Studies of the decay $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}e^{-}e^{+}$ at NA48

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On behalf of the NA48/2 collaboration

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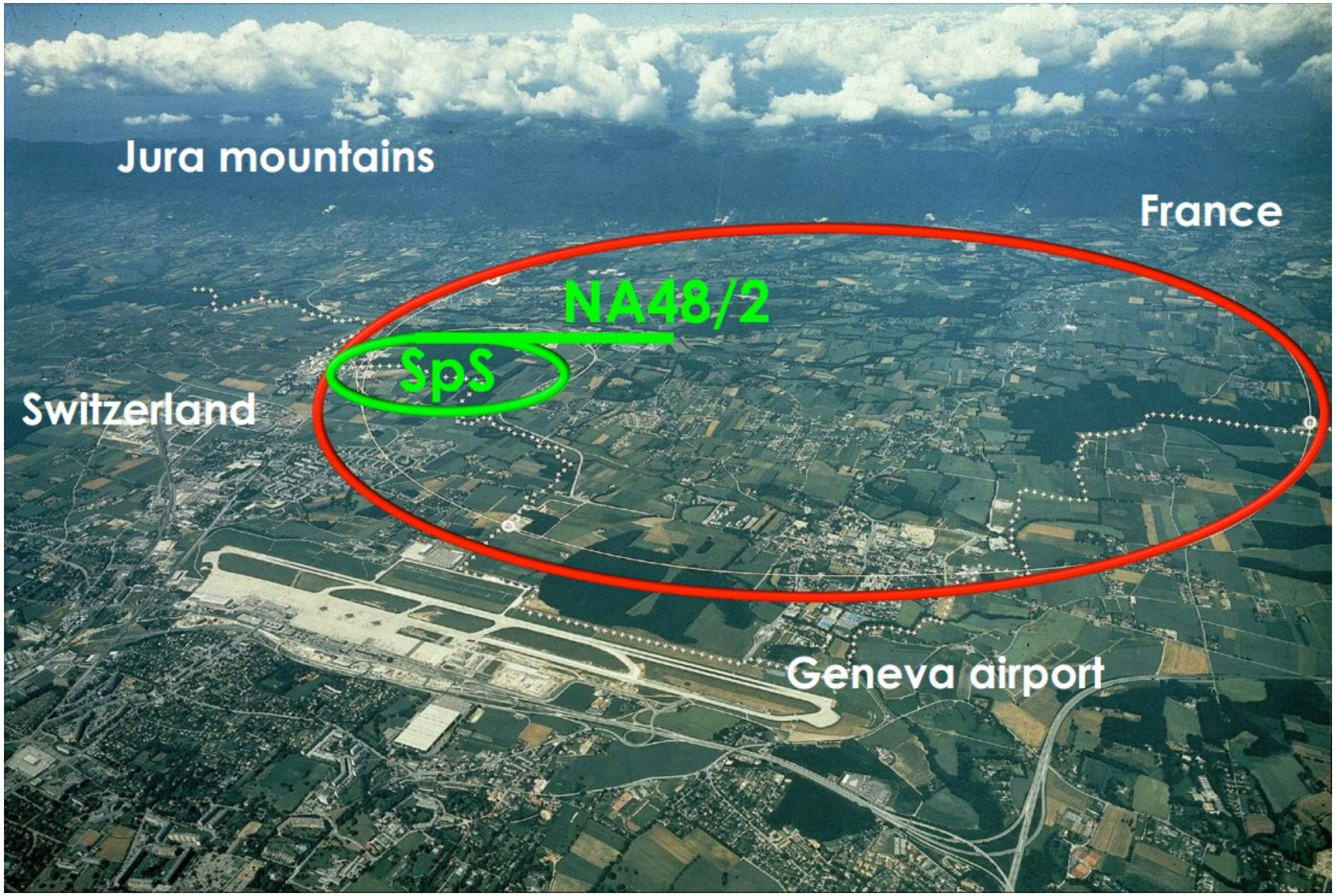
Outline

- the NA48/2 experiment: beam line and detector
- ChPT and chiral studies in NA48/2
- The new measurement of $K^{\pm} \rightarrow \pi^{\pm} \pi^{0} e^{+} e^{-}$
- Conclusion

NA48/2 at SPS



- Located at SPS north area
- A collaboration of 15 institutes from Austria, France, Germany, Italy, Russia, CERN, UK, USA

The NA48/2 experiment

Goals:

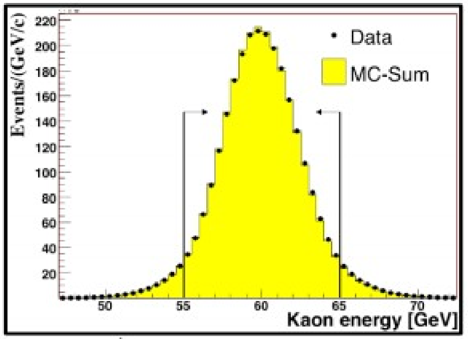
- Was designed for precision measurement of direct CP violation in $K_{3\pi}$ decays.
- Tests of CKM unitarity, ππ scattering lengths, ChPT tests, lepton universality.

