

NA62 experiment at CERN SPS

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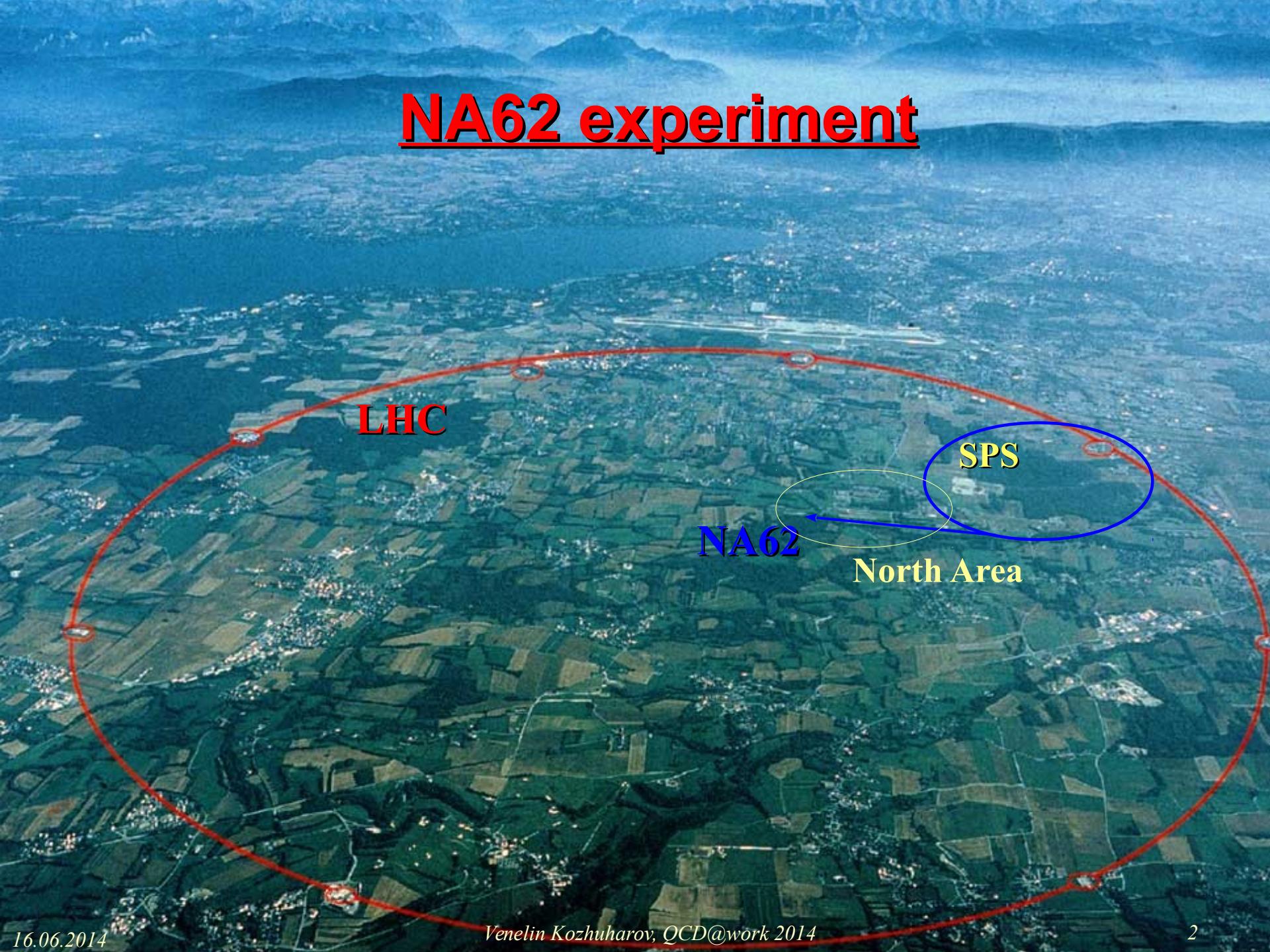
QCD@work

16 June 2014

on behalf of the NA62 collaboration

**Birmingham, Bratislava, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati,
Glasgow, Liverpool, Louvain, Mainz, Merced, Moscow, Naples, Perugia, Pisa,
Prague, Protvino, Rome I, Rome II, San Luis Potosí, Stanford, Sofia, Turin**

NA62 experiment



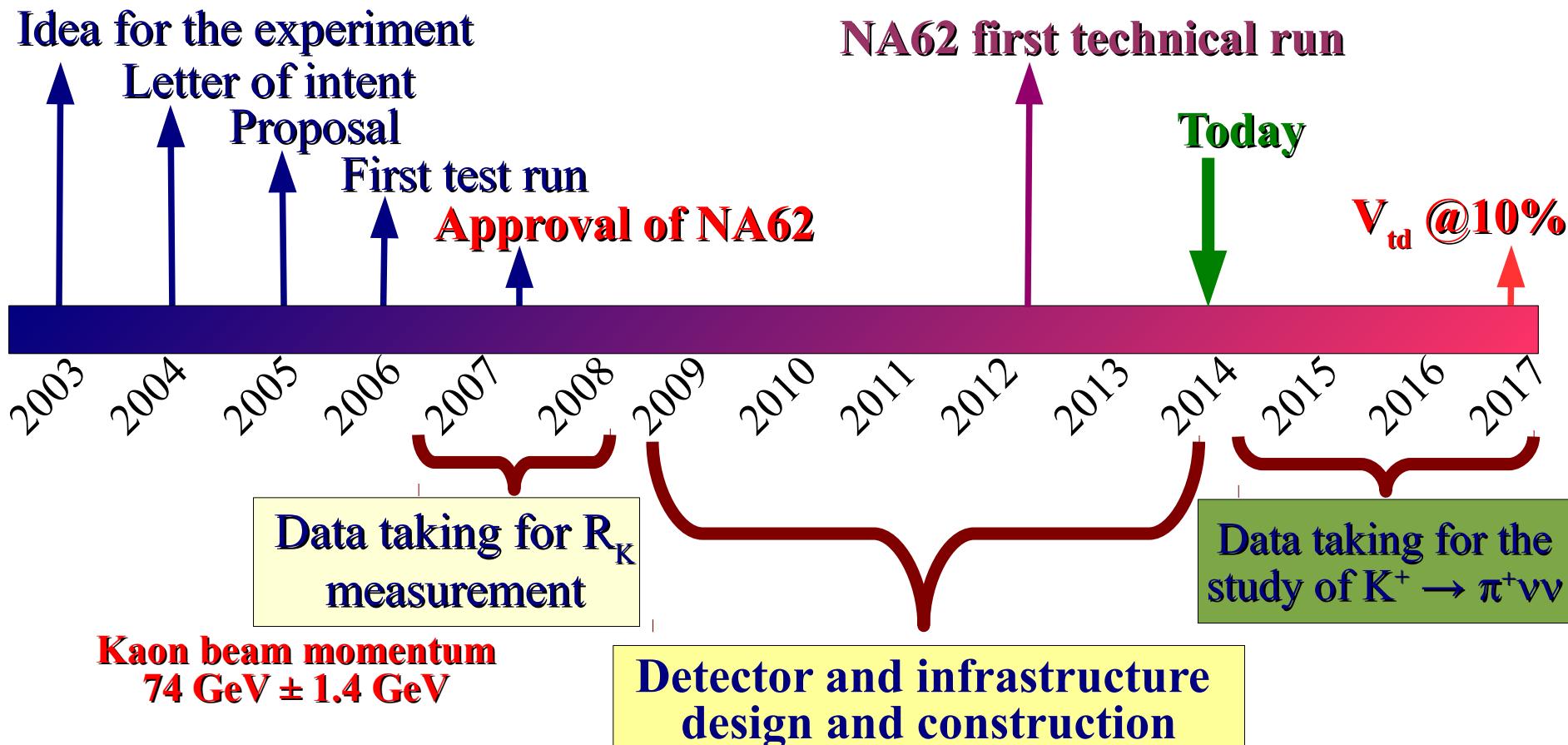
LHC

NA62

SPS

North Area

NA62 experiment



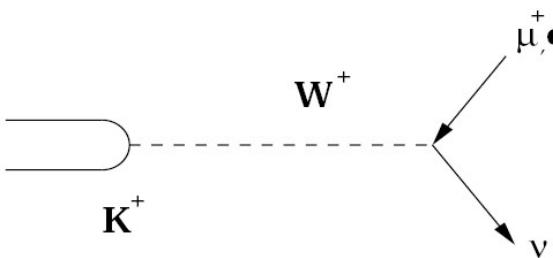
RK phase of the NA62 experiment uses NA48 beam and detector

Overview

- NA62 early phase
 - R_K measurement
 - ChPT tests with $K^\pm \rightarrow \pi^\pm \gamma\gamma$
- NA62 golden channel: $K^+ \rightarrow \pi^+ \nu\nu$
- Experimental setup
- NA62 physics reach
- Conclusion

Ke2: Motivation

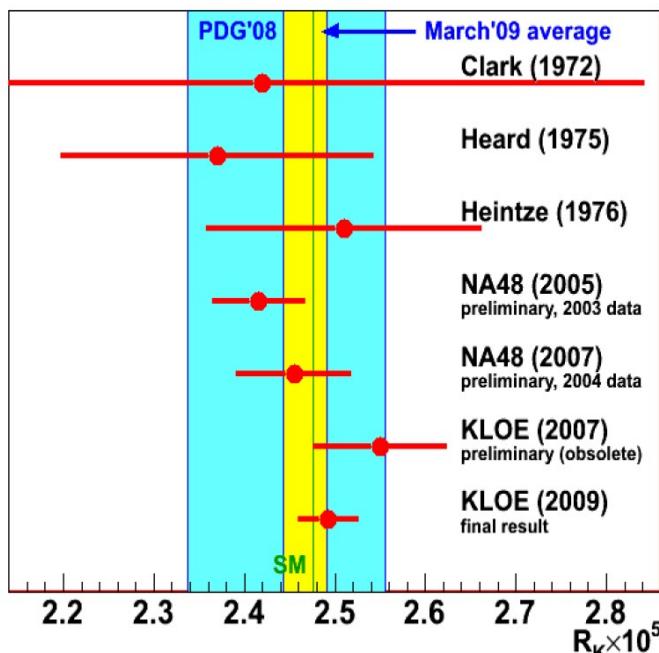
Within the Standard Model:


$$R_M := \frac{\Gamma(M \rightarrow e\nu_e(\gamma))}{\Gamma(M \rightarrow \mu\nu_\mu(\gamma))} = \frac{m_e^2}{m_\mu^2} \left(\frac{m_M^2 - m_e^2}{m_M^2 - m_\mu^2} \right)^2 (1 + \delta R_M)$$

