The sFLASH measurement of Air Fluorescence

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Basic Idea

- Deposit E_{em} energy equivalent to ~ 10^{18} eV using SLAC ESA electron test beam
- (10^9 e @ 10-15 GeV in a picosecond bunch) into air-equivalent material (Alumina Al_2O_3). Shower develops in 1-3 r.l. of Alumina.
- Measure air-fluorescence photons after shower exits into air (3 m of air before beam dump)
- Fluorescence yield of 10^{18} eV electromagnetic shower near shower maximum in 1 m of air.

Differences from previous attempts

- Thick target FLASH experiment: measured relative air fluorescence as function of Alumina rad. length in 28.5 GeV electron beam. No absolute yield measurement. Shower measured in thin 2.5 cm air chamber.
- MacFly measured relative yield as function of radiation length of Cu target using 50 GeV low intensity slow spill proton beam. Measured relative yield. Absolute yield had large systematic errors (+/- 23%).
- Picosecond beam pulses at SLAC means very large signals are possible . ESA geometry allows shower to develop in meters of air (corrections for delta rays minimized compared to thin chambers)

- Goal of sFLASH
- < 10% systematic error measurement of absolute yield of air Fluorescence efficiency integrating over the same electron energy distribution found in 10^{18} eV cosmic ray showers, using same filters and pmt's used in HiRes and TA experiment. In addition a narrow band 337 filter was used in one tube.
- Measure S_F/I_b where I_b is measured using RF horn and induction coil.

Air fluorescence yield measurement at SLAC National Accelerator Laboratory: sFLASH experiment.

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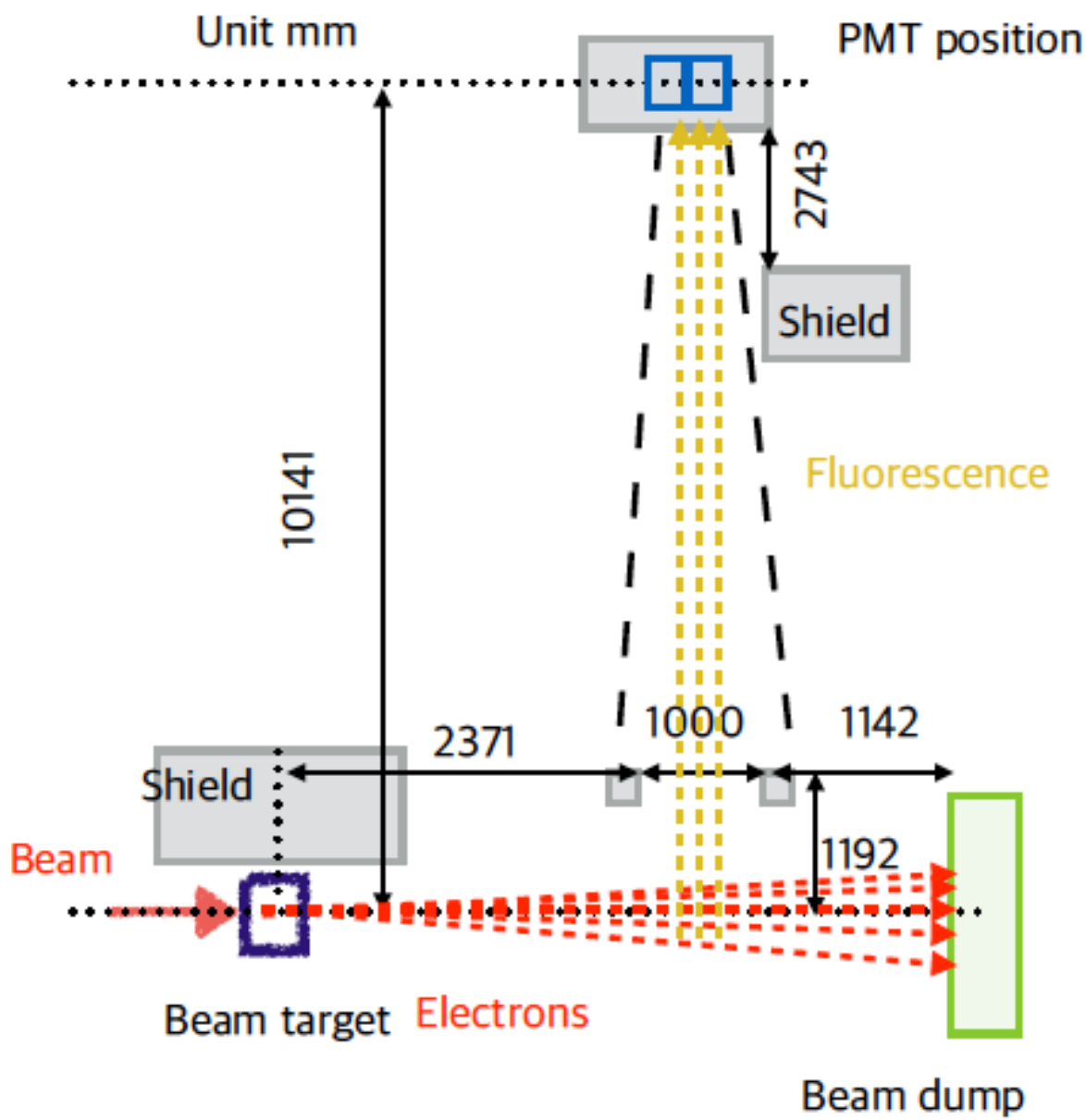
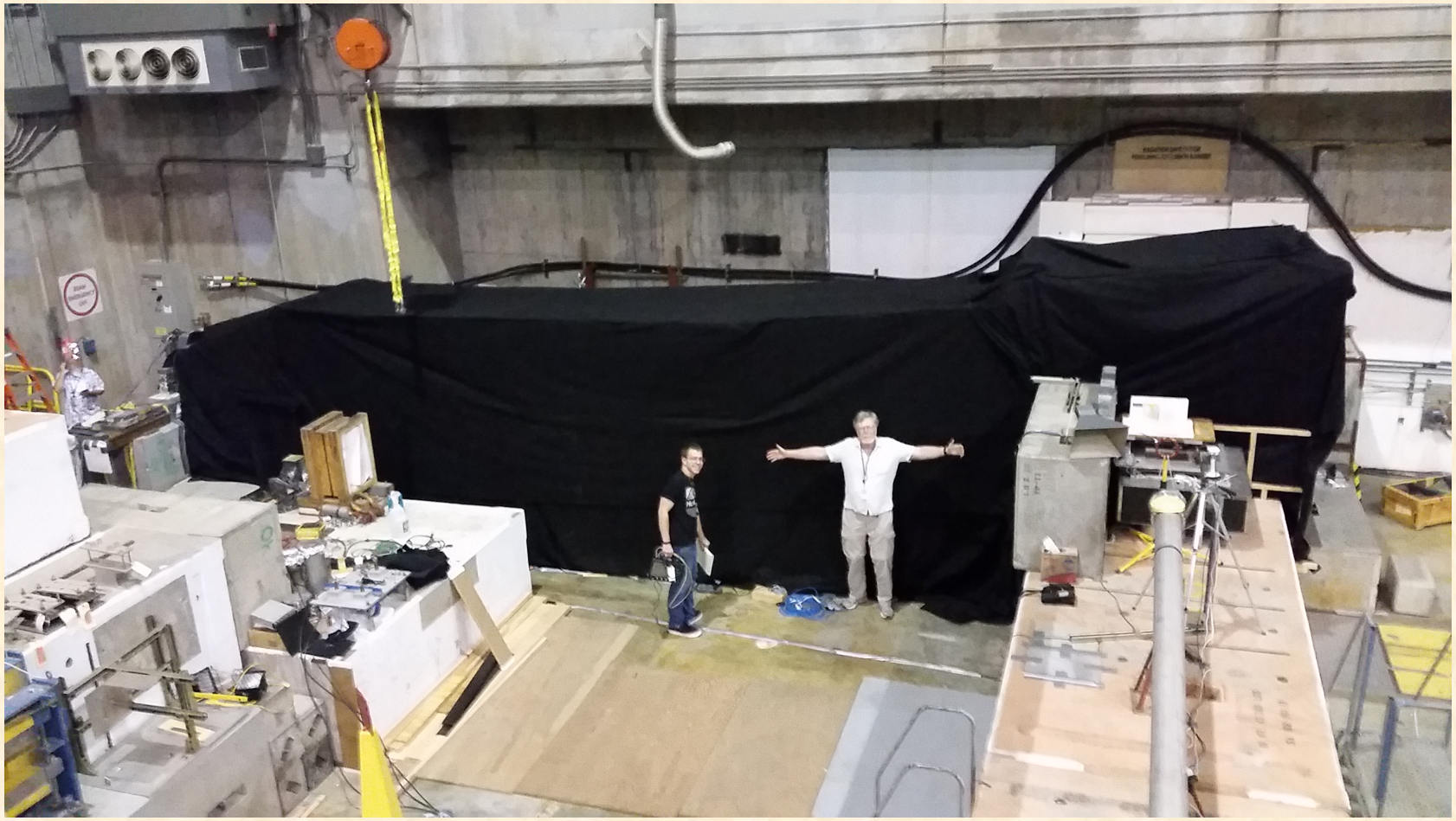
(Dated: September 25, 2016)

We measured the total air air fluorescence yield from secondary cascades in the laboratory environment. An alumina target of different radiation length was placed in the electron beam at SLAC National Accelerator Center and the total amount of UV light was measured using several photo-multiplier tubes. The low background noise was achieved by placing the photo-multipliers away from the electron beam in the heavily shielded enclosure. The measured fluorescence yield is XXX. The background radiation is the major contributor to the systematic error.

