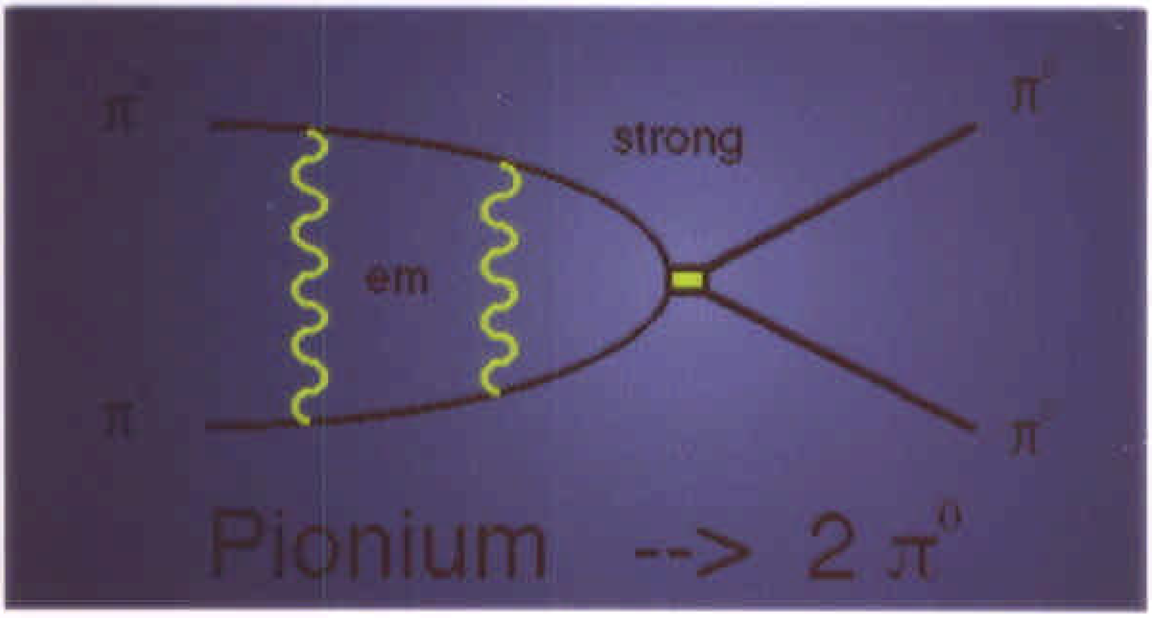
DIRAC EXPERIMENT AT CERN

LIFE TIME MEASUREMENT OF $\pi^+\pi^-$ ATOMS TO TEST LOW ENERGY QCD PREDICTIONS

(Status Report)



- Introduction
- Measurement of Dimeson Atoms $A_{2\pi}$ lifetime of $\mathcal{O}$(femtoseconds) and its implications
- The DIRAC magnetic double arm spectrometer (PS-212)
- Preliminary results from 1999 data analysis

30 th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

Osaka, Japan, 27 July - 2 August 2000

Armando Lanaro on behalf of DIRAC Collaboration

INTRODUCTION

Bound states of 2 strongly interacting particles ($\pi\pi$, πK, πN, KN,...) are a source of model independent data for testing QCD predictions at low energy.

The $A_{\pi^+\pi^-}$ is a weakly-bound Coulomb system. The involved "dynamical scales" (i.e.: m_π, Q, E_b) are small compared to the typical hadronic scale ($\sim 1GeV$)

⇩

$\chi\mathcal{L}$ + e.m.

