DIRAC

(DImeson Relativistic Atomic Complexes)

FIRST OBSERVATION OF πK ATOM AND ITS LIFETIME MEASUREMENT

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Number of institutes 18   Number of participants 83

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First Observation of πK Atom and its Lifetime Measurement

- Motivation
- Method of $A_{\pi K}$ and $A_{2\pi}$ observation and lifetime measurement
- Preliminary results for $A_{2\pi}$
- Request on 2001 and 2002 for the $A_{2\pi}$ lifetime measurement
- Modification of the DIRAC setup for first $A_{\pi K}$ observation and for its lifetime measurement
- Time scale and cost estimation for the $A_{\pi K}$ experiment

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$\pi\pi$ scattering

$m_u, m_d \neq 0$

- $\mathcal{L}_{QCD}$ is noninvariant under chiral $SU(2)_L \times SU(2)_R$ transformations

$\mathcal{L}_{QCD} = \mathcal{L}^{inv} + \mathcal{L}^{noninv}$

- QCD vacuum is noninvariant under chiral transformations $\Rightarrow$ 3 massive pseudo-scalar particles (π^+, π^-, π^0)
- Goldstone nature of these particles $\Rightarrow$ small cross-sections for $\pi\pi$ interaction at low energy

πK scattering

$m_u, m_d, m_s \neq 0$

- $\mathcal{L}_{QCD}$ is noninvariant under chiral $SU(3)_L \times SU(3)_R$ transformations

$\mathcal{L}_{QCD} = \mathcal{L}^{inv} + \mathcal{L}^{noninv}$

- QCD vacuum is noninvariant under chiral transformations $\Rightarrow$ 8 massive pseudo-scalar particles ($\pi^\pm$, π^0, $K^\pm$, K^0, $\overline{K^0}$, η)
- Goldstone nature of these particles $\Rightarrow$ small cross-sections for πK interaction at low energy

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The Goldstone nature of pseudo-scalar mesons implies that their interaction at low energy is weak. These mesons can be studied in the framework of ChPT.

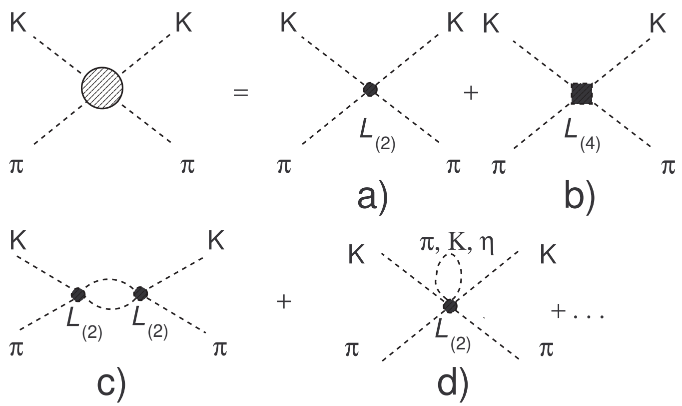
$\Rightarrow$ precise prediction of πK scattering lengths.

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

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

The πK scattering amplitude

Up to now the πK scattering amplitude has been evaluated at next-to-leading order in ChPT



$$\mathcal{L}_{eff} = \mathcal{L}_{(2)} + \mathcal{L}_{(4)},$$
$$A = A_2 + A_4.$$

The πK S-wave scattering lengths with isospin 1/2 and 3/2 are:

$$a_{1/2} = 0.19 \pm 0.02, \quad a_{3/2} = -0.05 \pm 0.02 \ (M_{\pi^+}^{-1}).$$

- V. Bernard, N. Kaiser and U. Meissner, Nucl. Phys. **B357** (1991) 129;
- M. Jamin, J.A. Oller, A. Pich, hep-ph/0006045.

$$a_{1/2} - a_{3/2} = 0.23 \pm 0.01 \quad (M_{\pi^+}^{-1})$$

- A. Roessl, Nucl. Phys. **B555** (1999) 507.

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πK scattering: experimental results

$K^+p \to$	$K^+\pi^-\Delta^{++}$	TRI68,MER71,BIN72,MAT74
	$K^0\pi^0\Delta^{++}$	CHL75,DUN77,BRA77,EST78
	$K^+\pi^+\Delta^0$	DEB69
	$K^0\pi^+p$	BAK75,BAL76,BAL78,MAR78
	$K^+\pi^+n$	DUN77,EST78,BRA77
$K^-p \to$	$K^-\pi^-\Delta^{++}$	KIR71,JON73,LIN73,BRA77,DUN77,EST78
	$K^-\pi^+n$	YUT71,AGU73,FOX74,LAU75,GRA77, SPI77,DUN77,BRA77,EST78
	$K^-\pi^0p$	AGU73,GRA77,SPI77
	$\overline{K}^0\pi^-p$	AGU73,GRA77,SPI77,BAL78,MAR78
$K^+n \to$	$K^+\pi^-p$	FIR72,FOX74,BAK75
	$K^0\pi^+n$	BAK75
$K^-n \to$	$K^-\pi^+p$	BAK70,CHO70,ANT71

$$2 \leqslant E_K \leqslant 13 \text{ GeV}, \quad 750 < M_{\pi K} < 1300 \text{ MeV}$$

Measured πK S-wave scattering lengths for the isospin $I = 1/2$ state

	BIN72	MAT74	FOX74	EST78
$a_{1/2}$	0.168	0.220 ± 0.035	0.280 ± 0.056	0.335 ± 0.006

Measured πK S-wave scattering lengths for the isospin $I = 3/2$ state

	BAK70	CHO70	ANT71	KIR71	JON73	EST78
$a_{3/2}$	-0.085	-0.092	-0.078	-0.096	-0.072	-0.14 ± 0.07

πK scattering lengths determined by using dispersion relations, K-matrix and ChPT

