DIRAC / PS212

(DImeson Relativistic Atomic Complexes)

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

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Kyushu Univ. Fukuoka, Moscow NPI, Paris VI Univ., Prague TU,
Prague FZU-IP ASCR, Protvino IHEP,
Santiago de Compostela Univ., Tokyo Metropolitan Univ.,
Trieste Univ./INFN, Tsukuba KEK, Waseda Univ.

Number of institutes 19 Number of participants 83

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Outline

- Introduction (time scale, theoretical aspects)
- Method of lifetime measurement and the DIRAC setup
- Observation of $\pi^+\pi^-$ atoms in Pt, Ni and Ti target
- Lifetime measurement and statistical precision (Ni & Ti)
- Setup modifications for 2002
- Conclusion and outlook

Time Scale

• Approved – Preparation:	8 February 1996 – 1998
• Installation – Start:	March – Oct. 1998
• Data taking to observe $A_{2\pi}$ with Ni and Pt targets:	June–Nov. 1999 (4 months)
• Evidence of $A_{2\pi}$ detection (Pt):	Report at SPSC 5/9/2000
• Data taking to measure the $A_{2\pi}$ lifetime within 20%:	May–Nov. 2000 (5 months)
• Data taking $\rightarrow \tau_{A_{2\pi}}$ (10%):	April – Oct. 2001 (3 PS-spills) 2002 (7 months)

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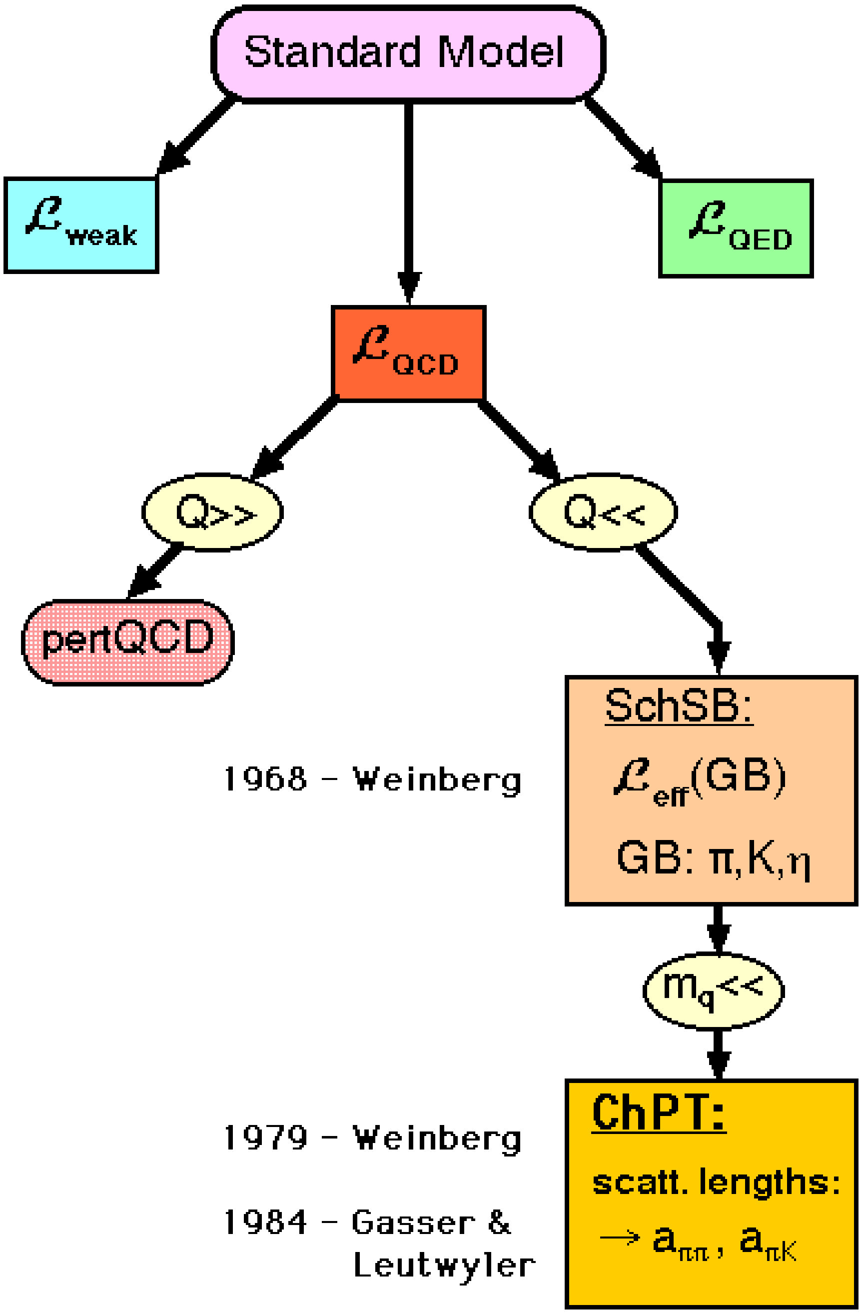
Theoretical motivation



Glossary:

pertQCD : perturbative QCD
SchSB : spontaneous chiral symmetry breaking
GB : Goldstone boson
ChPT : chiral perturbation theory

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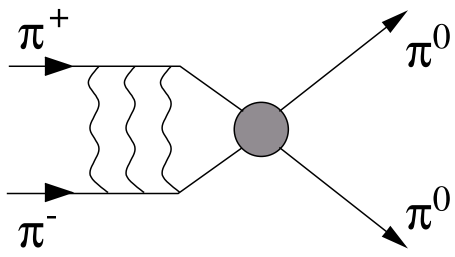

$$1/\tau_n = \Gamma_n^{2\pi^0} + \Gamma_n^{2\gamma}\ (0.36\%) \quad \Longrightarrow \quad \Gamma_n^{2\pi^0} = C\Delta^2|\psi_n|^2, \quad \Delta \doteq (a_0 - a_2):$$

- J. Uretsky and J. Palfrey, PR **121** (1961) 1798.
- S. Bilenky et al., Sov. JNP **10** (1970) 469.

$$\boxed{\delta\tau/\tau = 10\% \quad \Longrightarrow \quad \delta\Delta/\Delta = 5\%}$$

$$\Gamma_n = \Gamma_{l.o.}(1 + \delta_\Gamma):$$

- H. Jallouli and H. Sazdjian, PR D58 (1998) 014011.
- M. Ivanov, V. Lyubovitskij, E. Lipartia, A. Rusetsky, PR D58 (1998) 094024.
- A. Gall, J. Gasser, V. Lyubovitskij, A. Rusetsky, PR D64 (2001) 016008:

$$\delta_\Gamma = (5.8 \pm 1.2)\% \quad \Longrightarrow \quad \tau = (2.9 \pm 0.1) \cdot 10^{-15}\,\mathrm{s}$$

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Progress in calculating $\Delta \doteq (a_0 - a_2)$:

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

$\Longrightarrow$ Workshop on Hadronic Atoms, Oct. 11 - 12 2001, CH-3012 Bern

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$\pi\pi$ scattering and quark condensate

If $(a_0 - a_2)_{\rm exp} = (a_0 - a_2)_{\rm th} \Longrightarrow$ "quark condensate" is LARGE:

$$\langle 0|\bar{u}u|0\rangle = \langle 0|\bar{d}d|0\rangle = \langle 0|\bar{s}s|0\rangle \approx -(250\,\mathrm{MeV})^3, \quad B = \lim_{\hat{m}\to 0} |\langle 0|\bar{u}u|0\rangle|/F_\pi^2$$

$\Longrightarrow m_\pi^2 = 2B\hat{m} + \mathcal{O}(\hat{m})$ with B large, $\quad \hat{m} \doteq (m_u + m_d)/2$

$$\Longrightarrow \frac{m_s}{\hat{m}} \approx 25$$

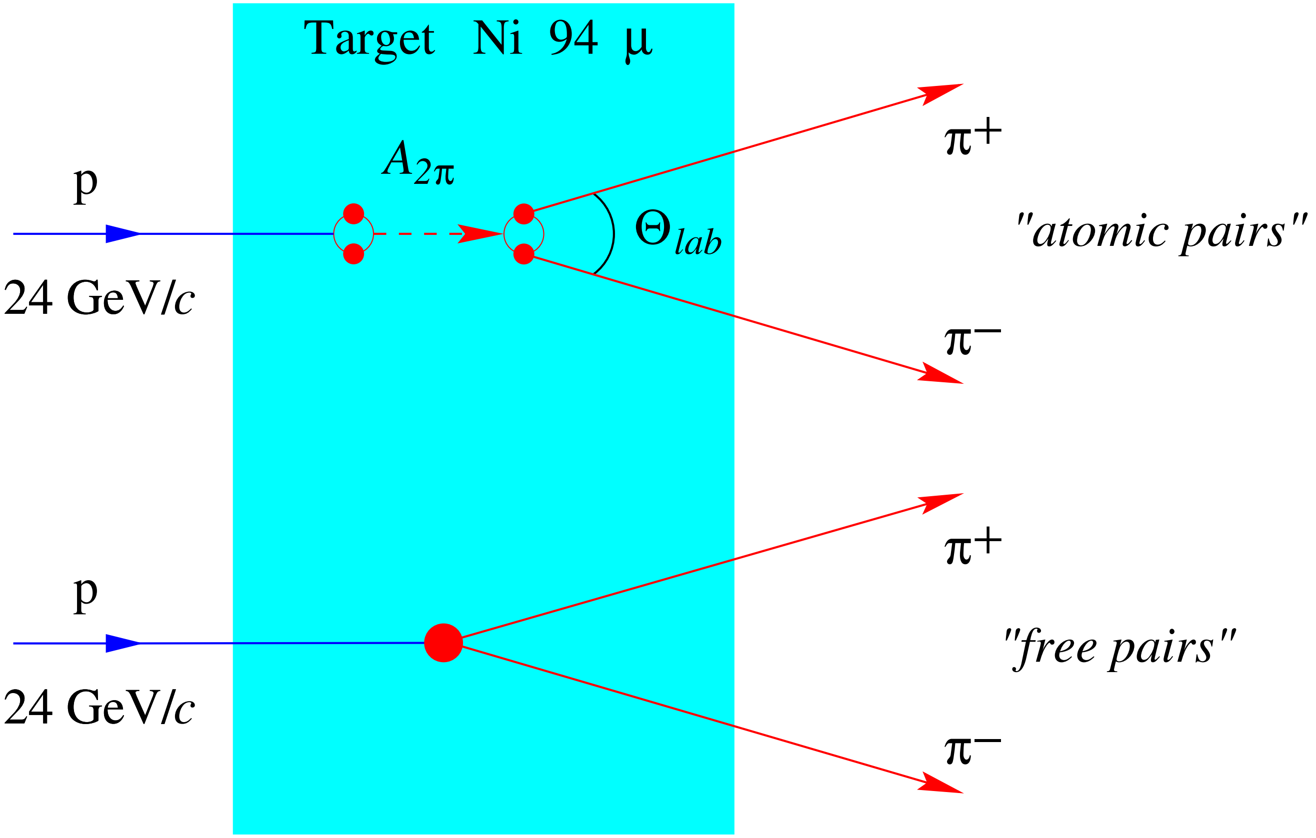
But if $(a_0 - a_2)_{\rm exp} > (a_0 - a_2)_{\rm th} \Longrightarrow$ QCD vacuum is not, what we think [J. Stern et al. 1991, 1995]:

$$\langle 0|\bar{u}u|0\rangle = \langle 0|\bar{d}d|0\rangle = \langle 0|\bar{s}s|0\rangle \approx -(90\,\mathrm{MeV})^3$$

