Analysis of PCB Exposure Tests

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LAL Orsay

- Motivation

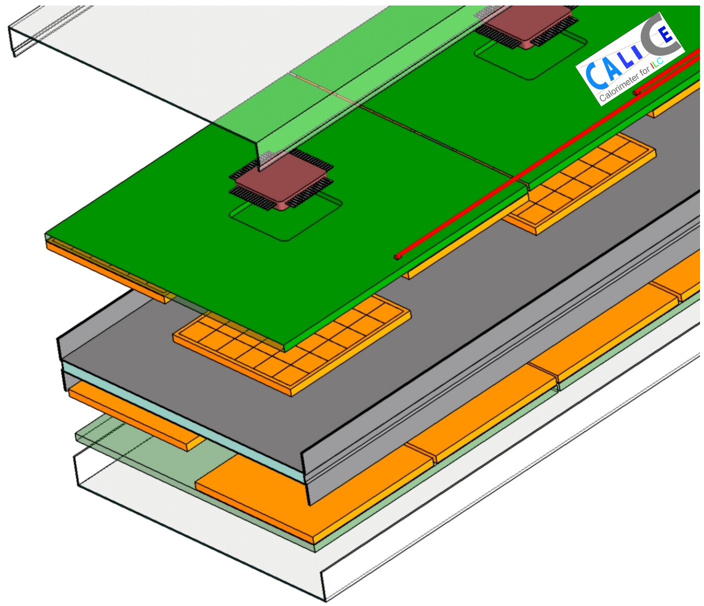
- Analysis and Results

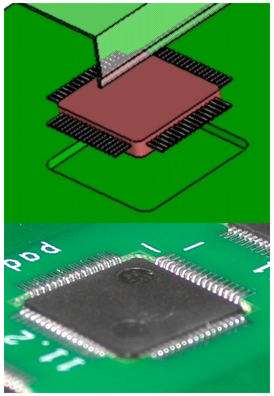
- Summary, Conclusion and Outlook

CALICE Collaboration Meeting Casablanca/Maroc Sept. 2010

Introduction

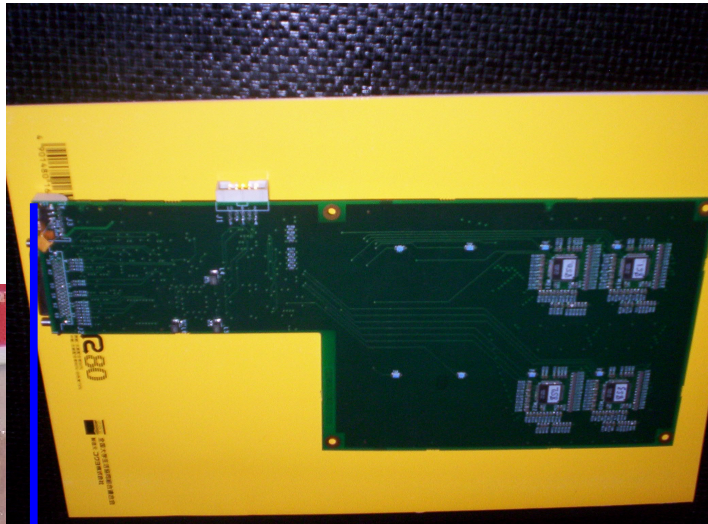
Calorimeter Electronics to be interleaved with layer structure



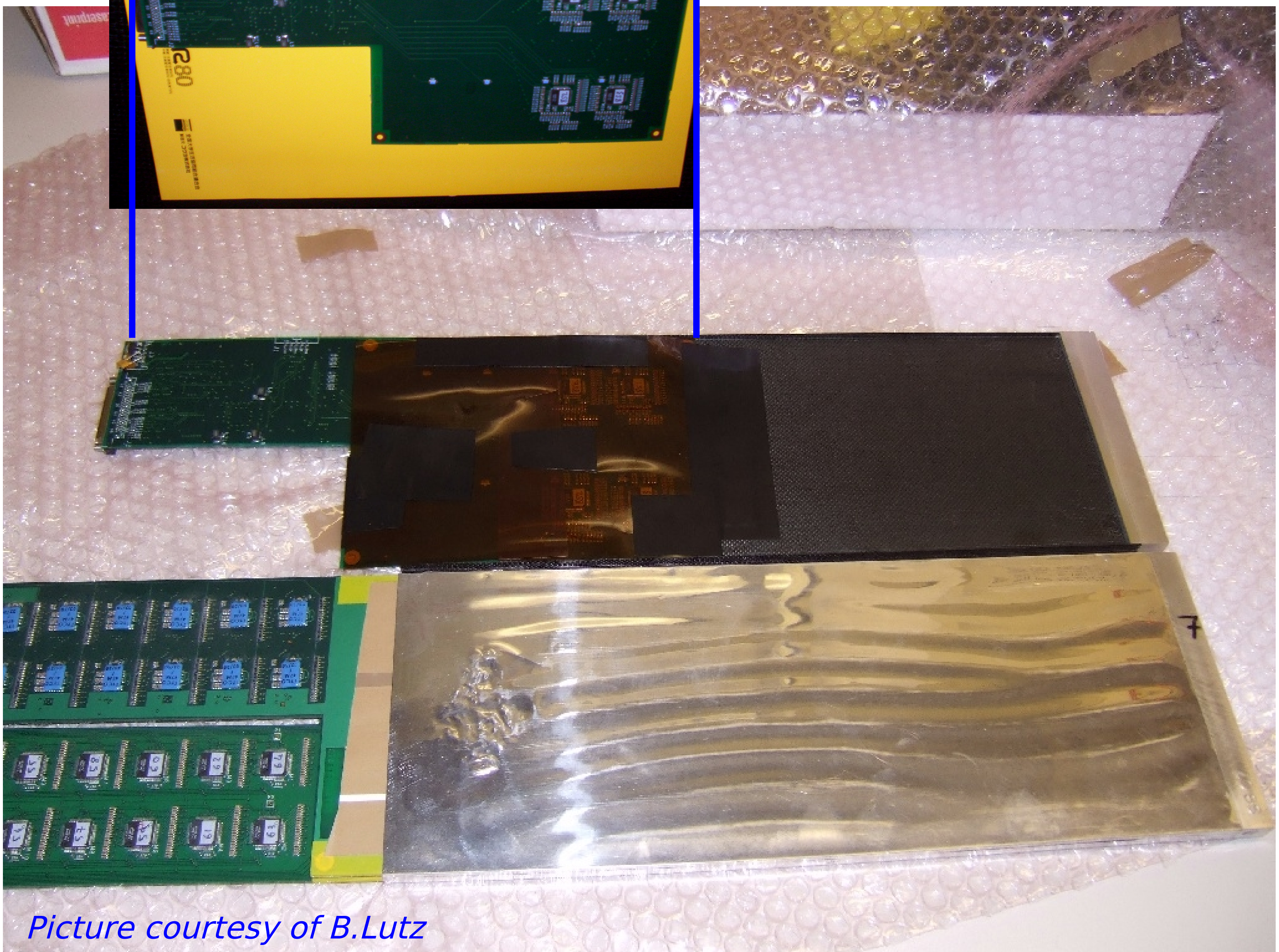


Do high energetic showers create signals directly in electronics ?
If yes, rate of faked signals ?

Special PCB in Ecal Prototype during CERN 07 testbeam – Experimental Setup I



Test PCB
- equipped with
  PHY3 chip set



Prepared slab
- W dummy
- capton and paper
  for electrical shielding

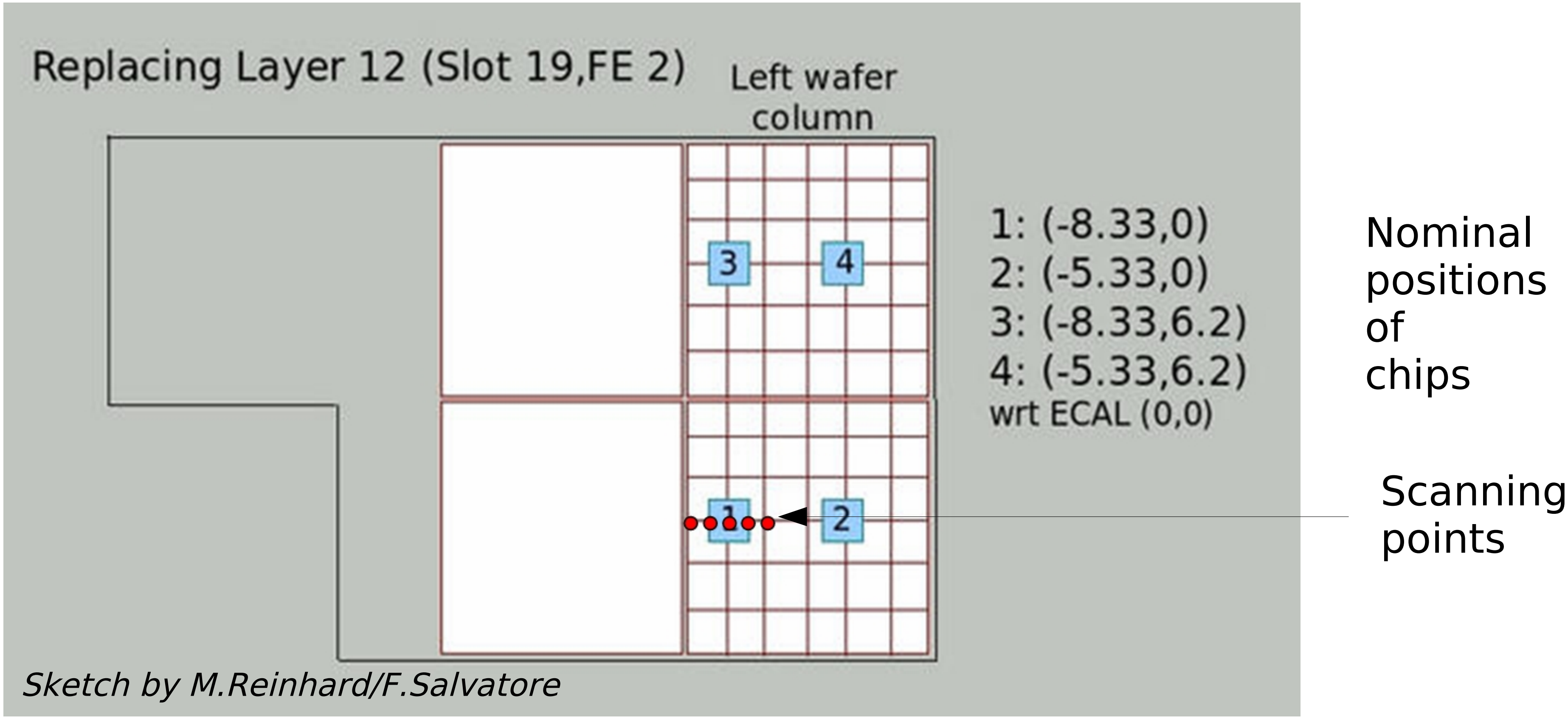
Usual slab

Picture courtesy of B.Lutz

Special PCB in Ecal Prototype during CERN 07 testbeam – Experimental Setup II

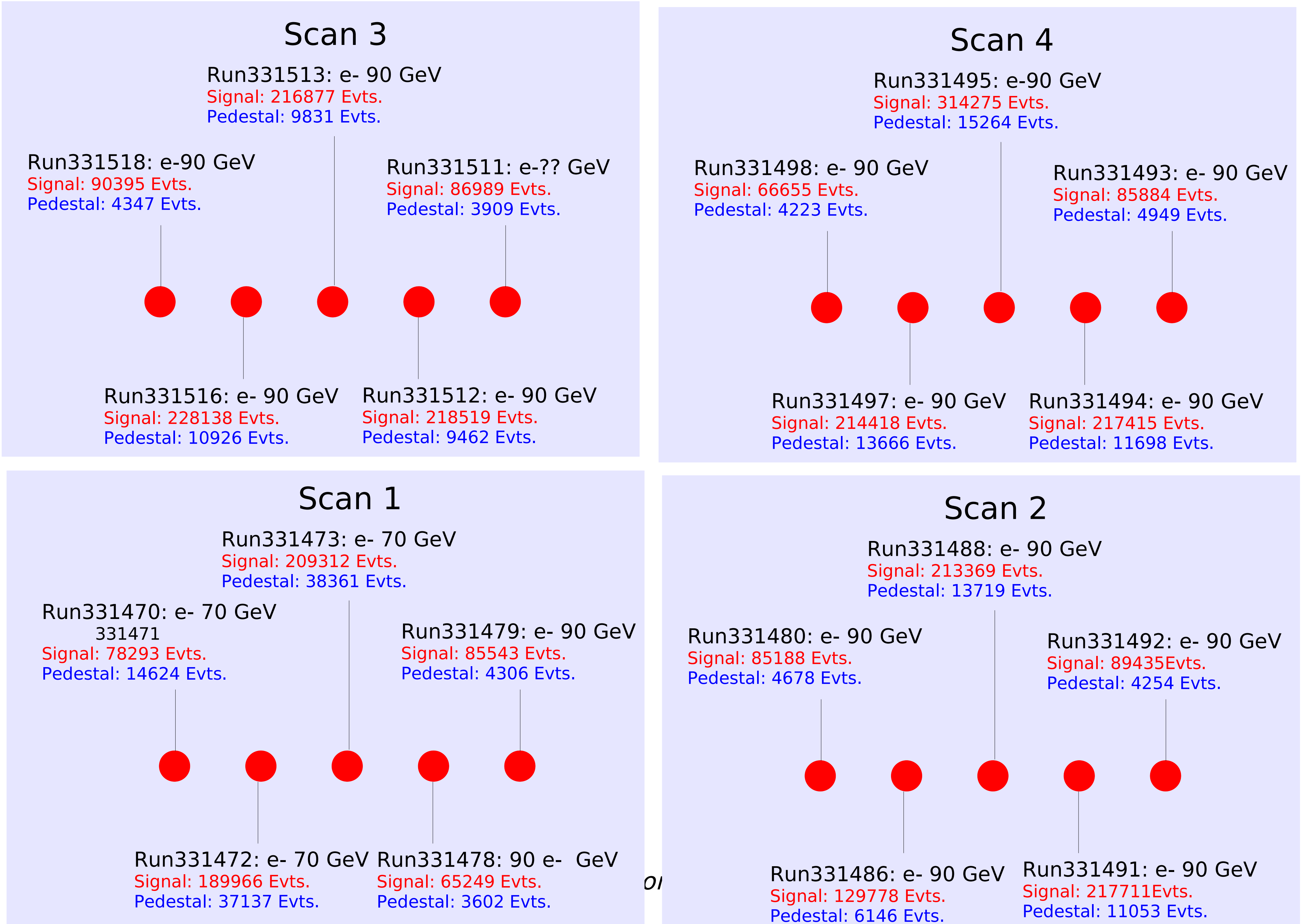
- PCB positioned at place of layer 12 in Ecal ~ shower maximum
  x,y position identical to layer 2

- Schematic view of test PCB - 'Expect' signals from 72 pads, 4x18 = 2 Wafer



- 2.6 10^6 events with 90 GeV electrons (- 5.8 10^5 with 70 GeV electrons)
  At least 70 K at each scan point
  Runs 331462 – 331518

Statistics of Analysis



On Run Selection and Observations

- Runs selected according to entries in the logbook
  No comments on bad quality by shift crew

- Switch of energy between Run 331473 and Run 331478
  - Change in pedestal rate
    20% of all events -> 5% of all events
    Still at least 3500 of (valuable) pedestal events

- at least 70k events at each point
  - mostly 90 kEvents for off center runs
  - > 200k at (nominal) chip center

Accompanying Remarks

Disclaimer I:

The following is based on the motivation to quantify parasitic effects (upper limits) and on the observation that the noise spectra of the chips are not “simple”

Disclaimer II:

- Concentration of runs with central nominal impact on cells
- Otherwise prohibitive number of plots
- If at all largest effect
- Still enough means for comparison with chips out of beam

Principal Component Analysis - PCA

Following 'cooking recipe' a la ATL-LARG-99-009
(Mathematical 'proof' for the following in my lab book)

1) Noise Vector: $\vec{b} = \vec{u} + c\,\vec{\alpha}$

Incoherent noise ($\vec{u}$)

Magnitude and 'direction' of coherent noise ($c\,\vec{\alpha}$)

2) Covariance Matrix: $B = \sigma^2 \cdot I + \sigma_c^2 \vec{\alpha}\,\vec{\alpha}^T$

With: $\langle u_i u_j \rangle = \sigma^2 \delta_{ij}$ incoherent noise

$\sigma_c^2 =$ Variance of c

3) Eigenvalues and eigenvectors of covariance matrix:

$\vec{\alpha}$ is eigenvector to (largest) eigenvalue $\sigma^2 + \sigma_c^2$

Any other eigenvector (orthogonal) to $\vec{\alpha}$ is eigenvector to eigenvalue σ^2

=> Expect flat spectrum of matrix B except for one (or few) eigenvalue associated with α

Coherent channel noise via $\sigma_c \cdot \vec{\alpha}$

4) Incoherent Channel noise via: $B' = B - \sigma_c^2 \alpha \alpha^T$

=> Matrix with incoherent channel noise on diagonal and off-diagonal elements flat and zero

5) Estimation of c -Parameter

Since all channels are equal, the variance $\sum u_i^2$ reaches a minimum

Estimation of c-Parameter by minimising

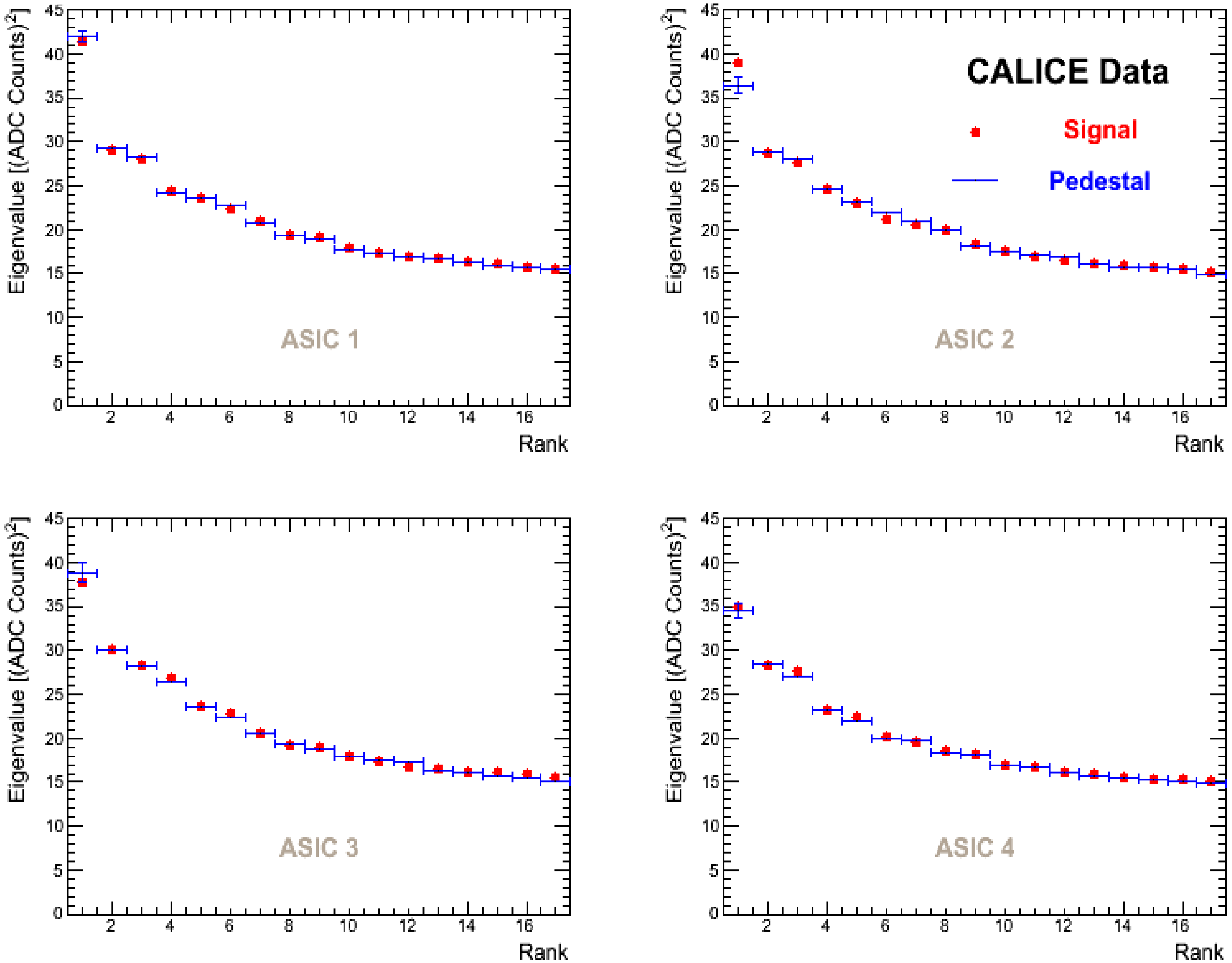
$$\sum (b_i - c\,\alpha_i)^2$$

$$\Rightarrow \quad c = \vec{\alpha}\,\vec{b}$$

By determining α_i and measuring b_i (the actual ADC count)
c can be calculated on an event-by-event basis

Eigenvalues of Covariance Matrix

$\sigma^2 + \sigma_c^2$



- Mostly clear prominent eigenvalues

=> Coherent noise

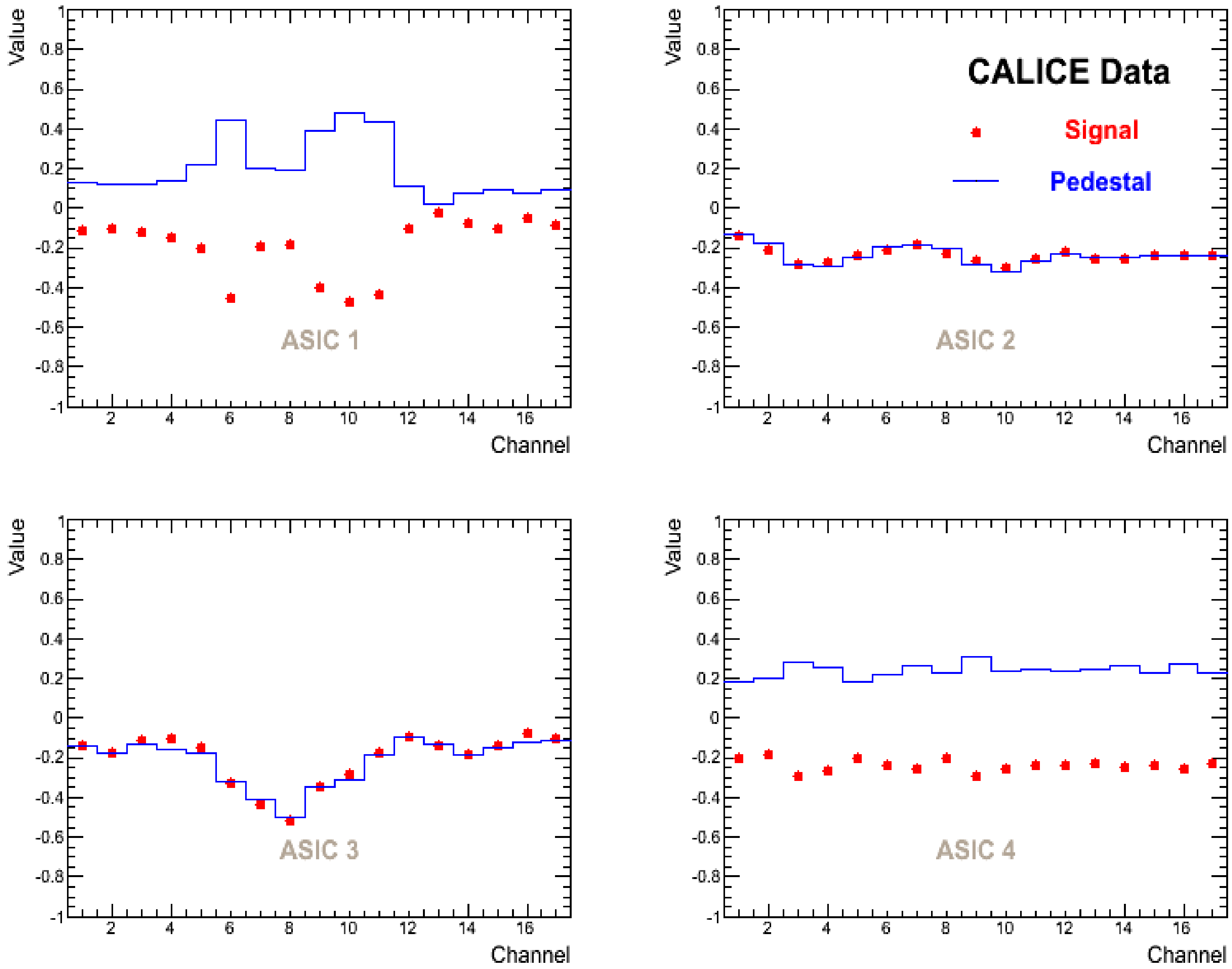
- Where less prominent: Still visible step

- Fairly flat spectrum of other eigenvalues

- Excellent agreement between Signal and Pedestal

Channel Nr.