Data taking:

- 4 months in 2003 + 4 months in 2004 with simultaneous K^+ and K^- beam with $N_{K+}/N_{K-} \sim 1.8$
- $\sim 2 \times 10^{11}$ $K^{\pm}$ decays in the fiducial decay region

The Beam Line

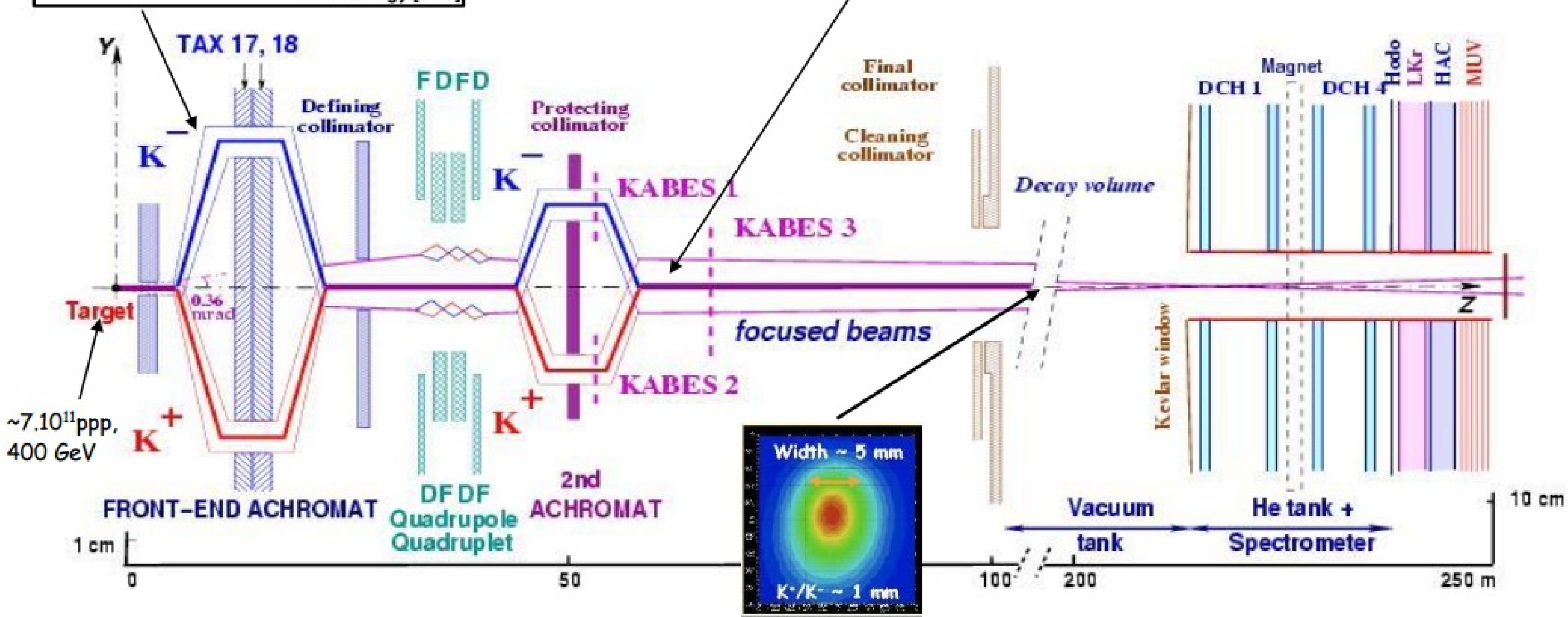
Simultaneous K^+ and K^- beams



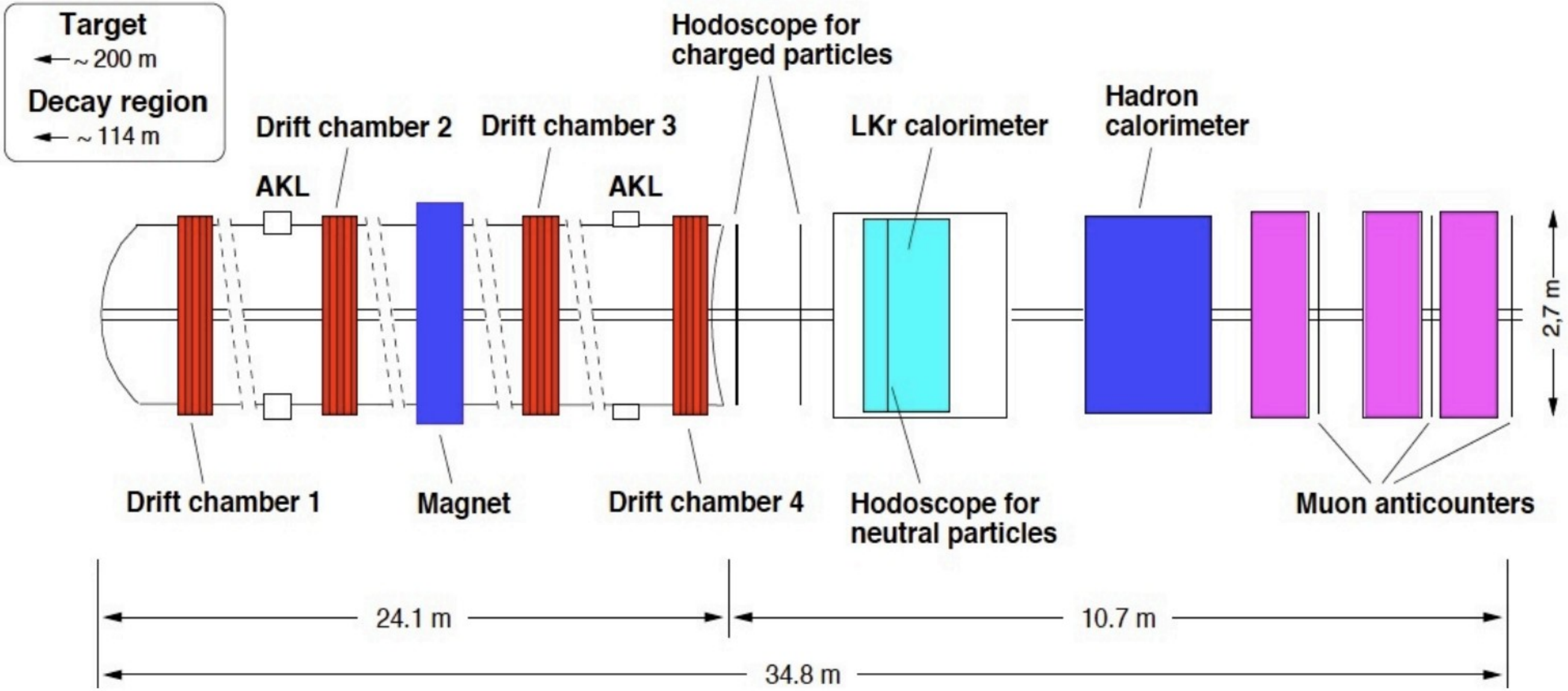
P_K = 60±3 GeV/c

2-3M K/spill (π/K~10), π-decay products stay in the beam pipe.
Flux ratio K+/K- ≈1.8

Beams coincide within ~1mm all along 114m decay volume



NA48/2 detectors



- **Magnetic Spectrometer**
  - 4 drift chambers and a dipole magnet
  - $\sigma(p)/p = 1.02\% + 0.044 * p\%$ [p in GeV/c]
- **Hodoscope for charged particles**
  - Fast for trigger
  - Time measurement ~ 150 ps
- **Liquid Krypton Calorimeter (Lkr)**
  - High granulatity (13248 cells of 2x2 cm^2)
  - Quasi-homegeneous (7 m^3 liquid Kr, 28 X_0)
  - $\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [E in GeV]

The Chiral Perturbation Theory

- Effective field theory for the analysis of the low energy properties of the strong interaction.
- ChPT is an ideal framework to describe kaon decays.
- $\Delta S=1$ $O(p^4)$ chiral lagrangian can be written as:

$$L_{\Delta S=1} = L^2_{\Delta S=1} + L^4_{\Delta S=1} \simeq G_8 F^4 < \lambda_6 D_\mu U^\dagger D^\mu U > + G_8 F^2 \sum N_i W^i$$