$\Longrightarrow m_\pi^2 = 2B\hat{m} + 4A\hat{m}^2 + \ldots$ with B small

$$\Longrightarrow \frac{m_s}{\hat{m}} < 25$$

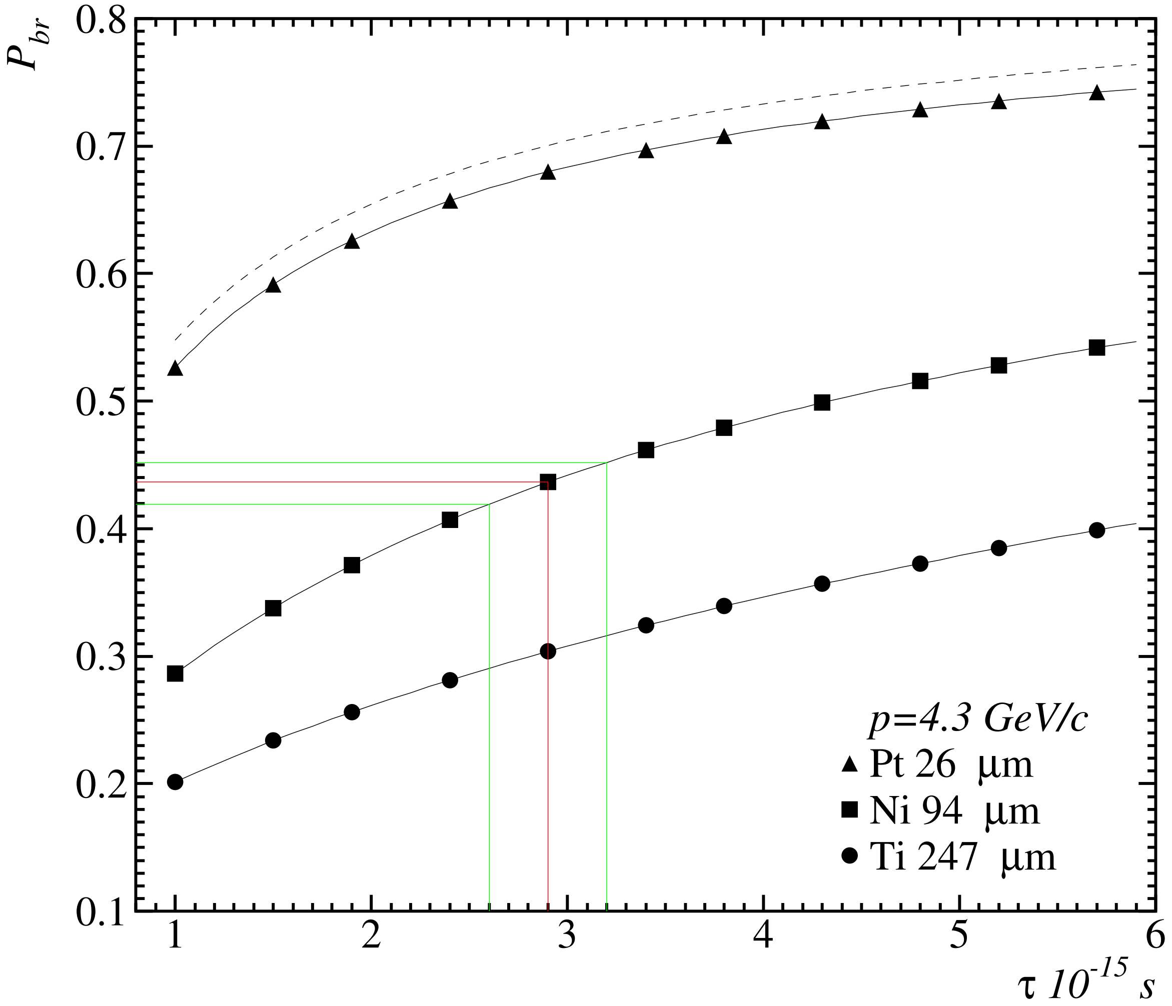
Method of Observation



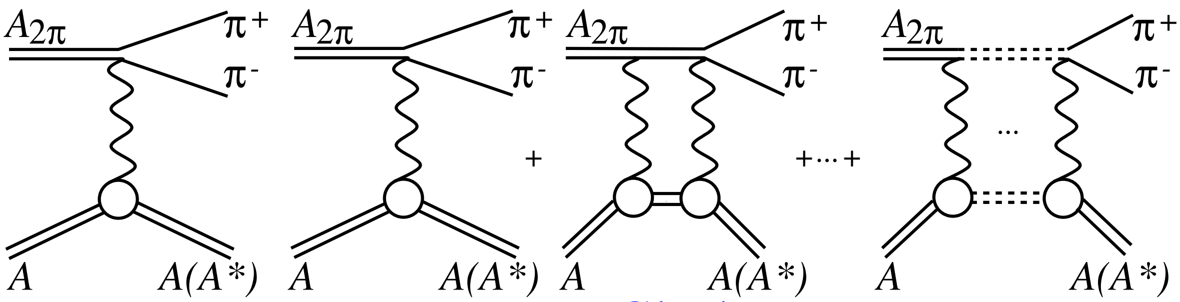
Atomic pairs

cm momentum $Q < 3$ MeV$/c$: $\vec{p}_+ \approx \vec{p}_-$ $\Theta_{lab} < 2.5$ mrad

Probability of $A_{2\pi}$ breakup in targets



$\delta\tau = 10\%$ corresponds to $\delta P_{\rm br} \approx 4\%$



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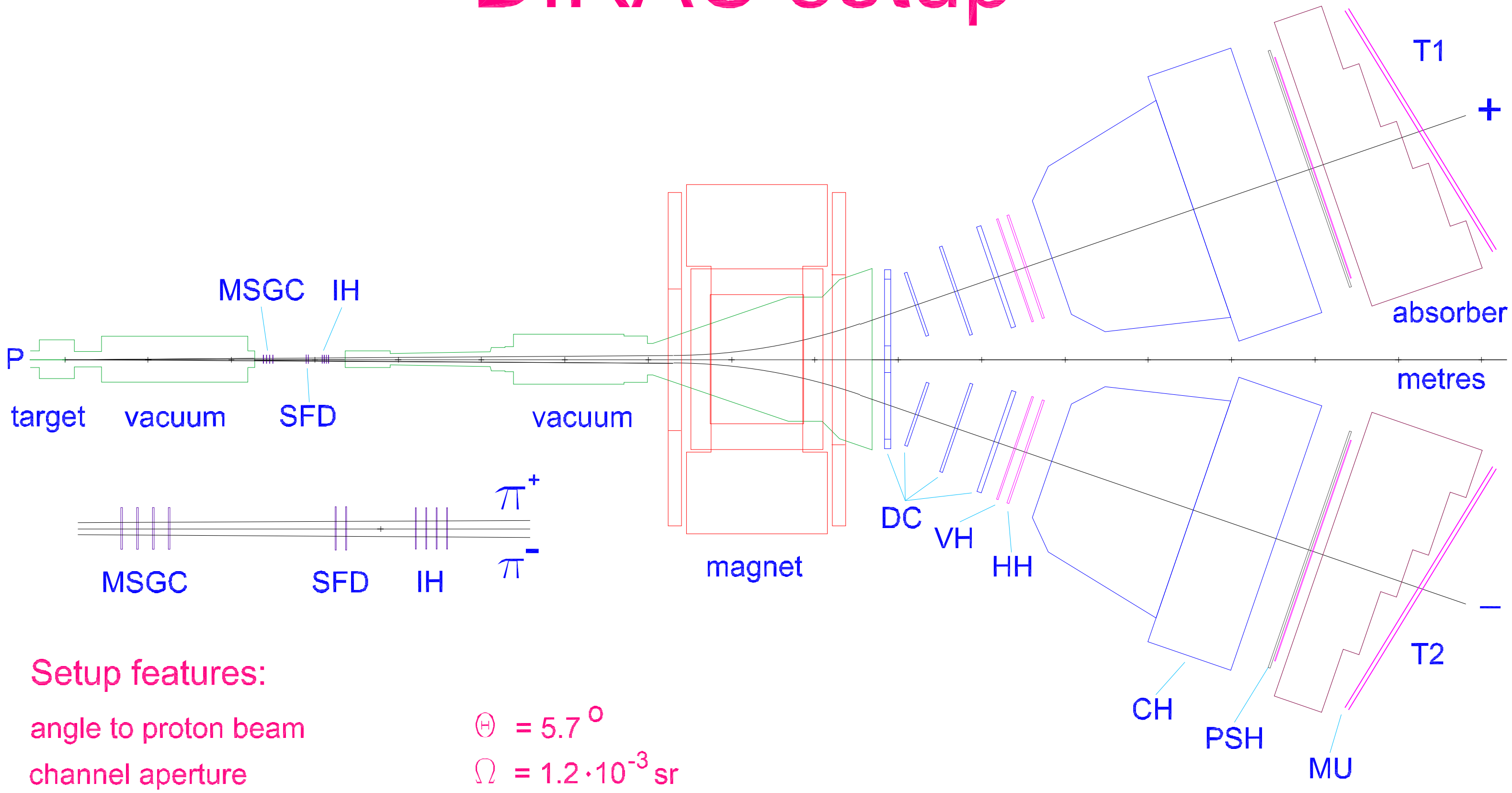
DIRAC setup



Setup features:

angle to proton beam	$\Theta = 5.7^{o}$
channel aperture	$\Omega = 1.2 \cdot 10^{-3}$ sr
momentum range	$1.2 \leqslant p_\pi \leqslant 7$ GeV/c
resolution on relative momentum	$\sigma_{Q_x} = \sigma_{Q_y} =$ 0.4 MeV/c, $\sigma_{Q_L} =$ 0.6 MeV/c

