Kaon Experiments at CERN
Recent Results and Prospects

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NuFact 2016
ICISE, Quy Nhon, August 21-27, 2016

Outline

- **The Kaon Factory at CERN**
- **NA48/n & NA62: brief history**
- **Tests of SM and search for New Physics**
  - Measurement of R_K
  - Lepton Flavour/Number Violation studies
  - Search for two-body resonances
  - Search for Heavy Neutrino production
- **The $K^+ \to \pi^+ \nu \bar{\nu}$ decay**
  - Motivation and strategy of the measurement
  - Performance during the 2015 run
  - Status and future prospects
- **Summary and Outlook**

The Kaon Factory at CERN

- ➔ Precision measurements in the minimal flavour laboratory
- ➔ Many Kaon decays can proceed, or are enhanced, by contributions from new physics particles
  - ✓ study explicit Violations of SM, such as LFV/LNV
  - ✓ probe the flavour sector by means of FCNC
  - ✓ test of fundamental symmetries such as CP and CPT
  - ✓ study of strong interaction at low energy in exclusive processes

  ➔ Ideal environment to search for New Physics
- ➔ The CERN Kaon physics programme
  - ➔ The main goal of the NA62 experiment is the measurement of the Branching Ratio of the $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ decay
  - ➔ Many other physics opportunities

Kaons at CERN

NA48
Main goal: Search for direct CPV
Measurement of ε'/ε
Beams: K_L / K_S

NA48/1
Main goal: Rare K_S decays and hyperon decays, CPV tests
Beams: K_S

NA48/2
Main goal: Search for direct CPV
Charge asymmetry measurement
Beams: K^+ / K^-

NA48

1997
2001
2002
2003
2004
2007
2008
2014
2018

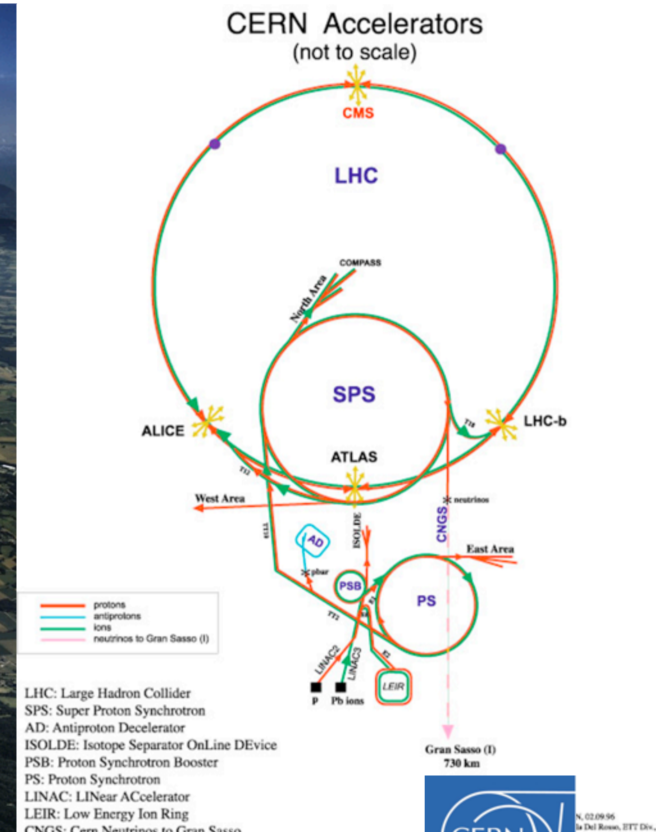
NA31 (1984-1990)
First evidence of direct CPV
Beams: K_L / K_S

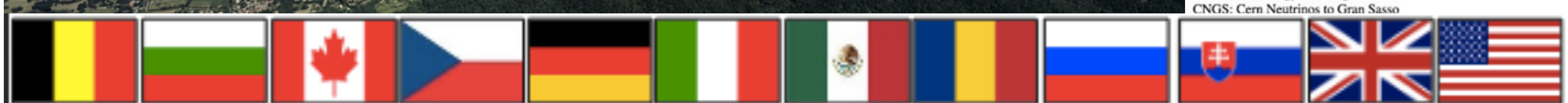
NA62

NA62 - R_K
Main goal: Test of μ-e universality R_K measurement
Beams: K^+ / K^-

NA62
Main goal: Rare kaon decays, measurement of $K^+ \to \pi^+\nu\bar{\nu}$
Beam: K^+

The NA48 and NA62 experiments



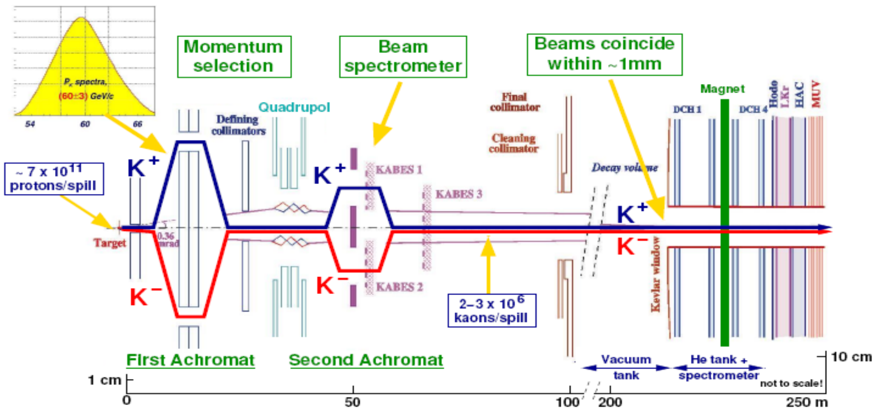


CERN

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow(INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP), Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver(UBC) → ~ 200 participants

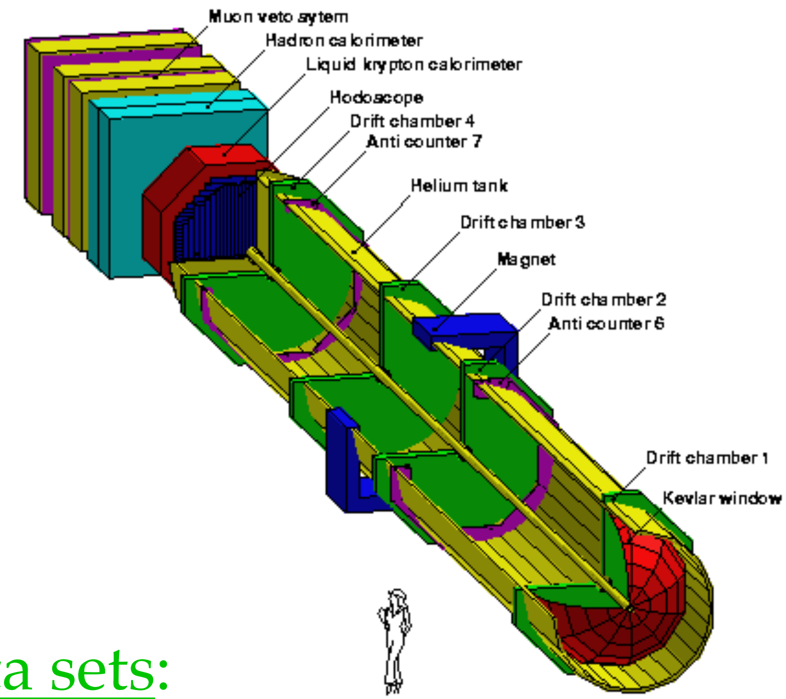
Test of μ-e universality
Measurement of
$R_K = \Gamma(K_{e2}) / \Gamma(K_{\mu 2})$

R_K - Detector and data taking



	2003-2004	2007
Kaon momentum	60 ± 3 GeV/c	74 ± 1 GeV/c
Momentum kick	120 MeV/c	265 MeV/c

Same detector for NA48/2 and NA62



Main detector components:

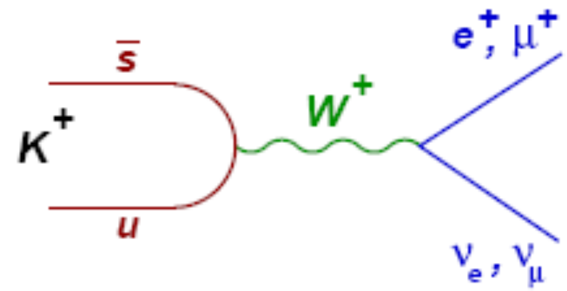
- Magnetic spectrometer (4 DCHs):
  4 views: redundancy ⇒ efficiency
  $\sigma(p)/p = 1.02\% + 0.044\%\ p\ [GeV/c]$ (2003)
  $\sigma(p)/p = 0.48\% + 0.009\%\ p\ [GeV/c]$ (2007)
- Hodoscope: fast trigger and
  precise time measurement (150ps)
- Liquid Krypton e.m. calorimeter:
  High granularity, quasi–homogeneous
  $\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]
- Hadron calorimeter, photon vetos, muon veto counters

Data sets:

- NA48/2: six months in 2003–04
- NA62-R_K: four months in 2007

R_K *in the SM*

Leptonic decays of light pseudoscalar mesons
not directly usable due to hadronic uncertainties



measure the ratio

- hadronic uncertainties cancel
- R_K very well predicted within the SM, well below 10^{-3}
- K_{e2} strongly helicity suppressed (V-A coupling)

→ enhanced sensitivity to non-SM effects

[V. Cirigliano and I. Rosell, Phys. Rev. Lett. (2007) 231801]

$$R_K = \frac{\Gamma\left(K^\pm \to e^\pm \nu_e\right)}{\Gamma\left(K^\pm \to \mu^\pm \nu_\mu\right)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \left(1 + \delta R_{QED}\right) = \left(2.477 \pm 0.001\right)\cdot 10^{-5}$$

helicity suppression ~10^{-5} radiative corrections

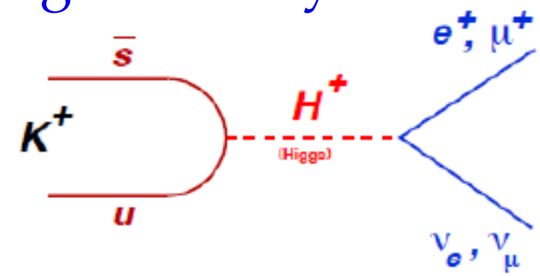
radiative corrections R_{QED} (few %) due to the IB part of the radiative decay $K^\pm \to e^\pm \nu\gamma$ are included in R_K definition and well computed in the SM

R_K beyond the SM

In several SM extensions, the presence of LFV terms introduces extra contribution to the SM amplitude, enhancing the decay rate

2HDM – tree level

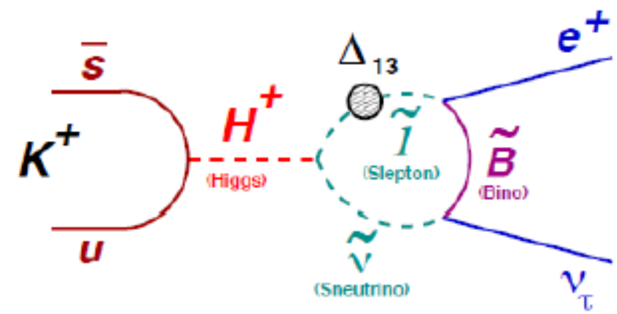
$K^{\pm} \longrightarrow l^{\pm}\nu$ can proceed via charged Higgs, $H^{\pm}$, exchange $\longrightarrow$ does not affect R_K



2HDM – one-loop level

Dominant contribution to R_K: $H^{\pm}$ mediated LFV with emission of ν_τ

$\longrightarrow R_K$ enhancement can be experimentally accessible



$$R_K^{LFV} = \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma_{LFV}(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}$$

[Fonseca, Romao and Teixeira, EPJC (2012) 2228]

$$R_K^{LFV} \approx R_K^{SM}\left[1 + \left(\frac{m_K^4}{m_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)\left|\Delta_{13}\right|^2 \tan^6\beta\right]$$

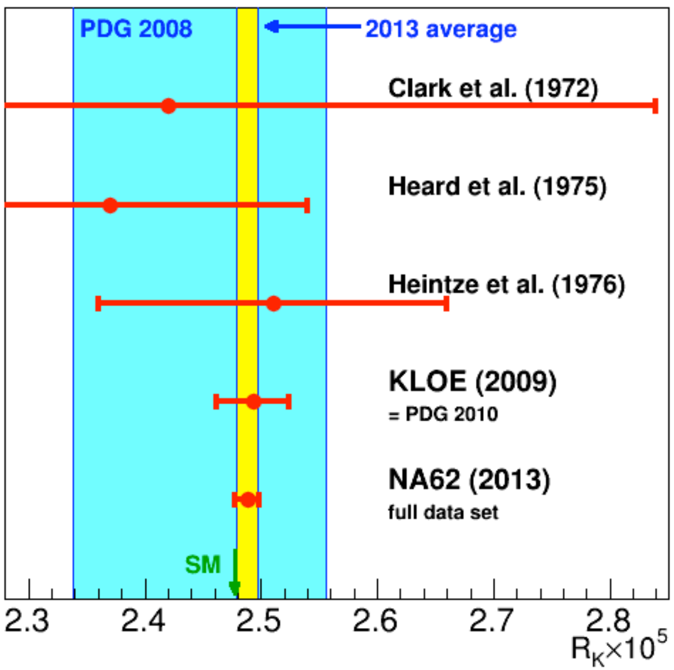
[Masiero, Paradisi, Petronzio, PRD 74, 2006]
[Lacker and Menzel, JHEP (2010) 006]
[Abada et al., JHEP 1302 (2013) 048]