D'Ambrosio PoS(EFT09)061

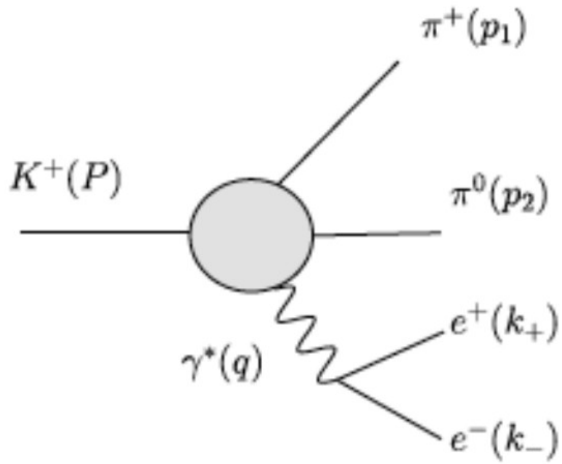
- At this order 37 free coefficients N to be determined by measurements.
- Combinations of such couplings are accessible by measuring Kaon decays branching fractions and form factors.

ChPT and Kaon decay

- Kaon decays give a great opportunity to test the weak part of ChPT Lagrangian
- NA48/2 has access to all the charged Kaon decay

Decay	$\mathcal{L}^4_{\Delta S=1}$ counterterms	
$K^+ \to \pi^+ l^+ l^-$	$N^r_{14} - N^r_{15}$	NA48/2 ee PLB 677 (2009) 246-254 μμ PLB 697 (2011) 107-115
$K_S \to \pi^0 l^+ l^-$	$2N^r_{14} + N^r_{15}$	NA48/1 ee Phys.Lett. B576 (2003) 43-54 μμ PLB 599 (2004) 197-211
$K^\pm \to \pi^\pm \gamma\gamma$	$N_{14} - N_{15} - 2N_{18}$	NA48/2 Phys.Lett. B730 (2014) 141-148
$K_S \to \pi^+ \pi^- \gamma$	$N_{14} - N_{15} - N_{16} - N_{17}$	
$K^\pm \to \pi^\pm \pi^0 \gamma$	$N_{14} - N_{15} - N_{16} - N_{17}$	NA48/2 EPJC 68 (2010) 75-87
$K_L \to \pi^+ \pi^- e^+ e^-$	$N^r_{14} + 2N^r_{15} - 3(N^r_{16} - N_{17})$	NA48 Eur.Phys.J. C30 (2003) 33-49
$K^+ \to \pi^+ \pi^0 e^+ e^-$	$N^r_{14} + 2N^r_{15} - 3(N^r_{16} - N_{17})$	**Still missing!**
$K_S \to \pi^+ \pi^- e^+ e^-$	$N^r_{14} - N^r_{15} - 3(N^r_{16} + N_{17})$	NA48 Eur.Phys.J. C30 (2003) 33-49

