FROM QUARKS TO THE COSMOS

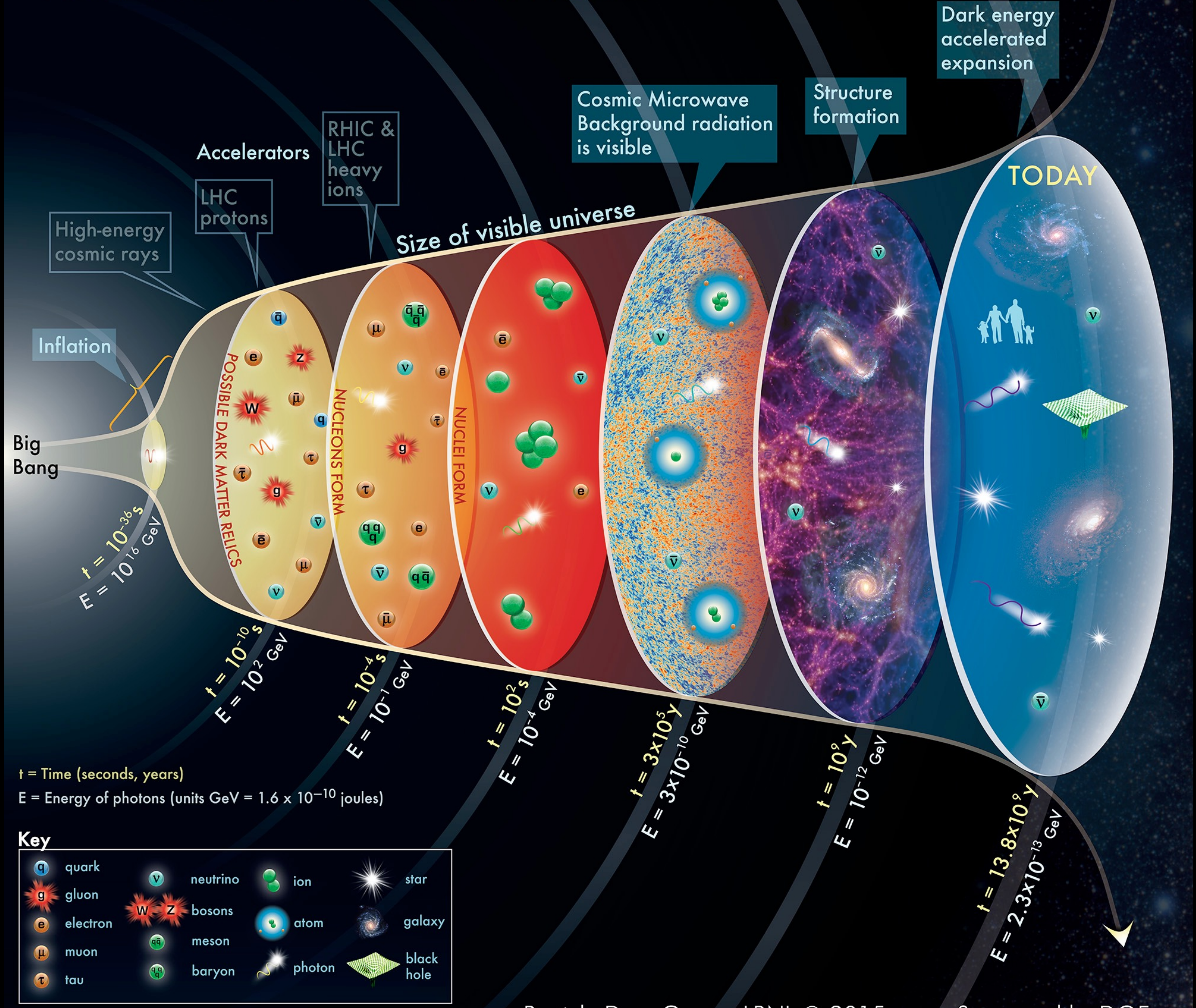
CLAIRE LEE

PARTICLE PHYSICIST, ATLAS EXPERIMENT, CERN

@CLAIRE_LEE

LIVE HERE
WORK AT AN EXPERIMENT HERE
WORK FOR A LAB HERE
BORN HERE

HISTORY OF THE UNIVERSE



t = Time (seconds, years)

E = Energy of photons (units GeV = 1.6 x 10^{-10} joules)

The concept for the above figure originated in a 1986 paper by Michael Turner.

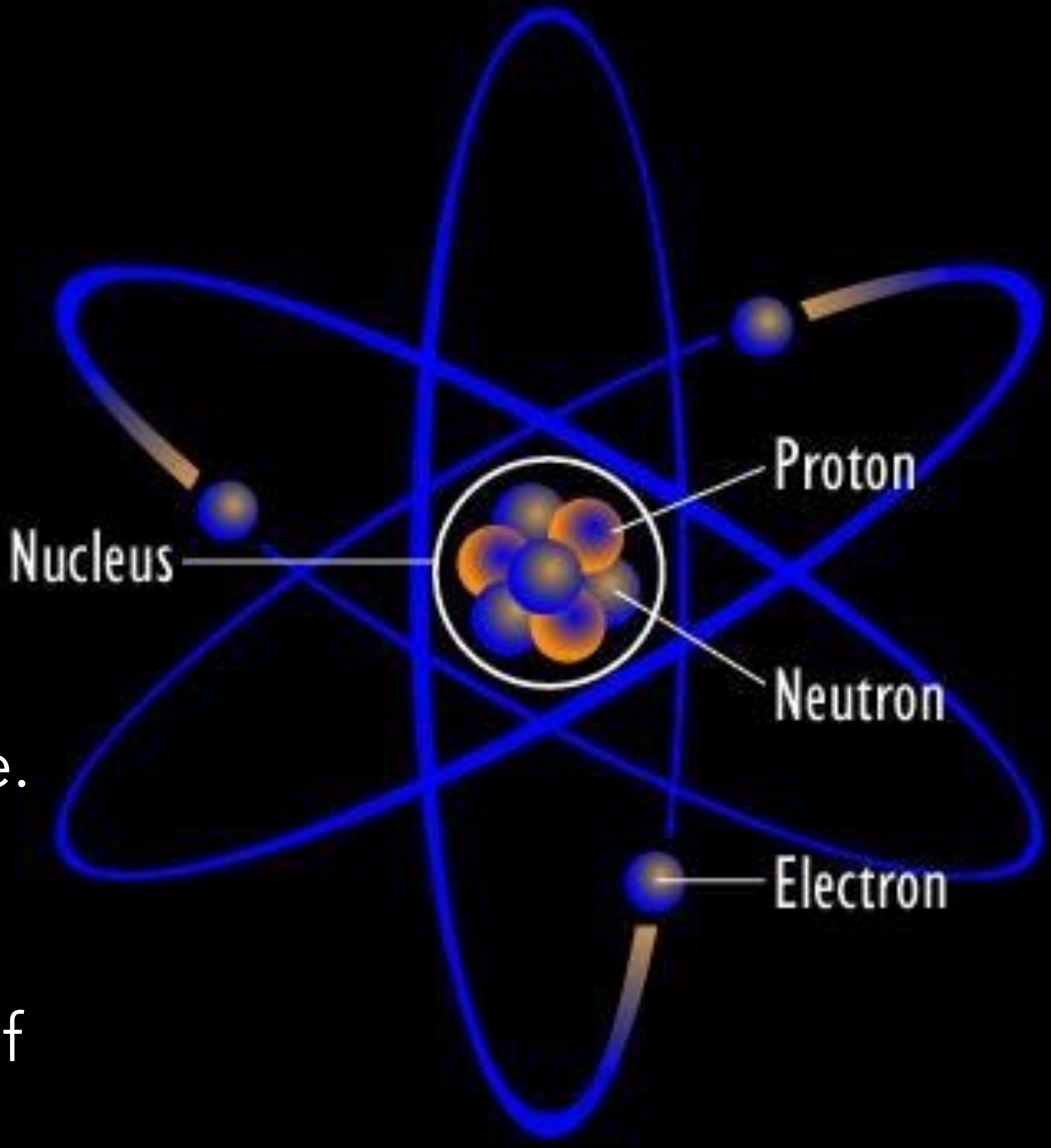
Particle Data Group, LBNL © 2015

Supported by DOE

WHAT PIECES DO YOU NEED TO BUILD THIS UNIVERSE?

HOW DO THESE PIECES FIT TOGETHER?

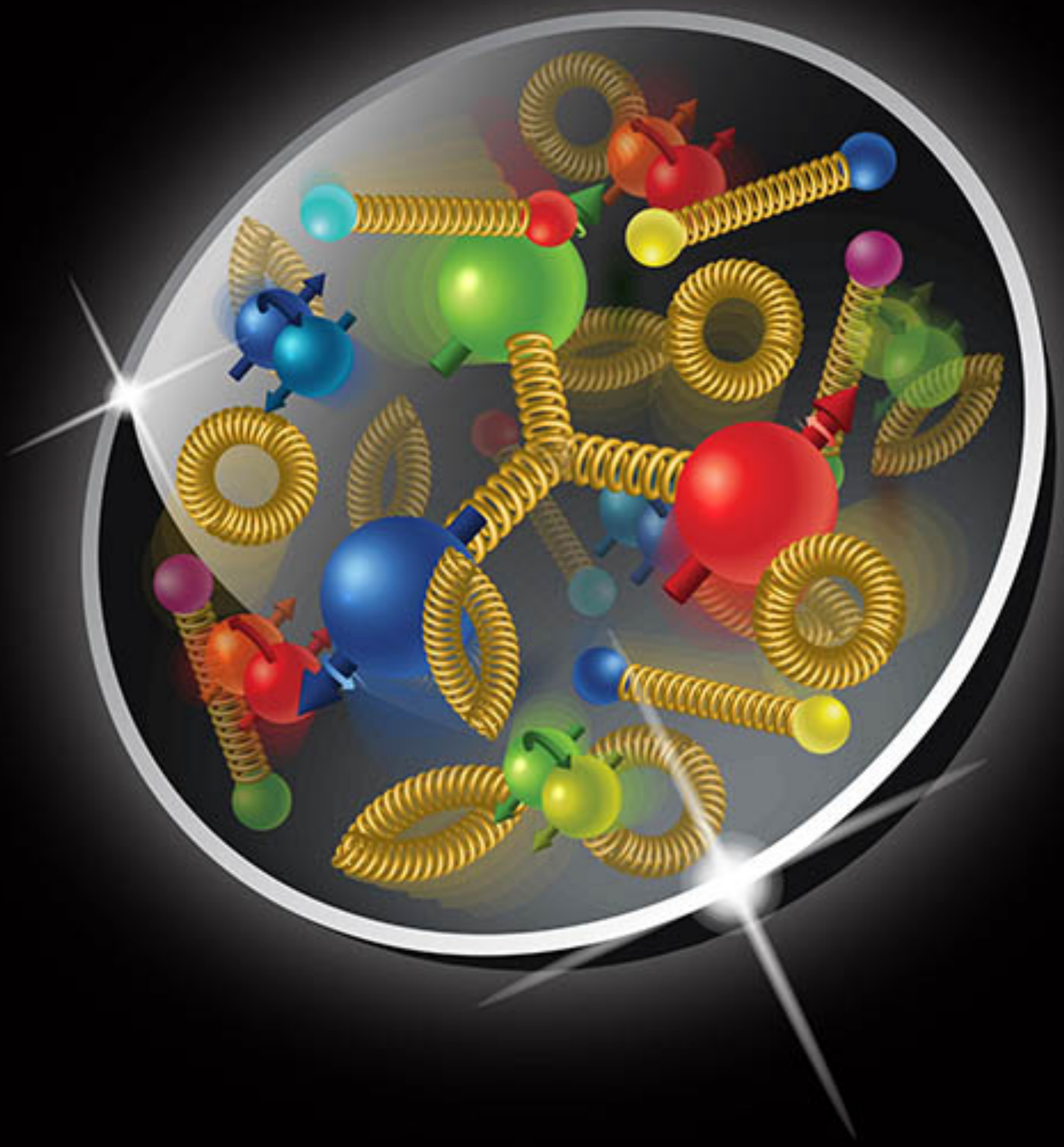
INSIDE AN ATOM



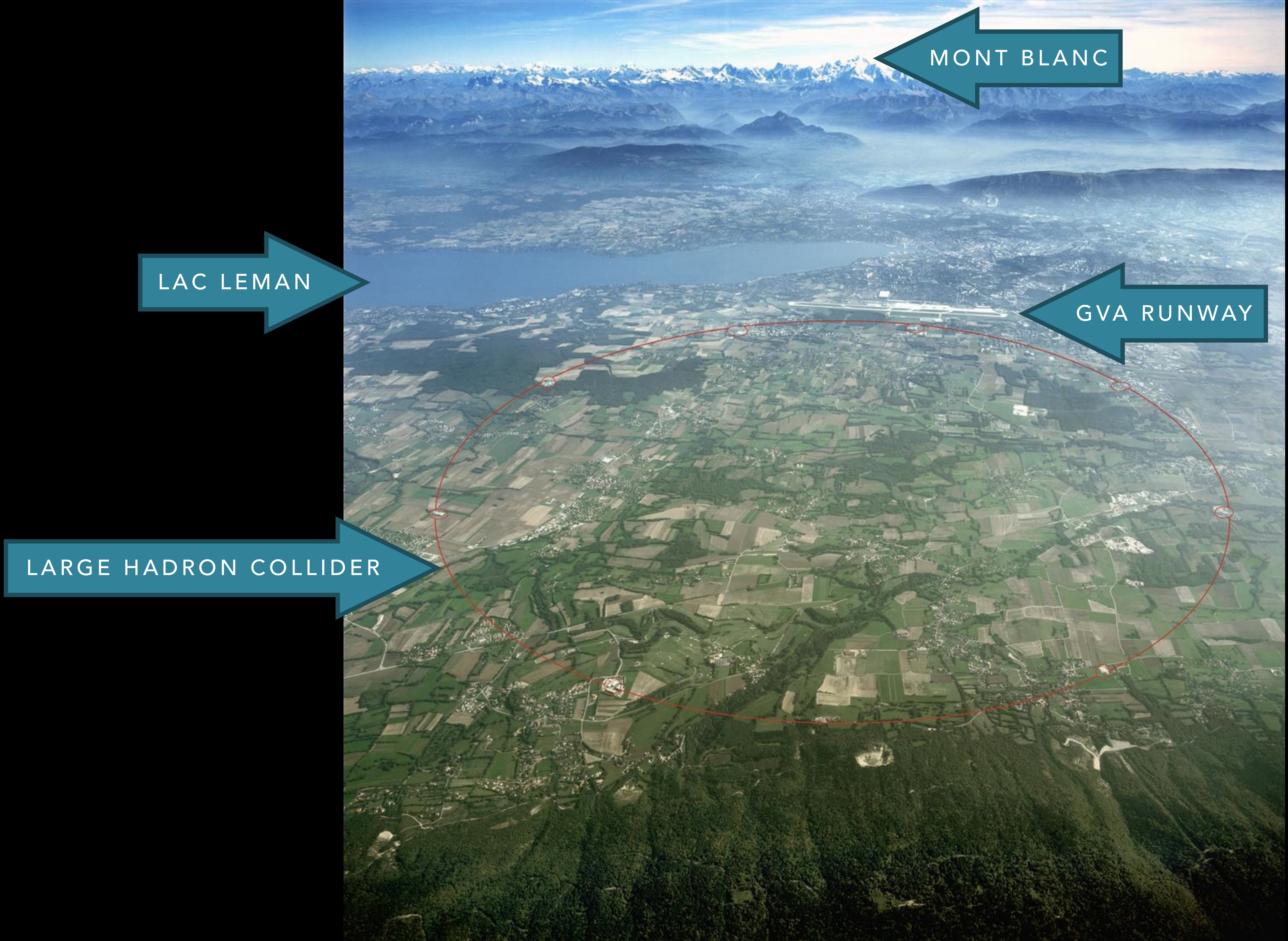
Most of an atom is empty space.

If the proton were a pea, the electron would be in the back of the stands at Old Trafford.

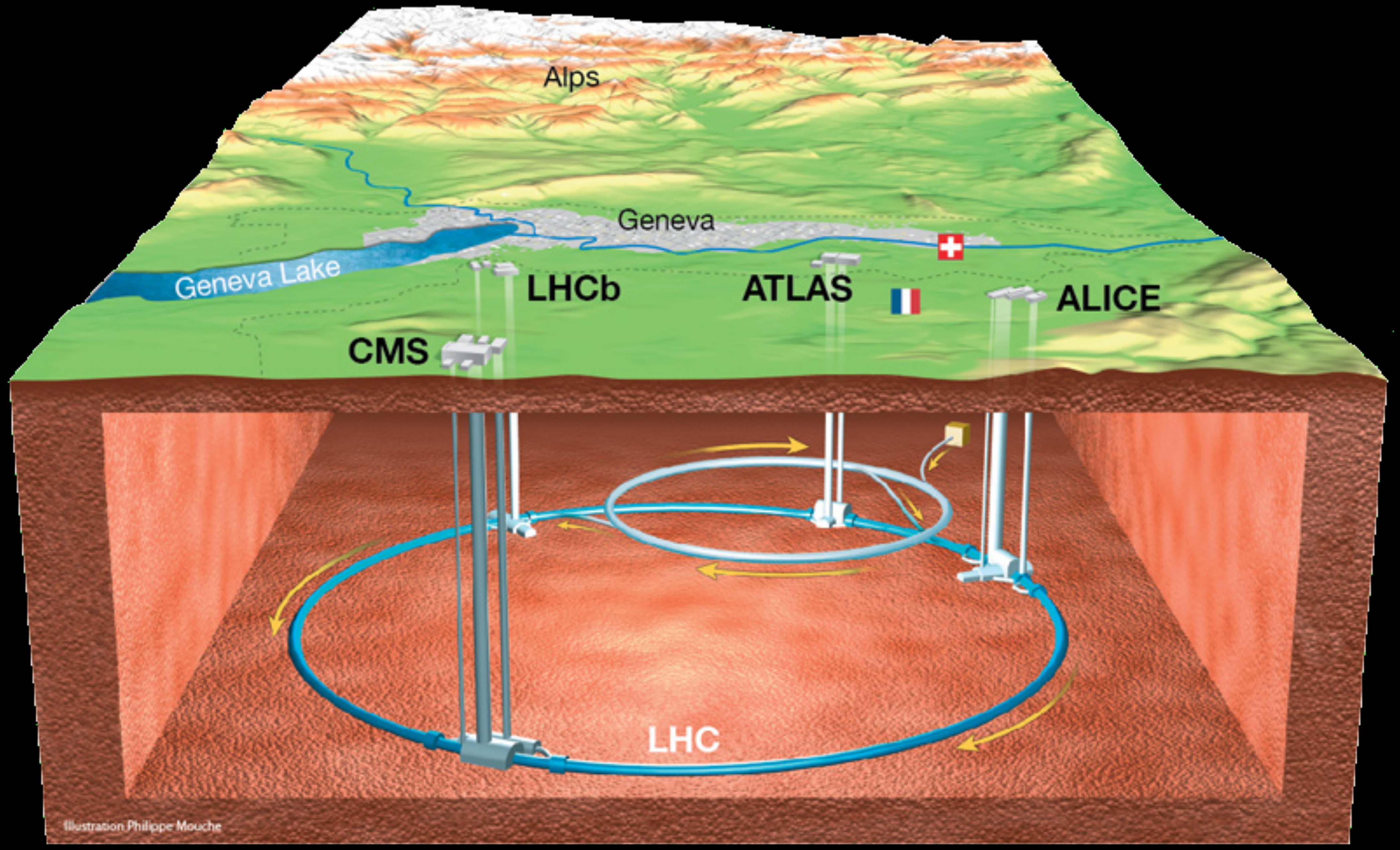
INSIDE A PROTON



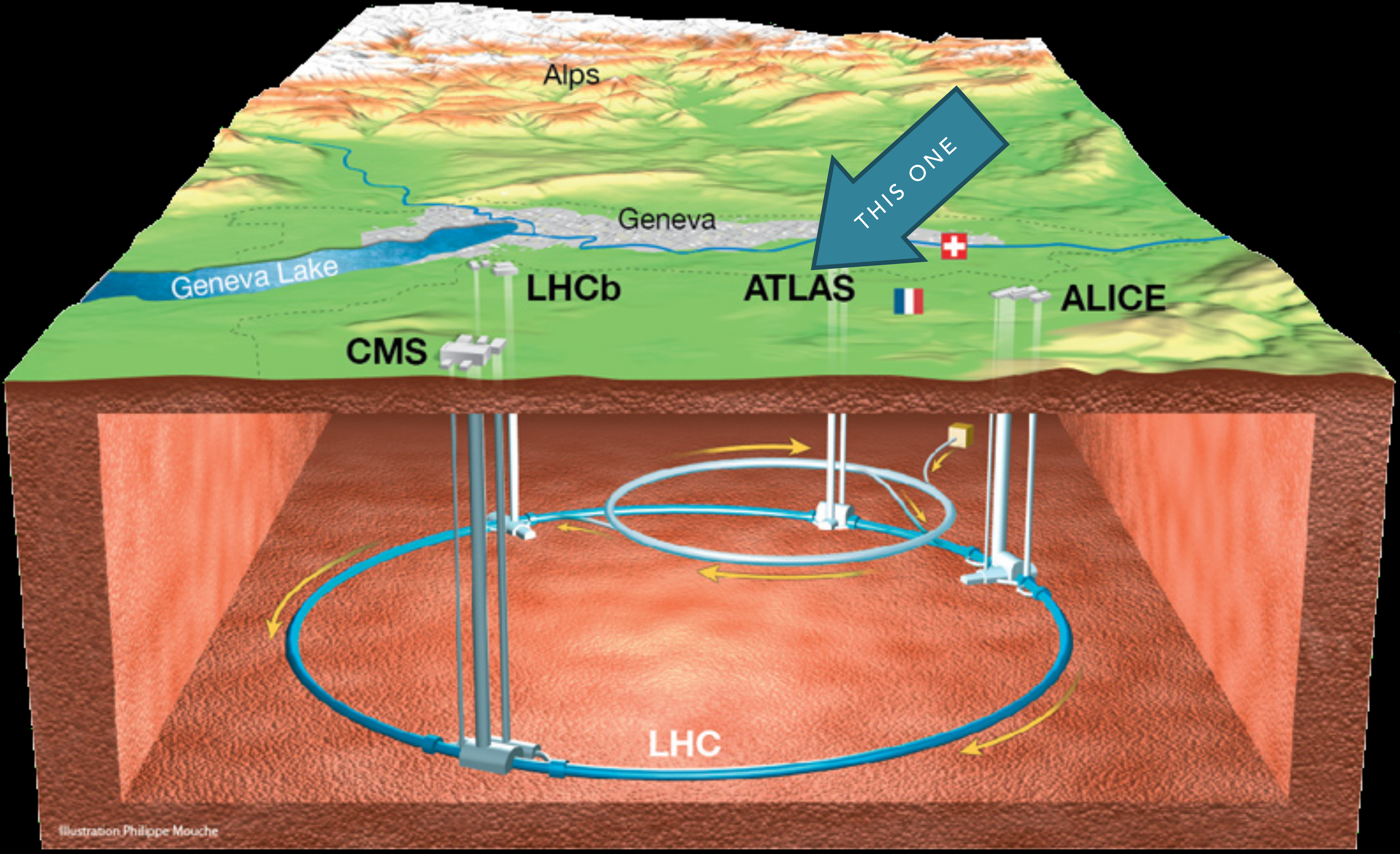
Quarks and gluons!


