Status Report of DIRAC

LIFETIME MEASUREMENT OF $\pi^+\pi^-$ AND $\pi^\pm K^\mp$ ATOMS TO TEST LOW-ENERGY *QCD*

L. Nemenov

Outline

1. 2001-2003 data, processing and analysis using GEM/MSGC

2. Status of 2008 data on $\pi^+\pi^-$ and $K^+\pi^-/K^-\pi^+$ atoms

3. Status of 2009 data

4. Schedule of 2008 & 2009 data processing and analysis

5. Plan for the 2010 run

6. In autumn 2010: submission of the new ADDENDUM
   "Observation of LONG-LIVED $\pi^+\pi^-$ atoms"

DIRAC Collaboration

75 Physicists from 19 Institutes

CERN
Geneva, Switzerland

Czech Technical University
Prague, Czech Republic

Institute of Physics ASCR
Prague, Czech Republic

Nuclear Physics Institute ASCR
Rez, Czech Republic

INFN-Laboratori Nazionali di Frascati
Frascati, Italy

Trieste University and INFN-Trieste
Trieste, Italy

University of Messina
Messina, Italy

KEK
Tsukuba, Japan

Kyoto Sangyou University
Kyoto, Japan

Tokyo Metropolitan University
Tokyo, Japan

IFIN-HH
Bucharest, Romania

JINR
Dubna, Russia

SINP of Moscow State University
Moscow, Russia

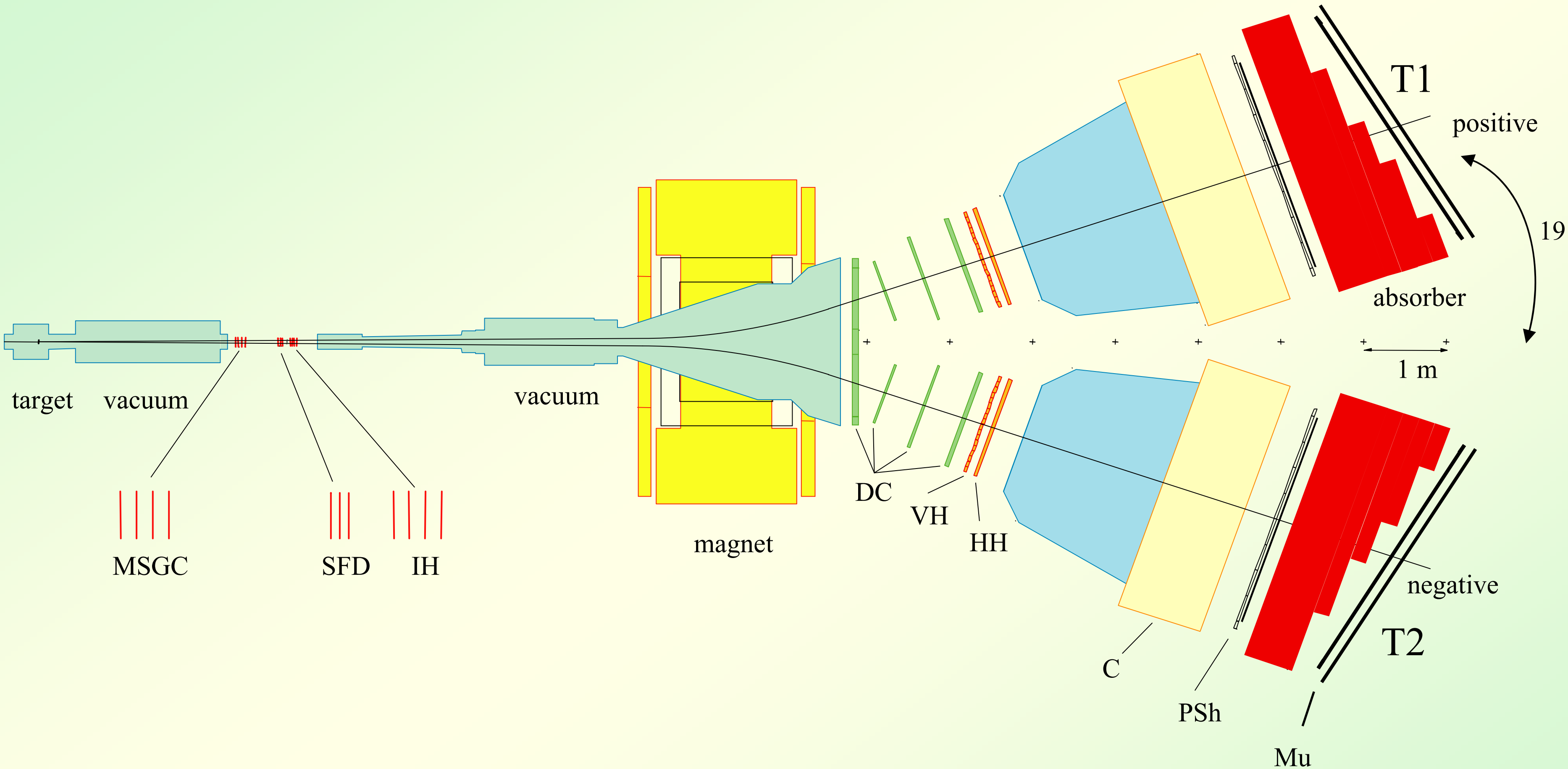
IHEP
Protvino, Russia

Santiago de Compostela University
Santiago de Compostela, Spain

Bern University
Bern, Switzerland

Zurich University
Zurich, Switzerland

DIRAC First Setup



DIRAC experimental results

$A_{2\pi}$ lifetime

2005 DIRAC (PL B619, 50)

$$\tau = \left(2.91\,{}^{+0.45}_{-0.38}\Big|_{stat}\;{}^{+0.19}_{-0.49}\Big|_{syst}\right)\text{fs} = \left(\ldots{}^{+0.49}_{-0.62}\Big|_{tot}\right)\text{fs}$$

...based on 2001 data (6530 atomic pairs)

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

2008 DIRAC (SPSC 22/04/08)

$$\boxed{\tau = \left(2.82\,{}^{+0.25}_{-0.23}\Big|_{stat} \pm 0.19\big|_{syst}\right)\text{fs} = \left(\ldots{}^{+0.31}_{-0.30}\Big|_{tot}\right)\text{fs}}$$

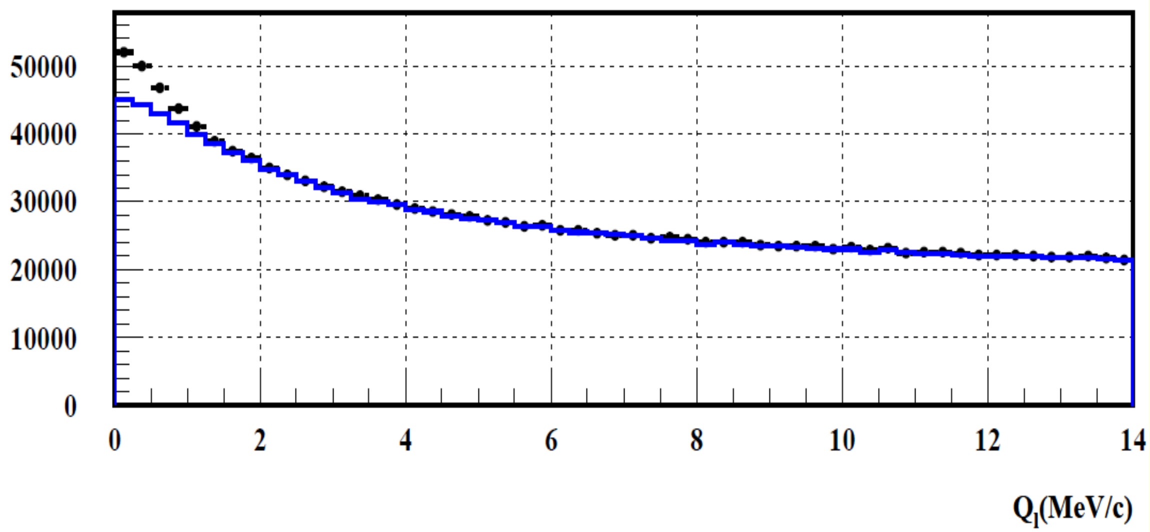
... part 2001-03 data (13300 atomic pairs)

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

Including GEM/MicroStripGasChambers => number of reconstructed atomic pairs is 20020

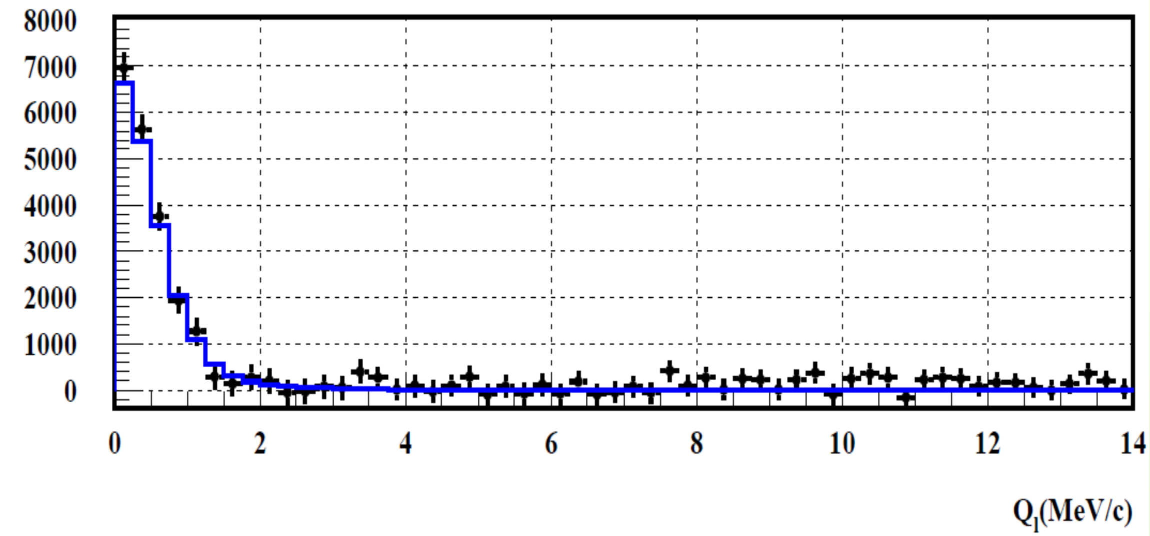
=> the statistical error in $|a_0\text{-}a_2|$ is 3.2%, and the full error will be <5%.

