Measurements of MDT chamber resolution from 2001 to 2010

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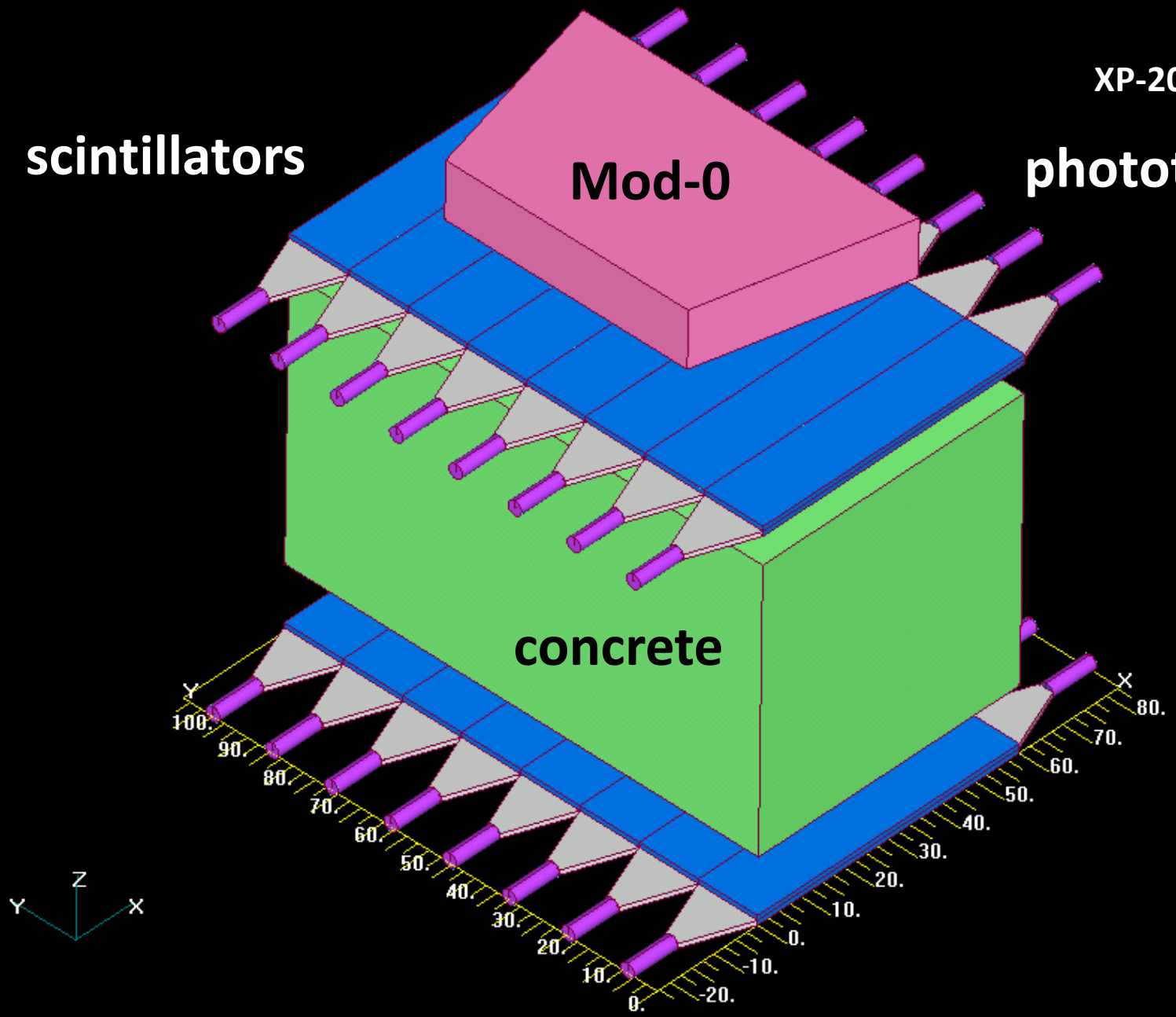
- MDT design parameters:
  - Operation at 3 bars of Ar-CO2 (93-7), with gas gain of 20,000.
  - Wire placement precision better than 20 microns.
  - Epoxy joint stability better than 5 microns.
  - 80 micron single tube resolution, dominated by longitudinal electron diffusion.
- My three greatest concerns:
  - Degradation of sealing materials leading to gas leaks.
  - Degradation of electronics leading to sparks.
  - Gas ageing leading to loss of gain and tracking resolution.
  - Poor ageing of epoxy leading to cracked joints and loss of resolution.
- For ten years I have been monitoring MDT performance for signs of the onset of these things. Most useful data:
  - ADC histograms
  - TDC histograms
  - Tube hits histograms (number of tubes hit per trigger)
  - Track fit residuals

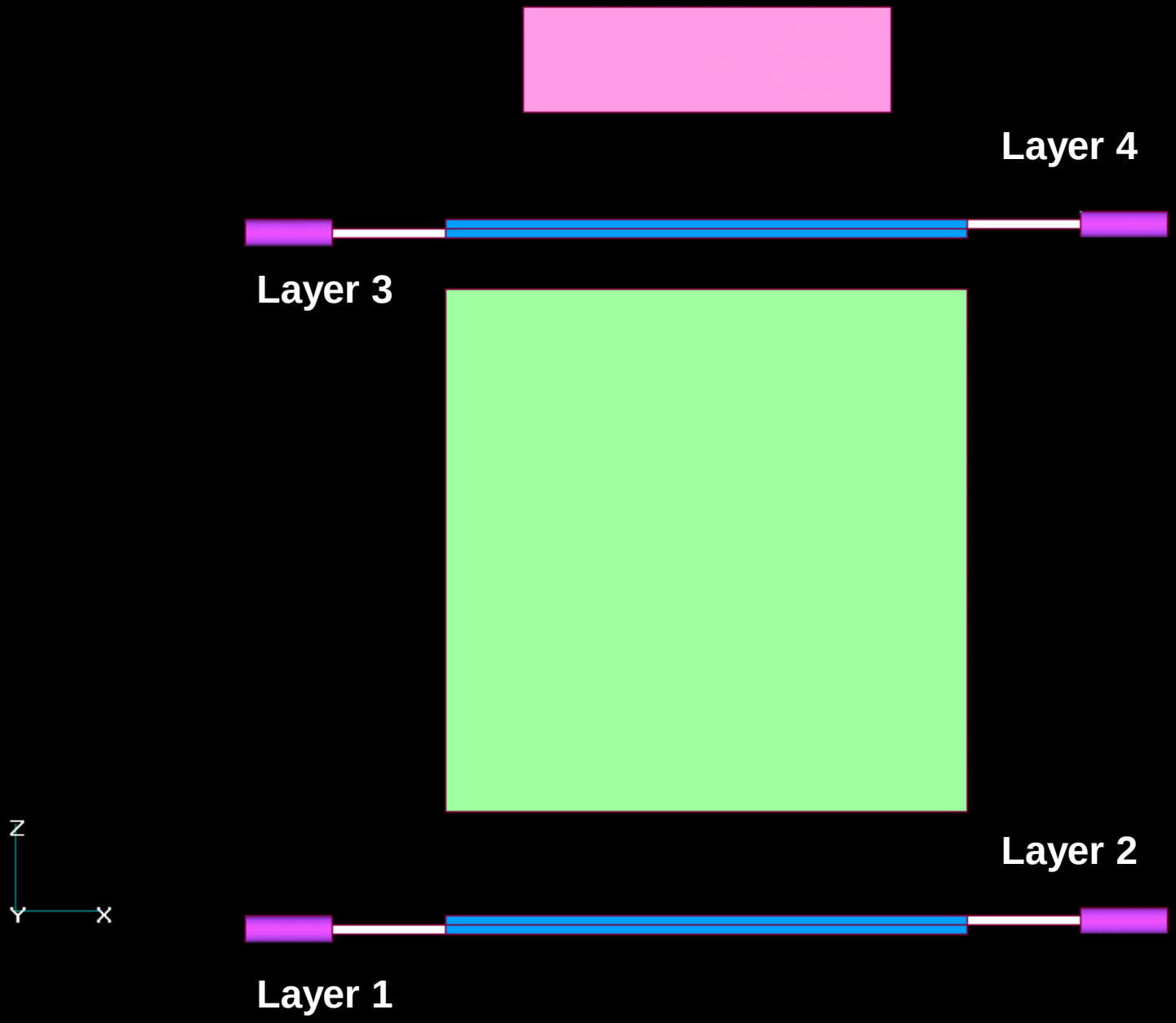
BMC Mod-0 (EIL1) was first ATLAS MDT chamber tested with nearly-standard MDT electronics

- Mod-0 built by Ahlen, Alex Marin, Rick Haggerty, Peter Hurst in May 2000
- Gas system installed on Mod-0 (Rick Haggerty) in January 2001
- Initial electrical tests (Joao Guimaraes da Costa) from January - March 2001
- DAQ set up and debugged (Ahlen) from April - May 2001
- Initial data taking on cosmic rays (Ahlen) from June - August 2001
- Initial data analysis (Ahlen) from September - October 2001
- Noise studies (G. Brandenburg, J. Oliver, D. Sherman) in November 2001

BMC Test Stand set up by Ahlen and Haggerty (Muon energy > 1 GeV)



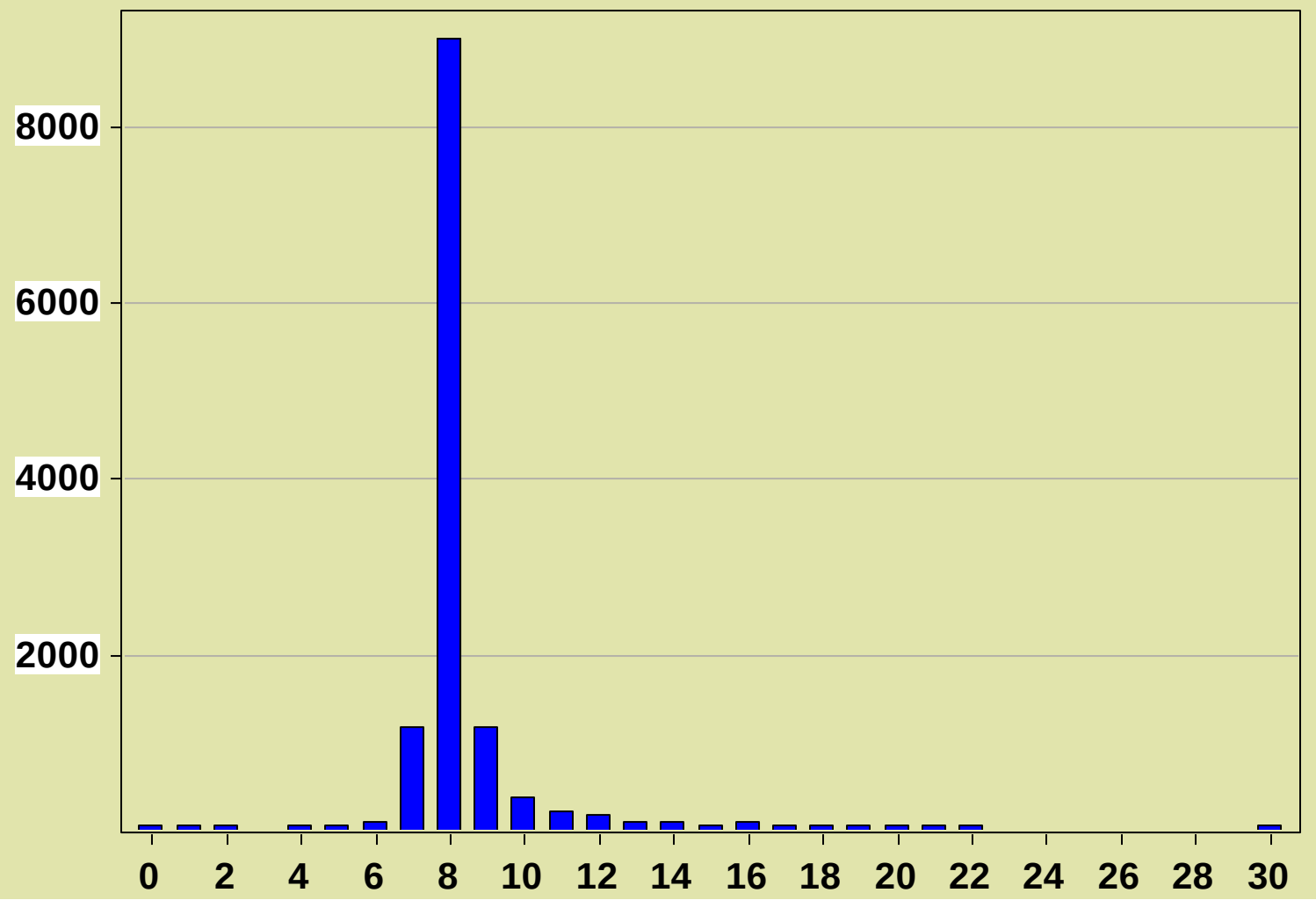
Side View



DAQ

- Standard run time was 25 minutes
- Trigger required q1 and q3 and q4
- 100,000 triggers in standard run
- 76,000 clean, single muons from scintillator data
- 16,000 events with 8 layers hit and 8 drift tubes hit
- Drift tube and PMT timing synchronized by having CSM-0 clock output go into one of the PMT TDC inputs
- T0 was determined to 0.4 ns

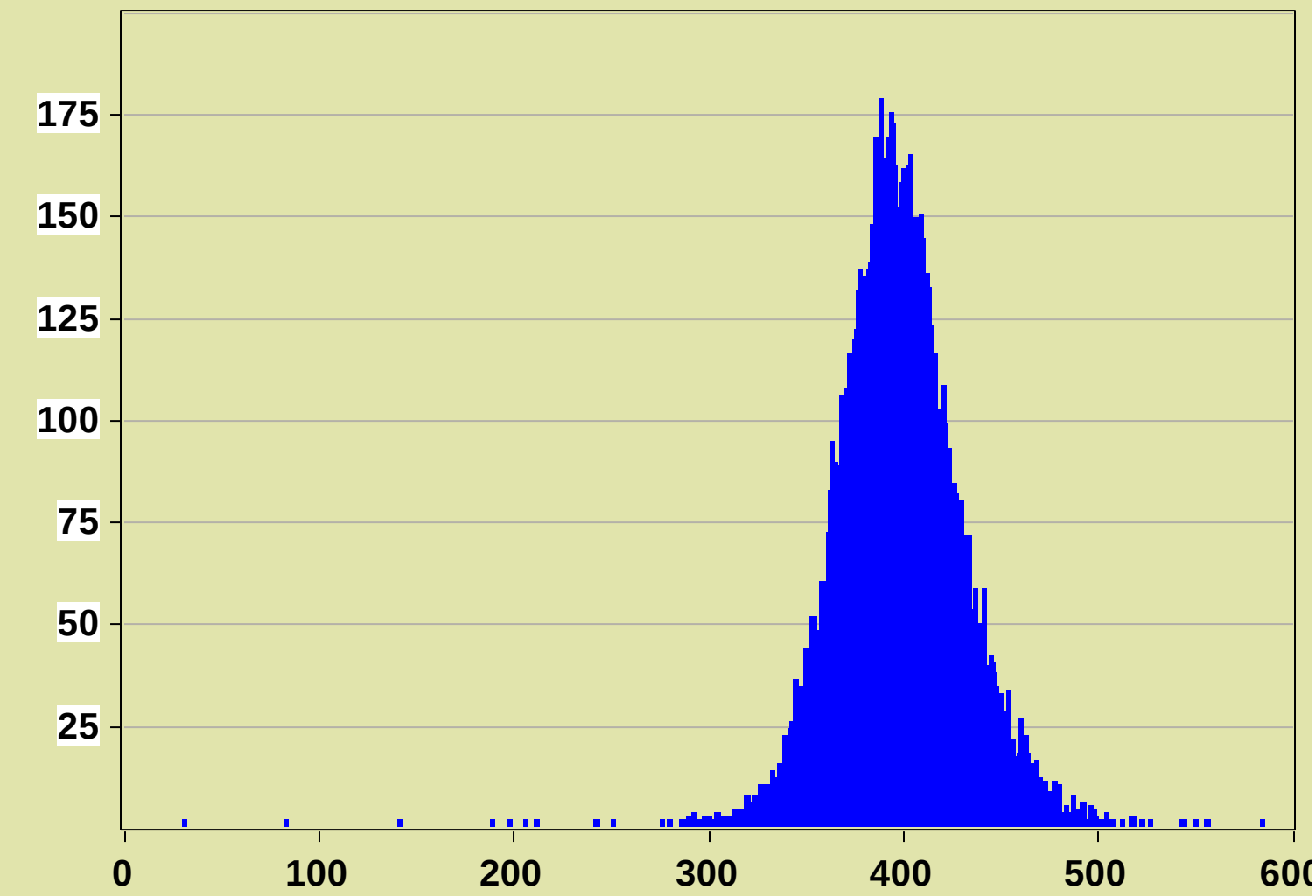
Drift tube hit distribution for muons selected with scintillator trigger (mean muon energy = 5 MeV)



Various timing corrections required to get good chamber resolution

- TDC card initialization offsets (12.5 ns)
- Clock (synchronization of scintillator and drift tubes)
- Transit of light along bottom scintillator
- Transit time along wire
- Time of flight
- Trigger time variations due to cable/electronics variations for bottom scintillator layer

