# $H \rightarrow \gamma\gamma$ with the IDEA calorimeter

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# The context

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50k simulated $e^+e^- \to HZ \to \gamma\gamma\nu\bar{\nu}$ collision events with the full idea geometry

- With magnetic field, with and without the solenoid material
    - but now focusing on the events with no solenoid
- Not using the full calorimeter granularity, rather the "coarse" one.
- Calibration constants from single electrons applied to all towers.
    - Update using the calibration constants for G4 10.5p1
- The idea is to study the calorimeter response to photons using the Higgs boson as a candle.

# New for this time

- Understanding the mass resolution:
  - **Response fine scan:** 5 M $H \rightarrow \gamma\gamma$ events at Sussex (can make the events available for everyone if needed).
    - Three days to get to 95% of jobs done
    - Events used to a fune analysis of the detector response to photons
  - Comparison with single particle simulation:
    - A full energy scan of photons in one random tower

# Step 2 - calibration based on tower energy share

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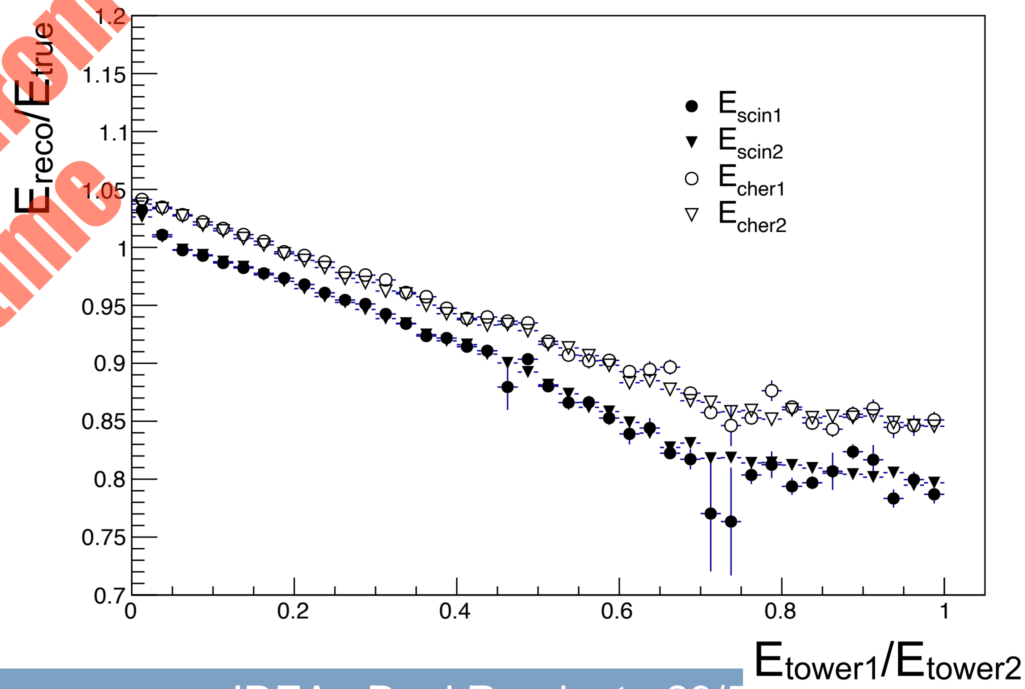
It is known that EM energy scale depends on impact point of the photon on the calorimeter

- tower constants derived by looking at single particle response shoot in the tower centre

—> Plot the energy the photon response as a function of energy share between the photon.

- Apply this as an additional calibration (by reading the calibration constant directly from this histogram)

Reminder from last time

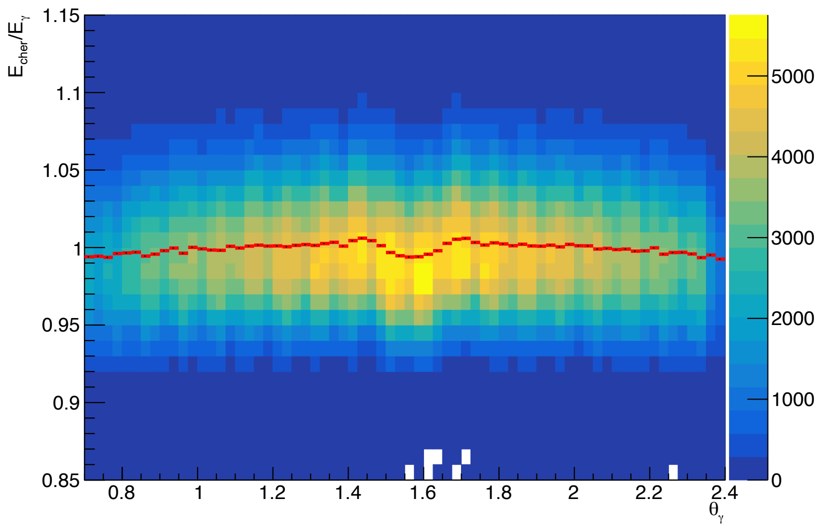


# Fine eta calibration scan

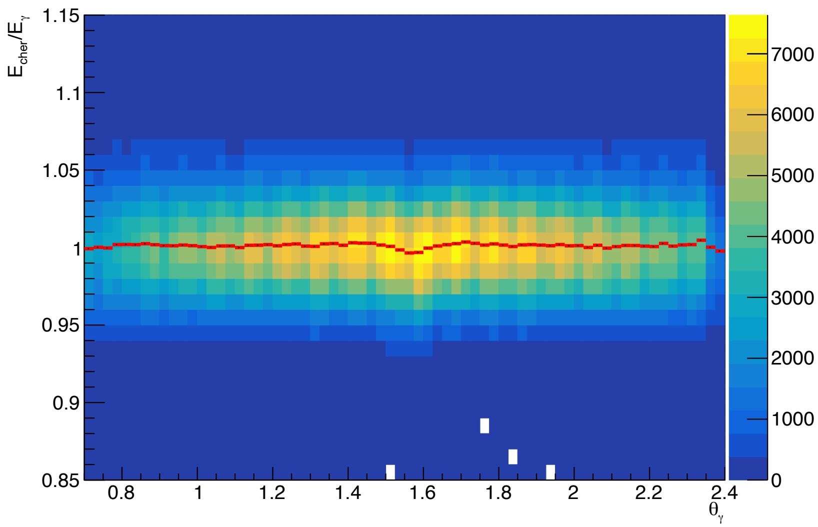
- All plots include the correction for the energy share between the two leading towers.
- Look at the photon response Vs theta. Is the response uniform?
- Derive a second correction:

  Flatten the response at 1 as a function of theta

Leading photon - scintillation signal




Leading photon - cherenkov signal



# Summary - energy calibration

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My photon energy is

$$E(\theta, E_{\text{share}}) = \alpha(E_{\text{share}})\beta(\theta) \sum_{i \epsilon \text{jet}} c_i n_i$$

$n_i \rightarrow$ number of photons in tower i

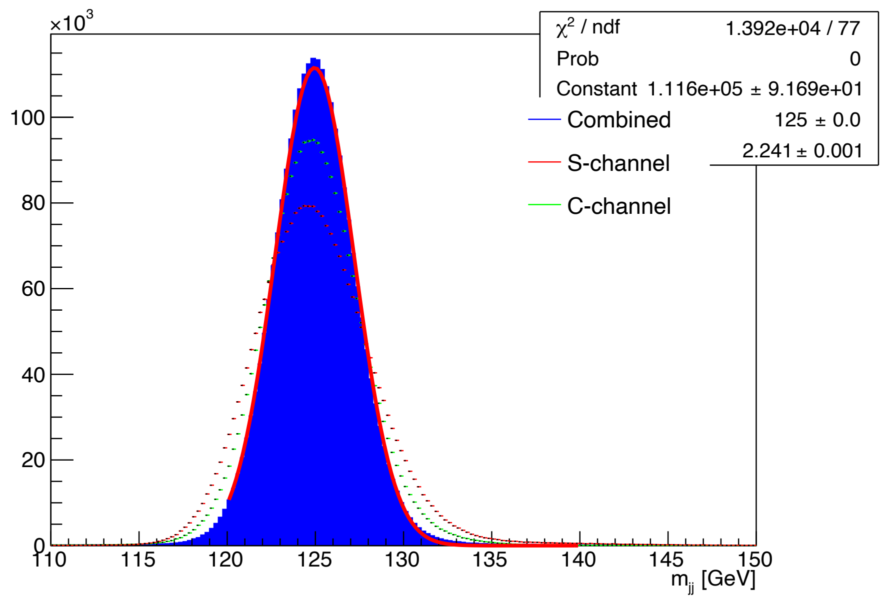
$E_{\text{share}} = \frac{E_1}{E_0} \rightarrow$ energy ratio of the two most energetic towers

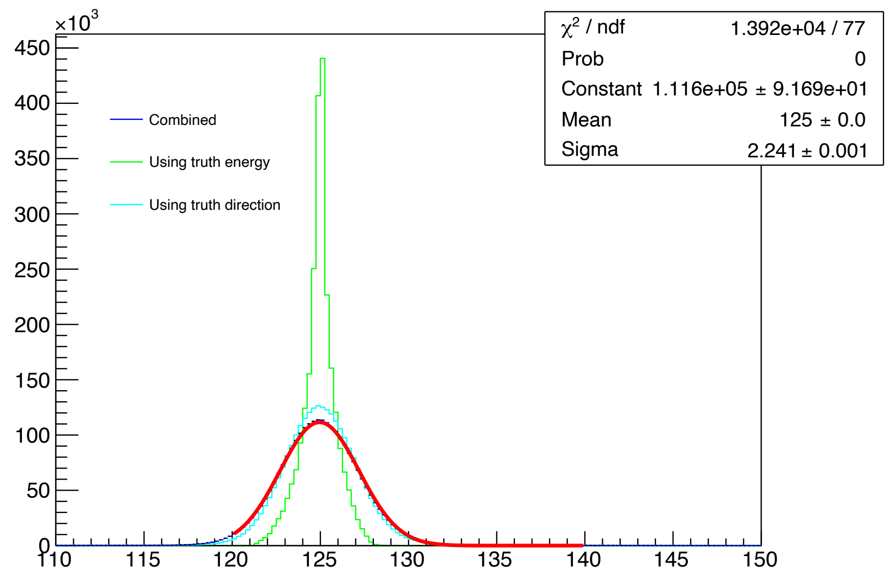
$c_i \rightarrow$ GeV/number of photons (derived with single electrons)

$\alpha(E_{\text{share}}) \rightarrow$ Correction for impact point in the tower - derived using truth, but in principle obtainable from $Z \rightarrow e^+e^-$

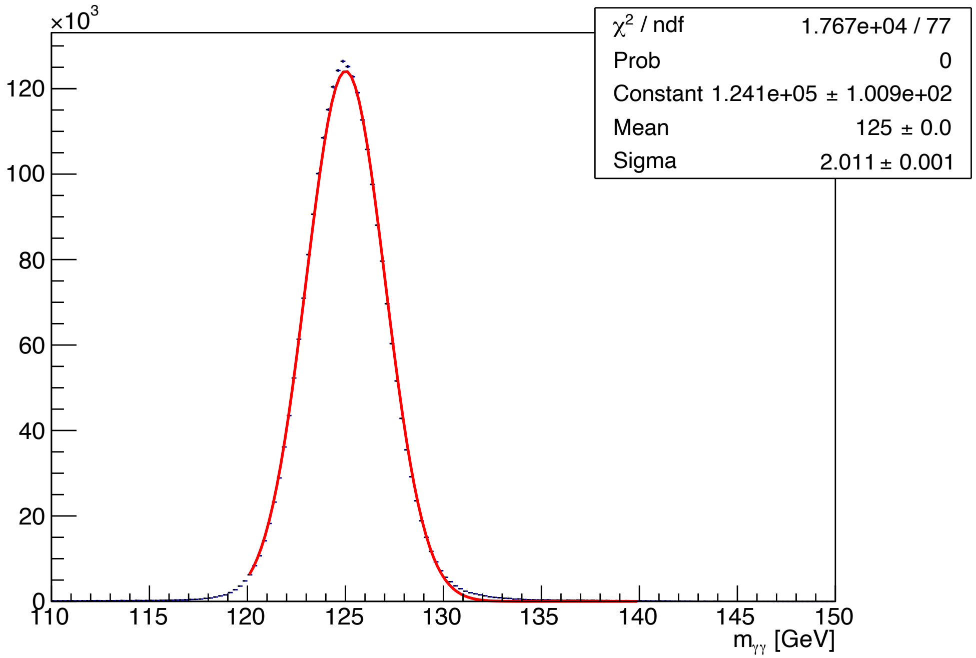
$\beta(\theta) \rightarrow$ residual theta correction