MONT BLANC
LAC LEMAN
GVA RUNWAY
LARGE HADRON COLLIDER

LARGE HADRON COLLIDER



- 27 km tunnel 100m underground
- More than 9000 magnets around the ring
- Sends protons round and round at 99.9999991% of the speed of light, and smashes them together **millions** of times per second
- 4 large experiments that try to work out what happened…



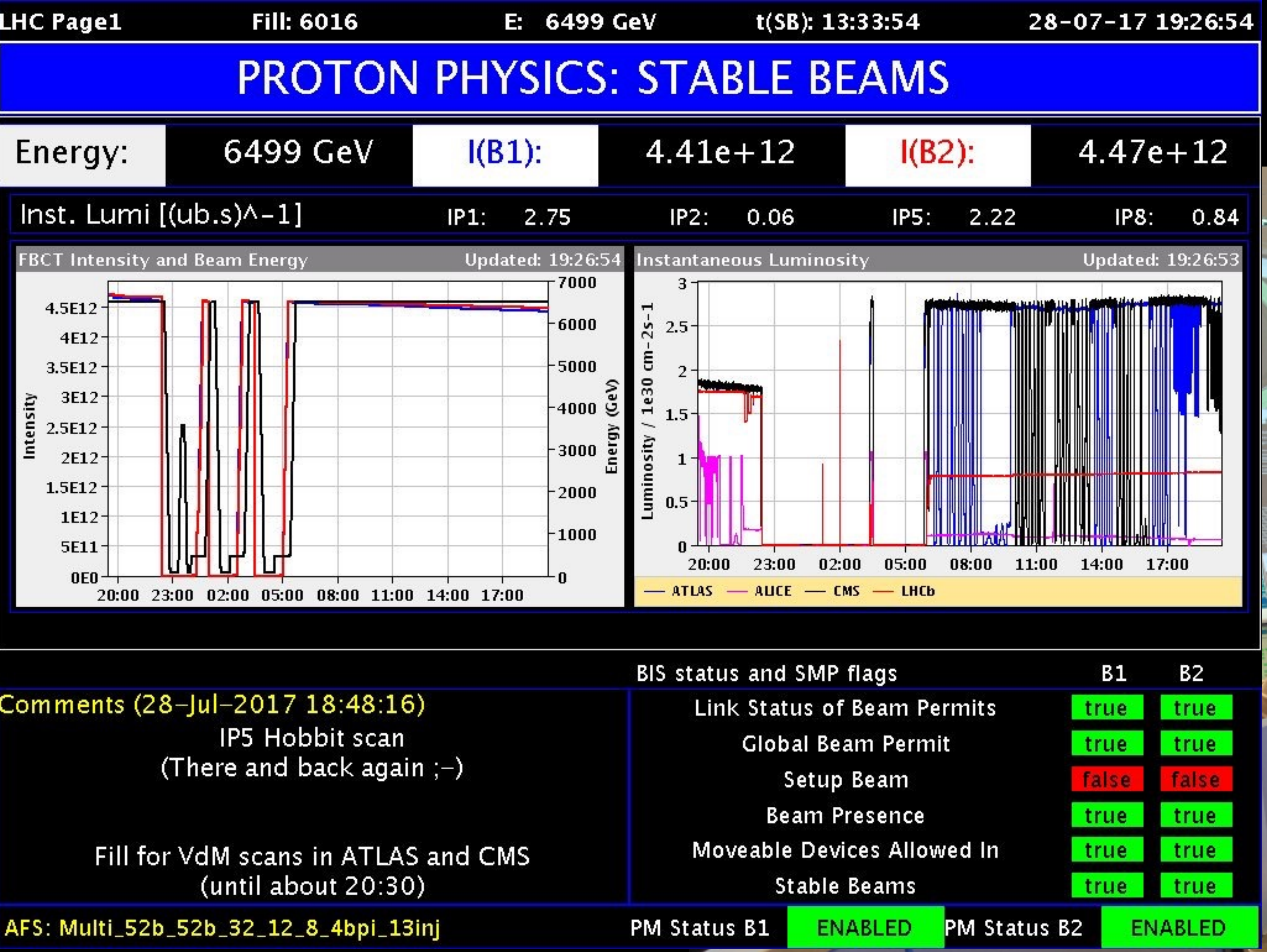
THIS ONE

Illustration Philippe Mouche

LHC BEAM ENERGY: 360 MEGAJOULES

THAT’S THE SAME AS 70 KG OF CHOCOLATE!

THE DAILY GRIND



LHC Page1 Fill: 6016 E: 6499 GeV t(SB): 13:33:54 28-07-17 19:26:54

PROTON PHYSICS: STABLE BEAMS

Energy:	6499 GeV	I(B1):	4.41e+12	I(B2):	4.47e+12

Inst. Lumi [(ub.s)^-1] IP1: 2.75 IP2: 0.06 IP5: 2.22 IP8: 0.84

Comments (28-Jul-2017 18:48:16)

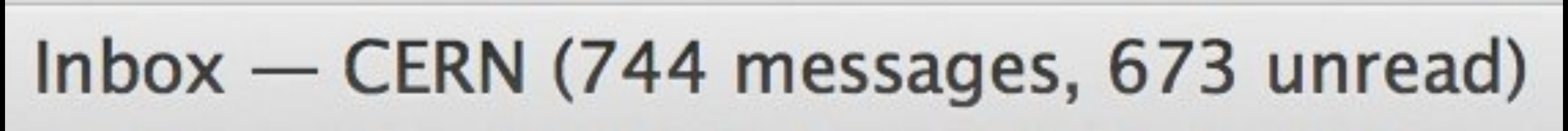
IP5 Hobbit scan
(There and back again ;-)

Fill for VdM scans in ATLAS and CMS
(until about 20:30)

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

AFS: Multi_52b_52b_32_12_8_4bpi_13inj PM Status B1 ENABLED PM Status B2 ENABLED

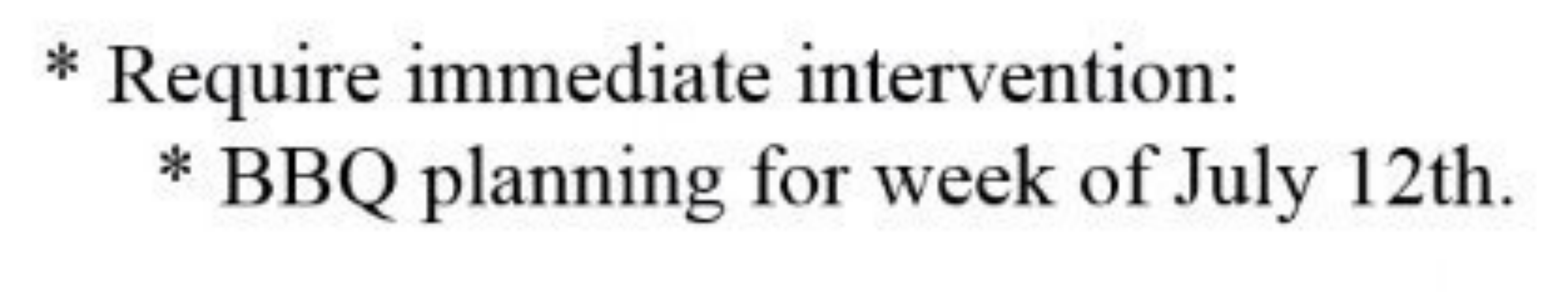
LIFE AS A PHYSICIST



Inbox — CERN (744 messages, 673 unread)

GOOD MORNING, INBOX

LIFE AS A PHYSICIST



- Require immediate intervention:
  - BBQ planning for week of July 12th.

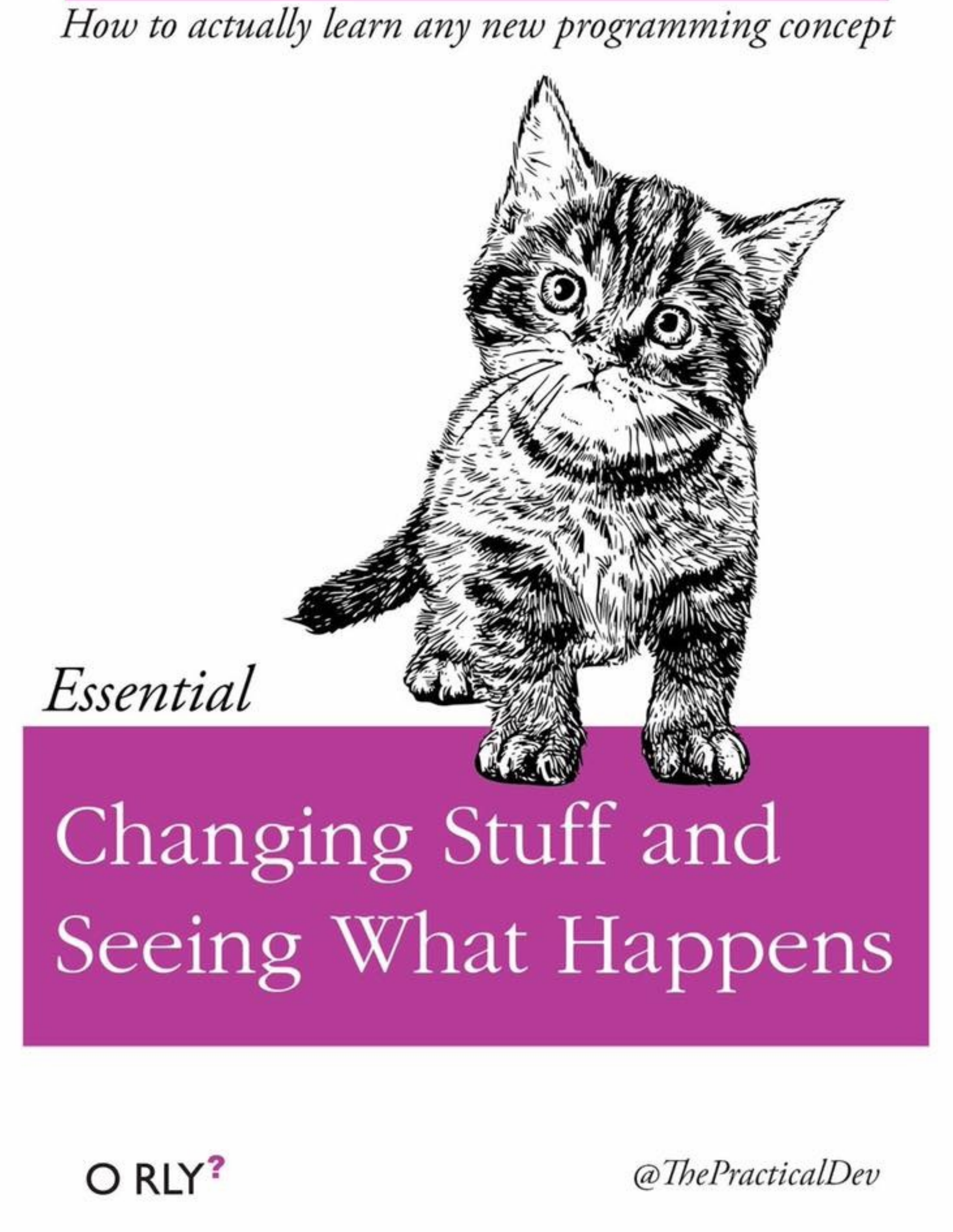
IMPORTANT OPERATIONS PLANNING

LIFE AS A PHYSICIST

- Moriond is now 143 Days away

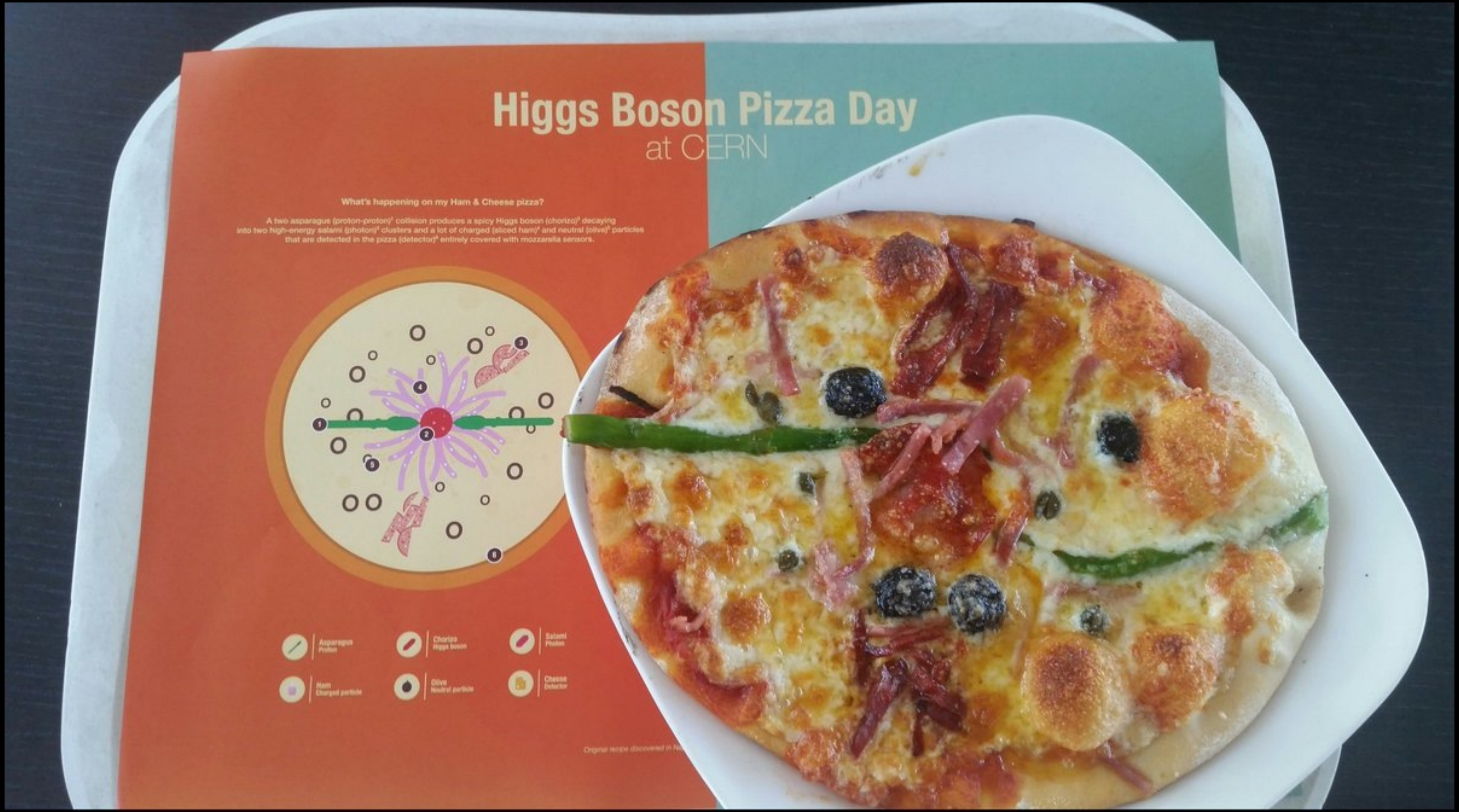
COUNTING DOWN TO DEADLINES

LIFE AS A PHYSICIST



DO SOME CODING

LIFE AS A PHYSICIST

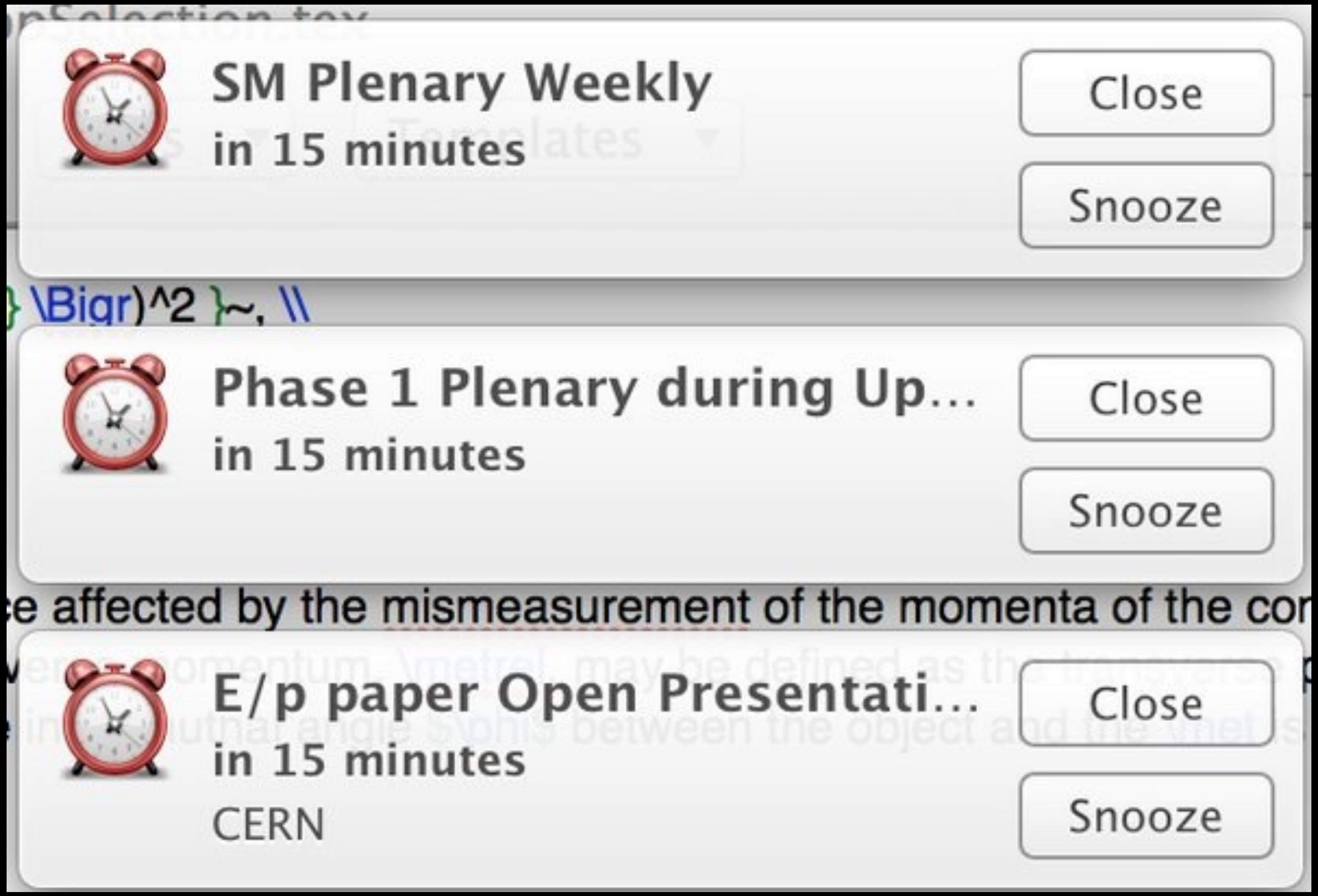


What's happening on my Ham & Cheese pizza?

A two asparagus (proton-proton)[1] collision produces a spicy Higgs boson (chorizo)[2] decaying into two high-energy salami (photon)[3] clusters and a lot of charged (sliced ham)[4] and neutral (olive)[5] particles that are detected in the pizza (detector)[6] entirely covered with mozzarella sensors.

