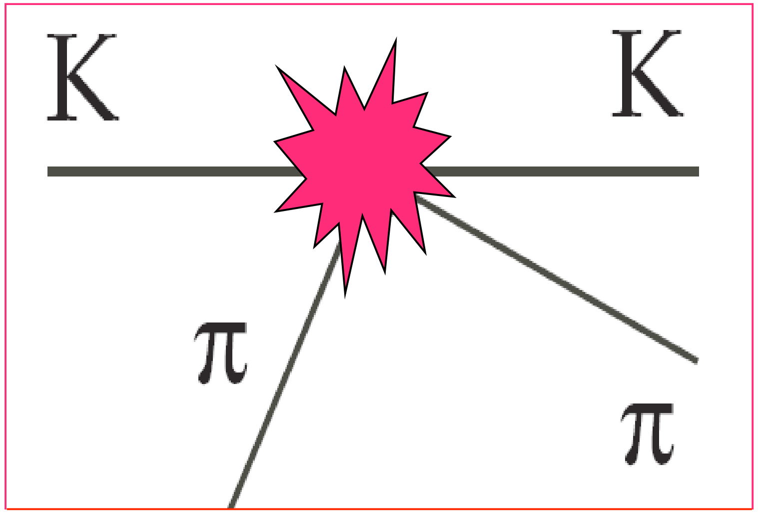
Search for πK-atoms with DIRAC II



Yves Allkofer
University Zurich
(On behalf of the DIRAC collaboration)

15th September 2008

DIRAC II collaboration

CERN
Geneva, Switzerland

Czech Technical University
Prague, Czech Republic

Institute of Physics ASCR
Prague, Czech Republic

Nuclear Physics Institute ASCR
Rez, Czech Republic

Ioannina University
Ioannina, Greece

INFN-Laboratori Nazionali di Frascati
Frascati, Italy

Trieste University and INFN-Trieste
Trieste, Italy

University of Messina
Messina, Italy

KEK
Tsukuba, Japan

Kyoto Sangyou University
Kyoto, Japan

Tokyo Metropolitan University
Tokyo, Japan

IFIN-HH
Bucharest, Romania

JINR
Dubna, Russia

SINP of Moscow State University
Moscow, Russia

IHEP
Protvino, Russia

Santiago de Compostela University
Santiago de Compostela, Spain

Basel University
Basel, Switzerland

Bern University
Bern, Switzerland

Zurich University *Zurich,* Switzerland
(Y. Allkofer, C. Amsler, S. Horikawa, C. Regenfus, J. Rochet)

Introduction to DIRAC

Chiral perturbation theory (ChPT) describes the hadronic interactions according to the SM below the chiral symmetry breaking scale.

ChPT gives precise prediction for the S-wave $\pi\pi/\pi K$ scattering length a_0, a_2, $a_{1/2}$ and $a_{3/2}$.

Many $\pi\pi/\pi K$ scattering analysis have been performed in the 70th by measuring the partial and total cross section ($d\sigma/d\Omega$, σ) in a model dependent way to obtain a_0, a_2, $a_{1/2}$ and $a_{3/2}$.

DIRAC's approach is unique :

DIRAC measures the scattering length in a model independent way through the lifetime of $\pi\pi/\pi K$-atoms which provides a **crosscheck of our understanding of low energy QCD**

DIRAC's main goals

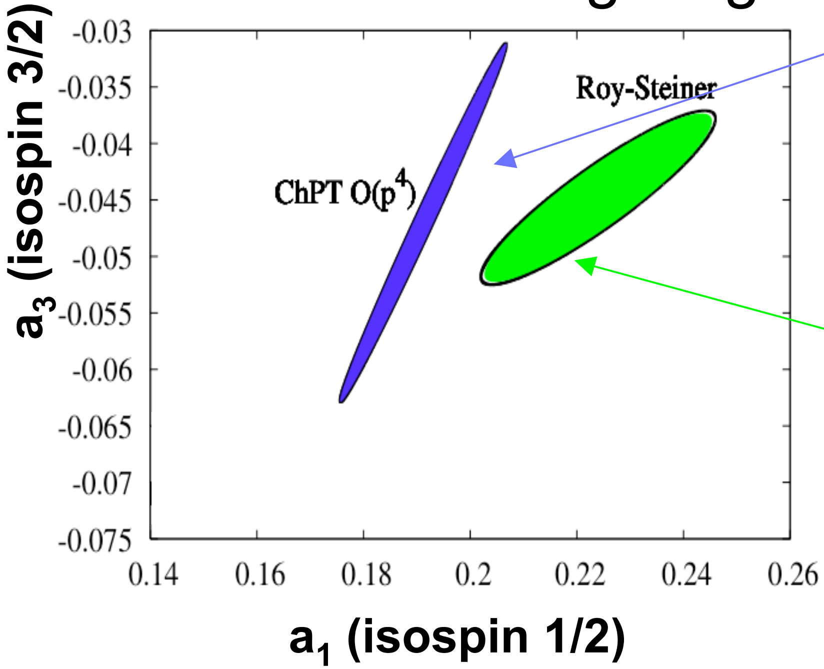
- Lifetime measurement of $\pi^+\pi^-$ atoms (pionium) in a model-independent way with precision better than 6%,which gives a precision for $|a_0 - a_2|$ better than 3%;

- Observation of $\pi^- K^+$ and $\pi^+ K^-$ atoms.

The measurement of the lifetime with precision of 20% and difference of the πK scattering lengths $|a_{1/2} - a_{3/2}|$ with accuracy of about 10%.

