PRECISION MEASUREMENTS WITH KAON DECAYS AT CERN

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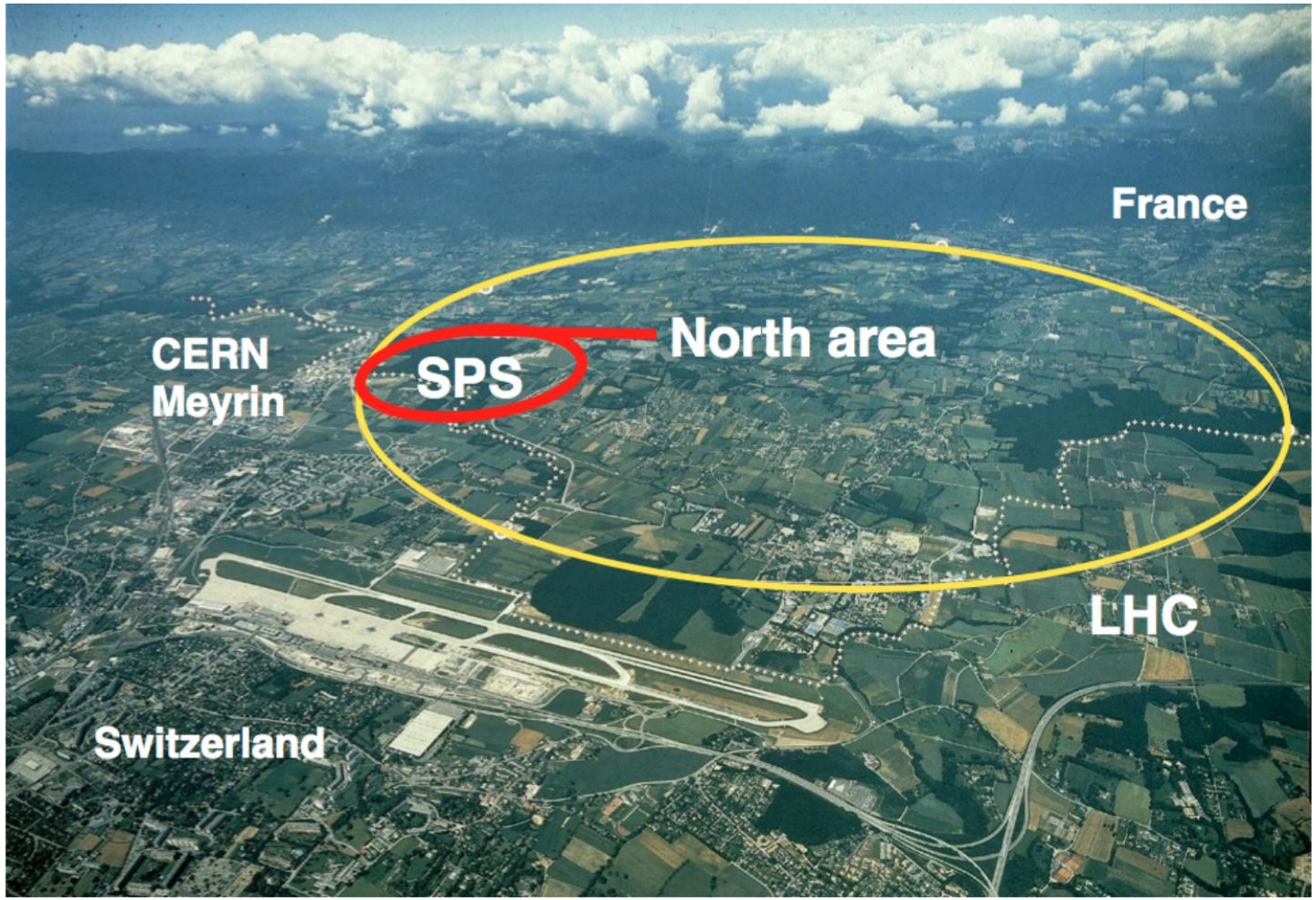
INFN NAPOLI

KAON EXPERIMENTS AT CERN



NA31: K_S / K_L (1984-1990)
First evidence of direct CPV in kaons

NA48, NA48/1: K_S / K_L (1997-2002)
Re(ε'/ε), Rare K_S and hyperon decays

NA48/2: K^+ / K^- (2003-2004)
Direct CPV, rare $K^\pm$ decays

NA62: K^+ / K^- (2007-2008)
$R_K = \Gamma(Ke\nu) / \Gamma(K\mu\nu)$

NA62: K^+ (2016-2018)
Physics Run1

NA62: K^+ (2021-now)
Physics Run2

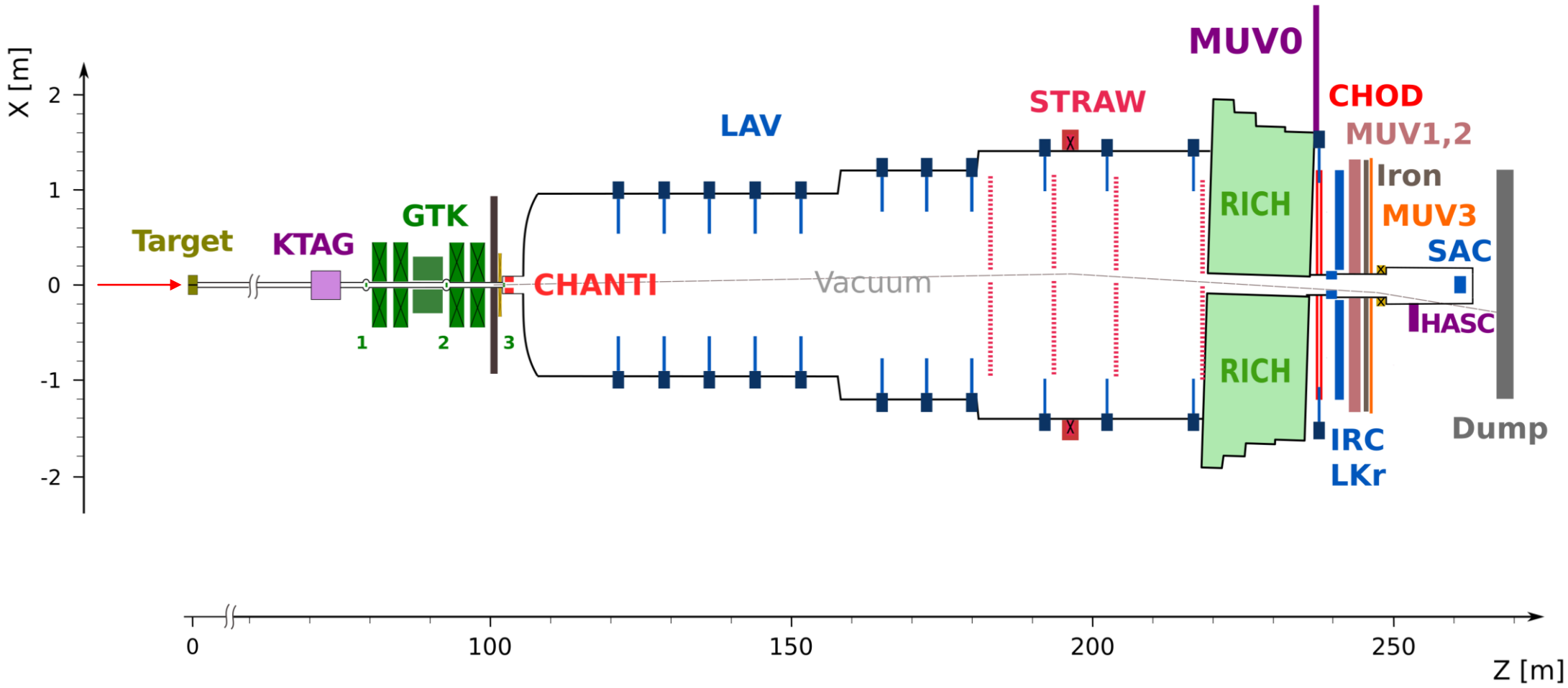
THE NA62 EXPERIMENT

- ~300 participants from ~30 institutions
- High-precision kaon experiment
- Technique:
  - Fixed target
  - Decay-in-flight
- Broad physics program:
  - Measurement of BR($K^+ \to \pi^+ \nu\bar{\nu}$)
  - Precision measurements
  - Tests of LFV / LNV
  - Exotic searches (DP, DS, ALP, HNL)

→ this talk

→ T. Blazek, 22/06

THE NA62 DETECTOR



JINST 12 (2017) P05025

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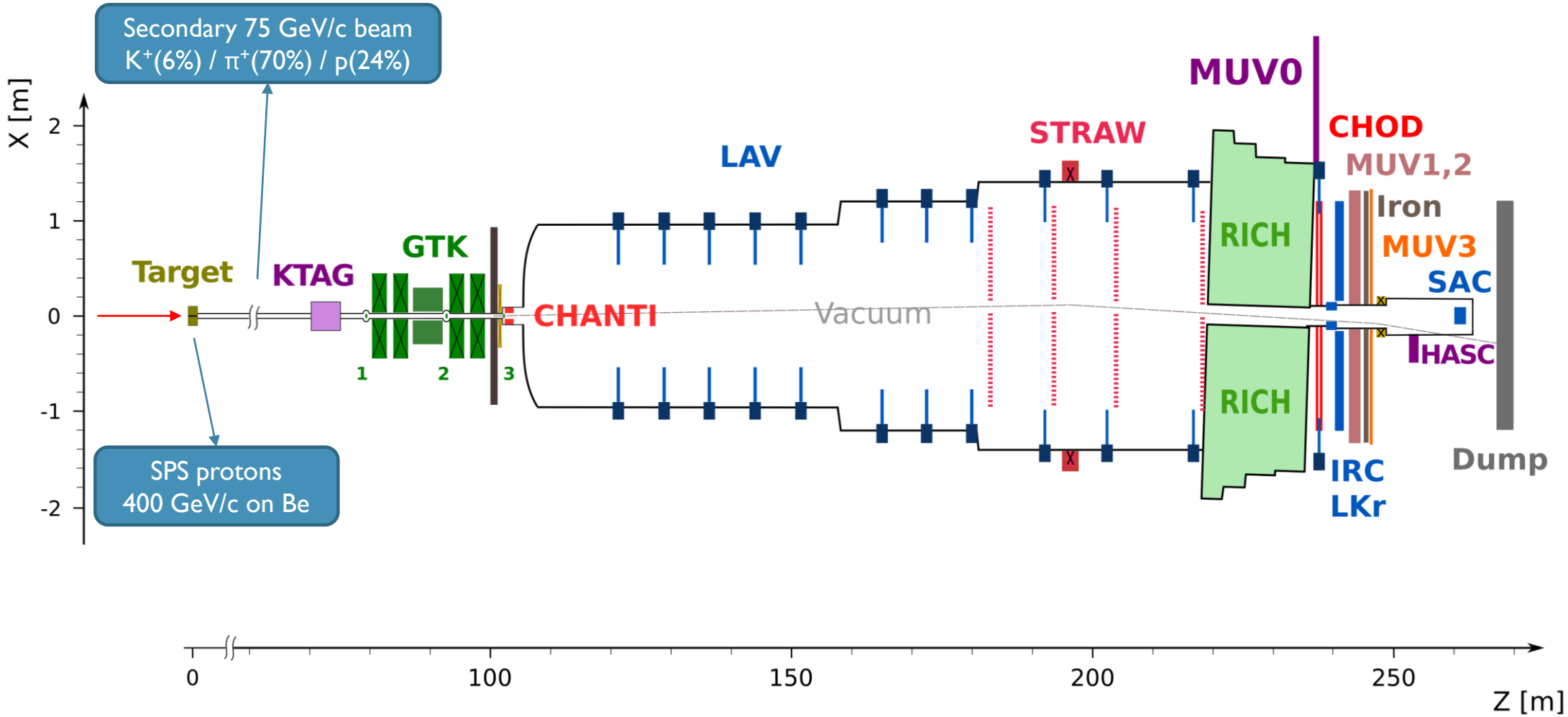

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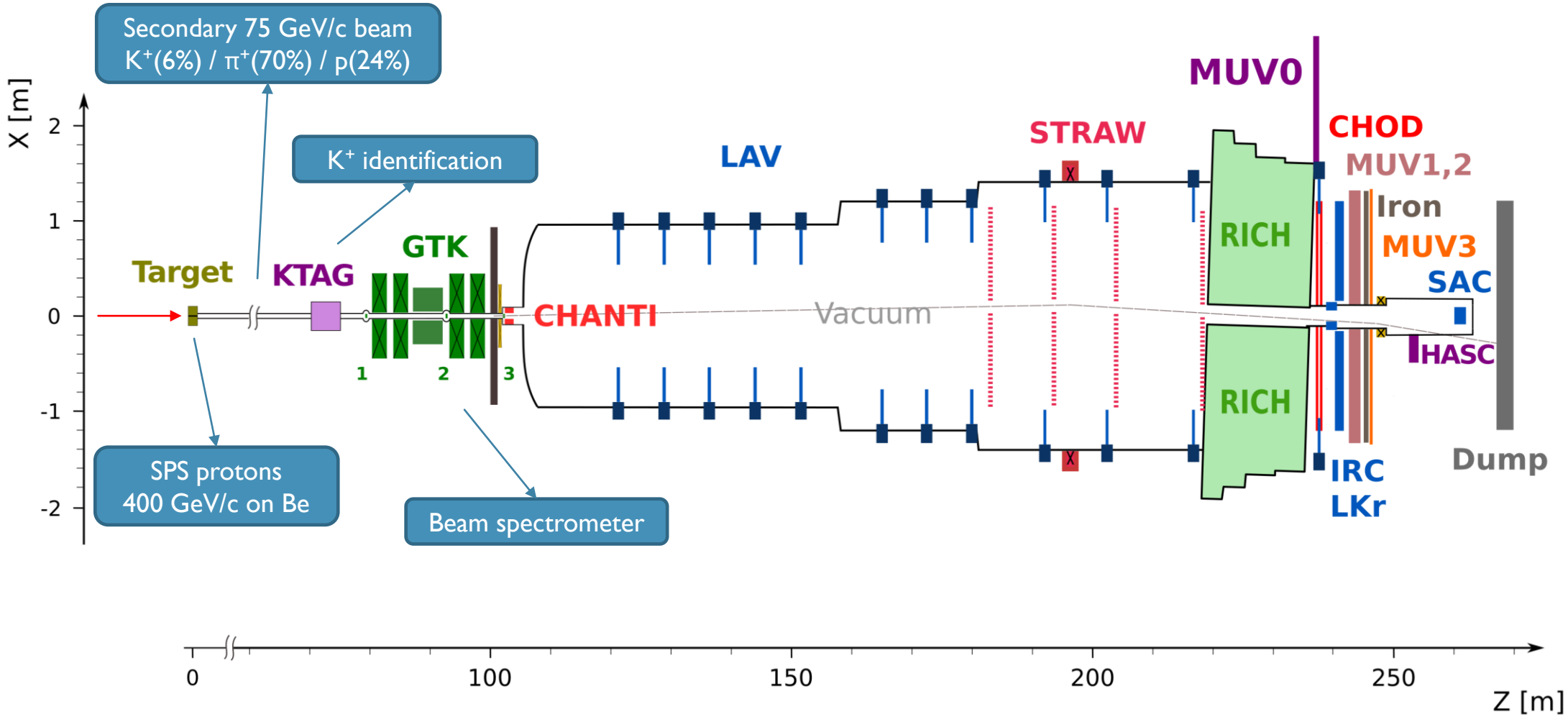