Elements of Eigenvector



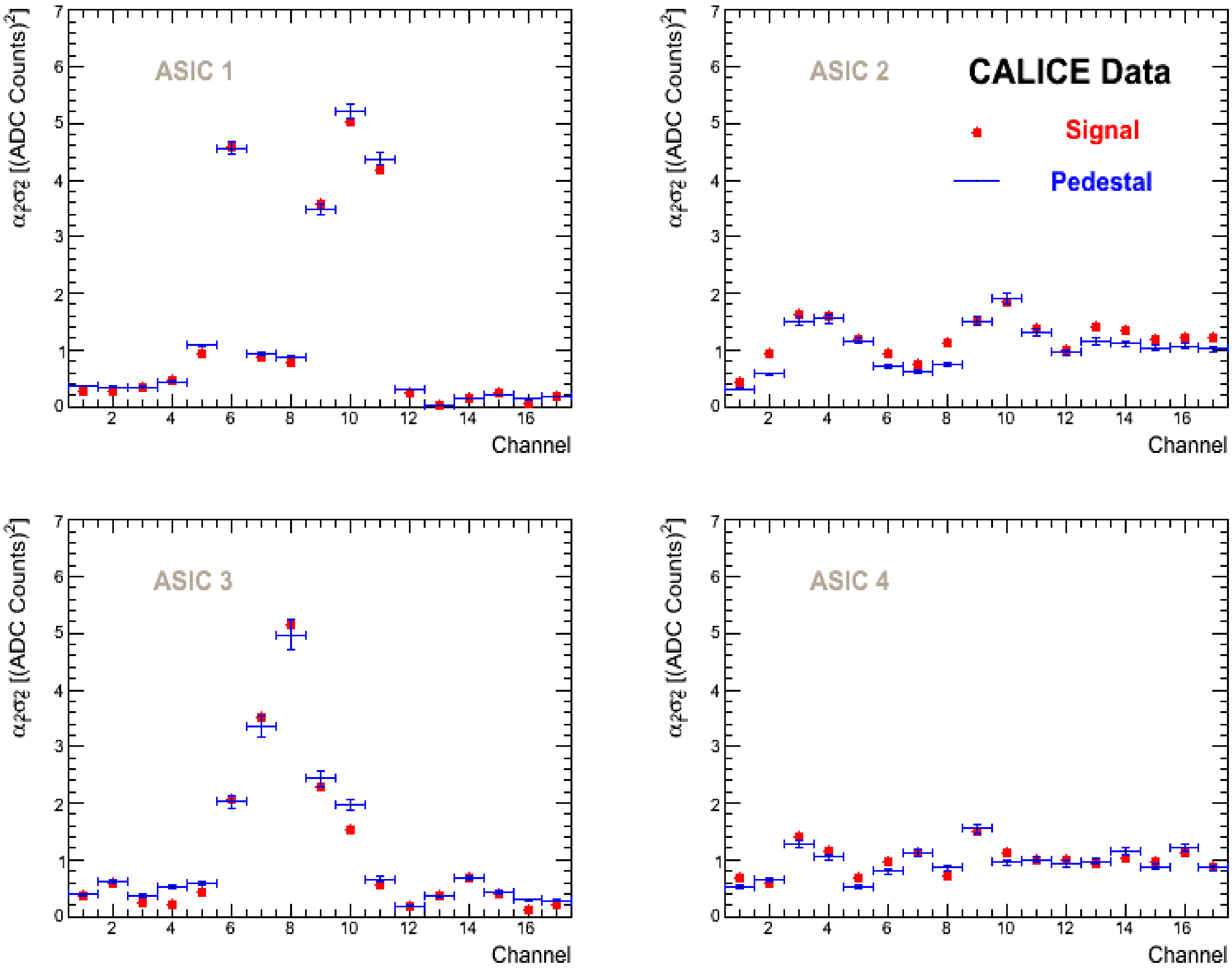
- Excellent agreement between Signal and Pedestal

modulo sign ambiguity (known feature of PCA)

Reveal channels with coherent noise

Channel Nr.

Coherent Noise Level



Different Patterns

- Concentrated for Chip 1 and Chip 3

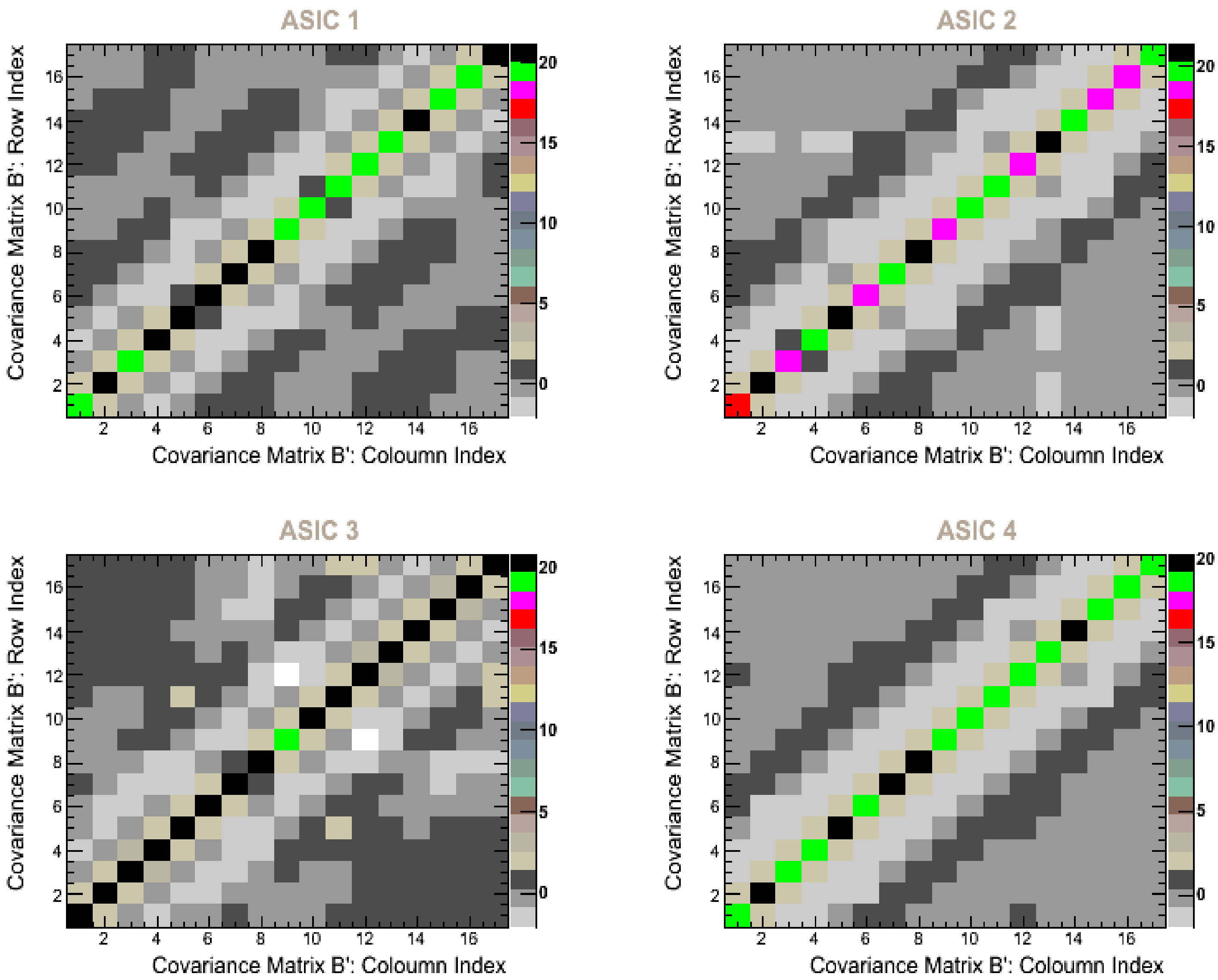
- Flat spectrum for Chip 2 and 4

- Excellent agreement between Signal and Pedestal

- Coherent noise level ~1 ADC Count

Channel Nr.

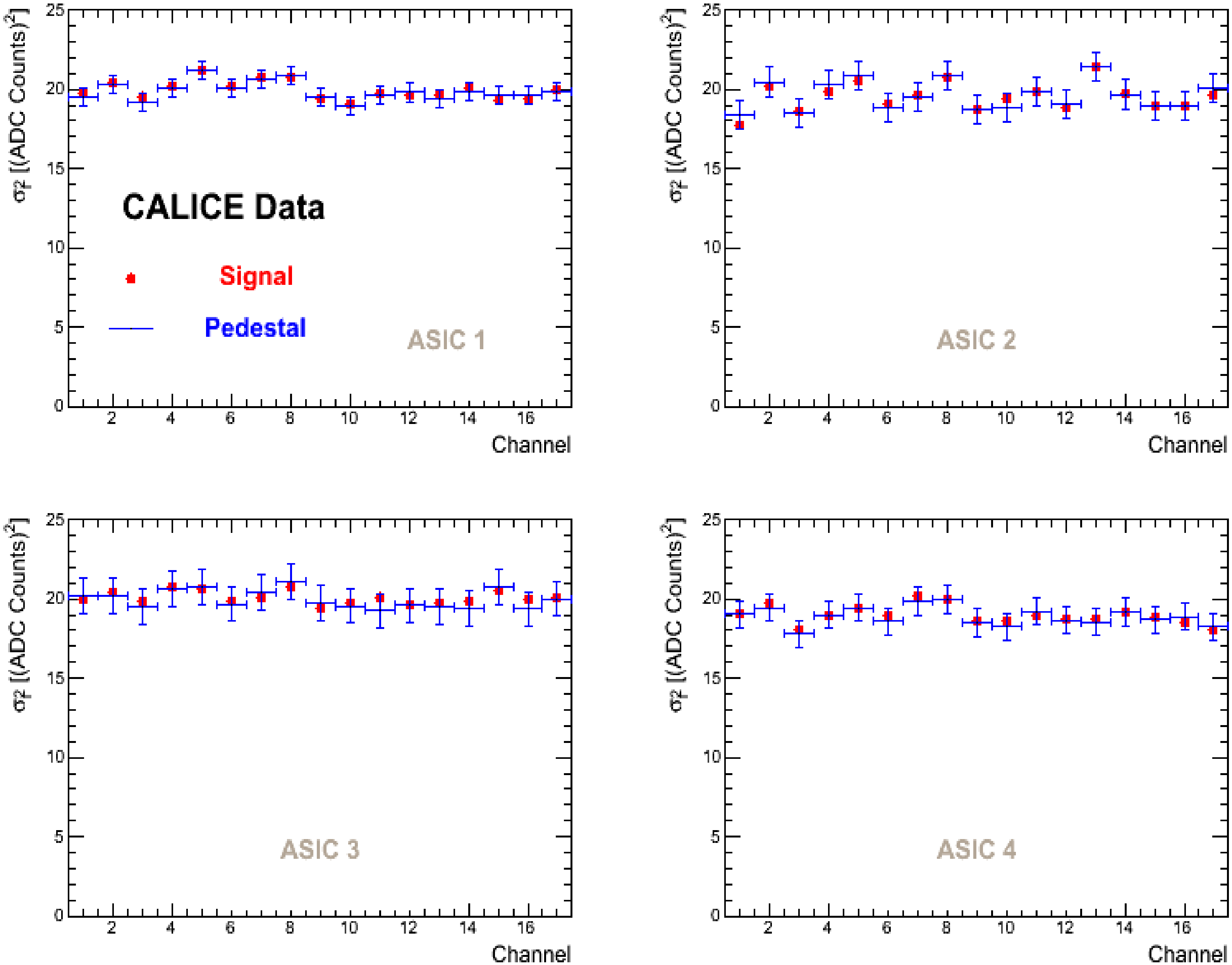
Matrix B' for Signal Events



Diagonal: Prominent with value ~20 (ADC Counts)^2
Off-Diagonal: Flat with value ~0

Incoherent Noise Level

Results for Scan 1



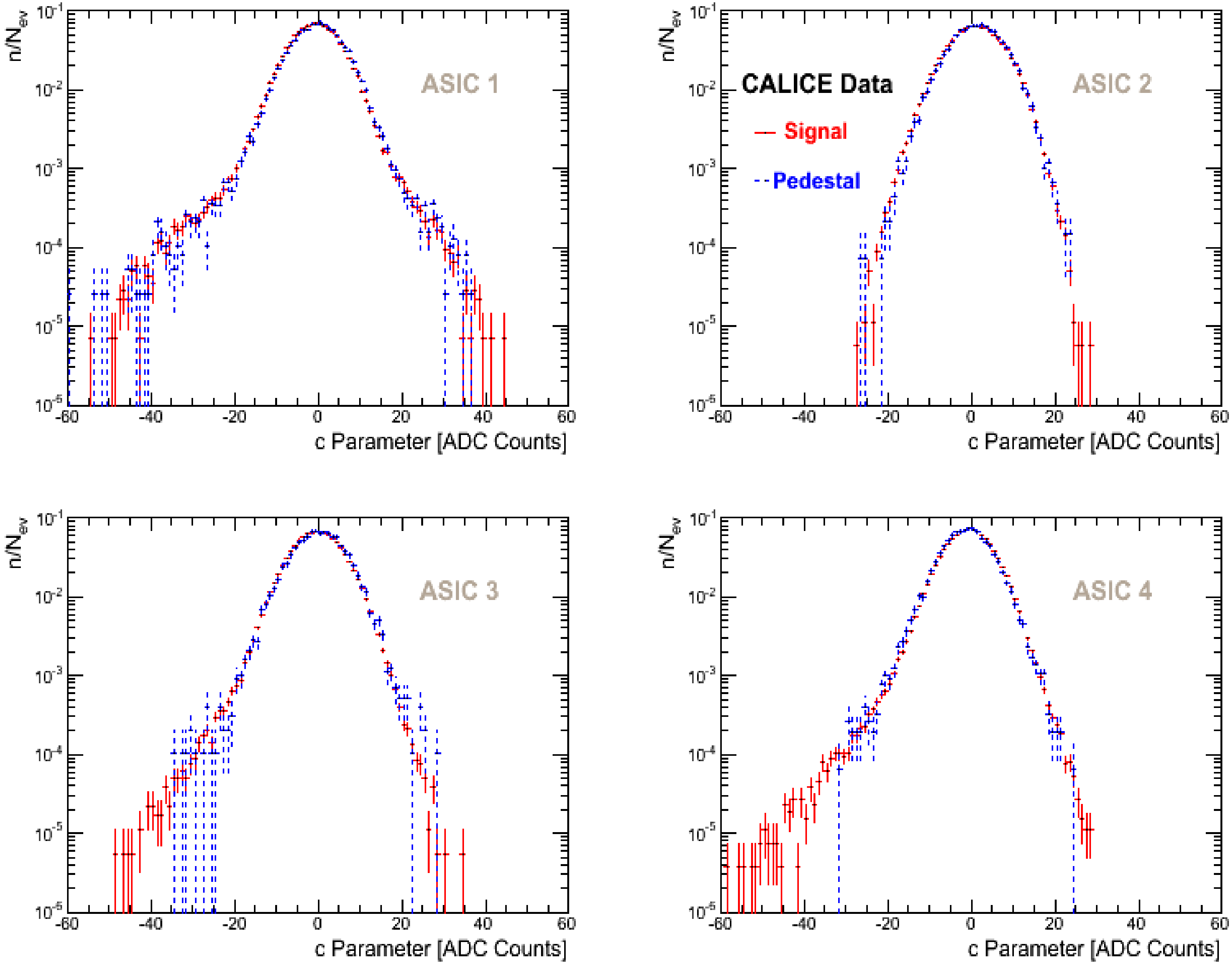
Channel Nr.

- Flat spectrum for all chips
- Incoherent noise level ~√20 ~4.5 ADC C.

$$\sqrt{\sigma_{ic}^2+\sigma_{cn}^2}\approx\sqrt{4.5^2+1}\approx 4.6$$

- In agreement with rms (see earlier)
- Excellent agreement between Signal and Pedestal

Spectrum of c-Parameter



- Good agreement between Signal and Pedestal

- In future application the values in these spectra can be used to subtract coherent noise!

- Here: Spectra used as input pdf for simulation of noise

Simulation of Noise

Noise vector: $\vec{b} = \vec{u} + c\vec{\alpha}$

Incoherent noise:
Simulated by Gaussian with width σ_i (see page 14)
and mean x_m (see talk 3/5/10)

Coherent noise:
α_i see above
c parameter spectrum, see above, as input to kernel estimation à la Cranmer (hep-ph/005309) as implemented in RooFit package (extension to root)
Final formular for channel i:

$$b_i = G\left(x_m - p_m, \sqrt{\sigma_i^2 - p_\sigma}\right) + (sign)\, K(c)\, \alpha_i$$

$$(sign) = \vec{\alpha_{ped}} \cdot \vec{\alpha_{sig}}$$

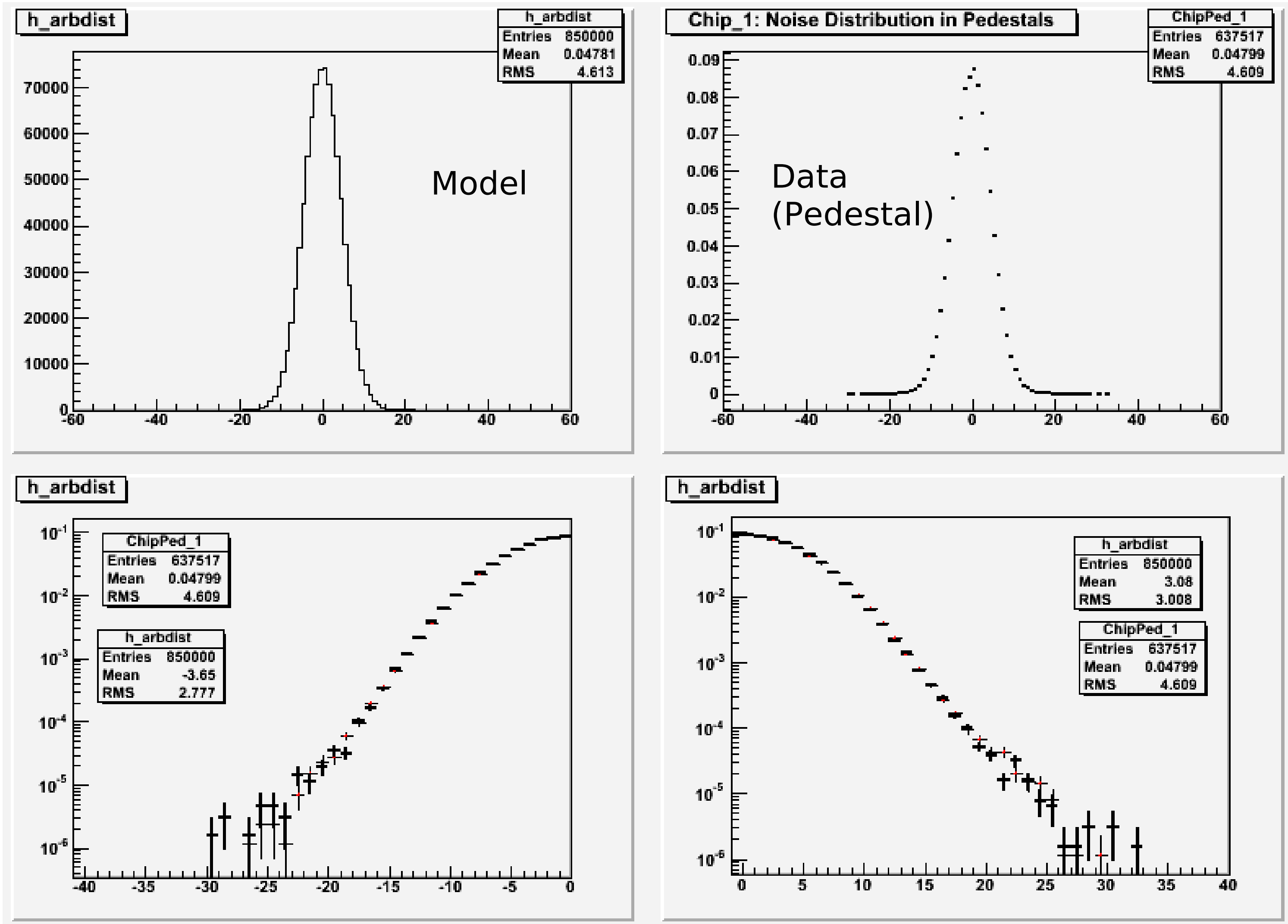
p_m, p_σ = corrections for imperfections of PCA

<u>Strategy:</u> - Establishment of noise model reduces drawback by relative small number of pedestal events

- Optimise model (i.e. adjust p_m, p_σ) for pedestal events to make predictions for signal events
Optimisation of agreement between model and pedestal w.r.t to χ^2/ndf
<u>Already now:</u> Typical value for $p_\sigma \sim 1.5$
Range for p_m = [-0.01, 0.15]

Agreement Pedestal Data and Model

Example: Chip 1 in Scan 1 – All noise spectra see below



Black: Data (Pedestal)

Red: Model

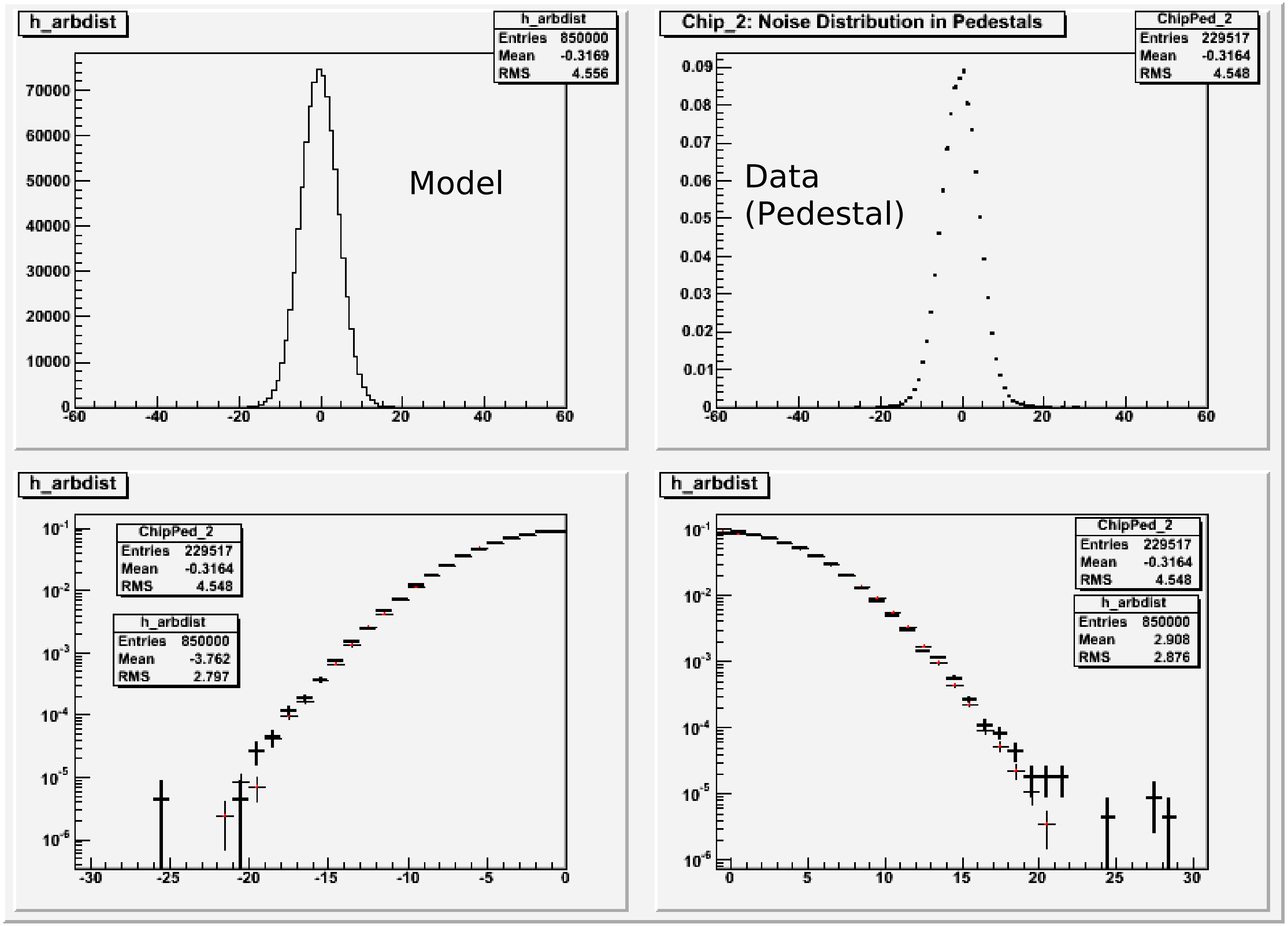
Excellent agreement over several orders of magnitude

Non gaussian component in tail correctly reproduced by Model

(remember only trivial component tuned, see page 16)

