$K^+ \longrightarrow \pi^+ \nu\bar{\nu}$ and R_K at NA62

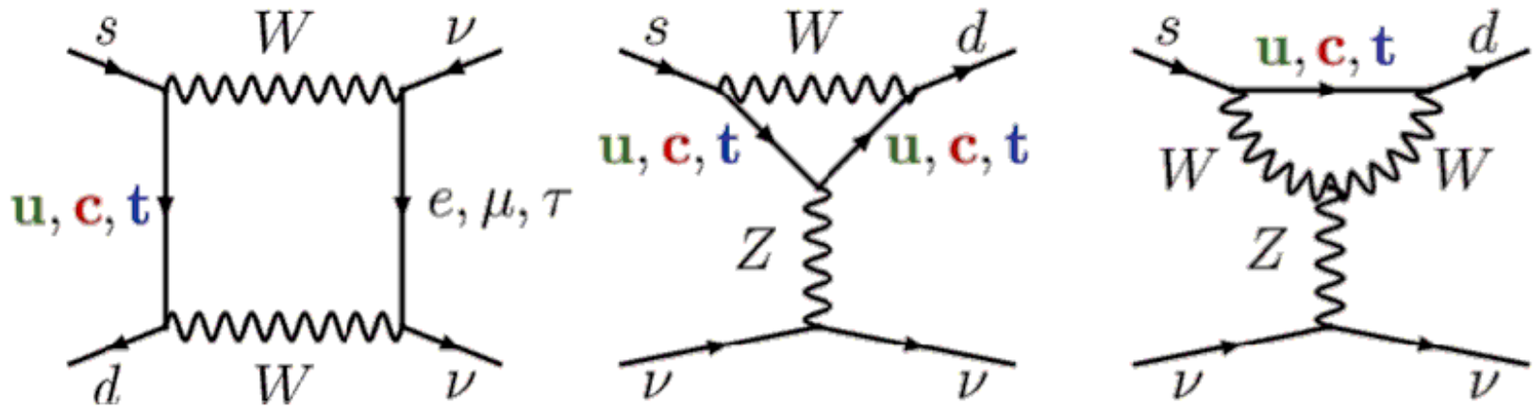
Ryan Page on behalf of the NA62 collaboration

Outline

- Kaon signatures of interest.
- PRINCIPLE GOAL: Measurement of $K^+ \longrightarrow \pi^+ \nu\bar{\nu}$ branching ratio.
- Previous Work - NA62-R_K Motivation.
- NA62 at CERN.
- NA62 Overview.
- NA62-R_K Overview and Results.
- Summary.

$K \to \pi \nu \bar{\nu}$ Motivation

- SM Feynman Diagrams - tree level forbidden in SM.



- Highly suppressed within SM.
- Highest CKM suppression factor.
- Theoretically very clean.

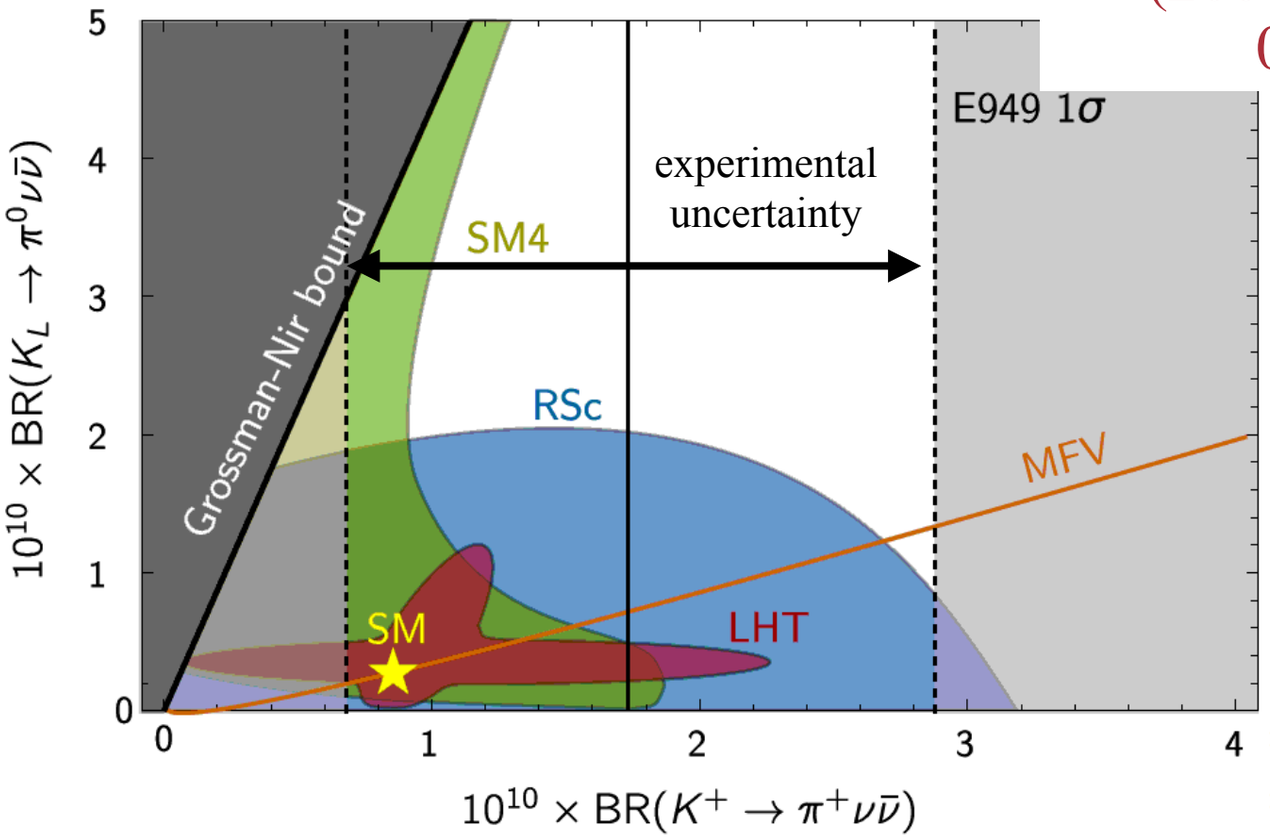
Mode	BR(10^{-11})
$K_L \to \pi^0 \nu\bar{\nu}$	$2.43 \pm 0.39 \pm 0.06$
$K^+ \to \pi^+ \nu\bar{\nu}$	$7.81 \pm 0.75 \pm 0.29$

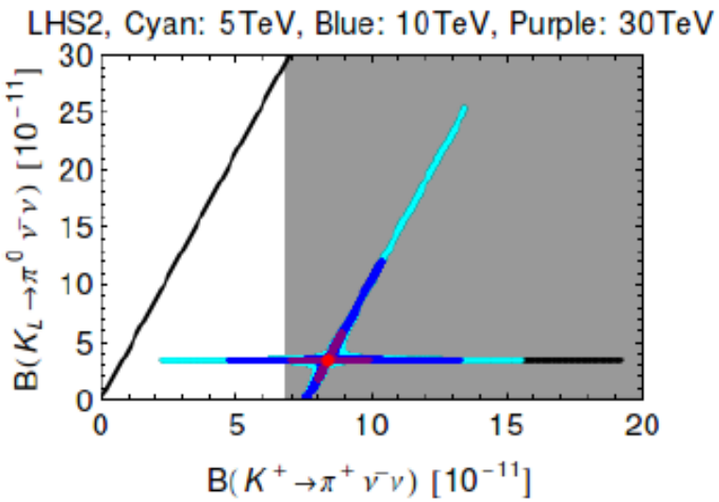
Phys.Rev. D83 (2011) 034030

K⟶πνν̄ Motivation

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

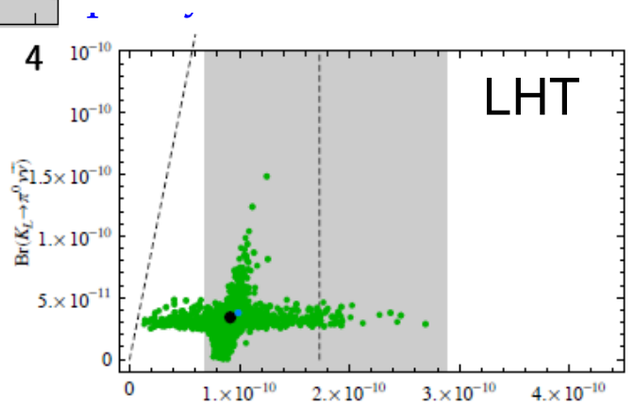
Phys. Rev. D77, 052003, (2008), Phys. Rev. D79 092004 (2009)



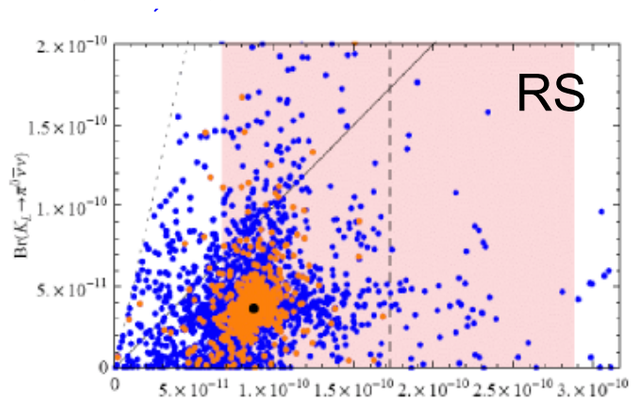


JHEP 1302 (2013) 116

- Sensitive new physics probe.
- Relatively unexplored.



