B-factory a

o f

B B f f

5 2 12

KEK K B-factory B f K CP B
P r E [1] CP] B r P a K B
Cf E r K B a C r
P o C P o [1]
C P o P r
f r B r
C P o - r C 3 o P o [
K K x y B K 16.8μm 15.0μm 0 C
r r 3 - B 2 o 8 P o r 2 3 K 8 P
o - r 0- 0xr - a 3 P

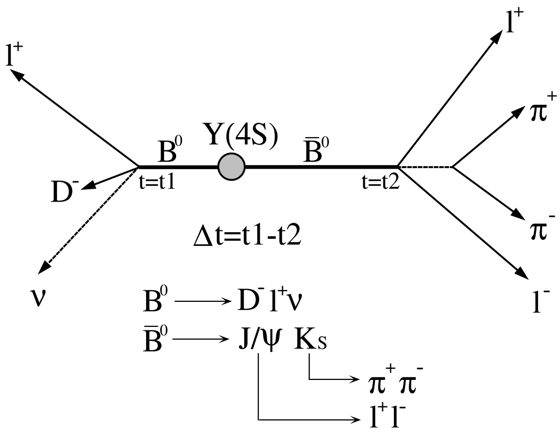
1

B-factory (KEK B-factory) B f r B K
- B f K) B r r E
B f K CP B E
CP B B Cf B Cf CP - B K BP
- B P c $B^0 \to J/\psi K_s$ $\bar{B}^0 \to J/\psi K_s$ CP
BP r 1.1 K ([1] t K BP BP .
B$\bar{B}$Cf o r EyK 1 CP -
B r $J/\psi K_s$ $_s$ B Cf (Δt)
r (τ_B) C B EyK C B Cf
r B^0 $_0$ $J/\psi K_s$ (1.2) E
r $\bar{B}^0$ $_0$ $J/\psi K_s$ B Cf K CP
] B $\frac{\Delta t}{\tau_B}$ 0 r Cf K BP K CP] B
K BP - 1.1 CP K B -
$\sin 2\phi = 0.6(\phi$ $-$ CP r K 0)
i o K CP s] B r =P a K Δt . B
Δt . B K 2 B Cf 2 P C [1]
B-factory K 2 P C r)

---

[1] B B

1.1: CP P



1.2: B C 2

( )

B-factory B f B f r B a (
$\Upsilon(4S)$ y 10.58GeV B.4oG $\Upsilon(4S)$
100% 4tf G B f 4V B f 4V B a 8 (B f 4V
B f 4V B r B f 4V 5.28GeV G
a $\Upsilon(4S)$ B 2 8 . G B f 4V B f 4V
1 0 346MeV/c B f 4V 1.3×10^{-12}
$\Upsilon(4S)$ 3 2 B f 4V 6 2 25μm
o / 8 B8 8 4oG 2 r / B 3 M 3
G M 4 r 0 %(%M%. G M %V %%5 [2]
[2] [2] KEK B-factory
0 G % %%(%M%. EE 8GeV MEE 3.5GeV G 3
$\Upsilon(4S)$ 3 EE % % 8 K %V %%5 a 2 8 . G
B f 4V B f 4V 6 K EE % % 8 %V %%5 6 2 B 83
G 8 160μm K 3 B M 2 B.4o Δt

$$\Delta t \simeq \frac{\Delta z}{c\beta\gamma} = \frac{(z_1 - z_2)}{c\beta\gamma} \tag{1.1}$$

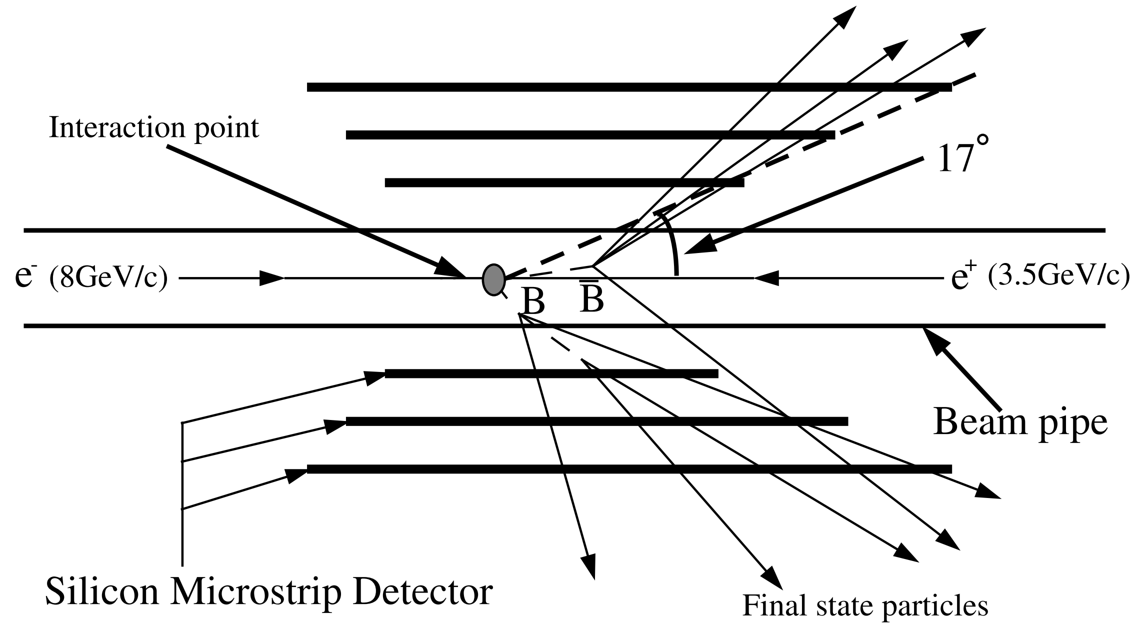
a 3 G- 3 3 G $\beta = c/v$ $\gamma = (1-\beta^2)^{-1}$ $\Delta z =$
$(z_1 - z_2)$ 2 B f 4V 2 E z 8 (% % 8) 5 %G CP BP
%%%a % A_{CP}

$$A_{CP} = \frac{\Gamma(B^0 \to J/\psi K_s) - \Gamma(\bar{B}^0 \to J/\psi K_s)}{\Gamma(B^0 \to J/\psi K_s) + \Gamma(\bar{B}^0 \to J/\psi K_s)} \tag{1.2}$$

5 5 A_{CP} 3 G B a K %P %%(%/%8 =PoK BP
80μm ΔzJ / / [1]
3 G MM M 2CB.4oK - 8 =Po CfG E
%P %%C%/%8 =Po 5 2 =PM %%%%%%%%P Ey %%%%
%%P G + 3 G 100μm E 0 CV 2rG= + +

---

[2]



1.3: . KEK B-factory

o E r r 1 K 1 E K a 3 o K B B - 3 E r K 3

3

3 3

3

KEK B-factory K 3 o r o (1.3)[1] B K 1991 K 9 B 3 K 3 9 o 9 3 K B 9 r r B-factory r 9 r 1.4K (9 [2] $B^0 \to J/\psi K_s$ ΔzJ / / $83 \pm 3\mu$m ΔzJ / /

---

3 1.3 17°
[1]

1.4: $B^0 \to J/\psi K_s$ $\Delta z J$ /

/ / K

B B-factory 1 2 :B r B

4or [1]

4o - 2 r 4o

- r r 4

2

2.1

2 p
n (p-n) n
(2.1(A)) p 2 4 2A A
A 3 2A A 3 n
3 (hole) n 3 4 2A A
5 2A 5 A 3 h n l
3 3 2A 5 2A
l 5 o - 3 l l n^+ p^+

2.1.1

p-n

n - n p

- p p

n - n

p (

) p-n n

n (p-n

) (ρ) n (E) 2.1(B) (C)

(EE C p-n B EE EE p-n

EE E 1V E 2.1(B) (C) Depleted

Zone l l e

EE2 B C n l

C EE d EE C 1 l

EE2 B EE D o o

C D o o -

2 EE E EE B n l EE2

C EE C o l 1 l C

B EE l 1 l EE2

EE2 B D C n (.

o 4 2 l 1 B EE B n

(. 3.6eV 2 l 3.0eV

2.1.2 2

p-n EE0 1V 3 l 1 n l EE

d B. 0 3 6 3 0 o .

( )

p-n

(2.1(D))

p n

2 ( )

- (2

2D 2.1(E) 2 1

n EE EE EE

D 2 p

2 E

EE (p-n - 2.2(A)

A E EE2) E (ρ(x))

$$\rho(x) = \begin{cases} eN_D & (-a < x \leq 0) \\ -eN_A & (0 < x \leq b) \end{cases} \tag{2.1}$$

(e N N_D N_A

$_A$ 0 $aN_D = bN_A$

φ x <

$$\frac{d^2\varphi}{dx^2} = -\frac{\rho(x)}{\varepsilon} \tag{2.2}$$

2 0 2.1 0 2.2

$$\frac{d^2\varphi}{dx^2} = \begin{cases} -\frac{eN_D}{\varepsilon} & (-a < x \leq 0) \\ +\frac{eN_A}{\varepsilon} & (0 < x \leq b) \end{cases} \tag{2.3}$$

3 0 3 EE E(E=$-\frac{d\varphi}{dx}$) EE EE2

0 - 3 E 3

$$E(x) = \begin{cases} -\frac{eN_D}{\varepsilon}(x+a) & (-a < x \leq 0) \\ +\frac{eN_A}{\varepsilon}(x-b) & (0 < x \leq b) \end{cases} \tag{2.4}$$

2.2(B) 2.4

$\varphi(x)$ p-n

V_{bi} V $\varphi(-a) = V + V_{bi}$ $\varphi(b) = 0$

-

$$\varphi(x) = \begin{cases} -\frac{eN_D}{\varepsilon}(x+a)^2 + (V + V_{bi}) & (-a < x \leq 0) \\ +\frac{eN_A}{\varepsilon}(x-b)^2 & (0 < x \leq b) \end{cases} \tag{2.5}$$

p-n B 2 $x = 0$ 0

$$(V + V_{bi}) - \frac{eN_D a^2}{2\varepsilon} = \frac{eN_A b^2}{2\varepsilon} \tag{2.6}$$

