Neutral hadron studies with isolated (semi)infinite calorimeters

Ron Cassell – SLAC

Detector Simulation Workshop

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Outline

- Motivation
- Detectors
- Analysis
- Calibrations
- Problems
- Progress on problems
- Still to do
- Conclusions

Motivation

- Isolate detector. Can study response without complication of EM in front.
- Isolate effects. Particle type, finite acceptance, interaction depth.
- Why bother? Just use the full detector simulations, fit for the EM and HAD response, and you're done! (next slide)

Why bother?

- Eventually, just fitting the full detector response may be the best solution. However, how to parameterize the fits probably requires a more detailed detector response understanding.
- Understanding why a resolution plot or a response curve has unexpected characteristics (even if the answer is the simulation is wrong) is important

Detectors

- For each study, remove all elements except the calorimeter being studied, and extend to 1000 layers and 30 m in z.
- Study responses to mono-energetic particles.
- Canonical set of particles – k0L, n, nbar, (gamma)
- Canonical energies – 2,3,4,5,10,15,20,25,30 GeV
- Canonical angle – 90 degrees

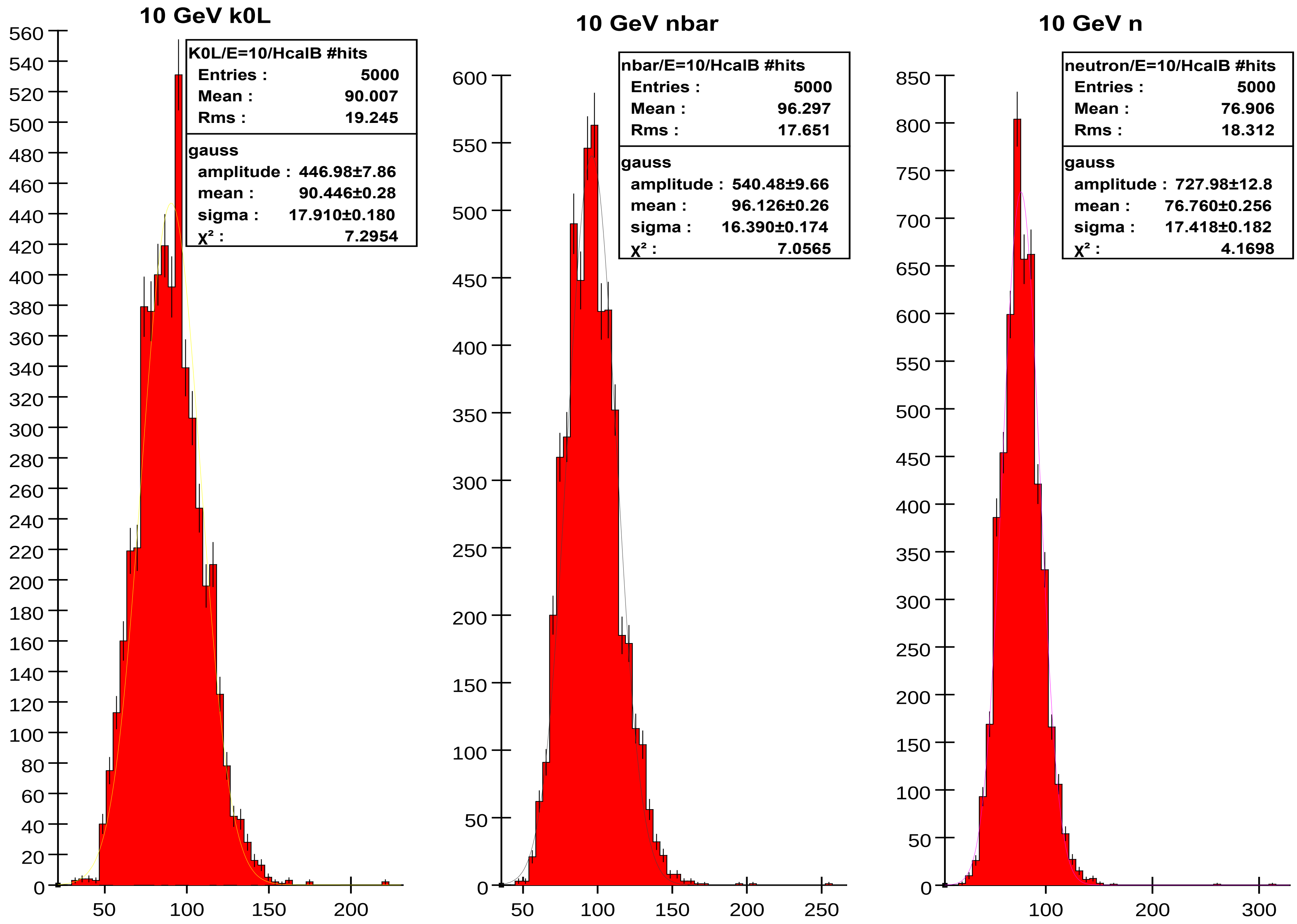
Detectors (cont)

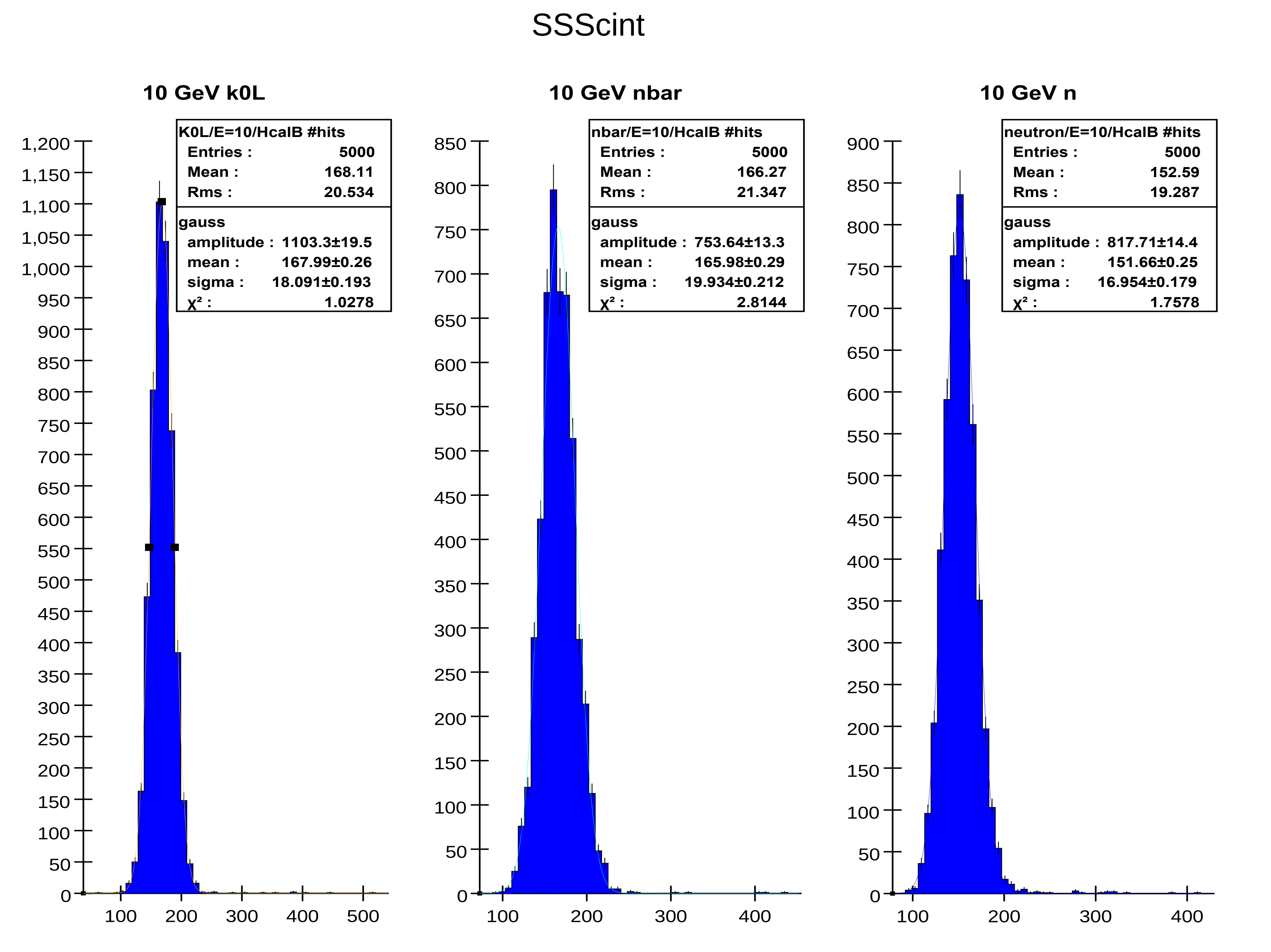
- All non-projective, Hcal fixed cells 10X10 mm, Ecal fixed cells 4X4 mm
- Hcals – SSRPC(sidaug05), SSScint(sidaug05_scint), WScint(cdcaug05), WRPC(cdcaug05_rpc)
- Ecals – 2.5mm W, 5mm W
- Variations – all elements active (SSRPC, WRPC). For SSRPC many variations including absorber width half, root2, all elements scaled root2, no B field, G10reversed, 1mm cell size
- By no means a complete set. Detectors created as needed to study problems

Analysis

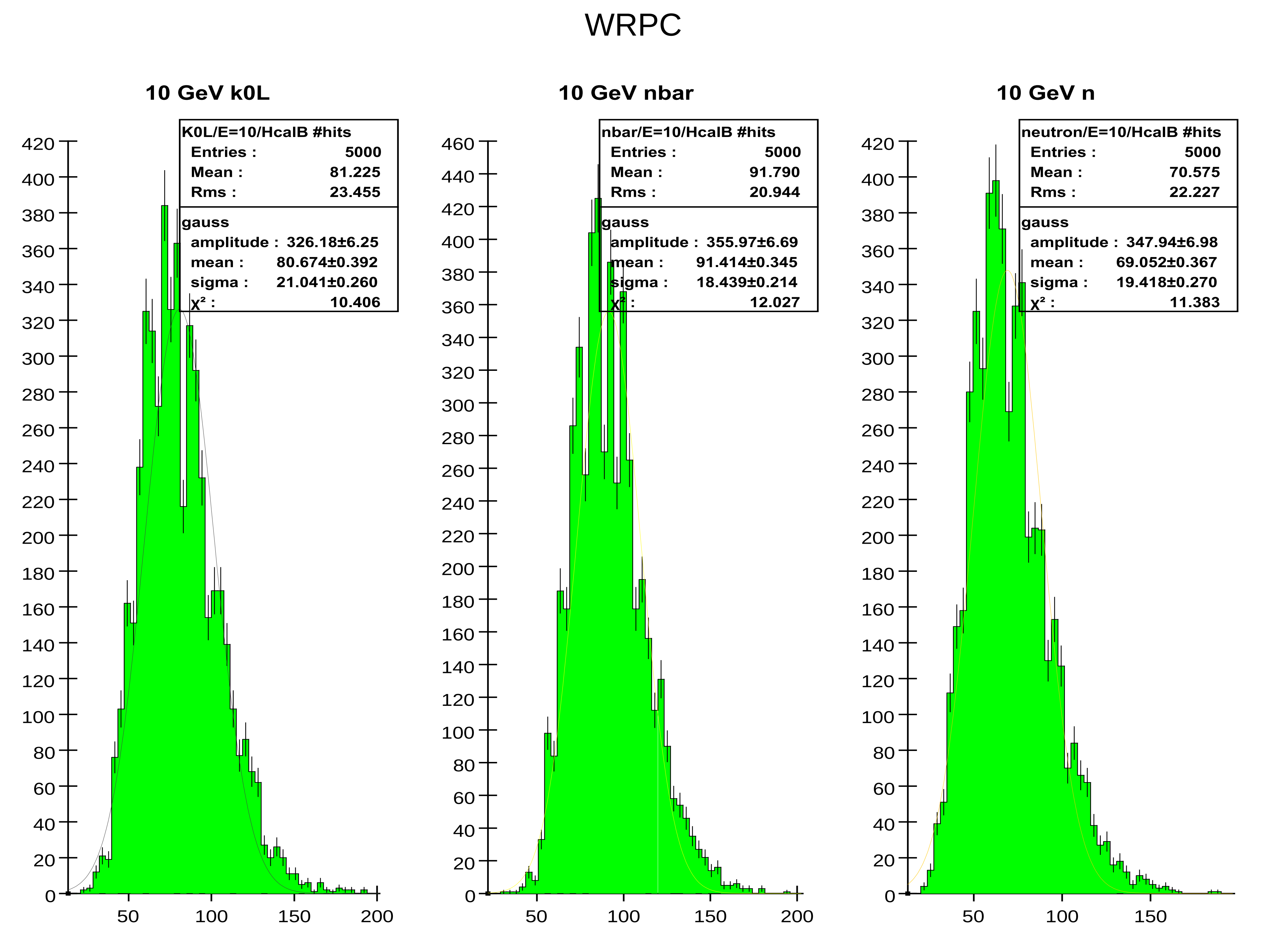
- Look at response (#hits) for each energy, using mean and rms for further study
- Hit definition: RPC – Edep > 0, t < 100ns. Scint – Edep >~ 1/3 mip, t < 100 ns.

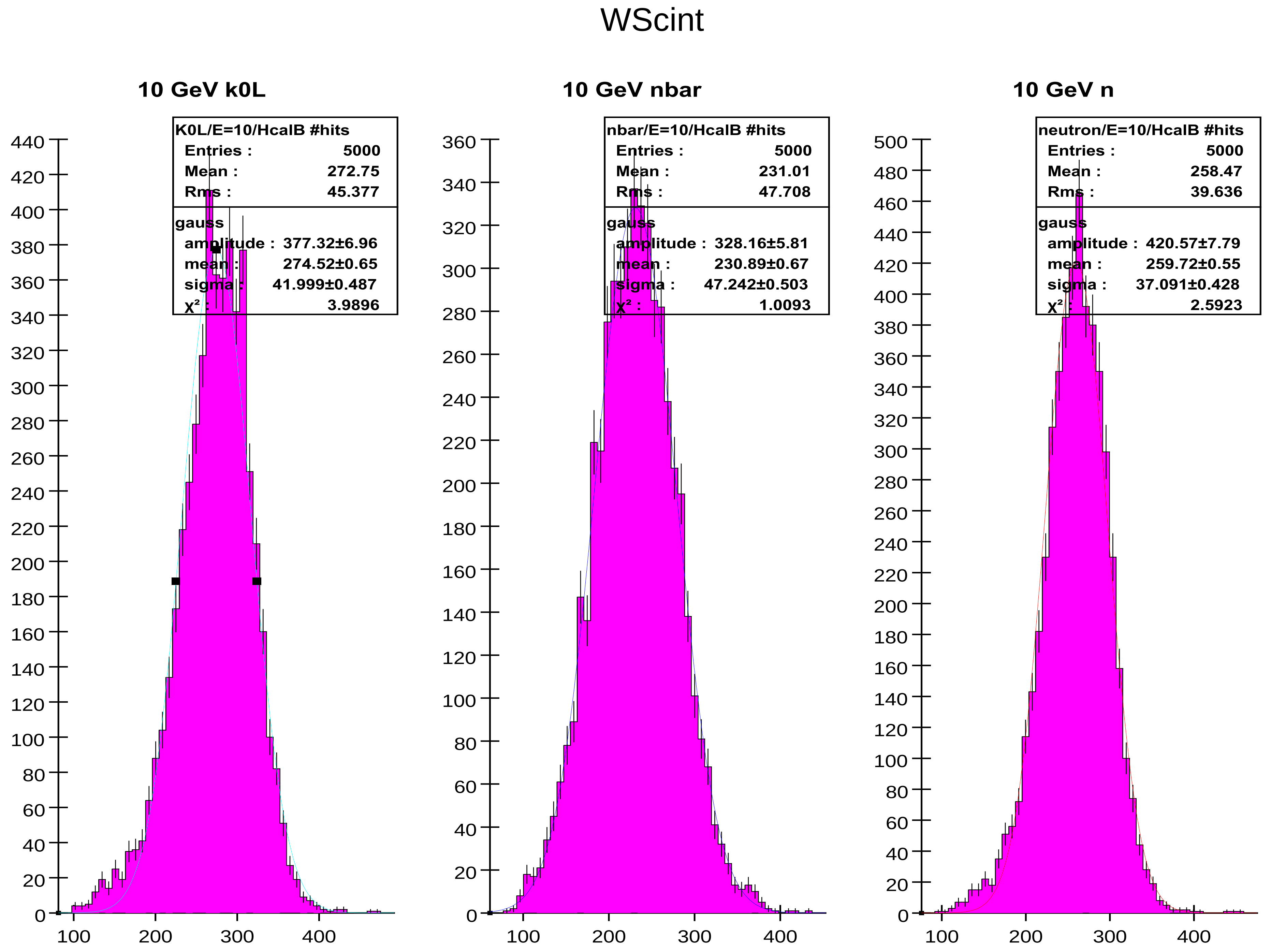
SSRPC


10 GeV k0L
K0L/E=10/HcalB #hits
Entries : 5000
Mean : 90.007
Rms : 19.245
gauss
amplitude : 446.98±7.86
mean : 90.446±0.28
sigma : 17.910±0.180
χ² : 7.2954
10 GeV nbar
nbar/E=10/HcalB #hits
Entries : 5000
Mean : 96.297
Rms : 17.651
gauss
amplitude : 540.48±9.66
mean : 96.126±0.26
sigma : 16.390±0.174
χ² : 7.0565
10 GeV n
neutron/E=10/HcalB #hits
Entries : 5000
Mean : 76.906
Rms : 18.312
gauss
amplitude : 727.98±12.8
mean : 76.760±0.256
sigma : 17.418±0.182
χ² : 4.1698