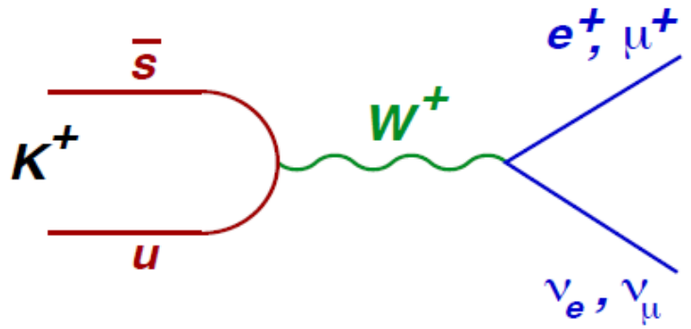
Acta Phys. Polon. B41 (2010) 657



JHEP 0903 (2009) 108

R_K In the SM

- Lepton Universality test:



$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{\text{rad.corr.}})$$

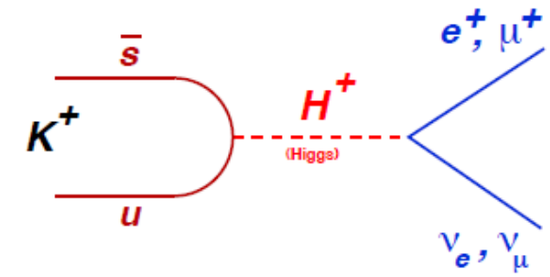
$$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$$

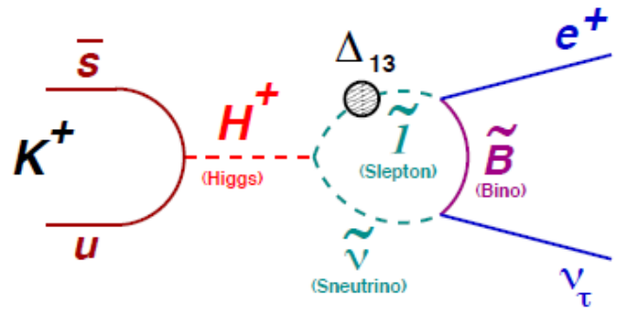
Cirigliano and Rosell,
PRL 99 (2007) 231801

- Excellent accuracy within the SM.
- Radiative correction known to few %.
- Suppression of SM contribution $\Longrightarrow$ potential of NP observation.

R_K Beyond SM

- 2 Higgs Doublet Model at tree level ⟹
  - R_K not affected.
- 2HDM at one loop level ⟹
  - R_K enhanced enough to be experimentally accessible.





[Girrbach, Nierste, arXiv:1202.4906]

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

- In MSSM NP << 0.1% after Higgs, B →τν, μμ[Fonseca et.al, EPJ C72 (2012) 2228]
- However - NP > 1% level possible from sterile fermions [Abada, et al, JHEP 1302 (2013) 48, JHEP 1402 (2014) 091]