δR_M arises from the radiative corrections, $M=\pi^\pm, K^\pm$

V. Cirigliano, I. Rosell, Phys.Rev.Lett.99:231801,2007

For K^\pm : $R_K = (2.477 \pm 0.001) * 10^{-5}$



Experimental error on R_K :
*more than order of magnitude
larger than the theoretical*

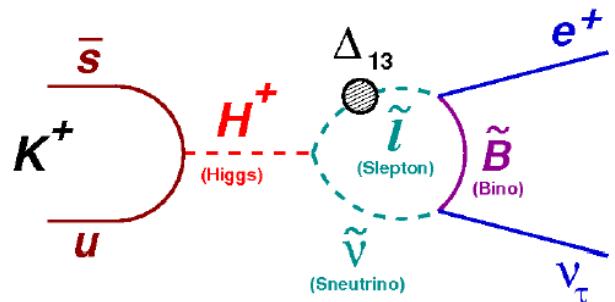
Ke2: Motivation

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Standard Model prediction:

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



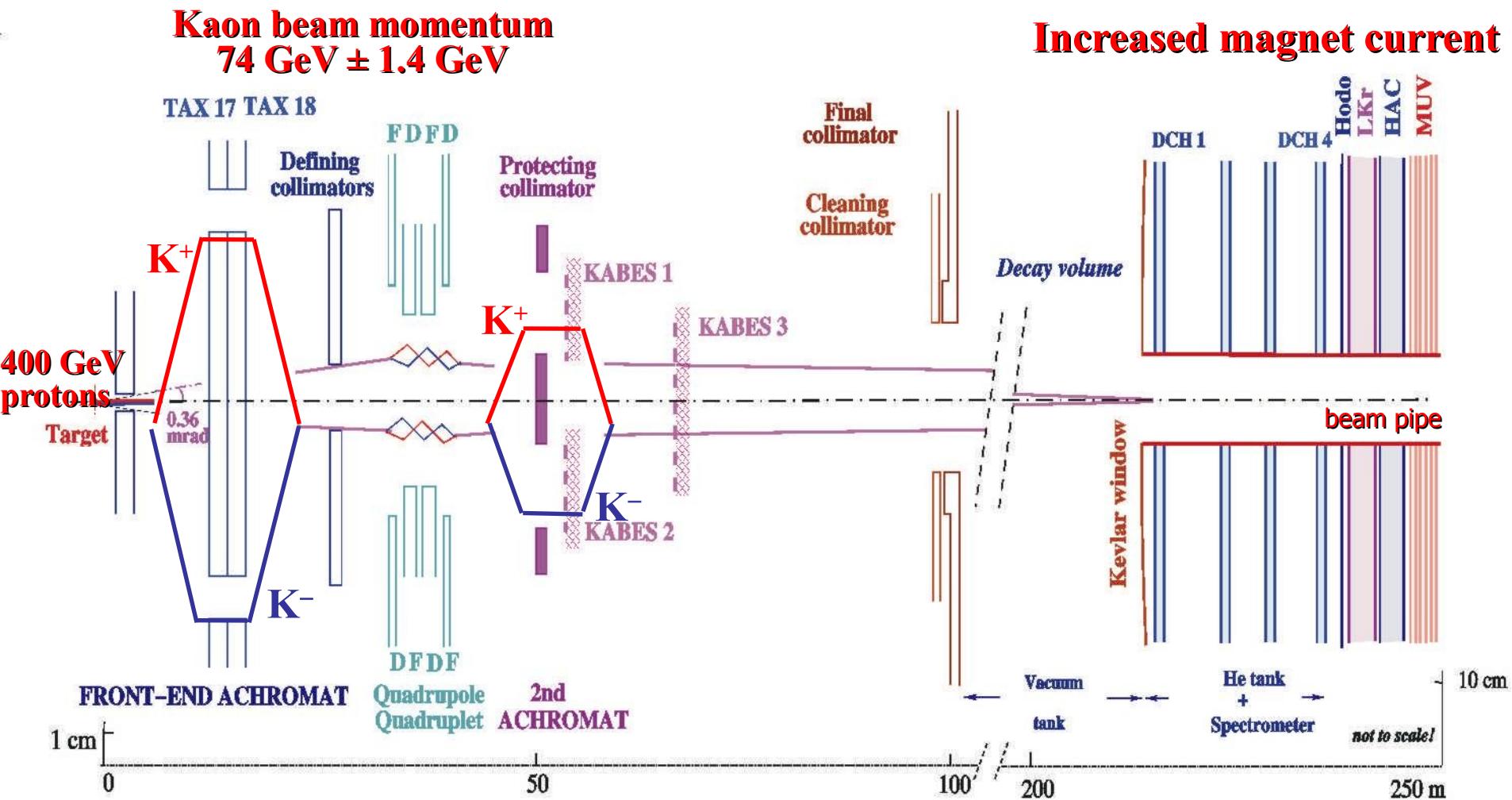
$$R_K^{\text{LFV}} \simeq R_K^{\text{SM}} \left[1 + \left(\frac{m_K^4}{M_H^4} \right) \left(\frac{m_\tau^2}{m_e^2} \right) |\Delta_R^{31}|^2 \tan^6 \beta \right]$$

A. Masiero et al. Phys.Rev. D74 (2006) 011701

- The value of R_K could be different in case of SUSY and LFV models – the correction could be as high as %
- Measurement of R_K at with sub per cent precision tests the μ -e universality and provides a sensible test of the SM

Beam setup

Using NA48/2 beam and detector setup



Detector setup

- Magnetic spectrometer (DCH)