Agreement Pedestal Data and Model

Example: Chip 2 in Scan 2 – All noise spectra see below



Black:
Data (Pedestal)
Red: Model

Excellent agreement over several orders of magnitude

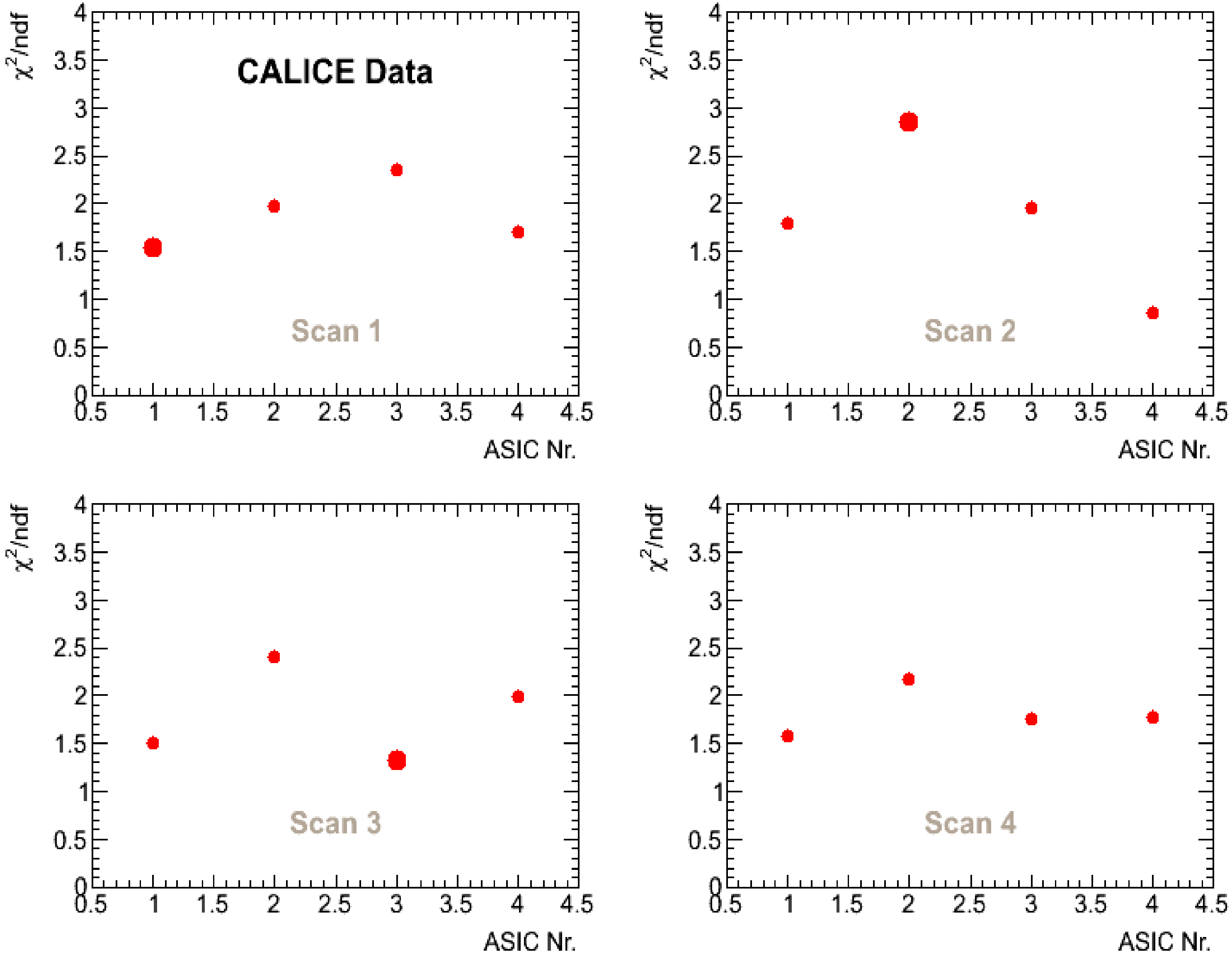
Non gaussian component in tail correctly reproduced by model

(remember only trivial component tuned, see page 16)

Extreme outliers not-reproduced

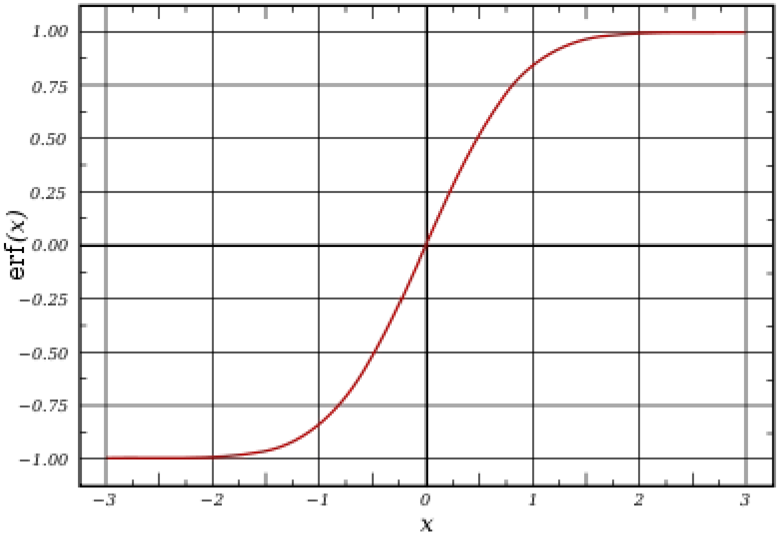
χ^2/ndf between Data and Model

Optimisation for central impact only



χ^2/ndf ~ 2 for 100k simulated events – at least 2.5 times data statistics
Worst results for Chip 2

A Final Correction



Errorfunction: $erf\left(\frac{\Delta x}{2\sqrt{2}\sigma}\right)$

With Δx = Difference between data and model
σ = statistical uncertainty of data

Errorfunction gives probability that true value lies within Δx

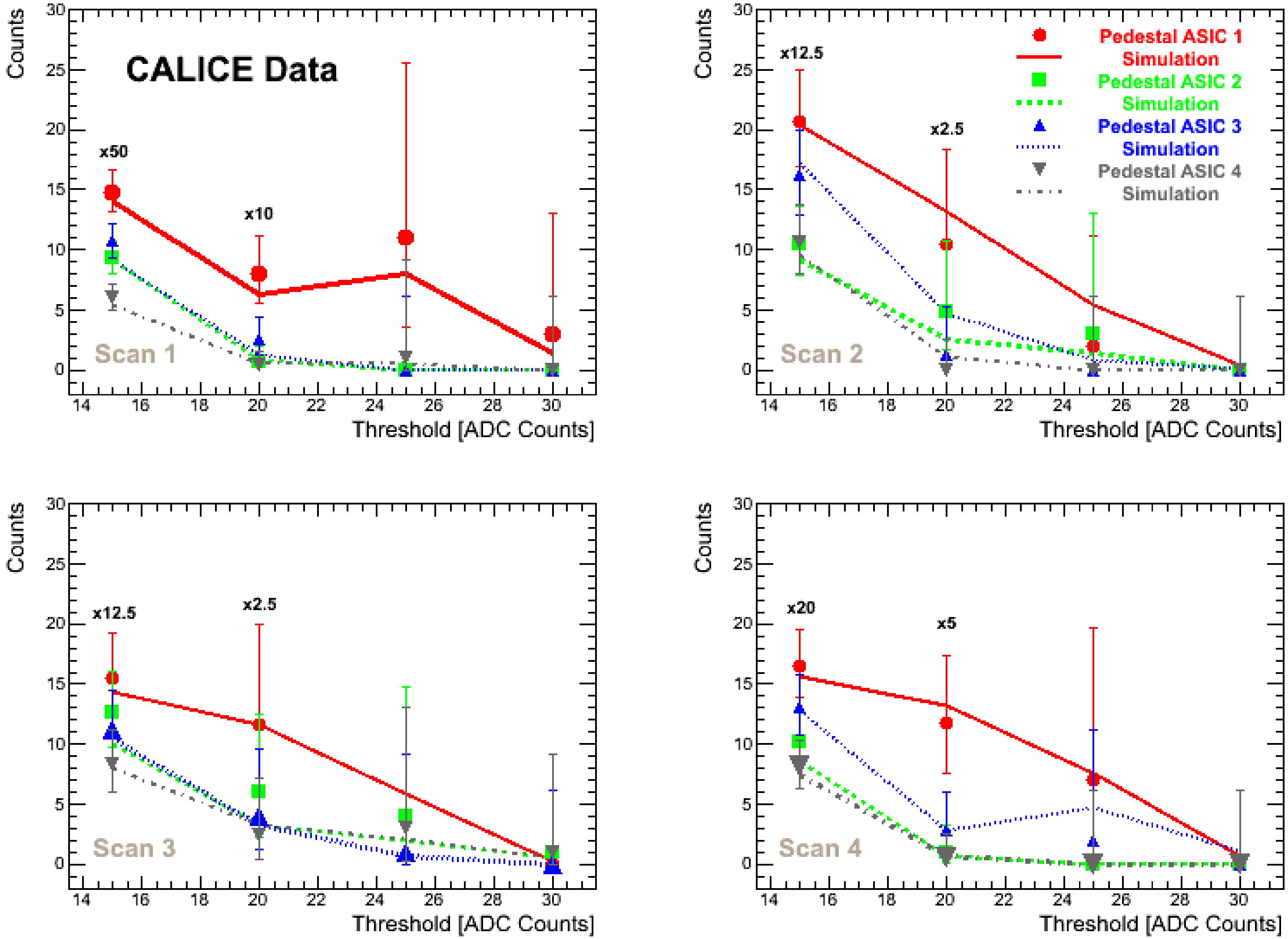
Complementary Errorfunction: $erfc = 1 - erf\left(\frac{\Delta x}{2\sqrt{2}\sigma}\right)$

Correction of Model by adding: $f(\Delta x, \sigma) = \left[1 - erf\left(\frac{\Delta x}{2\sqrt{2}\sigma}\right)\right] \cdot \Delta x$

to the individual bin content of the model spectra

Remark: Correction *inspired* by recent BABAR analysis (B. Malaescu, M. Davier)

Agreement (Pedestal) Data – Model in Tail – Positive Hits

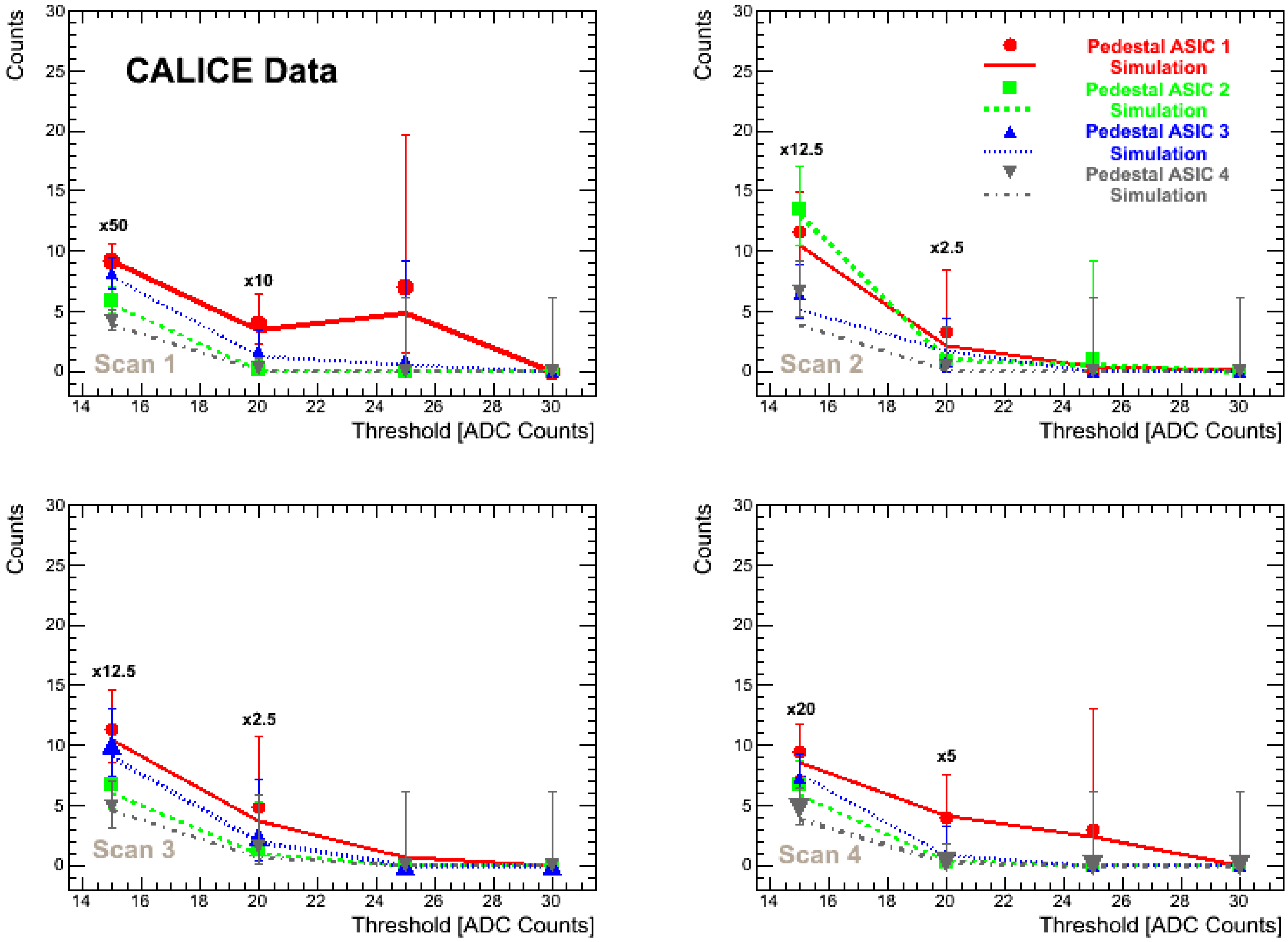


- Data – Model agree mostly within 97.3% CL (≙ 3σ for n->∞)

- Remember complexity of noise distribution!!!

Satisfactory up to excellent reproduction of noise spectra by model

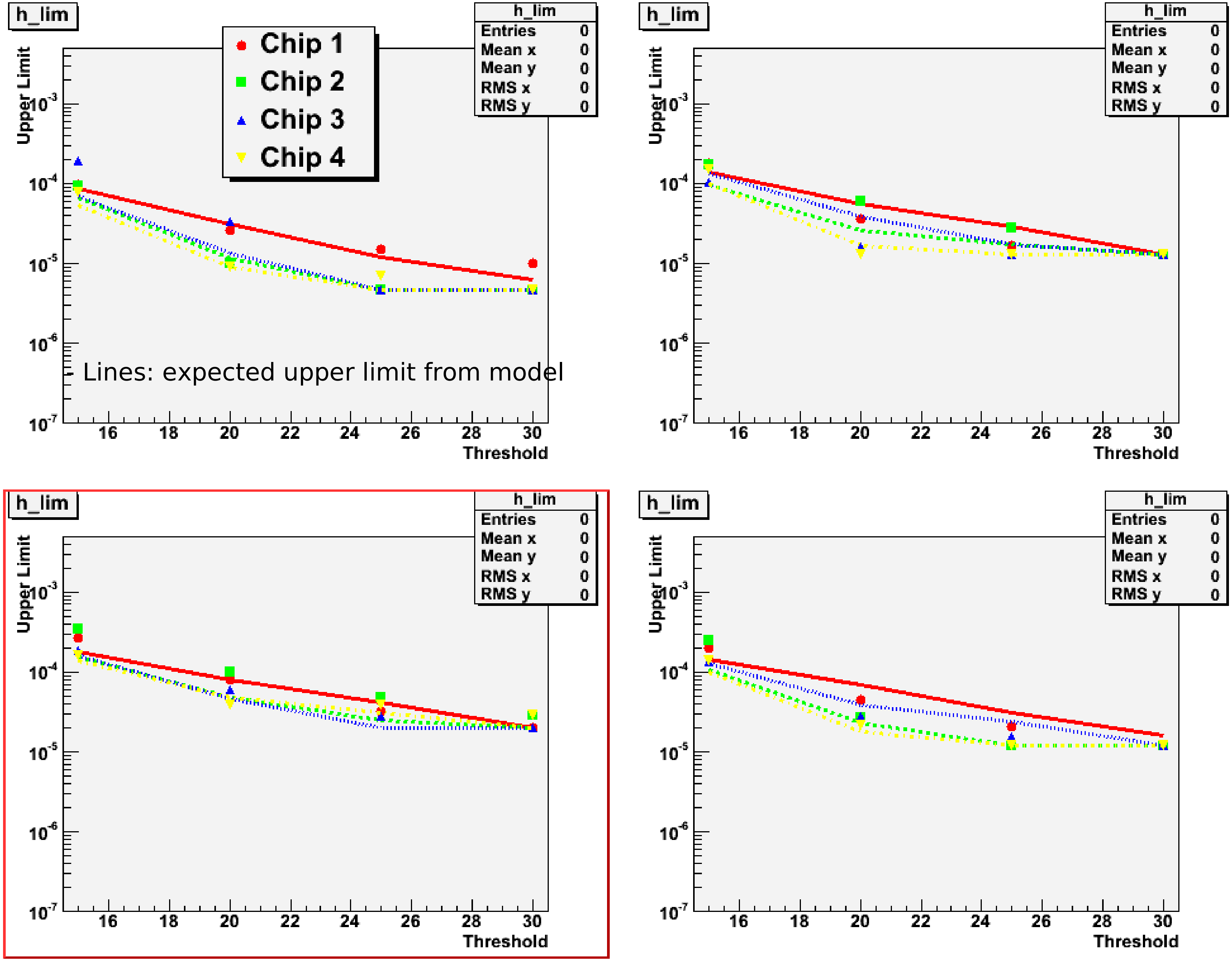
Agreement (Pedestal) Data – Model in Tail – Negative Hits



- Data – Model agree mostly within 97.3% CL (≙ 3σ for n->∞)
- Remember complexity of noise distribution!!!

Satisfactory up to excellent reproduction of noise spectra by model

Upper Limits for “Parasitic” Hits for Pedestals – Positive Hits

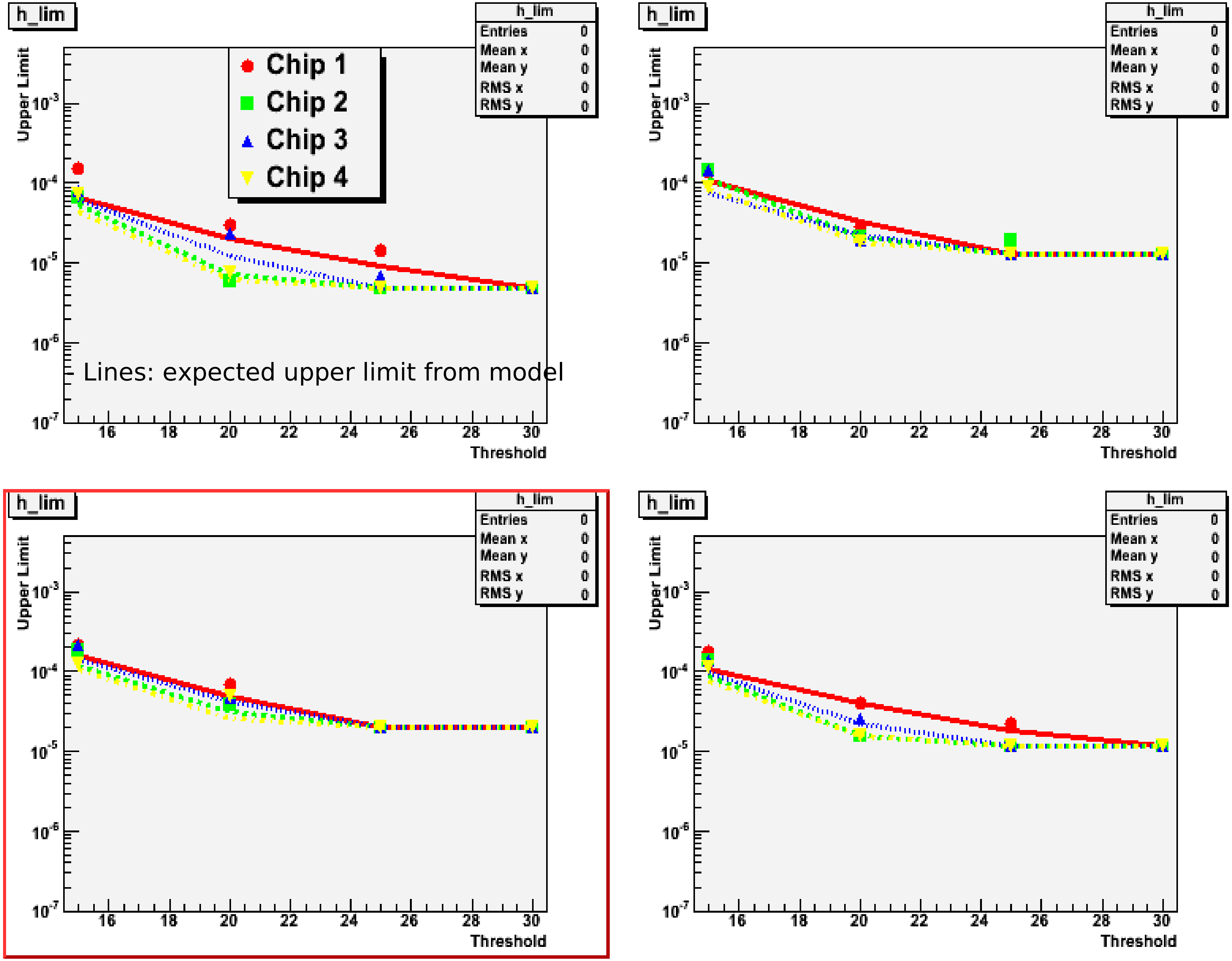


Limits at 95% CL

- Expect points exactly on lines
- Observe points relative close to lines
- Residual “weakness” of model

Reliable model => Extraction of Reliable upper limits possible

Upper Limits for “Parasitic” Hits for Pedestals – Negative Hits



- Lines: expected upper limit from model

Limits at 95% CL

- Expect points exactly on lines

- Observe points relatively close to lines

Works better for negative than for postive hits

- Residual “weakness” of model

Reliable model => Extraction of Reliable upper limits possible

Application of Model to Signal Events

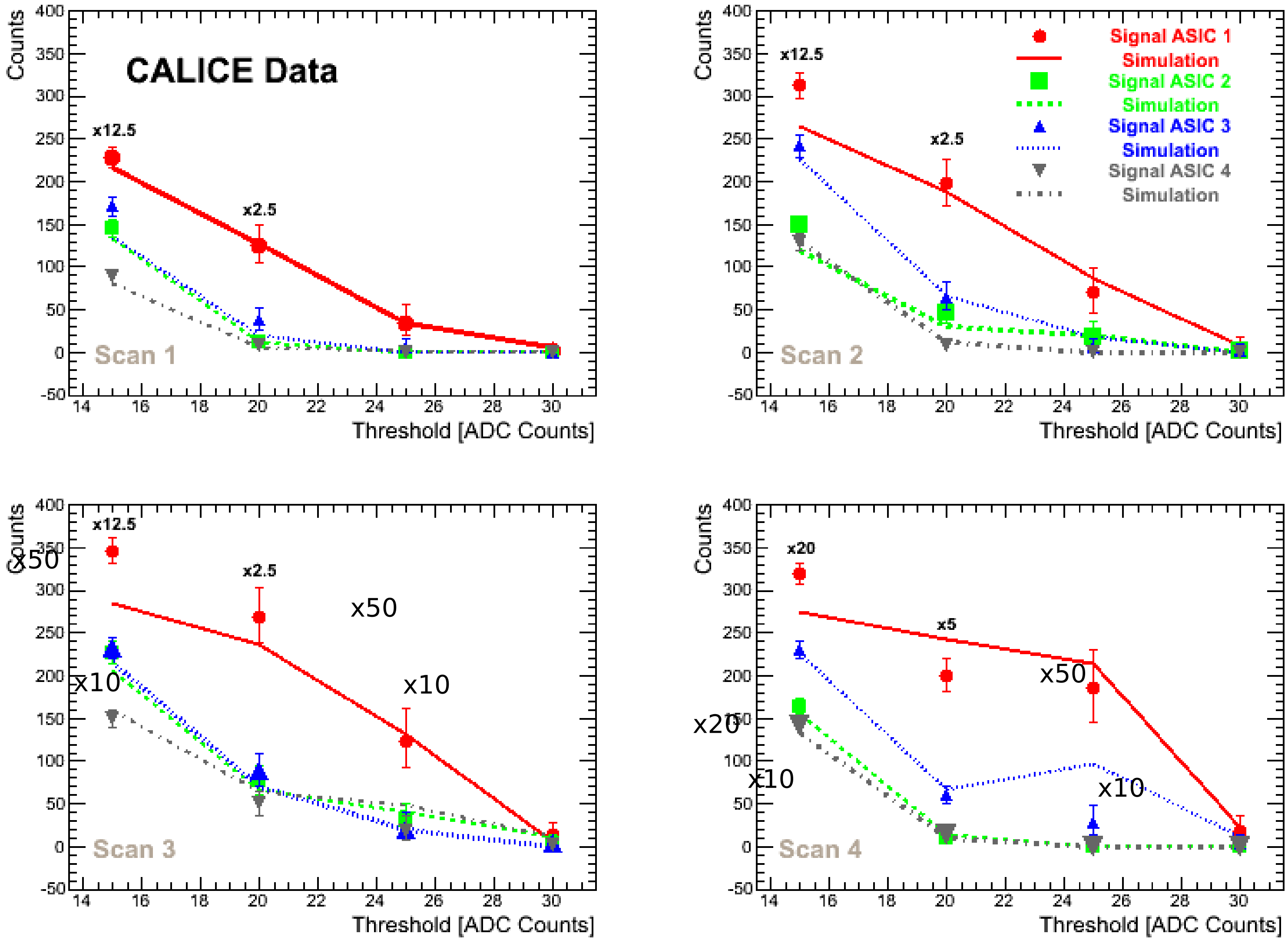
Some remarks:

- The model was only tuned to pedestals and is “blindly” applied to signal spectra

- Number of Signal events > 10xNumber of Pedestal Events
  => Considerable extrapolation

- For signal events there are signals (=> activity) in the rest of the detector which may influence the spectra of the chips under study

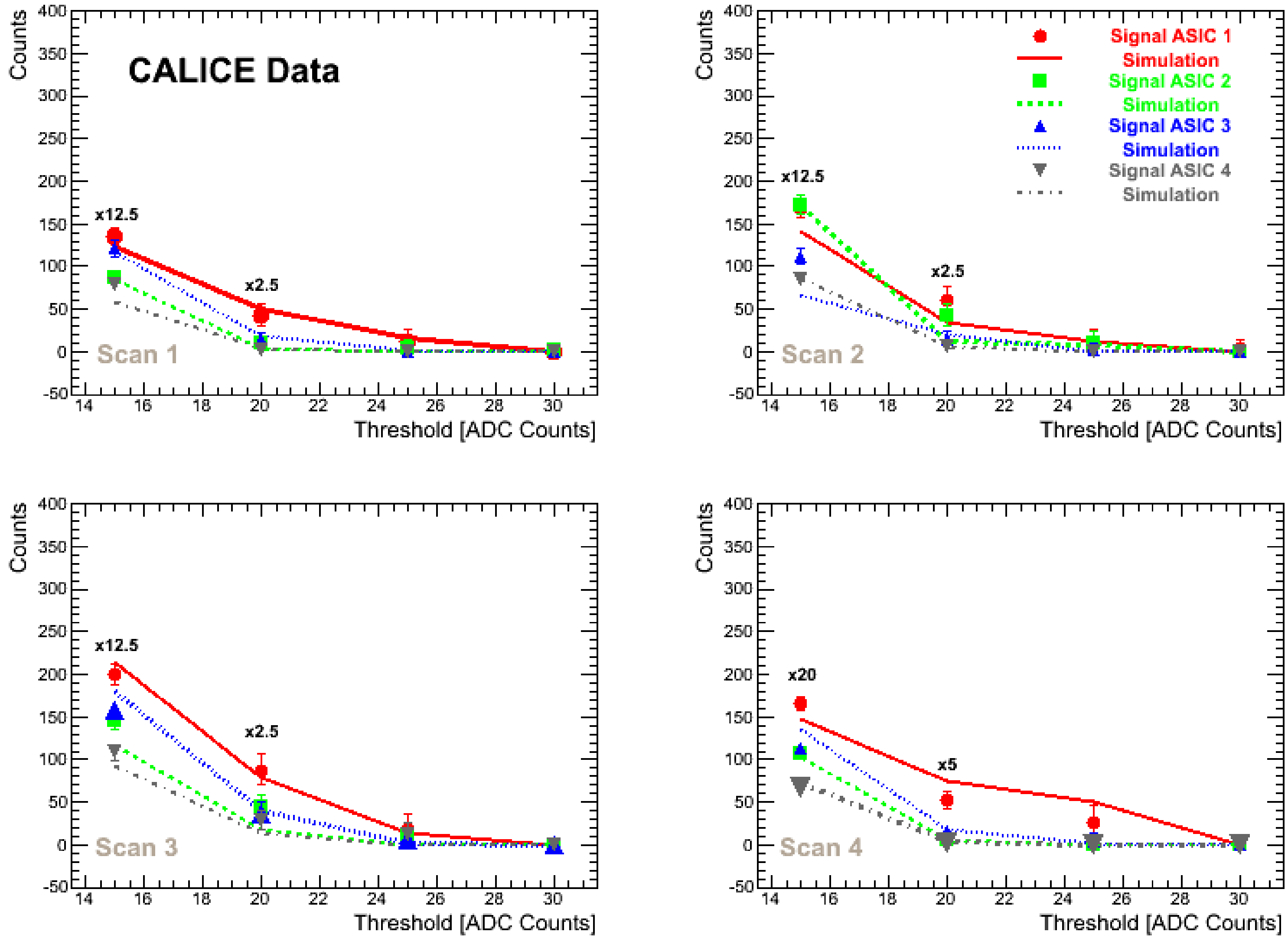
Agreement (Signal) Data – Model in Tail – Positive Hits



- Data – Model agree still often within 97.3% CL ($\triangleq 3\sigma$ for n->∞)
- Remember complexity of noise distribution!!!