NA62 at CERN

R_K phase

2007: $K_{e2}/K_{\mu 2}$

2008: $K_{e2}/K_{\mu 2}$

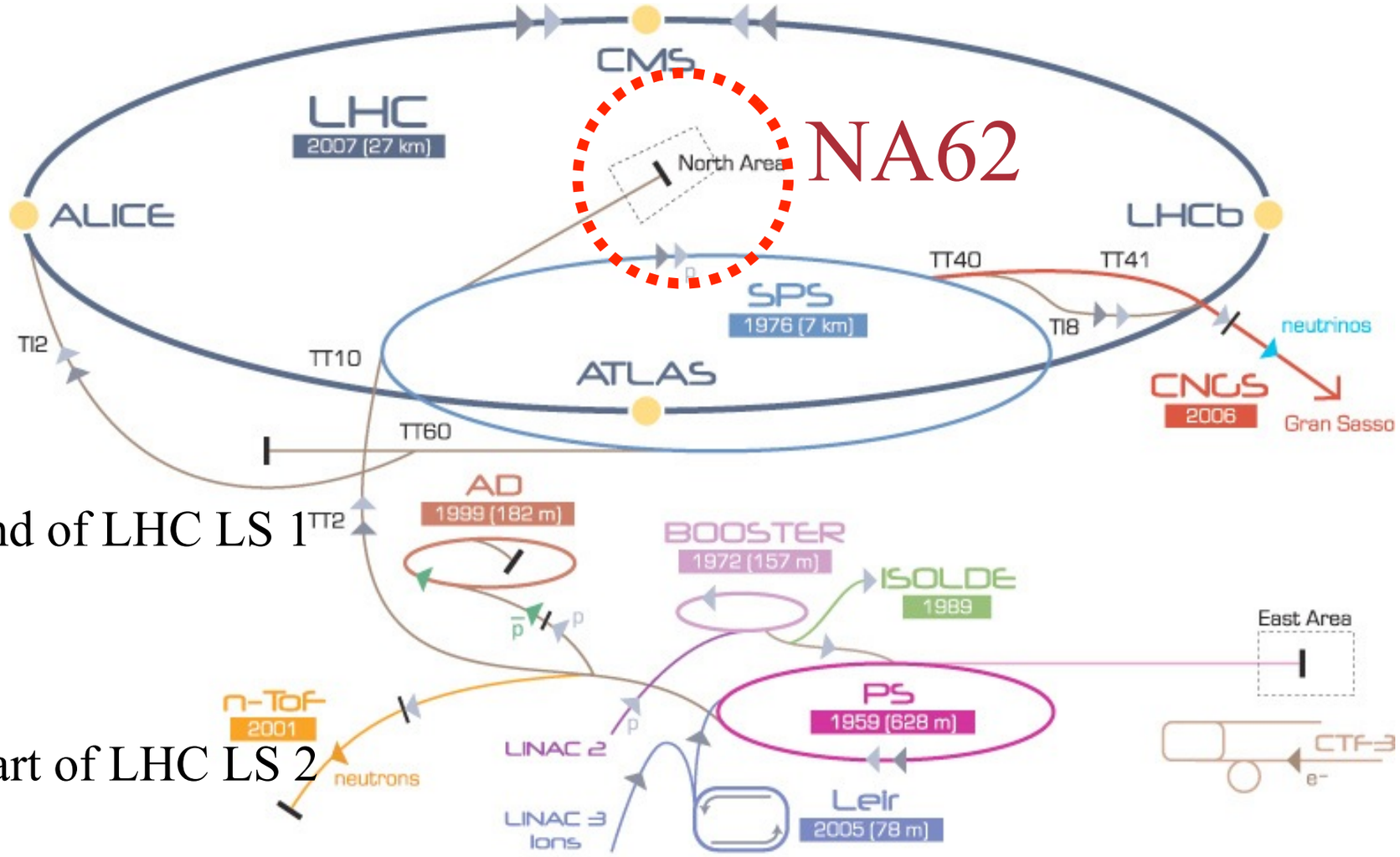
2012: Technical Run

2014: Commissioning and first data

End of LHC LS 1

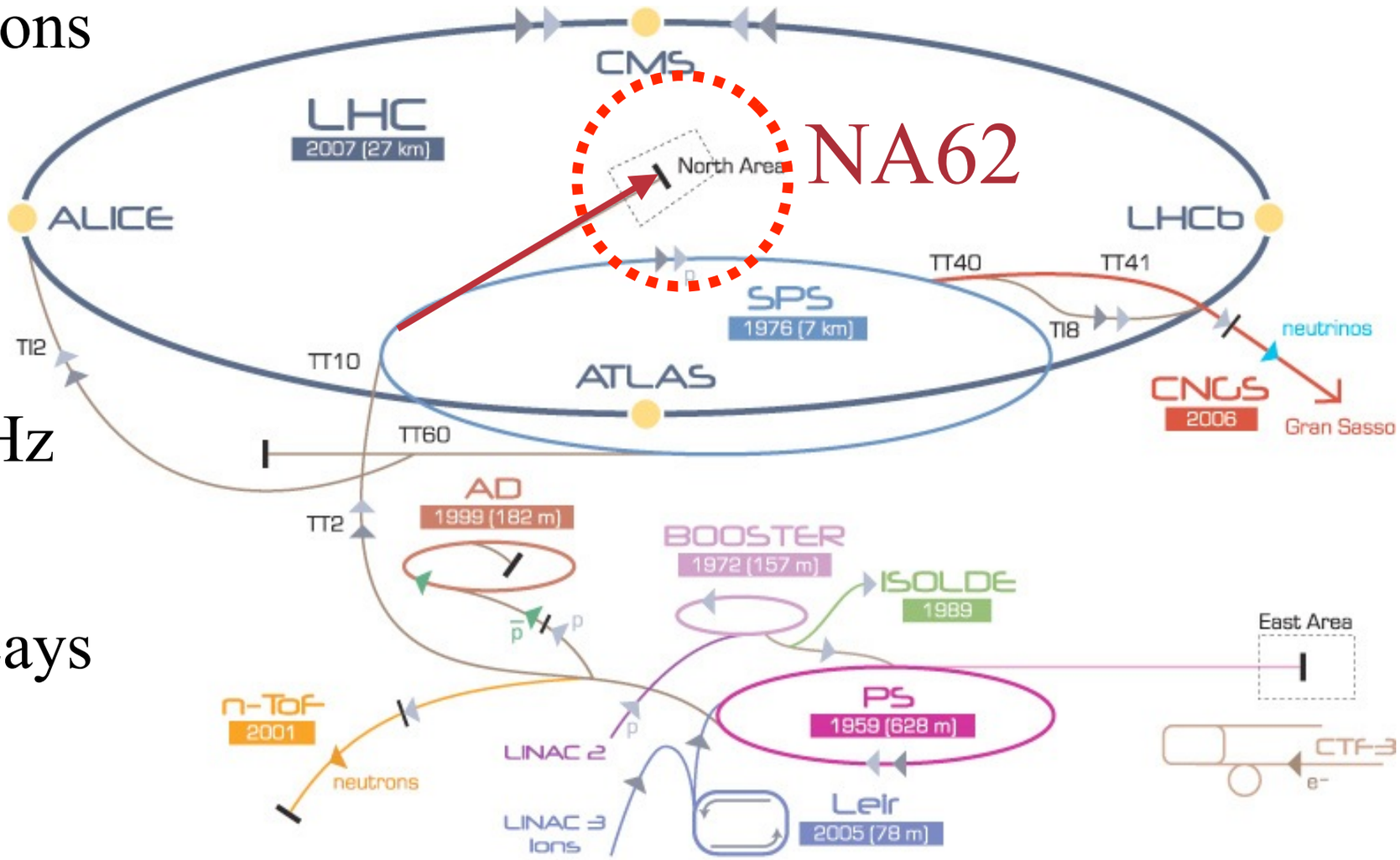
2015-17: Data Taking

Start of LHC LS 2



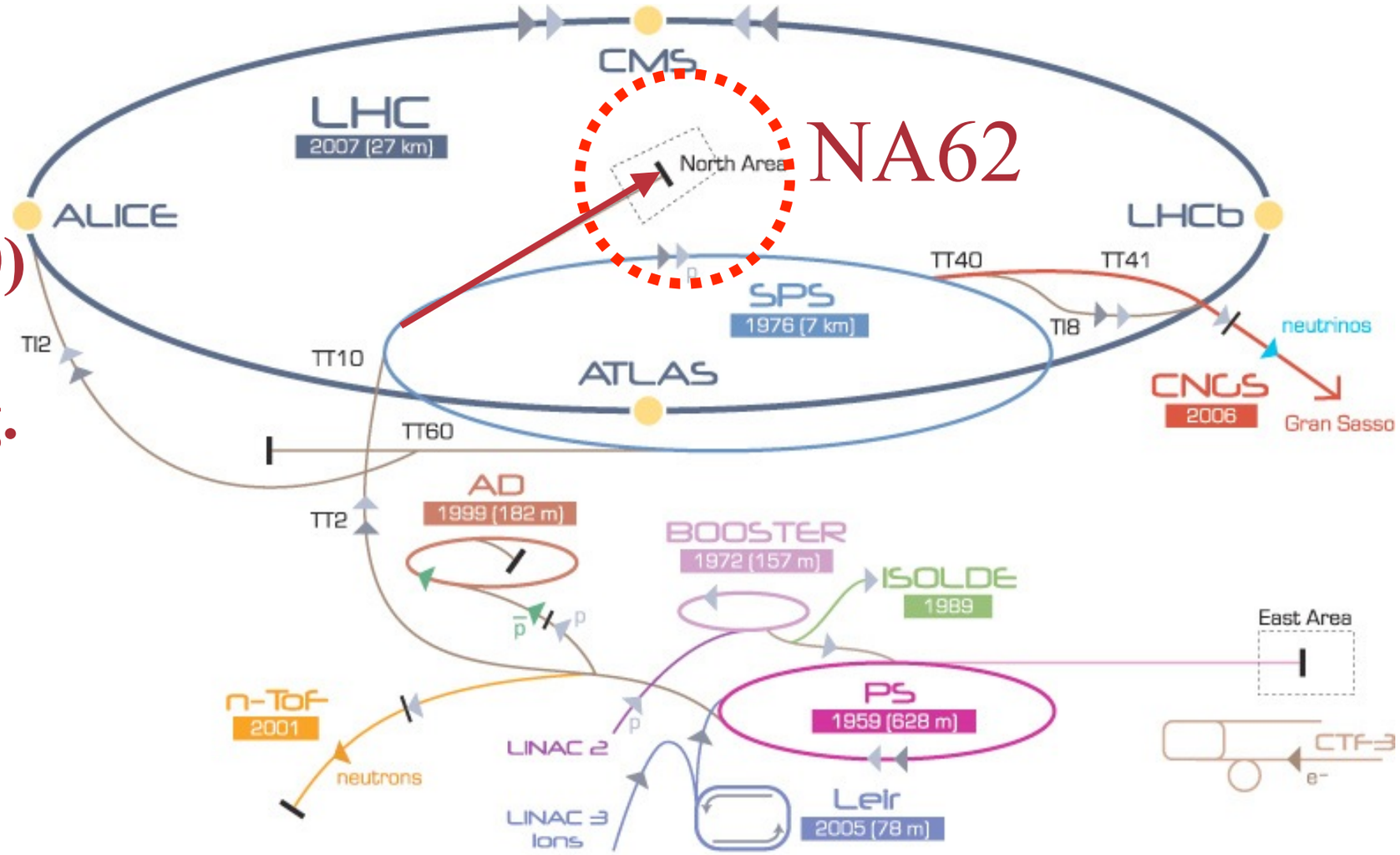
NA62 at CERN

- SPS delivering protons at 400 GeV.
- Hadron flux of 750 MHz generated.
- Kaon flux of 50 MHz at 75 GeV.
- ~10 MHz Kaon decays in decay volume.



NA62 at CERN

- **AIM: Collect O(100) events in first two years of data taking.**
- **AIM: S/B ~ 10.**