$aN_D = bN_A$ ε

$$(a+b)a = \frac{2\varepsilon(V + V_{bi})}{eN_D} \tag{2.7}$$

= 6 0 d $d = a + b$ ε

ε ε < < ε $N_A \gg N_D$

ε ε N $aN_D = bN_A$ ε $a \gg b$ ε NN n B

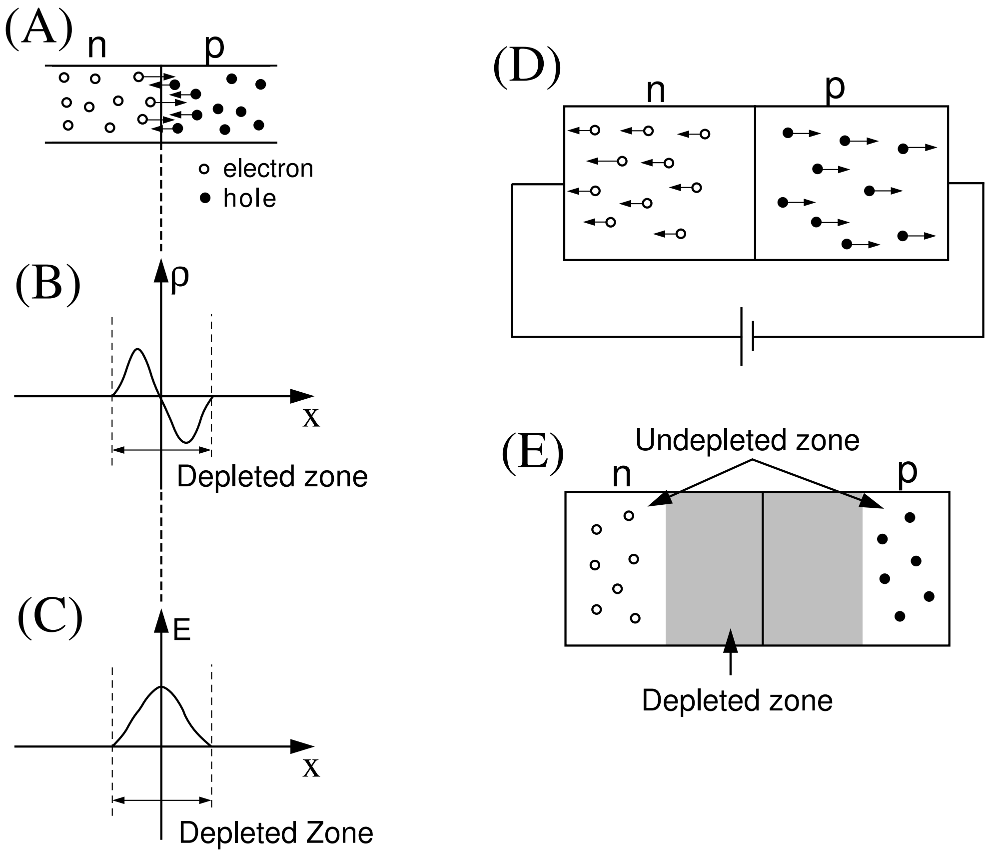
- = 7 $d \simeq a$ a

$$d \simeq \sqrt{\frac{2\varepsilon(V + V_{bi})}{eN_D}} \tag{2.8}$$

7 = n 7 B ρ_d ε N μ ε $\rho_d = 1/e\mu N_D$ i ε 2.8

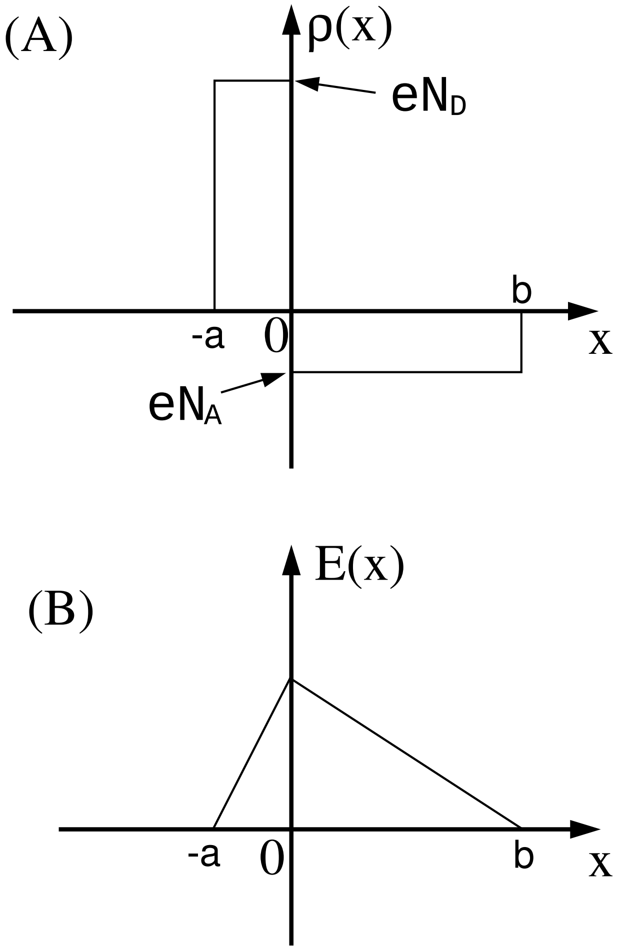
$$d \simeq \sqrt{2\varepsilon(V + V_{bi})\mu\rho_d} \tag{2.9}$$

= = 5 9 05 9 05 + 9 (10 0) 6 0 9 05 9 8 (1 8 5 9 05 B 6 0 n 9 B - B 7 +

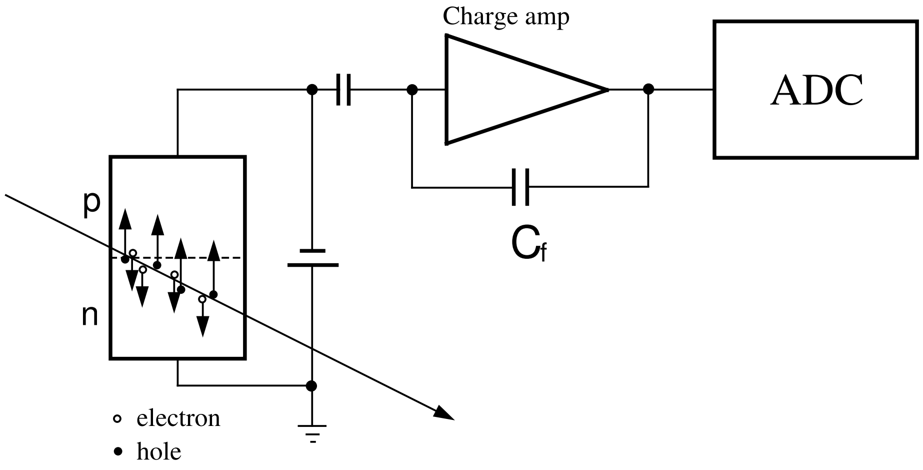


(A)
n
p
electron
hole
(B)
ρ
x
Depleted zone
(C)
E
x
Depleted Zone
(D)
n
p
(E)
Undepleted zone
n
p
Depleted zone

2.1:



2.2: 2



2.3:

2.1.3 .

3 . **2**

2 **2** **3**

2 2.3

3 3 2

Q V Q

C_f

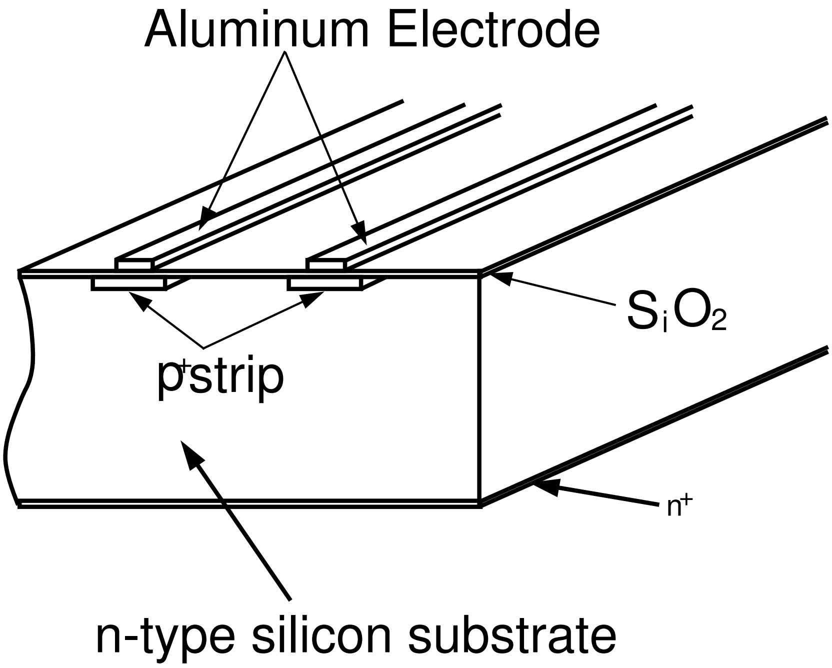
$$V = \frac{Q}{C_f} \tag{2.10}$$

= 0 . ADC(

0 -) A ADC . - 2=

3 = A C ADC 2= . 3

=



2.4: 4

2.2

2.2.1

2.4 4 4 n 4 (n-type silicon substrate) e : p^+ 1 1 a 4o p^+

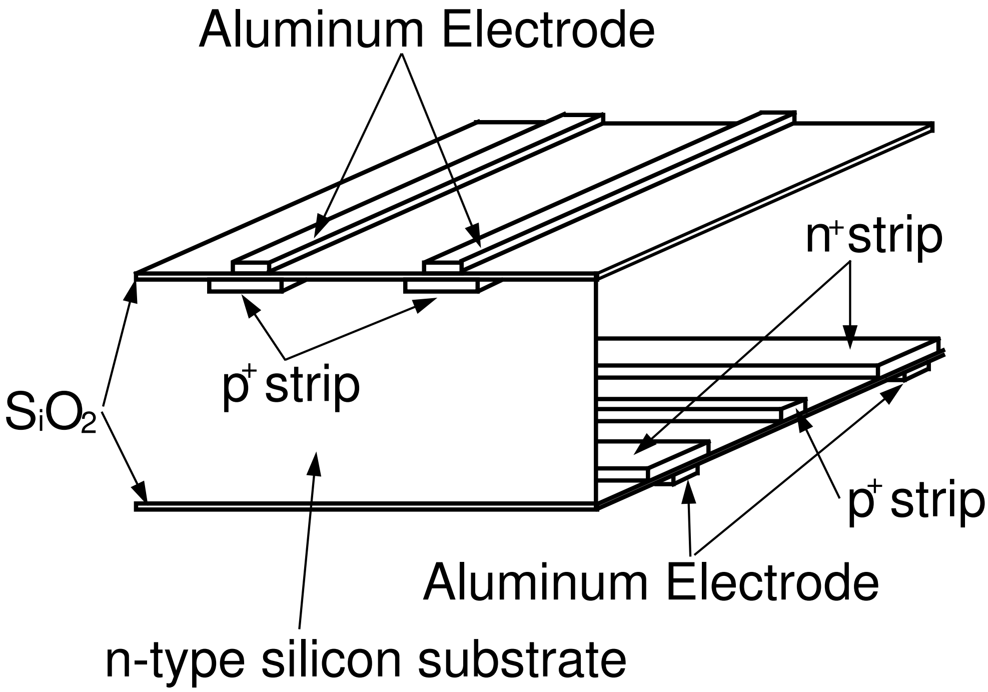
10kV∼100kV 2 . 0 . l k 0l s 4p 280μm∼300μm 4V3V t μm∼ μm p^+ ( ) (B) k . l 3 s 4p s 2000 Å 8 S_iO_2 10μm k i l k O S_iO_2 cm∼ 10cm t

10μm 100
1000
0 0 p-n 0
0 p-n
0 1 0
p-n 0
0 p
m
n
0
0

2.2.2

1 1
m 1 2
m n n 2.5
m ( )
1 5 m
( ) 2.5 2.4
1 p^+ n^+
n^+ ( )
- m 4 5
0 2 p-n 0 4 1
0 n (n^+)
n^+

n 5 5 (


Aluminum Electrode
n+ strip
p+ strip
SiO2
p+ strip
Aluminum Electrode
n-type silicon substrate

2.5:

2.6: n$^+$

2.5 n$^+$ p$^+$
n$^+$ 2.6[3]
p 3 p 5 n 300μm
2 n$^+$
n$^+$ 50μm
p$^+$ 2 n$^+$ 25μm 3 m
6 3 0 6 3 0 6 3 6 3 0 2
n$^+$ +
p$^+$ 2 n$^+$

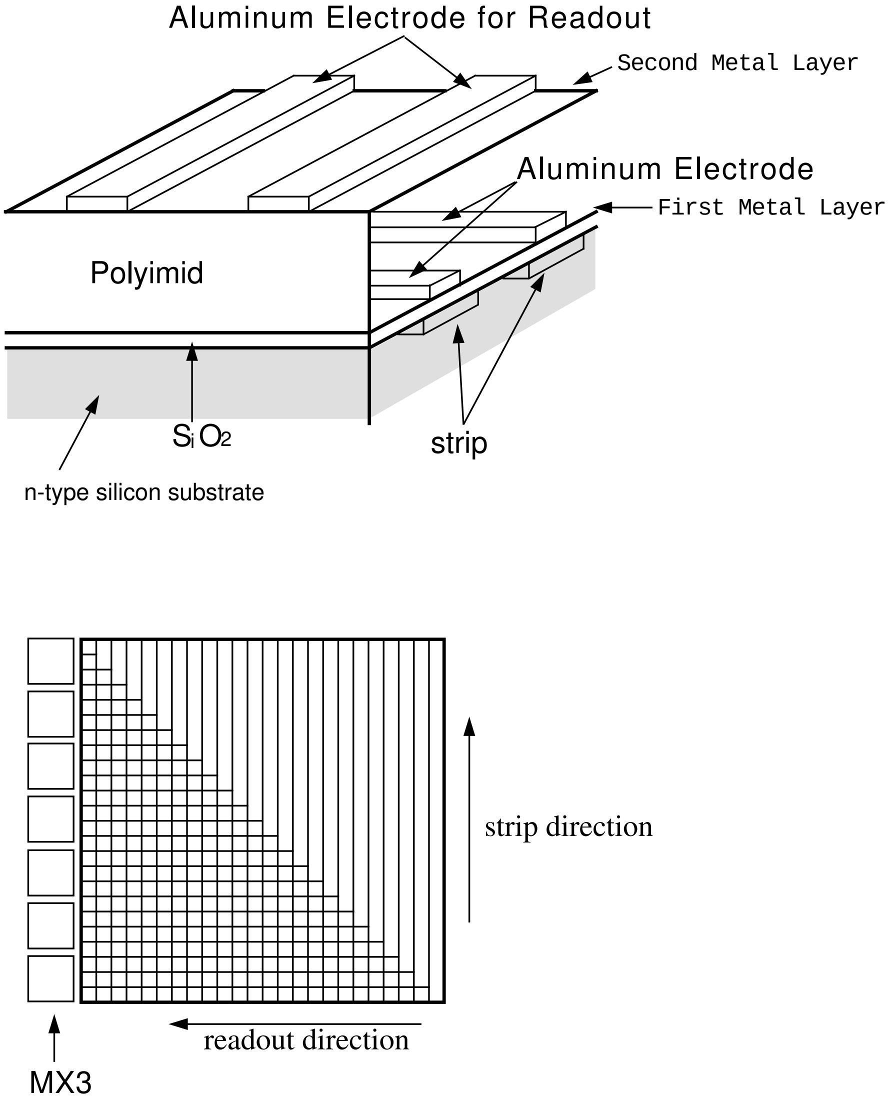
1
2 5 : 3

2.2.3 2

CERN N LEP 3 0 N 0 ALEPH 0 N LL 3
m H C P P C P H AH [4] 2.7

2.7: ALEPH P P

P P n z
p r-φ n
P 7 r-φ r 100% P 7 2
1 P A L LEP H %%%%.
1 0 L A L A 2
7 7 KEK B-factory %%%%. B
K A L A 2 : Hr1 A LIH
1 K P K a K P o B r 2.8 K 1oA r
2 8r %%%%%K%EHK r B K
P 8 r %%H%%% 8 H K 7 LL 2.8 K 8
P o LIK K %%%%% 1oA r :n K P 7 %%%%K%
EHK r %%H%%H K % K %%%%% A r %%%%K%
EHK % r 2 E B0A H 8 %%%%%H %7%%p H
K A r B 1 A %%%%% LIK A r B 2 A H %


Aluminum Electrode for Readout
Second Metal Layer
Aluminum Electrode
First Metal Layer
Polyimid
S_iO_2
strip
n-type silicon substrate
strip direction
readout direction
MX3

2.8: 2

2.8 2 . 8 8

2.3 2

3

2 2 3 2 2.2.1 8

2 8 2 .

