Rare kaon decays
Present and perspective with NA62

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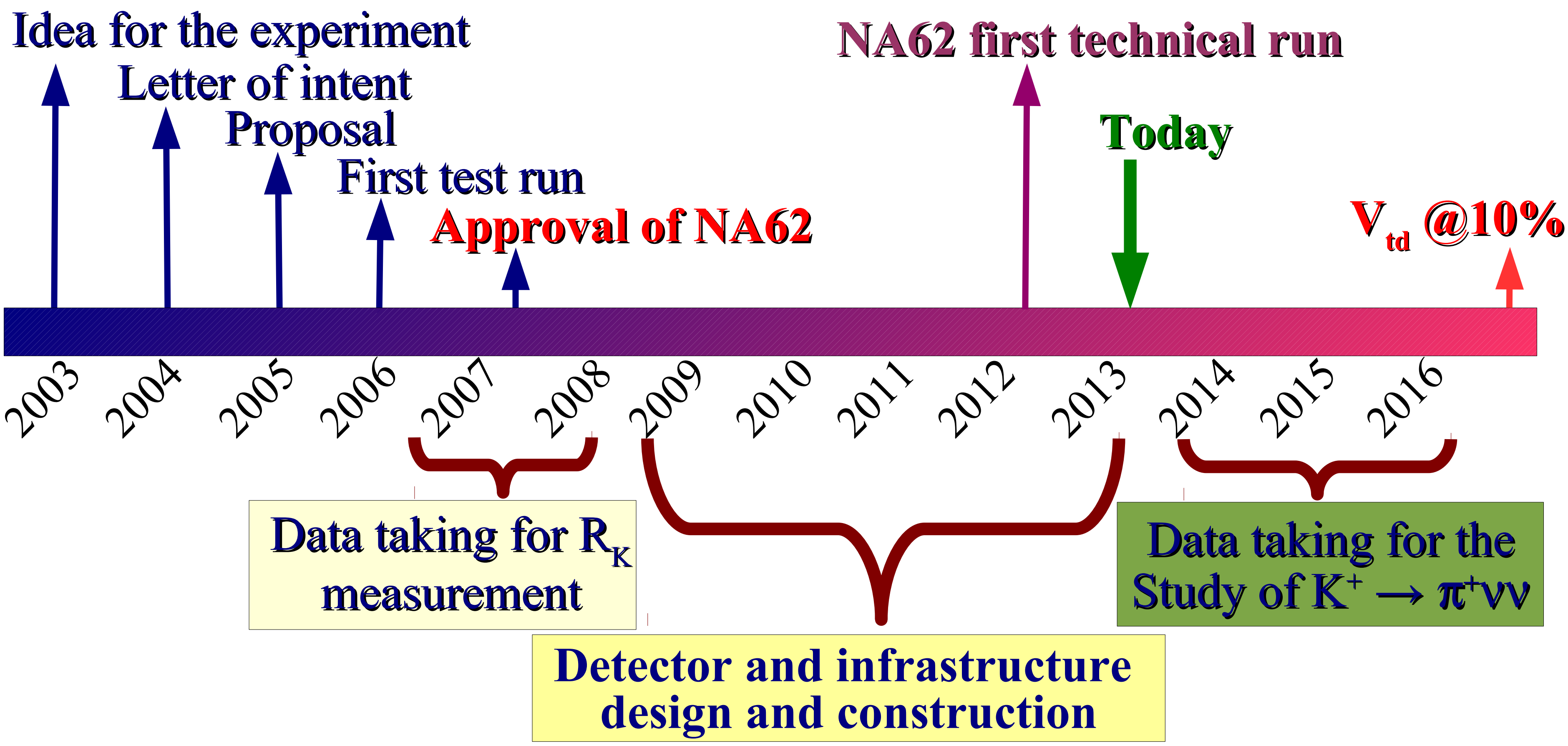
on behalf of the NA62 collaboration

Overview

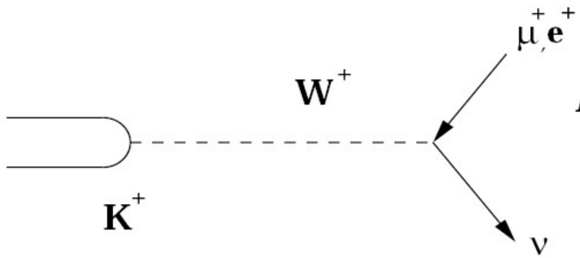
- NA62 present results
  - Lepton universality
  - Tests of ChPT
- NA62 golden channel: $K^+ \to \pi^+ \nu\nu$
- Rare decays at NA62
- Conclusion

NA62 experiment



Ke2: Motivation

Within the Standard Model:

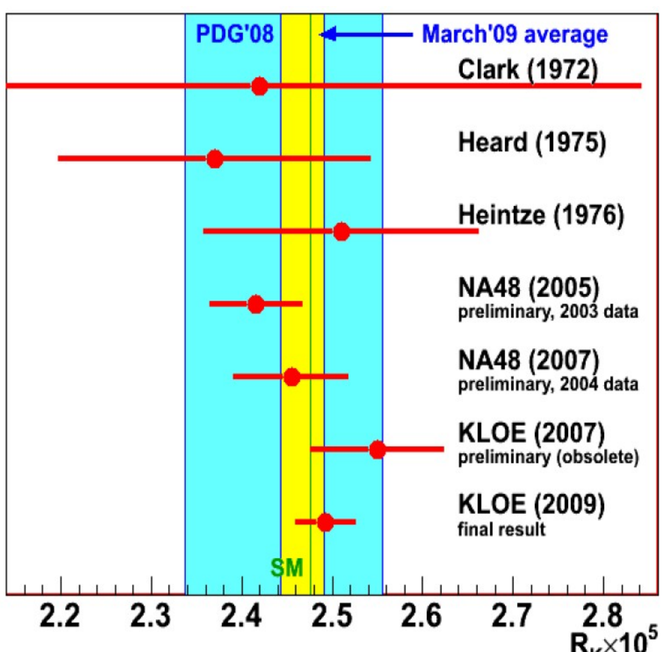


$$R_M := \frac{\Gamma(M \to e\nu_e(\gamma))}{\Gamma(M \to \mu\nu_\mu(\gamma))} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_M^2 - m_e^2}{m_M^2 - m_\mu^2}\right)^2 \left(1 + \delta R_M\right)$$

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

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

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

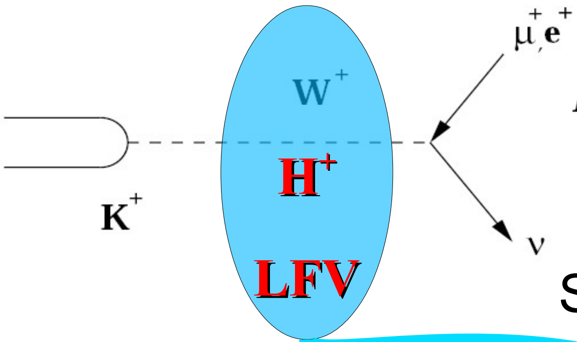


Experimental error on R_K:

more than order of magnitude larger than the theoretical

Ke2: Motivation

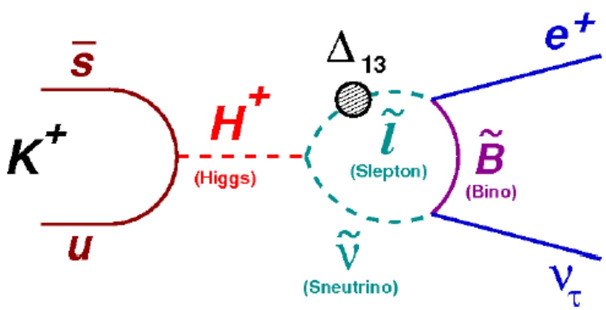
Within the Standard Model:



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

Standard Model prediction:

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



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

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

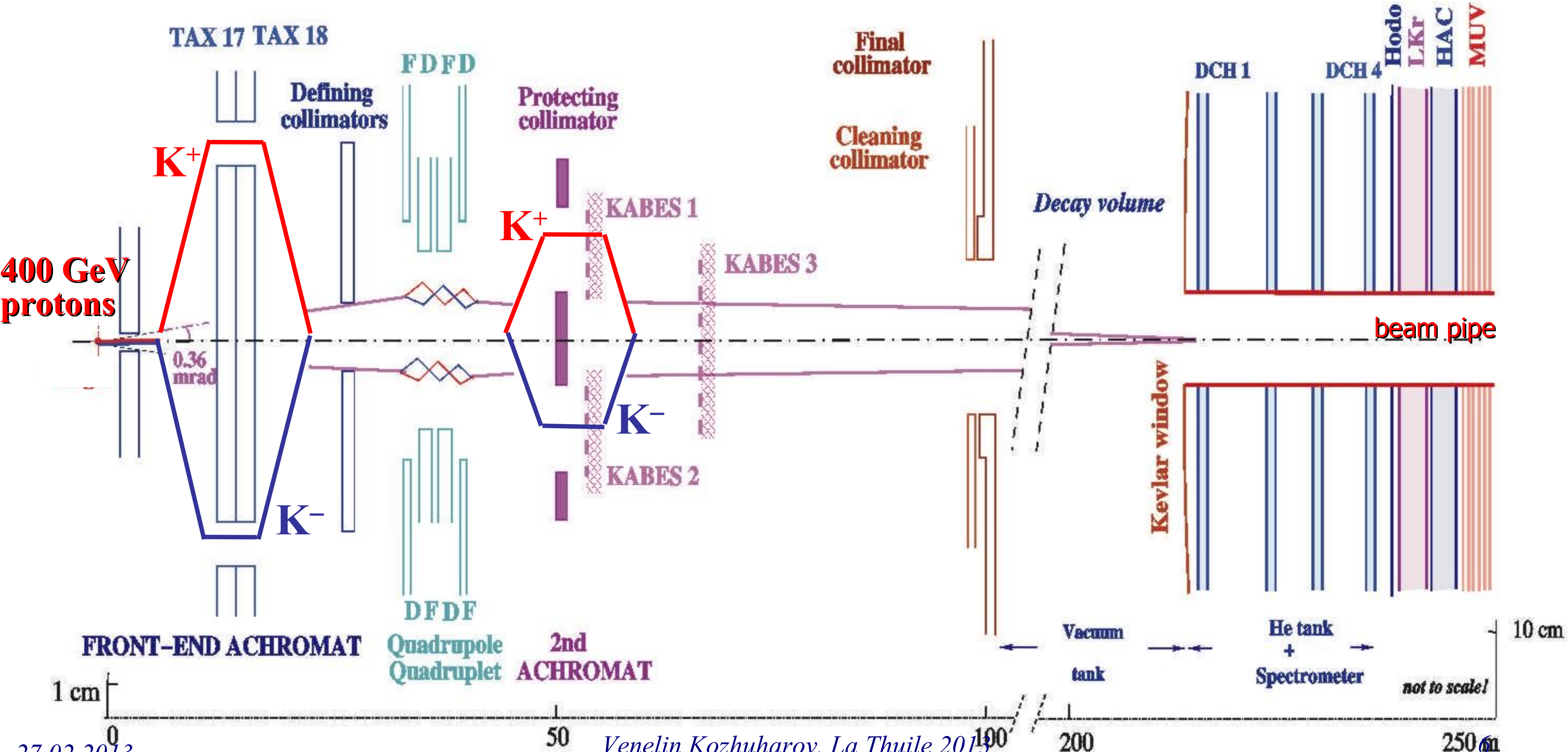
- The value of R_K could be different in case of SUSY and LFV models – the correction could be as high as %
- Measurement of R_K at with sub per cent precision tests the μ-e universality and provides a sensible test of the SM