If $\chi\mathcal{L}$ were to fulfill $\chi S \Rightarrow$ Goldstone bosons (π) would not interact at "zero energy":

$$a_0^{I=0}, a_0^{I=2} \longrightarrow 0$$

but $m_q \neq 0 \Longrightarrow$ explicit $\chi SB \Longrightarrow m_\pi \neq 0,\ a_0^{0,2} \neq 0$

a_0^0, a_0^2 measure the extent of χSB introduced by non vanishing quark masses

Theoretical progress in the calculation of $\Delta = |a_0^0 - a_0^2|$

In χPT the Effective Lagrangian which describes the interaction between pions is an expansion in (even) terms:

$$\mathcal{L}_{eff} = \mathcal{L}^{(2)} + \mathcal{L}^{(4)} + \mathcal{L}^{(6)} + \ldots$$

1966 Weinberg: $\mathcal{L}^{(2)} \longrightarrow \Delta = 0.20\ m_\pi^{-1}$
Phys. Rev. Lett 17 (1966) 616

1984 Gasser-Leutwyler: $\mathcal{L}^{(4)}_{1-loop} \longrightarrow \Delta = 0.25 \pm 0.01\ m_\pi^{-1}$
Ann. Phys. 158(1984) 142

1995 M.Knecht et al.
Nucl. Phys. B457 (1995) 513

1996 J.Bijnens et al. : $\mathcal{L}^{(6)}_{2-loops} \longrightarrow \Delta = 0.258 \pm < 3\%\ m_\pi^{-1}$
Phys. Lett. B374 (1996) 210 $a_0^0 = 0.217\ m_\pi^{-1}$

Experimental Status

- $K^+ \rightarrow \pi^+ \pi^- e^+ \nu_e$ $a_0^0 = 0.28 \pm 0.05\ m_\pi^{-1}$

Model independent (L. Rosselet et al. Phys. Rev. D (1977) 574)

New measurement at BNL (E865) $a_0^0 = 0.229 \pm 0.036\ m_\pi^{-1}$

- $\pi N \rightarrow \pi\pi N$ near threshold $a_0^0 = 0.223 \pm 0.025\ m_\pi^{-1}$

Model dependent (M. Kermani et al. Phys. Rev C58 (1998) 3431)

DIRAC

(DImeson Relativistic Atomic Complex)

collaboration

Basel Univ., Bern Univ., Bucharest IAP, CERN, Dubna JINR, Frascati LNF-INFN, Kyoto-Sangyo Univ., Kyushu Univ. Fukuoka, Moscow NPI, Osaka City Univ., Paris VI Univ., Prague TU, Prague FZU-IP ASCR, Prague UK MFF, Protvino IHEP, Santiago de Compostela Univ., Trieste Univ.-INFN, Tsukuba KEK, Waseda Univ.

Number of institutes 19 Number of participants 85

our aim:

To measure the lifetime, τ, of $\pi^+\pi^-$ atoms with 10% precision in order to determine the difference between $\pi\pi$ S-wave scattering lengths, $\Delta = |a_0^0 - a_0^2|$, to 5%, the same level of accuracy as χPT calculations.

$$\frac{1}{\tau} = \Gamma = \underbrace{\frac{2}{9}\alpha^3 p^* (a_0^0 - a_0^2)^2}_{\Gamma_{LO}^{DESER}} (1 + \delta_{NLO})$$

δ_{NLO} ~6%

(J. Gasser et al. Phys. Lett. B 471 (1999) 244)

⬇

$$\frac{\delta\tau}{\tau} = 10\% \rightarrow \frac{\delta\Delta}{\Delta} = 5\%$$

Implications of the DIRAC experimental result

Since the χSB *term of* $\mathcal{L}_{QCD} \propto < 0|\overline{q}q|0 >$, *the measurement will submit the concept of* χSB *and our understanding of the QCD vacuum structure to a crucial test.*

- *If* $(a_0^0 - a_0^2)^{exp} = (a_0^0 - a_0^2)^{th}$ *from* $S\chi PT$:

$$< 0|\overline{q}q|0 > \simeq -(250 MeV)^3 \quad large!$$

the linear term provide the dominant contribution to the meson mass expansion

$$m_\pi^2 = \mathbf{B}(m_u + m_d) + ... \qquad \mathbf{B} =< 0|\overline{q}q|0 > / f_\pi^2.$$

and $\frac{m_s}{m_u+m_d} \simeq 25 \Longrightarrow a_0^0 = 0.206 \div 0.217$ *(NNLO)*

