DIRAC collaboration plans on 2014-2015

L. Nemenov

December 17, 2013

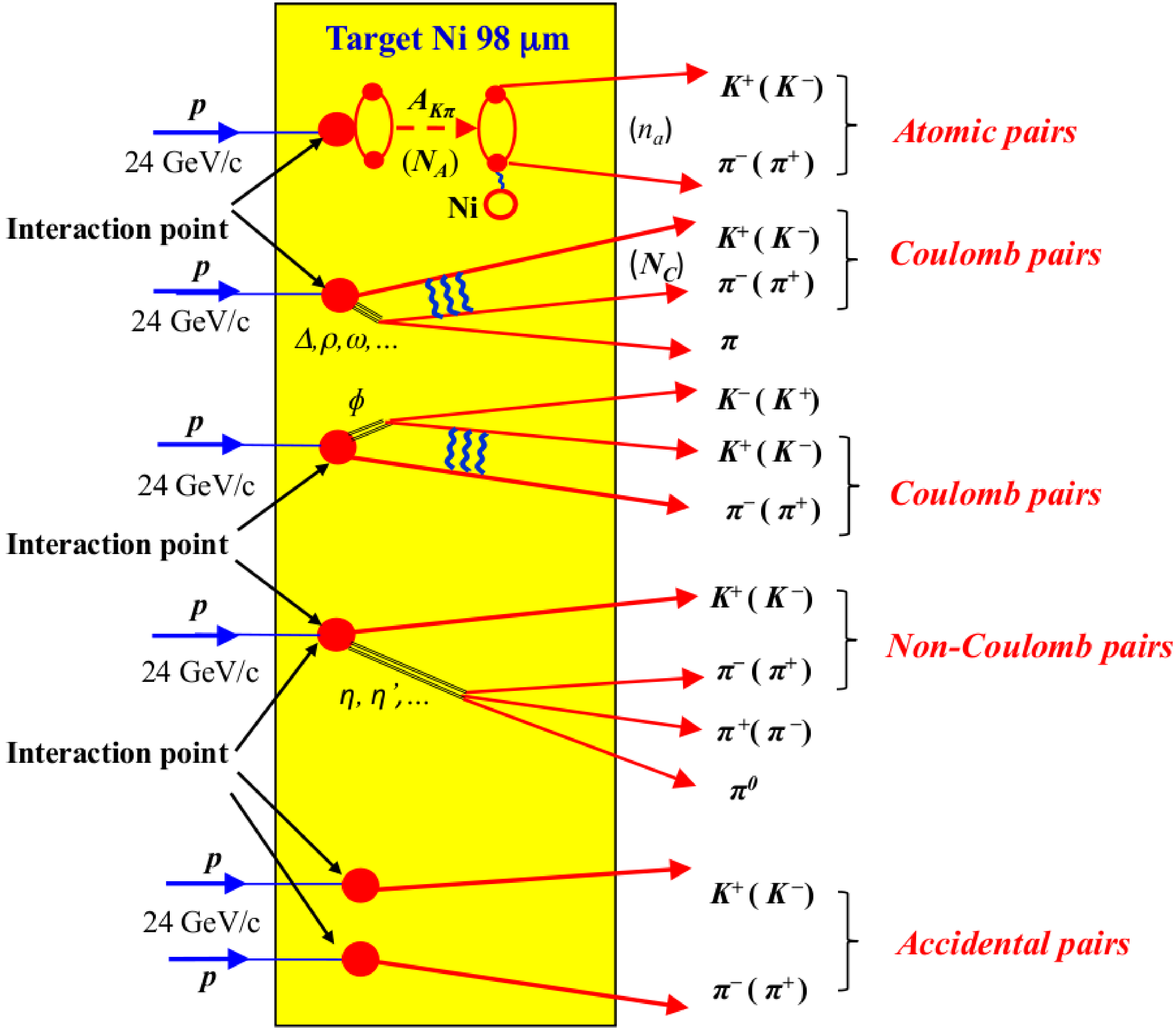
DIRAC collaboration planning for 2014

- I. $K\pi$ atoms.
  Publish the paper "First $K\pi$ atom lifetime measurement" (January 2014).
  Enlarge the published statistics using data with large background.
- II. Long-lived atoms.
  Finish analysis and publish the paper: "First observation of the long-lived $\pi^+\pi^-$ atoms" (October 2014). Study the possibility to evaluate a lowest value of Lamb shift from existing data.
- III. Continue the $\pi^+\pi^-$ atoms data analysis.
- IV. K^+K^- pairs analysis.
  Analyze existing experimental data to search for K^+K^- Coulomb pairs signal and extract the K^+K^- number of atoms produced simultaneously with Coulomb pairs.
- V. $\pi^+\mu^-$, $\pi^-\mu^+$ and $\mu^+\mu^-$ pairs analysis.
  Begin the analysis of existing experimental data to search for $\pi^+\mu^-$, $\pi^-\mu^+$ and $\mu^+\mu^-$ Coulomb pairs signal and to extract the $\pi\mu$ and $\mu^+\mu^-$ atoms produced simultaneously with Coulomb pairs.
- VI. Project preparation on SPS.

Number of people participating in the data process and analysis

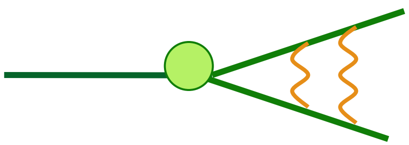
- 1. Bern 1
- 2. CERN 1
- 3. Bucharest 4
- 4. Dubna 9
- 5. Prague 2
- 6. Protvino 2
- Total 19

