

A new measurement of the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ branching ratio at the NA62 experiment

Radoslav Marchevski

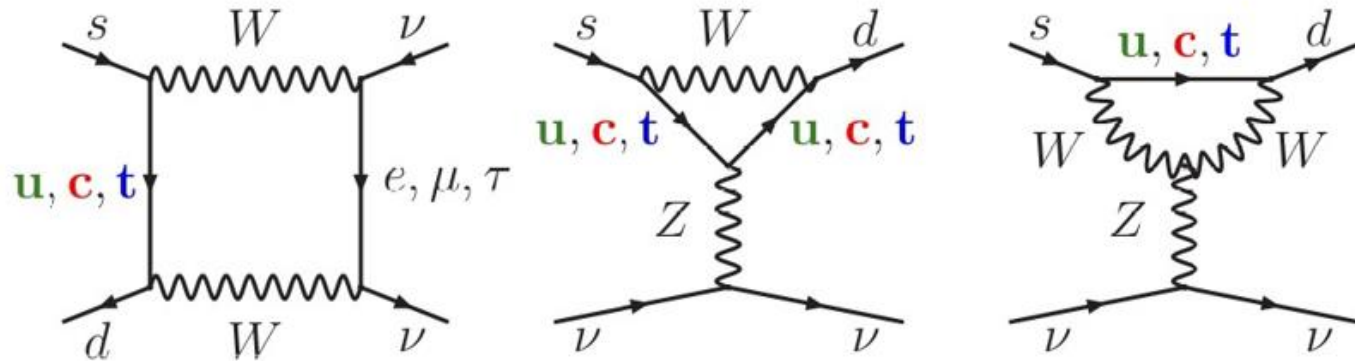
on behalf of the NA62 collaboration

EPFL

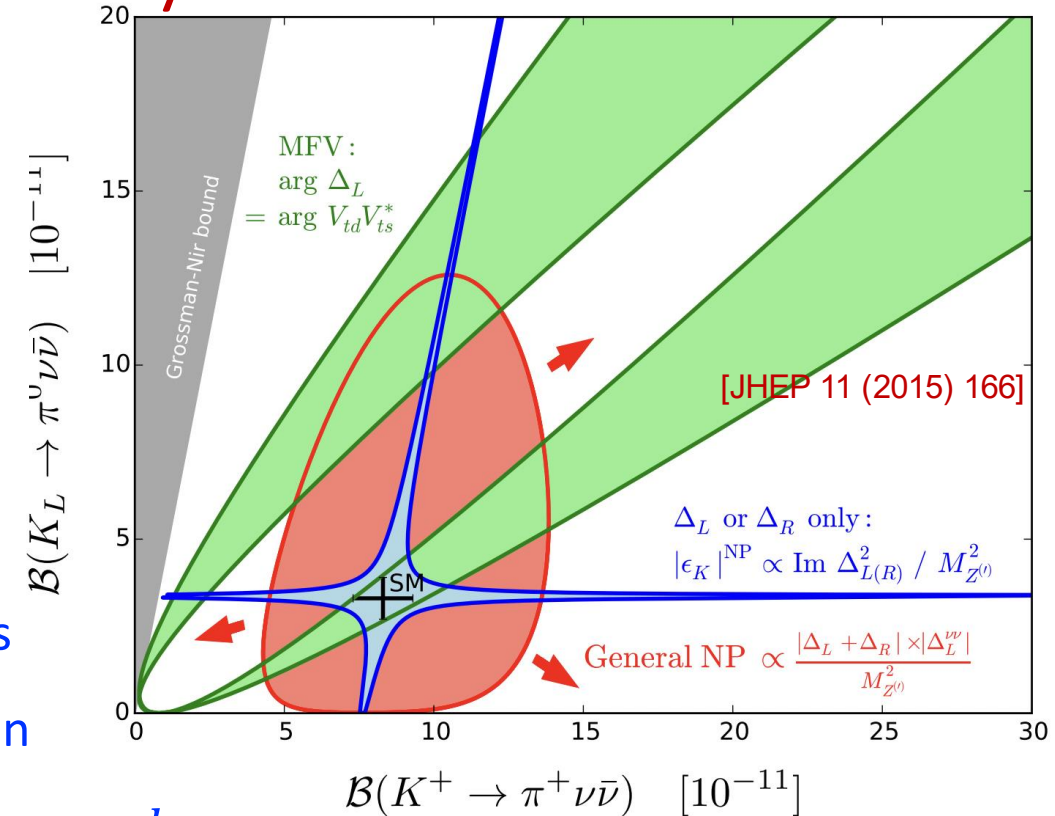


17th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon, MENU 2026
Long Island, United States, Oct 19th – 23rd, 2026

Golden modes $K \rightarrow \pi \nu \bar{\nu}$: SM and beyond



- $s \rightarrow d$ transition sensitive to the CKM structure of the SM:
 - **tree-level FCNCs forbidden** $\rightarrow$ **loop + CKM suppression**
- Theoretically clean process: **dominated by short-distance physics**
- $K - \pi$ Form Factor (FF) extracted from $K \rightarrow \pi l \nu_l$: **sub-% precision**
- Sensitive to new physics in the lepton sector as well: **involves ν_e, ν_μ , and ν_τ**



Theory Status

$$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})_{\text{SM}} \approx 8.5 \times 10^{-11} (\pm 5\%)$$

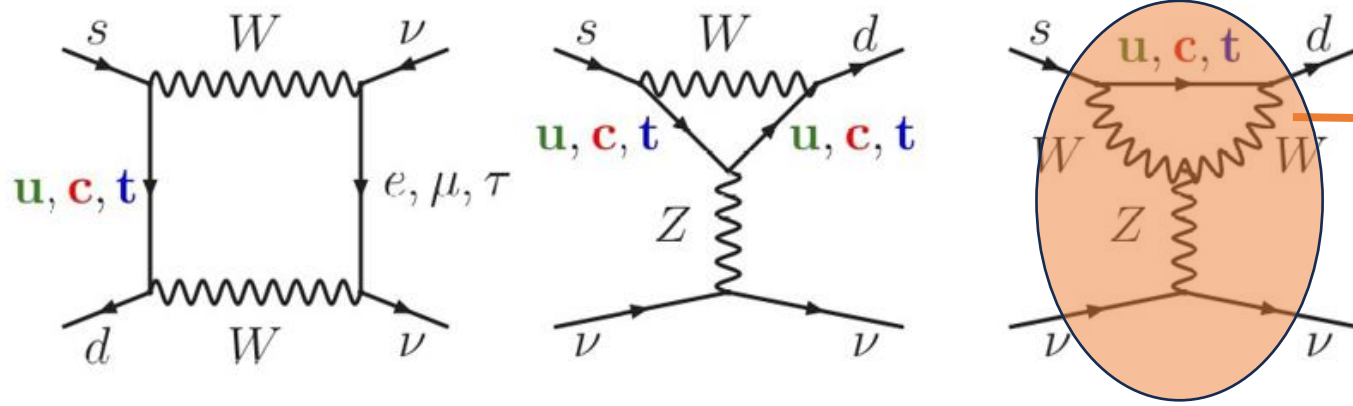
$$\mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu})_{\text{SM}} \approx 3 \times 10^{-11} (\pm 6\%)$$

Experimental Status

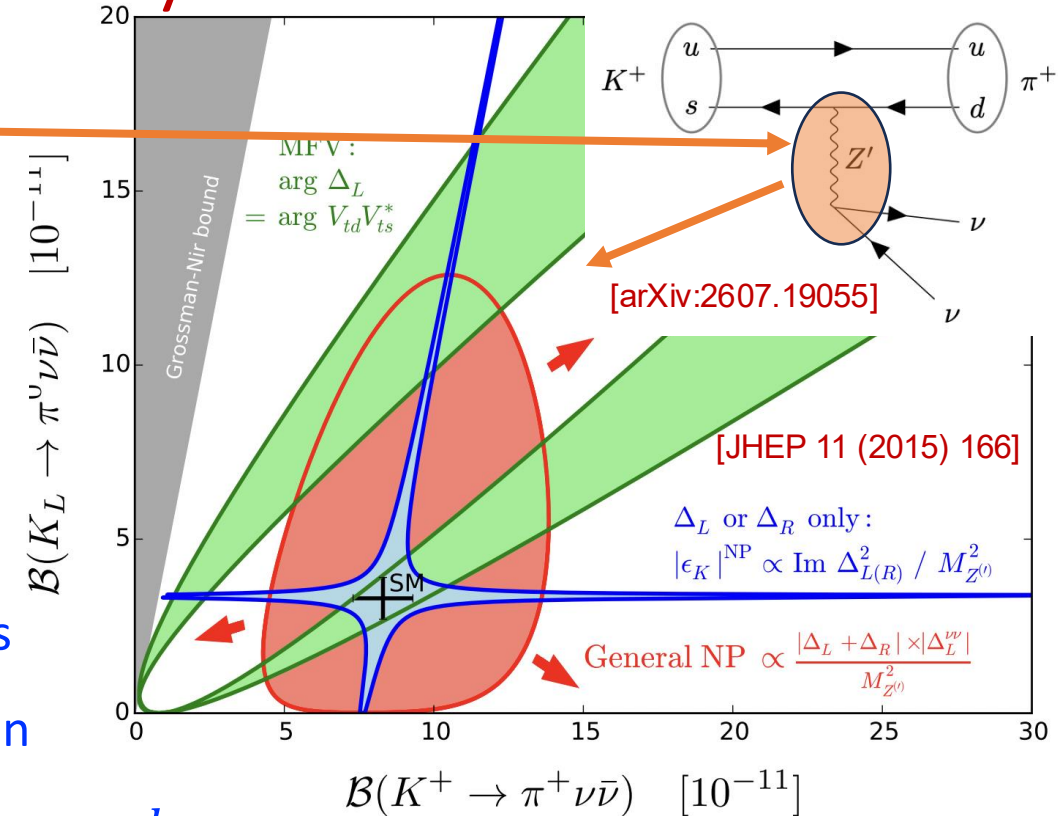
$$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})_{2016-22}^{\text{NA62}} = (13.0_{-3.0}^{+3.3}) \times 10^{-11}$$

$$\mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu})_{2021}^{\text{KOTO}} < 2.2 \times 10^{-9}$$

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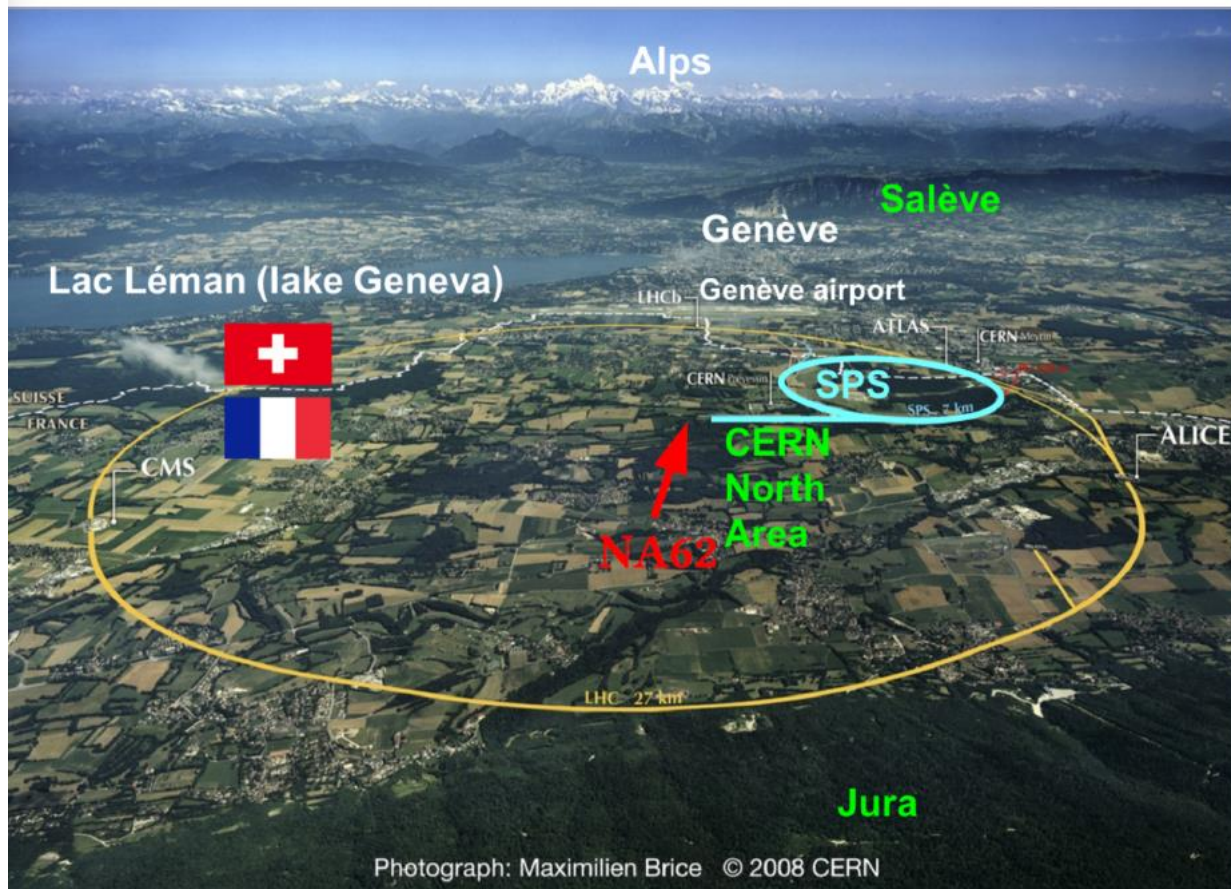
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NA62 experiment at CERN