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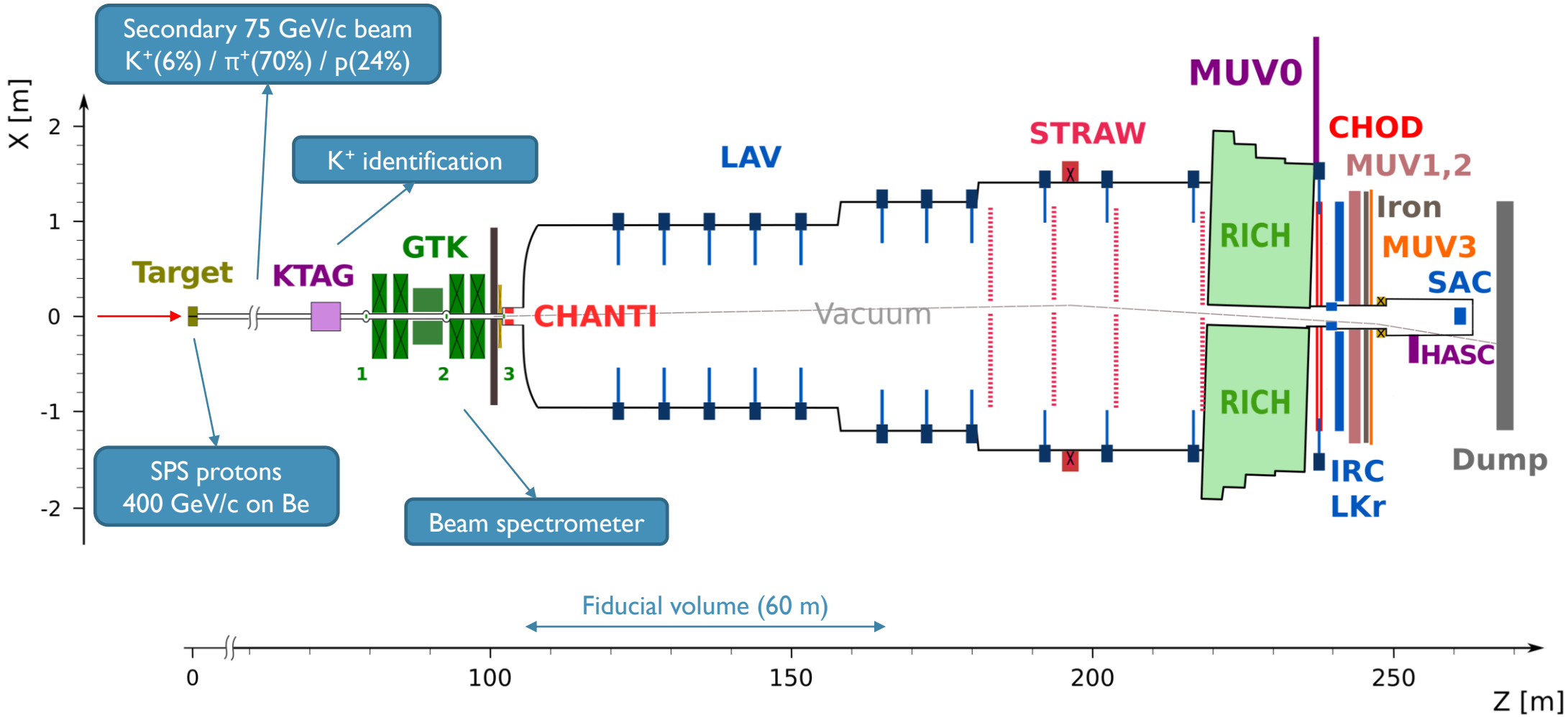

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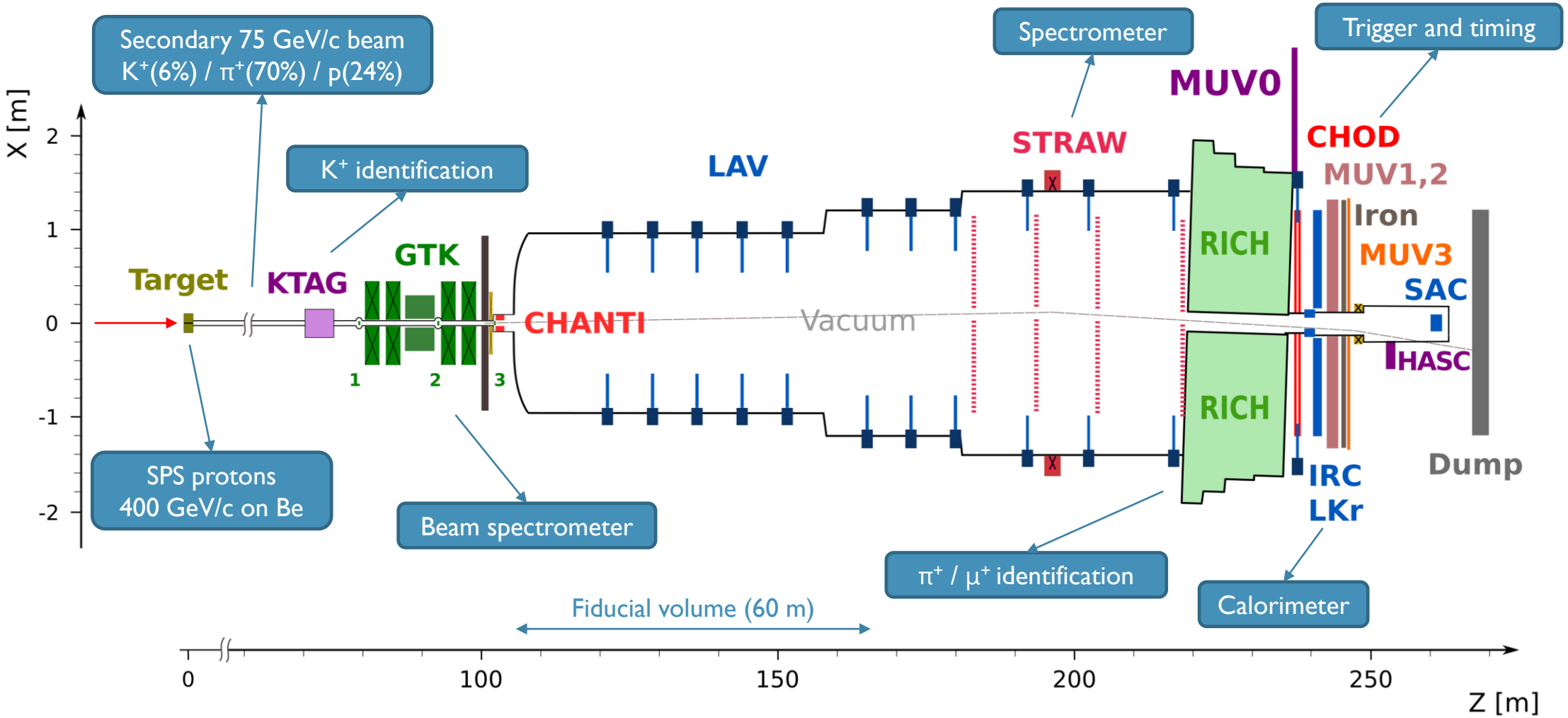
THE NA62 DETECTOR



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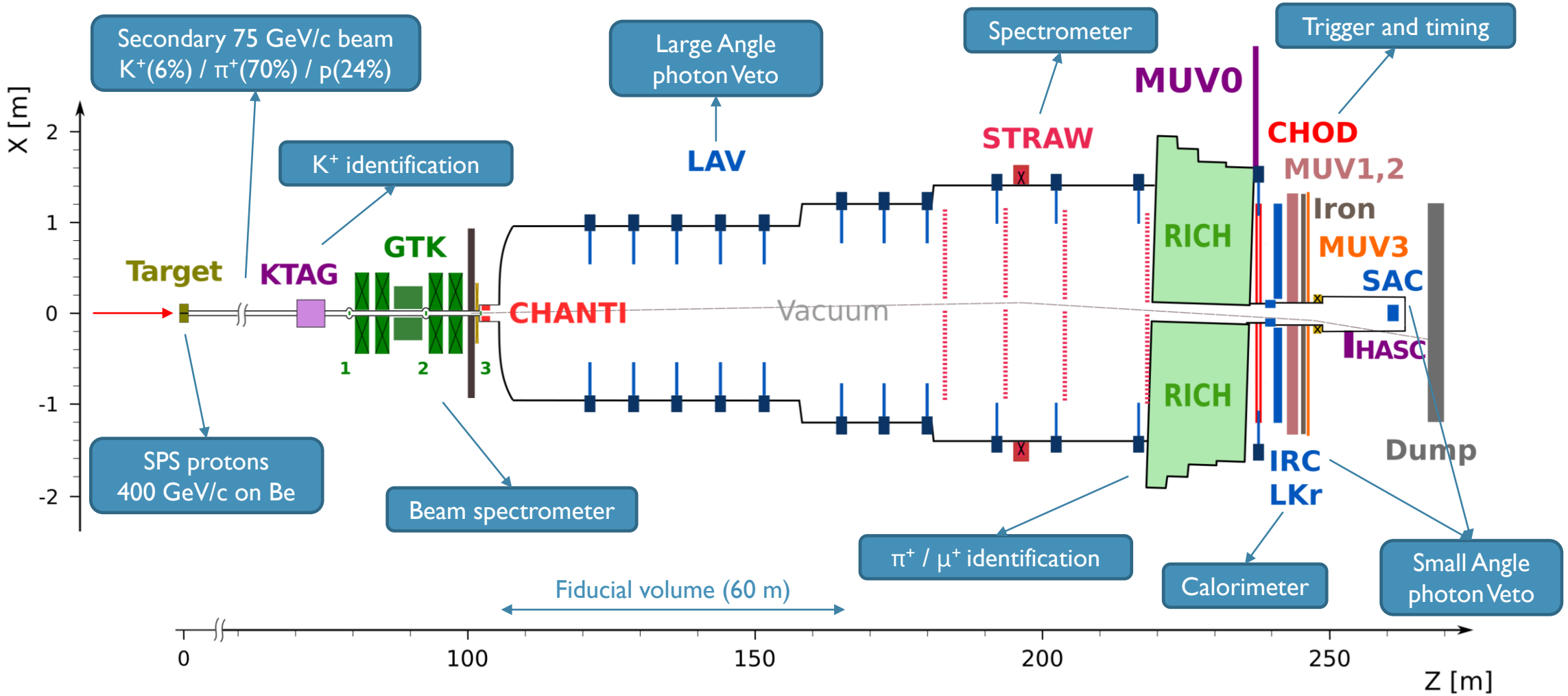

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OUTLINE

NA62 main goal

- $K^+ \to \pi^+ \nu\bar{\nu}$

NA62 latest precision measurements

- $K^+ \to \pi^0 e^+ \nu\gamma$ ($K_{e3\gamma}$)
- $K^+ \to \pi^+ \mu^+ \mu^-$
- $K^+ \to \pi^+ \gamma\gamma$

NA48/2 preliminary result

- $K^\pm \to \pi^0 \pi^0 \mu^\pm \nu$ ($K_{\mu 4}^{00}$)

NA62 dataset

Run1 (this talk)

- 2016: 30 days, 2×10^{11} useful K decays
- 2017: 161 days, 2×10^{12} useful K decays
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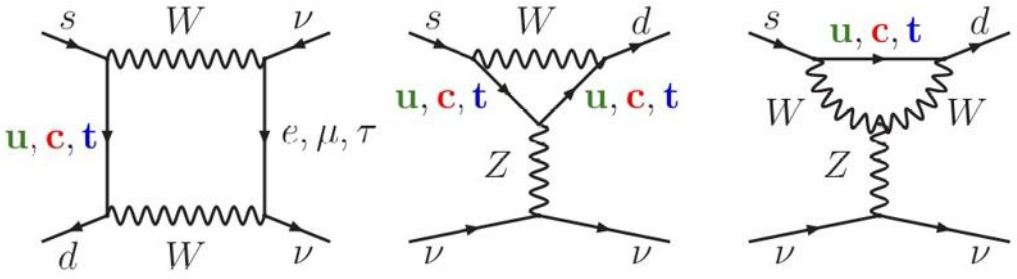
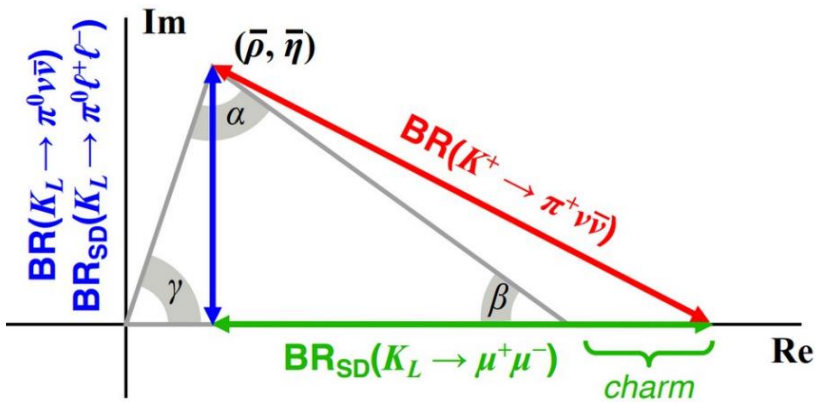
Run2 (analysis in progress)

- 2021: 85 days
- 2022: 215 days
- 2023 – LS3: ongoing

$K^+ \to \pi^+ \nu\bar{\nu}$

THEORY

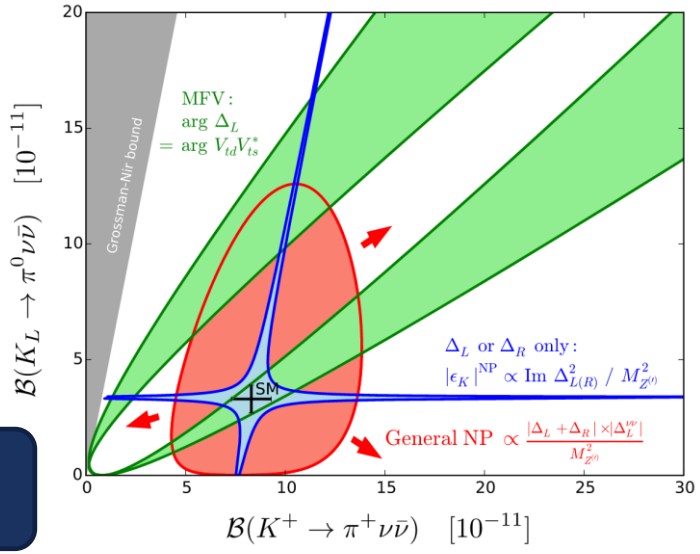




- FCNC s → d, high CKM suppression
- Theoretically clean, dominated by short distance
- Hadronic form factor extracted from $K_{\ell 3}$
- Uncertainty largely from CKM parameters

$$BR(K^+ \to \pi^+ \nu\bar{\nu})_{SM} = (8.4 \pm 1.0) \times 10^{-11}$$

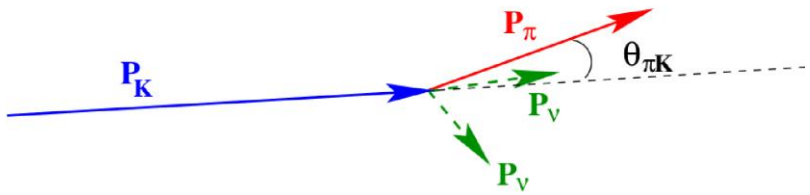
JHEP 11 (2015) 033



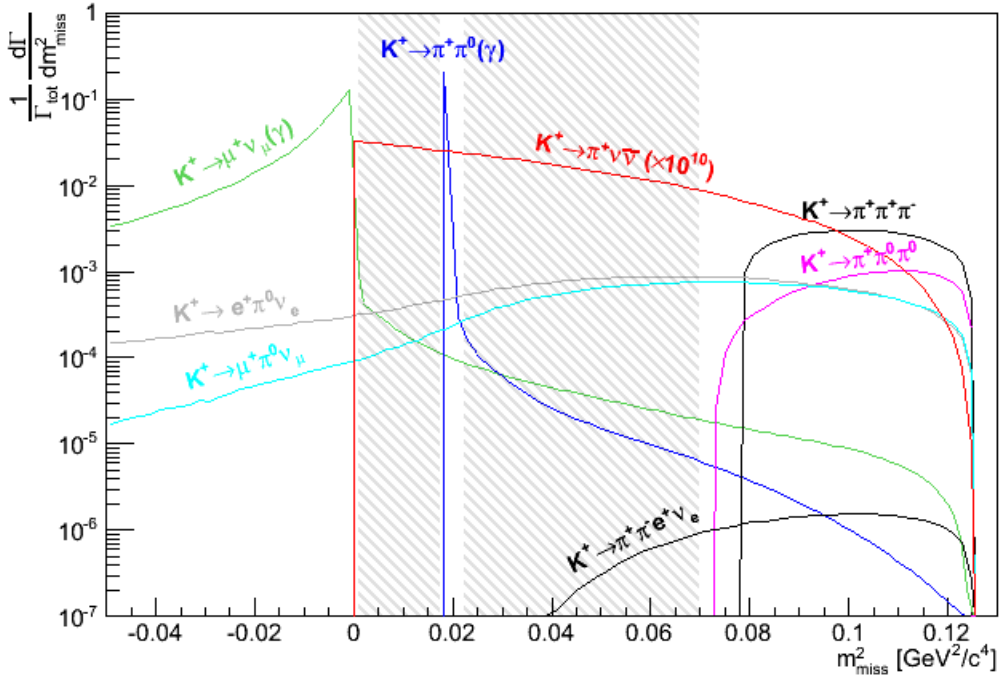
- $K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L \to \pi^0 \nu\bar{\nu}$ are correlated
- Very sensitive to new physics
- Kaons can constrain the UT independently from B physics

Acta Phys.Polon.B 53 6, A1 (2021)

$K^+ \to \pi^+ \nu\bar{\nu}$



$m^2_{miss} = (P_K - P_\pi)^2$



Performances

- Kinematic suppression $O(10^4)$
- Muon suppression $O(10^7)$
- π^0 suppression $O(10^7)$
- Timing between sub-detectors O(100 ps)

