DIRAC experiment
(PS 212)

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SPS Committee, October 22, 2013

DIRAC Collaboration

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Tokyo Metropolitan University
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IFIN-HH
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Dubna, Russia

SINP of Moscow State University
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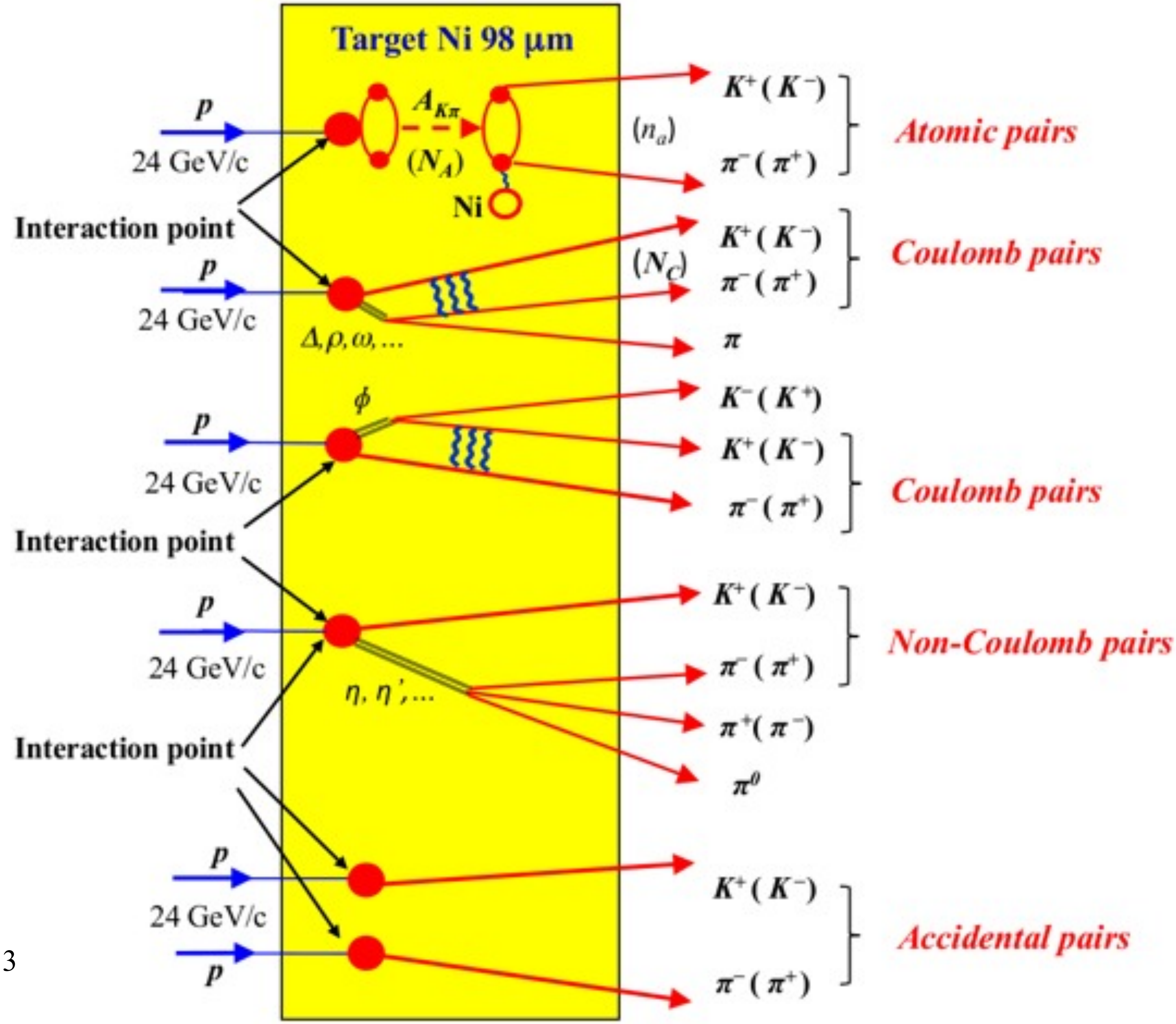
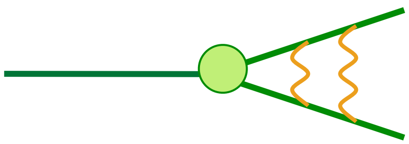
1. First measurements of $K^+\pi^-$ and $K^-\pi^+$ atoms lifetime and $K\pi$ scattering lengths in s-state.

Method of $K\pi$ atom observation and investigation



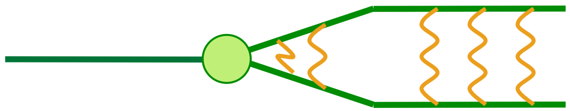
Coulomb pairs and atoms

For the charged pairs from the short-lived sources and small relative momentum Q there is strong Coulomb interaction in the final state.
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 pairs



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

Atoms

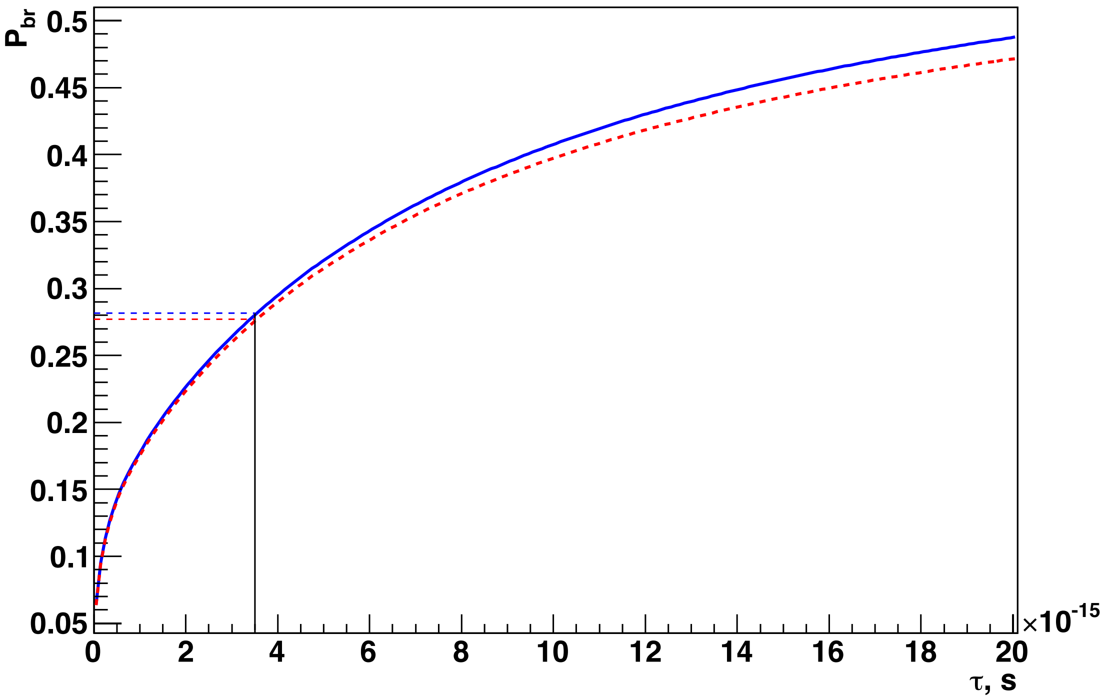
There is a precise ratio between the number of produced Coulomb pairs (N_C) with small Q and the number of atoms (N_A) produced in the way as these Coulomb pairs:

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

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

Break-up probability

Solution of the transport equations provides one-to-one dependence of the measured break-up probability P_{br} on π^+K^- lifetime τ.

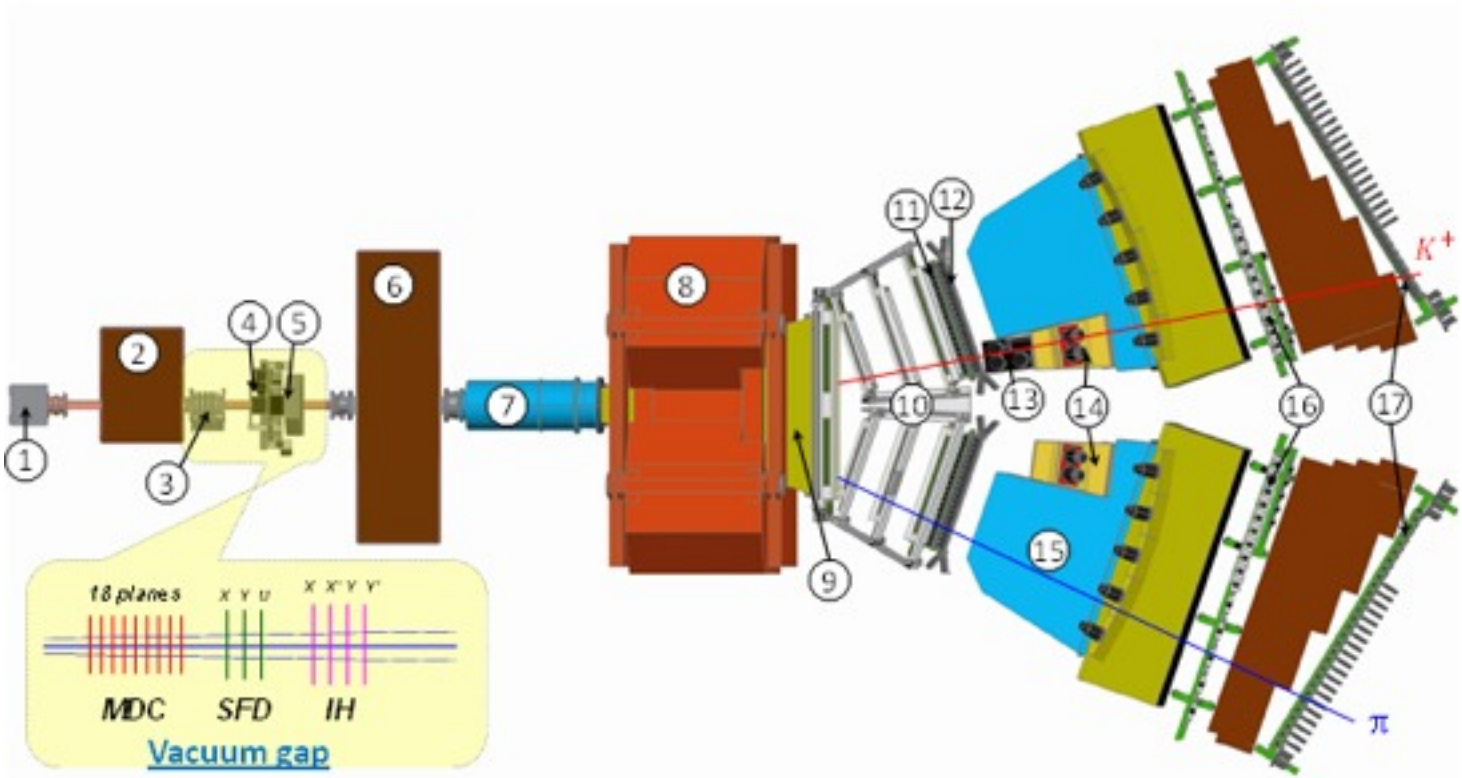


$$Pbr^{th} = 0.278 \begin{smallmatrix}+0.012\\-0.011\end{smallmatrix}$$

$$\tau^{th} = (3.5 \pm 0.4) \times 10^{-15} s$$

target Ni 108μm (solid) Ni 98μm (dashed)

