I am a Particle Physicist - A What?

Christos Leonidopoulos

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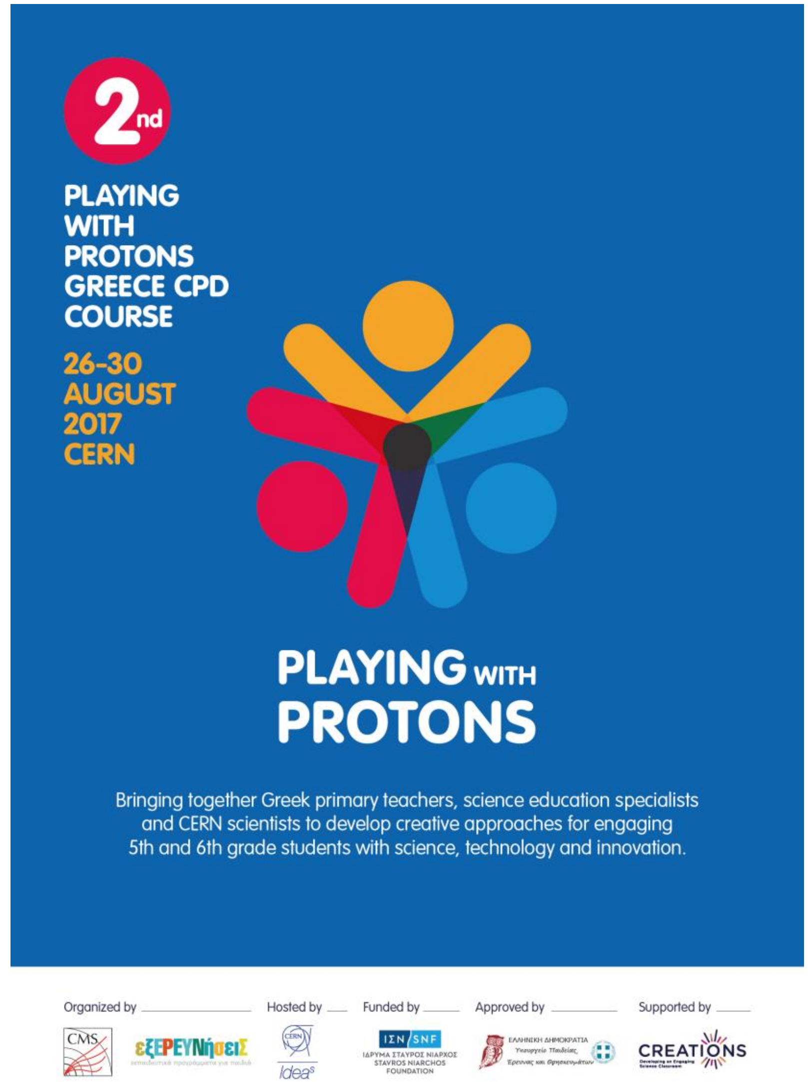
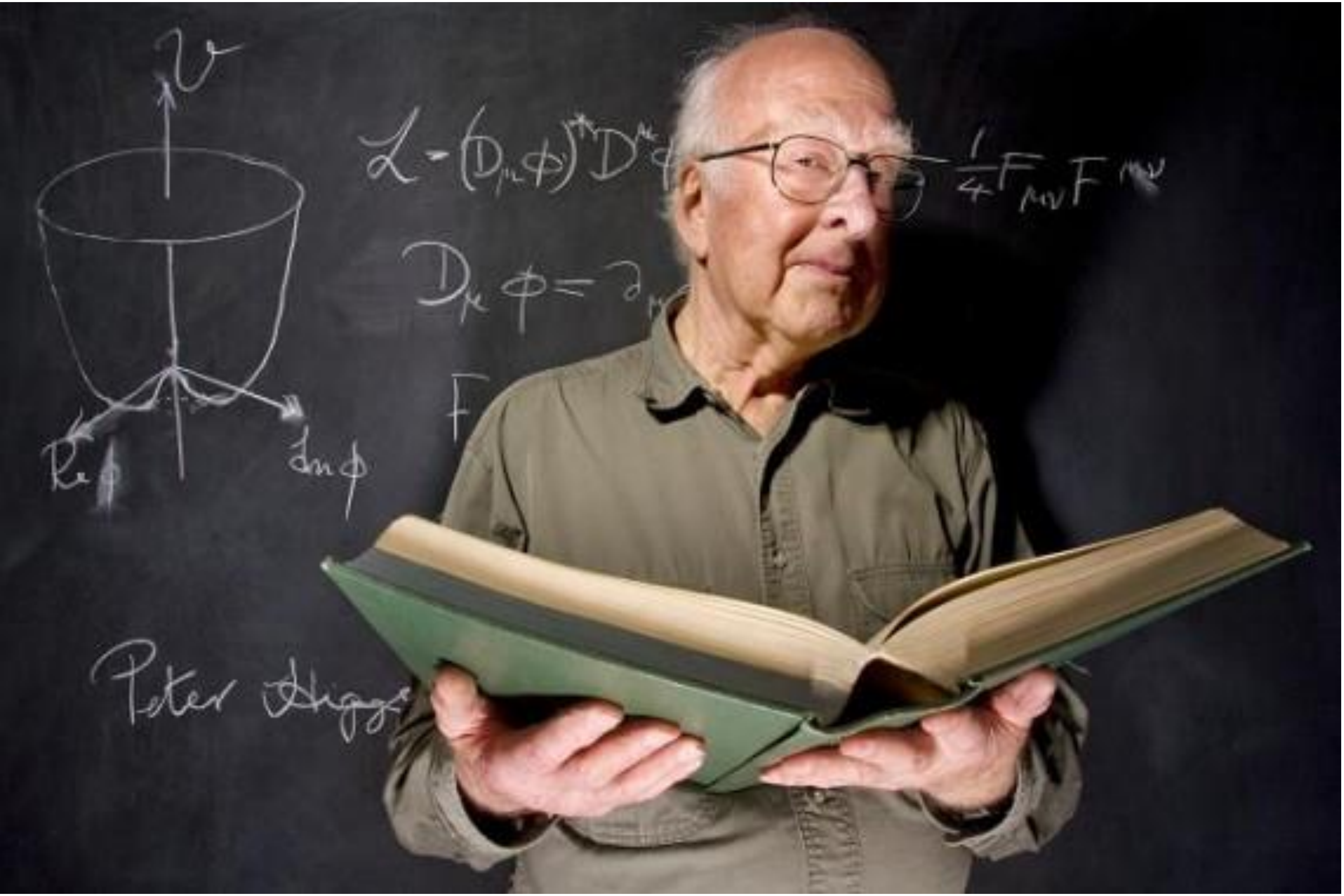




- What does a Higgs boson look like?
- Why are the detectors so huge?
- Fine, but what exactly do **you** do?
- What are the next steps?

