CRAYS: a photometric calibration of TA FD camera

Sept. 14th 2011, 8th AFWS @ KIT

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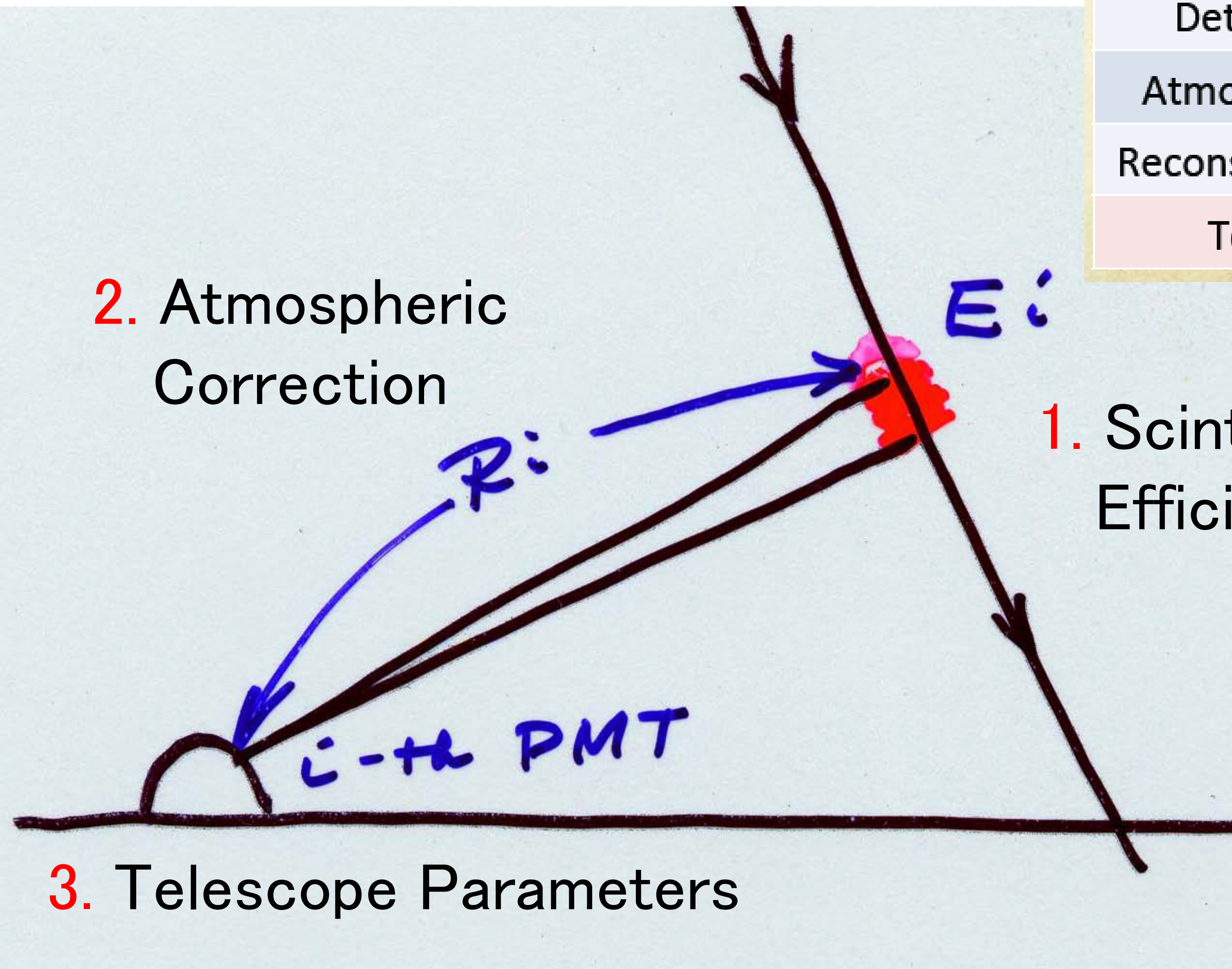
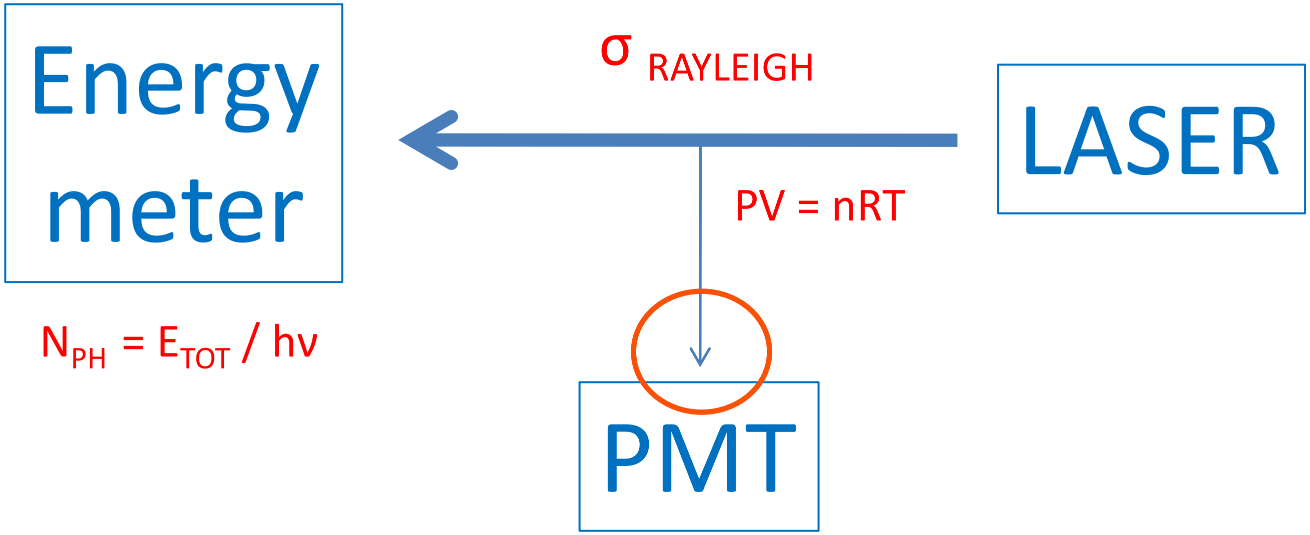
Determination of FD Energy

Systematic uncertainty

Source	ΔE/E
Fluorescence yield	11%
Detector	10%
Atmosphere	11%
Reconstruction	10%
Total	21%



How to Calibrate?



