Status Report of the DIRAC Experiment - PS 212

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Contents

1. Experimental check of QCD using π^+K^- $\pi^- K^+$ and $\pi^+\pi^-$ atoms.

2. π^+K^- and $\pi^- K^+$ atoms status

3. Long-lived $\pi^+\pi^-$ atom lifetime first measurement.

4. Observation of K^+K^- Coulomb pairs and K^+K^- atoms production.

5. Short-lived $\pi^+\pi^-$ atoms analysis.

6. The new physical method to investigate the particle production in the coordinate space.

7. $K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$ and K^+K^- atom production at SPS CERN

DIRAC set-up

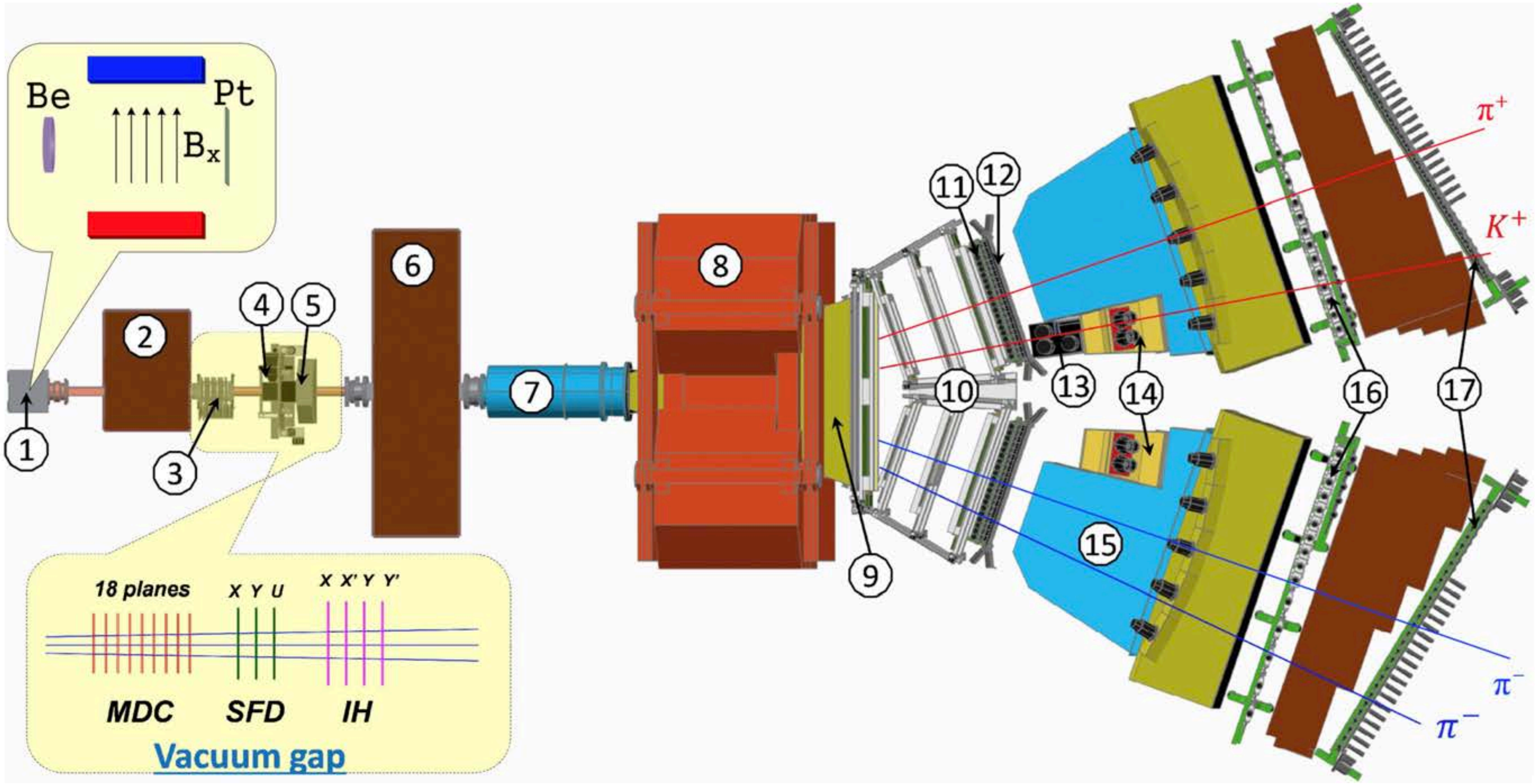
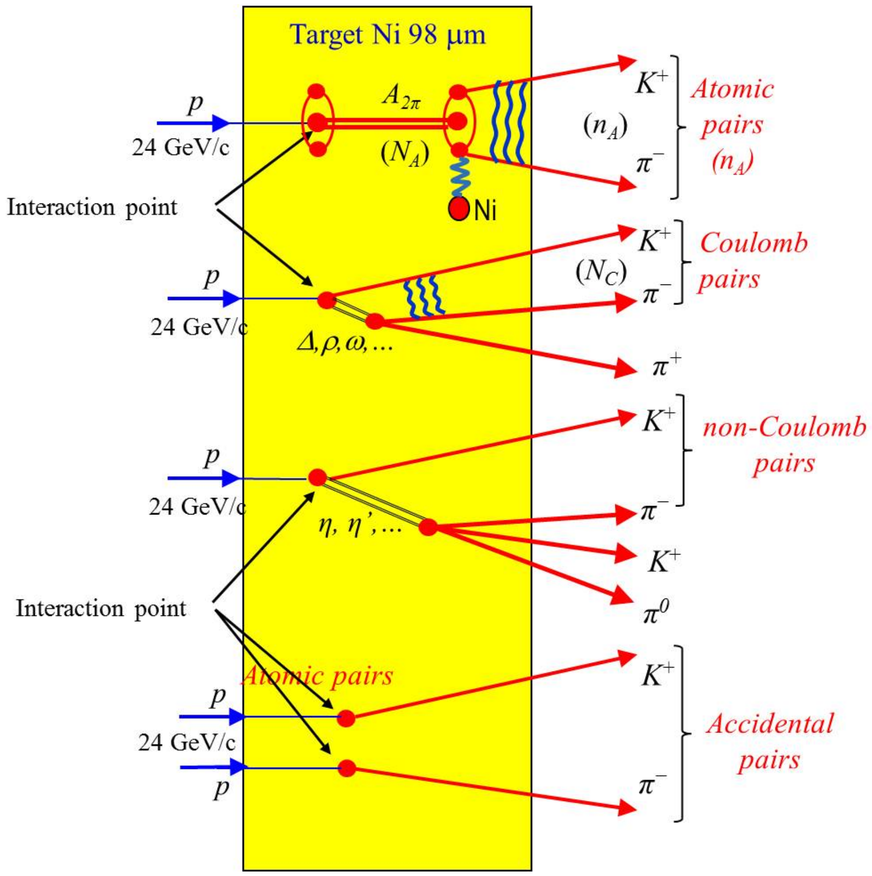


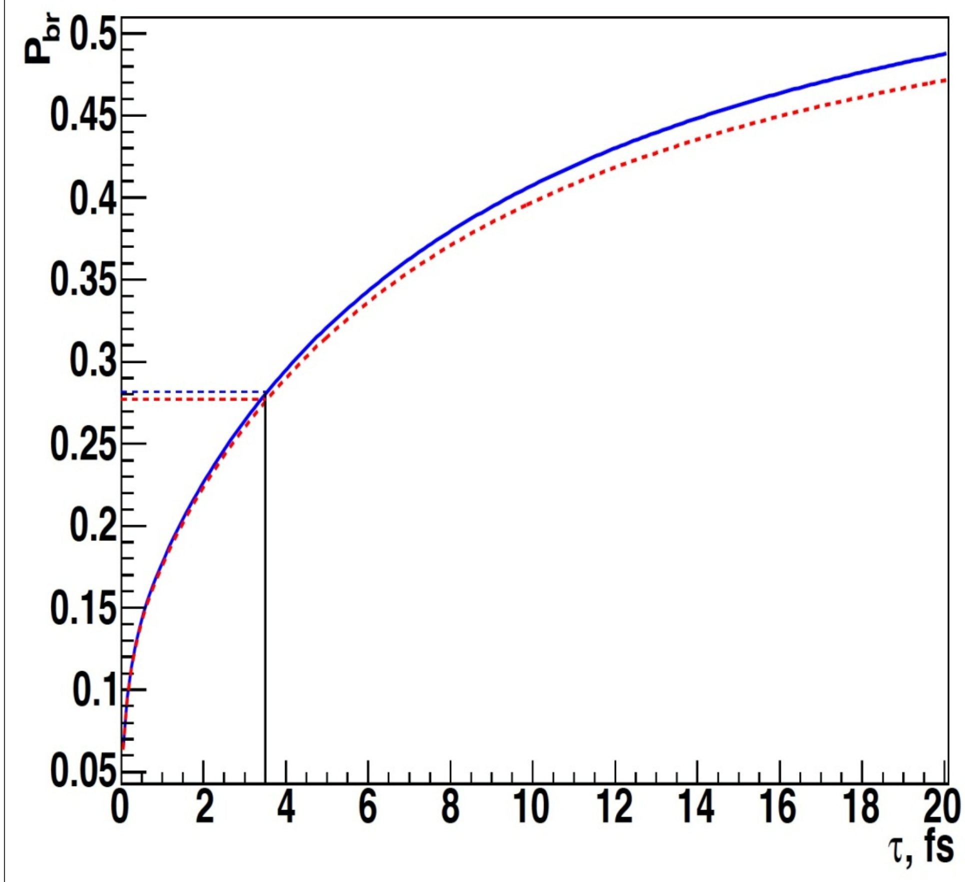
Fig. 2. General view of the DIRAC setup:
1 -- target station with insertion, showing the *Be* target, magnetic field and *Pt* breakup foil; 2 -- first shielding;
3 -- microdrift chambers (MDC); 4 -- scintillating fiber detector (SFD); 5 -- ionisation hodoscope (IH);
6 -- second shielding; 7 -- vacuum tube; 8 -- spectrometer magnet; 9 -- vacuum chamber; 10 -- drift chambers (DC);
11 -- vertical hodoscope (VH); 12 -- horizontal hodoscope (HH); 13 -- aerogel Cherenkov; 14 -- heavy gas Cherenkov;
15 -- nitrogen Cherenkov; 16 -- preshower (PSh); 17 -- muon detector.
(The plotted symmetric and asymmetric events are a $\pi^+\pi^-$ and $K^+\pi^-$ pair, respectively.)

The πK atom lifetime and πK scattering length

$$\frac{1}{\tau} = R\,|a_{1/2}-a_{3/2}|^2$$

$\tau_{th} = (3.5 \pm 0.4) \times 10^{-15}$ s. The evaluation error from this relation for $|a_{1/2}-a_{3/2}|$ is 1%





QCD Lagrangian and its prediction

The QCD Lagrangians use the $SU(3)_L*SU(3)_R$ and $SU(2)_L*SU(2)_R$ chiral symmetry breaking.

$$\mathcal{L}(u,d,s) = \mathcal{L}(3) = \mathcal{L}_{sym}(3) + \mathcal{L}_{sym.br.}(3)$$

$$\mathcal{L}(u,d) = \mathcal{L}(2) = \mathcal{L}_{sym}(2) + \mathcal{L}_{sym.br.}(2)$$

$\mathcal{L}_{sym.br.}$ is proportional to m_q

$e^+e^- \rightarrow$ hadrons

QCD provides cross sections with 1% precision

1. Perturbation theory is working at high momentum transfer Q.
2. Unitarity condition.

At large Q, contribution of $\mathcal{L}_{sym.br.}$ to the cross section is proportional to $1/Q^4$.
Therefore these experiments checked only the $\mathcal{L}_{sym}$ prediction precision.

To check the total $\mathcal{L}(3)$ Lagrangian predictions, we must study the low momentum transfer Q processes.

Tools: Lattice calculations and Chiral Perturbation Theory (ChPT)

Lattice----- $\mathcal{L}(3)$, $\mathcal{L}(2)$ ChPT------Effective Lagrangians.

