# Lectures on calorimetry

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Lecture 4

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# Plan of lectures

Lecture 1

- Why/what calorimeters ?
- Physics of EM showers
- Calorimeter Energy Resolution

Lecture 2

- Physics of hadronic showers
- ATLAS & CMS calorimeters
- Calorimeter Objects

Lecture 3

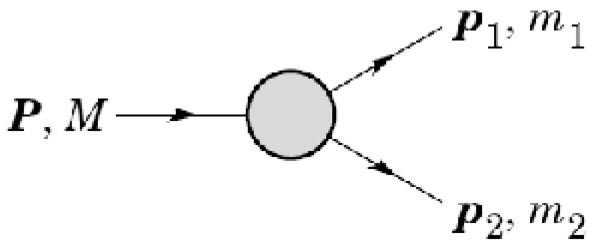
- Example of calorimeters (suite)
- Future of calorimetry

Lecture 4

Tutorial
Exercises

# Resolution

- Two-body decay. Ex: H→γγ

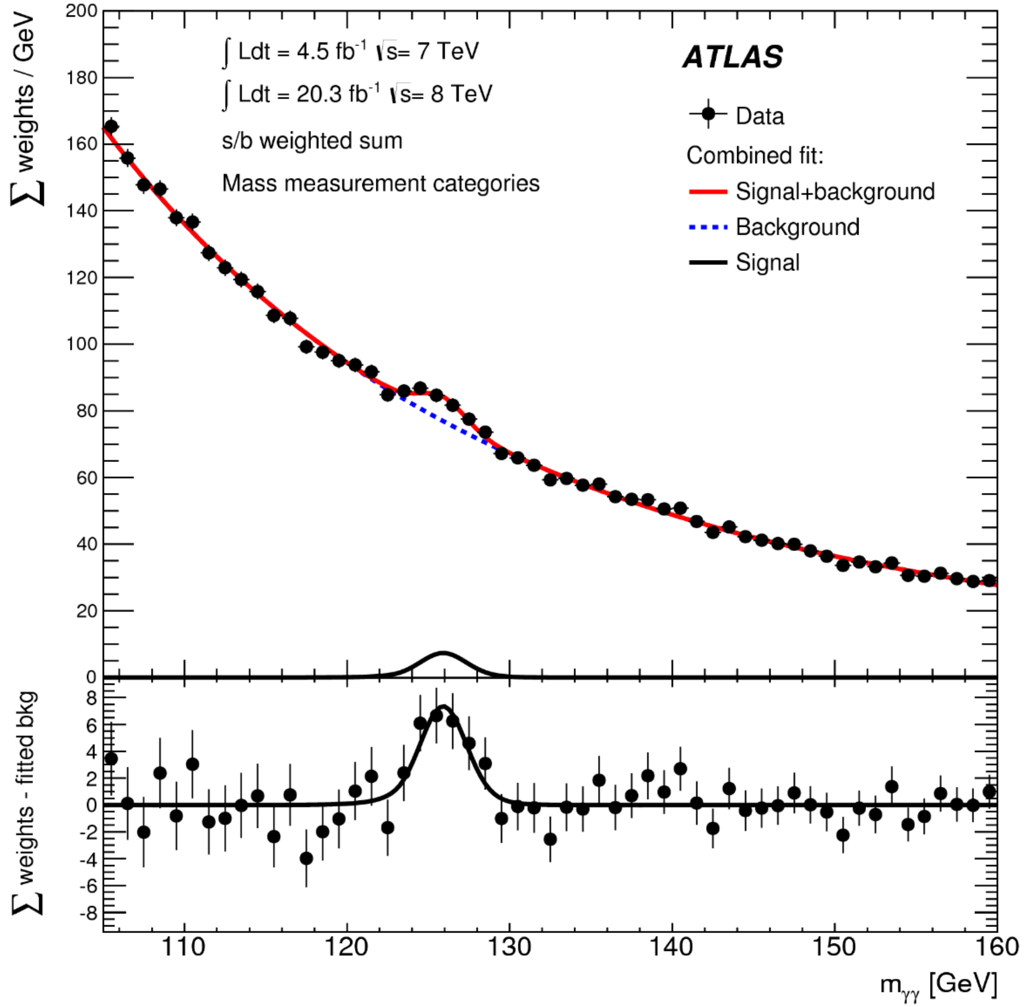


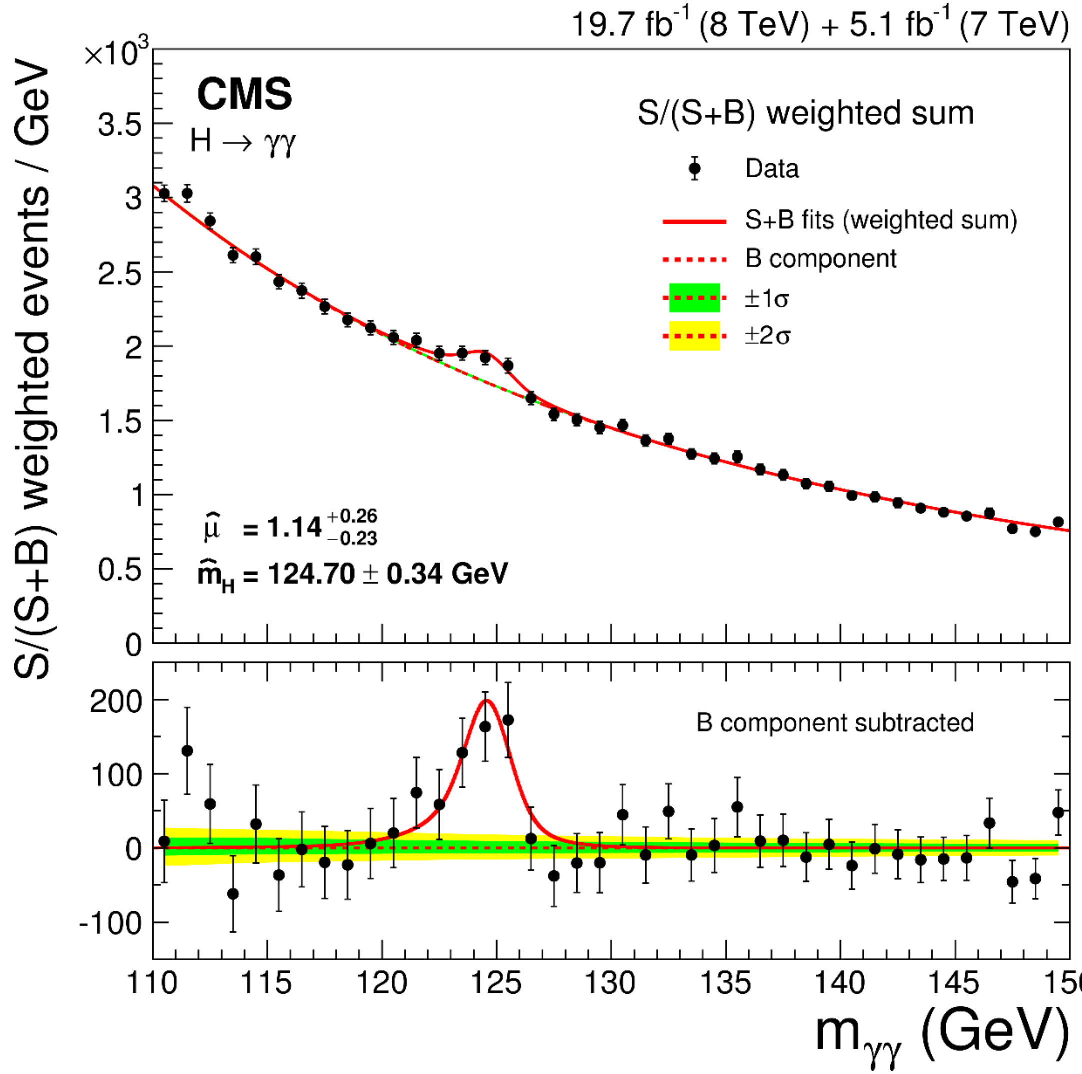

$$m_{\gamma\gamma} = 2E_1E_2(1-\cos\theta_{\gamma\gamma})$$

$$\frac{\sigma_m}{m_{\gamma\gamma}} = \frac{1}{2}\sqrt{\left(\frac{\sigma_{E1}}{E_1}\right)^2 + \left(\frac{\sigma_{E2}}{E_2}\right)^2 + \left(\frac{\sigma_\theta}{tg\theta/2}\right)^2}$$