Method of Kπ atom observation and investigation



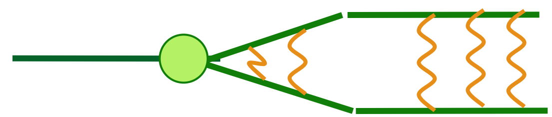
Coulomb pairs and atoms

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

Coulomb pairs



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

Atoms

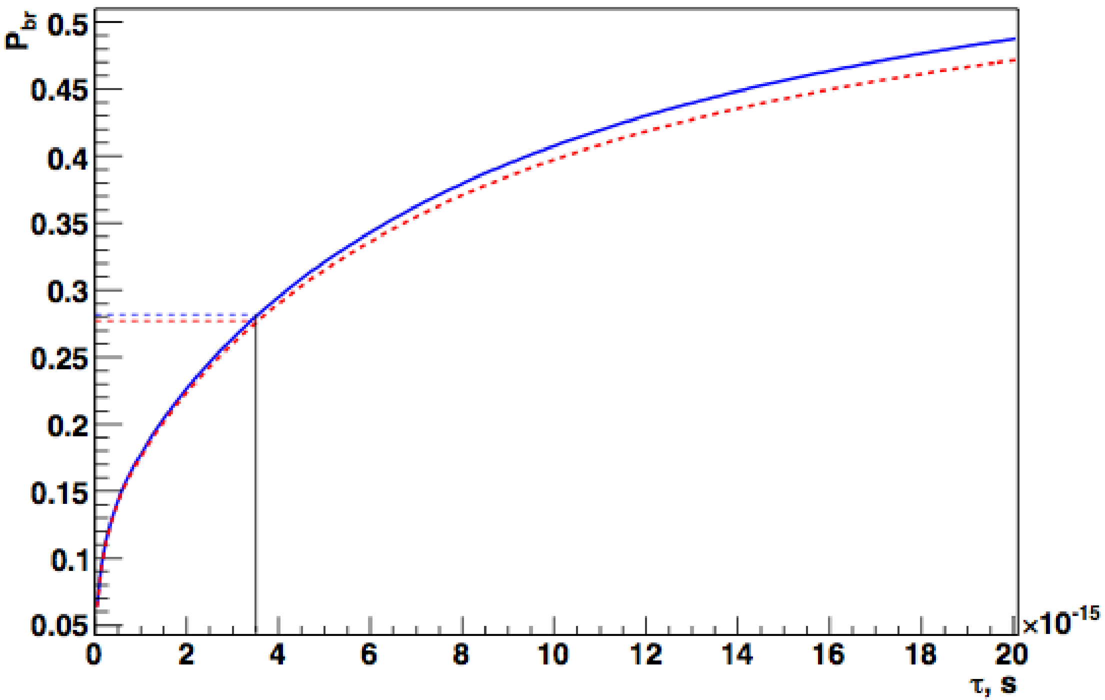
There is a precise ratio between the number of produced Coulomb pairs (N_C) with small Q and the number of atoms (N_A) produced in the way as these Coulomb pairs:

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

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

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.