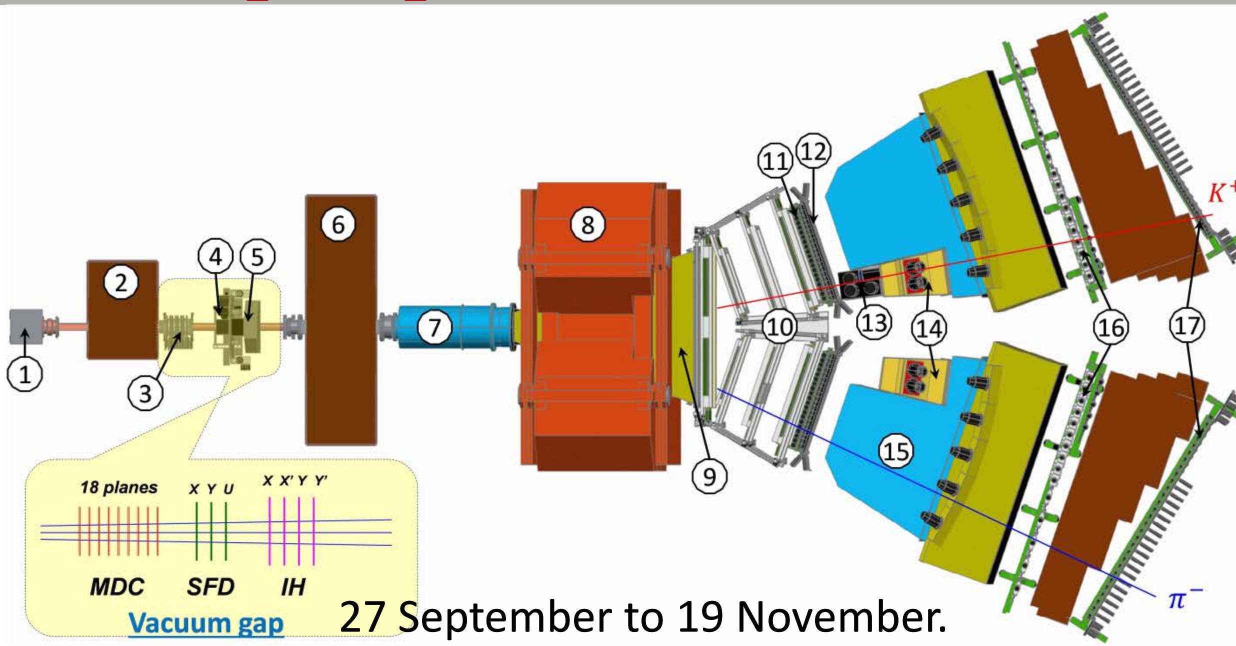
Measurement of the πK scattering length

The *S*-wave *πK* scattering lengths $a_{1/2}$ and $a_{3/2}$ in the chiral symmetry world are zero. Therefore the scattering length values $a_{1/2}$ and $a_{3/2}$ are very sensitive to the $\mathcal{L}_{sym.br.}(3)$.

For Lattice QCD the *πK* interaction at threshold is a relatively simple process. It gives *πK* scattering length values with an average precision of 5%.
This precision will be improved in the near future.

There is only one experimental data: DIRAC collaboration observed 349±62 *πK* atomic pairs (*Phys.Rev.Lett*. 2016) and measured $|\boldsymbol{a}_{1/2}-\boldsymbol{a}_{3/2}|$ with an average precision of 34% (*Phys.Rev.D* 2017).

DIRAC setup, experimental and theoretical data



27 September to 19 November.

Experiment	Detected atomic pairs (n_A)	τ (10^{-15} sec)	$a^- = \frac{1}{3}(a_{1/2}-a_{3/2})$	Average error
DIRAC	349±61(stat)±9(syst) =349±62(tot) (5.6σ)	$5.5^{+5.0}_{-2.8}$	$0.072^{+0.031}_{-0.020}$	34%

Theory	P.Buttiker et al., Eur.Phys.J. (2004)	K.Sasaki et al., Phys.Rev. (2014)	Z.Fu, Phys.Rev. (2013)	S.R.Beame et al. Phys.Rev (2008)	C.Lang et al.,Phys.Rev. (2012)	J.Bijnens et al., J. High Energy Phys. (2004)
a^-	0.090±0.005	0.081	0.077	0.077	0.10	0.089
Method	Roy-Steiner equations	Lattice calculations	Lattice calculations	Lattice calculations	Lattice calculations	ChPT, two loops

QCD and Chiral Lagrangian predictions check with long-lived $\pi^+\pi^-$ atoms

The DIRAC collaboration Phys.Lett.(2015) observed 436±61 pion pairs from the long-lived ($\tau \geq 1\times10^{-11}$ sec) $\pi^+\pi^-$ atom breakup in Pt foil(Phys.Lett.(2015).

The short-lived atoms lifetime measurement allowed to evaluate ππ scattering length combination $a_0 - a_2$.
The study of the long-lived atoms will allow to measure the Lamb shift depending on another ππ scattering length combination: $2a_0+a_2$ and to evaluate the a_0, a_2 separately.

The $\pi^+\pi^-$ atoms production in Be target

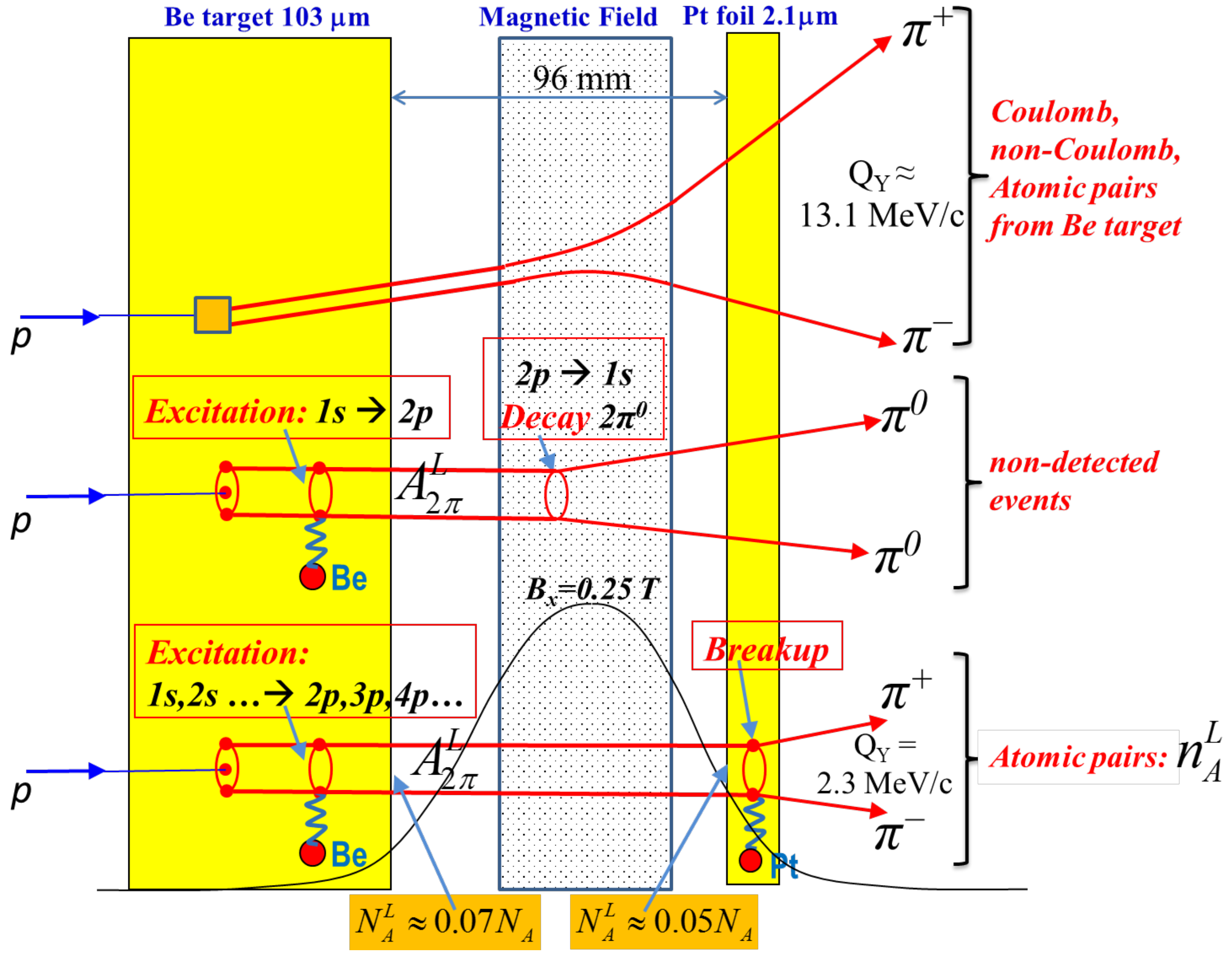


Fig. 1 Method to observe long-lived $A^L{}_{2\pi}$ by means of a breakup foil (*Pt*). The most of the produced $\pi^+\pi^-$ atoms decay (~70%) or are ionized (~6%) in the *Be* target. The excited (long lived) atoms (~24%) are investigated here.

$\pi^+\pi^-$ atom lifetime and decay lengths

n	$\tau_{2\pi}$ (10^{-11}sec)		Decay length $A_{2\pi}$ in L.S. (cm) for γ=16 ($\lambda_{ns}=c \cdot \gamma \cdot \tau_{nl}$)	
	s (l=0) $\tau_{ns}=\tau_{1s} \cdot n^3$	p (l=1)	s (l=0)	p (l=1)
1	$2.9 \cdot 10^{-4}$	-	$1.39 \cdot 10^{-3}$	-
2	$2.32 \cdot 10^{-3}$	1.17	$1.11 \cdot 10^{-2}$	5.6
3	$7.83 \cdot 10^{-3}$	3.94	$3.76 \cdot 10^{-2}$	19
4	$1.86 \cdot 10^{-2}$	9.05	$8.91 \cdot 10^{-2}$	43
5	$3.63 \cdot 10^{-2}$	17.5	$1.74 \cdot 10^{-1}$	84
6	$6.26 \cdot 10^{-2}$	29.9	$3.01 \cdot 10^{-1}$	144
7	$9.95 \cdot 10^{-2}$	46.8	$4.77 \cdot 10^{-1}$	225
8	$1.48 \cdot 10^{-1}$	69.3	$7.13 \cdot 10^{-1}$	333

