Status Report of DIRAC

LIFETIME MEASUREMENT OF $\pi^+ \pi^-$
ATOMS TO TEST LOW ENERGY QCD PREDICTIONS

and

DIRAC Addendum

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

75 Physicists from 18 Institutes

CERN
Geneva, Switzerland

Tokyo Metropolitan University
Tokyo, Japan

Czech Technical University
Prague, Czech Republic

IFIN-HH
Bucharest, Romania

Institute of Physics ASCR
Prague, Czech Republic

JINR
Dubna, Russia

Ioannina University
Ioannina, Greece

SINF of Moscow State University
Moscow, Russia

INFN-Laboratori Nazionali di Frascati
Frascati, Italy

IHEP
Protvino, Russia

Trieste University and INFN-Trieste
Trieste, Italy

Santiago de Compostela University
Santiago de Compostela, Spain

University of Messina
Messina, Italy

Basel University
Basel, Switzerland

KEK
Tsukuba, Japan

Bern University
Bern, Switzerland

Kyoto Sangyou University
Kyoto, Japan

Zurich University
Zurich, Switzerland

CERN 2006 SPS and PS Experiments Committee
L. Nemenov
2 May 2006
Outline

I. DIRAC Addendum

- Modified DIRAC setup
- Vacuum Channel and Shielding
- Detectors
- Readout system
- Trigger
- DAQ

II. The goal of the 2006 RUN

III. Status of DIRAC Analysis
Main goal of DIRAC Addendum

- **Lifetime measurement, in a model-independent way, of $A_{2\pi}$ atoms with precision better than 6%, which gives a precision for $|a_0 - a_2|$ better than 3%; this will provide a sensitive check for understanding the chiral symmetry breaking in QCD, giving an indication about the value of the quark condensate.**

- **Observation of $A_{\pi K}$ and $A_{K\pi}$ atoms.**
  The measurement of their lifetime with precision of 20% and difference of $\pi K$ scattering lengths $|a_{1/2} - a_{3/2}|$ with accuracy about 10%.

- **Observation of the long-lived (metastable) states of $A_{2\pi}$, with the possibility of measuring the energy difference between $ns$ and $np$ states, and of determining the value of $2a_0 + a_2$ in a model-independent way.**

  All these steps are important for a crucial check of the predictions of low energy QCD and for understanding the nature of the QCD vacuum.
Present low energy QCD predictions for $\pi\pi$ scattering lengths:

ChPT predicts s-wave scattering lengths:

$a_0 = 0.220 \pm 0.005 (2.3\%)$
$a_2 = -0.0444 \pm 0.0010 (2.3\%)$
$a_0 - a_2 = 0.265 \pm 0.004 (1.5\%)$

First result:

L. Rosselet et al.,

$a_0 = 0.28 \pm 0.05 (18\%)$ using Roy eqs.

DIRAC current results, 2001 data:

$a_0 - a_2 = 0.264 \pm 7.5\% (stat) \pm 3\% (syst)$

Results from E865/BNL experiment:

$K \rightarrow \pi^+ \pi^- e^+ \nu_e(K_{e4})$

using Roy eqs.

$a_0 = 0.203 \pm 0.033 (16\%)$  $a_2 = -0.055 \pm 0.023 (42\%)$

using Roy eqs. and chiral symmetry constraints $a_2 = f_{ChPT}(a_0)$

$a_0 = 0.216 \pm 0.013 (stat) \pm 0.004 (syst) \pm 0.002 (theor)$
$\delta a_0 = \pm 6\% (stat) \pm 2\% (syst) \pm 1\% (theor)$

Results from NA48/2: $K^+ \rightarrow \pi^0 \pi^0 \pi^+$


$a_0 - a_2 = 0.268 \pm 3.7\% (stat) \pm 1.5\% (syst) \pm 4.8\% (ext)$

Expected results of DIRAC (upgraded) at PS CERN:

$\tau(A_{2\pi}) \rightarrow \delta(a_0 - a_2) = \pm 2\% (stat) \pm 1\% (syst) \pm 1\% (theor)$
What new will be known if $\pi K$ scattering length will be measured?