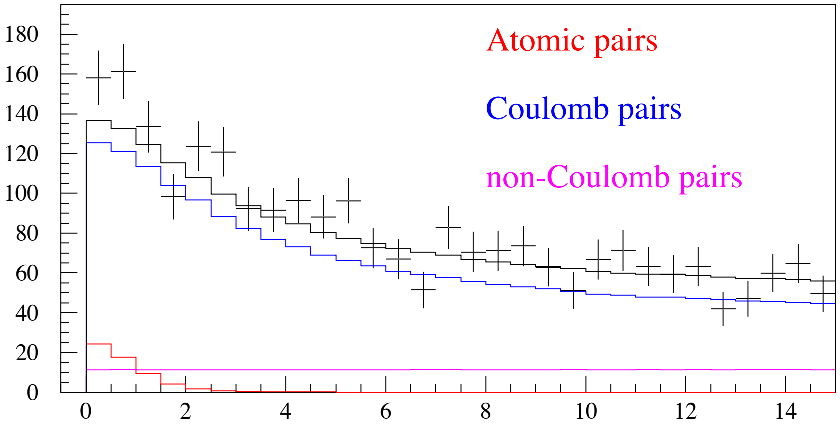
Experimental setup

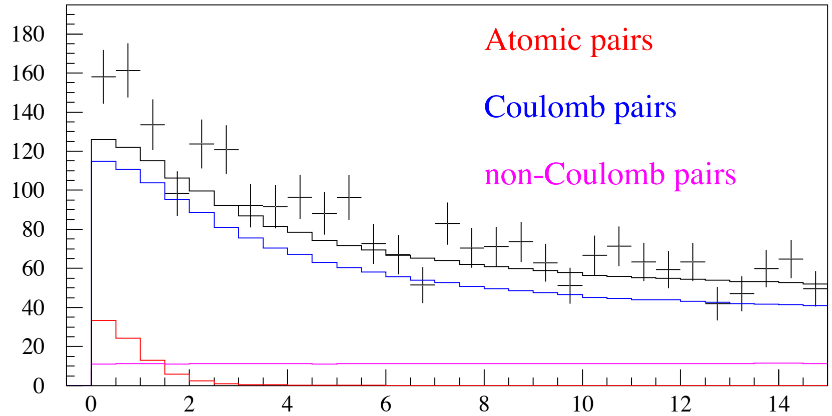


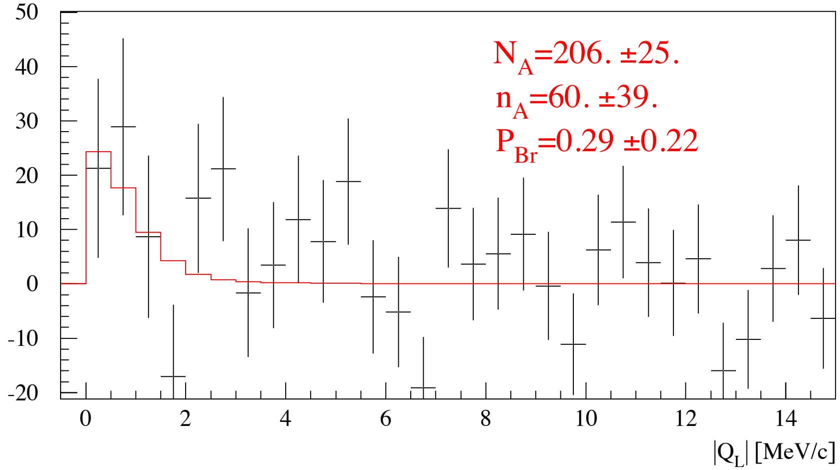
1 Target station with Ni foil; 2 First shielding; 3 Micro Drift Chambers; 4 Scintillating Fiber Detector; 5 Ionization Hodoscope; 6 Second Shielding; 7 Vacuum Tube; 8 Spectrometer Magnet; 9 Vacuum Chamber; 10 Drift Chambers; 11 Vertical Hodoscope; 12 Horizontal Hodoscope; 13 Aerogel Čerenkov; 14 Heavy Gas Čerenkov; 15 Nitrogen Čerenkov; 16 Preshower; 17 Muon Detector

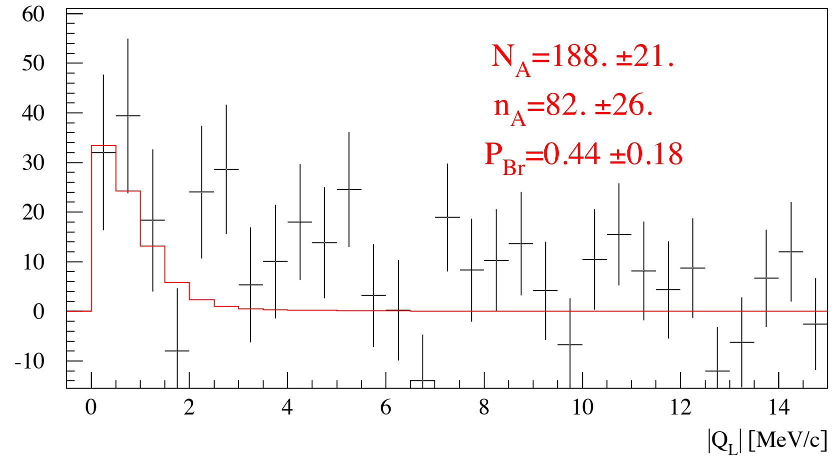
$K^-\pi^+$ atoms - run 2008-2010

Run 2008-2010, statistics with low and medium background (2/3 of all statistics).







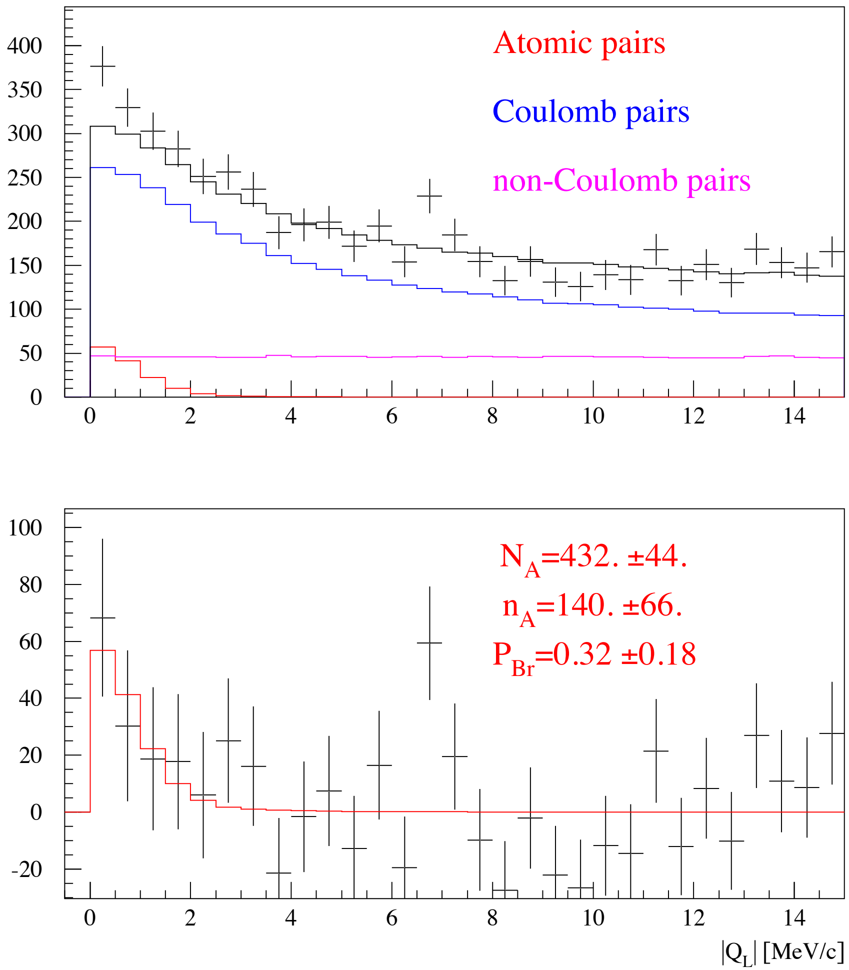


$|Q_L|$ distribution analysis on $|Q_L|$ for Q_T < 4 MeV/c

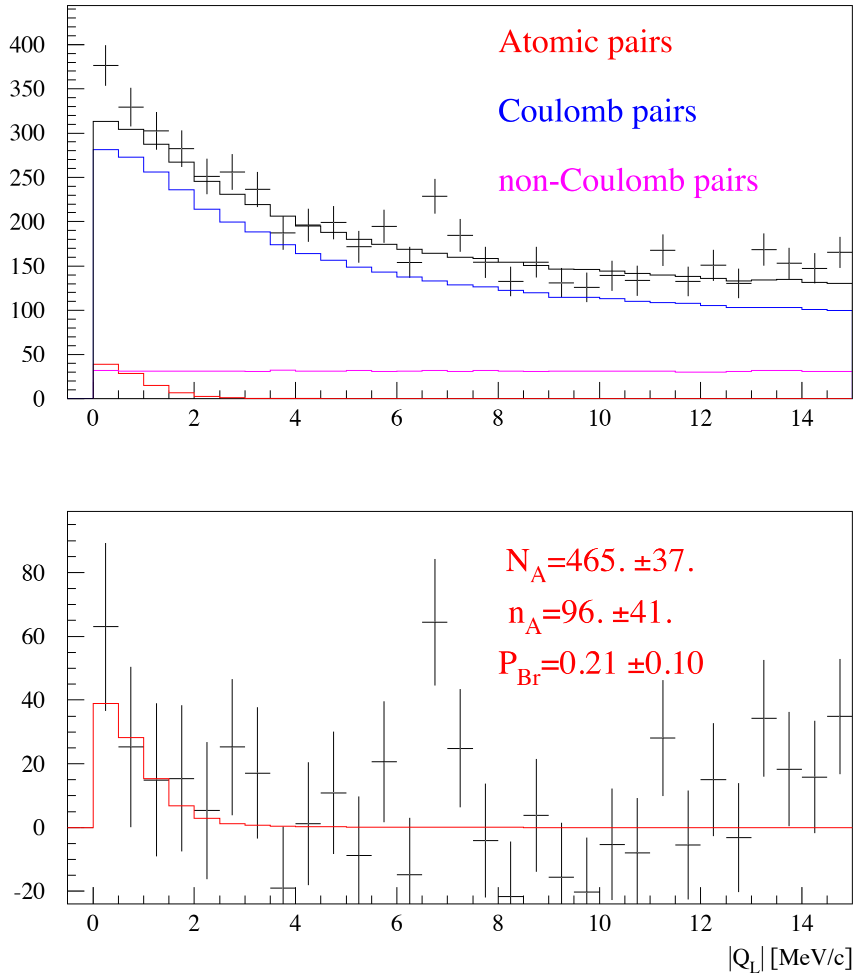
$|Q_L|$ distribution analysis on $|Q_L|$ and Q_T for Q_T < 4 MeV/c

$K^+\pi^-$ atoms - run 2008-2010

Run 2008-2010, statistics with low and medium background (2/3 of all statistics).



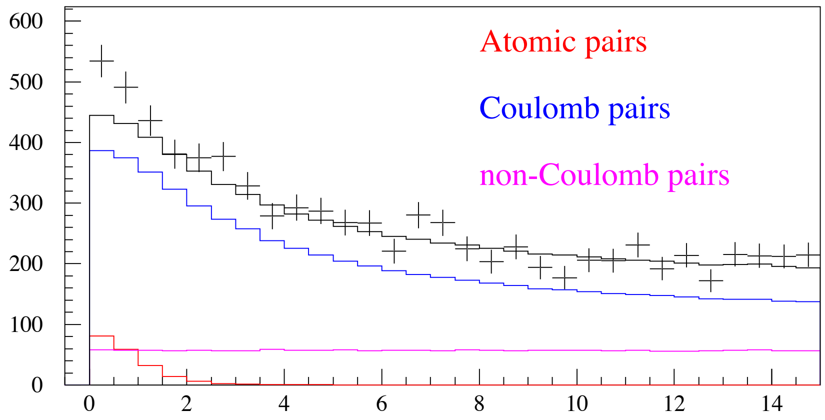
$|Q_L|$ distribution
analysis on $|Q_L|$ for Q_T < 4 MeV/c

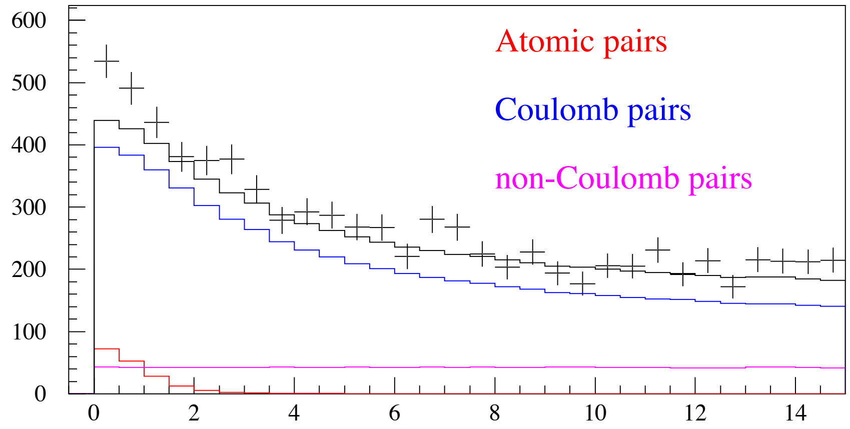


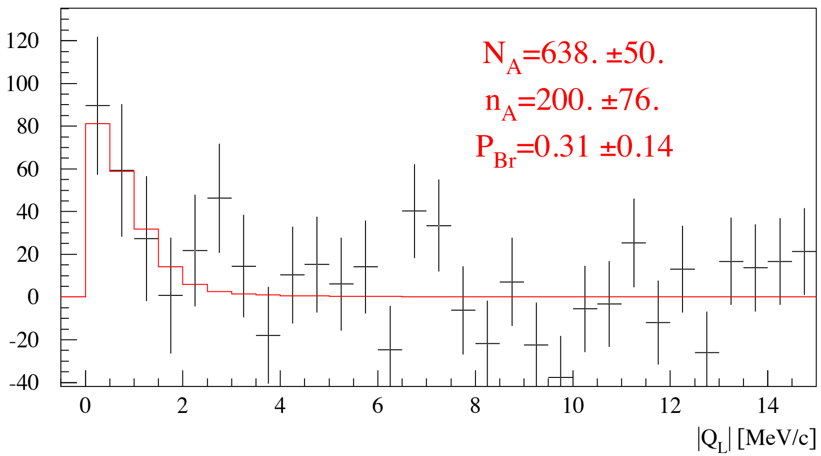
$|Q_L|$ distribution
analysis on $|Q_L|$ and Q_T for Q_T < 4 MeV/c

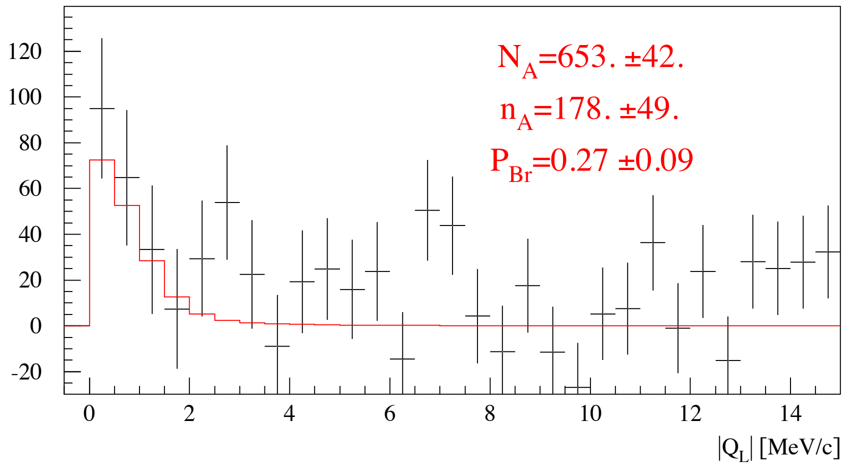
$K^-\pi^+$ + $K^+\pi^-$ atoms – run 2008-2010

Run 2008-2010, statistics with low and medium background (2/3 of all statistics).









