

# Recent NA62 Results

Exploring the Zepto-universe with Rare K Decays

Augusto Ceccucci / CERN

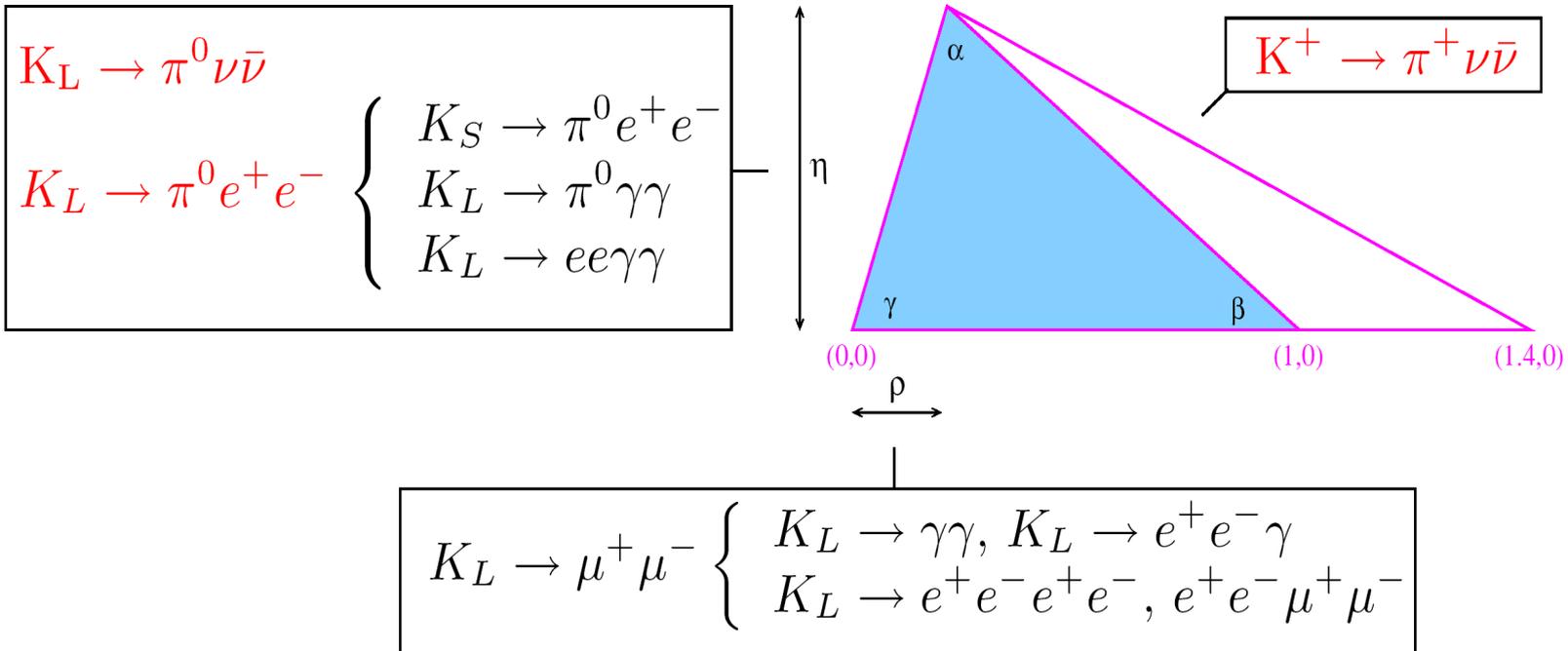


# Outline

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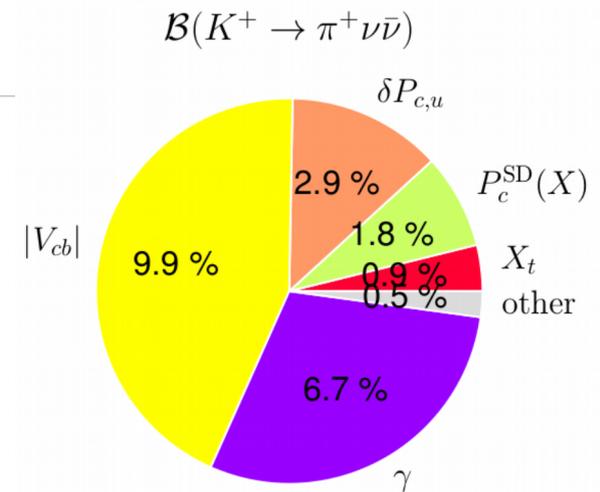
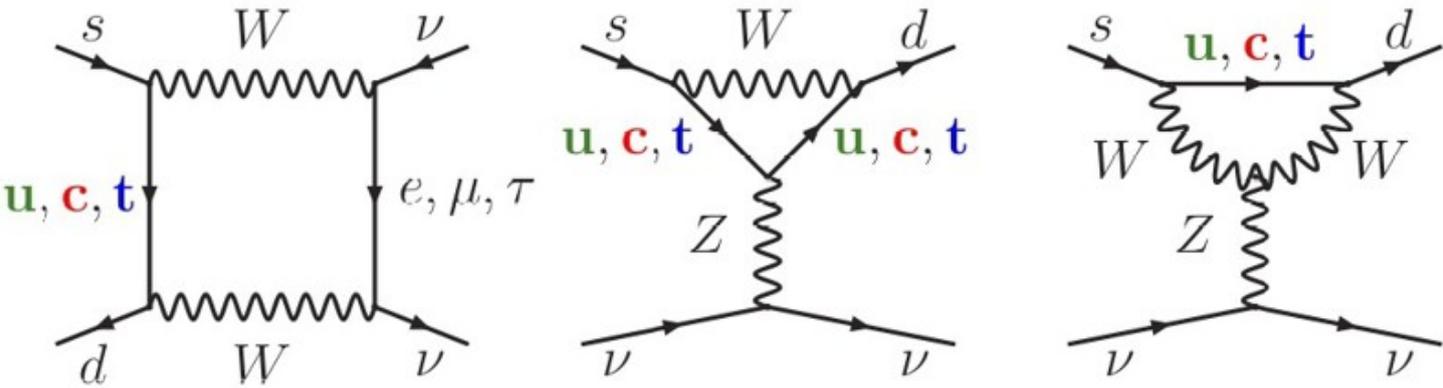
- $K^+ \rightarrow \pi^+ \nu \nu$  decays in the SM
- NA62 experiment
- $K^+ \rightarrow \pi^+ \nu \nu$  @ NA62 (2017 data)
- Summary and prospects

# Kaons and the CKM unitarity triangle



- The CKM unitarity triangle can be constrained by kaon physics alone
- Comparison with B physics can provide description of NP flavour dynamics

# The FCNC process $K \rightarrow \pi \nu \bar{\nu}$



Parametric uncertainty dominates

[Buras. et. al., JHEP11(2015)033]

- FCNC loop processes:  $s \rightarrow d$  coupling and highest CKM suppression
- Theoretically clean: Short distance contribution
- Hadronic matrix element measured with  $K_{l3}$  decays
- SM predictions: Buras. et. al., JHEP11(2015)033

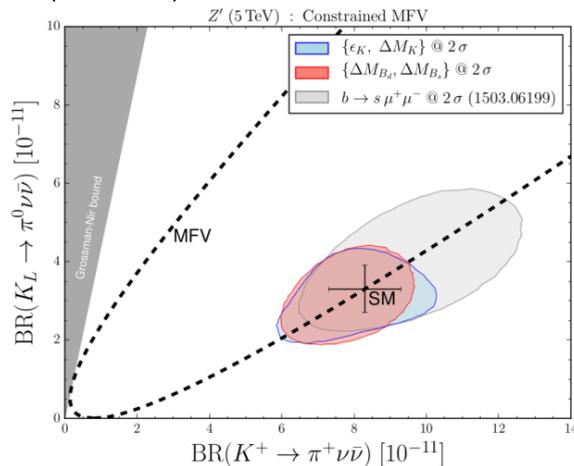
$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.84 \pm 0.03) \times 10^{-10} \left( \frac{|V_{cb}|}{0.0407} \right)^2 \left( \frac{\gamma}{73.2^\circ} \right)^{0.74} = (0.84 \pm 0.10) \times 10^{-10}$$

$$BR(K_L \rightarrow \pi^0 \nu \bar{\nu}) = (0.34 \pm 0.05) \times 10^{-10} \left( \frac{|V_{ub}|}{0.00388} \right)^2 \left( \frac{|V_{cb}|}{0.0407} \right)^2 \left( \frac{\sin \gamma}{\sin 73.2^\circ} \right)^2 = (0.34 \pm 0.06) \times 10^{-10}$$

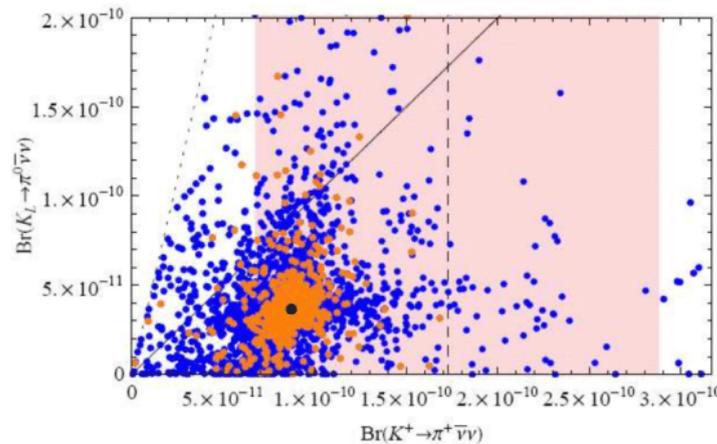
# $K \rightarrow \pi \nu \bar{\nu}$ beyond the Standard Model

- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- MSSM analyses [Tanimoto, Yamamoto, PTEP 2016 (2016) no.12, 123B02], [Blazek, Matak, Int.J.Mod.Phys. A29 (2014) no.27], [Isidori et al. JHEP 0608 (2006) 064]
- Simplified Z, Z' models [Buras, Buttazzo, Kneijens, JHEP11(2015)166]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, Eur.Phys.J. C76 (2016) 182]
- LFU violation models [Isidori et al., Eur. Phys. J. C (2017) 77: 618]
- Leptoquarks [S. Fajfer, N. Košnik, L. Vale Silva, arXiv:1802.00786v1 (2018)]
- Constraints from existing measurements (correlations model dependent)

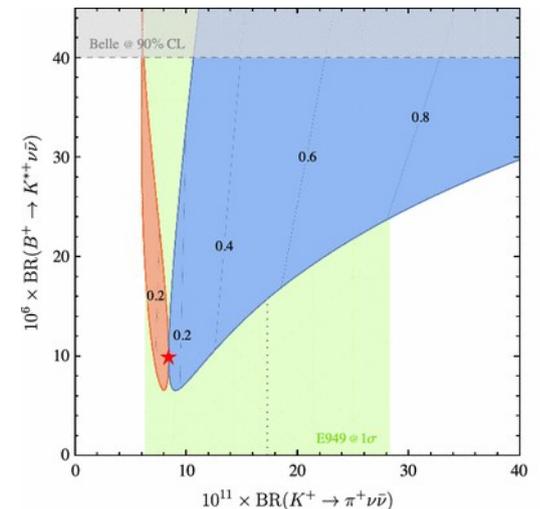
$Z'(5 \text{ TeV})$  in Constrained MFV



Randall Sundrum

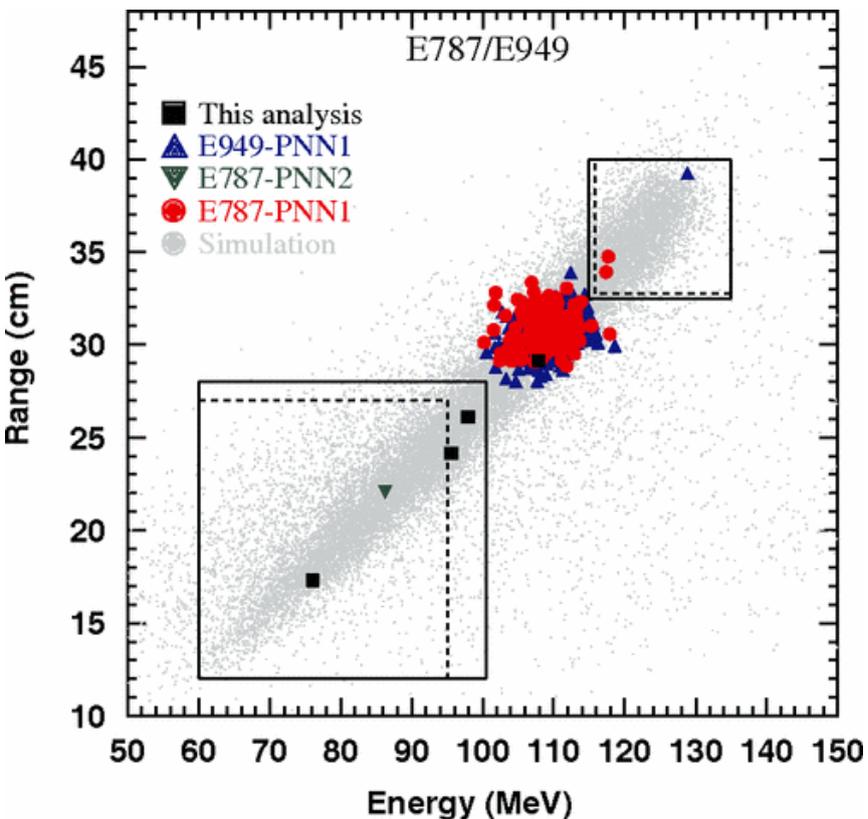


LFU violation

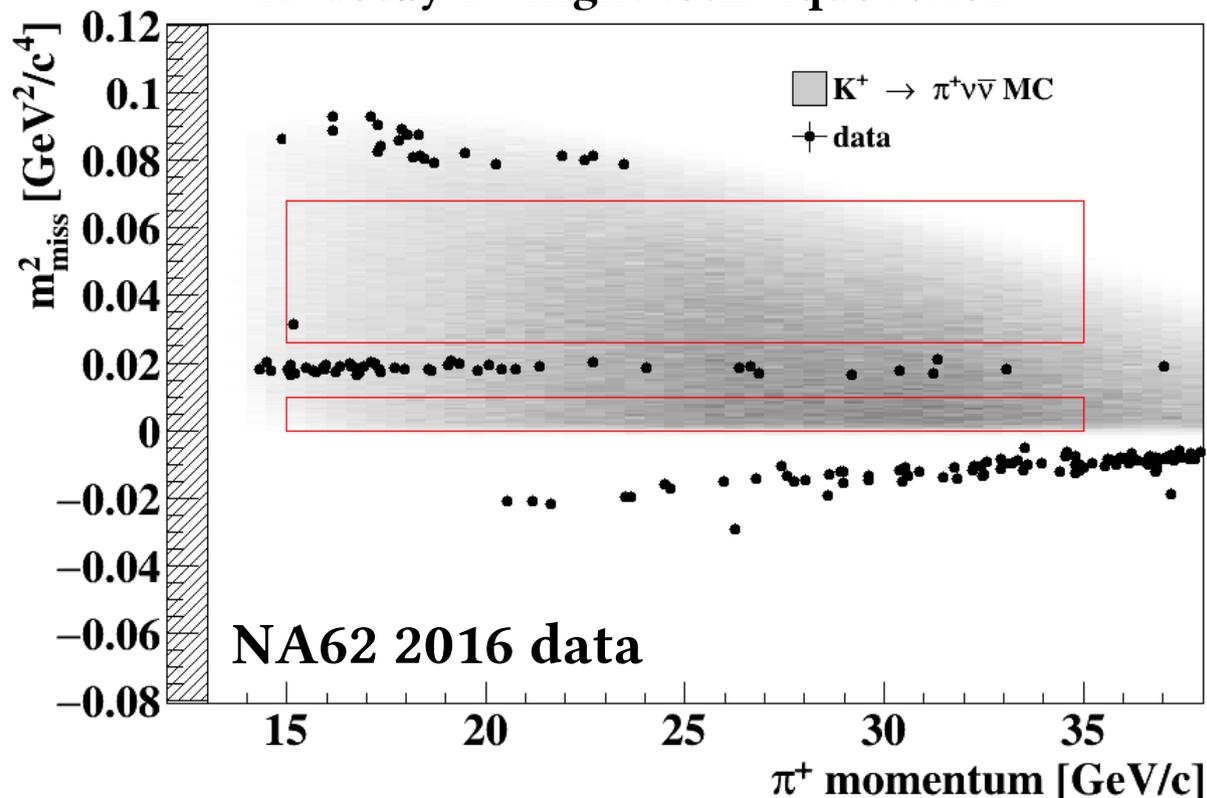


# State of the art $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ experiments

$K^+$  decay-at-rest technique E787/E949



$K^+$  decay-in-flight technique NA62



$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (1.73_{-1.05}^{+1.15}) \times 10^{-10}$$

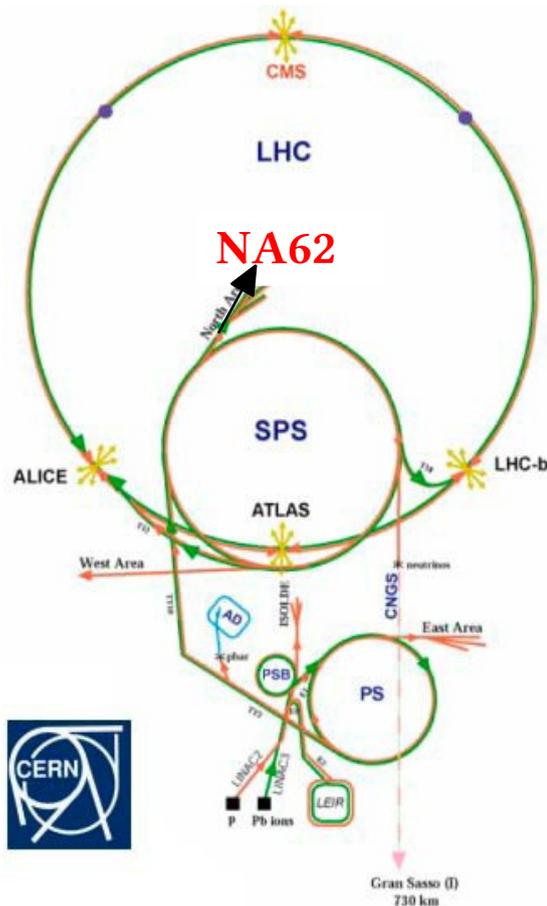
Phys. Rev. D 79, 092004 (2009)

Phys. Rev. D 77, 052003 (2008)

$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 14 \times 10^{-10} \text{ @ 95\% CL}$$

Phys. Lett. B 791, 156 (2019)

# The NA62 experiment



## NA62 timeline

Dec 2008: NA62 Approval

2009 – 2014: Detector R&D and installation

2015: Commissioning

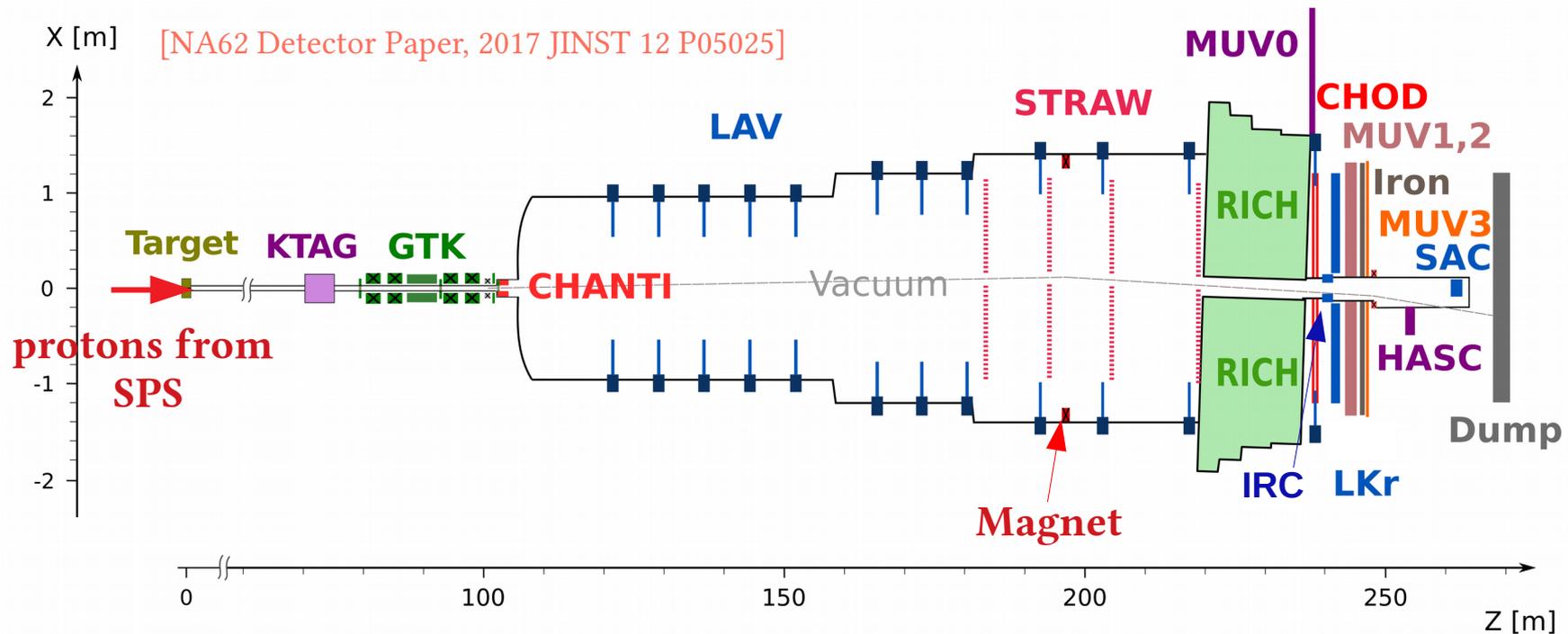
2016 – 2018: NA62 Run 1

2021 -2024 NA62 Run 2 (2021 already guaranteed)

*NA62 primary goal: measurement of the ultra rare kaon decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$*

NA62 Collaboration consist of ~ 200 participants from: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Glasgow, Lancaster, Liverpool, Louvain, Mainz, Moskow, Naples, Perugia, Pisa, Prague, Protvino, Rome I, Rome II, San Luis Potosi, Turin, TRIUMF, Vancouver UBC

# NA62 detector



## ■ SPS Beam:

- ★ 400 GeV/c protons
- ★  $1.9 \times 10^{12}$  protons/spill
- ★ 3.5s spill
- ★  $\sim 10^{18}$  POT/year

