Structure in the UHE-cosmic ray spectrum, laboratory calibration and a BL-Lac puzzle

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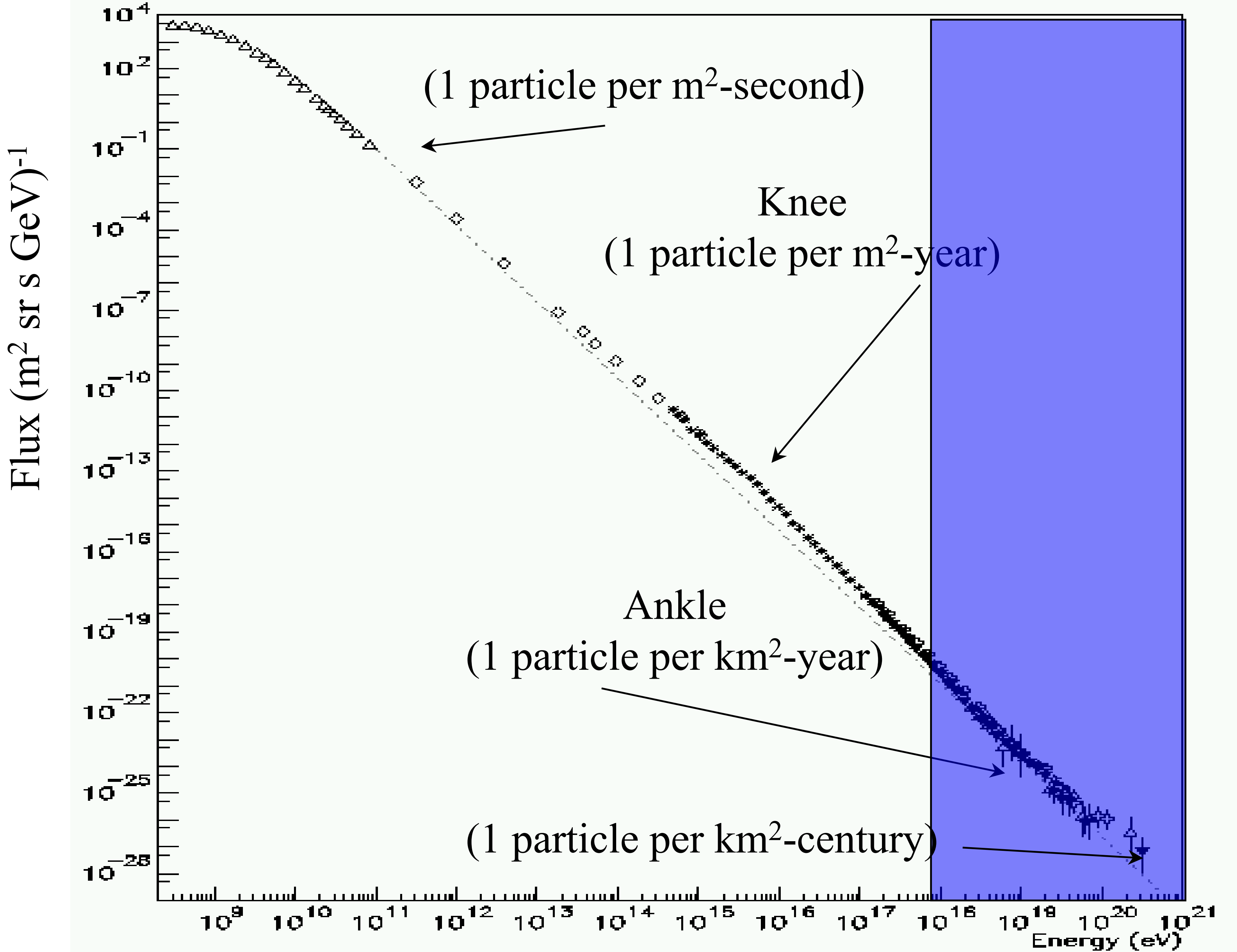
Outline

- GZK, HiRes and AGASA
- The ankle and the second knee
- Fluorescence efficiency and the energy scale
- FLASH thin target
- FLASH thick target
- UHE cosmic ray anisotropy – HiRes and AGASA
- BL-Lac correlations
- Status of Telescope Array (TA) experiment



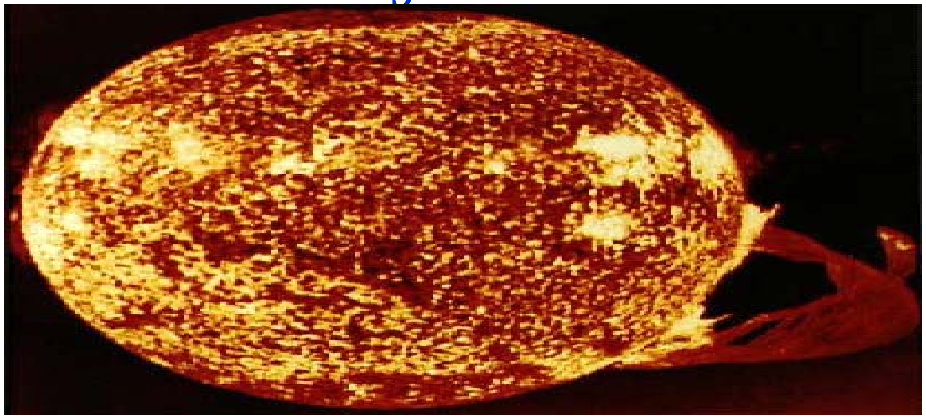
(1 particle per m²-second)
Knee
(1 particle per m²-year)
Ankle
(1 particle per km²-year)
(1 particle per km²-century)
Flux (m² sr s GeV)⁻¹
Energy (eV)

Physics of the UHE Cosmic Ray Spectrum

- Below first knee – SN shock acceleration – HESS results may be first experimental confirmation
- How galactic C.R. are accelerated beyond ~10^15 eV remains unclear.
- Spectrum deviates from simple power law at second knee and ankle.
- Extragalactic flux may appear above 10^18eV
- GZK cutoff should occur near 6 x 10^19 eV if sources are distant enough.

Sources of Cosmic Rays

➔The Sun

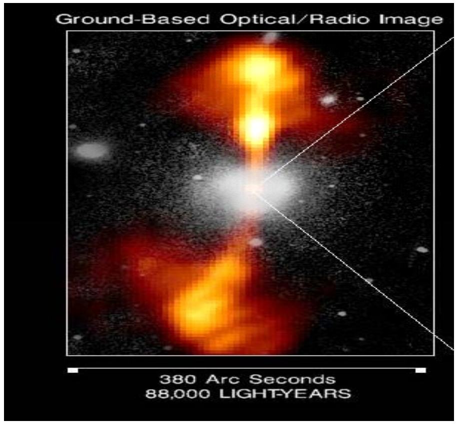


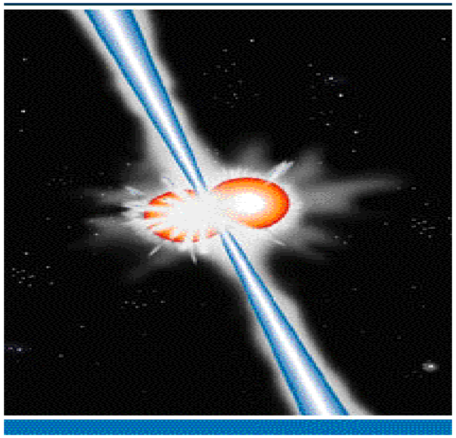
- ➔**Solar Wind**
- ➔**Low Energy < 10^9 eV**

➔Supernovae

- ➔**Capable of accelerating particles to 10^{15} eV**

➔AGNs / GRBs …

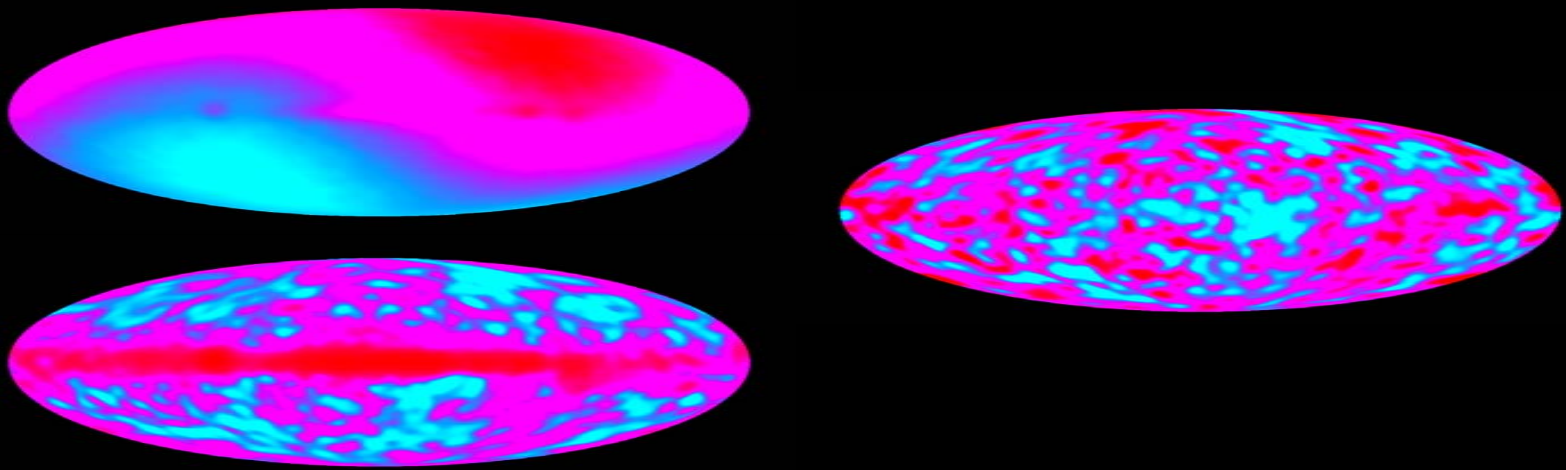




- ➔**Possible sources for UHECRs**

Propagation through Universe

COBE map of microwave background

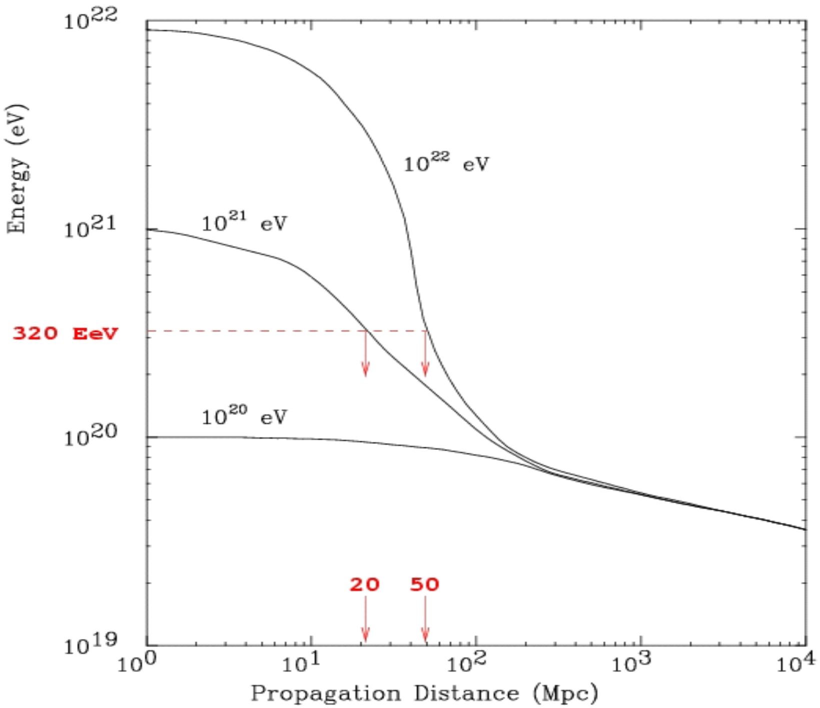


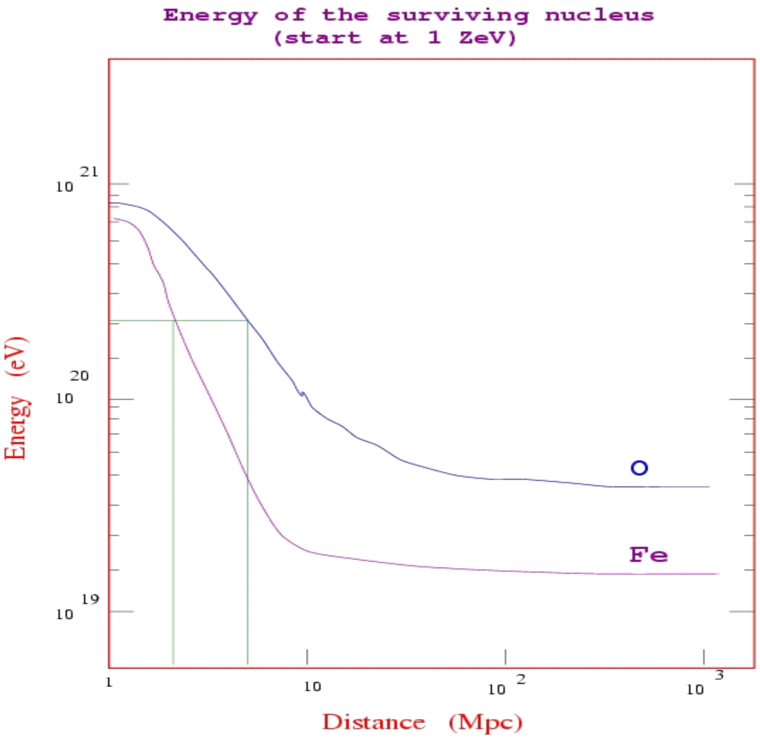
For protons with energy exceeding E_{GZK}=5 x 10^{19} eV,
s> $m_{\pi}c^2$ for collisions between the proton and cosmic microwave background photons and pion photoproduction becomes possible...

→ **GZK Cutoff**

The Greisen-Zatsepin-Kuzmin cutoff results in the degradation of the energy of protons after a distance of 50 Mpc.

The Problem of the GZK cutoff





⇨Charged particles with E > 5 x 10^{19} eV will travel at most 100 Mpc before their energy drops below the cutoff…

⇨None of the observed UHECRs above the GZK cutoff points back to a likely astrophysical source inside the GZK volume….

Some Recent History

- Fly's Eye (air fluorescence)_ experiment in Utah (1982-1992) observes ankle structure and a single post GZK event ~3 x 10^20 eV.
- AGASA (ground array) experiment in Japan observes ~ 8 events beyond 10^20 eV. Claim GZK cutoff does not exist and small scale clustering exists
- HiRes (air fluorescence) experiment (1996 to present) – search for GZK cutoff and clustering.

Future History

- Pierre Auger experiment (Hybrid surface and fluorescence) being built in Argentina.
- Telescope Array (Hybrid surface and fluorescence) experiment (Japan-US) being built in Utah.
- Possible Northern Auger proposal.
- EUSO – space based ESA proposal to observe cosmic rays from space.

HiRes Collaboration

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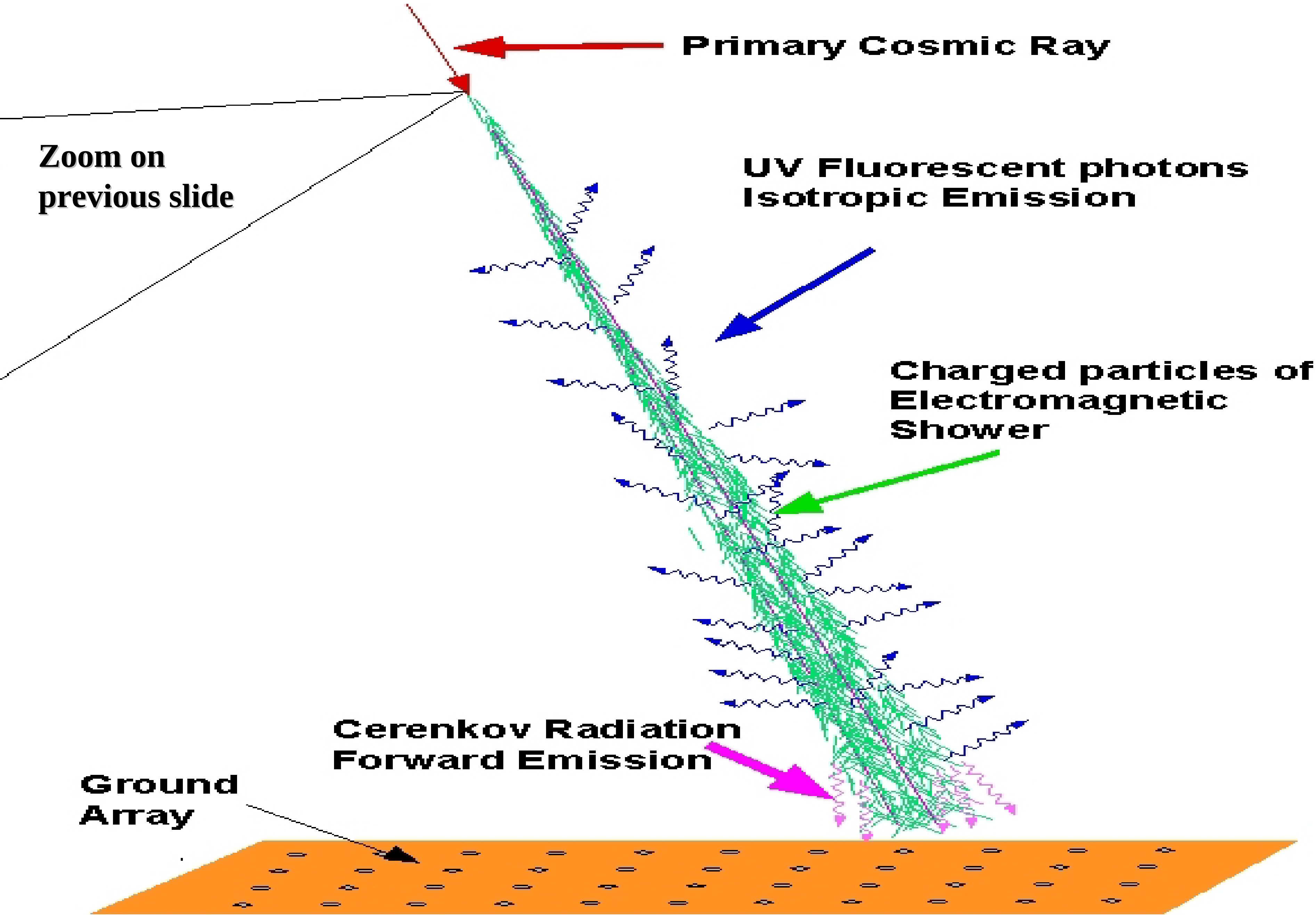
Introduction

- HiRes is an air- fluorescence experiment studying UHE cosmic rays. Technique based on previous Fly's Eye experiment.
- Monocular: wider energy range ($10^{17.4} < E < 10^{20.5}$ eV), best statistics.
- Stereo: best reconstruction, covers $10^{18.0} < E < 10^{20.5}$ eV.
- In this energy range expect to study:
  - Transition from galactic to extragalactic sources via spectral structure, composition and anisotropy.
  - Two spectral features due to interactions between cosmic ray protons and CMBR photons:
    - Suppression above threshold ($10^{19.8}$ eV) for pion production (GZK suppression).
    - Feature near 10^{18} eV due to e^+e^- pair production for extragalactic flux
    - Possible composition changes (heavy to light)
    - Possible gamma ray signatures
    - Possible anisotropy

Extensive Air Showers



The Two HiRes Detectors

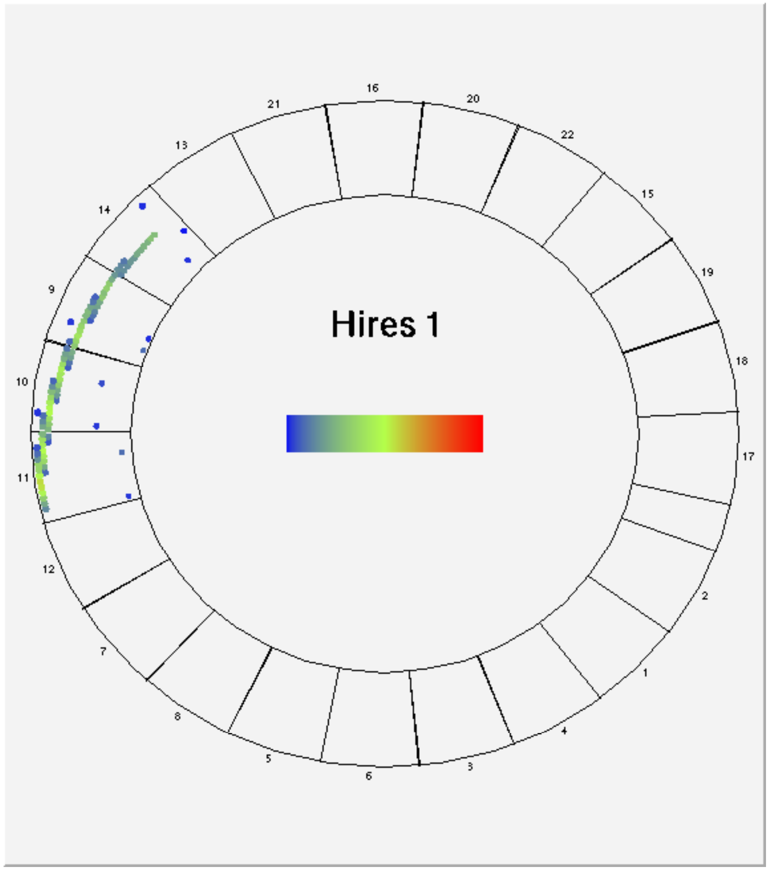
- HiRes1: atop Five Mile Hill
- 21 mirrors, 1 ring (3<altitude<17 degrees).
- Data taking began in 1997

- HiRes2: Atop Camel's Back Ridge
- 12.6 km SW of HiRes1.
- 42 mirrors, 2 rings (3<altitude<31 degrees).
- Data taking began in 2000

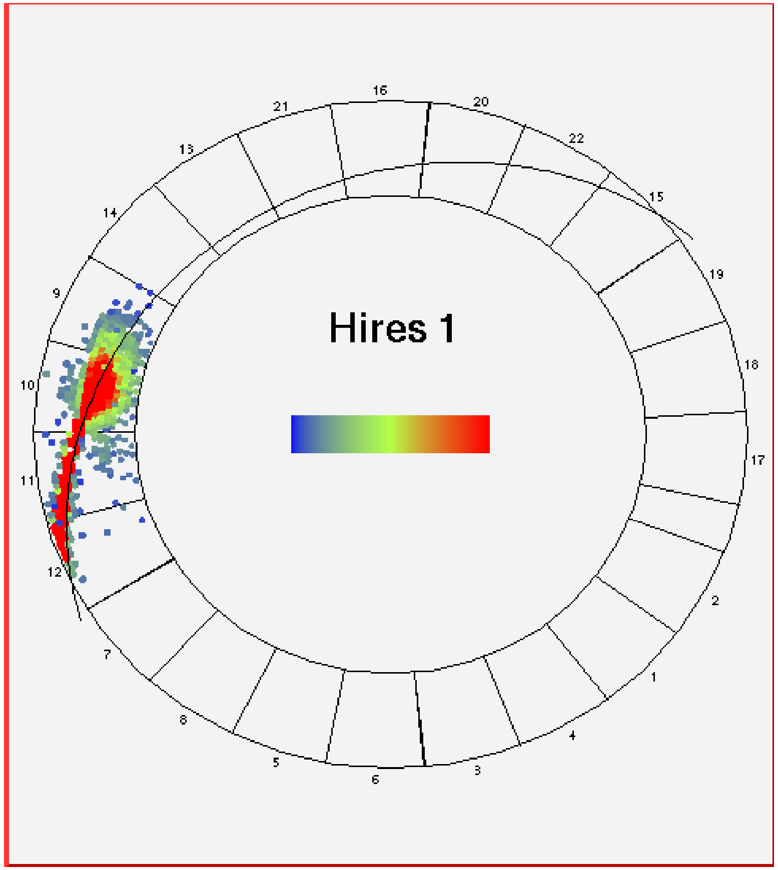
Mirrors and Phototubes

- 4.2 m^2 spherical mirror
- 16 x 16 array of phototubes, .96 degree pixels.

Finding Clouds with the Steerable Lasers

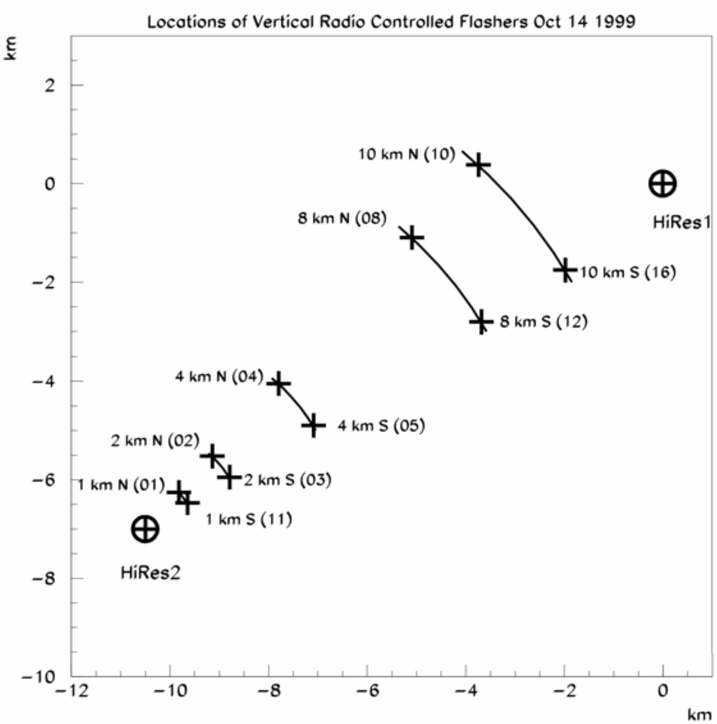


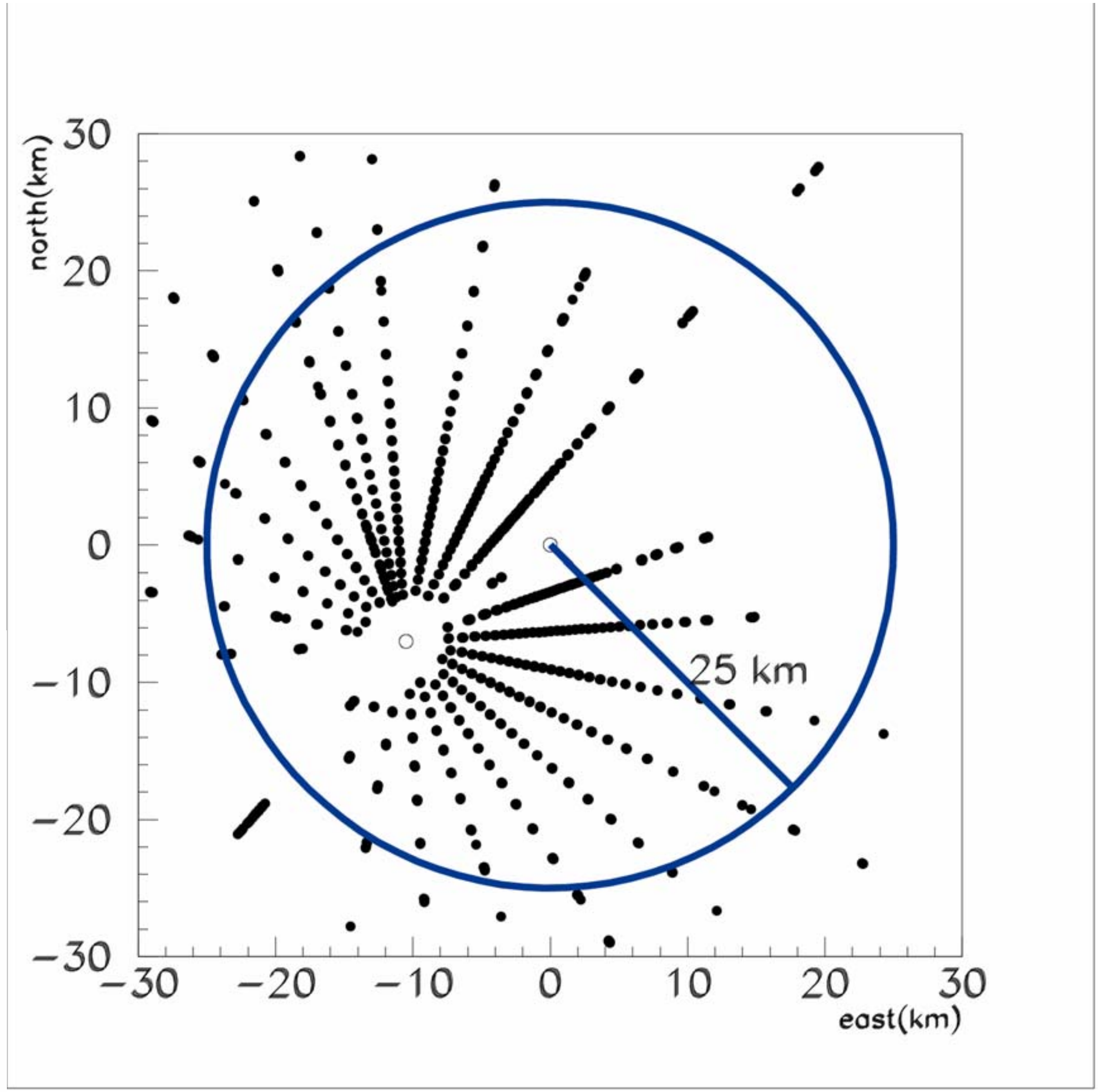
Typical Laser Shot



Laser Strikes a Cloud

Atmospheric Monitoring: Using the atmosphere as a calorimeter requires a knowledge of its properties in order to maintain calibration. In stereo observations this is a large systematic uncertainty.

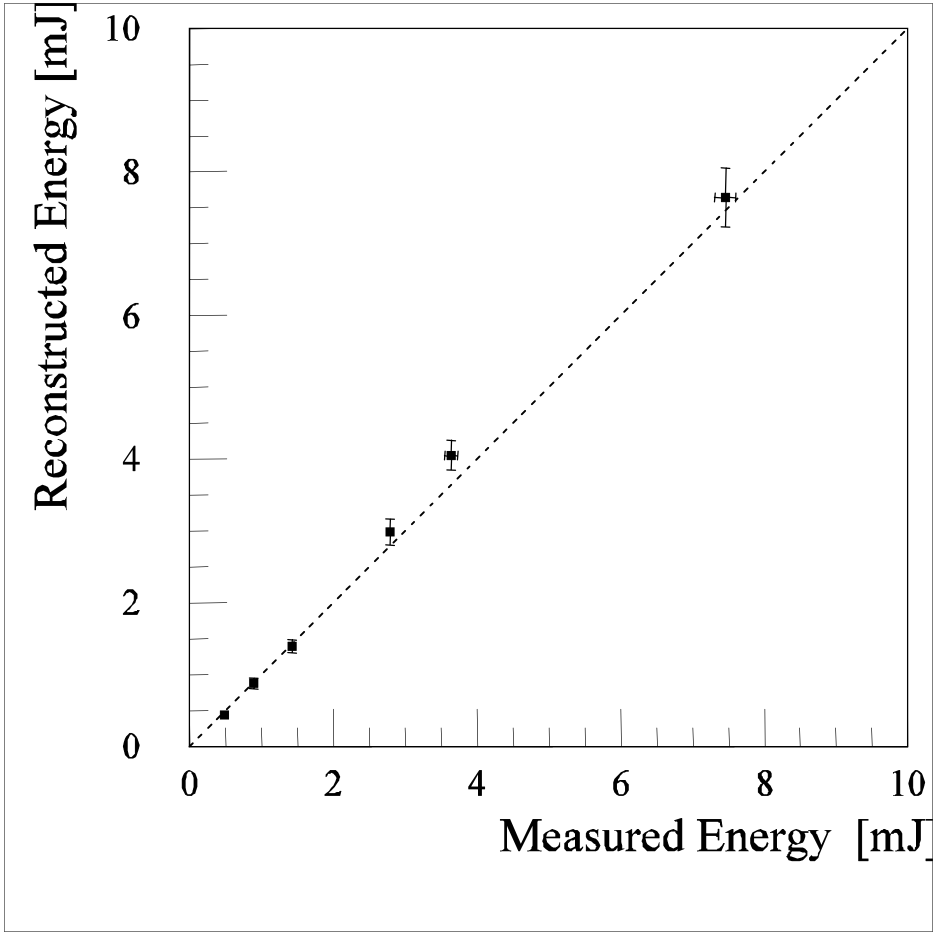




Steerable laser can sweep through most of our aperture and provide hourly corrections

Scattered light from horizontal laser shot – data and MC prediction

Check Overall Calibration and Linearity by Reconstructing YAG Laser Energy

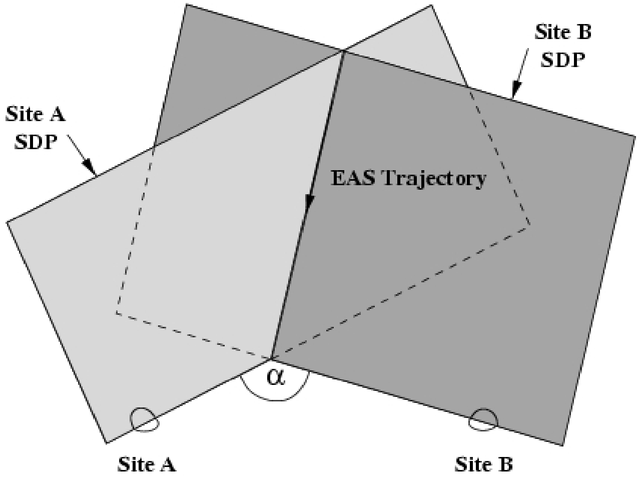


Monocular Data Analysis

- Pattern recognition.
- Fit SDP.
- Time fit (HiRes2),
  5^o resolution.
- Profile plot.
- Gaisser-Hillas fit.
- Profile-constrained fit
  (HiRes1),
  7^o resolution.