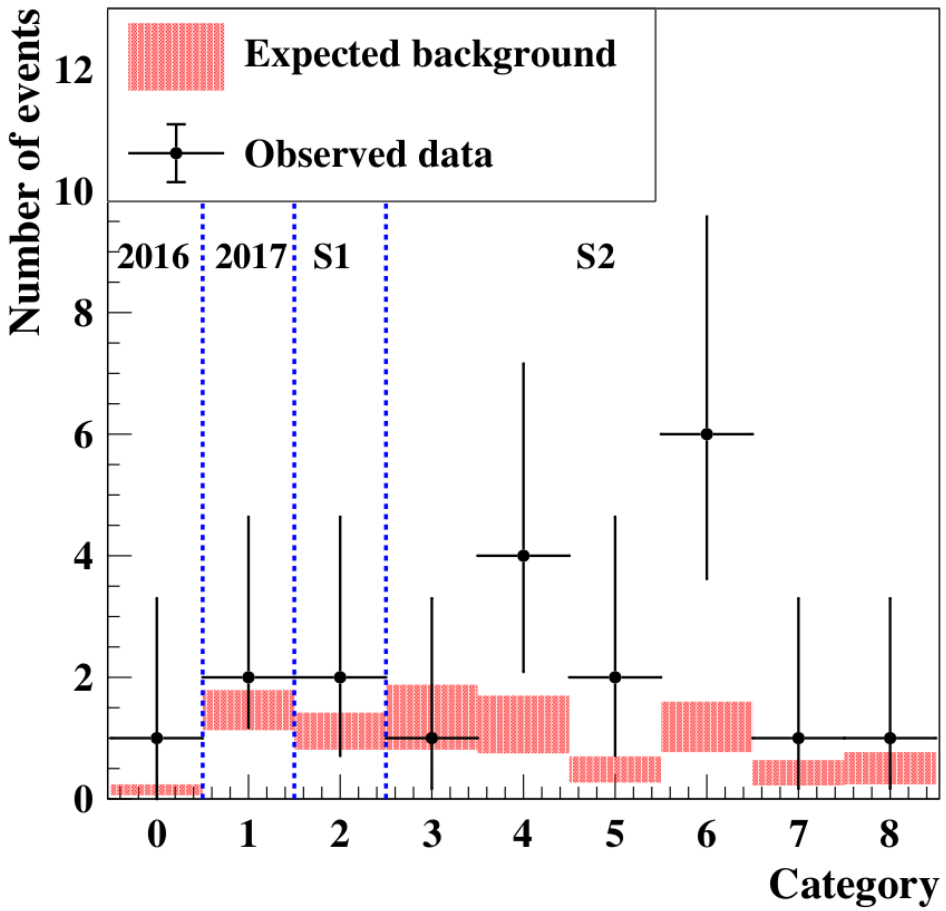
Selection

- K^+, π^+ track reconstruction
- Track matching, vertex reconstruction
- π^+ identification, μ^+ rejection
- Multi-track rejection, photon veto
- Kinematics (m^2_{miss}, p_π)

Analysis

- Momentum range: $15 < p_\pi < 45$ GeV/c
- Signal regions blinded during the analysis
- Data-driven background estimate
- 7 categories depending on hardware and momentum

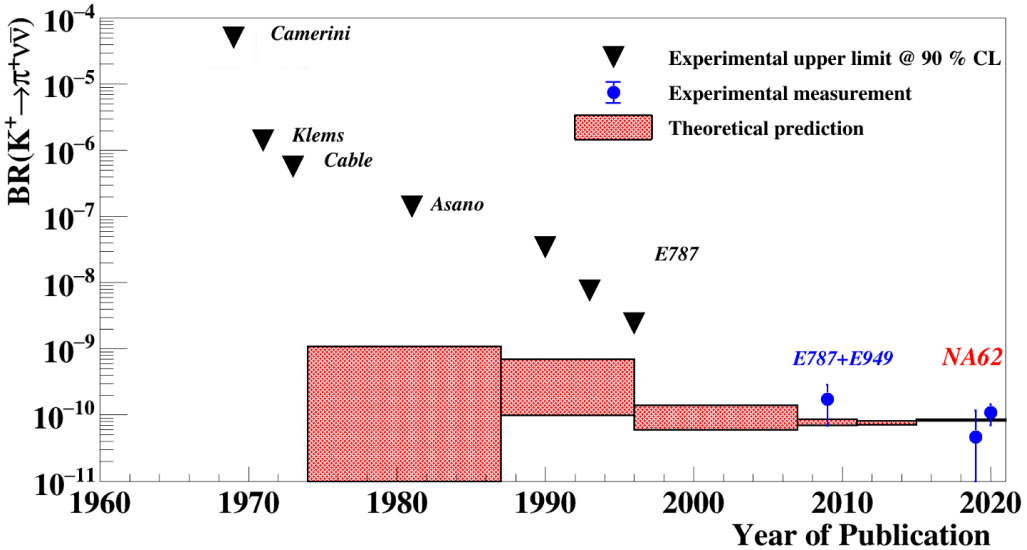
$K^+ \to \pi^+ \nu\bar{\nu}$



- Single Event Sensitivity: $(0.839 \pm 0.053_{syst}) \times 10^{-11}$
- Expected SM signal events: $10.01 \pm 0.42_{syst} \pm 1.19_{ext}$
- Expected background events: $7.03^{+1.05}_{-0.82}$
- Observed events: 20
- Significance: 3.4σ

$$BR(K^+ \to \pi^+ \nu\bar{\nu})^{NA62}_{16+17+18} = (10.6\ ^{+4.0}_{-3.8}|_{stat} \pm 0.9_{syst}) \times 10^{-11}$$

JHEP 06 (2021) 093



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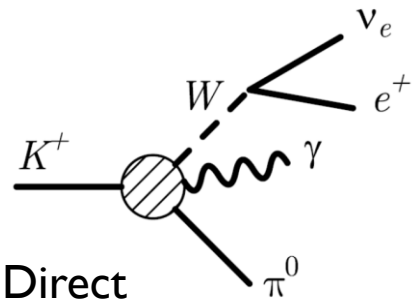
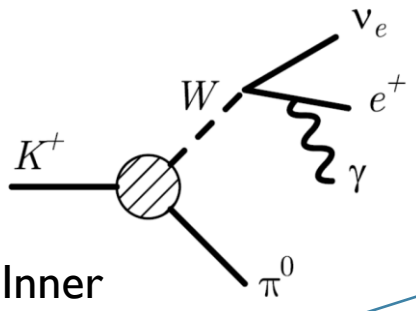
THEORY



Direct Emission



Inner Brehmsstrahlung

divergent for E_γ and $\theta_{e,\gamma} \to 0$

Eur. Phys. J. C 50 (2007) 557

$$R_j = \frac{BR(\pi^0 e^+ \nu\gamma \mid j\text{-th phase space region})}{BR(\pi^0 e^+ \nu(\gamma))}$$

	$E_\gamma^j,\ \theta_{e\gamma}^j$	ChPT
$R_1 \times 10^2$	$E_\gamma > 10$ MeV, $\theta_{e\gamma} > 10°$	1.804 ± 0.021
$R_2 \times 10^2$	$E_\gamma > 30$ MeV, $\theta_{e\gamma} > 20°$	0.640 ± 0.008
$R_3 \times 10^2$	$E_\gamma > 10$ MeV, $0.6 < \cos\theta_{e\gamma} < 0.9$	0.559 ± 0.006

T-odd observable

$$\xi = \frac{\vec{p_\gamma} \cdot \vec{p_e} \times \vec{p_\pi}}{m_K^3}$$

Test of T-asymmetry

$$A_\xi = \frac{N_+ - N_-}{N_+ + N_-}:$$

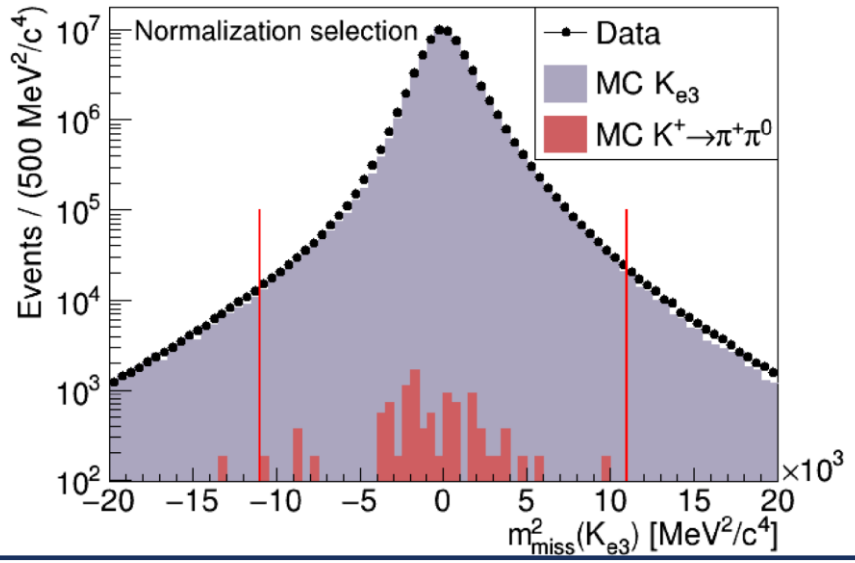
-10^{-4} to -10^{-5} (SM and beyond)

$K^+ \to \pi^0 e^+ \nu\gamma$

SELECTION

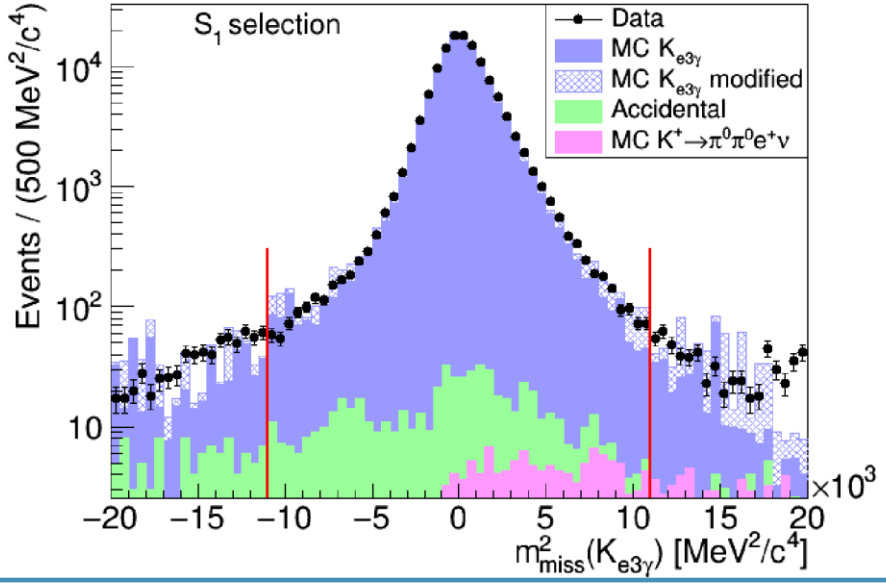
Normalization

- One downstream track with e^+ PID
- Vertex with a K^+ upstream track
- 2γ in LKr with $m(\gamma\gamma)$ compatible with π^0
- Veto on additional photons
- Cut on $m^2_{miss}(K_{e3}) = (P_K - P_{\pi 0} - P_e)^2$



Signal

- One downstream track with e^+ PID
- Vertex with a K^+ upstream track
- 2γ in LKr with $m(\gamma\gamma)$ compatible with π^0 + radiative γ
- Veto on additional photons
- Cut on $m^2_{miss}(K_{e3\gamma}) = (P_K - P_{\pi 0} - P_e - P_\gamma)^2$ and $m^2_{miss}(K_{e3})$



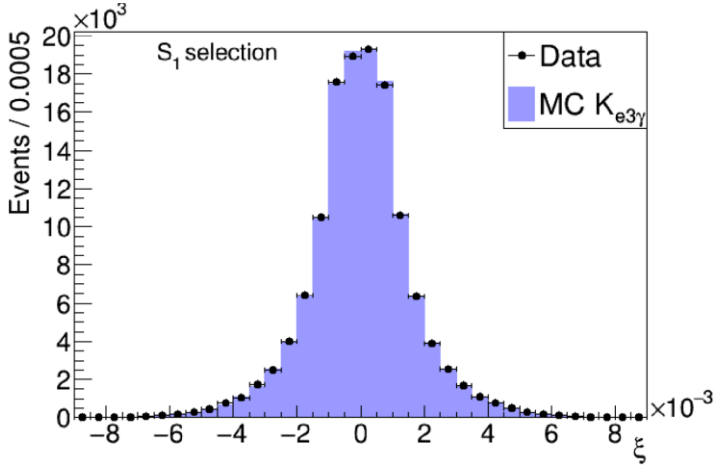
$K^+ \to \pi^0 e^+ \nu\gamma$

ANALYSIS

	Normalization	S_1	S_2	S_3
Selected candidates	6.6420×10^7	1.2966×10^5	0.5359×10^5	0.3909×10^5
Acceptance	$(3.842 \pm 0.002)\%$	$(0.444 \pm 0.001)\%$	$(0.514 \pm 0.002)\%$	$(0.432 \pm 0.002)\%$
Accidental	—	$(4.9 \pm 0.2 \pm 1.3) \times 10^2$	$(2.3 \pm 0.2 \pm 0.3) \times 10^2$	$(1.1 \pm 0.1 \pm 0.5) \times 10^2$
$K^+ \to \pi^0\pi^0 e^+\nu$	—	$(1.1 \pm 1.1) \times 10^2$	$(1.1 \pm 1.1) \times 10^2$	$(0.1 \pm 0.1) \times 10^2$
$K^+ \to \pi^+\pi^0\pi^0$	—	< 20	< 20	< 20
$K^+ \to \pi^+\pi^0$	$(1.0 \pm 1.0) \times 10^4$	—	—	—
Total background	$(1.0 \pm 1.0) \times 10^4$	$(6.0 \pm 1.8) \times 10^2$	$(3.4 \pm 1.2) \times 10^2$	$(1.2 \pm 0.6) \times 10^2$
Fractional background	1.6×10^{-4}	0.46×10^{-2}	0.64×10^{-2}	0.29×10^{-2}

$$R_j = \frac{\mathcal{B}(K_{e3\gamma^j})}{\mathcal{B}(K_{e3})} = \frac{N^{\rm obs}_{Ke3\gamma^j} - N^{\rm bkg}_{Ke3\gamma^j}}{N^{\rm obs}_{Ke3} - N^{\rm bkg}_{Ke3}} \cdot \frac{A_{Ke3}}{A_{Ke3\gamma^j}} \cdot \frac{\epsilon^{\rm trig}_{Ke3}}{\epsilon^{\rm trig}_{Ke3\gamma^j}}$$

- Bkg from accidental activity in LKr: data-driven estimation with timing sidebands
- Bkg from e^+ mis-ID / undetected γ: estimated from MC
- Systematics: LKr response correction, bkg estimation, veto of additional radiative γ, theory, MC sample size



$$A_\xi^{\rm NA62} = A_\xi^{\rm Data} - A_\xi^{\rm MC}$$

- A_ξ^{MC}: contribution due to detector + selection
- Systematics: MC sample size

$K^+ \to \pi^0 e^+ \nu\gamma$

RESULTS

	ChPT O(p⁶)	ISTRA+	OKA	NA62
	Eur. Phys. J. C 50 (2007) 557 Eur. Phys. J. C 48 (2006) 427	Phys. Atom. Nucl. 70 (2007) 702	Eur. Phys. J. C 81.2 (2021) 161 JETP Lett. 116 (2022) 608	arXiv:2304.12271, submitted to JHEP
$R_1 \times 10^2$	1.804 ± 0.021	1.81 ± 0.03 ± 0.07	1.990 ± 0.017 ± 0.021	1.715 ± 0.005 ± 0.010
$R_2 \times 10^2$	0.640 ± 0.008	0.63 ± 0.02 ± 0.03	0.587 ± 0.010 ± 0.015	0.609 ± 0.003 ± 0.006
$R_3 \times 10^2$	0.559 ± 0.006	0.47 ± 0.02 ± 0.03	0.532 ± 0.010 ± 0.012	0.533 ± 0.003 ± 0.004
$A_\xi(S_1) \times 10^3$			–0.1 ± 3.9 ± 1.7	–1.2 ± 2.8 ± 1.9
$A_\xi(S_2) \times 10^3$	-0.059		7.0 ± 8.1 ± 1.5	–3.4 ± 4.3 ± 3.0
$A_\xi(S_3) \times 10^3$		0.015 ± 0.021	–4.4 ± 7.9 ± 1.9	–9.1 ± 5.1 ± 3.5

Decay rates

- Factor > 2 more precise than previous measurements
- Relative uncertainty < 1%
- 5% smaller than ChPT prediction O(3σ)