πK scattering lengths

S-wave scattering length



theory

ChPT

V.Bernard *et al*.,Nucl.Phys. B357 (1991) 2757

$$m_\pi(a_0^{1/2} - a_0^{3/2}) \simeq 0.238 \pm 0.002$$

Dispersions relations

P.Buettiker *et al*,Eur.Phys.J C33 (2004) 409

$$m_\pi(a_0^{1/2} - a_0^{3/2}) \simeq 0.269 \pm 0.015$$

experiment

Model independent results are absent

$$K^+ p \to K^+ \pi^- \Delta^{++}$$
$$K^+ p \to K^+ \pi^+ n$$

e.g. P.Estabrooks *et al*.,Nucl.Phys.B133(1978)490

$$m_\pi(a_0^{1/2}) = 0.335 \pm 0.006$$
$$m_\pi(a_0^{3/2}) = -0.14 \pm 0.07$$

DIRAC's approach

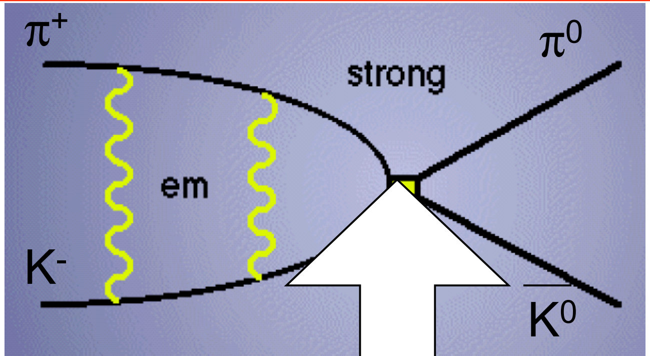
The dominant decay channel of πK-atoms

$$\pi^{\pm} K^{\mp} \rightarrow \pi^{0} \overset{(-)0}{K}$$

$$\Gamma(\pi^{0} \overset{(-)0}{K}) = \frac{1}{\tau} = \frac{8\alpha^{3}}{9}\left(\frac{M_{\pi} M_{K}}{M_{\pi} + M_{K}}\right)^{2} p \left|a_{0}^{1/2} - a_{0}^{3/2}\right|^{2} (1+\delta)$$

