Fluorescence Efficiency Measured by Beta Source

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

Measurement History

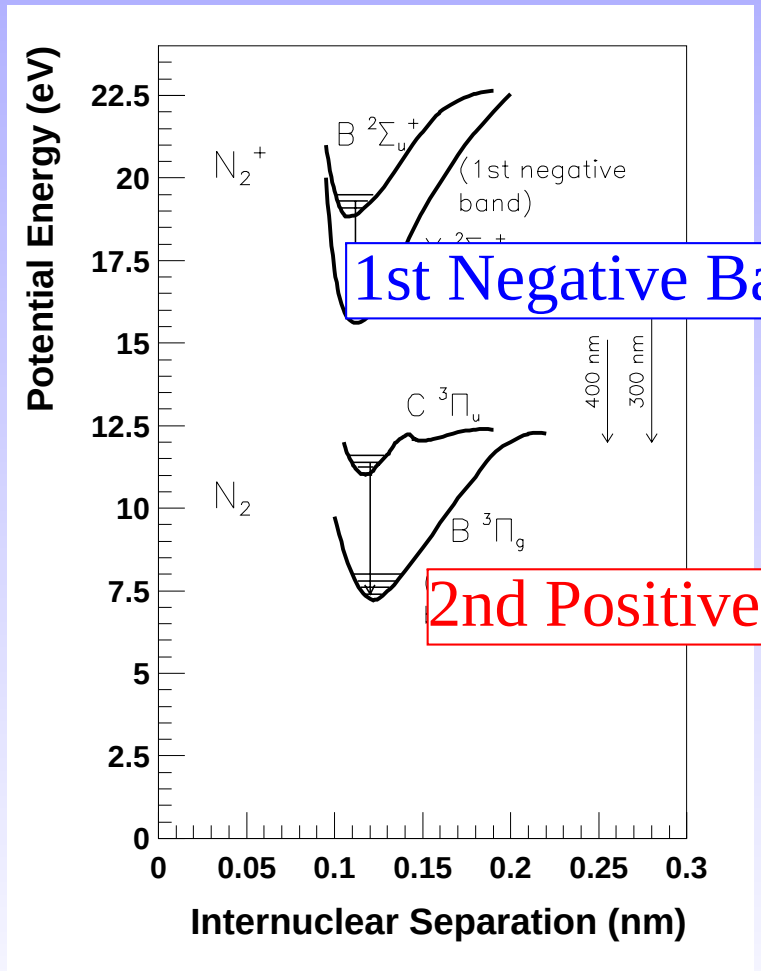
Astroparticle Physics, **20** (2003) 293–309.
M.Nagano, K.Kobayakawa, N.Sakaki and K.Ando

- √ fluorescence yield measured with 6 filters
- √ two component analysis
- √ Bunner's result was used for unmeasured lines

ICRC2003(Tsukuba),Airlight-03

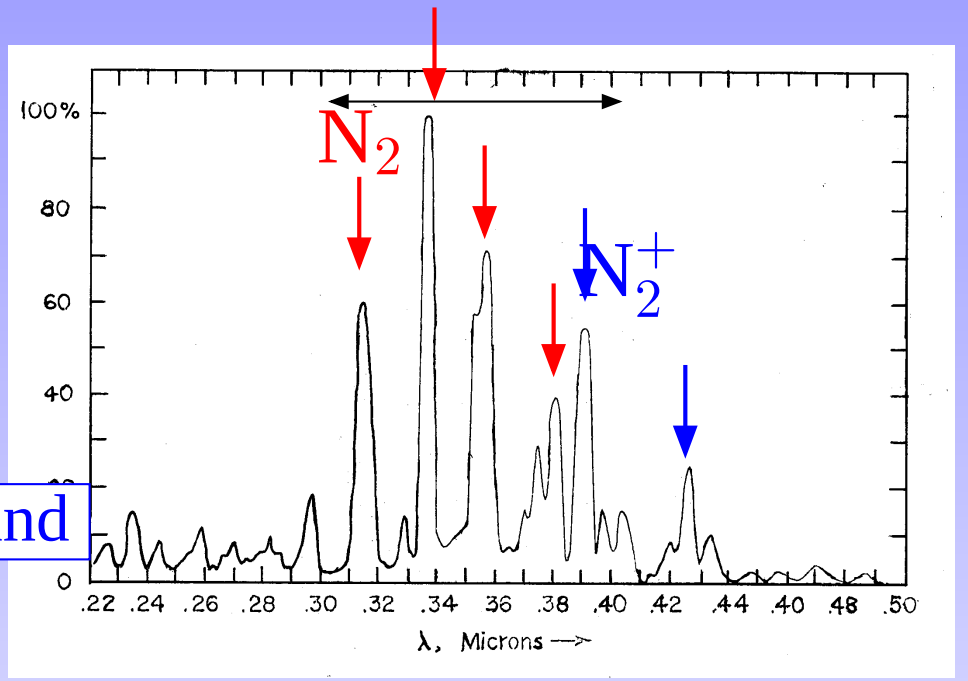
- √ fluorescence yield measurement with 6+10 filters
- → **300–430nm is covered with our own measurement**

