

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

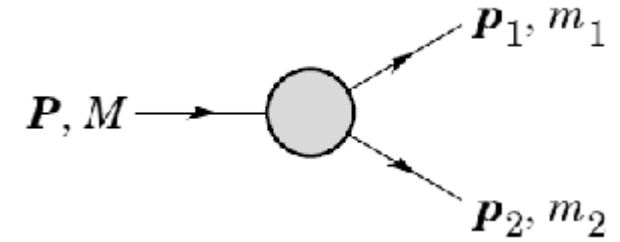
Lecture 4

Tutorial
Exercises

Resolution

- Two-body decay. Ex: $H \rightarrow \gamma\gamma$

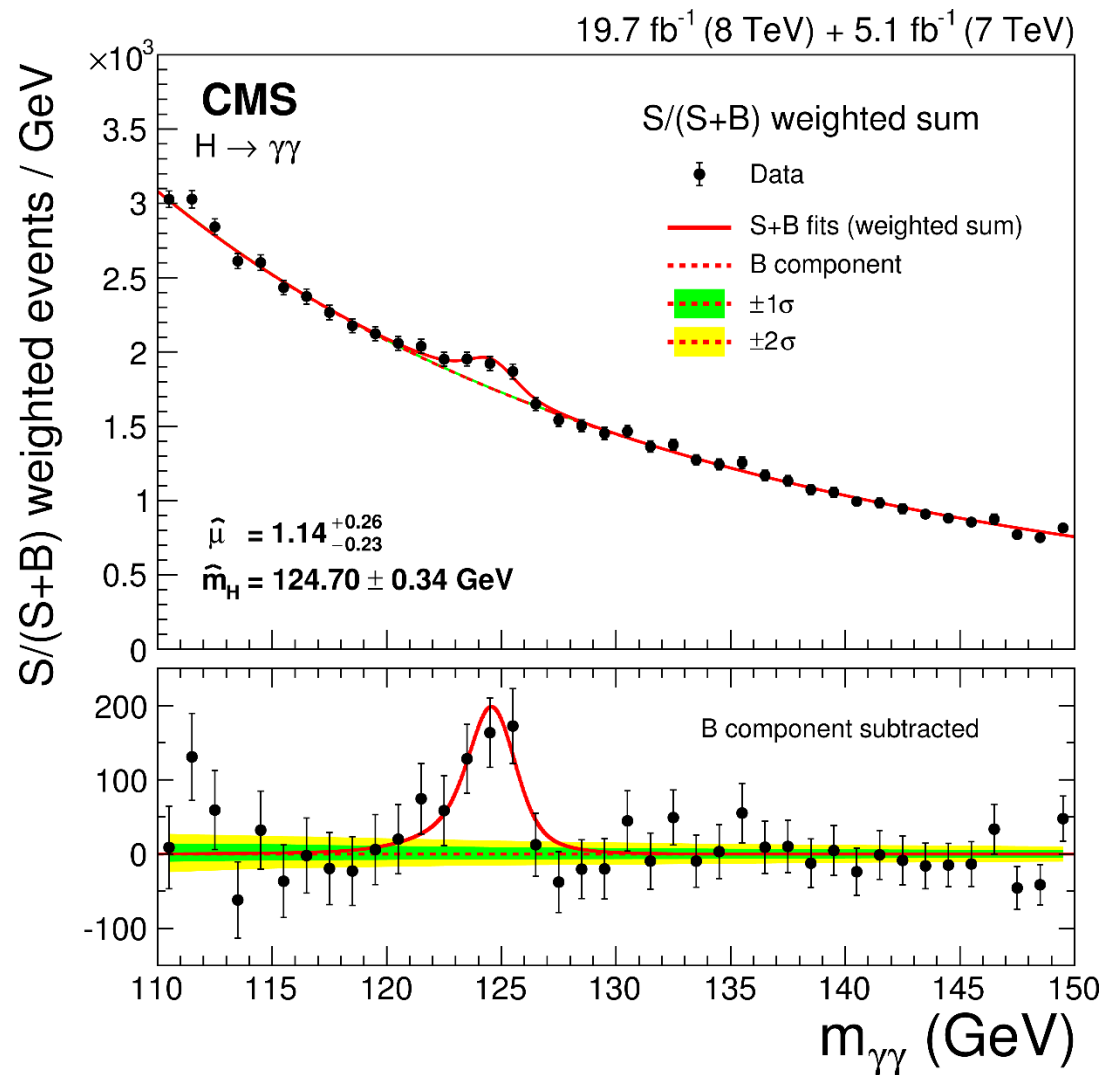
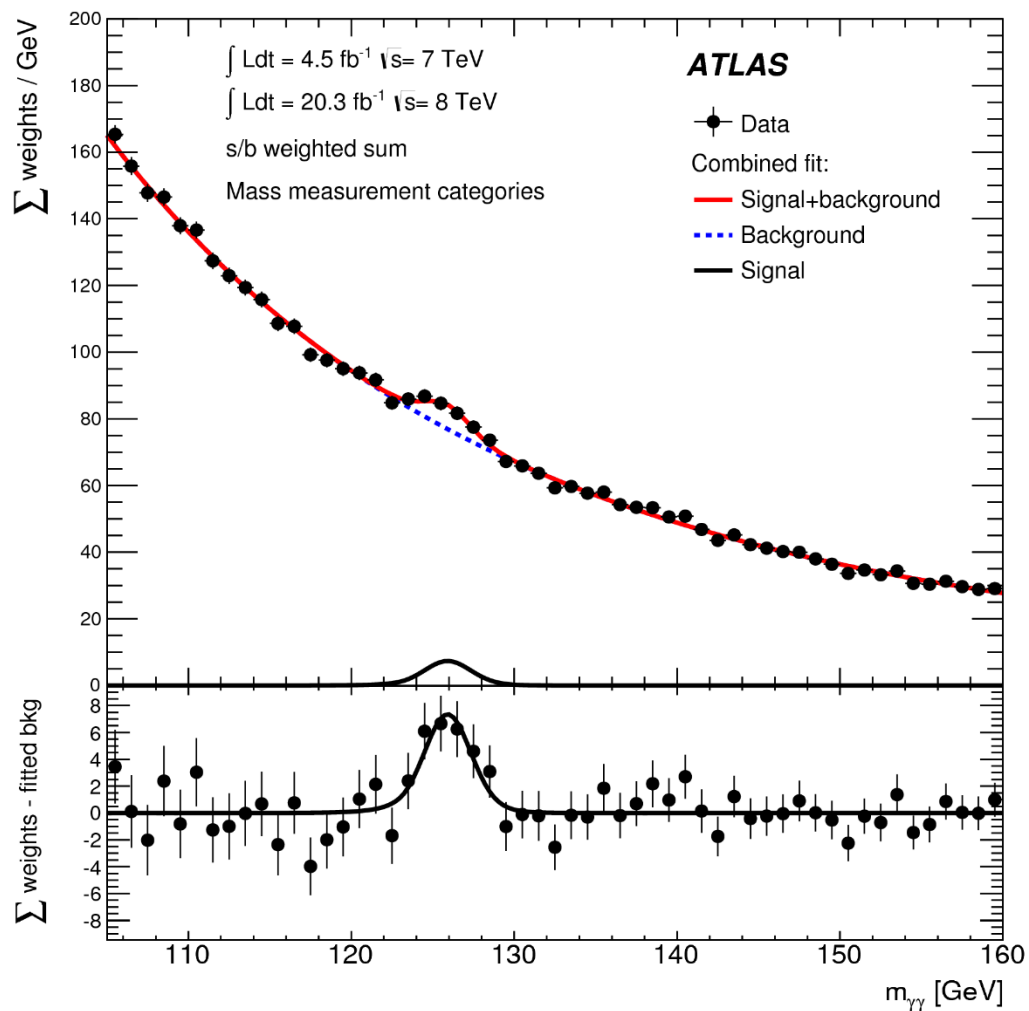
$$m_{\gamma\gamma} = 2E_1E_2(1 - \cos\theta_{\gamma\gamma})$$