$|Q_L|$ distribution
analysis on $|Q_L|$ for Q_T < 4 MeV/c

$|Q_L|$ distribution
analysis on $|Q_L|$ and Q_T for Q_T < 4 MeV/c

Absolute systematic error analysis on P_{br}

	QL	Q_L, Q_T
Correction on Lambda width	0.0071	0.0039
Uncertainty of multiple scattering in Ni target	0.00054	0.0032
Accuracy in description of SFD response	0.0003	0.0008
Finite size of production region	0.00006	0.00006

Individual absolute systematical errors on P_{br} for different data sets:

Accuracy of
$K^+\pi^-$ spectrum measurement:

Year	QL	QL,QT
2008	0.0030	0.0028
2009	0.0053	0.0044
2010	0.0046	0.0036

Accuracy of
$K^-\pi^+$ spectrum measurement:

Year	QL	QL,QT
2008	0.0093	0.0072
2009	0.0047	0.0048
2010	0.0021	0.0017

Accuracy of
background spectrum for $K^+\pi^-$:

Year	QL	QL,QT
2008	0.0028	0.0015
2009	0.0044	0.0025
2010	0.0036	0.0022

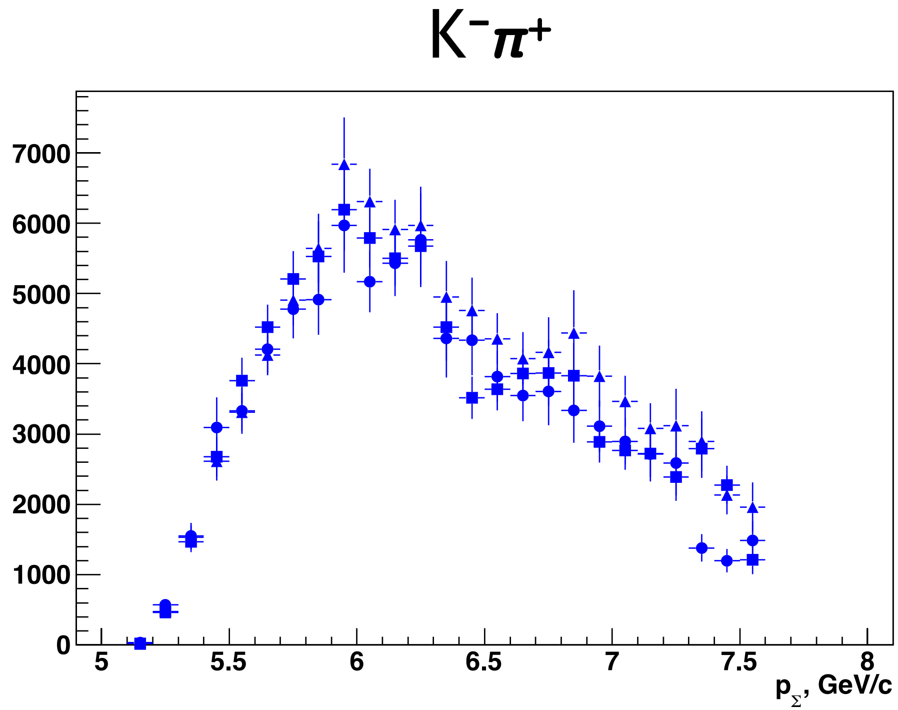
Accuracy of
background spectrum for $K^-\pi^+$:

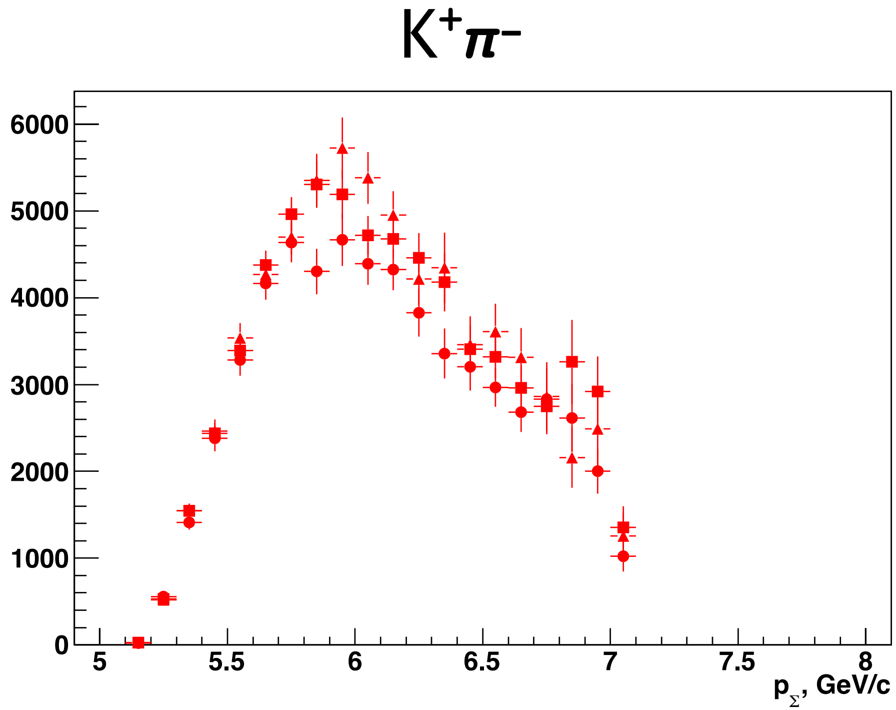
Year	QL	QL,QT
2008	0.0072	0.0067
2009	0.0048	0.0028
2010	0.0017	0.0043

$K^+\pi^-$ and $K^-\pi^+$ pairs analysis

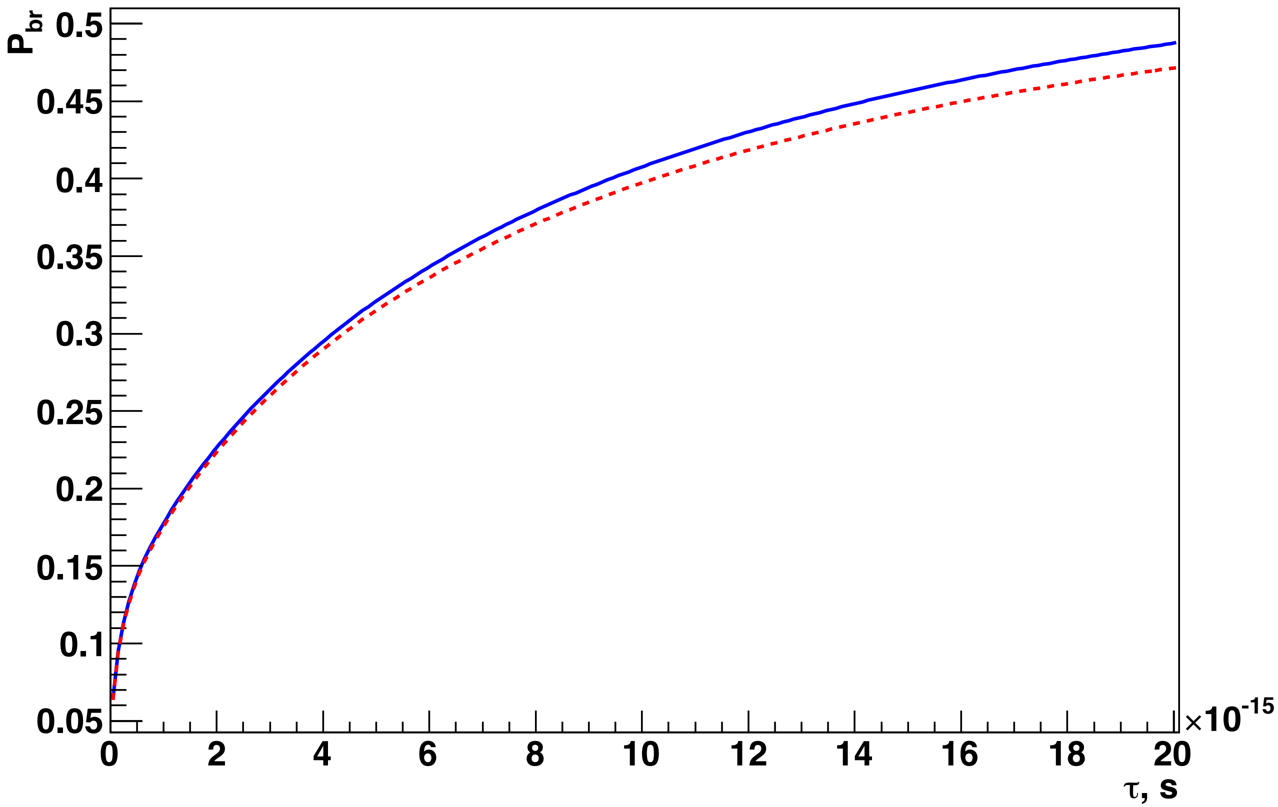
	$K^-\pi^+$ pairs 2008-2010	$K^+\pi^-$ pairs 2008-2010	$K^-\pi^+$ and $K^+\pi^-$ pairs sum 2008-2010
$N_A(Q_L)$	206±25	432±44	638±50
$N_A(Q_L-Q_T)$	188±21	465±37	653±42
$n_A(Q_L)$	60±39	140±66	200±76
$n_A(Q_L-Q_T)$	82±26	96±41	178±49
$P_{br}(Q_L)$	0.29±0.22	0.32±0.18	0.31±0.14
$P_{br}(Q_L-Q_T)$	0.44±0.18	0.21±0.10	0.27±0.09
P_{br}^{theor}			$0.278^{+0.012}_{-0.011}$

Experimental spectra of $K^-\pi^+$ (left) and $K^+\pi^-$ (right) pairs for different data periods 2008 ●, 2009 ▲ and 2010 ■