- *If* $(a_0^0 - a_0^2)^{exp} \neq (a_0^0 - a_0^2)^{th}$

$$< 0|\overline{q}q|0 > \backsim -(90 MeV)^3 \quad small!$$

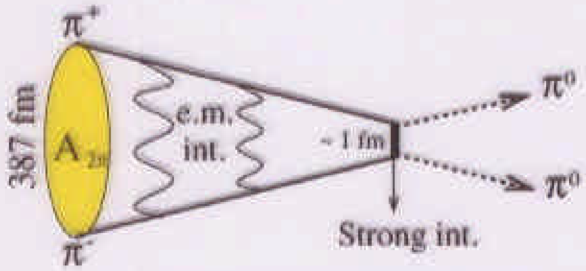
the QCD vacuum is different from what we think $\Rightarrow G\chi PT$

$$m_\pi^2 = \mathbf{B}(m_u + m_d) + \mathbf{A}(m_u + m_d)^2 + ...$$

and $\frac{m_s}{m_u+m_d} < 10 \Longrightarrow a_0^0 \geq 0.27$ *(NNLO)*

Dimeson atoms ($A_{2\pi}$) production and detection

$A_{2\pi}$ features



π^+ and π^- form a weakly-bound atom:

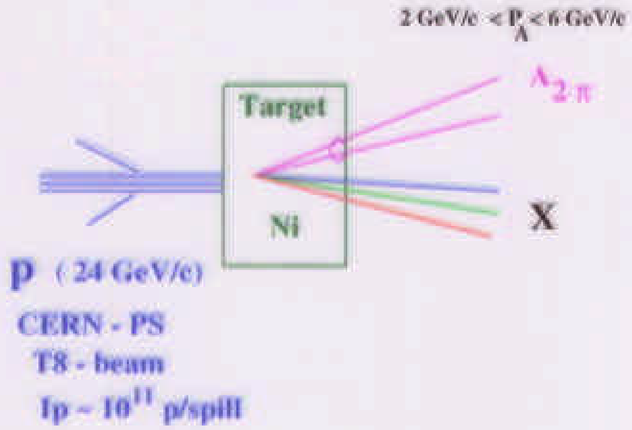
$$E_b = -1.86\ keV \qquad J^{PC} = 0^{++}$$
$$r_B = 387\ fm \qquad p_B \sim 0.5\ MeV/c$$

which decays by strong interaction:

$$\boxed{\tau \approx 3.25 \cdot 10^{-15}\ s}$$

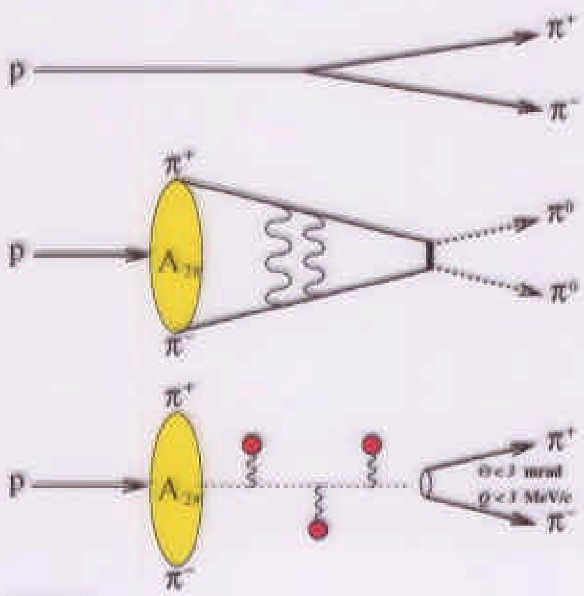
J. Gasser et al. hep-ph/9910438

$A_{2\pi}$ Production



Pionium atoms are produced from Coulomb interaction in the final state when the relative distance between 2 pions is $\sim$ fm.