Stereo Analysis

- Intersection of shower-detector planes determines geometry, 0.6^0 resolution.
- Timing does as well for parallel SDP's.
- Two measurements of energy, X_{max}. Allows measurement of resolution.

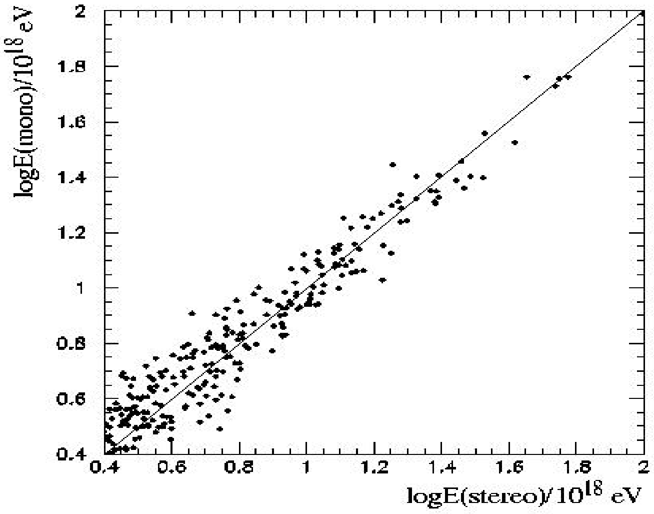


Stereo Data Checks on Monocular Reconstruction

- We use monocular data because of larger statistics and lower energy threshold.
- Stereo subset allows check of monocular energy resolution
- Function is similar to hybrid data – use precisely measured subset to study resolution and biases.
- PCF HiRes I monocular reconstruction has shorter tracks and hence poorer resolution.

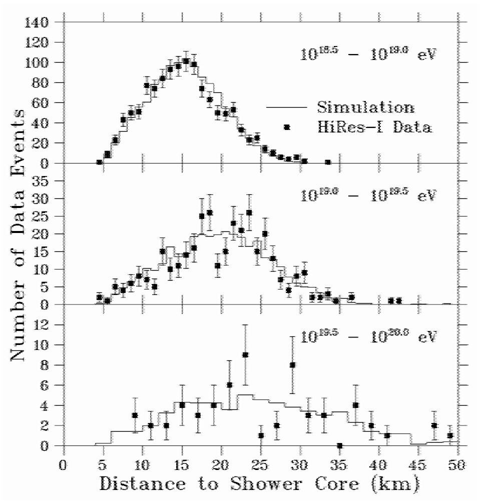
HiRes1 Energy Reconstruction

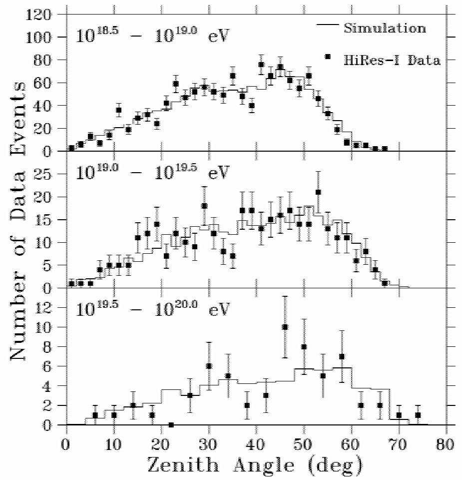
- Test HiRes1 PCF energy reconstruction using events seen in stereo.
- Reconstructed energy using mono PCF geometry vs. energy using stereo geometry.
- Good agreement



Monocular Spectra:
Data / Monte Carlo Comparisons

Inputs to Monte Carlo:
Fly's Eye stereo spectrum; HiRes/Mia and HiRes Stereo composition; library of Corsika showers.
Detailed nightly information on trigger logic and thresholds, live mirrors, etc.
Analyze MC with exact programs used for data.

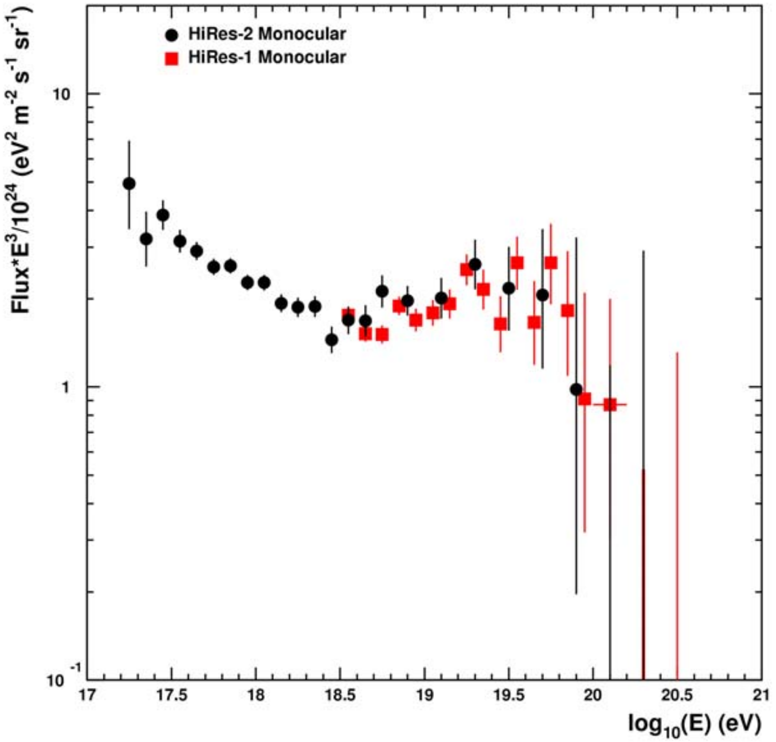




Result: excellent simulation of the data.

HiRes I and II Apertures

Monocular Spectra

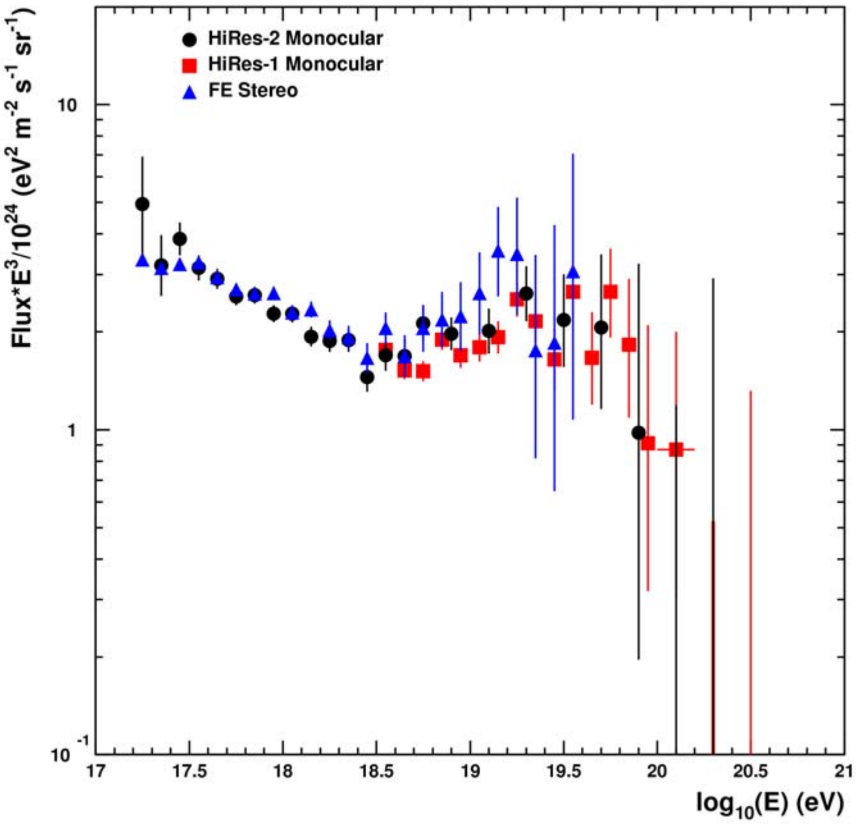


HiRes1: 7/97-2/03
Hi/res2: 12/99-9/01

-Ankle near 3 EeV is clearly observed. Excellent agreement between HiRes I and II.
-2002-2004 data being analyzed –Hires II has lower energy threshold.

Two Spectra: HiRes Mono and Fly's Eye Stereo

- Fly's Eye Stereo spectrum shows ankle structure.
- HiRes mono in good agreement



Does the Spectrum Continue Unabated as a Power Law?

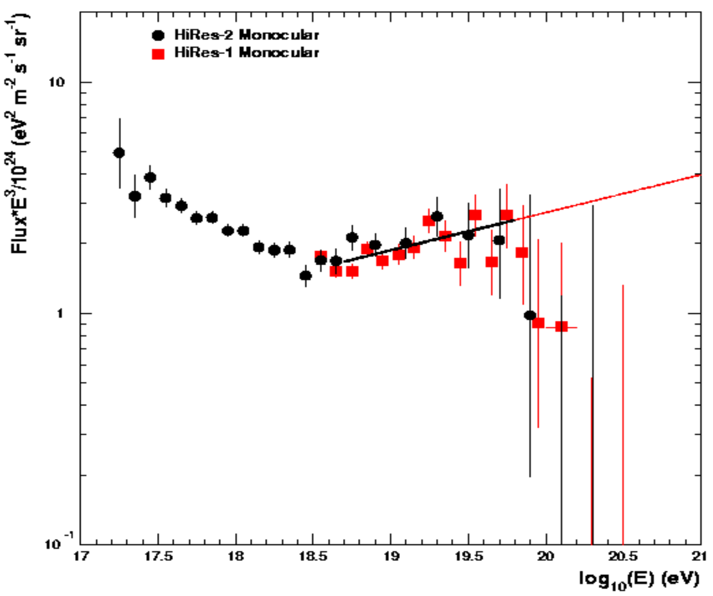
Fit from ankle to pion production threshold.

Extend beyond:

Expect 29.0 events, see 11, Poisson probability = 1×10^{-4}

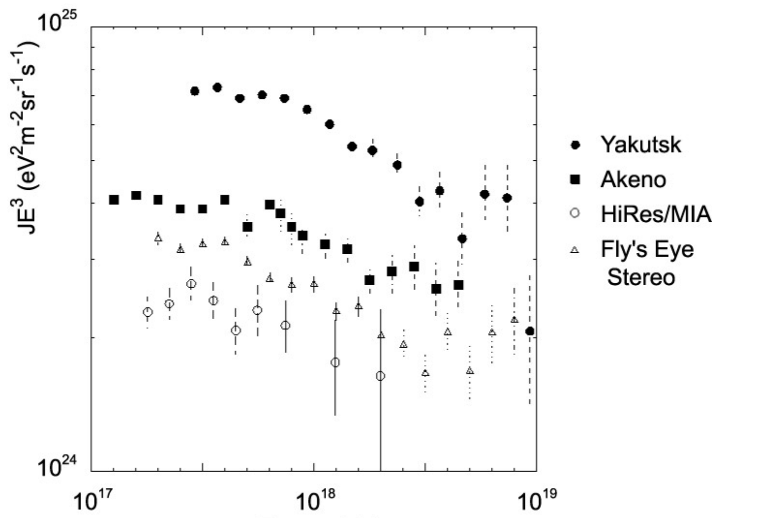
Suppression is significant.

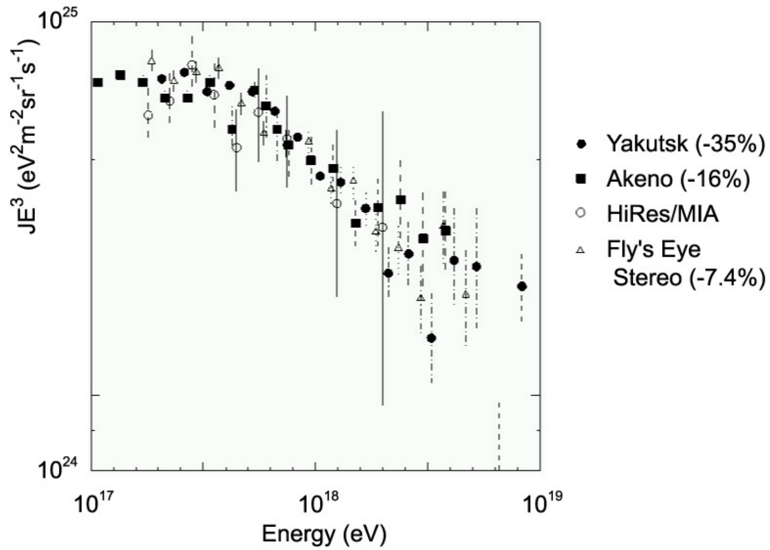
We have good sensitivity, but the events are not there.



Second Knee at $10^{17.6}$ eV

- Yakutsk, Akeno, Fly's Eye Stereo, HiRes Prototype/MIA all saw flat spectrum followed by a steepening in the power law. The break is called the second knee.
- Correct for varying energy scales: all agree on location of the second knee.
- There are THREE spectral features in the UHE regime



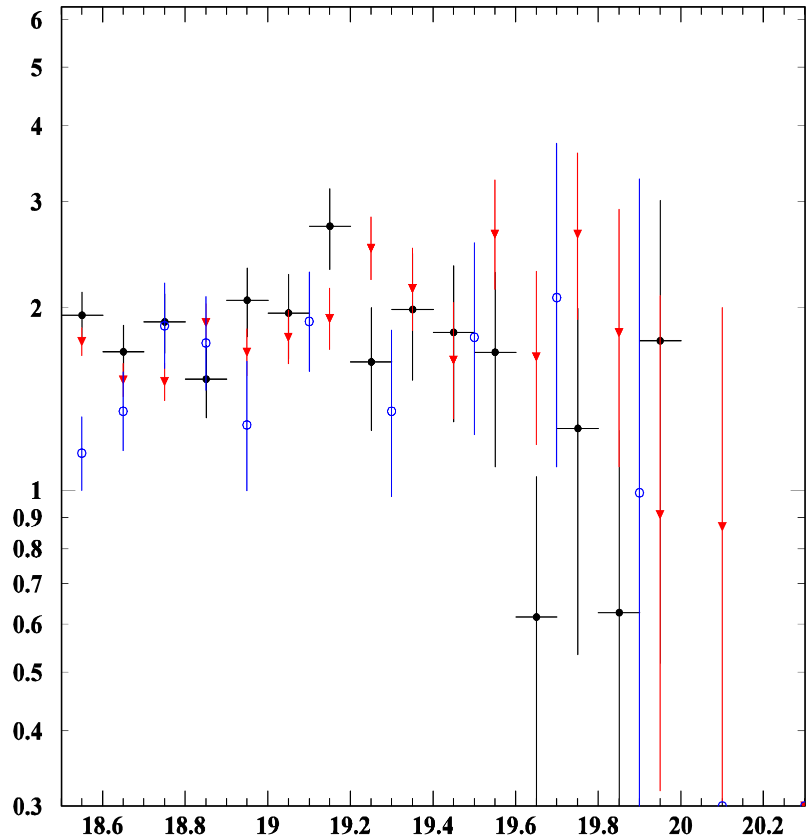


Role of Stereo Data

- Stereo data has best energy resolution
- Statistics poorer than HiRes I monocular
- Present stereo data can be used to confirm the spectrum normalization from 3 to 100 EeV.
- Continue to accumulate Stereo Data to match moncular sensitivity at highest energies

Stereo Spectrum Comparison Above 3 EeV

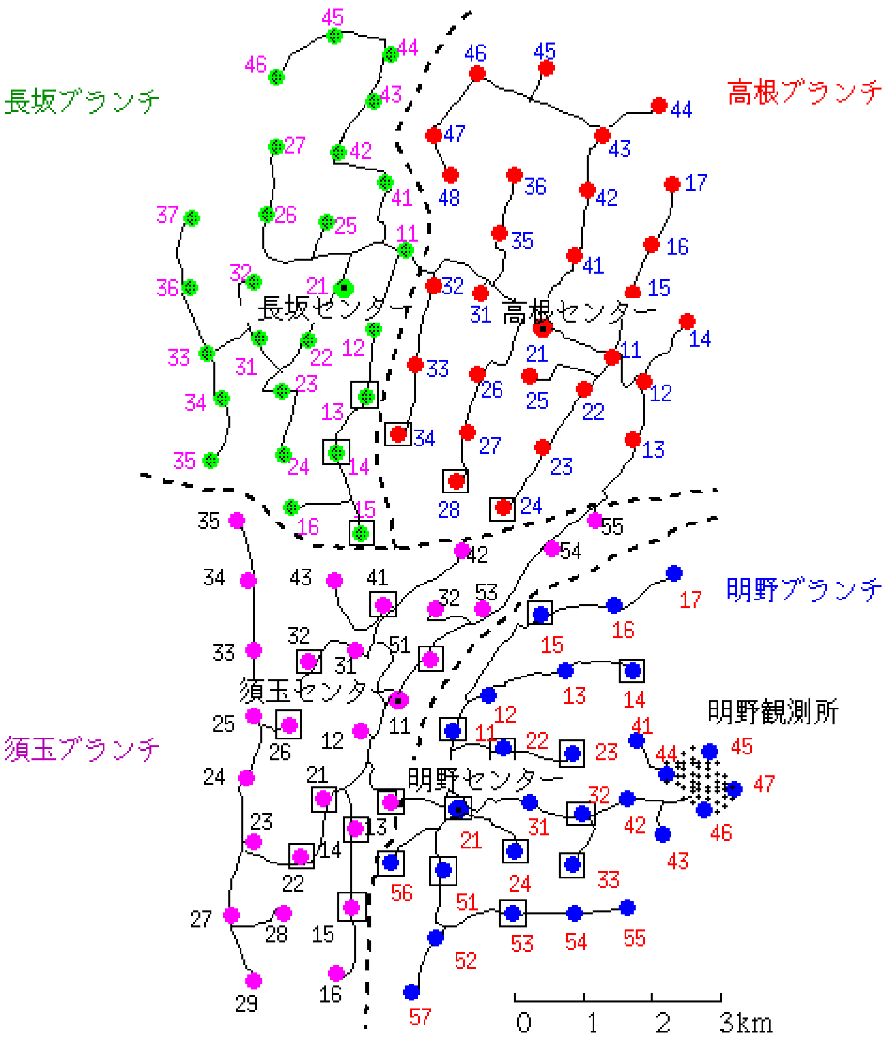
Stereo: black
HiRes1 mono: red
HiRes2 mono: blue



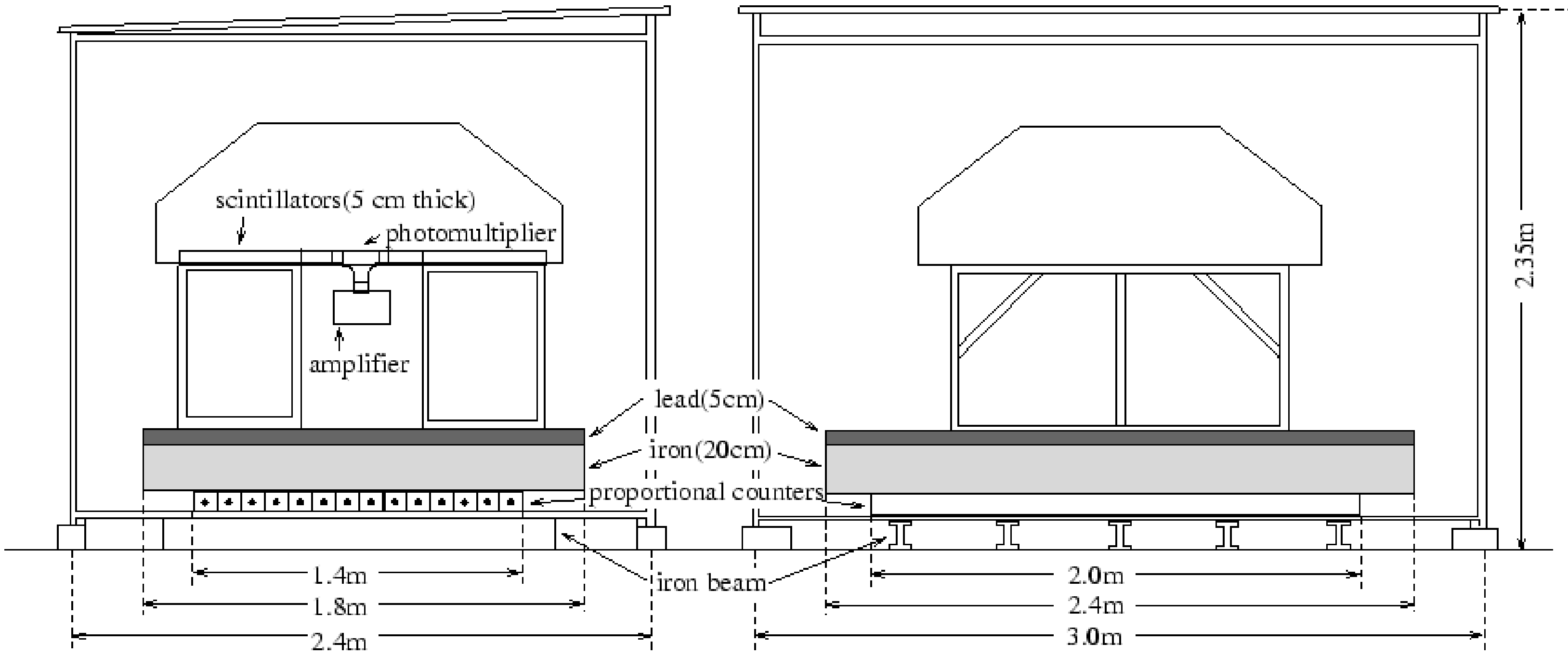
In agreement with mono, But poorer statistics.

AGASA site in western Japan

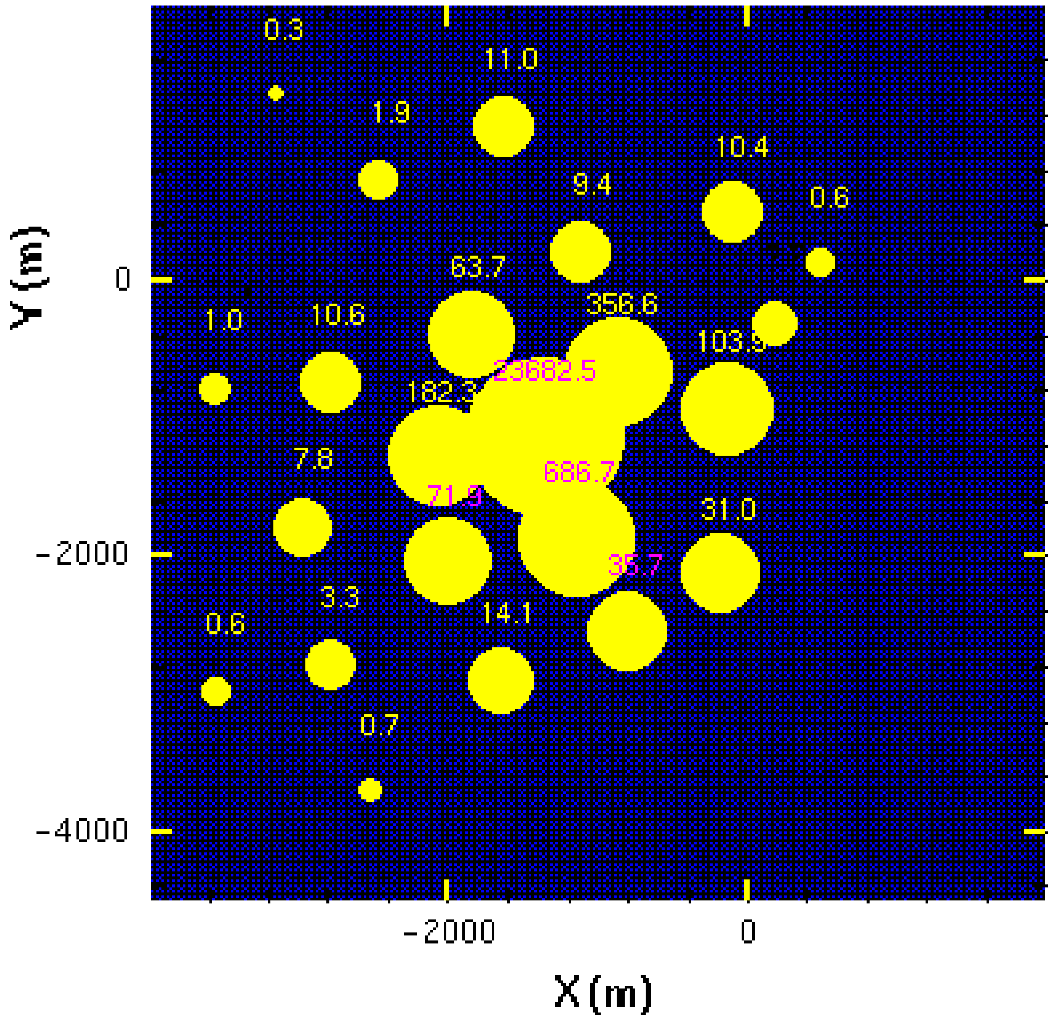
Layout of AGASA



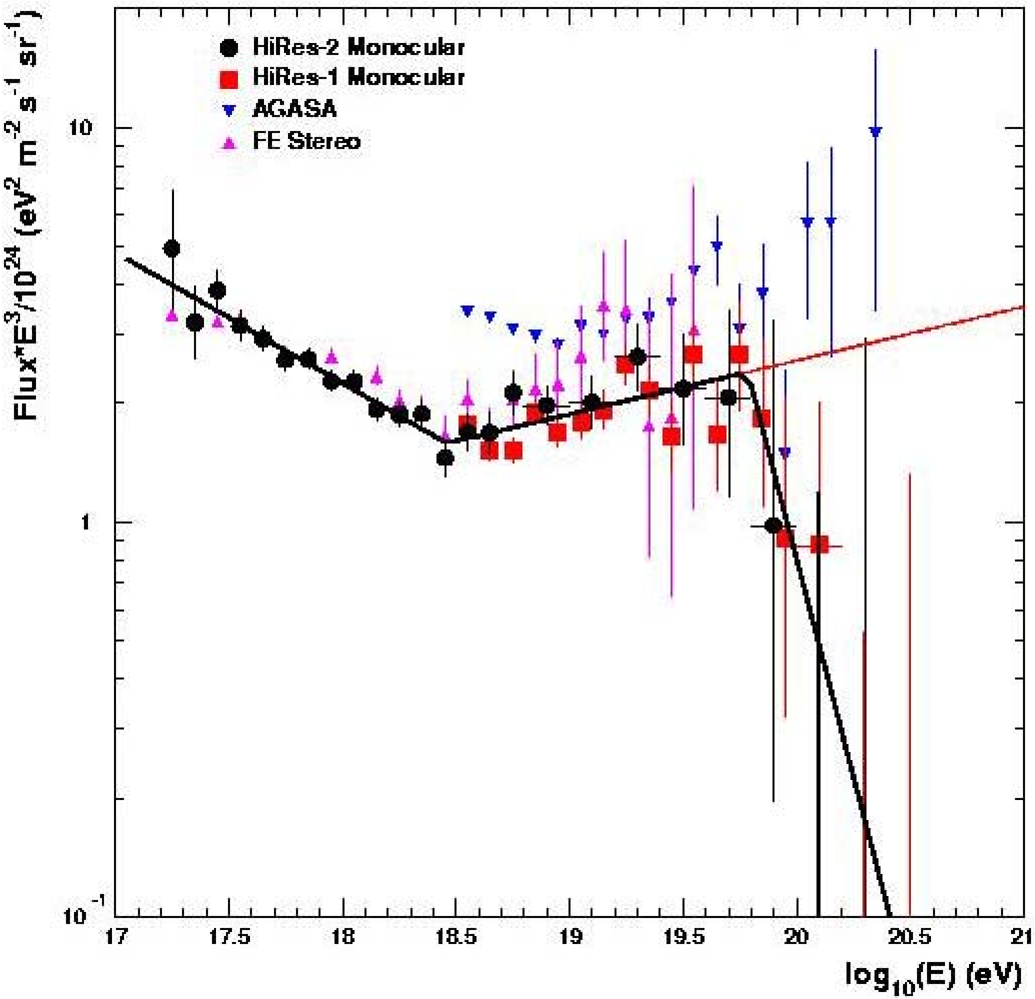
AGASA scintillation detector



Footprint of Highest Energy Event in AGASA



Linear fit with two
Floating break points



Main Systematic Uncertainties

- Phototube calibration: 10%
- **Fluorescence yield: 15-20%**
- Unobserved energy in shower: 5%
- Modeling of the atmosphere: 15%

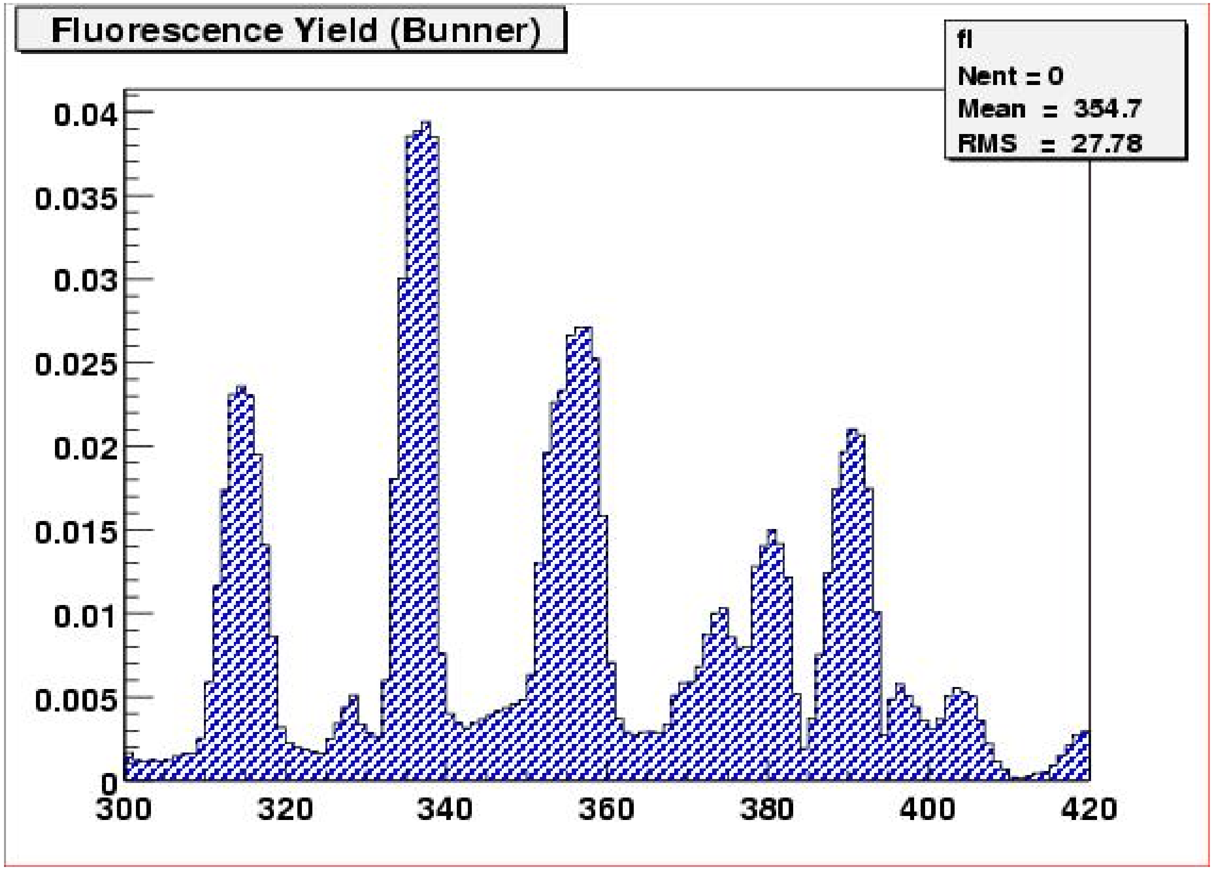
Importance of Energy Scale

- 25% energy shift will bring AGASA normalization into agreement with HiRes.
- Positions of GZK cutoff, pileup, ankle and second knee are all astrophysically meaningful. Absolute energy is important.
- Understanding systematics of ground array measurement