LUNCHTIME! :)

LIFE AS A PHYSICIST



SM Plenary Weekly
in 15 minutes

} \Bigr)^2 }~, \\

Phase 1 Plenary during Up…
in 15 minutes

e affected by the mismeasurement of the momenta of the co

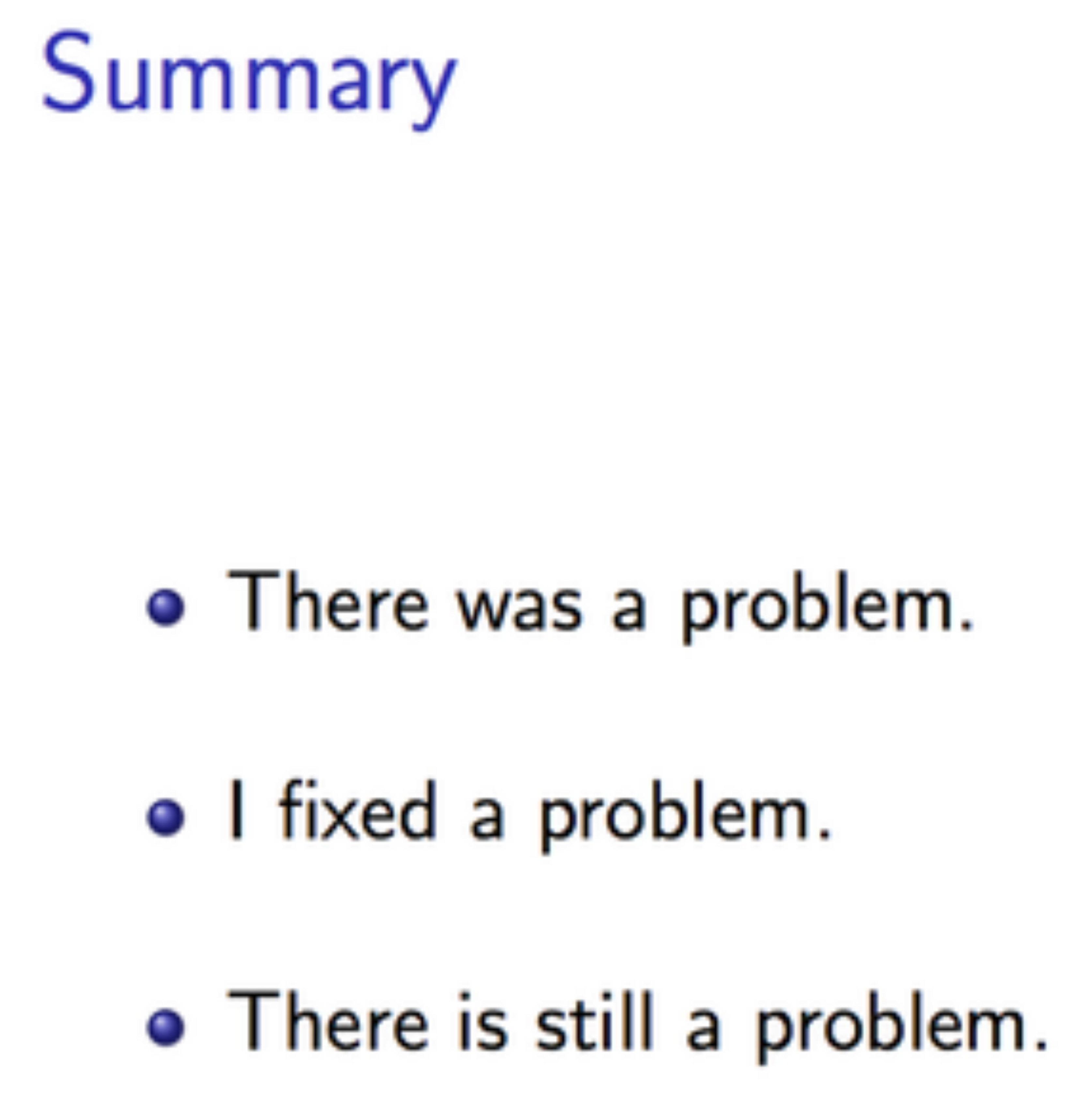
E/p paper Open Presentati…
in 15 minutes
CERN

AFTERNOONS ARE USUALLY FULL OF MEETINGS

LIFE AS A PHYSICIST

THIS IS WHAT I CALL “WORK-LIFE BALANCE”

LIFE AS A PHYSICIST

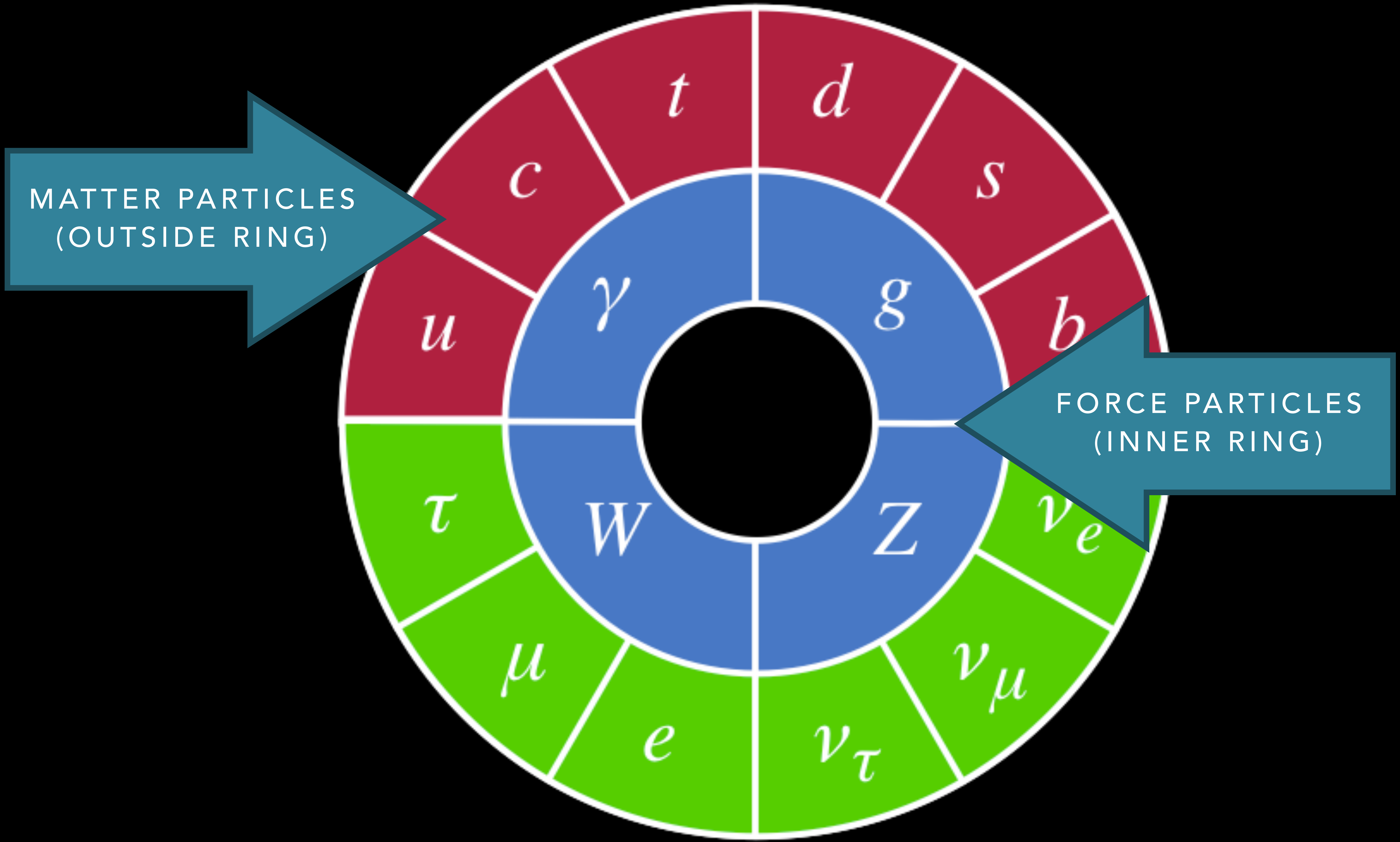


Summary

- There was a problem.
- I fixed a problem.
- There is still a problem.

RESEARCH, SUMMARISED

THE STANDARD MODEL OF PARTICLE PHYSICS (PRE-2012)

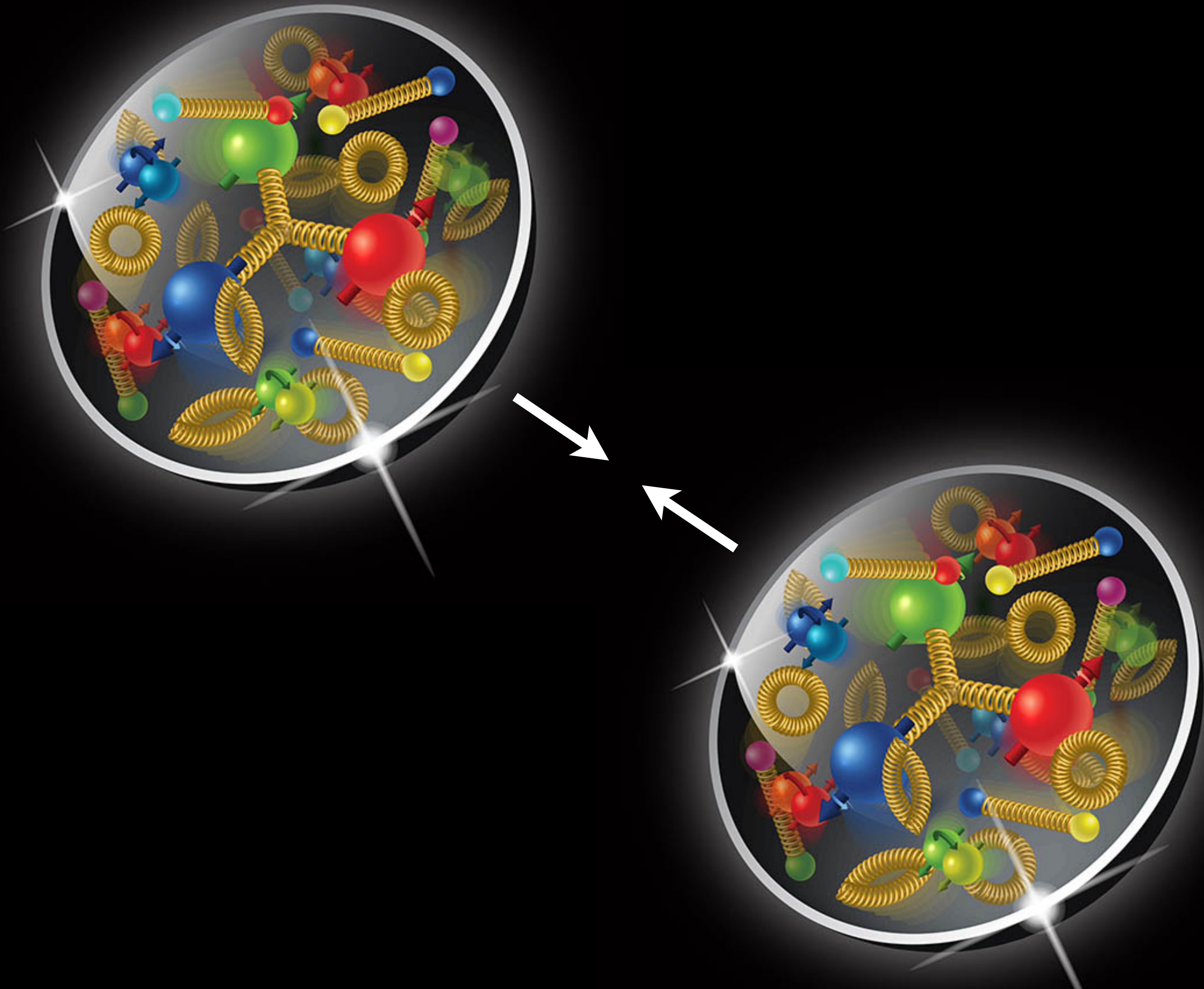


MATTER PARTICLES
(OUTSIDE RING)

FORCE PARTICLES
(INNER RING)

(IMAGE FROM PARTICLE FEVER)

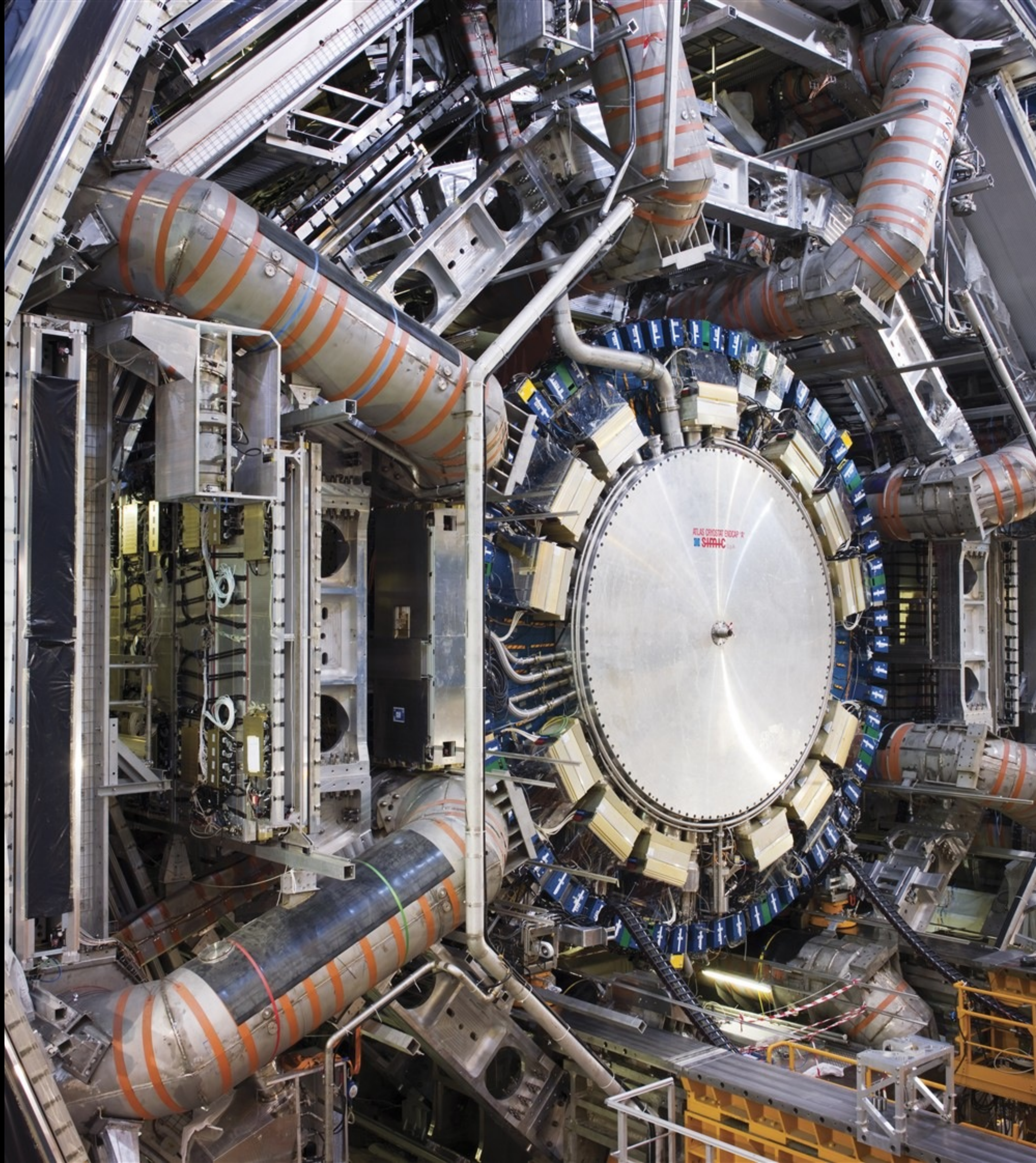
FACTORY OF PARTICLES



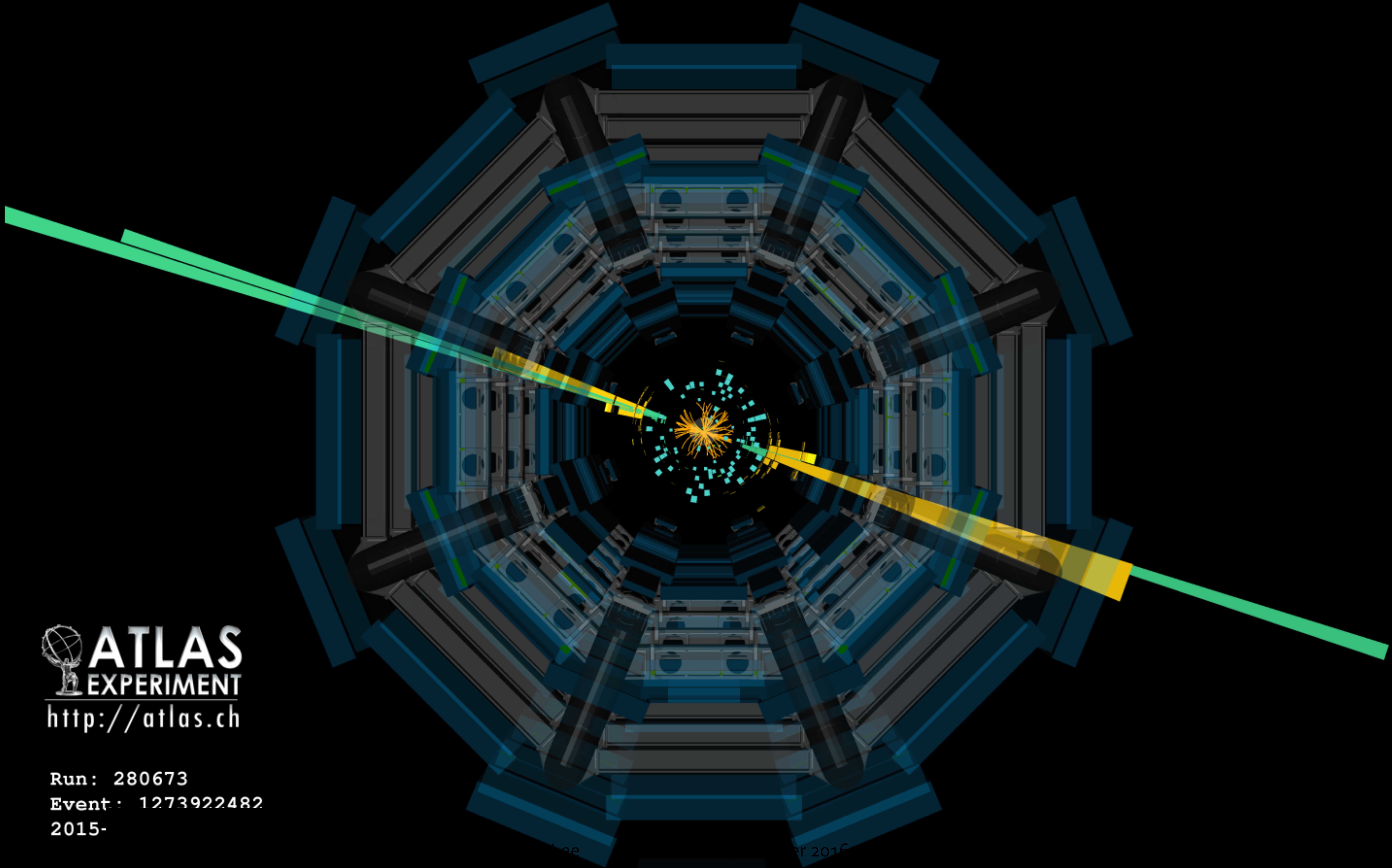
BUNCH CROSSINGS IN THE LHC HAPPEN **40 MILLION TIMES** PER SECOND