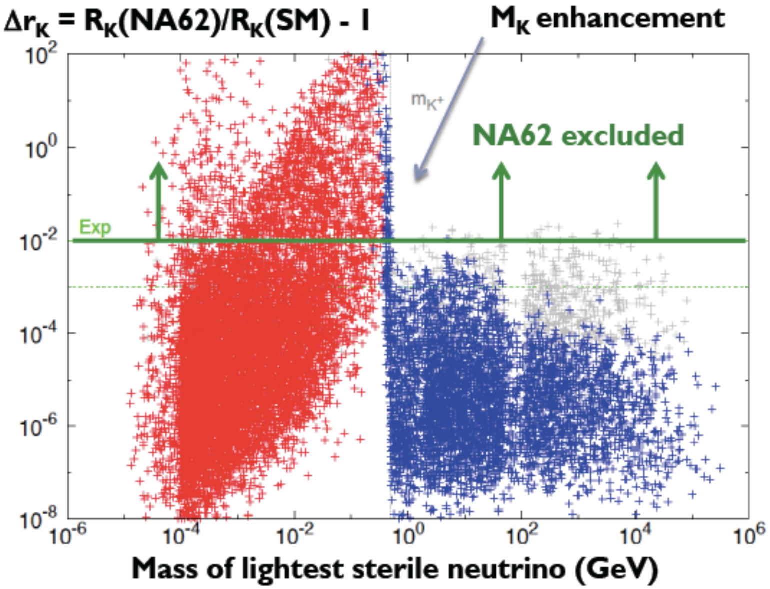
R_K final result

$$R_K = \left(2.488 \pm 0.007_{stat} \pm 0.007_{syst}\right) \cdot 10^{-5}$$

Phys Lett B 719 (2013) 326

- World Ke2 statistics increased by a factor of 10
- In agreement with SM expectation, within 1.2 σ
- Motivation for improved precision R_K measurem





[Abada et al., JHEP 1402 (2014) 091]

World average	R_K x 10^5	precision
PDG 2008	2.447 ± 0.109	4.5%
2014	2.488 ± 0.009	0.4%

Prospects: NA62 → 1 M events (downscaled trigger) expected (2 years data taking), statistical uncentainty ~ 0.1% → Total uncertainty expected ~ 0.2%

The $K^{\pm} \rightarrow \pi^{\mp}\mu^{\pm}\mu^{\pm}$ decay
Search for LNV
and 2-body resonances

Interest and motivation

Asaka-Shaposhnikov model (νMSM) [PLB 620 (2005) 17]

- 3 sterile neutrinos, N_i, added in the SM to explain: dark matter and baryon asymmetry in the Universe
- The lightest (N_1, mass $\mathcal{O}$(keV)) is a dark matter candidate
- $N_{2,3}$, mass $\mathcal{O}$(100 MeV - few GeV), responsible for neutrino mass and BAU
- Active - sterile neutrino mixing described by U matrix
- In $K^{\pm}$ decays, for $m_{2,3} < m_K - m_\mu$

$$K^{\pm} \to \mu^{\pm} N; \qquad N \to \pi^{\pm}\mu^{\mp} \qquad\qquad BR(K^{\pm} \to \mu^{\pm} N) \times BR(N \to \pi^{\pm}\mu^{\mp}) \sim |U_{\mu 4}|^4$$

Shaposhnikov-Tkachev model [PLB 639 (2006) 414]

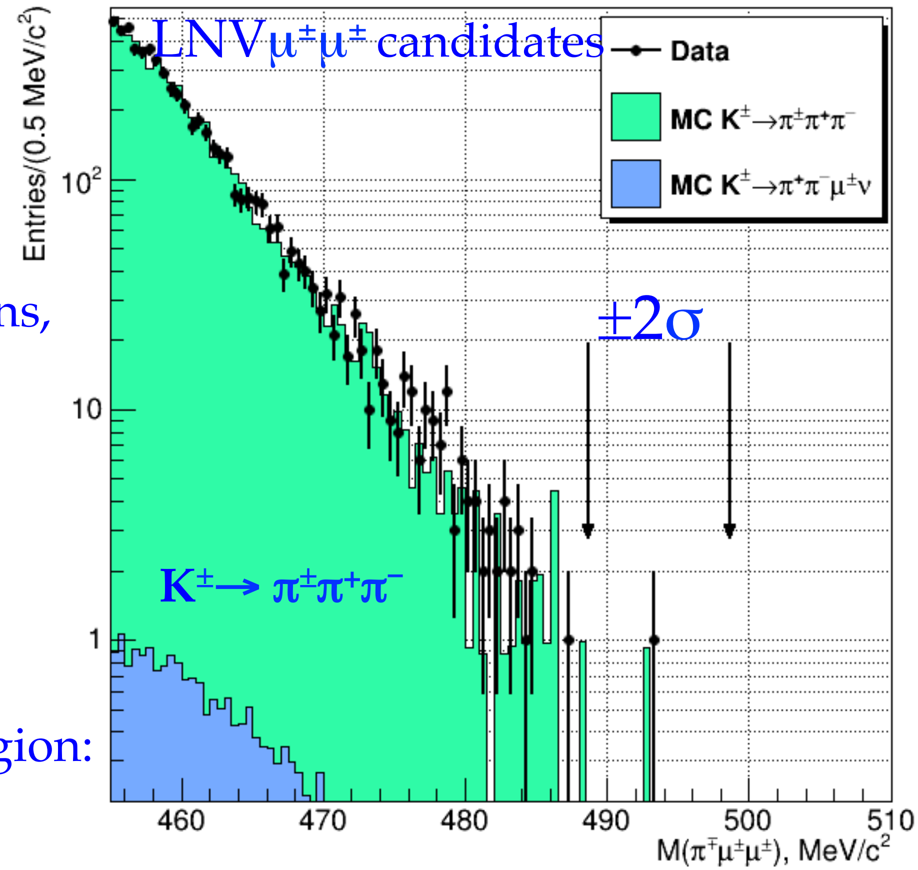
- νMSM + real scalar field (inflaton χ) with scale-invariant couplings to explain Universe homogeneity and isotropy
- χ - Higgs mixing (θ), χ unstable $\tau \sim 10^{-8} - 10^{-12}$ s
- Production in Kaon decays for $m_\chi < 354$ MeV / c^2

$$BR(K^{\pm} \to \pi^{\pm}\chi) = 1.3 \times 10^{-3} \left(\frac{2|\vec{p}_\chi|}{M_K} \right) \theta^2$$

LNV - Same Sign muon sample

Blind analysis

- Selection based on simulation of $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$ and $K^\pm \to \pi^\pm \pi^+ \pi^-$ (background, $\pi \to \mu$, similar topology)
- 3-track vertex topology, 2-same sign muons, 1 odd-sign pion, no missing momentum, muon ID
- Signal region: $|M_{\pi\mu\mu} - M_K| < 5$ MeV/c^2
- Control region: $M_{\pi\mu\mu} < 480$ MeV/c^2



Result

Number of Kaon decays in fiducial decay region: 1.64×10^{11} (from reconstructed $K^\pm \to \pi^\pm \pi^+ \pi^-$)

Events in signal region: $N_{obs} = 1$

Expected background (from MC): $N_{exp} = 1.16 \pm 0.87$

$BR(K^\pm \to \pi^\mp \mu^\pm \mu^\pm) < 8.6 \times 10^{-11}$ @ 90% CL

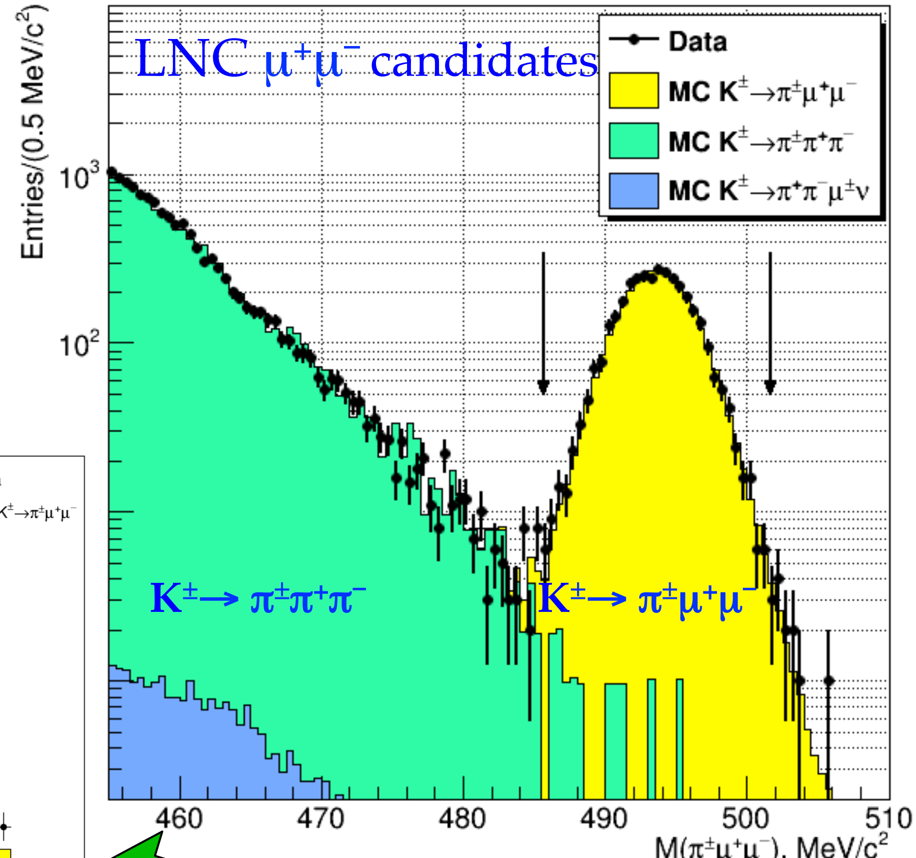
Rolke-Lopez statistical treatment

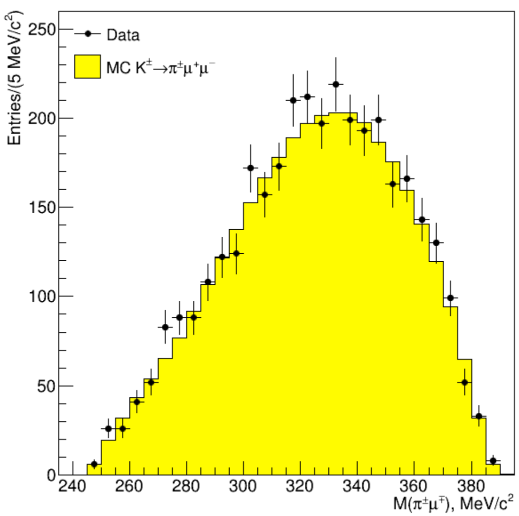
factor of ~ 13 improvement, paper in preparation

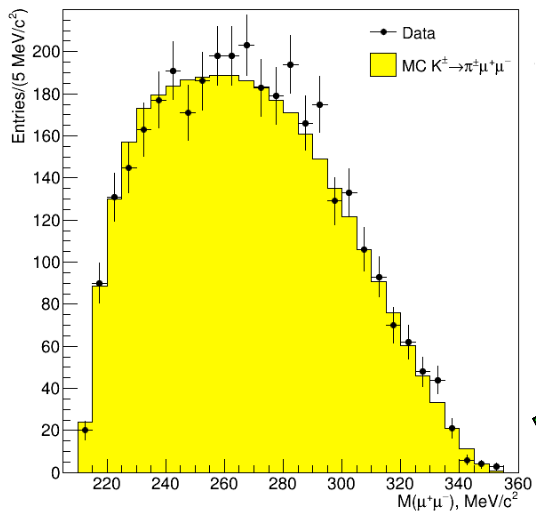
LNC - Opposite Sign muon sample

Selection

- Similar to same sign sample
- 3-track vertex topology, 2-opposite sign muons, 1 pion, no missing momentum, muon ID
- Signal region: $|M_{\pi\mu\mu} - M_K| < 8$ MeV/c^2







To be scanned searching for peaks in invariant masses

Result

Events in signal region: $N_{obs} = 3489$, Background: $(0.36 \pm 0.10)\%$

Improved selection wrt published NA48/2 measurement of BR and FF [PLB 697 (2011)107]