Fluorescence from Nitrogen



1st Negative Band

2nd Positive Band



Data from

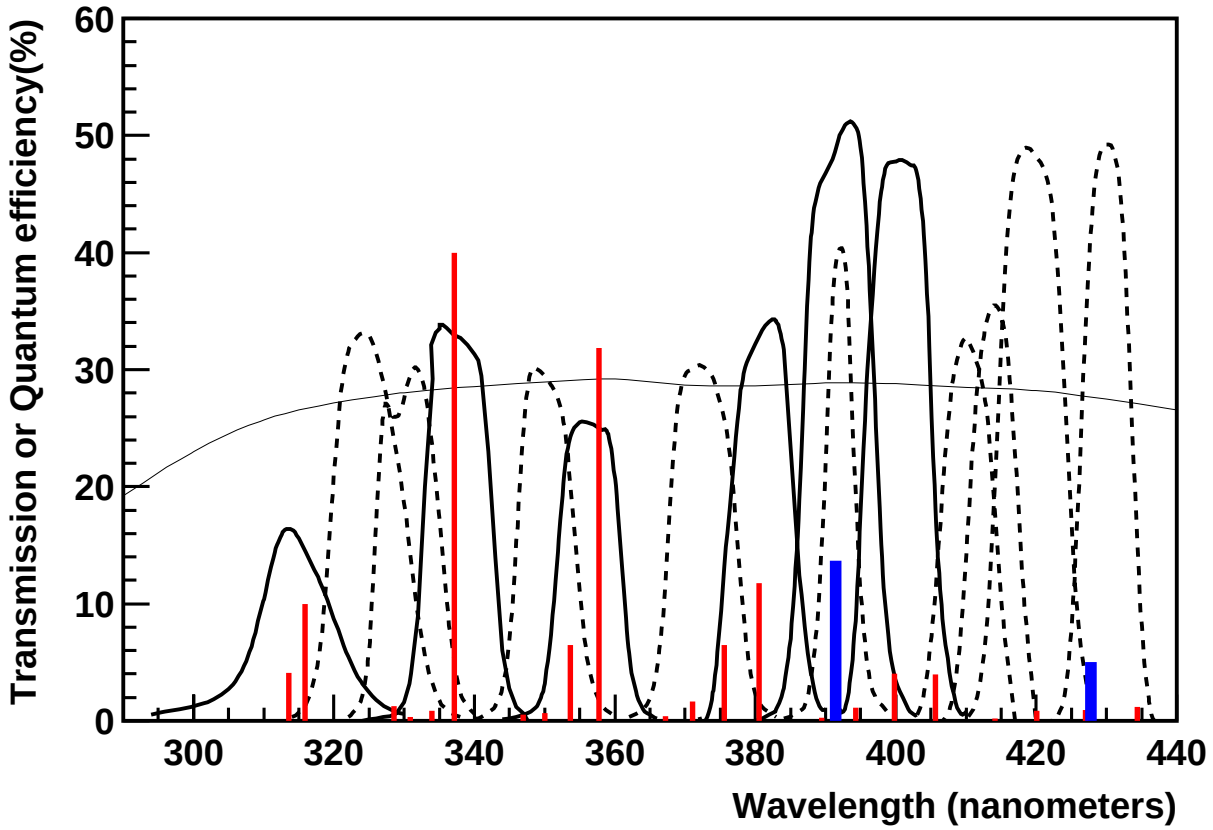
Bunner(1964): weighted average of 3 experiments with an accuracy of not better than 30%

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

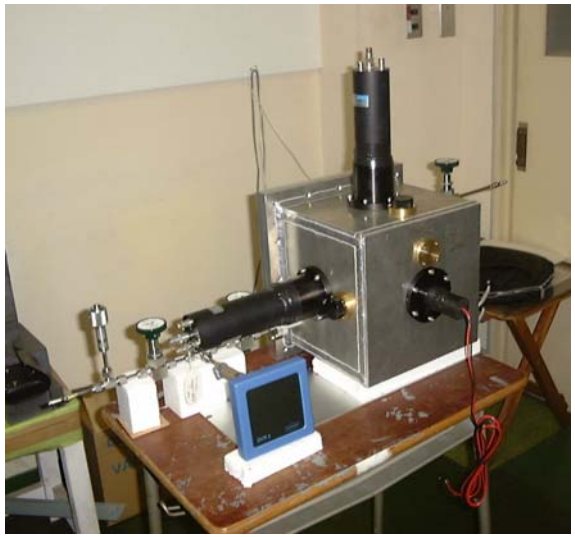
are mainly used in UHECR exp.

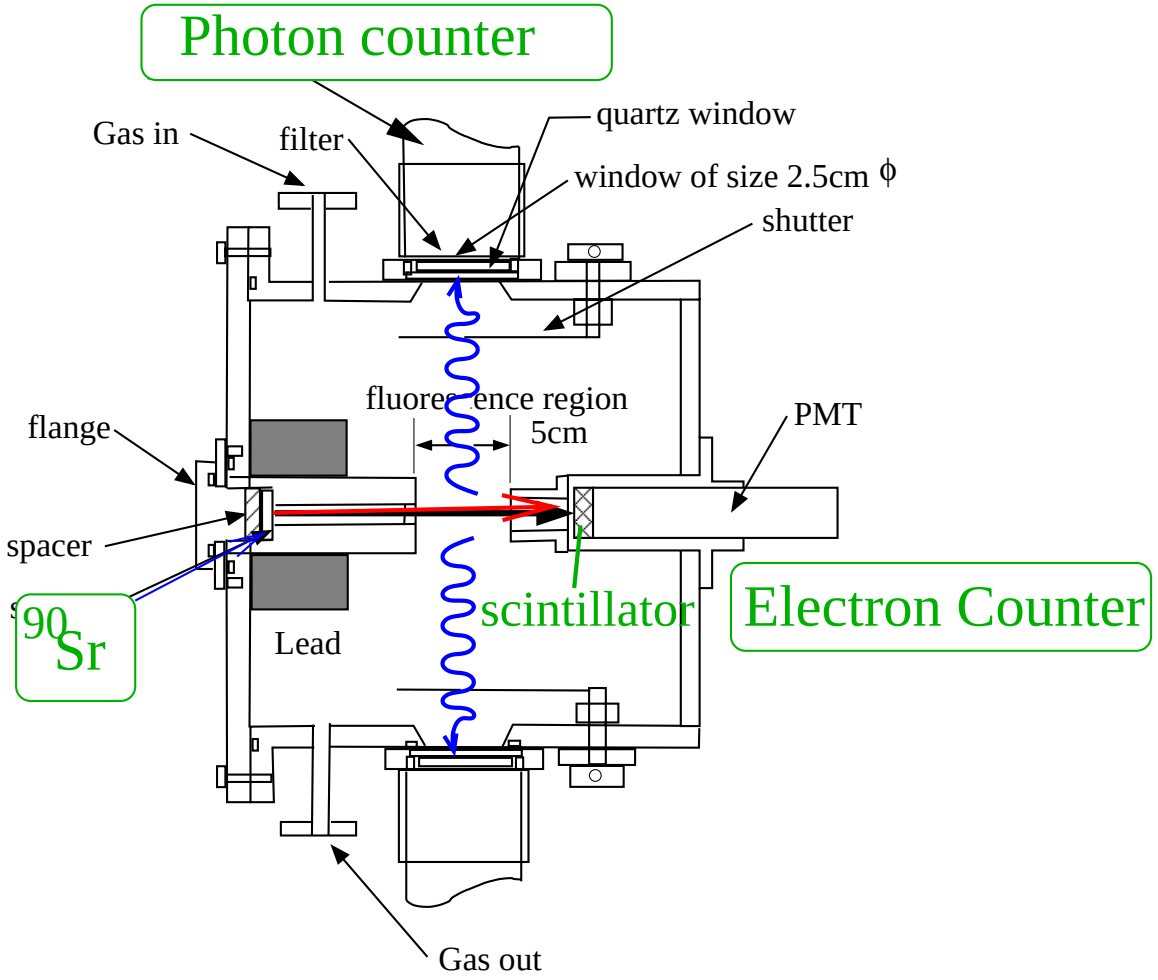
Filter

16 filters are used.