DIRAC results with GEM/MSGC



Q_L distribution

←All events

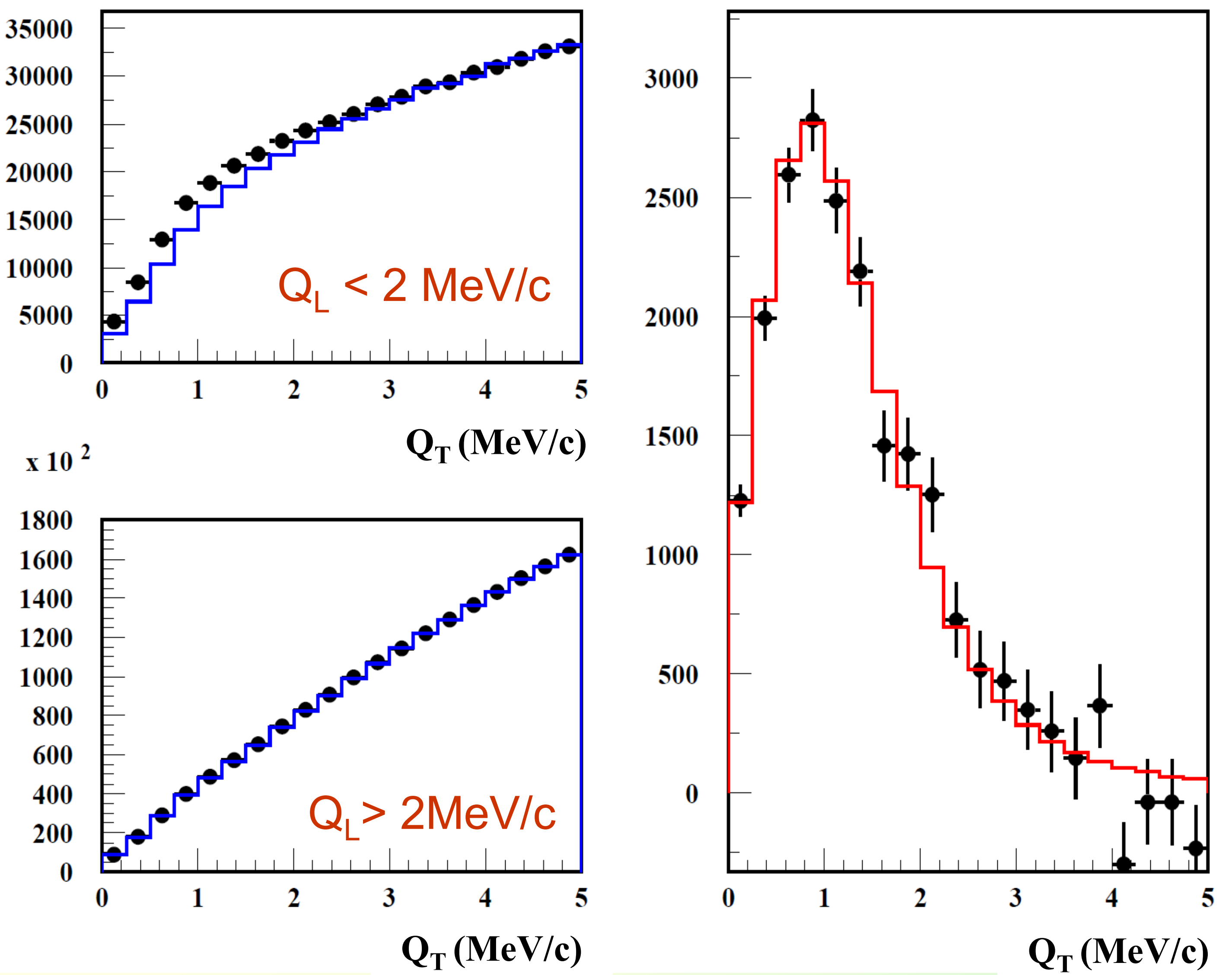


←After background subtraction:

$\mathbf{n_A \sim 20020}$

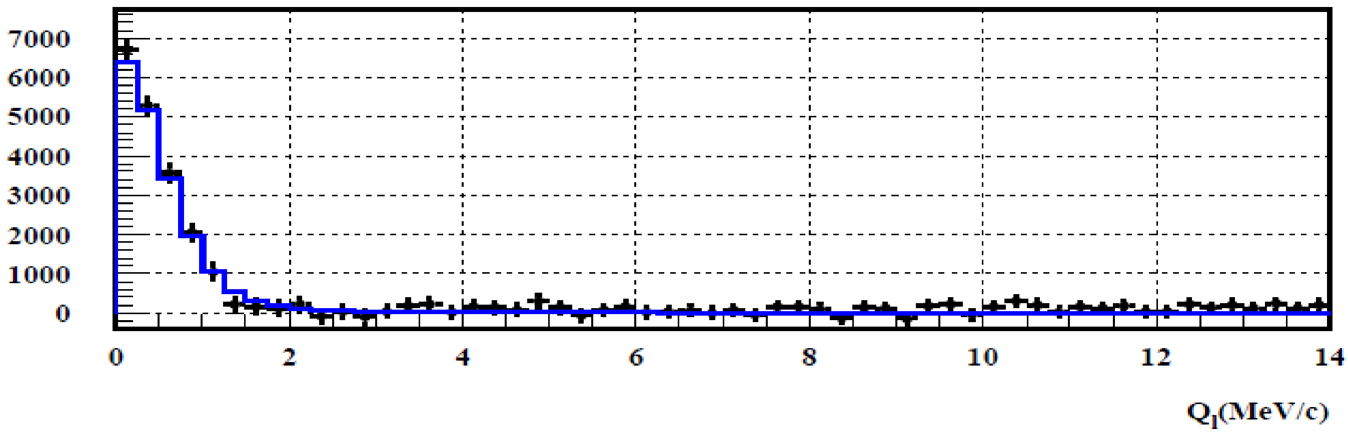
DIRAC results with GEM/MSGC

Q_T distribution

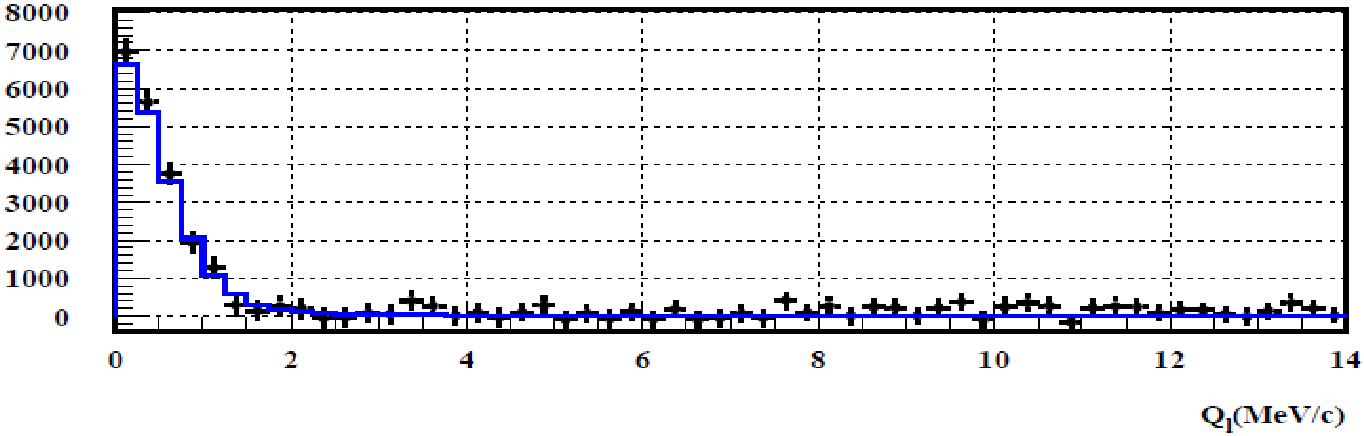


← After background subtraction for Q_L<2MeV/c:

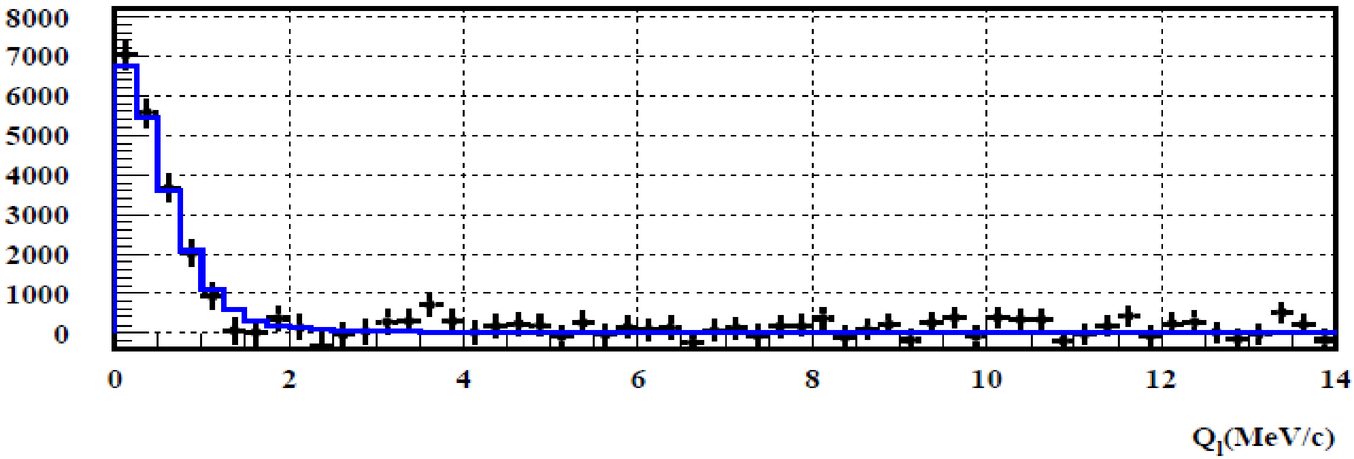
$n_A \sim 20020$



Q_L for $Q_T < 3$ MeV/c



Q_L for $Q_T < 4$ MeV/c



Q_L for $Q_T < 5$ MeV/c

Comparition with other experimental results

$K \to 3\pi$:

2009 **NA48/2** (EPJ C64, 589) ...without constraint between a_0 and a_2:

$$\Rightarrow a_0 - a_2 = 0.2571 \pm 1.9\%\big|_{stat} \pm 1.0\%\big|_{syst} \pm 0.5\%\big|_{ext} = \ldots \pm 2.2\%$$

and 3.4% theory uncertainty

...with ChPT constraint between a_0 and a_2:

$$\Rightarrow a_0 - a_2 = 0.2633 \pm 0.9\%\big|_{stat} \pm 0.5\%\big|_{syst} \pm 0.7\%\big|_{ext} = \ldots \pm 1.3\%$$

and 2% theory uncertainty

Ke4:

2009 **NA48/2** (CD09, Bern) ...without constraint between a_0 and a_2:

$$\Rightarrow a_0 = 0.2220 \pm 5.8\%\big|_{stat} \pm 2.3\%\big|_{syst} \pm 1.7\%\big|_{theo} = \ldots \pm 6.4\%$$

$$\Rightarrow a_2 = -0.0432 \pm 20\%\big|_{stat} \pm 7.9\%\big|_{syst} \pm 6.5\%\big|_{theo} = \ldots \pm 22\%$$

...with ChPT constraint between a_0 and a_2:

$$\Rightarrow a_0 = 0.2206 \pm 2.2\%\big|_{stat} \pm 0.8\%\big|_{syst} \pm 2.9\%\big|_{theo} = \ldots \pm 3.7\%$$

Schedule for the 2001-2003 data process and analysis

1. Final values and evaluation of errors for the π-π atoms breakup probabilities Wbr :   before the end of June 2010

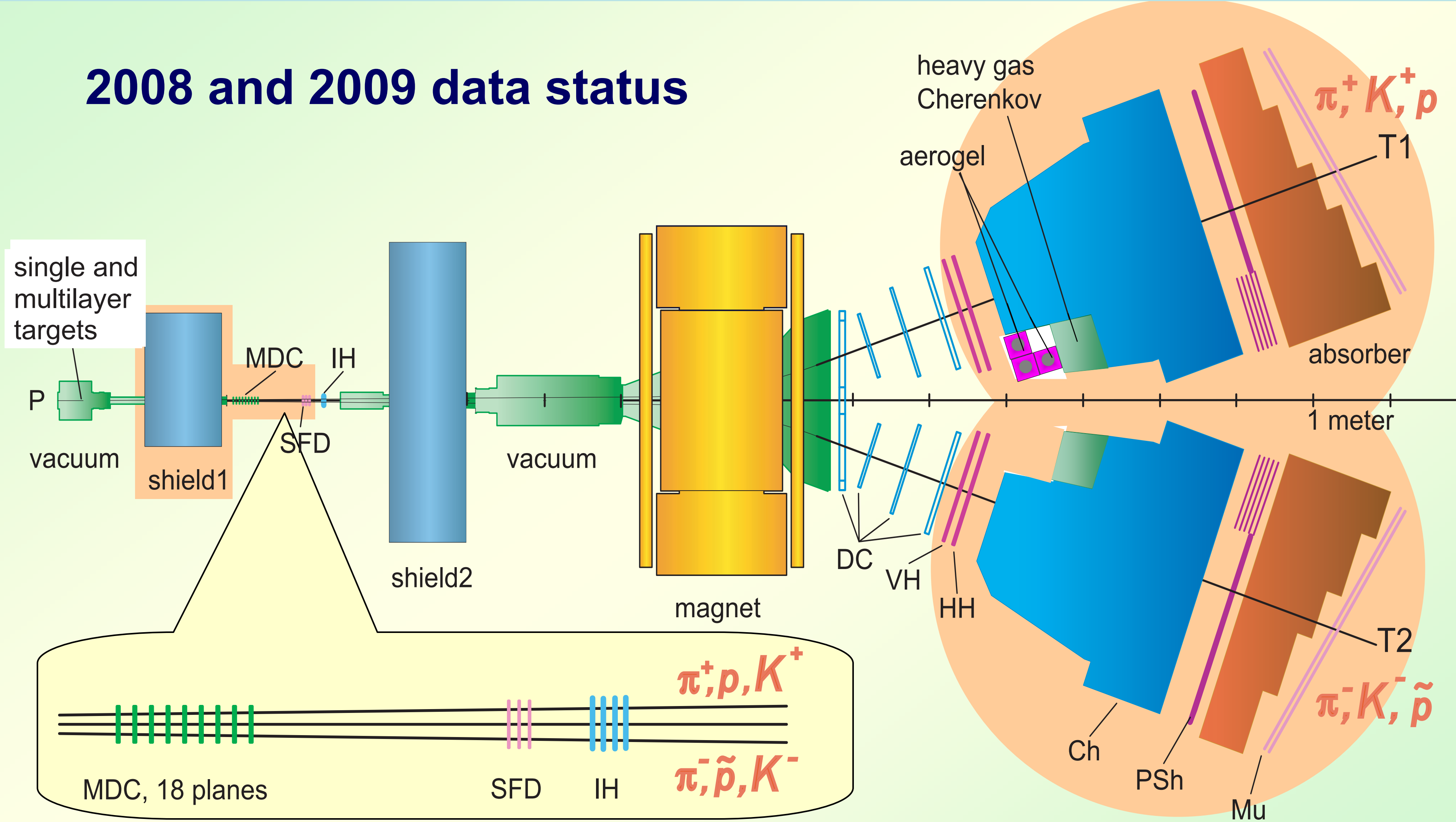
2. Measurement of the π-π atom life-time (τ) using Wbr(τ,p_A) averaged on the atom momentum p_A: before the end of July 2010

3. Final evaluation of the π-π atom life-time measurement using Wbr(τ,p_A) calculated for different atom momentum intervals: before the end of September 2010

