Fluorescence in ***A***ir from ***Sh***owers (FLASH)

Thin Target Results

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Fluorescence from ***A***ir in ***Sh***owers (FLASH)

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The FLASH Experiment

- **Thin Target Experiment**
  - Electron beam passes through gas volume.
  - Measure fluorescence yield Y=photons / m e^-.
- **Thick Target Experiment**
  - Electron beam showered before passing through air.
  - Details of this part of experiment in talk by John Belz.

FLASH Timeline

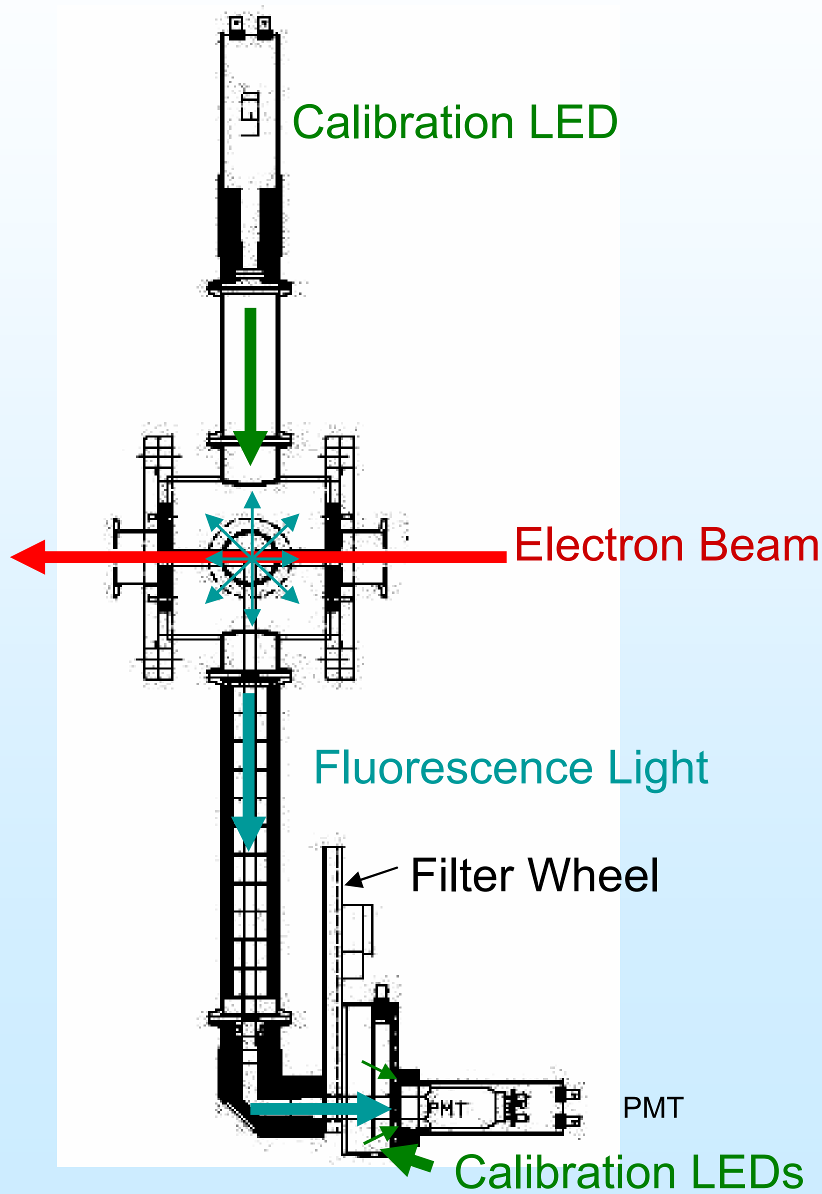
- **June 2002**
  - T-461: SLAC Test Beam (3 weeks). Total yield 300-400.
- **Sept 2003**
  - Thin target data run (3 weeks). Total yield and spectral shape.
- **Dec 2003**
  - Bad Liebenzell ☺
- **Jan 2004**
  - Thick target mode test beam. (3 days).
- **June 2004**
  - Thick Target run (2 weeks). Yield vs. shower age.
- **July 2004**
  - Thick and Thin target runs (10 days). Two experiments 10 days!
- **2005-2006**
  - Calibration + Calibration + ☹

Outline

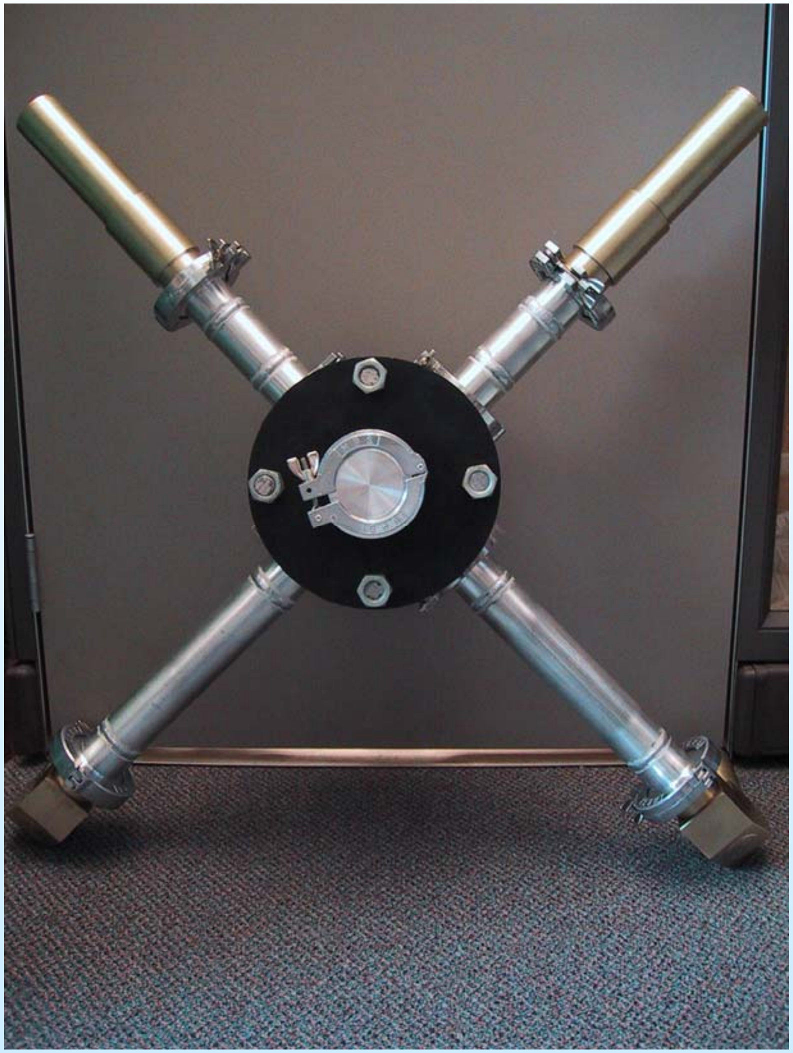
- Experimental setup.
- Photon Counting
  - Flash Optical System Calibration
  - $N_{photons/m}$
- Particle Counting
  - FLASH Toroid Calibration
  - N_{e-}
- Total and spectral photon yields
- Results**

Thin Target Chamber

- Thin Target Chamber
  - Symmetric system allows for yield to be measured twice simultaneously.
    - "North and South"
  - Two LED based calibration systems used.
  - Remotely operable filter wheel.

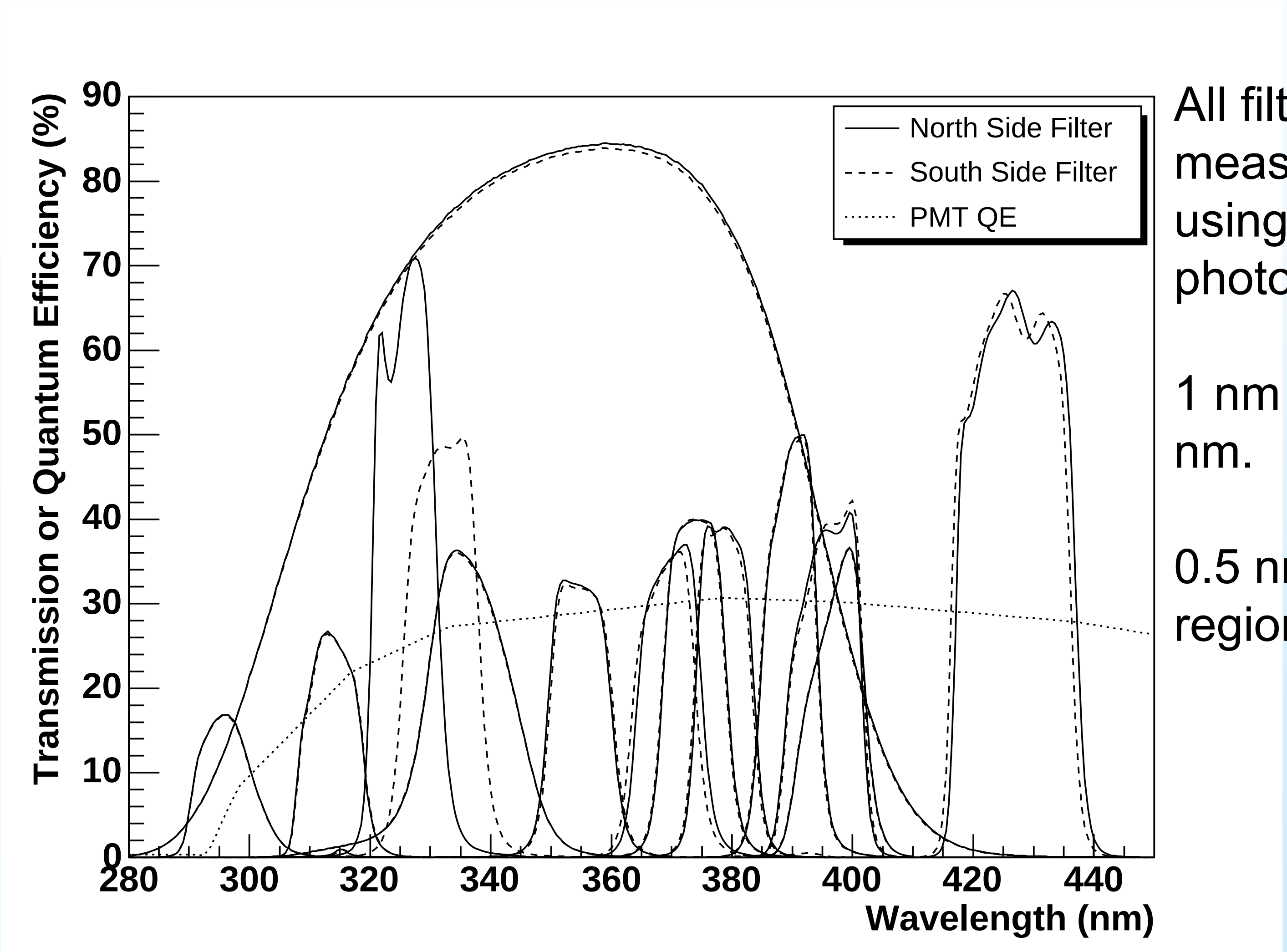


Thin Target Chamber



- Design allows dual measurements AND provides room for lead shielding.