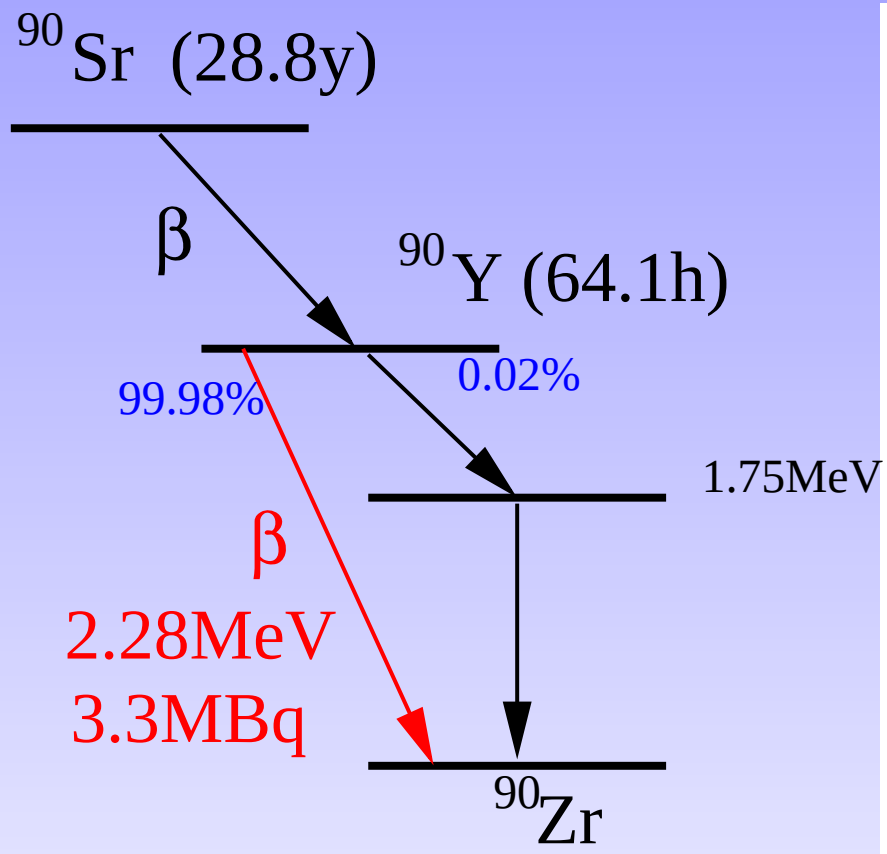


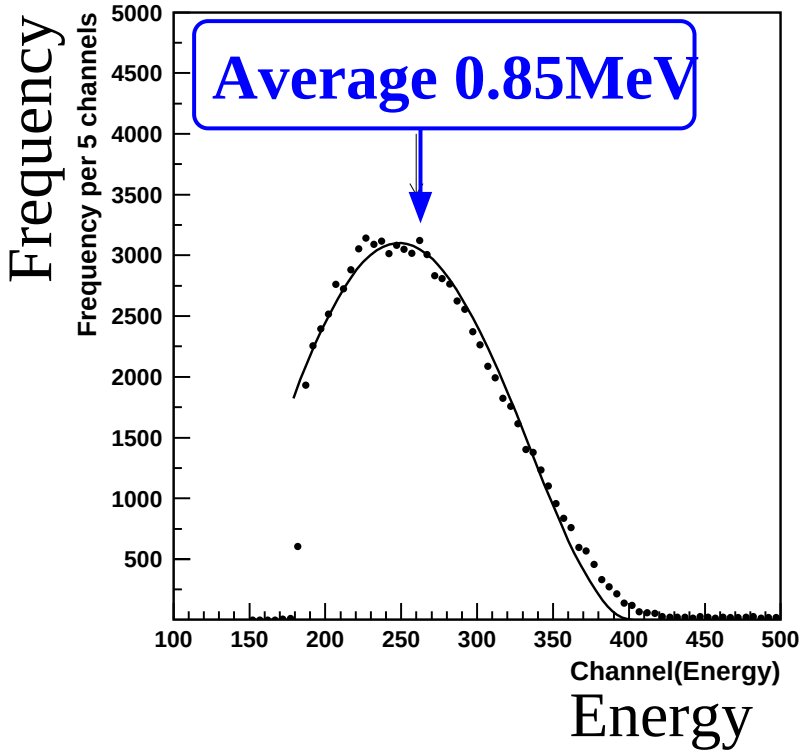
chamber



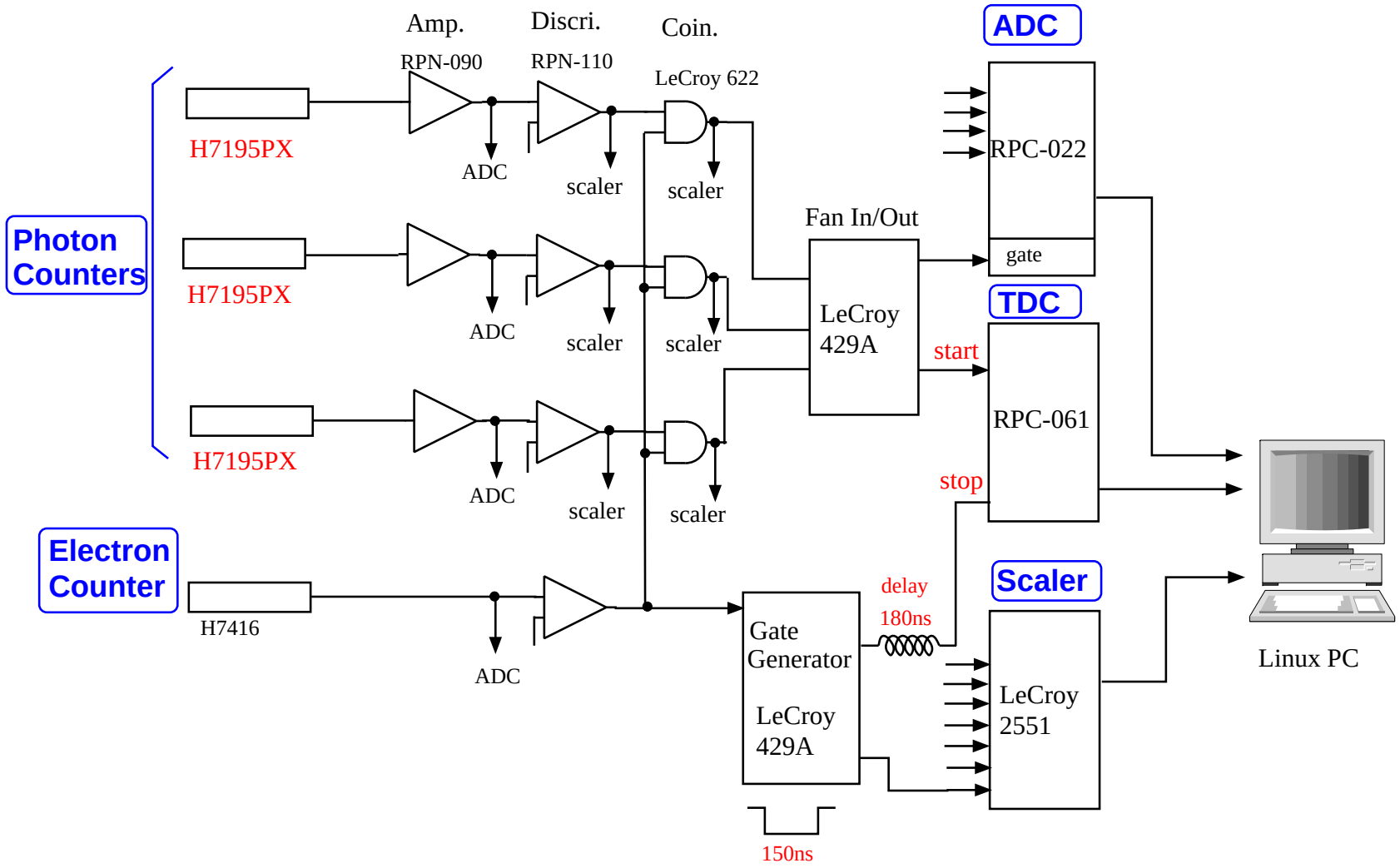

Photon counter
Gas in
filter
quartz window
window of size 2.5cm ϕ
shutter
fluorescence region
5cm
PMT
flange
spacer
90Sr
Lead
scintillator
Electron Counter
Gas out

Electron beam