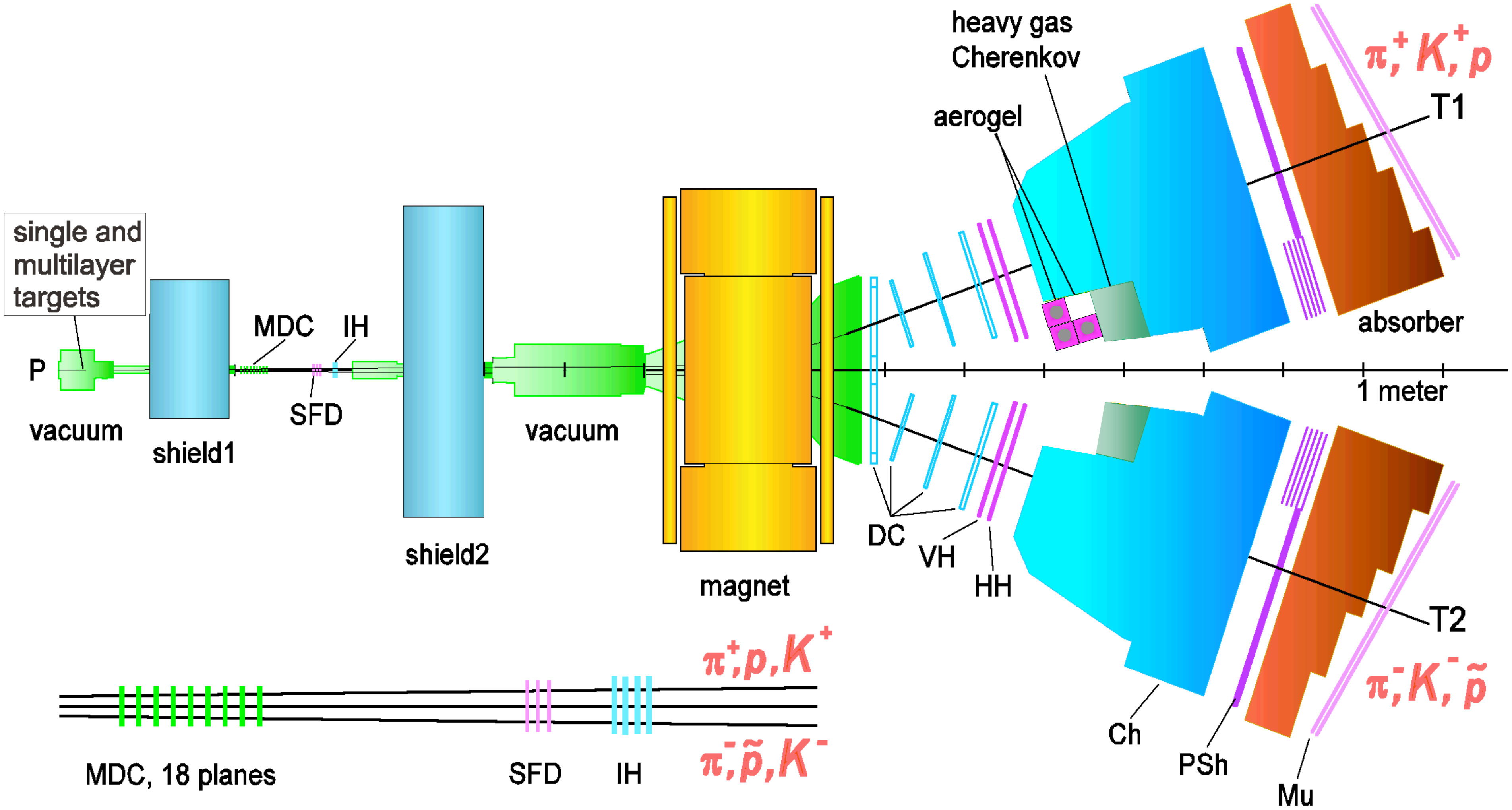
τ = 3.7 ± 0.4 fs

J. Schweizer, Phys. Lett. **B 587** (2004) 33



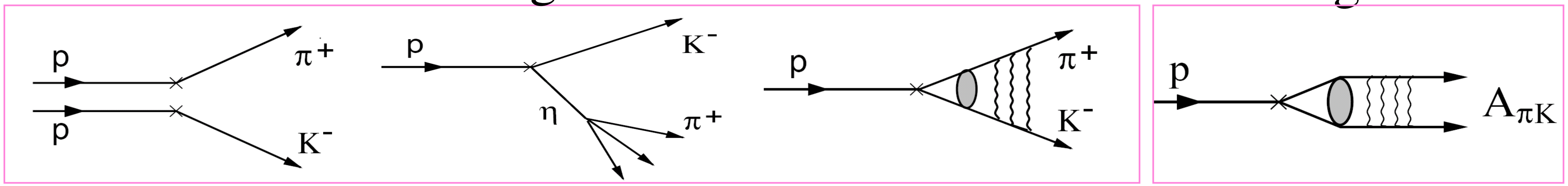
DIRAC II aims to measure the lifetime of πK-atoms in order to check SU(3) ChPT

The DIRAC II spectrometer



Different types of events

Background | Signal



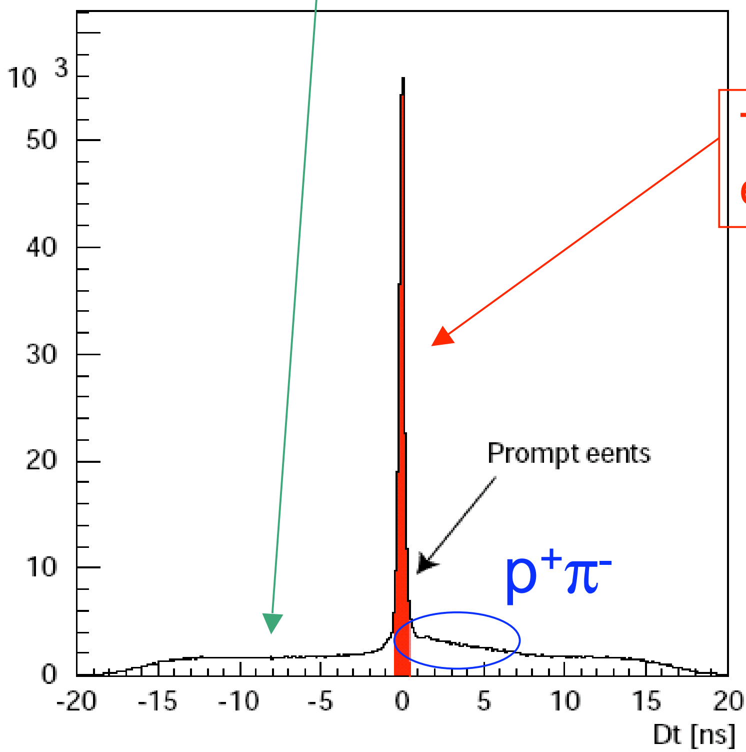
Accidental pairs N_{acc}

Non Coulomb pairs N_{nC}

Coulomb pairs, N_C

πK atoms N_A (produced)

