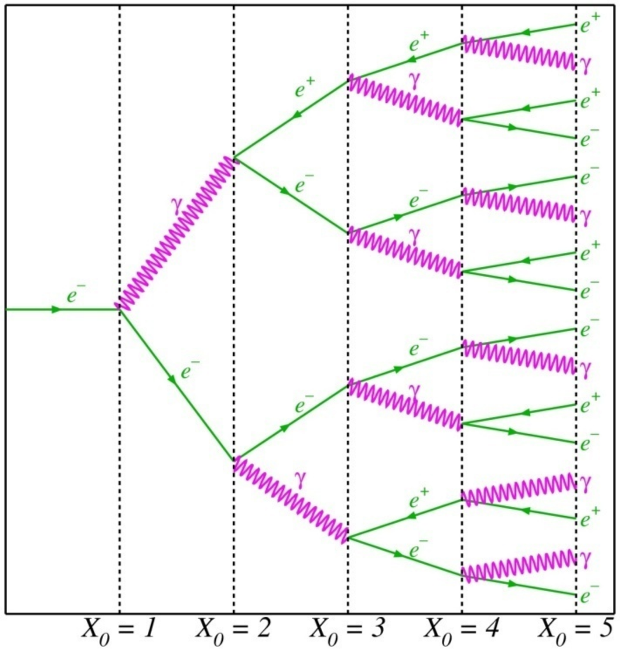
Electromagnetic Showers



incident γ E_0

χ_0 ↓

Converts to 2 electrons $E_e = \dfrac{E_0}{2}$

$\sim 2\chi_0$ ↓

Each electrons will have emitted a brems photon of energy $E_\gamma = \dfrac{E_0}{4}$

Now have 4 particles energy $\dfrac{E_0}{4}$

Number of particles after $t \cdot \chi_0$ $\quad N = 2^t$

Average energy $E(t) = \dfrac{E_0}{2^t}$

At the critical energy $\quad E_t(\max) = \dfrac{E_0}{2^{t\max}} = E_C$

↗ *assume this is max depth*

$$N_{\max} \approx \frac{E_0}{E_c} \qquad t_{\max} = \frac{\ln(E_0/E_c)}{\ln 2}$$

$t_{\max} \sim \ln E_0$ — shower grows as *ln E*

$N_{\max} \propto E_0$ — linear energy measurement

$\sigma_E \sim \sqrt{N} \sim \sqrt{E}$ — resolution improves with energy

Monte Carlo Simulation of an EM Shower

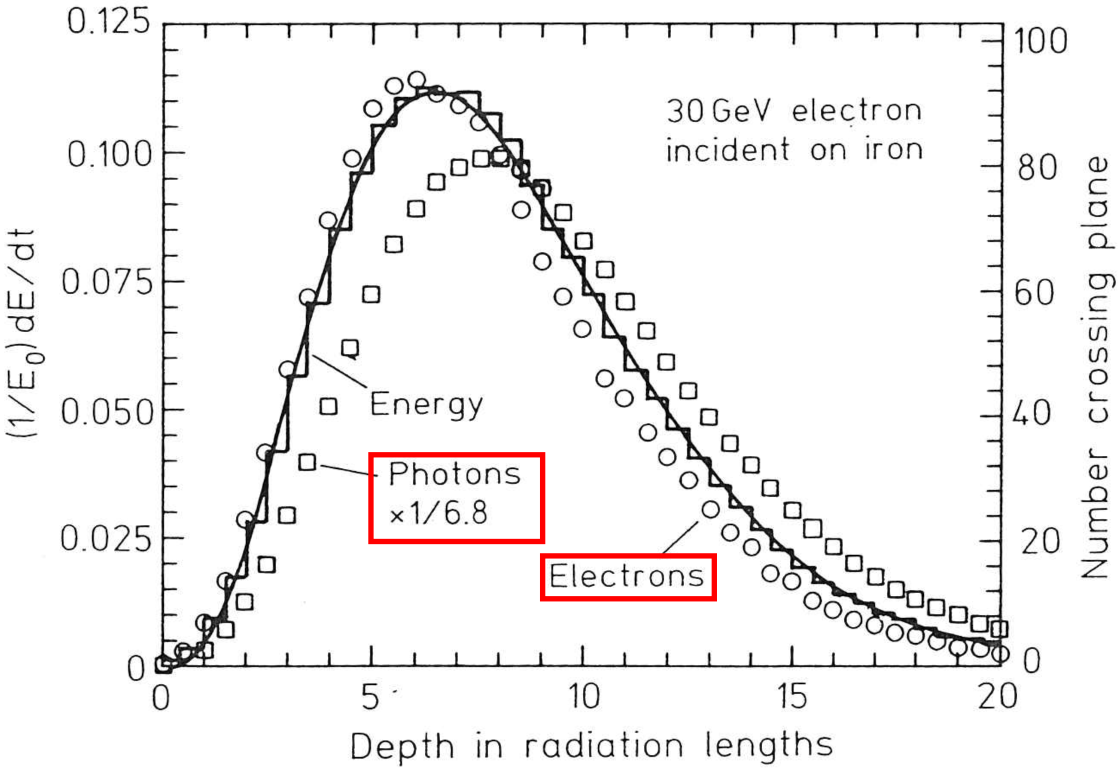
$$\frac{dE}{dt} = E_0 \frac{b(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