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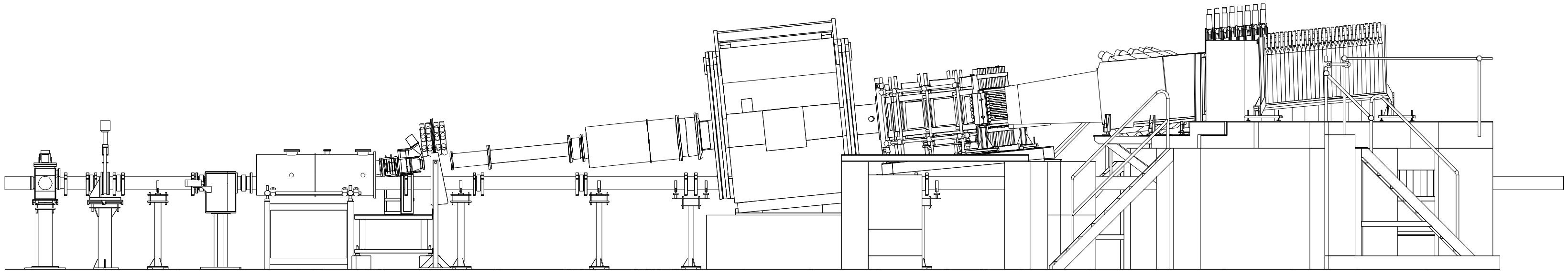
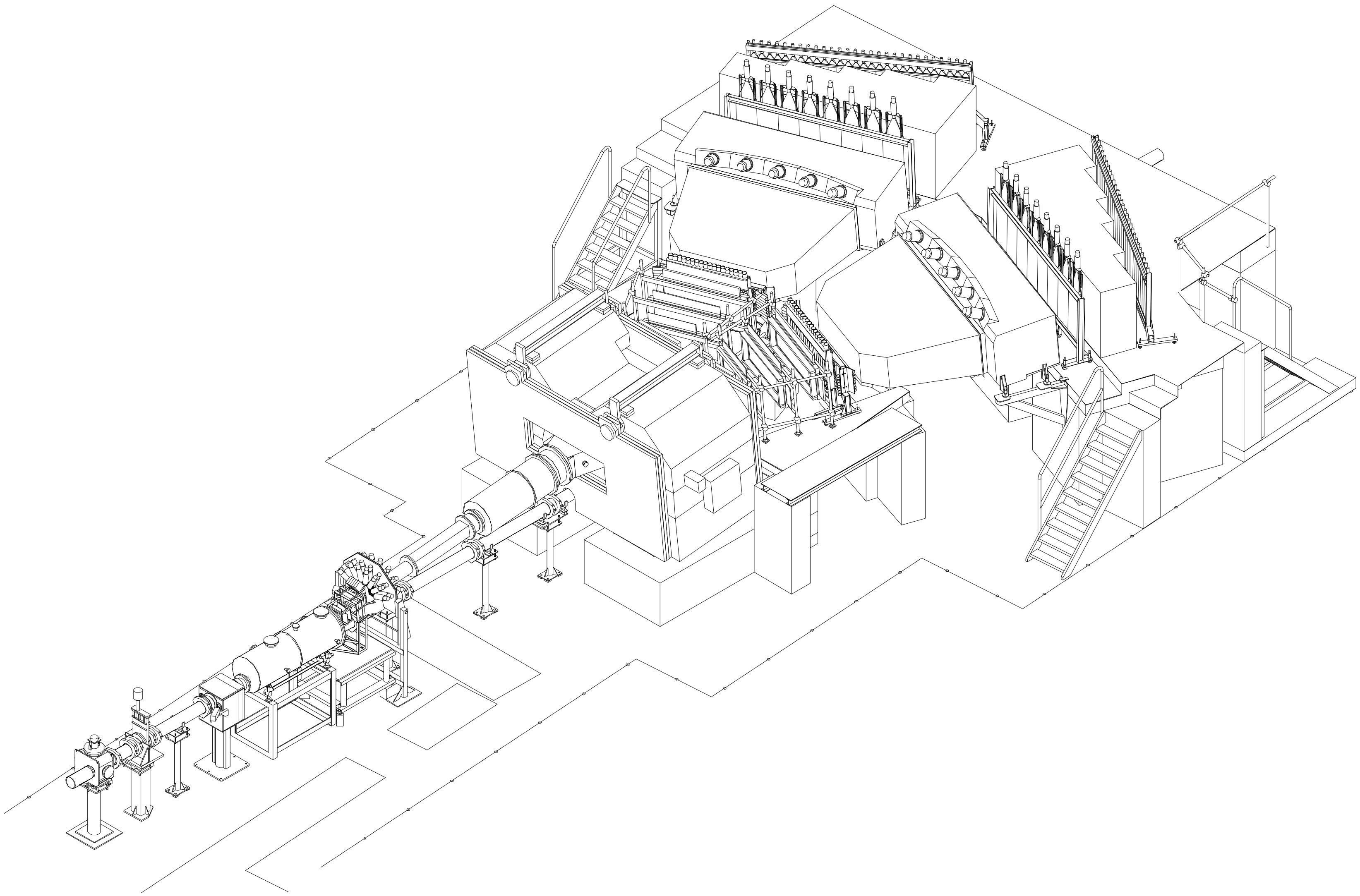
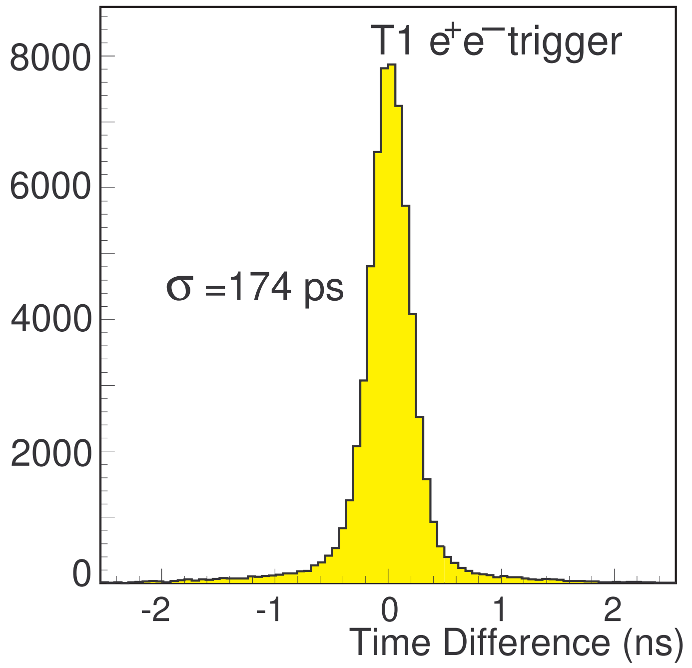
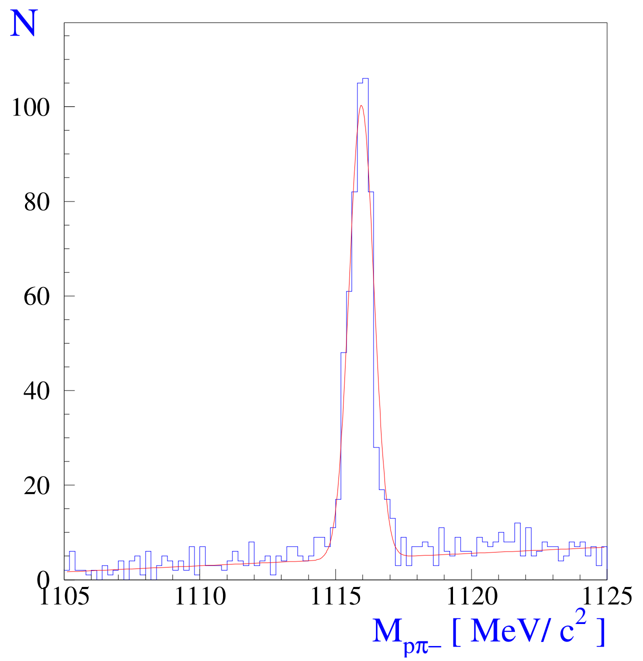




Calibration Measurements



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$/c^2$.

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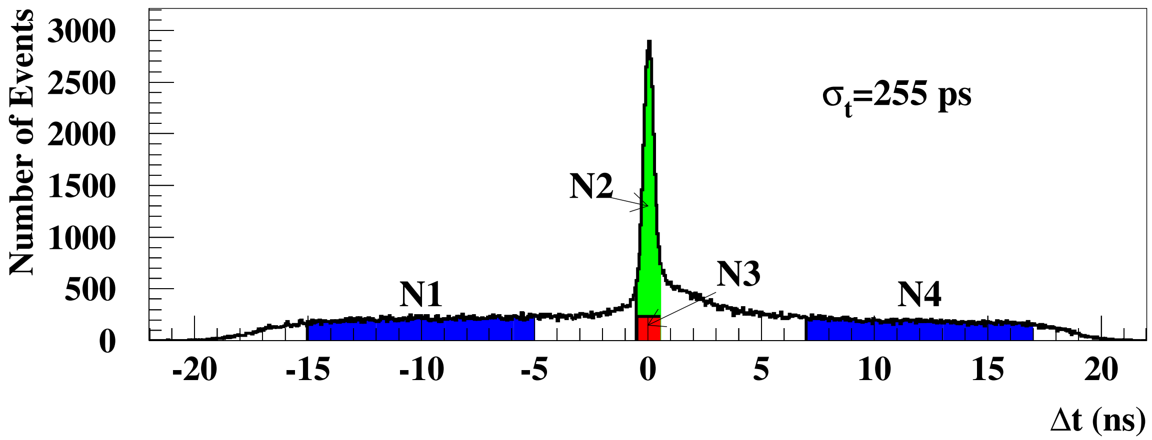
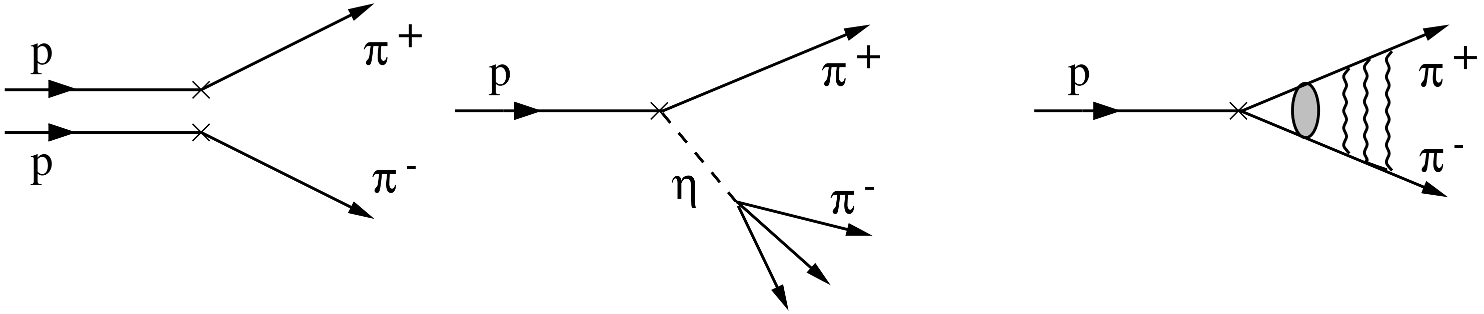




