An Estimation of Ti and Ni Calibration X-rays Yields by GEANT4 Simulation

Shinji Okada, Hideyuki Tatsuno
2005.7.12

1 Introduction

Ti and Ni X-rays are used for energy calibration at E570. It is necessary to decide these foils positions and sizes. In order to avoid attenuating Kaonic Helium X-ray by foils, the position is limited, upstream target cell Mylar, downstream target cell Mylar glue point and/or the center of SDD support. We estimated reasonable points by GEANT4 simulation.

2 Geometry

Simulation geometry is shown on Fig.1, 2, 3. z axis is beam direction and $z = 0$ is target center. Fig.1 is $z = 75$ mm Mylar glue point simulation. $y > 0$ higher half circle is Ni foil and $y < 0$ lower half circle is Ti foil. Fig.2 is $z = -75$ mm upstream Mylar backside simulation. Fig.3 is cone foils simulation at $z = 133$ mm. X-rays are shot only on these foils with the distribution of π^- profile. This means when charged particles (mainly π^-) hit foils, always X-rays are radiated, but now π^- is virtual and only X-ray is shot.

Some X-rays are detected by SDDs (orange boxes), so from the detected number ratio of radiated X-rays and shot X-rays, the attenuation effect and solid angle efficiency is measured. Next by the normalization for K-shell ionization cross sections, true X-rays yields are calculated.

3 Simulation

3.1 $z = 75$ mm 500,000 beamOn

On the Fig.1 geometry 500,000 X-rays are shot. X-rays are distributed π^- profile gaussian (x and y direction) at this point. Results are shown in Table.1.

3.2 Normalization

3.2.1 Ni X-ray Case

Radiated X-rays number N is

$$N = N_{\mathrm{obs}}/\mathrm{efficiency} = (\mathrm{through}\,\pi^-) \times \sigma_K\,[\mathrm{cm}^2] \times \omega_K \times N_A \times \frac{8.91\,[\mathrm{g/cm}^3]}{58.70\,[\mathrm{g/mol}]} \times 10^{-3}\,[\mathrm{cm}] \qquad (1)$$

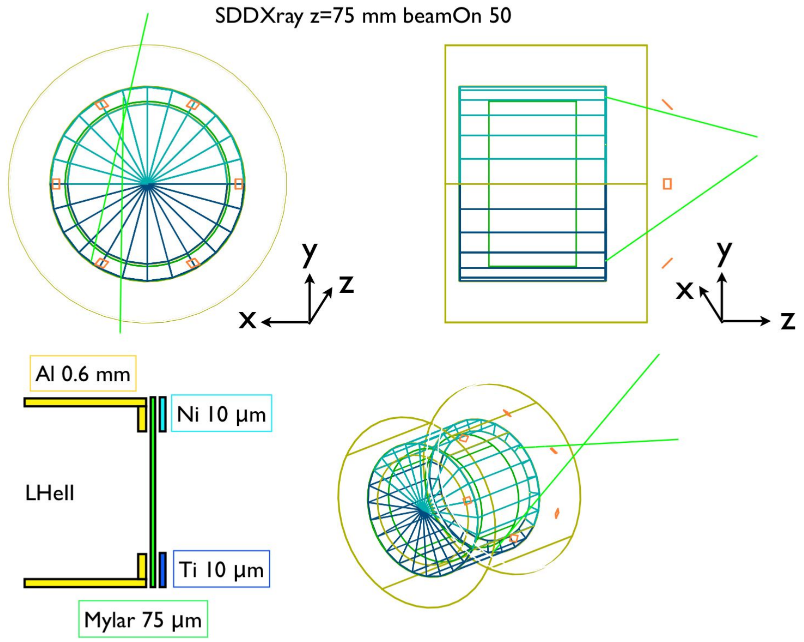


Fig.1 $z = 75$ mm Mylar glue point simulation. 50 particles are "beamOn"ed, three X-rays are radiated (can see only two).

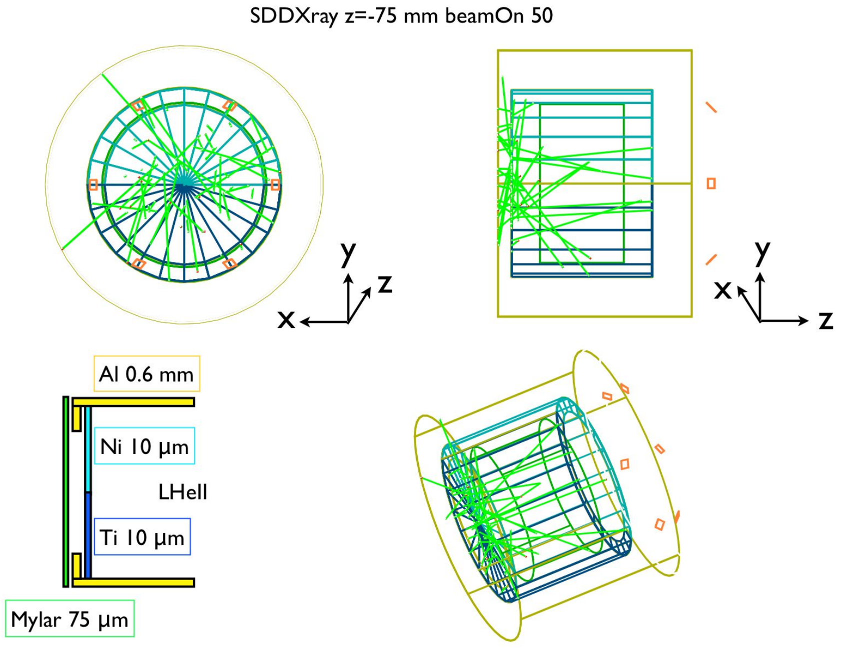


Fig.2 $z = -75$ mm upstream Mylar backside simulation. However many π^- hit these half disc foils and many X-rays are radiated, only few X-rays reach SDDs because of large attenuation.