1 8 8 8 2 σ_{int}

p

$$\sigma_{int} = \frac{p}{\sqrt{12}} \tag{2.11}$$

2 2

2 B =

=8 2 = (B B.4) (= σ_{int}

i i i

S/N

8 1 N 2 =

= 2 = B 8 = 4 N N B / (N

B / S/N / 8 = 2 = B N

N 2 2 =

n B N N 2 = = N

N 1 = n B N N N N 2

=

1 8 B 4 N 2 8 B 8 = 4

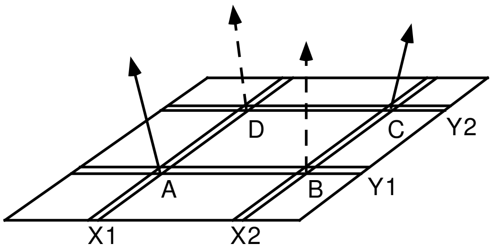
stereo ambiguity o B8 2.9N 2 N N 1

N 8 = 4o 9 X1 X2 Y1 Y2 = N . 9 8= 9g N

A C N B D N D

N D stereo ambiguity N D N N 8 = 4oN N B

N 8 = 2YAmN 8 y i 2r/ =



2.9: stereo ambiguity

o 9 . i s [1] 2 9g i o 9 . i s i o o 9 . r p n a 2 n 9 . p n 2 m y 9go r stereo ambiguity r 2r p n 2 m 2 9

: 2s 2r e r 9 9

2.4 4

4

4 (HAMAMATSU SSDMX3) S o (HAMAMATSU 2DSS-DMX3) 3 i o M . 9 A 3 2 VLSI[2] 2.10 3 9g H VLSI 9gIt r 200 2 Hy 3Hg b r 0 e I V 3V 100μm

LL o IU B 0 :r 7 7n - I 2A7 b [10] : 2s 3 r U s 9 o 7 3 o LL o - r I 2A7 3

---

[1] 4 4.5

[2] ^{2} 1 .

2.10: MX3

0 c-1-5 2 0 X 5 a-4-5 p 2 0 X a-5-7 n 2 0 X M7 4 5 4 MM 2.1 5 2 4 1 256 c M 4 1 768 c M . 5

[cm^2]	6.5×2.56
[μm]	10
6 [μm]	10
[cm]	6.5
[μm]	25
[μm]	50
	512
c	256
5 [μm]	300
S_iO_2 [Å]	2200

A	c-1-5	a-4-5	a-5-7
[cm^2]	1.92×1.92	1.92×1.92	1.92×1.92
9 (p,n)[μm]	30,20	30,30	30,20
6 (p,n)[μm]	26,16	26,16	26,16
9 9 (p,n)[cm]	1.92,1.92	1.92,1.92	1.92,1.92
9 4 3 (p,n)[μm]	50,50	50,50	50,50
7 4 3 (p,n)[μm]	50,50	50,50	50,50
9 (p,n)	384,384	384,384	384,384
7 A c (p,n)	384,384	384,384	384,384
4p 8 5 [μm]	300	300	300
S_iO_2 (p,n)[Å]	2200,2200	2200,2200	2200,2200
2 6 0 A	5 7	p	n
] 8 5 [μm]		2−2.5	2−2.5
2 A 6 [μm]		10	10

2.1: 7 3 m9 8 4 (: 8 4 2 : 8 4)

3

3.1 .

2 (2.2.1)

1cm 200∼400 c 2

0 4 c .

) ADC A c

2) A c C 0 4 4

D . A 2 VLSI C . 1 D . C1

0 ADC A 0 L I

m C 4 D . A I 2 VLSI 1

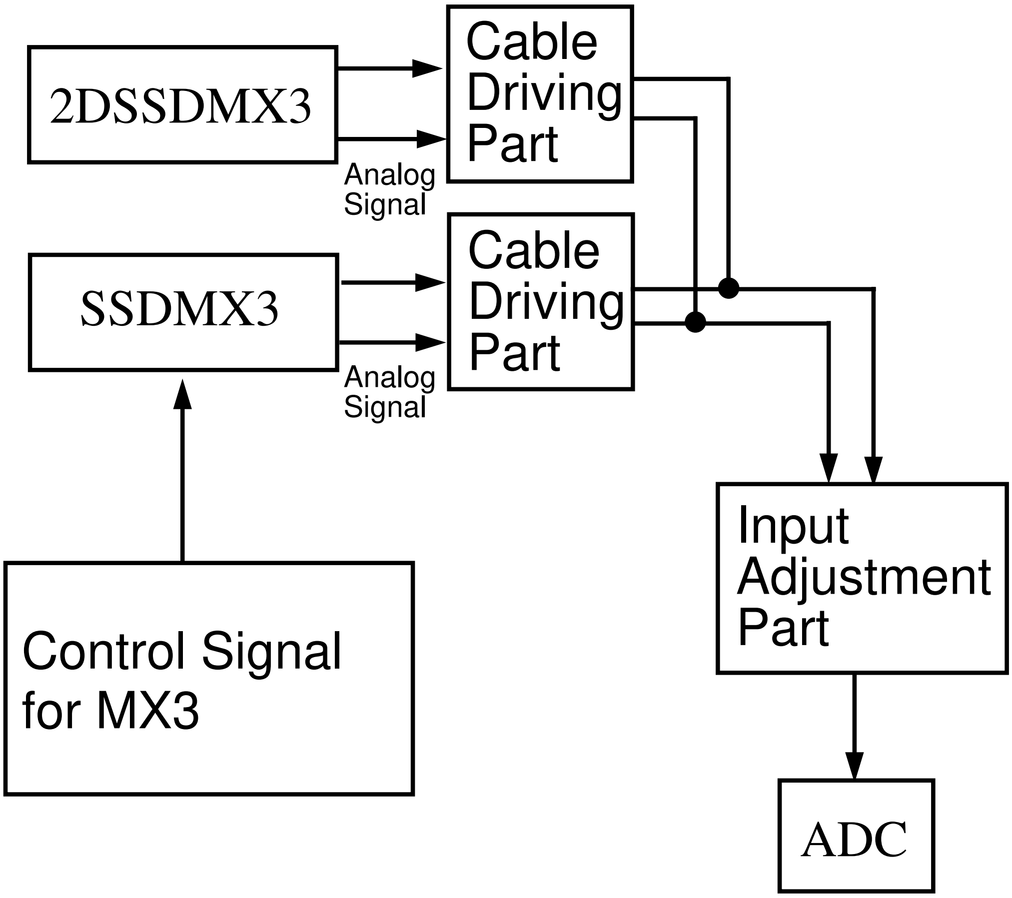
) I C (RAL) MX3 3 MX3 M

. I 3.1 (. I MX3 0

3 m . I MX3 4 . A I

ADC D40 I S . ADC

. 3 I D 0 2 4 C1 L

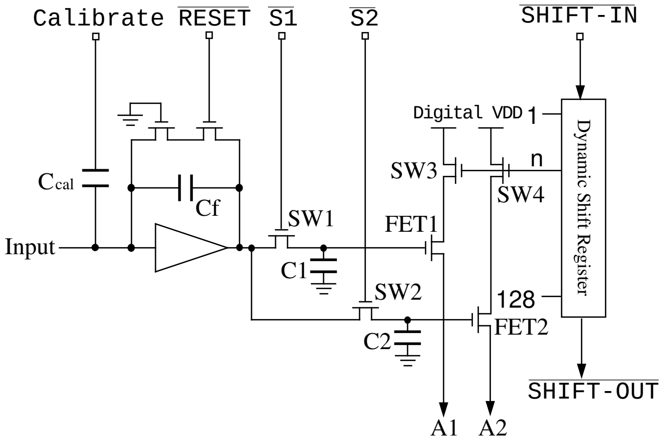

2DSSDMX3
Analog Signal
Cable Driving Part
SSDMX3
Analog Signal
Cable Driving Part
Control Signal for MX3
Input Adjustment Part
ADC

3.1: 3

3.1: MX3

3.1.1 Double Correlated Sampling S . 3d

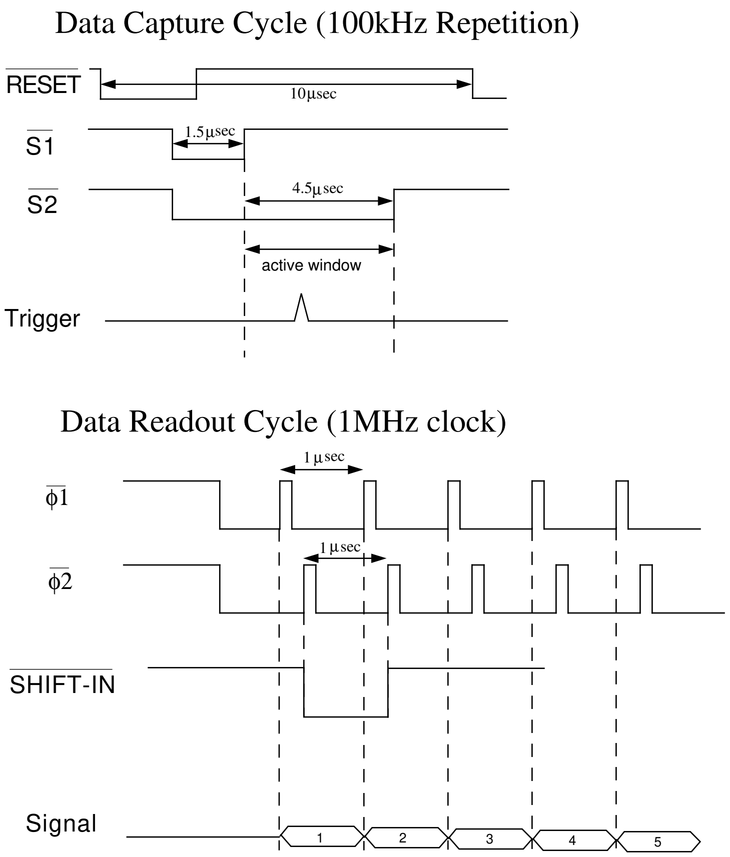
3.1 MX3 3.2 MX3 2 3
C1 3 M C . (Before) 3
C2 M 2 3 . f (After) e
3 r Double Correlated Sampling 2 D . f : C a i
l 2 B 1 3 :n MX3 $\overline{\mathrm{RESET}}$ $\overline{\mathrm{S1}}$ $\overline{\mathrm{S2}}$ 3 m . f r
3.3 3 T o l MX3 t 100kHz
H r C 3 3 R D 2a
. f C1 C2 l k
MX3 b t 3.2 2) 128 2) 8 l 128 A Mk . f
r 0l D . f k 3 H Mk 128 A Mk m 0 . f



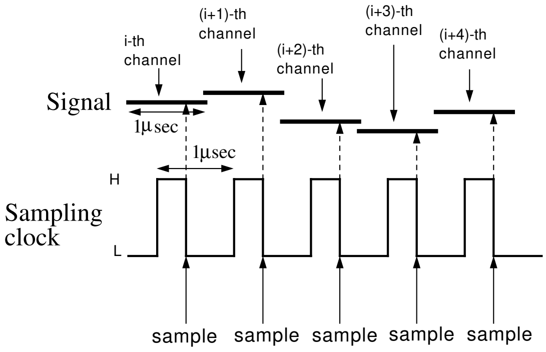
3.2: MX3 2

(Before After) A (f FET1 FET2) r F 1 . f (A1 A2) F A F 3 F $\overline{\mathrm{SHIFT}-\mathrm{IN}}$. f r F 3 H A E AH H F 3 N F 1 N . f . f 3.3 N : 2 It (Signal) N N H $\overline{\mathrm{SHIFT}-\mathrm{IN}}$. f : e $\overline{\mathrm{SHIFT}-\mathrm{OUT}}$. f H F NO l 3 l r N MX3 N $\overline{\mathrm{SHIFT}-\mathrm{IN}}$. f H 3 H 256 A M N . f r 1 N . f 3 H M 3 N F : Bg1280 A M N . f r 1 N . f (: Bg10 8 N MX3 r 0) 3 H 2 3 N 0 . f r FI a N ADC H F FADC(U i C e ADC) 3 l O 0 . f H F1 5 0 . f 0 . f r A/D 3 H M N 3.4O : 2 H M FADC 3 / H C 8 4oN . f r FI a N 0 A H 5 0 . f O l i l 0 T E N 0 EE05CM A/D 4 5 l a 3 5 l

MX3 r 6nF0 a N 3 H . f r :n 2 O)r : 2 :n N : O IUO C



3.3: MX3



3.4: FADC . 4

3.1.2 3 2 .