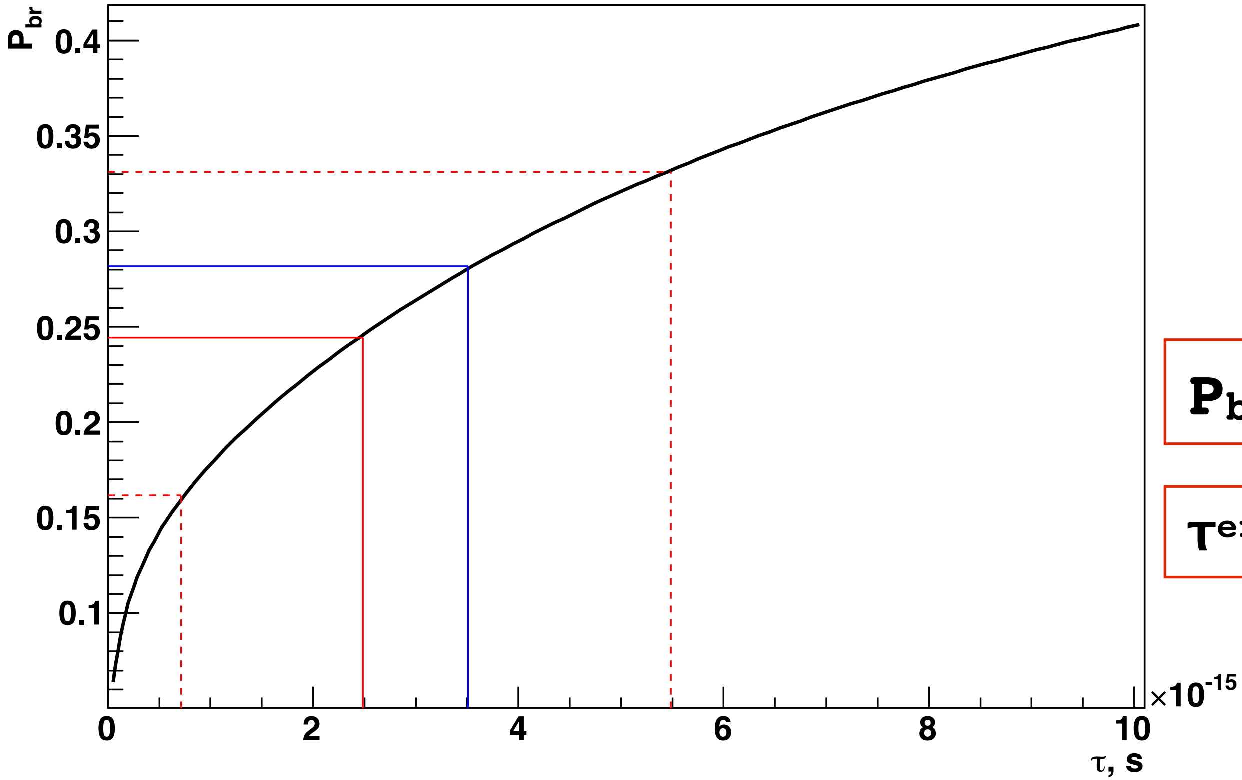
Probability of break-up as a function of lifetime in the ground state for $A(K\pi)$ in Ni target of thickness $98\mu m$ in 2008 (dashed) and $108\mu m$ (in 2009 and 2010) (solid) in the DIRAC experimental conditions



Experimental result(red) and theoretical estimation(blue) are superimposed over $P_{br}(\tau)$ dependence for $K^-\pi^+$ atoms on Ni 108μm target in 2009. Q_L, Q_t-analysis.

$$P_{br}^{th} = 0.278 \begin{smallmatrix}+0.012\\-0.011\end{smallmatrix}$$

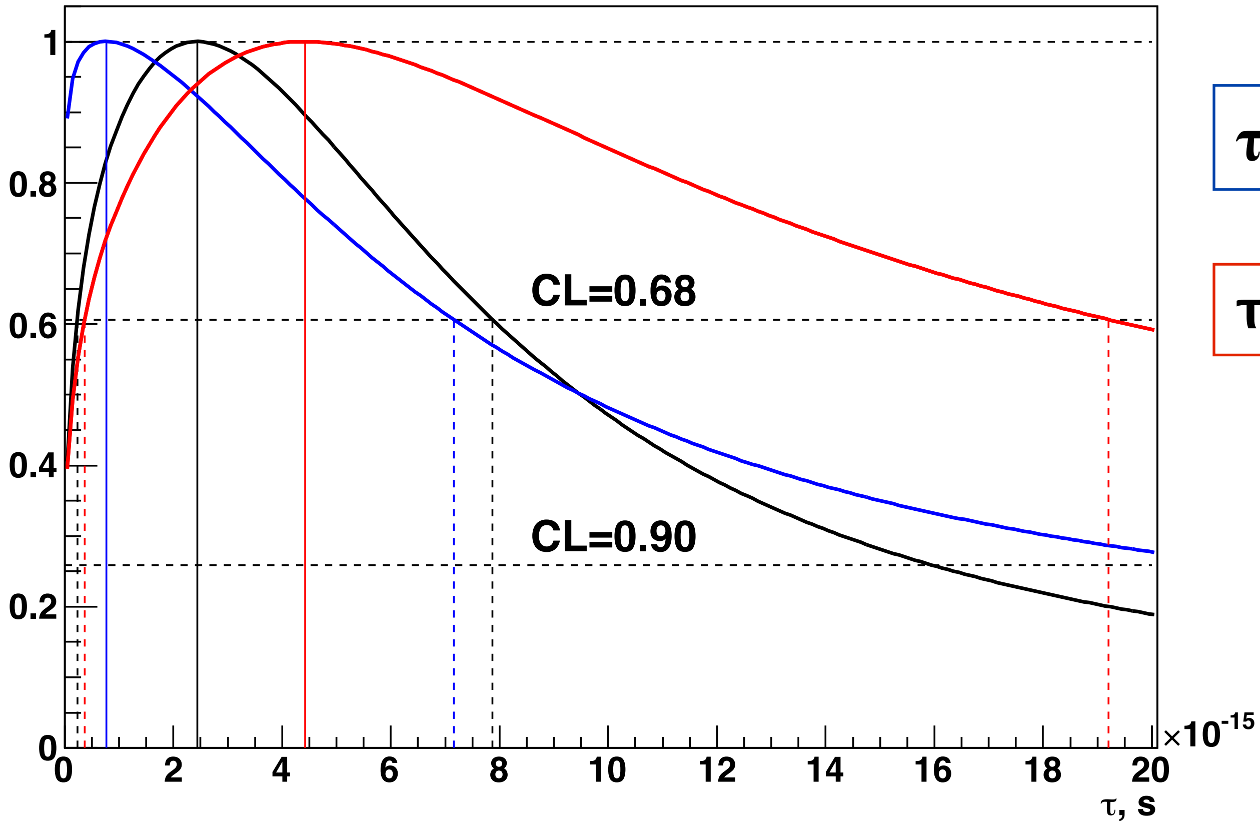
$$\tau^{th} = (3.5 \pm 0.4) \times 10^{-15} s$$



$$P_{br}^{exp} = 0.24 \begin{smallmatrix}+0.09\\-0.08\end{smallmatrix}$$

$$\tau^{exp} = (2.48 \begin{smallmatrix}+3.00\\-1.77\end{smallmatrix}) \times 10^{-15} s$$

Likelihood functions for $A(K^-\pi^+)$(blue), $A(K^+\pi^-)$(red) and combined (black) lifetime estimations. (QL)-analysis

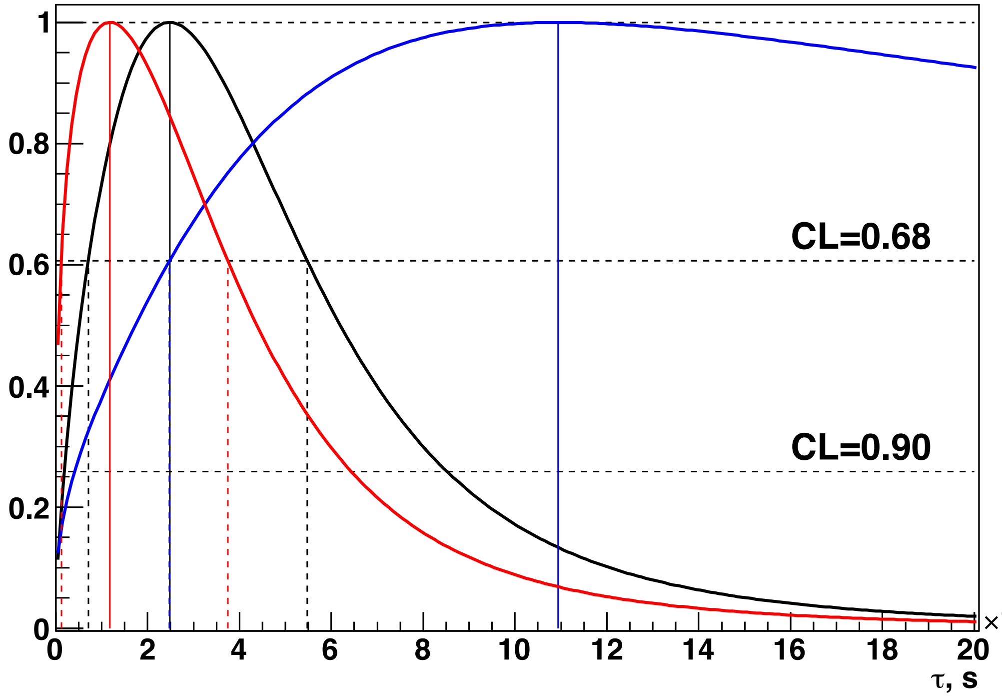


$\tau^{th} = (3.5\pm0.4)\mathrm{x}10^{-15}\mathrm{s}$

$\tau^{exp} = (2.4^{+5.4}_{-2.2})\mathrm{x}10^{-15}\mathrm{s}$

Likelihood functions for $A(K^-\pi^+)$(blue), $A(K^+\pi^-)$(red) and combined (black) lifetime estimations. (QL,Qt)-analysis

τ^{th} = $(3.5\pm0.4)\times10^{-15}$s



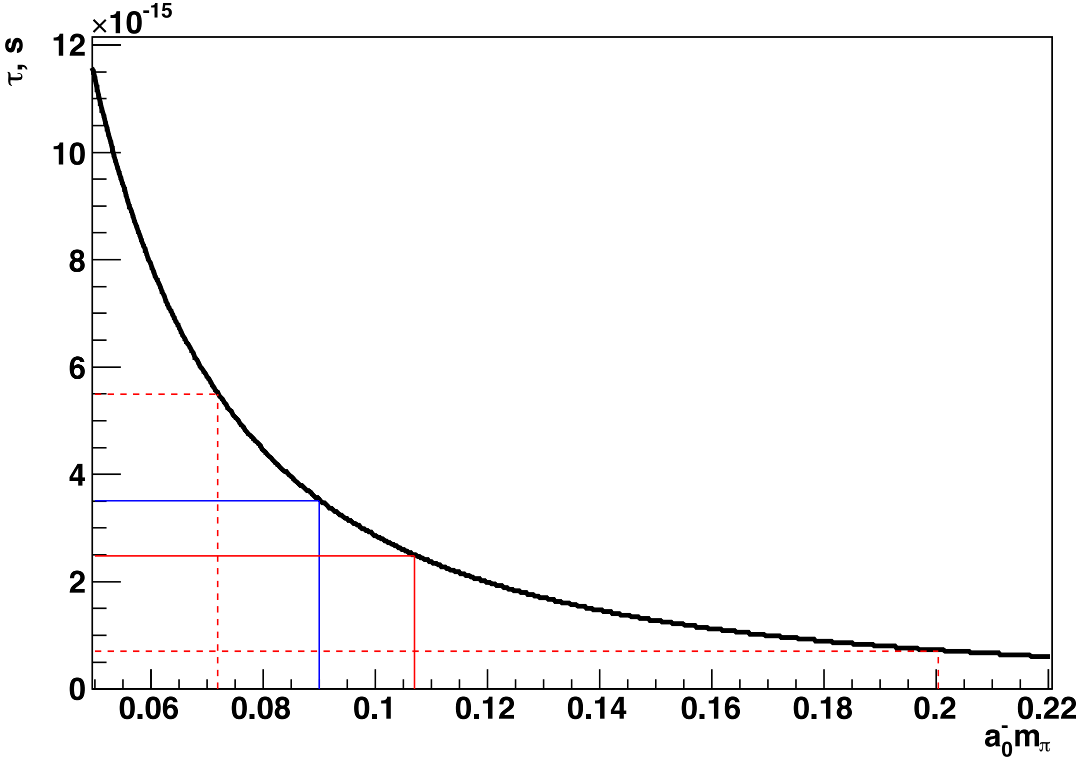
Q_L–Q_T analysis

$$\tau^{exp} = (2.5\ {}^{+3.0}_{-1.8}\,(stat)\ {}^{+0.2}_{-0.1}\,(syst))\times10^{-15}\,s$$

Q_L analysis

$$\tau^{exp} = (2.4\ {}^{+5.4}_{-2.2}\,(stat)\ {}^{+0.4}_{-0.1}\,(syst))\times10^{-15}\,s$$

Dependence of Kπ atom lifetime in the ground state τ_{1S} on $|a_0^-| = 1/3|a_{1/2}-a_{3/2}|$.
Experimental result (red) vs theoretical estimation (blue). (Q_L,Q_t)-analysis.