Time of flight rms = single PMT rms = 400 ps

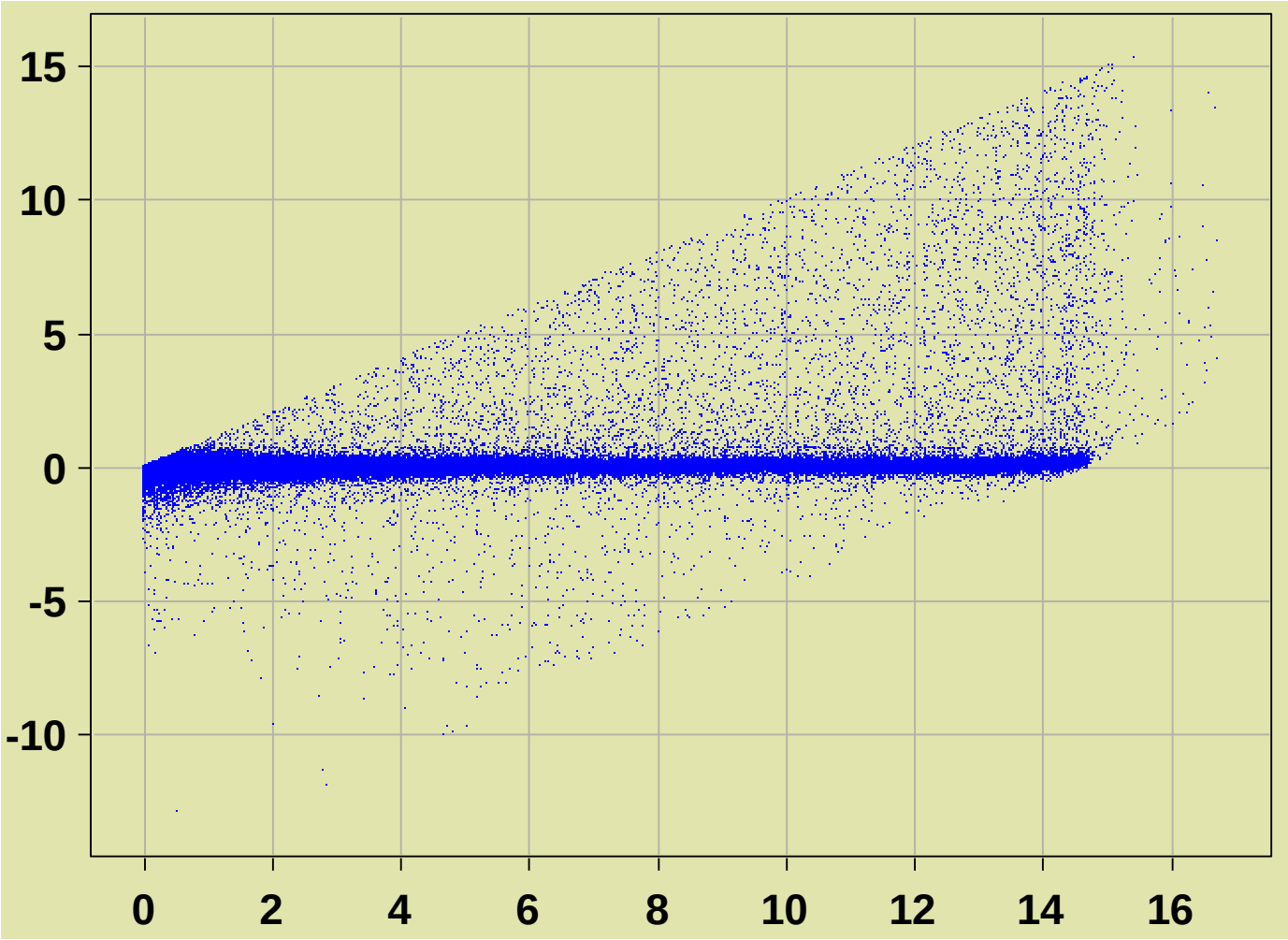


Time of flight (1 bin = 15 ps)

Resolution study

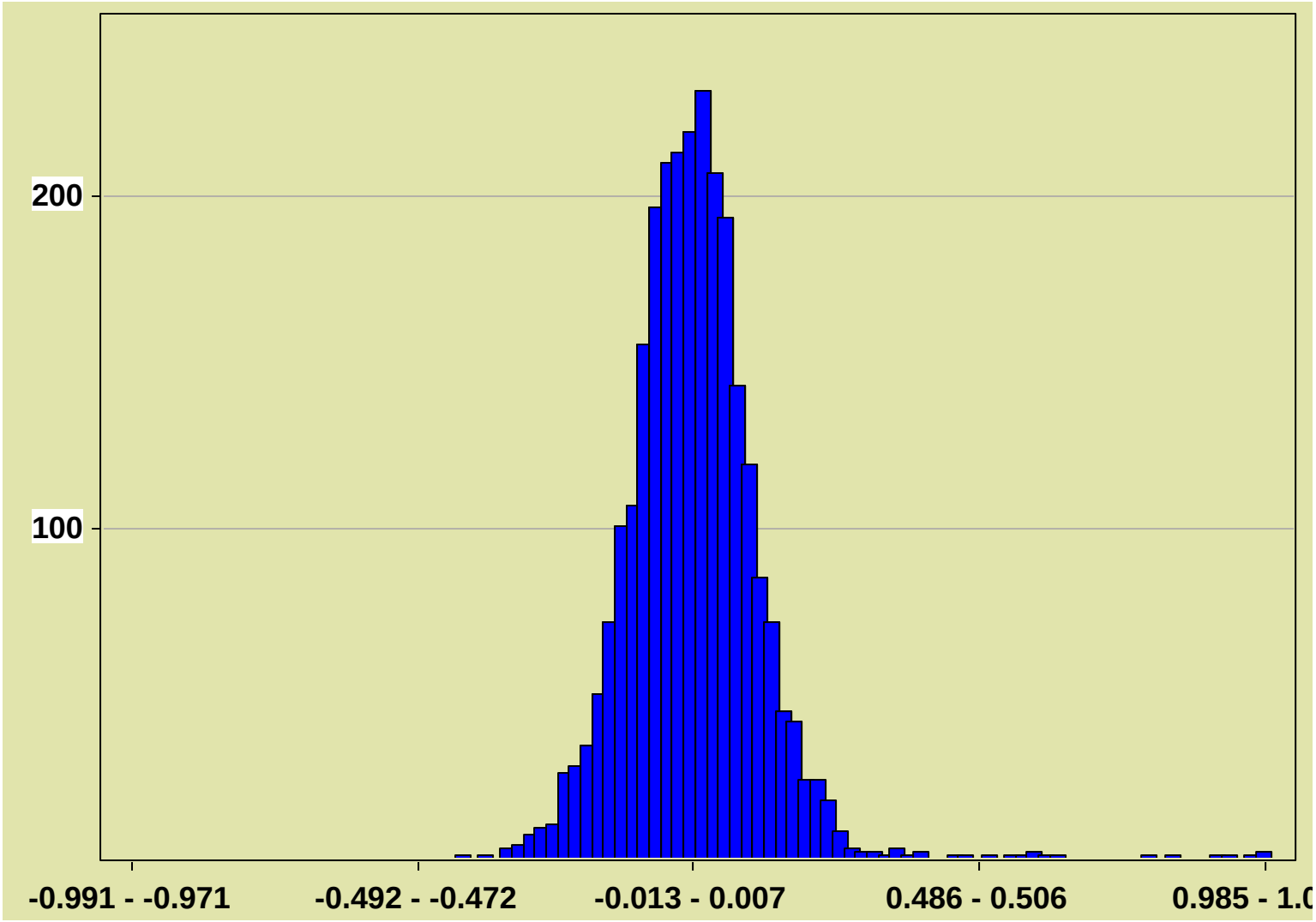
- Select layer not used for track fit
- Best of 128 possibilities for 7 other layers
- Reject worst tube
- Best of 64 possibilities for 6 layers
- Compare fit position with excluded layer's impact parameter

Residuals (fitted impact parameter minus circle radius in mm) for layer 3. 5% of hits are due to delta rays



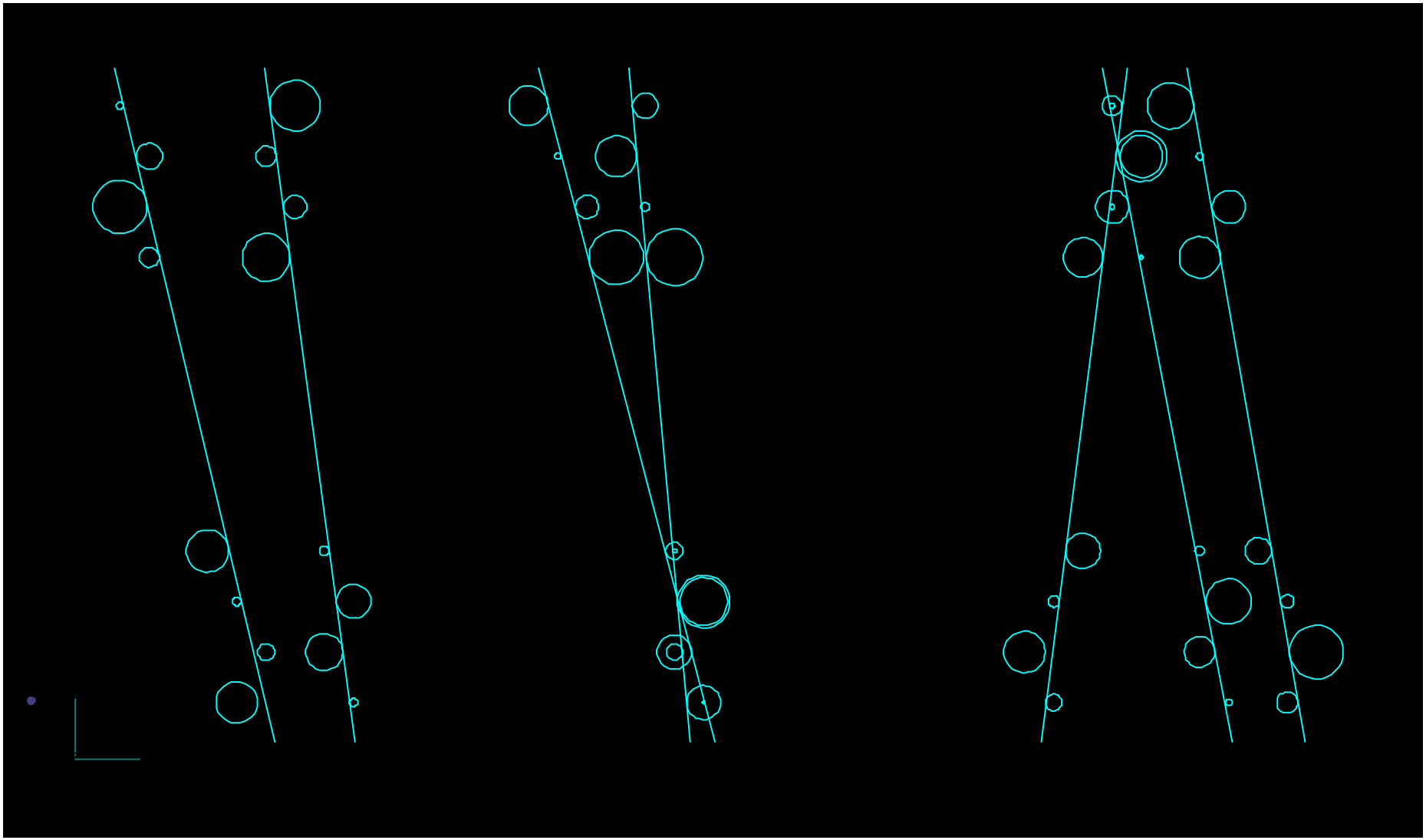
Impact parameter (mm)

Residuals for layer 3: FWHM/2.35 = 85 microns



Residual (mm)

7 muon tracks superimposed



Track fitting tests during integration 2003 to 2004

- Each of the 80 fully integrated BMC chambers was tested at Harvard in a modified version of the cosmic ray test stand.
- The chambers were on rolling tables and moved under trigger scintillators.
- The resolutions were not quite as good as for Mod-0 due to the absence of the concrete shield, allowing electrons and low energy muons to trigger the chambers.
- Mod-0 ran continuously from 2001 to 2003 with only one problem (a spark problem that disappeared while it was being investigated).

Commissioning at CERN, 2005 to 2007

- All Small Wheel and Big Wheel chambers were evaluated with “Noise Runs” in Building 180 and after installation in the ATLAS cavern.
- Most of the “Noise” was due to gamma rays from surrounding material and from chamber materials.
- We used a 3kHz periodic trigger, 1.2 μs window, since it was not practical to have trigger chambers.
- 15 hour standard run has 194 sec live time.
- Typical number of cosmic rays was 25,000 per 15 hr run.

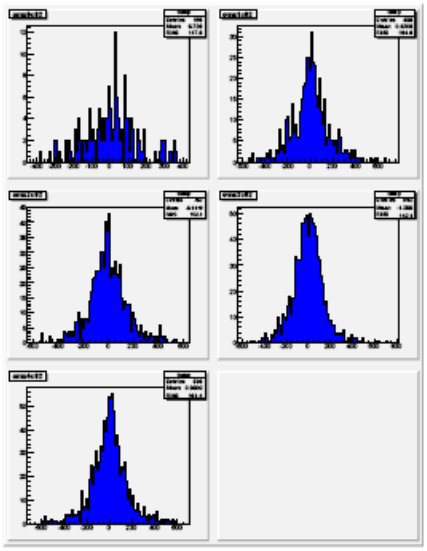
Ahlen's Track Fitting Program

- Modified for commissioning testing at CERN (used floating T_0 since no trigger).
- Consider each of 256 possibilities for each event (left or right side of wire) (64 for EM, EO).
- Consider each of (as many as) 1000 possible values of $T_{0.}$
- Select case for which the sum of the square errors is minimized.
- No attempt to reject delta rays; delta-ray-free events can be identified from chi-square: 0.95^8 = 66% of 8 layer chambers, 0.95^6 = 73% of 6 layer chambers.

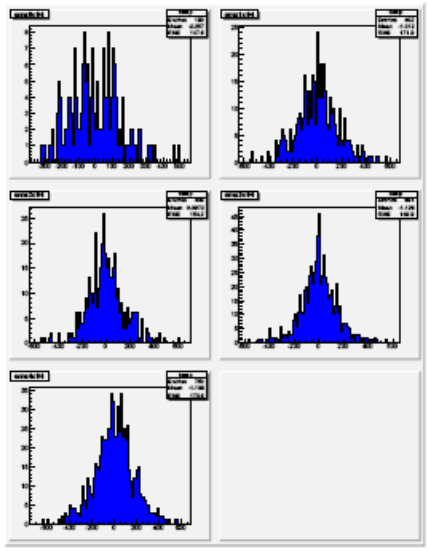
Resolution in pit with cosmic rays using 15 hr Noise Runs

- Enough events for cosmic ray track fitting in pit.
- Mean muon energy from wall = 50 GeV.
- Periodic 3kHz trigger, 15 hr runs.
- Residual distributions on next 2 slides for 80 Big Wheel C side chambers in pit.
- Graham Rowlands did this for senior thesis at BU.
- FWHM of residual distributions $\approx$ 200 microns.

