**DIRAC collaboration status report**

**SPSC, January 2018.**

**I. Long-lived states of π+π− atoms.**

1. The published DIRAC experimental result on observation of long-lived π+π**−** atoms is used for the first measurement of the long-lived π+π**−** atom lifetime. All data are reprocessed using improved procedure of analysis. The preliminary value of the lifetime is:

The lifetime of the long-lived atom in 2p state is:

 $τ\_{2p}=0.\left.22\_{-0.18}^{+1.6}\right|\_{tot}×10^{-11}s$

 QED: $τ\_{2p}=1.17×10^{-11}s$

The measured ground state lifetime is:

 $τ\_{1s}=\left.3.15\_{-0.26}^{+0.28}\right|\_{tot}×10^{-15}s$

The first draft of corresponding paper is ready and will be published as CERN preprint before the April of 2018.

2. A possibility of evaluation of limit for the π+π**−** atom Lamb shift, using existing data, will be studied in 2018.

**II. Status of K+π− and K−π+ atoms investigation.**

The paper “**Measurement of the** *πK* **atom lifetime and the** *πK* **scattering length”** published as a CERN preprint (CERN-EP-2017-137) and in Phys. Rev. D 96, 052002 (2017).

**III. K+K− pair analysis.**

1. Investigation of *K+K−* pairs was performed in 2017 with improved procedure of the particles identification using time-of-flight technique and the data from heavy gas Cherenkov counters. At present time the data of RUN 2009 and RUN 2010 were processed. After background subtraction, the full laboratory momentum spectrum of *K+K−* pairs in the RUN 2010 was evaluated (see Fig.1).

 For the observation of the signal from the *K+K−* Coulomb pairs were selected *K+K−* pairs with the low laboratory momentum 2.6 <P <4.0 GeV/c and with the high laboratory momentum 6 < P <10 GeV/c because in these two intervals the level of the background is relatively small (see the errors on Fig.1).

The time-of-flight distribution for the low momentum interval show on the Fig.2. The proton-antiproton pairs are absent as for them the ΔT is less than -6 ns. For ΔT less than -0.5ns, the number of *K+K−* and π+π− pairs are comparable. The time-of-flight distribution for the high momentum interval shown on Fig.3. For the pions with this momentum the efficiency of the Cherenkov’s counter with heavy gas is near 0.95. Therefore, the suppression of π+π− pairs is high and this background is negligible. For the low and high momentum intervals, the selecting procedure choose the ranges over ΔT with contribution of *K+K−* pairs more than 50% of the total statistics. The admixture of π+π− pairs in the low momentum interval and admixture of proton-antiproton in the high momentum interval were defined using events distributions over ΔT.

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| **Fig.1.** Distribution of *K+K−* pairs in the RUN 2010 over full pair momentum in lab system. Number of pairs is 93000. The total number of *K+K−* pairs in 2009-2010 is around 180000. |

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|  **Fig.2**. Time of flight distribution  (low momentum interval). |  **Fig.3**. Time of flight distribution  (high momentum interval). |

The distributions of the selected events on *QL* for the three values of *QT* for both intervals on P is shown in Fig.4 for the RUN 2009 and 2010. The admixtures of π+π− and proton-antiproton pairs calculated as *K+K−* pairs were subtracted. Nevertheless, the background of π+π− pairs can existing. Therefore, the experimental distributions of selected events were fitting by the sum of simulated distributions of *K+K−* pairs and the experimental distributions of experimental π+π− pairs processed with kaon masses. This analysis gives the minimum number of *K+K−* pairs and maximum possible number of π+π− pairs. In the distributions of *K+K−* pairs there is a clear signature of the Coulomb enhancement. In the RUN 2009 and 2010 in this analysis were identified 4534 ± 364 *K+K−* pairs with *QT*  less than 6 MeV/c and 2635 ± 366 π+π− pairs.

The number of produced *K+K−* atoms (em) will be evaluated first time from the number of *K+K−* Coulomb pairs with small relative momentum in their center of mass. The distributions of *K+K−* pairs on *Q* are shown in Fig.5. The experimental distributions on *QL*  divided by the simulated distributions calculated in the point-like approach are presented in Fig.6.

2. Simulation of *K+K−* atoms yield and spectrum for proton momentum 24 GeV/c and 450 GeV/c using CERN version of FRITIOF generator is finished:

DIRAC-NOTE-2016-07 “The estimation of production rates of *K+K−* and proton-antiproton atoms in proton-nucleus interactions at 450 GeV/c,” O. Gortchakov [JINR], L. Nemenov [JINR]

3. Results of *K+K−* pairs investigation will be finished and published in 2018.

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| **Fig.4**. Experimental distributions of events selected. Events are fitted by simulated distribution of K+K− pairs (red) and experimental distribution of pure π+π− (blue) processed with K masses. The integral number of K+K− pairs is 4534 ± 364, the number of π+π− pairs is 2635 ± 366. |

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| **Fig.5**. K+K− distribution over |Q| for events, selected with criterion QT < 4 MeV/*c*.  |

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| **Fig.6**. Distribution of K+K− experimental Coulomb pairs over |QL| for events, selected with criterion QT < 4 MeV/*c*. divided on the simulated distribution calculated for the pairs point-like production. The ratio decreasing in the region |QL|< 7 MeV/*c* caused by the mechanism of the pairs nonpoint-like production: part of K mesons are generated in Lambda (1520) resonance decays and Coulomb correlations are decreased by large distance between particles.  |

**IV. Proton-antiproton pair analysis**

In 2018 DIRAC will perform a search for proton-antiproton Coulomb pairs and thus proton- antiproton atoms with the same strategy as in the K+K− case (see section III). Investigation results will be published in 2019. In the final data analysis the new measurements of multiple scattering will be included. The dedicated paper will be ready before June of 2018.