$A_{2\pi}$ Detection



Enhance $A_{2\pi}$ ionization (breakup)

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

with respect to annihilation

$$A_{2\pi} \rightarrow \pi^0\pi^0$$

using a dense/thin target in which $\lambda_{ann} \sim \lambda_{ion} \sim 20\mu m$. The signature is an excess of $\pi^+\pi^-$ pairs with same quadri-momentum and small opening angle:

$$Q < 3\ MeV/c\ ;\ E_+ \approx E_-;$$
$$\Theta_{lab} < 3\ mrad$$

Lifetime Measurement

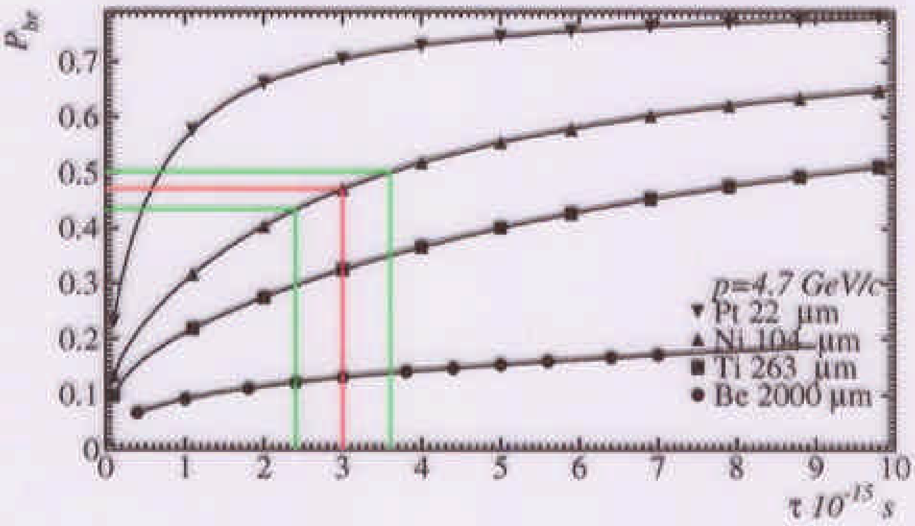
The measurement of $\tau_{A_{2\pi}}$ *will be done by comparison of experimentally observed* P_{ion}^{exp} *with the theoretical value* (P_{ion}^{th}).