Cherenkov and scintillation jet combined with a simple arithmetic average



# Neglecting angular resolution




Reminder: 2 GeV on mass mean
2/√2 = 1.4 GeV on the energy.
Assuming 60 GeV photons this
means 2.3% in energy.

| Calibration applied | Higgs boson mass resolution (GeV) |
|---|---|
| $\sum_{i \epsilon \text{jet}} c_i E_i$ | 2.89 |
| $\beta(E_{\text{share}}) \sum_{i \epsilon \text{jet}} c_i E_i$ | 2.29 |
| $\alpha(\theta)\beta(E_{\text{share}}) \sum_{i \epsilon \text{jet}} c_i E_i$ | 2.24 |
| $\alpha(\theta)\beta(E_{\text{share}}) \sum_{i \epsilon \text{jet}} c_i E_i$ and use truth direction | 2.01 |

# Verifying response in one tower

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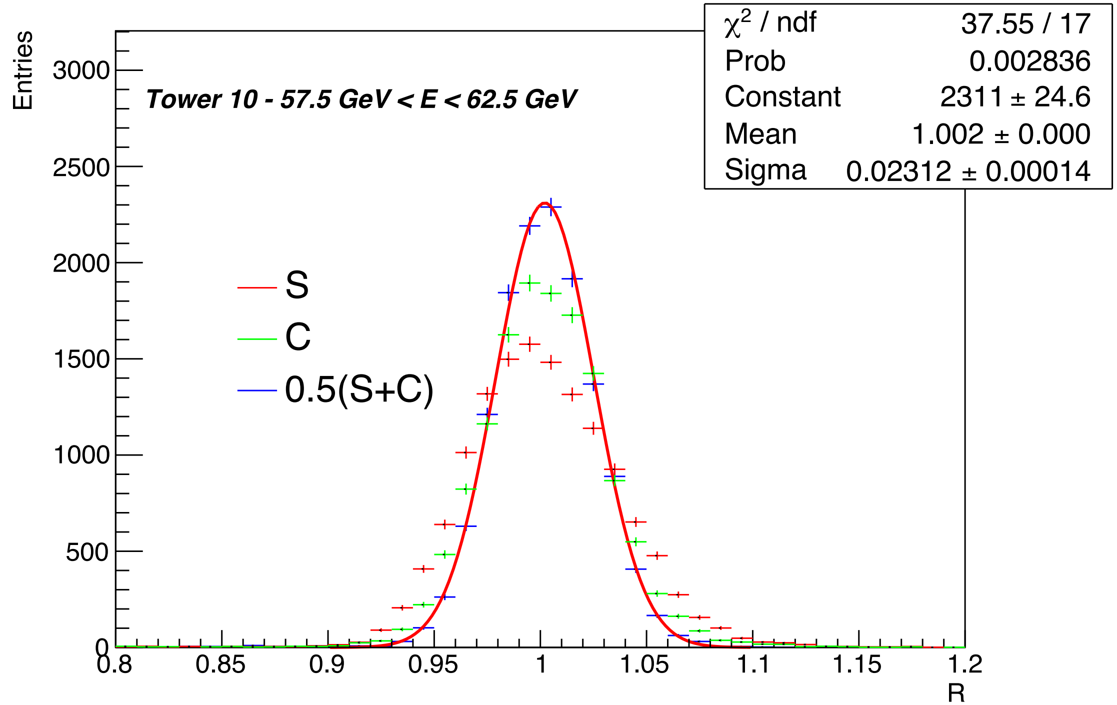
$R = \frac{E_\gamma^{\text{reco}}}{E_\gamma^{\text{truth}}}$, histogram filled with $55\ \text{GeV} < E_\gamma^{\text{truth}} < 65\ \text{GeV}$, truth level photon direction $\theta_\gamma, \phi_\gamma$ such as to get all photons in a specific tower

Next step is to double check the resolution with single particles



# Single particle

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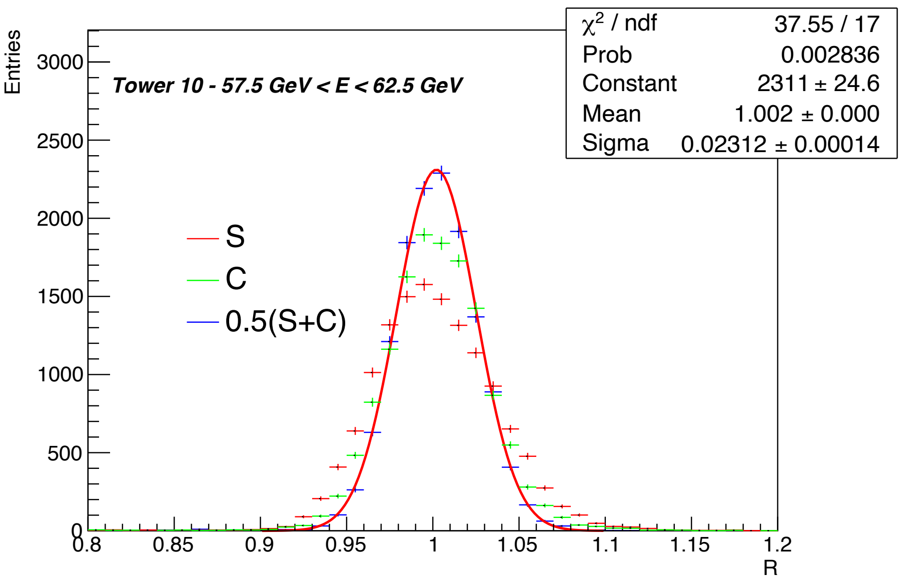
Generated **5000 E=60 GeV single photon events** in tower 10. The beam is **pencil-like.**

Despite applied calibration, $H \to \gamma\gamma$ single photon energy resolution **about 20% worse** than in single particle configuration. Why?