$|a_0^-|^{exp}\, m_\pi = 0.11\ ^{+0.09}_{-0.04}$

$|a_0^-|^{th} m_\pi = 0.090 \pm 0.005$
[P.Buettiker 2004]

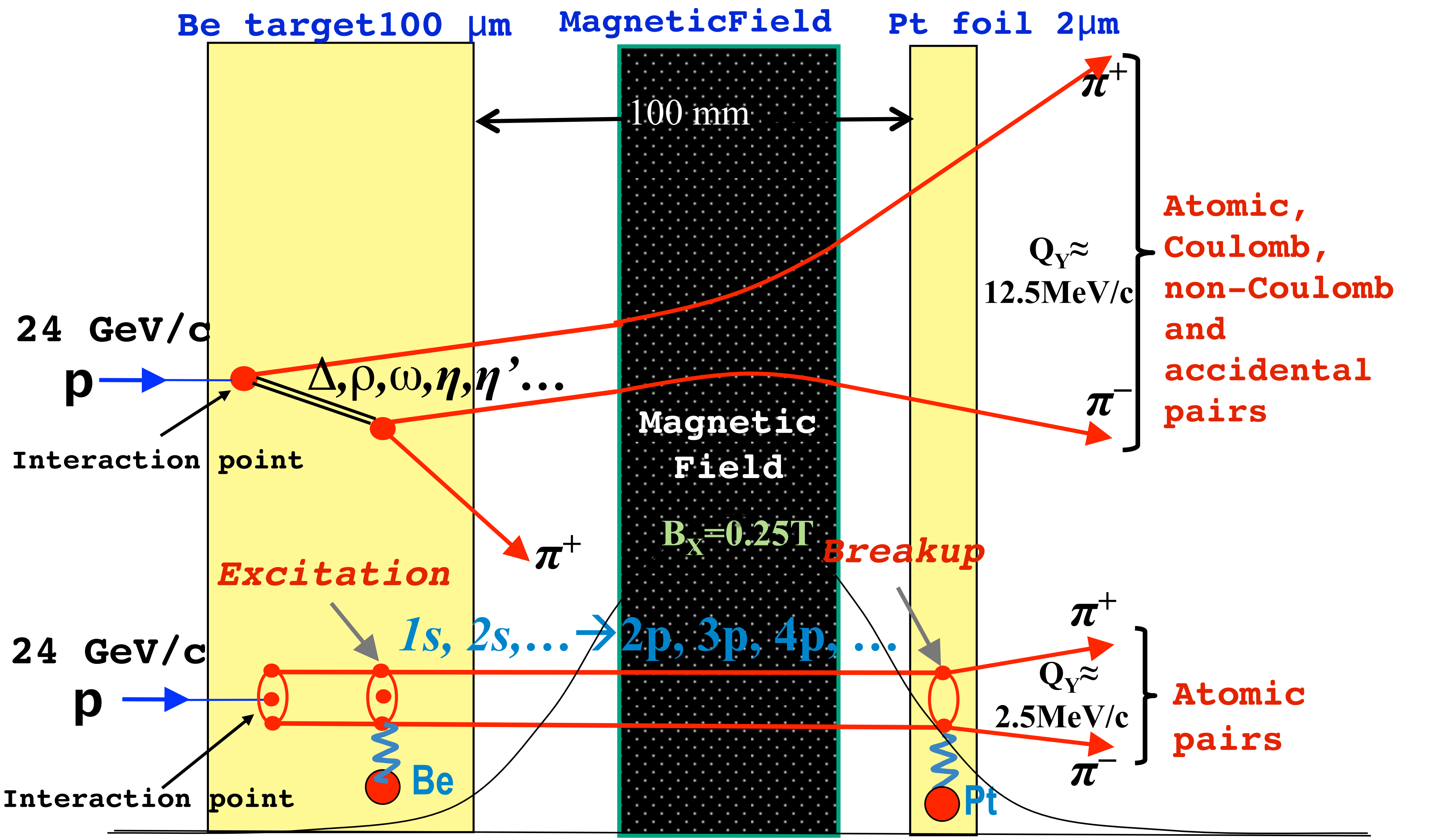
2. Search for long-lived $\pi^+\pi^-$ atoms

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

The observation of $\pi^+\pi^-$ atom long-lived states opens the future possibility to measure the energy difference between ns and np states $\Delta E(ns-np)$ and the value of $\pi\pi$ scattering lengths $|2a_0+a_2|$.

If a resonance method can be applied for the $\Delta E(ns-np)$ measurement, then the precision of $\pi\pi$ scattering length measurement can be improved by one order of magnitude relative to the precision of other methods.

Method for observing long-lived $\pi^+\pi^-$ atoms with breakup Pt foil



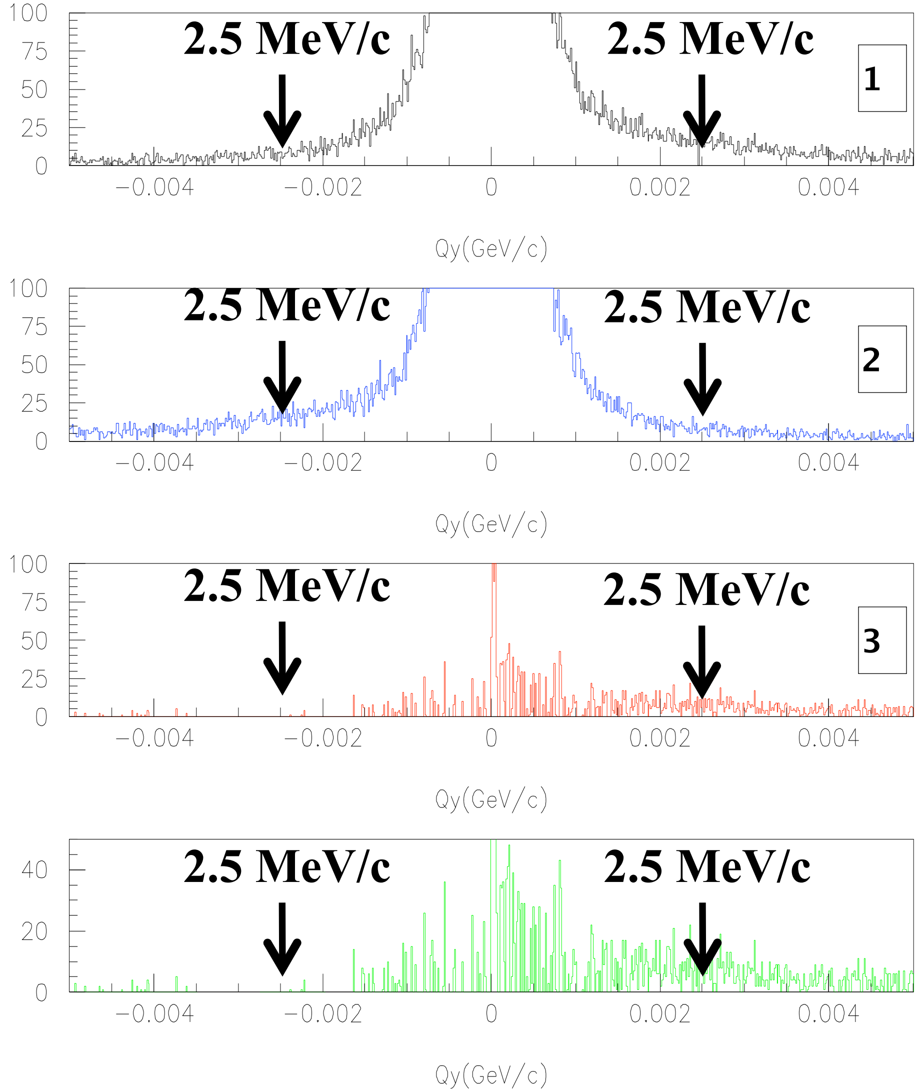
for γ =17

l(2p) = 5.7cm, l(3p) = 19cm, l(4p) = 44cm, l(5p) = 87cm
l(2s) = 0.14mm, l(3s) = 0.46mm, l(4s) = 1.1mm

Q_y distribution for e^+e^- pair

Original Q_y

Mirrored Q_y



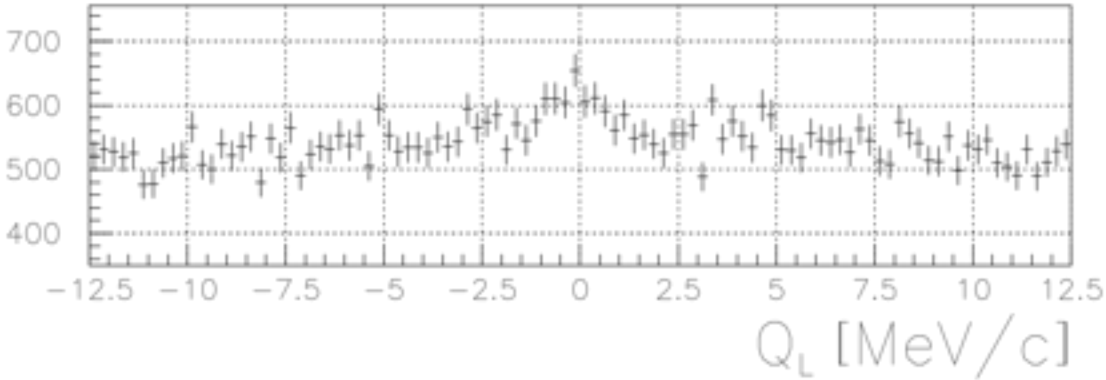
Subtraction

1 − 2

Enlarged scale

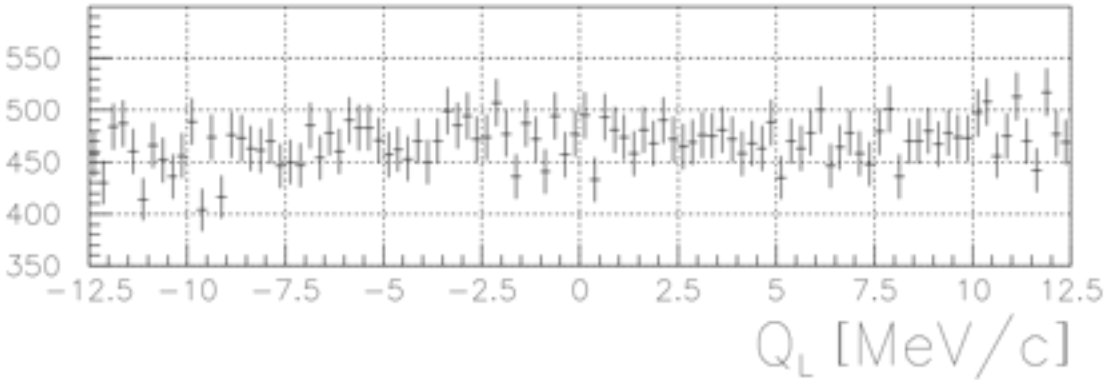
Long-lived $\pi^+\pi^-$ atoms

Experimental distribution of $\pi^+\pi^-$ pairs over Q_L

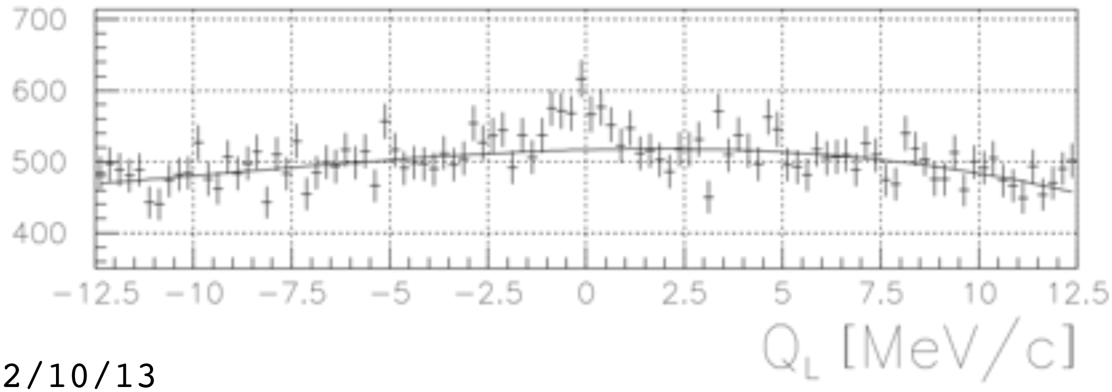


Prompt (with accidental) pairs in the searched signal region selected by the cut

$$\sqrt{Q_X^2 + \left(Q_Y - 2.5\frac{MeV}{c} \right)^2} < 1.5\frac{MeV}{c}$$



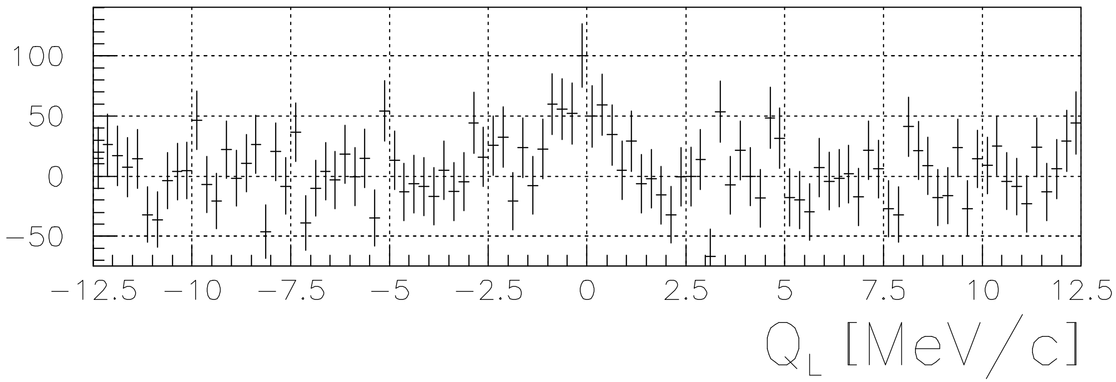
Accidental pairs



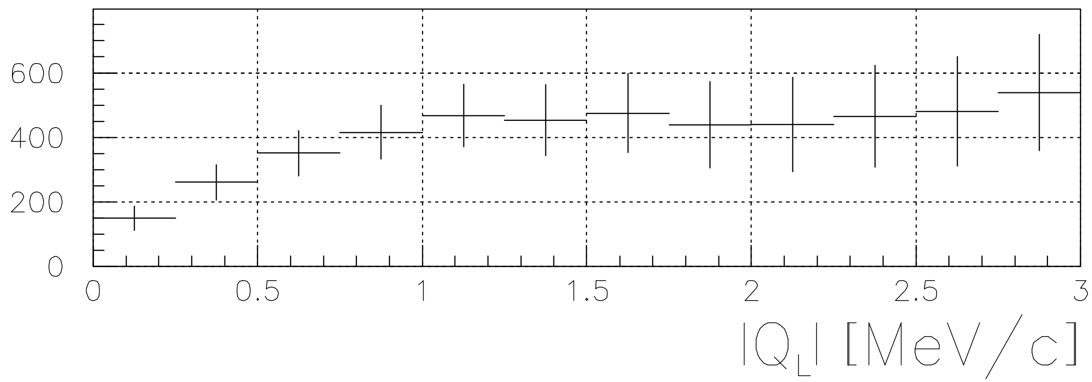
Real pairs and polynomial background fit(for $|Q_L|$>3MeV/c)