T-asymmetry

- Compatible with no asymmetry
- Improved precision
- Uncertainty still $O(10^2)$ larger than predictions

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$K^+ \to \pi^+\mu^+\mu^-$

THEORY

- FCNC, long distance dominated, mediated by $K^+ \to \pi^+\gamma^*$ JHEP 02 (2019) 049
- Test of LFU by comparing $K^+ \to \pi^+e^+e^-$
- One-photon-inclusive differential decay width:

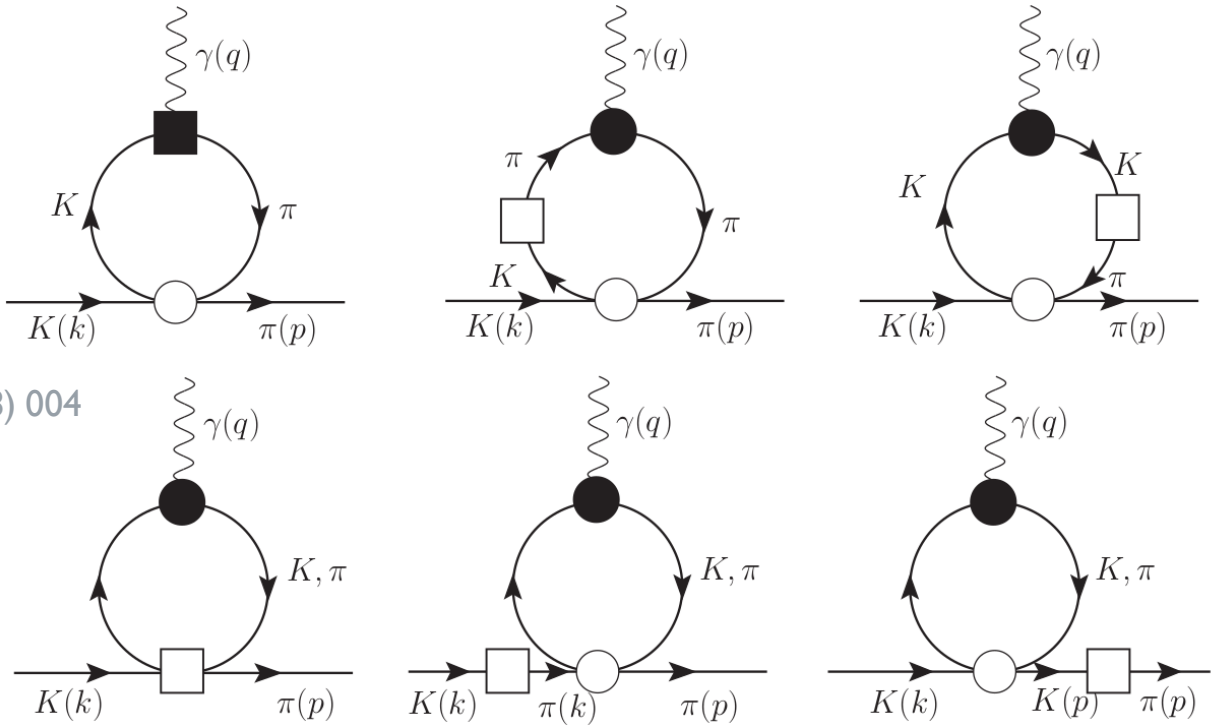
$$\frac{\mathrm{d}\Gamma(z)}{\mathrm{d}z} = g(z)\cdot|W(z)|^2 + \frac{\mathrm{d}\Gamma_{\text{4-body}}(z)}{\mathrm{d}z}$$

where $z = m(\mu^+\mu^-)^2/m_K^2$

- Form factor parametrized by ChPT at $O(p^6)$ JHEP 08 (1998) 004

$$W(z) = G_F m_K^2(a_+ + b_+ z) + W^{\pi\pi}(z)$$

- Measurements:
  - a_+, b_+
  - Model-independent BR
  - Forward-backward asymmetry



$K^+ \to \pi^+\mu^+\mu^-$

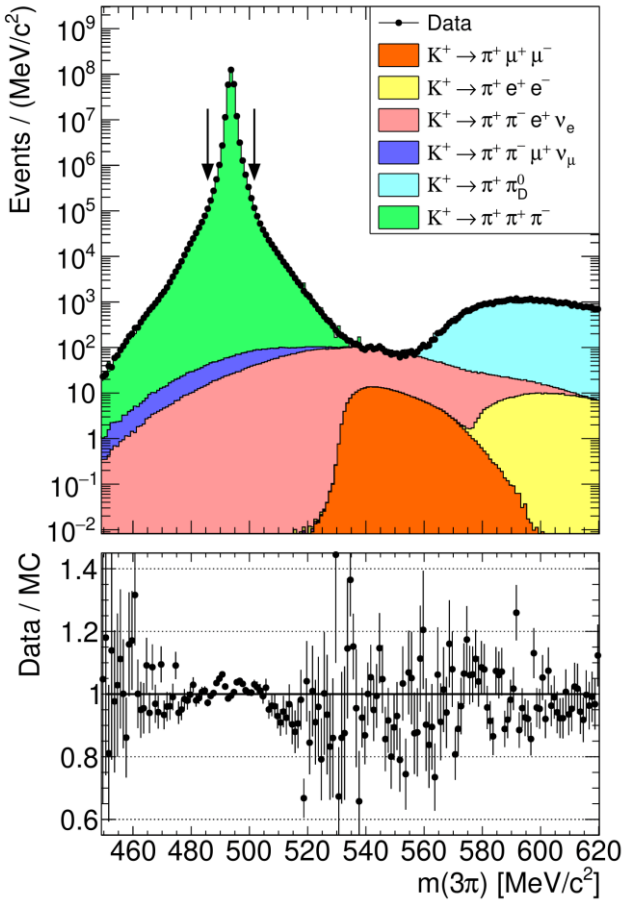
SELECTION

Normalization: $K^+ \to \pi^+\pi^+\pi^-$
- Abundant (BR ~ 5.6%)
- Kinematically similar
- Cancellation of systematics

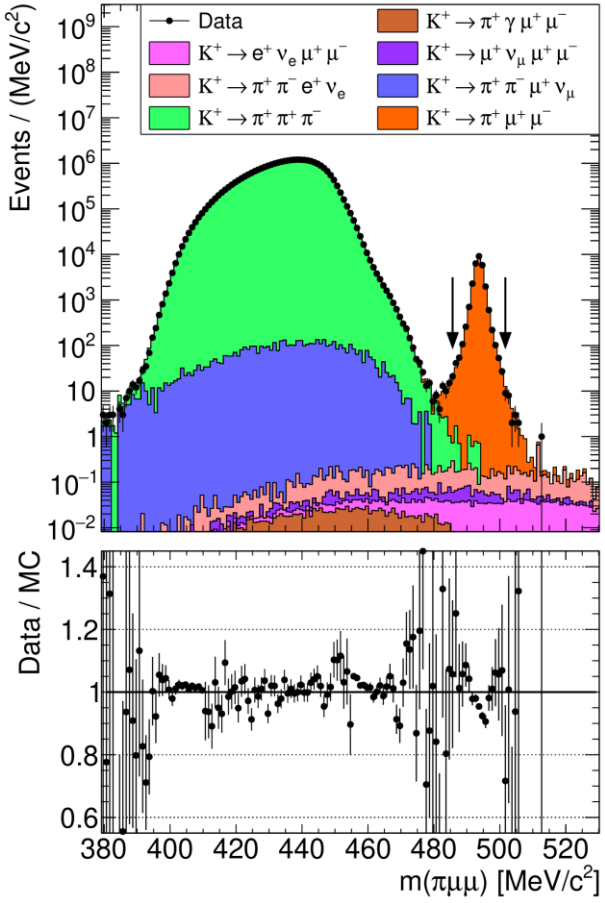
Selection
- 3-track vertex topology
- Event in time with KTAG
- π^+ calorimetric PID
- μ calorimetric PID
- $m(\pi\mu\mu)$, $m(3\pi)$ requirements

Effective kaon decays: $(3.48 \pm 0.09_{syst} \pm 0.02_{ext}) \times 10^{12}$
Selected events: 27679
Expected background events: 7.8 ± 5.6

Normalization



Signal



$K^+ \to \pi^+\mu^+\mu^-$ FORM FACTOR AND BRANCHING RATIO

50 equipopulated bins of z:

$$\left(\frac{d\Gamma(z)}{dz}\right)_i = \frac{N_{\pi\mu\mu,i}}{A_{\pi\mu\mu,i}} \cdot \frac{1}{\Delta z_i} \cdot \frac{1}{N_K} \cdot \frac{\hbar}{\tau_K}$$

$\chi^2(a_+,b_+)$ fit

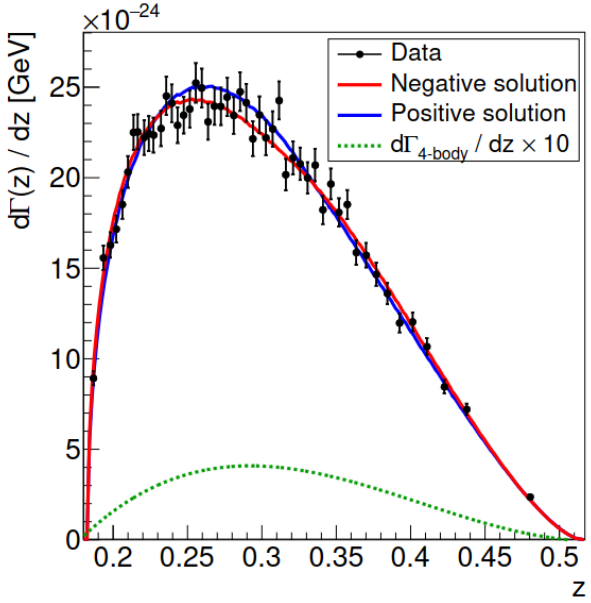
- Theoretically preferred negative solution
- Additional χ^2 minimum: positive solution

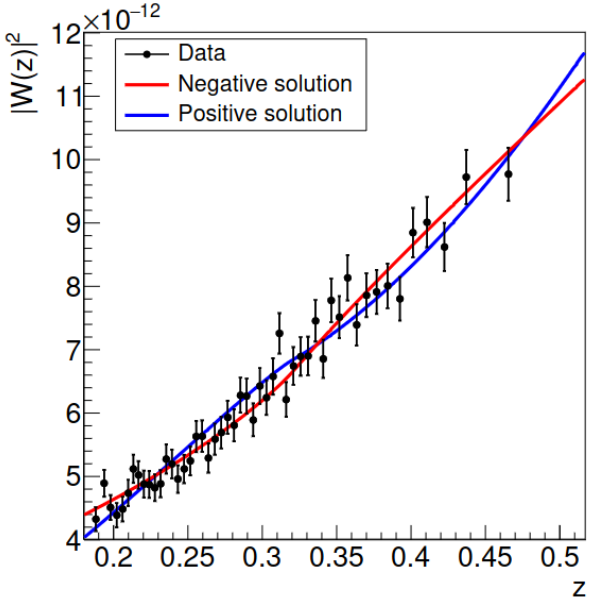
Model-independent BR from integration of $d\Gamma/dz$

$a_+ = -0.575 \pm 0.013$, $b_+ = -0.722 \pm 0.043$

χ^2 / ndf = 45.1 / 48, $\rho(a_+,b_+) = -0.972$

$BR(K^+ \to \pi^+\mu^+\mu^-) = (9.15 \pm 0.08) \times 10^{-8}$

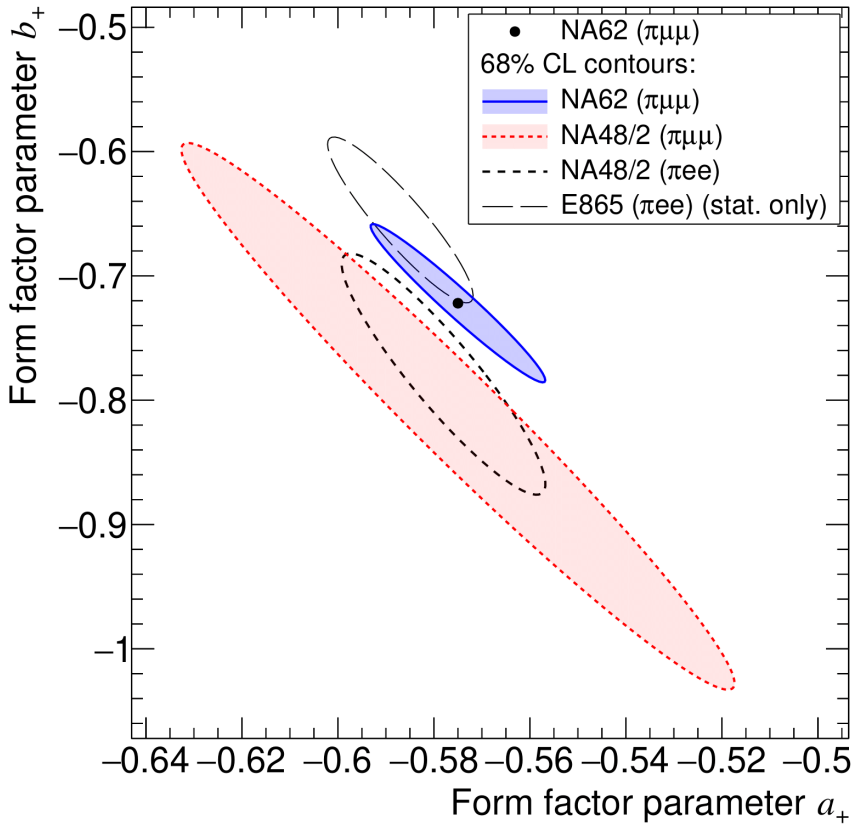


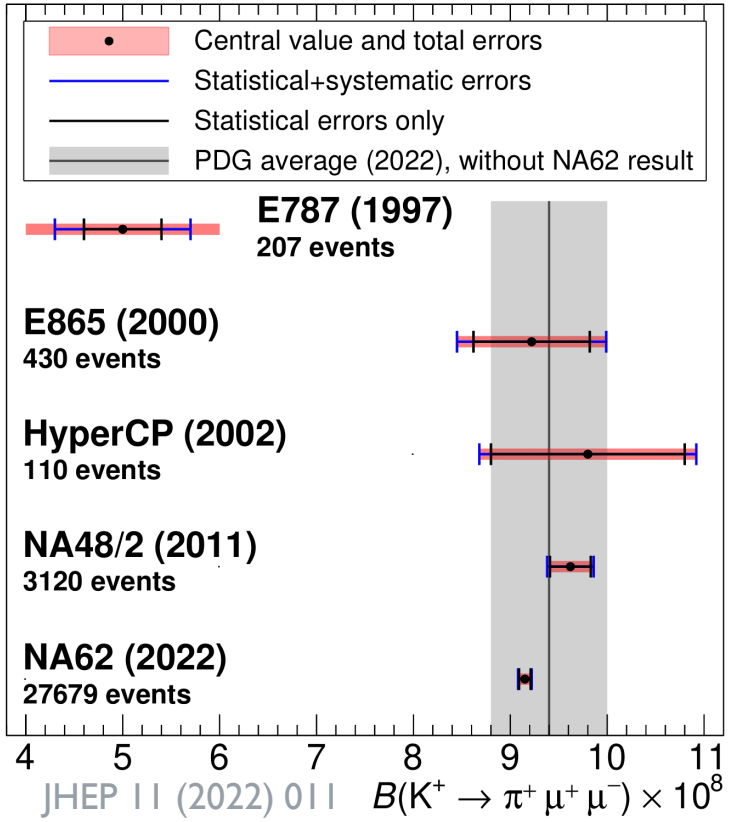


	δa_+	δb_+	$\delta\mathcal{B}_{\pi\mu\mu} \times 10^8$
Statistical uncertainty	0.012	0.040	0.06
Trigger efficiency	0.002	0.008	0.02
Reconstruction and particle identification	0.002	0.007	0.02
Size of the simulated $K_{\pi\mu\mu}$ sample	0.002	0.007	0.01
Beam and accidental activity simulation	0.001	0.002	0.01
Background	0.001	0.001	—
Total systematic uncertainty	0.003	0.013	0.03
$K_{3\pi}$ branching fraction	0.001	0.003	0.04
$K_{\pi\mu\mu}$ radiative corrections	0.003	0.009	0.01
Parameters α_+ and β_+	0.001	0.006	—
Total external uncertainty	0.003	0.011	0.04