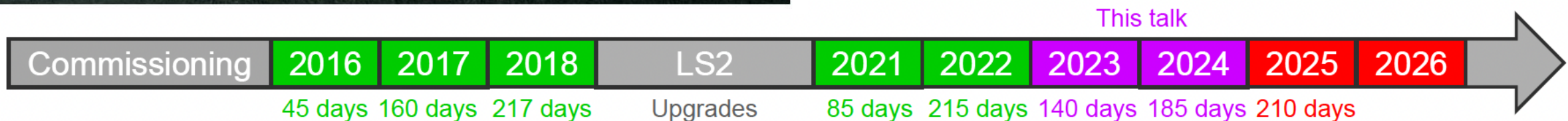


~ 200 collaborators from 35 institutions



High precision kaon experiment:

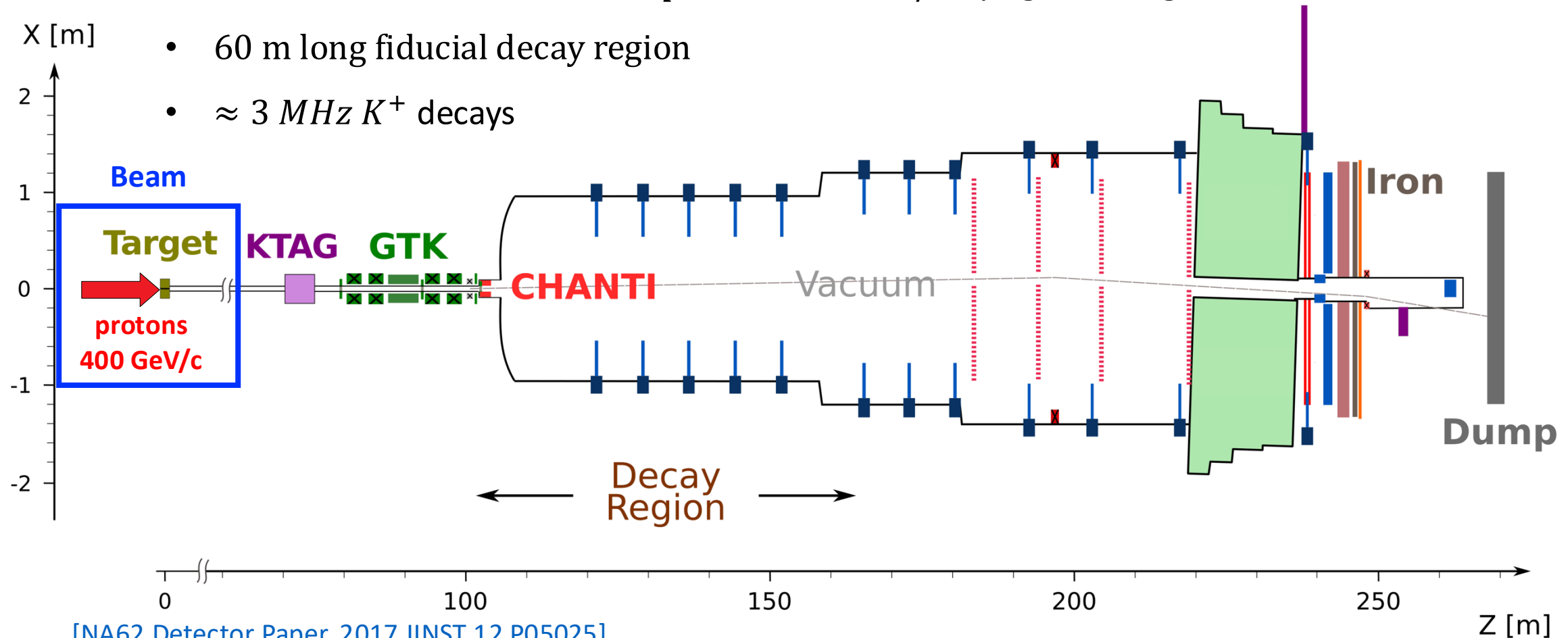
- *Primary goal:* $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ measurement
- *Technique:* fixed-target and decay in flight
- Previous results: [PLB 791 (2019) 156] [JHEP 11 (2020) 042][JHEP 06 (2021) 093] [JHEP 02 (2025) 191]
- *Broad physics program:*
 - precision measurements of kaon and pion decays
 - HNL and LFV/LNV searches in kaon and pion decays
 - Hidden Sector searches with kaons + dump mode
 - neutrino tagging



NA62 experiment

Secondary beam:

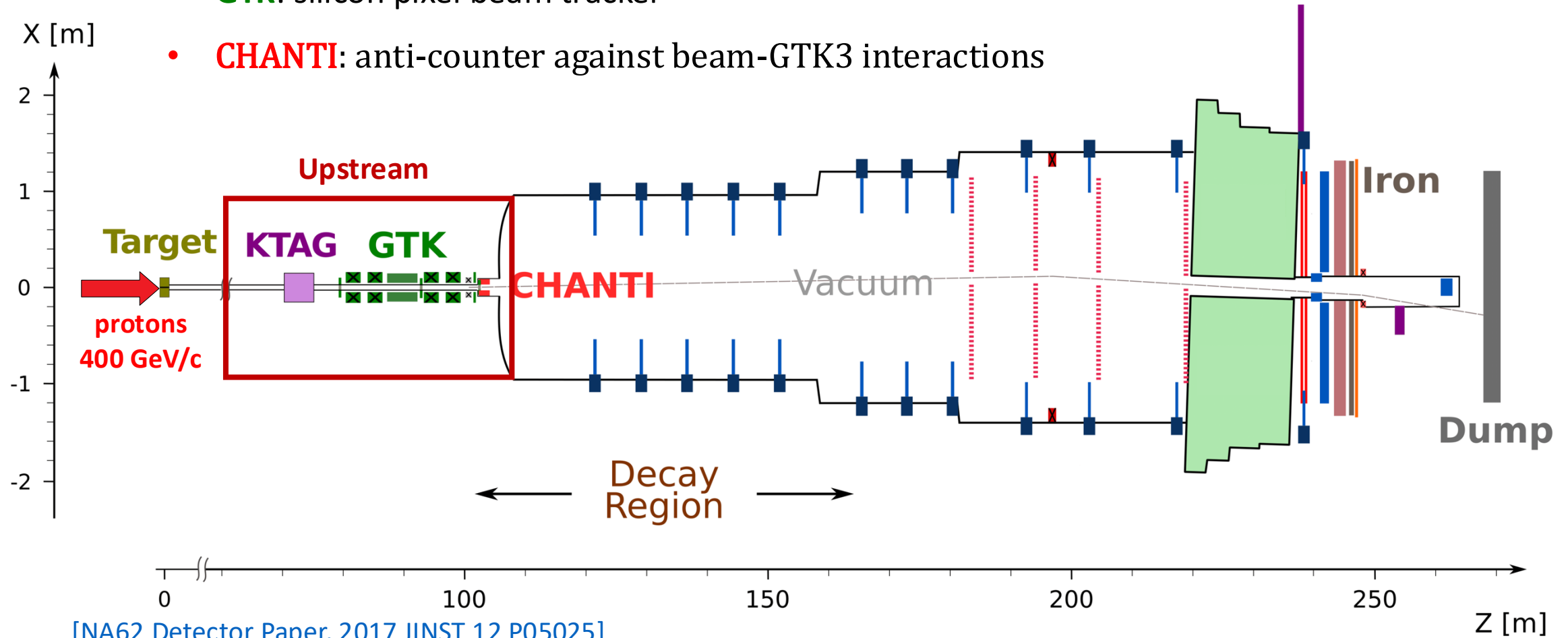
- unseparated positively-charged beam: π^+ (70%), p (23%), K^+ (6%)
- almost monochromatic beam: $p = 75 \pm 1 \text{ GeV}/c$ flying at 0° angle
- 60 m long fiducial decay region
- $\approx 3 \text{ MHz } K^+$ decays



NA62 experiment

Upstream region (K^+):

- **KTAG**: differential Cherenkov counter for K^+ ID
- **GTK**: silicon pixel beam tracker
- **CHANTI**: anti-counter against beam-GTK3 interactions

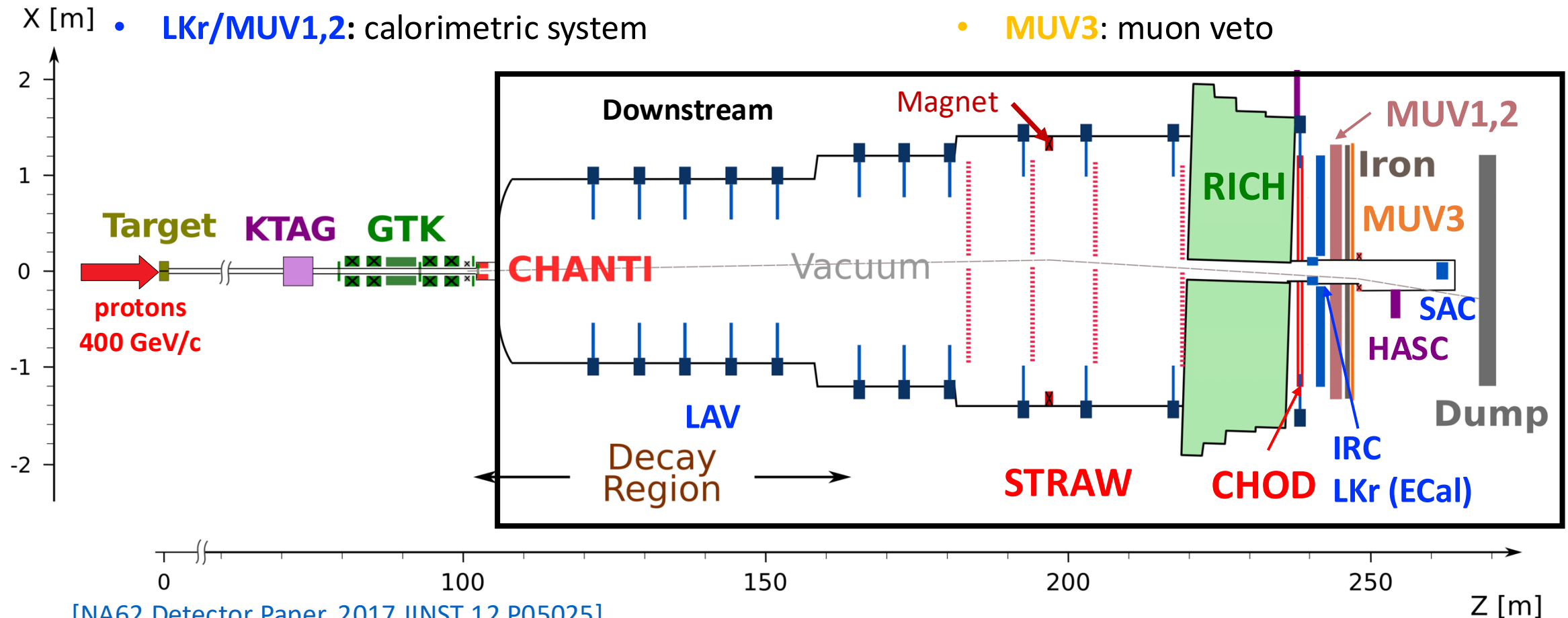


[NA62 Detector Paper, 2017 JINST 12 P05025]