**V. Coulomb correlations as a possible new physical method to investigate the particles production in the coordinate space.**

The observation of *K+K−* Coulomb pairs and possible observation of proton-antiproton Coulomb pairs allows to investigate in 2018 the possibility to use the Coulomb correlations in *K+K−* and proton-antiproton pairs as a new physical tool to study the particles production in coordinate space. The calculation of the relative yields of *K+K−* and proton-antiproton pairs and atoms in the DIRAC experiment and on SPS are presented.

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| **Atom** | **Bohr radius *aB* [fm]** | **Resonance cτ [fm]** |
| *π*+*π*– | 387 | ω(782) 23 |
| *πK* | 248 | ω(782) + φ(1020) |
| *K*+*K*– | 109 | φ(1020) 46 |
| $$p\overline{p}$$ | 58 |  |

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|  | **Z** | **A** | **Nuclear radius [fm]** |
| Be | 04 | 9.012 | 2.56 |
| Ni | 28 | 58.69 | 4.78 |
| Pt | 78 | 195.08 | 7.13 |

$A\_{c}\left(r^{\*},a\_{B}\right)=A\_{c}\left(0\right)\left[1-\frac{2r^{\*}}{a\_{B}}+…\right]$, $  A\_{c}\left(0\right)\~\frac{1}{q}$

Coulomb correlation with extended pair production region $r^{\*}$

Point-like Coulomb correlation

**VI. Investigation of K+π−, K−π+ and π+π− atoms production in
p-nucleus interaction at proton momentum 24 GeV/c and 450 GeV/c**

1. The paper “The estimation of production rates of K+π–, K–π+ and π+π– atoms in proton-nucleus Interactions at 450GeV/c” published in the J.Phys. G: Nucl. Phys. 43 (2016) 095004.

The dedicated analysis has shown that, taking into account the yields of dimesoatoms at 450 GeV/c $ (θ\_{lab}=4°)$ and the working conditions at SPS, the number of π+π−, K+π– and K–π+ atoms generated per time unit will be 122, 5311 and 245 times higher than in the DIRAC experiment. The significant increase in the K+π– and K–π+ atoms statistics will allow to measure $|a\_{^{1}/\_{2}}-a\_{^{3}/\_{2}}|$ with precision of 5% and to check our understanding of the chiral $SU(3)\_{L}×SU(3)\_{R}$ symmetry breaking of QCD. The setup upgrade and geometry modification will allow to improve this precision significantly.

In the DIRAC experiment there were observed 436 ± 57stat ± 23syst long-lived π+π− atoms with the lifetime s. The higher energy of proton beam and the simple change of the experiment scheme open a new possibility for the investigation of the long-lived π+π− atoms. In the new scheme the number of π+π− atoms, generated per time unit will be more than 12 times higher than in DIRAC experiment. The background will be also significantly decreased. The statistics increasing and significant background suppression open a possibility to use the resonance method for measurement of only one parameter, the Lamb shift, and to evaluate the combination of the ππ scattering lengths $2a\_{0}+a\_{2}$. This measurement uses only the Lorenz transformation and quantum mechanics.

**VII. The short-lived π+π− atom lifetime measurement**

1. In the past the π+π− pairs from 2008-2010 data were used as calibration process for the *πK* pairs analysis. Preliminary results on the short-lived atom lifetime measurement based on all available 2008-2010 data now are ready. The average probability of π+π− atom breakup for the Ni targets of 98 mkm thickness (RUN 2008) and 109 mkm.(RUNS 2009-2010) was evaluated as Pbr= 0.474 ± 0.01. It is in agreement with the value Pbr= 0.46 ± 0.013 obtained for the 98mkm target and published in 2011. In the final data analysis the new measurements of multiple scattering will be include.

2. The current value of systematical error in the π+π− atom lifetime measurement is equal to statistical uncertainty. The main part of systematical error arises due to an uncertainty in 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), 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 of ±2σ. The achieved precision of multiple scattering investigation is better on one order of magnitude than in the previous experiments. The dedicated paper will be published in 2018.

**VIII. Preparation of a Letter of Intent and the activity in PBC Committee**

The report about the investigation of dimesoatoms at SPS energy was presented at the workshop “Physics Beyond Colliders” in 2016 and the work with PBC Committee is continuing during 2017: the dedicated reports were presented on the Beam Working Group in February 2017 and on the QCD working group in March 2017. The one of the main requirement of the Beam Working Group is decreasing of the future setup width up to 6 meters. The dedicated scheme with the width less than 6 meters is ready and was presented on the PBC Committee in November 2017.

**IX. Measurement of *K*+π−, *K*−π+ and π+π− atoms production cross sections in proton interaction with Be, Ni and Pt nuclei basing of 2007-2012 experimental data will be done in 2019**

Dedicated measurements of the proton flux and the dead time in electronics and 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. The dedicated paper will be published in 2019.