Absolutely calibrated light source

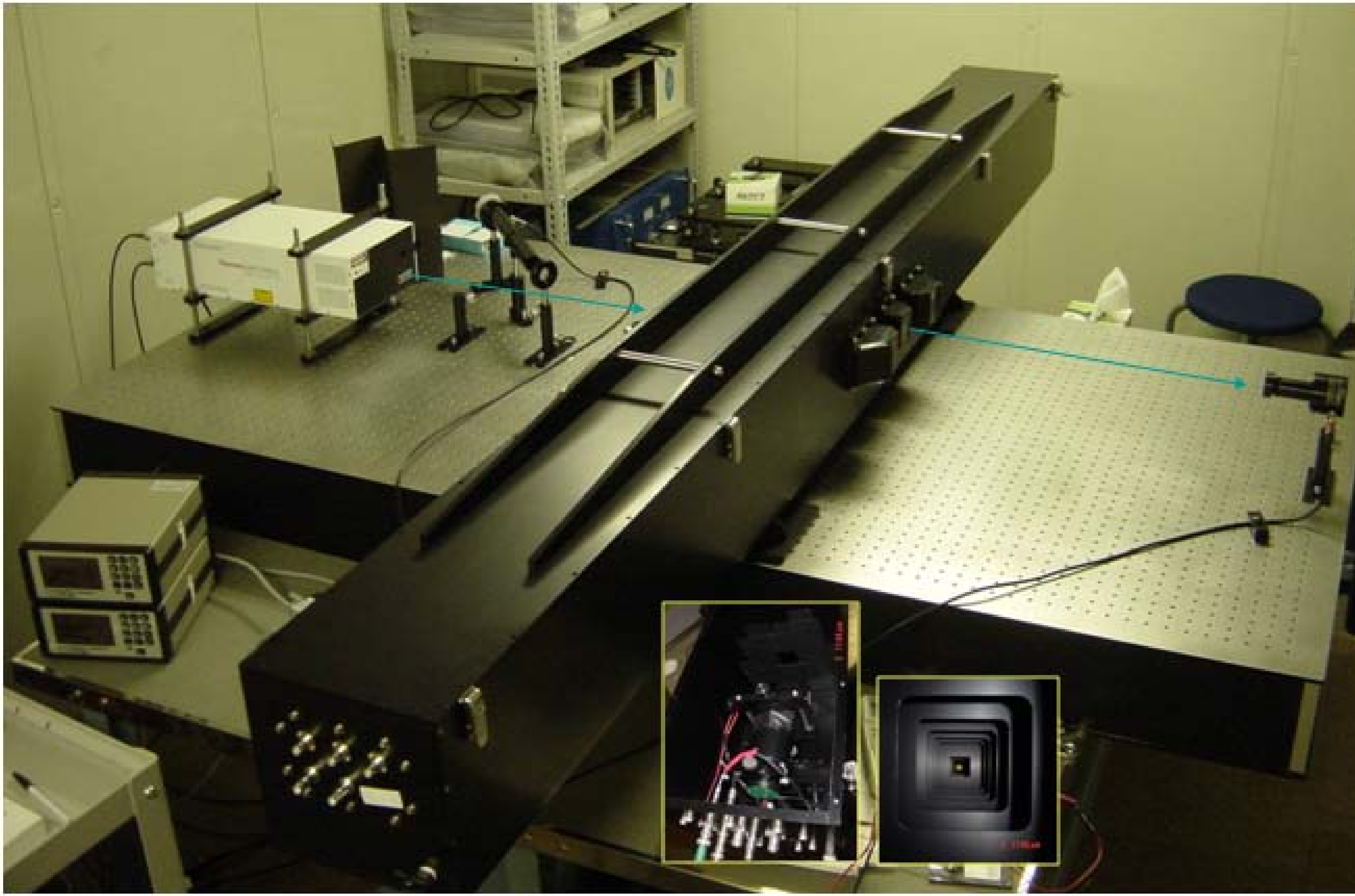
- Pulsed (~4ns)
- UV (~337nm)
- Large # of photons (~100 photons/cm^2)
- Linear with pressure (~ 0 photons/cm^2)

CRAYS : Calibration using RAYleigh Scattering

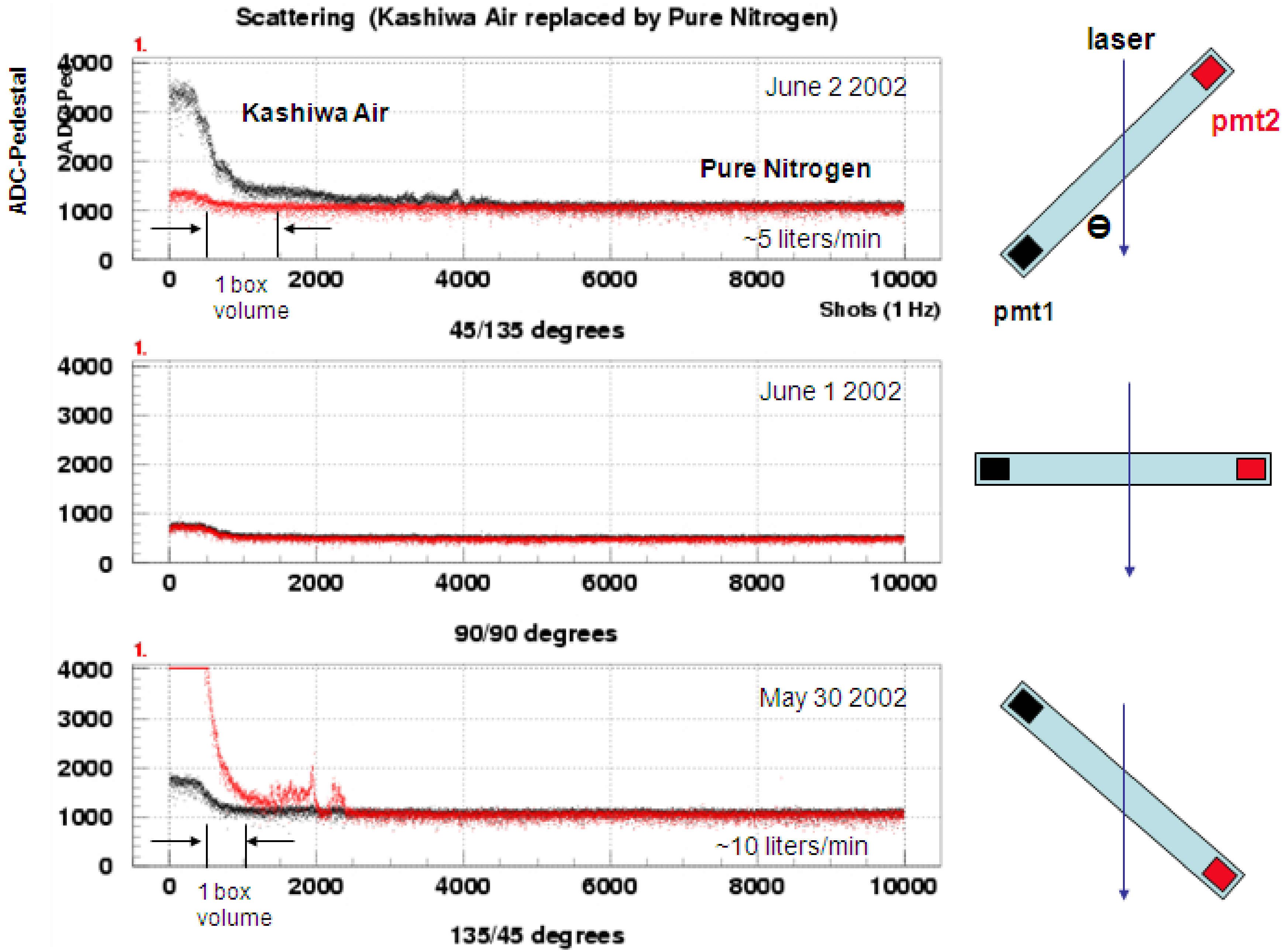
- Original idea by discussion with L.Wiencke (2002)
- H.Naus & W.Ubachs: Optics Lett.25 (2000)

  Rayleigh scattering's σ measured with 1% accuracy
- CRAYS-I by L.Wiecke (2002)
- CRAYS-II by N.Sakurai (2004)
- IceCube PMT calib. in 1-ph mode by S.Yoshida (2007)
- TA PMT calib. in full intensity mode by S.Kawana (2008)

