



Точное измерение времени жизни $\pi^+\pi^-$ атома в эксперименте ДИРАК

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Дубна, 1-4 декабря

DIRAC collaboration



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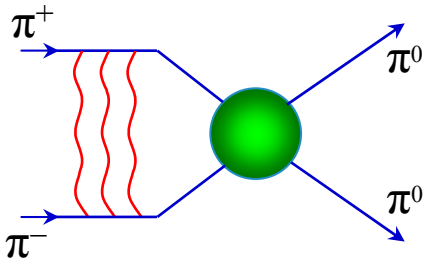
Zurich, Switzerland

Pionium lifetime

Pionium ($A_{2\pi}$) is a hydrogen-like atom consisting of π^+ and π^- mesons:

$$E_B = -1.86 \text{ keV}, \quad r_B = 387 \text{ fm}, \quad p_B \approx 0.5 \text{ MeV}$$

The lifetime of $\pi^+\pi^-$ atoms is dominated by the annihilation process into $\pi^0\pi^0$:



$$\Gamma = \frac{1}{\tau} = \Gamma_{2\pi^0} + \Gamma_{2\gamma} \quad \text{with} \quad \frac{\Gamma_{2\gamma}}{\Gamma_{2\pi^0}} \approx 4 \times 10^{-3}$$

$$\Gamma_{1S,2\pi^0} = R |a_0 - a_2|^2 \quad \text{with} \quad \frac{\Delta R}{R} \approx 1.2\%^*$$

Uretsky 1961; Bilenkiy 1969

* Gasser et al (2001)

a_0 and a_2 are the $\pi\pi$ S-wave scattering lengths for isospin $I=0$ and $I=2$.

$$\tau = (2.9 \pm 0.1) \times 10^{-15} \text{ s}$$

$$\frac{\Delta \tau}{\tau} = 10\% \Rightarrow \frac{\Delta |a_0 - a_2|}{|a_0 - a_2|} = 5\%$$

Theoretical Status

In ChPT the effective Lagrangian which describes the $\pi\pi$ interaction is an expansion in (even) terms:

$$L_{eff} = L^{(2)} + L^{(4)} + L^{(6)} + \dots$$

1966 Weinberg (tree):	$L^{(2)}$	$a_0 - a_2 = 0.20$
1984 Gasser-Leutwyler (1-loop):	$L^{(4)}$	$a_0 - a_2 = 0.25 \pm 0.01$
1995 Knecht et al. (2-loop):	$L^{(6)}$	gChPT
1996 Bijnsens et al. (2-loop):	$L^{(6)}$	$a_0 - a_2 = 0.258 \pm (< 3\%)$
2001 Colangelo et al. (& Roy):	$L^{(6)}$	$a_0 - a_2 = 0.265 \pm 0.004(1.5\%)$

And the theoretical results for the scattering lengths up to 2-loops are:

	Tree (Weinberg)	1-loop (Gass.&Leut.)	2-loop (Bijnsens et al.)	2loop+Roy (Colangelo et al.)
a_0	0.16	0.203	0.219	$0.220 \pm 2.3\%$
a_2	-0.045	-0.043	-0.042	$-0.044 \pm 2.3\%$

These results (precision) depend on the low-energy constants (LEC) l_3 and l_4 . Because l_3 and l_4 are sensitive to the quark condensate, precise measurements of a_0 , a_2 are a way to study the structure of the QCD vacuum. Lattice gauge calculations from 2006 provided values for these l_3 and l_4 .

Production of pionium

Atoms are Coulomb bound state of two pions produced in one proton-nucleus collision

$$\frac{d\sigma_{nlm}^A}{d\vec{P}} = (2\pi)^3 \frac{E_A}{M_A} \left| \psi_{nlm}^{(C)}(0) \right|^2 \frac{d\sigma_s^0}{d\vec{p}_+ d\vec{p}_-} \bigg|_{\vec{p}_+ = \vec{p}_-} \quad \sigma_A = k\sigma_C (Q < Q_0)$$

Nemenov 1985

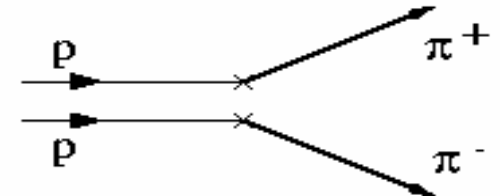
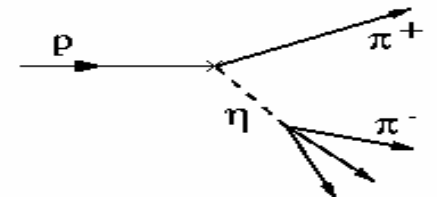
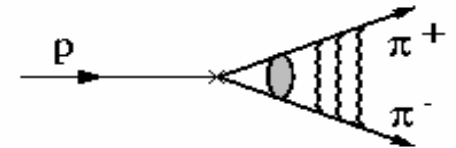
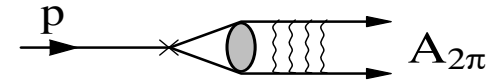
Background processes:

Coulomb pairs. They are produced in one proton nucleus collision from fragmentation or short lived resonances and exhibit Coulomb interaction in the final state

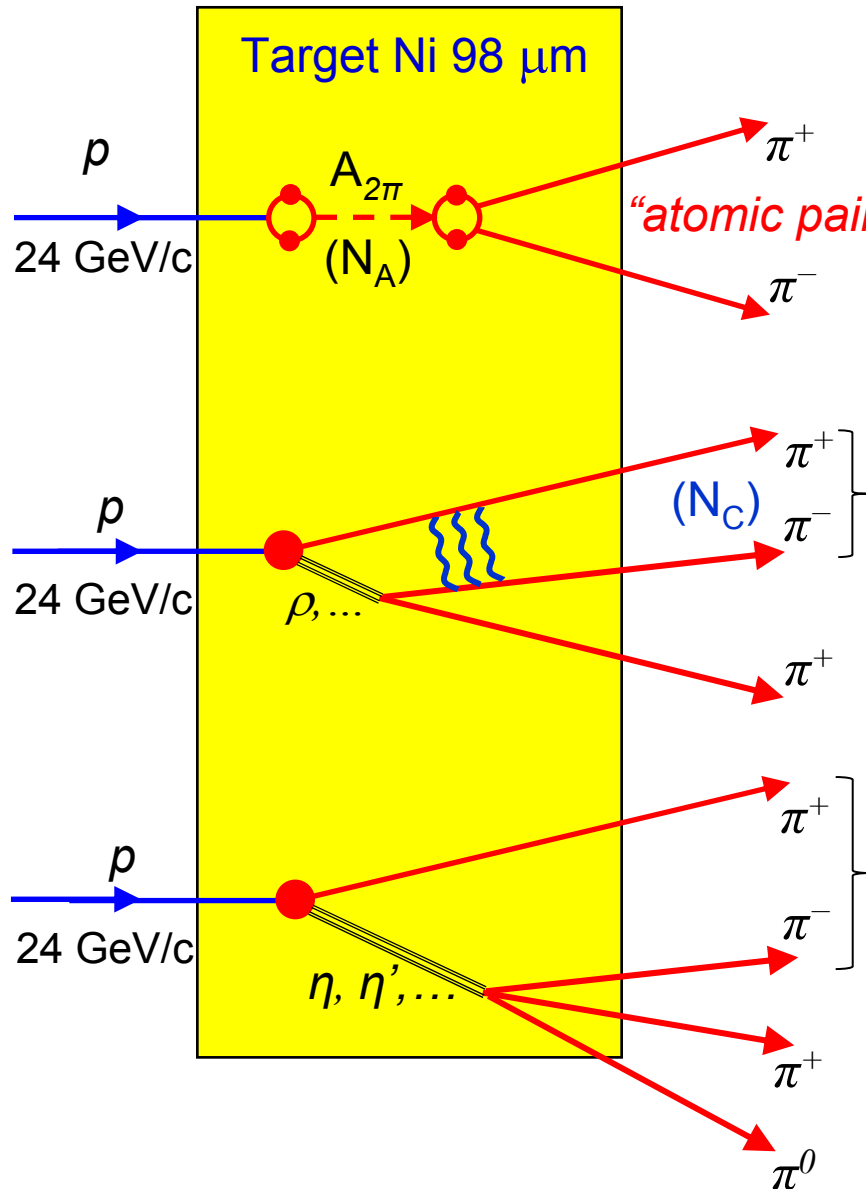
$$\frac{d^2\sigma_C}{d\vec{p}_+ d\vec{p}_-} = A_C(q) \frac{d\sigma_s^0}{d\vec{p}_+ d\vec{p}_-}, \quad A_C(q) = \frac{2\pi n_\pi \alpha / q}{1 - \exp(-2\pi n_\pi \alpha / q)}$$

Non-Coulomb pairs. They are produced in one proton nucleus collision. At least one pion originates from a long lived resonance. No Coulomb interaction in the final state

Accidental pairs. They are produced in two independent proton nucleus collision. They do not exhibit Coulomb interaction in the final state



Method of $A_{2\pi}$ observation and lifetime measurement



$\tau(A_{2\pi})$ is too small to be measured directly.

E. m. interaction of $A_{2\pi}$ in the target:

$$A_{2\pi} \rightarrow \pi^+ \pi^-$$

$$Q < 3 \text{ MeV}/c, \Theta_{\text{lab}} < 3 \text{ mrad}$$

Coulomb from short-lived sources

$$N_A = K(Q_0) N_C(Q < Q_0) \text{ with known } K(Q_0)$$

$$\text{Breakup probability: } P_{\text{br}} = n_A / N_A$$

non-Coulomb from long-lived sources

Lifetime and breakup probability

The P_{br} value depends on the lifetime value, τ . To obtain the precise $P_{br}(\tau)$ curve a large differential equation system must be solved:

$$\frac{dp_{nlm}(s)}{ds} = \sum_{n'l'm'} a_{nlm}^{n'l'm'} p_{n'l'm'}(s)$$

where s is the position in the target, p_{nlm} is the population of a definite hydrogen-like state of ponium. The $a_{nlm}^{n'l'm'}$ coefficients are given by:

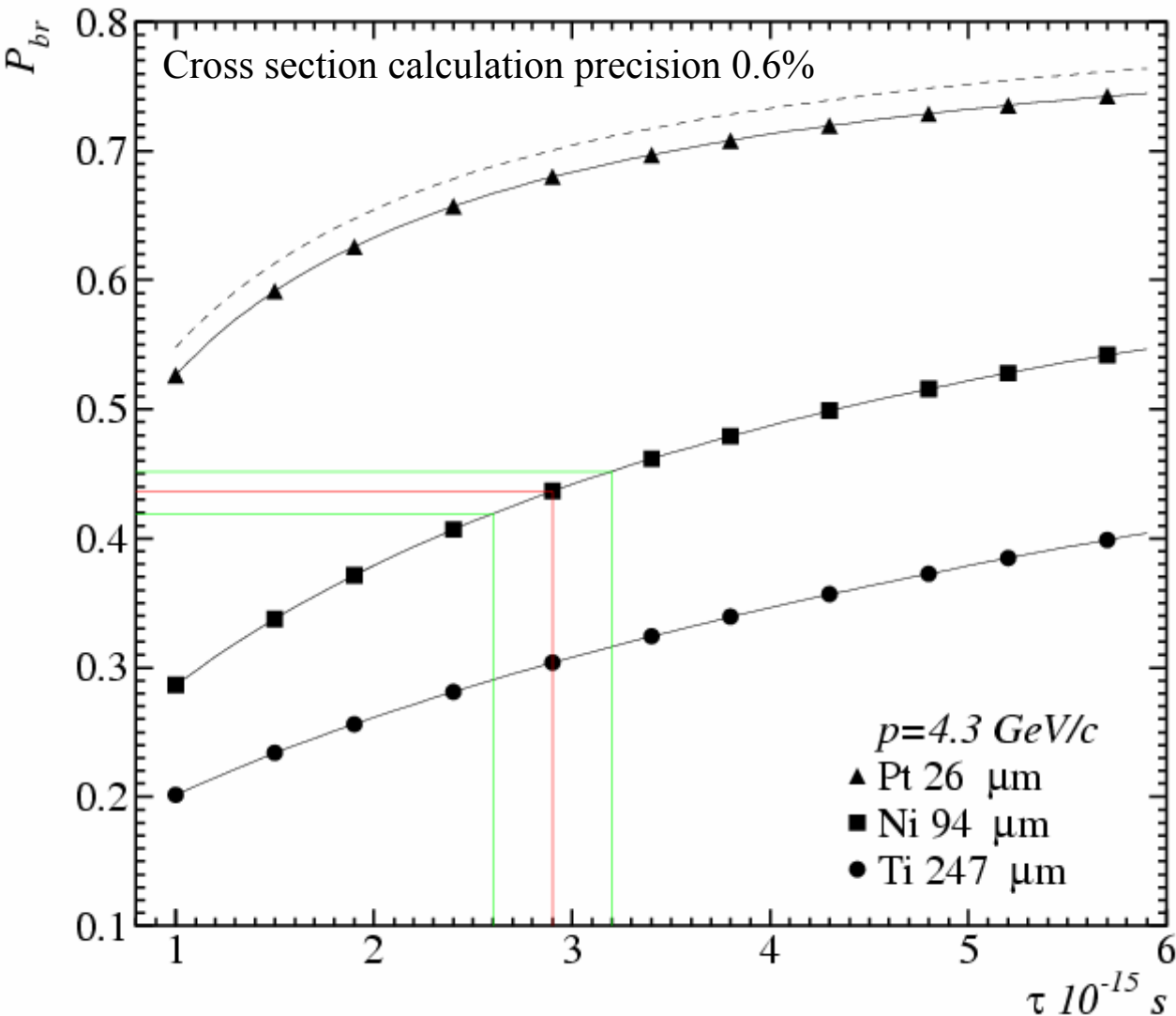
$$a_{nlm}^{n'l'm'} = \frac{\sigma_{nlm}^{n'l'm'} \rho N_0}{A} \quad \text{if } nlm \neq n'l'm', \quad a_{nlm}^{nlm} = -\frac{\sigma_{nlm}^{tot} \rho N_0}{A} - \begin{cases} 2M_\pi / Pc\tau_n & l=0. \\ 0 & l \neq 0. \end{cases}$$