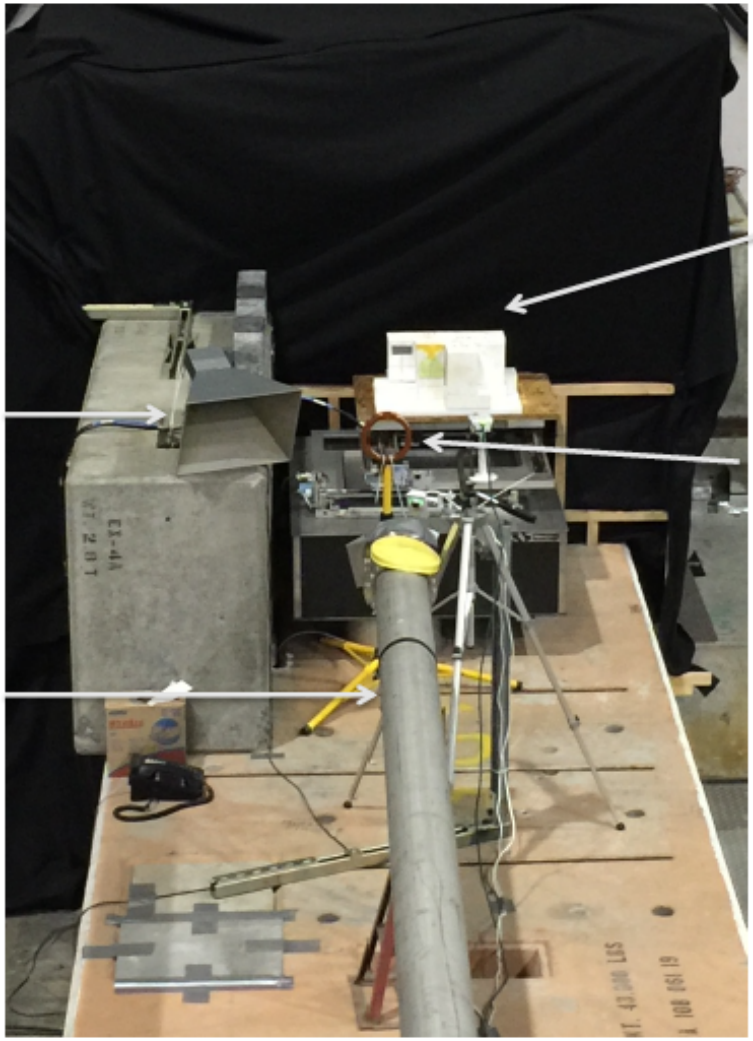
sFLASH Geometry Sep



End Station A



ICT and s-band horn

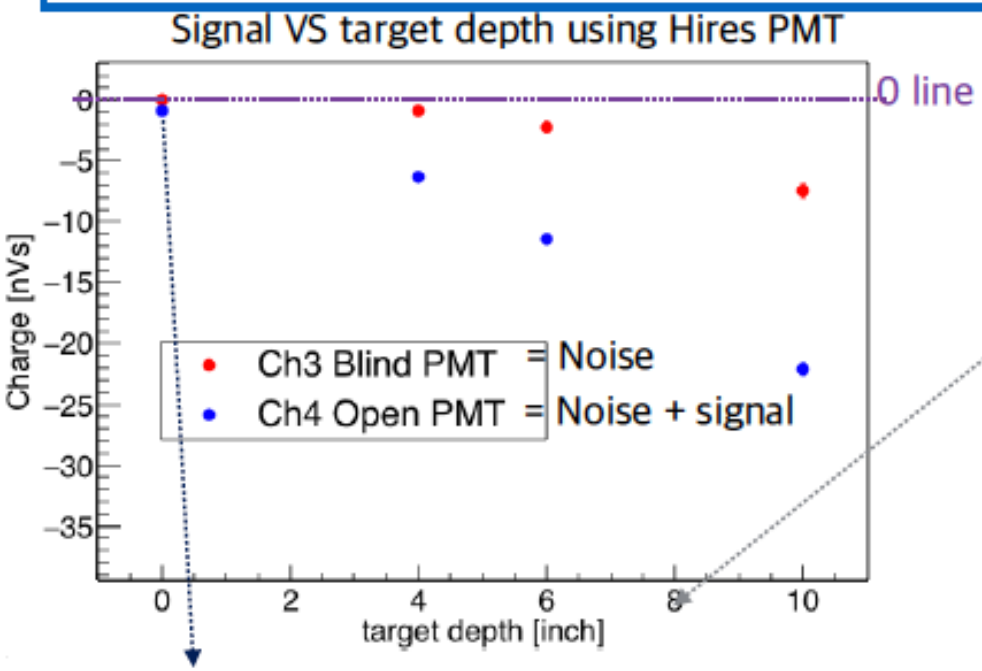


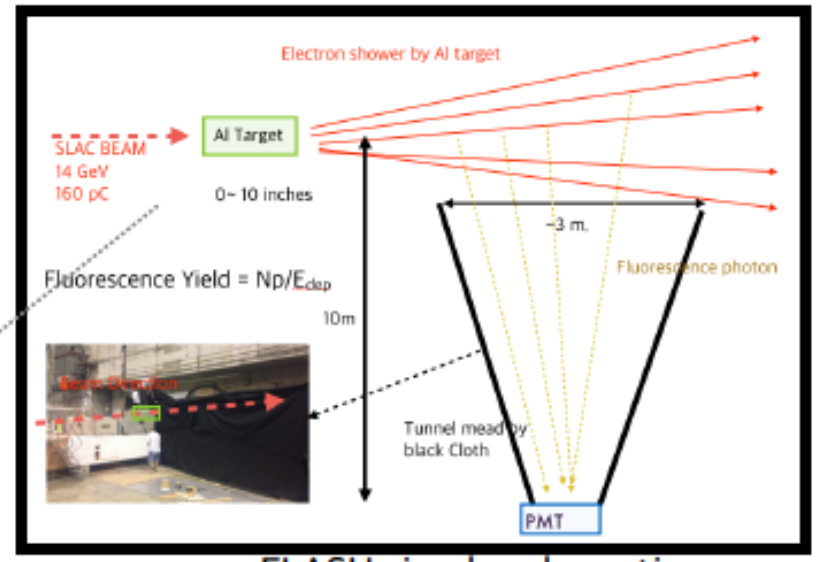
First test in July to study backgrounds

- A first test using HiRes tubes was done in July.
- Beam background determined using adjacent blind tubes run at identical gain.
- Find S/N deteriorates with increasing number of radiation lengths ~ 2/1 at 3 r.l.
- Signal strength agrees within 10% with predictions using GEANT energy deposit calculations and fluorescence efficiency.
- Conclude that method should work if S/N can be improved.

Summary of July sFLASH

- Target: Estimation of beam background.





sFLASH simple schematic

- 0.85 nVs ⇒ 6000photons/7.89cm² =~760/cm² at hires PMT by Charles

- We need to improve S/N with noise rejection or getting higher signal

Systematics

- $N_s = N_f + R_b + N_{Ch}$
- R_b measured using

  a. blinded tubes

  b. "shower curtain" – remote controlled window blind system

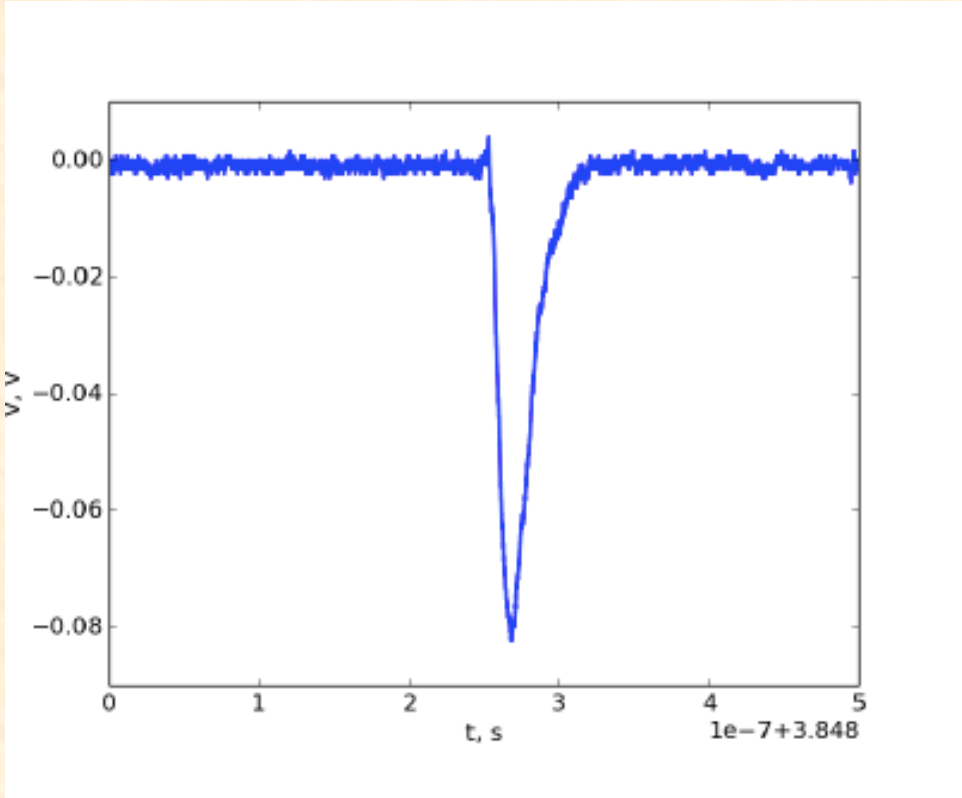
N_{ch} – scattered Cherenkov radiation. Cherenkov angle is ~ 2deg, but some photons can Rayleigh scatter on air molecules at 90 deg

Improvements in September Run

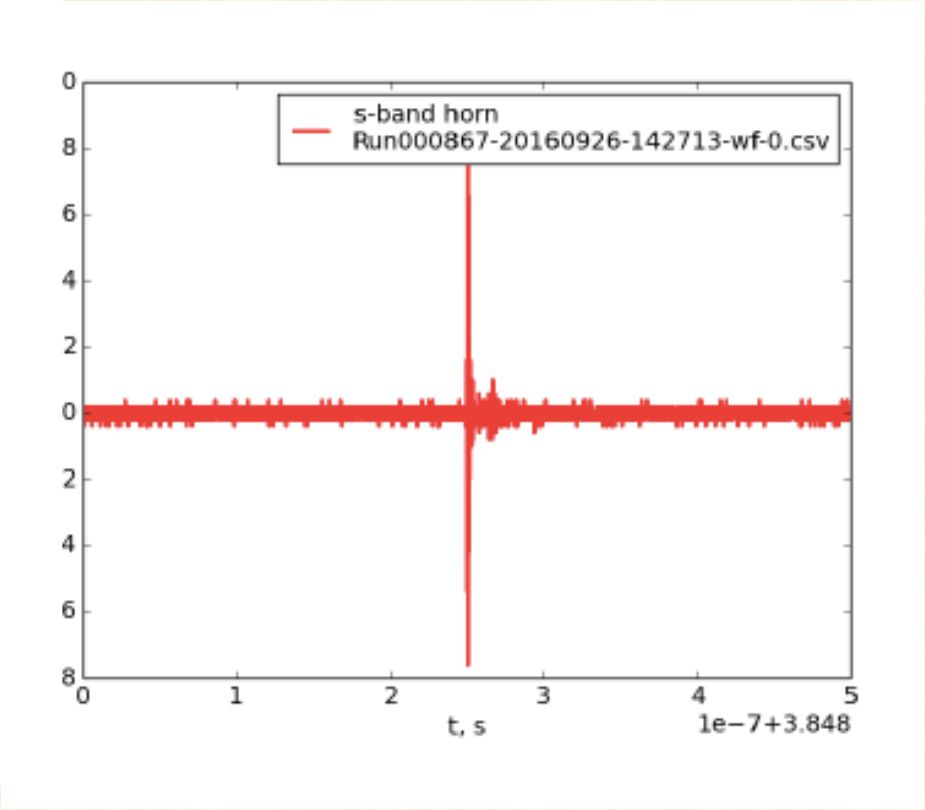
- Placed pmt and Pb shielding on “beam left” and added concrete shielding at target and at beam dump.
- Added CRAYS calibrated TA tubes to HiRes tubes.
- UV LED in FOV allows calibration using photostatistics
- Added a FOV defining 1m x 1.5m window with remotely controllable blind
- Background measured with blind tubes and with blind up/blind down runs using signal tubes.

- Some early results at 0, 1, 2 and 3 rl.
- Beam intensity monitoring at ~ 2-3% level.
- ~ 10 x better S/N than previous run
- Some differences between blinded tube signals and open tubes with closed blinds still need to be understood