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

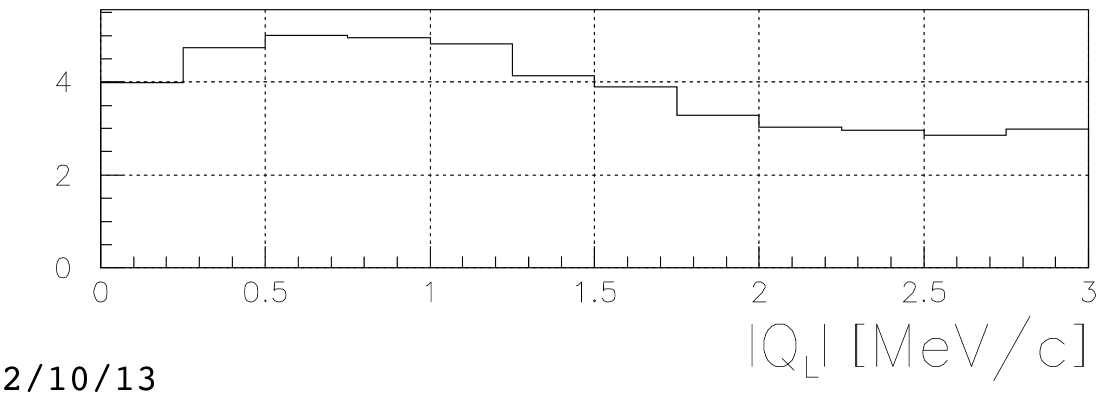
Difference between real $\pi^+\pi^-$ pairs and polynomial fit (Q_L > 3MeV/c)



Q_L distribution of $\pi^+\pi^-$ pairs after background subtraction.
The peak could be due to the long-lived $\pi^+\pi^-$ atom breakup in the Pt foil.



Total number of $\pi^+\pi^-$ pairs in the peak region as a function of $|Q_L|$ for Q_T < 1.5MeV/c



Total number (fig. above) divided by the error as a function of $|Q_L|$ for Q_T < 1.5MeV/c:

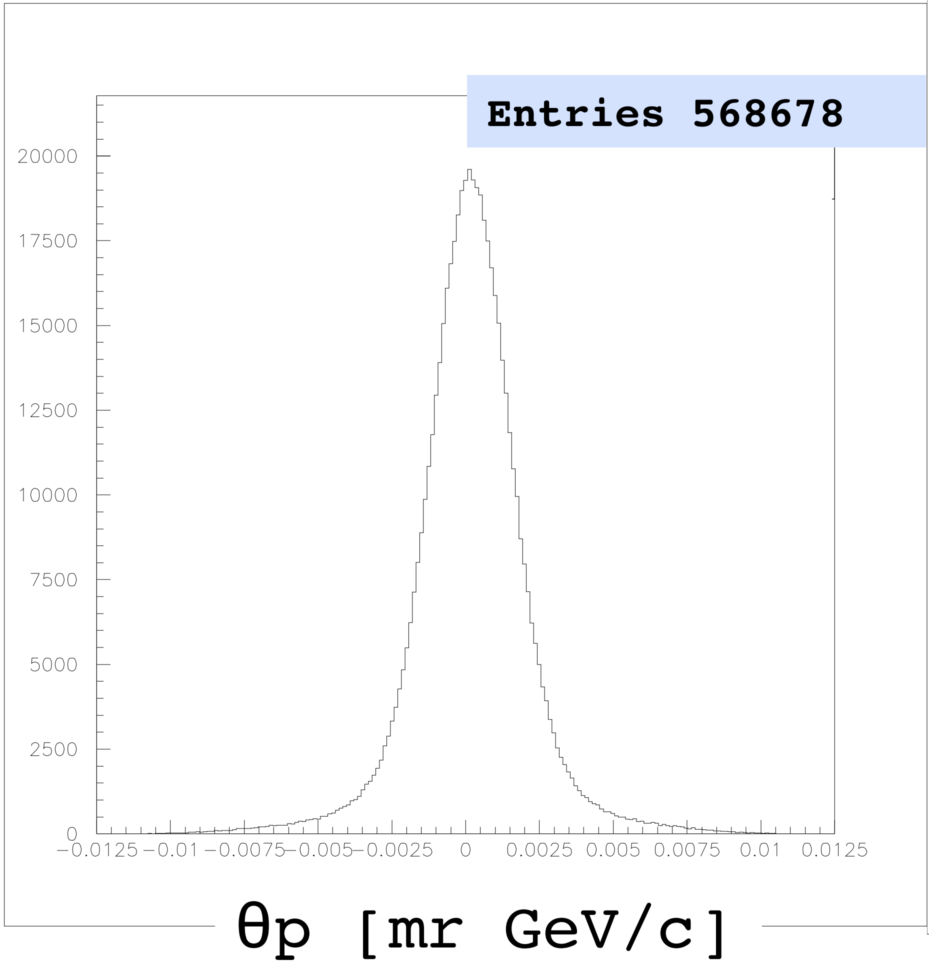
signal/error ~ 5σ

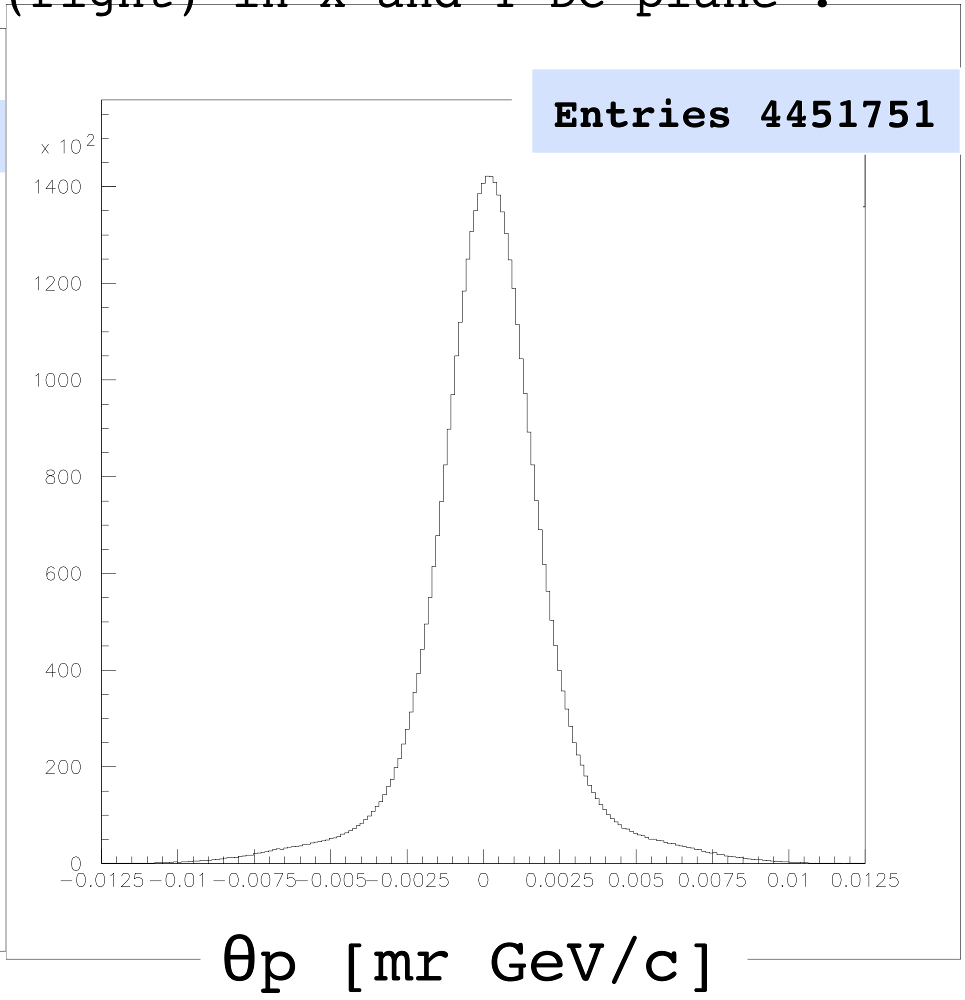
(without data analysis optimization)

3. Status of $\pi^+\pi^-$ atom investigation

Multiple scattering in Ni(100μm)

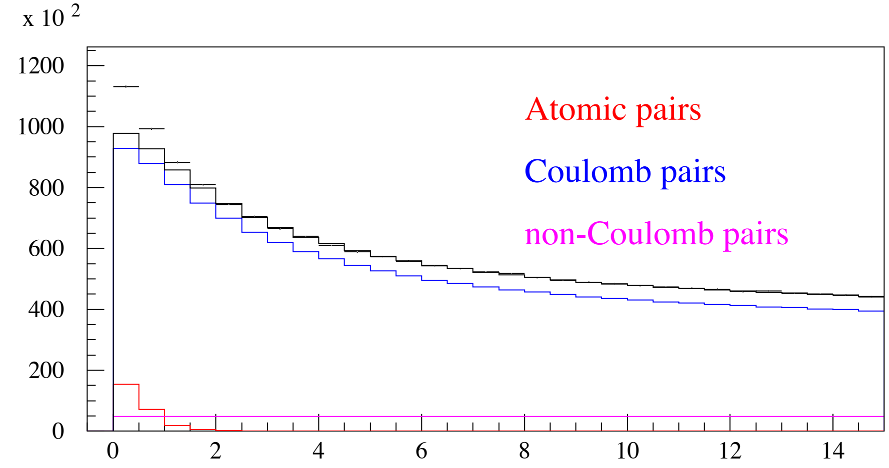
The events as a function of the multiple scattering angle θ and the particle momentum p. Events with only **one track** (left) and **one or more tracks** (right) in X and Y DC plane .

