Correction for the SiPM non-linearity
(new perspective on saturation curve)

for AHCAL SiPM with scintillator tile

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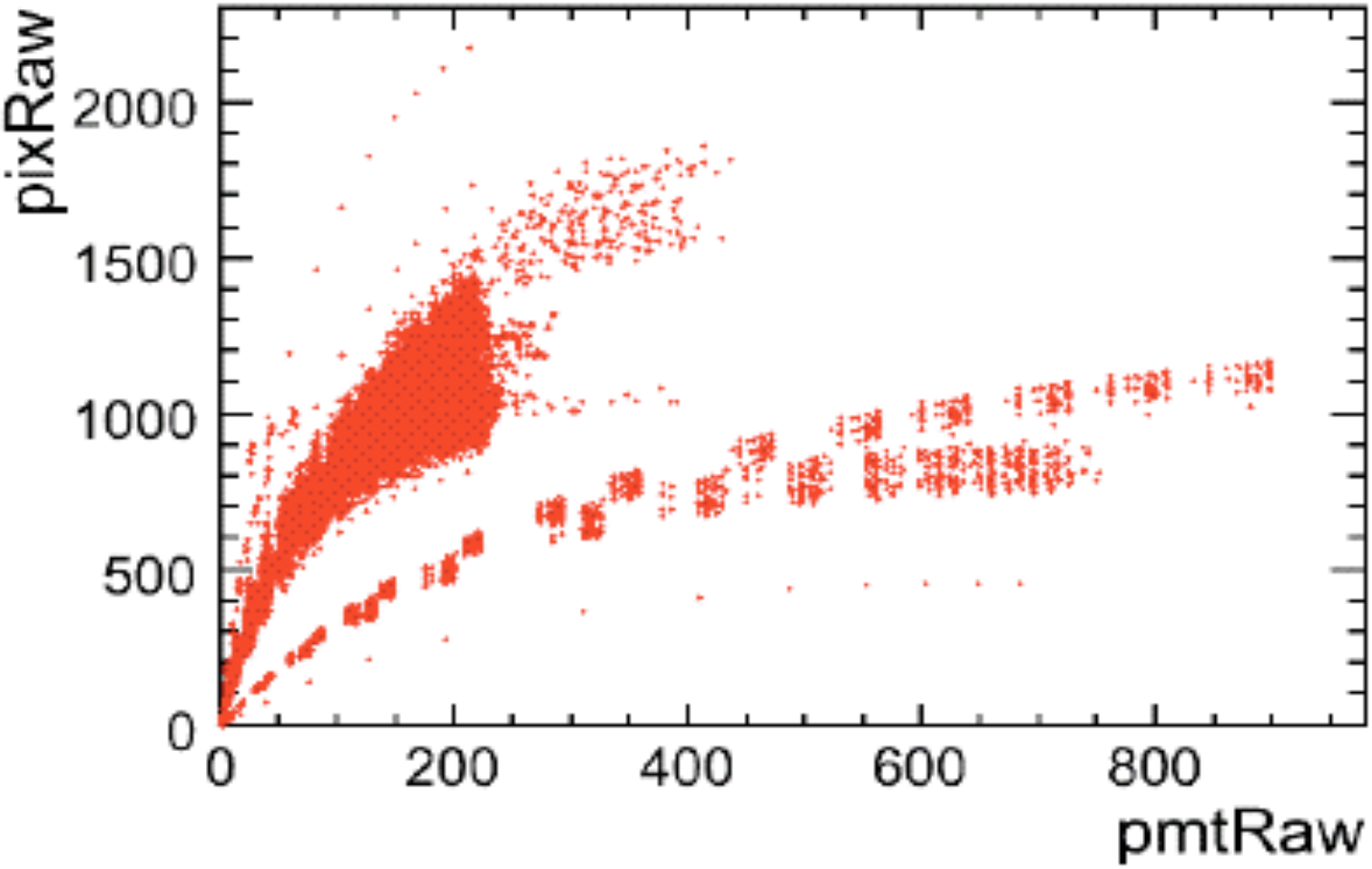
Natural units

- In physics, natural units are physical units of measurement defined in such a way that certain selected universal physical constants are normalized to unity; that is, their numerical value becomes exactly 1.

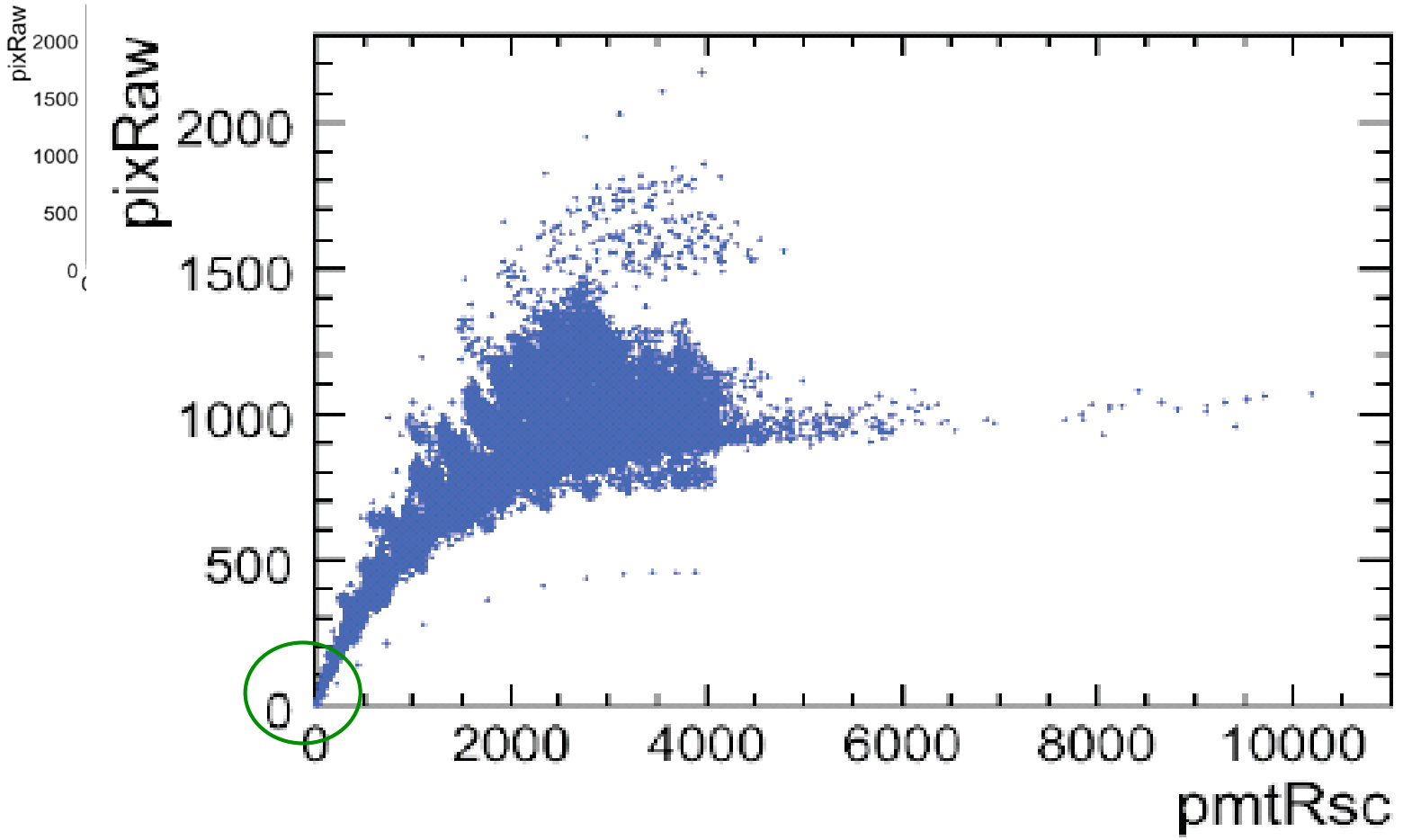
-- From wikipedia

SiPM response curve (ITEP measurement)