NA62 experiment

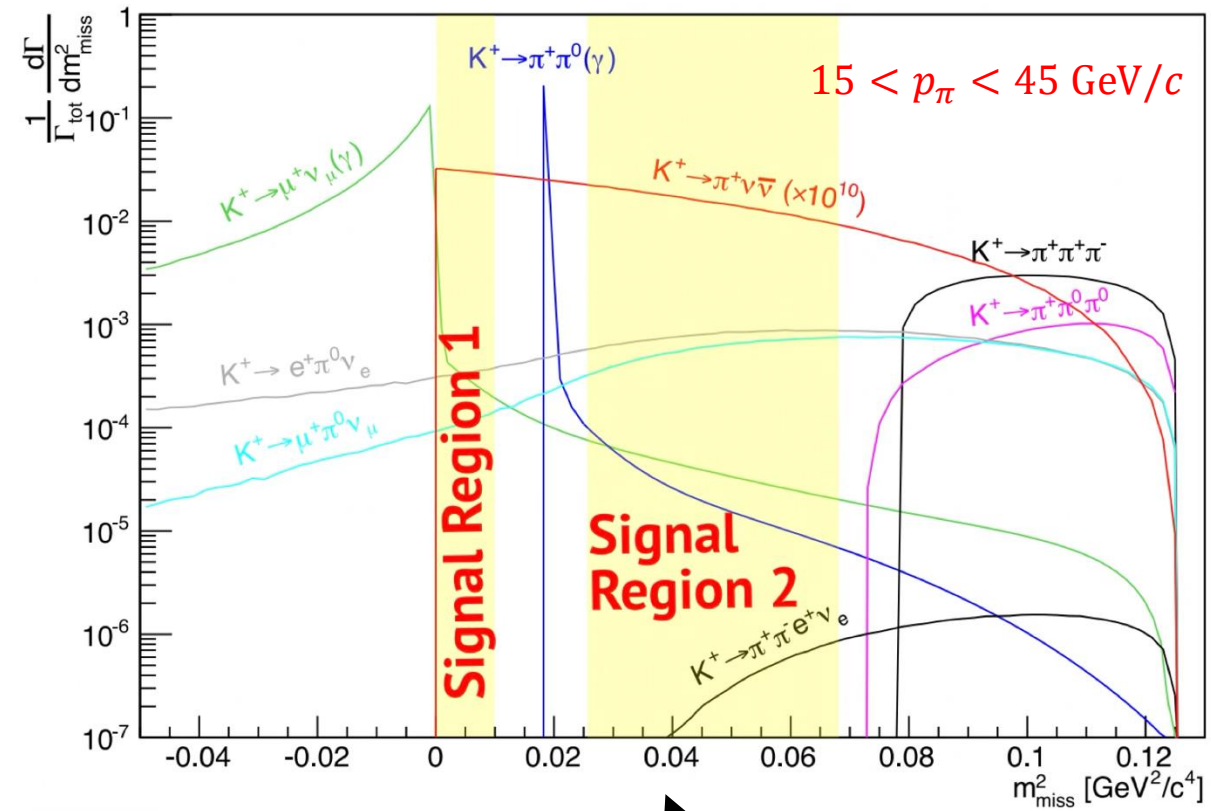
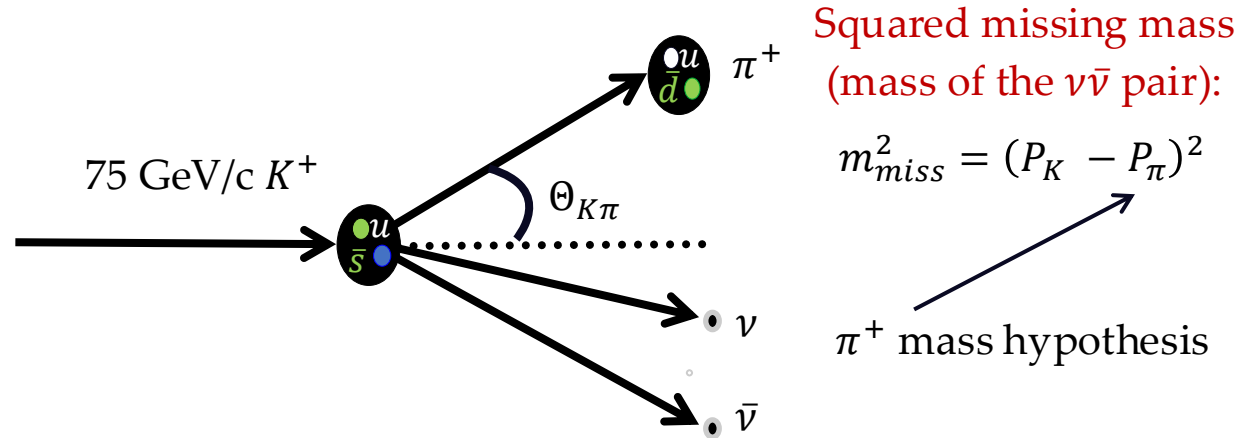
Downstream region (π^+):

- **STRAW**: straw spectrometer in vacuum ($1.6\% X_0$)
- **CHOD**: scintillator hodoscopes
- **LKr/MUV1,2**: calorimetric system
- **RICH**: Cherenkov detector for $\pi/\mu/e$ ID
- **LAV/IRC/SAC**: photon veto detectors
- **MUV3**: muon veto



[NA62 Detector Paper, 2017 JINST 12 P05025]

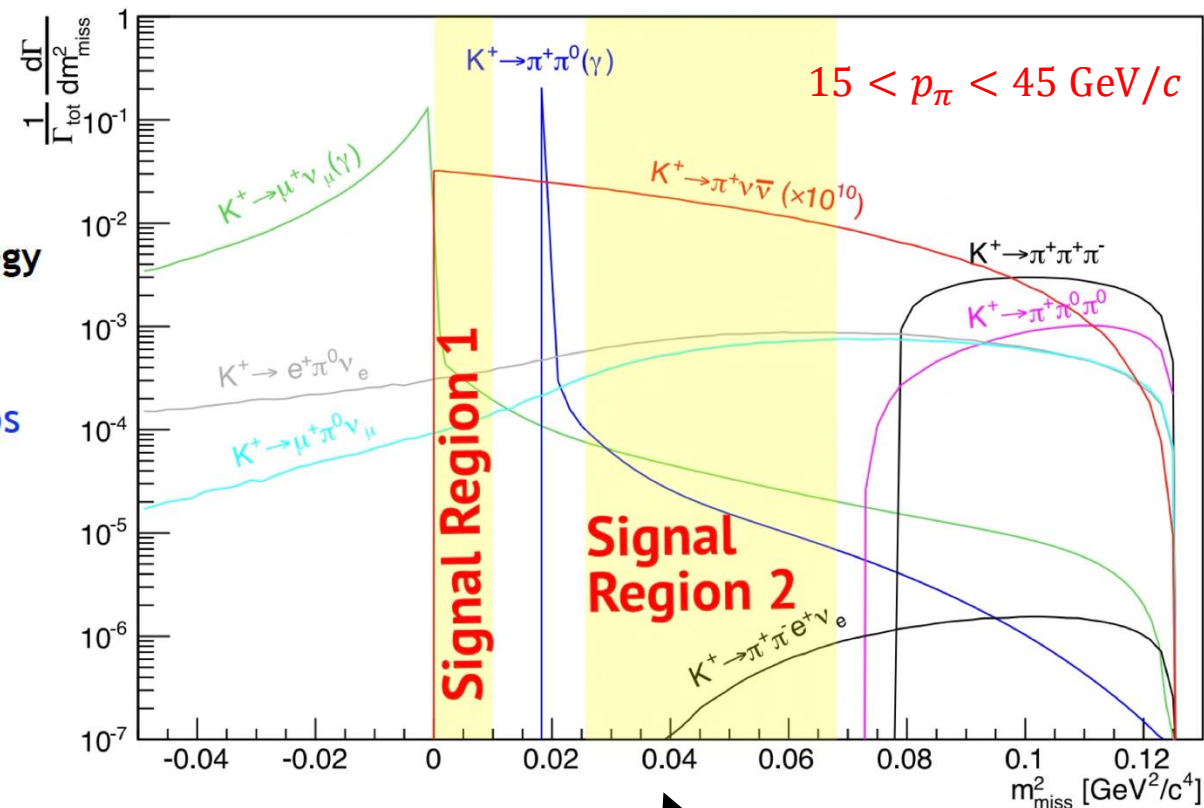
Analysis strategy



- Highly boosted decay: $(75 \pm 1) \text{ GeV}/c \ K^+$ ($\gamma \sim 150$)
- Large undetectable missing energy carried away by the neutrinos
- All energy from visible particles must be detected
- π^+ momentum range $15 - 45 \text{ GeV}/c$ ($E_{\text{miss}} > 30 \text{ GeV}$)
- Hermetic detector coverage and $O(100\%)$ detector efficiency needed

Analysis strategy

Decay mode	Branching Ratio [PDG]	Rejection strategy
$K^+ \rightarrow \mu^+ \nu_\mu$	$(63.56 \pm 0.11) \%$	PID
$K^+ \rightarrow \pi^+ \pi^0$	$(20.67 \pm 0.08) \%$	π^0/γ vetos
$K^+ \rightarrow \pi^+ \pi^+ \pi^-$	$(5.583 \pm 0.024) \%$	kinematics
$K^+ \rightarrow \pi^+ \pi^- e^+ \nu_e$	$(4.247 \pm 0.024) \times 10^{-5}$	
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	8.4×10^{-11} [benchmark SM value]	



**“Flat signal”
peaking background**

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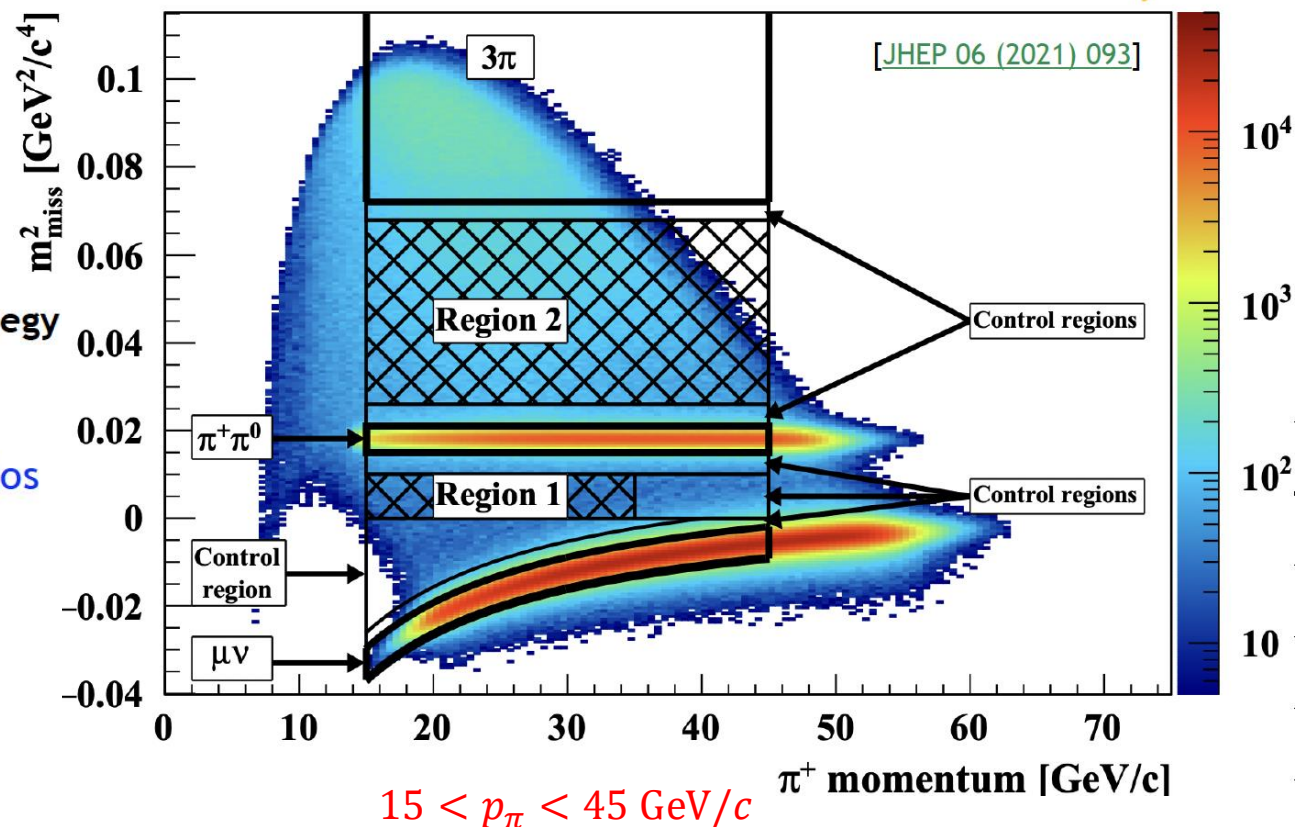
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PID

π^0/γ vetos

kinematics

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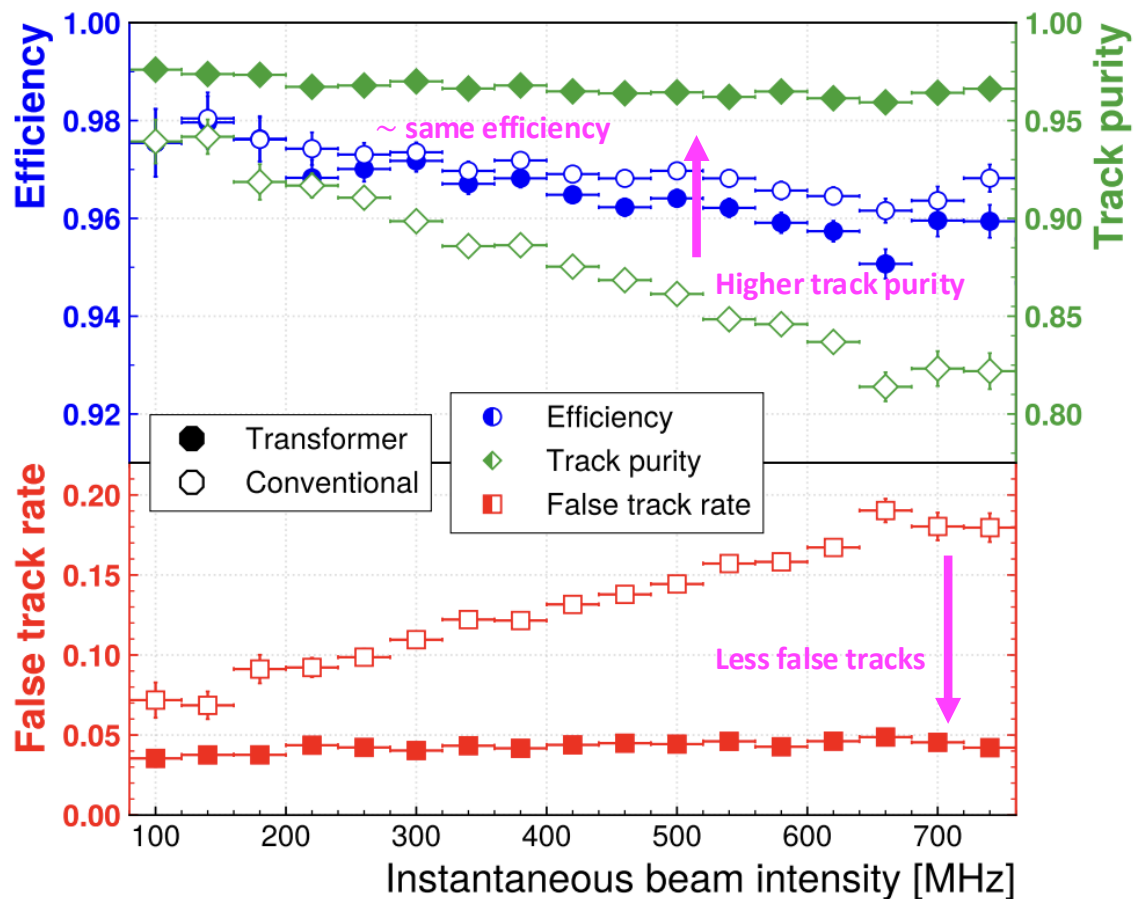
• Requirements:

- Kinematic suppression – $O(10^4)$
- μ^+ rejection – $O(10^7) \Rightarrow P(\mu^+ \rightarrow \pi^+ \text{ misID}) = (1.3 \pm 0.1) \times 10^{-7}$ with $\varepsilon(\pi \text{ ID}) = 75.3\%$
- π^0 rejection – $O(10^7) \Rightarrow \eta_{\pi^0} = (1.24 \pm 0.04) \times 10^{-8}$ with $\varepsilon_{RV} = 72.3\%$
- Time resolution – $O(100 \text{ ps})$

Improvements for the 2023 – 2024 analysis

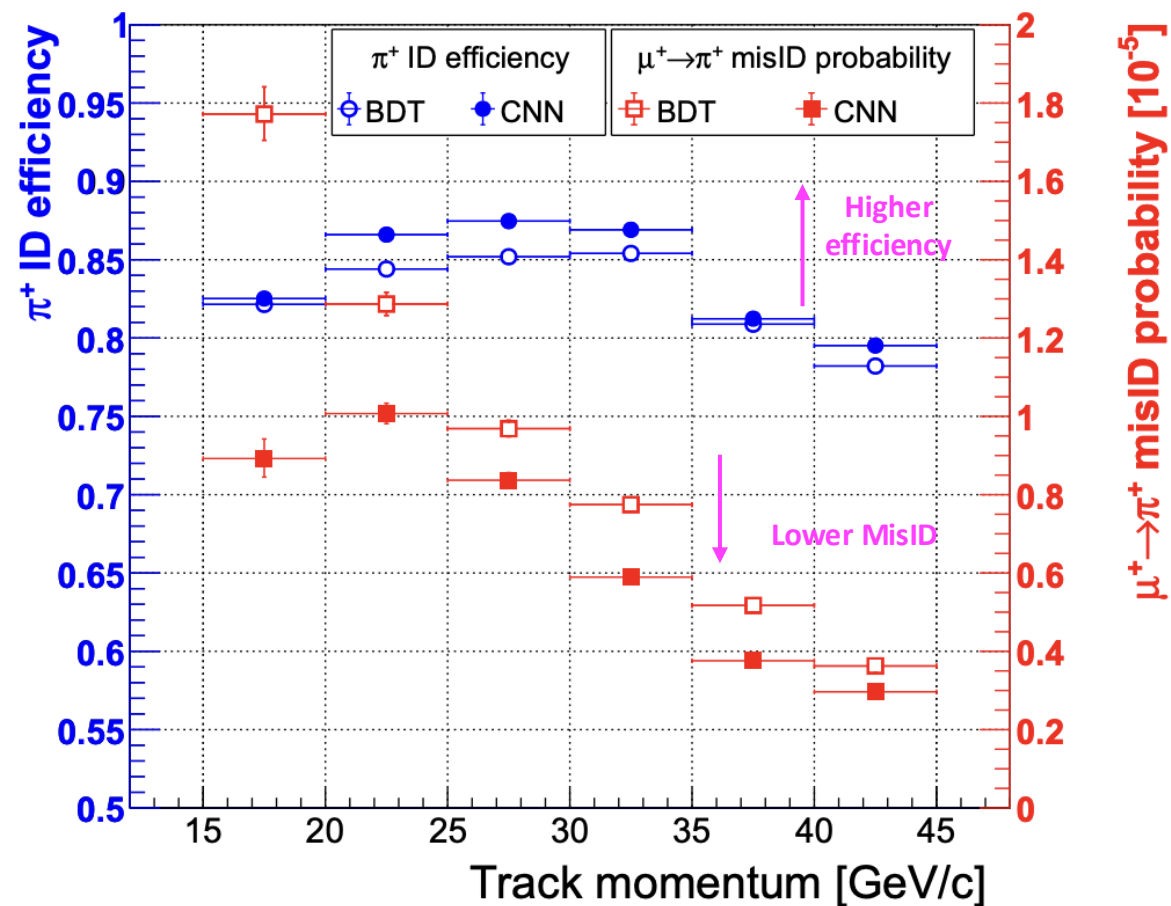
$K^+ - \pi^+$ matching

New: 4D beam tracking with ML



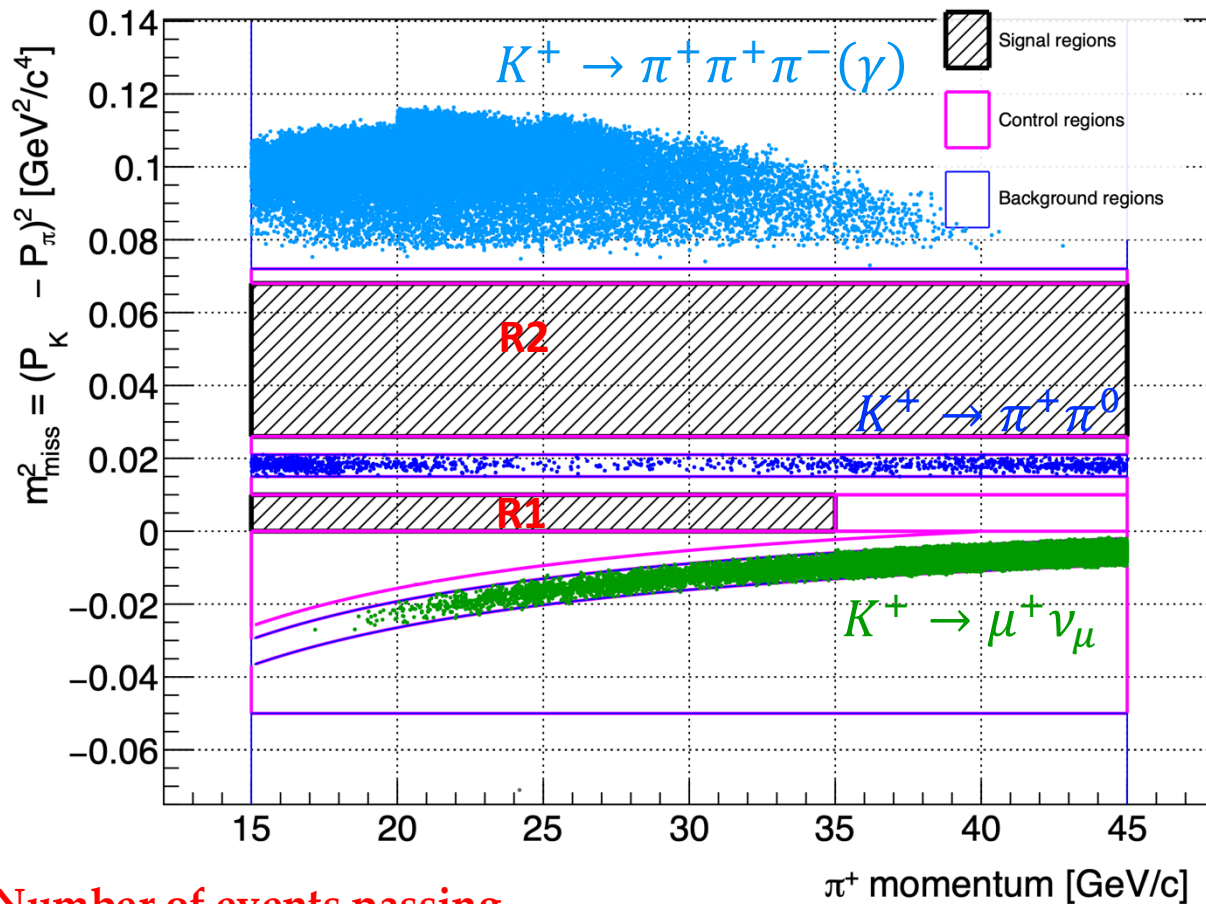
Calorimetric π^+/μ^+ PID

New: new CNN-based classifier

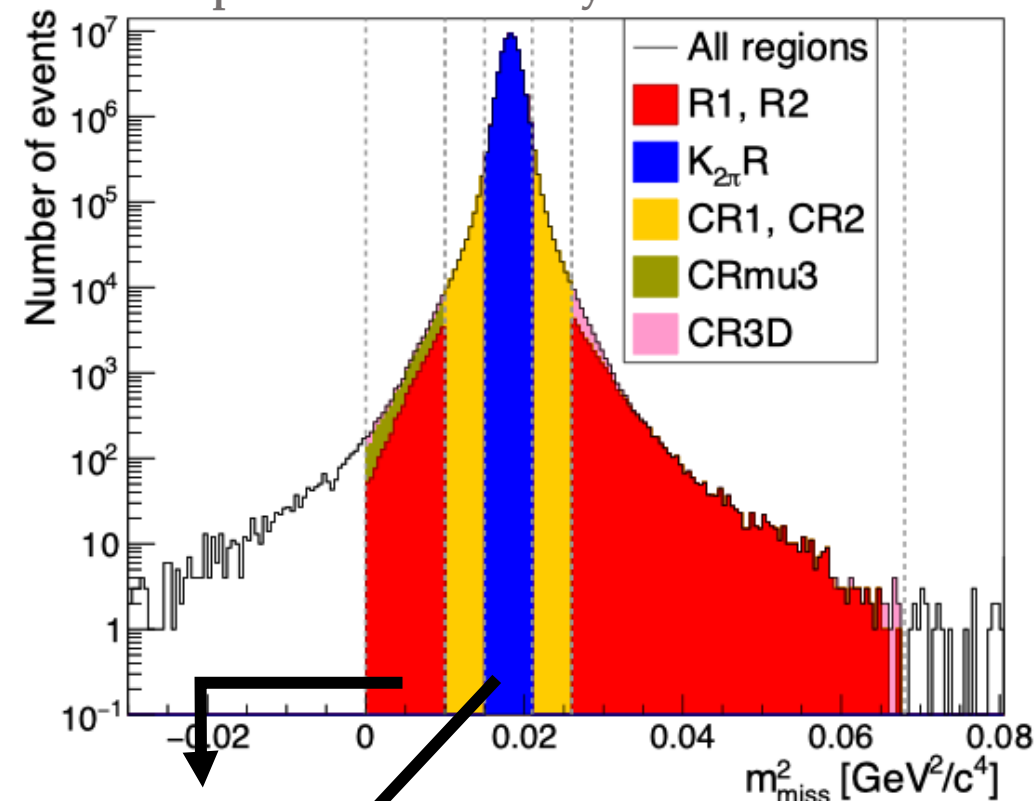


[arXiv:2607.16413]

Background from m_{miss}^2 mis-reconstruction



$K^+ \rightarrow \pi^+ \pi^0(\gamma)$
Control sample of $K^+ \rightarrow \pi^+ \pi^0$ events with $\pi^0 \rightarrow \gamma\gamma$, both photons detected by the LKr



$$\begin{aligned} N_{bg}(K^+ \rightarrow \pi^+ \pi^0(\gamma)) &= 1.19 \pm 0.10 \\ N_{bg}(K^+ \rightarrow \mu^+ \nu_\mu(\gamma)) &= 1.39 \pm 0.29 \\ N_{bg}(K^+ \rightarrow \pi^+ \pi^+ \pi^-) &= 0.25 \pm 0.05 \end{aligned}$$

$$N_{bg} = N_{bkgR} \cdot f_{tail} = N_{bkgR} \cdot \frac{N_{SR}^{CS}}{N_{bkgR}^{CS}}$$