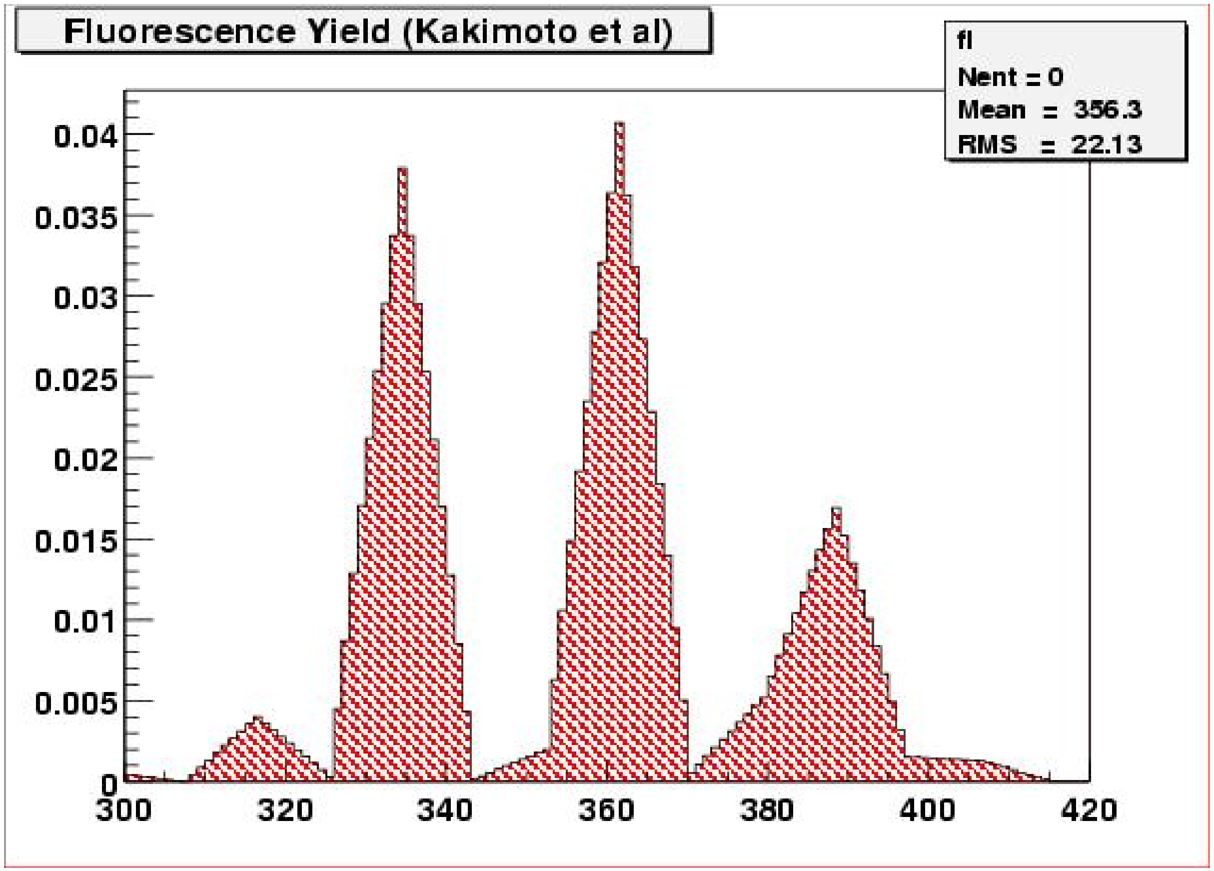
Energy Scale

- Fluorescence efficiency uncertainty is significant contributor to error budget.
- Fluorescence spectral lines relative uncertainty can introduce non-linear effects due to 1/lambda^4 Rayleigh scattering.
- Need to do laboratory experiments to reduce errors – thin and thick target!

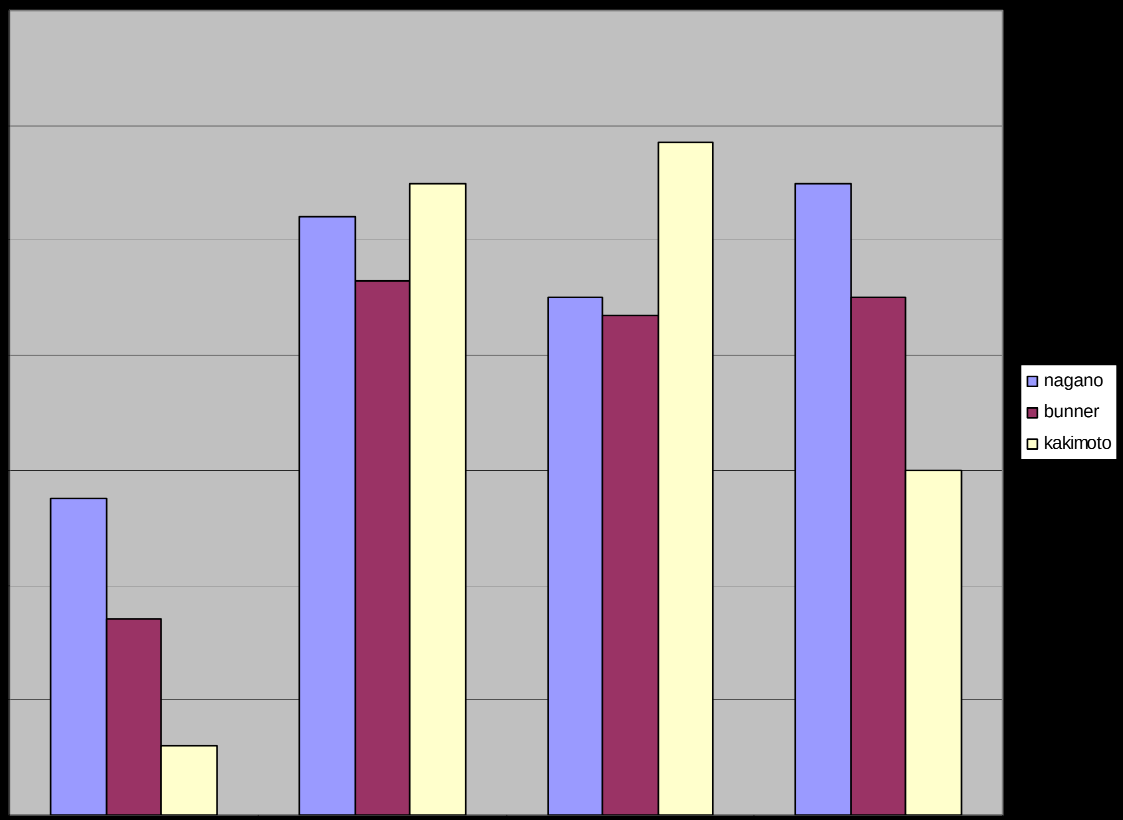
Flourescence Yield, Bunner's Thesis



Kakimoto et al. Measurement



Comparison of Fluorescence Yields for major spectral line groups



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

J. Belz[1], D.R. Bergman[5], Z. Cao[2], S. Cavanaugh[5], F.Y. Chang[4], P. Chen[3*], C.C. Chen[4], C.W. Chen[4], C. Field[3], A. Goldammer[1], D. Guest[1], C. Hast[3], P. Huentemeyer[2], M.A. Huang[4], W-Y. P. Hwang[4], R. Iverson[3], C.C.H. Jui[2], G.-L. Lin[4], E.C. Loh[2], K. Martens[2], J.N. Matthews[2], J.S.T. Ng[3], A. Odian[3], L. Perera[5], **K. Reil[3]**, S. Schnetzer[5], J.D. Smith[2], P. Sokolsky[2*], R.W. Springer[2], S.B. Thomas[2], G.B. Thomson[5], H. Vincke[3], D. Walz[3], A. Zech[5]

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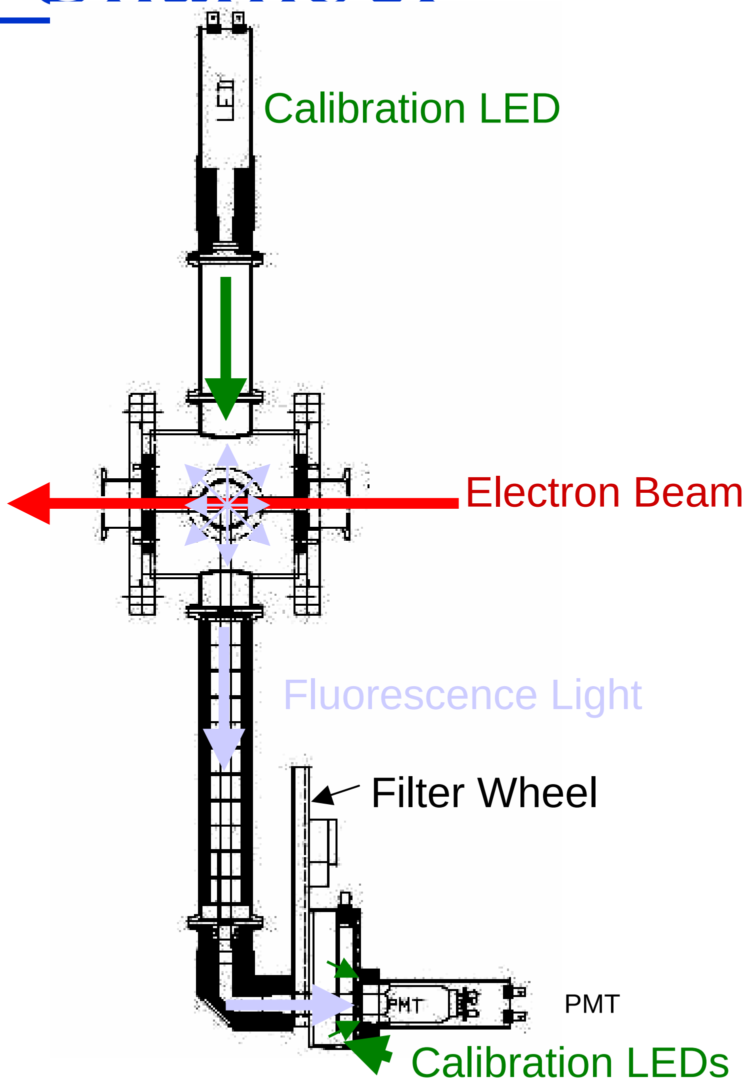
[*] Collaboration Spokespersons

The FLASH Experiment

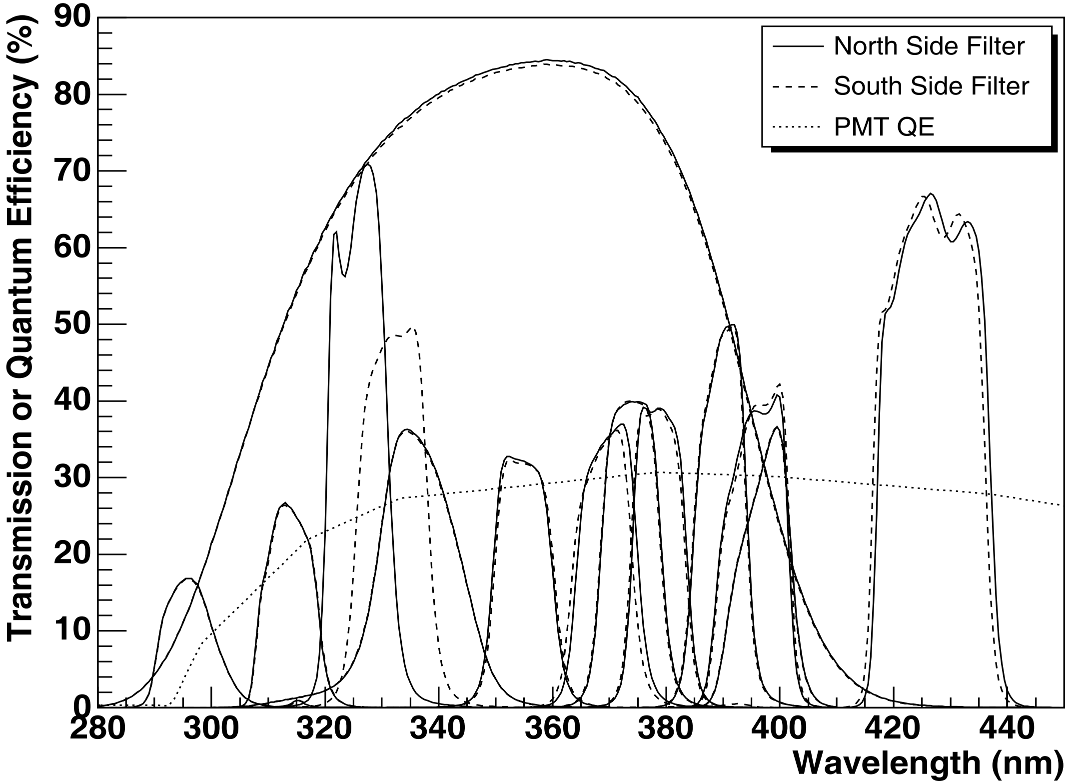
- **Thin Target Experiment**
  - Electron beam passes through gas volume.
  - Measure fluorescence yield Y=photons / m e^-.
- **Thick Target Experiment**
  - Electron beam showered before passing through air.
  - Use air-equivalent material to produce air shower in the laboratory.

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.



Narrow Band Filters



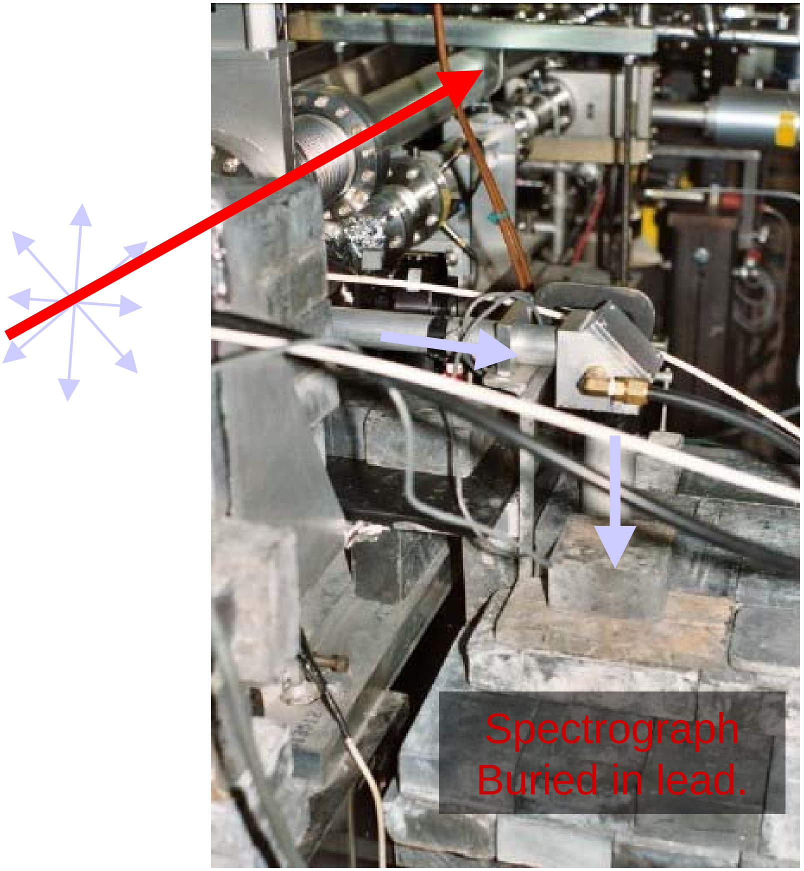
All filter transmissions were measured by HiRes group using their spectro-photometer setup.

1 nm steps from 200 to 800 nm.

0.5 nm steps in fluorescence region.

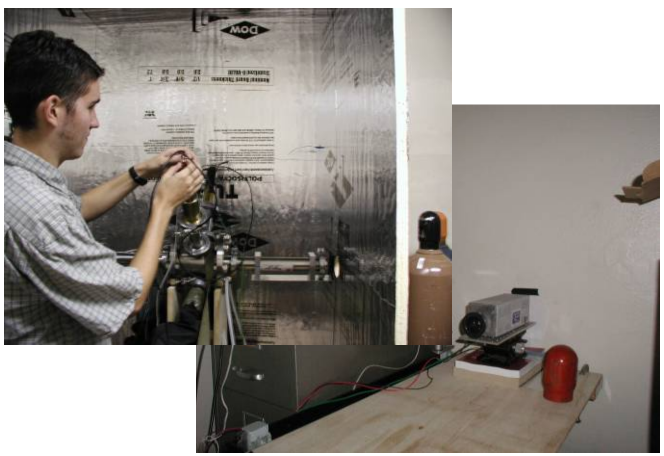
Spectrograph

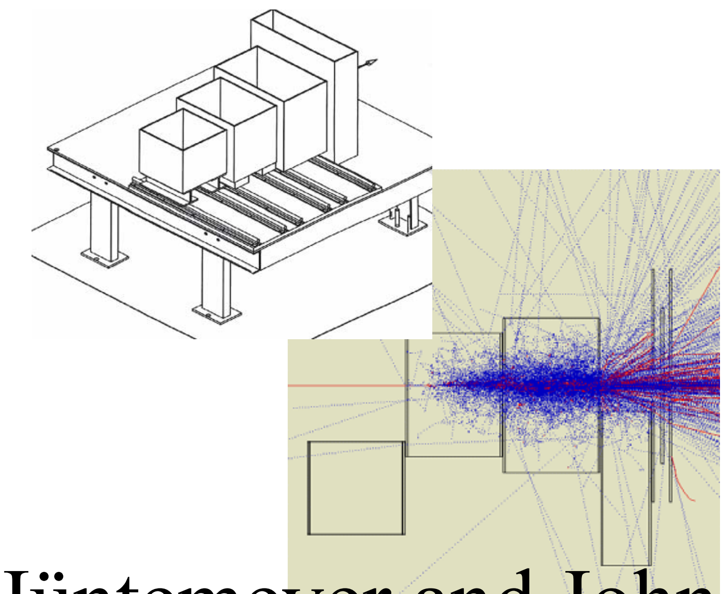
- Spectrograph
  - The electron beam passes through a gas volume.
  - Fluorescence light reflected into a spectrograph system.
  - 32 channel PMT relative line strengths calibrated using Deuterium lamp.



Thick Target & Calibration

- Most of the FLASH effort over the last year has focused on **two things**:



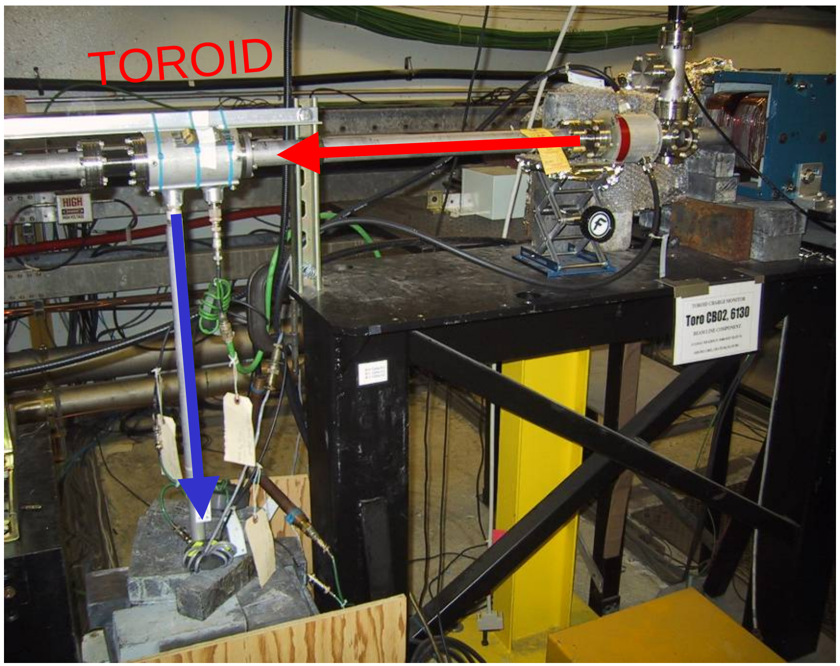


- Refer to talks by Petra Hüntemeyer and John Matthews.

FLASH Timeline

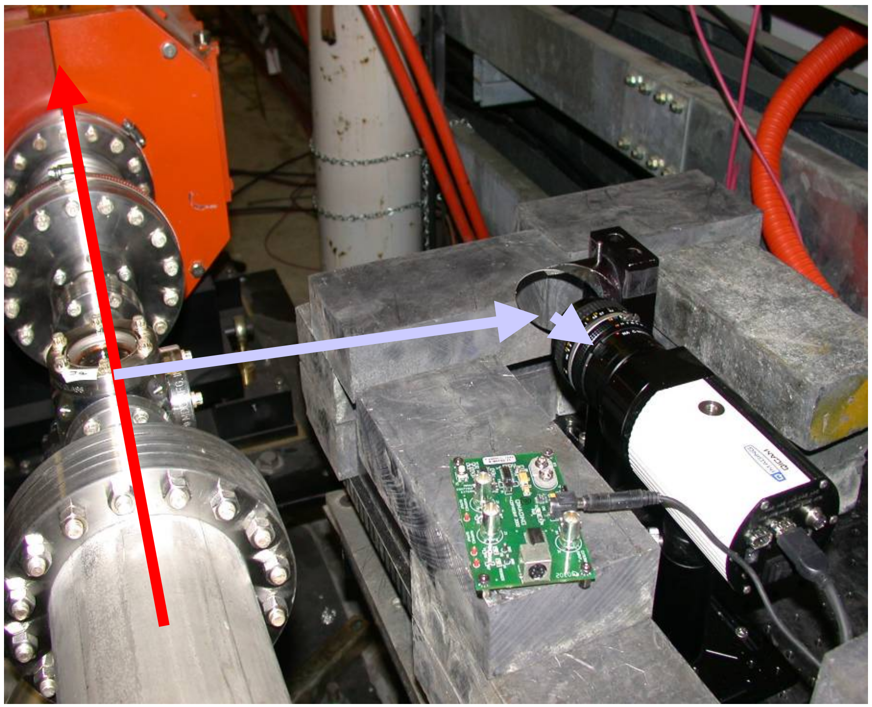
- **June 2002**
  - T-461: SLAC Test Beam (3 weeks). Total yield 300-400.
- **Sept 2003**
  - Thin target data run (3 weeks). Total yield and spectral shape.
- **Dec 2003**
  - Bad Liebenzell ☺
- **Jan 2004**
  - Thick target mode test beam. (3 days).
- **June 2004**
  - Thick Target run (2 weeks). Yield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

FLASH Experimental Equipment



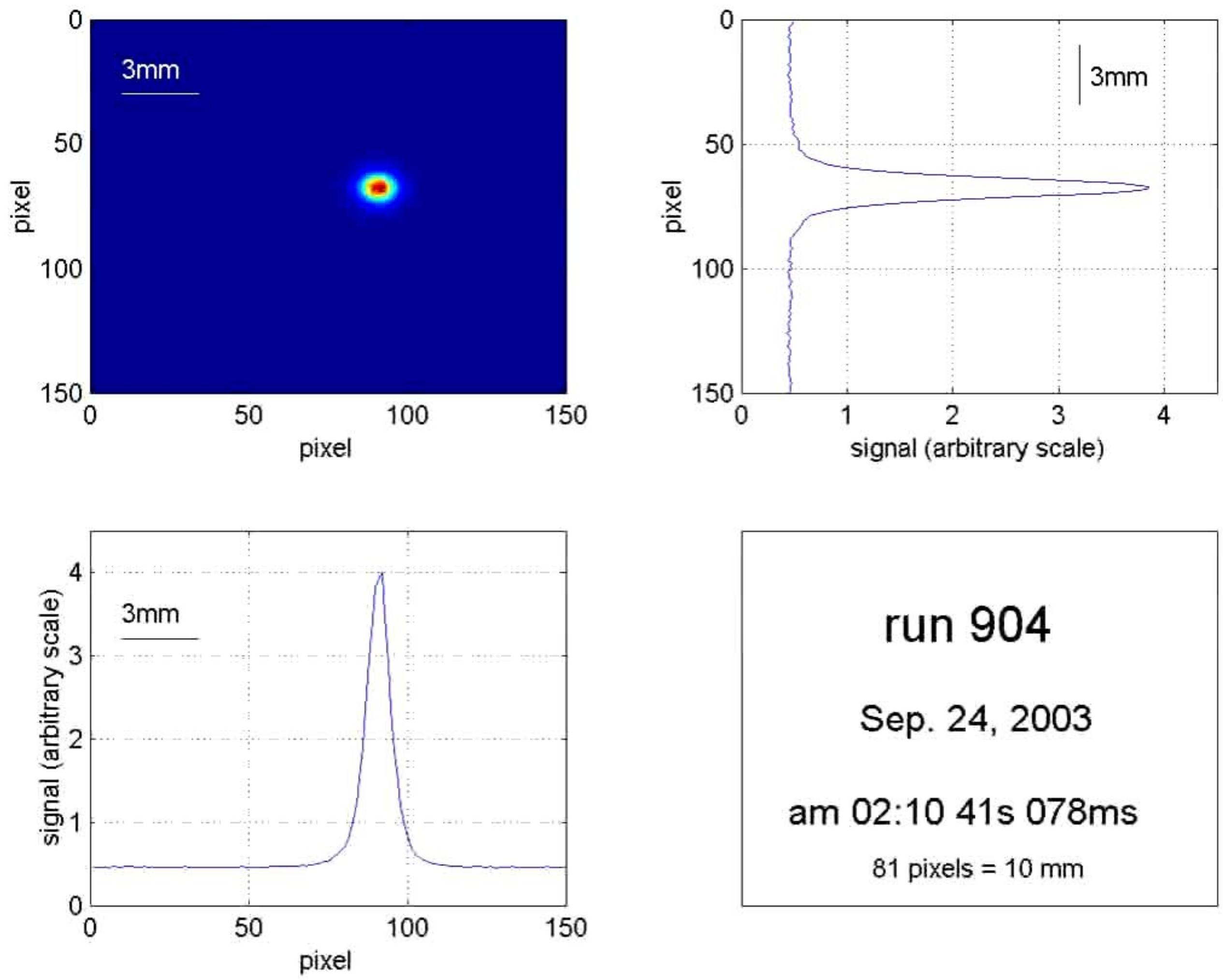
- The toroid used by FLASH experiment:
  - Local readout electronics allowed toroid to readout $<10^7$ to $>10^{10}$ e- per pulse.
  - The toroid itself was just a “standard” SLAC toroid.

FLASH Experimental Equipment



- Beam Spot Monitor
  - Used optical transition radiation (OTR) to image beam spot.
  - Provided real time visual feedback on spot shape and position.

Beam Spot Monitor



Thin Target Run

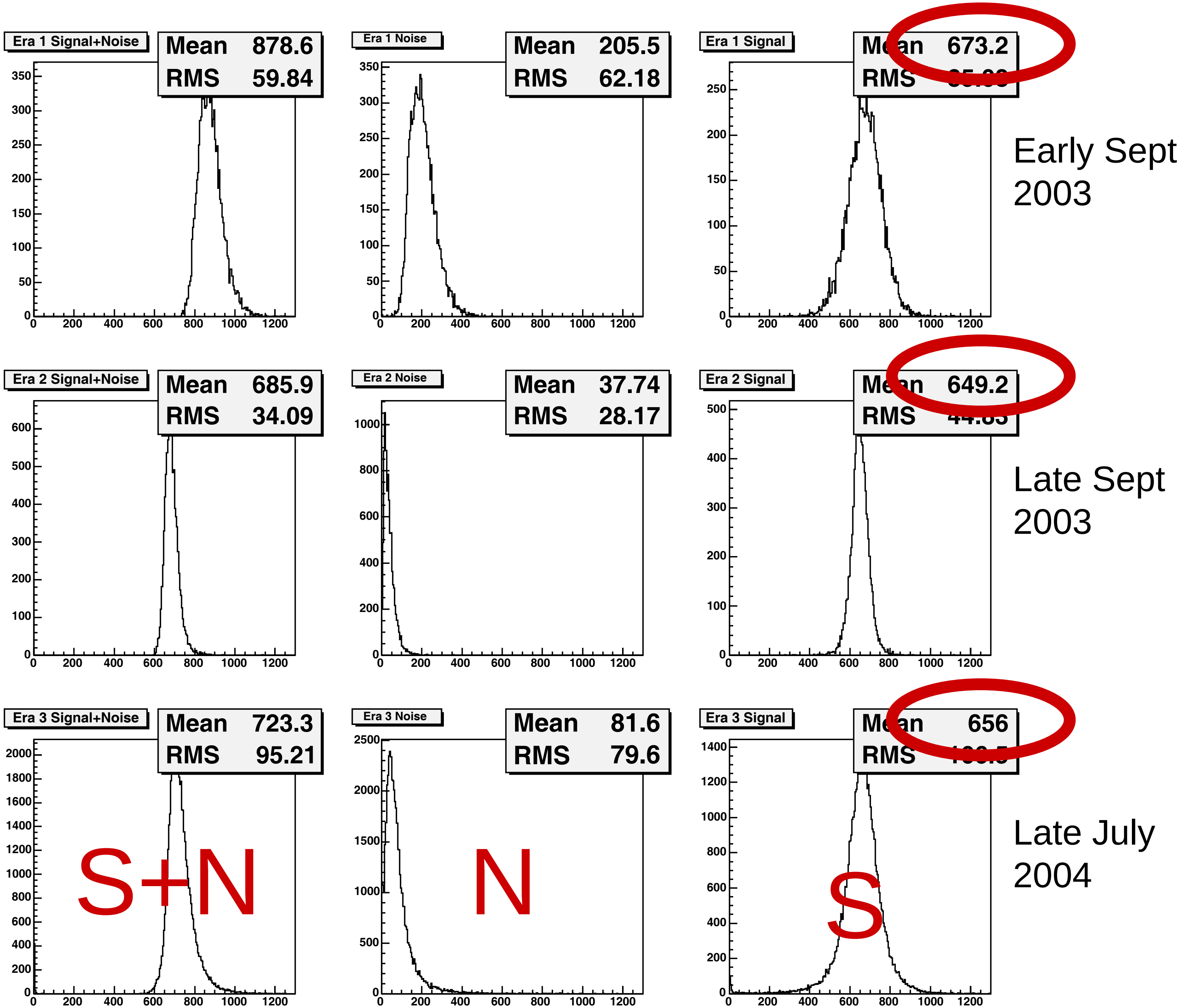
- Data taken in September 2003.
- Subset retaken in July 2004.
  - Confirmed **stability** of system
  - Results are **reproducible**.
- **12 Narrow band filters** (296-425 nm) plus
  - Plus **HiRes** (300-400 nm), **open** and **black** filters.
- Pressures from **atmospheric** down to **5 torr**.
- Pure N_2, dry air and humid (SLAC) air.
- 15 filter settings * 8 pressures * 3 gases *
  5000 events / 10 Hz = 50 hours * overhead

Fluoresence Measurement

- We want to measure fluorescence yield.
  - $\mathbf{Y_i = N_{photons} / N_{e-}\ m}$
- Measure N_{e-} using the toroid.
- Measure PMT signal on ADC N_{ADC}.
  - $N_{ADC}=N_{measured}-N_{Pedestal}-\mathbf{N^{*}_{Background}}$.
- Optical Calibration converts N_{ADC} to $N_{photons}/m$
  - Calibration* $= N_{ADC} / (N_{photon} / m)$
  - This calibration discussed in detail by Petra Hüntemeyer in following talk.