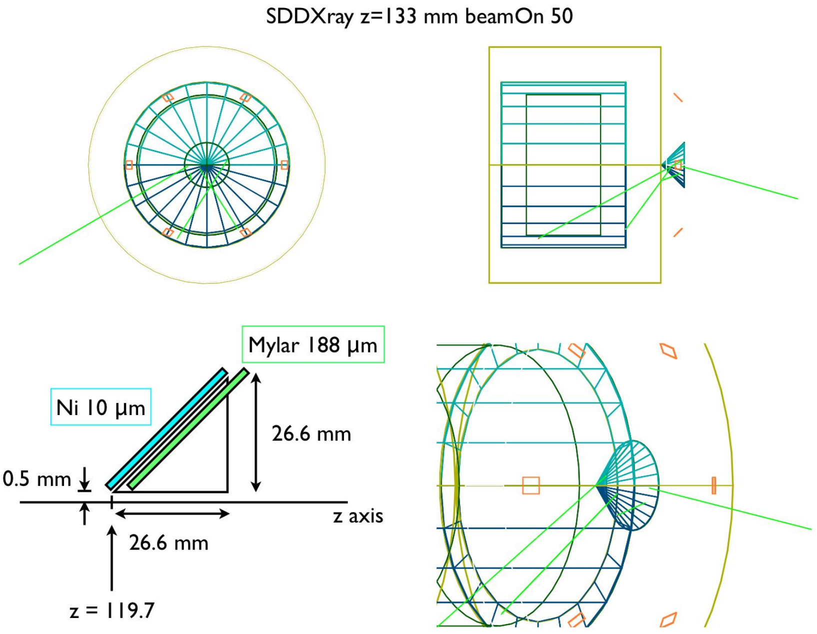


Fig.3 $z = 133$ mm cone foils simulation. To avoid attenuating Kanoic Helium X-rays and to cover solid angle for SDDs, foils are tilted. This position is most reasonable for π^- inducing.

Table.1 The Number of X-rays detected by 6 SDDs at $z = 75$ mm and the number of X-rays radiated (= through π^-). And total efficiency of detection (attenuation, solid angle).

X-ray	through π^-	observed X-ray	total efficiency (%)
Ni	24039	82	0.3411
Ti	28183	118	0.4187
Other		2	

Where σ_K is K-shell ionization cross section, ω_K is K-fluorescence yield, N_A is Avogadro's number. σ_K is calculated from the data of E549 test, so $\sigma_K = 232.974 \pm 12.053$ barn, and $\omega_K = 0.414$, through $\pi^- = 24039$ are substituted,

$$\begin{aligned} N &= (232.974 \pm 12.053) \times 10^{-24} \times 24039 \times 0.414 \times 6.02 \times 10^{23} \times \frac{8.91}{58.70} \times 10^{-3} \\ &= 211.866 \pm 10.961 \end{aligned} \tag{2}$$

then detection efficiency is considered,

$$N_{\text{obs}} = (211.866 \pm 10.961) \times 0.003411 = 0.722675 \pm 0.037388 \tag{3}$$

And the total π^- number is 1212568 [counts/spill], times the ratio,

$$N_{\text{obs}} = (0.722675 \pm 0.037388) \times 1212568/500000 = 1.75256 \pm 0.09067 \,[\text{counts/spill}] \tag{4}$$

This means Ni Ka X-ray will be detected 1.75 [counts/spill].

3.2.2 Ti X-ray Case

Radiated X-rays number N is

$$N = N_{\text{obs}}/\text{efficiency} = (\text{through}\,\pi^-) \times \sigma_K\,[\text{cm}^2] \times \omega_K \times N_A \times \frac{4.54\,[\text{g/cm}^3]}{47.867\,[\text{g/mol}]} \times 10^{-3}\,[\text{cm}] \tag{5}$$

This time $\sigma_K = 561.376 \pm 82.202$ barn, and $\omega_K = 0.219$, through $\pi^- = 24039$ are substituted,

$$\begin{aligned} N &= (561.376 \pm 82.202) \times 10^{-24} \times 24039 \times 0.219 \times 6.02 \times 10^{23} \times \frac{4.54}{47.867} \times 10^{-3} \\ &= 168.745 \pm 28.969 \end{aligned} \tag{6}$$

then detection efficiency is considered,

$$N_{\text{obs}} = (168.745 \pm 28.969) \times 0.004187 = 0.706535 \pm 0.121293 \tag{7}$$

And the total π^- number is 1212568 [counts/spill], times the ratio,

$$N_{\text{obs}} = (0.706535 \pm 0.121293) \times 1212568/500000 = 1.71344 \pm 0.29415\,[\text{counts/spill}] \tag{8}$$

This means Ti Ka X-ray will be detected 1.71 [counts/spill] (but it's error is large).

3.3 $z = -75$ mm 500,000 beamOn

On the Fig.2 geometry 500,000 X-rays are shot. X-rays are distributed π^- profile gaussian (x and y direction) at this point. Results are shown in Table.2.

Table.2 The Number of X-rays detected by 6 SDDs at $z = -75$ mm and the number of X-rays radiated (= through π^-). And total efficiency of detection (attenuation, solid angle).

