Fluorescence in air excited by electrons from a Sr90 source

Naoto Sakaki

(Aoyama Gakuin University)

collaboration with M.Nagano, Y.Watanabe, K.Kobayakawa and K.Ando

Paper(s)

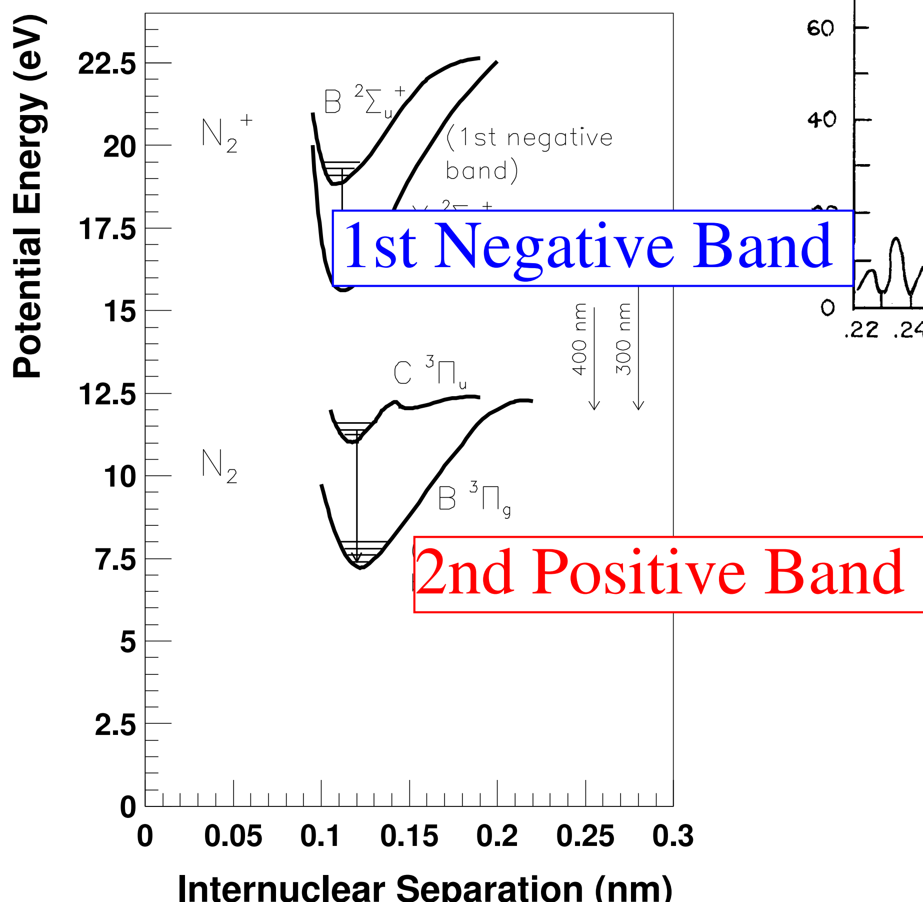
Astroparticle Physics, **22** (2004) 235–248.
M.Nagano, K.Kobayakawa, N.Sakaki and K.Ando

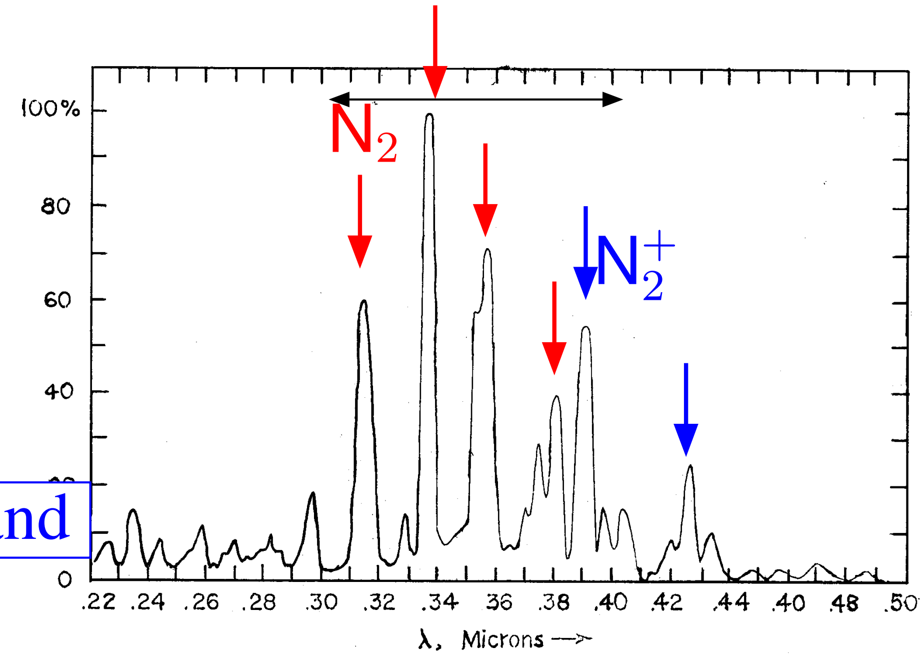
- fluorescence yield in dry air for 15 bands
- two component analysis

$\longrightarrow$ **300–430nm is covered with our own measurement**

Astroparticle Physics, **20** (2003) 293–309.
M.Nagano, K.Kobayakawa, N.Sakaki and K.Ando

Fluorescence from Nitrogen





Data from

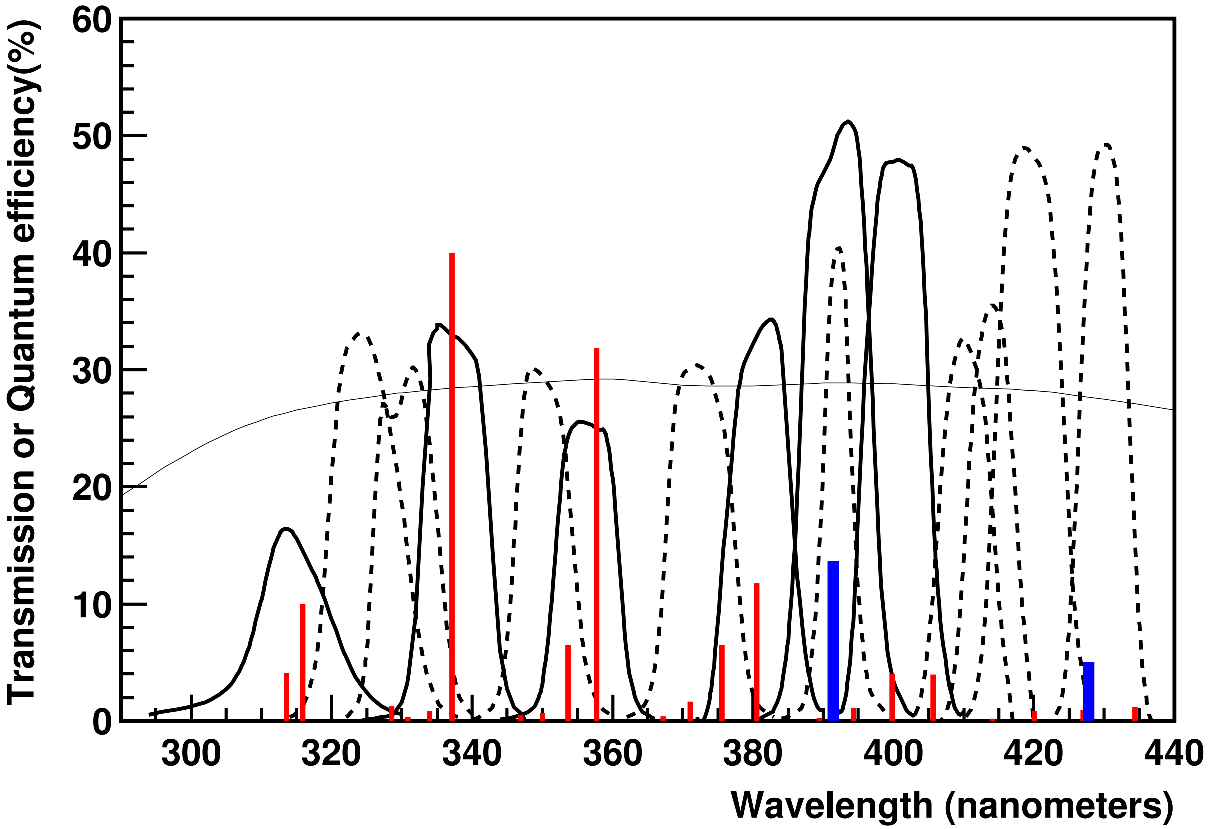
Bunner(1964): weighted average of
3 experiments with an accuracy
of not better than 30%