Beam setup

Using NA48/2 beam and detector setup

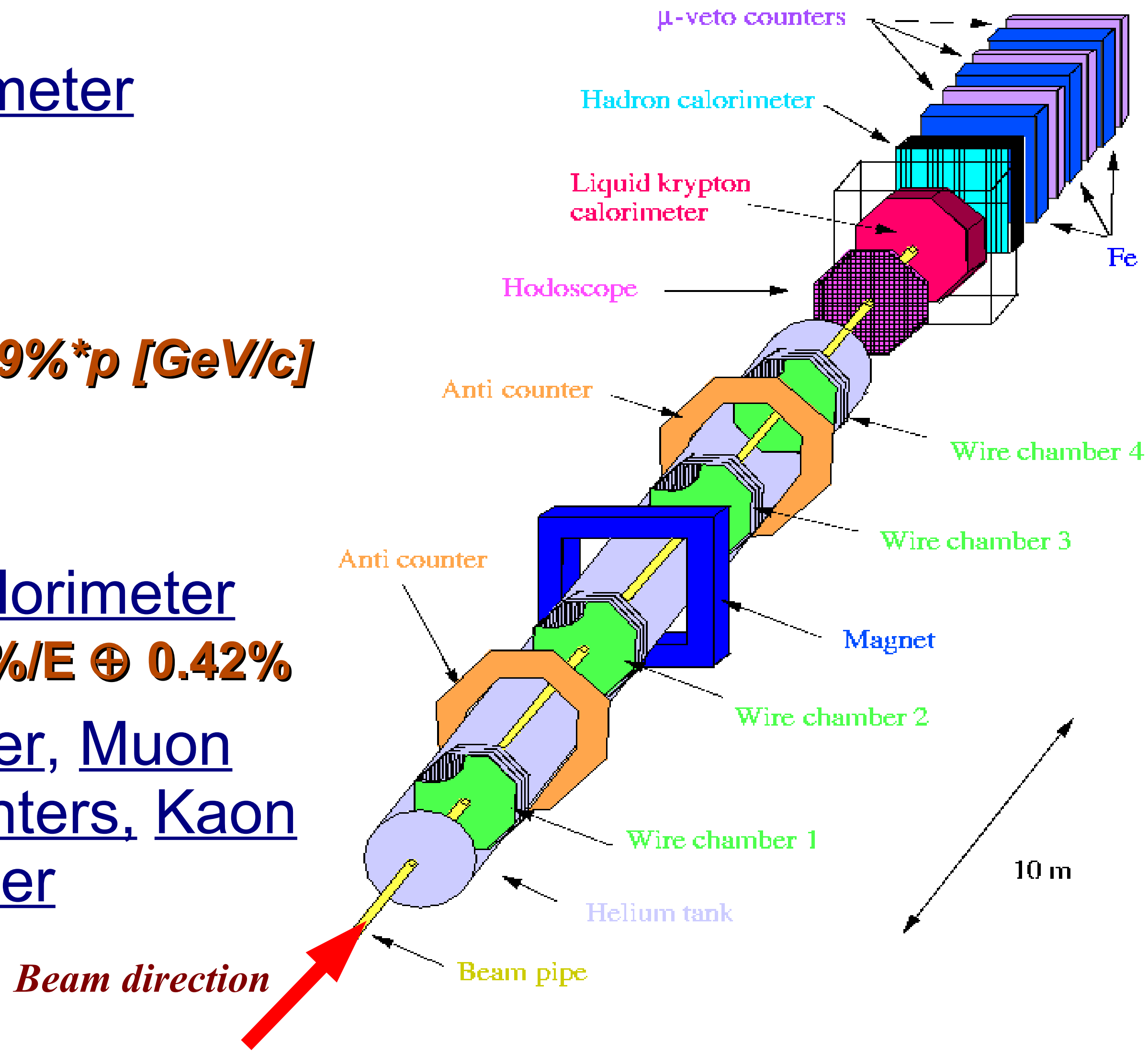
Kaon beam momentum
74 GeV ± 1.4 GeV

Increased magnet current

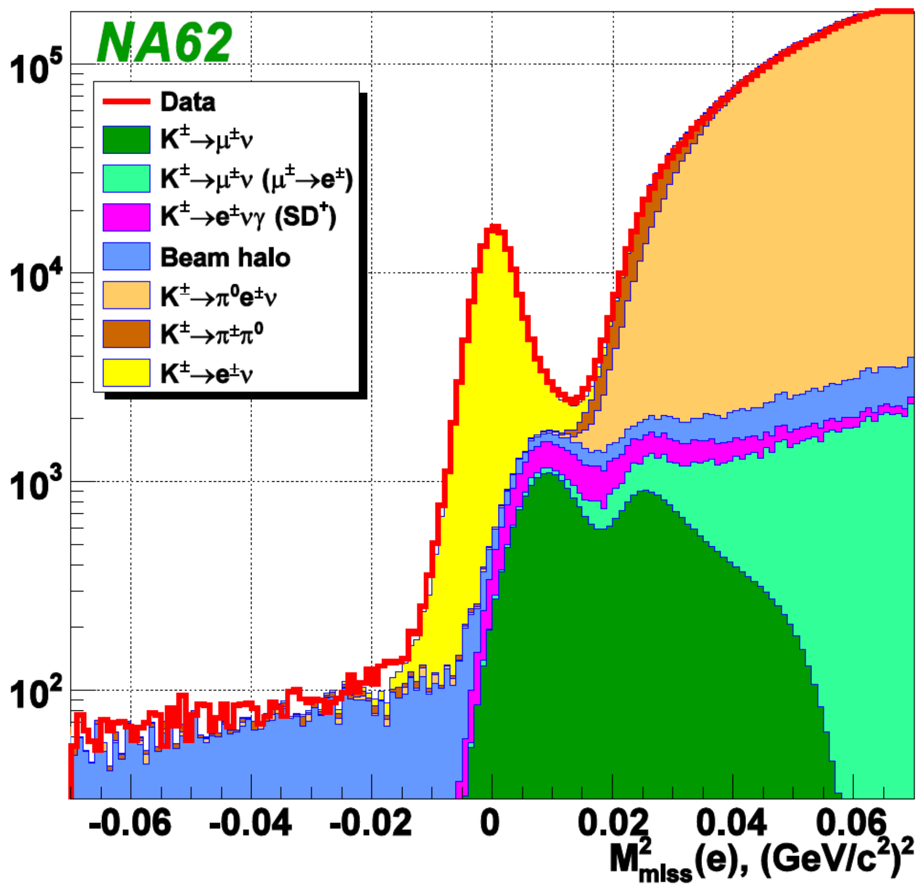


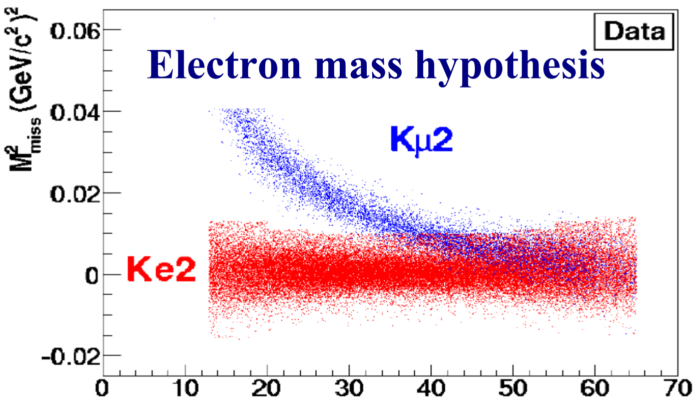
Detector setup

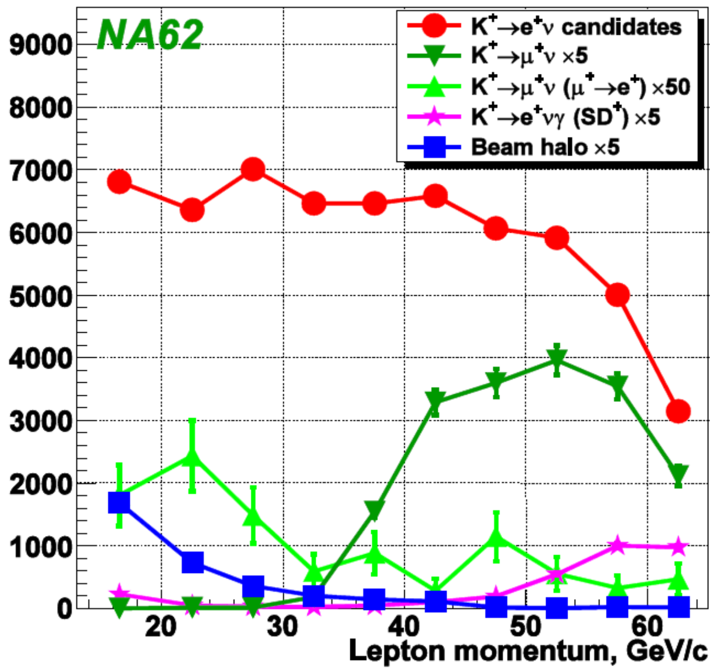
- Magnetic spectrometer (DCH)
  4 drift chambers
  $p_{\perp}^{kick}$ = 265 MeV/c
  $\Delta p/p = 0.48\% \oplus 0.009\% * p$ [GeV/c]
- Hodoscope
  $\sigma(t)$ = 150 ps
- Liquid Krypton Calorimeter
  $\Delta E/E \cong 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$
- Hadron Calorimeter, Muon counters, Anticounters, Kaon Beam Spectrometer