X-ray	through π^-	observed X-ray	total efficiency (%)
Ni	233805	147	0.06287
Ti	255524	53	0.02074
Other		2	

3.4 Normalization

3.4.1 Ni X-ray Case

Calculate same as before... Radiated X-rays number N is

$$\begin{aligned} N &= (232.974 \pm 12.053) \times 10^{-24} \times 233805 \times 0.414 \times 6.02 \times 10^{23} \times \frac{8.91}{58.70} \times 10^{-3} \\ &= 2060.62 \pm 106.61 \end{aligned} \tag{9}$$

then detection efficiency is considered,

$$N_{\text{obs}} = (2060.62 \pm 106.61) \times 0.0006287 = 1.29551 \pm 0.067024 \tag{10}$$

And the total π^- number is 1267934 [counts/spill], times the ratio,

$$N_{\rm obs} = (1.29551 \pm 0.067024) \times 1267934/500000 = 3.28525 \pm 0.17000\,\text{[counts/spill]} \tag{11}$$

This means Ni Ka X-ray will be detected 3.28 [counts/spill].

3.4.2 Ti X-ray Case

Radiated X-rays number N is This time $\sigma_K = 561.376 \pm 82.202$ barn, and $\omega_K = 0.219$, through $\pi^- = 255524$ are substituted,

$$\begin{aligned} N &= (561.376 \pm 82.202) \times 10^{-24} \times 255524 \times 0.219 \times 6.02 \times 10^{23} \times \frac{4.54}{47.867} \times 10^{-3} \\ &= 1793.68 \pm 262.25 \end{aligned} \tag{12}$$

then detection efficiency is considered,

$$N_{\rm obs} = (1793.68 \pm 262.25) \times 0.0002074 = 0.372010 \pm 0.054473 \tag{13}$$

And the total π^- number is 1267934 [counts/spill], times the ratio,

$$N_{\rm obs} = (0.372010 \pm 0.054473) \times 1267934/500000 = 0.943368 \pm 0.138137\,\text{[counts/spill]} \tag{14}$$

This means Ti Ka X-ray will be detected 0.94 [counts/spill].

3.5 $z = 133$ mm 500,000 beamOn

On the Fig.3 geometry 500,000 X-rays are shot. X-rays are distributed π^- profile gaussian (x and y direction) at this point. Results are shown in Table.3.

Table.3 The Number of X-rays detected by 6 SDDs at $z = 133$ mm and the number of X-rays radiated (= through π^-). And total efficiency of detection (attenuation, solid angle).

X-ray	through π^-	observed X-ray	total efficiency (%)
Ni	35726	99	0.277109
Ti	37330	89	0.238414
Other		3	

3.6 Normalization

3.6.1 Ni X-ray Case

Calculate same as before... the total π^- number is 1186434 [counts/spill] at $z = 133$ mm, so

$$N_{\rm obs} = (314.868 \pm 16.2898) \times 0.00277109 \times 1186434/500000 = 2.07039 \pm 0.10711\,\text{[counts/spill]} \tag{15}$$

This means Ni Ka X-ray will be detected 2.07 [counts/spill].

3.6.2 Ti X-ray Case

$$N_{\text{obs}} = (262.043 \pm 38.3708) \times 0.0002074 = 0.372010 \pm 0.054473 \tag{16}$$

And the total π^- number is 1267934 [counts/spill], times the ratio,

$$N_{\text{obs}} = (262.043 \pm 38.3708) \times 0.00238414 \times 1186434/500000 = 1.48244 \pm 0.21707\,[\text{counts/spill}] \tag{17}$$

This means Ti Ka X-ray will be detected 1.48 [counts/spill].

4 Conclusion

Simulation results summarized on Table.4 .

Table.4 The summary of simulation results.

	$z = 75$ circle	$z = -75$ disc	$z = 133$ cone	total
Ni [counts/spill]	1.753	3.285	2.070	7.108
Ti [counts/spill]	1.713	0.9434	1.482	4.138
Foil area [cm^2]	100	314	31.5	445.5

If all foils are used, Ni K_α X-ray can be seen 7.108 [counts/spill] and Ti K_α X-ray can be seen 4.138 [counts/spill]. But at $z = -75$ disc foil, Ti X-ray is attenuated by Mylars and target, so it's foil area performance is bad. On the other hand, $z = 133$ cone foil has very good foil area performance. This is because, it is recommended that more larger cone foils and downstream Mylar glue point foils are used and not used upstream Mylar disc foil.

The two positions circle and cone foils are enough for energy calibration. The estimated Kaonic Helium X-ray count rate is