Time correlated events



decay

π^0 K^0

ionization

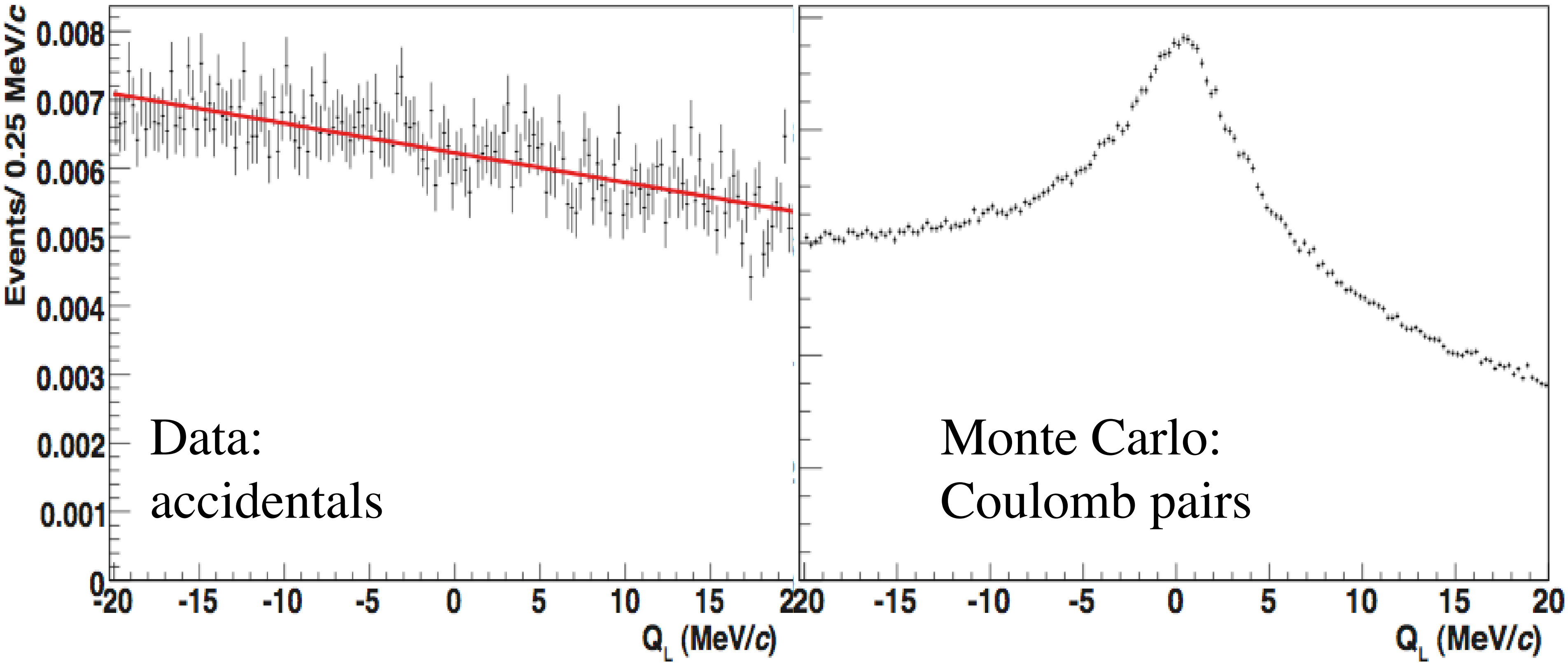
$\pi^{\pm}$ $K^{\mp}$

detected

Atomic pairs

DIRAC looks for an excess of pairs with a very low relative momentum Q

Shape of the correlated background : CC pairs



Shape of non Coulomb correlated background: non-Coulomb pairs and accidental pairs.

Shape of Coulomb correlated pairs.

Event selections

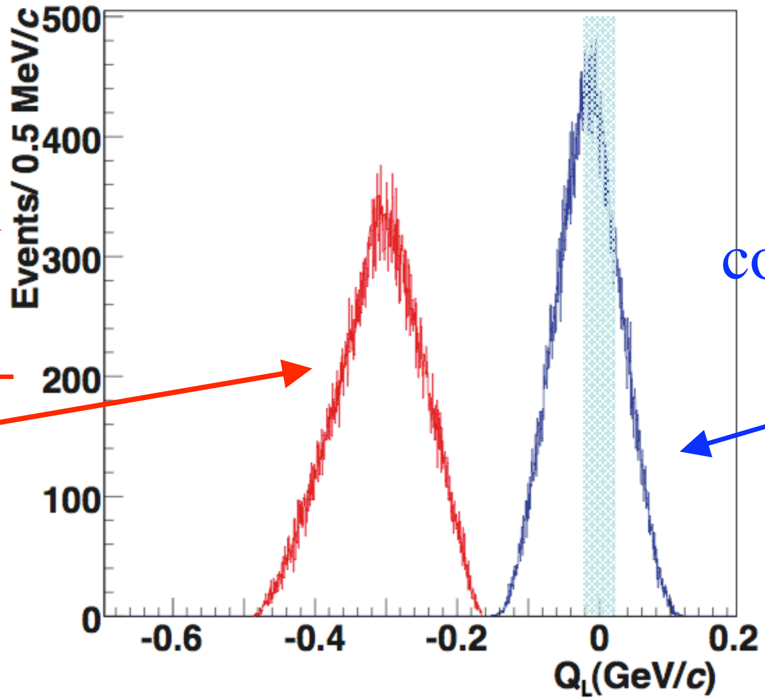
- electrons rejection (N_2 Cherenkov counter, preshower detector)
- muons rejection (muon counter, preshower detector)
- pions rejection (Heavy gas Cherenkov counter)
- proton rejections for $K^+\pi^-$ candidates (aerogel Cherenkov counter)
- $|Q_l| < 20$ MeV/c
- $|Q_T| < 8$ MeV/c
- 3.75 < P(kaon) < 8 GeV/c
- 1.2 < P(pion) < 2.1GeV/c
- 5.1 < P(pion + kaon) < 10 GeV/c
- time difference between the left and right arm $|\Delta t| < 0.5$ ns

π^- K^+ analysis

ππ–pairs contamination

Contamination from ππ-pairs occurs due to inefficiencies in the heavy gas Čerenkov detector.

Selected ππ-pairs (heavy gas counter in coincidence) reconstructed as $\pi^- K^+$-pairs.



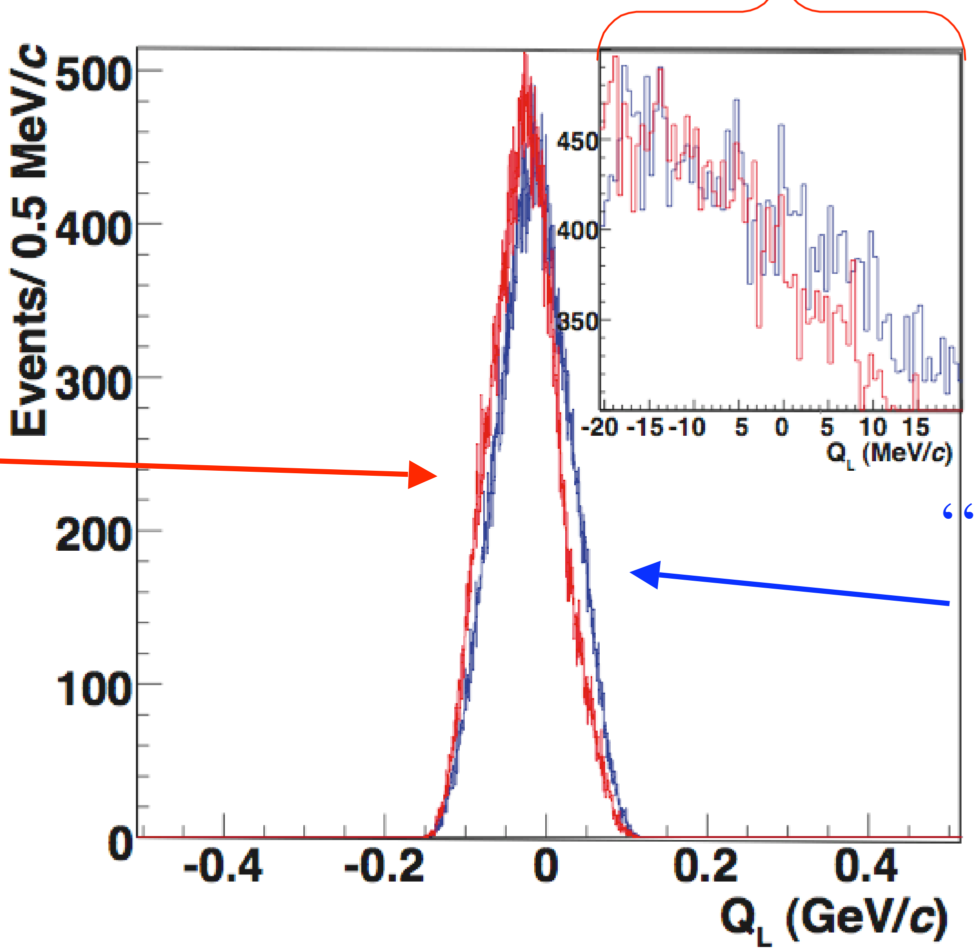
''real'' $\pi^- K^+$-pairs correctly reconstructed.