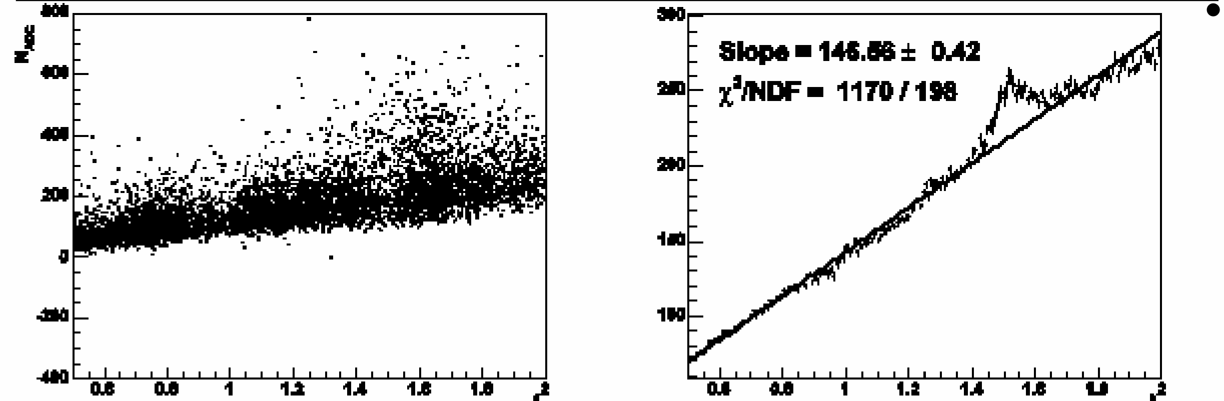
***These two things are the most difficult!**

Reproducibility 2%

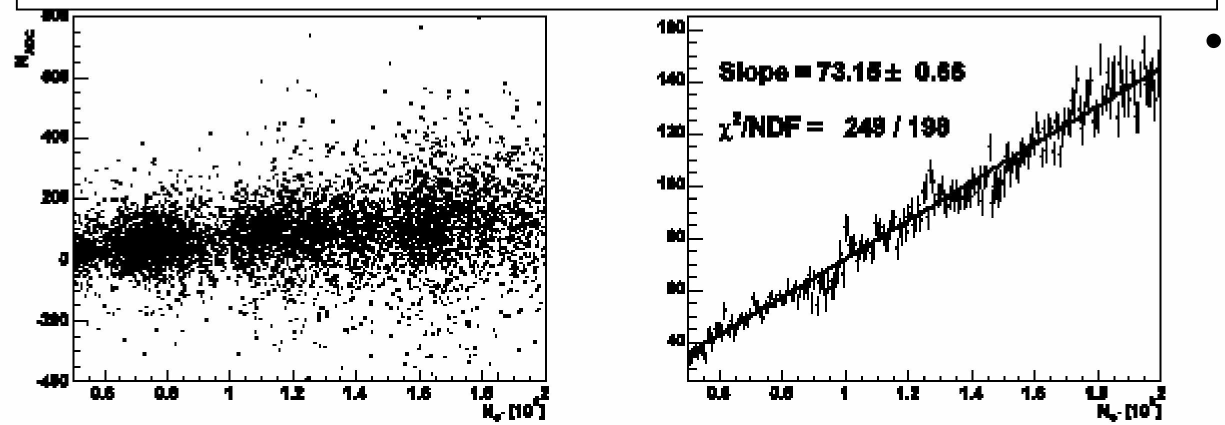


Beam related Background.

Signal + Noise vs Beam Charge



Signal vs Beam Charge



- Subtract background using
  1) Blind Tube 1 * ratio
  2) Blind Tube 2 * ratio
  3) BG Counter * ratio
  4) Signal from (nearest) black filter run.
- For example, the 4 methods in an representative run have a spread of less than 1%.

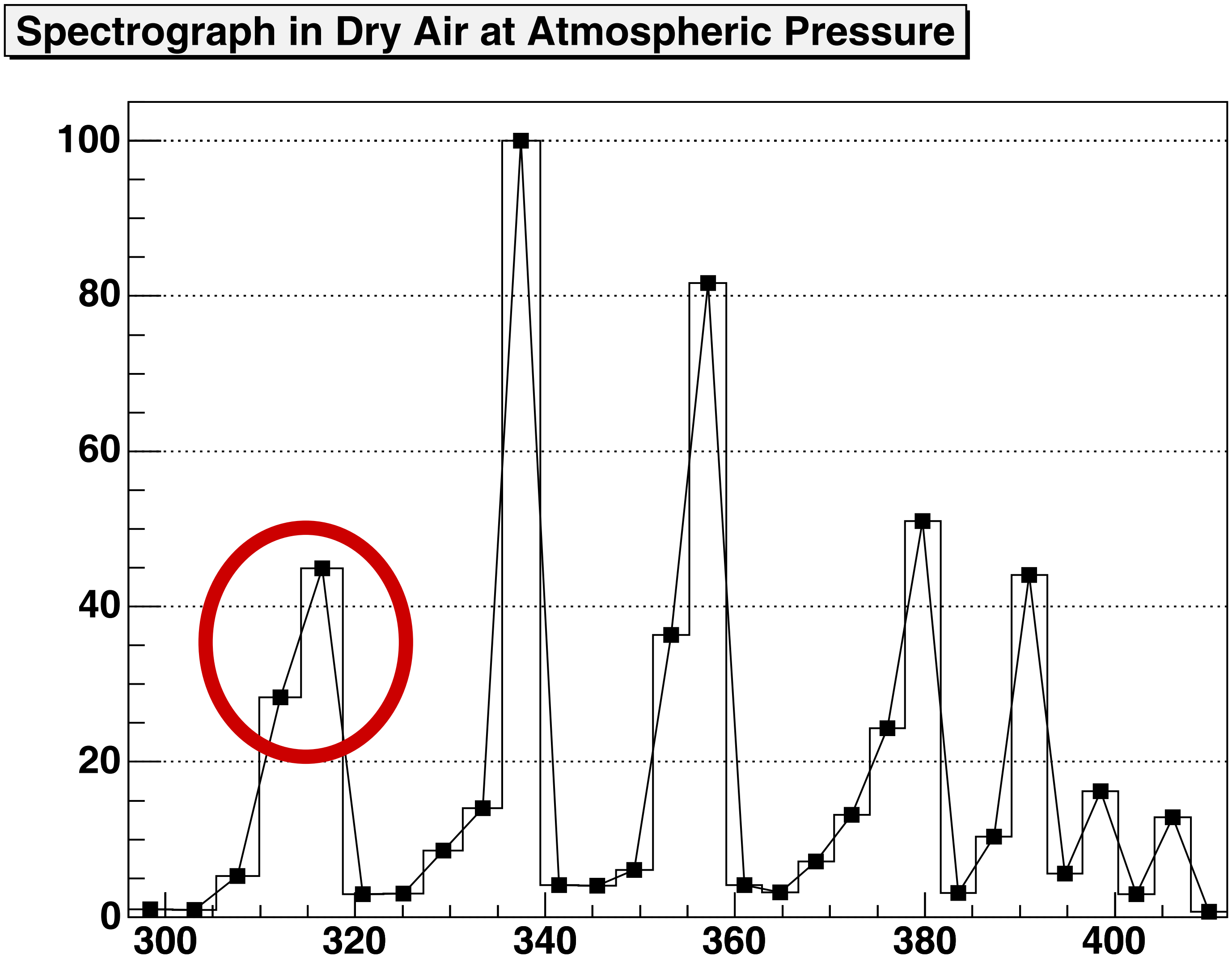
Ratio's are found using ADC counts from black filter runs.

Fluoresence Measurement

- We measured fluorescence yield for individual lines AND between 300 and 400 nm using HiRes filter AND total (296-425) using open filter.

$$-\mathbf{Y_i = N_{photons} / N_{e-}\ m}$$

Spectrograph Spectrum

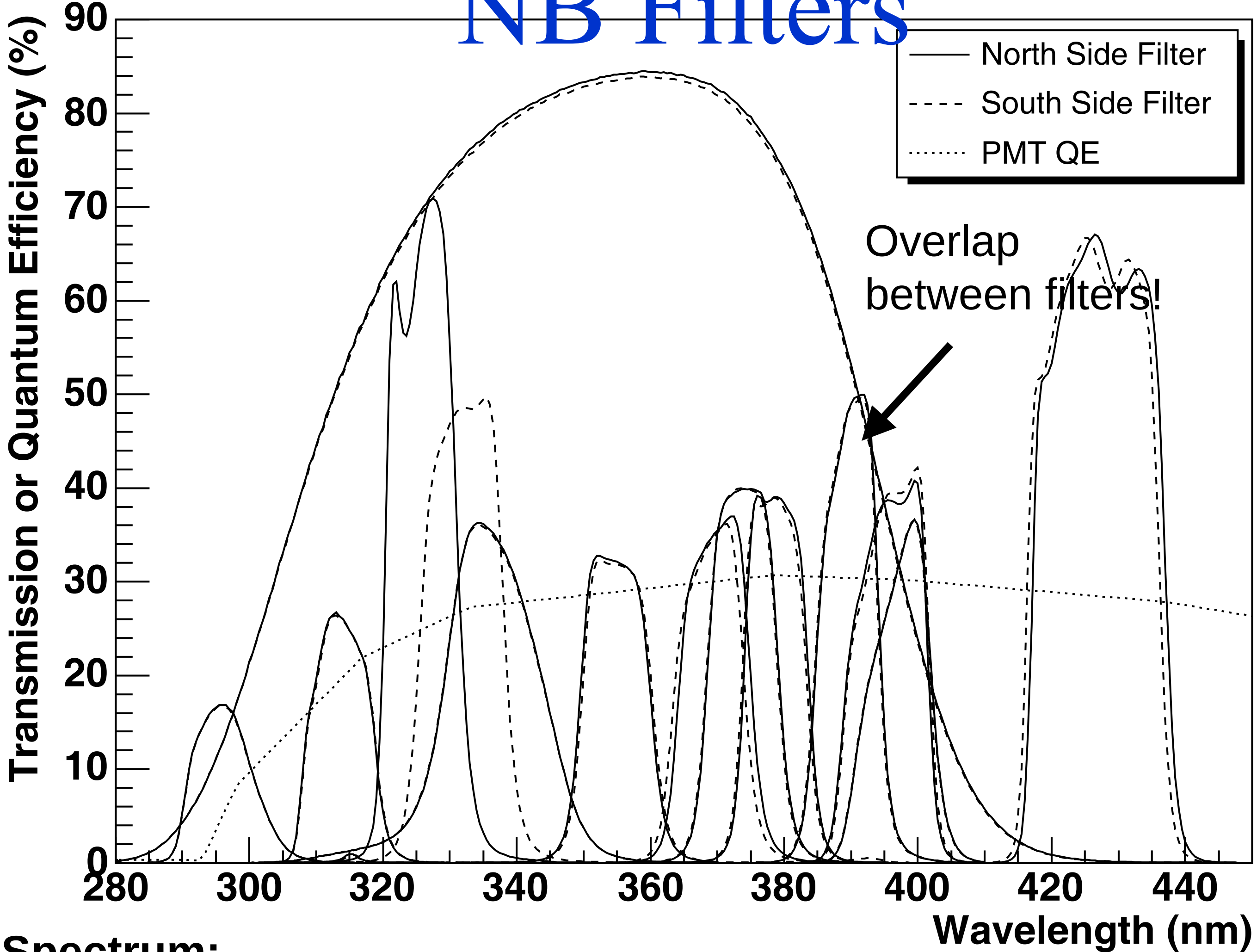


Spectral shape as **measured by spectrograph**.

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

Also have lower resolution to include 296 and 425 lines.

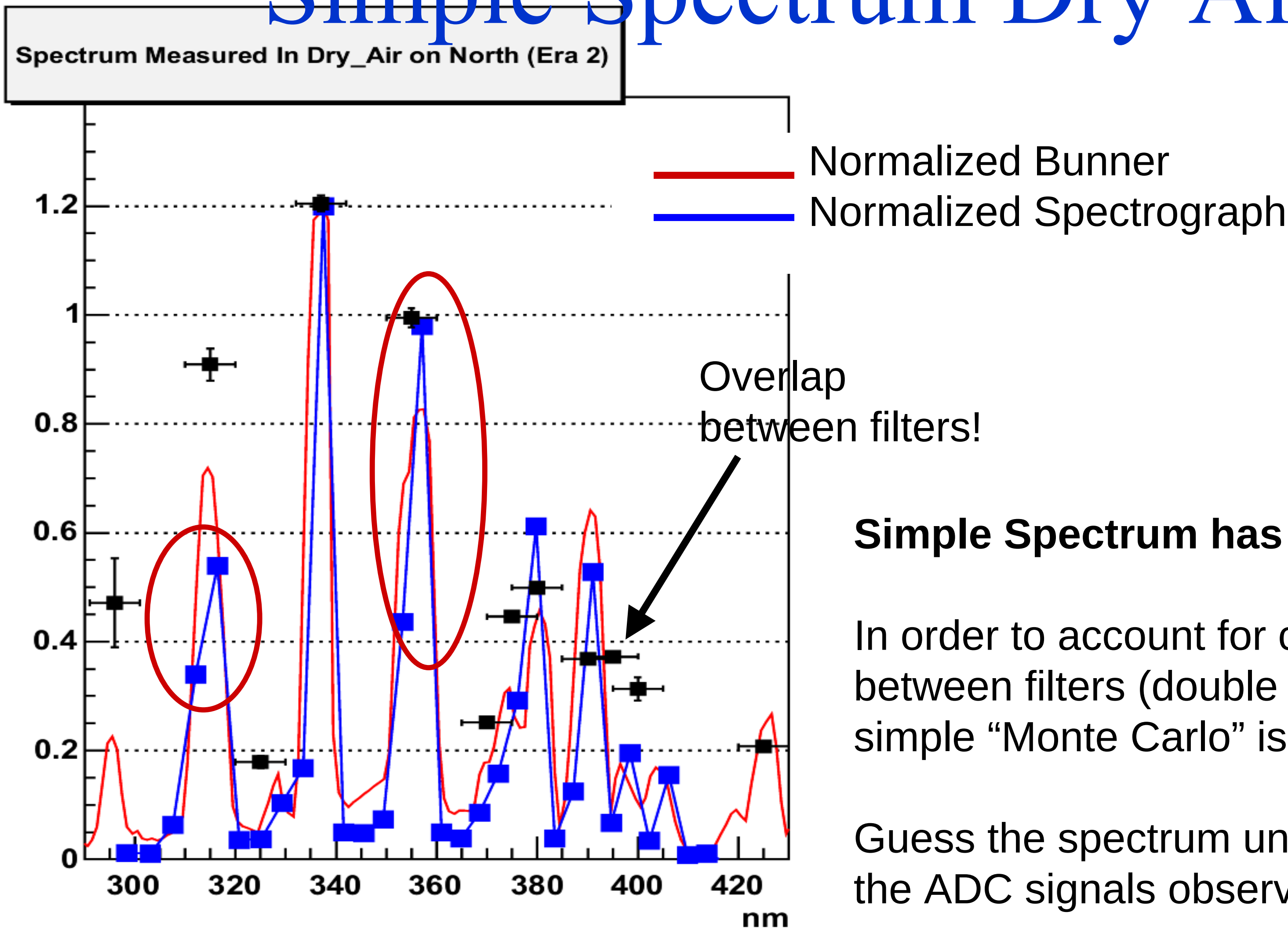
NB Filters



Simple Spectrum:

Take Y_i and correct for filter transmission and PMT qe.

Simple Spectrum Dry Air

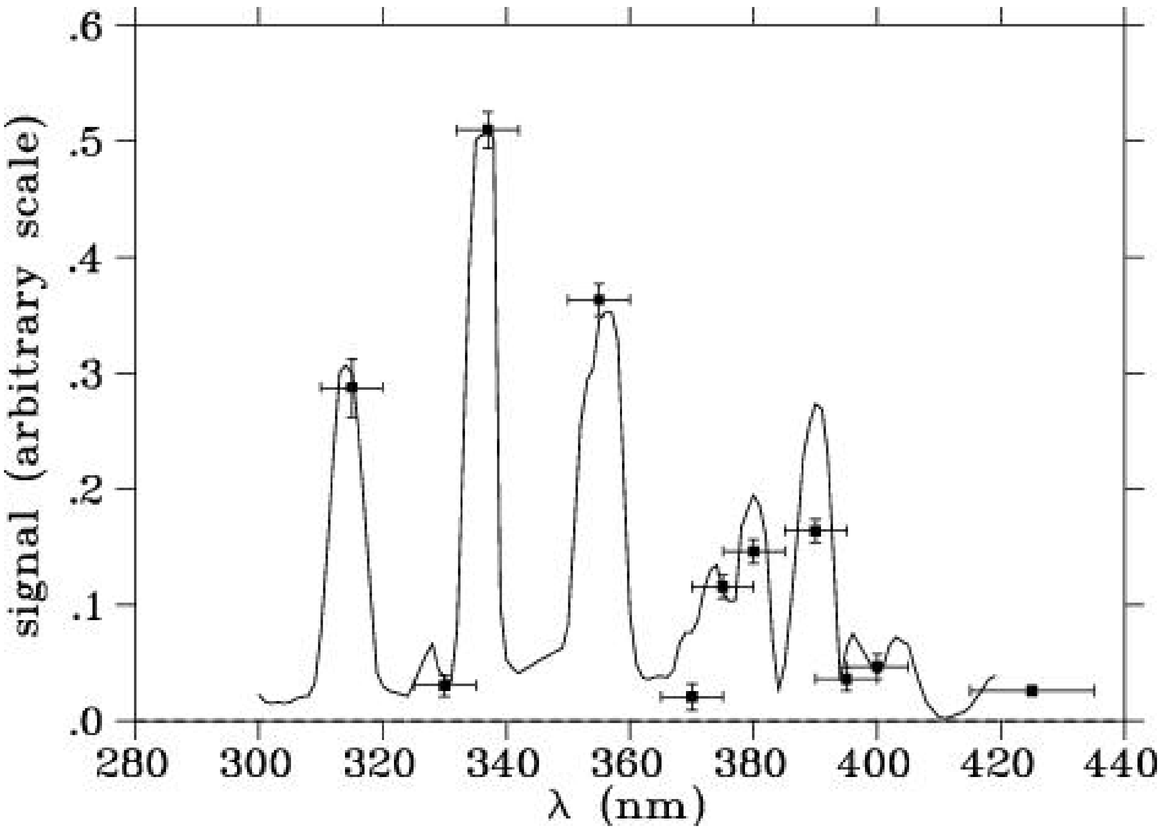


Simple Spectrum has problems!

In order to account for cross talk between filters (double counting) a simple “Monte Carlo” is used.

Guess the spectrum until it produces the ADC signals observed.

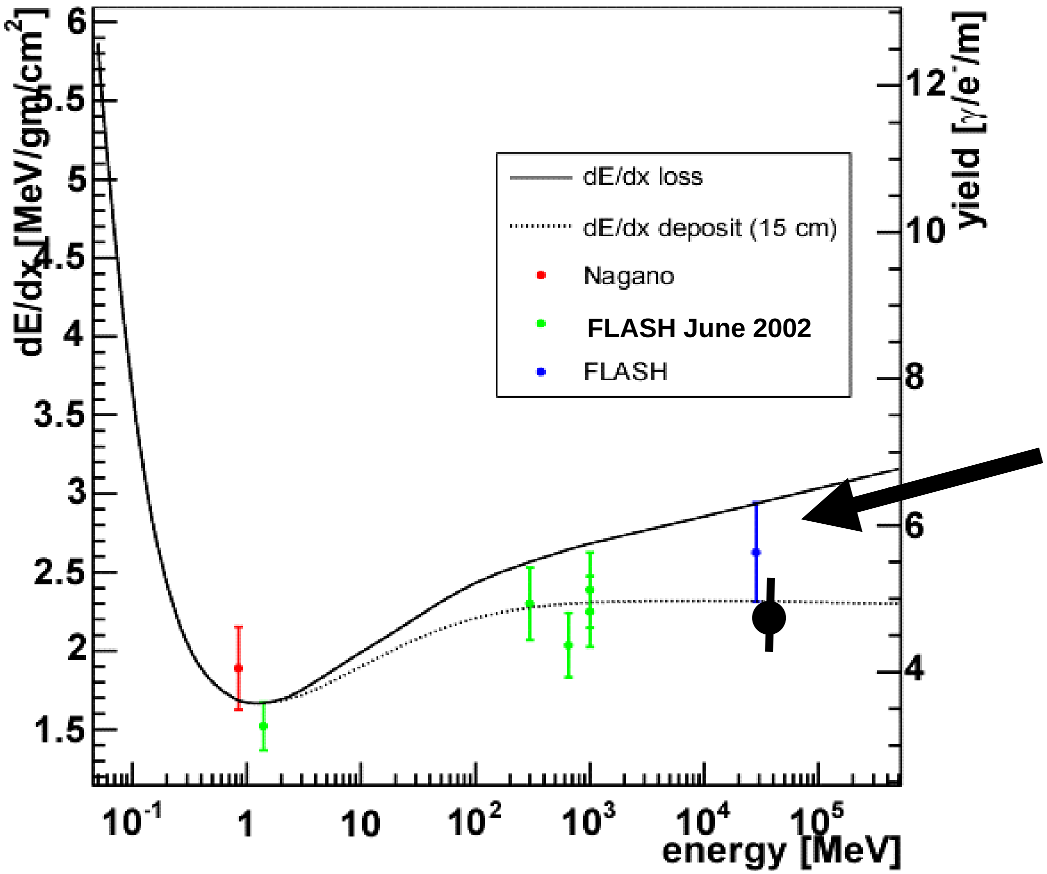
FLASH – Thin Target Spectrum



And the answer is…

- The yield in dry air (300 - 400 nm) is
  - 4.5 photons per meter per e^-.
- Including 296 and 425 lines yield is
  - 5.1 photons per meter per e^-.
- With this spectral shape assumption
  - the sum of the line strengths AND
  - the total yield as measured by HiRes and open filters agree within 1%.
  - Predicts both NB signals and total signal.

FLASH Results



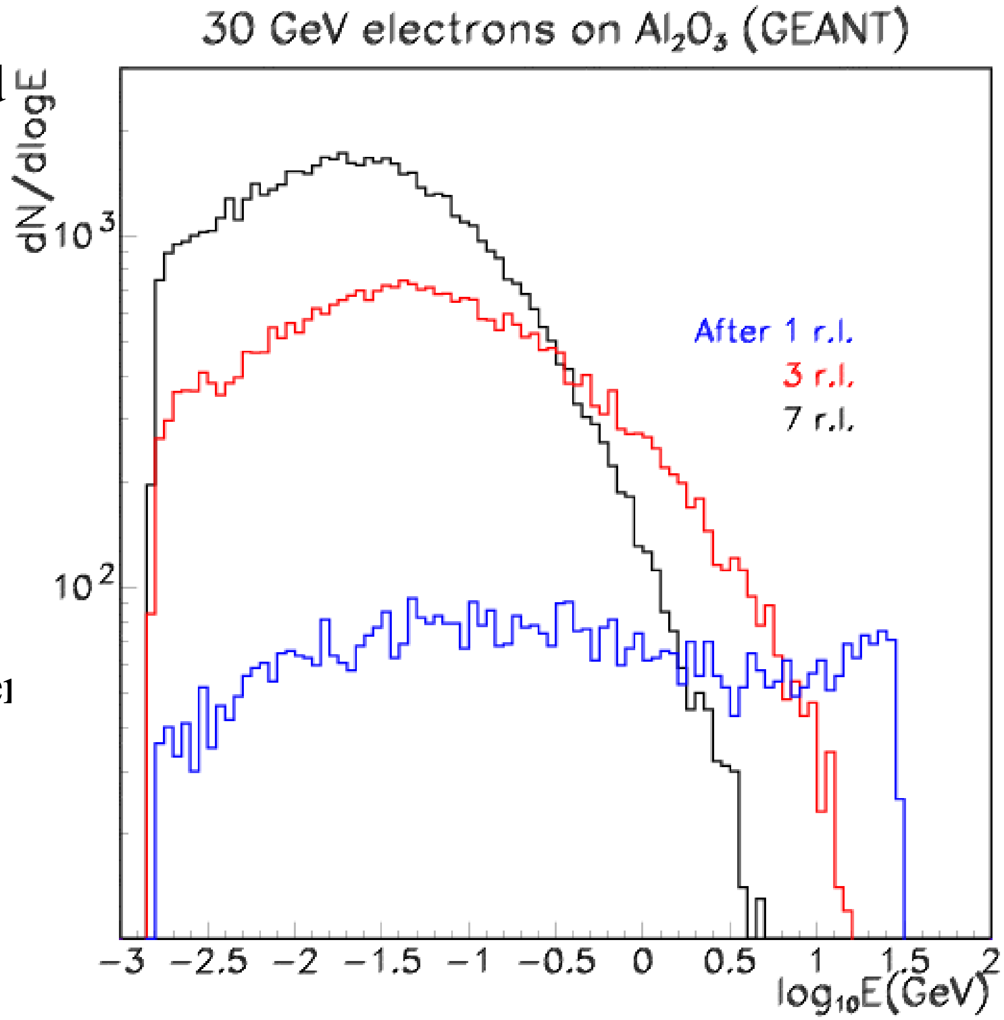
Toroid used in June 2002 recalibrated.

FLASH

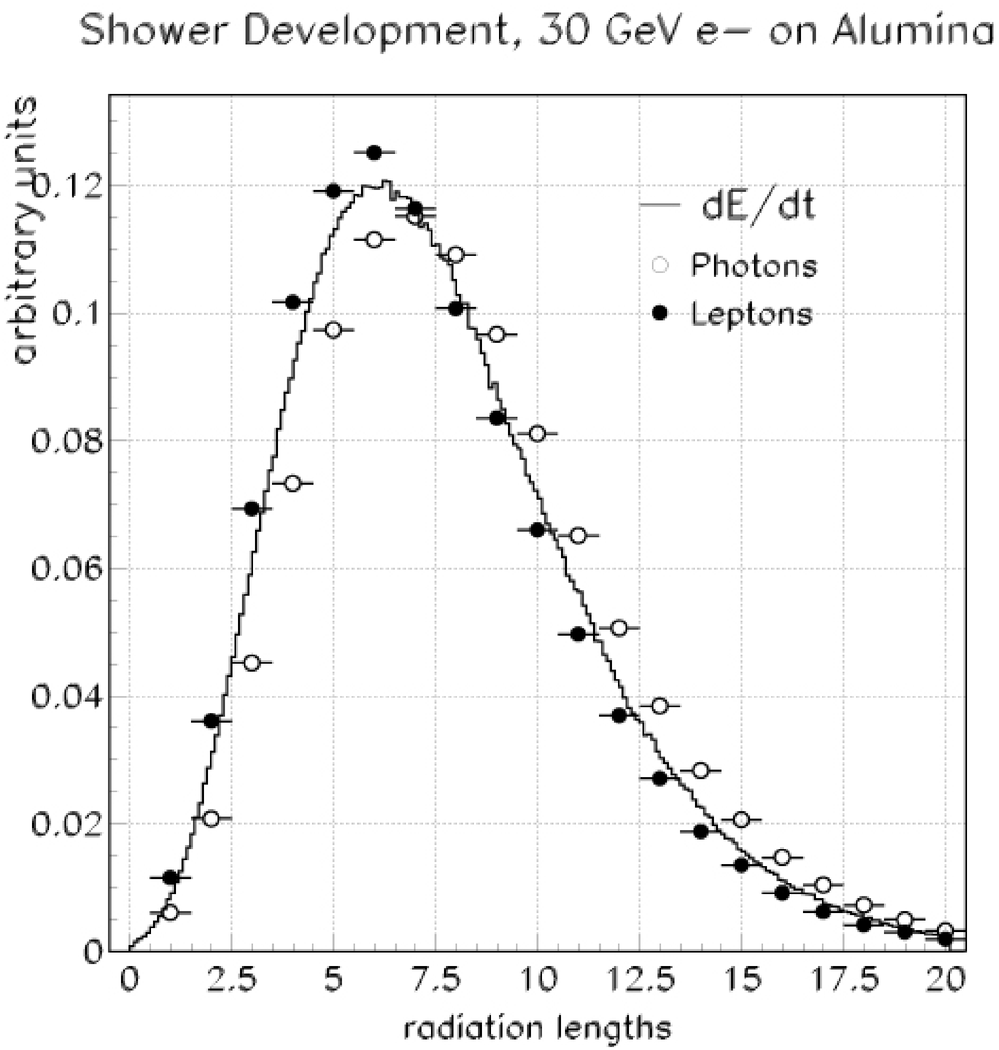
- FLASH Thick Target Experiment
- and Preliminary Results

Thick Target Run Motivation

- Understand how fluorescence yield depends on the incident particle energy, to ~100 keV.
- Check hypothesis that nitrogen fluorescence is proportional to energy deposition dE/dT; a key assumption in airshower modeling.
- Mean electron energies near shower max are very similar for 30 GeV electrons and 10^{19} eV protons: SLAC is the right location!

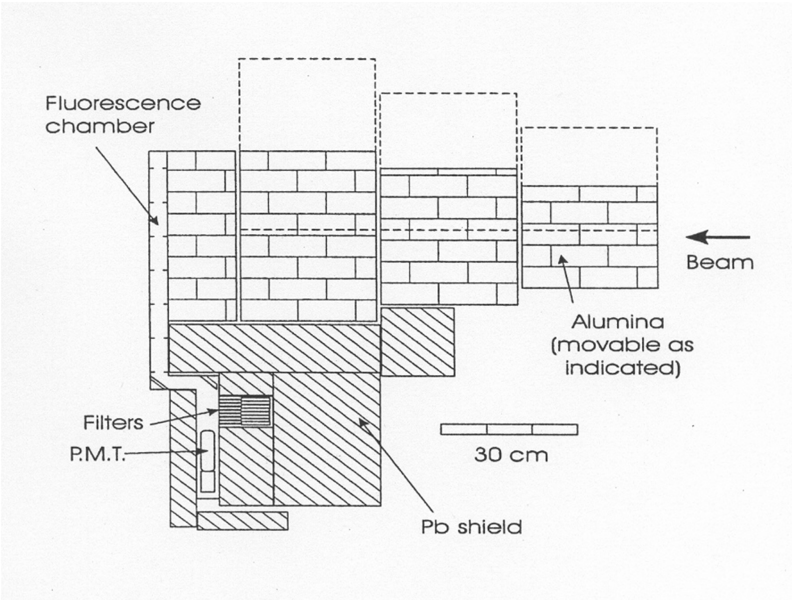


Thick Target Run Motivation

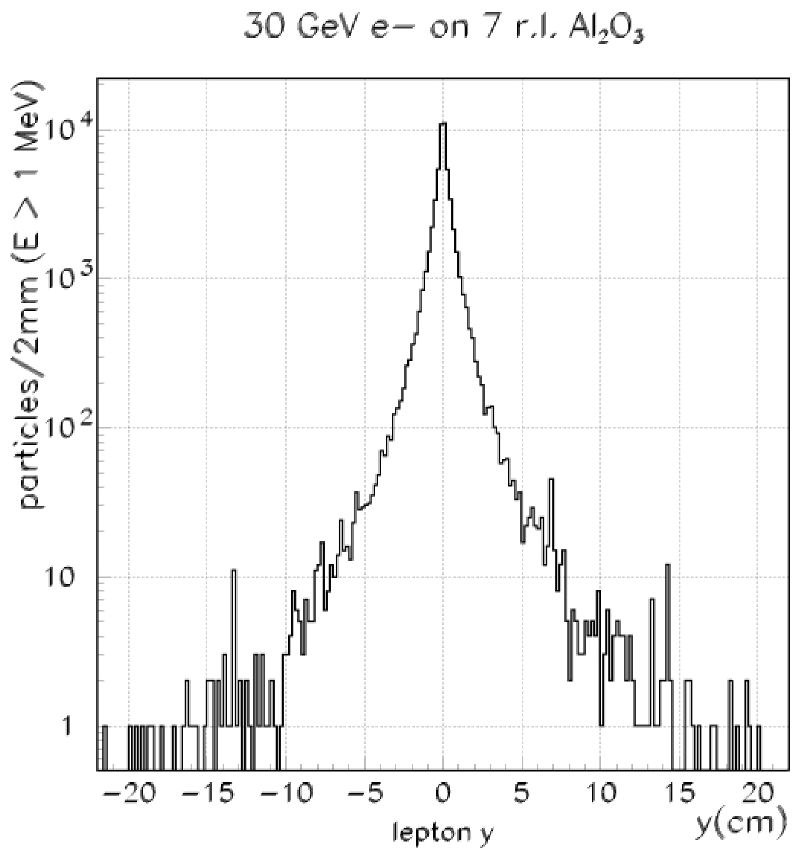


- Strategy: produce a shower with similar characteristics to electromagnetic airshower in the lab.
- Test observed yields against EGS and GEANT simulations, predicted energy loss curves.

