CERN, April 2015

DIRAC collaboration status report 2015

I. Long-lived $\pi^+\pi^-$ atom – first observation

Experimental distributions of $\pi^+\pi^-$ pairs as a function of relative momentum Q components have been fitted by simulated distributions of atomic, Coulomb and non-Coulomb pairs generated on the Pt foil and Be target. Their corresponding numbers n_A, N_C and N_{nC} are free parameters in the fit. In the analysis using two dimensional $|Q_L|$-Q_T distributions the experimental data in the intervals $0 \le Q_L \le 15$ MeV/c and $0 \le Q_T \le 2$ MeV/c have been analysed using two dimensional simulated distributions.

The projection of the two dimensional distributions of experimental $\pi^+\pi^-$ pairs and the three types of simulated pairs on the Q_L axis are presented in the upper plot of figure 1 . In the low Q_L region one observes an excess of events over the sum of Coulomb and non-Coulomb pairs, where atomic pairs are expected. After background subtraction there is a statistically significant signal (lower plot of figure 1) with $n_A=433\pm57$. The signal shape is described by simulated distribution of atomic pairs created by long-lived atoms breaking in the Pt foil. The upper plot of figure 2 shows the projection of the same two dimensional distributions on the Q_T axis with the same free parameters. After background subtraction in the low region one observes a statistically significant signal with the shape described by the simulated Q_T distribution of atomic pairs created after long-lived atoms break up in the Pt foil (lower plot of figure 2). The number of atomic pairs in the region $0 \le Q_T \le 4.0$ MeV/c was determined to be $n_A=426\pm56$. The atomic pair selection efficiency for different cuts on Q_T is known from the simulation. Using this efficiency the total number of atomic pairs created in the Pt foil is 488±64.

In the one-dimensional analysis the distributions over $|Q_L|$ are fitted using different cuts $Q_T \le 0.5$, 1.0, 1.5, 2.0 MeV/c to study explicitly the stability of the number of atomic pairs to the background level. The numbers of atomic pairs detected n_A and total numbers of atomics pairs are show in table 1. The background level at $Q_T \le 2$ MeV/c is 17 times higher than the background at $Q_T \le 0.5$MeV/c. Nevertheless, the values in the one-dimensional and two-dimensional analyses coincide, taking into account their statistical errors. This confirms the signal stability to the background level and to the limits on Q_T where the analysis is performed.

Table 1 Results of data analyses for data collected in 2012 for different Q_T cuts. Estimation of atomic pair number and total atomic pair number, taking into account the selection efficiency (pair fit criterion on Q_T), fit quality χ^2/ndf and background contribution coming from Coulomb, non-Coulomb and accidental pairs. Errors are statistical only.

Q_T^{cut}	n_A	n_A^{tot}	χ^2/ndf	Background for Q_T ≤1.5 MeV/c
Q_T <0.5 MeV/*c*	152±29 (5.2σ)	467±88	29/27	971
Q_T <1.0 MeV/*c*	349±53 (6.5σ)	489±75	19/27	3692
Q_T <1.5 MeV/*c*	386±78 (4.9σ)	454±91	22/27	9302
Q_T <2.0 MeV/*c*	442±105 (4.2σ)	495±117	22/27	16774
Two-dimensional fit over $Q_L Q_T$ ***Q_T <2.0 MeV/c***	**433±57 (7.6σ)**	**488±64**	**138/140**	**16790**