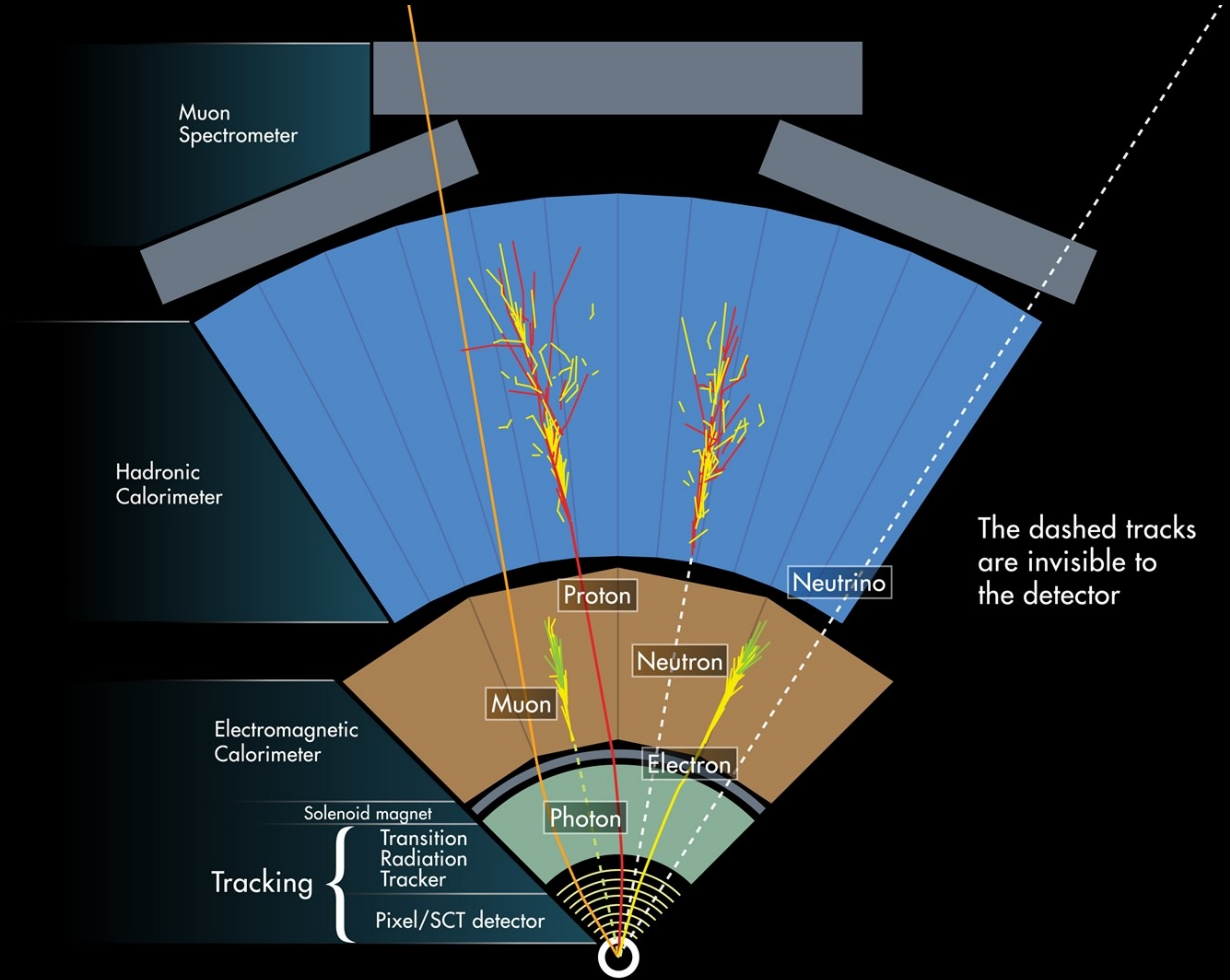
THE ATLAS EXPERIMENT

- 3500 different people (about half are students)
- 178 different institutions
- 38 different countries
- 1 common goal

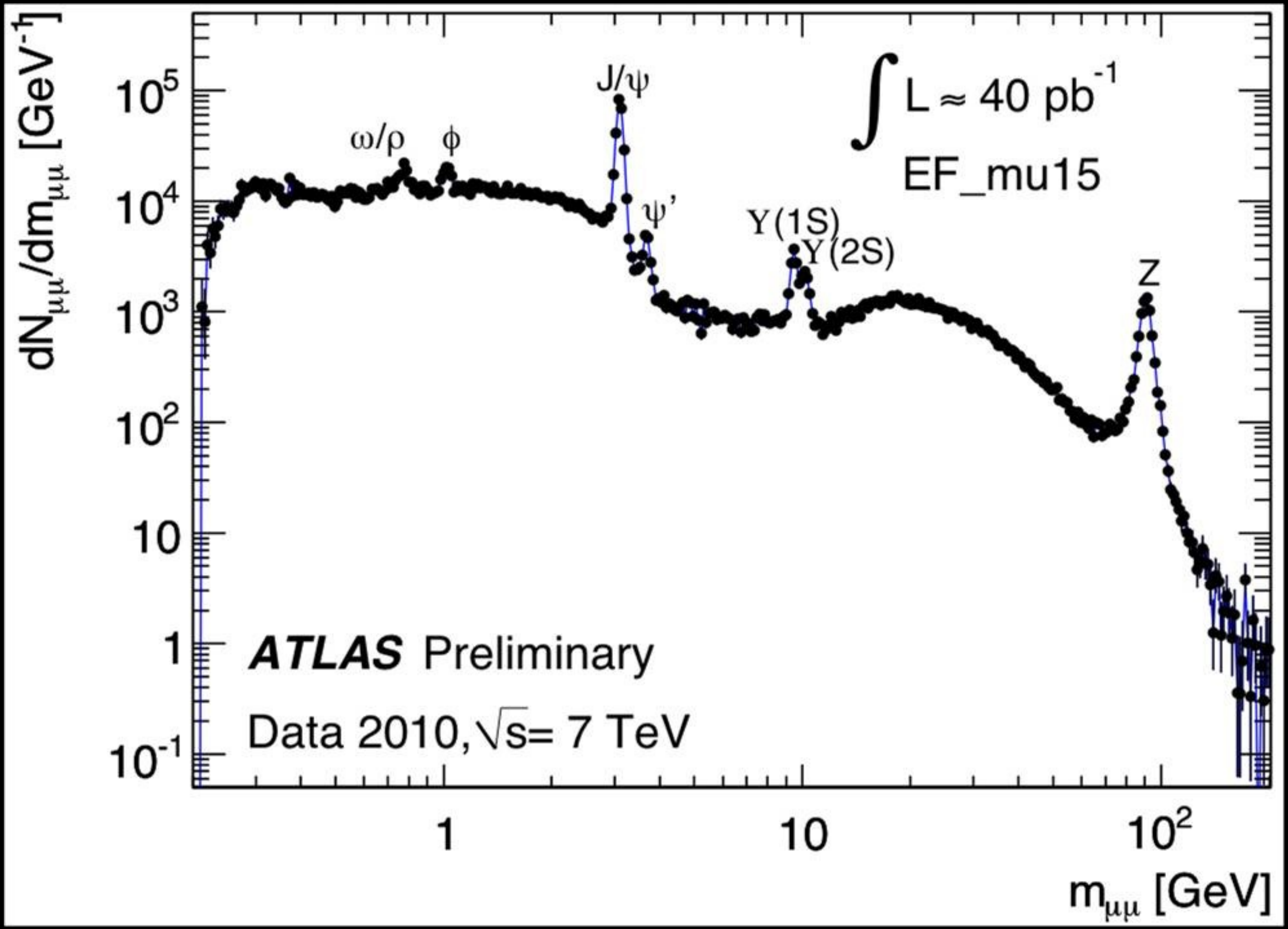


ATLAS WEIGHS 7000 TONS - THAT'S 100 OF THESE


ATLAS
EXPERIMENT
http://atlas.ch
Run: 280673
Event: 1273922482
2015-

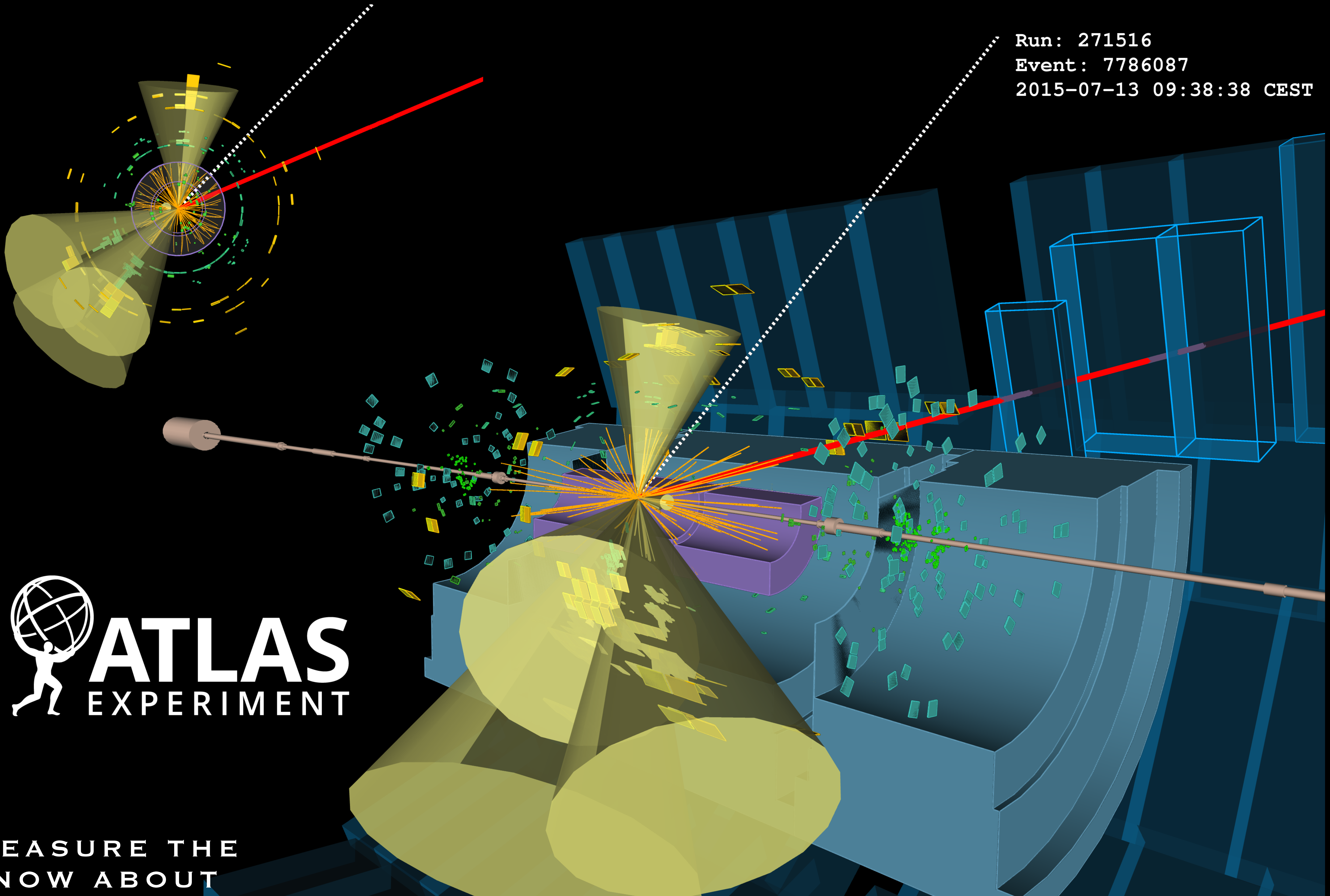


The dashed tracks
are invisible to
the detector



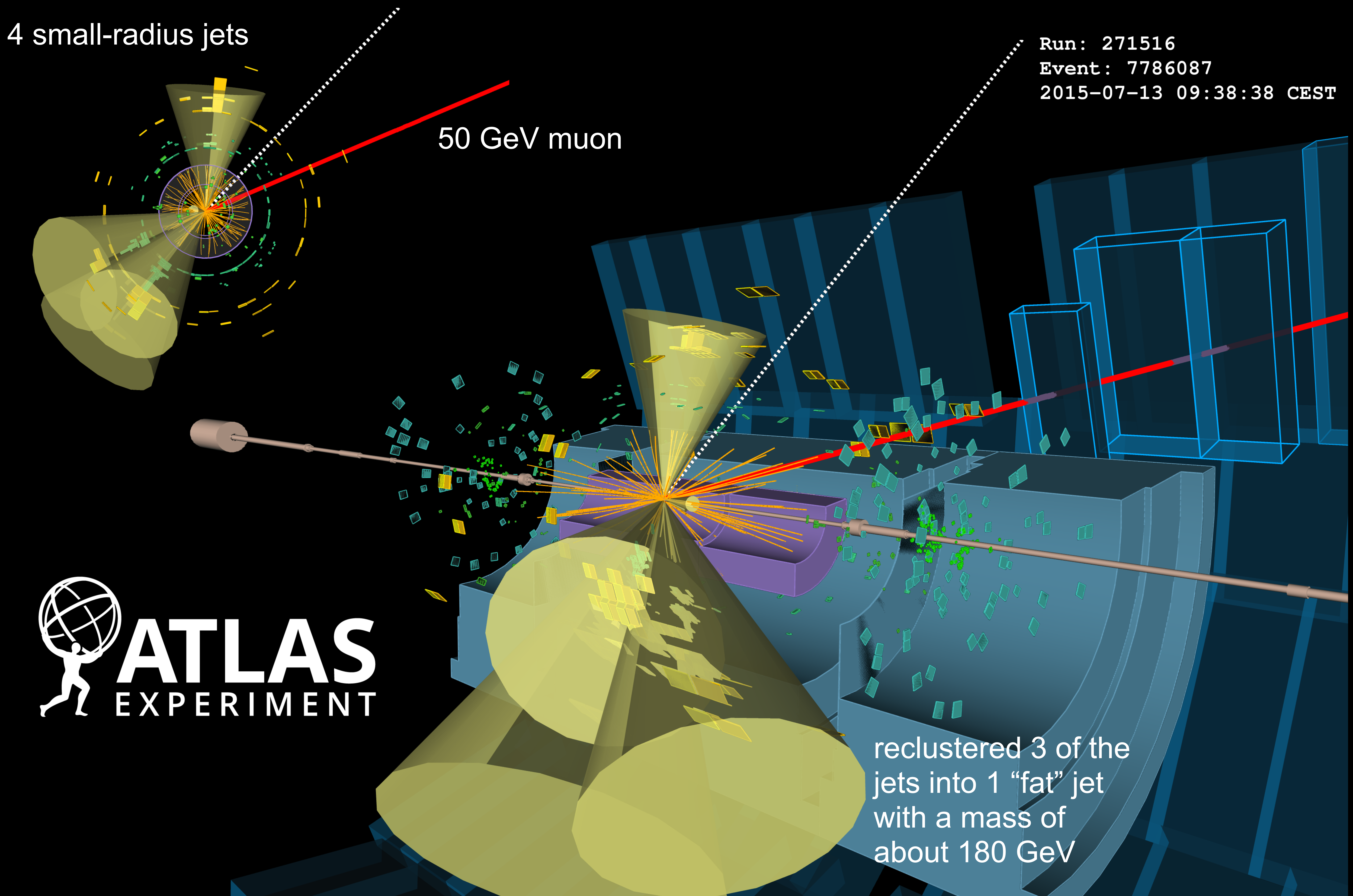
"REDISCOVERING" THE STANDARD MODEL: PROOF OUR DETECTOR WORKS WELL

CANDIDATE BOOSTED TOP QUARK PAIR, JULY 2015



ATLAS EXPERIMENT

FIRST, WE MEASURE THE STUFF WE KNOW ABOUT



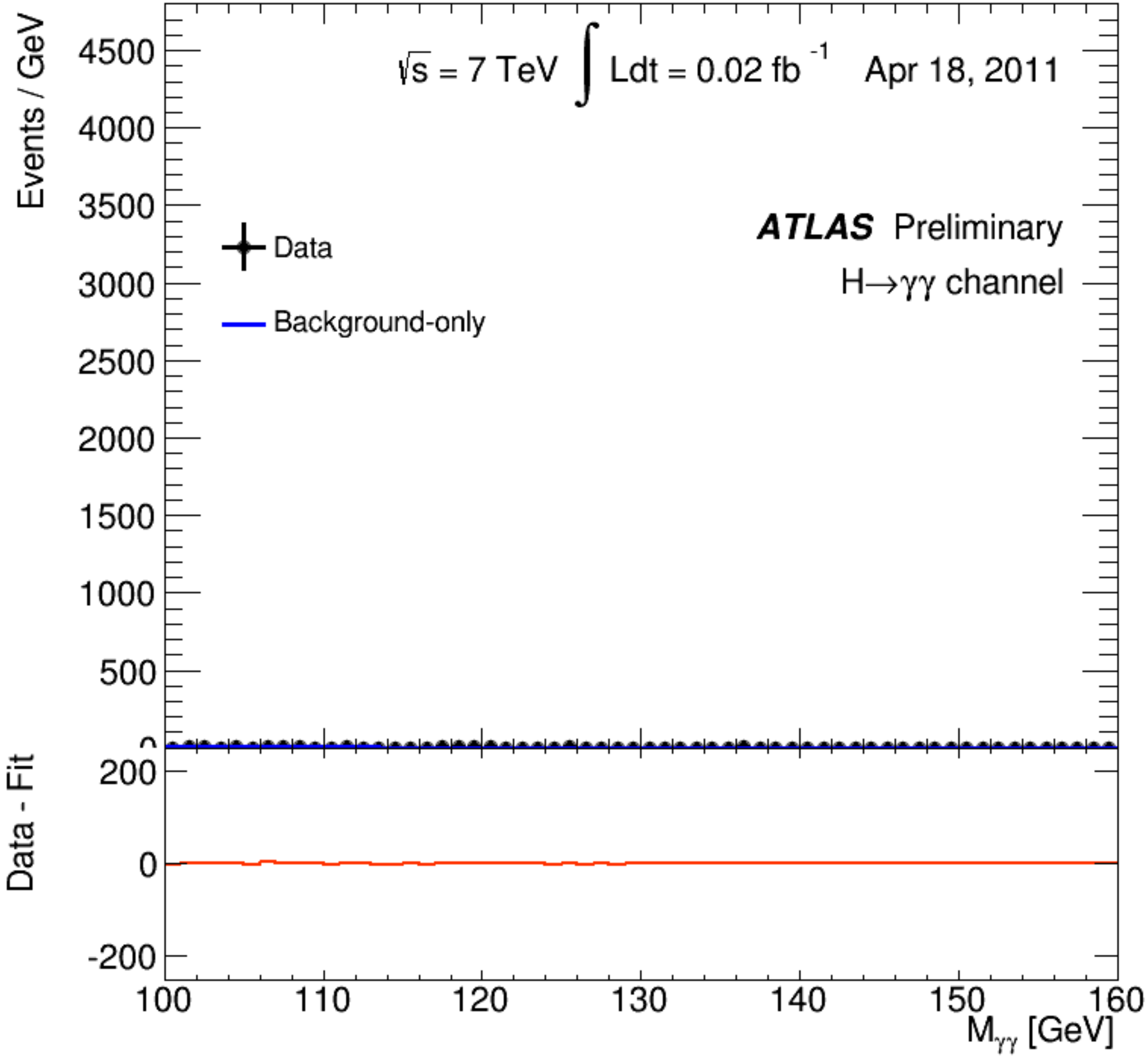
reclustered 3 of the jets into 1 “fat” jet with a mass of about 180 GeV