Long-lived states of $\pi^+\pi^-$ atoms

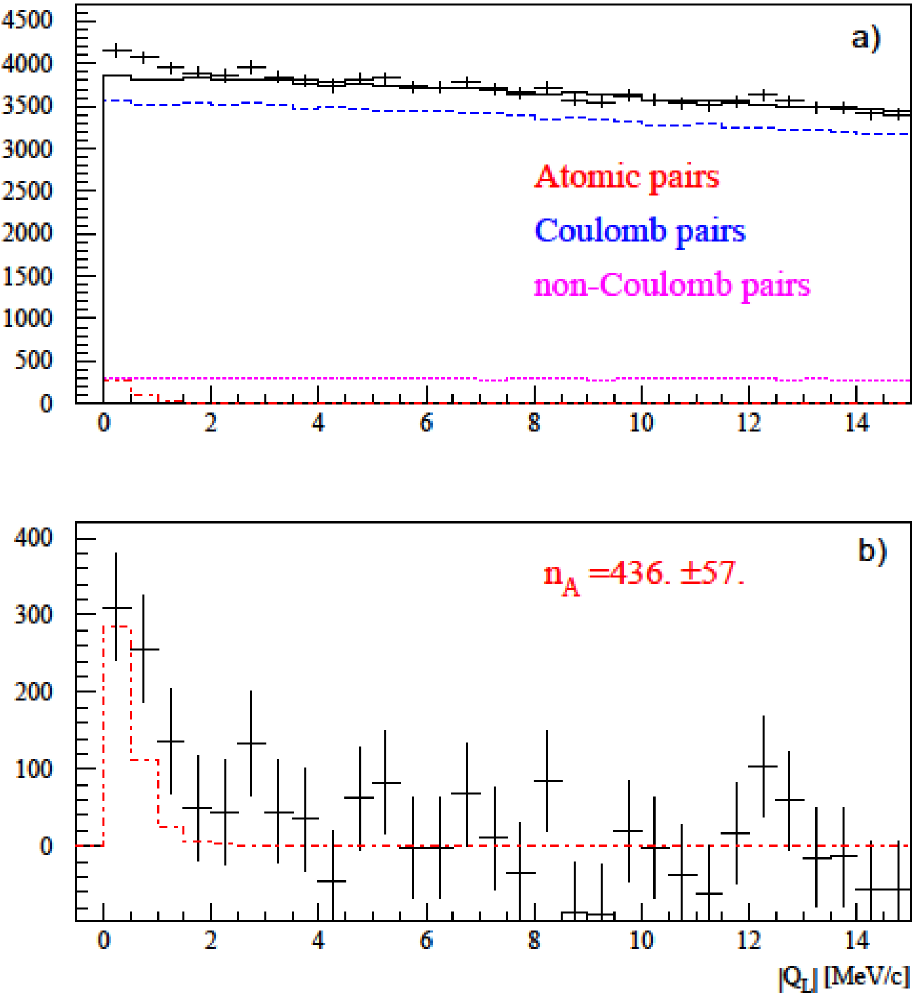


Fig. 6. |Q_L| distribution of $\pi^+\pi^-$ pairs for Q_T< 2.0 MeV/c

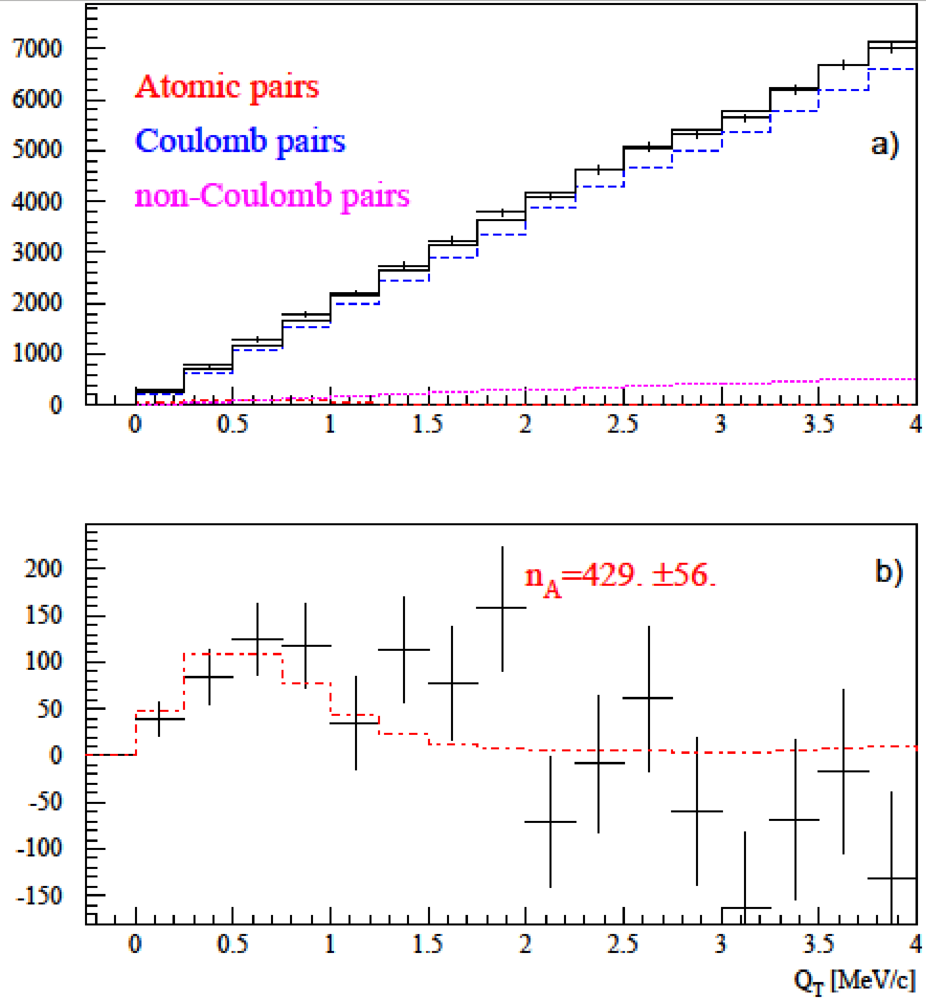


Fig.7. Q_T distribution of $\pi^+\pi^-$ pairs for |Q_L|< 2 MeV/c

a) Experimental distribution (points with statistical error) and the simulated background (solid line).
b) Experimental distribution after background subtraction (points with statistical error) and the simulated distribution of atomic pairs (dotted-dashed line). The fit procedure has been applied to the 2-dimensional (|Q_L|,Q_T) distribution.

Lifetime of long-lived $\pi^+\pi^-$ atoms

Number of atoms generated on Be target: $N_A = 16960 \pm 290|_{\text{tot}}$

Number of long-lived atoms after Be target: $N_A^{L,\text{Be}} = 1153 \pm 104|_{\text{tot}}$

Number of atoms entered Pt foil: $N_A^{L,\text{Pt}} = 501^{+184}_{-80}|_{\text{tot}}$

Number of atomic pairs after Pt foil: $n_A = 436 \pm 157|_{\text{tot}}$

The lifetime of long-lived atom in simple approach:

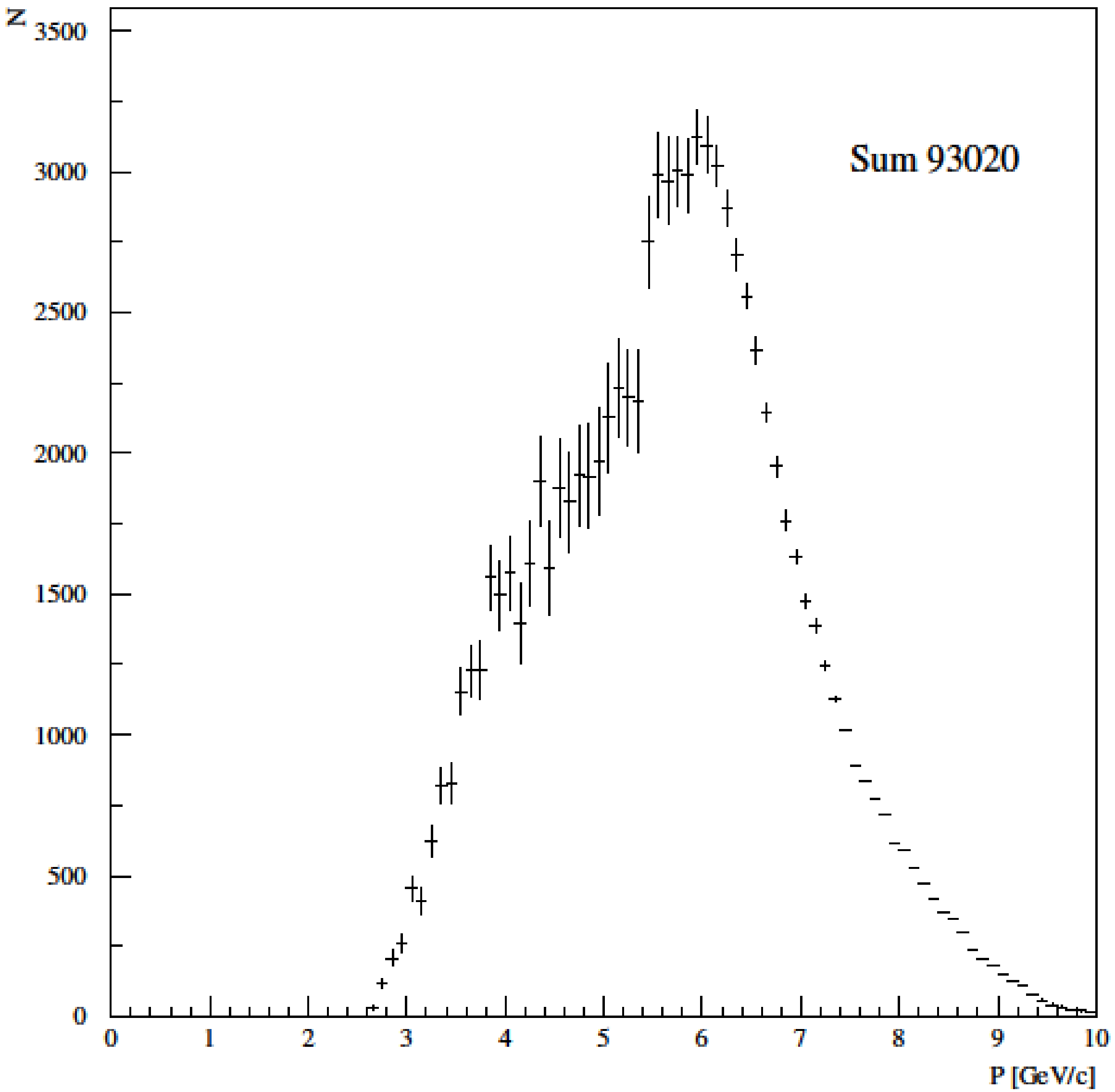
$$\tau_L = \left(1.21 \pm 0.19|_{\text{stat}} \begin{matrix}+0.75\\-0.18\end{matrix}\Big|_{\text{syst}}\right) \times 10^{-11} = 1.21^{+0.77}_{-0.26}\Big|_{\text{tot}} \times 10^{-11}\text{s}$$

$$\text{QED: } \tau_{2p} = 1.17 \times 10^{-11}\text{s}$$

The measured ground state lifetime: $\tau_{1s} = 3.15^{+0.28}_{-0.26}\Big|_{\text{tot}} \times 10^{-15}\text{s}$

K^+K^- pair analysis

Search for the K^+K^- Coulomb pairs signal



Distribution of K^+K^- pairs in the RUN 2010 over the full pair momentum in laboratory system.

For the K^+K^- Coulomb pair signal analysis it was selected pairs with low lab. momentum 2.6<P<4.0 GeV/c and high lab. momentum 6<P<10 GeV/c.
In these two intervals the level of the background is relatively small (see the error bar values).

K^+K^- pair analysis

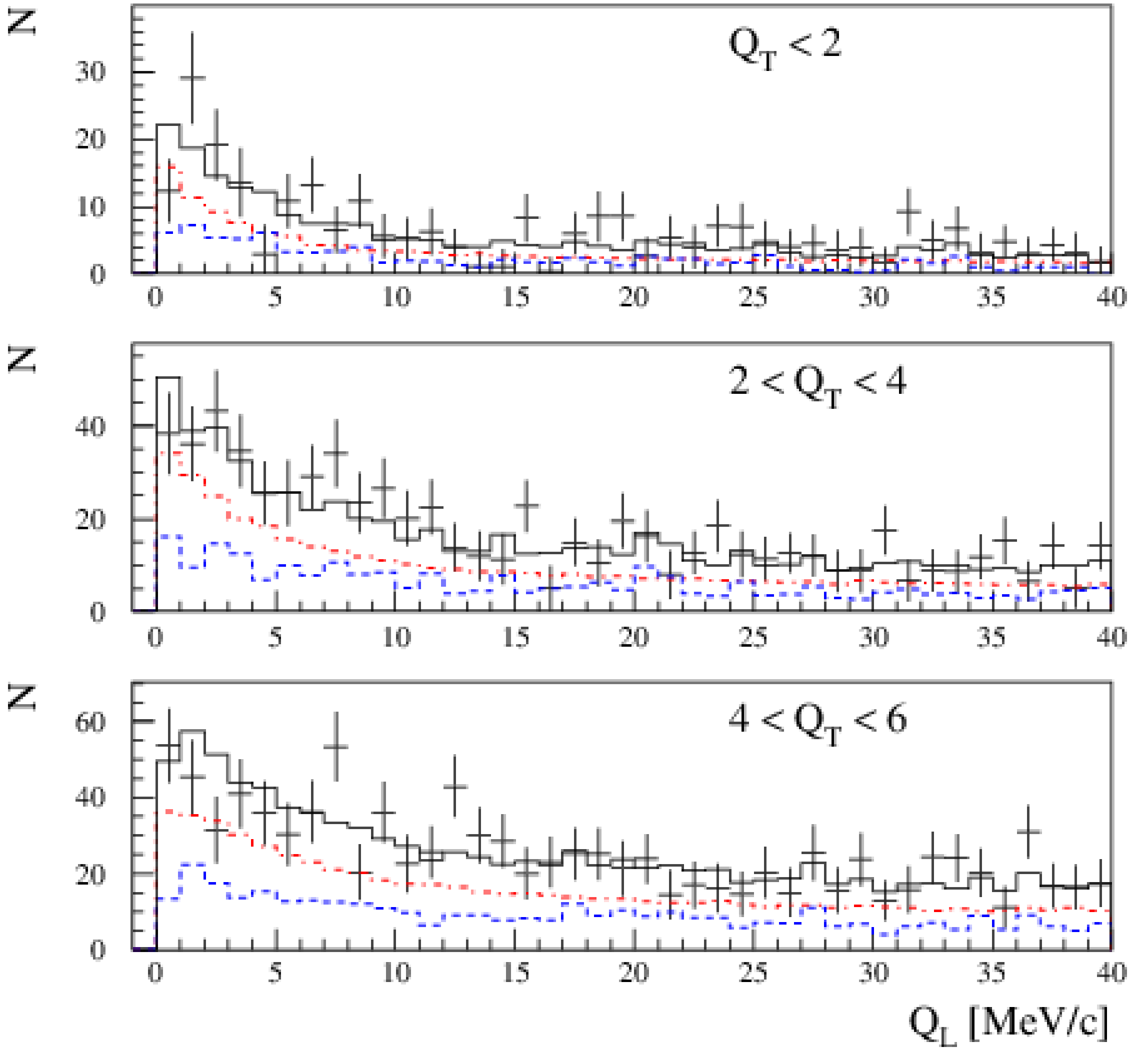


Fig.6. Experimental distributions of selected events. Events are fitted by the simulated distribution of K^+K^- pairs (red) and experimental distribution of pure $\pi^+\pi^-$ (blue) processed with kaon masses. The number of K^+K^- pairs is 2180 ± 200, the number of $\pi^+\pi^-$ pairs is 1340 ± 200.

K^+K^- pair analysis

1. 2180 ± 200 K^+K^- pairs with $Q_T < 6$ MeV/c were identified in the RUN 2010. The total number of K^+K^- pairs with $Q_T < 6$ MeV/c after processing of all statistics is expected to be about 4000 events.

2. The number of produced K^+K^- atoms and upper limit of their lifetime will be evaluated for the first time from the number of K^+K^- Coulomb pairs with small relative momentum in their center of mass.

