# A study of the impact of SiPM non-linearity on ECAL Performance

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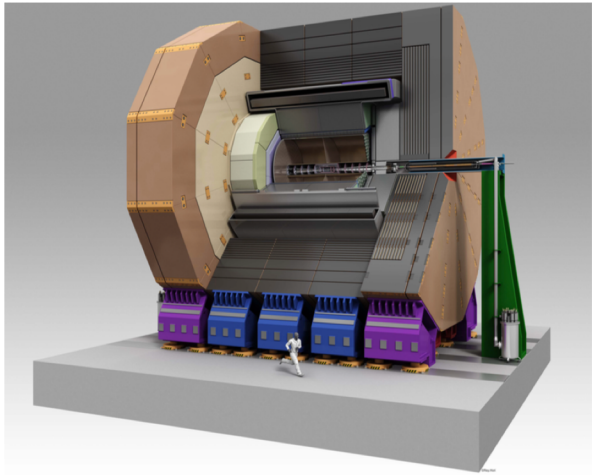
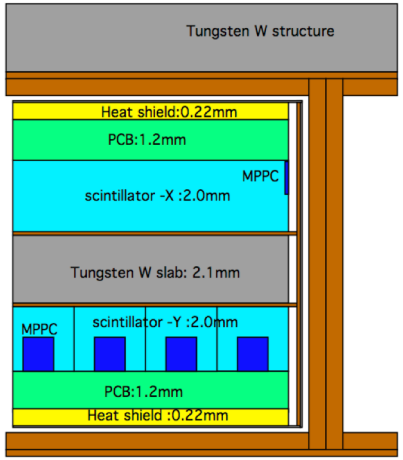
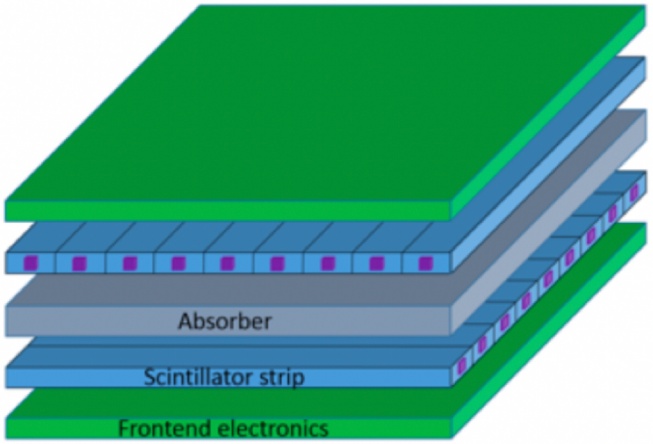
CALICE Collaboration Meeting
Utrecht, Netherlands
April 11, 2019

# Sci-W ECAL Option

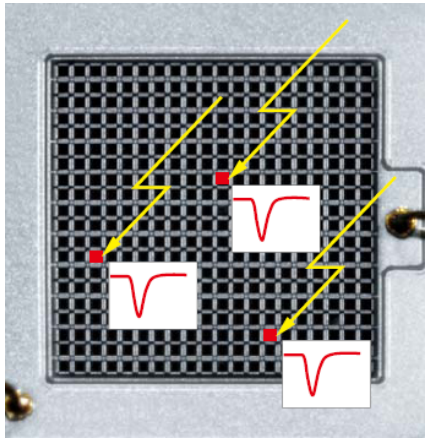
- Both ILD and CEPC have adopted the high-granularity Sci-W detector concept as one of their ECAL options.
- SiPM, as a novel compact photo sensor, is the key element in realizing the high granularity required for the Sci-ECAL.