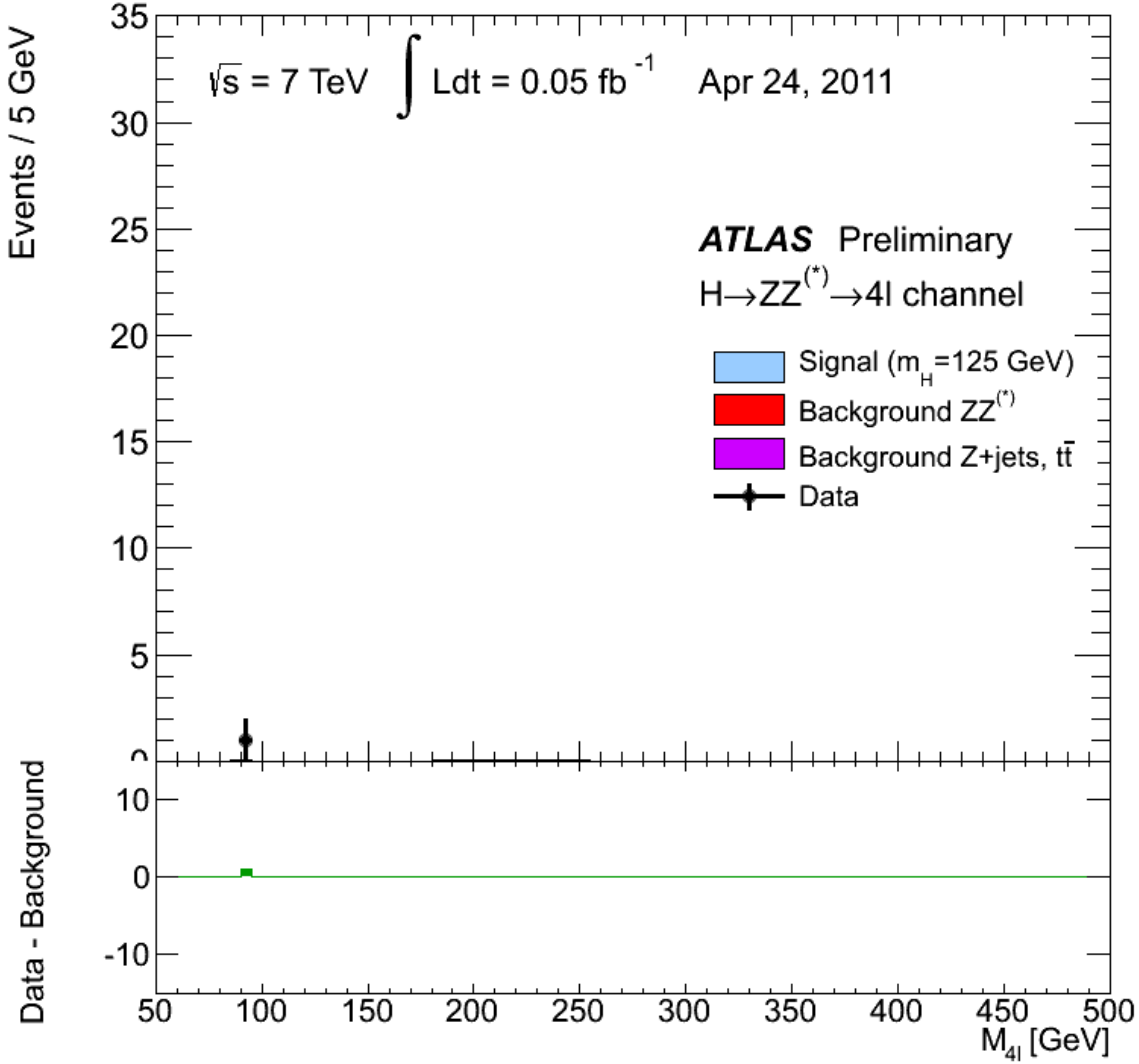
I’M NOT FAT

I’M JUST BIG CONED

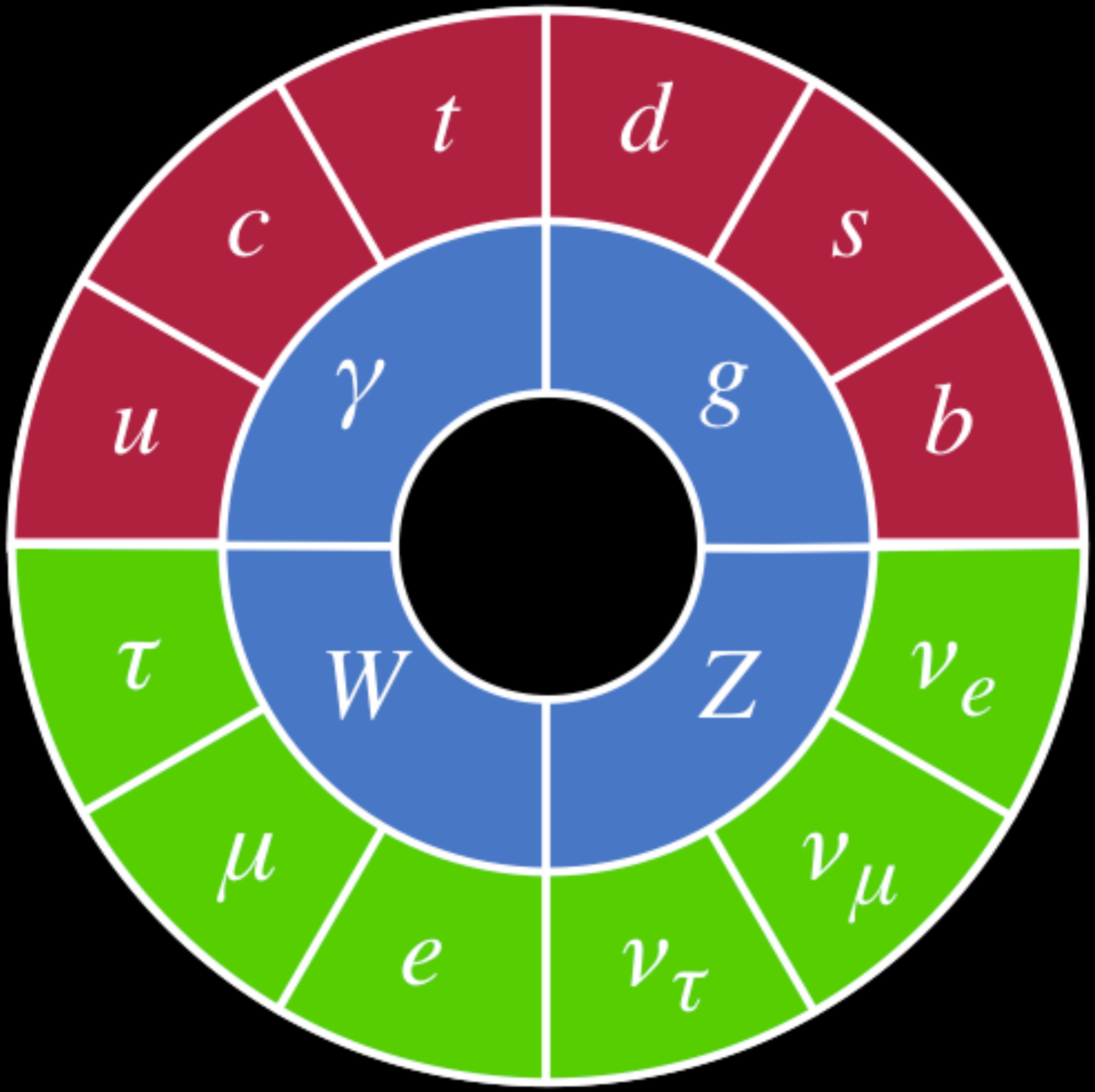
THEN WE CAN HUNT FOR THINGS WE EXPECT, BUT HAVEN'T DISCOVERED YET

2 PHOTONS





4 ELECTRONS OR MUONS



t
d
c
s
u
γ
g
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τ
W
Z
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μ
ν_μ
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ν_τ

THE FORMULA OF THE UNIVERSE:

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g^2_s f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu +$$

$$\frac{1}{2}ig^2_s(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu -$$

$$M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c^2_w}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H -$$

$$\frac{1}{2}m^2_h H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c^2_w}M \phi^0 \phi^0 - \beta_h[\frac{2M^2}{g^2} +$$

$$\frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu -$$

$$W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu -$$

$$W^-_\nu \partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu -$$

$$W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu +$$

$$\frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c^2_w(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) +$$

$$g^2 s^2_w(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu -$$

$$W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] -$$

$$\frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2] -$$

$$gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c^2_w}Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) -$$

$$W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ -$$

$$\phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s^2_w}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) +$$

$$igs_w MA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c^2_w}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) +$$

$$igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] -$$

$$\frac{1}{4}g^2\frac{1}{c^2_w}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s^2_w - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s^2_w}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- +$$

$$W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s^2_w}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- +$$

$$W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c^2_w - 1)Z^0_\mu A_\mu\phi^+\phi^- -$$

$$g^1 s^2_w A_\mu A_\mu\phi^+\phi^- - \bar{e}^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m^\lambda_u)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial +$$

$$m^\lambda_d)d^\lambda_j + igs_w A_\mu[-(\bar{e}^\lambda\gamma e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma d^\lambda_j)] + \frac{ig}{4c_w}Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1 +$$

$$\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s^2_w - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\frac{4}{3}s^2_w - 1 - \gamma^5)u^\lambda_j) +$$

$$(\bar{d}^\lambda_j\gamma^\mu(1 - \frac{8}{3}s^2_w - \gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt{2}}W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1 + \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(1 +$$

$$\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt{2}}W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1 + \gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1 + \gamma^5)u^\lambda_j)] +$$

$$\frac{ig}{2\sqrt{2}}\frac{m^\lambda_e}{M}[-\phi^+(\bar{\nu}^\lambda(1 - \gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1 + \gamma^5)\nu^\lambda)] - \frac{g}{2}\frac{m^\lambda_e}{M}[H(\bar{e}^\lambda e^\lambda) +$$

$$i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m^\kappa_d(\bar{u}^\lambda_j C_{\lambda\kappa}(1 - \gamma^5)d^\kappa_j) + m^\lambda_u(\bar{u}^\lambda_j C_{\lambda\kappa}(1 +$$

$$\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt{2}}\phi^-[m^\lambda_d(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1 + \gamma^5)u^\kappa_j) - m^\kappa_u(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1 - \gamma^5)u^\kappa_j] -$$

$$\frac{g}{2}\frac{m^\lambda_u}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m^\lambda_d}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m^\lambda_u}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) +$$

$$\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \frac{M^2}{c^2_w})X^0 + \bar{Y}\partial^2 Y +$$

$$igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+ Y) +$$

$$igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) +$$

$$igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) -$$

$$\frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c^2_w}\bar{X}^0 X^0 H] + \frac{1-2c^2_w}{2c_w}igM[\bar{X}^+ X^0\phi^+ -$$

$$\bar{X}^- X^0\phi^-] + \frac{1}{2c_w}igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + igMs_w[\bar{X}^0 X^-\phi^+ -$$

$$\bar{X}^0 X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]$$

F or D: FORCE PARTICLES

Ψ: MATTER PARTICLES

Φ: HIGGS BOSON

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

DESCRIBES THE FORCES

$$+ i \bar{\psi} \not{D} \psi + h.c.$$

HOW FORCES ACT ON MATTER

$$+ \psi_i y_{ij} \psi_j \phi + h.c.$$

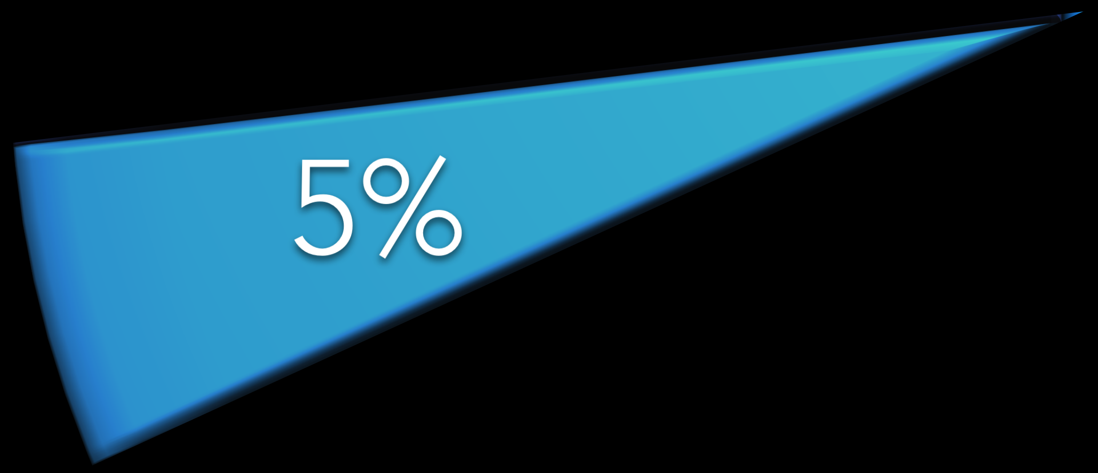
HOW PARTICLES GET MASS

$$+ |D_\mu \phi|^2 - V(\phi)$$

HOW THE HIGGS WORKS

THE COMPOSITION OF THE UNIVERSE

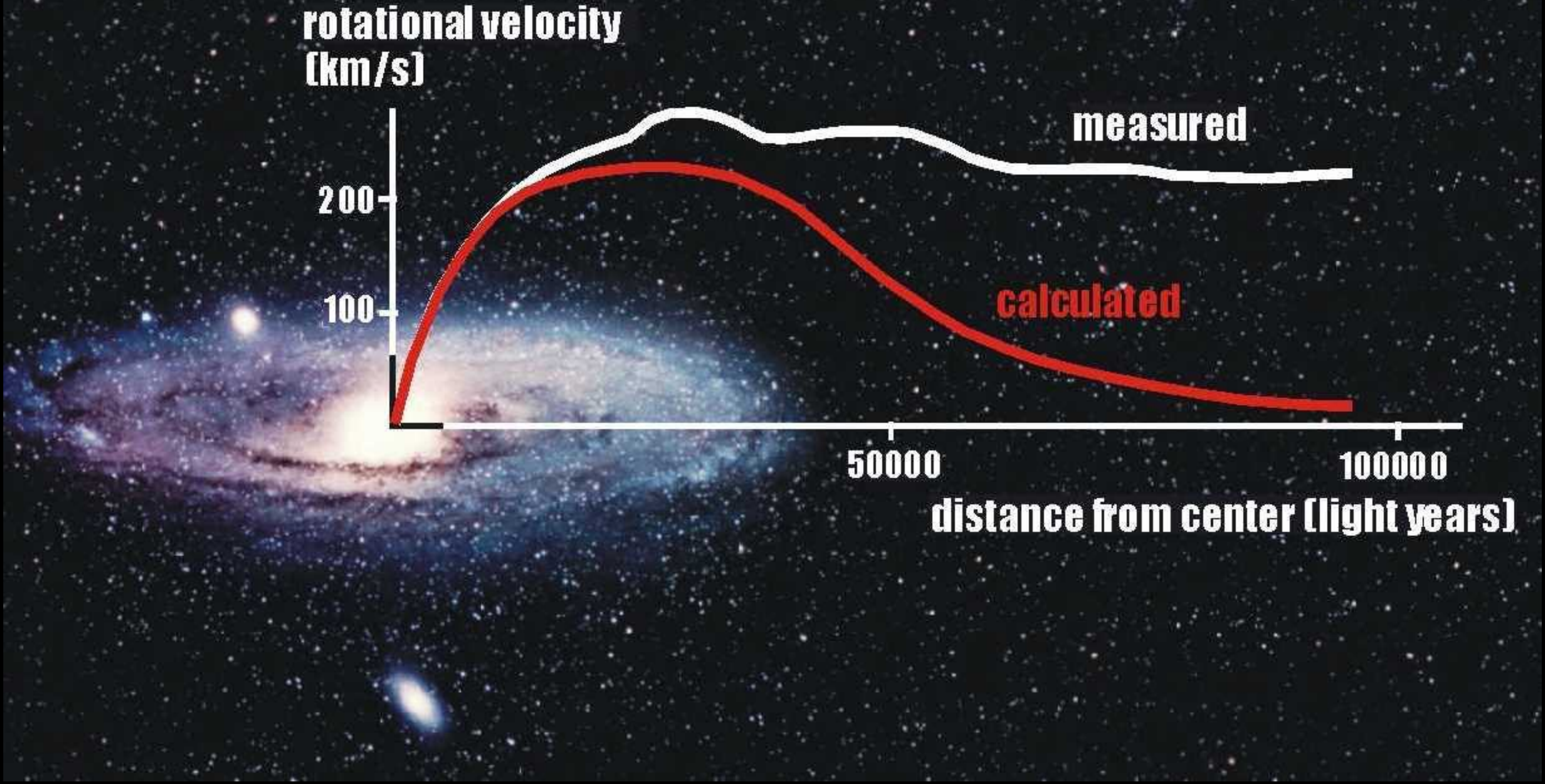
DARK MA

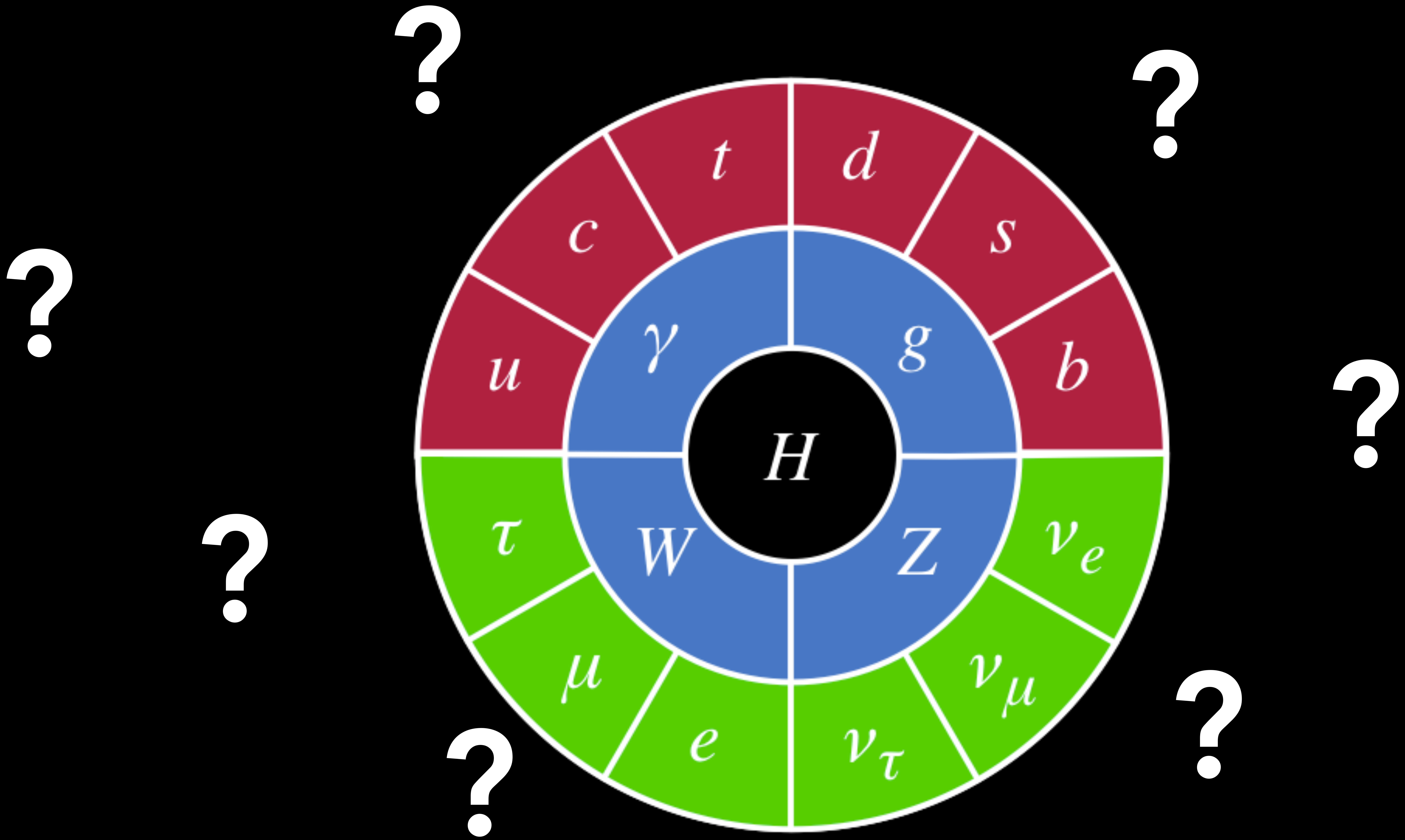


NORMAL MATTER

$$\begin{aligned}\mathcal{L} &= -\tfrac{1}{4}F_{\mu\nu}F^{\mu\nu} \\ &+ i\bar{\psi}\not{D}\psi + h.c. \\ &+ \psi_i y_{ij}\psi_j\phi + h.c. \\ &+ |D_\mu\phi|^2 - V(\phi)\end{aligned}$$

NERGY


rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)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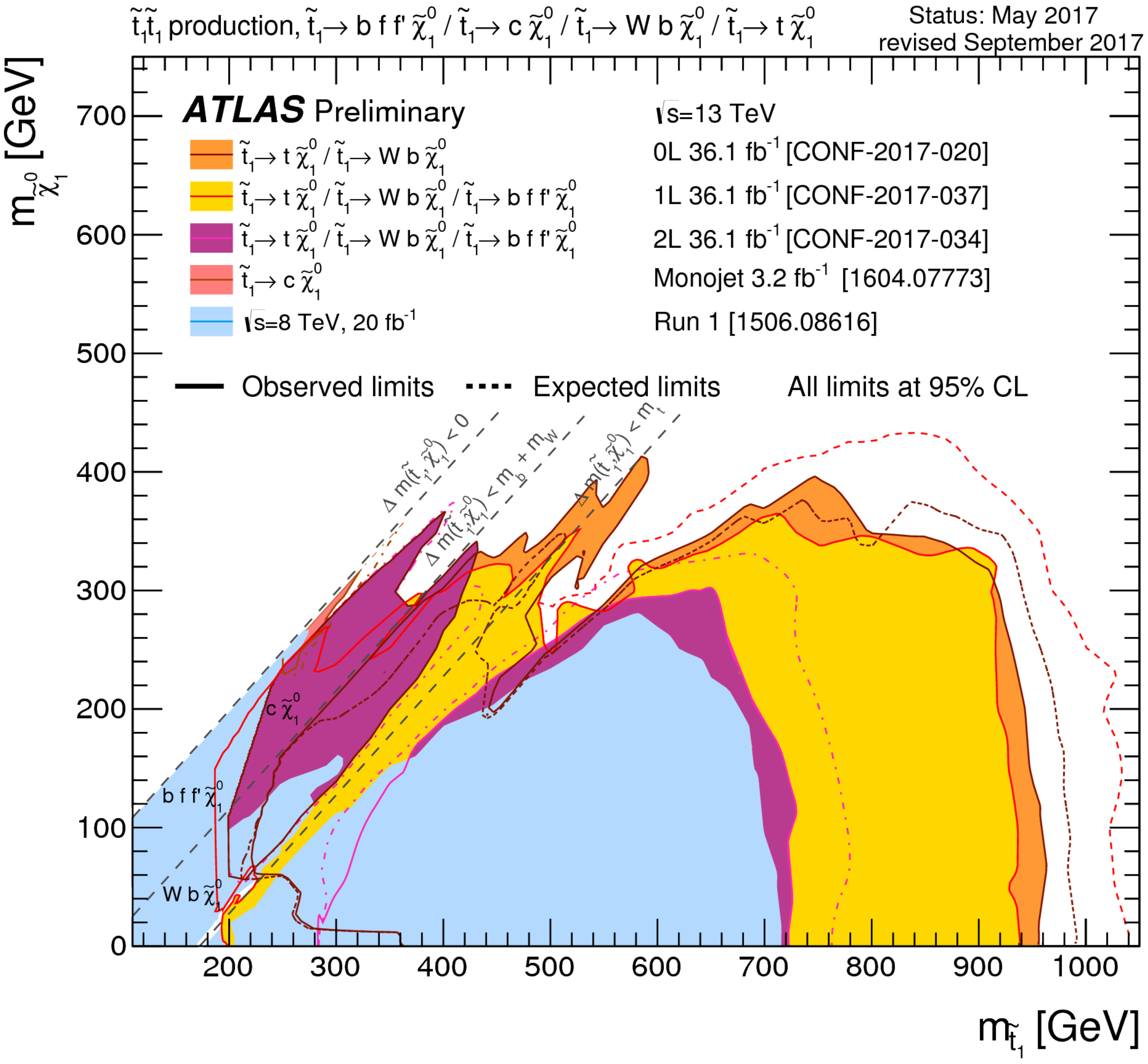
Particle Fever
08-21-13


$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$ / $\tilde{t}_1 \to c \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \to t \tilde{\chi}_1^0$
Status: May 2017
revised September 2017
ATLAS Preliminary
$\sqrt{s}$=13 TeV
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ — 0L 36.1 fb^{-1} [CONF-2017-020]
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$ — 1L 36.1 fb^{-1} [CONF-2017-037]
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$ — 2L 36.1 fb^{-1} [CONF-2017-034]
$\tilde{t}_1 \to c \tilde{\chi}_1^0$ — Monojet 3.2 fb^{-1} [1604.07773]
$\sqrt{s}$=8 TeV, 20 fb^{-1} — Run 1 [1506.08616]
Observed limits
Expected limits
All limits at 95% CL
$\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) < 0$
$\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) < m_b + m_W$
$\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) < m_t$
$c\,\tilde{\chi}_1^0$
$b f f' \tilde{\chi}_1^0$
$W b \tilde{\chi}_1^0$
$m_{\tilde{\chi}_1^0}$ [GeV]
0
100
200
300
400
500
600
700
200
300
400
500
600
700
800
900
1000
$m_{\tilde{t}_1}$ [GeV]

WHAT PIECES DO YOU NEED TO BUILD THIS UNIVERSE?