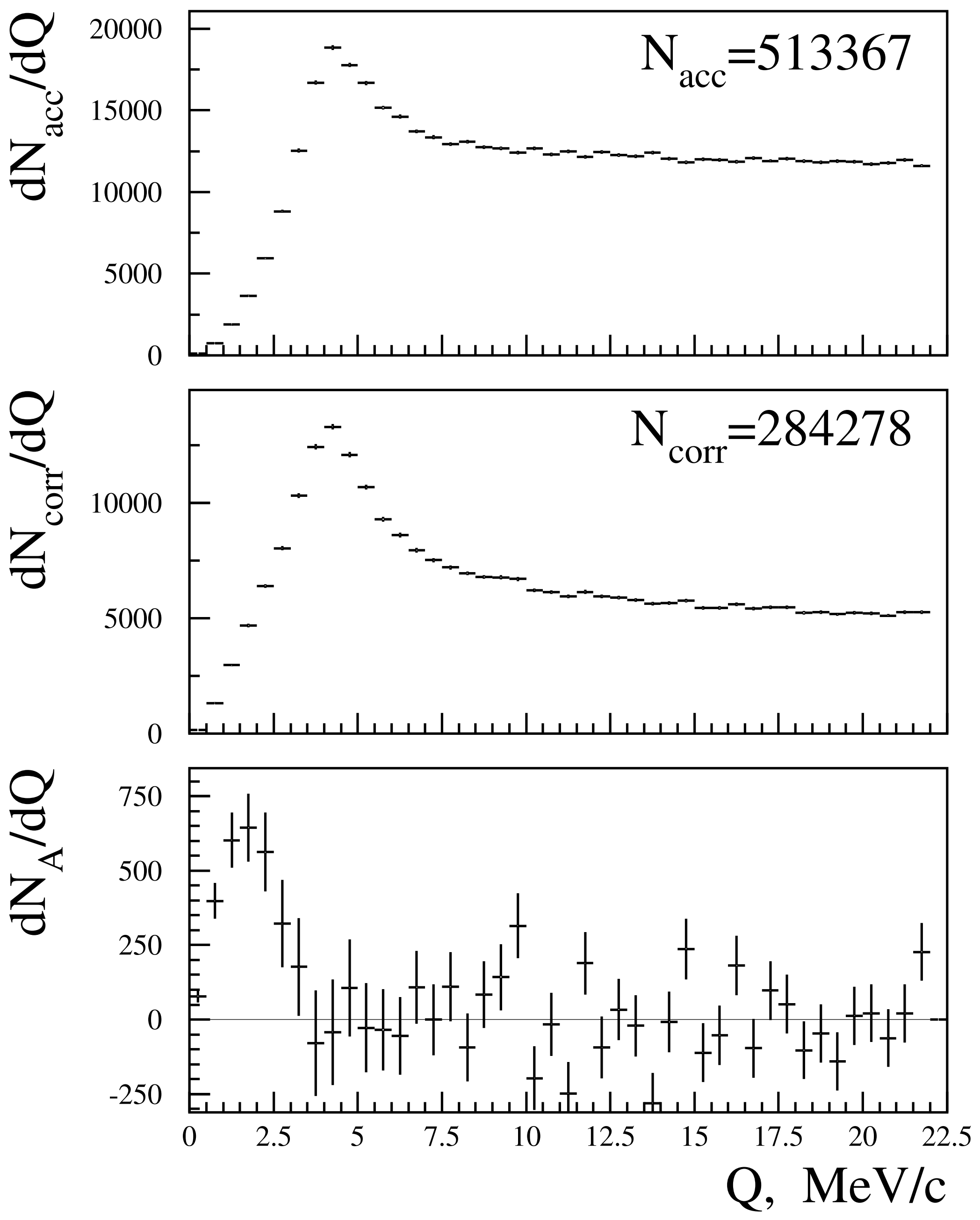
Accidentals — non-Coulomb pairs — Coulomb pairs

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

$$\frac{dN_{\mathrm{corr}}}{dQ} = \frac{dN^{long}_{\mathrm{corr}}}{dQ} + \frac{dN^{short}_{\mathrm{corr}}}{dQ} = N\Phi(Q)\left[(1+kQ)A_c(Q)+f\right]$$

N, k, f — free parameters

Ni2000



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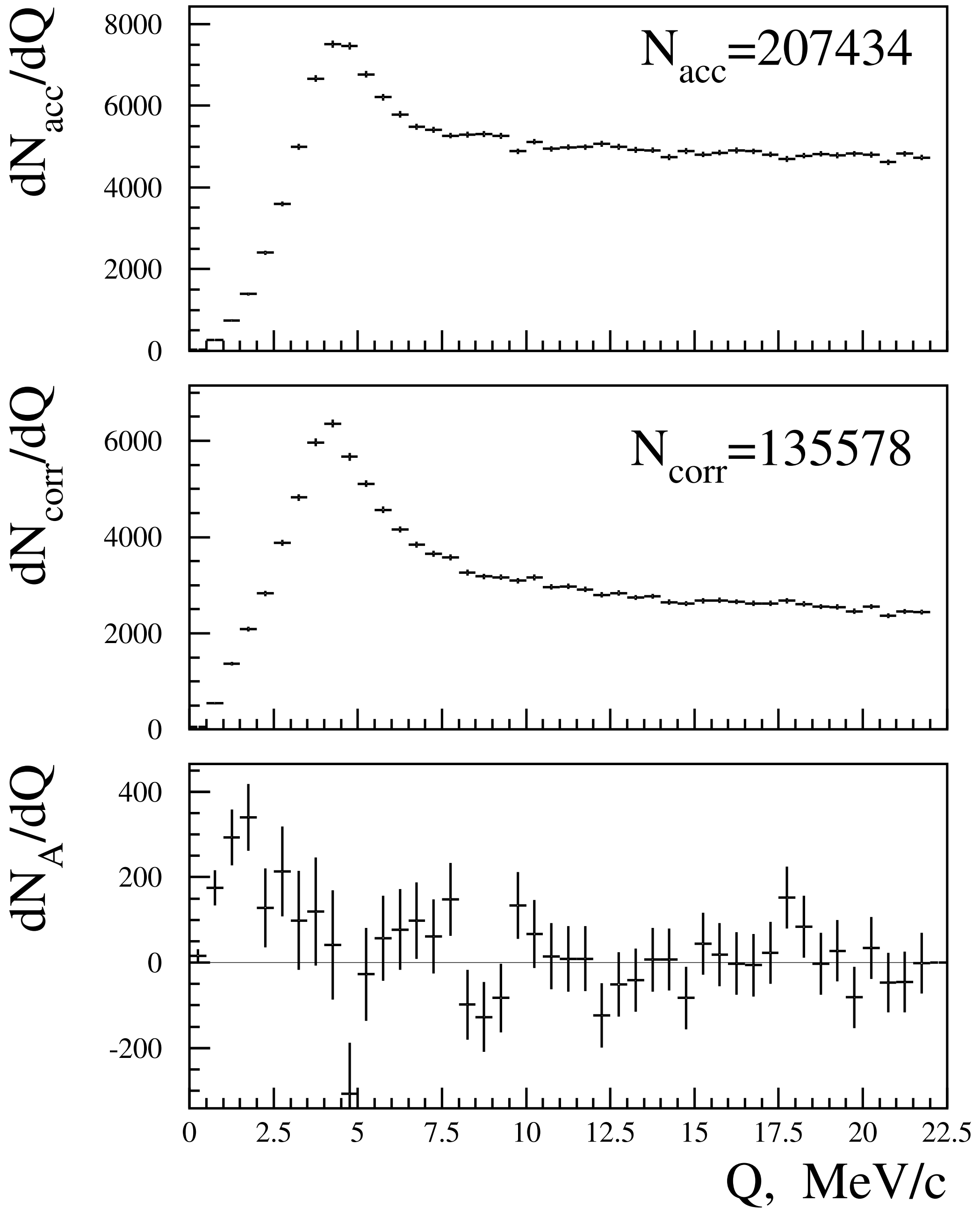
Ti2000



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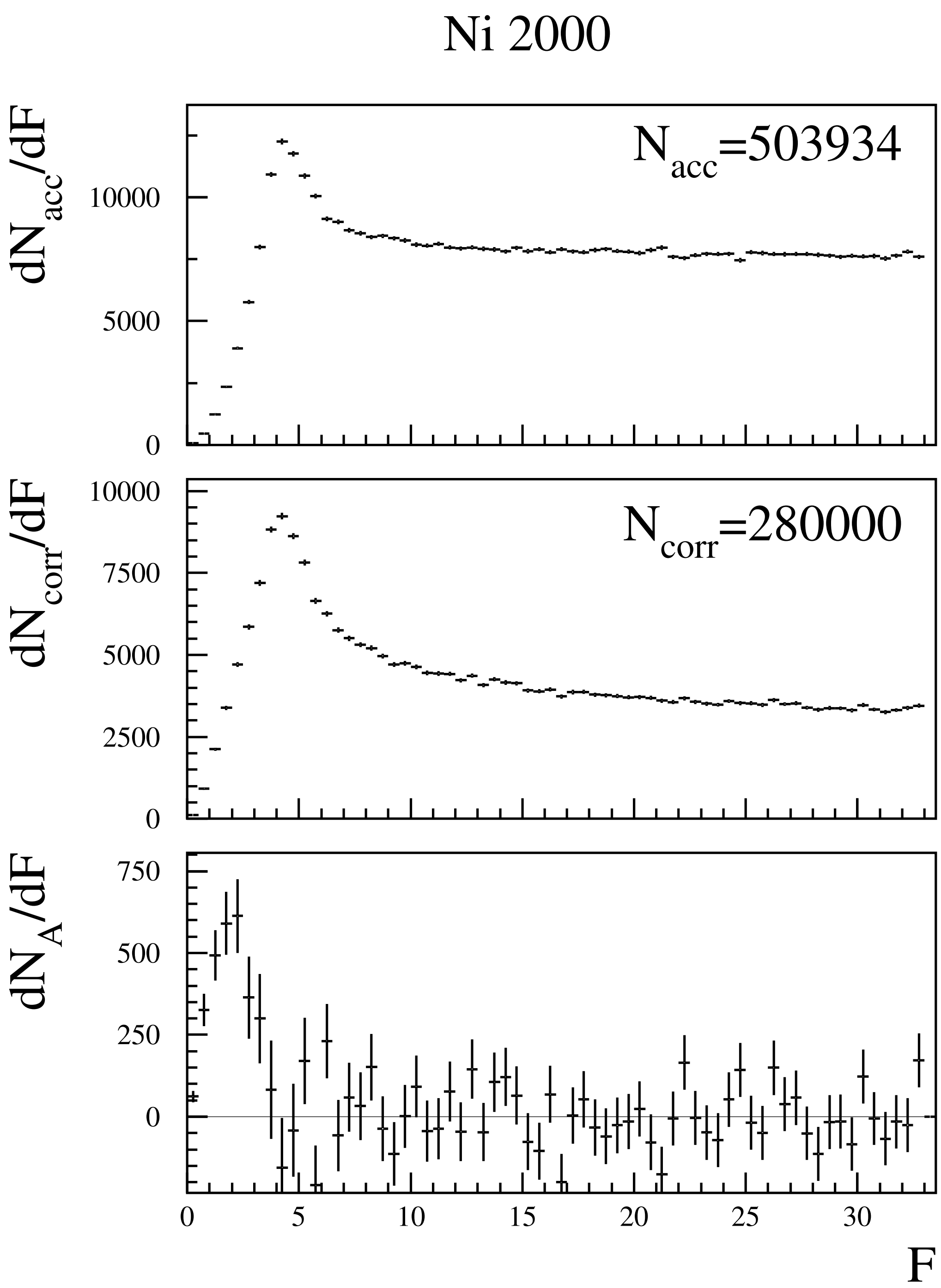

$$F = \sqrt{\left(\frac{Q_L}{\sigma_{Q_L}}\right)^2 + \left(\frac{Q_X}{\sigma_{Q_X}}\right)^2 + \left(\frac{Q_Y}{\sigma_{Q_Y}}\right)^2}.$$

