First observation of $K \to \pi^+\pi^0 e^+e^-$ decay at NA48

R. Fantechi

CERN and INFN – Sezione di Pisa
on behalf of the NA48/2 Collaboration

The NA48/2 Collaboration
Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Florence, Mainz,
Northwestern, Perugia, Pisa, Saclay, Siegen, Turin, Vienna

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Outline

- The NA48/2 beam and detector
- The measurement of $K^{\pm} \to \pi^{\pm}\pi^{0}e^{+}e^{-}$
- Prospects and conclusions

NA48: site and history

Earlier: NA31

NA48 discovery of direct CPV
- 1997: ε'/ε: K_L+K_S
- 1998: K_L+K_S
- 1999: K_L+K_S | K_S HI
- 2000: K_L only | K_S HI
- 2001: K_L+K_S | K_S HI

NA48/1
- 2002: K_S/hyperons

NA48/2
- 2003: K^+/K^-
- 2004: K^+/K^-

NA62 R_K phase
- 2007: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests
- 2008: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests

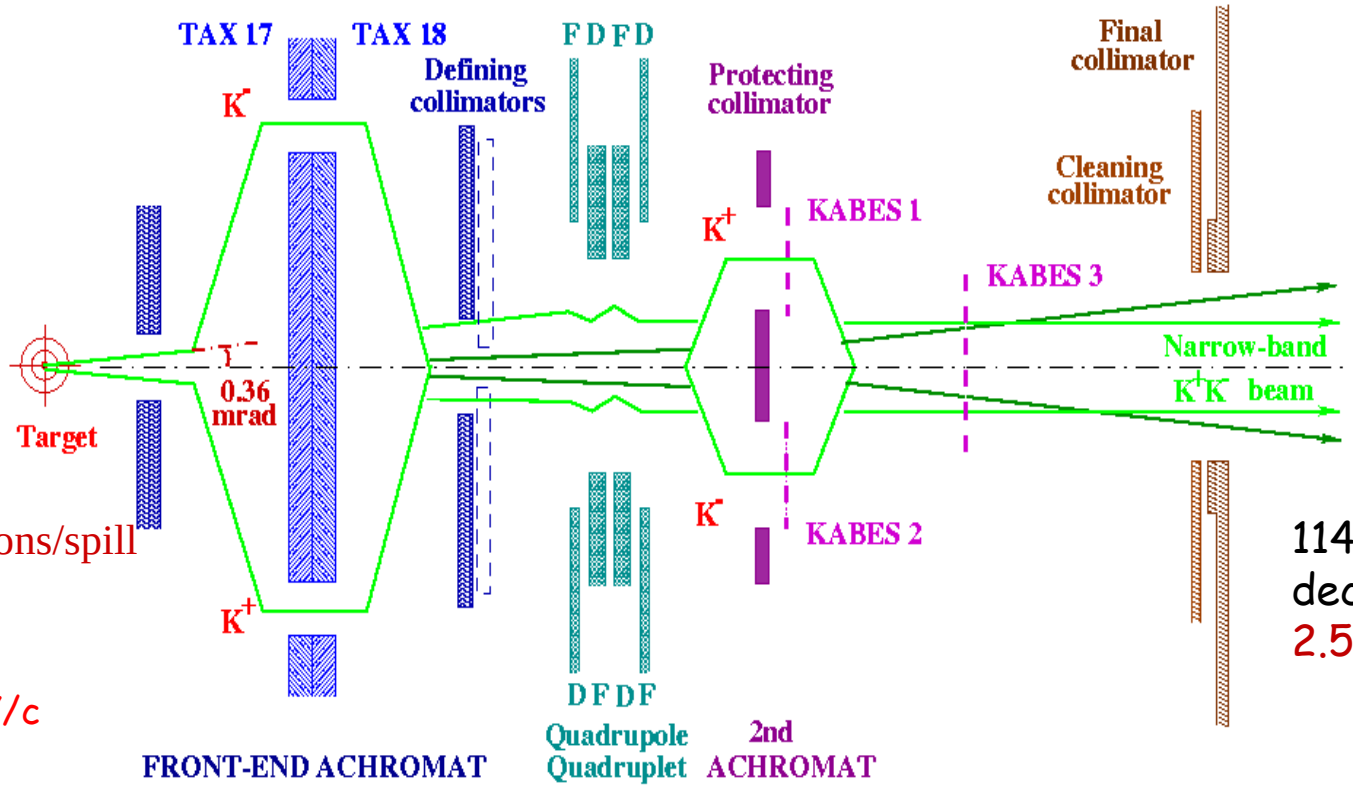
NA62
- 2014: pilot run
- *2015:* 1st $K^+ \to \pi^+ \nu\bar{\nu}$ run