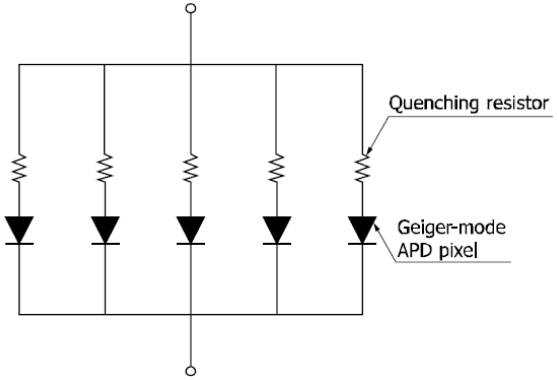


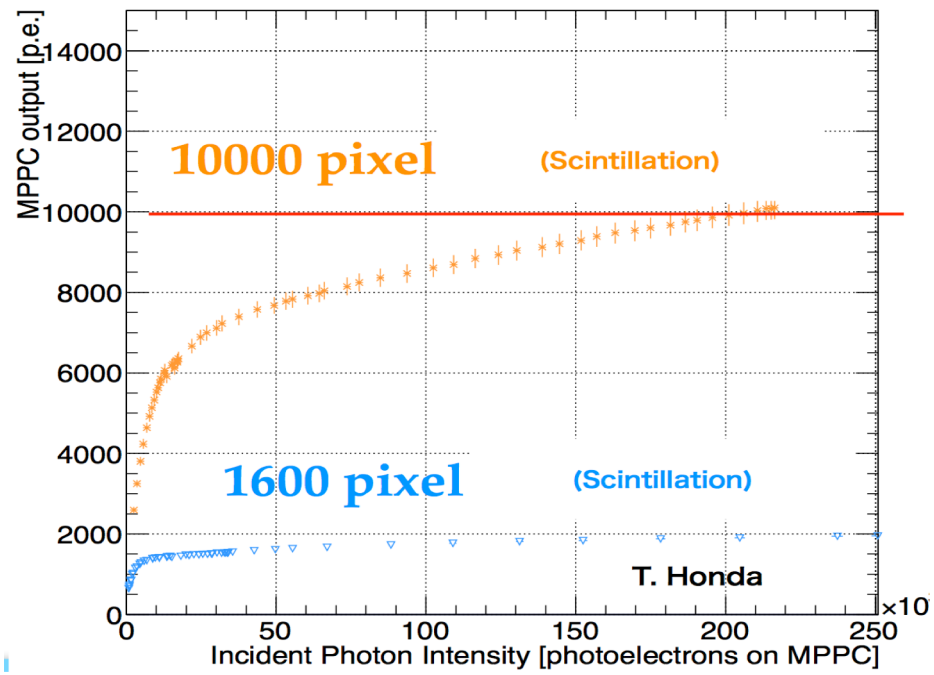
# SiPM



- A digital photon counting device
- counting resolution limited by number of pixels in a given area




- Non-linear response due to saturation when detecting photons of high intensity



# Modeling of SiPM Response

- Assuming m photons uniformly incident on a SiPM with N pixels.
- The probability for one photon to hit a certain pixel is 1/N and the total number of the photons that all pixels have received is always m :

$$p_{X_i} = \frac{1}{N}\ (i = 1, \dots, N) \qquad k_1 + k_2 + \cdots + k_N = m$$

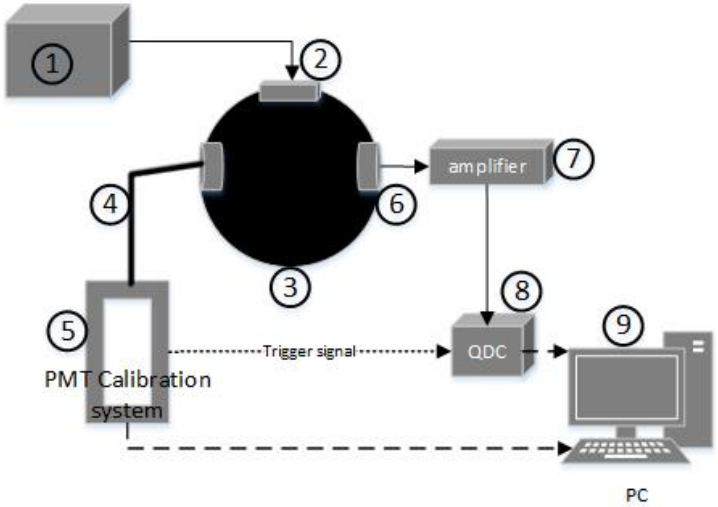
- Then simply multinomial distribution

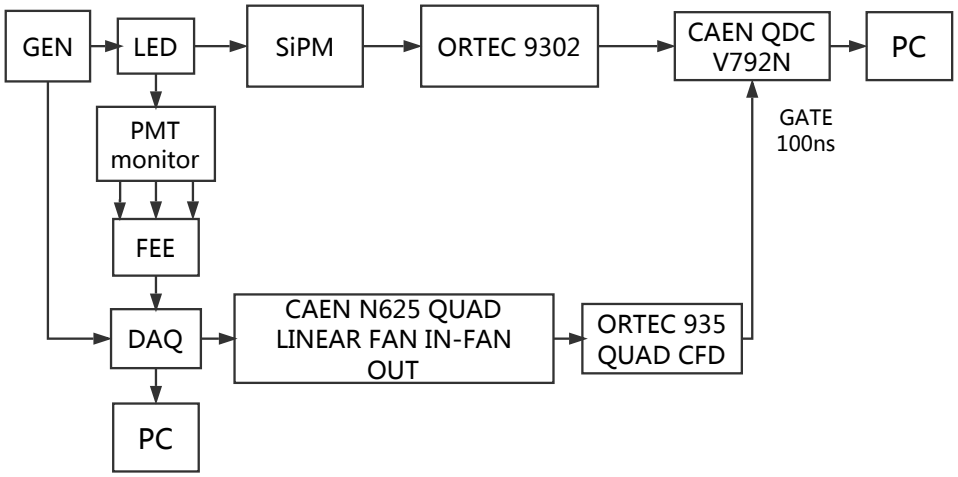
$$P(X_1 = k_1, \dots, X_N = k_N) = \frac{m!}{k_1! k_2! \dots k_N!} \cdot P_1^{k_1} \cdots P_N^{k_N} = \frac{m!}{k_1! k_2! \dots k_N!} \cdot \left(\frac{1}{N}\right)^m$$