Kakimoto et al.(1996):
1.4-1000MeV electron

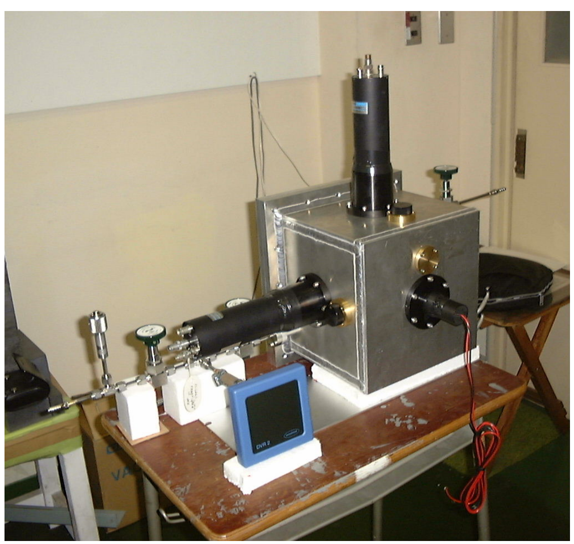
are mainly used in UHECR exp.

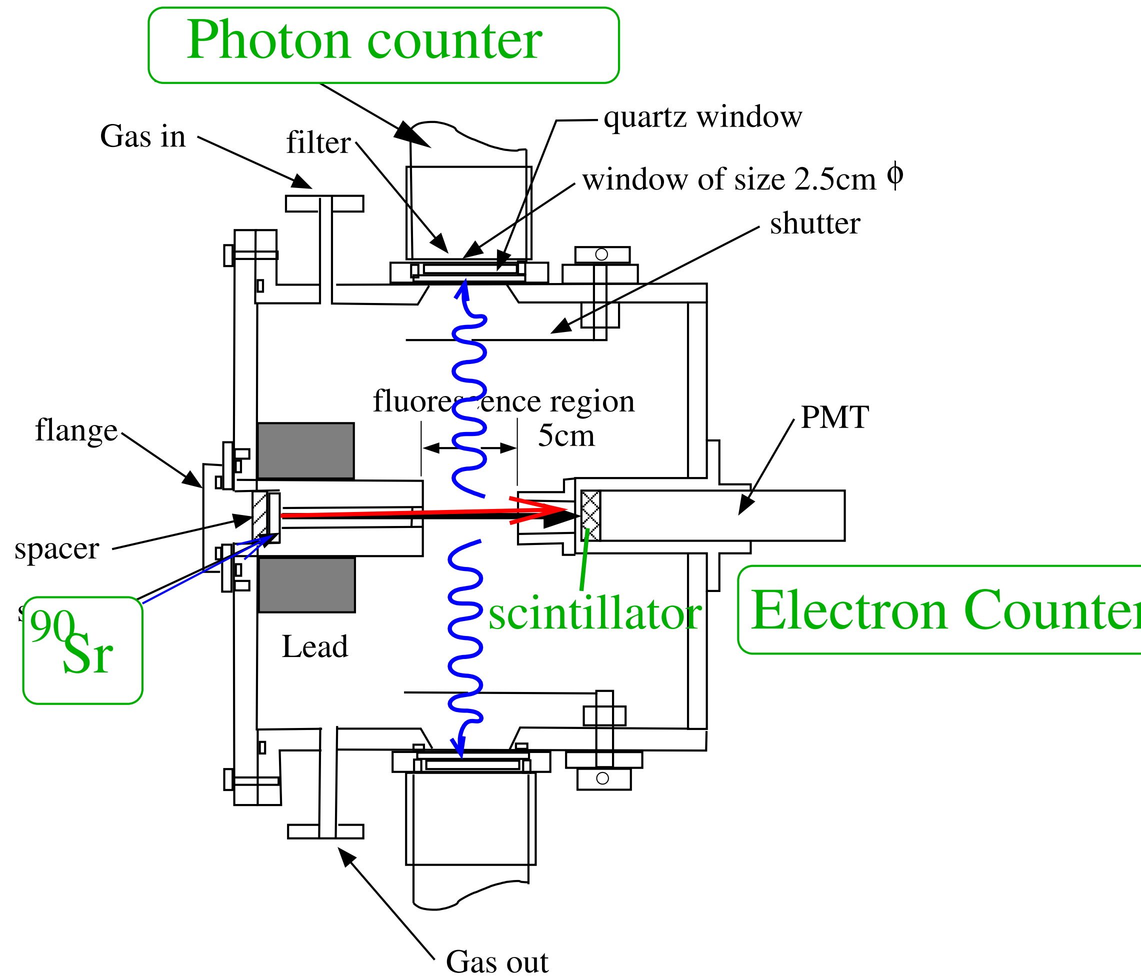
Filter

15 filters are used.