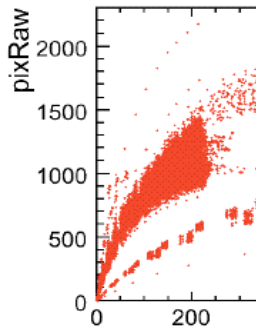
- That is real life!
- What we have to do, was not only what you have seen on this plot!
- Some improvement has been done day after day.

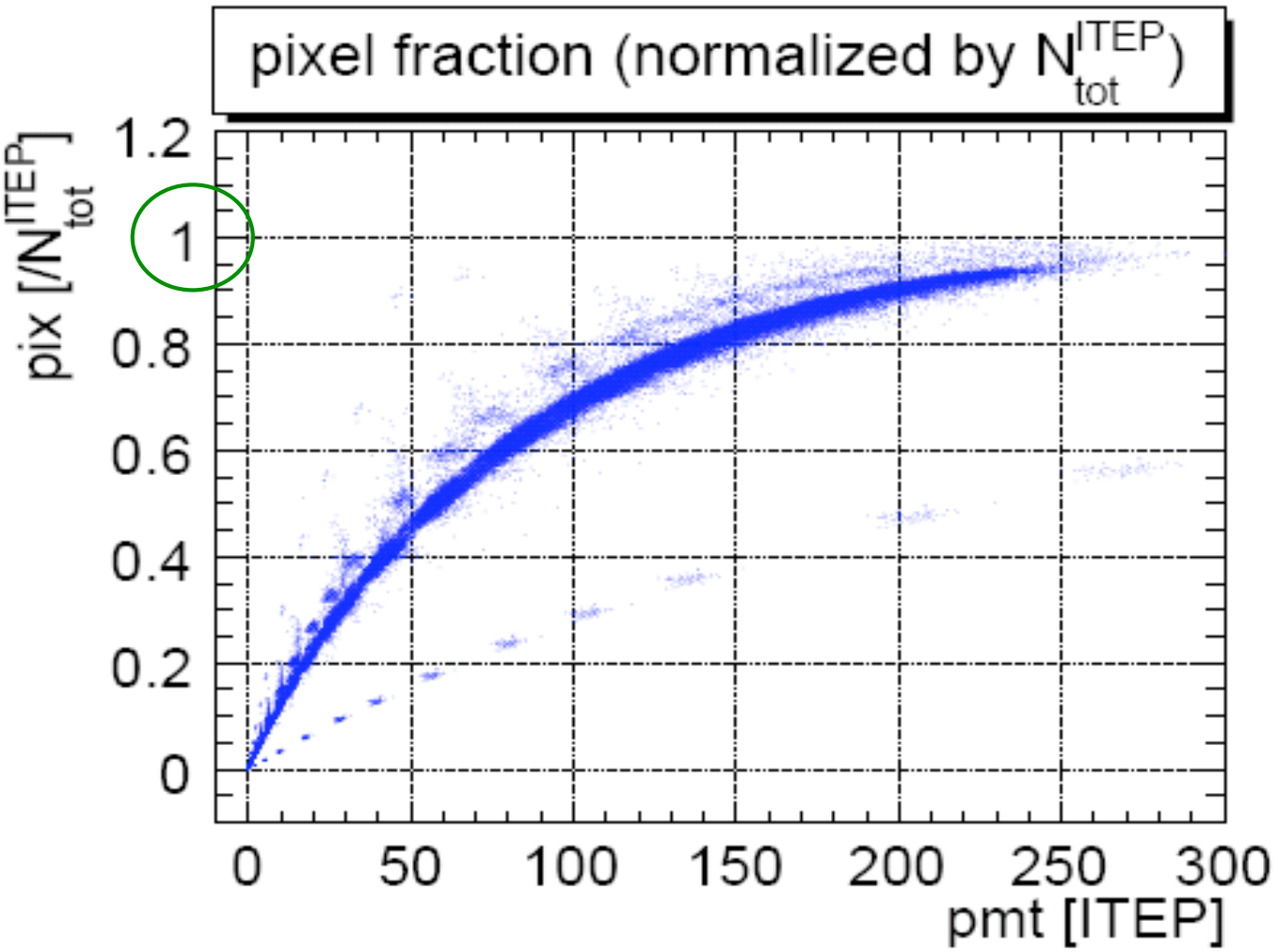
SiPM response curve (ITEP measurement)

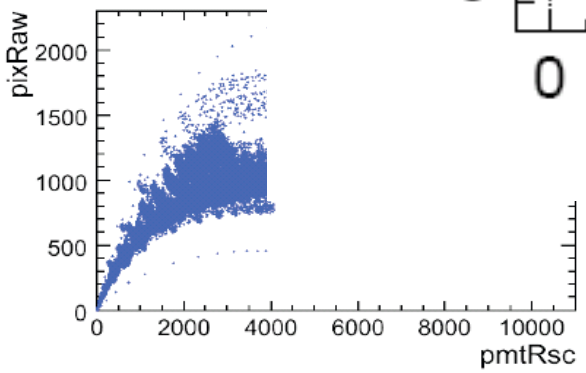


- Slope: corrected by fitting the first 10 ITEP measurement points, and rescale X.
  - Why? Because it is linearity at low intensive light range.