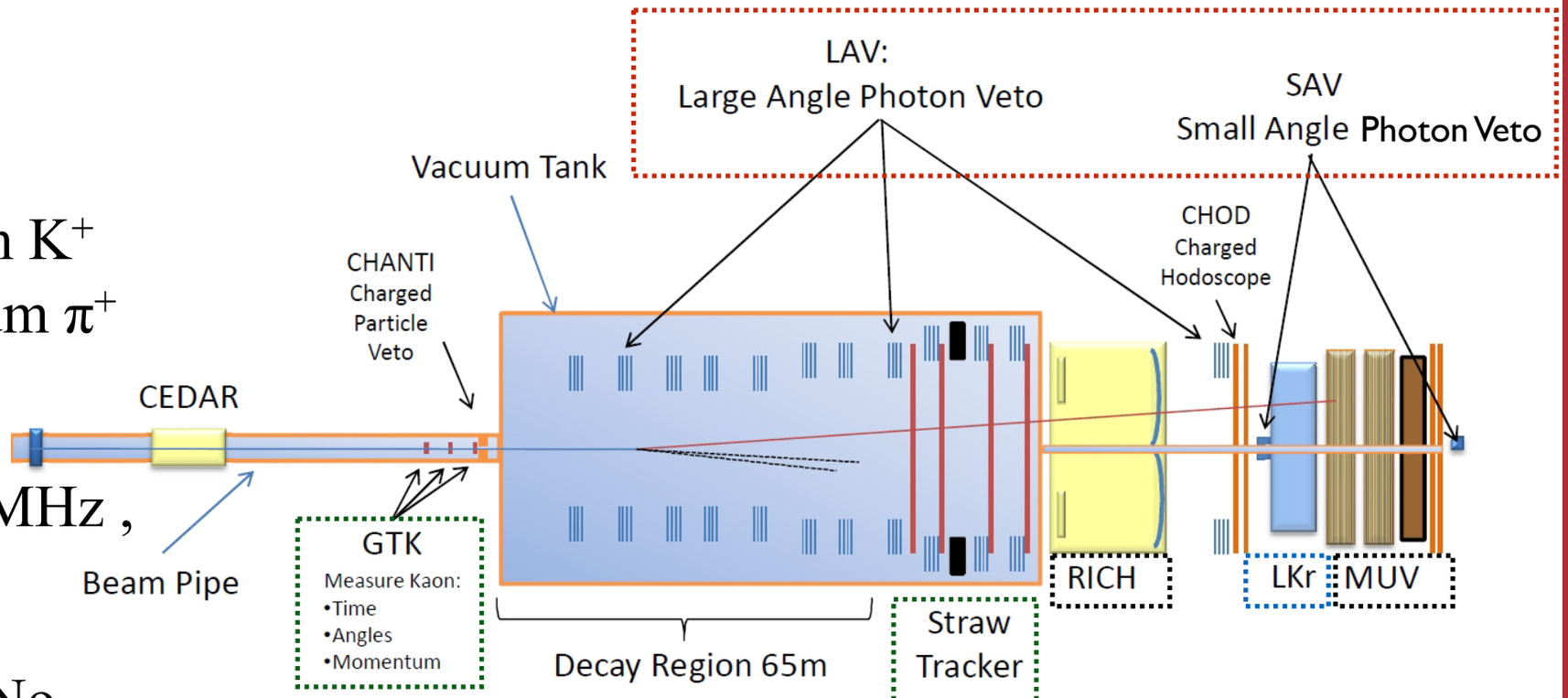
NA62 Detectors

- Signature: high momentum K^+ (75 GeV)⟹ low momentum π^+ (15-35 GeV).

- Trigger: L0 10 MHz → 1 MHz , High level → < 20kHz.

  - L0 - 1 Charged Track, No Muons, Calorimetry fitting single Pion in final state.

- Highly efficient photon veto for missing energy (>40 GeV).



Decay Mode	Branching Ratio	Background Rejection
$K^+ \to \mu^+\nu$	63% (called $K_{\mu 2}$)	μ PID, Two-Body Kinematics
$K^+ \to \pi^+\pi^0$	21%	Photon Veto, Two-Body Kinematics
$K^+ \to \pi^+\pi^+\pi^-$	6%	Charged Particle Veto, Kinematics
$K^+ \to \pi^+\pi^0\pi^0$	2%	Photon Veto, Kinematics
$K^+ \to \pi^0\mu^+\nu$	3% (called $K^+_{\mu 3}$)	Photon Veto, μ PID
$K^+ \to \pi^0 e^+\nu$	5% (called K^+_{e3})	Photon veto, E/p

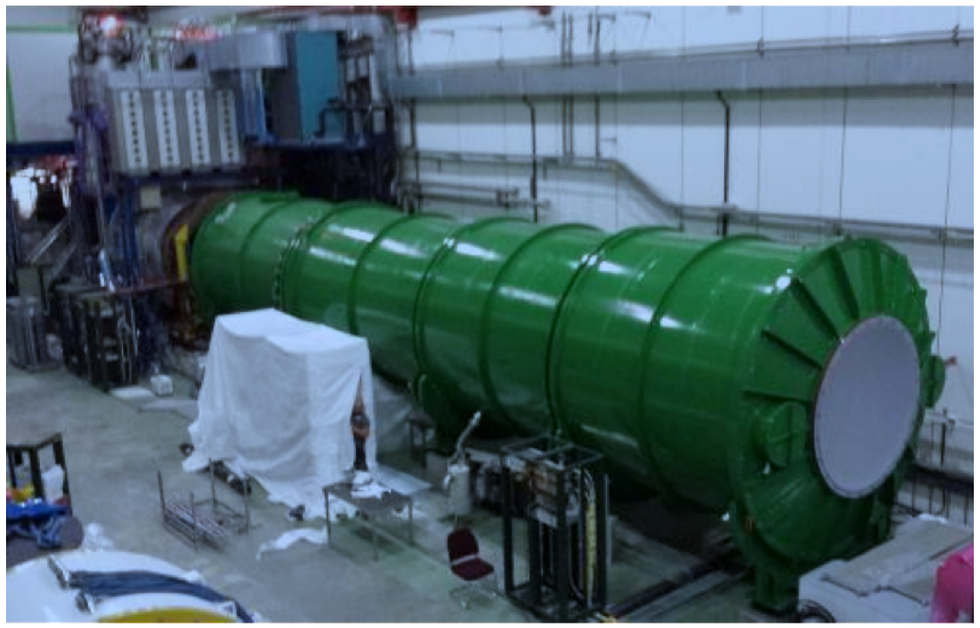
Particle ID

KTAG - K^+

- Precise timing information for K^+.
- $\sigma < 100$ ps.
- Tagging of K^+ with efficiency > 95%.

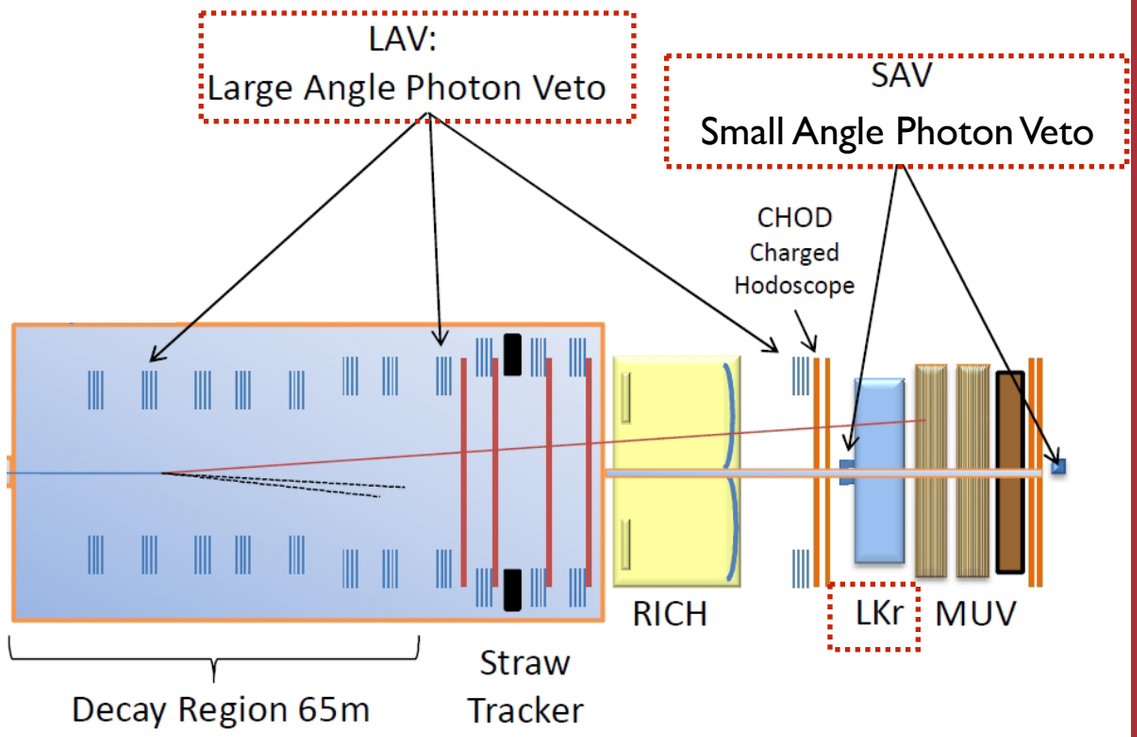
RICH - π^+

- π/μ separation $\Longrightarrow$ μ rejection of $>10^2$ up to 35 GeV. [NIM A 621 2010]
- Precise timing of π^+.
- $\sigma < 100$ ps.