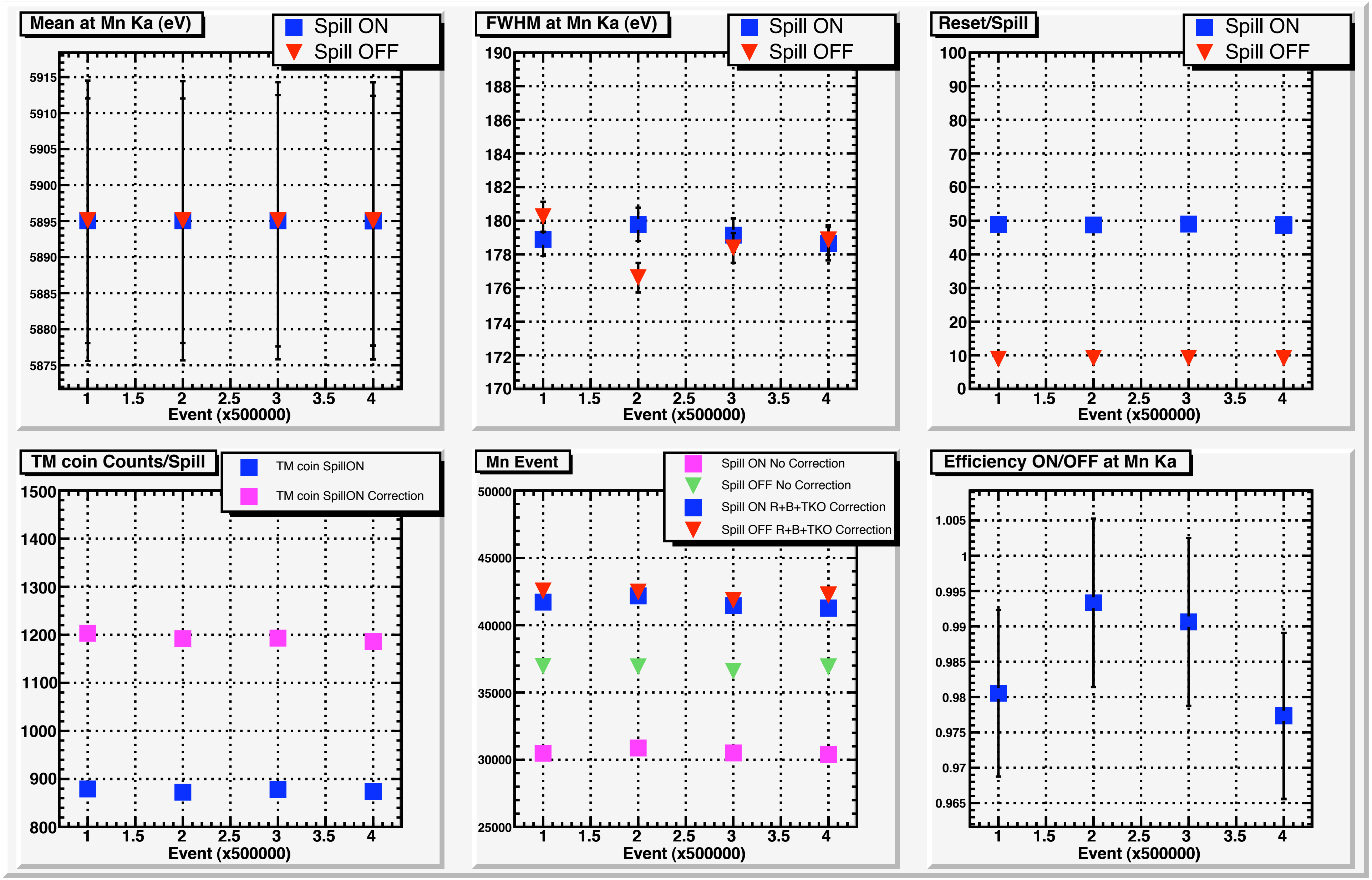
$$\begin{aligned} N_{K^-\text{He}} =& 6000[\text{Stopped}\,K^-] \times \frac{1}{6} \times 0.16 \times \frac{1}{400}[\text{SDD efficiency}] \\ & \times 30\%[\text{vertex counter solid angle coverage}] \times \frac{3}{4}[\text{DAQ acceptance}] = 0.09\,[\text{counts/spill}]. \end{aligned} \tag{18}$$

So, calibration X-rays will be seen about 30 times larger than Kaonic Helium X-ray.

Typical analysis result at a production run

Mn mean has large error 1σ ~ 10 eV,
because Mn Kb X-ray is low statistic.

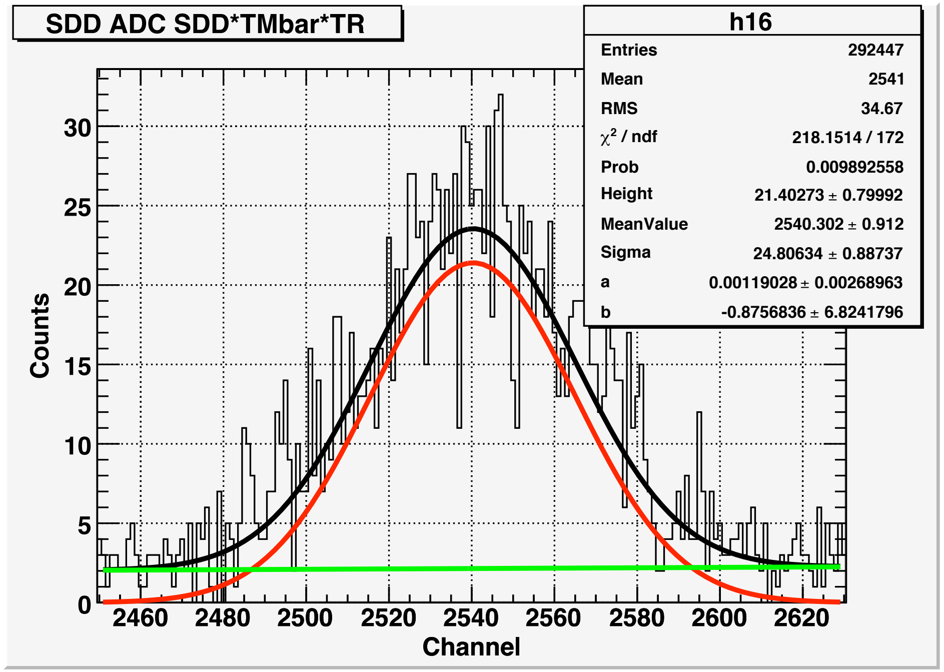
500,000 events correspond to 430 spills (10 min).