LNV and LNC resonance search

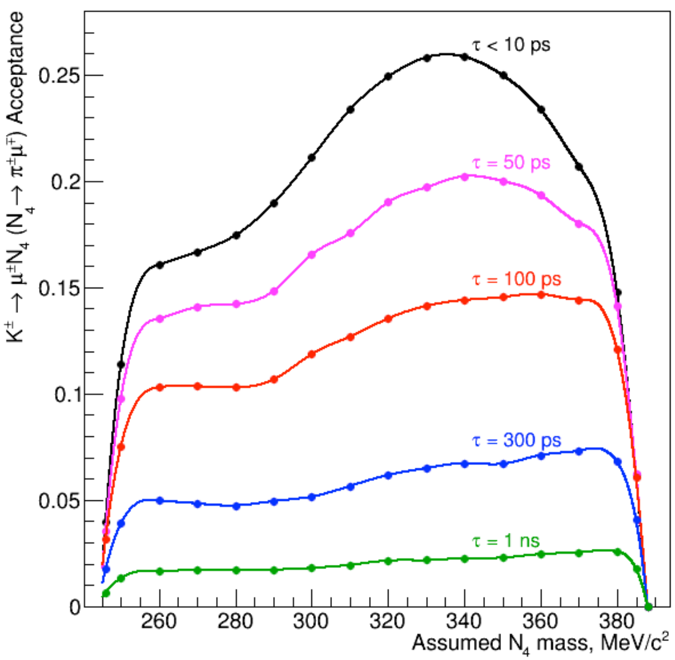
- Peak search on πμμ candidates performed assuming different mass hypotheses
- For each mass hypothesis (M_{res}), observed events in data (N_{obs}) vs expected events from MC (N_{exp}) gives UL (signal) (Rolke-Lopez statistical treatment)

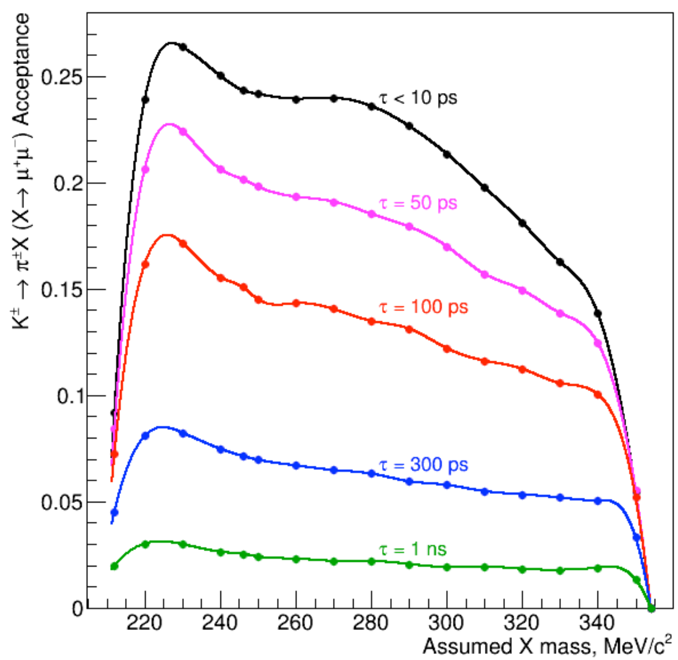
LNV - Majorana neutrinos in $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$

- 284 M_{res} tested, two possibility, closest invariant mass to M_{res} considered

Search for resonances in $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$

- Both invariant mass $M(\pi^{\pm}\mu^{\mp})$ and $M(\mu^{+}\mu^{-})$ are probed with 267, 280 hypoteses resp.



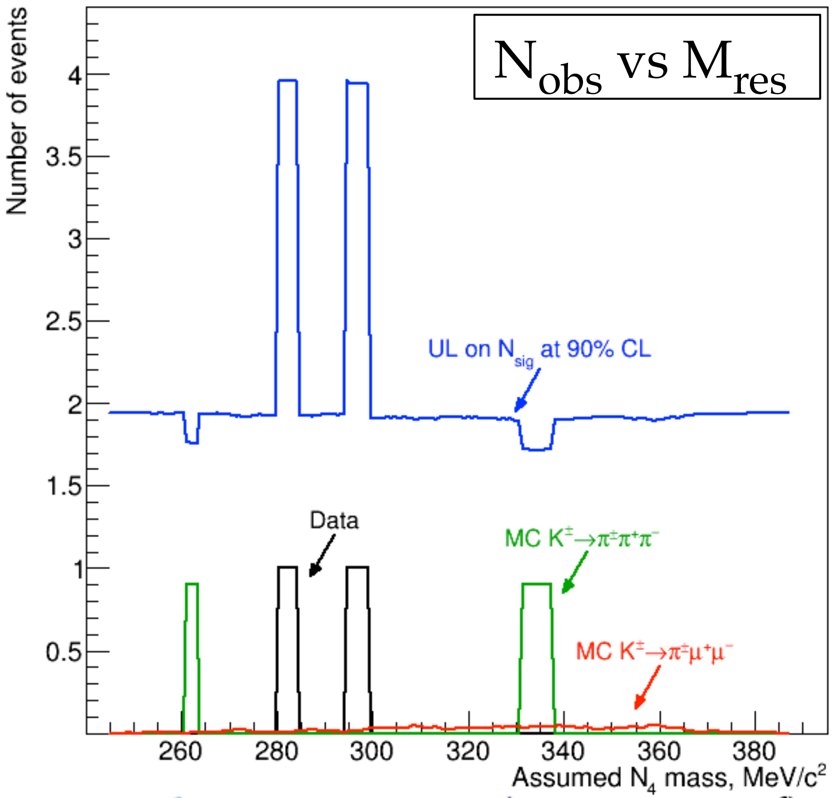


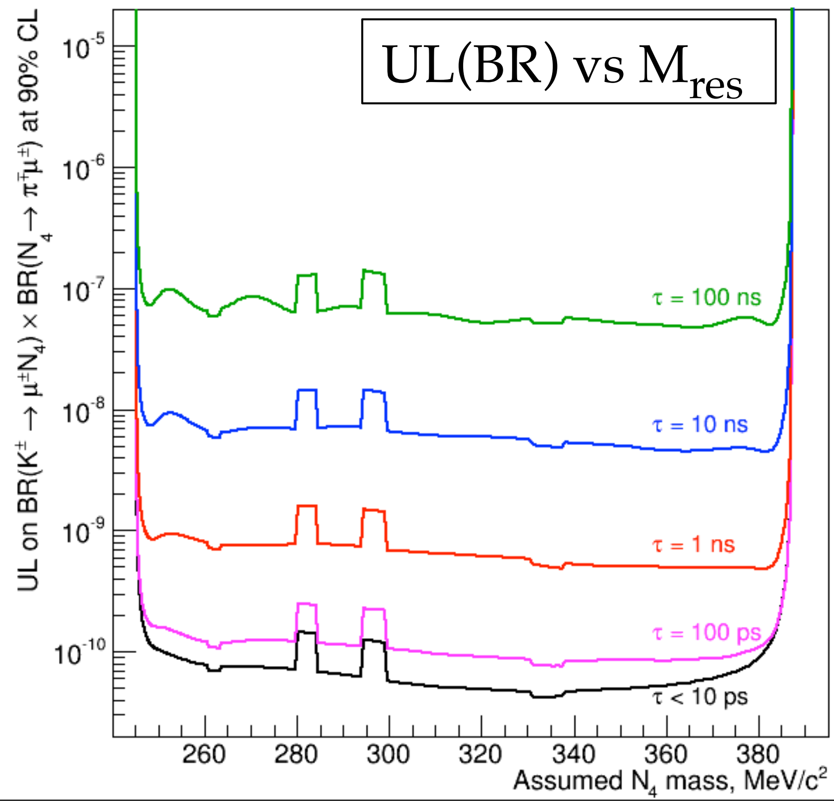
$$UL(BR) = \frac{UL(N_{sig})}{N_K * Acceptance}$$

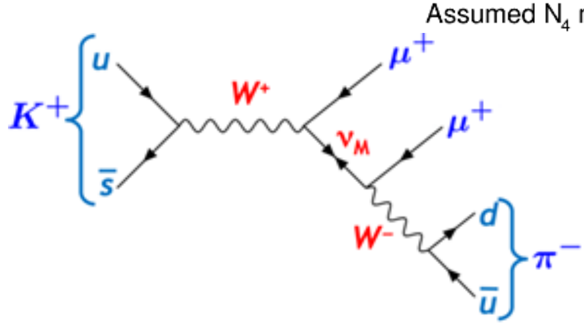
statistical significance

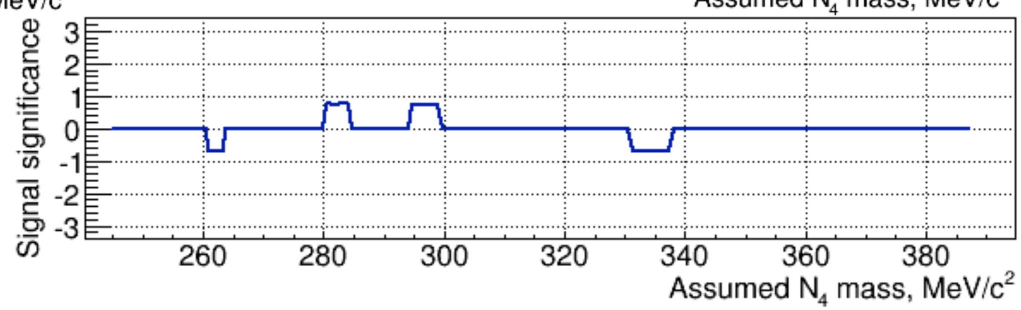
$$z = \frac{N_{obs} - N_{exp}}{\sqrt{\delta N_{obs}^2 + \delta N_{exp}^2}}$$

$K^{\pm} \rightarrow \mu^{\pm} N_4$ *with* $N_4 \rightarrow \pi^{\mp} \mu^{\pm}$



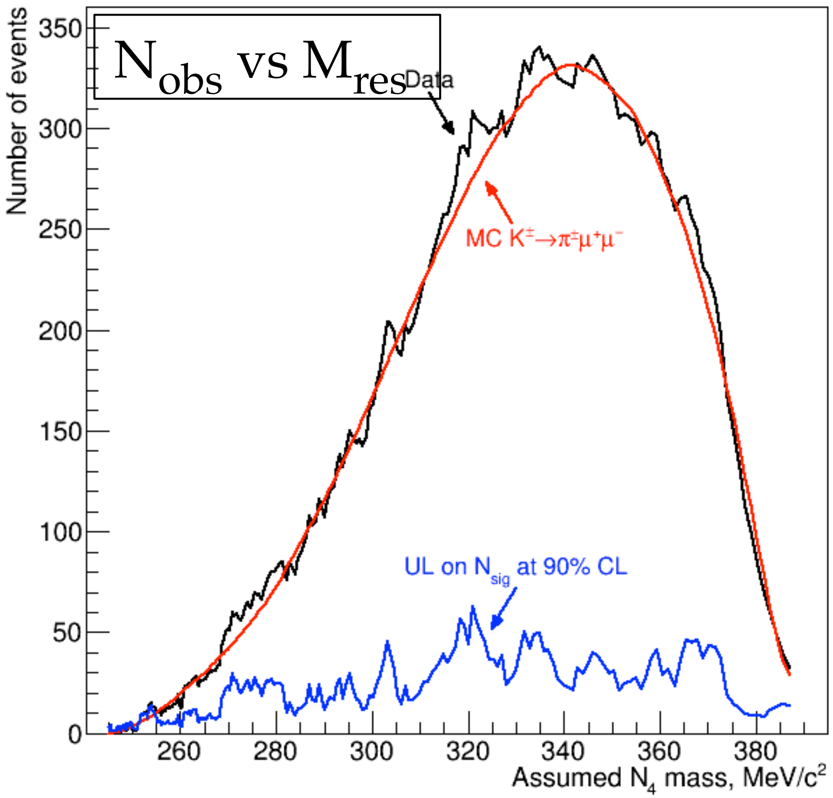


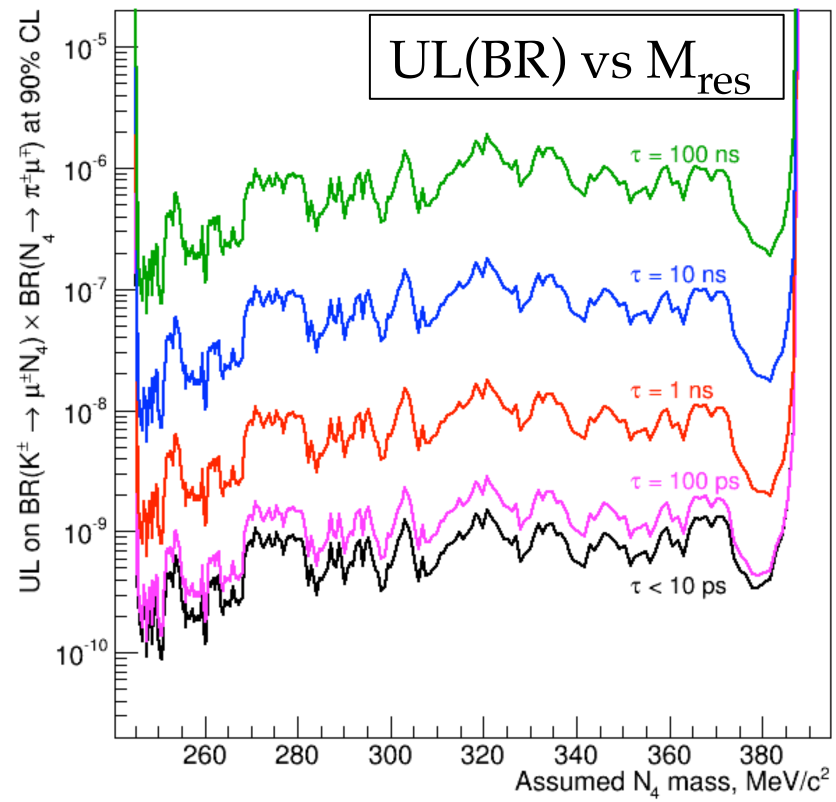


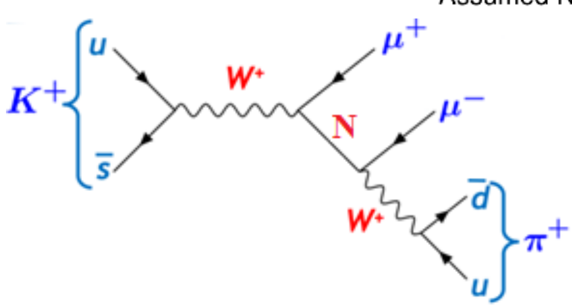


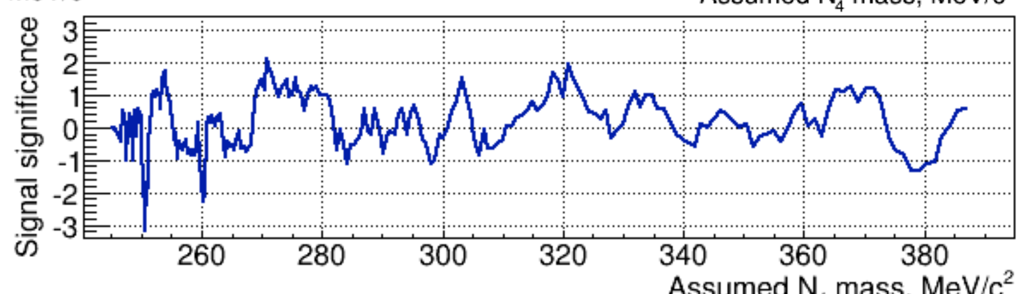
Never exceeds $+3\sigma$: no signal observed ➡ UL(BR)~10^{-10} for $\tau < 100$ ps