SiPM response curve (ITEP measurement)

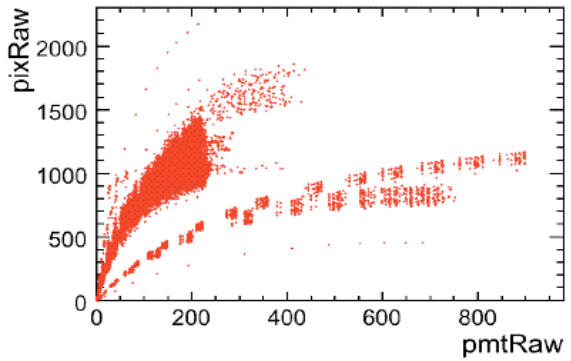


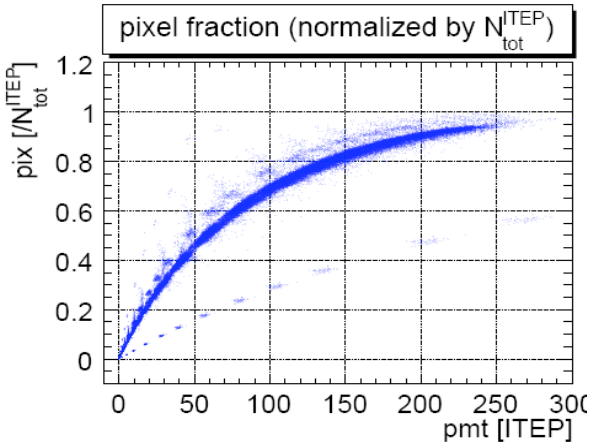


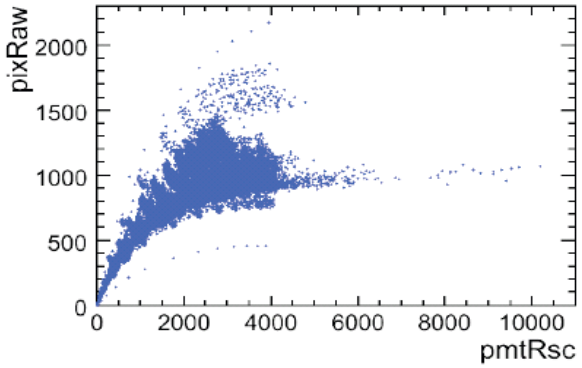


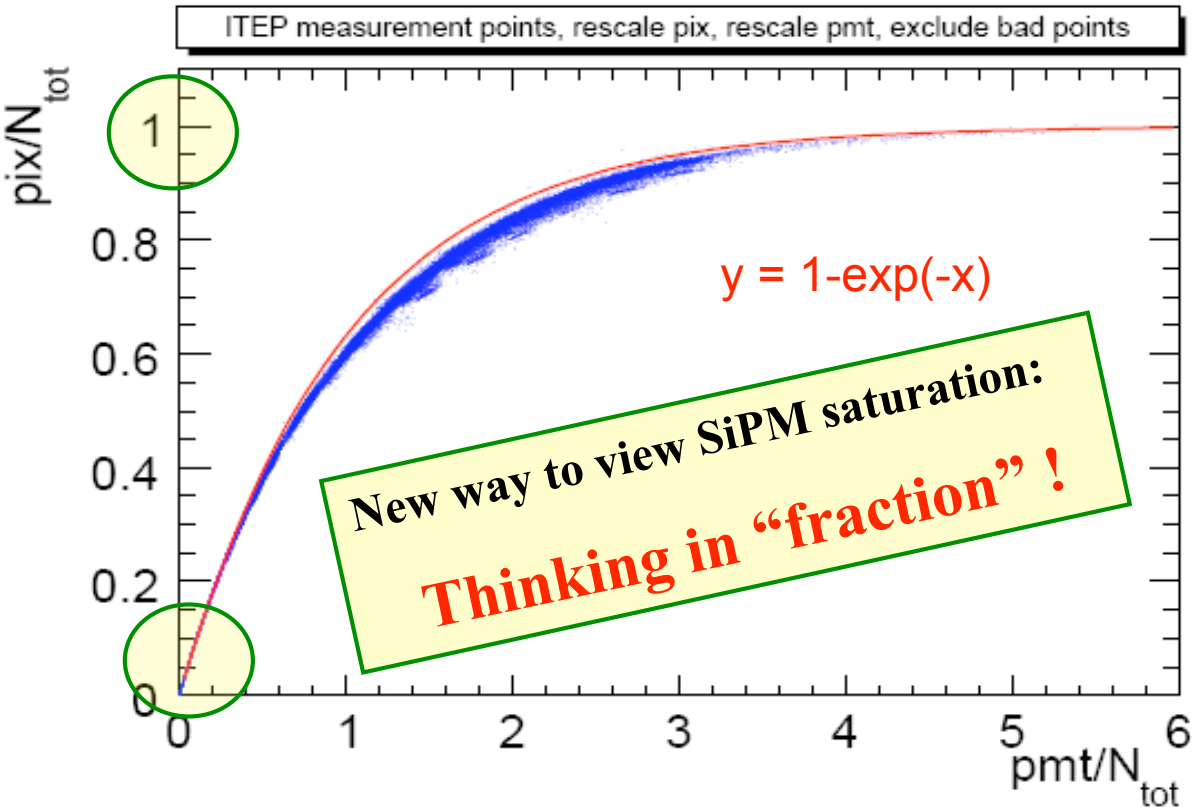
- Total pixel numbers: extracted by fitting the last 5 ITEP measurement points
- Only normalization for Y, and nothing more here.

SiPM response curve (ITEP measurement)









- Total pixel numbers: extracted by fitting the last 5 ITEP measurement points
- Slope: corrected by fitting the first 10 ITEP measurement points
- Bad points: removed base on double exponential fit

Saturation response (theory)

- If one agree this " $y=N_{tot}*(1-\exp(-x/N_{tot}))$ " formula which could describe the saturation response curve.
  - N_{tot} is the total effective pixel number for each SiPM.
  - Let's assume the photon efficiency for each pixel is identical.
  - I totally agree that the real world is more complicate. Let's start to think from theory, then extend to think in the real world later.

- Think about these examples:
  - $y = 1156*(1-\exp(-x/1156))$
  - $y = 900*(1-\exp(-x/900))$

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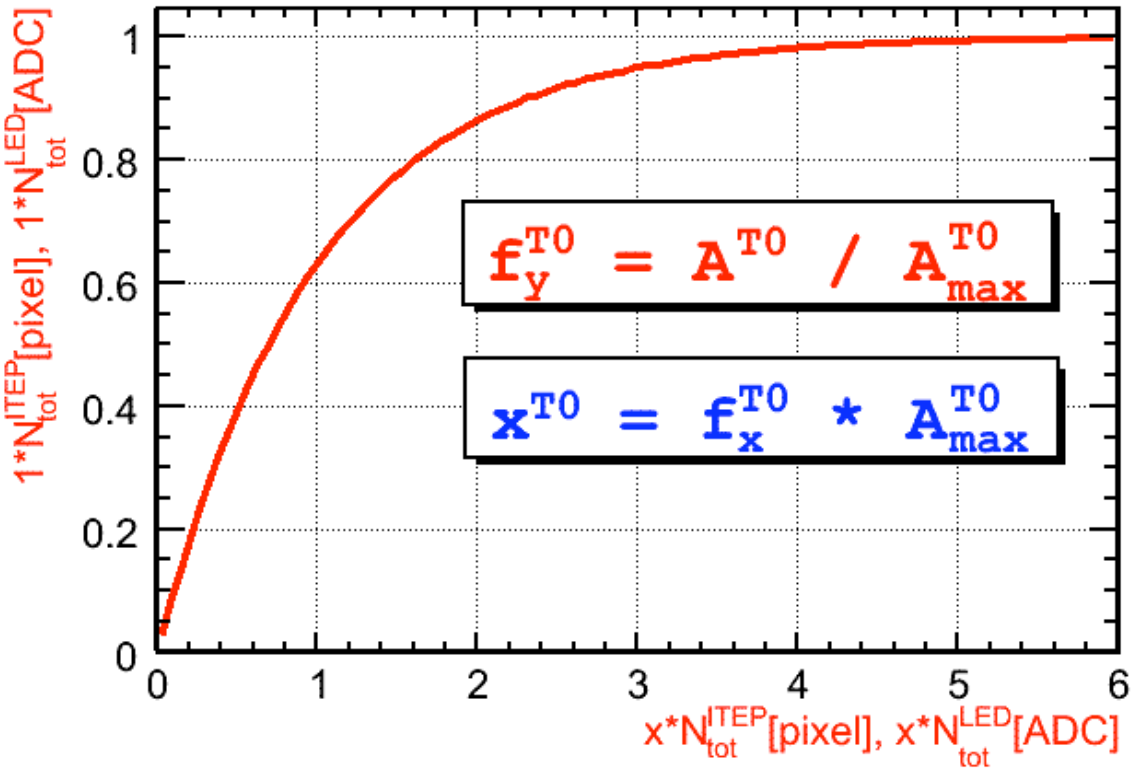
- Think about these examples:
  - $y = 1156*(1-\exp(-x/1156))$, $N_{tot} = 1156$
  - $y = 900*(1-\exp(-x/900))$, $N_{tot} = 900$