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

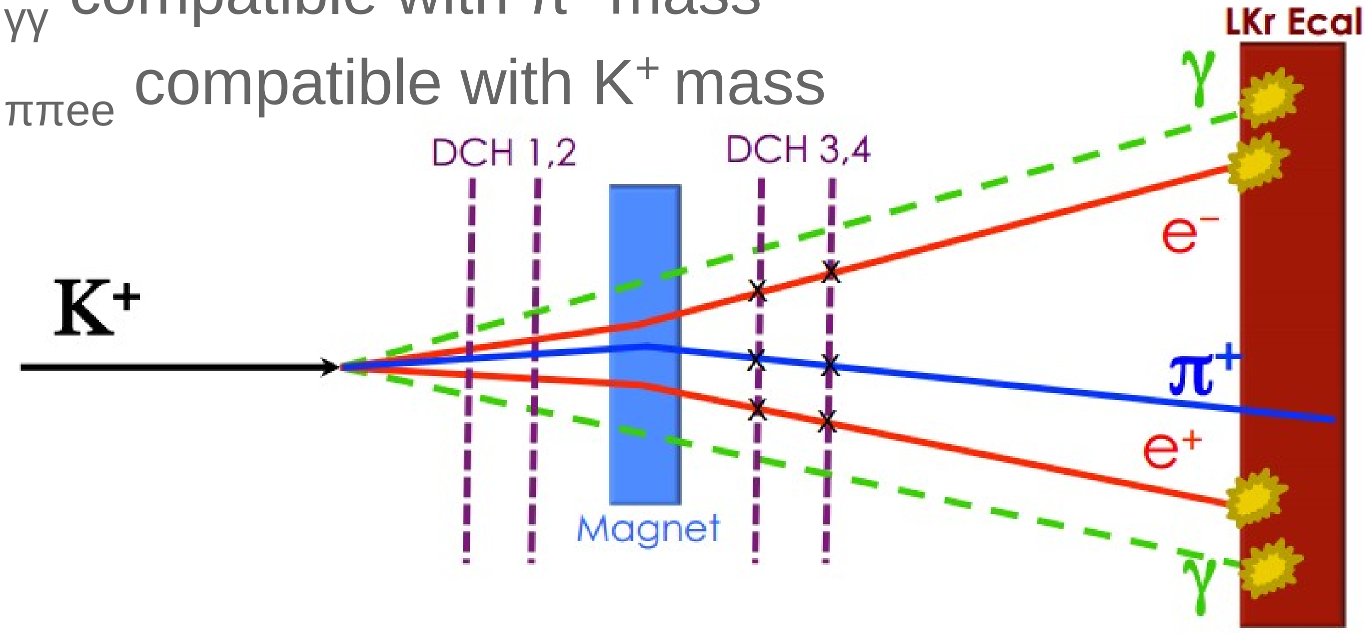


- This decay was never observed so far
- The γ^{*} is produced by two different mechanisms: Inner Bremsstrahlung (IB) and Direct Emission (DE)
- DE have electric and magnetic component
- It offers some opportunities for chiral theory tests:
  - Electric Interference ($\Gamma_{ib}\Gamma_{E}$) can confirm 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 can be used to extract the sign of the magnetic term Γ_{M} (impossible to extract in $K^{\pm} \longrightarrow \pi^{\pm}\pi^{0}\gamma$)
  - Charge asymmetry not contaminated by indirect CP violation (as in K^{0})

Reconstruction Strategy

Selection:

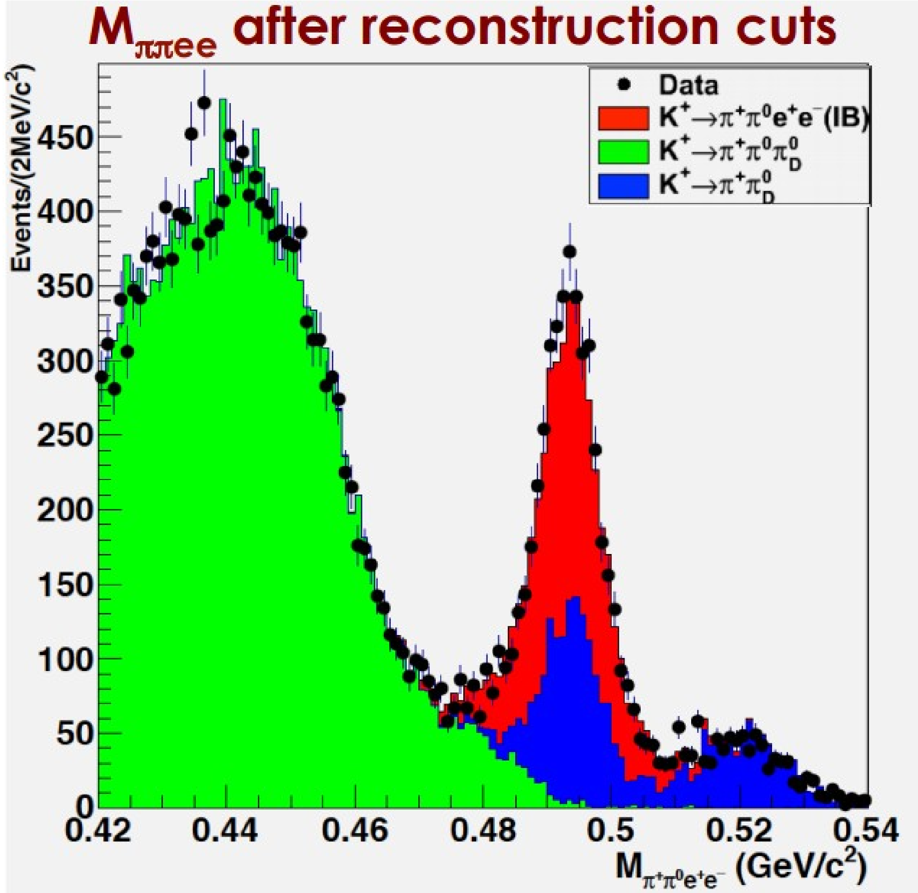
- 2003 data sample
- 3 good tracks
- 2 electron and pion identification by E/p
- 2 photon clusters
- $M_{\gamma\gamma}$ compatible with π^0 mass
- $M_{\pi\pi ee}$ compatible with K^+ mass