Narrow Band Filters



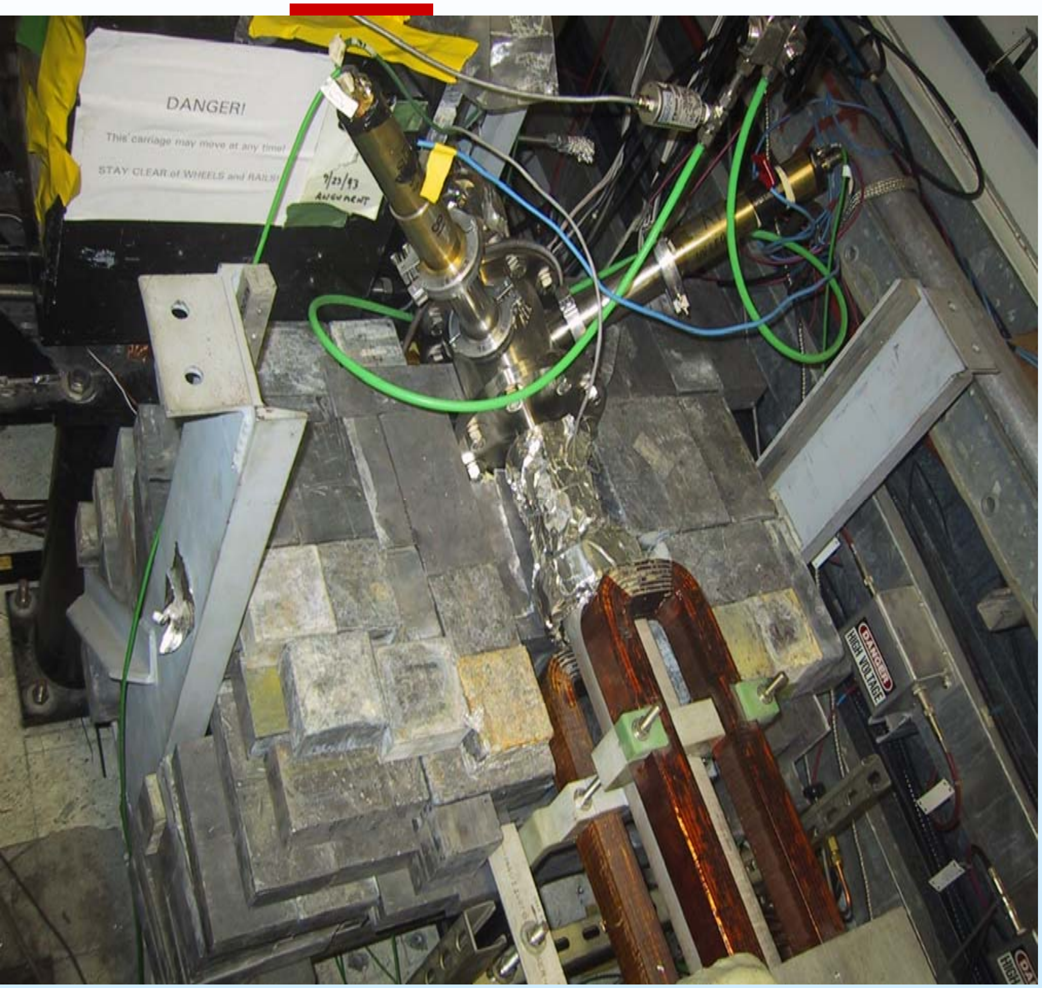
All filter transmissions were measured by HiRes group using their spectro-photometer setup.

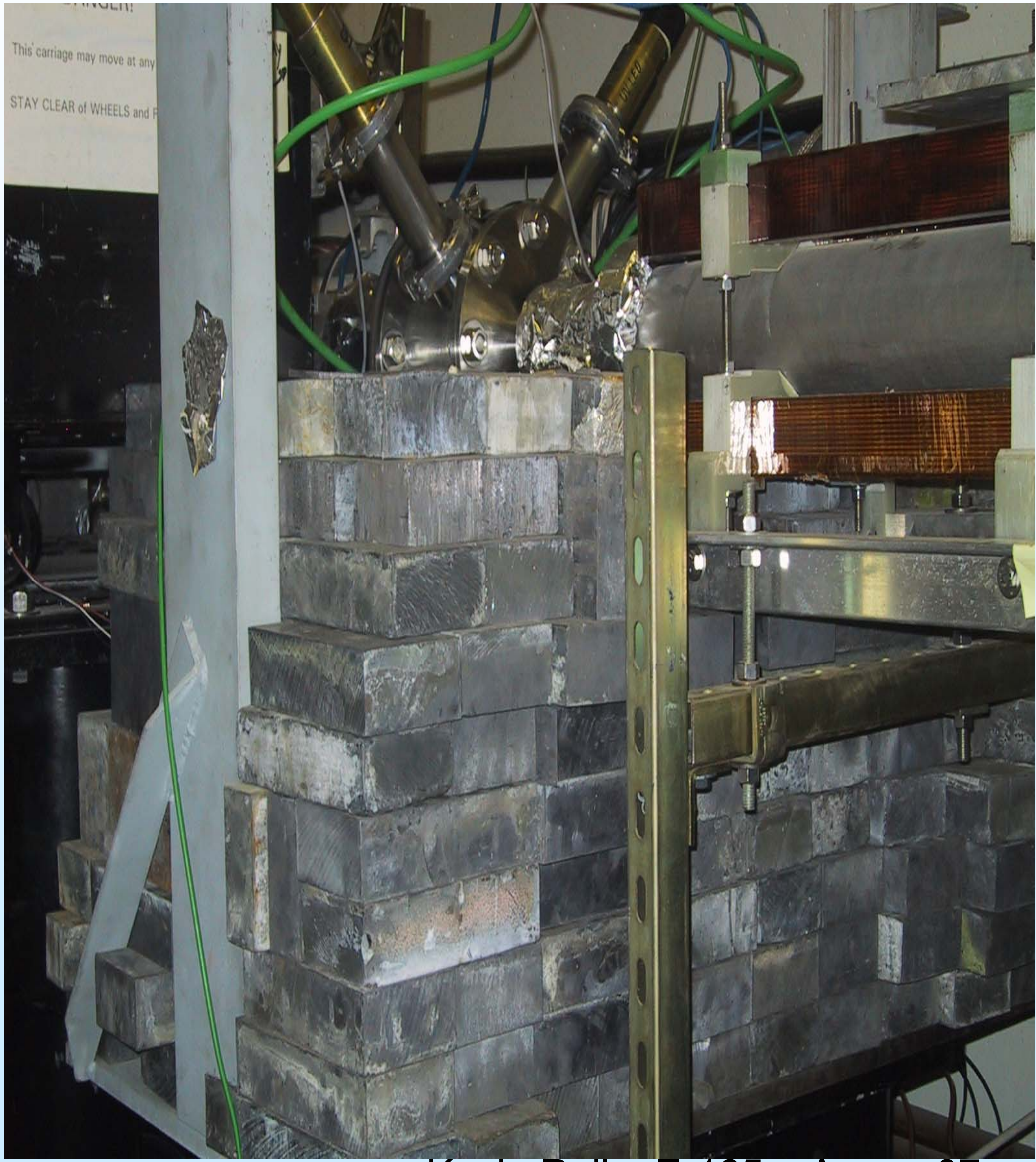
1 nm steps from 200 to 800 nm.

0.5 nm steps in fluorescence region.