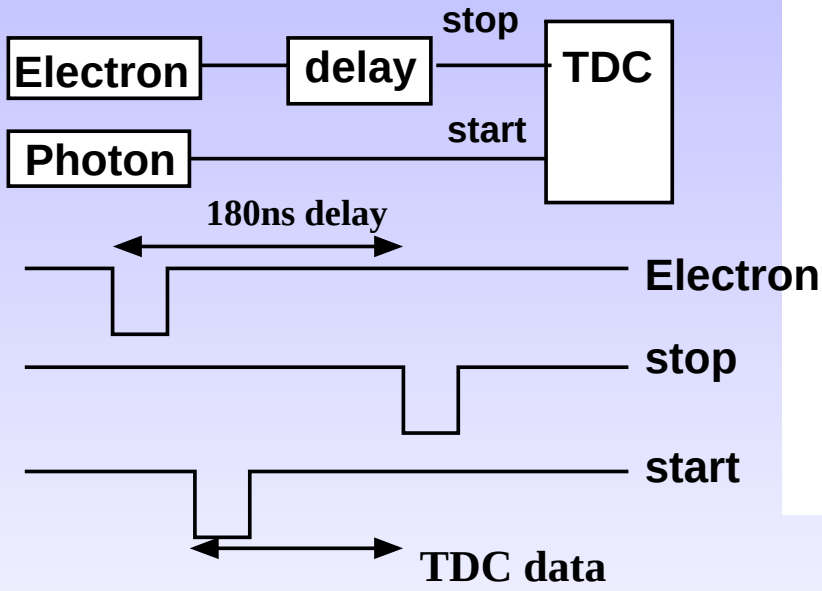
Block diagram of DAQ

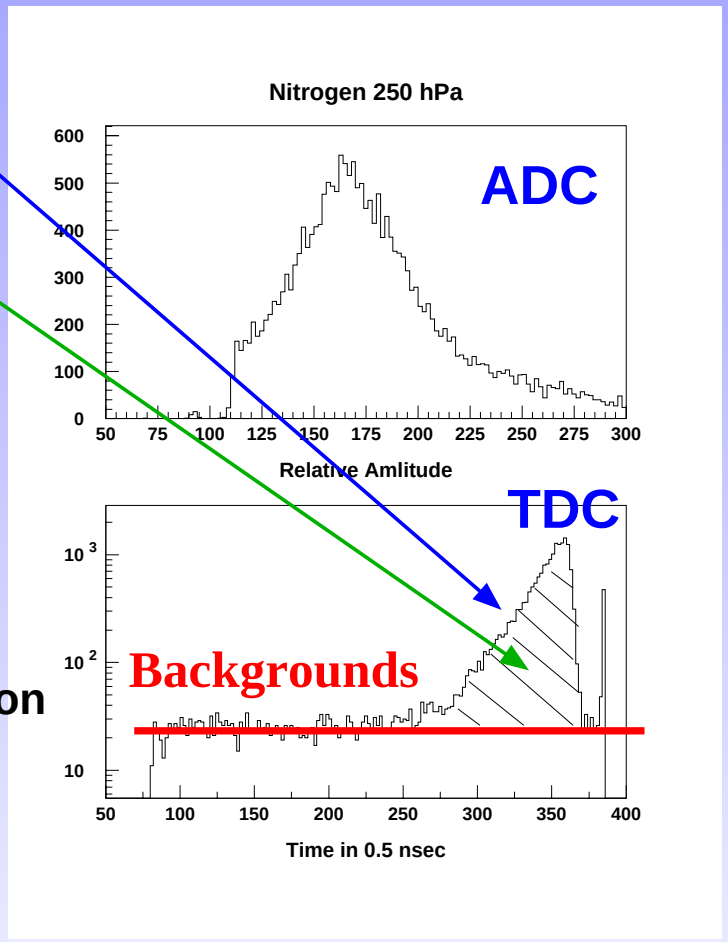


ADC and TDC data

$$e^{-\frac{t}{\tau}}$$

Total number of signal counts





Photon Yields/Electron

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

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)