- Taking into account photon detection efficiency using binominal sampling
- The number of registered photons (fired pixels) is then

$$n = \sum_{i=1}^{N} I(k_i^{PDE} > 0)$$

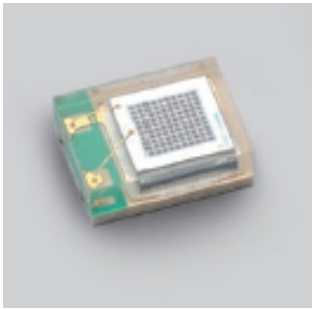
# Validation of the Model



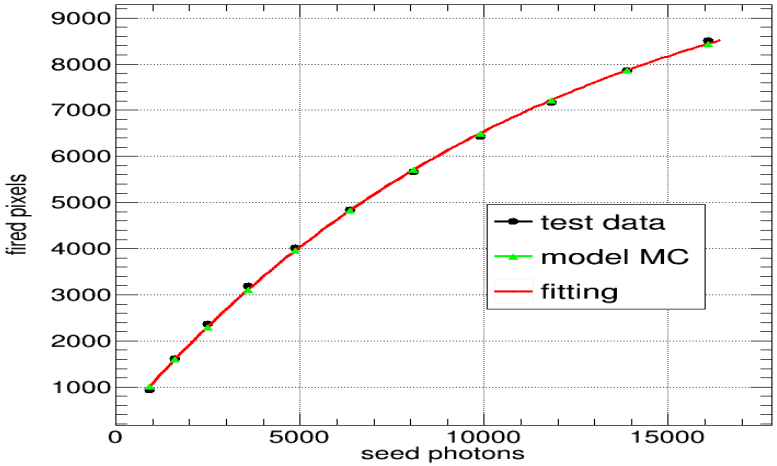




S12571-010P

10um pitch ,1mm x 1mm
10000 pixel



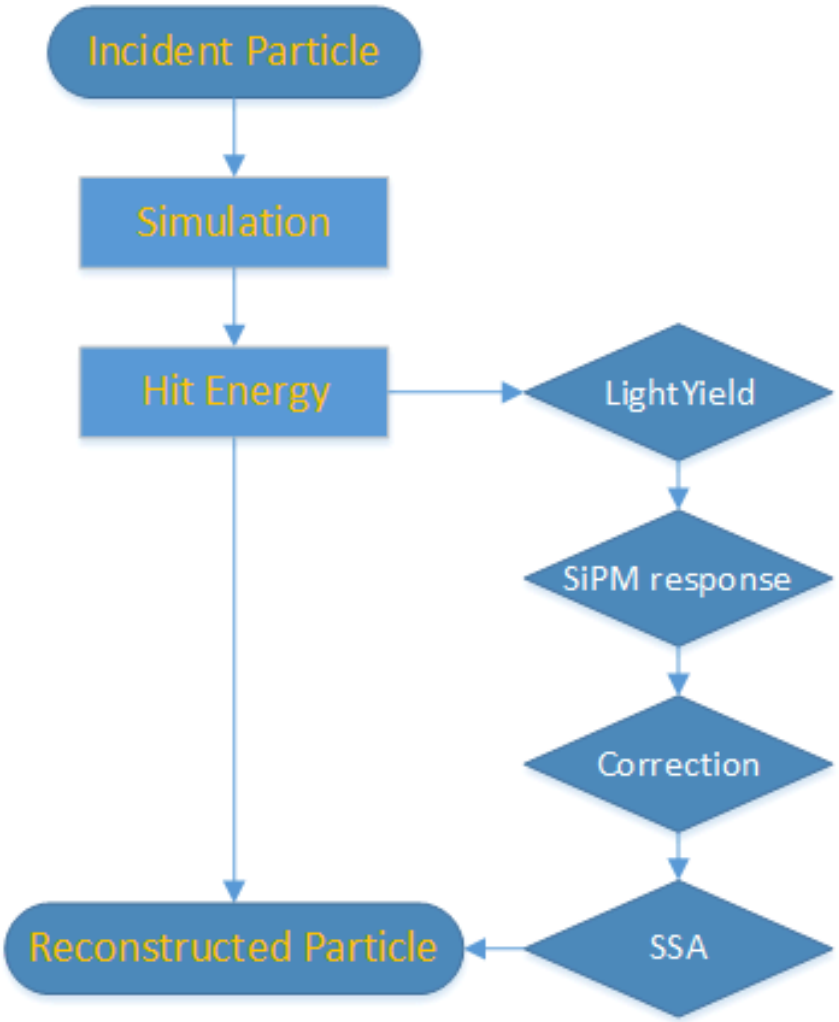
The model can describe the measured non-linear response curve very well. The curve can then be used to correct for the non-linearity (saturation) .



# A Simplified Sci-ECAL Geometry

- 30 layers
- ( 1 barrel + 2 endcaps ) that can fit in the CEPC detector
- Scintillator strip: $5mm \times 45mm \times 2mm$
- Absorber(W): $2.8\ mm$
- PCB: $2\ mm$