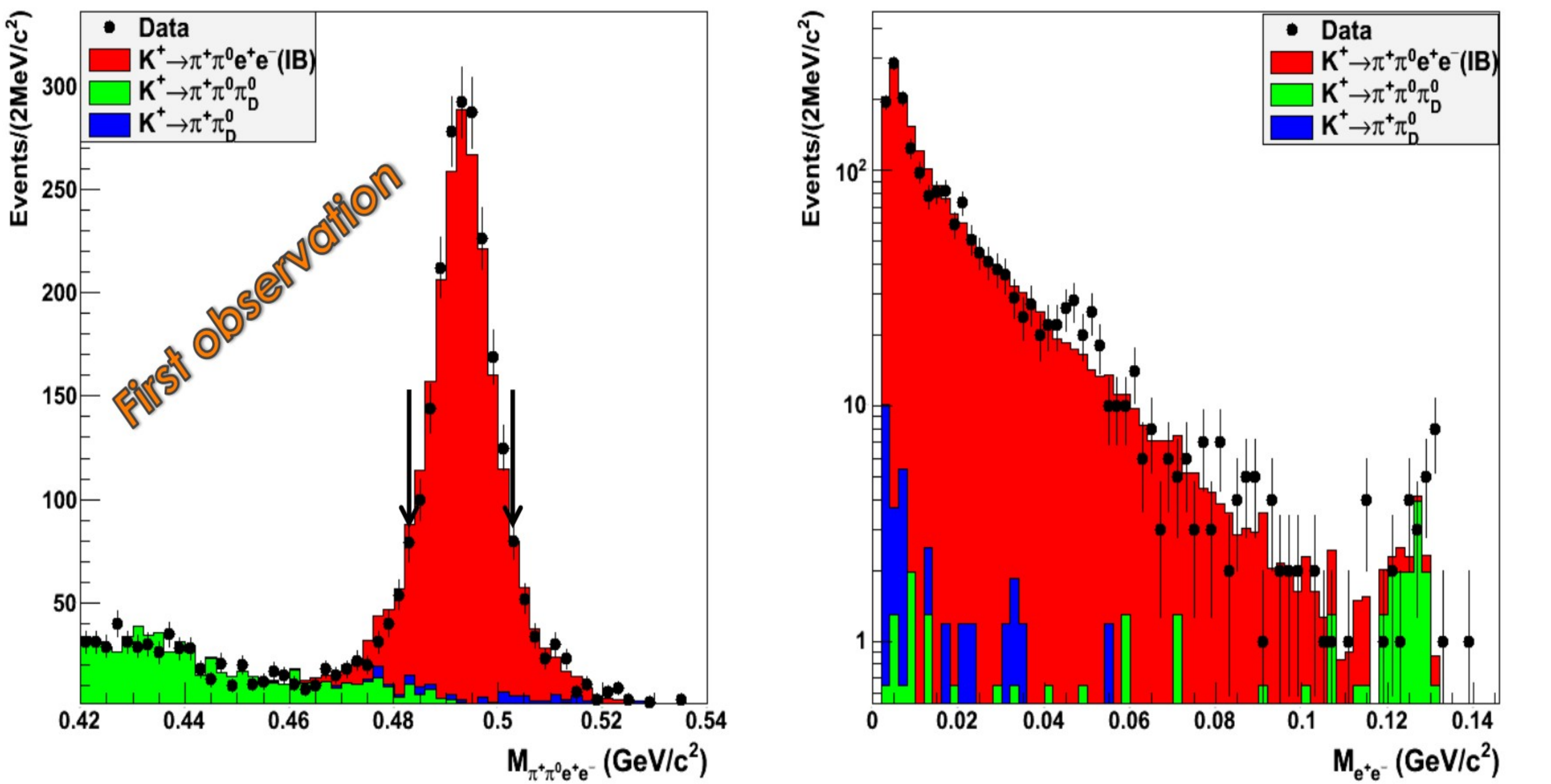
Background Source

- $K^{\pm} \longrightarrow \pi^{\pm}\pi^{0}_{D}(\gamma) \longrightarrow \pi^{\pm}e^{+}e^{-}\gamma$
  with an extra or radiated γ

- $K^{\pm} \longrightarrow \pi^{\pm}\pi^{0}\pi^{0}_{D}(\gamma) \longrightarrow \pi^{\pm}\pi^{0}e^{+}e^{-}\gamma$
  with a lost or merged γ