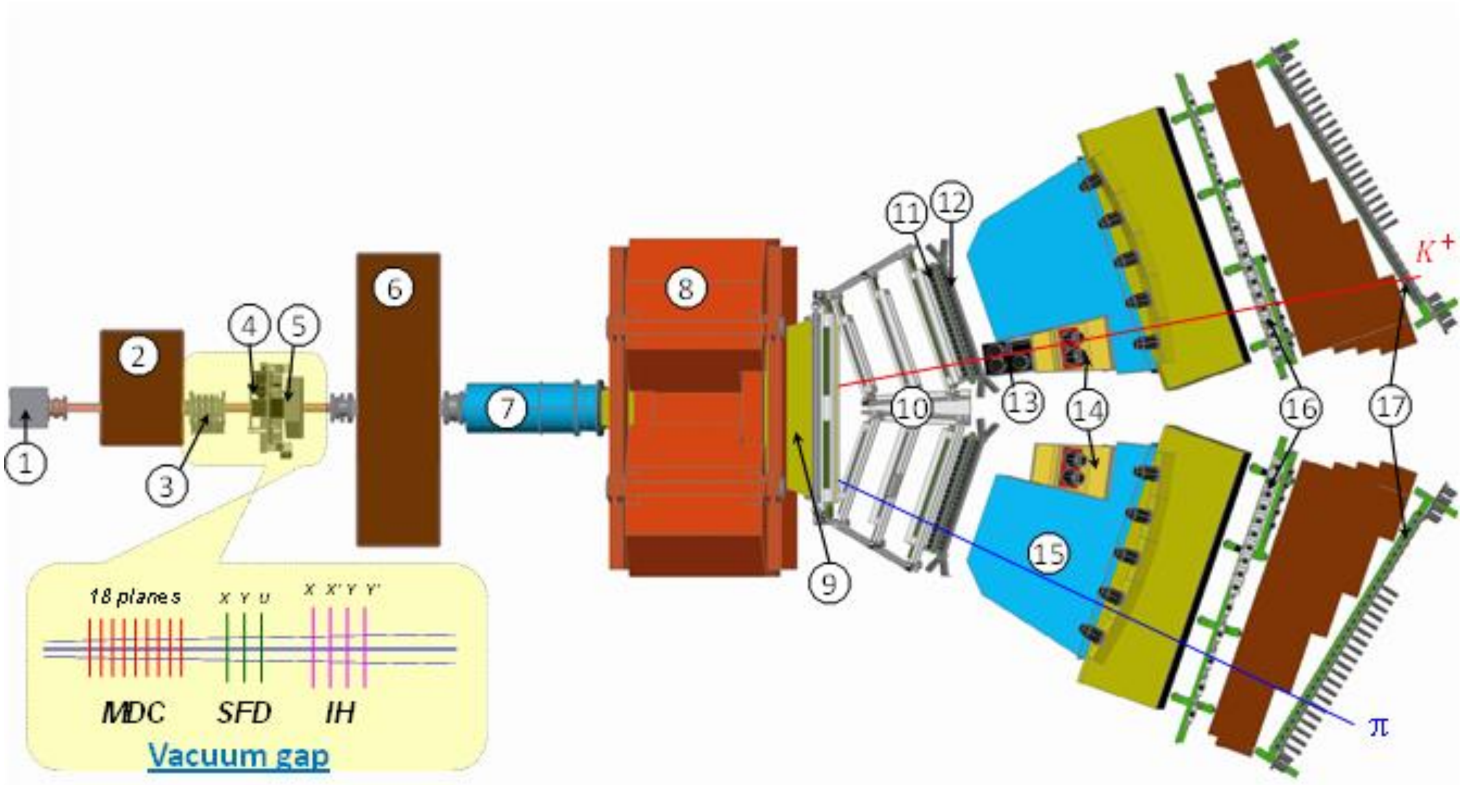


$P_{br}^{th} = 0.278 \begin{matrix} +0.012 \\ -0.011 \end{matrix}$

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

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

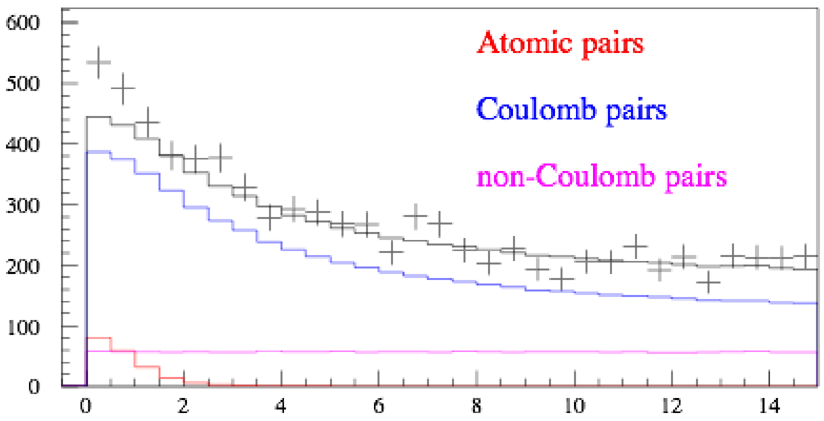
Experimental setup

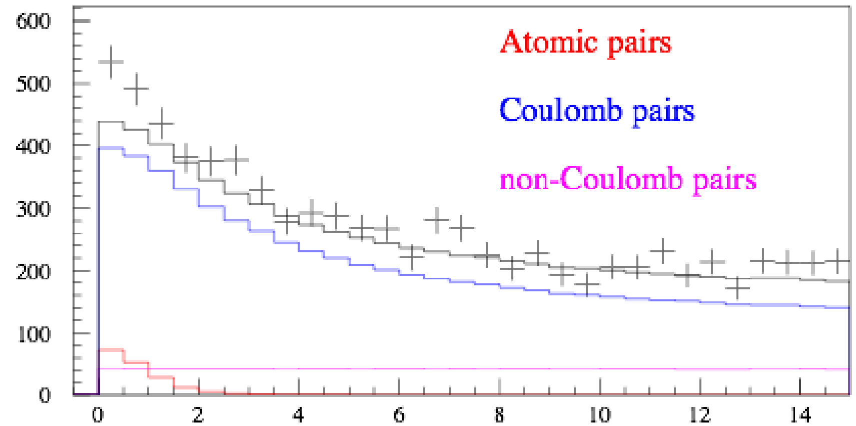


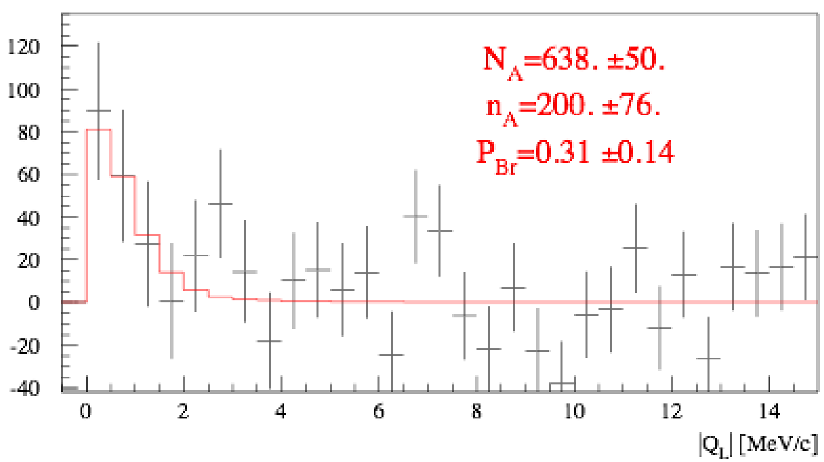
1 Target station with Ni foil; **2** First shielding; **3** Micro Drift Chambers; **4** Scintillating Fiber Detector; **5** Ionization Hodoscope; **6** Second Shielding; **7** Vacuum Tube; **8** Spectrometer Magnet; **9** Vacuum Chamber; **10** Drift Chambers; **11** Vertical Hodoscope; **12** Horizontal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

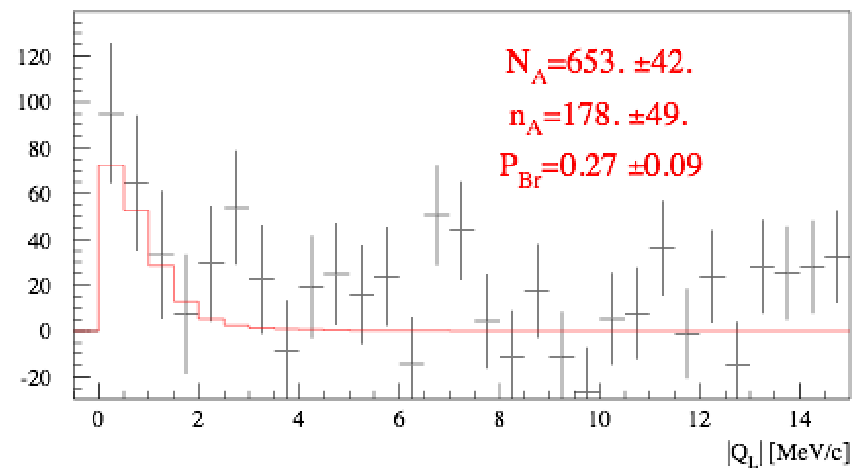
$K^-\pi^+$ + $K^+\pi^-$ atoms - run 2008-2010

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





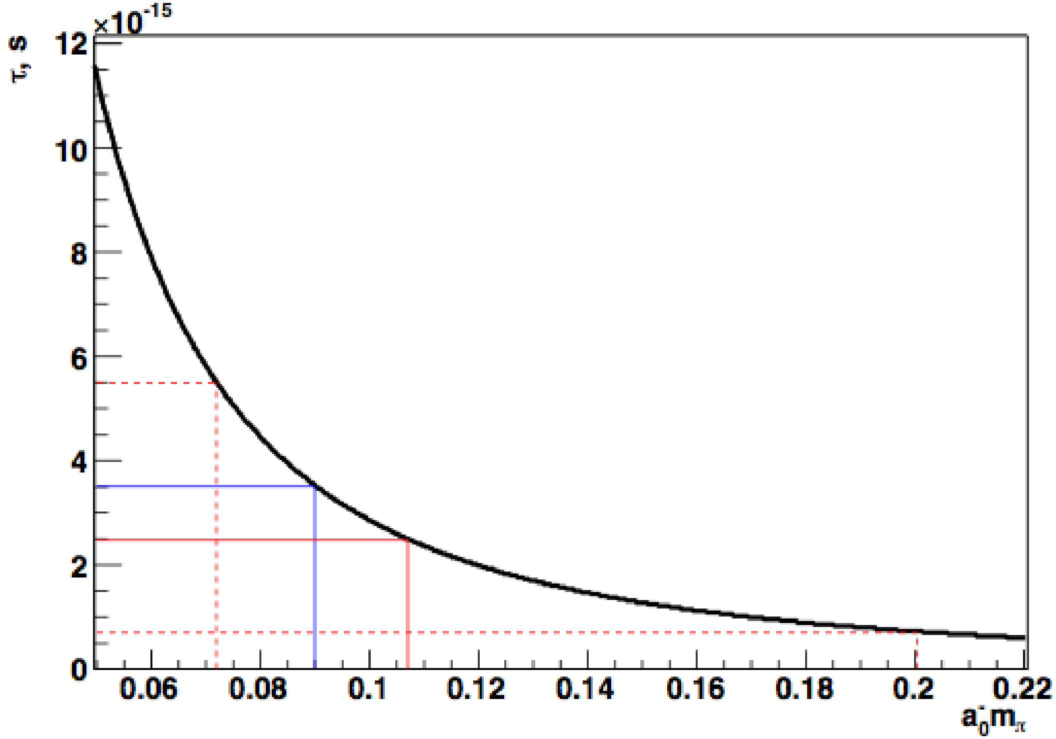




$|Q_L|$ distribution
analysis on $|Q_L|$ for Q_T < 4 MeV/c

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

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.
Paper will be published in January 2014.