HOW DO THESE PIECES FIT TOGETHER?

WHAT ARE THE OTHER PIECES?

WWW.HOME.CERN

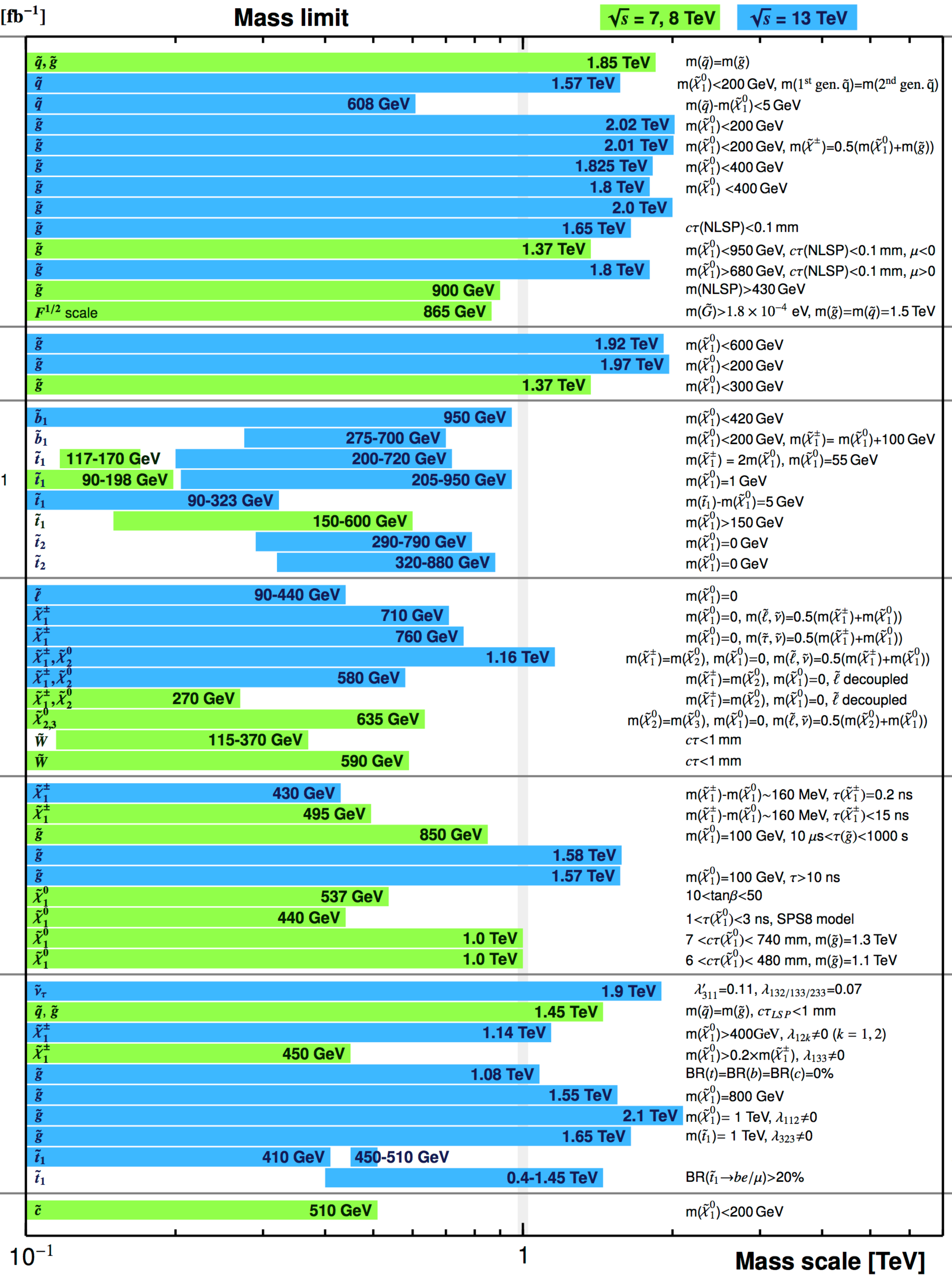
BACKUP

ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

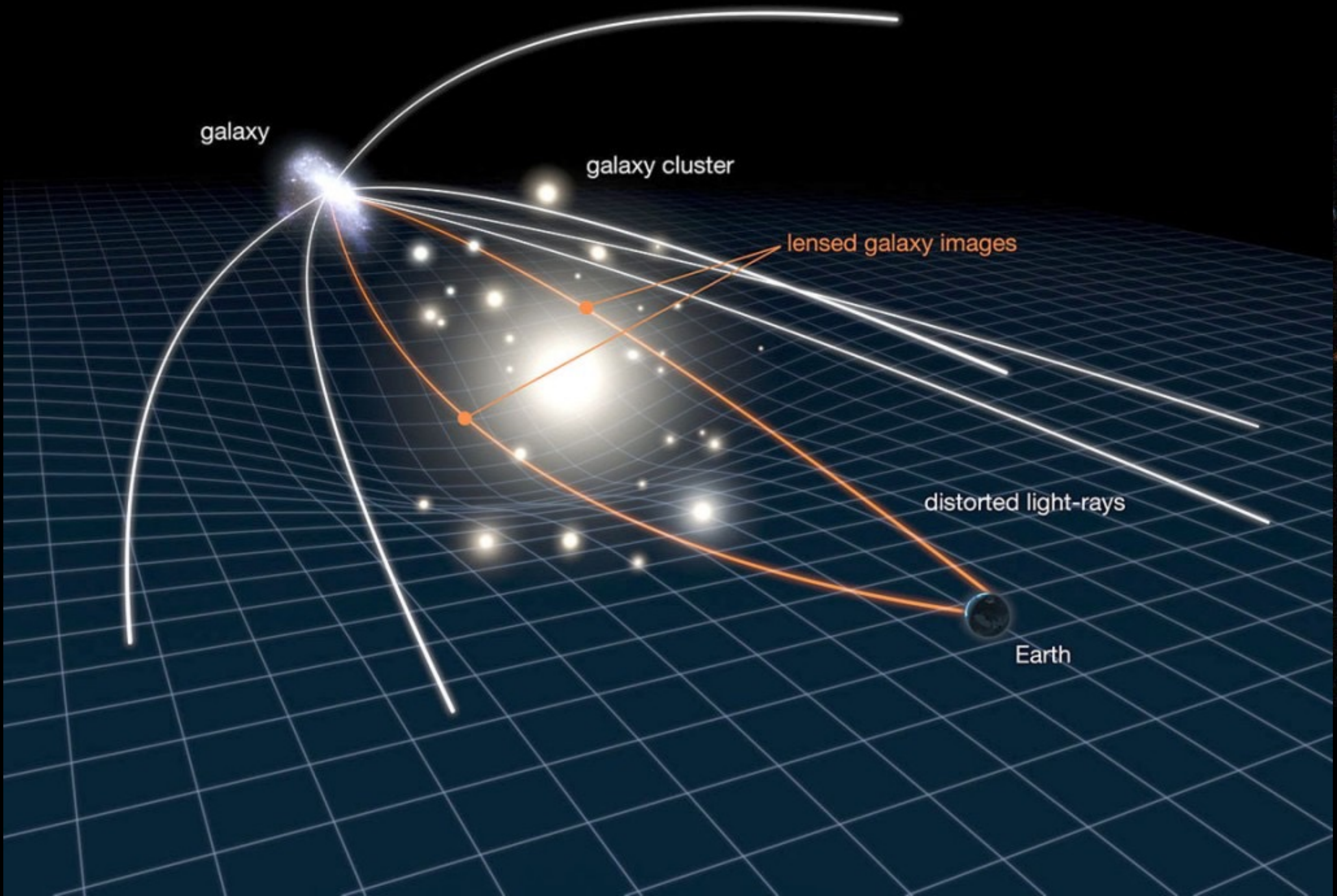
ATLAS Preliminary

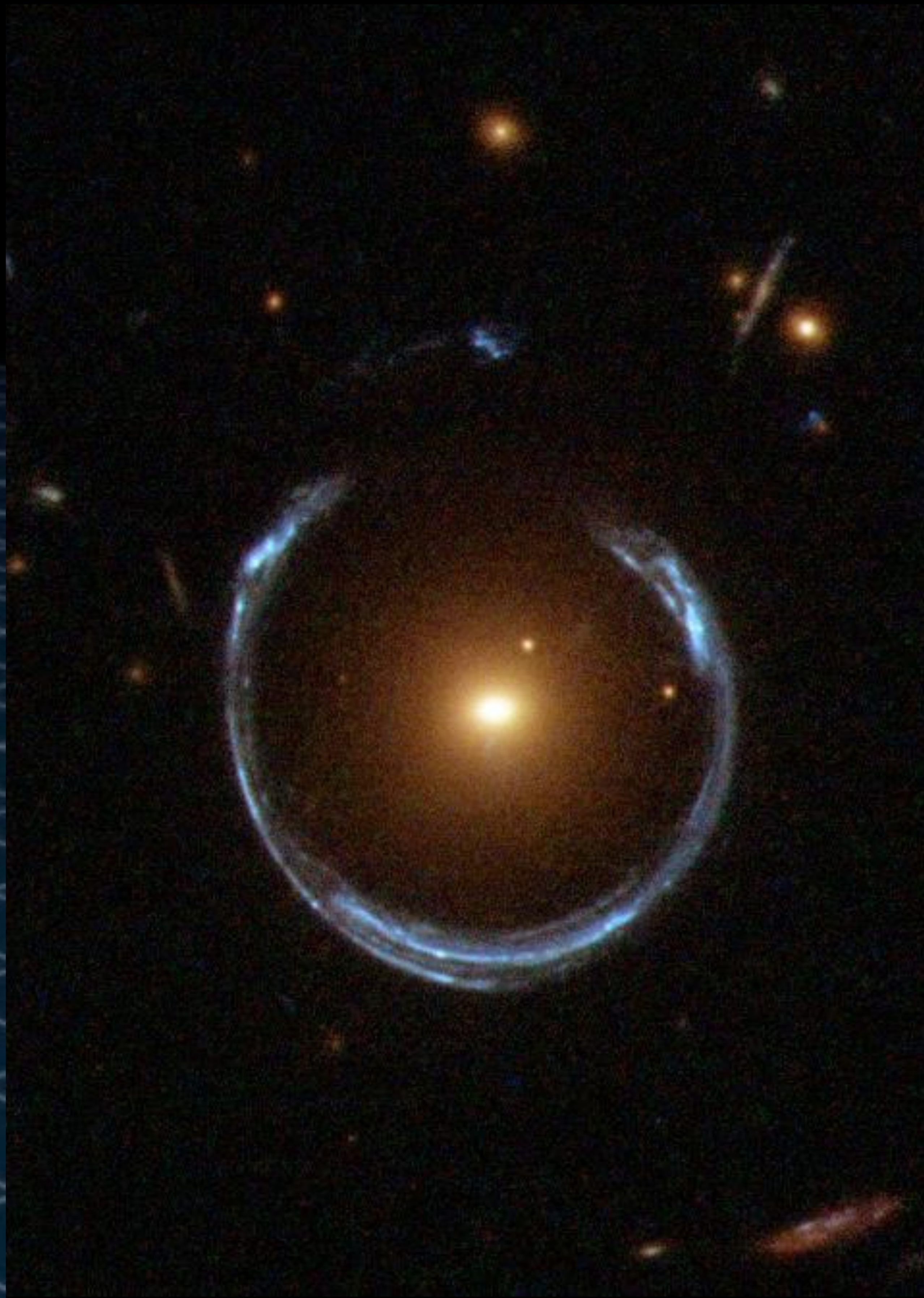
$\sqrt{s}$ = 7, 8, 13 TeV



	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 🟩 1.85 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{q}$ 🟦 1.57 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2017-022
	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$ 🟦 608 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<5 GeV	1604.07773
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 🟦 2.02 TeV	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 🟦 2.01 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}^{\pm}$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	36.1	$\tilde{g}$ 🟦 1.825 TeV	m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2017-030
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	$\tilde{g}$ 🟦 1.8 TeV	m($\tilde{\chi}_1^0$) <400 GeV	ATLAS-CONF-2017-033
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$ 🟦 2.0 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	3.2	$\tilde{g}$ 🟦 1.65 TeV	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 🟩 1.37 TeV	m($\tilde{\chi}_1^0$)<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde{g}$ 🟦 1.8 TeV	m($\tilde{\chi}_1^0$)>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 🟩 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 🟩 865 GeV	m($\tilde{G}$)>1.8 × 10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	$\tilde{g}$ 🟦 1.92 TeV	m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	36.1	$\tilde{g}$ 🟦 1.97 TeV	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 🟩 1.37 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$ 🟦 950 GeV	m($\tilde{\chi}_1^0$)<420 GeV	ATLAS-CONF-2017-038
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	2 e,μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$ 🟦 275-700 GeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}_1^{\pm}$)= m($\tilde{\chi}_1^0$)+100 GeV	ATLAS-CONF-2017-030
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 🟩 117-170 GeV 🟦 200-720 GeV	m($\tilde{\chi}_1^{\pm}$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$ 🟩 90-198 GeV 🟦 205-950 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616, ATLAS-CONF-2017-020
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	$\tilde{t}_1$ 🟦 90-323 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)=5 GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 🟩 150-600 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\rightarrow\tilde{t}_1 + Z$	3 e,μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$ 🟦 290-790 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2017-019
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\rightarrow\tilde{t}_1 + h$	1-2 e,μ	4 b	Yes	36.1	$\tilde{t}_2$ 🟦 320-880 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2017-019
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	36.1	$\tilde{\ell}$ 🟦 90-440 GeV	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm}$ 🟦 710 GeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\rightarrow\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}_1^{\pm}$ 🟦 760 GeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\tau},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-035
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 🟦 1.16 TeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	36.1	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 🟦 580 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 🟩 270 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\rightarrow\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 🟩 635 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$ 🟩 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$	2 γ	-	Yes	20.3	$\tilde{W}$ 🟩 590 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^{\pm}$ 🟦 430 GeV	m($\tilde{\chi}_1^{\pm}$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^{\pm}$)=0.2 ns	ATLAS-CONF-2017-017
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$ 🟩 495 GeV	m($\tilde{\chi}_1^{\pm}$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^{\pm}$)<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 🟩 850 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$ 🟦 1.58 TeV		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$ 🟦 1.57 TeV	m($\tilde{\chi}_1^0$)=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 🟩 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 🟩 440 GeV	1<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\rightarrow eev/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 🟩 1.0 TeV	7 <$c\tau$($\tilde{\chi}_1^0$)< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\rightarrow Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$ 🟩 1.0 TeV	6 <$c\tau$($\tilde{\chi}_1^0$)< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\rightarrow\tilde{\nu}_{\tau} + X$, $\tilde{\nu}_{\tau}\rightarrow e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	3.2	$\tilde{\nu}_{\tau}$ 🟦 1.9 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 🟩 1.45 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}_1^{\pm}$ 🟦 1.14 TeV	m($\tilde{\chi}_1^0$)>400GeV, $\lambda_{12k}\neq0$ ($k = 1, 2$)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow\tau\tau\nu_e, e\tau\nu_{\tau}$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 🟩 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 🟦 1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 🟦 1.55 TeV	m($\tilde{\chi}_1^0$)=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 🟦 2.1 TeV	m($\tilde{\chi}_1^0$)= 1 TeV, $\lambda_{112}\neq0$	ATLAS-CONF-2017-013
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow\tilde{t}_1t$, $\tilde{t}_1\rightarrow bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 🟦 1.65 TeV	m($\tilde{t}_1$)= 1 TeV, $\lambda_{323}\neq0$	ATLAS-CONF-2017-013
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$ 🟦 410 GeV 🟦 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow b\ell$	2 e,μ	2 b	-	36.1	$\tilde{t}_1$ 🟦 0.4-1.45 TeV	BR($\tilde{t}_1\rightarrow be/\mu$)>20%	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde{c}\rightarrow c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 🟩 510 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

**Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*


galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

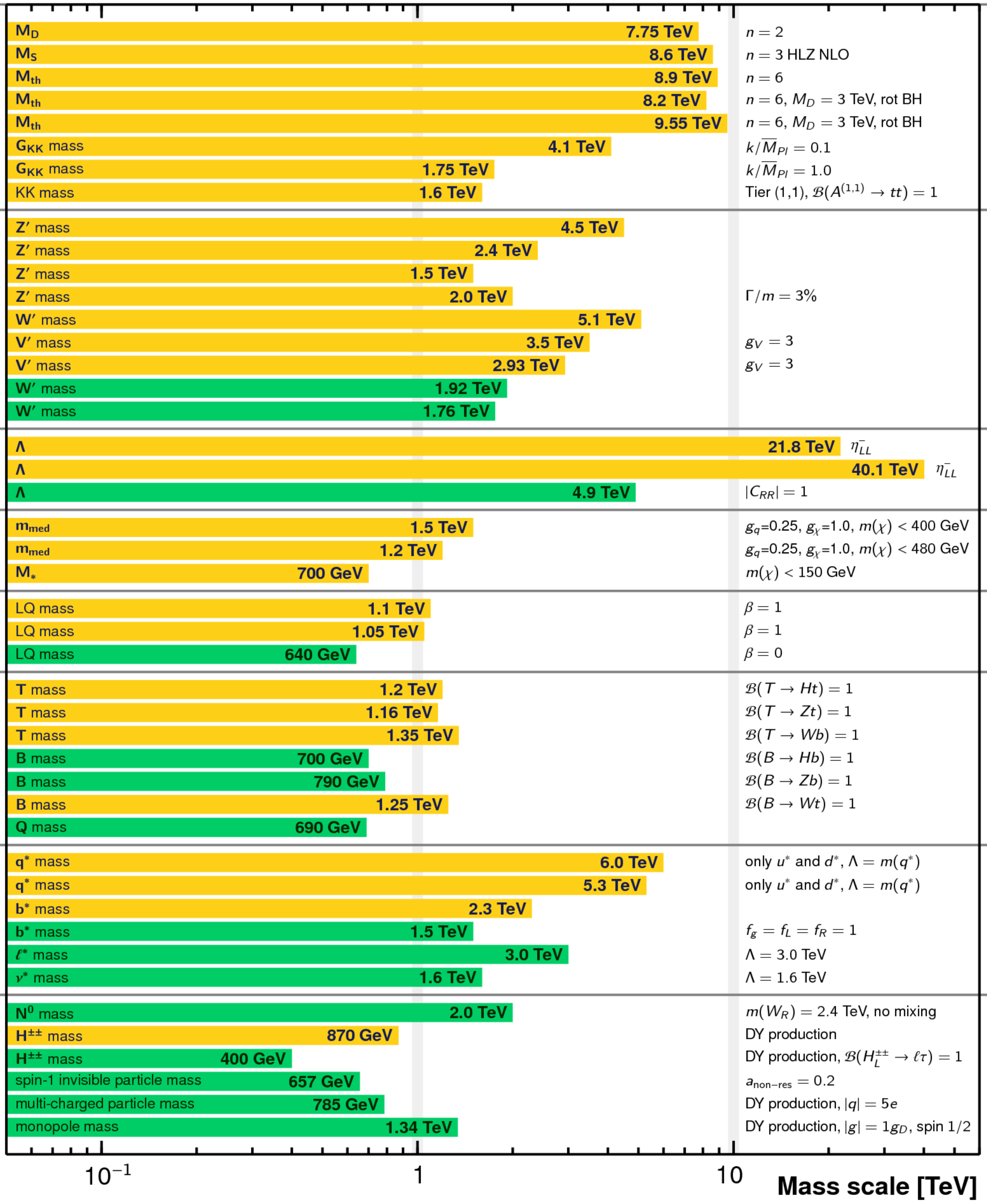


ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\,dt = (3.2 - 37.0)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