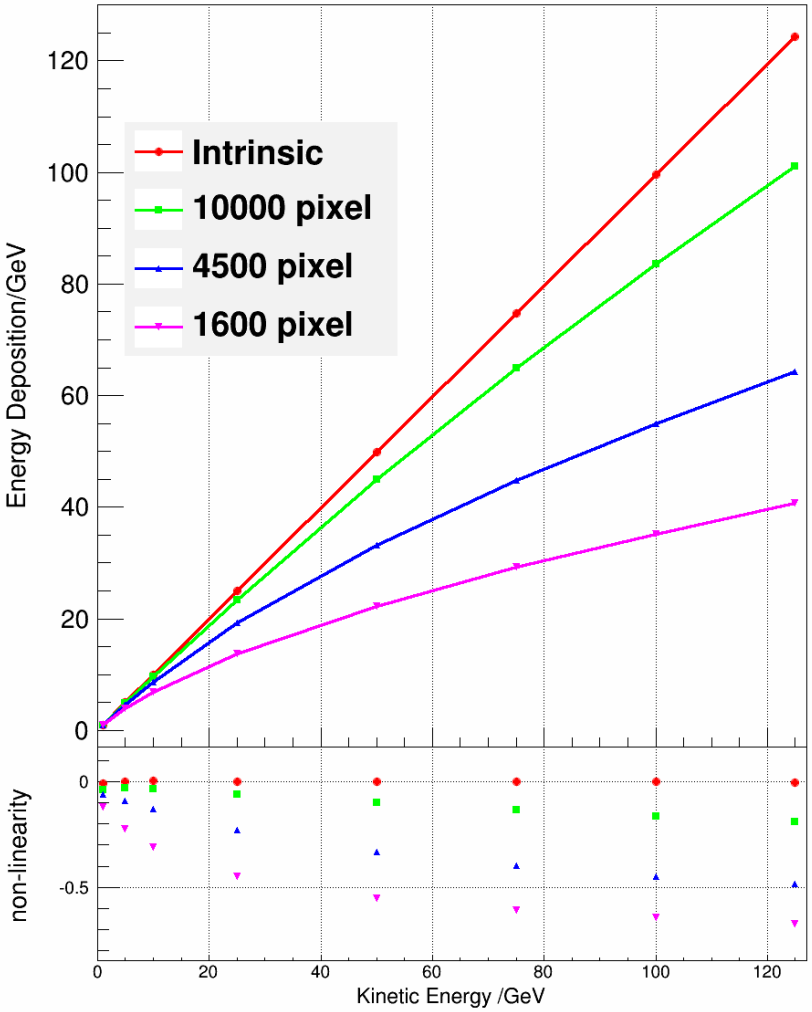
# The Full Simulation Chain



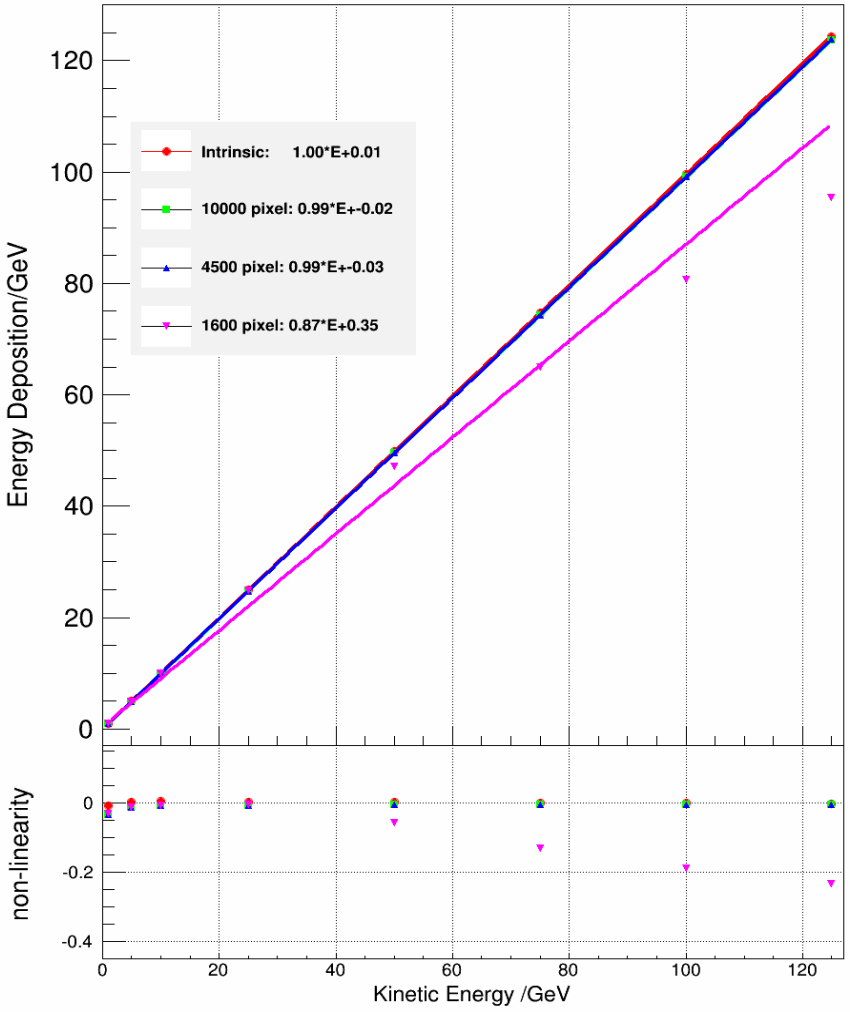

| ECAL Digitization |
|---|
| **Hit Energy** |
| Transform energy to light yield (LY) (352keV/MIP, 20p.e./MIP) |
| Detection threshold: 0.5MIP |
| Get fired SiPM pixel with LY (using model on page4, random outcome) |
| Correct for saturation using the response curve Recover LY |
| Transform LY to energy |
| If < 0.5 MIP, set energy to 0 |
| Apply strip splitting algorithm |
| Reconstruction |

