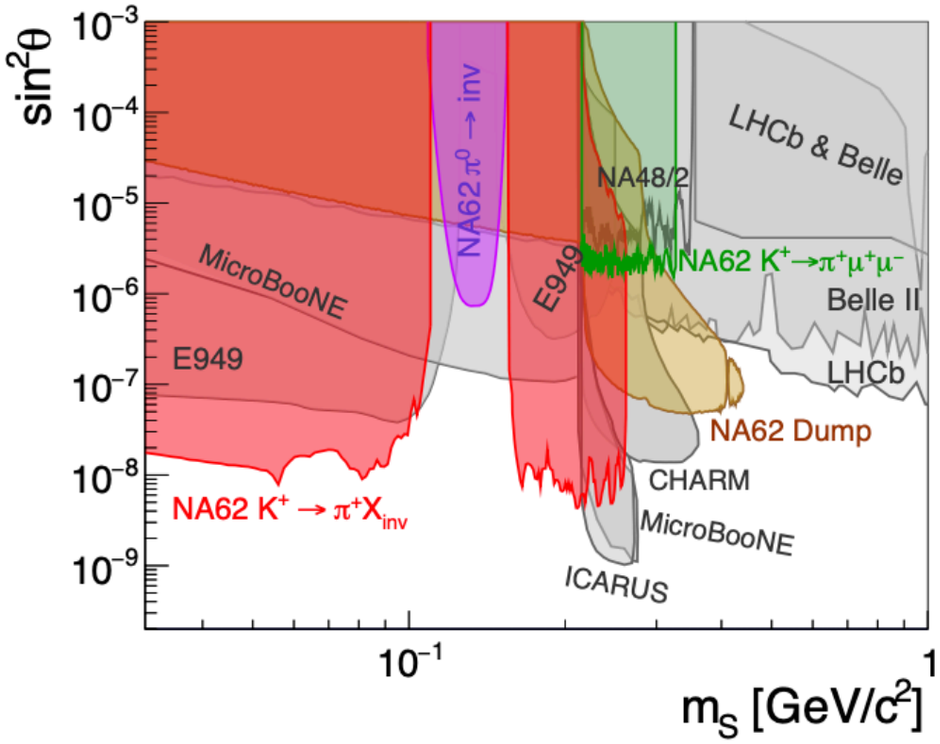

BC4

X is stable or decays into hidden sector particles

colour

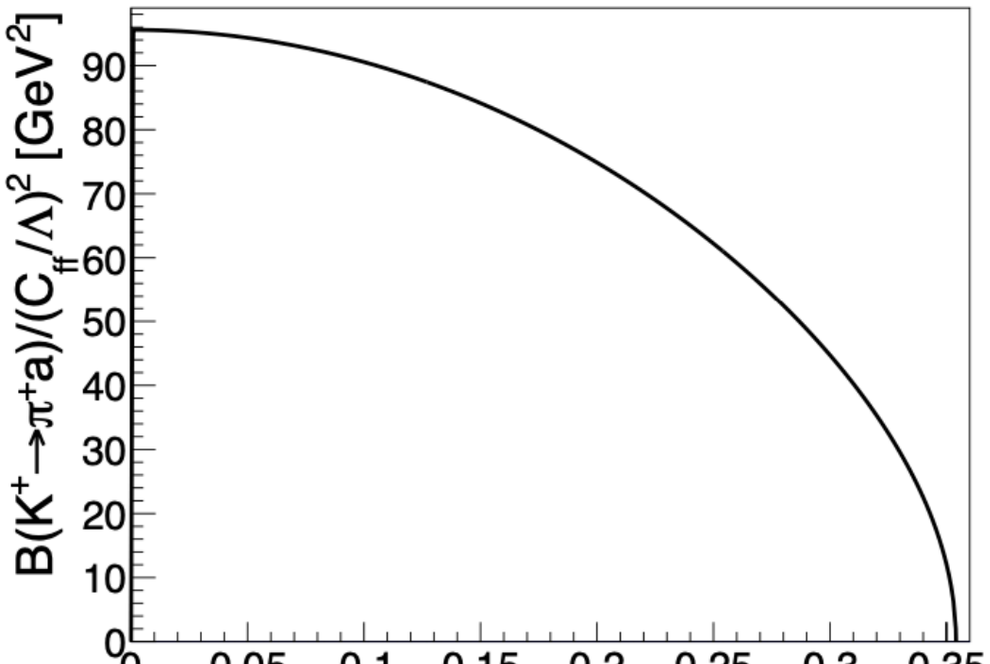
X lifetime in ns

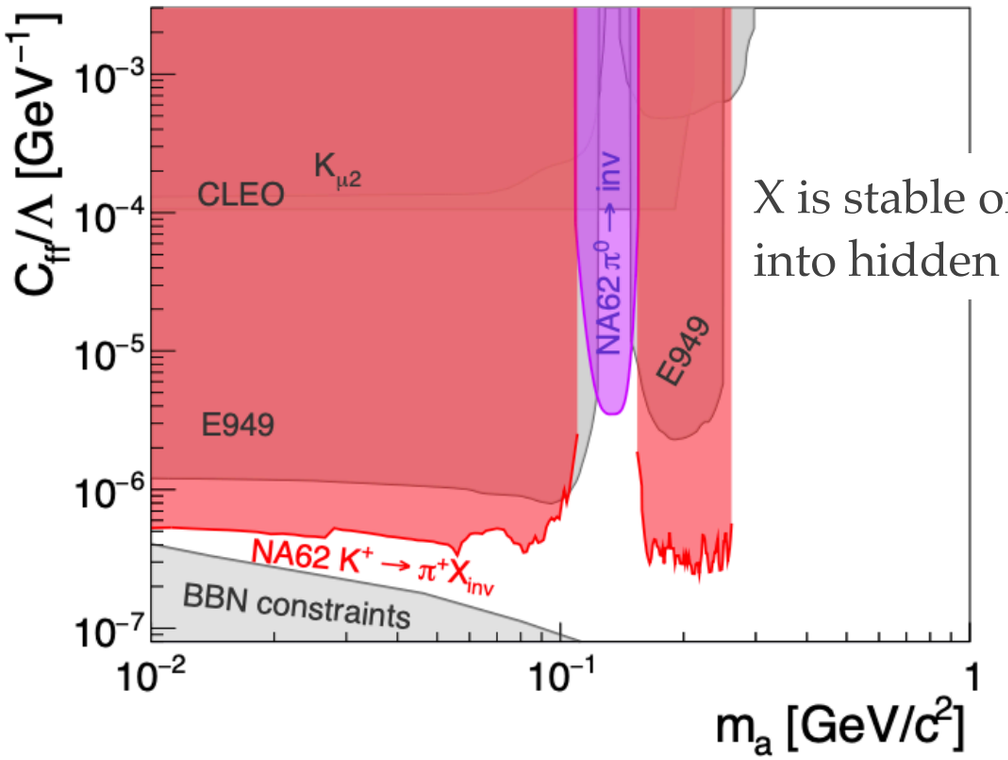


# $K^+ \to \pi^+ X$ models

Another collaboration
