Experimental evidence for πK-atoms

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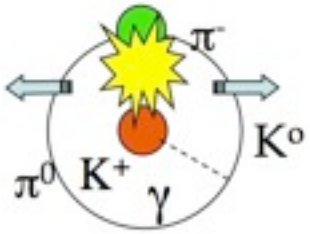
Abstract (nr. 710)

We present evidence for the first observation of electromagnetically bound pion-kaon pairs (piK- atoms) with the DIRAC-II experiment at the CERN-PS. The mean life of piK- atoms is related to the s-wave piK-scattering lengths, a measurement of which is relevant to low energy QCD, in particular chiral perturbation theories including the s-quarks. The atoms are produced by a 24 GeV/c proton beam in a thin Pt-target and the dissociated pions and kaons analyzed in a two-arm magnetic spectrometer. The observed enhancement at low relative momentum corresponds to the production of 173 +- 54 piK-atoms. From these first data we derive a lower limit for the mean life of 0.8 fs at the 90% confidence level.



Kπ-atoms

Coulomb force:

- E (1s) = 2.9 keV
- r_B (1s) = 250 fm

non relativistic

Strong force:

- ΔE ≈ 10 eV stronger binding
- $\pi^- K^+$ decays to $\pi^0 K^0$:
  prediction: τ ≈ 3.7 fs

} 73'000 revolutions

from non-relativistic effective field theory

($\pi^+ K^-$ decays to $\pi^0 \overline{K^0}$)

Kπ-atoms not seen before, therefore theoretical prediction for τ from scattering lengths:

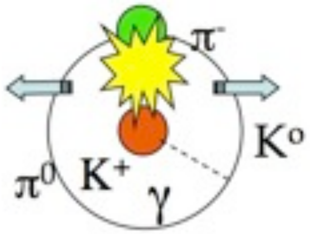
reduced mass

$$\Gamma_{1s} = \frac{1}{\tau} = 8p^*\mu^2\alpha^3\left[\frac{1}{3}(a_3 - a_1)\right]^2(1+\delta)$$

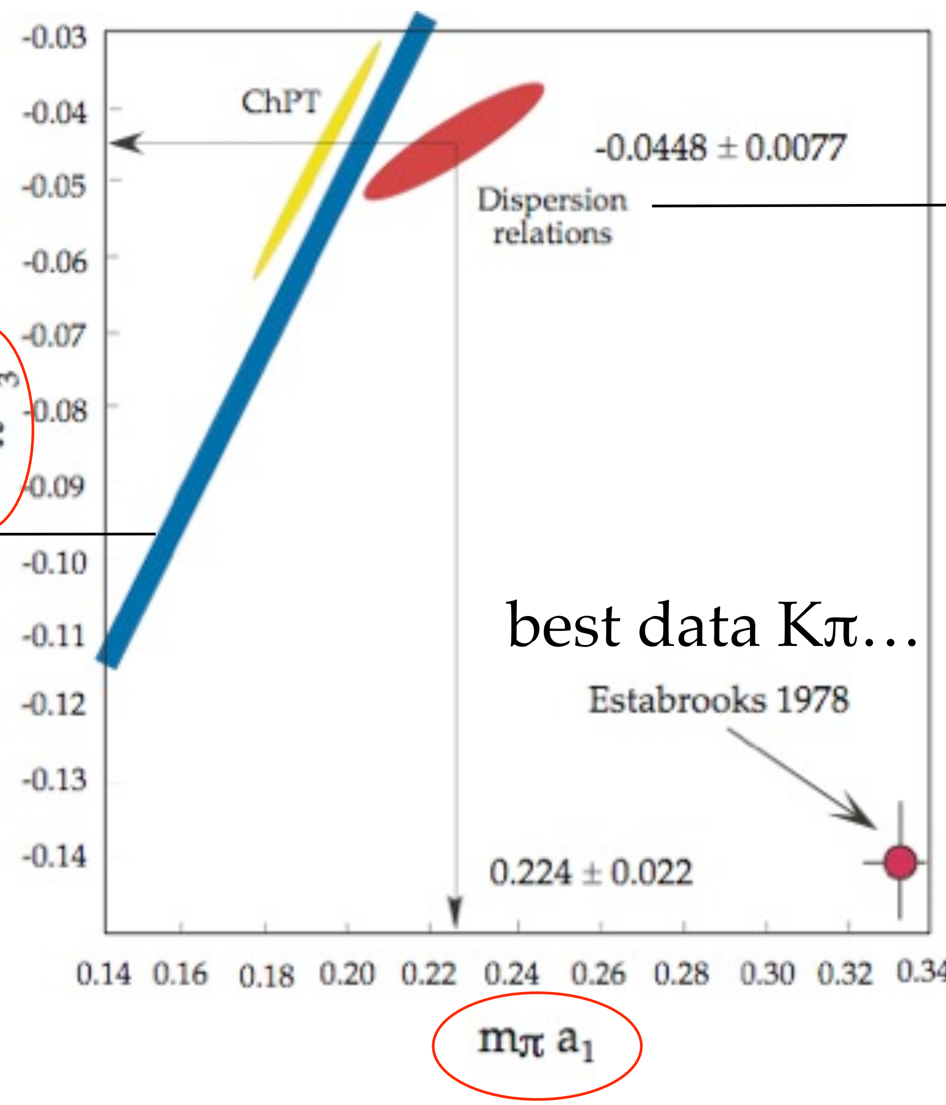
with $\delta = (4.0 \pm 2.2)\%$ from isospin breaking

c.m.s mom. (11.8 MeV/c)

a_1, a_3 : S-wave scattering lengths
Isospin (Kπ) = 1/2, 3/2



Scattering lengths a_1, a_3



planned
with Dirac II

Büttiker et al., Eur. Phys. J. C 33, 409–432 (2004)

all data on Kπ –> Kπ
(KN scattering)
ππ-> KK, unitarity, etc…

$$a_1 - a_3 = 0.269 \pm 0.015$$

$$\tau = 3.7 \pm 0.4 \quad \text{fs}$$

realistic: $1 < \tau < 5$ fs !!

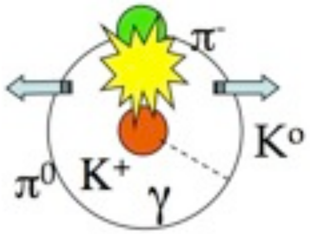
Motivation for a measurement of τ: better $|a_1 - a_3|$ data (10%):