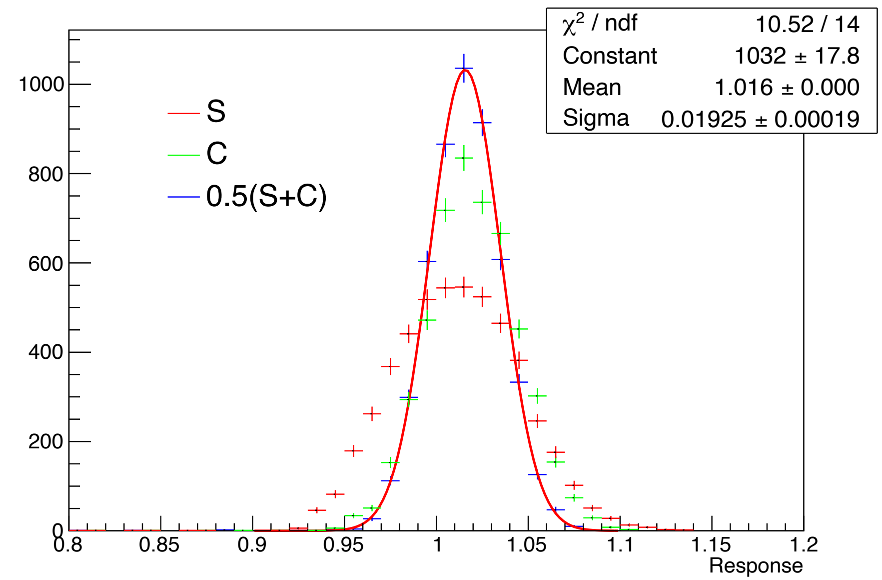
- Hp: degradation of the resolution with the impact point (the $\beta(E_{\mathrm{share}})$ correction).

Study the **single particle resolution** at 60 GeV as a function of the **beam opening angle**.

$H \to \gamma\gamma$




Single particle



# Single particle response

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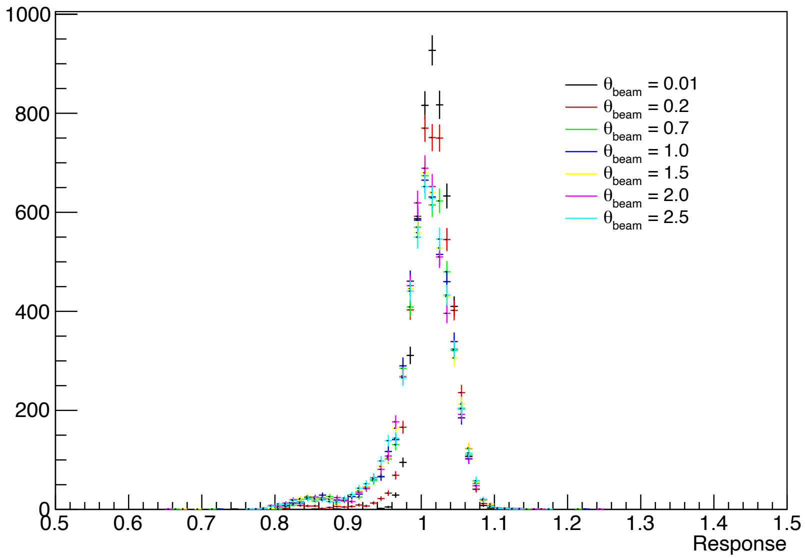
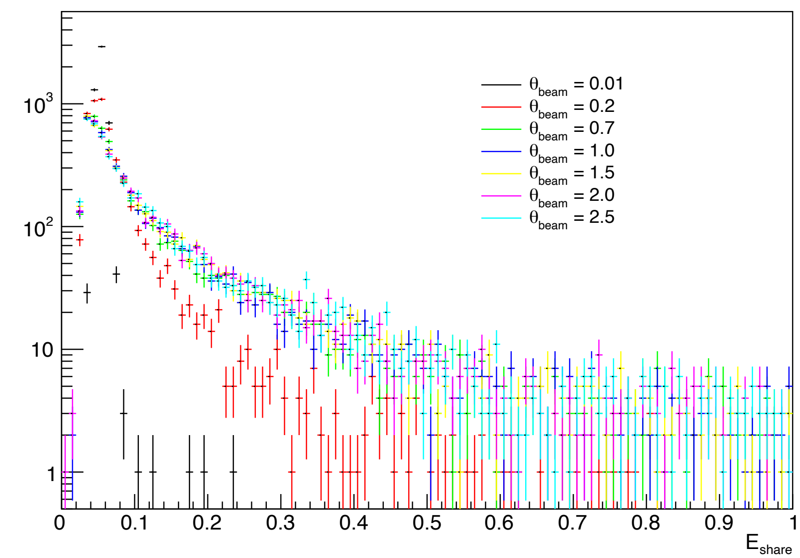
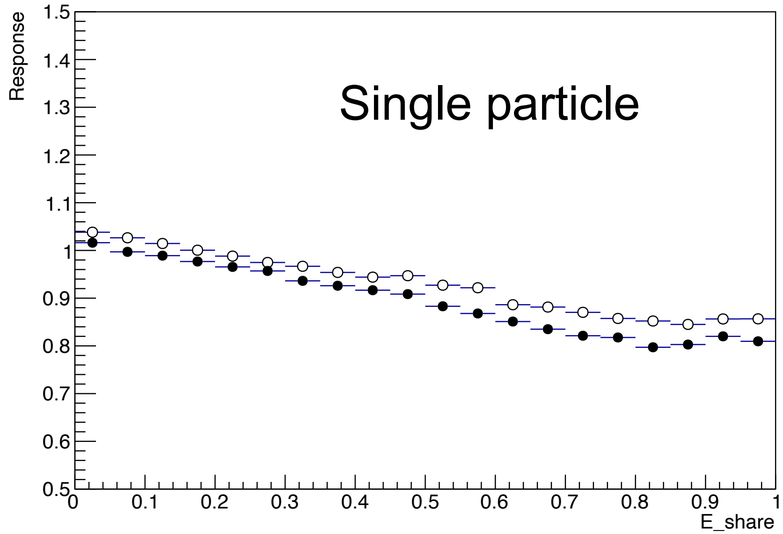
- Use a 60 GeV beam1d single particle beam with increasing opening angle and look at the response (no $\beta(E_{share})$ calibration applied).
- Resolution **worsening up to a plateau** (roughly corresponding to the cell theta
- Clear evolution of the $E_{share}$ tail with the angle