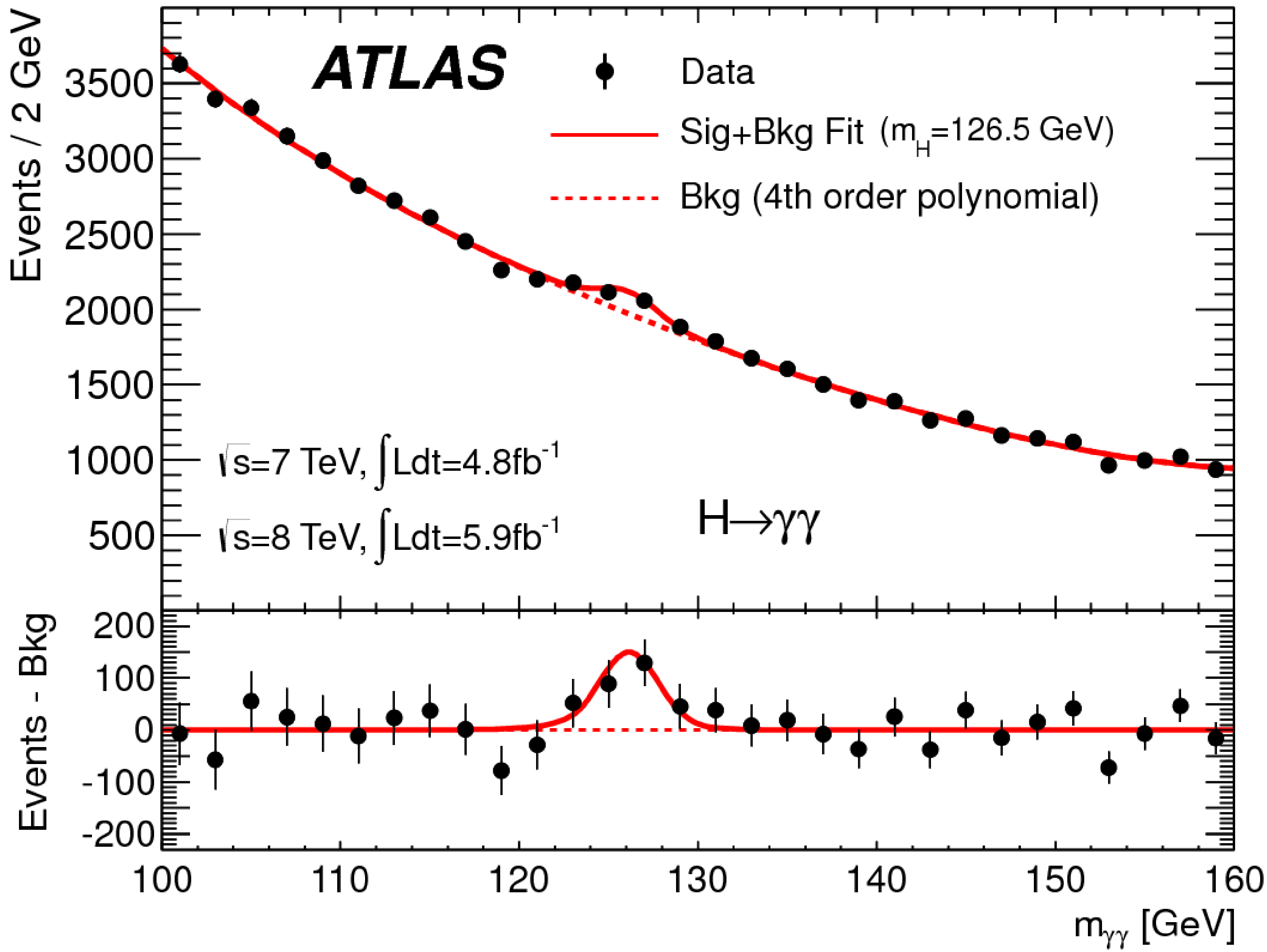

Peter

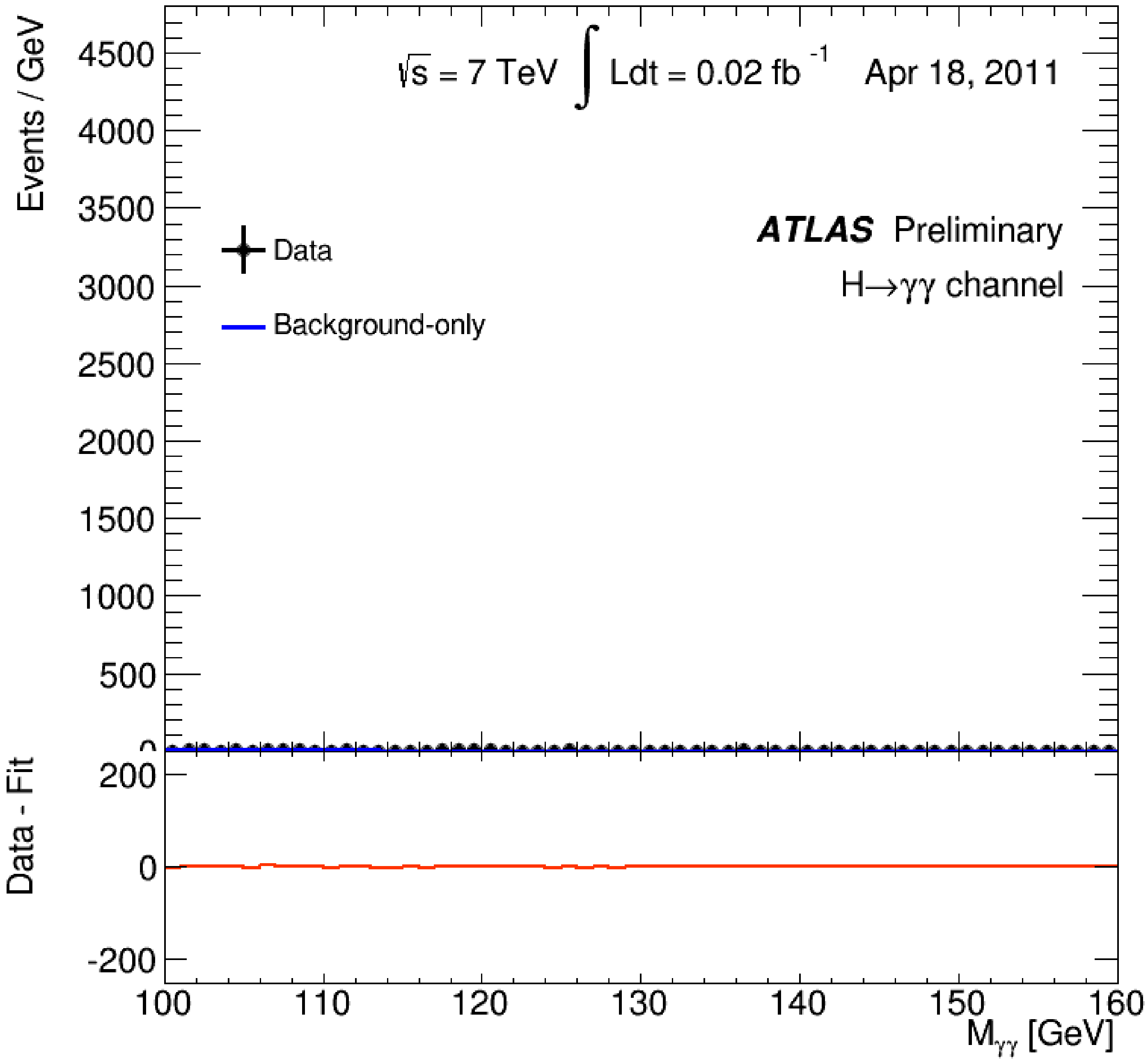
What does a Higgs boson look like?