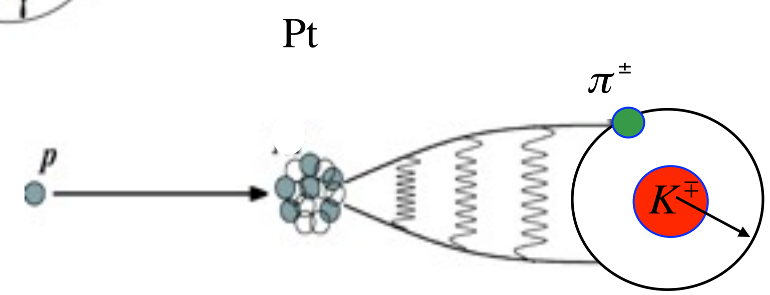
10 % means 20 % on τ

ChPT extended to s-quark

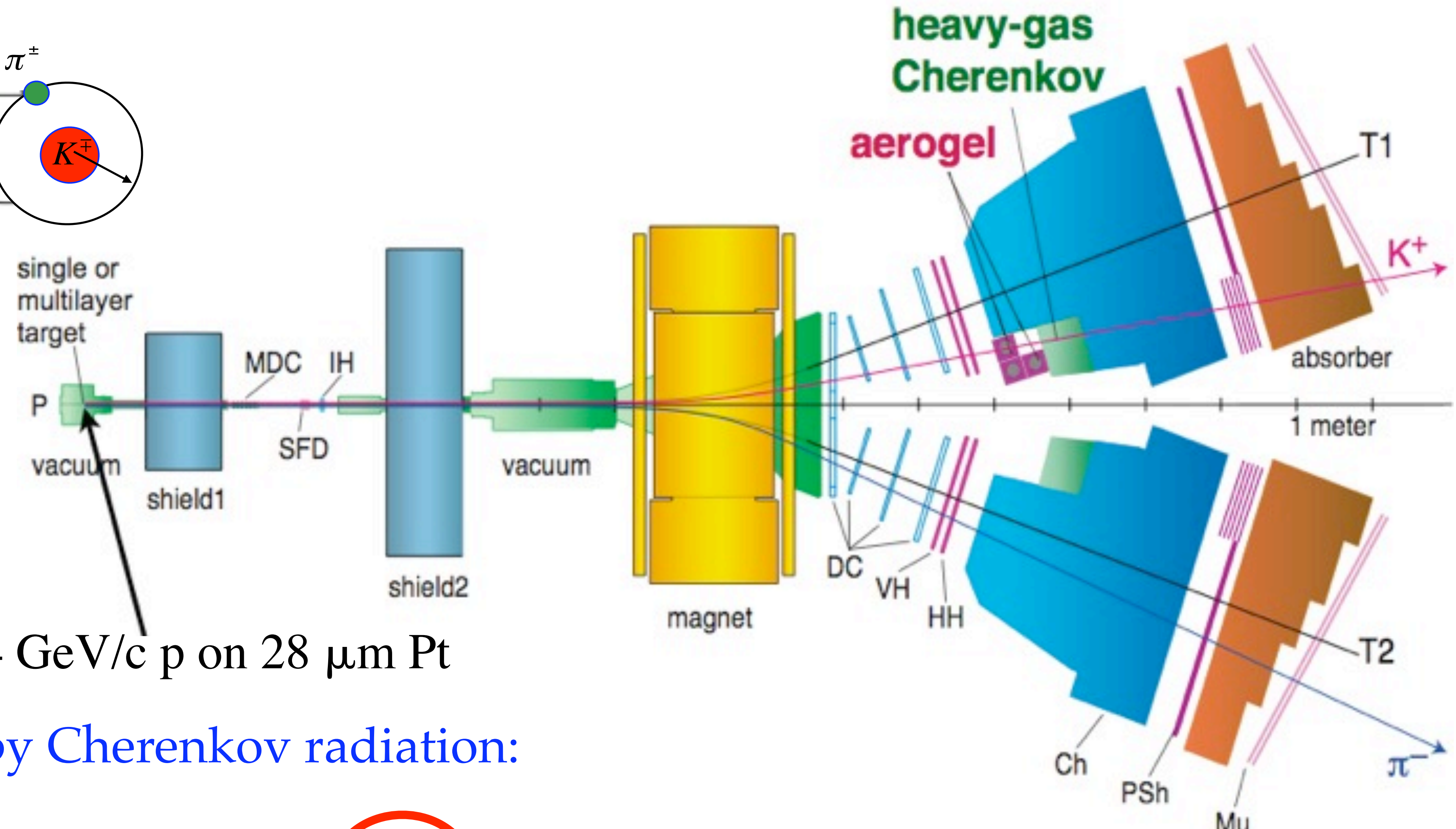
Pionium: $\pi^+\pi^-$ atoms: [u,d-quarks] very good agreement between ChPT and lifetime measurements from the DIRAC-experiment at CERN. B. Adeva et al., PLB 619 (2005) 50

DIRAC-II (PS212)



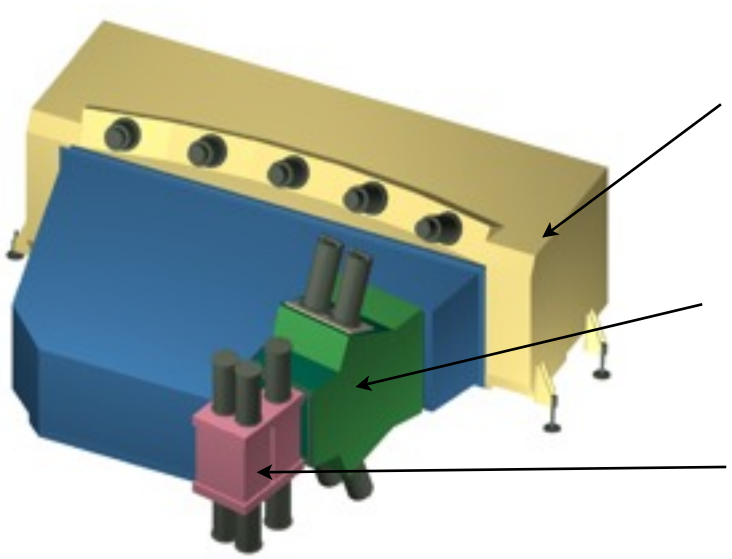


We measure the nr. of surviving atoms by ionizing them in a thin target

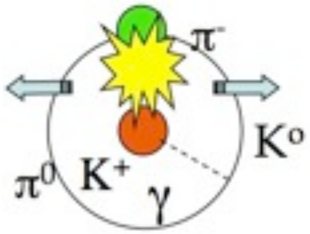


24 GeV/c p on 28 μm Pt

Particle identification by Cherenkov radiation:

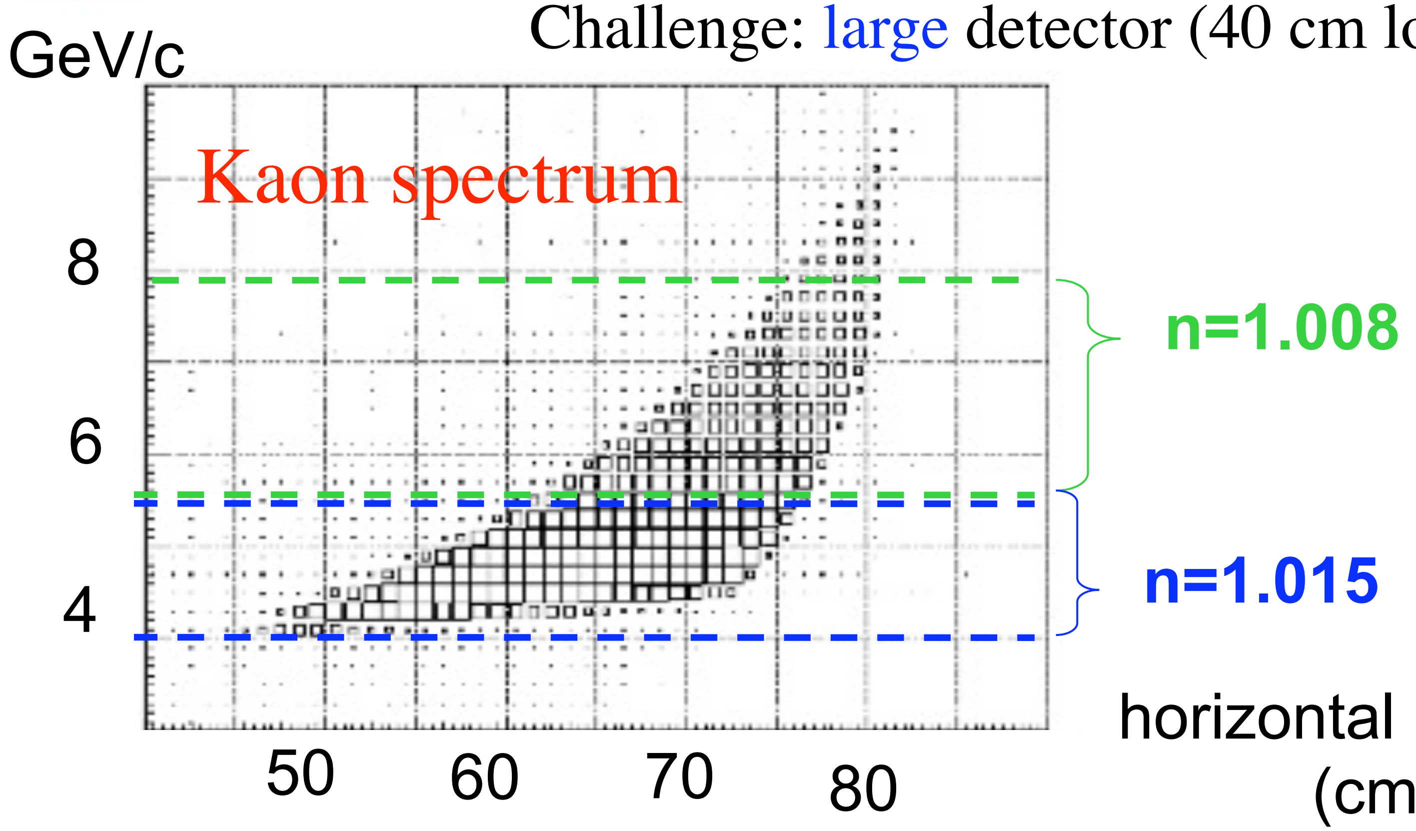


π K p	~~e~~	N_2 (1 bar, veto)
K p	~~π~~	Heavy gas (C_4F_{10}, veto)
K	~~p~~	Aerogel (Uni Zürich)



Design (novel development) of aerogel counters

Challenge: large detector (40 cm long) with low light yield (+UV absorption)

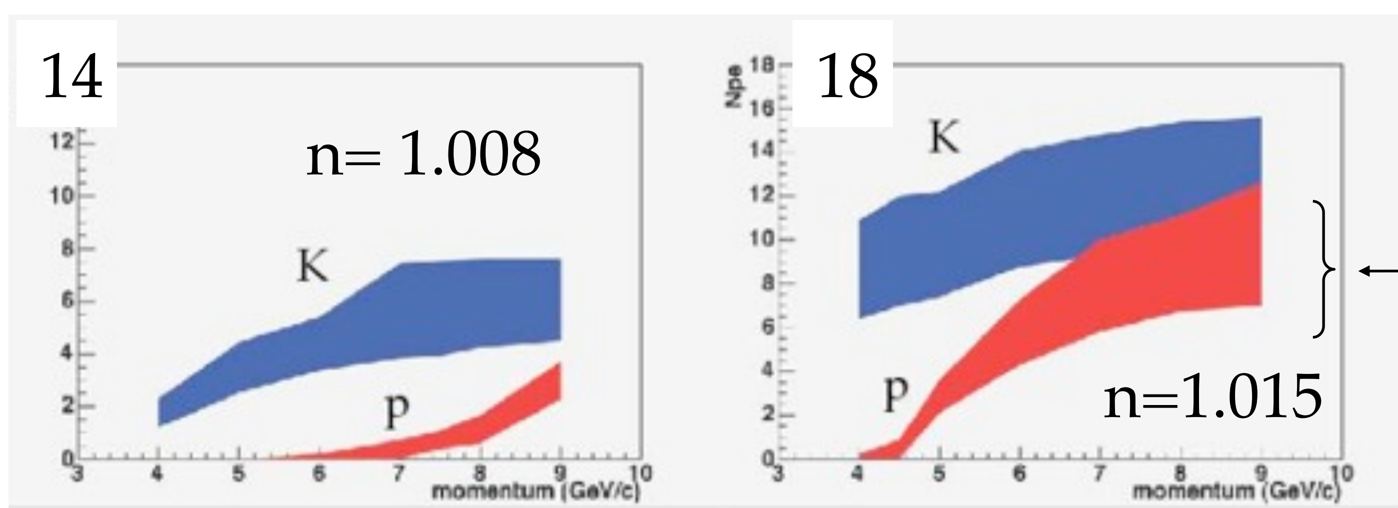


horizontal position (cm)

K⁺ signal wanted but not p signal...
N(p) >> N(K)

Photoelectrons for 10 cm thickness:

(Measurement with cosmic muons)

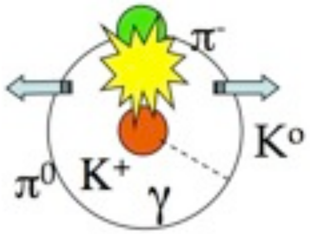


3 momentum 10 3 momentum 10 [GeV/c]

near
far
from PM

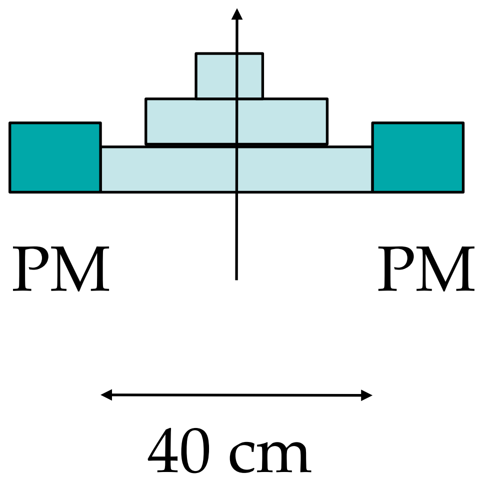
2 indices at high momenta (small angles)