$K^{\pm} \rightarrow \mu^{\pm} N_4$ with $N_4 \rightarrow \pi^{\pm} \mu^{\mp}$



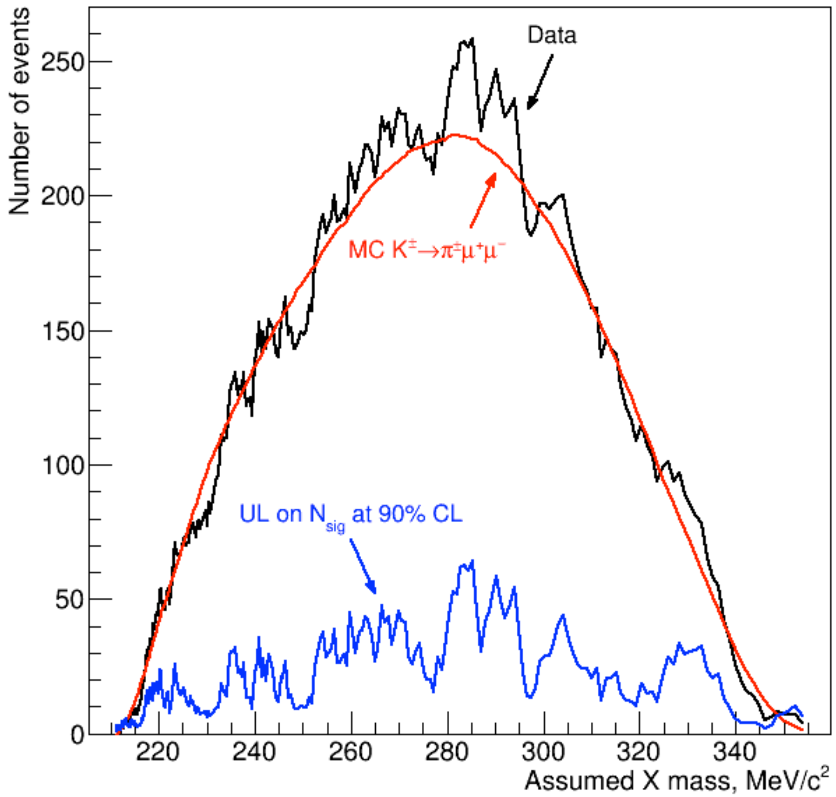


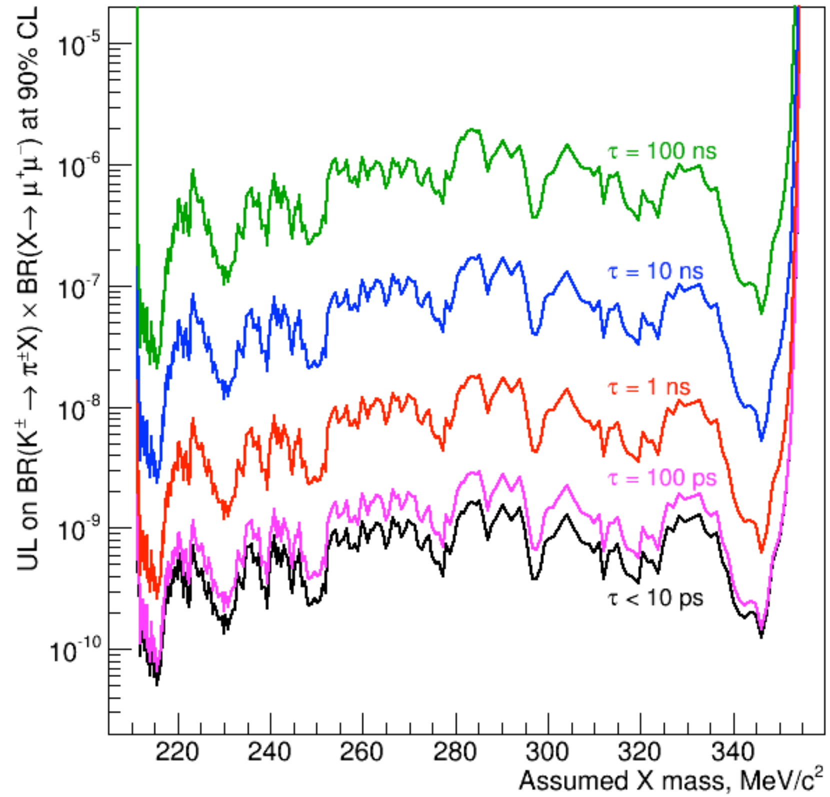


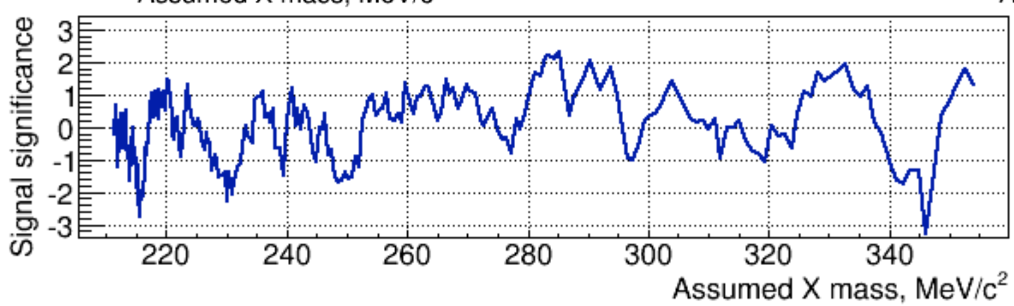


Never exceeds $+3\sigma$: no signal observed ➡ UL(BR)~10^{-9} for $\tau < 100$ ps

$K^{\pm} \to \mu^{\pm} X$ with $X \to \mu^{+} \mu^{-}$







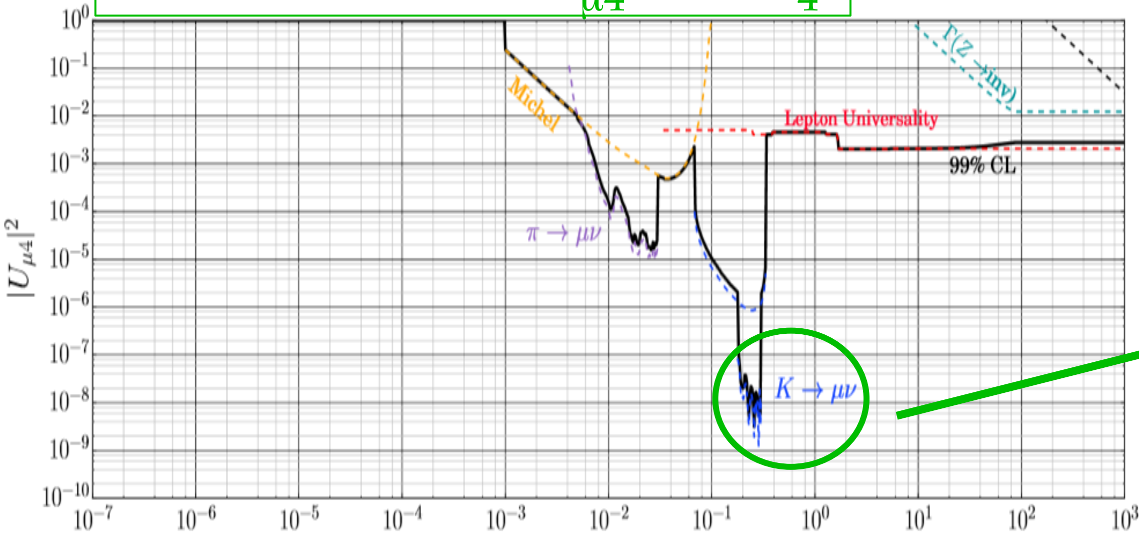
Never exceeds +3σ: no signal observed → UL(BR)~10^{-9} for $\tau < 100$ ps

Search for
Heavy Neutrino production

HNL global limits

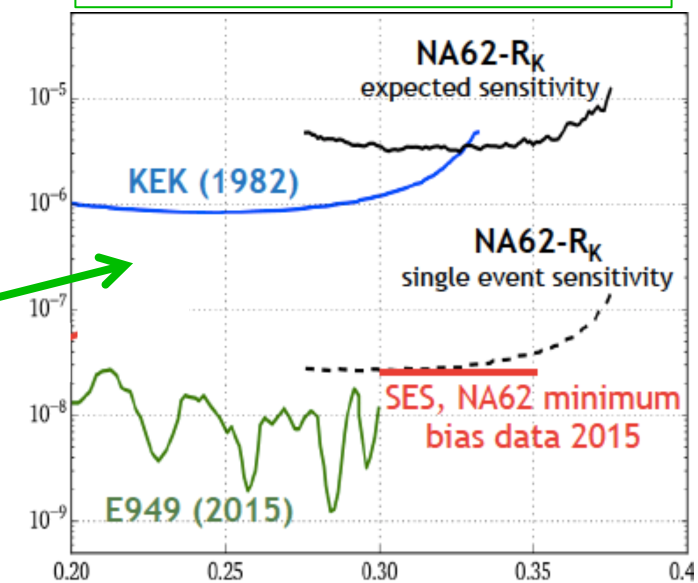
- In contrast to decay searches, production searches are model independent
- Most stringent limits are set by Kaon experiments

Global limits on $|U_{\mu 4}|^2$ vs m_4



[De Gouvea and Kobach, PRD93 (2016) 033005]

Limits on $|U_{\mu 4}|^2$ vs m_4 from $K^{\pm} \to \mu^{\pm}\nu$



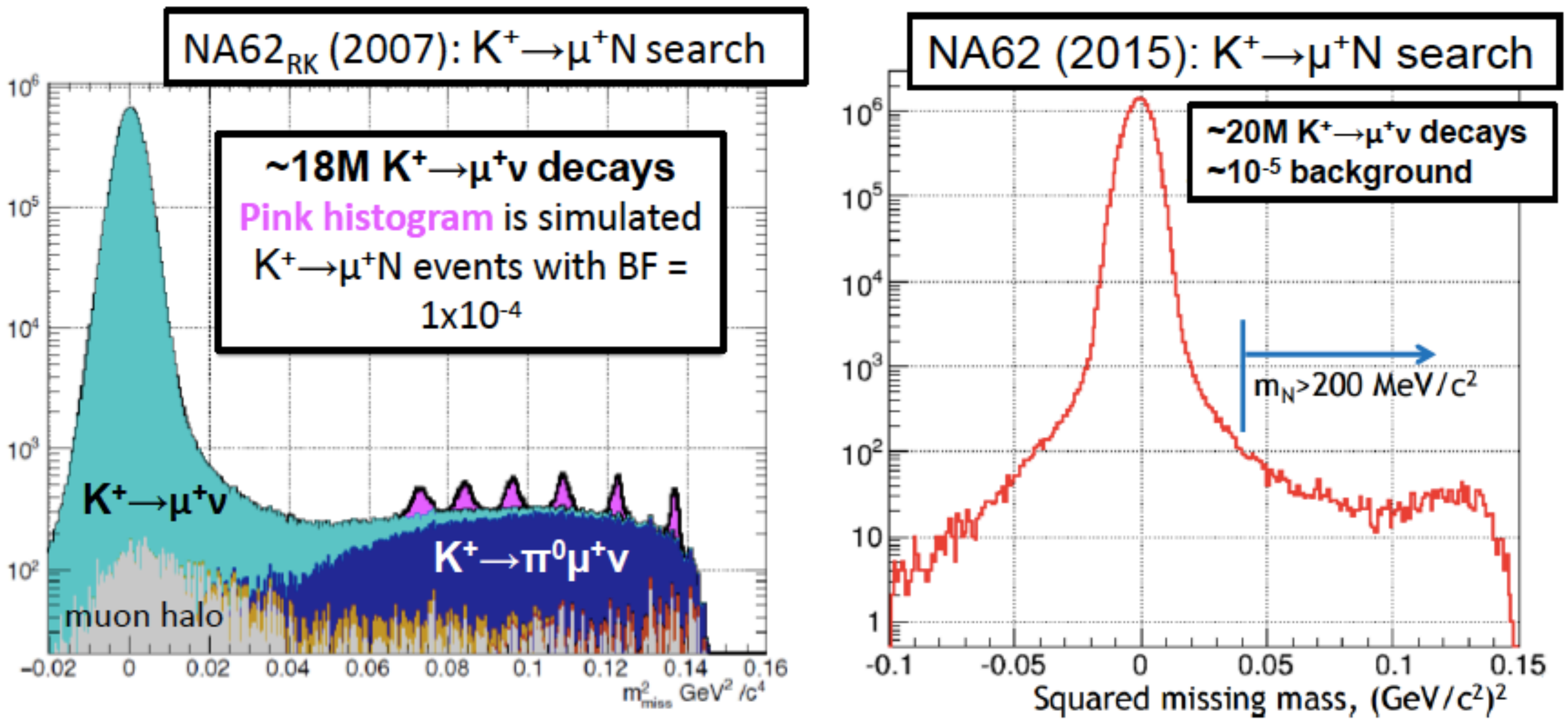
Search for HNL production

Peak search for $K^+ \to \mu^+ N$ at NA62-R_K (2007 data)