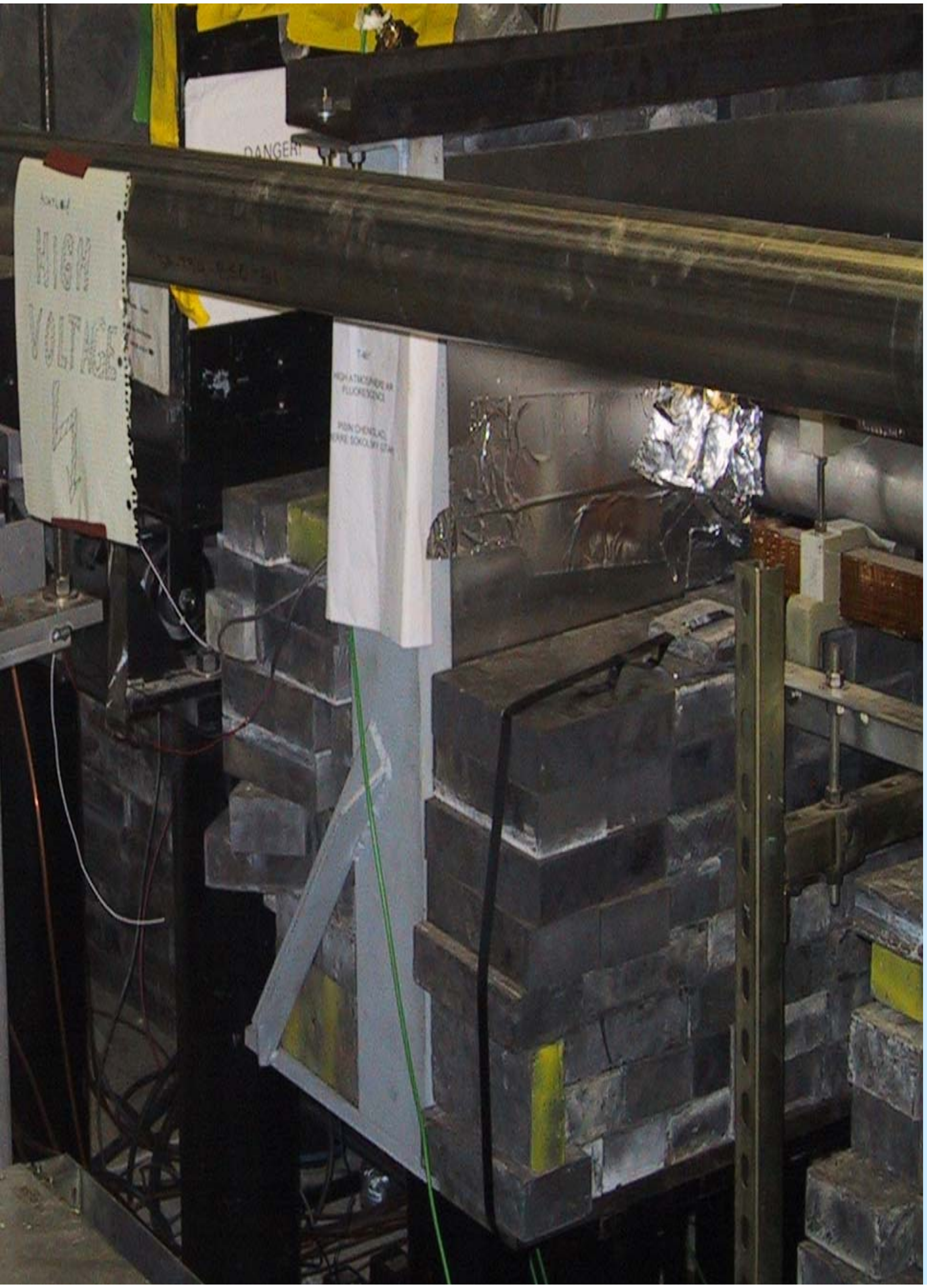
FLASH=

<u>**FL**</u>uorescence <u>**A**</u>nd <u>**SH**</u>eilding



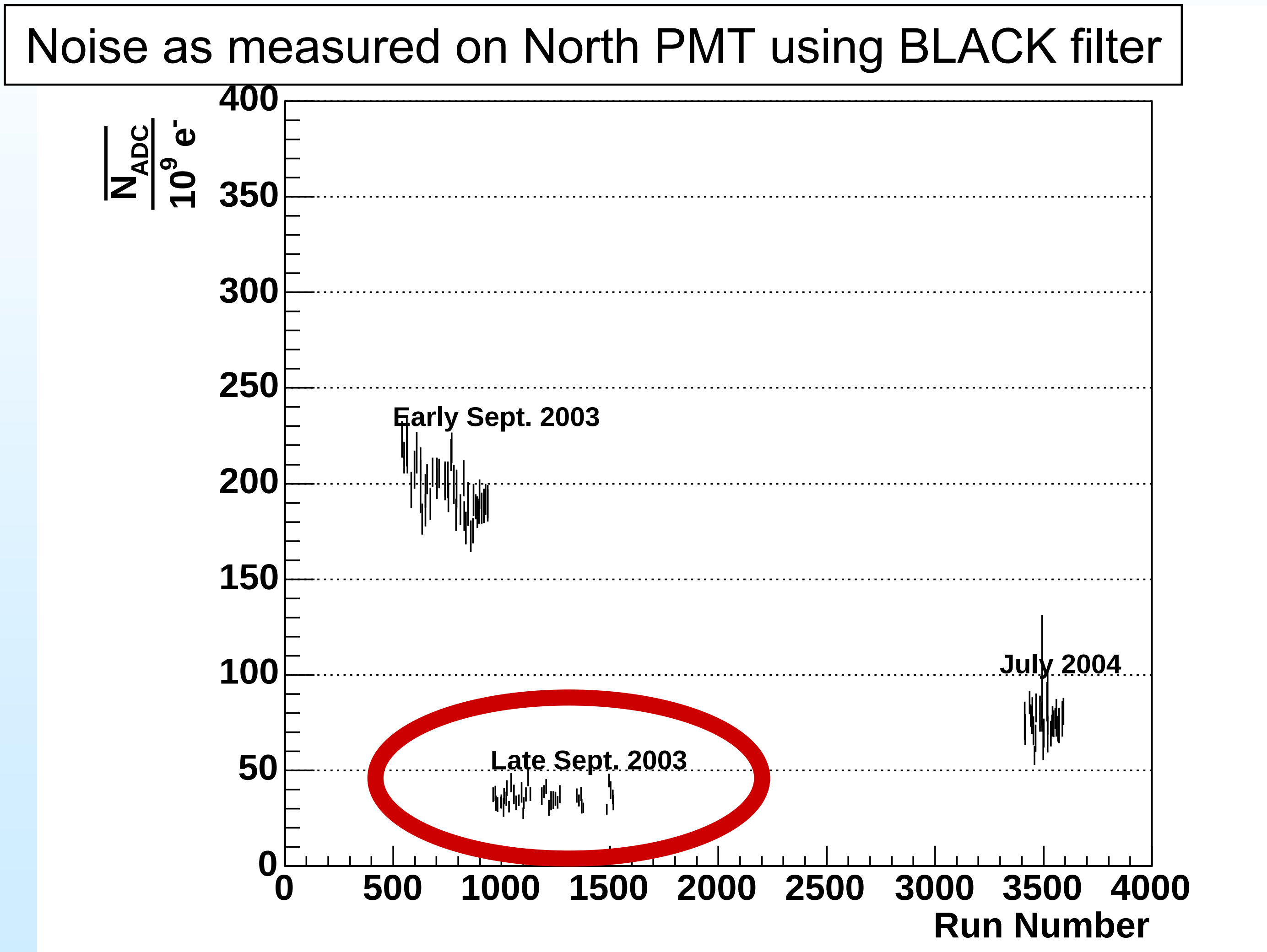


Shielding


DANGER!
HIGH VOLTAGE


ANGER!
may move at any time!
R of WHEELS and RAILS!
B1

Beam Related Backgrounds



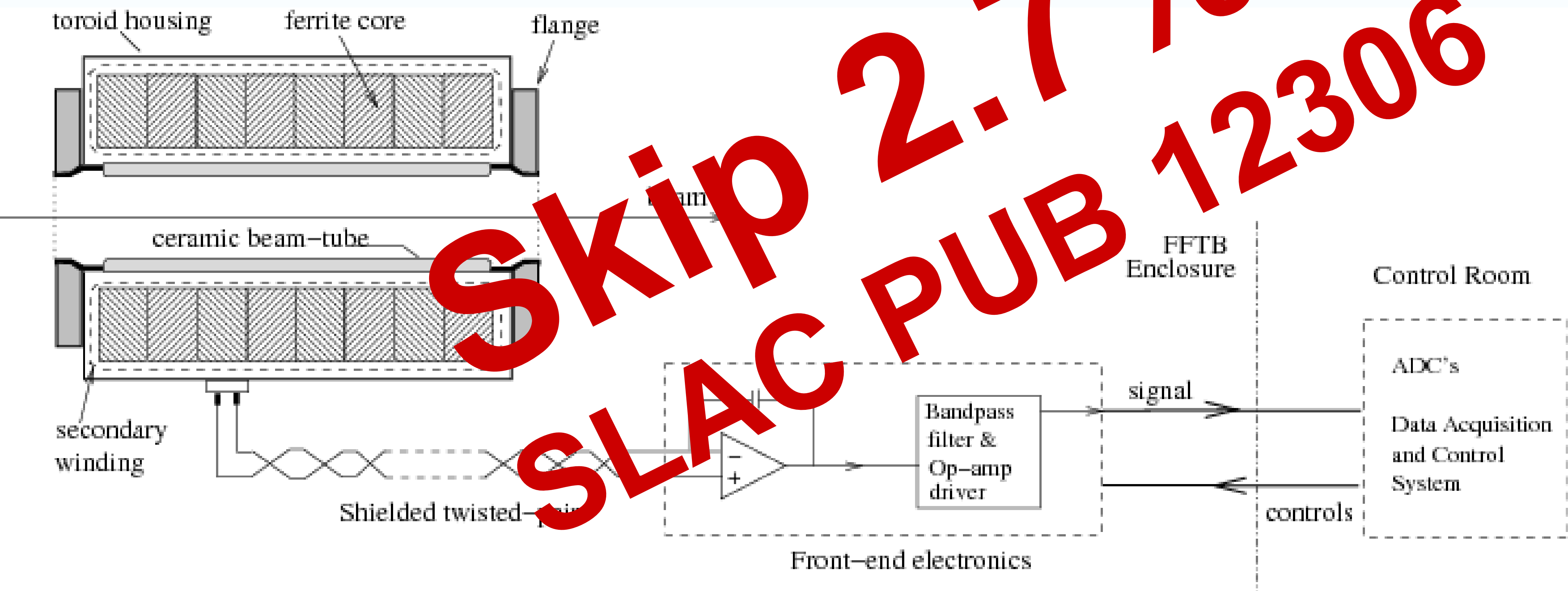
Data taken during three noise "eras".

Reduced noise using lead and preventing beam scraping.

FLASH Toriod

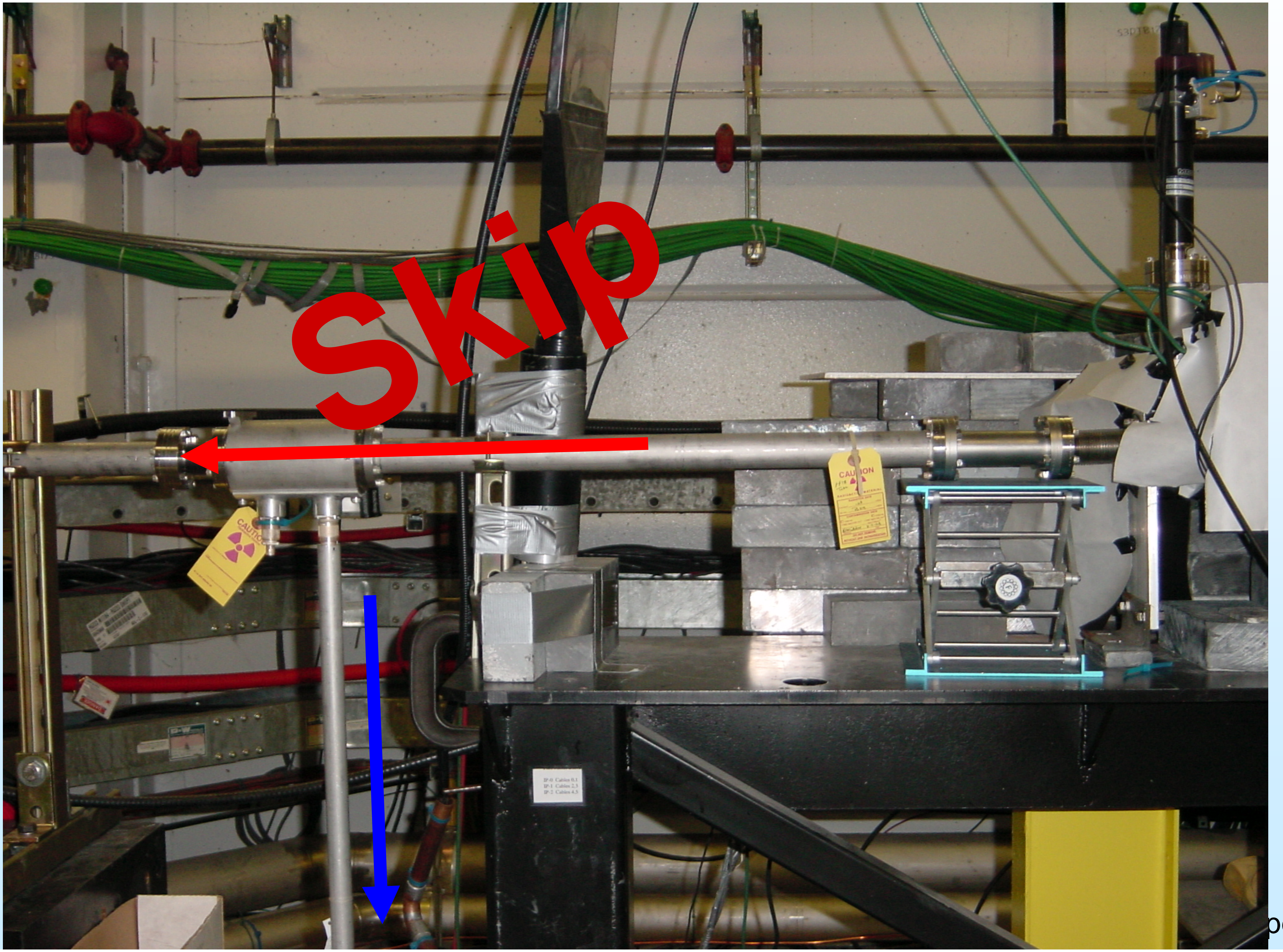
Skip 2.7%

SLAC PUB 12306

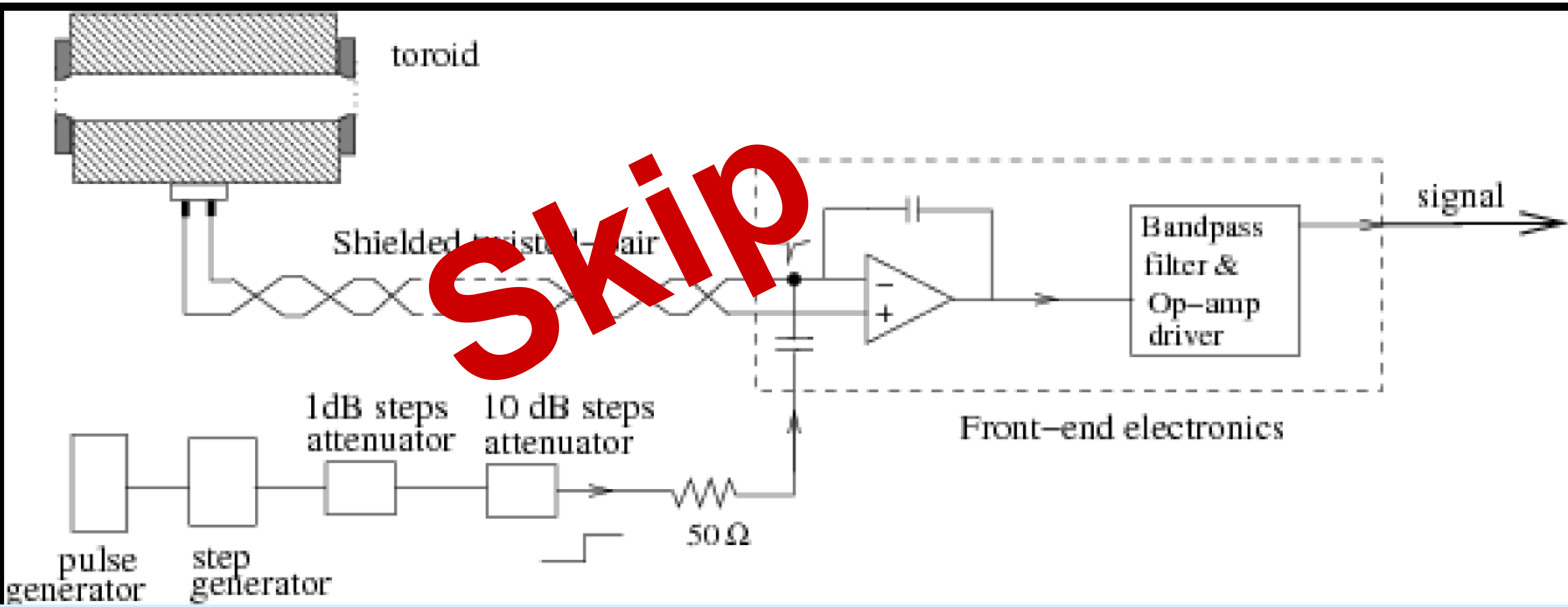


- Custom front end electronics to allow beam charge measurements from 10^7-10^{10} e^- at ~2%.