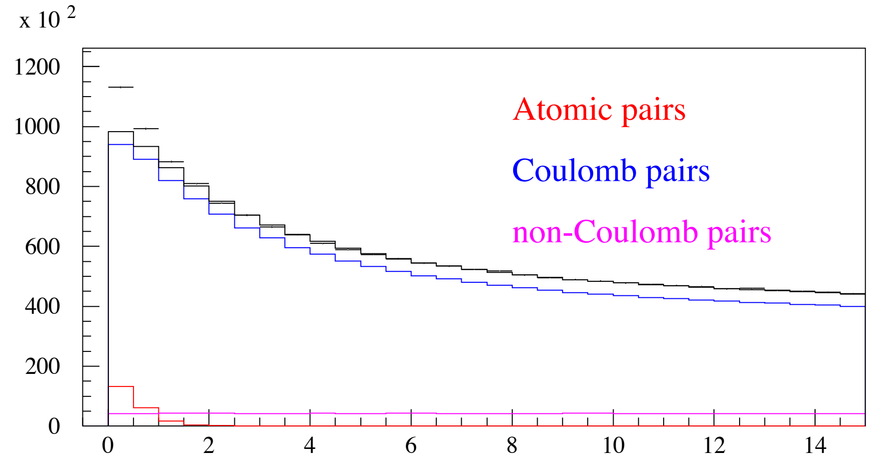


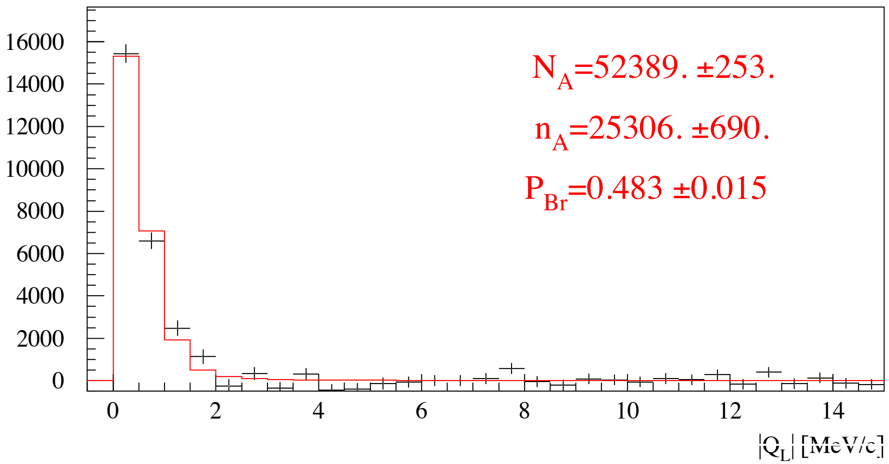


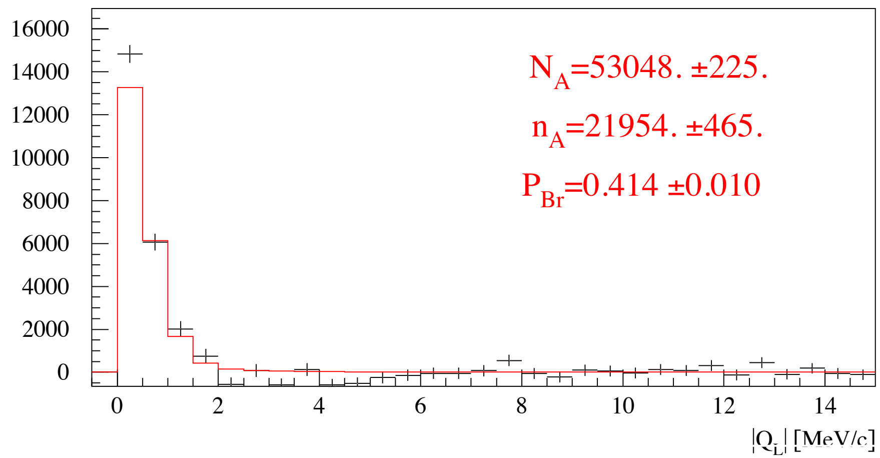
$\pi^-\pi^+$ atoms - run 2008-2010

Run 2008-2010, statistics with low and medium background (2/3 of all statistics).







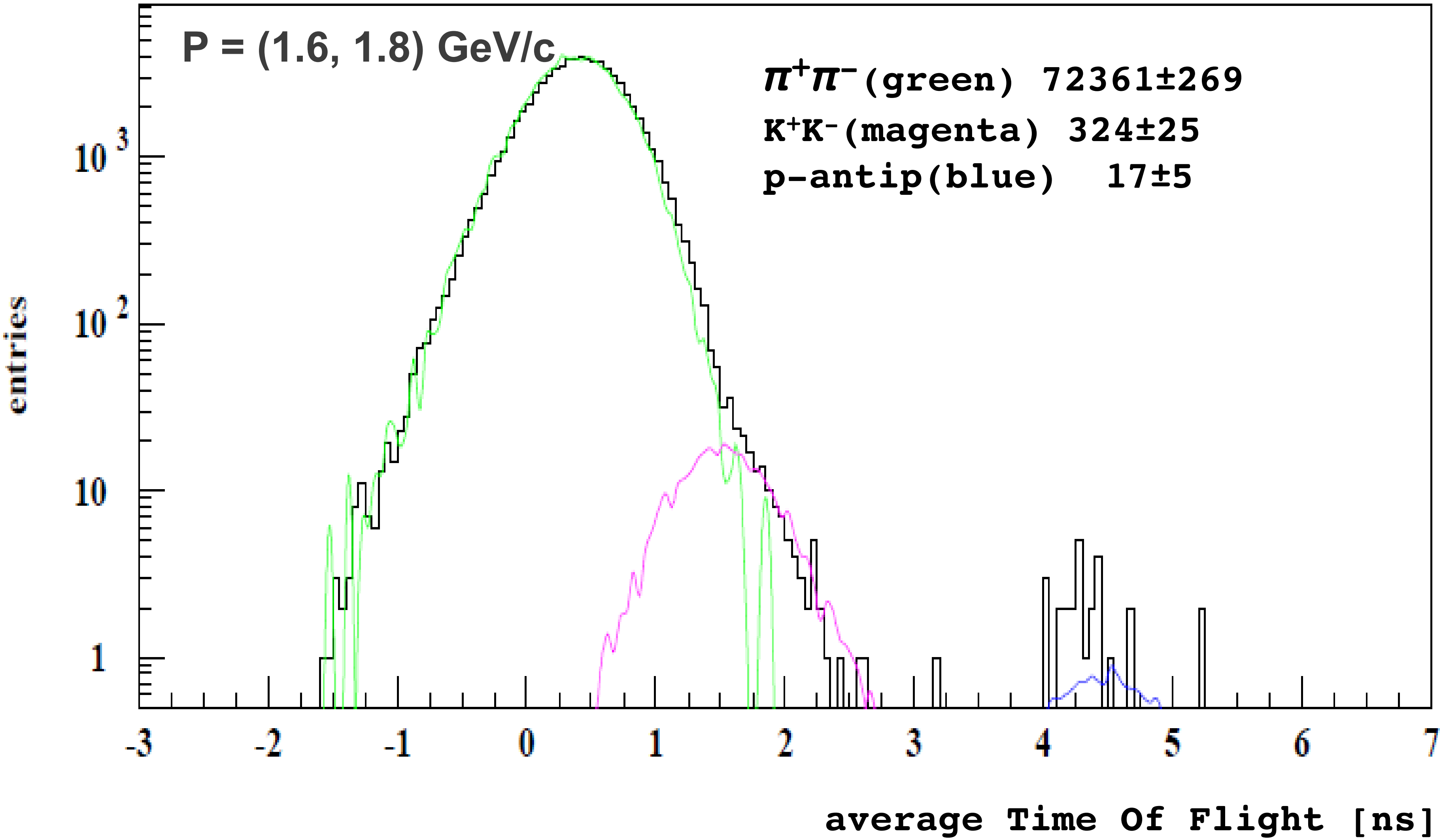


$|Q_L|$ distribution analysis on $|Q_L|$ for Q_T < 4 MeV/c

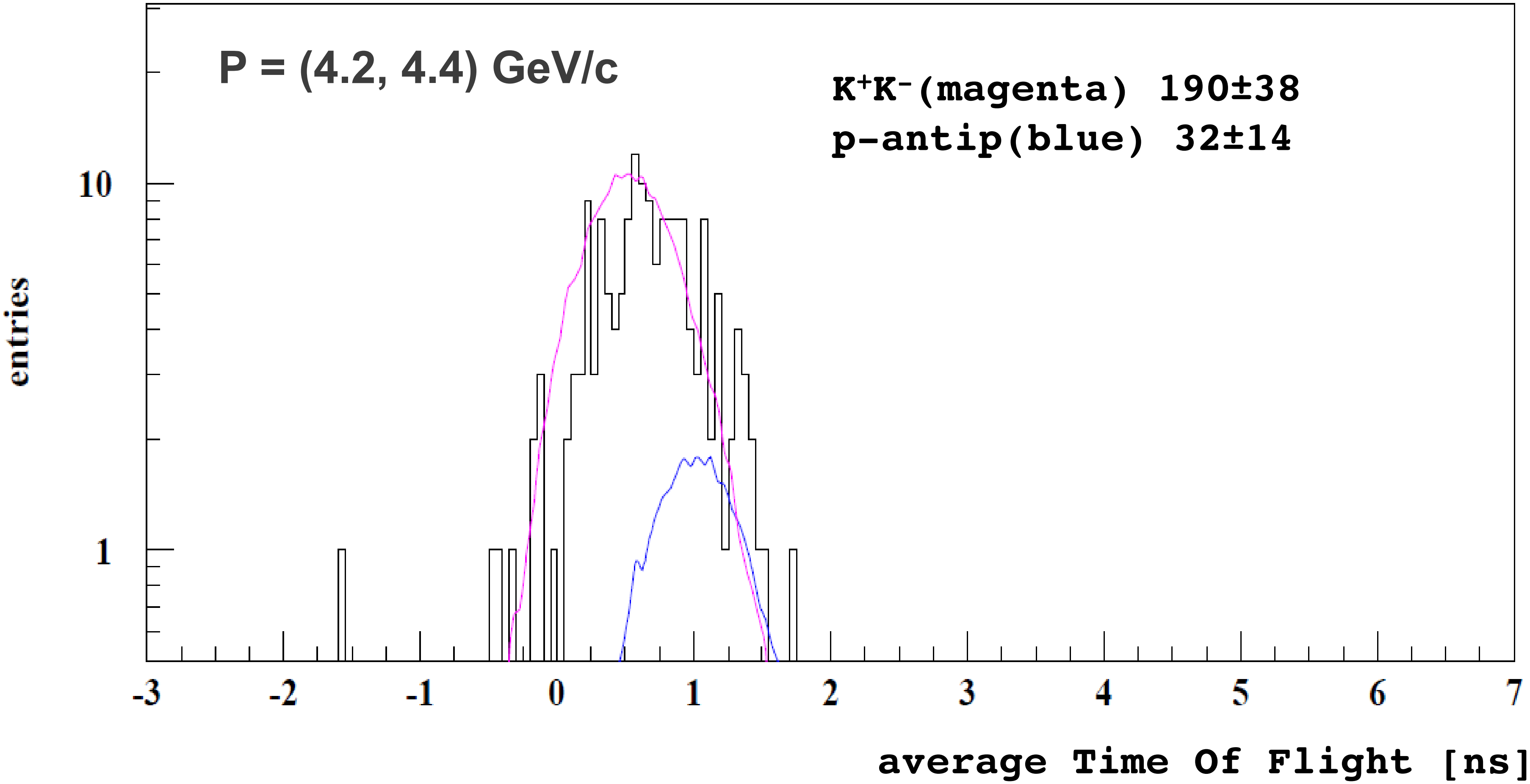
$|Q_L|$ distribution analysis on $|Q_L|$ and Q_T for Q_T < 4 MeV/c

4. Status of K^+K^- and p anti-p pairs investigation.

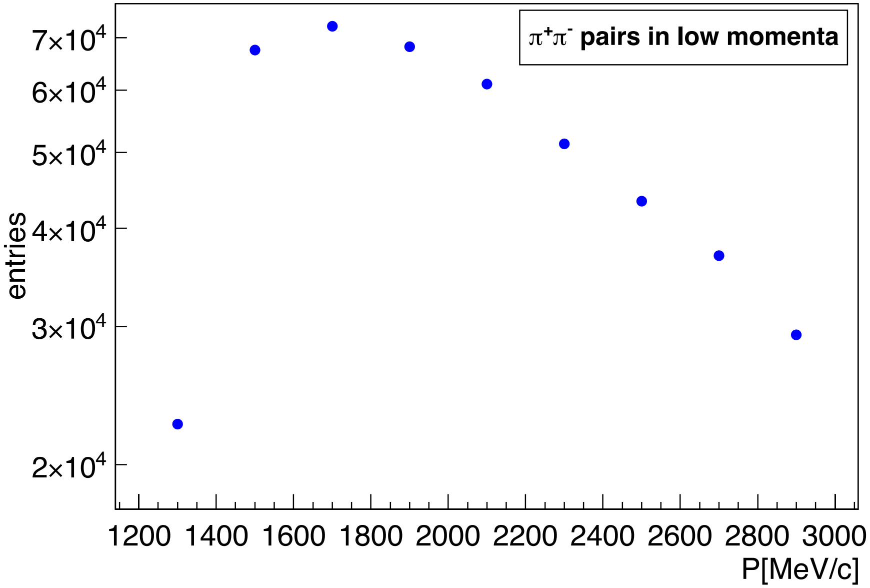
Search of K^+K^- and p-antiproton pair using Time Of Flight. Low momentum range