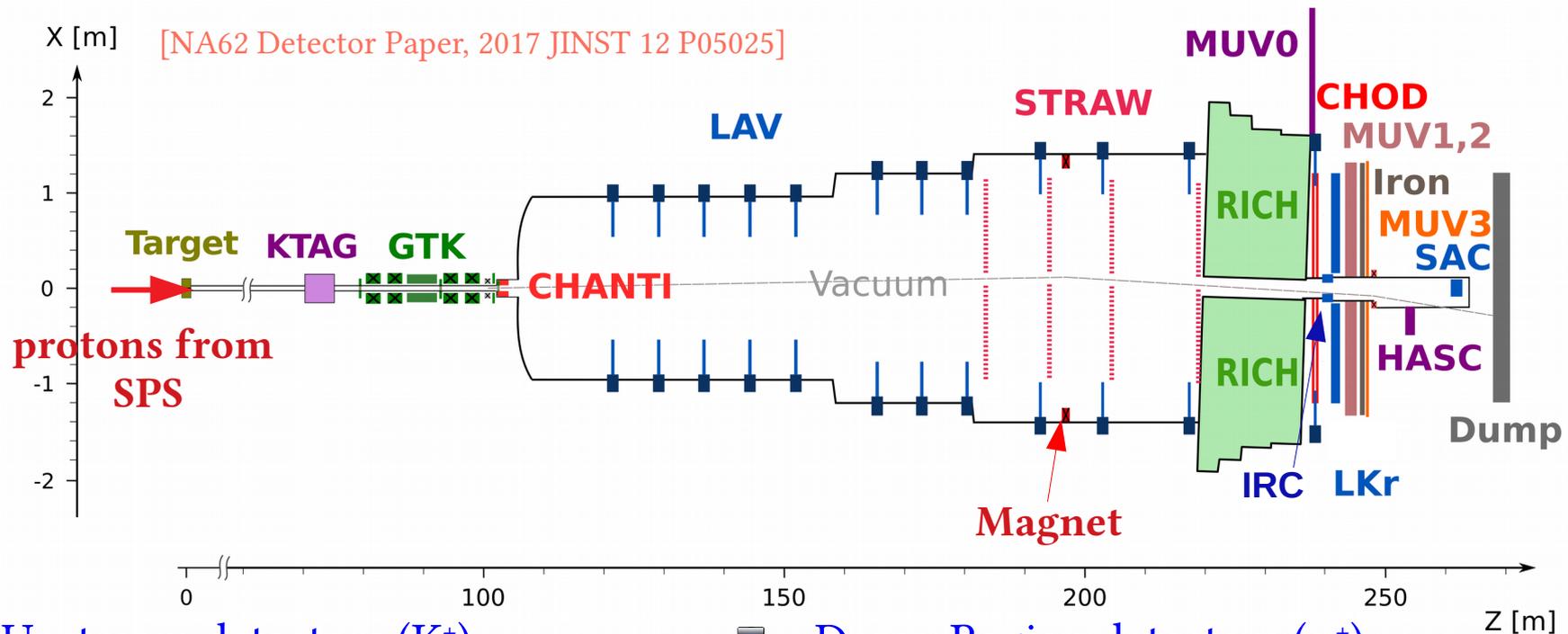
## ■ Secondary positive Beam:

- ★ 75 GeV/c momentum, 1% rms
- ★ 100  $\mu$ rad divergence (RMS)
- ★ 60x30 mm<sup>2</sup> transverse size
- ★  $K^+(6\%)/\pi^+(70\%)/p(24\%)$
- ★ 450 MHz of particles at GTK3

## ■ Decay Region:

- ★ 60 m long fiducial region
- ★  $\sim 3$  MHz  $K^+$  decay rate
- ★ Vacuum  $\sim O(10^{-6})$  mbar

# NA62 detector



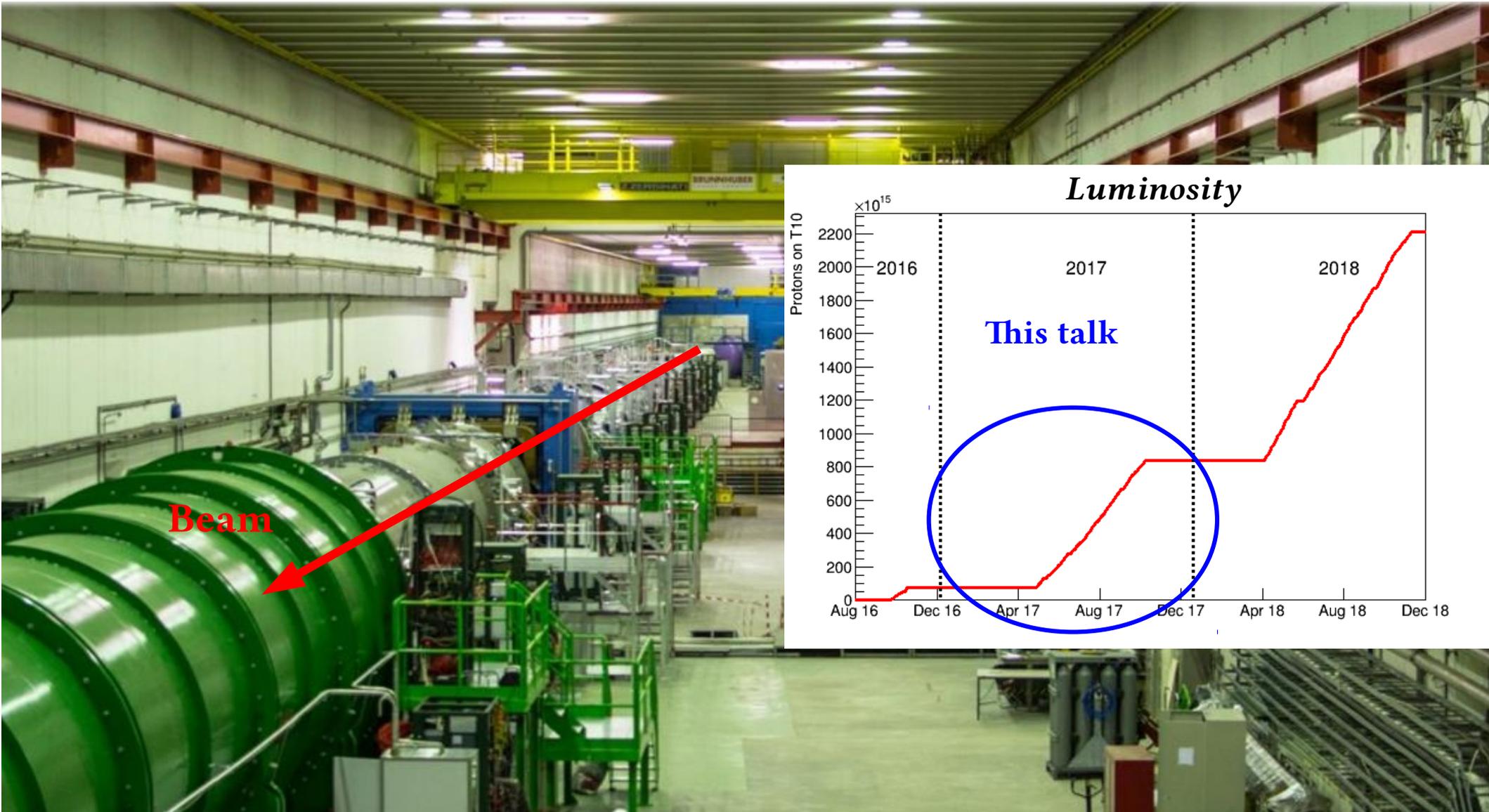
## ■ Upstream detectors ( $K^+$ ):

- ★ **KTAG:** Differential Cherenkov counter for  $K^+$  ID
- ★ **GTK:** Si pixel beam tracker
- ★ **CHANTI:** Anti-counter for inelastic beam-GTK3 interactions

## ■ Decay Region detectors ( $\pi^+$ ):

- ★ **STRAW:** track momentum spectrometer
- ★ **CHOD:** Scintillator hodoscopes
- ★ **LKr/MUV1/MUV2:** Calorimetric system
- ★ **RICH:** Cherenkov counter for  $\pi/\mu/e$  ID
- ★ **LAV/SAC/IRC:** Photon veto detectors
- ★ **MUV3:** Muon veto

# NA62 detector

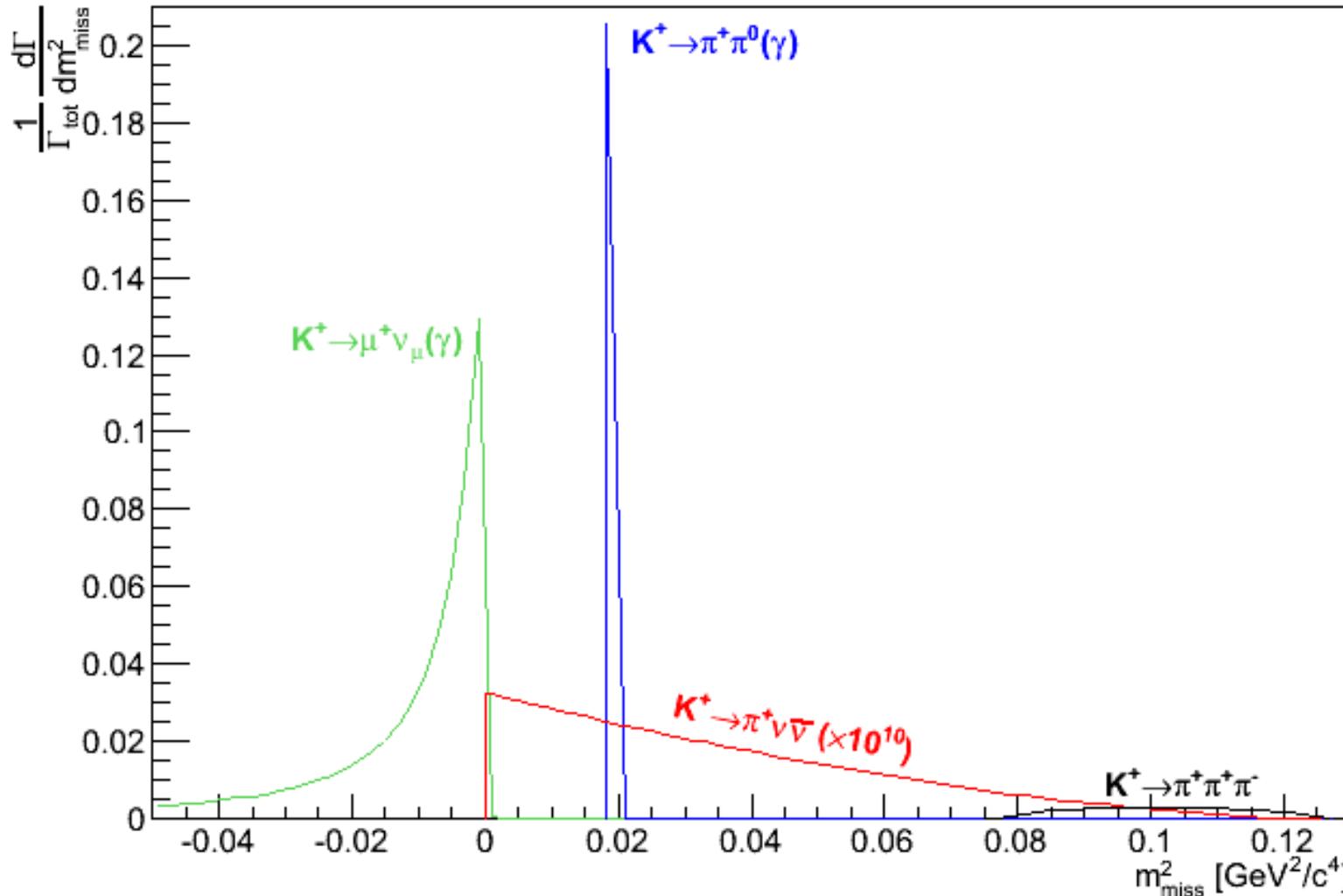
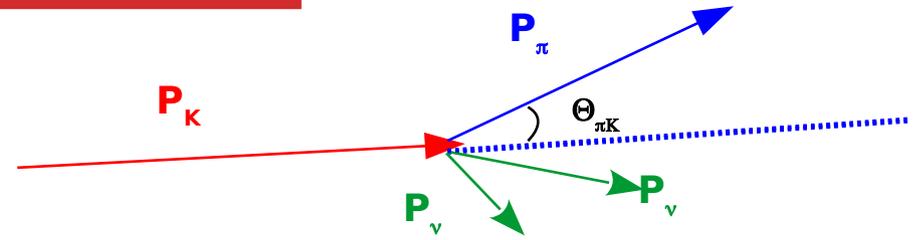


# Analysis strategy

Decay-in-flight  
technique

$$m_{\text{miss}}^2 = (\mathbf{P}_K - \mathbf{P}_{\pi^+})^2$$

$\pi^+$  mass hypothesis

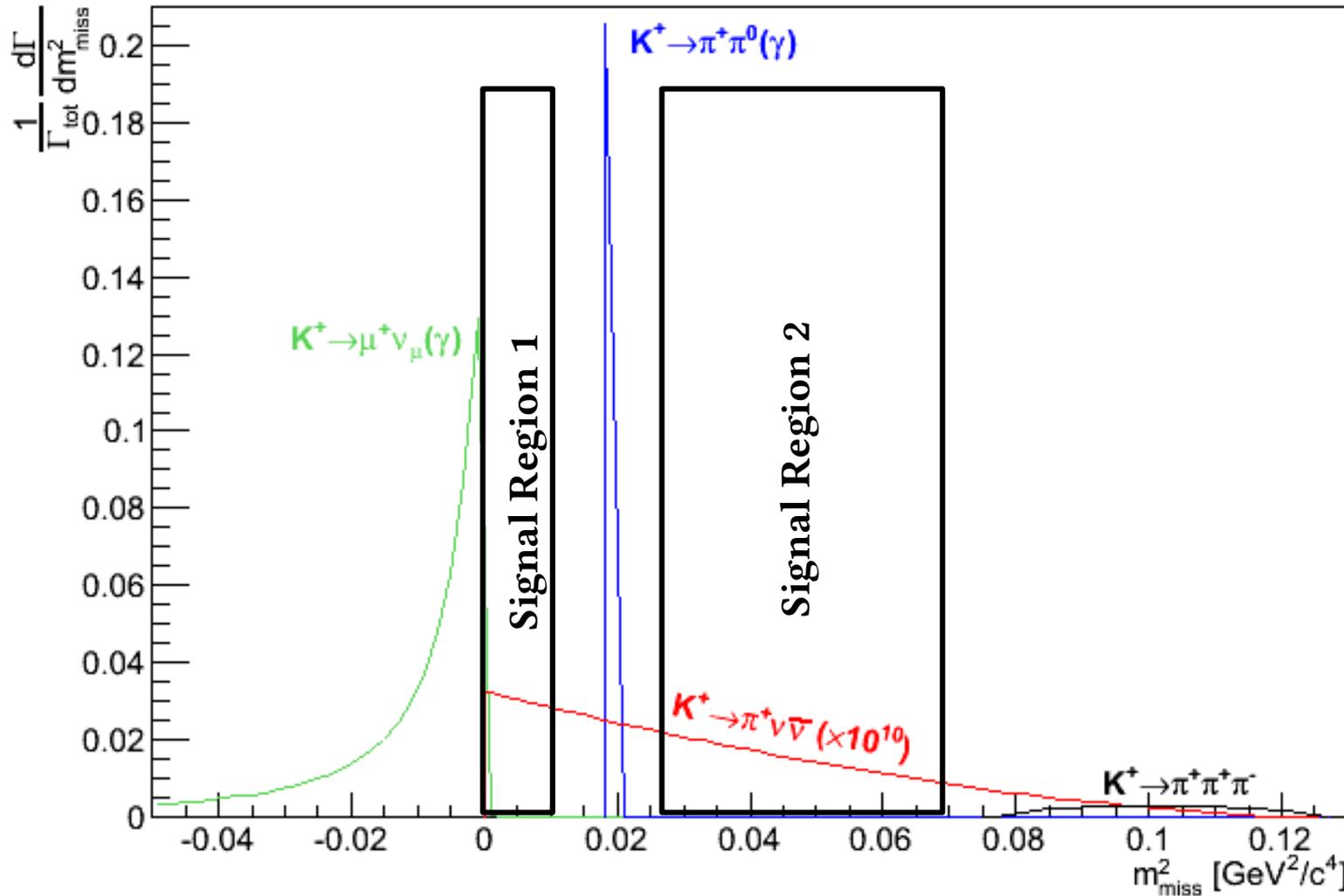
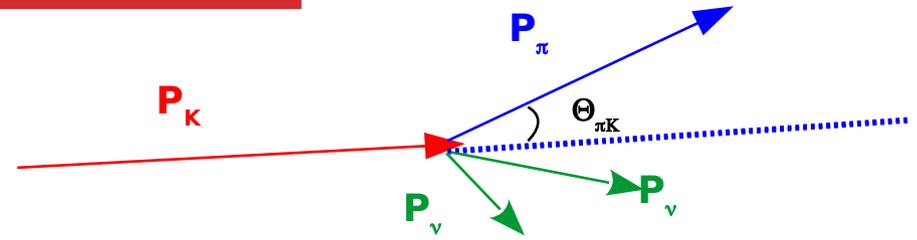


# Analysis strategy

Decay-in-flight  
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$$m_{\text{miss}}^2 = (\mathbf{P}_K - \mathbf{P}_{\pi^+})^2$$

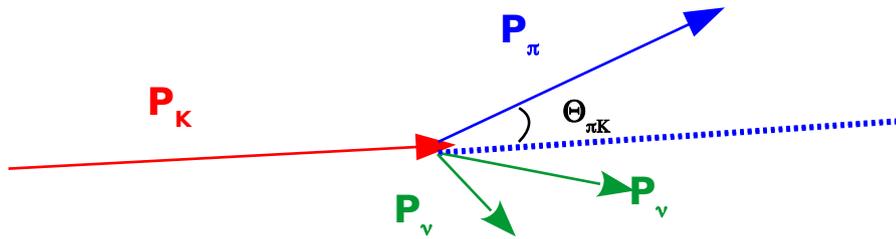
$\pi^+$  mass hypothesis



# Analysis strategy

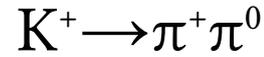
Decay-in-flight  
technique

$$m_{\text{miss}}^2 = (\mathbf{P}_K - \mathbf{P}_{\pi^+})^2$$

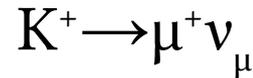


Process

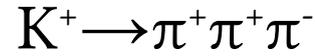
Branching ratio



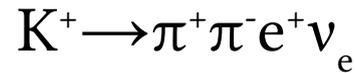
0.2066



0.6356



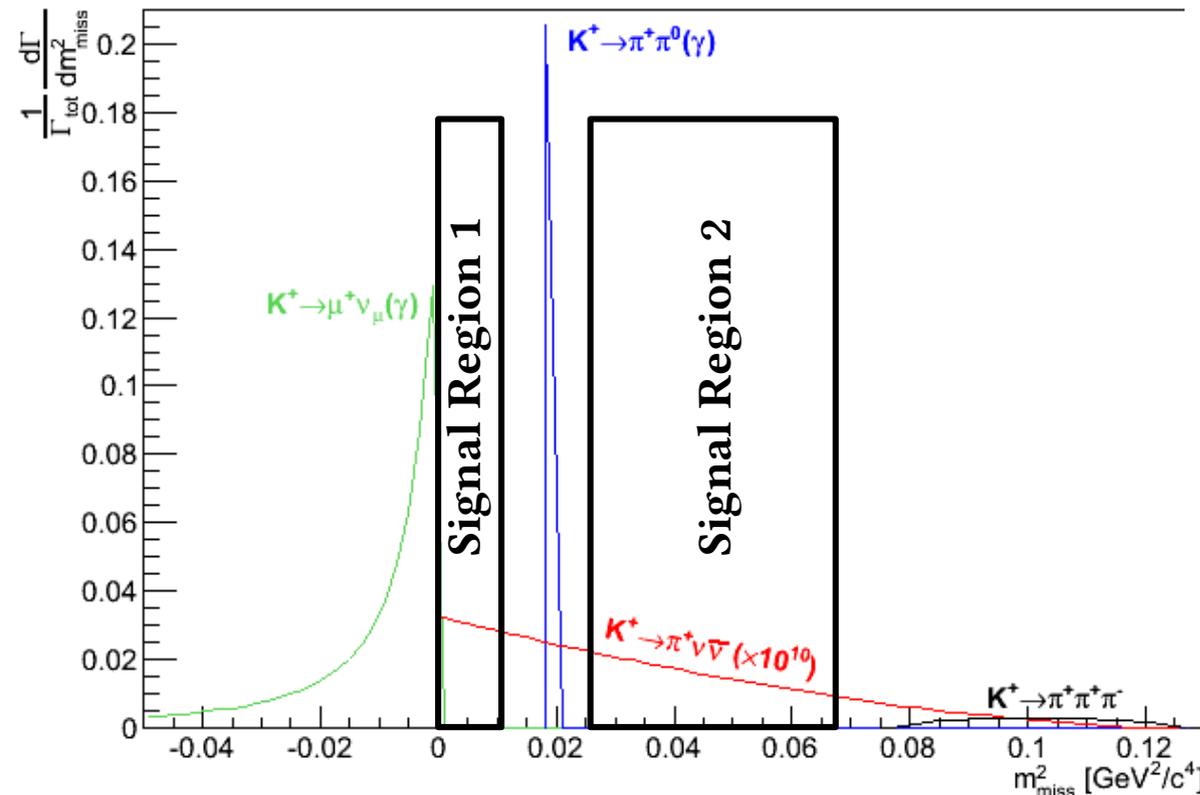
0.0558



$4.3 \times 10^{-5}$



$8.4 \times 10^{-11}$



$$15 < P_{\pi^+} < 35 \text{ GeV}/c$$

+ Particle ID (Cherenkov detectors)

Particle ID (Calorimeters)