Kaon decay in flight experiments.
NA62: currently ~200 participants, 30 institutions

The NA48/2 Beam

NA48/2 beam (2003-2004): simultaneous K^+/K^-

$N(K^+)/N(K^-) = 1.8$



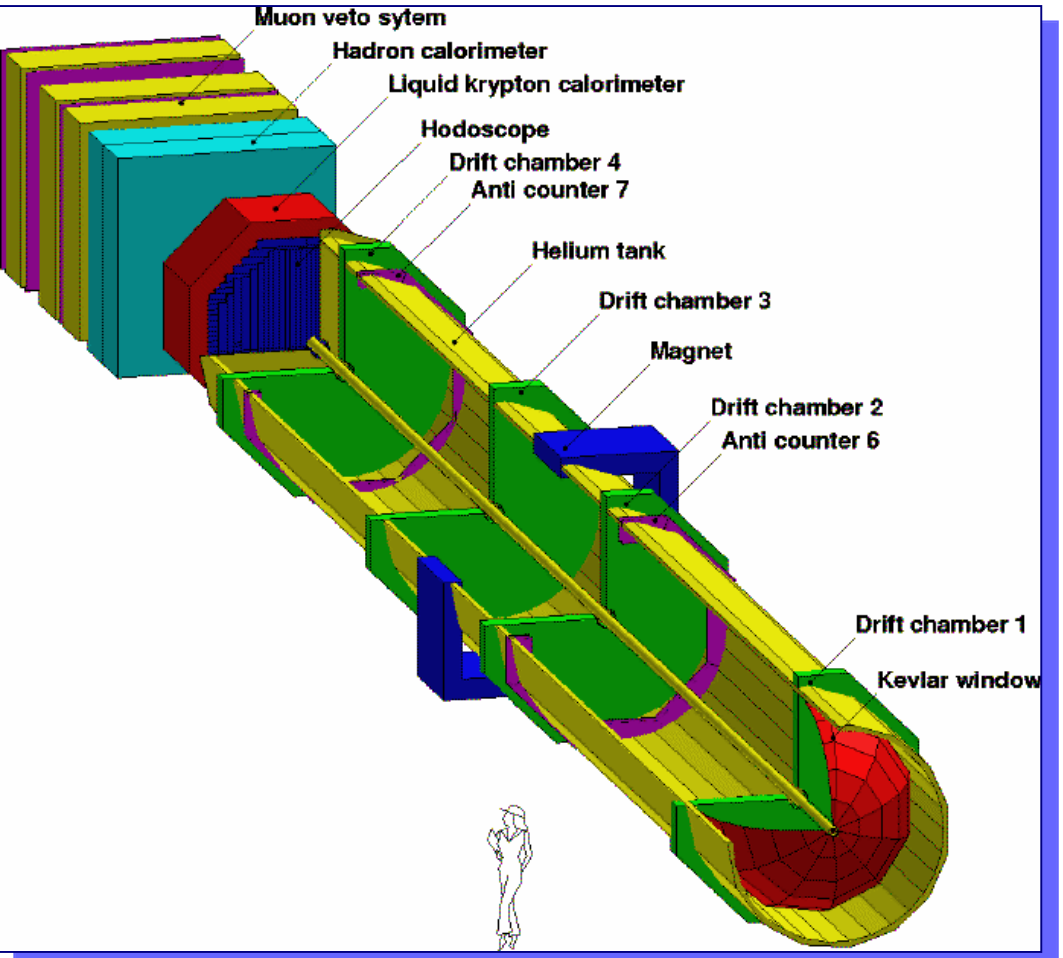
1.8×10^{12} protons/spill
400 GeV/c

$P_K = (60 \pm 3)$ GeV/c

114 m long
decay volume
2.5×10^7 K/spill

K decays in the vacuum tank: 22%
Beam size: 4x4 mm^2, 10x10 μr

The NA48/2 Detector



LKr Calorimeter:
$\sigma(E)/E \cong 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$