$$\tau^{exp} = (\,2.5\ ^{+3.00}_{-1.77}\,) \times 10^{-15} s$$

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

$$|a_0^-|^{th} m_\pi = 0.090 \pm 0.005$$

[P.Buettiker 2004]

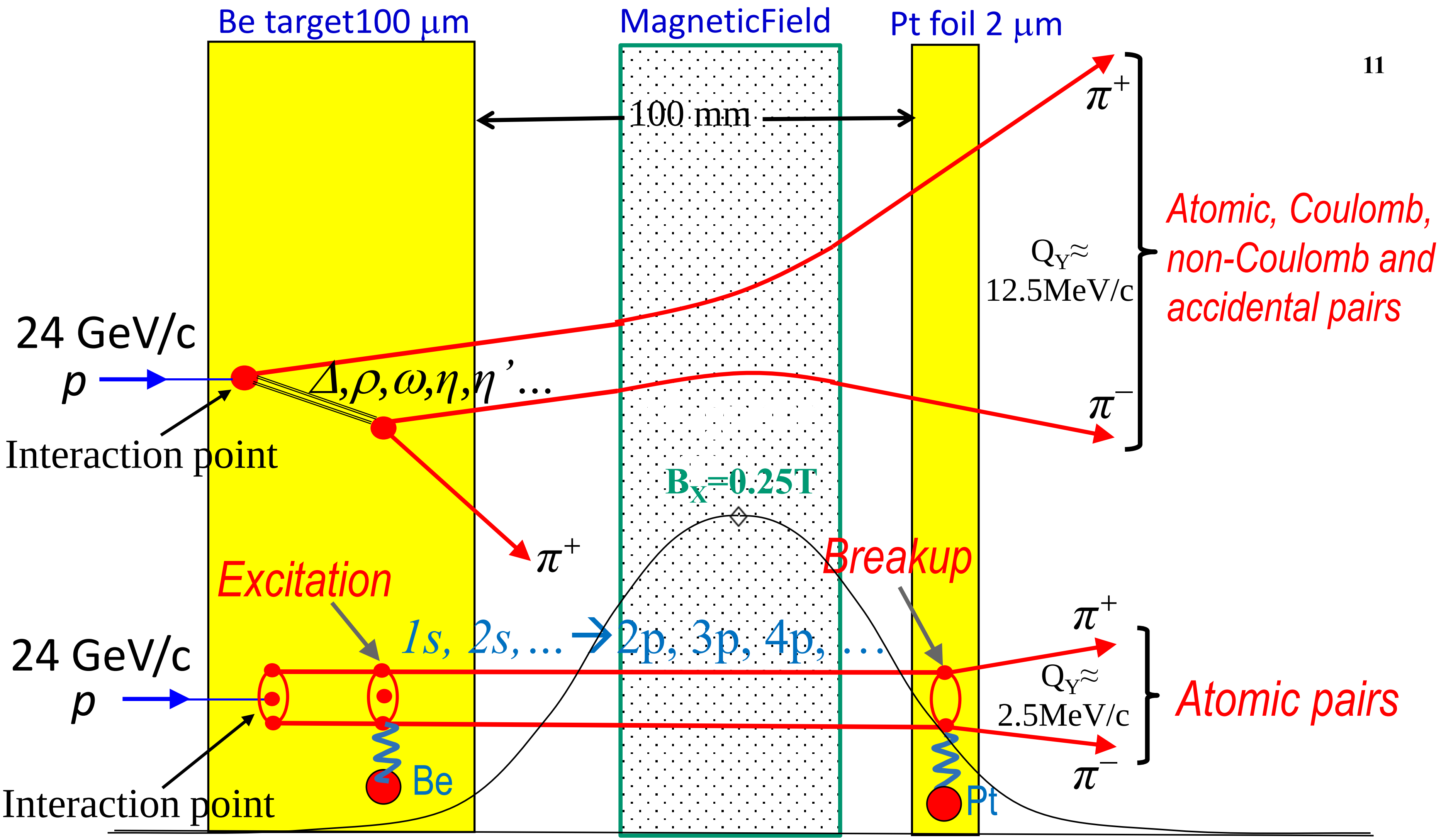
Improve the published results using data with large background (1/3 of the total statistic) and data obtained on Pt target in 2007.

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 ΔE(ns-np) and the value of ππ scattering lengths $|2a_0+a_2|$.

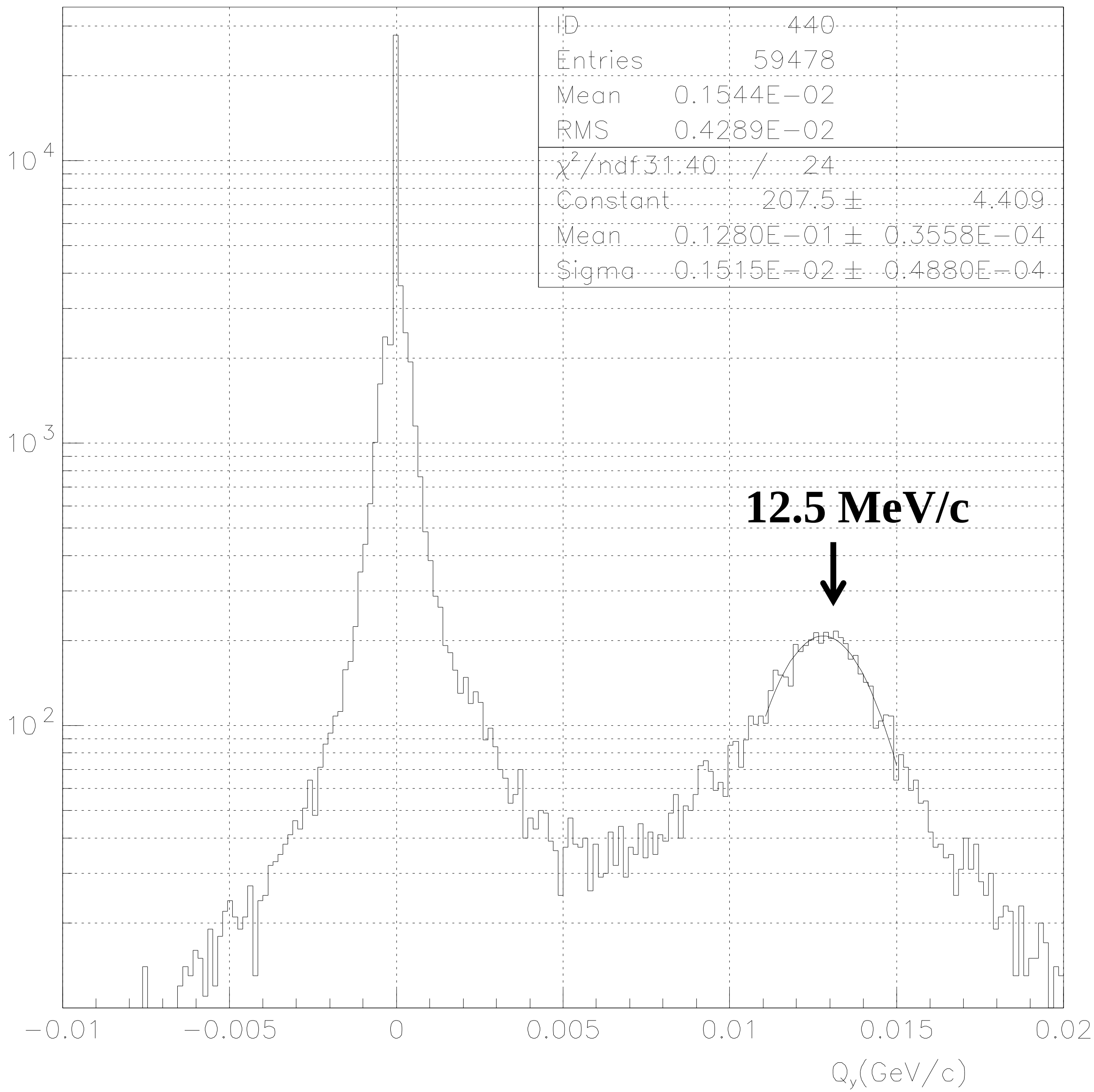
If a resonance method can be applied for the ΔE(ns-np) measurement, then the precision of ππ scattering length measurement can be improved by one order of magnitude relative to the precision of other methods.