Event selection







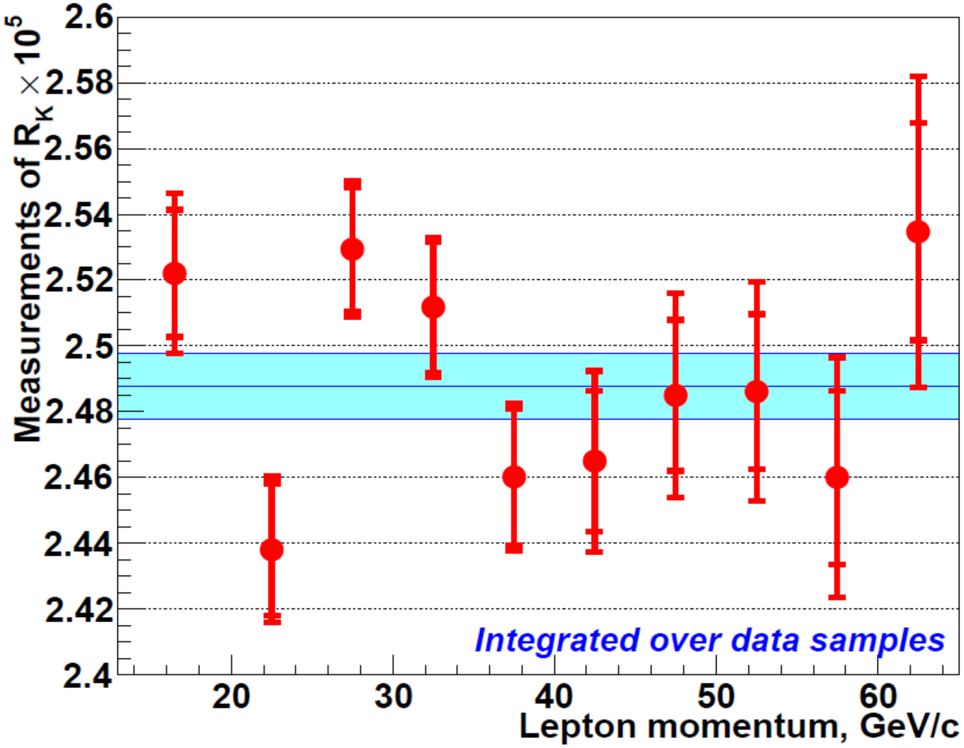
- Reconstructed ~150k Ke2 candidates
  - Background contribution: (10.95± 0.27)%
    - Dominated by $K\mu2$

R_K extraction

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

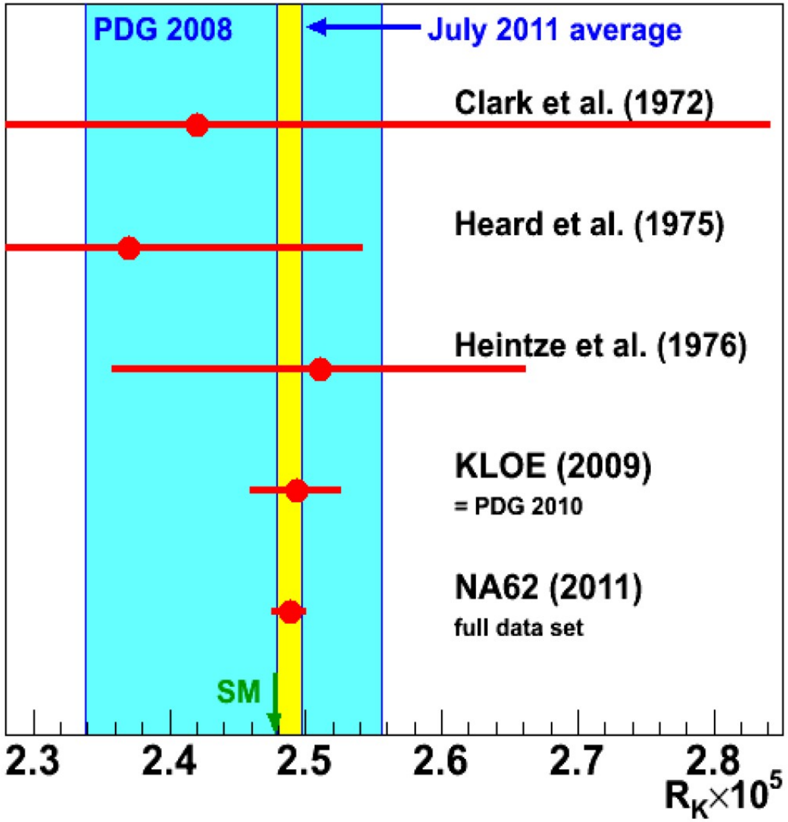
$N(K_{l2})$	*K_{l2} event candidates*
$N_B(K_{l2})$	*Background in Kl2*
f_l	*Lepton ID efficiency*
f_{LKr}	*Global LKr inefficiency*
$\epsilon(K_{l2})$	*K_{l2} trigger efficiency*
$A(K_{l2})$	*K_{l2} accceptance*
D	*Downscaling of $K\mu 2$ trigger*

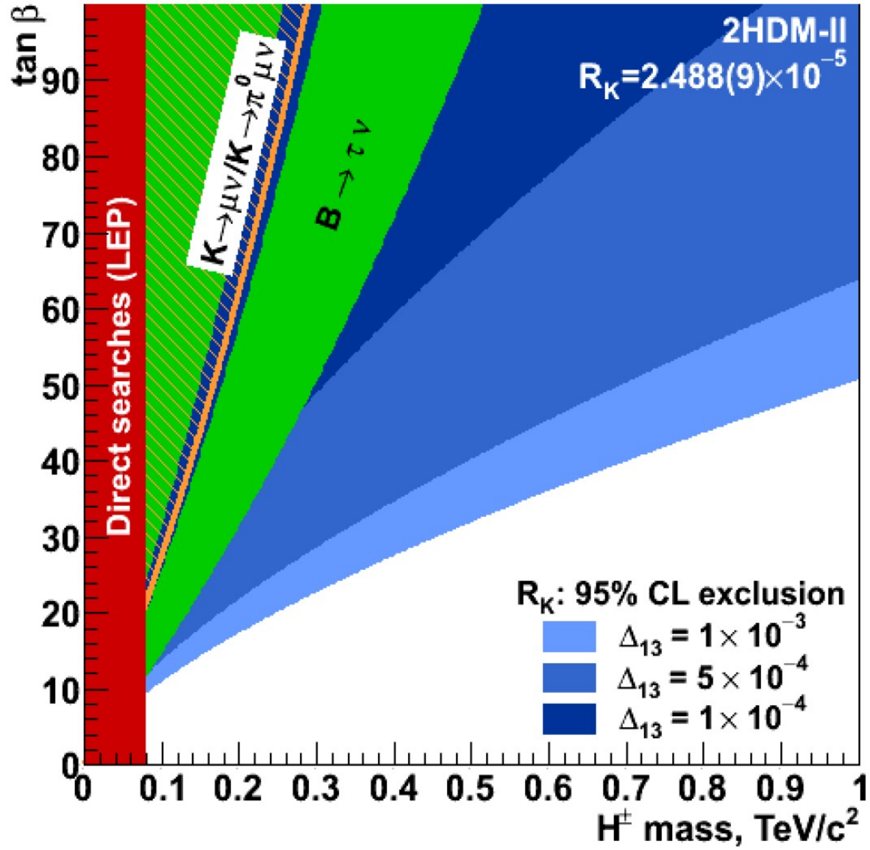
Systematic effect	$\Delta R_K/R_K$[‰]
Kμ2 background	1.6
Ke3 and K2π background	1.2
Matter composition	1.2
Beam halo	0.8
Ke2γ (SD+) background	0.8



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

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:

room for improvement

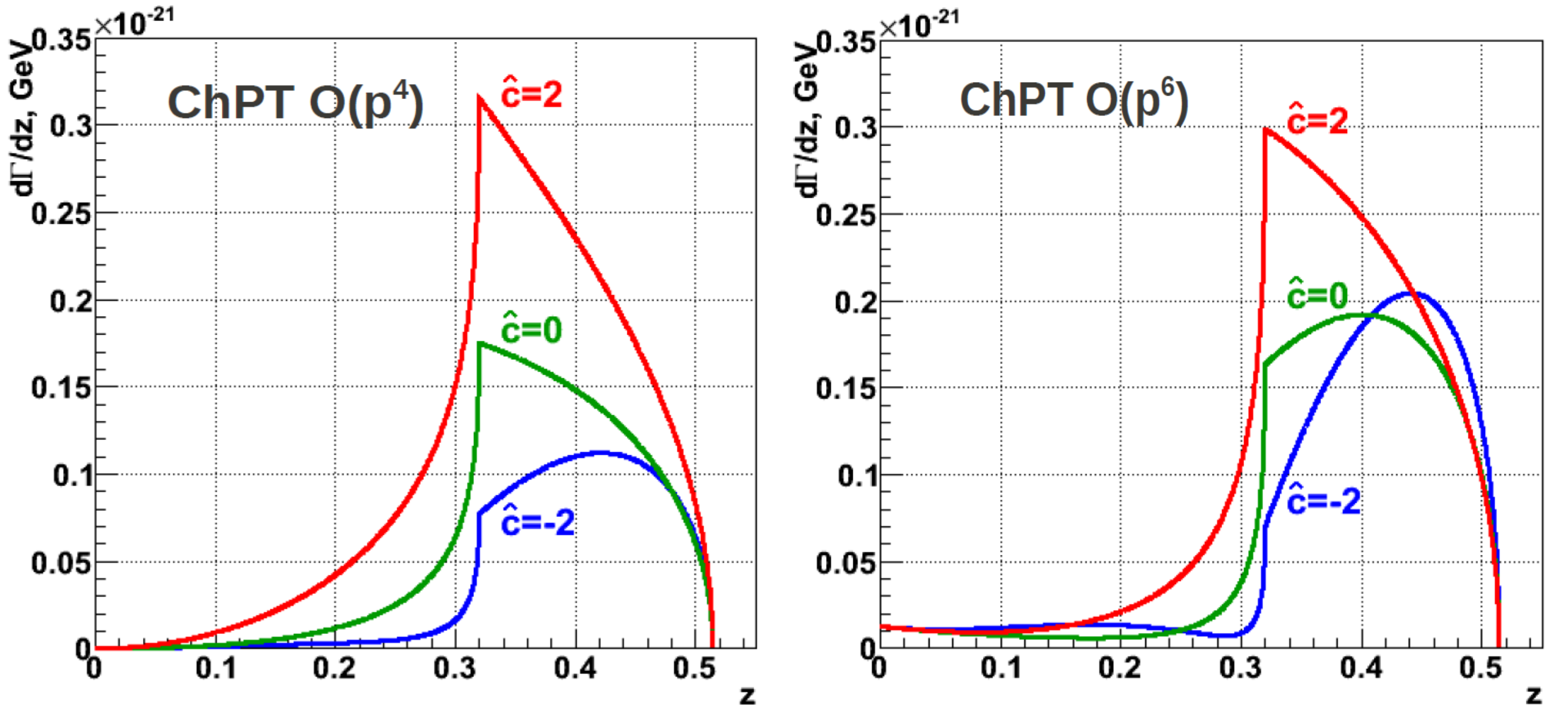
ChPT tests: K→πγγ decay

- Dependence on a single parameter **ĉ** at O(p⁴) and O(p⁶)