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

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

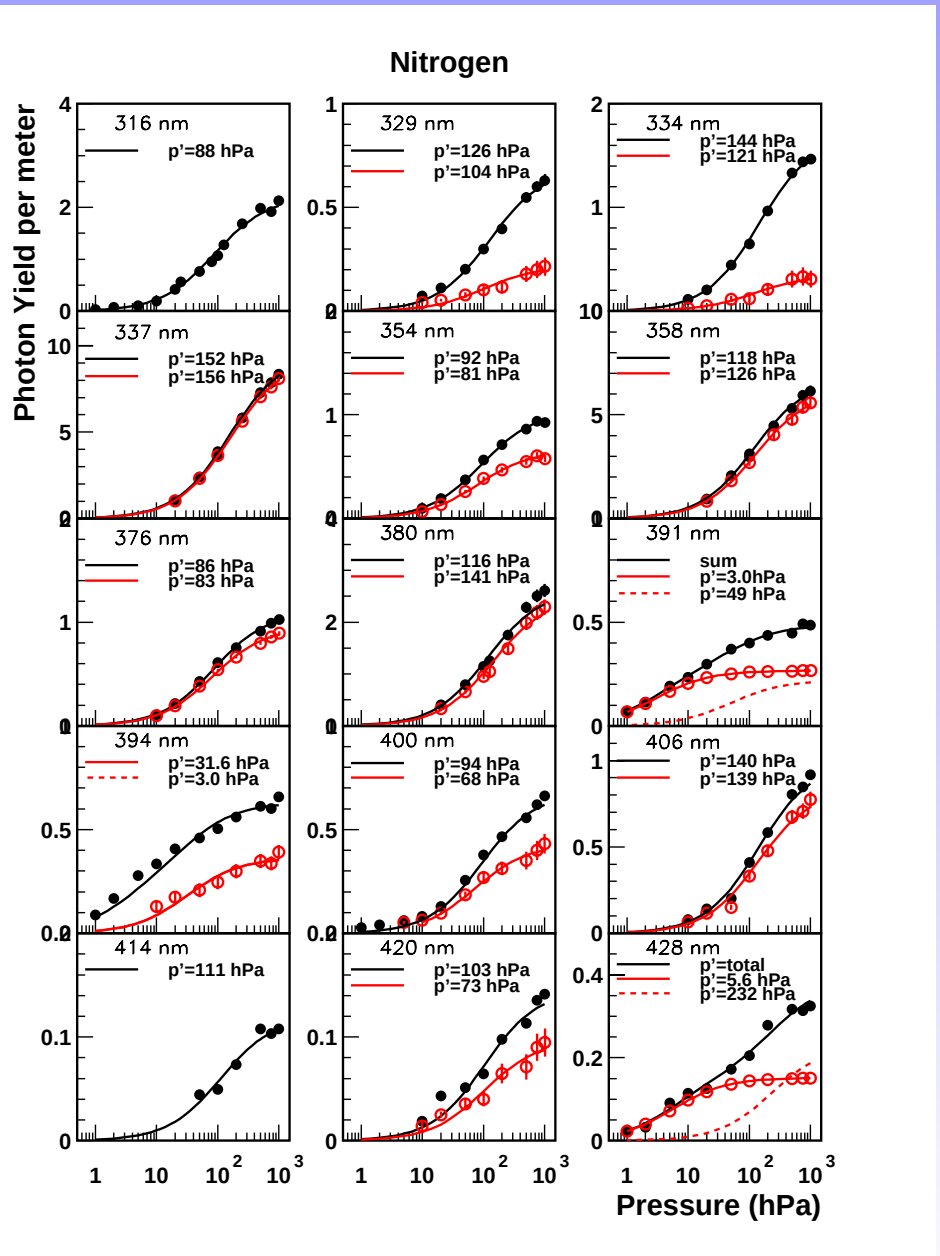
Photon Yield (Nitrogen)

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

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

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

preliminary



Nitrogen (preliminary)

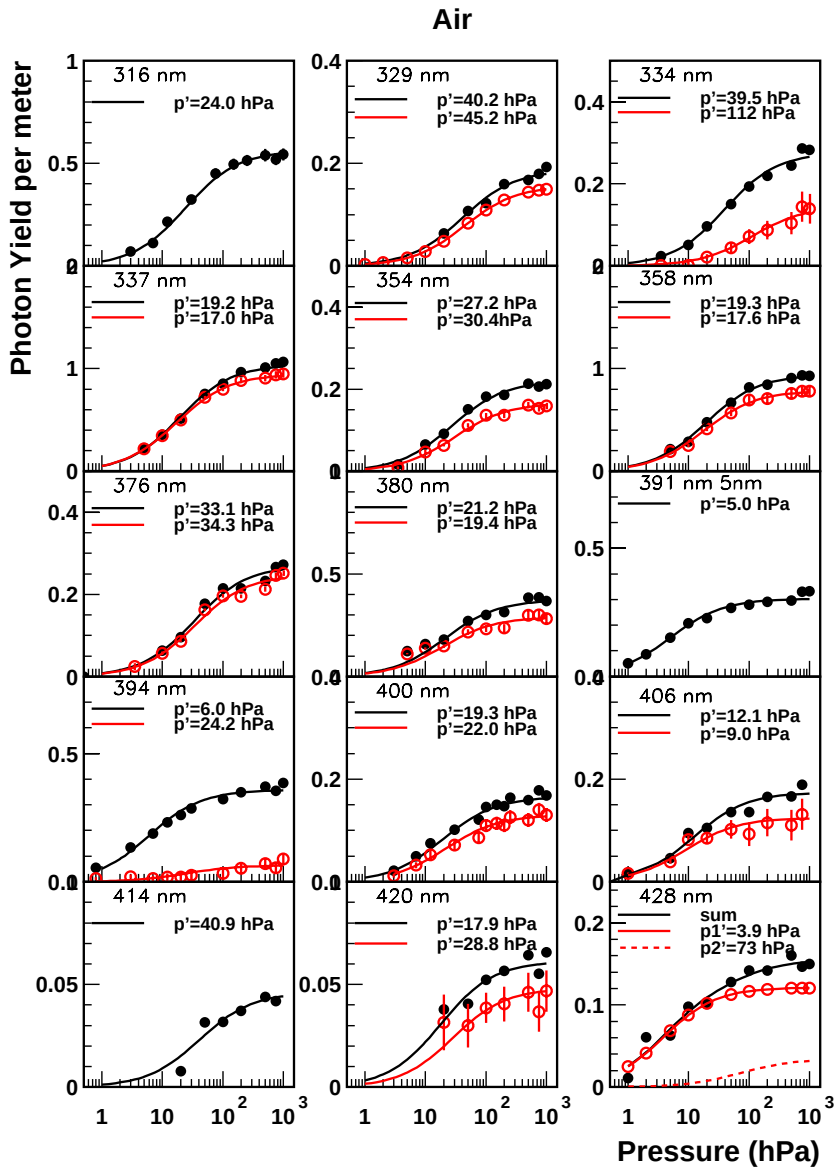
main λ(nm)	ϵ m^{-1}	p' hPa	C $\times 10^{-2}$/(hPa·m)	E° $\times 10^{-4}$
316	2.03 ±0.18	88.3 ± 7.5	2.50 ±0.05	5.07 ±0.10
329	0.308±0.066	121. ±22.	0.285±0.032	0.546±0.061
337	8.01 ±0.25	156. ± 4.	5.92 ±0.10	11.3 ±0.2
354	0.608±0.043	81.2 ± 4.9	0.809±0.031	1.46 ±0.06
358	5.48 ±0.30	126. ± 6.	4.90 ±0.15	8.77 ±0.28
376	0.883±0.058	82.8 ± 4.6	1.15 ±0.04	1.97 ±0.07
381	2.17 ±0.25	141. ±14.	1.75 ±0.10	2.95 ±0.17
391	0.266±0.031	2.98± 0.35	8.93 ±0.31	14.6 ±0.5
394	0.35 ±0.10	31.6 ± 7.0	1.15 ±0.23	1.87 ±0.37
400	0.406±0.035	67.9 ± 4.8	0.638±0.030	1.02 ±0.05
406	0.73 ±0.15	139. ±25.	0.60 ±0.06	0.95 ±0.095
414	0.110±0.031	111. ±24.	0.110±0.020	0.170±0.031
420	0.088±0.023	103. ±23.	0.094±0.015	0.143±0.023
427	0.188±0.113	$232.^{+144.}_{-71.}$	0.099±0.0038	0.149±0.057
428	0.151±0.031	5.6 ± 1.1	2.72 ±0.24	4.07 ±0.37
Sum	21.25 ±0.54	(300nm∼406nm)		
Sum	21.79 ±0.56	(300nm∼430nm)		