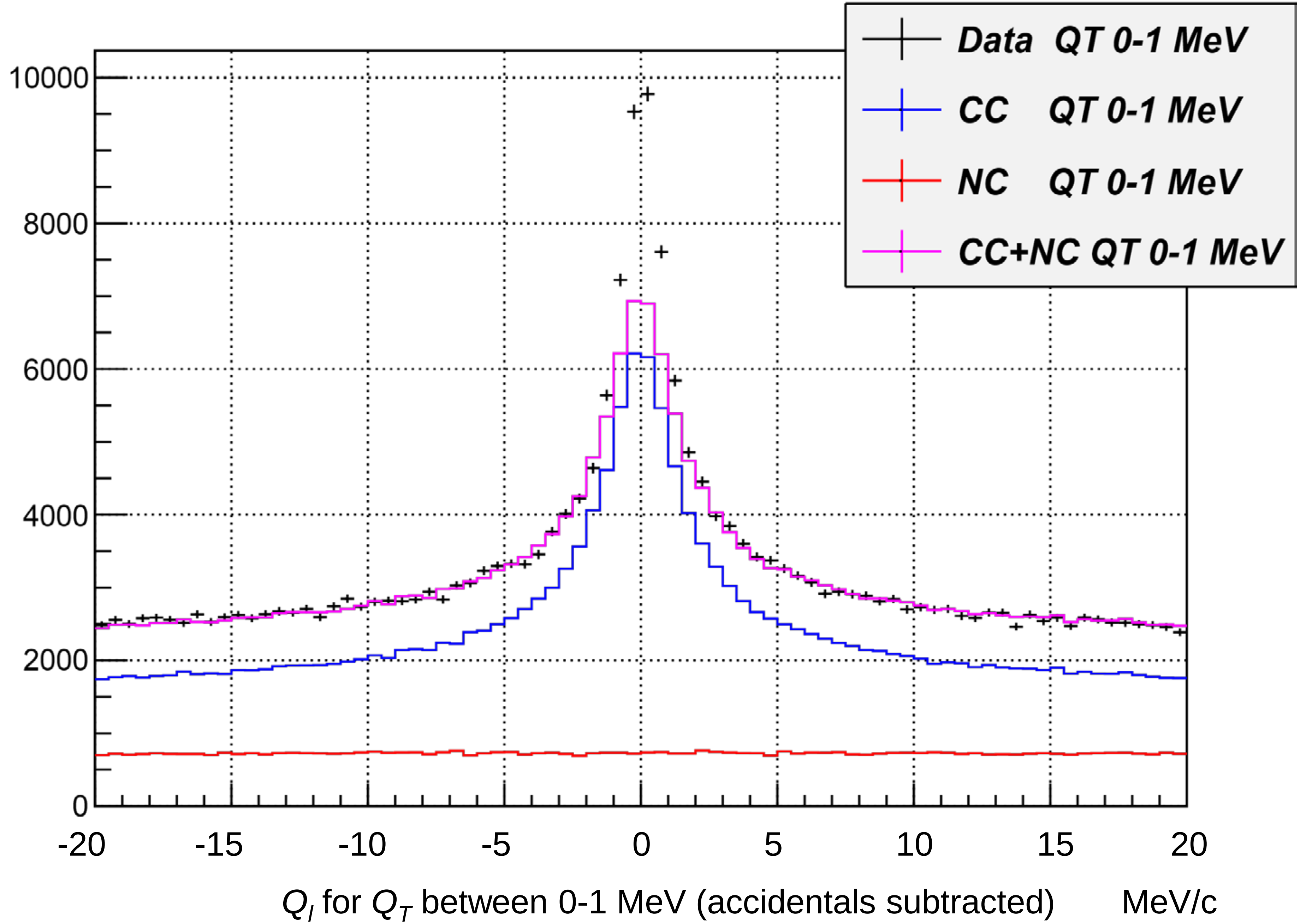
3. The simulation of K^+K^- atoms yield and spectrum using CERN version of FRITIOF generator for proton momentum 24 GeV/c and 450 GeV/c is finished.

4. Results of K^+K^- pairs investigation will be finished and published in 2018.

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.

Investigation results will be published in 2019.



Data QT 0-1 MeV
CC QT 0-1 MeV
NC QT 0-1 MeV
CC+NC QT 0-1 MeV
10000
8000
6000
4000
2000
0
-20
-15
-10
-5
0
5
10
15
20
Q_l for Q_T between 0-1 MeV (accidentals subtracted) MeV/c

Coulomb correlations

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

The shape of Coulomb correlation curve for K^+K^- and proton-antiproton pairs is expected to be much sensitive to the size of particle production region compared to the case of $\pi^+\pi^-$ pairs. Thus, detailed study of this shape could open a possibility to evaluate the size of production region for such pairs. The investigation is planned for 2018.

Coulomb correlations

Atom	Borh radius a_B [fm]	Resonance $c\tau$ [fm]
$\pi^+\pi^-$	387	ω(782) 23
K^+K^-	109	ϕ(1020) 46
$p\bar{p}$	58	

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

Coulomb correlation with account of size of pair production region r^*

$$A_c(r^*, a_B) = A_c(0)\left[1 - \frac{2r^*}{a_B} + \cdots\right]$$

Point-like Coulomb correlation

Experimental results

$\left(\text{scattering length in } m_\pi^{-1}\right)$

K→3π:

2009 **NA48/2** (EPJ C64, 589)

$$\Rightarrow a_0 - a_2 = 0.2571 \pm 0.0048\big|_{stat} \pm 0.0025\big|_{syst} \pm 0.0014\big|_{ext} = \ldots \pm 2.2\%$$

plus additional 3.4% theory uncertainty

Ke4:

2010 **NA48/2** (EPJ C70, 635)

$$\Rightarrow a_0 = 0.2220 \pm 0.0128\big|_{stat} \pm 0.0050\big|_{syst} \pm 0.0037\big|_{theo} = \ldots \pm 6.4\%$$

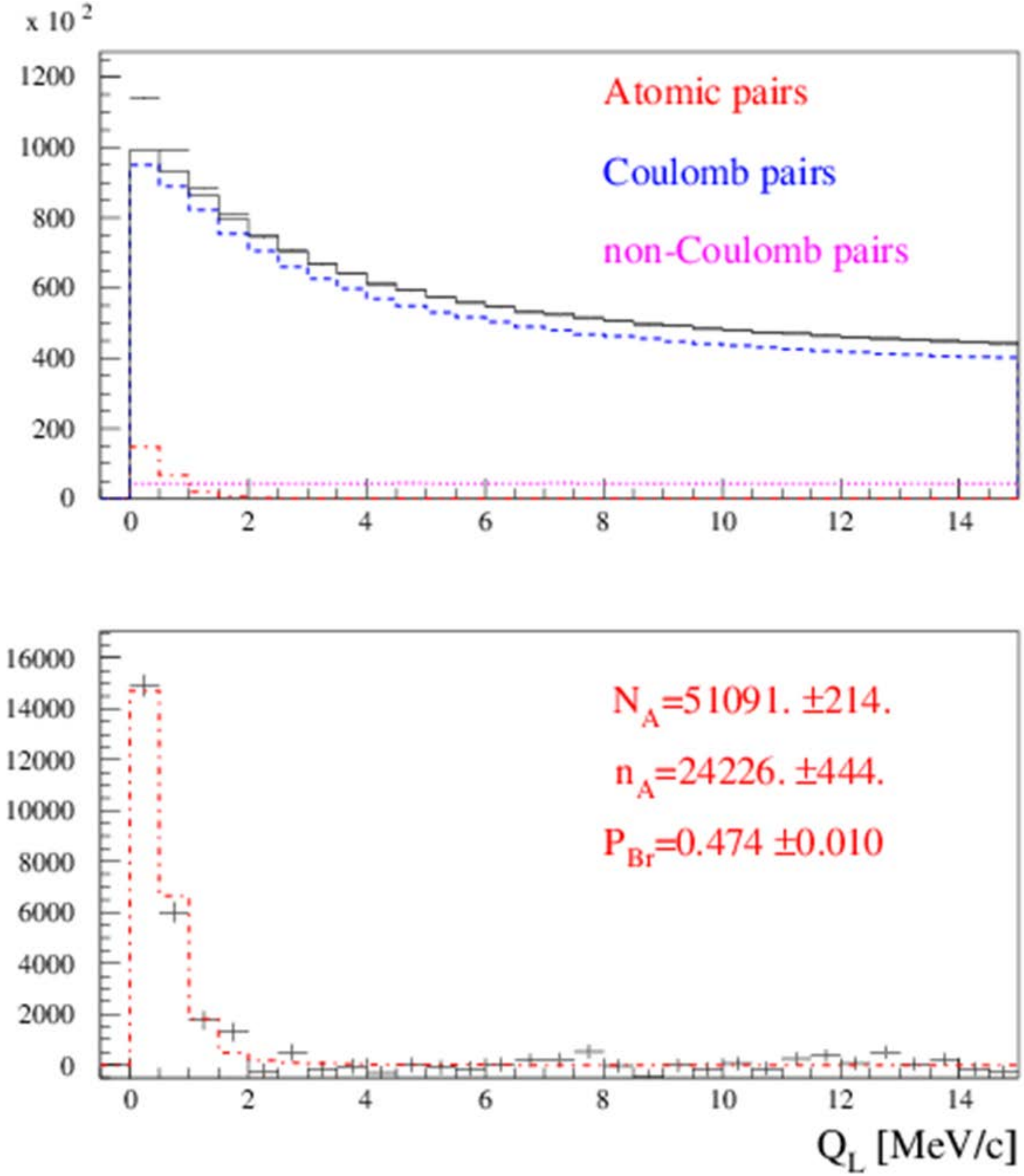
$$\Rightarrow a_2 = -0.0432 \pm 0.0086\big|_{stat} \pm 0.0034\big|_{syst} \pm 0.0028\big|_{theo} = \ldots \pm 22\%$$

$\pi^+\pi^-$ atom:

2011 **DIRAC** (PLB 704, 24)

$$\Rightarrow \left| a_0 - a_2 \right| = 0.2533 \begin{matrix} +0.0078 \\ -0.0080 \end{matrix}\Bigg|_{stat} \begin{matrix} +0.0072 \\ -0.0077 \end{matrix}\Bigg|_{syst} = \ldots \begin{matrix} +4.2\% \\ -4.4\% \end{matrix}$$

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



Preliminary results on the short-lived atom lifetime measurement based on all available 2008-2010 data are presented in Fig. 1 and 2.

Fig.1. Distribution over $|Q_L|$ for events, selected with criterion $Q_T < 4$ MeV/c. Fractions of atomic, Coulomb and non-Coulomb pairs were obtained by fitting the distri-bution over $(|Q_L|, Q_T)$ with criteria: $|Q_L|<15$ MeV/c, $Q_T < 4$ MeV/c.
N_A, n_A and P_{br}. are the number of produced atoms, detected atomic pairs and probability of the atoms breaking in the target respectively.

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

1. The average probability of $\pi^+\pi^-$ atom breakup for the Ni targets of 98 μm thickness (RUN 2008) and 109 μm (RUNS 2009-2010) was evaluated as $P_{br} = 0.474 \pm 0.01$. It is in agreement with the value $P_{br} = 0.46 \pm 0.013$ obtained for the 98 μm target and published in 2011.
In the final data analysis, the new measurements of multiple scattering will be included.
The dedicated paper will be ready before June of 2018.

2. The current value of systematical error in the $\pi^+\pi^-$ atom lifetime measurement is equal to the statistical uncertainty. The main part of the systematical error arises due to an uncertainty in the multiple scattering in the Ni target.
To reduce this error, we did an experimental study of the multiple scattering in the targets:
Be: 100 and 2000 μm; Ti: 250 μm ; Ni: 50, 109 and 150 μm and Pt: 2 and 30 μm.
For Be (2000 μm), Ni (109 μm) 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 $\pm 2\sigma$.

The achieved precision of multiple scattering investigation is better by one order of magnitude than in the previous experiments.