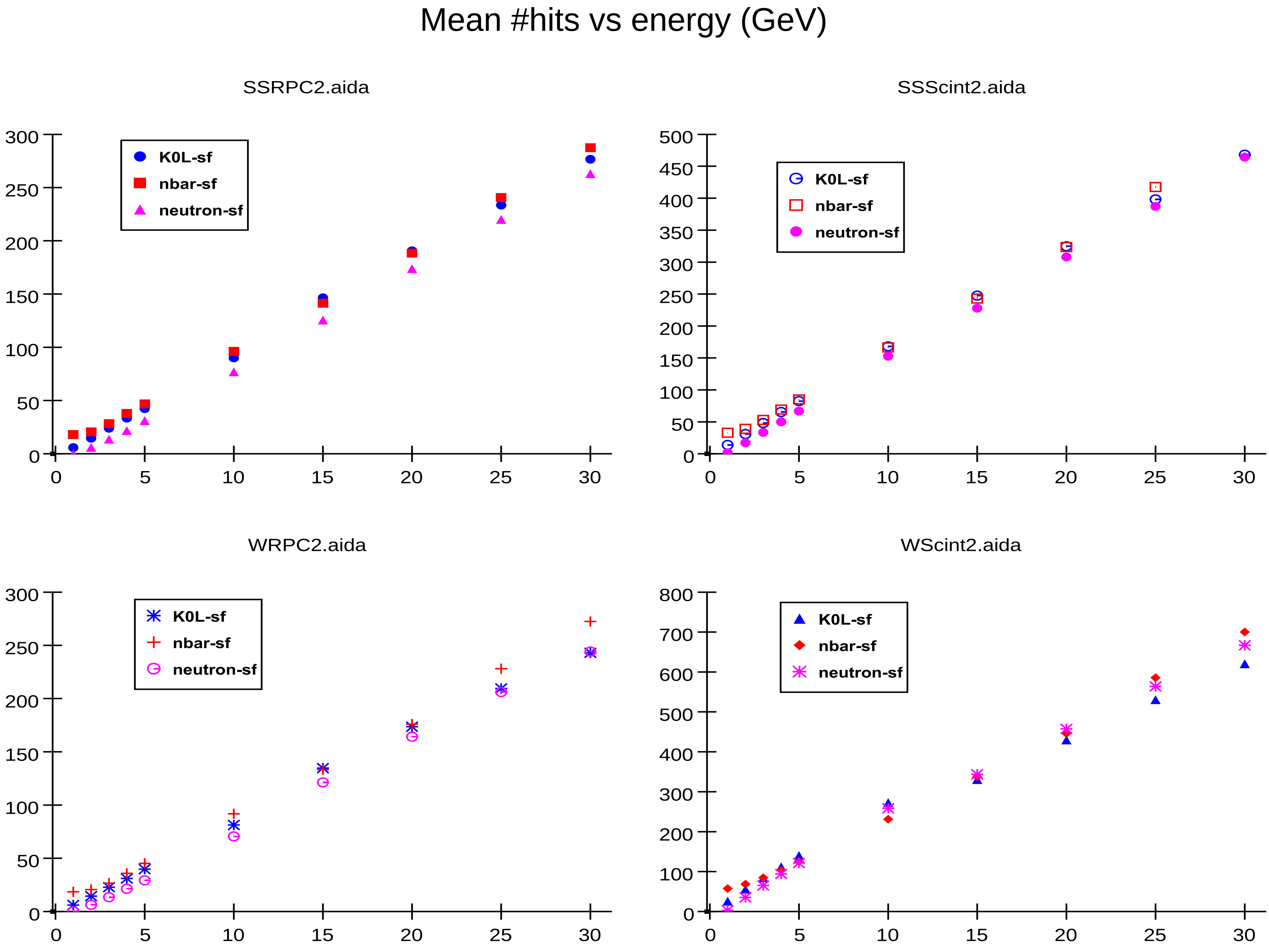


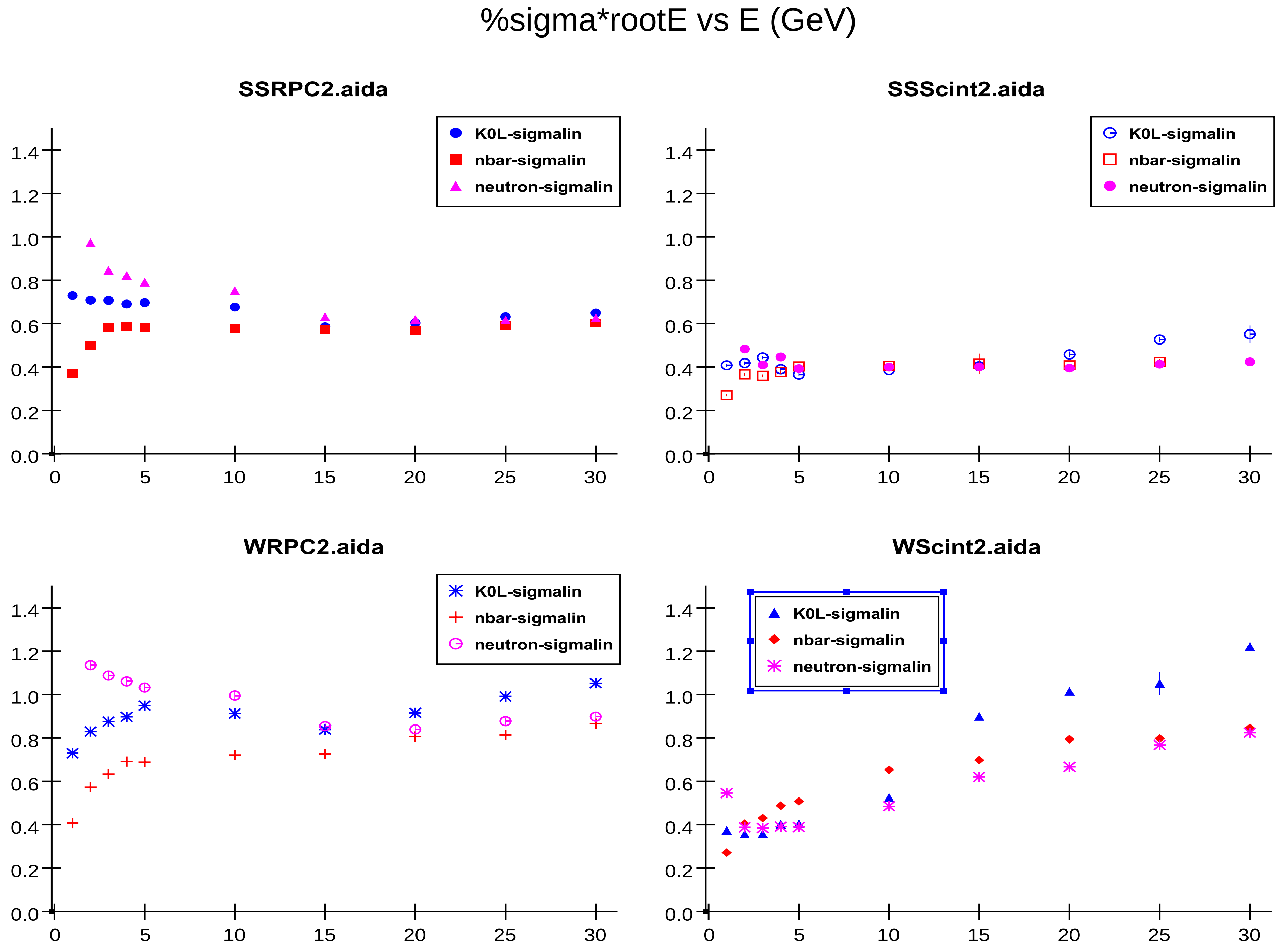
SSScint
10 GeV k0L
K0L/E=10/HcalB #hits
Entries : 5000
Mean : 168.11
Rms : 20.534
gauss
amplitude : 1103.3±19.5
mean : 167.99±0.26
sigma : 18.091±0.193
χ² : 1.0278
10 GeV nbar
nbar/E=10/HcalB #hits
Entries : 5000
Mean : 166.27
Rms : 21.347
gauss
amplitude : 753.64±13.3
mean : 165.98±0.29
sigma : 19.934±0.212
χ² : 2.8144
10 GeV n
neutron/E=10/HcalB #hits
Entries : 5000
Mean : 152.59
Rms : 19.287
gauss
amplitude : 817.71±14.4
mean : 151.66±0.25
sigma : 16.954±0.179
χ² : 1.7578


WRPC
10 GeV k0L
K0L/E=10/HcalB #hits
Entries : 5000
Mean : 81.225
Rms : 23.455
gauss
amplitude : 326.18±6.25
mean : 80.674±0.392
sigma : 21.041±0.260
χ² : 10.406
10 GeV nbar
nbar/E=10/HcalB #hits
Entries : 5000
Mean : 91.790
Rms : 20.944
gauss
amplitude : 355.97±6.69
mean : 91.414±0.345
sigma : 18.439±0.214
χ² : 12.027
10 GeV n
neutron/E=10/HcalB #hits
Entries : 5000
Mean : 70.575
Rms : 22.227
gauss
amplitude : 347.94±6.98
mean : 69.052±0.367
sigma : 19.418±0.270
χ² : 11.383


WScint
10 GeV k0L
K0L/E=10/HcalB #hits
Entries : 5000
Mean : 272.75
Rms : 45.377
gauss
amplitude : 377.32±6.96
mean : 274.52±0.65
sigma : 41.999±0.487
χ² : 3.9896
10 GeV nbar
nbar/E=10/HcalB #hits
Entries : 5000
Mean : 231.01
Rms : 47.708
gauss
amplitude : 328.16±5.81
mean : 230.89±0.67
sigma : 47.242±0.503
χ² : 1.0093
10 GeV n
neutron/E=10/HcalB #hits
Entries : 5000
Mean : 258.47
Rms : 39.636
gauss
amplitude : 420.57±7.79
mean : 259.72±0.55
sigma : 37.091±0.428
χ² : 2.5923

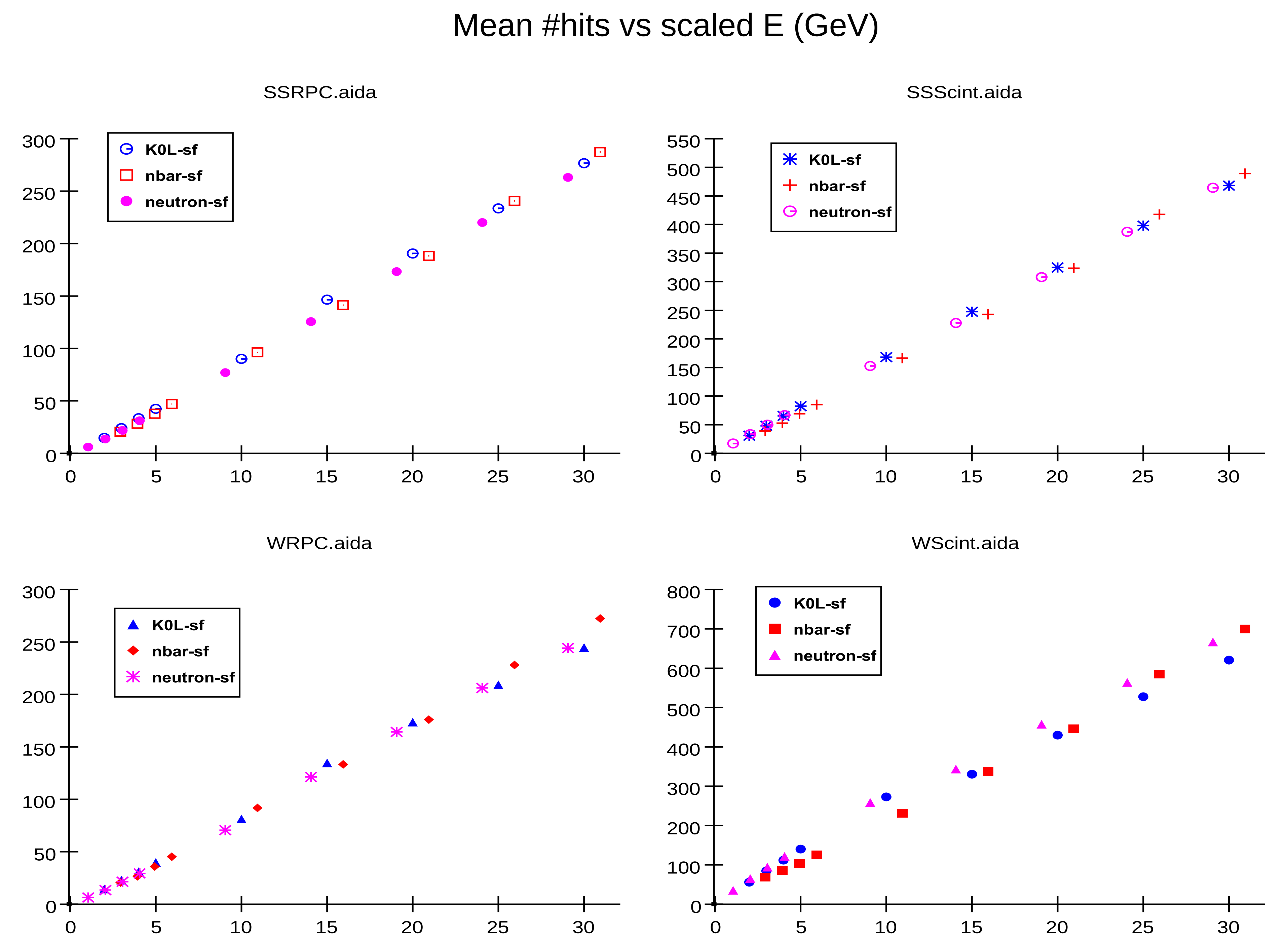
- These are examples of the response plots. All the response curves are available: /nfs/slac/g/lcd/public_data/ILC/singleParticle/isolated_detector_aida/*Raw.aida
- Look at means and rms vs energy


Mean #hits vs energy (GeV)
SSRPC2.aida
K0L-sf
nbar-sf
neutron-sf
SSScint2.aida
K0L-sf
nbar-sf
neutron-sf
WRPC2.aida
K0L-sf
nbar-sf
neutron-sf
WScint2.aida
K0L-sf
nbar-sf
neutron-sf

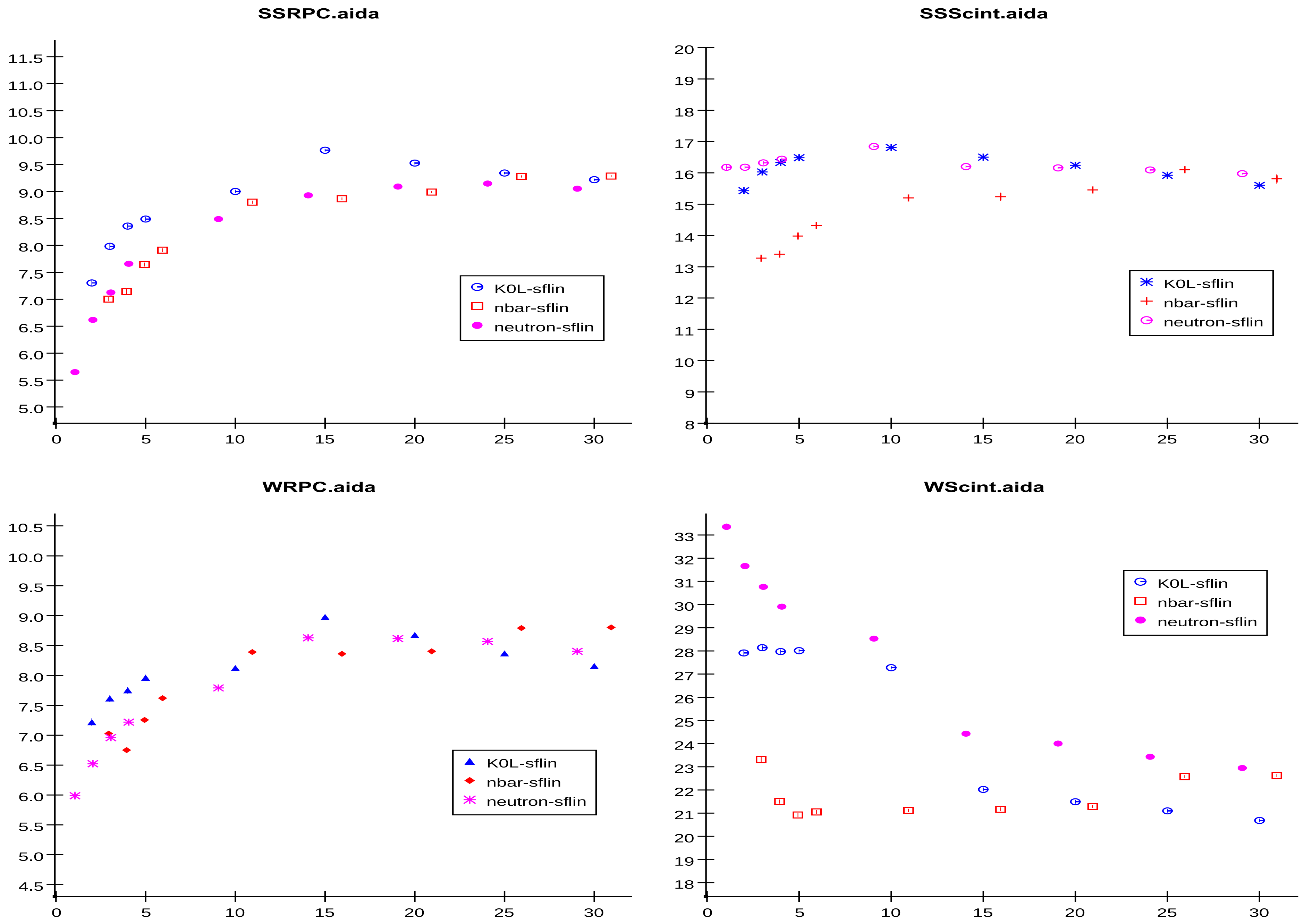

%sigma*rootE vs E (GeV)
SSRPC2.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin
SSScint2.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin
WRPC2.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin
WScint2.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin

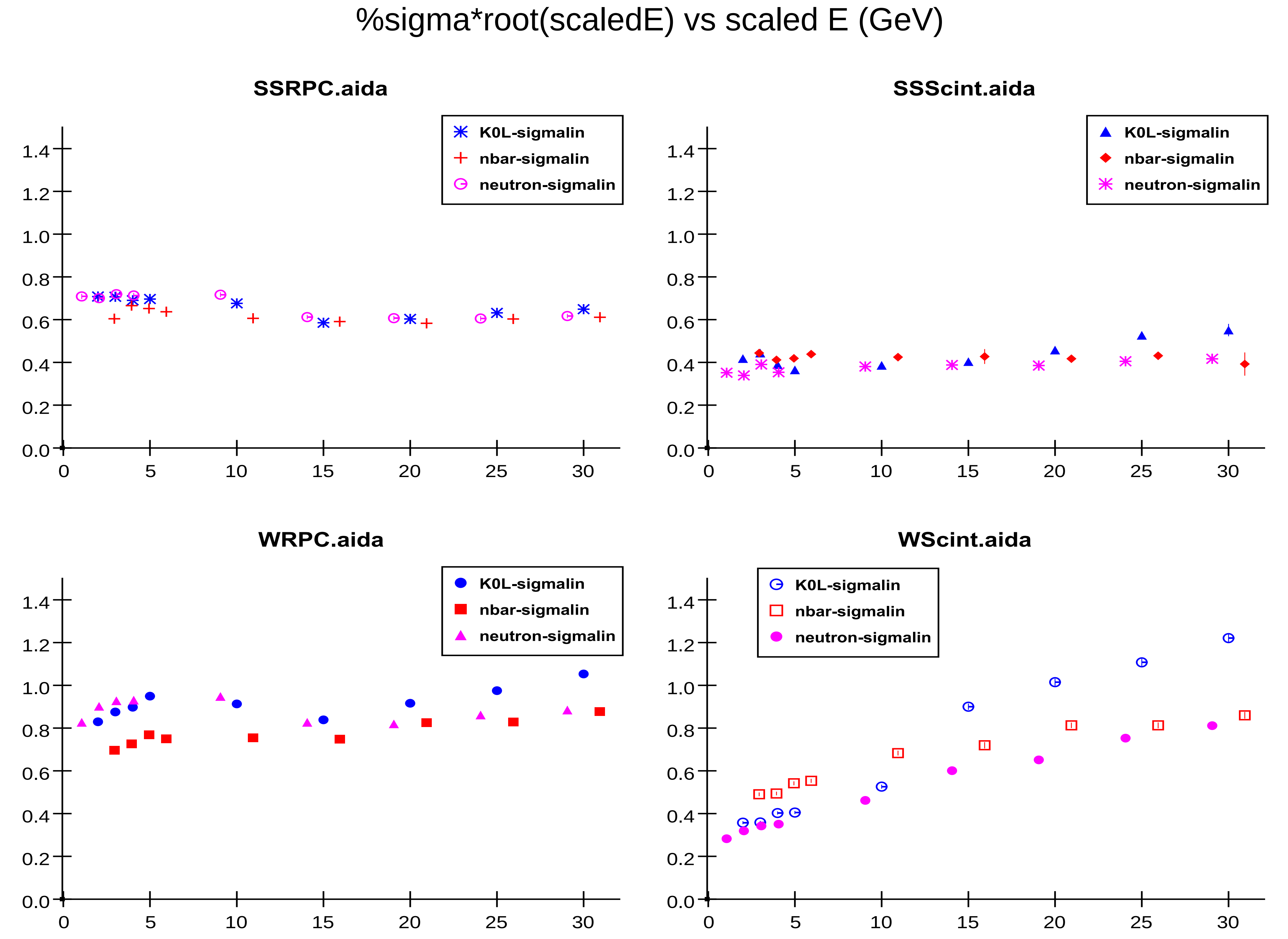
What do we expect?

- The detector measures ionization energy. Unlike EM processes, where all the particle's energy is eventually converted to ionization energy, all the hadron's energy is NOT converted. The maximum energy available varies by particle type. Neutron=E-nmass, nbar=E+nmass, and k0L=E. The detector response is a (hopefully constant?) fraction of the ionization energy.
- Look at response vs scaled energy = maximum energy available


Mean #hits vs scaled E (GeV)
SSRPC.aida
K0L-sf
nbar-sf
neutron-sf
SSScint.aida
K0L-sf
nbar-sf
neutron-sf
WRPC.aida
K0L-sf
nbar-sf
neutron-sf
WScint.aida
K0L-sf
nbar-sf
neutron-sf

#hits/scaled E vs scaledE

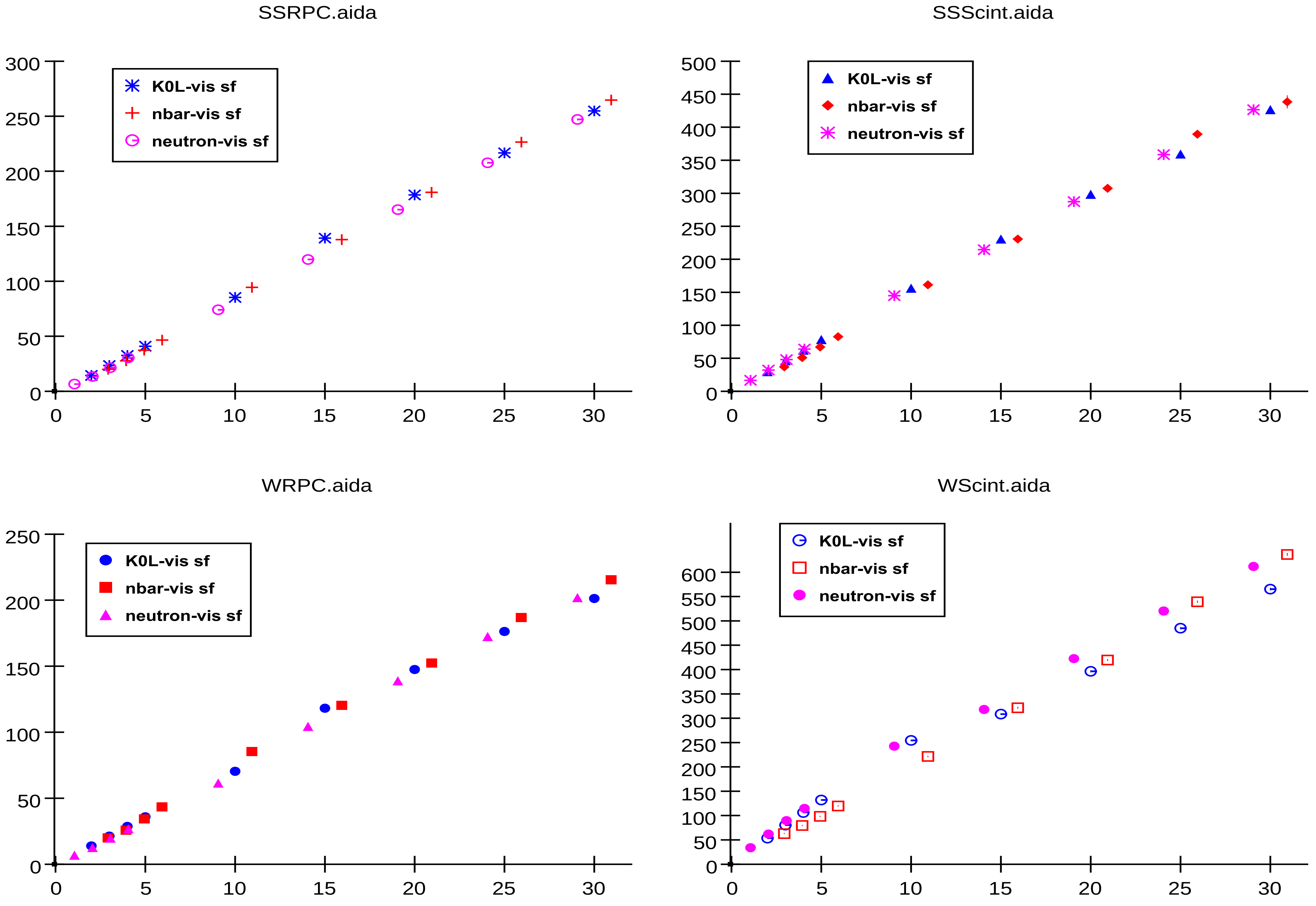


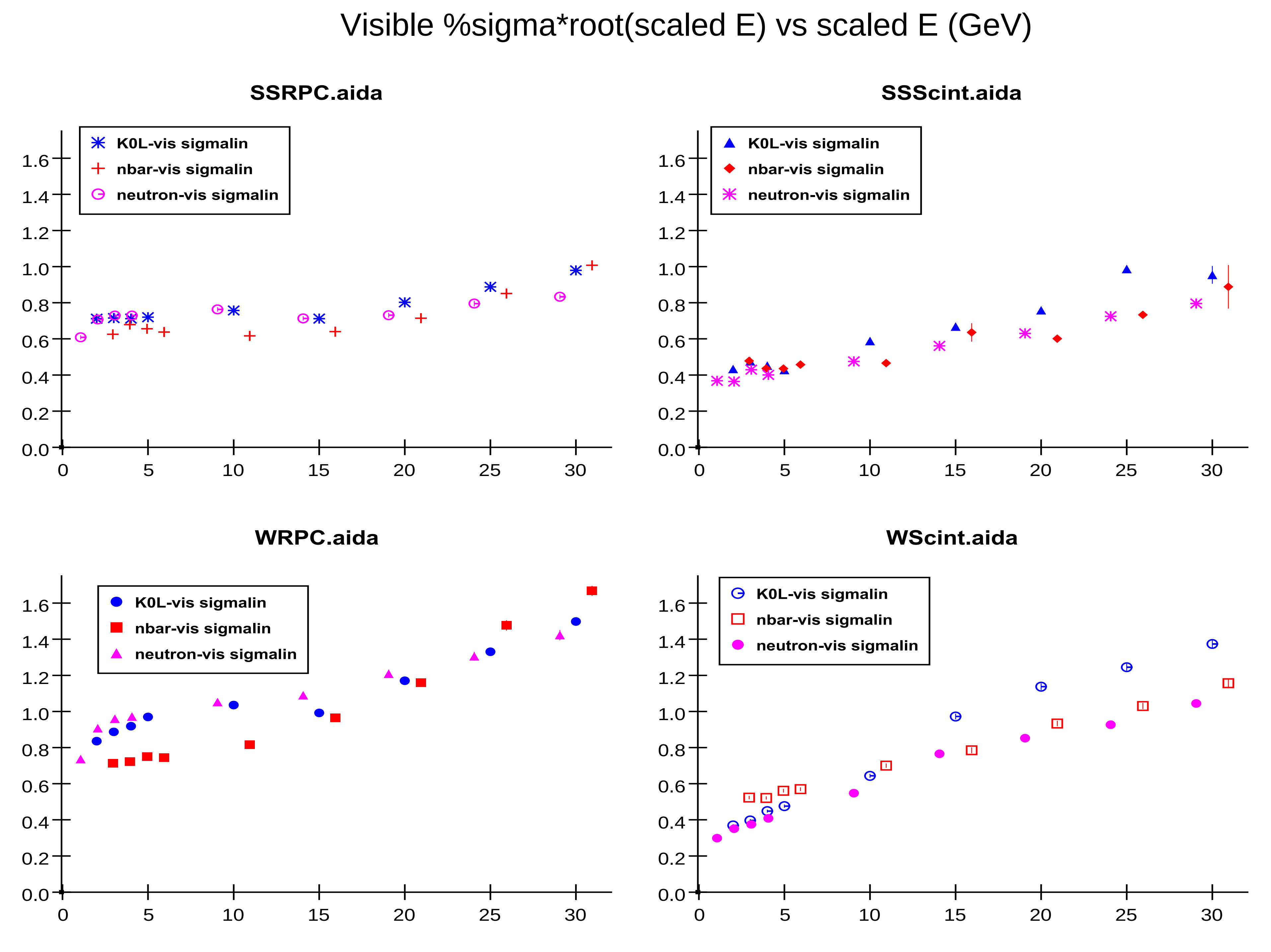


%sigma*root(scaledE) vs scaled E (GeV)
SSRPC.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin
SSScint.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin
WRPC.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin
WScint.aida
K0L-sigmalin
nbar-sigmalin
neutron-sigmalin

- Using scaled energy allows us to combine the different hadrons on the same scale
- So far, looked at infinite detector response. Look at finite detector.

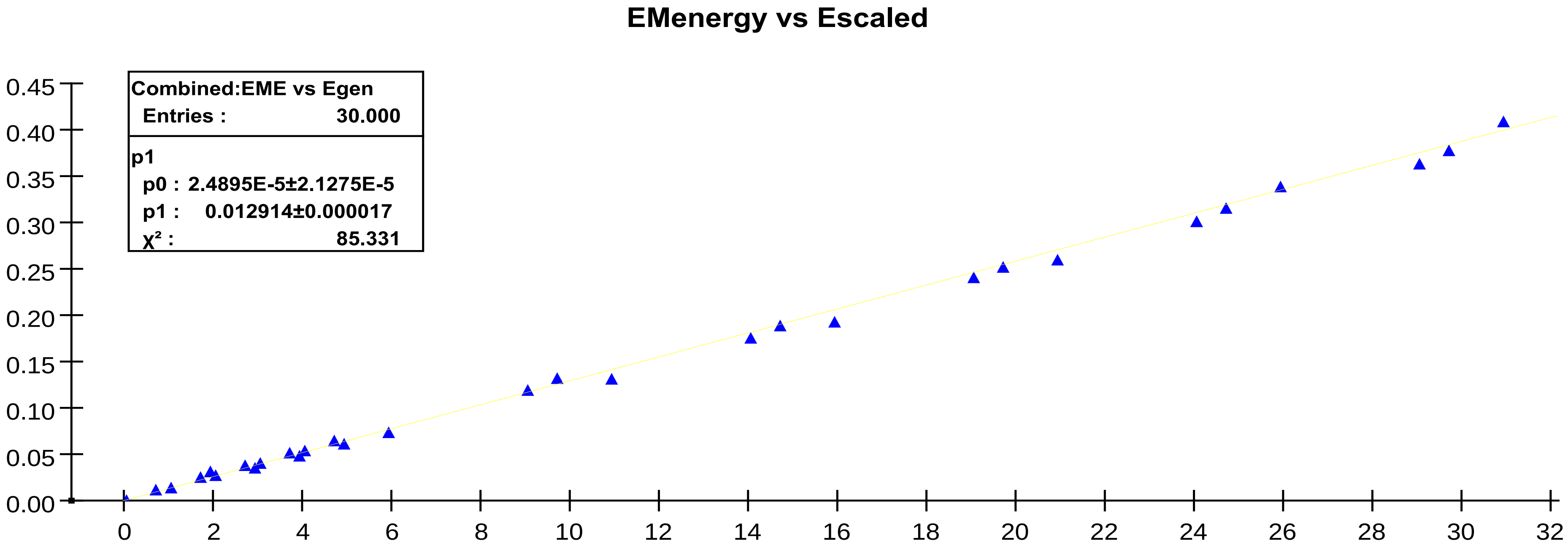
Visible #hits vs scaled E (GeV)