Two little problems in “seeing” the Higgs:

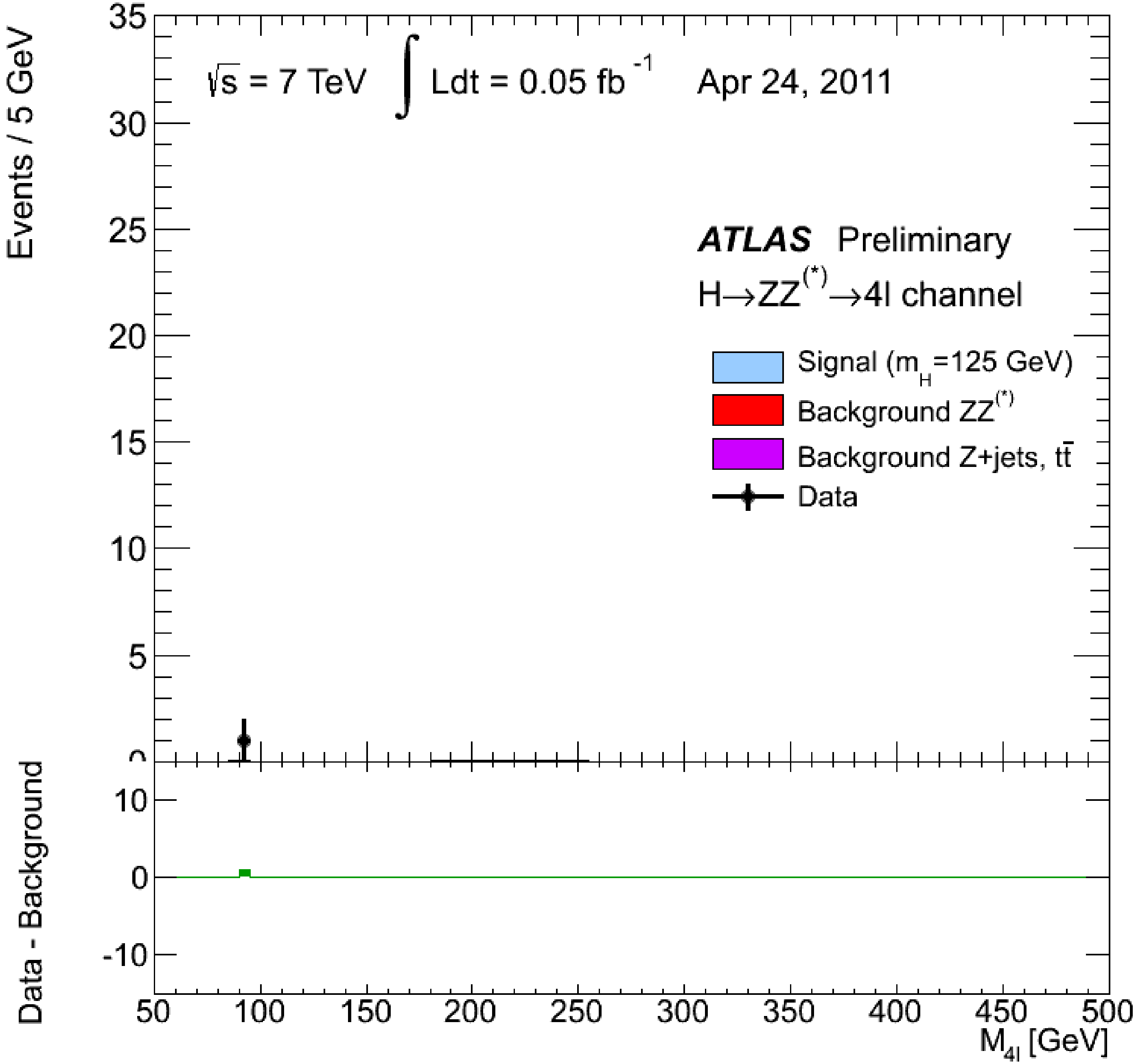
- The probability of creating a Higgs boson at the LHC in a p-p collision?
  - One in a billion

- The Higgs boson does not live long!
  - Lifetime: 10^{-22} sec


ATLAS
Data
Sig+Bkg Fit (m_H=126.5 GeV)
Bkg (4th order polynomial)
√s=7 TeV, ∫Ldt=4.8fb^-1
√s=8 TeV, ∫Ldt=5.9fb^-1
H→γγ
Events / 2 GeV
Events - Bkg
m_γγ [GeV]
3500
3000
2500
2000
1500
1000
500
200
100
0
-100
-200
100
110
120
130
140
150
160