FLASH Toroid



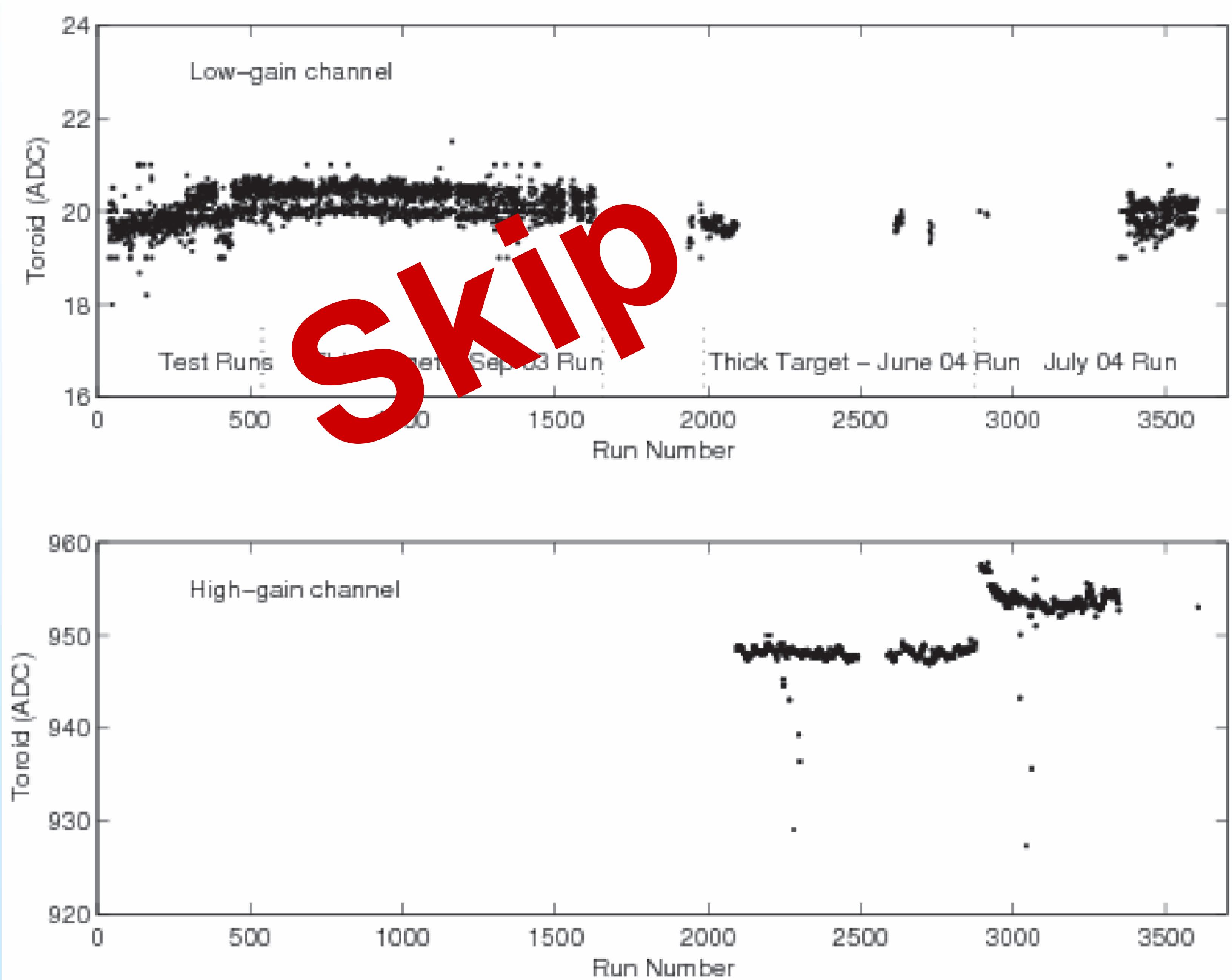
Flash Toroid



- Include the ability to inject charge to track response and calibrate.

Toroid Tracking

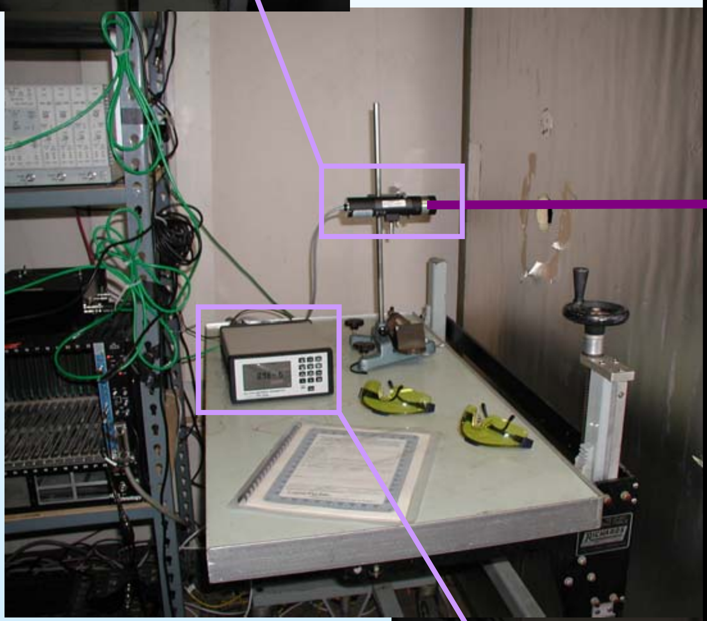
Skip



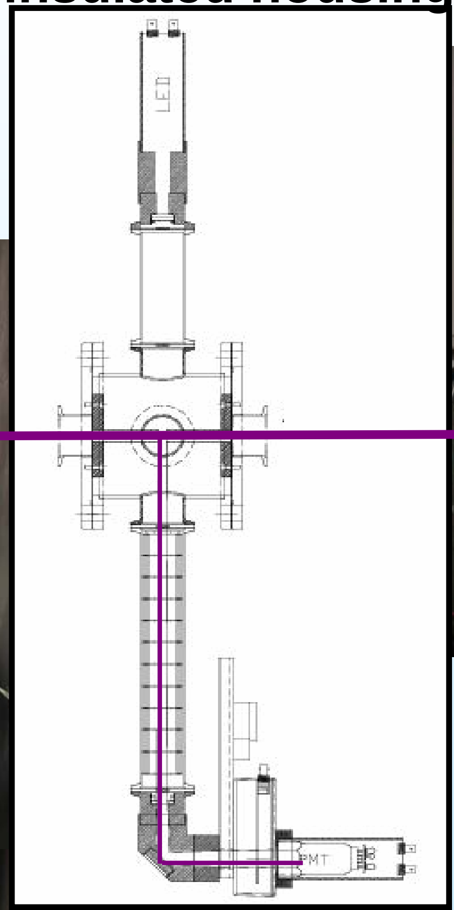
Optical Calibration

RjP-734 Energy probe

σ=5%



insulated housing

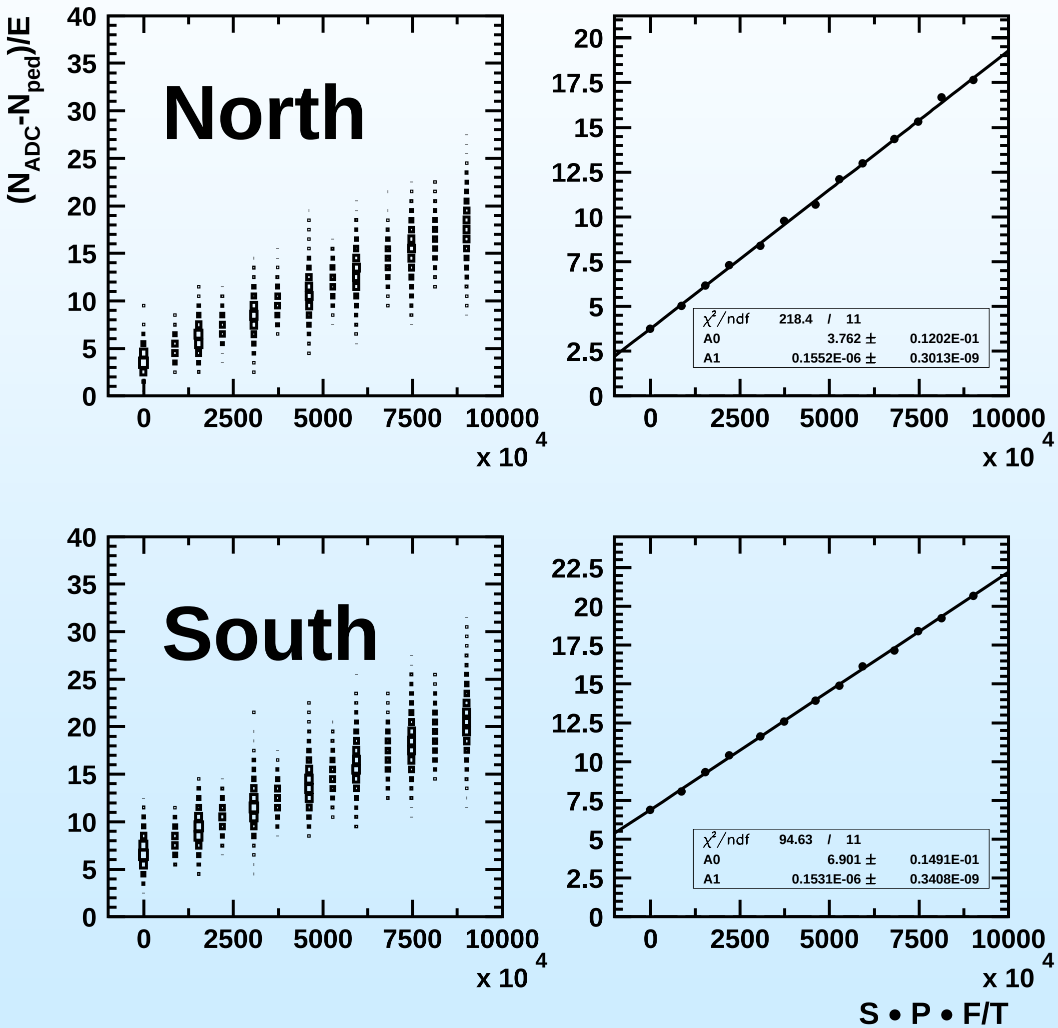


Nitrogen laser
337 nm, 160 μJ

Radiometer →

Rayleigh Scattering
→calculation based on Bucholtz, Appl. Opt. Vol. **34**, 2765-2773 (1995)