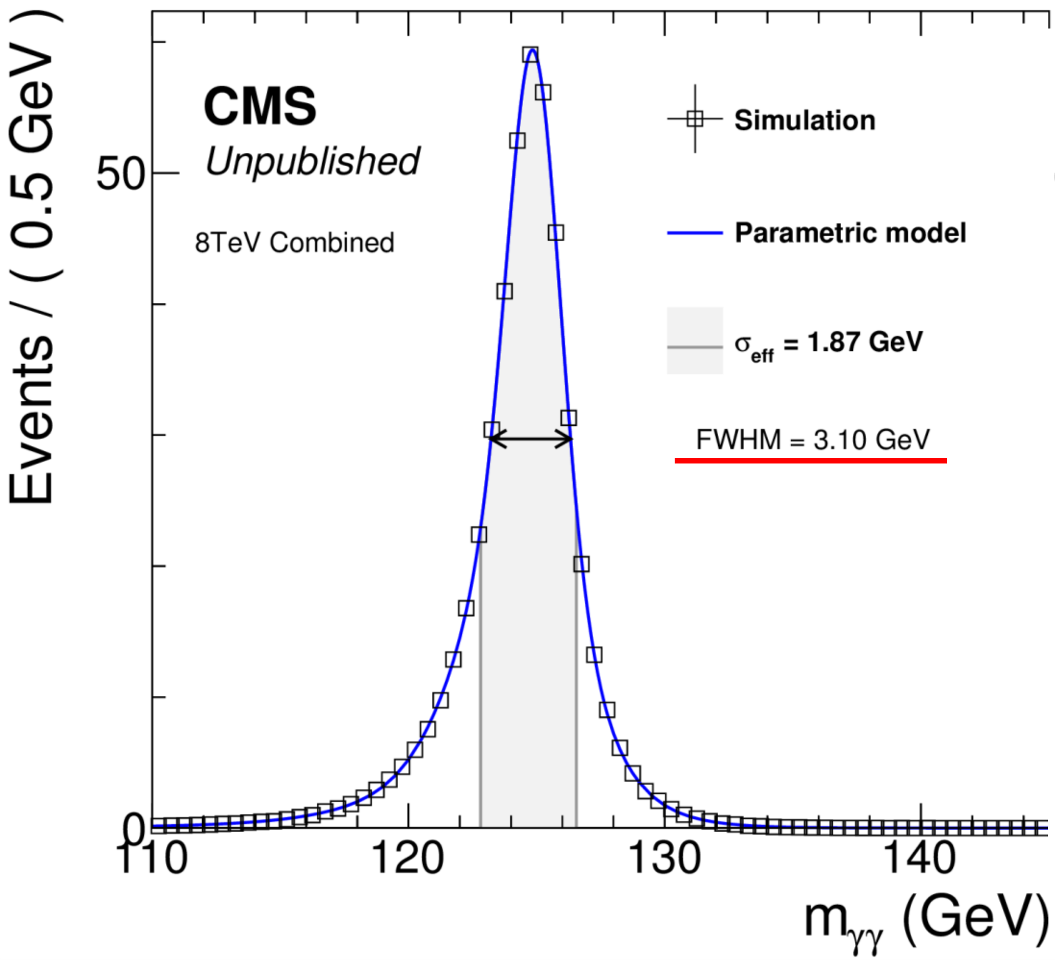
- Resolution on E comes from calorimeters
- How do we measure position of photons ? (in CMS and ATLAS)