$\sigma(x) = \sigma(y) \cong (4.2/\sqrt{E} \oplus 0.6)\text{mm} \cong$ 1.5mm@ 10 GeV

Spectrometer:

$\sigma(P)/P \cong 1.02\% \oplus 0.044\ P[\text{GeV}/c]\%$

Scintillator hodoscope: fast trigger and good time resolution (150 ps)

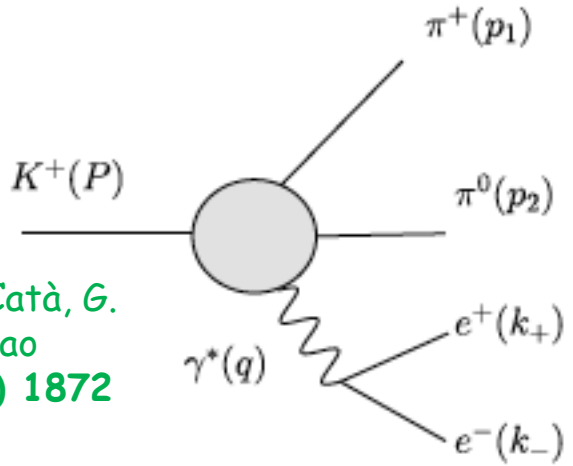
Efficient trigger chain for 3-track vertices using the hodoscope multiplicity at L1 and drift chamber track reconstruction at L2

$K^{\pm} \longrightarrow \pi^{\pm}\pi^{0}\gamma^{*} \longrightarrow \pi^{\pm}\pi^{0}e^{+}e^{-}$ motivations

- Never observed
- Inner bremsstrahlung, direct emission (E,M) and interference components

$$\frac{d^3\Gamma}{dE_\gamma^* dT_c^* dq^2} = \frac{d^3\Gamma_B}{dE_\gamma^* dT_c^* dq^2} + \frac{d^3\Gamma_E}{dE_\gamma^* dT_c^* dq^2} + \frac{d^3\Gamma_M}{dE_\gamma^* dT_c^* dq^2} + \frac{d^3\Gamma_{\rm int}}{dE_\gamma^* dT_c^* dq^2},$$

L. Cappiello, O. Catà, G. D'Ambrosio ,D.Gao
EPJ C72 (2012) 1872



- Interference Γ_B Γ_E can confirm the discrepancy in sign with the theoretical prediction observed by NA48/2 in $K^{\pm} \longrightarrow \pi^{\pm}\pi^{0}\gamma$ EPJC 68 (2010) 75-87

- Magnetic interference is genuine $\pi\pi ee$ and can be used to extract the sign of the magnetic term Γ_M (impossible to extract in $\pi^{\pm}\pi^{0}\gamma$).

- P violating observables in the dilepton pair coupling can be used to access short distance physics using K^+ only (NA62)