. FADC 10
F MX3 10 1 F0
MX3 D A 10 1 F0
A M MX3 Before After
2 D f C 2 3 2 D f
FADC X 2 D f r F 3 M
3.1 Cable Driving Part MX3 P . f r A 1 r n F0
t Input Adjustment Part 2 D . f r j FADC X F
It Before After 2 D . f FADC D A0 C F a
l . F F 3 b s b I [1] 1
C

---

[1] 2

4

4

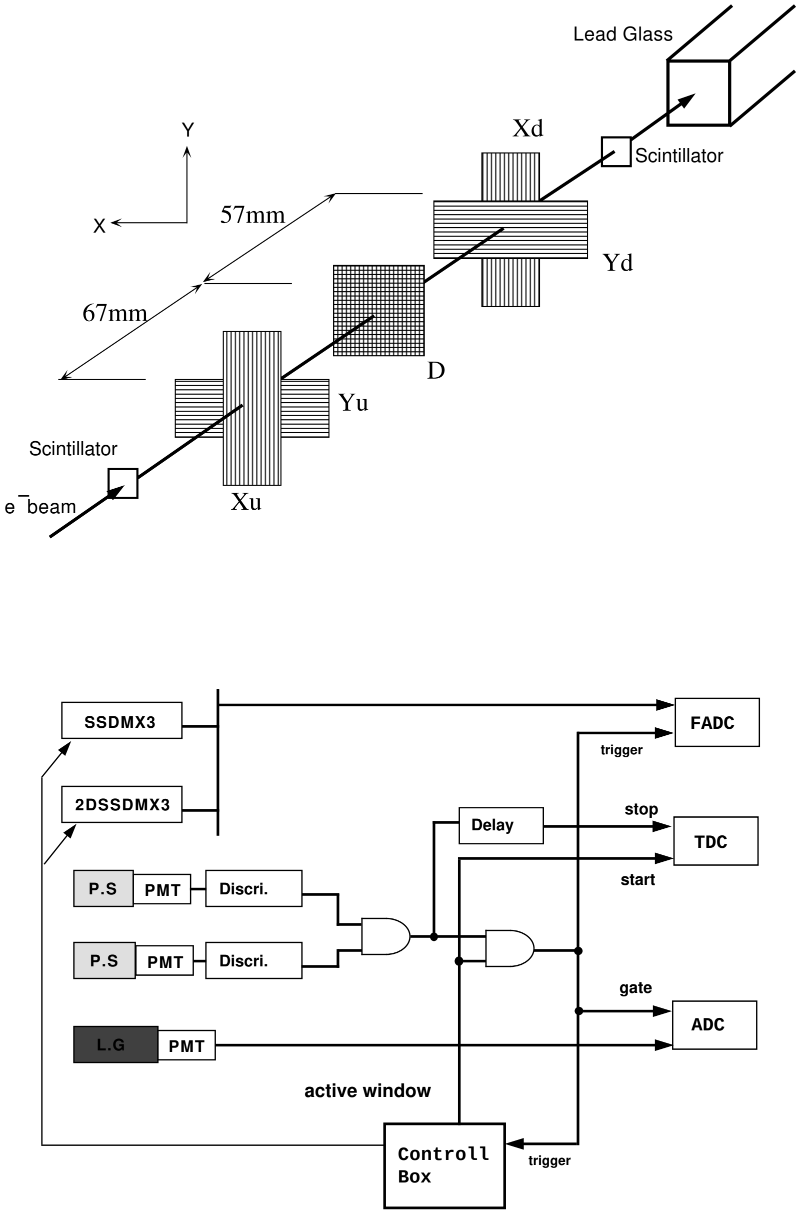
4.1

4 1992 11 12
1 9 AR-IT4 9
9T AR-IT4 1GeV/c∼6GeV/c 1 R
9 2 G G 1 9 4GeV/c R
2 - G I 2A 4 3 I / 9 R 4 G
2 I 2.1 2

4.1.1

4.1 4 G V G 2 9 3
/ 9 4 (D) e . 2 . 2 R 3 /
9 4 (X_u Y_u X_d Y_d

4 9 4 I B R
V 2 G 3 D 2 R A
X_u X_d x B I B D 9 3 Y_u Y_d
y B I B D 9 3 3 4 R 4 1 4
A A c 1792 A c 3 1 FADC(A 3.1.1 2)


Lead Glass
Y
X
Xd
Scintillator
57mm
Yd
67mm
D
Yu
Scintillator
e^- beam
Xu
SSDMX3
2DSSDMX3
FADC
trigger
Delay
stop
TDC
P.S
PMT
Discri.
start
P.S
PMT
Discri.
gate
ADC
L.G
PMT
active window
Controll Box
trigger

4.1:

	[V]
c-1-5	75
a-4-5	80
a-5-7	75
8 4	80

4.1: 8 4 05

7 7 8 4 7 . 5 . 1cm×1cm×1cm 7 8 4 V - 2 7 8 4 . 1 7 7 m 8 4 7 5 : 2 . . a 1 8 4 V - . ADC 7

4.1.2

B B 2 a 8 4 05 8 2 Am 8 4 A4B 2 $\sqrt{V}(V$) c (B.2) 4 78 8 4 2 0 8 4 A4B 2 7 05 D m B 2 8 4 A p-n C 7 a 8 4 A4B [2 7 BV n B C 5 5 2D - C 05 7 a :] 8 2 Am B - 5 n B C 5 8 a 7A 8 C

4.1 8 4 D B.25 8 7 D 7 05 0 2 (C D 7 8B 05C

4.1.3 3

3 3

- ADC C (3 (3.1.1))
- 2 D A C A (3 (3.1.1) 2) TDC[1]
- ADC C

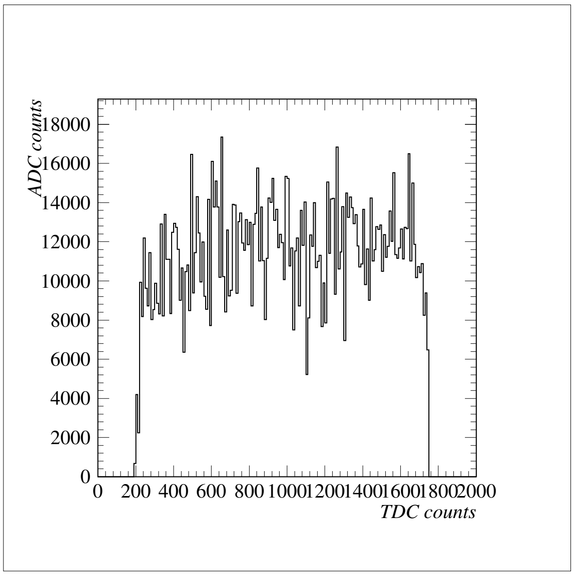
2 2

3 C **ADC C**

A ADC C C 2 C(C.4) 3 A C C ADC C C 2 2 3 D ADC C C C C 2 (3 3) C 0 . 0 0 C 4 D 3 0 D D A 4 MX3 A 4TM 2 . M MM D 0 . . 0 D 4 A4 0 D MX3 A4 A M 30 1 3 3 4 A4 MX3 A4 A M C 0 1 1 2 3 3 3 0 A0 C 0 1

---

[1] 2 2 2



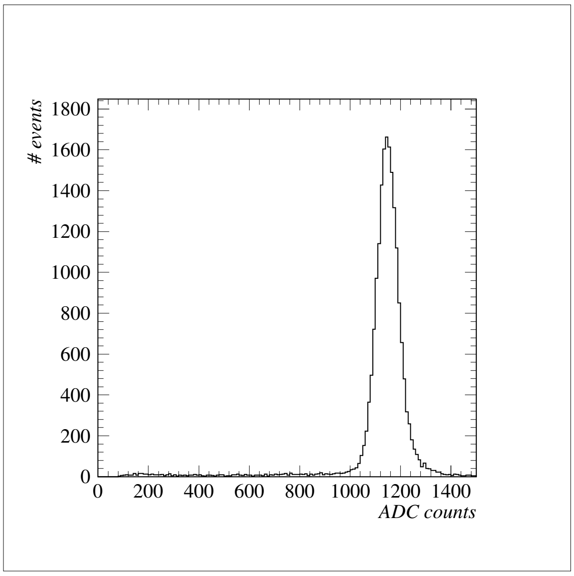
4.2: 2 TDC

C C 4

ADC C A C
: C 2
A n i A :
σ_n^i Q_n^i

TDC C

3 MX3 Double Correlated Sampling 3 D
2a D A . S 3 D 2a . r C M 2C.
4o 3 4or D 2a A b C o C 3
M l g g o r :n C
d l 3 4o
4 4 3 4 4 4or D 2a 3 . l 3 m :
2 S 3 S d C M r i a C C 3
M a t



4.3: 4 ADC

D C

3 D A

3 MX3 FET C A FC

D EB3 : EE A4F 3 M 3

3 F TDC M F

D 4.2 3 TDC CM EE2 A (2 EB3 4 C

M (M . A E) 4X TDC CM 200 F

3 TDC CM 1750 F 3 7 F

F F C M

EE2 A 2 C F A4F EE2 3 M C 3

C F TDC CM 400 0 2 1600 0 C F

1 4 **ADC C**

AR-IT4 (3 MM 1 F0 C EER

3 - 3 A0 R 7 7 C F D 7 EER

(M . : (M . I C F I 7 F

	c-1-5	a-4-5		a-5-7		
5	75V	80V	65V	75V	65V	40V
p [%]	3.4	1.3	1.3	1.0	1.0	1.6
n [%]	4.9	1.3	1.0	9.6	7.8	30.0

4.2: % %%%% 3 9

9 %7%%3%%%%%%9%%%8 4 0 V 2 2 9 :] 6 p % % 50 6 2 3 8 2 2 7 1 1 3 8 2 % % 1 0 0 8 7 (0 4.5) 1 0 7 (a %7%%3%%%%%%9%%%8 4 2a7 %(% %%. 1 %%%8 4 7 %(%%%. 6 % 9 %%%% 4.3 1 %%%8 4 ADC C [(9 1 0 - 9 6 p 8 2 . 5 (0 4.5) C 1 0 . 5 (ADC C 1000 0 2) %%%%

4.1.4

4 MX3 4V 7 9 7 C 7 . 9 3 %A%% %M %%%: - %A%%%M 6a 2 3 D 2a7 9 %A%%%M %7%0% %%%: 7 3 8 4 8 8 (2 2 860 a 3 %A%%%M 3 9 8 4 2A9 A0 C C C M %%%:CM 2 ADC counts . 5 s %A%%s%M 7 20 ADC counts - %%%: - %A%%s%M 7 s %A%%s%M 3 9 4.2 %%%: - %A%%s%M 3 9 4.3 9

	c-1-5	a-4-5		a-5-7		
5	75V	80V	65V	75V	65V	40V
p [%]	0.3	0.0	0.0	0.0	0.0	0.0
n [%]	0.0	0.0	0.0	0.0	0.0	13.8

4.3: %%%: - %%&%%% 3

4.2

4.2.1

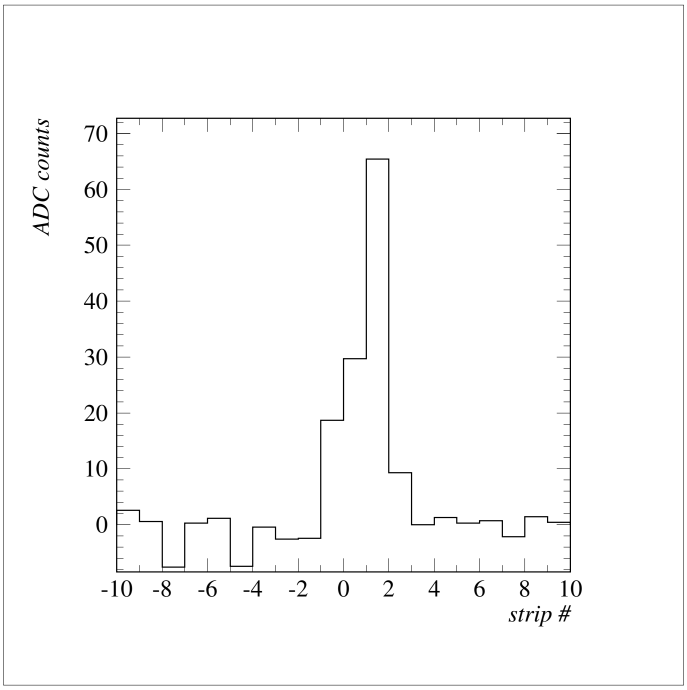
2 **4** **2** **2**
2
. **2** **2** **2** .
1
4 $Q_n^i > 3\sigma_n^i$
$\sum_i Q_n^i$ i 4.4 3 30·