Photon veto

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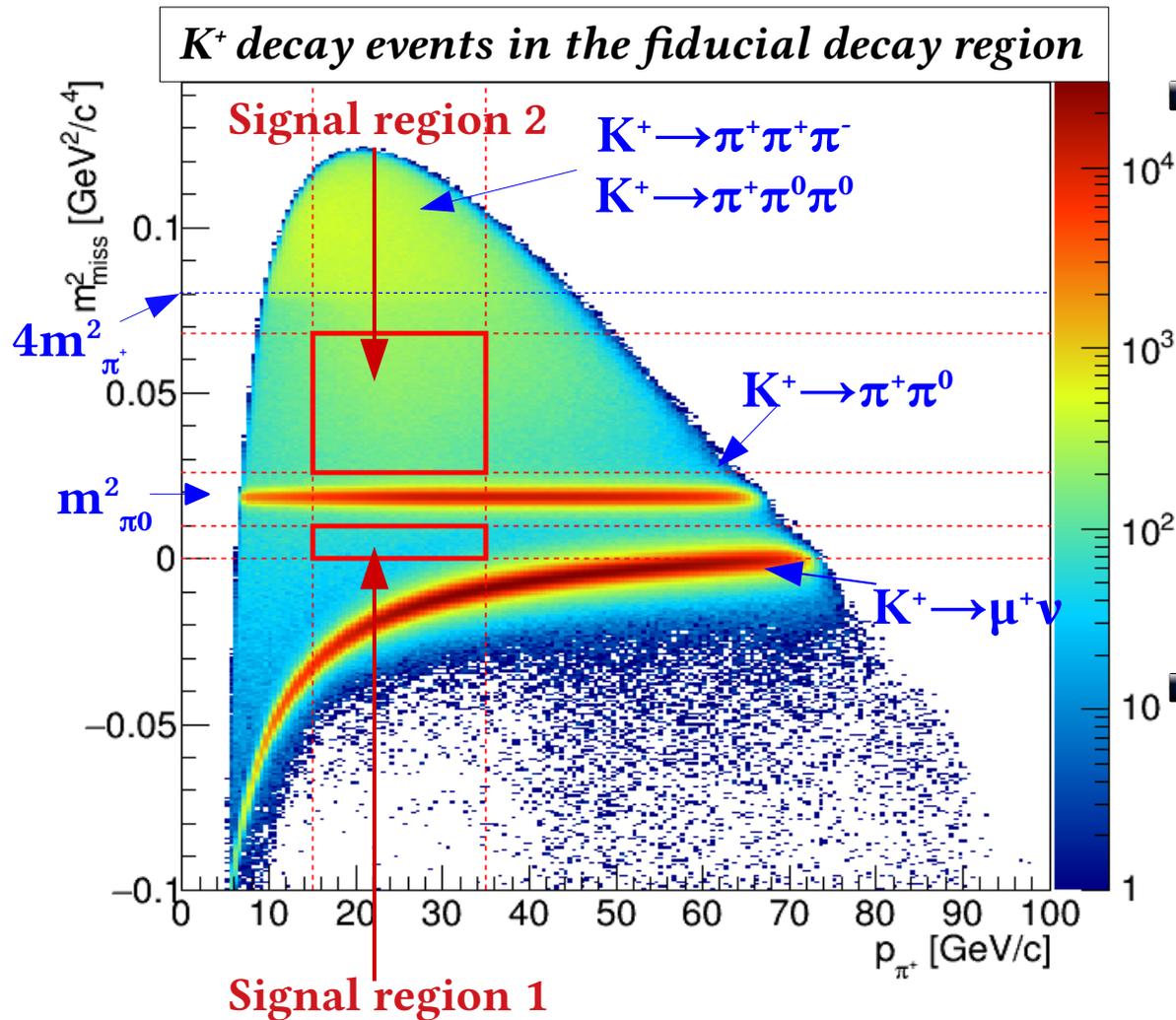
# 1. Signal Selection

# Keystones of the analysis

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- Muon suppression  $> 10^7$
- $\pi^0$  suppression (from  $K^+ \rightarrow \pi^+ \pi^0$ )  $> 10^7$
- Excellent time resolution  $O(100\text{ps})$
- Kinematic suppression  $\sim O(10^4)$

# Signal selection



$m_{\text{miss}}^2$  computed under  $\pi^+$  mass hypothesis

## Selection criteria

- ★ single track decay topology
- ★  $\pi^+$  identification
- ★ photon rejection
- ★ multi-track rejection

## Performance

- ★  $\epsilon_{\mu^+} \sim 10^{-8}$  (64%  $\pi^+$  efficiency)
- ★  $\epsilon_{\pi^0} = (1.4 \pm 0.1) \cdot 10^{-8}$
- ★  $\sigma(m_{\text{miss}}^2) = 1 \cdot 10^{-3} \text{ GeV}^2/c^4$
- ★  $\sigma_T \sim O(100 \text{ ps})$

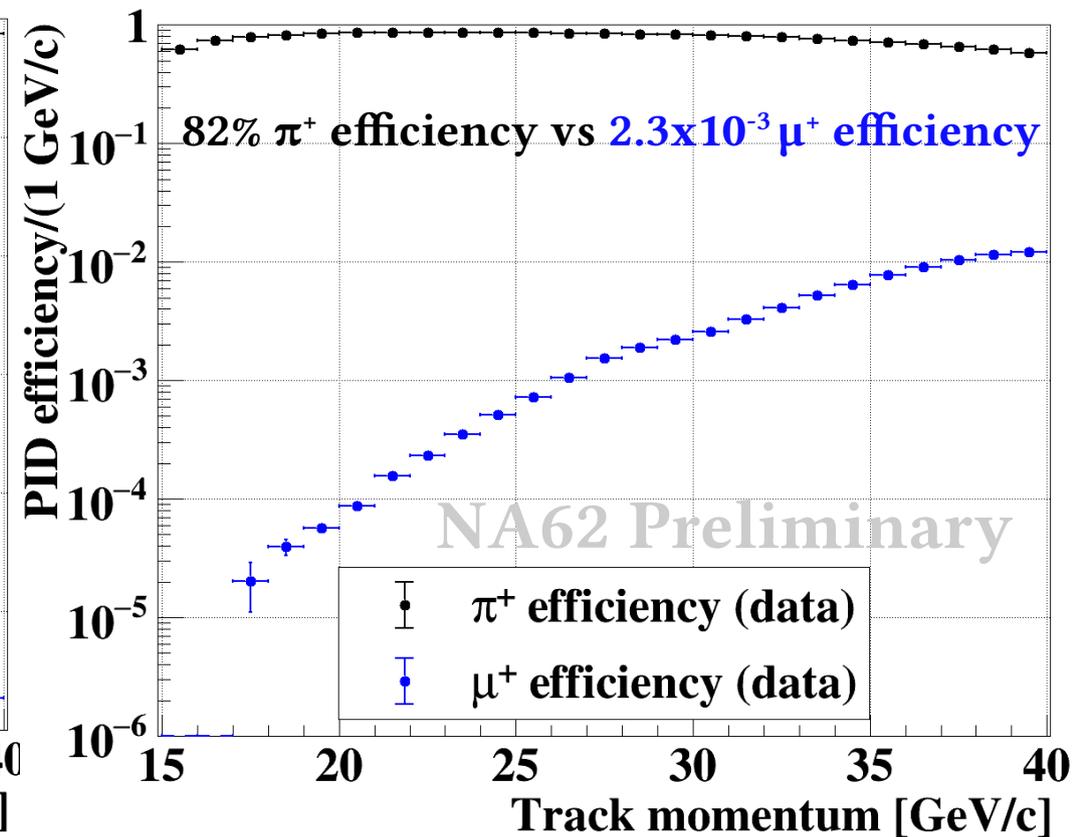
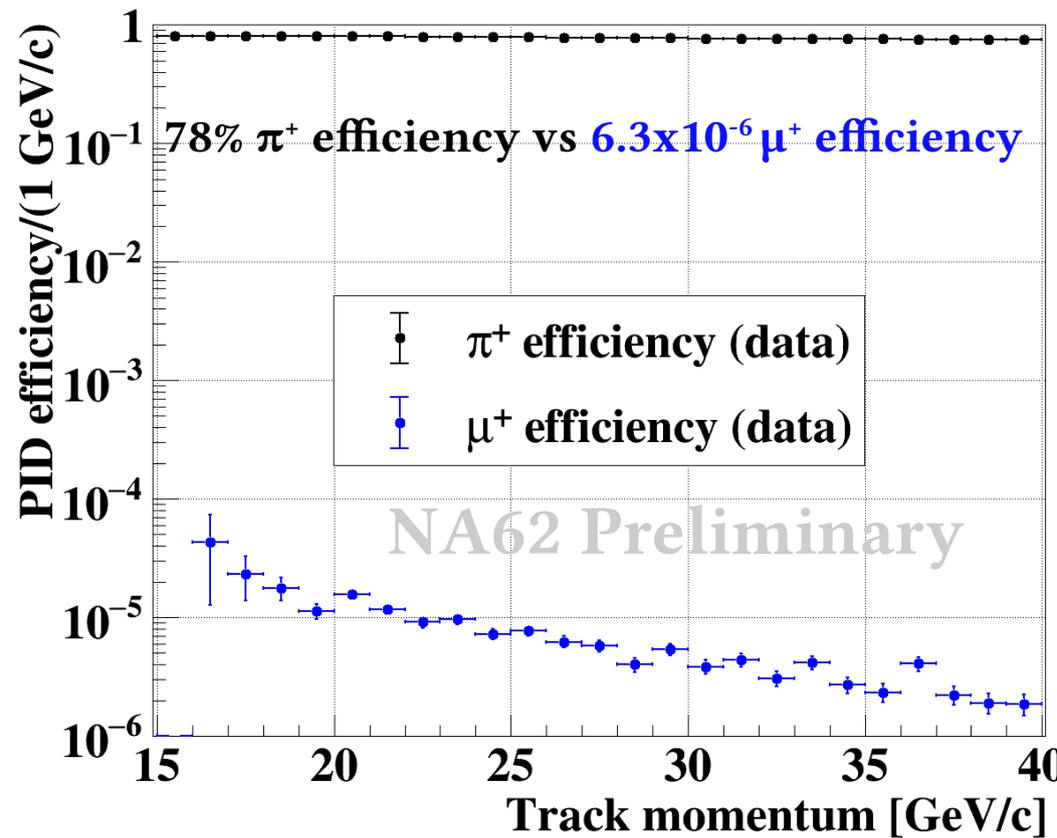
# Keystones of the analysis: Particle identification

## Calorimetric PID

- ◆ Machine learning approach (BDT)
  - Energy deposition
  - Energy sharing
  - Shower shape profiles

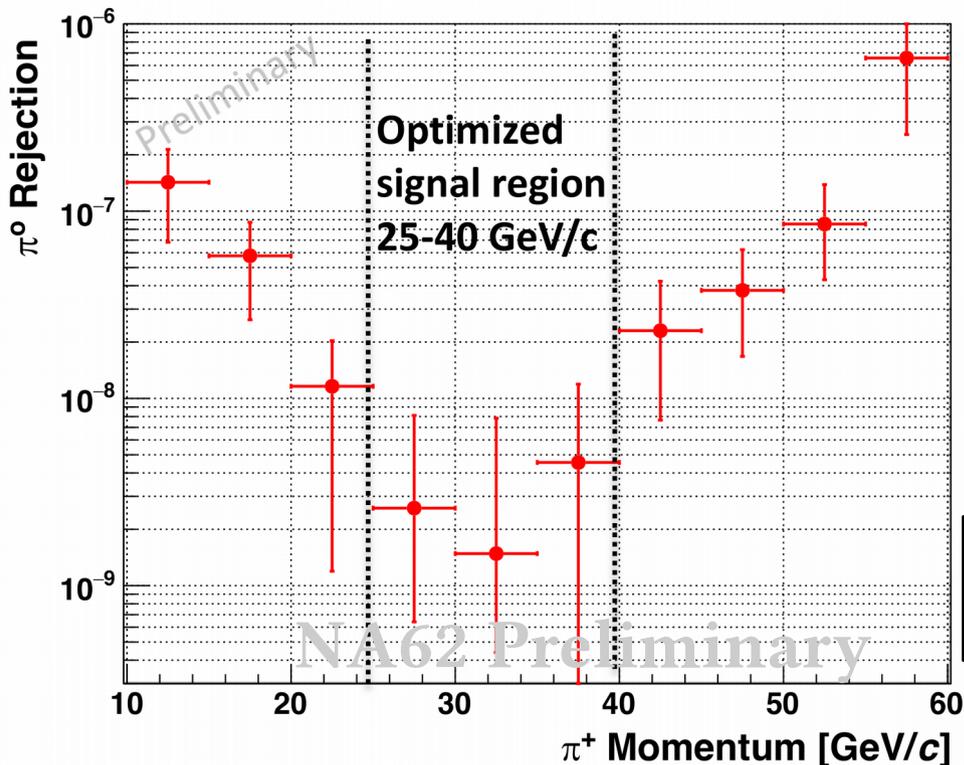
## RICH PID

- ◆ Track driven likelihoods discriminant for  $\pi/\mu/e$  separation
- ◆ Particle mass using track momentum
- ◆ Momentum measurement under mass hypothesis (velocity spectrometer)



# $\pi^0$ suppression and search for $\pi^0 \rightarrow$ invisible

- A priori evaluation of  $\pi^0$  suppression of  $K^+ \rightarrow \pi^+ \pi^0$  decays ( $0.015 < m_{\text{miss}}^2 < 0.021 \text{ GeV}^2/c^4$ )
  - ★ Selection and trigger stream identical to  $K^+ \rightarrow \pi^+ \nu \nu$  (1/3 of the data set used)
  - ★ Single- $\gamma$  detection efficiency from control  $K^+ \rightarrow \pi^+ \pi^0$  data (Tag & Probe)
  - ★  $\pi^0$  suppression evaluated from convolution with MC  $K^+ \rightarrow \pi^+ \pi^0(\gamma)$
  - ★ Validation: side bands with expected rejection  $O(10^{-7})$  where  $\pi^0 \rightarrow$  invisible excluded [E949, PRD72 (2005)]
- $\pi^0$  suppression expected =  $(2.8^{+5.9}_{-2.1}) \times 10^{-9}$  ( $\pi^+$  momentum region 25-40 GeV/c)

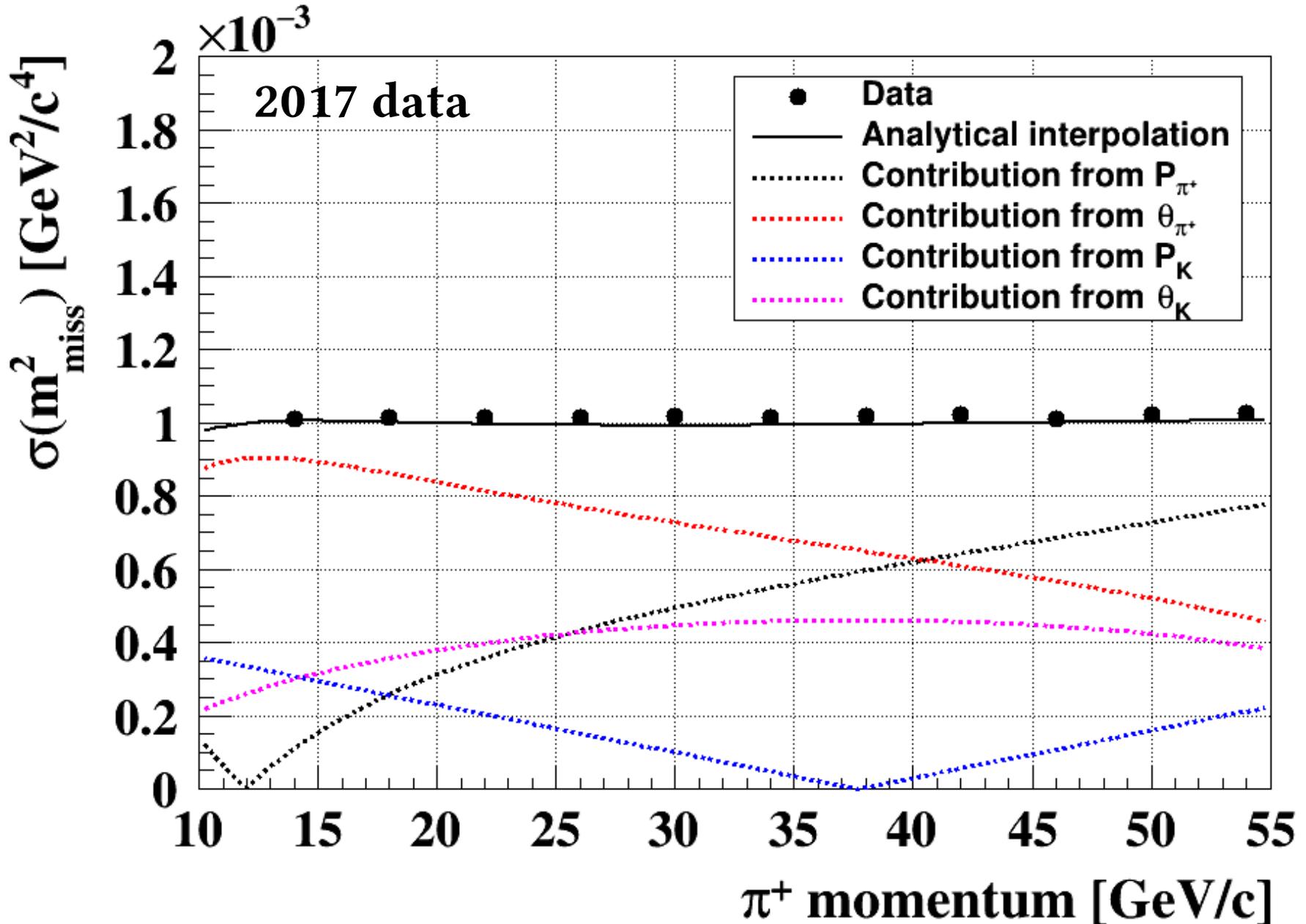


## ■ Results

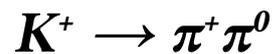
- ★  $\text{BR}(\pi^0 \rightarrow \text{invisible})$  normalized to  $\pi^0 \rightarrow \gamma\gamma$
- ★ Expected background:  $10^{+22}_{-8}$  events
- ★ Observed: 12 events

**$\text{BR}(\pi^0 \rightarrow \text{invisible}) < 4.4 \times 10^{-9}$  @ 90% CL**  
UL 60 times stronger than previous measurements

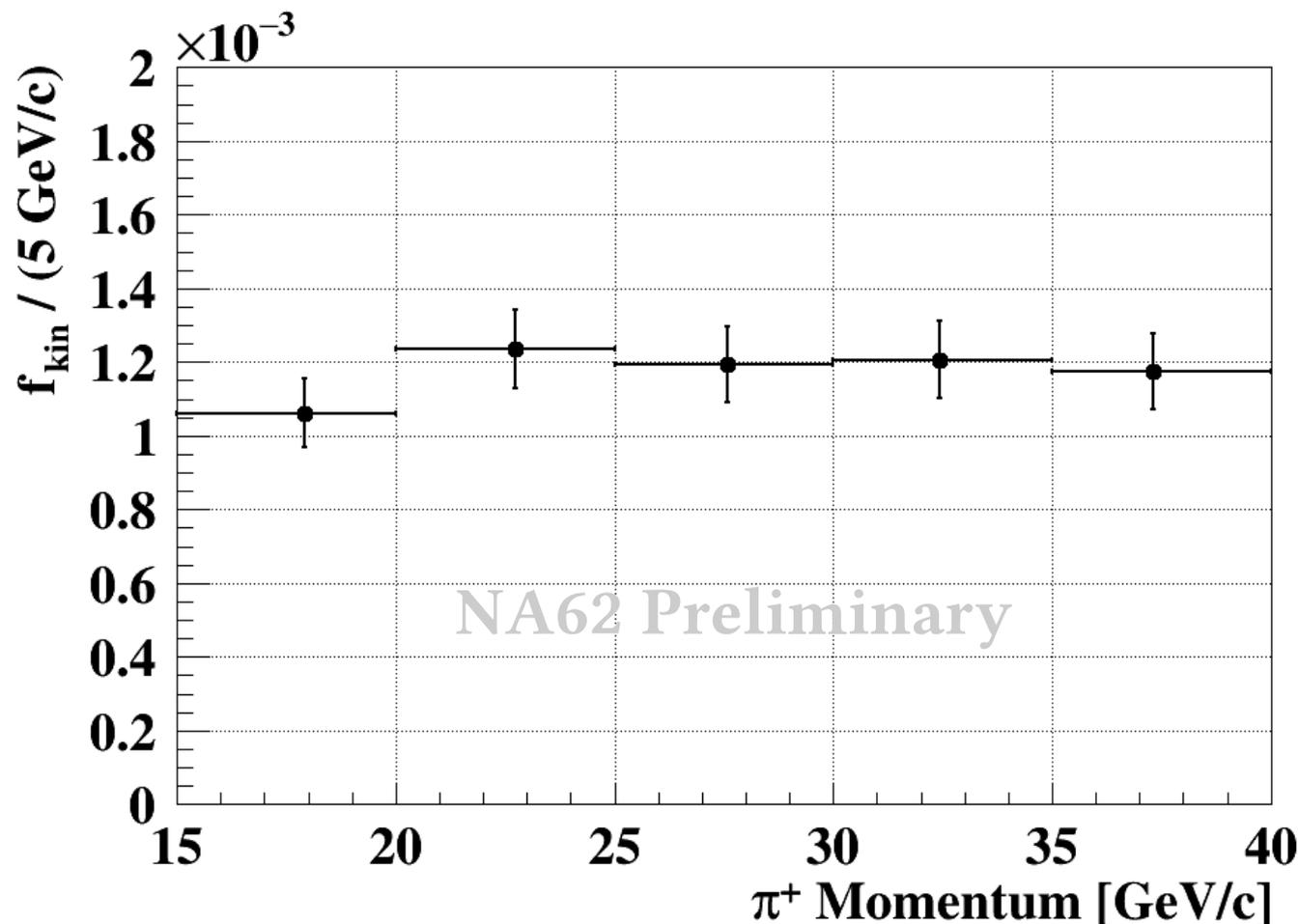
# Keystones of the analysis: Kinematic resolution