Optical Calibration

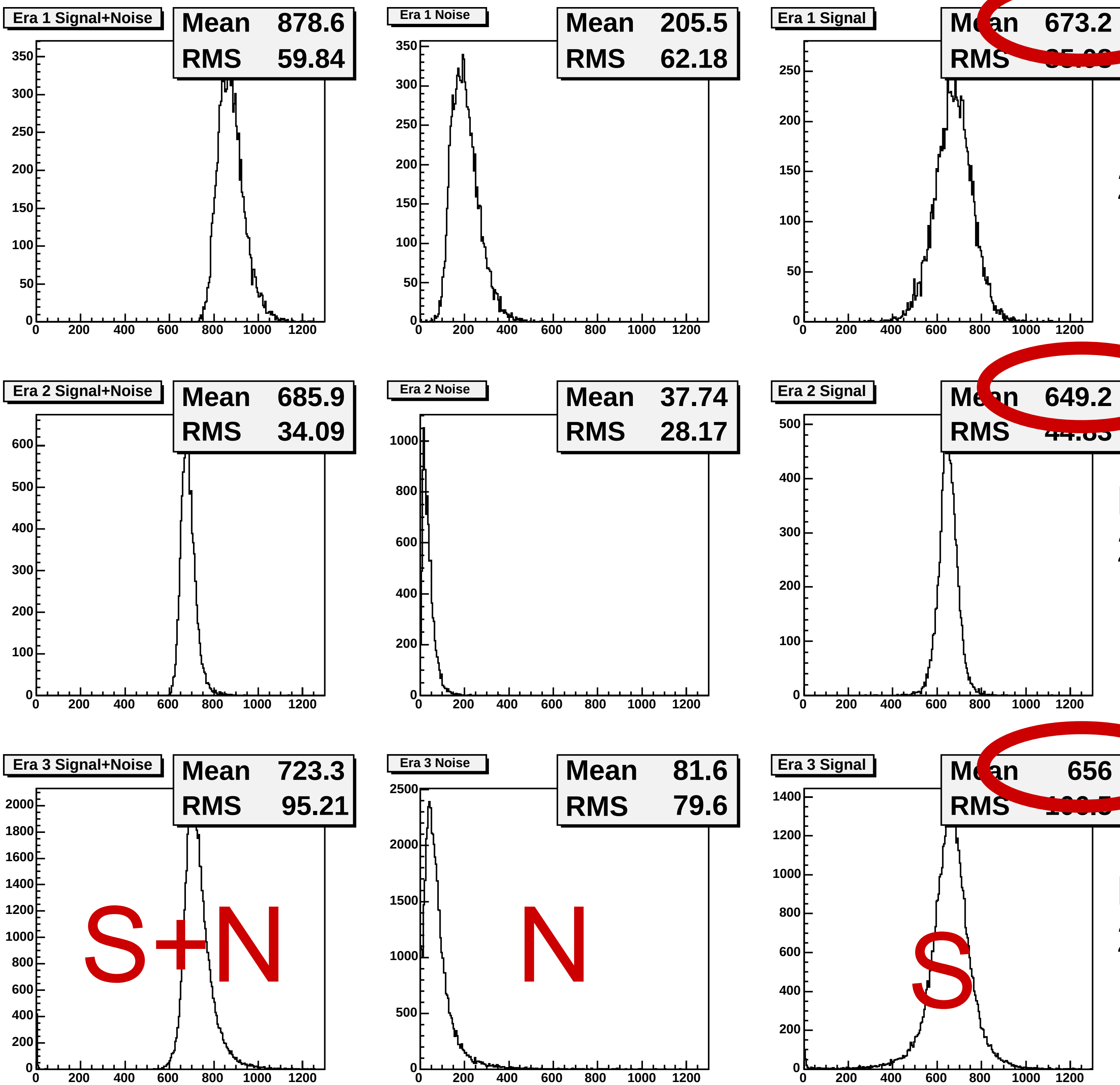


- Number of photons from Rayleigh scattering well known.
- Linear with pressure.
- Known # photons and same geometry gives
  - $N_{photons}/m/ADC_{counts}$
- Uncertainties later.

Thin Target Run

- Data taken in September 2003.
- Subset retaken in July 2004.
  - Confirmed **stability** of system
  - Results are **reproducible**.
- **12 Narrow band filters** (296-425 nm) plus
  - Plus **HiRes** (300-400 nm), **open** and **black** filters.
- Pressures from **atmospheric** down to **5 torr**.
- Pure N_2, dry air and humid (SLAC) air.

Reproducibility 2%



Early Sept 2003

Late Sept 2003

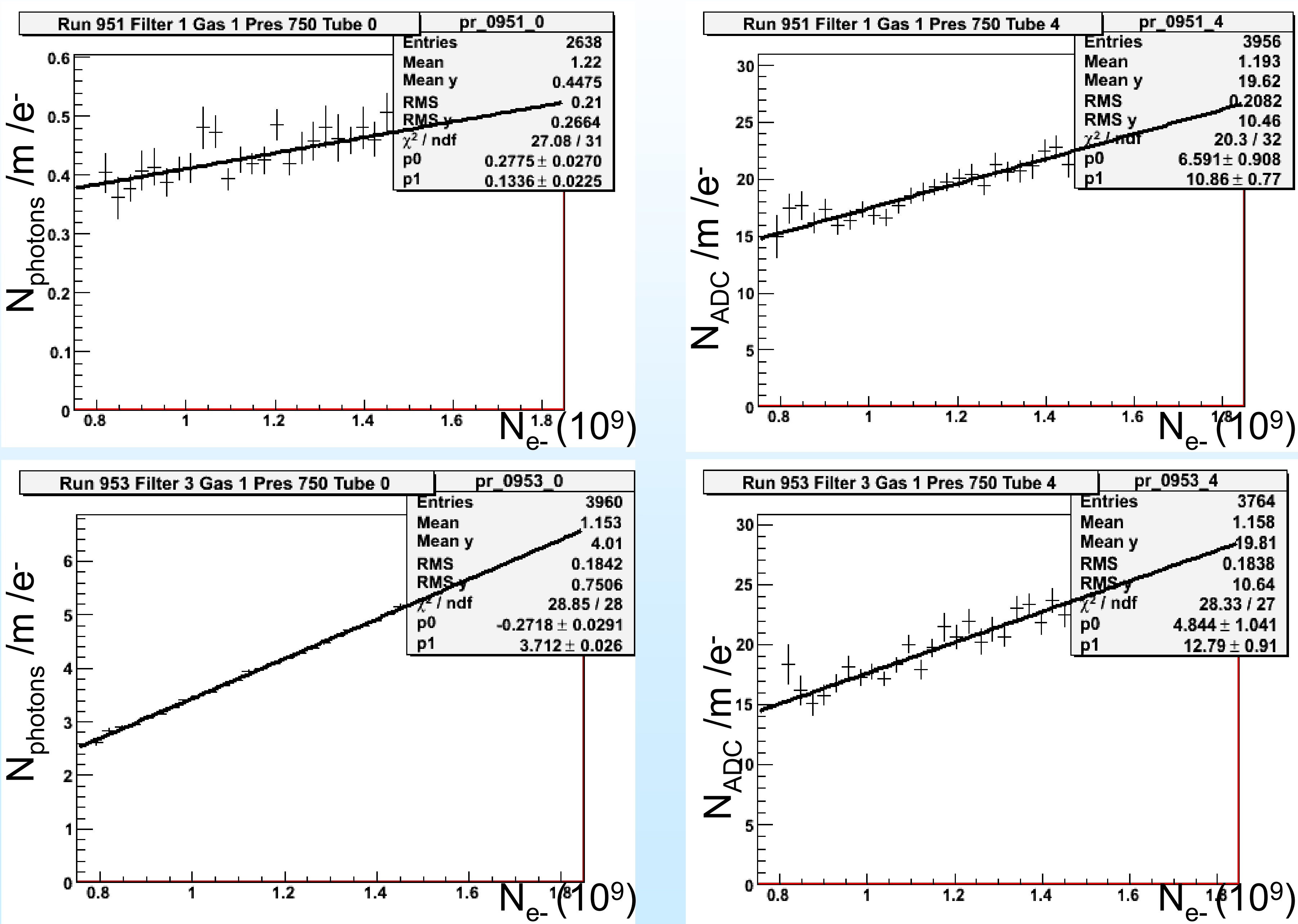
Late July 2004

Fluoresence Measurement

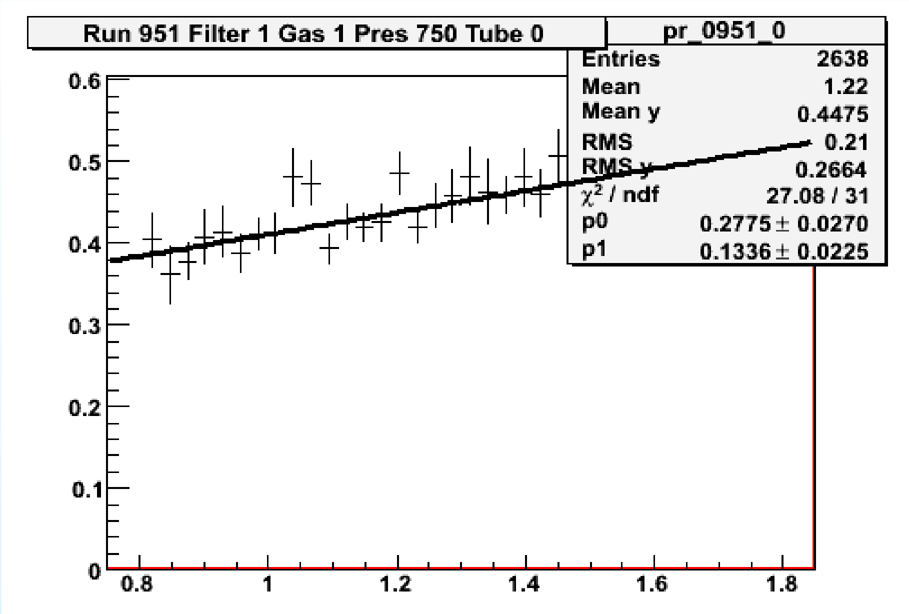
- We want to measure fluorescence yield
  - $Y_i = N_{photons} / N_{e-}\ m$
  - (@ <10%)
- Measure N_{e-} using the toroid
  - (2.7 % @10^9 e^-)
- Measure PMT signal on ADC N_{ADC}.
  - $N_{ADC}=N_{measured}-N_{Pedestal}-N^*_{Background}$.
  - @ 1% level for wide band & 5% level for narrow band
- Optical Calibration converts N_{ADC} to $N_{photons}/m$
  - Calibration* = $N_{ADC} / (N_{photon} / m)$
  - @

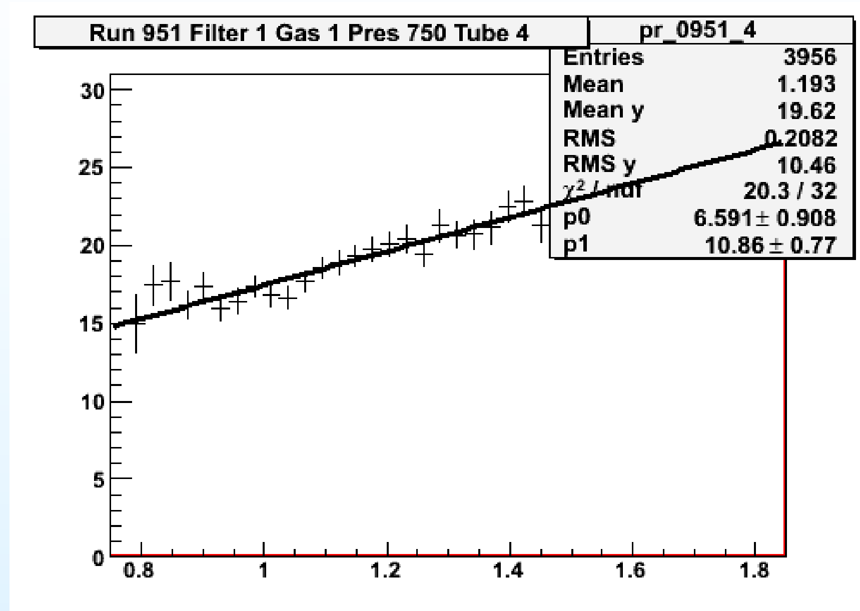
*These two things are the most difficult!