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

This is the main difference between $\pi \pi$ and $\pi K$ scattering!
Time scale for the $A_{2\pi}$ and $A_{\pi K}$ experiment

2006

- Manufacture and installation of new detectors and electronics: 6 months
- Test of the Upgraded setup and calibration: 3 months

2007 and 2008

- Measurement of $A_{2\pi}$ lifetime: 12 months
  
  In this time 86000 $\pi\pi$ atomic pairs will be collected to measure $A_{2\pi}$ lifetime with precision of:

  \[
  \frac{\sigma}{\tau} = 6\%, \quad \frac{\sigma(a_0 - a_2)}{a_0 - a_2} = 3\%
  \]

  At the same time we also plan to observe $A_{\pi K}$ and $A_{K\pi}$;
  to detect 5000 $\pi K$ atomic pairs to estimate $A_{\pi K}$ lifetime with precision of:

  \[
  \frac{\sigma}{\tau} = 20\%, \quad \frac{\sigma(a_{1/2} - a_{3/2})}{a_{1/2} - a_{3/2}} = 10\%
  \]

This estimation of the beam time is based on the $A_{2\pi}$ statistics collected in 2001 and on the assumption of having 2.5 spills per supercycle during 20 hours per day.
Method of $A_{\pi K}$ and $A_{K\pi}$ observation and lifetime measurement

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

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

$A_{\pi K} \rightarrow \pi^+K^-$

$A_{K\pi} \rightarrow K^+\pi^-$

$Q < 3\text{MeV/c}, p_K = \frac{m_K}{m_\pi} p_\pi, \Theta_{\text{lab}} < 3\text{ mrad}$

- 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 $Q$: $Q_x \approx Q_y \approx Q_L \approx 0.5\text{ MeV/c}$
Trajectories of $\pi^-$ and $K^+$ from the $A_{\pi K}$ break-up

Numbers are the $\pi^-$ and $K^+$ momenta in GeV/c

The $A_{\pi K}$, $\pi^-$ 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>
Upgraded DIRAC experimental set-up description

CERN 2006 SPS and PS Experiments Committee

L. Nemenov

2 May 2006
Vacuum Channel and Shielding

Responsibility: JINR (Dubna, Russia)

Time Schedule:
Installed in March 2006, vacuum tests are done. Completed.

L. Nemenov
2 May 2006
Microdrift Chambers (I)

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

Characteristics:
- spatial accuracy $< 22 \pm 4 \, \mu m$ from the beam test;
- double track resolution $< 200 \, \mu m$;
- one plane efficiency at the beam intensity $I = 2 \times 10^{11}$ protons per spill $> 98$%;
- total detector thickness $< 5 \times 10^{-3} \, X_0$;
- drift time $< 30 \, ns$;
- time resolution $< 1 \, ns$;
- readout time $< 3 \, \mu s$.

According to the results of MDC tests in 2003-2004, the detector stability has to be improved for the DIRAC heavy radiation conditions. This improvement will be achieved by some modification of MDC electrodes.
**Time Schedule:**

February-April 2006:
preparation of new electrodes at JINR.

May-June 2006:
tests of the modified MDC detector with a radioactive source for high voltage.

July 2006:
the MDC detector will be mounted in the DIRAC setup at CERN.
Scintillation Fiber Detector (I)

Responsibility: Japan Universities (Japan); IHEP (Protvino, Russia); JINR (Dubna, Russia); INFN-Trieste (Trieste, Italy); University of Messina (Messina, Italy)

Characteristics:
- Size of the plane: $100 \times 100 \text{ mm}^2$
- Thickness of the material for one plane: $3 \text{ mm (1\% X}_0$)
- Mean light output: $\approx 11 \text{ p.e.}$
- Mean Detector Efficiency: $\approx 98 \%$
- Time Resolution without coordinate and amplitude corrections: $\approx 0.46 \text{ ns}$
- Space resolution: $60 \text{ \mu m}$
- New electronics ($\text{ADC-TDC for each channel}$): 920 channels

Time Schedule:
Production of fiber layers is finished. Housings are ready. Two detectors will be assembled in the middle of July and will be installed on the setup in August after beam tests on T11
Scintillation Fiber Detector (II)

CERN 2006 SPS and PS Experiments Committee

L. Nemenov

2 May 2006
Present status of the Drift Chamber (DC) System.
The DC system consists of four chamber modules per arm including 6 sensitive planes in X and Y projection.