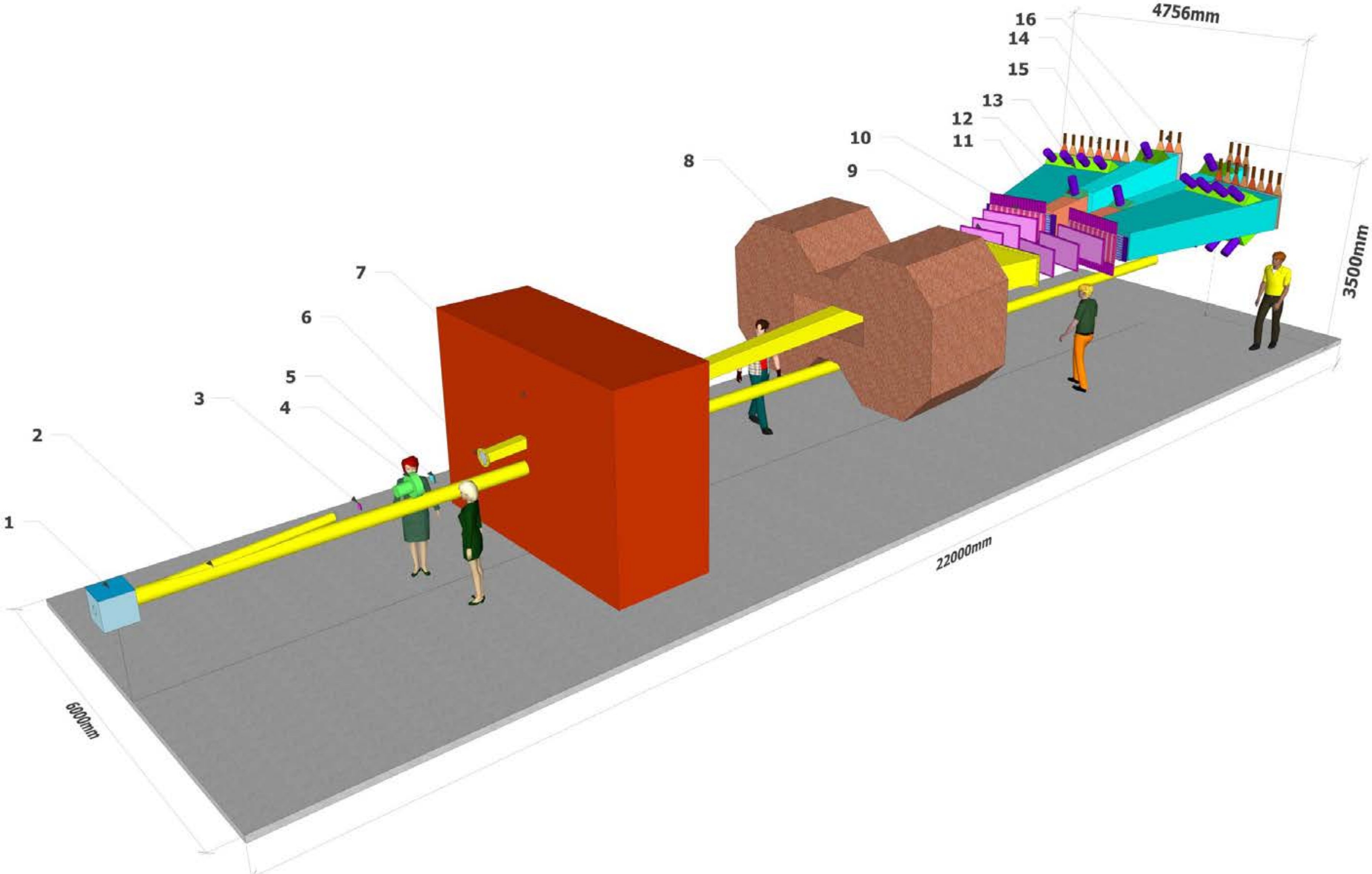
Measurement of the πK and ππ scattering length on SPS CERN

The number of produced $A_{2\pi}$, $A_{\pi^+K^-}$ and $A_{\pi^-K^+}$ per time unit at SPS CERN at p_p = 450*Gev/c*, will be 12±2, 53±11 and 24±5 times higher than in the DIRAC experiment [J.Phys. G: Nucl. Phys. 43 (2016)]

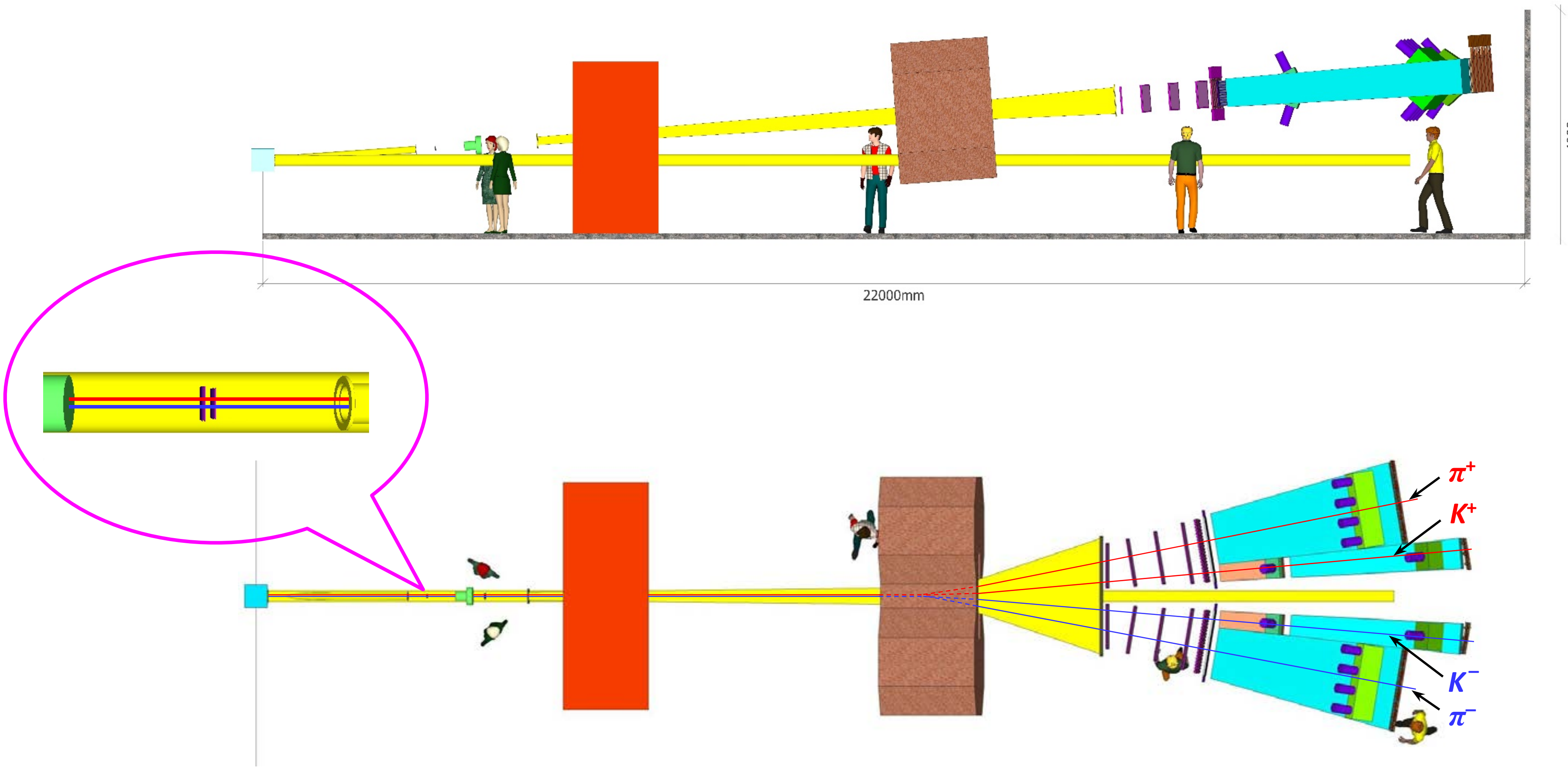
For the setup with the same parameters as in the DIRAC experiment and running time 5 months the expected statistical (sysematic) precision for πK scattering length $|a_{1/2}-a_{3/2}|$ is ~5% (2%). (The DIRAC error is 34%). It allows to check with the same accuracy predictions of the total $\mathcal{L}(3)$ QCD Lagrangian based on the chiral $SU(3)_L$*$SU(3)_R$ symmetry breaking.

Simultaniously the expected number of $\pi^+\pi^-$ atomic pairs n_A=400000 . The statistical (systematic) precision of the $\pi^+\pi^-$ scattering length will be: 0.7% (2%).

DIRAC++ (Setup Isometric view)



DIRAC++ Setup (top view)



Plan of the DIRAC collaboration in 2018 s

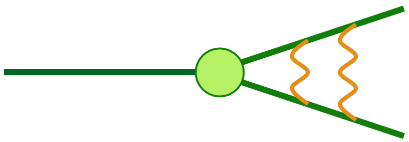
1. Production of Coulomb K^+K^- pairs, evaluation of the correspondent number of produced K^+K^- atoms and upper limit of their lifetime will be published for the first time.
2. The measurement of the long-lived $\pi^+\pi^-$ atom lifetime will be finished and published.
3. The measurement of the short-lived $\pi^+\pi^-$ atom lifetime and $\pi\pi$ scattering length will be finished and published.
4. To search for the Coulomb proton-antiproton pairs.
5. To investigate the possibility of using the Coulomb correlations in K^+K^- and proton-antiproton pairs as a new physical tool to study the particles production in the coordinate space.
6. To measure the multiple scattering in thin layers of 4 materials with the precision better by one order of magnitude than in the previous experiments.
7. To prepare the LOI for hadronic atoms study at SPS CERN to check the low-energy QCD predictions .

Thank you

Additional slides

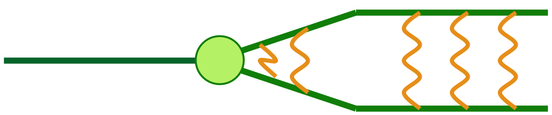
Coulomb pairs and atoms

For charged pairs from short-lived sources and with small relative momenta Q , Coulomb final state interaction has to be taken into account.
This interaction increases the production yield of the free pairs with Q decreasing and creates atoms.



$\pi^+\pi^-$, $K^+\pi^-$, $K^-\pi^+$, K^+K^-, $\pi^+\mu^-$, $\pi^-\mu^+$

Coulomb pair



$(\pi^+\pi^-)$, $(K^+\pi^-)$, $(K^-\pi^+)$, (K^+K^-), $(\pi^+\mu^-)$, $(\pi^-\mu^+)$

Atom

There is a precise ratio between the number of produced Coulomb pairs (N_C) with small Q and the number of atoms (N_A) produced simultaneously with Coulomb pairs:

$$N_A = K(Q_0) N_C (Q \le Q_0), \quad \frac{\delta K(Q_0)}{K(Q_0)} \le 10^{-2}$$

$$n_A \text{ - atomic pairs number}, \quad P_{br} = \frac{n_A}{N_A}$$

The $\pi^+\pi^-$ atomic states distribution at the exit of Be target on quantum numbers (n l m)

n	l	m	$\pi^+\pi^-$ atom distrib.(%)	sum_m (%)	sum_l,m (%)
1	0	0	11.66	11.66	11.66
2	0	0	3.58	3.58	6.07
	1	-1 ; 1	2 x 1.24	2.49	
3	0	0	0.67	0.67	2.23
	1	-1 ; 1	2 x 0.43	0.85	
	2	-2 ; 2	2 x 0.28	0.70	
		0	0.14		
4	0	0	0.19	0.19	1.10
	1	-1 ; 1	2 x 0.14	0.29	
	2	-2 ; 2	2 x 0.12	0.31	
		0	0.070		
	3	-3 ; 3	2 x 0.10	0.31	
		-1 ; 1	2 x 0.052		
5	0	0	0.077	0.08	0.75
	1	-1 ; 1	2 x 0.065	0.13	
	2	-2 ; 2	2 x 0.060	0.16	
		0	0.041		
	3	-3 ; 3	2 x 0.056	0.18	
		-1 ; 1	2 x 0.035		
	4	-4 ; 4	2 x 0.053	0.20	
		-2 ; 2	2 x 0.031		
		0	0.028		
6	0	0	0.044	0.044	0.68
	1	-1 ; 1	2 x 0.039	0.079	
	2	-2 ; 2	2 x 0.038	0.11	
		0	0.030		
	3	-3 ; 3	2 x 0.037	0.13	
		-1 ; 1	2 x 0.028		
	4	-4 ; 4	2 x 0.036	0.15	
		-2 ; 2	2 x 0.027		
		0	0.025		
	5	-5 ; 5	2 x 0.036	0.17	
		-3 ; 3	2 x 0.026		
		-1 ; 1	2 x 0.024		
7	0	0	0.032	0.032	0.77
	1	-1 ; 1	2 x 0.030	0.061	
	2	-2 ; 2	2 x 0.030	0.086	
		0	0.026		
	3	-3 ; 3	2 x 0.030	0.11	
		-1 ; 1	2 x 0.026		
	4	-4 ; 4	2 x 0.030	0.13	
		-2 ; 2	2 x 0.025		
		0	0.025		
	5	-5 ; 5	2 x 0.030	0.16	
		-3 ; 3	2 x 0.025		
		-1 ; 1	2 x 0.025		
	6	-6 ; 6	2 x 0.030	0.18	
		-4 ; 4	2 x 0.025		
		-2 ; 2	2 x 0.024		
		0	0.024		
8	0	0	0.028	0.028	0.95
	1	-1 ; 1	2 x 0.028	0.055	
	2	-2 ; 2	2 x 0.027	0.080	
		0	0.026		
	3	-3 ; 3	2 x 0.027	0.11	
		-1 ; 1	2 x 0.026		
	4	-4 ; 4	2 x 0.027	0.13	
		-2 ; 2	2 x 0.026		
		0	0.025		
	5	-5 ; 5	2 x 0.027	0.16	
		-3 ; 3	2 x 0.026		
		-1 ; 1	2 x 0.025		
	6	-6 ; 6	2 x 0.028	0.18	
		-4 ; 4	2 x 0.026		
		-2 ; 2	2 x 0.025		
		0	0.025		
	7	-7 ; 7	2 x 0.028	0.21	
		-5 ; 5	2 x 0.026		
		-3 ; 3	2 x 0.026		
		-1 ; 1	2 x 0.026		
>=9				0.028	0.028
				Total sum:	24.19%