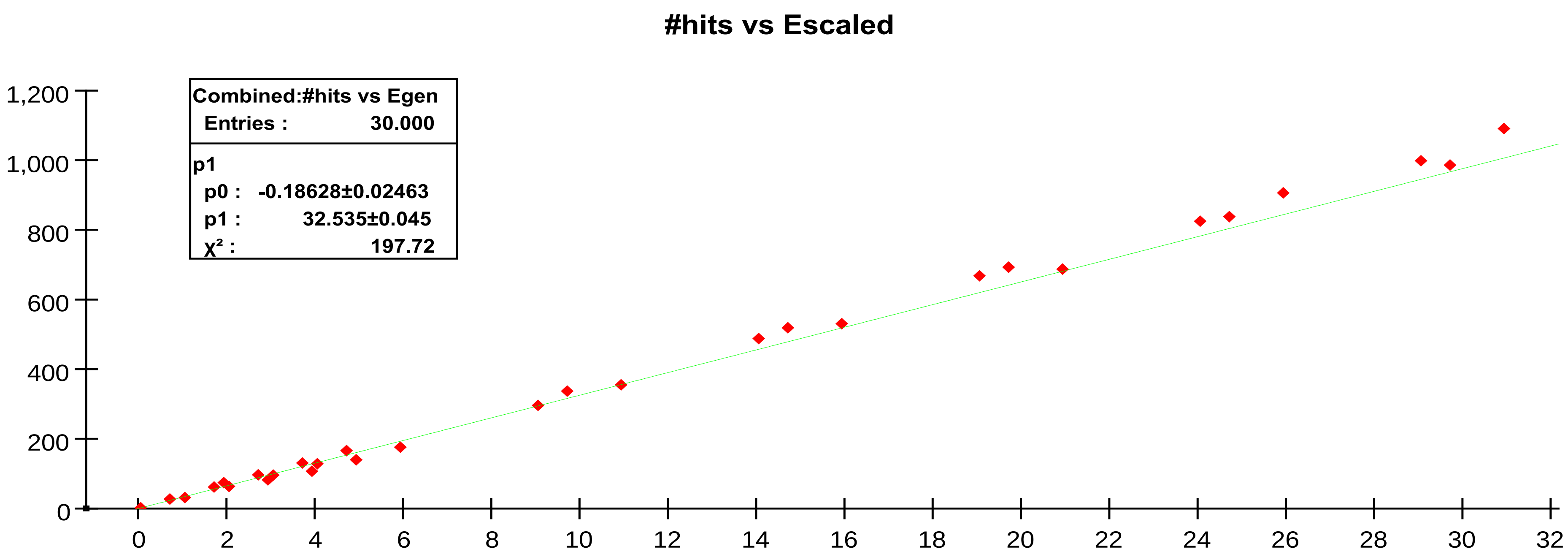

Visible %sigma*root(scaled E) vs scaled E (GeV)
SSRPC.aida
K0L-vis sigmalin
nbar-vis sigmalin
neutron-vis sigmalin
SSScint.aida
K0L-vis sigmalin
nbar-vis sigmalin
neutron-vis sigmalin
WRPC.aida
K0L-vis sigmalin
nbar-vis sigmalin
neutron-vis sigmalin
WScint.aida
K0L-vis sigmalin
nbar-vis sigmalin
neutron-vis sigmalin

Ecal

- Use same procedure for Ecal.
- Can use analog or digital counting.
- Look at both

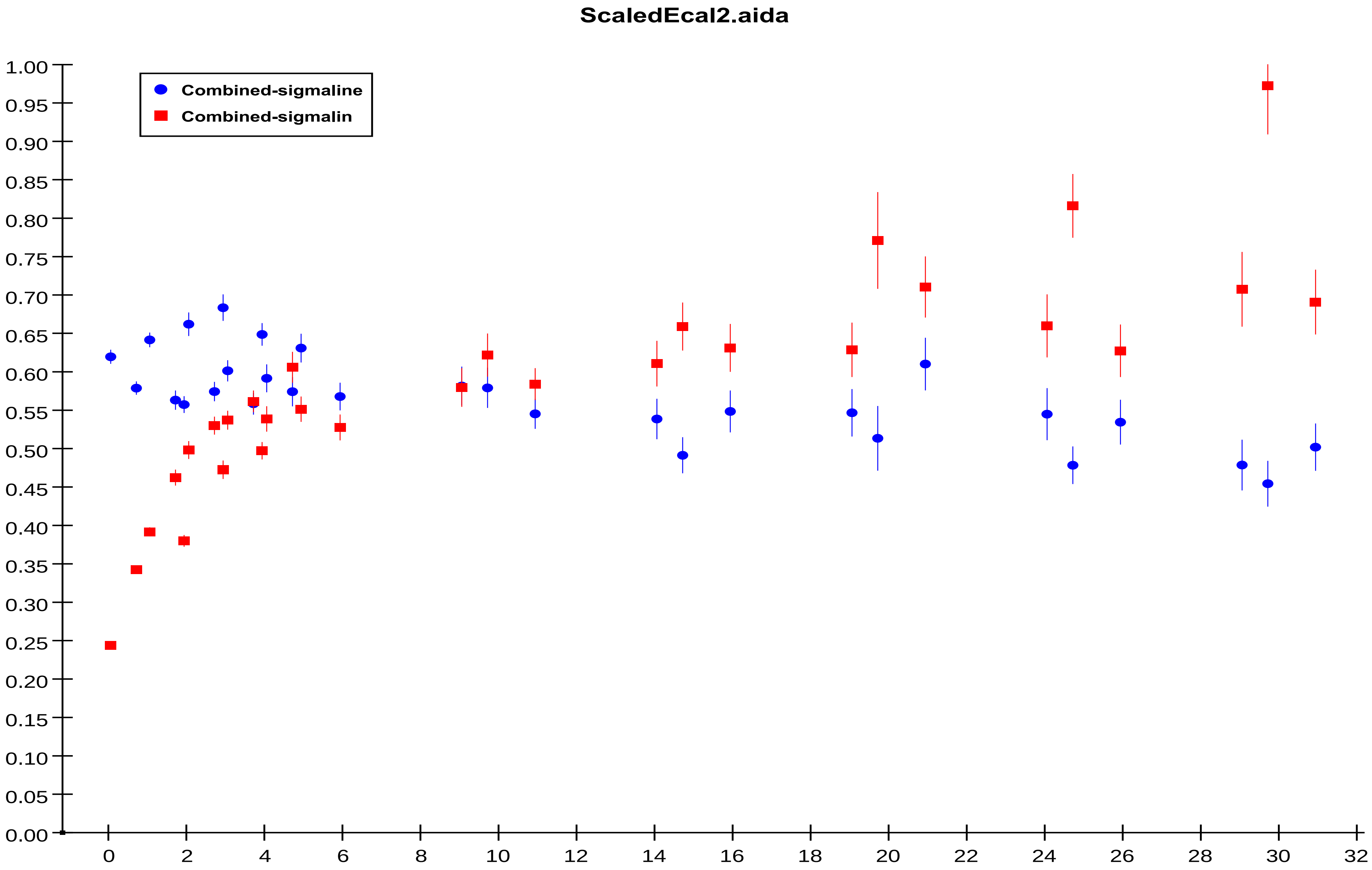


EMenergy vs Escaled
Combined:EME vs Egen
Entries : 30.000
p1
p0 : 2.4895E-5±2.1275E-5
p1 : 0.012914±0.000017
χ² : 85.331
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32



#hits vs Escaled
Combined:#hits vs Egen
Entries : 30.000
p1
p0 : -0.18628±0.02463
p1 : 32.535±0.045
χ² : 197.72
1,200
1,000
800
600
400
200
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

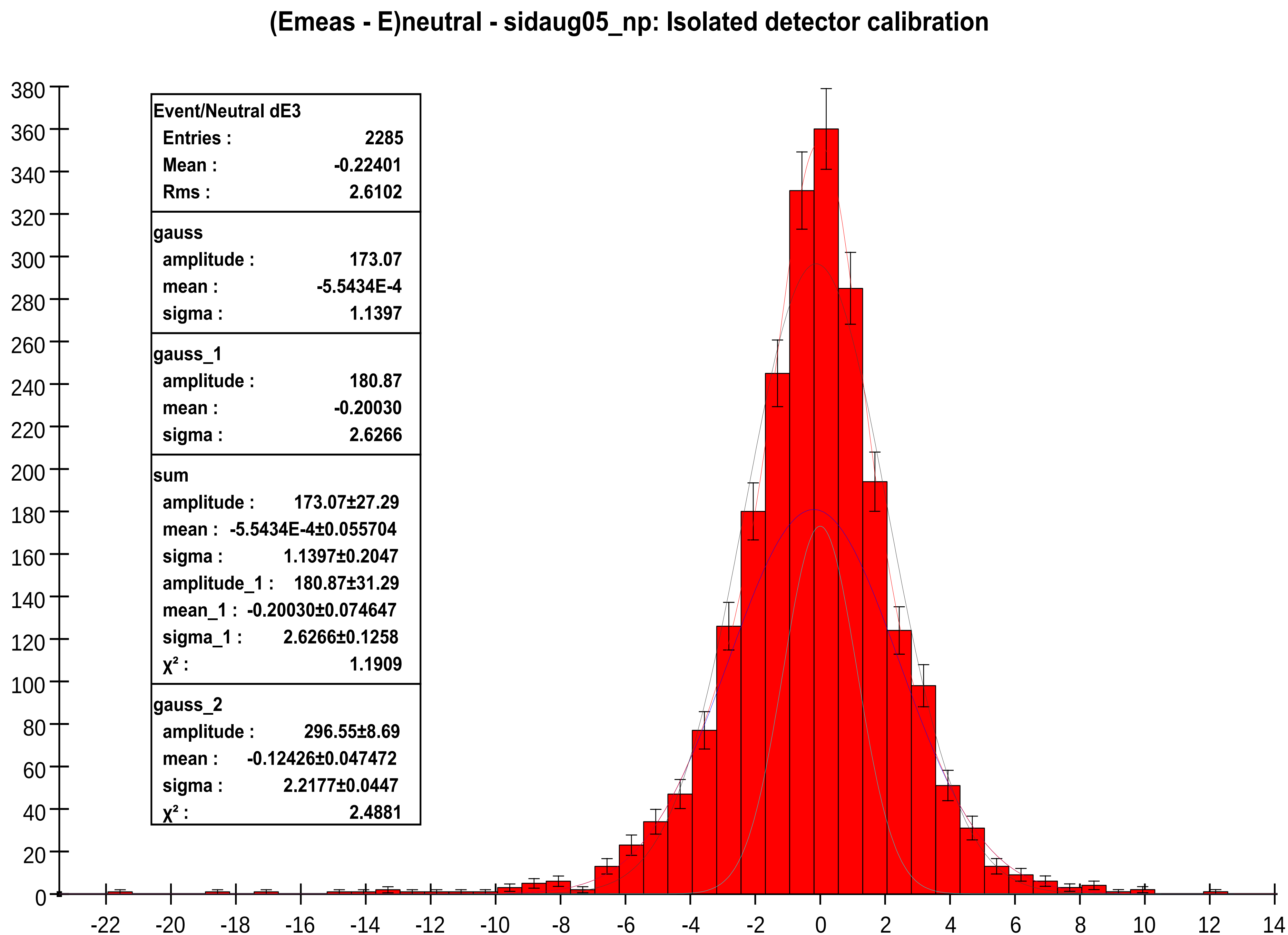
%sigma*root(scaledE) vs scaledE

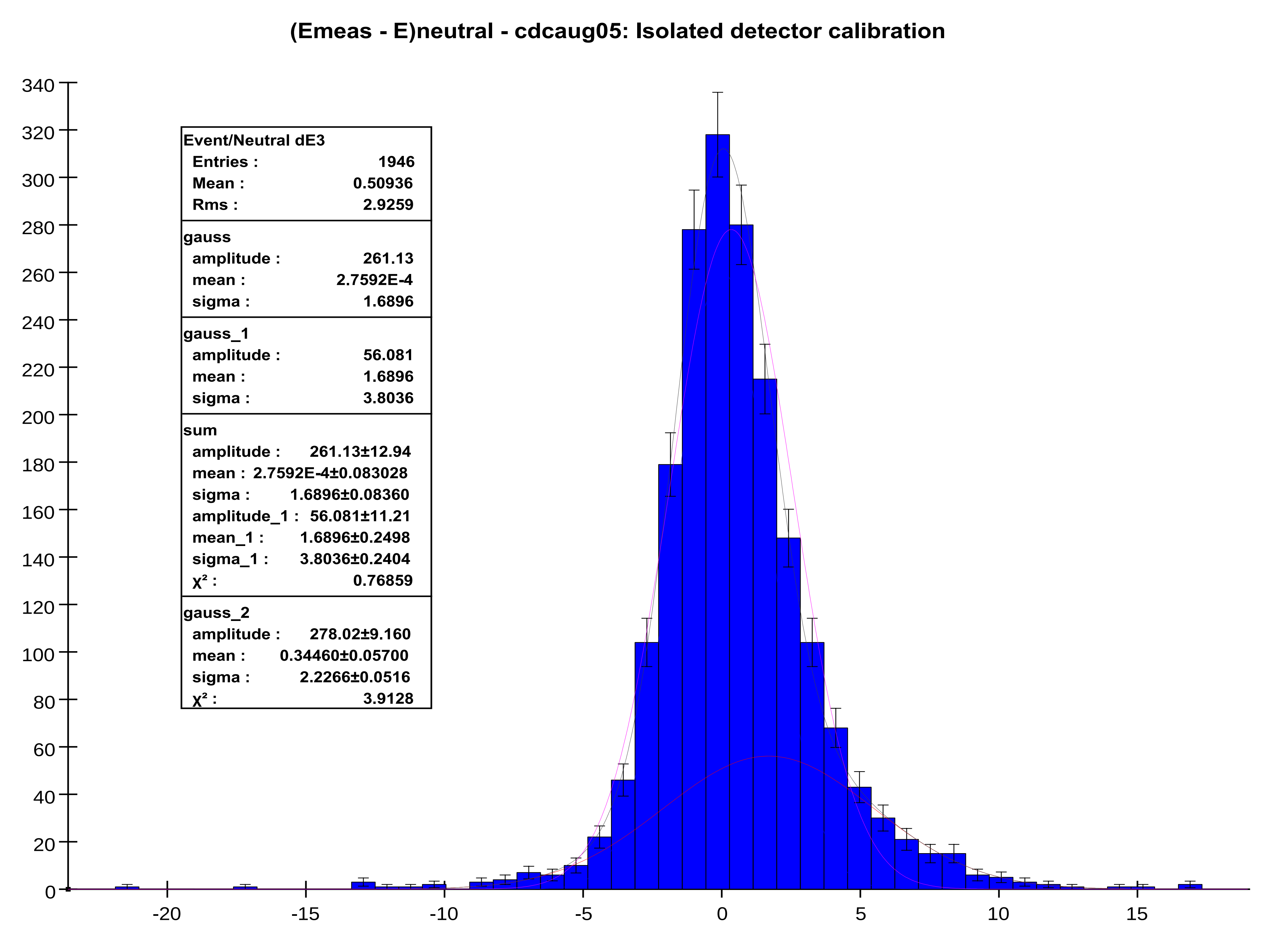


- Perhaps some resolution to be gained by using Ecal as digital for small # hits
- So far been dealing with isolated detectors. Use the information to calibrate and apply to actual detectors.