- Think in fraction: $fy = y/N_{tot}$, $fx = x/N_{tot}$
  - $fy = (1-\exp(-fx))$
  - $fy = (1-\exp(-fx))$
  - The maximum number is still needed. But anyway, one could think it in pixel, MIP or ADC now.

From ITEP to testbeam data (theory)



- Here we think and talk about the most channels which are neither ADC saturation nor LED saturation.
- For the ADC and LED saturation, we may think about them in another way. How to find them out, and to improve them next time.

- Thinking in fraction for ITEP measurement:
  - One could get the red response curve in fraction from ITEP measurement.
- Thinking in fraction for testbeam data:
  - The fraction "fy = signal [ADC] / NmaxLED [ADC]", which will be corrected by the saturation curve to obtain the factor "fx", in principle.
  - x [ADC] = fx * NmaxLED [ADC] , x [MIP] = fx * NmaxLED [MIP]

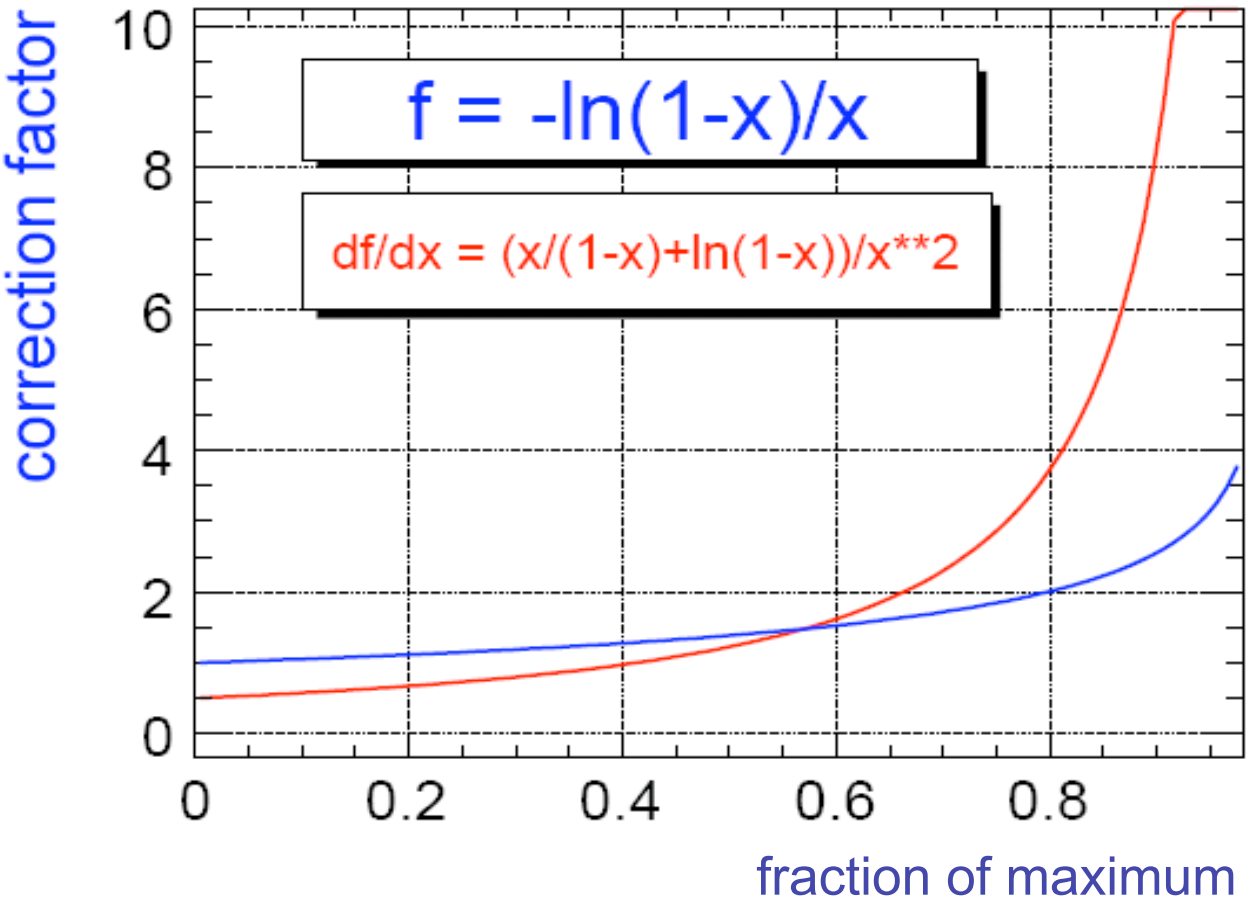
The important keys

- Thinking in fraction (occupancy), we found more clearly that one important key number is the **maximum effective pixel number**, whatever it is in pixels, in MIPs or in ADCs…
  - ➔ Try to use the more precise one which we could have in hand, or the well understood one.

- Due to the ITEP measurement could not be used directly,
  - ➔ Try to find a better way to "rescale" the measured value.

- Thinking in the fraction of the total effective pixels, may help to understand the data from both the ITEP measurement and the maximum "pixels" in-situ.
  - ➔ Using the fraction is a good choice,
    - It shows the ITEP measurement is not so different among all SiPMs
    - It gives us a freedom to chose the maximum in any unit, then we may use the more precise one, or well understood one.
    - We may reconstruct the data with only one formula, and corrected it for each SiPM according to the maximum effective pixel number.
    - Easily to estimate the error.