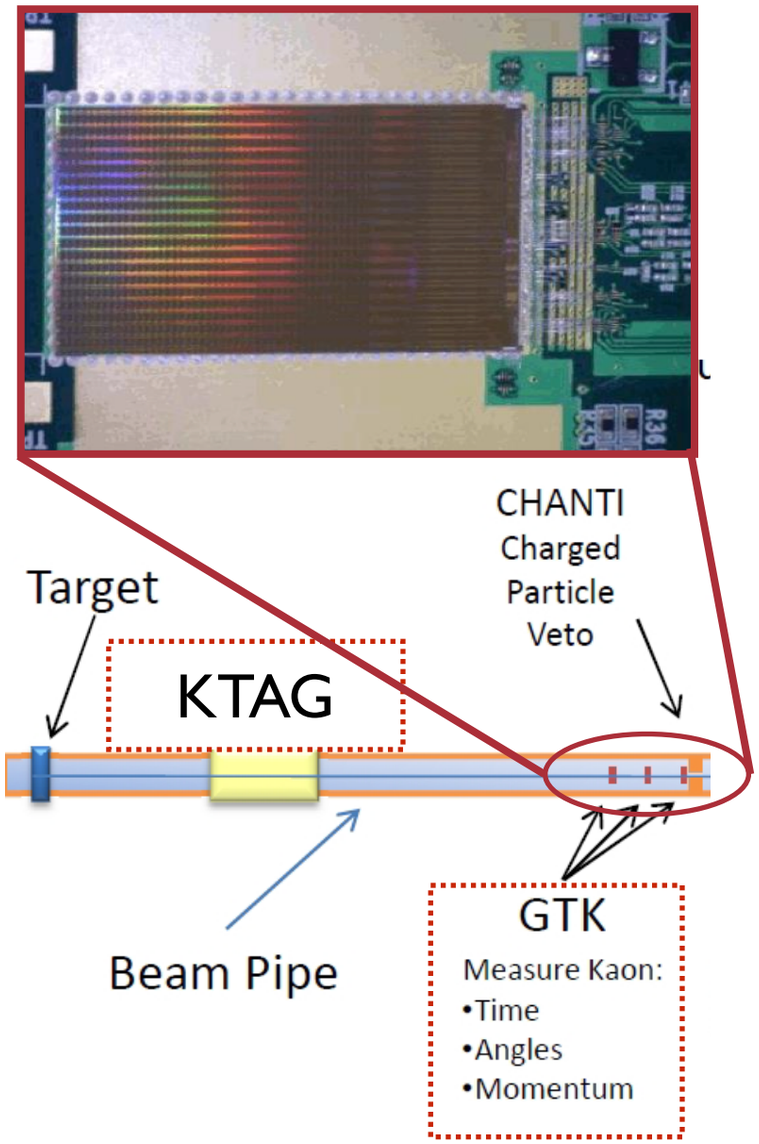
Photon Veto

- Hermetic photon coverage vital in suppressing $K^+ \rightarrow \pi^+\pi^0$.
- $\pi^0 \rightarrow \gamma\gamma$ rejection inefficiency at 10^{-8}.
- Coverage of 50 mrad achieved with:
  - Large Angle Vetoes: 8.5 - 50 mrad.
  - LKr Calorimeter: 1- 8.5 mrad.
  - Small Angle Vetoes: ≤ 1 mrad.



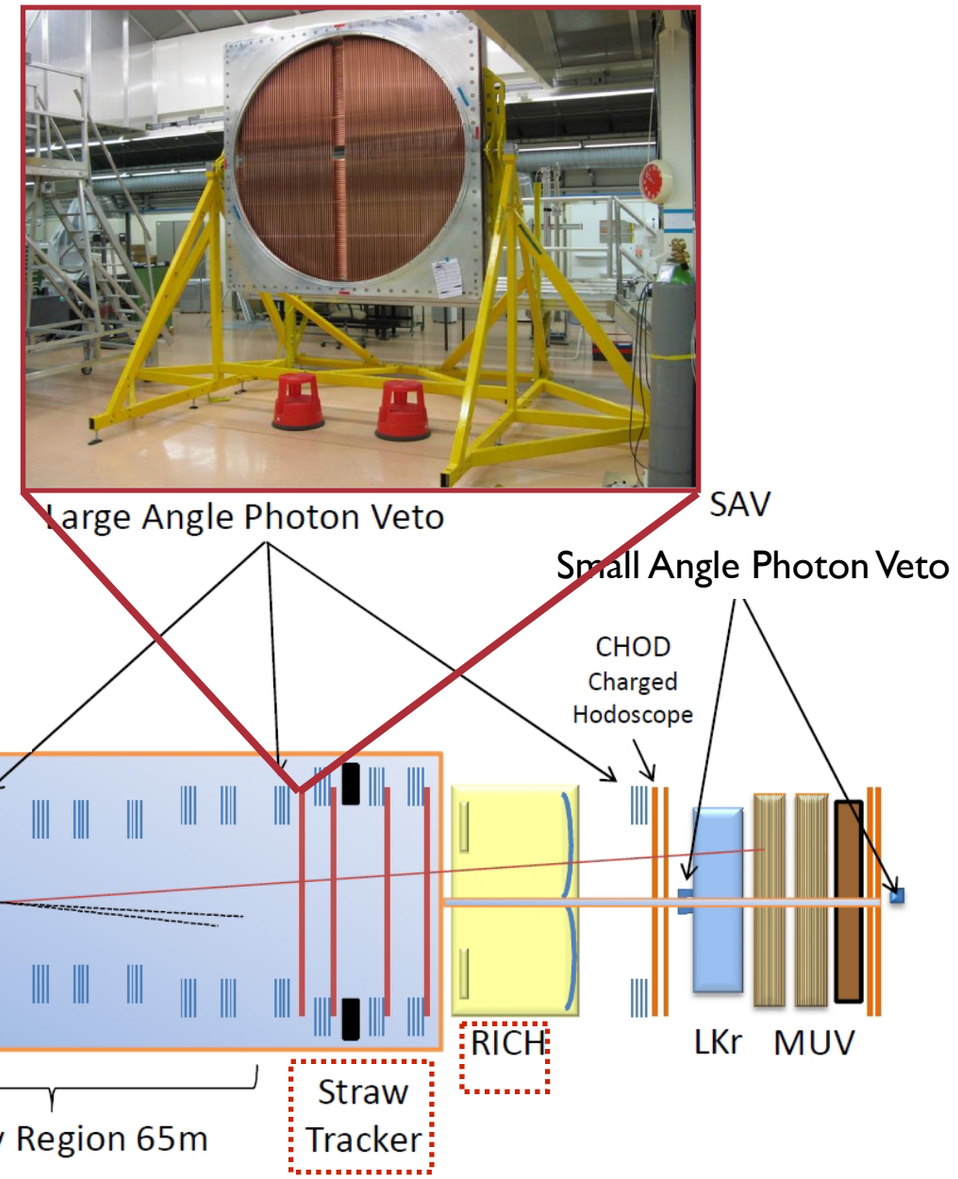
Kaon Reconstruction

- Giga Tracker:
  - Kaon track reconstruction.
  - Si pixel sensors - 300 x 300 μm.
  - Momentum measurement.
    - $\delta(p)/p \sim 0.2\%$.
  - Time resolution $\sigma \sim 200$ ps/station.
- KTAG:
  - Precise timing.