The first module (DC1) has a frame common to both arms; it has two active regions of 80×40 cm² housing 6 planes of signal wires (X, Y, W, X’, Y’, W’).

Three modules are then place on each spectrometer arm:
- DC2 with an active area of 80×40 cm² and 2 wire planes (X, Y);
- DC3 with an active area of 112×40 cm² and 2 wire planes (X, Y);
- DC4 with an active area of 128×40 cm² and 4 wire planes (X, Y, X’, Y’).

After successful and long drift chamber operation at the first stage of the experiment, it was decided to perform full revision of all drift chambers.

Time Schedule:
Both DC1 modules were repaired. High Voltage tests for this modules will be fulfilled in July, installation in the DIRAC setup is planning at the begin of August.

DC2, DC3 and DC4 modules were repaired (spares also), tested under High Voltage and installed in the DIRAC setup.
**Time Schedule:**

**VH:** All slabs of the Vertical Hodoscopes were refreshed and together with new support installed back. Four additional scintillation slabs will be added to the existing Vertical Hodoscopes at the end of July.

**HH:** New longer Horizontal Hodoscopes will be installed before the end of May. There will be 32 slabs (16 slabs per arm) by $1500 \times 25 \times 25 \text{ mm}^3$.

**Responsibility:** IHEP (Protvino, Russia); Czech Technical University (Prague, Czech Republic); Zurich University (Zurich, Switzerland); Santiago de Compostela University (Santiago de Compostela, Spain)

**Photomultipliers:** PHILIPS XP2012 gift of P. Jenni to DIRAC
Aerogel Čerenkov detector (I)

Responsibility:
Zurich University (Zurich, Switzerland)
Aerogel Cherenkov detector (II)

The sandwich design

Intensity

Wavelength (nm)

240 280 320 360 400

TPB (88020)

pT (86470)

Other WLS

POPOP (15150, 15080)

n=1.05

CERN 2006 SPS and PS Experiments Committee

L. Nemenov

2 May 2006
The pyramid design

- In blue: box design.
- In red: Pyramid design with 2 layers of thickness 2 cm.
- In green: Pyramid design with 2 layers of thickness 4 cm.
The n=1.008 counter

Time schedule:
- PMs already arrived and calibrated
- Aerogel from Novosibirsk (n=1.008) and Panasonic (n=1.015) already arrived
- The mechanics are in production and should be ready beginning May
- Quick test using cosmic rays during May-June
- Installation in DIRAC experiment in July
Cherenkov detector (C_4F_{10}) - I

Responsibility: INFN (Frascati National Lab, Italy); IFIN-HH (Bucharest, Romania); JINR (Dubna, Russia); Zurich University (Zurich, Switzerland); Adviser: O. Ullaland (CERN)
Time Schedule:

Box with flat and spherical mirrors supports and PM housings will be finished and tested for leakproofness in May.

Flat mirrors are ready.
Spherical mirrors will be ready before end of June.

Mirror evaporation – July

Photomultipliers will be delivered in July.

Assembling – July-August.

Setting up in DIRAC – before middle of August.

Gas system – July-August.
Preshower detector (I)

Responsibility: IFIN-HH (*Bucharest*, Romania)

Time Schedule:
New preshower was installed in April 2006.
Muon detector

Responsibility: IHEP (Protvino, Russia)

24 slabs (12 slabs per arm) will be added to the existing muon scintillation hodoscopes in order to increase their acceptance.

Without these slabs background of non-identified muons from pion decays will increase by few percent.