Correction factor (theory)



- For example: the cell in the EM shower center in a high energy e+ testbeam run,
  - ▶ The most probable value of fraction: ~83%.
  - ▶ Maximum effective pixels: ~5% error gives ~20% shift of the spectrum

Good news from LED run

Maximum effective pixel number from large statistic
66 CERN LED runs, 144 FNAL LED runs
Strong correlation between CERN and FNAL was seen
Max effective pixel number is ~80% of SiPM Physical pixel number

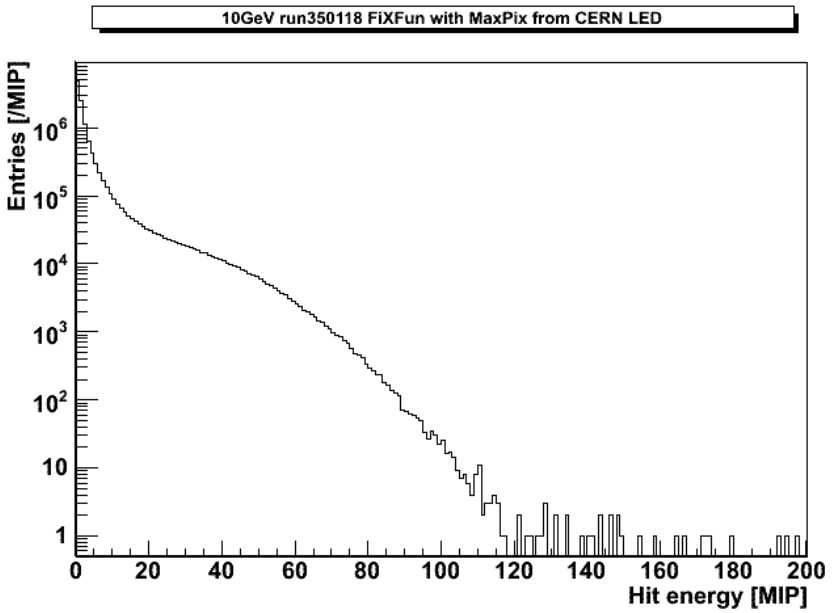
How to use them for deSaturation

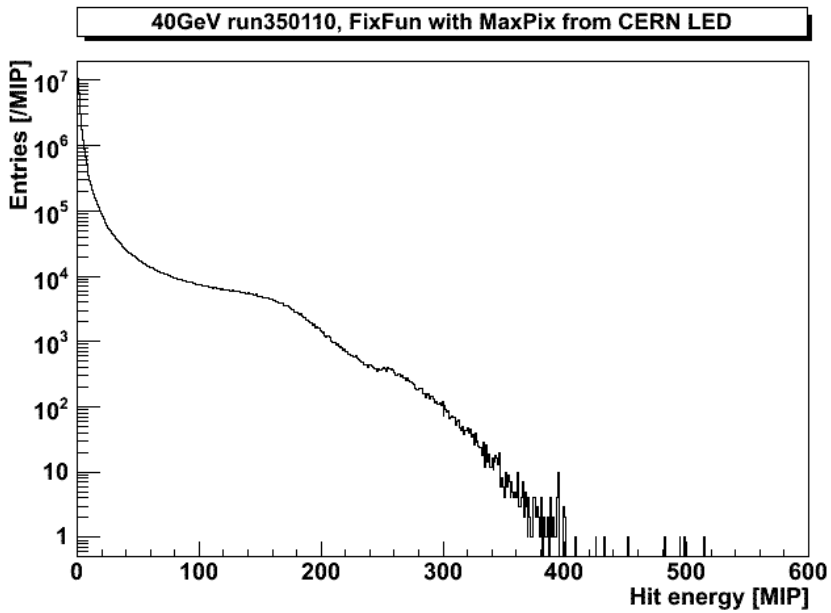
- Use the maximum effective pixel number from large statistic LED runs.
  - Write into database, and use it to extract the fraction (occupancy) for each SiPM.
  - For such channels which have no maximum effective pixel number, a default value (80%*1156) was used.

- Use this very very simple saturation response formula, and a linearity correction parameters, which are extracted from in-situ saturation response curve.
  - The formula and parameters have to been tested also with large statistic analysis jobs.
  - Each plot from the analysis has to be understood.

- Some very preliminary results will be shown to you here.