4 drift chambers

$$p_{\perp}^{\text{kick}} = 265 \text{ MeV}/c$$

$$\Delta p/p = 0.48\% \oplus 0.009\% * p [\text{GeV}/c]$$

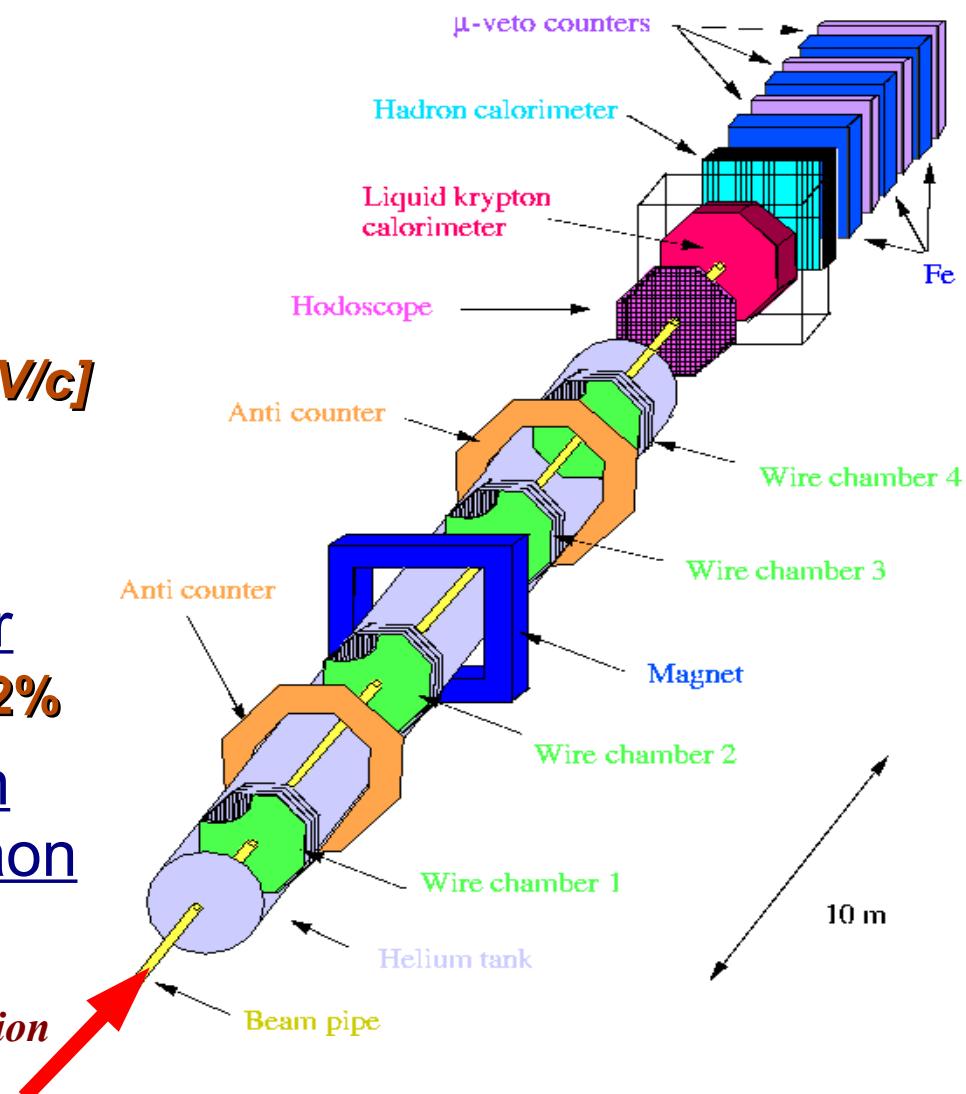
- Hodoscope

$$\sigma(t) = 150 \text{ ps}$$

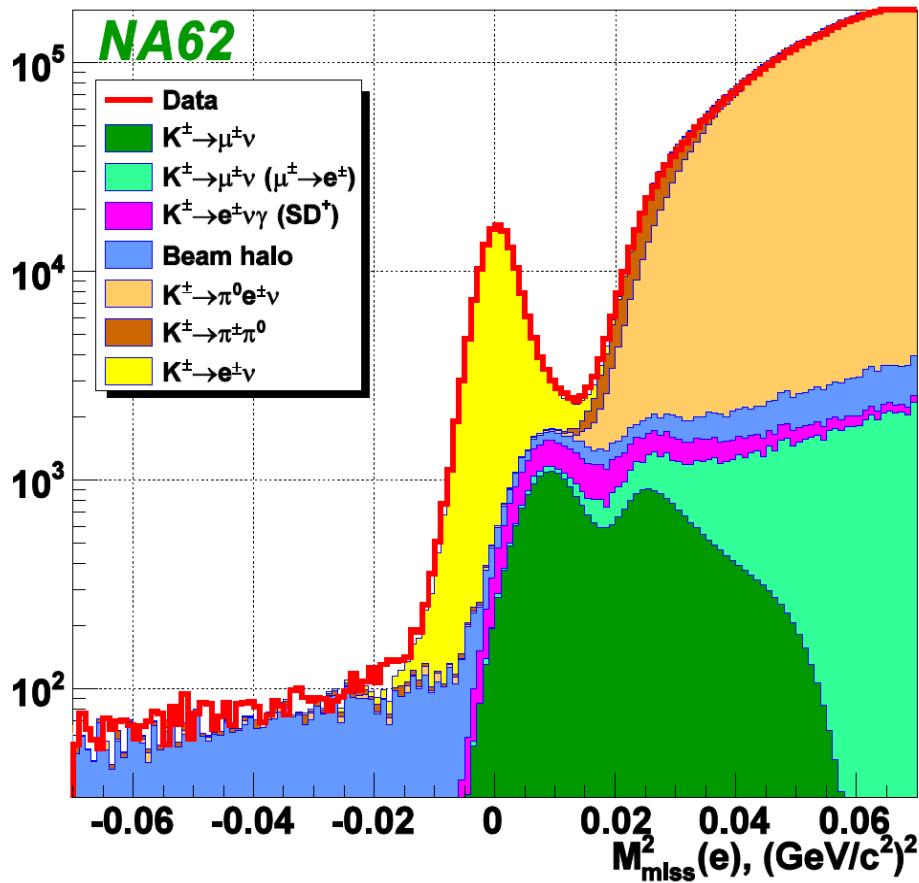
- Liquid Krypton Calorimeter

$$\Delta E/E \approx 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$$

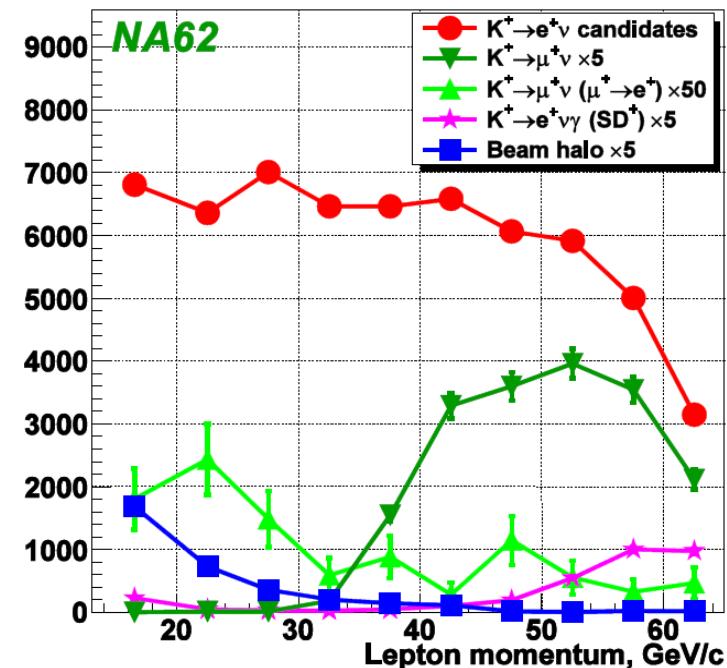
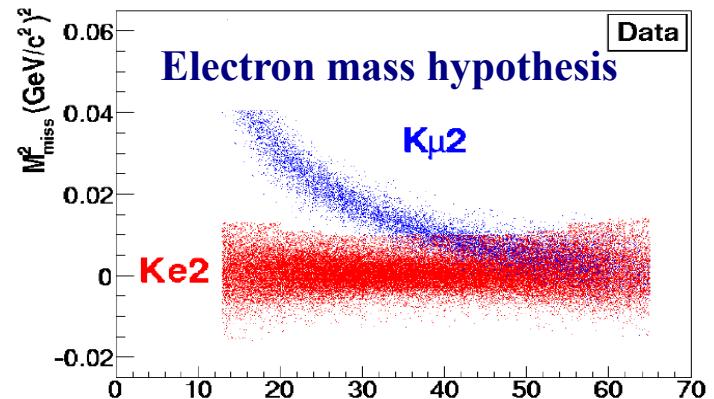
- Hadron Calorimeter, Muon counters, Anticounters, Kaon Beam Spectrometer



Event selection



- Reconstructed $\sim 150k$ Ke2 candidates
 - Background contribution: $(10.95 \pm 0.27)\%$
 - Dominated by $K\mu 2$

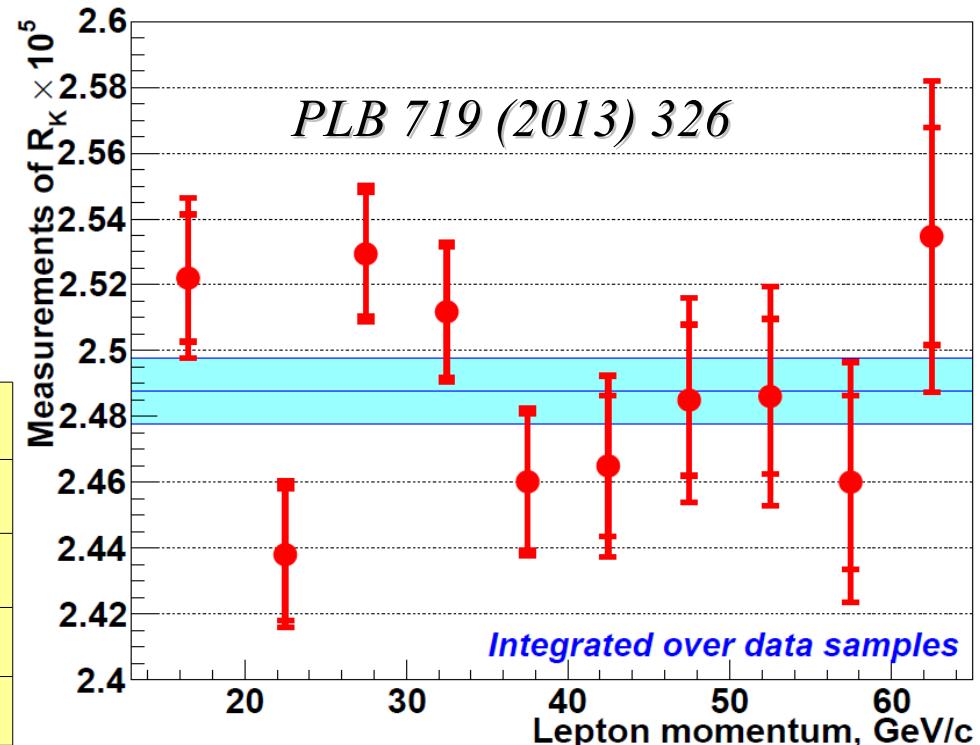


R_K extraction

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \cdot \frac{A(K_{\mu 2})}{A(K_{e2})} \cdot \frac{f_{\mu} \times \epsilon(K_{\mu 2})}{f_e \times \epsilon(K_{e2})} \cdot \frac{1}{f_{LKr}}$$

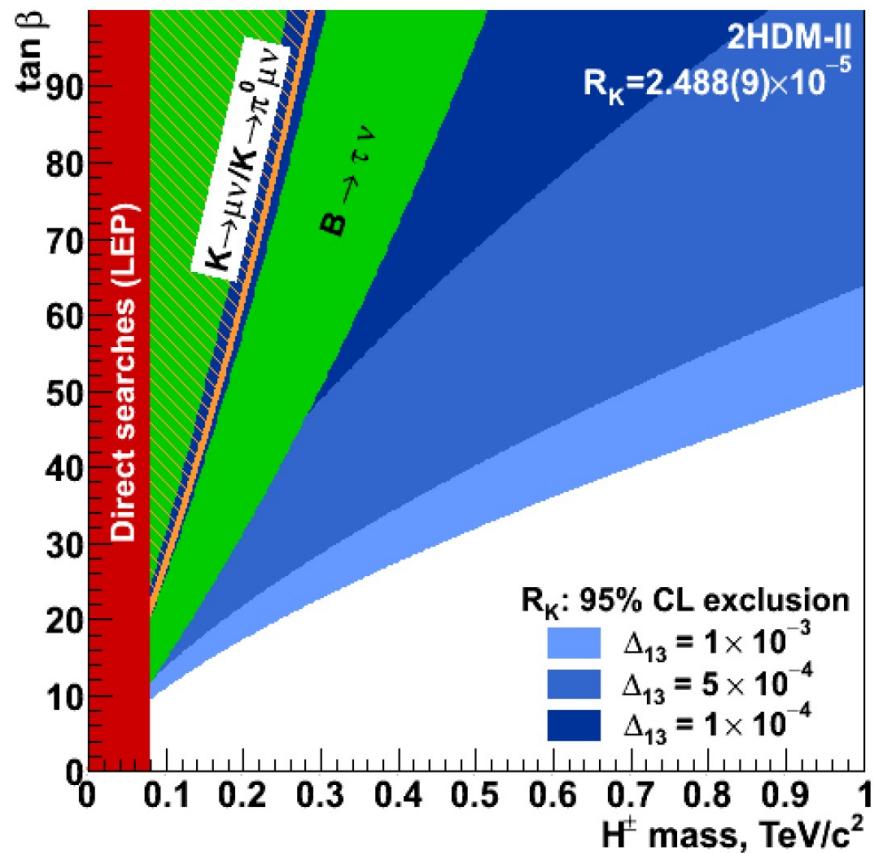
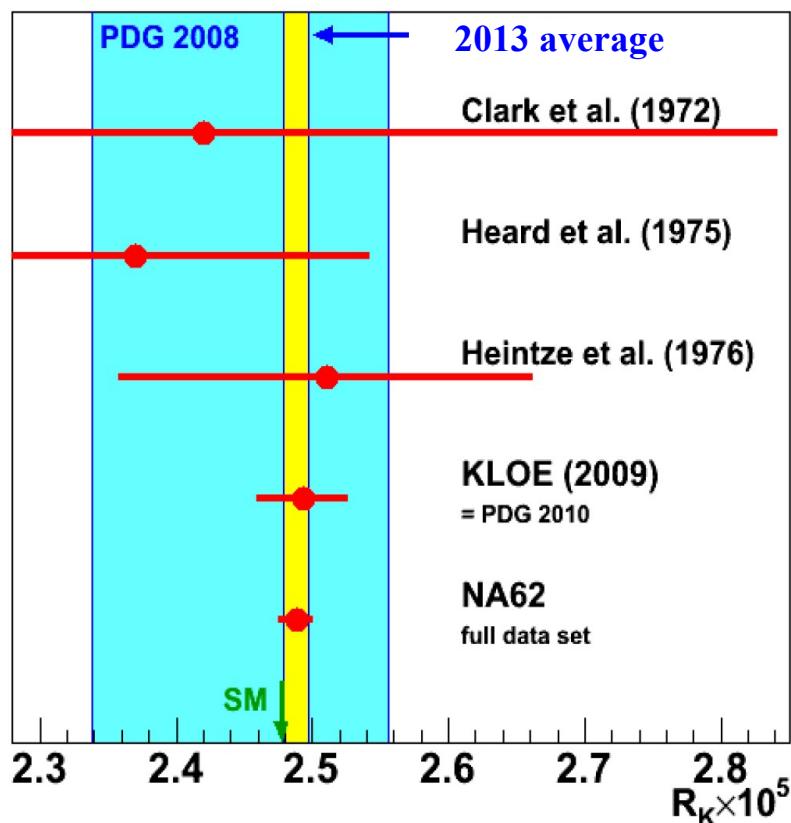
N(K _{I₂})	K_{I₂} event candidates
N _B (K _{I₂})	Background in KI2
f _I	Lepton ID efficiency
f _{LKr}	Global LKr efficiency
ε(K _{I₂})	K_{I₂} trigger efficiency
A(K _{I₂})	K_{I₂} acceptance
D	Downscaling of Kμ2 trigger