	LAN77	JOH78	KAR80	JAM00	ChPT
$a_{1/2}$	0.237	0.240 ± 0.002	0.13 ± 0.09	0.31	0.19 ± 0.02
$a_{3/2}$	-0.074	-0.05 ± 0.06	-0.13 ± 0.03	-0.12	-0.05 ± 0.02
$a_{1/2} - a_{3/2}$			$0.21 \div 0.32$		0.23 ± 0.01

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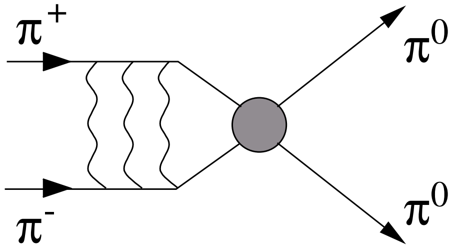
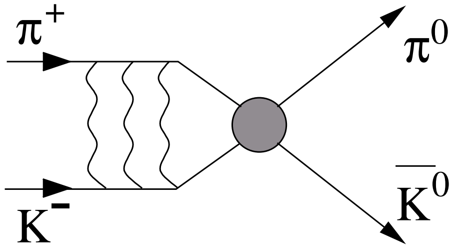
πK atom decay $\Rightarrow$ πK scattering lengths

(model-independent method)

$A_{2\pi}$



$A_{\pi K}$



In leading order of isospin breaking:

$1/\tau_{n,0} \approx C_1(a_0 - a_2)^2 |\Psi_{n,0}(0)|^2$

$\tau_{1,0} = 3.0 \cdot 10^{-15}$ s

$1/\tau_{n,0} \approx C_2(a_{1/2} - a_{3/2})^2 |\Psi_{n,0}(0)|^2$

$\tau_{1,0} = 4.8 \cdot 10^{-15}$ s

$$A_{\pi K}: \qquad \frac{\Delta\tau}{\tau} = 20\% \quad \Rightarrow \quad \frac{\Delta(a_{1/2} - a_{3/2})}{a_{1/2} - a_{3/2}} = 10\%$$

- S. M. Bilenky et al., Sov. J. Nucl. Phys. **10** (1969) 469.

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

$A_{\pi K}$ and $A_{2\pi}$ yields with respect to the $A_{2\pi}$ yield in the present setup ($A_{2\pi} = 1.8 \cdot 10^{-9}$ / p–Ni interaction)

Setup modification	Present setup	Rotated detectors	Both channel and detectors rotated
$A_{2\pi}$	1	0.78	0.14
$A_{\pi^+K^-}$	0.010	0.029	0.032
$A_{K^+\pi^-}$	0.018	0.053	0.058
$A_{\pi^+K^-} + A_{K^+\pi^-}$	0.028		

Yield of $A_{\pi^+K^-}$ as a function of the magnetic field H ($H_0 = 1.65$ T)

H/H_0	1.0	0.9	0.8	0.7	0.6
$A_{\pi K}$	$5.8 \cdot 10^{-11}$	$6.2 \cdot 10^{-11}$	$6.4 \cdot 10^{-11}$	$6.3 \cdot 10^{-11}$	$5.7 \cdot 10^{-11}$

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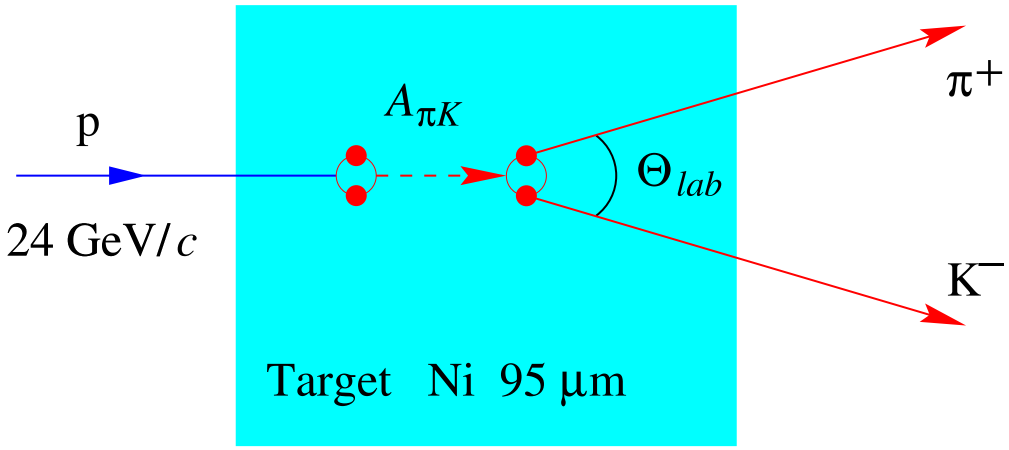
Method of Observation



"Atomic pairs":

$$Q_{c.m.s.} < 3\ \mathrm{MeV}/c, \quad p_{K^-} = \frac{m_K}{m_\pi} p_{\pi^+}, \quad \Theta_{lab} < 3\ \mathrm{mrad}$$

Main features of the DIRAC setup

1. Thin targets: $X_0 \sim 7 \cdot 10^{-3}$, Nuclear efficiency $3 \cdot 10^{-4} \div 5 \cdot 10^{-3}$
2. Vacuum spectrometer
3. Intensive proton beam $\sim 10^{11}$ proton/spill
4. Multilevel trigger