Photon Yield (Air)

Mixture of

N_2: 78.8%
O_2: 21.2%

Preliminary

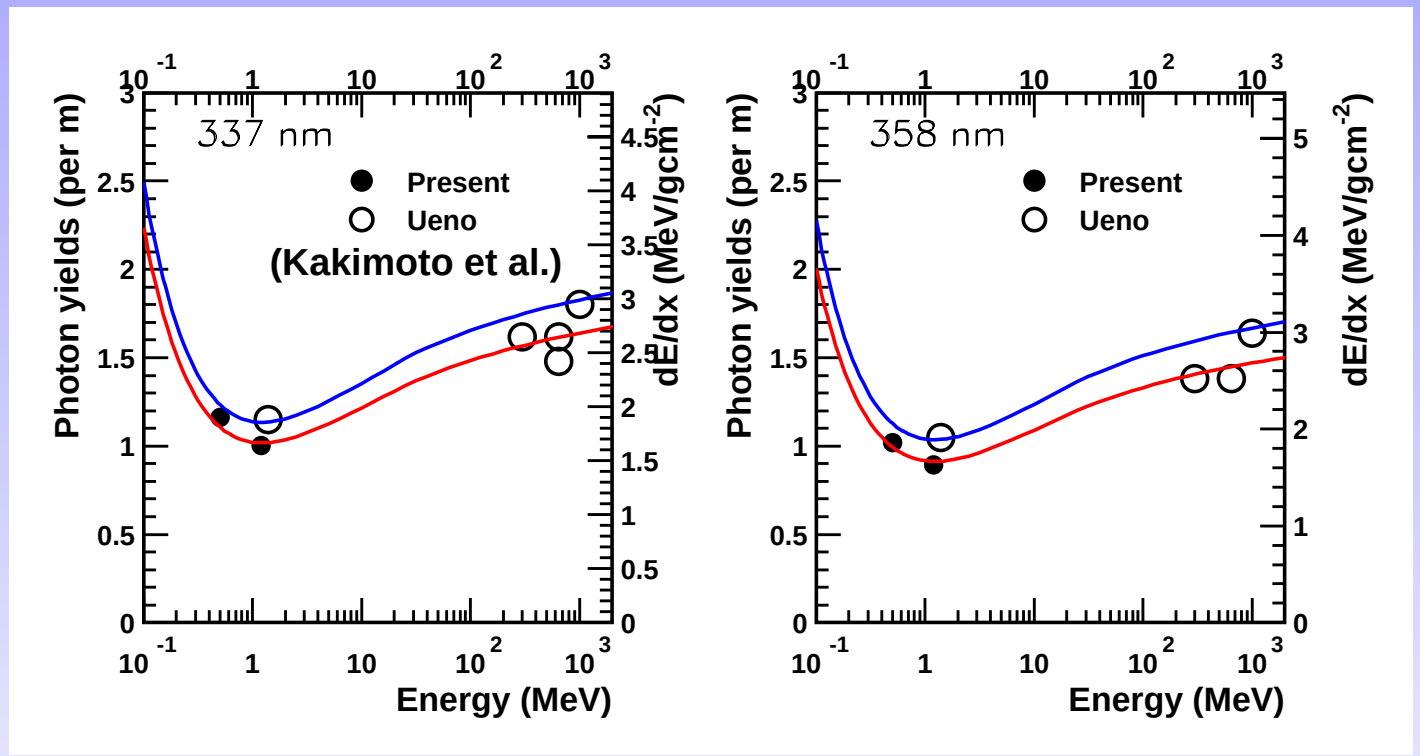


Air (preliminary)

main λ(nm)	ϵ m^{-1}	p' hPa	C $\times 10^{-2}$/(hPa·m)	E° $\times 10^{-4}$
316	0.550±0.057	24.0 ± 2.0	2.34 ±0.14	4.62 ±0.28
329	0.150±0.025	45.2 ± 5.2	0.348±0.028	0.650±0.052
337	0.929±0.031	17.0 ± 0.5	5.56 ±0.10	10.28 ±0.18
354	0.161±0.025	30.4 ± 3.7	0.547±0.054	0.964±0.095
358	0.770±0.081	17.6 ± 1.5	4.45 ±0.28	7.76 ±0.49
376	0.240±0.036	34.3 ± 4.1	0.724±0.066	1.20 ±0.11
381	0.285±0.049	19.4 ± 2.6	1.50 ±0.16	2.46 ±0.27
391	0.302±0.020	5.01± 0.25	6.04 ±0.24	9.62 ±0.39
394	0.063±0.033	24.2 ± 9.4	0.267±0.093	0.42±0.15
400	0.128±0.026	22.0 ± 3.3	0.594±0.078	0.93 ±0.12
406	0.123±0.040	9.0 ± 2.5	1.38 ±0.24	2.12 ±0.37
414	0.044±0.023	41. ±17.	0.113±0.037	0.200±0.056
420	0.047±0.007	28.8 ± 3.3	0.167±0.017	0.248 ±0.025
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	4.58 ±0.41
Sum	3.70 ±0.14	(300nm∼406nm)		
Sum	3.95±0.15	(300nm∼430nm)		