JHEP 11 (2022) 011

$K^+ \to \pi^+\mu^+\mu^-$ COMPARISON WITH PREVIOUS RESULTS

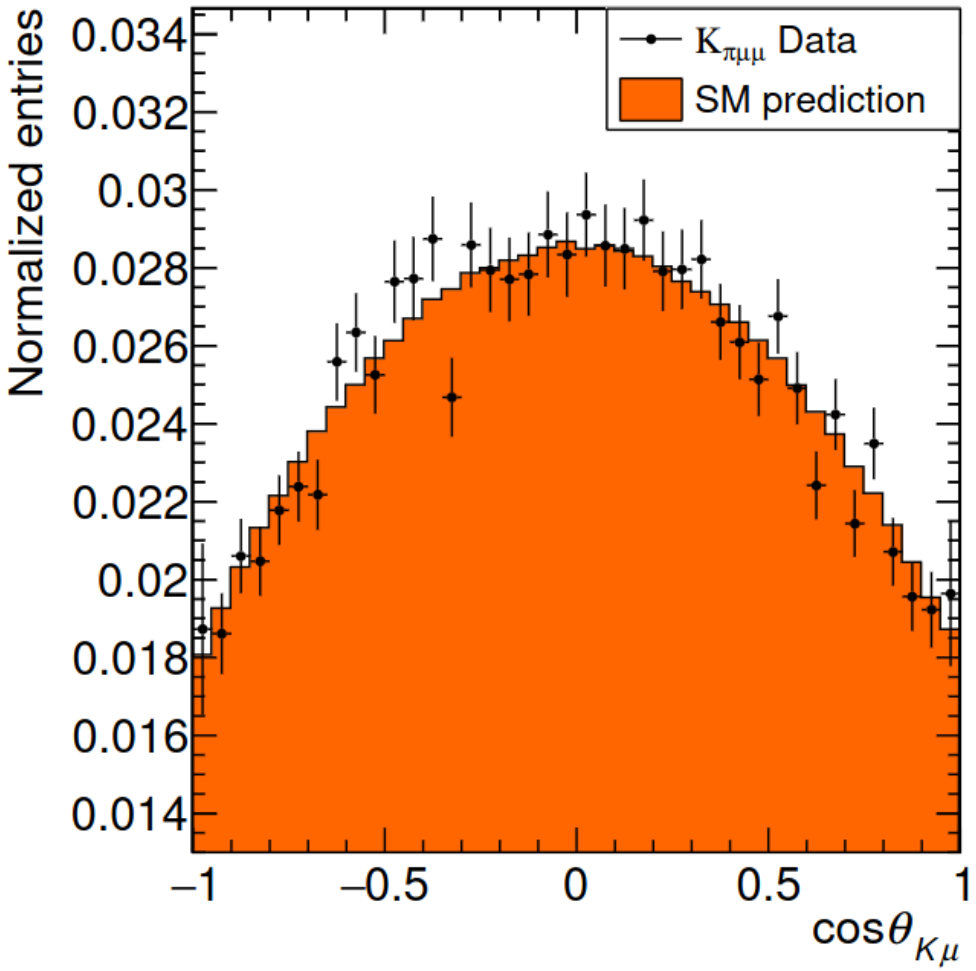




JHEP 11 (2022) 011

- Much improved precision
- Sample size ~9x larger than NA48/2
- No evidence for LFU violation

$K^+ \to \pi^+\mu^+\mu^-$ FORWARD-BACKWARD ASYMMETRY



angle between K^+ and μ^- in $\mu\mu$ rest frame

$$A_{\mathrm{FB}} = \frac{\mathcal{N}(\cos\theta_{K\mu} > 0) - \mathcal{N}(\cos\theta_{K\mu} < 0)}{\mathcal{N}(\cos\theta_{K\mu} > 0) + \mathcal{N}(\cos\theta_{K\mu} < 0)}$$

$A_{FB} = (0.0 \pm 0.7_{stat} \pm 0.2_{syst} \pm 0.2_{ext}) \times 10^{-2}$ @ 68% CL

$|A_{FB}| < 0.9 \times 10^{-2}$ @ 90% CL

JHEP 11 (2022) 011, JHEP 06 (2023) 040

OUTLINE

NA62 main goal

- $K^+ \to \pi^+ \nu\bar{\nu}$

NA62 latest precision measurements

- $K^+ \to \pi^0 e^+ \nu\gamma$ ($K_{e3\gamma}$)
- $K^+ \to \pi^+ \mu^+ \mu^-$
- $K^+ \to \pi^+ \gamma\gamma$

NA48/2 preliminary result

- $K^\pm \to \pi^0 \pi^0 \mu^\pm \nu$ ($K_{\mu 4}^{00}$)

NA62 dataset

Run1 (this talk)

- 2016: 30 days, 2×10^{11} useful K decays
- 2017: 161 days, 2×10^{12} useful K decays
- 2018: 217 days, 4×10^{12} useful K decays

Run2 (analysis in progress)

- 2021: 85 days
- 2022: 215 days
- 2023 – LS3: ongoing

$K^+ \to \pi^+\gamma\gamma$

THEORY

Phys. Lett. B 386 (1996) 403

- Long distance dominated ⟶ crucial ChPT test

- Kinematic variables

$$z = \frac{(q_1+q_2)^2}{m_K^2} = \left(\frac{m_{\gamma\gamma}}{m_K}\right)^2, \quad y = \frac{p(q_1-q_2)}{m_K^2}$$

p: K^+ 4-momentum
$q_{1,2}$: γ 4-momenta
m_K: K^+ mass
$m_{\gamma\gamma}$: di-photon invariant mass

- Decay width parametrized by a real parameter $\hat{c}$

$$\frac{\partial\Gamma}{\partial y \partial z}(\hat{c}, y, z) = \frac{m_K}{2^9\pi^3}\left[z^2\left(\left|A(\hat{c}, z, y^2) + B(z)\right|^2 + |C(z)|^2\right) + \left(y^2 - \frac{1}{4}\lambda(1, r_\pi^2, z)\right)^2 |B(z)|^2\right]$$

nonzero at $O(p^6)$

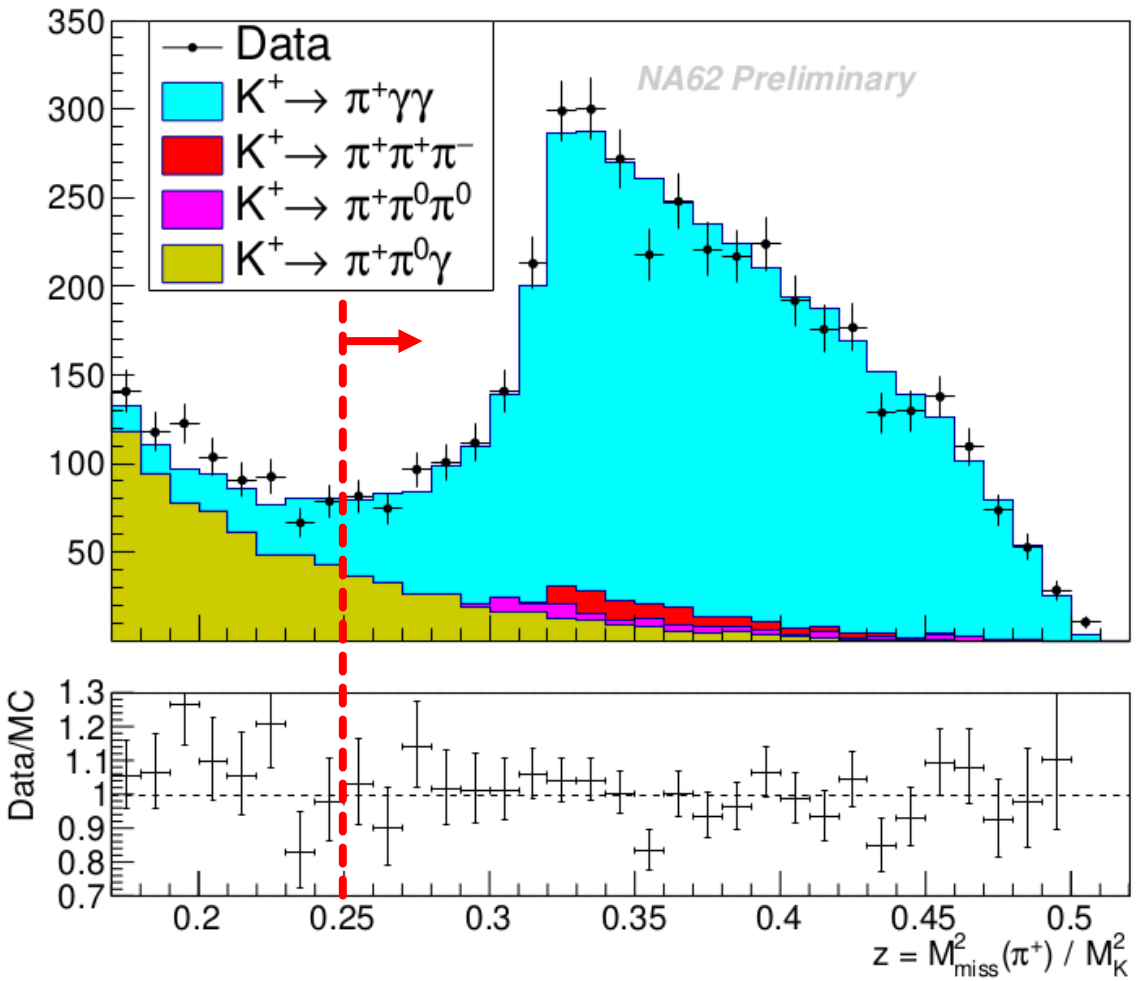
- Goals:
  - Measure $\hat{c}_6$
  - Extrapolate model-dependent BR

$K^+ \to \pi^+\gamma\gamma$

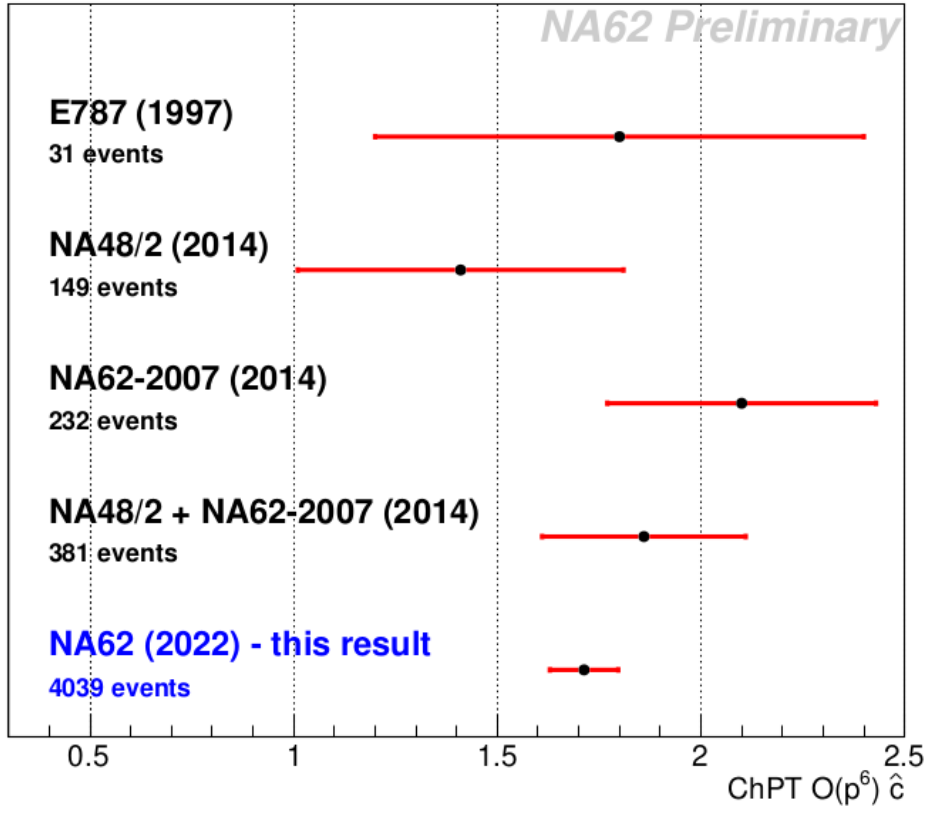
Selection
- K^+, π^+ matching tracks + 2 clusters in LKr
- $z = (P_K - P_\pi)^2 / M_K^2$
- 4039 events observed
- 393 ± 20 background events expected

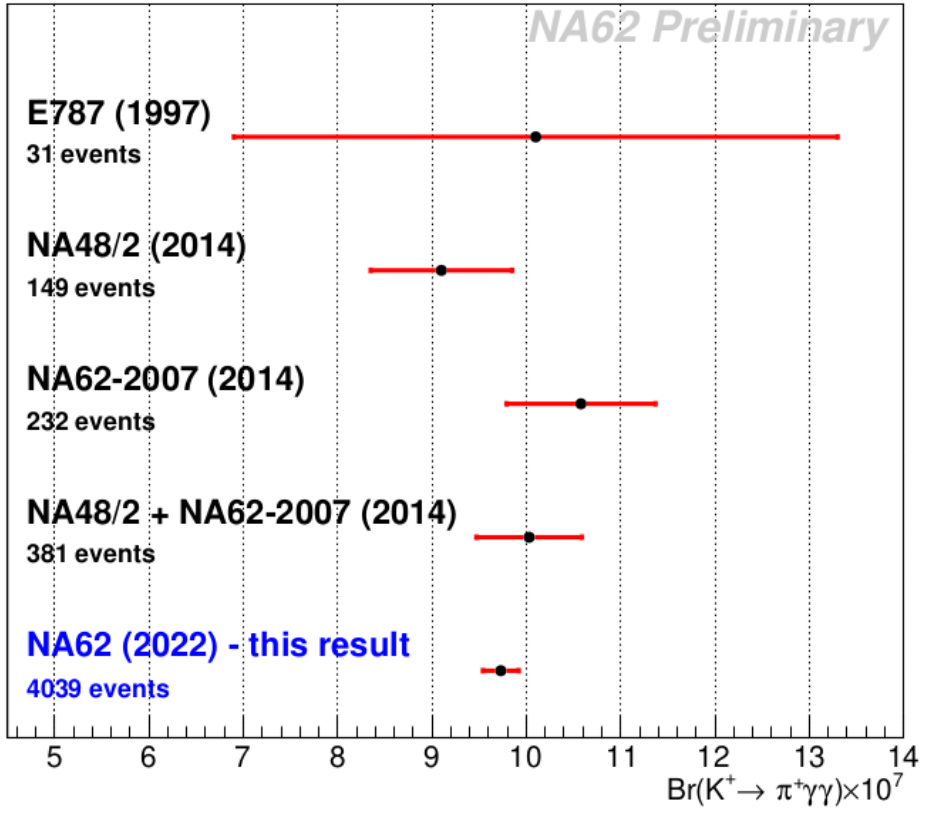
Background
- Cluster merging: $K^+ \to \pi^+\pi^0\gamma$, $K^+ \to \pi^+\pi^0\pi^0$
- Missing tracks: $K^+ \to \pi^+\pi^+\pi^-$
- Estimated with MC, validated with control regions

Fit procedure
- MC reweighted for different values of ĉ
- Scan of ĉ to find maximum likelihood
- External parameters fixed: Rev. Mod. Phys. 84 399 (2012), Science 368 (2020) 6490, Nucl.Phys. B648 (2003) 317 (to be updated to use arXiv:2209.02143)



$K^+ \to \pi^+\gamma\gamma$





$\hat{c}_6 = 1.713 \pm 0.075_{stat} \pm 0.037_{syst}$

$BR(K^+ \to \pi^+\gamma\gamma) = (9.73 \pm 0.17_{stat} \pm 0.08_{syst}) \times 10^{-7}$