$$P_{ion} = \frac{n_a}{N_a} = f(L_{Target}, Z, P_{A_{2\pi}}, \tau_{A_{2\pi}})$$

n_a # *of ionized* $A_{2\pi}$
N_a # *of produced* $A_{2\pi}$

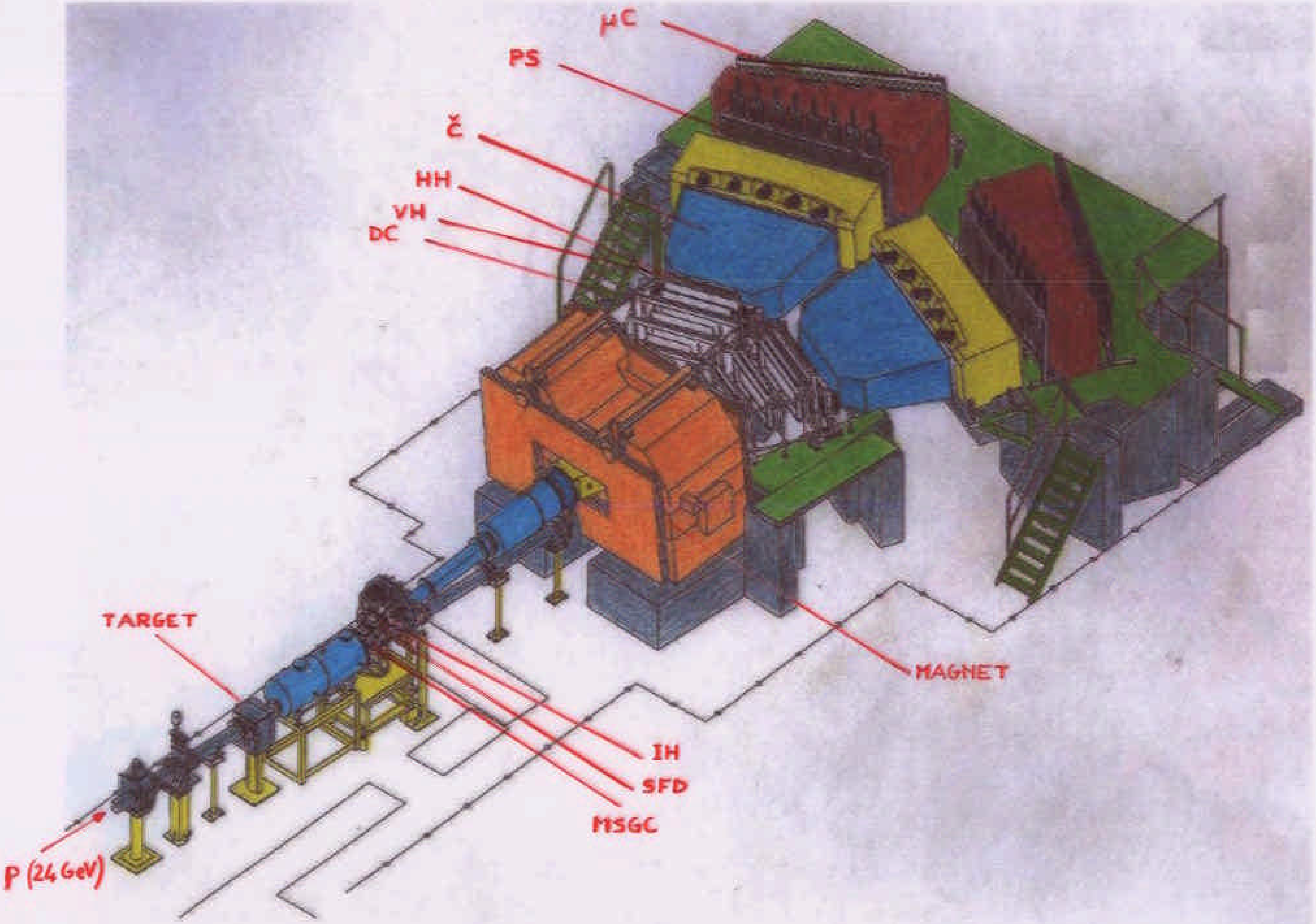
- $P_{ion}^{th} = 1 - (P_{dsc} + P_{ann})$

Probability of $A_{2\pi}$ *breakup in targets* ($\delta_{th} \backsim 1\,\%$)

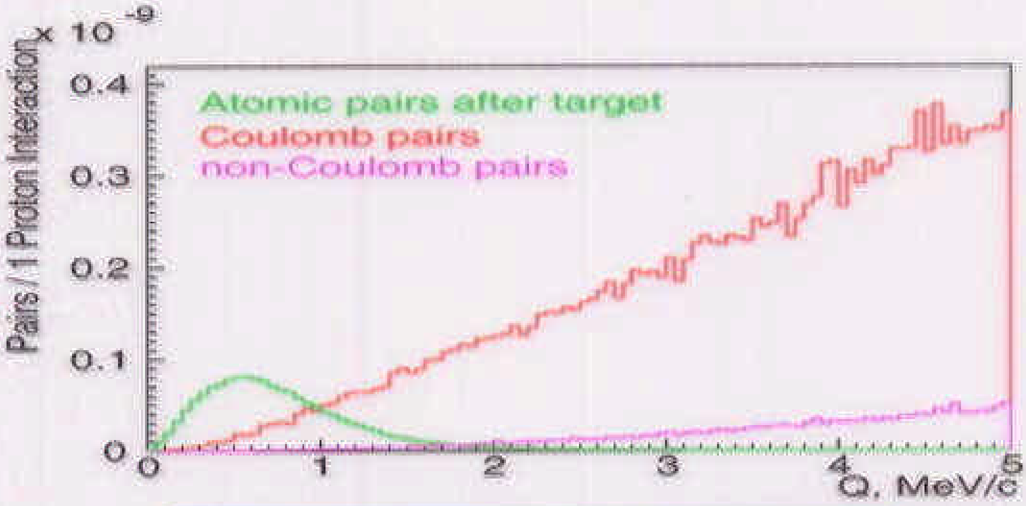


- $P_{ion}^{exp} = \frac{n_a}{N_a}$ — n_a *measured from excess of low-Q* $\pi^+\pi^-$ *pairs;* N_a *calculated from ratio of* $\pi^+\pi^-$ *pairs from discrete and continuum spectrum*

$$P_{ion}^{exp}(\backsim 4\%) \Rightarrow \tau_{A_{2\pi}}(\backsim 10\%) \Rightarrow \Delta(\backsim 5\%)$$