Beam intensity monitoring

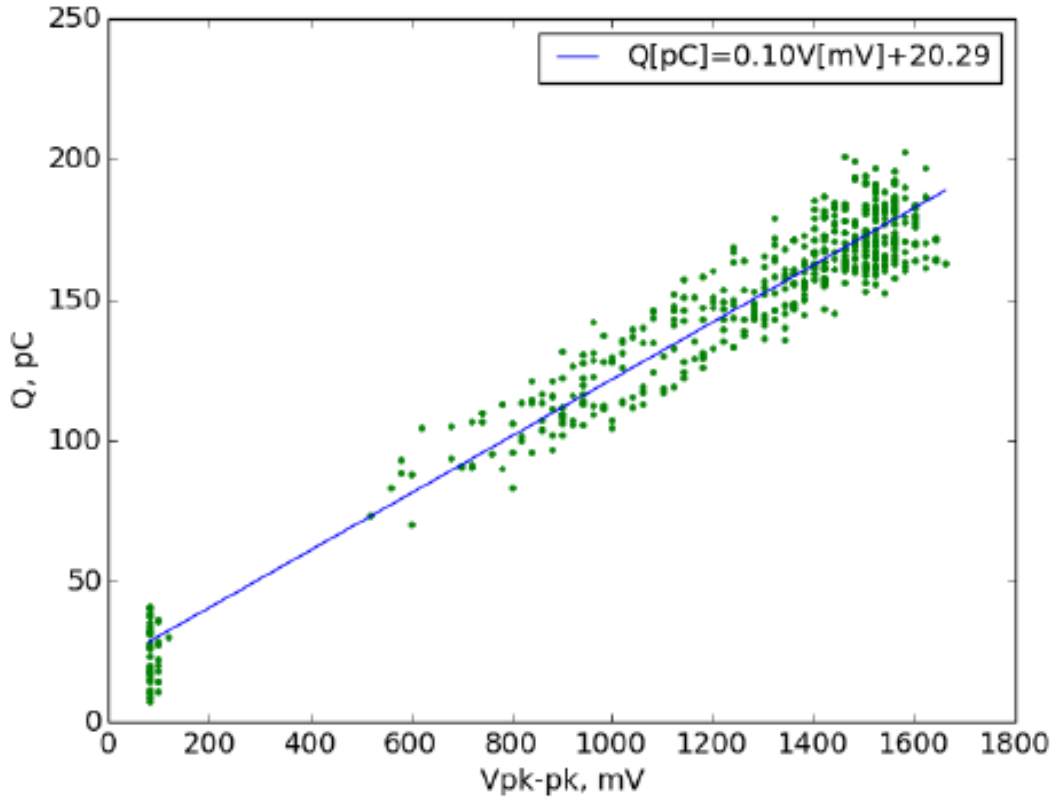


Coil

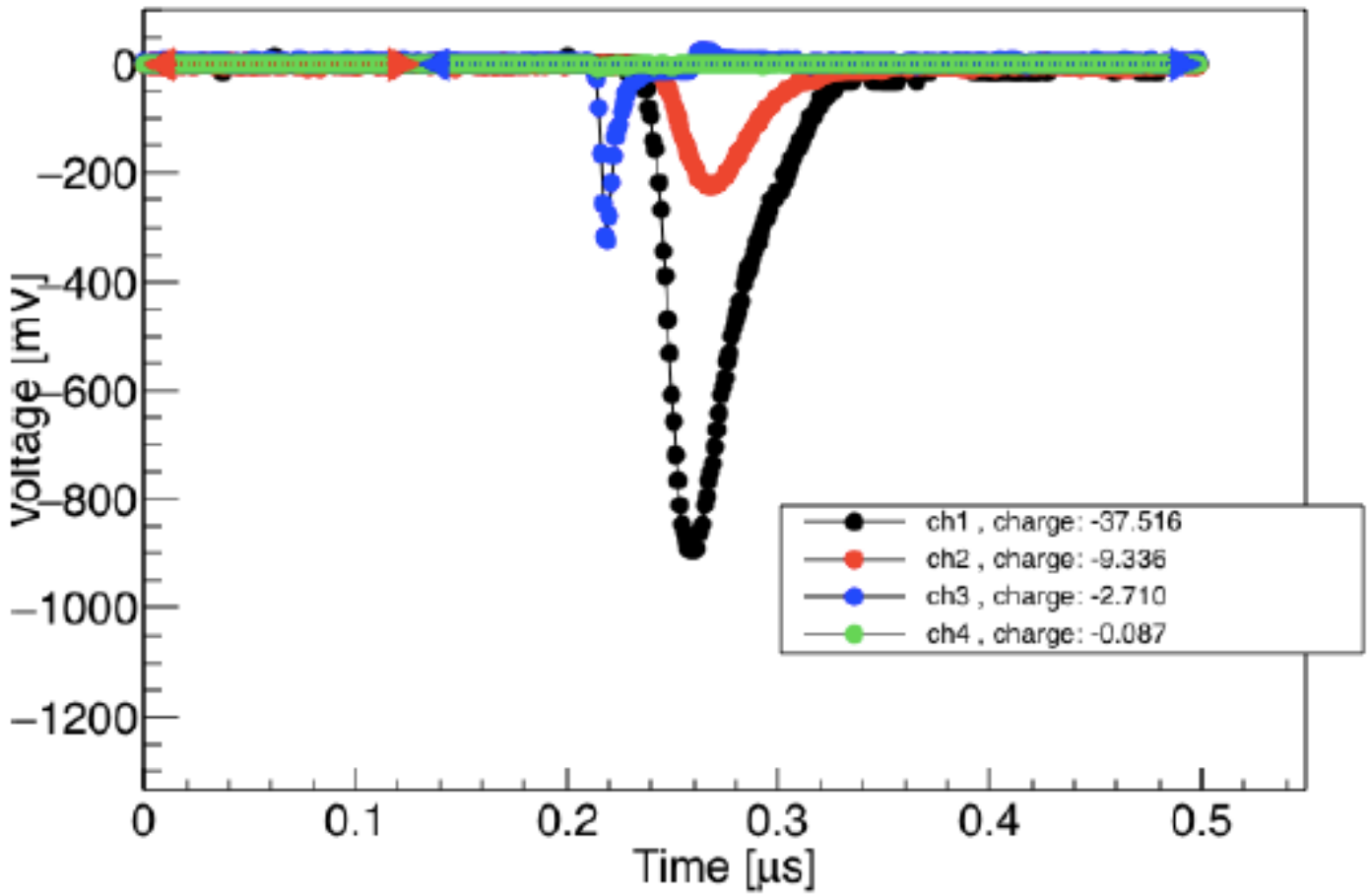


Horn

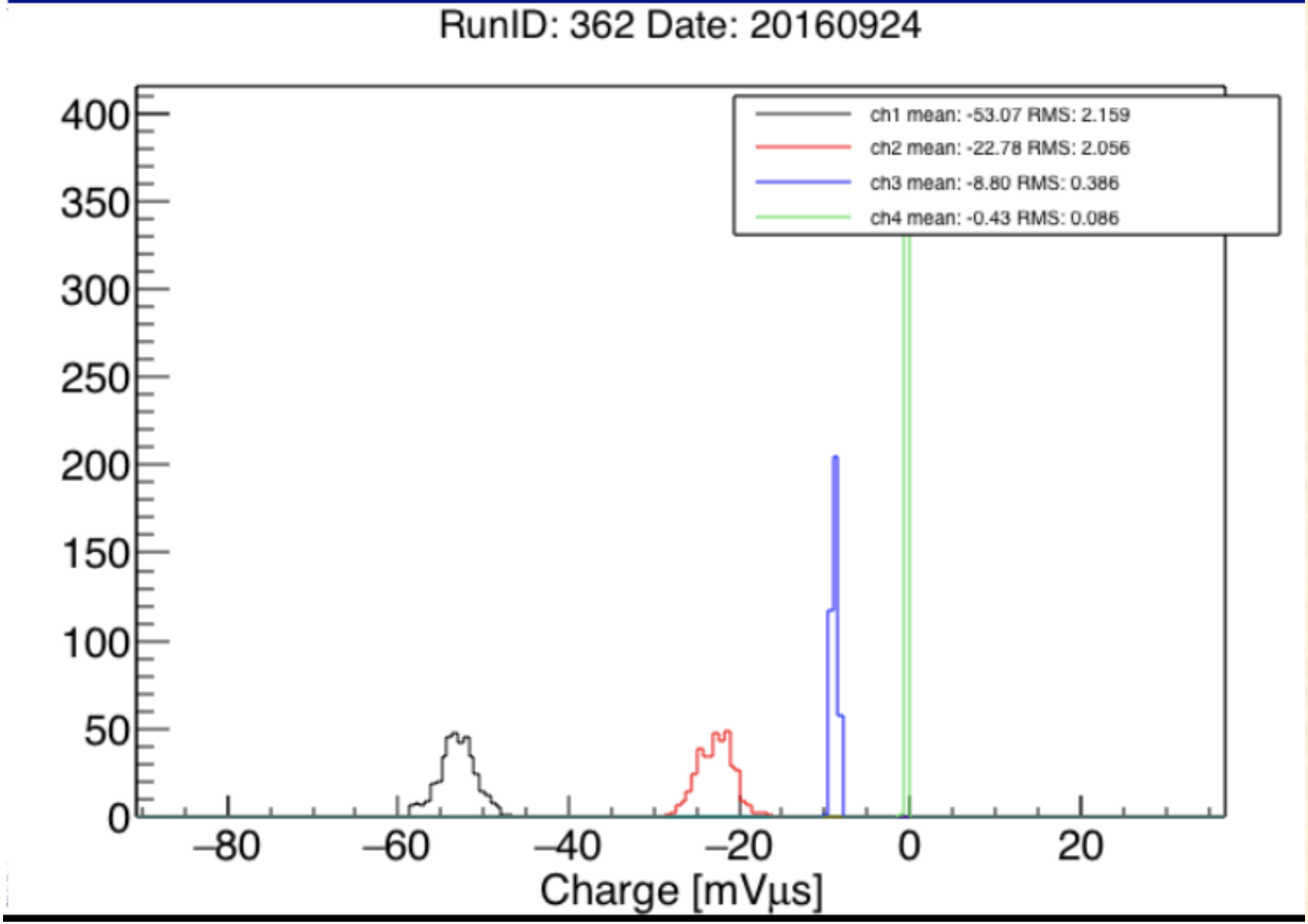
Run 867, ICT vs horn



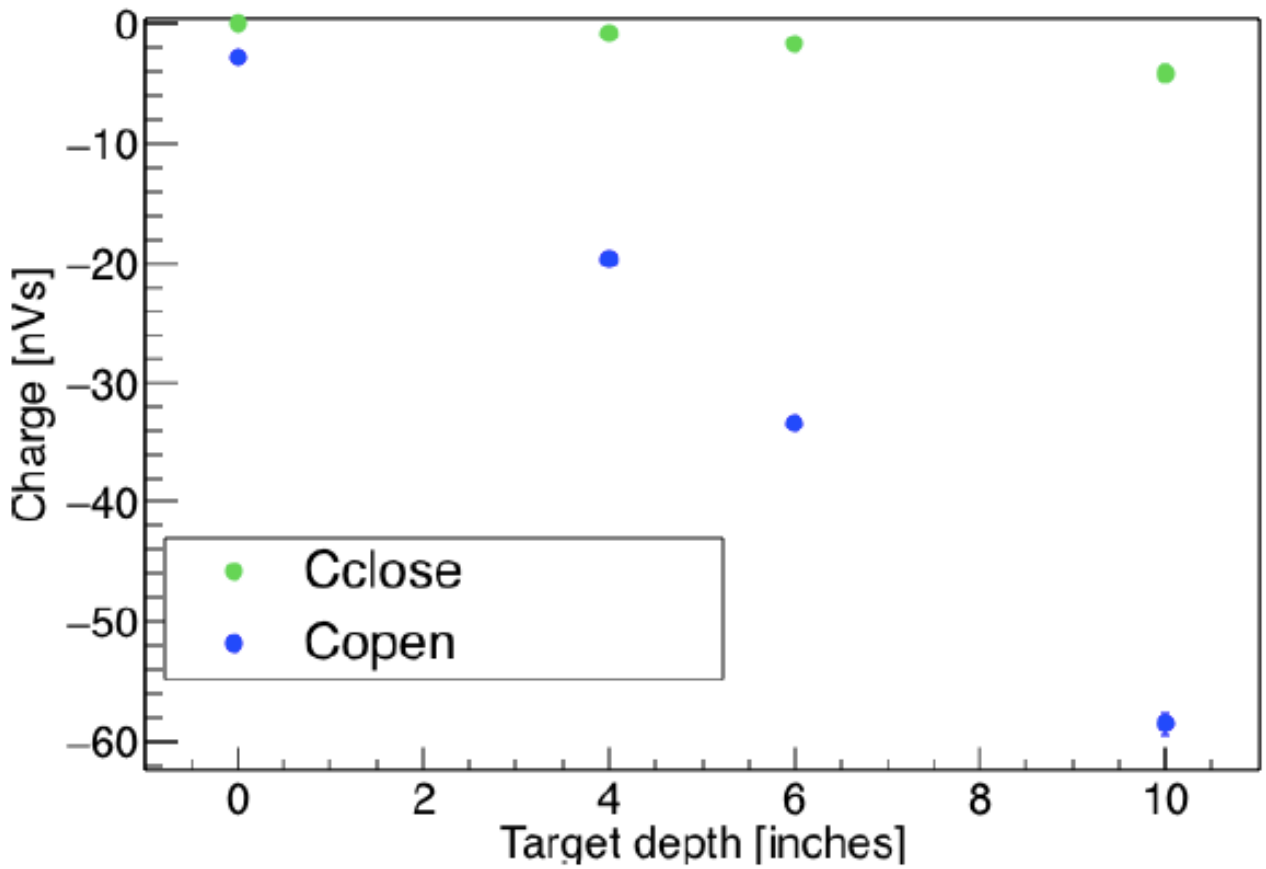
Run355 1rl


0
−200
−400
−600
−800
−1000
−1200
Voltage [mV]
0
0.1
0.2
0.3
0.4
0.5
Time [μs]
ch1 , charge: -37.516
ch2 , charge: -9.336
ch3 , charge: -2.710
ch4 , charge: -0.087

3rl signal

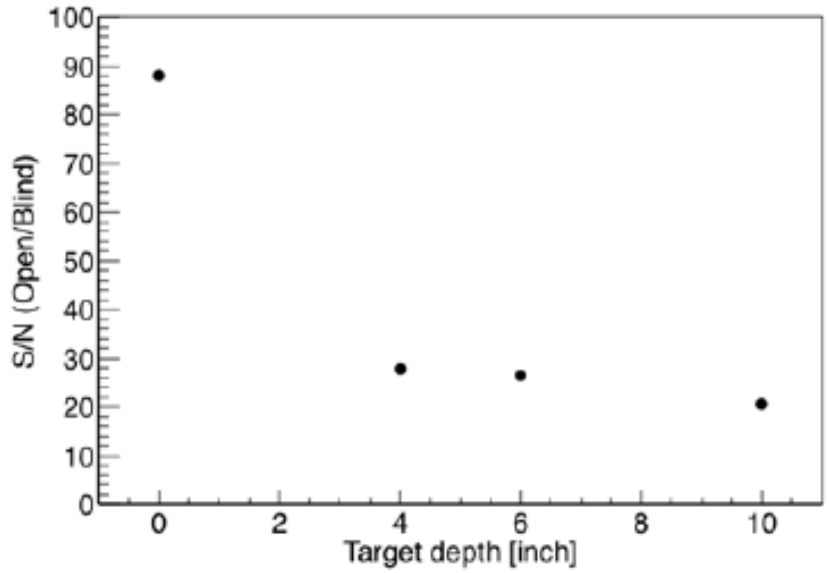

RunID: 362 Date: 20160924
ch1 mean: -53.07 RMS: 2.159
ch2 mean: -22.78 RMS: 2.056
ch3 mean: -8.80 RMS: 0.386
ch4 mean: -0.43 RMS: 0.086
400
350
300
250
200
150
100
50
0
−80
−60
−40
−20
0
20
Charge [mVμs]

Target depth vs Signal (CRAYS)