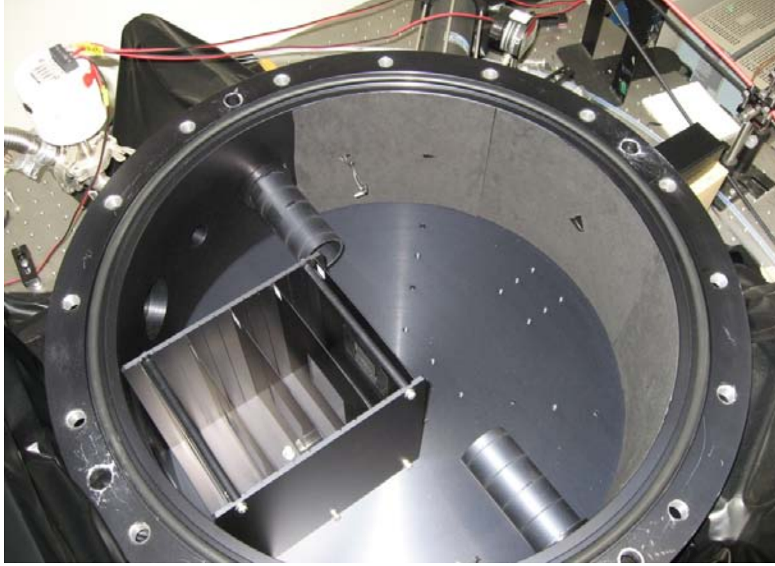
CRAYS-I

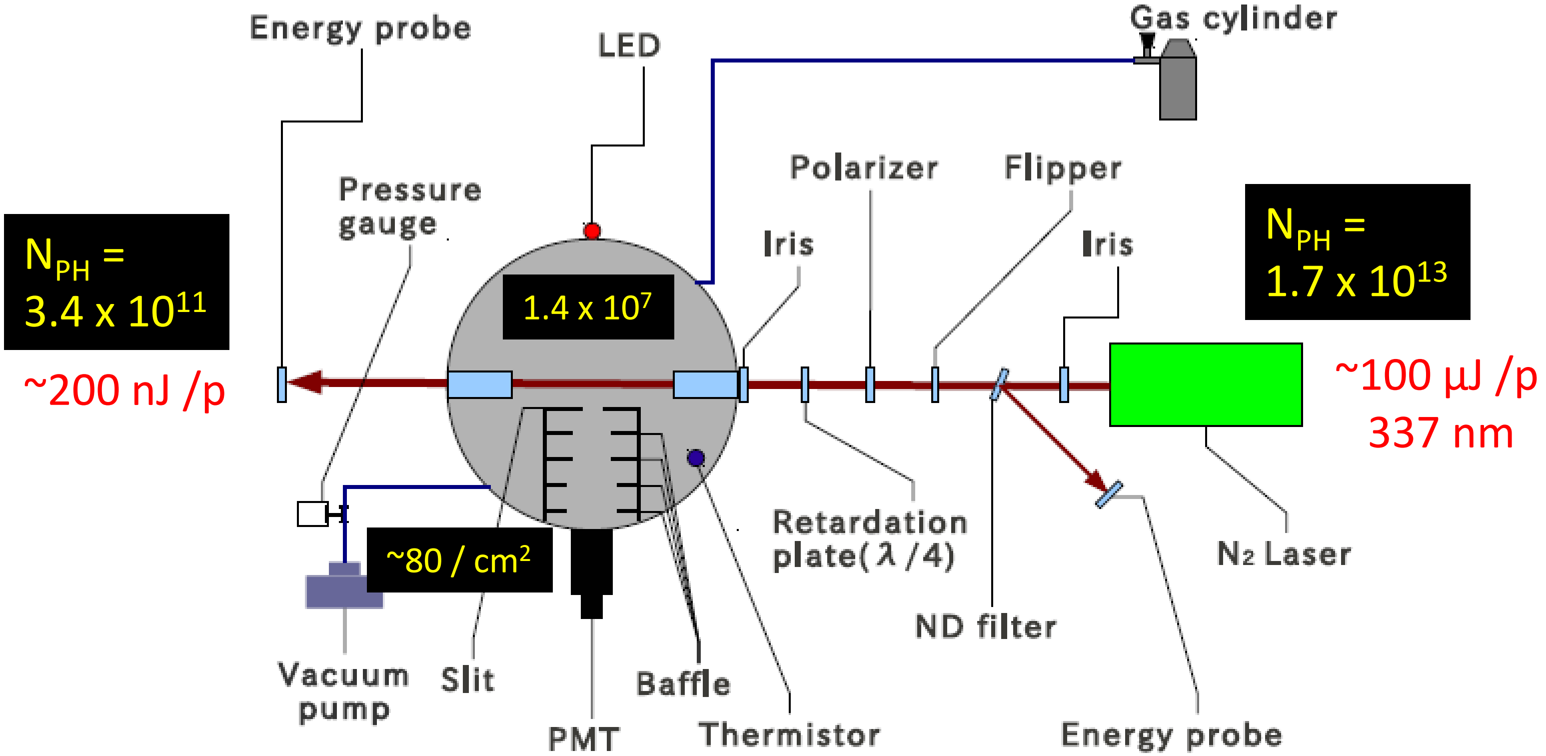


CRAYS-I


Scattering (Kashiwa Air replaced by Pure Nitrogen)
ADC-Pedestal
June 2 2002
Kashiwa Air
Pure Nitrogen
~5 liters/min
1 box volume
Shots (1 Hz)
45/135 degrees
laser
pmt2
pmt1
θ
June 1 2002
90/90 degrees
May 30 2002
~10 liters/min
1 box volume
135/45 degrees

CRAYS-II





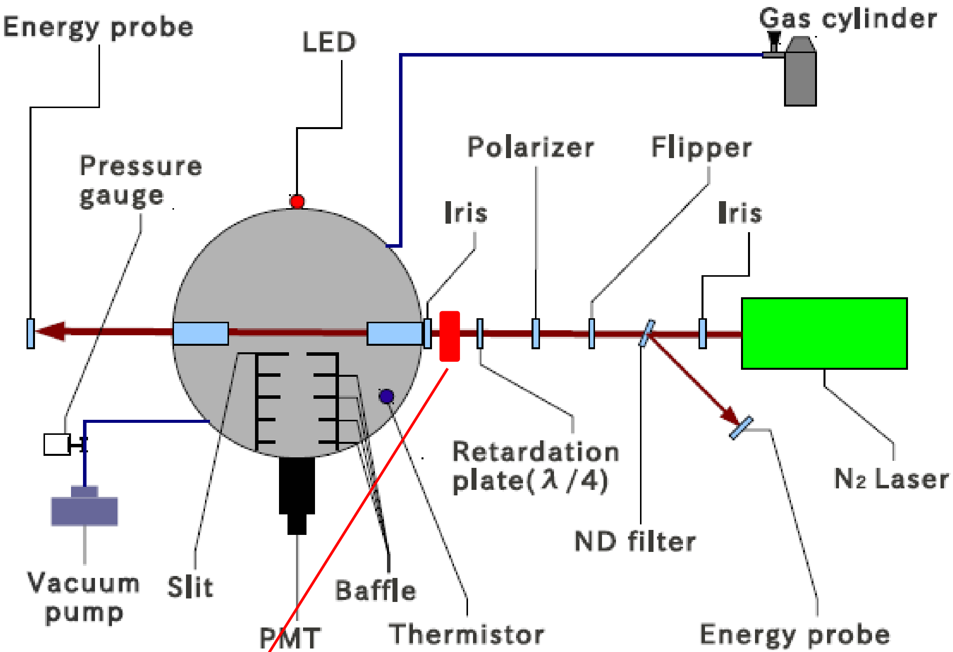
Mercury Pressure Gauge

Room Temp. Meas.