Thick Target Vessel Design



- Goal: Sum fluorescence light produced in a "slice" of an EM shower.



- Even after shower max beam spot is fairly compact and can be contained in 50x50 cm^2 detection region

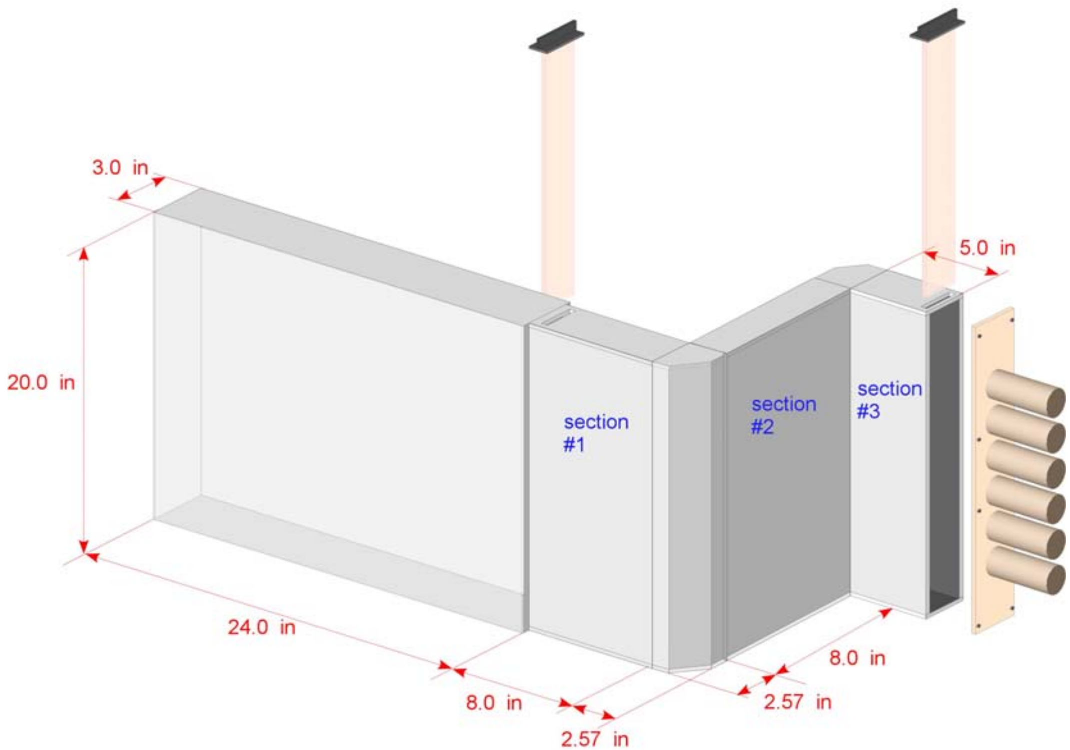
Thick Target Vessel Design

• Reduce scattered and non-fluorescence (Cherenkov) contributions to collected light

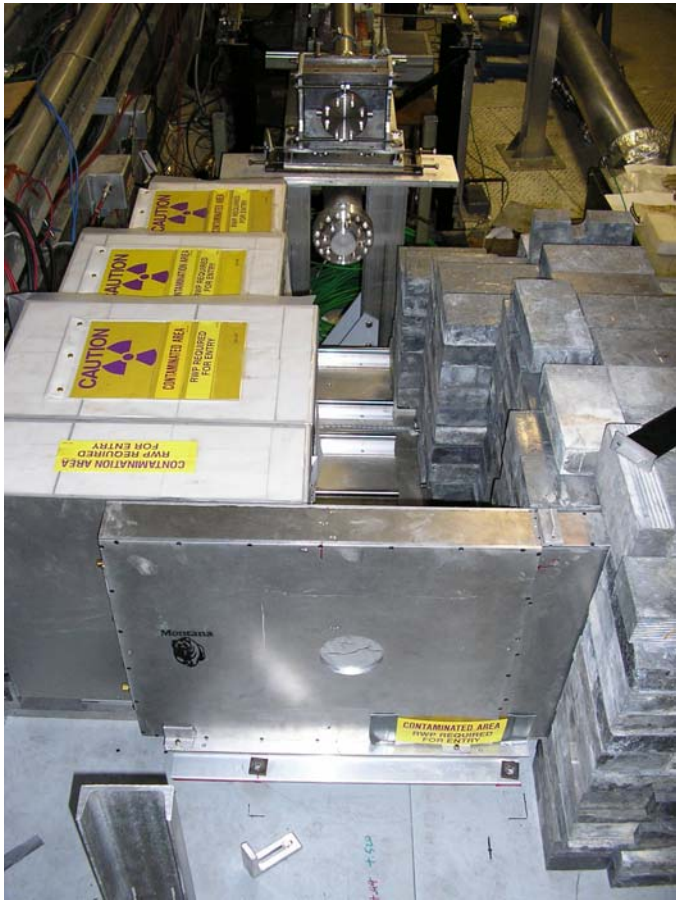
• Reduce backgrounds from stray particles hitting light detectors

• Drop-in mechanical shutter, (background studies) and filter holder.

Flash thick target vessel design



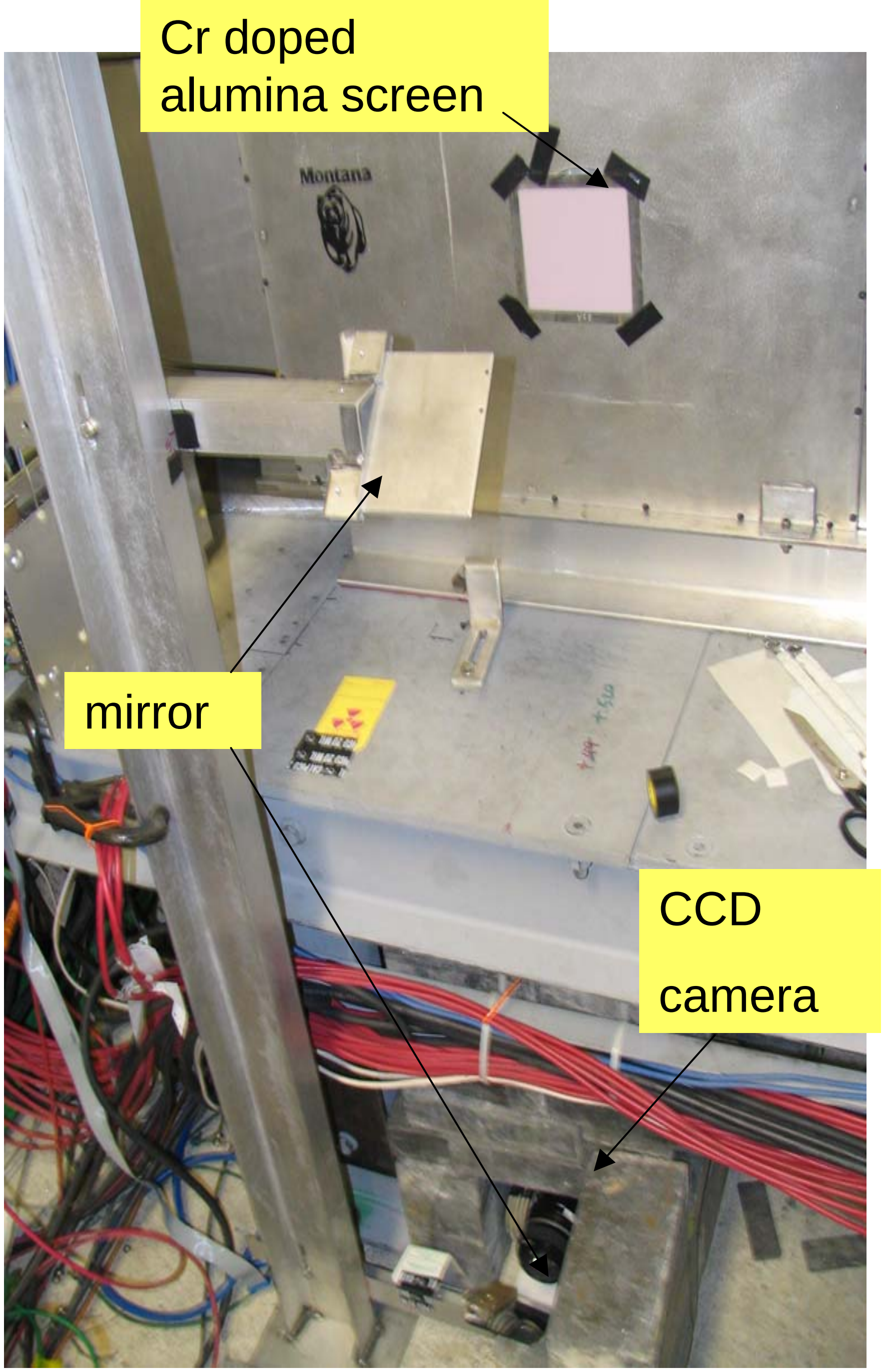
Thick Target Fluorescence Chamber *in situ*



Other Measurements; Ion Chamber

- Direct measurement of ionization produced by beam particles.
- Collected simultaneously with fluorescence data; important crosscheck of data and simulation.

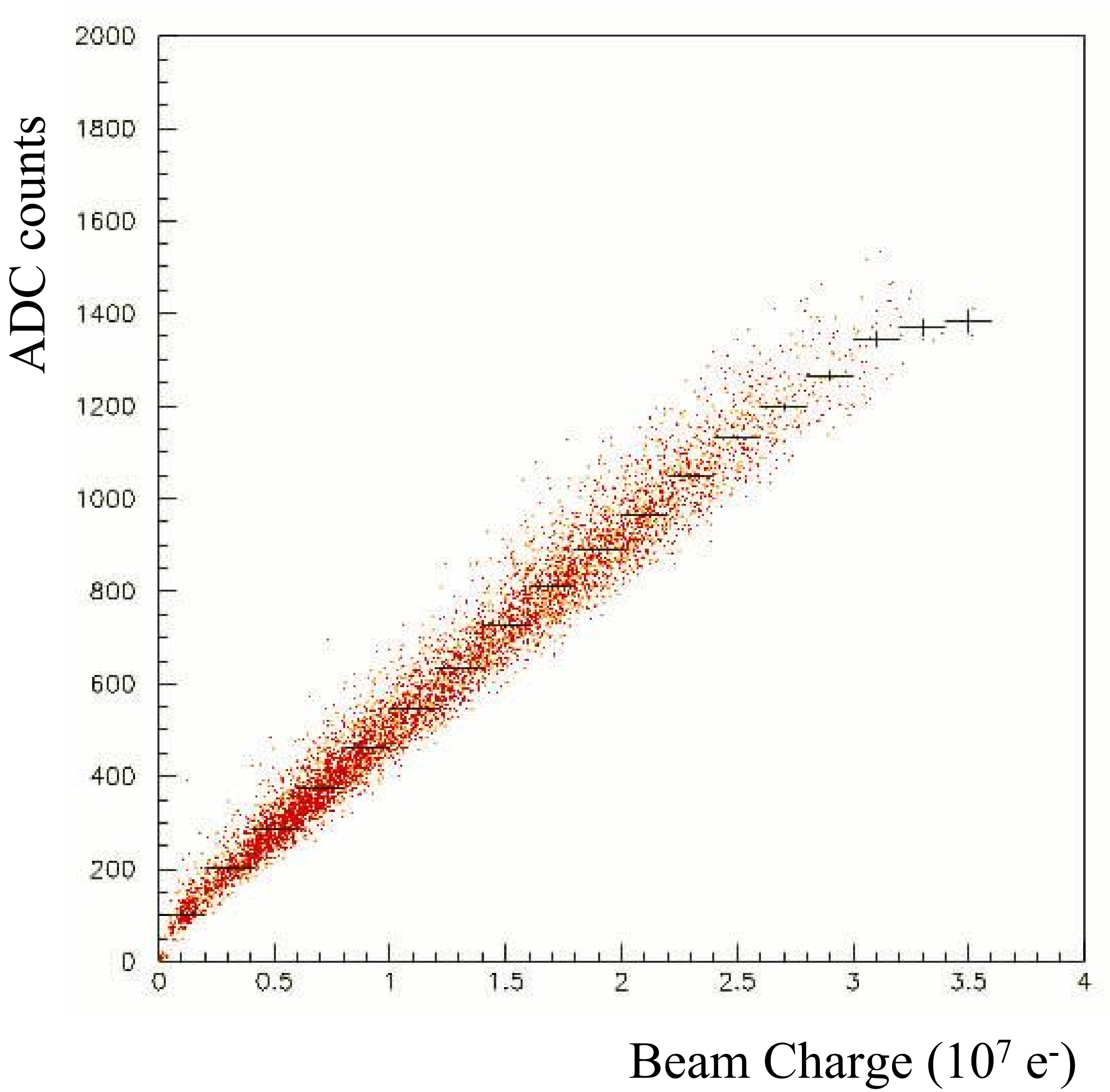
Other Measurements; Lateral Profile with Diamond Pixel Detectors



Other Measurements;

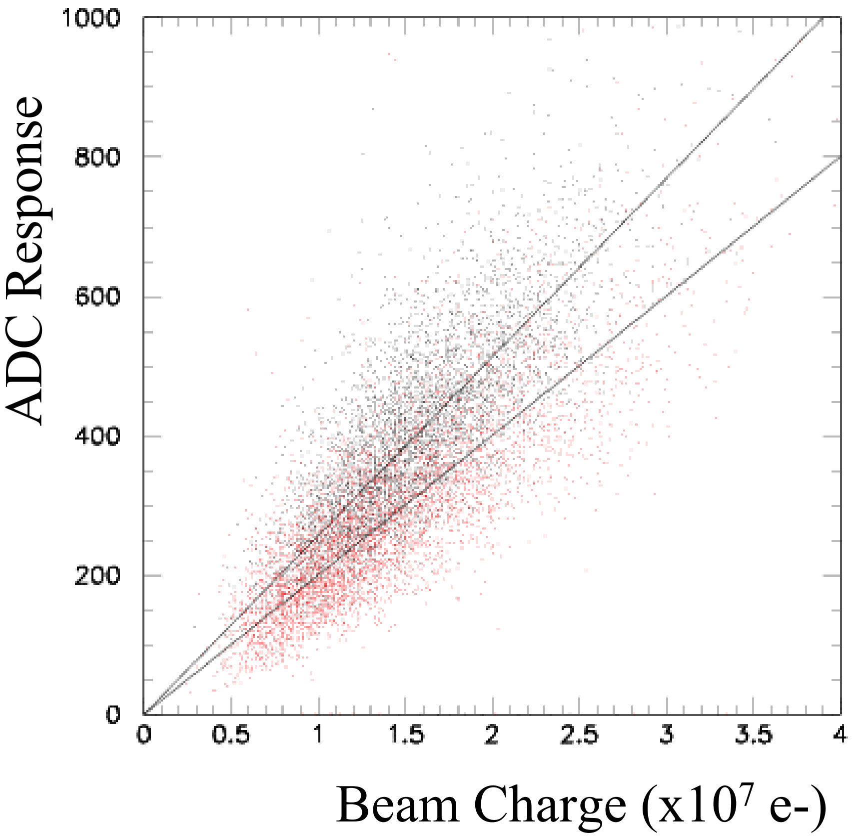
Scintillation Screen and CCD Camera for lateral shower profile measurement.

Fluorescence Vessel Data

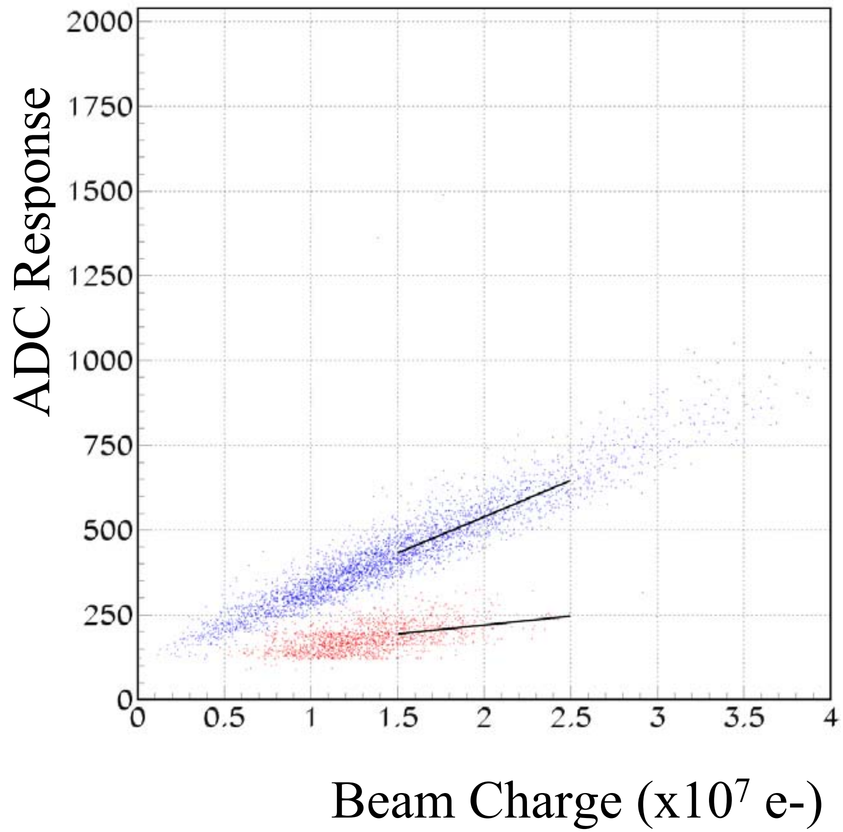


- PMT ADC Counts vs. Beam Charge
- Fit slope in linear region
- Note:
  10^7 30 GeV electrons = $3x10^{17}$ eV airshower.

Signal to Noise: Shielding Effects



6/16/04 @14 r.l.
s/n = 0.1



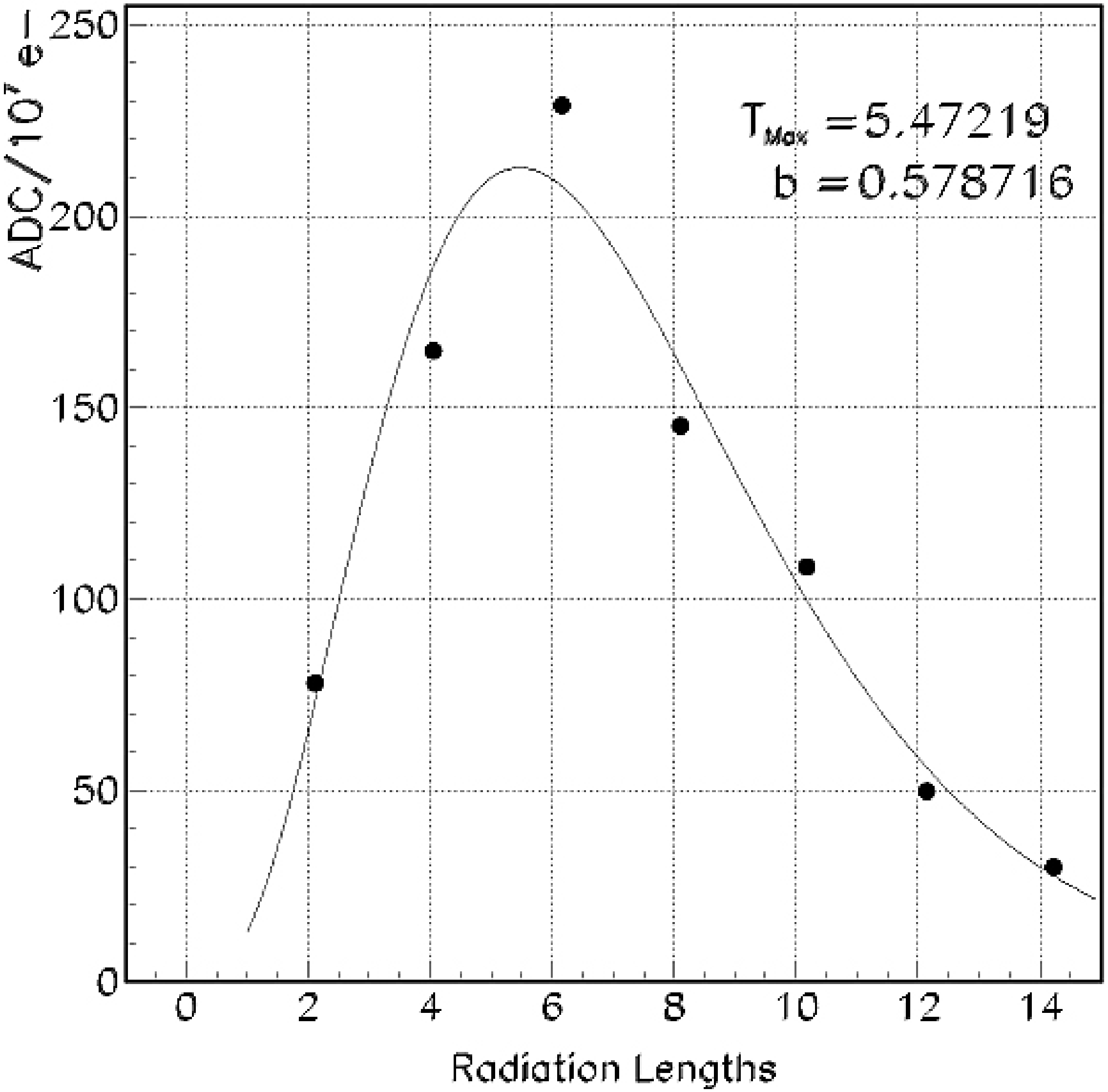
6/21/04 @14 r.l.
s/n = 4

Longitudinal Profile: First Attempt

- Light yield as a function of Al_2O_3 radiation lengths. Average over five series of runs.
- Statistical uncertainty smaller than points.
- Curve:

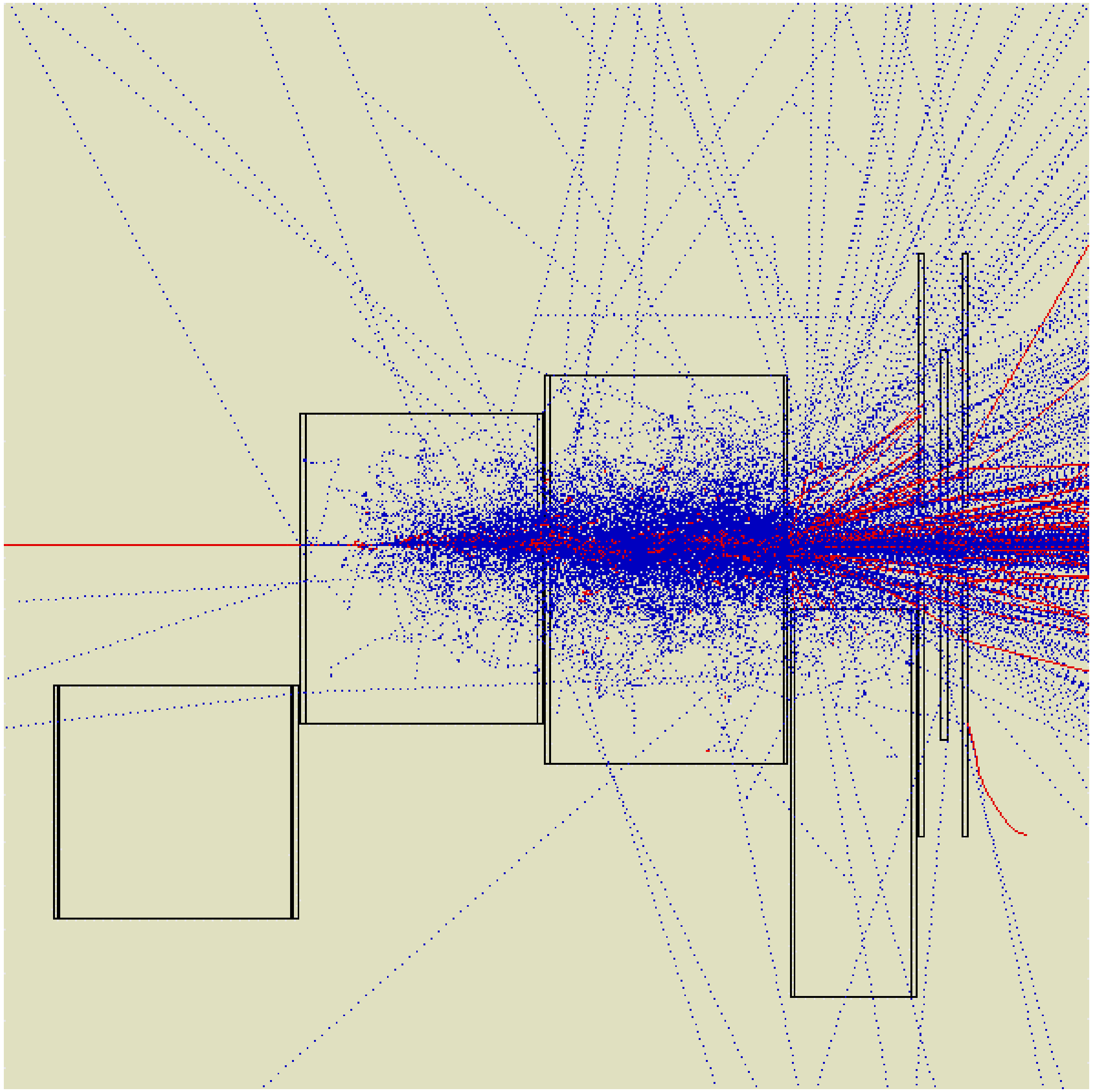
$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

- Points at 4, 8, 12 r.l. systematically low?



What’s happening?

- Light yield is low at 4, 8, and 12 r.l.
- The 2 R.L. alumina mover “shadowed” fluorescence vessel.
- Dispersion of beam also produced additional signal loss.
- Well modeled in GEANT!



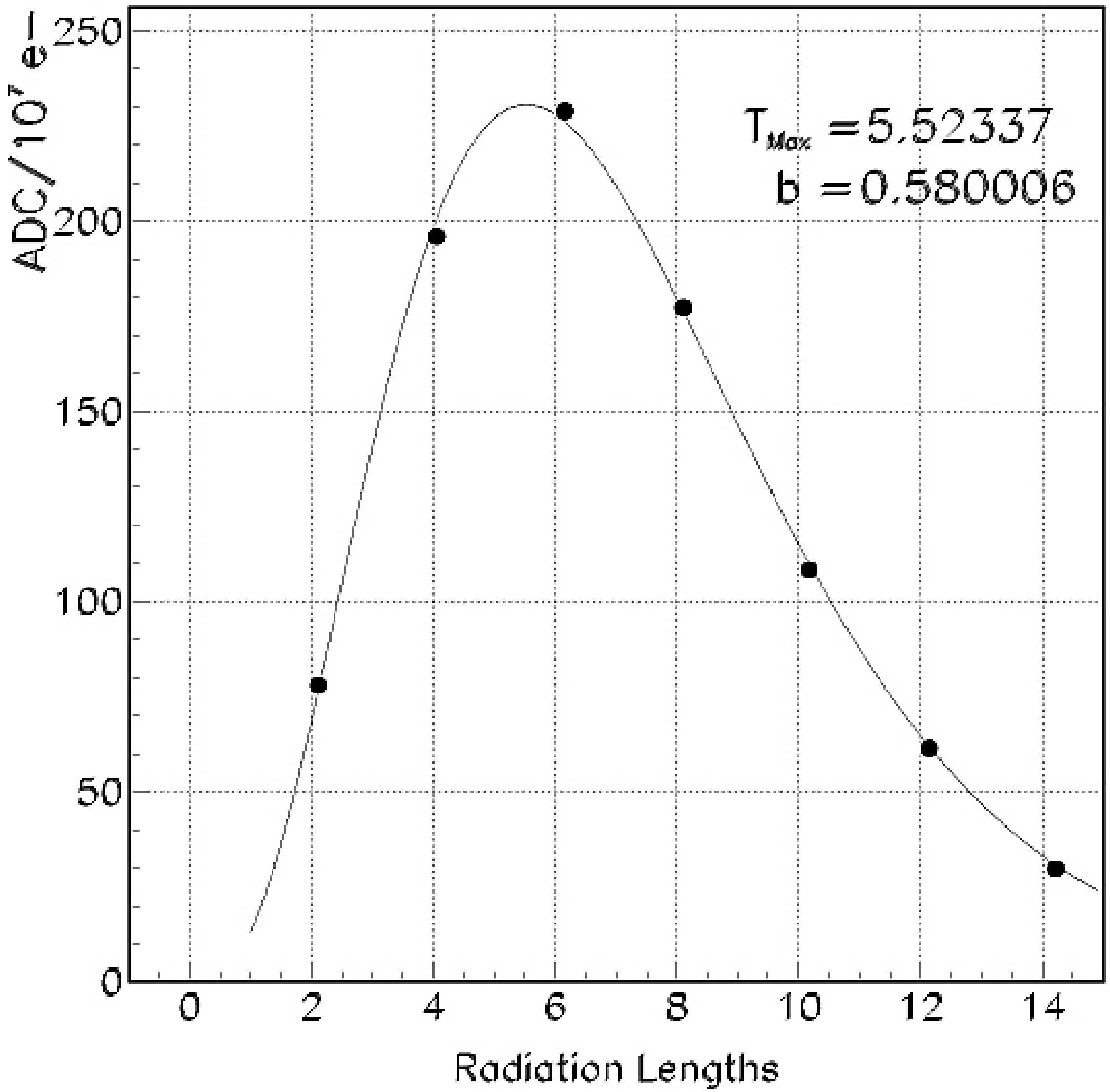
Corrected Longitudinal Profile

- Light yields at 4, 8, 12 r.l. rescaled with geometrical correction factor, derived from GEANT 3.2 lepton counting.

- Fit dE/dT shower max at 5.5 radiation lengths agrees well with critical energy model prediction.