Systematic effect	ΔR _K *10 ⁵
Kμ2 background	0.004
Ke3 and K2π background	0.003
Matter composition	0.002
Beam halo	0.002
Ke2γ (SD+) background	0.002



NA62 result: $R_K = (2.488 \pm 0.007_{\text{stat}} \pm 0.007_{\text{syst}}) \times 10^{-5}$

Results



- Combined result: $R_K = (2.488 \pm 0.009) * 10^{-5}$
compatible with the SM prediction
- Still order of magnitude bigger error than the SM:
NA62 might be able to achieve 0.2%

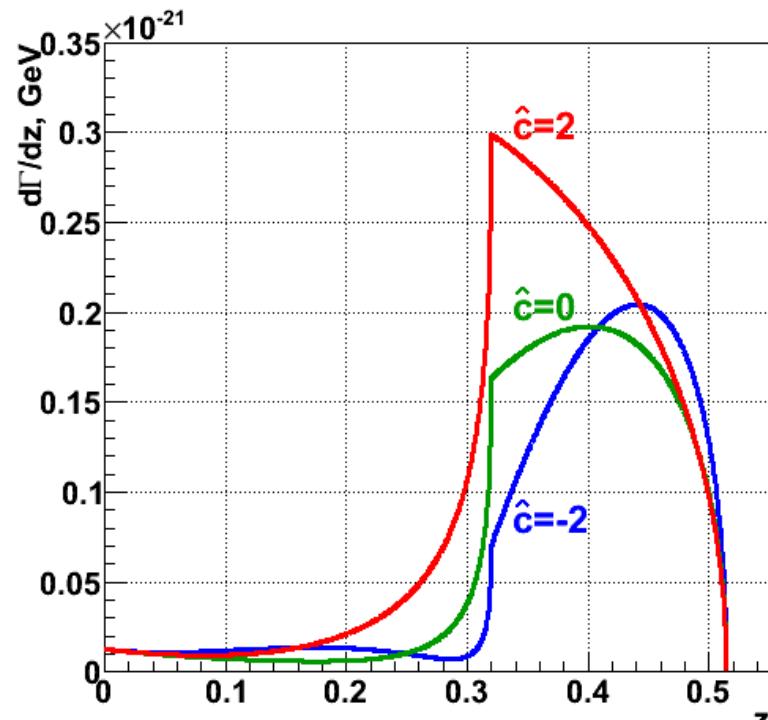
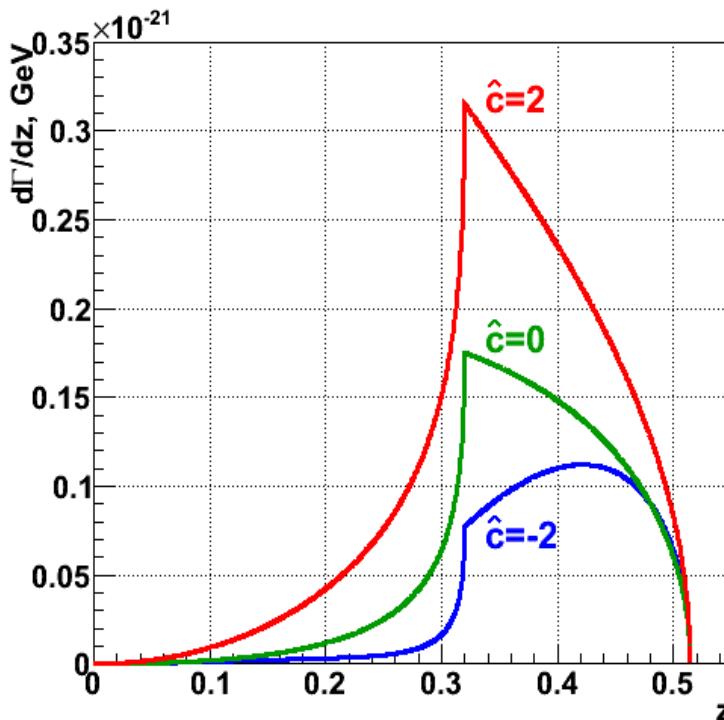
ChPT tests: $K \rightarrow \pi \gamma \gamma$ decay

- Dependence on a single a priori unknown parameter \hat{c} at $O(p^4)$ and $O(p^6)$

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

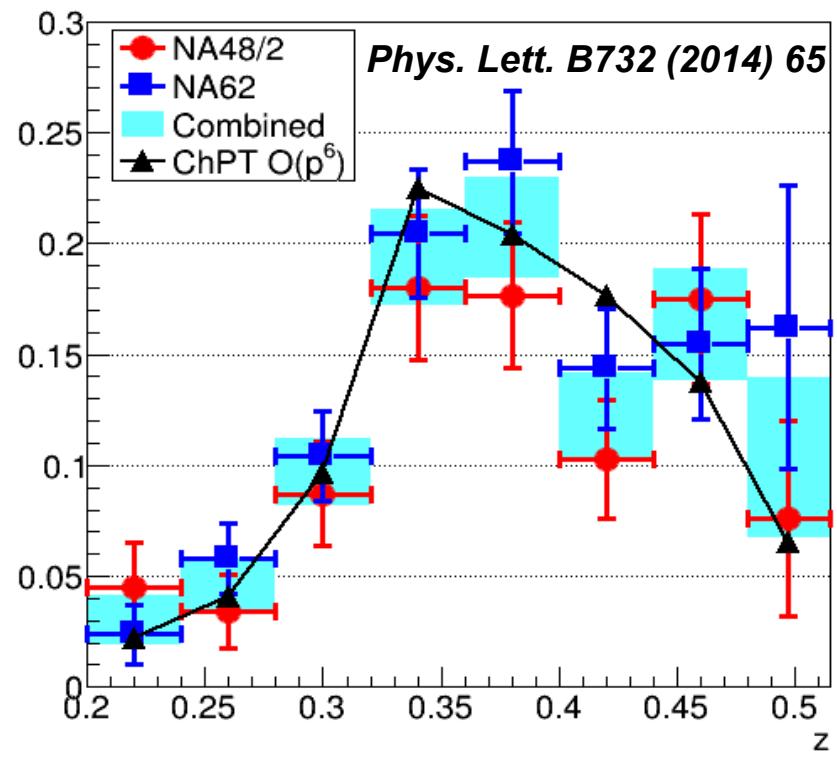
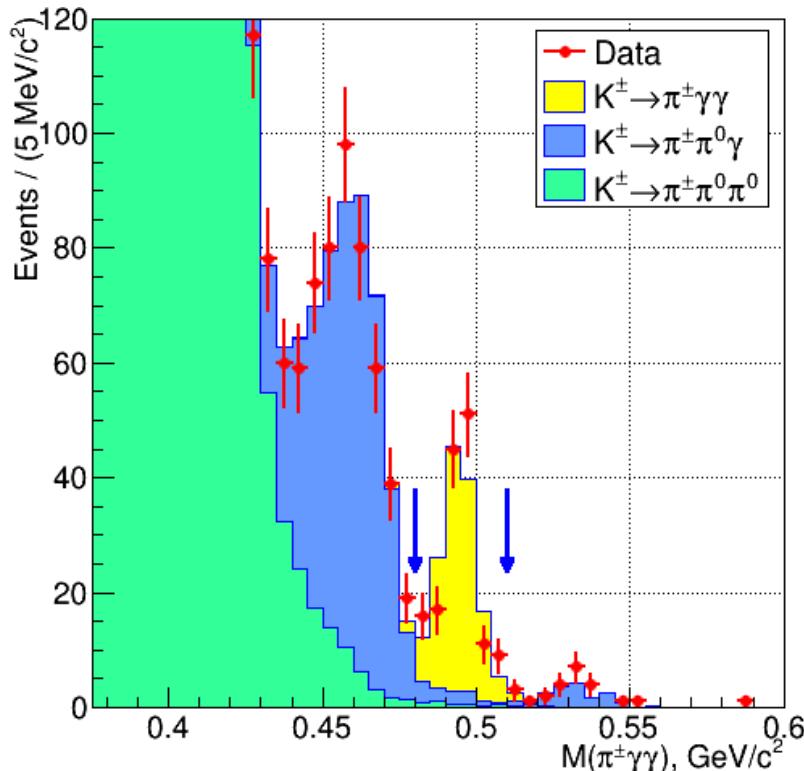
where $z = \left(\frac{m_{\gamma\gamma}}{m_K}\right)^2$, $y = \frac{p(q_1 - q_2)}{m_K^2}$

pole contribution
loop contribution
loop $O(p^6)$



ChPT tests: $K \rightarrow \pi \gamma \gamma$ decay

- BNL E787: 31 candidates *PRL 79 (1997) 4079*
- NA48/2: 2004, 149 candidates, ~11% background, *Phys. Lett. B730 (2014) 141*
- NA62: 2007 data, downscaled trigger – 232 candidates, ~7% background,**