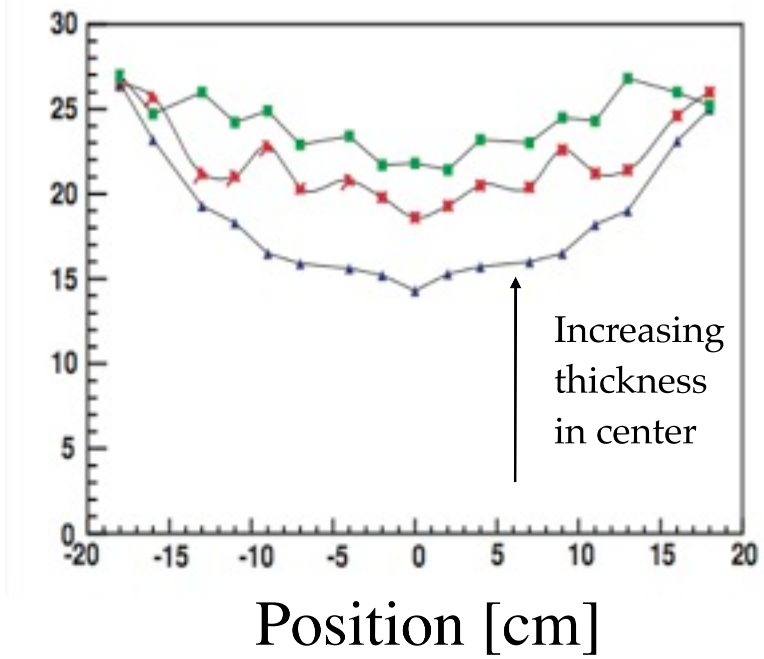
Friday, 17 July, 2009



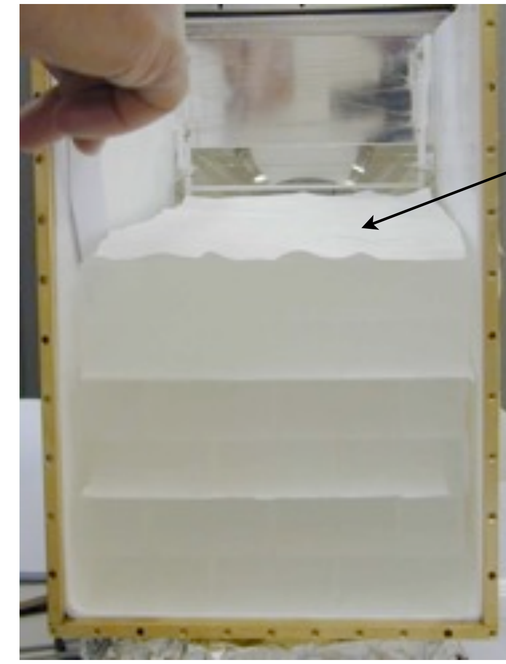
Trick 1:

Light yield





Trick 2:

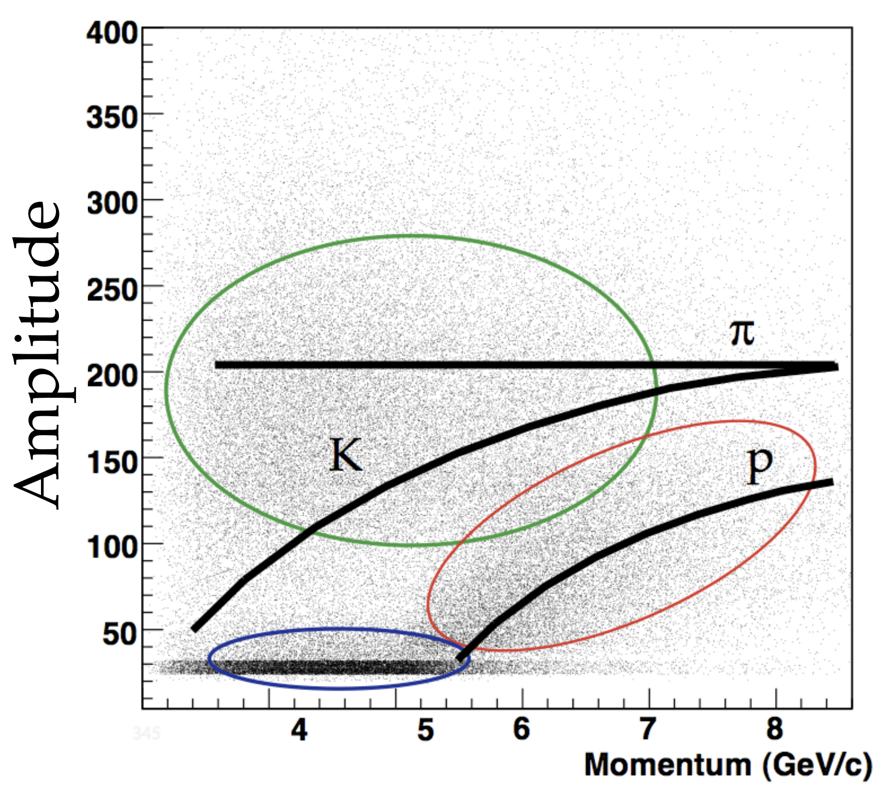


Wavelength shifter:

TPB dissolved in chloroform on Tetratex

n=1.008

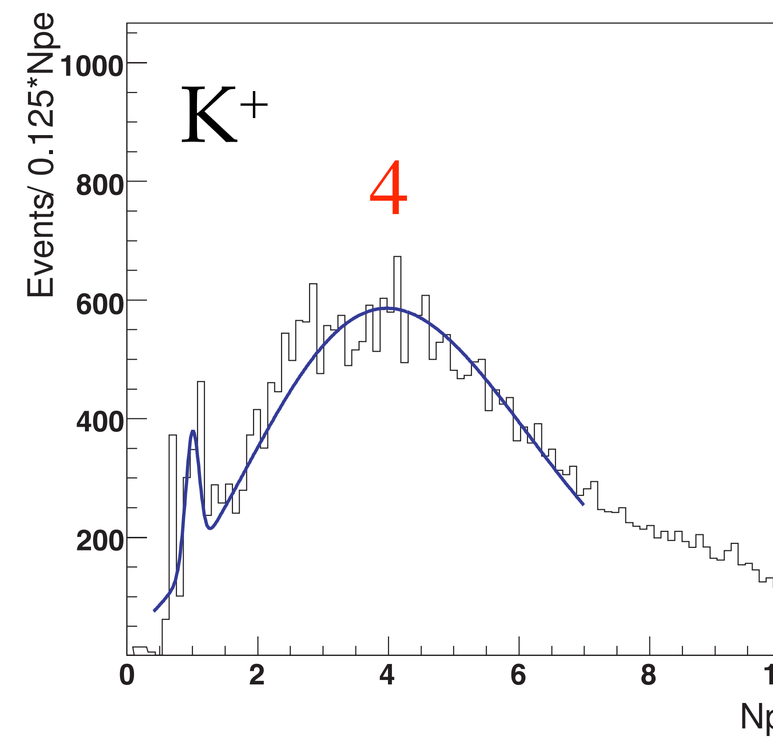
Beam data:



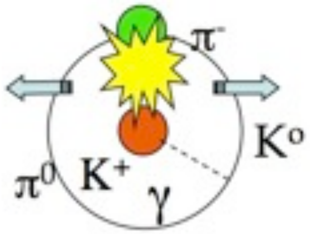
(from K^- spectrum with reversed polarity)

94% efficiency for K

93% rejection for p

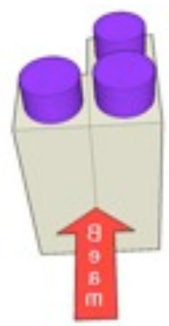


Number of photoelectrons in n=1.015



14 liters n=1.008 from Novosibirsk
(238 tiles, 3 €/cm³) (ρ = 0.039 g/cm³)

24 liters n=1.015 from Panasonic
(248 tiles, 1.6 $/cm³)

