LIFETIME MEASUREMENT OF $\pi^+ \pi^-$ AND $\pi^\pm K^\mp$ ATOMS TO TEST LOW-ENERGY QCD
DIRAC collaboration

75 Physicists from 19 Institutes

- CERN, Geneva, Switzerland
- Czech Technical University, Prague, Czech Republic
- Institute of Physics ASCR, Prague, Czech Republic
- Nuclear Physics Institute ASCR, Rez, Czech Republic
- 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

SPS and PS experiments Committee

L. Nemenov 22 April 2008
   1. Main tasks
   2. Upgrade setup.
   3. Characteristics of the new detectors.
   4. Data taking.
   5. Status of the data process.

II. RUN 2008.
   1. Main tasks.
   2. Status of the new electronics and DAQ.
   3. RUN schedule.

III. $A_{2\pi}$ lifetime measurement and expected physical results after RUN 2008 and RUN 2009.
Plan for the run 2007

• Tuning of all detectors downstream the magnet

• Start of the data taking towards the first observation of $A_{\pi K}$ and $A_{K\pi}$

• Tuning of the Scintillating Fiber Detector and the Ionization hodoscope with the new electronics in parallel with data taking.

• Tuning of the Micro Drift Chambers in parallel with data taking.
**Method of \( A_{\pi K} \) and \( A_{K\pi} \) observation and lifetime measurement**

\( \tau(A_{\pi K}) \) is too small to be measured directly

e.m. interaction of \( A_{\pi K} \) in the target

\[
A_{\pi K} \rightarrow \pi^+ K^-
\]

\[
A_{K\pi} \rightarrow K^+ \pi^-
\]

\( Q < 3 \text{MeV/c}, \quad p_K = \frac{m_K}{m_\pi} P_\pi, \Theta_{lab} < 3 \text{ mrad} \)

- Coulomb from short-lived sources
- non-Coulomb from long-lived sources

**Main features of the DIRAC set-up**

- Thin targets: \( \sim 7 \times 10^{-3} X_0 \), Nuclear efficiency: \( 3 \times 10^{-4} \)
- Magnetic spectrometer
- Proton beam \( \sim 10^{11} \) proton/spill
- Resolution on \( Q \): \( Q_x \approx Q_y \approx Q_L \approx 0.5 \ \text{MeV/c} \)

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Trajectories of $\pi^{-}$ and $K^{+}$ from the $A_{\pi K}$ break-up

The numbers to the right of the tracks lines are the $\pi^{-}$ and $K^{+}$ momenta in GeV/c

The $A_{K\pi}$, $\pi^{-}$ and $K^{+}$ momenta are shown in the following table:

<table>
<thead>
<tr>
<th>$P_{\text{atom}}$ (GeV/c)</th>
<th>$P_{\pi}$ (GeV/c)</th>
<th>$P_{K}$ (GeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.13</td>
<td>1.13</td>
<td>4.0</td>
</tr>
<tr>
<td>5.77</td>
<td>1.27</td>
<td>4.5</td>
</tr>
<tr>
<td>6.41</td>
<td>1.41</td>
<td>5.0</td>
</tr>
<tr>
<td>10.26</td>
<td>2.26</td>
<td>8.0</td>
</tr>
</tbody>
</table>

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Upgraded DIRAC experimental setup

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Upgraded DIRAC experimental setup description

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All Cherenkov detectors

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Cherenkov detector $\text{C}_4\text{F}_{10}$

Responsibility: JINR (Dubna, Russia) with participation of INFN (Frascati National Lab, Italy); IFIN-HE (Bucharest, Romania); Zurich University (Zurich, Switzerland);
Adviser: O. Ullaland (CERN)
Cherenkov detector quality factor $N_0 = 125$ cm$^{-1}$

Efficiency to detect pions with momenta >4 GeV is >99.5%

$N_{p.e.} = LN_0 \left(1 - \frac{1}{\beta^2 n^2}\right) = LN_0 \sin^2 \Theta_C$

$\langle n(C_4F_{10}) \rangle = 1.00135$

$N_{p.e.} (\beta = 1) \approx 30$ p.e.
Aerogel Cherenkov detector I

Responsibility:
Zurich University (Zurich, Switzerland)

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Aerogel Cherenkov detector II

Responsibility:
Zurich University (Zurich, Switzerland)

The n=1.008 counter

Status:
Aerogel detectors were installed on the setup

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Aerogel: Kaon and proton signal III