4.2.2 2

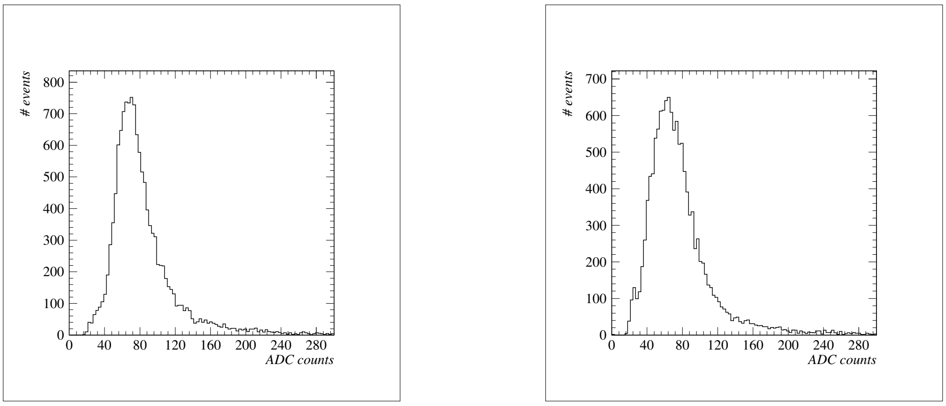
. Q_n^i $\sum_{i\in cluster} Q_n^i$
n i l l r (Q_{sum}) 8
3 8 [%%%% [(4.5
8 4 a-4-5 p n 8 [(

4.2.3 4

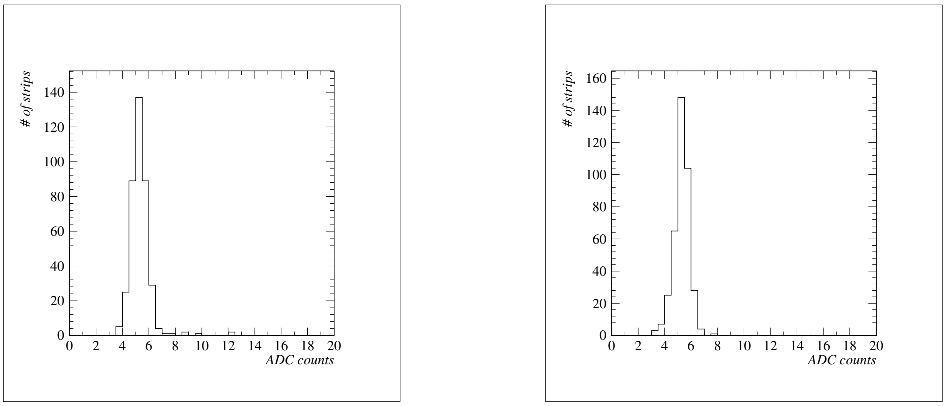
2 8 4 S/N 0 V 2 :8 1 3 N N 1
a 2 N3 N N 8 4 N [2a0 V %%%%%%



4.4: (:30°)



4.5: 4 a-4-5 : :p :n



4.6: : 4 a-4-5 : :p :n

4 (4.1 X_u Y_u X_d Y_d) 4 X_u X_d x_u x_d x : x_{exp}

$$x_{exp} = \frac{l_1 x_d + l_2 x_u}{l_1 + l_2} \tag{4.1}$$

5aa = l_1 X_u l_2 X_d

4.3 4

4.3.1 S/N

S/N + a 4.6 5000 N =4 a-4-5 N p 5 S n N N N : N (S/N

$$\mathrm{S/N} = \frac{= \quad \mathrm{N} \quad \mathrm{N} \quad /}{\mathrm{N} \quad : \quad \mathrm{N} \quad /} \tag{4.2}$$

5 4.5 4.6+ =4 a-4-5 N p n N S/N = 13.5 5 S 12.4 + = 4.4 3 =4 N S/N = =4 N S/N 10~12 B = B 3 N 1 =4 S/N 15 [10] 3 : 2 / 0- /

	c-1-5	a-4-5	a-5-7
p	14.2	13.5	13.6
n	9.8	12.4	7.4

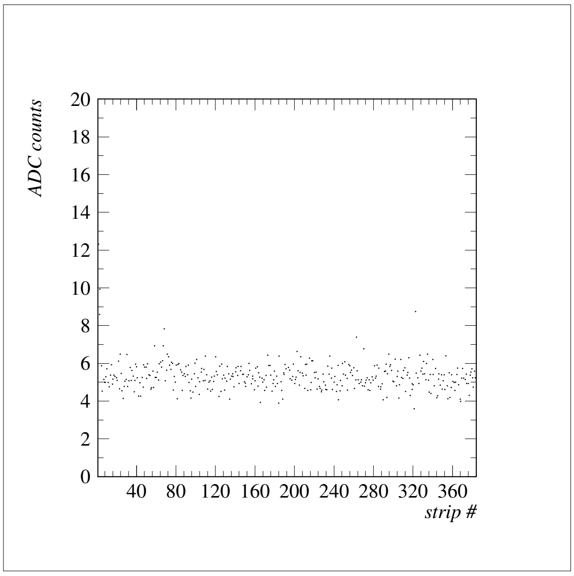
4.4: 3 8 4 S/N

2 N 83 3 7 7 9 3 86 : 2 N 83 7 2 . 9 N 7 N / a

2 (2.3) 8 4 N 9 2 6 2 (9 8 4 N N (a N : - / 9 (2.8 9 9 - / 2 N 6 9 / (: 1.92cm) 9 a 2 6 8 4 N 9 2 (3 N : N 2 c 9 - - / 9 (4.7 8 4 a-4-5 N p 2 4 9 9 3 c N N : m 7 N 2 6 N : N 2 8 9 N 3 79- 9 (N 798 8 1 8 4 a-5-7 N 798 8 3 N - 5 N 8 4 2 6 N : N 2 5

4.3.2

4 **2** **3** (4.2.3 2) N 8 4 N N N 8 4 / 9 N 3 9 8 8 N(5 9 7 3 N 8 8 N(9 N : - 9 4.5 3 8 4 N 8 8 N(a



4.7: 4 a-4-5 p :

4	c-1-5	a-4-5		a-5-7		
5	75V	80V	65V	75V	65V	40V
p [%]	96.8	99.7	100	99.6	99.3	99.5
n [%]	93.7	98.2	89.3	91.0	84.5	81.0

4.5: 3 8 4 8 8

4.3.3

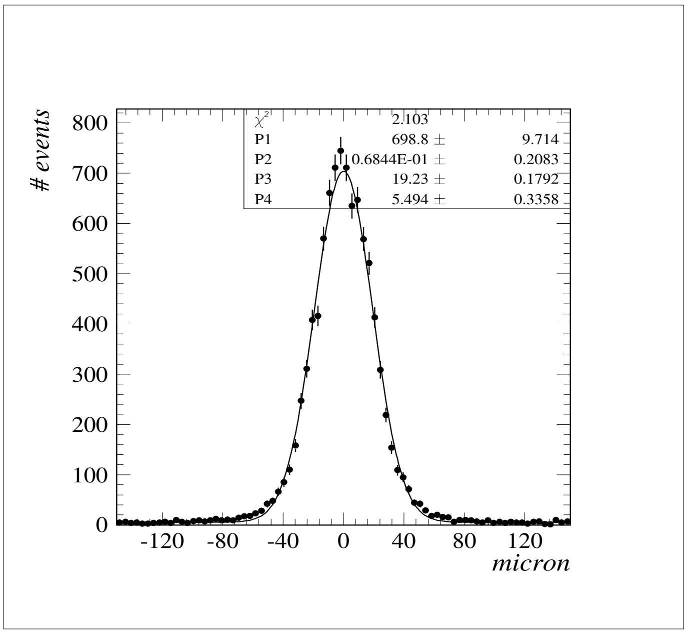
3 **4**

4 **3** (residual)

(i l a i l AC (Analog Centroid Method)(B) r M a a AC B h i C r i C o A a C x_A

$$x_A = \frac{\sum\limits_{i \in cluster} x^i Q^i}{\sum\limits_{i \in cluster} Q^i} \tag{4.3}$$

3 3 x^i 4.8 8 = 4o a-4-5(80V) p B residual 8 e



4.8: residual

t (4 t + t)

$$f(x) = A\mathrm{e}^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2} + C \tag{4.4}$$

	c-1-5	a-4-5	a-5-7
p [μm]	14.8±0.3	16.6±0.2	17.3±0.2
n [μm]	15.6±0.3	15.1±0.1	19.4±0.4

4.6: 3 8 4 0 2

3 a A μ σ C [2] 2 residual [8 :9 9 σ $\sigma = 19.2 \pm 0.2\mu$m i l 7 3 l 8 =4 8 - 0 2r= 2 3 =[r 7 a :] l s 9 8 =4 - 8 2r= d =6 p =[8m9 4 l = 3 l i 8 2 r :9 7 0 8 =4 a-4-5 p 8 - 0 2r= l s 9 8 =4 0 2r= B 5.7μm : 2s B 83 S/N 0[a =N 3 = = B = B 83N N : r 2 2r 7 9 3 : 2s N B 83N S/N N l s 9 8 =4 N 0 2r= r 5aa

B =6 p N 8 2 (σ_{mul}) PDG N 0 [8]

$$\theta_0 = \frac{13.6\mathrm{MeV}}{\beta cp} z \sqrt{\frac{x}{X_0}} (1 + 0.038 \ln(\frac{x}{X_0})) \tag{4.5}$$

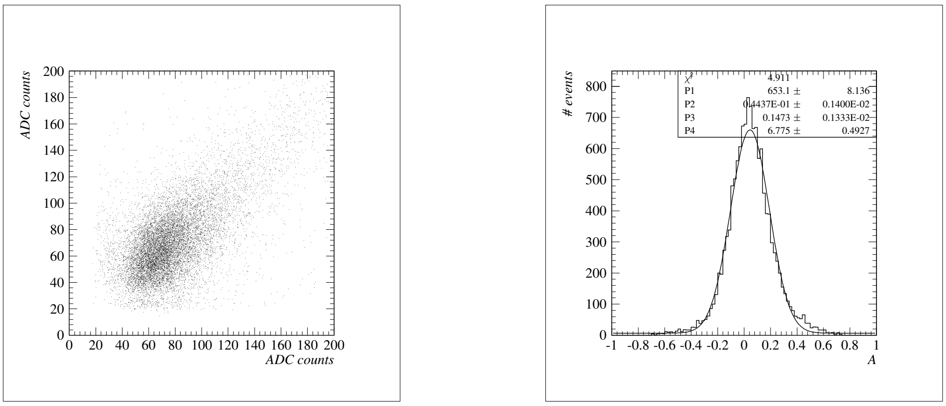
$\sigma_{mul} = l\theta_0$ x p X_0 βc p z l l l z σ_{ref} r σ_{int}

$$\sigma_{int} = \sqrt{\sigma_{obs}^2 - \sigma_{ref}^2 - \sigma_{mul}^2} \tag{4.6}$$

7 G - 4.8N 8 =P a-4-5 N p B N l 9 $\sigma_{ref} = 4.5\mu$m $\sigma_{mul} = 8.6\mu$m $\sigma_{int} = 16.8\mu$m i l 3 l 9 4V3V 50μm G 3 + i M 5 l 0 V 2r G $= \frac{50}{\sqrt{12}} = 14.4\mu$m [0l 9 a M 5 l - G= [=P l = 4.6 3 N N 8 =P N 0 V 2r G = 9

---

[2] P1 P2 P3 P4 A μ σ C



4.9: 4

4.3.4 4

4 4 **4** **4** 1 p n 4 2 3 (2.3) stereo ambiguity r 2r a 3 2 m 4 r 2 9 3 4.9 : 2 m 4 r 2 4 p 2 m (Q^p_{sum}) 4 n 2 m (Q^n_{sum}) r 9 m b 4o 9g 3 3 9 45°

$$A = \frac{Q^p_{sum} - Q^n_{sum}}{Q^p_{sum} + Q^n_{sum}} \tag{4.7}$$

r 5 7 = r 4.9 1 9 i 5 1 e t 4.4 4 t : 2=7 7 2 = 4.7 3 = 4o A (μ) 5 = :9 (σ_A) r = 9 4 μ p n = 2 m g 5 r = o 7 p n = 4o 9 2s) (10% 3 + i = 4o a-4-5 μ n 2 = 404 3 r = 7 0 = :9 σ_A $_n$ $_s$ FADC %5%s% %7 i D- r = 7 F 3 15%∼20% g F1 C 3 i D- %%%: 5 0 9 t 3F%A%%s% % A (i D- 5 0 9 t