Satisfactory reproduction of noise spectra by model
However significant differences visible

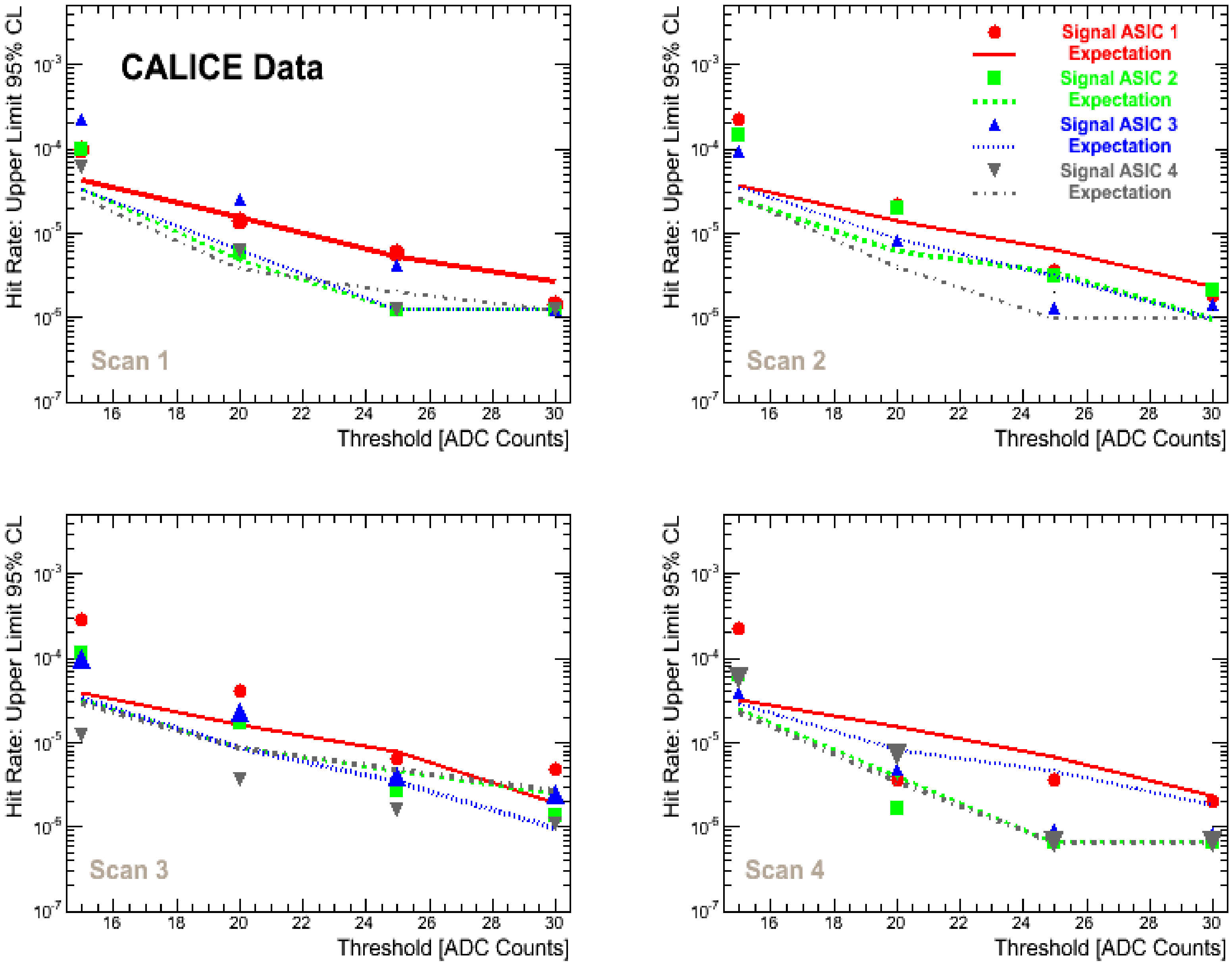
Agreement (Signal) Data – Model in Tail – Negative Hits



- Data – Model agree still mostly within 97.3% CL (≙ 3σ for n->∞)
- Remember complexity of noise distribution!!!
- Better agreement for negative hits

Satisfactory reproduction of noise spectra by model
However significant differences visible

Upper Limits for "Parasitic" Hits for Signal Events – Positive Hits

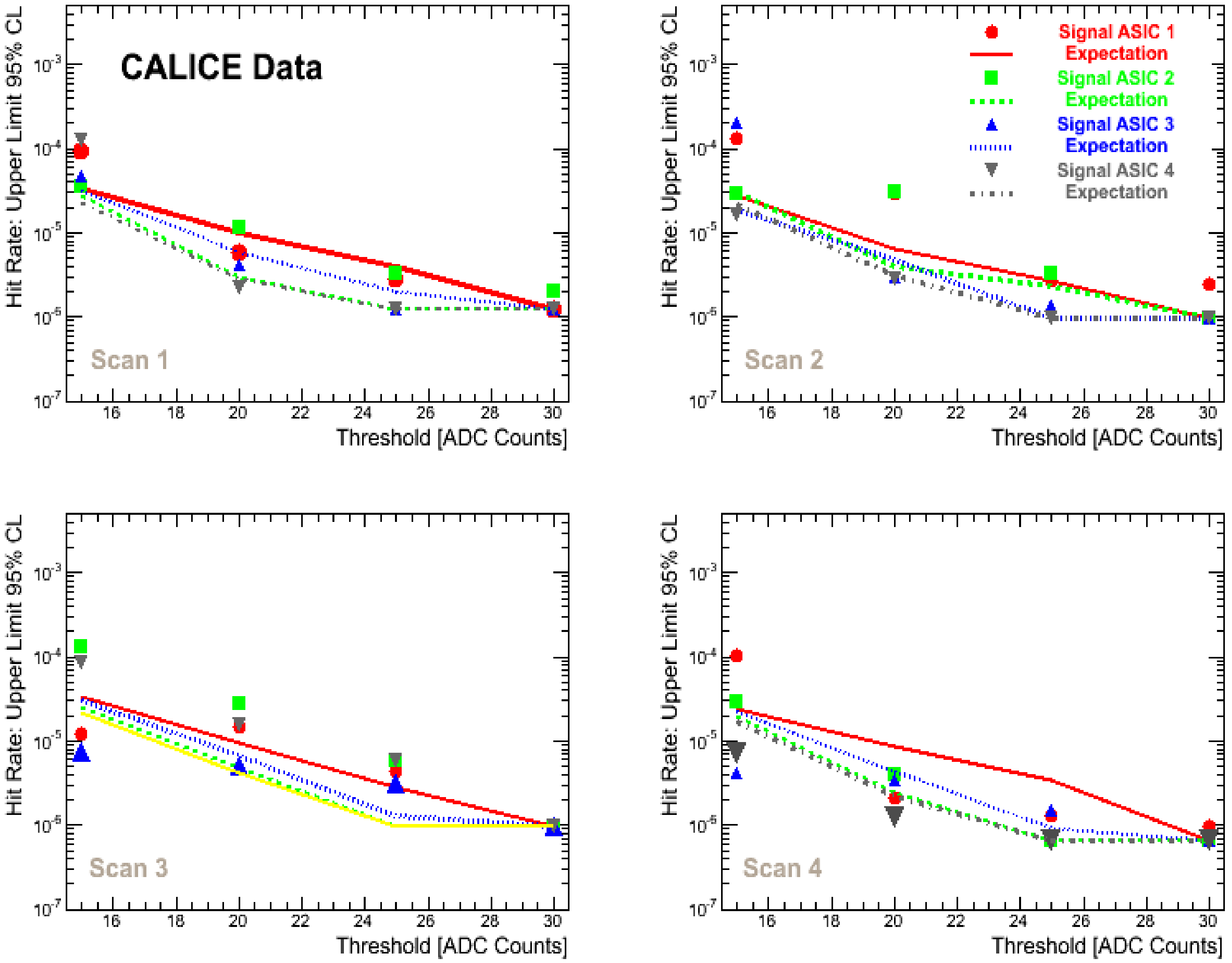


Limits at 95% CL

- Points further away from lines
- Amplification of residual disagreement observed for pedestal events

Expected and derived limit agree always within factor of 10 (often better)

Upper Limits for “Parasitic” Hits for Signal Events – Negative Hits



Limits at 95% CL

- Points further away from lines

- Amplification of residual disagreement observed for pedestal events

Expected and derived limit agree always within factor of 10 (often better)

Comments on Upper Limits and final Results

- Model often successful in predicting upper limits also for signal events!!!

- No visible influence of beam in noise spectra

  Exposed chips vary comparable to non-exposed chips

  => Effect of beam is smaller than other effects on the noise spectrum

- The partially large differences in the upper limits are an amplification of the residual discrepancies observed already for the pedestal events

- Weaknesses of the model
  - Relative small number of pedestal events

    => Difficult to construct model and to extrapolate it to signal statistics
  - Cross talk between chips (not taken into account)
  - Interspersed noise from signals in other parts of detector

- Upper limit ~5×10^{-6} for typical noise cut of 25 ADC Counts (0.6 of a MIP)

  At e.g. ILC: Typically ~2500 cells in a tt event above noise

  10 k for 0.5×0.5 cm^2 cells

Summary and Conclusion

- Detailed monitoring of mean of noise distributions
  and
  noise analysis based on PCA gives confidence that pedestals can well be used to model the chip responses

- PCA allows for dedicated investigation of noise structure of detector

- PCA gives no evidence that beam in VFE distorts signals

- No visible influence of beam on exposed chips
  effects of beam smaller than other parasitic effects

- As fruitful side goodie of analysis:

  - Algorithms at hand for "professional" noise analysis of at least all analogue calorimeters of CALICE!!!!
  - Can be transformed into general "Noise analysis suite" (after cleaning and structuring of my code)
  - Be very careful with simple analysis to obtain coherent noise (Not reliable)

Improvements of the measurement

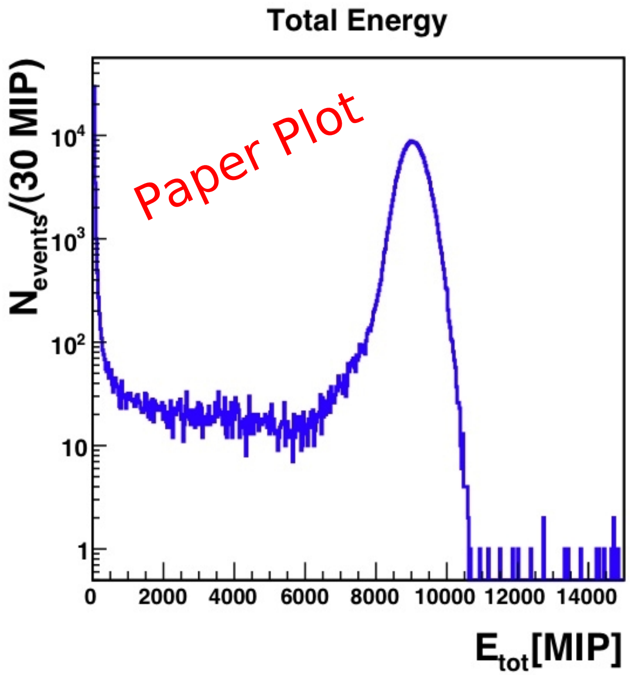
- Need better controlled setup

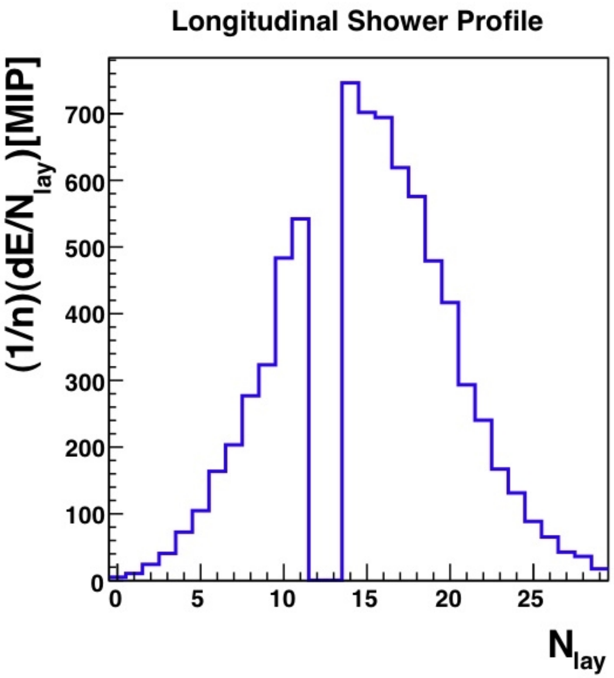
  Layer integrated into full detector maybe not beneficial for measurement
  - Layer would need to be super-isolated from rest of detector
  - Maybe single board in low energy (~10 MeV) not too intensive electron beam would lead to better results

- Number of pure pedestal events are to be at least equal to number pedestal events to construct a reliable model

Backup Slides

Basic Spectra and Alignment

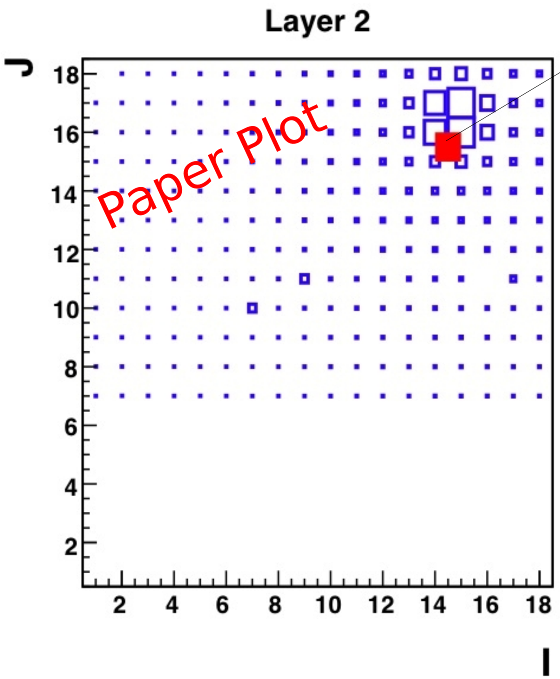


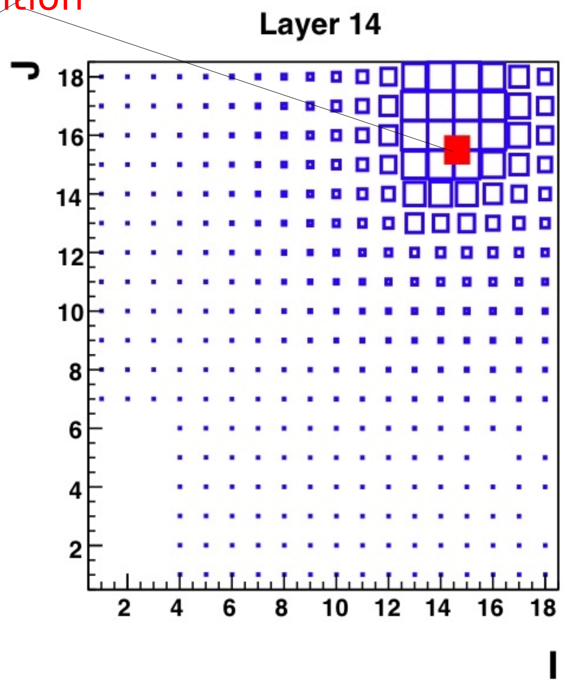


90 GeV run (331495)

- Clear Energy Peak
- Special Board place at ~ shower maximum

Projected Chip Position





Hit Maps

- Layer 2
  Same xy-Position as Special Board
- Layer 14
  First instrumented Layer after Special board

Chip(s) well within lateral shower extension

Disabling of zero suppression in reco output

- Three Scenarios:

1) No pedestal correction
2) Full pedestal Corrections
3) Pedestal Corrections restricted to signals from Chips

Remember that there are still 216 entries for the layer in the data files

- General Methodology:

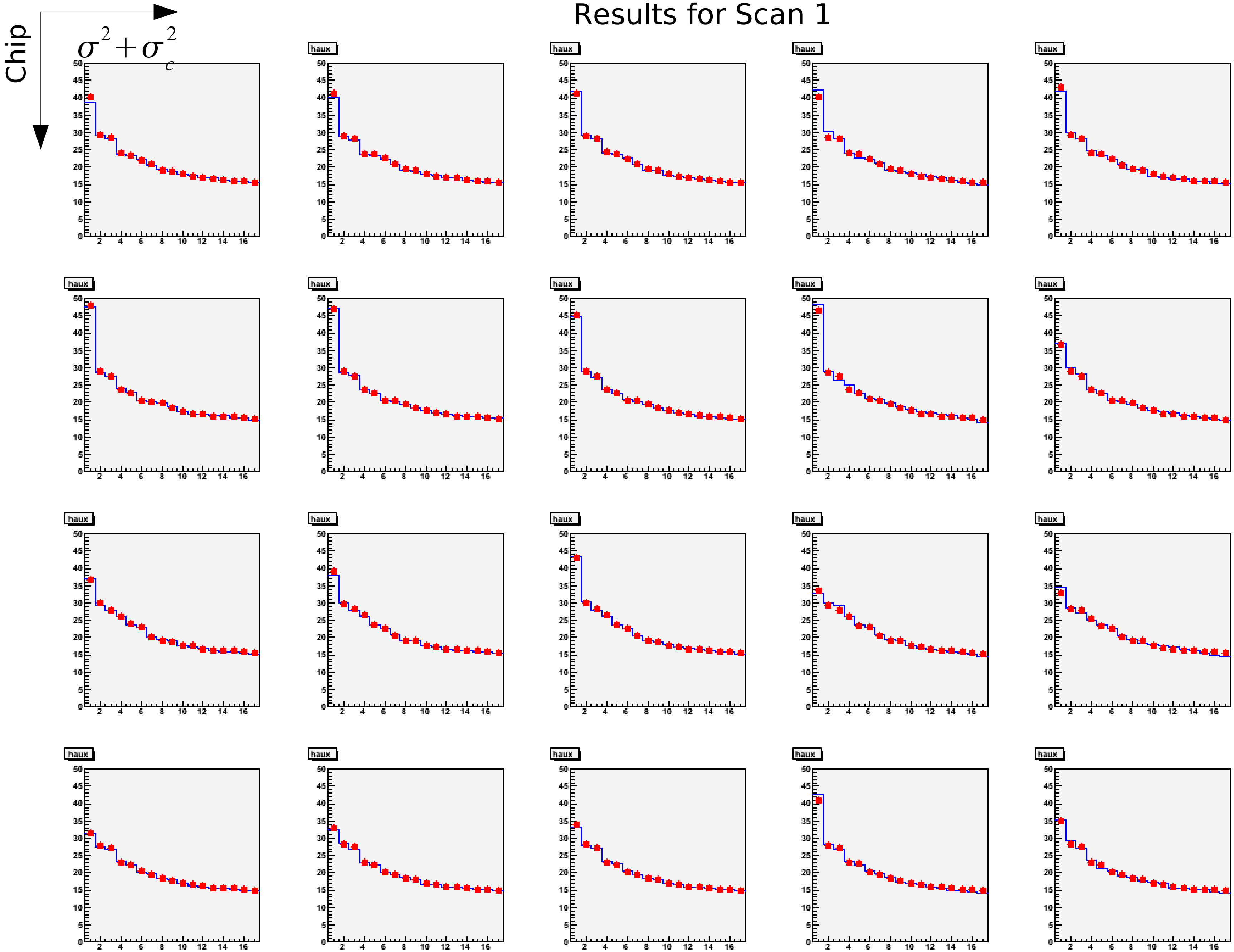
Subdivision of Runs into BeamTrigger and
Pedestal Trigger Events (Oscillator Trigger) interleaved with beam events
Corrections are applied (or not) to pedestal as well as to signal events

Note: The reconstruction s/w had to be tweaked a bit for that

Eigenvalues of Covariance matrix

Results for Scan 1

Scan Point



Channel Nr.