Sum run data fitting

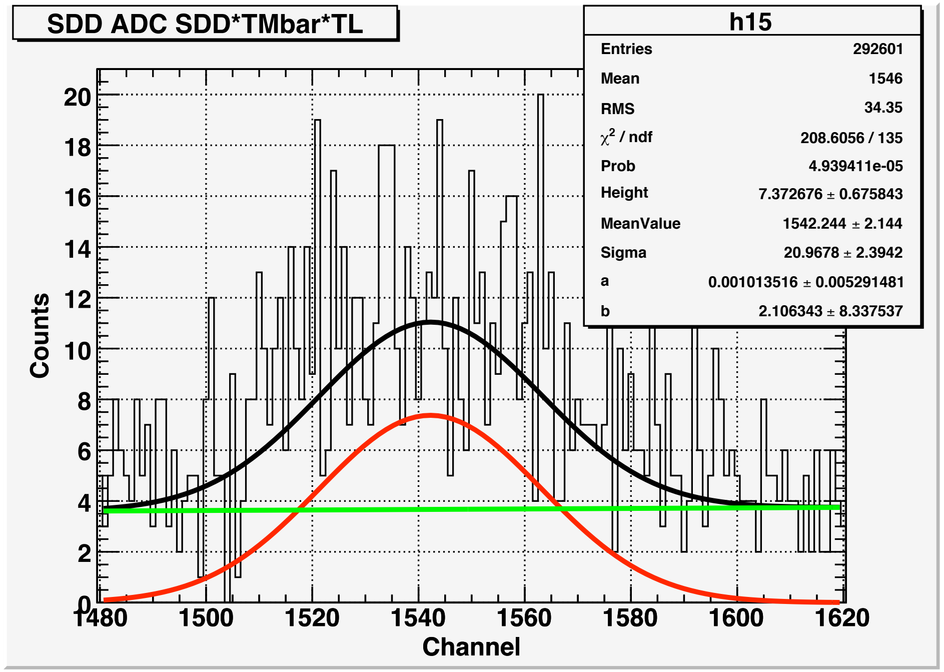
21628 spills, 9 hours detection

Ni



Mean = 7493.23 (eV) error = 15.5866
FWHM = 175.486 (eV) error = 6.28352
Event = 1330.83 (Counts) error = 68.85

Ti



Mean = 4498.6 (eV) error = 13.0163
FWHM = 147.94 (eV) error = 16.8941
Event = 387.497 (Counts) error = 56.7408

Mn Kb's error propagates to X-rays mean, so X-ray mean has large error

It is necessary to calibrate from higher statistic peaks

E570 meeting

2005/07/12 S.Okada and H.Tatsuno

1 Summary of trigger scheme of SDD test experiment at E549

1.1 Trigger logic

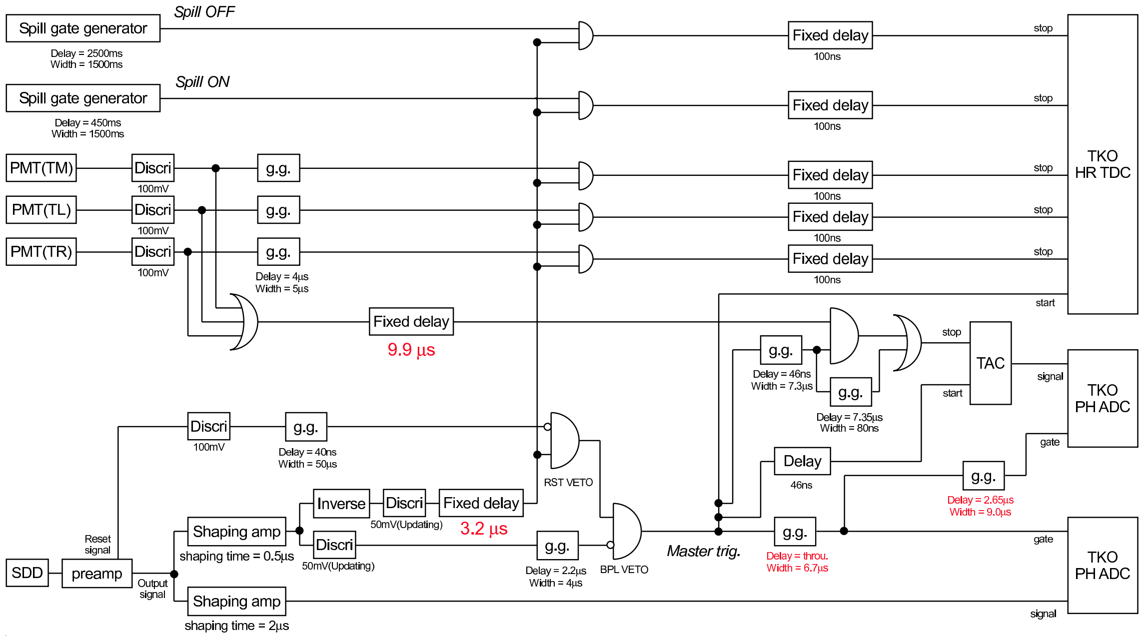


Figure 1: Trigger logic diagram for E549 SDD test experiment

1.2 Module list

Module list for test experiment at E549		
module	model number	borrowed from ...
Shaping amp (0.5μs)	ORTEC 570*	Banpaku-san
Shaping amp (2μs)	ORTEC 572	SKS
TAC	ORTEC 467	Hayano-lab.
PH ADC	TKO 32CH PH ADC (T005)	KEK electronics equipment pool

* These modules have been used in KpX experiment. We have borrowed four ORTEC 570 modules from Banpaku-san.