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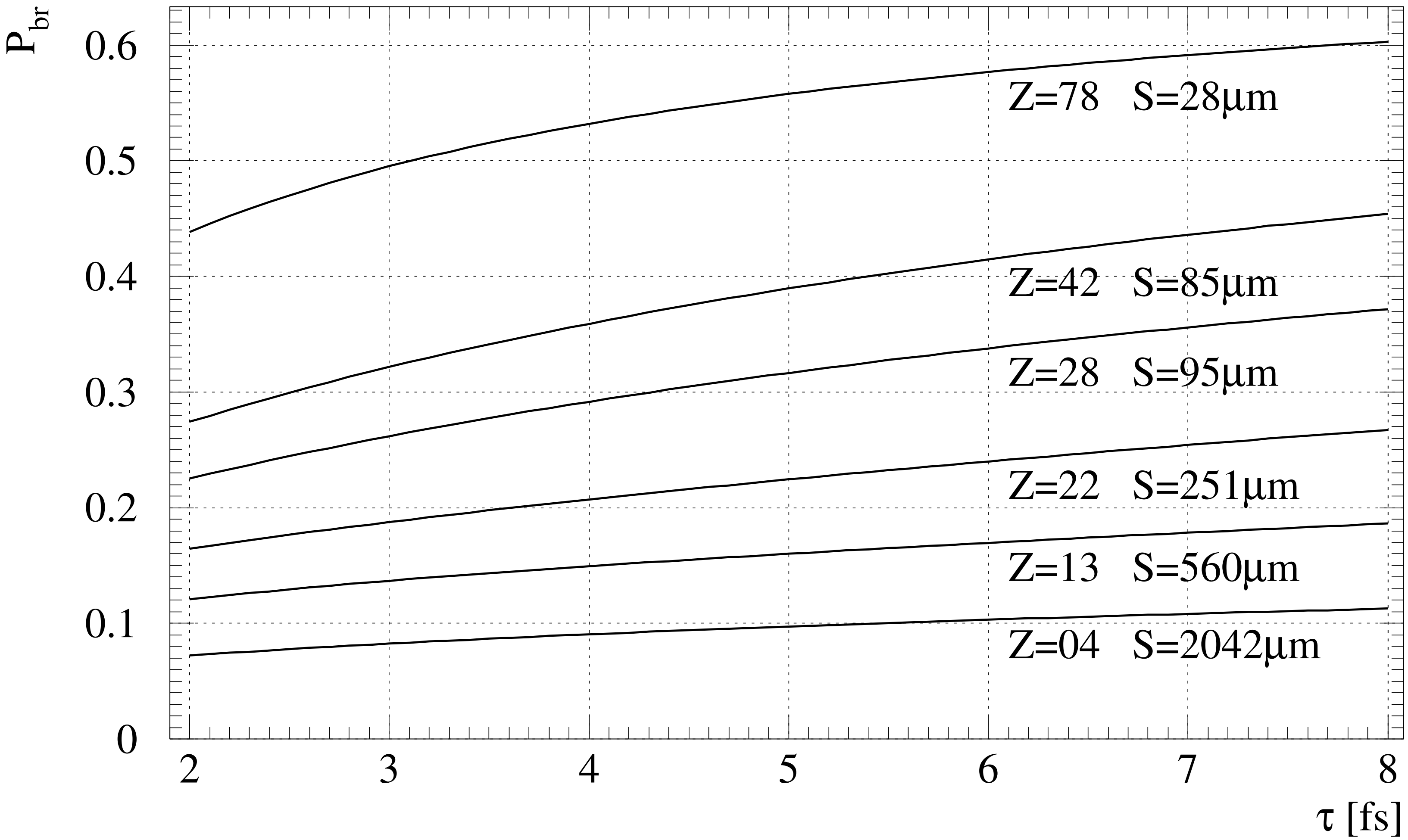
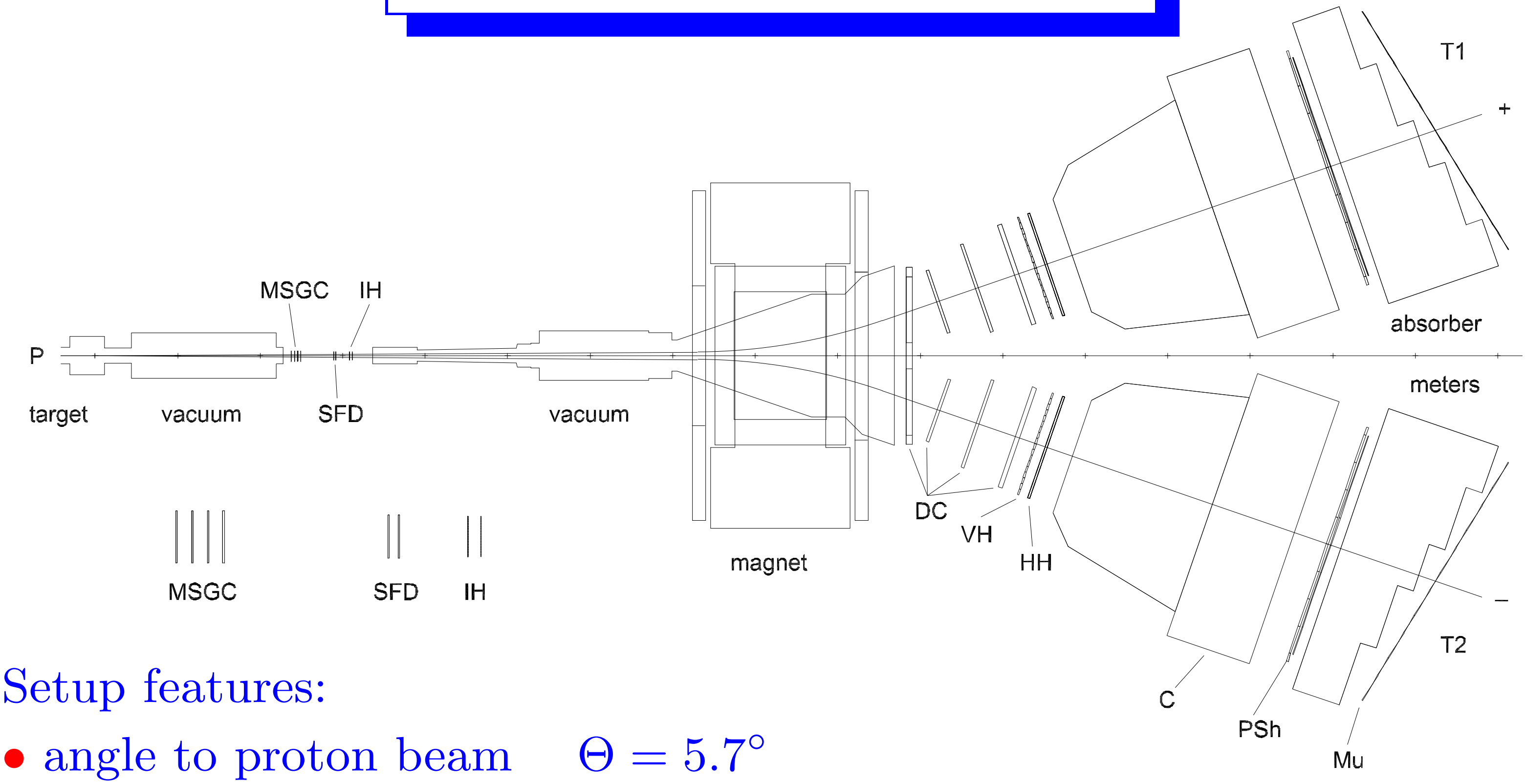
Probability of $A_{\pi K}$ breakup in targets