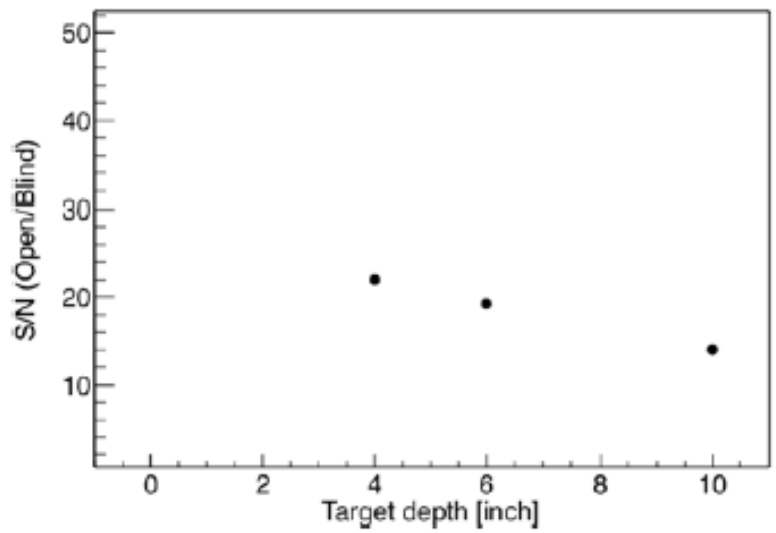


S/N

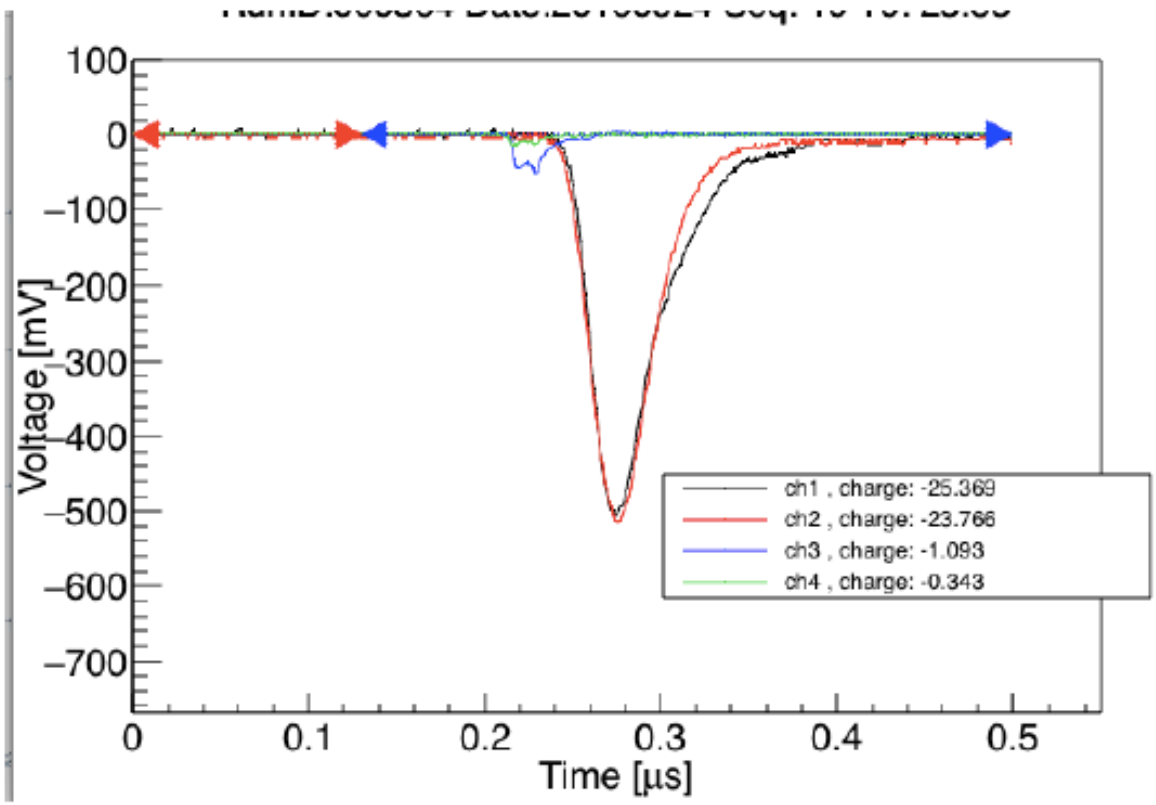
HIRES TUBE



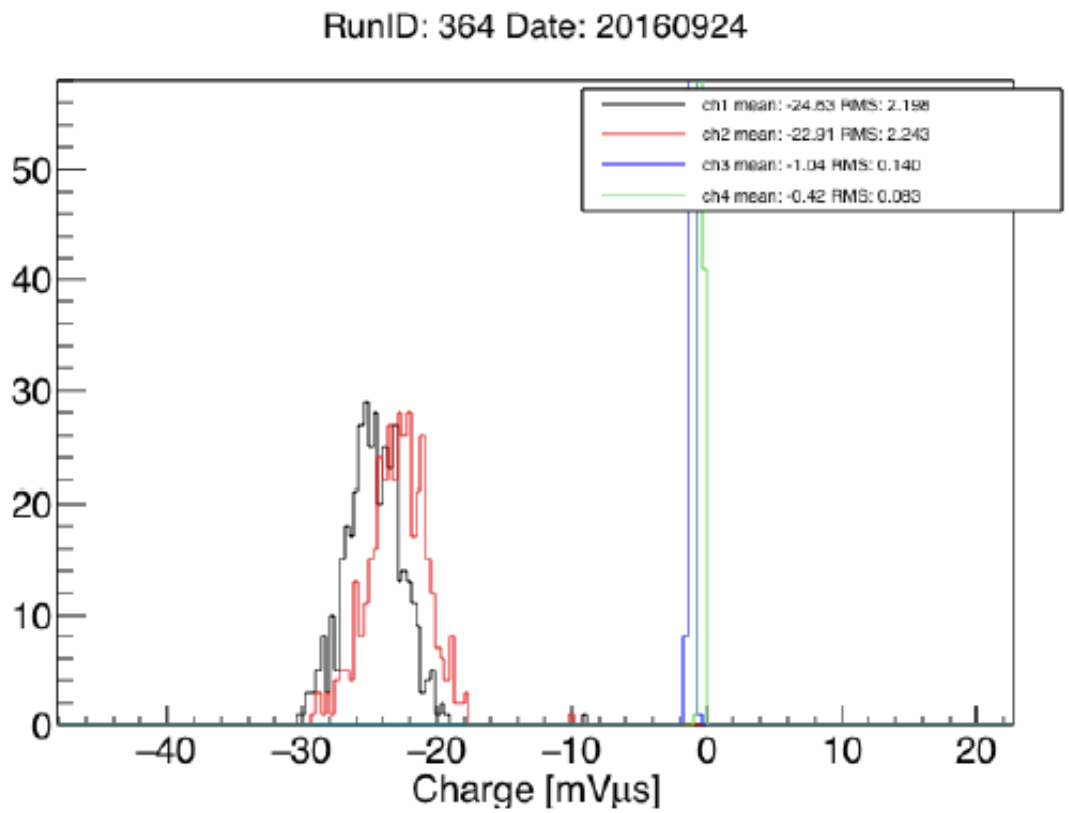
CRAYS TUBE



signal 3rl blind down



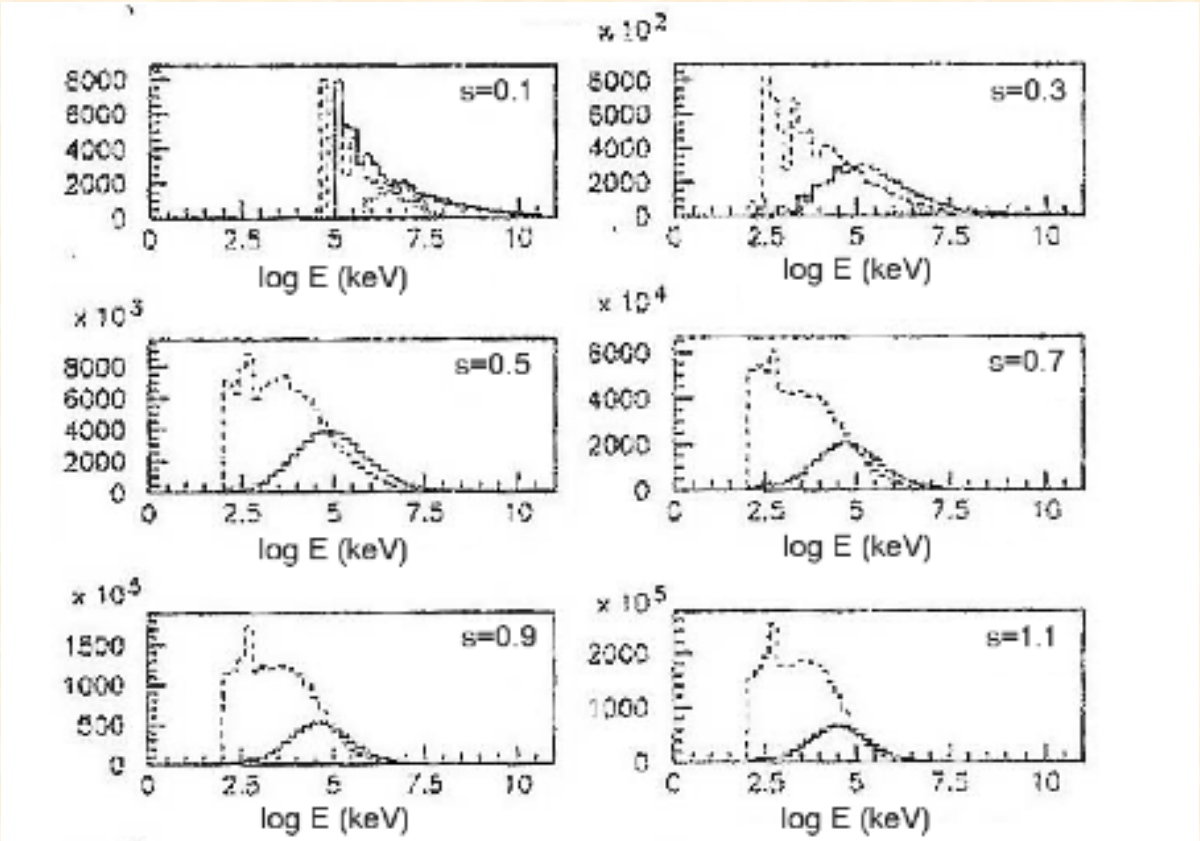
signal 3rl blind down



Simulating Energy Deposition

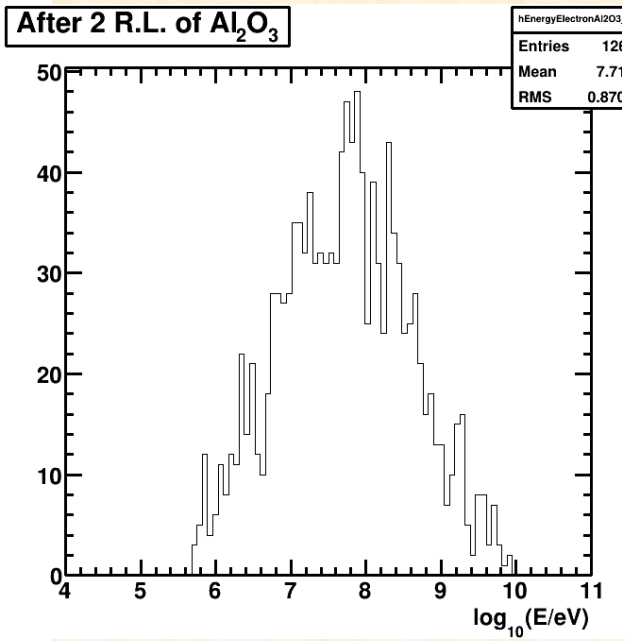
- Use Geant and Fluka
- Input detailed geometry of target, shielding and beam dump.
- Determine energy deposition as function of transverse distance from beam and longitudinal distance.