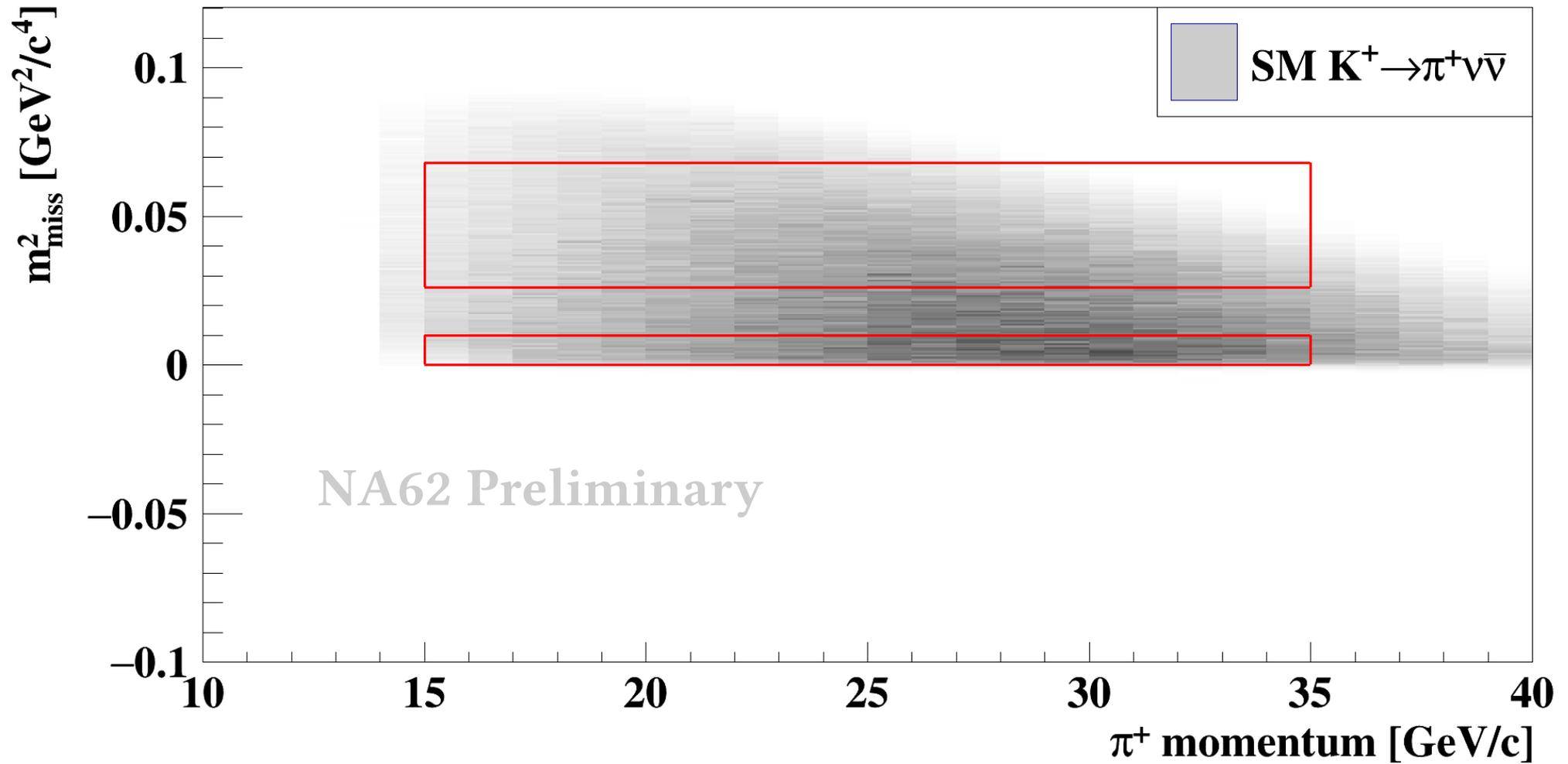
# Keystones of the analysis: Kinematic suppression



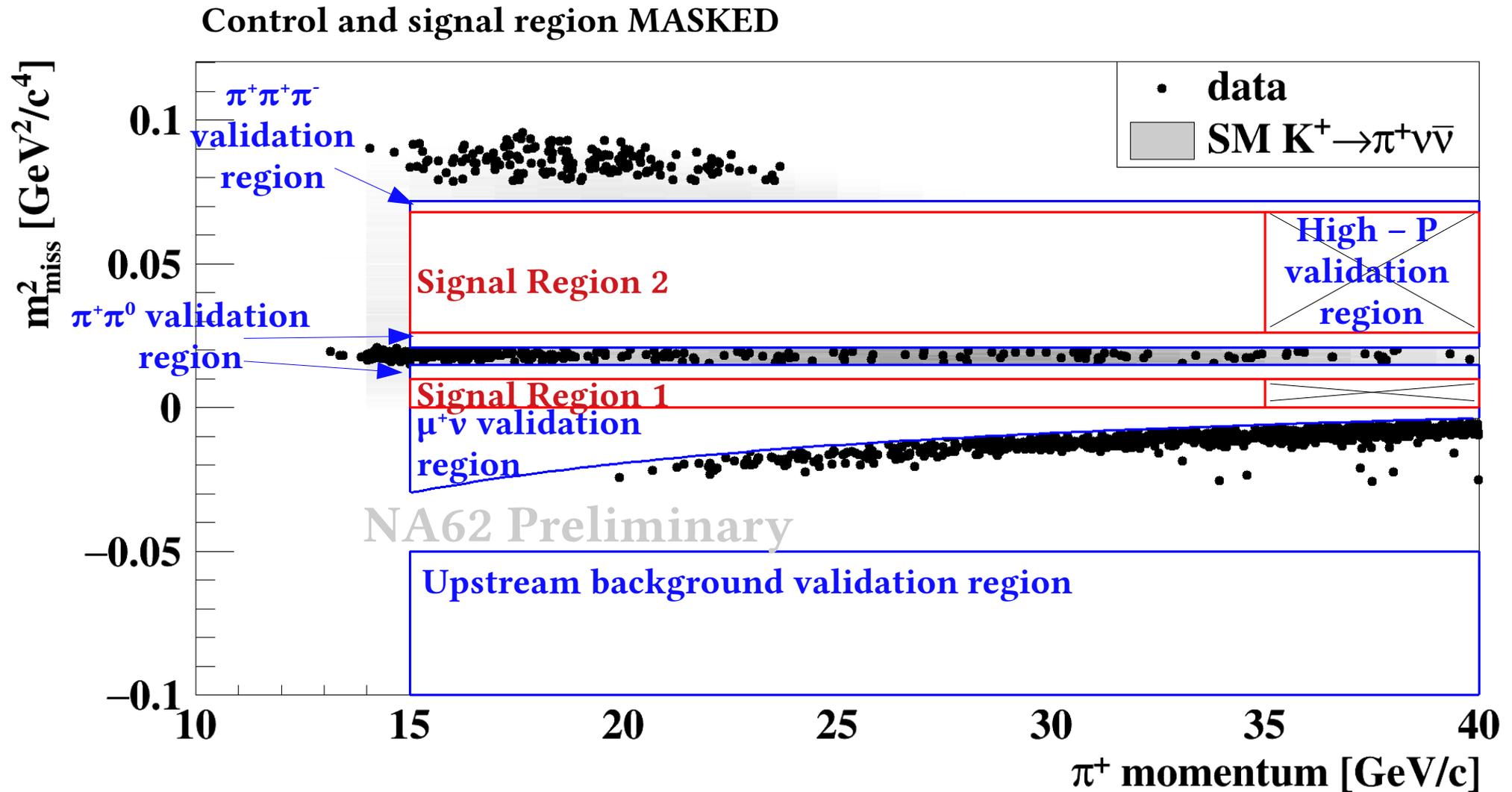
- ◆ Kinematic suppression measured on  $K^+ \rightarrow \pi^+ \pi^0$  decays in data
- ◆ Fraction of events  $\pi^+ \pi^0$  entering  $m_{\text{miss}}^2$  signal region



# Signal acceptance



# Data after signal selection

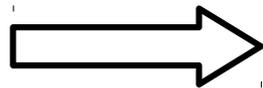


# Single Event Sensitivity: Results

◆ Integrated over beam intensity and  $\pi^+$  momentum

$$\text{S.E.S.} = (0.389 \pm 0.021) \times 10^{-10} \quad N_{\pi\nu\nu}^{\text{exp}} = 2.16 \pm 0.12 \pm 0.26_{\text{ext}}$$

S.E.S error budgeted



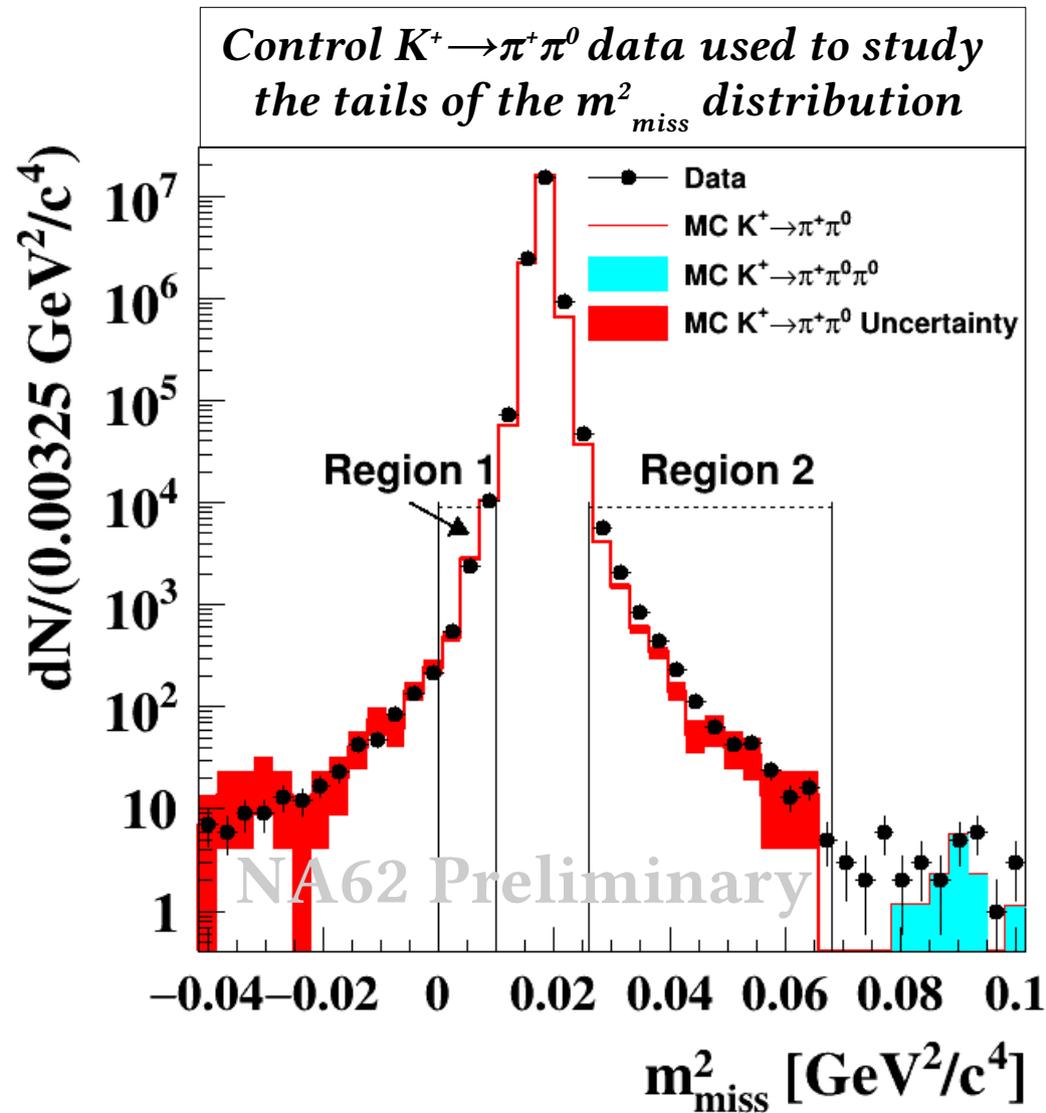
Source	Uncertainty $\times 10^{-10}$
L0 trigger	$\pm 0.015$
Acceptance	$\pm 0.012$
Random veto	$\pm 0.008$
L1 trigger	$\pm 0.003$
Normalization background	negligible

◆ External error on  $N_{\pi\nu\nu}^{\text{exp}}$  from  $\text{Br}(\pi\nu\nu) = (0.84 \pm 0.10) \times 10^{-10}$

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# 3. Background evaluation and validation

# Background: $K^+ \rightarrow \pi^+ \pi^0$



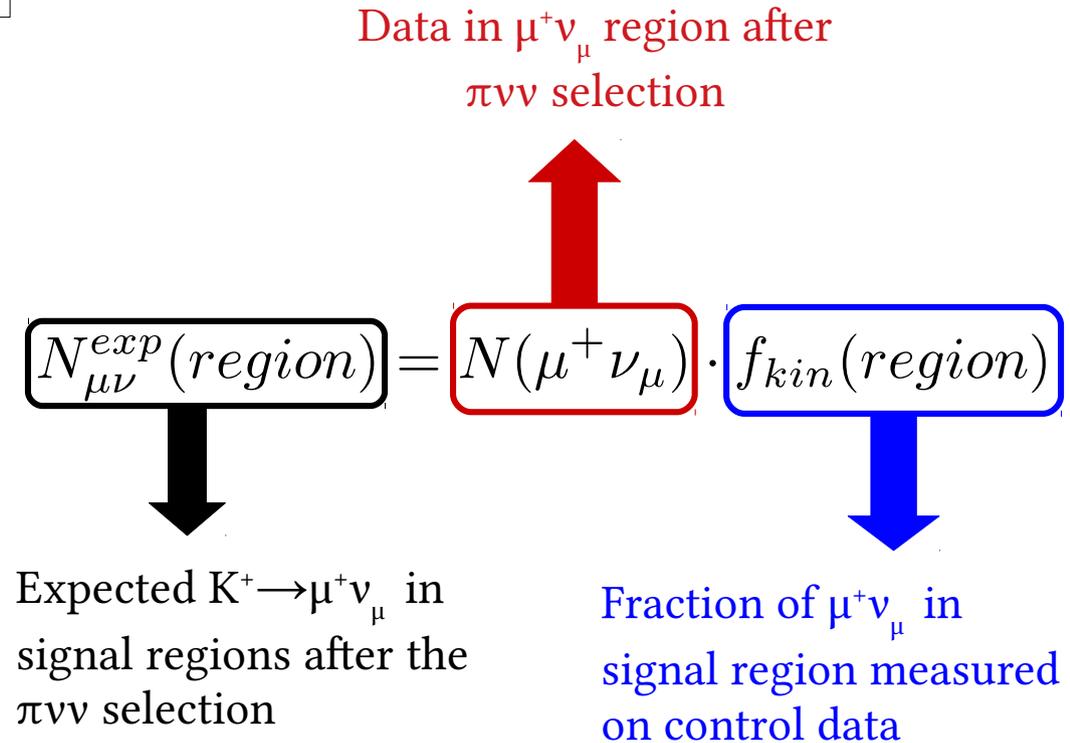
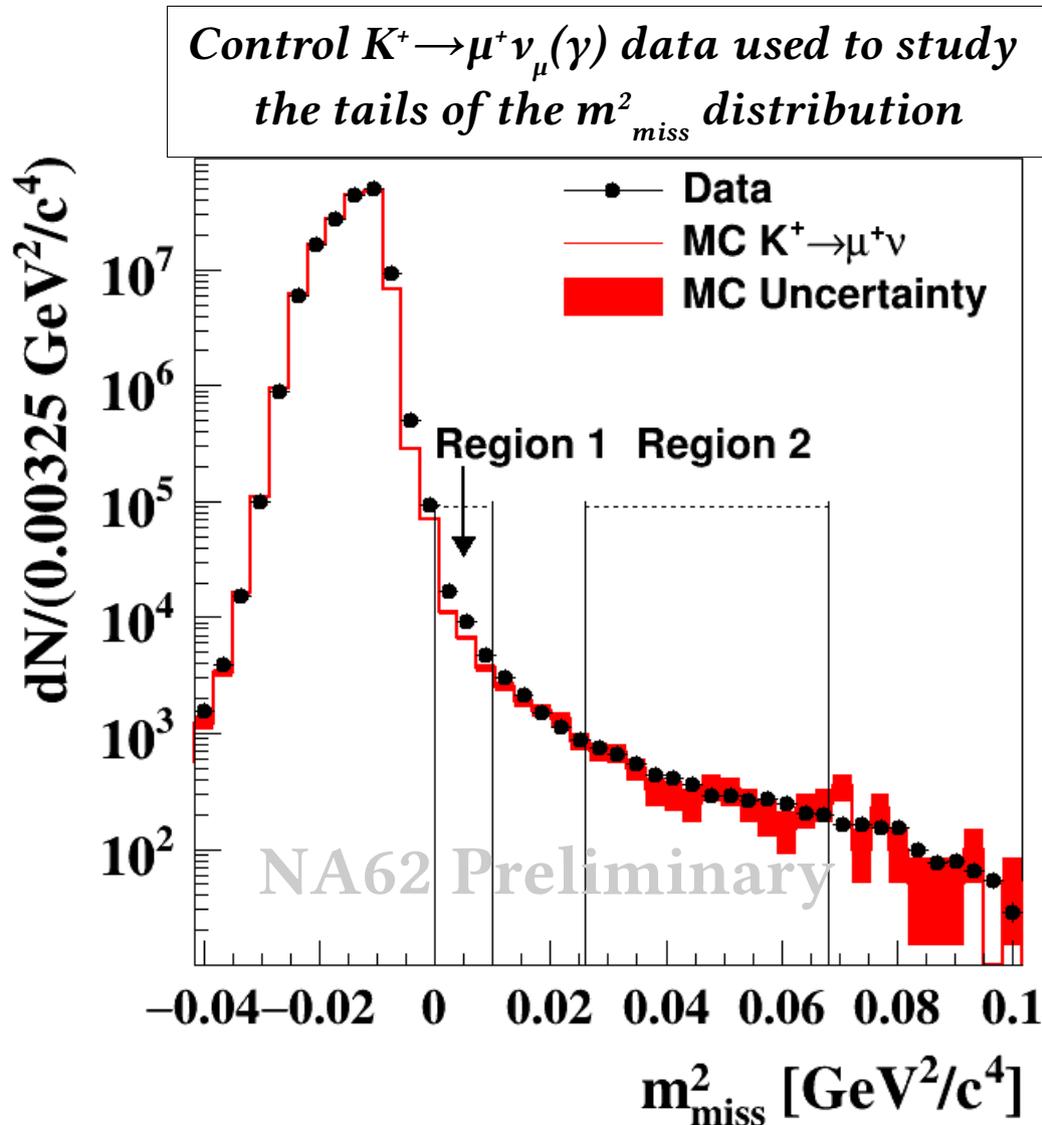
Data in  $\pi^+ \pi^0$  region after  $\pi\nu$  selection (including  $\pi^0$  rejection)

$$N_{\pi\pi}^{exp}(region) = N(\pi^+ \pi^0) \cdot f_{kin}(region)$$

Expected  $K^+ \rightarrow \pi^+ \pi^0$  in signal regions after the  $\pi\nu$  selection

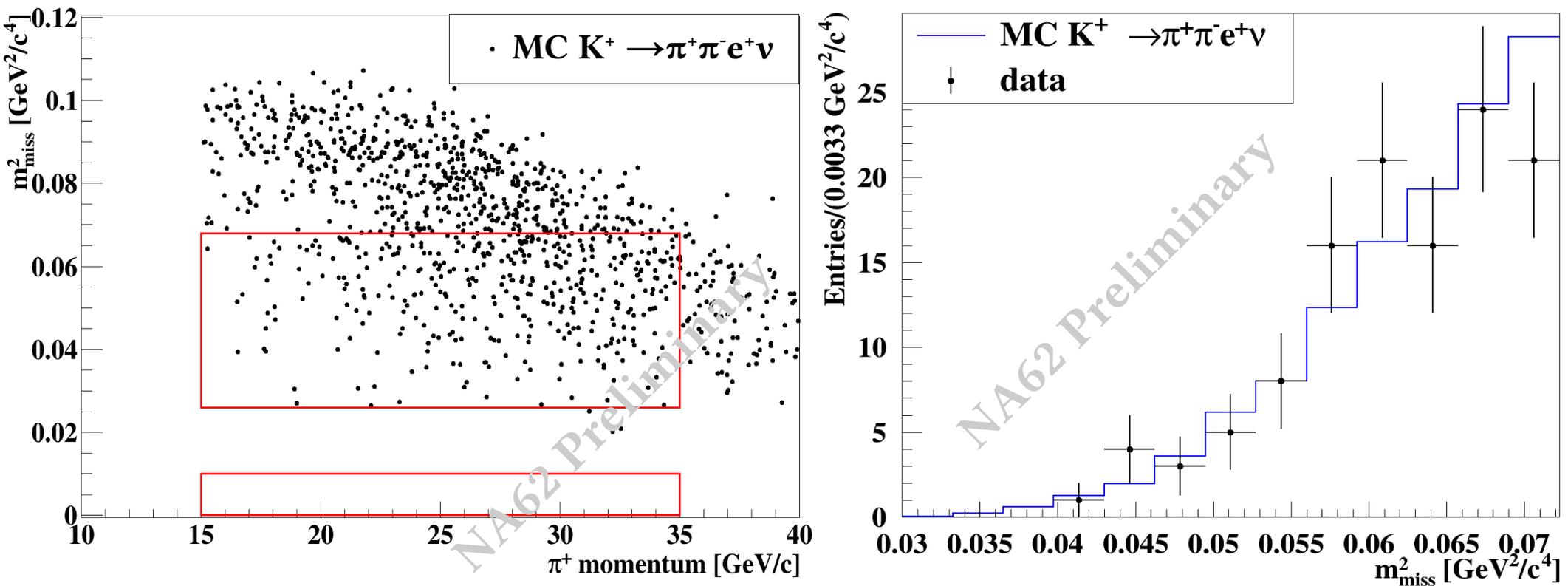
Fraction of  $\pi^+ \pi^0$  in signal region measured on control data