$\sigma_{nlm}^{n'l'm'}$ being the ponium-target atom cross section, N_0 the Avogadro Number, ρ the material density and A its atomic weight.

The detailed knowledge of the cross sections (Afanasyev&Tarasov; Trautmann et al) (Born and Glauber approach) together with the accurate solution of the differential equation system permits us to know the curves within 1%.

Break-up probability

Solution of the transport equations provides one-to-one dependence of the measured break-up probability (P_{br}) on pionium lifetime τ

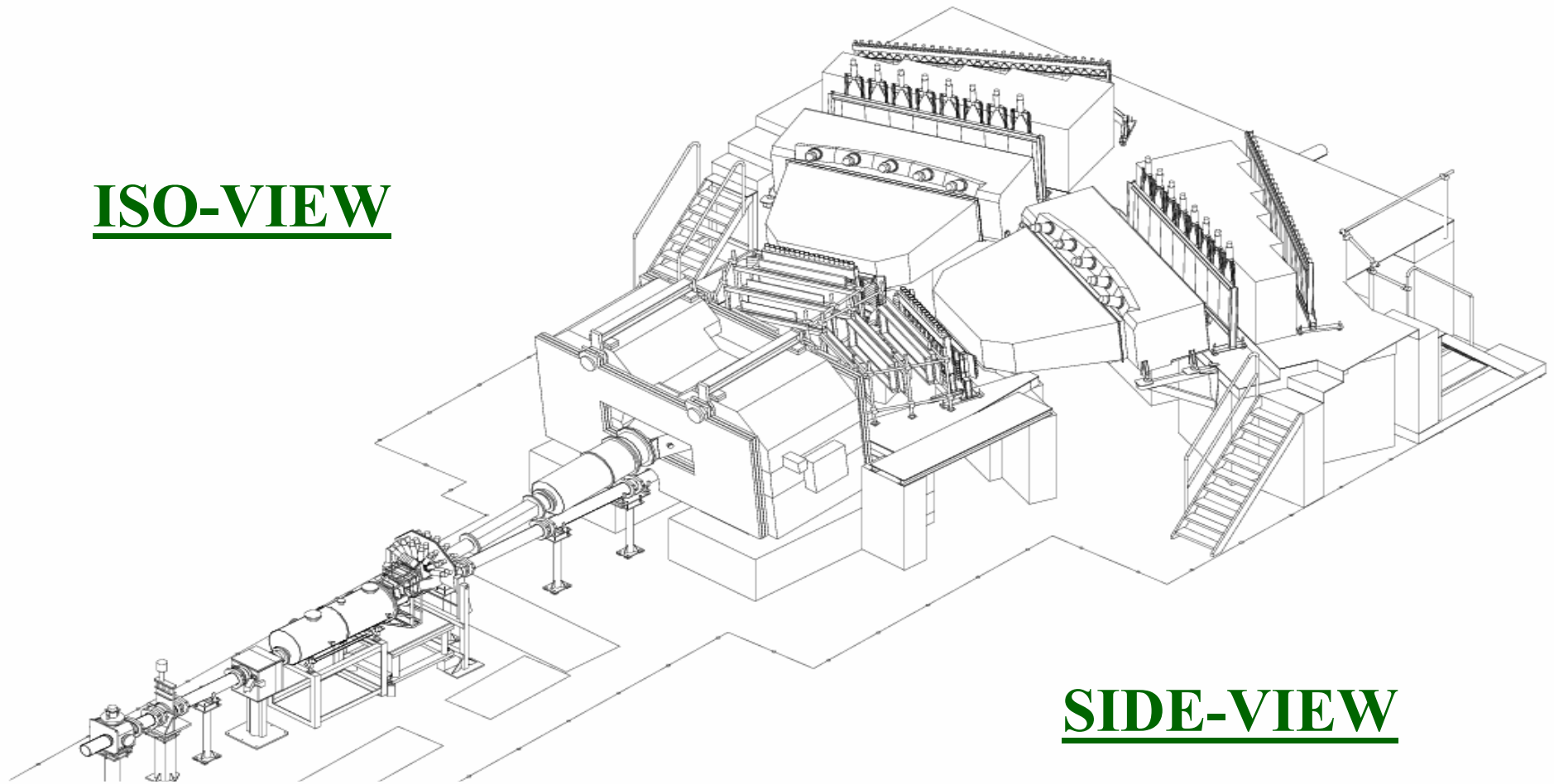


$\delta\tau=10\% \rightarrow \delta P_{br}=4\%$

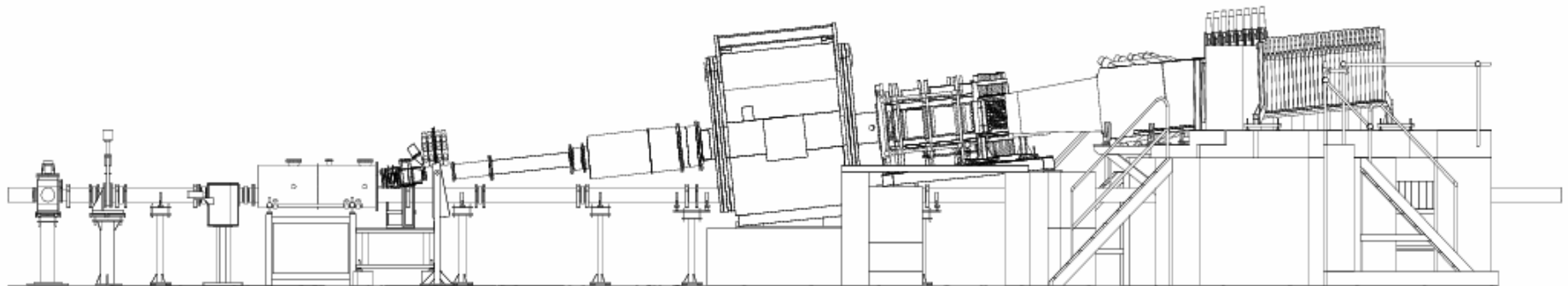
All targets have the same thickness in radiation lengths $6.7 \cdot 10^{-3} X_0$