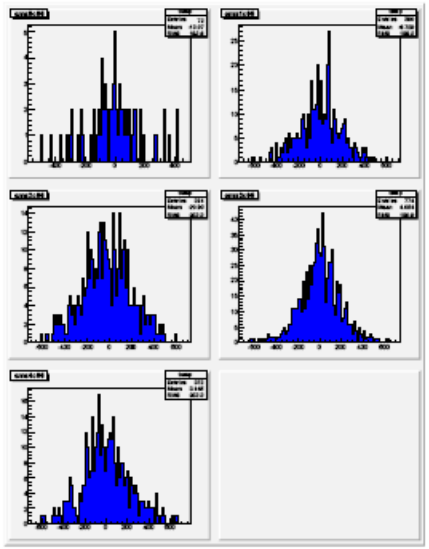
Residuals for Small Sectors



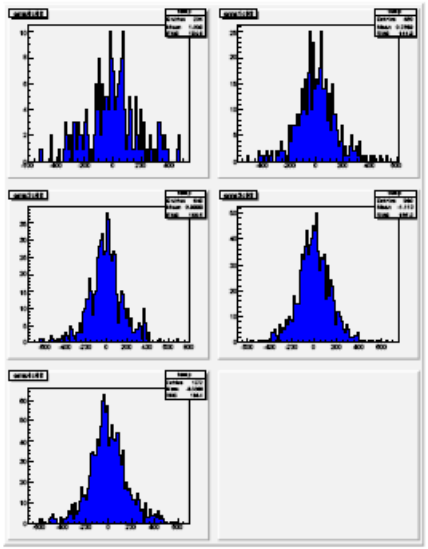
(a) Residuals of emsc02



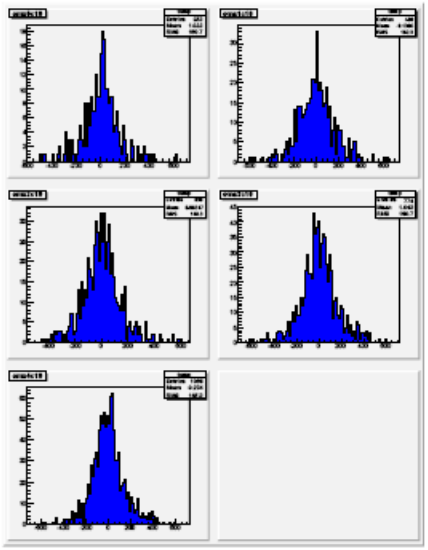
(b) Residuals of emsc04



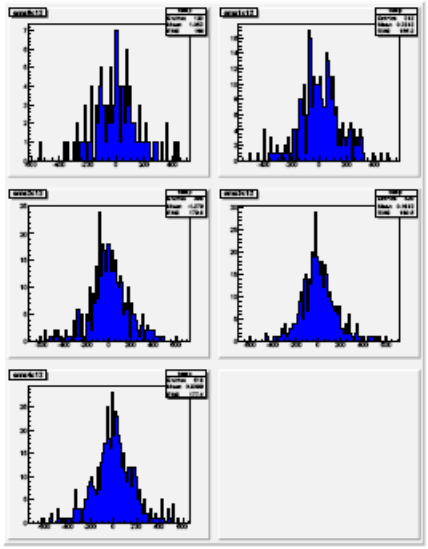
(c) Residuals of emsc06



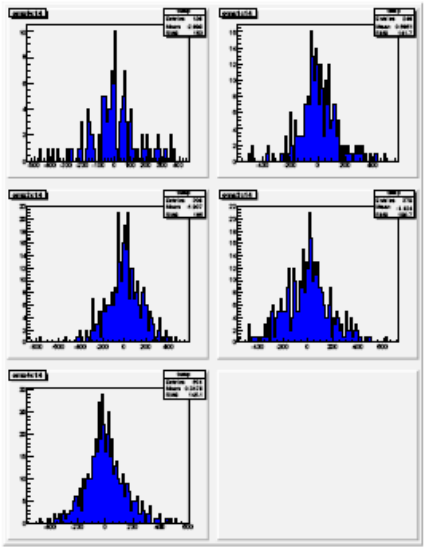
(d) Residuals of emsc08



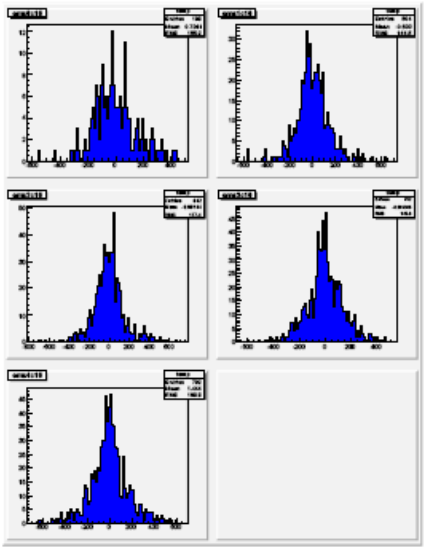
(a) Residuals of emsc10



(b) Residuals of emsc12

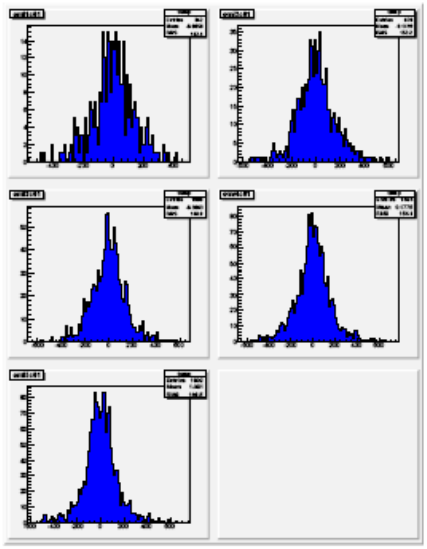


(c) Residuals of emsc14

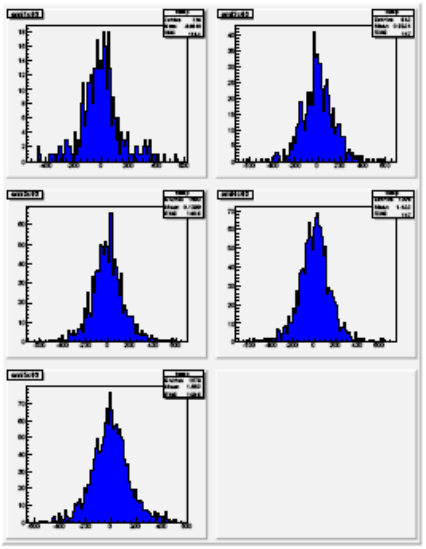


(d) Residuals of emsc16

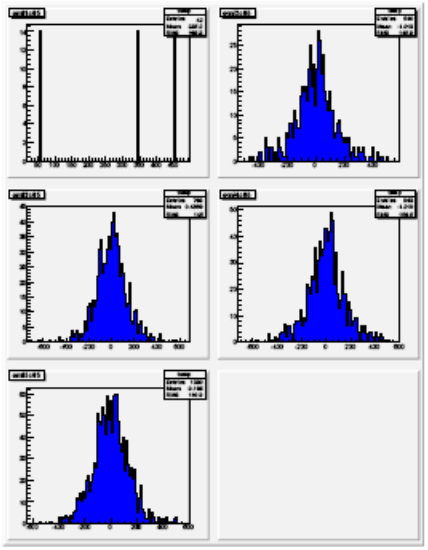
Residuals for Large Sectors



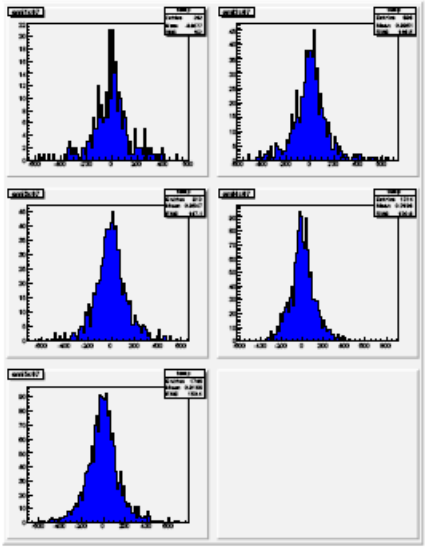
(a) Residuals of emlc01



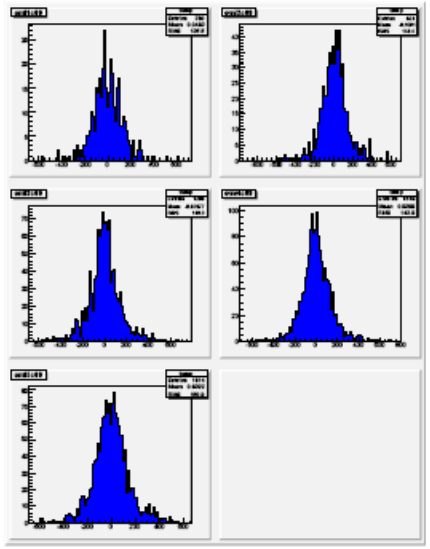
(b) Residuals of emlc03



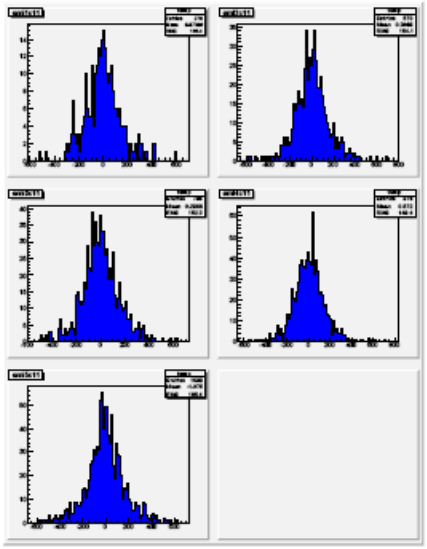
(c) Residuals of emlc05



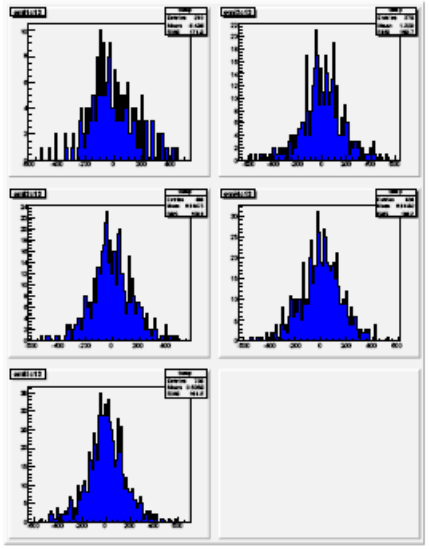
(d) Residuals of emsc07



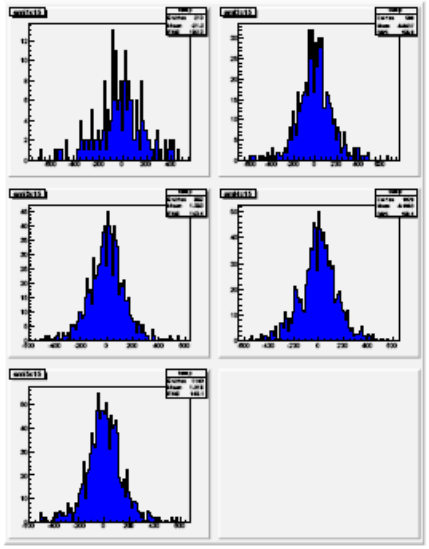
(a) Residuals of emlc09



(b) Residuals of emlc11



(c) Residuals of emlc13



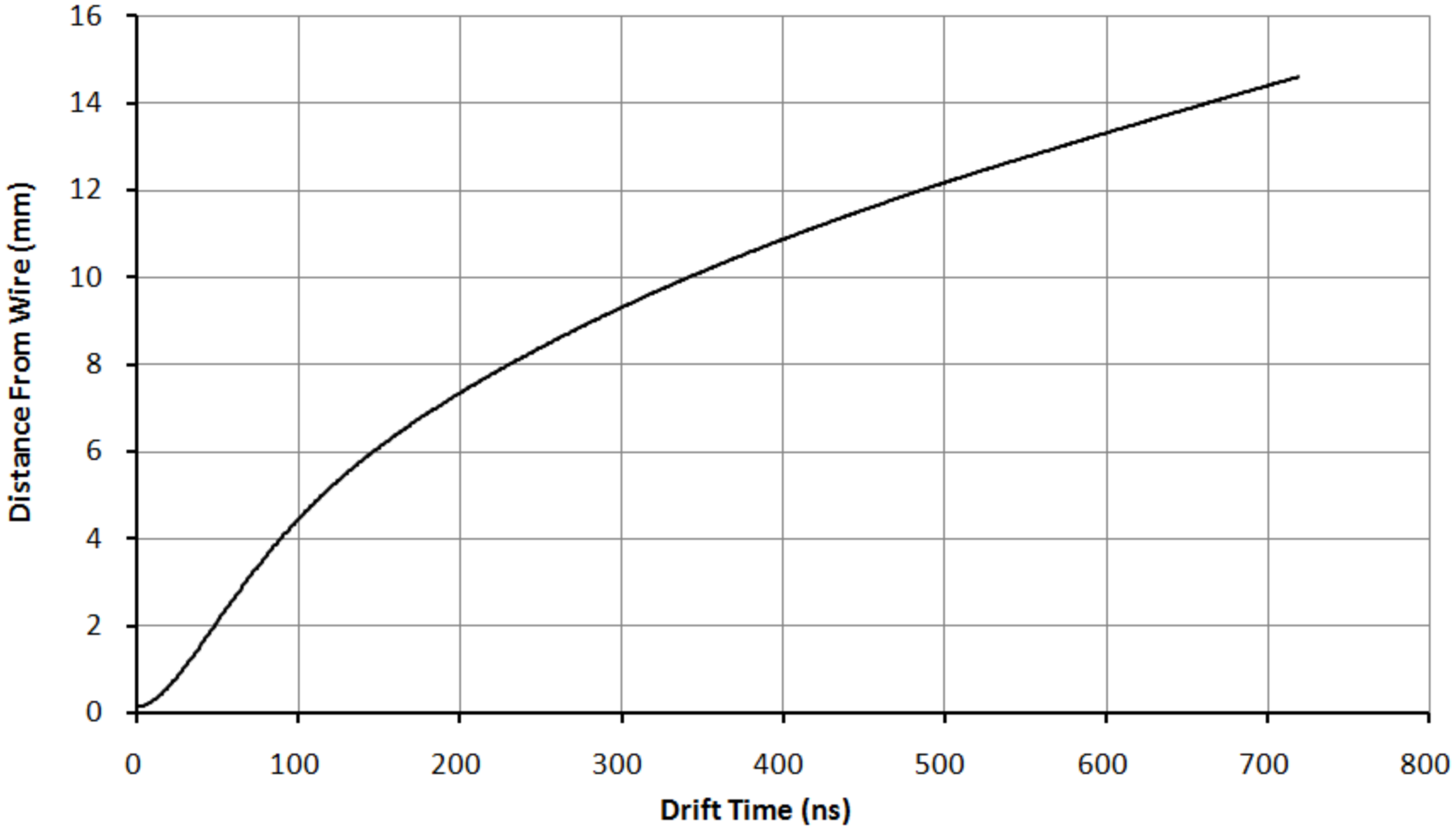
(d) Residuals of emlc15

Resolution studies with endcap chambers for cosmic runs Fall 2008

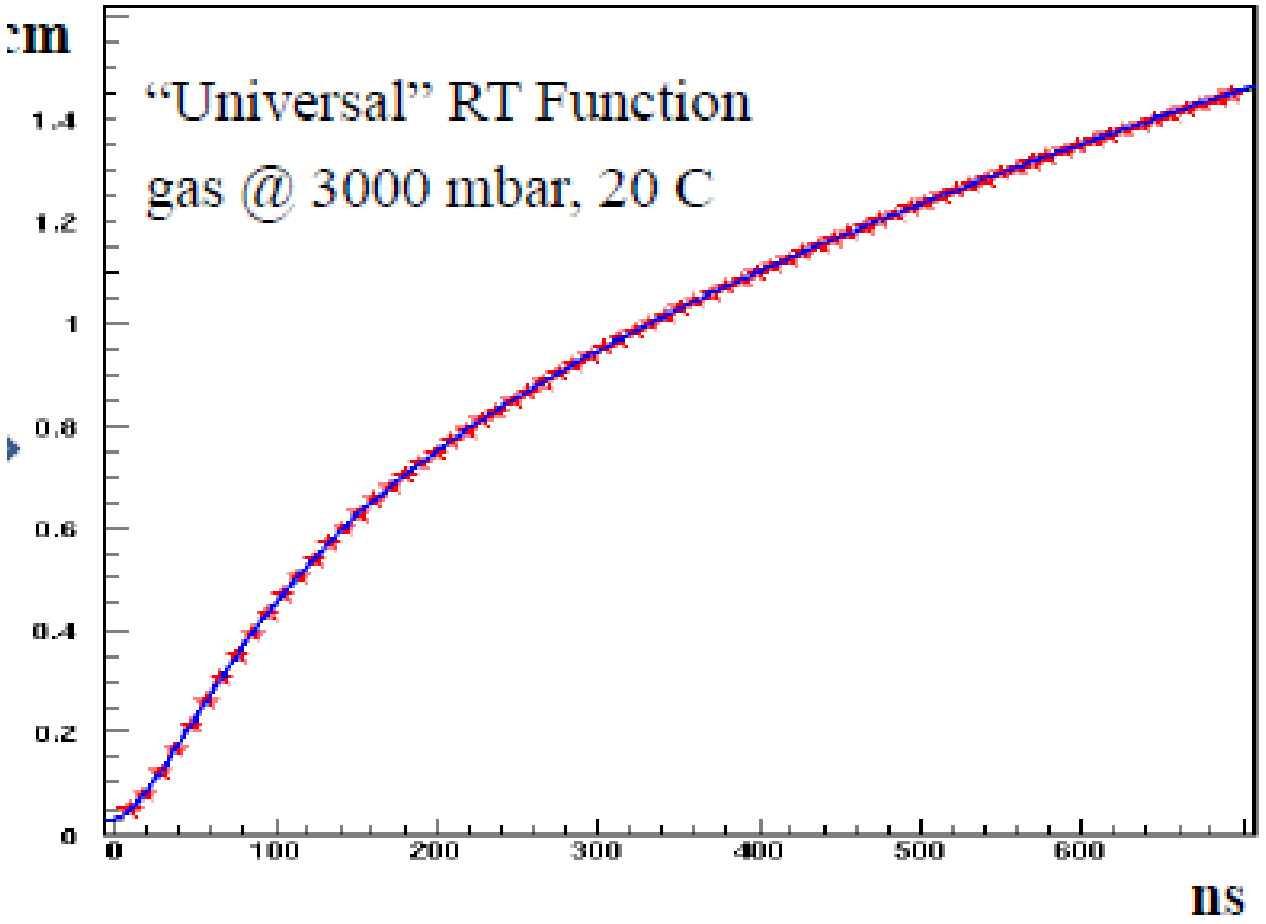
- From run 91060.
- Three-fold coincidence: EO + EM + EI (muon energy is typically larger than 20 GeV).
- Tubes selected by ATLAS tracking program.
- Keep events with exactly 8 hits (EI), 6 hits (EM, EO).
- Exclude events with multiple options.
- 632 events, 290 Chambers:
  - 86 EI Chambers
  - 86 EM Chambers
  - 118 EO Chambers

RT function used

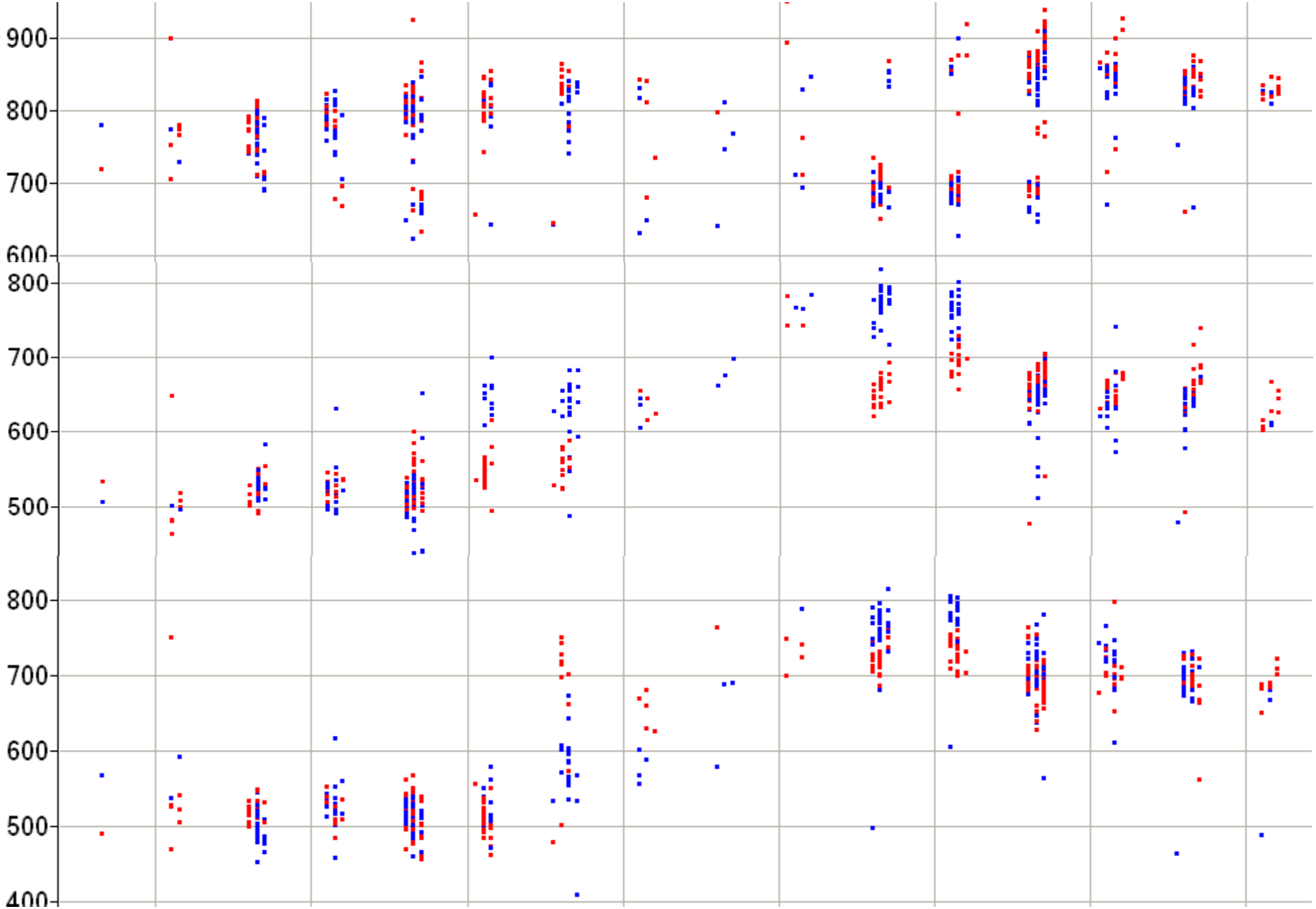
(from Dan Levin's standard stretched for 2% increase in T_{max})