# Background: $K^+ \rightarrow \mu^+ \nu_\mu (\gamma)$ IB



# Background: $K^+ \rightarrow \pi^+\pi^-e^+\nu$

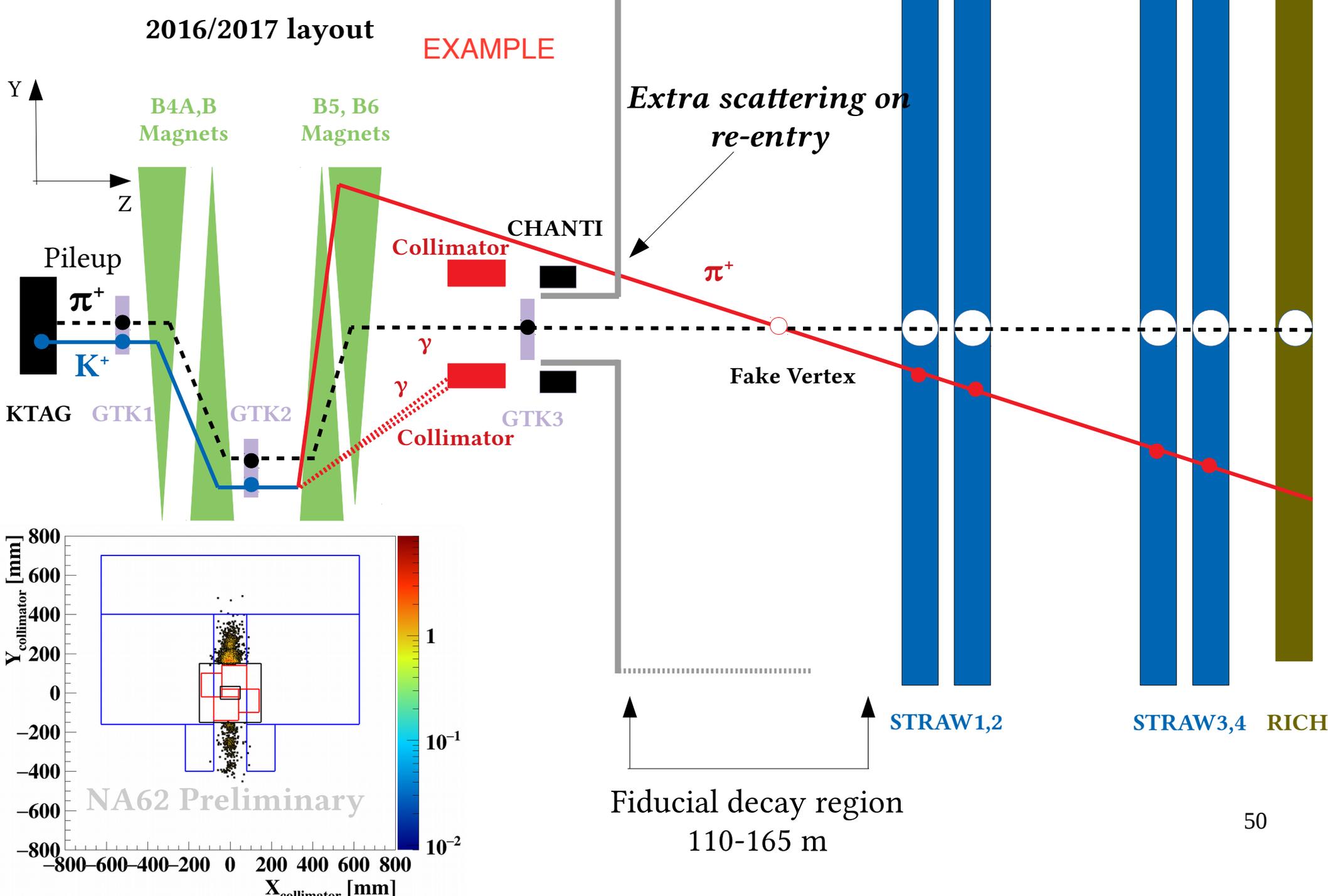
- Sample of  $2 \times 10^9$  MC generated  $K^+ \rightarrow \pi^+\pi^-e^+\nu$  decays used for background estimation
  - ★ Correlation between  $m_{\text{miss}}^2$ , kinematics and multi-track rejection
- MC simulation validated using data
- $K^+ \rightarrow \pi^+\pi^-e^+\nu$  expectation normalized to S.E.S. ( $m_{\text{miss}}^2$  shape well reproduced)



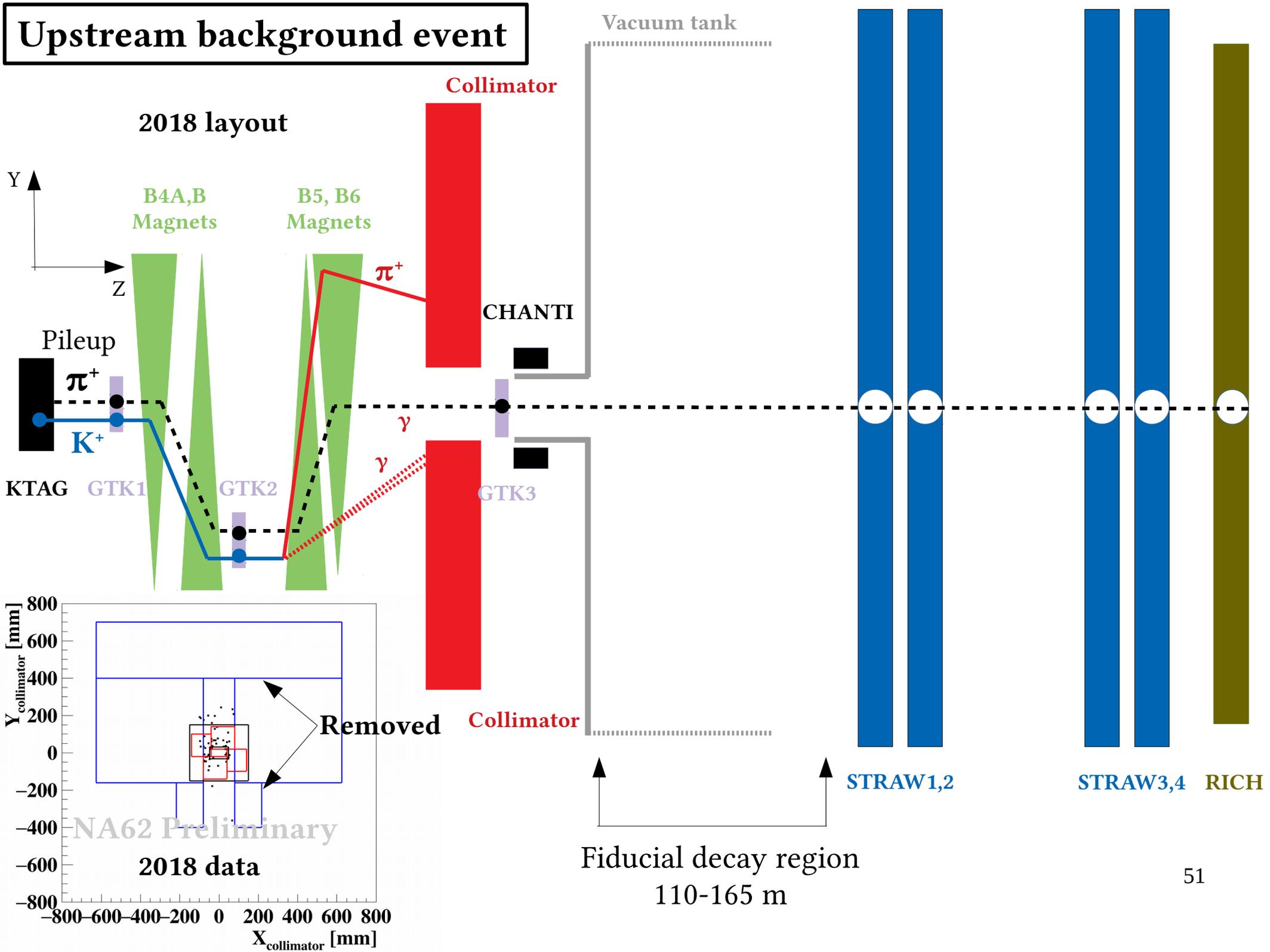
# K<sup>+</sup> decay background summary

Process	Expected events
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ (SM)	$2.16 \pm 0.12_{stat} \pm 0.26_{ext}$
$K^+ \rightarrow \pi^+ \pi^0(\gamma)$ IB	$0.29 \pm 0.03_{stat} \pm 0.03_{syst}$
$K^+ \rightarrow \mu^+ \nu_\mu(\gamma)$ IB	$0.15 \pm 0.02_{stat} \pm 0.04_{syst}$
$K^+ \rightarrow \pi^+ \pi^- e^+ \nu_e$	$0.12 \pm 0.05_{stat} \pm 0.03_{syst}$
$K^+ \rightarrow \pi^+ \pi^- \pi^+$	$0.02 \pm 0.02_{syst}$
$K^+ \rightarrow \pi^+ \gamma \gamma$	$0.005 \pm 0.005_{syst}$
$K^+ \rightarrow l^+ \pi^0 \nu_l$	negligible
Total background	$0.59 \pm 0.06_{stat} \pm 0.06_{syst}$

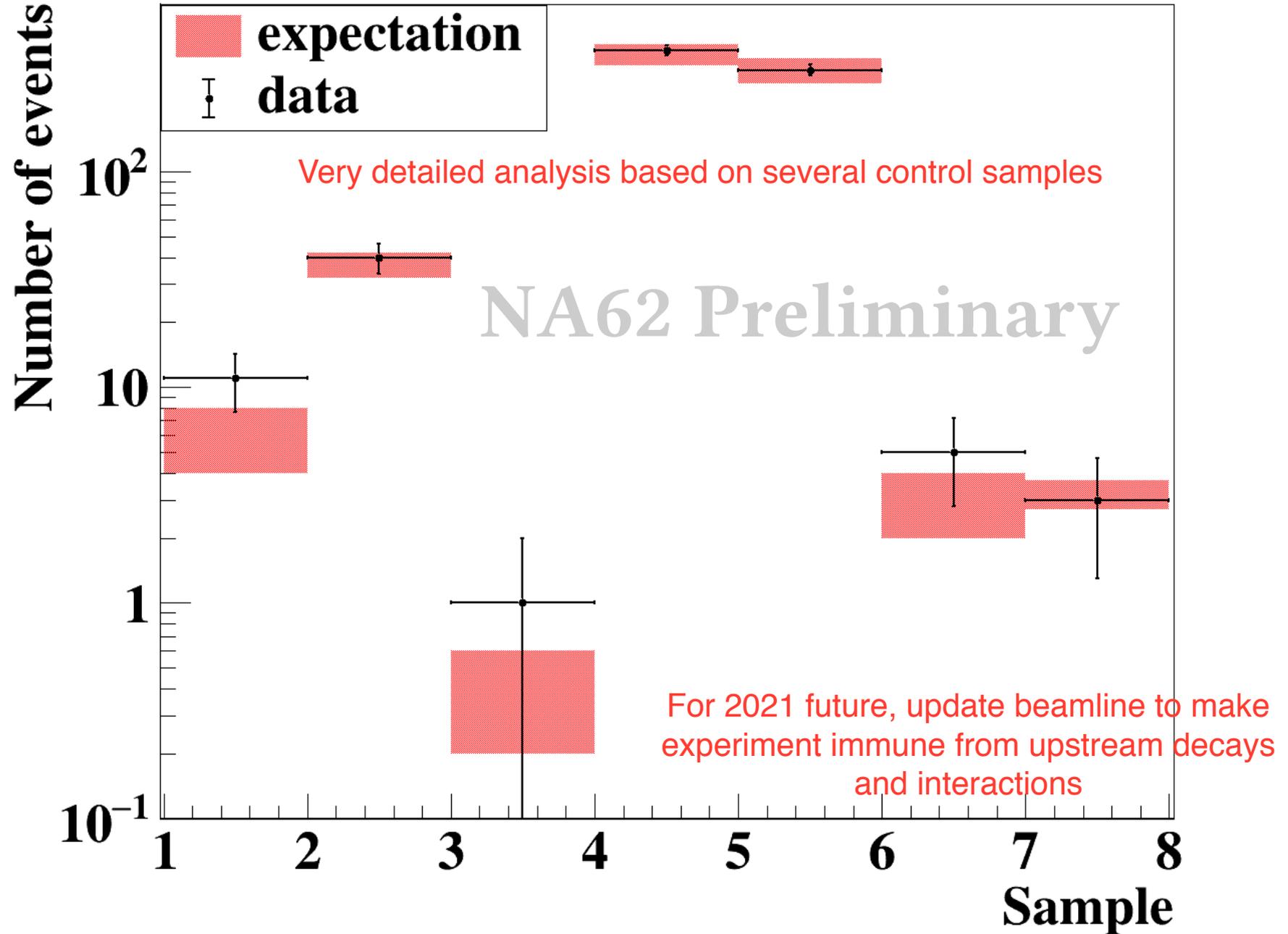
# Upstream background event



# Upstream background event



# Background: Upstream decays validation



# Total expected background

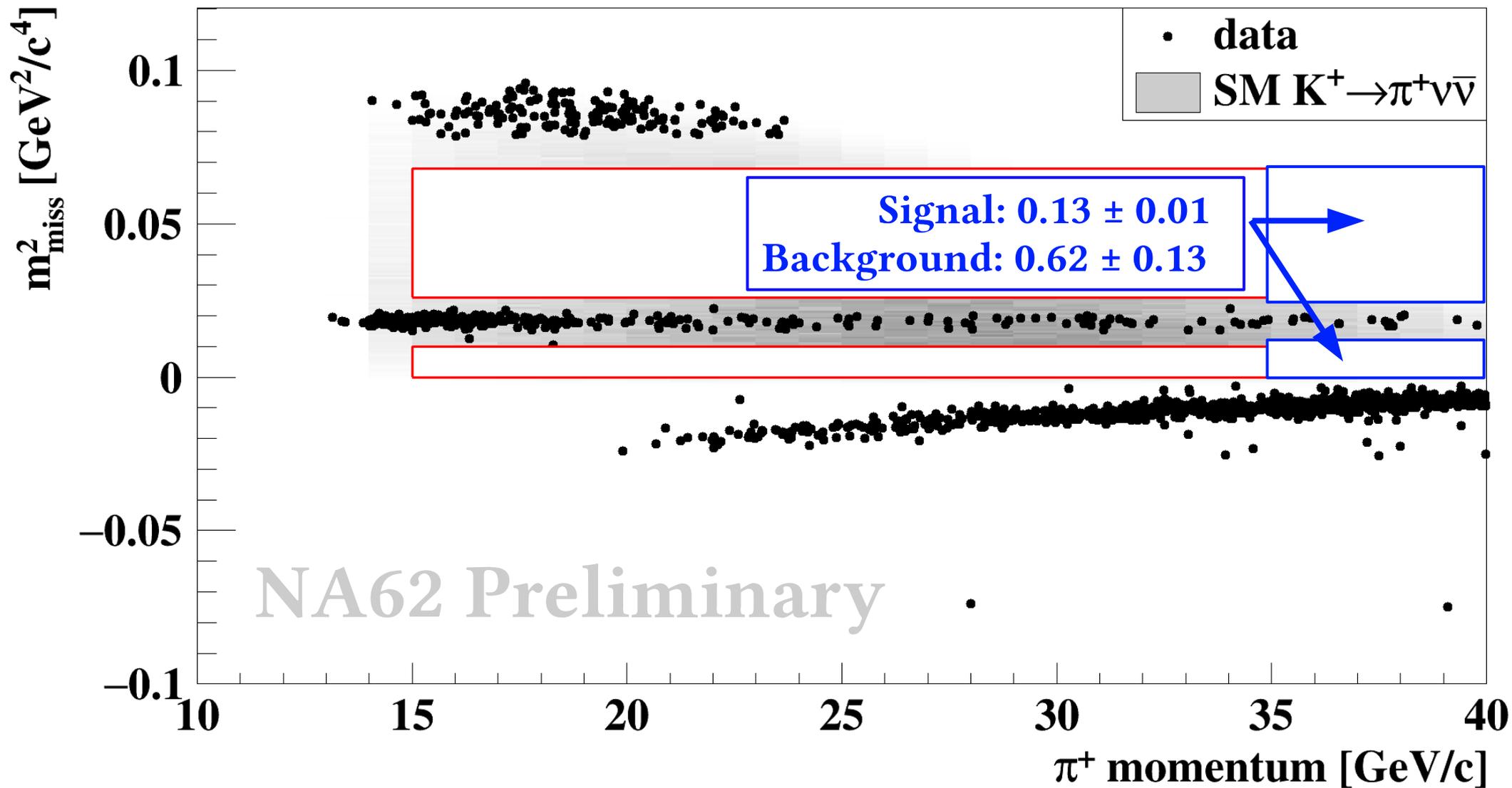
Process	Expected events
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ (SM)	$2.16 \pm 0.12_{stat} \pm 0.26_{ext}$
$K^+ \rightarrow \pi^+ \pi^0(\gamma)$ IB	$0.29 \pm 0.03_{stat} \pm 0.03_{syst}$
$K^+ \rightarrow \mu^+ \nu_\mu(\gamma)$ IB	$0.15 \pm 0.02_{stat} \pm 0.04_{syst}$
$K^+ \rightarrow \pi^+ \pi^- e^+ \nu_e$	$0.12 \pm 0.05_{stat} \pm 0.03_{syst}$
$K^+ \rightarrow \pi^+ \pi^- \pi^+$	$0.02 \pm 0.02_{syst}$
$K^+ \rightarrow \pi^+ \gamma \gamma$	$0.005 \pm 0.005_{syst}$
$K^+ \rightarrow l^+ \pi^0 \nu_l$	negligible
Upstream background	$0.9 \pm 0.2_{stat} \pm 0.2_{syst}$
Total background	$1.5 \pm 0.2_{stat} \pm 0.2_{syst}$

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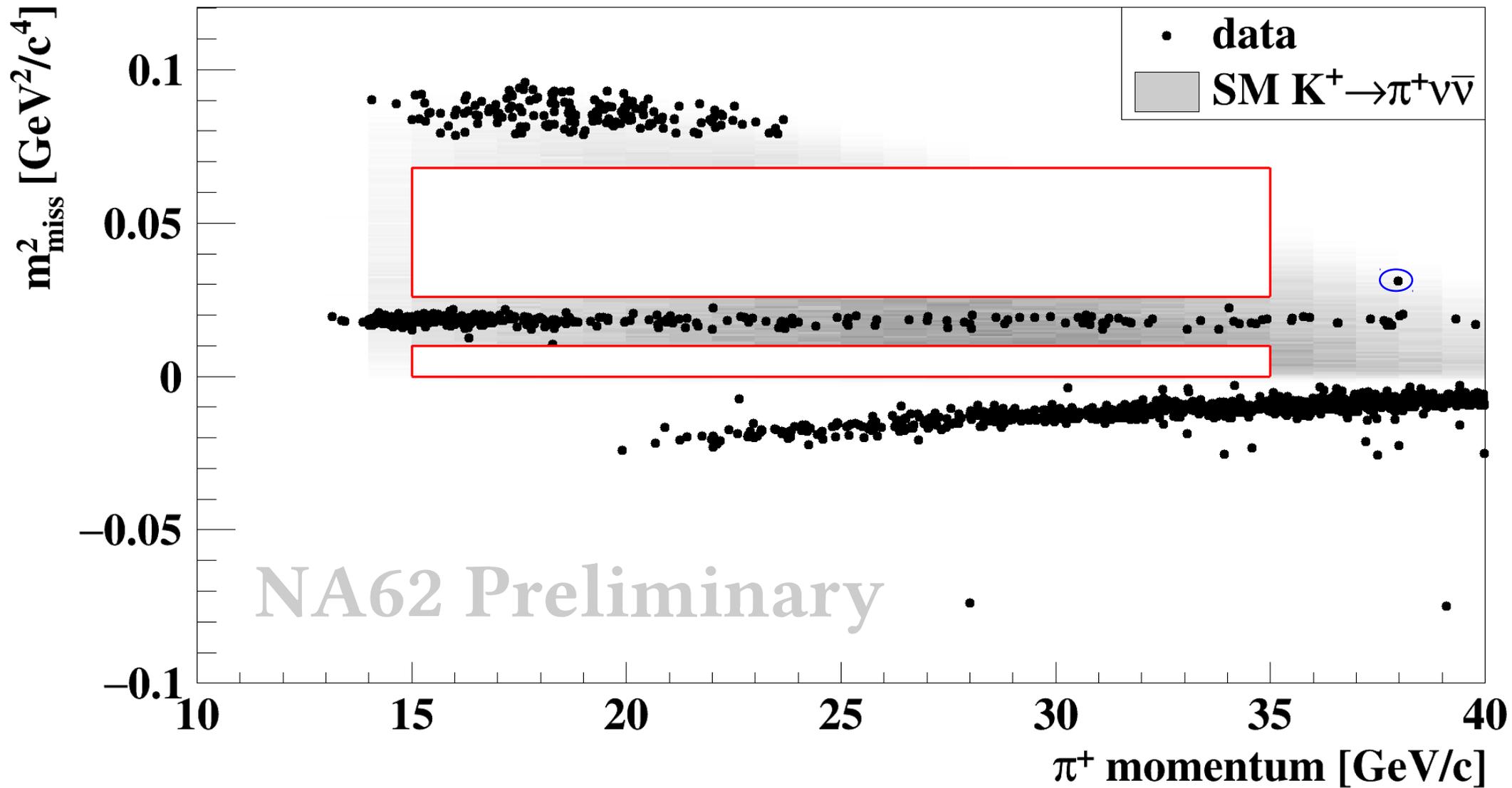
# 4. Unblinding signal regions