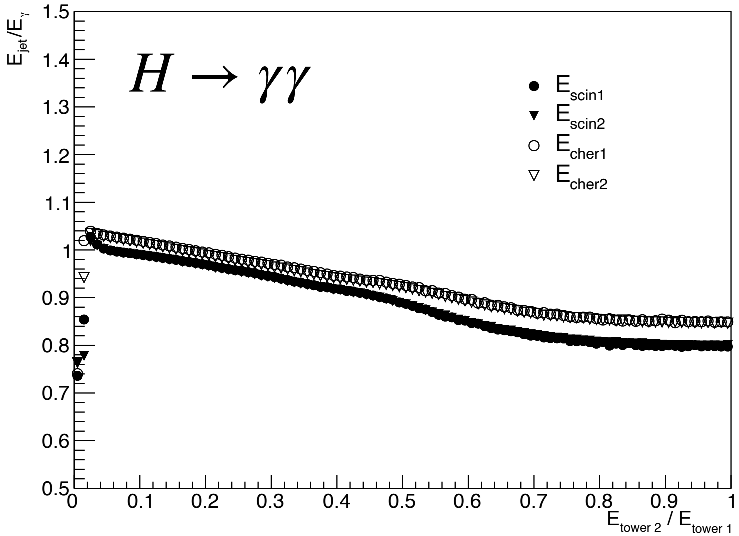


# Single particle $\beta(E_{share})$ correction

Re-deriving the $\beta(E_{share})$ correction from single particle and comparing to $H \to \gamma\gamma$. Consistency between the two.

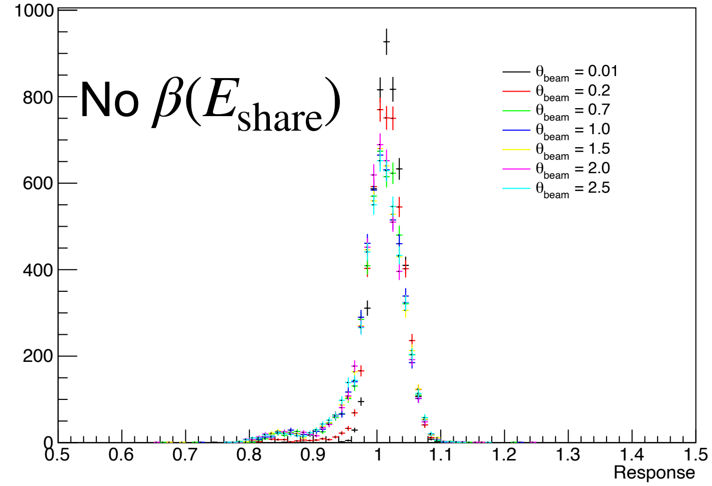


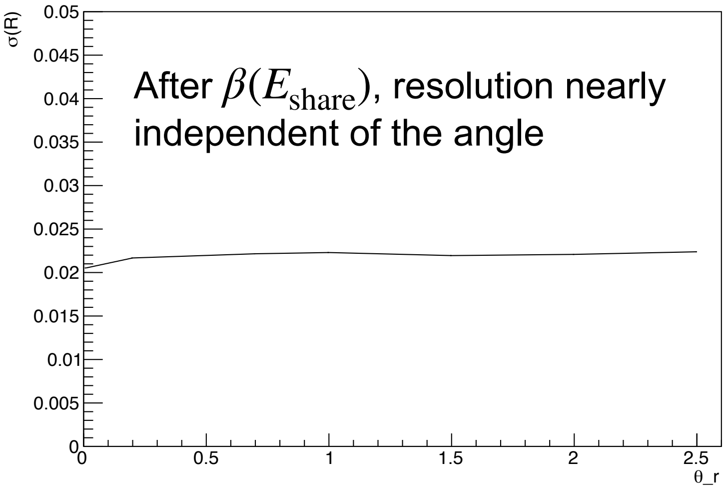



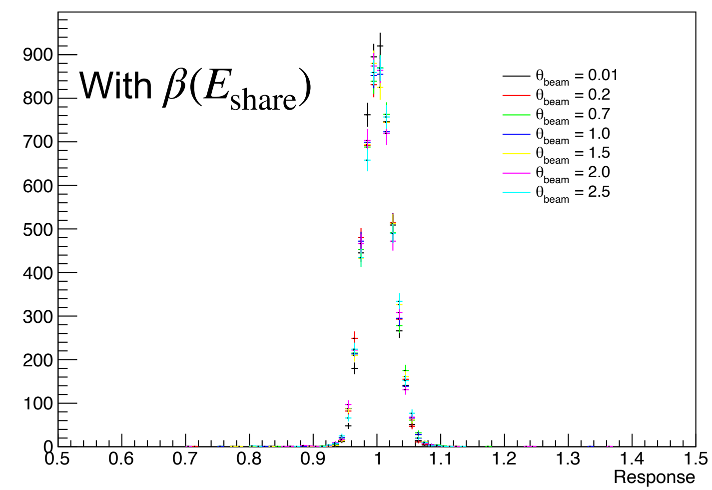
# Applying $\beta(E_{share})$ correction

Application of $\beta(E_{share})$ brings **the resolution in full consistency with collision events** (it was 2.3%)

- Not fully recovering the ideal, pencil-like beam resolution, though….. but I will call it a day



# Summary

Few things I have learnt:

- Derived a **set of corrections** for photons that bring the Higgs boson mass resolution to $\sigma_m = 2\ \mathrm{GeV}$ (neglecting angular resolution), or relative resolution of 1.6%
    - The most important correction is $\beta(E_{\mathrm{share}})$
- Resolution about **20% worse than expected from single particle studies**.
- **However:** when angular smearing is introduced to single particles, resolution **fully consistent with collision events**

Next Step:

- see effect of additional material (solenoid) upstream the calorimeter.