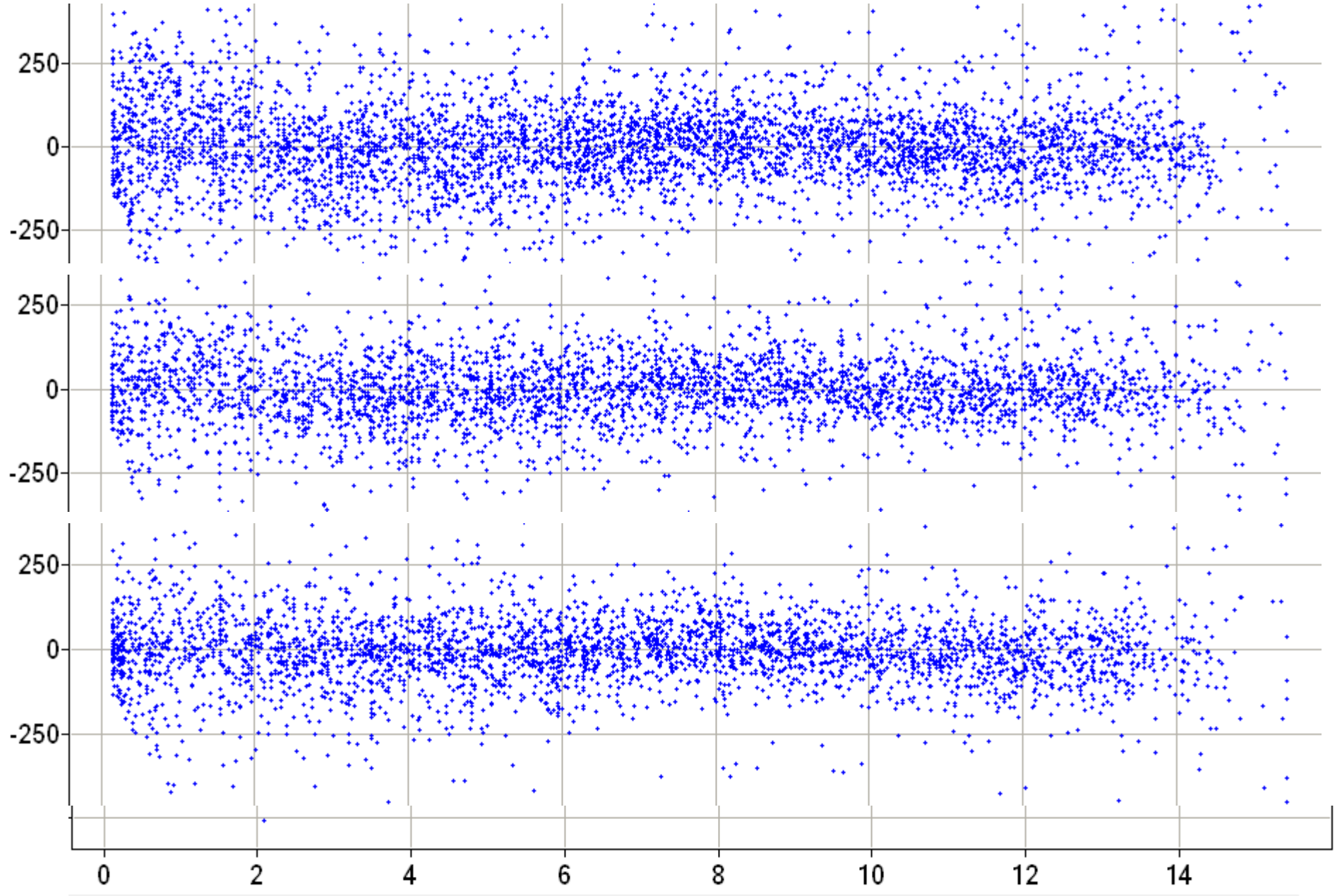
Dan Levin's Universal RT Function, which he modifies as appropriate for differing conditions



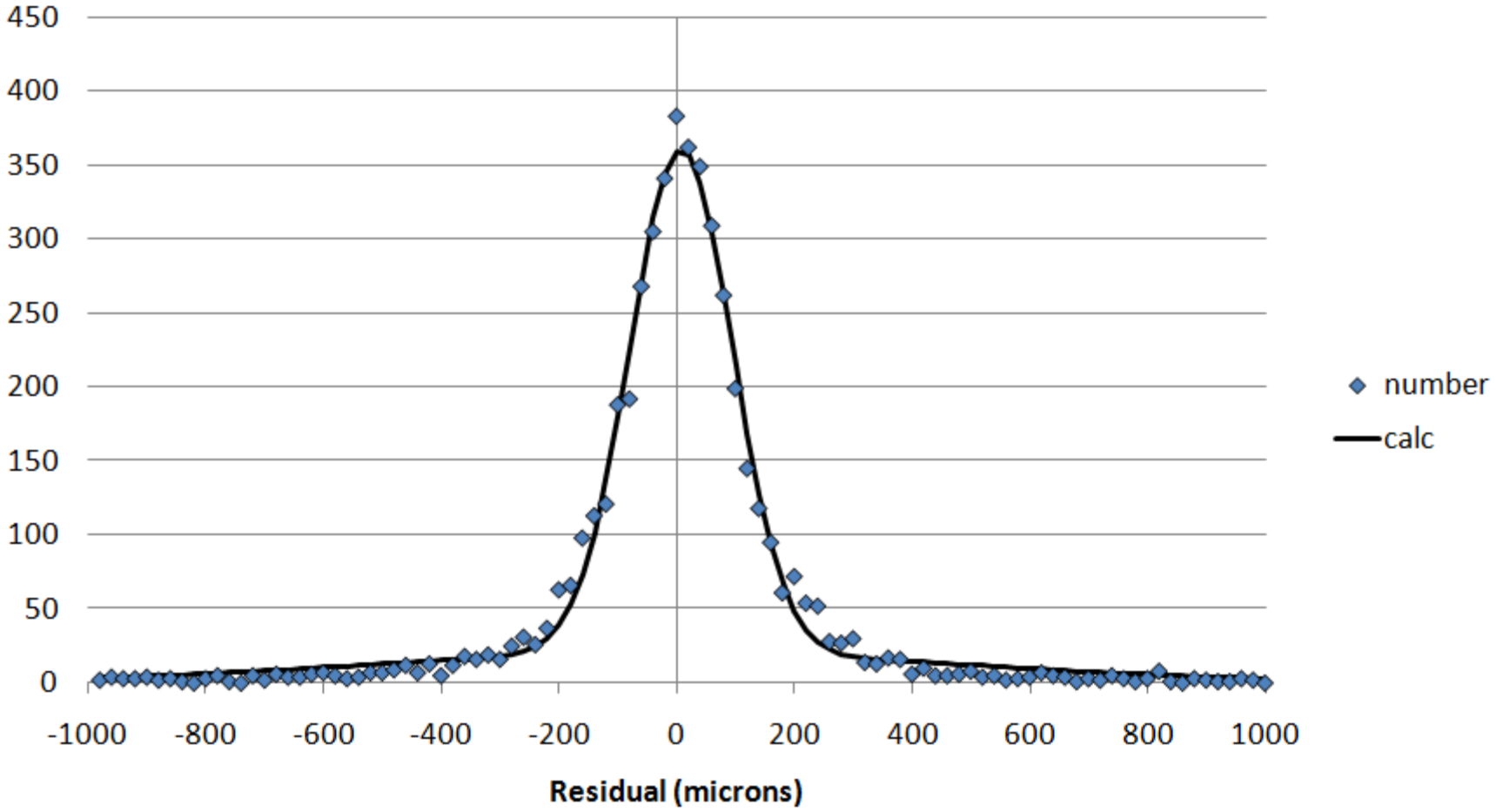
T0(EI top,EM,EO) vs. EM Chamber # (color for EC)



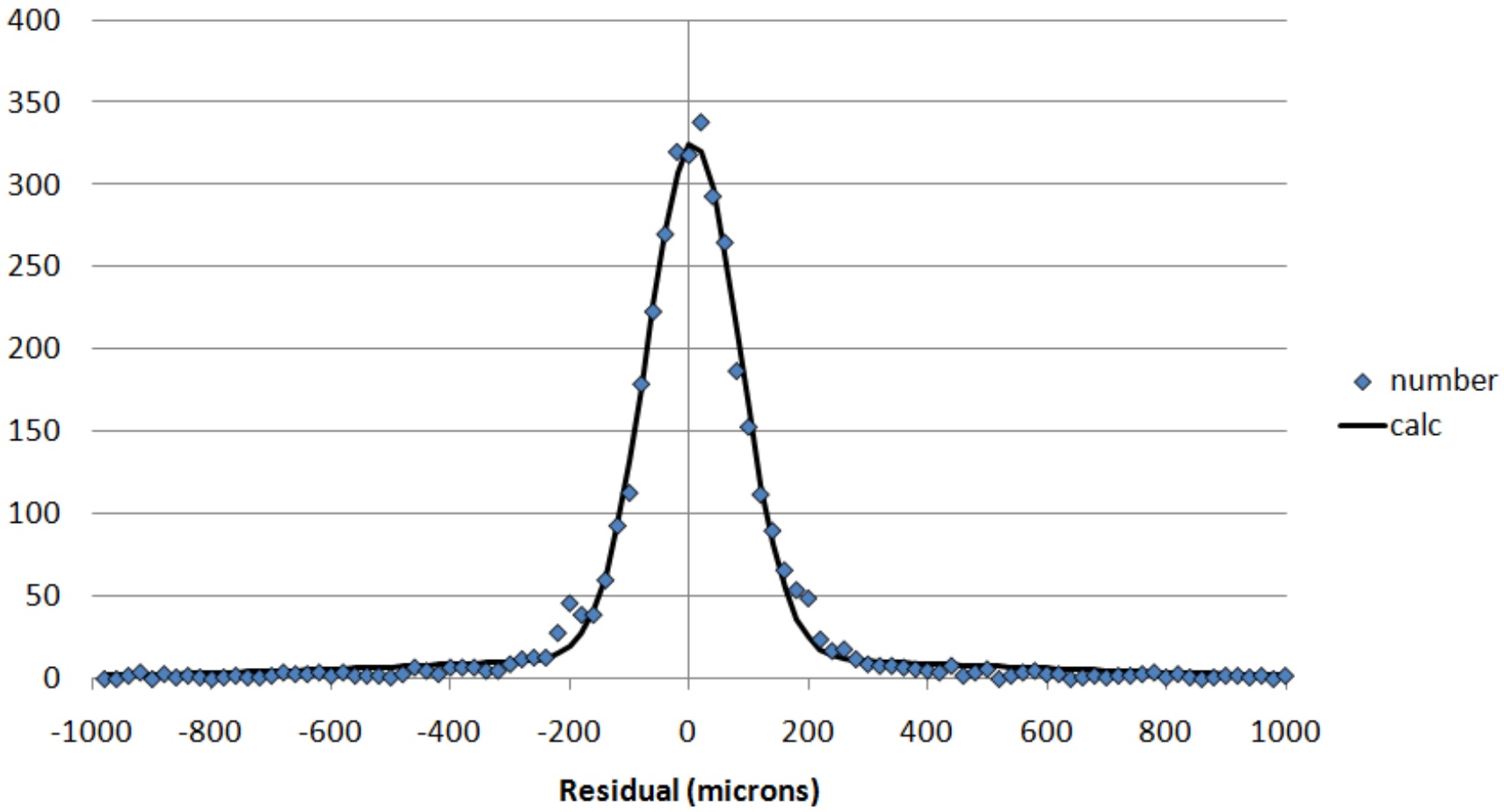
Residuals (μm) vs R (mm) (EI top, EM middle, EO bottom)



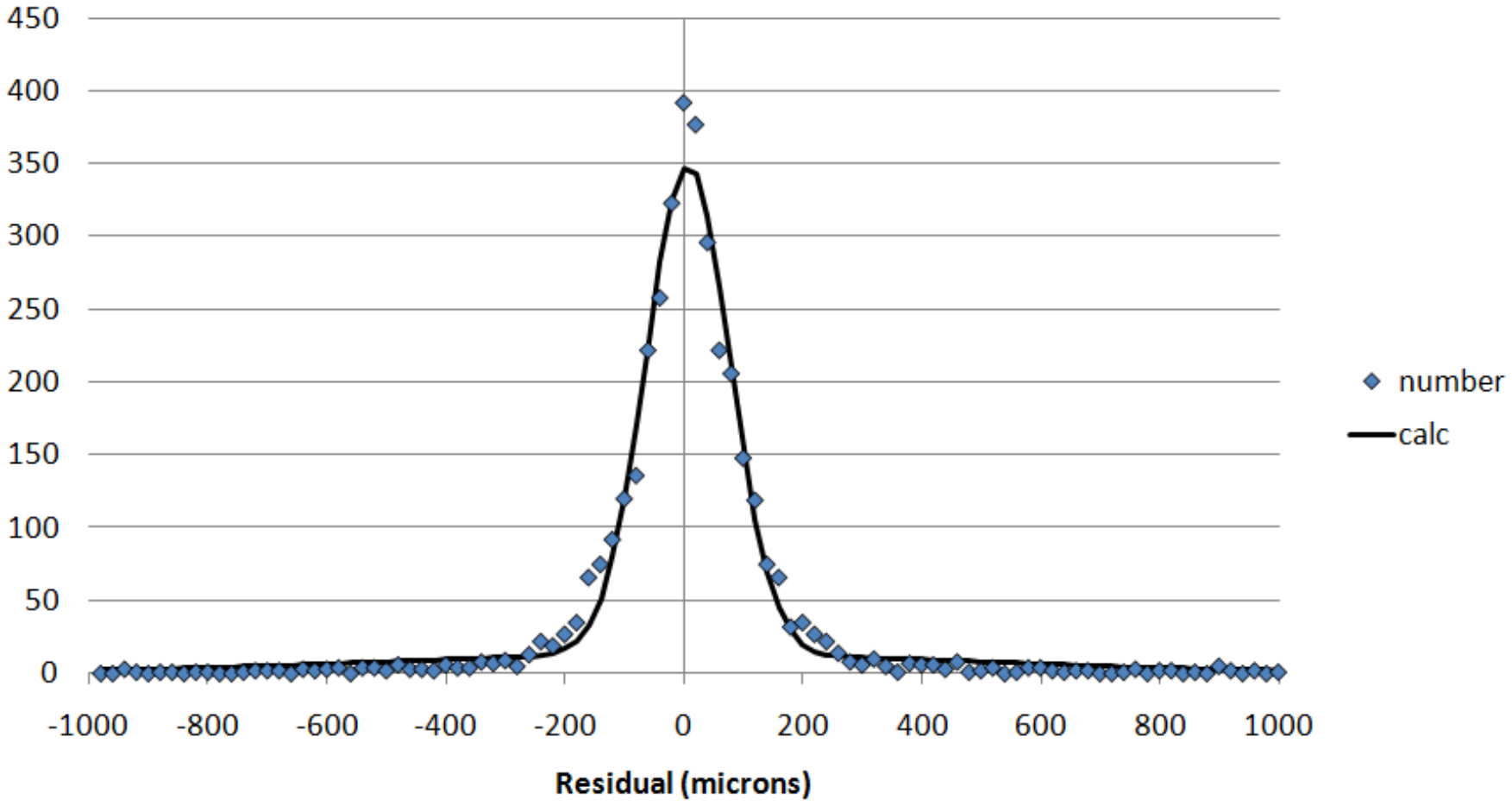
EI residuals, σ_{narrow} = 87 μm
Single tube resolution = 87*sqrt(8/5) = 110 μm



EM residuals, σ_{narrow} = 77 μm
Single tube resolution = 77*sqrt(6/3) = 109 μm



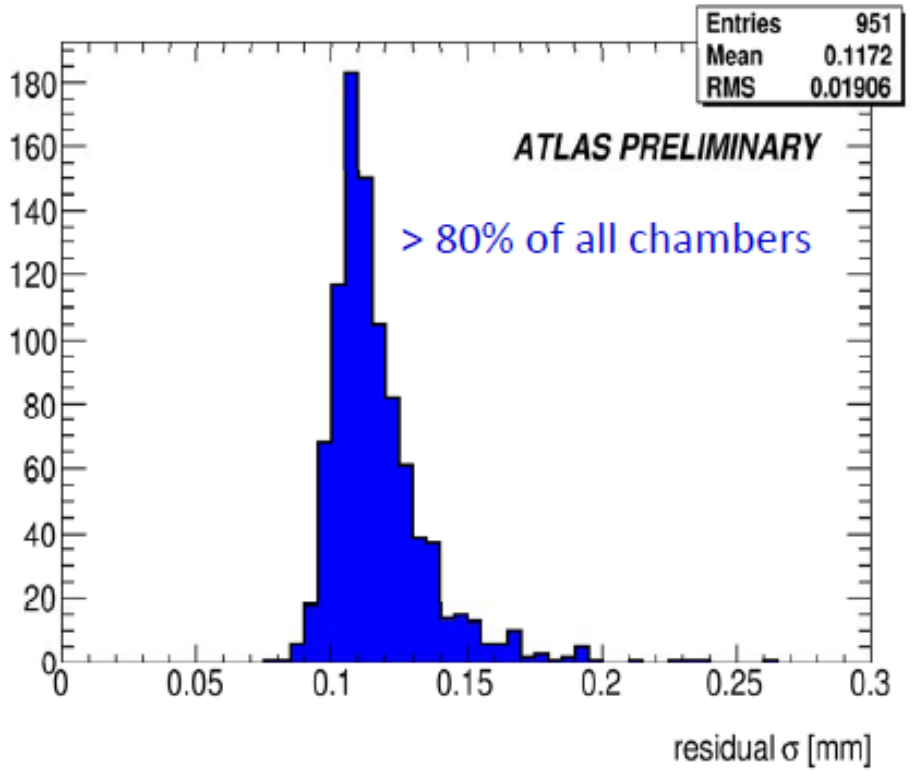
EO residuals, σ_{narrow} = 71 μm
Single tube resolution = 71*sqrt(6/3) = 100 μm