with theorists
using NA62 data set
arXiv:2503.05865

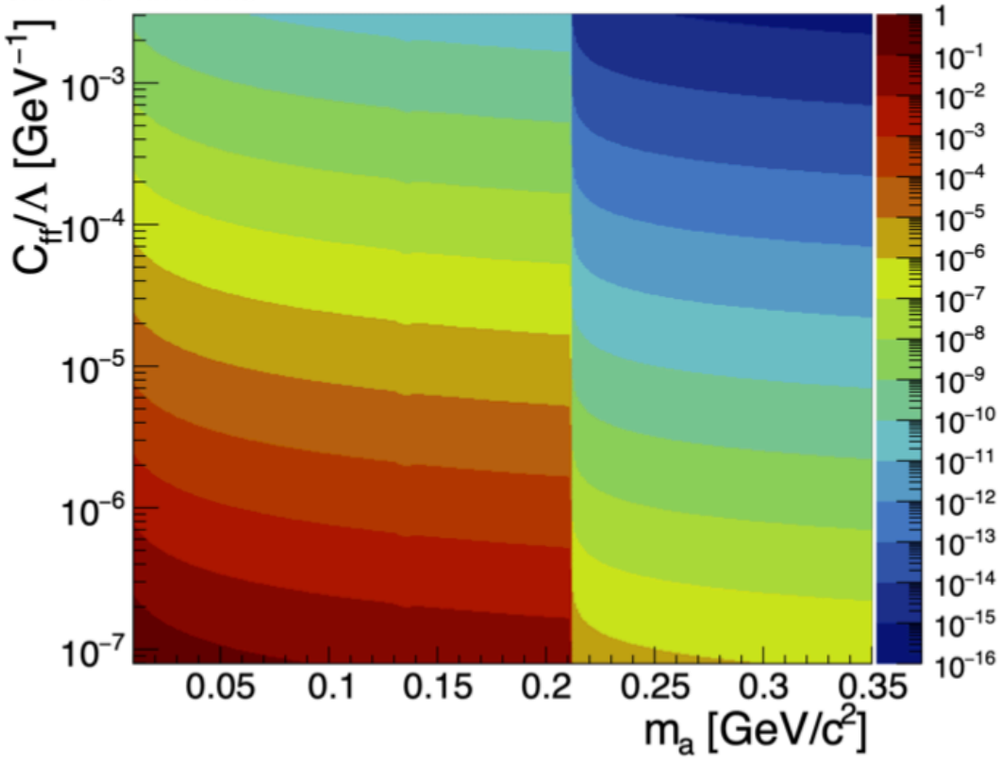


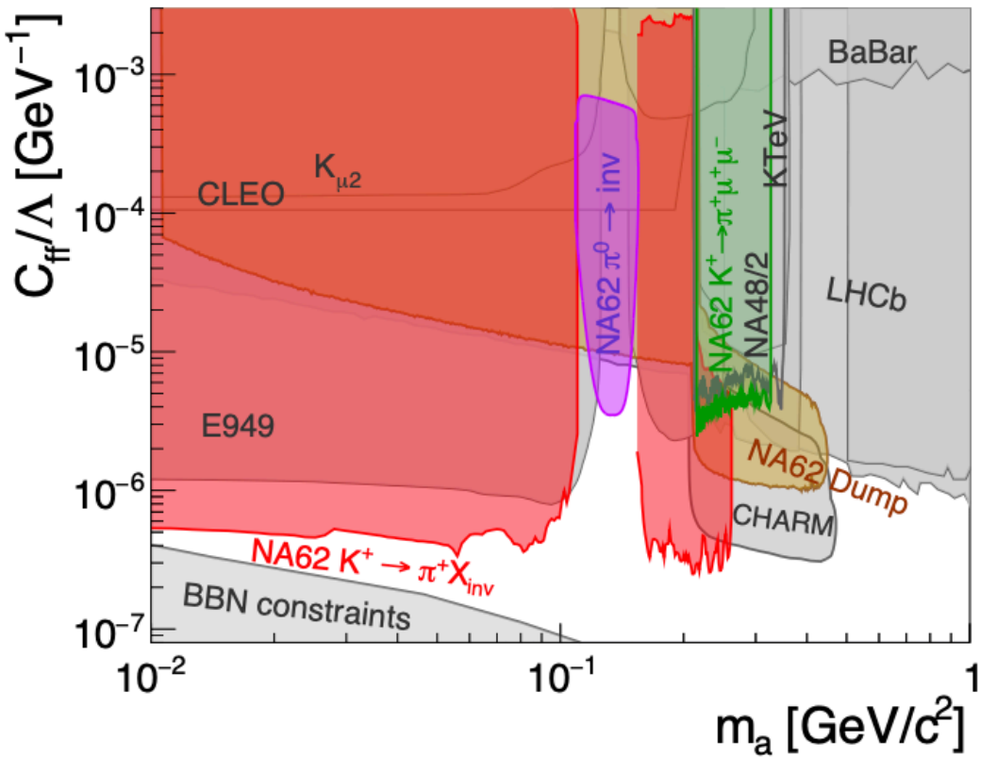




BC10

X is stable or decays
into hidden sector particles

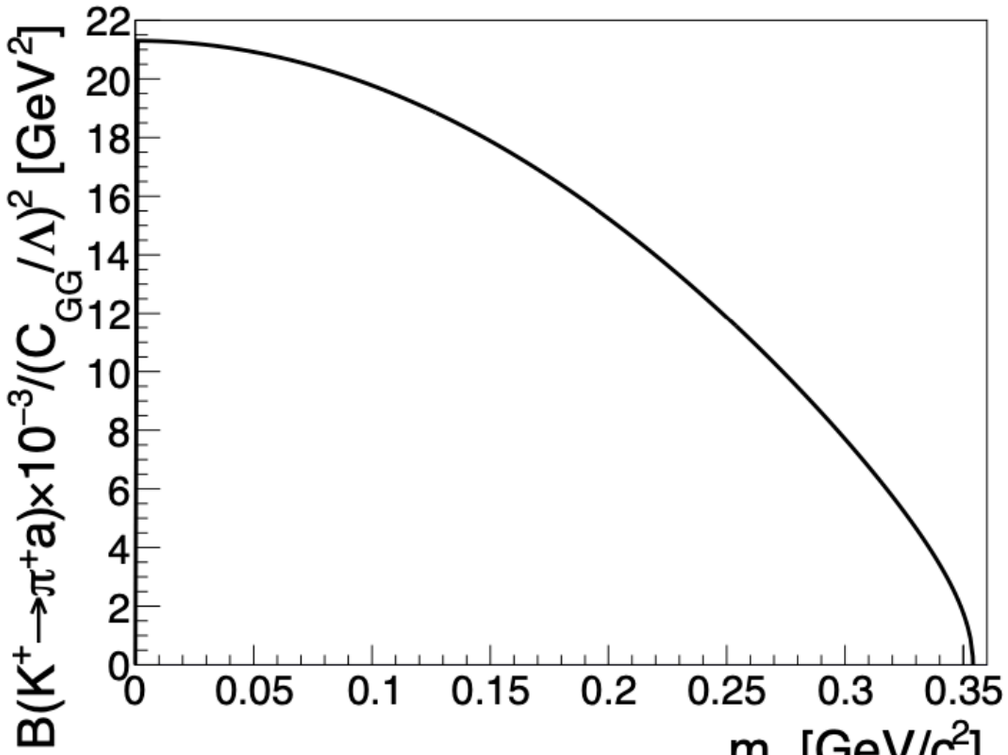
colour