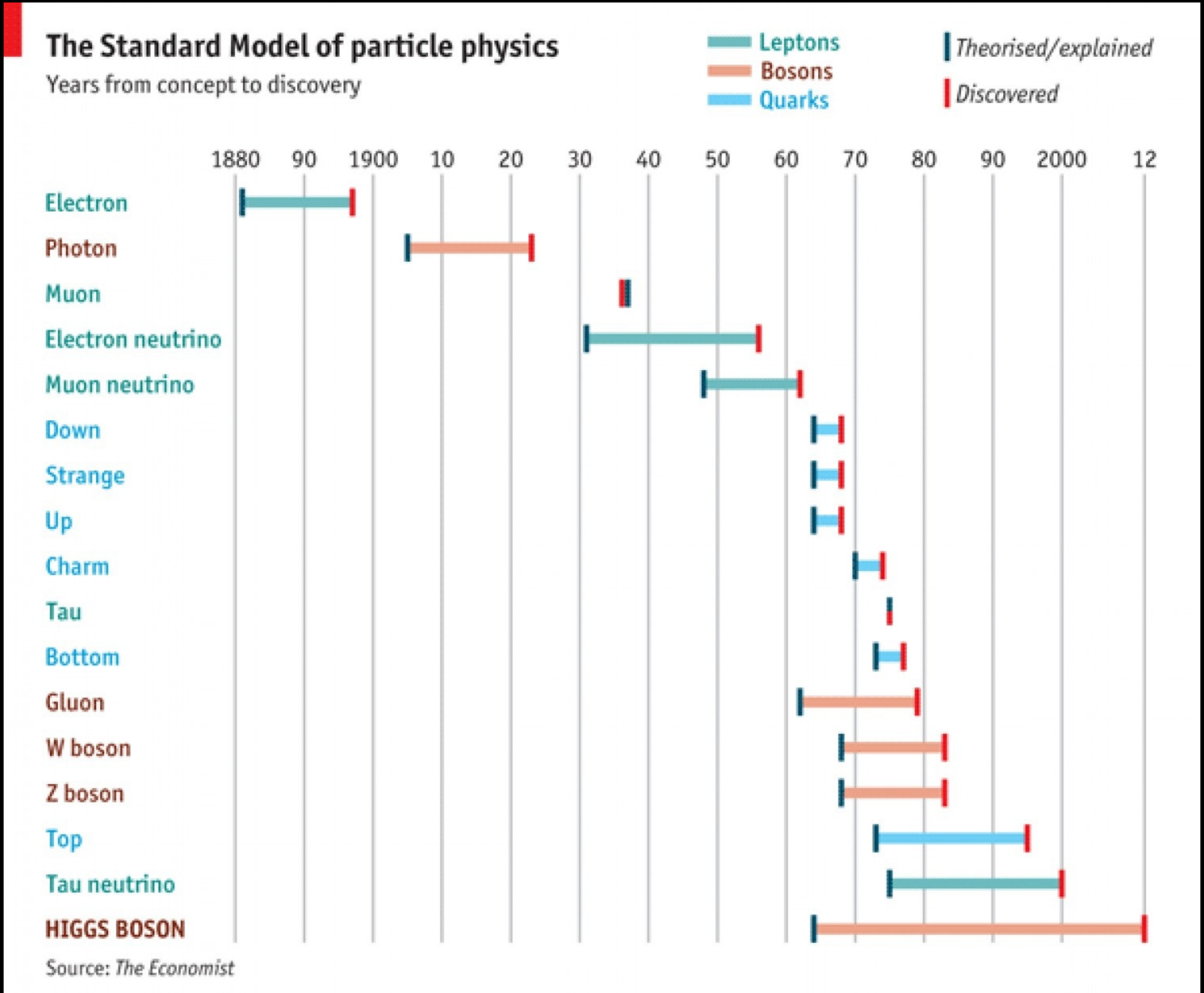


	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\,dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	🟨 M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	🟨 M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	🟨 M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	🟨 M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	🟨 M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	🟨 G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	36.1	🟨 G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	🟨 KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	🟨 Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	🟨 Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	🟨 Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	3.2	🟨 Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	36.1	🟨 W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	36.7	🟨 V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	🟨 V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	🟩 W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	🟩 W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	🟨 Λ 21.8 TeV η_{LL}^{-}		1703.09217
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	🟨 Λ 40.1 TeV η_{LL}^{-}		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/≥3 e, μ	≥1 b, ≥1 j	Yes	20.3	🟩 Λ 4.9 TeV	$\lvert C_{RR} \rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	🟨 m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	0 e, μ, 1 γ	≤ 1 j	Yes	36.1	🟨 m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	🟨 M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	🟨 LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	🟨 LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	🟩 LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	🟨 T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	36.1	🟨 T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	🟨 T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	🟩 B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	🟨 B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	🟨 q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	🟨 q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	🟨 b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	🟩 b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	🟩 ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	🟩 ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	2 e, μ	2 j	–	20.3	🟩 N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	🟨 $H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	🟩 $H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	🟩 spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	🟩 monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1509.08059

🟩 $\sqrt{s}$ = 8 TeV 🟨 $\sqrt{s}$ = 13 TeV

**Only a selection of the available mass limits on new states or phenomena is shown.*

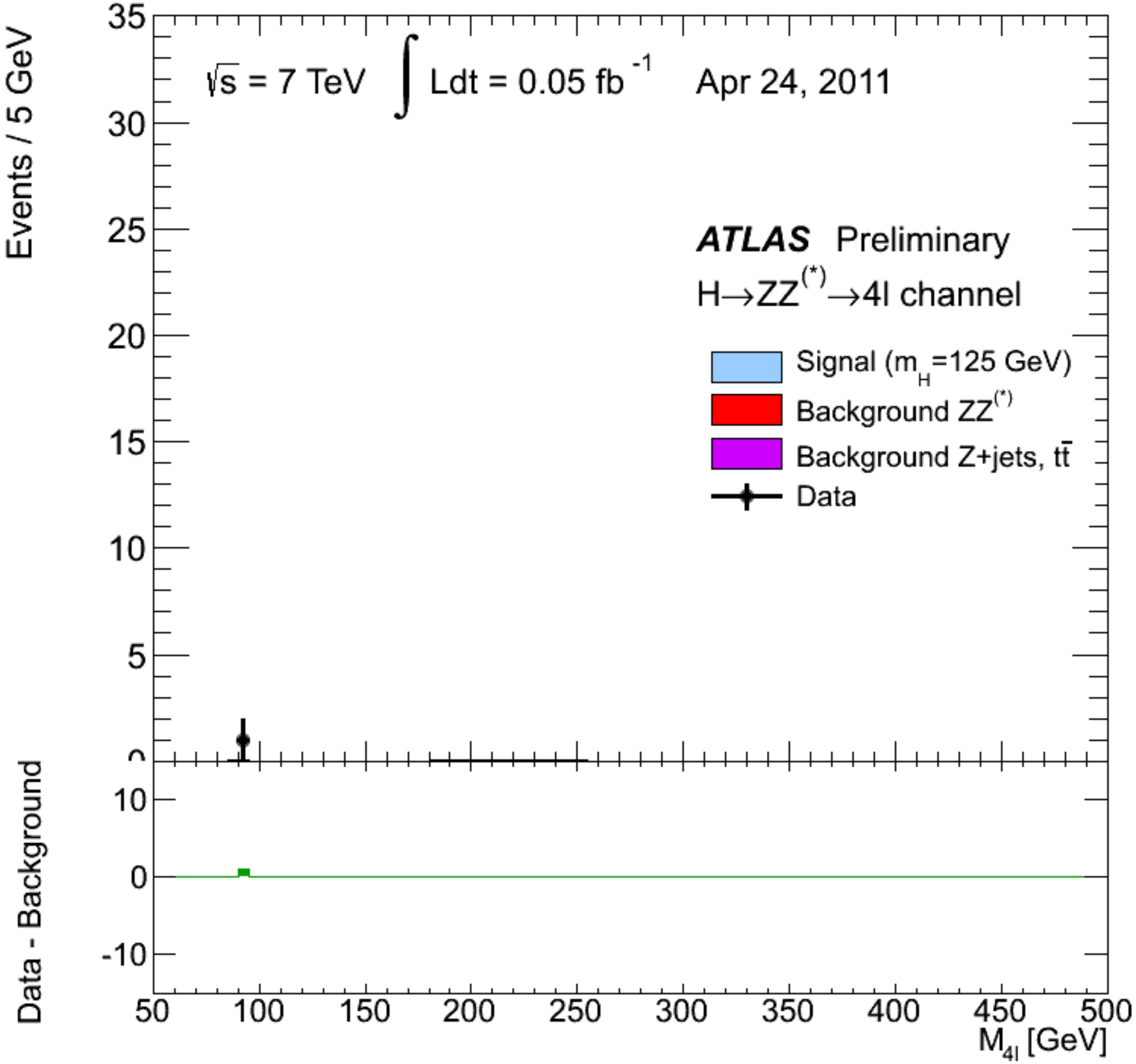
†Small-radius (large-radius) jets are denoted by the letter j (J).

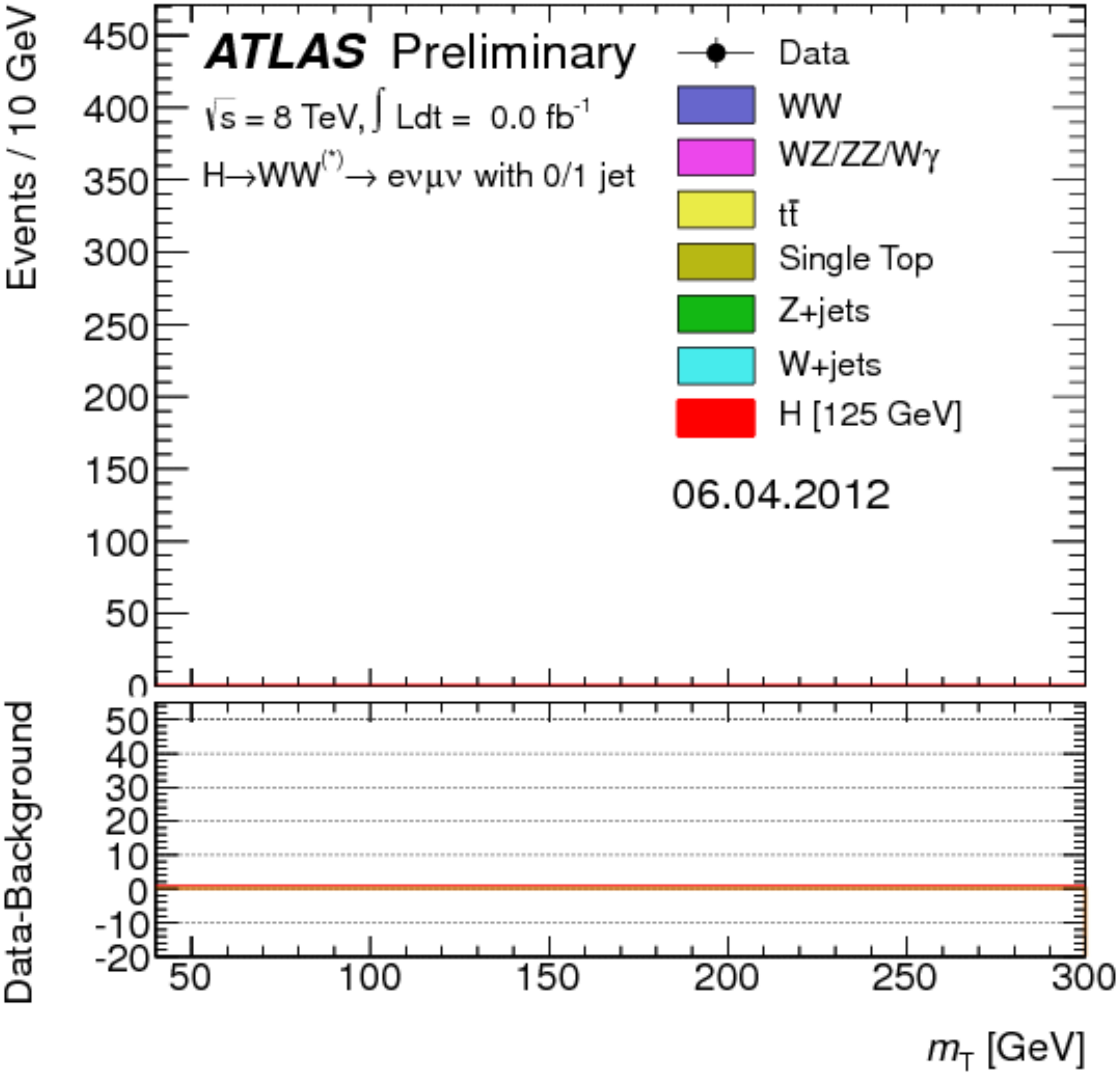


The Standard Model of particle physics

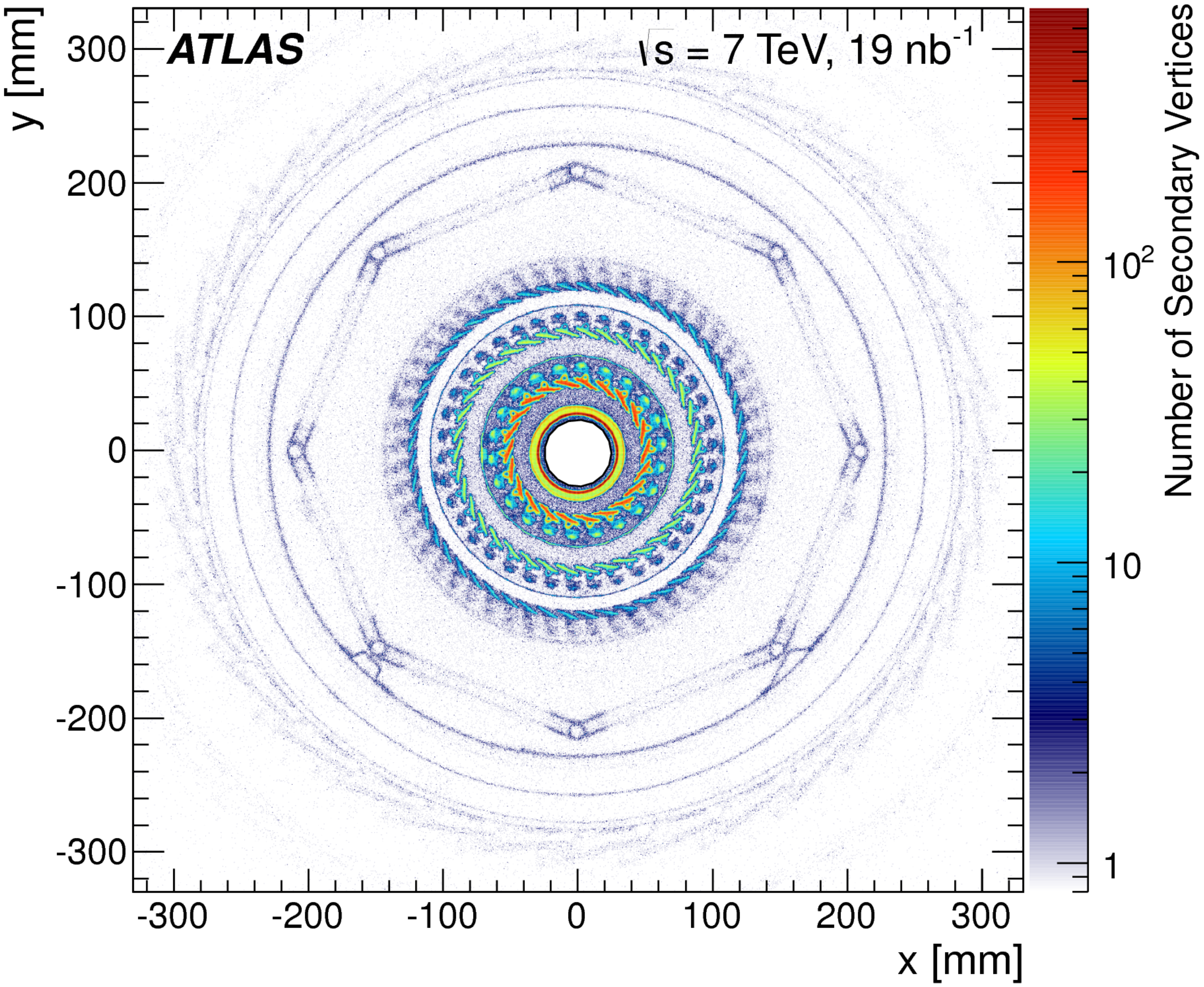
Years from concept to discovery

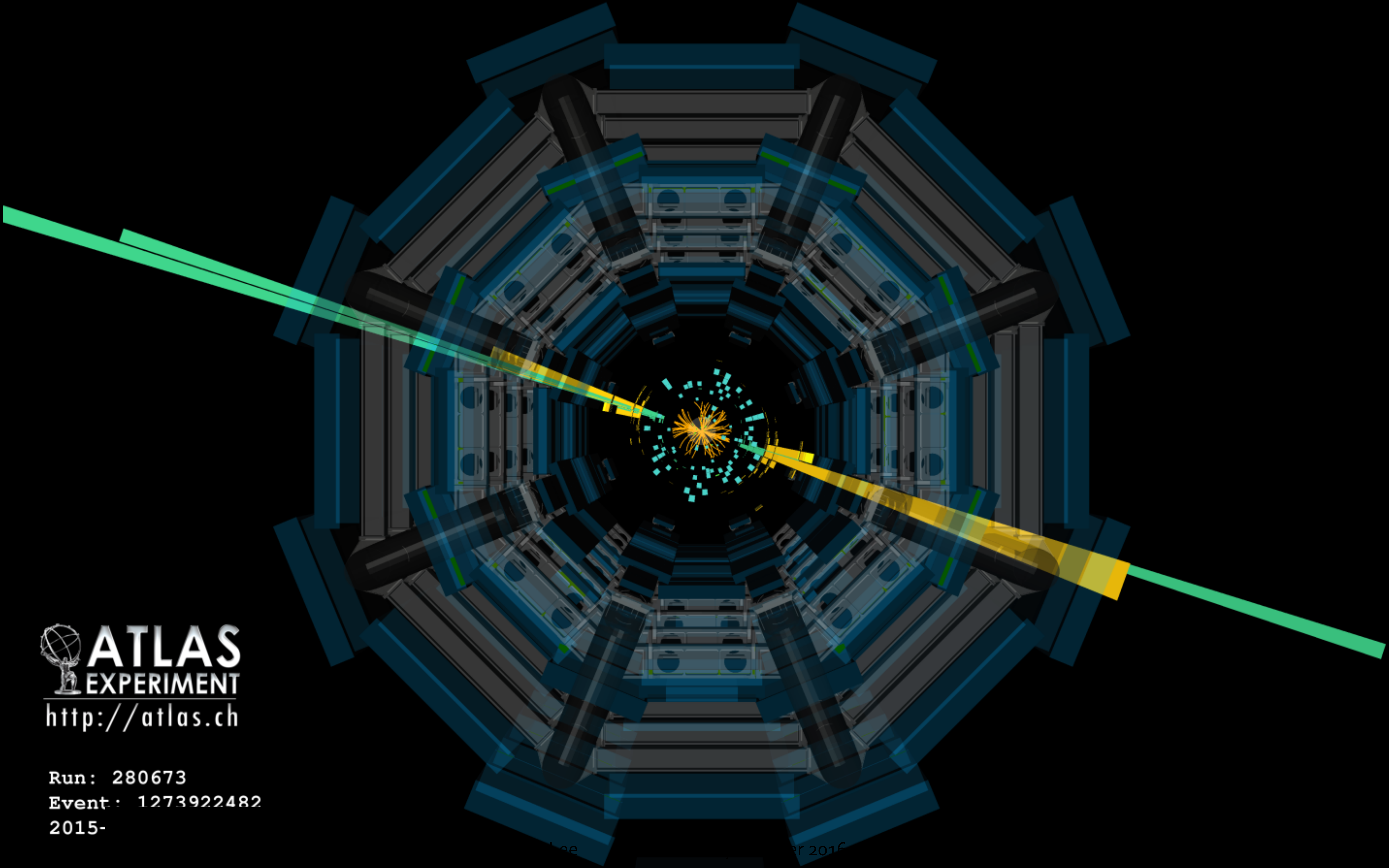
Source: *The Economist*


$\sqrt{s}$ = 7 TeV
$\int Ldt$ = 0.05 fb^{-1}
Apr 24, 2011
ATLAS Preliminary
$H \rightarrow ZZ^{(*)} \rightarrow 4l$ channel
Signal (m_H=125 GeV)
Background $ZZ^{(*)}$
Background Z+jets, $t\bar{t}$
Data
Events / 5 GeV
35
30
25
20
15
10
5
0
Data - Background
10
0
-10
50
100
150
200
250
300
350
400
450
500
M_{4l} [GeV]


ATLAS Preliminary
$\sqrt{s}$ = 8 TeV, $\int$ Ldt = 0.0 fb^{-1}
H→WW$^{(*)}$→ eνμν with 0/1 jet
Data
WW
WZ/ZZ/Wγ
$t\bar{t}$
Single Top
Z+jets
W+jets
H [125 GeV]
06.04.2012
Events / 10 GeV
450
400
350
300
250
200
150
100
50
0
Data-Background
50
40
30
20
10
0
-10
-20
50
100
150
200
250
300
m_T [GeV]