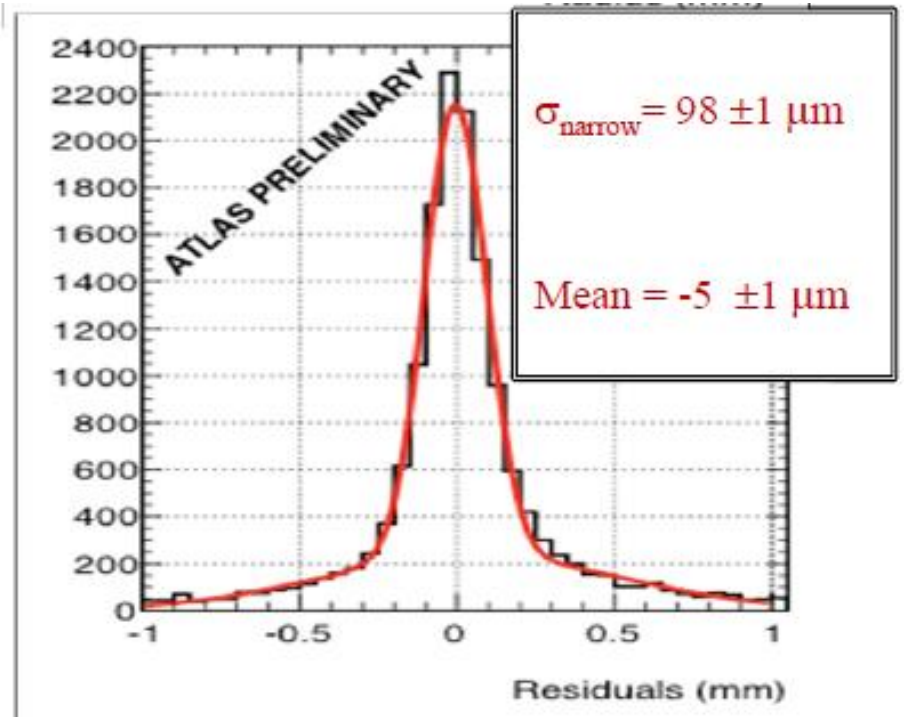


From Dan Levin's commissioning fits using excluded tube to determine resolution

Average Width: 117 μm (includes outliers)

Peak of (σ_{narrow}): 105 μm

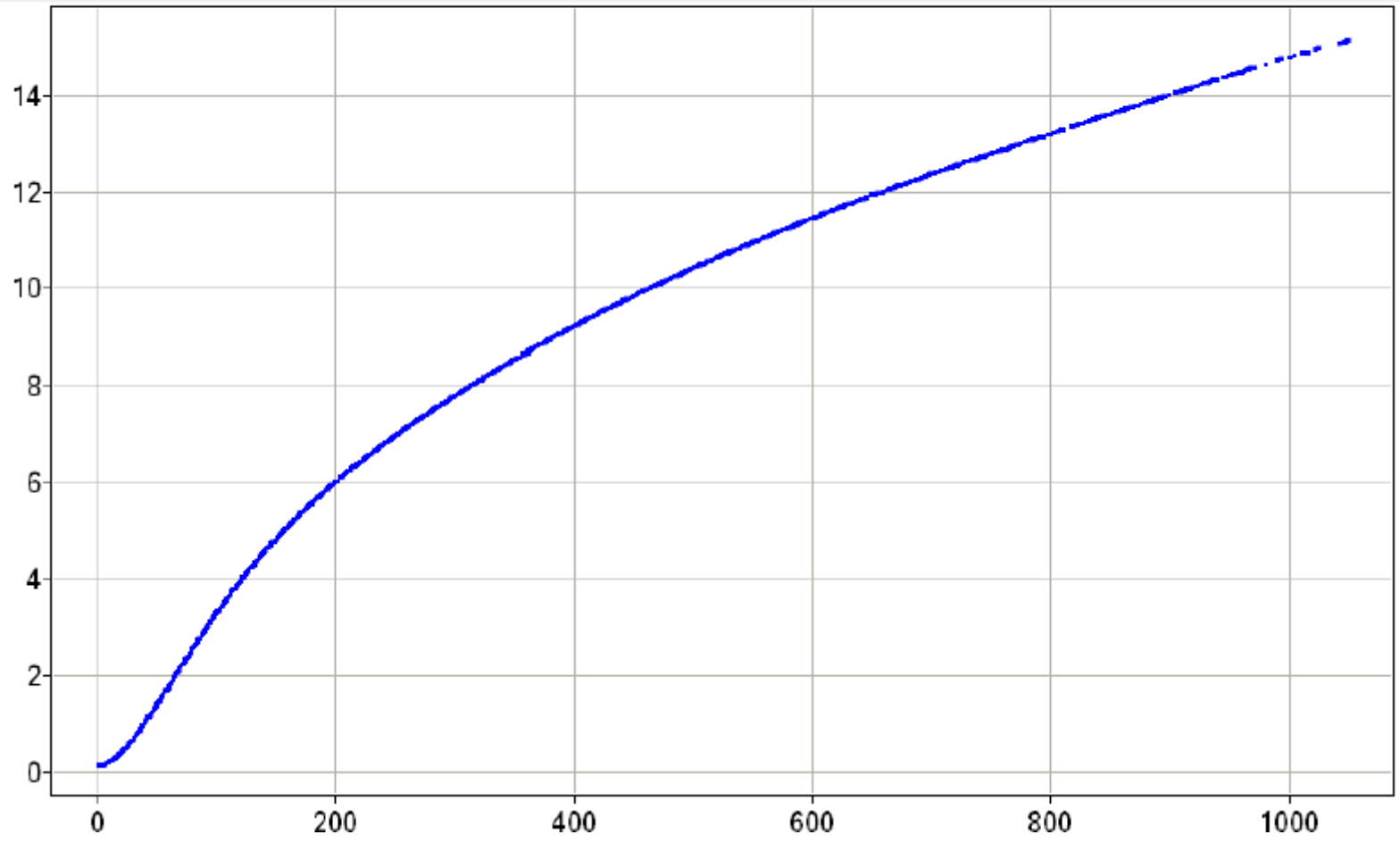




Resolution in late 2009 of EI Chambers

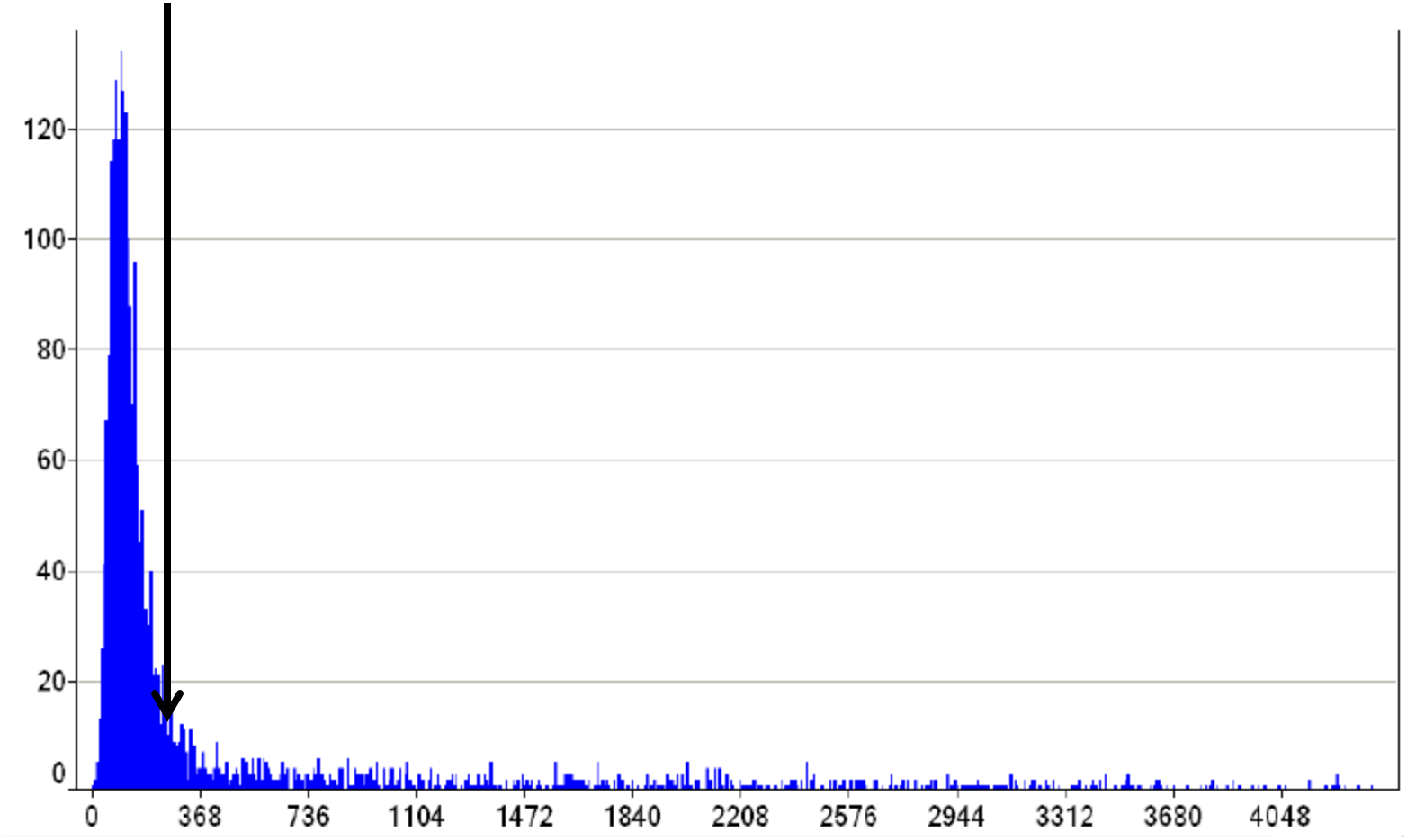
- Cosmic ray run 131576
- EI, EM, EO coincidence
- 8-6-6 hits
- Only one option for segments
- Only one chamber involved in each station
- 2742 events

RT function (Ahlen): r(mm) vs. TDC channel



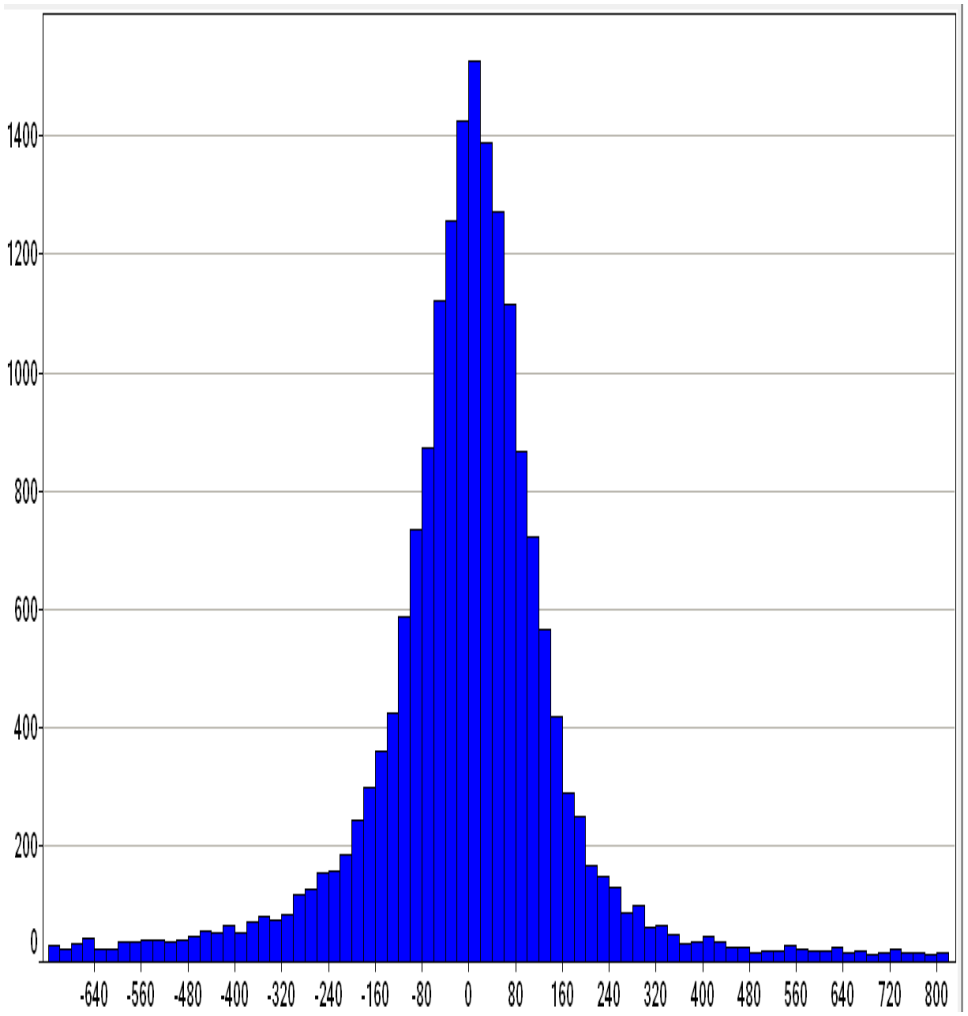
66% of the EI segments should have no delta rays

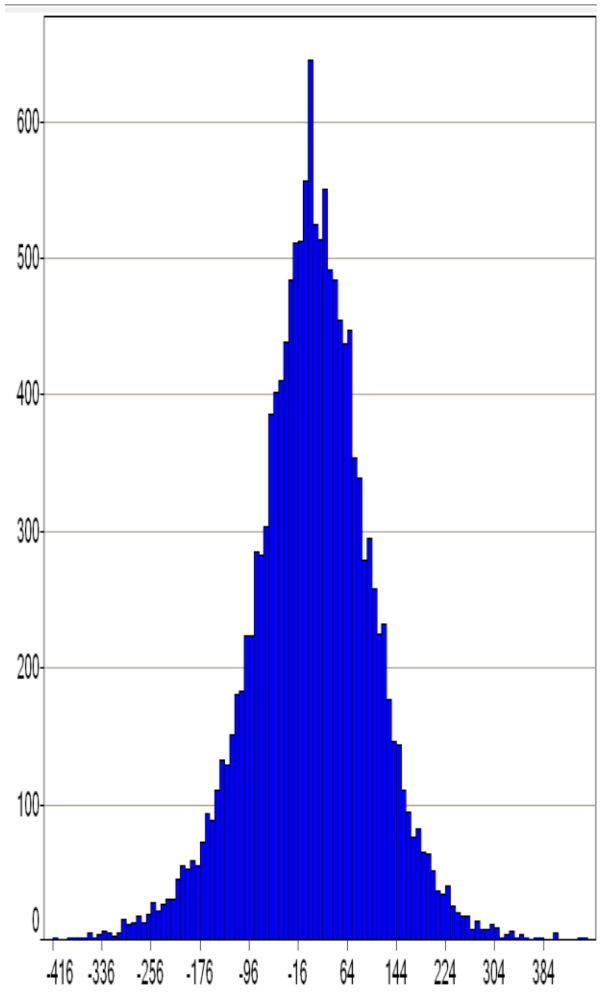
Tail of chi distribution for Ahlen's fits shows evidence of delta rays (chi > 240 μm for 32% of events)



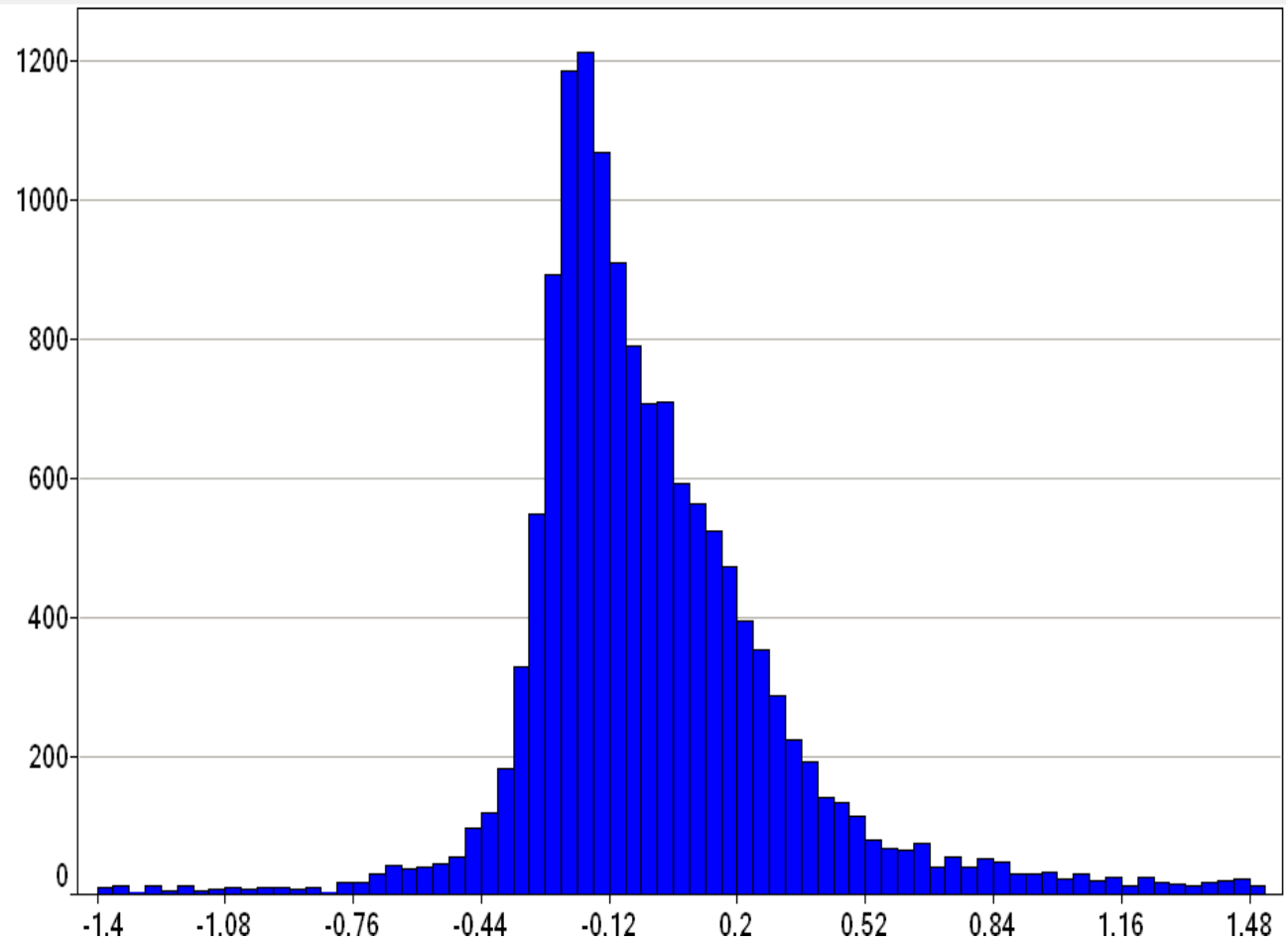
Residuals for Ahlen fits: FWHM/2.35 = 97 μm for EI chambers