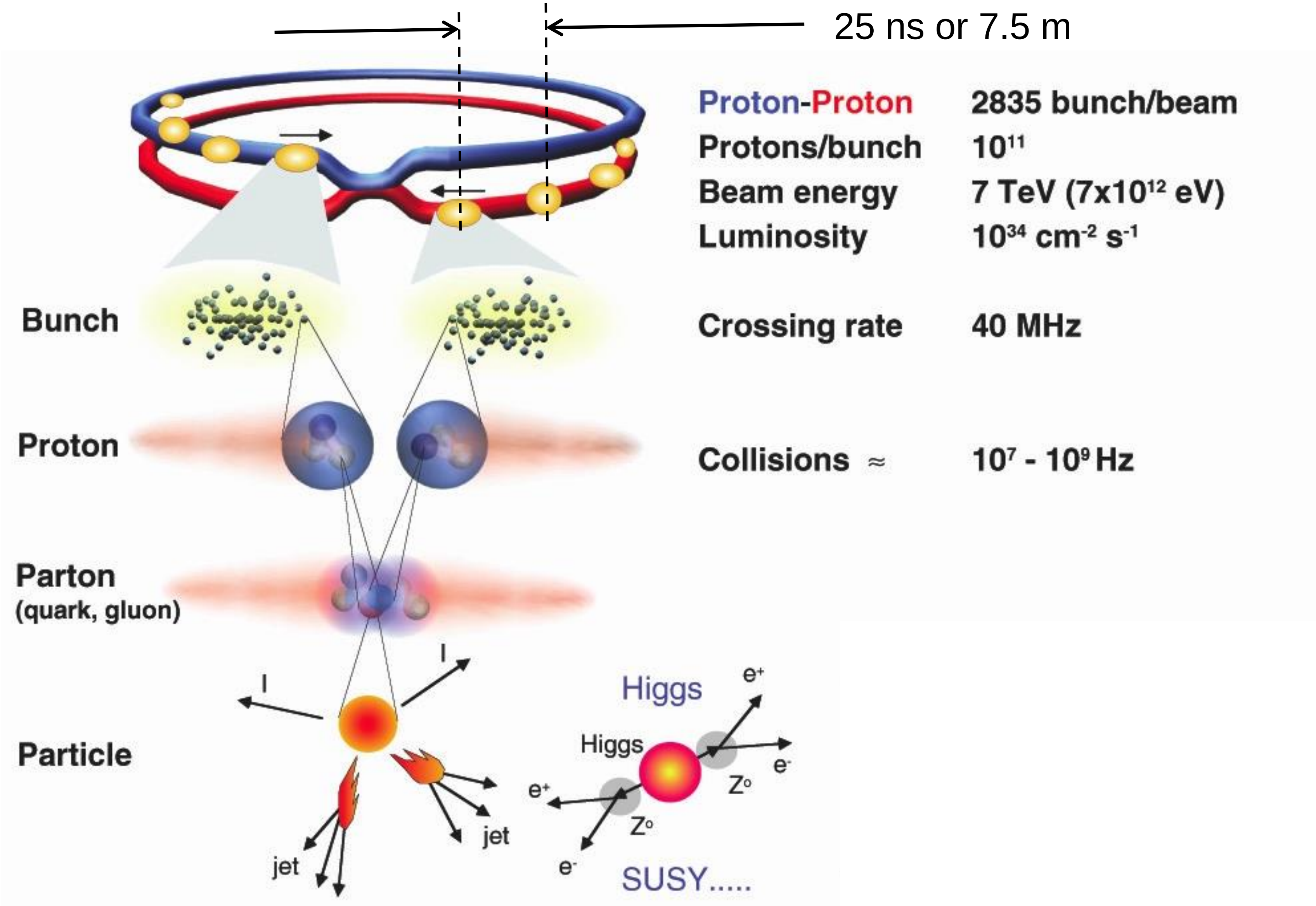
$\sqrt{s}$ = 7 TeV $\int$ Ldt = 0.02 fb^{-1} Apr 18, 2011
ATLAS Preliminary
H→γγ channel
Data
Background-only
Events / GeV
4500
4000
3500
3000
2500
2000
1500
1000
500
Data - Fit
200
0
-200
100
110
120
130
140
150
160
$M_{\gamma\gamma}$ [GeV]



√s = 7 TeV
∫ Ldt = 0.05 fb⁻¹
Apr 24, 2011
ATLAS Preliminary
H→ZZ(*)→4l channel
Signal (mH=125 GeV)
Background ZZ(*)
Background Z+jets, tt̄
Data
Events / 5 GeV
Data - Background
M4l [GeV]

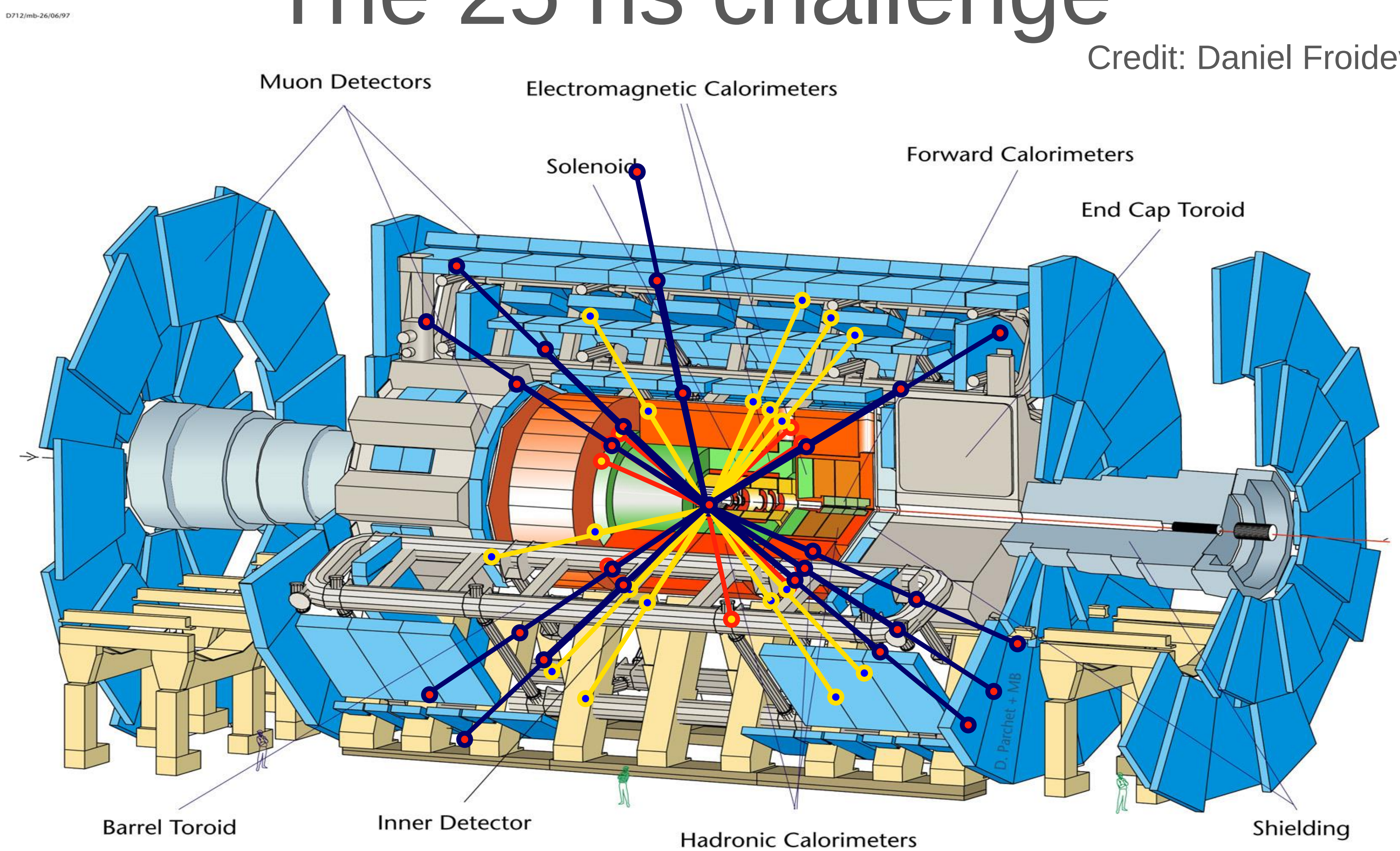
Why are the detectors so huge?

LHC numbers


25 ns or 7.5 m
Proton-Proton
2835 bunch/beam
Protons/bunch
10^{11}
Beam energy
7 TeV ($7x10^{12}$ eV)
Luminosity
10^{34} cm^{-2} s^{-1}
Bunch
Crossing rate
40 MHz
Proton
Collisions ≈
10^7 - 10^9 Hz
Parton
(quark, gluon)
Particle
l
l
jet
jet
Higgs
Higgs
e^+
e^-
Z^o
e^+
Z^o
e^-
SUSY.....