- 3 months of data taking, no downscaled trigger ~ 10^8 K+ decay in fiducial volume

Peak search for $K^+ \to \mu^+ N$ at NA62 (2015 data)

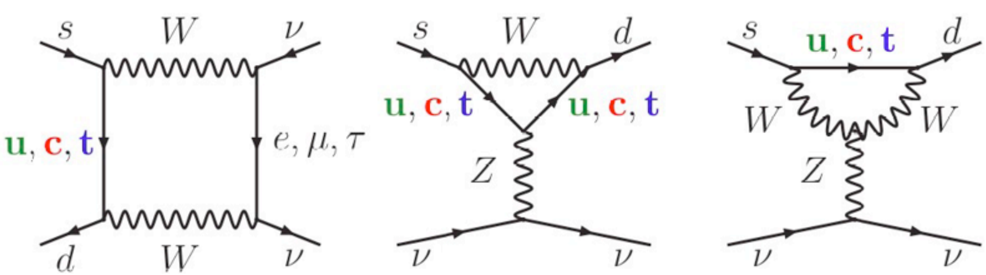
- Integrated 2007 K^+ flux reached in 1 week of minimum bias data
- Low background (hermetic veto, K^+ tagger); search region extends into lower m_N
- $K^+ \to e^+ N$ ⇒ background conditions allow to set a limits on this decay

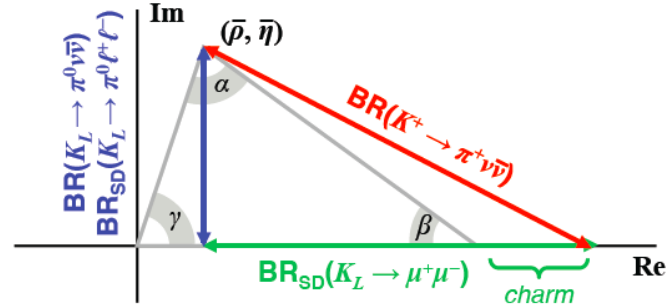


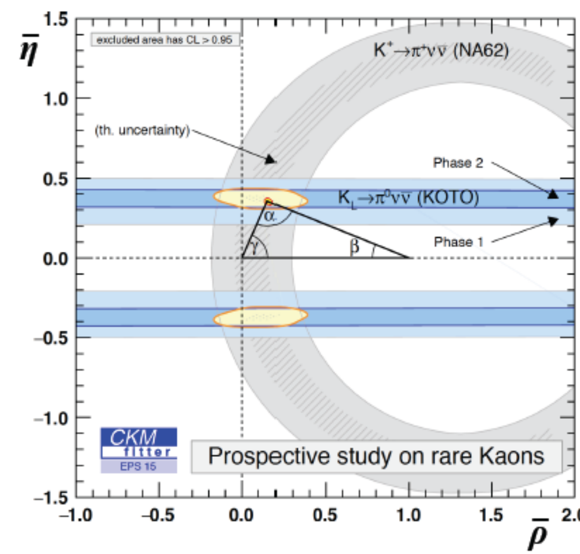
Measurement of the ultra-rare decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$

$K \to \pi\nu\nu$ in the SM . . .

- FCNC process forbidden at tree level ➡ room for NP up to 10xSM
- Short distance contribution dominated by Z penguin and W box diagrams
- "Super-clean" theoretically hadronic ME extracted from measured quantities (Ke3)
- Very small BR due to the CKM top coupling ➡ $A \sim (m_t/m_W)^2 |V_{ts}^* V_{td}| \approx \lambda^5$
- Measurement of $|V_{td}|$ complementary to those from B-B mixing and $B \to \rho\gamma$
- $\delta BR/BR = 10\%$ ➡ $\delta|V_{td}|/|V_{td}| = 7\%$.







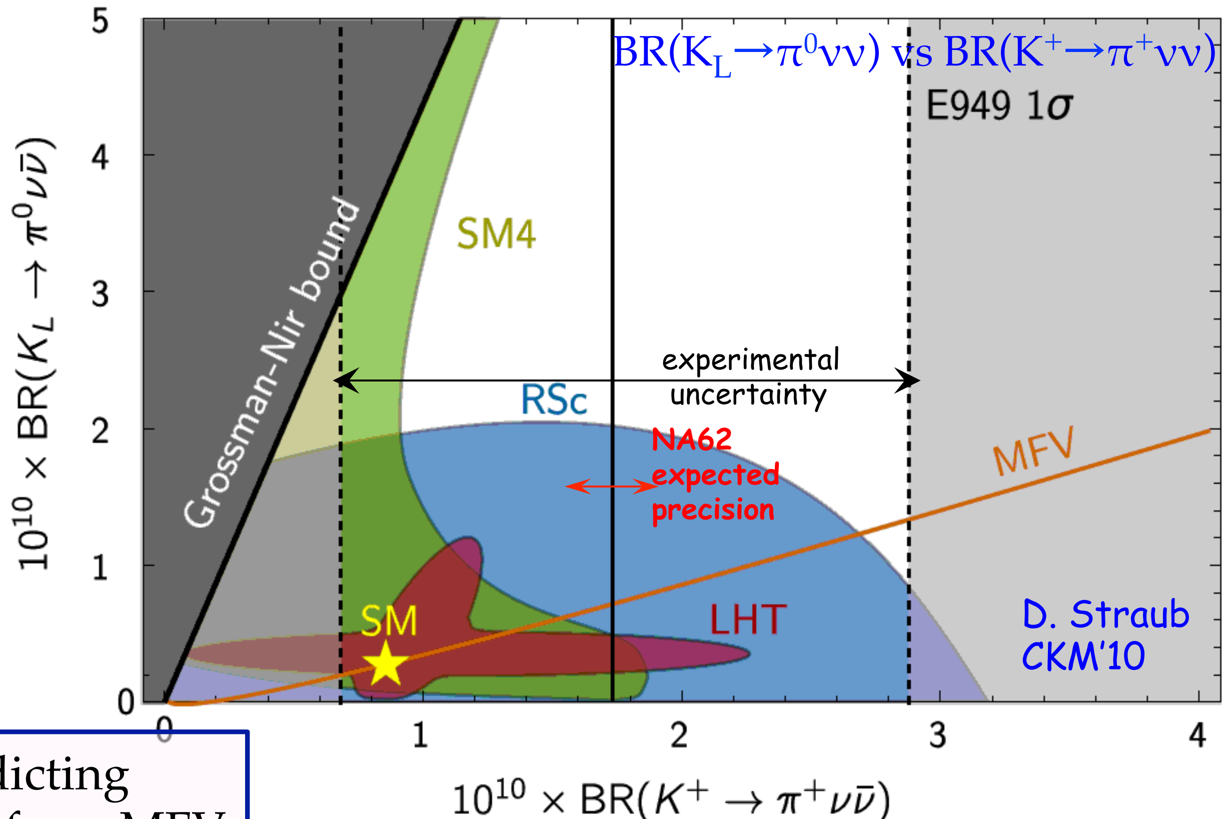
BR × 10^{11}	SM Prediction	Experiments
$K^+ \to \pi^+ \nu \bar\nu$	8.4 ± 1 [1]	$17.3^{+11.5}_{-10.5}$ [2]
$K^0 \to \pi^0 \nu \bar\nu$	3.4 ± 0.6 [1]	< 2600 (@90% CL) [3]

[1] Buras et al., JHEP 11 (2015) 033; Brod et al., Phys.Rev. D83 (2011) 034030
[2] BNL E787/E949: Phys.Rev. D77 (2008) 052003; Phys.Rev. D79 (2009) 092004
[3] KEK E391a: Phys.Rev. D81 (2010) 072004

. . . and beyond the SM

Several SM extensions predict sizable deviations for the BR

→ Possibility to distinguish among different models



NP models predicting high deviations from MFV

Randall-Sundrum

Littlest Higgs with T-parity

SM 4th generation

[Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]

[Blanke, Buras, Recksiegel, arXiv:1507.06316 (2015)]

[Buras, Buttazzo, Knegjens, arXiv:1507.08672 (2015)]

NA62 - Experimental principles

- Goal → 10% precision Branching Ratio measurement
- $O(100)$ $K^+ \to \pi^+ \nu\bar{\nu}$ events in ~ two years of data taking

Statistics
- BR(SM) ~ 8.4×10^{-11}
- Acceptance: 10%
- K decays: 10^{13}

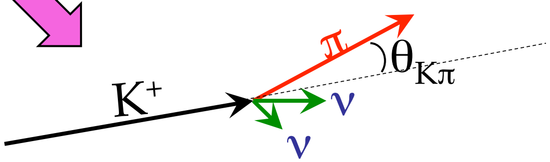
Systematics
- $\geq 10^{12}$ background rejection
- $\leq 10\%$ precision on background measurement

Kaon intensity & signal efficiency → High momentum K^+ beam

Signal purity & detector redudancy → Decay in-flight technique

Very challenging experiment

Weak signal signature

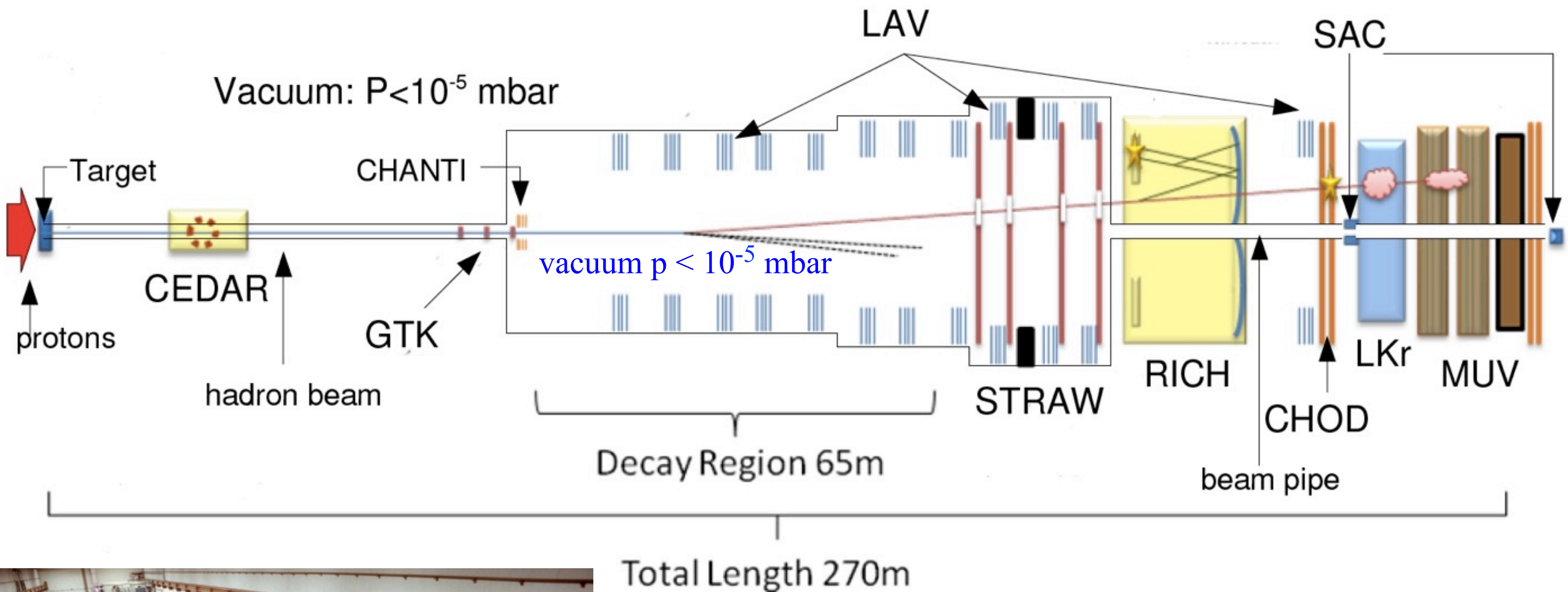


$m^2_{miss} = (P_K - P_\pi)^2$

Huge background

Decay		BR
$\mu^+\nu$	($K_{\mu 2}$)	63.5%
$\pi^+\pi^0$	($K_{\pi 2}$)	20.7%
$\pi^+\pi^+\pi^-$		5.6%
$\pi^0 e^+\nu$	(K_{e3})	5.1%
$\pi^0\mu^+\nu$	($K_{\mu 3}$)	3.3%