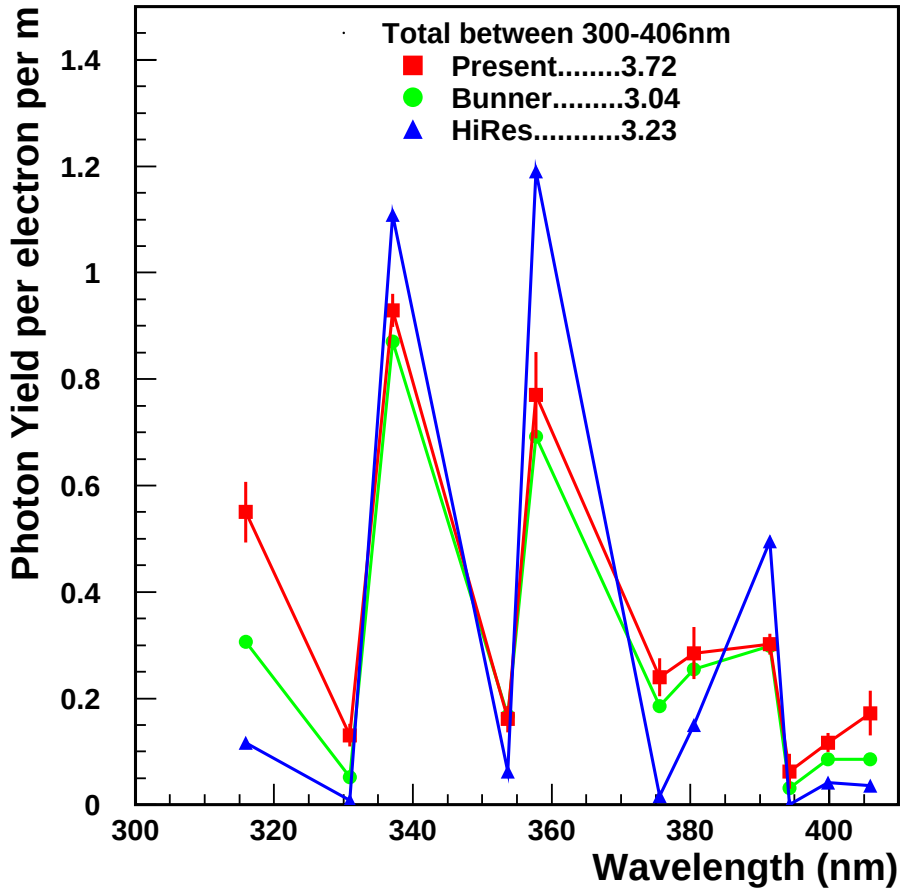
Energy dependence of Photon Yield

Air of 1 atm. pressure



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

Photon yields between 300 and 406nm



3.72/3.04=1.22
3.72/3.23=1.15

Photon yields as a function of ρ and T

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

where

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

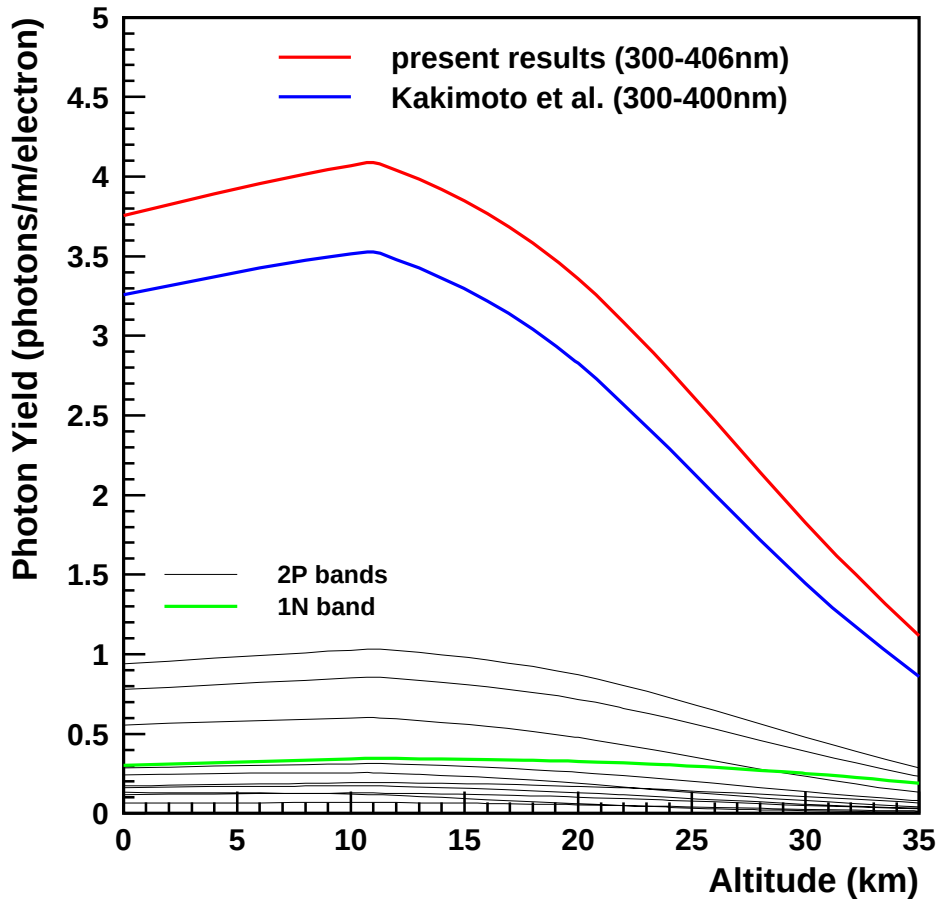
$$B_i = \frac{R_{N_2}\sqrt{T}}{p_i'}$$

A and B of various bands (preliminary)

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 ±0.4	0.576±0.049	19.7 ±1.2	2.04±0.17
329	2.48±0.28	0.420±0.077	2.93±0.24	1.09±0.13
337	51.5 ±0.9	0.325±0.008	46.8 ±0.9	2.89±0.08
354	7.04±0.27	0.626±0.038	4.60±0.45	1.62±0.20
358	42.6 ±1.3	0.404±0.018	37.5 ±2.4	2.79±0.24
376	10.0 ±0.4	0.614±0.034	6.09±0.56	1.43±0.17
381	15.3 ±0.9	0.360±0.035	12.6 ±1.4	2.54±0.34
391	77.7 ±2.7	17.1 ±2.0	50.8 ±2.1	9.79±0.51
394	10.0 ±2.0	1.61 ±0.36	2.25±0.78	2.03±0.79
400	5.55±0.26	0.748±0.053	5.50±0.66	2.23±0.34
406	5.22±0.52	0.366±0.066	11.6 ±2.0	5.5 ±1.5
414	0.96±0.17	0.458±0.099	1.12±0.31	1.20±0.50
420	0.82±0.13	0.49 ±0.11	1.40±0.14	1.71±0.20
427	0.86±0.03	0.22 ±0.10	0.40±0.18	0.68±0.40
428	23.7 ±2.1	9.1 ±1.8	26.4 ±2.4	12.7 ±1.9