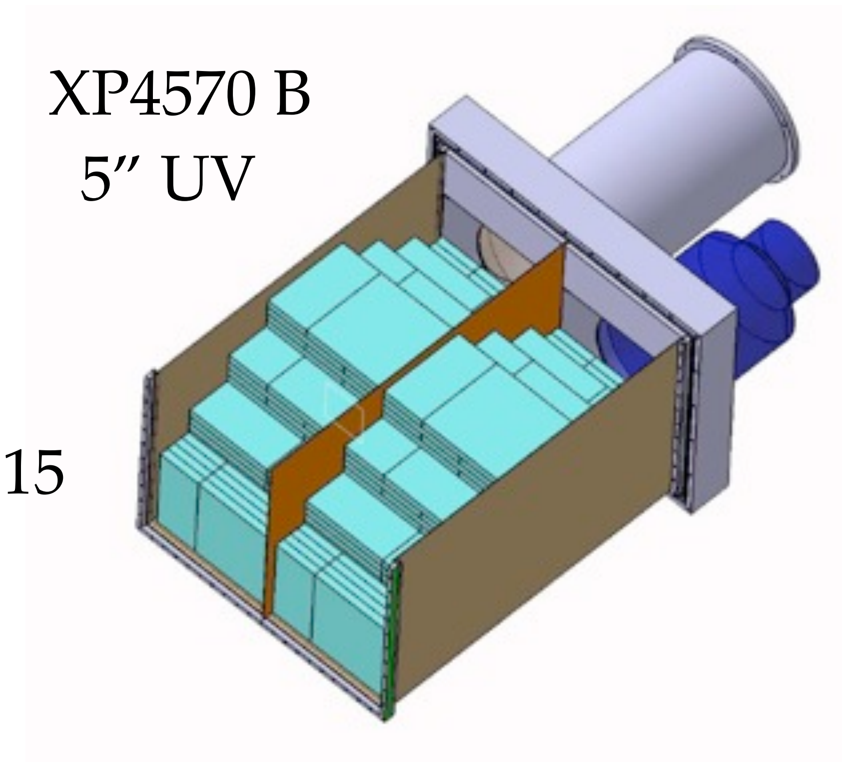


1.008

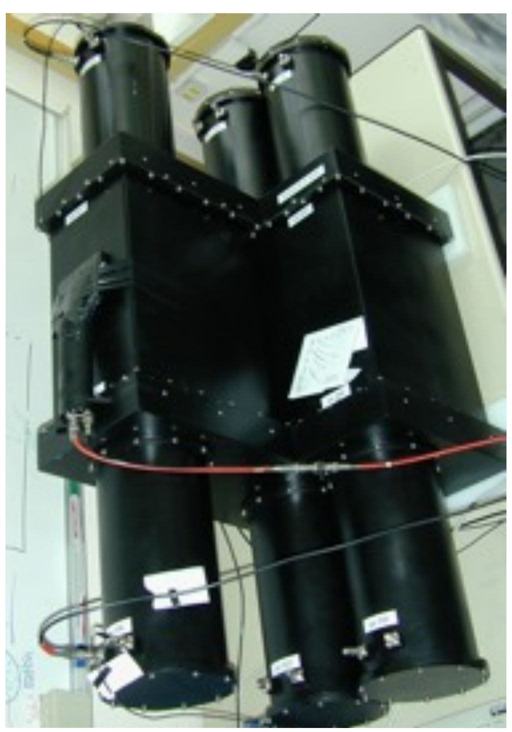
1.015

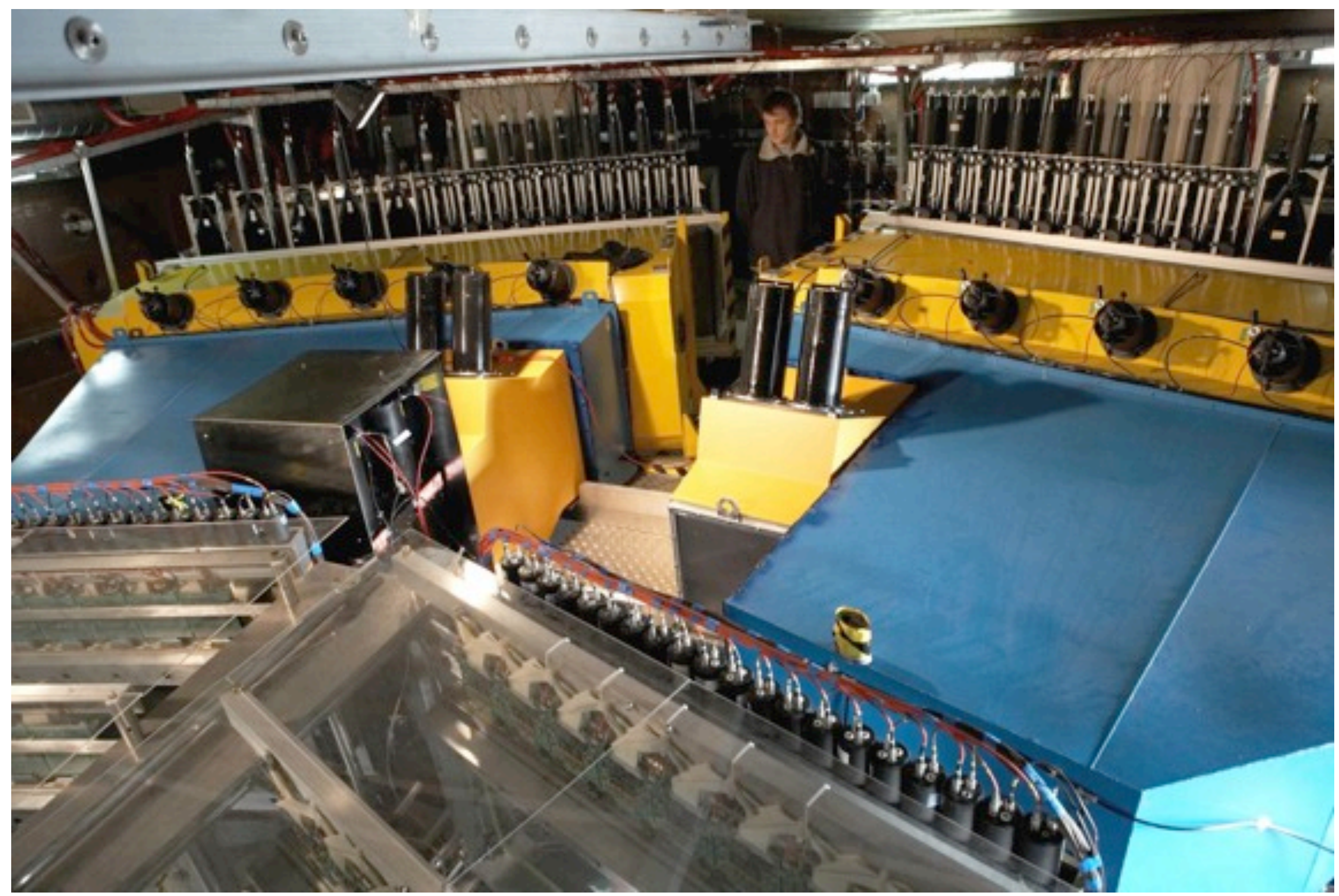
XP4570 B
5″ UV

n = 1.015



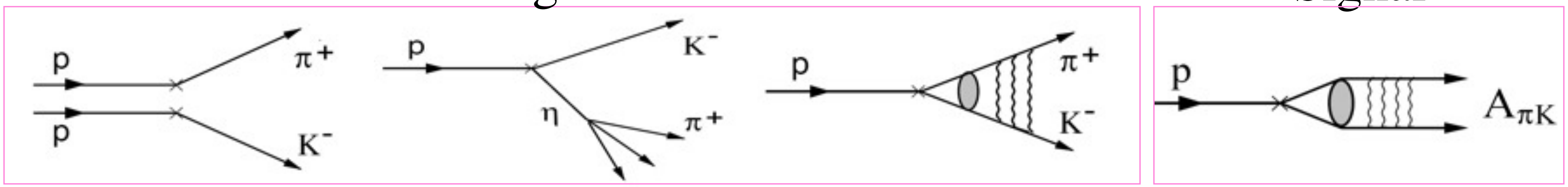
40 cm



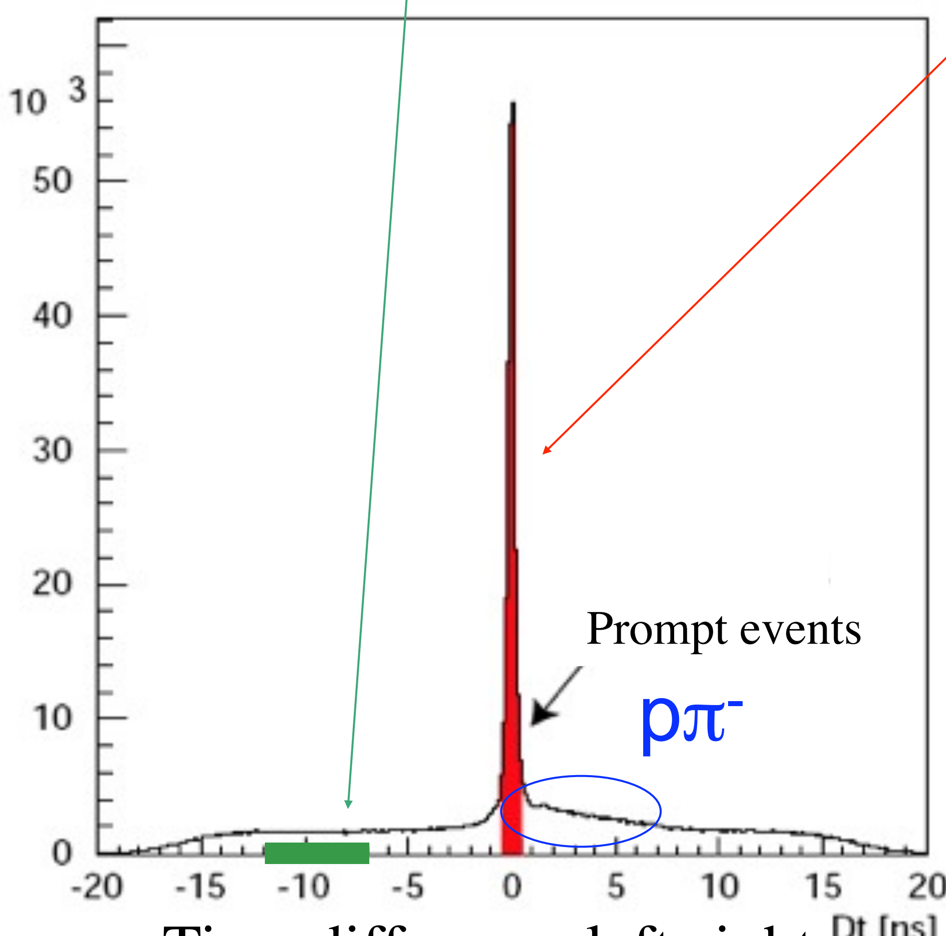


Very first data (2007)

Background | Signal



Accidental pairs | Non Coulomb pairs | Coulomb correlated pairs | πK atoms



Time difference left-right