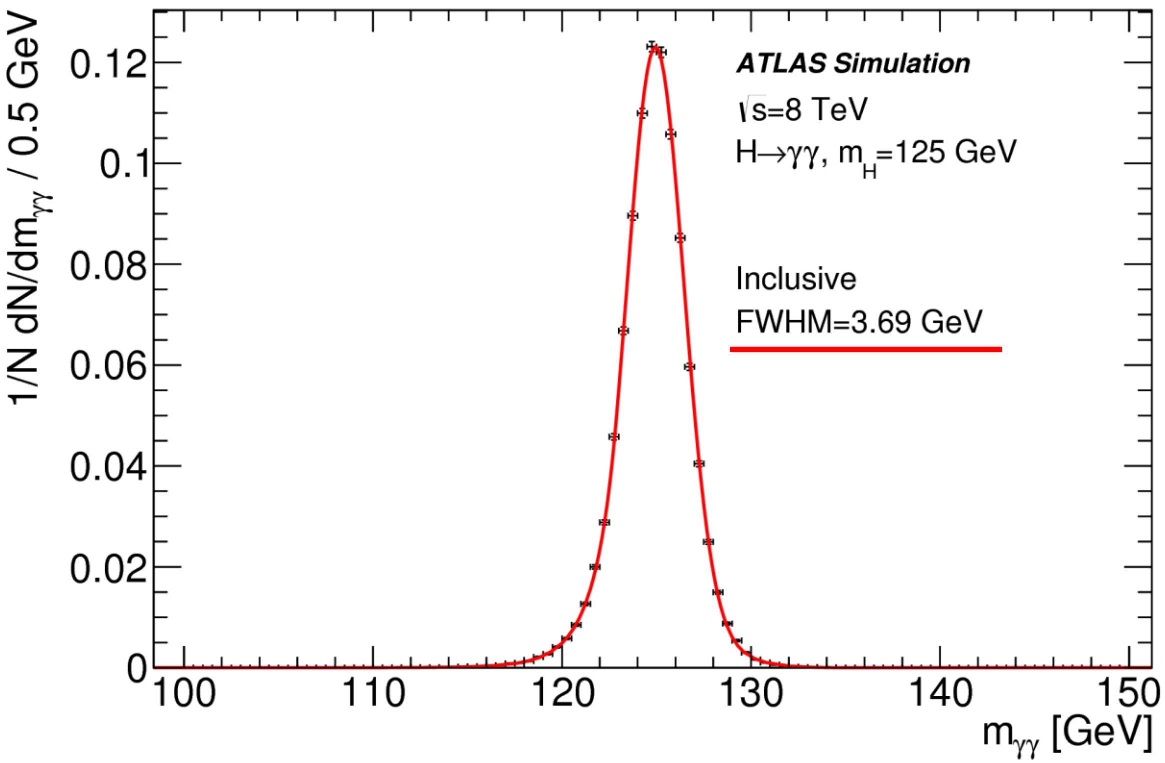
# ATLAS/CMS Results (1)



# ATLAS/CMS Results (2)



# Resolution (again)

**CMS**

$$\frac{\sigma(E)}{E} = \frac{0.03}{\sqrt{E(GeV)}} \oplus \frac{0.3}{E(GeV)} \oplus 0.005$$

(test beam)

**ATLAS**

$$\frac{\sigma(E)}{E} = \frac{0.1}{\sqrt{E(GeV)}} \oplus \frac{0.3}{E(GeV)} \oplus 0.007$$

(test beam)

- Fill the table for both calorimeters
- Comment ?

| | 10 GeV | 1 TeV |
|---|---|---|
| Stochastic (GeV) | | |
| Noise (GeV) | | |
| Constant (GeV) | | |
| $\sigma$(E ) (GeV) | | |
| $\sigma$(E ) / E (%) | | |

# Exercise: Crystal Calorimeter

| | Atomic Mass | X0 (g.cm-2) | $R_M$(g.cm-2) |
|---|---|---|---|
| Cs | 132.9 | 8.31 | 15.53 |
| I | 126.9 | 8.48 | 15.75 |