Present DIRAC setup

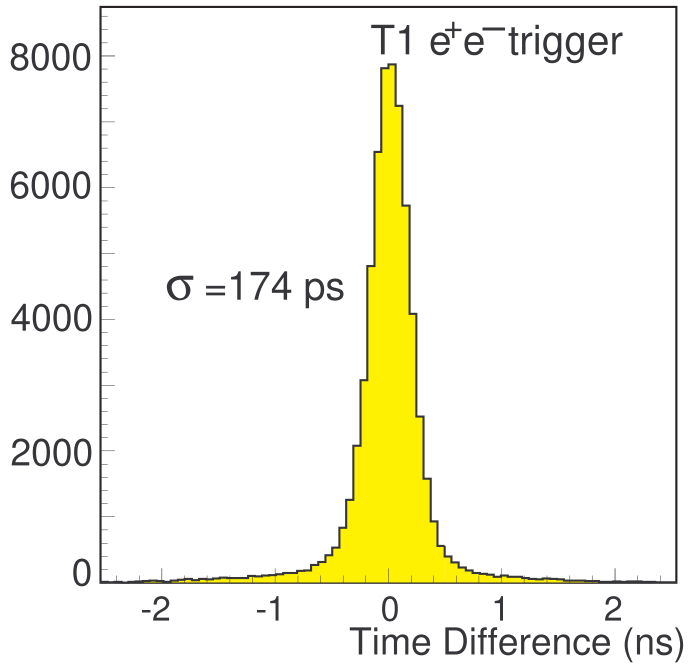


Setup features:

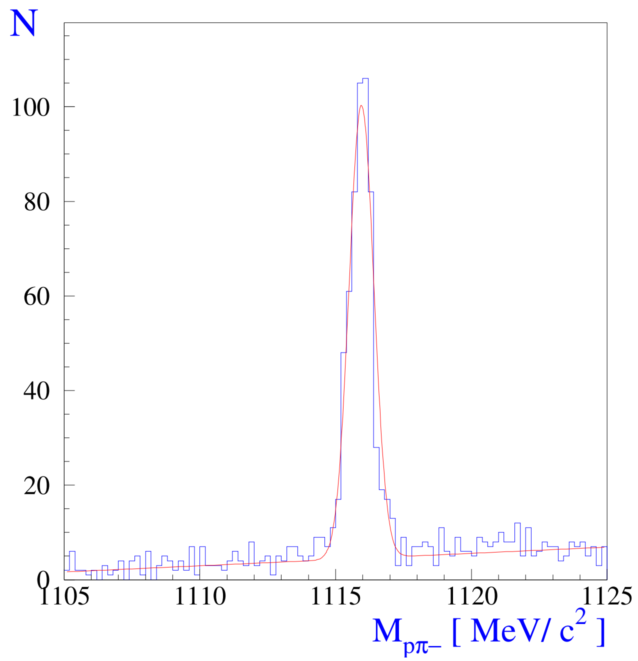
- angle to proton beam $\Theta = 5.7^\circ$
- channel aperture $\Omega = 1.2 \cdot 10^{-3}$ sr
- momentum range $1.2 \leqslant p_\pi \leqslant 7$ GeV/c
- resolution on