Variable of interest: Q_L longitudinal component of the relative momentum in the center of mass.

πp–pairs contamination

Region of interest for the πK analysis

Selected π^-p-pairs (aerogel counter in anticoincidence) reconstructed as π^-K^+-pairs.

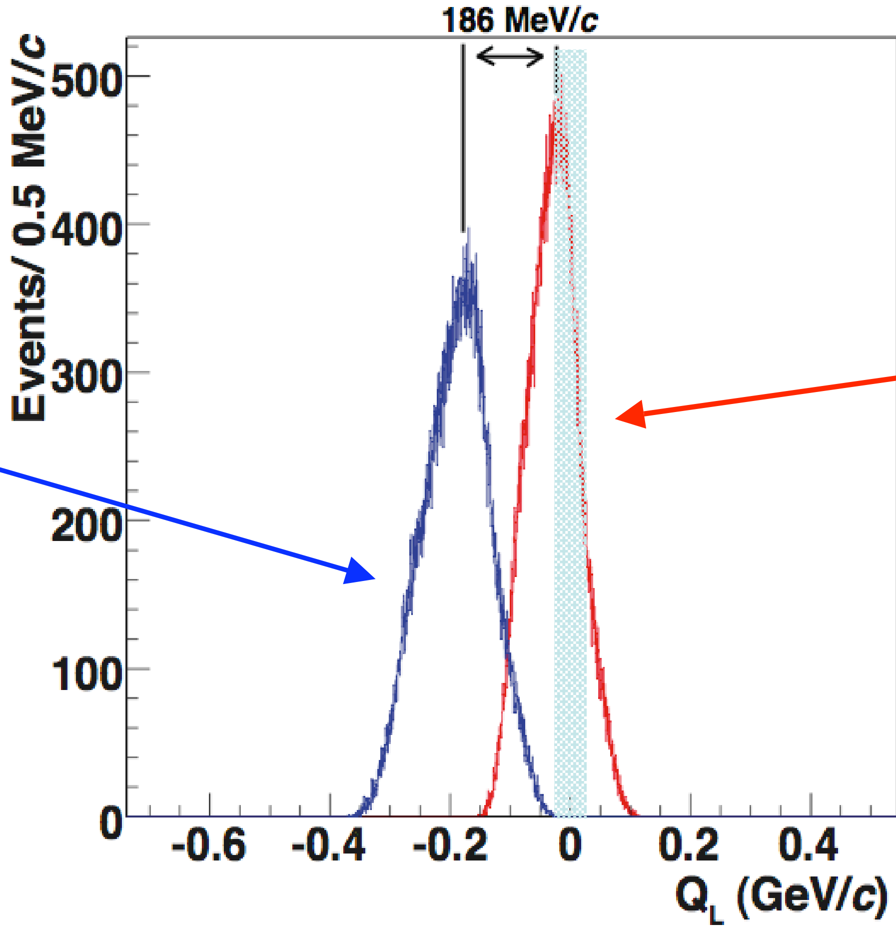


"real" π^-K^+-pairs correctly reconstructed.

Locally π^-K^+ and π^-p-pairs have the same shape.

πp Coulomb-pairs contamination

Selected $\pi^{-}p$-pairs (aerogel in anti coincidence) reconstructed as $\pi^{-}K^{+}$-pairs.



Selected $\pi^{-}p$-pairs (aerogel in anti coincidence) correctly reconstructed.

The Coulomb correlation enhancement for low $|Q_L|$ is shifted outside the region of interest, i.e. for $|Q_L| < 20$ MeV/c.