Blue:Pedestals
Red: Signal

- Mostly clear prominent eigenvalues

=> Coherent noise

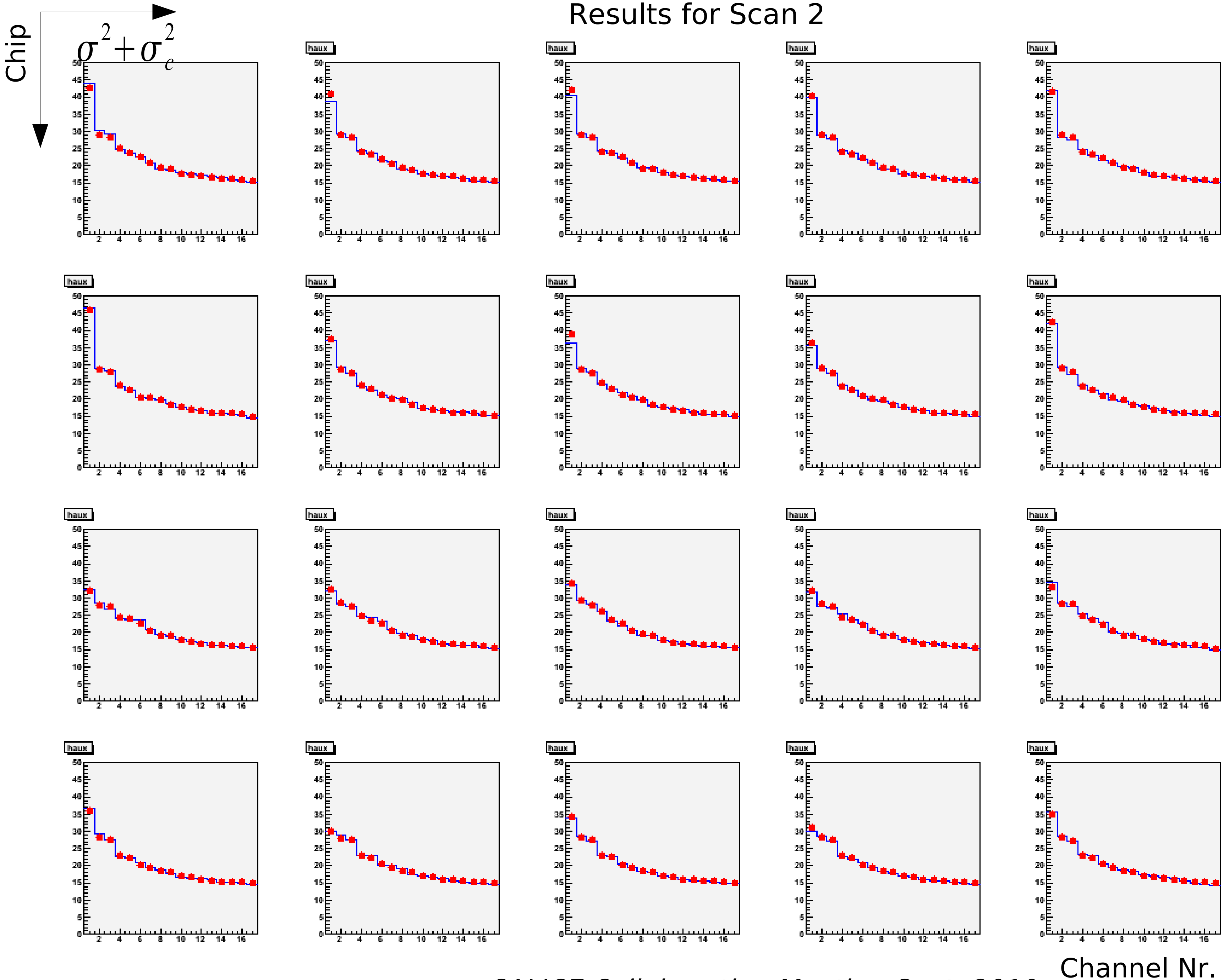
- Where less prominent: Still visible step

- Fairly flat spectrum of other eigenvalues

- Excellent agreement between Signal and Pedestal

Eigenvalues of Covariance matrix

Results for Scan 2



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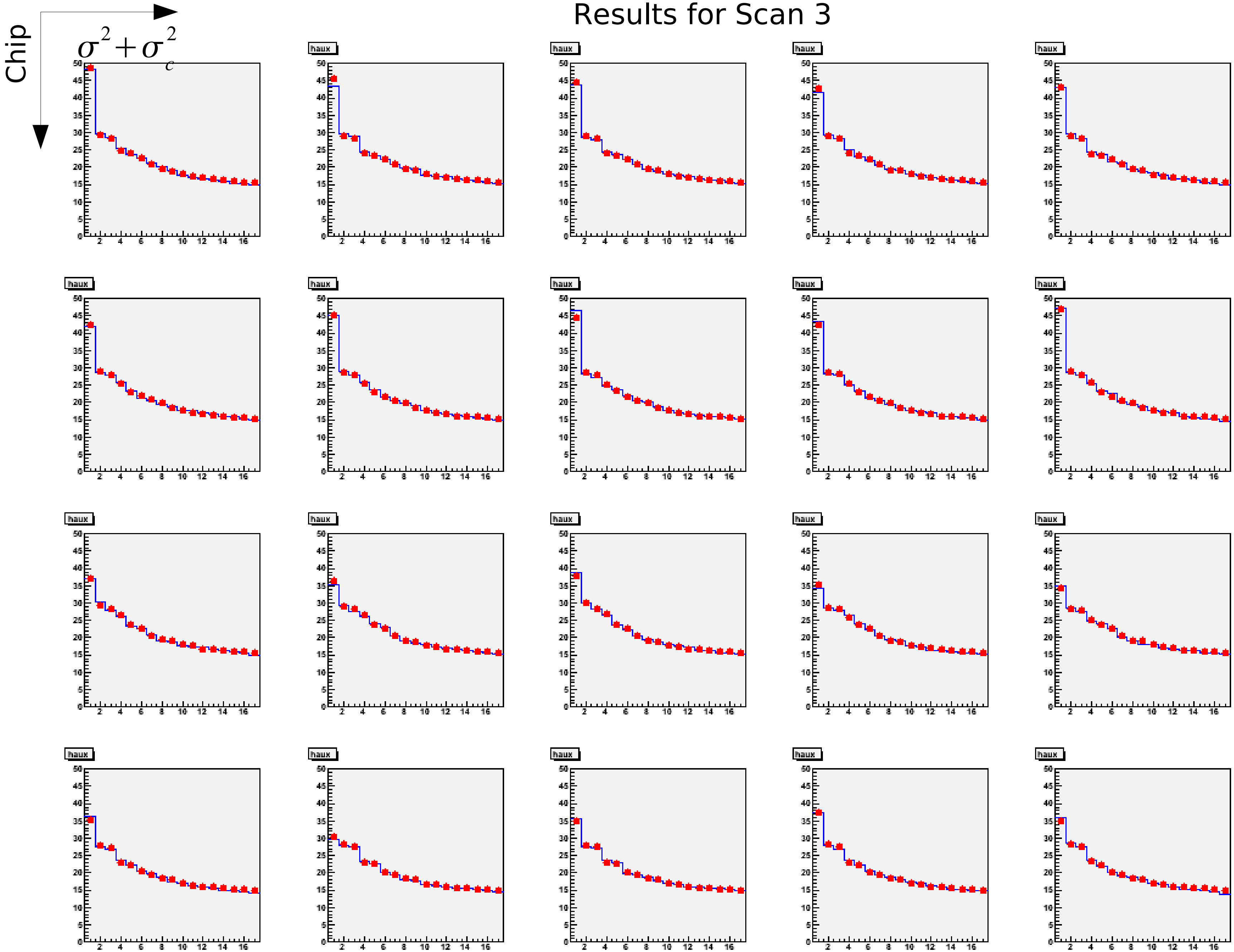
Eigenvalues of Covariance matrix

Results for Scan 3



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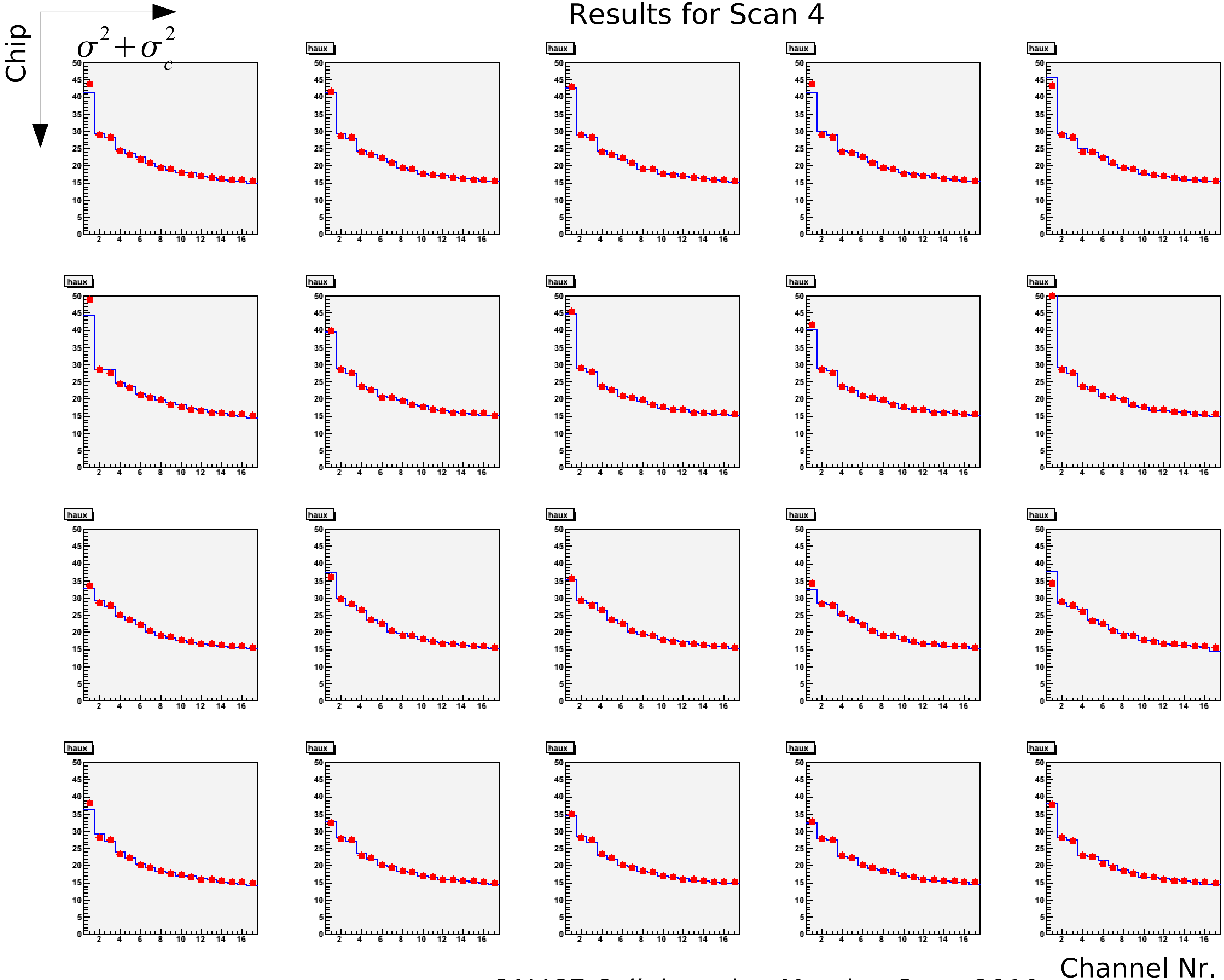
Eigenvalues of Covariance matrix

Results for Scan 4



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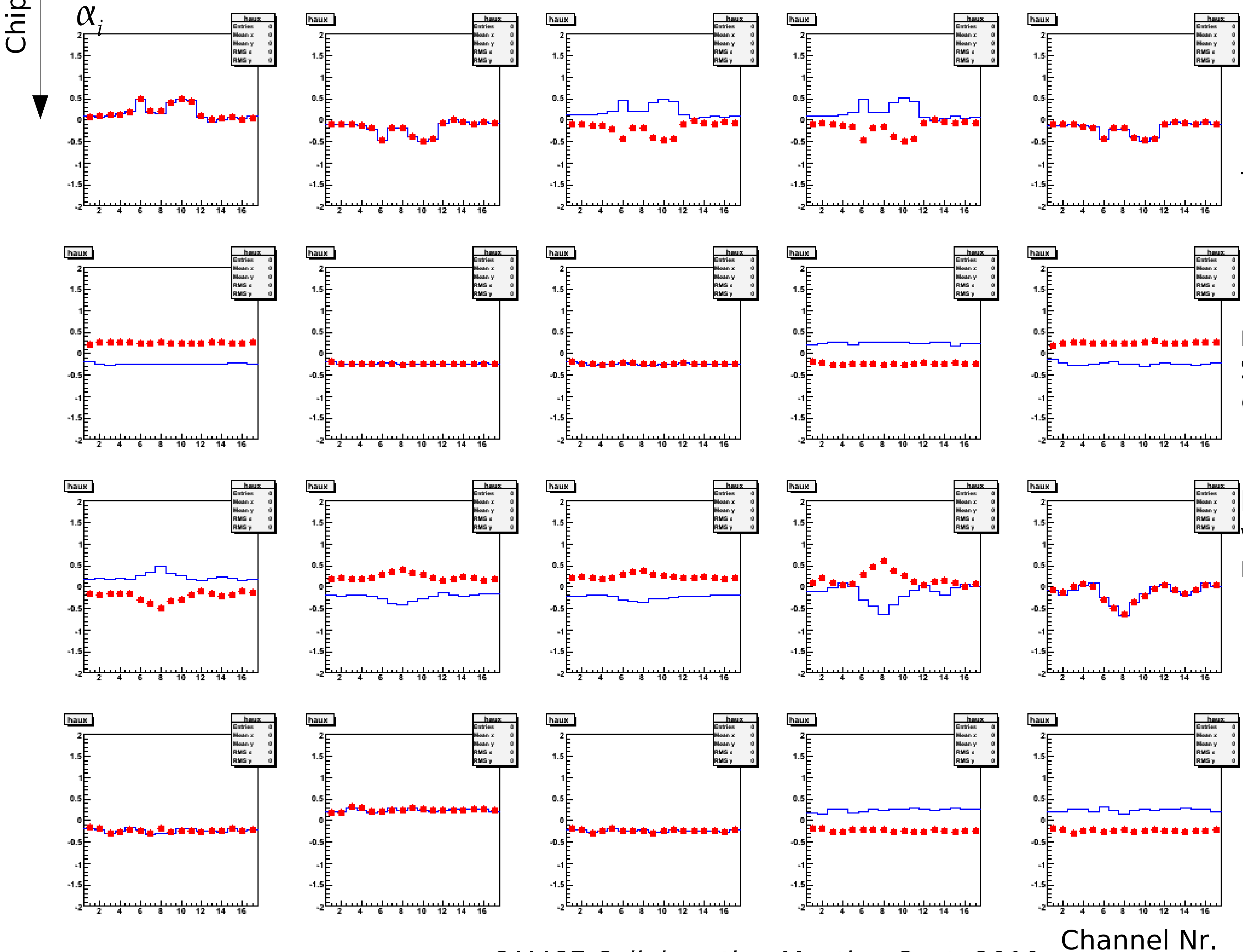
New - Elements of Eigenvector

Results for Scan 1



Blue:Pedestals

Red: Signal

- Excellent agreement between Signal and Pedestal

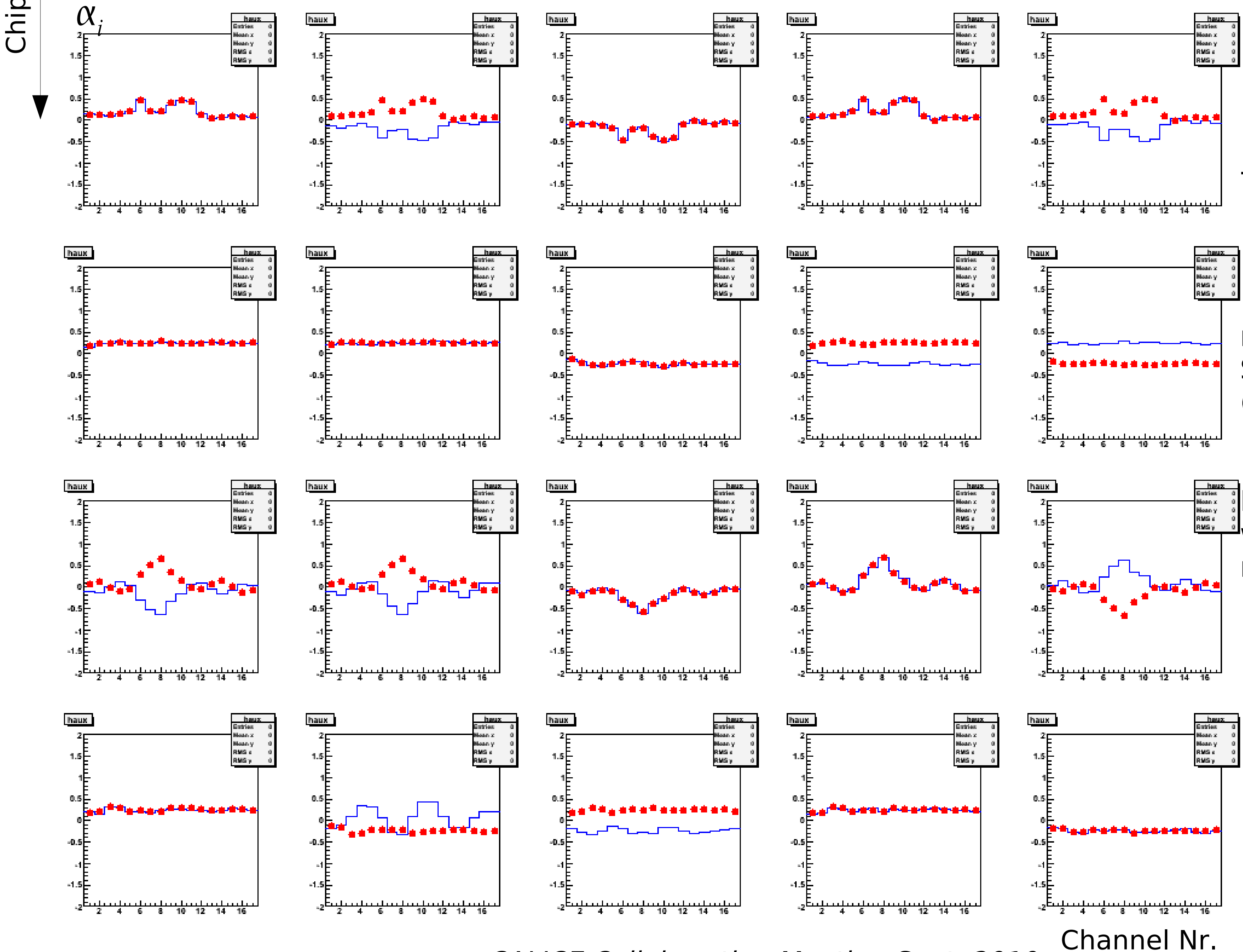
modulo Sign ambiguity (known feature of PCA)

Reveal channels with coherent noise

New - Elements of Eigenvector

Results for Scan 2

Scan Point



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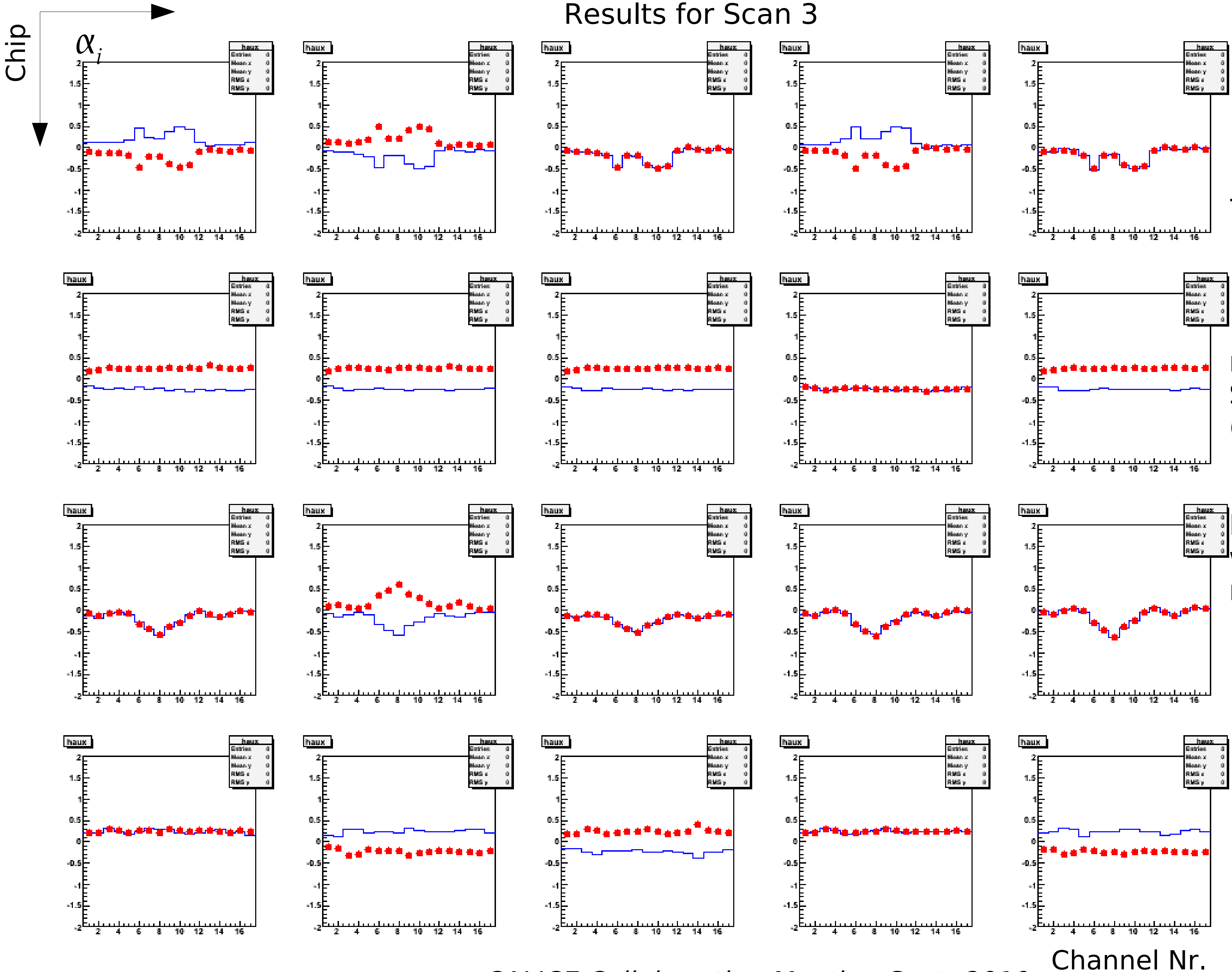
Reveal channels with coherent noise

New - Elements of Eigenvector

Results for Scan 3



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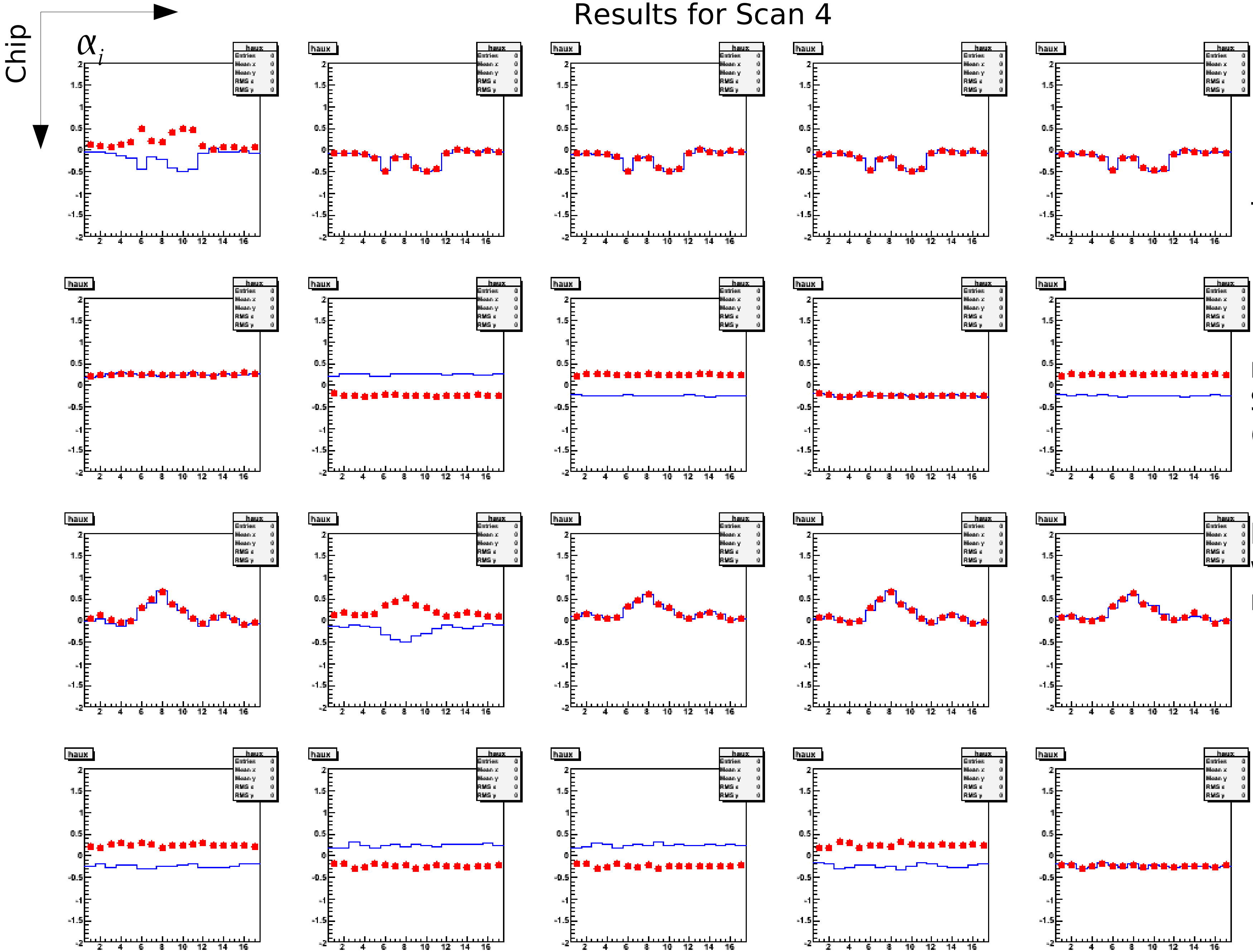
Reveal channels with coherent noise

New - Elements of Eigenvector

Results for Scan 4

Scan Point



Blue:Pedestals
Red: Signal

- Excellent agreement between Signal and Pedestal

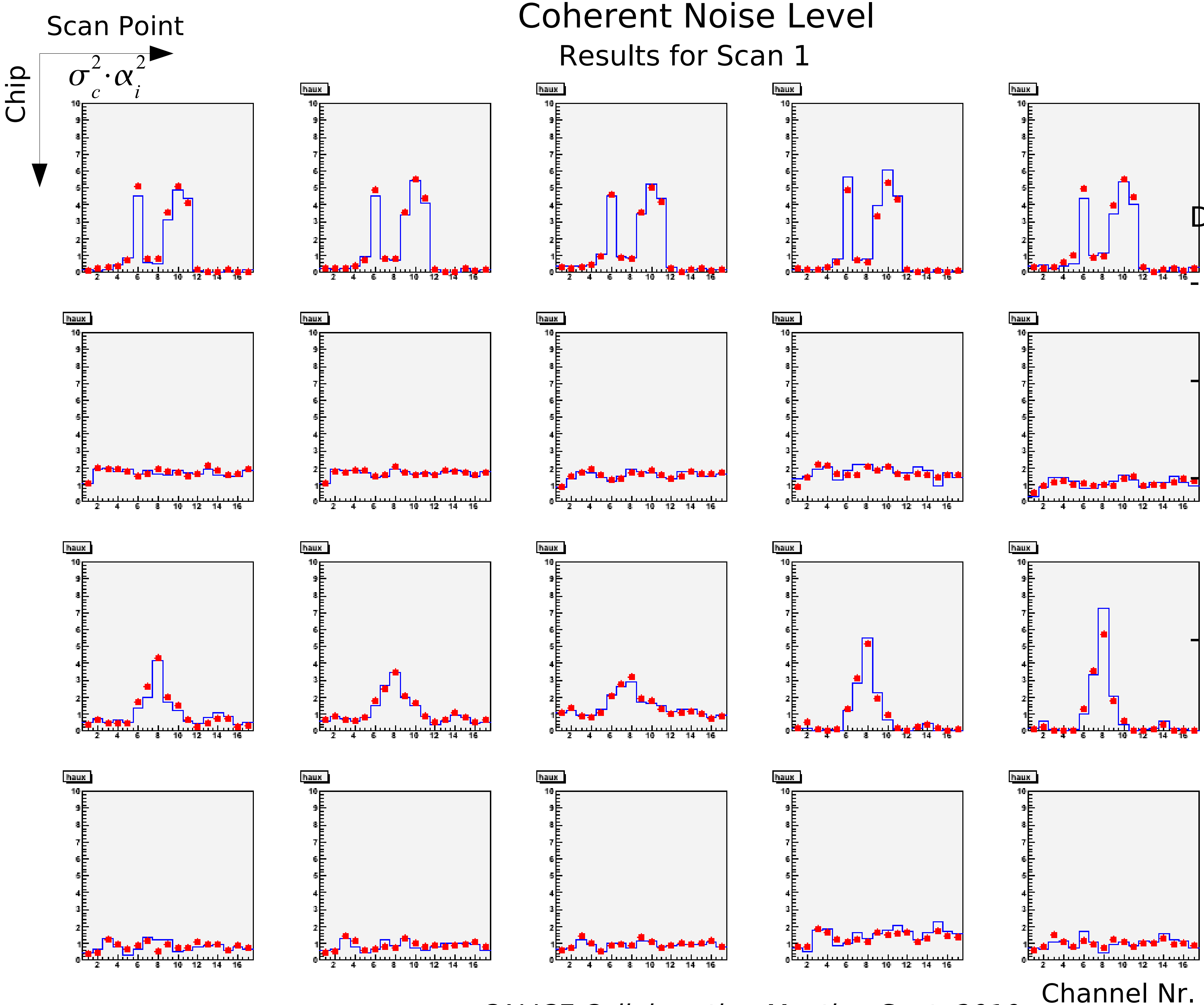
modulo Sign ambiguity (known feature of PCA)

Reveal channels with coherent noise

Channel Nr.