Full detector simulations

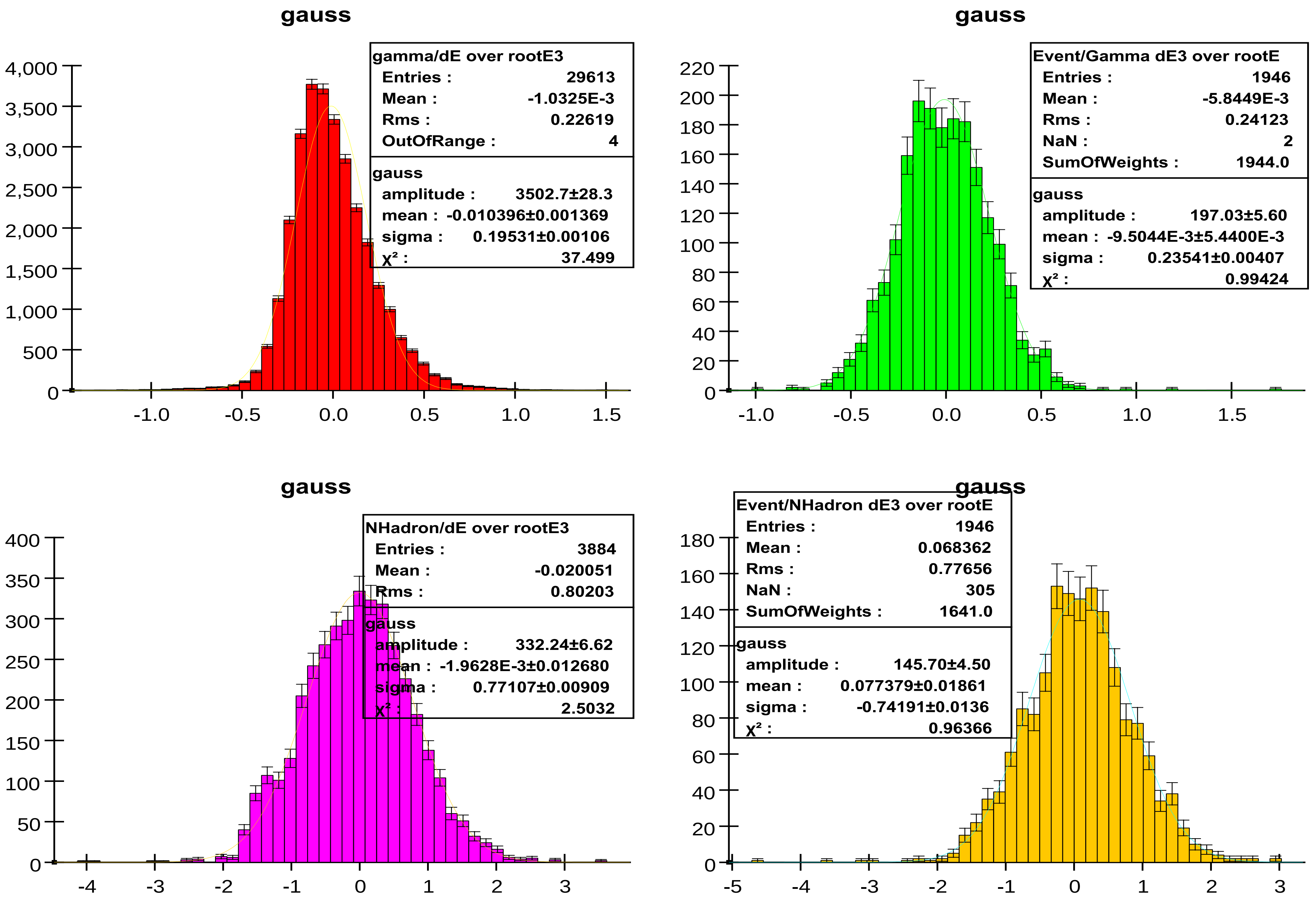
- Use Zpole events, apply calibration from isolated detector studies
- Cut on evts with (sum of particle energies with theta > 45 degrees) > 89 GeV
- Make “perfect pattern recognition” plots of delta E neutrals


(Emeas - E)neutral - sidaug05_np: Isolated detector calibration
Event/Neutral dE3
Entries : 2285
Mean : -0.22401
Rms : 2.6102
gauss
amplitude : 173.07
mean : -5.5434E-4
sigma : 1.1397
gauss_1
amplitude : 180.87
mean : -0.20030
sigma : 2.6266
sum
amplitude : 173.07±27.29
mean : -5.5434E-4±0.055704
sigma : 1.1397±0.2047
amplitude_1 : 180.87±31.29
mean_1 : -0.20030±0.074647
sigma_1 : 2.6266±0.1258
χ² : 1.1909
gauss_2
amplitude : 296.55±8.69
mean : -0.12426±0.047472
sigma : 2.2177±0.0447
χ² : 2.4881
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14

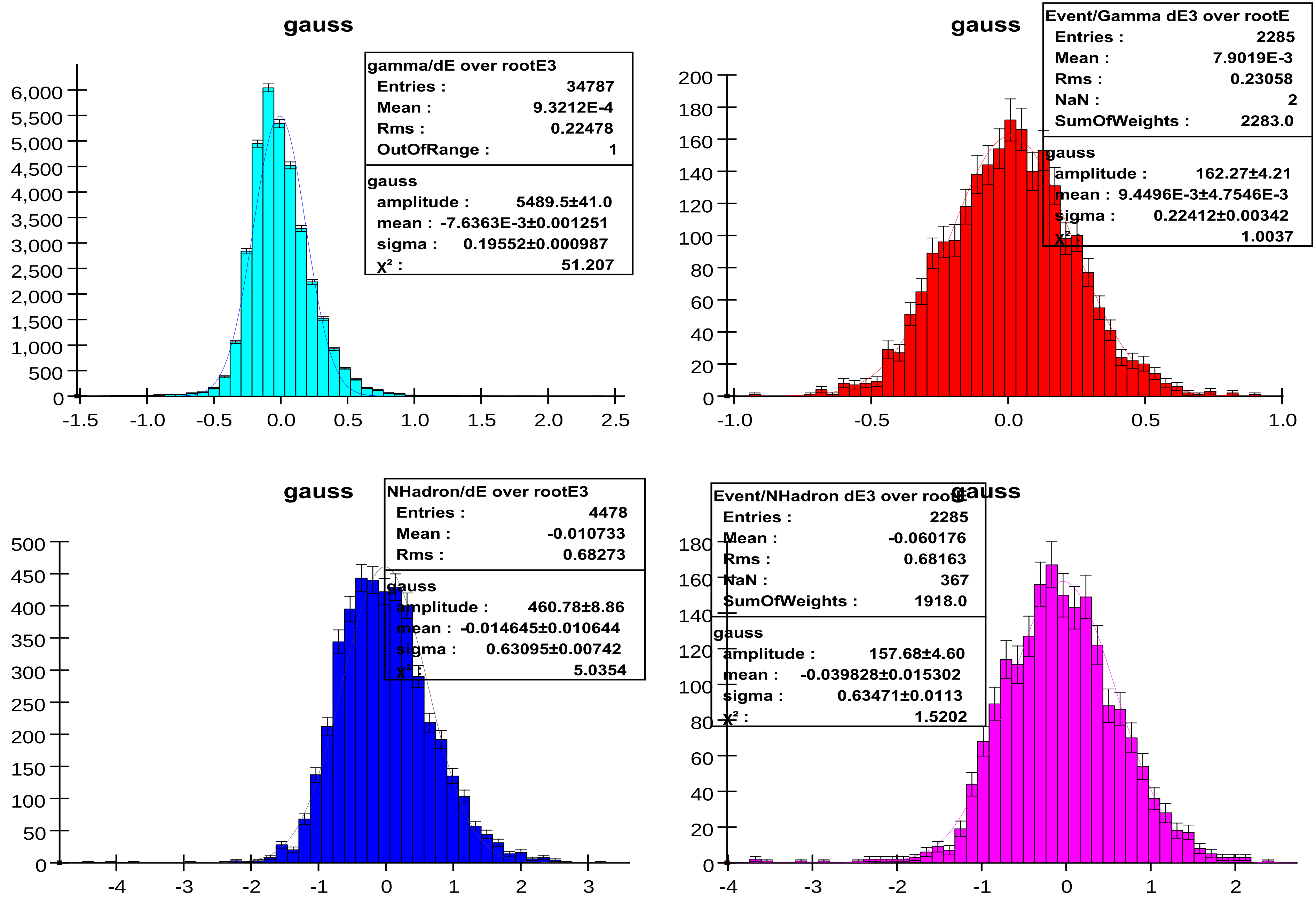


(Emeas - E)neutral - cdcaug05: Isolated detector calibration
Event/Neutral dE3
Entries : 1946
Mean : 0.50936
Rms : 2.9259
gauss
amplitude : 261.13
mean : 2.7592E-4
sigma : 1.6896
gauss_1
amplitude : 56.081
mean : 1.6896
sigma : 3.8036
sum
amplitude : 261.13±12.94
mean : 2.7592E-4±0.083028
sigma : 1.6896±0.08360
amplitude_1 : 56.081±11.21
mean_1 : 1.6896±0.2498
sigma_1 : 3.8036±0.2404
χ² : 0.76859
gauss_2
amplitude : 278.02±9.160
mean : 0.34460±0.05700
sigma : 2.2266±0.0516
χ² : 3.9128
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
-20 -15 -10 -5 0 5 10 15

Cdcaug05_np


gauss
gamma/dE over rootE3
Entries : 29613
Mean : -1.0325E-3
Rms : 0.22619
OutOfRange : 4
gauss
amplitude : 3502.7±28.3
mean : -0.010396±0.001369
sigma : 0.19531±0.00106
χ² : 37.499
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-1.0
-0.5
0.0
0.5
1.0
1.5
gauss
Event/Gamma dE3 over rootE
Entries : 1946
Mean : -5.8449E-3
Rms : 0.24123
NaN : 2
SumOfWeights : 1944.0
gauss
amplitude : 197.03±5.60
mean : -9.5044E-3±5.4400E-3
sigma : 0.23541±0.00407
χ² : 0.99424
220
200
180
160
140
120
100
80
60
40
20
0
-1.0
-0.5
0.0
0.5
1.0
1.5
gauss
NHadron/dE over rootE3
Entries : 3884
Mean : -0.020051
Rms : 0.80203
gauss
amplitude : 332.24±6.62
mean : -1.9628E-3±0.012680
sigma : 0.77107±0.00909
χ² : 2.5032
400
350
300
250
200
150
100
50
0
-4
-3
-2
-1
0
1
2
3
gauss
Event/NHadron dE3 over rootE
Entries : 1946
Mean : 0.068362
Rms : 0.77656
NaN : 305
SumOfWeights : 1641.0
gauss
amplitude : 145.70±4.50
mean : 0.077379±0.01861
sigma : -0.74191±0.0136
χ² : 0.96366
180
160
140
120
100
80
60
40
20
0
-5
-4
-3
-2
-1
0
1
2
3

Sidaug05_np

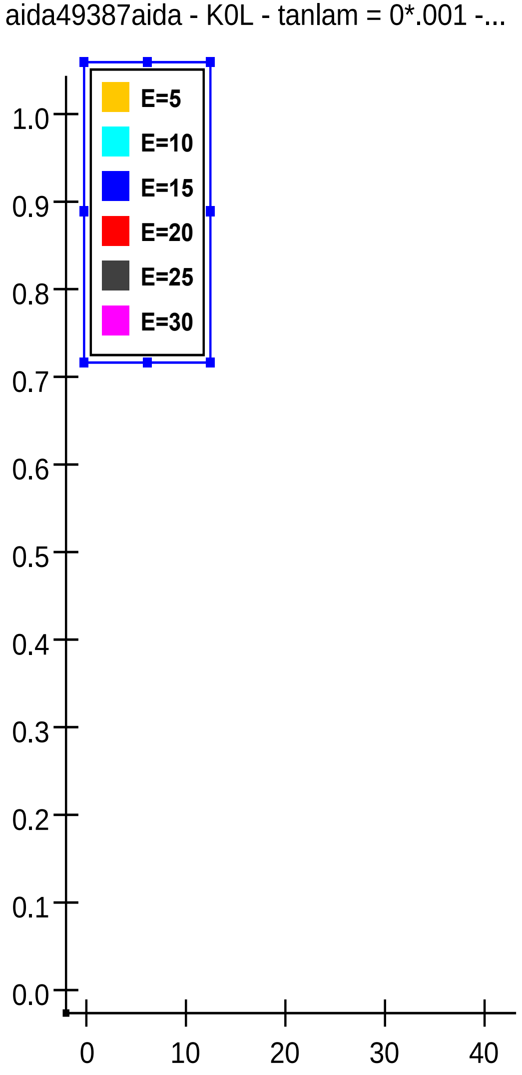


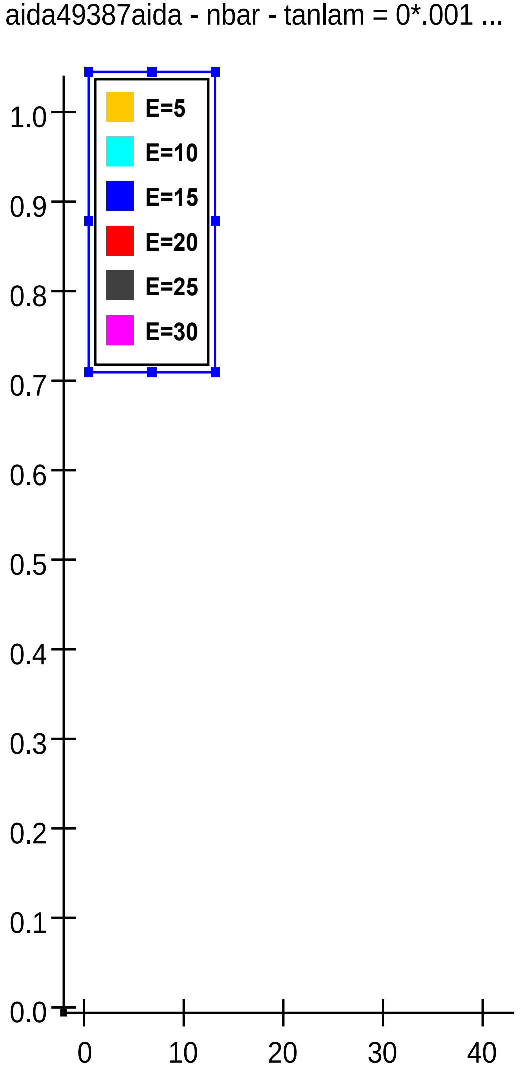
gauss
gamma/dE over rootE3
Entries : 34787
Mean : 9.3212E-4
Rms : 0.22478
OutOfRange : 1
gauss
amplitude : 5489.5±41.0
mean : -7.6363E-3±0.001251
sigma : 0.19552±0.000987
χ² : 51.207
gauss
Event/Gamma dE3 over rootE
Entries : 2285
Mean : 7.9019E-3
Rms : 0.23058
NaN : 2
SumOfWeights : 2283.0
gauss
amplitude : 162.27±4.21
mean : 9.4496E-3±4.7546E-3
sigma : 0.22412±0.00342
χ² : 1.0037
gauss
NHadron/dE over rootE3
Entries : 4478
Mean : -0.010733
Rms : 0.68273
gauss
amplitude : 460.78±8.86
mean : -0.014645±0.010644
sigma : 0.63095±0.00742
χ² : 5.0354
gauss
Event/NHadron dE3 over rootE
Entries : 2285
Mean : -0.060176
Rms : 0.68163
NaN : 367
SumOfWeights : 1918.0
gauss
amplitude : 157.68±4.60
mean : -0.039828±0.015302
sigma : 0.63471±0.0113
χ² : 1.5202

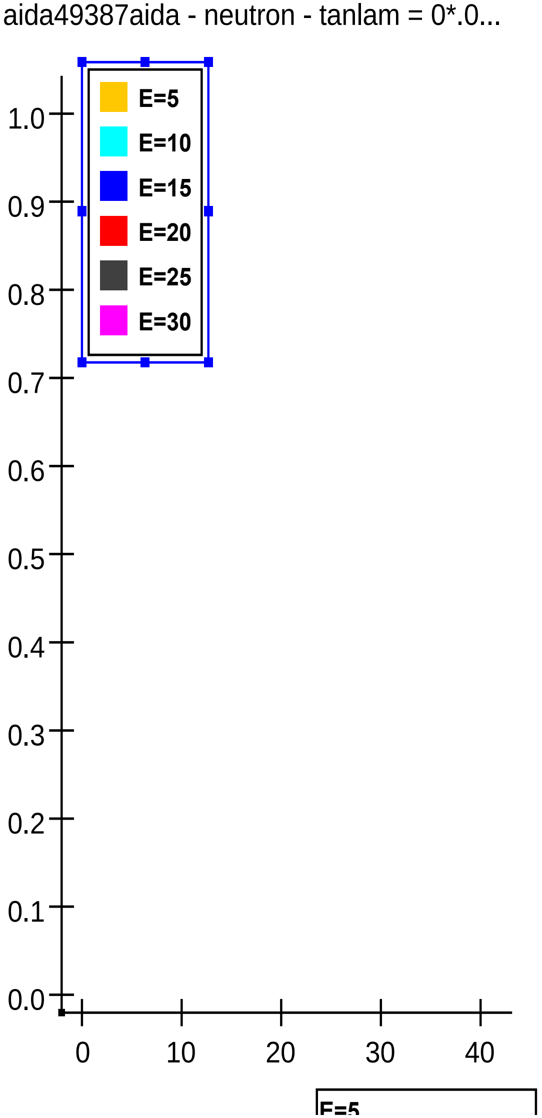
Side bars

- Simulation problem in G4
- Incident angle correction – sqrt dependence still a mystery
- Transverse spread study in progress
- Resolution improvement using interaction point of hadron in progress