Experiment and beam



- 400 GeV/c SPS primary protons
- 3 x 10^{12} protons/pulse
- 75 GeV/c unseparated hadron beam ($\Delta p/p \pm 1\%$)
- Kaon component → 6%
- 800 MHz → 50 MHz kaons→ 6 MHz decays
- 4.8 x 10^{12} K^+ decays/y → SES ~ 10^{-12}

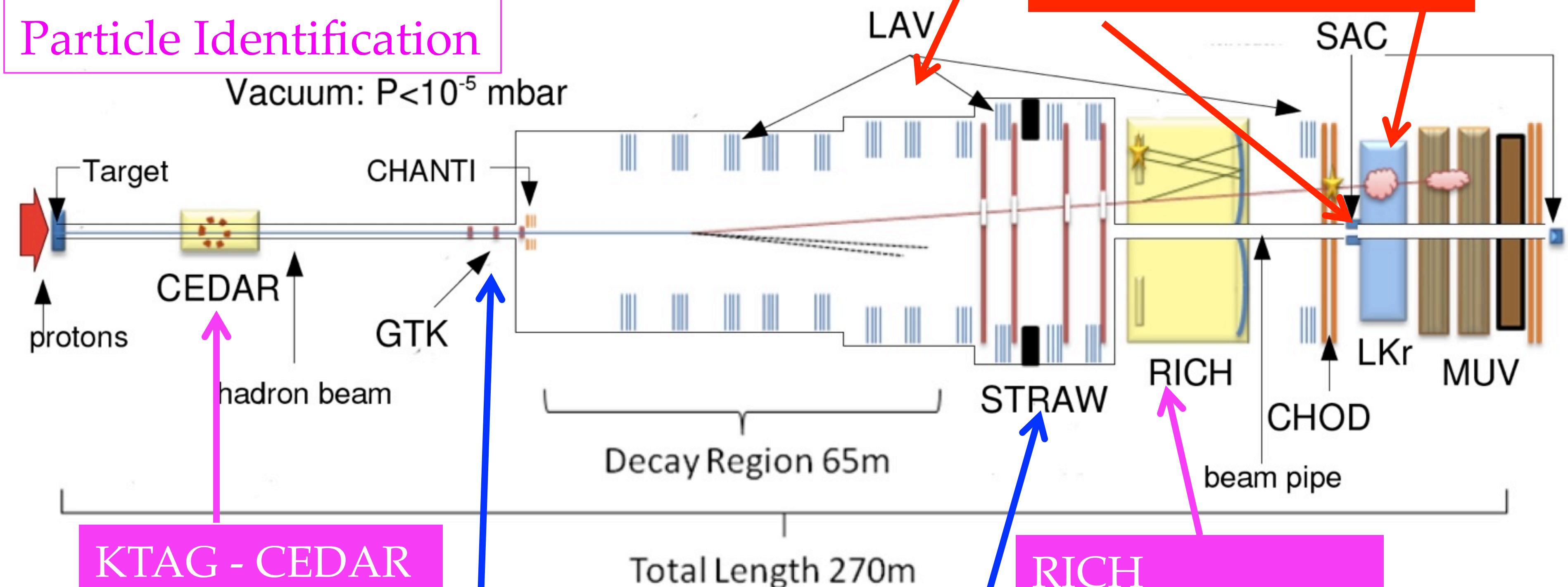
Detector layout

Beam and secondary particle tracking

Hermetic photon vetoes

Particle Identification

LAV	8.5 - 50 mrad
LKr	1- 8.5 mrad
SAV	< 1 mrad



KTAG - CEDAR
K^+ identification

RICH
π/μ identification

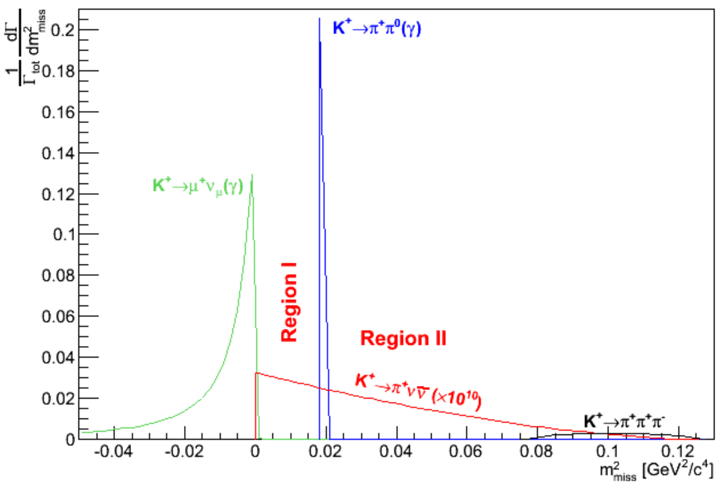
GIGATRACKER
3 Si-pixel stations $\sigma_t < 200$ ps

STRAW chambers in vacuum
4 stations + dipole magnet

Background and kinematics

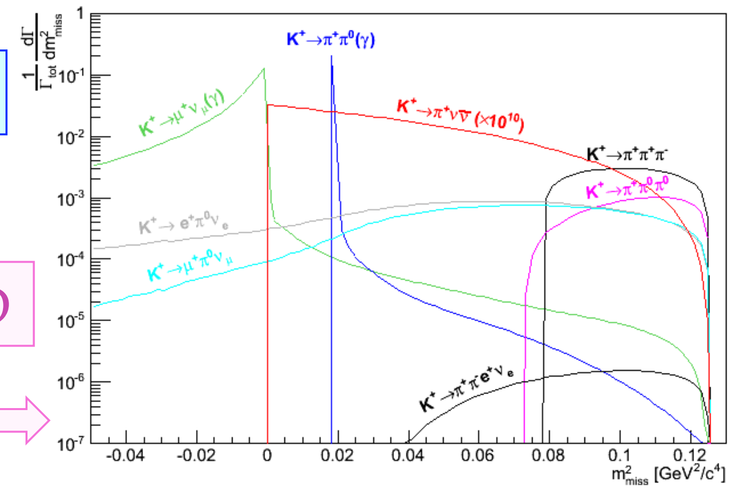
92% Bkg separated from signal by kinematic cuts

8% not separated



missing mass

Veto and PID



$m^2_{miss} = (P_K - P_\pi)^2$ defines low bkg signal regions separated by $K^+ \to \pi^+\pi^0$

extend in the signal region, kinematics doesn't help

- ✓ high resolution m^2_{miss} reconstruction
- ✓ measure precisely kaon and pion momenta
- ✓ keep multiple scattering as low as possible

Gigatracker (kaon)
Straw chambers (pion)

- ✓ Suppress $K^+ \to \pi^+\pi^0$ background
- ✓ Reject offline decays with γ
- ✓ K^+ identification in the had beam
- ✓ 10^{-3} $\pi-\mu$ separation

Photon veto system
Particle Identification

Analysis strategy and background sources

Key analysis requirements

- ✓ 1 track $15 < P_{\pi+} < 35$ GeV / c and PID in the RICH
- ✓ z_{vert} in the 65 m long decay region
- ✓ No γs in LAV, LKr, IRC, SAC
- ✓ No μs in MUVs
- ✓ 1 beam particle in Gigatracker with K PID by KTAG

Expected backgrounds

Decay	evt/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12})	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
$K^+ \to \pi^+ \pi^- e^+ \nu$ + other 3 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$(IB)	1.5
$K^+ \to \mu^+ \nu \gamma$(IB)	0.5
$K^+ \to \pi^0 e^+ (\mu^+) \nu$, others	negligible
Total background	< 10

Experimental status

NA62 data taking

- ✓ First data from pilot run in fall 2014
- ✓ First physics run June-November 2015
- ✓ 2016 run in progress (April-November)
- ✓ Expect to take data through 2018 (until LS2)

Beamline commissioned up to full intensity

Detector status

- ✓ Gigatracker partially commissioned
- ✓ Spectrometer, PID detectors, photon vetoes all fully operational

Trigger and data acquisition status

- ✓ Level-0 trigger fully operational
- ✓ Level-1 and level-2 triggers partially commissioned

Data and reconstruction quality under study using 2015 data

- ✓ Minimum-bias data at 1% beam intensity

Physics runs 2016 - 2018

- ✓ Currently running at 20% (50%) intensity
- ✓ Expect to collect few SM $K^+ \to \pi^+ \nu\nu$ events by the end of 2016 run, on track

Signal selection

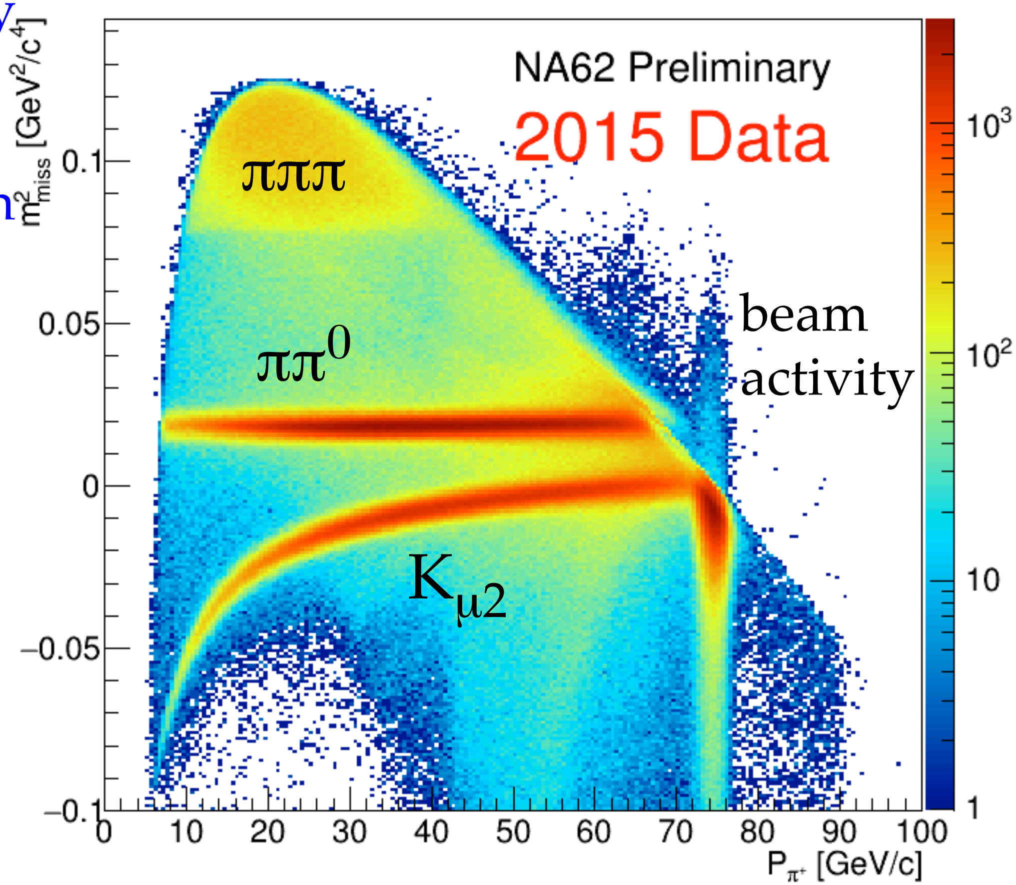
Minimum-bias data at 1% beam intensity

one - track selection

- ✓ single downstream track topology
- ✓ Beam track matching the downstream track
- ✓ Beam track matching a K signal in Kaon ID
- ✓ Downstream track matching energy in calorimeters

timing

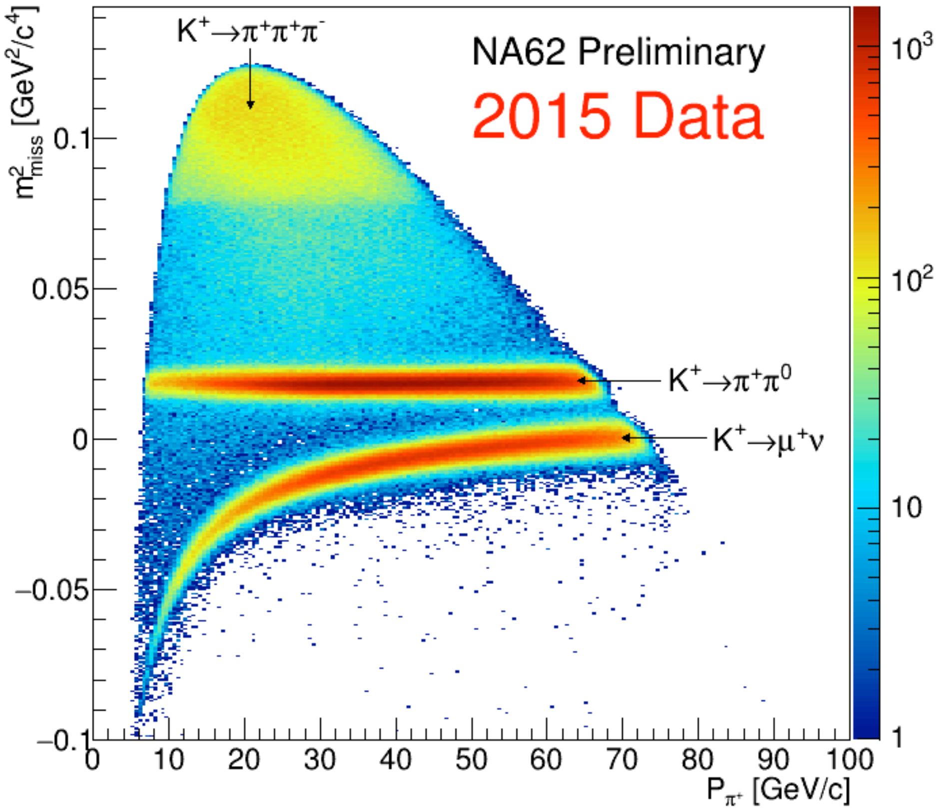
- ✓ Match with hit in CHOD ($\sigma_t \sim 200$ ps)
- ✓ Match with hit in KTAG ($\sigma_t \sim 100$ ps)
- ✓ Association to hits in LKr, RICH, muon vetoes