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

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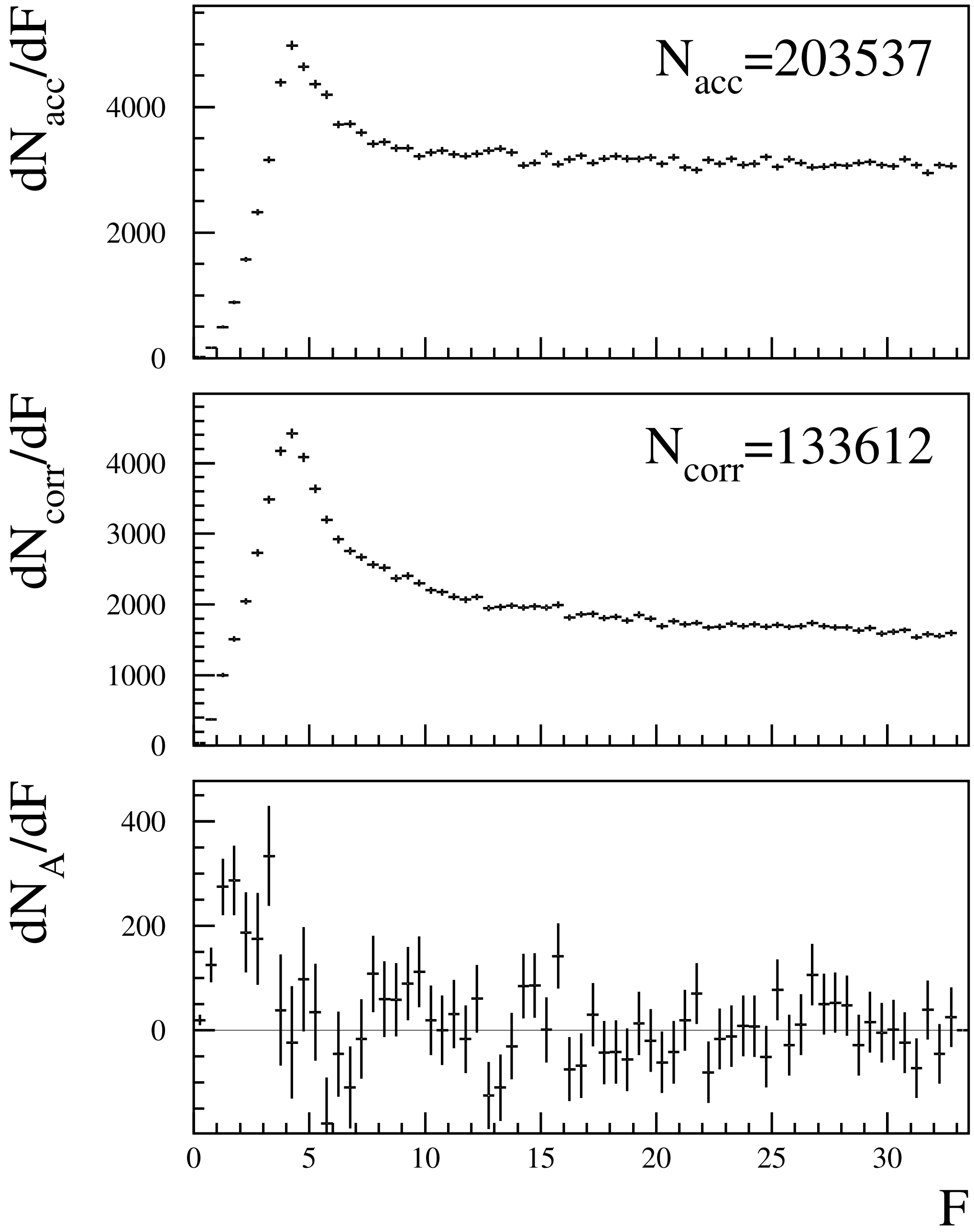
Ti2000

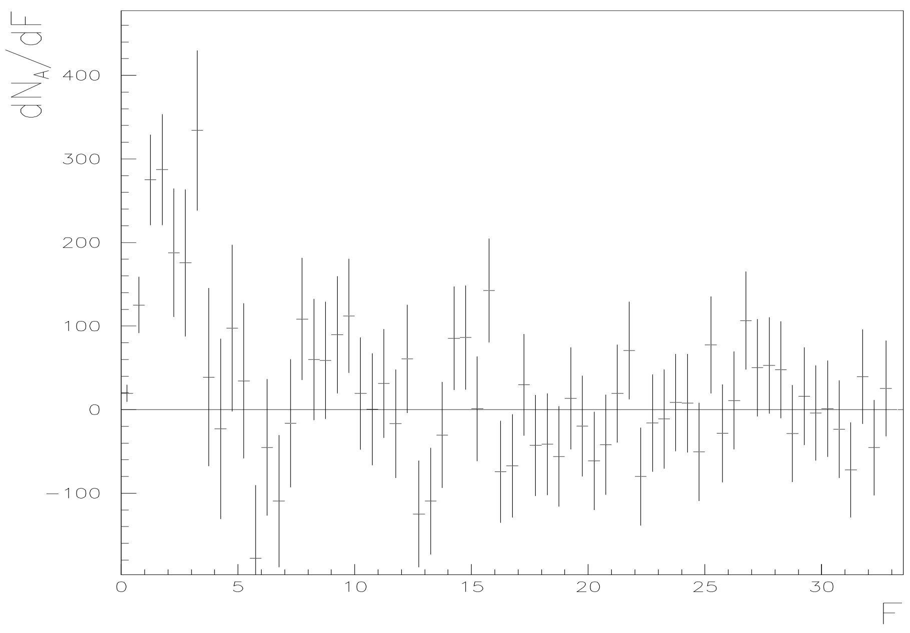


$$F = \sqrt{\left(\frac{Q_L}{\sigma_{Q_L}}\right)^2 + \left(\frac{Q_X}{\sigma_{Q_X}}\right)^2 + \left(\frac{Q_Y}{\sigma_{Q_Y}}\right)^2}.$$

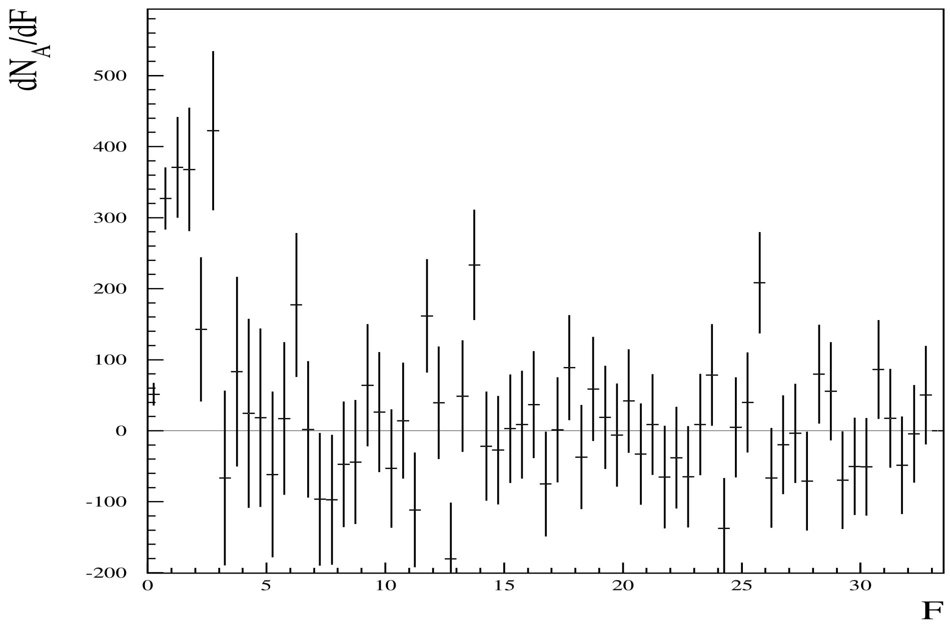
$\sigma_{Q_L} = 0.65$ MeV$/c$, $\quad \sigma_{Q_X} = \sigma_{Q_Y} = 1$ MeV$/c$.