There is an optimal target material for a given lifetime

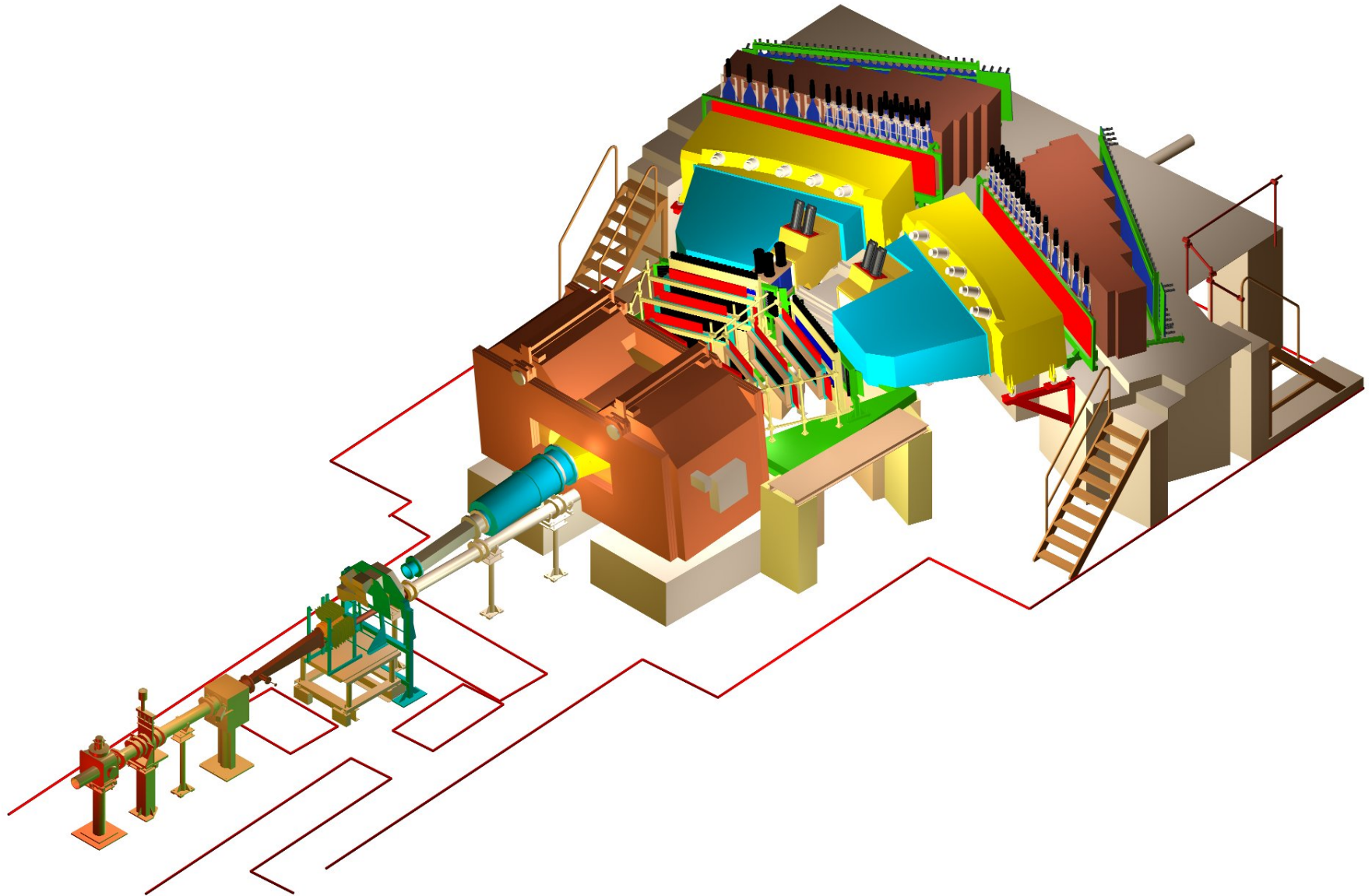
ISO-VIEW



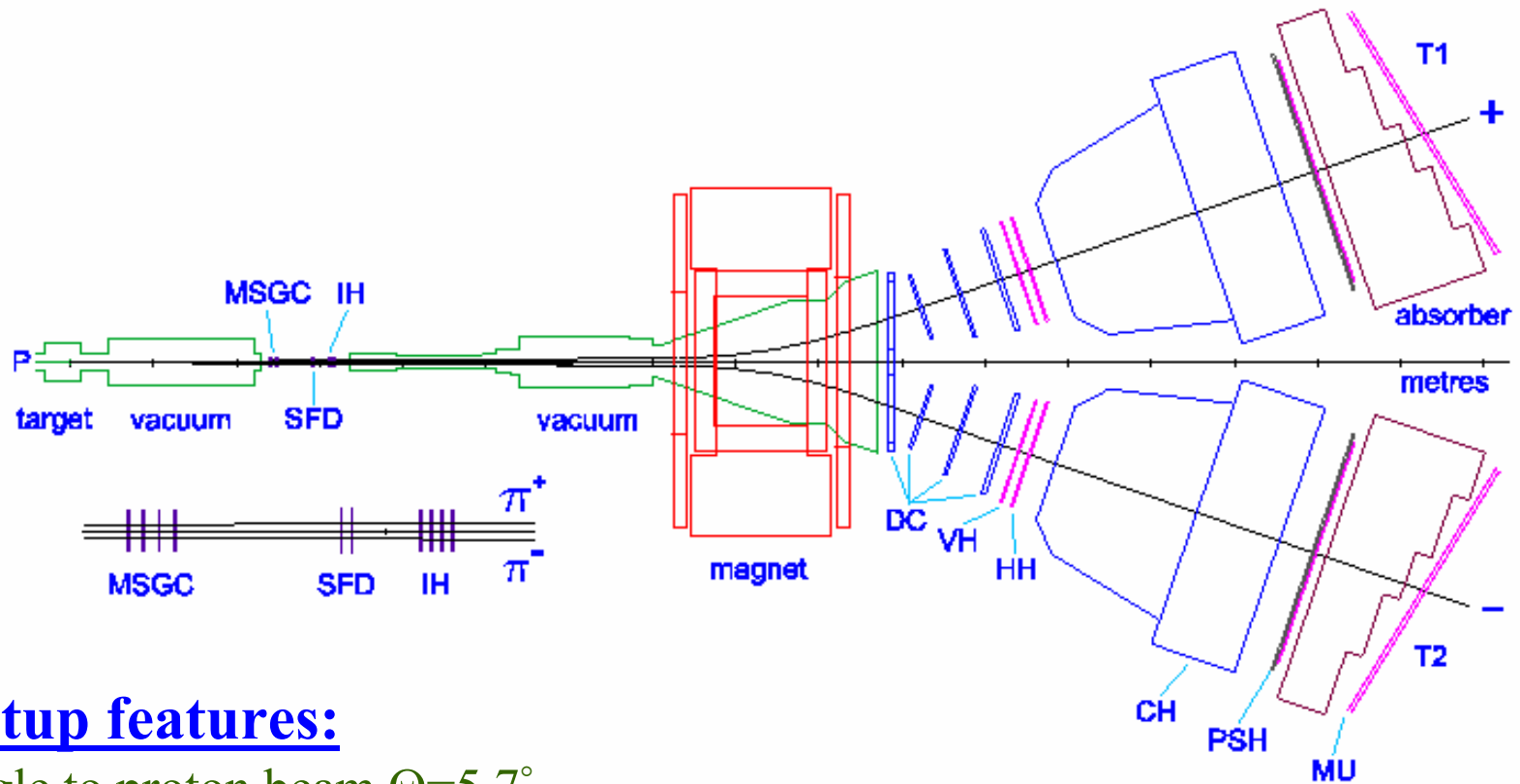
SIDE-VIEW



DIRAC experimental setup 2007



DIRAC Spectrometer



Setup features:

angle to proton beam $\Theta=5.7^\circ$

channel aperture $\Omega=1.2 \cdot 10^{-3}$ sr

magnet 2.3 T·m

momentum range $1.2 \leq p_\pi \leq 7$ GeV/c

Thin targets: $\sim 7 \times 10^{-3} X_0$, Nuclear efficiency: 3×10^{-4}

resolution on relative momentum $\sigma_{QX} \approx \sigma_{QY} \leq 0.3$ MeV/c, $\sigma_{QL} \approx 0.5$ MeV/c

Proton beam $\sim 10^{11}$ proton/spill

Analysis based on MC

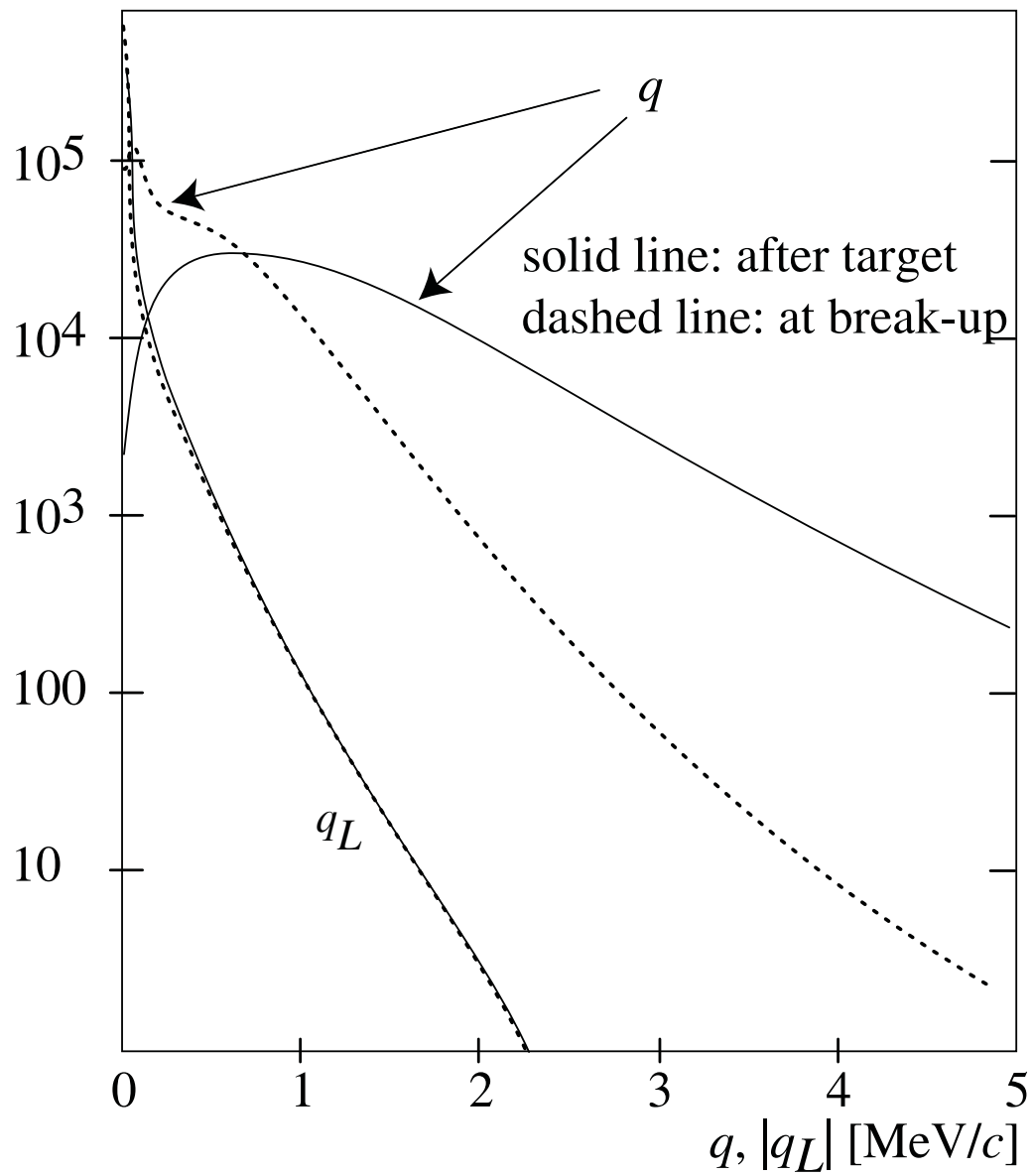
Atoms are generated in **nS states** using measured momentum distribution for **short-lived** sources. The atomic pairs are generated according to the evolution of the atom while propagating through the target

Background processes:

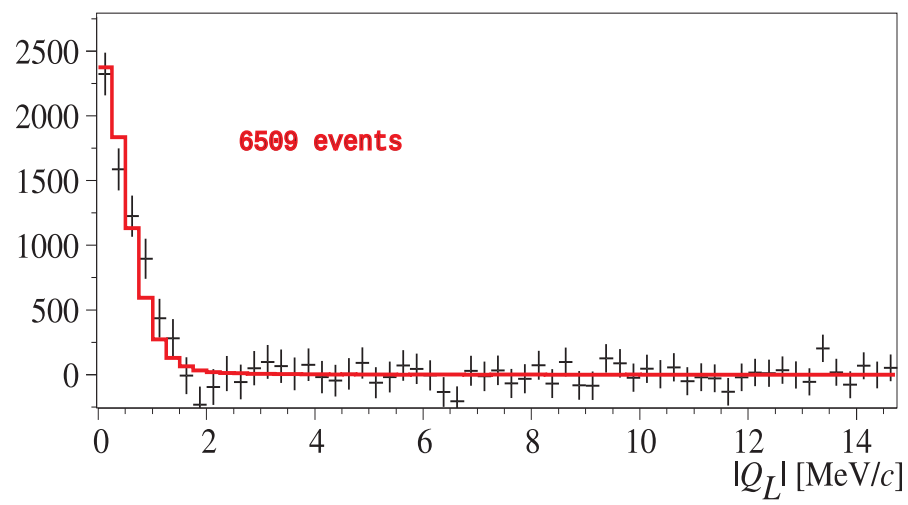
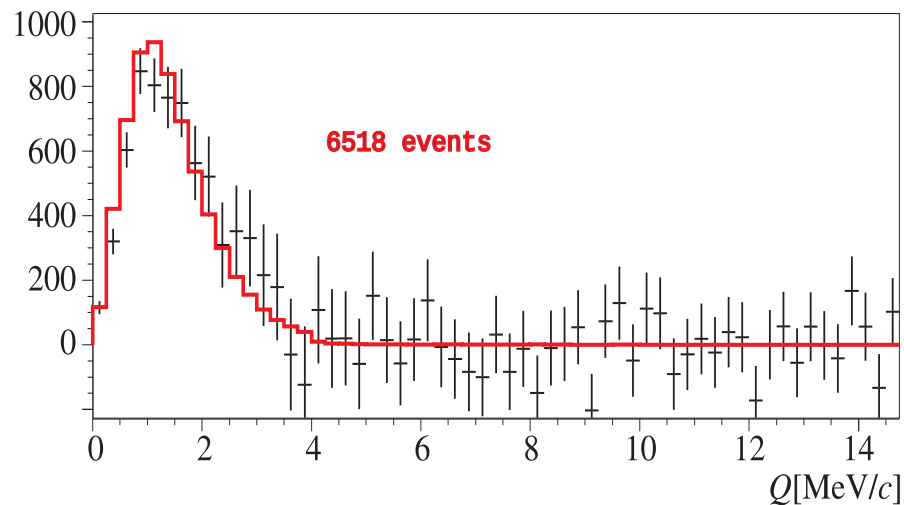
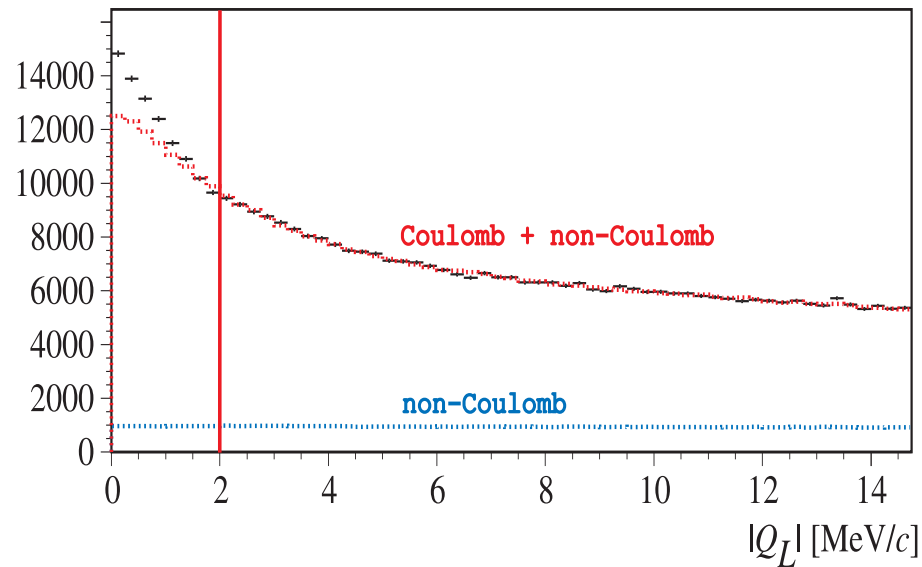
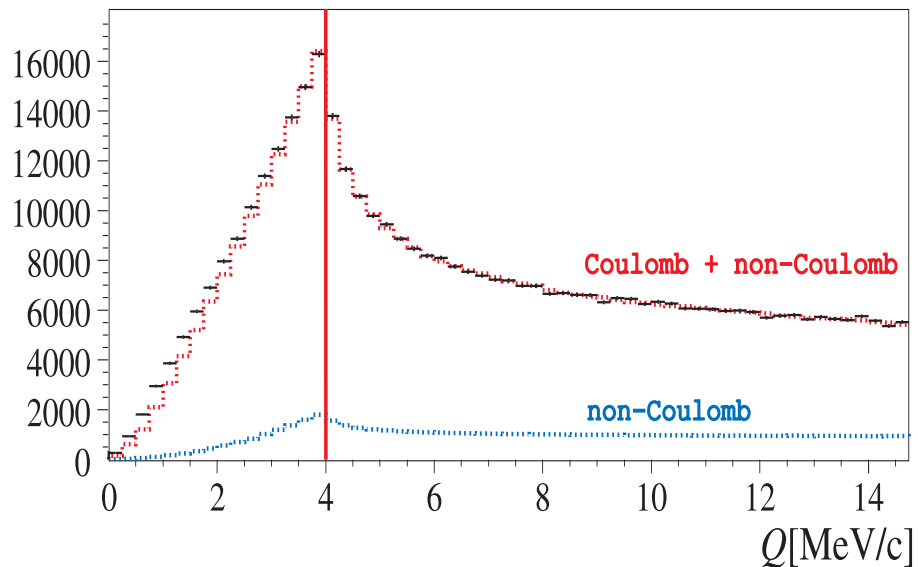
Coulomb pairs are generated according to $A_c(Q)Q^2$ using measured momentum distribution for **short-lived** sources.