For chi < 240 μm: FWHM/2.35 = 90 μm

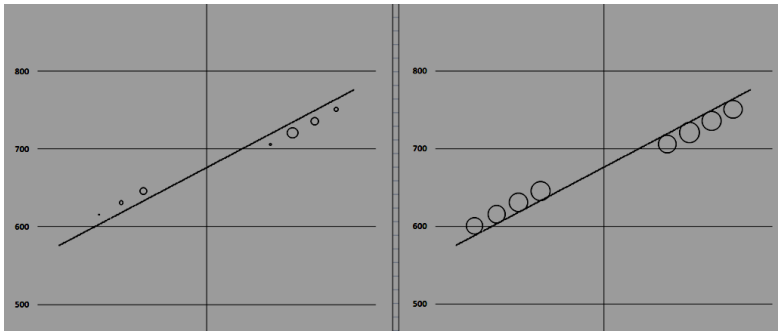


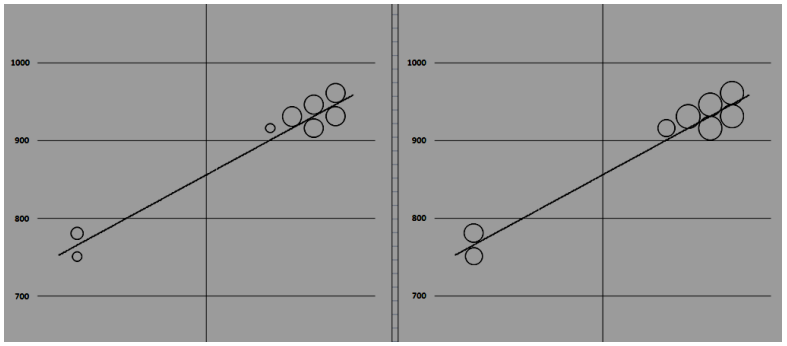


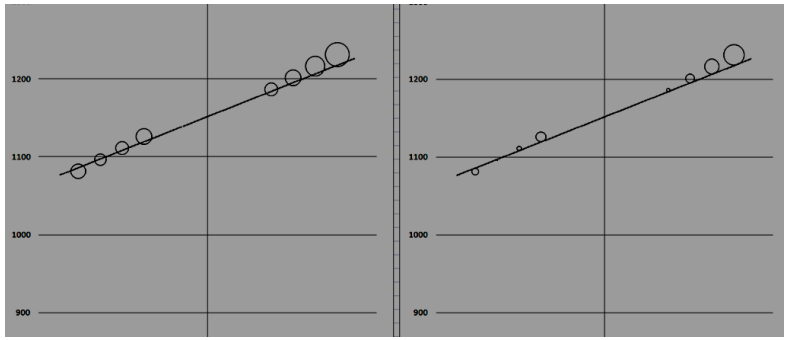
Ahlen r(mm) minus Moore r(mm) for chi < 240 μm (no delta rays); FWHM/2.35 = 150 μm

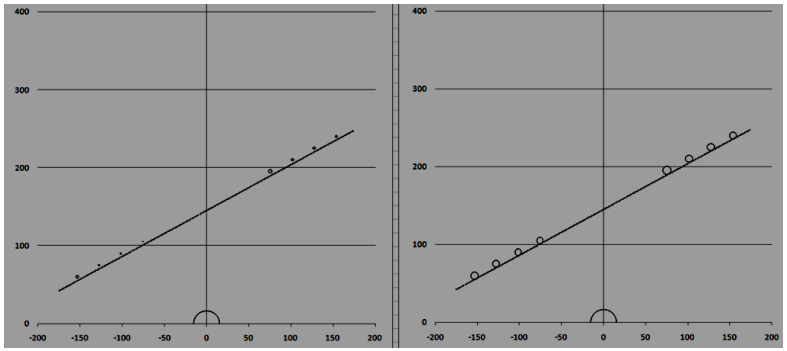


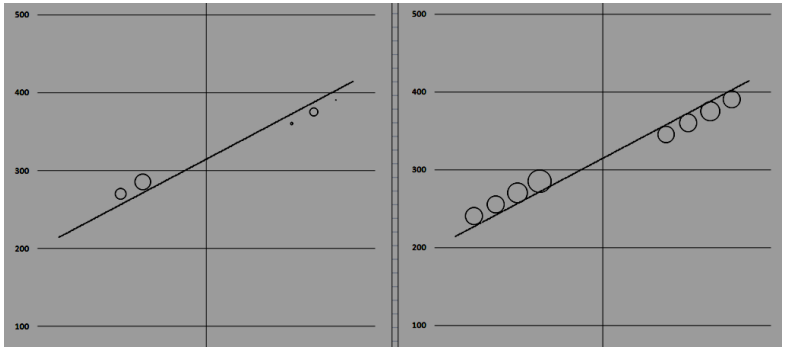
Agreement is good for most events; some events with poor agreement are shown: Moore fit on left, Ahlen fit on right.

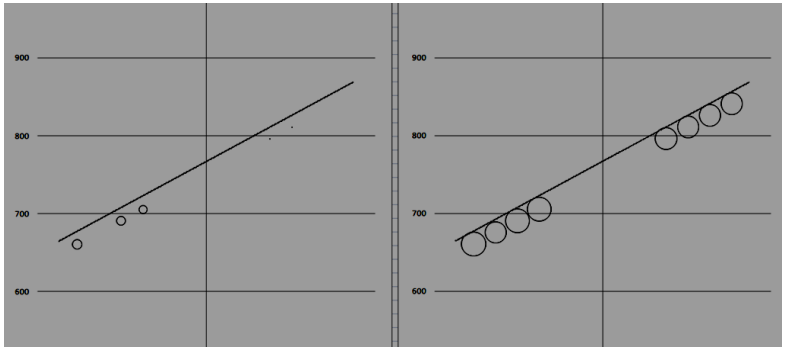








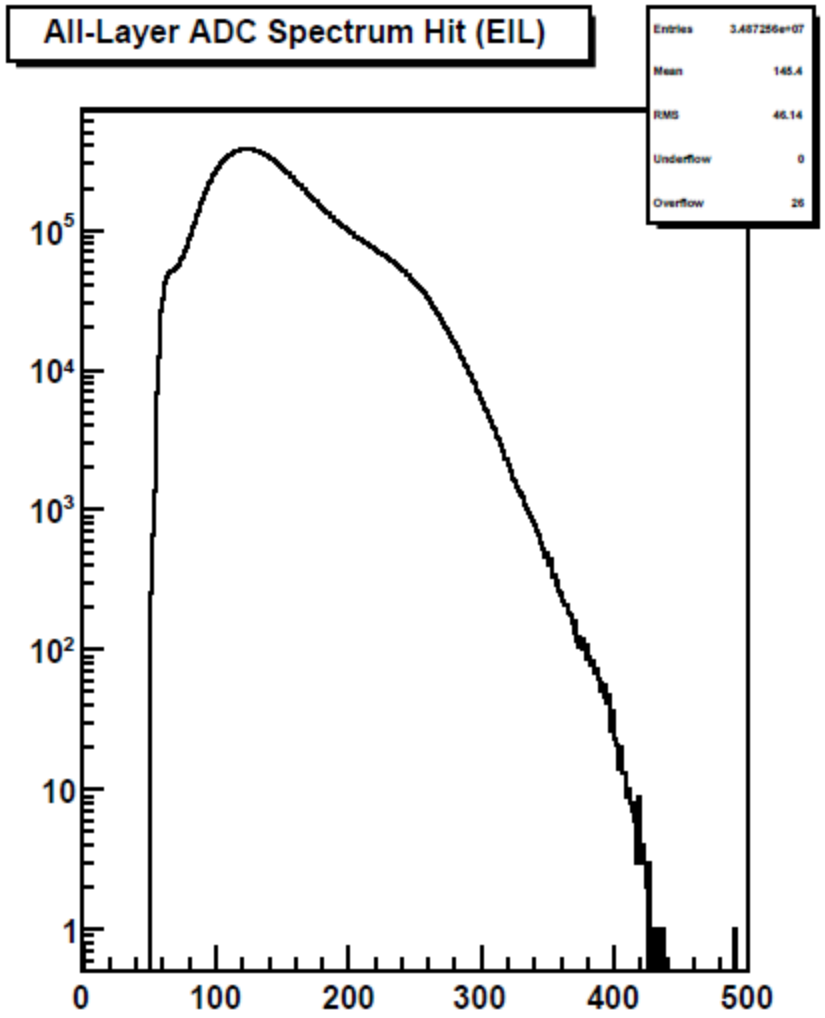


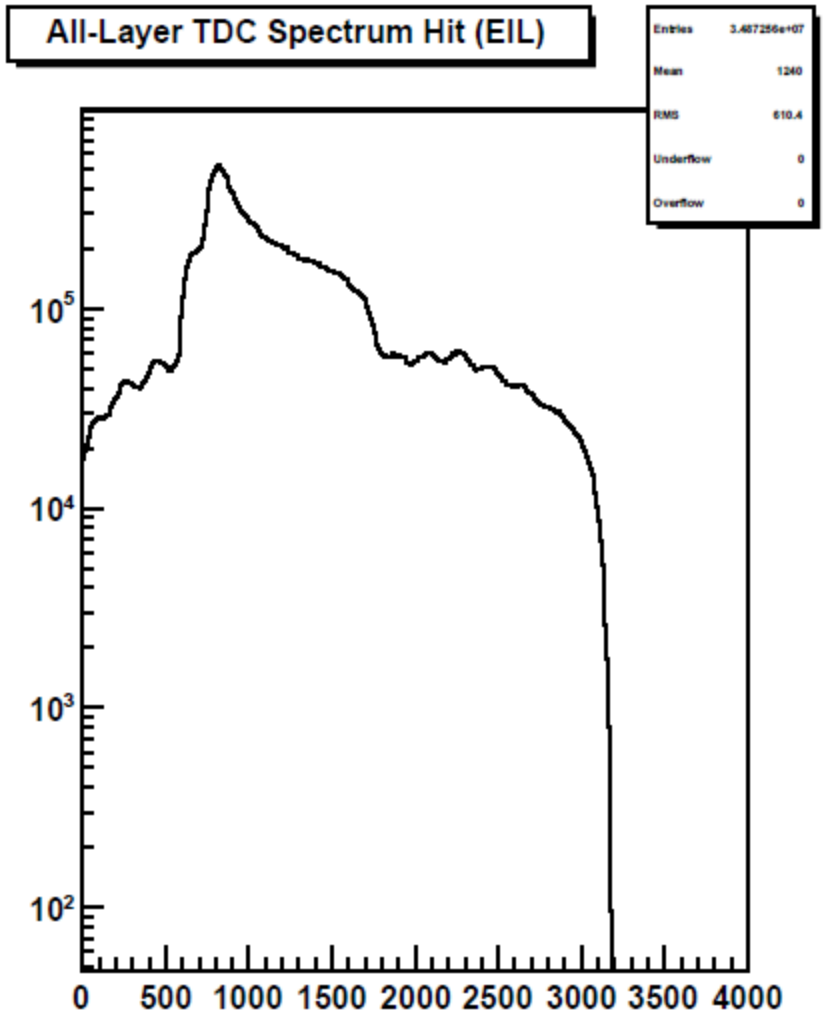


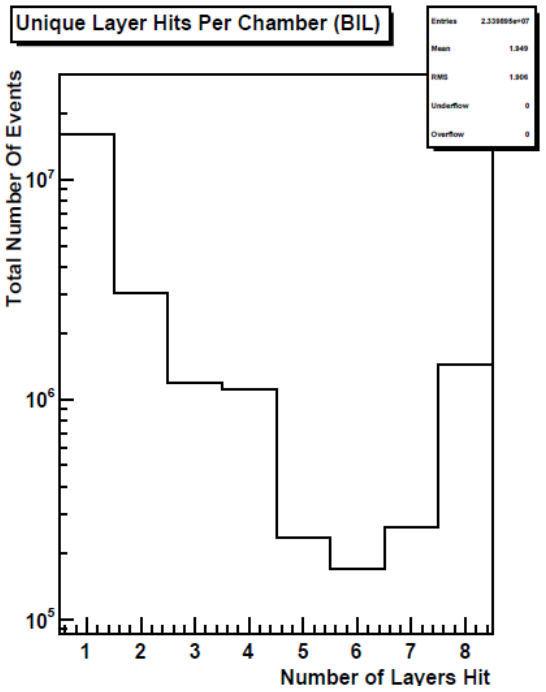
Studies of MDT performance for high luminosity run using raw data

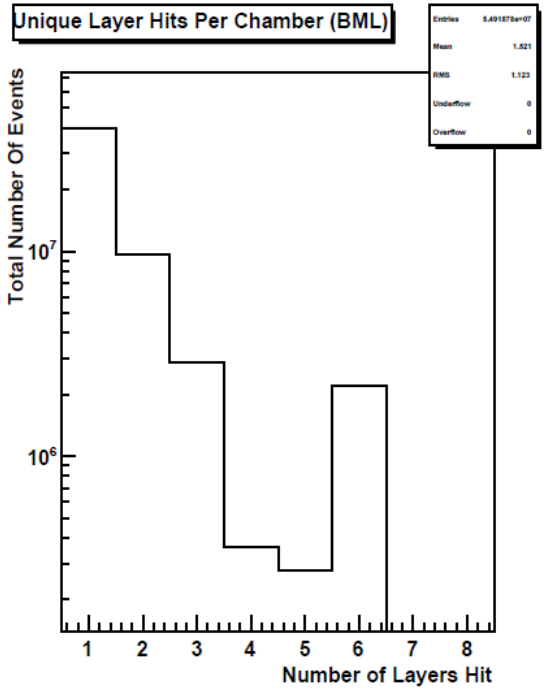
- Analysis being done by Mike Kruskal using tools he developed for high energy neutron induced crosstalk studies.
- We are using run 167776.
  - October 27, 2010
  - 6305 nb^{-1}
  - Peak luminosity = 1.81 x 10^{32} $cm^{-2}s^{-1}$
  - 348 colliding bunch pairs
  - 150 ns bunch spacing
  - 7,283,888 muon triggered events analyzed

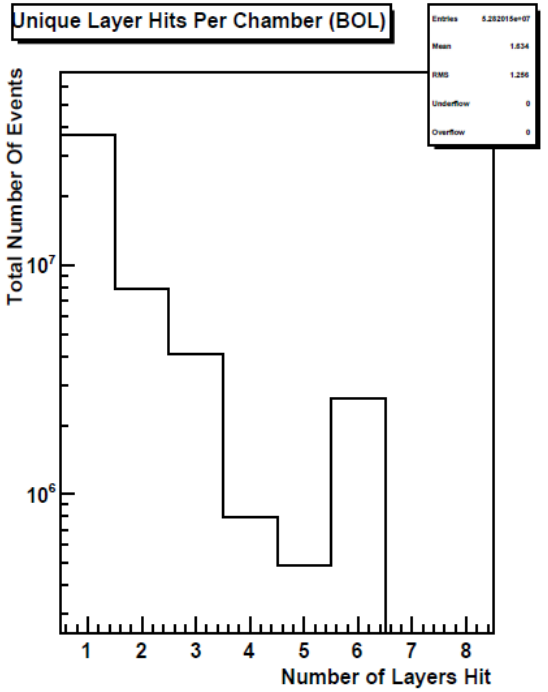
ADC > 50 cut; 150 ns bunch spacing is apparent