OUTLINE

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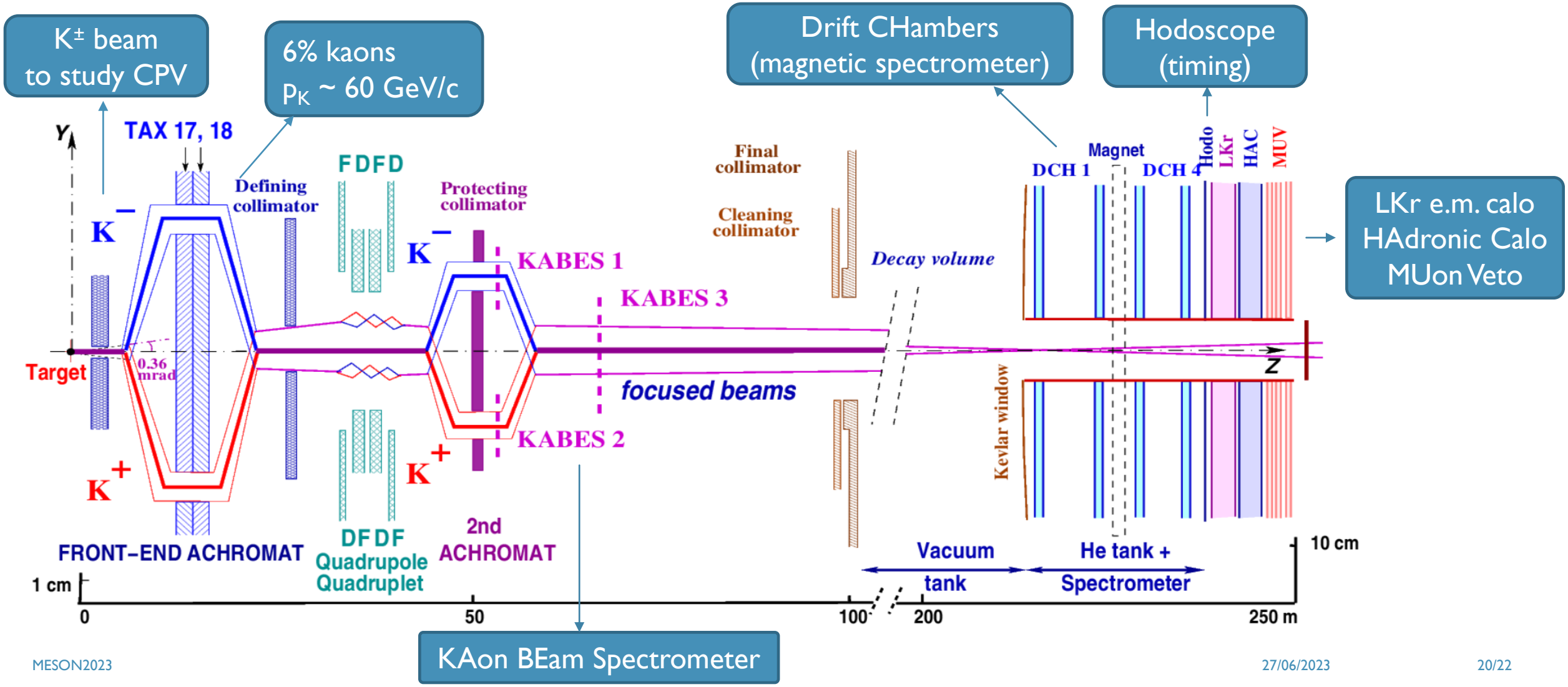
THE NA48/2 DETECTOR



$K^{\pm} \to \pi^0\pi^0\mu^{\pm}\nu$ ($K_{\mu4}^{00}$)

Theory and status

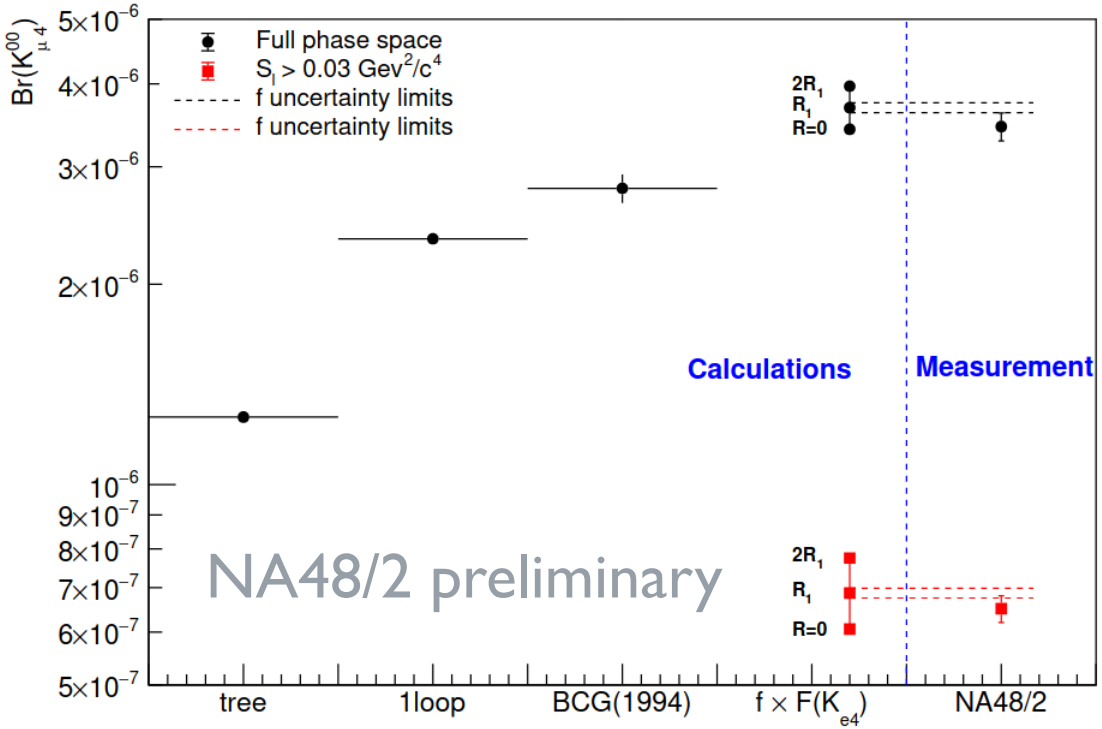
K_{l4} mode	BR [10^{-5}]	N_{cand}	
$K_{e4}^{\pm}$	4.26 ± 0.04	1108941	NA48/2 (2012)
K_{e4}^{00}	2.55 ± 0.04	65210	NA48/2 (2014)
$K_{\mu4}^{\pm}$	1.4 ± 0.9	7	Bisi et al. (1967)
$K_{\mu4}^{00}$			

- First observation of muon mode with $\pi^0\pi^0$
- Test of ChPT

- $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$ as normalization channel
- $K^{\pm} \to \pi^0\pi^0(\pi^{\pm}\to\mu^{\pm}\nu)$ largest background
- $S_\ell = M^2(\mu^{\pm}\nu) > 0.03$ GeV^2 / c^4

$$BR(K^{\pm} \to \pi^0\pi^0\mu^{\pm}\nu, S_\ell > 0.03\ GeV^2) = (0.65 \pm 0.03) \times 10^{-6}$$
$$BR(K^{\pm} \to \pi^0\pi^0\mu^{\pm}\nu) = (3.4 \pm 0.2) \times 10^{-6}$$

- 2437 events observed
- $354 \pm 33_{stat} \pm 62_{syst}$ background events expected



Theory: Nucl. Phys. B 427 (1994) 427, Phys.Rev.D 15 (1977) 574

SUMMARY

$K^+ \to \pi^+ \nu\bar{\nu}$	NA62 Run1	JHEP 06 (2021) 093
$K^+ \to \pi^0 e^+ \nu\gamma$	NA62 Run1	arXiv:2304.12271, submitted to JHEP
$K^+ \to \pi^+ \mu^+ \mu^-$	NA62 Run1	JHEP 11 (2022) 011
$K^+ \to \pi^+ \gamma\gamma$	NA62 Run1	preliminary, final results in progress
$K^\pm \to \pi^0 \pi^0 \mu^\pm \nu$	NA48/2	preliminary, final results in progress

NA62 will take data until LS3
…stay tuned!

SUMMARY

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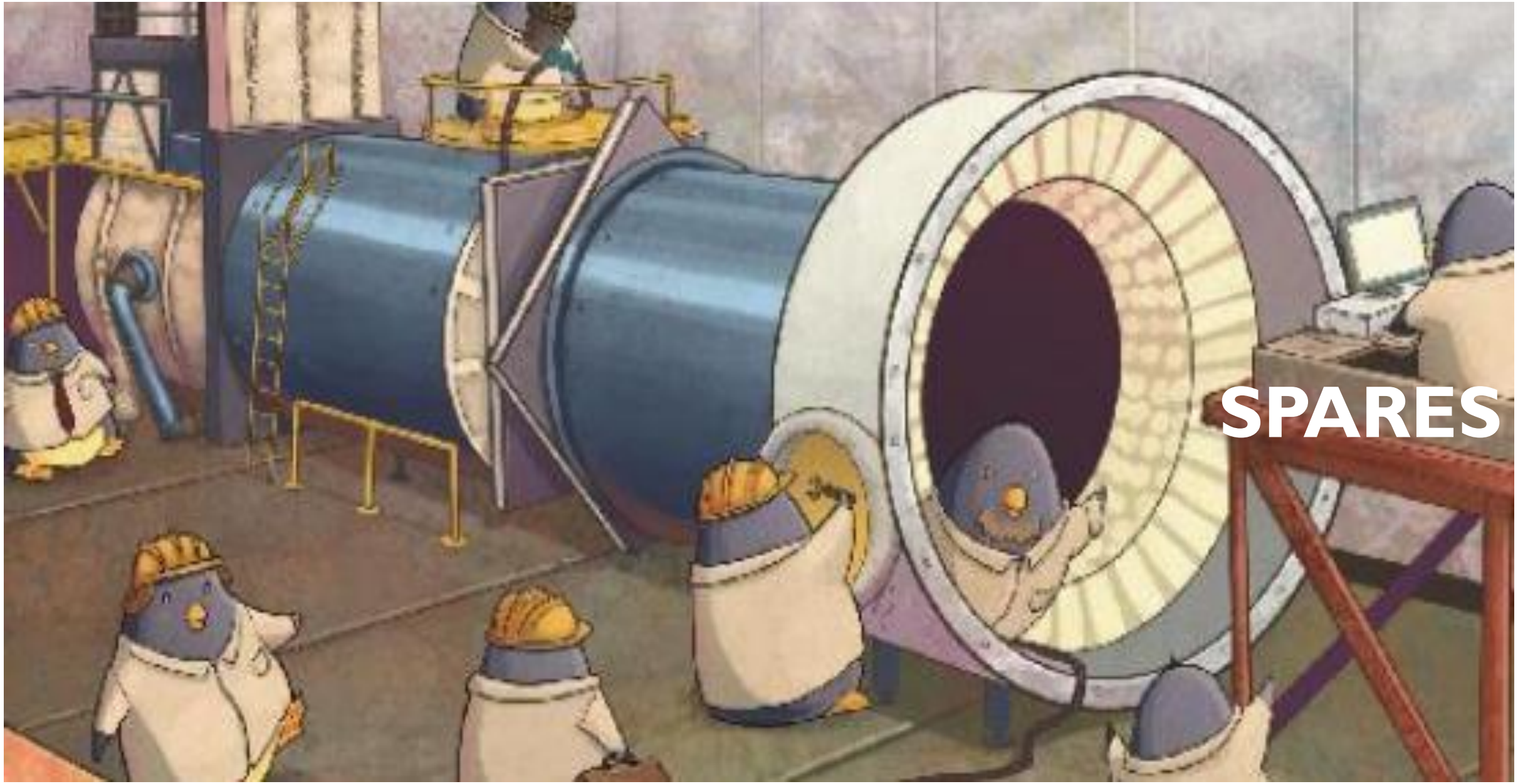
THANK YOU!


SPARES

RECENT THEORETICAL PROGRESS ON $K \to \pi\nu\bar{\nu}$

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

$$BR(K_L \to \pi^0\nu\bar{\nu}) = (2.94 \pm 0.15) \times 10^{-11}$$

Acta Phys. Polon. B 53.6 (2021) A1

$$BR(K^+ \to \pi^+\nu\bar{\nu}) = (7.73 \pm 0.61) \times 10^{-11}$$

$$BR(K_L \to \pi^0\nu\bar{\nu}) = (2.59 \pm 0.29) \times 10^{-11}$$

PoS BEAUTY2020 (2021) 056

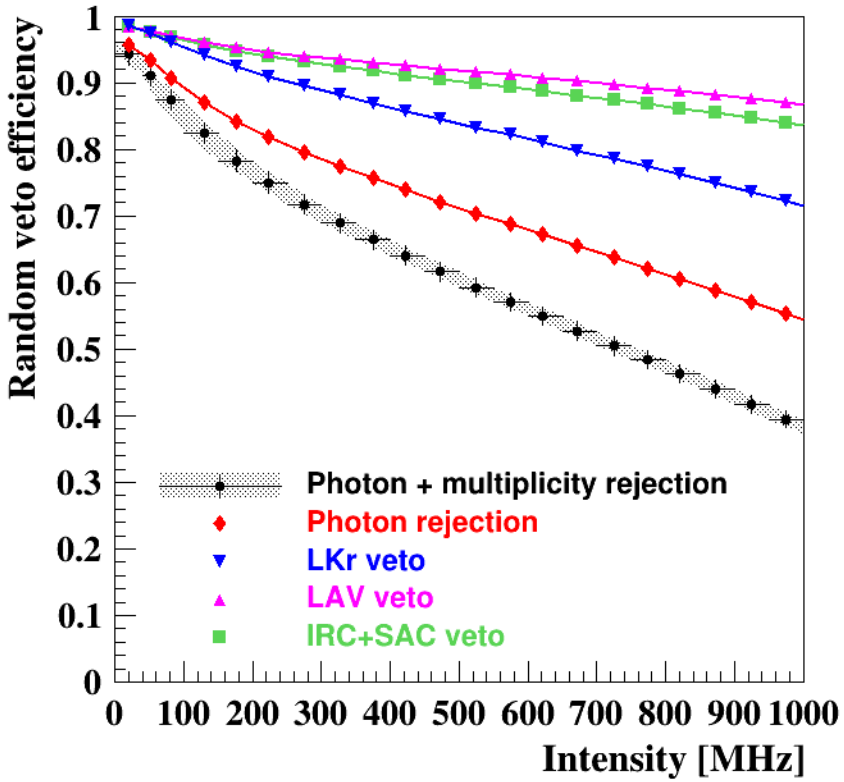
SINGLE EVENT SENSITIVITY

$$N^{exp}_{\pi\nu\nu} = N_{\pi\pi}\, \varepsilon^{PNN}_{trig}\, \varepsilon_{RV}\, \frac{A_{\pi\nu\nu}}{A_{\pi\pi}}\, \frac{BR(\pi\nu\nu)}{BR(\pi\pi)}$$

$$SES = \frac{BR(\pi\nu\nu)}{N^{exp}_{\pi\nu\nu}}$$

	Subset S1 *	Subset S2 *
$N_{\pi\pi} \times 10^{-7}$	3.14	11.6
$A_{\pi\pi} \times 10^{2}$	7.62 ± 0.77	11.77 ± 1.18
$A_{\pi\nu\bar{\nu}} \times 10^{2}$	3.95 ± 0.40	6.37 ± 0.64
$\epsilon^{\mathrm{PNN}}_{\mathrm{trig}}$	0.89 ± 0.05	0.89 ± 0.05
ϵ_{RV}	0.66 ± 0.01	0.66 ± 0.01
$SES \times 10^{10}$	0.54 ± 0.04	0.14 ± 0.01
$N^{\mathrm{exp}}_{\pi\nu\bar{\nu}}$	$1.56 \pm 0.10 \pm 0.19_{\mathrm{ext}}$	$6.02 \pm 0.39 \pm 0.72_{\mathrm{ext}}$

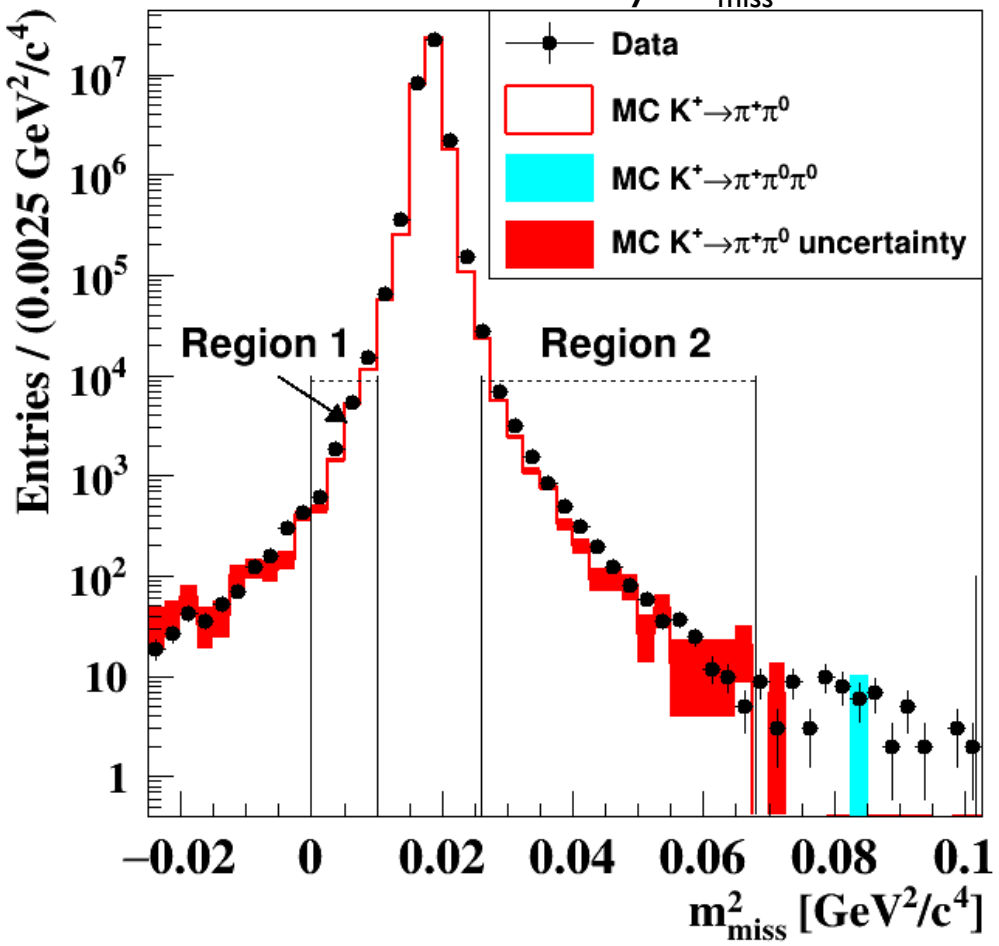
* different hardware configurations



- $K^+ \rightarrow \pi^+ \pi^0$ normalization channel
- Cancellation of systematic effects
- Random Veto: efficiency loss due to beam activity