relative momentum $\sigma_{Q_\perp} = 0.3$ MeV/c, $\sigma_{Q_L} = 0.6$ MeV/c

Calibration Measurements

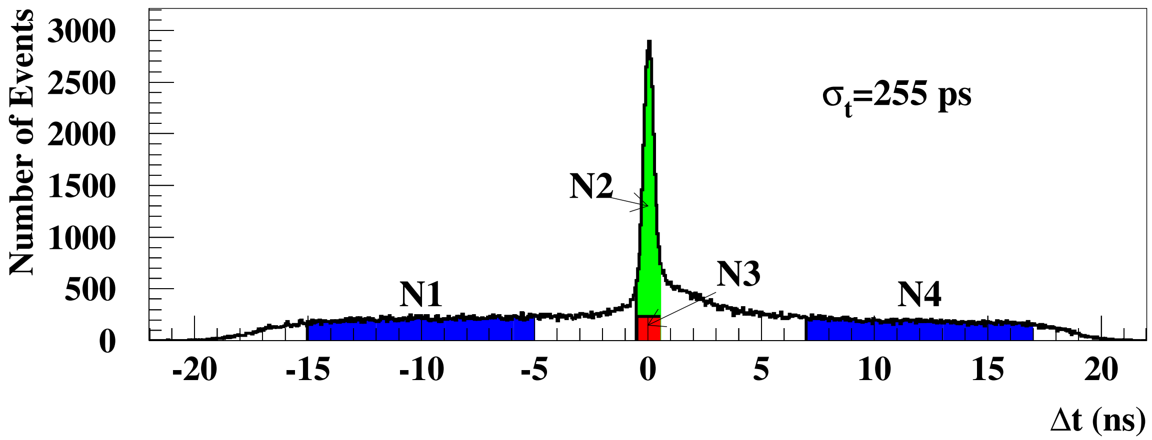


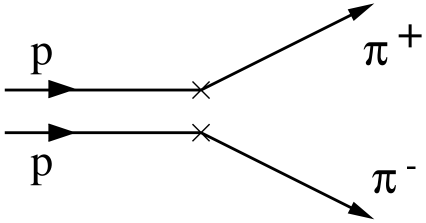
VH time difference spectrum for electron-positron T1 trigger

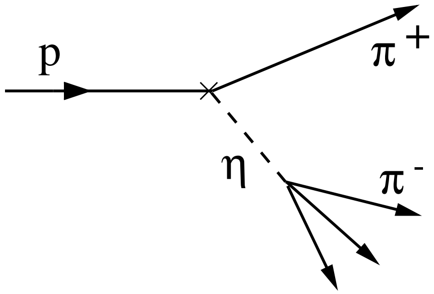


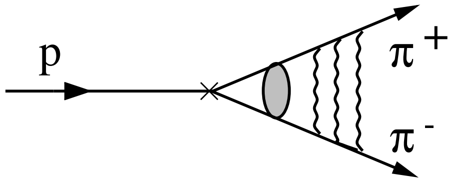
Mass distribution for $p\pi^-$ pairs from Λ decay at $4.7 < p_\Lambda < 6.5$ GeV$/c$; $\sigma_\Lambda = 0.43$ MeV$/c^2$.

- E. Hartouni et al., Phys. Rev. Lett. **72** (1994) 1322: $\sigma_\Lambda = 0.49$ MeV$/c^2$.









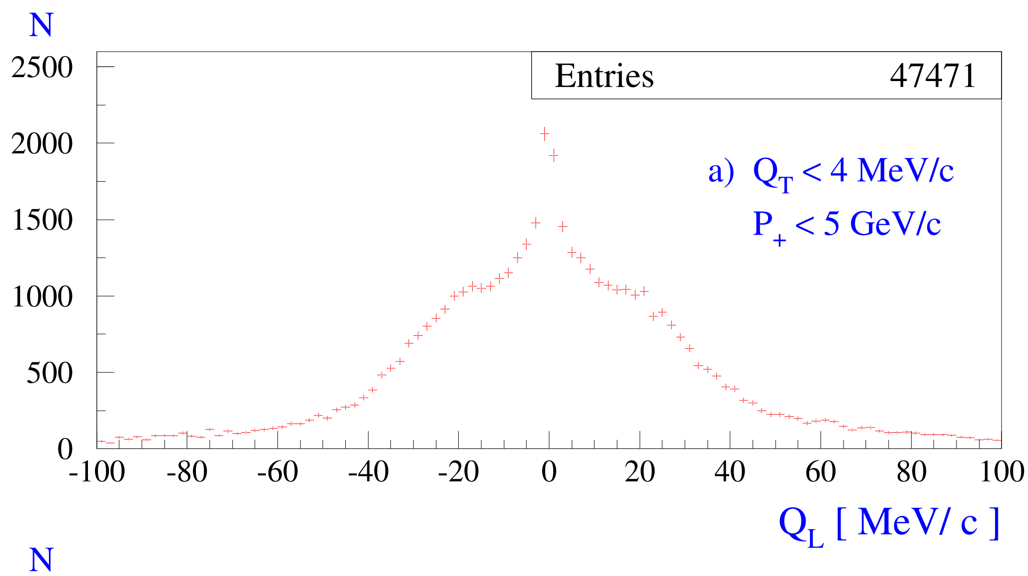
$$\frac{dN_{\rm acc}}{dQ} \propto \Phi(Q) \qquad \frac{dN^{\rm long}_{\rm real}}{dQ} \propto \Phi(Q) \qquad \frac{dN^{\rm short}_{\rm real}}{dQ} \propto \Phi(Q)(1+kQ)A_{\rm C}(Q)$$