ionization in target

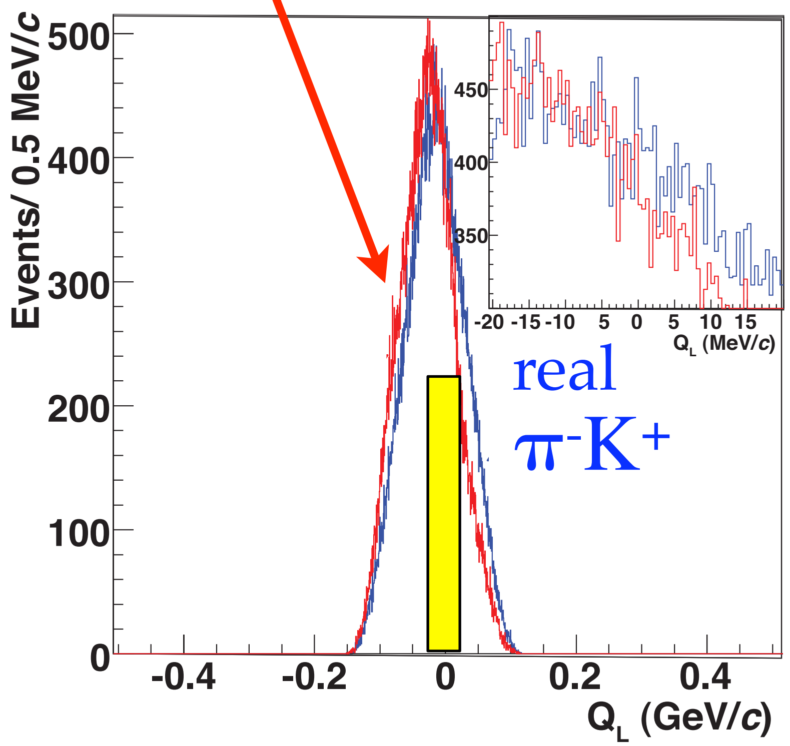
"atomic" pairs

$\pi^{\pm} K^{\mp}$

- Look for an excess of pairs with very low relative momentum Q_L
- A large number of atomic pairs means a long mean life of the atom

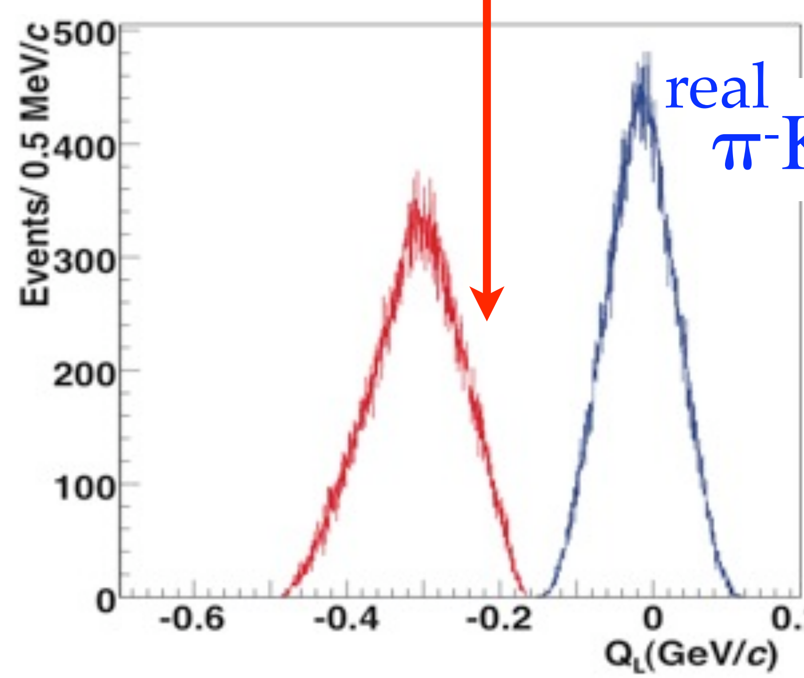
Background from $p\pi$ and $\pi\pi$

1) choose $p\pi^-$ events with p misidentified as K^+ (using accidentals)