25±1 ^{0}C

CaF_2 with AR coat used for all windows

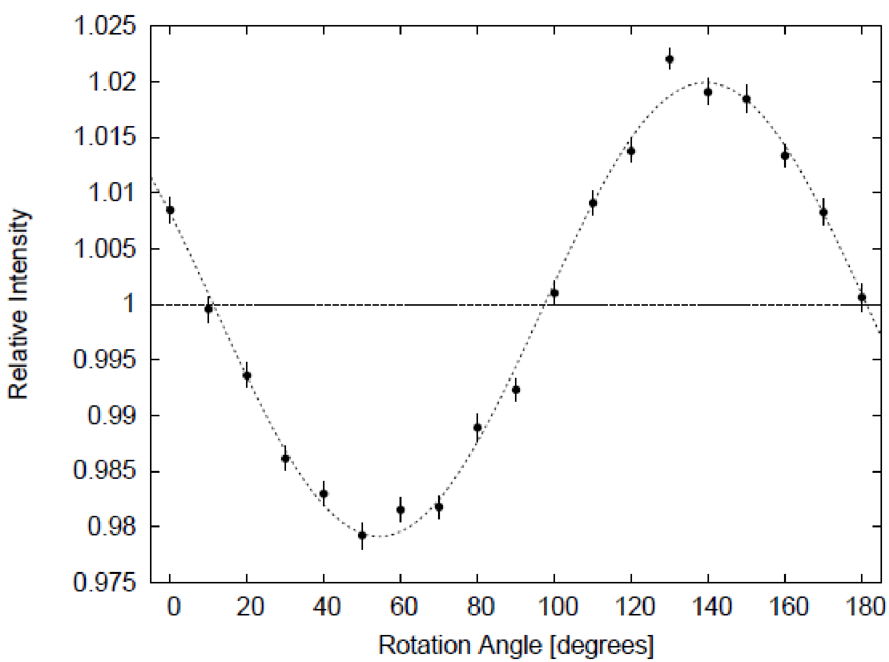
Check-1: polarization



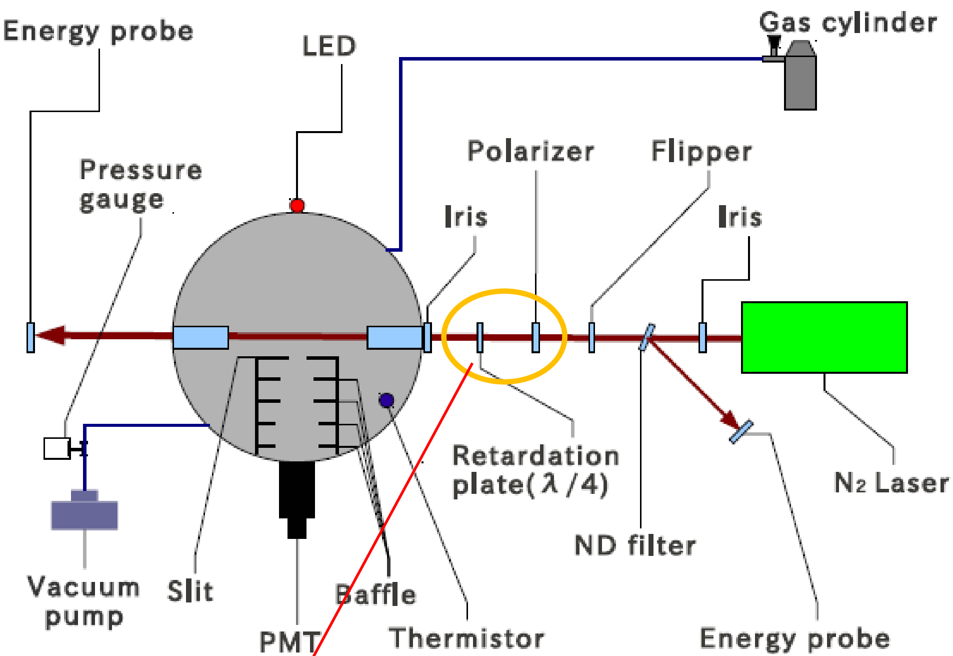
2% vertical pol.

➢No effect on X-section

1. Polarizer + λ/4 produces circular pol..
2. Insert another polarizer after λ/4
3. Rotate pol. angle & measure laser energy

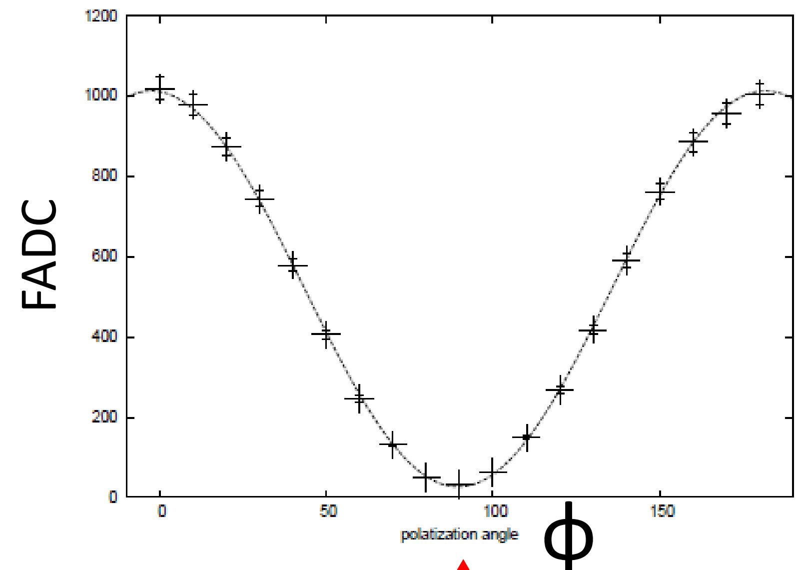


Check-2: Rayleigh ϕ dep?



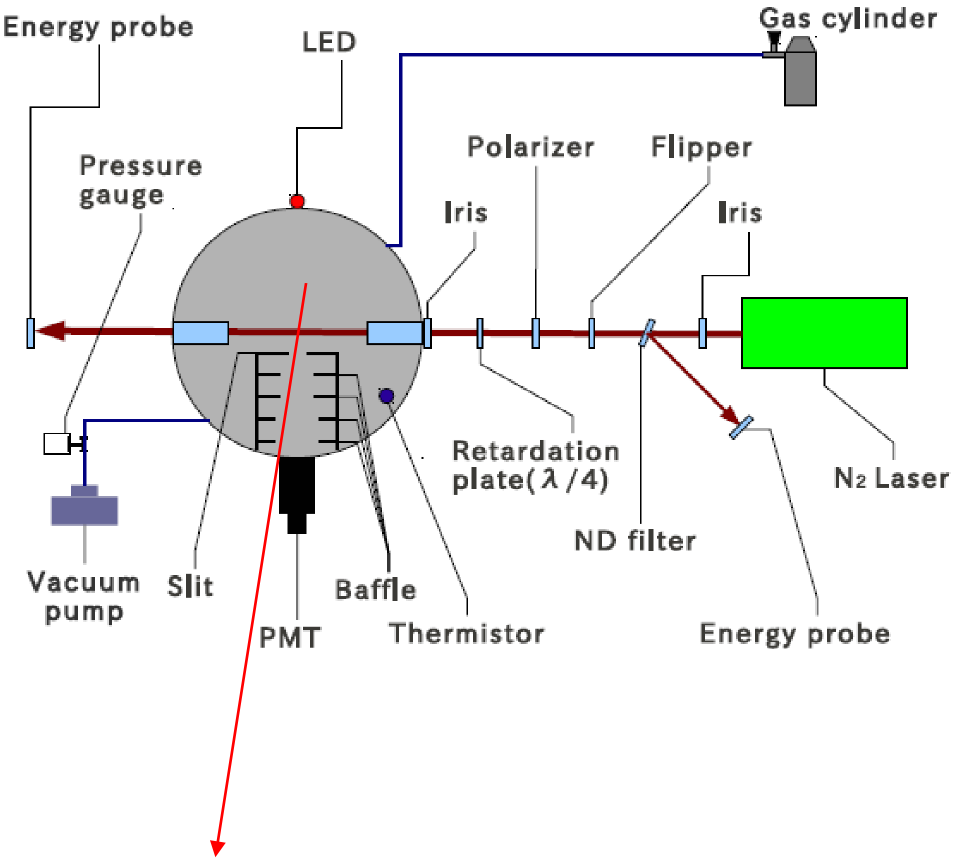
1. Remove λ/4 and make full linear pol..
2. Rotate pol. angle & measure PMT output.