Control Sample events in Background Region

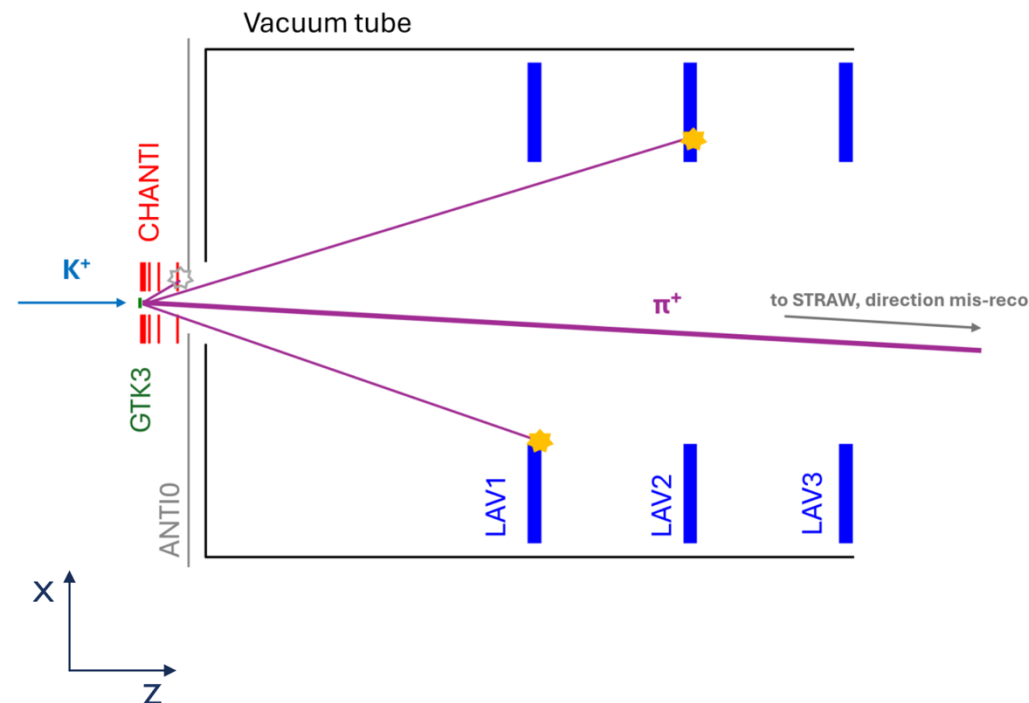
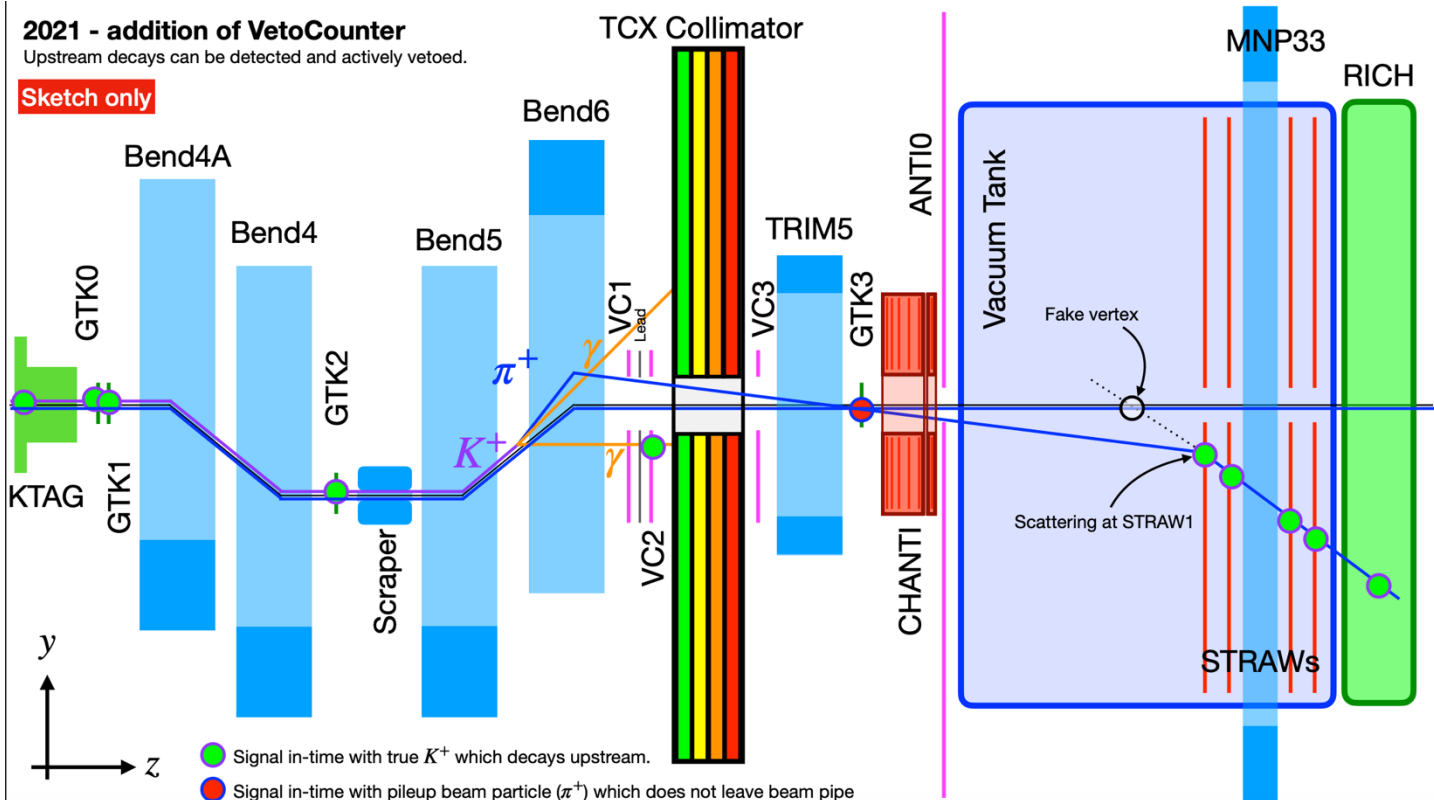
Upstream background

Decays or interactions of beam particles upstream of the fiducial volume (62% of total background)

2021 - addition of VetoCounter

Upstream decays can be detected and actively vetoed.

Sketch only



Upstream decays suppressed by factor 2 using VetoCounter (VC)

LAV1 veto reduces total background by 30% in 2023–24 dataset with $\mathcal{O}(\%)$ signal loss

Fully data-driven background evaluation:

$$N_{\text{bg}}^{\text{Ups.}} = 7.5_{-2.2}^{+2.9}$$

Signal sensitivity

$$N_{\pi\nu\bar{\nu}}^{\text{SM,exp}}(p_i) = \frac{\mathcal{B}_{\pi\nu\bar{\nu}}^{\text{SM}}}{\mathcal{B}_{SES}(p_i)} = \frac{\mathcal{B}_{\pi\nu\bar{\nu}}^{\text{SM}}}{\mathcal{B}_{\pi\pi}} \frac{A_{\pi\nu\bar{\nu}}(p_i)}{A_{\pi\pi}(p_i)} D_0 N_{\pi\pi}(p_i) \varepsilon_{\text{trig}}(p_i) \varepsilon_{RV}$$

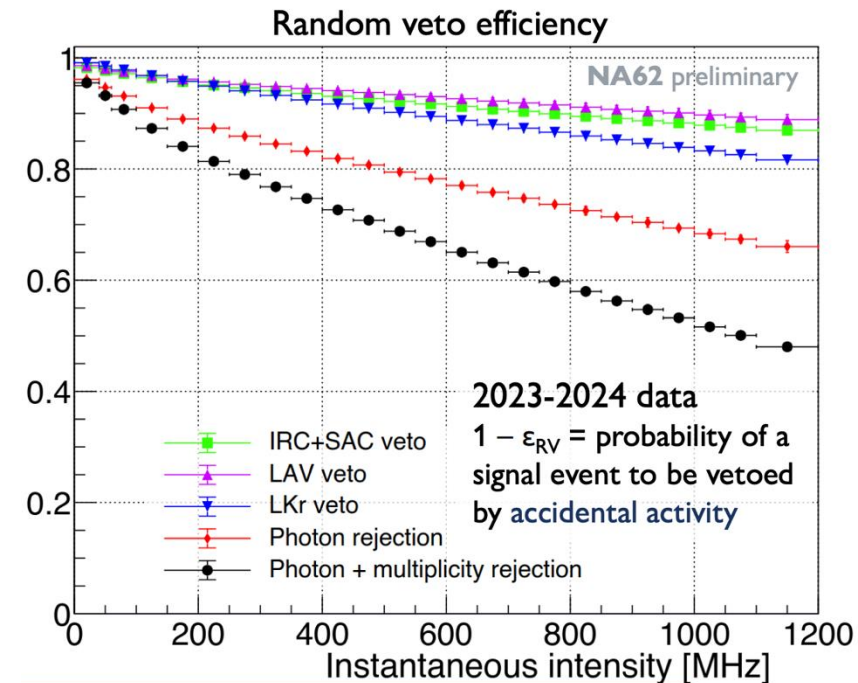
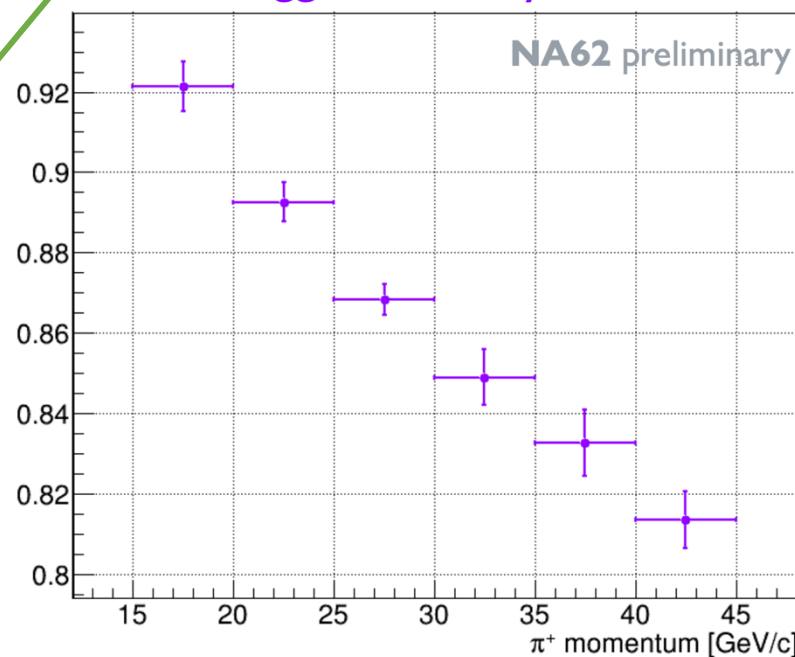
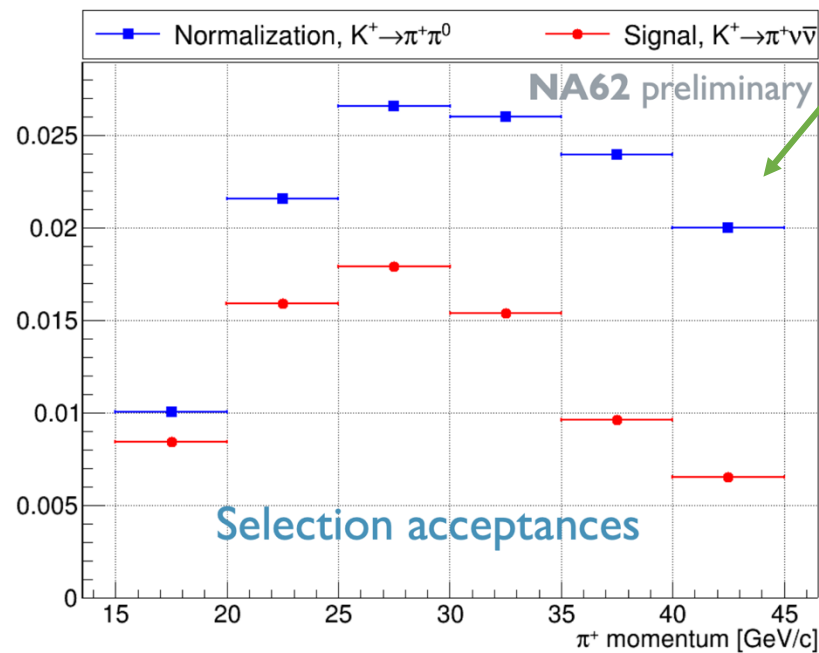
8.4×10^{-11}
(benchmark value)

Normalisation trigger
downscale = 400

of normalisation
events

20.7% [PDG]

Trigger efficiency ratio



- Acceptances evaluated at 0 intensity
- Intensity dependence captured in ε_{RV}
- $\varepsilon_{\text{trig}} = (86.4 \pm 1.2)\%$
- Improved systematics evaluation

- Improved RV efficiency: $1.14 \times \varepsilon_{RV}$
 - Mainly due to $600 \rightarrow 450$ MHz
(operational conditions optimization
from August 2023 [SPSC-SR-345])

Signal sensitivity and background expectation

[arXiv:2607.16413]

$$N_{\pi\nu\bar{\nu}}^{\text{SM,exp}}(p_i) = \frac{\mathcal{B}_{\pi\nu\bar{\nu}}^{\text{SM}}}{\mathcal{B}_{\text{SES}}(p_i)} = \frac{\mathcal{B}_{\pi\nu\bar{\nu}}^{\text{SM}}}{\mathcal{B}_{\pi\pi}} \frac{A_{\pi\nu\bar{\nu}}(p_i)}{A_{\pi\pi}(p_i)} D_0 N_{\pi\pi}(p_i) \varepsilon_{\text{trig}}(p_i) \varepsilon_{\text{RV}}$$

Quantity	Value
$N_{\pi\pi}$	Number of normalisation events
$A_{\pi\pi}$	Normalisation acceptance
N_K	Effective number of K^+ decays
$A_{\pi\nu\bar{\nu}}$	Signal acceptance
$\varepsilon_{\text{trig}}$	Trigger efficiency ratio
ε_{RV}	Random veto efficiency
$\mathcal{B}_{\text{SES}}$	Single event sensitivity
$N_{\pi\nu\bar{\nu}}^{\text{SM}}$	Number of expected SM $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events

Background	Events
$K^+ \rightarrow \pi^+ \pi^0(\gamma)$	1.19 ± 0.10
$K^+ \rightarrow \mu^+ \nu(\gamma)$	1.39 ± 0.29
$K^+ \rightarrow \pi^+ \pi^+ \pi^-$	0.25 ± 0.05
$K^+ \rightarrow \pi^+ \pi^- e^+ \nu$	$1.59^{+0.51}_{-0.43}$
$K^+ \rightarrow \pi^+ \gamma \gamma$	0.04 ± 0.04
$K^+ \rightarrow \pi^0 \ell^+ \nu$	< 0.001
Upstream	$7.5^{+2.9}_{-2.2}$
Total	$12.0^{+2.9}_{-2.2}$