Coherent Noise Level

Results for Scan 1



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Different Patterns

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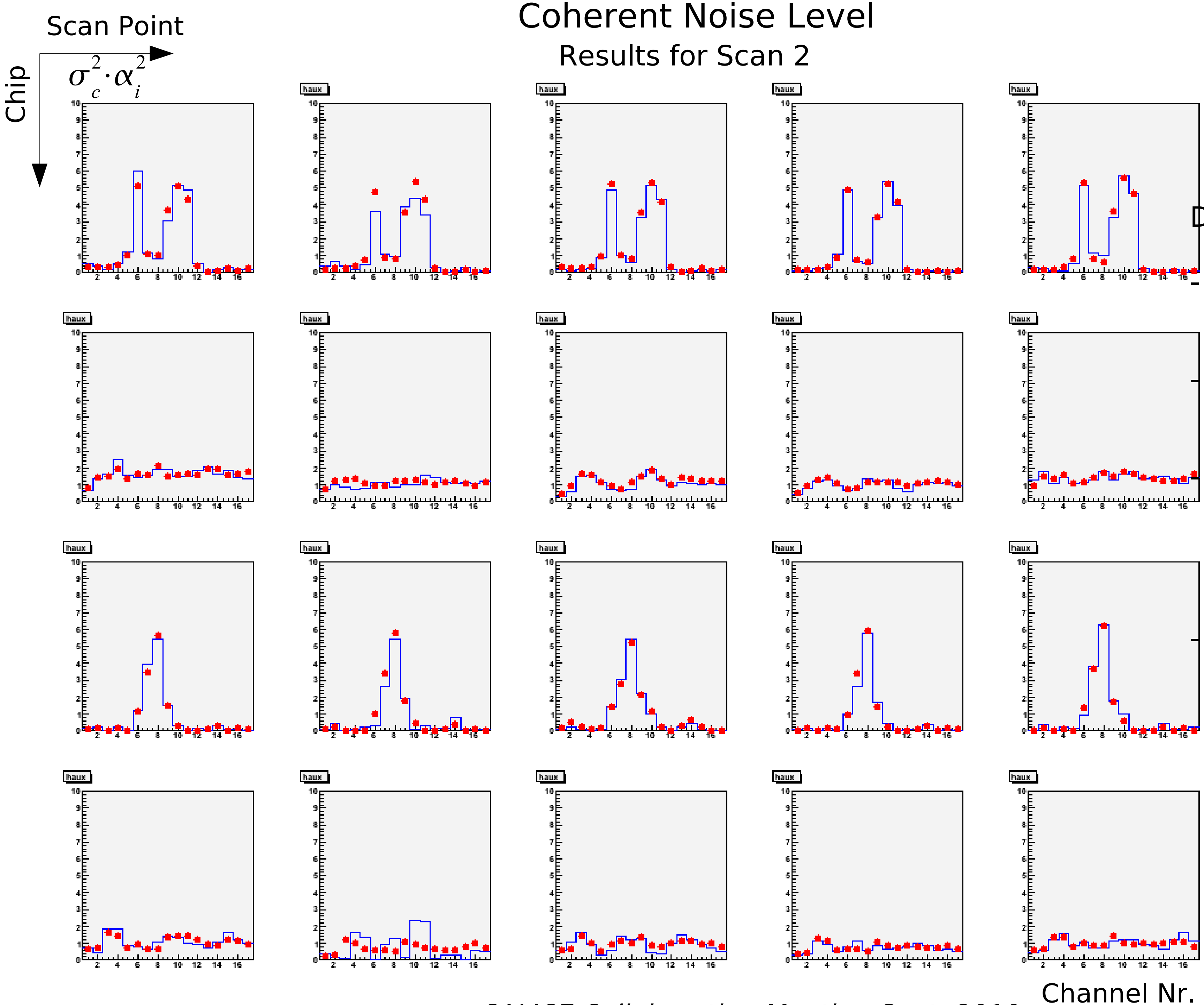
- Coherent Noise level ~1 ADC Count in agreement with simple analysis

Coherent Noise Level

Results for Scan 2



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Different Patterns

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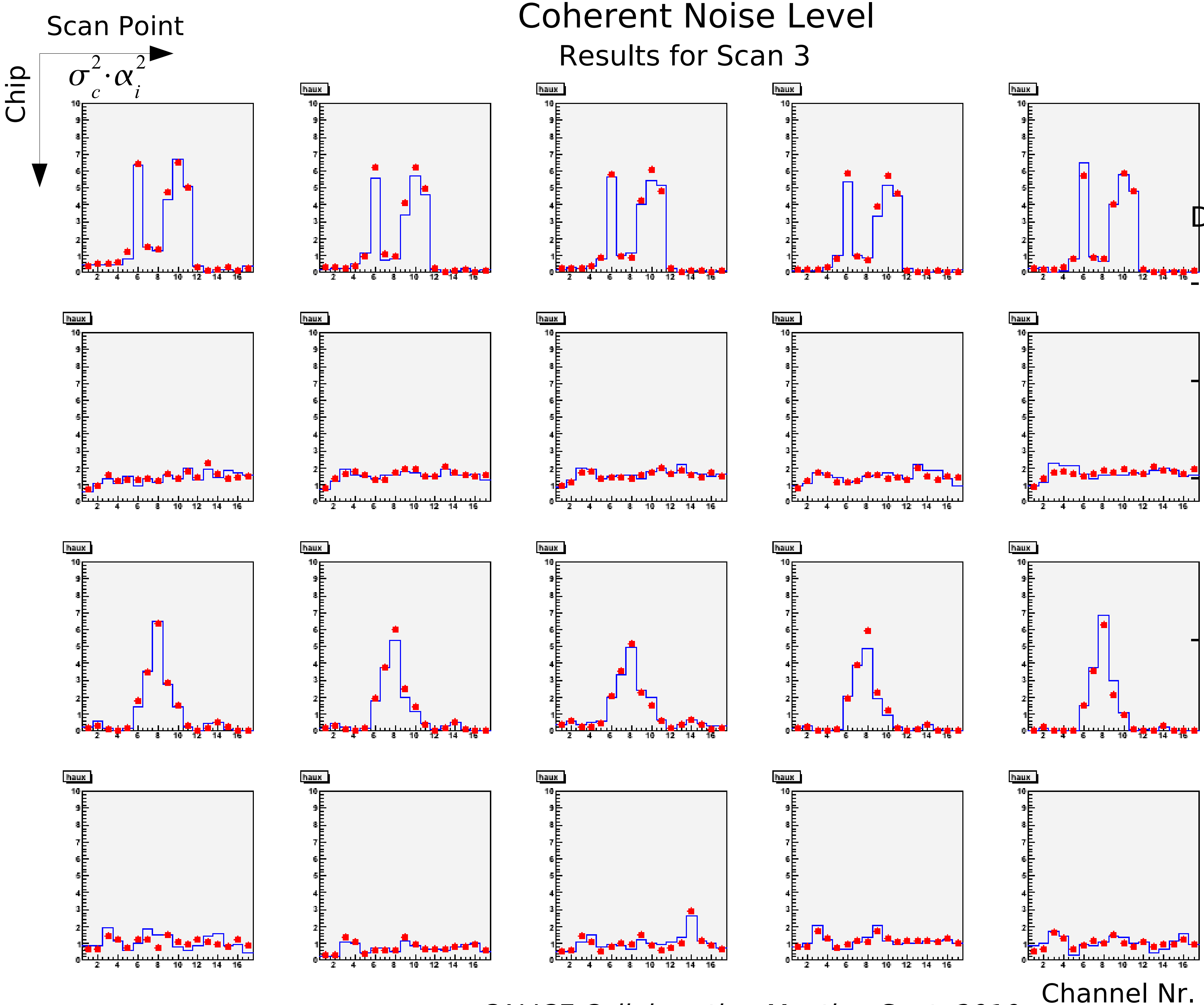
Coherent Noise Level

Results for Scan 3

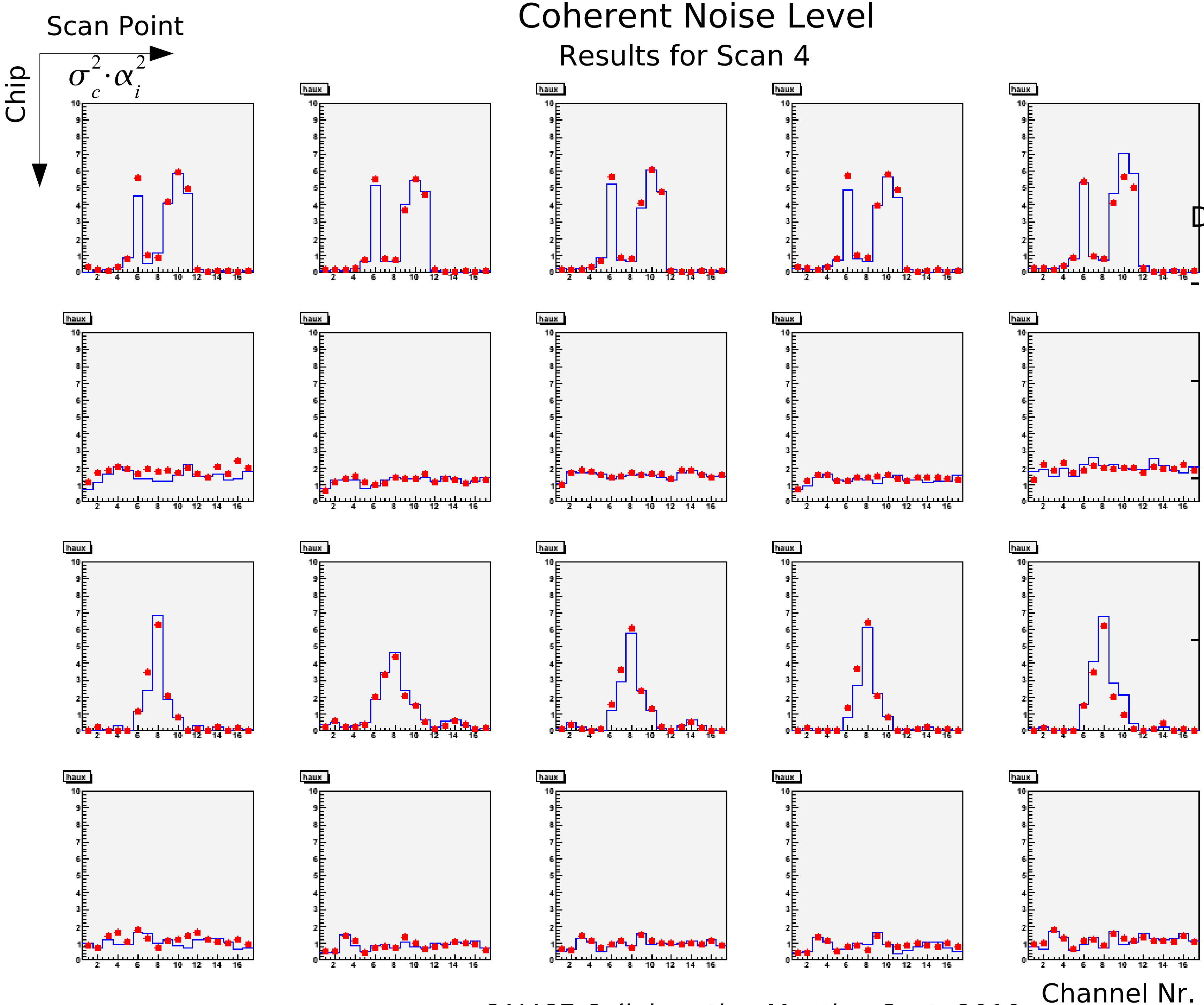


Different Patterns

- Concentrated for Chip 1 and Chip 3
- Flat spectrum for Chip 2 and 4
- Excellent agreement between Signal and Pedestal
- Coherent Noise level ~1 ADC Count in agreement with simple analysis

Coherent Noise Level

Results for Scan 4



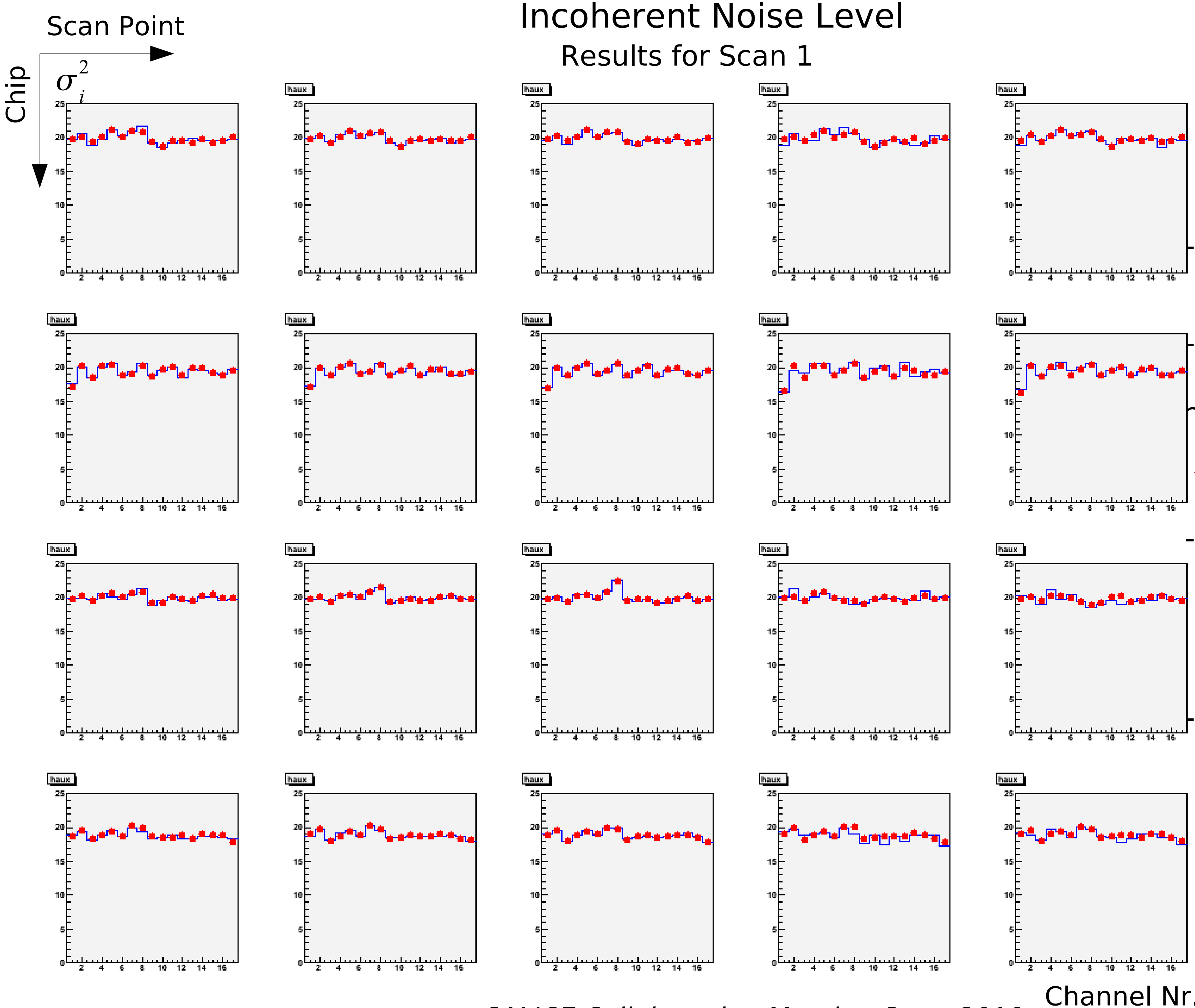
Blue:Pedestals
Red: Signal

Different Patterns

- Concentrated for Chip 1 and Chip 3
- Flat spectrum for Chip 2 and 4
- Excellent agreement between Signal and Pedestal
- Coherent Noise level ~1 ADC Count in agreement with simple analysis

Incoherent Noise Level

Results for Scan 1



Blue:Pedestals
Red: Signal

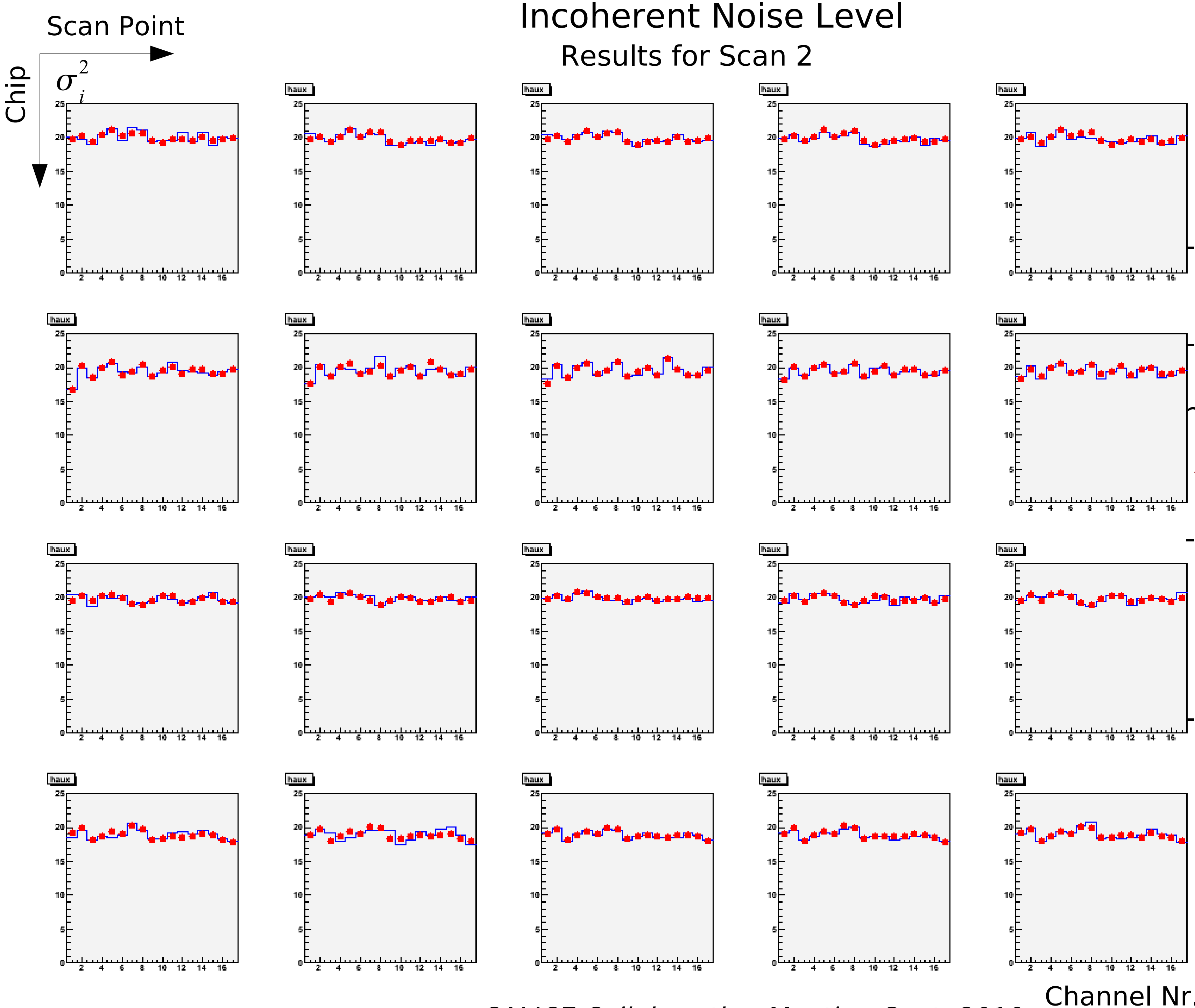
- Flat spectrum for all Chips 2
- Incoherent Noise level ~√20 ~4.5 ADC C.

$$\sqrt{\sigma_{ic}^2+\sigma_{cn}^2} \approx \sqrt{4.5^2+1} \approx 4.6$$

- In agreement with σ_G (see above) and rms (see earlier)
- Excellent agreement between Signal and Pedestal

Incoherent Noise Level

Results for Scan 2



Blue:Pedestals
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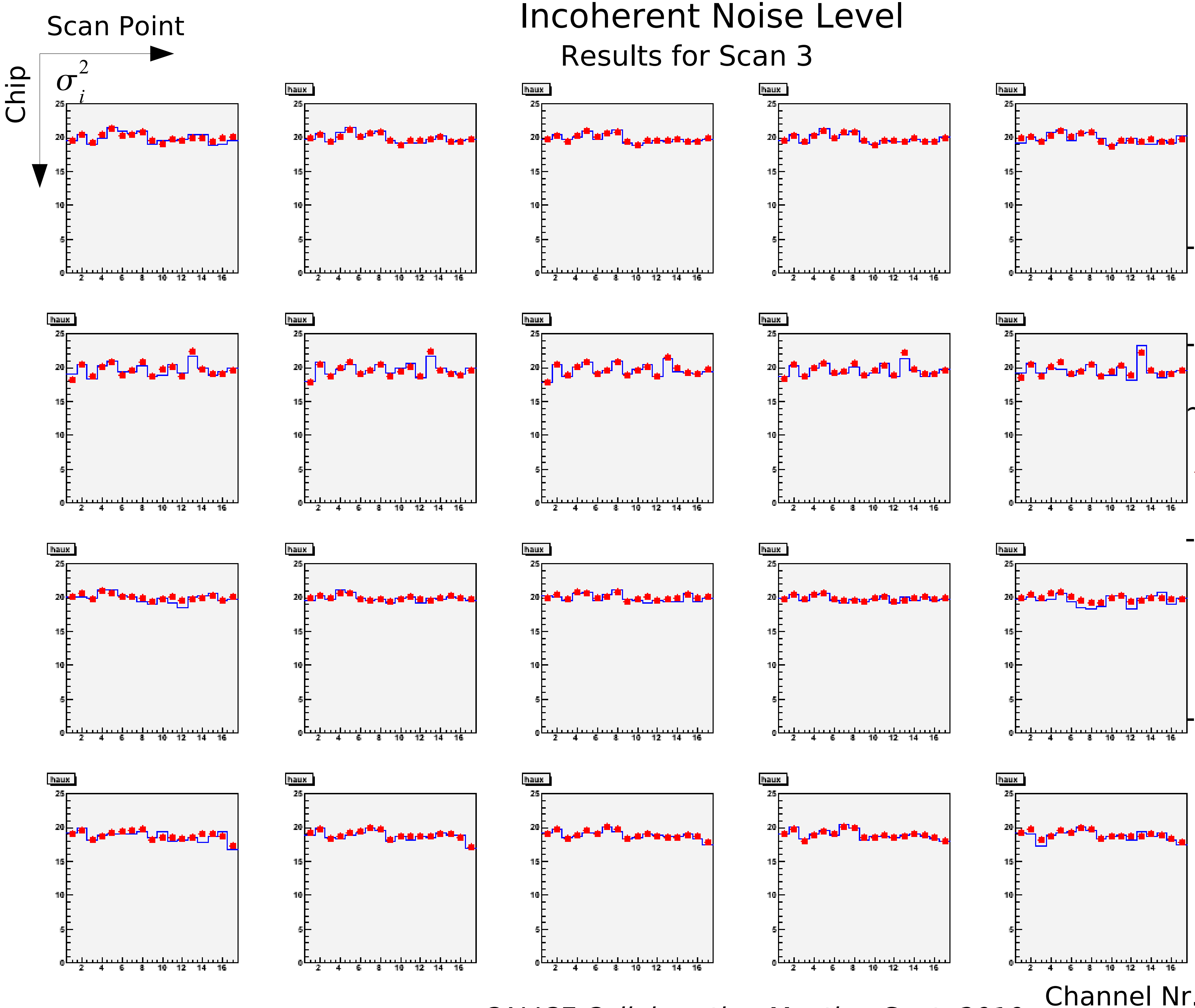
Incoherent Noise Level