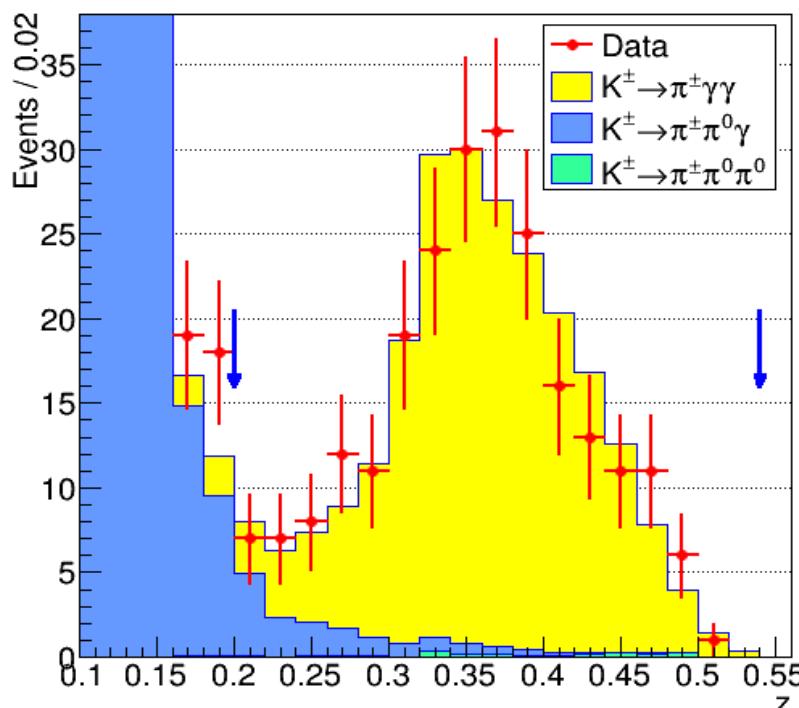
cut at z = 0.2 due to $K^+ \rightarrow \pi^\pm \pi^0 \gamma$ background

$$\text{BR}(K^\pm \rightarrow \pi^\pm \gamma\gamma)_{\text{MI}, z > 0.2} = (0.965 \pm 0.061_{\text{stat}} \pm 0.014_{\text{syst}}) * 10^{-6}$$

ChPT tests: $K \rightarrow \pi \gamma\gamma$ decay

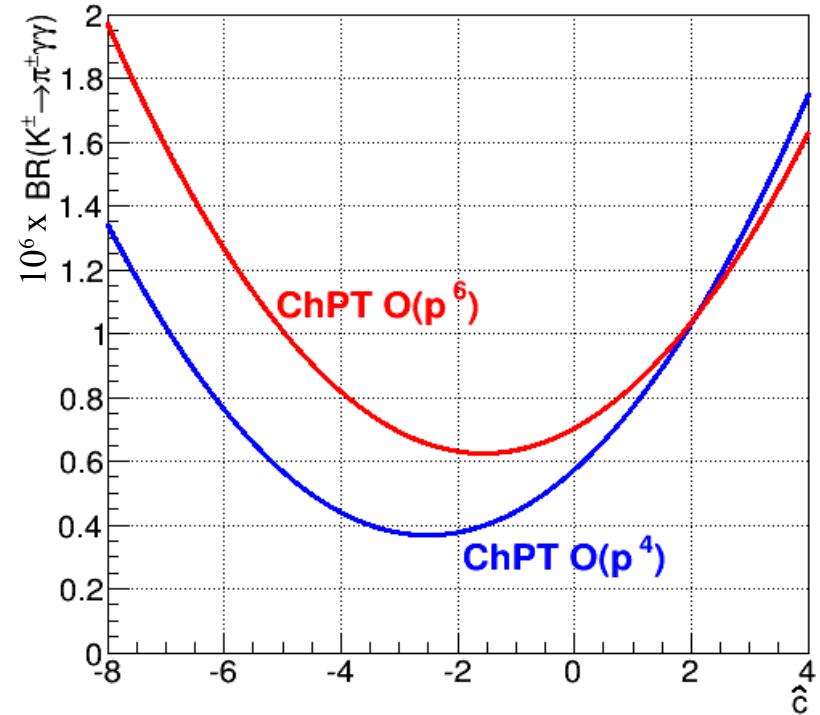
- NA62 results:

$$\begin{aligned} O(p^4): \hat{c} &= 1.93 \pm 0.26_{\text{stat}} \pm 0.08_{\text{syst}} \\ O(p^6): \hat{c} &= 2.10 \pm 0.28_{\text{stat}} \pm 0.18_{\text{syst}} \end{aligned}$$



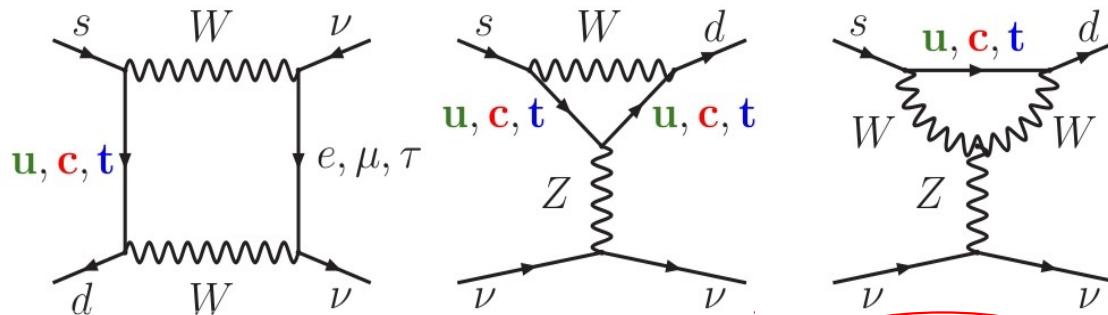
- Combined NA48/2+NA62 results:

$$\begin{aligned} O(p^4): \hat{c} &= 1.72 \pm 0.20_{\text{stat}} \pm 0.06_{\text{syst}} \\ O(p^6): \hat{c} &= 1.86 \pm 0.23_{\text{stat}} \pm 0.11_{\text{syst}} \end{aligned}$$



- Not enough statistics for clear discrimination between $O(p^4)$ and $O(p^6)$
- Assuming $O(p^6)$: $\text{BR}(K^+ \rightarrow \pi^+ \gamma\gamma)_{p6} = (1.003 \pm 0.051_{\text{stat}} \pm 0.024_{\text{syst}}) \times 10^{-6}$

FCNC decays: $K \rightarrow \pi \nu \bar{\nu}$



$$\text{Br}(K^+ \rightarrow \pi^+ \nu \bar{\nu}(\gamma)) = \kappa_+ (1 + \Delta_{\text{EM}}) \left[\left(\frac{\text{Im} \lambda_t}{\lambda^5} X_t \right)^2 + \left(\frac{\text{Re} \lambda_c}{\lambda} (P_c + \delta P_{c,u}) + \frac{\text{Re} \lambda_t}{\lambda^5} X_t \right)^2 \right]$$

$$\begin{aligned}\lambda &= V_{us} \\ \lambda_c &= V_{cs}^* V_{cd} \\ \lambda_t &= V_{ts}^* V_{td}\end{aligned}$$

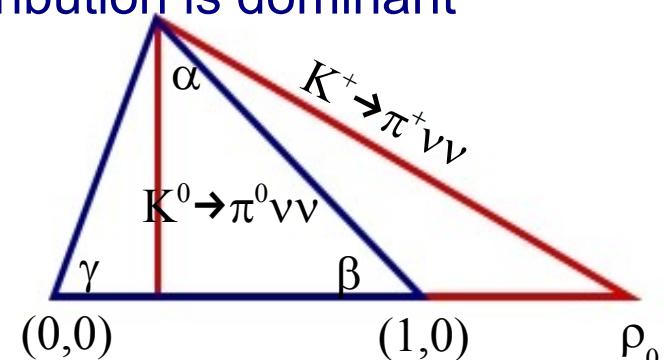
k_+ - hadronic matrix element
measured from semileptonic decays

charm quark contribution

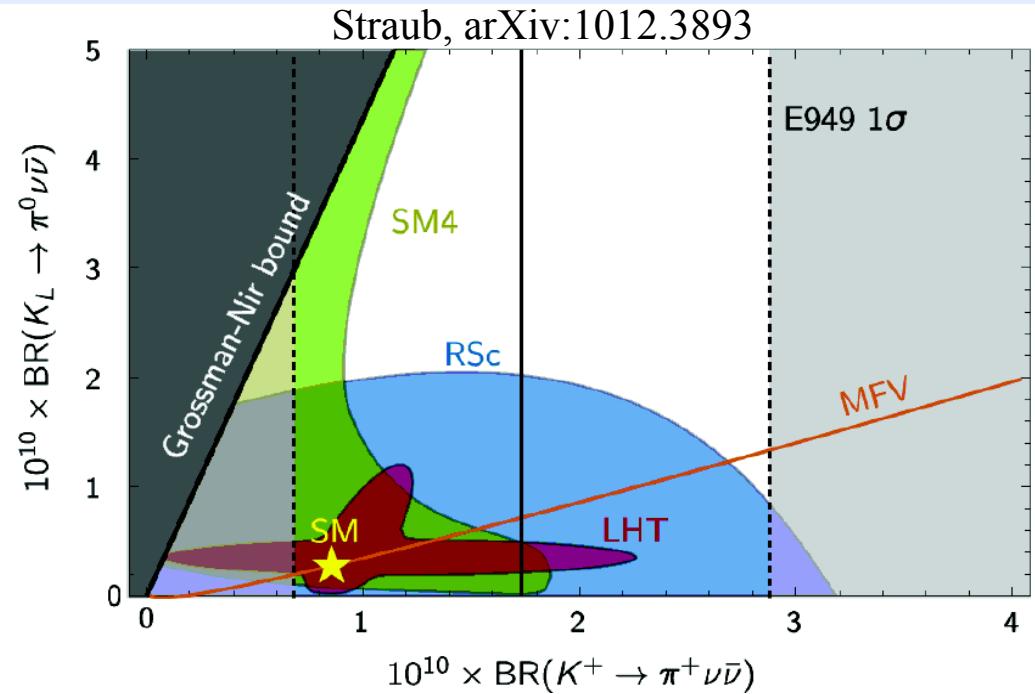
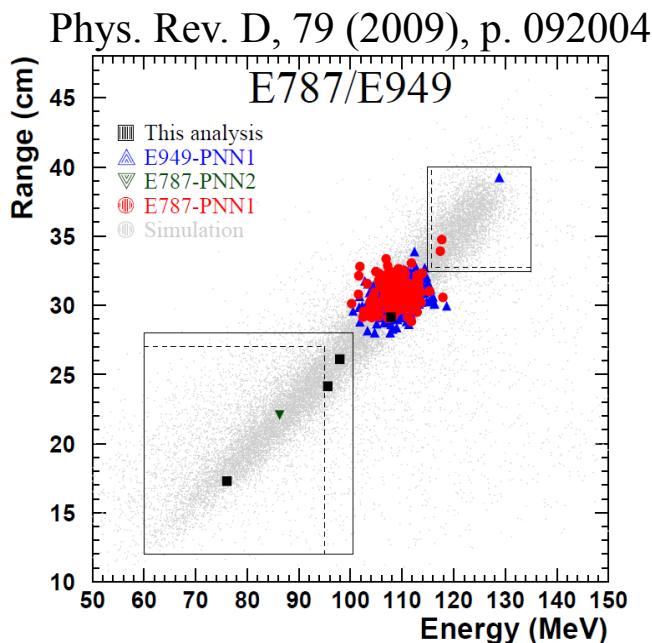
- Very clean theoretically – short distance contribution is dominant
- Charm loop under control
- Standard Model prediction:

$$\text{Br}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (7.81 \pm 0.80) \times 10^{-11}$$

Brod, Gorbahn, Stamou, Phys. Rev. D, 034030 (2011)



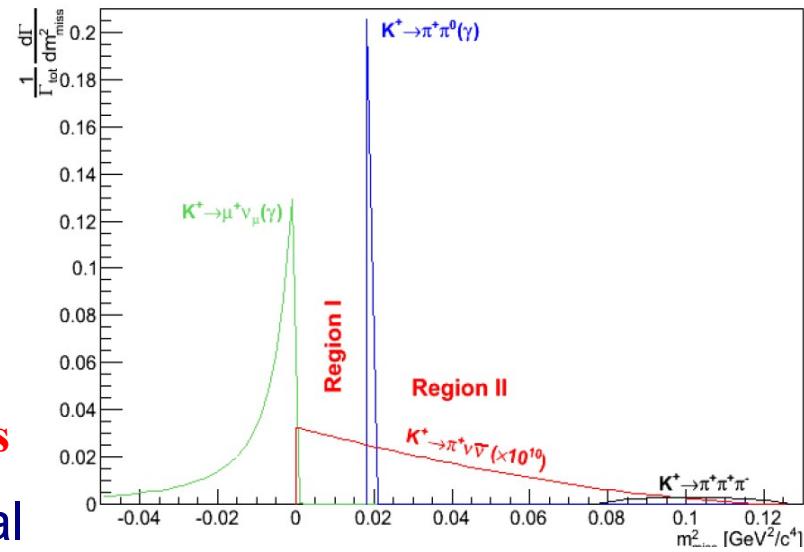
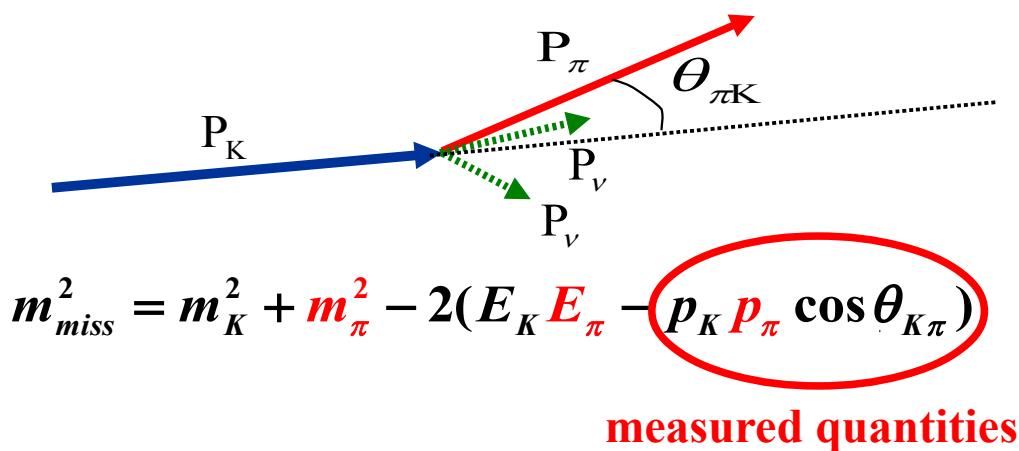
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ status



- E949 result based on 7 events:
 $\text{Br } (K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) * 10^{-10}$ (~two times SM)
- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ sensitive to NP contribution

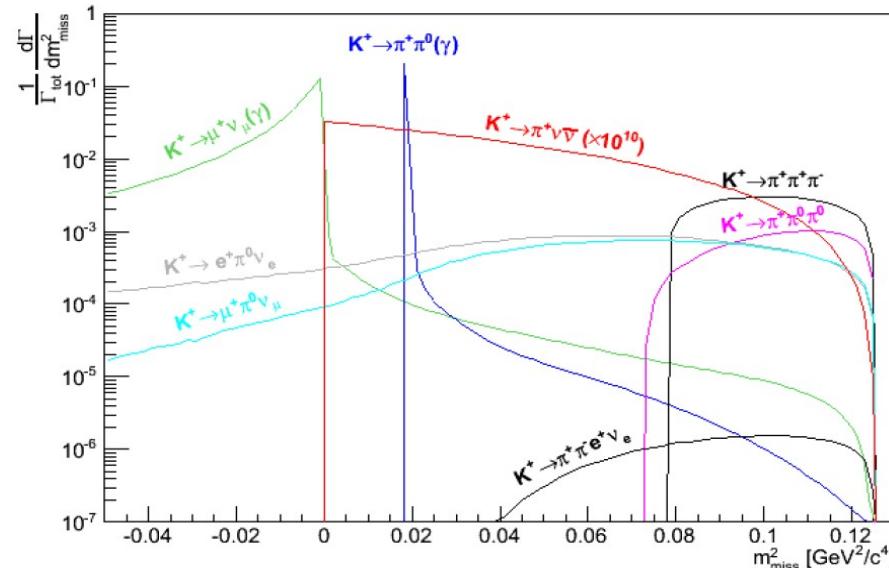
NA62 @ CERN SPS aims to collect O(100) $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events and perform a 10 % measurement of V_{td}

Experimental technique



- Single observable decay product in the final state
- 92% of the background is with closed kinematics: **define 2 signal regions**

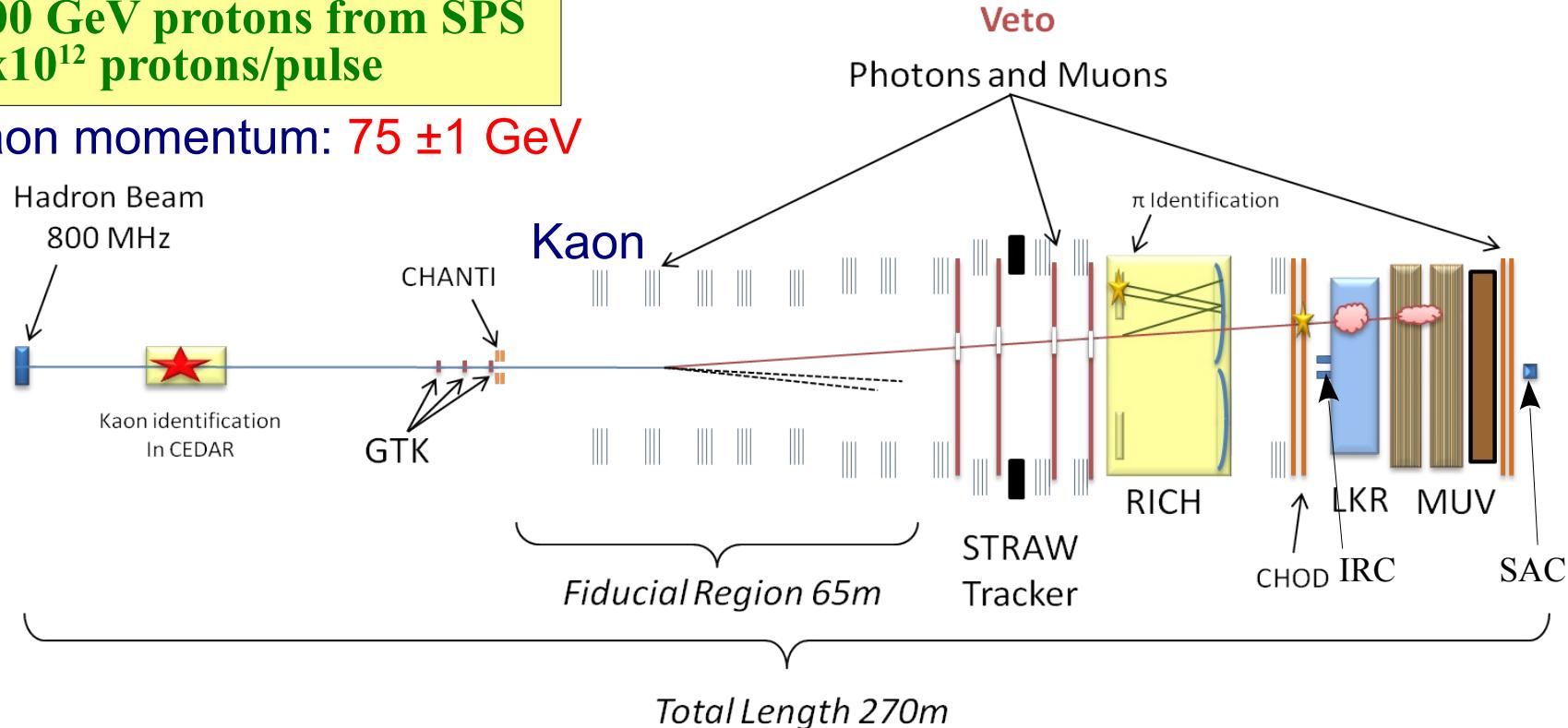
Event selection
 Kinematics reconstruction
 Particle identification
 Particle vetoing