BACKGROUND FROM K^+ DECAYS

Control $\pi^+ \pi^0$ data to study m^2_{miss} distribution



Number of events in $\pi^+ \pi^0$ region after $\pi\nu\nu$ selection

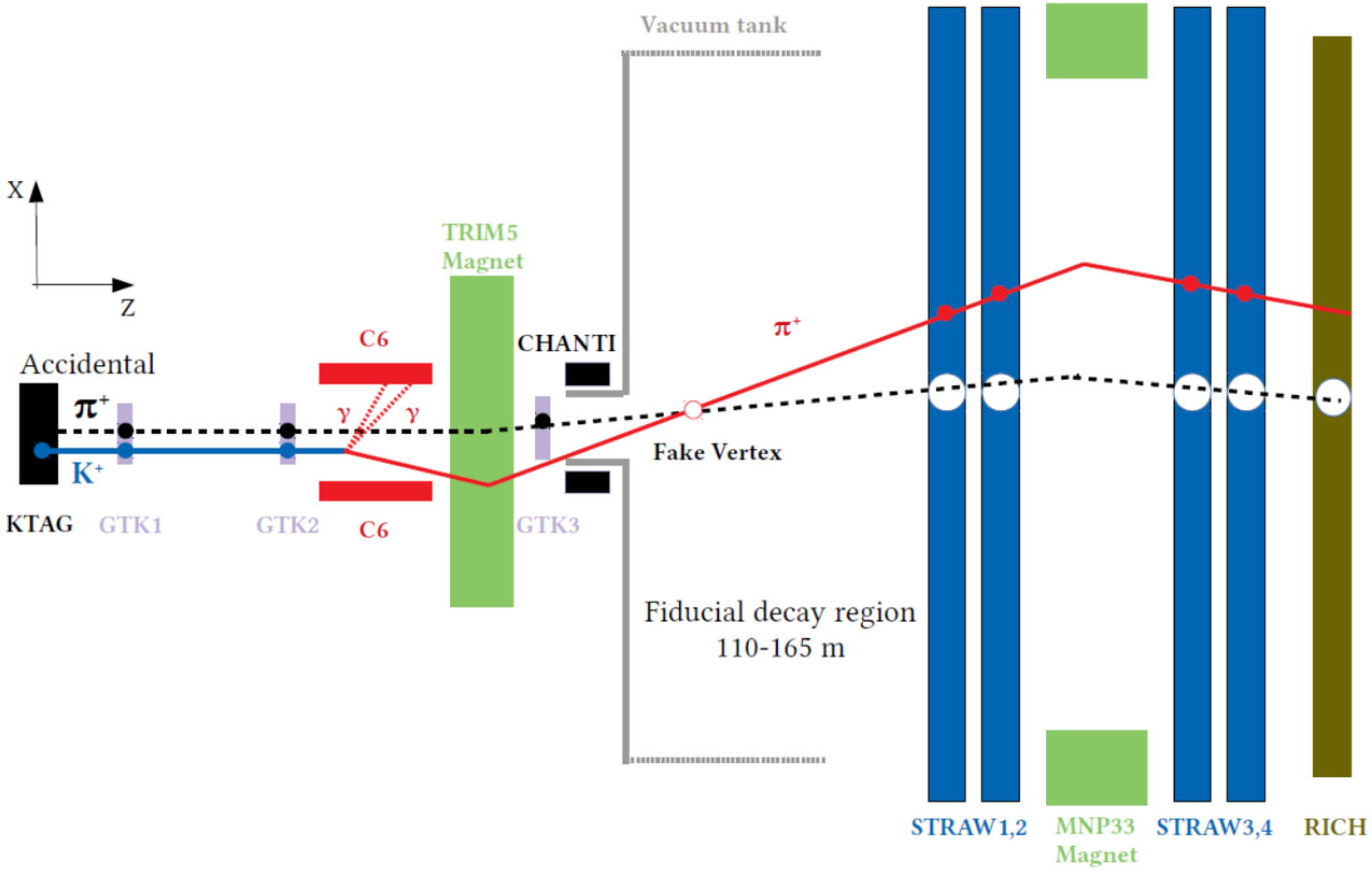
$$N^{exp}_{\pi\pi}(SR) = N(\pi^+\pi^0)\, f_{kin}(SR)$$

Expected $K^+ \to \pi^+ \pi^0$ events in signal region

Fraction of $\pi^+ \pi^0$ in signal region, measured on control data

- $K^+ \to \mu^+ \nu_\mu$ and $K^+ \to \pi^+ \pi^+ \pi^-$ backgrounds: similar procedure
- $K^+ \to \pi^+ \pi^- e^+ \nu_e$ evaluated with MC simulations
- Validation with control regions

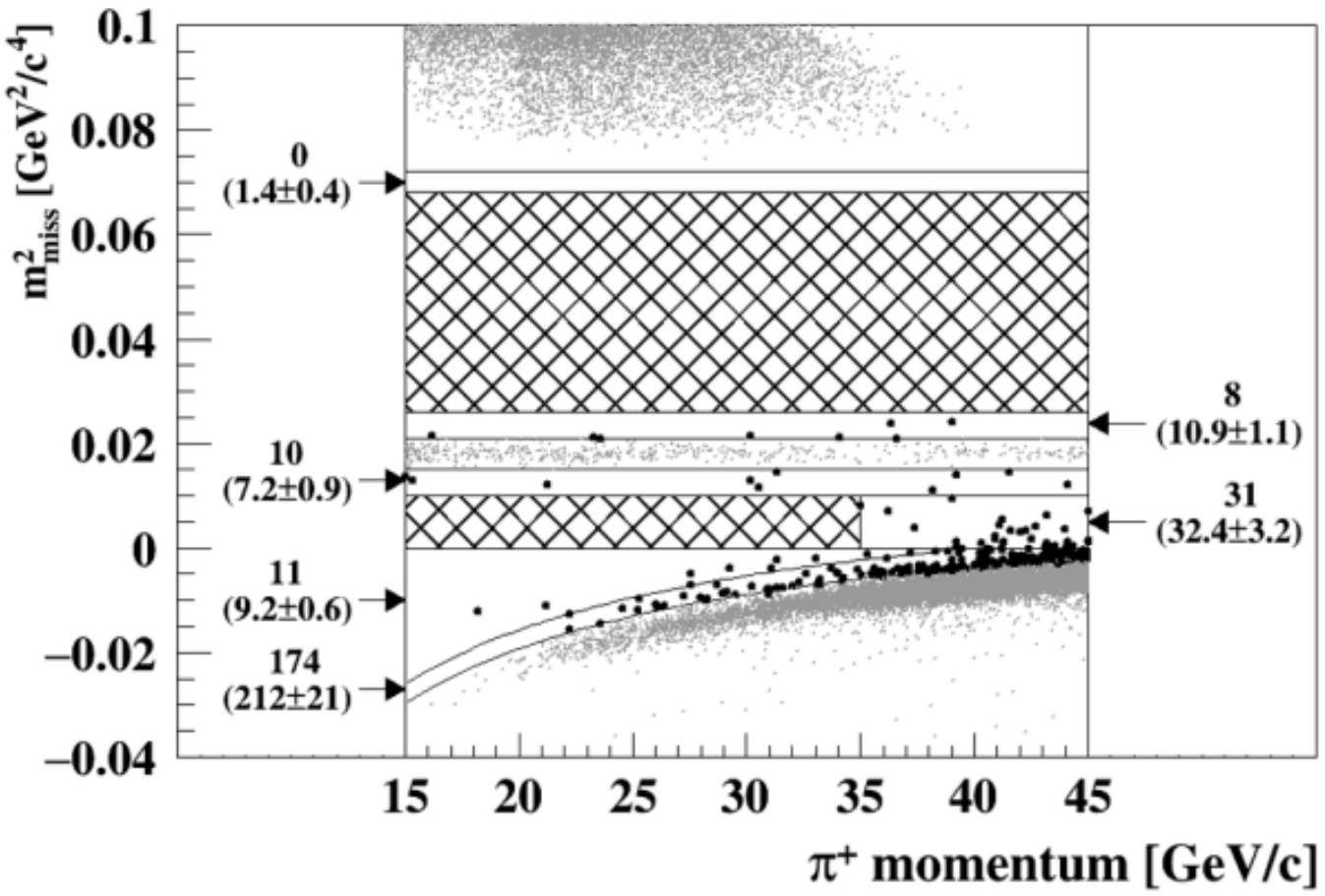
UPSTREAM BACKGROUND



- Pions produced upstream of the fiducial volume
  - Early kaon decays
  - Interaction of beam particles with beam spectrometer material
- Fake association of detected pions to accidental particles

- New collimator installed in June 2018
- Geometrical cuts & BDT cut on backtracked pion position
- Kaon-pion association effective
- Data-driven background estimation

EXPECTED BACKGROUND SUMMARY

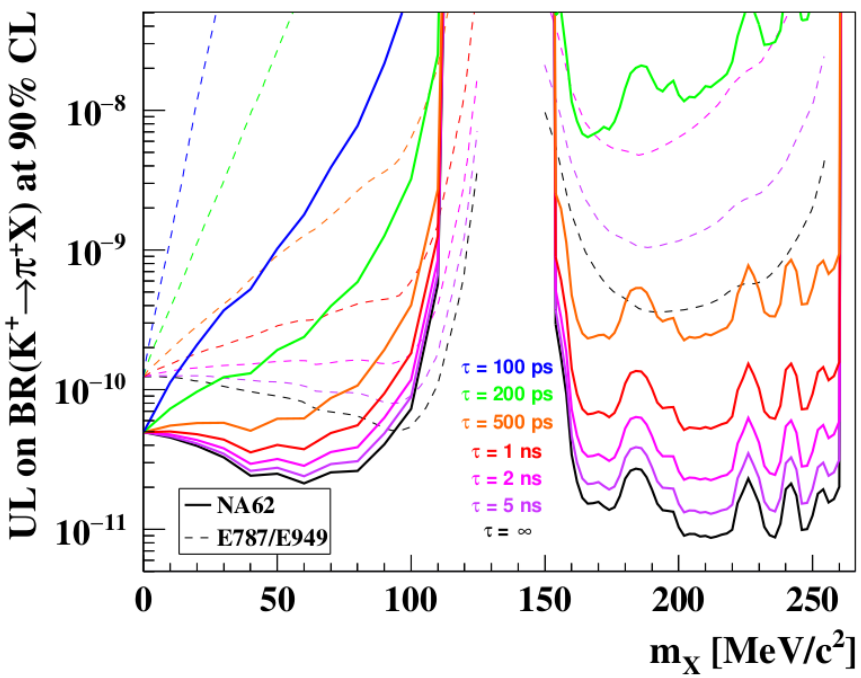


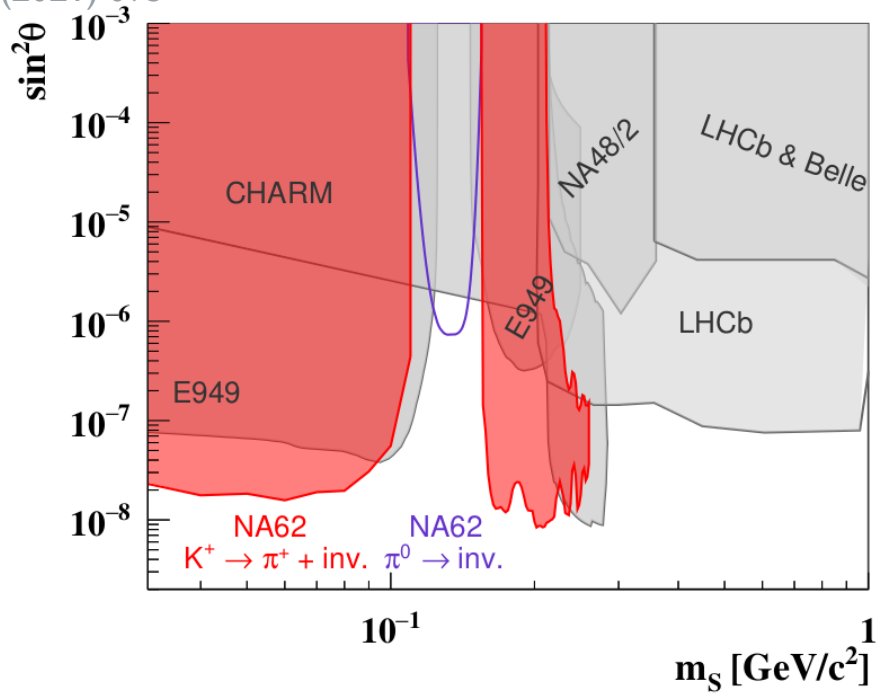
Background	Subset S1	Subset S2
$\pi^+\pi^0$	0.23 ± 0.02	0.52 ± 0.05
$\mu^+\nu$	0.19 ± 0.06	0.45 ± 0.06
$\pi^+\pi^-e^+\nu$	0.10 ± 0.03	0.41 ± 0.10
$\pi^+\pi^+\pi^-$	0.05 ± 0.02	0.17 ± 0.08
$\pi^+\gamma\gamma$	< 0.01	< 0.01
$\pi^0 l^+\nu$	< 0.001	< 0.001
Upstream	$0.54^{+0.39}_{-0.21}$	$2.76^{+0.90}_{-0.70}$
Total	$1.11^{+0.40}_{-0.22}$	$4.31^{+0.91}_{-0.72}$

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

- Peak search in m^2_{miss} distribution
- Width from resolution
- Main background: SM $K^+ \to \pi^+ \nu\bar{\nu}$
- Acceptance from MC simulation

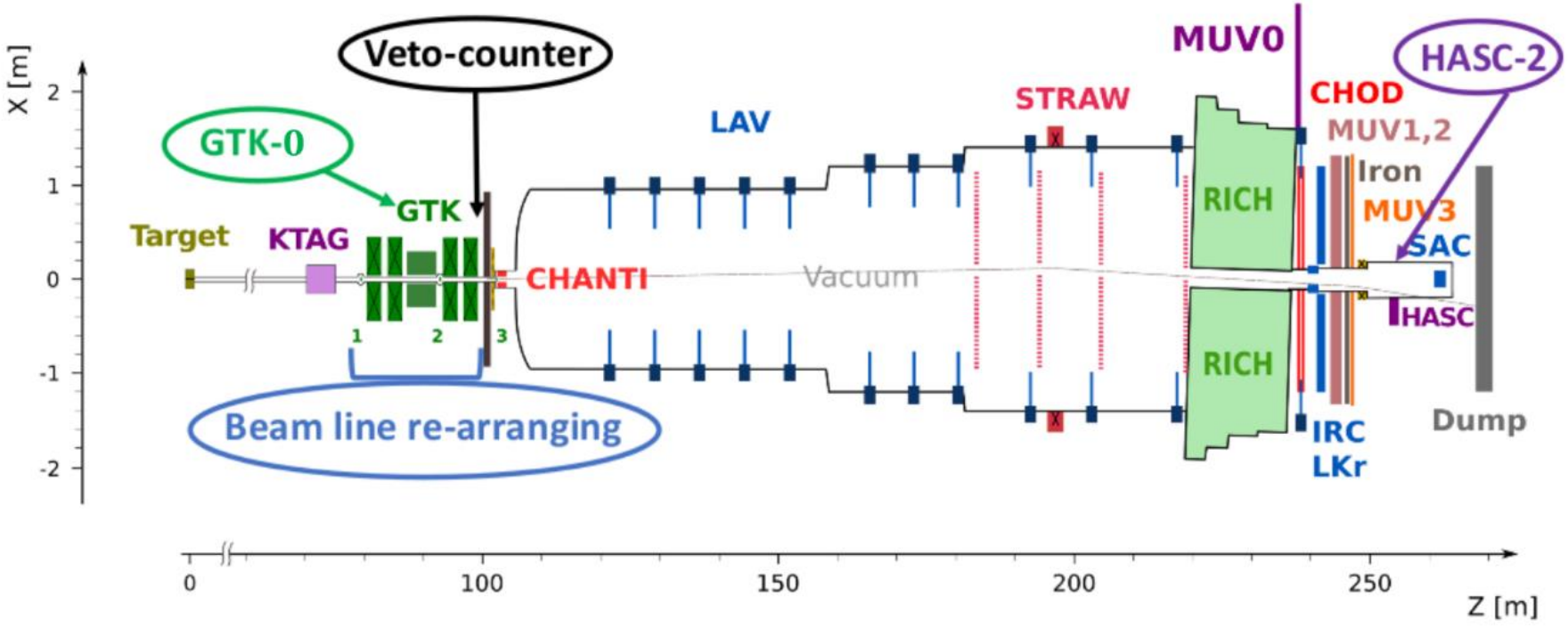
JHEP 06 (2021) 093





- Limits with finite lifetime: assume decay to visible particles in geometric acceptance
- Interpretation in dark scalar model with mixing with Higgs ($\sin^2\theta$)