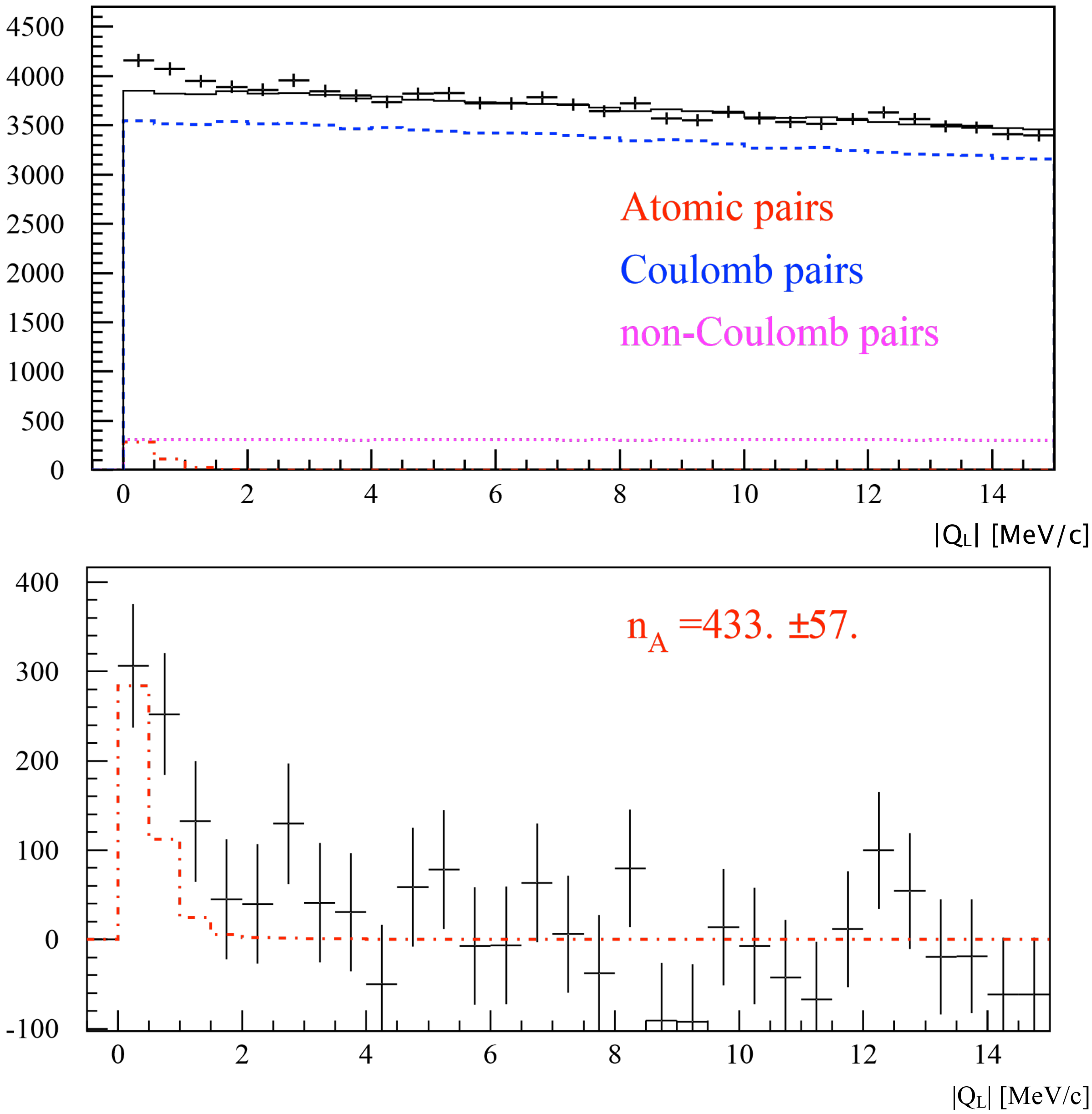

Fig.1 Distribution of $\pi^+\pi^-$ pairs as a function of the absolute value of the longitudinal component of the relative momentum $|Q_L|$ at Q_T<2.0 MeV/*c*. The upper picture shows the experimental distribution (points with errors) and all simulated background (black solid line). The lower picture shows the distribution after the background subtraction (points with errors) and simulated distribution of atomic pairs (red dotted-dashed line). The fitting procedure was done with parameters evaluated from the two-dimensional $|Q_L|$ Q_T distribution analysis.