X lifetime in ns



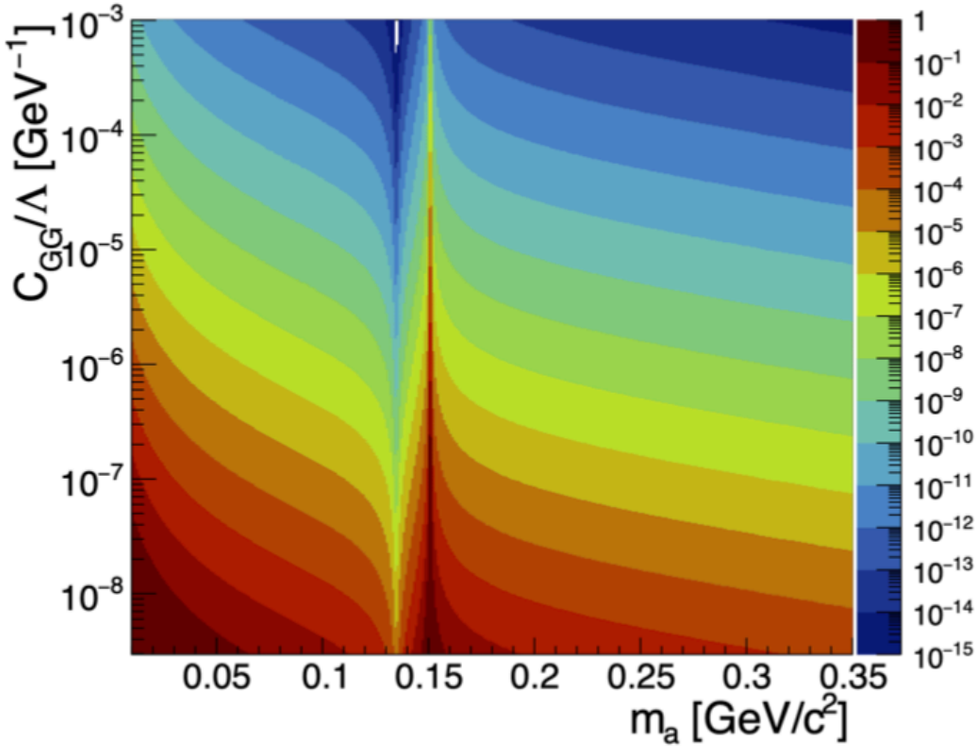



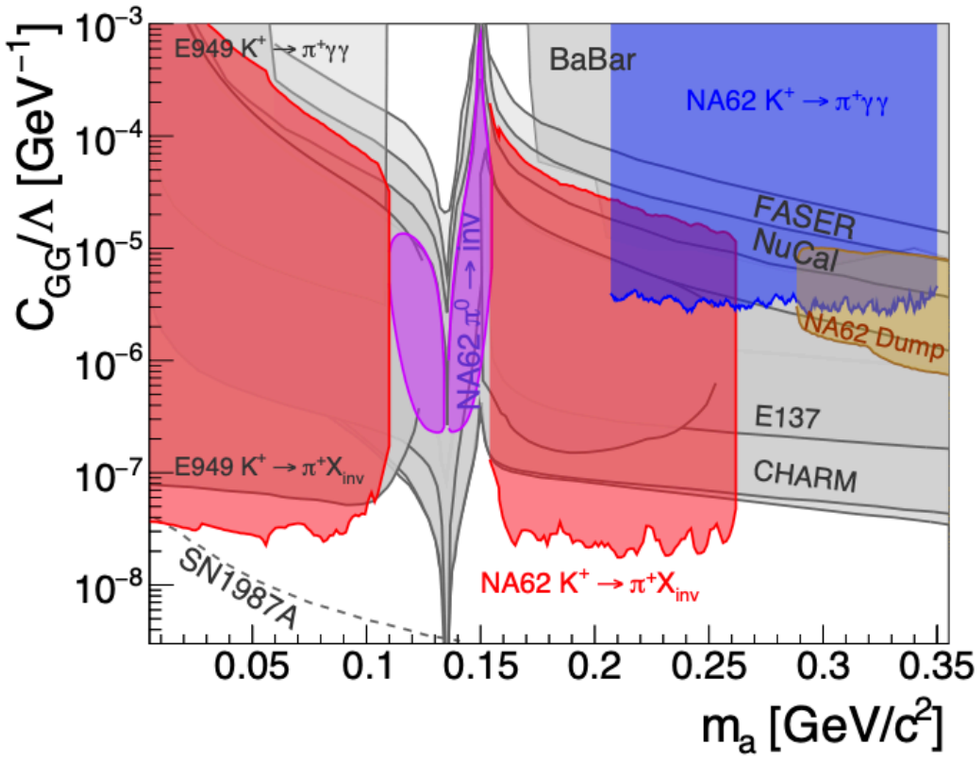
# $K^+ \to \pi^+ X$ models

BC11




colour
X lifetime in ns



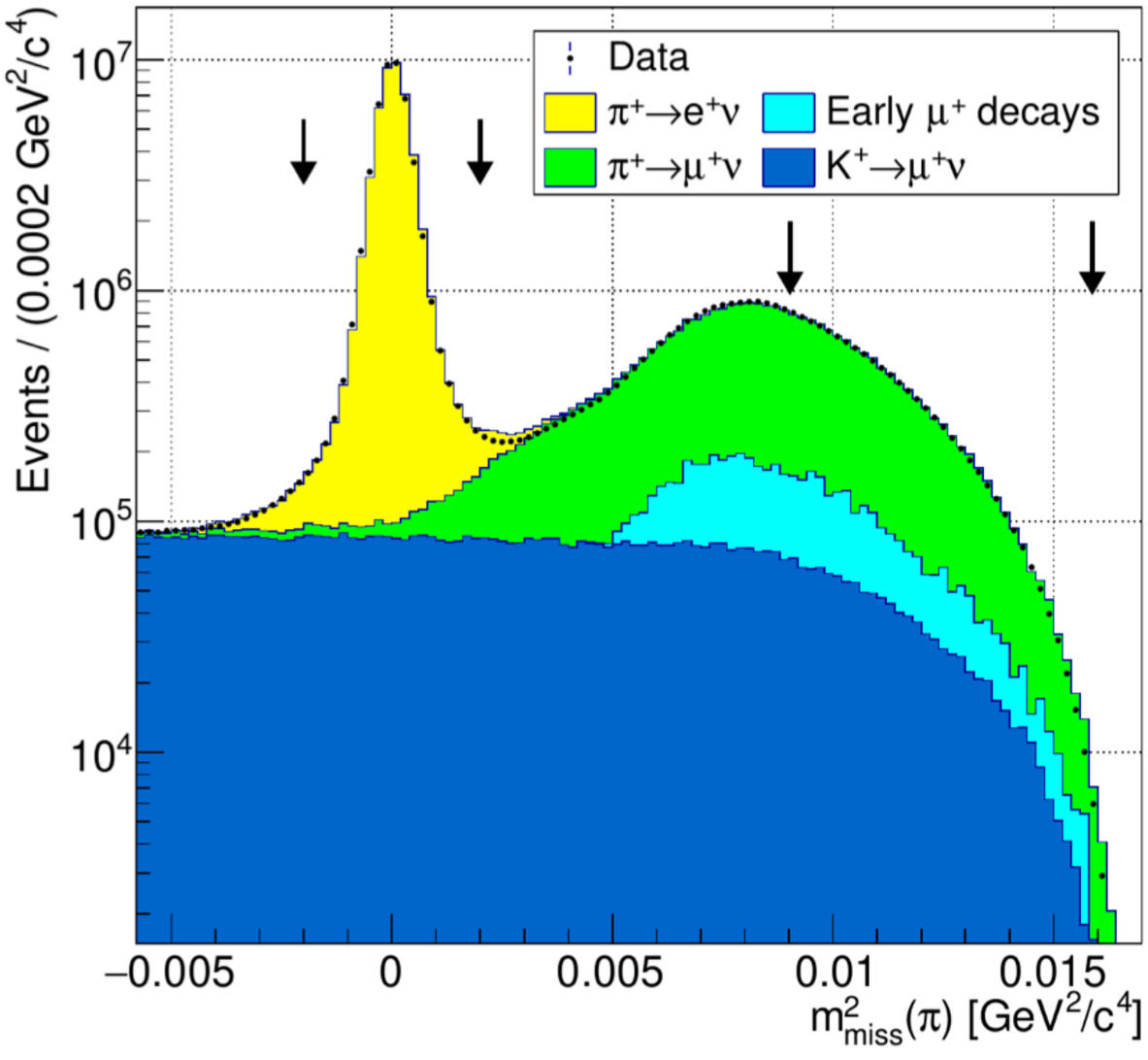



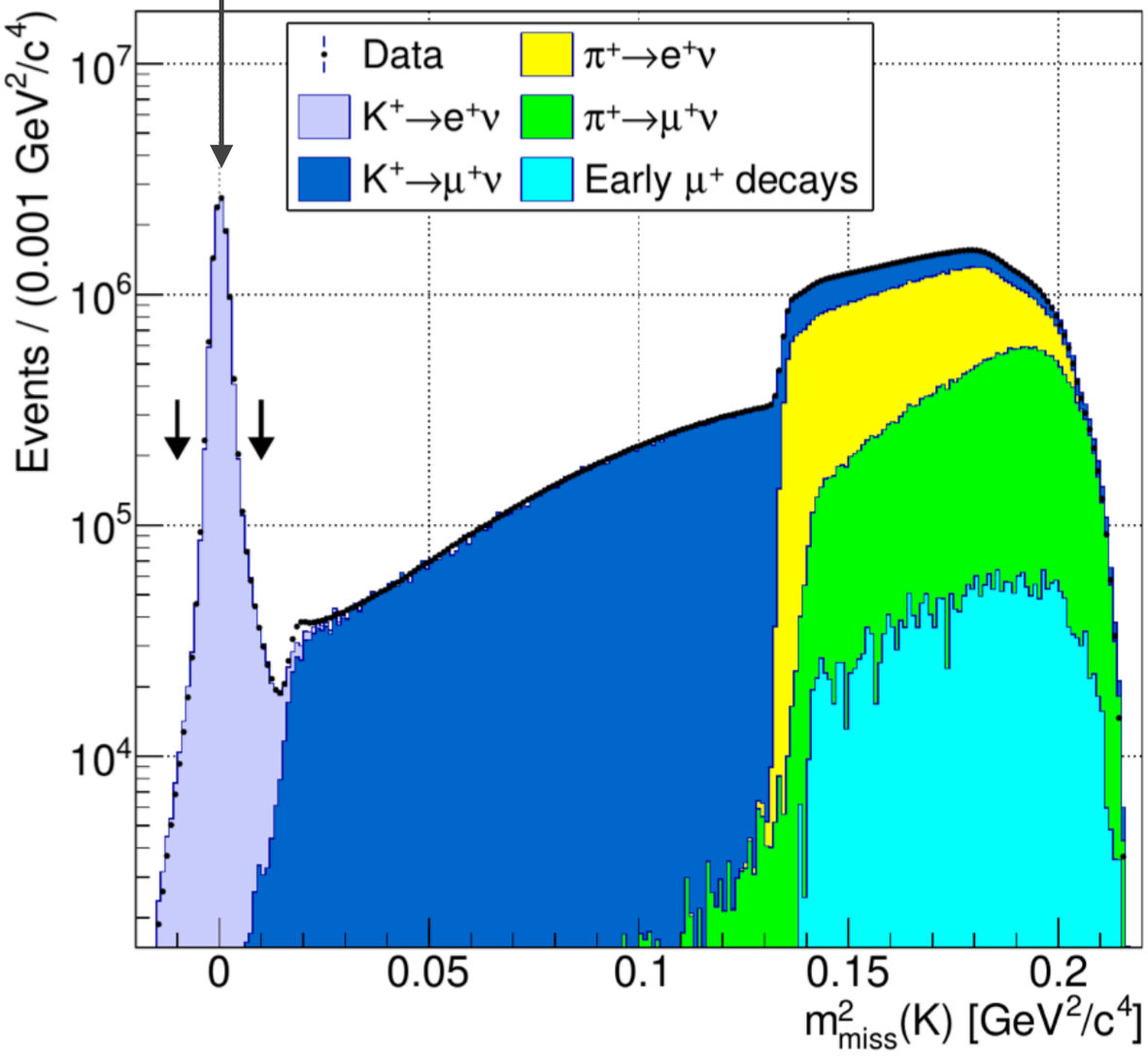
# $\pi^+ \to e^+ N$ search (2017-2024)

- Use the main $K^+ \to \pi^+ \nu\nu$ trigger. Despite of kaon ID in the trigger pions can pass by due to an accidental time-coincidence with a beam kaon. Single positron selection with no other activity.