Non-Coulomb pairs are generated according to Q^2 using measured momentum distribution for **long-lived** sources.

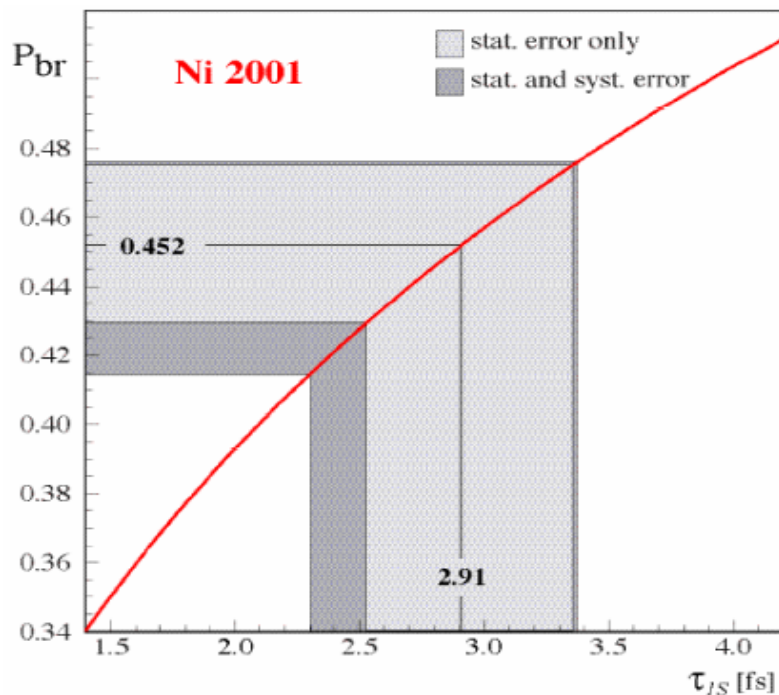
Atomic pairs MC



Atomic pairs (2001)



Lifetime of Pionium



Result from DIRAC:

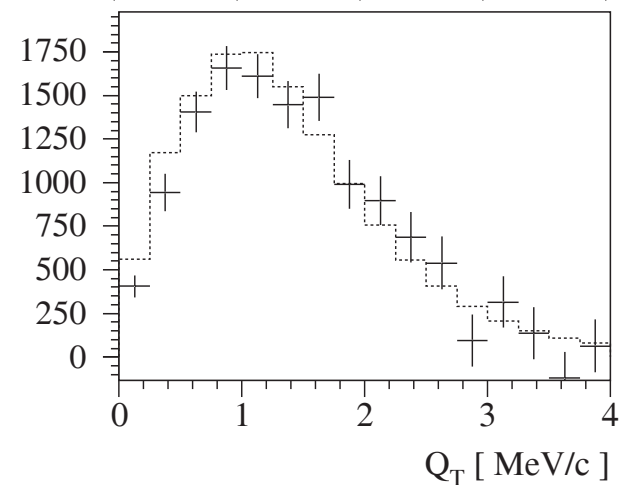
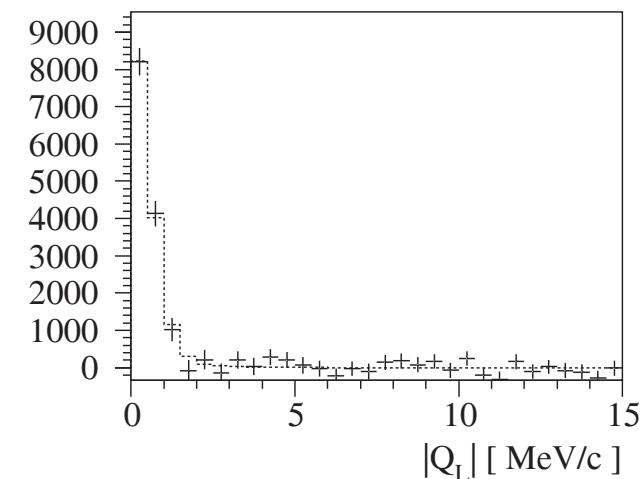
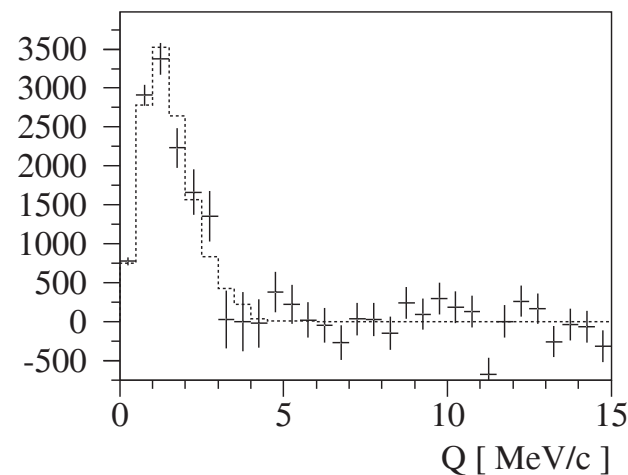
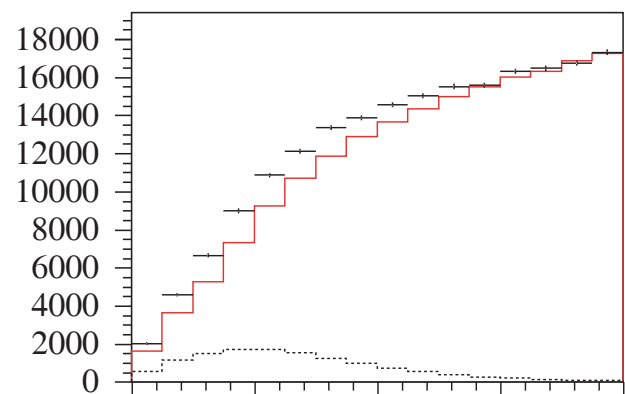
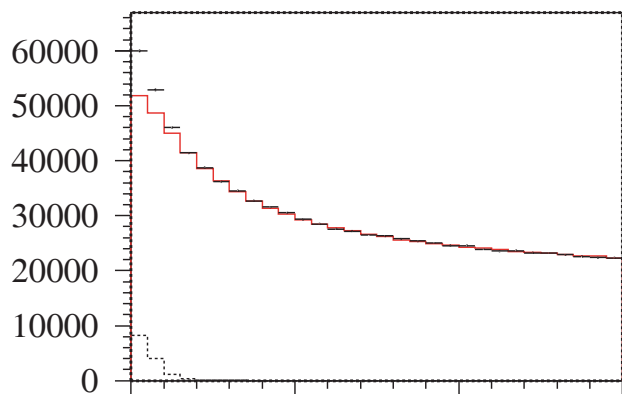
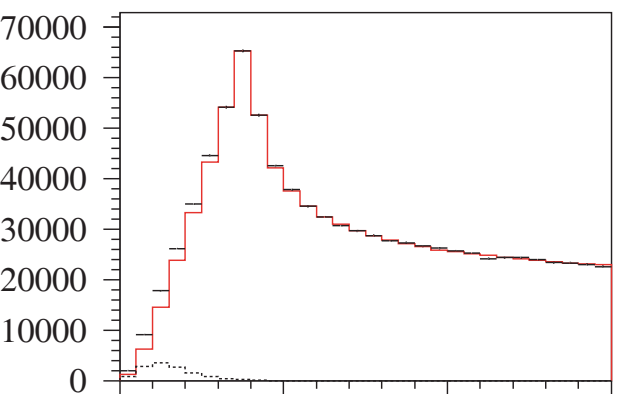
$$\tau = \left(2.91^{+0.45}_{-0.38} \right)_{stat} \left({}^{+0.19}_{-0.49} \right)_{syst} \text{ fs}$$

ChPT prediction:

$$\tau = (2.9 \pm 0.1) \text{ fs}$$

Phys. Lett. B 619 (2005) 50-60; [hep-ex/0504044](https://arxiv.org/abs/hep-ex/0504044)