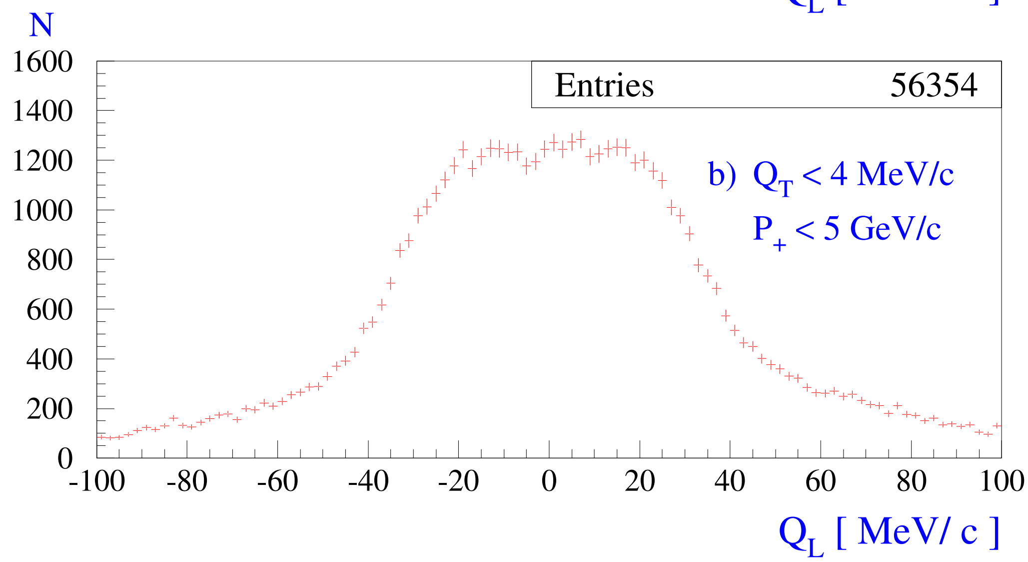
$$\frac{dN_{\rm real}}{dQ} = N\Phi(Q)\left[(1+kQ)A_c(Q)+f\right]$$

$$\frac{dN_{\rm real}/dQ}{dN_{acc}/dQ} \propto (1+kQ)A_c(Q)+f$$

Preliminary results

Autumn 1999 (Pt)





The event distribution of Q_L

a) for "real" and "accidental" pairs;

b) for "accidental" pairs.

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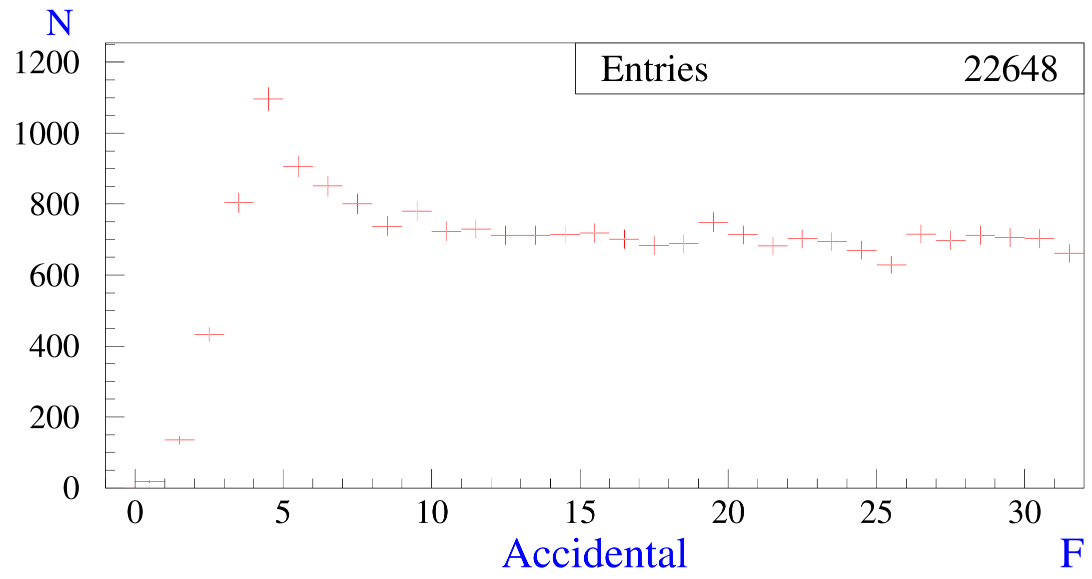
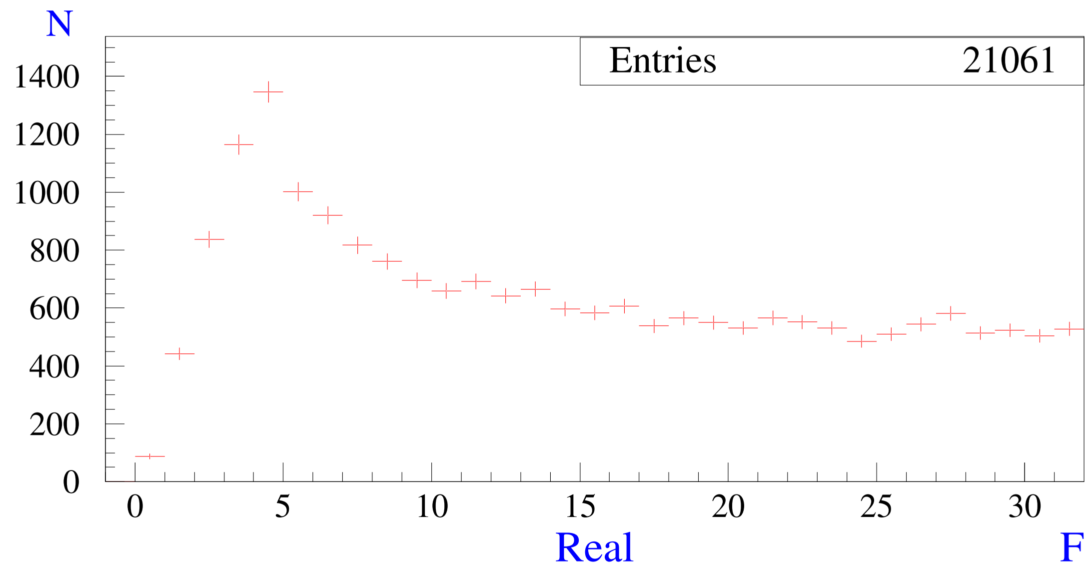
Autumn 1999 (Pt)