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

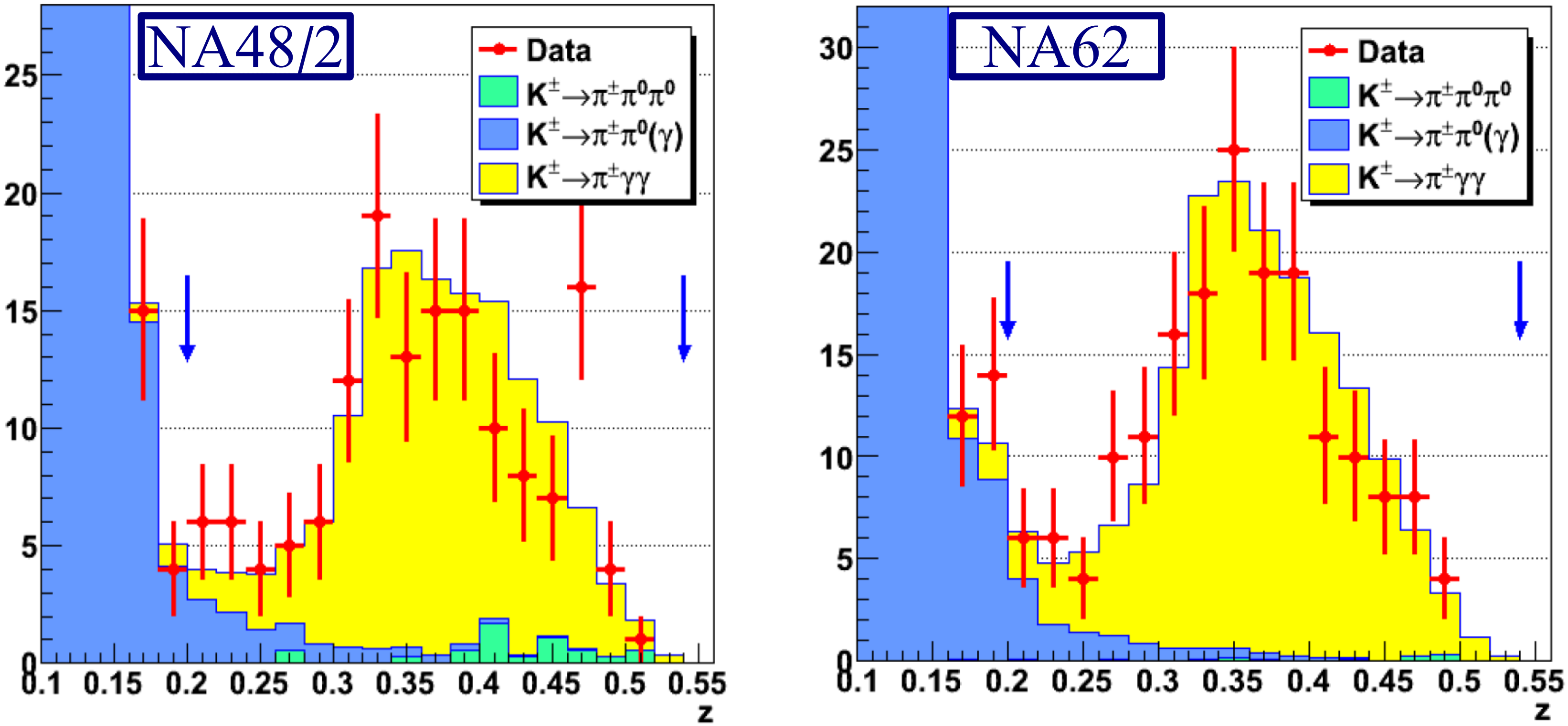
where $z=\left(\frac{m_{\gamma\gamma}}{m_K}\right)^2$, $y=\frac{p(q_1-q_2)}{m_K^2}$

loop contribution (A) **pole contribution** (C) **loop O(p⁶)** (B)



ChPT tests: K→πγγ decay

- Event candidates ~322 (BNL E787: 31 candidates *PRL79 (1997) 4079*)
  - NA48/2: 2004 minimum bias run, ~3 days – 147 events, ~11% background
  - NA62: 2007 data, 3 months, downscaled trigger – 175 events, ~7% background



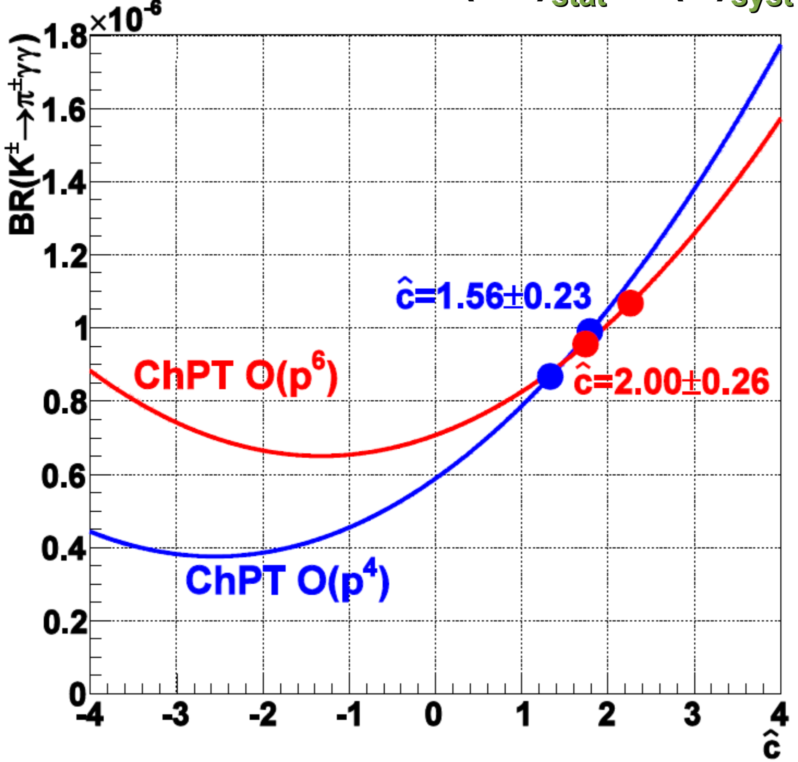
cut at z = 0.2 due to K→ππγ background

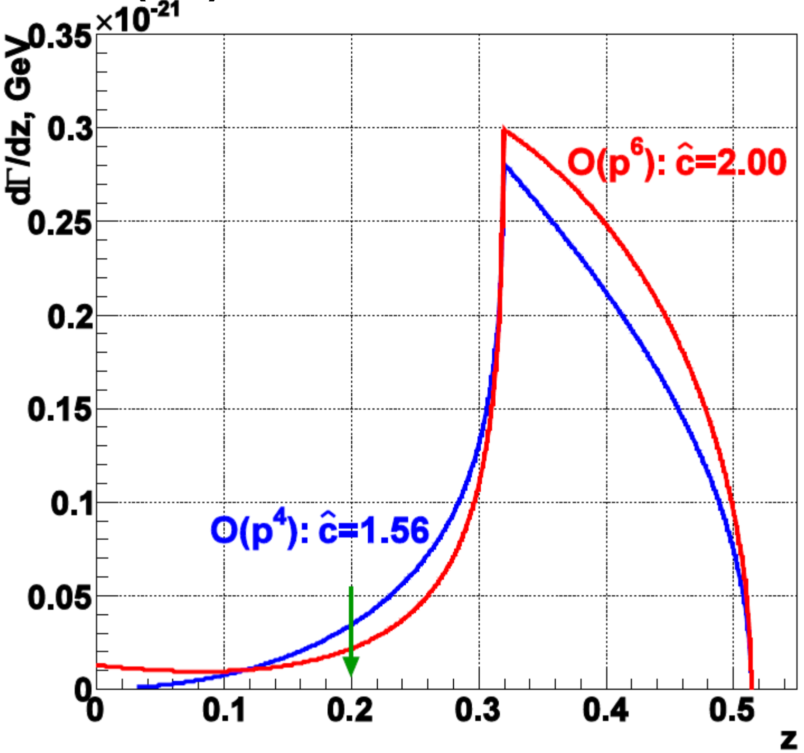
ChPT tests: K→πγγ decay

- Combined NA48/2+NA62 preliminary results:

  $O(p^4)$: $\hat{c} = 1.56 \pm (22)_{stat} \pm (7)_{syst} = 1.56\ (23)$

  $O(p^6)$: $\hat{c} = 2.00 \pm (24)_{stat} \pm (9)_{syst} = 2.00\ (26)$





- Not enough statistics for clear discrimination between $O(p^4)$ and $O(p^6)$
- Assuming $O(p^6)$: **$BR(K\to\pi\gamma\gamma) = (1.01 \pm 0.06)*10^{-6}$**

ChPT tests: K→eνγ(SD+)

- Ke2 decay (*and consequently* ***Ke2γ$_{IB}$***) helicity suppressed
- Structure dependent emission of the same order as brehmstrahlung