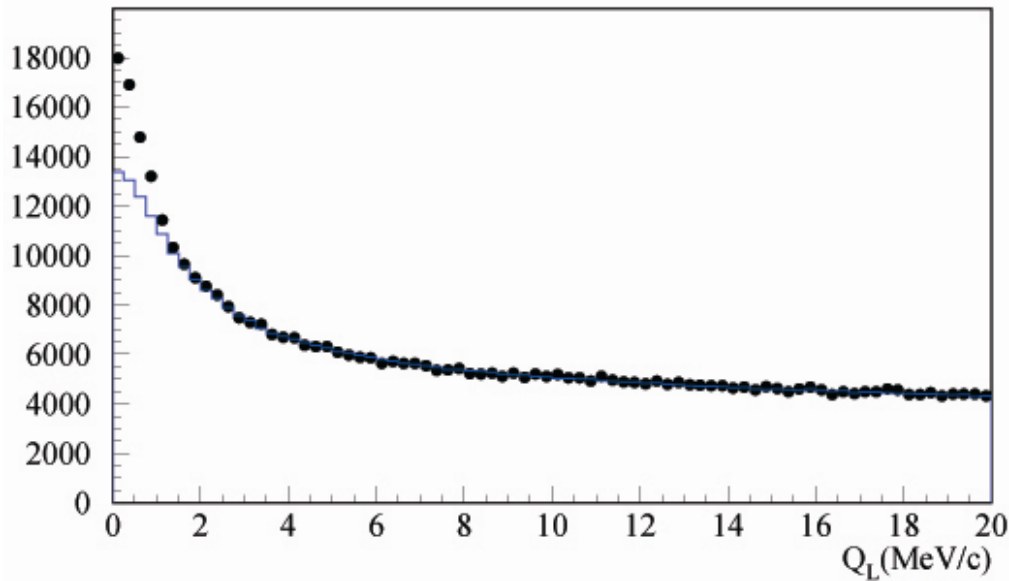
Experimental results 2001-2003



Experimental results 2001-2003

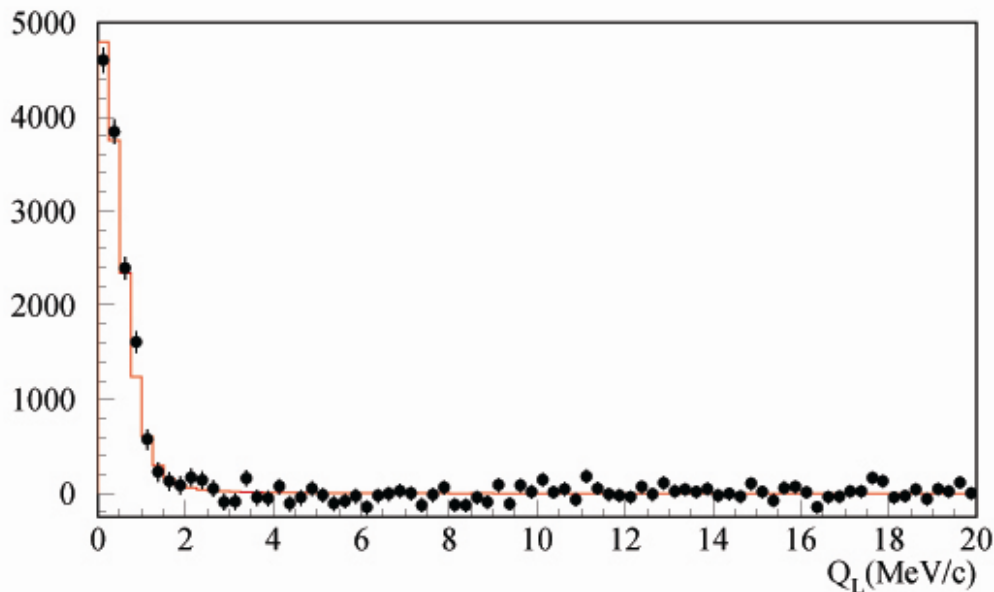
Proton momenta, GeV/ c	Target thickness, μm	n_A^{exp}	$N_{CC}^{\text{exp}}, 10^3$	P_i
24	94	4438 ± 192	328.4 ± 3.2	0.459 ± 0.022
24	98	5011 ± 274	402.1 ± 4.0	0.421 ± 0.025
20	98	3851 ± 192	291.7 ± 3.1	0.446 ± 0.025
Total		13300 ± 386	1022.1 ± 6.0	

DIRAC preliminary results with GEM/MSGC



Q_L distribution

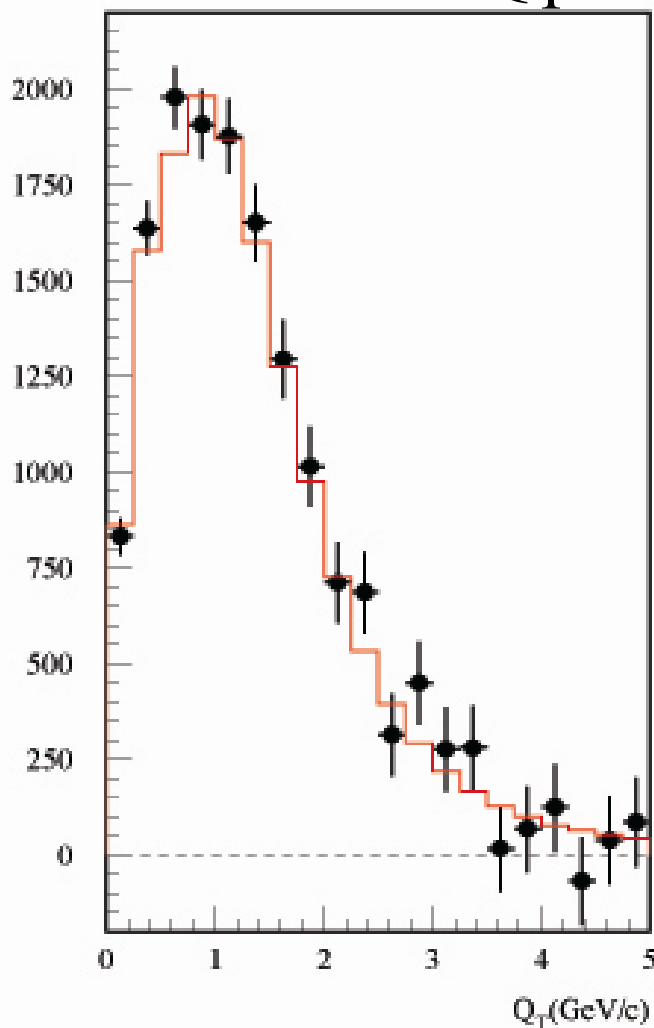
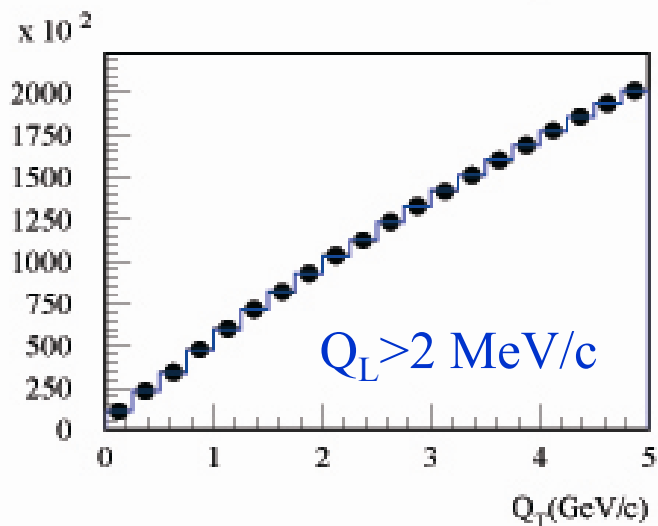
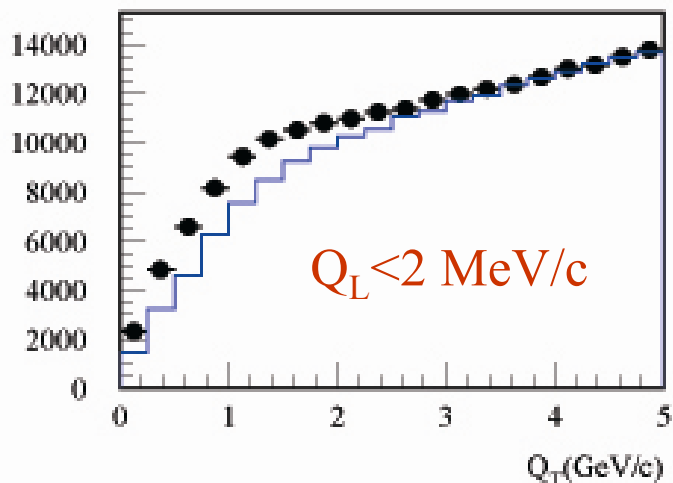
← All events



← After background
subtraction

DIRAC preliminary results with GEM/MSGC

Q_T distribution



← After
background
subtraction for
 $Q_L < 2$ MeV/c

DIRAC Experimental results

$A_{2\pi}$ lifetime

2005 **DIRAC** (PL B619, 50) $\tau = \left(2.91^{+0.45}_{-0.38} \Big|_{stat} \quad {}^{+0.19}_{-0.49} \Big|_{syst} \right) \text{ fs} = \left(\dots {}^{+0.49}_{-0.62} \Big|_{tot} \right) \text{ fs}$

...based on 2001 data (6530 observed atoms)

$$\Rightarrow |a_0 - a_2| = 0.264 \pm 7.2\% \Big|_{stat} \pm {}^{10}_{-3}\% \Big|_{syst} = \dots \boxed{\pm {}^{13}_{-8}\% \Big|_{tot}}$$

2008 **DIRAC** (SPSC 22/04/08) $\tau = \left(2.82^{+0.25}_{-0.23} \Big|_{stat} \pm 0.19 \Big|_{syst} \right) \text{ fs} = \left(\dots {}^{+0.31}_{-0.30} \Big|_{tot} \right) \text{ fs}$

...major part 2001-03 data (**13300** observed atoms)

$$\Rightarrow |a_0 - a_2| = 0.268 \pm 4.4\% \Big|_{stat} \pm 3.7\% \Big|_{syst} = \dots \boxed{\pm 5.5\% \Big|_{tot}}$$

Including GEM/MicroStripGasChambers => number of reconstructed events is **18000**
=> the statistical error in $|a_0 - a_2|$ is **3%**, and the expected full error is **<5%**.

Comparison with other experimental results

$K \rightarrow 3\pi$

2006 NA48/2 (PL B633, 173)

...with ChPT constraint between a_0 and a_2 :

$$\Rightarrow a_0 - a_2 = 0.264 \pm 2.3\%|_{stat} \pm 1.5\%|_{syst} \pm 4.9\%|_{ext} = \dots \pm 5.6\%|_{tot}$$

2009 NA48/2 (seminar at CERN)

...without constraint (a_2 free):

$$\Rightarrow a_0 - a_2 = 0.257 \pm 1.9\%|_{stat} \pm 0.8\%|_{syst} \pm 0.4\%|_{ext} \pm 3.5\%|_{th} = \dots \pm 4.1\%|_{tot}$$

$$\Rightarrow a_2 = -0.024 \pm 54\%|_{stat} \pm 38\%|_{syst} \pm 8.3\%|_{ext} \pm 63\%|_{th} = \dots \pm 92\%|_{tot}$$

...with ChPT constraint between a_0 and a_2 :

$$\Rightarrow a_0 - a_2 = 0.263 \pm 0.8\%|_{stat} \pm 0.4\%|_{syst} \pm 0.8\%|_{ext} \pm 1.9\%|_{th} = \dots \pm 2.2\%|_{tot}$$

Comparison with other experimental results

Ke4:

2008 NA48/2 (EPJ C54, 411)

...without constraint (a_2 free):

$$\Rightarrow a_0 = 0.233 \pm 6.9\%|_{stat} \pm 3.0\%|_{syst} = \dots \pm 7.5\%|_{tot}$$

$$\Rightarrow a_2 = -0.0471 \pm 23\%|_{stat} \pm 8.5\%|_{syst} = \dots \pm 25\%|_{tot}$$

2009 NA48/2 (seminar at CERN)

...without constraint (a_2 free):

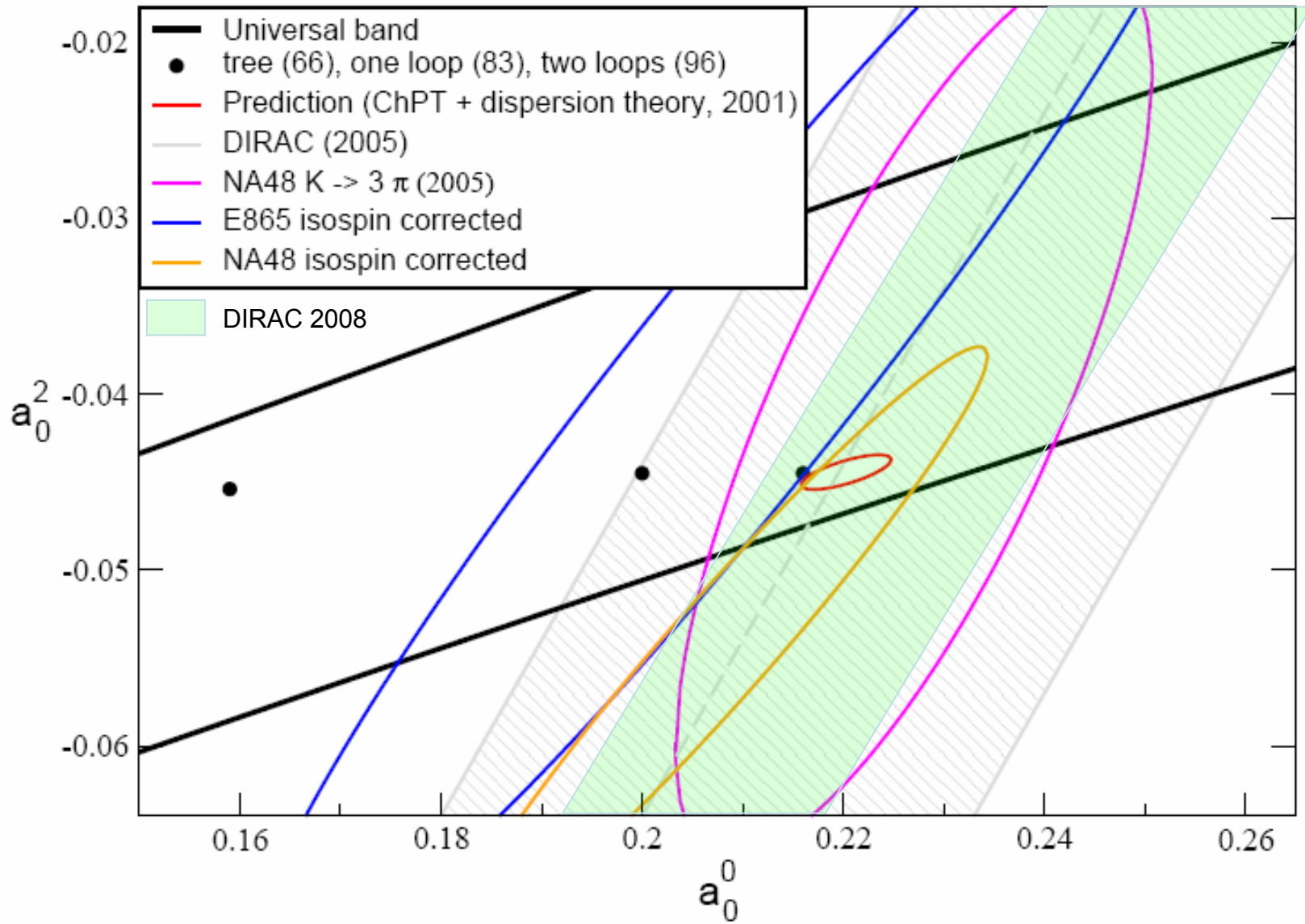
$$\Rightarrow a_0 = 0.2220 \pm 5.8\%|_{stat} \pm 2.3\%|_{syst} \pm 1.7\%|_{th} = \dots \pm 6.5\%|_{tot}$$

$$\Rightarrow a_2 = -0.0432 \pm 20\%|_{stat} \pm 7.9\%|_{syst} \pm 6.5\%|_{th} = \dots \pm 22\%|_{tot}$$