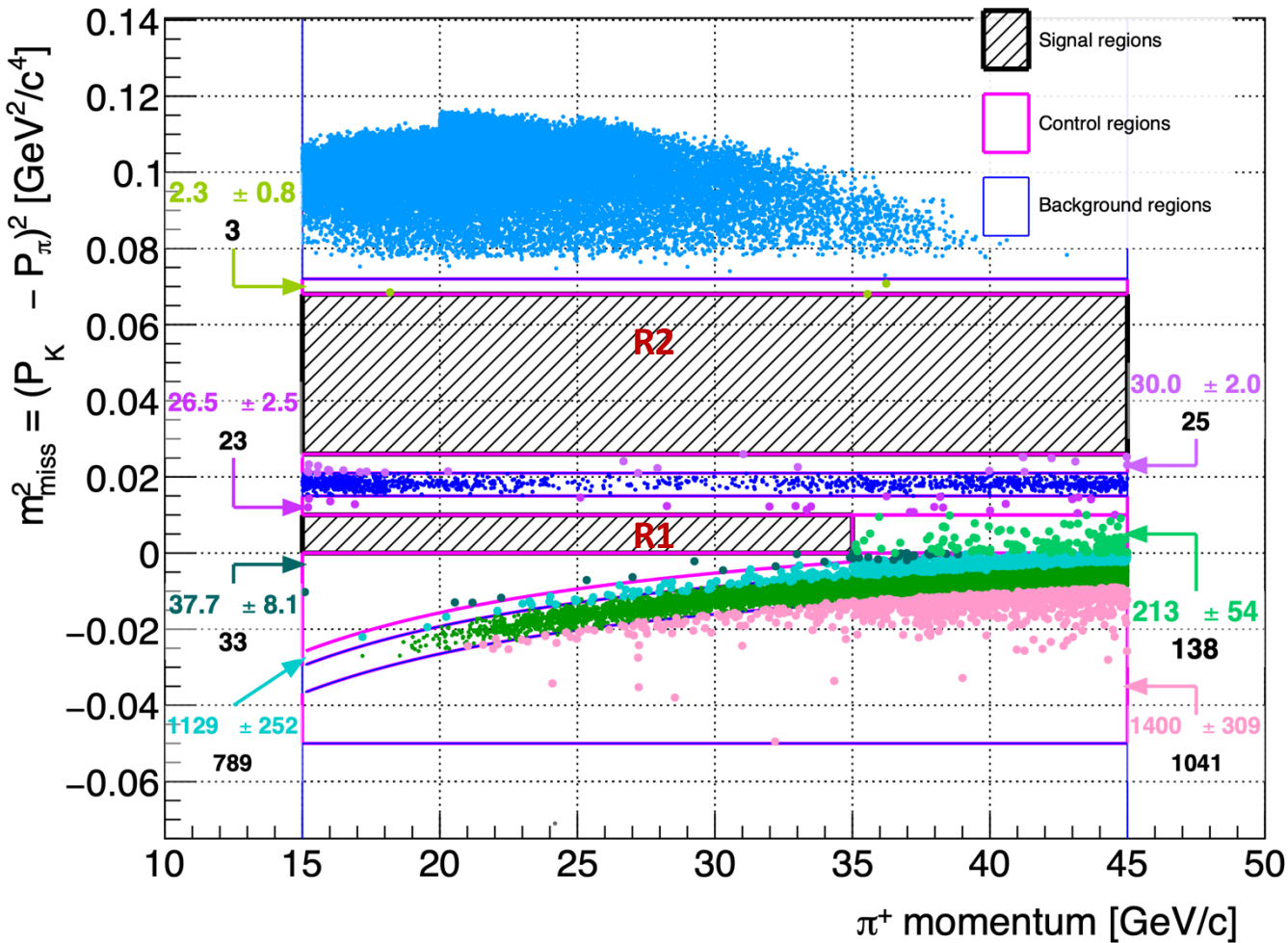
- $2.3\times$ number of SM signal events expected than 2021-22 data analysis
- 2023+2024: $\sqrt{S+B}/S \approx 0.25$ compared to 0.5 for previous analysis
- By far the most sensitive analysis so far

Combining with previous 2016—22 dataset:

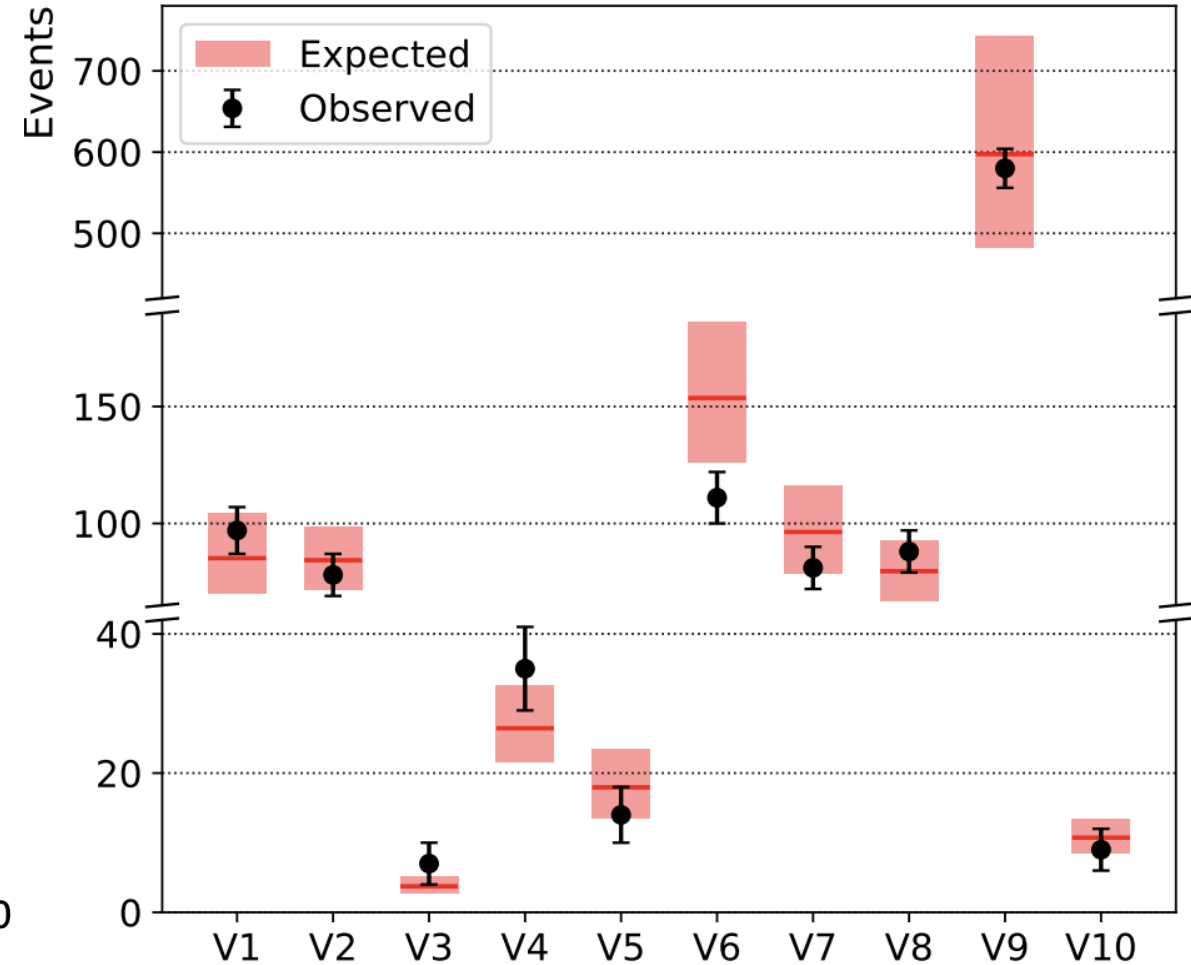
$$N_{bg} = 30^{+4}_{-3}, N_{\pi\nu\bar{\nu}}^{\text{SM,exp}} = 43 \pm 1$$

$\Rightarrow$ **expected SM significance $> 5\sigma$**

Background validation



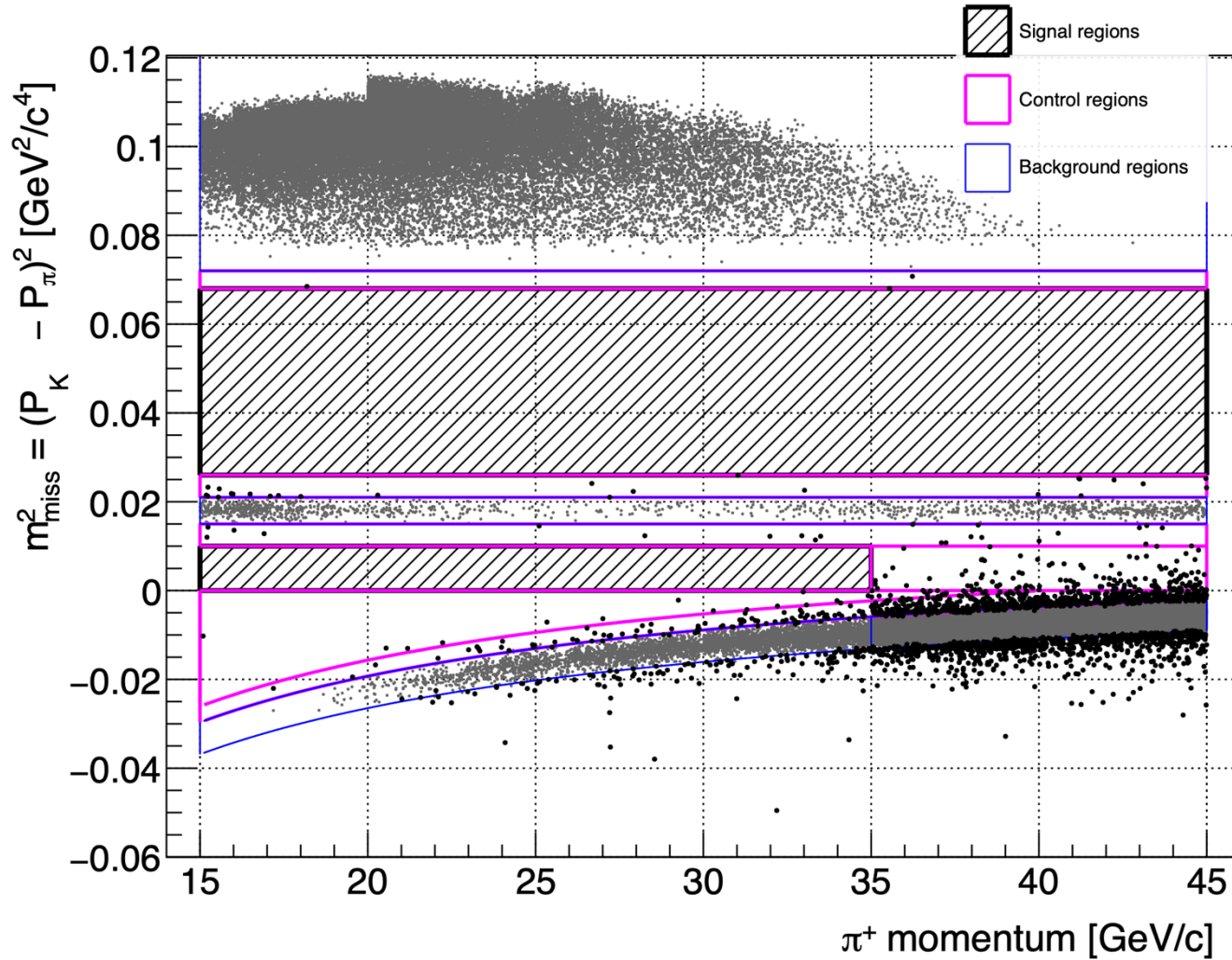
Use control regions to validate predictions for K^+ decays in FV:
 $p - \text{value} = 0.65$



Validate upstream background with 10 independent samples enriched with different upstream background mechanisms:
 $p - \text{value} = 0.79$

Background regions

2023-2024 data



Expected SM signal: $N_{\pi\nu\bar{\nu}}^{SM} \approx 23$

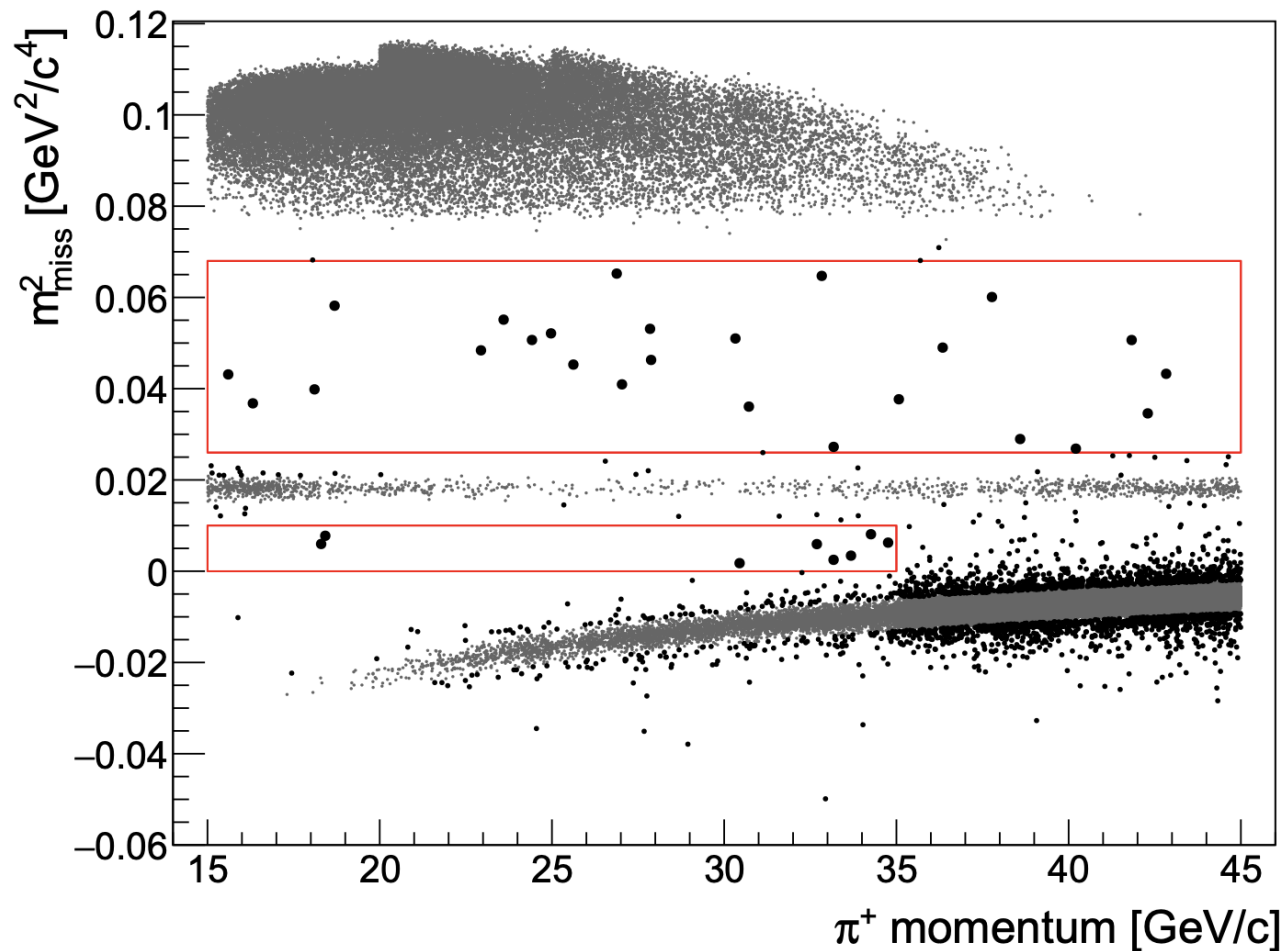
Expected background: $N_{bg} = 12.0^{+2.9}_{-2.2}$