# ECAL Energy Linearity

No SiPM non-linearity correction



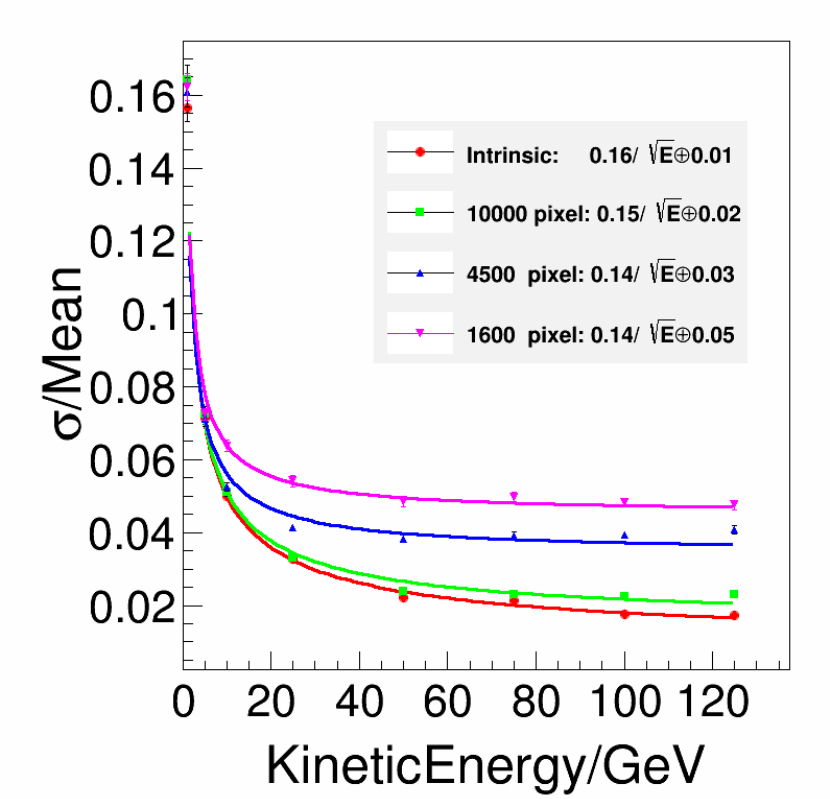

With SiPM non-linearity correction



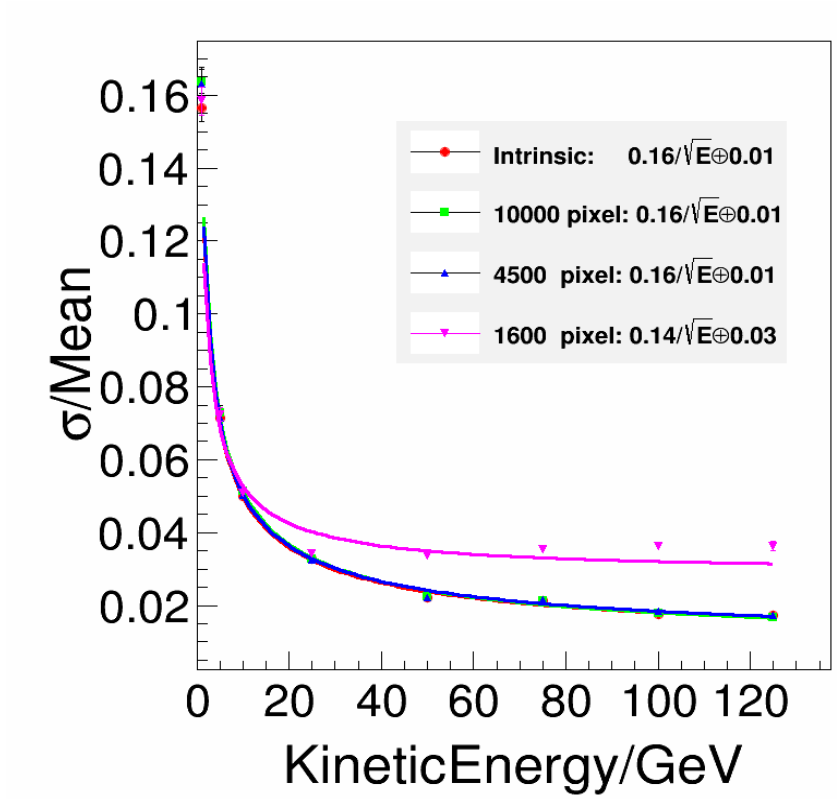

Single photon events

# ECAL Energy Resolution

No SiPM non-linearity correction




With SiPM non-linearity correction



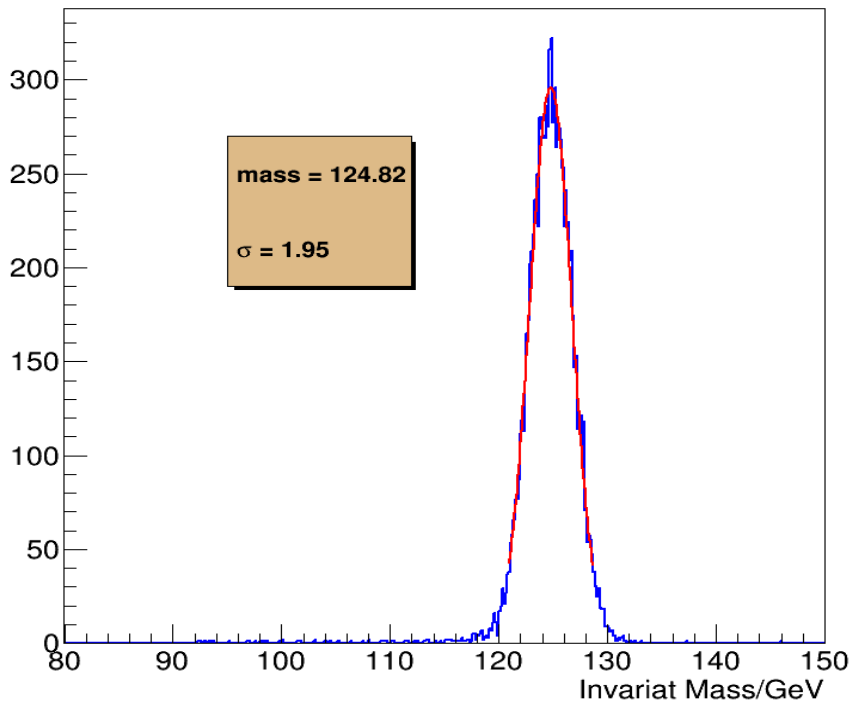

SiPM parameters

| Number of Pixels | 10000 | 4500 | 1600 |
|---|---|---|---|
| MIP LY / p.e. | 20 | 50 | 60 |
| PDE / % | 10 | 25 | 30 |