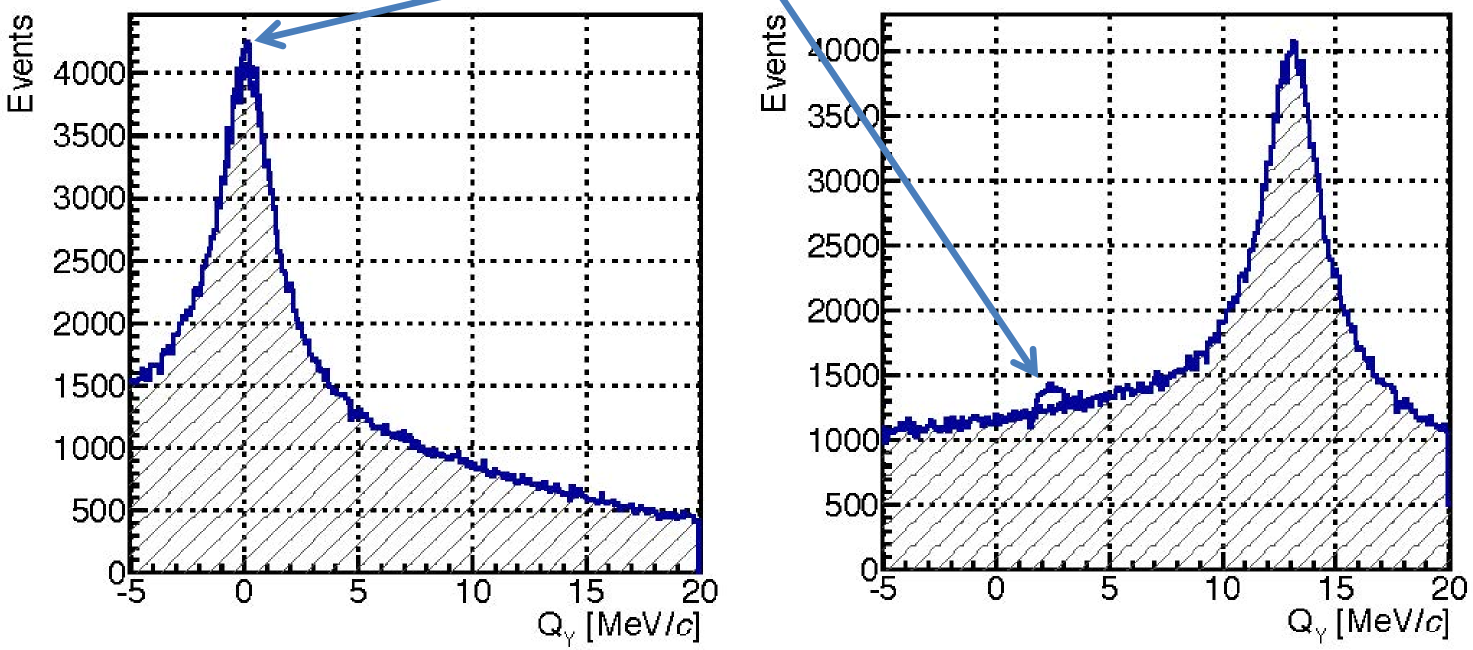
The background reduction with magnetic field for long-lived $A_{2\pi}$ observation

V. Yazkov

Q_y distribution of "atomic pairs" (signal) above the background of $\pi^+\pi^-$ Coulomb pairs produced in Beryllium target, without (left) and with (right) magnet used in 2012 run.

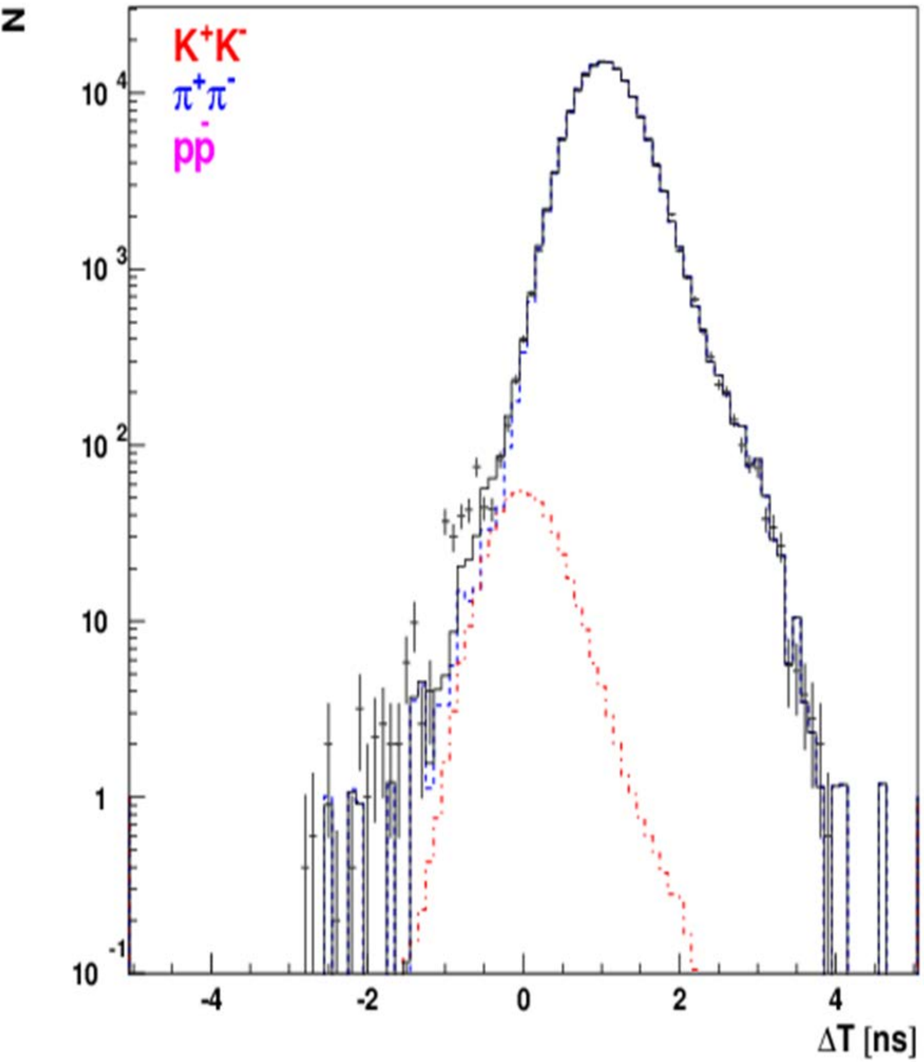
Selected events with the cut: $\sqrt{Q_X^2 + Q_L^2} < 2MeV/c$

Expected signal (atomic pairs) from broken up long-lived $\pi^+\pi^-$ atoms

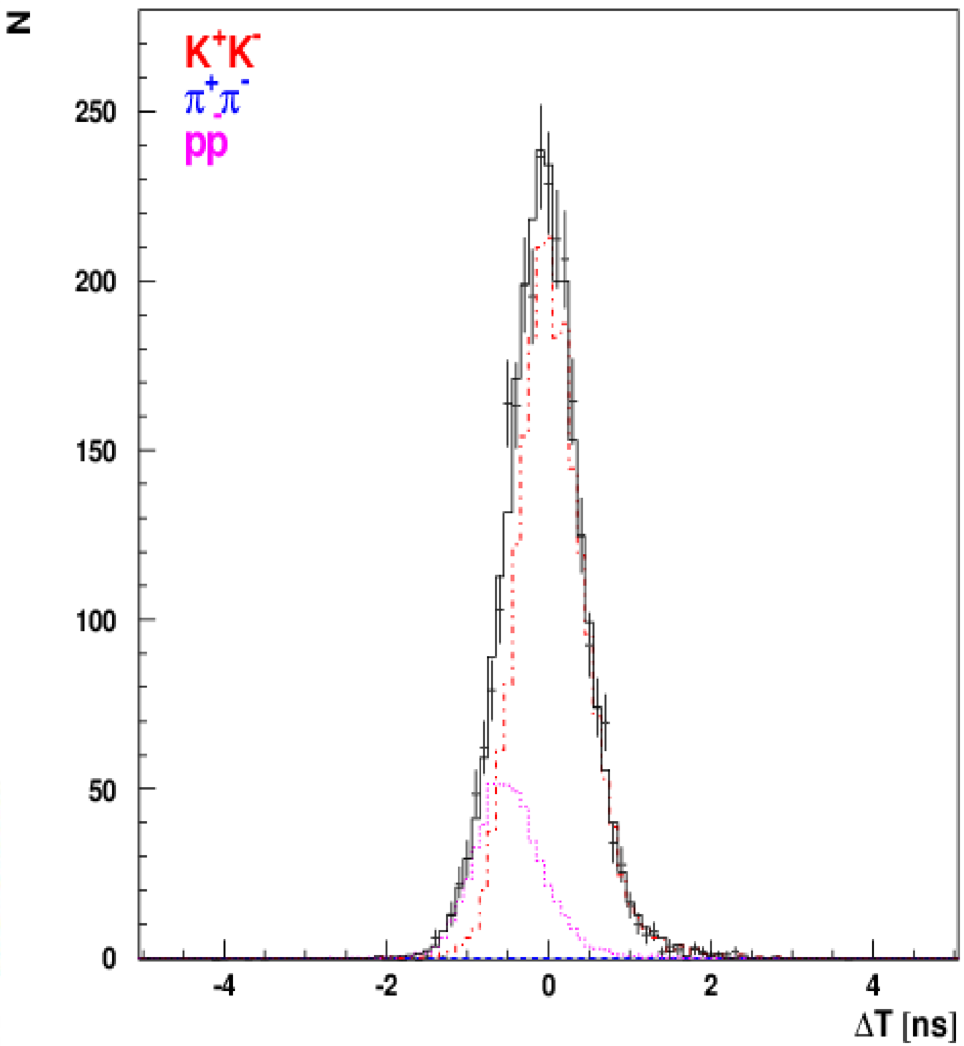


Simulation without magnet   Simulation with magnet

K^+K^- pair analysis



The time-of-flight distribution for the low momentum interval



The time-of-flight distribution for the high momentum interval

K^+K^- atom and its lifetime

The A_{2K} lifetime is strongly reduced by strong interaction (OBE, scalar meson f_0 and a_0) as compared to the annihilation of a purely Coulomb-bound system (K^+K^-).

K^+K^- interaction complexity ↓

$\tau\ (A_{2K} \to \pi\pi, \pi\eta)$	K^+K^- interaction
1.2×10^{-16} s [1]	Coulomb-bound
8.5×10^{-18} s [3]	momentum dependent potential
3.2×10^{-18} s [2]	+ one-boson exchange (OBE)
1.1×10^{-18} s [2]	+ f'_0 (I=0) + πη-channel (I=1)
2.2×10^{-18} s [4]	ChPT

References: [1] S. Wycech, A.M. Green, Nucl. Phys. A562 (1993), 446;
[2] S. Krewald, R. Lemmer, F.P. Sasson, Phys. Rev. D69 (2004), 016003;
[3] Y-J Zhang, H-C Chiang, P-N Shen, B-S Zou, PRD74 (2006) 014013;
[4] S.P. Klevansky, R.H. Lemmer, PLB702 (2011) 235.

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

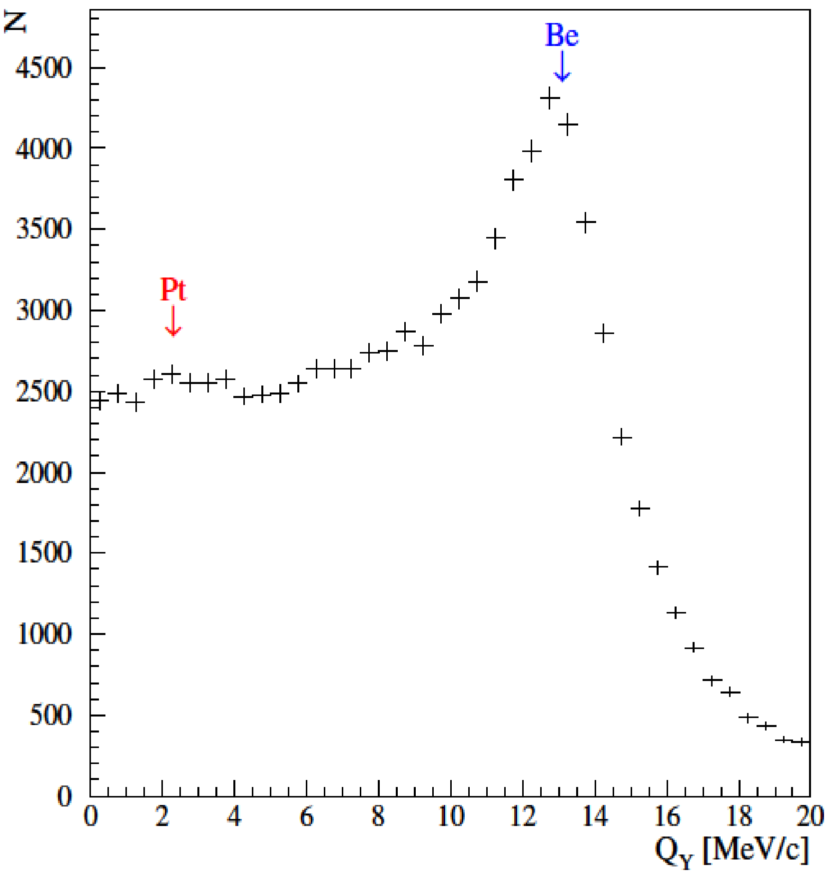


Fig. 3. Experimental distribution of the $\pi^+\pi^-$ pairs over Q_Y. Data selected with criteria $|Q_X|< 2$ MeV/c and $|Q_L|< 2$ MeV/c.
The indicated peaks are due to $\pi^+\pi^-$ pairs produced in the *Pt* foil and *Be* target.