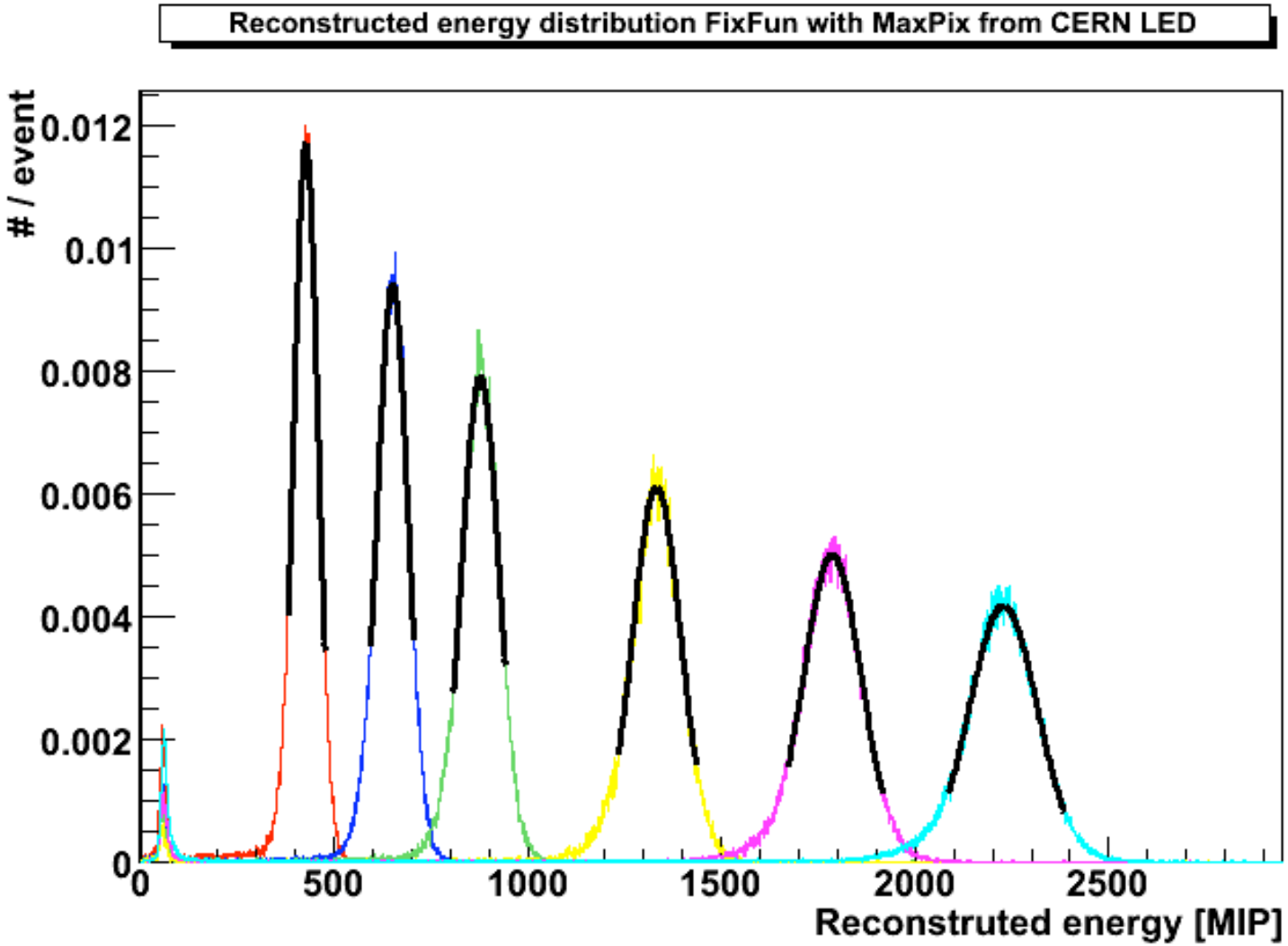
Single hit energy spectrum





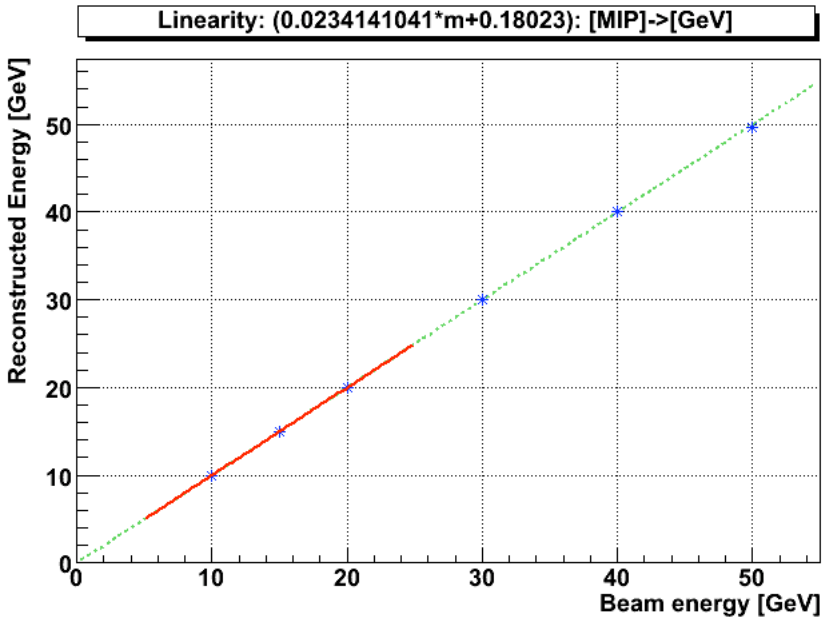
- Use the maximum effective pixel number from large statistic LED runs.
- 10 GeV single hit energy spectrum: OK
- 40 GeV single hit energy spectrum:
  - less than 300 MIPs from MC.
  - The curve looks not smooth.

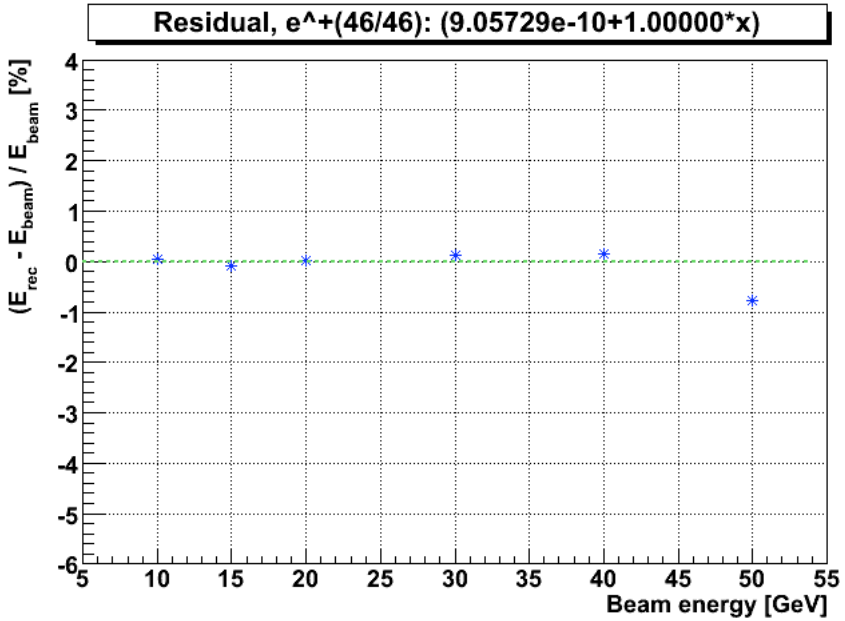
Reconstructed energy spectrum



- Use the maximum effective pixel number from large statistic LED runs.
- Simple selection on “beamBit = = 1”

Positron runs



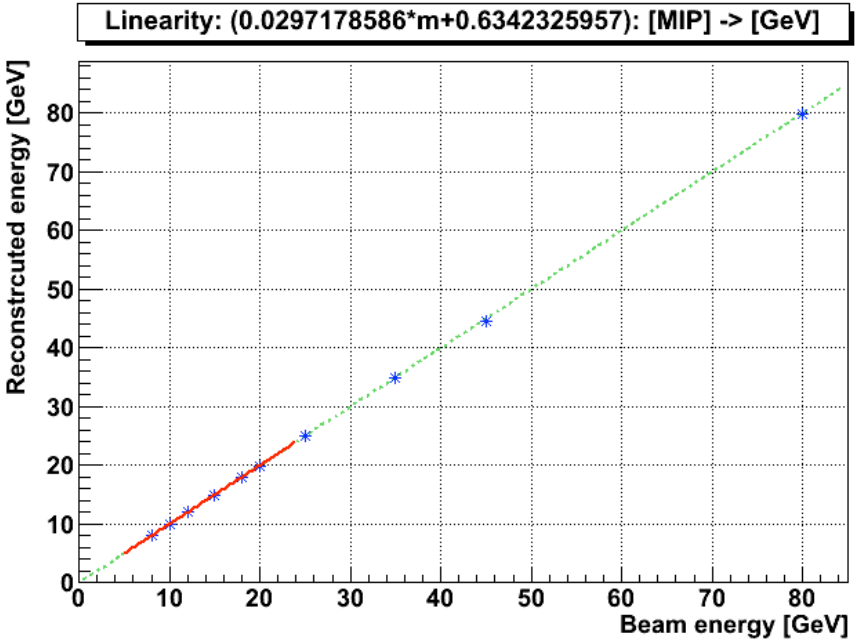


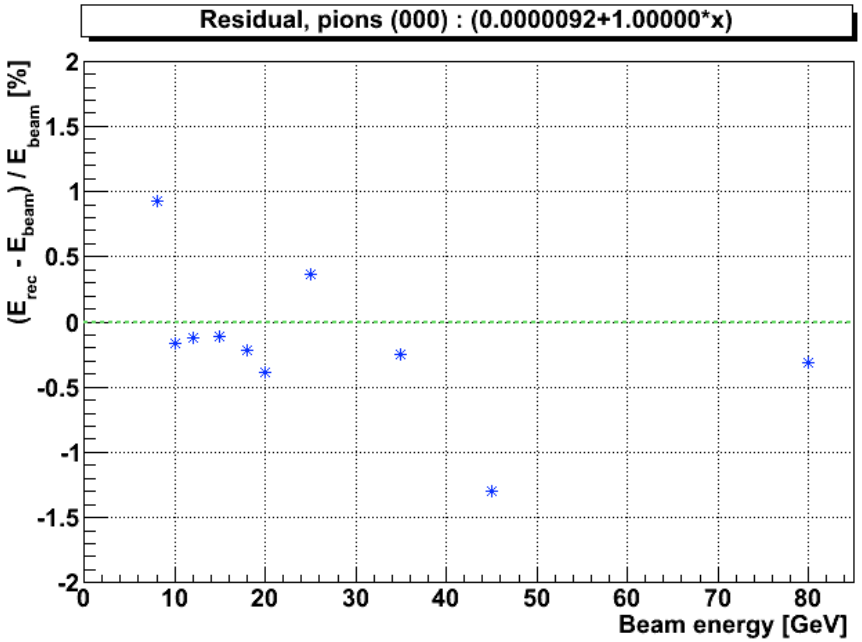
- positron runs from CERN test-beam, AHCAL only, without ECAL in front.