The 25 ns challenge

Credit: Daniel Froidevaux



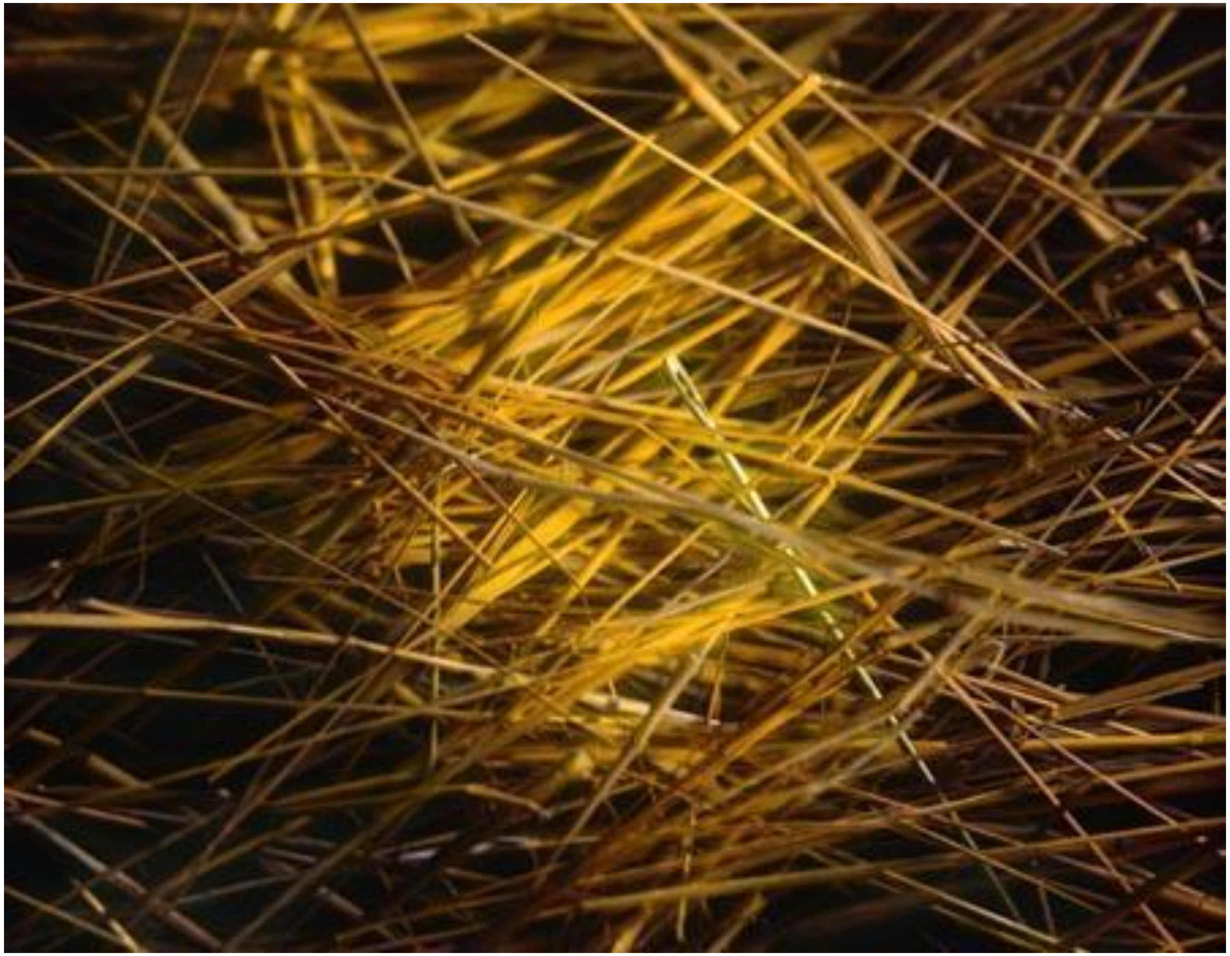
Interactions every 25 ns …

- In 25 ns particles travel 7.5 m

Cable length ~100 meters …

- In 25 ns signals travel 5 m

*Fine, but what exactly do **you** do?*

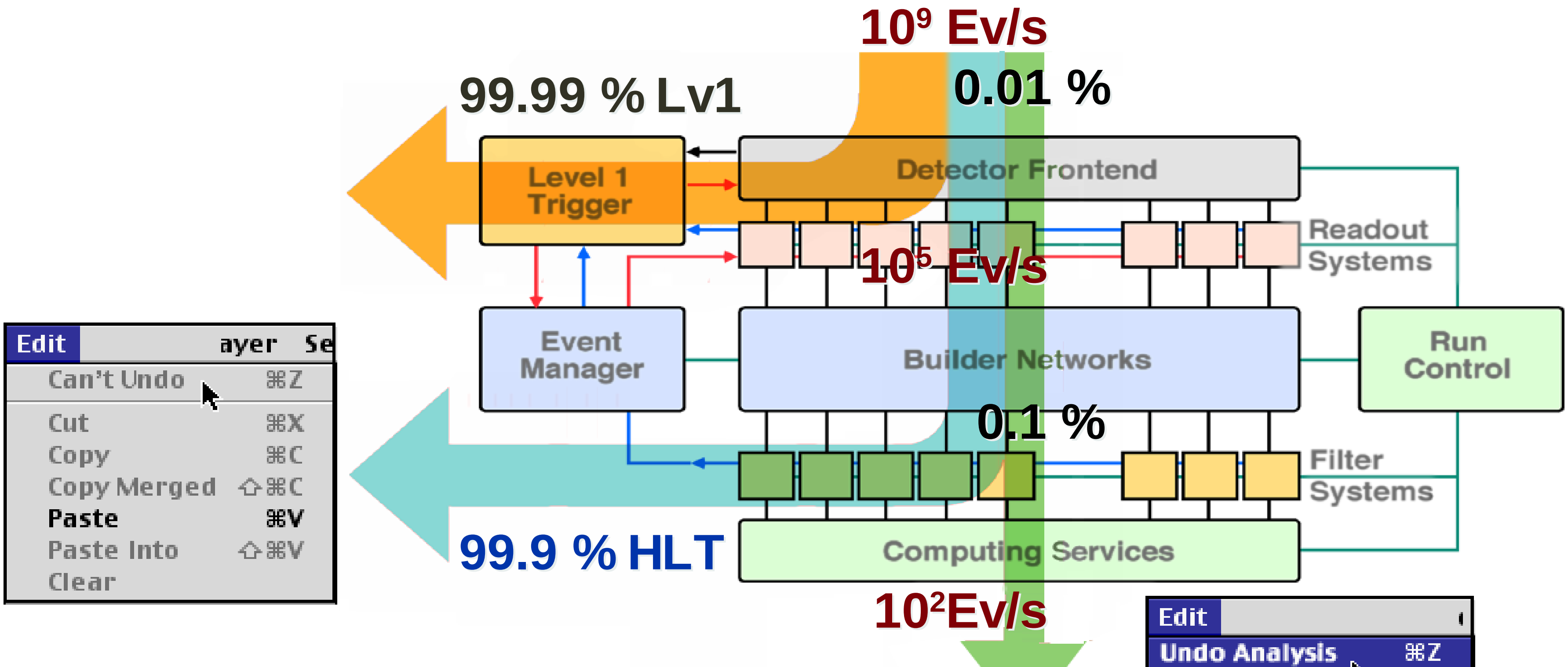


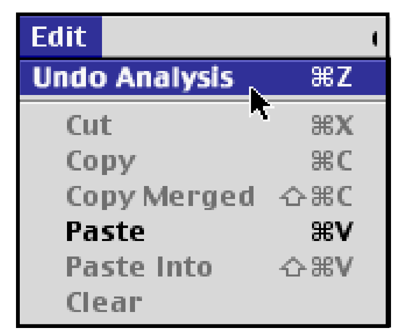
- Collision rate at LHC?   1 Billion Hz
- Events selected for permanent storage? 1 kH

Background is a Disease

Meet the Cure

The Trigger





Which begs the question(*):

Will all the exciting New Physics be included in the small fraction of selected events?