...with ChPT constraint between a_0 and a_2 :

$$\Rightarrow a_0 = 0.2206 \pm 2.2\%|_{stat} \pm 0.8\%|_{syst} \pm 2.9\%|_{th} = \dots \pm 3.7\%|_{tot}$$

$$a_0 - a_2$$



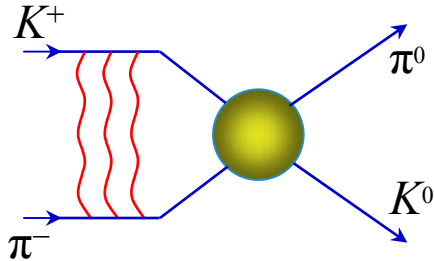
$K^+\pi^-$ and $K^-\pi^+$ atoms lifetime

$K\pi$ -atom ($A_{K\pi}$) is a hydrogen-like atom consisting of K^+ and π^- mesons:

$$E_B = -2.9 \text{ keV} \quad r_B = 248 \text{ fm} \quad p_B \approx 0.8 \text{ MeV}$$

The $K\pi$ -atom lifetime (ground state 1S), $\tau=1/\Gamma$ is dominated by the annihilation process into $K^0\pi^0$:

$$A_{K^+\pi^-} \rightarrow \pi^0 K^0 \quad A_{\pi^+K^-} \rightarrow \pi^0 \bar{K}^0$$



$$\Gamma_{1S, K^0 \pi^0} = R_K \left| a_{1/2} - a_{3/2} \right|^2 \quad \text{with} \quad \frac{\Delta R_K}{R_K} \approx 2\% \quad *$$

* J. Schweizer (2004)

From Roy-Steiner equations: $a_0^{1/2} - a_0^{3/2} = 0.269 \pm 0.015$

↓

$$\tau = (3.7 \pm 0.4) \cdot 10^{-15} \text{ s}$$

If $\frac{\Delta \Gamma}{\Gamma} = 20\% \Rightarrow \frac{\Delta \left| a_{1/2} - a_{3/2} \right|}{\left| a_{1/2} - a_{3/2} \right|} = 10\%$

πK scattering lengths

I. ChPT predicts s-wave scattering lengths:

$$a_0^{1/2} = 0.19 \pm 0.2 \quad a_0^{3/2} = -0.05 \pm 0.02$$

V. Bernard, N. Kaiser,
U. Meissner. – 1991

$L^{(2)}, L^{(4)}$ *and 1-loop*

$$a_0^{1/2} - a_0^{3/2} = 0.23 \pm 0.01 \quad \text{A. Rossel. – 1999}$$

J. Bijnens, P. Talaver. – April 2004

$L^{(2)}, L^{(4)}, L^{(6)}$ *and 2-loop*

II. Roy-Steiner equations:

$$a_0^{1/2} - a_0^{3/2} = 0.269 \pm 0.015$$

P. Büttiker et al. – 2004

πK scattering

What new will be known if πK scattering length will be measured?

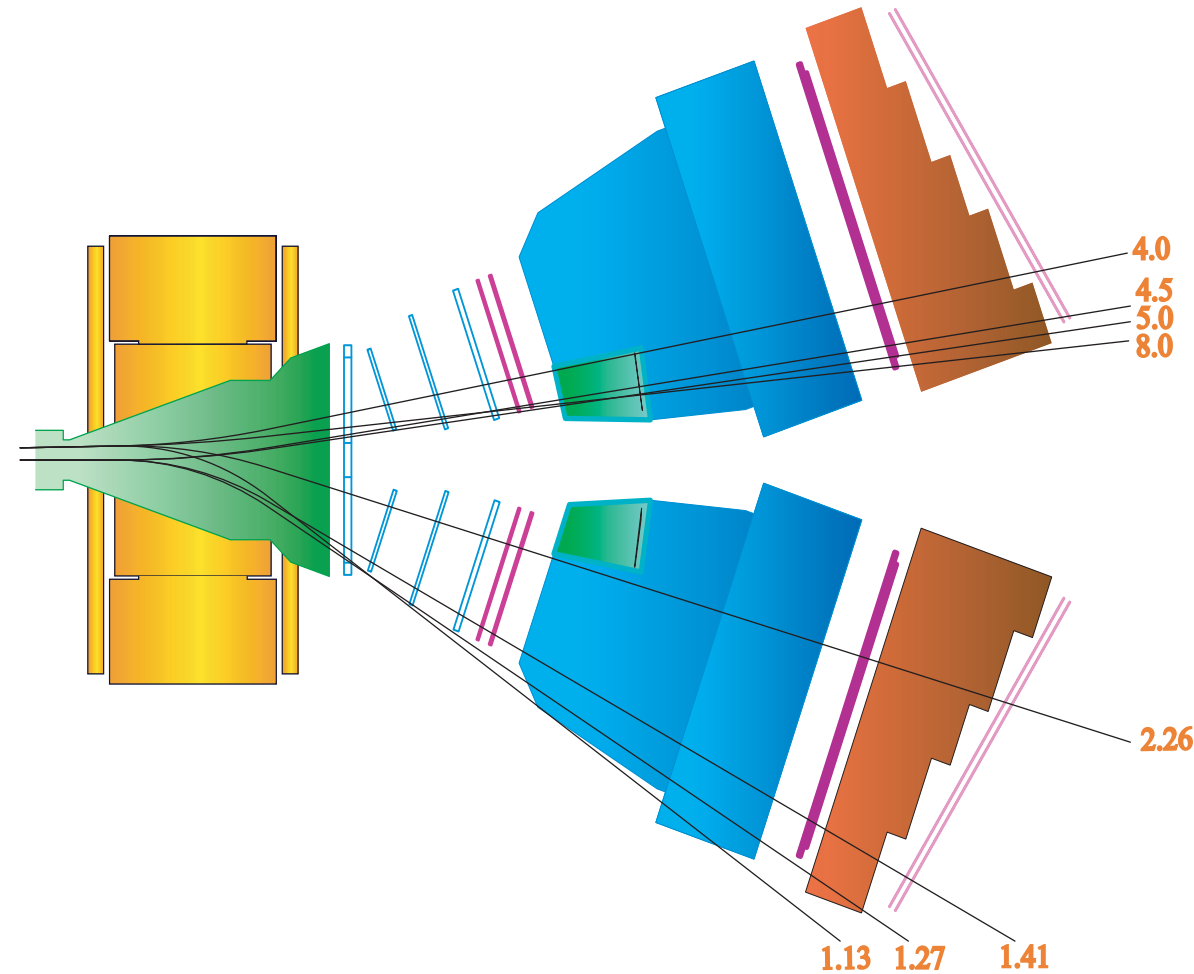
The measurement of the s -wave πK scattering lengths would test our understanding of the chiral $SU(3)_L \times SU(3)_R$ symmetry breaking of QCD (u , d and s quarks), while the measurement of $\pi\pi$ scattering lengths checks only the $SU(2)_L \times SU(2)_R$ symmetry breaking (u , d quarks).

This is the principal difference between $\pi\pi$ and πK scattering!

Experimental data on the πK low-energy phases are absent

Trajectories of π^- and K^+ from the $A_{K\pi}$ break-up

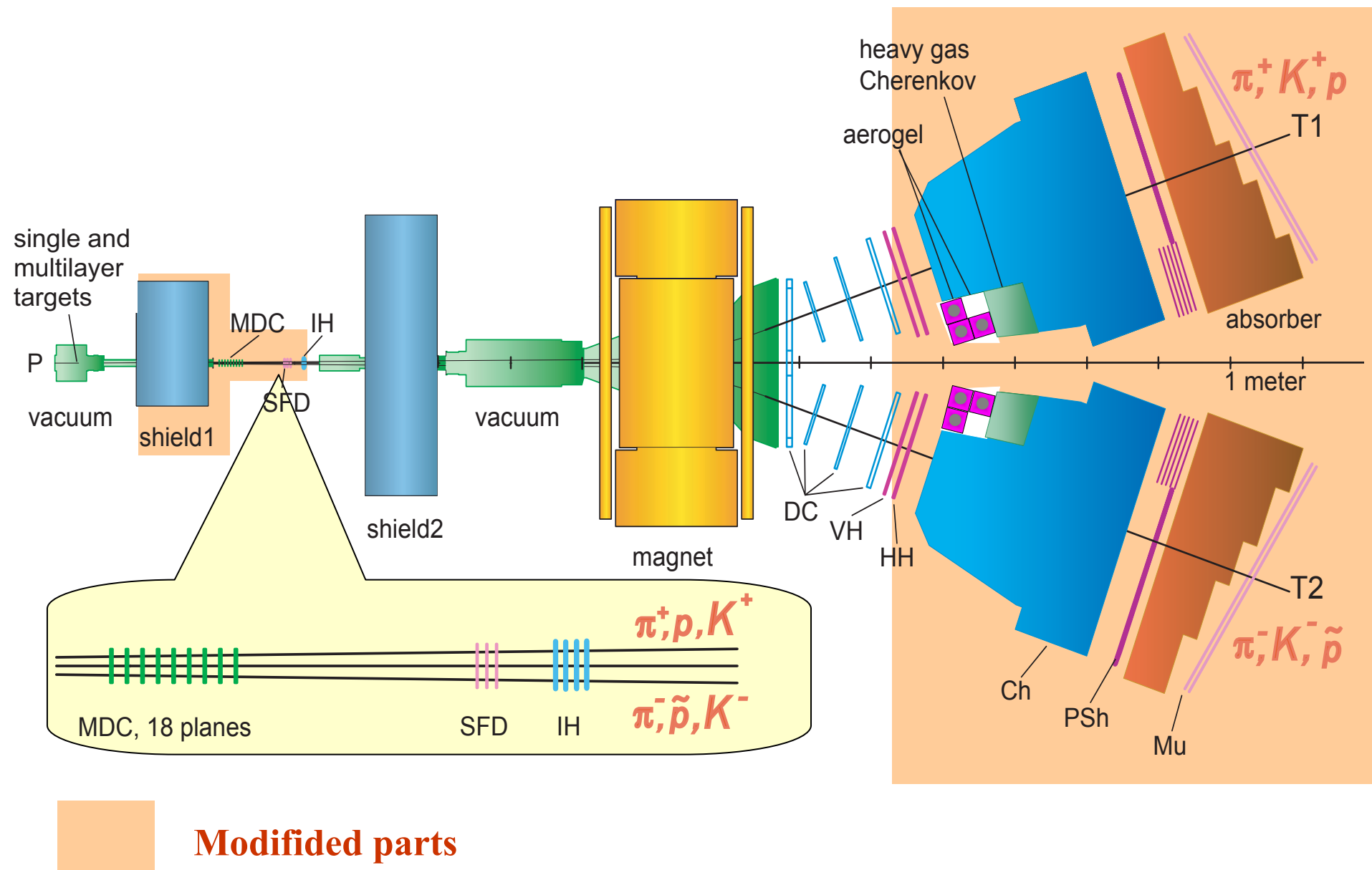
The numbers to the right of the tracks lines
are the π^- and K^+ momenta in GeV/c