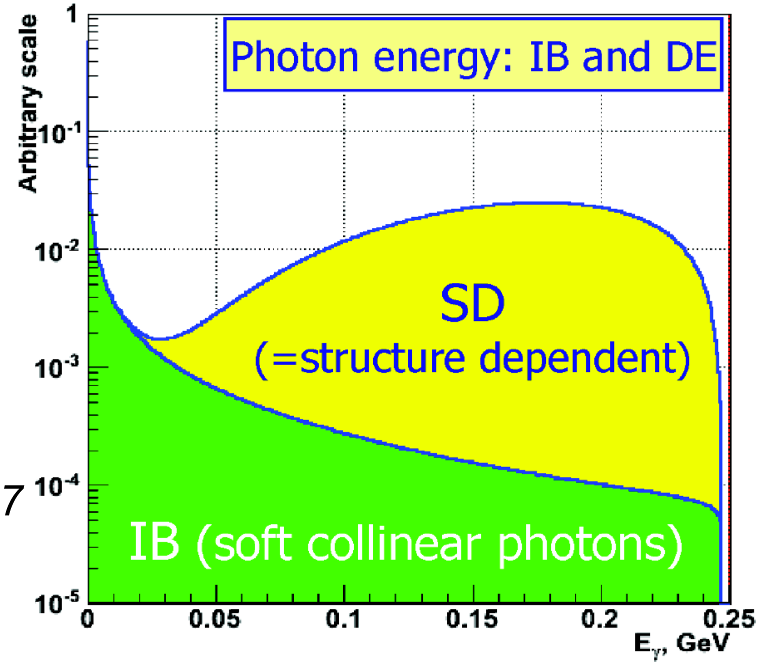
$$\frac{d\Gamma_{SD}}{dx\,dy} \sim [(F_V+F_A)^2 * f_{SD+}(x,y) + (F_V-F_A)^2 * f_{SD-}(x,y)]$$

$x = 2E\gamma/M_K$, $y = 2E_e/M_K$

- $f_{SD}(x,y)$ known functions, depending only on kinematics
- Form factors F_V and F_A:
  - Constant at $O(p^4)$
  - F_V shows a slope at $O(p^6)$
- Present measurement: KLOE

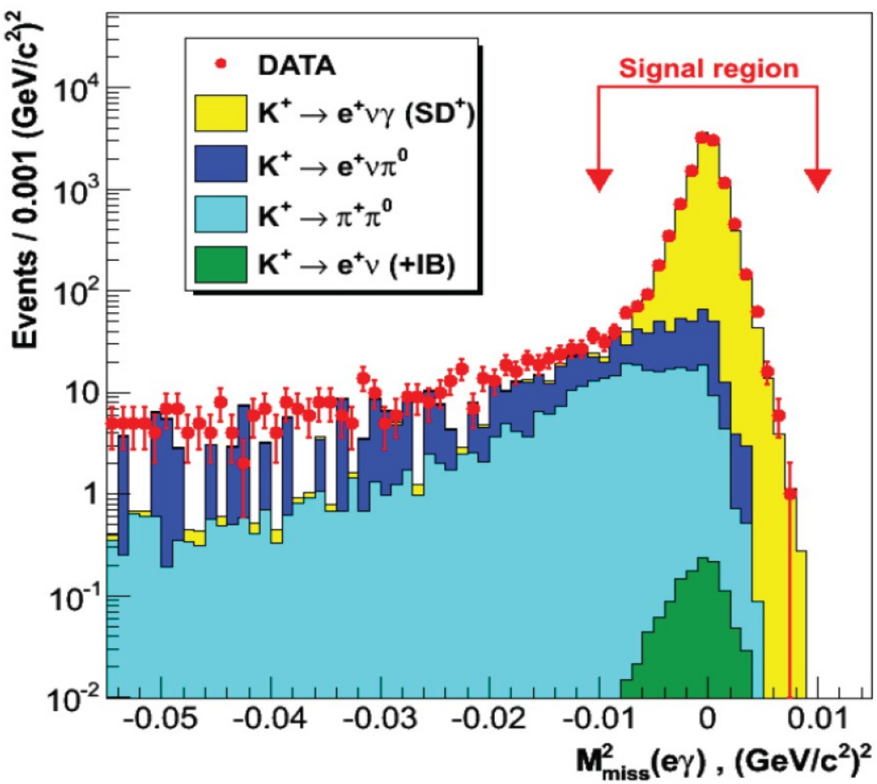
Eur. Phys. J. C64 (2009) 627

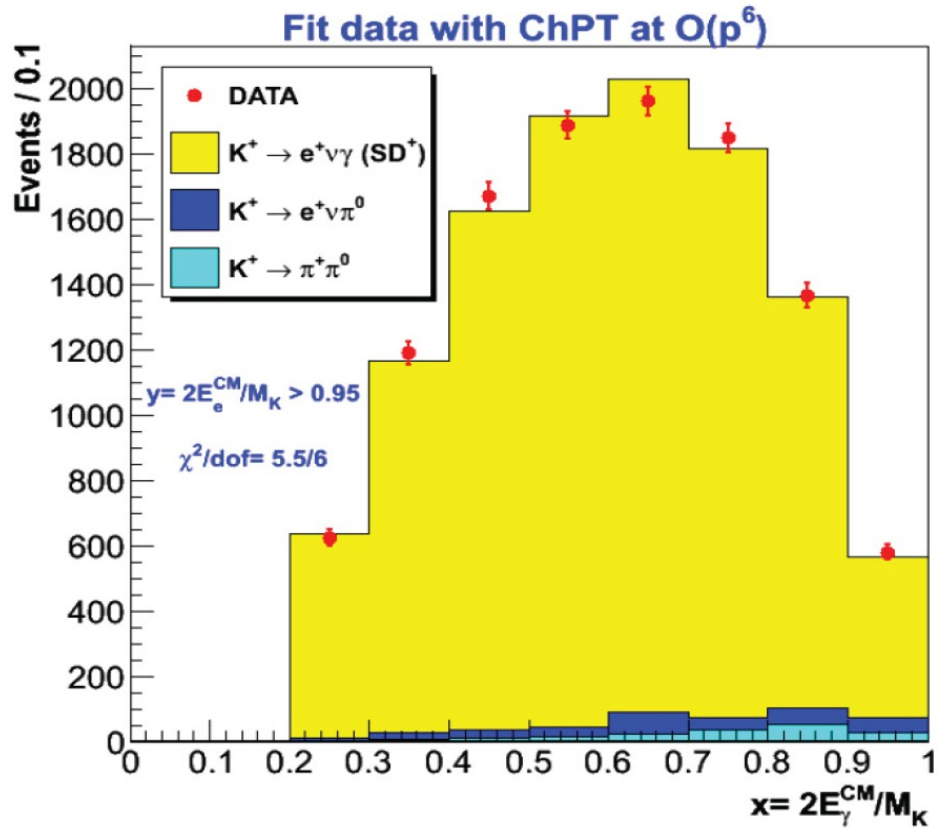
  - 1484 events, $E_\gamma^* > 10$MeV , $p_e^* > 200$MeV
  - Agreement with $O(p^4)$ but data favour slope



ChPT tests: K→eνγ(SD+)

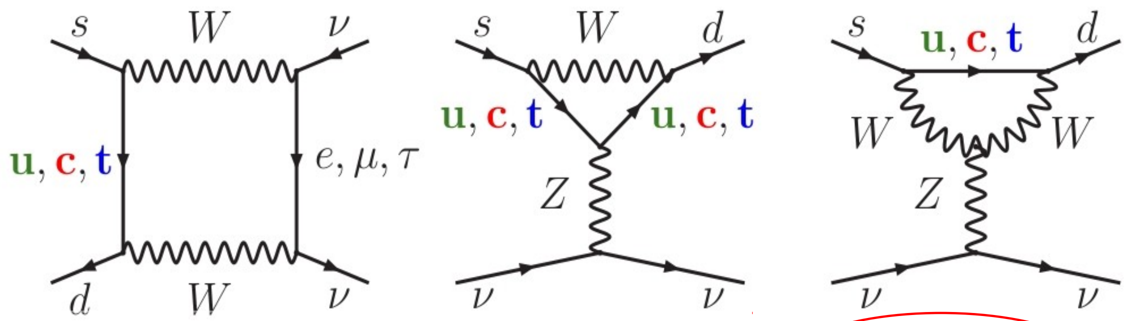
- NA62: **~10000 event** candidates with p_e^*>234 MeV
- Background **~5%**, Acceptance **~7%**





Model independent measurement of the FF in progress

FCNC decays: K→πνν



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

$\lambda = V_{us}$
$\lambda_c = V^*_{cs}V_{cd}$
$\lambda_t = V^*_{ts}V_{td}$

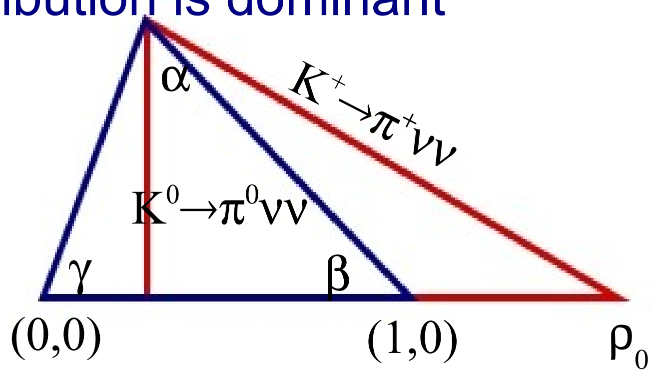
k_+ - hadronic matrix element
measured from semileptonic decays

charm quark contribution

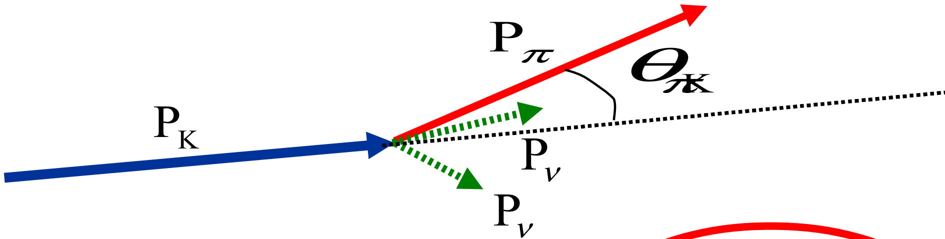
- Very clean theoretically – short distance contribution is dominant
- Charm loop under control

- Standard Model prediction:
  $\mathrm{Br}(K^+ \to \pi^+\nu\nu) = (7.81 \pm 0.80) \times 10^{-11}$