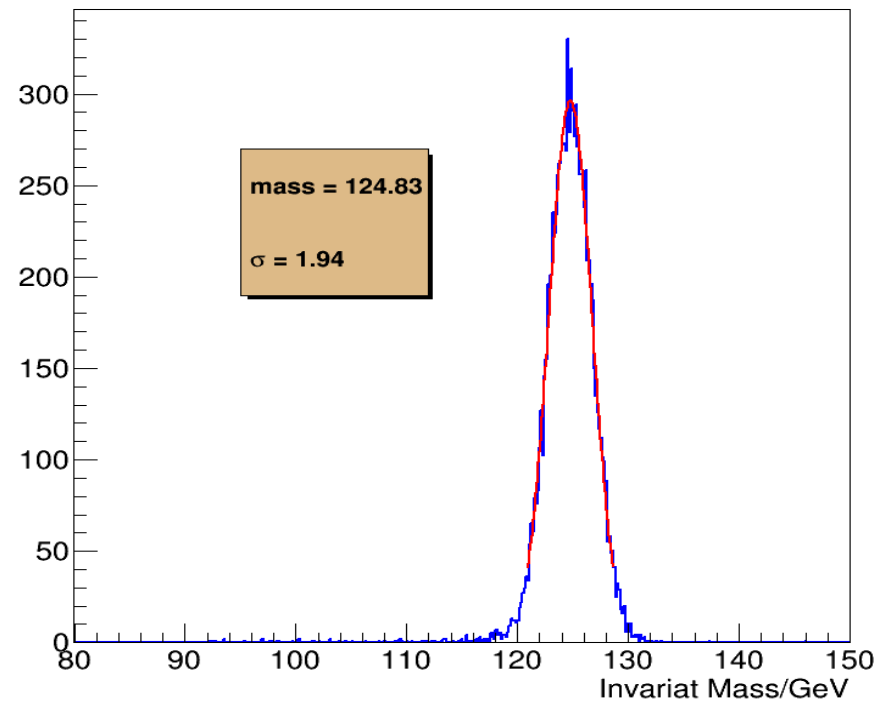
# ECAL Mass Resolution

- Using H→$\gamma\gamma$ as a benchmark process

10000-pixel SiPM

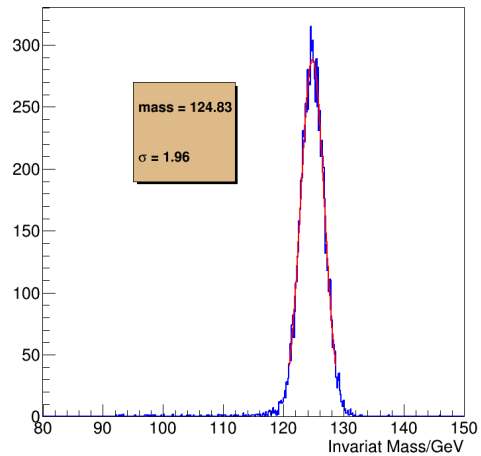



Infinite-pixel SiPM

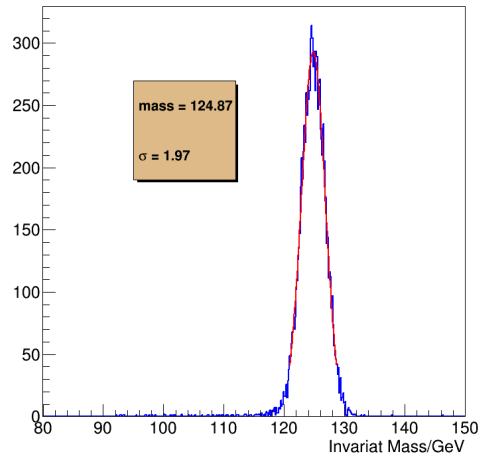


# H→γγ with Different SiPM Linearity

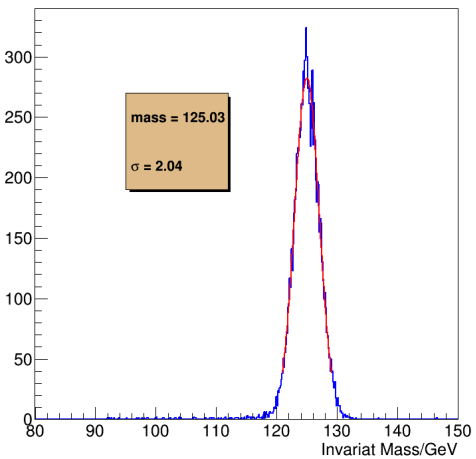
4800 pixels



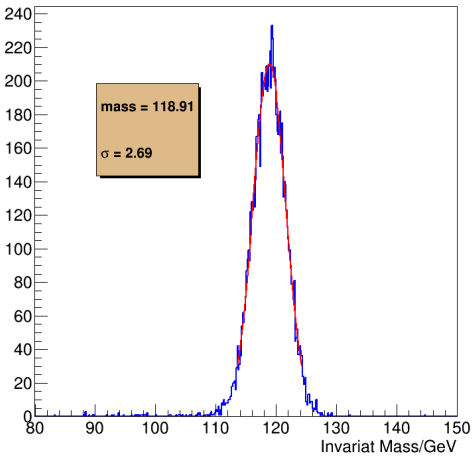

2600 pixels




1600 pixels




800 pixels



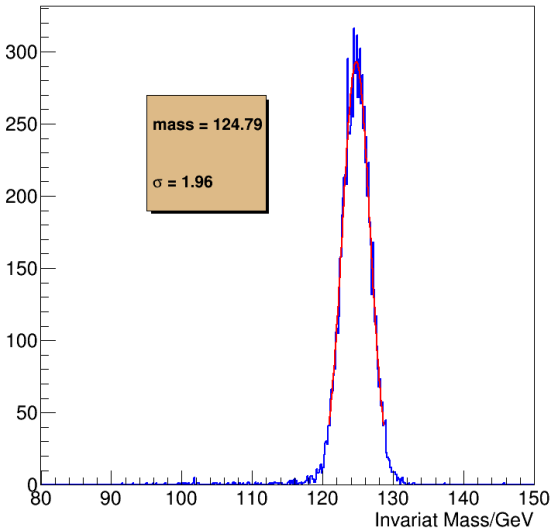

SiPM non-linearity correction applied in all cases

| Number of Pixels | infinite | 10000 | 4800 | 2600 | 1600 | 800 |
|---|---|---|---|---|---|---|