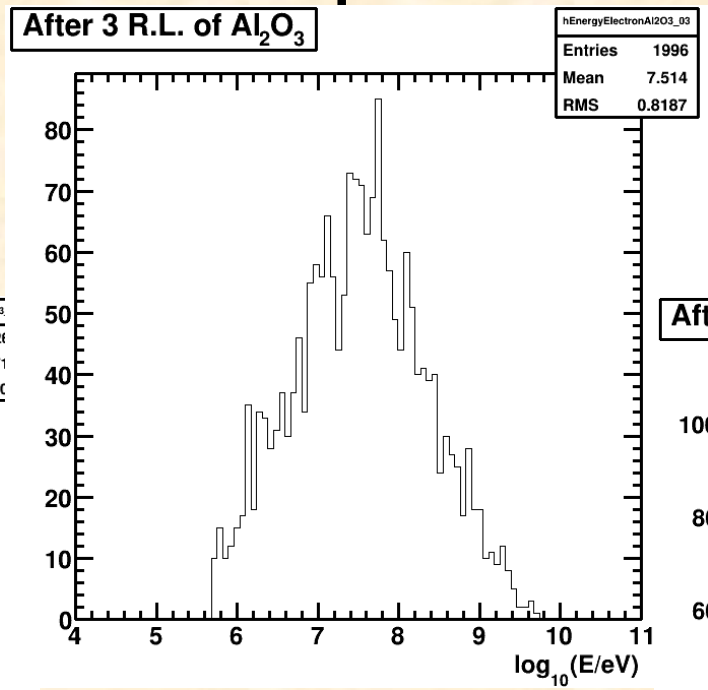
- Energy distributions of electrons and photons in CORSIKA simulated EAS – 10^{18} eV shower

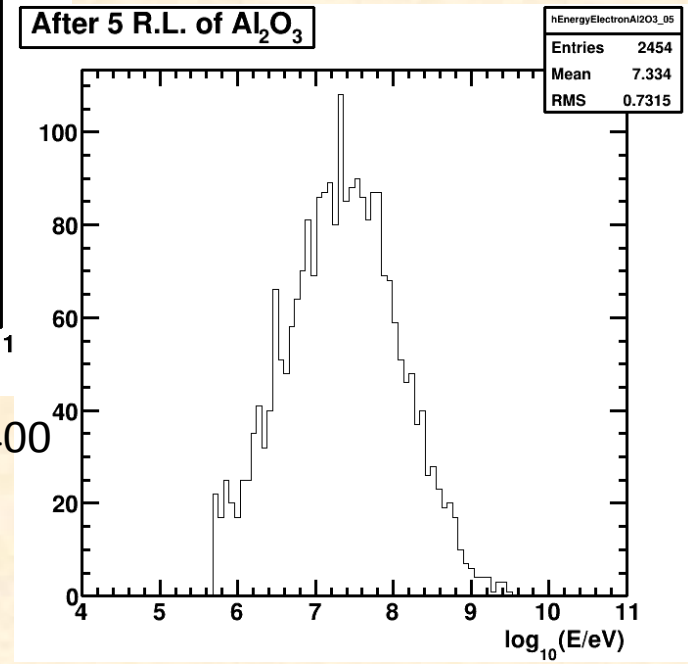


s=.9 – s=1.1, Eav: 40-31 MeV

Electron Energy Distributions – 10 GeV Alumina pre-shower



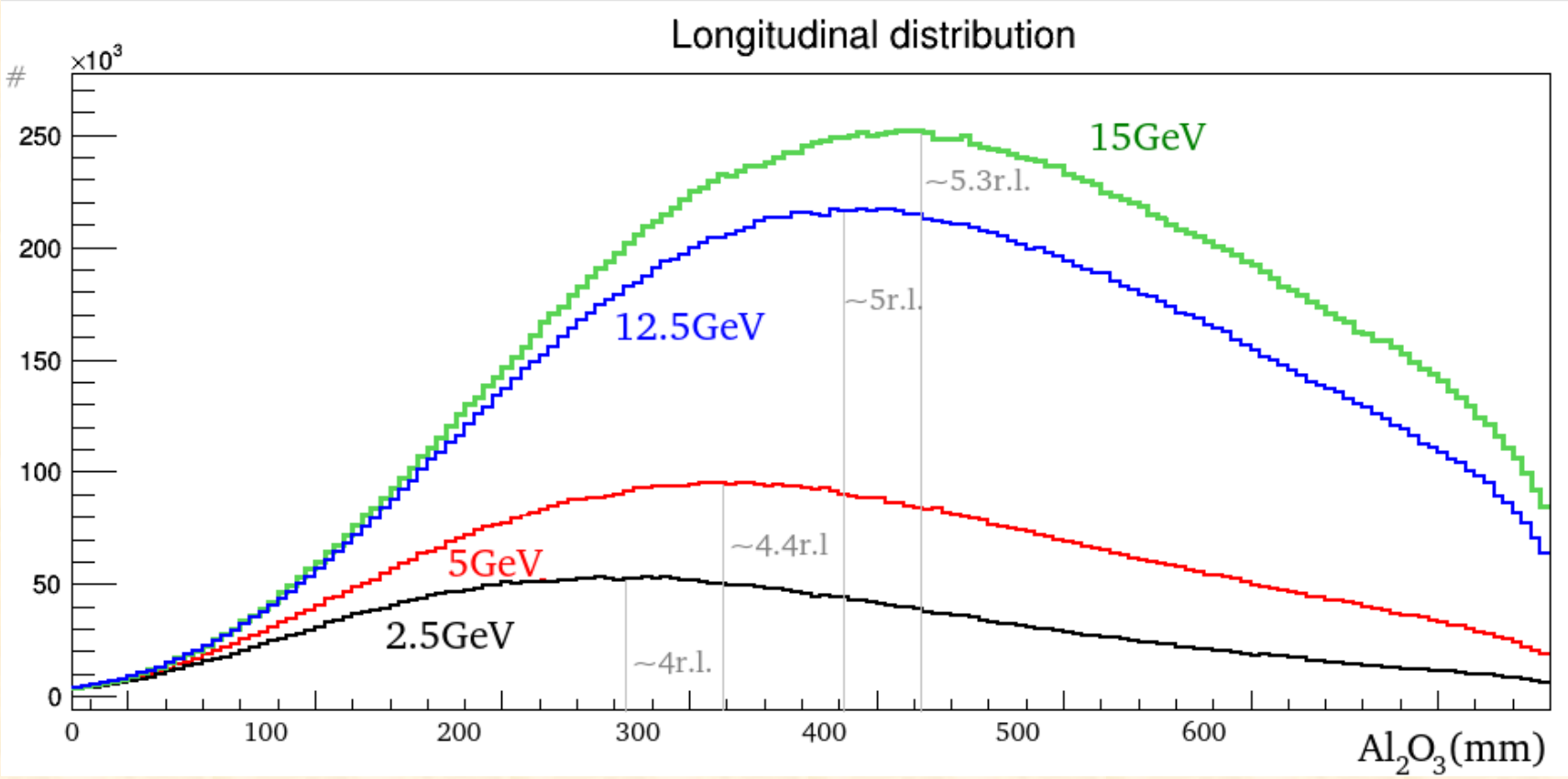




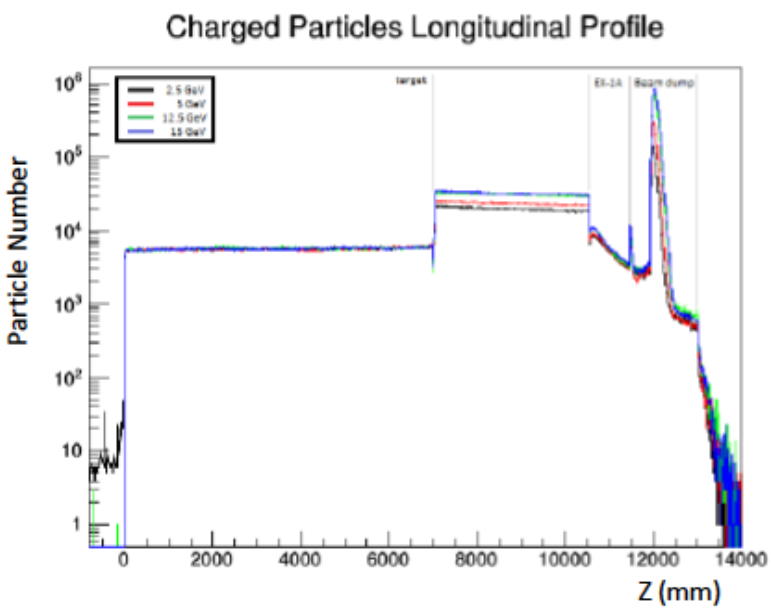
Eav=32.7MeV. FWHM:3-400

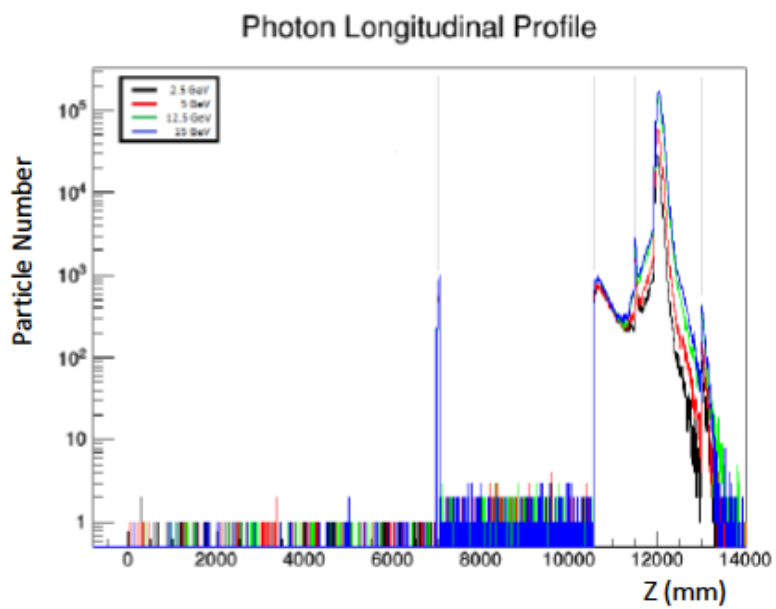
Eav = 51.5 Mev, FWHM:3-630MeV

Eav=21.6, FWHM:1-100MeV

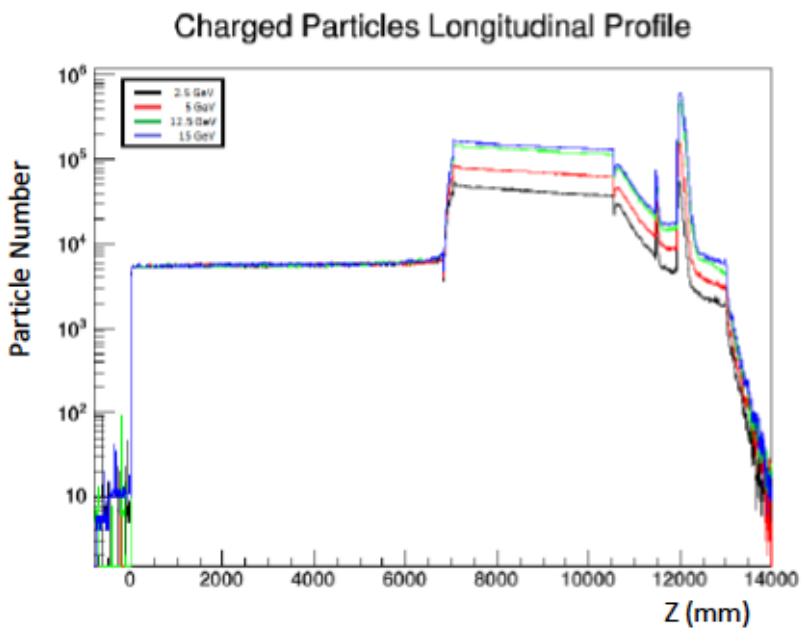

Longitudinal distribution
#
×10^3
250
200
150
100
50
0
0
100
200
300
400
500
600
Al2O3(mm)
15GeV
12.5GeV
5GeV
2.5GeV
~5.3r.l.
~5r.l.
~4.4r.l
~4r.l.

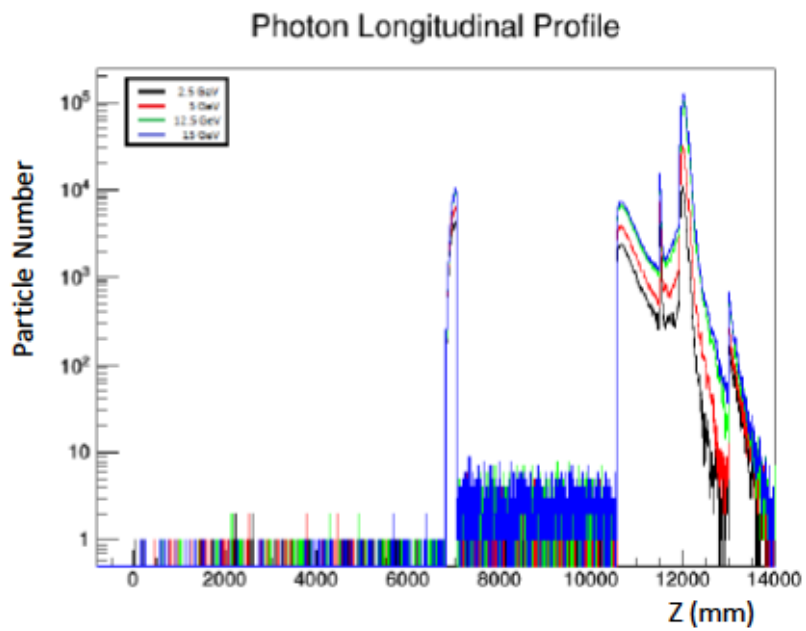
Longitudinal Profile (R.L.=1)



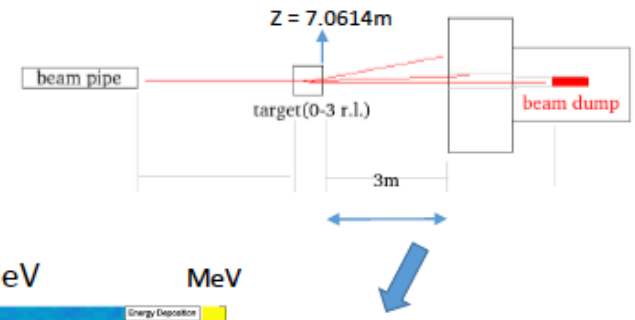


Longitudinal Profile (R.L.=3)