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

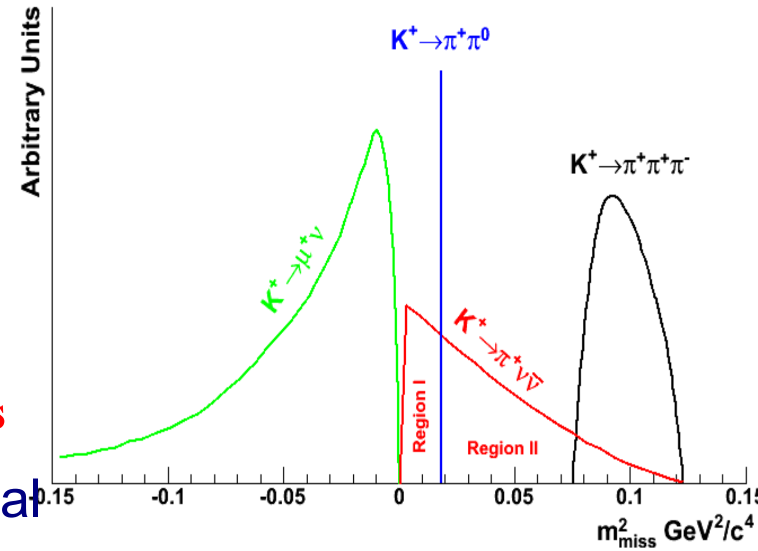


Experimental technique

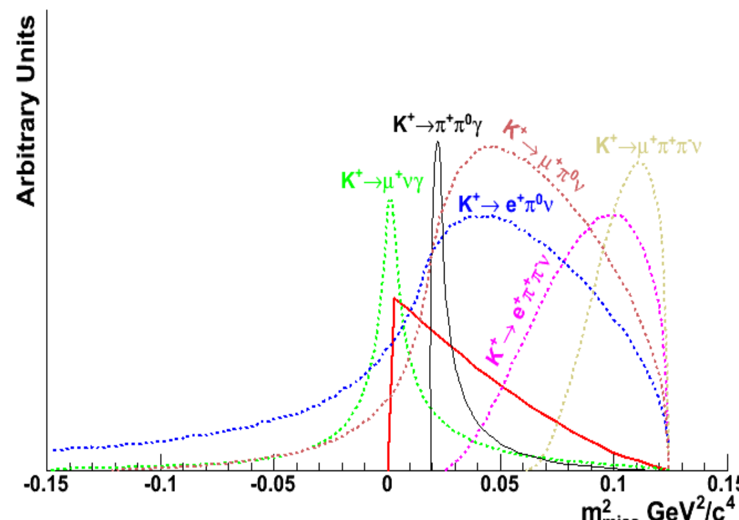


$$m^2_{miss} = m^2_K + m^2_\pi - 2(E_K E_\pi - p_K p_\pi \cos\theta_{K\pi})$$

measured quantities



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



Event selection

Kinematics reconstruction

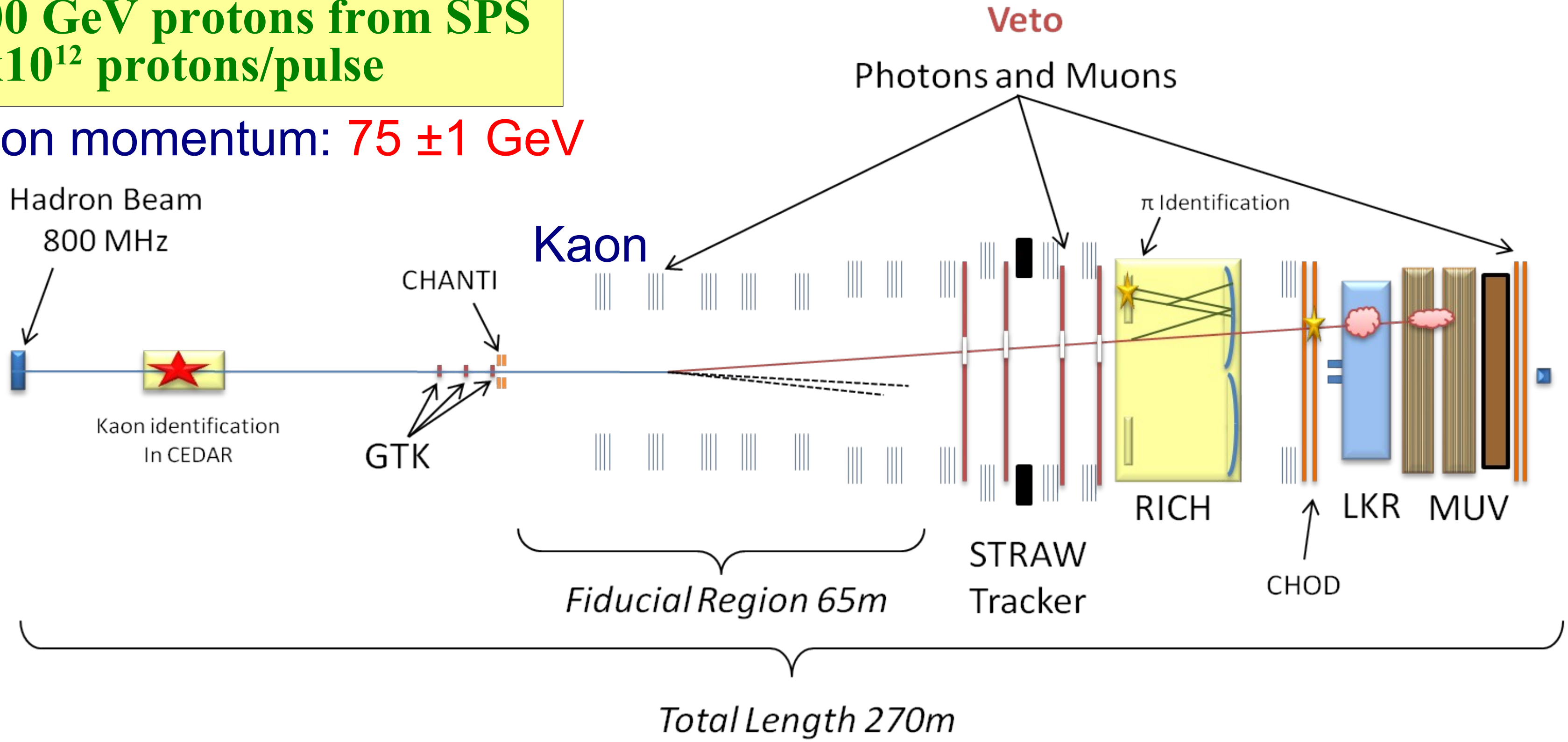
Particle identification

Particle vetoing

Experimental setup

400 GeV protons from SPS
$3x10^{12}$ protons/pulse

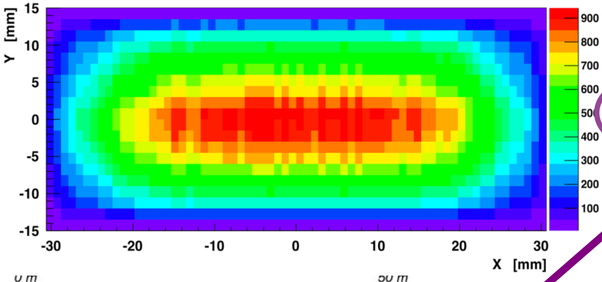
Kaon momentum: 75 ±1 GeV

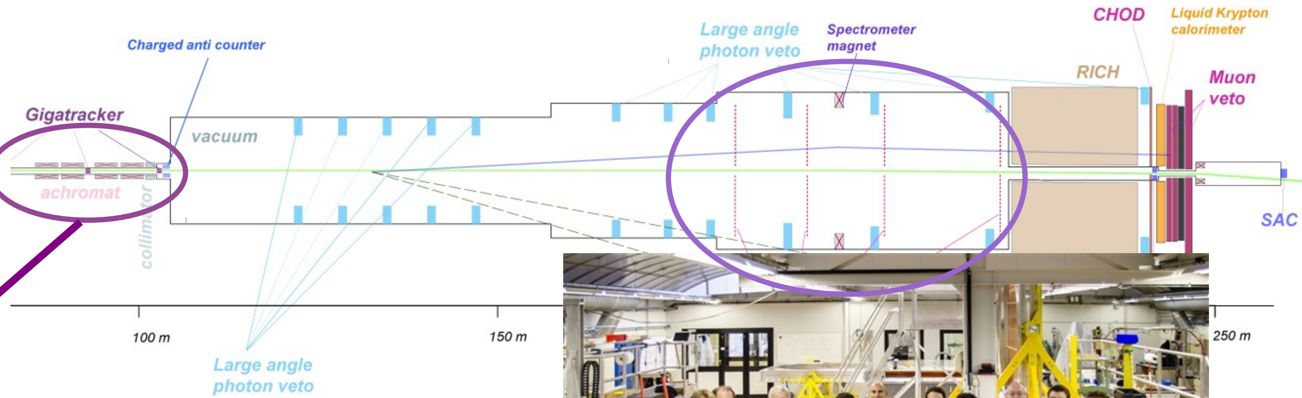


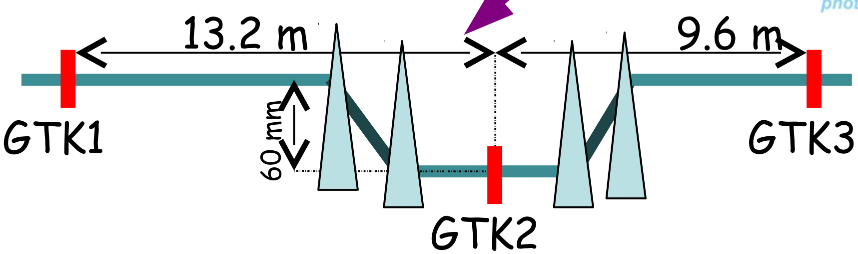
Unseparated hadron beam: kaon component 6%