Experimental setup

400 GeV protons from SPS
 3×10^{12} protons/pulse

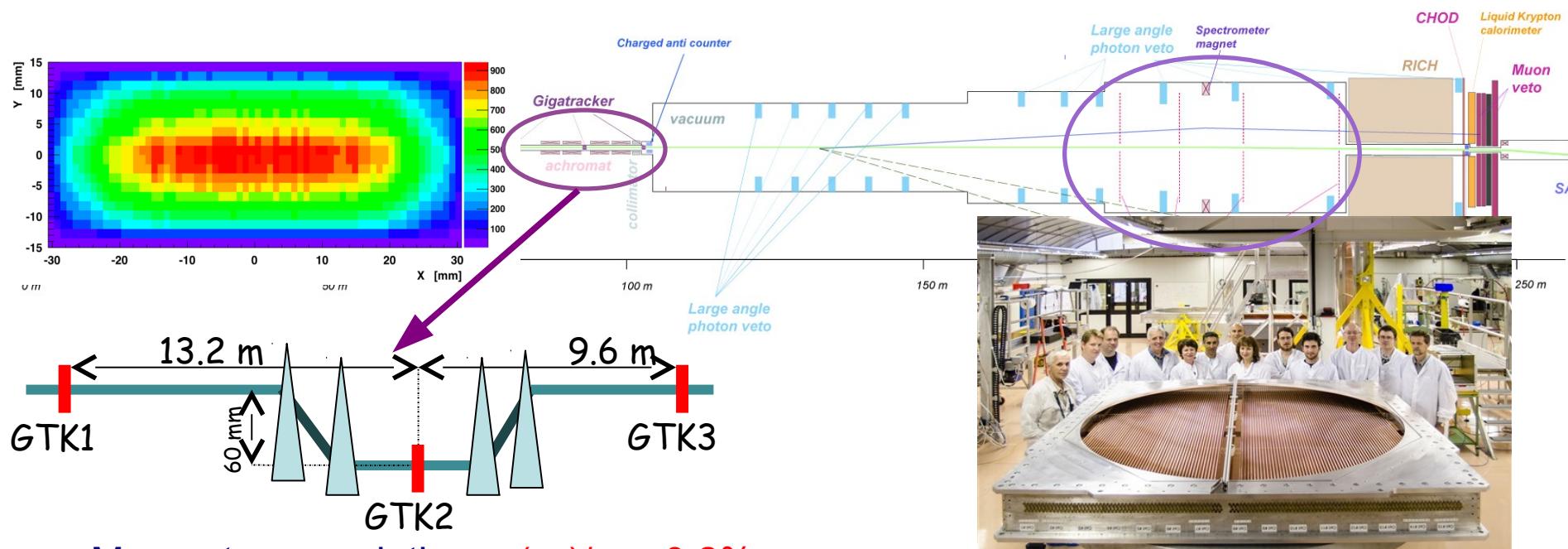
Kaon momentum: 75 ± 1 GeV



Unseparated hadron beam: kaon component 6%

Expected 4.5×10^{12} kaon decays per year

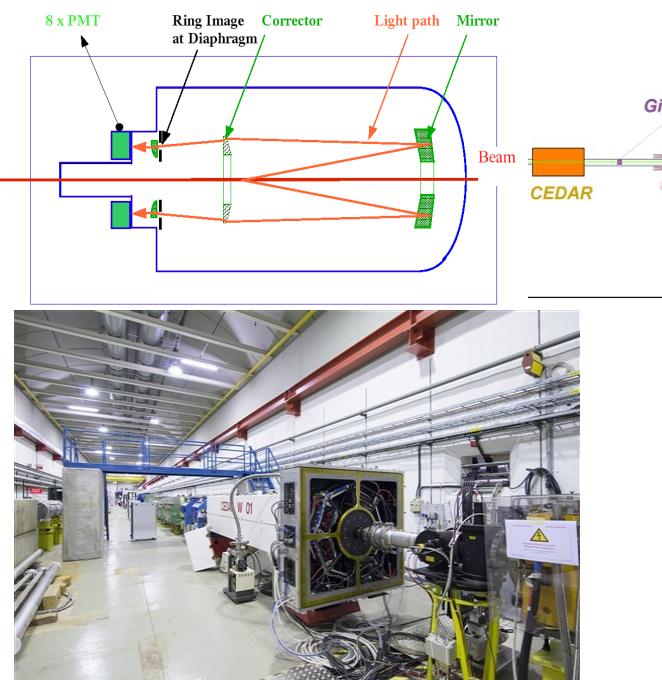
Kinematics



- Momentum resolution: $\sigma(p_K)/p_K \sim 0.2\%$
- Angular resolution: $16 \mu\text{rad}$
- $200 \mu\text{m}$ sensor + $300 \mu\text{m}$ chip
 $<0.5\% \times 0$
- Time resolution $\sim 200 \text{ ps/station}$
- Spectrometer in vacuum
- Straw tubes: 4 chambers, 4 views/chamber, 4 staggered layers/view
- Momentum resolution
 $\sigma(p)/p \sim 0.3\% \oplus 0.007\% * p(\text{GeV}/c)$
- 2 views operated during TR

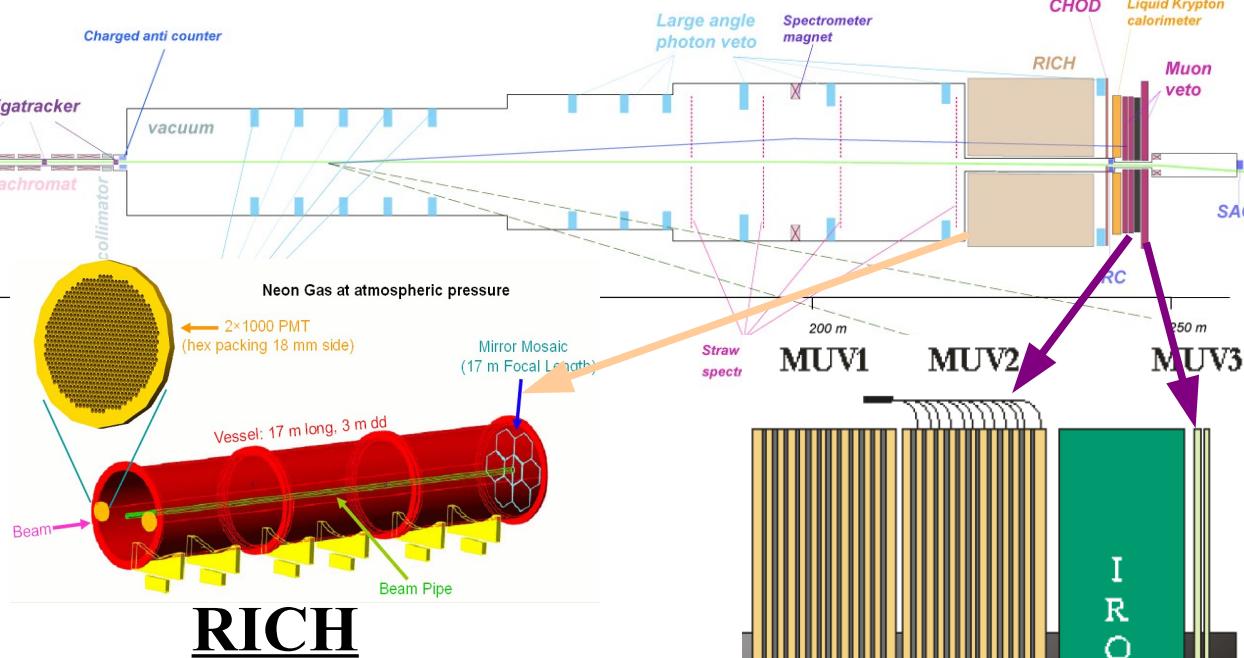
Resolution on $M_{\text{miss}}^2 \sim 0.001 \text{ GeV}^2/\text{c}^4$

Particle identification



KTAG

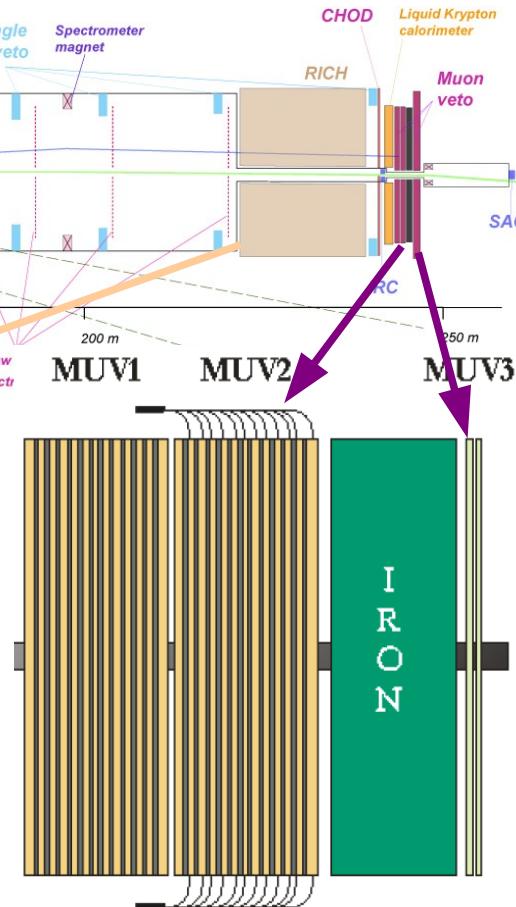
- CEDAR with 3.6bar H₂
- 100 ps time resolution
- Tests during TR
 - alignment
 - pressure scans



π/μ separation up to 35 GeV
Full length prototype tested

- half radius
- 2 x 1000 PMT 18 mm pixel size
- N_{hits} ~ 17/event
- Time resolution: ~ 70 ps

[NIM A 621, 2010]