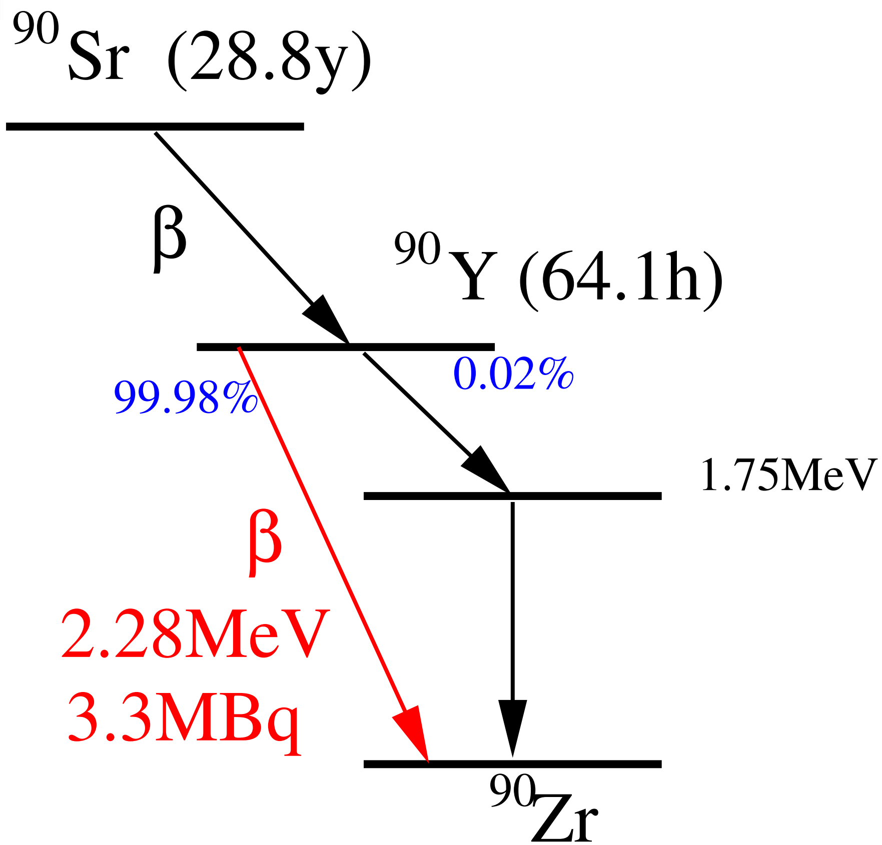


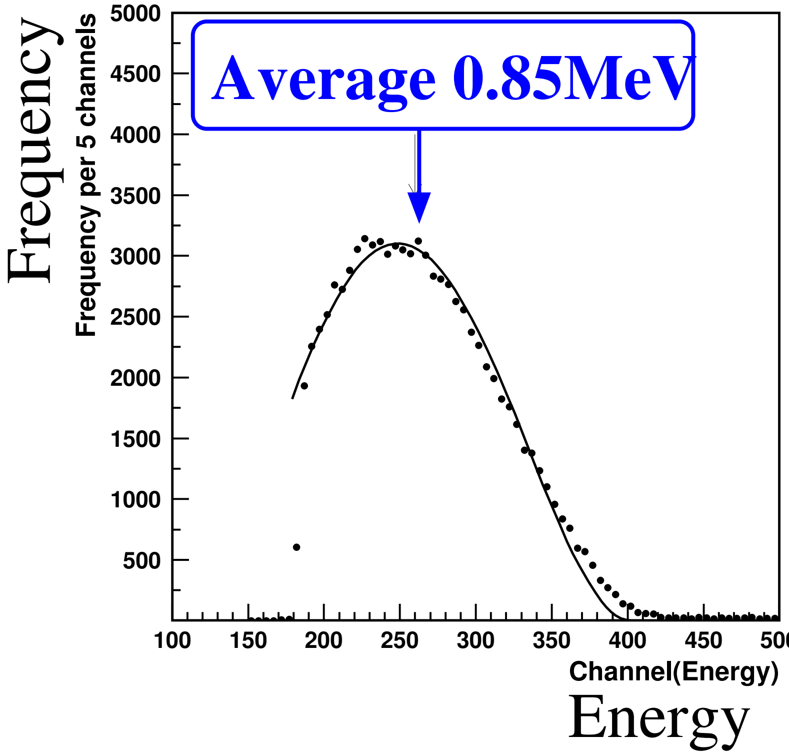
chamber



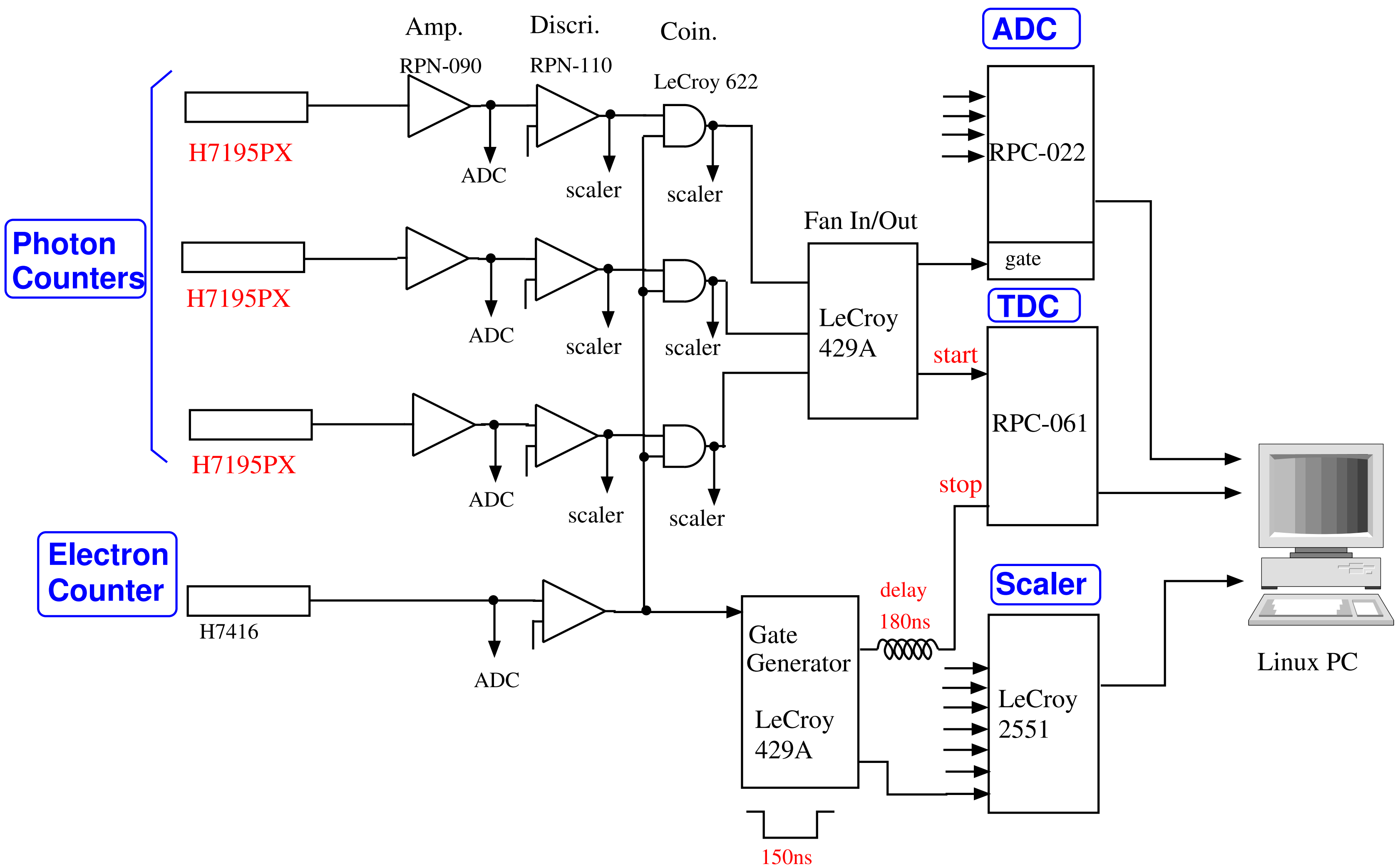

Photon counter
Gas in
filter
quartz window
window of size 2.5cm ϕ
shutter
fluore ence region
5cm
flange
PMT
spacer
90Sr
scintillator
Electron Counter
Lead
Gas out

Electron beam

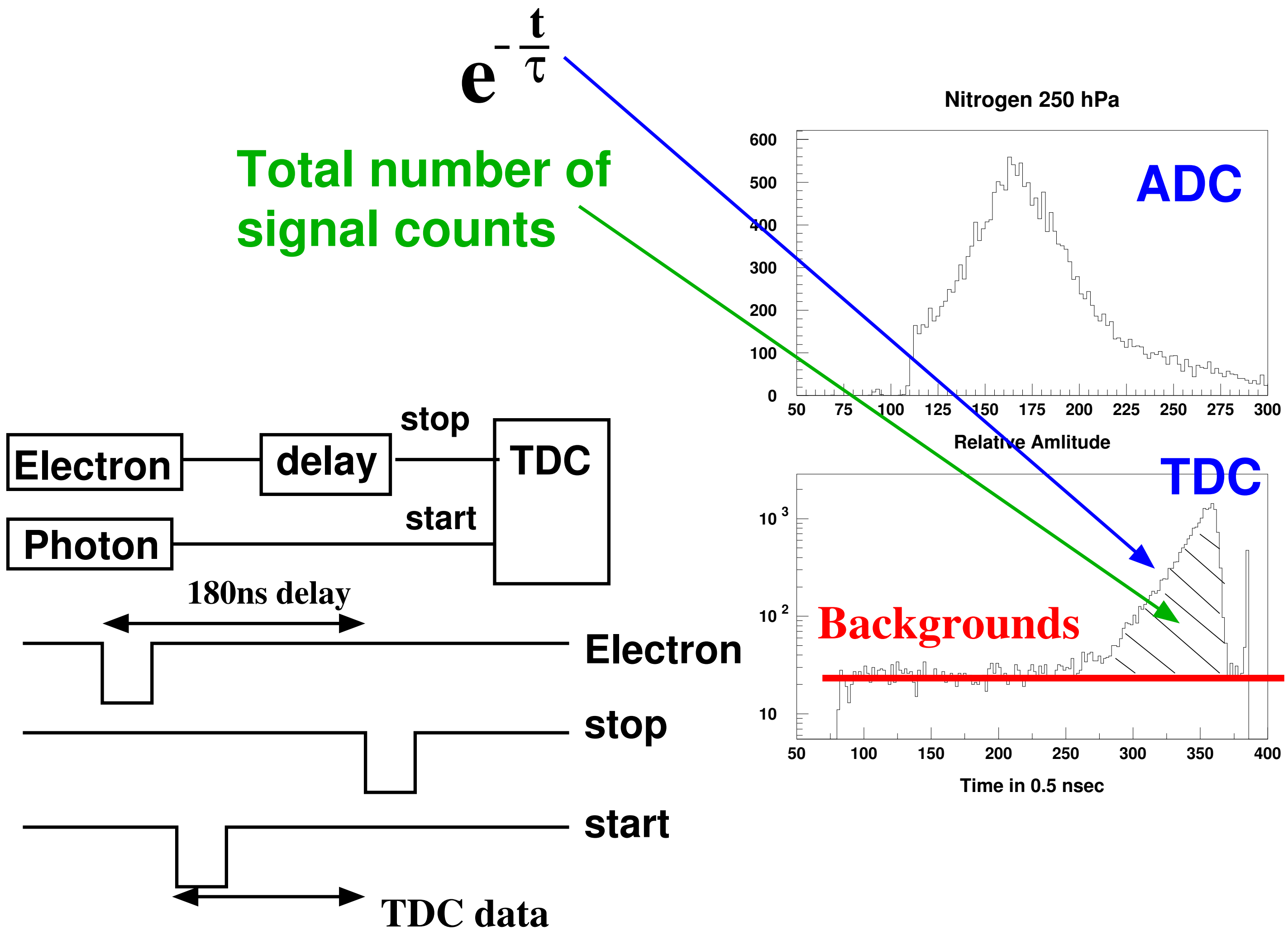




Block diagram of DAQ



ADC and TDC data



Photon Yields by Electron

$$Y = \frac{N}{I \times a \times \Omega \times \eta \times f \times \mathrm{Q.E.} \times \mathrm{C.E.}}$$