(*) LHC upgrade: 1B CHF, CMS+ATLAS detectors: 1.2B CHF

What are the next steps?

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▶ François Englert
▶ Peter Higgs

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The Nobel Prize in Physics 2013
François Englert, Peter Higgs

The Nobel Prize in Physics 2013

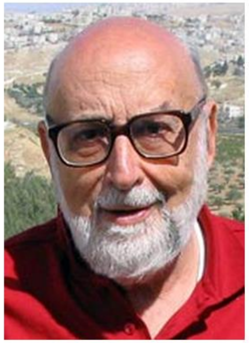
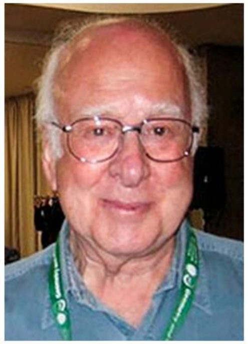


Photo: Pnicolet via Wikimedia Commons
François Englert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Peter W. Higgs

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

...the interchange of α and β, whereas the second one is antisymmetric

...aightforward algebra yields

$$
\begin{aligned}
(4\pi\Sigma)^{d/2} \exp&\left[\frac{\alpha_{23}\alpha_{14}q^2 + \alpha_{12}\alpha_{34}k^2 + 2(\alpha_1\alpha_3 - \alpha_2\alpha_4)q\cdot k}{\Sigma}\right] J_{\alpha\beta\mu\nu}\,\mathrm{tr}\,(\gamma_\nu\gamma_\sigma\gamma_\mu\gamma_\lambda\gamma_\alpha\gamma_\rho\gamma_\beta\gamma_\lambda) \\
&= -4(d-2)\{Q_\rho Q_\sigma(k^2 - 2q^2) + Q_\rho q_\sigma[-k\cdot(k+2q) + 4q\cdot Q] + Q_\rho k_\sigma[(k+2q)\cdot q - 2k\cdot Q] \\
&\quad + k_\rho q_\sigma Q\cdot(k-2q) - k_\rho k_\sigma Q\cdot(q-Q) + 2q_\rho q_\sigma Q\cdot(k-Q) - \delta_{\rho\sigma}(k+q-Q)\cdot(q-Q)Q\cdot(k-Q)\} \\
&\quad + 4(6-d)\{(\delta_{\rho\sigma}k^2 - k_\rho k_\sigma)Q\cdot(Q-q) - (\delta_{\rho\lambda}k\cdot Q - Q_\rho k_\lambda)[\delta_{\lambda\sigma}k\cdot(Q-q) - k_\lambda(Q-q)_\sigma]\} \\
&\quad - \frac{4(d-2)}{2\Sigma}\{(2-d)(2q_\rho q_\sigma - k_\rho k_\sigma) + (d-2)\delta_{\rho\sigma}[(k+q-Q)\cdot(q-Q) - Q\cdot(k-Q)] \\
&\quad + 2\delta_{\rho\sigma}(k-2Q)\cdot(k+2q-2Q)\} \\
&\quad + \frac{4(6-d)}{2\Sigma}\{[k^2\delta_{\rho\sigma} - k_\rho k_\sigma](d-2)\} - \frac{4(d-2)}{4\Sigma^2}[\delta_{\rho\sigma}d(d+2)] \\
&\equiv -4(d-2)A_1 + 4(6-d)A_2 - \frac{4(d-2)}{2\Sigma}B_1 + \frac{4(6-d)}{2\Sigma}B_2 - \frac{4(d-2)}{4\Sigma^2}C_1
\end{aligned}
\qquad (8\text{-}119)
$$

...ere the origin and the denomination of each term is clear and we have used the symmetry between ...d σ.

The q integration must now be carried out. We write

$$\frac{1}{q^2} = \frac{\alpha_{23}\alpha_{14}}{\Sigma}\int_0^\infty dx\,\exp\left(-\frac{x\alpha_{23}\alpha_{14}q^2}{\Sigma}\right) \qquad (8\text{-}120)$$

...integrand involves

$$\exp\left[-\frac{(x+1)\alpha_{23}\alpha_{14}q^2 + \alpha_{12}\alpha_{34}k^2 + 2(\alpha_1\alpha_3 - \alpha_2\alpha_4)q\cdot k}{\Sigma}\right]$$

...wers of q, we perform a new shift of integration variable

$$q = q' - \alpha k$$

$$\alpha = \frac{\alpha_1\alpha_3 - \alpha_2\alpha_4}{(x+1)\alpha_{14}\alpha_{23}} \qquad (8\text{-}121)$$

...y,

$$Q = \hat{\alpha}_{23}q' + zk$$

$$z = \frac{\alpha_{34}}{\Sigma} - \frac{\alpha_1\alpha_3 - \alpha_2\alpha_4}{\Sigma(x+1)\alpha_{14}} \qquad \hat{\alpha}_{23} = \frac{\alpha_{23}}{\Sigma} \qquad (8\text{-}122)$$

... the coefficient of q^2 in the exponential

$$y \equiv (x+1)\frac{\alpha_{23}\alpha_{14}}{\Sigma} \equiv \frac{1}{x'}\frac{\alpha_{23}\alpha_{14}}{\Sigma} \qquad (8\text{-}123)$$

...esired amplitude $\Gamma^{(b)}_{\rho\sigma}(k)$ reads

$$\times\int\frac{d^dq'}{(2\pi)^d}e^{-yq'^2}\left[-4(d-2)A_1 + \cdots - \frac{4(d-2)}{4\Sigma^2}C_1\right] \qquad (8\text{-}124)$$