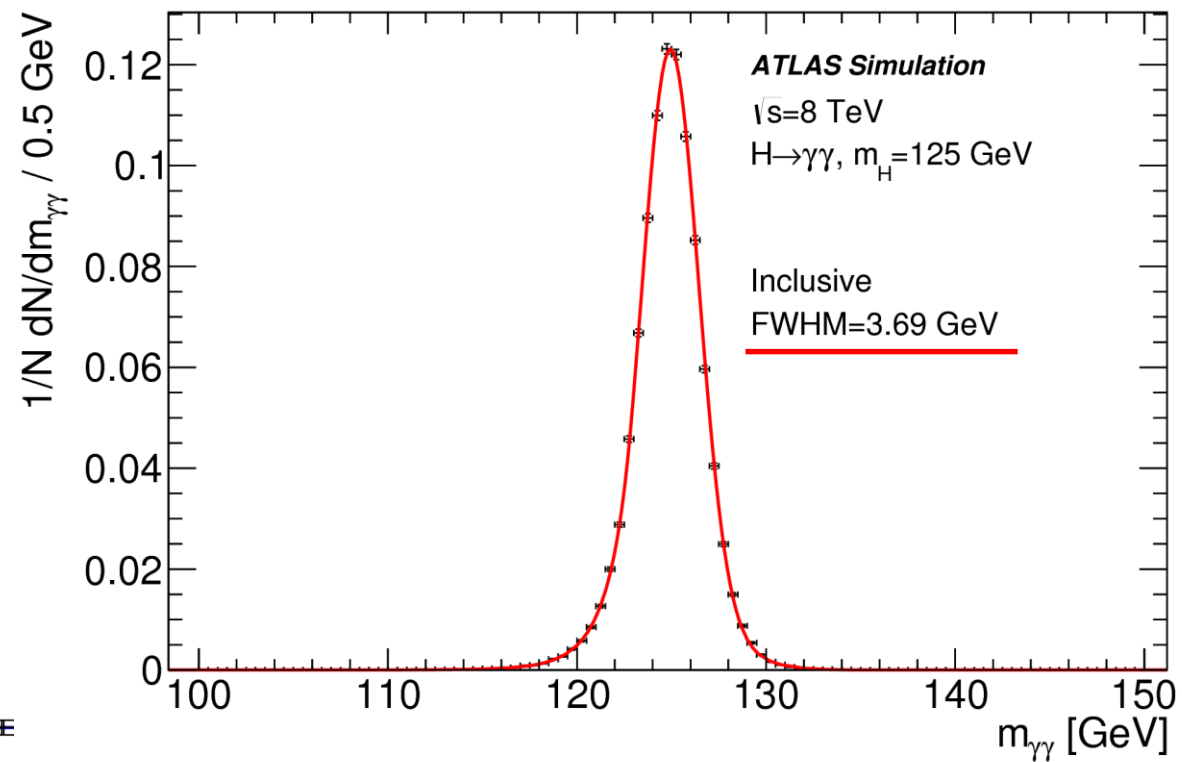
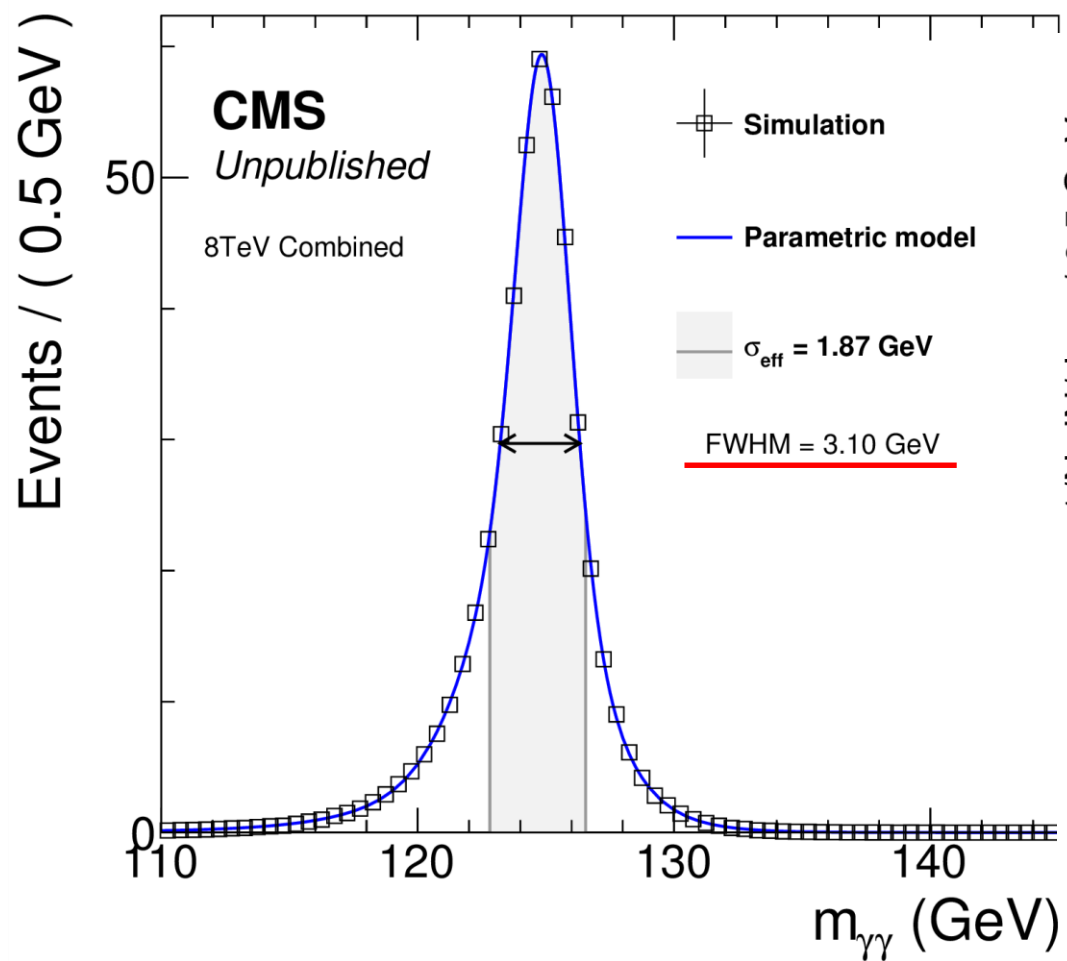
$$\frac{\sigma_m}{m_{\gamma\gamma}} = \frac{1}{2} \sqrt{\left(\frac{\sigma_{E1}}{E_1}\right)^2 + \left(\frac{\sigma_{E2}}{E_2}\right)^2 + \left(\frac{\sigma_\theta}{\text{tg}\theta/2}\right)^2}$$