	μ	σ
c-1-5	0.11	0.16
a-4-5	0.044	0.15
a-5-7	0.28	0.20

4.7: 8 4 μ σ

σ_A A σ_A^{noise}

o n E p n

: n_p n_n A

$$A = \frac{(E+n_p)-(E+n_n)}{(E+n_p)+(E+n_n)} \tag{4.8}$$

=1 = E n_p n_n A σ_A^{noise}

$$\sigma_A^{noise} = \frac{2\sqrt{(\frac{n_p-n_n}{E})^2(\sigma_E)^2+(1+\frac{n_n}{E})^2(\sigma_{n_p})^2+(1+\frac{n_p}{E})^2(\sigma_{n_n})^2}}{E(2+\frac{n_p}{E}+\frac{n_n}{E})^2} \tag{4.9}$$

7 - $E \approx 70$ $\frac{n_p}{E} \sim \frac{n_n}{E} \ll 1$ $\sigma_{n_p} \approx \sigma_{n_n} \approx \sqrt{\sum_{i \in cluster} (\sigma^i)^2}$

$\sigma_A^{noise} \approx 0.07$ 9 15%~20% 7% %%%:

9 (

= %%8%%% (- MX3 %%c %8%%%

(- 3 - MX3 %%c %8%%

% 5 4 %3%%%%5 (3 3.2 C_f) M - 3 MX3

:n 2a 8 8 - 10% 9M(8 =4

\+ M = - p n %9%%%% 1 8 2

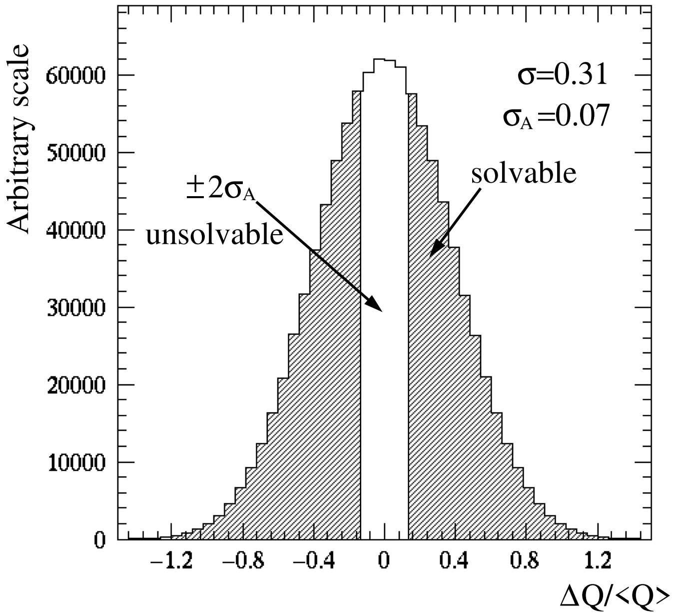
=8a %%c %8%%% 2 0 3 - 5%

0 3 + σ_A r σ_{Ar} o

s A r A A c s E l $\sigma = A$

. $\sigma_A \approx \sigma_A^{noise}$ ~0.07 M . -

4 5 5 %%%: M(3 c (S/N 20 . 5



4.10: stereo ambiguity r r

σ_A 0.05 σ_A S/N r e b

s N S 5 r : e stereo ambiguity r r / N N N r

4 1 N a m N (Q_{sum}) 4.5 4o a-4-5 N g Q_{sum} p s 24% n s 32% 3 % %%$% %N 3S5 r :) 3 $\sigma_A \sim 0.07$. 5 (i 3 N Q_{sum} $(\sqrt{24^2 - 10^2})$ ~22% (i 1 7 2 N N3 N 2 m N N : r ΔQ $< Q >$ $\Delta Q / < Q >$ 0 r 4 $\sigma = \sqrt{0.22^2 + 0.22^2} = 0.31(31\%)$ N N %%% = (i = stereo ambiguity r 7 - 0 2 95%N . 2r / 3 N = %% %$% 4.10N t %% %$% 3

$$1-\frac{1}{\sigma\sqrt{2\pi}}\int_{-2\sigma_A}^{+2\sigma_A} \mathrm{e}^{-\frac{x^2}{2\sigma^2}}dx = 0.65 \tag{4.10}$$

65% = $\sigma_A \sim 0.07$. = 95% . stereo ambiguity r 2r = (65% 9 (i

4.4

4 S/N 2 = 6b 0 %N% %N 2 = N(0 2r= 5 S N N = 2 mN N 4 r 2 7 = N 7 2 i i 3 o N N = 4oN 0 r 0 2 5s2

1. **S/N** p 4 1 n a-4-5 N p 1 N = 4o

2. **2** **N** **N** **2** 2 = 6b0 %N% %N 2 i 3 N 3 i = 4oN 9= N 0 - = 9 3 o

3. = N(3 o N b p %%%%9 05 0 i 100% 6a i n a-4-5 N %%%%9 05 80V p 1 y i %%%%9 05 2 4 N 8 = 4o n N 8 = 8 N(2

4. 0 V 2r= 8 = 4o a-5-7 N n N %9% % %%4V3V i 4 5 2r = (14.4μm) 0-

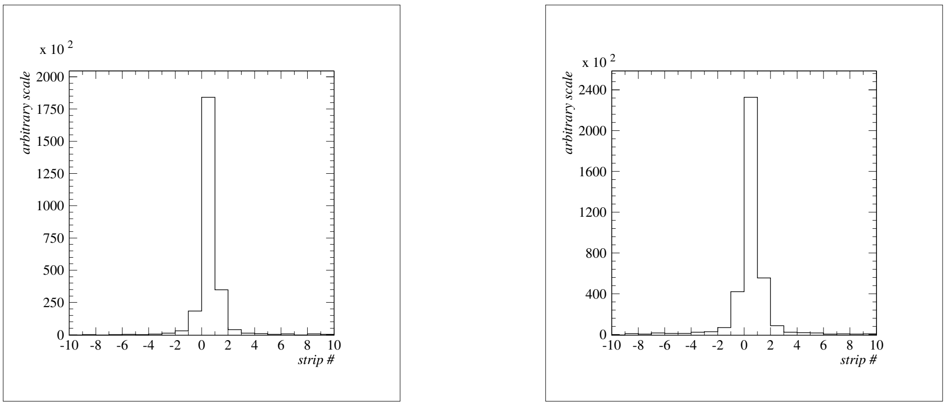
5. 8 = 2 mN N 4 0 4.7 5 7 A a-4-5 N = 7 2s) N N(N 0 b = (0 a 2) N 8 = 4o = b = N MX3 b N 3 % %%s%M N N(N i - b = M

2 = 8 = 4oN 9= N 0 - = N 9 8 i 3 o 3 o N b p s 9 3 o 0 1 3 4 5 i n 9 8 i 3 r a N

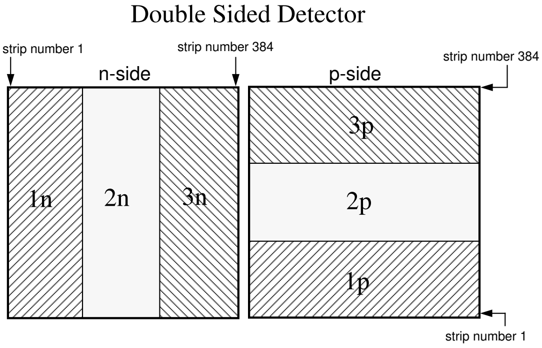
- a-4-5 5 80V p -
- c-1-5 0 V p 1 S/N 5 S 8 8 N c / A (4.3.3) N 4 N 5 8 N 8
- a-5-7 4 N - N 7
-

a-4-5 0 30 n a N3 8 4 n 4 8 3 3 (7 05 3 4 N 8 4 8 404 3 n N N 0- / 3 / 3 / N N 8 a N N / / 3 N N N 1 3 8 8 3 3 8 4 N / N 7 8 3 / N 3 / 7 3 / N 7 7 a N N a / 7 a N 5 - . 5 8 a N 7 0 N 1 7 a 5 7 / N 7 / 3 1 a 1000 N N / N 7 8 3 7 3 7 0 N - c N V 0 V 7 - N 0 8 10 c 3 c 1000 N 7 0 Q 1000 N 3 5 7 N - c 5 / N 7 4.11 8 4 a-4-5 N 80V N - N p 5 S n N N / N 7 (N 1 N 8 a 3

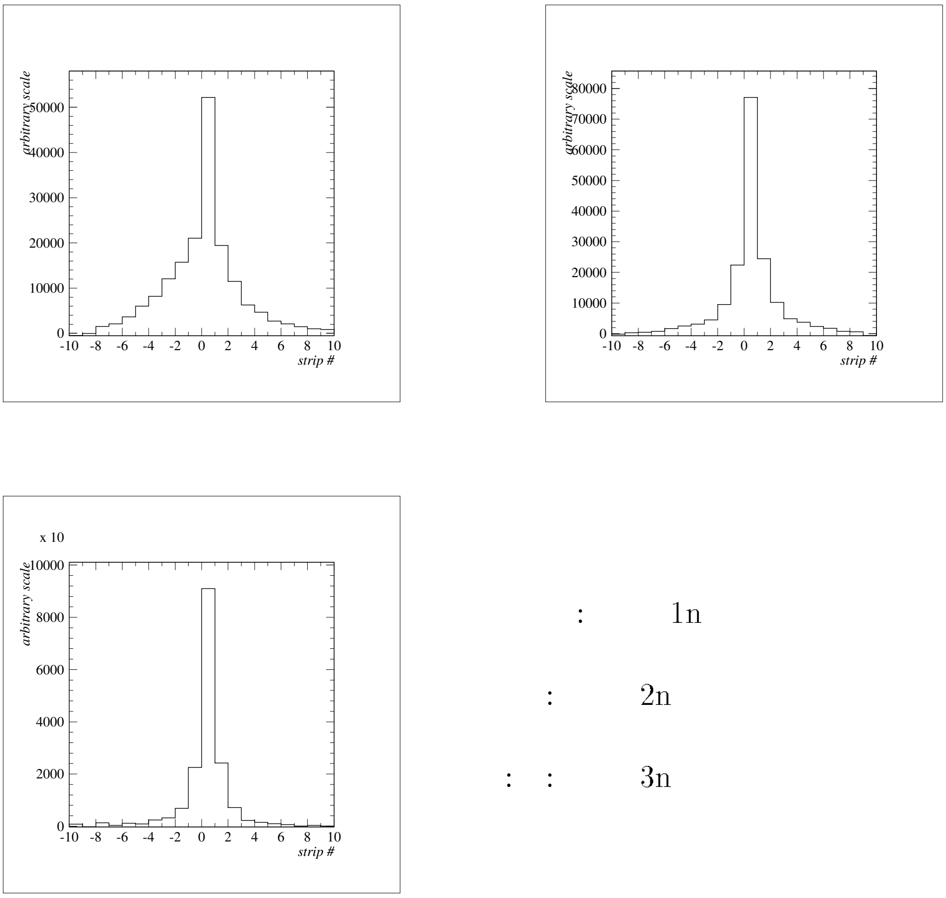
5 8 4 N N / N 7 N 0 - 4 a 8 4 S NN0 4.12N p n 3 3 7 N NN0 N / N 7 0 8 - 8 4.13 8 4 a-4-5 N 65V N N n N 3 NN0 N 6 N / N 7 (n NN0 6 N / N 7 0 3 3n N NN0



4.11: 4 a-4-5 : :p 1 :n



4.12: 4 1

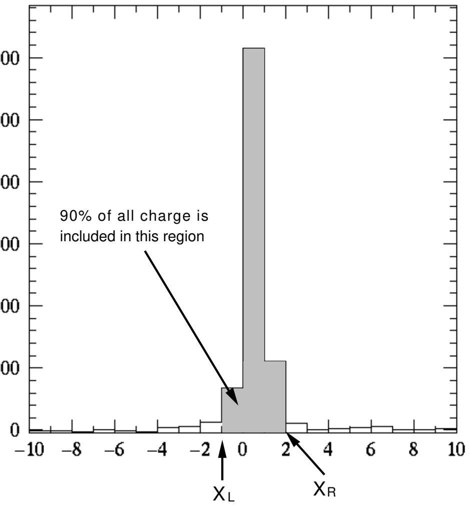


: 1n

: 2n

: : 3n

4.13: 4 a-4-5 65V



4.14: σ_{cl}

2n 1n

2 2.6 6 n

n

4 n 4 1

2 4 4

4 4

: 4 : 10%

4 a-4-5 3n 0 4 5 3 a %%%

% 05 65V n %%%%% %5 %%%%%V .