Altitude dependence of Photon Yield

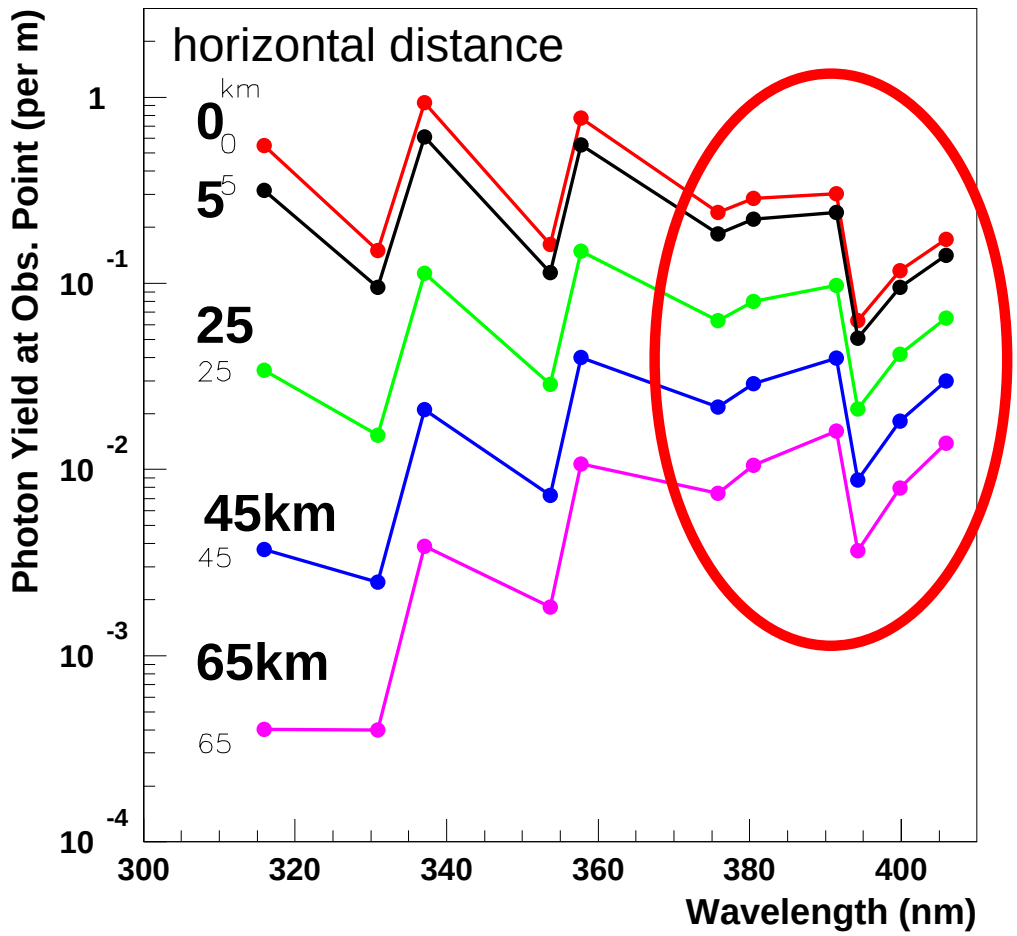
US standard atmosphere 1976



0.85MeV electron

Photon attenuation with distance

Rayleigh scattering only



important at far distance

Assumptions

- ✓ CORSIKA 6.020 (QGSJET)
- ✓ Proton at E=10^{19},10^{20} with $\theta = 0, 60^{\circ}$
- ✓ 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

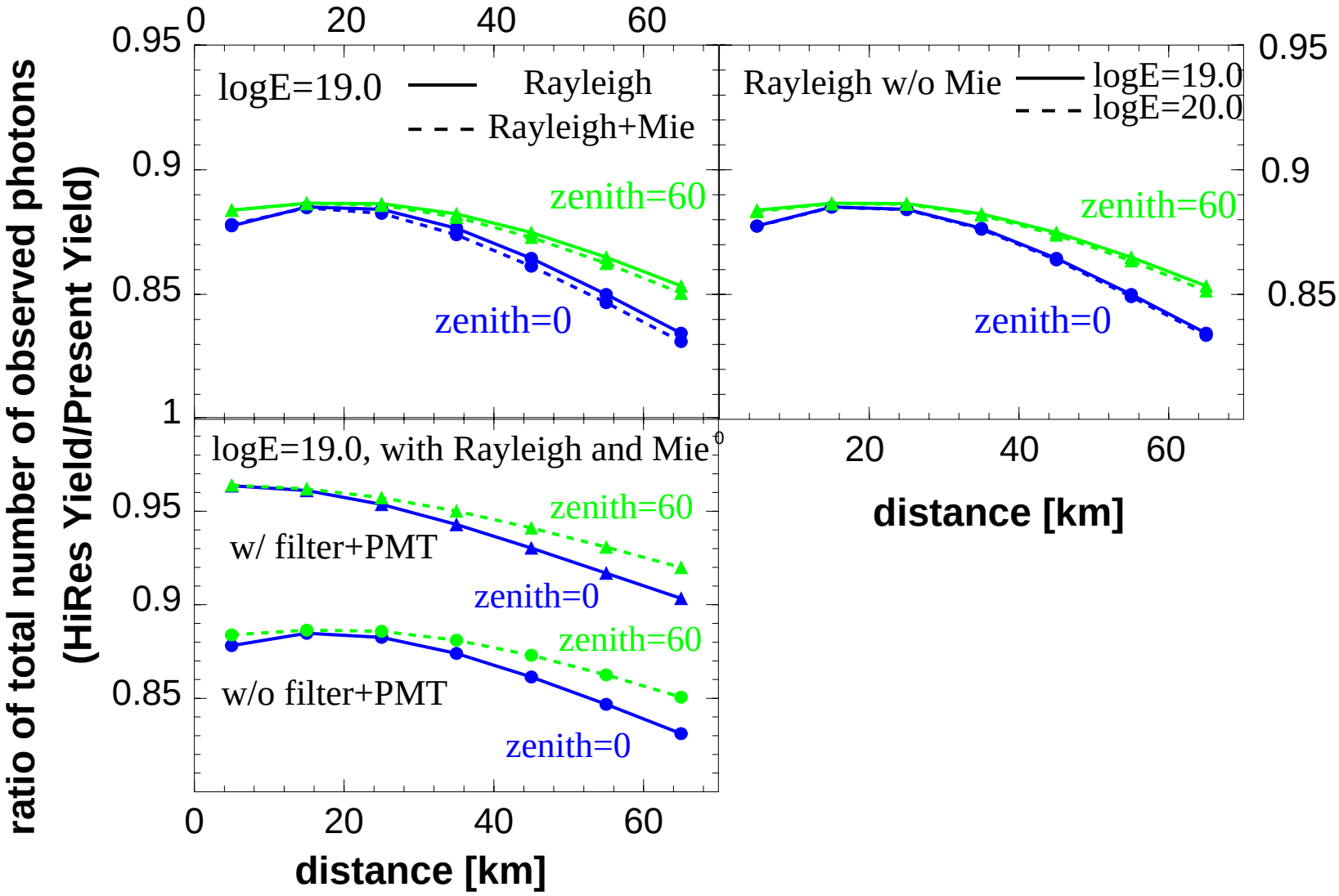
  $$T_R = \exp\left[-\frac{|x_1 - x_2|}{X_R}\left(\frac{400[\mathrm{nm}]}{\lambda}\right)^4\right]$$

- ✓ 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



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 are 22% larger than the summary by Bunner at 1013 hPa and 20°C.
- ✓ and 15% larger than that used by the HiRes group.
  The observed number of photons was estimated as a function of the distance between the shower trajectory and the observational site taking into account the wave length dependence of Rayleigh scattering, detector response. It is possible that HiRes energy is largely estimated, if the present yield is used.
- ✓ 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.