Y:	Photon Yield per unit length
I:	Total number of electrons
N:	Total number of signal counts
a:	Length of the fluorescence portion
Ω:	Solid angle of the PMT
η:	Quartz window transmission
f:	filter transmission
Q.E.:	Quantum efficiency of the PMT
C.E.:	Collection efficiency of the PMT

Systematic errors

Item	Errors
Quantum Efficiency (Q.E.) of PMT	5%
Collection Efficiency (C.E.) of PMT	10%
Transmission coefficient of filter	5%
Contamination from lines at the tail of filter transmission	2%
Other parameters (I,a,Ω,η)	4%
Total	13%

Statistical error in each run is less than 3%.

Two Component Analysis

392nm filter = 391.4nm(1N)+394.3(2P)
428nm filter = 427.8nm(1N)+427.0(2P)

$$Y_{\rm obs} = Y_1 + Y_2 = \frac{C_1 p}{1 + p/p'_1} + \frac{C_2 p}{1 + p/p'_2}$$

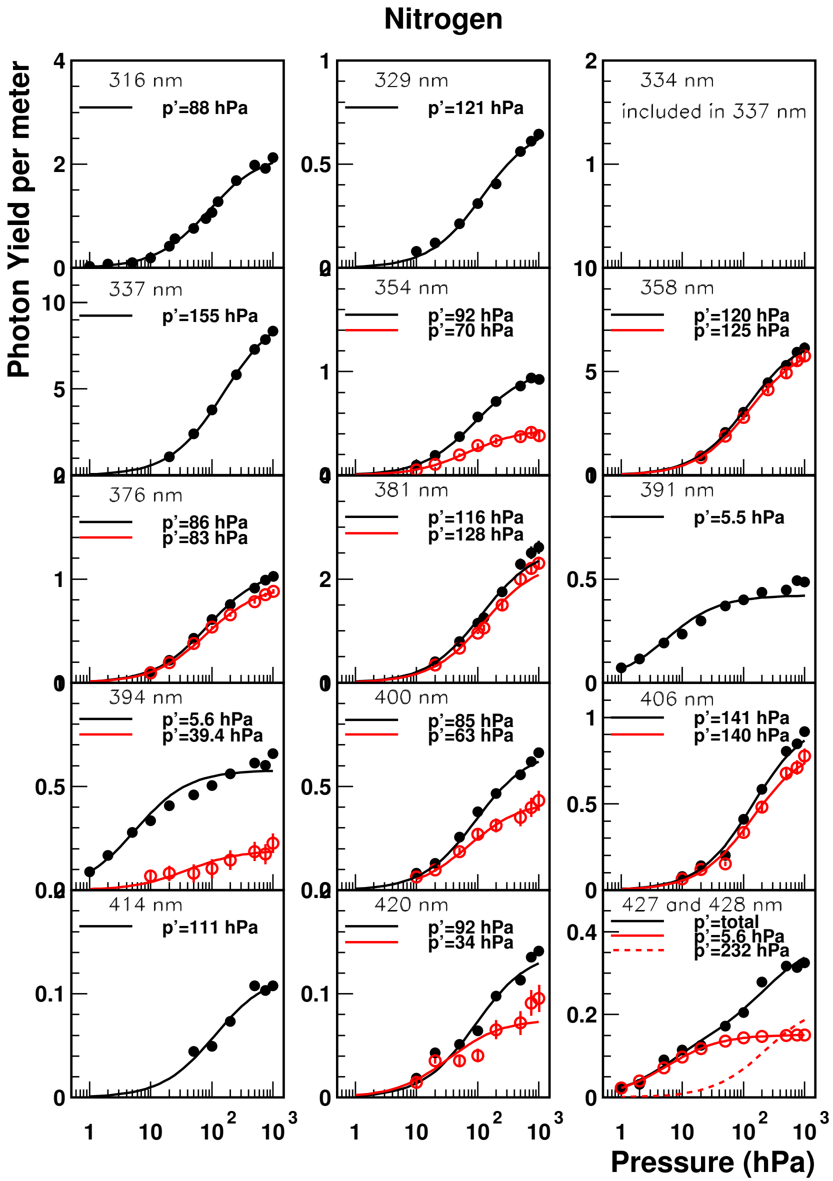
C_1, C_2, p'_1, p'_2 are determined with LS method.

Photon Yield (Nitrogen)

$$Y_i = C_i \frac{p}{1 + p/p'}$$

$$C_i = \frac{1}{R_{N_2} T(h\nu_i)} \frac{\mathrm{d}E}{\mathrm{d}x} E_i^o$$

Red curves are Y_i after subtraction of other bands in the filter



Parameters (Nitrogen)

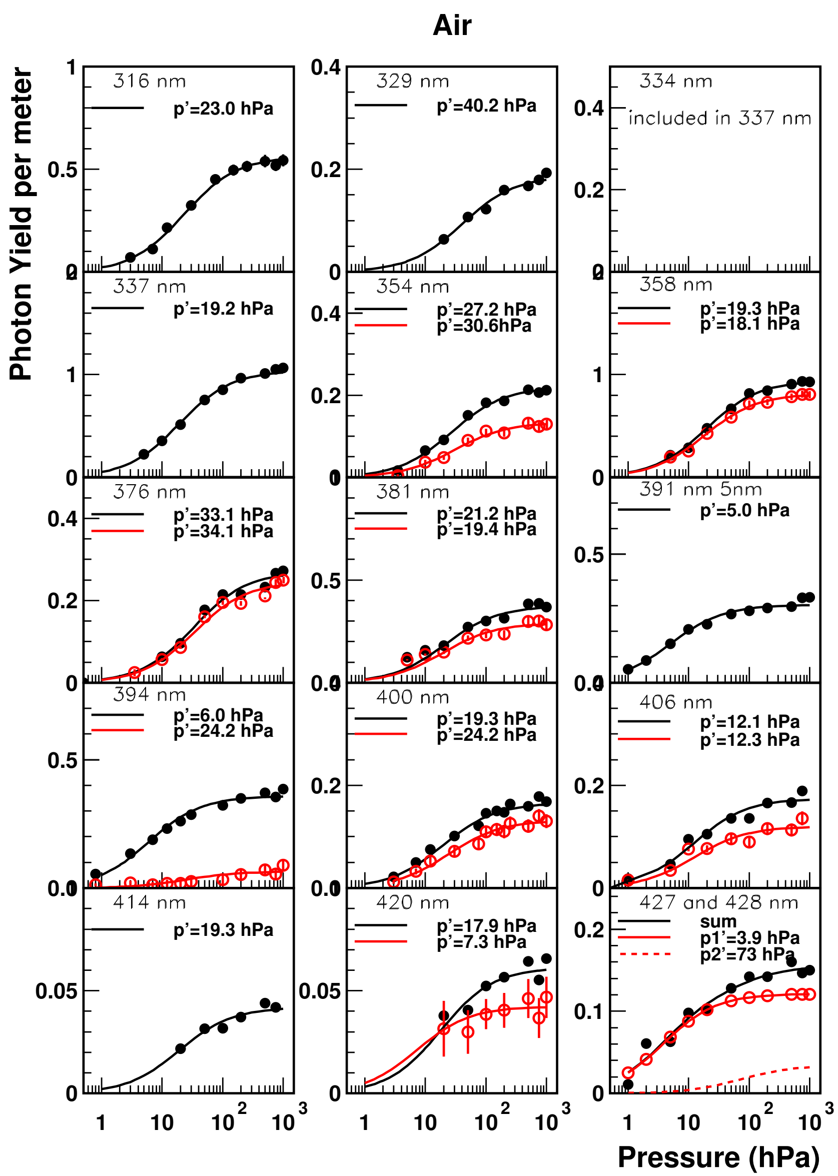
main λ(nm)	ϵ m^{-1}	p' hPa	C $\times 10^{-2}$/(hPa·m)	E° $\times 10^{-4}$
316	2.03 $\pm$0.21	88.1 $\pm$ 7.5	2.51 $\pm$0.14	5.07 $\pm$0.28
329	0.622$\pm$0.063	121. $\pm$10.	0.575$\pm$0.033	1.12 $\pm$0.06
337	8.28 $\pm$0.25	155. $\pm$ 4.	6.16 $\pm$0.10	11.7 $\pm$0.2
354	0.417$\pm$0.044	70.3 $\pm$ 6.4	0.634$\pm$0.035	1.15 $\pm$0.06
358	5.64 $\pm$0.31	125. $\pm$ 6.	5.07 $\pm$0.16	9.07 $\pm$0.29
376	0.873$\pm$0.059	82.5 $\pm$ 4.7	1.14 $\pm$0.04	1.95 $\pm$0.07
381	2.09 $\pm$0.25	128. $\pm$14.	1.84 $\pm$0.09	3.08 $\pm$0.16
391	0.419$\pm$0.049	5.46$\pm$ 0.50	7.72 $\pm$0.54	12.6 $\pm$0.9
394	0.185$\pm$0.078	39.4 $\pm$12.5	0.49 $\pm$0.13	0.79 $\pm$0.22
400	0.399$\pm$0.036	62.9 $\pm$ 4.8	0.674$\pm$0.033	1.08 $\pm$0.05
406	0.73 $\pm$0.15	140. $\pm$25.	0.597$\pm$0.064	0.94 $\pm$0.10
414	0.108$\pm$0.029	111. $\pm$24.	0.108$\pm$0.017	0.167$\pm$0.027
420	0.073$\pm$0.028	34. $\pm$10.	0.222$\pm$0.050	0.338$\pm$0.076
427	0.188$\pm$0.113	232. $^{+144.}_{-\ 71.}$	0.099$\pm$0.038	0.148$\pm$0.057
428	0.151$\pm$0.031	5.6 $\pm$ 1.1	2.72 $\pm$0.24	4.07 $\pm$0.36
Sum	21.69 $\pm$0.55	(300nm$\sim$406nm)		
Sum	22.20 $\pm$0.56	(300nm$\sim$430nm)		