- 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

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

(test beam)

ATLAS

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

(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	X_0 (g.cm ⁻²)	R_M (g.cm ⁻²)
Cs	132.9	8.31	15.53
I	126.9	8.48	15.75

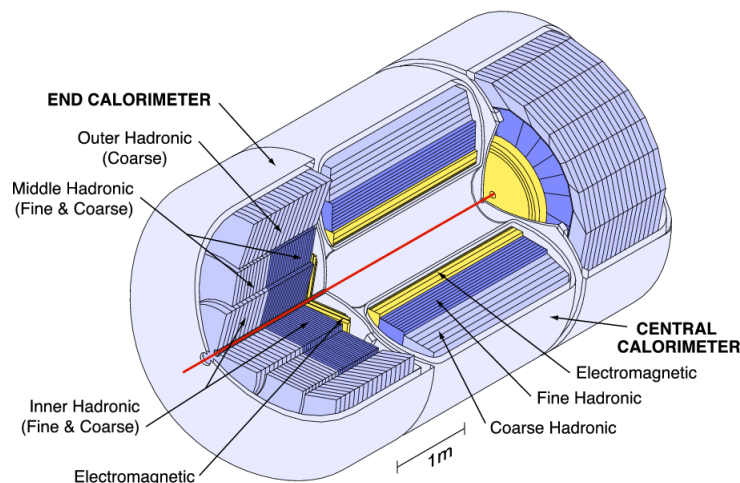
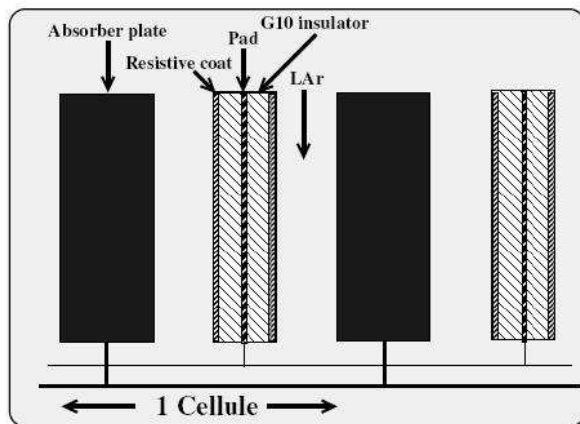
- 1) Compute the radiation length of a CsI crystal (g.cm⁻²)
- 2) Given its density (4.51 g.cm⁻³), give X_0 in cm
- 3) Given the critical Energy $E_C=11.17$ MeV, deduce the Moliere Radius (g.cm⁻² and cm)
- 4) Compute the Moliere Radius with the formula for composite material. Compare to 3).