The event distributions of F for "accidental" and for "real" pairs.

$$F = \sqrt{\left(\frac{Q_L}{\sigma_{Q_L}}\right)^2 + \left(\frac{Q_X}{\sigma_{Q_X}}\right)^2 + \left(\frac{Q_Y}{\sigma_{Q_Y}}\right)^2}.$$

$\sigma_{Q_L} = 0.65$ MeV$/c$, $\sigma_{Q_X} = \sigma_{Q_Y} = 1$ MeV$/c$.

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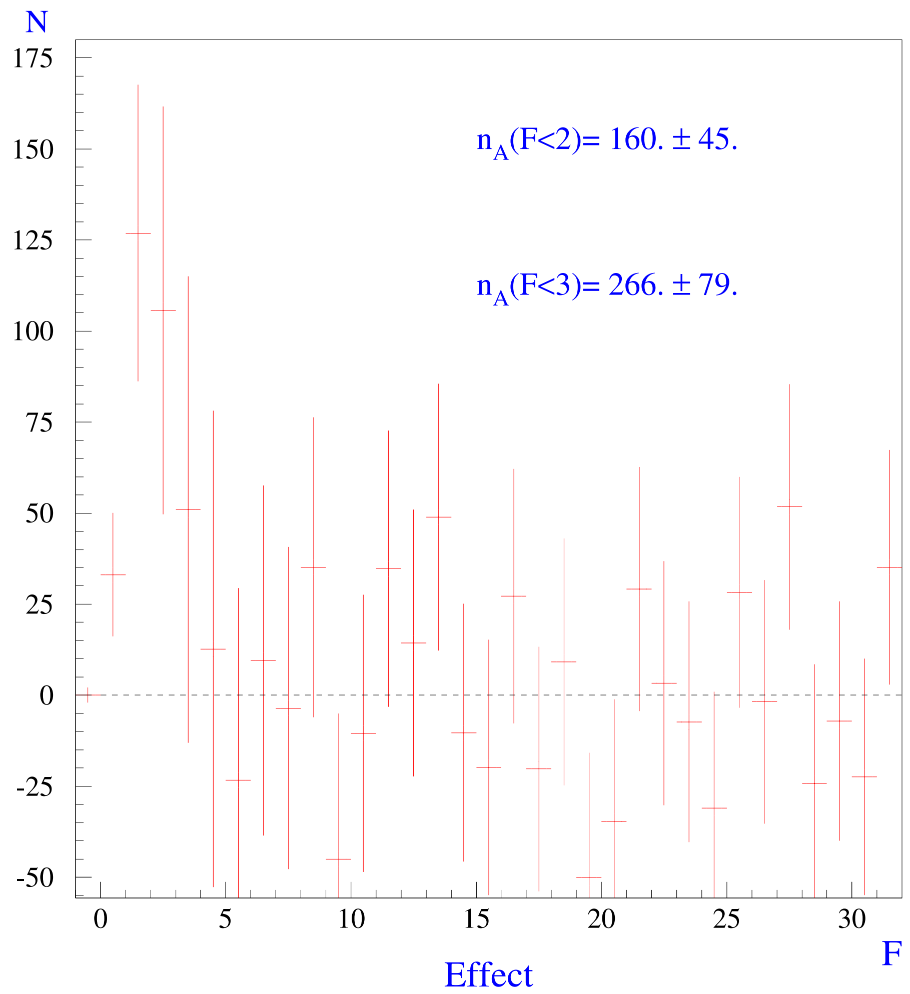
Autumn 1999 (Pt)



The difference between the experimental distribution dN_{real}/dF and the approximation function $A(F)$, describing the contribution of pairs from free states.

Expected results for $A_{2\pi}$ lifetime measurement in 2000–2002

	Sum. 2000	Aut. 2000	2001	2002
Intensity (p/spill)	10^{11}	$\geqslant 10^{11}$	$\geqslant 1.3 \cdot 10^{11}$	$\geqslant 1.3 \cdot 10^{11}$
n_A/day(20h, 1spill)	23	23	26	26
$\tau_{supercycle}$	14.4 s	14.4 s	16.8 s	16.8 s
N_{spills}	1 or 2 or 3	2	3	3
Exposition	56 days	56 days	5.5(6.5) months	5.5(6.5) months
n_A (Ni)	2000	2500	13000	13000
$\sum n_A$(Ni)	4500 ± 320		13000 ± 500	13000 ± 500
$\Delta P_{br} / P_{br}$	$8 \cdot 10^{-2}$		$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
$\frac{\Delta\tau}{\tau} \left(\frac{\Delta(a_0-a_2)}{a_0-a_2}\right)$	20% (10%)		13% (7%)	13% (7%)

Sources of losses:

- Readout time – 18% → 9%
- Tracking – 25%
- SFD(Y) (without MSGC) – 20%

Improvements:

- Angular distribution of "atomic pairs"
- Collimation and local shielding
- New SFD plane (+20%)

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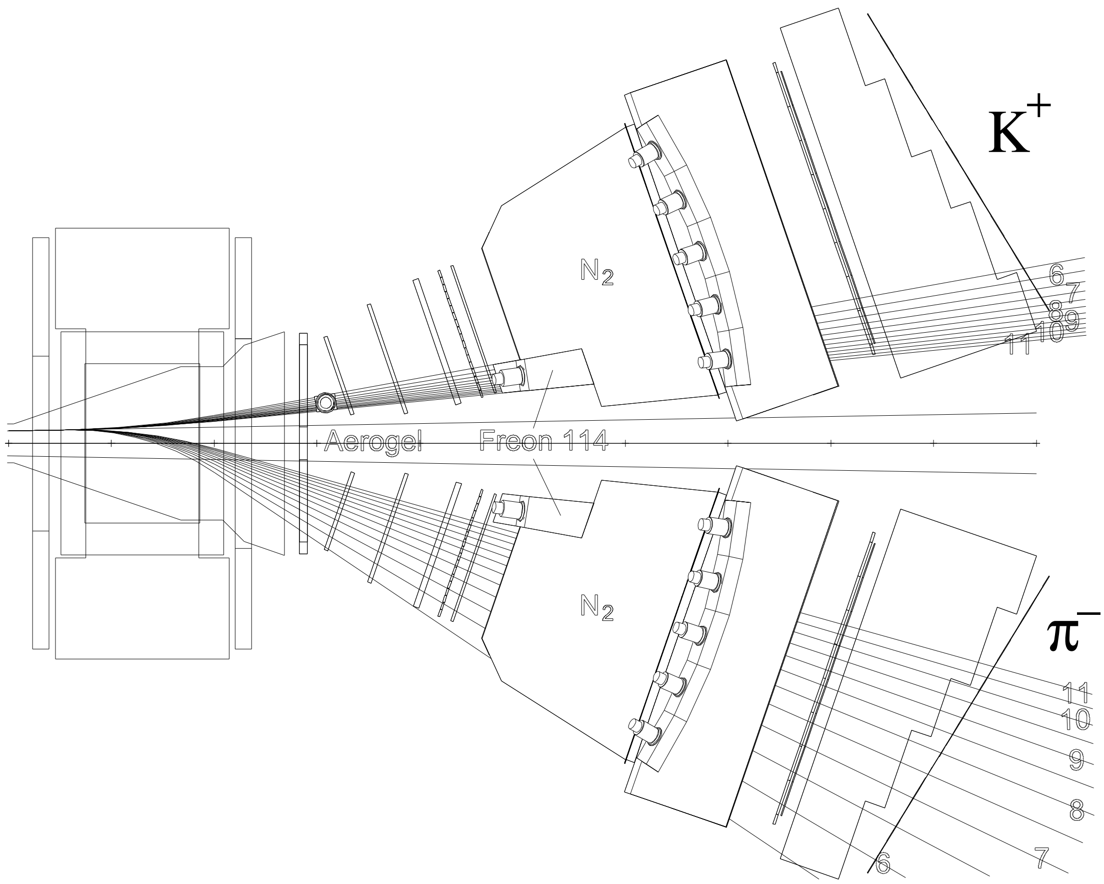
Modifications of the DIRAC setup



Trajectories of π^- and K^+ from the $A_{K^+\pi^-}$ breakup for the existing geometry with Freon 114 Cherenkov counter and with Silica Aerogel threshold Cherenkov detector. The labels on the trajectory lines are the $A_{K^+\pi^-}$ momenta in GeV/c.

Expected results for $A_{\pi K}$ lifetime measurement

- Intensity $2 \cdot 10^{11}$ p/spill, $\tau_{supercycle} = 16.8$ s, $N_{spills} = 3$.
- Exposition (data taking / full time): 3.5/6.5 months in 2003,
  5.5/6.5 months in 2004,
  5.5/6.5 months in 2005.

	Present geometry	Modified geometry
	$n_{A_{\pi^+K^-}} + n_{A_{K^+\pi^-}}$	$n_{A_{K^+\pi^-}}$
	2500 ± 220	5300 ± 320
$\Delta P_{br} / P_{br}$	10%	7%
$\frac{\Delta\tau}{\tau}\left(\frac{\Delta(a_{1/2}-a_{3/2})}{a_{1/2}-a_{3/2}}\right)$	30% (15%)	20% (10%)

Improvements:

- Optimisation of the data processing
- Angular distribution of "atomic pairs"
- Collimation and local shielding

Time scale for the $A_{\pi K}$ experiment

2002	Completion of data taking started in 2001 for 10% precise $A_{2\pi}$ lifetime measurement with present geometry.
	Installation of the Cherenkov counters (aerogel and Freon 114) and the third scintillating fibre plane.
	The setup tuning for observation of $A_{\pi K}$.
2003	Installation of the fourth plane SFD and one of the precise coordinate detectors upstream the magnet.
	Data taking for the $A_{\pi K}$ observation.
2004 – 2005	Modification of the setup geometry.
	Measurement of $A_{\pi K}$ lifetime with 20% precision.

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Cost estimation

Detectors upstream the magnet:

• MSGC upgrade	120 kCHF	OR
• Double-sided silicon microstrip detector	80 kCHF	OR
• Micro Drift Chambers	50 kCHF	OR
• SFD upgrade	345 kCHF	

Detectors downstream the magnet:

• Freon 114 detectors	50 kCHF
• Silica aerogel detector	15 kCHF