**CERN,October 2015.**

**DIRAC collaboration status report.**

## I. Long-lived states of $\pi^+\pi^-$ atoms.

1. Paper "First observation of long-lived $\pi^+\pi^-$ atoms" accepted for publication in Physics Letters B.

The number of atomic pairs from long-lived $\pi^+\pi^-$ atoms breakup in the Pt foil is:

$n_A=436\pm57|_{stat}\pm23|_{syst}=436\pm61|_{tot}$ (7.1 σ).

2. The measurement of the long-lived $\pi^+\pi^-$ atom lifetime.

The total number of produced $\pi^+\pi^-$ atoms in Be target has been evaluated from experiment. The number of long-lived $\pi^+\pi^-$ atom at the Be target exit, their distribution on quantum numbers *n, l, m* and breakup probability in the Pt foil has been calculated. Using the experimental value of broken long-lived $\pi^+\pi^-$ atoms $n_A$ and the known momentum distribution of atom will allows to measure the long-lived atoms lifetime. The preliminary value of the lifetime will be presented in April 2016.

3. A possibility of evaluation of limit for the $\pi^+\pi^-$ atom Lamb shift, using existing data, will be studied in the first part of 2016.

4. The data of 2011 run will be used to evaluate the number of $\pi^+\pi^-$ atoms and atomic pairs generated on Be target that can improve the above result obtained with 2012 data.

## II. Status of $K^+\pi^-$ and $K^-\pi^+$ data process.

1. The Monte-Carlo simulation with the improved SFD response for the runs of 2007, 2008, 2009, 2010 and 2012 are ready. The analysis of the Lambda width using M.C. with the improved SFD response has been performed.

2. The improved procedure of $K^+$, $\pi^+$ and protons identification using time of flight is ready and applied to the runs 2007, 2008, 2009, 2010 and 2012 data. This procedure enlarged the statistic of $K\pi$ pairs on 30% for 2008-2010 runs.

3. The procedure of matching the downstream tracks with SFD hits will be modified accounting a dependence of the expected hits region on particle momenta. The main aim of this procedure is to improve the quality of the statistics with the low and medium background and to process for first time the part of the statistics with high background (1/3 of the total data).

4. The preliminary results on $K^+\pi^-$ and $K^-\pi^+$ atoms investigation using all the data available from 2007, 2008, 2009 and 2010 runs and with the improved analysis will be ready in April 2016.

**III. The $\pi^+\pi^-$ atom lifetime measurement.**

1. At present time the $\pi^+\pi^-$ pairs are using as calibration process for the $\pi K$ pairs analysis. Preliminary results on the $\pi^+\pi^-$ atom lifetime measurement based on all available data will be ready at the end of 2016.

2. The current systematical error in the $\pi^+\pi^-$ atom lifetime measurement is equal to statistical uncertainty. The main part of systematical error arise due to the multiple scattering in the Ni target. To reduce this error we continue experimental study of the multiple scattering of our targets: Ni: 50, 109 and 150 microns; Be: 100 and 2000 microns; Pt: 2 and 30 microns and Ti: 250 microns. For Be (2000 microns) and Ni (109 microns) the difference between theoretical and experimental r.m.s. is 0.4% and 0.8% accordingly. The r.m.s. values were calculated in the interval $\pm 2\sigma$.

**IV. $K^+K^-$ pair analysis.**

1. The search for $K^+K^-$ Coulomb pairs in the existing data will be performed in 2016 with improved procedure of the particles identification using time-of-flight technique. The number of produced $K^+K^-$ atoms can be extracted from the number of $K^+K^-$ Coulomb pairs. During the first part of the work, $K^+K^-$ pairs with a total momentum in the laboratory system between 2.8 GeV/c and 6.0 GeV/c will be analyzed. In this range identification of $K^+K^-$ pairs is more simple. If we will see a signal, then we will continue to the higher momentum region 6.0 - 9.6 GeV/c.

2. Simulation of $K^+K^-$ pairs and of $K^+K^-$ atoms for proton momentum 24 GeV/c and 450 GeV/c using CERN version of FRITIOF generator is in progress.

3. The theoretical investigation of the $K^+K^-$ atom wave functions for S and P states and the $K^+K^-$ atom lifetime for S and P states need to be performed.

**V. Proton-antiproton pair analysis**

DIRAC will perform in 2016 a search for proton-antiproton Coulomb pairs and thus proton-antiproton atoms with the same strategy as in the $K^+K^-$ case (see section IV).