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



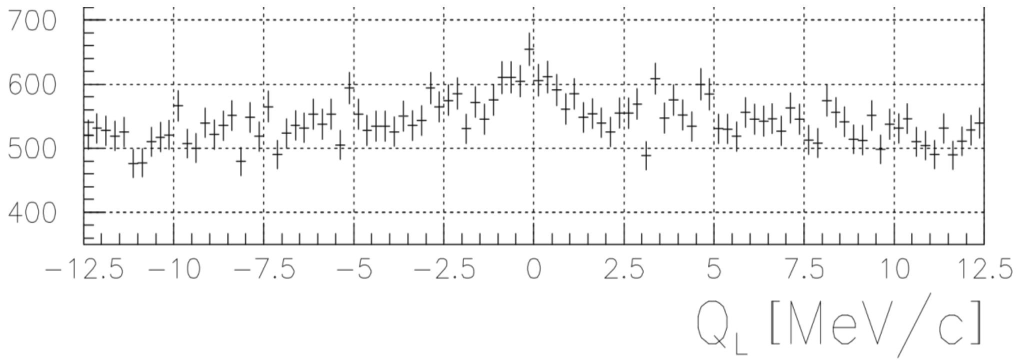
for $\gamma = 17$	$l(2p) = 5.7$ cm, $l(3p) = 19$ cm, $l(4p) = 44$ cm, $l(5p) = 87$ cm $l(2s) = 0.14$ mm, $l(3s) = 0.46$ mm, $l(4s) = 1.1$ mm

Q_y distribution for e^+e^- pair



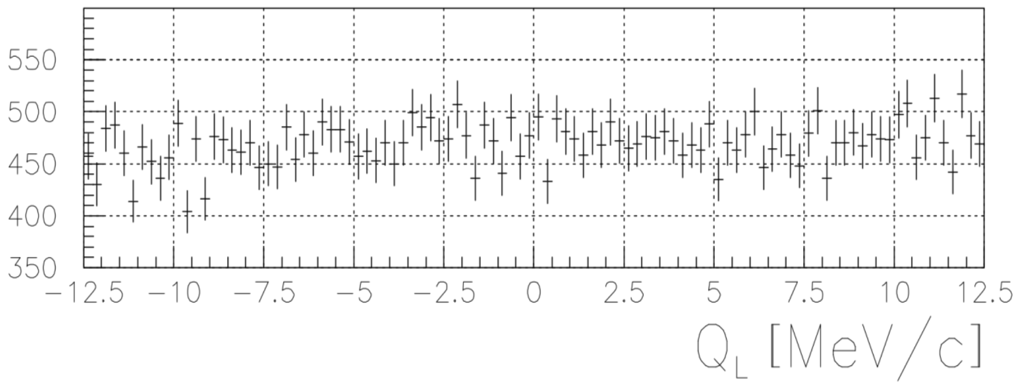
Long-lived $\pi^+\pi^-$ atoms

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

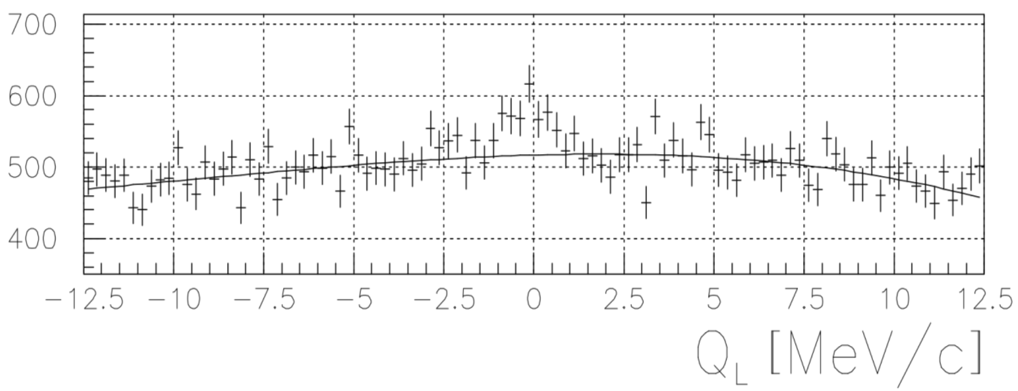


Prompt **(with accidental) pairs in the searched signal region selected by the cut**