4. Draft of the paper: before the middle of November 2010

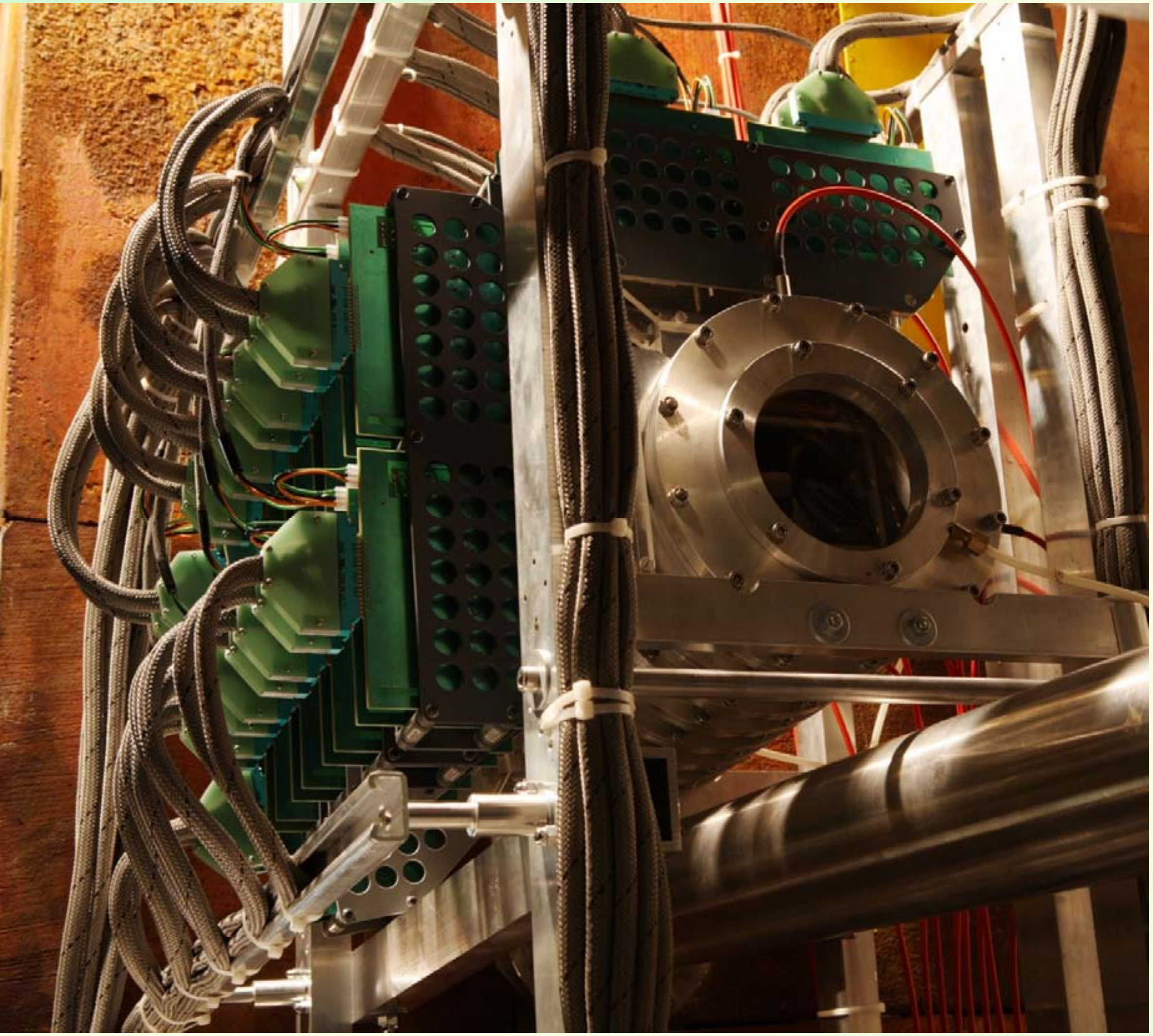
Upgraded DIRAC experimental setup

2008 and 2009 data status

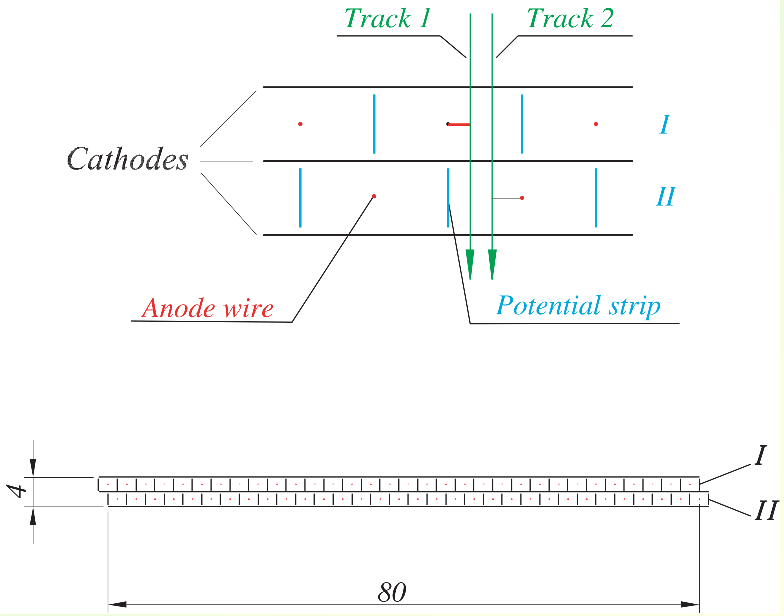


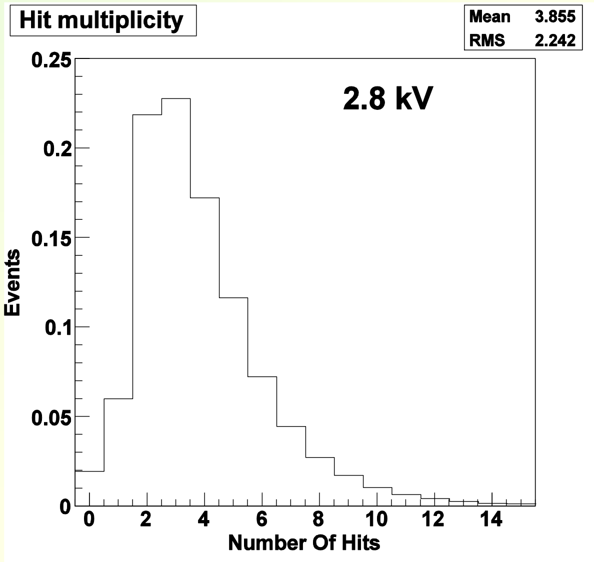
Modifided parts

MICRO Drift Chambers



Micro Drift Chambers II





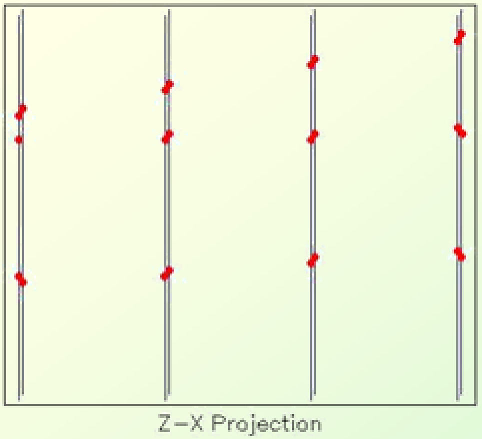
The cell dimensions are:

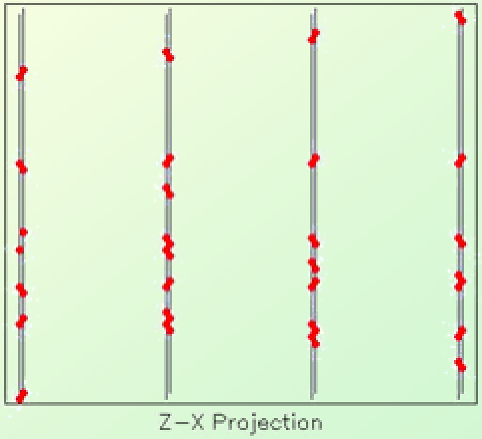
2 mm along the beam direction

2.4 mm perpendicular to the beam direction.

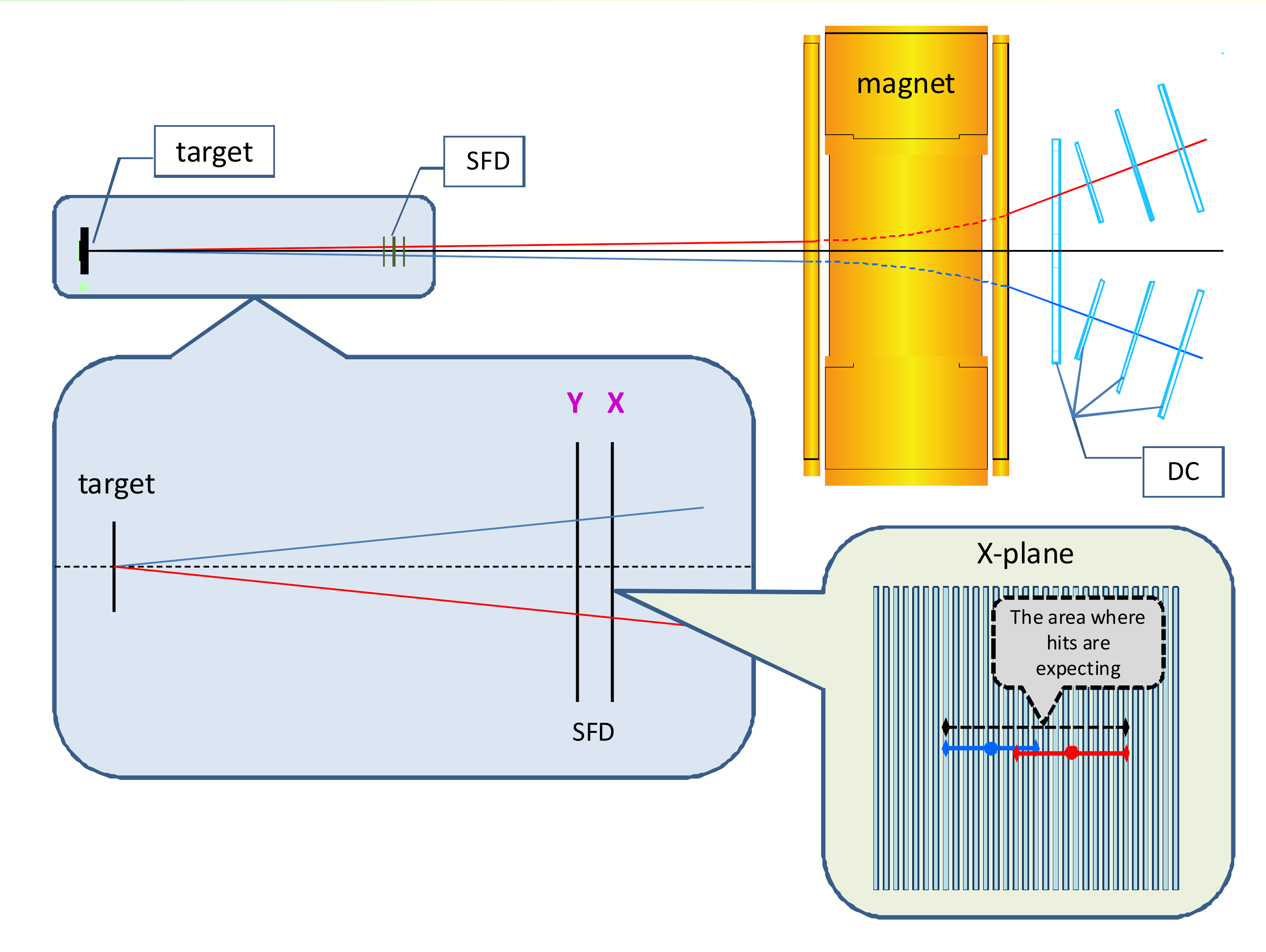
Maximum drift time less than 30 ns.

Examples of event

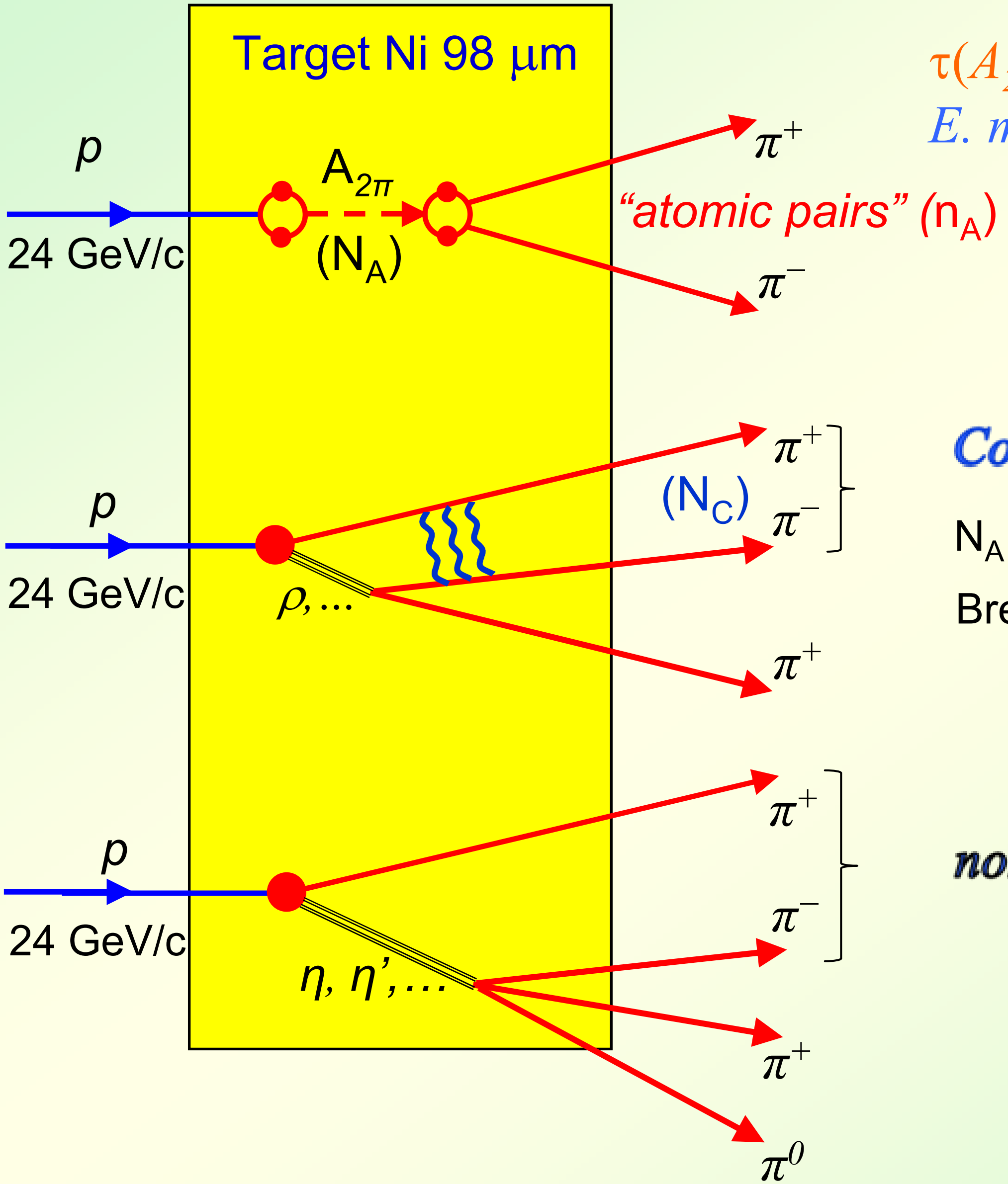




Extrapolation to the target



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:

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

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

Coulomb *from short-lived sources*

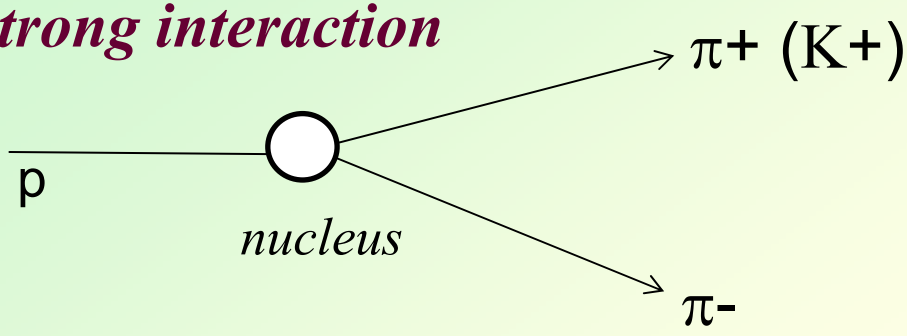
$N_A = K(Q_0)\ N_C(Q<Q_0)$ with known $K(Q_0)$

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

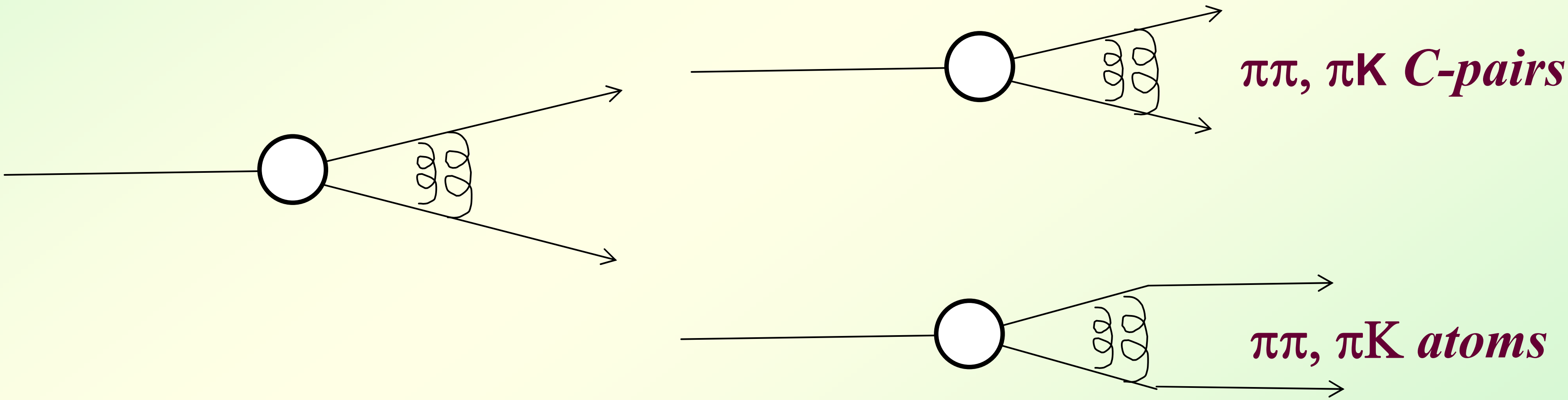
non-Coulomb *from long-lived sources*

Coulomb pairs and atoms

Strong interaction



For small Q there are Coulomb pairs :



The yield strongly increases with Q decreasing.

Relation between Coulomb pairs and atoms

There is a precise (1%) ratio :

$$\frac{d\sigma^{A}_{nlm}}{d\vec{P}} = (2\pi)^3 \frac{E}{M} \left|\psi^{(C)}_{nlm}(0)\right|^2 \frac{d\sigma^0_s}{dp_1 dp_2} \propto \frac{d\sigma}{dp_1} \cdot \frac{d\sigma}{dp_2}$$

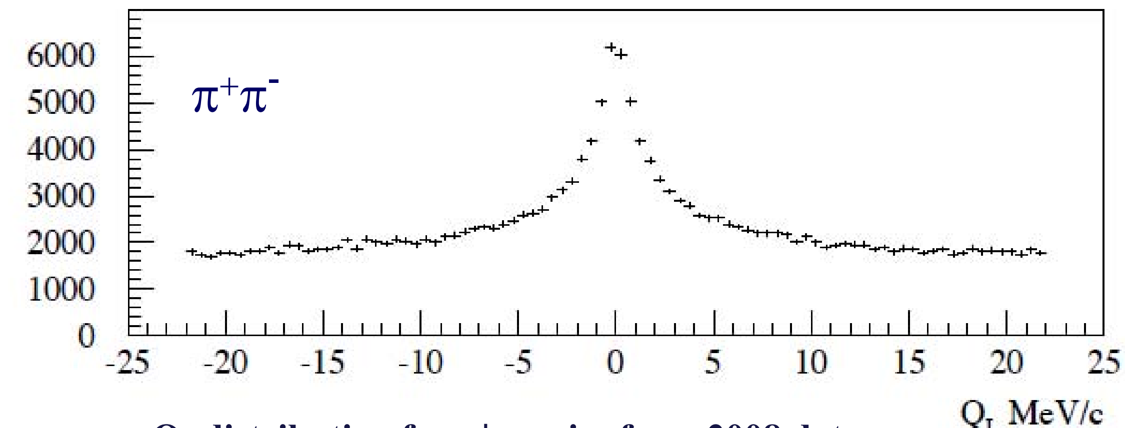
for atoms $\vec{v}_1 = \vec{v}_2$ *where* $\vec{v}_1, \vec{v}_2$ *– velocities of particles in the lab frame for all types of atoms*

for $A_{2\pi}$ *production* $\vec{p}_1 = \vec{p}_2$

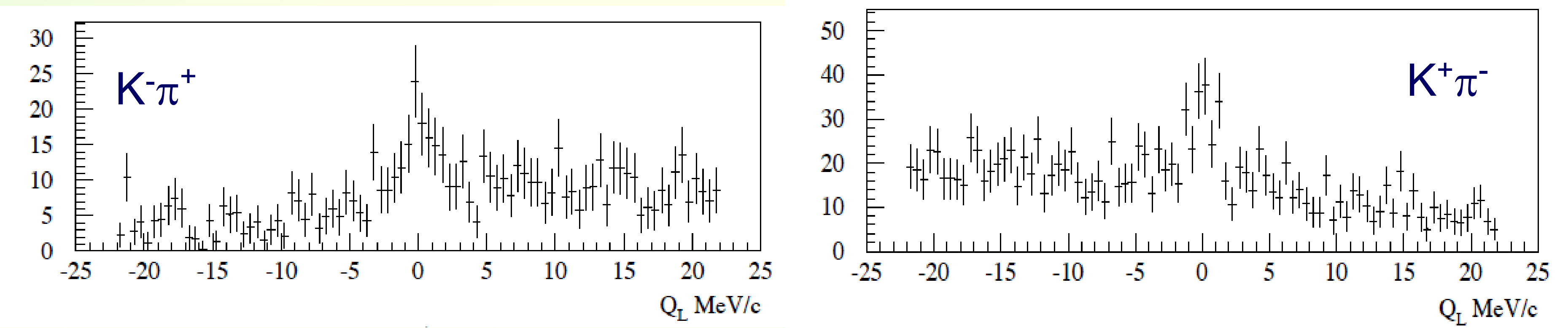
for $A_{\pi K}$ *production* $\vec{p}_\pi = \frac{m_\pi}{m_K} \vec{p}_K$

Coulomb pairs can be constructed from experimental accidentals or from Monte Carlo.

Q_L distributions from 2008 data



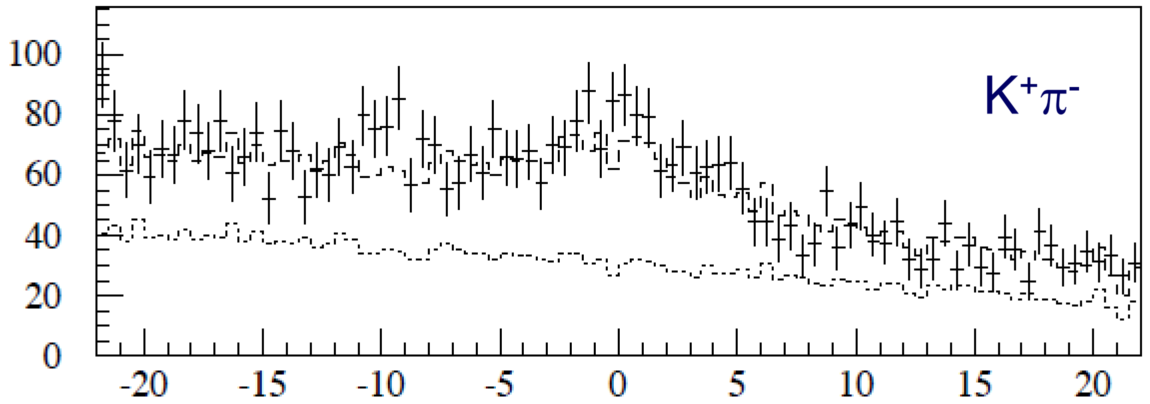
Q_L distribution for $\pi^+\pi^-$ pairs from 2008 data



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

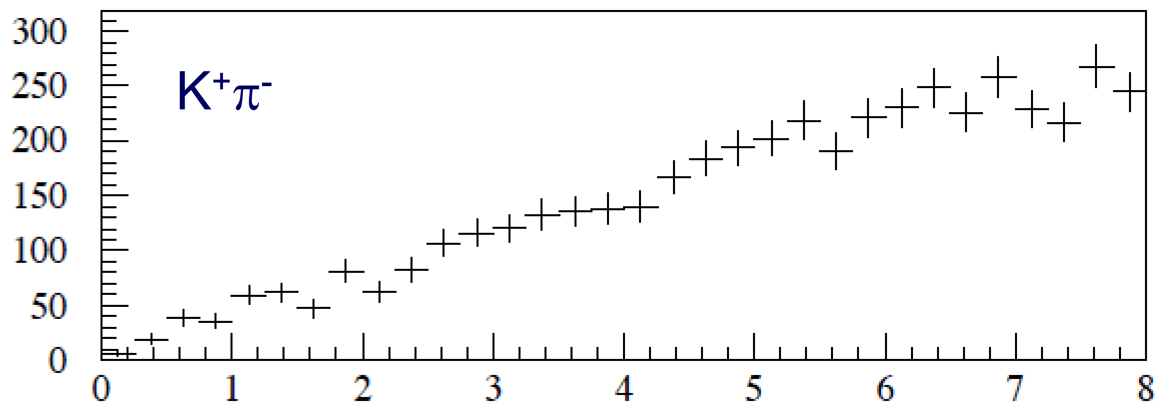
Q_L and Q_T distributions from 2007 data

Downstream tracking ONLY



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

Q_L MeV/c



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

Q_T MeV/c

Predictions

Table 3: Predictions for πK pairs of both signs with the Nickel target

	2008 + 2009			2008 + 2009+2010
reconstruction efficiency	N_A	n_A	$n_A/Error$	$n_A/Error$
42%	255	79	3.06 ± 0.37	3.79 ± 0.46
63%	442	137	4.07 ± 0.49	5.15 ± 0.62
80%	561	174	4.54 ± 0.55	5.74 ± 0.70