1.3 Timing relation

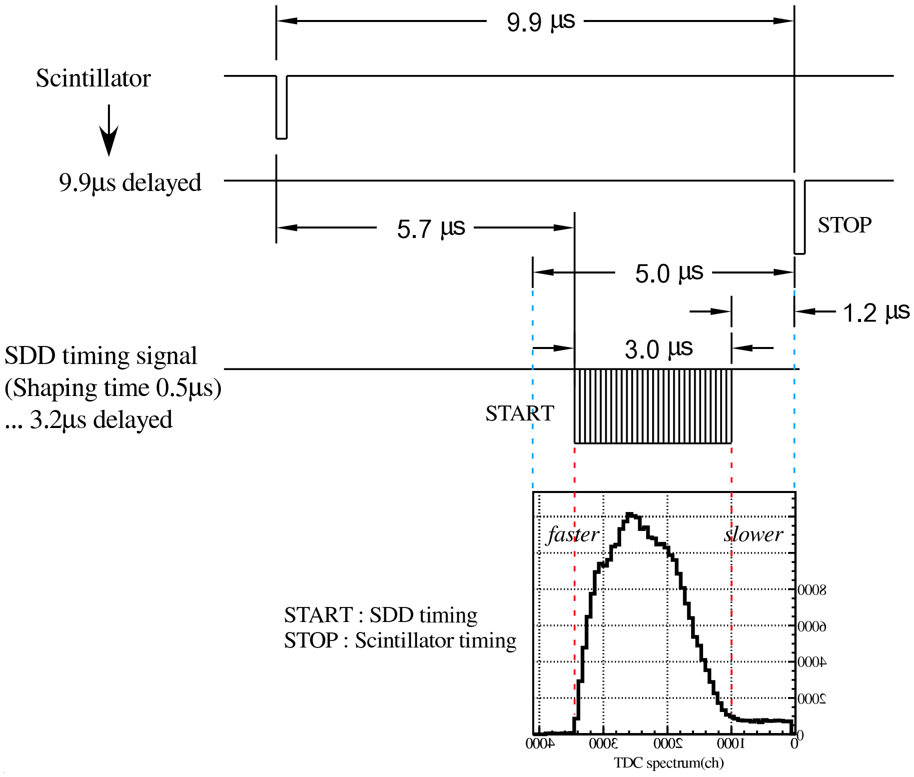


Figure 2: TDC start and stop timing

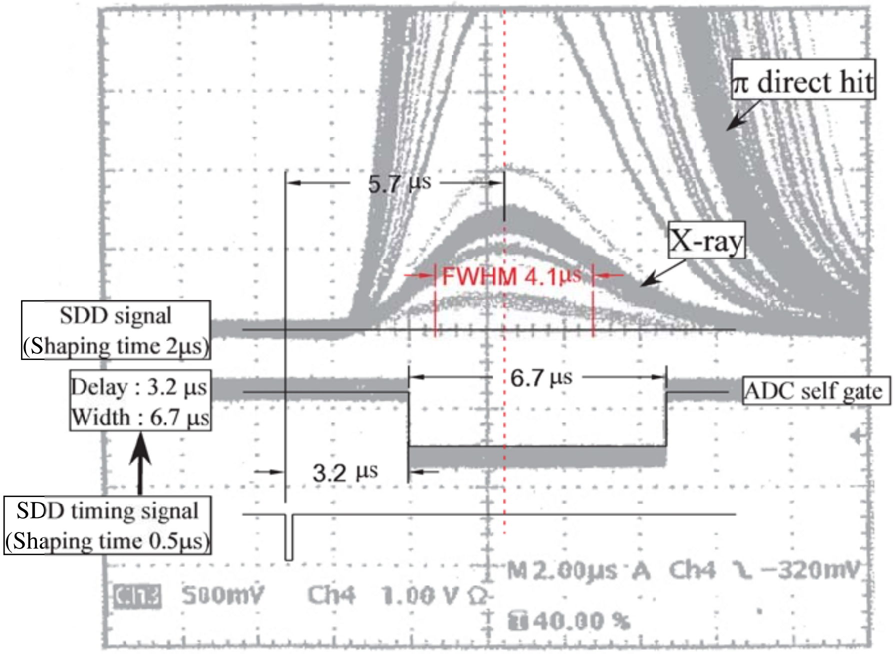


Figure 3: ADC gate timing (SDD self trigger)

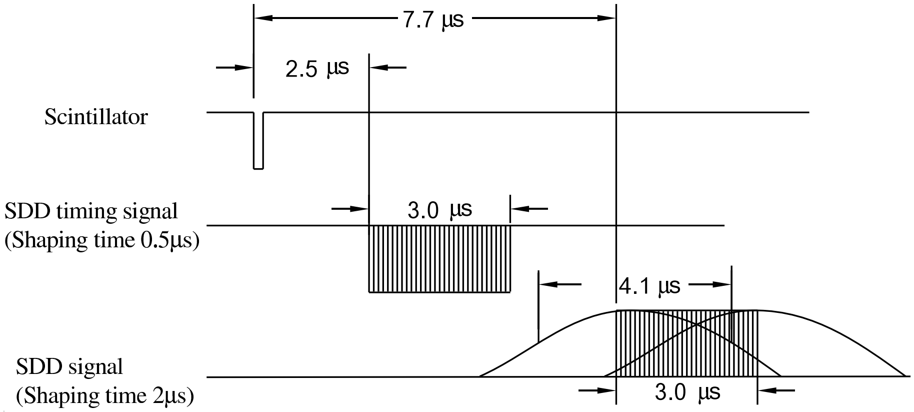
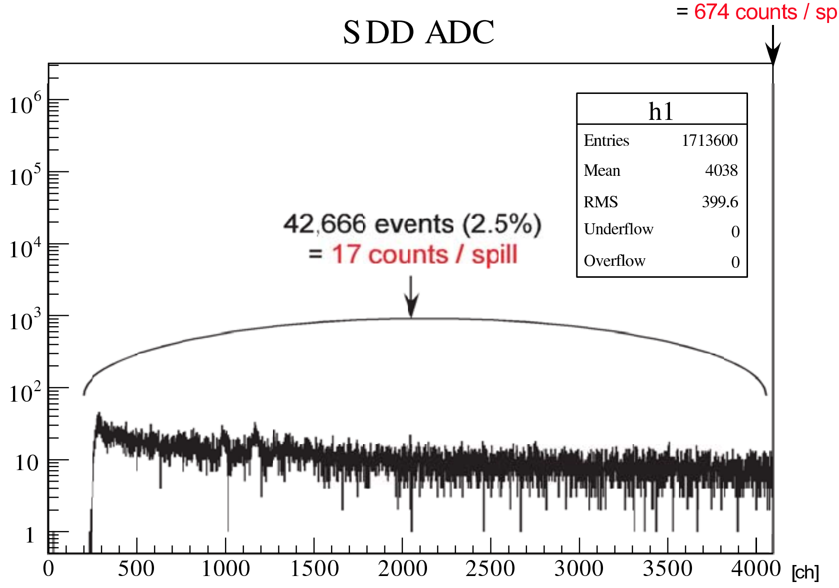