Observed: $N_{obs} = ?$

Signal regions

2023-2024 data

[arXiv:2607.16413]

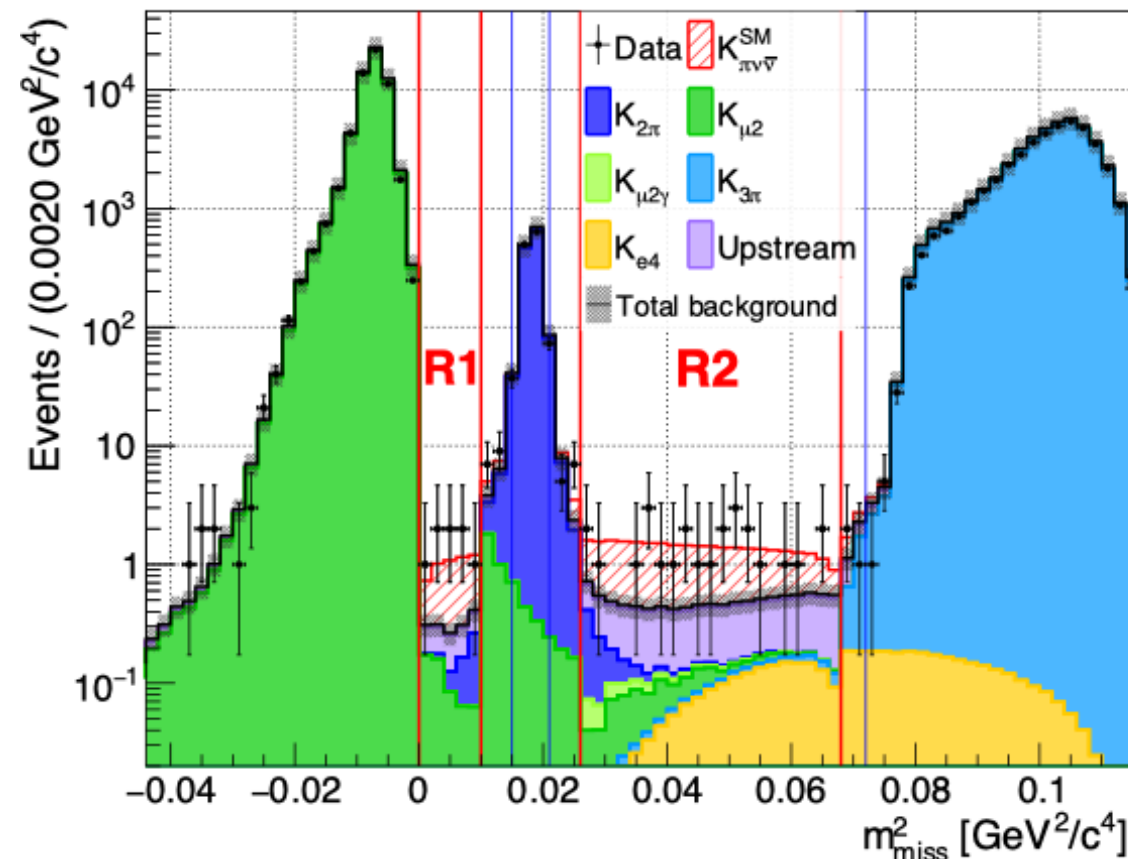


Expected SM* signal: $N_{\pi\nu\bar{\nu}}^{SM} = 22.9 \pm 1.1$

Expected background: $N_{bg} = 12.0^{+2.9}_{-2.2}$

Observed: $N_{obs} = 33$

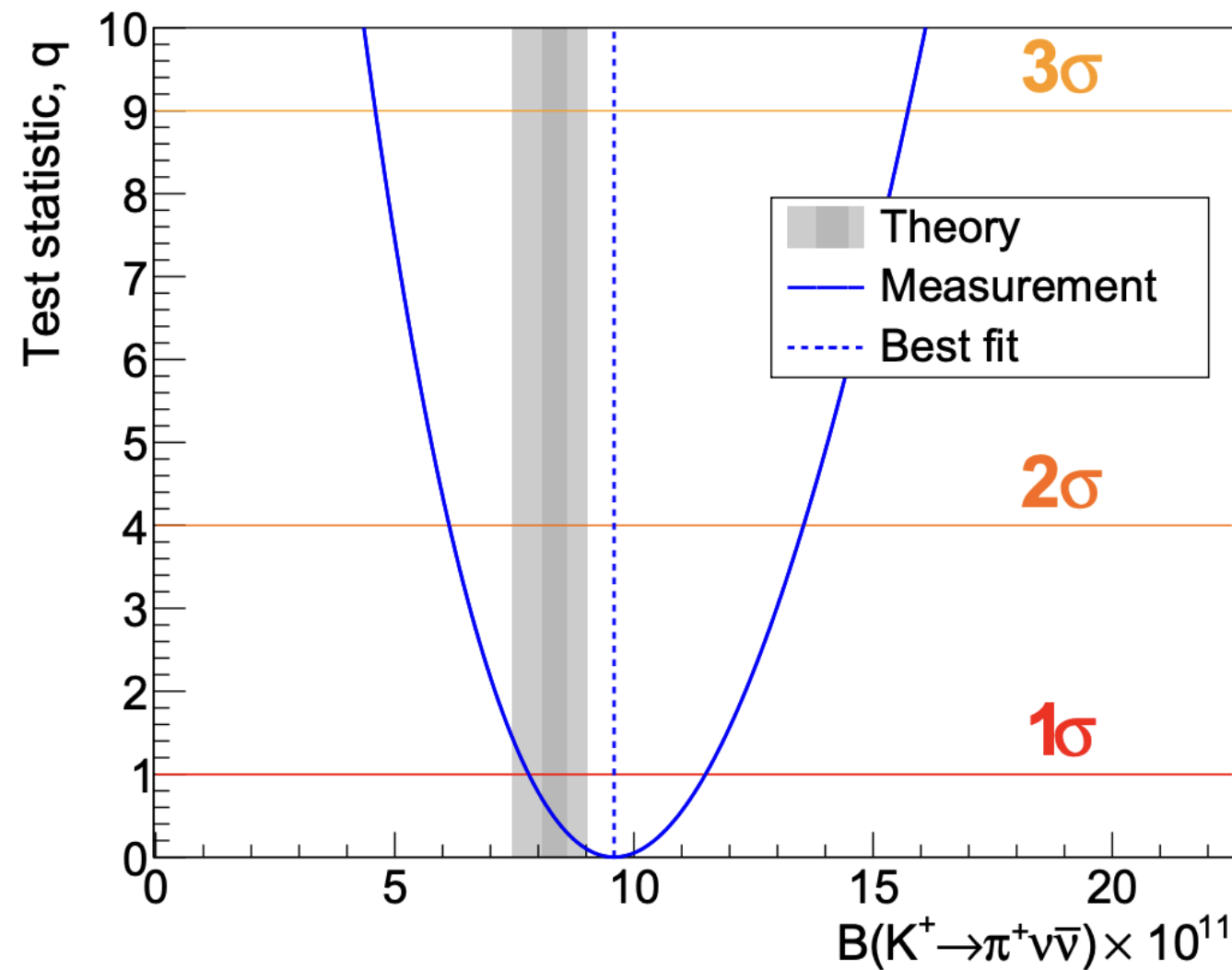
1D projection with different background predictions & SM signal expectation* with $\mathcal{B}_{SM} = 8.4 \times 10^{-11}$ [not a fit]:



$$\mathcal{B}_{\pi\nu\bar{\nu}}^{23-24} = \left(7.2^{+2.2}_{-1.9} \Big|_{stat} \quad {}^{+0.9}_{-0.9} \Big|_{syst} \right) \times 10^{-11} = (7.2^{+2.3}_{-2.1}) \times 10^{-11}$$

Combine: 2016—2024 dataset

[arXiv:2607.16413]