| MIP LY / p.e. | 20 | 20 | 20 | 20 | 20 | 20 |
| Mass / GeV | 124.83 | 124.82 | 124.83 | 124.87 | 125.03 | 118.91 |
| $\sigma/Mean$ | 1.55% | 1.56% | 1.57% | 1.58% | 1.63% | 2.26% |

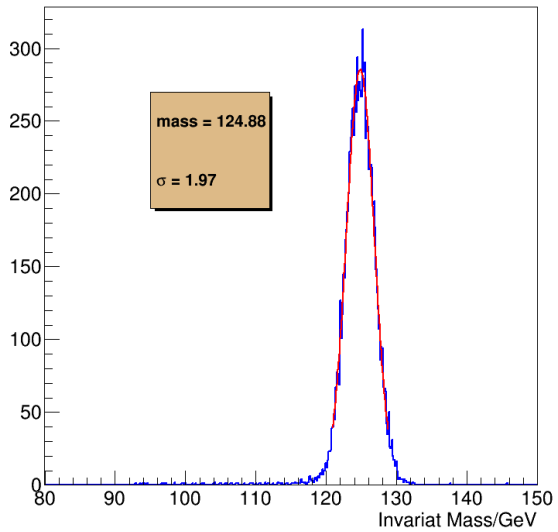
LY remains the same to see the net effect of changing number of pixels

# Returning to Normal PDE

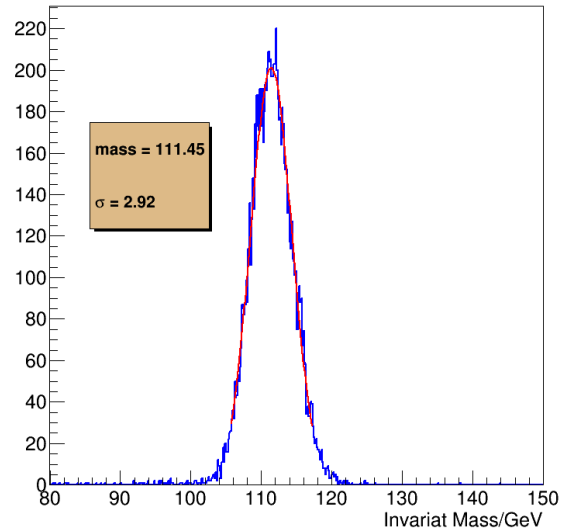
10000 pixels




4500 pixels




1600 pixels




| Pixel | 10000 | 4500 | 1600 |
|---|---|---|---|
| MIP LY / p.e. | 20 | 50 | 60 |
| PDE / % | 10 | 25 | 30 |
| Mean / GeV | 124.79 | 124.88 | 111.45 |
| $\sigma/Mean$ | 1.57% | 1.58% | 2.62% |