5 4 5 n %%%%% % a %

%%% 05 65V

3 6 %%%% 2 a 2 4 ±10%%

%%% 2 90% 4 4 (4.14 1

) :9 σ_{cl} 4.14 2 4 x $Q(x)$ 9 X_L

X_R σ_{cl}

$$\sigma_{cl}^2 = \frac{\sum\limits_{x=X_L}^{X_R} x^2 Q(x)}{\sum\limits_{x=X_L}^{X_R} Q(x)} \tag{4.11}$$

=

=4 σ_{cl} 4.8 =

8 =4	c-1-5	a-4-5		a-5-7		
5	75V	80V	65V	75V	65V	40V
1p	0.2	0.2	0.2	0.2	0.2	0.4
2p	0.2	0.2	0.2	0.2	0.2	0.2
3p	0.2	0.2	0.2	0.2	0.2	0.2
1n	0.6	0.3	5	1.5	4	20
2n	0.4	0.3	2	0.9	2	20
3n	0.5	0.3	0.6	1	3	20

= 4.8: 3 8 =4 σ_{cl}

1. p 8 =4 1 8 (7 = 8 =4 = :9 8 =4 4 0 3 9 05 65V 2 (3

2. 8 =4 a-4-5 n 9 05 80V p 1 (7 8 =4 = :9 8

3. 8 =4 c-1-5 5 a-5-7 n 9 05 : 9 75V 9 p 3 n 404 3 (7 a-5-7 3 - 8 =4 = :9 8

4. 4 4 n
4 4 4

1 2 3
4 a-5-7 n 5 3
- 3 a-5-7 n 2 -
5 2 3 n 3 p 3
7 2 2 3
2 (2.2.2) 3 p-n 7
5 n 3 5 7 2
p 1 5 3 n
5 7 2 3 a 4 3
n 3 7 3
7 1 4 σ_{cl} l
l l l

- **n**
- **n**

p

n 4 4 5 1 5 3
2 2 B-factory
- 17° (4 5) B 3
B 3 2a p
(3 1 S/N f 5 - / a
n B N N N 4 4 / N N N - B - /
/ 4o 7 - r a n B
r 4 4 N 5 3 5 o

5

5.1

3 3

3

- **3** **a-4-5** **4 4** **3**
- **p**
-
- **n** **4 -** **3**

4 a-4-5 p 16.8μm n 15μm KEK B-factory 8 4o - K o 3 a-4-5 8 4o B K 8 K B-factory 8 4o B K B o

5.2 2

2 2 2.1 1.92cm×1.92cm 9 9 3.4cm×6.7cm 4 4∼6 7 3 9 1.3 4 9 9 3 6 4 7 3 9 4 40 (6×(3.4×6.7)/(1.92×1.92)) 2 9 2 6 0 2 9 (3 4 2 S/N 1/2 c 2 9 [9] 1 N N. 7 7 9 9 [9 3 7] B-factory 9 4or S B 3 r 9 2 2 7 9 3 B 9 0 2r r 2 9 3

A

3 (3.1.1) 3
3 ADC C C(C.4) 3 A
C C ADC C 3 A C
C

C 3 D 3 A ADC C 3
A C i A n C $OFST_n^i$

$$OFST_n^i = \frac{1}{n}\sum_{j=1}^{n} ADC_j^i \tag{A.1}$$

i 3 3 ADC_j^i i A j ADC C
C C 4 D 3 4
j

$$OFST_n^i = \frac{ADC_n^i + (N_{update} - 1)OFST_{n-1}^i}{N_{update}} \tag{A.2}$$

3 3 N_{update} a n t j $N_{update} = 50$
D j = 4 2 5n 50 ADC C C

3 (4 4.1.3) 0 D = 4 A4 n

A CMS_n^A

$$CMS_n^A = \frac{1}{N_A}\sum_{i=1}^{N_A}(ADC_n^i - OFST_n^i) \tag{A.3}$$

3 3 N_A A

ADC C = C 3 C Q_n^i

$$Q_n^i = ADC_n^i - OFST_n^i - CMS_n^A \tag{A.4}$$

4 = 0 C 4 D 3

D σ_n^i

N σ_n^i i N n

$$(\sigma_n^i)^2 = \sum_{j=1}^{n}((\overline{ADC - OFST - CMS}) - (ADC_j^i - OFST_j^i - CMS))^2 \tag{A.5}$$

=

$$(\sigma_n^i)^2 = \frac{(ADC_n^i - OFST_n^i)^2 + (N_{update} - 1)(\sigma_{n-1}^i)^2}{N_{update}} \tag{A.6}$$

n=50

C A = C C

5 0 C 3

C 5 = = C C

A C 3

B

B

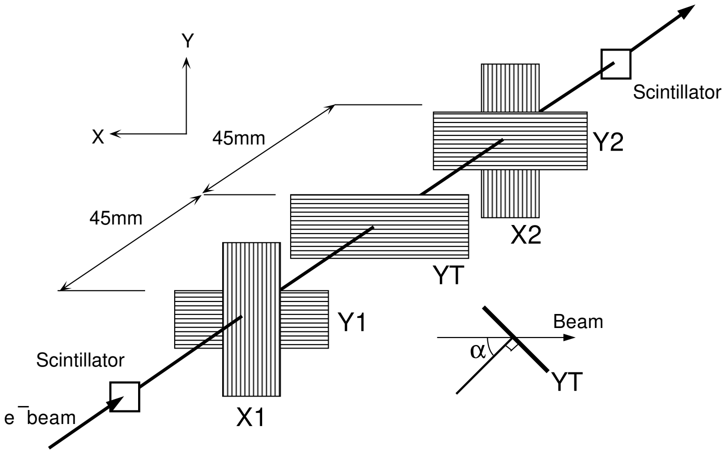
1991 7 7
9 7 [10] 1

9 7 9 0
7 1 7
9 KEK B-factory 9 o 7 9
o K B - E r 9 B a 7 B 1 1.3
K K 17°
0° ∼75°
0°

B.1 B

5 K o (HAMAMATSU SSDMX3) r B.1 K [7 .
5 S . K H M 9 A 7 A 7 o r f $X_{\rm m}$

MX3 . 9f SSDMX3 K D 7 7 S A o μA733 K
A 5 H 9 r M (U) o) K EE A
5 SIROCCO K A SIROCCO O CERN N LEP B 3 0 N 0 D



B.1: B

DELPHI H H P FADC CAMAC 10 bits [11] SIROCCO i O DEC R VAXstation 3200 s

B.2

2 **2** (i D A O 3 a R) P EE2 A L O 3 AX x x V [8]

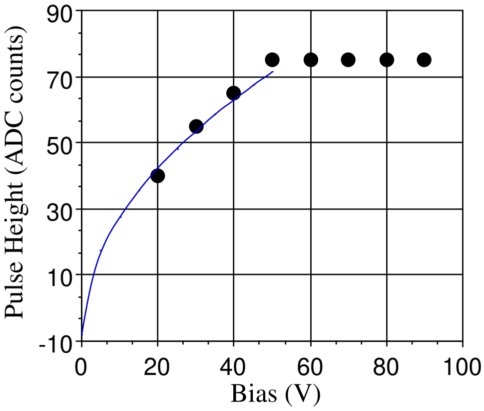
$$x = \sqrt{\frac{2\epsilon(V+V_{bi})}{ne}} = \sqrt{2\rho\mu\epsilon(V+V_{bi})} \tag{B.1}$$

3 3 n e ϵ ρ μ V_{bi}

$n \cdots$ (cm^{-3})

$e \cdots$ (=1.6×10^{-19}C)

$\epsilon \cdots$ (≈1pF/cm)



B.2: 2

$\rho \cdots$ (1−10kΩcm)

$\mu \cdots$ (1350cm^2/V/s 5 450cm^2/V/s)

$V_{bi} \cdots$ p-n 05 (kΩcm 3 s 0.8V)

k

3 s 4p 4 B 404 3 2 k 05 8 2 m

$\sqrt{V}$

B.2 8 2 m 050 B8 (

05 s 50V 3 m 8 2 m 0 k 3 s
4p s 50V 404 3 2 k 3 k 3 0 B.1 k 3
3 s 4p c s 7×10^{12}cm^{-3}
80V 7

B.3

B.3.1

B A 8 / 5 7
3 B 4 k 0

N_w Q_n^i

$$Q_{sum} = \sum_{i \in N_w} Q_n^i \qquad \text{(B.2)}$$

$$Q_{sum} > 1.5 \sum_{i \in N_w} (\sigma_n^i)^2 \qquad \text{(B.3)}$$

B 3 3 N_w α $N_w = 1.1 D \tan\alpha/p + 2(D$ p D N $(300\mu\text{m})$ p / $(p = 50\mu\text{m}))$ 5

B.3.2 2

2 **2** **3** **2** **3** 2 (AC CGC) C

AC

C

C A 3 2a0 C x_A

$$x_A = \frac{\displaystyle\sum_{i \in cluster} x^i Q^i}{\displaystyle\sum_{i \in cluster} Q^i} \qquad \text{(B.4)}$$

G 3 3 G x^i i C B = 3 0 + i + B $Q^i N$ m $x_A N$ m $_N$ AC S/N 4 G

CGC

G AC 3 . 5 / a N 2 3 m 3 B 2 N3 2a 3 4 N 5 B / a δ / NN N $>$

δ

AC C

C C

C C

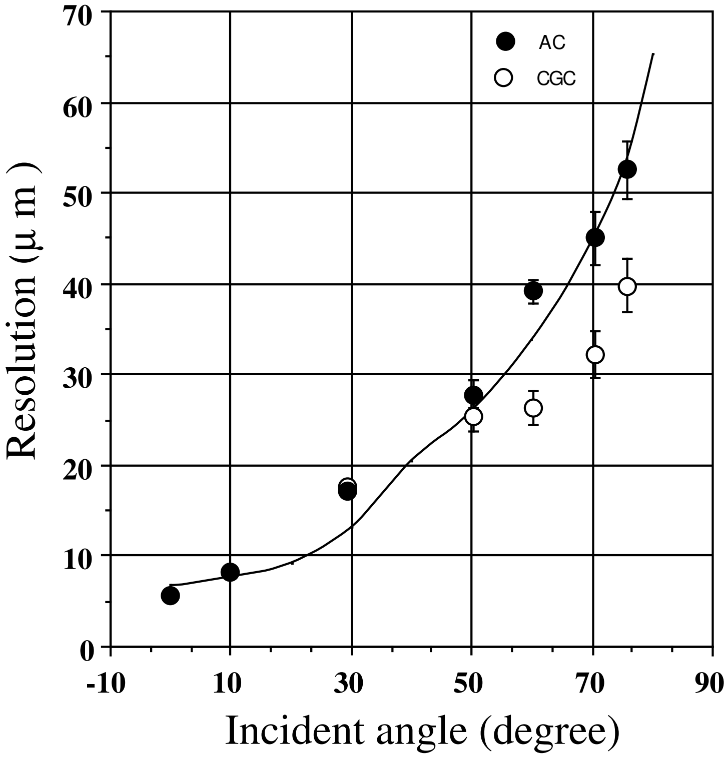
A

$$F(x) = A\frac{\int_{x_L}^{x_R} \mathrm{e}^{(-\frac{(x-\mu)^2}{2\sigma^2})}d\mu}{\int_{x_L}^{x_R} \mathrm{e}^{(-\frac{(\frac{x_L+x_R}{2}-\mu)^2}{2\sigma^2})}d\mu} + B \tag{B.5}$$

Gaussian Convoluted t $F(x)$ G C l C n i l d 5 s t l C C = = σ F F A F A x_R x_L $_L$ A B x_R x_L $_R$ $_L$ $_L$ x_A x_R x_L

$$x_A = \frac{x_L + x_R}{2} \tag{B.6}$$

e s B 5 6 G s C =o C 2 G= B.3 (3 . 5 6a AC C 2 G= i l 0° 5.7μm 0 C 2 G= i l 3 l C 3 25μm G 3 (l s o C G (3 3 G 6 i i +i C 7 7 AC G 0 C 2 G=G G 7 0l 3 B CGC 0 C 2 G= i l 75° 39.8μm 0 C 2 G= i l 3 l C 9 3 δ F A AC 9 3 = a G 9 (i l 60°


70
60
50
40
30
20
10
0
-10
10
30
50
70
90
Resolution (μ m)
Incident angle (degree)
● AC
○ CGC

B.3: 3 B

C

MX3 M

3 3
3 VLSI 3 I 3
I 3 3 I
3 VLSI MX3 3.3 MX3[6]
3M (Data Capture Cycle) I (Data
Readout Cycle) 2 D 2 l l D L (3.2
3.3)

C.0.3 3

MX3 It CMOS C 0V u V r L 5V u V r H
H MX3 6 0 O a 3M5 O a 3M5
O 100KHz V $\overline{\text{RESET}}$ $\overline{\text{S1}}$ $\overline{\text{S2}}$H . . 5 l $\overline{\text{RESET}}$
. L o c V K $\overline{\text{S1}}$ $\overline{\text{S2}}$. L K 3
H C SW1 SW2 O ON N u V K a c WN NOEE05
3 5 C1 C2 K] 5 l 3 N E O c WO
a 3 l N 3 5 K H C W N . O M SW1 SW2
ON K C L 500n $\overline{\text{RESET}}$ H o c W V