Figure 4: Summary of SDD timing

1.4 Typical SDD count rate



run#64 ...without ^{55}Fe source (about 3hours data ~ 2480spill(effective))

Overflow (pion direct hit event)
1,670,934 events (97.5%)
= 674 counts / spill

42,666 events (2.5%)
= 17 counts / spill

accept ratio : about 88%
>>> SDD single hit rate ~ 785 counts / spill

Figure 5: SDD single count rate per spill (without ^{55}Fe source)

2 Trigger and DAQ system at E570

2.1 Intensity ratio between real kaonic helium x-ray and calibration x-rays

The count numbers (per spill) of Ni and Ti calibration peak estimated by a simulation with real geometry by using measured K-shell ionization and excitation cross sections for minimum ionizing pion are respectively about 2 (Ni) and 1 (Ti) counts/spill (for cone type foil). In case these foils are additionally put on the front face of target cell and near side of overlap width part of target cell, the count rate will be increased by 3 times higher at most.

Estimated count rates (per spill) for kaonic helium x-rays ,L_α, L_β and L_γ, are as follows.

$$\begin{aligned}
Y_{K-He}(L_\alpha) &= 6000(\text{stopped kaon per spill}) \times 1/6(\text{stopping ratio for real}) \\
&\quad \times 0.09(\text{intensity per stopped kaon for } L_\alpha) \times 1/400(\text{SDD efficiency}) \\
&\quad \times 0.3(\text{VTC solid angle}) \times 0.75(\text{DAQ accept ratio}) \\
&= 0.05 \text{ [counts/spill]} \\
Y_{K-He}(L_\beta) &= 0.03 \text{ [counts/spill] } (L_\beta \text{ intensity per stopped kaon} = 0.05) \\
Y_{K-He}(L_\gamma) &= 0.01 \text{ [counts/spill] } (L_\gamma \text{ intensity per stopped kaon} = 0.02)
\end{aligned}$$

So the Ni and Ti calibration peak intensities will be respectively obtained 40 and 20 times higher than that of real kaonic helium L_α peak (without considering DAQ accept ratio) when we take the SDD self trigger events. If we do not take SDD self trigger events in particular, the ratio between the count rate due to accidental coincidence within kaon trigger and real kaonic L_α peak rate will be 8 % as follows.

$$\begin{aligned}
&2(\text{count/spill(Ni)}) \times 7 \times 10^{-6}(\text{sec (ADC gate width)}) \\
&\quad \times 500(\text{trigger rate per spill})/1.7(\text{sec (spill period)})/0.05(Y_{K-He}(L_\alpha)) = 0.08
\end{aligned}$$

Even allowing for additional foil (× 3) and difference of K-shell ionization (excitation) cross section for fast pion and the slow stopping kaon ($\times \sim 4$ [see T.M.Ito et.al. PRC**58**, 2366 (1998)]), the ratio will be 24 ×4 × $(R_1 + R_2 + R_3)$ % at most, where $R_{1,2,3}$ denote kaon stopping ratio at each foil location (∼50 % ?).

2.2 Trigger

- In order to increase as many x-ray events as possible, we plan to take the unbiased "$\text{K}_{stop}\times$ VTC × VDC veto" trigger at E570 instead of taking "$\text{K}_{stop}\times$ VTC / 10" and "$\text{K}_{stop}\times$ VTC × NC" triggers. On the run280 at E549 which is a dedicated run for the study of E570 trigger, we confirmed that by adding "VDC veto" the number of "$\text{K}_{stop}\times$ VTC" trigger is reduced by 65 % (=790/1210). In this case, the accept ratio was reduced by 7.6 % (83.7%→75.9%). (see case 1)

- As shown in Fig.5, SDD single count rate is about 17 per spill if we can cut the overflow events on trigger level (applying upper threshold by another discriminator). The count rate of eight SDDs will be about 150. In case the SDD self trigger ($\sim$ 150) is added as SDD calibration trigger, the accept ratio was reduced by about 3 % additionally. (see case 2 and 3)

Number of trigger per spill

Trigger type	E549 normal trig.	E570 trig.		
		case 1 (run280[i])	case 2 case 1 + self trig.	case 3 E549 + self trig.
$K_{stop}\times$ beam / 600	10	10	10	10
$K_{stop}\times$ VTC / 10	100	-	-	100
$K_{stop}\times$ PA × PB	100	100	100	100
$K_{stop}\times$ VTC × NC	340	-	-	340
$K_{stop}\times$ VTC × VDC veto	-	790	790	-
SDD self trigger	-	-	150	150
total	550	900	1050	700
accept (calc.)	461	683	766	561
accept ratio [ii]	83.7 %	**75.9 %**	**73.0 %**	**80.2 %**

[i] This is a dedicated run for study of E570 trigger at E549.

[ii] The accept ratio is determined by the dead time attributed to its DAQ system, which is about 600 μsec (TKO conversion time 300μsec + computer busy 300μsec), and is calculated by the following equation : $m \times T = k + m \times k \times t$, where m =True count rate, T =Counting period, k =Number of count in a time T, and t =Dead time. The measured trigger number accepted by DAQ system was consistent with calculated one.