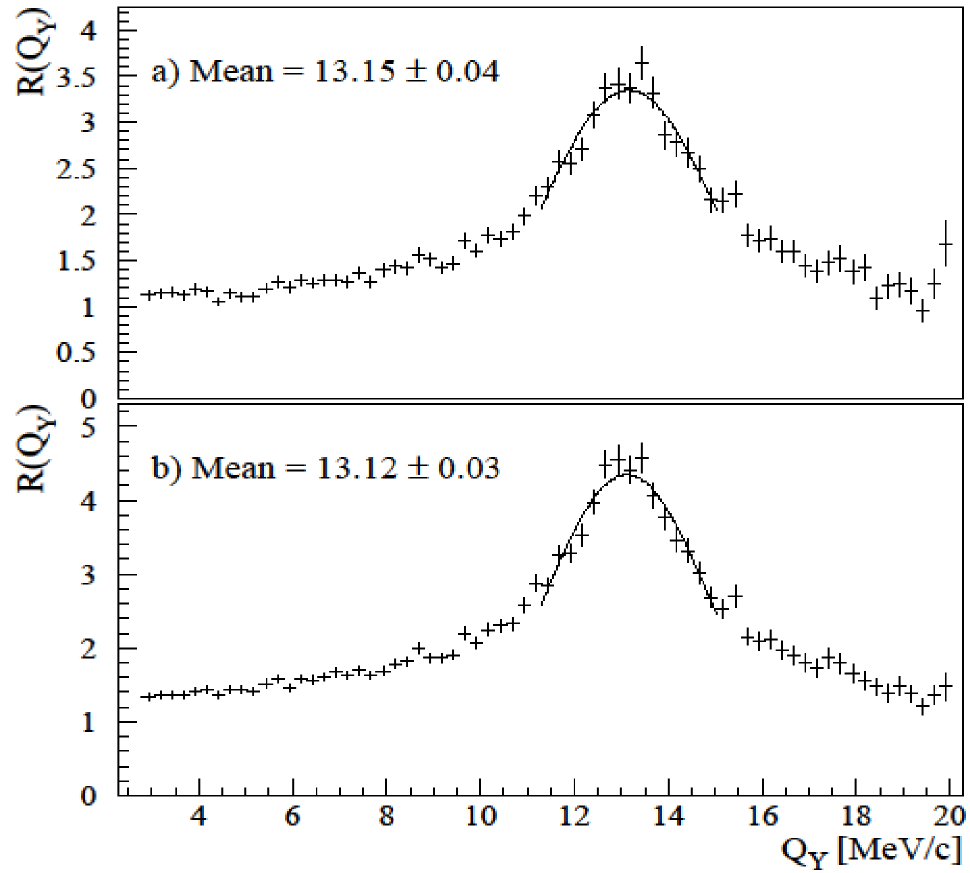


Fig. 4. Ratio of the prompt to accidental $\pi^+\pi^-$ pairs over Q_Y projection.
Top: Experimental distribution, the peak at Q_Y=13.15MeV/c corresponds to the Coulomb pairs produced in the *Be* target.
Bottom: Simulated distribution.

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

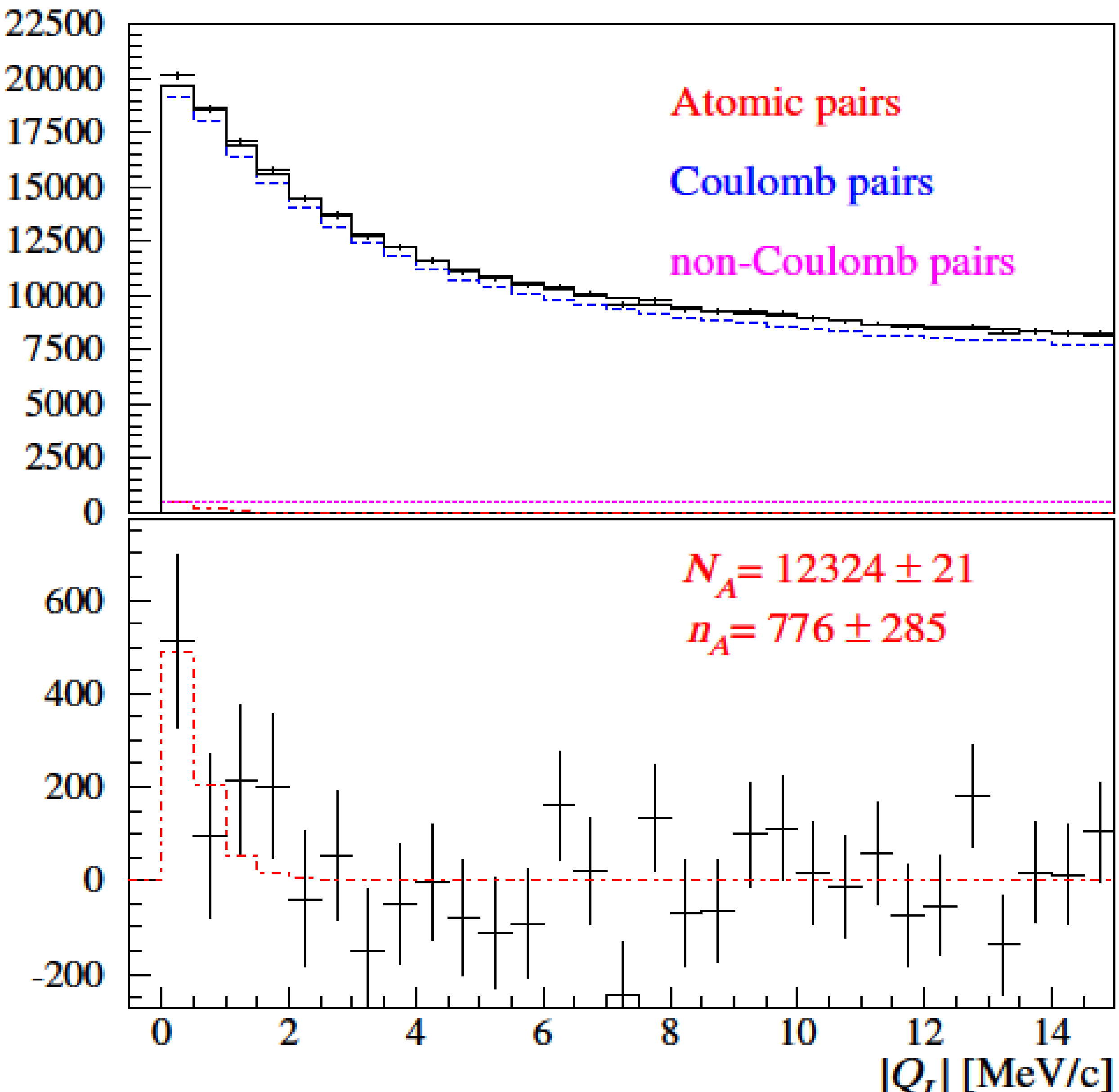


Fig. 5. a) Experimental distribution of $\pi^+\pi^-$ pairs (points with error bars) for the Beryllium (*Be*) target fitted by a sum of simulated distributions of "atomic", "Coulomb" and "non-Coulomb" pairs. The background distribution of free ("Coulomb", "non-Coulomb") pairs is shown as black line
b) Difference distribution between the experimental and simulated free pair distributions compared with the simulated distribution of "atomic pairs"

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

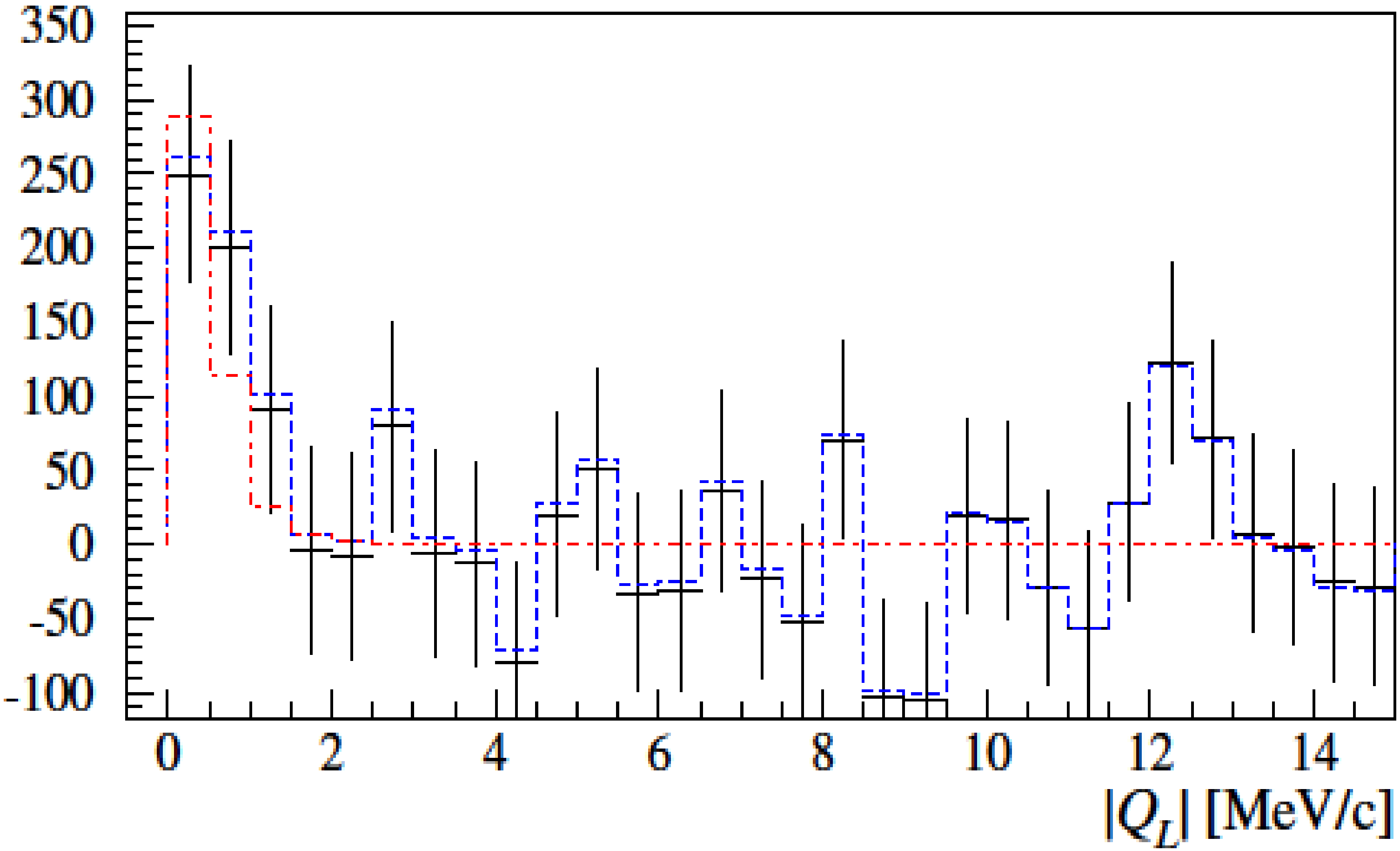
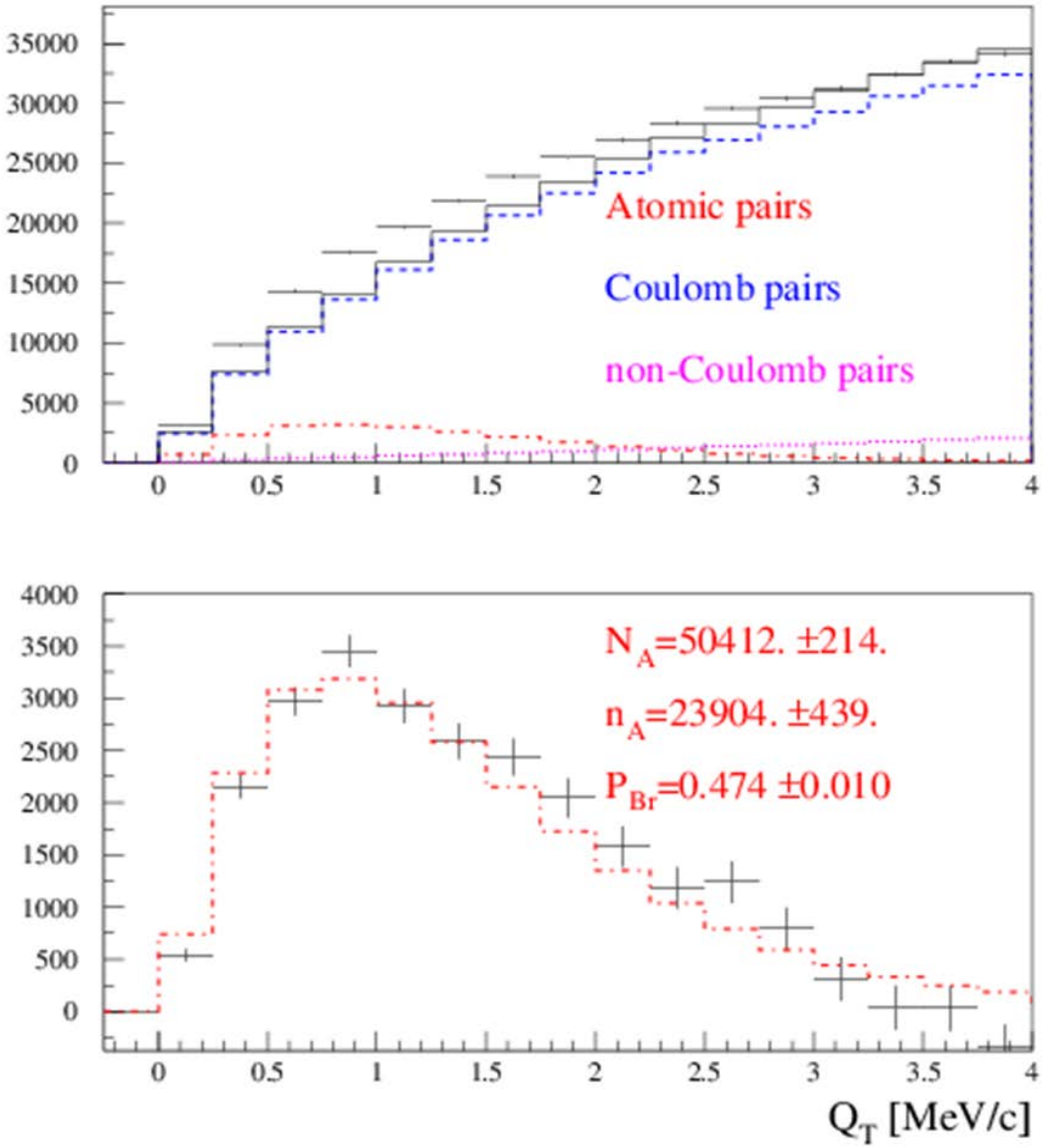