Table 4: Prediction for πK pairs of both signs with the Platinum target (2007) and Nickel target (2008+2009)

	2007 + 2008 + 2009
reconstruction efficiency	$n_A/Error$
42%	3.82 ± 0.35
63%	4.67 ± 0.45
80%	5.08 ± 0.51

Accuracy of $|a_{1/2}-a_{3/2}|$ measurement

Accuracy of the measurement	5σ (20%)	6σ (17%)	6.5σ (15%)
τ (s)	$(3.7^{+60\%}_{-43\%})\cdot 10^{-15}$	$(3.7^{+51\%}_{-38\%})\cdot 10^{-15}$	$(3.7^{+46\%}_{-32\%})\cdot 10^{-15}$
$\delta_{avreage}\lvert a_{1/2} - a_{3/2}\rvert$	26 %	23 %	20 %

Accuracy and formulae

$$N_A^{\pi^+\pi^-} = 8000 \pm 190, \quad N_A^{K^+\pi^-} = 70 \pm 24, \quad N_A^{K^-\pi^+} = 45 \pm 18.$$

$$\rho = N_A^{\pi^+\pi^-} / \left(N_A^{K^+\pi^-} + N_A^{K^-\pi^+} \right) = 70 \pm 18\,.$$

$$\frac{d\sigma_{nlm}^A}{d\vec{p}_A} = (2\pi)^3 \frac{E_A}{M_A} \left|\psi_{nlm}(0)\right|^2 \frac{d\sigma_s^0}{d\vec{p}_1 d\vec{p}_2}\bigg|_{v_1 = v_2}$$

$$\frac{d\sigma_s^0}{d\vec{p}_1 d\vec{p}_2} = \frac{1}{\sigma_{inel}} \frac{d\sigma}{d\vec{p}_1} \frac{d\sigma}{d\vec{p}_2} R(\vec{p}_1, \vec{p}_2)$$

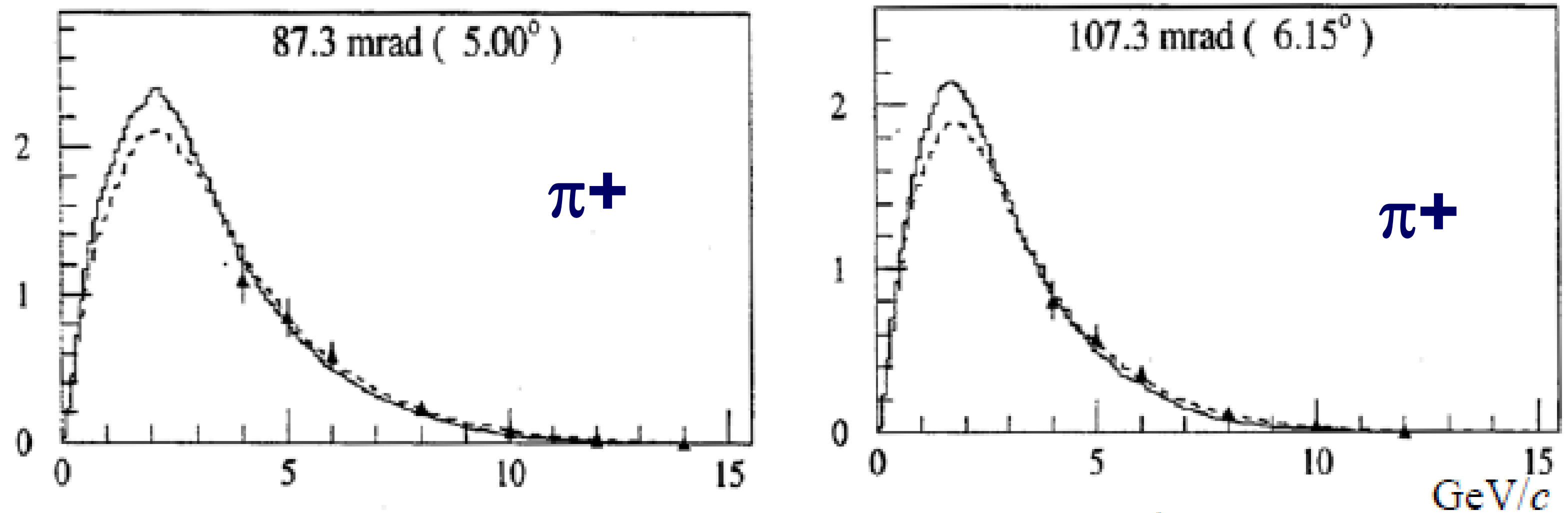


Figure 8: Comparison of the experimental inclusive yield of π^+ from pAl interaction at 24 GeV with the simulated in FRITIOF-7 – solid line and FRITIOF-6 – dashed line.

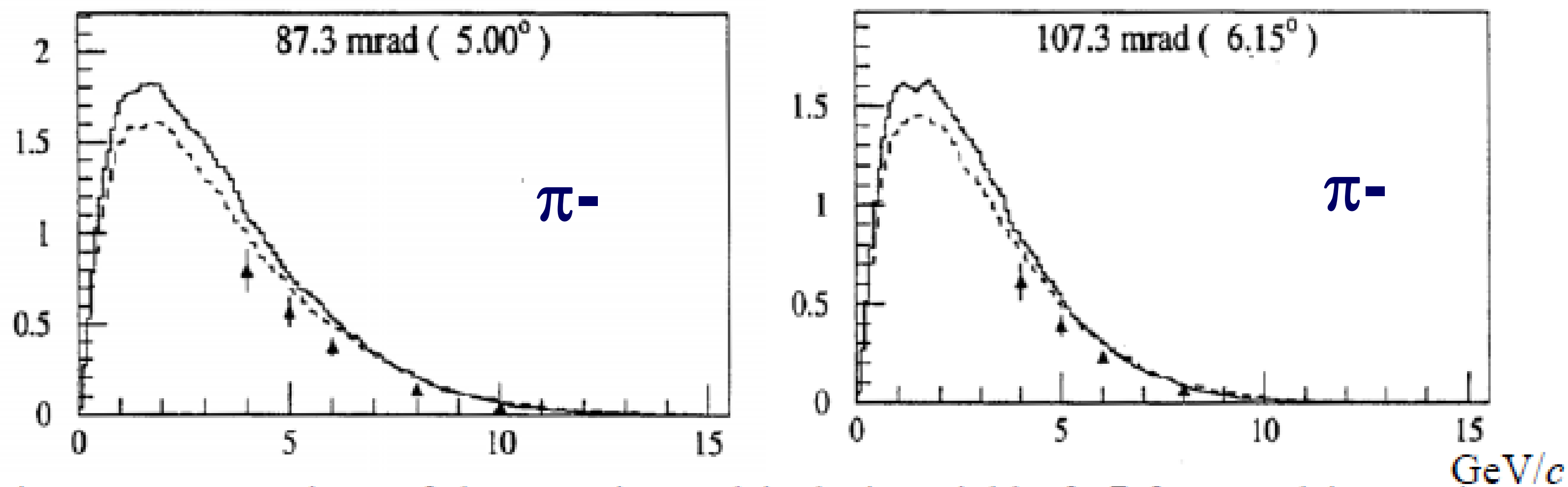


Figure 9: Comparison of the experimental inclusive yield of π^- from pAl interaction at 24 GeV with the simulated in FRITIOF-7 – solid line and FRITIOF-6 – dashed line.

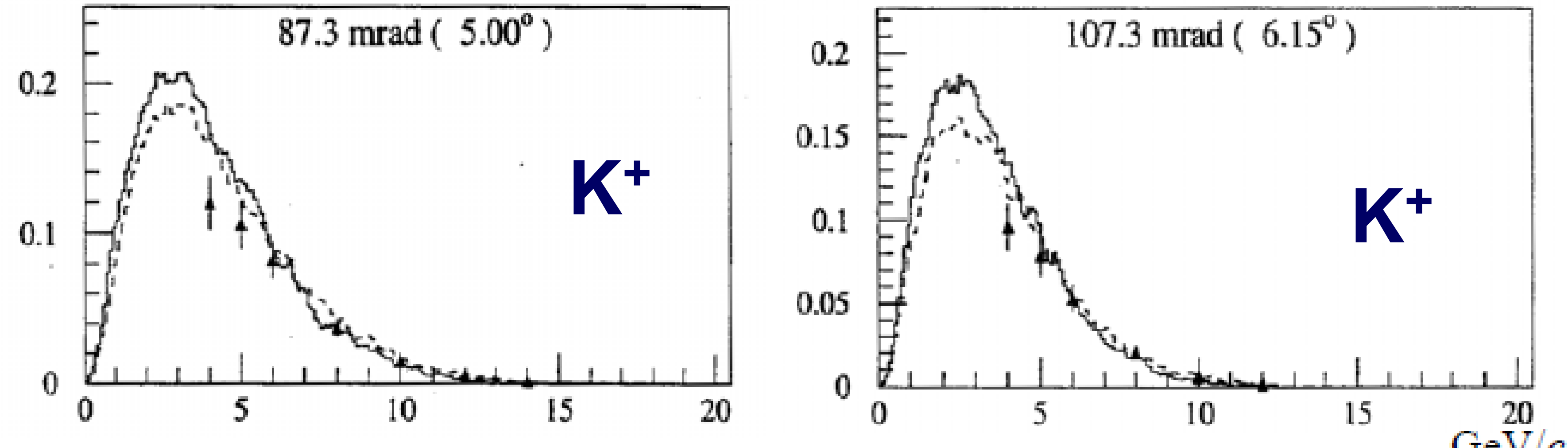


Figure. 10: Comparison of the experimental inclusive yield of K^+ from pAl interaction at 24 GeV with the simulated in FRITIOF-7 – solid line and FRITIOF-6 – dashed line.