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



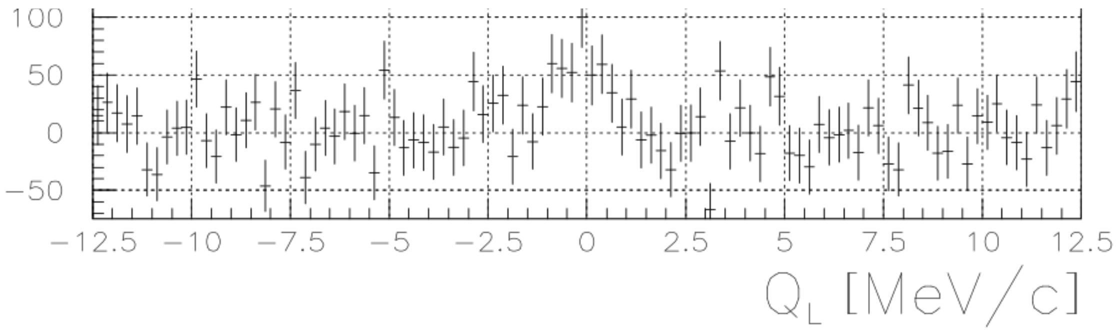
Accidental pairs



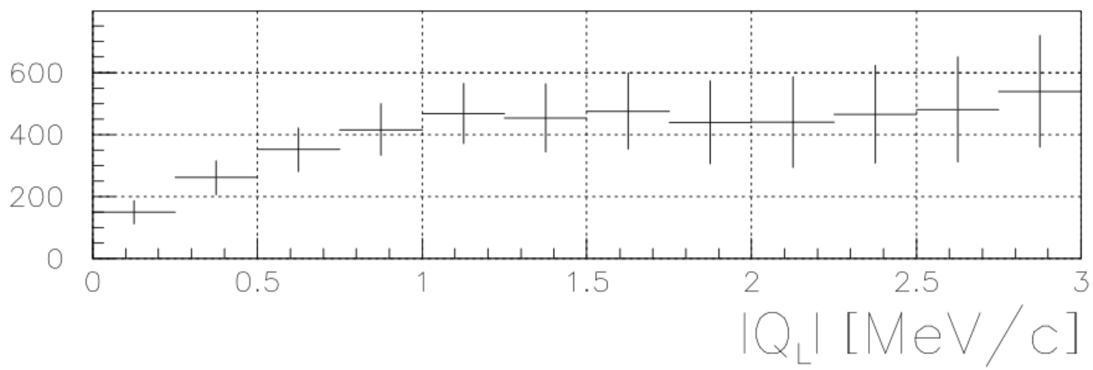
Real pairs and polynomial background fit(for $|Q_L|$>3MeV/c)

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

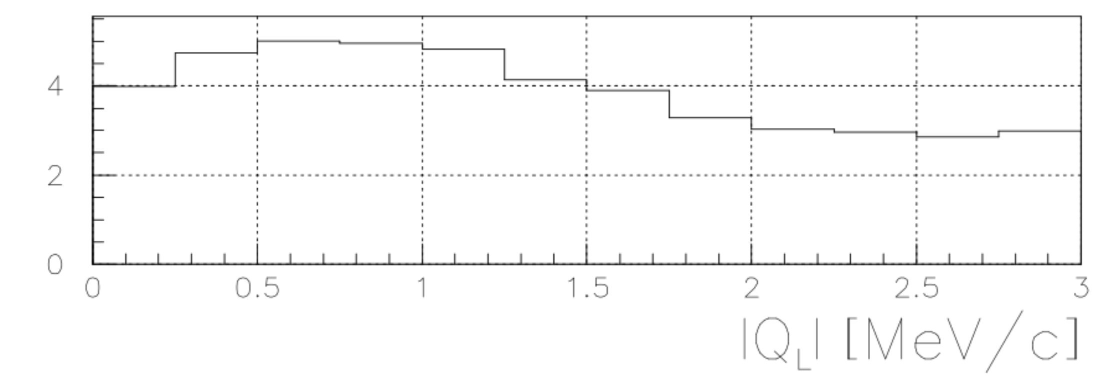
Difference between real $\pi^+\pi^-$ pairs and polynomial fit (Q_L > 3MeV/c)



***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)

Finish analysis and publish the paper : "First observation of the long-live $\pi^+\pi^-$ atoms"(October 2014)
Study the possibility to evaluate a lowest value of the Lamb shift from existing data.

$\pi^+\pi^-$ data

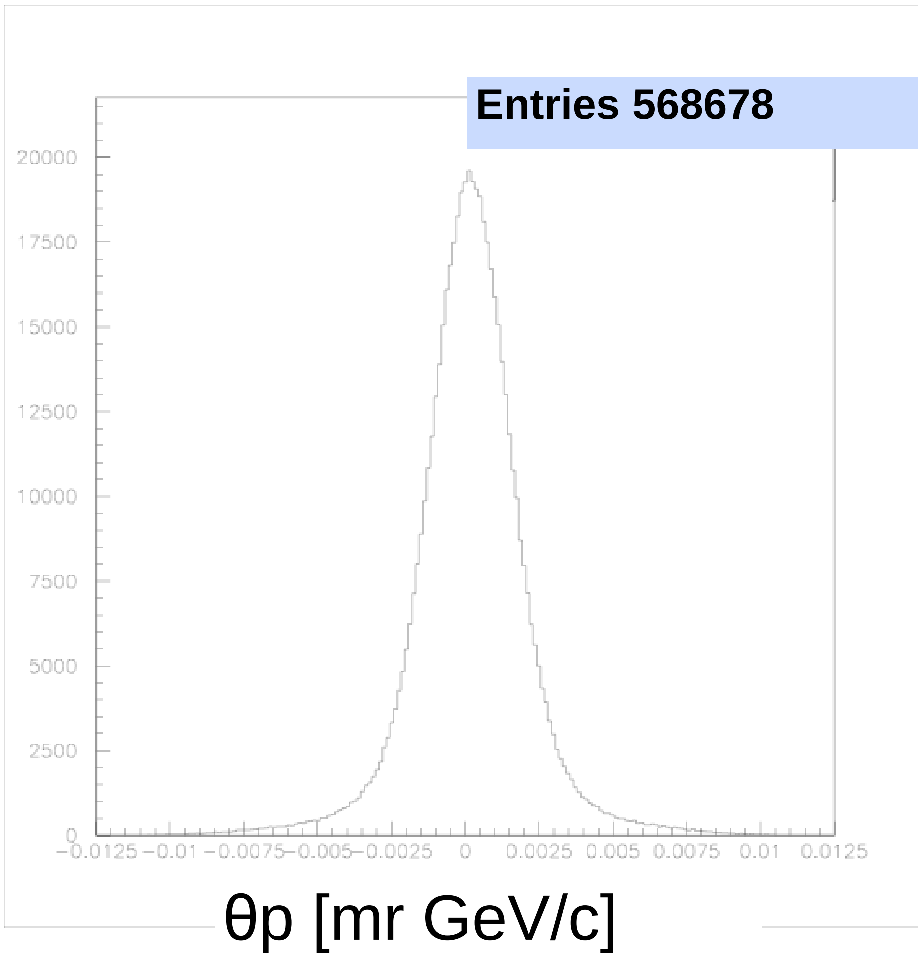
Statistics for measurement of $|a_0-a_2|$ scattering length difference and expected precision