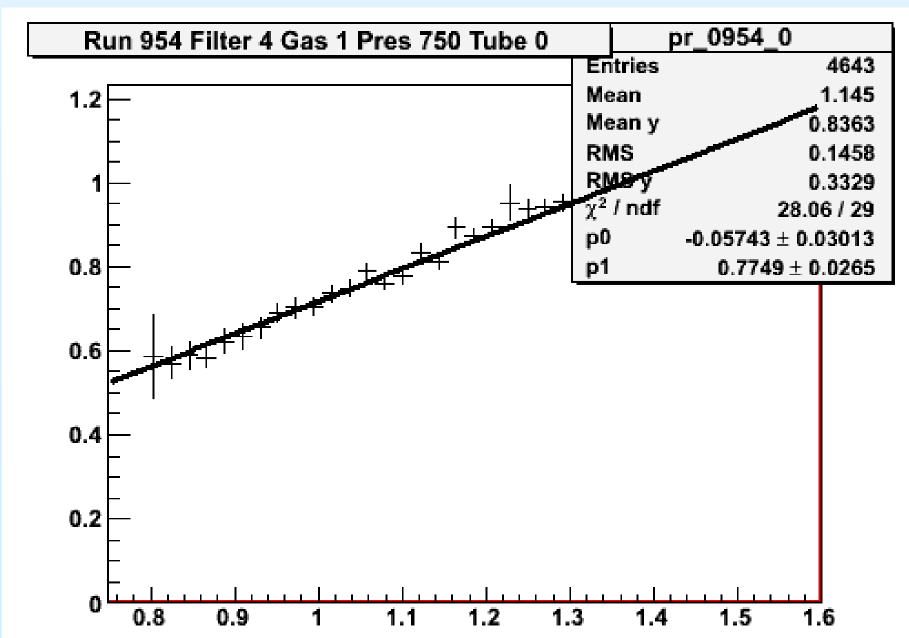
Data (HiRes filter)

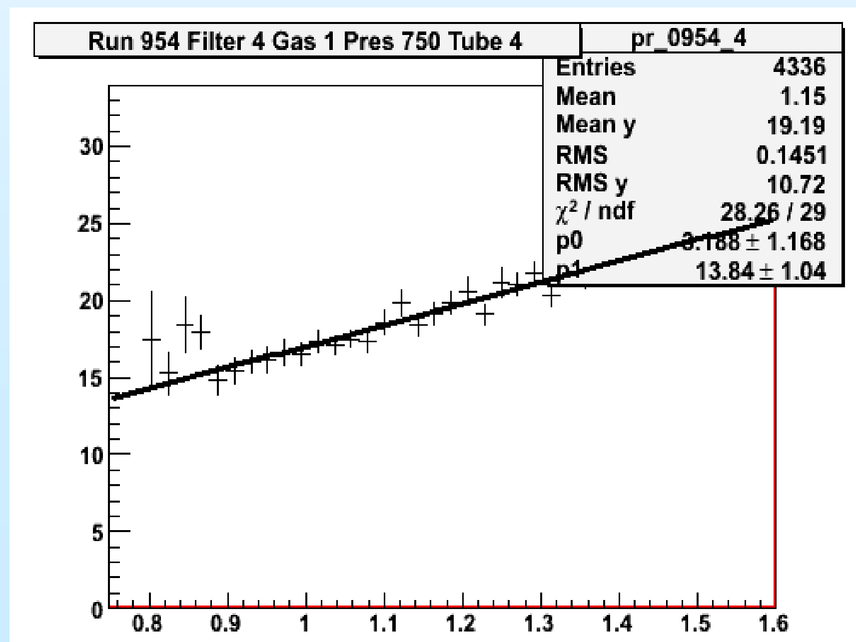


Data (337 narrowband)

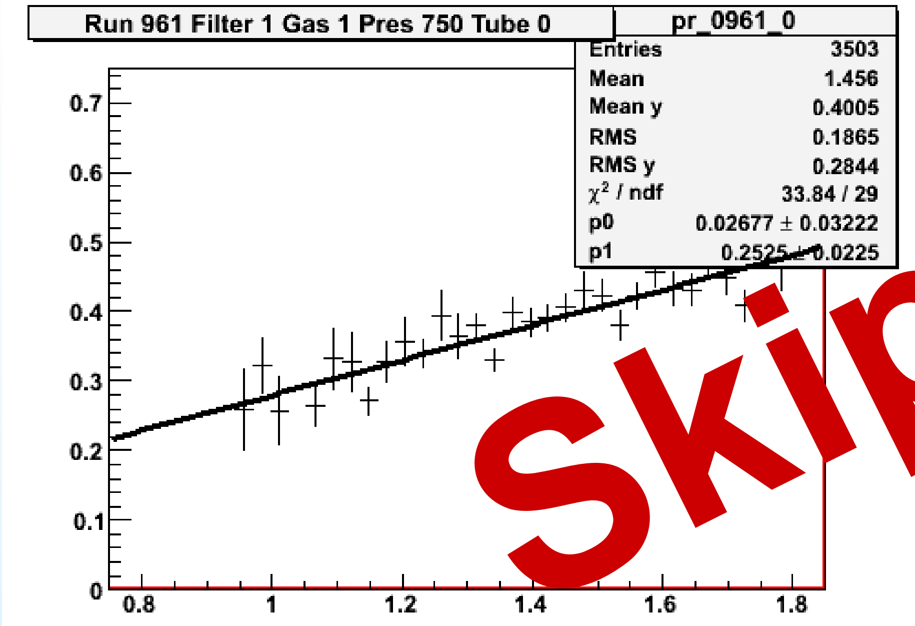


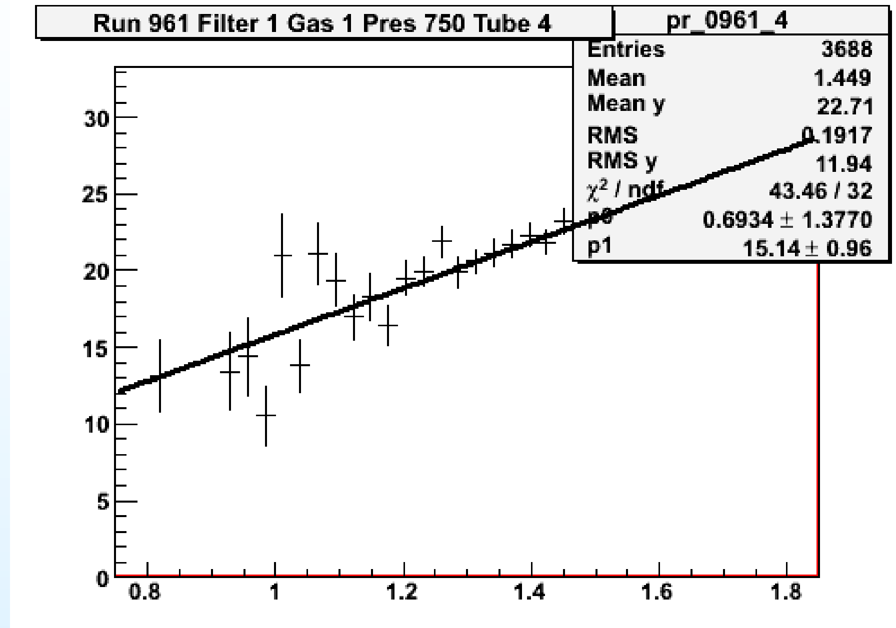


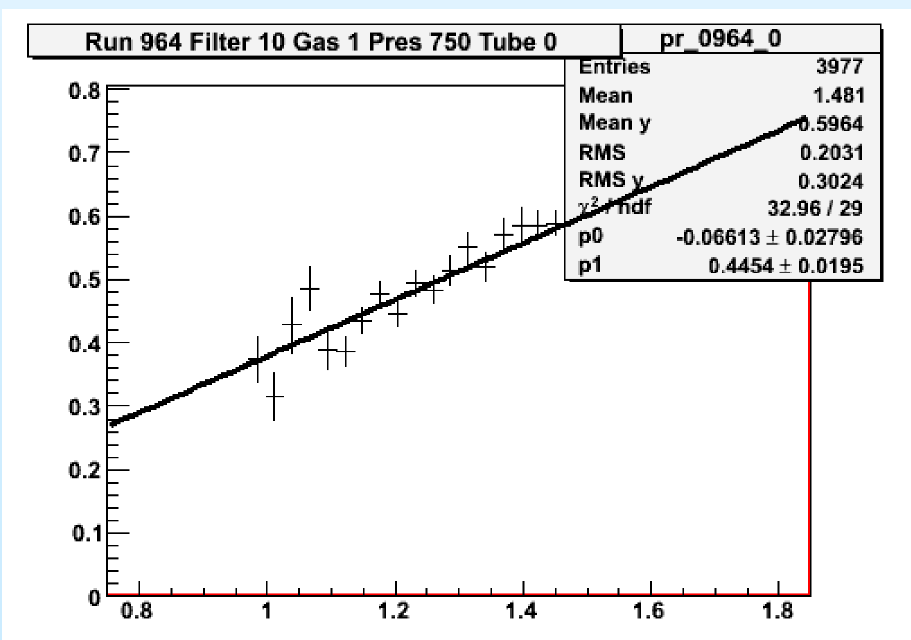


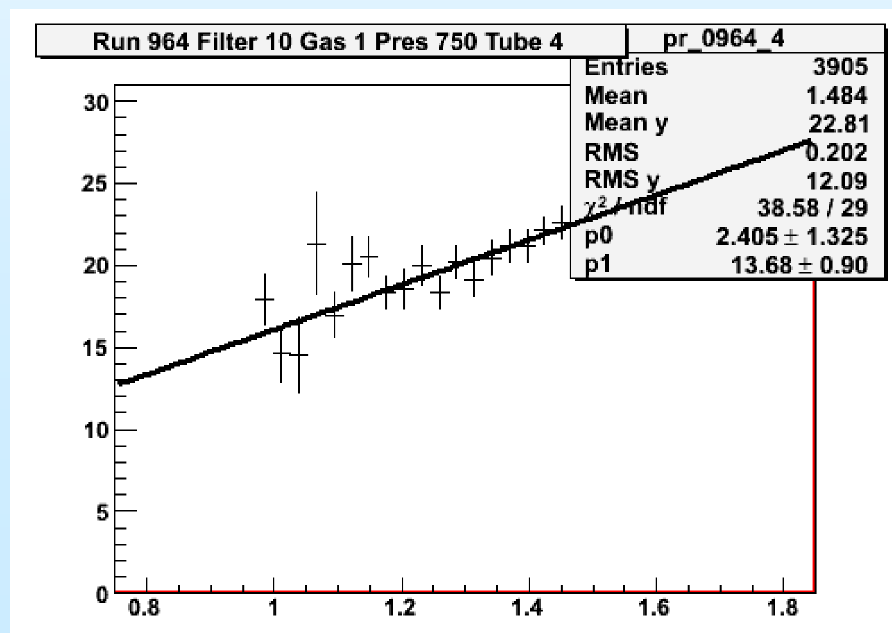


Data (315 nm narrowband)









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Uncertainties

- Energy Probe: +/- 5%
- "Theory" Uncertainty (difference between gains derived with Bucholtz/Bhodaine):

  +/-0.2%
- Excluding lowest pressure point in Fit:

  +/-0.2%
- Temperature uncertainty (+/- 2 deg C):

  +/-1.1 %
- HiRes filter vs no filter discrepancy:

  +/- 1.75 (North PMT), +/-0.5 % (South PMT)
- Uncertainty from the spread of the dE/dx deposition (see Clive's note "Comparison of Rayleigh Scattering and Fluorescence Acceptance", based on EGS4 study):

  +/- 2%
- SLAC-Utah transfer uncertainty: ≤ 4.2% (conservative estimate)
- Toroid 2.7%
- Background subtraction ~2% wide band ~5%+ narrow band

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Optical Calibration II: Relative with Silicon Photo Diode

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- Following uncertainties are considered:
  - Relative expanded uncertainty of sipd calibration
  - Residuals of the fit of a polynomial (4th order)
- Uncertainty range:

  ~ (0.5 – 2)%

Plot from relative calibration memo 09/2006

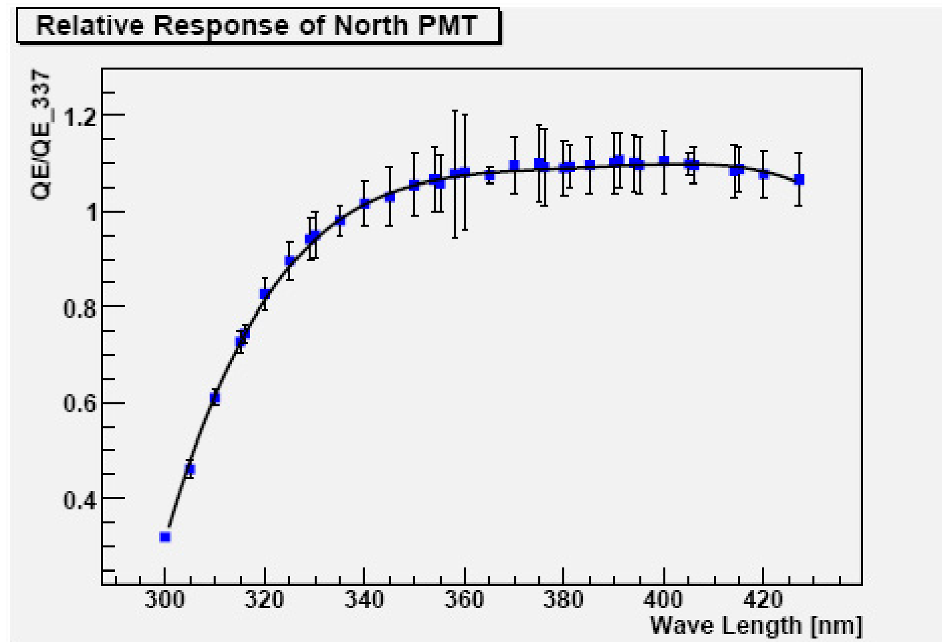


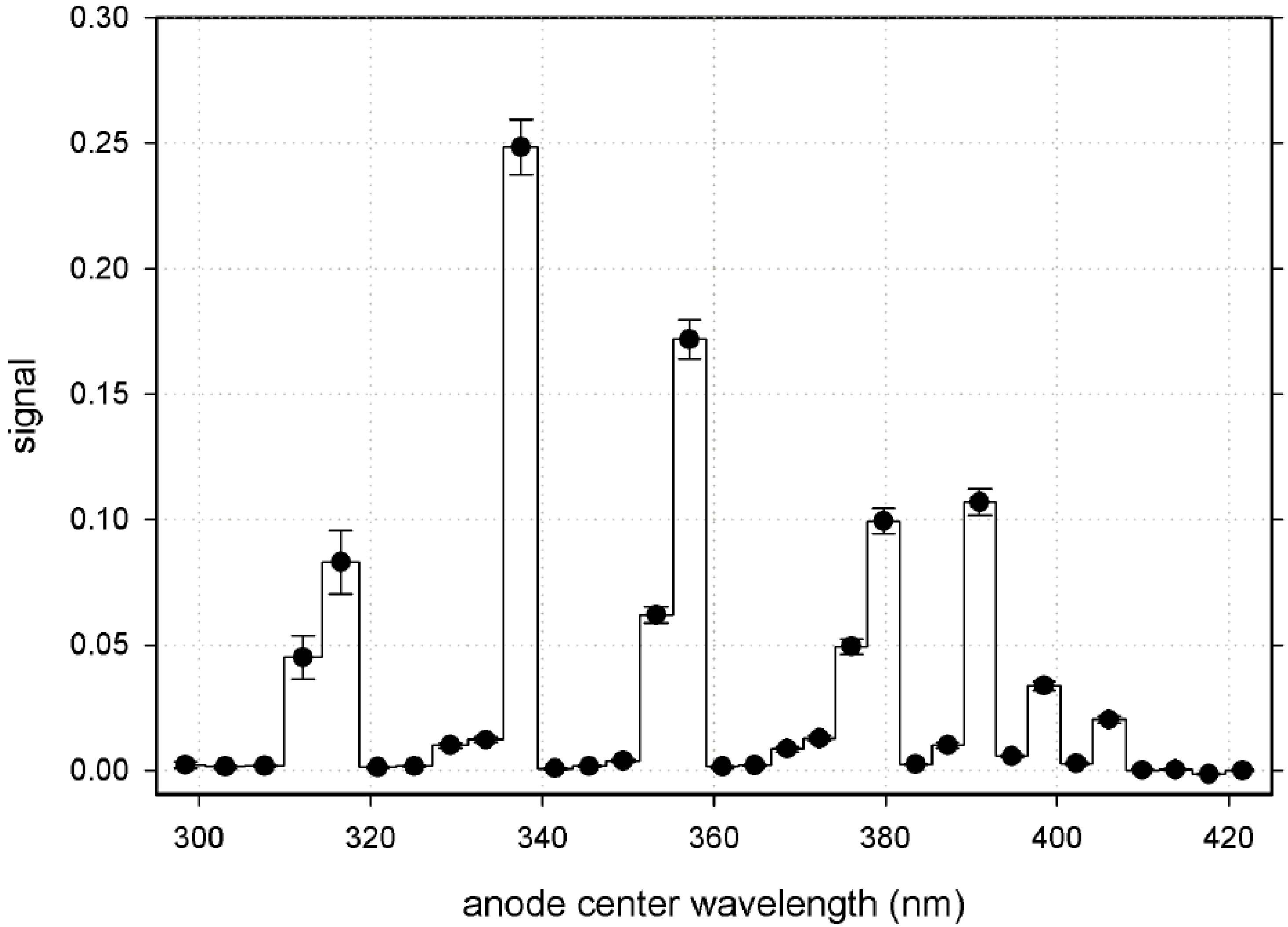
Figure 2: Relative responsivity of the North PMT.

Uncertainties

	N	S
Optical		
Energy Probe	5.0	5.0
Theory	0.2	0.2
Fit	0.2	0.2
Temp	1.1	1.1
HiRes vs no filter	1.8	0.5
dE/dx	2.0	2.0
ADC Transfer	4.2	4.2
Toroid	2.7	2.7
BG	1.0	1.0
Sum (quadrature)	7.7	7.5

Spectrograph Spectrum

Spectrograph in Dry Air at Atmospheric Pressure



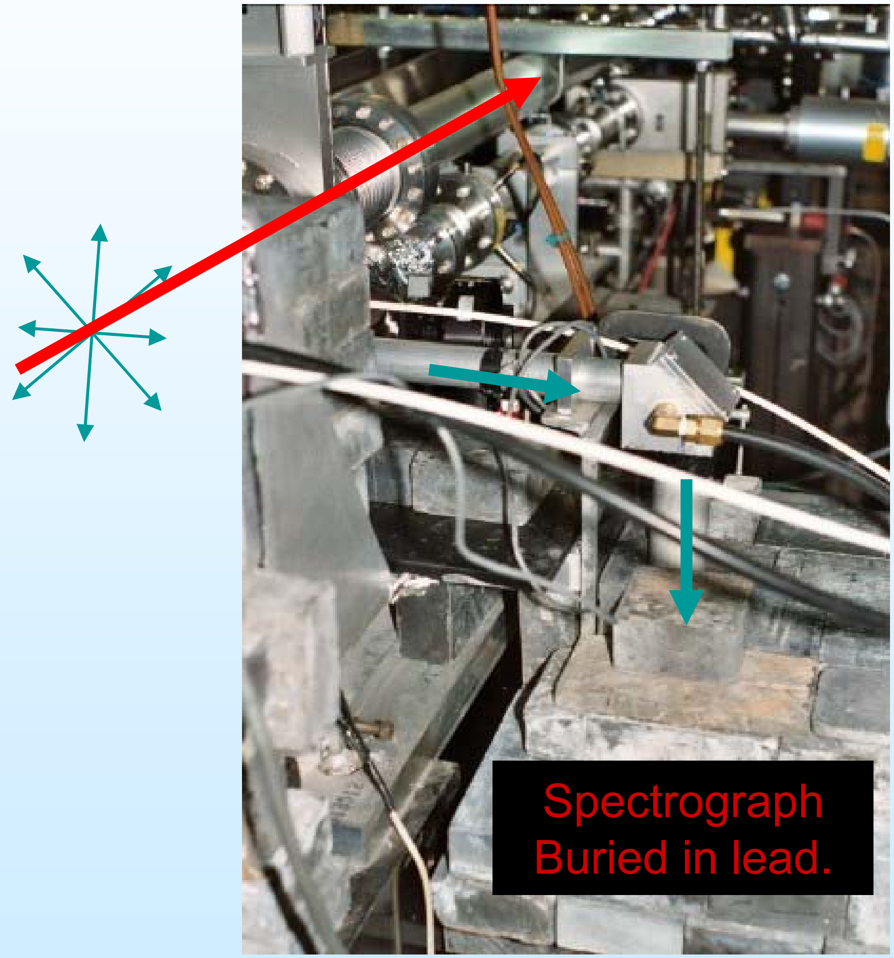
Spectral shape as **measured by spectrograph**.

System calibrated for **RELATIVE** line strength only.

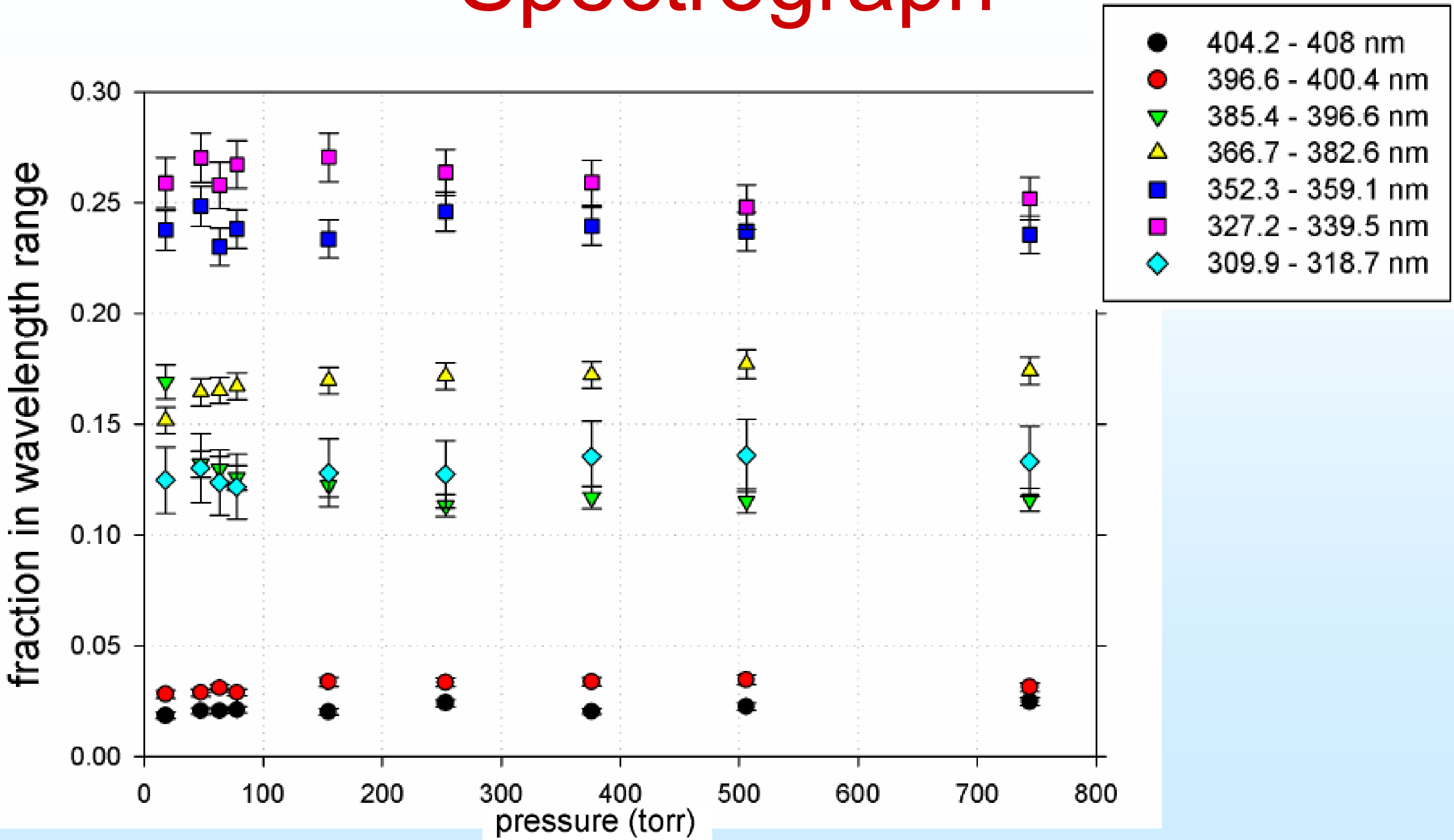
Also have lower resolution to include 296 and 425 lines.