μC
PS
Č
HH
VH
DC
TARGET
MAGNET
IH
SFD
MSGC
P (24 GeV)

PRELIMINARY ANALYSIS RESULTS

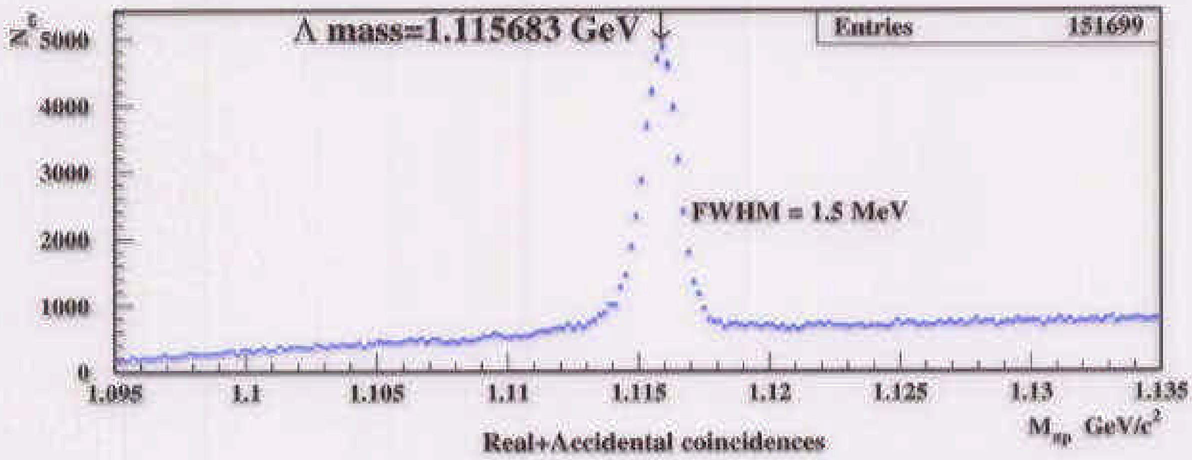


MC Simulation of Q distribution

- *DIRAC data takings:*

RUN	*TARGET*	I_p *(p/spill)*	*TRIGGERS*
Jun-Nov 1999	*Ni* *Pt*	$2 \div 8 \times 10^{10}$ $14 \div 18 \times 10^{10}$	150×10^6 80×10^6
May-Jul 2000	*Ni*	10×10^{10}	200×10^6

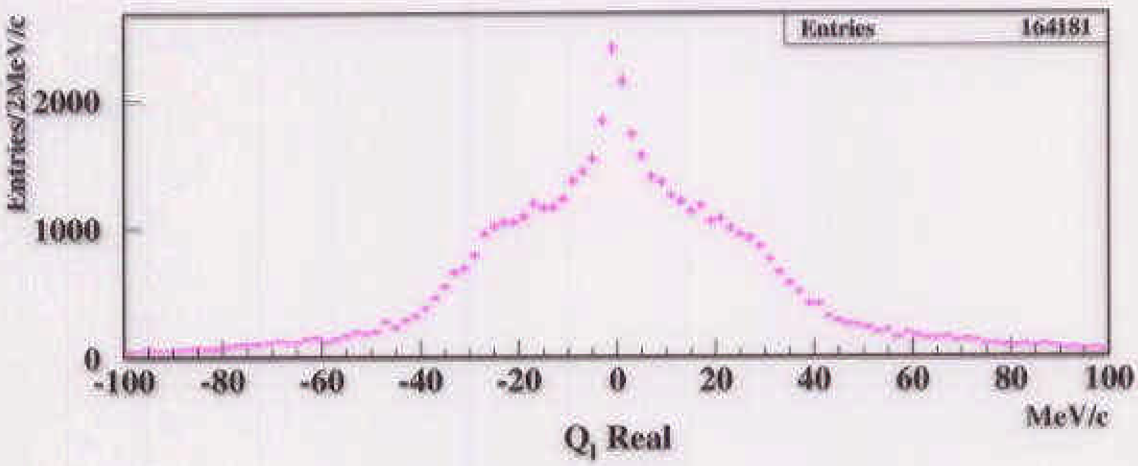
- Λ *decay* $\Rightarrow$ *momentum resolution [Pt (28 μm) - run99]*