Time Schedule:
The new slabs will be installed in 2007.
Readout System (I)

Responsibility: JINR (Dubna, Russia); Basel University (Basel, Switzerland); IFIN-HH (Bucharest, Romania); Santiago de Compostela University (Santiago de Compostela, Spain); Zurich University (Zurich, Switzerland)

Logical output signals for trigger (flat cables)

ADC&TDC signals for readout (maximal distance ~10 m)

CENTRAL STORAGE (IT DIVISION)
Trigger

Responsibility: JINR (Dubna, Russia)

The List of Triggers:

1. \( A_{\pi\pi} \quad A_{\pi K} \quad A_{K\pi} \)
2. \( \pi^+\pi^- \quad \pi^+K^- \quad K^+\pi^- \)
3. \( \pi^-\pi^- \text{ and } (\pi^+\pi^+, pp) \)
4. \( K^+K^- \text{ and } p\bar{p} \)
5. \( e^+e^- \text{ and } (e^+e^-e^+e^-) \)
6. \( \pi^-\pi^- (\pi^+ \text{ or } \bar{p}), \)
   \( \pi^-\pi^- (\pi^+\pi^+) \),
   \( \pi^+\pi^+ (\pi^-) \text{ and } \)
   \( \pi^+\pi^+ (\pi^-\pi^-) \)

Expected number of triggers per spill \( \sim 4000 \), event volume 4 Kbytes
Expected volume of data per spill \( \sim 16 \text{ Mbytes} \) (~50 Mbytes/supercycle)

(current transmitting capacity of the line with IT-division (~50 Mbytes/supercycle))

Time Schedule:
Tuning of the Trigger System with the specified performances will be begun at the end of the DIRAC 2006 run.
Status of the new electronics

Readout System

- **ADC-TDC**: 51 modules
  - Three prototypes were made and tested.
- **Transmitter 1\textsuperscript{st} level**: 9 modules
  - Prototype was made and tested.
- **Transmitter 2\textsuperscript{nd} level**: 4 modules
  - Design was finished, no prototype.
- **Auxiliary module**: 3 modules
  - Design was finished, no prototype.

**Time Schedule:**
All modules will be ready in July and will be checked before the end of August, including chain ADC-TDC – TRANSMITTER I – TRANSMITTER II and the dedicated software. Electronics starts to work with SFD and IH. These detectors are not in the trigger.

Trigger System

- **Shaper K436**: 20 modules
  - Prototypes were made and tested
- **Level translator**: 21 modules
  - Prototypes were made and tested
Time Schedule:
Revising software for automatic and interactive on-line monitoring of data. This work was done partly in March 2006, and will be finished during test runs in August-September 2006. Upgrading and tuning hardware and operating systems for computers which are critical for data acquisition system July-August 2006. Software for handling with new electronic modules was written in April-May 2006.
The goal of the 2006 RUN

I. To tune all detectors with current trigger electronics and DAQ and to collect data for $\pi^+\pi^-$, $\pi^-K^+$ and $\pi^+K^-$ pairs. Analysis of this data will give a possibility to calculate the number of $A_{2\pi}$, $A_{K\pi}$ and $A_{\pi K}$.

II. To install and to test new electronics with Scintillating Fiber Detector and Ionization Hodoscope of DIRAC setup.
DIRAC analysis

Improvements on systematics in $P_{Br}$

- CC background: no improvement $\pm 0.007$
- Signal shape: no improvement $\pm 0.002$
- Multiple scattering: measured to $\pm1\%$ (DONE) $+0.002/-0.002$
- $K^+K^-/p\bar{p}$ admixtures: to be measured* $+0.000/-0.023$
- Finite size effects: to be measured** $+0.000/-0.017$
- Total: $+0.008/-0.030$

* To be measured in 2007/2008 with new PID
** To be measured in 2006/2008 with new trigger for identical particles at low $Q$

Improvements on data quality by fine tuning

- Adjustments of drift characteristics almost run-by-run
- B-field adjustment and alignment tuning with $\Lambda$-mass
  $\Rightarrow$ New pre-selection for all runs (DONE)

Comments on analysis strategies

Using only downstream detectors (Drift chambers) and investigating only $Q_L$ causes less sensitivity to multiple scattering and to the signal shape. Studies are under way and very promising.