It is then a pure matter of patience to compute

$$
\begin{aligned}
(4\pi y)^{d/2}\int\frac{d^dq'}{(2\pi)^d}e^{-yq'^2}A_1 &= k_\rho k_\sigma\frac{\alpha_{23}\alpha_{14} + 2(\alpha_1 - \alpha_3)(\alpha_4 - \alpha_2)}{2y\Sigma^2}(d-2) \\
&\quad + \delta_{\rho\sigma}\Bigg[(k^2)^2 z(1-z)(\alpha+z)(1-\alpha-z) \\
&\quad + \frac{k^2}{2y}\left\{2\hat{\alpha}_{23}(1-\hat{\alpha}_{23})[\alpha + 2z - 2z(\alpha+z)] + \frac{2(\alpha_1-\alpha_3)(\alpha_4-\alpha_2)}{\Sigma^2}\right\} \\
&\quad - \frac{k^2 d}{2y}[(\alpha+z)(1-\alpha-z)\hat{\alpha}^2_{23} + (1-\hat{\alpha}_{23})^2 z(1-z)] \\
&\quad + \frac{d(d+2)}{4y^2}\hat{\alpha}^2_{23}(1-\hat{\alpha}_{23})^2\Bigg]
\end{aligned}
$$

$$
\begin{aligned}
(4\pi y)^{d/2}\int\frac{d^dq'}{(2\pi)^d}e^{-yq'^2}B_1 &= (2-d)(2\alpha^2-1)k_\rho k_\sigma \\
&\quad - (d-2)\delta_{\rho\sigma}\left\{\frac{1}{y} + k^2[(\alpha+z)(1-\alpha-z) + z(1-z)] - \frac{d}{2y}[\hat{\alpha}^2_{23} + (1-\hat{\alpha}_{23})^2]\right\} \\
&\quad + 2\delta_{\rho\sigma}\left[k^2(1-2z)(1-2z-2\alpha) - 2\hat{\alpha}_{23}(1-\hat{\alpha}_{23})\frac{d}{y}\right]
\end{aligned}
$$

$$(4\pi y)^{d/2}\int\frac{d^dq'}{(2\pi)^d}e^{-yq'^2}A_2 = \frac{d-2}{2y}\hat{\alpha}_{23}(1-\hat{\alpha}_{23})(k_\rho k_\sigma - k^2\delta_{\rho\sigma})$$

Consequently,

$$
\begin{aligned}
\Gamma^{(A_2+B_2)}_{\rho\sigma} &= -\frac{e^4}{(4\pi)^d}4(6-d)(d-2)(k^2\delta_{\rho\sigma} - k_\rho k_\sigma)\int_0^1\frac{dx'}{x'^2}\int_0^\infty\frac{d\alpha_1\cdots d\alpha_4\alpha_{23}\alpha_{14}(1-x')}{2\Sigma^{d/2+2}y^{d/2}} \\
&\quad \times\exp\left[-\frac{\alpha_{12}\alpha_{23}\alpha_{34}\alpha_{41} - x'(\alpha_1\alpha_3 - \alpha_2\alpha_4)^2}{\Sigma\alpha_{23}\alpha_{14}}k^2\right] \\
&= -\frac{e^4}{(4\pi)^d}2(6-d)(d-2)(k^2\delta_{\rho\sigma} - k_\rho k_\sigma)(k^2)^{d-4}\Gamma(4-d) \\
&\quad \times\int_0^1 dx'\,x'^{d/2-2}(1-x')\int_0^1\frac{d\alpha_1\cdots d\alpha_4\delta(1-\alpha_1-\alpha_2-\alpha_3-\alpha_4)}{(\alpha_{14}\alpha_{23})^{3d/2-5}} \\
&\quad \times[\alpha_{12}\alpha_{23}\alpha_{34}\alpha_{41} - x'(\alpha_1\alpha_3 - \alpha_2\alpha_4)^2]^{d/2-4}
\end{aligned}
$$

After the change of variables,

$$\alpha_1 = \beta u \qquad \alpha_2 = (1-\beta)v \qquad \alpha_3 = (1-\beta)(1-v) \qquad \alpha_4 = \beta(1-u)$$

$$\alpha_{14} = \beta \qquad \alpha_{23} = 1-\beta$$

$$[\alpha_{12}\alpha_{23}\alpha_{34}\alpha_{41} - x'(\alpha_1\alpha_3 - \alpha_2\alpha_4)^2] = \beta(1-\beta)\{[\beta(1-u) + (1-\beta)(1-v)]\ \ldots$$

$$\times \int \frac{d^d q'}{(2\pi)^d} e^{-yq'^2} \left[-4(d-2)A_1 + \cdots - \frac{4(d-2)}{4\sum^2} C_2 \right]$$

It is then a pure matter of patience to compute

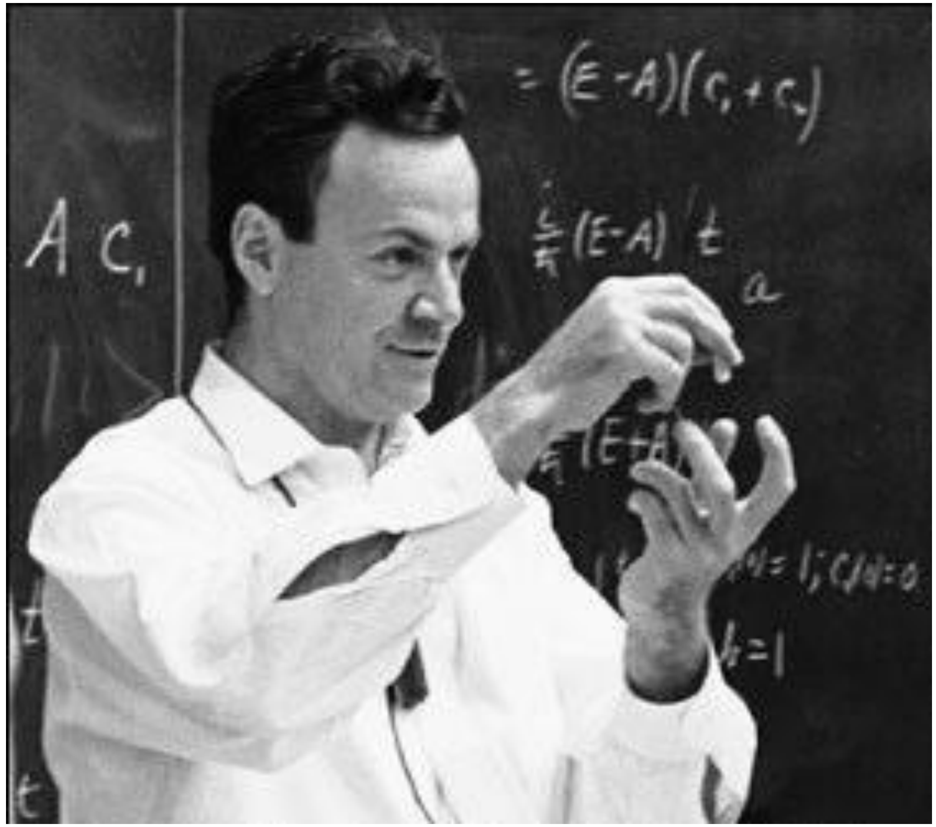
$$(4\pi y)^{d/2} \int \frac{d^d q'}{(2\pi)^d} e^{-yq'^2} A_1 = k_\rho k_\sigma \frac{\alpha_{23}\alpha_{14} + 2(\alpha_1 - \alpha_3)(\alpha_4 - \alpha_2)}{2y\sum^2}(d-2)$$
$$+ \delta_{\rho\sigma}\Bigg[(k^2)^2 z(1-z)(\alpha+z)(1-\alpha-z)$$
$$+ \frac{k^2}{2y}\left\{ 2\hat{\alpha}_{23}(1-\hat{\alpha}_{23})[\alpha + 2z - 2z(\alpha+z)] + \frac{2(\alpha_1-\alpha_3)(\alpha_4-\alpha_2)}{\sum^2} \right\}$$
$$- \frac{k^2 d}{2y}\left[(\alpha+z)(1-\alpha-z)\hat{\alpha}_{23}^2 + (1-\hat{\alpha}_{23})^2 z(1-z) \right]$$
$$+ \frac{d(d+2)}{4y^2}\hat{\alpha}_{23}^2(1-\hat{\alpha}_{23})^2 \Bigg] \tag{8-124}$$