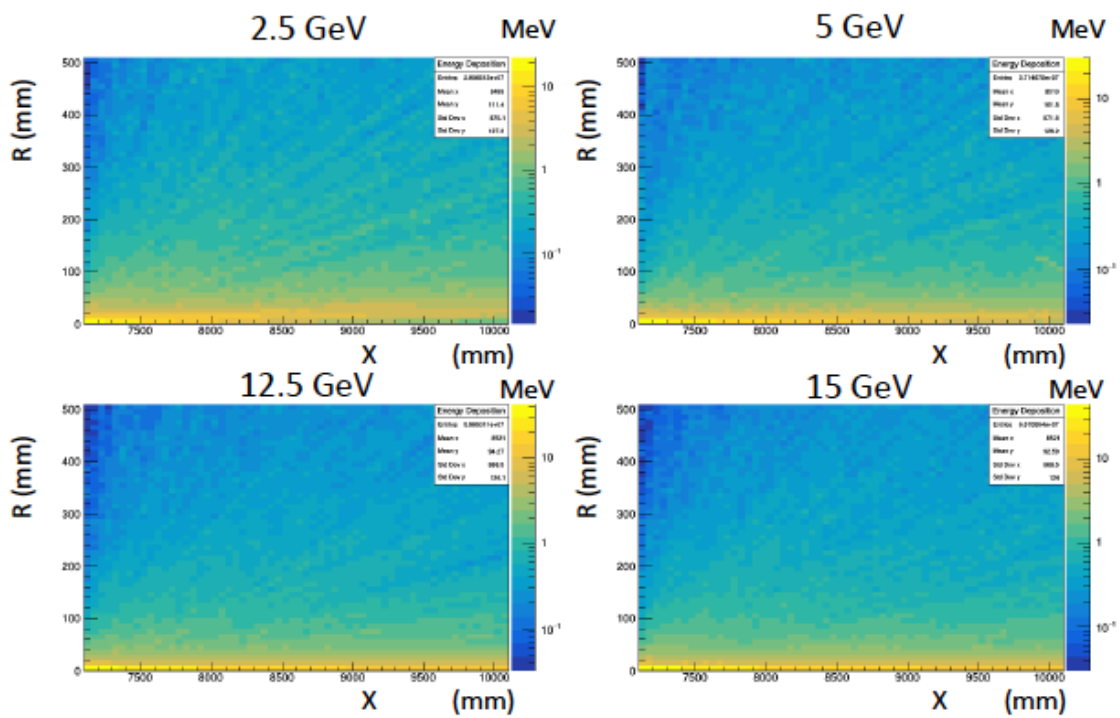




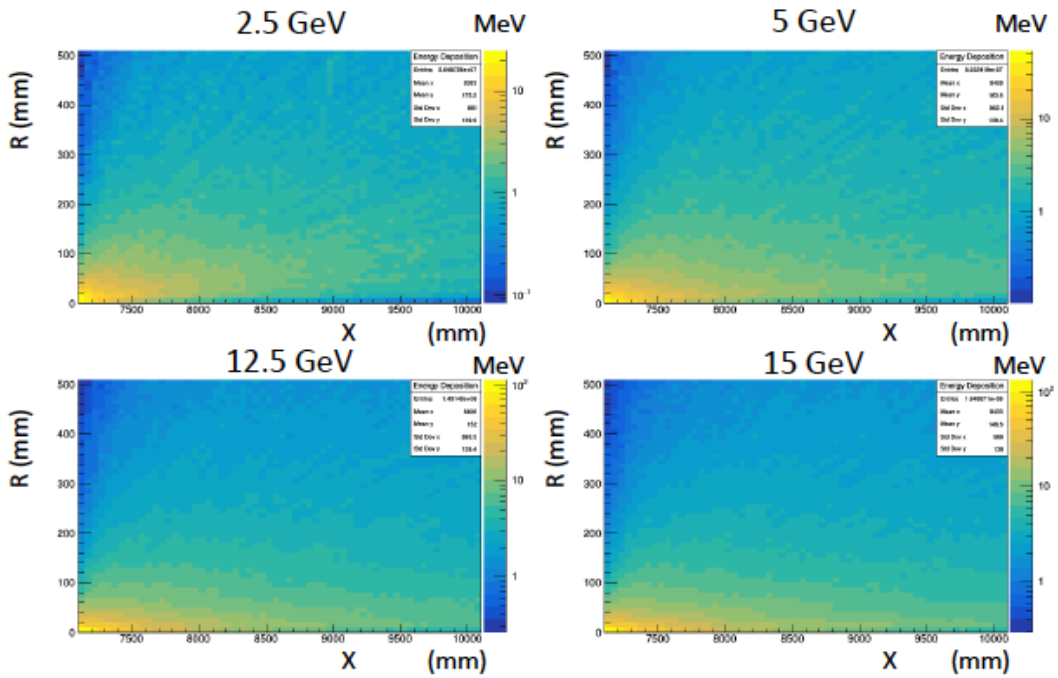
Energy deposition(R.L.=1)

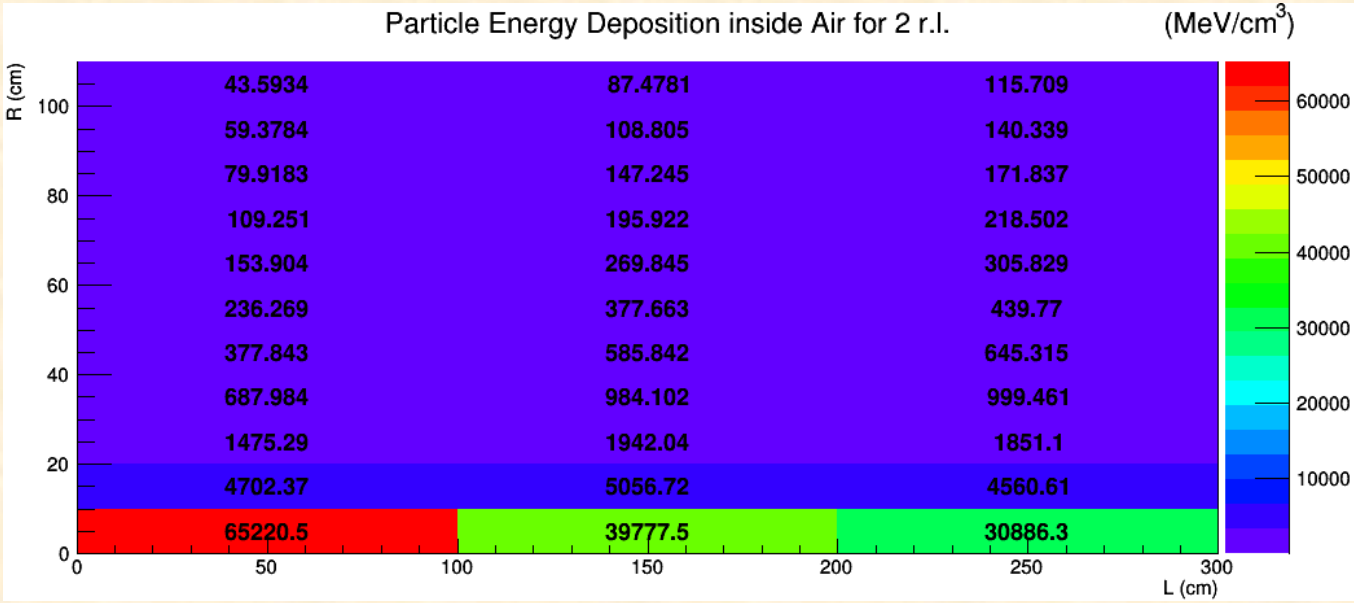


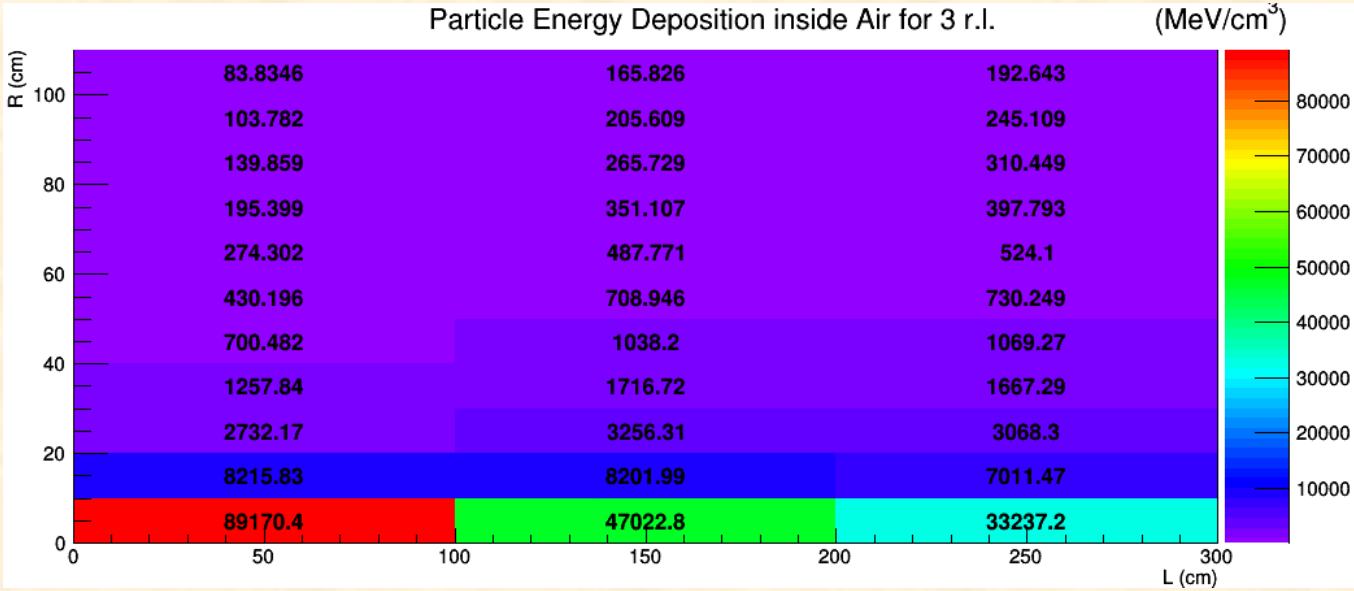
$$R = \sqrt{x^2 + y^2}$$



Energy deposition(R.L.=3)



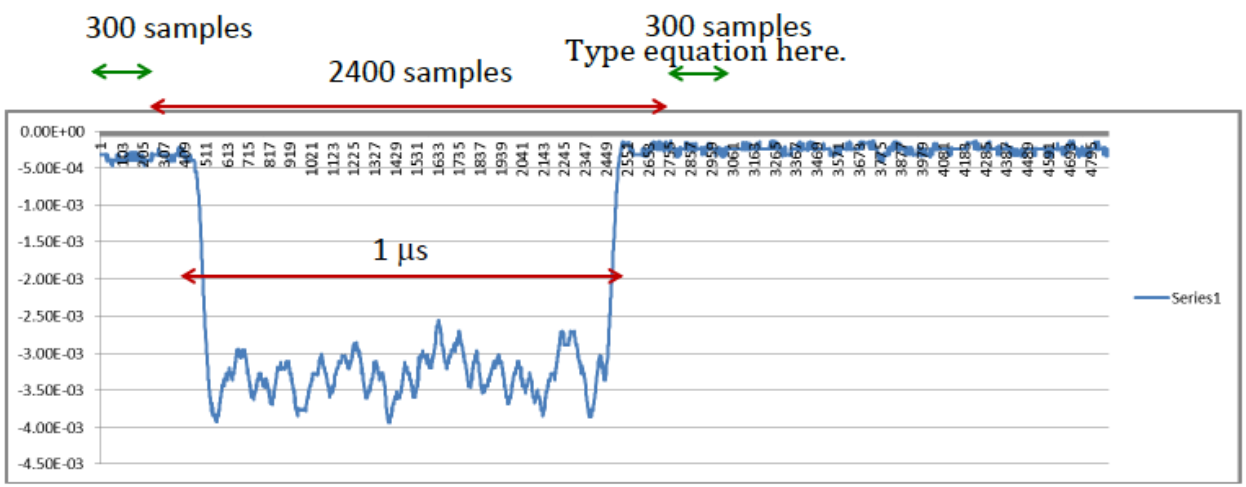

Particle Energy Deposition inside Air for 2 r.l.
(MeV/cm3)
R (cm)
L (cm)
43.5934
87.4781
115.709
59.3784
108.805
140.339
79.9183
147.245
171.837
109.251
195.922
218.502
153.904
269.845
305.829
236.269
377.663
439.77
377.843
585.842
645.315
687.984
984.102
999.461
1475.29
1942.04
1851.1
4702.37
5056.72
4560.61
65220.5
39777.5
30886.3


Particle Energy Deposition inside Air for 3 r.l.
(MeV/cm3)
R (cm)
L (cm)
83.8346
165.826
192.643
103.782
205.609
245.109
139.859
265.729
310.449
195.399
351.107
397.793
274.302
487.771
524.1
430.196
708.946
730.249
700.482
1038.2
1069.27
1257.84
1716.72
1667.29
2732.17
3256.31
3068.3
8215.83
8201.99
7011.47
89170.4
47022.8
33237.2

Calibration using UV LED –compare result with standard calibration for HiRES

Photo-statistics calibration

- Using UVLED, ampl=150, on S PMT in run 107: **terminated in 50ohm**
- Average samples 1-300, and 2701-3000 for baseline
- Integrate from sample 301-2700 for signal (record in nVs)
- Look at variance in signal area for photo-statstics