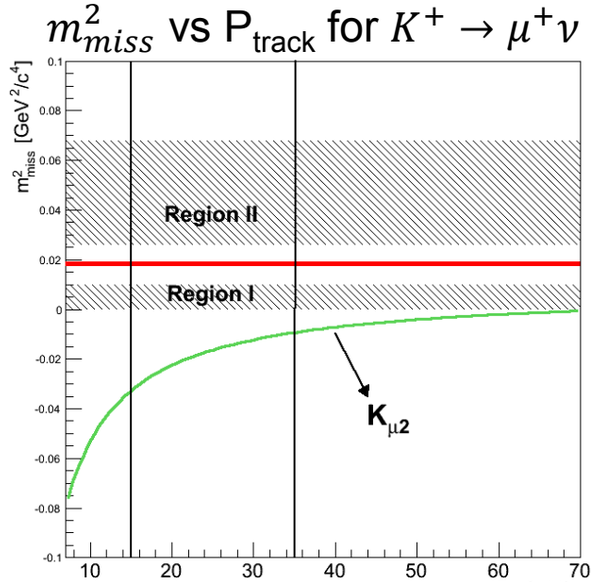
Pion Reconstruction

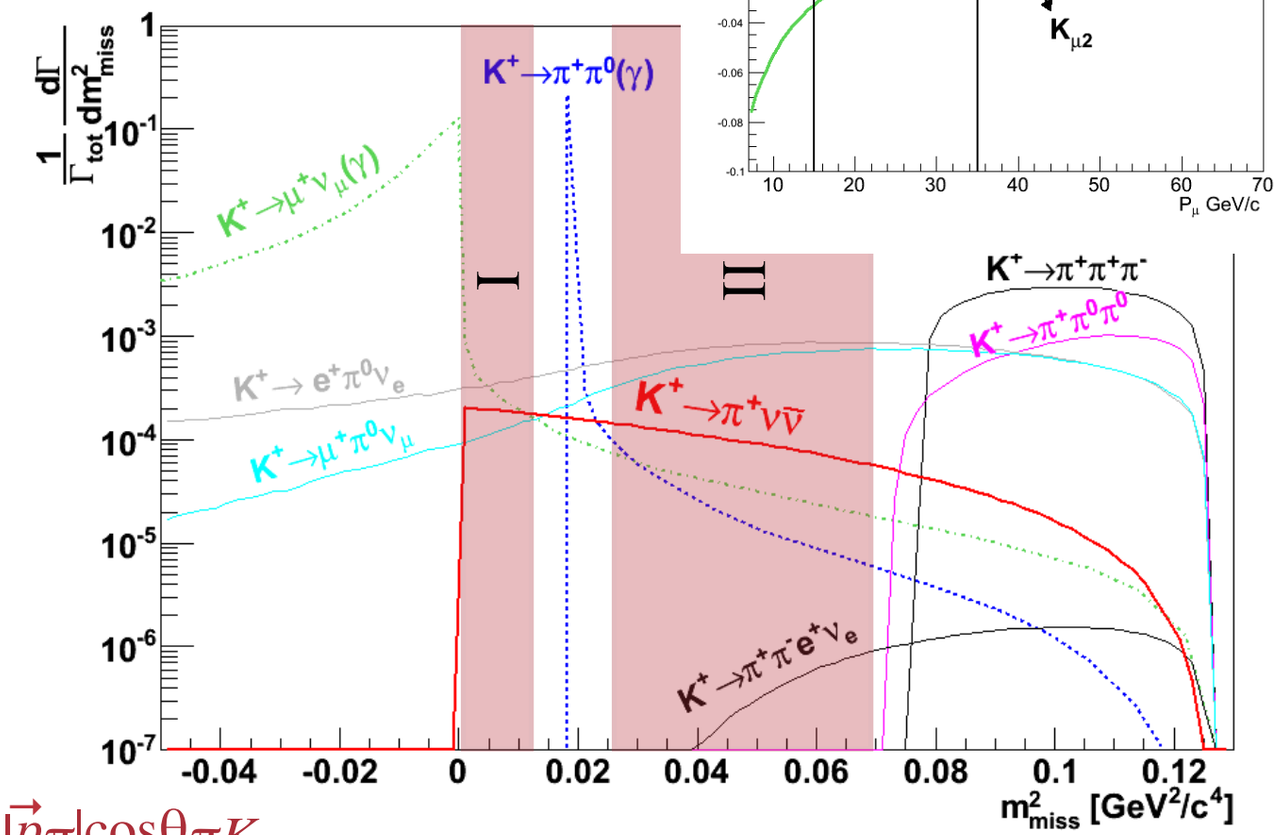
- Straw spectrometer - 4 chambers:
  - Dipole magnet with 265 MeV p_t kick.
  - π^+ track and momentum reconstruction.
  - $\delta(p)/p \sim 0.3\%$, $\sigma_x = \sigma_y < 130\ \mu m$.
- RICH:
  - Precise timing.



Signal Selection

- Missing mass variable used to reject ~92% of background.
- Two regions (below and above the $K^+ \to \pi^+\pi^0$ peak) are considered where the signal is not dominated by background.





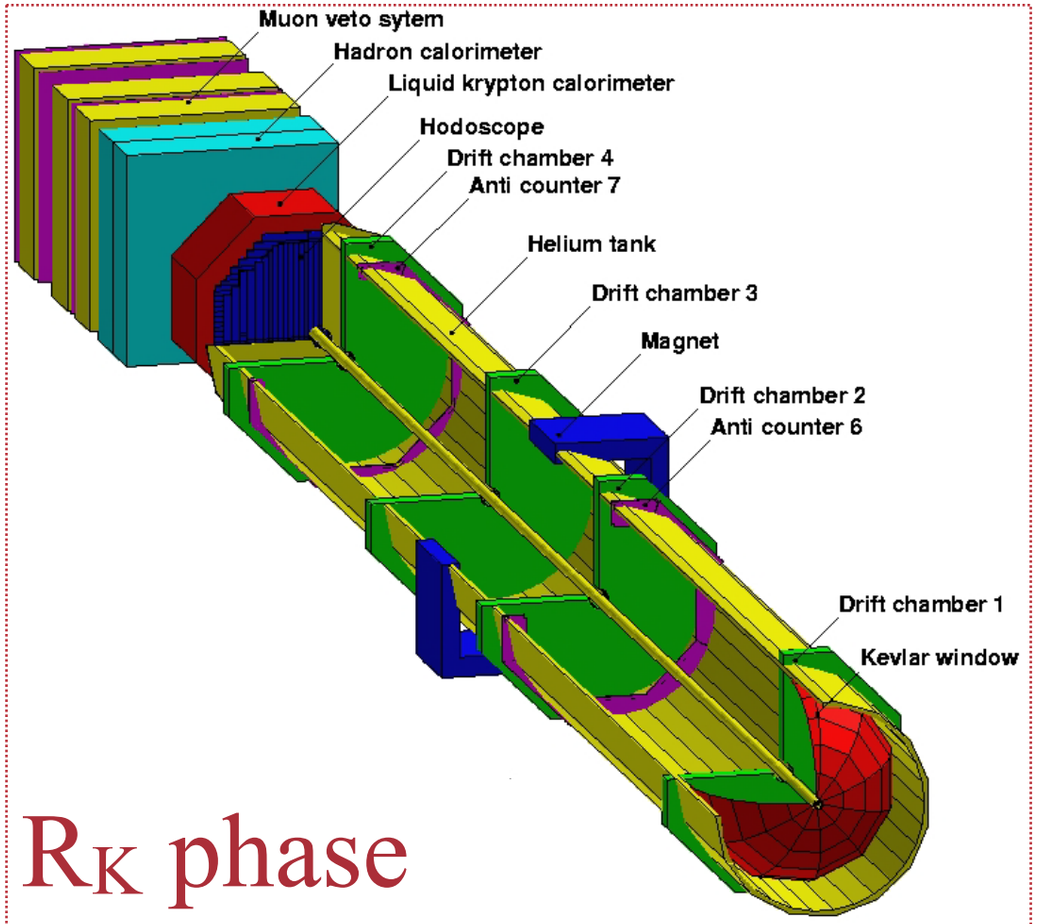
$$m^2miss = (PK - P\pi) = m^2K + m^2\pi - 2EKE\pi + 2|\vec{p}K||\vec{p}\pi|\cos\theta\pi K$$

Sensitivity

Decay	evts/year
$K^+ \to \pi^+ \nu\bar{\nu}$	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 track 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