Fractional loss of hits vs interaction layer

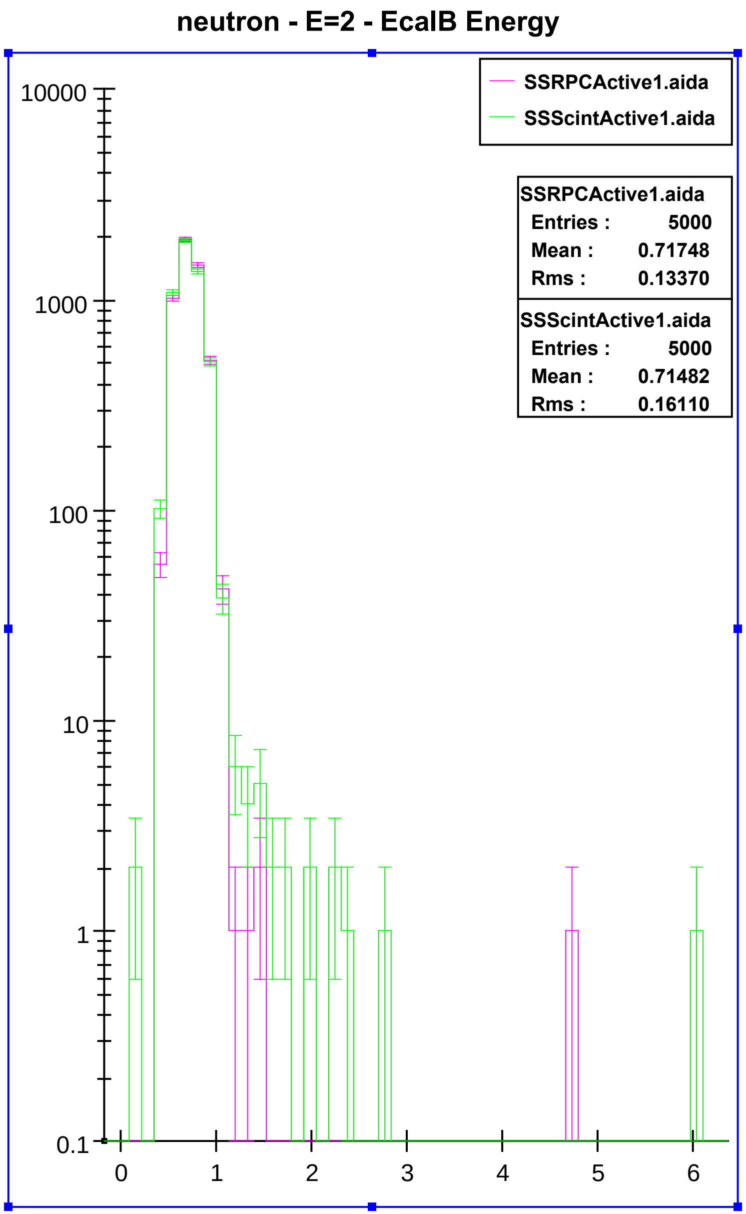


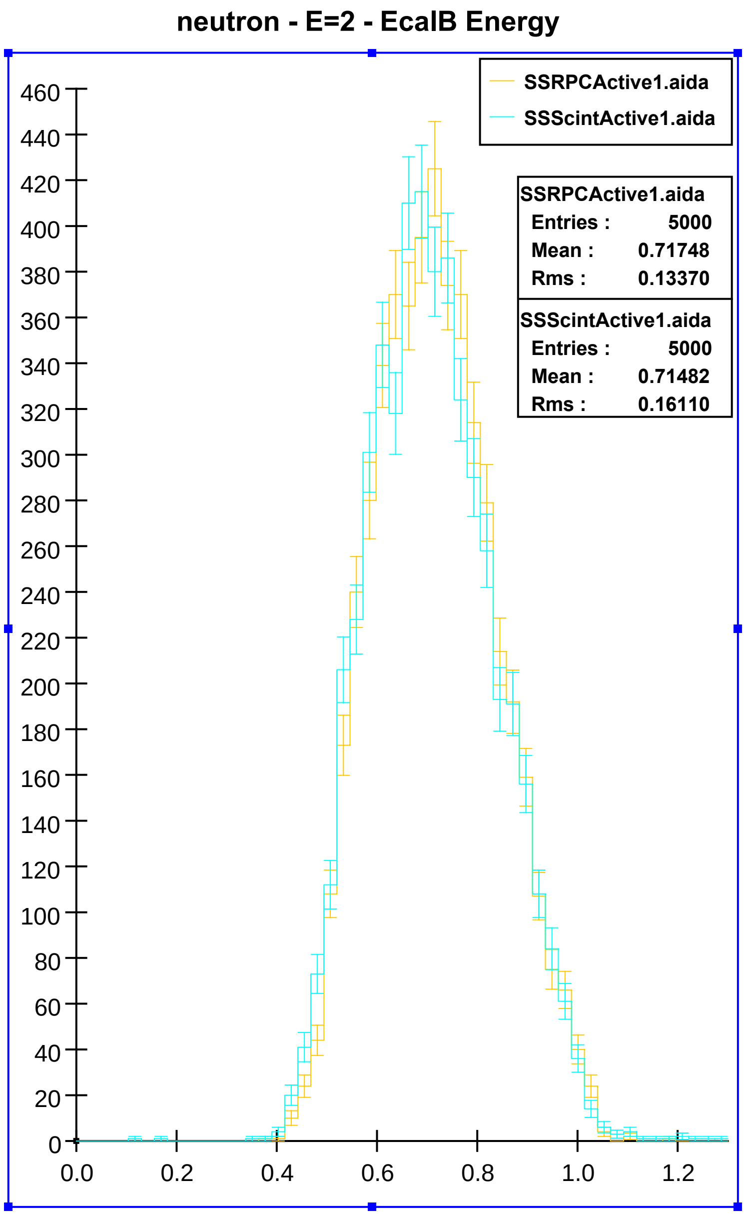


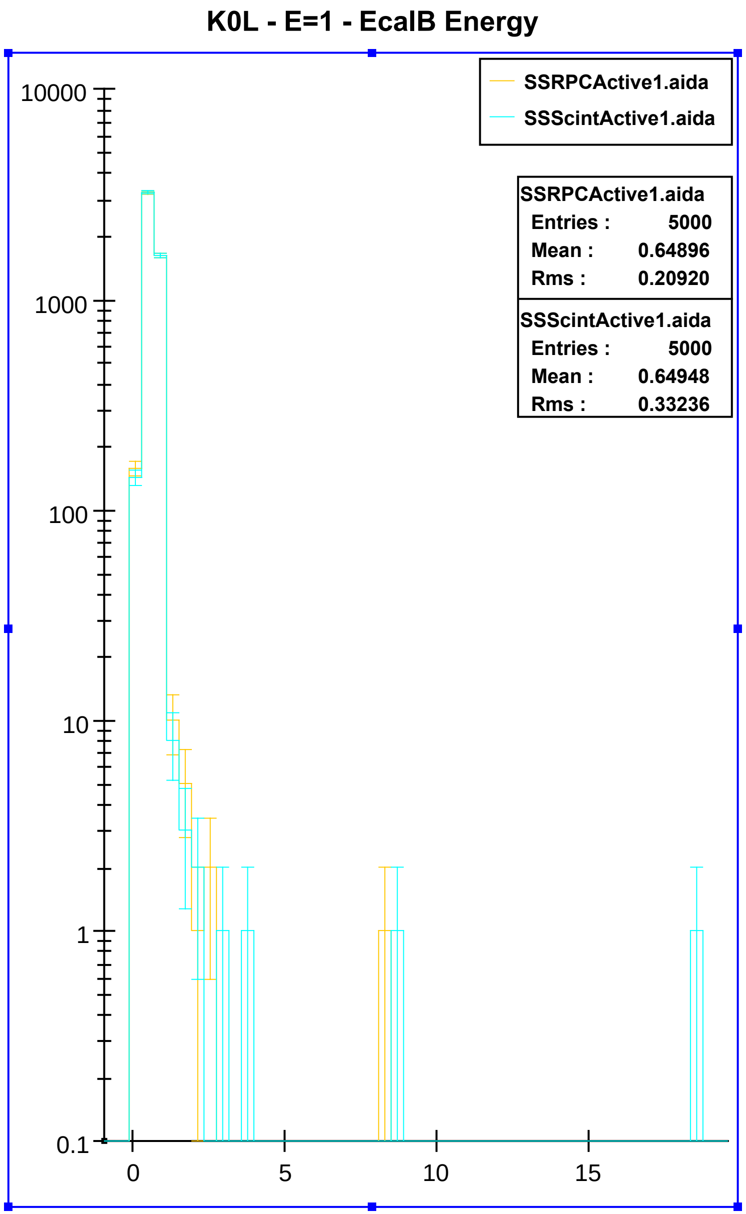


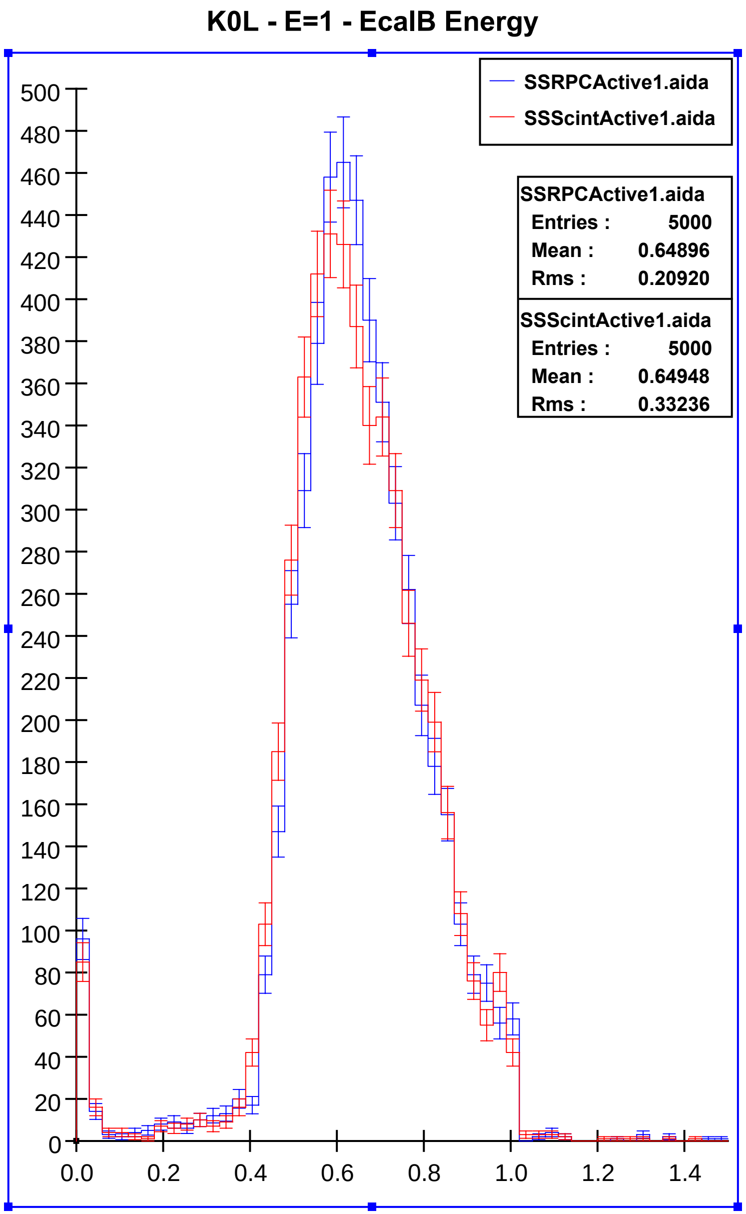
G4 problem:Detector configurations

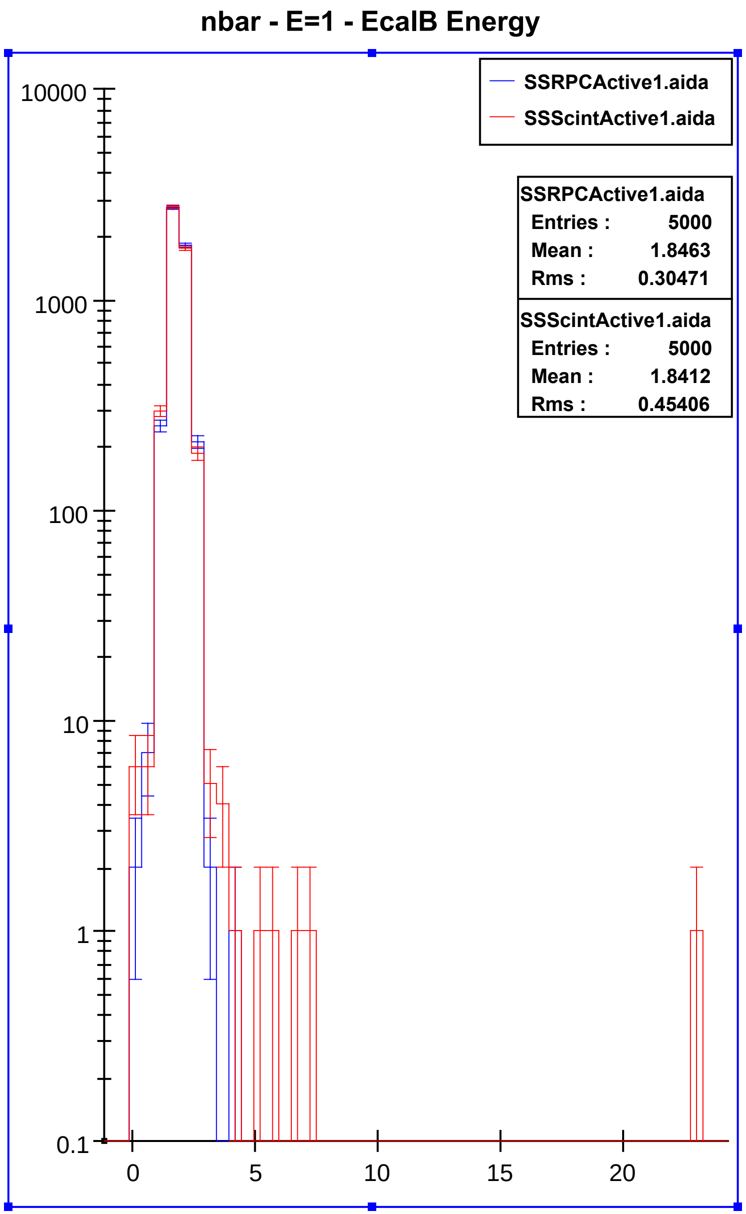
- HCAL -2cm stainless steel absorber RPC or scintillator configuration
- All other elements removed
- HCAL extended to 1000 layers, 30 meters in Z
- All elements made active, so all ionization energy recorded

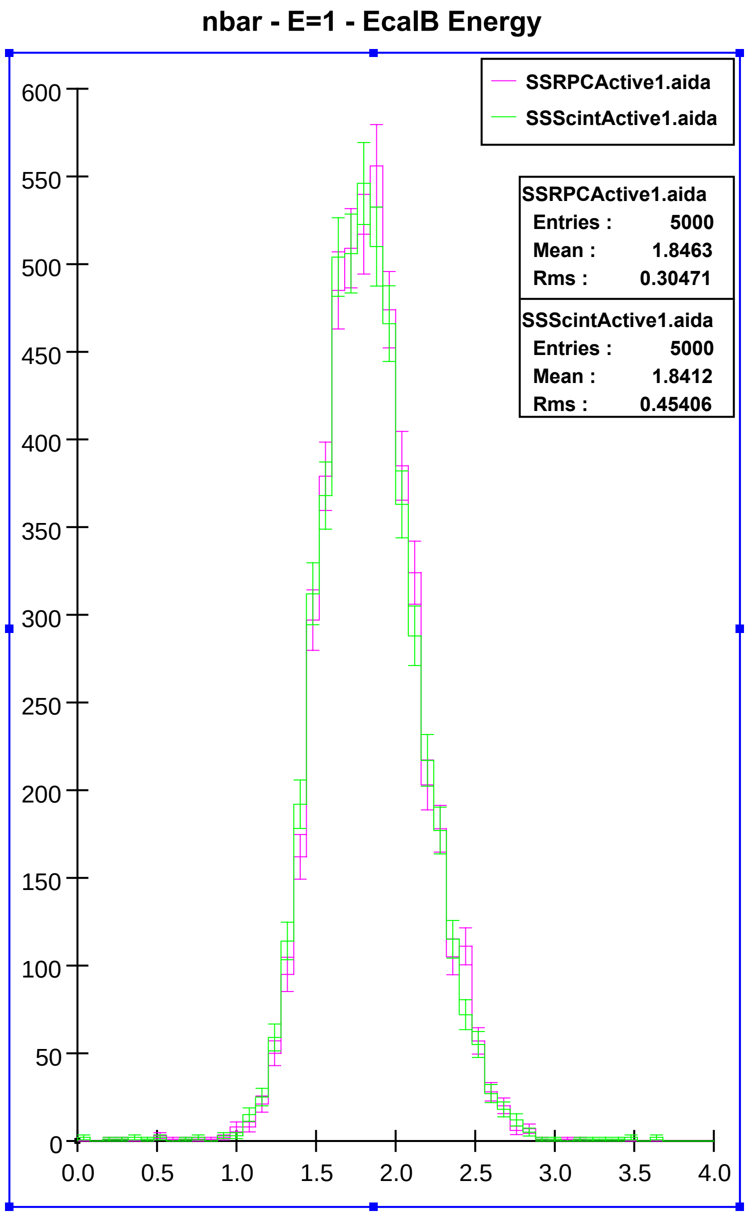

neutron - E=2 - EcalB Energy
SSRPCActive1.aida
SSScintActive1.aida
SSRPCActive1.aida
Entries : 5000
Mean : 0.71748
Rms : 0.13370
SSScintActive1.aida
Entries : 5000
Mean : 0.71482
Rms : 0.16110
10000
1000
100
10
1
0.1
0
1
2
3
4
5
6


neutron - E=2 - EcalB Energy
SSRPCActive1.aida
SSScintActive1.aida
SSRPCActive1.aida
Entries : 5000
Mean : 0.71748
Rms : 0.13370
SSScintActive1.aida
Entries : 5000
Mean : 0.71482
Rms : 0.16110
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2