The Stan(dard) HiRes PMT Model

Npe = 1.55 x mean^2/variance
The standard QE @ 355 nm (UVLED) is 0.278
The standard collection efficiency is 0.9
The area of the PMTs is 791.7 mm^2
The UV filter transmission @355 nm is 0.87

Mean signal= μ, St. Dev. signal=σ, Tube Gain (nVs/pe) = g

Mean #pe = n, we have $\mu = gn$, and $\sigma = g\alpha\sqrt{n}$ (here $\alpha^2 = 1.55$)

$$\frac{\mu^2}{\sigma^2} = \frac{g^2 n^2}{g^2 \alpha^2 n} = \frac{n}{\alpha^2} \rightarrow n = \alpha^2 \frac{\mu^2}{\sigma^2} = 1.55 \cdot \left(\frac{2.9176}{0.0561}\right)^2 = 4.19 \times 10^3$$

And the gain is then

$$g = \frac{\mu}{n} = \frac{2.9176 \text{ nVs}}{4.19 \times 10^3 \text{ pe}} = 0.696 \text{ pVs/pe}$$

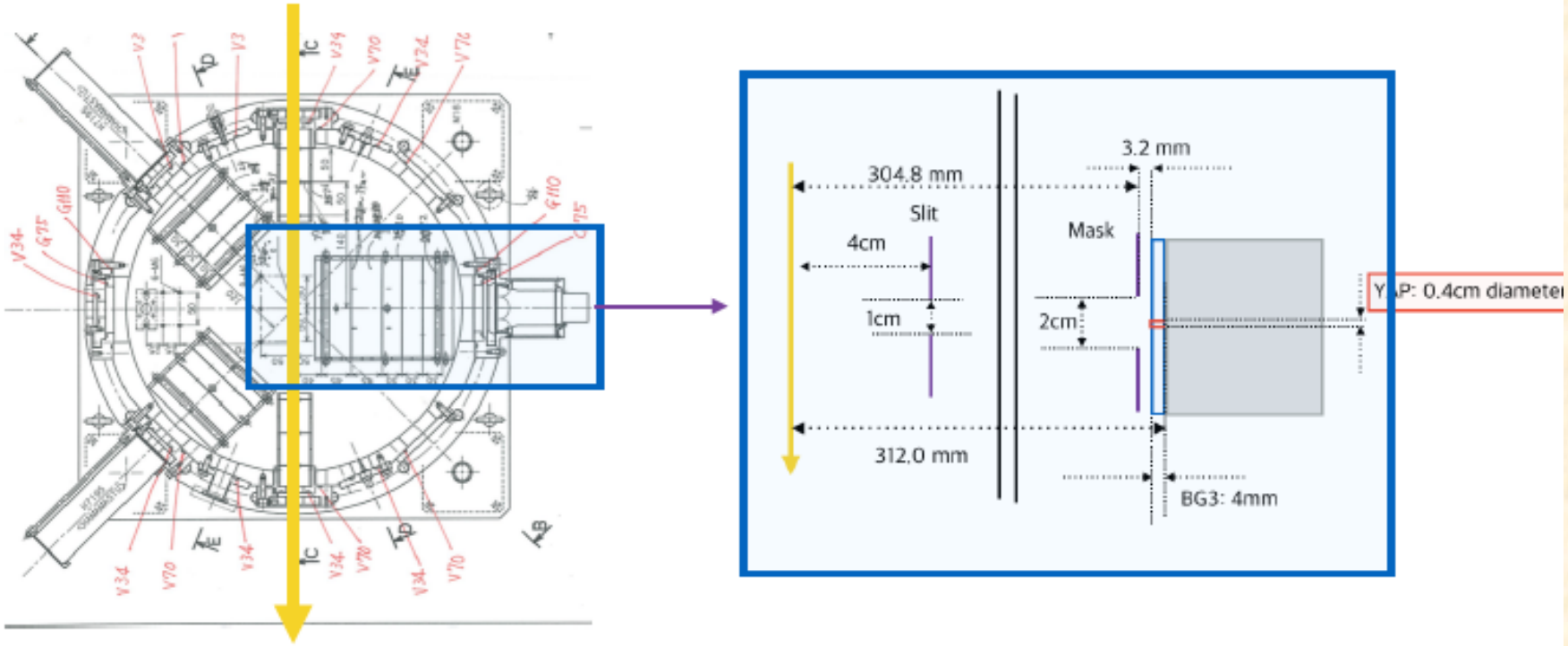
Or in terms of charge:

$$G = \frac{g}{R} = \frac{0.696 \text{ pVs/pe}}{50\ \Omega} = 13.9 \text{ fC/pe}$$

CRAYS tube calibration

- Use Nitrogen laser in pressurized vessel with accurate geometry.
- Measure laser intensity and calculate 90 deg Rayleigh scattering.
- Systematics depend on laser probe calibration and Rayleigh scattering calculation
- Should achieve < 5% absolute calibration.

Geometry (1)



Distance between Chamber center to surface of photocathode is 312.0 mm
Uncertainty of distance is 0.5mm: (BK-MF):0.2mm, measurement accuracy 0.3mm

Uncertainties

Item	2008 [%]	This [%]	Comments
1.Cross section	2.8	2.8??	Polarization Scattering and so on This: We will estimate using simulation with updated condition
2.Density	1.3	1??	Chamber pressure and temperature This: Device calibration is unknown, We will buy or calibrate
3.Geometry	3.0	1	Distance between beam and PMT and Slit Size
4.Signal Integration	2.0	0?	Difference between FD SDF and Camac (This: using only Scope)
5.Noise subtraction	1.9	0.2	Rejection of Noise This: ~0.1% of noise
6.Laser power	5.0	3.0	New Probe accuracy is about 3.0%
Total	7.8	4.3?	Quadrature summation of above items

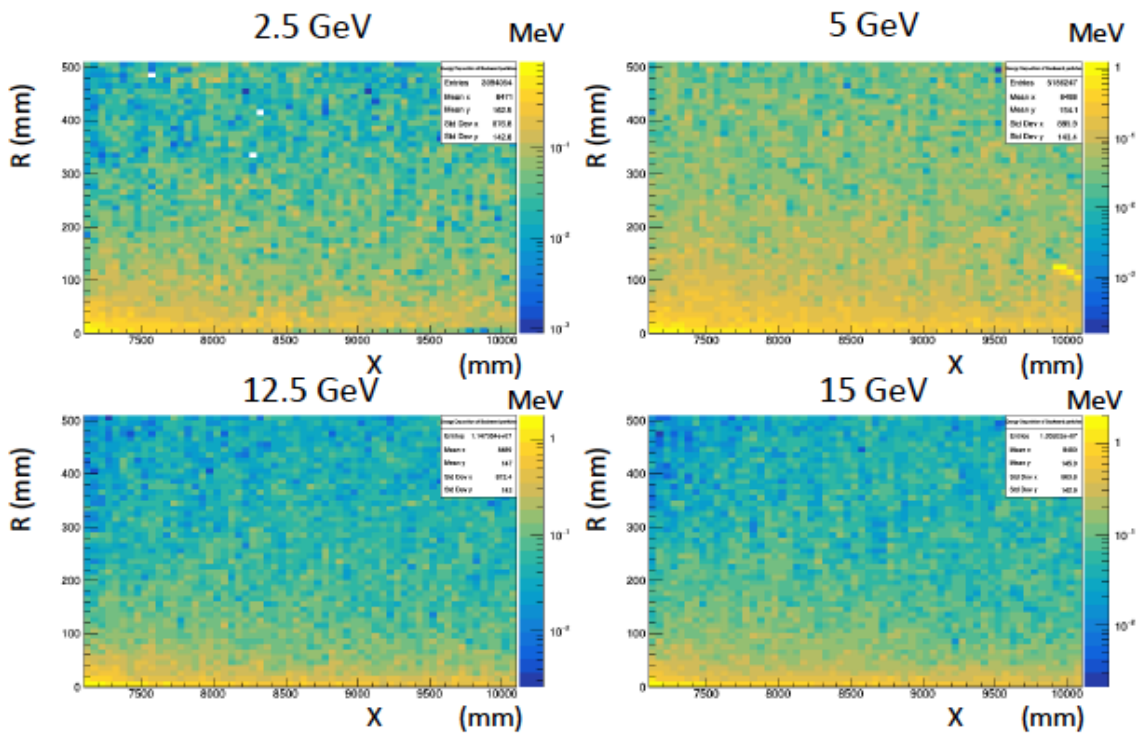
Systematic Errors on S_F/I_b

- Beam intensity pulse/pulse 2-3% (based on ANITA experience with same instrumentation)
- PMT calibration – CRAYS and new energy probe: 5%
- Ray tracing, geometry 1%
- Background subtraction 1-2%
- Want to keep systematics to 10% or less

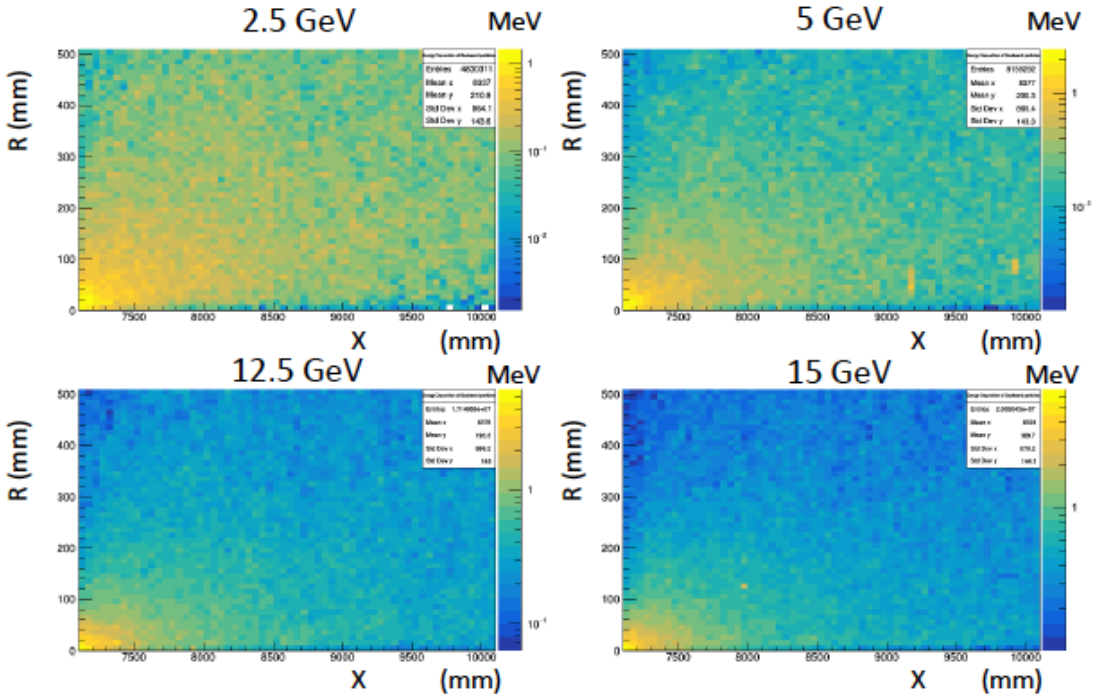
Conclusion

- sFLASH had a successful run at SLAC, accumulated high statistics data under varying conditions with good beam stability.
- Data analysis and simulation proceeding
- More runs possible if warranted.
- Stay tuned for results!

Energy deposition of Particle Going Backward (R.L.=1)



Energy deposition of Particle Going Backward (R.L.=3)



MacFLY setup

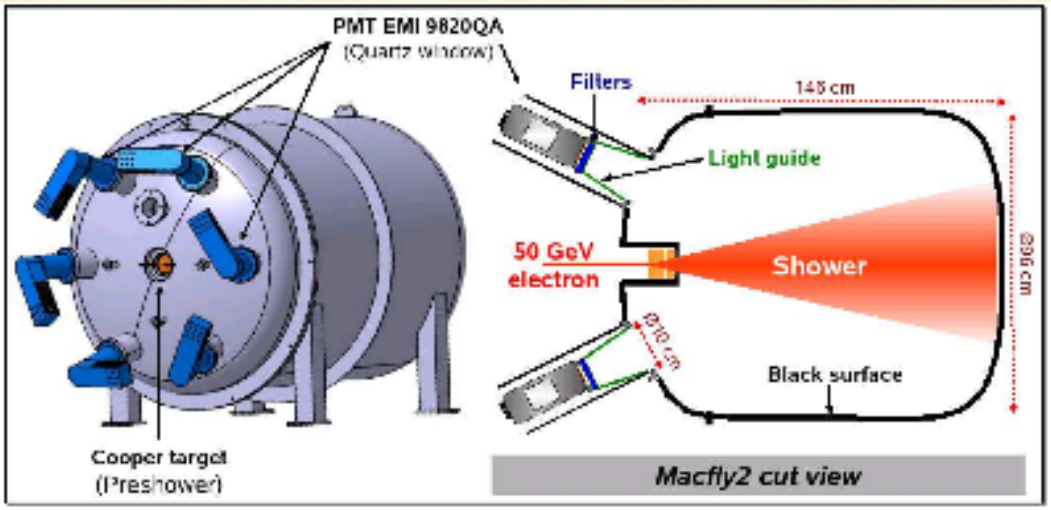
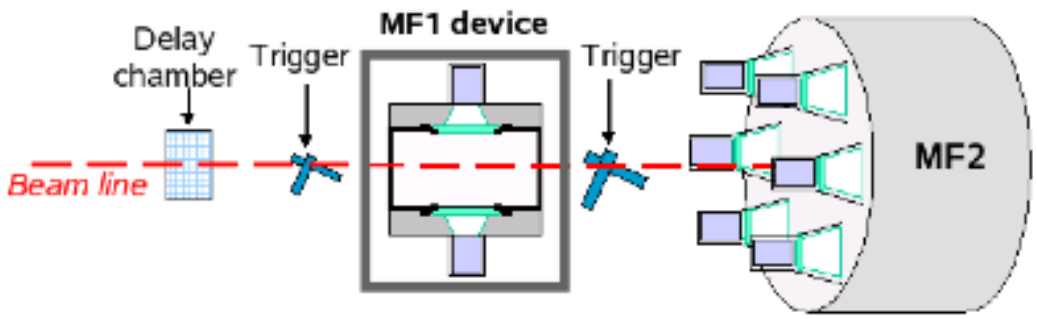


Fig. 1. The MF2 chamber: schematic view (left) and cut view (right).