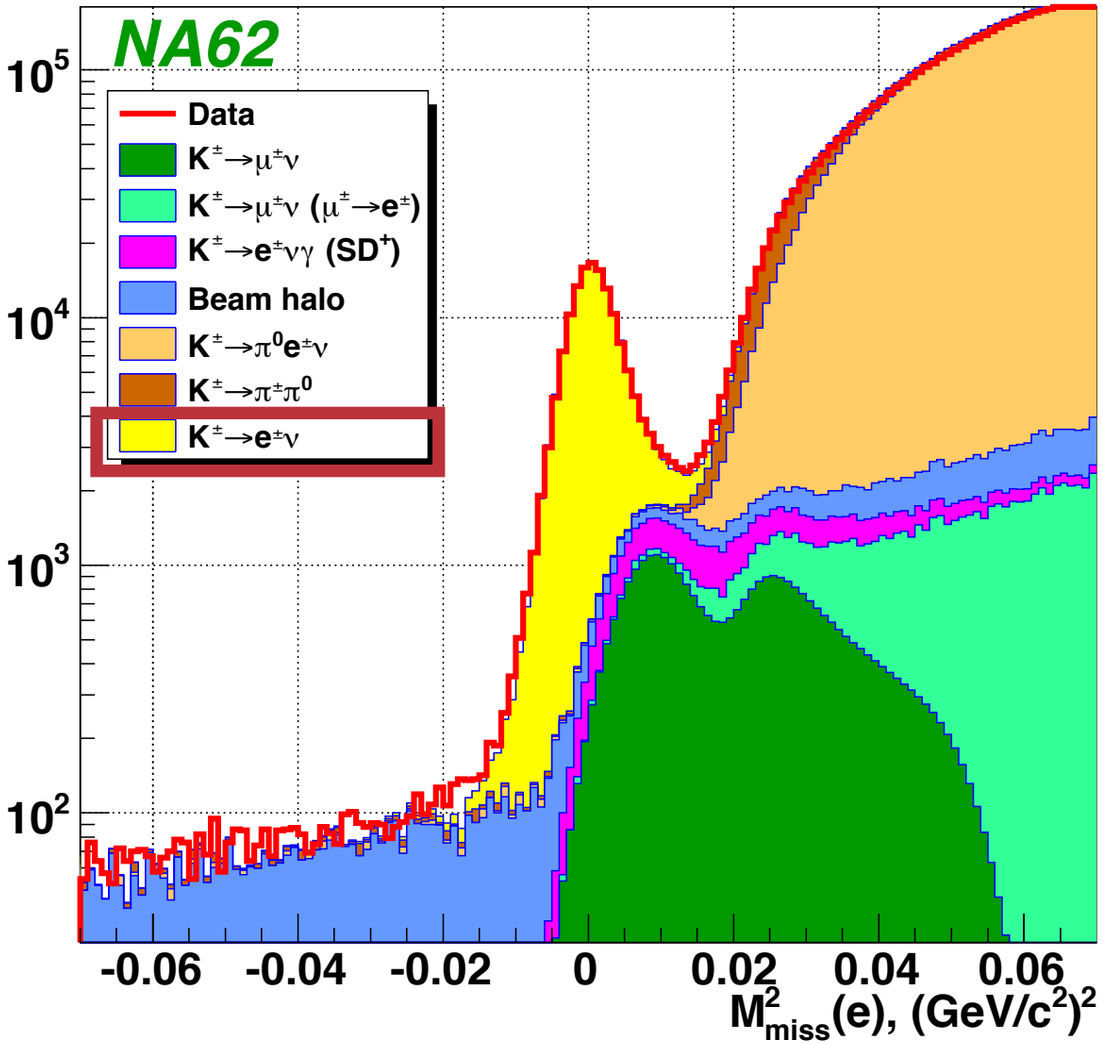
NA62-R_K Phase Overview

- $K^{\pm}$ at 60 GeV with $\delta P_K/P_K \sim 1\%$ - narrow momentum beam.
- Maximum decay rate ~ 100 kHz.
- Main Sub-detectors:
  - Drift chamber based spectrometer - momentum measurement $\Longrightarrow \delta p/p = 0.48\% \oplus 0.009\%\ p$ (p in GeV)
  - Scintillator hodoscope - fast trigger, time measurements $\Longrightarrow$ 150 ps
  - Liquid Krypton EM calorimeter - energy measurement
    $\Longrightarrow \sigma_E/E = 3.2\%/E^{1/2} \oplus 9\%/E \oplus 0.42\%$ (E in GeV)
    $\Longrightarrow \sigma_x = \sigma_y = 4.2\text{mm}/E^{1/2} \oplus 0.6\text{mm}$



R_K phase

R_K - K_{e2} Candidates

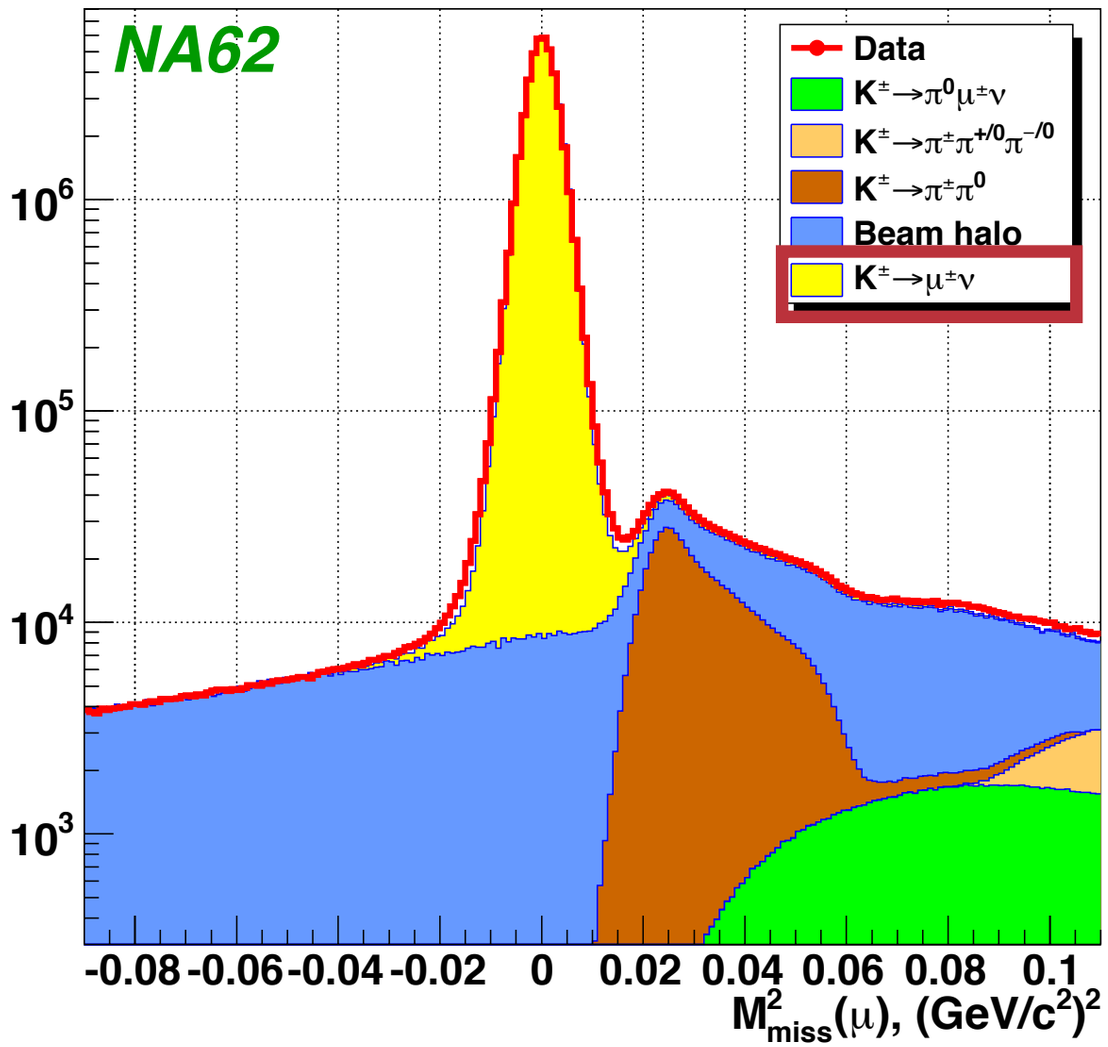


- **145,958** events selected.
- Background:
  - B/(B+S) = (10.95 ± 0.27) %.

Source	B/(B+S)
$K_{\mu 2}$	(5.64±0.20)%
$K_{\mu 2}$ ($\mu \to e$)	(0.26±0.03)%
$K_{e2\gamma}$ (SD)	(2.60±0.11)%
K_{e3}	(0.18±0.09)%
$K_{2\pi}$	(0.12±0.06)%
Opposite sign K	(0.04±0.02)%
Beam Halo	(0.04±0.02)%
Total	(10.95±0.27)%