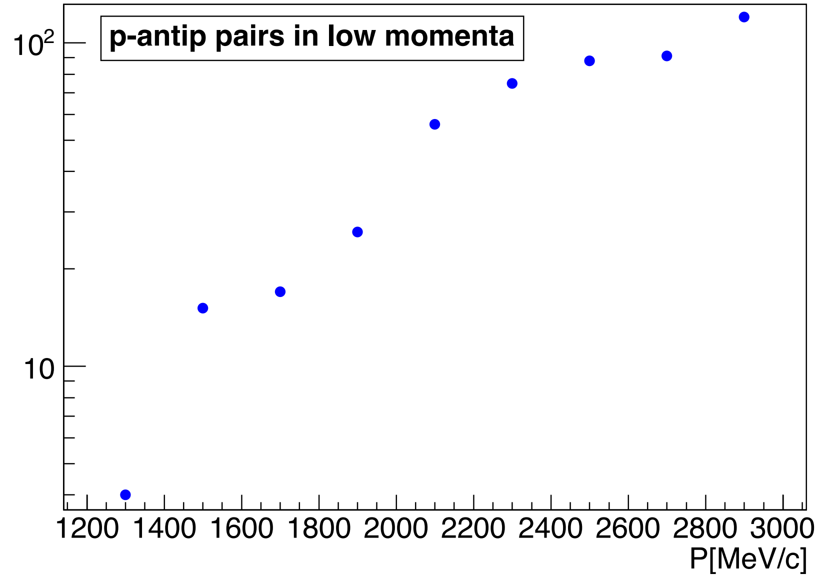


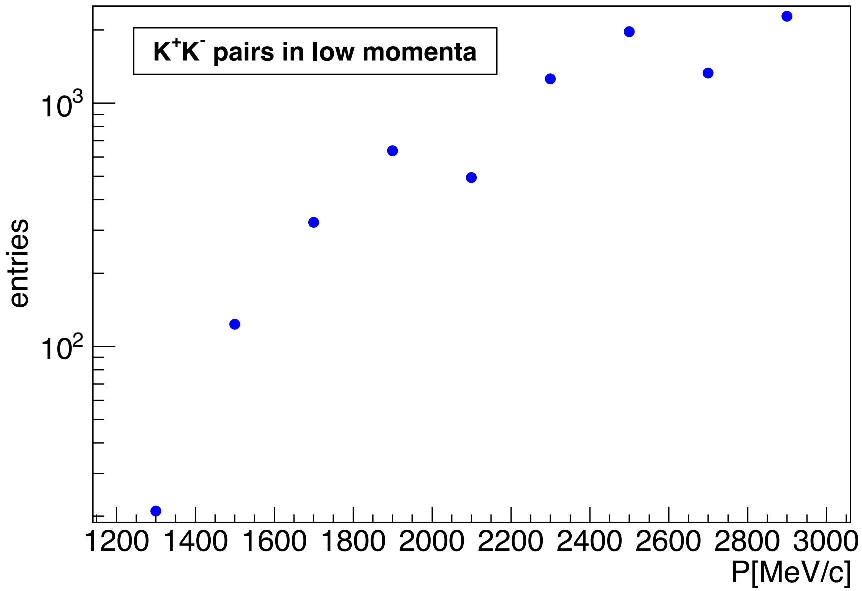
Search of K^+K^- and p-antiproton pair using Time Of Flight. High momentum range



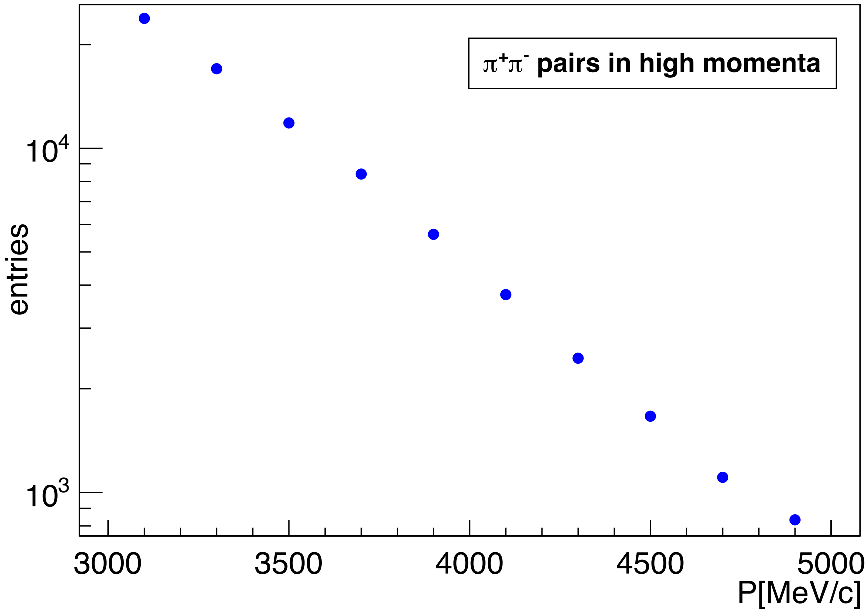
The $\pi^+\pi^-$ K^+K^- and p-antiproton numbers of pairs as a function of their momentum (low momentum)

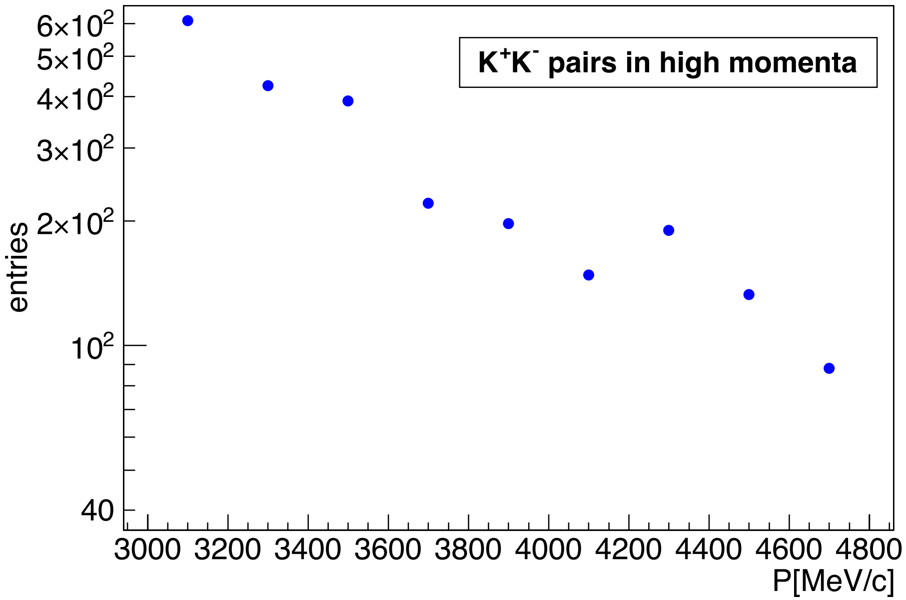


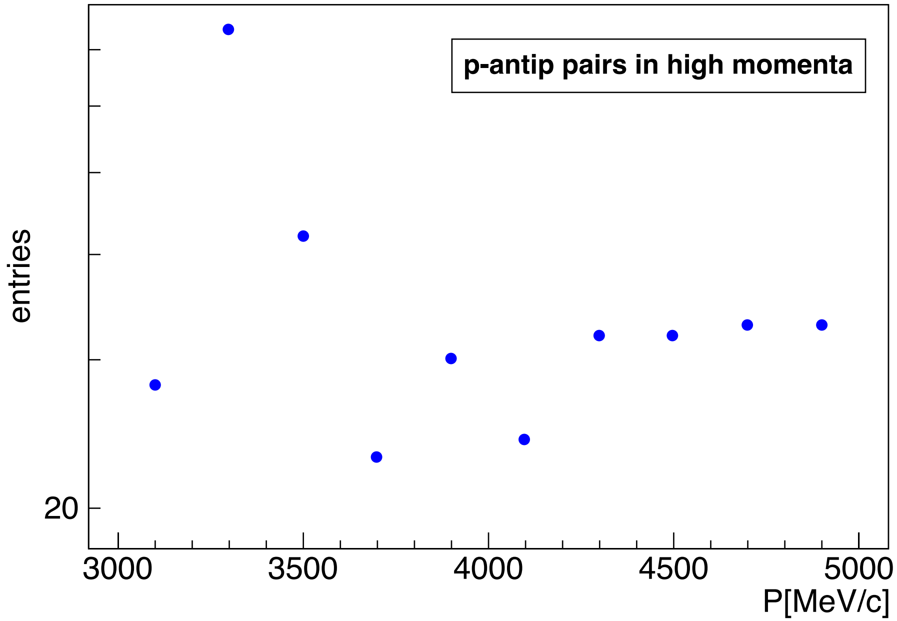




The $\pi^+\pi^-$ K^+K^- and p-antiproton numbers of pairs as a function of their momentum (high momentum)







5. Generation of $K^+\pi^-$, $K^-\pi^+$ and $\pi^+\pi^-$ atoms in p-nuclear interaction at proton beam momentum 24 GeV/c and 450 GeV/c.

DIRAC prospects at SPS CERN

Yield of dimeson atoms per one p-Ni interaction, detectable by DIRAC upgradeδ setup

E_p	PS - 24 GeV			SPS - 450 GeV								
Θ_{lab}	5.7^0			5.7^0			4^0			2^0		
Atoms	$\pi^+\pi^-$	$K^-\pi^+$	$K^+\pi^-$	$\pi^+\pi^-$	$K^-\pi^+$	$K^+\pi^-$	$\pi^+\pi^-$	$K^-\pi^+$	$K^+\pi^-$	$\pi^+\pi^-$	$K^-\pi^+$	$K^+\pi^-$
W_A	1.1E-9	2.6E-11	4.4E-11	1.0E-8	2.0E-10	2.1E-10	1.8E-8	9.3E-10	1.2E-9	2.7E-8	2.3E-9	3.0E-9
W_A^N	1	1	1	9.7	7.5	4.7	17.2	35.4	27.2	25.8	86.9	68.7
W_A/W_π	7.0E-8	1.7E-9	2.9E-9	2.3E-7	4.4E-9	4.7E-9	2.0E-7	1.0E-8	1.3E-8	8.3E-8	7.0E-9	9.2E-9
W_A^N/W_π^N	1	1	1	3.	2.6	1.6	2.9	6.0	4.6	1.2	4.0	3.2
				A multiplier factor due to spill duration: ~ 4								
Total gain				13	10	6	12	24	18	5	16	13

DIRAC collaboration plans

I.K-pi atoms.

1. To publish paper about K-pi atom lifetime measurement in ***January 2014.***
2. To study the possibility of K-pi pairs with high background (1/3 of total statistics) process and analysis: ***June 2014.***
3. To reprocess 2007 run data on K-pi atoms generated on Pt target and analyse it using Monte-Carlo: ***October 2014.***

II.Long-lived atoms.

1. To finish analysis of the data with low and medium background and publish the dedicated paper: ***October 2014.***
2. To study the possibility of pi-pi pairs with high background (1/3 of total statistics) process and analysis: ***June 2014.***
3. To study the possibility of the Lamb shift minimum value evaluation from the existing experimental data: ***January 2015.***
4. To study the possibility of run 2011 data process and analysis: ***October 2014.***

III.pi+pi- pairs analysis.

1. To finish analysis of the data with low and medium background : ***April 2015.***
2. To study the possibility of pi-pi pairs with high background (1/3 of total statistics) process and analysis: ***April 2015.***
3. To correct data 2001-2003 using new experimental data on K+K- and P-antiP yields and the new experimental data on the multiple scattering: ***October 2015.***

IV.K+K- pairs analysis.

1. To analyse existing experimental data to search for K+K- Coulomb pairs signal. These pairs allow to extract the K+K- atoms number produced simultaneously with Coulomb pairs. Preliminary results: ***January 2015***.

V.P-antiproton pairs analysis.

1. To analyse existing experimental data to search for p-antiproton Coulomb pairs signal. These pairs allow to extract the p-antiproton atoms number produced simultaneously with Coulomb pairs. Preliminary results: ***January 2015***.

VI.Investigation of K+pi-, K-pi+, pi+pi-, K+K- atoms production in P-nucleus interactions at proton momentum 24GeV/c and 450GeV/c.

1. Publication as DIRAC note in January 2015 using generator describing inclusive cross sections of K+,K-,pi+,pi- production in proton-nucleus interactions the dimesoatoms yields at 24GeV/c and 450GeV/c.
2. Preparation the Letter of Intent about investigation of dimesoatoms on SPS CERN: ***January 2015***.

VII.pi+mu- and pi-mu+ pairs analysis.

1. To analyse existing experimental data(2010-2012) to search for pi+mu- and pi-mu+ Coulomb pairs signal. These pairs allow to extract the pi-mu atoms number produced simultaneously with Coulomb pairs. Preliminary results: ***October 2015***.

IX. mu+mu- pairs analysis.

To analyse existing experimental data(2001-2003 and 2007-2012) to search for mu+mu- Coulomb pairs signal. These pairs allow to extract the mu+mu- atoms number produced simultaneously with Coulomb pairs.
Preliminary results: ***October 2015***.

X. Using experimental data 2001-2003 and 2007-2012 to measure the dimesoatoms production cross sections in proton interactions with Be, Ti, Ni and Pt nucleus: ***end of 2015***.

XI. Using experimental data 2001-2003 and 2007-2012 to measure the pi+,pi- pi0,K+,K-, p,antiproton, deuteron inclusive cross sections in proton interactions with Be, Ti, Ni and Pt nucleus: ***end of 2015.***

XII. Using experimental data 2001-2003 and 2007-2012 to measure the correlation functions at at small relative momentum of pi+pi-, K+pi- ,K-pi+ pairs generating in proton interactions with Be, Ti, Ni and Pt nucleus: ***end of 2015***.

Thank you
for your attention!