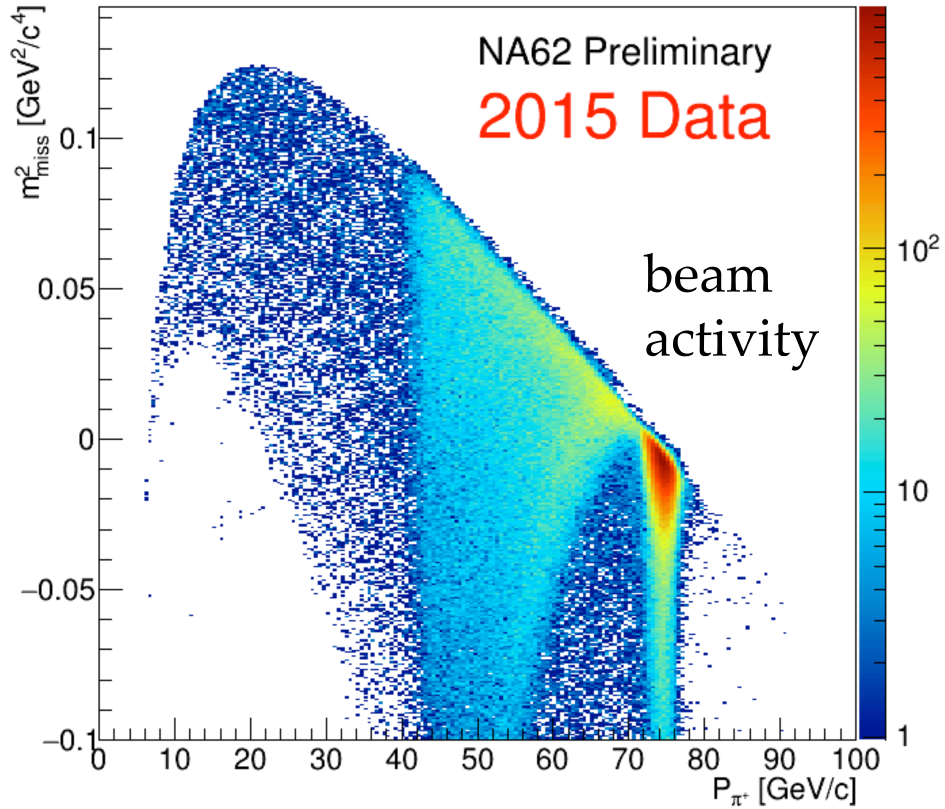


Signal selection and kaon ID

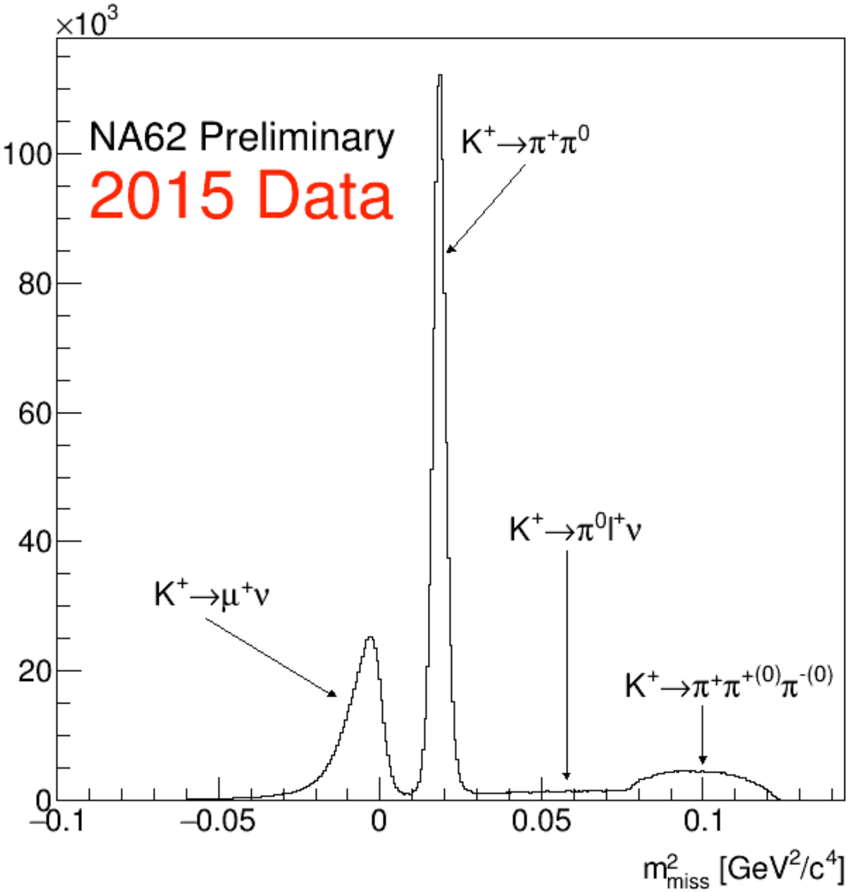
1-track selection
K^+ identification in KTAG
Track origin in the fiducial region

1-track selection
NO K^+ identification in KTAG
Beam activity



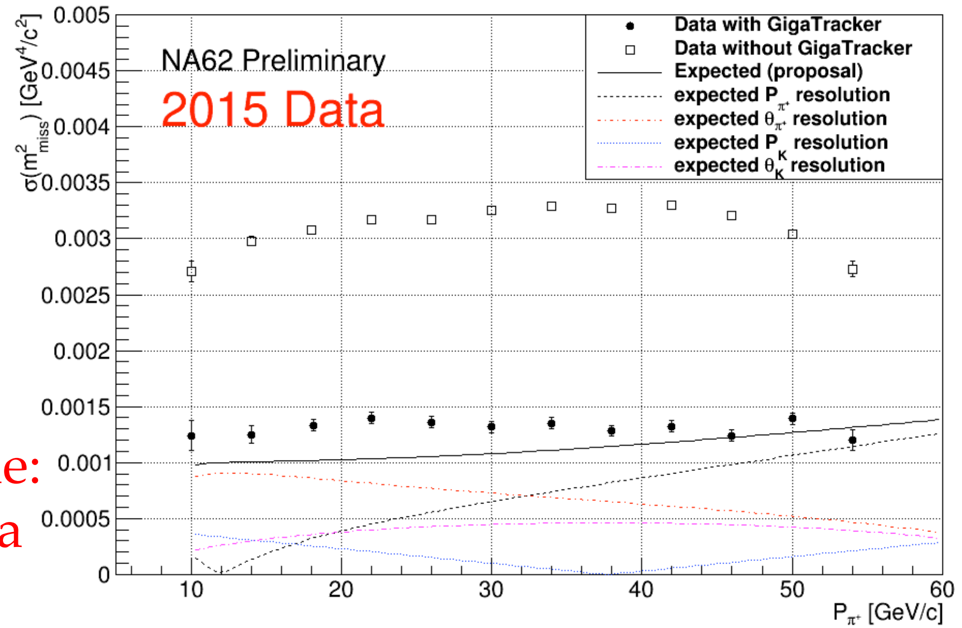


Kinematics



Goal: 10^4 - 10^5 rejection for 2-body decays

- ✓ Kinematics reconstructed with Gigatracker and Straw tracker
- ✓ LKr to obtain clean sample of $\pi\pi^0$ events to study m_{miss} resolution

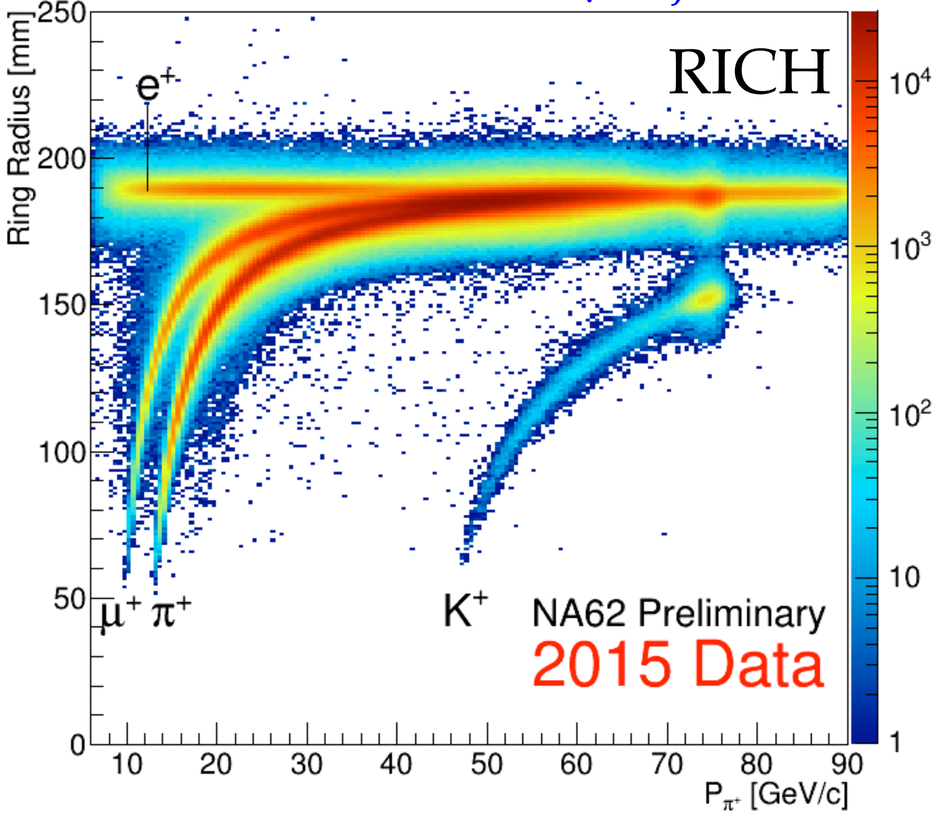


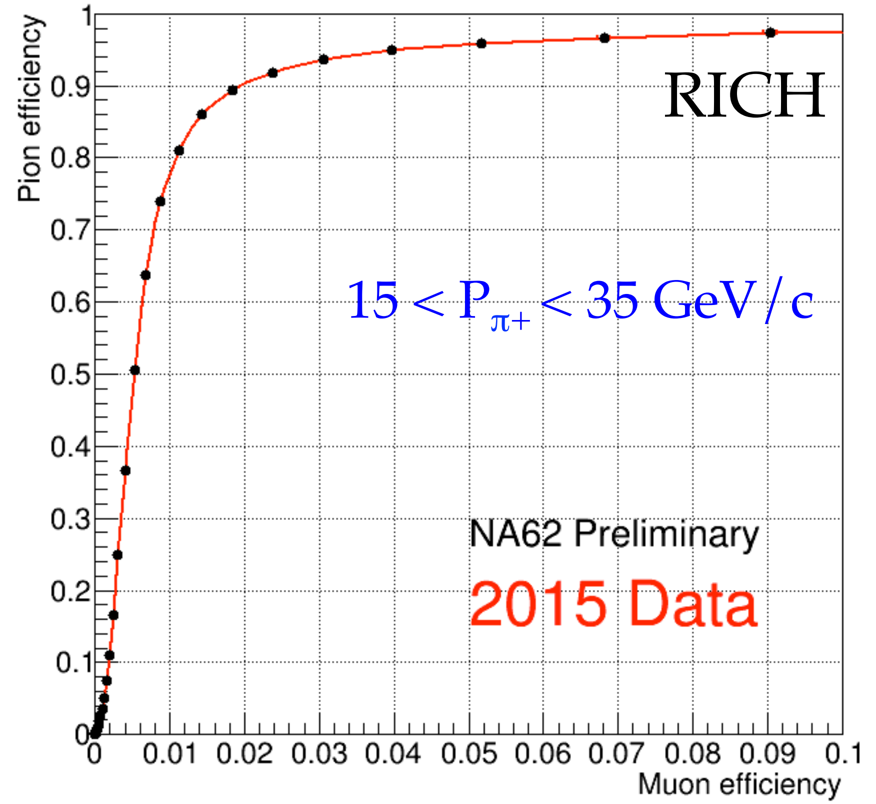
m_{miss} resolution close to design value: $O(10^3)$ rejection obtained in 2015 data