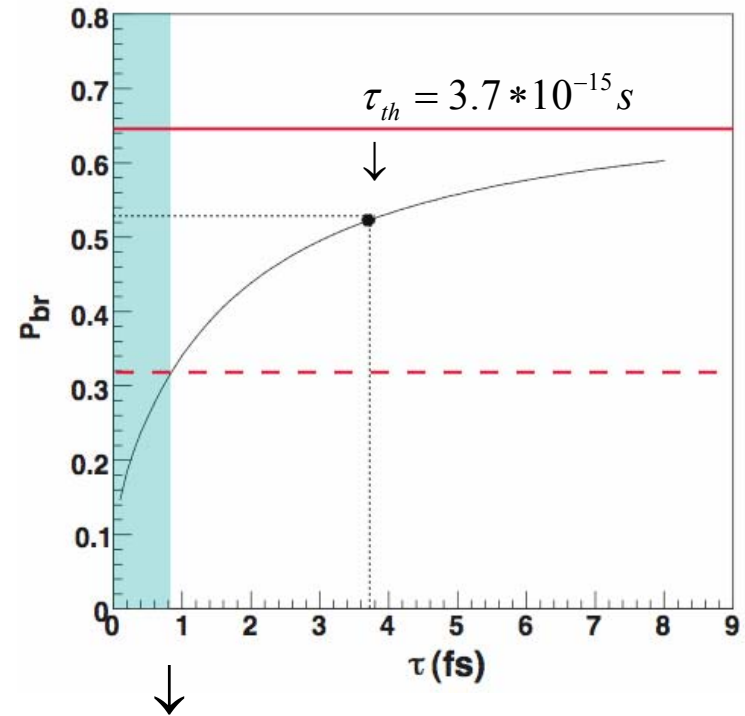
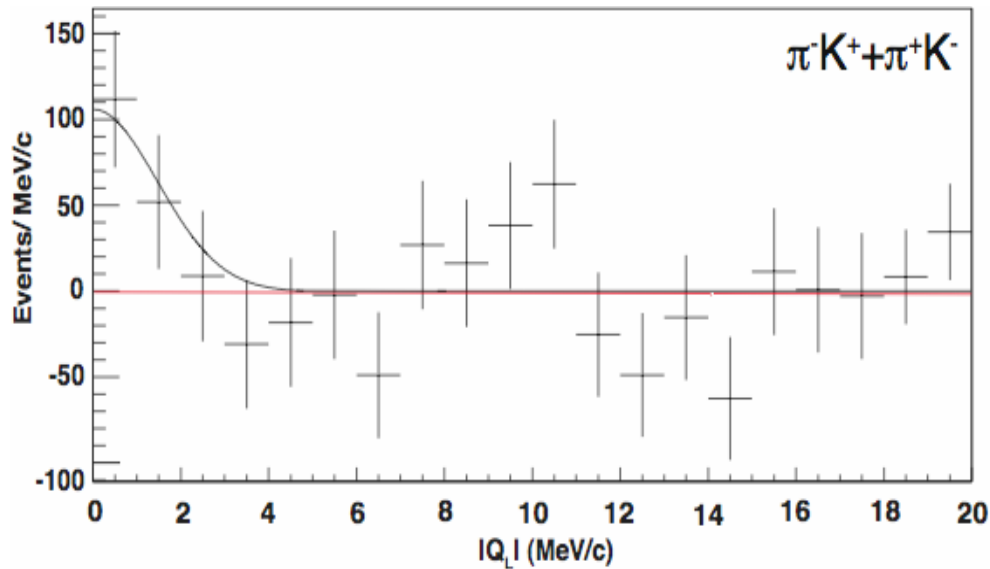
The $A_{K\pi}$, π^- and K^+
momenta are shown
in the following table:

P_{atom} (GeV/c)	P_{π} (GeV/c)	P_K (GeV/c)
5.13	1.13	4.0
5.77	1.27	4.5
6.41	1.41	5.0
10.26	2.26	8.0

Upgraded DIRAC experimental setup



π^-K^+ and π^+K^- atom signal

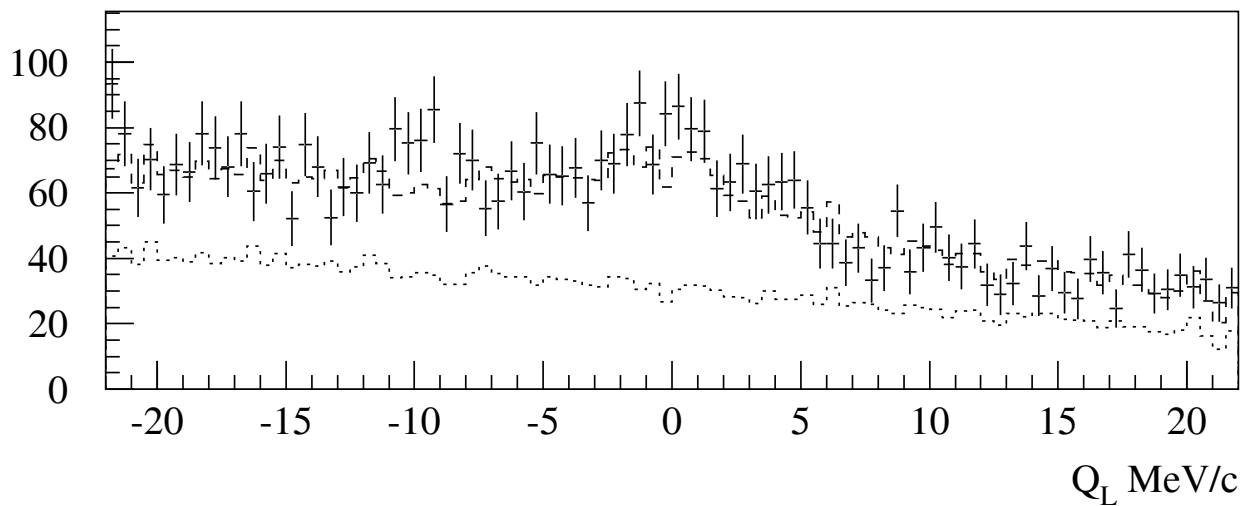


In total:

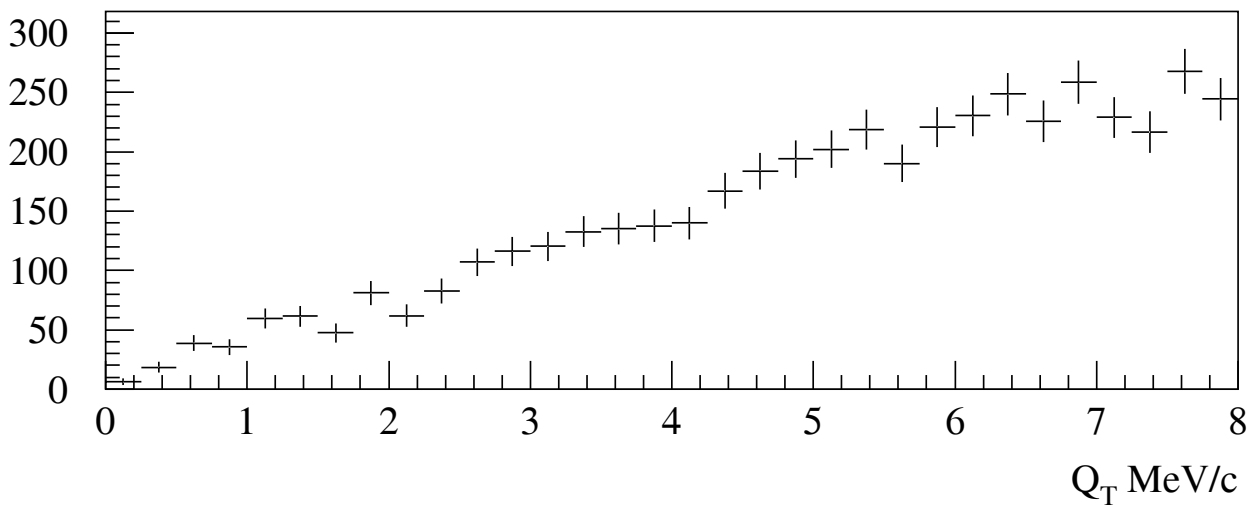
173 ± 54 πK -atomic pairs are observed
with a significance of 3.2σ .

$\tau > 0.8 * 10^{-15} s$ at 90% CL

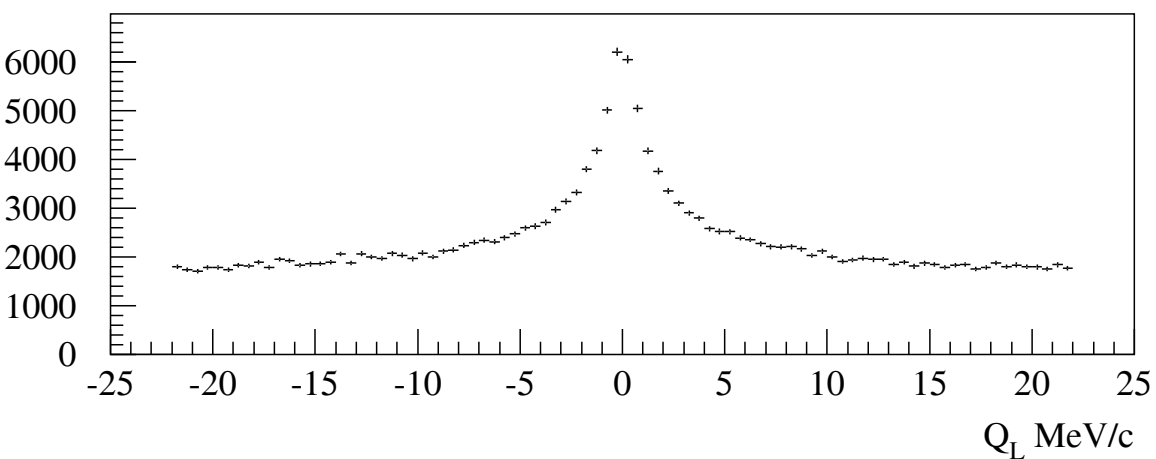
B. Adeva et al., "Evidence for πK -atoms with DIRAC", Physics Letters B 674 (2009) 11
Y. Allkofer, PhD Thesis, Universität Zürich, 2008.



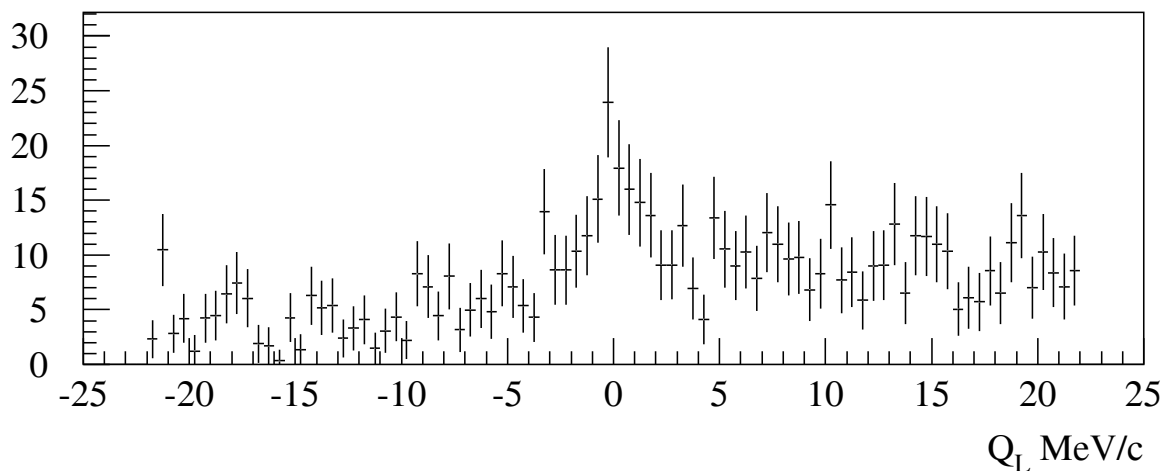
Q_L -distribution for $K^+\pi^-$ pairs from 2007 data