$\propto \cos(2\phi)$



Remaining ~3%: BG + N_2 depolarization effect

Check-3: Pressure curve & Ar/N_2 ratio

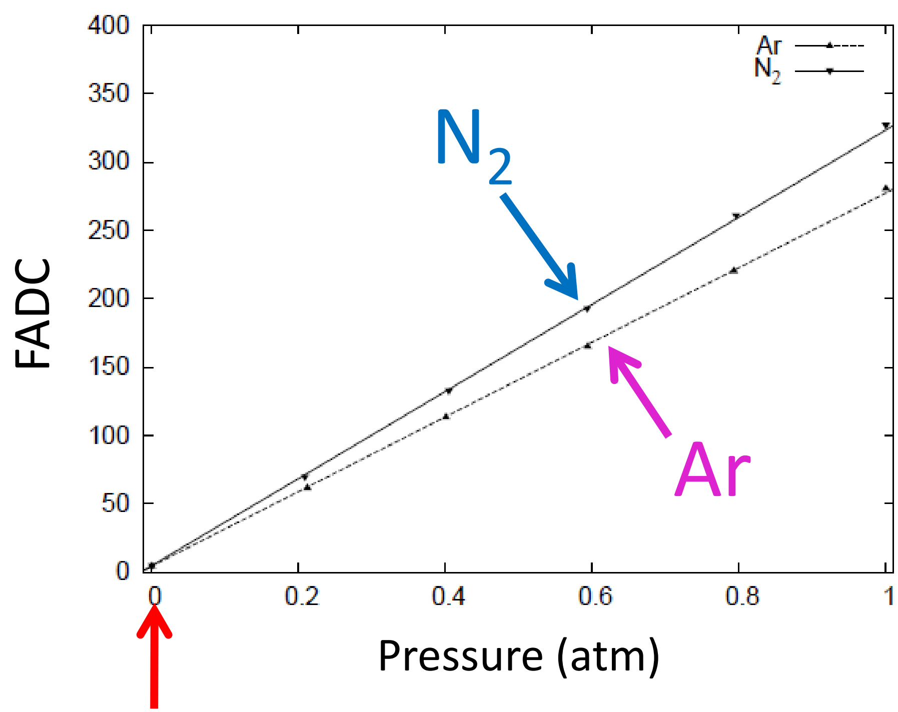


1. Fill N_2 and change P, measure PMT output
2. Repeat the same with Ar

Rayleigh scattering of N_2 laser on N_2 gas is OK.