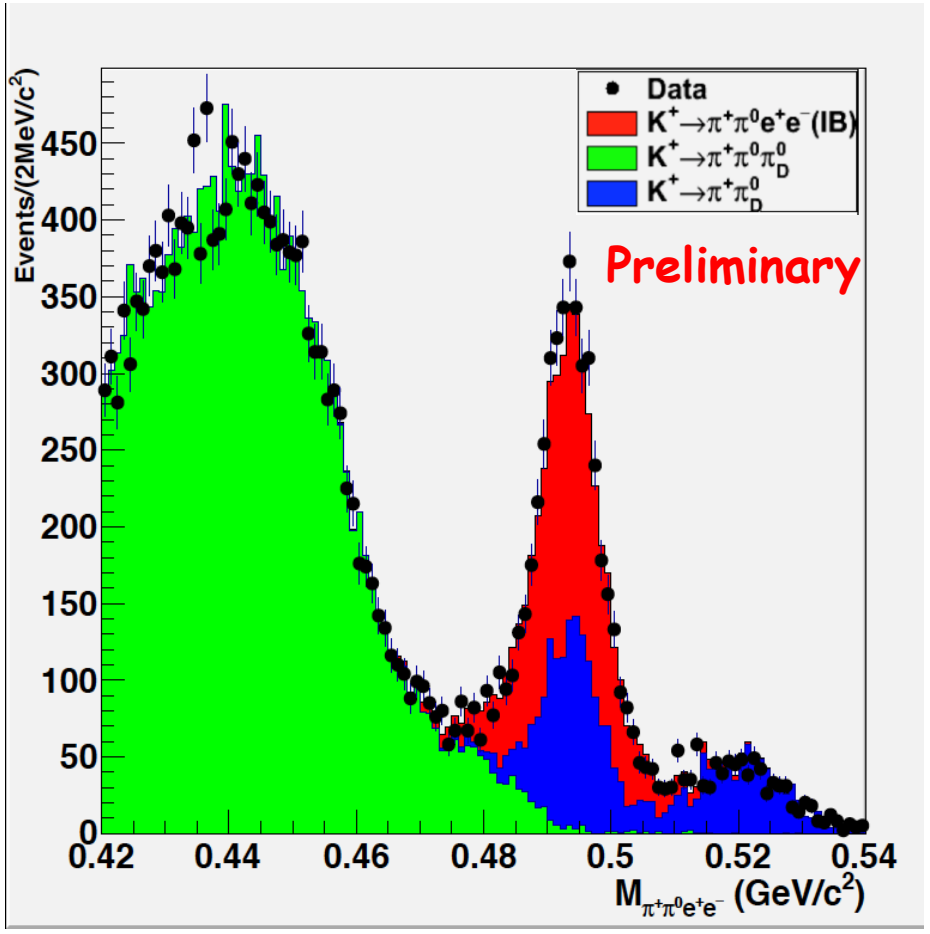
- Charge asymmetry not contaminated by indirect CP violation (as in K^0)

Data analysis

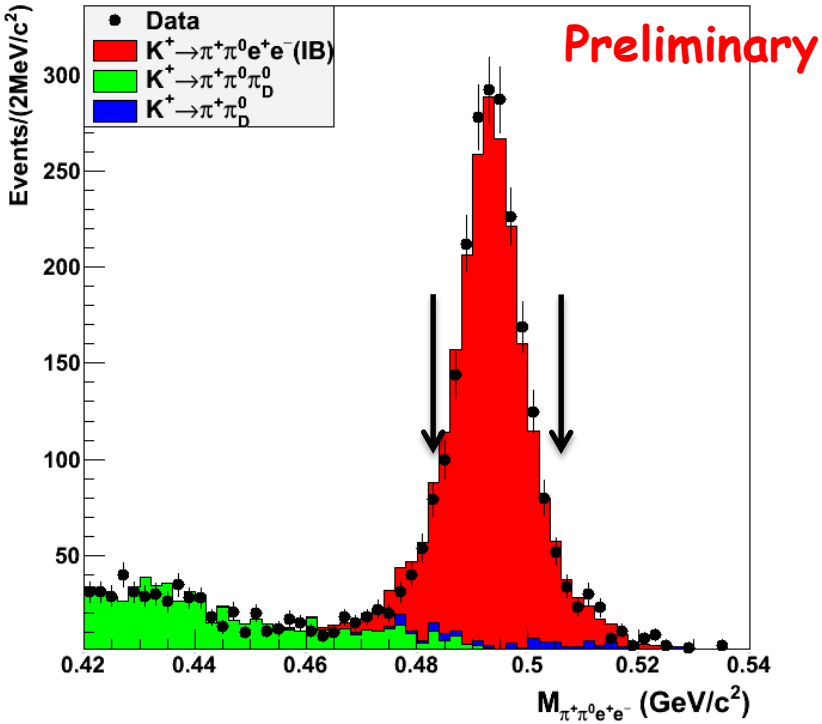
- Data collected in 2003 have been used
- Montecarlo simulation at tree level
  - Following the paper from L. Cappiello et al.
  - Inner bremsstrahlung, direct emission (dominant M contribution) and BE interference
  - Radiative correction implemented with Coulomb corrections and Photos package
- Selection cuts
  - 3 reconstructed tracks coming from one decay vertex
  - Electron/pion separation using E/P
  - 2 reconstructed γ clusters giving the π^0 mass
  - $P_e > 2GeV/c$
  - $P_{\pi\pi ee}$ within 56 and 64 GeV/c
  - $483.677\ GeV/c^2 < M_{\pi\pi ee} < 503.677\ GeV/c^2$