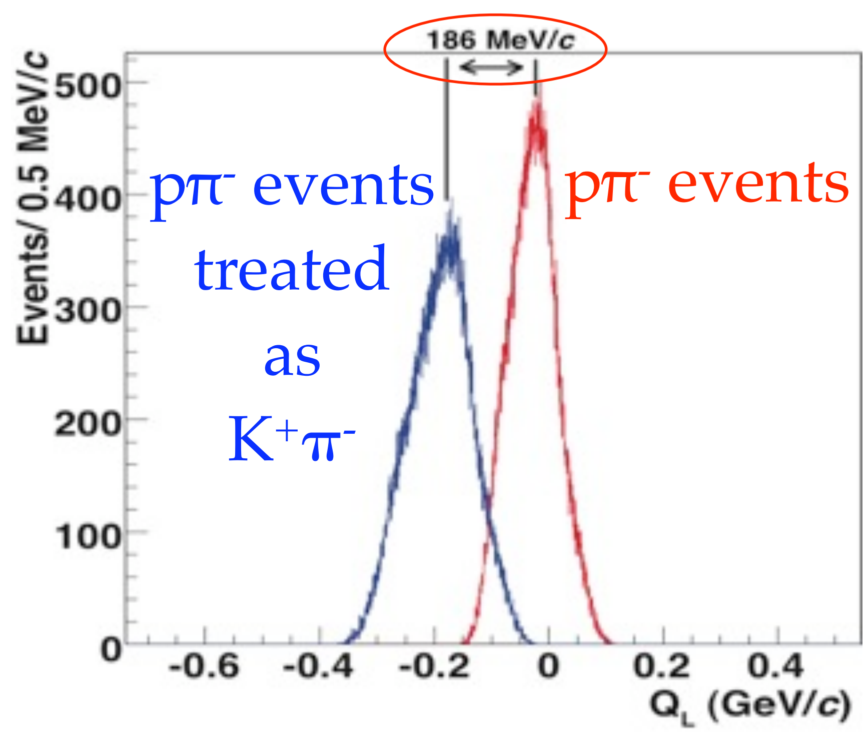
Q_L

2) choose $\pi^+\pi^-$ events with π^+ misidentified as K^+

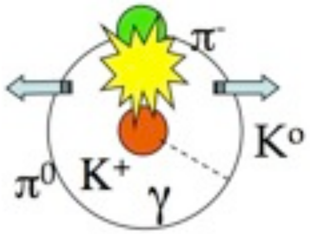


not in the relevant Q_L~0 region

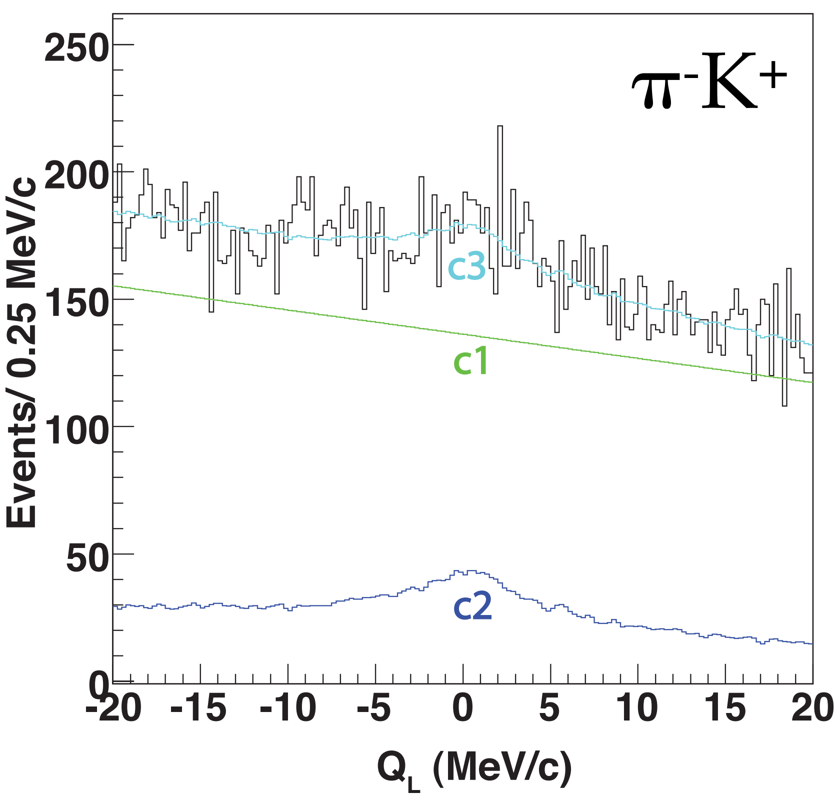
Accidental (time uncorrelated) pairs can be used to describe the smooth background in Q_L

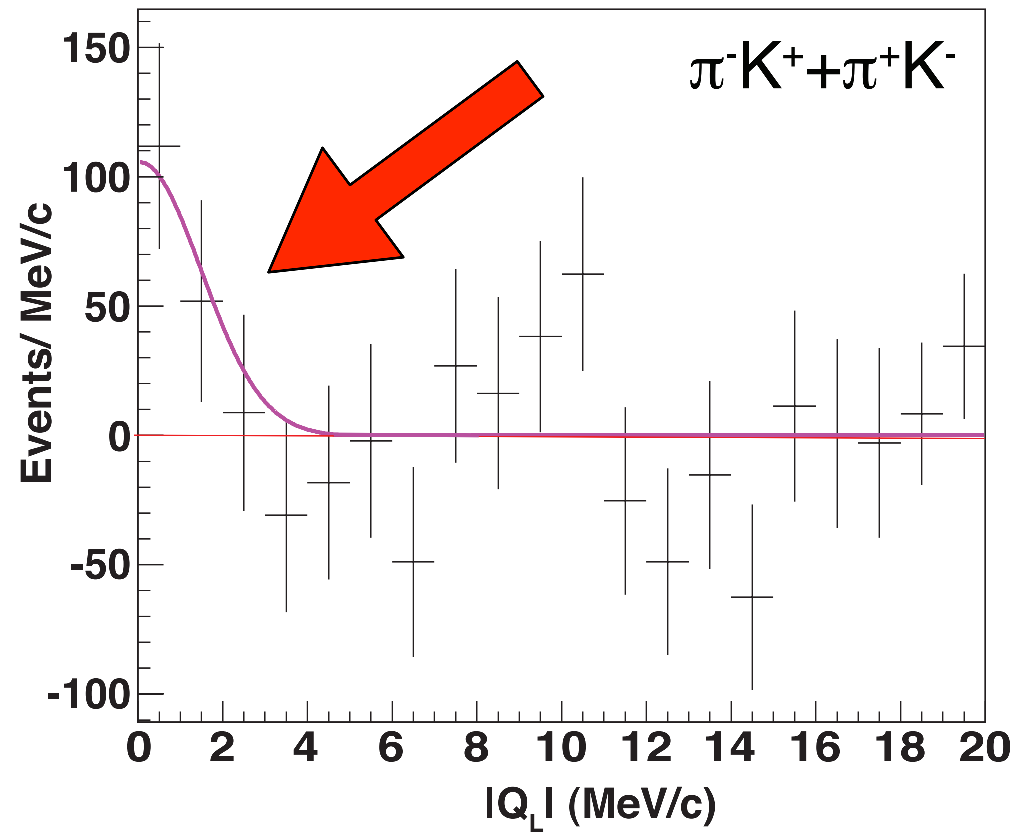


3) Enhancement due to Coulomb $p\pi^-$ pairs would be shifted out of Q_L~0 region