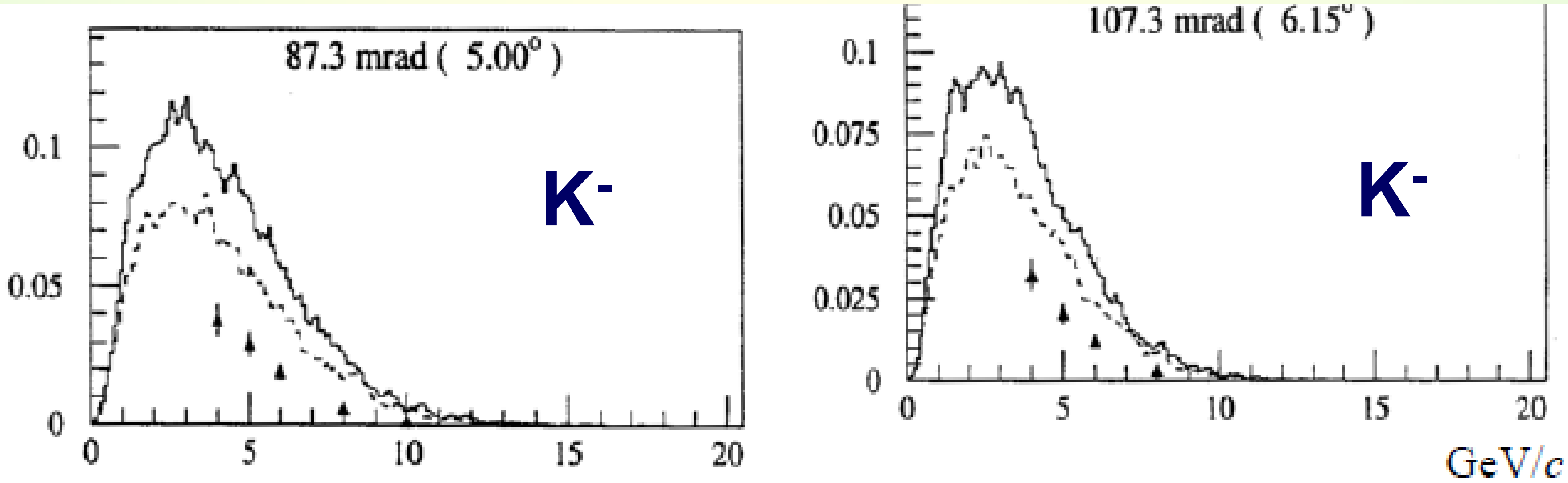


Figure 11: Comparison of the experimental inclusive yield of K^- from pAl interaction at 24 GeV with the simulated in FRITIOF-7 – solid line and FRITIOF-6 – dashed line.

Status of 2009 data

The calibrations of the drift chambers and of all other detectors are completed.

The preselection of the experimental data will begin in one month.

The Monte-Carlo simulation will be equivalent to the 2008 one.

Schedule of 2008/9 data processing and analysis

Kπ and ππ pairs from experimental and MonteCarlo data of 2008 will be processed using information from all detectors.

The experimental pairs will be analyzed and fitted using the Monte-Carlo distributions of Coulomb and non-Coulomb pairs.

The number of **K**π and ππ atomic pairs will be evaluated.
The total number of atoms produced will be estimated.

All experimental data for 2009 will be preselected and ntuples will be obtained.

All these results will be ready before the end of September 2010.

Plan for the 2010 run

Installation of the new memories to increase the reliability of the DAQ and to decrease the dead time of the readout system.

Check the 8 bunch injection to PS, proposed by R.Steerenberg.

Few days will be used to take data using a thin Be target (100 micrometers) to study the experimental conditions necessary to observe long-lived π-π atoms.

Aim for the 2010 run

The principal aim of this run is:

• the data taking needed for the $K^+ \pi^-$ and $K^- \pi^+$ atoms observation and their lifetime measurement.

• to obtain the statistics of π-π atoms which will allow to measure their lifetime with a precision of 6% or better and the difference of π-π scattering lengths with a precision of 3% or better.

New Addendum foreseen for Autumn 2010

The main aim of the new addendum is the observation of the long-lived $\pi^+\pi^-$ atoms.

This observation will open the possibility to measure in a model independent way the Lamb shift and to determine the new combination of the $\pi\pi$ scattering lengths $2a_0 + a_2$.

Energy Splitting between np - ns states in (π^+ - π^-) atom

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

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

For $n = 2$

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

$\Delta E_2^s \approx -0.45\ eV$ *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*

$\Rightarrow$ $\Delta E_2 \approx -0.56$ 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

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

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

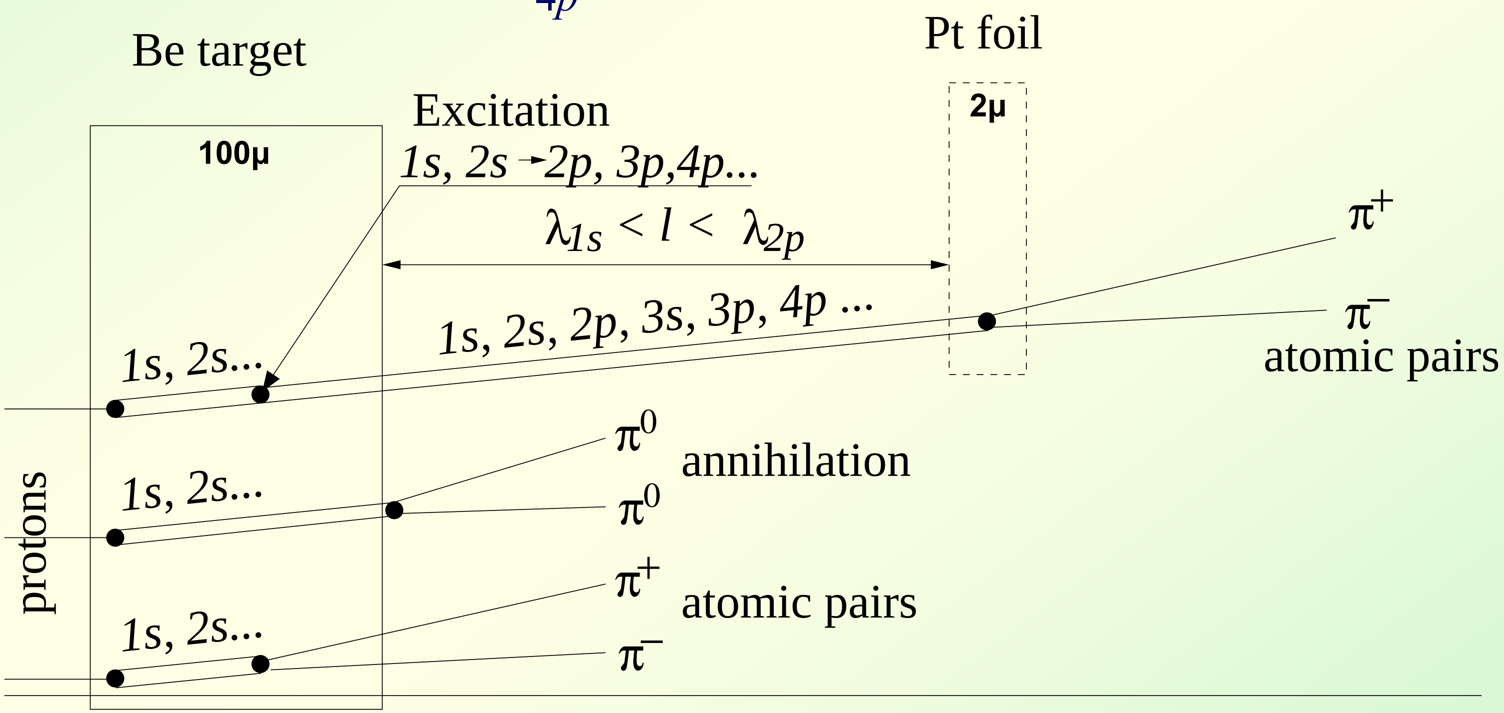


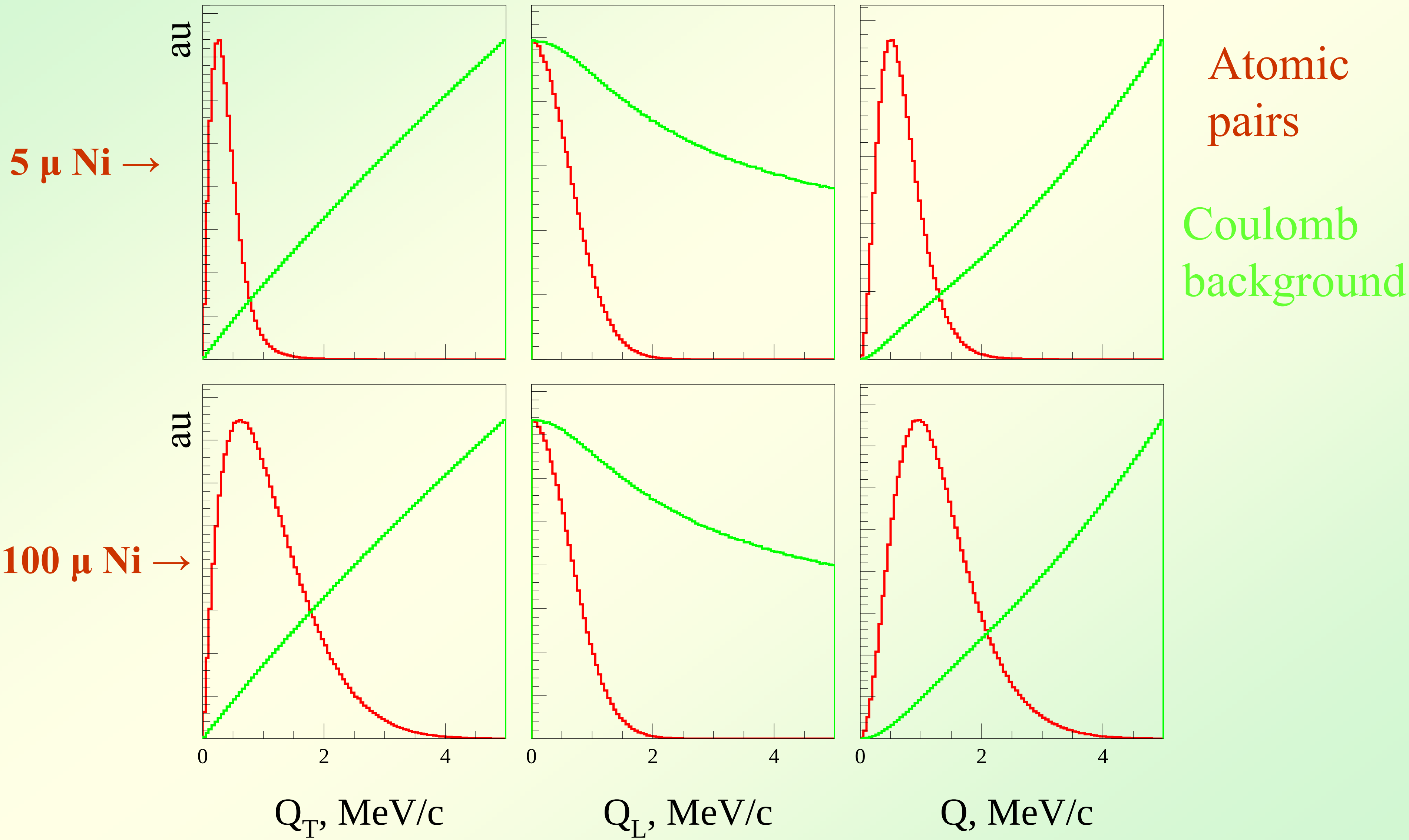
Illustration for observation of the $A_{2\pi}$ long-lived states with breaking foil.