Photon Yield (Dry Air)

Mixture of

N_2: 78.8%

O_2: 21.2%

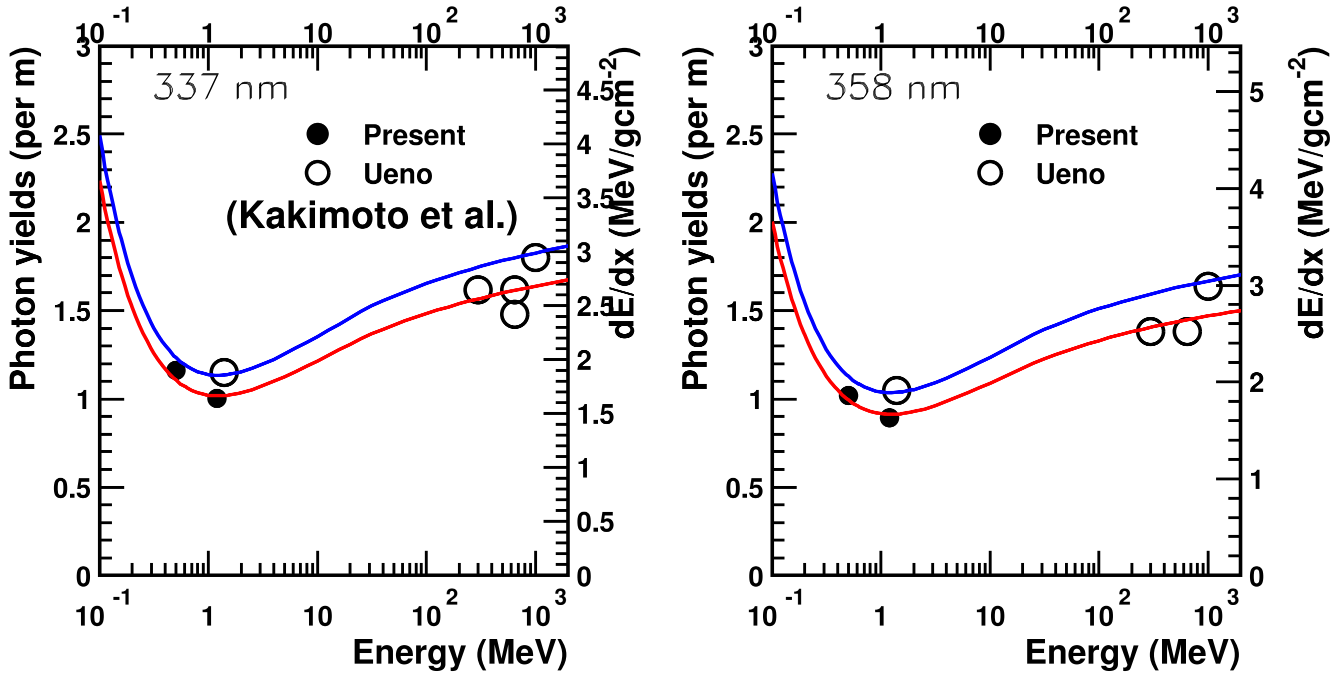


Parameters (Dry Air)

main λ(nm)	ϵ m^{-1}	p' hPa	C $\times10^{-2}$/(hPa·m)	E° $\times10^{-4}$
316	0.549±0.057	23.0 ± 1.9	2.44 ±0.15	4.80 ±0.29
329	0.180±0.026	40.2 ± 4.6	0.465±0.042	0.880±0.080
337	1.021±0.060	19.2 ± 0.7	5.43 ±0.15	10.01 ±0.27
354	0.130±0.022	30.6 ± 3.9	0.437±0.046	0.769±0.080
358	0.799±0.080	18.1 ± 1.4	4.50 ±0.28	7.82 ±0.48
376	0.238±0.036	34.1 ± 4.1	0.722±0.068	1.20 ±0.11
381	0.287±0.050	19.4 ± 2.6	1.51 ±0.17	2.46 ±0.27
391	0.302±0.020	5.02± 0.26	6.04 ±0.25	9.60 ±0.39
394	0.063±0.033	24.2 ± 9.4	0.267±0.093	0.42 ±0.15
400	0.129±0.019	24.2 ± 2.8	0.544±0.053	0.847±0.082
406	0.118±0.019	12.3 ± 1.6	0.972±0.010	1.49 ±0.15
414	0.041±0.009	19.3 ± 3.4	0.217±0.031	0.327±0.047
420	0.042±0.015	7.3 ± 1.9	0.58 ±0.13	0.86 ±0.20
427	0.032±0.023	$72.\ ^{+60.}_{-23.}$	0.047±0.021	0.069±0.031
428	0.121±0.022	3.86± 0.59	3.14 ±0.28	4.57 ±0.41
Sum	3.81 ±0.13	(300nm∼406nm)		
Sum	4.05 ±0.14	(300nm∼430nm)		