Negative kaon spectrum for $p=4.5-5$ GeV/c

$n=1.015$

module

$N_{pe} = 6.9$

Pure proton signal from $\Lambda$ decay and TOF separation

$n=1.008$

module

$N_{pe} = 3.9$

Proton rejection efficiency for a cut in the ADC 20 channels above pedestal:

- 94.2 % for the heavy aerogel @ $p=4.5-5$ GeV/c
- 89.3 % for the light aerogel @ $p=6-8$ GeV/c

Kaon detection efficiency for the same cut:

- 95.6 % for the heavy aerogel @ $p=4.5-5$ GeV/c
- 92.4 % for the light aerogel @ $p=6-8$ GeV/c
Preshower detector I

Responsibility: IFIN-HH (Bucharest, Romania)

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Preshower detector II

PREFSHOWER ADC SPECTRA

Pion spectrum after 35 mm Pb (second layer)

Electron spectrum after 35 mm Pb (second layer)

Pion spectrum after 25 mm Pb (first layer)

Electron spectrum after 25 mm Pb (first layer)

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Scintillation Fiber Detector I

Sensitive area = 98.5 x 107 mm²
Scintillation Fiber Detector II

Characteristics:

- Size of the plane: 100 × 100 mm²
- Thickness of the material for one plane: 3 mm (1% X₀)
- Mean light output: ≈ 11 p.e.
- Mean Detector Efficiency: ≈ 98 %
- Time Resolution without coordinate and amplitude corrections: ≈ 0.46 ns
- Space resolution: σ ≈ 60 μm
- New electronics (ADC-TDC for each channel): 960 channels

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Number of channels tested with F1
- SFD-X: 464 channels (out of 480)
- IH: all 64 channels

Optimum threshold
- SFD-X: ~15–20 mV
- IH: ~20 mV
Micro Drift Chambers I

Responsibility: JINR (Dubna, Russia), Basel University (Basel, Switzerland)

Main features:

- High spatial accuracy \( \sigma < 30 \, \mu m \) (2004 result);
- Distinguish two close tracks with distance < 200 \( \mu m \);
- Efficiency > 98% at \( I = 2 \times 10^{11} \) protons/spill;
- total detector thickness <5\( \times 10^{-3} \) \( X_0 \);
- time resolution < 1 ns;
- readout time < 3 \( \mu s \).

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Status
During 2007 run Micro Drift Chambers with the new electrodes and all electronics were finally implemented into the DIRAC setup and DAQ system. Data with different MDC working condition were collected.
Micro Drift Chambers III

Beam profile, reconstructed by MDC

Drift time: $\tau \sim 23\text{ns}$

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Run 2007

- Improvement of the proton beam time structure and the beam intensity distribution at spills. R. Steerenberg, A. Grudiev, L. Gatignon et al.

- Beam intensity about $1.9 \times 10^{11}$ proton/spill

  1st level triggers numbers

  $3200(\pi^+\pi^-)+2100(K^+\pi^-)+1000(\pi^+K^-)=6300$ 1/spill

- Number of recorded events 2000 1/spill is near to the hardware limit of DAQ

- Full number of $\pi^+\pi^-$ and $\pi K$ events recorded during 3 months of data taking is $1.4 \times 10^9$
Estimation of $A_{\pi K}$ and $A_{K\pi}$ atom fluxes

First estimation of $A_{2\pi}$ observed in 2007 with Pt target: 10000±3000 (with suppression factor 2 in respect to $\pi K$ atom trigger)

From theory and FRITIOF6 simulation production of atoms relates as:

$$\frac{N(A_{2\pi})}{N(A_{\pi K} + A_{K\pi})} \approx 14$$

Assuming an additional factor of inefficiency for kaonic atoms of 2 and using expected value of the lifetime 3.7 fs we estimate the number of collected kaonic atoms: $n_{A_{\pi K}} + n_{A_{K\pi}} = 700 \pm 200$. This value coincides with the estimations made in Addendum and reported at SPSC last year.

Before autumn 2008 we will prepare a paper titled:

“Search for $\pi K$ atoms” or
“Observation of $\pi K$ atoms”
RUN 2008 Main tasks.