**arXiv:2507.07345v1**

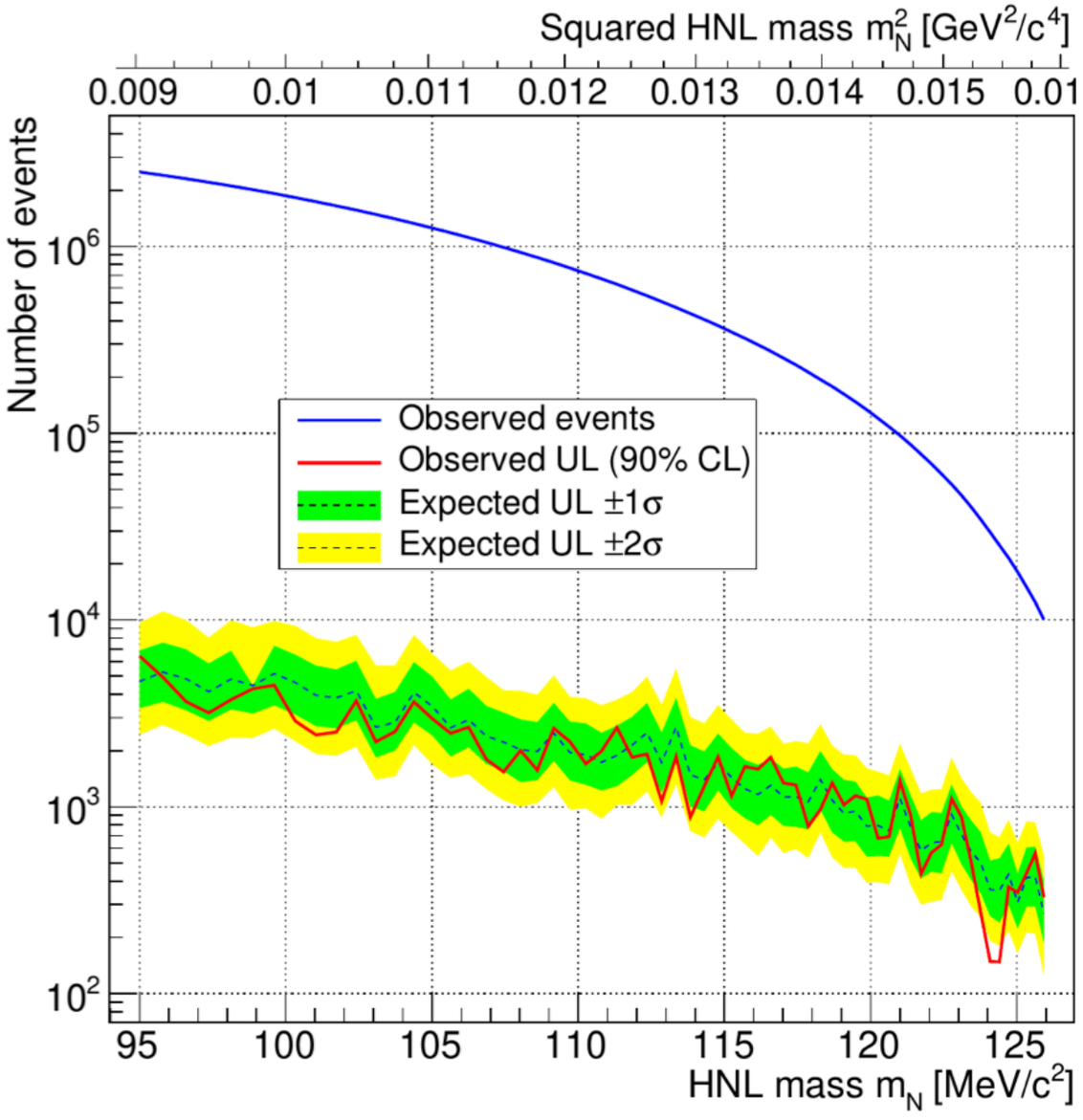
extract number of kaon decays

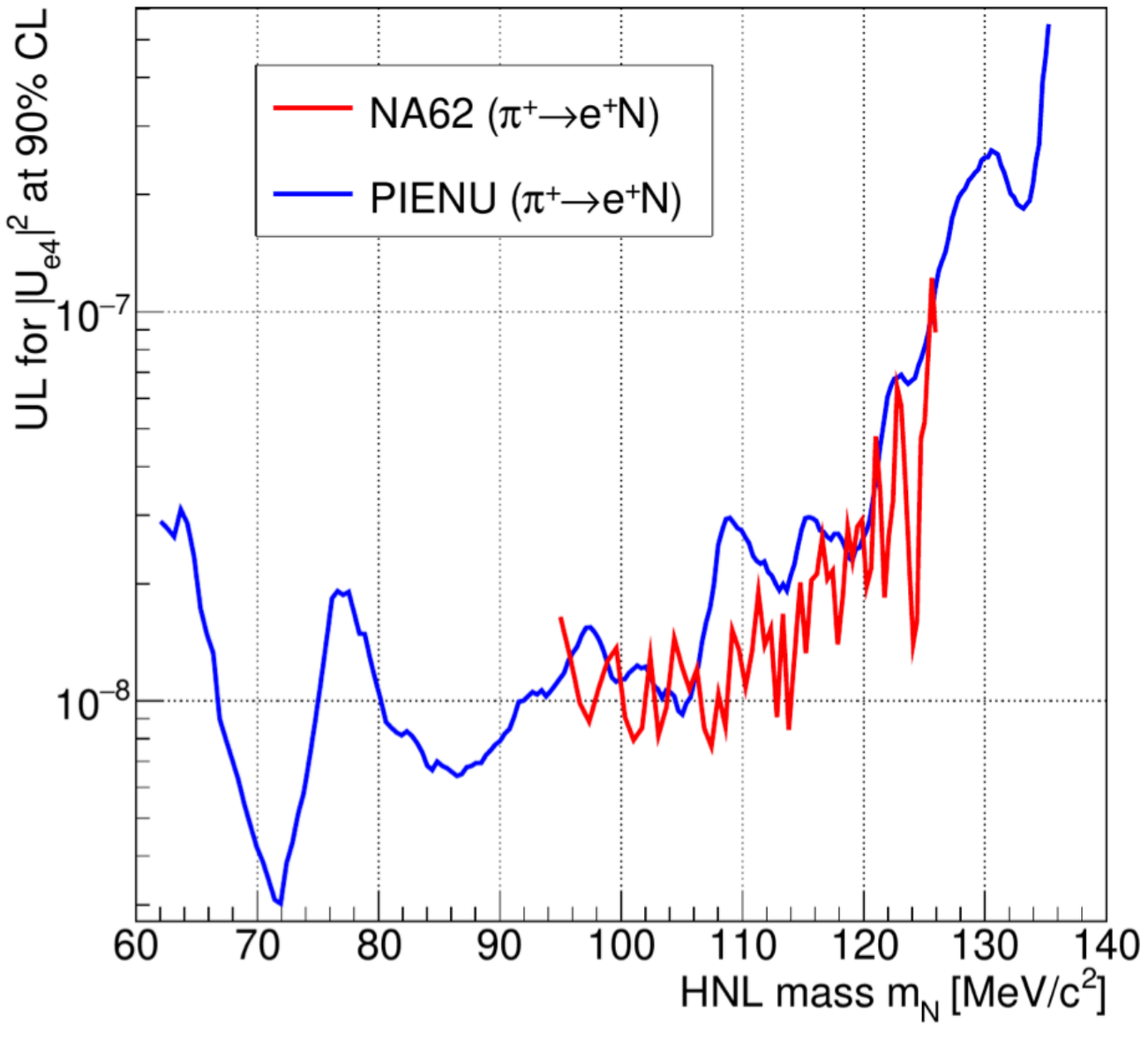


# $\pi^+ \to e^+ N$ search (2017-2024)

- Peak search: data driven background estimation — sideband fits with masked signal region for each mass hypothesis