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 X_0)
 - Use the formula: $t_{\max} = \ln(E/E_c) - t_1$, $t_1=1$ for e^- , 0.5 for γ
- 3) Compute the 95% longitudinal containment (in unit of X_0) 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

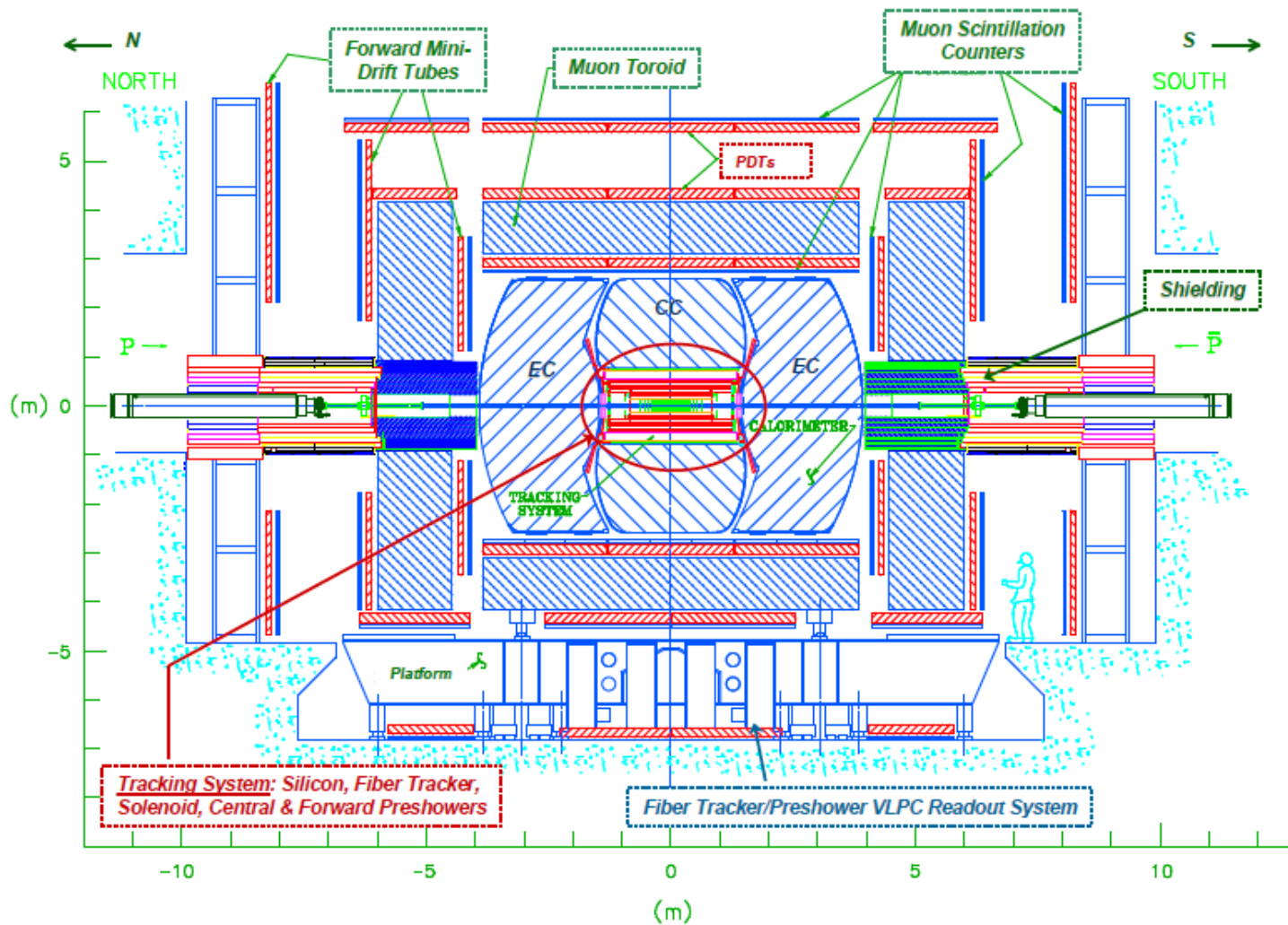
One cell of the U/LAr central EM calorimeter of DØ is made of a sandwich of 3mm U plate and 2x2.3mm LAr gap.

- 1) Compute the X0 for the sandwich (in g.cm⁻²)
- 2) Compute the average density of the sandwich
- 3) Give X0 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