Spectrograph

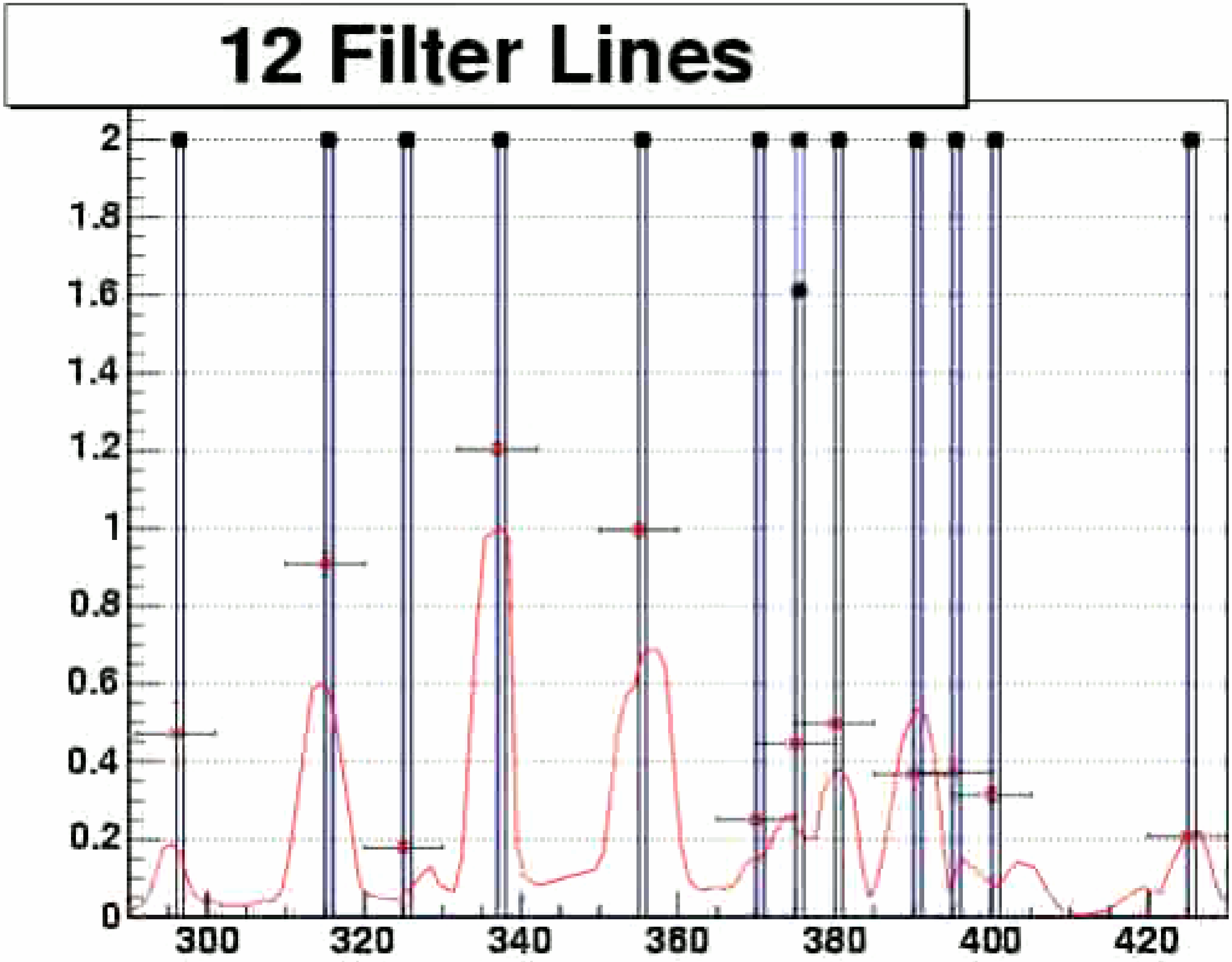
- Spectrograph
  - The electron beam passes through a gas volume.
  - Fluorescence light reflected into a spectrograph system.
  - 32 channel PMT relative line strengths calibrated using Deuterium lamp.



Spectrograph



FLASH MC



12 Filter Lines
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
300
320
340
360
380
400
420

Spectral Results

Filt	Dry Air T%	750 ADC	ADC RMS	Err	Err RMS	Pred
Open	100.0	5.31	0.475 %	2.7 %		5.307
HiRes	84.5	3.87	0.810 %	2.8 %		4.585
Black	0.0	-0.05	0.000	2.5 %		
296 nm	16.5	0.09	1084.091 %	3.3 %		0.543
315 nm	26.0	0.24	46.585 %	2.1 %		0.910
330/325 nm	49.0	0.15	57.208 %	5.5 %		0.311
337 nm	36.5	0.66	12.061 %	2.9 %		1.806
355 nm	32.0	0.49	15.630 %	2.6 %		1.533
370 nm	36.0	0.16	47.623 %	3.0 %		0.446
375 nm	40.0	0.20	25.956 %	2.3 %		0.510
380 nm	38.5	0.25	17.779 %	1.9 %		0.659
390 nm	49.5	0.30	18.564 %	3.0 %		0.598
395 nm	40.0	0.27	16.290 %	1.9 %		0.671
400 nm	36.0	0.15	89.746 %	5.4 %		0.417
425 nm	64.0	0.26	14.175 %	2.5 %		0.405

Spectral Results

Filt	SLAC Air T%	750 ADC	ADC RMS	Err	Err RMS	Pred
Open	100.0	4.88		-10.4 %		4.879
HiRes	84.5	3.68		-10.7 %		4.352
Black	0.0	-0.17		-10.2 %		
296 nm	16.5	-0.34	1.040	-12.2 %		-2.086
315 nm	26.0	0.20	45.406 %	-11.4 %		0.766
330/325 nm	49.0	-0.15		-13.6 %		-0.313
337 nm	36.5	0.52		-12.9 %		1.420
355 nm	32.0	0.42		-11.1 %		1.317
370 nm	36.0	-0.24		-12.7 %		-0.661
375 nm	40.0	0.23		-13.4 %		0.570
380 nm	38.5	0.32		-11.3 %		0.833
390 nm	49.5	0.40		-11.1 %		0.813
395 nm	40.0	0.29		-12.2 %		0.730
400 nm	36.0	0.08		-12.3 %		0.214
425 nm	64.0	-0.13		-12.7 %		-0.199

Spectral Results

Filt	N_2 T%	750 ADC	ADC RMS	Err	Err RMS	Pred
Open	100.0	-0.11	0.001	0.1 %		-0.110
HiRes	84.5	-0.11	0.001	0.1 %		-0.130
Black	0.0	0.01	0.000	2.8 %		
296 nm	16.5	-0.08	0.773	2.6 %		-0.455
315 nm	26.0	0.82	15.019 %	2.4 %		3.160
330/325 nm	49.0	0.39	9.514 %	2.3 %		0.786
337 nm	36.5	5.44	1.592 %	3.1 %		14.894
355 nm	32.0	3.74	2.170 %	2.8 %		11.672
370 nm	36.0	0.51	10.963 %	2.2 %		1.422
375 nm	40.0	1.26	4.954 %	2.7 %		3.145
380 nm	38.5	1.99	3.100 %	2.7 %		5.163
390 nm	49.5	0.54	6.449 %	1.9 %		1.088
395 nm	40.0	0.56	8.876 %	2.1 %		1.407
400 nm	36.0	0.46	12.586 %	2.3 %		1.267
425 nm	64.0	0.53	6.061 %	2.2 %		0.823

And the answer is…

- Use measured spectra and normalize to our HiRes filter measurement.
  - Then look how accurately each narrowband filter signal is.
  - Use Bunner, Airfly, Nagano/Kakimoto, and FLASH spectra.
  - Make a spectrum up to match all observations? ☹

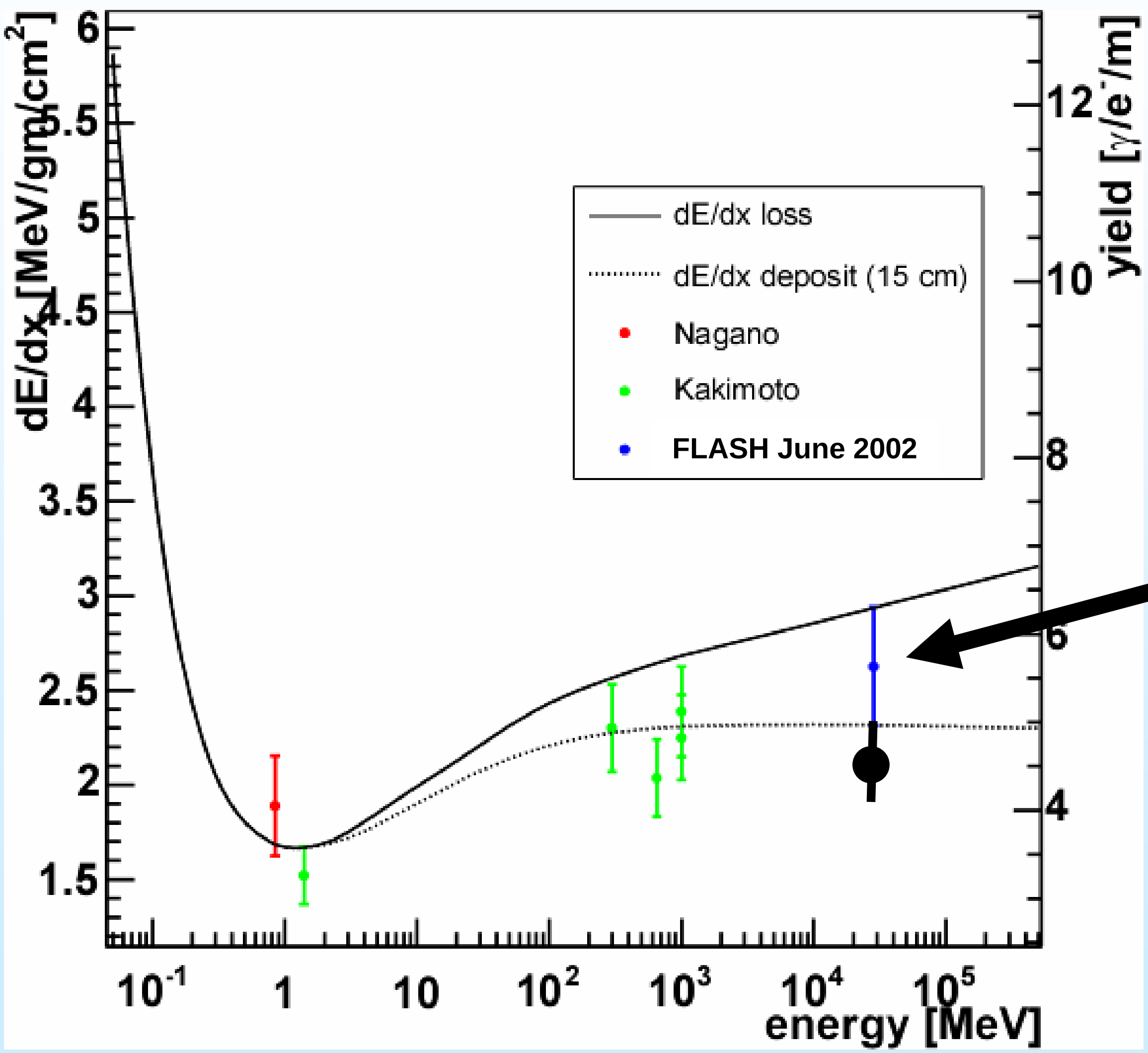
Other Spectral Assumptions

- Bunner Spectrum
  - Normalize to 337 nm filter signal.
  - 5.0 ph/m/e^-.
- All Known Fluorescence Lines
  - Listed, for example, in table 9 of Naganos paper
  - Allow all lines to vary.
  - 4.65

Skip

- Spectrograph Shape
  - Normalize to 337 nm filter signal.
  - 5.2 photons/m/e^-.
- In **all cases** the **solution is higher** when you allow some of the light to be away from the peak filter transmission.
- In all cases the measured totals (HiRes and open) no longer agree.

FLASH Results



Toroid used in June 2002 recalibrated.

Conclusions

1) Total fluorescence yield for photons between 300 and 400 nm from electrons at 28.5 GeV.
2) Have seen small discrepancies in all published spectra and our two measurements as well.
3) Yield follows dE/dx
4) Quenching of yield due to H_2O
5) Yield seems to be well known.
6) Watch the arxiv!