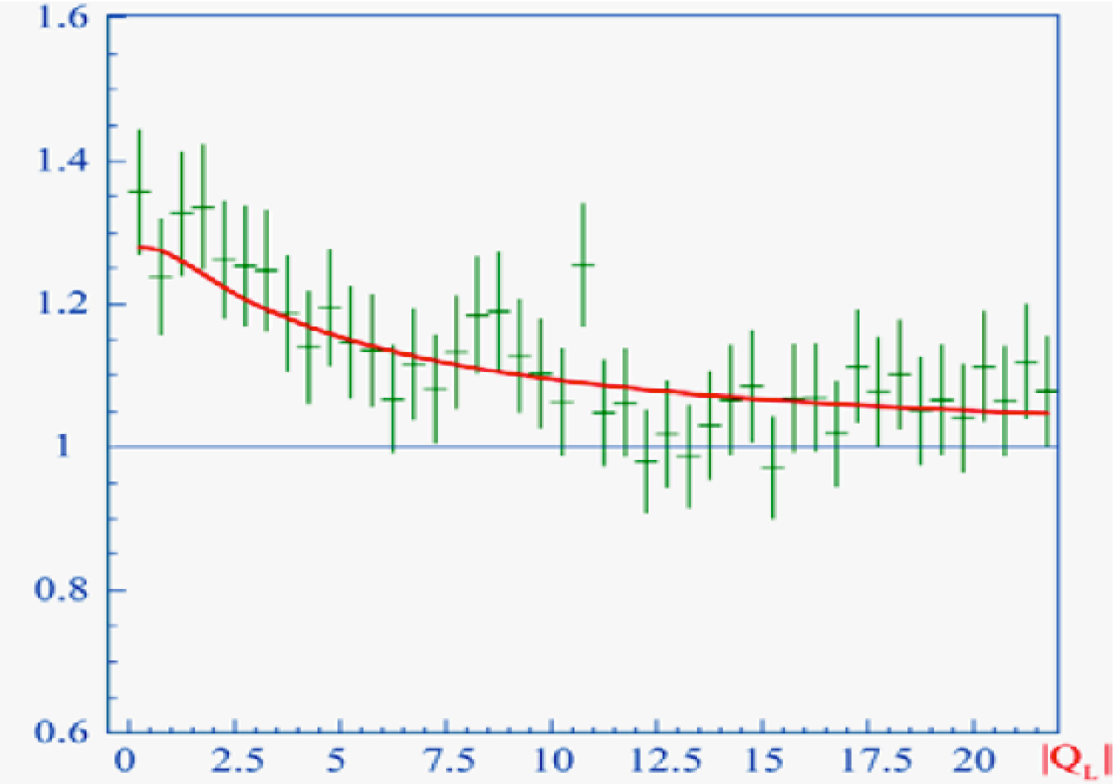
Summary Background description

- $\pi^- K^+$ Coulomb correlated background has an enhancement for low $|Q_L|$ on top a linear distribution.
- Coulomb uncorrelated background, i.e. non-Coulomb and accidentals pairs have a linear Q_L distribution with the same slope.
- no contaminations from $\pi\pi$-pairs.
- only Coulomb uncorrelated background from π^-p-pairs with locally the same slope in Q_L than for $\pi^- K^+$ pairs.

Background can be described using two distributions:

- Accidental pairs extracted from the data,
- Coulomb correlated pairs from MC simulation.