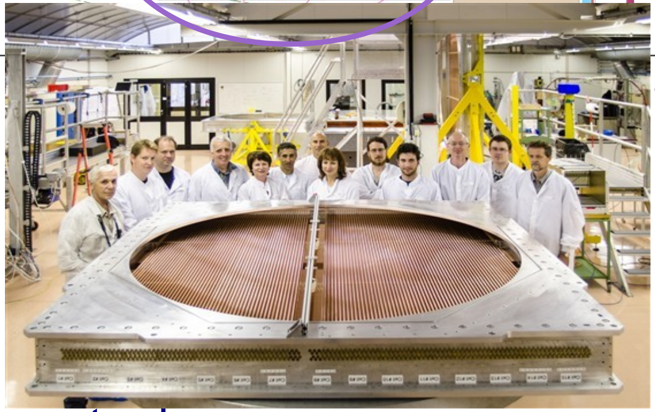
Expected $4.5*10^{12}$ kaon decays per year

Kinematics







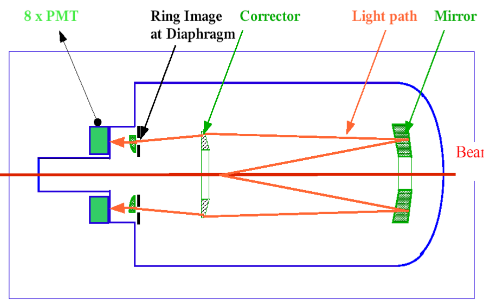


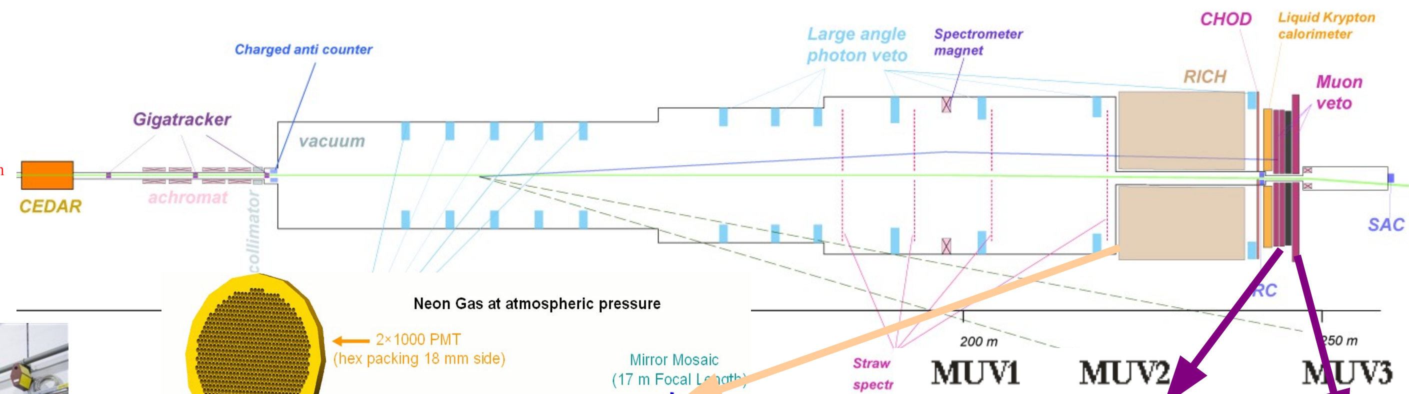
- Momentum resolution: $\sigma(p_K)/p_K \sim 0.2\%$
- Angular resolution: 16 μrad
- 200 μm sensor + 300 μm chip
  <0.5% X0
- Time resolution ~200 ps/station

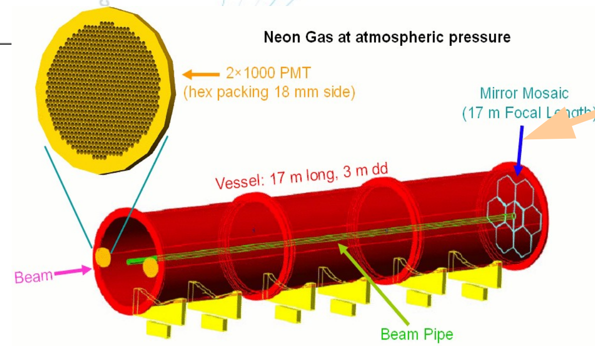
- Spectrometer in vacuum
- Straw tubes: 4 chambers, 4 views/ chamber, 4 staggered layers/view
- Momentum resolution
  $\sigma(p)/p \sim 0.3\% \oplus 0.007\% * p(GeV/c)$
- 2 views operated during TR

Resolution on M^2_{miss} ~0.001 GeV^2/c^4

Particle identification







KTAG

- CEDAR with 3.6bar H_2
- 100 ps time resolution
- Tests during TR
  - **alignment**
  - **pressure scans**

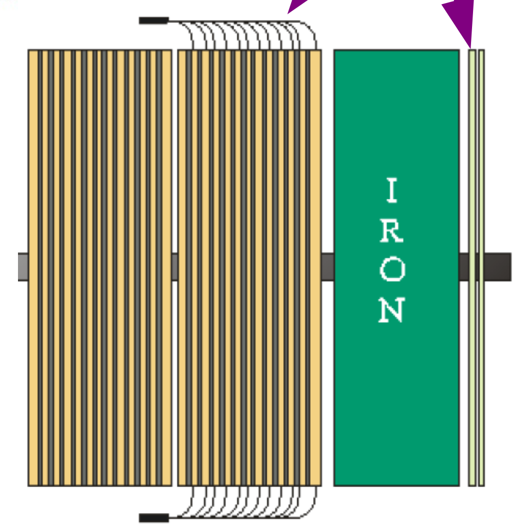
RICH

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]

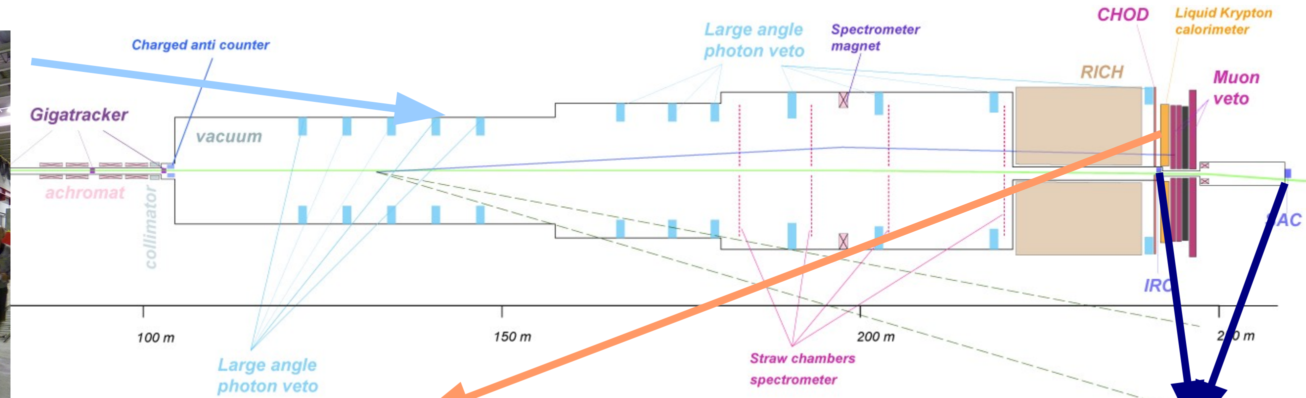


MUV/HAC

iron scintillator sandwitch

π/μ separation & trigger

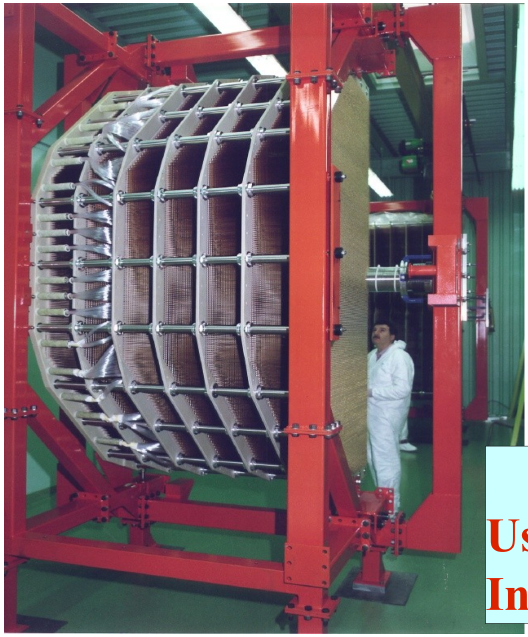
Photon vetoes



LAV

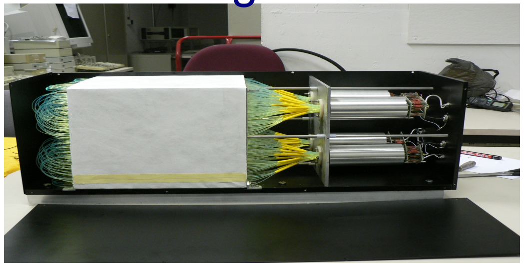
- 12 stations in vacuum
- Angles from 8.5 to 50 mrad
- Lead glass from OPAL