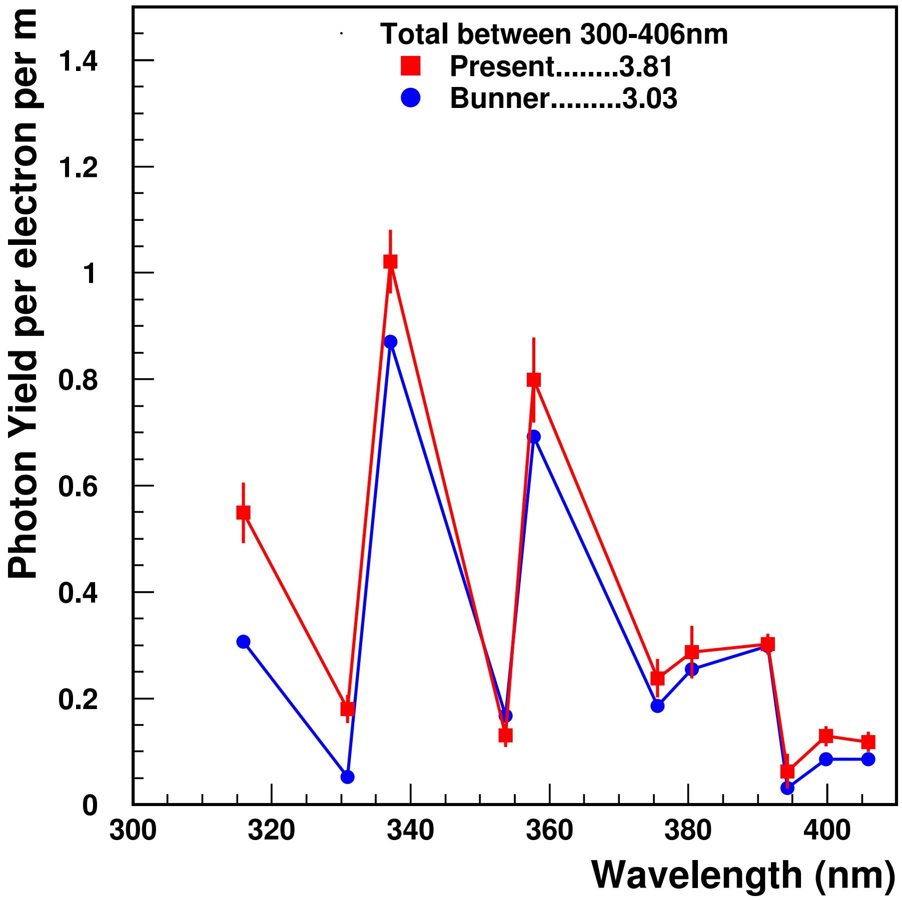
Energy dependence of Photon Yield

Air of 1 atm. pressure



$\frac{\mathrm{d}E}{\mathrm{d}x}$ curves are adjusted at 1.2MeV

Photon yields between 300 and 406nm



3.81/3.03=1.26

Photon yields as a function of ρ and T

$$Y_i = \frac{A_i \rho}{1 + \rho B_i \sqrt{T}}$$

where

$$A_i = \frac{\frac{\mathrm{d}E}{\mathrm{d}x} E_i^0}{h\nu_i}$$

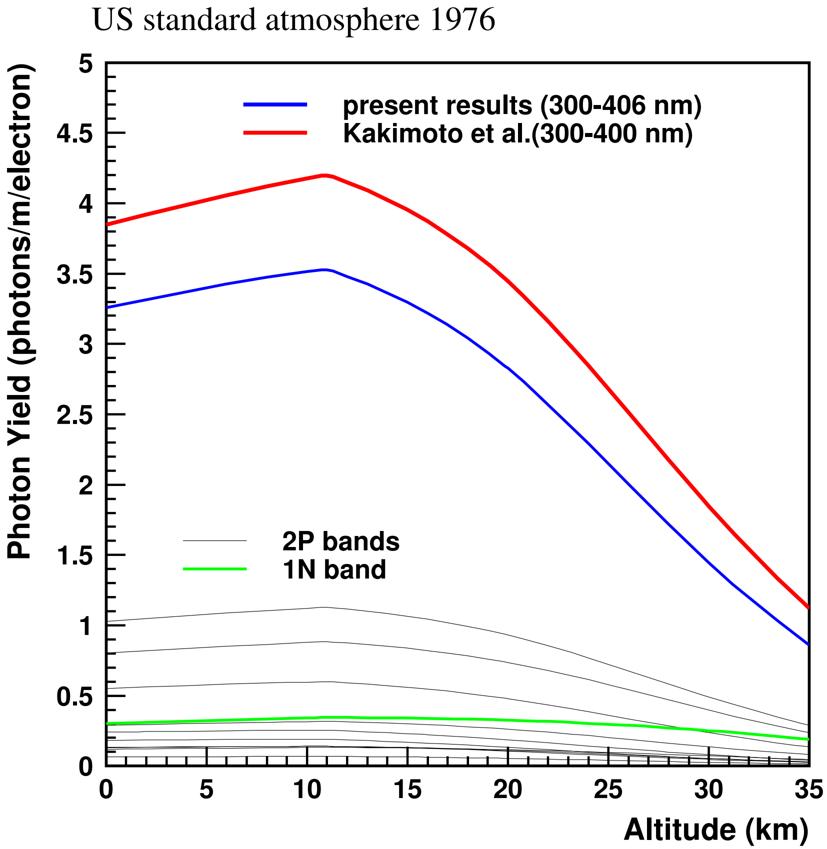
$$B_i = \frac{R_{N_2}\sqrt{T}}{p'_i}$$

A and B in various bands

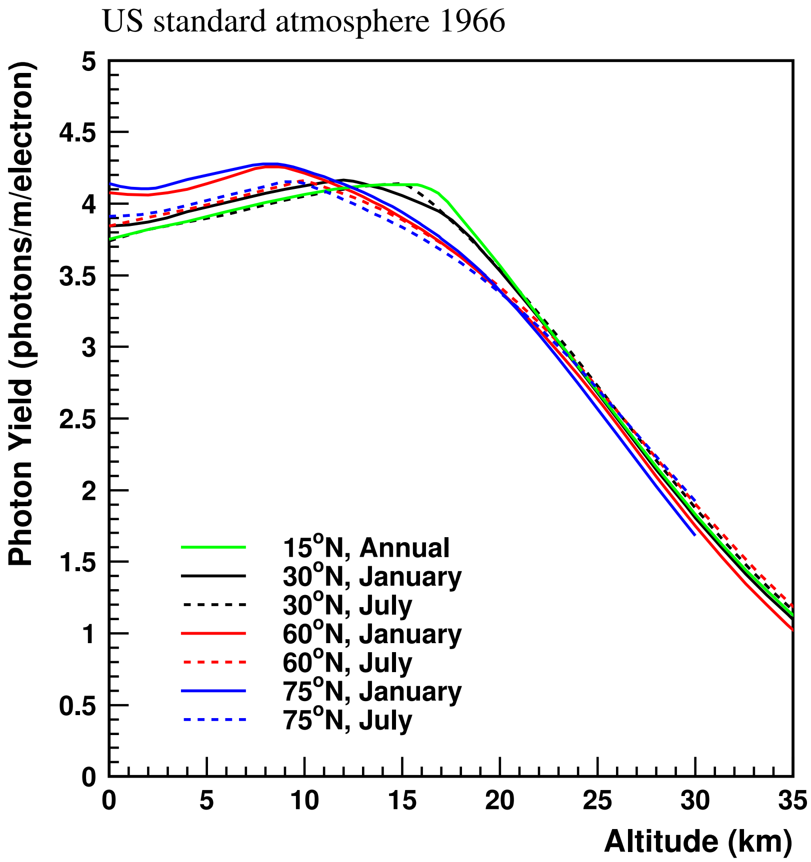
main λ(nm)	Nitrogen		Air	
	A	B	A	B
	m^2kg^{-1}	$m^3kg^{-1}K^{\frac{1}{2}}$	m^2kg^{-1}	$m^3kg^{-1}K^{\frac{1}{2}}$
316	21.8 ±1.2	0.577±0.049	20.5 ±1.3	2.14±0.18
329	5.00±0.29	0.419±0.035	3.91±0.35	1.22±0.14
337	53.6 ±0.9	0.328±0.008	45.6 ±1.2	2.56±0.10
354	5.52±0.31	0.723±0.066	3.68±0.39	1.60±0.21
358	44.1 ±1.4	0.407±0.019	37.8 ±2.3	2.72±0.22
376	9.95±0.35	0.616±0.035	6.07±0.57	1.44±0.17
381	16.0 ±0.8	0.397±0.042	12.7 ±1.4	2.53±0.35
391	67.2 ±4.7	9.31 ±0.86	50.8 ±2.1	9.80±0.51
394	4.3 ±1.2	1.29 ±0.41	2.25±0.78	2.03±0.79
400	5.87±0.28	0.808±0.061	4.58±0.44	2.03±0.23
406	5.20±0.56	0.363±0.064	8.18±0.82	3.99±0.52
414	0.94±0.15	0.46 ±0.10	1.83±0.26	2.55±0.45
420	1.93±0.43	1.49 ±0.46	4.9 ±1.1	6.8 ±1.7
427	0.86±0.33	0.22 ±0.10	0.40±0.18	0.68±0.38
428	23.7 ±2.1	9.1 ±1.8	26.5 ±2.4	12.7 ±1.9