Background Suppression



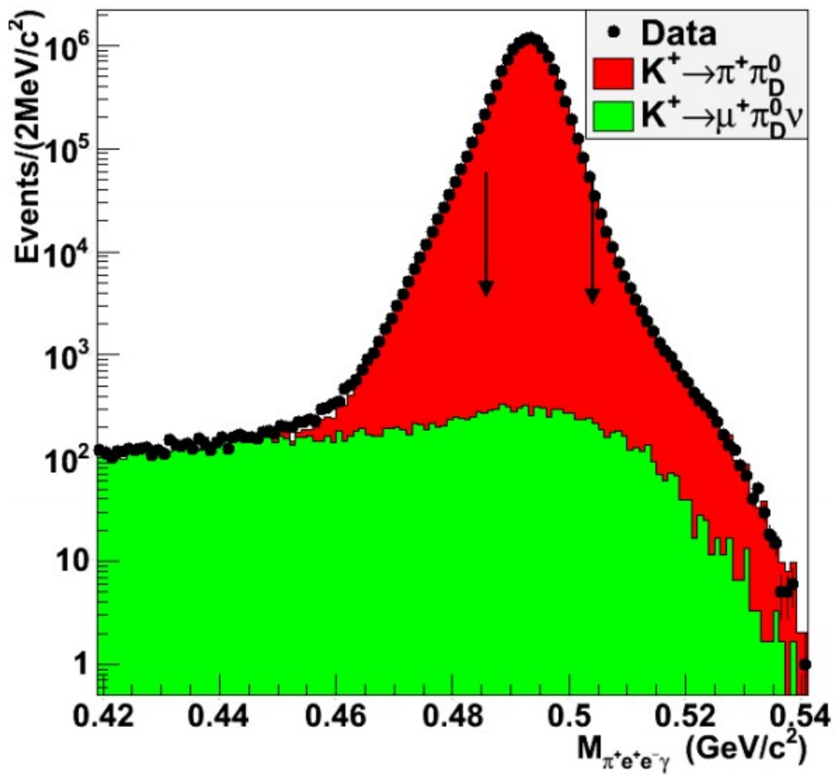
- total number of $\pi^\pm \pi^0 e^+ e^-$ candidates is 1916
- cutting on $|m_{ee\gamma} - m_{\pi 0}| > 5$ MeV to suppress $K_{2\pi D}$
- cutting on $m_{\pi\pi} > 120$ MeV to suppress $K_{3\pi D}$

- BG candidates from $K_{2\pi D} = 26 \pm 5.1$
- BG candidates from $K_{3\pi D} = 30 \pm 5.5$
- Number of genuine $\pi^\pm \pi^0 e^+ e$ events is 1860

Normalization channel

The number of $K^{\pm}$ decays is measured using the $K^{\pm} \longrightarrow \pi^{\pm} \pi^{0}_{D} (\gamma)$ reference channel (2003 data only)

Quantity	value	Value %
N_{tot} events	6714917±2591	0.04%
Statistical error		**0.04%**
Acceptance	(3.555±0.002)%	0.002%
Trigger efficiency	(97.64± 0.04)%	0.04%
BG in PPD sample	3365±58	$8 \cdot 10^{-4}$%
Syst rad correction	0.78%	0.78%
Systematics		**0.78%**
$BR(\pi^{+}\pi^{0}_{D}(\gamma))$	$(2.425 \pm 0.073) \times 10^{-3}$	3.01%
External error		**3.1%**



$$N_{kdecays} = (7.97 \pm 0.03_{Stat} \pm 0.06_{Sys} \pm 0.24_{Ext}) \times 10^{10} = (7.97 \pm 0.25) \times 10^{10}$$

Error completely dominated by external error

Table of errors of $\pi^{\pm}\ \pi^0\ e^+\ e^-$ BR

Systematic	Value
N of signal events (1916)	2.35% sqrt(1916)/1860
Total Statistical	**2.35%**
Radiative correction on IB	0.5%
Signal total acceptance	0.34% (Stat err acc)
	1% systematic (fraction mixture)
Back ground subtraction	0.4% (error on BG 7.4/1860)
	0.05% (systematic due to Rad Cor pp_D)
Trigger efficiency	0.65% (statistical error)
Total systematics	**1.40%**
Kaon flux measurement	3.10% (from BR($K^{\pm} \longrightarrow \pi^{\pm}\pi^0_D$ (γ)))
Total external	**3.10%**

- Systematic error dominated by model dependent acceptance
- External error from BR ($K^{\pm} \longrightarrow \pi^{\pm}\pi^0_D$ (γ)) dominates the total error

The $\pi^{\pm}\ \pi^0\ e^+\ e^-$ BR

- Model dependent BR measurement:
  - This sample of NA48/2 data is not sensitive to DE and INT
  - Model dependent BR computed using total acceptance in which the relative weight of the 3 components are obtained from (Eur. Phys. J. C (2012) 72:1872)