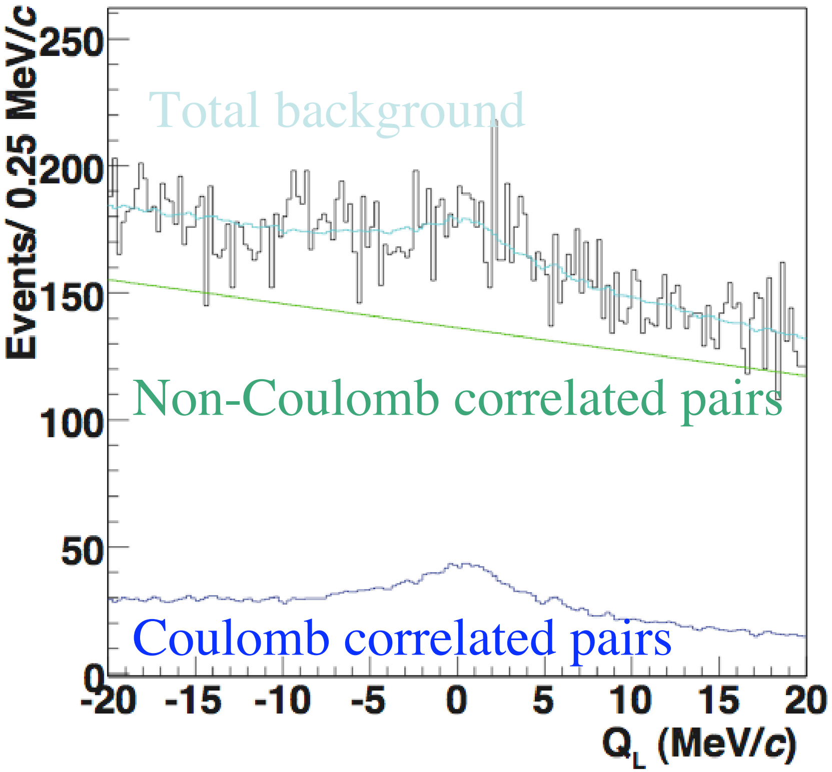
Coulomb correlated $\pi^- K^+$-pairs

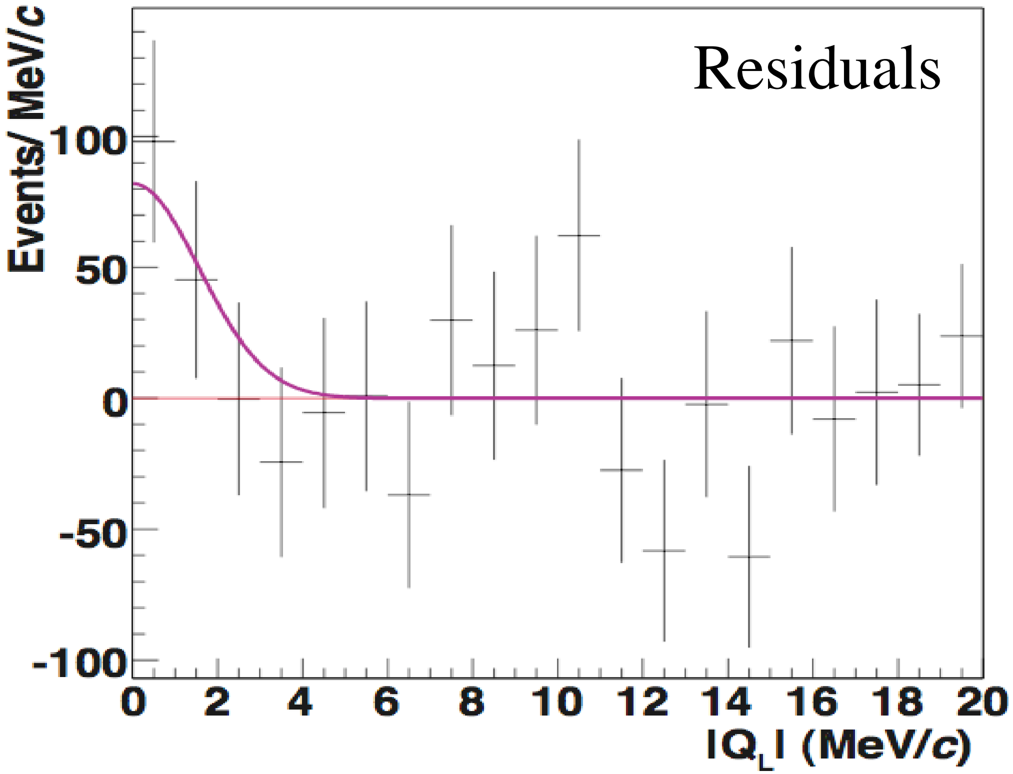


$|Q_L|$ shape for time correlated events (Coulomb pairs πK-pairs and $\pi^- K^+$, $\pi^- p$ non-Coulomb pairs) divided by accidental pairs.

Existence of Coulomb correlated $\pi^- K^+$-pairs is demonstrated without the use of **Monte Carlo**.

Fit function and results

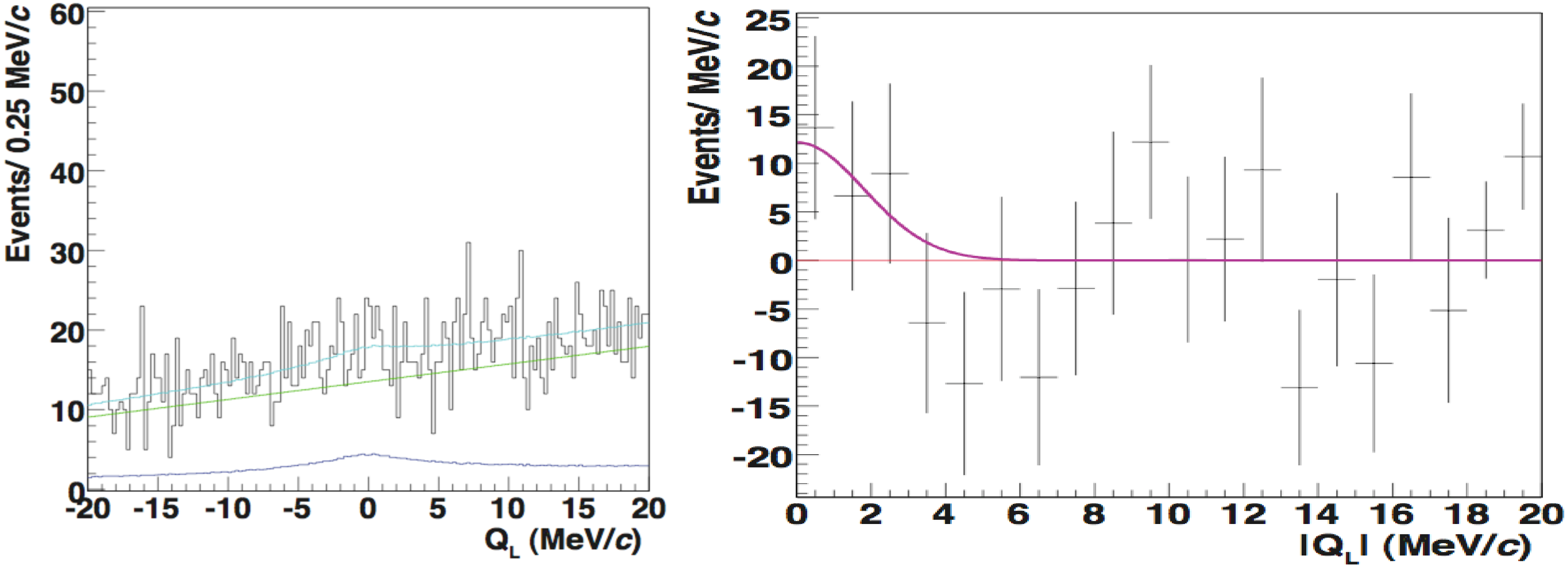




143±53 detected $\pi^{-}K^{+}$-atomic pairs

$K^-\pi^+$ analysis

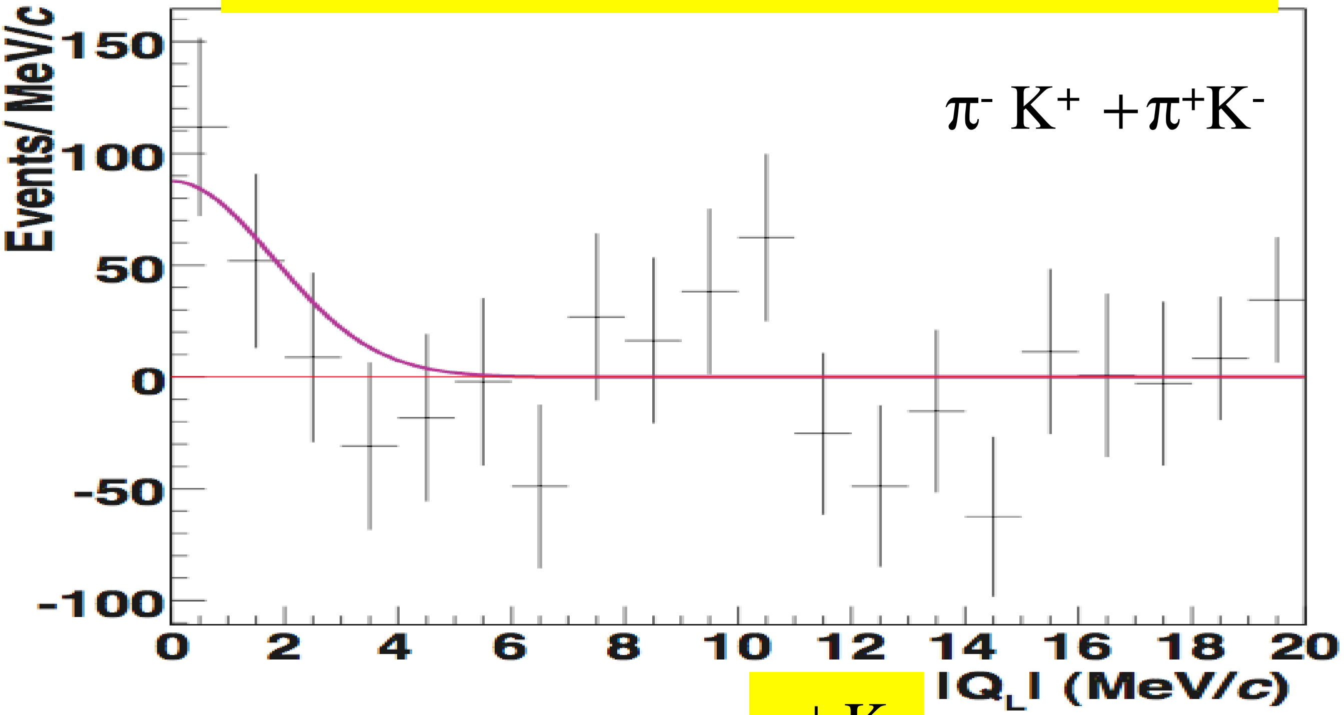
Similar to the $K^+\pi^-$ analysis one can extract $K^-\pi^+$-atoms.