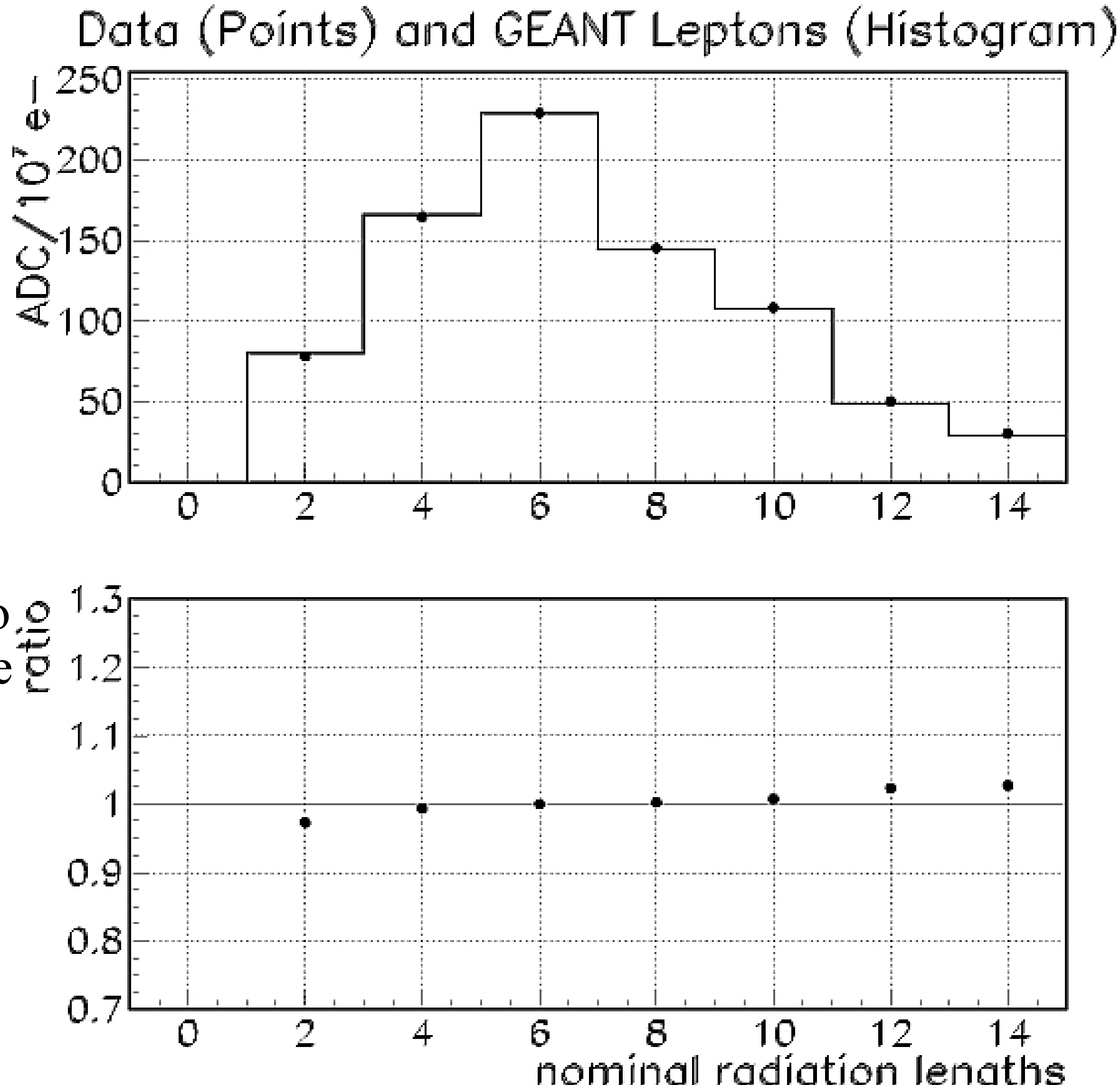
- Curve:

$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$



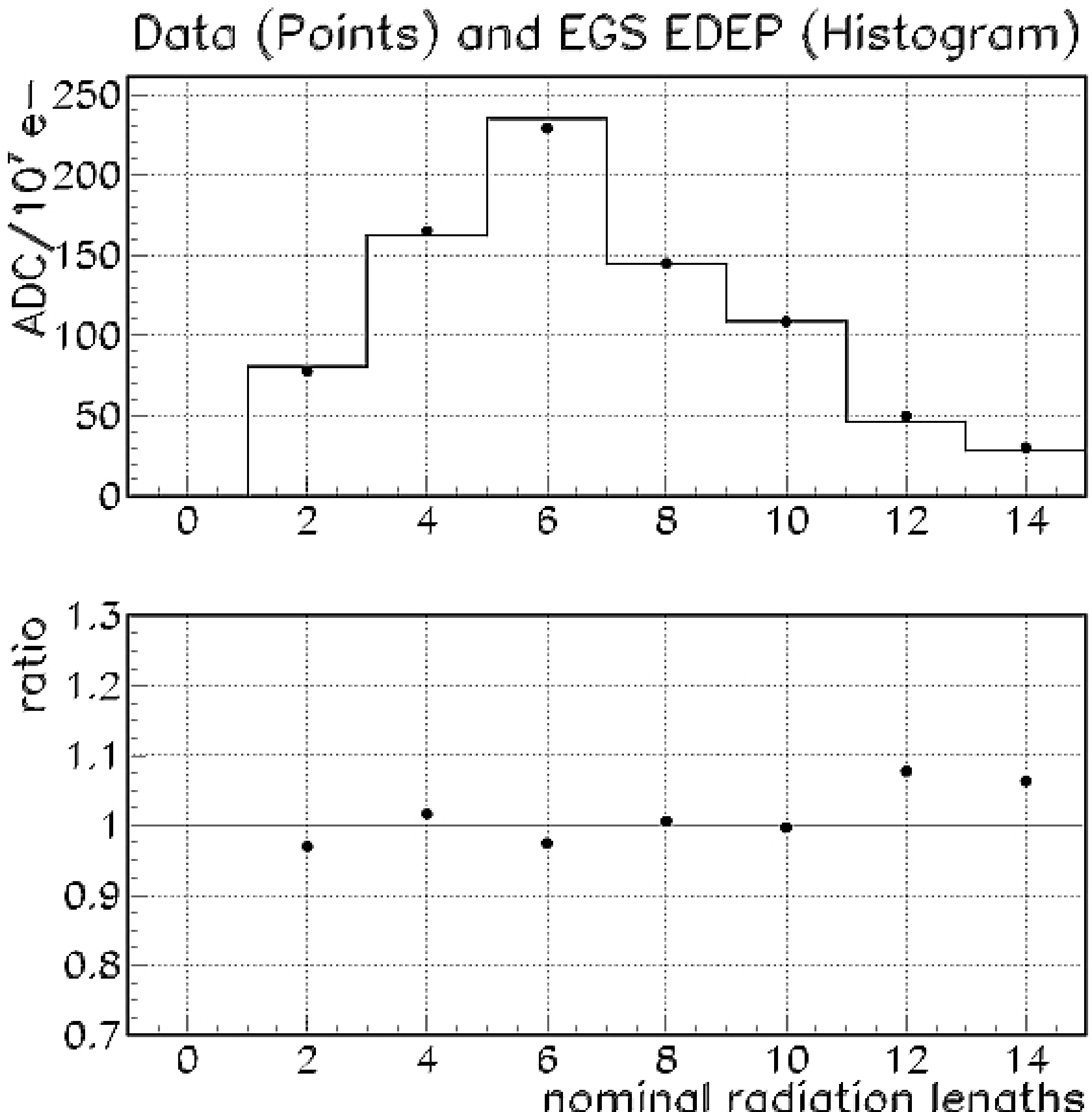
Comparison to GEANT 3.2

- Overlay fluorescence data with GEANT e^+e^- counts as function of depth.
- Areas under curves normalized
- Small slope expected due to differences between particle and energy deposition distributions.

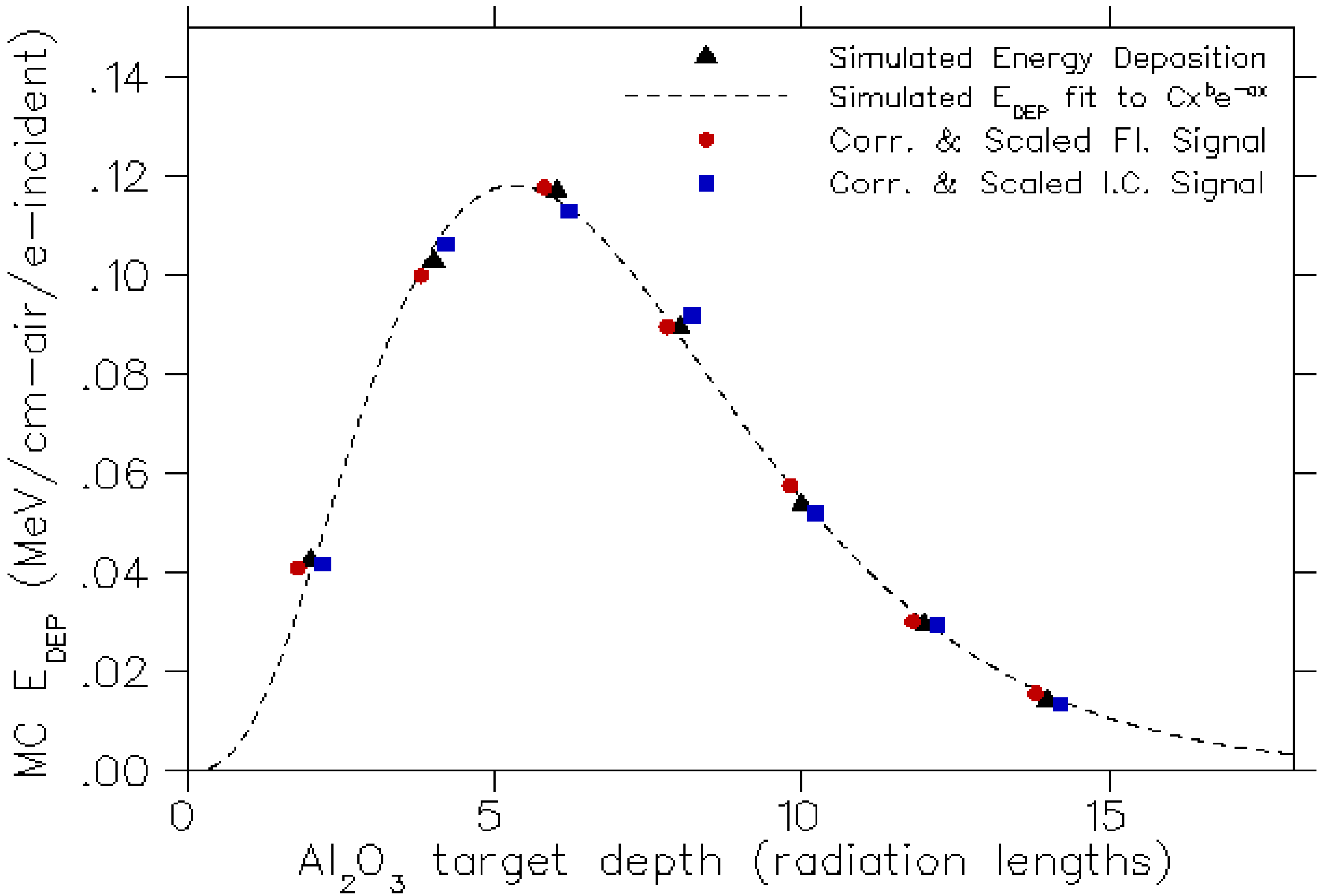


Comparison to EGS

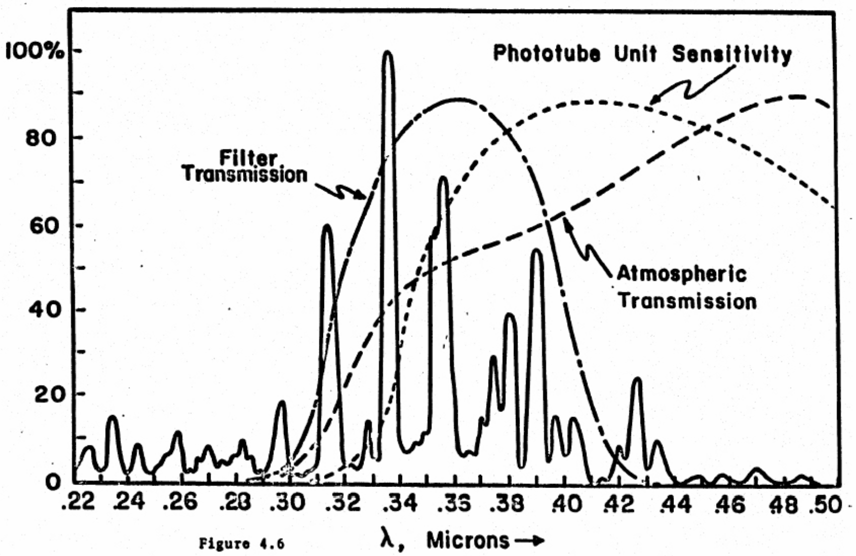
- Overlay fluorescence data with EGS energy deposition.
- Areas under curves normalized
- Larger ratio at 4,8,12 due to residual geometric effects?



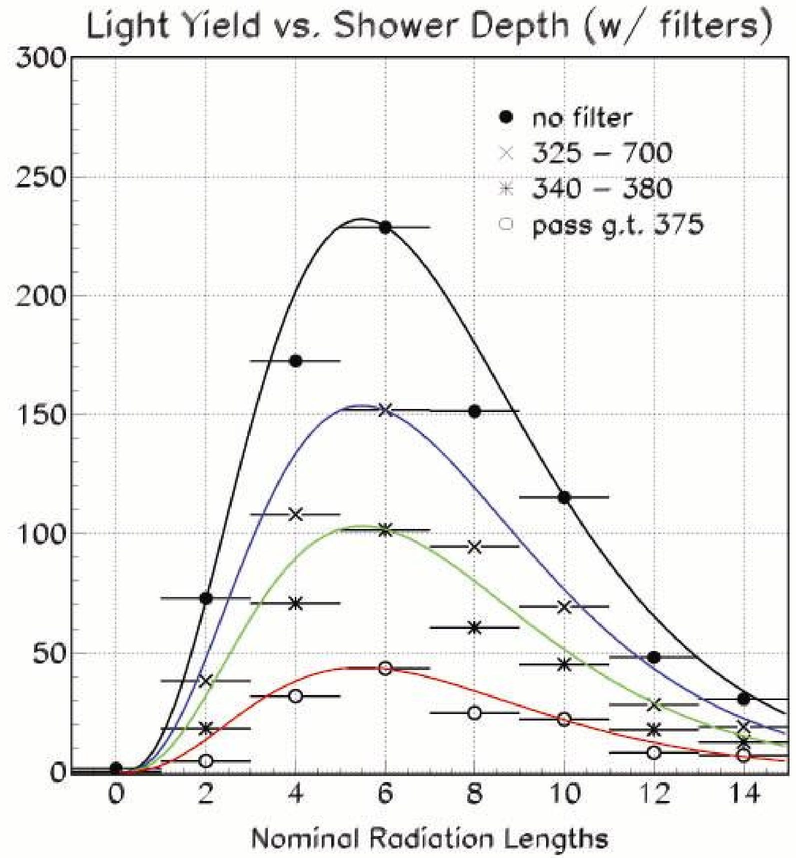
Ion Chamber: Comparison with Fluorescence Yield



Light Yield Using Various Band-Pass Filters

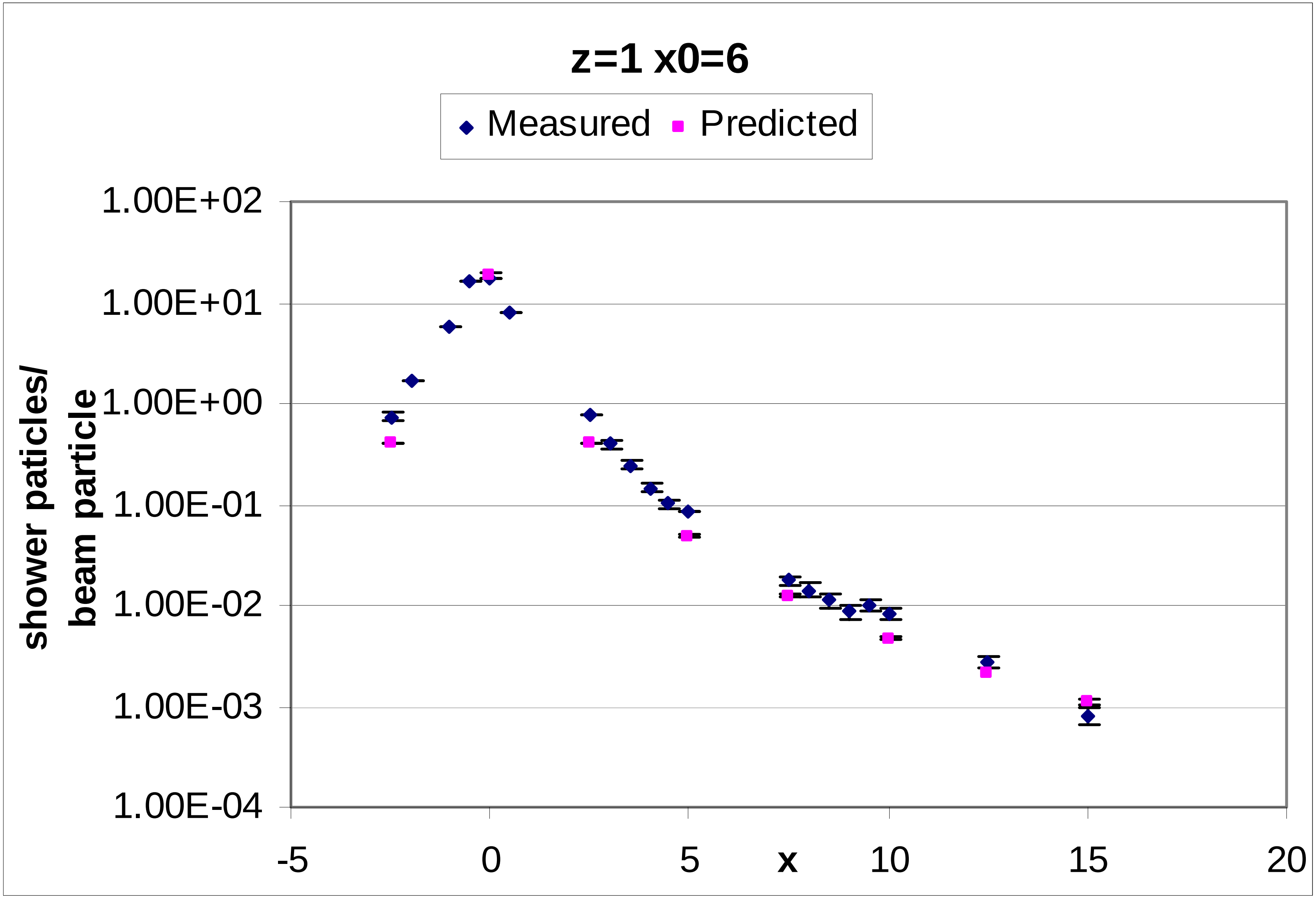


- Using band-pass filters, we can isolate the contributions of several different wavelength bands to the overall light yield.



- Analysis in progress, but results so far consistent with expectations.

Diamond Detector Profile; Z=1 x0=6



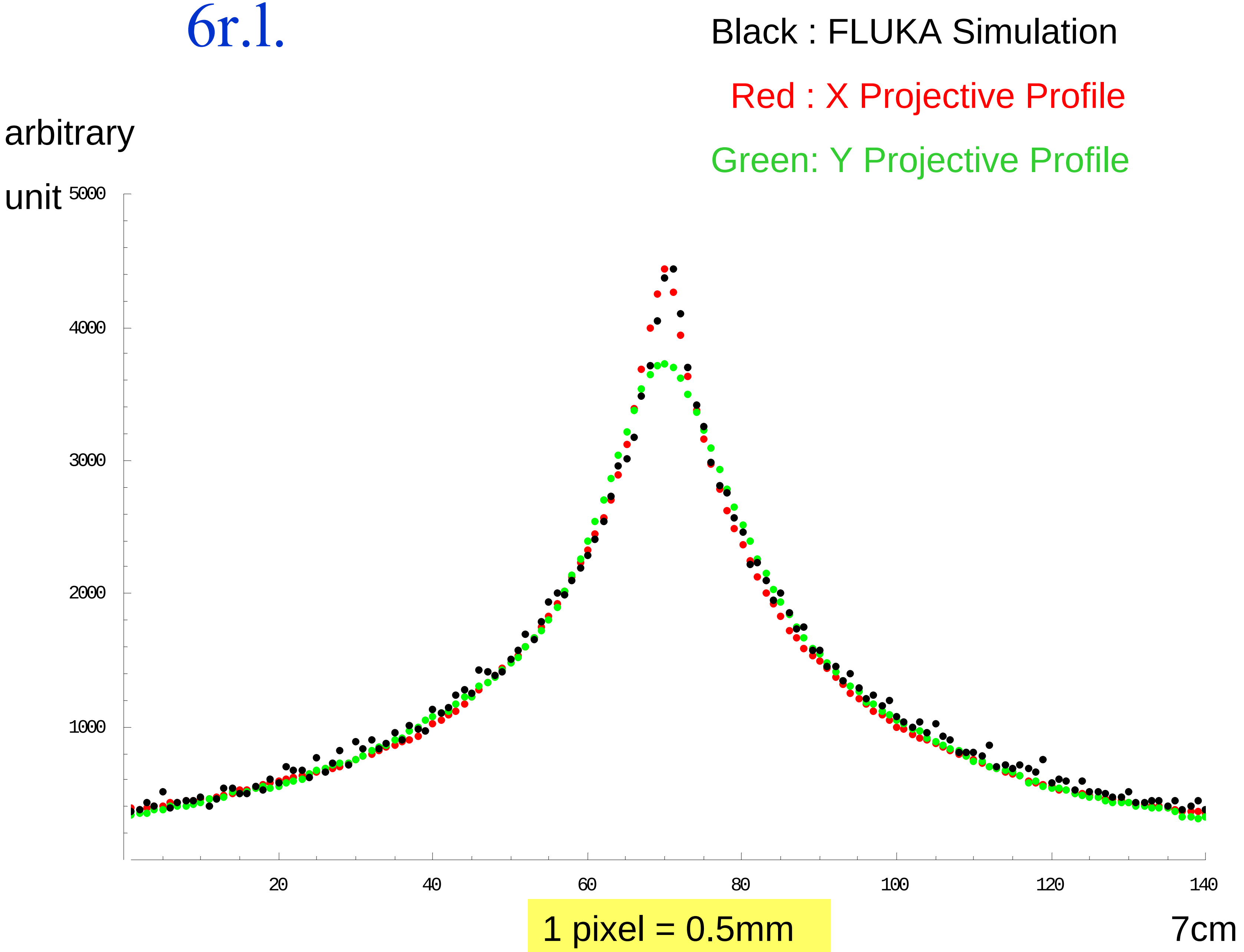
Diamond Shower Profile Conclusions

- Overall, the data at x=0 is consistent with predicted values (ratio ~1)
- Also, the predicted values at positions other than x=0 are consistently less than the measured data (ratio ~0.5 to 0.6)
- At the moment, we do not fully understand either of these results, but suspect they can be attributed to
  - nonlinearity of the diamond at position x=0
  - beam position fluctuations
  - diamond cross calibration

CCD Camera Lateral Shower Profile Measurements

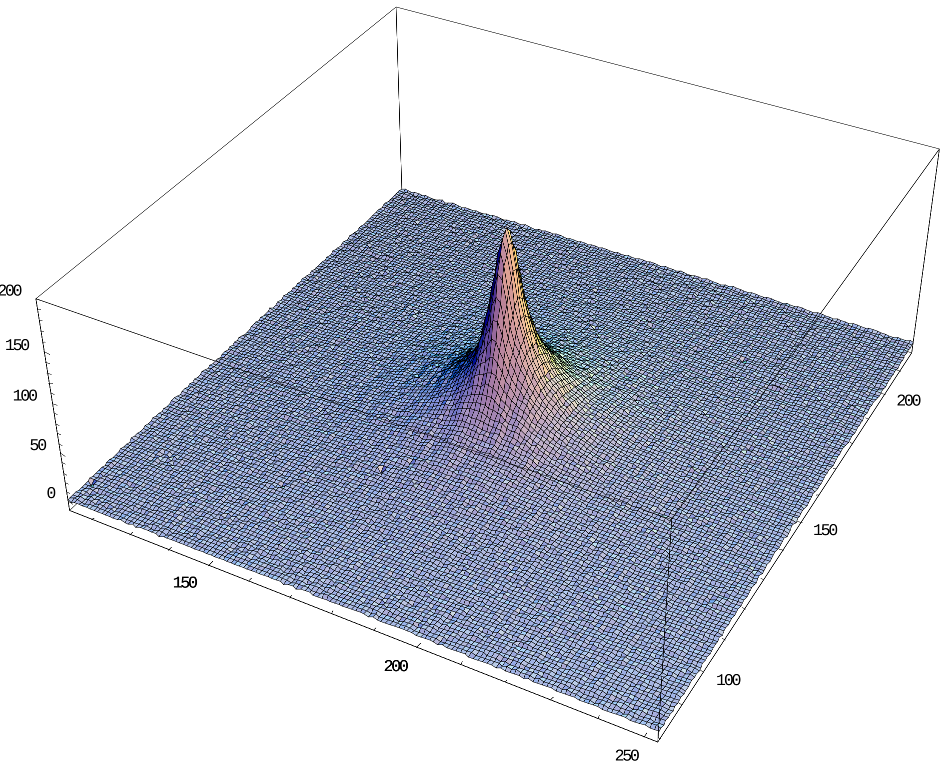
- Chromium-Doped scintillator screen in path of shower particles.
- Scintillation light recorded by CCD camera.
- Provides direct measure of shower lateral profile, compare with FLUKA simulation package.

6r.l.

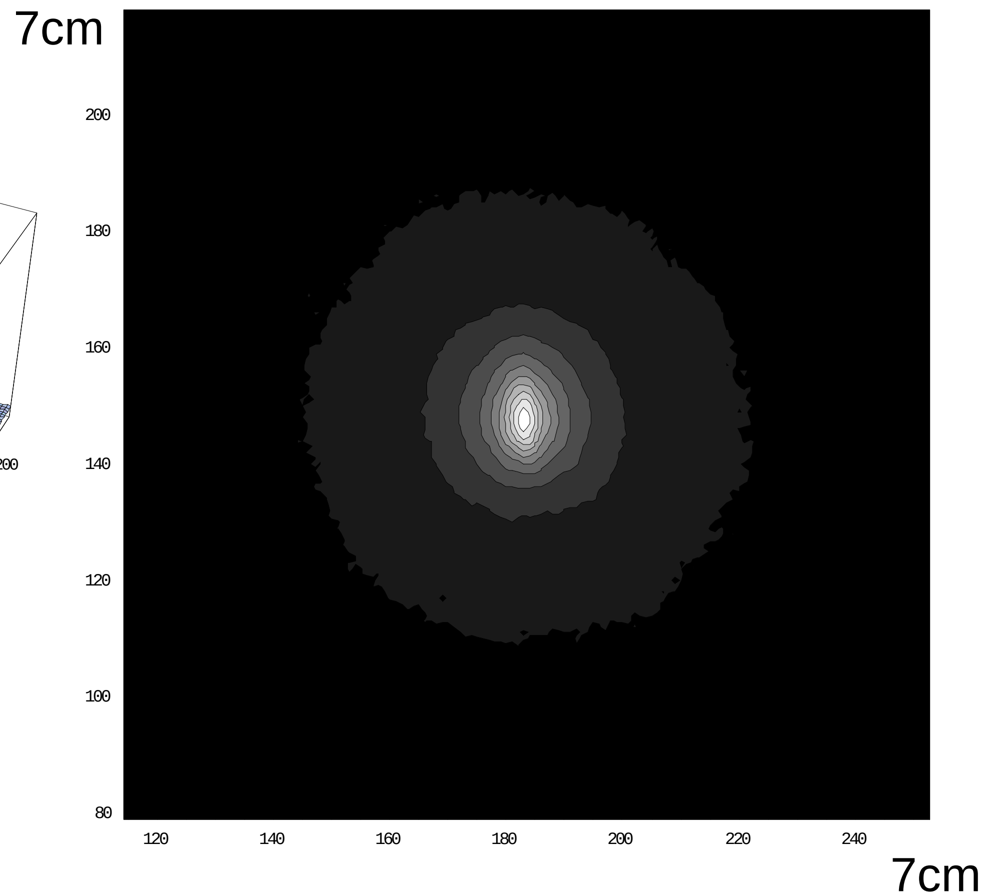


Black : FLUKA Simulation
Red : X Projective Profile
Green: Y Projective Profile
arbitrary
unit
5000
4000
3000
2000
1000
20
40
60
80
100
120
140
1 pixel = 0.5mm
7cm

6r.l.

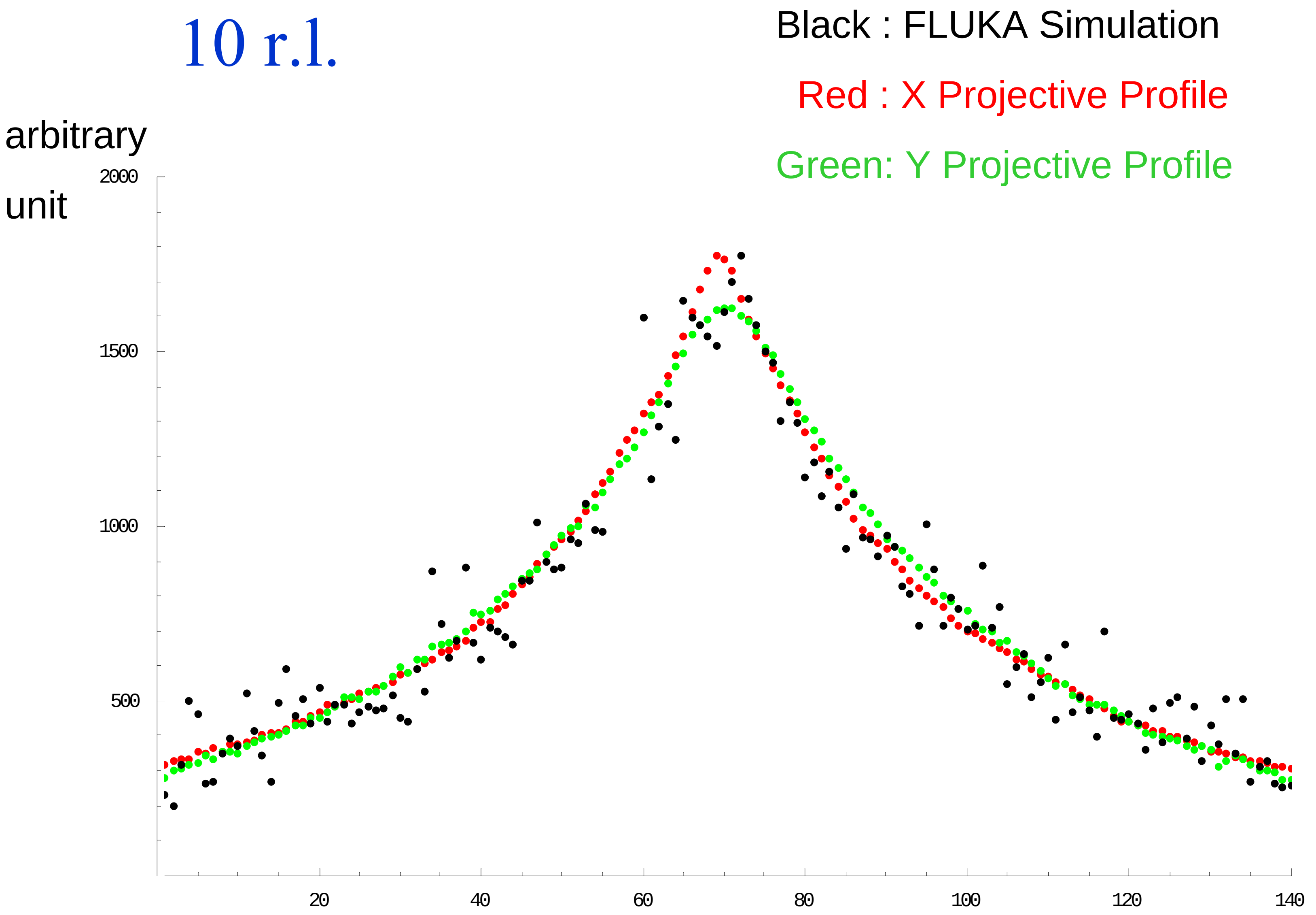


200
150
100
50
0
150
200
250
100
150
200



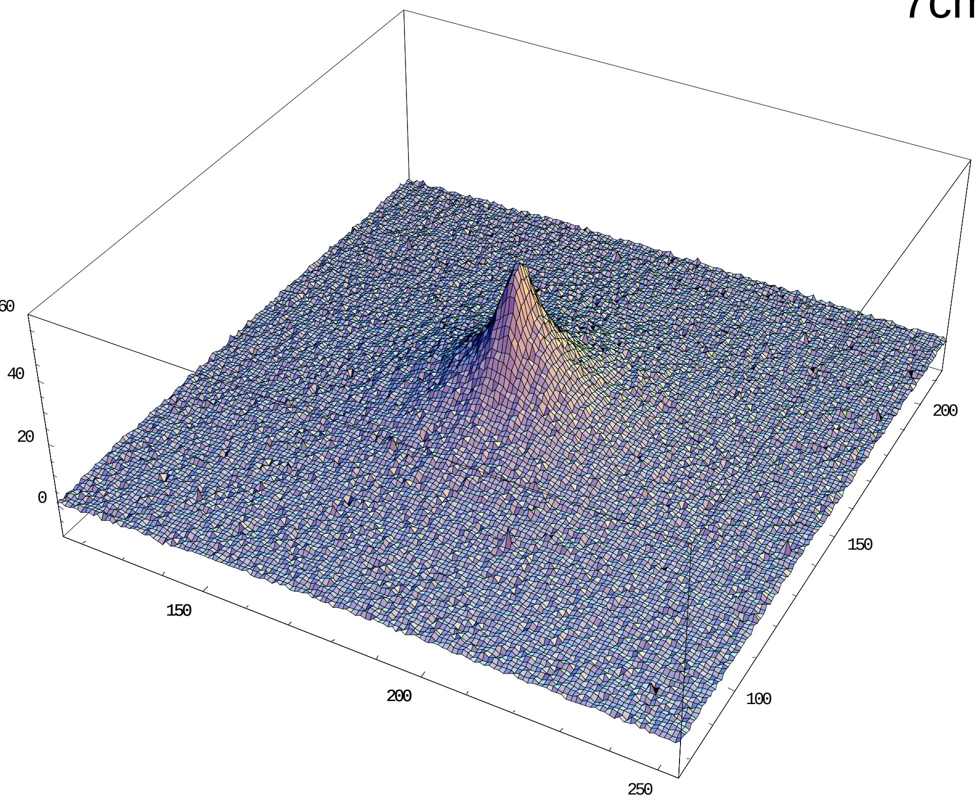
7cm
200
180
160
140
120
100
80
120
140
160
180
200
220
240
7cm

10 r.l.