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

  - $BR(K^{\pm} \rightarrow \pi^{\pm}\pi^0 e^- e^+)_{Theory} = 4.0995 \times 10^{-6} \times (1 + 1/71 + 1/128) = 4.19 \times 10^{-6}$

D'Ambrosio et al (private communication)

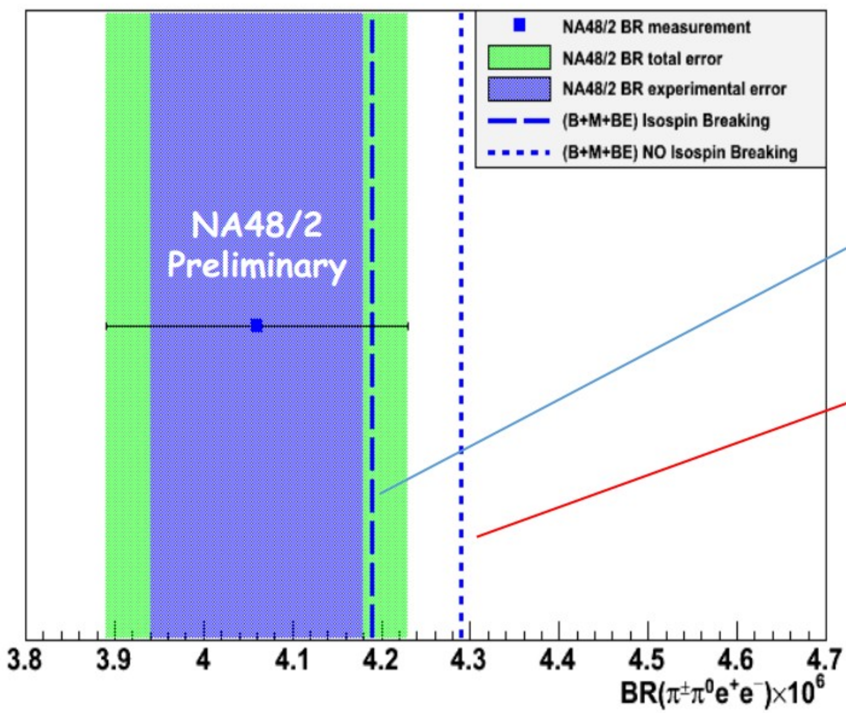
  - PRELIMINARY total branching ratio measurement:

$$BR(ppee) = \frac{N_{ppee} - N_{BG}}{K_{Flux} \cdot Acc_{ppee}^{TOT} \cdot \varepsilon_{ppee}} = (4.06 \pm 0.10_{stat} \pm 0.06_{sys} \pm 0.13_{ext}) \cdot 10^{-6}$$

Comparison with theory

Results are in good agreement within <1σ even with missing radiative corrections

$$BR(ppee)^{Theory}_{Total} = 4.19 \cdot 10^{-6} \qquad BR(ppee)^{NA48/2}_{Total} = (4.06 \pm 0.17_{Tot}) \cdot 10^{-6}$$



L. Cappiello, O. Cata, G. D'Ambrosio, Dao Neng-Gao, Eur. Phys. J. C 72:1872 (2012) :

Isospin breaking (private communication)

$BR(K^{\pm} \to \pi^{\pm}\pi^{0}e^{-}e^{+})^{Theory} = 4.19 \cdot 10^{-6}$

No isospin breaking (published)

$BR(K^{\pm} \to \pi^{\pm}\pi^{0}e^{-}e^{+})^{Theory} = 4.29 \cdot 10^{-6}$

No radiative corrections in the theoretical predictions!

Rad. corr. is taken into account in the experimental result via Photos implementation in the MC simulaton.

Conclusion

- First observation of $K^{\pm} \to \pi^{\pm}\pi^{0}e^{-}e^{+}$ by the NA48/2 Collaboration.
- Preliminary BR($K^{\pm} \to \pi^{\pm}\pi^{0}e^{-}e^{+}$) measurement based on 1860 candidates:

$$BR(ppee) = \frac{N_{ppee} - N_{BG}}{K_{Flux} \cdot Acc_{ppee}^{TOT} \cdot \varepsilon_{ppee}} = (4.06 \pm 0.10_{stat} \pm 0.06_{sys} \pm 0.13_{ext}) \cdot 10^{-6}$$

- Statistical precision can be reduced significantly including 2004 data
- Observation of DE and INT components requires radiative correction in theoretical model.
- Final result expected for the end of the year.