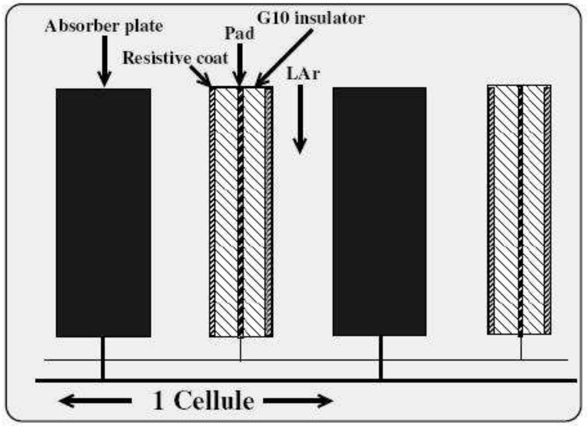
1) Compute the radiation length of a CsI crystal (g.cm-2)
2) Given its density (4.51 g.cm-3), give X0 in cm
3) Given the critical Energy $E_C$=11.17 MeV, deduce the Moliere Radius (g.cm-2 and cm)
4) Compute the Moliere Radius with the formula for composite material. Compare to 3).

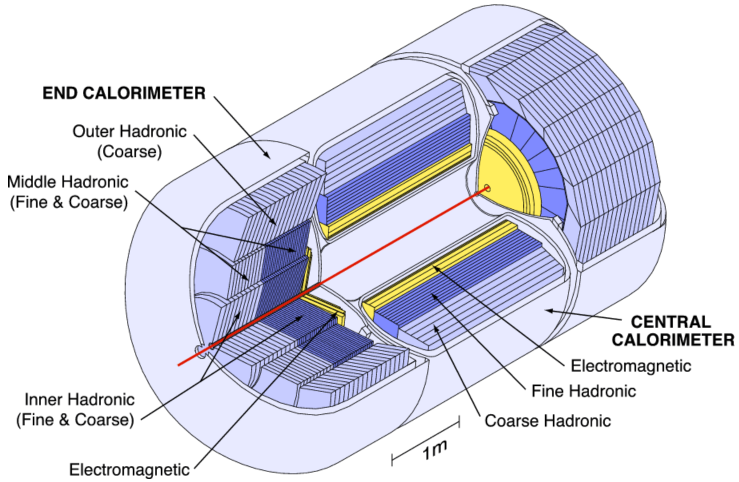
# Exercise: EM showers in various materials

Take e- with E=100 GeV and E=1 TeV going through Cu (Z=29) and W(Z=74)

1) Compute the critical energy $E_C$ for each material.
2) For each material and energy, where does the shower max occurs (in unit of X0)
   - Use the formula: $t_{max}= \ln(E/E_c) - t1$, t1=1 for e-, 0.5 for $\gamma$
3) Compute the 95% longitudinal containment (in unit of X0) in each case
4) Compute the Moliere Radius of each material.
5) Which material would you choose to build an EM calorimeter. Why ?

# Exercise: DØ Calorimeter




| | Z | X0 ($g.cm^{-2}$) | ρ ($g.cm^{-3}$) |
|---|---|---|---|
| U | 92 | 6 | 19 |
| LAr | 18 | 19.6 | 1.4 |

| | | ηxφ |
|---|---|---|
| EM1 | 2 X0 | 0.1 x 0.1 |
| EM2 | 2 X0 | 0.1 x 0.1 |
| EM3 | 6.8 X0 | 0.05 x 0.05 |
| EM4 | 9.8 X0 | 0.1 x 0.1 |