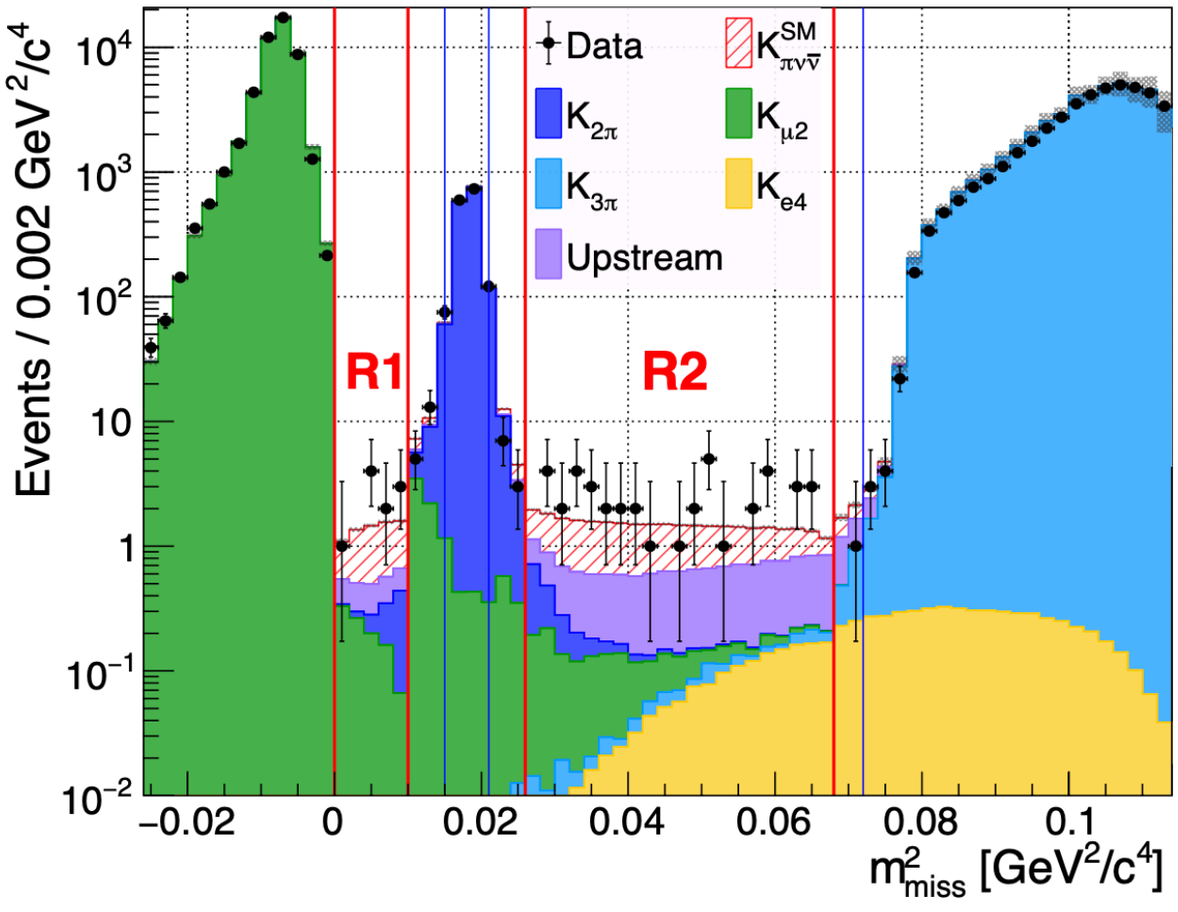
# Summary

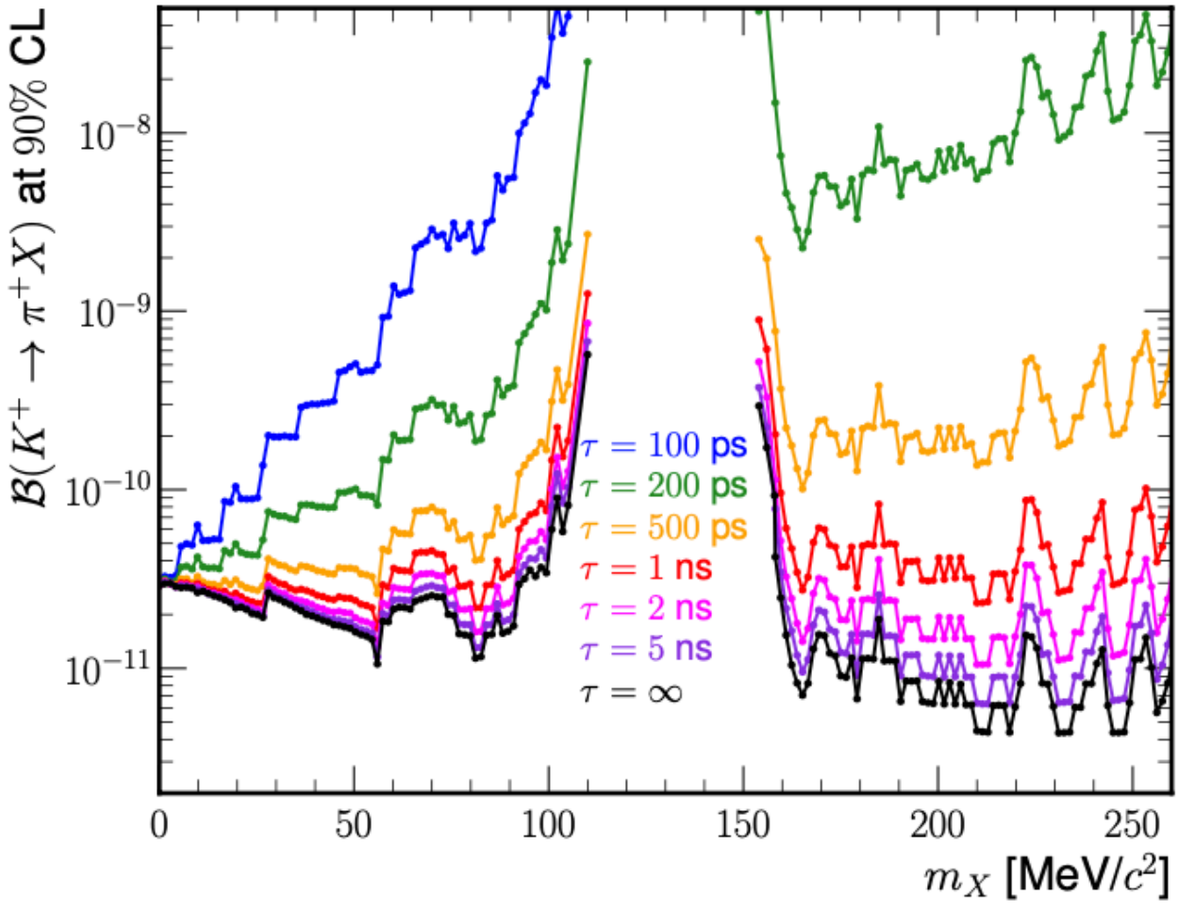
- World-leading constraints on the $K^+ \to \pi^+ X$ decays (X is visible or invisible) are set.
  - Model-independent constraints can be used for any new physics model.
- New search for heavy neutrinos in $\pi^+ \to e^+ N$ decay is performed.

# BACKUP

# $K^+ \to \pi^+ X$, X is invisible

Interpretation of $K^+ \to \pi^+ \nu\nu$ result with 2016–2022 data set [JHEP02 (2025) 191].
Peak search: $K^+ \to \pi^+ \nu\nu$ is the main background and number of background events is estimated using SM branching ratio.