MacFLY results

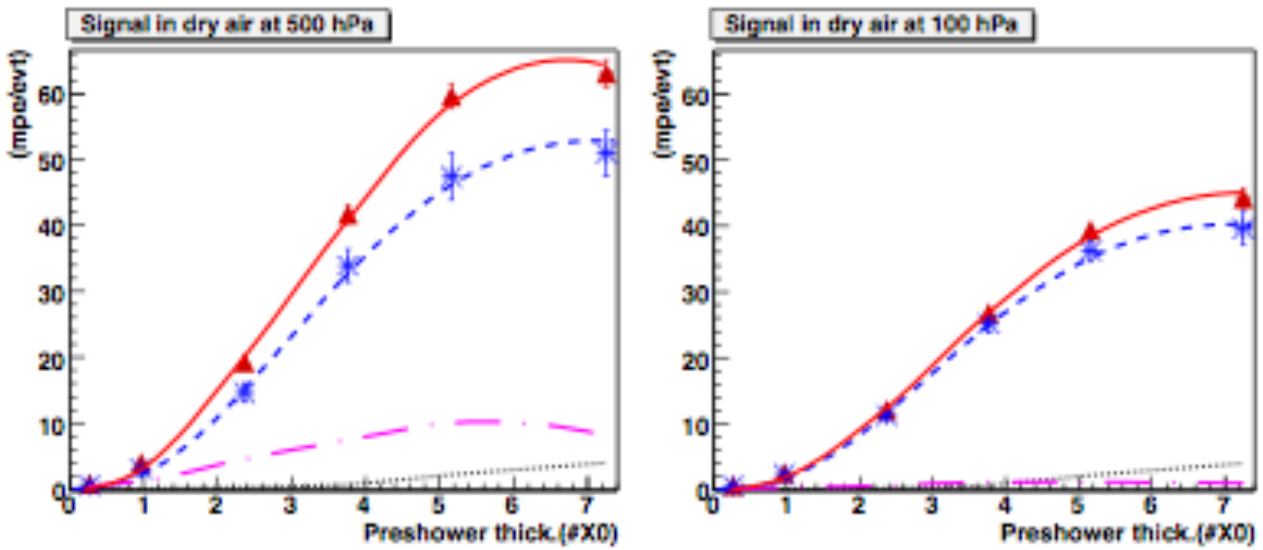
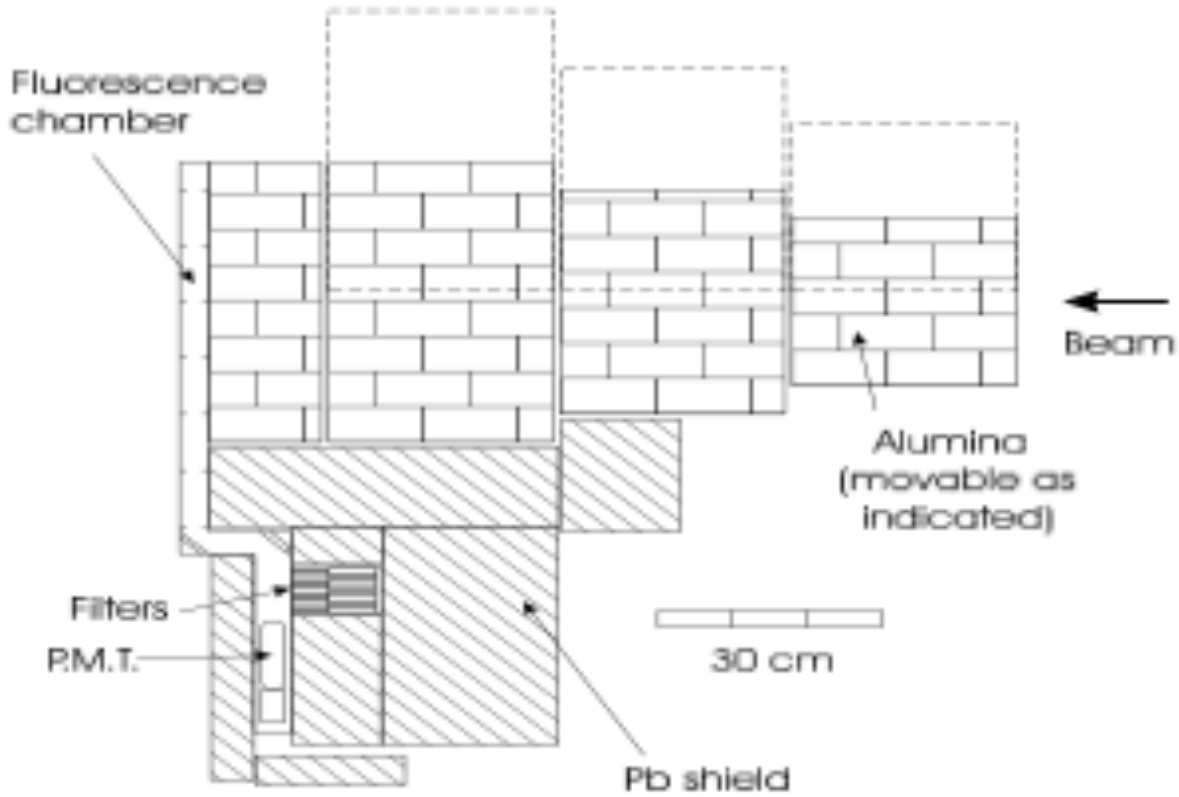


Fig. 4. Measured light in dry air at 500 hPa (left) and 100 hPa (right) in milli-photoelectron per event (mpe/evt) as a function of the pre-shower thickness (in X_0). Triangles represent the total signal (DL); dotted line is for the Bgd estimation from vacuum measurements; dot-dashed curve is the CDL simulation; stars are the FDL data (after substraction of Bgd and CDL); dashed line is the FLY model for showers. The solid line is the sum of the all contributions.

MacFLY systematic errors

Errors sources	Absolute	relative
MF1 calibration	13.7%	-
MF1/MF2	18%	-
Geometrical distribution	~ 3%	~ 3%
DL reconstruction	~ 3%	~ 3%
CDL Simulation	~ 1.5%	~ 1.5%
Bgd Measurement	~ 1.5%	~ 1.5%
TOTAL	**23.1%**	**~ 4.7%**

Original Thick Target layout



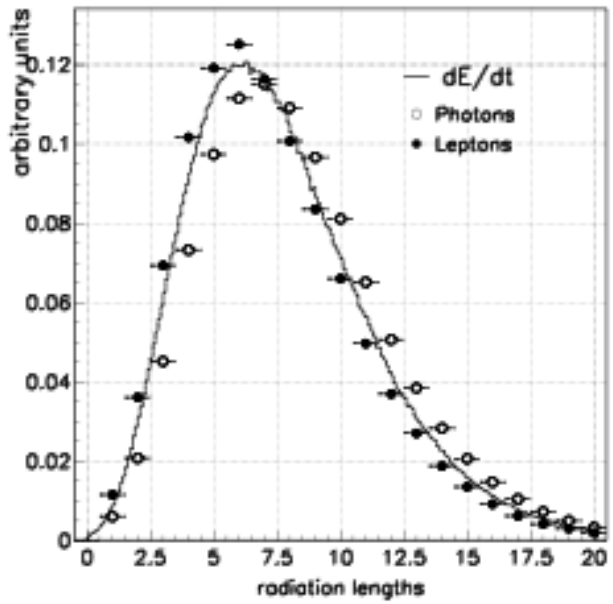
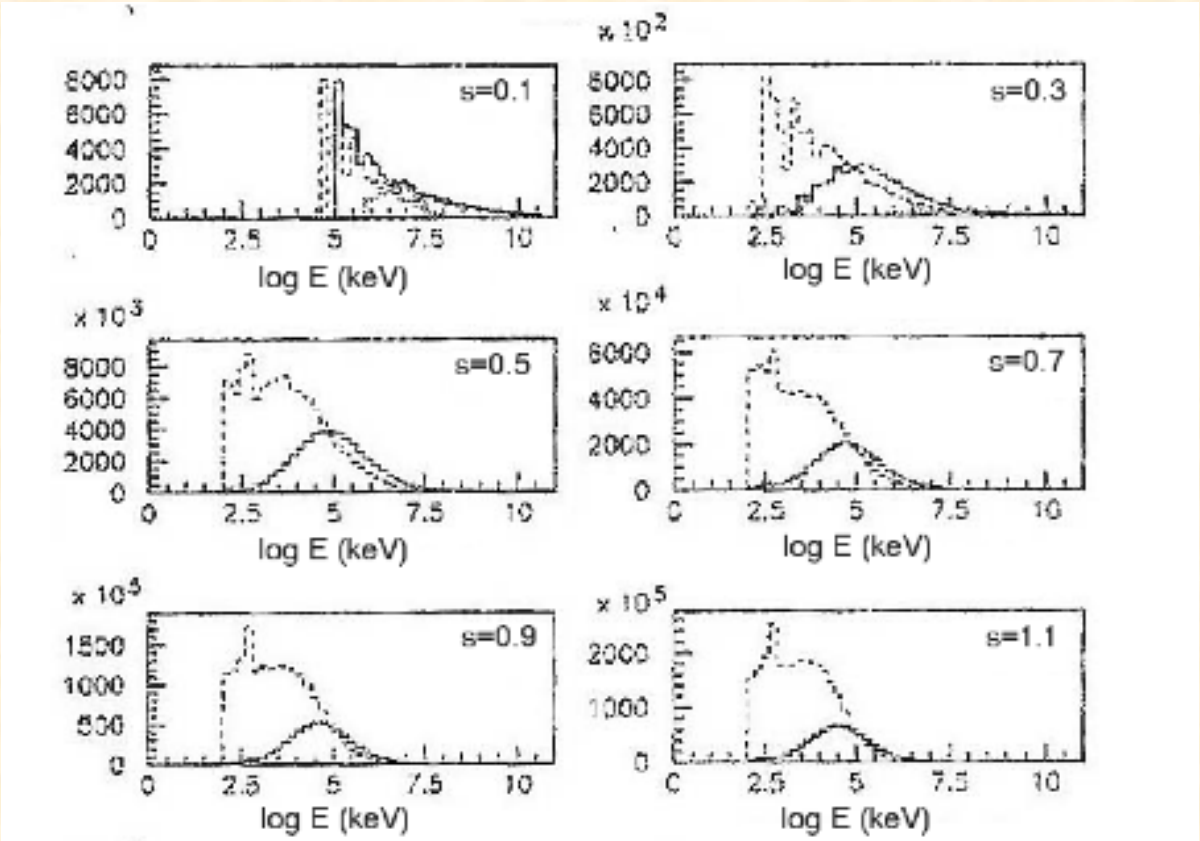


Figure B:1: Results of a GEANT shower simulation of 30 GeV electrons incident on an alumina (Al_2O_3) radiator. The histogram shows the total particle energy loss per radiation length dE/dt. Closed circles indicate the number of electrons crossing planes at one radiation length intervals, open circles represent photons crossing the same planes. Curves are normalized to have the same area, with an arbitrary vertical scale. An energy cutoff of 1 MeV applies to all particles contributing to these plots.

- Energy distributions of electrons and photons in CORSIKA simulated EAS



Alumina Al_2O_3

- Density 3.7 gm/cm^3
- Rad length = 7.5 cm – 24% different from air in gm/cm^2
- Critical Energy in EAS: E_c~ 800 MeV/(Z+1.2)
- E_c Air – Z_{air} ~7; E_c ~ 100 MeV or 10^8 eV
- Corsika simulation shows peak electron energy close to this number : Note FWHM goes from 10^7 to 10^9 eV: 10 MeV to 1 GeV electron energies.
- E_c Alumina – Z Alumina – (2x13+3x8)/5 =10
- Ec = 70 MeV. We should get from 7 to 700 MeV electrons at shower max.