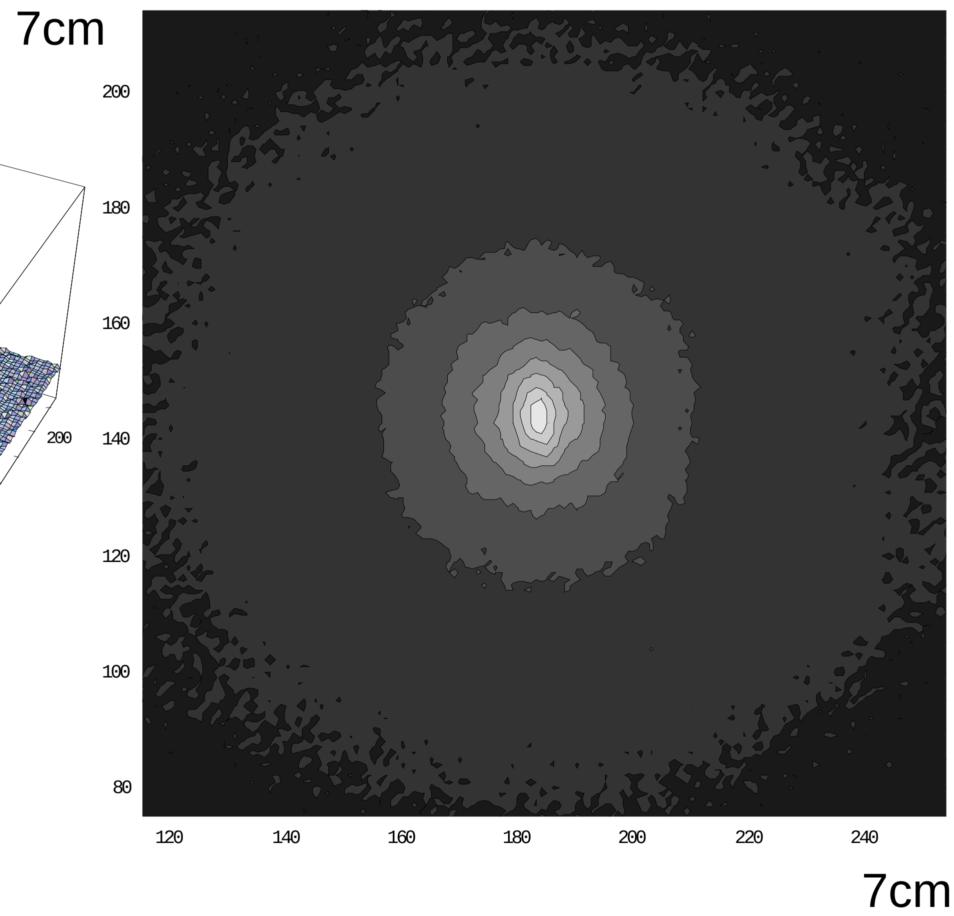


1 pixel = 0.5mm

10r.l.



60
40
20
0
150
200
250
100
150
200



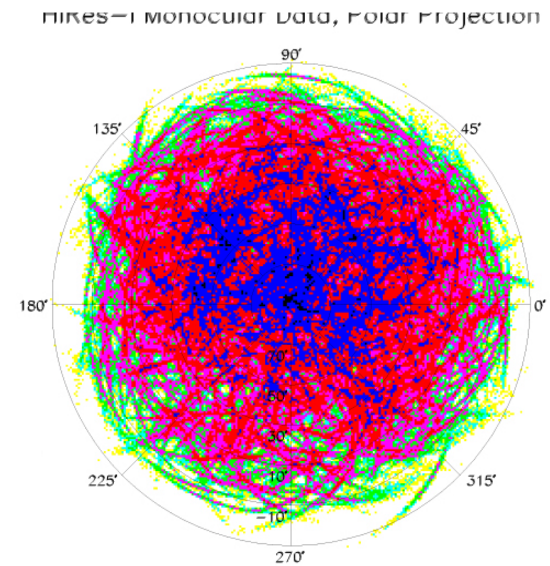
7cm
200
180
160
140
120
100
80
120
140
160
180
200
220
240
7cm

FLASH Thick Target: Conclusions

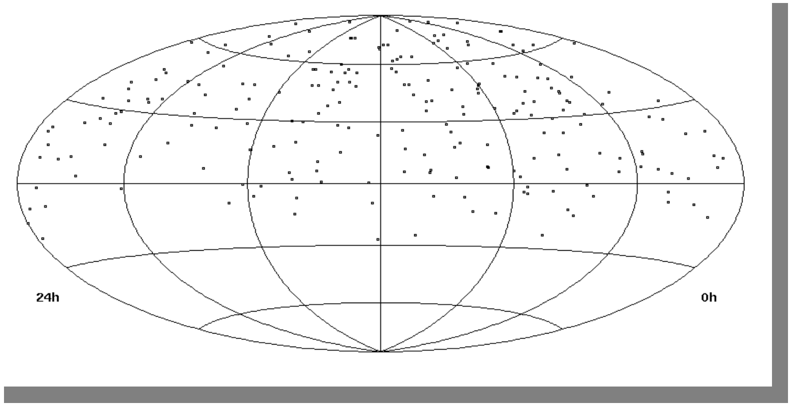
- Good data collected in thick-target mode summer 2004!
- Preliminary analyses indicate the results are well understood:
  – GEANT and EGS good predictor of fluorescence and ion chamber longitudinal signals.
  – Fluorescence yield shows good agreement with empirical dE/dt model.
  – Band-pass filter data still under study.
- Lateral profile measurements from diamond pixel detectors and CCD camera system. Continuing work to understand profiles in context of shower simulation software.

Anisotropy Searches

- HiRes1 mono anisotropy:
  asymmetric error bars,
  7x0.5 deg. sq.,
  area=14 deg. sq.

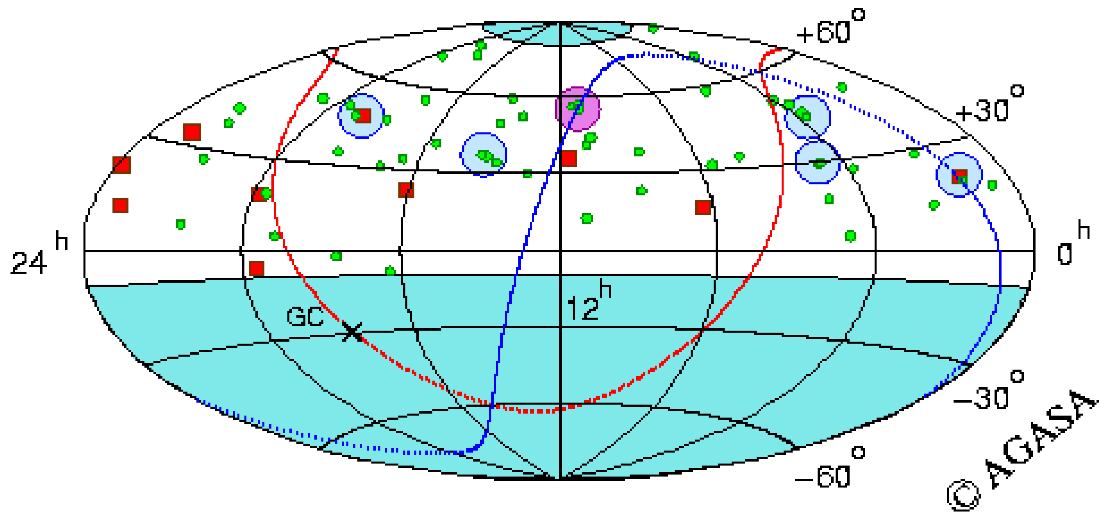


- Stereo anisotropy:
  tiny error bars:
  0.5x0.5 deg. sq.,
  area=1 deg. sq.



- AGASA events:
  area=20 deg.sq.

AGASA small-scale clustering

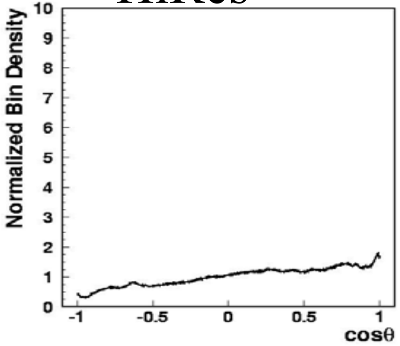


Anisotropy Searches: Autocorrelation

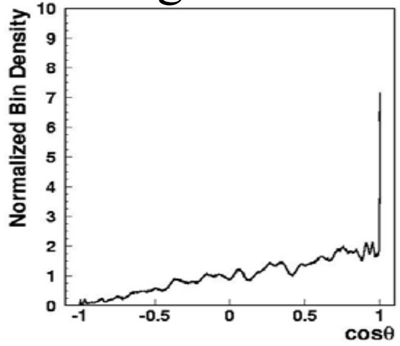
- HiRes1 mono autocorrelation:

  None seen.

HiRes

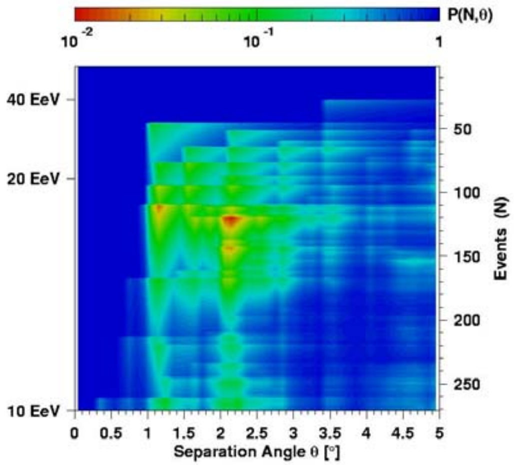


Agasa



- Stereo autocorrelation: scan in energy and angular scale.

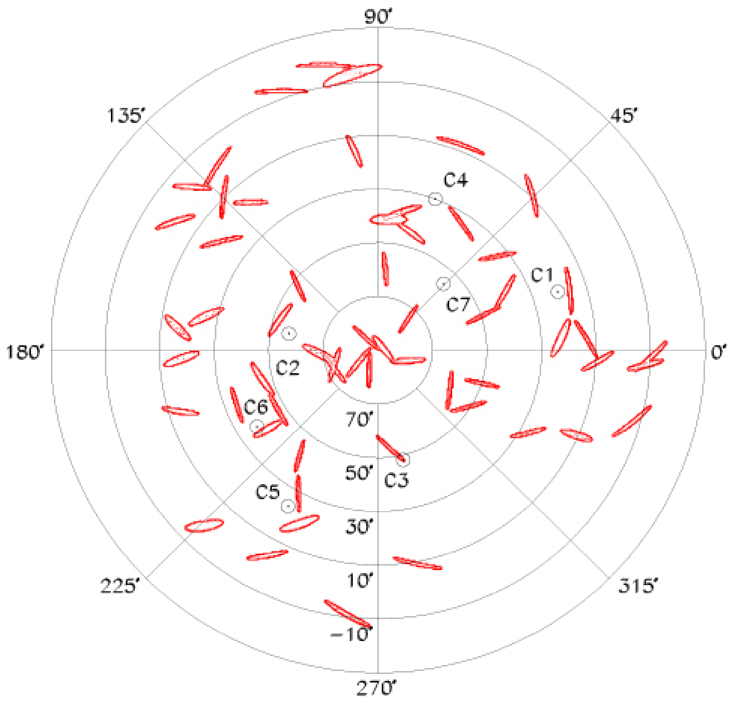
  None found: most significant point has P_{chance}=.52



Search for Sources of Constant Intensity

- Promote the 6 Agasa clusters to be **sources** of UHE cosmic rays.
- We should see them too.
- Search for HiRes1 mono overlaps at 3 sigma, find 5 events, expect 4.2 randomly.
- Consistent with chance overlaps.
- Joint probability is 0.0013
- The 6 Agasa clusters are NOT sources of constant intensity.
- Caveat: if 2 Agasa clusters are of random origin, then joint probability is 0.010

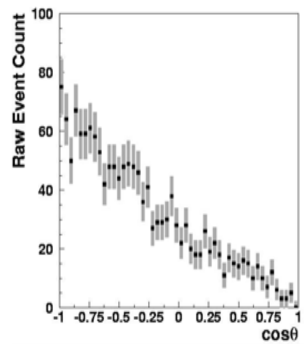
- Stereo analysis under way.

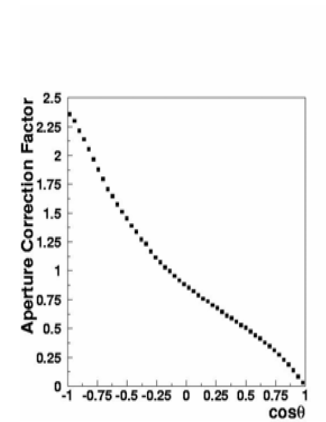


Large Scale Anisotropy Search: Dipole Enhancement

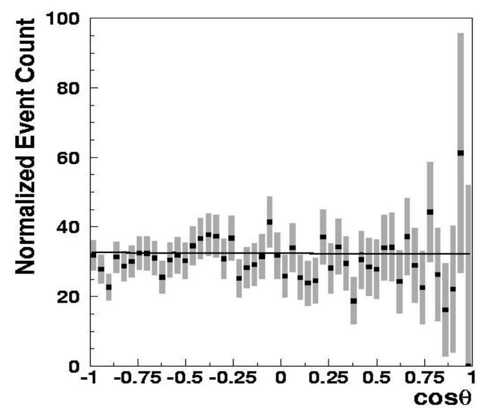
(suggested by Biermann *et al.*, and Farrar *et al.*)

$$n=\frac{1}{2}*\square\frac{\alpha}{2}\cos\theta$$





Source Location	α
Galactic Center	.01 ± .05
Centaurus A	-.02 ± .06
M87	-.02 ± .03



BL Lac Correlations with HiRes Events

Chad Finley

Salt Lake City

January, 2005

Gorbunov BL Lacs:

Veron Catalog, Table II

All objects:

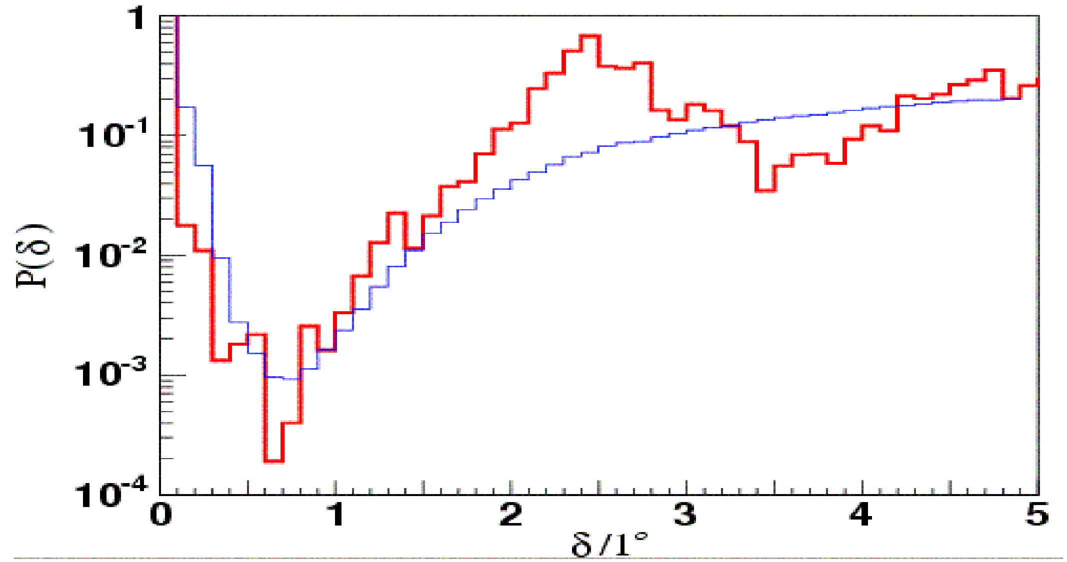
- classified as “BL”
- magnitude < 18

Corresponds to:

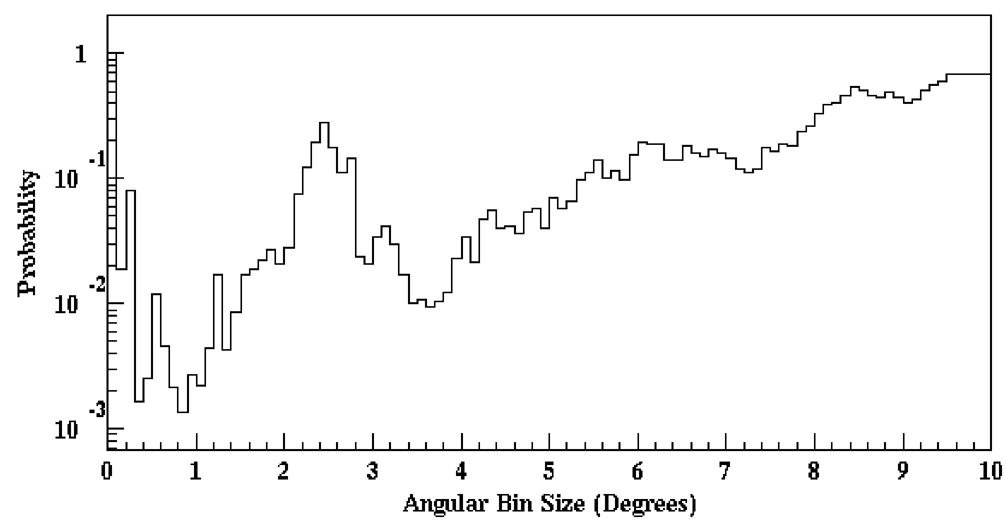
- Veron 10th Catalog: 156 objects
- Veron 11th Catalog: 178 objects

Claim: Excess number of BL Lacs near HiRes events > 10 EeV, consistent with HiRes angular resolution ~ 0.6º

(See 11 pairs < 0.8º, expect ~ 3, probability ~ 5×10^{-4})



Gorbunov et al., astro-ph/0406654



Our result (using Veron 11th Catalog)

Counting pairs within some angular separation is less than ideal analysis:

- arbitrary bin-size

- large fluctuations from one bin to the next

- lose information about actual angular separation, replaced with either/or information only

Maximum Likelihood Method addresses these issues

Maximum Likelihood Method for Multiple Sources

We hypothesize that n_s events come from a source, and $(N-n_s)$ come from background. For just one source, the partial probability for the ith event is:

$$P_i(n_s) = n_s Q(x_i) + (N-n_s)\, B(x_i)$$

$Q(x_i)$ is the probability that the ith event could come from the source, given the angular resolution of the event and the distance to the source.

$B(x_i)$ is the probability that the ith event could come from background, given the HiRes acceptance to the location x_i of the event in the sky.

We let $L(n_s) = \text{Product } P_i(n_s)$, and find the value of n_s which maximizes the ratio

$$R = L(n_s) / L(0)$$

For the present case with many sources, we adopt the following simple hypothesis: an ensemble of equal luminosity sources, where the jth source is weighted by the HiRes exposure to the source's location:

$$Q(x) = \text{Sum} \left(Q_j(x)\; W_j / (\text{Sum } W) \right)$$

Gorbunov BL Lacs

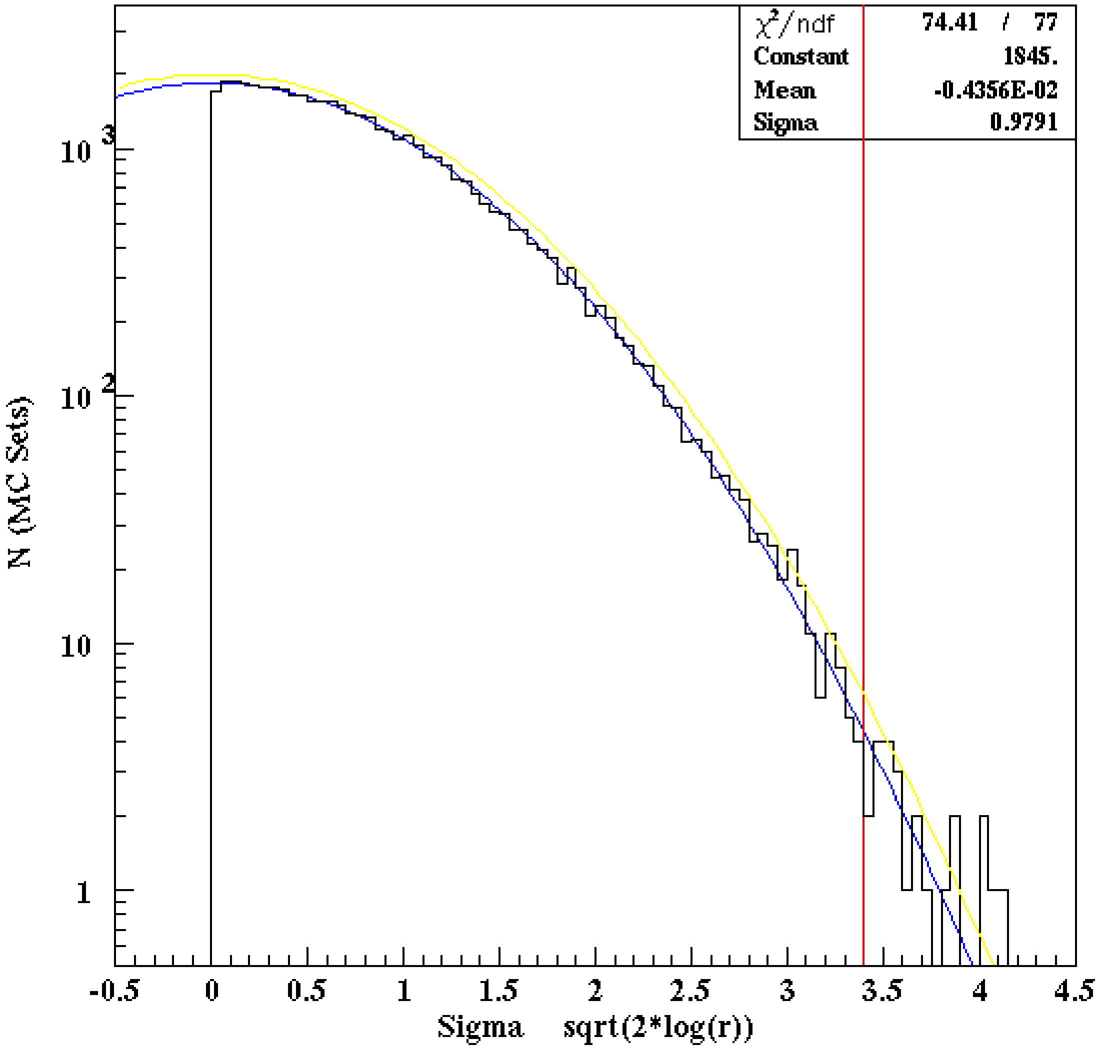
HiRes Events >10 EeV

ML Result:

Log(R)= 5.77

n_s = 8.3

Prob. = 2.4×10^{-4}



- 2 log (R) = χ^2
- Actual results of MC very near to normal distribution

Gorbunov BL Lacs

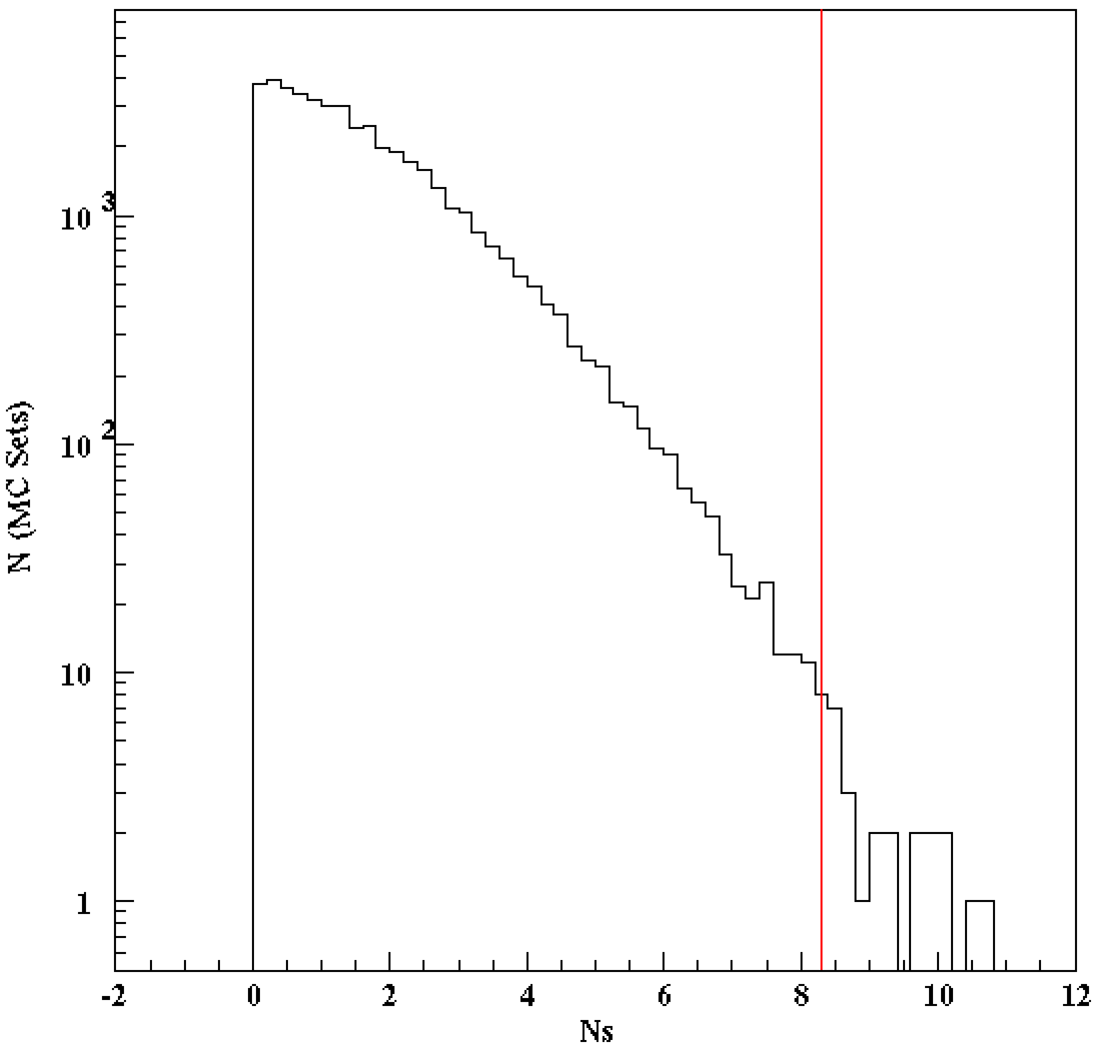
HiRes Events >10 EeV

ML Result:

Log(R)= 5.77

n_s = 8.3

Prob. = 2.4×10^{-4}



What is strange about this result:

Small fraction (~3%) of cosmic rays must be neutral; 10^{19} eV charged particle would be deflected many degrees by Galactic Magnetic Field

Neutral Candidates:

photons (mean free path ~ few Mpc)

neutrons (mean distance before decay < 1 Mpc)

neutrinos?

However, BL Lacs range from ~ 50 Mpc to ~ Gpc

In any event, if primaries are neutral, then there is no reason signal should stop at 10^{19} eV.

Does this set of BL Lacs correlate with HiRes < 10 EeV ?

Gorbunov BL Lacs

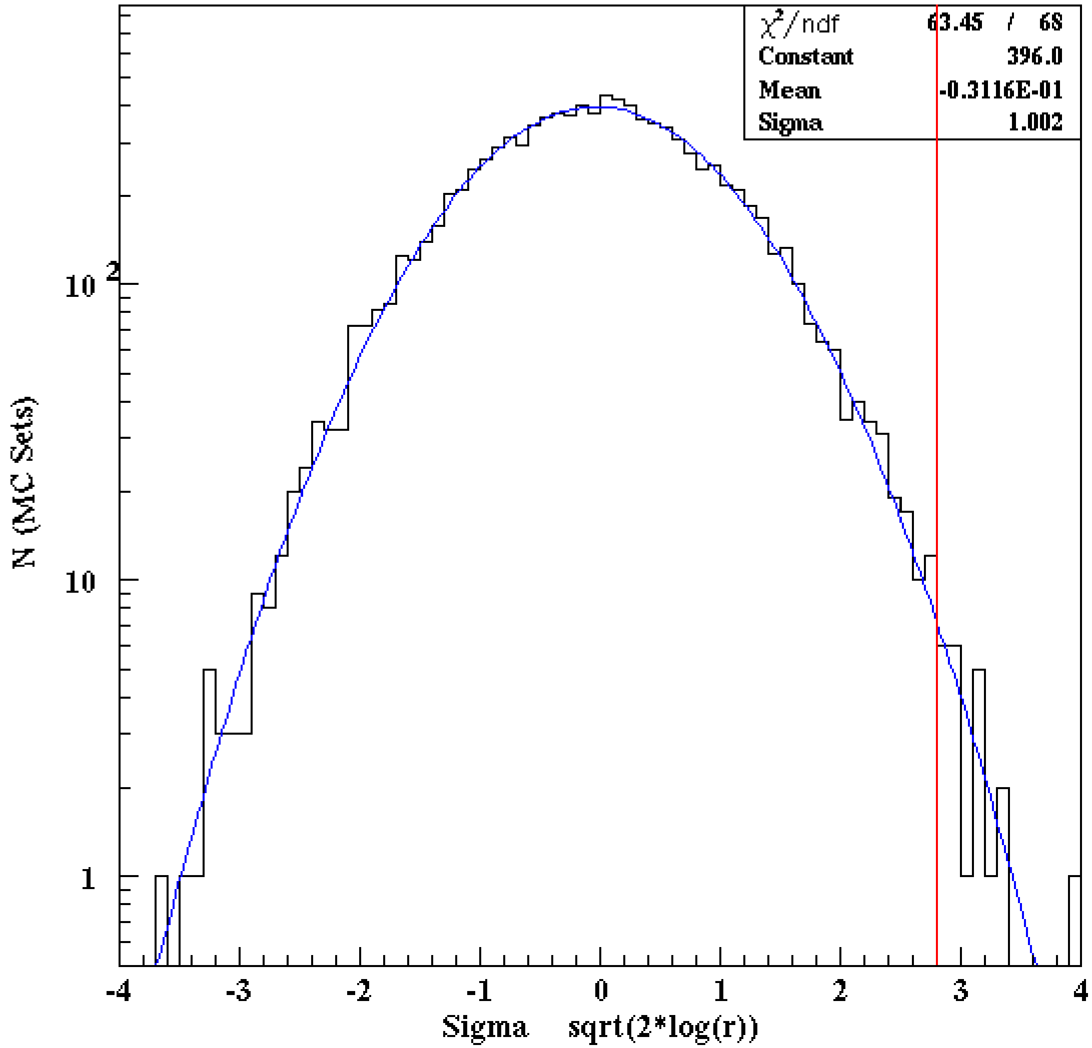
HiRes Events <10 EeV

ML Result:

Log(R)= 3.91

n_s = 22.4

Prob. = 2.2×10^{-3}



Q: Does ML Method ever *not* see correlations?