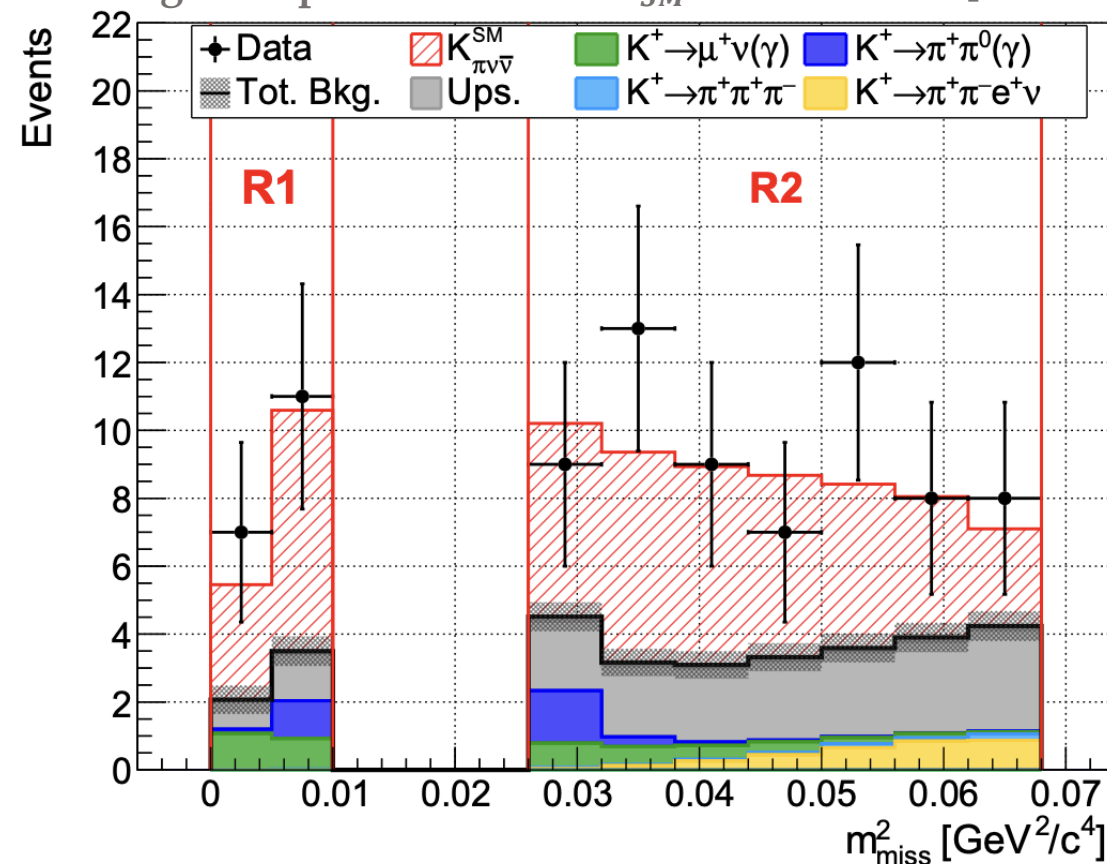


Expected SM* signal: $N_{\pi\nu\bar{\nu}}^{SM} = 43 \pm 1$

Expected background: $N_{bg} = 30^{+4}_{-3}$

Observed: $N_{obs} = 84$

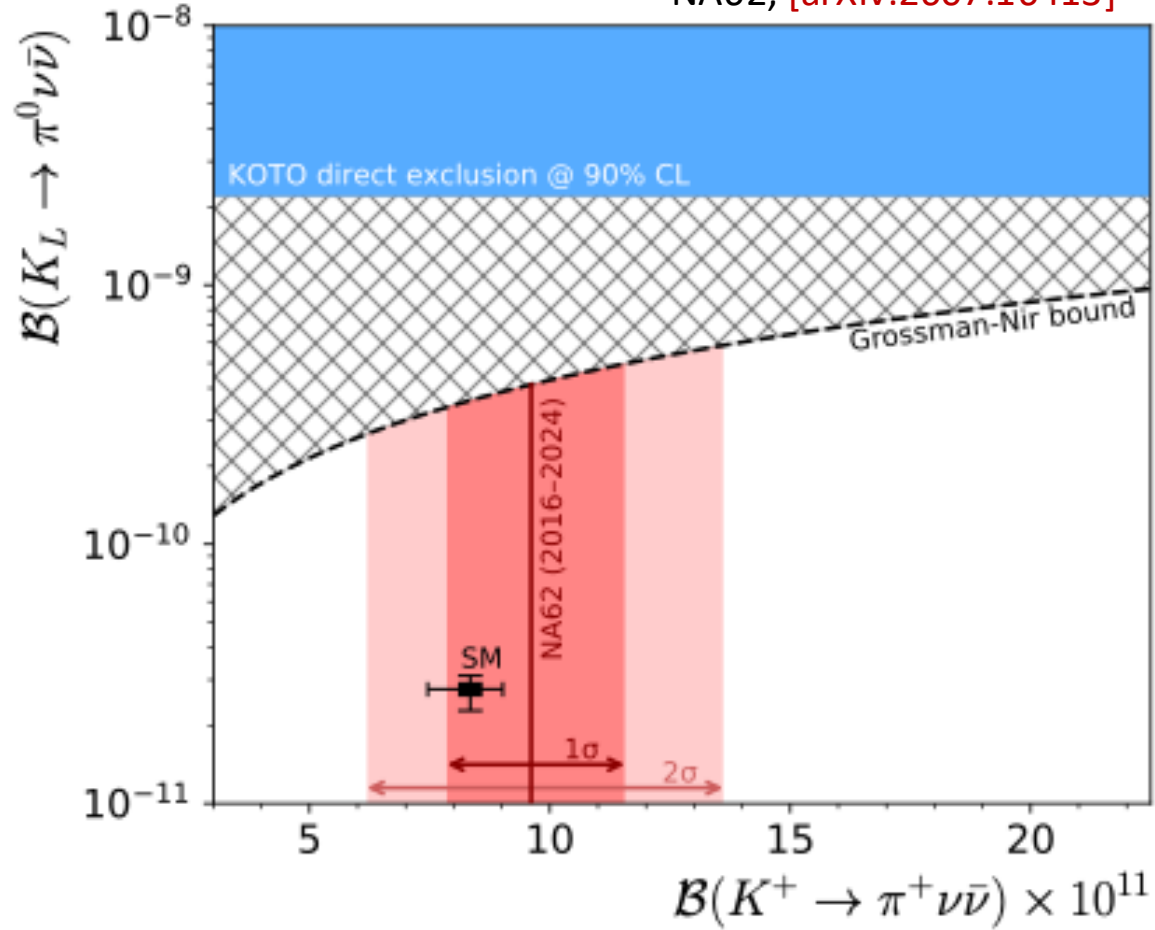
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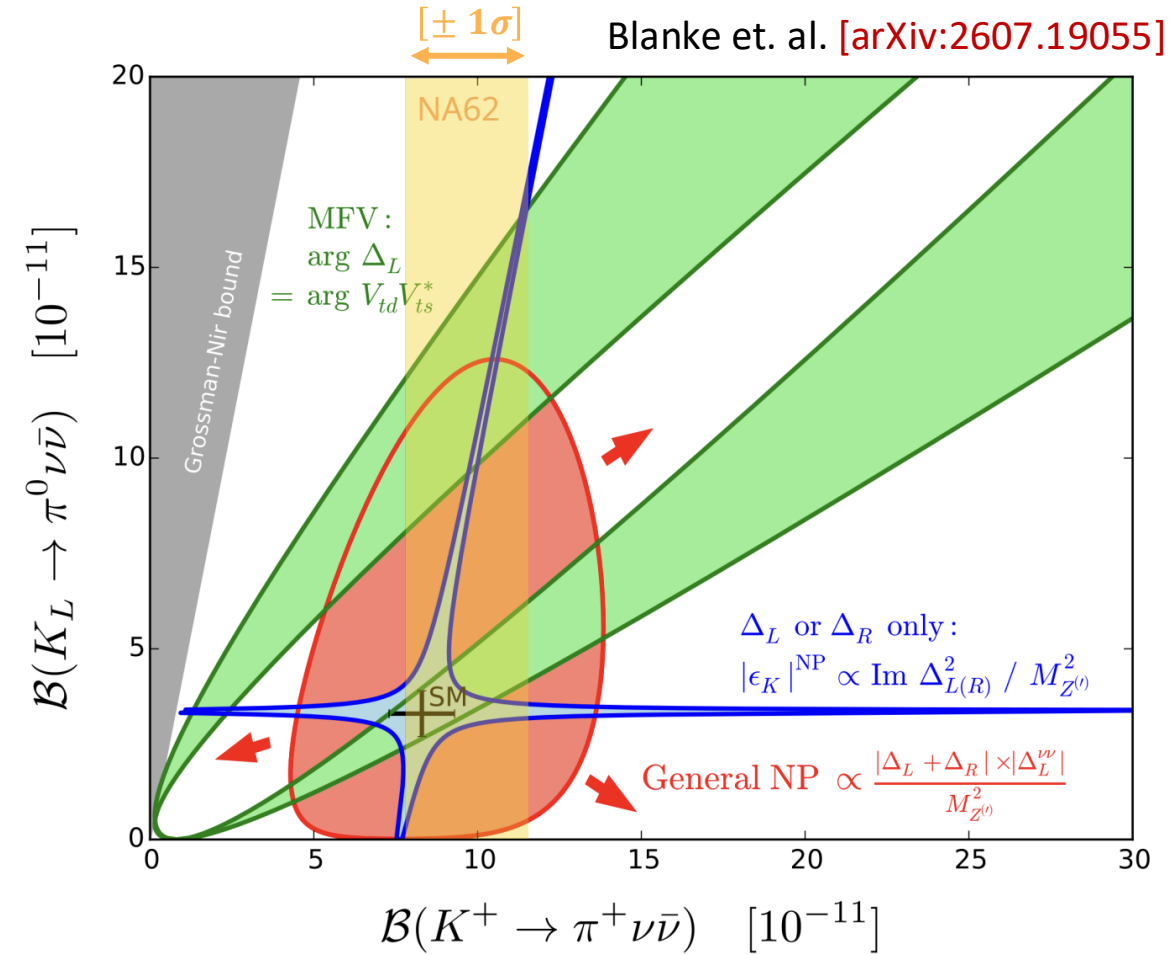
$$\mathcal{B}_{\pi\nu\bar{\nu}}^{16-24} = \left(9.6^{+1.8}_{-1.6} \Big|_{stat} \quad {}^{+0.8}_{-0.6} \Big|_{syst} \right) \times 10^{-11} = (9.6^{+1.9}_{-1.8}) \times 10^{-11}$$

The global picture

NA62, [arXiv:2607.16413]

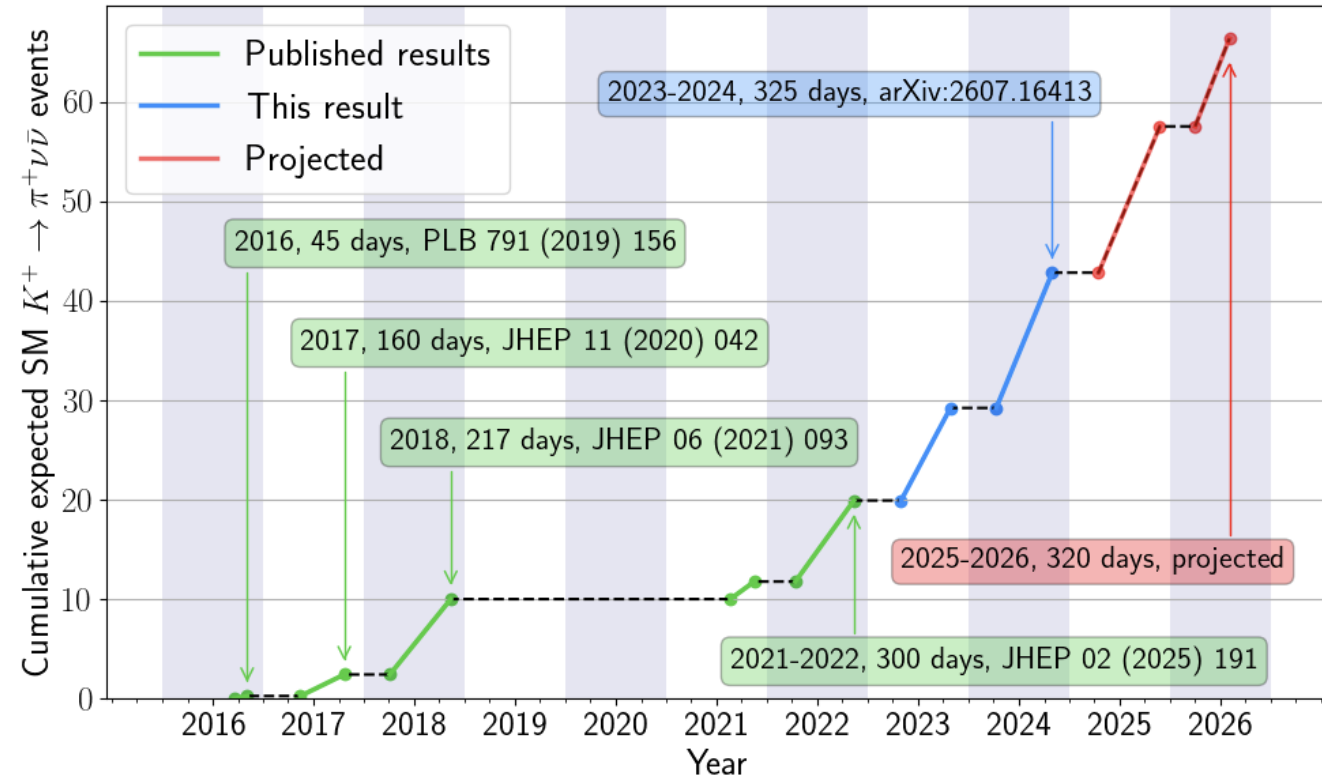
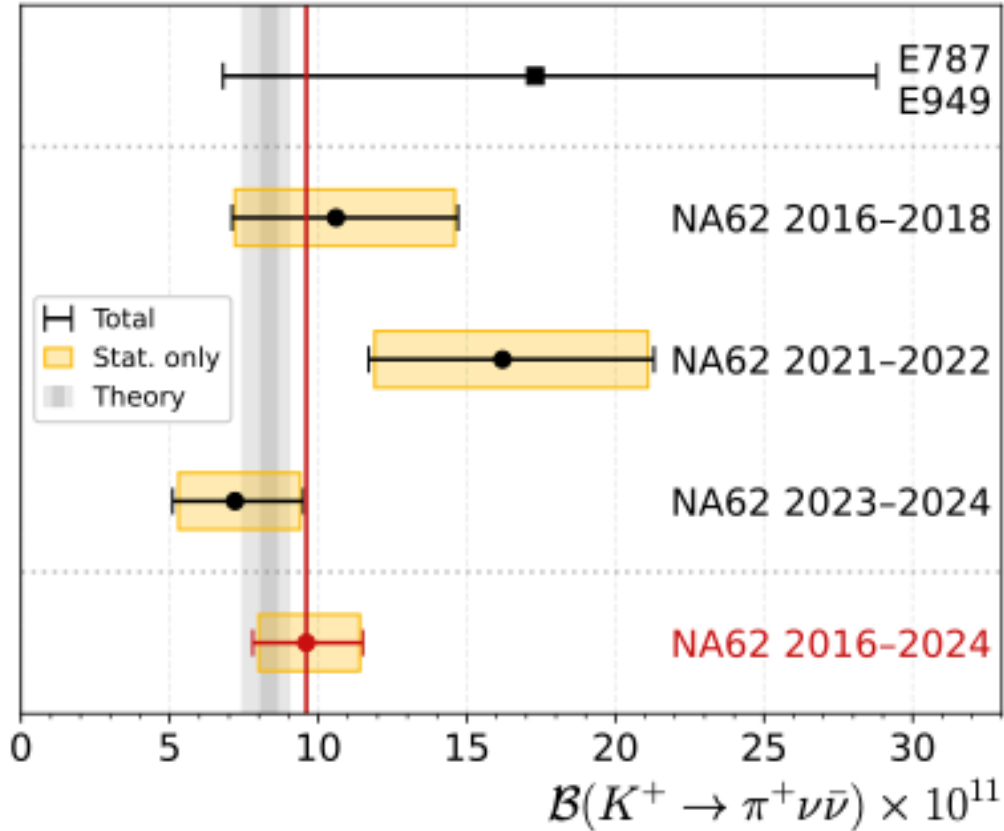


Blanke et. al. [arXiv:2607.19055]



- $\mathcal{B}_{\pi\nu\bar{\nu}}^{16-24}$ is compatible with SM – within the 20% uncertainty
- BUT: still a lot of space for New Physics in rare kaon decays [arXiv:2607.19055]
 - **NA62:** (improve) $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, **LHCb:** $K_S \rightarrow \mu^+ \mu^-$, **KOTO-II:** $K_L \rightarrow \pi^0 \nu \bar{\nu}$, $K_L \rightarrow \pi^0 \ell^+ \ell^-$, ...

Conclusion and prospects



- *2x signal acceptance * flux + Backgrounds reduced = major sensitivity boost: expected SM significance $> 5\sigma$*
- **Branching ratio measured to $< 20\%$ precision**
 - $\mathcal{B}_{\pi\nu\bar{\nu}}^{16-24} = (9.6^{+1.9}_{-1.8}) \times 10^{-11}$ (result compatible with SM)
- *2025—2026 dataset incoming (1/3 of total): target BR precision improvement $20\% \rightarrow 15\%$*