**VI. Investigation of $K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$, $K^+K^-$ atom production in p-nucleus interaction at proton momentum 24 GeV/c and 450 GeV/c**

A DIRAC note on the simulation of the inclusive production of $K^+$, $K^-$, $\pi^+$ and $\pi^-$ in p-nucleus interactions at 24 GeV/c and 450 GeV/c is published. The minimum yields of $K^+\pi^-$, $K^-\pi^+$ and $\pi^+\pi^-$ atoms in p-nucleus interactions at proton momenta of 24 and 450 GeV/*c* are given in the table 1.

The beam time during super cycle on SPS on factor 5 more than on the PS. It gives additional increasing for the atom production per time unity. For the long-lived atoms investigation one can used the new scheme of experiment allowing to increase the number of produced dimesoatoms per unity time more than on two orders. In this scheme, the background of Coulomb and nonCoulomb pairs will be decreased more than on the order of magnitude relative background in the DIRAC experiment scheme. The possibility of the new scheme of experiment on SPS will be studied in 2016 together with a possibility to use the resonance method, which allows to measure the energy

levels splitting in $\pi^+\pi^-$ atom and the new combination of $\pi\pi$ scattering length. In this method for the experimental data analysis are using only quantum mechanics and Lorenz transformation.

Table 1: The yield of $\pi^+\pi^-$, $\pi^+K^-$ and $K^+\pi^-$ atoms $W_A$ into the aperture of $10^{-3}$ *sr* taking into account the setup acceptance and pion and kaon decays per one p-Ni interaction at the proton momenta $P_p$ = 24 and 450 GeV/c for different emission angle $\theta_{lab}$. The correlation function $R_{24GeV/c}$ were set to be equal to $R_{450GeV/c}$. We have fix the yields of DIRAC at the PS at 24 Gev/c as reference, and for the other energies we indicate the yields as ratio to this reference also.

| $\theta_{lab}$ | 5.7° | 4° | 2° | 0° |
|---|---|---|---|---|
| $E_p$ | 24 GeV/c | 450 GeV/c | 450 GeV/c | 450 GeV |
| yield of $\pi^+\pi^-$ atoms | | | | |
| $W_A$ | $(1.73 \pm 0.09)10^{-9}$ | $(1.7 \pm 0.2) \cdot 10^{-8}$ | $(3.0 \pm 0.5) \cdot 10^{-8}$ | $(3.9 \pm 0.6) \cdot 10^{-8}$ |
| | 1 | $9.7 \pm 1.5$ | $17.5 \pm 2.8$ | $22.7 \pm 3.6$ |
| yield of $\pi^+K^-$ atoms | | | | |
| $W_A$ | $(1.46 \pm 0.09)10^{-11}$ | $(6.6 \pm 1.1) \cdot 10^{-10}$ | $(1.31 \pm 0.21) \cdot 10^{-9}$ | $(1.52 \pm 0.24) \cdot 10^{-9}$ |
| | 1 | $45 \pm 8$ | $87 \pm 15$ | $104 \pm 18$ |
| yield of $K^+\pi^-$ atoms | | | | |
| $W_A$ | $(4.2 \pm 0.3) \cdot 10^{-11}$ | $(7.9 \pm 1.6) \cdot 10^{-10}$ | $(1.8 \pm 0.4) \cdot 10^{-9}$ | $(2.2 \pm 0.5) \cdot 10^{-9}$ |
| | 1 | $18.6 \pm 4.1$ | $41 \pm 9$ | $52 \pm 11$ |

## VII. Preparation of a Letter of Intent about the investigation of hadronic atoms at SPS energy.

Letter of Intent will be prepared and submitted after investigation of the possibility to increase significantly the yields of dimesoatoms per time unit and background suppression. The planning time for the submission is October 2016.

## VIII. Instrumental publication

The paper "Updated DIRAC spectrometer at CERN PS for the investigation of $\pi\pi$ and $K\pi$ atoms" has been submitted to NIM.

**IX. Measurement of $K^+\pi^-$, $K^-\pi^+$ and $\pi^+\pi^-$ atoms production cross sections in proton interaction with Be, Ni and Pt nuclei basing of 2007-2012 experimental data will be done in 2017.**

Dedicated measurements of the proton flux and the dead time of electronics and of DAQ were done for these purposes. Estimation of systematic biases in our cross sections can be done basing on extrapolation of single particle production cross sections available for 32 GeV/c protons.

**X. $\pi^+\mu^-$ and $\pi^-\mu^+$ pair analysis**

The 2010 experimental data has been searched for $\pi^+\mu^-$ and $\pi^-\mu^+$ Coulomb pairs with the aim of extracting the number of $\pi\mu$ atoms produced simultaneously with the Coulomb pairs. An upper limit on the atom production will be calculated and published as DIRAC before the end of 2017.