Results for Scan 3



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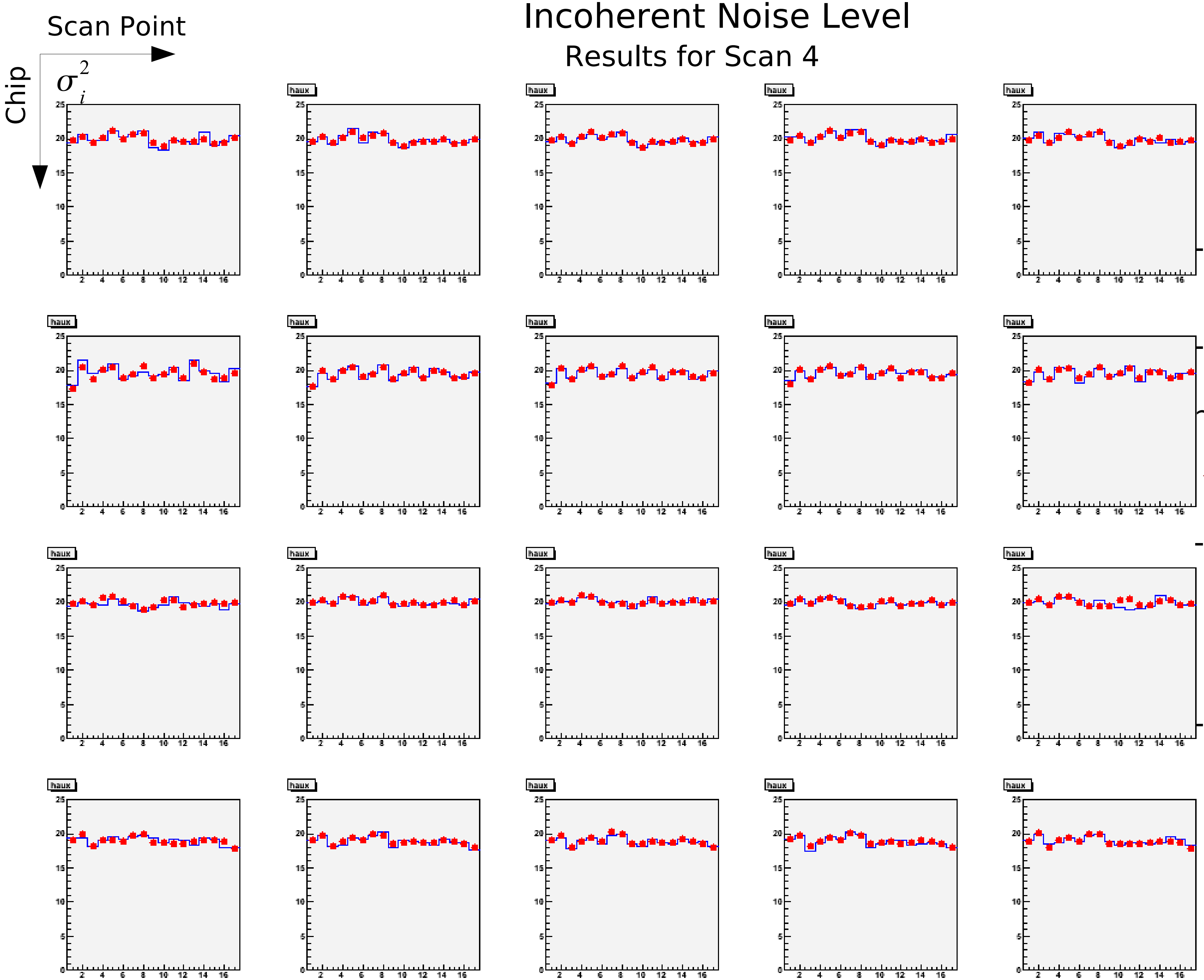
Incoherent Noise Level

Results for Scan 4



Blue:Pedestals
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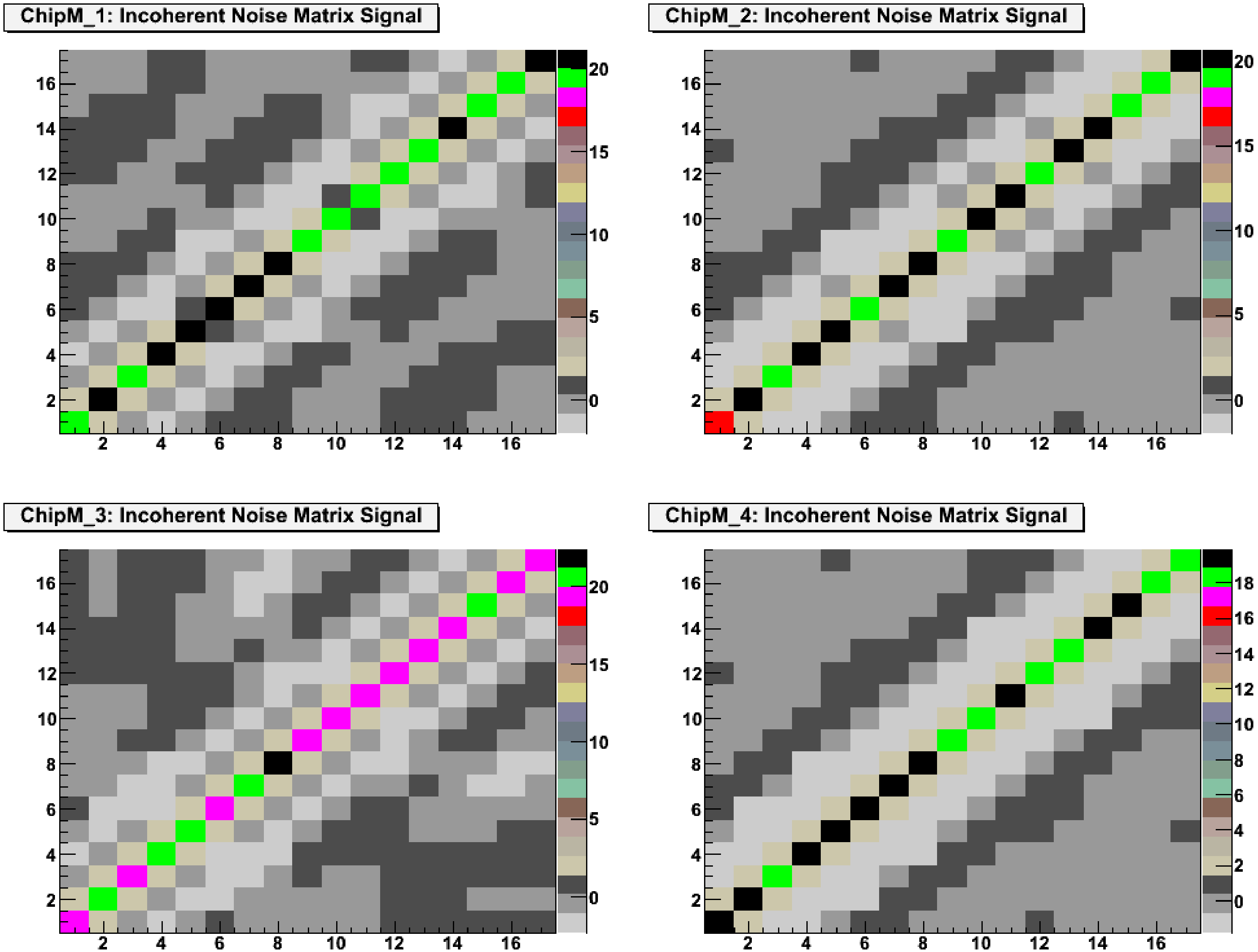
$$\sqrt{\sigma_{ic}^2+\sigma_{cn}^2}\approx\sqrt{4.5^2+1}\approx 4.6$$

- In agreement with σ_G (see above) and rms (see earlier)
- Excellent agreement between Signal and Pedestal

Matrix B'

Example for central impact Scan 1 – Signal Events

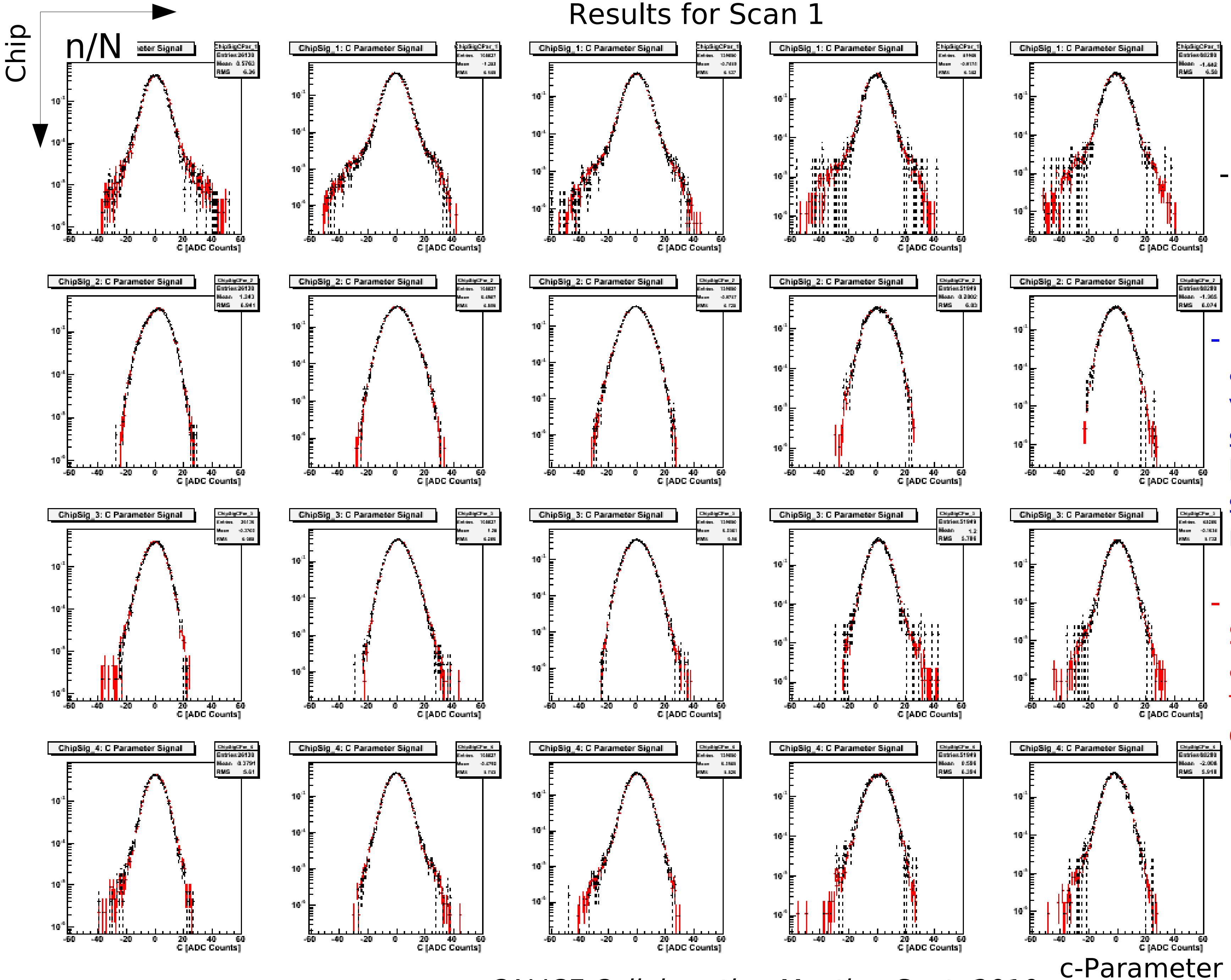


Diagonal: Prominent with value ~20 (ADC Counts)^2
Off-Diagonal: Flat with value ~0

All matrices B' on request ;-)
(39 more plots)

Spectrum of c-Parameter

Results for Scan 1



Black:Pedestals
Red: Signal

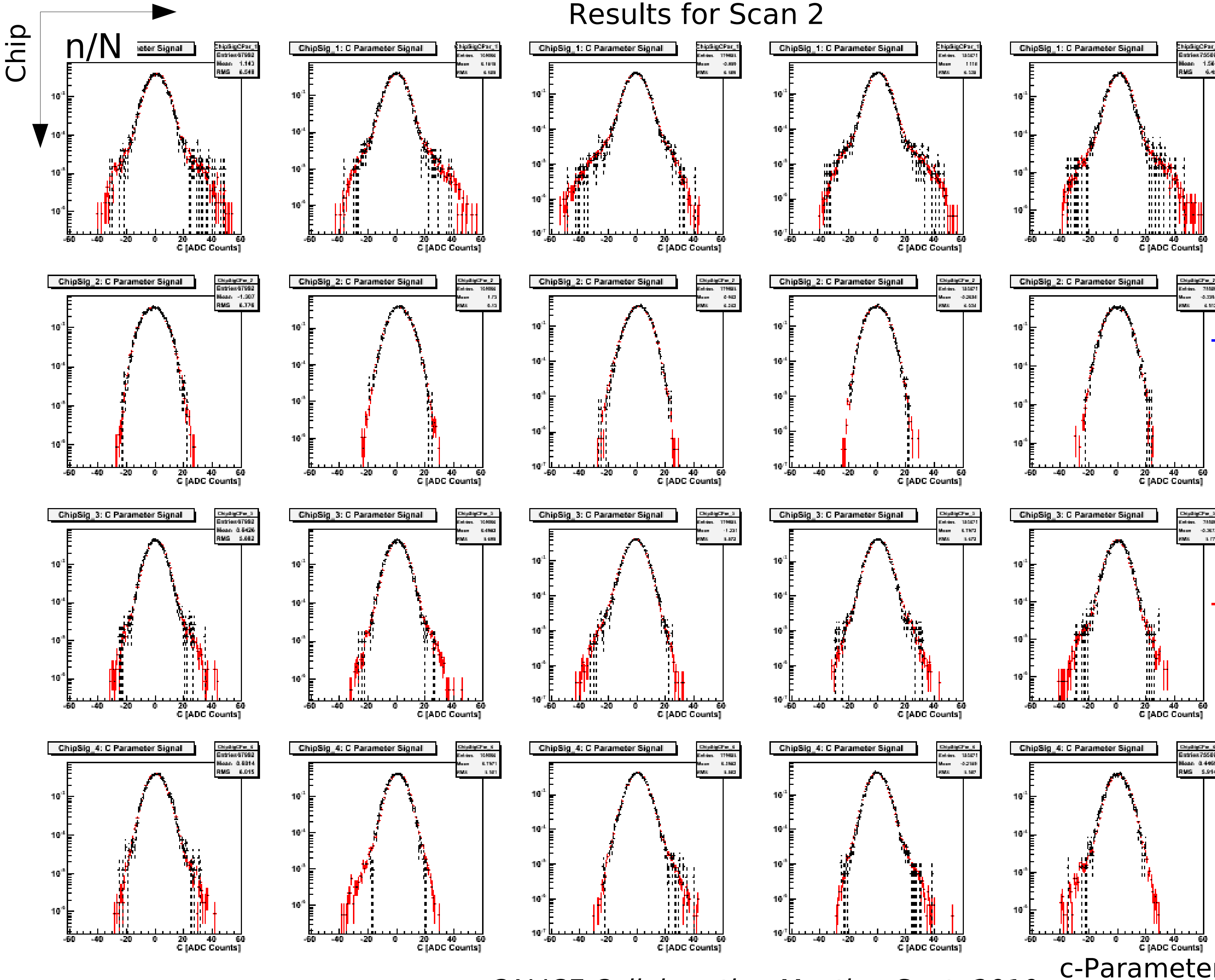
- Excellent agreement between Signal and Pedestal

- In future application the values in these spectra can be used to subtract coherent noise!

- Here: Spectra used as input pdf for simulation of noise

Spectrum of c-Parameter

Results for Scan 2



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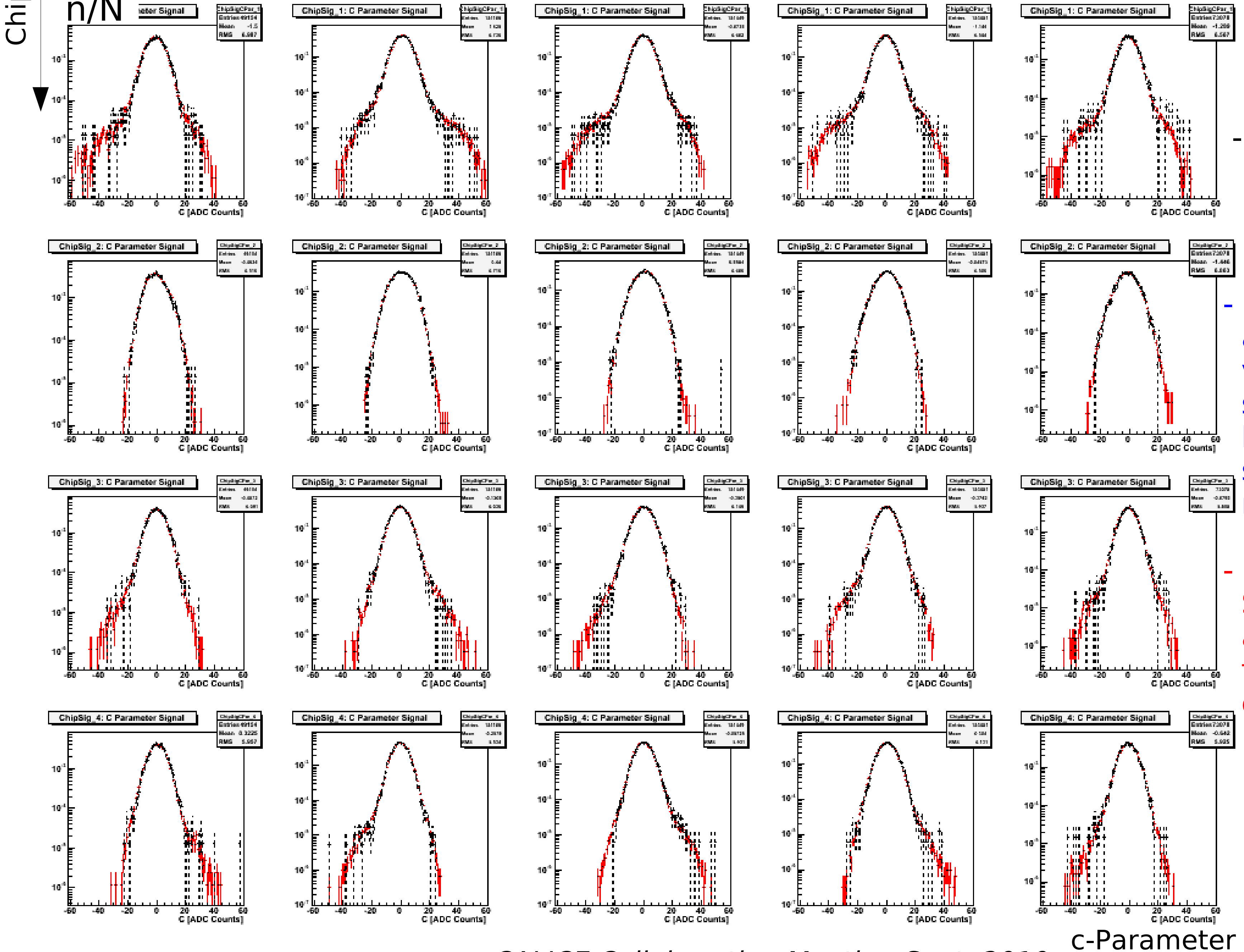
Spectrum of c-Parameter

Results for Scan 3



Black:Pedestals
Red: Signal

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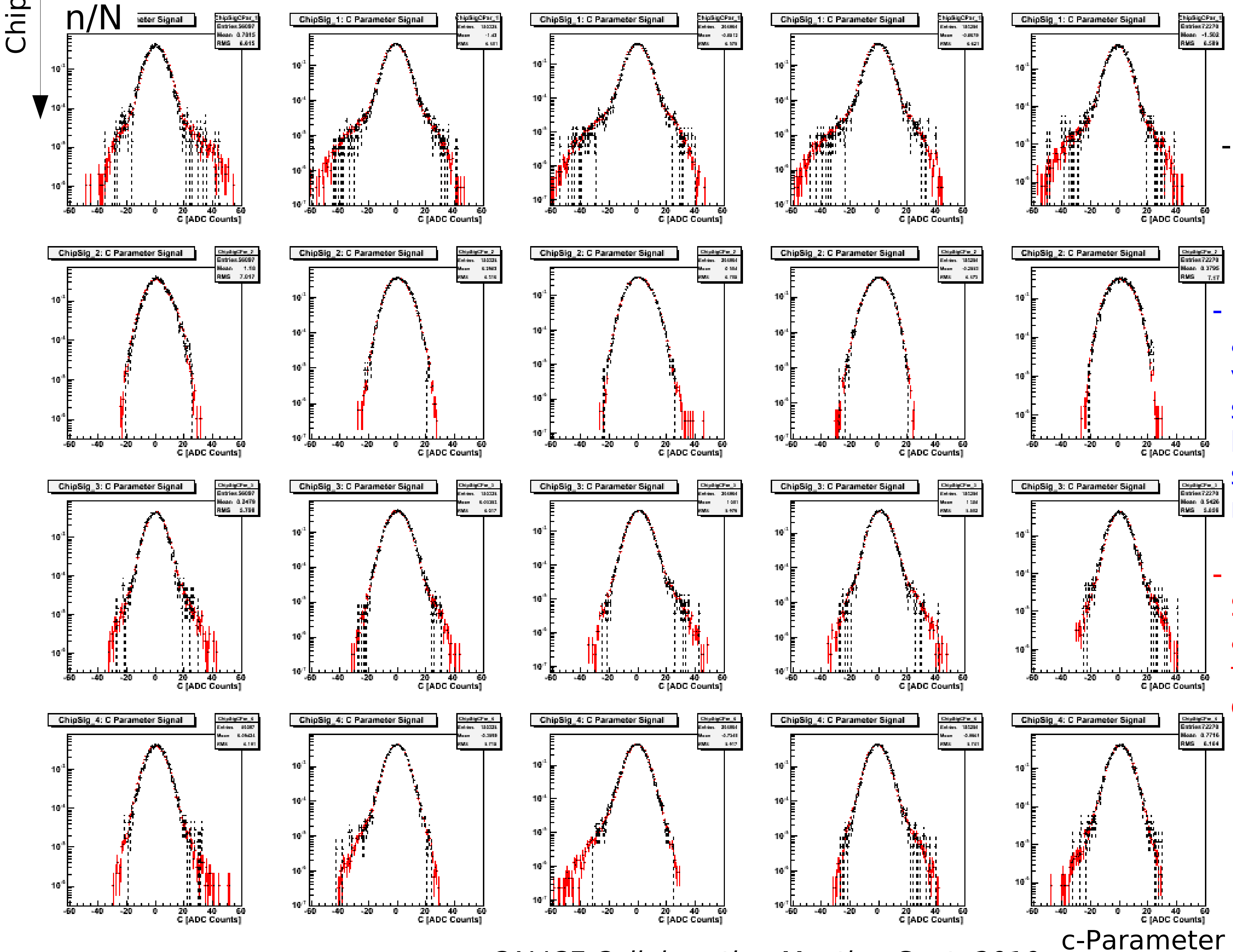
- Here: Spectra used as input pdf for simulation of noise

Spectrum of c-Parameter

Results for Scan 4

Scan Point



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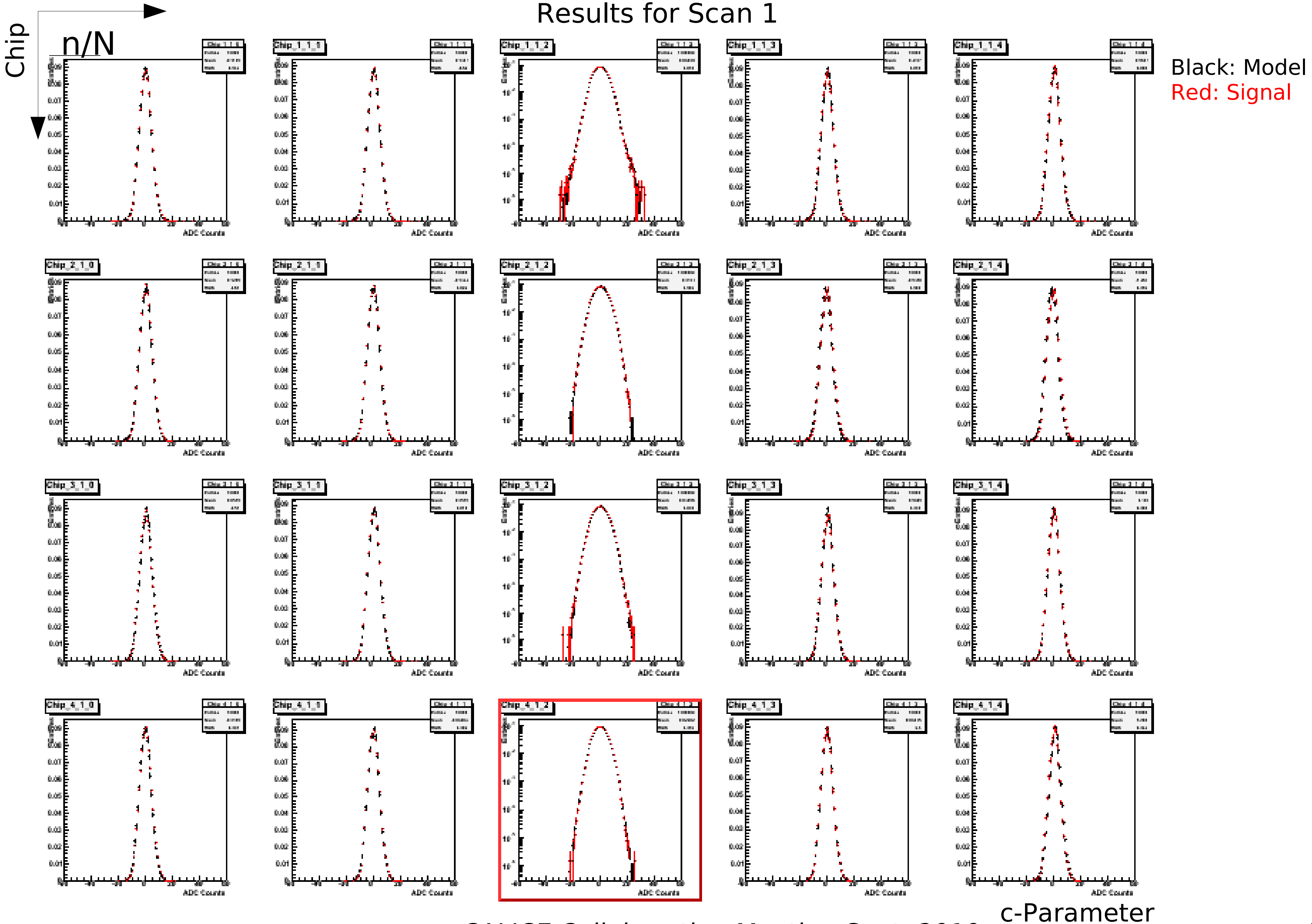
- Here: Spectra used as input pdf for simulation of noise