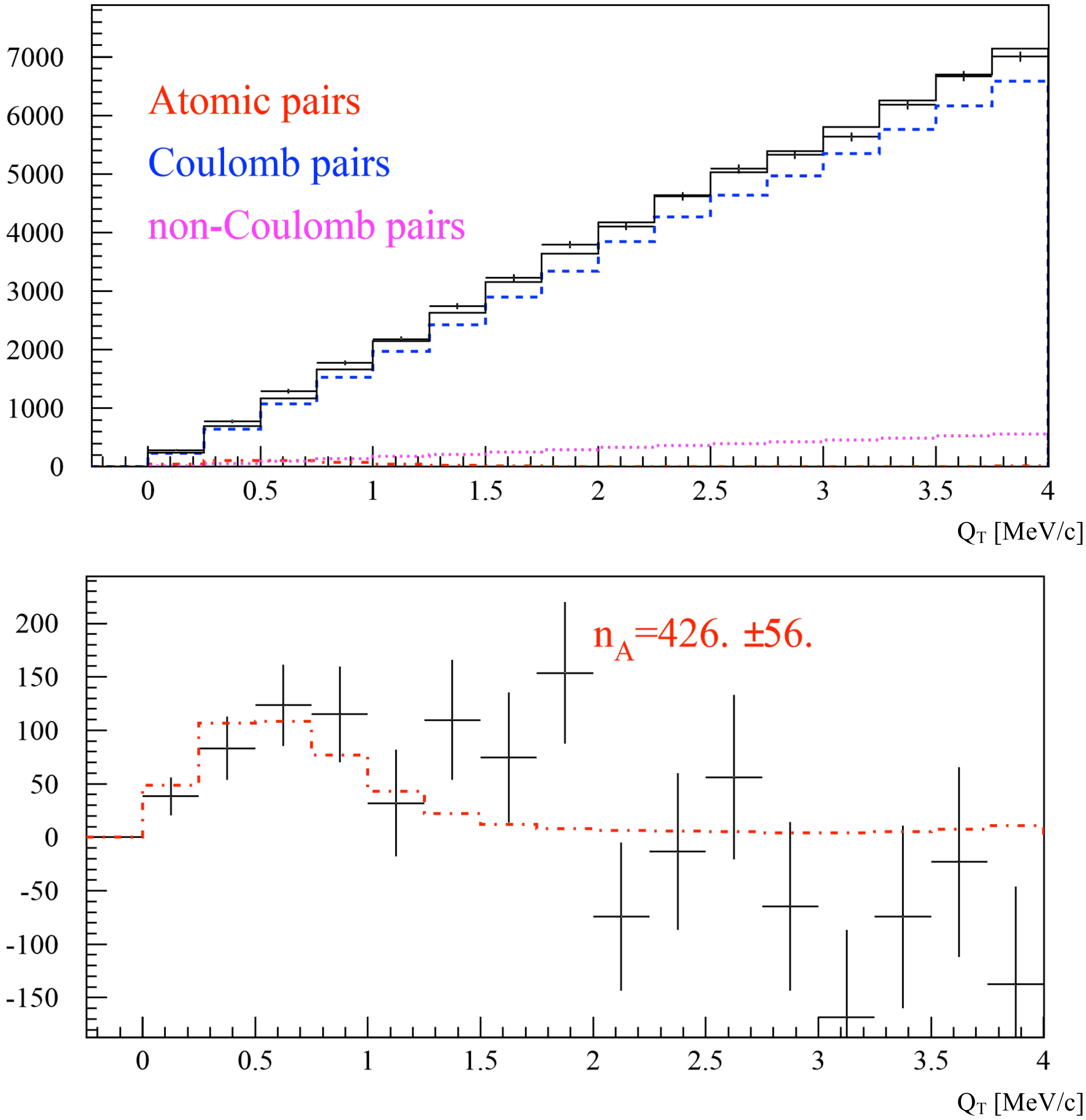

Fig.2 Distribution of $\pi^+\pi^-$ pairs over the transverse component of the relative momentum Q_T at $|Q_L|<2.0$ MeV/c. The upper picture shows the experimental distribution (points with errors) and all simulated background (black solid line). The lower picture shows the distribution after the background subtraction (points with errors) and the simulated distribution of atomic pairs (red dotted-dashed line). The fitting procedure used the parameters evaluated from the two-dimensional $|Q_L|Q_T$ distribution analysis.

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The measurement of the number of atomic pairs n_A depends on the accuracy of the description of the simulated distributions for ``Coulomb'', ``non-Coulomb'' and ``atomic pairs''. If the shapes of the simulated distributions differ from the experimental ones then the values of the fit parameters could be biased. For the case of the search for long-lived atoms, the shapes of the ``Coulomb'' and ``non-Coulomb'' pairs generated in the Be target are similar in phase-space. Therefore only an error in the ``atomic pair'' (Pt) distribution could lead to a systematic error. The reasons for the uncertainty in resolution over Q_L and Q_T have been investigated for data collected in 2001-2003 and 2008-2010. Two main sources of systematic errors have been found. The final accuracy of the Lambda correction (modification of the resolution as function of Q_L comparing widths of experimental and simulated distributions of Proton-π^- pairs from the Lambda decay) gives a systematic error of 4.4. The accuracy of the Pt foil thickness measurement induces the main uncertainty in the resolution as a function of Q_T. It gives a systematic error of 22.0 for the two-dimensional analysis. For the one-dimensional analysis over $|Q_L|$ this error is practically 0.