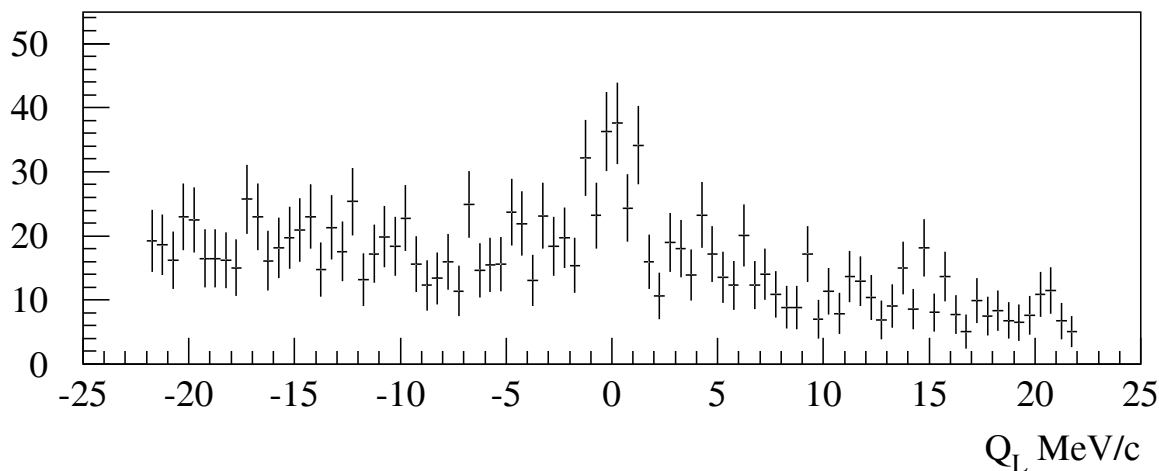
Q_T -distribution for $K^+\pi^-$ background pairs from 2007 data



Q_L -distribution for $\pi^+\pi^-$ pairs
from 2008 data



Q_L -distribution for π^+K^- pairs
from 2008 data



Q_L -distribution for $K^+\pi^-$ pairs
from 2008 data

Results of 2009

The comparison of the events collected in years 2008 and 2009 in the DIRAC experiment.

Year	Number of spills	Number of days	Spills/day
2008	$7.0 \cdot 10^5$	95	7400
2009	$10.9 \cdot 10^5$	164	6600

The time correlated events were selected by the cuts in the transverse and longitudinal components Q_x , Q_y and Q_L :

$\pi\pi$	$Q_x \leq 6 \text{ MeV/c}$	$Q_y \leq 6 \text{ MeV/c}$	$Q_L \leq 30 \text{ MeV/c}$
πK	$Q_x \leq 8 \text{ MeV/c}$	$Q_y \leq 8 \text{ MeV/c}$	$Q_L \leq 30 \text{ MeV/c}$

Year	$\pi^+\pi^-$	π^+K^-	$K^+\pi^-$
2008	$4.8 \cdot 10^6$	$2.7 \cdot 10^4$	$4.2 \cdot 10^5$
2009	$7.3 \cdot 10^6$	$3.4 \cdot 10^4$	$7.5 \cdot 10^5$

Metastable Atoms

For $p_A = 5.6 \text{ GeV/c}$ and $\gamma = 20$

$$\left\{ \begin{array}{ll} \tau_{1s} = 2.9 \times 10^{-15} \text{ s}, & \lambda_{1s} = 1.7 \times 10^{-3} \text{ cm} \\ \tau_{2s} = 2.3 \times 10^{-14} \text{ s}, & \lambda_{2s} = 1.4 \times 10^{-2} \text{ cm} \\ \tau_{2p} = 1.17 \times 10^{-11} \text{ s}, & \lambda_{2p} = 7 \text{ cm} \\ & \lambda_{3p} \approx 23 \text{ cm} \\ & \lambda_{4p} \approx 54 \text{ cm} \end{array} \right.$$

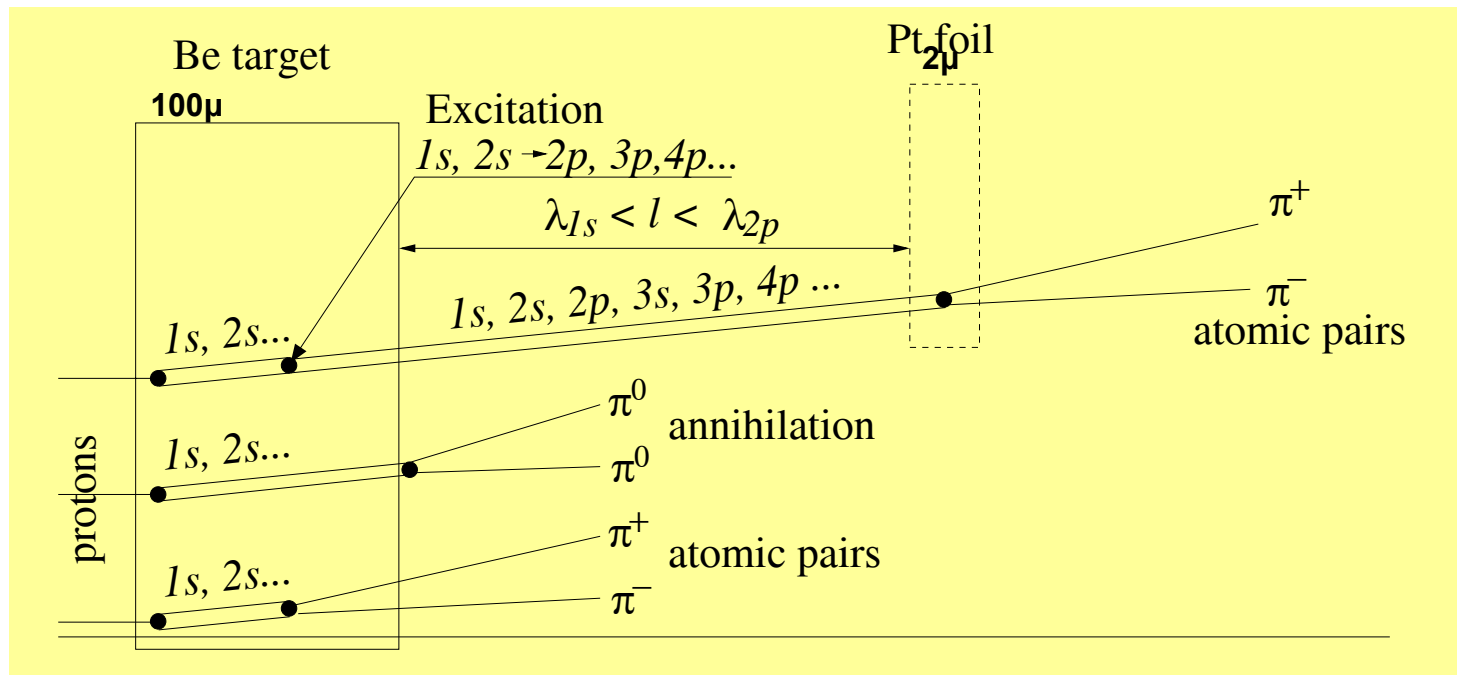


Illustration for observation of the $A_{2\pi}$ long-lived states with breaking foil.

Energy splitting between np - ns states in $\pi^+\pi^-$ atom

$$\Delta E_n \equiv E_{ns} - E_{np}$$

$$\Delta E_n \approx \Delta E_n^{vac} + \Delta E_n^s \quad \Delta E_n^s \sim 2a_0 + a_2$$

For $n = 2$

$$\Delta E_2^{vac} = -0.107 \text{ eV} \text{ from QED calculations}$$

$$\Delta E_2^s \approx -0.45 \text{ eV} \text{ numerical estimated value from ChPT}$$

$$a_0 = 0.220 \pm 0.005$$

$$a_2 = -0.0444 \pm 0.0010$$

(2001) *G. Colangelo, J. Gasser and H. Leutwyler*

$$\Rightarrow \Delta E_2 \approx -0.56 \text{ eV}$$

(1979) A. Karimkhodzhaev and R. Faustov

(1983) G. Austen and J. de Swart

(1986) G. Efimov *et al.*

(1999) A. Gashi *et al.*

(2000) D. Eiras and J. Soto

(2004) J. Schweizer, EPJ C36 483

A. Rusetsky, *priv. comm.*

Metastable Atoms

Probabilities of the $A_{2\pi}$ breakup (Br) and yields of the long-lived states for different targets provided the maximum yield of summed population of the long-lived states: $\Sigma(l \geq 1)$

Target Z	Thickness μ	Br	Σ $(l \geq 1)$	$2p_0$	$3p_0$	$4p_0$	Σ $(l=1, m=0)$
04	100	4.45%	5.86%	1.05%	0.46%	0.15%	1.90%
06	50	5.00%	6.92%	1.46%	0.51%	0.16%	2.52%
13	20	5.28%	7.84%	1.75%	0.57%	0.18%	2.63%
28	5	9.42%	9.69%	2.40%	0.58%	0.18%	3.29%
78	2	18.8%	10.5%	2.70%	0.54%	0.16%	3.53%

Prospects of DIRAC

Creation of an intense source of $\pi\pi$, πK and other exotic atoms at SPS proton beam and using them for accurate measurements of **all** S-wave $\pi\pi$ and πK scattering length to check the precise low energy QCD predictions

DIRAC prospects at SPS CERN

Yields of atoms at PS and SPS

Yield of dimeson atoms per one proton-Ni interaction, detectable by DIRAC upgrade setup at $\Theta_L=5.7^\circ$						
24 GeV				450 GeV		
E_p	$A_{2\pi}$	$A_{K^+\pi^-}$	$A_{\pi^+K^-}$	$A_{2\pi}$	$A_{K^+\pi^-}$	$A_{\pi^+K^-}$
W_A	$1.1 \cdot 10^{-9}$	$0.52 \cdot 10^{-10}$	$0.29 \cdot 10^{-10}$	$0.13 \cdot 10^{-7}$	$0.10 \cdot 10^{-8}$	$0.71 \cdot 10^{-9}$
W_A^N	1.	1.	1.	12.	19.	24.
W_A/W_π	$3.4 \cdot 10^{-8}$	$16. \cdot 10^{-10}$	$9. \cdot 10^{-10}$	$1.3 \cdot 10^{-7}$	$1. \cdot 10^{-8}$	$7.1 \cdot 10^{-9}$
W_A^N/W_π^N	1.	1.	1.	3.8	6.2	8.
				A multiplier due to different spill duration ~4		
Total gain	1.	1.	1.	15.	25.	32.

DIRAC prospects at SPS CERN

Present low-energy *QCD* predictions for $\pi\pi$ and πK scattering lengths

$\pi\pi$ $\delta a_0 = 2.3\%$ $\delta a_2 = 2.3\%$ $\delta(a_0 - a_2) = 1.5\%$...will be improved by *Lattice* calculations

πK $\delta a_{1/2} = 11\%$ $\delta a_{3/2} = 40\%$ $\delta a_{1/2} = 10\%$ $\delta a_{3/2} = 17\%$...will be significantly improved by *ChPT*

$\underbrace{\hspace{10em}}_{ChPT} \quad \underbrace{\hspace{10em}}_{Roy-Steiner}$

Planned results of DIRAC ADDENDUM at PS CERN after 2008-2009

$$\tau(A_{2\pi}) \rightarrow \delta(a_0 - a_2) = \pm 2\%(stat) \pm 1\%(syst) \pm 1\%(theor)$$

$$\tau(A_{\pi K}) \rightarrow \delta(a_{1/2} - a_{3/2}) = \pm 10\%(stat) \pm \dots \pm 1.5\%(theor)$$

2010-2011 Observation of metastable $\pi^+\pi^-$ atoms and study of a possibility to measure its Lamb shift.

Study of the possibility to observe K^+K^- and $\pi^\pm\mu^\mp$ atoms using 2008-2009 data.

DIRAC at SPS CERN beyond 2011

$$\tau(A_{2\pi}) \rightarrow \delta(a_0 - a_2) = \pm 0.5\%(stat)$$

$$(E_{np} - E_{ns})_{\pi\pi} \rightarrow \delta(2a_0 + a_2)$$

$$\tau(A_{\pi K}) \rightarrow \delta(a_{1/2} - a_{3/2}) = \pm 2.5\%(stat)$$

$$(E_{np} - E_{ns})_{\pi K} \rightarrow \delta(2a_{1/2} + a_{3/2})$$

Thank you for your attention