# Final background validation

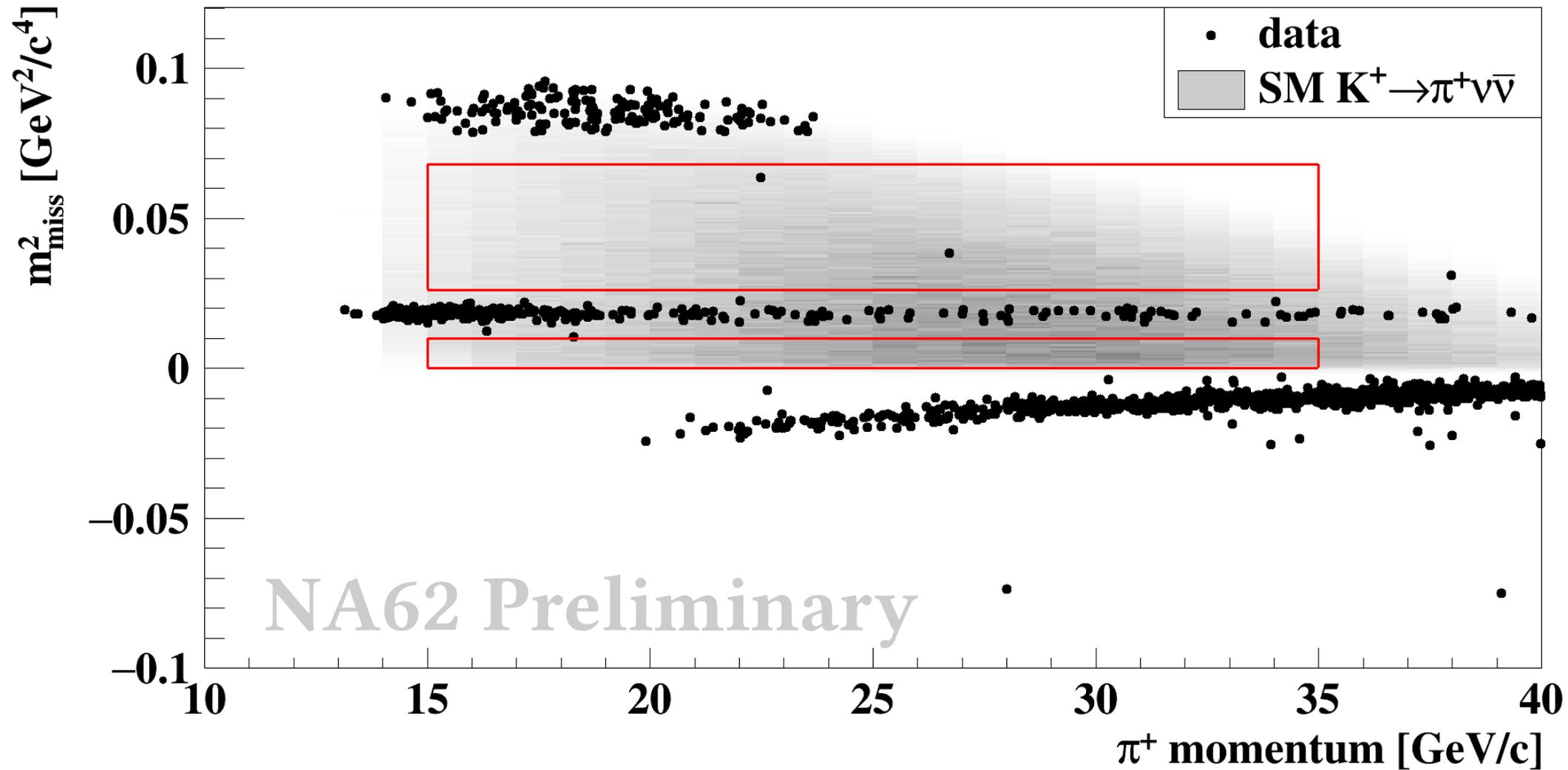
*Signal and background evaluated in the 35-40 GeV/c signal-like region*



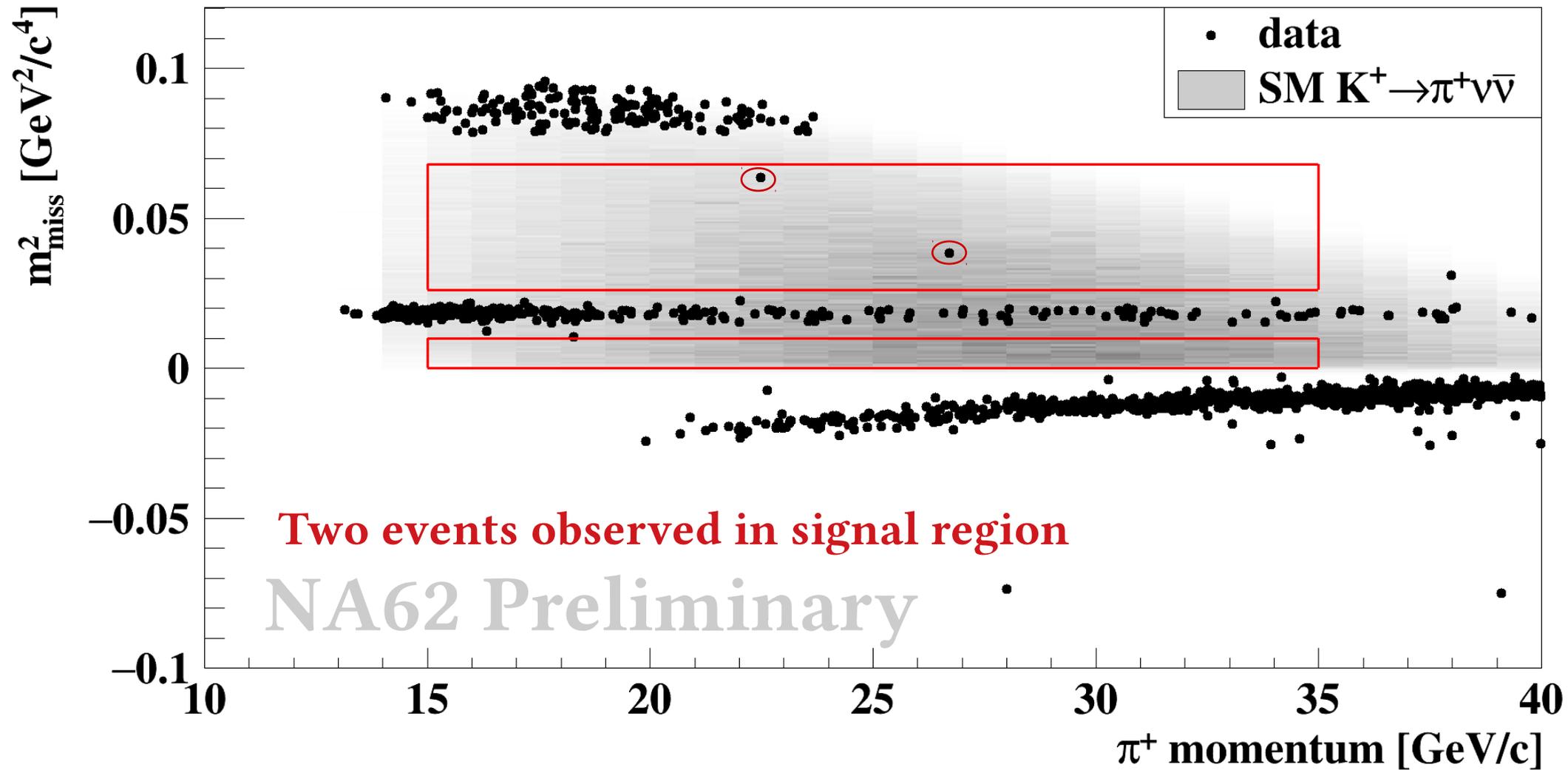
# Final background validation



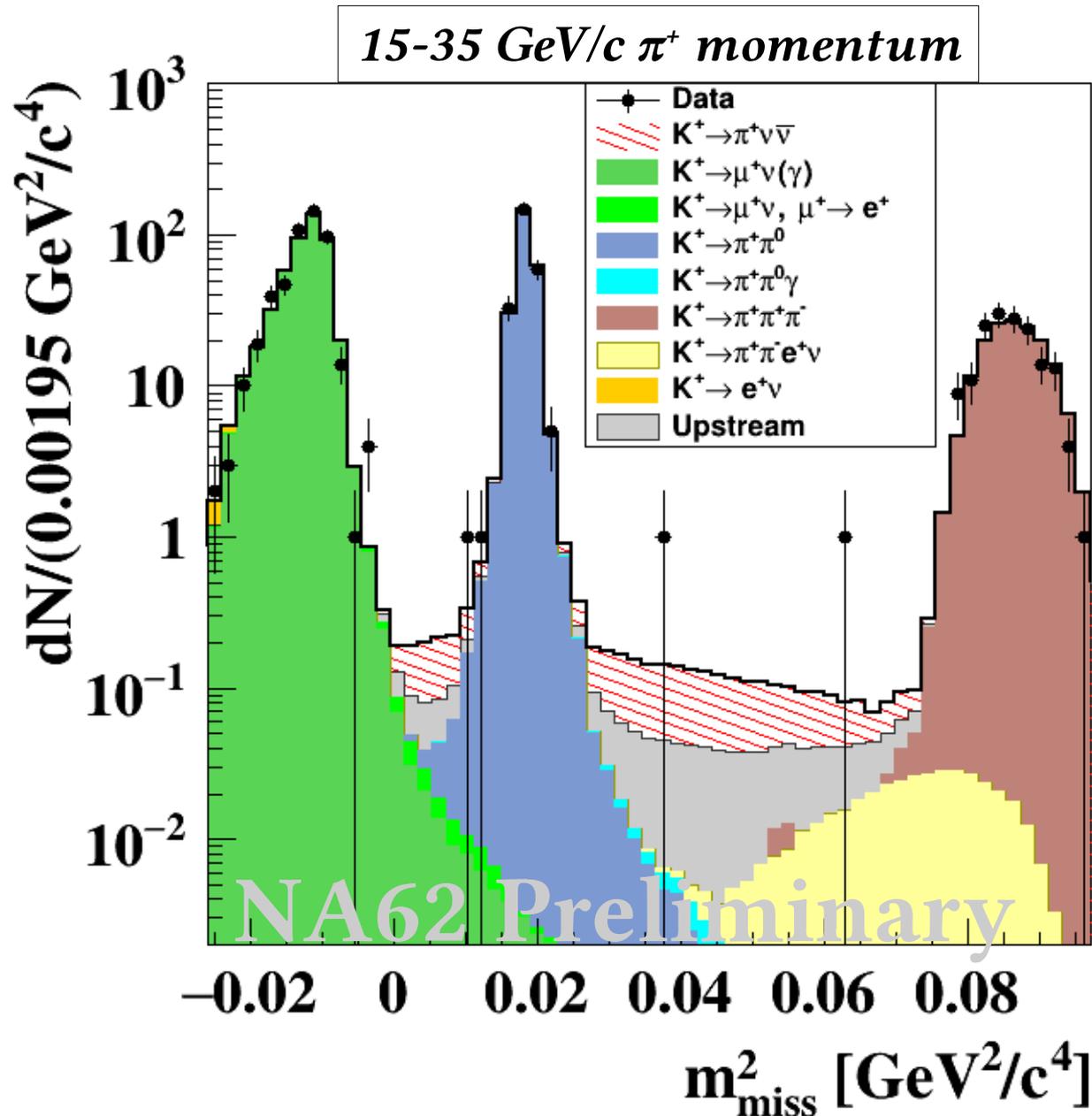
# Opening the box



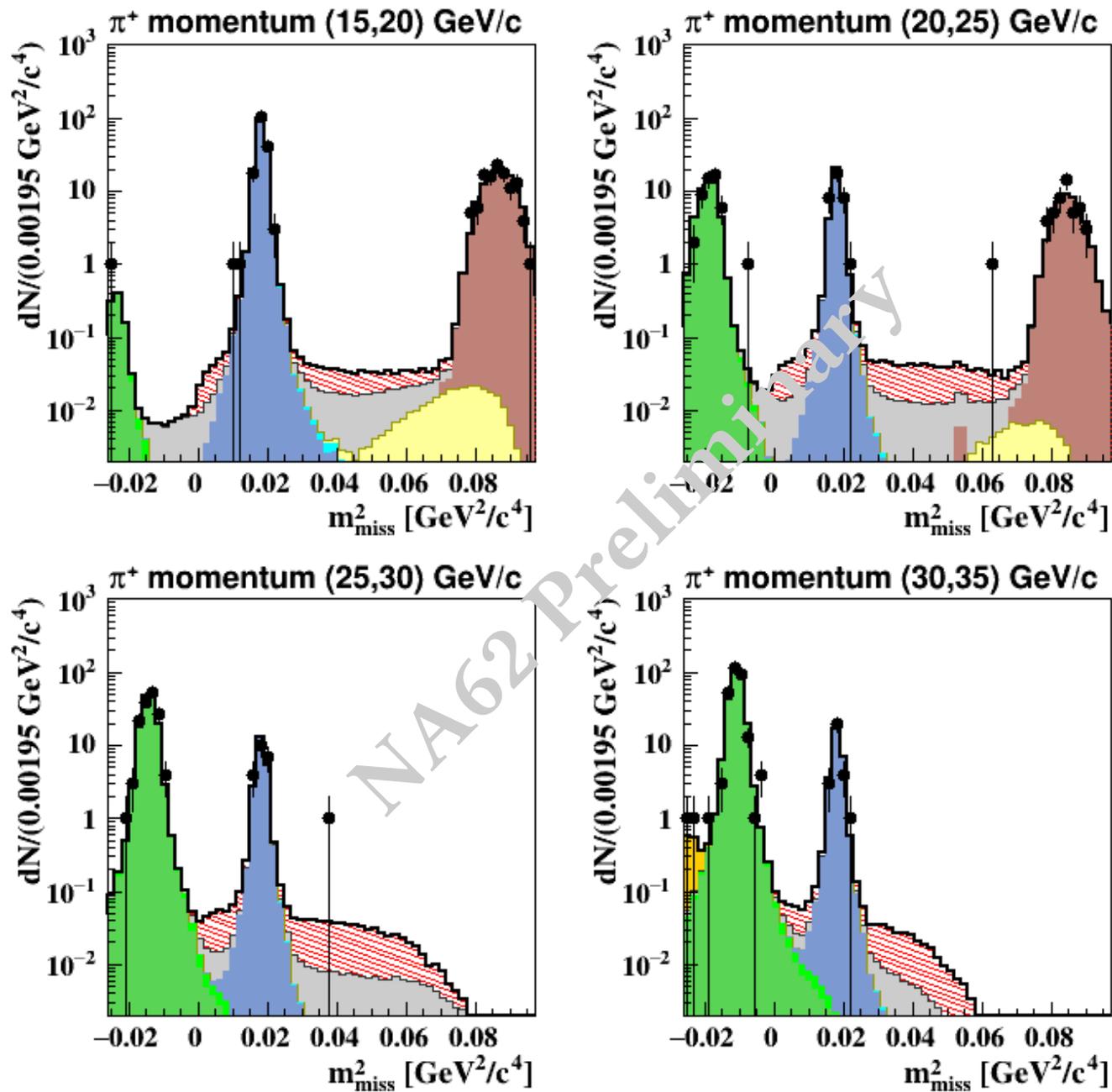
# Opening the box



# $m_{\text{miss}}^2$ signal and background 2017



# $m_{\text{miss}}^2$ signal and background 2017



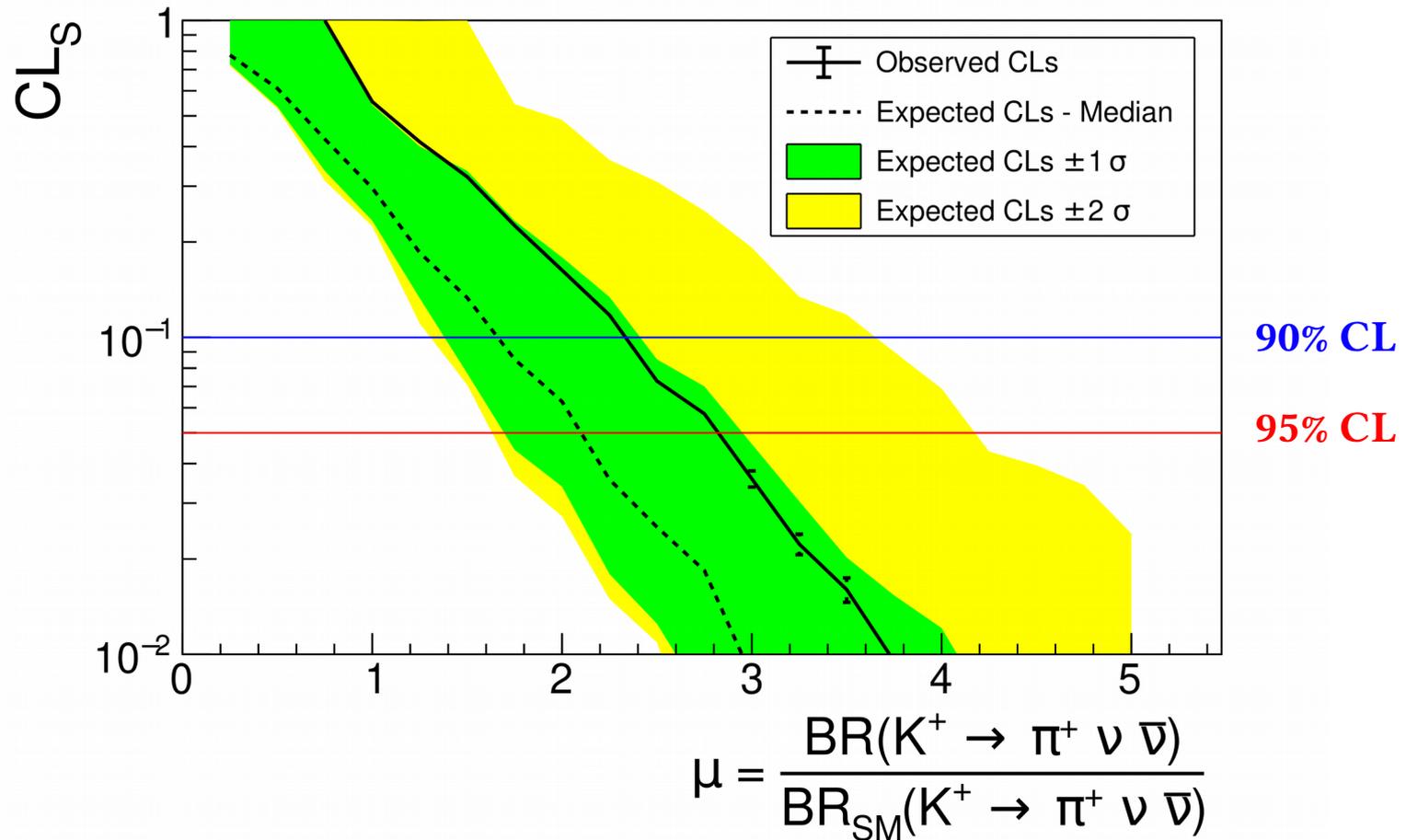
# 2016+2017 result

## Counting experiment:

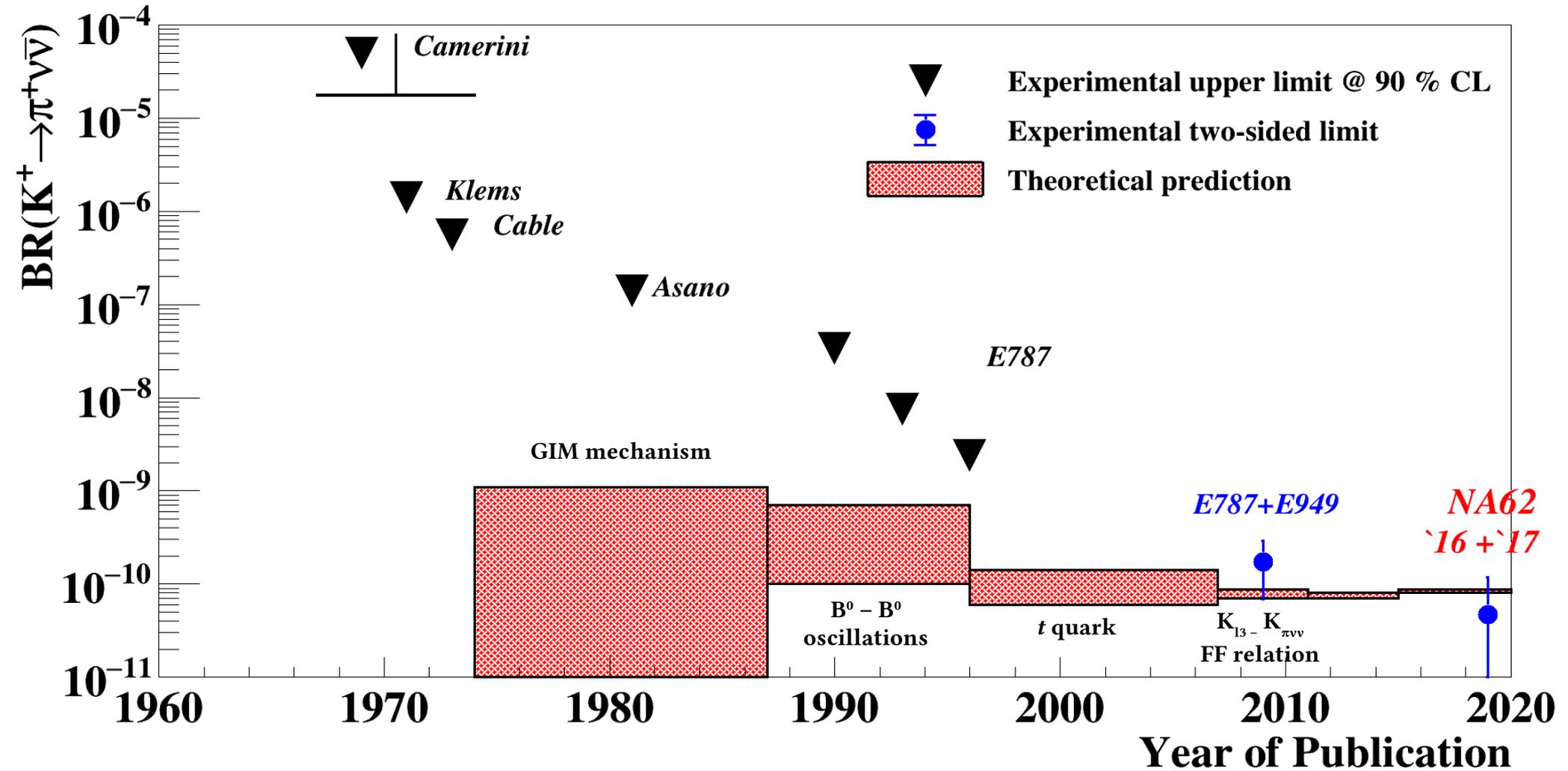
Events observed	3
Single event sensitivity	$(0.346 \pm 0.017) \times 10^{-10}$
Expected background	$1.65 \pm 0.31$