# Backup

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# H →$\gamma\gamma$ - the basics

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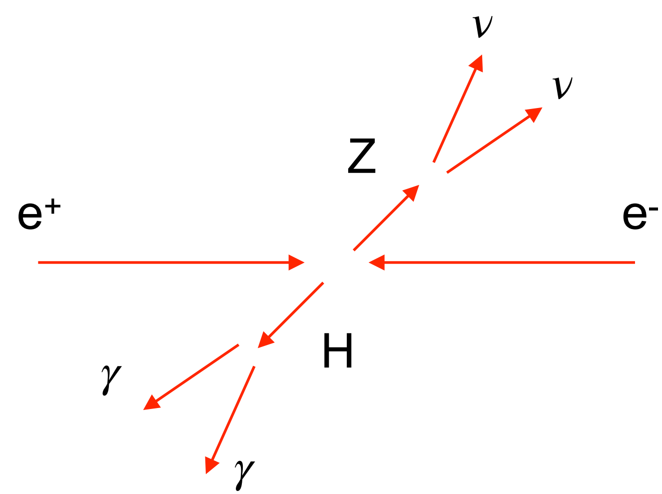
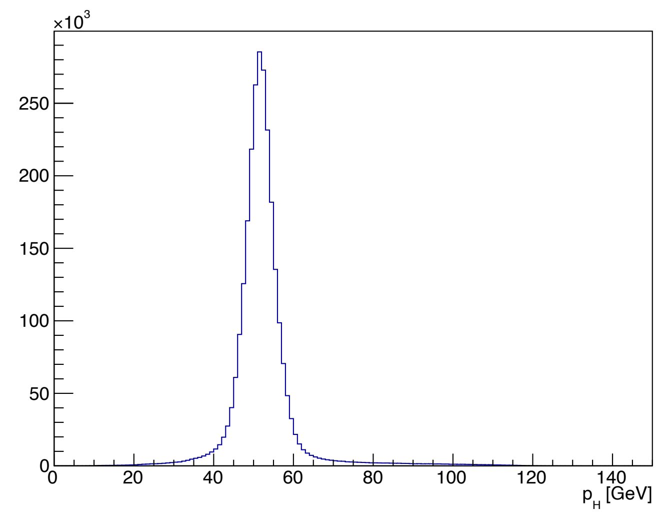
Z and H produced in a reference frame where $\sqrt{s} = 240\ \mathrm{GeV}$. For $m_H = 125\ \mathrm{GeV}$ and $m_Z = 91.2\ \mathrm{GeV}$, the momentum of the Higgs boson is

$$p_H = \frac{\sqrt{s + m_H^2 - m_Z^2}}{2\sqrt{s}} = 51.6\ \mathrm{GeV}$$




The spectrum of each photon is flat in energy (composition of monochromatic two-body decay in Higgs CM + Higgs boost)

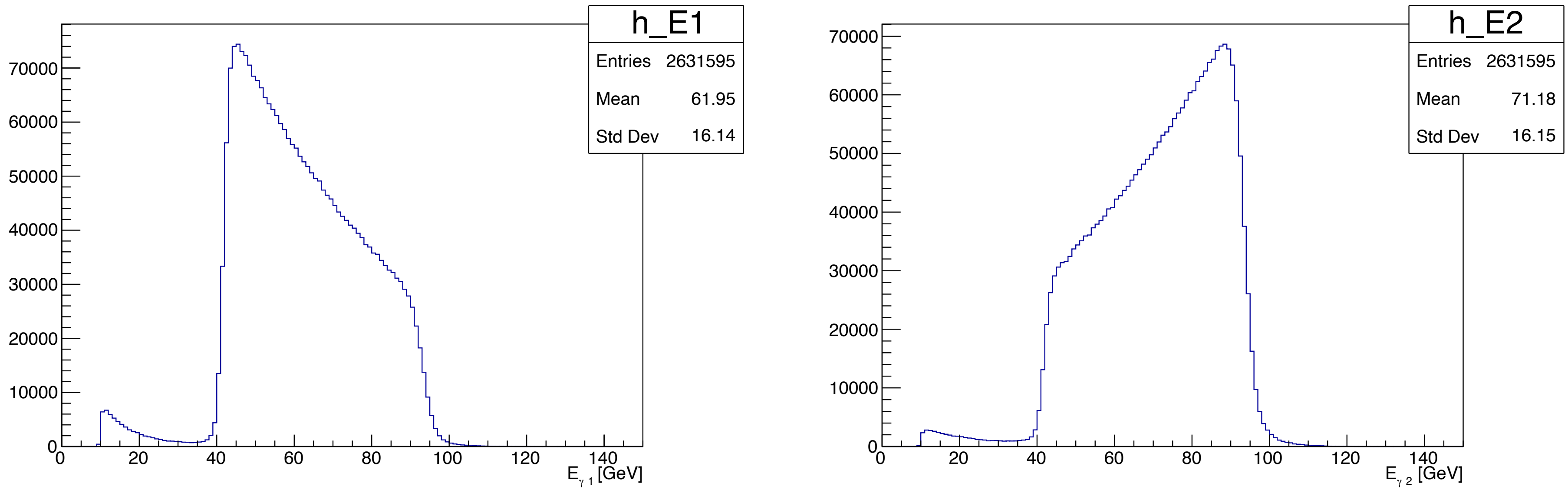
# $H \rightarrow \gamma\gamma$ - the basics