K0L - E=1 - EcalB Energy
SSRPCActive1.aida
SSScintActive1.aida
SSRPCActive1.aida
Entries : 5000
Mean : 0.64896
Rms : 0.20920
SSScintActive1.aida
Entries : 5000
Mean : 0.64948
Rms : 0.33236


K0L - E=1 - EcalB Energy
SSRPCActive1.aida
SSScintActive1.aida
SSRPCActive1.aida
Entries : 5000
Mean : 0.64896
Rms : 0.20920
SSScintActive1.aida
Entries : 5000
Mean : 0.64948
Rms : 0.33236


nbar - E=1 - EcalB Energy
SSRPCActive1.aida
SSScintActive1.aida
SSRPCActive1.aida
Entries : 5000
Mean : 1.8463
Rms : 0.30471
SSScintActive1.aida
Entries : 5000
Mean : 1.8412
Rms : 0.45406

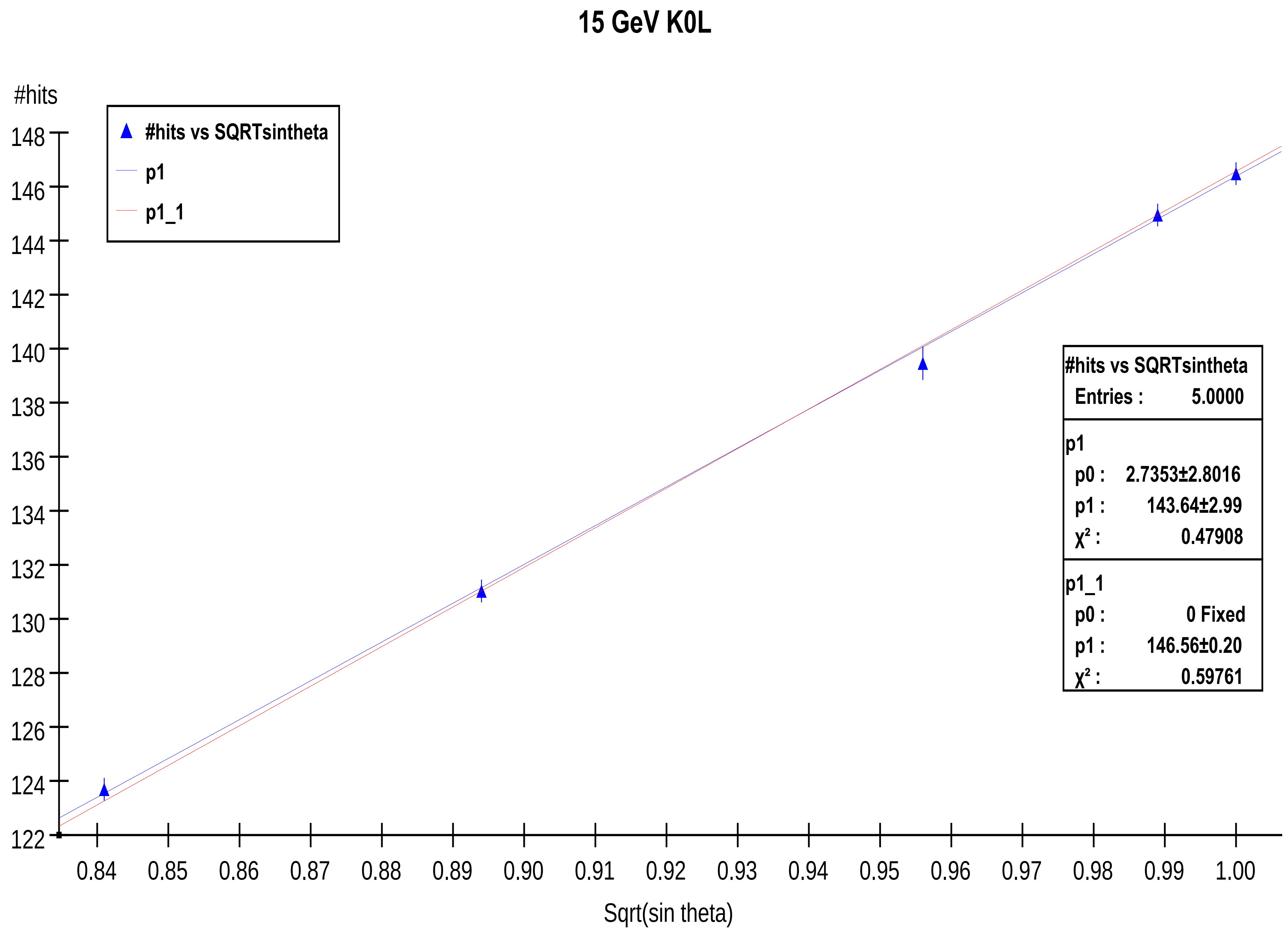

nbar - E=1 - EcalB Energy
SSRPCActive1.aida
SSScintActive1.aida
SSRPCActive1.aida
Entries : 5000
Mean : 1.8463
Rms : 0.30471
SSScintActive1.aida
Entries : 5000
Mean : 1.8412
Rms : 0.45406

G4 problem

- Too much energy from neutron capture process has been observed elsewhere: see http://www.ilcldc.org/meetings/ldcmeeting271005/musat/Low%20Energy%20Neutron%20Capture%20process
- Nbar process probably has a bug
- Remember, all our sampling calorimeter simulations are critically dependent on getting the low energy processes right.

Incident angle correction

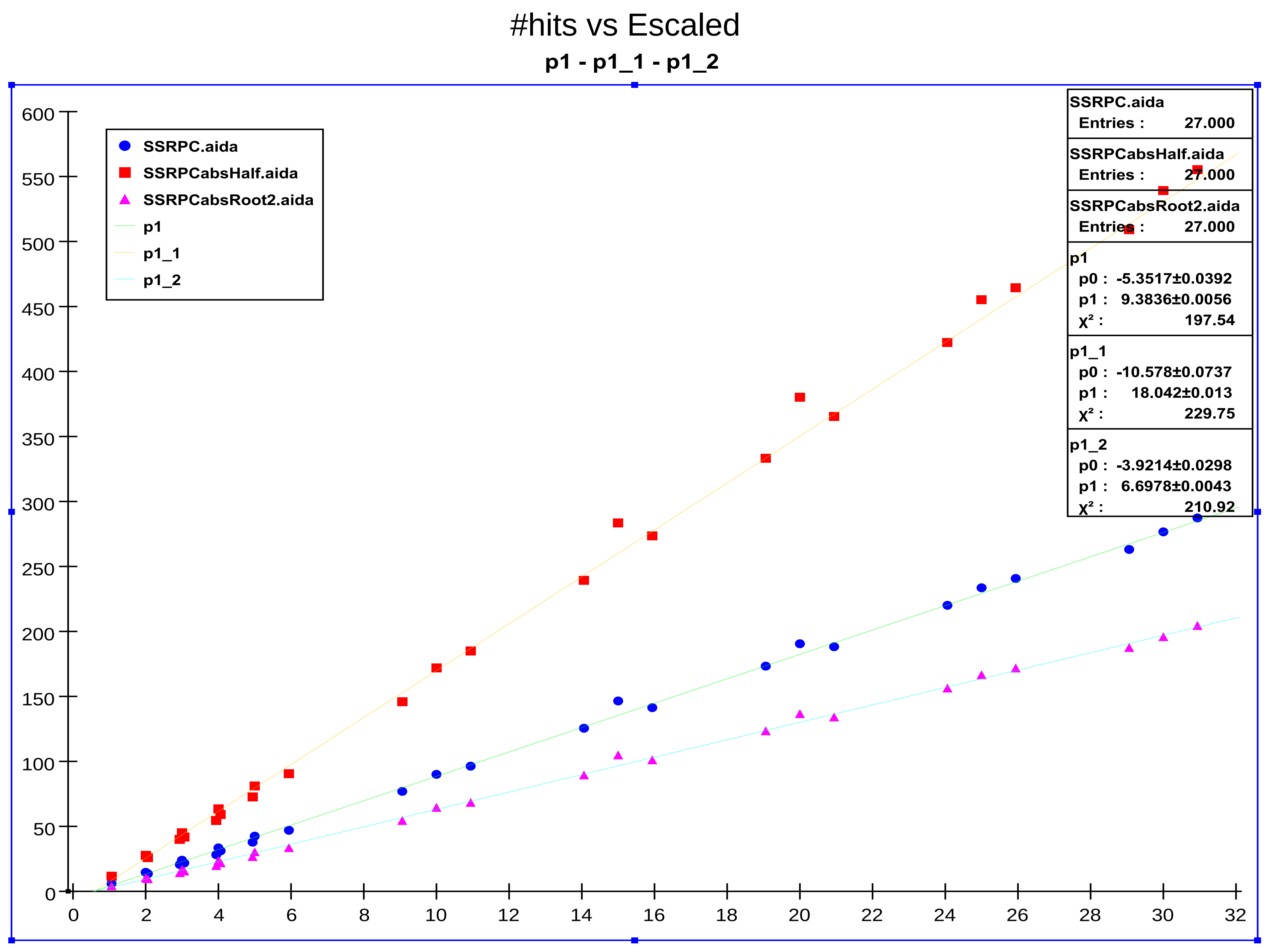
- Previously showed response of SSRPC detector at 45 degrees ~ .84 * response at 90 degrees, independent of particle type and Energy
- Looked at 15 GeV k0L's at 5 incident angles
- Seems to scale with sqrt(sin theta) instead of linearly



15 GeV K0L
#hits
#hits vs SQRTsintheta
p1
p1_1
#hits vs SQRTsintheta
Entries : 5.0000
p1
p0 : 2.7353±2.8016
p1 : 143.64±2.99
χ² : 0.47908
p1_1
p0 : 0 Fixed
p1 : 146.56±0.20
χ² : 0.59761
148
146
144
142
140
138
136
134
132
130
128
126
124
122
0.84
0.85
0.86
0.87
0.88
0.89
0.90
0.91
0.92
0.93
0.94
0.95
0.96
0.97
0.98
0.99
1.00
Sqrt(sin theta)

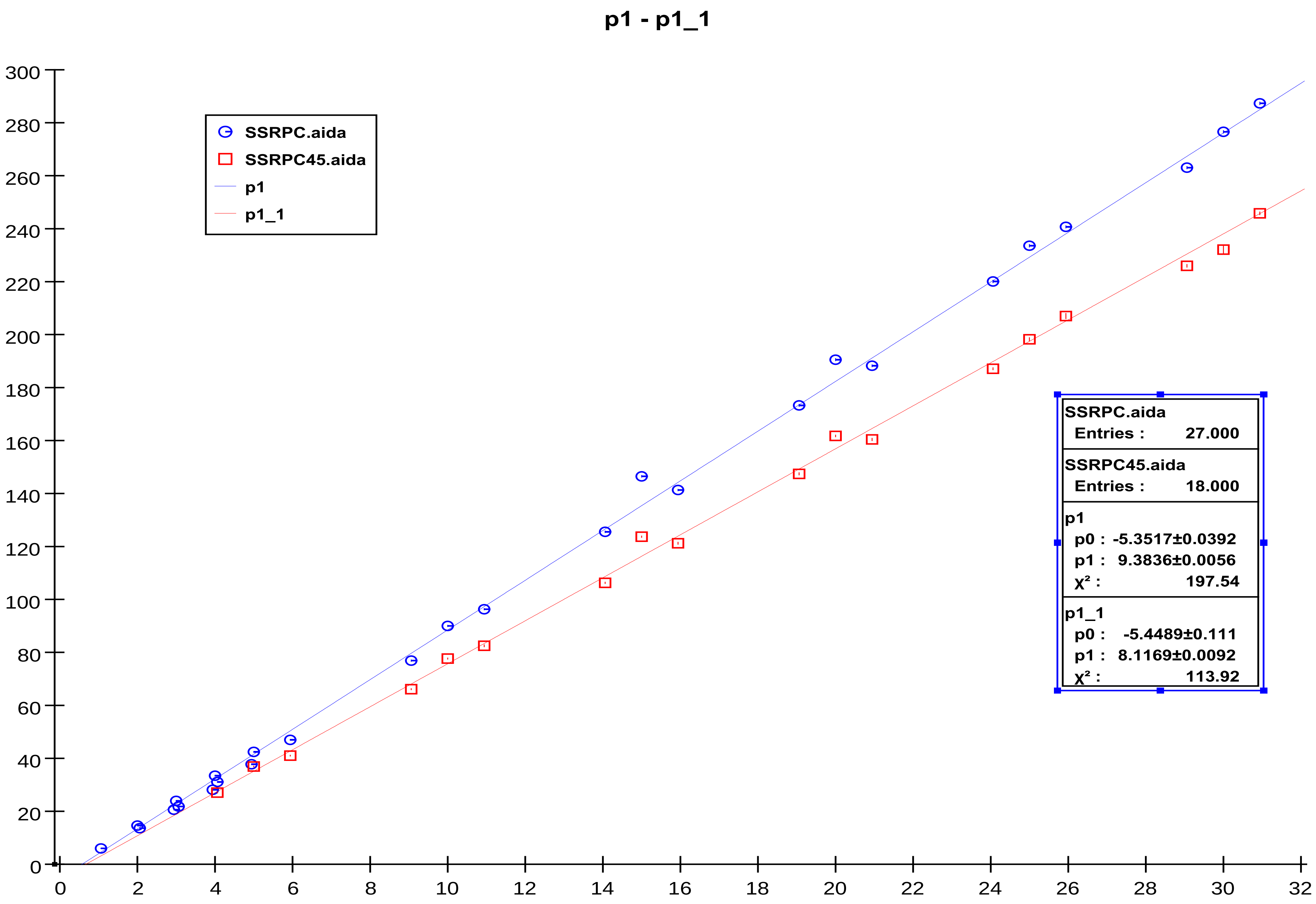
Angle correction studies

- Expected 45 degree incidence to be the same (or at least similar) to increasing the absorber width by root2.
- Try a variety of checks to explain the difference
- First, vary the absorber width at 90 degree incidence

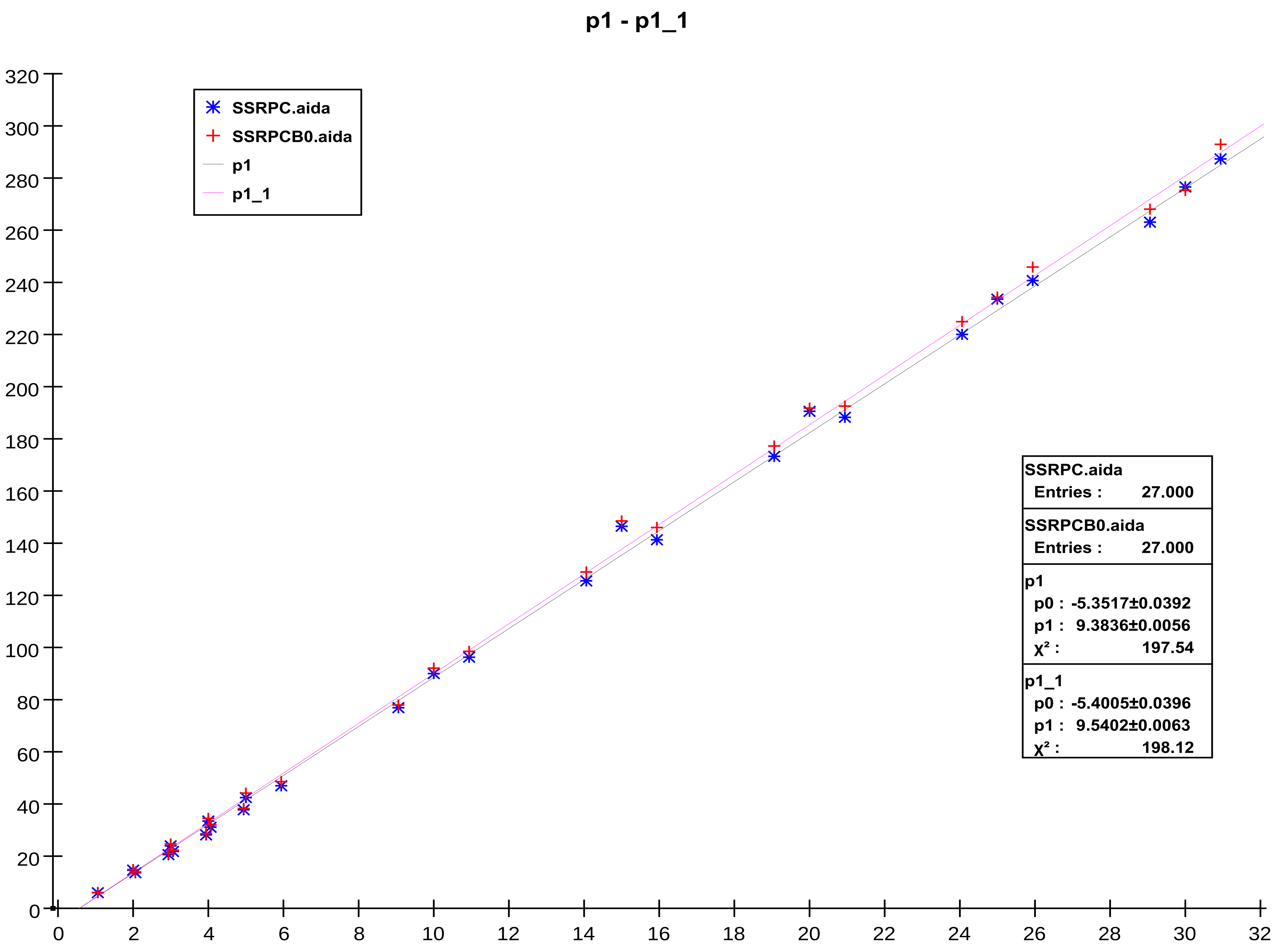


#hits vs Escaled
p1 - p1_1 - p1_2
SSRPC.aida
SSRPCabsHalf.aida
SSRPCabsRoot2.aida
p1
p1_1
p1_2
SSRPC.aida
Entries : 27.000
SSRPCabsHalf.aida
Entries : 27.000
SSRPCabsRoot2.aida
Entries : 27.000
p1
p0 : -5.3517±0.0392
p1 : 9.3836±0.0056
χ² : 197.54
p1_1
p0 : -10.578±0.0737
p1 : 18.042±0.013
χ² : 229.75
p1_2
p0 : -3.9214±0.0298
p1 : 6.6978±0.0043
χ² : 210.92