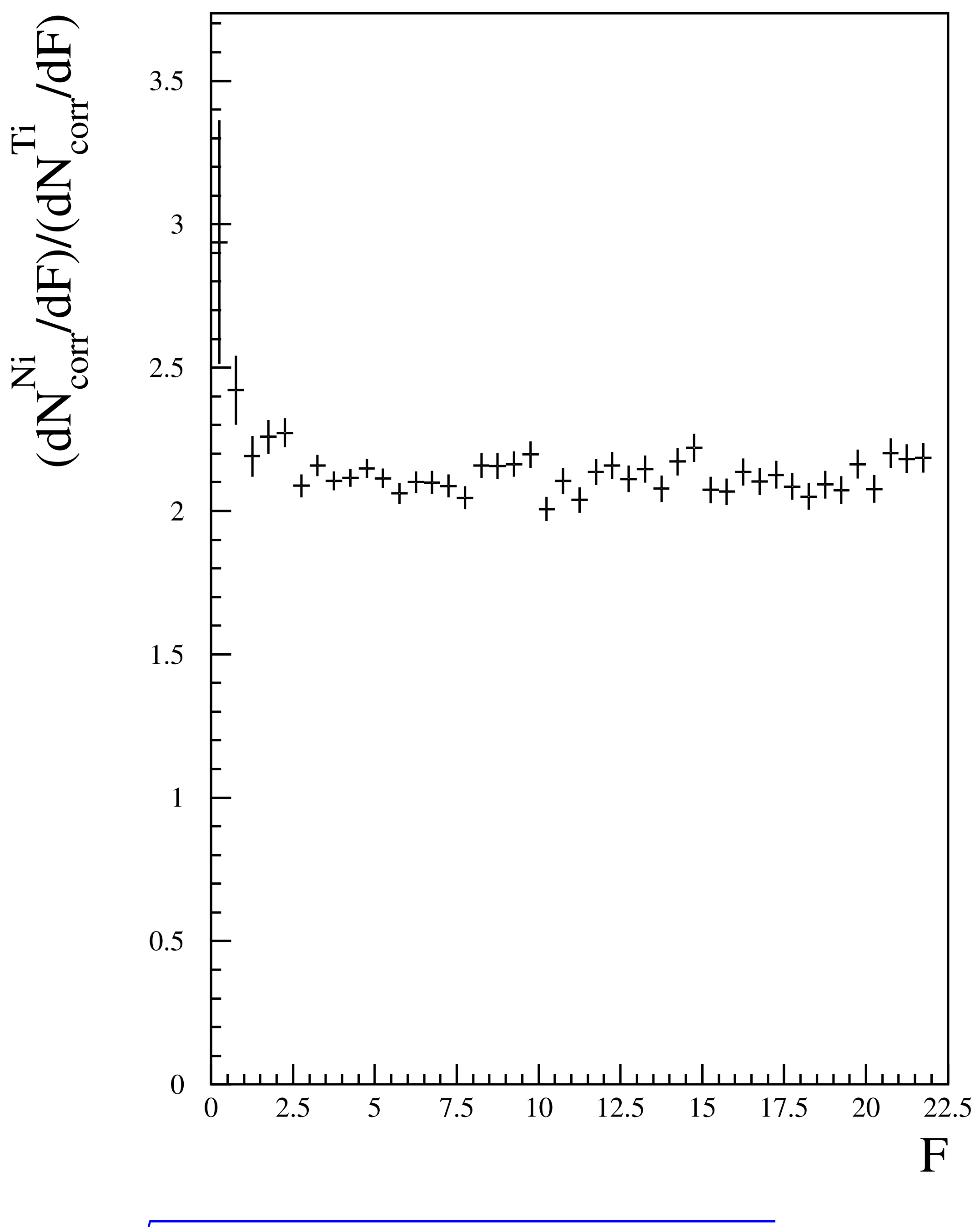
Ti Target

Ti2000



Ti 2001





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

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

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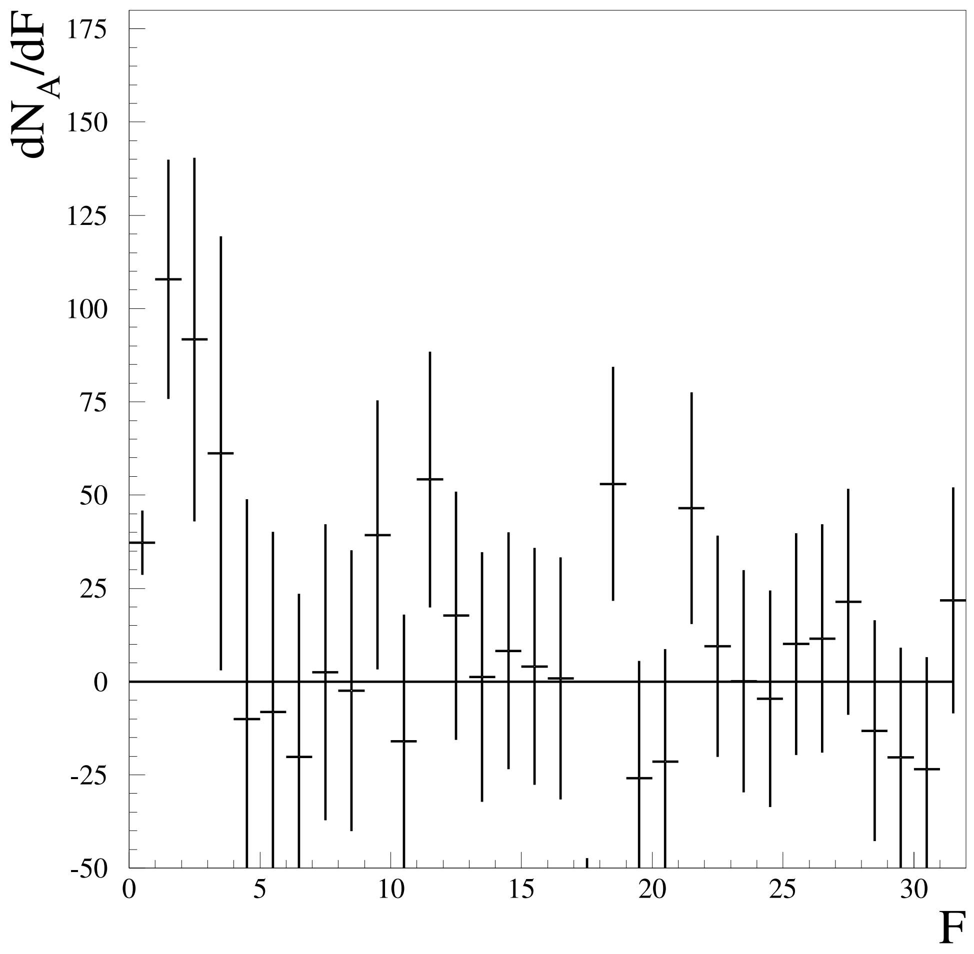
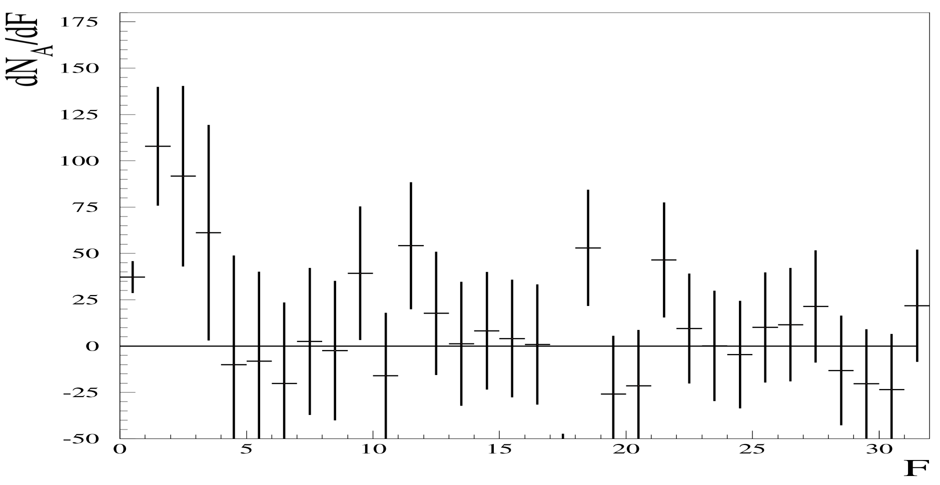
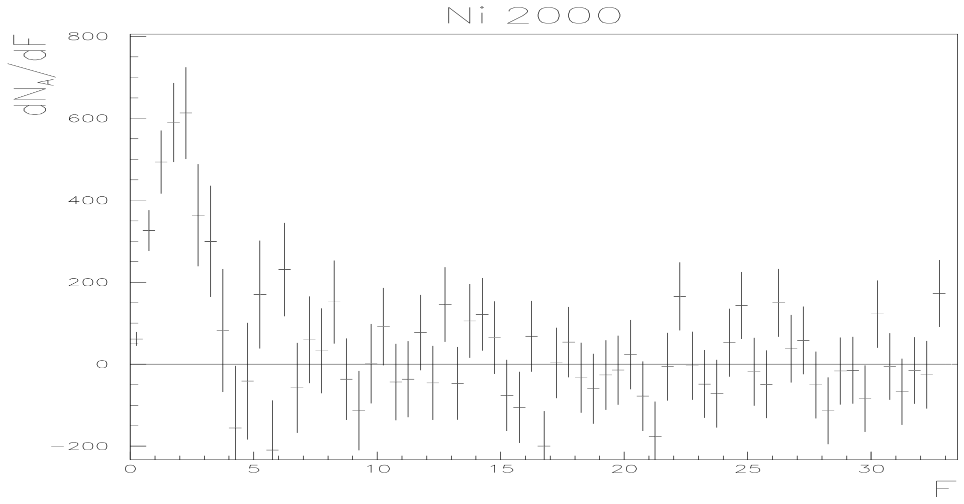
Autumn 1999 (Pt)

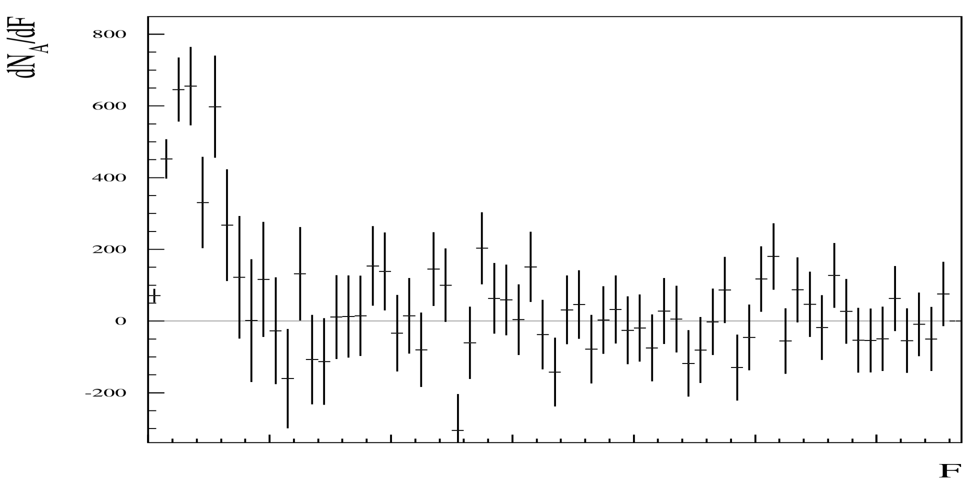


The difference between the experimental distribution dN_{real}/dF and the approximation function $A(F)$, describing the contribution of pairs from free states.

Pt 1999







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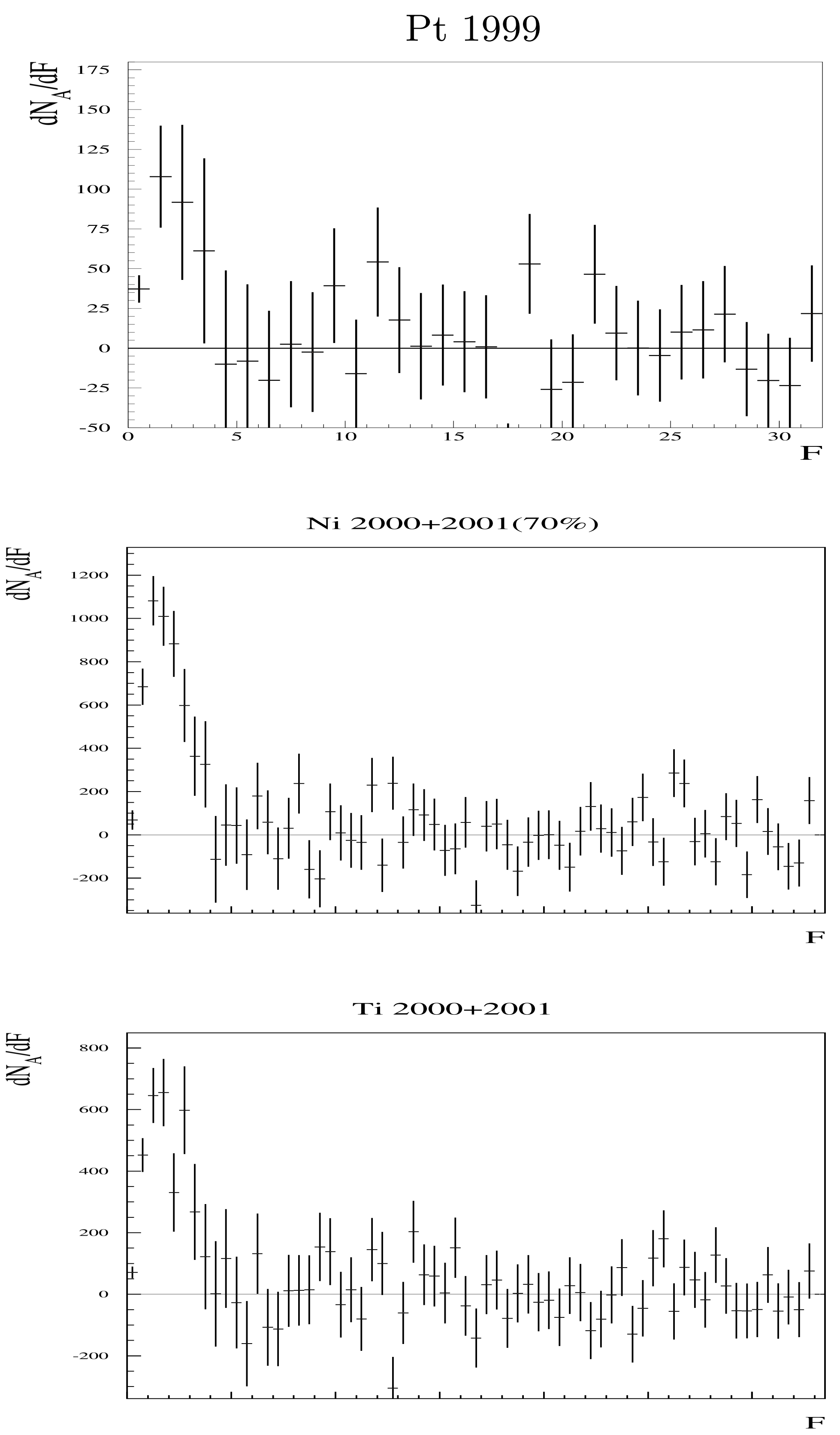
Pt 1999
dN_A/dF
175
150
125
100
75
50
25
0
-25
-50
0
5
10
15
20
25
30
F
Ni 2000+2001(70%)
dN_A/dF
1200
1000
800
600
400
200
0
-200
F
Ti 2000+2001
dN_A/dF
800
600
400
200
0
-200
F