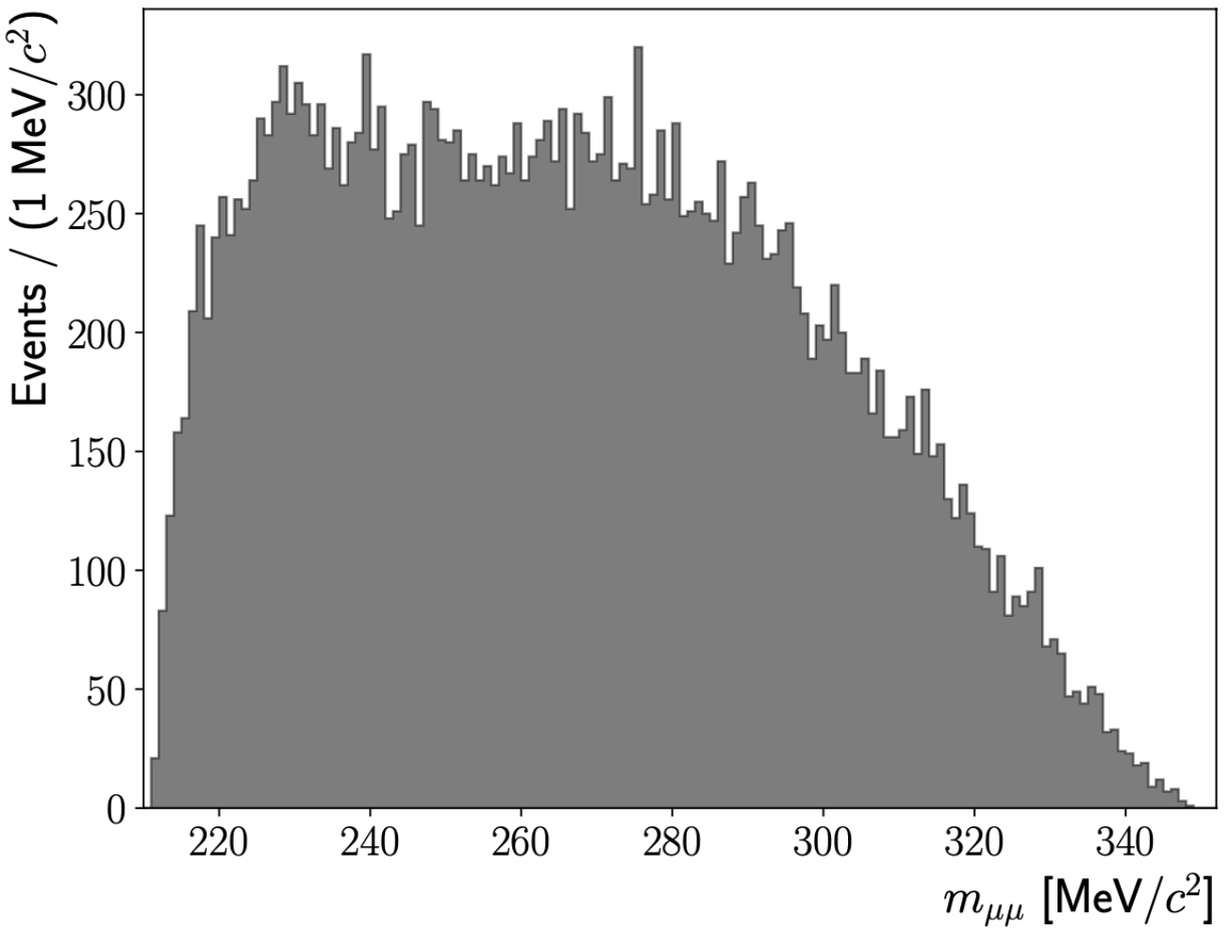


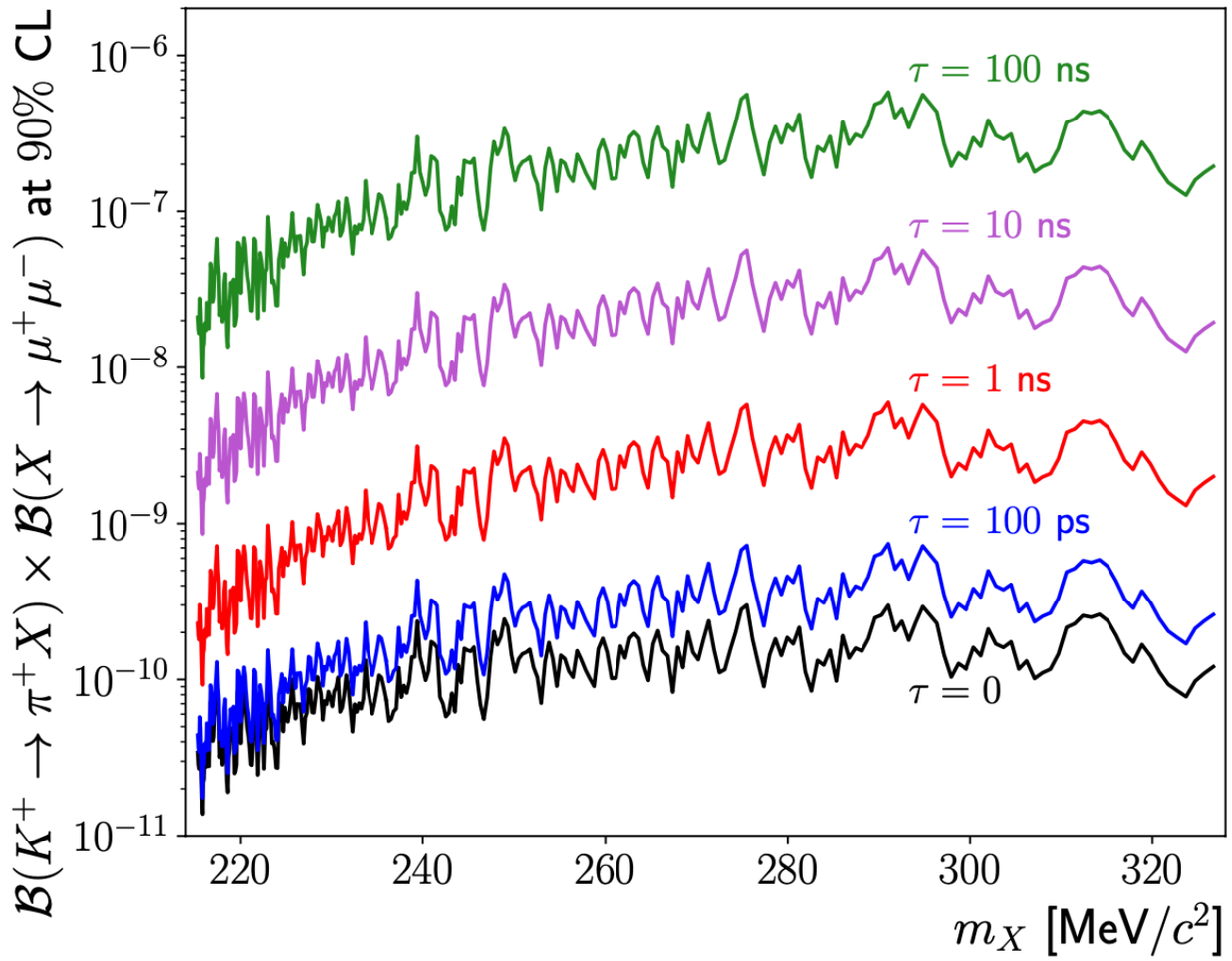




Model-independent constraints

# $K^+ \to \pi^+ X, X \to \mu^+\mu^-$

Interpretation of $K^+ \to \pi^+\mu^+\mu^-$ result with 2017–2018 data set [JHEP 11 (2022) 011].
Peak search: data driven background estimation — sideband fits with masked signal region for each mass hypothesis.