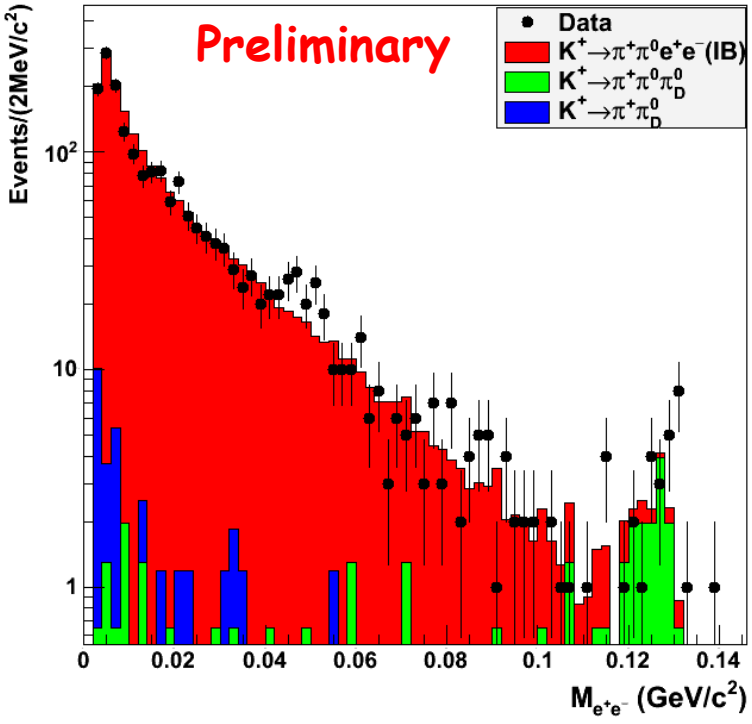
Main sources of background

- $K^{\pm} \to \pi^{\pm}\pi^0\pi^0_D$ ($K_{3\pi D}$)
  - $K^{\pm} \to \pi^{\pm}\pi^0 e^+e^- \gamma$ with one photon undetected or merged with one electron cluster
  - Require $|M_{\pi\pi}|^2 > 0.12\ GeV^2/c^4$
    - Missing e^+e^- system can be light
- $K^{\pm} \to \pi^{\pm}\pi^0_D(\gamma)$ ($K_{2\pi D}$)
  - $K^{\pm} \to \pi^{\pm}e^+e^- \gamma$ with an additional photon (radiative or accidental)
  - No combination $e^+e^- \gamma$ should have $|M_{ee\gamma} - M_{\pi 0}| < 7\ MeV/c^2$