“Anti Gorbunov”

BL Lacs

- mag > 18
- 313 objects

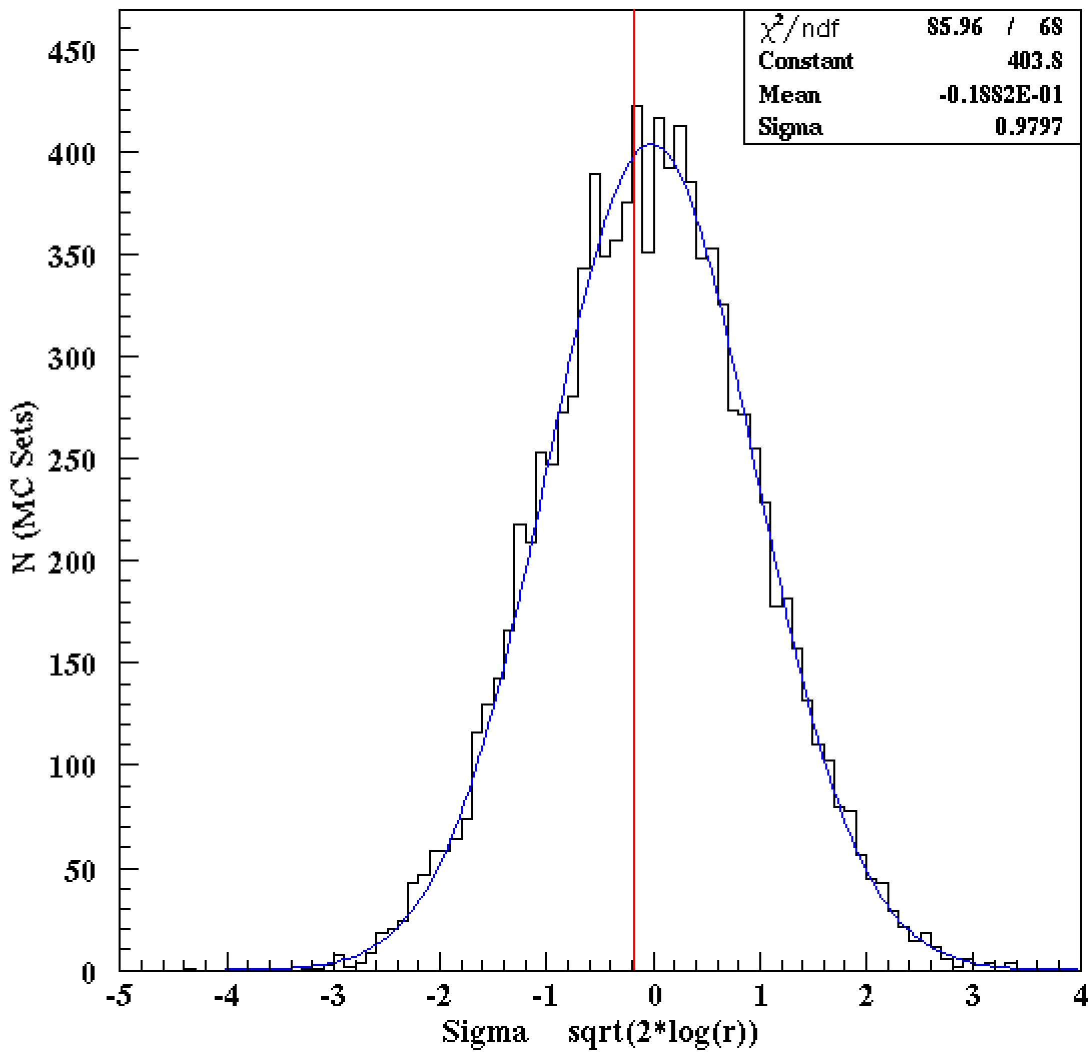
HiRes Events <10 EeV

ML Result:

Log(R)= -0.015

n_s = -1.5

Prob. = 56 %



“Anti Gorbunov”

BL Lacs

- mag > 18
- 313 objects

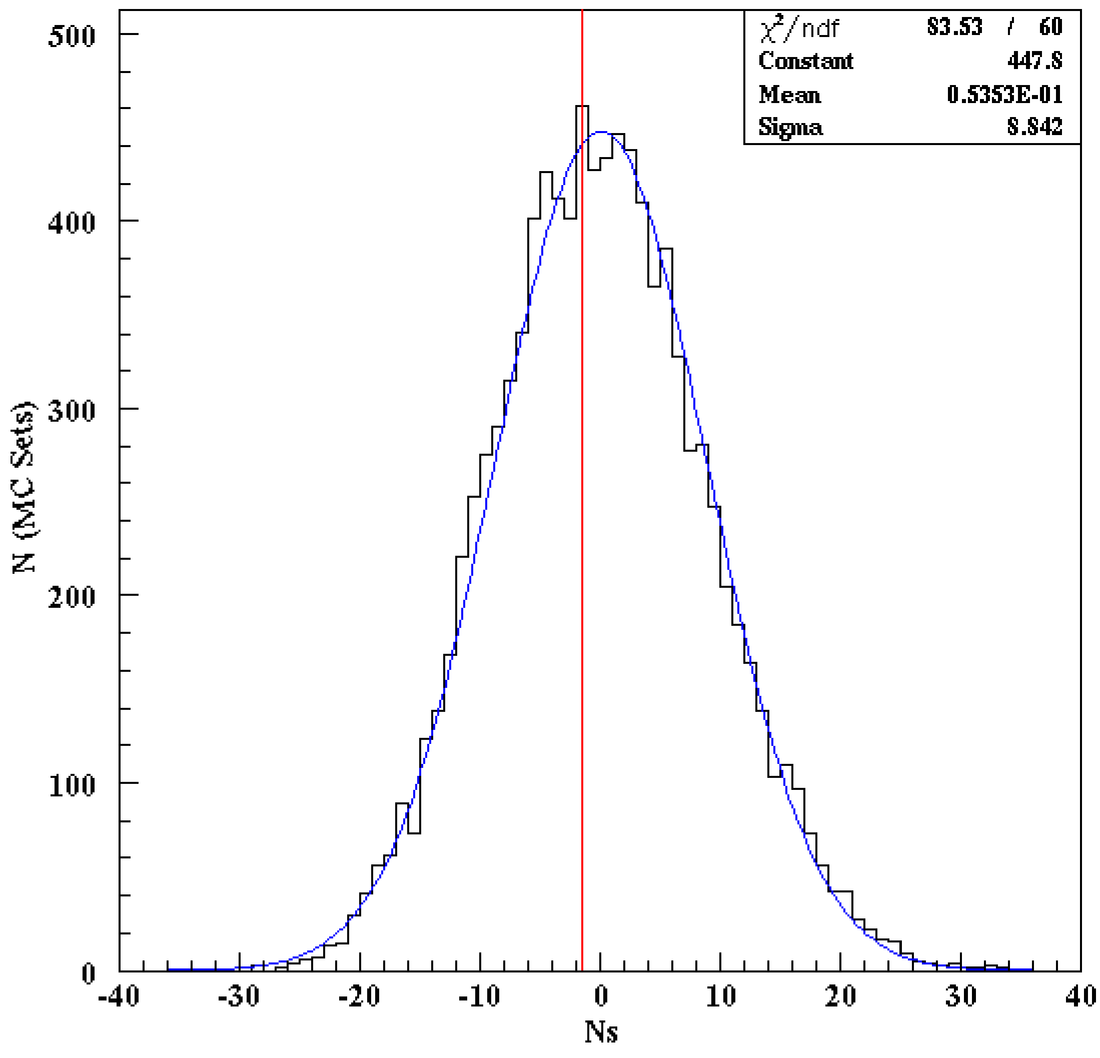
HiRes Events <10 EeV

ML Result:

Log(R)= -0.015

n_s = -1.5

Prob. = 56 %



Gorbunov BL Lacs

All HiRes Events

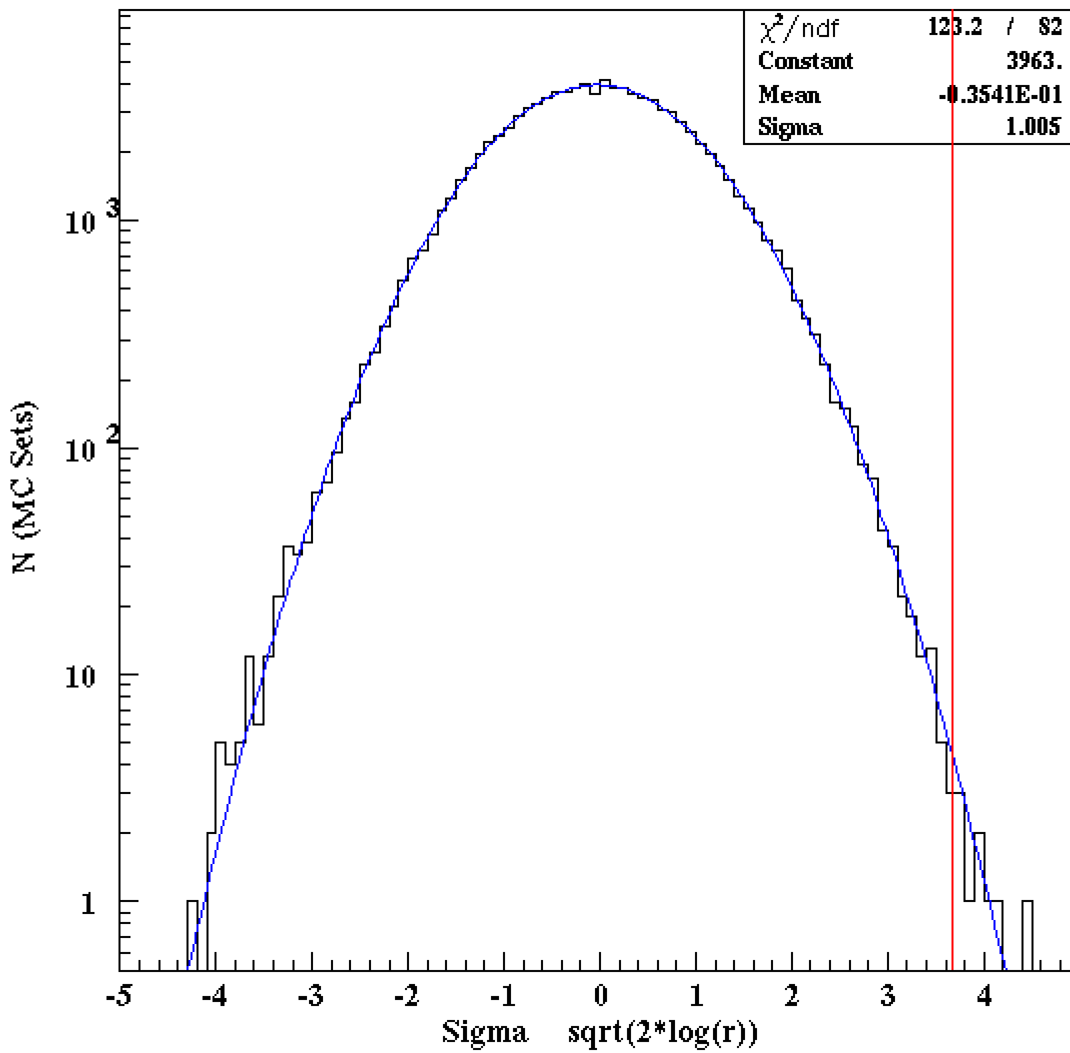
ML Result:

Log(R)= 6.75

n_s = 30.6

Prob. = 10^{-4}

How testable is this with new, independent data?



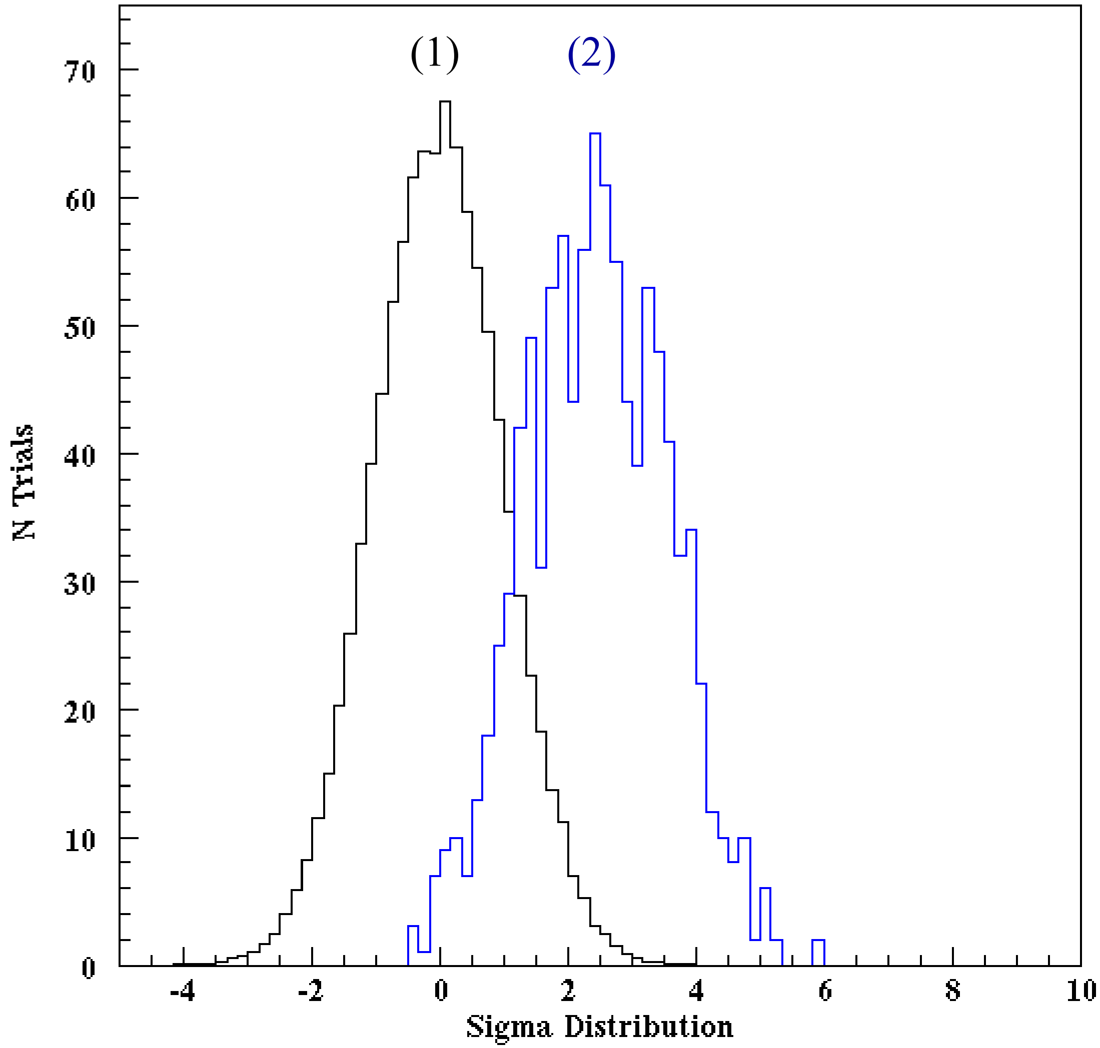
Predictions:

If no correlation is seen in new data:

1) Normal Distribution

If same correlation is seen in future data, expected signal strength:

2) 2000 events



Predictions:

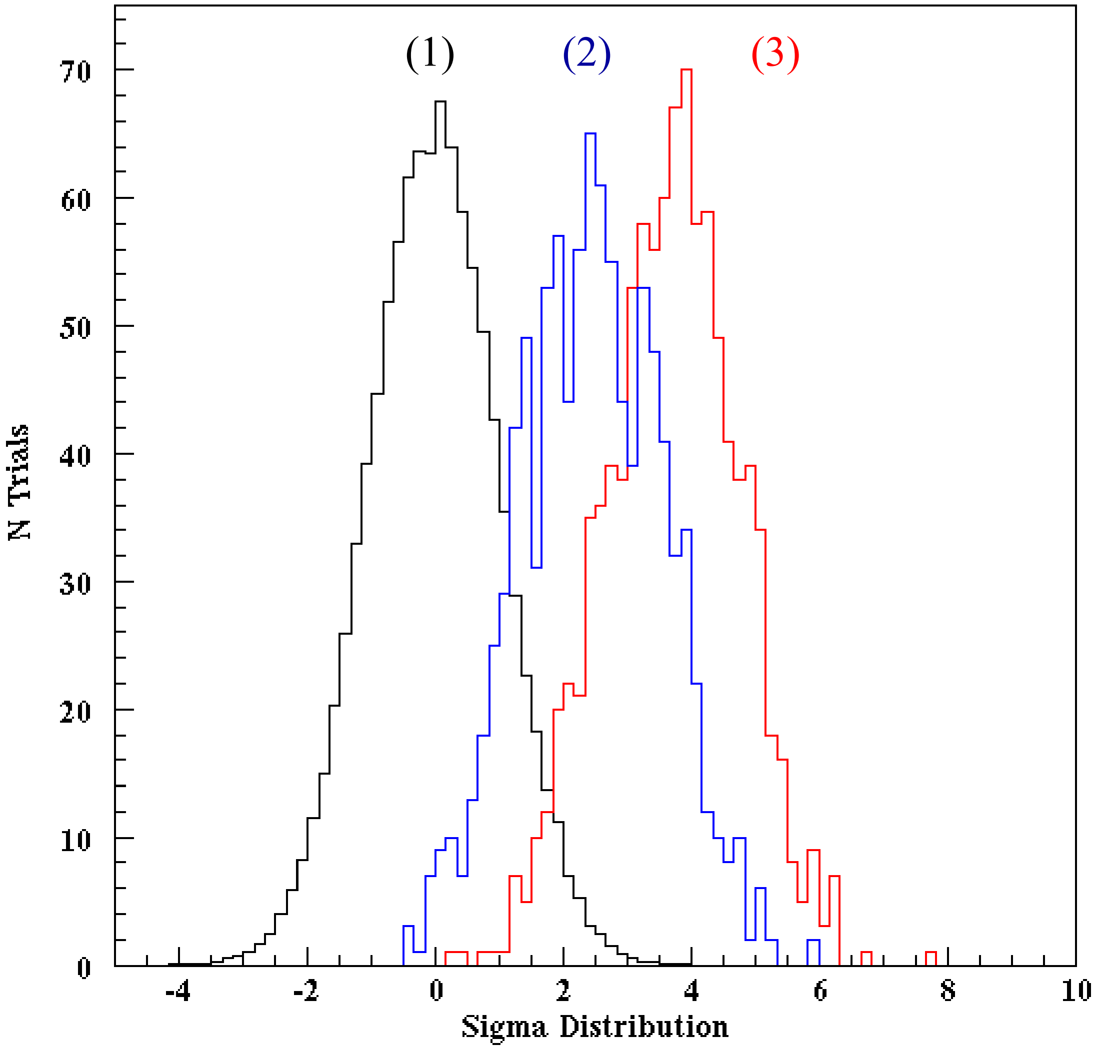
If no correlation is seen in new data:

1) Normal Distribution

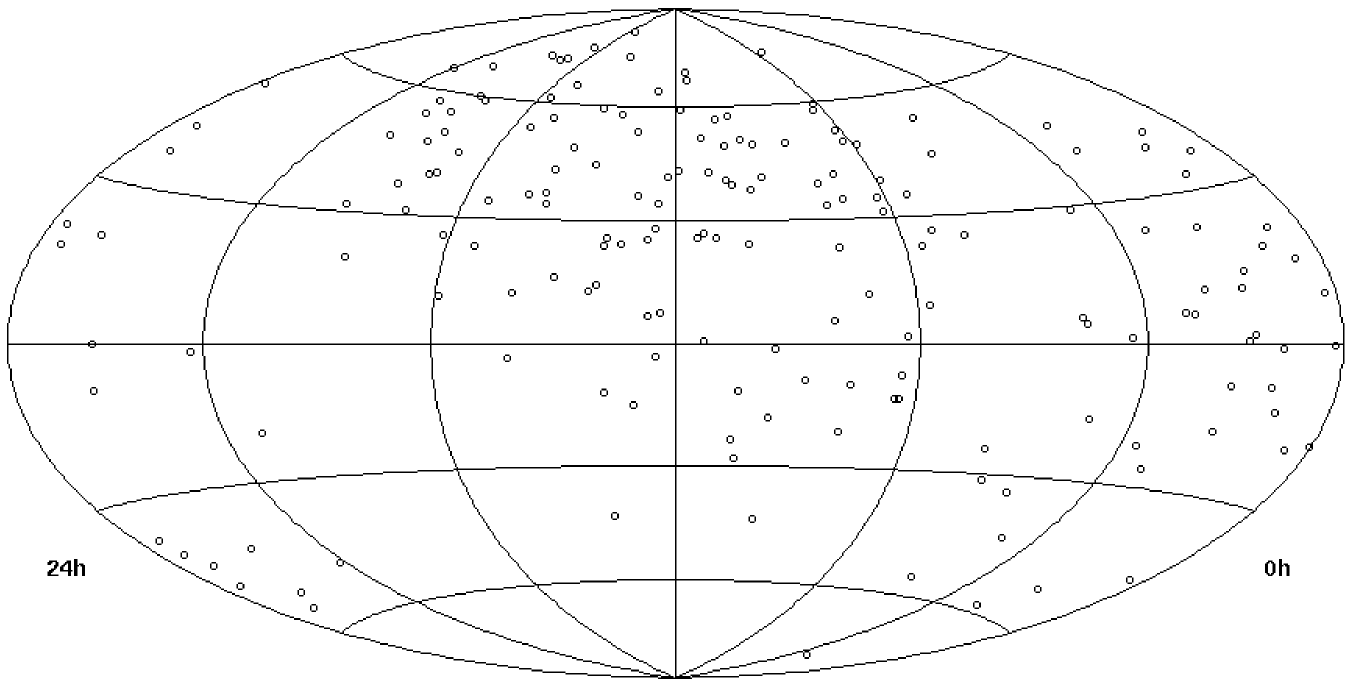
If same correlation is seen in future data, expected signal strength:

2) 2000 events

3) 4495 events (equals current data sample)



The BL Lac Hypothesis is testable with a few years of HiRes data (1 year has already been accumulated since end of this data set in Jan 2004)



HiRes sees the majority of the selected BL Lacs, Auger does not.

All Objects in Veron Catalog

- (876 confirmed and probable BL Lacs)

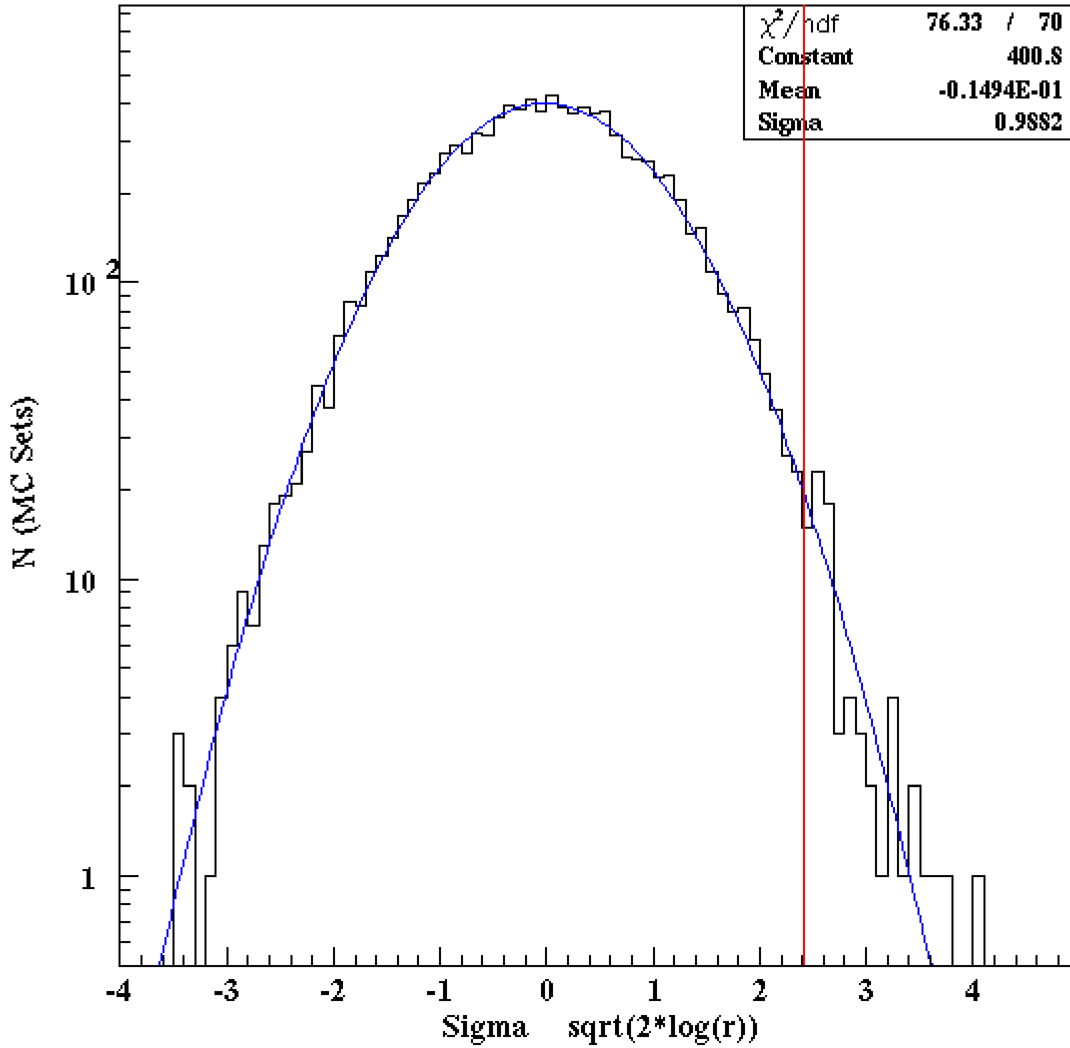
All HiRes Events

ML Result:

Log(R)= 2.93

n_s = 36.4

Prob. = 7.3×10^{-3}



Summary: HiRes Physics Results

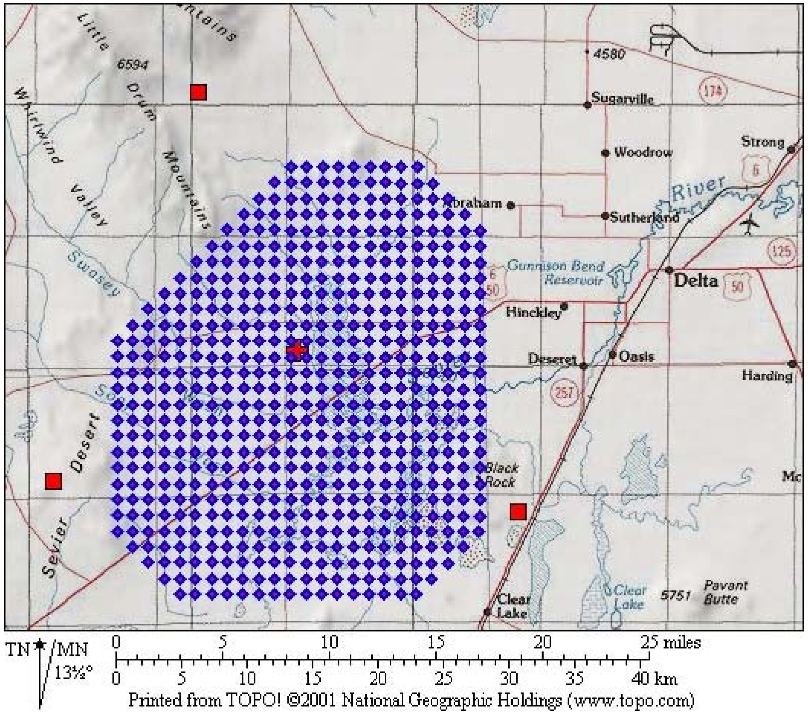
- HiRes mono spectra:
  - Clear evidence for ankle structure near 3 EeV;
  - Inconsistent with continuing power law spectrum beyond 60 EeV; Consistent with GZK prediction (but cannot exclude weaker continuing flux).
  - Previous experiments show consistent evidence of second knee near .5 EeV
- HiRes stereo spectrum:
  - Normalization agrees well with mono.
  - Modest statistics as yet;
  - Will extend energy coverage and statistics;
- Stereo composition measurement:
  - Composition is light from 10^{18} to $10^{19.4}$
  - Change in elongation at about 10^{18} eV.

Conclusions, continued

- Disagreement with AGASA in normalization and in number of events above 10^20 eV.
- Fluoresecence efficency important in setting the energy scale.
- FLASH experiment largely confirms original spectral shape.
- FLASH experiment confirms calorimetric nature of air fluorescence experiments.
- No evidence of small scale clustering in HiRes data.
- No confirmation of AGASA clustering.
- Evidence for correlation with GL-Lac's seems to be growing. Confirmation with independent data set is crucial.

Telescope Array (TA)

- Large ground array 10 X AGASA.
- **Three** fluorescence detector stations:
  - Fluorescence aperture > Ground array aperture.
  - Energy range from below $10^{18.5.}$ to $10^{20.5}$ eV.
  - Infill array for improved low energy measurements.
  - Excellent site: Millard Co. Utah; has mountains for fluorescence detectors, flat valley floor for ground array.
  - Good atmosphere, detectors above the aerosol muck.
  - Funding from Japan and US
  - Construction under way
  - Complete Construction in 2007

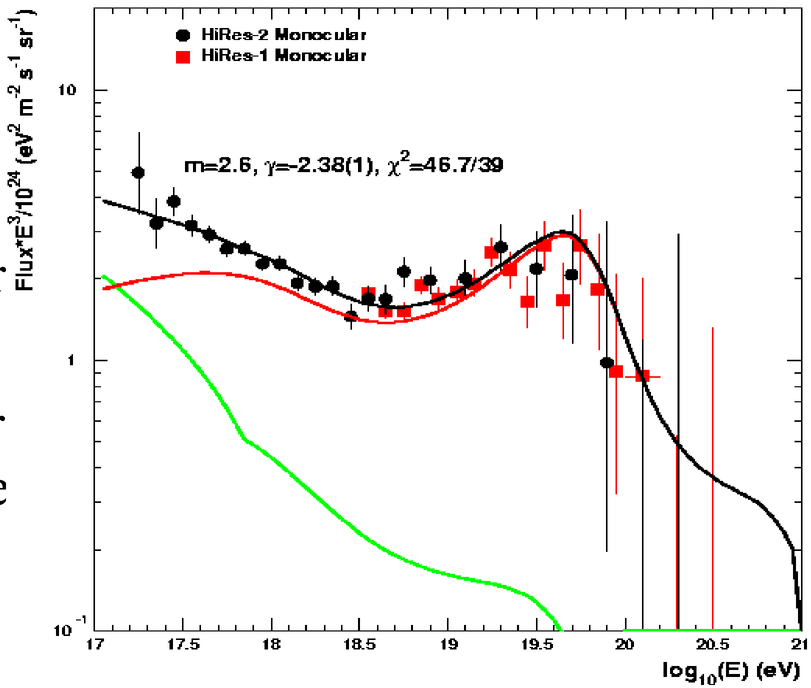


The "Ultimate" UHECR Experiment

- Achilles heel of UHECR experiments: varying energy scales between experiments + narrow energy ranges covered per experiment.
- The ultimate experiment would stand alone.
- Wide energy coverage: below $10^{17.0}$ to $10^{20.5}$ eV.
- See the second knee, ankle, and GZK suppression all in one experiment.
- Characteristics:
  - Spectrum: need excellent resolution. Fluorescence detectors are necessary.
  - Composition: Seeing X_{max} is very important. Again need fluorescence.
  - A large ground array is necessary. Muon detection is important
  - Ground array spacing must be graduated to extend energy range.
  - Ground array great for anisotropy above 10^{19} eV.
- Observe the galactic/extragalactic transition via composition change.
- Measure all the effects of the CMBR on cosmic ray propagation.
- Measure average properties of extragalactic sources.
- Search for anisotropy.

Example of Possible Galactic – Extragalactic Transition

- Origins of Galactic flux remain a mystery
- Galactic flux could be separated if its composition is different (Xmax tagged spectrum)
- Maximum energy of galactic sources is important clue to their origin
- Hints of galactic anisotropy near 1 EeV by AGASA and Fly's nee to be followed up



TALE Proposal

- Move/upgrade HiRes detectors to TA experiment (in ~ 2006).
- TA FD + HiRes stereo pairs extend fluorescence aperture to lower and higher energies.
- Infill AGASA array + muon array.
- If Auger North is co-sited, becomes very powerful wide energy bandwidth experiment.
- Nucleus exists or is funded (TA + HiRes).