$$\Rightarrow \quad t_{max} = \frac{a-1}{b} = 1.0(\ln y + C_i)$$

$t_{max} \sim \ln E_0$

$y = E/E_C$

$C_i = -0.5(e), +0.5(\gamma)$



Calc $t_{max} = (\ln y + C_i)$

↓

Put b=0.5

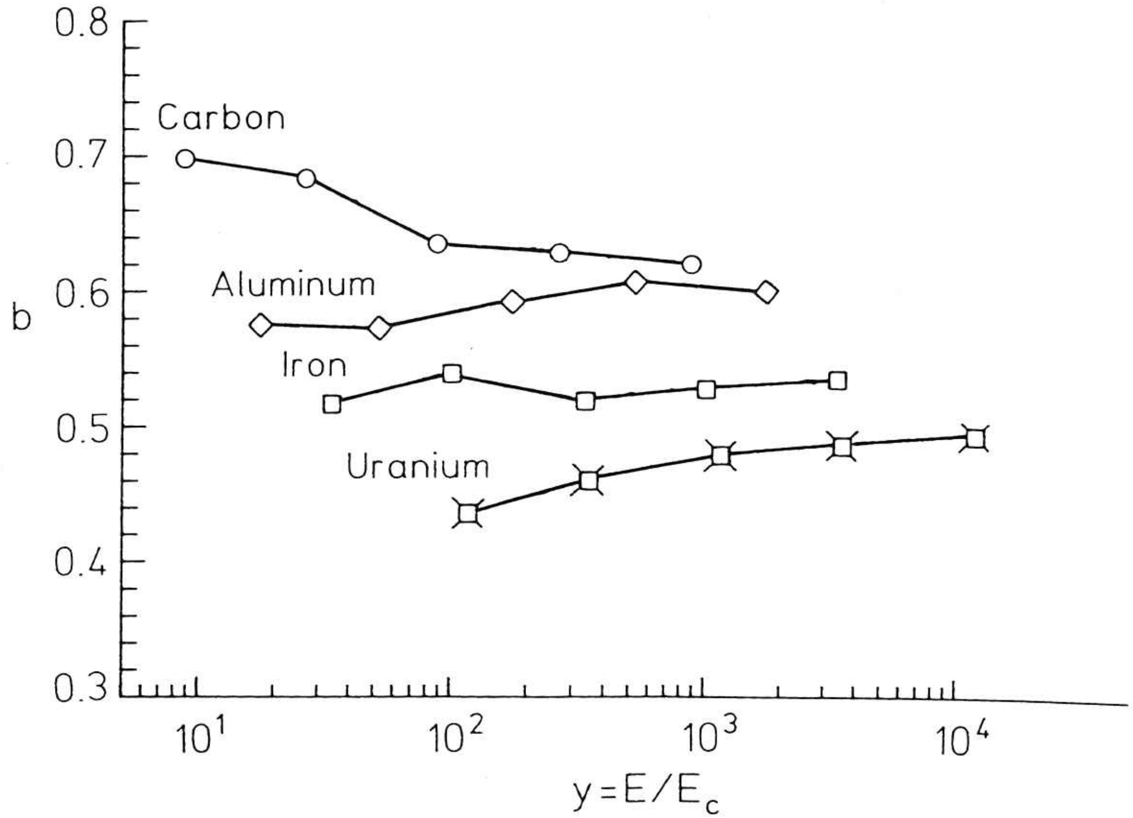
↓

Get a from $t_{max} = \frac{a-1}{b}$

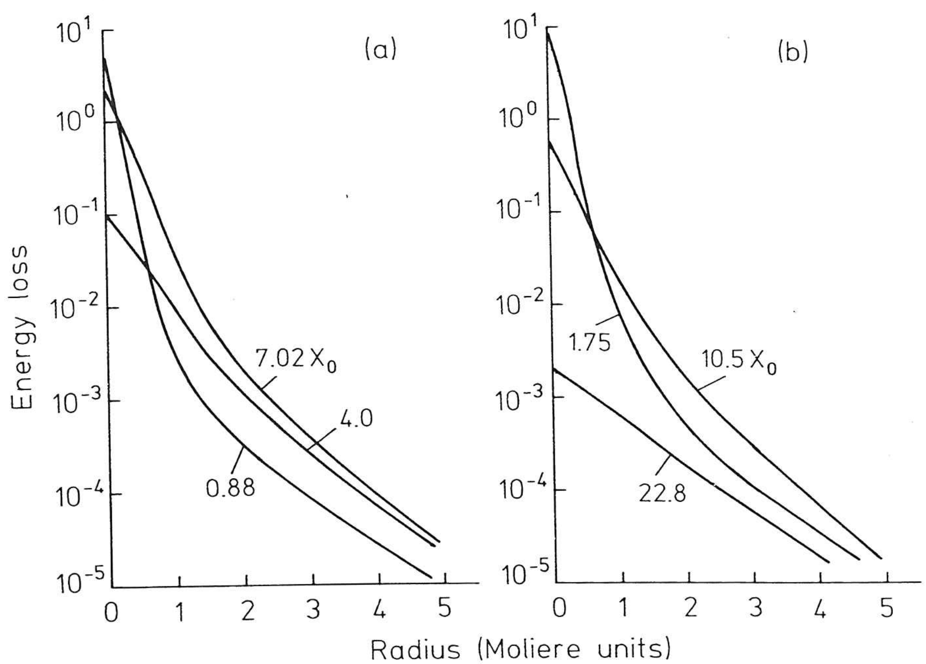
↓

$$\frac{dE}{dt}$$

“b” is sort of material independent



Transverse Shower Profile



- Shower Broadens as it develops
  - Pair
  - Brems
  - Compton
  - Multiple Coulomb
- Shower Broadens as it develops
  - dense central core
  - spreading with depth

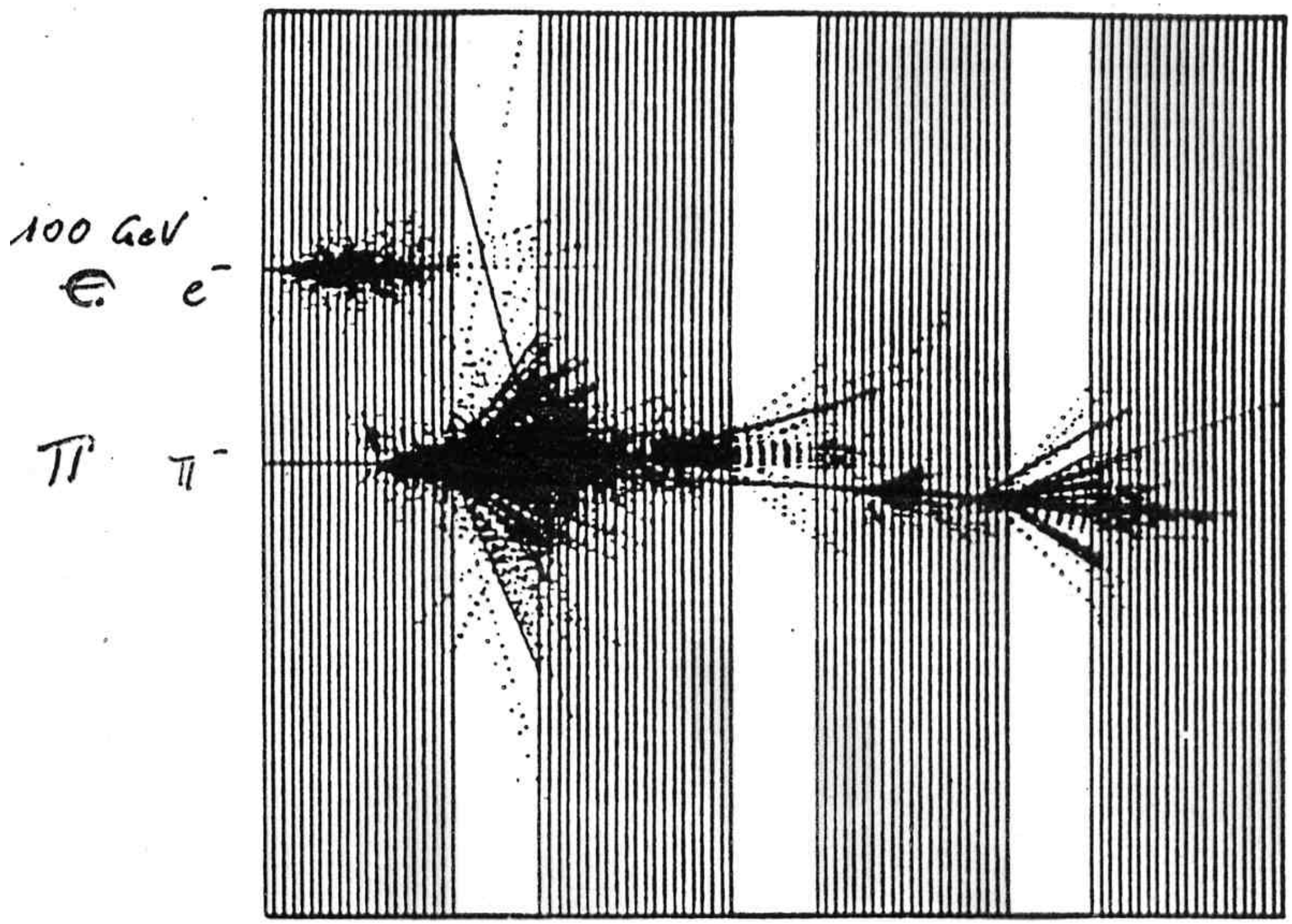
- Moliére Radius

$$R_M = \chi_0 \frac{E_S}{E_C}$$

$$E_S = m_e c^2 \sqrt{\frac{4\pi}{\alpha}} = 21.2\, MeV$$

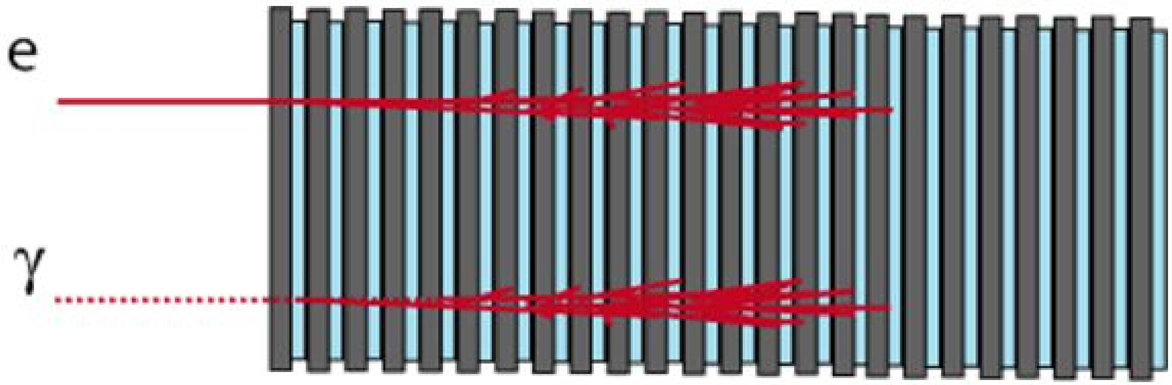
- Like radiation length, Moliére radius scales for different materials
- In terms of Moliére radius, shower width is roughly independent of material - 90% of energy in $2 \times R_M$

Comparison of Hadronic & Electromagnetic Showers



Electromagnetic Calorimeter Types

- "lead-scintillator sandwich" calorimeter



Energy resolutions:

□E/E ~ 20%/√E

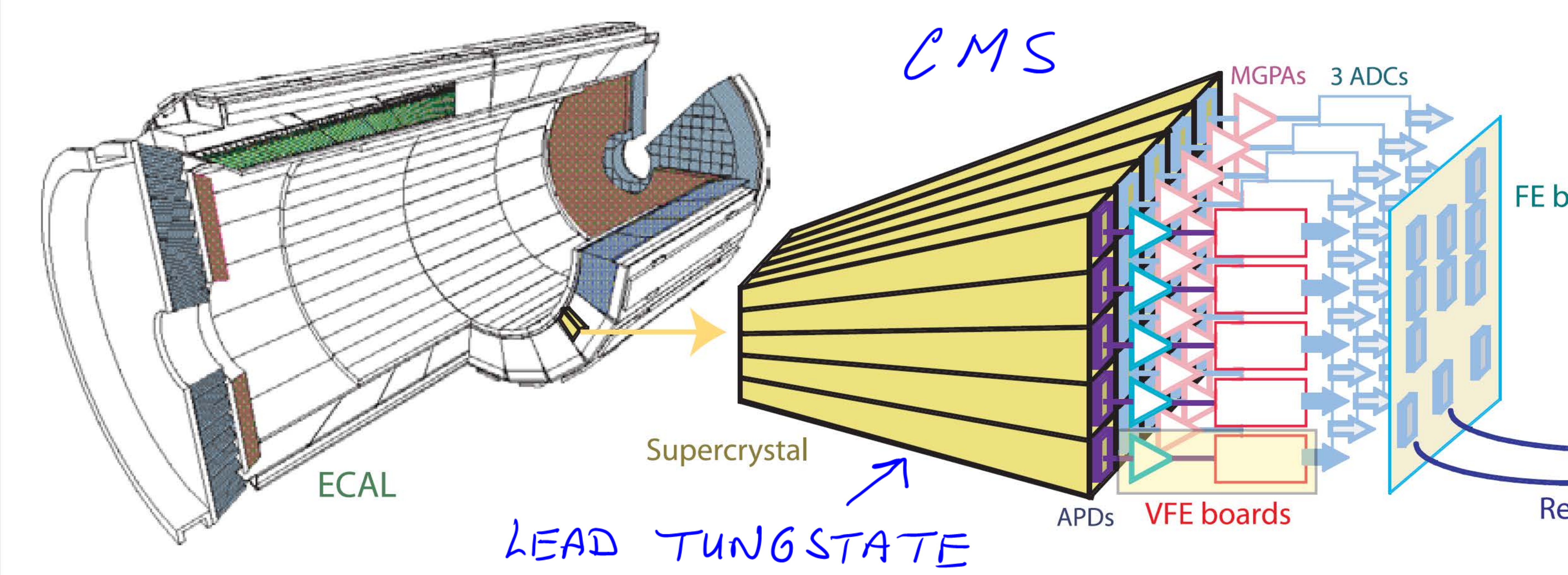
- exotic crystals (BGO, PbW, ...)

□E/E ~ 1%/√E

- liquid argon calorimeter

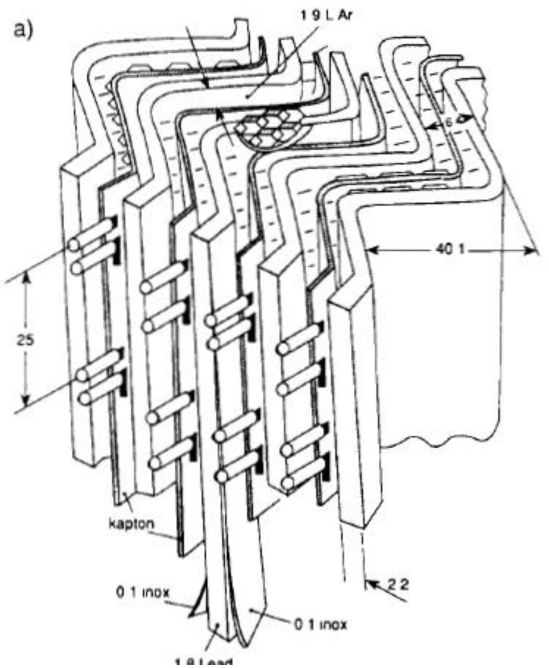
□E/E ~ $\frac{13\%}{\sqrt{E}}$

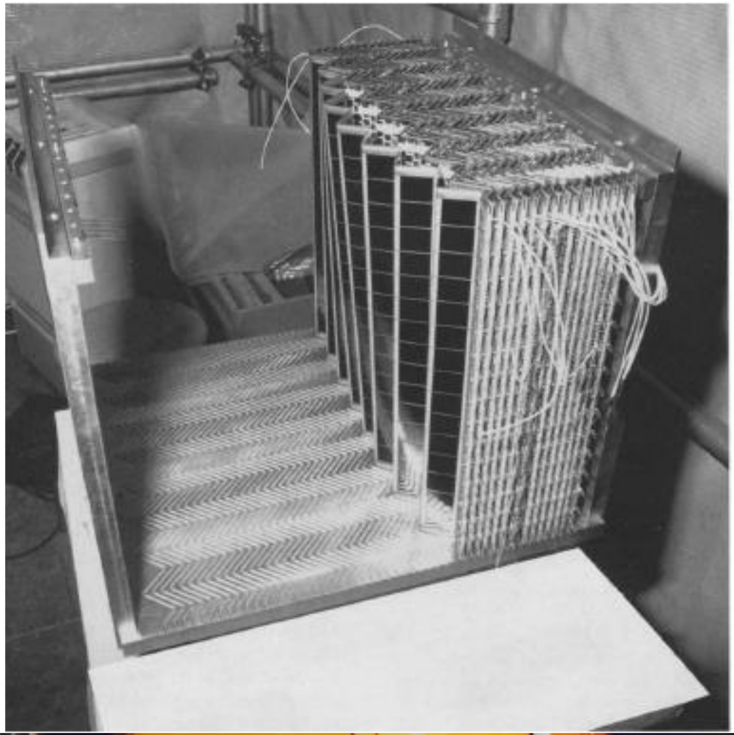
18%/√E


CMS
MGPAs
3 ADCs
Supercrystal
ECAL
APDs
VFE boards
LEAD TUNGSTATE

First Prototype

- Designed between January and April 1990
- Build between April and July
- Exposed to test beam in July-August, using
  the cryostat and FE electronics of Helios expt
- Demonstrated the concept was sound,
  although the electronics was not yet fast enough





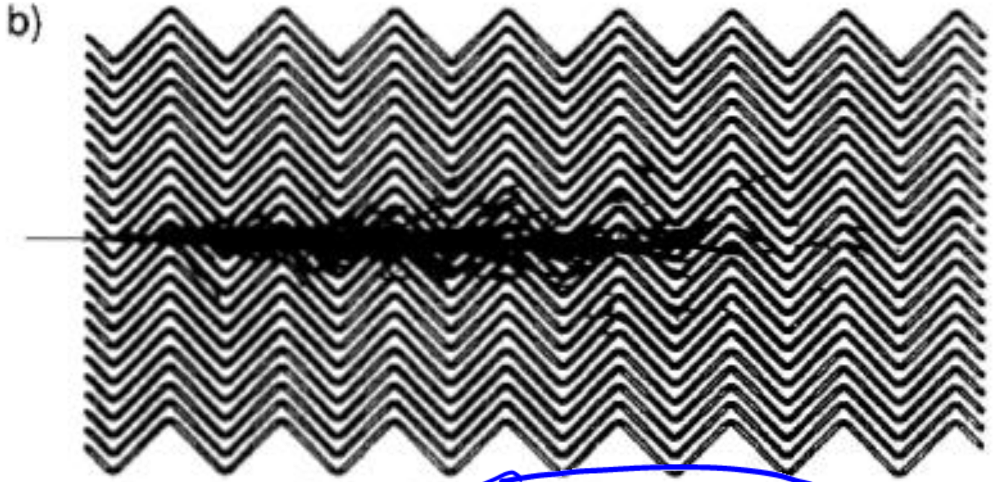
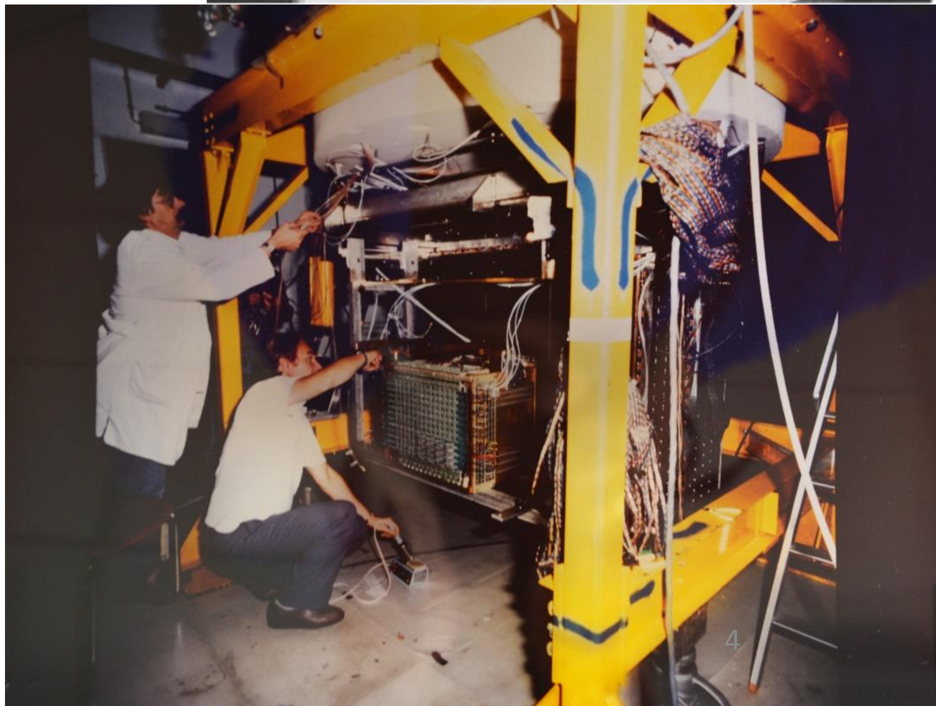