8 built, 2 operated during Technical run



SAC and IRC

– shashlyk type detectors
– RO during TR

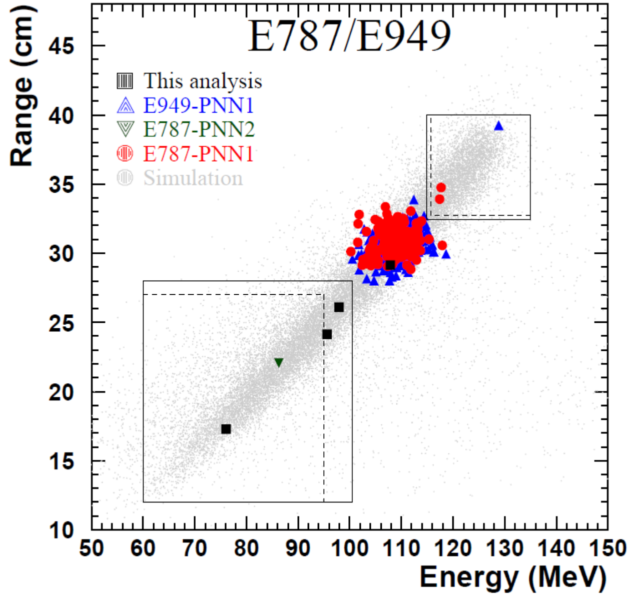


LKr

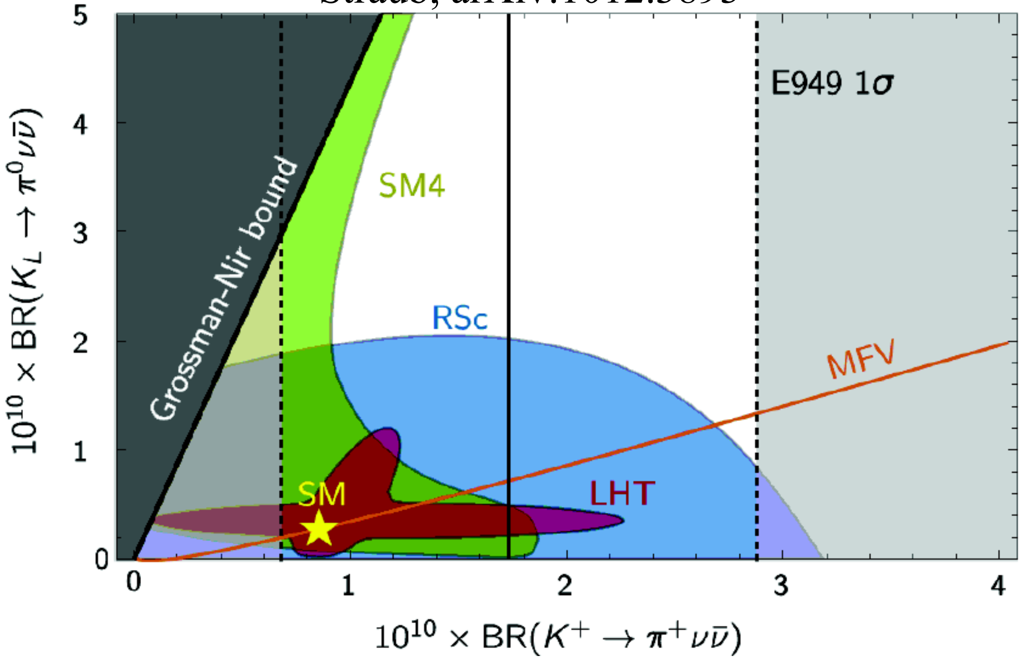
Using the NA48 EM callorimeter
Inefficiency for $E\gamma>10GeV$ $\eta< 8*10^{-6}$

K+→π+νν status

Phys. Rev. D, 79 (2009), p. 092004



Straub, arXiv:1012.3893



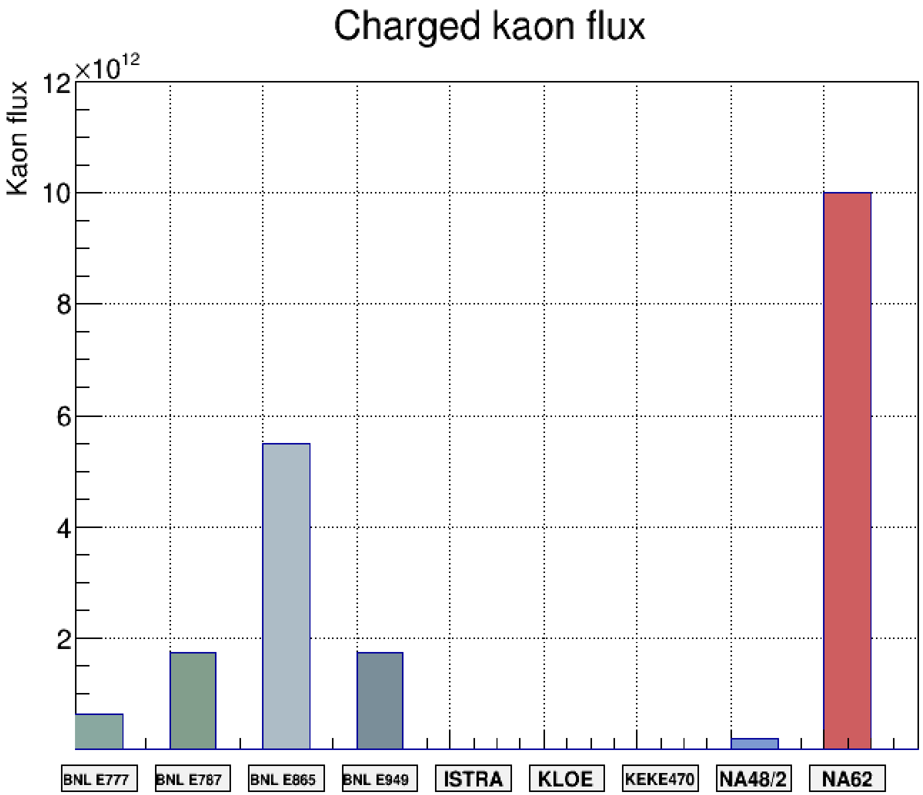
- E949 result based on 7 events:

  $Br(K^+ \to \pi^+ \nu\nu) = (1.73^{+1.15}_{-1.05}) \cdot 10^{-10}$ (~two times SM)

- $K^+ \to \pi^+ \nu\nu$ sensitive to NP contribution

NA62 @ CERN SPS aims to collect O(100) $K^+ \to \pi^+ \nu\nu$ events and perform a 10 % measurement of Vtd

NA62: kaon rare decay studies



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

LFV modes:

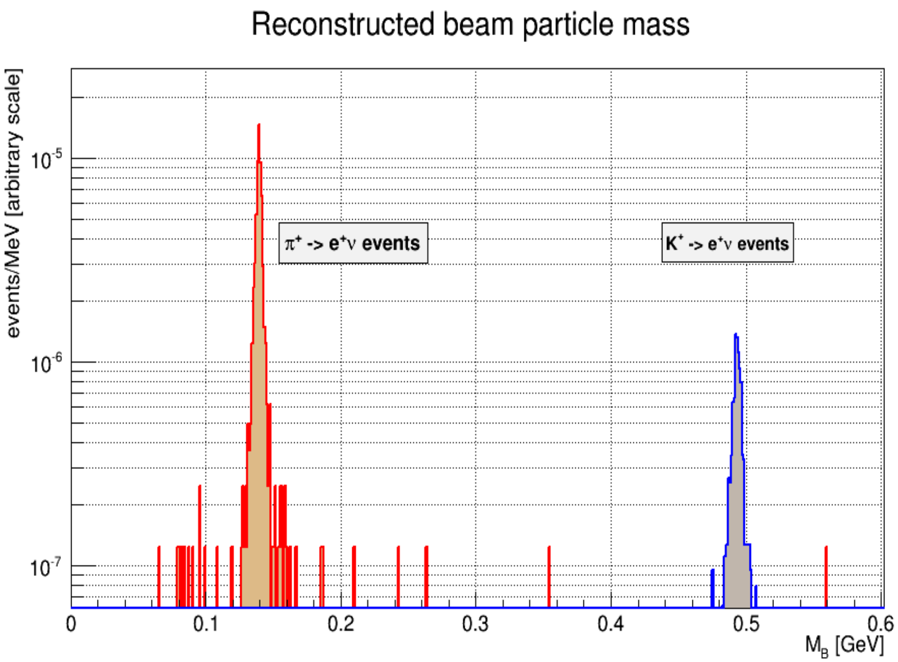
Mode	90% CL	Exp
$K^+ \to \pi^- \mu^+ e^+$	$5*10^{-10}$	E865
$K^+ \to \pi^- e^+ e+$	$6.4*10^{-10}$	E865
$K^+ \to \pi^- \mu^+ \mu^+$	$1.1*10^{-9}$	NA48/2

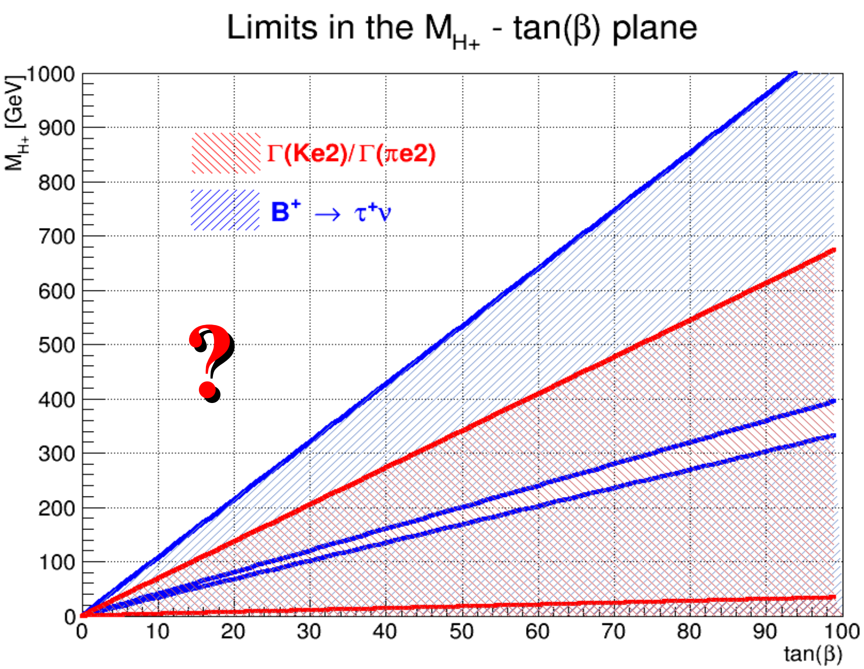
NA62 could reach 10^{-12} single event sensitivity

The measurement of RK could also be improved

Measurement of Γ(Ke2)/Γ(πe2)

- **Is it possible to profit from simultaneous pion and kaon beams?**
- Standard Model: $R^l_{K\pi} = \left|\frac{V_{us}}{V_{ud}}\right|^2 \times \frac{f_K^2 m_K}{f_\pi^2 m_\pi} \times \left(\frac{1 - m_l^2/m_K^2}{1 - m_l^2/m_\pi^2}\right)^2 \times (1 + \delta_{em})$
- MSSM: $R^l_{K\pi}(\mathrm{MSSM}) = R^l_{K\pi}(\mathrm{SM}) \times (1 - r_H^K)^2, \quad r_H^K = \frac{m_K^2}{M_{H+}^2}\left(1 - \frac{m_d}{m_s}\right)\frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}$
- **0.5 % measurement sensitive to inaccessible regions to B→τν**





Conclusion

- Rare kaon decays provide a very challenging opportunity to search for physics beyond the Standard Model
- Result for R_K based on 2007 NA62 data presented
- Extensive tests of Chiral Perturbation theory undergoing
- NA62 experiment is in its final construction phase preparing for data taking
- 10% measurement of $Br(K^+ \rightarrow \pi^+ \nu\nu)$ expected soon
- NA62 is the present laboratory of charged kaon physics