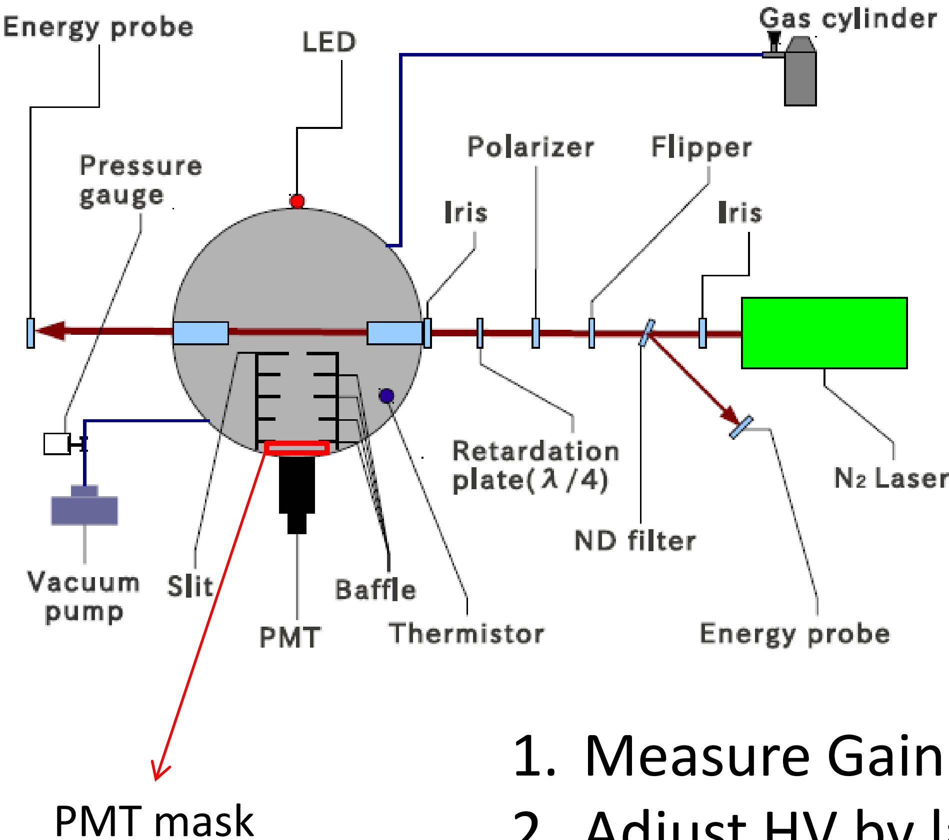
Ar/N_2 = 0.857 ±0.007

theory = 0.859



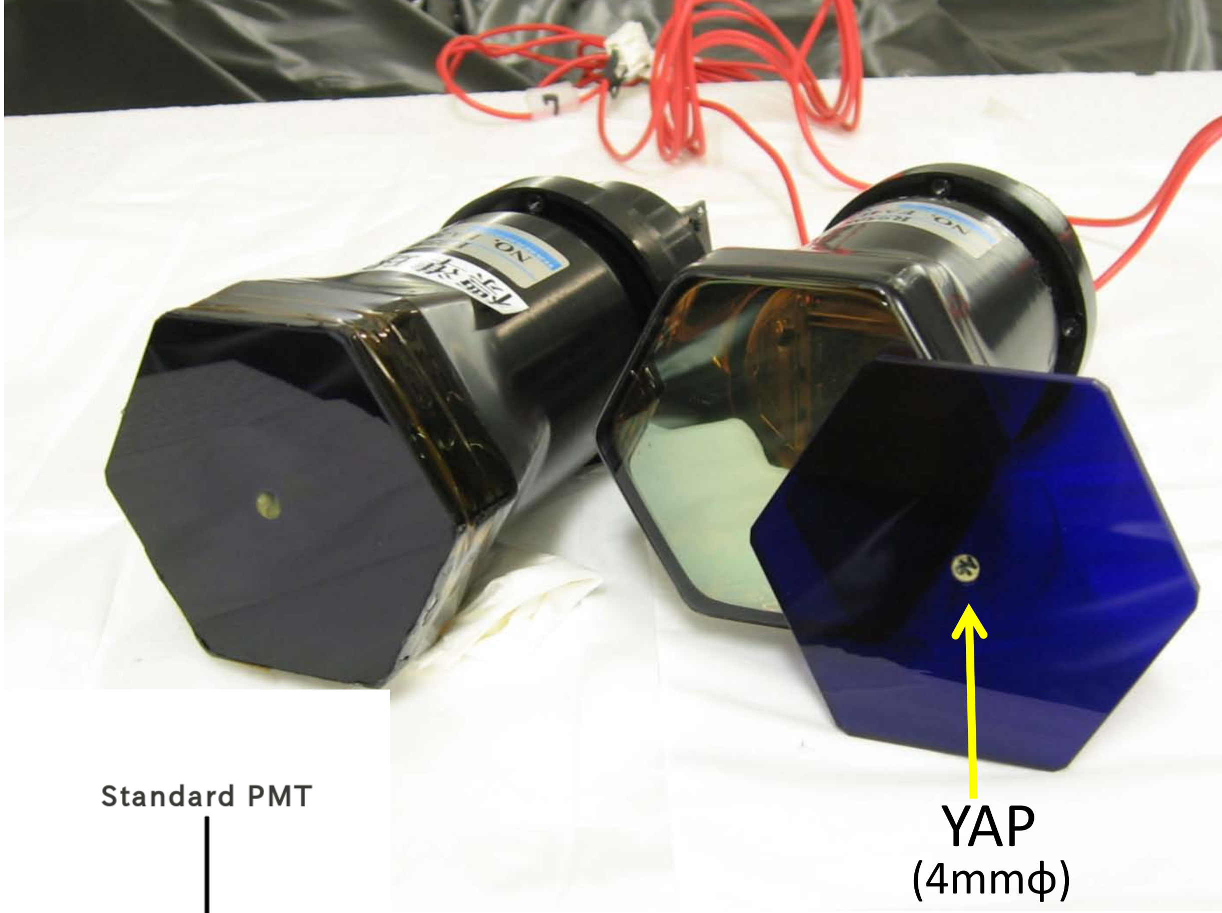
BG < 2% at 0 atm

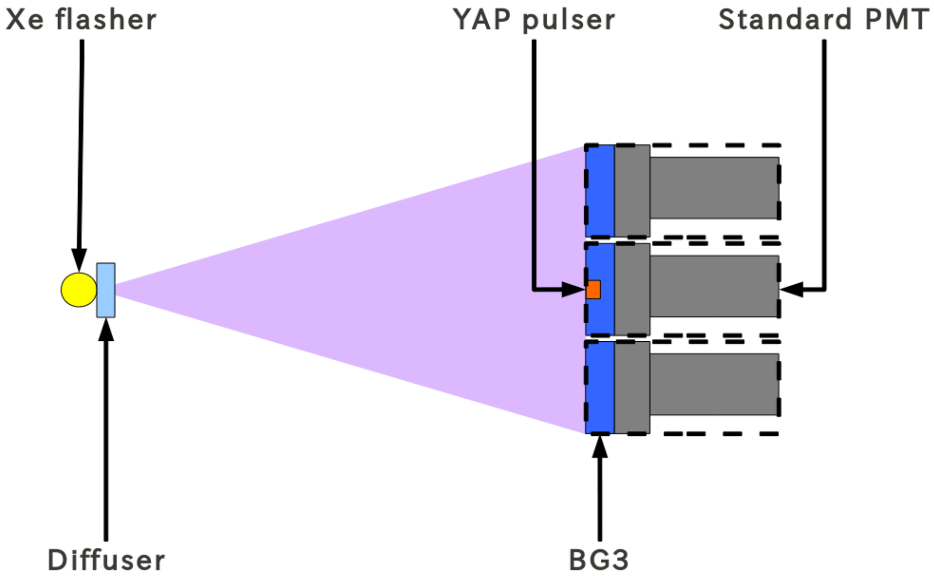
Calibration Procedure for 75 PMTs with YAP

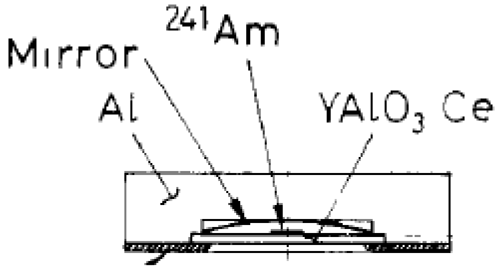


1. Measure Gain sensitivity %/V by UV-LED
2. Adjust HV by laser for targeted calib. value
   ~ 2.3 [photons / ΣFADC counts]
3. Measure with 20mmϕ, 36mmϕ mask and
   No mask
4. Measure YAP for future PMT gain tracing

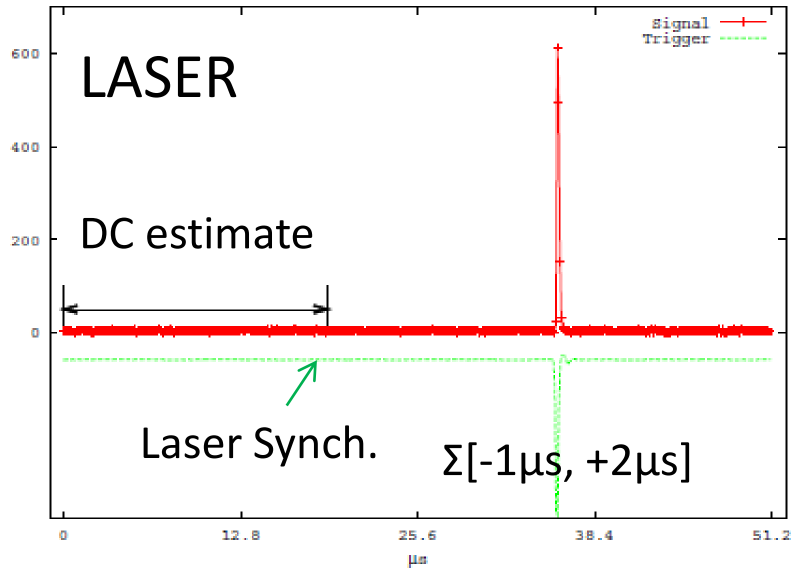
Standard PMT, YAP & Xenon flasher







Signal integration

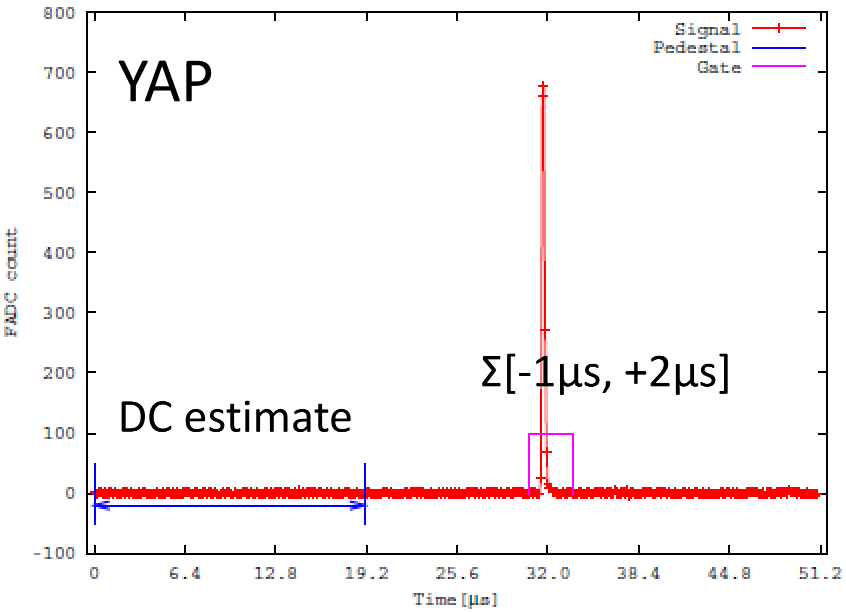


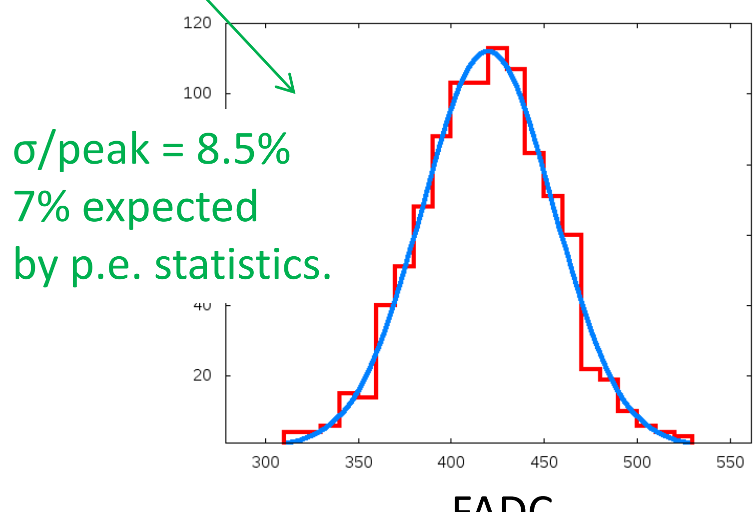
Triple subtraction

1. Pedestal DC
2. Flipper-IN (no laser light)
3. Vacuum (no Rayleigh scattering)

Flipper-OUT: 10 x 100 ev	Flipper-IN: 10 X 100 ev

Σ(FADC – dc) - Σ(FADC – dc)