Fig. 2. (a) Artist's view of the accordion calorimeter geometry. (b) Development of a 40 GeV electron shower (Monte Carlo simulation). Only charged tracks above 10 MeV are shown.

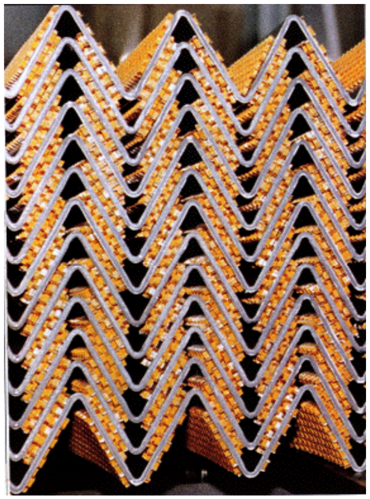
ATLAS



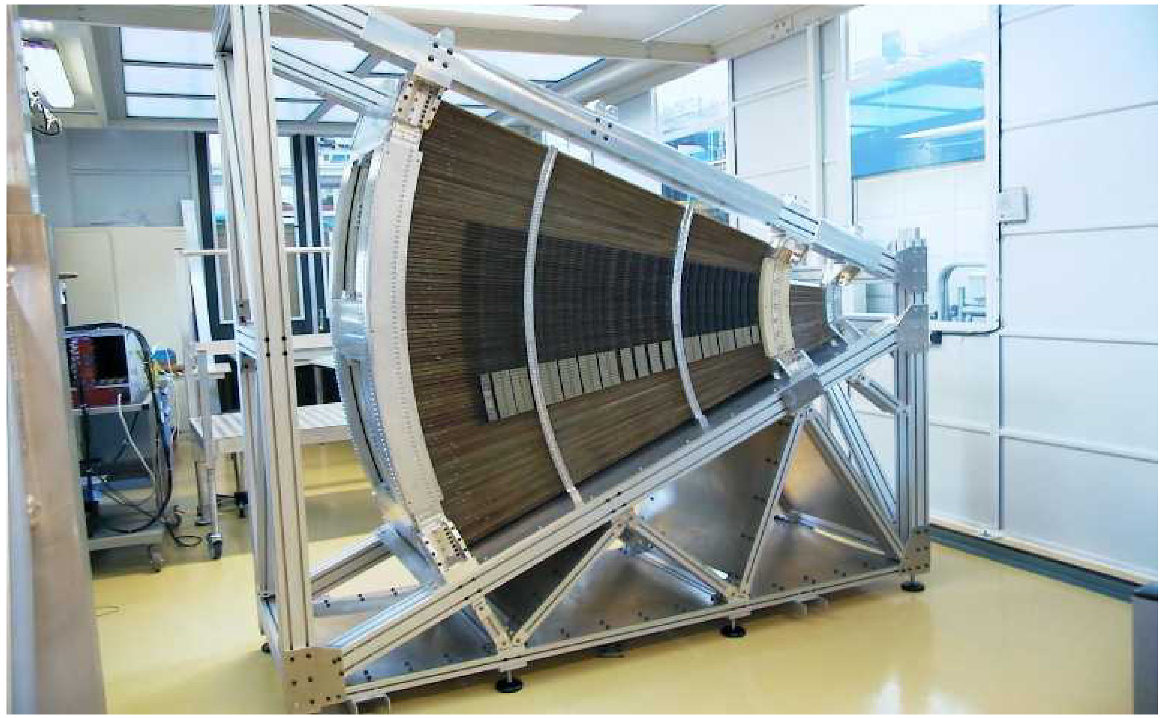
ATLAS

Prototype of EM endcap