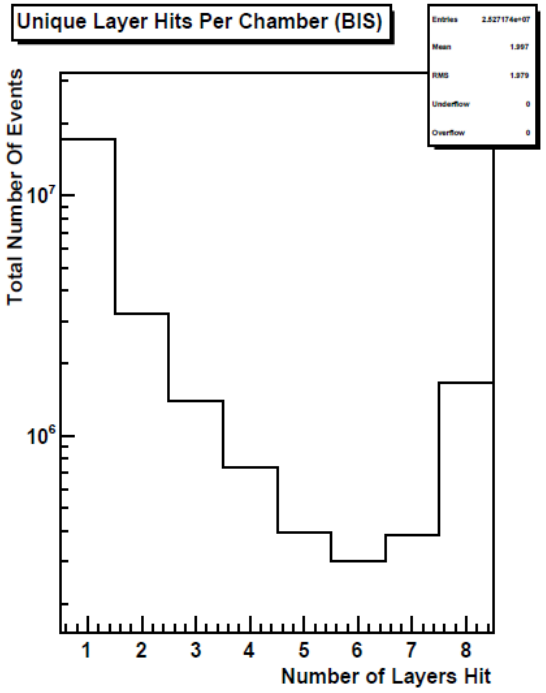


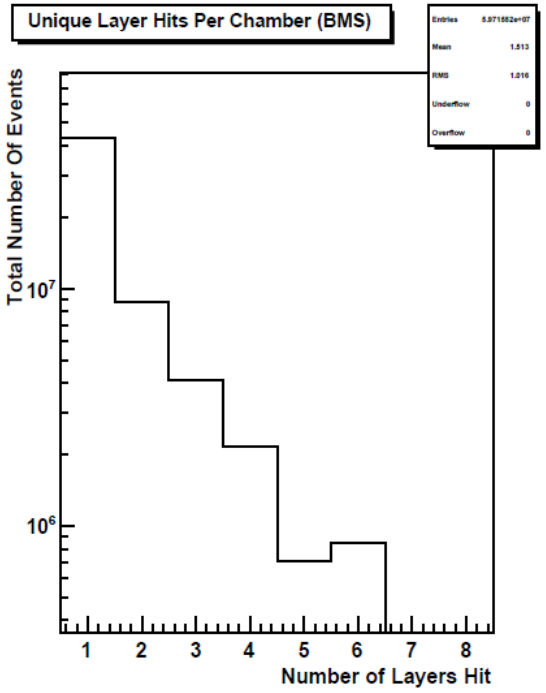


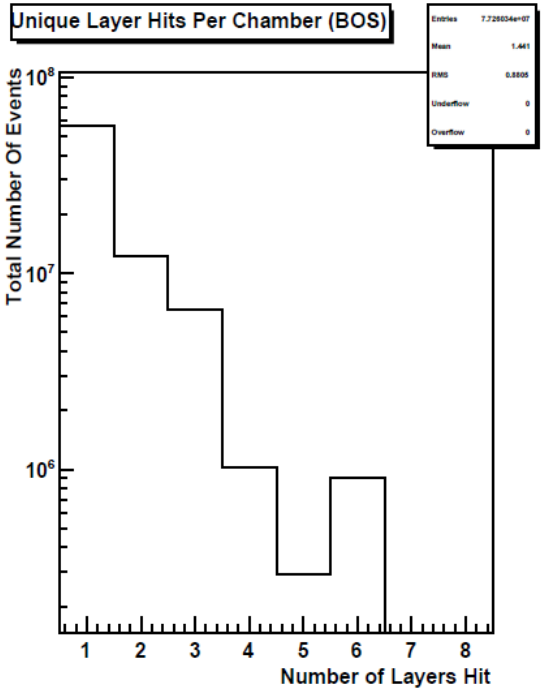

Unique Layer Hits Per Chamber (BIL)
Total Number Of Events
Number of Layers Hit

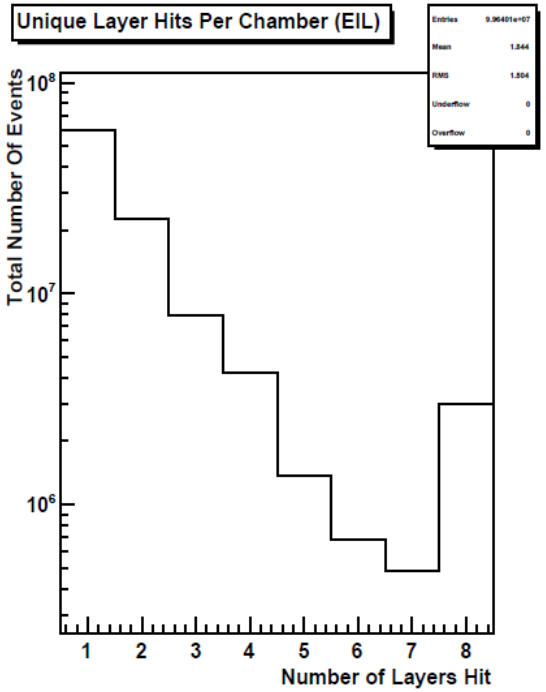

Unique Layer Hits Per Chamber (BML)
Total Number Of Events
Number of Layers Hit

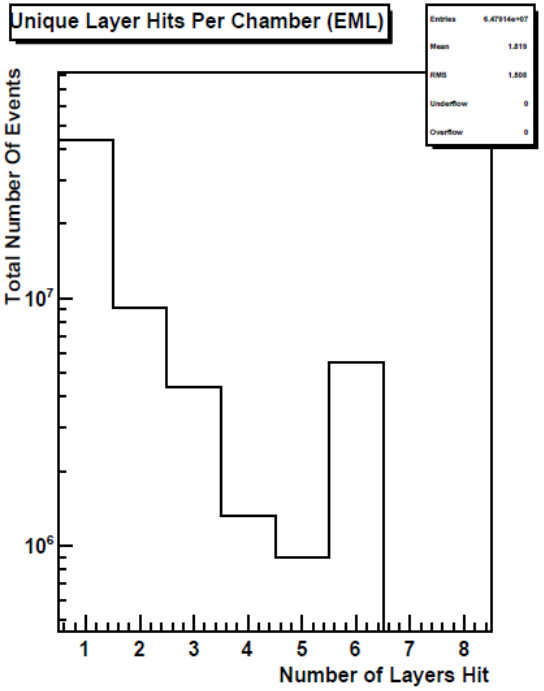

Unique Layer Hits Per Chamber (BOL)
Total Number Of Events
Number of Layers Hit

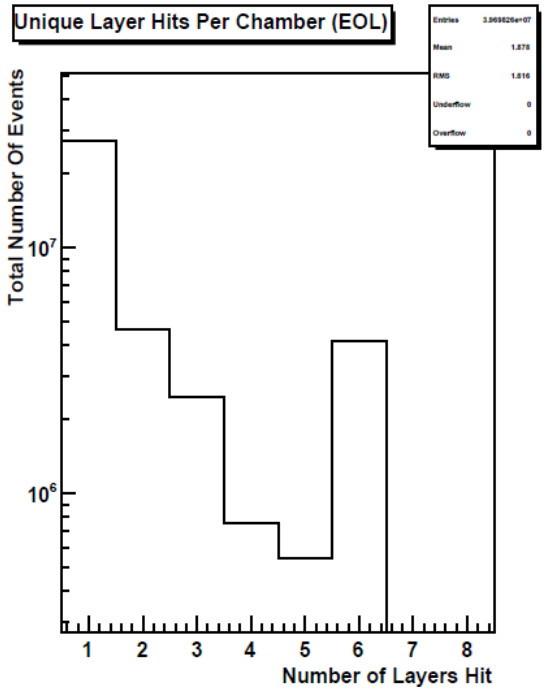

Unique Layer Hits Per Chamber (BIS)
Total Number Of Events
Number of Layers Hit

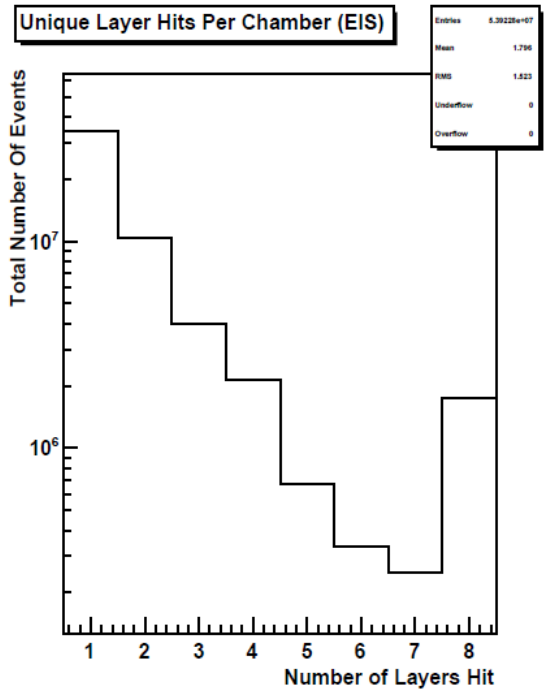

Unique Layer Hits Per Chamber (BMS)
Total Number Of Events
Number of Layers Hit

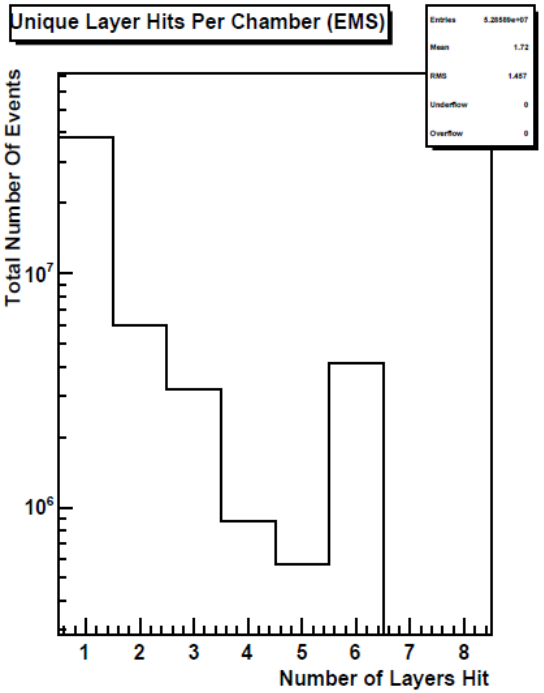

Unique Layer Hits Per Chamber (BOS)
Total Number Of Events
Number of Layers Hit

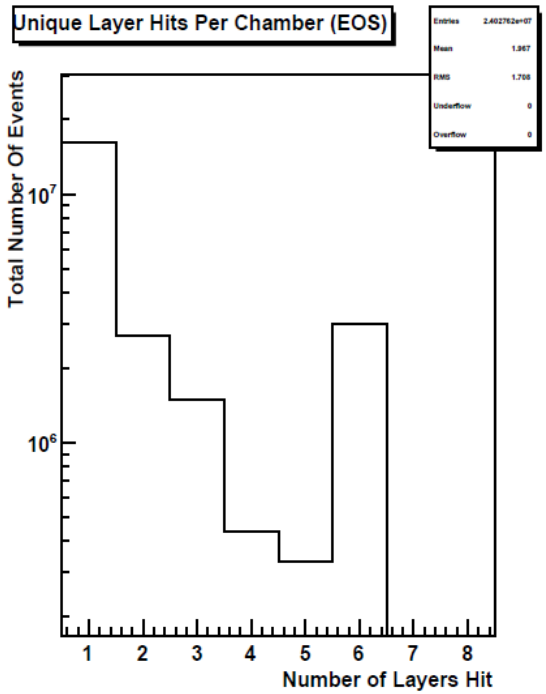

Unique Layer Hits Per Chamber (EIL)
Total Number Of Events
Number of Layers Hit

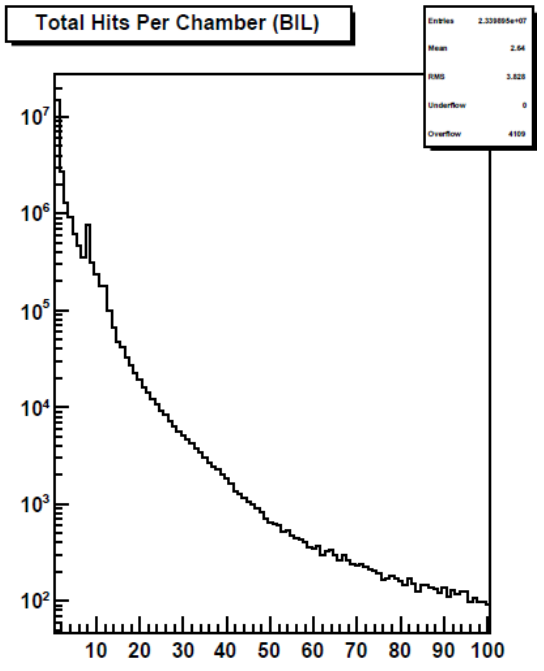

Unique Layer Hits Per Chamber (EML)
Total Number Of Events
Number of Layers Hit

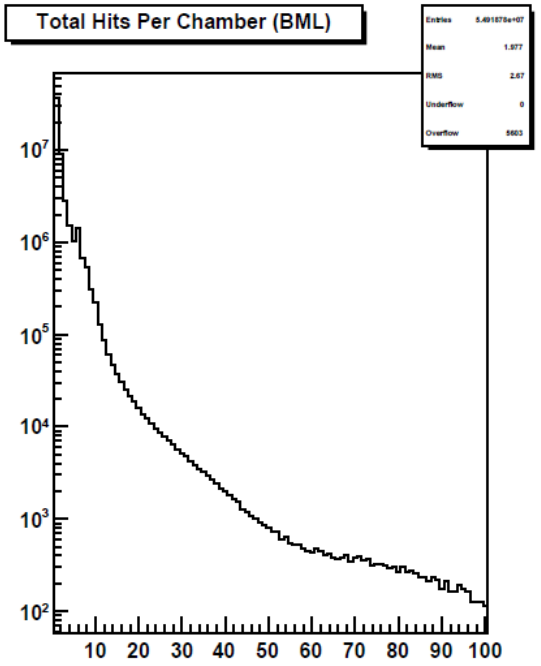

Unique Layer Hits Per Chamber (EOL)
Total Number Of Events
Number of Layers Hit

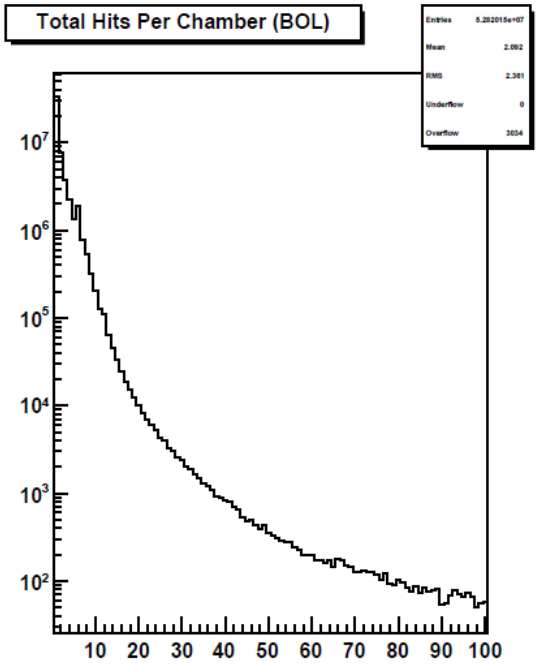

Unique Layer Hits Per Chamber (EIS)
Total Number Of Events
Number of Layers Hit

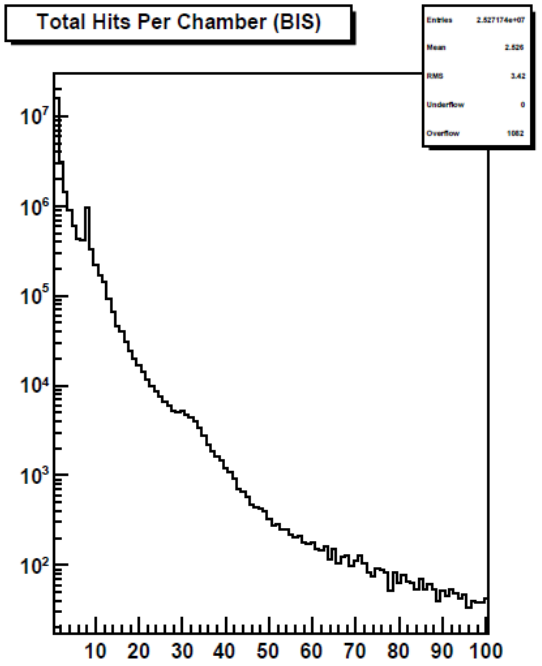

Unique Layer Hits Per Chamber (EMS)
Total Number Of Events
Number of Layers Hit

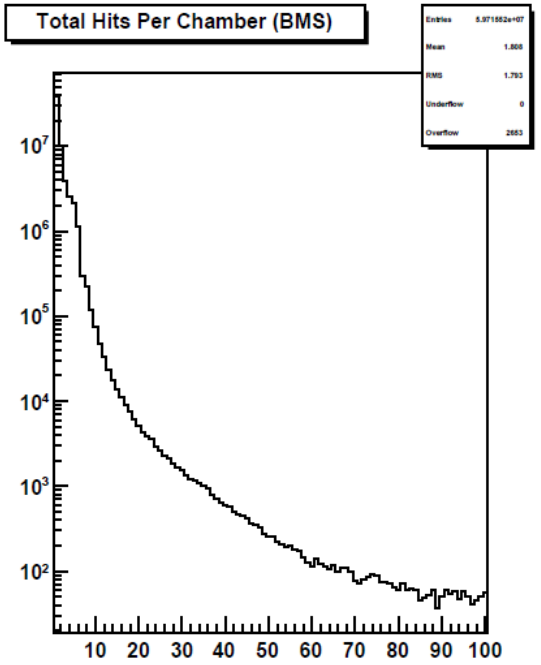

Unique Layer Hits Per Chamber (EOS)
Total Number Of Events
Number of Layers Hit

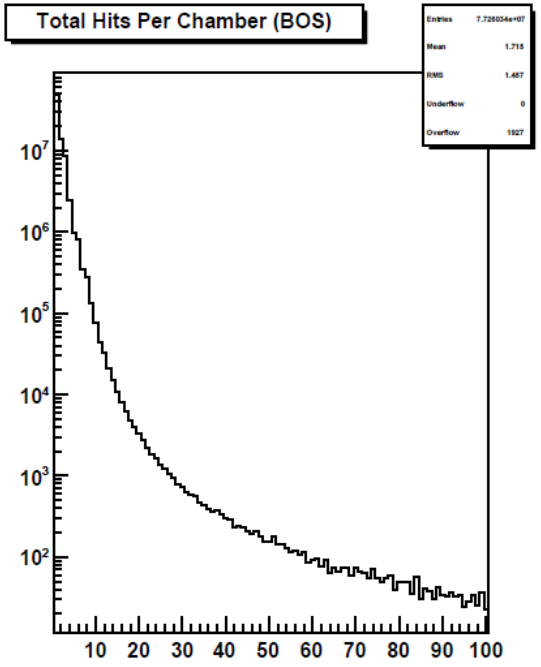

Total Hits Per Chamber (BIL)
Entries 2.339895e+07
Mean 2.64
RMS 3.828
Underflow 0
Overflow 4109
10^7
10^6
10^5
10^4
10^3
10^2
10 20 30 40 50 60 70 80 90 100

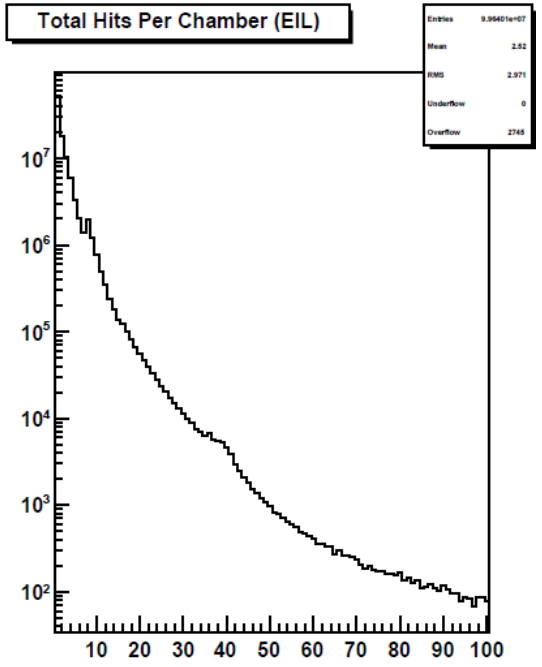

Total Hits Per Chamber (BML)
Entries 5.491878e+07
Mean 1.977
RMS 2.67
Underflow 0
Overflow 5603
10^7
10^6
10^5
10^4
10^3
10^2
10 20 30 40 50 60 70 80 90 100

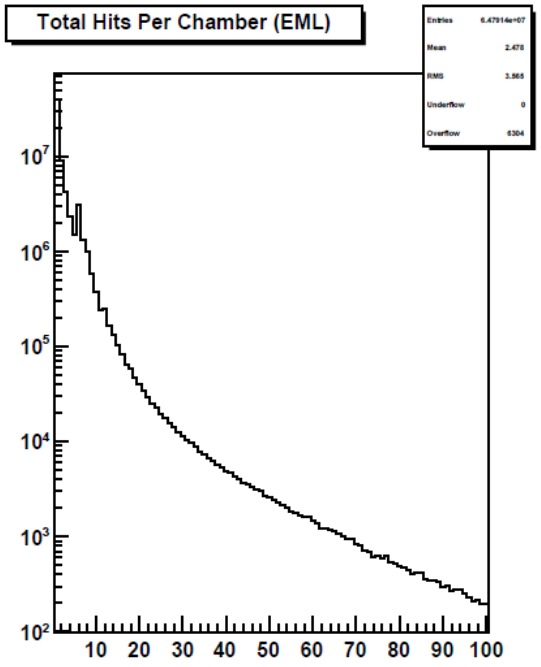

Total Hits Per Chamber (BOL)
Entries 5.282015e+07
Mean 2.092
RMS 2.381
Underflow 0
Overflow 3034
10^7
10^6
10^5
10^4
10^3
10^2
10 20 30 40 50 60 70 80 90 100