Another problem is the hypothetical admixture of ``Coulomb'' and ``atomic'' pairs generated due to the interaction of beam halo protons with the Platinum foil. The peak induced by the Coulomb interaction in the final state would be in the same position as ``atomic pairs'' from metastable atoms. The level of the beam halo and the intensity of interactions with the Platinum foil have been investigated. It is shown that the flux of particles generated on the Platinum foil is practically negligible at its working position. Nevertheless, as an additional check, data have been analysed with ``Coulomb pairs'' generated in the Platinum foil instead of ``atomic pairs'' from metastable atoms. It has been shown statistically that the peak cannot be produced by ``Coulomb pairs'' generated in the Platinum foil. From the two-dimensional analysis, the evaluated number of atomic pairs is n_A=433±61 or 7.1 standard deviations, taking into account both statistical and systematic errors.

To obtain the expected number of atomic pairs after long-lived atoms breakup in the Pt foil the pairs generated on the Be target were analysed. For the evaluation of the initial value of Q_Y(Q_T) 12.9 MeV/c was subtracted from the reconstructed Q_Y. The two-dimensional experimental $|Q_L|$-Q_T distribution has been fitted by simulated distributions of atomic, Coulomb and non-Coulomb pairs generated in the Be target. Their corresponding numbers n_A, N_C and N_{nC} are free parameters in the fit. After obtaining N_C from the fit, the total number of $\pi^+\pi^-$ atoms Na=17043+-410 was calculated using the precise (1%) ratio between Na and the number of Coulomb pairs with small Q. It is known from the simulation that about 2.5% of the produced $\pi^+\pi^-$ atoms, Na, break in the Pt foil generating 426+-10 atomic pairs; this is in agreement with the measured quantity of 433+-57. This value does not take into account the influence of the magnetic field between the target and the Pt foil. The influence of this field on the atoms with n=2,3,4 is not significant because its strength is small.