## Two-sided 68% band:

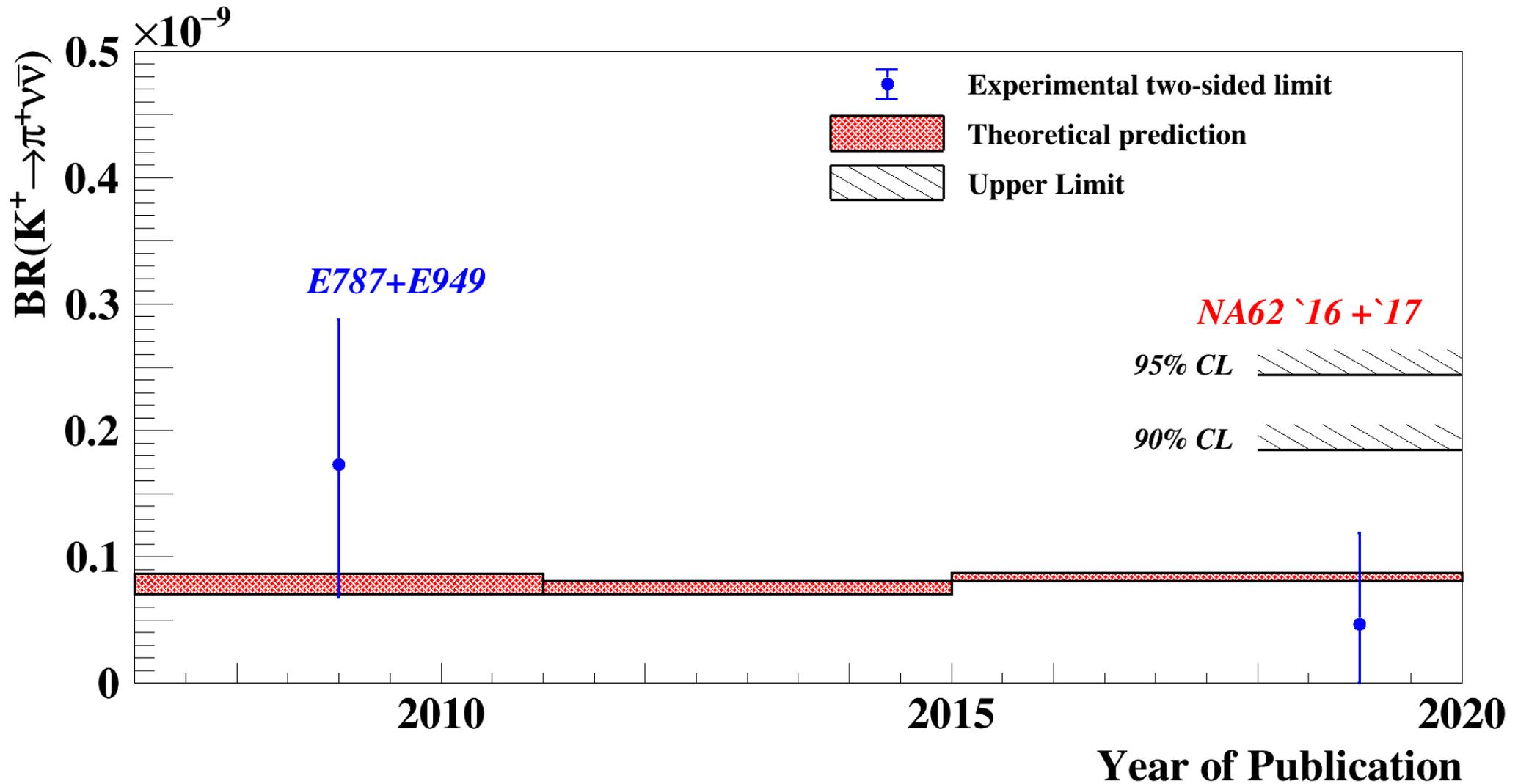
$$\text{Br}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.47^{+0.72}_{-0.47}) \times 10^{-10}$$



# $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ : historical perspective

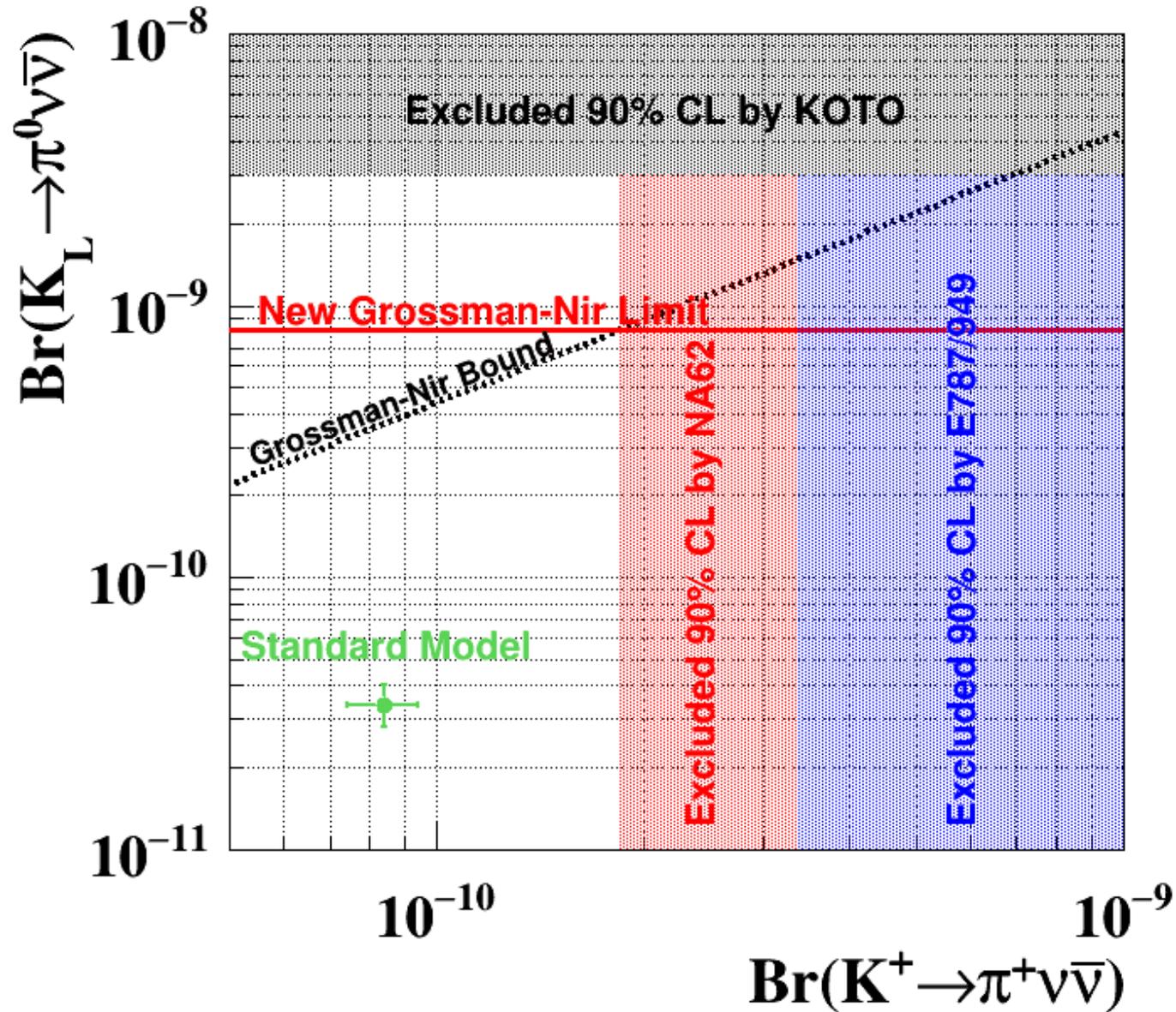


# $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ : historical perspective



# $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ : Grossman – Nir limits

- Grossman – Nir limit:  $\text{Br}(K_L \rightarrow \pi^0 \nu \bar{\nu}) < 8.14 \times 10^{-10}$  @ 90% CL



# Conclusions

---

- Two events in signal region observed in 2017 data
- 2016+2017 NA62 result

$$BR(K^+ \rightarrow \pi^+ \nu\nu) < 1.85 \times 10^{-10} \text{ @ 90 \% CL}$$

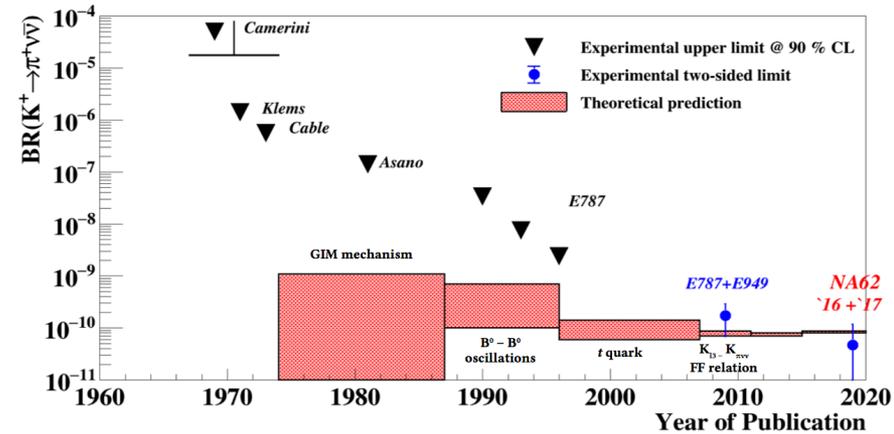
$$BR(K^+ \rightarrow \pi^+ \nu\nu) = 0.47_{-0.47}^{+0.72} \times 10^{-10}$$

- Constraints on the largest enhancements allowed by NP models

2018 Data: Two times more data to be analysed, improved data taking conditions

# NA62 Prospects (Short term)

- Collected so far  $6 \cdot 10^{12}$  Kaon decays:
- 50 (5)  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  (SM) for 10 (1) % acceptance
- Need to run after LS3 to reach “100 events”
- Addendum to run after LS2 Submitted to SPSC
- Running in 2021 recommended for approval



Kinematic selection and geometrical acceptance	0.16
Cut at final collimator against upstream background (box cut)	0.63
Z vertex cut to tighten the sensitive decay volume definition	0.90
Z vertex versus radius cut at Straw chamber against $K \rightarrow 3\pi$ background	0.90
Selection criteria against random veto (RV) in the veto detectors	0.64
Kaon-pion association efficiency	0.75
Particle Identification (PID) efficiency	0.65
Trigger efficiency	0.87
Detector efficiency	0.80
DAQ efficiency	0.75
Overall signal efficiency	0.013

**Target: 100 “SM events”**

**Combined effort to recover acceptance for the data already taken and significantly improve for the 2021 run**

# NA62 & Terra Incognita

## Middle Age

- Griffin, beast
  - A beast with the body of a lion and the wings and head of an eagle
- Hydrus, serpent
  - The enemy of the crocodile, which it kills from the inside
- Mandrake, plant
  - A plant with human-shaped roots, that shrieks when it is pulled from the earth
- Manticore, beast
  - A composite beast with a man's face, a lion's body and the stinger of a scorpion

<http://bestiary.ca/beasts.htm>

## Modern Times

- Heavy Neutral Lepton
  - A RH cousin of the neutrino that may explain dark matter, neutrino mixing and baryogenesis
- Dark Photon
  - Invisible (or visible) heavy photon that may explain the g-2 anomaly and dark matter
- Dark Scalar
  - A minimally coupled scalar field postulated to account for the dark matter
- Axion like particle
  - Something like an extension of the “QCD axion” that couples to EM and strong interactions

I will refer to the comparisons presented in the BSM group of the “Physics Beyond Collider” (PBC) study ([arXiv:1901.09966](https://arxiv.org/abs/1901.09966)) and in the PBC summary ([arXiv:1902.00260](https://arxiv.org/abs/1902.00260))

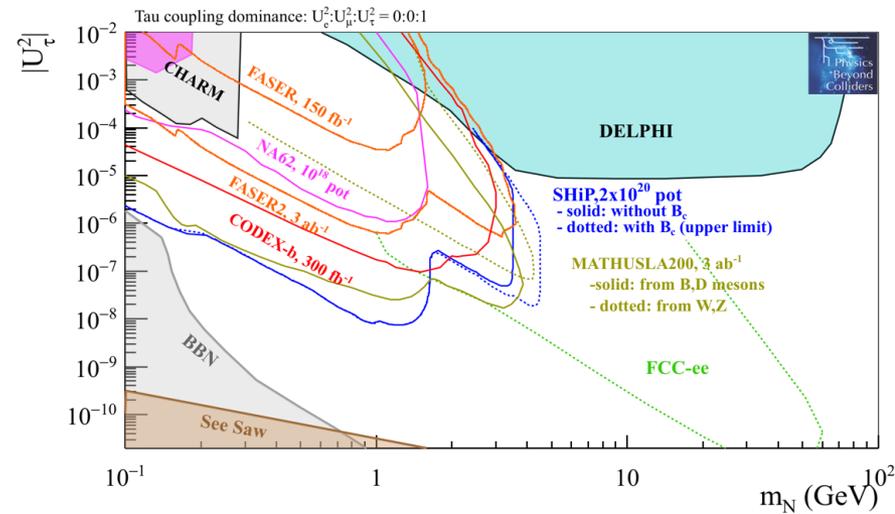
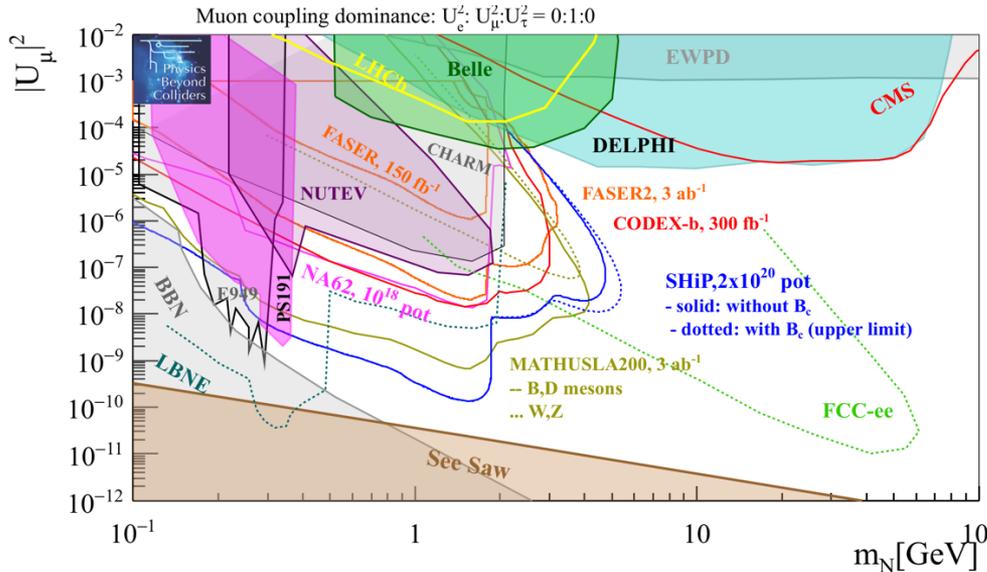
# Heavy Neutral Leptons

Physics Beyond Collider (PBC) Summary: [arXiv:1902.00260](https://arxiv.org/abs/1902.00260)

PBC BSM WG Report: [arXiv:1901.09966](https://arxiv.org/abs/1901.09966)

PBC BC7 Benchmark: HNL coupling to  $\mu$

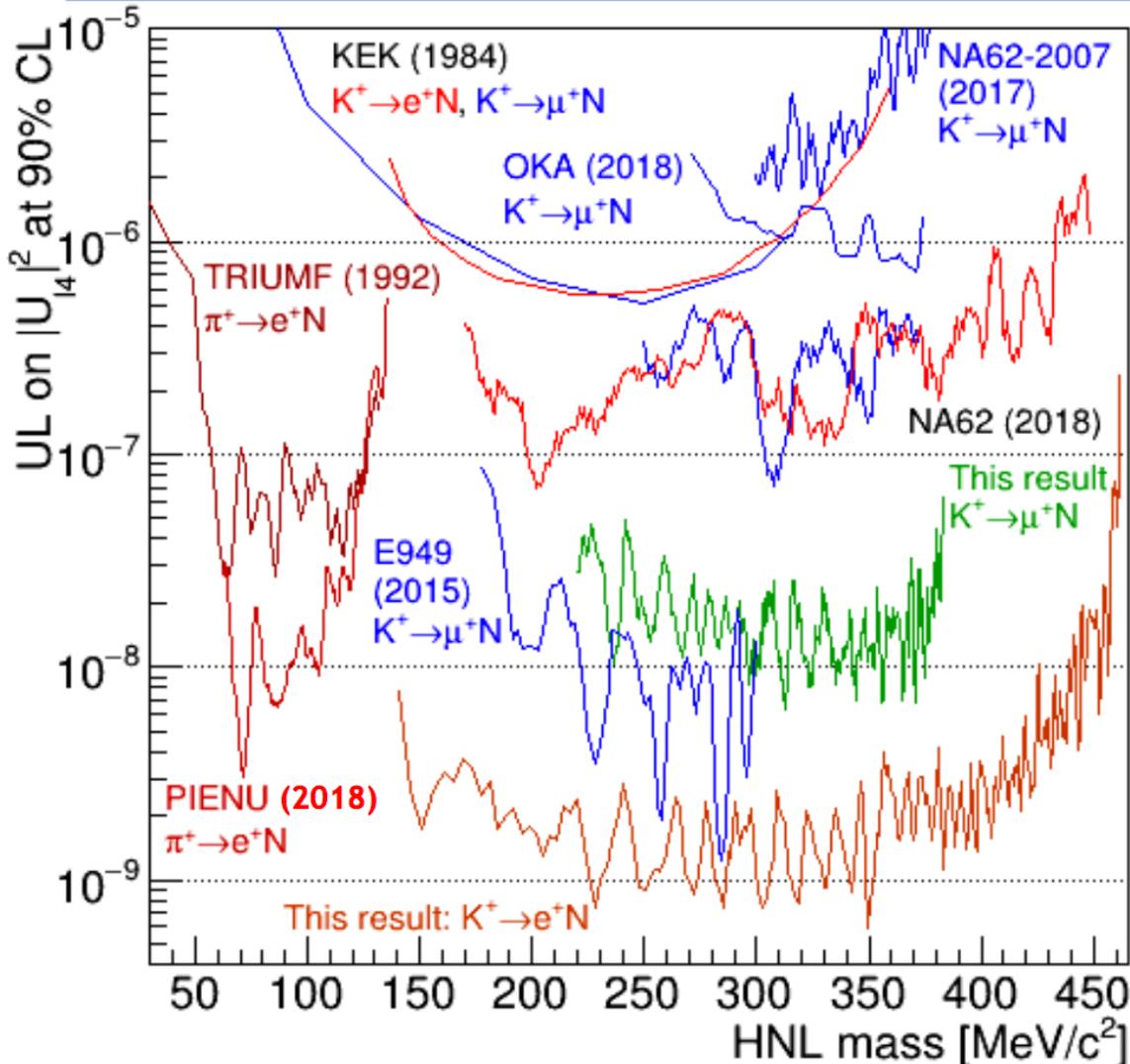
PBC BC8 Benchmark: HNL coupling to  $\tau$



Experiments considered in the PBC study

# HNL production searches: summary

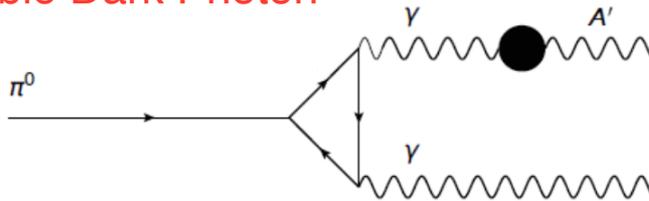
$|U_{\ell 4}|^2$  limits vs  $m_{\text{HNL}}$  from production searches



- ❖ **Preliminary NA62 result** based on  $\sim 1/3$  of the data set.
- ❖ Improvements over earlier production searches by up to two orders of magnitude in terms of  $|U_{\ell 4}|^2$ .
- ❖ In the muon case, sensitivity approaches the E499 one; search extends to **383 MeV/c<sup>2</sup>**.
- ❖ With the full data set, will improve by less than a factor of **2**.