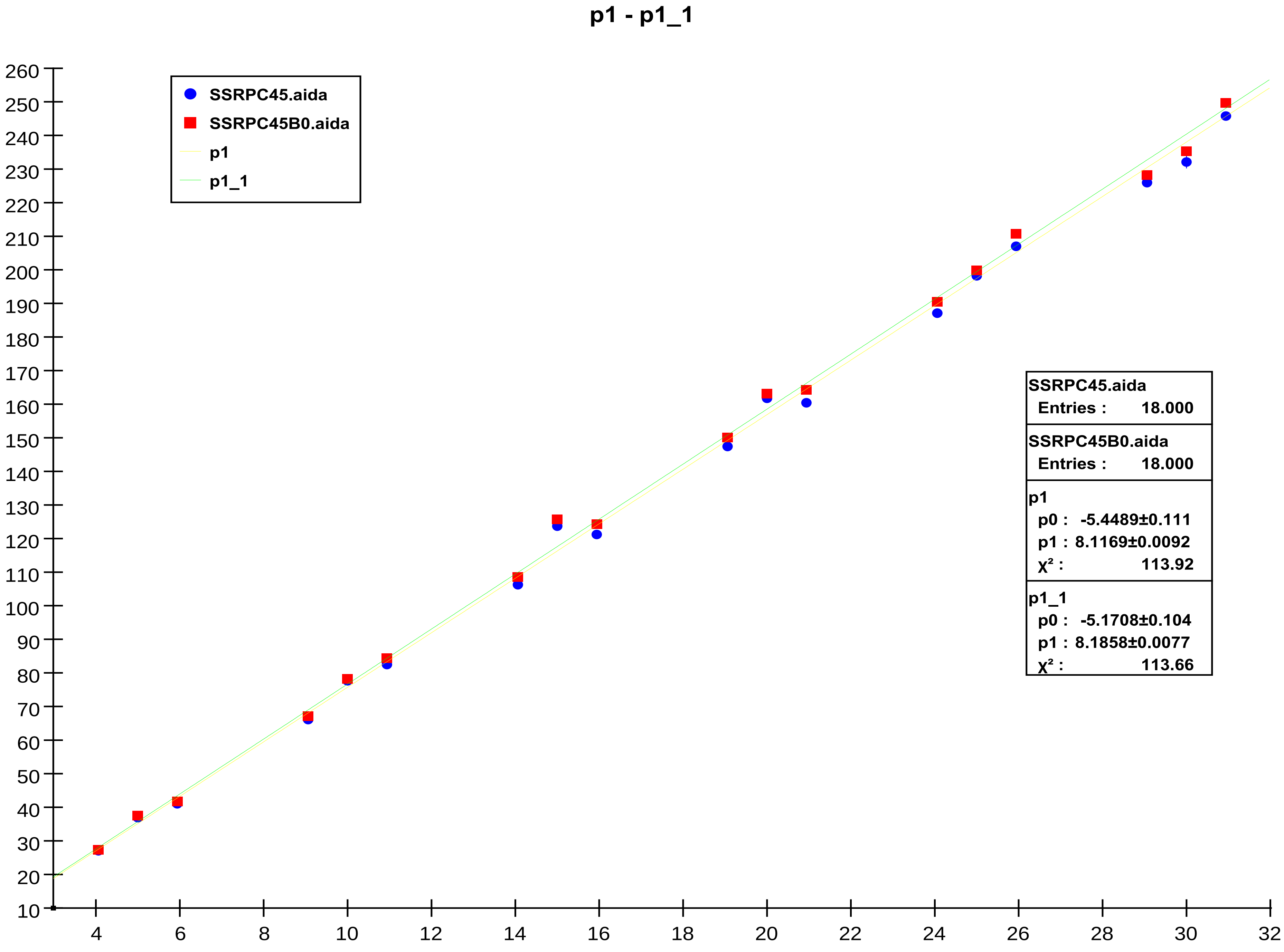
#hits vs Escaled



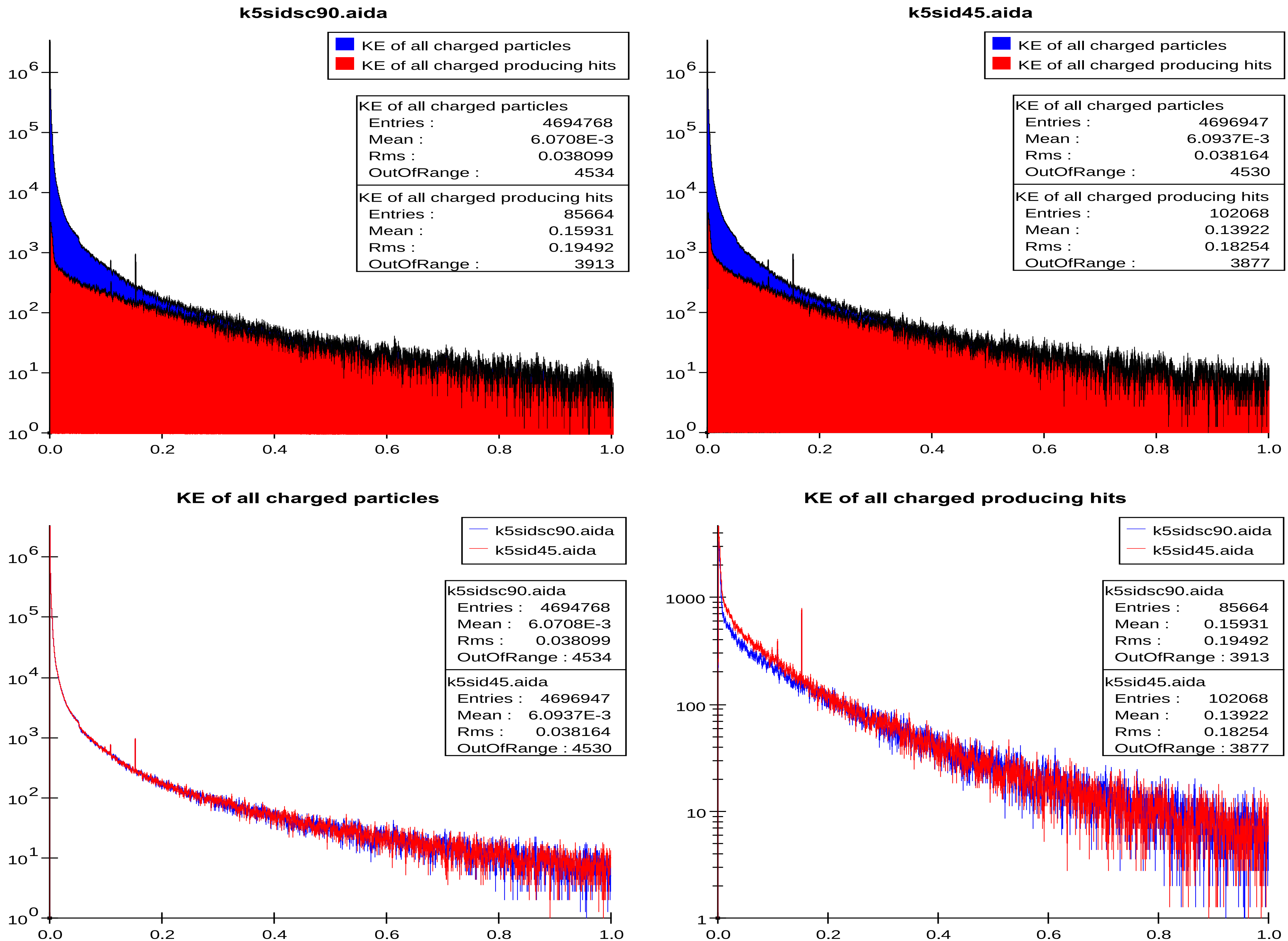
- At 90 degrees, the number of hits varies nearly linearly with the absorber width.
- At 45 degree incidence, not close to root2 increase in absorber width
- Maybe it’s the B field



p1 - p1_1
SSRPC.aida
SSRPCB0.aida
p1
p1_1
SSRPC.aida
Entries : 27.000
SSRPCB0.aida
Entries : 27.000
p1
p0 : -5.3517±0.0392
p1 : 9.3836±0.0056
χ² : 197.54
p1_1
p0 : -5.4005±0.0396
p1 : 9.5402±0.0063
χ² : 198.12

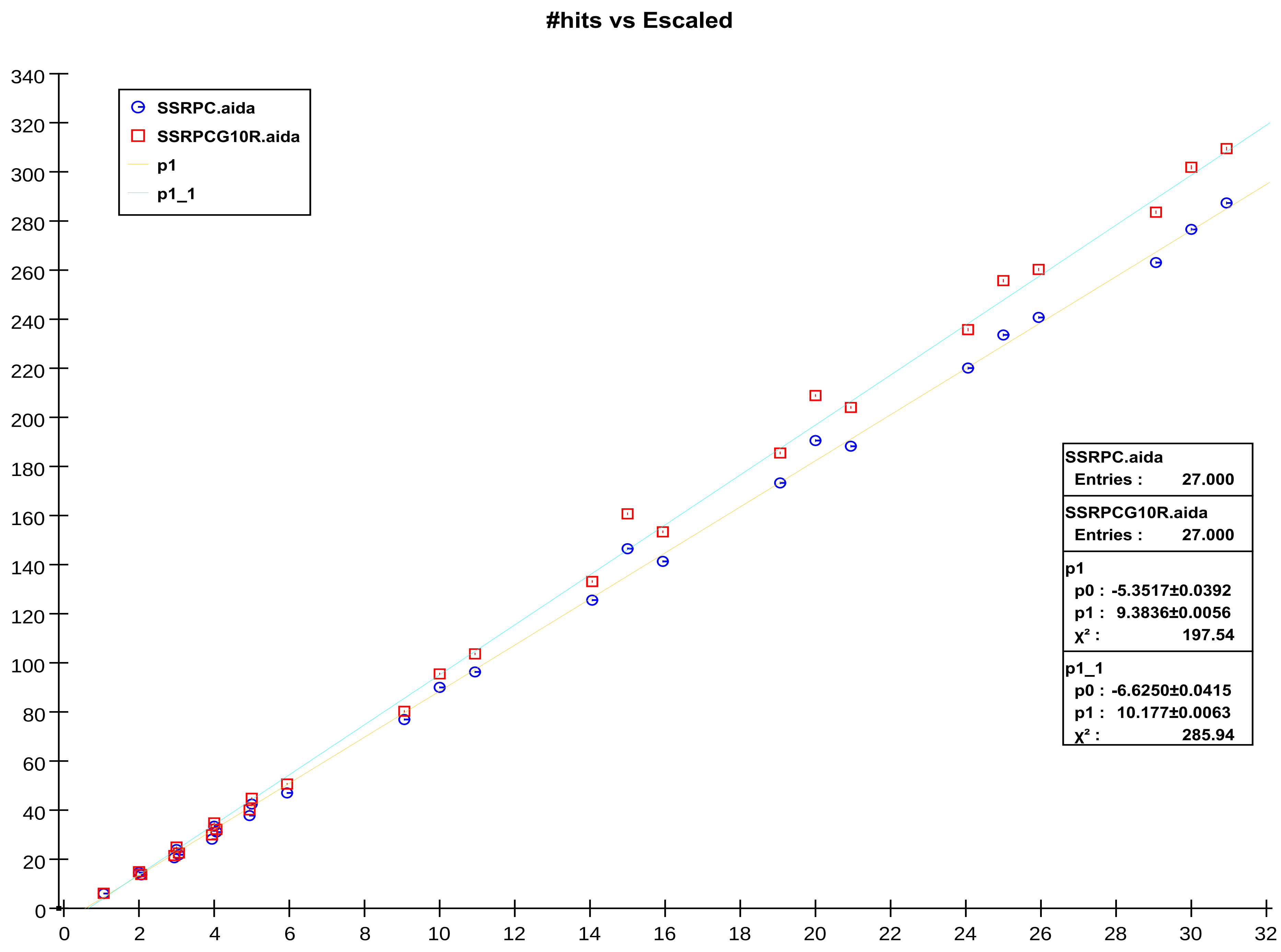

p1 - p1_1
SSRPC45.aida
SSRPC45B0.aida
p1
p1_1
SSRPC45.aida
Entries : 18.000
SSRPC45B0.aida
Entries : 18.000
p1
p0 : -5.4489±0.111
p1 : 8.1169±0.0092
χ² : 113.92
p1_1
p0 : -5.1708±0.104
p1 : 8.1858±0.0077
χ² : 113.66
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

- B field small effect
- Tried scaling all elements (not just absorber) by root2, small effect
- At a loss, so put whole detector in a tracking region to try to find the difference
- Work in progress, but answer probably related to steeply falling energy distribution of charged particles in shower development.


k5sidsc90.aida
KE of all charged particles
KE of all charged producing hits
KE of all charged particles
Entries : 4694768
Mean : 6.0708E-3
Rms : 0.038099
OutOfRange : 4534
KE of all charged producing hits
Entries : 85664
Mean : 0.15931
Rms : 0.19492
OutOfRange : 3913
k5sid45.aida
KE of all charged particles
KE of all charged producing hits
KE of all charged particles
Entries : 4696947
Mean : 6.0937E-3
Rms : 0.038164
OutOfRange : 4530
KE of all charged producing hits
Entries : 102068
Mean : 0.13922
Rms : 0.18254
OutOfRange : 3877
KE of all charged particles
k5sidsc90.aida
k5sid45.aida
k5sidsc90.aida
Entries : 4694768
Mean : 6.0708E-3
Rms : 0.038099
OutOfRange : 4534
k5sid45.aida
Entries : 4696947
Mean : 6.0937E-3
Rms : 0.038164
OutOfRange : 4530
KE of all charged producing hits
k5sidsc90.aida
k5sid45.aida
k5sidsc90.aida
Entries : 85664
Mean : 0.15931
Rms : 0.19492
OutOfRange : 3913
k5sid45.aida
Entries : 102068
Mean : 0.13922
Rms : 0.18254
OutOfRange : 3877

Another aside

- What if we put the electronics outside the RPC?
- ~8.5% more hits in the RPC


#hits vs Escaled
SSRPC.aida
SSRPCG10R.aida
p1
p1_1
SSRPC.aida
Entries : 27.000
SSRPCG10R.aida
Entries : 27.000
p1
p0 : -5.3517±0.0392
p1 : 9.3836±0.0056
χ² : 197.54
p1_1
p0 : -6.6250±0.0415
p1 : 10.177±0.0063
χ² : 285.94
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

Still needed

- Understanding of difference between 45 degree incidence and 90 degree incidence with detector scaled by root2
- Some metric of the transverse spread of the hits for comparing detectors
- Correction for depth of initial interaction (significant resolution gain possible)
- Fix Geant4
- Look at charged hadrons

Conclusions

- Studying isolated detectors is useful way to break down the details of hadron interactions
- Calibrations from such studies give reasonable results when used in full detector simulations
- Generating special detectors with special needs(all active elements, all particles saved) and the ability to analyse events from these detectors is nearly trivial in the SLIC/JAS3/org.lcsim structure
- (personal opinion) Understanding the messy details is essential for the simulations to have any relevance in designing detectors