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

The experimental data obtained in 2007, 2008, 2009, 2010 and 2012 were reprocessed. For each run period a new geometry calibration was performed and the new experimental ntuples were produced. The scintillating fiber detector response was improved for the 2007, 2008, 2009 and 2010 runs and before the end of April the new response will be finished for the 2012 run. The new Monte-Carlo ntuples are ready for the runs in 2007 and 2008. The 2009 and 2010 new M.C. ntuples will be ready before the end of May and the 2012 run will be finished in the middle of June. The main aim of this analysis is to use the data with the Pt and Ni targets with low background and part of the statistics with high background to detect the $K^+\pi^-$ and $K^-\pi^+$ atomic pairs at the level of 5 standard deviations and to improve the precision of the K-pi scattering length measurements.

III. K^+K^- pair analysis

The search for K^+K^- Coulomb pairs in the existing data will be performed, and the number of K^+K^- atoms, produced simultaneously with the Coulomb pairs, will be extracted. During the first part of the work, until July 2015, we will analyse K^+K^- pairs with a total momentum in the laboratory system (l.s.) between 2.8 GeV/c and 6.0 GeV/c.
Should we see a signal, Coulomb pairs will also be searched for in the higher momentum region between 6.0 GeV/c and 9.6 GeV/c.

IV. Proton-antiproton pair analysis

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 IV). The search for the proton-antiproton Coulomb pairs in the lower momentum region will be finished before May 2016.

V. $\pi^+\mu^-$ and $\pi^-\mu^+$ pair analysis

Analogously the 2010 experimental data will be searched for $\pi^+\mu^-$ and $\pi^-\mu^+$ Coulomb pairs with the aim of extracting the number of πμ atoms produced simultaneously with the Coulomb pairs. The analysis was finished in January 2015. An upper limit on the atom production will be calculated.

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^-, π^+ and π^- in p-nucleus interactions at 24GeV/c and 450GeV/c is under preparation. The 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.

Table 1: The yield of $\pi^+\pi^-$, π^+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 versus emission angle θ_{lab}. Correction factors are used and $R_{24\mathrm{GeV/c}}$ were set to be equal to $R_{450\mathrm{GeV/c}}$. are yields normalized one for DIRAC at PS.

θ_{lab}	5.7°	4°	2°	0°
E_p	24 GeV/c	450 GeV/c	450 GeV/c	450 GeV
The yield of $\pi^+\pi^-$ atoms				
W_A	$(1.73 \pm 0.09)\cdot10^{-9}$ 1	$(1.7 \pm 0.2)\cdot10^{-8}$ 9.7 ± 1.5	$(3.0 \pm 0.5)\cdot10^{-8}$ 17.5 ± 2.8	$(3.9 \pm 0.6)\cdot10^{-8}$ 22.7 ± 3.6
The yield of π^+K^- atoms				
W_A	$(1.46 \pm 0.09)\cdot10^{-11}$ 1	$(6.6 \pm 1.1)\cdot10^{-10}$ 45 ± 8	$(1.31 \pm 0.21)\cdot10^{-9}$ 87 ± 15	$(1.52 \pm 0.24)\cdot10^{-9}$ 104 ± 18
The yield of $K\pi$ atoms $+\,-$				
W_A	$(4.2 \pm 0.3)\cdot10^{-11}$ 1	$(7.9 \pm 1.6)\cdot10^{-10}$ 18.6 ± 4.1	$(1.8 \pm 0.4)\cdot10^{-9}$ 41 ± 9	$(2.2 \pm 0.5)\cdot10^{-9}$ 52 ± 11

VII. Preparation of a Letter of Intent about the investigation of dimesonic atoms at SPS energy before November 2015

VIII. Use of experimental data 2007-2012 to measure production cross sections for $K^+\pi^-$, $K^-\pi^+$ and $\pi^+\pi^-$ atoms in proton interaction with Be, Ni and Pt nuclei in 2016

IX. Instrumental publication

The second draft of the paper "Updated DIRAC spectrometer at CERN PS for the investigation of $\pi\pi$ and $K\pi$ atoms" has been distributed within the collaboration. This paper covers all the details of the detectors and discusses the overall performance of the spectrometer.