Detail of Kaptons

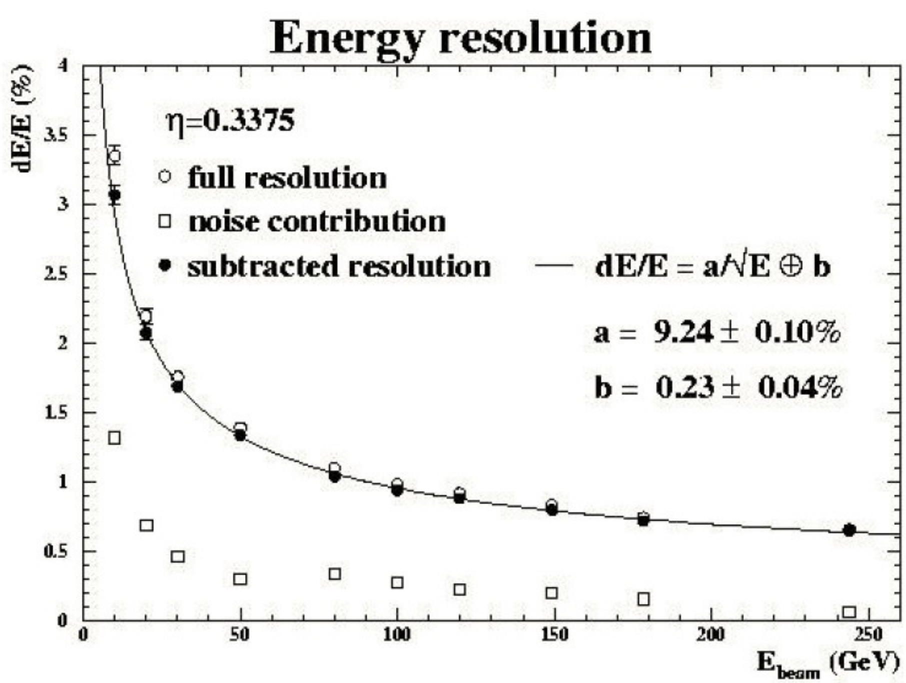


ACCORDIAN STRUCTURE

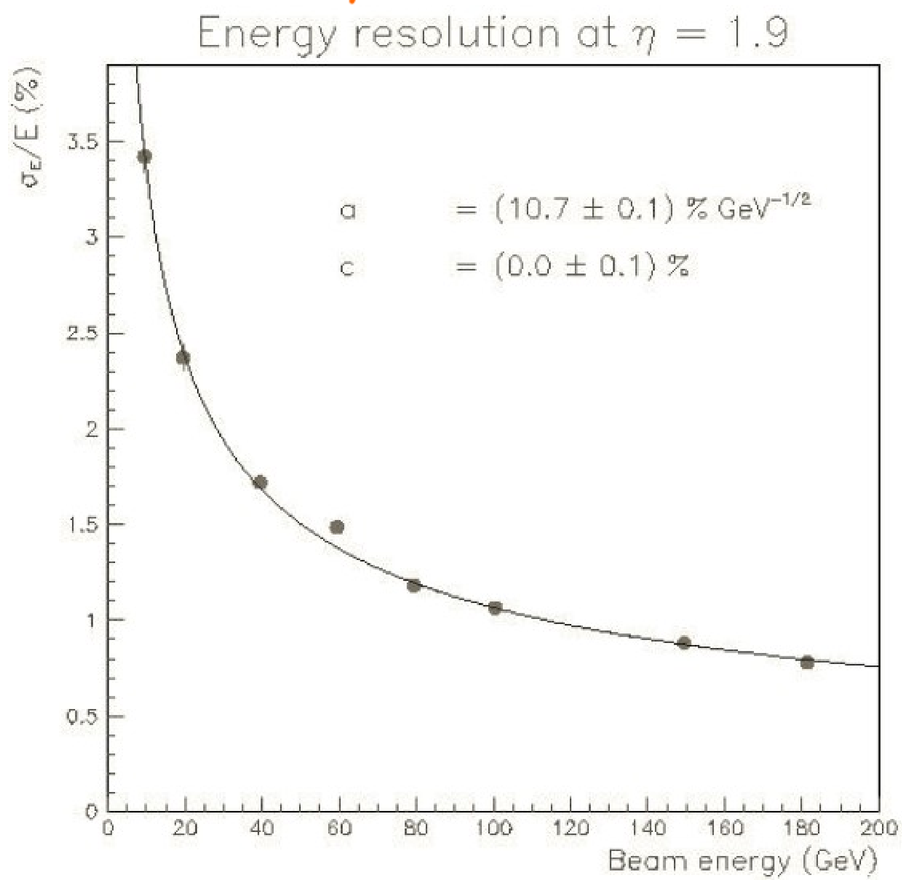


ATLAS EM CAL ENERGY RESOLUTION

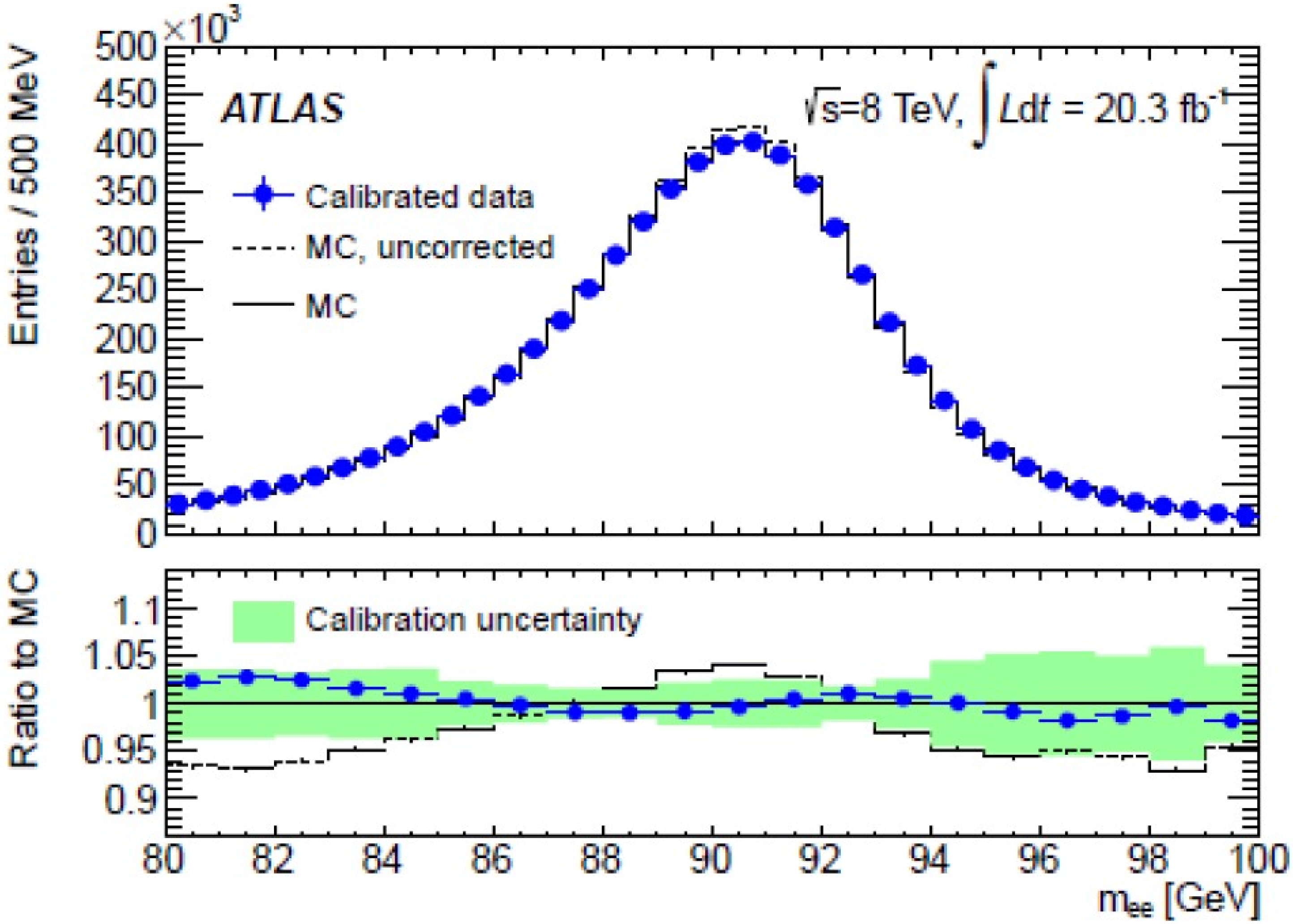
BARREL



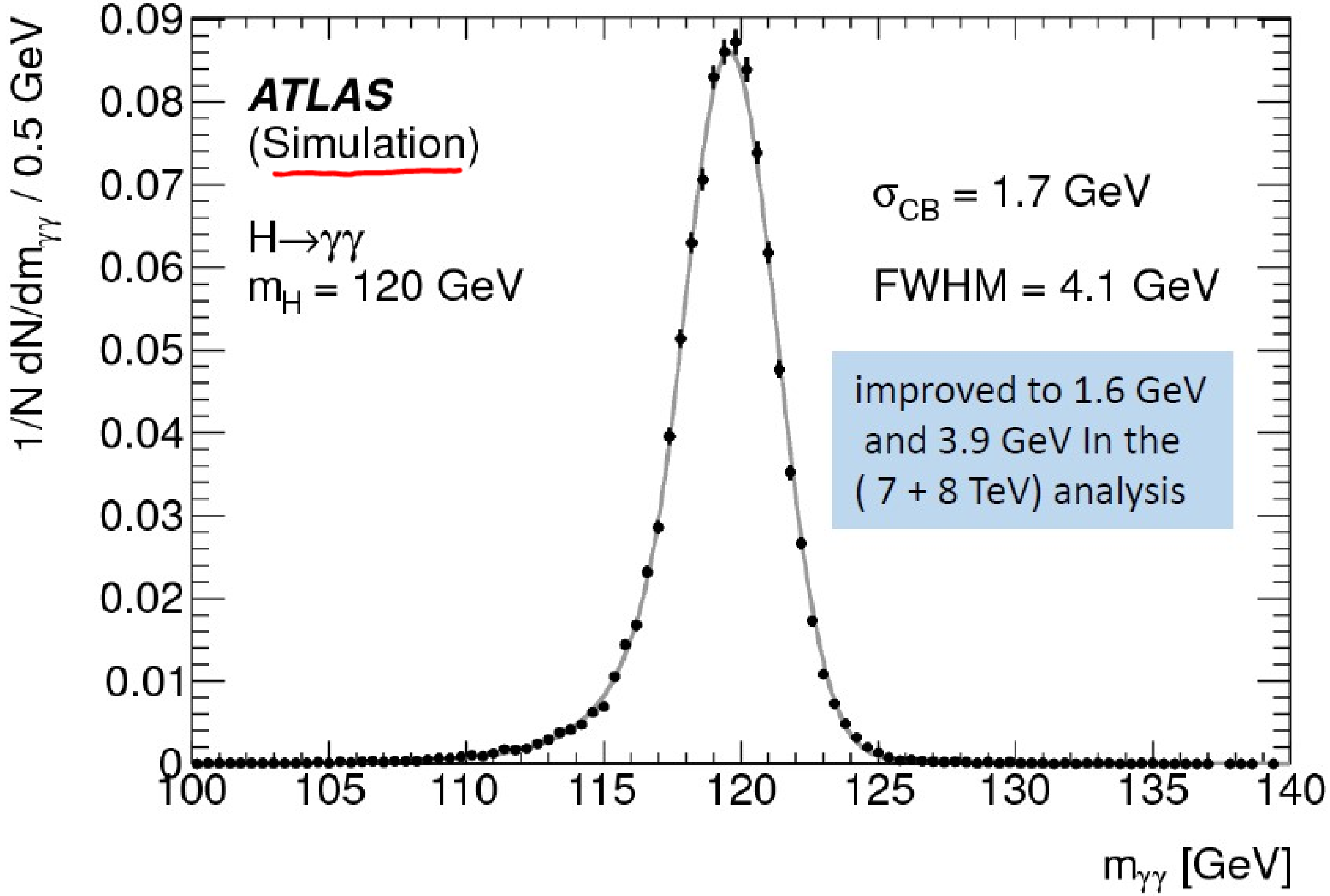
END CAP

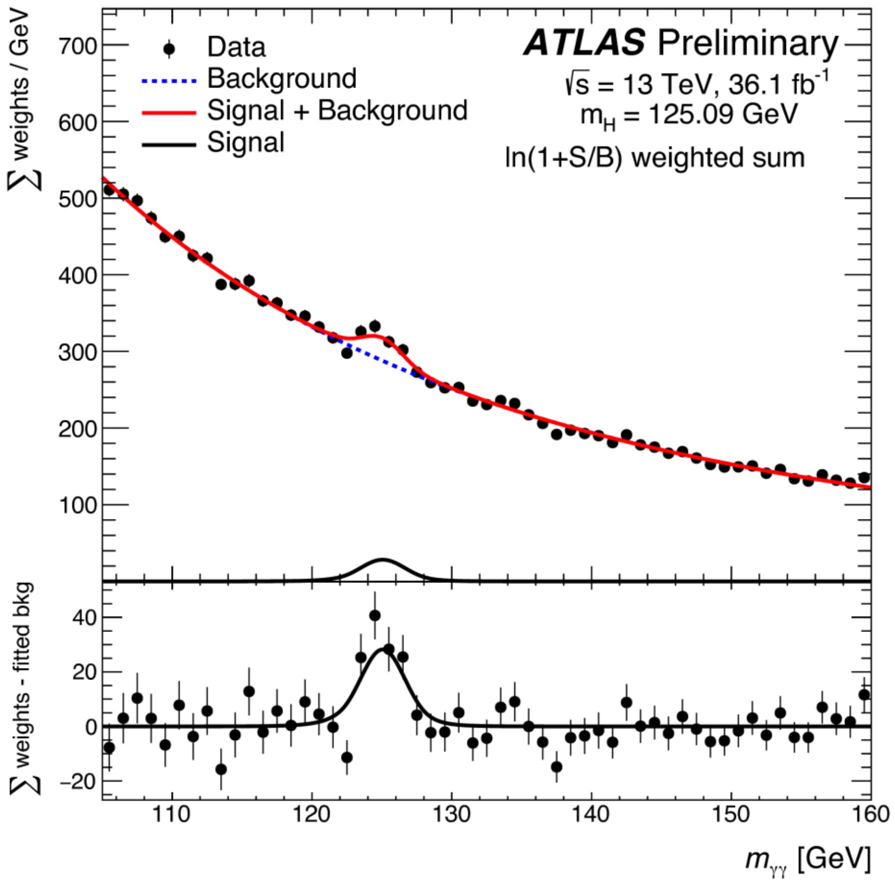