MUV/HAC

iron scintillator sandwich
 π/μ separation & trigger

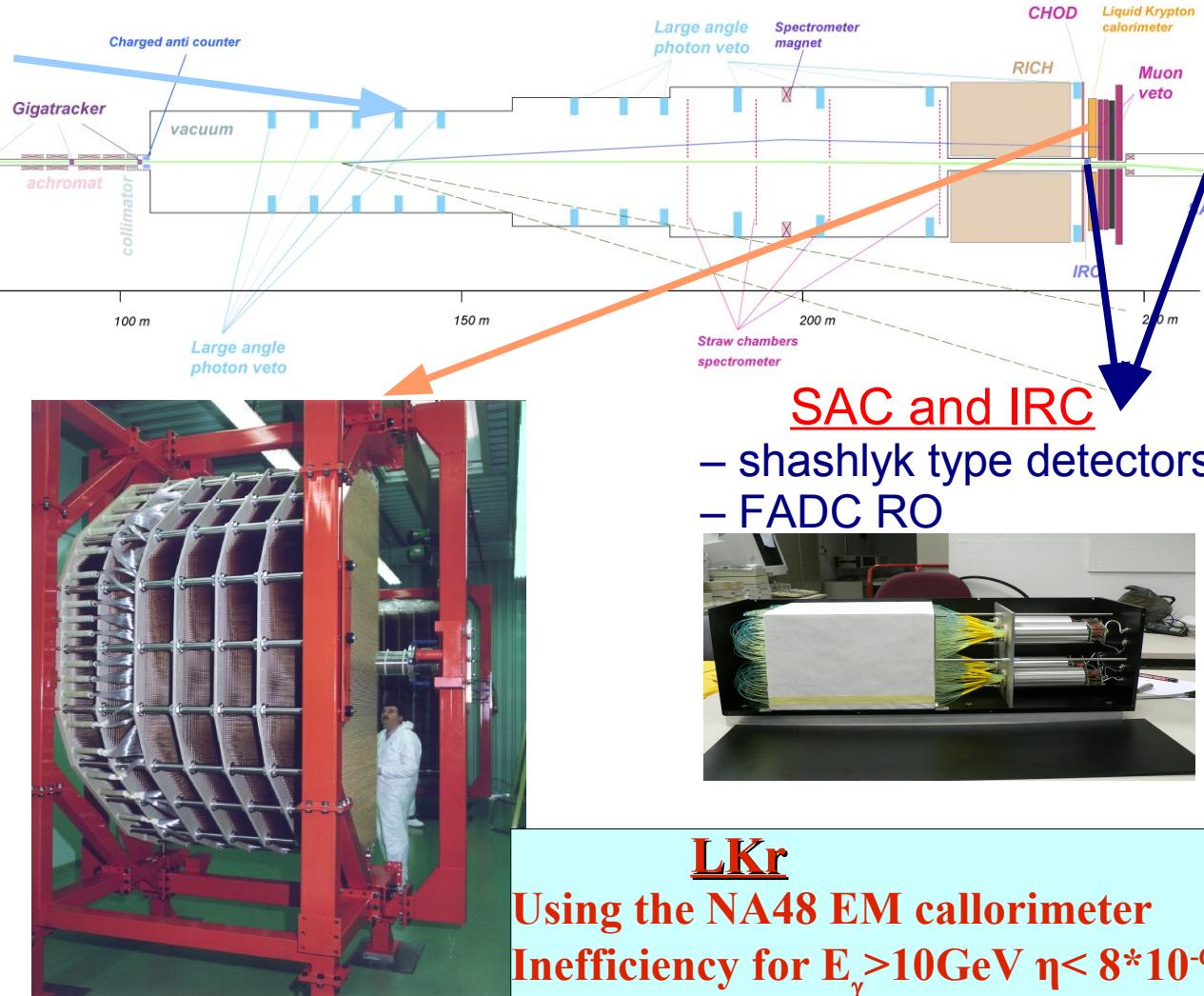
Photon vetoes



LAV

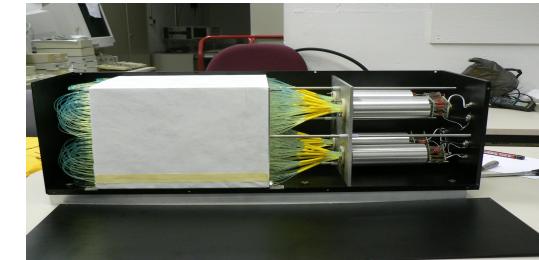
- 12 stations in vacuum
- Angles from 8.5 to 50 mrad
- Lead glass from OPAL

8 built, 2 operated
during Technical run



SAC and IRC

- shashlyk type detectors
- FADC RO



LKr

Using the NA48 EM calorimeter
Inefficiency for $E_\gamma > 10\text{GeV}$ $\eta < 8 \times 10^{-6}$

Present status



total flux: 4.5×10^{12}



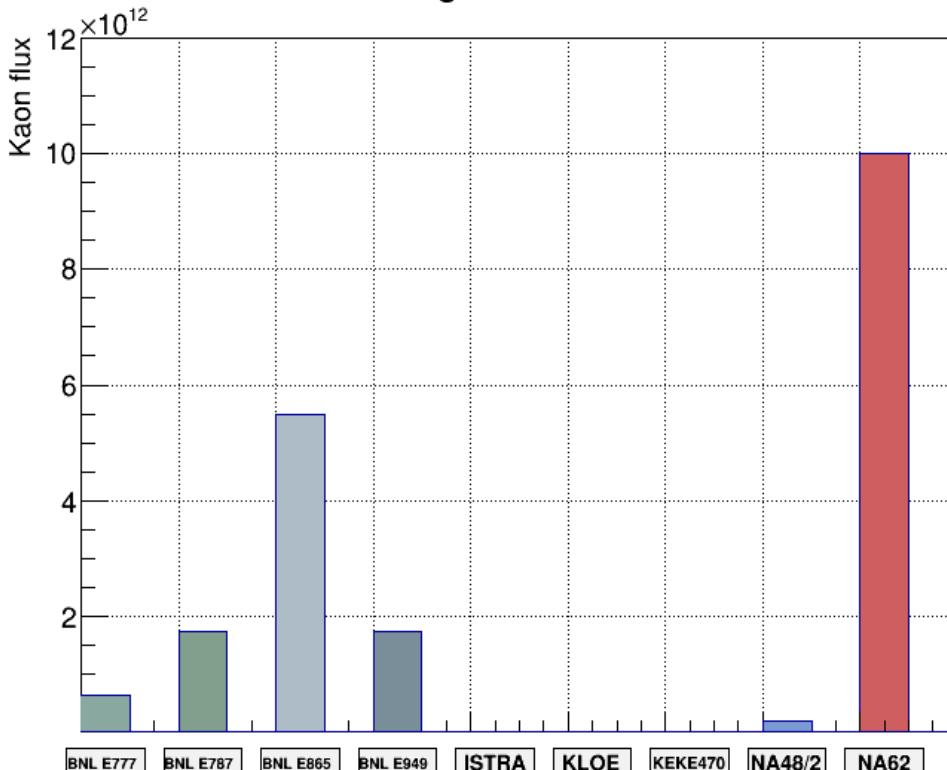
- Start of data taking in October
 - Reduced intensity
- Nominal beam intensity 2015 - 2017

$\geq 100 K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events before LS2

Decay	Events/year
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	45
$K^+ \rightarrow \pi^+ \pi^0$	5
$K^+ \rightarrow \mu^+ \nu$	1
$K^+ \rightarrow \pi^+ \pi^+ \pi^-$	<1
$K^+ \rightarrow \pi^+ \pi^- e^+ \nu + 3\text{trk}$	<1
$K^+ \rightarrow \pi^+ \pi^0 \gamma$ (IB)	1.5
$K^+ \rightarrow \mu^+ \nu \gamma$ (IB)	0.5
$K^+ \rightarrow \pi^0 e(\mu)^+ \nu$	negligible
Total background	<10

NA62: kaon rare decay studies

Charged kaon flux



- Excellent particle veto efficiency
- Excellent momentum resolution
- Particle ID efficiency
- High kaon flux

Improving kaon measurements:

Mode	Present	Expected
R_K	0.4%	0.2%
$K^+ \rightarrow \pi^+ \gamma\gamma$	<500 events	10^5 events
$K^+ \rightarrow \pi^0 \pi^0 e^+ \nu$	66000	$O(10^6)$
$K^+ \rightarrow \pi^0 \pi^0 \mu^+ \nu$	66000	$O(10^5)$

M12 decays:

- 0.5% measurement of $R_{K\pi} = \Gamma(K\pi 2)/\Gamma(\pi e 2)$ sensitive to new physics

NA62 as a probe for New Physics

Mode	Physics	90% CL present limit	NA62
$K^+ \rightarrow \pi^+ \mu^+ e^-$	LFV	1.3×10^{-11}	$10^{-12}/10^{-13}$
$K^+ \rightarrow \pi^+ \mu^- e^+$	LFV	5.2×10^{-10}	$10^{-12}/10^{-13}$
$K^+ \rightarrow \pi^- \mu^+ e^+$	LNV	5×10^{-10}	$10^{-12}/10^{-13}$
$K^+ \rightarrow \pi^- e^+ e^+$	LNV	6.4×10^{-10}	10^{-12}
$K^+ \rightarrow \pi^- \mu^+ \mu^+$	LNV	1.1×10^{-9}	$10^{-12}/10^{-13}$
$K^+ \rightarrow \mu^- \nu e^+ e^+$	LFV/LNV	2×10^{-8}	10^{-12}
$K^+ \rightarrow e^- \nu \mu^+ \mu^+$	LFV/LNV	No data	10^{-12}
$K^+ \rightarrow \pi^+ X^0$	New particle	$5.9 \times 10^{-11} m_{X_0} = 0$	10^{-12}
$K^+ \rightarrow \pi^+ \chi \chi$	New particle	-	10^{-12}
$K^+ \rightarrow \pi^+ \pi^+ e^- \nu$	$\Delta S \neq \Delta Q$	1.2×10^{-8}	10^{-11}
$K^+ \rightarrow \pi^+ \pi^+ e^- \nu$	$\Delta S \neq \Delta Q$	1.2×10^{-8}	10^{-11}
$K^+ \rightarrow \pi^+ \gamma$	Angular momentum	2.3×10^{-9}	10^{-12}
$K^+ \rightarrow \mu^- \nu_h, \nu_h \rightarrow \nu \gamma$	Heavy neutrino	$m(\nu_h)$ up to 350 MeV	

Conclusion

- High statistics kaon studies provide a very challenging opportunity to search for physics beyond the Standard Model
- Result from NA62 2007/2008 data taking presented
- NA62 experiment is in its final construction phase preparing for data taking in October
- 10% measurement of $\text{Br}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ waits behind the corner
- NA62 is the present laboratory for charged kaon physics