Accuracy in mass resolution $\sim$ *1 MeV* $\Rightarrow \frac{\delta p}{p} \leqslant 0.5\%$

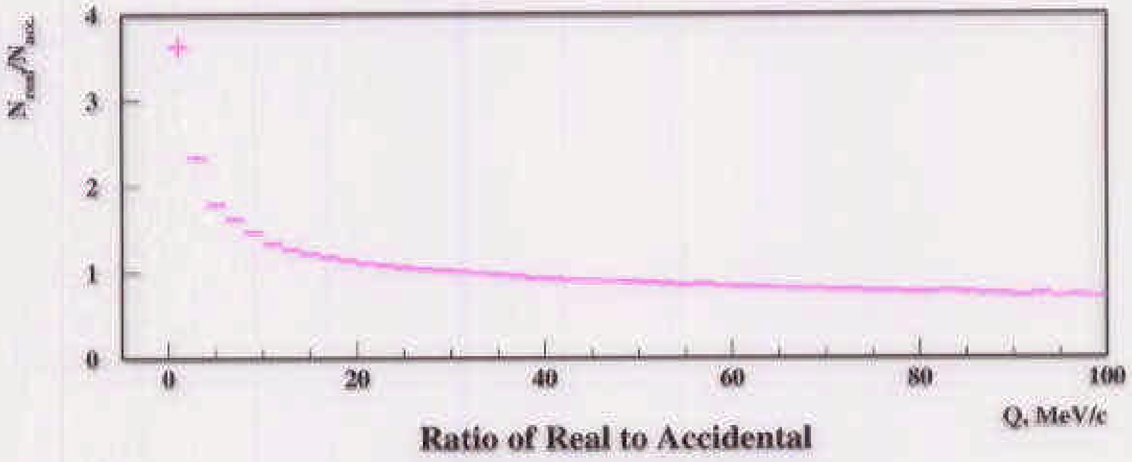
- *Selection of pairs with $Q_T < 4MeV/c$*

Coulomb correlated $\pi^+\pi^-$ pairs



Coulomb correlated $\pi^+\pi^-$ pairs with small $\overrightarrow{Q}$ ($\overrightarrow{P_1} \approx \overrightarrow{P_2}$) are a sensitive tool to control the setup alignment. A misalignment has influence on precision of reconstructed momenta and opening angle of pairs ($< Q_l >= 0.0095MeV/c$).

Coulomb correlation function



The ratio between Q-distributions of correlated and accidental pairs (no FSI) shows at low Q the Coulomb enhancement due to FSI.

SUMMARY AND OUTLOOK

- *DIRAC Commissioning:*
  Fall of 1998

- *Data Takings:*
  From June to November 1999 (16 weeks) using Ni and Pt targets
  In progress since May 2000 using Ni target

- *Data Analysis:*
  A preliminary analysis of 1999 data has shown:
  - ⇒ Good detector performances
  - ⇒ Evidence of Coulomb correlated $\pi^+\pi^-$ pairs

  A new analysis of 1999 and 2000 data is in progress

- *Plans:*
  To measure $\tau_{A_{2\pi}}$ with **20%** accuracy requires $\sim$ 4000 Atomic pairs (year 2000)

  Present yield: $\sim$ 3 Atomic pairs/million triggers

  $\tau_{A_{2\pi}}$ with **10%** accuracy expected in year 2001-2002