Target (N_2) Density

- n/V by state equation; $PV = nRT$
- van der Waals correction negligible
- Chamber P =
  gauge-P + abs.-P by mercury gauge.
- Gas temp. measured.

of expected photons by ray tracing

Rayleigh scattering cross section †

- Theoretical formula:

$$\sigma_R(\nu) = \frac{24\pi^3\nu^4}{N^2}\left(\frac{n(\nu)^2-1}{n(\nu)^2+2}\right)^2 F_k(\nu)$$

$$F_k(\nu) = 1.034 + 3.17\times10^{-12}\nu^2$$

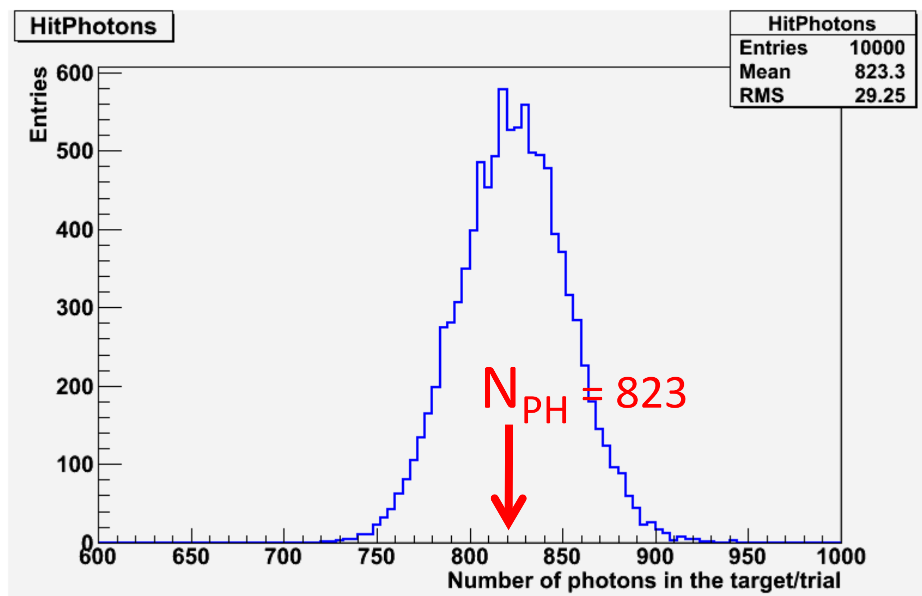
$$10^8[n(\nu)-1] = 5989.242 + \frac{3.3632663\times10^{14}}{1.44\times10^{10}-\nu^2}\ (256\le\lambda\le468[\mathrm{nm}])$$

↓

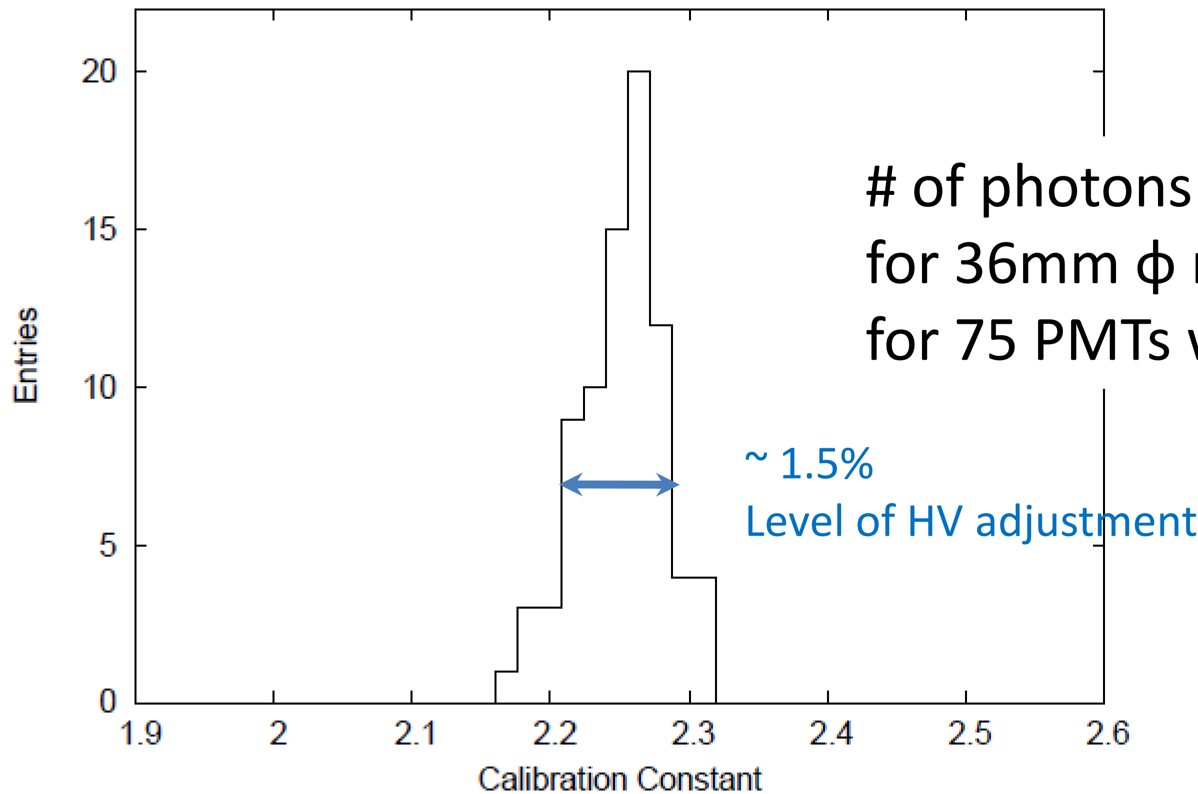
$$\frac{d\sigma}{d\Omega} = \frac{3}{16\pi}(1+\cos^2\theta)\ \times\ 3.50\ \times\ 10^{-26}\ \mathrm{cm}^2$$

- 200 nJ laser pulse
- N_2 gas at 25ºC
- 1000 hPa
- Given geometry (36mm ϕ PMT mask)
- Wall reflection :
  2.3% random (or mirror) ref.