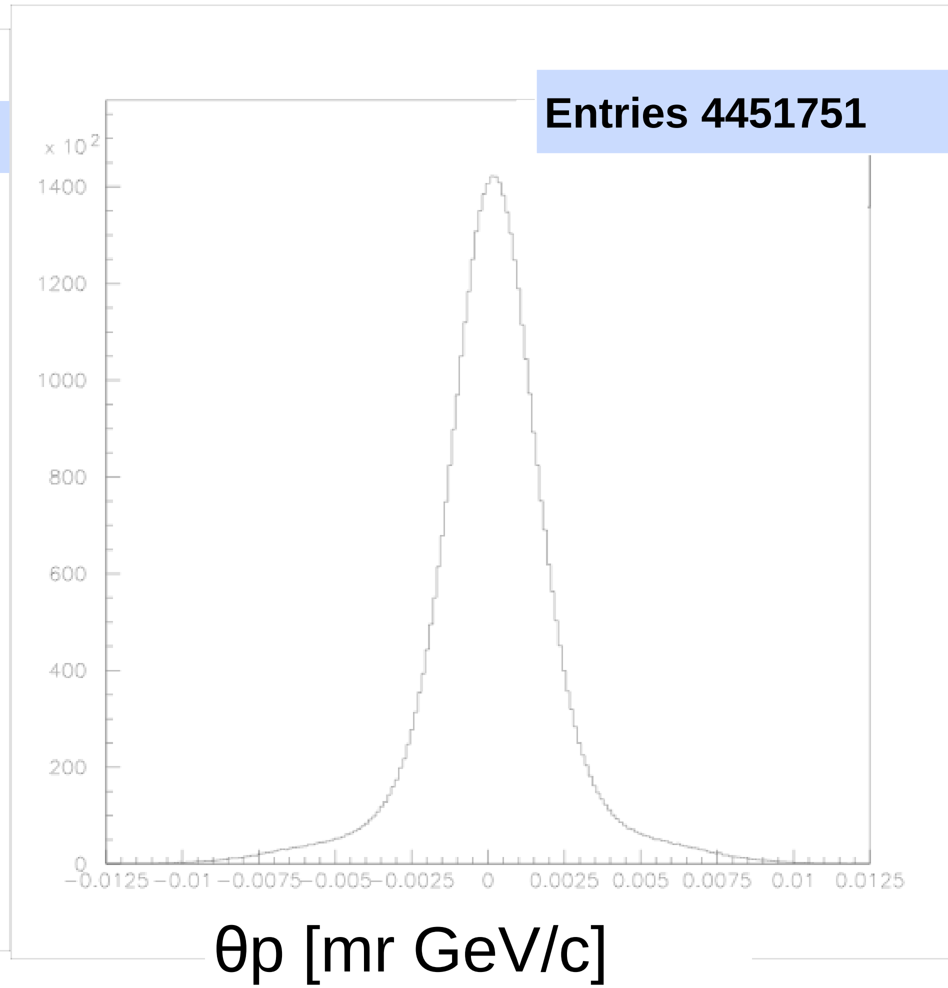
Year	n_A	$\delta_{stat}(\%)$	$\Delta_{syst}(\%)$	$\delta_{syst}(\%)$MS	$\delta_{tot}(\%)$
2001-2003	21000	3.1	3.0	2.5	4.3
2008-2010*	25000	3.1	3.0	2.5	4.3
2001-2003 2008-2010	46000	2.2	3.0 2.1	2.5 1.25	3.7 3.0

* There is 1/3 of the data with a higher background whose implication will be investigated.

Multiple scattering in Ni(100μm)

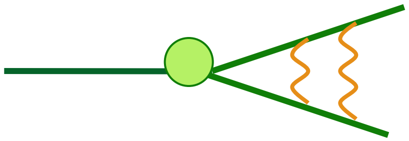
The events as a function of the multiple scattering angle θ and the particle momentum p. Events with only **one track** (left) and **one or more tracks** (right) in X and Y DC plane .



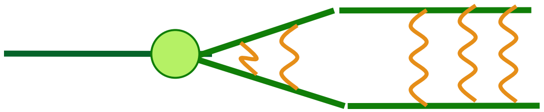


Coulomb pairs and atoms

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.



Coulomb pairs



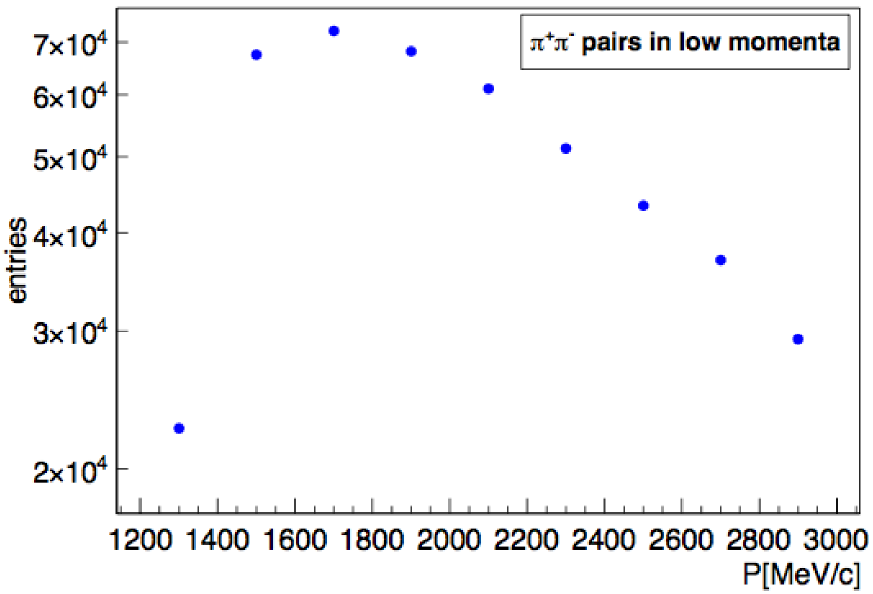
Atoms

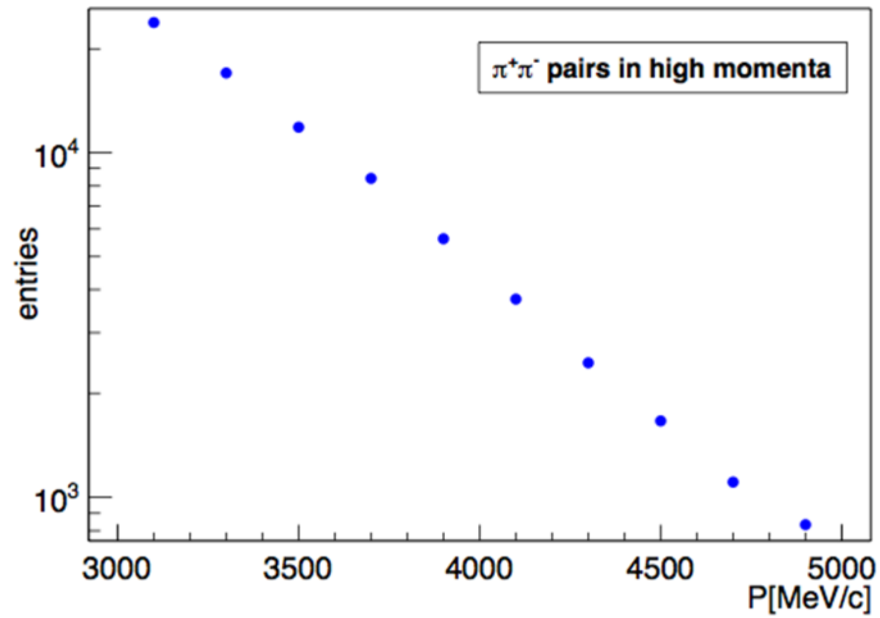
There is a precise ratio between the number of produced Coulomb pairs (N_C) with small Q and the number of atoms (N_A) produced in the way as these Coulomb pairs:

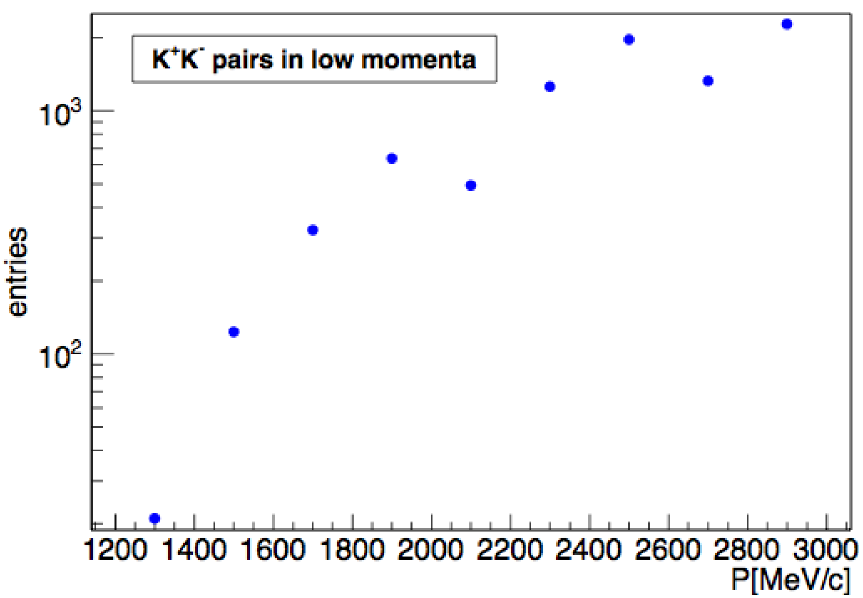
$$N_A = K(Q_0) N_C (Q \leq Q_0), \quad \frac{\delta K(Q_0)}{K(Q_0)} \leq 10^{-2}$$

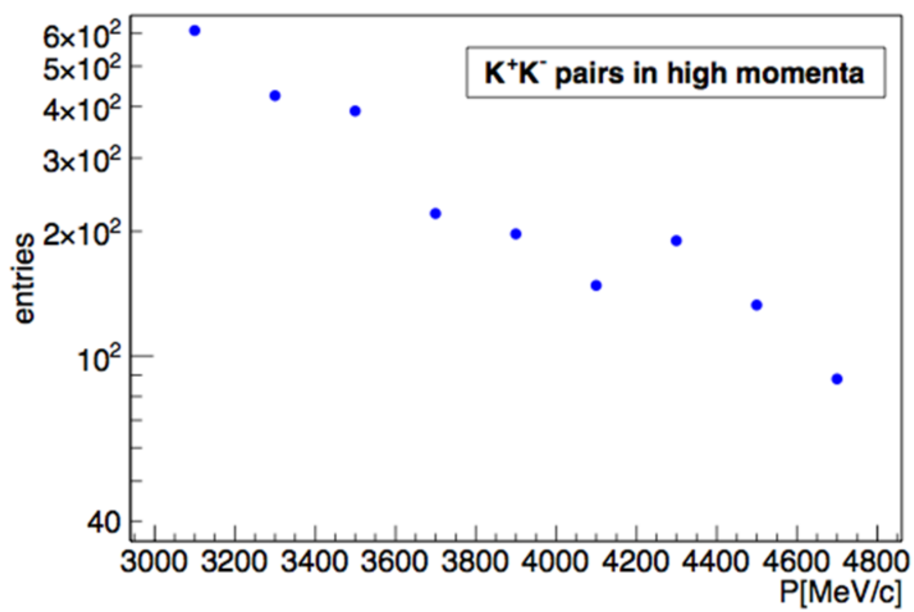
$$n_A \text{ - atomic pairs number,} \quad P_{br} = \frac{n_A}{N_A}$$

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









Begin the analysis of existing experimental data to search for $\pi^+\mu^-$, $\pi^-\mu^+$ and $\mu^+\mu^-$ Coulomb pairs signal and to extract the $\pi\mu$ and $\mu^+\mu^-$ atoms produced simultaneously with Coulomb pairs.

DIRAC prospects at SPS CERN

Yield of dimeson atoms per one p-Ni interaction, detectable by DIRAC 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^N/W_π^N	1	1	1	3.3	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

Thank you

for your attention!

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

Published results on $\pi^+\pi^-$ atom lifetime and scattering length

DIRAC data	τ_{1s} $(10^{-15}$ s)					$\lvert a_0-a_2 \rvert$					Reference
	value	stat	syst	*theo**	tot	value	stat	syst	*theo**	tot	
2001	2.91	$^{+0.45}_{-0.38}$	$^{+0.19}_{-0.49}$		$\left[^{+0.49}_{-0.62}\right]$	0.264	$^{+0.017}_{-0.020}$	$^{+0.022}_{-0.009}$		$\left[^{+0.033}_{-0.020}\right]$	PL B 619 (2005) 50
2001-3	3.15	$^{+0.20}_{-0.19}$	$^{+0.20}_{-0.18}$		$\left[^{+0.28}_{-0.26}\right]$	0.2533	$^{+0.0078}_{-0.0080}$	$^{+0.0072}_{-0.0077}$		$\left[^{+0.0106}_{-0.0111}\right]$	PL B 704 (2011) 24

* theoretical uncertainty included in systematic error

NA48	K-decay	a_0-a_2				Reference
		value	stat	syst	theo	
2009	$K_{3\pi}$	0.2571	± 0.0048	± 0.0029	± 0.0088	EPJ C64 (2009) 589
2010	K_{e4} & $K_{3\pi}$	0.2639	± 0.0020	± 0.0015		EPJ C70 (2010) 635

DIRAC Budget

DIRAC expenses in 2014 (CHF)

4000	Cars
1000	Telephone
115000	Subsistence for data processing and analysis
90000	Salary
210000	**TOTAL**

DIRAC resources in 2014 (CHF) (November 10,2013)
without subsistence costs of Prague, Japan and Bucharest groups
which participate in the data processing and analysis.

36000 Reserve from 2013

56000 JINR
60000$ were requested for 2014
100000$ were contributed for 2013
including expenses for DIRAC's dismantling

30000 Russia
32000$ were requested for 2014
42000$ were contributed for 2013
including expenses for DIRAC's dismantling

10000 Prague (as contributed in 2013)

5000 Japan (as contributed in 2013)

15000 Romania (expectation)
30000 were contributed in 2013
including expenses for DIRAC's dismantling

152000 TOTAL

In summary:

210000	Expenses
152000	Resources - DIRAC resources (December 16,2013)
58000	**Deficit**