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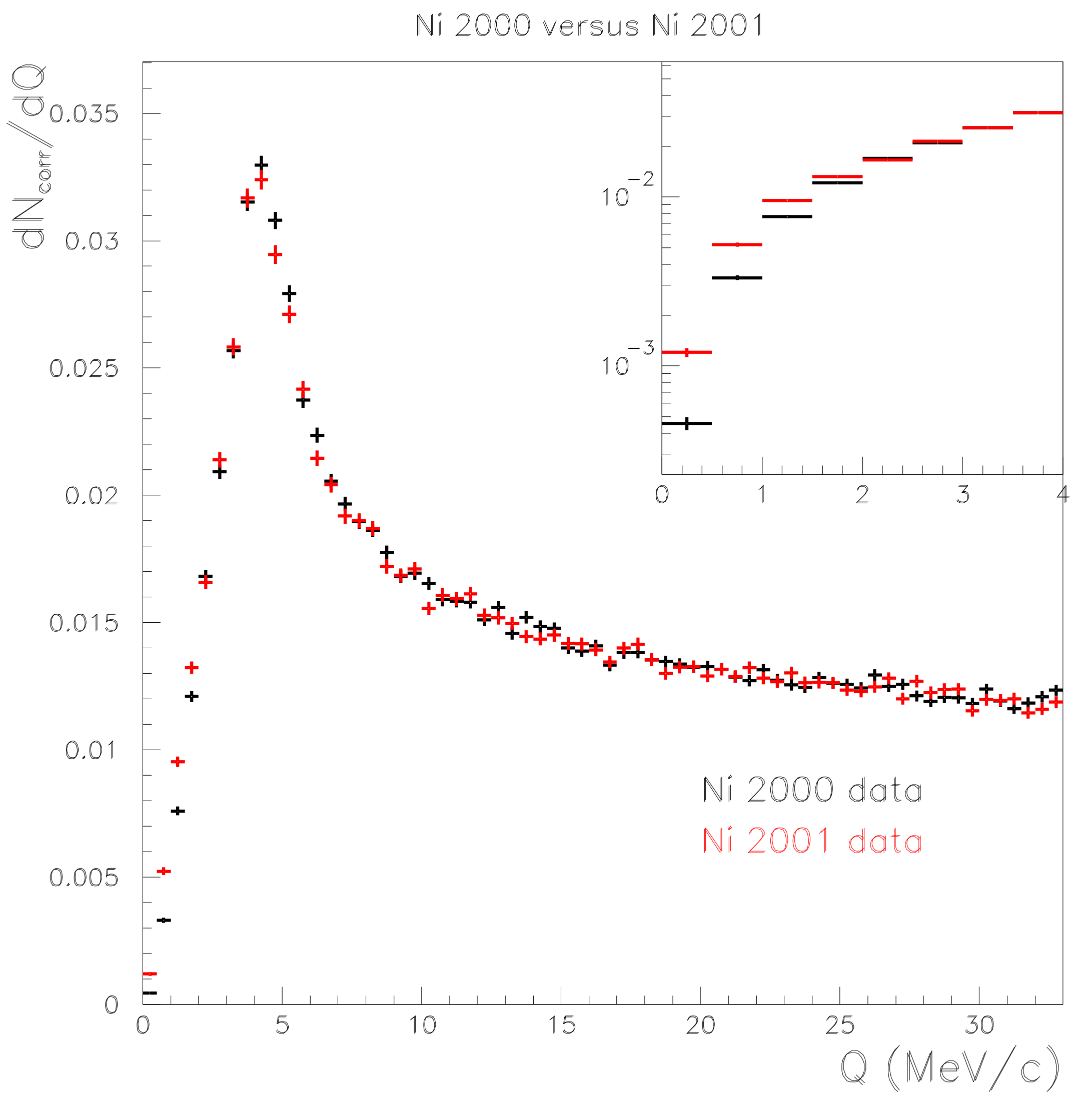
Summer 2001 analysis (Ni target)

(Preliminary results)



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Probability of $A_{2\pi}$ ionisation and its precision for $F \leq 2$

Run	status	n_A	N_C	n_A/N_C	W_{ion}^{exp}	W_{ion}^{th}
Pt-99 *(21 days)*	analysed	150±35	250±30	0.58±0.16	0.81±0.24	0.68±0.01
Ni-00 *(89 days)*	analysed	1470±140	4730±130	0.31±0.04	0.43±0.05	
Ti-00 *(31 days)*	analysed	710±100	2010±85	0.35±0.06	0.49±0.09	
Ti-01 *(46 days)*	analysed	1120±130	3820±120	0.29±0.04	0.36±0.05	
Ni-01 *(72 days)*	progress	2120±170	6630±150	-	±0.04	
Ni-01 *(45 days)*	expected	1330±140	4150±120	-	±0.04	
Ni-00/01 *(206 days)*	all	4920±270	15510±230	-	±0.025	0.436±0.022 (*)
Ti-00/01 *(77 days)*	all	1830±160	5830±150	-	0.39±0.04	0.304±0.017 (*)

(*) *Providing* $\frac{\Delta\tau}{\tau}$ *=14% for both Ni, Ti* *or* $\frac{\Delta\tau}{\tau}$ *=10% with Ni+Ti targets*

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$A_{2\pi}$ Lifetime *(Preliminary)*

$\tau(\text{Ni 2000}) = (2.8^{+1.1}_{-0.8}) \cdot 10^{-15}\ s \quad \pm 34\%$

$\tau(\text{Ti 2000-2001}) = (5.4^{+1.5}_{-1.3}) \cdot 10^{-15}\ s \quad \pm 26\%$

$\tau(\text{Ni+Ti}) = (3.6^{+0.9}_{-0.7}) \cdot 10^{-15}\ s \quad \pm 22\%$

$\Delta\tau/\tau$ *(expected from 2000-2001)*= $\pm 14\%$

(only statistical errors)

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Plans for 2002

$\frac{\Delta\tau}{\tau}$=10% $\nearrow$ $\frac{\Delta\tau}{\tau}$(Ni)=14% [$\frac{\Delta W_{ion}}{W_{ion}}$=5.0%]: n_A=(7600-4920)$\simeq$2700

(to be collected)

$\frac{\Delta\tau}{\tau}$=10% $\searrow$ $\frac{\Delta\tau}{\tau}$(Ti)=14% [$\frac{\Delta W_{ion}}{W_{ion}}$=5.6%]: n_A=(10000-2950)$\simeq$7000

(to be collected)

Expected rate of reconstructed atomic pairs $\simeq$ 50 n_A/day

Necessary Beam time:

Ni target = 2700/50 = 54 days (∼ 2 months)
Ti target = 7000/50 = 140 days (∼ 4.6 months)

Requests to CERN for 2002:

7 months of running time with 2÷4 spills/PS scycle

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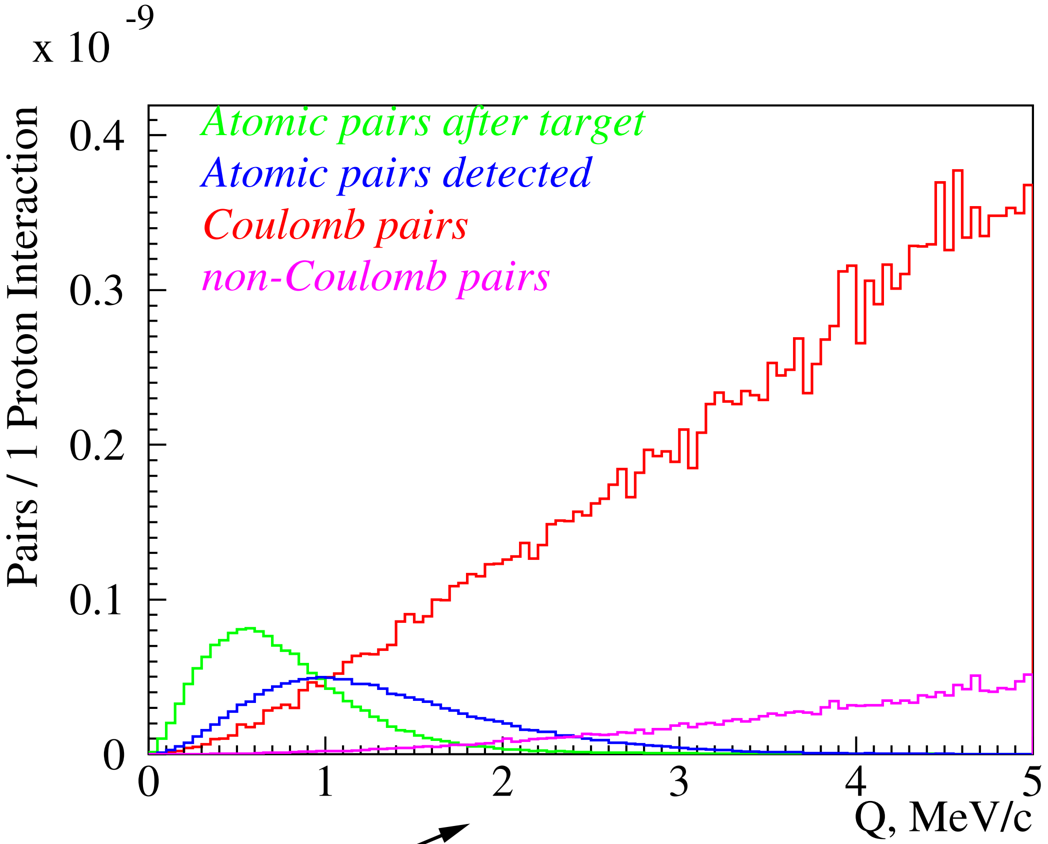