R_K - $K_{\mu 2}$ Candidates

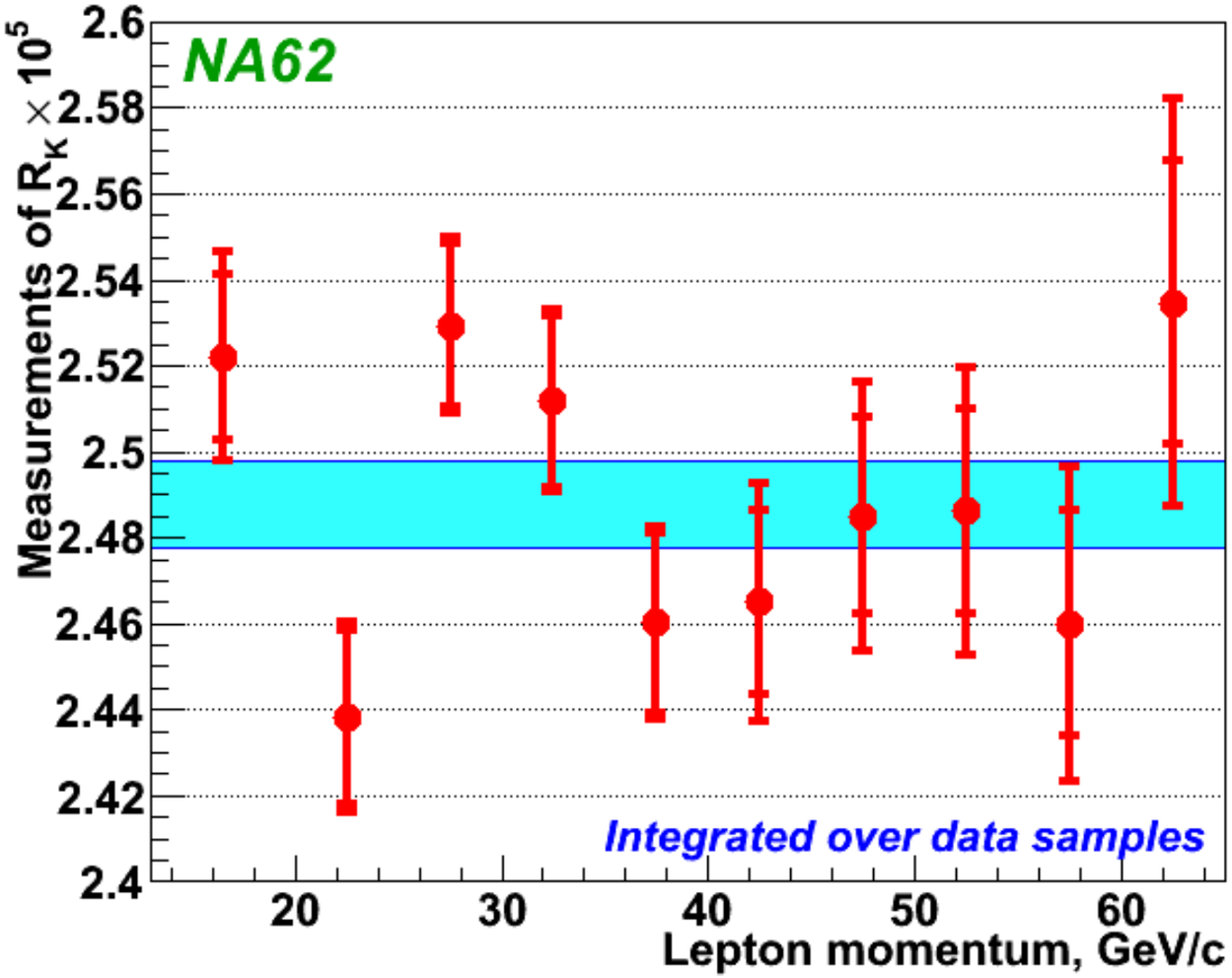
- **42.817 M events** (collected with pre-scaled trigger).
- Main background coming from beam halo muons:
  - (0.50±0.01)%

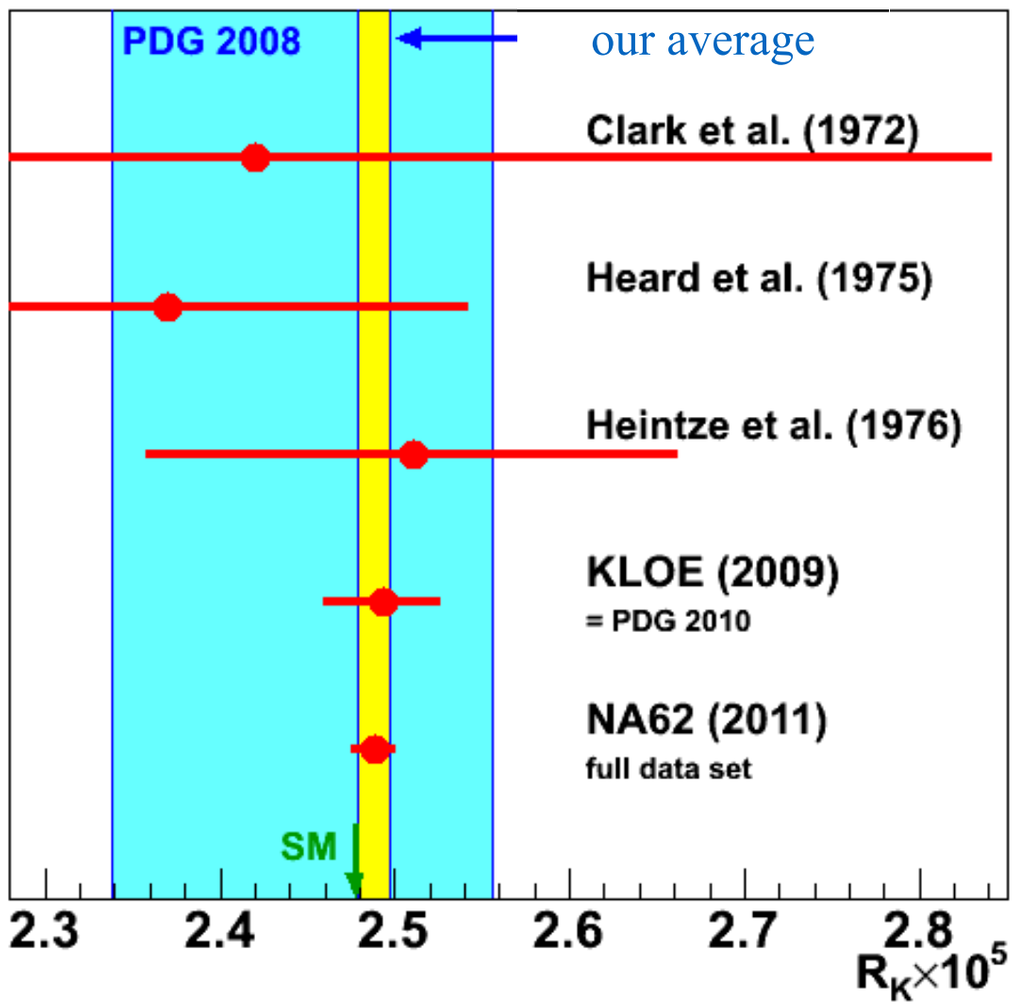


NA62-R_K Result

$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{sys}) \times 10^{-5}$$
$$= (2.488 \pm 0.010) \times 10^{-5}$$

Phys. Lett. B 719 (2013) 326





Summary

- NA62-RK (2007-2008):
  - Stringent test of Lepton Universality at unprecedented precision of 0.4%.

$$R_K = Br(K^{\pm} \rightarrow e^{\pm}\nu)/Br(K^{\pm} \rightarrow \mu^{\pm}\nu) = (2.488 \pm 0.010) \times 10^{-5}$$

- NA62 (2014-):
  - Construction and commissioning progressing well.
  - Set for low intensity run starting in October.
  - Aiming for SM single event sensitivity for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ by end of first run.
  - Aim for O(100) SM events after two year with S/B ~ 10.

BACK UP

NA62 Potential Decays

Decay	Physics	Present limit (90% C.L.) / Result	NA62
$\pi^+\mu^+e^-$	LFV	1.3×10^{-11}	0.7×10^{-12}
$\pi^+\mu^-e^+$	LFV	5.2×10^{-10}	0.7×10^{-12}
$\pi^-\mu^+e^+$	LNV	5.0×10^{-10}	0.7×10^{-12}
$\pi^-e^+e^+$	LNV	6.4×10^{-10}	2×10^{-12}
$\pi^-\mu^+\mu^+$	LNV	1.1×10^{-9}	0.4×10^{-12}
$\mu^-\nu e^+e^+$	LNV/LFV	2.0×10^{-8}	4×10^{-12}
$e^-\nu\mu^+\mu^+$	LNV	No data	10^{-12}
π^+X^0	New Particle	$5.9 \times 10^{-11}\ m_{X^0} = 0$	10^{-12}
$\pi^+\chi\chi$	New Particle	–	10^{-12}
$\pi^+\pi^+e^-\nu$	$\Delta S \neq \Delta Q$	1.2×10^{-8}	10^{-11}
$\pi^+\pi^+\mu^-\nu$	$\Delta S \neq \Delta Q$	3.0×10^{-6}	10^{-11}
$\pi^+\gamma$	Angular Mom.	2.3×10^{-9}	10^{-12}
$\mu^+\nu_h, \nu_h \to \nu\gamma$	Heavy neutrino	Limits up to $m_{\nu_h} = 350\ MeV$	
R_K	LU	$(2.488 \pm 0.010) \times 10^{-5}$	>×2 better
$\pi^+\gamma\gamma$	χPT	< 500 events	10^5 events
$\pi^0\pi^0e^+\nu$	χPT	66000 events	O(10^6)
$\pi^0\pi^0\mu^+\nu$	χPT	-	O(10^5)