$$(4\pi y)^{d/2} \int \frac{d^d q'}{(2\pi)^d} e^{-yq'^2} B_1 = (2-d)(2\alpha^2 - 1)k_\rho k_\sigma$$
$$-(d-2)\delta_{\rho\sigma}\left\{ \frac{1}{y} + k^2[(\alpha+z)(1-\alpha-z) + z(1-z)] - \frac{d}{2y}[\hat{\alpha}_{23}^2 + (1-\hat{\alpha}_{23})^2] \right\}$$
$$+ 2\delta_{\rho\sigma}\left[k^2(1-2z)(1-2z-2\alpha) - 2\hat{\alpha}_{23}(1-\hat{\alpha}_{23})\frac{d}{y} \right]$$

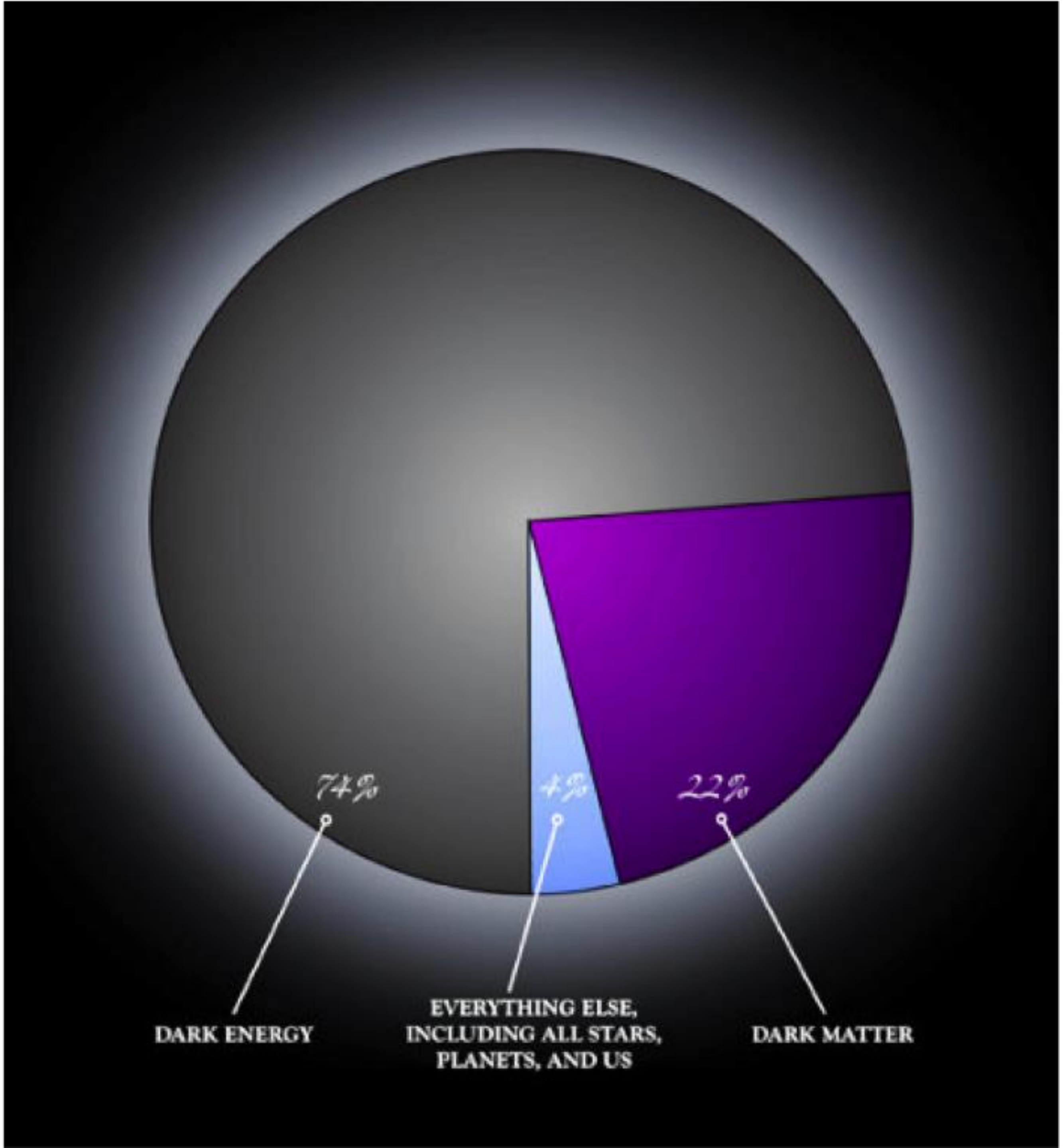
$$(4\pi y)^{d/2} \int \frac{d^d q'}{(2\pi)^d} e^{-yq'^2} A_2 = \frac{d-2}{2y}\hat{\alpha}_{23}(1-\hat{\alpha}_{23})(k_\rho k_\sigma - k^2 \delta_{\rho\sigma})$$

Consequently,

$$\Gamma_{\rho\sigma}^{(A_2+B_2)} = -\frac{e^4}{(4\pi)^d} 4(6-d)(d-2)(k^2\delta_{\rho\sigma} - k_\rho k_\sigma) \int_0^1 \frac{dx'}{x'^2} \int_0^\infty \frac{d\alpha_1 \cdots d\alpha_4 \alpha_{23}\alpha_{14}(1-x')}{2\sum^{d/2+2} y^{d/2}}$$
$$\times \exp\left[-\frac{\alpha_{12}\alpha_{23}\alpha_{34}\alpha_{41} - x'(\alpha_1\alpha_3 - \alpha_2\alpha_4)^2}{\sum \alpha_{23}\alpha_{14}} k^2 \right]$$
$$= -\frac{e^4}{(4\pi)^d} 2(6-d)(d-2)(k^2\delta_{\rho\sigma} - k_\rho k_\sigma)(k^2)^{d-4}\Gamma(4-d)$$
$$\cdots d\alpha_4 \frac{\delta(1-\alpha_1-\alpha_2-\alpha_3-\alpha_4)}{[illegible]^{d/2-5}} [illegible]$$



As if we had a theory with “...accuracy akin to measuring the distance between New York and Los Angeles and being off by the width of a human hair” −Richard Feynman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"...and I think this was the only justification for the way in which my name has become attached to the particle which was eventually discovered at the LHC. So it was essentially an accident which followed on from the rejection of the rather shorter version of that paper."