29±15 detected π^+K^--atomic pairs.

$\pi^- K^+ + \pi^+ K^-$ atomic pairs

$\pi^- K^+ + \pi^+ K^-$ atomic pairs: 173 ±54



$\pi^- K^+$

Atomic pairs	Coulomb pairs (Q_L<3.25 MeV/c)
143±52	972 ±233

$\pi^+ K^-$

Atomic pairs	Coulomb pairs (Q_L<3.25 MeV/c)
29±15	165 ±108

Ionization Probability

To measure the lifetime of πK-atoms, one has to determine the ionization probability P_{br}.

The number of Coulomb pairs (N^C) and produced atoms (N^A) are proportional:

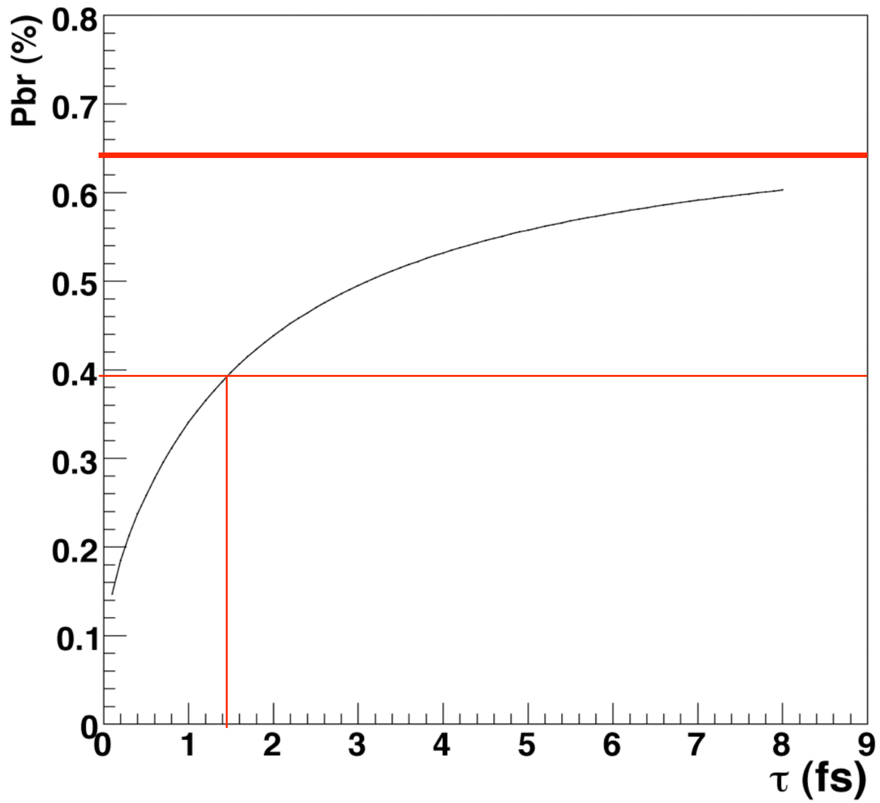
$$N^A = k^{th} \cdot N^C (Q < 3.25 MeV/c), \; k^{th} = 0.615$$

The ionization probability (P_{br}) is the number ionized atoms (n^A) divided by the number of produced atoms:

$$P_{br} = \frac{n^A}{N^A} = \frac{n^A}{k \cdot N^C (Q < 3.25 MeV/c)}$$

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

Lifetime measurement



An atom while traveling through the target can either:

- be (de-)exited (P_{ex}): (ex: 2S-->2P)
- be ionized (P_{br}): $\pi^{\pm}K^{\mp} \rightarrow \pi^{\pm} + K^{\mp}$
- decay (P_{decay}): $\pi^{\pm}K^{\mp} \rightarrow \pi^{0} + \overset{(-)}{K^{0}}$

$P_{br}=1-P_{decay}-P_{ex}$

$\tau \geq 1.5 \cdot 10^{-15}$ s with 84% confidence level.

Summary and Outlook

Thanks to efficient particle identification from pioneering run 2007:

- observation of Coulomb correlation in πK-pairs production in p-nucleus interactions.
- first evidence for production of πK-atoms.
- first experimental estimation of a lower limit of πK atoms lifetime.

Data taking in 2008 and 2009 with Ni-target and full setup should provide the 10% aimed accuracy.