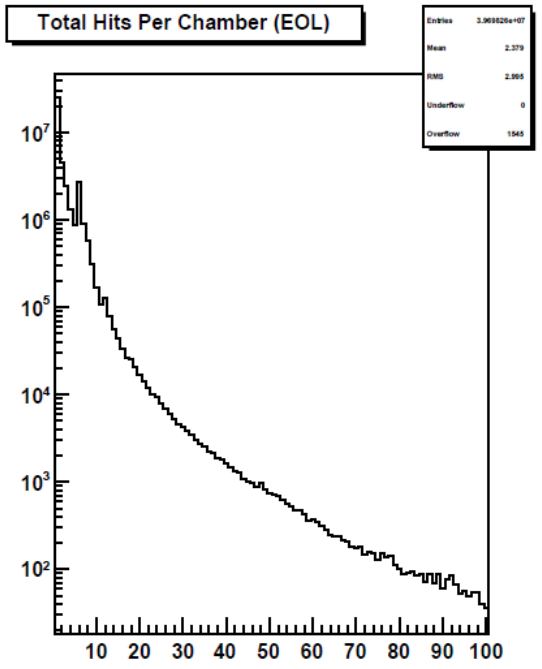

Total Hits Per Chamber (BIS)
Entries 2.527174e+07
Mean 2.526
RMS 3.42
Underflow 0
Overflow 1062
10^7
10^6
10^5
10^4
10^3
10^2
10 20 30 40 50 60 70 80 90 100

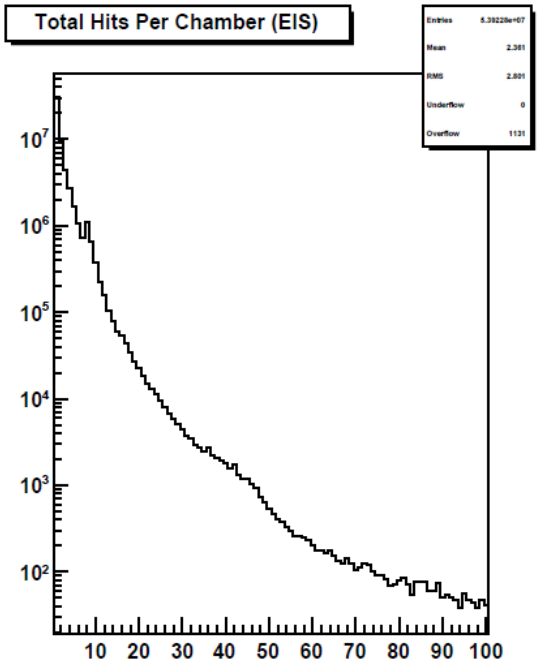

Total Hits Per Chamber (BMS)
Entries 5.971582e+07
Mean 1.806
RMS 1.793
Underflow 0
Overflow 2663
10^7
10^6
10^5
10^4
10^3
10^2
10 20 30 40 50 60 70 80 90 100

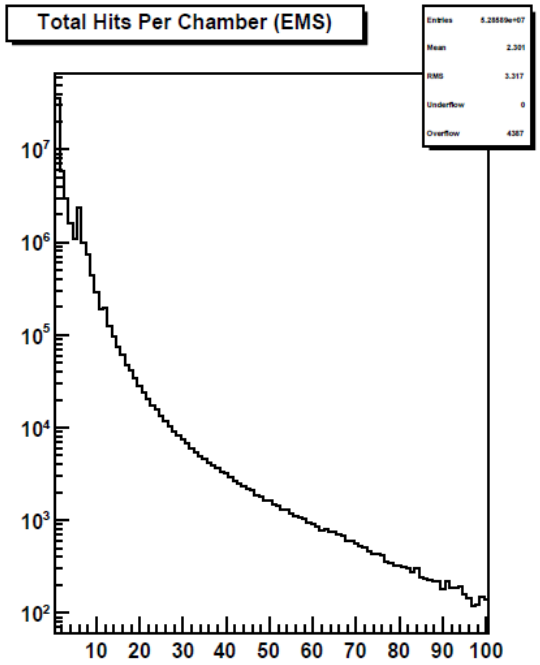

Total Hits Per Chamber (BOS)
Entries 7.726034e+07
Mean 1.715
RMS 1.457
Underflow 0
Overflow 1927
10^7
10^6
10^5
10^4
10^3
10^2
10 20 30 40 50 60 70 80 90 100

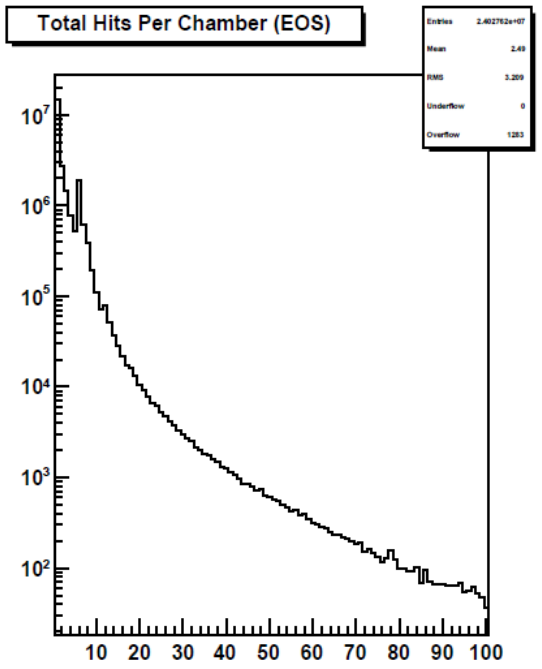

Total Hits Per Chamber (EIL)
Entries 9.95401e+07
Mean 2.62
RMS 2.971
Underflow 0
Overflow 2745
10 20 30 40 50 60 70 80 90 100


Total Hits Per Chamber (EML)
Entries 6.47914e+07
Mean 2.478
RMS 3.565
Underflow 0
Overflow 6304
10 20 30 40 50 60 70 80 90 100

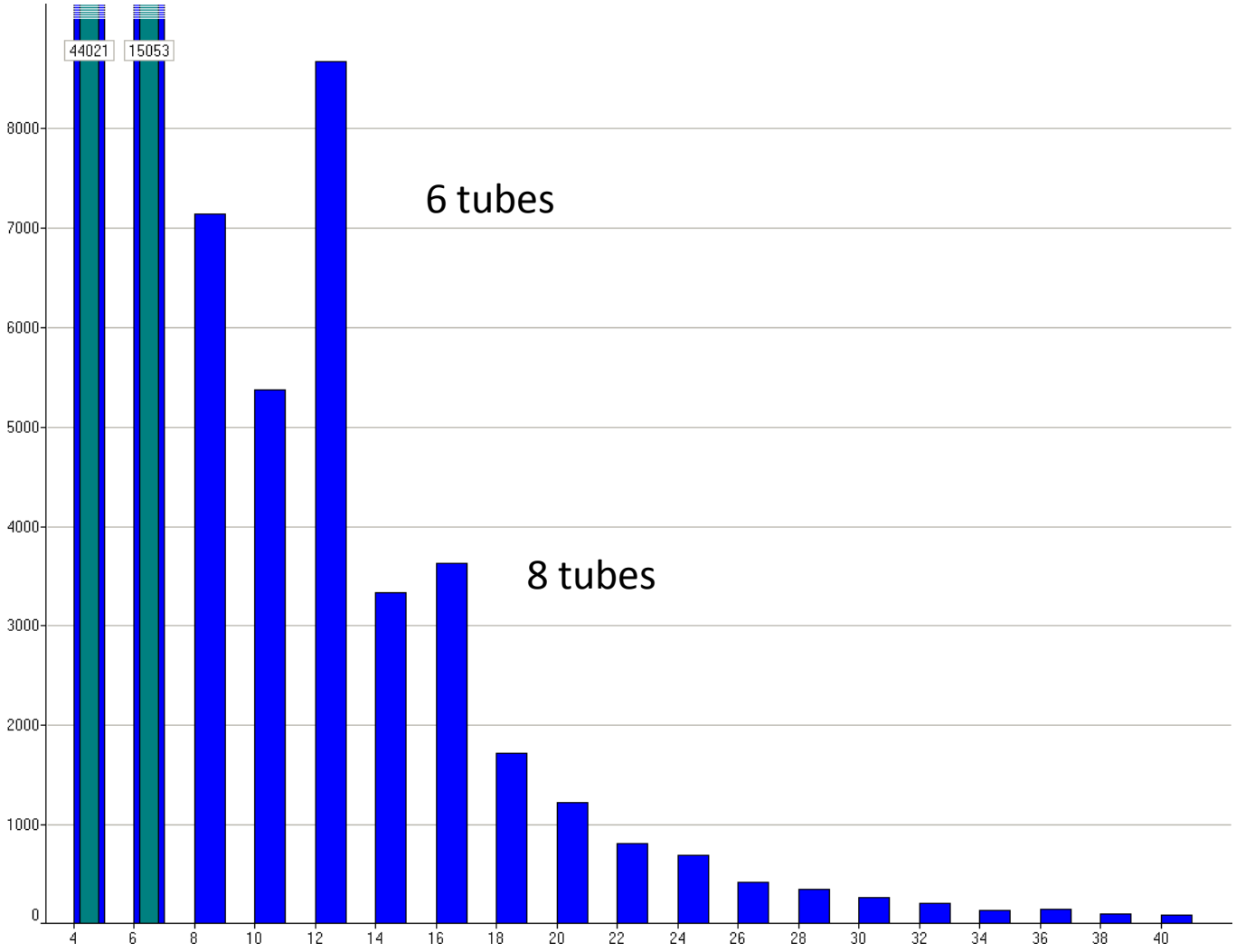

Total Hits Per Chamber (EOL)
Entries 3.969826e+07
Mean 2.379
RMS 2.995
Underflow 0
Overflow 1545
10 20 30 40 50 60 70 80 90 100


Total Hits Per Chamber (EIS)
Entries 5.39228e+07
Mean 2.361
RMS 2.801
Underflow 0
Overflow 1131
10 20 30 40 50 60 70 80 90 100


Total Hits Per Chamber (EMS)
Entries 5.28589e+07
Mean 2.301
RMS 3.317
Underflow 0
Overflow 4387
10 20 30 40 50 60 70 80 90 100


Total Hits Per Chamber (EOS)
Entries 2.402762e+07
Mean 2.49
RMS 3.209
Underflow 0
Overflow 1283
10 20 30 40 50 60 70 80 90 100

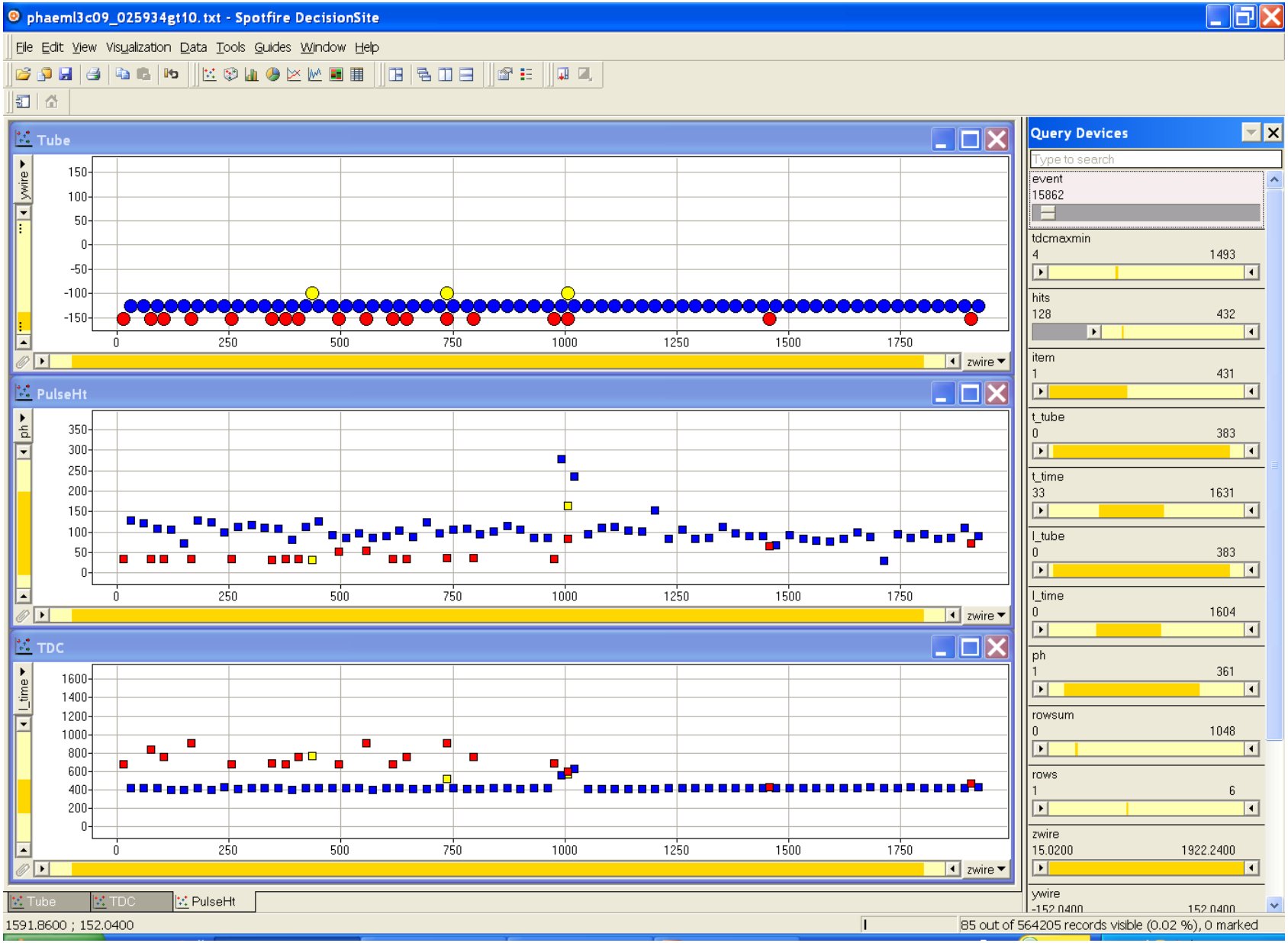
Hit histogram for noise run for EML1C09 in Bldg 180



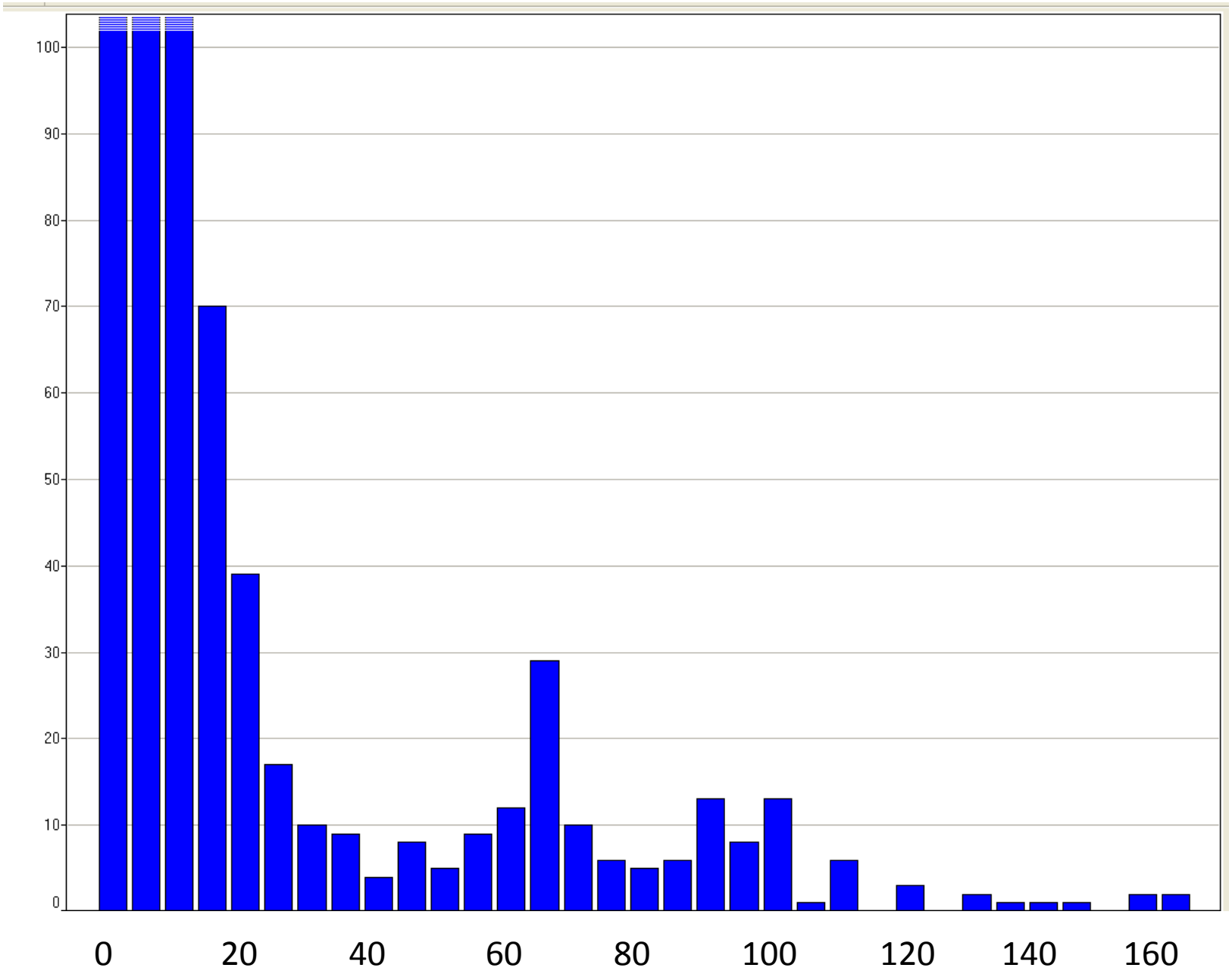
High multiplicity events were observed in 15 hour commissioning runs

- Very large multiplicity events
  - Two neighboring tubes with large pulses that arrive late.
  - Other tubes hit at same time.
  - Cross talk mainly on same layer with reduced effect on adjacent layers – probably cross talk along HV path.
  - All chambers seem to have this “feature” – typical rates are about 0.1 Hz.
  - Some chambers had rates > 10 Hz; these were fixed by replacing the HV Hedgehog Card.

Single layer event – two neighboring channels with big pulses arrive late



EML3C09 tube hit distribution in Pit – peak around 64 tubes, number in layer



Future Work

- Continue to characterize tracks for this run, to identify simple techniques for extracting muon segments and tracks from data.
- Use our track fitting program to measure muon segment T0's (and compare to BCID) and determine track fit residuals at 1.8 x 10^{32} $cm^{-2}s^{-1}$ luminosity.
- Study simple methods for global track fitting.