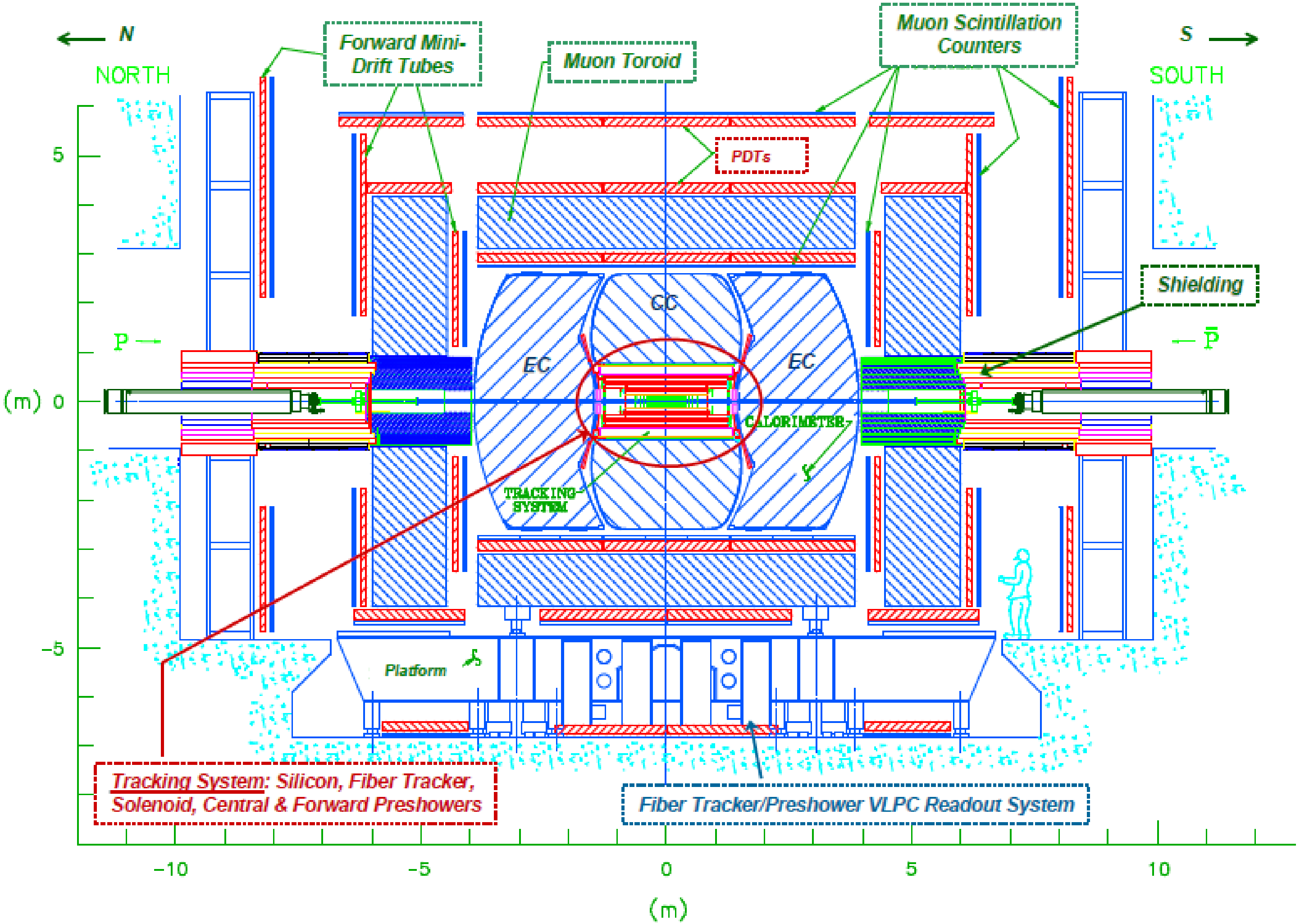
One cell of the U/LAr central EM calorimeter of DØ is made of a sandwich of 3mm U plate and 2x2.3mm LAr gap.

1) Compute the XO for the sandwich (in g.cm-2)
2) Compute the average density of the sandwich
3) Give XO in cm
4) Compute the position of the shower max (in units of X0) for an electron with E=45 GeV

5) The EM part has four sections with different granularity and X0.
Comment wrt to the result on question 4.

6) During RunII, a magnet was added before the calorimeters as well as a pre-shower (Pb/scintillating fibers). What is the impact on the shower max ? What are the consequences on the calorimetric performance ? What is the role of the pre-shower ?

# Particle Flow & DØ




B-field = 2 T (solenoid)

ECAL radius: 0.8 m

Can you imagine a Particle Flow algorithm with this detector ? Why ?

# BACK UP SLIDES