- [GeV] = 0.0234141041 [MIP/GeV] * m [MIP] + 0.18023 [MIP]
- [GeV] = m [MIP] / 42.7093 [GeV/MIP] + 0.18023 [MIP]

- Y = 1.00000 * X + 9.05729e-10 [GeV], (offset: 0.000000905729 [MeV])

Pion runs





- Poin runs from CERN test-beam, AHCAL only, without ECAL in front.

- [GeV] = 0.0297178586 [MIP/GeV] * m [MIP] + 0.6342325957 [MIP]
- [GeV] = m [MIP] / 33.6498 [GeV/MIP] + 0.6342325957 [MIP]

- Y = 1.00000 * X + 0.0000092 [GeV], (offset: 0.0092 [MeV])

Saturation in ADC and LED

Which method has to face these situations?

Saturation in ADC and LED

- Q: If we do not have information about how many effective pixels for the SiPM, (for example ADC saturation channels, or LED saturation channels). Could you have any way to do saturation correction for this SiPM?
  - ➔ Except using the average of maximum number for this method, this method has no other better solution currently.
  - ➔ Does any other method have a good solution?

- The ADC and LED saturation may be identified:
  - ➔ Some ideas are on test at DESY now.

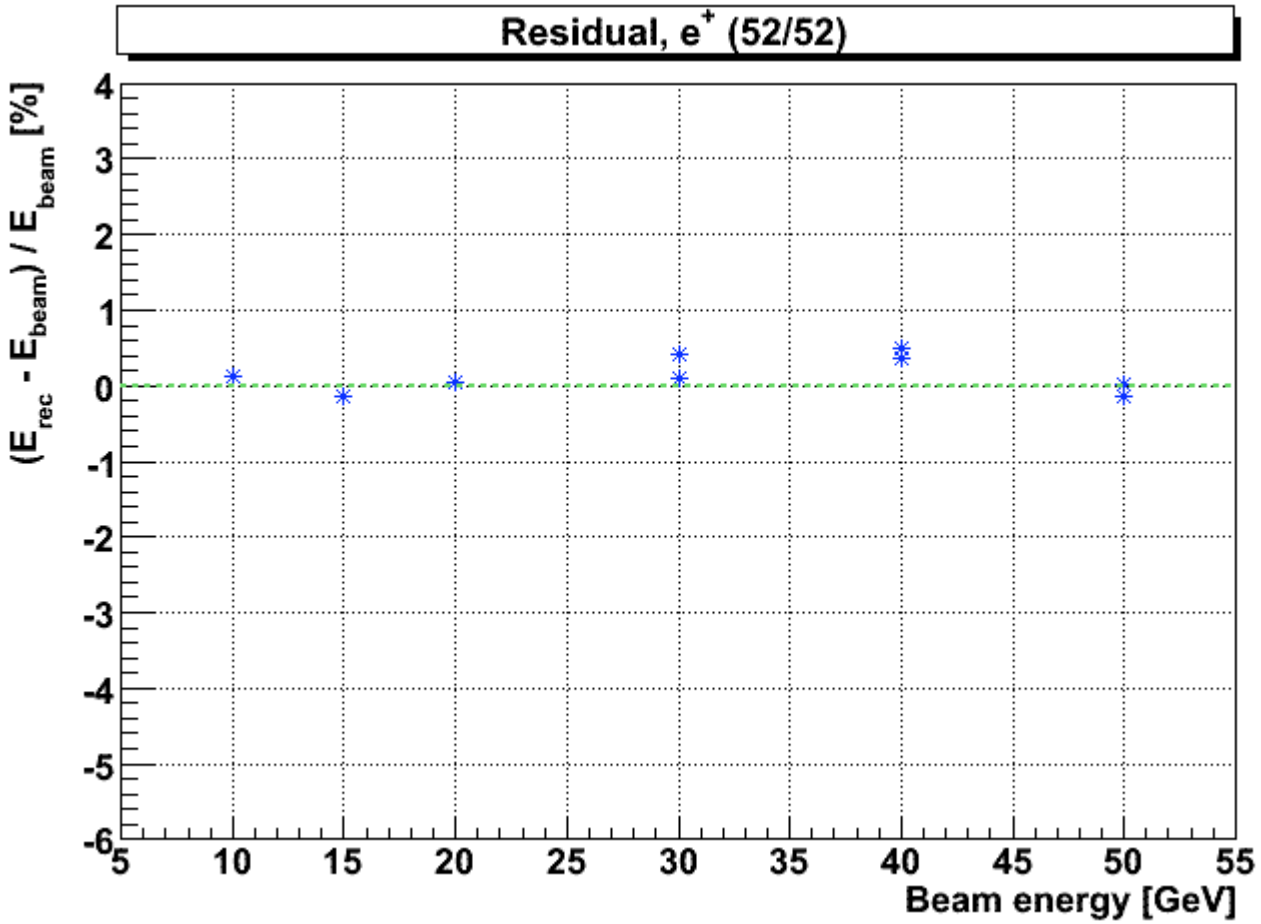
- Just one slide here to mention the same problems for also other methods, but not intent to rise the discussion for them now.