The minimum and maximum photon energy in the lab frame are given by

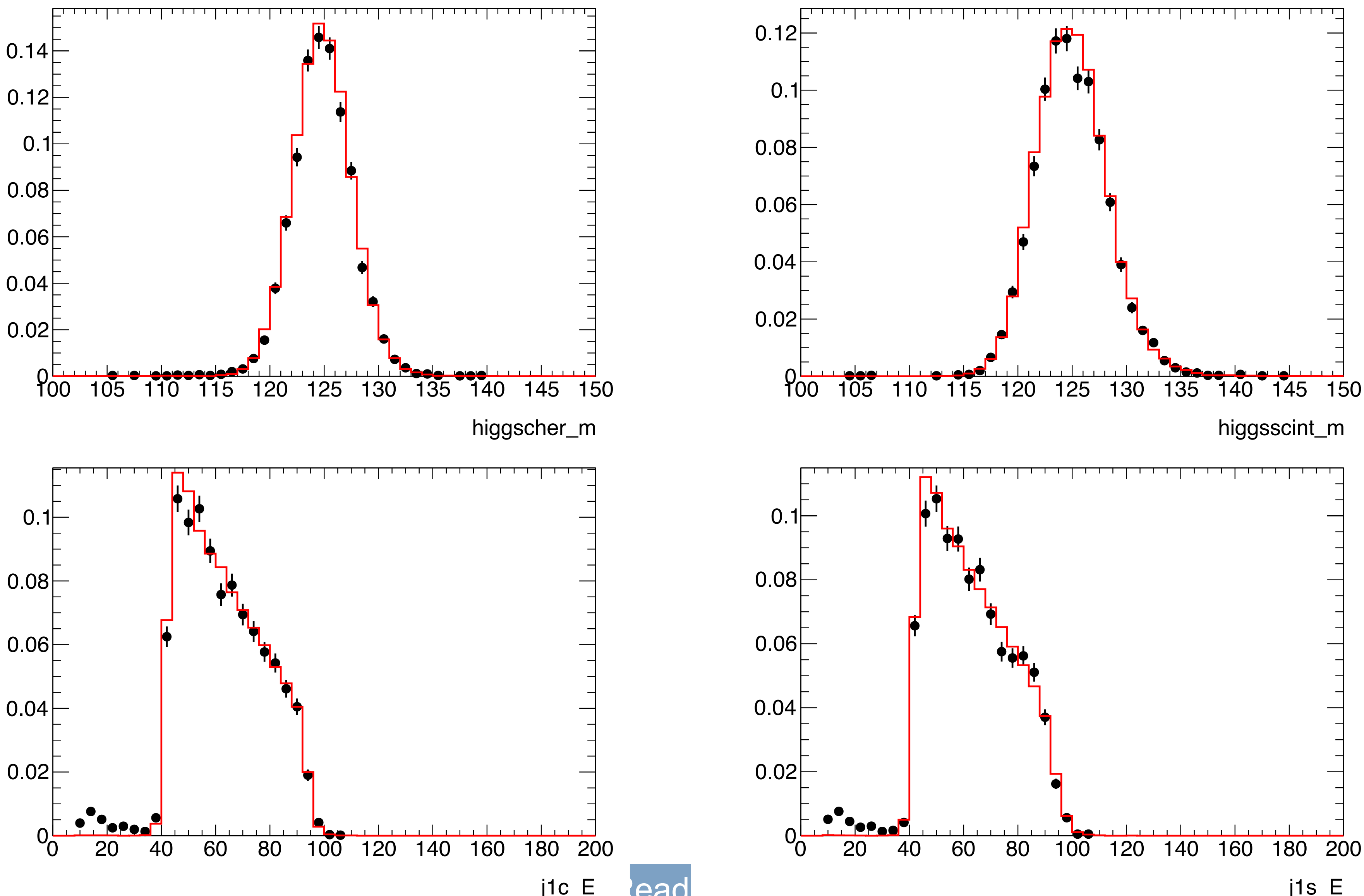
$$E_{\pm} = \gamma \frac{m_H}{2} \left(1 \pm \beta\right) \qquad \gamma = \frac{E_H}{m_H} = 1.08 \qquad \beta = \frac{p_H}{E_H} = 0.38$$

$$E_{\min} = 41.8 \text{ GeV} \qquad E_{\max} = 93.4 \text{ GeV}$$

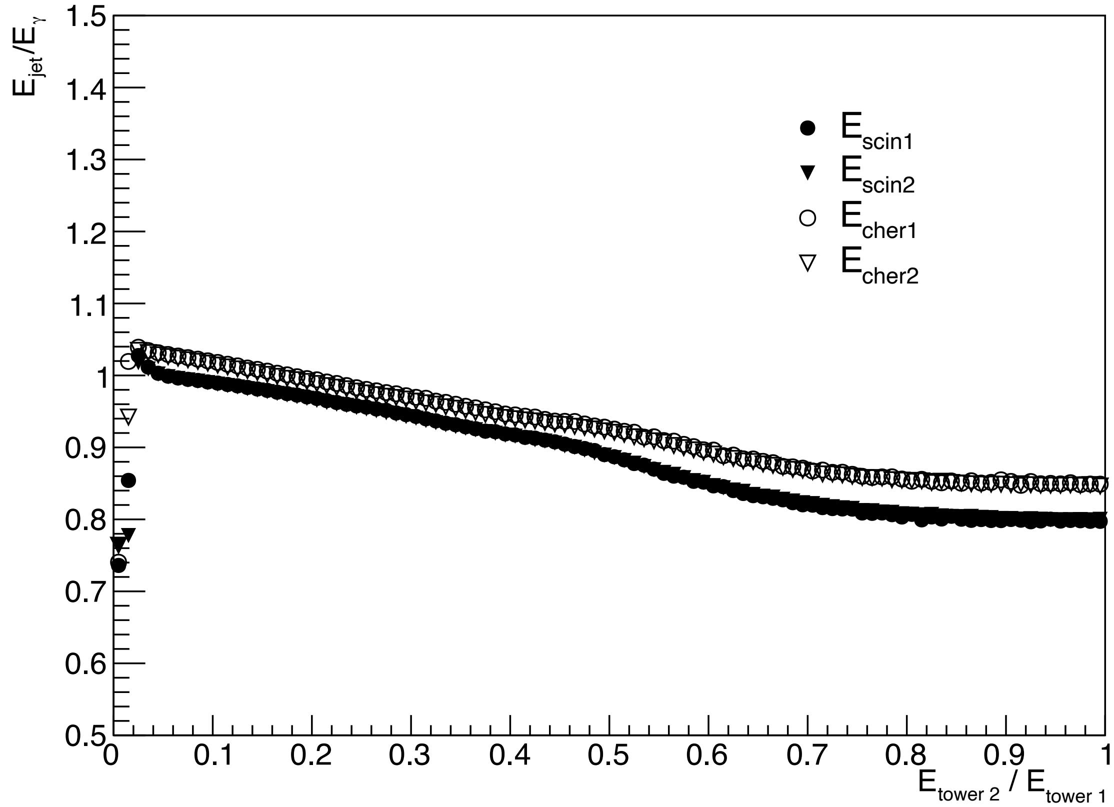
Distribution not flat, probably just some bias in the order used for reconstruction