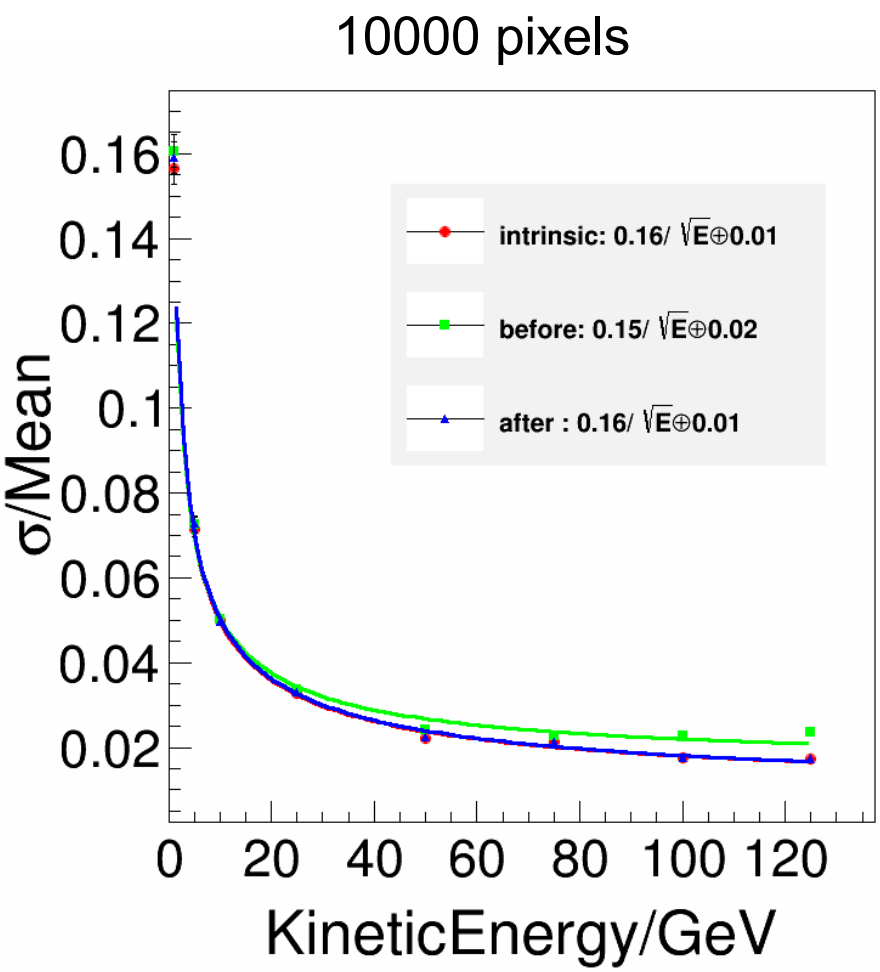
# Summary

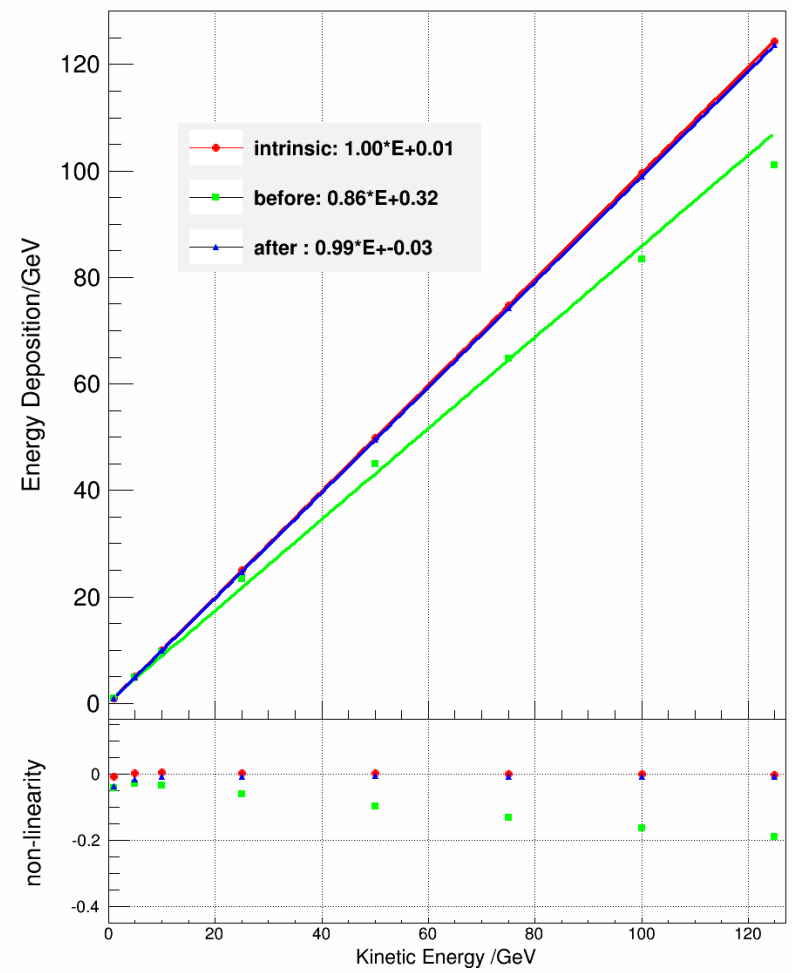
- Non-linear response of SiPM has been simulated and implemented in a full ECAL simulation chain.
- The impact of the SiPM non-linearity on Sci-ECAL performance has been studied based on the simulation.
- With no more than five thousand SiPM pixels, a Sci-ECAL can have a good linearity and resolution for ~> 100GeV EM objects when correcting for SiPM non-linearity.
- $H \rightarrow \gamma\gamma$ measurement is even less demanding in terms of SiPM dynamic range.

# Backup

# Adding 10% non-uniformity

- Adding additional 10% non-uniformity to light yield barely has visible impact on ECAL energy response.



# Adding Photon Poisson Fluctuation

- Adding Photon Poisson Fluctuation makes little difference to ECAL energy response.

10000 pixels