ATLAS EM $Z^0 \to e^+e^-$



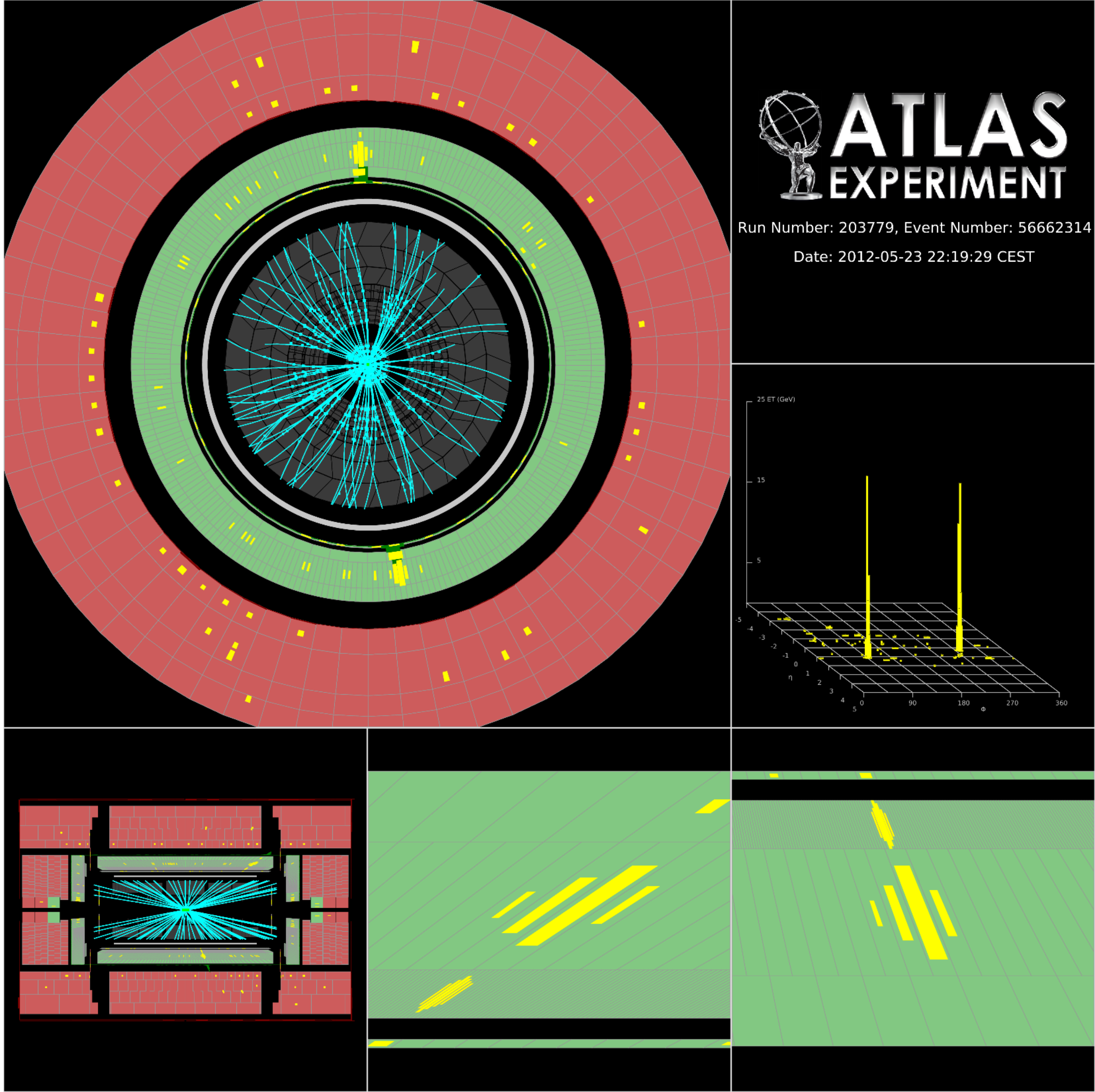
ATLAS EM CAL $H \to \gamma\gamma$



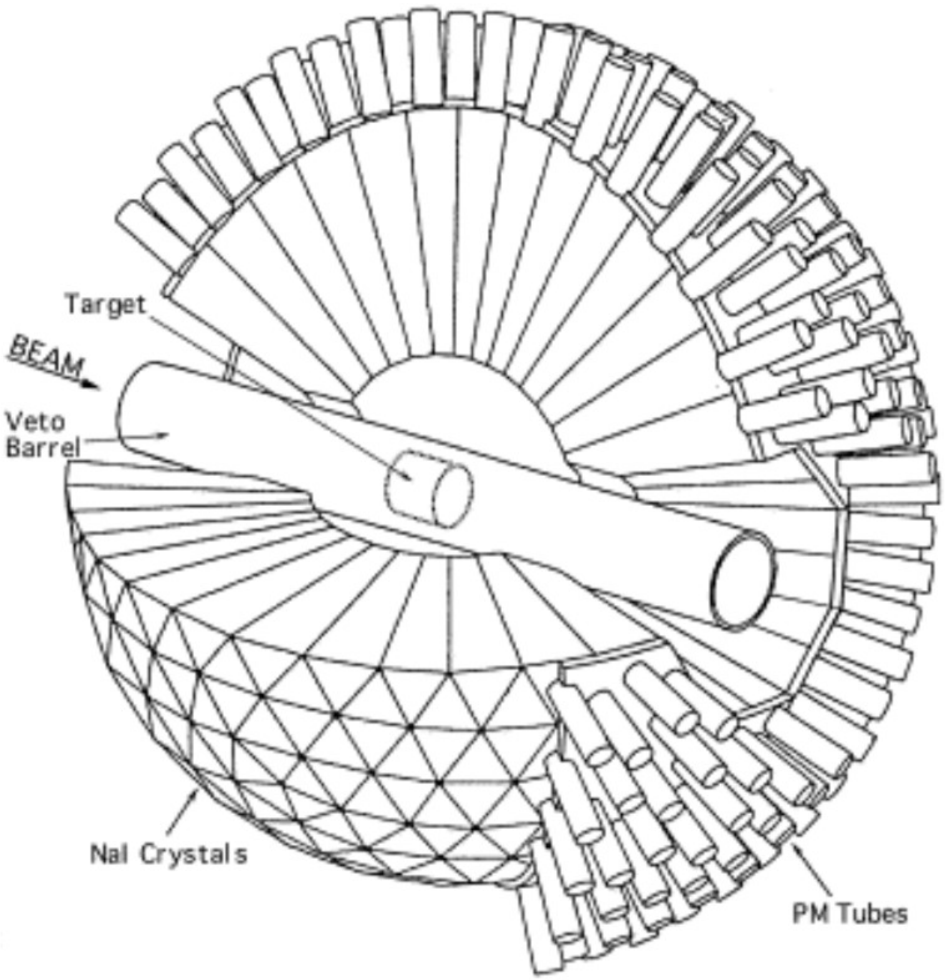


$H \to \gamma\gamma$

From RD-Schaffer's CERN seminar Sept 5th
And CONF-2017-047



CRYSTAL BALL AT SPEAR e^+e^-