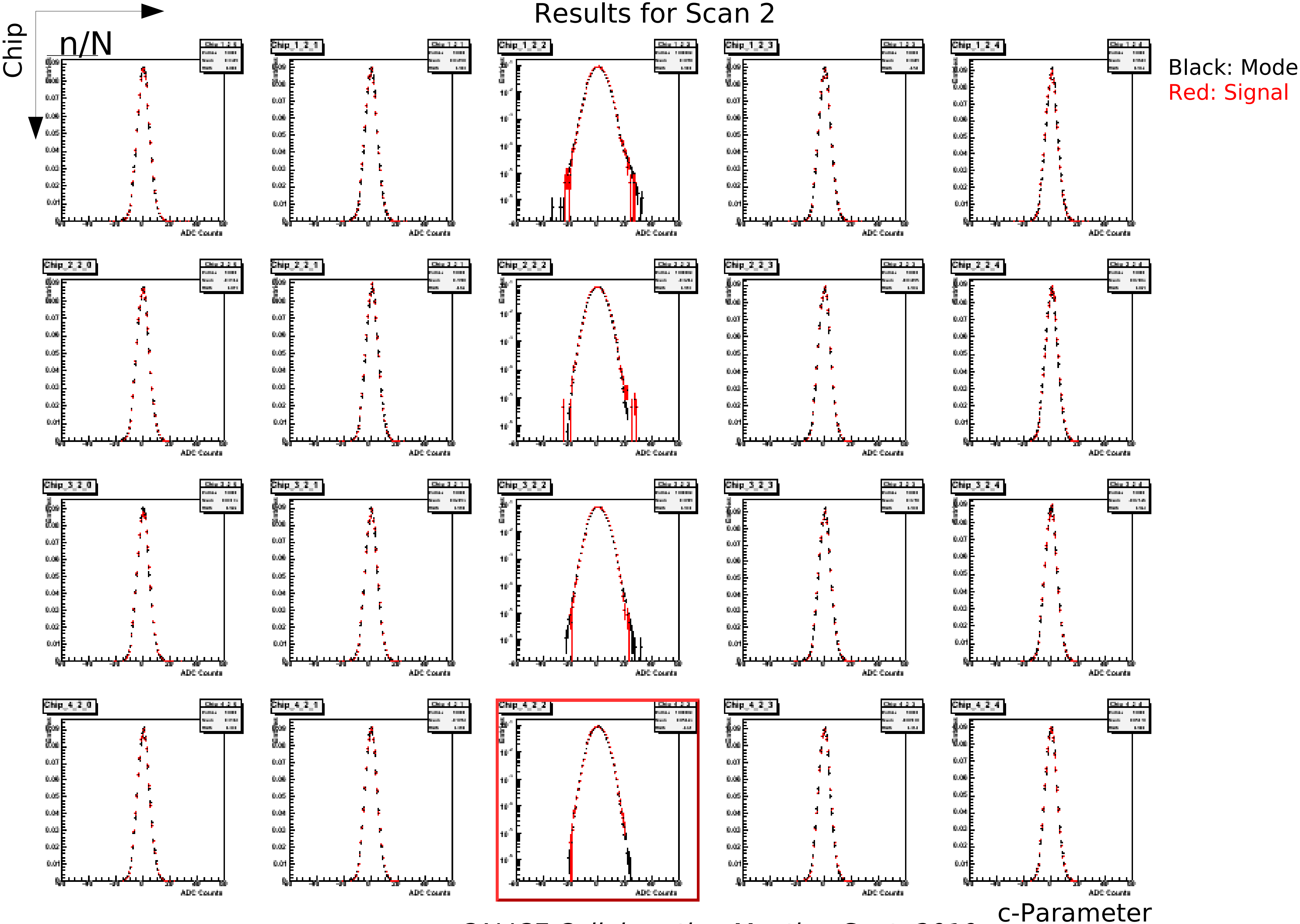
Comparison of noise spectra – Model ,-> Data (Pedestal)

Results for Scan 1



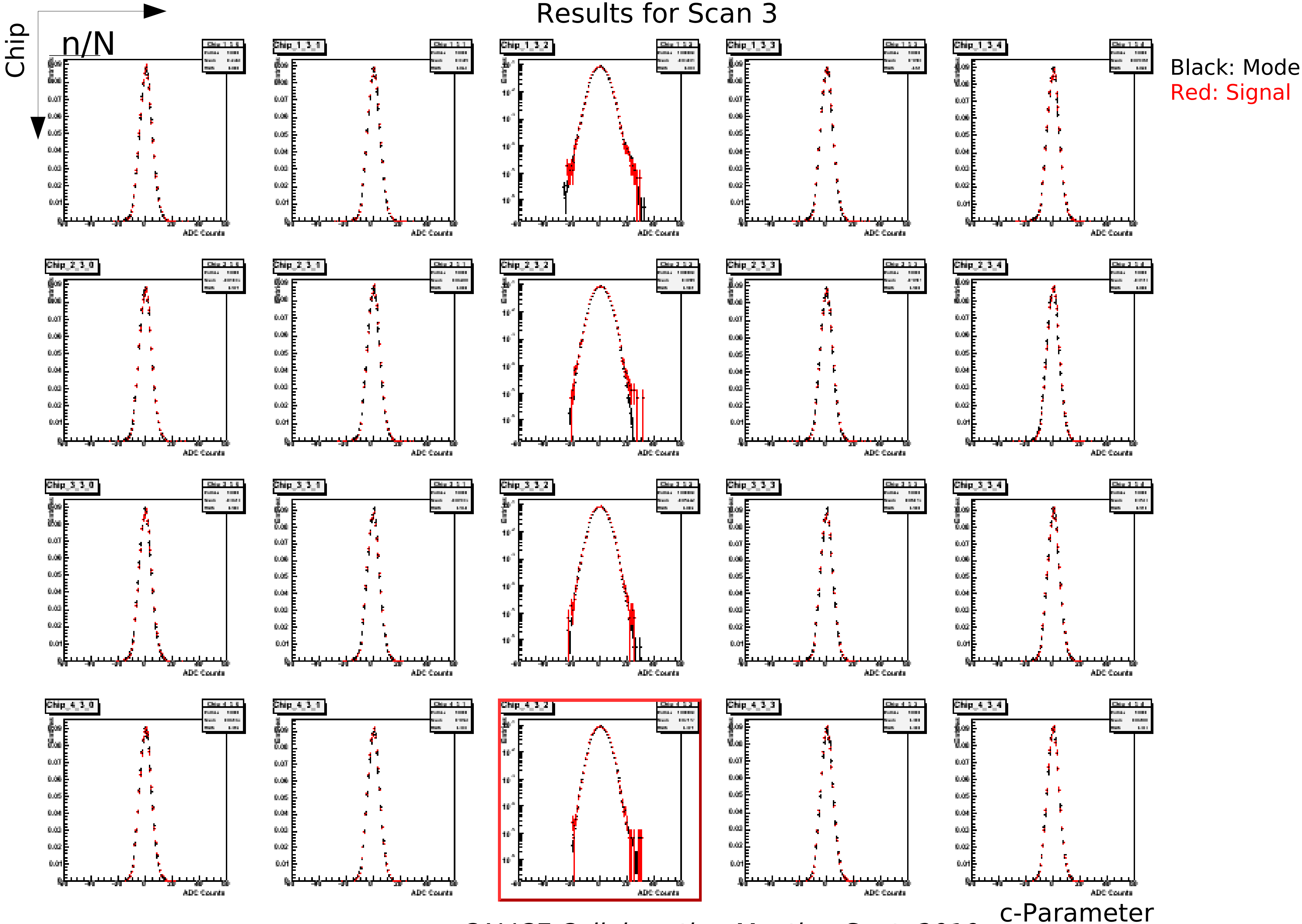
Comparison of noise spectra – Model ,-> Data (Pedestal)

Results for Scan 2



Comparison of noise spectra – Model ,-> Data (Pedestal)

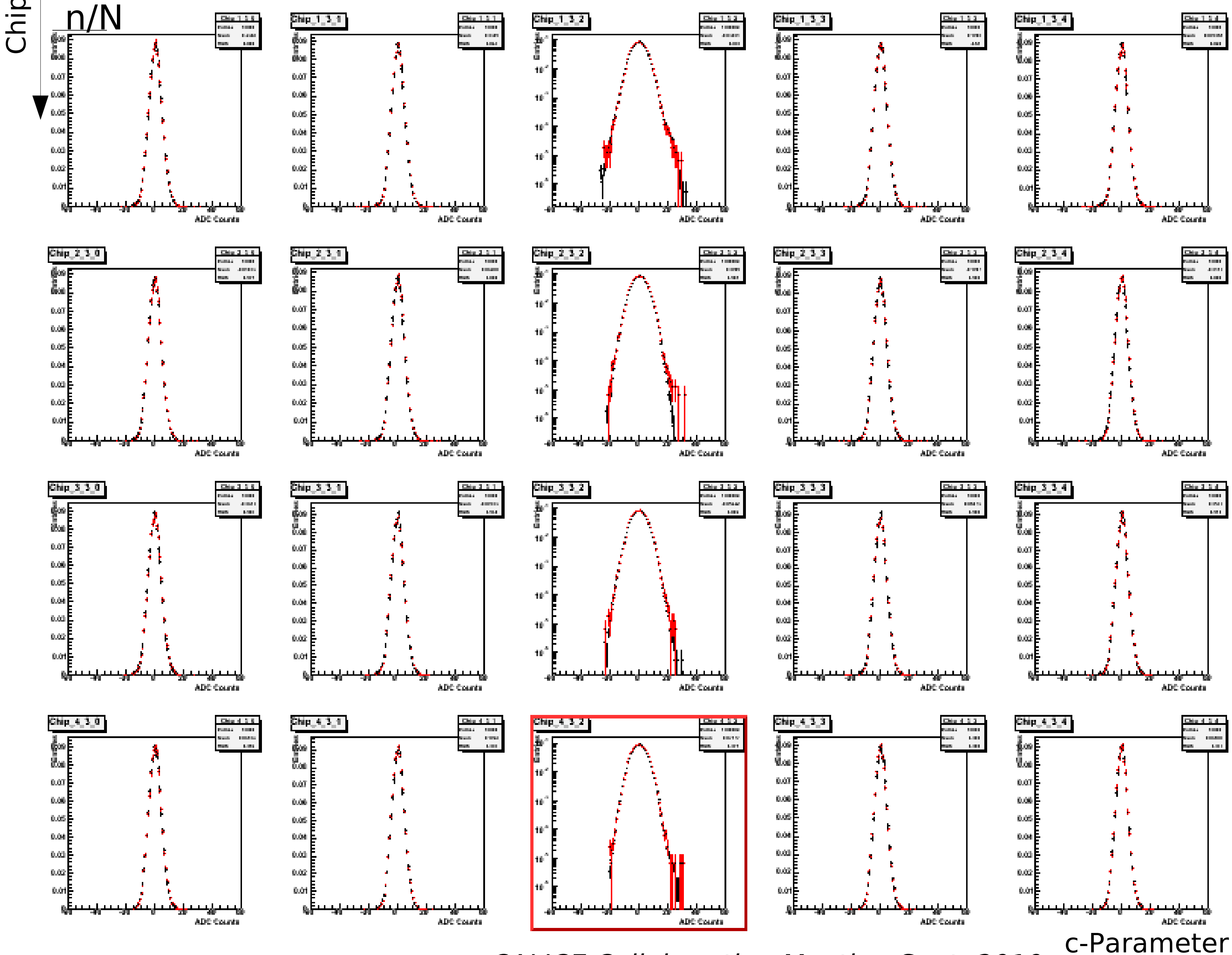
Results for Scan 3



Comparison of noise spectra – Model ,-> Data (Pedestal)

Results for Scan 4

Scan Point



Black: Model
Red: Signal

Calculation of upper Limits

- Aim: Upper Limits/Probabilities as a function of the Threshold

- Requires calculation of limits with underlying background

Probability Density Function (Frequentist Approach):

$$f'(n;\lambda_S+\lambda_B)=f(n;\lambda_S+\lambda_B)/\sum_{n_B=0}^{k} f(n_B;\lambda_B)$$ f, f' are Poissonnian Densities

Presence of Background via numerator (Approach á la Zech NIM A277)

Using this pdf the Confidence Limits/Upper Limits
can be calculated using regular statistics techniques

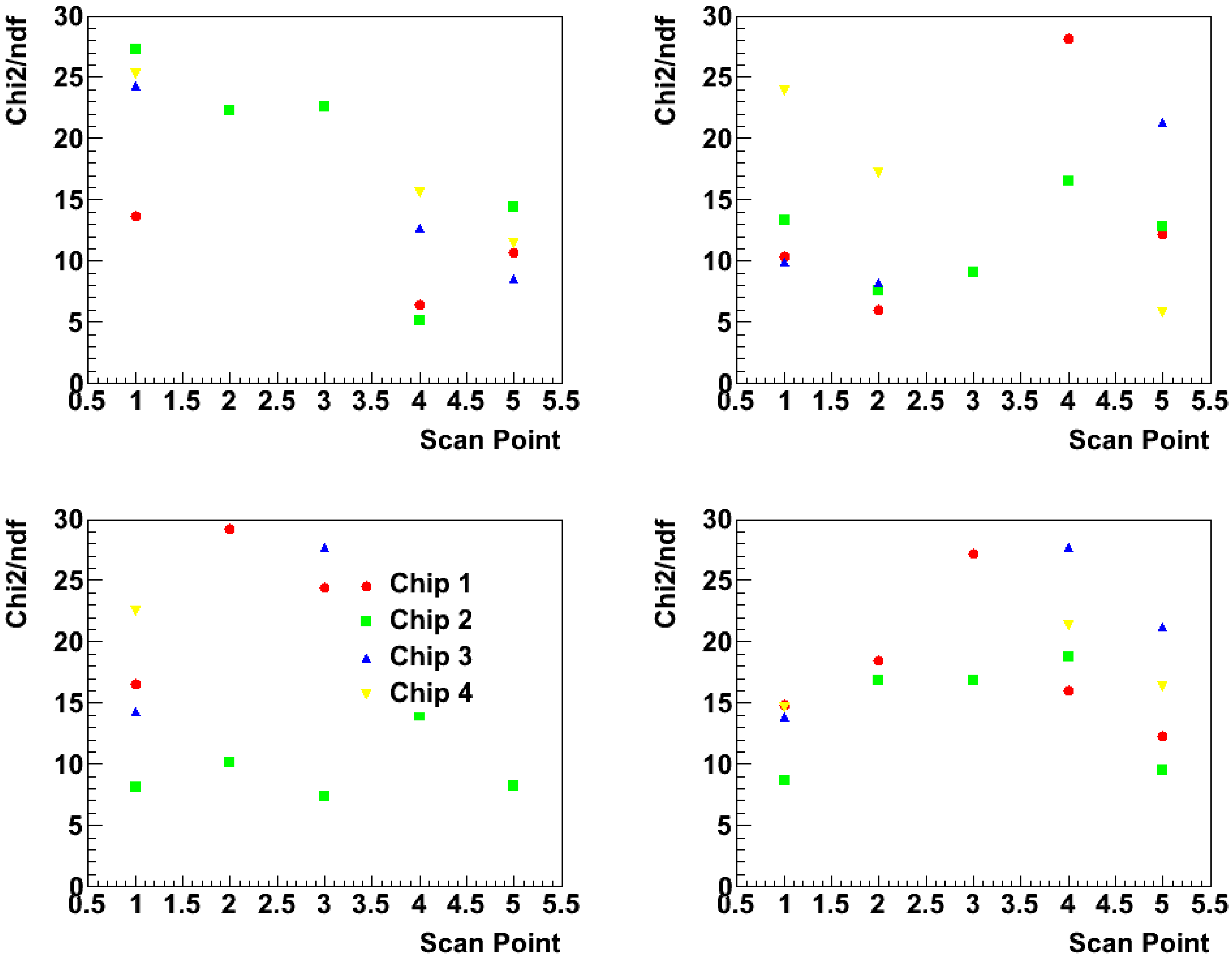
Here: S. Brandt, Datenanalyse, pp.183

Developed ("c++ fied") program to calculate upper limits in the presence of known background.

Background is noise which is present independent of all potential parasitic effects from the beam

Ιντερµ εζζο Ι – χ^2/ndf between Data and Model for 'Maïve' Model

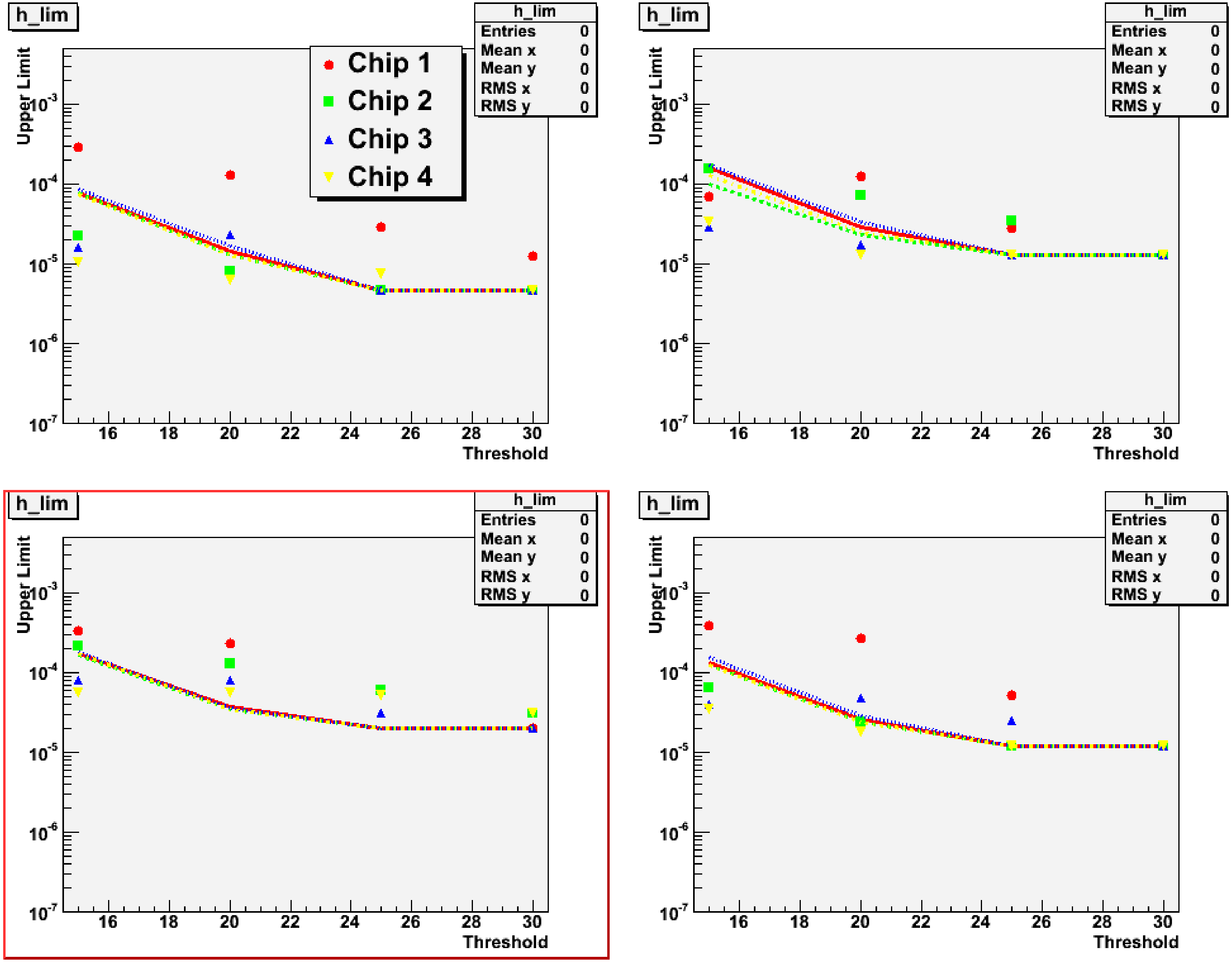
Using mean and sigma of pedestal spectra – Positive Hits



Much worse agreement between data and 'naïve' model

Intermezzo II – Upper Limits from 'Naïve' Model for Pedestal Events

Using mean and sigma of pedestal spectra – Positive Hits

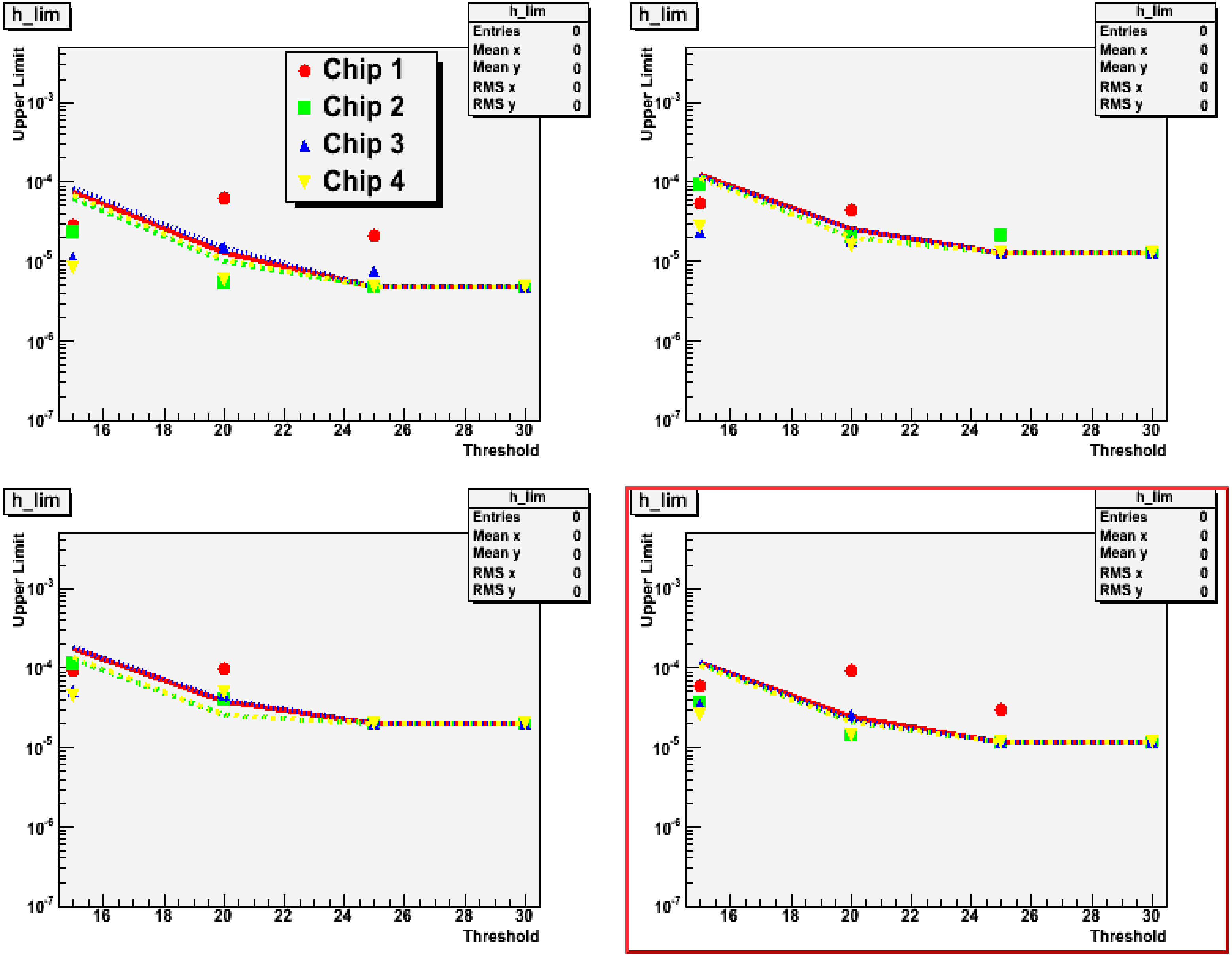


Much worse:

In particular Chip 1

Intermezzo III – Upper Limits from 'Naïve' Model for Pedestal Events

Using mean and sigma of pedestal spectra – Negative Hits



Also worse than developped noise model