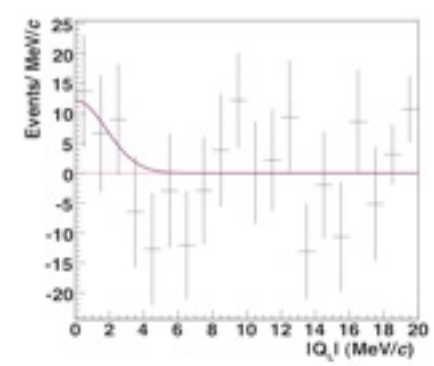
- The non-Coulomb pairs are well described from accidentals (c1)
- The Coulomb pairs must be simulated (c2)



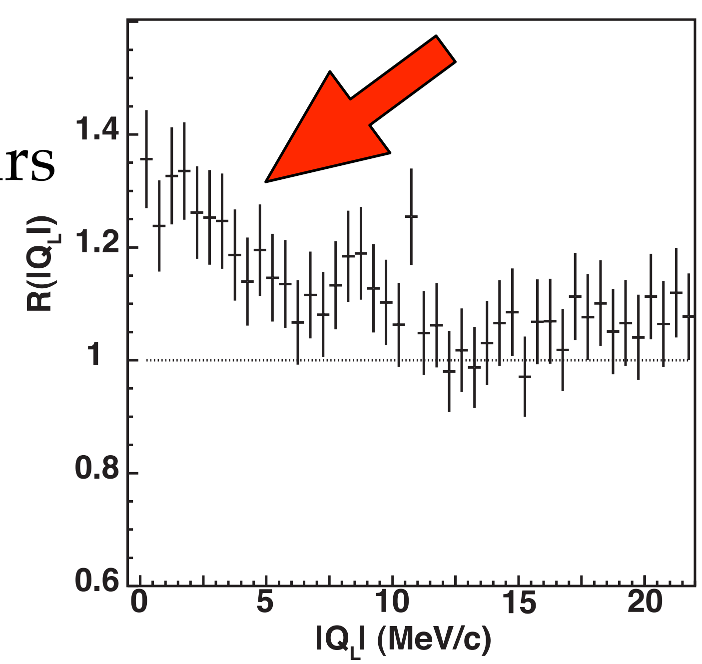


$C_3 - C_1 - C_2$

π⁺K⁻-atoms



Coulomb / non-Coulomb pairs

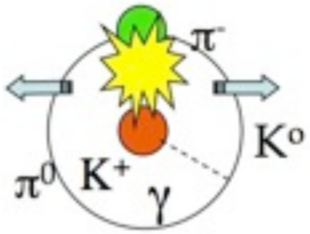


173 ± 54 pairs, 3.2σ

Significant?

Coulomb pairs observed → atoms must also exist. Prediction with $\tau = 3.7$ fs:

147 ± 36 pairs consistent!



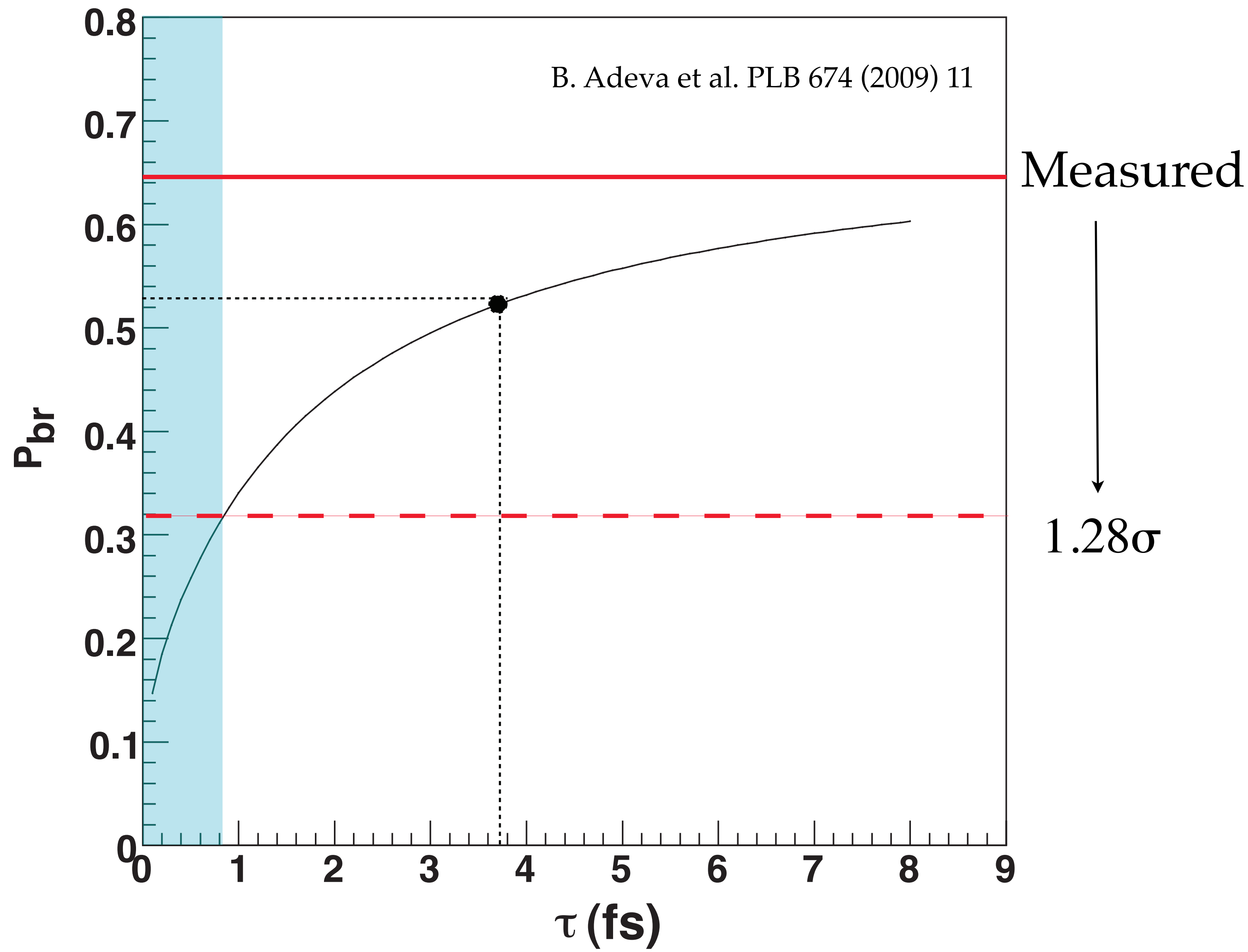
Breakup probability and mean life τ

P_{br} =
number of atomic pairs /
number of produced atoms
(calculated from the number of Coulomb pairs)

$P_{br} = 64 \pm 25\ \%$

$\tau > 0.8$ fs @ 90% C.L.

$|\Delta a| = |a_1 - a_3| < 0.58\ m_\pi^{-1}$



- πK-atoms have been observed
- more data with 98 μm Ni-target (lower P_{br}, but rising)
- goal: 20% error on τ = 10% error on |Δa|

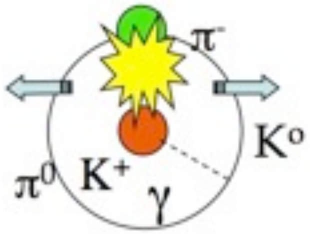
Conclusions

We have presented the first evidence
for the production of Kπ atoms

173 ± 54 Kπ atoms
Significance increased by the observation of Coulomb pairs

A lower limit on the mean life is established
with CL 90%: $\tau > 0.8$ fs

The goal of the DIRAC-II experiment
is to measure the mean life
with a precision of 20%



Participants

80 Physicists from 18 Institutes

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