Metastable Atoms

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

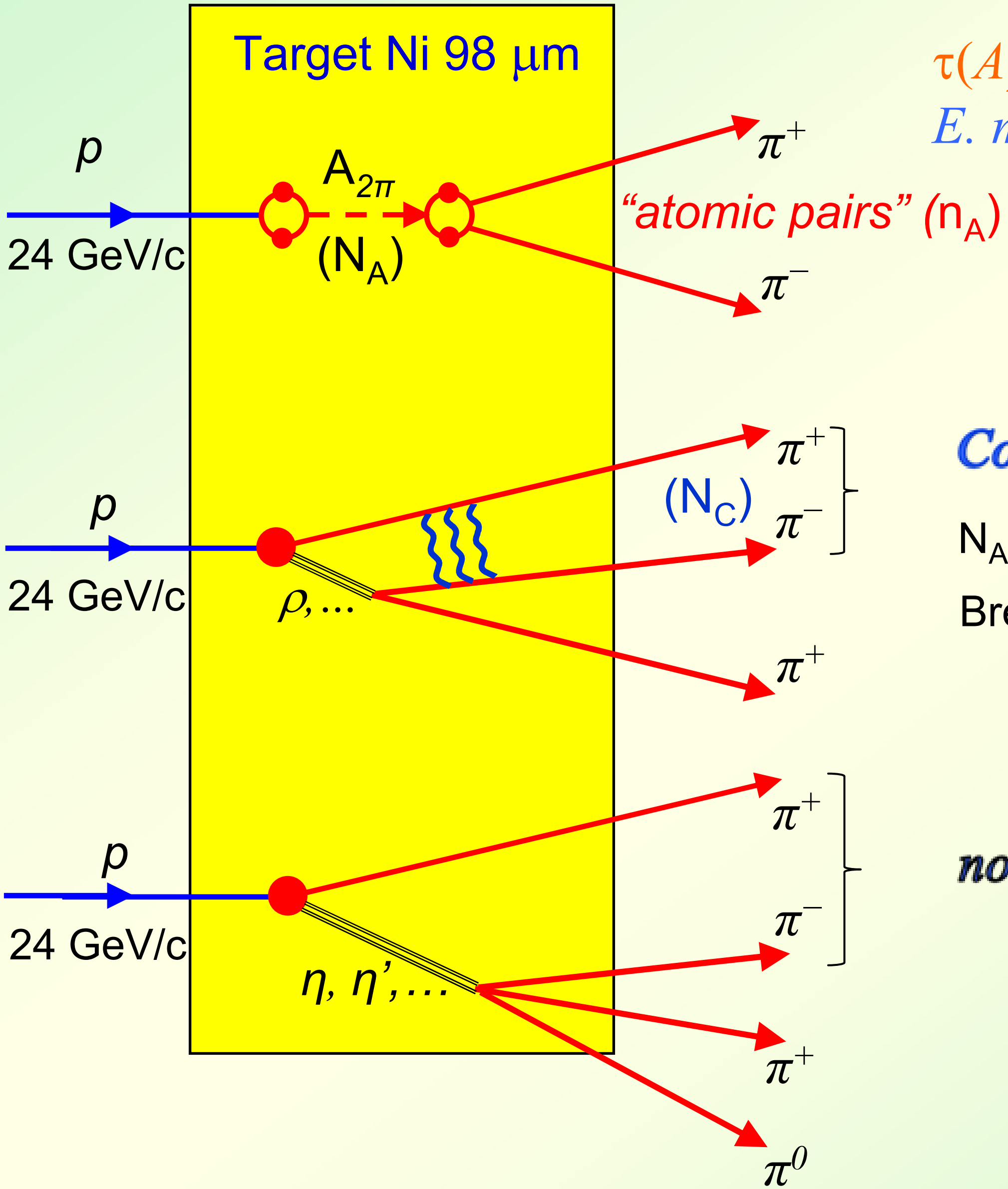
Target Z	Thickness μ	Br	Σ $(l \geq 1)$	$2p_0$	$3p_0$	$4p_0$	Σ $(l = 1, m = 0)$
04	100	4.45%	5.86%	1.05%	0.46%	0.15%	1.90%
06	50	5.00%	6.92%	1.46%	0.51%	0.16%	2.52%
13	20	5.28%	7.84%	1.75%	0.57%	0.18%	2.63%
28	5	9.42%	9.69%	2.40%	0.58%	0.18%	3.29%
78	2	18.8%	10.5%	2.70%	0.54%	0.16%	3.53%

Metastable Atoms - Backgrounds



Thank you for your attention

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:

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

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

Coulomb *from short-lived sources*

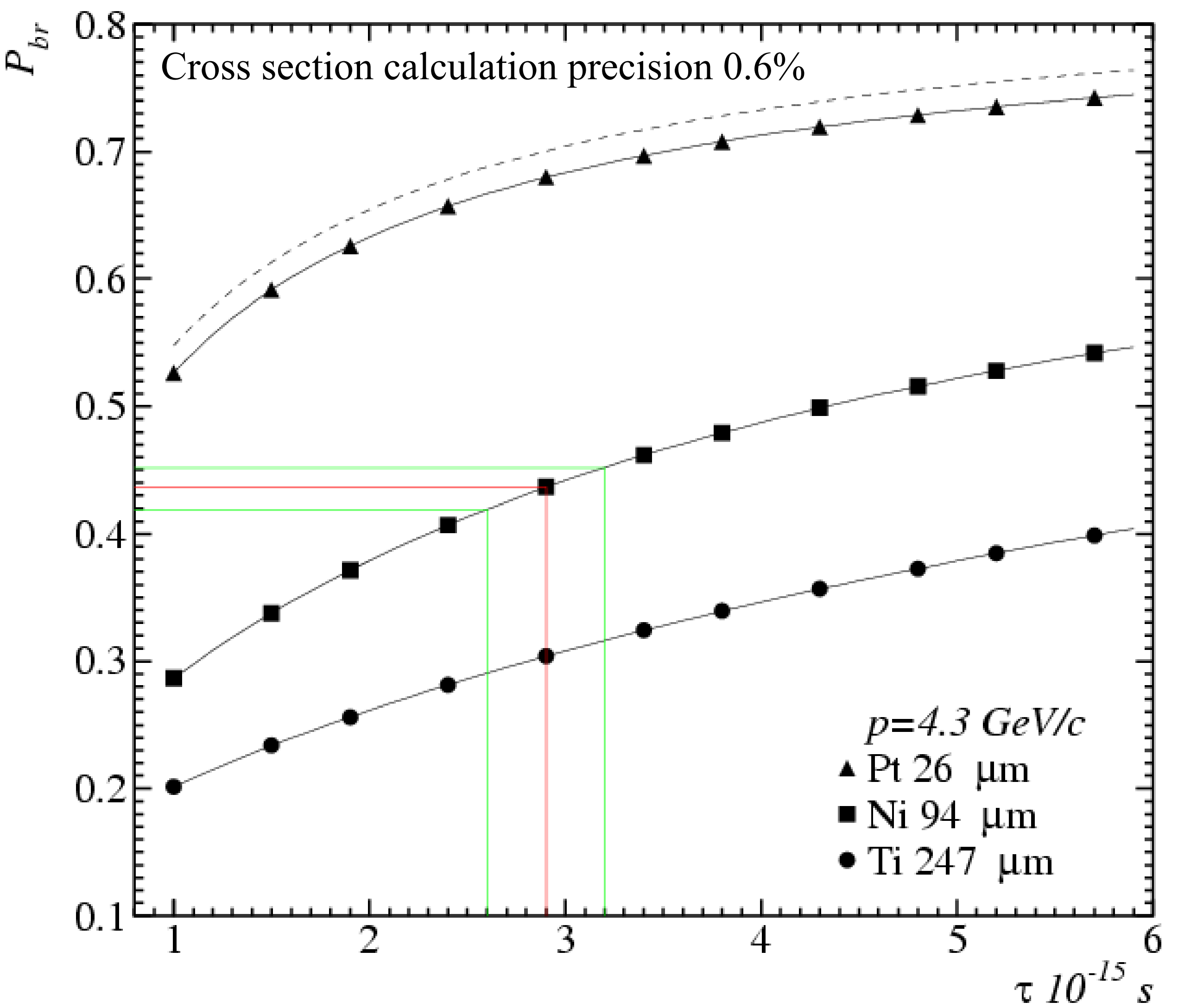
$N_A = K(Q_0)\ N_C(Q<Q_0)$ with known $K(Q_0)$

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

non-Coulomb *from long-lived sources*

Breakup probability

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



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

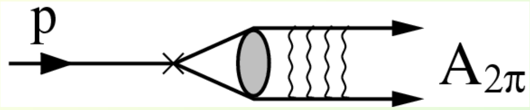
There is an optimal target material for a given lifetime

$A_{2\pi}$ and $A_{\pi K}$ production

$$\frac{d\sigma_{nlm}^{A}}{d\vec{P}} = (2\pi)^3 \frac{E}{M} \left|\psi_{nlm}^{(C)}(0)\right|^2 \frac{d\sigma_s^0}{dp_1 dp_2} \propto \frac{d\sigma}{dp_1} \cdot \frac{d\sigma}{dp_2}$$

for atoms $\vec{v}_1 = \vec{v}_2$ *where* $\vec{v}_1, \vec{v}_2$ *– velocities of particles in the lab frame for all types of atoms*

for $A_{2\pi}$ *production* $\vec{p}_1 = \vec{p}_2$



for $A_{\pi K}$ *production* $\vec{p}_\pi = \frac{m_\pi}{m_K} \vec{p}_K$

Theoretical status

In ChPT the effective Lagrangian, which describes the ππ interaction, is an expansion in (even) terms:

$$L_{eff} = \underset{\text{(tree)}}{L^{(2)}} + \underset{\text{(1-loop)}}{L^{(4)}} + \underset{\text{(2-loop)}}{L^{(6)}} + \cdots$$

Colangelo et al. in 2001, using ChPT (2-loop) & Roy equations:

$$\left.\begin{aligned} a_0 &= 0.220 \pm 2.3\% \\ a_2 &= -0.0444 \pm 2.3\% \end{aligned}\right\} \quad a_0 - a_2 = 0.265 \pm 1.5\%$$

These results (precision) depend on the low-energy constants (LEC) l_3 and l_4:
Lattice gauge calculations from **2006** provided values for these l_3 and l_4.

Because l_3 and l_4 are sensitive to the quark condensate,
precision measurements of a_0, a_2 are a way
to study the **structure** of the QCD vacuum.