Summary

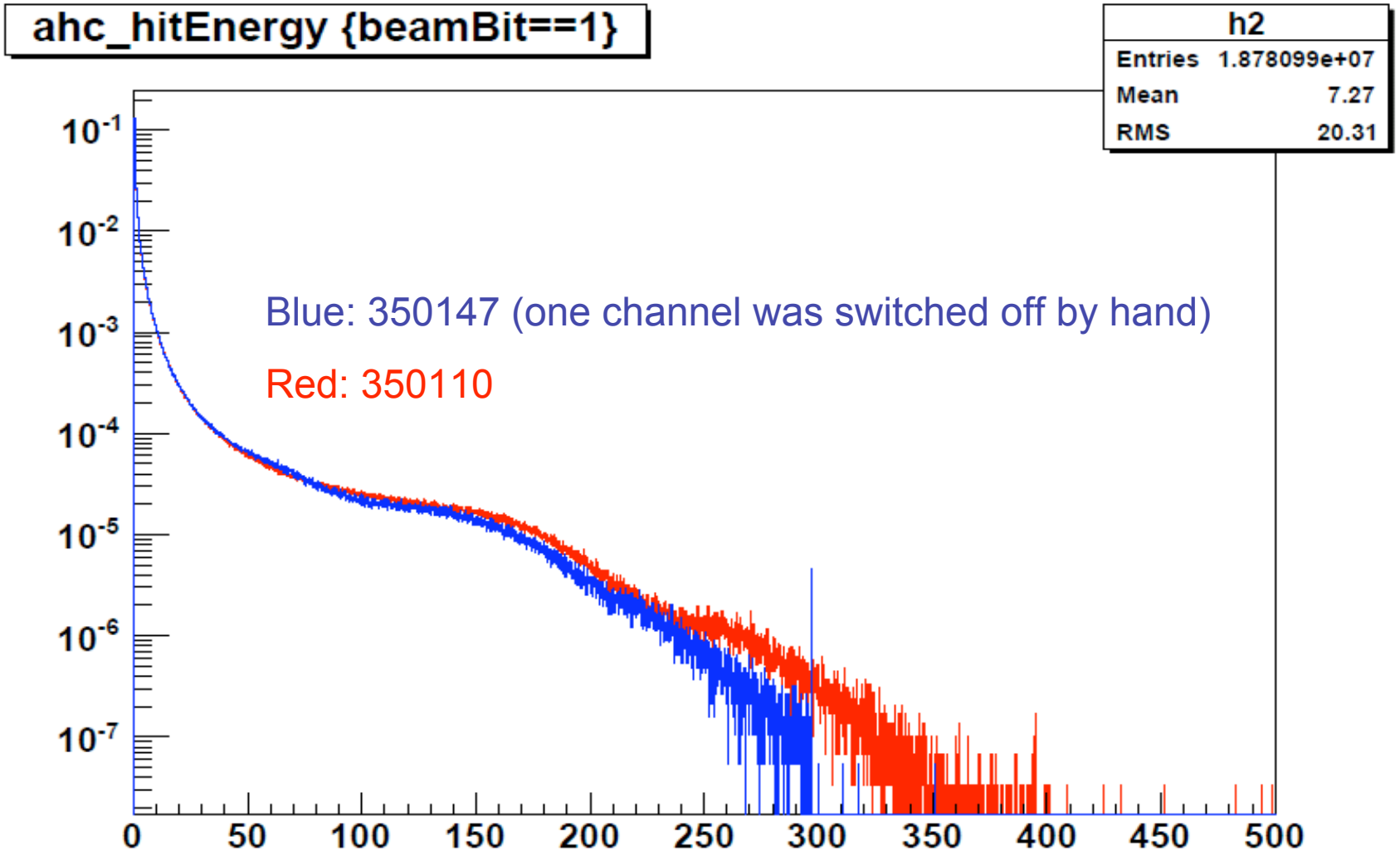
- These saturation correction studies are based on the fixed function and maximum effective pixel number from 66 CERN LED runs currently.
- Thinking in the fraction of the total effective pixels may help to understand the data from both the ITEP measurement and the maximum effective “pixels”.

Backup

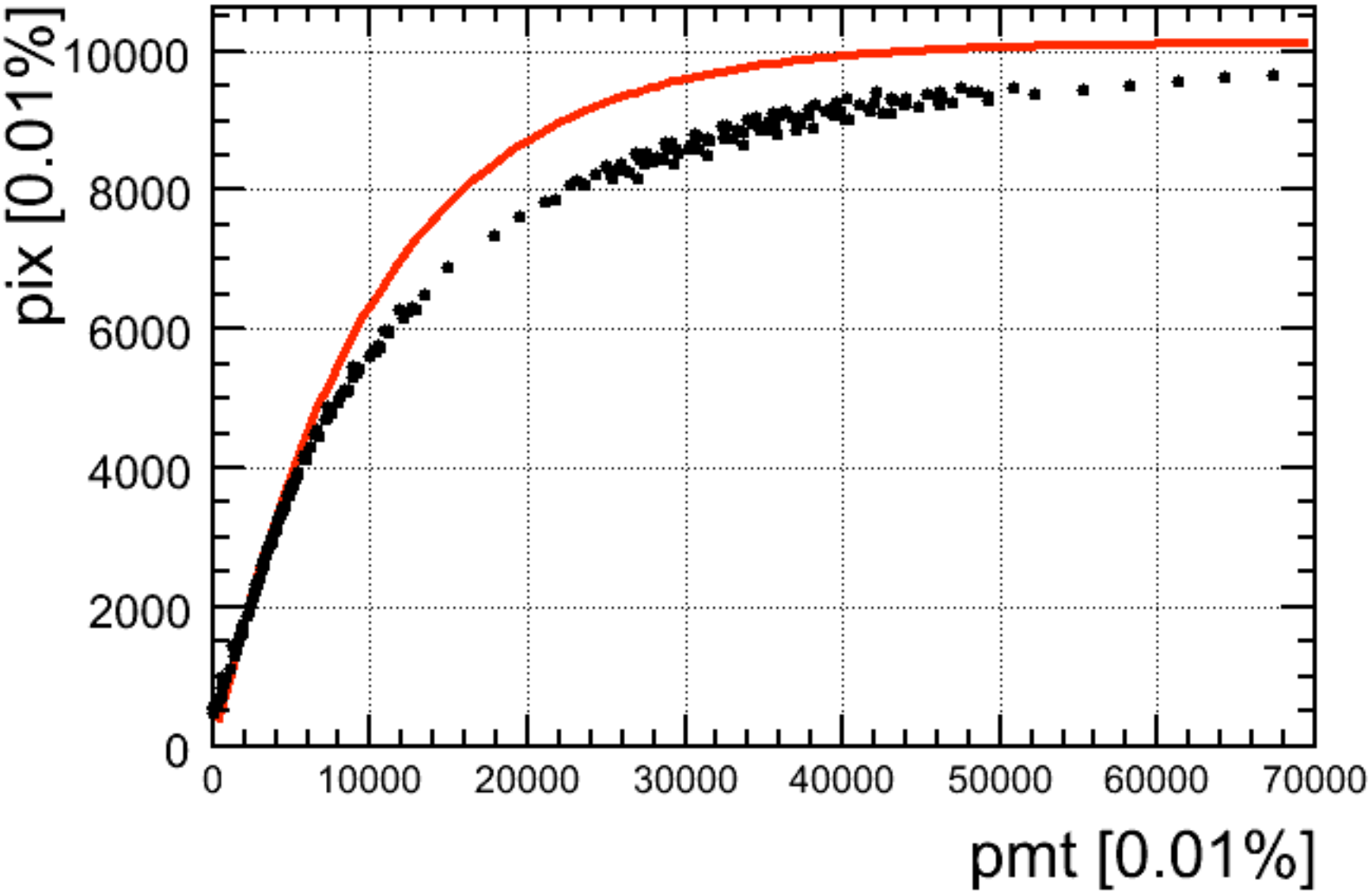
Positron runs



Single hit energy



LED in-situ


pix [0.01%]
10000
8000
6000
4000
2000
0
0
10000
20000
30000
40000
50000
60000
70000
pmt [0.01%]

LED in-situ