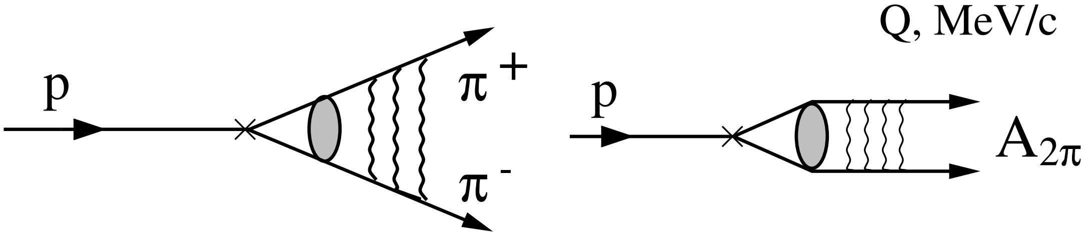

Coulomb pair

Dimesoatom

$$\frac{dn_{\mathrm{A}}}{dQ} \Bigg/ \frac{dN_{\mathrm{C}}}{dQ}$$ — is model-independent

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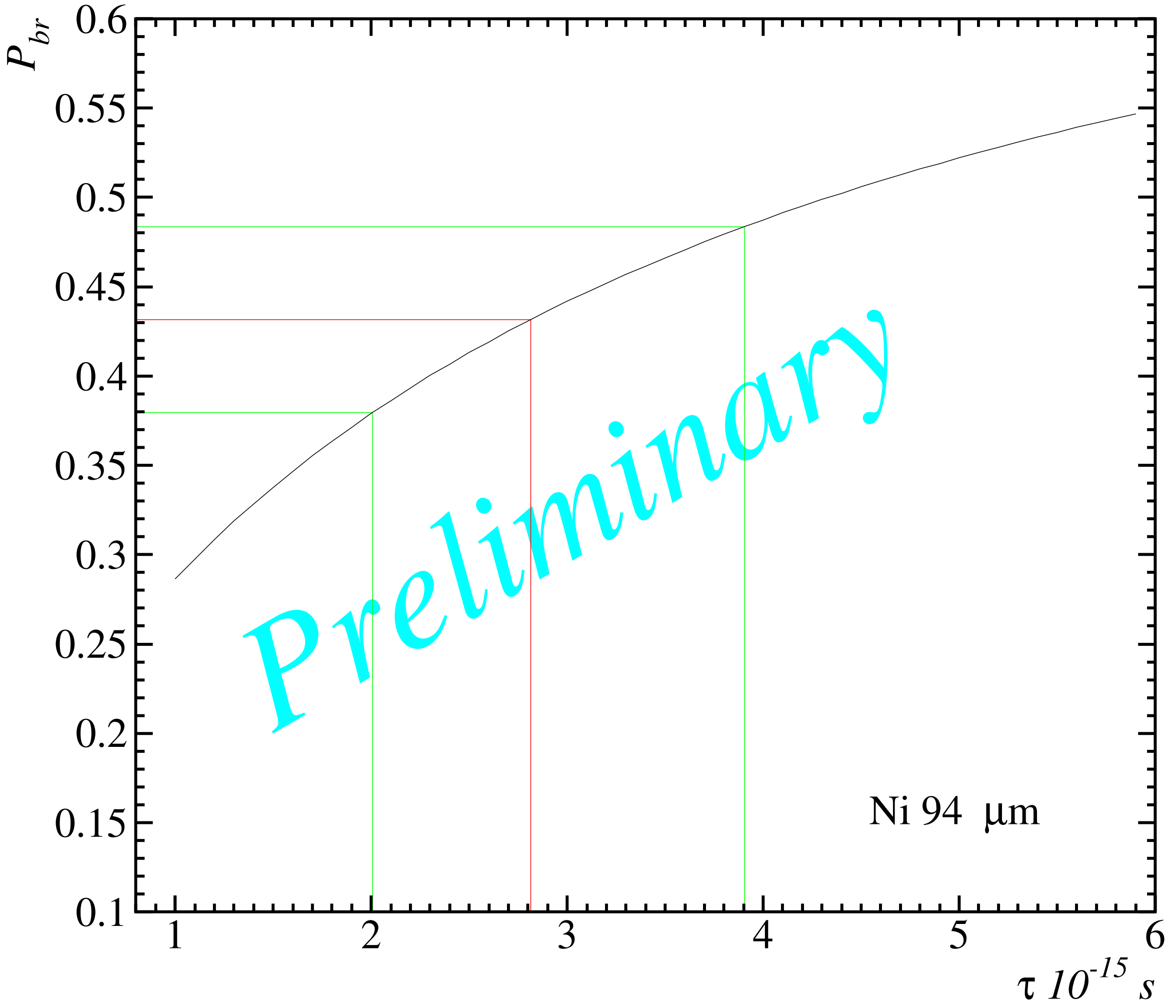
Ni 2000



$$\tau = (2.8^{+1.1}_{-0.8}) \cdot 10^{-15}\ s$$

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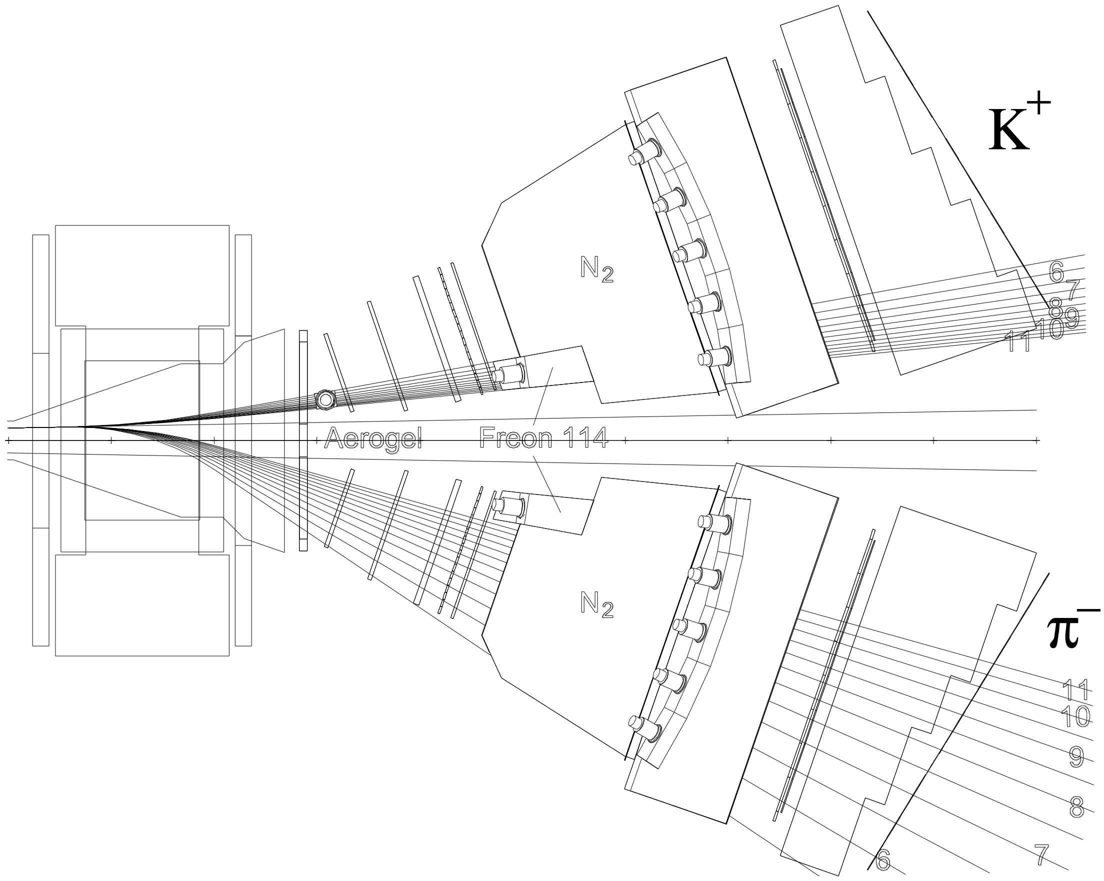
Modifications of DIRAC setup ($A_{K\pi}$)



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

πK Atom

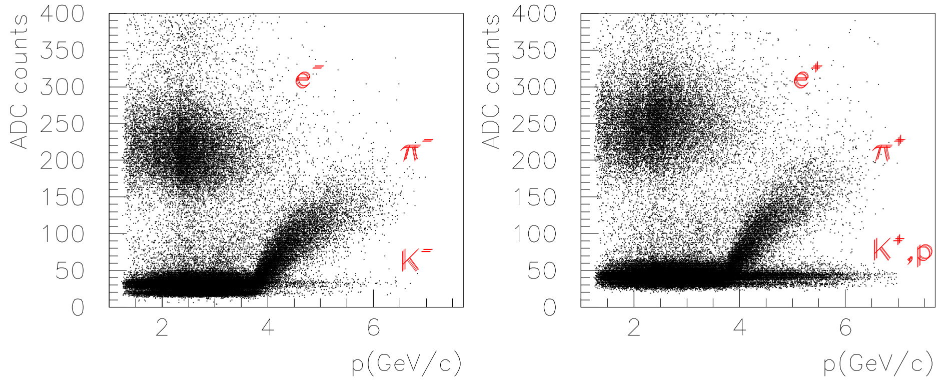
CHERENKOV TEST WITH HEAVY GAS

May 31-June 3, 2001

Aim: test πK discrimination for p>4.0 GeV/c, using the present threshold Cherenkov counters

Radiator: 90% SF_6 + 10% N_2 n=1.00067

p^e_{th}=13.6 MeV/c, p^{π}_{th}=3.8 GeV/c, p^K_{th}=13.2 GeV/c



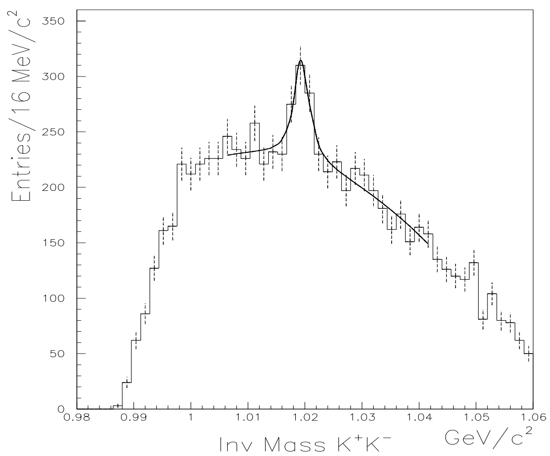
particle	p (GeV/c)	n^{th}_{pe}	n^{exp}_{pe}
$e^{\pm}$	> threshold	33	28
$\pi^{\pm}$	4.3 ÷ 5.0	12	10
$\pi^{\pm}$	5.0 ÷ 6.0	16	15
$\pi^{\pm}$	6.0 ÷ 7.0	21	20

$\phi \rightarrow K^+K^-$

M(BW)=1019.4 ± 0.6 MeV

Γ(BW)=3.22 ± 1.02 MeV

(15 hours of data taking)



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Conclusion and Outlook

- Around 5500 $\pi^+\pi^-$atomic pairs have been observed.

- Including data taking in 2002:
  A precision of 10% in the $\pi^+\pi^-$ atom lifetime measurement should be achieved.

- After updating the experimental setup:
  DIRAC will significantly improve the experimental precision for the lifetime $\tau_{A_{2\pi}}$ and, hence, for the scattering length $\Delta \doteq (a_0 - a_2)$.

- Study of Kπ atom as complementary activity:
  $\longrightarrow$ Observation of Kπ atom
  $\longrightarrow$ Measurement of $A_{K\pi}$ lifetime & corresponding scattering length

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