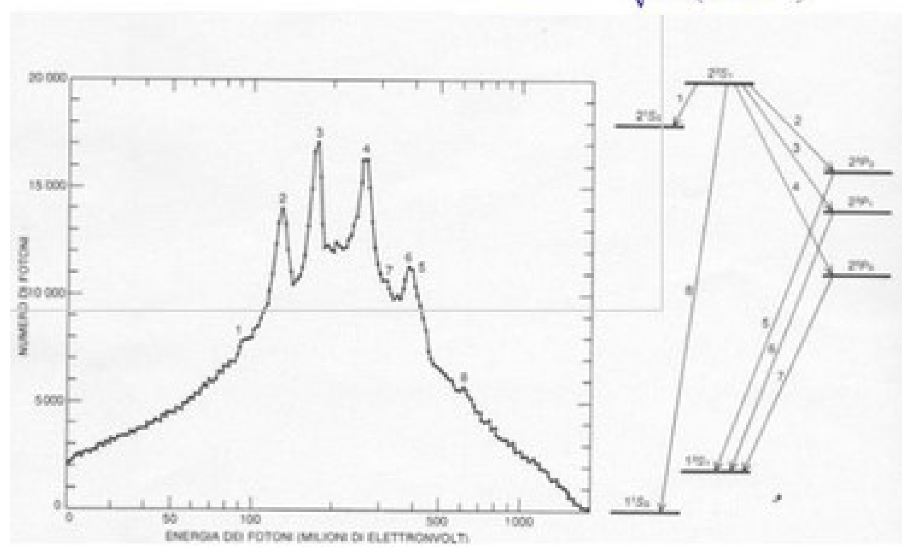


DETECT

$$\psi' \to \chi_c + \gamma \to J/\psi\gamma + \gamma \to l^+l^-\gamma\gamma$$

$$\psi' \to \eta_c + \gamma \to \gamma\gamma + \gamma$$

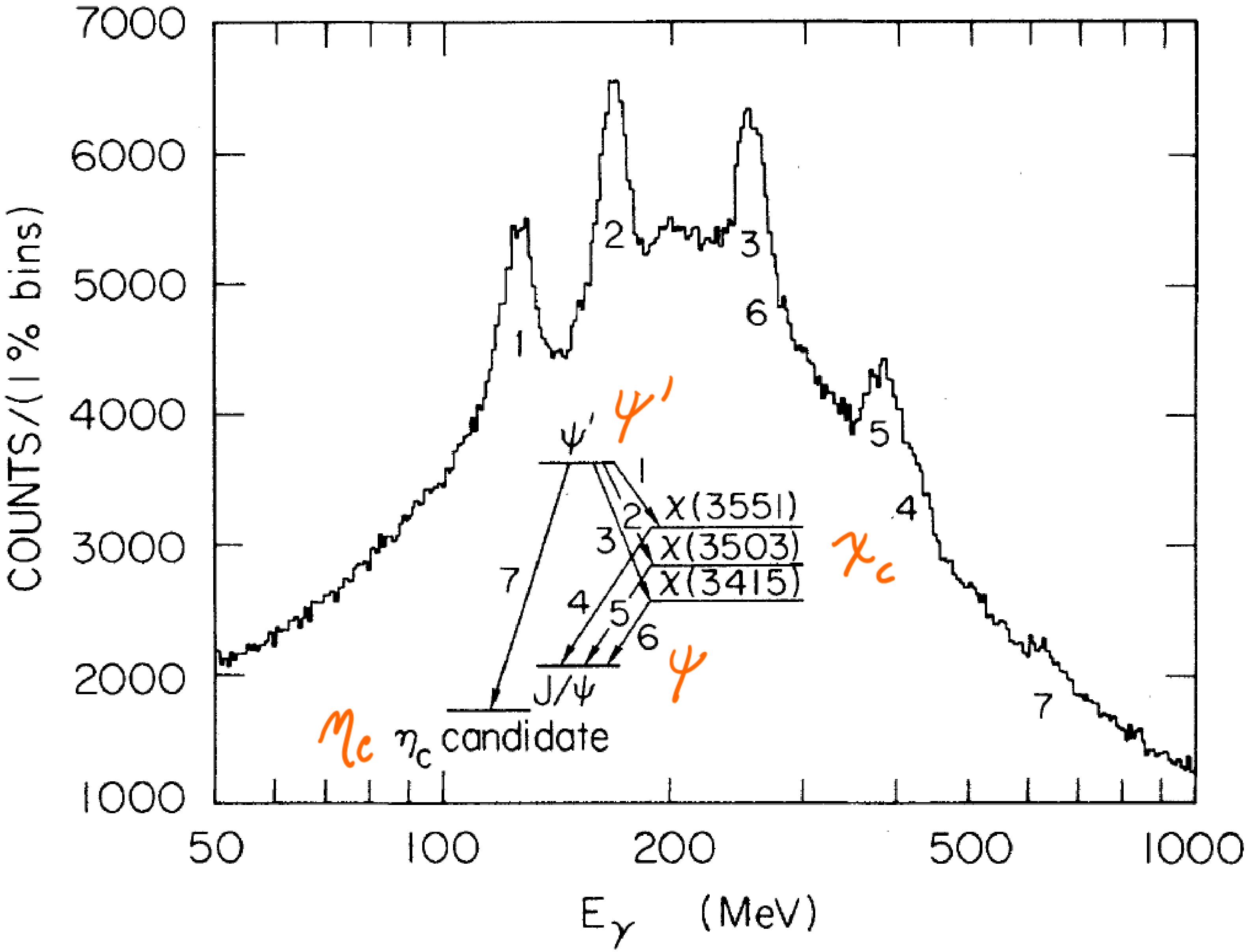
- energy resolution: $\frac{\sigma(E)}{E} = \frac{2.8\%}{\sqrt[4]{E(GeV)}}$