Altitude dependence of Photon Yield

0.85MeV electron

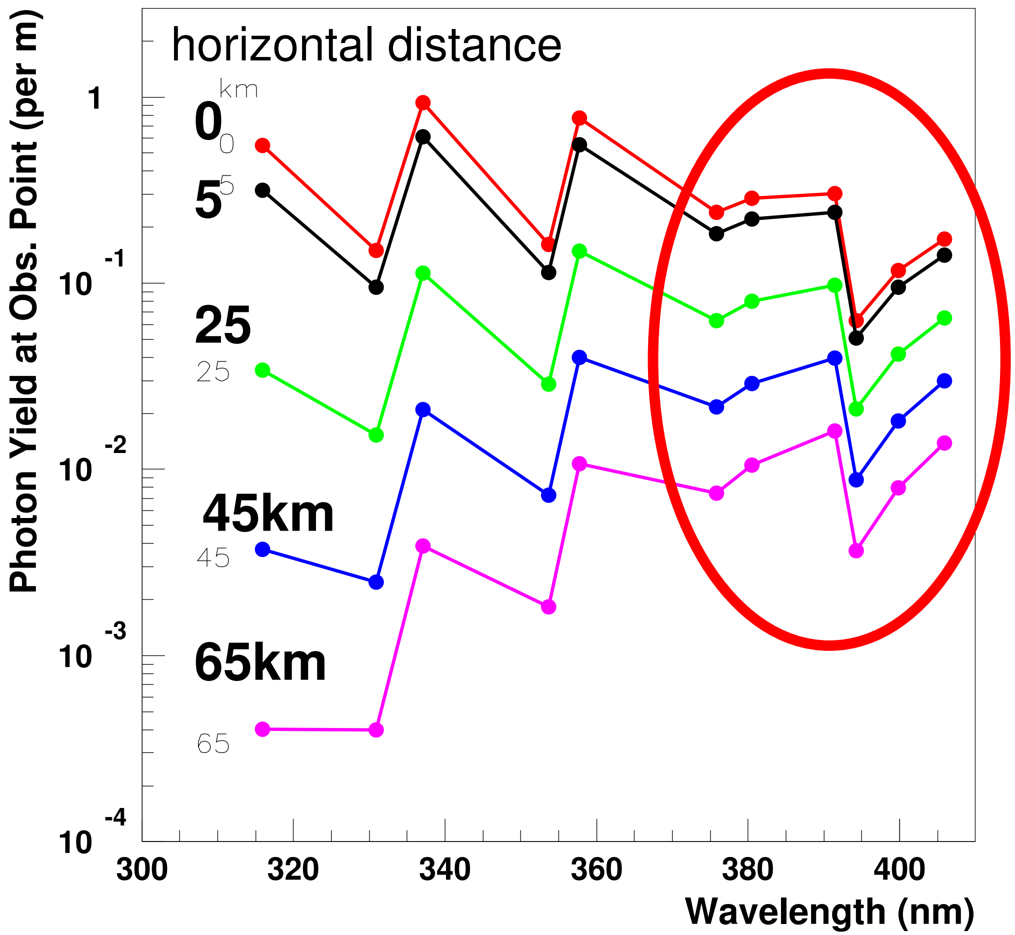


Seasonal effect



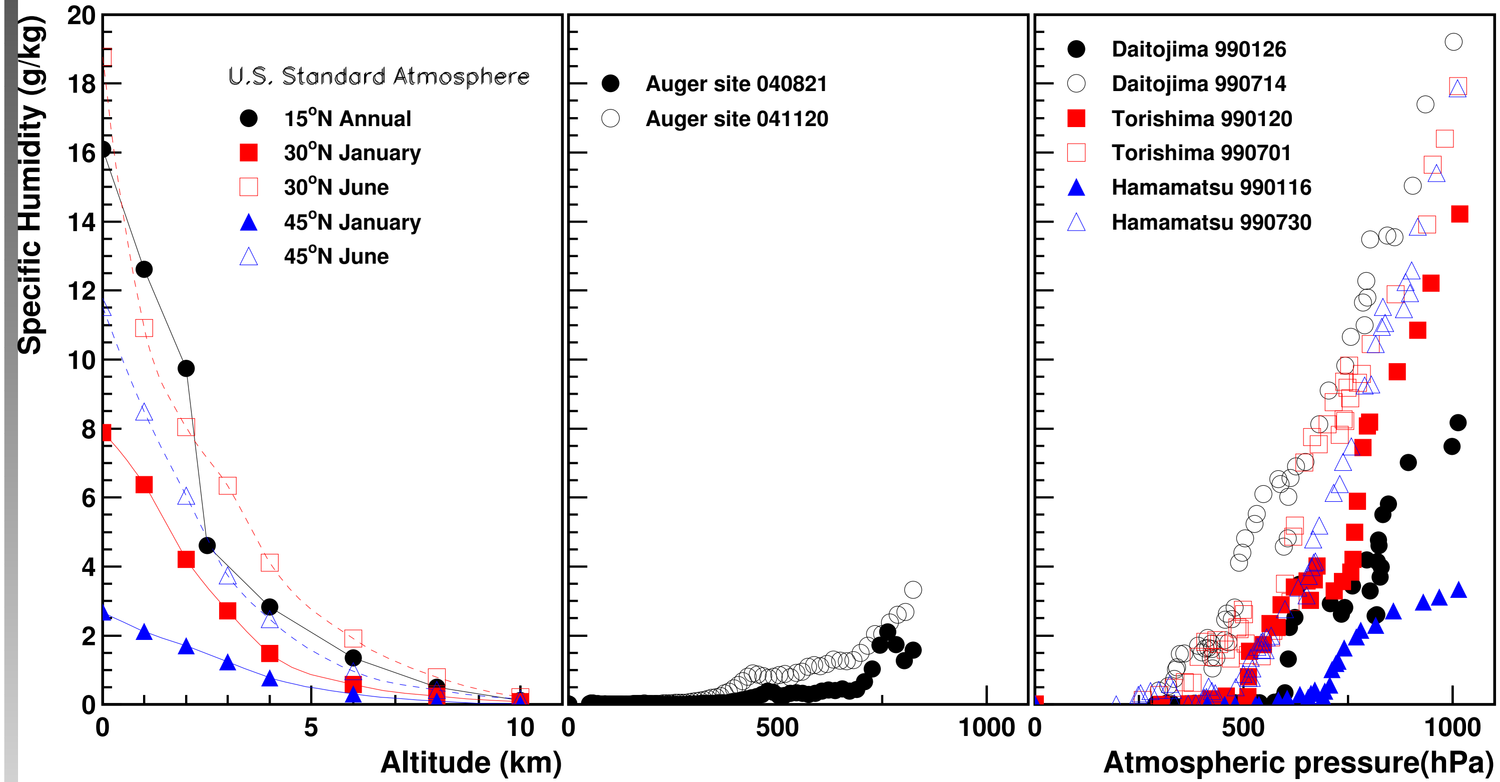
Photon attenuation with distance

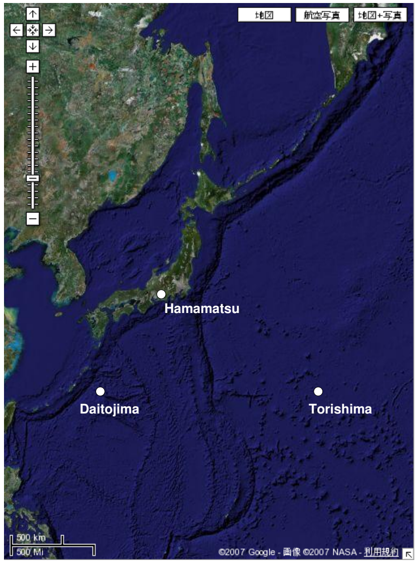
Rayleigh scattering only



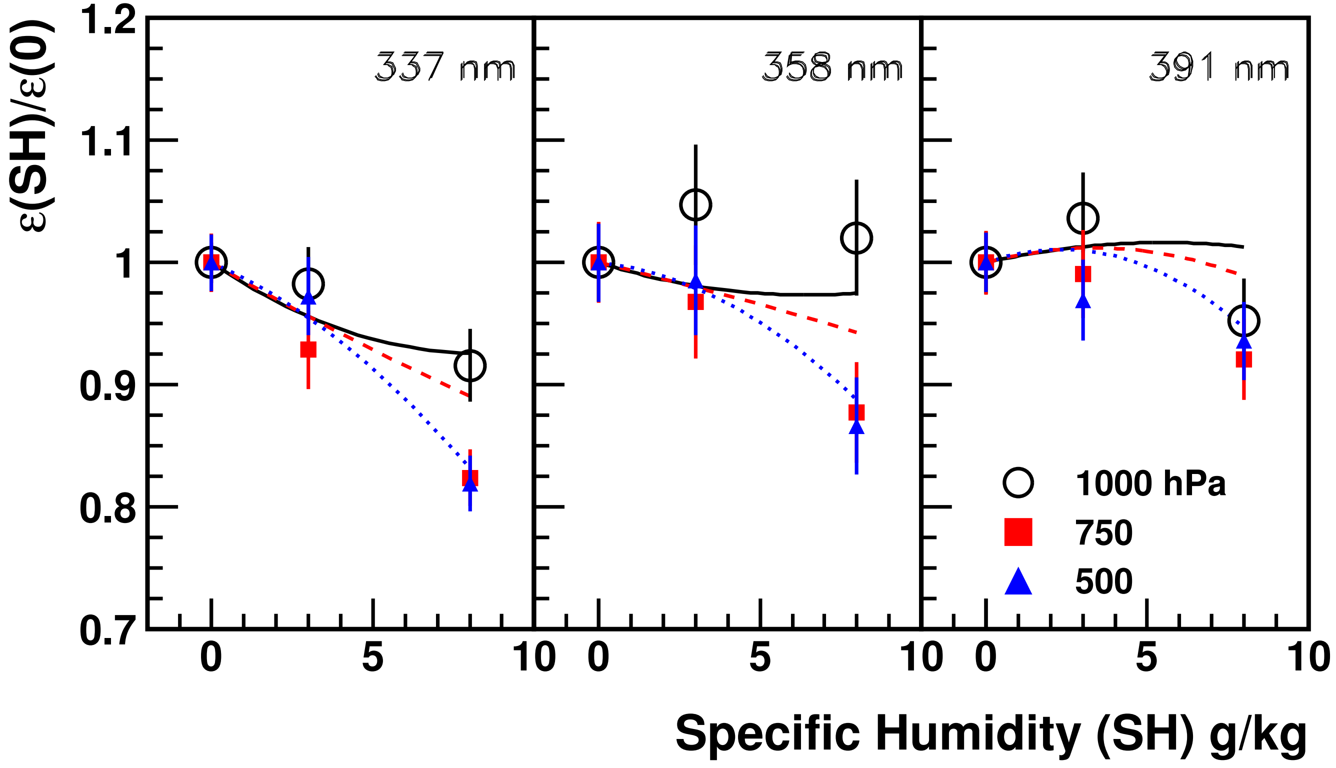
important at far distance

Specific Humidity





Water Vapor effect (very preliminary)

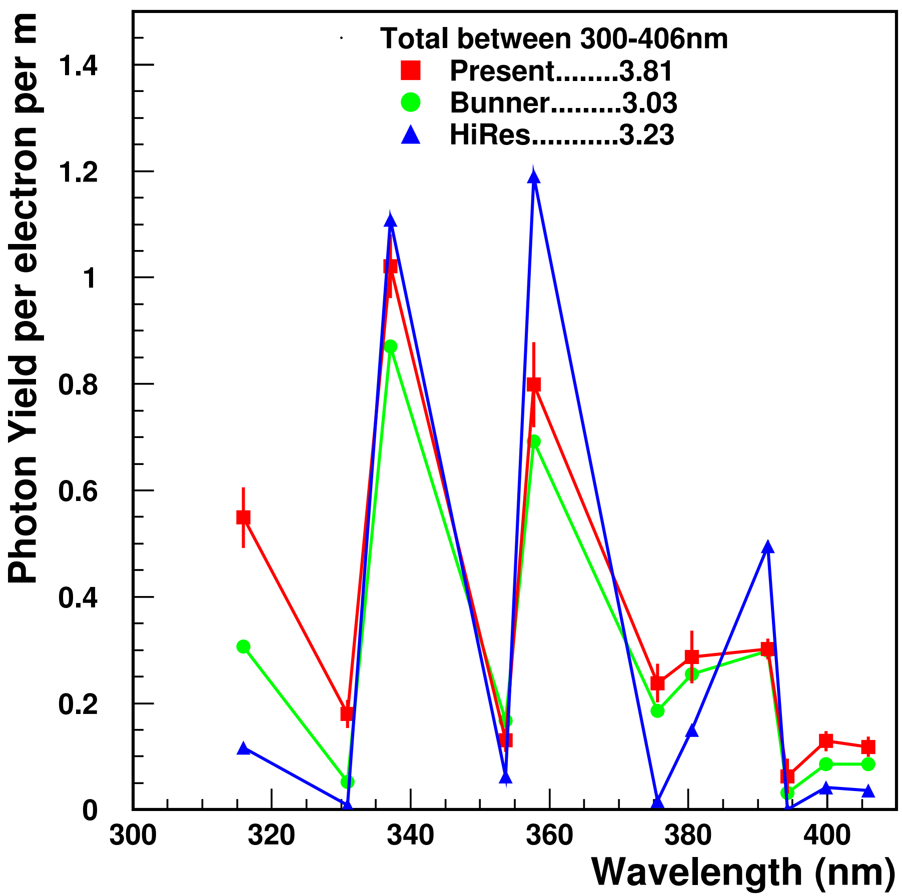


Sakaki et al.,ICRC29

Summary

- From the pressure dependence of photon yields, fluorescence efficiencies without collisional quenching are determined for 15 bands.
- Photon yields are determined as a function of the gas density and the temperature for 15 bands.
- Total photon yield between 300 and 406nm is 3.81 ± 0.13 ($\pm 13\%$ syst.), which is 22% larger than the summary by Bunner at 1013 hPa and 20°C.
- We need the detailed evaluation, taking account of the density and temperature dependence of each band and other factors which depend on wave length, in estimating the primary energy of cosmic rays.