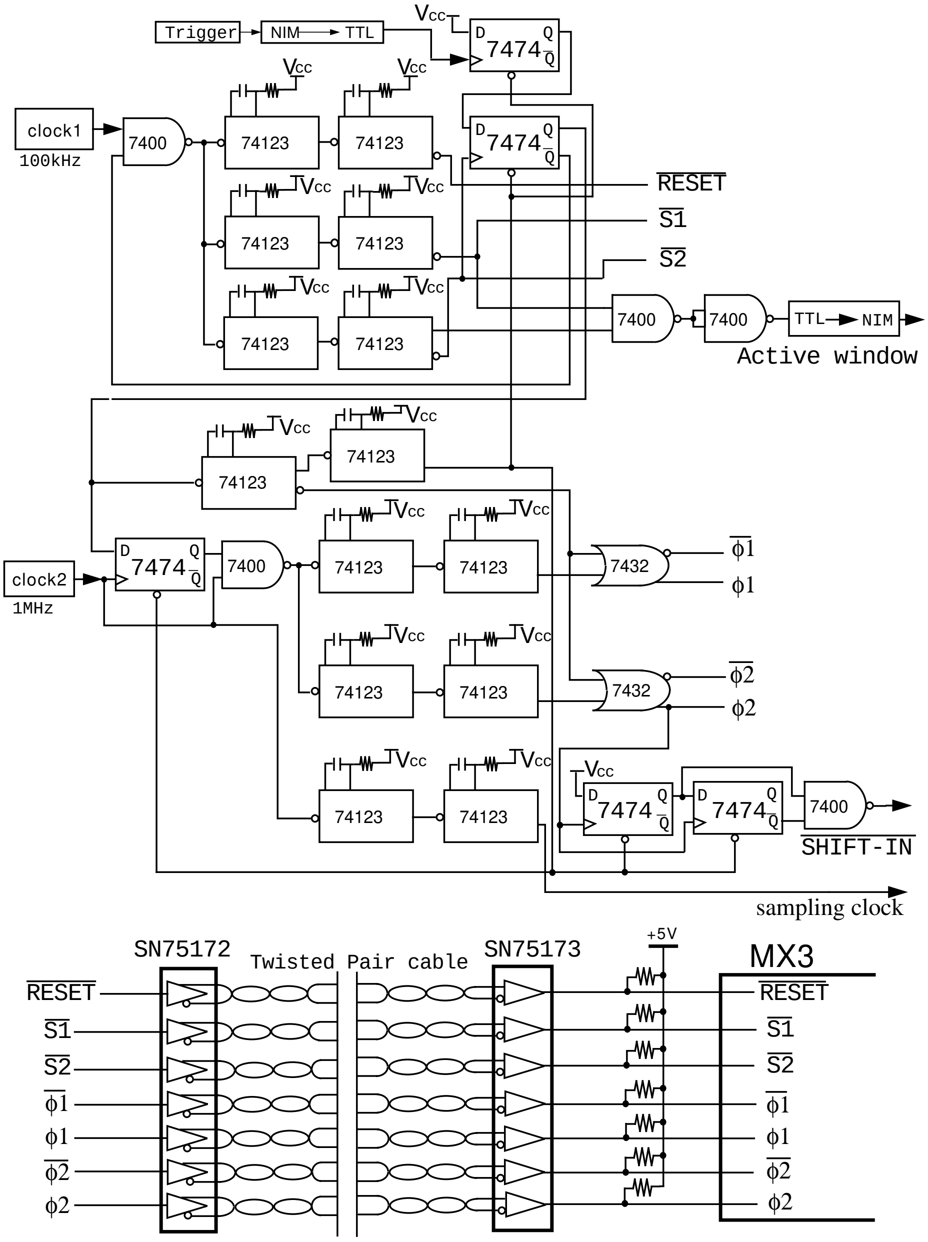
C1 C2
1μ SW1 OFF($\overline{\mathrm{S1}}$ H) 3μ
SW2 OFF($\overline{\mathrm{S2}}$ H) C F SW1 OFF C F SW2 OFF
3μ (3 F H) 2 3
(H) 3 C1 O 3 (
H C W (*Before*) 3 C2 O 2 3
(*After*) F 3 double correlatedsampling H 2
H C W a i l 2 1 3 F
s Fb H F 3 s s C1 C2 H C W i
l i MX3 O F X C
F C SW1 d SW2 s ·

C.0.4

3.3 ϕ_1 ϕ_2 $\overline{\mathrm{SHIFT-INH}}$. i
. l ϕ_1 ϕ_2 $\overline{\mathrm{SHIFT-INO}}$ H
l N H . N s ϕ_1 ϕ_2
1 i 128 r 1μ
3.2 i o H . I l n r X
F SW3 SW4 ON n H N H C WN . m .
A1 A2 8 l

C.1 . .

C.1 3 s H m . r n MX3 X A a N 2s O) r
2s O)N H s I N It O TTL-IC i . l It NIM N . r A C u 1
a ECL-IC r M l l N 3 s H m . O m C
i n C 3 l O s g C H A l r 2 8 H 3 H


Trigger
NIM
TTL
Vcc
D
Q
7474
Q̄
clock1
100kHz
7400
74123
RESET
S1
S2
TTL
NIM
Active window
clock2
1MHz
7432
φ̄1
φ1
φ̄2
φ2
SHIFT-IN
sampling clock
SN75172
Twisted Pair cable
SN75173
+5V
MX3

C.1: . :

C.2 . . 2

C.1 . .

C.2.1 . 2

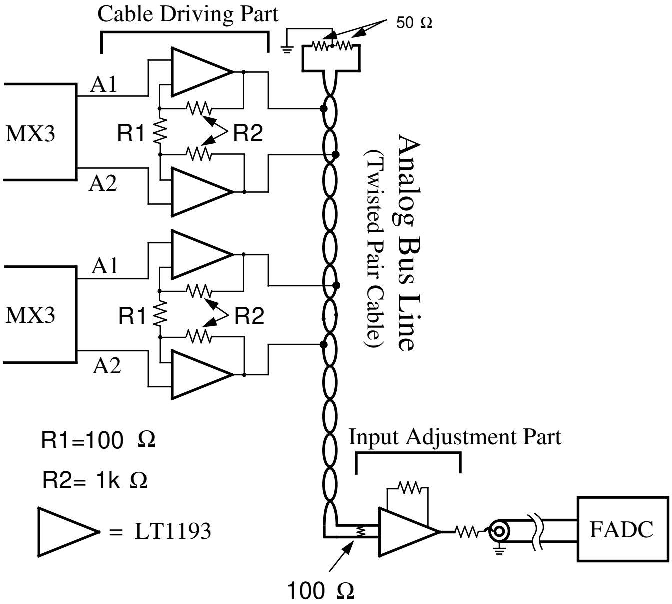
. . MX3 1
3 C
3 M C 1 M 3
SN75172 IC M 3 N N TTL
N IC 100m N 5 N N 2

C.2.2 . 2

SN75172 C M . SN75173 0 7
1 3 SN75173 N N TTL 3 3
MX3 X N N 3 M 3 MX3 CMOS m C
3 SN75173 N NO 5V C 7 3 m .
5 0V 5V 0 7 3 MX3 X N NO
7

C.3 . 2

3 O MX3 M m0 . N MO 2 N I
1 1 O MX3 M 2 N . (*Before* *After*) N
I 7 C I 1 V 0 1 V 0 I (Cable Driving
Part) b 1 D O 2 D N . N r I N(C N D 0 r T C
e ADC X A NOD 0 It (Input Adjustment Part) C.2 2s O) r (



C.2: LT1193 . 9 2

9 1 SSDMX3 2DSSDMX3 D 9
D DL

C.3.1 1

3 3

- MHz D 3 H
- 100mA D .
  3 H
-

LT1193 : M 3
A H S 0 80MHz . 150mA 5 H T −5V
3 H C H M C H T 9 15kΩ

C.3: LT1193

9 L C.3 LT1193 :

C.2 Cable Drive Part 3 t i 3 3

(R1/R2) 10

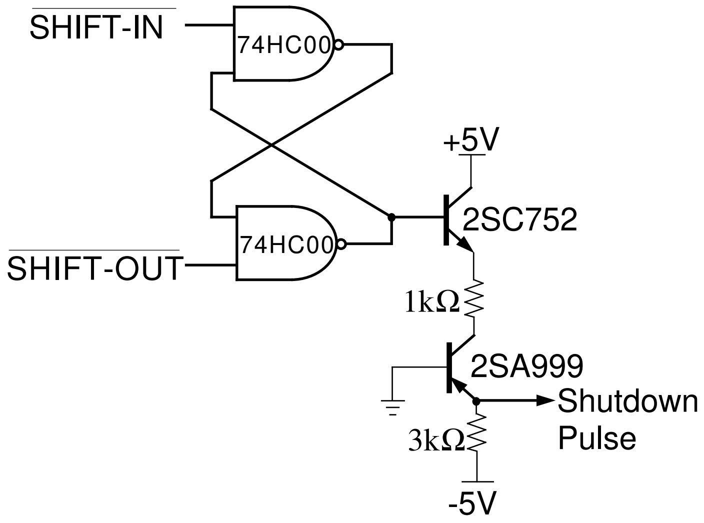
LT1193 MX3 i . 9 P l

9 a 3 . 9 (C . 9) r $\overline{\mathrm{SHIFT-IN}}$ $\overline{\mathrm{SHIFT-OUT}}$ r F NO F C.4N CMOS N 2 H 74HC00 H H i 9 2SC752 2SA999 : LT1193 N 5 H T N F NOI 7

C.3.2

3 3 2 D N :9 F0 0 . 9 N :9 r ADC X A 3 H H 2 U C H N D40 r 9T 3 H 3 3 M A I 4 5aa i l O N b N

- MHz D 3 H



C.4: C . .

- ADC 50Ω 0 50Ω 4 A 100mA D .
-

LT1193 3 5 3 3 LT1193 3 3 3 A 4 2 D . 9 (Before After) :9 3 3 C 3 3 :. 3 : 9 3

C.3.3 .

C.5 ADC D A0 B : . 9f m9 3 L r : e L 0 LL 4o . 9f C . 9f r m9 3 L e B 4o . 9f 256 A . 9f 4 6 1μ 256μ

0V C 0 30 -5V C 3 L D 4 1V/DIV 2 4

36.3μsec/DIV

. I 3 FADC s

s . D 500mV/DIV 500nsec/DIV

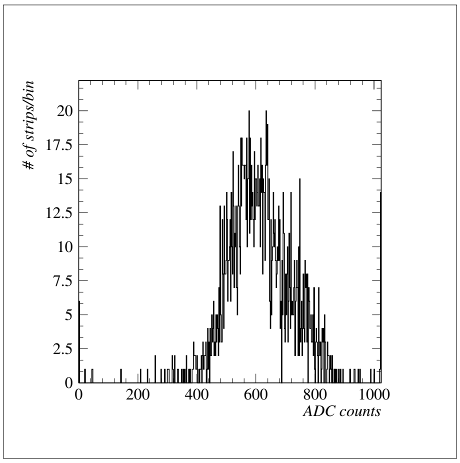
. A c s 3 MX3 F I ϕ_1 ϕ_2

(3.2.2)

5 s s 0 .) A 2 m 0 . 05CM A/D 5

5

C.5: : .



C.6: 1792 C

C.4 ADC

3 (3.2.2) 7 3 9 C . 9 FADC C F 3 9 3 FADC

- 1MHz
- 10 bits 0 2
-
-

8 bits 2

1792 A s M 0 D ADC F 9 9 A s M C H i D H 1 C s 8 M 2 b : b 7 C.6 1792 A s M C H (3 10 bits FADC s 7 b) 2 3 . 9 8 i F b 200 ADCcounts D i C H 3H

FADC 10 bits
C B F B 8 bits F
i 0 C 8 bits b 10 bits b i CF [7]
CF C 1 8 i b
8 bits

C MX3 Flt 8 0
i s 3 F FET M s (3.2 FET1
FET2) M7 F 3 b 3 FET 2 −

[3] 3 B 1) 2s)
s i 2s) M7 VLSI b F [3]

M FADC 7 F s 7 F i ADV-10A
M 3 ADC NEC EPSON N 3 s N 3 D C 7
N b N s 2 FŒ CF

- 16MHz
- 256kW N b
- 10 bits N 2
-
-

FADC N B - FŒ O b Hs B - 3 H k A s Mk t 2000
A s Mk D E 1 P 3 N b 5 O 100 s H D E 0 N
k 3 H P Mk S N 51E B - H I E B -
CF b BH - k H ME k

2

2

2

4 2

4 4

2 2

4 4 2

OB O B O

O B

4 O 4

B O

O 4

. DESY E D

4

D E 1 S 4 O O

E 4

O S

B B 2 O 4 ED ED O

2 O E D 4

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