• To tune DIRAC setup with the new front-end electronics, trigger logic, readout system and DAQ
• To perform data taking for the lifetime measurement of $A_{2\pi}$, $A_{K\pi}$ and $A_{\pi K}$
Front-end electronics and Readout System

Responsibility: JINR (Dubna, Russia) with participation of IFIN-HH (Bucharest, Romania); Zurich University (Zurich, Switzerland)

Experimental Area

- **SFD**
  - ADC-TDC (D412)
  - Transmitter (1st level)
  - Transmitter (2nd level)

- **VH**
  - ADC-TDC (D412)
  - Transmitter (1st level)

- **HH**
  - ADC-TDC (D412)
  - Transmitter (1st level)

- **Č**
  - ADC-TDC (D412)
  - Transmitter (1st level)
  - Transmitter (2nd level)

- **...**
  - ADC-TDC (D412)
  - Transmitter (1st level)

**Central storage (IT division)**

1. Logical output signals for trigger (flat cables)
2. ADC&TDC signals for readout (maximal distance ~10 m)

**Barrack**
- USB hubs
- Host computer

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Status of the new electronics

- All electronics is ready, tuned and will be installed before the run beginning.
- The setup tuning, in accordance to our plan, will be done during 6 weeks.

Data taking will continue 4 months.
Pion scattering lengths

Low-energy QCD predictions for $\pi\pi$ scattering lengths (s-wave):

\[
a_0 = 0.220 \pm 2.3\% \\
a_2 = -0.0444 \pm 2.3\% \\
a_0 - a_2 = 0.265 \pm 1.5\%
\]

Experiments

\[K \rightarrow \pi^+\pi^- e^+\nu_e(K_{e4}):\]

1) 1977 Geneva-Saclay: (PR D15, 574)
   \[a_0 = 0.28 \pm 18\% \) using Roy equations\]

2) 2001 E865 / BNL: (PRL 87, 221801)
   \[a_0 = 0.203 \pm 16\%  \]  *)
   \[a_2 = -0.055 \pm 42\%  \]

3) 2008 NA48 / 2: (EPJ C54, 411)
   \[a_0 = 0.233 \pm 7\%(stat) \pm 3\%(sys) = ... \pm 7.5\%  \)
   \[a_2 = 0.0471 \pm 23\%(stat) \pm 8\%(sys) \]

\[K \rightarrow \pi^0\pi^0\pi^+:\]

2006 NA48 / 2: (PL B633, 173)
\[a_0 - a_2 = 0.268 \pm 3.7\%(stat) \pm 1.5\%(sys) \pm 4.8\%(ext) = ... \pm 6.2\% \]
Experimental results 2001-2003

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# Experimental results

**Low-energy QCD predictions for scattering lengths (s-wave):**

<table>
<thead>
<tr>
<th>System</th>
<th>Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi\pi )</td>
<td>( a_0 - a_2 = 0.265 \pm 1.5% )</td>
</tr>
<tr>
<td>( \pi\K )</td>
<td>( a_1 - a_3 = 0.24 ) (1-loop)</td>
</tr>
<tr>
<td>( \pi\K )</td>
<td>( a_1 - a_3 = 0.269 \pm 6% ) (RS)</td>
</tr>
</tbody>
</table>

## Experiments

### \( A_{2\pi} \) lifetime:

1. **2005 DIRAC:**
   
   \[ a_0 - a_2 = 0.264 \pm 7.5\%(stat) \pm \frac{3}{8}\%(sys) = ... \pm \frac{8}{11}\% \]
   
   (based on 2001 data (6530 observed atoms))

2. **2008 DIRAC:**
   
   \[ a_0 - a_2 = 0.268 \pm 4.5\%(stat) \pm \frac{1.9}{2.2}\%(sys) = ... \pm \frac{4.9}{5.0}\% \]
   
   (preliminary, from major part 2001-03 data (13390 observed atoms))

3. **>2008 DIRAC:**
   
   \[ a_0 - a_2 = ... \pm 2\%(stat) \pm 1\%(sys) \pm 1\%(th) = ... \pm 2.4\% \]
   
   (after data collection in 2008 & 2009)

### \( A_{\pi\K} \) lifetime:

**>2008 DIRAC:**

\[ a_1 - a_3 = ... \pm 10\%(stat) \]

...after data collection in 2008 & 2009

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Run 2009 will increase the statistics of $A_{2\pi}$, $A_{\pi K}$ and $A_{K\pi}$ on factor 2.5
What new will be known if \( \pi K \) scattering length will be measured?

The measurement of the \( s \)-wave \( \pi K \) scattering lengths would test our understanding of the chiral \( SU(3)_L \times SU(3)_R \) symmetry breaking of QCD \((u, d\) and \( s \) quarks), while the measurement of \( \pi\pi \) scattering lengths checks only the \( SU(2)_L \times SU(2)_R \) symmetry breaking \((u, d\) quarks).

This is the main difference between \( \pi\pi \) and \( \pi K \) scattering!