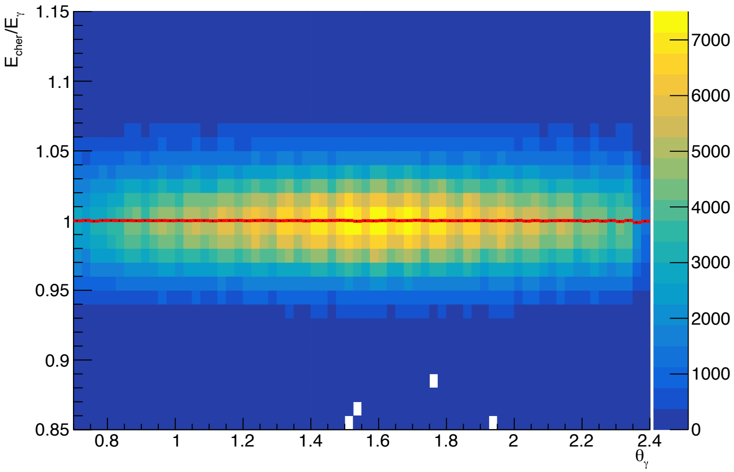
# Sussex simulation validation

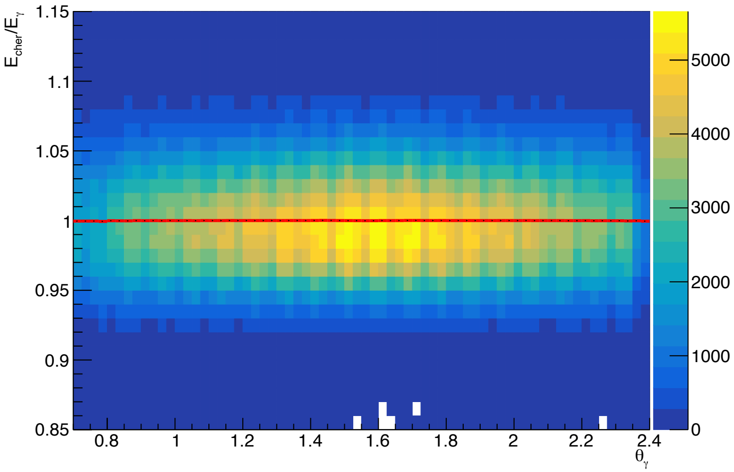


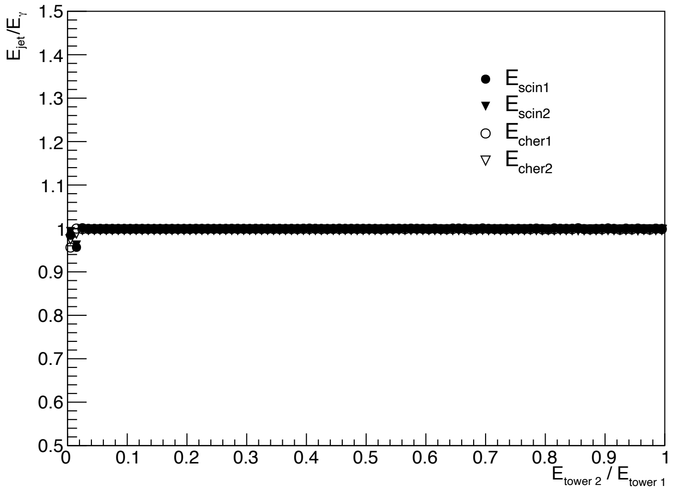
# Energy share calibration



# Fully calibrated response

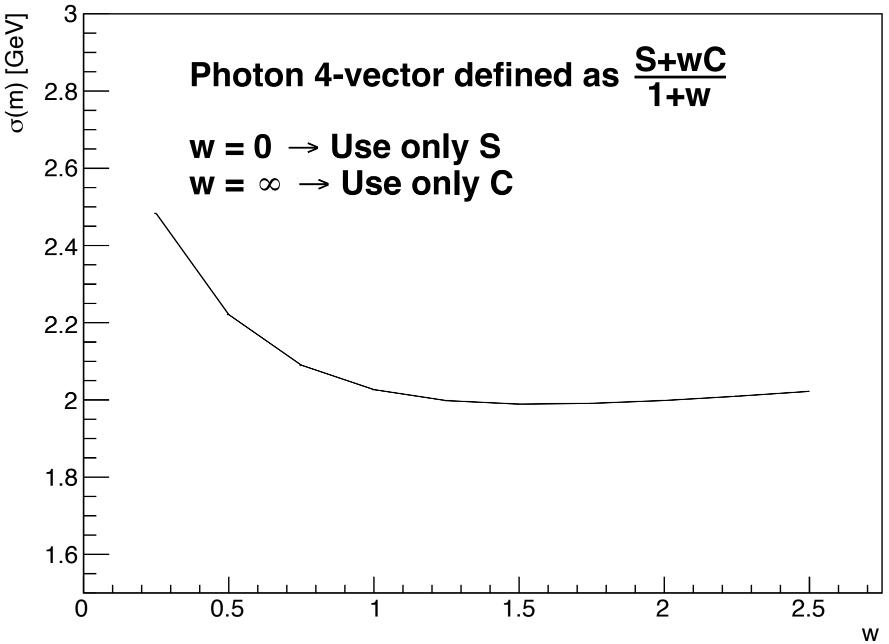


# S and C combination

Study of how much the mass resolution depend on the way S and C are combined



# Verify single particle configuration