Background subtraction





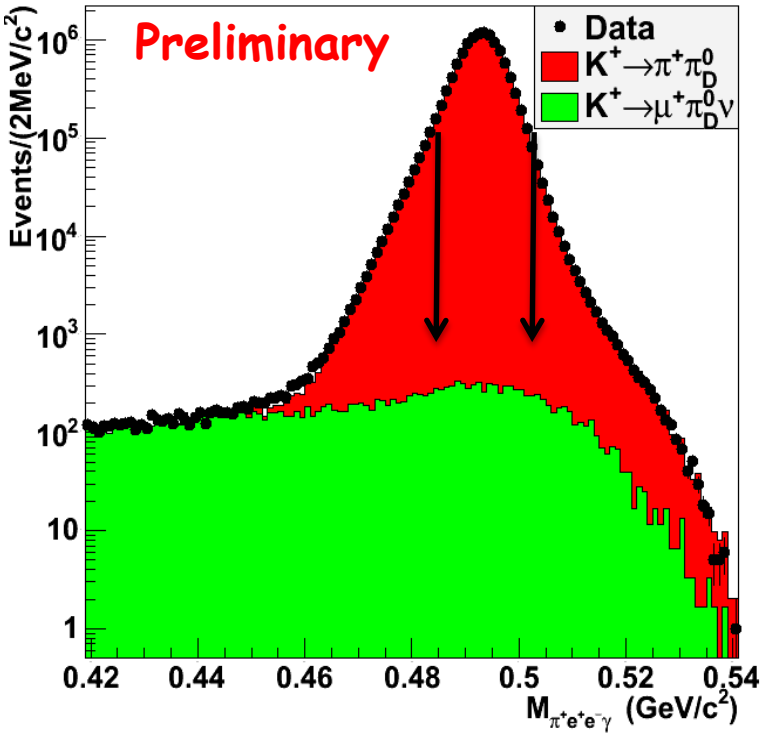
Background from $K_{3\pi D}$ = 30±5.5

Background from $K_{2\pi D}$ = 26±5.1

1916 $\pi^{\pm}\pi^0e^+e^-$ candidates

1860 bckg subtracted events

Normalization



Total kaon flux: $(7.97 \pm 0.25) \cdot 10^{10}$

- For normalization use the decay $K^{\pm} \to \pi^{\pm}\pi^0_D(\gamma)$, collected with the same trigger
- Very large sample with known BR (PDG)

# of events	6714917 ± 2591	0.04%
Statistical error		0.04%
Acceptance	(3.555±0.002)%	0.002%
Trigger efficiency	(97.64± 0.04)%	0.04%
Bkgd in $2\pi_D$ sample	3365±58	$8 \cdot 10^{-4}$ %
Radiative corrections	0.78%	0.78%
Systematic error		0.78
BR($\pi^+\pi^0_D(\gamma)$)	$(2.425 \pm 0.073) \times 10^{-3}$	3.01%
External error		3.01%

Error summary table

Error type	Δ(BR)	Δ(BR)/BR
1916 signal candidates		
Statistical origin	0.095	2.35%
Radiative correction on IB	0.020	0.50%
Signal total acceptance	0.014	0.34%(stat)
	0.041	1.00% (model dependence)
Background subtraction	0.016	0.40% (stat)
	0.002	0.05% (syst. Radcorr $2\pi_D$)
Trigger efficiency	0.026	0.65% (stat)
Total systematics	0.056	1.40%
Normalization measurement	$(2.425\pm0.073)\times10^{-3}$	3.01% (from $\pi^+\pi^0_D$ decay BR)
External error	0.126	3.01%

Main contributions:
-Model dependent acceptance for the systematic error
-Error on the $\pi^+\pi^0_D$ decay branching ratio for the external error

Branching ratio measurement

- The available statistics is not sensitive to DE and INT
- We have computed a model dependent branching ratio using a total acceptance in which the weights of the various components have been taken from Cappiello et al.

$$Acc^{Tot}_{\pi\pi ee} = \frac{Acc(IB) + Frac(DE)_{Th} \cdot Acc(DE) + Frac(INT)_{Th} \cdot Acc(INT)}{1 + Frac(DE)_{Th} + Frac(INT)_{Th}}$$

Frac(DE)=1/71 and Frac(INT)=1/128 computed in Cappiello et al. using inputs from the NA48 measurement of $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$

- The branching ratio is computed as

$$BR(\pi\pi ee) = \frac{N_{\pi\pi ee} - N_{BG}}{K_{Flux} \cdot Acc^{TOT}_{\pi\pi ee} \cdot \varepsilon_{\pi\pi ee}}$$