Fig. 8. $|Q_L|$ experimental distribution after subtraction of background obtained with 3 parameter fit (black points with statistical error) and after subtraction of background obtained with 2 parameter fit (blue dashed line), comparing to the simulated distribution of atomic pairs (red dotted-dashed line).

The fit procedures have been applied to the 1-dimensional $|Q_L|$ distribution.

The atomic pairs number in the region $|Q_L| < 2$, $Q_T < 4$ MeV/c obtained with 3 parameter fit is $n_A^L = 435\pm03$ and with 2 parameter fit is $n_A^L = 579\pm64$.

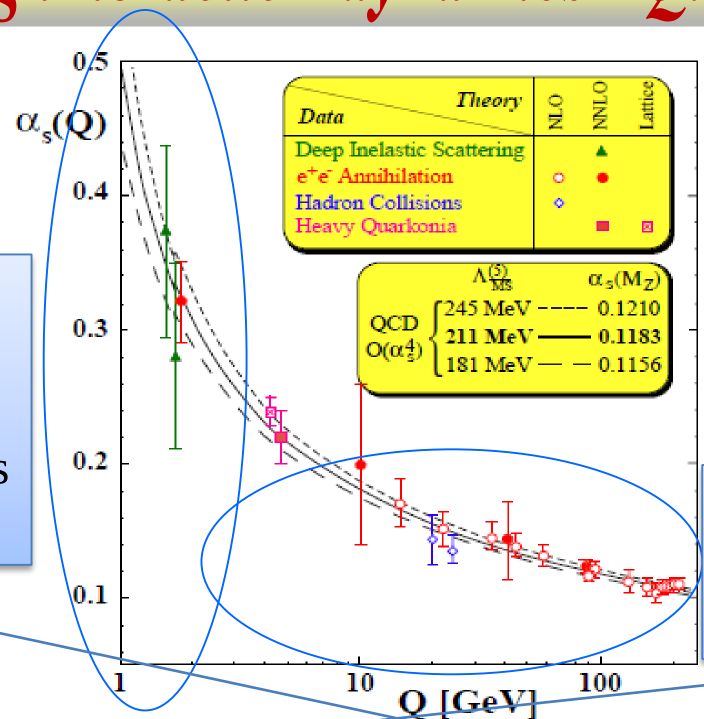
III. The short-lived $\pi^+\pi^-$ atom lifetime measurement



Preliminary results on the short-lived atom lifetime measurement based on all available 2008-2010 data are presented in Fig. 1 and 2.

Fig.2. Distribution over Q_T of events, selected with criterion $|Q_L| < 2$ MeV/c. Fractions of atomic, Coulomb and non-Coulomb pairs were obtained by fitting the distribution over ($|Q_L|$,Q_T) with criteria: $|Q_L|<15$ MeV/c, $Q_T < 4$ MeV/c. N_A, n_A and P_{br}. are the number of produced atoms, detected atomic pairs and probability of the atoms breaking in the target respectively.

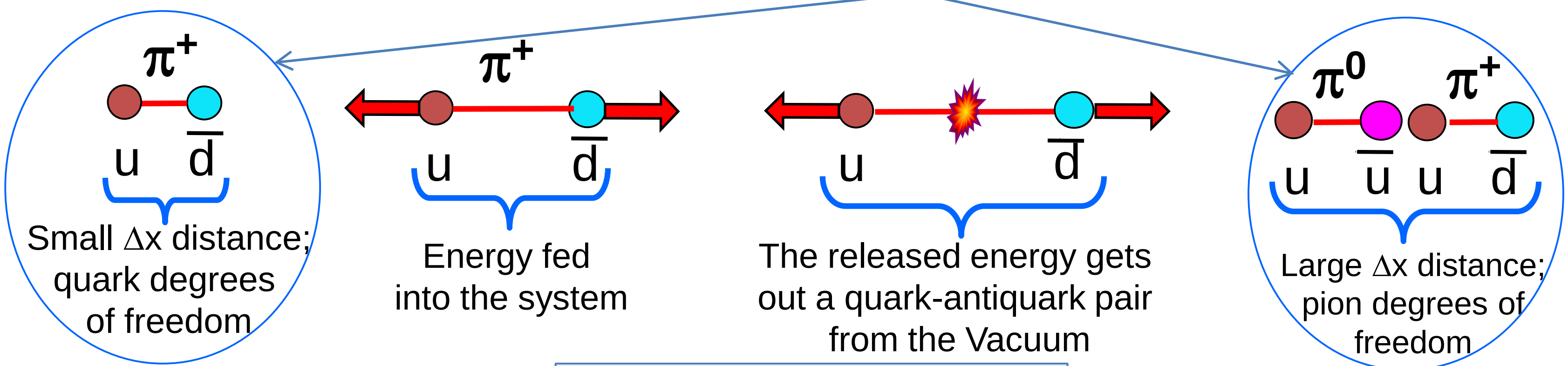
DIRAC search for strong interaction dynamics - Quark confinement



S. Bethke, J.Phys.G26:R27, 2000

α_S large – small Q^2
"quark confinement"
perturbative QCD not suitable.
Lattice QCD solve field equations on a space-time lattice by MC.

α_S small – large Q^2
"asymptotic freedom"
and perturbative QCD



"asymptotic freedom"

string breaks generate $q\overline{q}$ pair to reduce field energy

"quark confinement"
DIRAC

DIRAC++ (Detectors)

Setup element (number planes)	Aperture (cm)	Occupancy ($s^{-1} \cdot cm^{-2}$)	X_0 %	Resolution	
				Coordinate (μm)	Time (ns)
1. Target Station (*) 2. Vacuum system (*) 3. Vertex detector (2 ÷ 4 planes)	7.6 × 7.6	$(5 \div 20) \cdot 10^5$	0.7 ÷ 1.5	50	0.2
4. RICH?	9.0 × 9.0	$(4 \div 16) \cdot 10^5$	< 5		< 1
5. SFD (3 planes) (*)	10. × 10.	$(3 \div 12) \cdot 10^5$	2.7	60	0.3
6. Vacuum system (*) 7. Iron shielding wall (*) 8. Spectrometer magnet (*)	155 × 50				
9. Downstream Tracker (2 × 8)	75 ÷ 110×44	$(1 \div 10) \cdot 10^4$	4 ÷ 8	< 80	
10. Vertical Hodoscope (2 × 1 ÷ 2) (*)	112 × 44	$(1 \div 8) \cdot 10^4$			< 0.7
11. Horizontal Hodoscope (2) (*)	115 × 44	$(1 \div 8) \cdot 10^4$			< 0.5
12. Heavy Gas Cherenkov detector (2) (*)	30 × 49	$(1 \div 8) \cdot 10^4$			< 1.0
13. Nitrogen Cherenkov detector (2)	90 × 50	$(1 \div 10) \cdot 10^3$			< 1.0
14. Nitrogen Cherenkov detector (2)	37 × 53	$(1 \div 8) \cdot 10^4$			< 1.0
15. PreShower detector (2)	148 × 60	$(1 \div 8) \cdot 10^3$			< 1.0
16. PreShower detector (2)	56 × 60	$(5 \div 40) \cdot 10^3$			< 1.0
--. Ionisation Hodoscope (4 planes)	10. × 10.	$(4 \div 16) \cdot 10^5$	3		

*** - Existing parts of the Setup**   **? - Micro-Pattern Gas Detectors (MPGD)**

SPS beam time for πK scattering length measurement

The data at p_p = 24*GeV/c* and 450*Gev/c* were simulated, processed and analysed (V.Yazkov, DIRAC note, 2016 05).

Experimental conditions on SPS with Ni target

Thin *Ni* target, nuclear efficiency ~ 6×10^{-4}.

The proton beam can be used for other experiments.

Proton beam intensity: 3×10^{11} protons/s

(DIRAC worked at 2.7×10^{11} protons/s)

Number of spills: 4.5×10^{5} with spill duration 4.5 s

Data taking: 3000 spills per 24 hours.

Running time: 5 months

The expected number of πK atomic pairs: n_A=13000

(In the DIRAC experiment was n_A=349±62)

The statistical precision in these conditions for πK scattering length will be: ~5%

The expected systematic error will be at the level of 2%

The expected number of $\pi^+\pi^-$ atomic pairs n_A=400000

The statistical precision of the $\pi^+\pi^-$ scattering length will be: 0.7%

The expected systematic error will be at the level of 2%

$\mathcal{L}(2)$ and Chiral Lagrangian predictions check with short-lived $\pi^+\pi^-$ atoms

- The QCD Lagrangian $\mathcal{L}(2)$ and Chiral Lagrangian describe processes with *u* and *d* quarks, using $SU(2)_L * SU(2)_R$ chiral symmetry breaking.
- From the ChPT prediction for a_0 and a_2, the $\pi^+\pi^-$ atom lifetime in the ground state, given by $1/\tau = R|a_0 - a_2|^2$, is $\tau_{th} = (2.9 \pm 0.1) * 10^{-15}$ s.
- The evaluation error for $|a_0 - a_2|$ from this relation is 0.6%.
- These Lagrangians predict the S-wave $\pi^+\pi^-$ scattering lengths a_0 and a_2.

$\mathcal{L}(2)$ and Chiral Lagrangian predictions check with short-lived $\pi^+\pi^-$ atoms

ChPT	a_0 and a_2 a_0-a_2	2.3% precision 1.5% precision	Colangelo et al. Nucl.Phys.(2001)
Lattice calculations	a_0 a_2	4-10% precision ~1% precision	K.Sasaki et al., Phys.Rev. 2014, Z.Fu, Phys.Rev.(2013), C.Lang et al.,Phys.Rev.(2012), Feng et al., Phys. Lett.(2010), T.Yagy at al., arXiv:1108.2970, S.Beame et al. Phys.Rev(2008)
Experimental values	a_0-a_2	~ 4% precision	J.R.Bateley at al., Eur. Phys. J. (2009), J.R.Bateley at al., Eur. Phys. (2010), Adeva et al., Phys. Lett. (2011)
	a_0 a_2	~ 6% precision ~22% precision	J.R.Bateley at al., Eur. Phys. J. (2009), J.R.Bateley at al., Eur. Phys. (2010)
on SPS	a_0-a_2	~2% precision	DIRAC estimation