Downstream particle identification

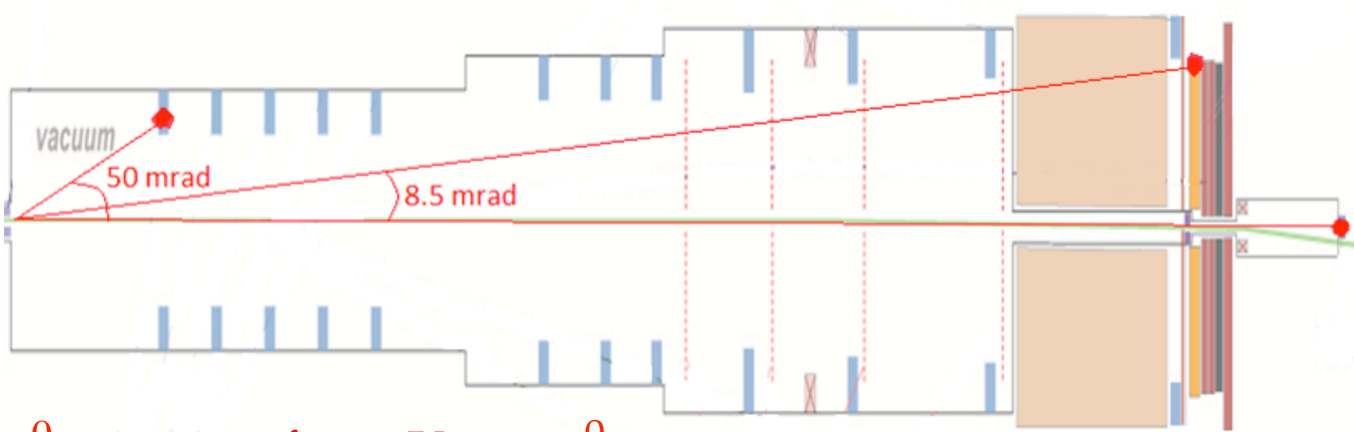
Goal: $O(10^7)$ π/μ separation (suppress $K_{\mu 2}$)

- ✓ RICH, calorimeters and muon veto
- ✓ RICH: $O(10^2)$ π/μ separation, 80% π^+ efficiency in 2015 (momentum range $15 < P_{\pi+} < 35$ GeV/c)
- ✓ Calorimeters: $O(10^6)$ μ rejection at 50% π efficiency (expected to improve)



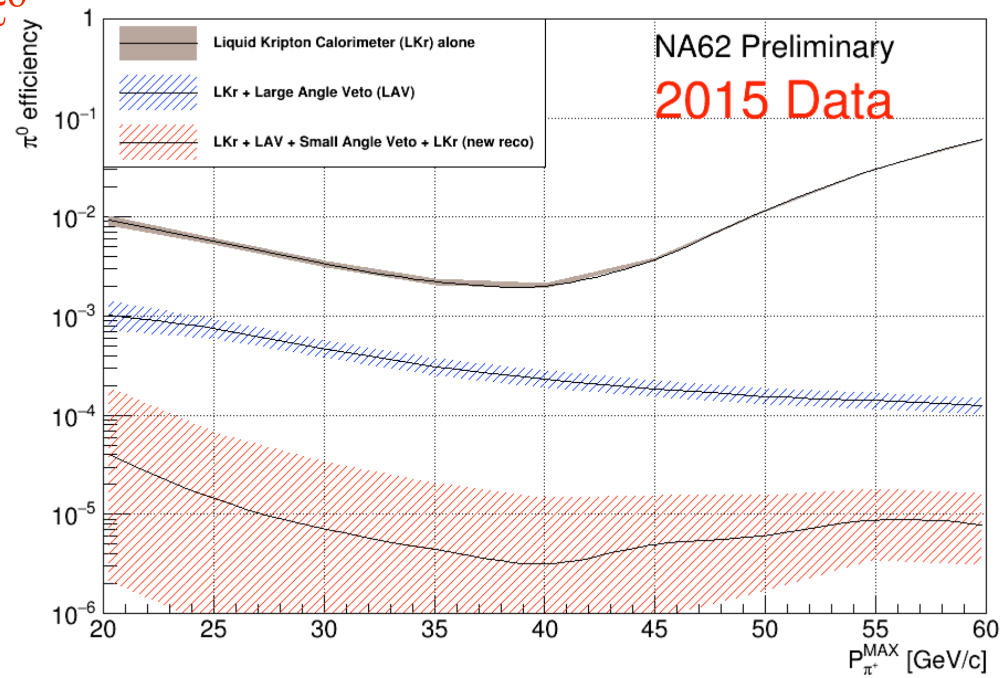


Photon rejection



Goal: $O(10^8)$ π^0 rejection from $K \to \pi\pi^0$

- ✓ EM calorimeters to exploit correlation between γs from π^0
- ✓ $P_{\pi+} < 35$ GeV / c → $E_{\pi 0} > 40$ GeV
- ✓ $O(10^2)$ obtained in 2015
- ✓ Measurement with minimum-bias data limited by statistics



Further NA62 physics programme

- Standard Kaon physics
  - ➔ χPT studies: $K^+ \rightarrow \pi^+\gamma\gamma$, $K^+ \rightarrow \pi^+\pi^0 e^+ e^-$, $K^+ \rightarrow \pi\pi l^+\nu$
  - ➔ Lepton universality studies: $R_K = \Gamma(K^+ \rightarrow e^+\nu)/\Gamma(K^+ \rightarrow \mu^+\nu)$
- LFV / LNV in Kaon decays
  - ➔ $K^+ \rightarrow \pi^+\mu^\pm e^\mp$, $K^+ \rightarrow \pi^-\mu^+ e^+$, $K^+ \rightarrow \pi^- l^+ l^+$,
- Heavy neutrino searches
  - ➔ $K^+ \rightarrow l^+\nu_H$
  - ➔ ν_H (from K, D decays) $\rightarrow \pi^\pm l^\mp$
- π^0 decays
  - ➔ $\pi^0 \rightarrow$ invisible, $\pi^0 \rightarrow 3\gamma$ (4γ), $\pi^0 \rightarrow \gamma U$
- Dark sector searches
  - ➔ Long living dark photon (from prompt mesons decays) $\rightarrow l^+ l^-$
  - ➔ Long living axion-like (produced in beam-dump config.) $\rightarrow \gamma\gamma$

Summary and outlook

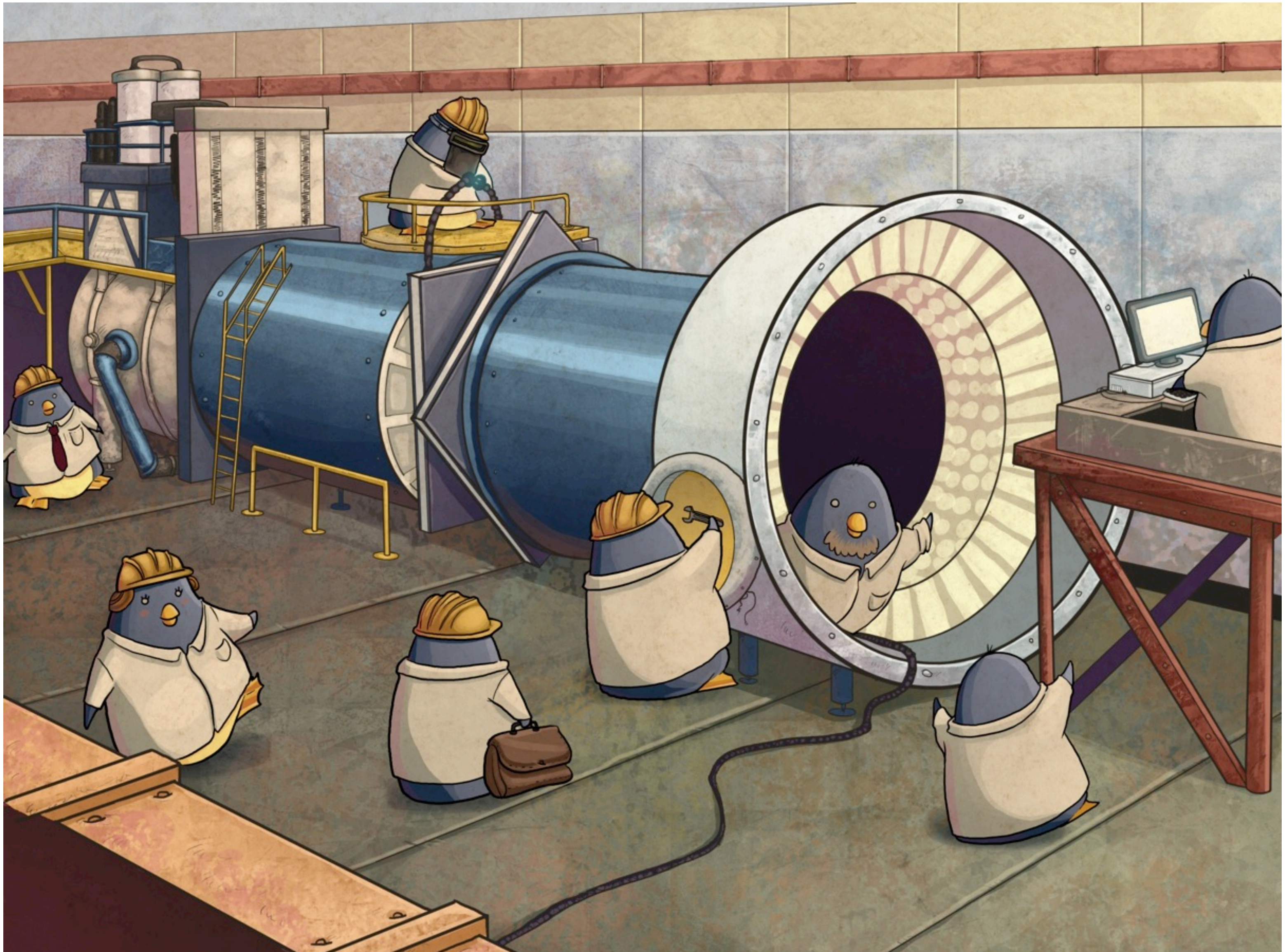
NA62 beamline and detector commissioned and tested up to nominal intensity

- Measurement of the R_K at NA62
  - ➔ result in agreement with SM expectation, within 1.2 σ
  - ➔ motivation for further measurement

- LNV in $K^{\pm} \rightarrow \pi^{\mp}\mu^{\pm}\mu^{\pm}$ and search for two-body resonances (UL set)

- The $K^{+} \rightarrow \pi^{+}\nu\bar{\nu}$ decay ➡ very challenging experiment
  - ➔ Collect *0*(100) events & provide a 10% BR measurement
  - ➔ First physics run in 2015
  - ➔ Minimum bias data collected at low intensity used for data quality studies ➡ consistent with design expectations
  - ➔ Data taking foreseen 2016 - 2018, currently running at 50% intensity
  - ➔ Expect to collect a few SM $K^{+} \rightarrow \pi^{+}\nu\nu$ events by end of 2016 run
  - ➔ On schedule for the measurement
- Many other Kaon measurements at the frontier of precision physics

NA62 Penguins at work

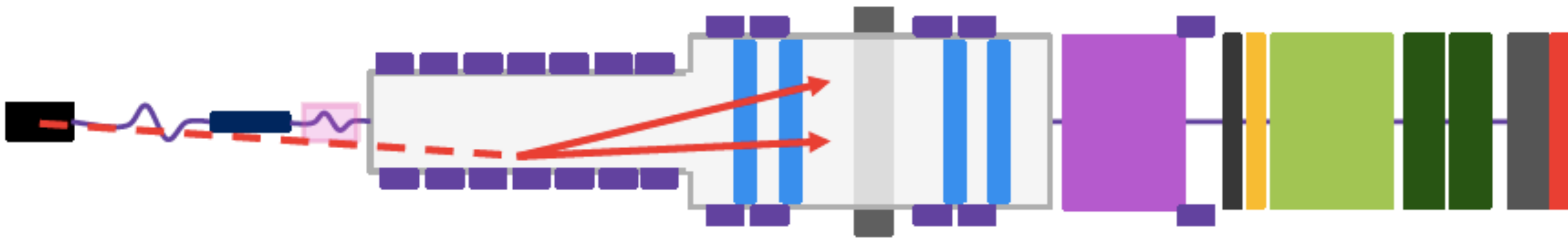



Thank you!

Additional information

Searches for HNL from the target

- HNL can be produced in meson decays at the T10 target
- These HNL can then decay inside the NA62 fiducial volume



- With zero background events, can probe beyond current limits
- Proof-of-principle from 2016 data: searches for dark photon and axion production at the target. Prospects for these searches are being evaluated