FUTURE



Goal: reach O(10%) precision by LS3

- Improvements in LKr reconstruction
- Optimizations in the analysis: random veto stable, background rejection, acceptance increased

- Additional GTK station
- Beam line re-arranging to swipe away upstream π^+
- New VetoCounter to detect upstream decays
- HASC-2 to further suppress $K^+ \rightarrow \pi^+ \pi^0$ decays
- Intensity increased from 60% to 100% of nominal

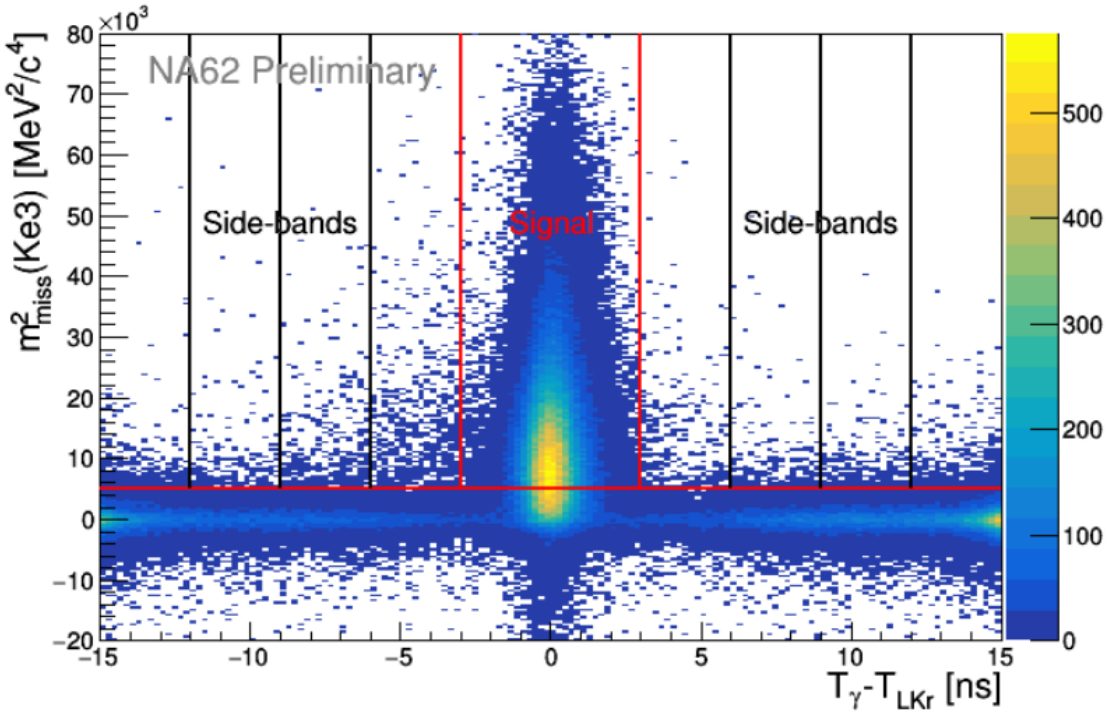
Beyond LS3

HIKE:
High Intensity Kaon Experiments

arXiv:2211.16586

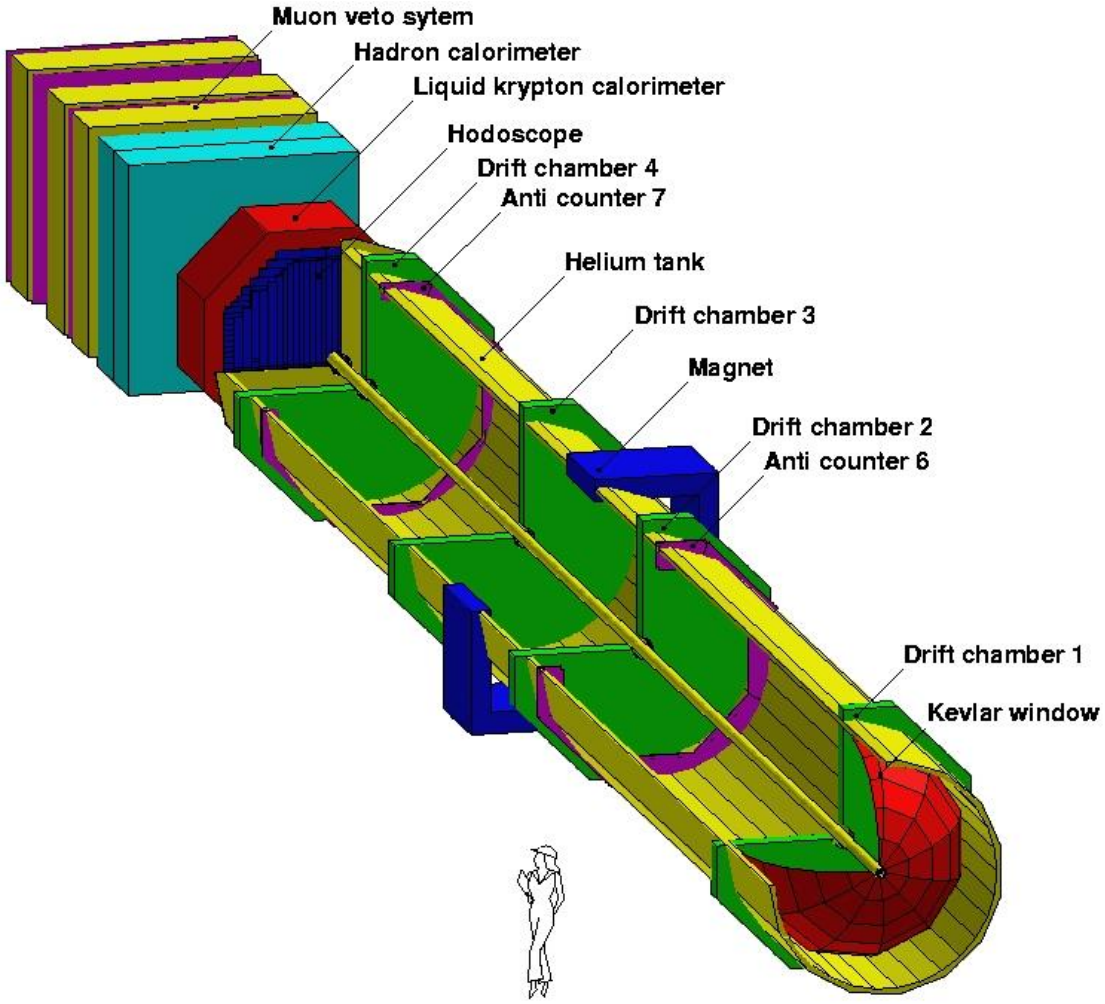
Main background source of Ke3γ selection: *accidentals*

Accidental event: $K^+ \to \pi^0 e^+ \nu$ decay (or K2π with π^+ mis-ID) + additional LKr cluster that mimics the radiative photon



- Dedicated cut in signal selection using $m^2_{miss}(Ke3)$ observable
- Background in signal region estimated with data from the out-of-time side-bands

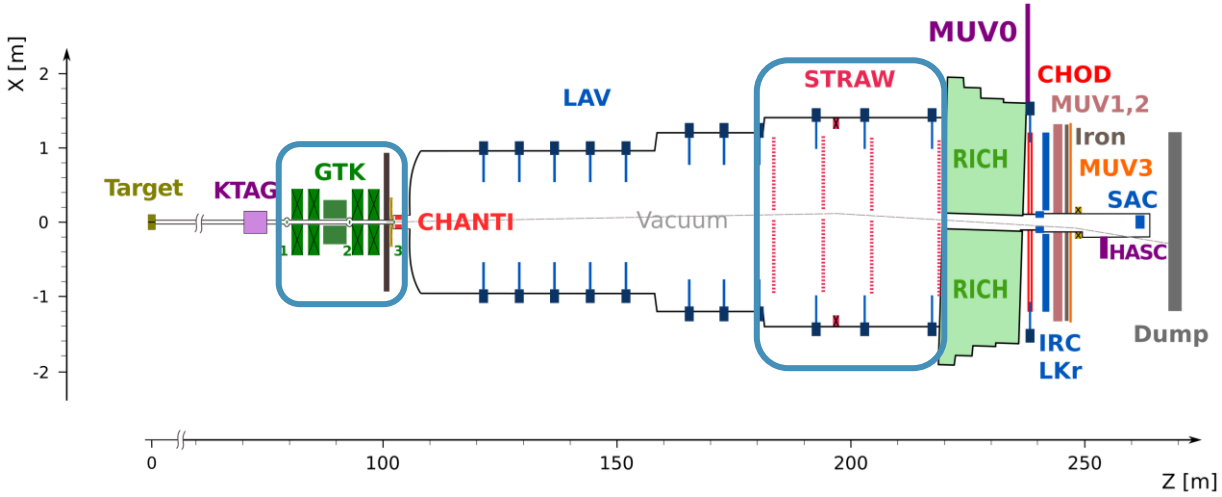
NA48/2 DETECTOR



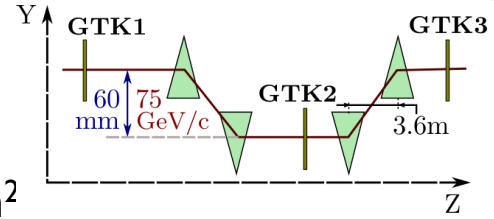
- KABES
  - $\sigma(X,Y) \sim 800\ \mu m$
  - $\sigma(p_K) / p_K \sim 1\%$
  - $\sigma(T) \sim 600$ ps
- Magnetic spectrometer (DCH1-DCH4)
  - $\sigma(X,Y) \sim 90\ \mu m$ per chamber
  - $\sigma(p_{DCH}) / p_{DCH} = (1.02 \oplus 0.044\ GeV^{-1} \times p_{DCH})\%$
- Scintillator HODoscope
  - $\sigma(T) \sim 150$ ps
- Liquid Krypton EM calorimeter (LKr)
  - $\sigma_x = \sigma_y = (0.42\ GeV^{1/2} / \sqrt{E_\gamma} \oplus 0.06)$ cm
  - $\sigma(E_\gamma) / E_\gamma = (3.2\ GeV^{1/2} / \sqrt{E_\gamma} \oplus 9.0\ GeV / E_\gamma \oplus 0.42)\%$

NA62 DETECTOR

SPECTROMETERS



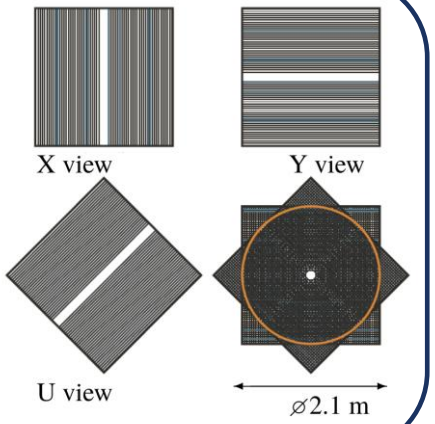
GigaTracKer



- 3 stations
- Si pixel size 300 × 300 μm^2
- σ_p / p = 0.2%, σ_θ = 16μrad, σ_t = 100 ps

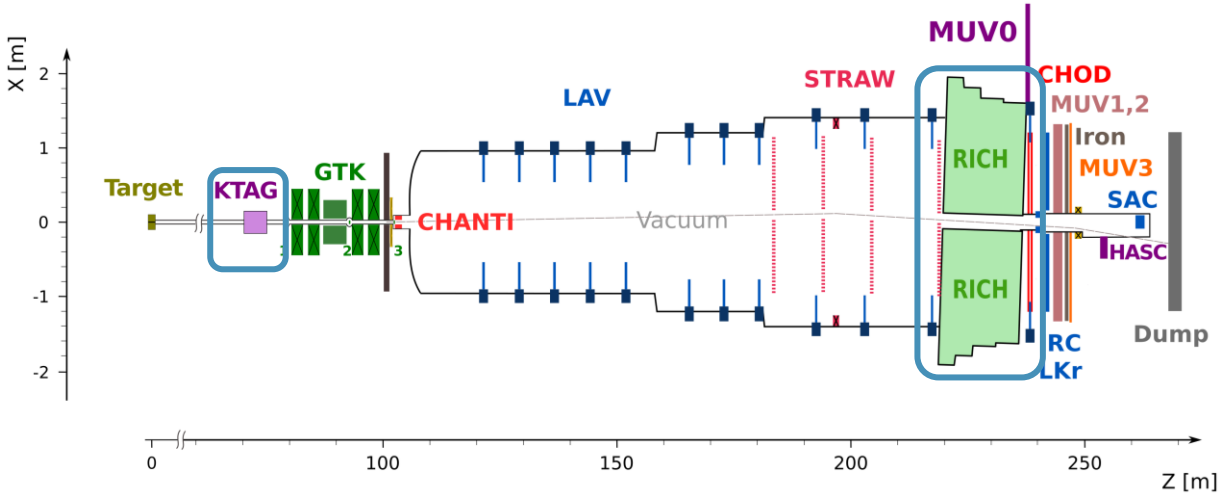
STRAW

- 4 straw tube chambers
- 4 views each
- $\sigma_p/p = 3\times10^{-3} \oplus 5\times10^{-5} GeV^{-1}\, p$
- σ_θ/μrad = 10 + 500 GeV / p



NA62 DETECTOR

PARTICLE IDENTIFICATION



Kaon TAGger

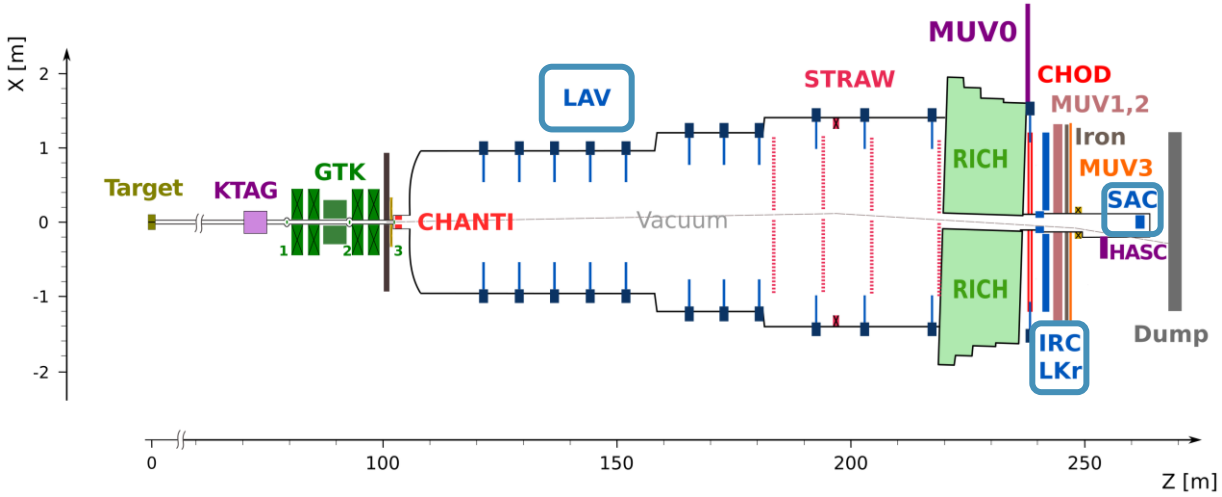
- Differential Cherenkov counter
- 5 m long vessel
- N_2 at 1.75 bar
- σ_t = 70 ps

Ring Imaging CHerenkov counter

- Differential Cherenkov counter
- Ne at atmospheric pressure
- σ_t = 100 ps

NA62 DETECTOR

PHOTON VETO



Large-Angle Veto

- 12 stations
- EM calorimeters (PbO 75%)
- Hermetic for photons between 10 and 50 mrad

LKr

- Photons emitted between 1 and 10 mrad + particle ID
- σ_E / E = 1.4% for E ~ 25 GeV
- $\sigma_{X,Y}$ ~ 1mm
- σ_t ~ 0.5 to 1 ns

Small-Angle Veto

- IRC + SAC
- Ensure hermeticity for photons down to 0°