DISCOVERY OF χ_c η_c

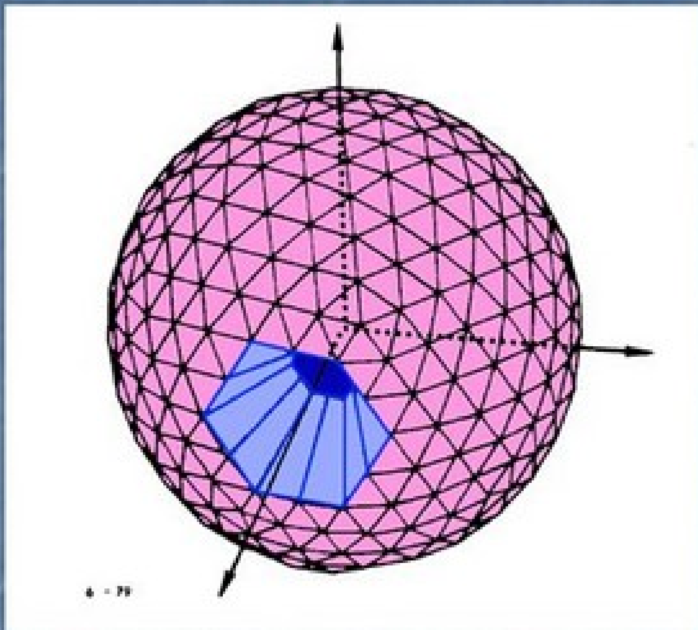
$\psi' \to \chi_c \, \gamma$

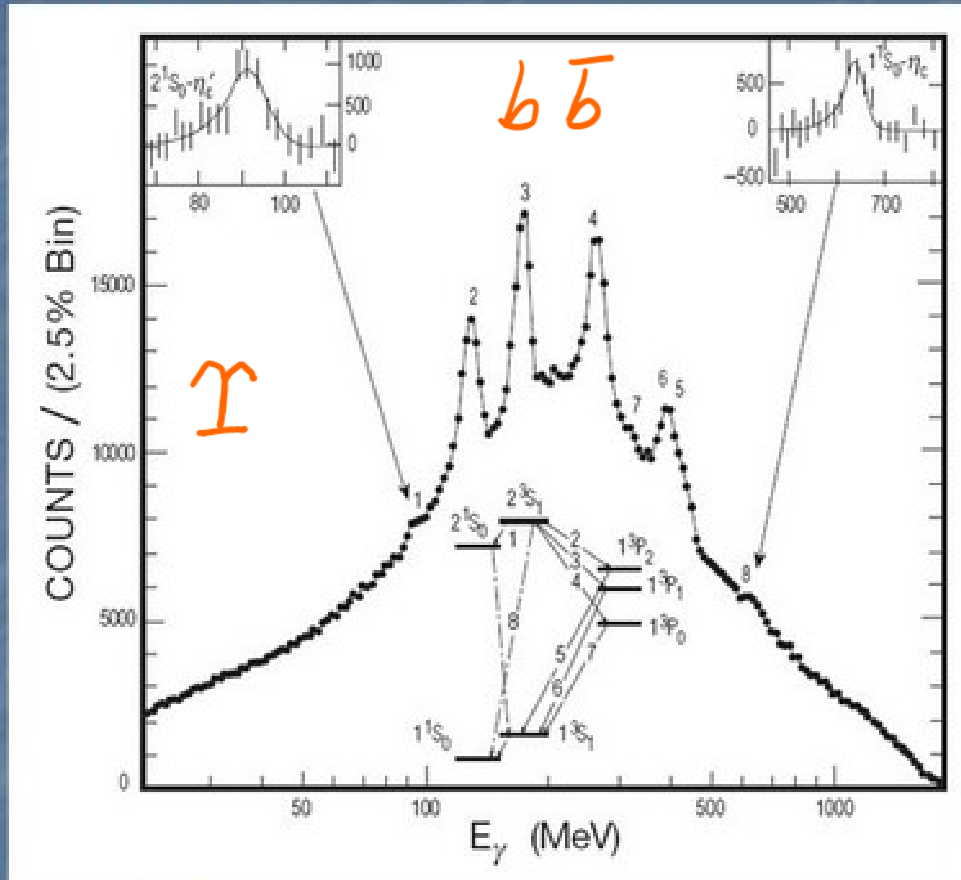
C $\quad -1 \qquad +1 \quad -1$



7000
6000
5000
4000
3000
2000
1000
COUNTS/(1% bins)
50
100
200
500
1000
E$_\gamma$ (MeV)
1
2
3
4
5
6
7
ψ'
χ(3551)
χ(3503)
χ(3415)
J/ψ
η$_c$ candidate
ψ'
χ$_c$
ψ
η$_c$

Crystal Ball NaI(Tl) Calorimeter

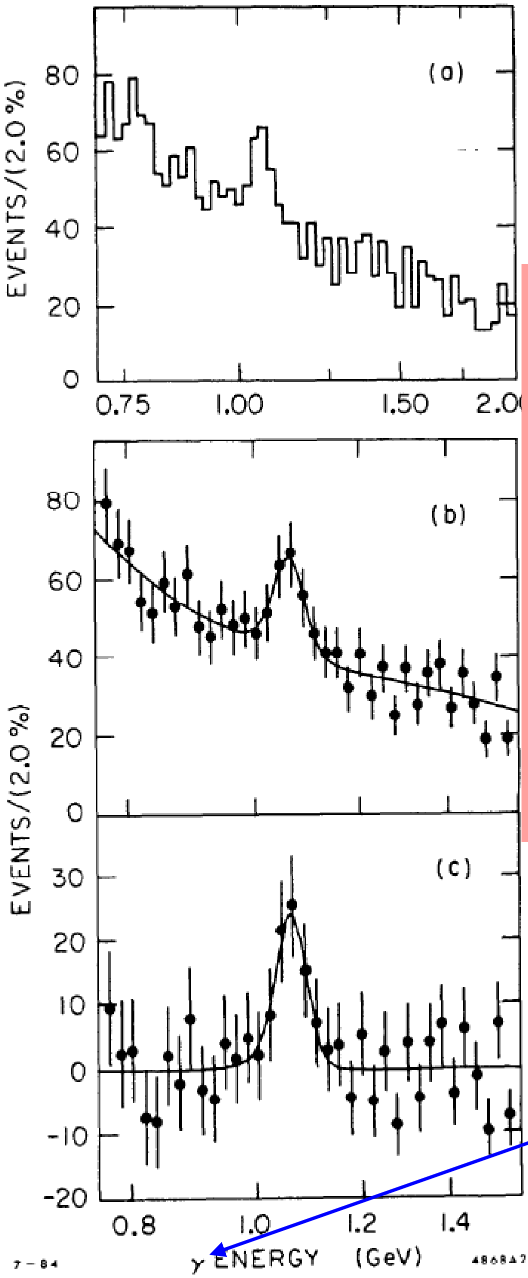




Number of crystals 672
Inner radius 25.4 cm
Outer radius 66.0 cm
Thickness 16 X_0
Solid angle coverage 93%
Photodetector PMT
Noise 0.05 MeV
Dynamic range 10^4

$$\frac{\sigma_E}{E} = \frac{2.8\%}{\sqrt[4]{E(\mathrm{GeV})}}$$

Inclusive photon spectrum at ψ(2S) resonance



Evidence for a Narrow Massive State in the Radiative Decays of the Upsilon* July 1984 (T/E)

Crystal Ball Collaboration

above (see Fig. 2b) now yields a significance of 4.2 standard deviations for the signal. The signal-parameters become

$$
\begin{aligned}
E_\gamma &= (1072 \pm 8 \pm 21)\ \mathrm{MeV} \\
M &= (8319 \pm 10 \pm 24)\ \mathrm{MeV} \\
\text{Counts} &= 87.1 \pm 20.5 \\
\chi^2 &= 24.8 \text{ for 32 degrees of freedom,}
\end{aligned}
\qquad (1)
$$

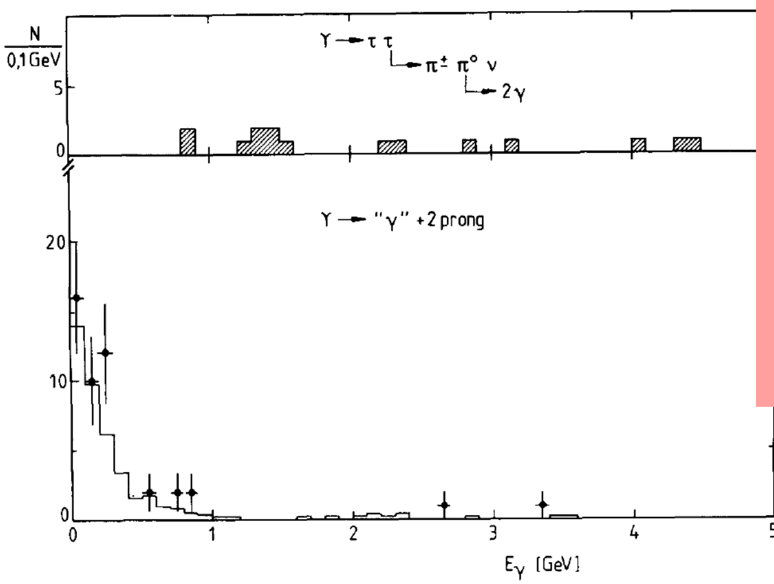
where the first error in E_γ or M is statistical and the second is systematic.[6]

$$\Upsilon(1S) \rightarrow \gamma H^0$$

Is the Higgs mass 8.3 GeV ???
At 4.2 sigma???

SEARCH FOR NARROW STATES COUPLING TO τ PAIRS IN RADIATIVE Υ DECAYS

The ARGUS Collaboration



In summary, we have observed no indication for narrow objects produced in radiative Υ decays and decaying into a τ pair. The present sensitivity is an order of magnitude to small to check the predictions from the standard model, if only one scalar Higgs particle is assumed. However, the result puts improved constraints on models with a more complicated Higgs structure.

Fig. 3. Photon spectrum from the decay $\Upsilon \to \gamma$ + two prongs used in search for the decay $\Upsilon \to \gamma X$, $X \to \tau^+\tau^-$. The hatched histogram shows the observed contribution from the decay $\Upsilon \to \tau^+\tau^-$ with one τ decaying into $\rho\nu$, the open histogram shows expected background contributions from other sources as described in the text.

Is the Higgs mass 8.3 GeV ???
At 4.2 sigma???

No, it isn't!