2.3 E570 trigger system

2.3.1 Conventional method

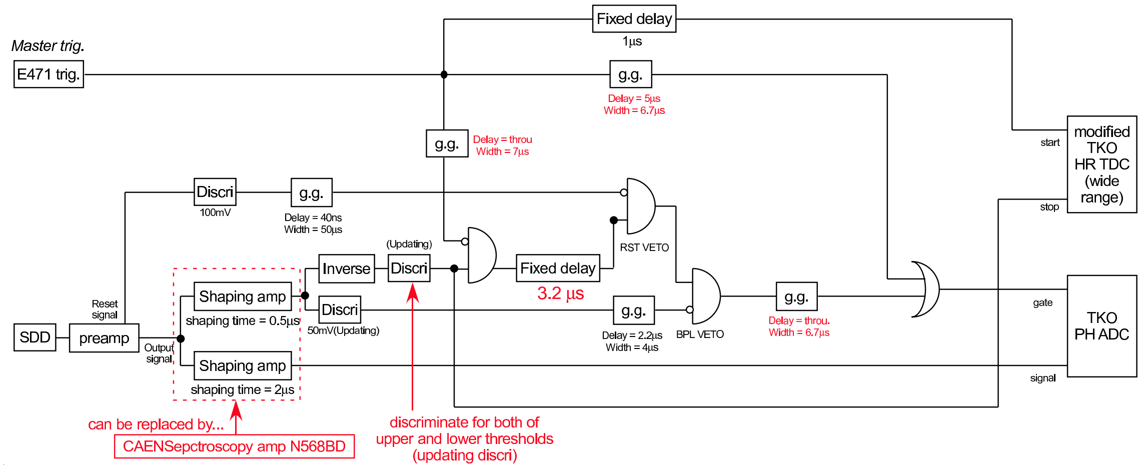


Figure 6: Trigger logic diagram for E570 (conventional method)

Module list for E570			
module	model number	number	will be borrowed from ...
Shaping amp (0.5, 2μs)	ORTEC 570	×16	Banpaku-san
PH ADC	TKO 32CH PH ADC	×1	KEK
TDC	TKO 16CH HR TDC	×1	KEK (ask Sasaki-san)

TAC	ORTEC 566	×8	393,000JPY (SEIKO EG&G)
TAC	ORTEC 567	×8	523,000JPY (SEIKO EG&G)

2.3.2 with VME TDC and ADC

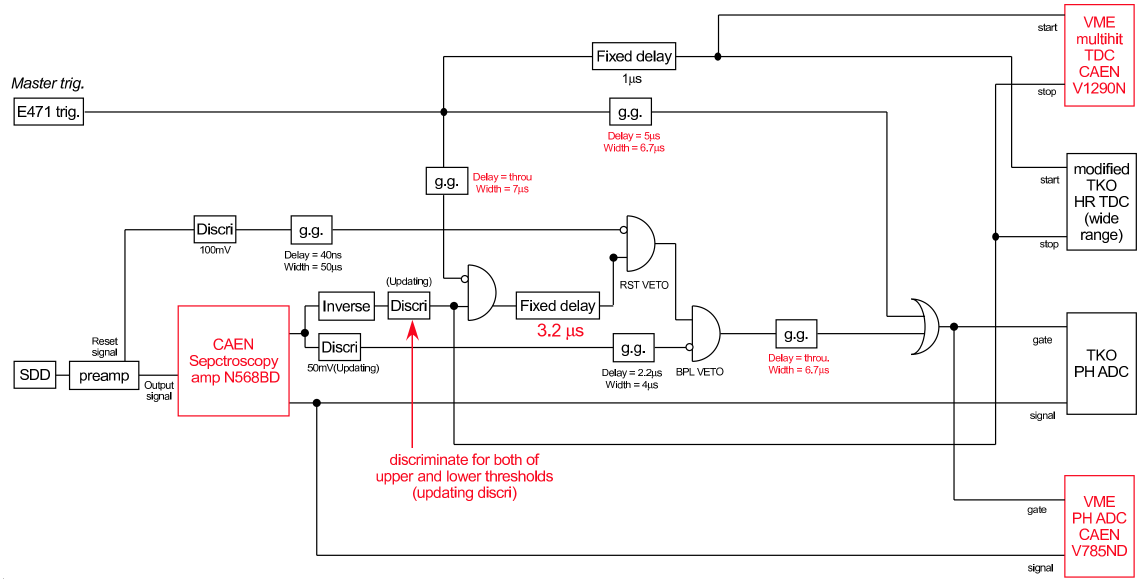


Figure 7: Trigger logic diagram for E570 with VME TDC and ADC

Module list for E570			
module	model number	number	cost (company)
NIM spectroscopy amp	CAEN 16 channel programmable spectroscopy amplifier: N568BD	×1	1,277,000JPY (SEIKO EG&G)
VME TDC	CAEN 16channel multihit TDC: V1290N	×1	825,000JPY (SEIKO EG&G)
VME ADC	CAEN 16channel multihit peak sensing ADC: V785ND conversion time : 2.8μsec/16ch	×1	768,000JPY (SEIKO EG&G)

E570 time schedule

		SDD	Target modification	Temperature control
7/11 (Mon) – 7/17 (Sun)	Operation check for all our SDDs			
7/18 (Mon) – 7/24 (Sun)				
7/25 (Mon) – 7/31 (Sun)	Preamp test	Three SDDs from SMI will arrive on ?（ask Hannes)	end of July : almost all parts will be delivered.	
8/01 (Mon) – 8/07 (Sun)	Start on target cooling test			
8/08 (Mon) – 8/14 (Sun)			8/10 ··· stainless end cap will be delivered.	
8/15 (Mon) – 8/21 (Sun)				Lakeshore340 / PT−102 will be delivered.
8/22 (Mon) – 8/28 (Sun)		Another two SDDs will be delivered from KETEK.(?)		
8/29 (Mon) – 9/04 (Sun)				
9/05 (Mon) – 9/11 (Sun)				
9/12 (Mon) – 9/18 (Sun)				
9/19 (Mon) – 9/25 (Sun)				
9/26 (Mon) –	from 9/27 ··· Beam time			