$N_{BG} < 1$



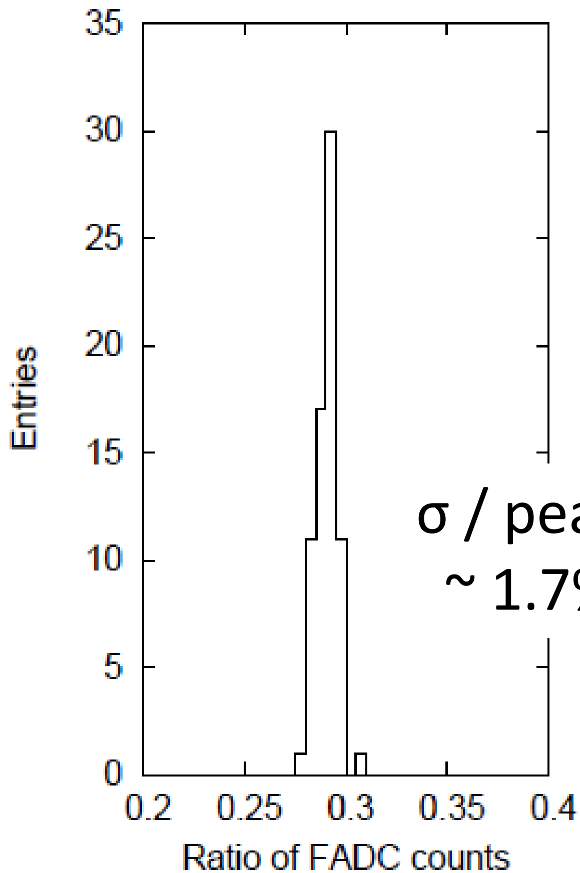
Determined Calibration Constant



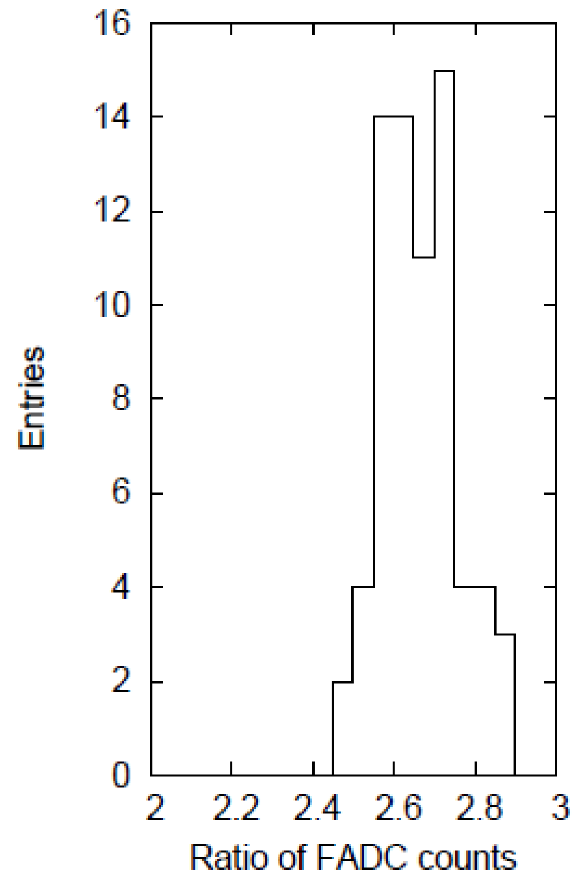
# of photons / FADC
for 36mm ϕ mask,
for 75 PMTs with YAP

2.25 Photons / FADC cnt ～ PMT Gain of 6×10^4

FADC with different PMT mask



σ / peak
~ 1.7%



σ / peak
~ 3.4%

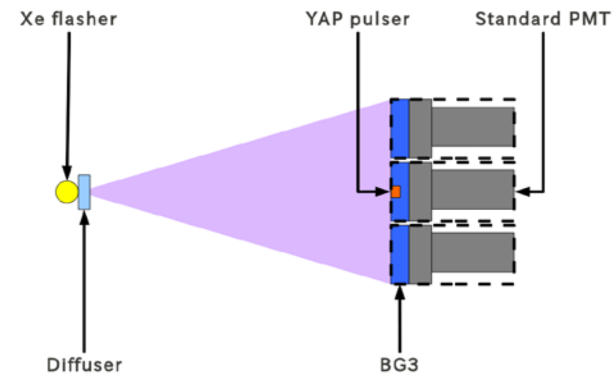
20mmϕ mask / 36mmϕ mask

no mask / 36mmϕ mask

Scale Uncertainty of CRAYS

	Error
Rayleigh scattering cross-section	1.0%
Molecular density (temperature and pressure)	2.0%
Measurement of laser energy	5.0%
Polarization of the laser beam	1.0%
Geometric aperture calculation	3.0%
Signal integration	2.0%
Background and noise subtraction	2.0%
Effect of geomagnetism	1.0%
Total (quadratic sum of above)	7.0%

Stability (Kashiwa > Utah)



- CRAYS-calibrated PMTs transported to Utah.
- 2PMTs / camera installed with same HV.
- PMT @ center = standard PMT.

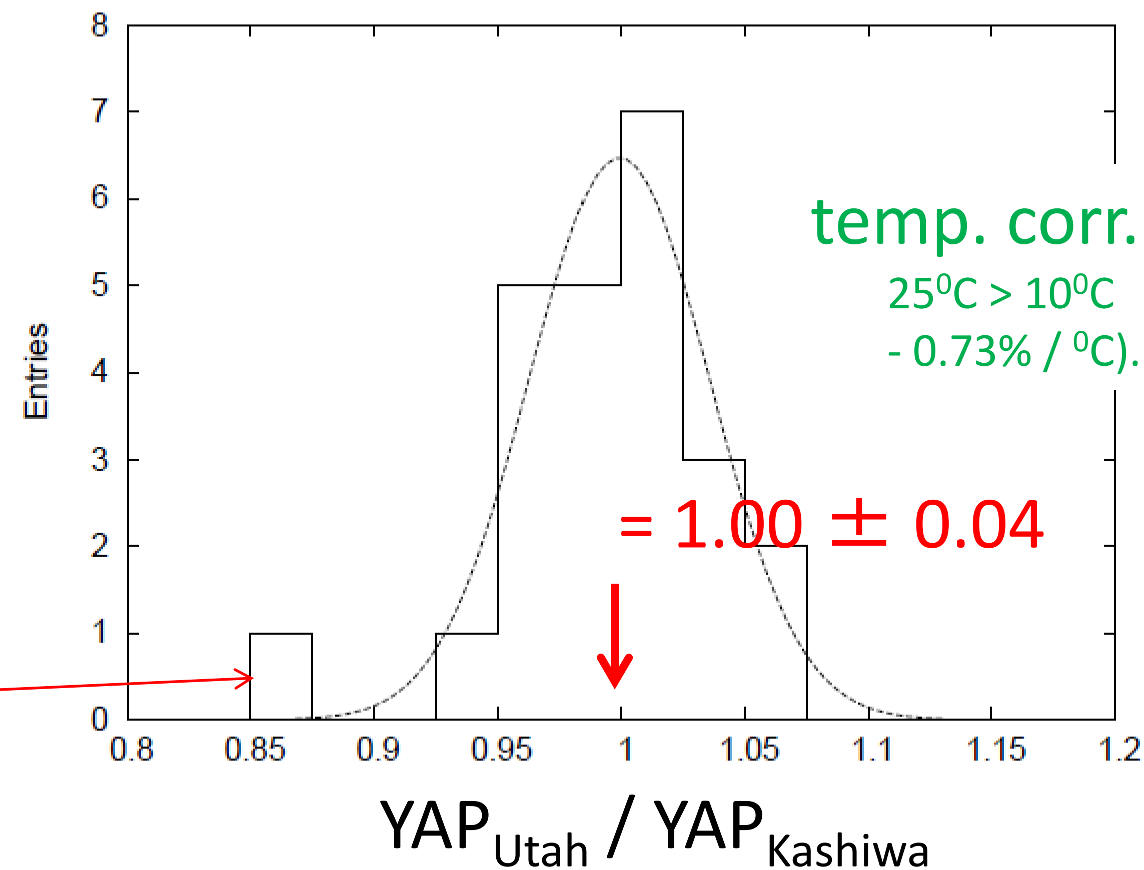
Kashiwa > Utah

1. HVPS
2. FADC and cable
3. Temperature
4. Geomagnetism etc.

are different.

+ PMT gain + YAP light

one PMT with 0.85
(YAP problem)



Summary

- TA FD camera: CRAYS calibration with YAP gain monitoring

- Abs. Scale Uncertainty ~ 0.07
- Calib. transport from Kashiwa to Utah = 1.00 ±0.04

not discussed today:

- Extension from standard PMT to other 255 PMTs by diffused xenon flasher
- Long term gain monitoring in situ (PMT aging?)
- Cross calibration with Electron Light Source (ELS)

good		this		1.000?		
AF Yield	x	CRAYS	x	FF	=	ELS (40MeV electron linac).

Determination of FD Energy

Source	ΔE/E
Fluorescence yield	11%
Detector	10%
Atmosphere	11%
Reconstruction	10%
Total	21%

Systematic uncertainty