# NA62: $\pi^0 \rightarrow \gamma + A'$ (invisible)

Invisible Dark Photon

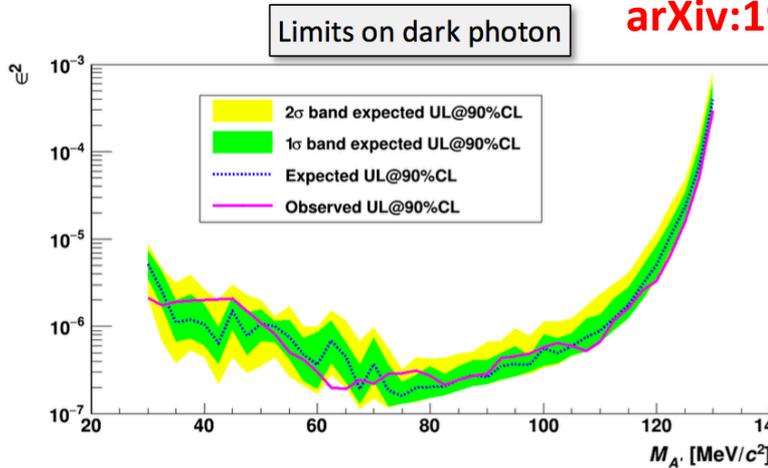
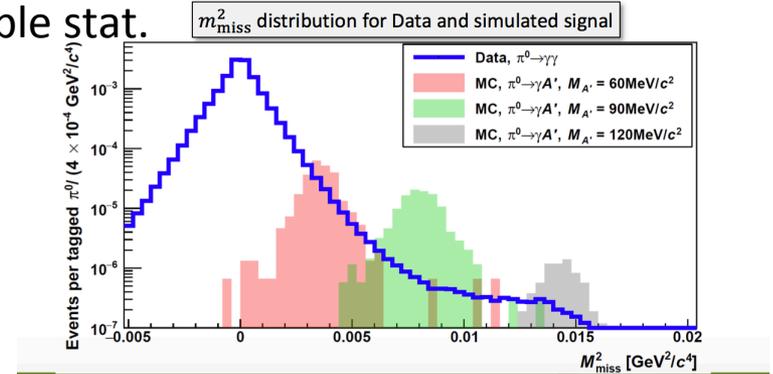


$\sim 4 \cdot 10^8$  tagged  $\pi^0$   
from  $K^+ \rightarrow \pi^+ \pi^0$

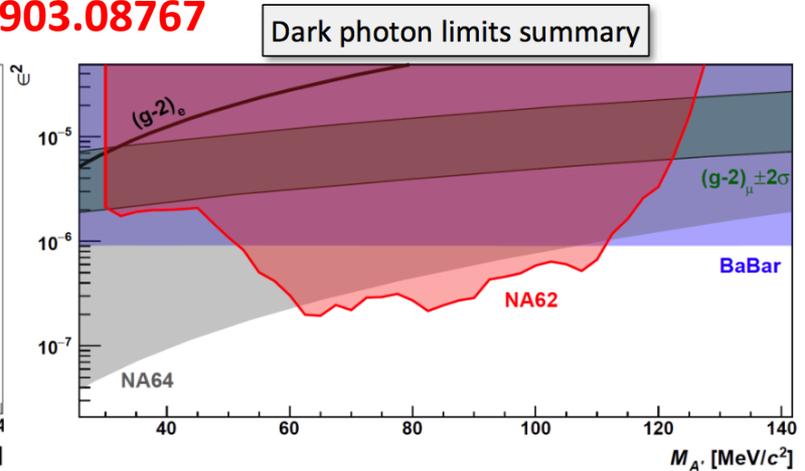
$\sim 1\%$  available stat.

$$m_{\text{miss}}^2 = (\mathbf{P}_K - \mathbf{P}_\pi - \mathbf{P}_\gamma)^2$$

$$\frac{\mathcal{B}(\pi^0 \rightarrow \gamma A')}{\mathcal{B}(\pi^0 \rightarrow \gamma \gamma)} = 2\varepsilon^2 \left(1 - \frac{m_{A'}^2}{m_{\pi^0}^2}\right)^3$$



arXiv:1903.08767



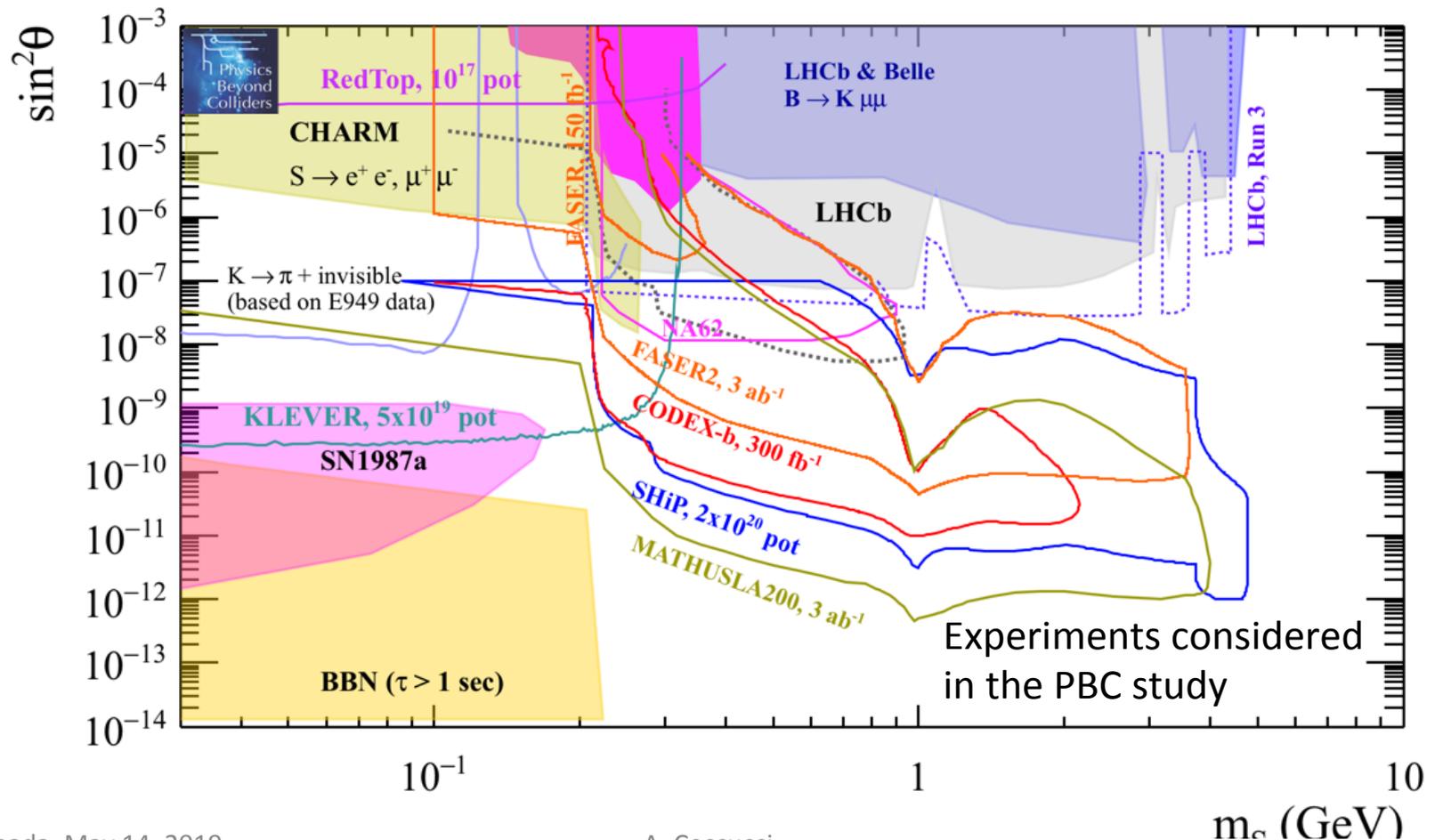
Complementary to searches with electrons

# Dark Scalar

Physics Beyond Collider (PBC) Summary: [arXiv:1902.00260](https://arxiv.org/abs/1902.00260)

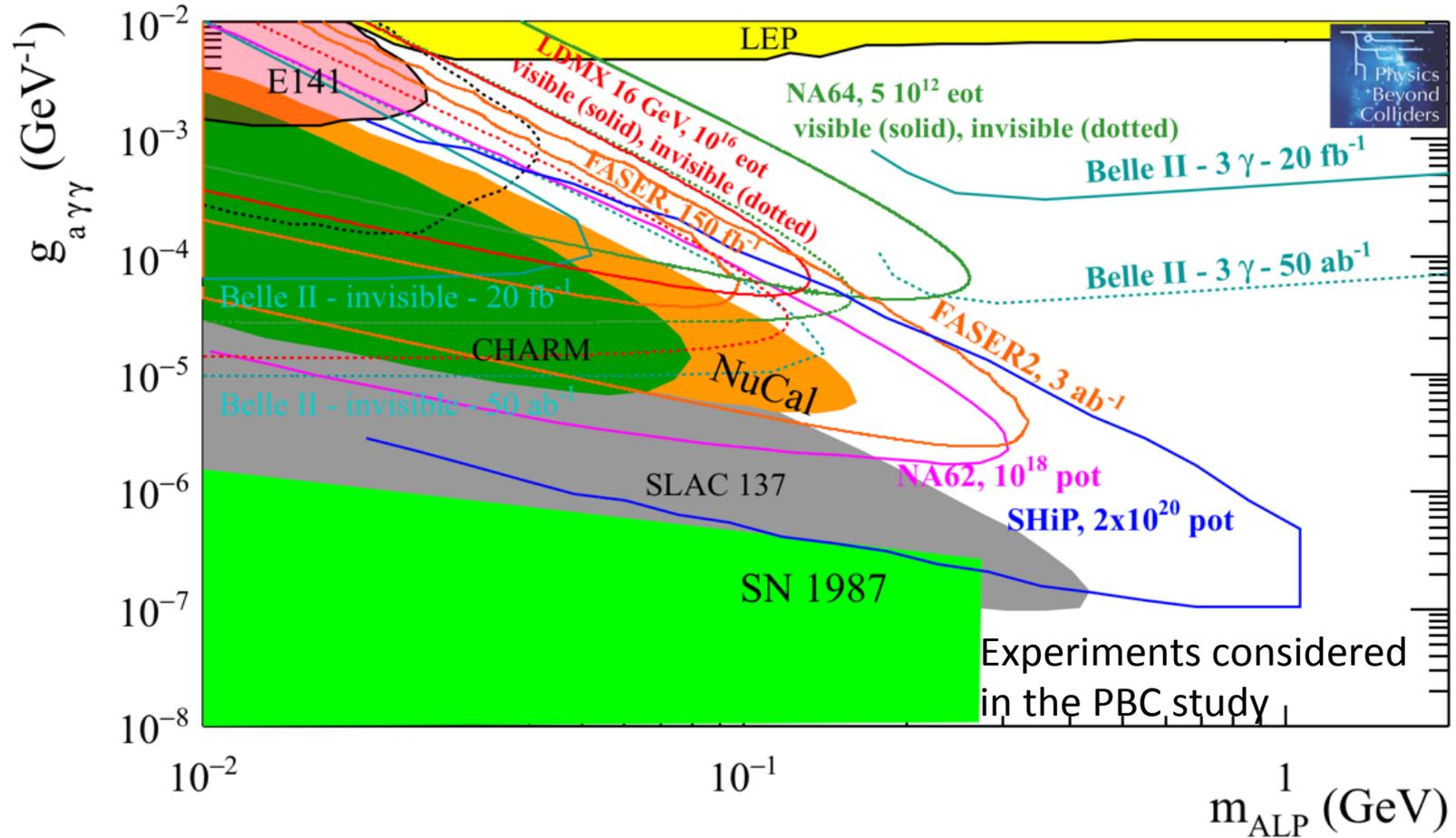
PBC BSM WG Report: [arXiv:1901.09966](https://arxiv.org/abs/1901.09966)

PBC BC4 Benchmark: Dark Scalar



# MeV-GeV Axion Like Particles (ALPs)

PBC BSM WG Report: [arXiv:1901.09966](https://arxiv.org/abs/1901.09966) PBC BC4 Benchmark: Dark Scalar



This plot made for photon couplings, studied also for fermions and gluons

**N.B. What can be explored with accelerators is a tiny fraction of the ALPs parameter space**

# NA62 Prospects (Longer term)

**NA62x4  $K^+ \rightarrow \pi^+ \nu\nu$  [ $\delta\text{Br}/\text{Br} \sim 5\%$ ] ?**

1. Four times more protons as proposed for KLEVER
2. 4D Pixel trackers with  $<50$  ps time resolution/station
3. Large surface fast “massless” trackers
4. High performance EM calorimeters with  $\sim 10$  ns FWHM

**$K_L^0 \rightarrow \pi^0 \nu\nu$  [ $\delta\text{Br}/\text{Br} \sim 20\%$ ] ?**

A  $K_L \rightarrow \pi^0 \nu\bar{\nu}$  experiment at the SPS

**KLEVER**

**KLEVER target sensitivity:**

5 years starting Run 4

60 SM  $K_L \rightarrow \pi^0 \nu\nu$

$S/B \sim 1$

$\delta\text{BR}/\text{BR}(\pi^0 \nu\nu) \sim 20\%$

60  $K_L \rightarrow \pi^0 \nu\nu$  events at SM BR

60 background events

$$\text{Signif.} \approx \frac{S_{\text{obs}} - S_{\text{SM}}}{\sqrt{S_{\text{obs}} + B_{\text{obs}}}}$$

If  $\text{BR}(K_L \rightarrow \pi^0 \nu\nu)$  is:

- Suppressed to  $0.25 \text{ BR}_{\text{SM}} \Rightarrow 5\sigma$
- Enhanced to  $2 \text{ BR}_{\text{SM}} \Rightarrow 5\sigma$
- Suppressed to  $0.5 \text{ BR}_{\text{SM}} \Rightarrow 3\sigma$

# 1. 4D Tracking State-of-the-art: NA62 Gigatracker ( $K^+ \rightarrow \pi^+ \nu\nu$ )



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PUBLISHED: July 12, 2



**The NA62 GigaTracker: a low mass high intensity beam 4D tracker with 65 ps time resolution on tracks**

G. Aglieri Rinella,<sup>a</sup> D. Alvarez Feito,<sup>a</sup> R. Arcidiacono,<sup>e</sup> C. Biino,<sup>e</sup> S. Bonacini,<sup>a</sup> A. Ceccucci,<sup>a</sup> S. Chiozzi,<sup>c</sup> E. Cortina Gil,<sup>b</sup> A. Cotta Ramusino,<sup>c</sup> H. Danielsson,<sup>a</sup> J. Degrange,<sup>a</sup> M. Fiorini,<sup>a,b,c,d</sup> L. Federici,<sup>a</sup> E. Gamberini,<sup>c,d,a</sup> A. Gianoli,<sup>c</sup> J. Kaplon,<sup>a</sup> A. Kleimenova,<sup>b</sup> A. Kluge,<sup>a</sup> R. Malaguti,<sup>c,d</sup> A. Mapelli,<sup>a</sup> F. Marchetto,<sup>e</sup> E. Martín Albarrán,<sup>a,b</sup> E. Migliore,<sup>e</sup> E. Minucci,<sup>b</sup> M. Morel,<sup>a</sup> J. Noël,<sup>a</sup> M. Noy,<sup>a</sup> G. Nüessele,<sup>b</sup> L. Perktold,<sup>a</sup> M. Perrin-Terrin,<sup>a,b,1,2</sup> P. Petagna,<sup>a</sup> F. Petrucci,<sup>c,d</sup> K. Poltorak,<sup>a</sup> G. Romagnoli,<sup>a</sup> G. Ruggiero,<sup>a,3</sup> B. Velghe<sup>b,4</sup> and H. Wahl<sup>d</sup>

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E-mail: [mathieu.perrin-terrin@cern.ch](mailto:mathieu.perrin-terrin@cern.ch)

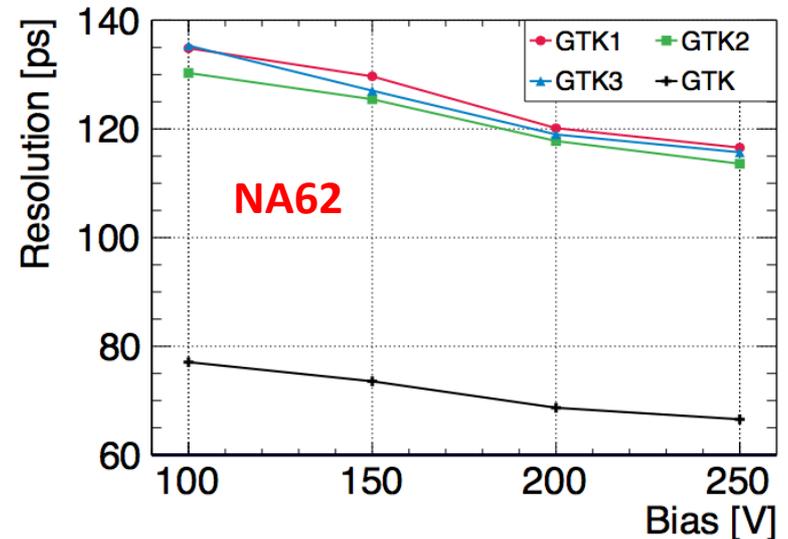
**ABSTRACT:** The GigaTracker (GTK) is the beam spectrometer of the CERN NA62 experiment. The detector features challenging design specifications, in particular a peak particle flux reaching up to 2.0 MHz/mm<sup>2</sup>, a single hit time resolution smaller than 200 ps and, a material budget of 0.5% X<sub>0</sub> per tracking plane. To fulfil these specifications, novel technologies were especially employed in the domain of silicon hybrid time-stamping pixel technology and micro-channel cooling. This article describes the detector design and reports on the achieved performance.

**KEYWORDS:** Particle tracking detectors; Particle tracking detectors (Solid-state detectors); Timing detectors; Detector cooling and thermo-stabilization

ARXIV EPRINT: [1904.12837](https://arxiv.org/abs/1904.12837)

300 x 300 micron<sup>2</sup> time res ~ 65 ps, ~ 0.5% X<sub>0</sub>/station

2019 JINST 14 P07010

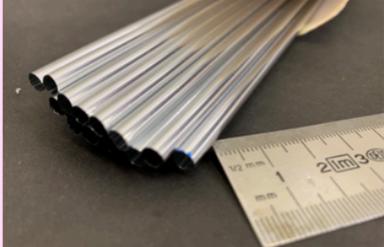


1 GHz hadron beam, intensity limited by tracker performance, not by proton availability  
→ Push time resolution to < 50 ps / station, reduce pixel pitch (e.g. LHCb Upgrade 2?)

## 2. Fast “Massless” tracking

# Straw Tracker Operational in Vacuum

- 🔧 **Key component** : “Thin wall” & “Small diameter” straw tube
- 🔧 NA62 collaboration developed *state-of-the-art* straw by the ultrasonic welding
  - 🔧 COMET collaboration have learned this technique at JINR and tried to develop own straw → For COMET Phase-I (Now under construction)
- 🔧 **Further thinner and smaller straw tube developed recently**
  - 🔧 Time to consider to develop the **new tracker** using **new straw** !!

	NA62	COMET Phase-I	New Straw
Straw Wall Thickness	36 $\mu\text{m}$	20 $\mu\text{m}$	12 $\mu\text{m}$
Straw Diameter	9.8 mm	9.8 mm	4.8 mm
Metal Deposition	Cu+Au, 70nm	Al, 70 nm	Al, 70 nm
Photo			
Current Status	In Operation	Under Construction	Just Developed

# Avenues towards the discovery of new physics

Jorgen D'Hondt Muon Collider Workshop Oct 9-11

	2020-2040 <i>HL-LHC era</i>	2040-2060 <i>Z/W/H/top-factory era</i>	2060-2080 <i>energy frontier era</i>
precision frontier	H couplings to few % $\nu$ mass/mixing/nature QGP phase-transition b/c-physics	H couplings to % EW & QCD & top QGP vs Lattice QCD b/c/ $\tau$ -physics	H couplings to % H self-coupling to % proton structure di-boson processes
NA62 breaking the SM	next-gen K-beams proton precision e & n EDM lepton flavor ( $\mu \rightarrow e$ )	p EDM storage rings	rare top decays small-x physics
NA62 direct searches	Beam Dump Facility eSPS (light DM) Long-Lived Signals / ALPs DM vs neutrino floor	heavy neutral lepton	new high-mass part. next-gen hidden exp. low-mass DM

# Hopefully the main message will come through

**This is what we should be doing in the medium term!**

Well motivated, competitive, cost-effective options, making good use of CERN's existing complex, beams, and expertise.

And NA62x4 → 5% ( $K^+$ )

## Rare decays and precise measurements

KLEVER ( $K_L^0 \rightarrow \pi^0 \nu \nu$ )

TauFV@BDF:  $\tau \rightarrow 3\mu$

REDTOP ( $\eta$  decays)

MUonE (hadronic vacuum polarization for ( $g-2_\mu$ ))

EDM proton storage ring

## Long-lived particles from LHC collisions

FASER, MATHUSLA, CODEX-b, milliQAN

## Other facilities:

$\gamma$ -factory from Partially Stripped Ions;

nuSTORM

## QCD measurements

COMPASS++, DIRAC++

NA61++, NA60++

Fixed target (gas, crystals) in ALICE & LHCb

## Non-accelerator projects

Exploit CERN's technology (RF, vacuum, magnets, optics, cryogenics) for experiments possibly located in other labs.

E.g. axion searches: IAXO (helioscope), JURA (Light Shining through Wall)

## Hidden sector with "beam dumps"

NA61++ (e, $\mu$ )

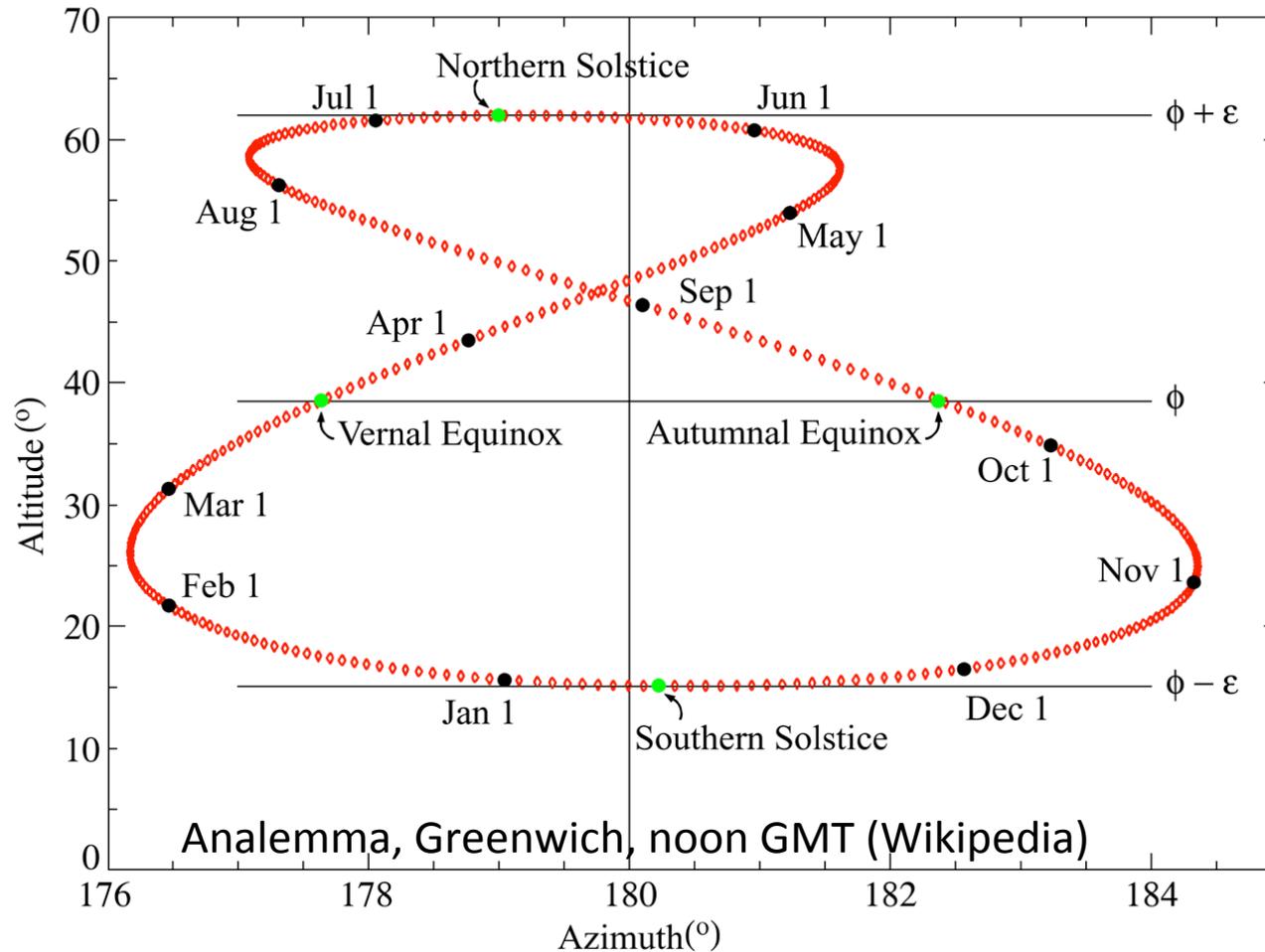
NA62++

Beam Dump Facility at North Area (SHiP)

LDMX@eSPS

AWAKE++

# Summary: NA62 and the Solstice



**Winter Solstice is the best moment to take stock, reflect and plan for the future, NA62 (and its sequels) will be ready to attack SM and explore the unknown for the years to come**