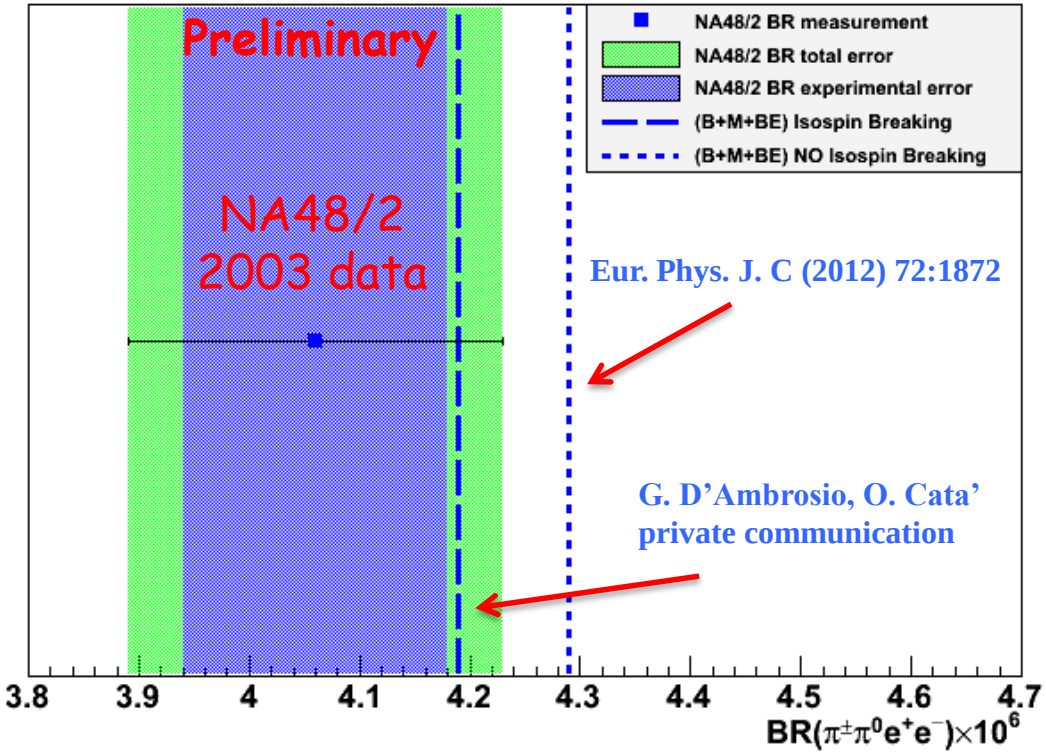
$$BR(\pi\pi ee) = (4.06 \pm 0.10_{stat} \pm 0.06_{sys} \pm 0.13_{ext}) \cdot 10^{-6}$$

Preliminary

Quantity	Value
$N_{\pi\pi ee}$	1916
	1860 ± 51 after BG sub
N_{BG}	55.8±7.4
K_{flux}	$(7.97 \pm 0.25_{tot}) \times 10^{10}$
Acceptance ($Acc^{TOT}_{\pi\pi ee}$)	(0.583±0.0019)%
Trigger efficiency ($\varepsilon_{\pi\pi ee}$)	(98.7±0.65)%

Comparison with theory

Theoretical predictions considering isospin breaking effects ($m_{\pi^+} \neq m_{\pi^0}$), unpublished, BR = $4.19 \cdot 10^{-6}$



$BR_{\pi\pi ee}^{NA48/2} = (4.06 \pm 0.17) \cdot 10^{-6}$

Compatible with theoretical prediction without radiative corrections

Radiative corrections included in the NA48/2 simulation using PHOTOS

Prospects and conclusions

- NA48/2 has observed for the first time the decay $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}e^{+}e^{-}$ with ~3% background contribution

- A model dependent branching ratio has been measured
  - $BR_{\pi\pi ee}^{NA48/2} = (4.06 \pm 0.17) \cdot 10^{-6}$

- Currently analysing 2003 + 2004 data
  - Improved statistics
  - Limit on charge asymmetry

- NA62 could improve the result
  - Almost hermetic photon veto detector $\rightarrow$ $K_{3\pi D}$ background strongly reduced
  - At least 20x statistics, possibility to look at Dalitz plot features
    - Disentangle DE and INT components