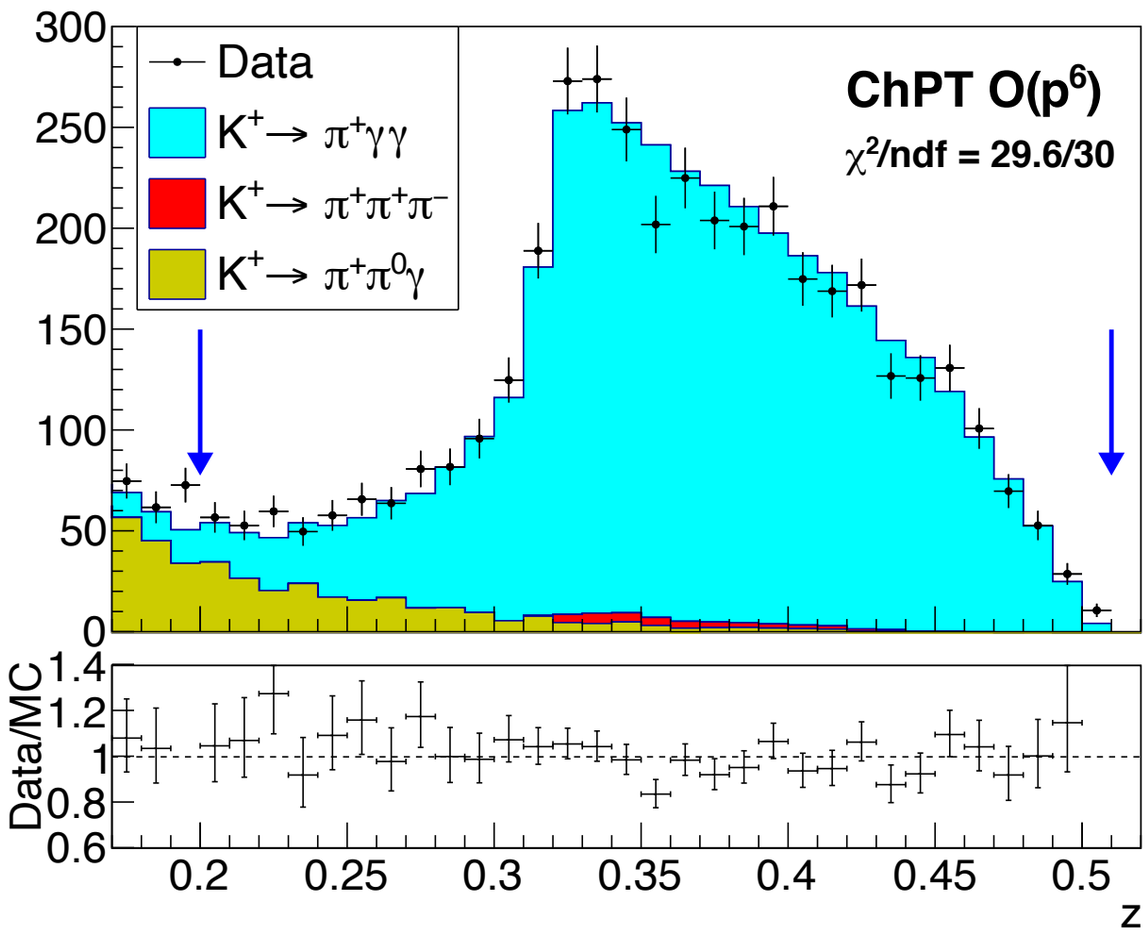


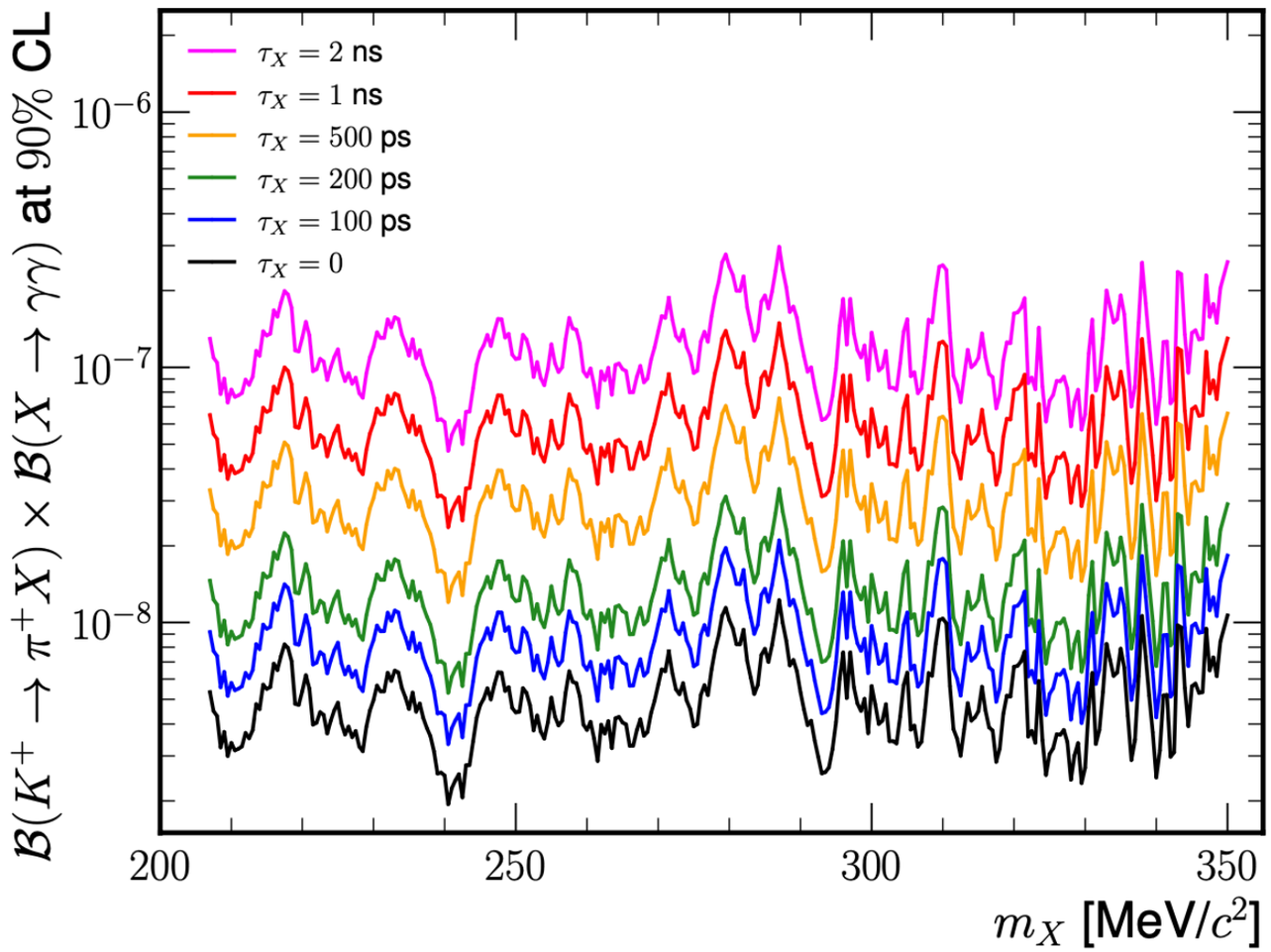

Model-independent constraints

# $K^+ \to \pi^+ X,\ X \to \gamma\gamma$

Interpretation of $K^+ \to \pi^+ \gamma\gamma$ result with 2017–2018 data set [PLB 850 (2024) 138513].
Peak search: $K^+ \to \pi^+ \gamma\gamma$ is the main background and number of background events is estimated using MC simulations.




$z = (P_K\text{-}P_\pi)^2 / (m_K)^2 = (m_{\gamma\gamma} / m_K)^2$




Model-independent constraints