- For space based observations such as JEM-EUSO, the quenching by water vapor should be taken into account. For ground based experiments such as Auger, HiRes, TA, it will be negligible. The measurement of photon yield in moist air is now in progress.

Photon yields between 300 and 406nm



3.81/3.03=1.26
3.81/3.23=1.18

Assumptions

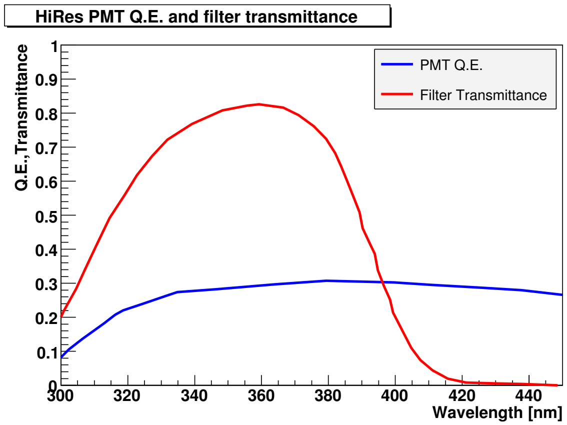
- CORSIKA 6.020 (QGSJET)
- Proton at E=10^{19},10^{20} with $\theta = 0, 60°$
- observation height is at 0 m a.s.l.
- $\mathrm{d}E/\mathrm{d}x$=2.19MeV/(g cm^2) for all electrons
- Transmission by Rayleigh scattering

$$T_R = \exp\left[-\frac{|x_1 - x_2|}{X_R}\left(\frac{400[\mathrm{nm}]}{\lambda}\right)^4\right]$$

- Transmission by Mie scattering (scale height H_M=1.2 km, horizontal attenuation $L_M = 25$km)

$$T_M = \exp\left(\frac{H_M}{L_M \cos\theta}\left[\exp\left(-\frac{h_1}{H_M}\right) - \exp\left(-\frac{h_2}{H_M}\right)\right]\frac{400[\mathrm{nm}]}{\lambda}\right)$$

- US standard atmosphere 1976
- λ dependence of HiRes filter transmission and Q.E. of HiRes PMT



Comparison of Observed total number of photons