THE ATLAS DETECTOR IS A DIGITAL CAMERA THAT CAN TAKE PHOTOS OF ITSELF





ATLAS EXPERIMENT
http://atlas.ch
Run: 280673
Event: 1273922482
2015-

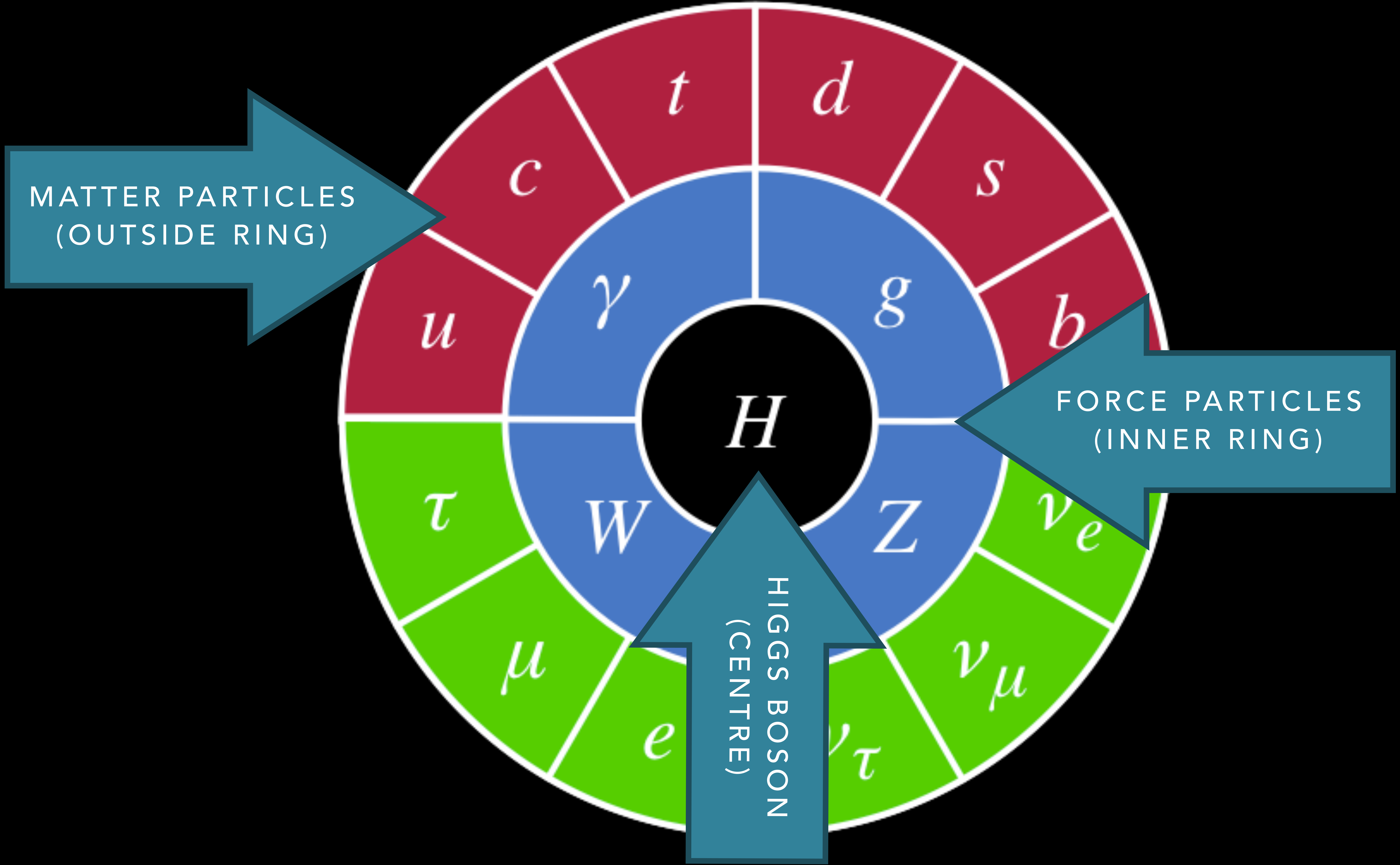
- Argentina
- Armenia
- Australia
- Austria
- Azerbaijan
- Belarus
- Brazil
- Canada
- Chile
- China
- Colombia
- Czech Republic
- Denmark
- France
- Georgia
- Germany
- Greece
- Israel
- Italy
- Japan
- Morocco
- Netherlands
- Norway
- Poland
- Portugal
- Romania
- Russia
- Serbia
- Slovakia
- Slovenia
- South Africa
- Spain
- Sweden
- Switzerland
- Taiwan
- Turkey
- UK
- USA
- CERN
- JINR

ATLAS Collaboration

July 2010


ROCLA
DSD

THE STANDARD MODEL TODAY

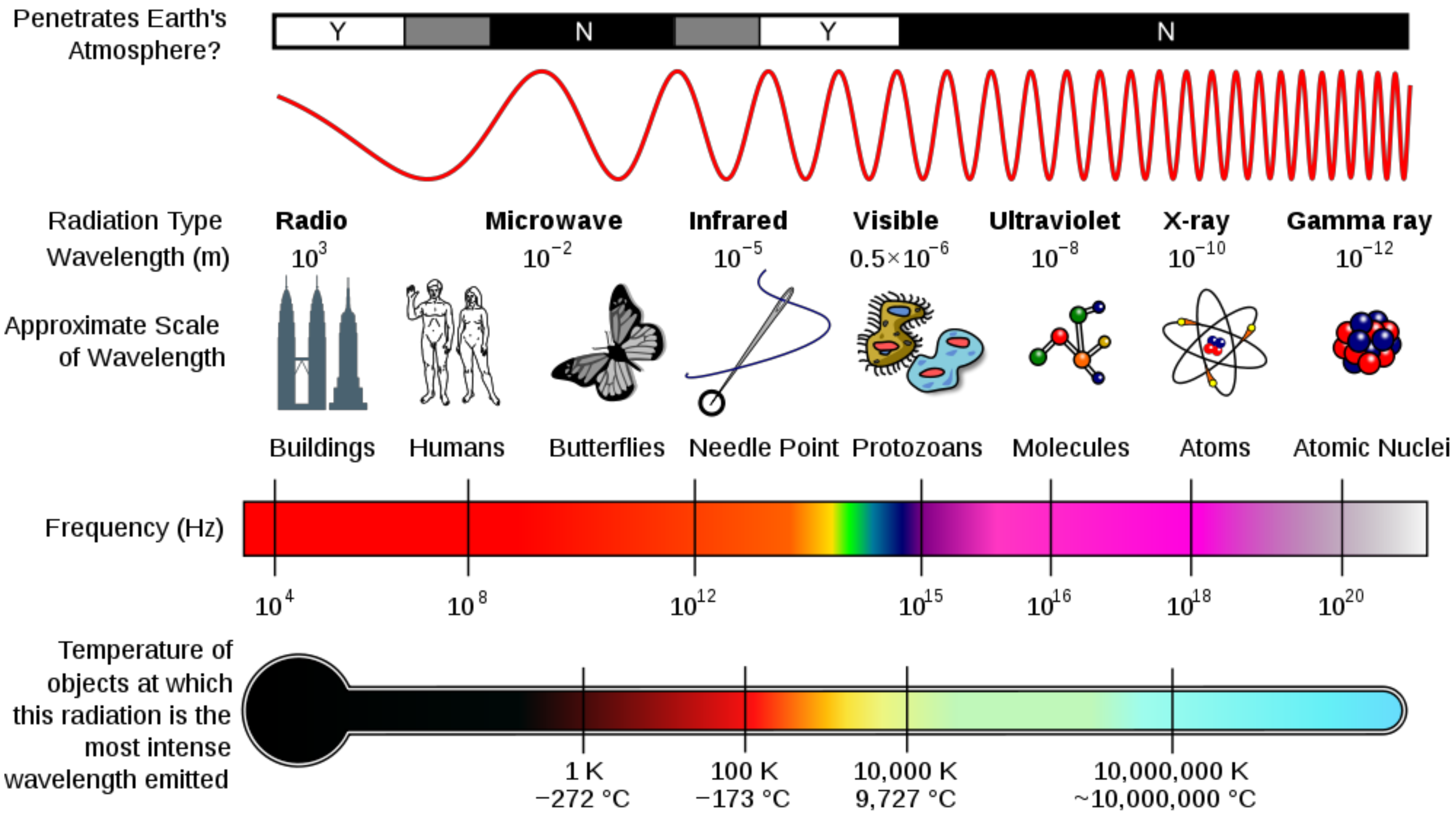


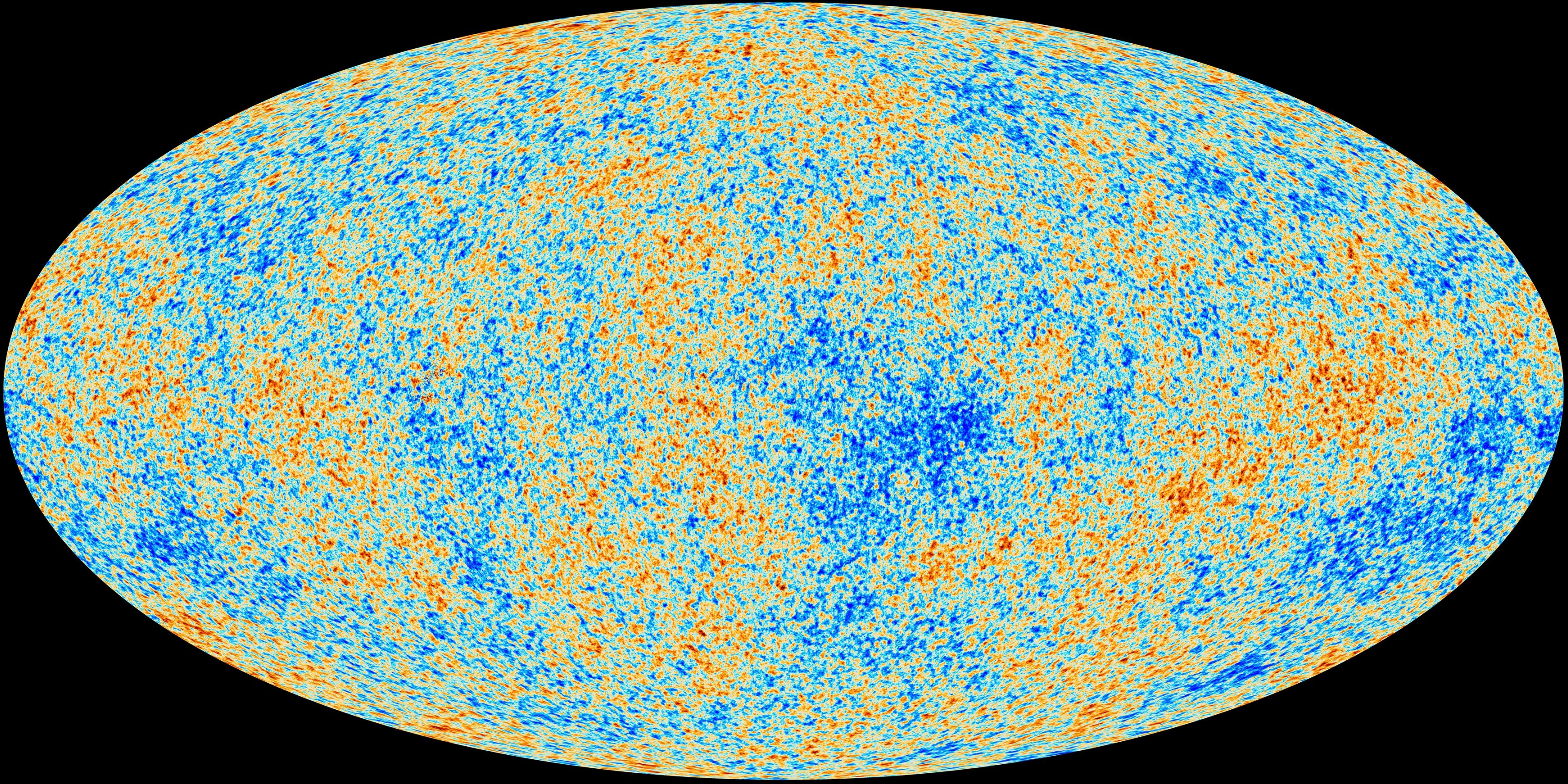
MATTER PARTICLES (OUTSIDE RING)

FORCE PARTICLES (INNER RING)

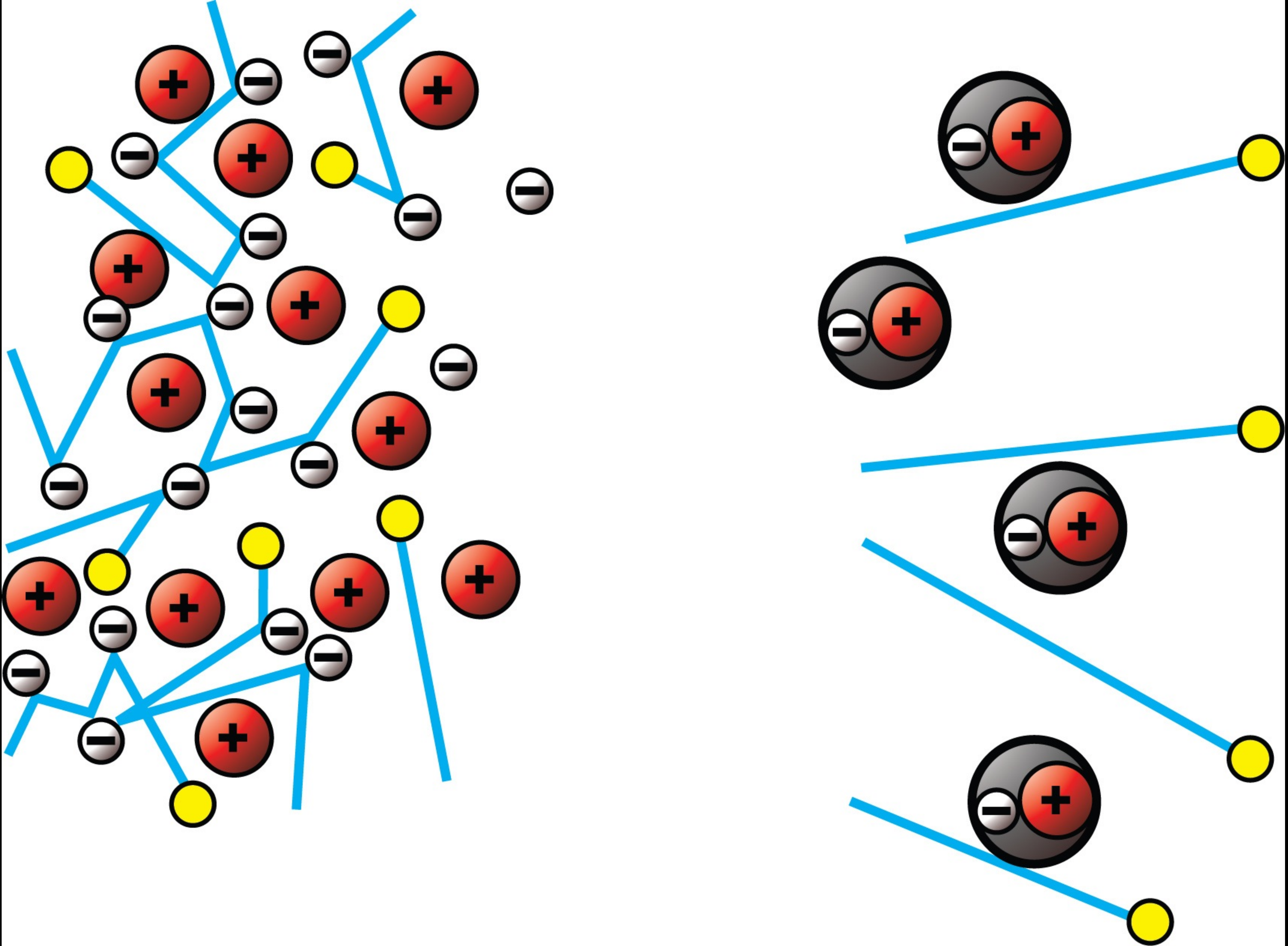
HIGGS BOSON (CENTRE)

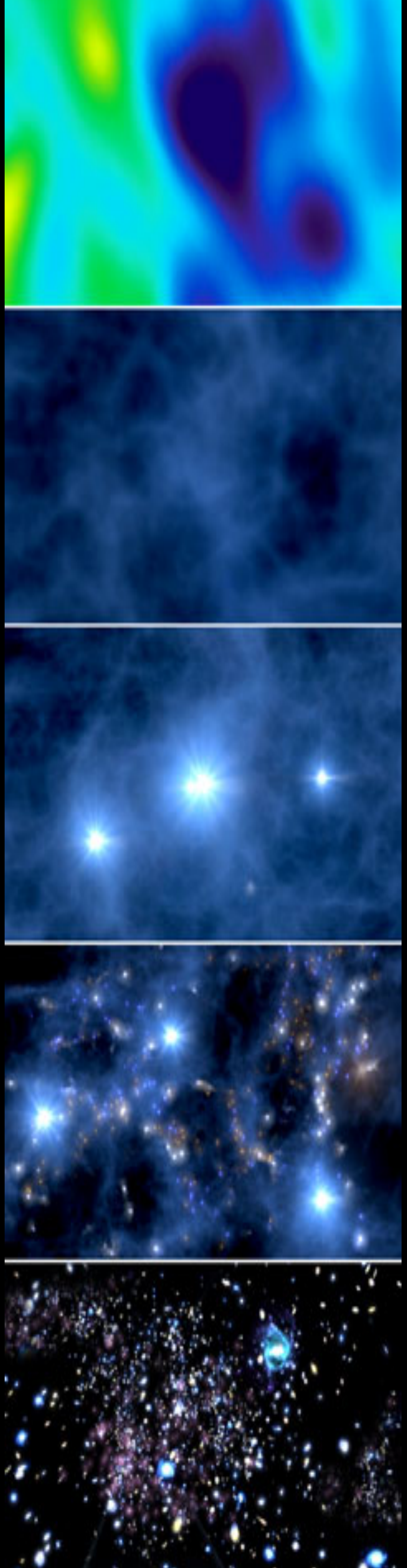
(IMAGE FROM PARTICLE FEVER)


Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Radio
10^{3}
Microwave
10^{-2}
Infrared
10^{-5}
Visible
0.5×10^{-6}
Ultraviolet
10^{-8}
X-ray
10^{-10}
Gamma ray
10^{-12}
Approximate Scale of Wavelength
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

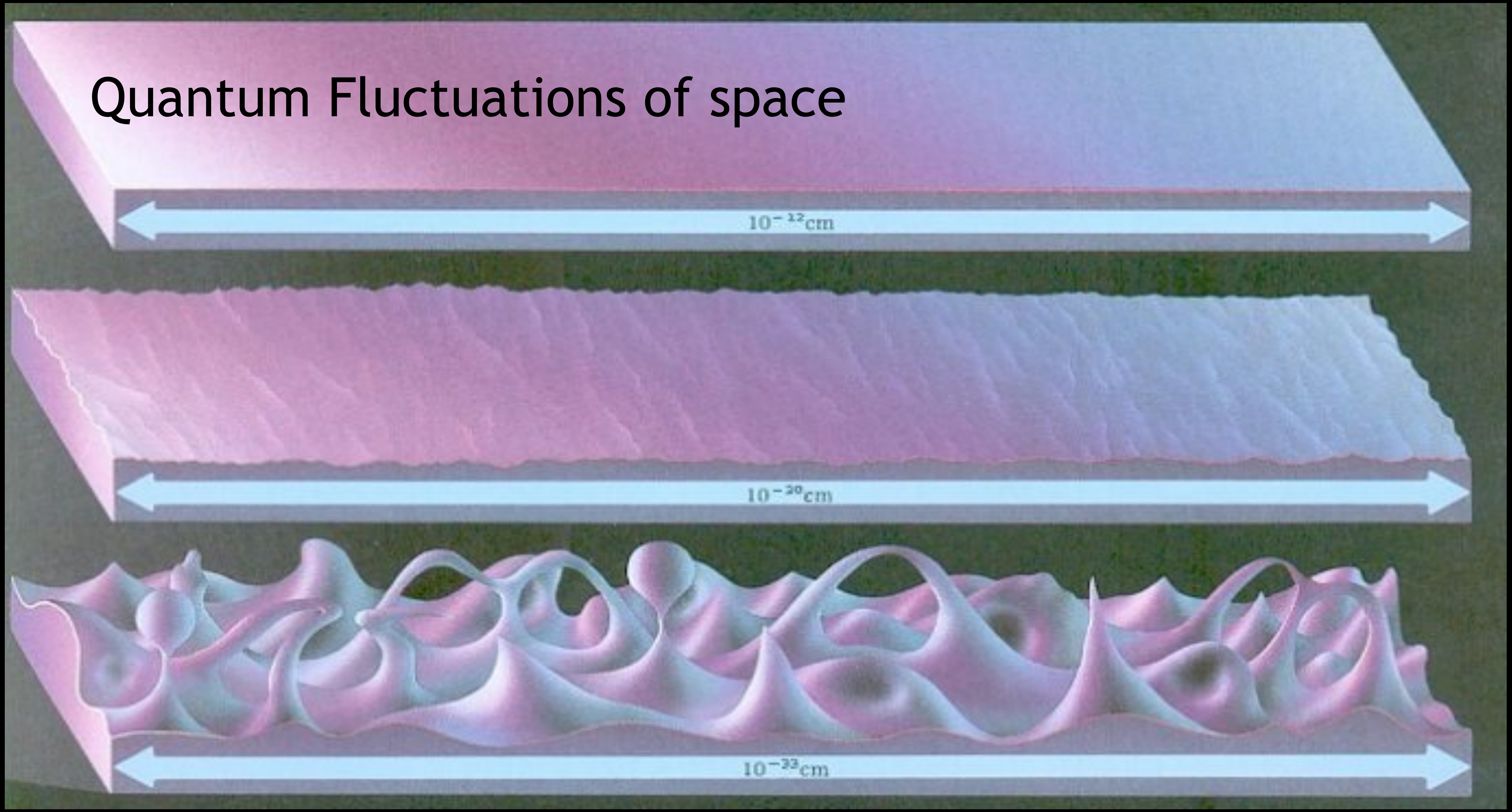


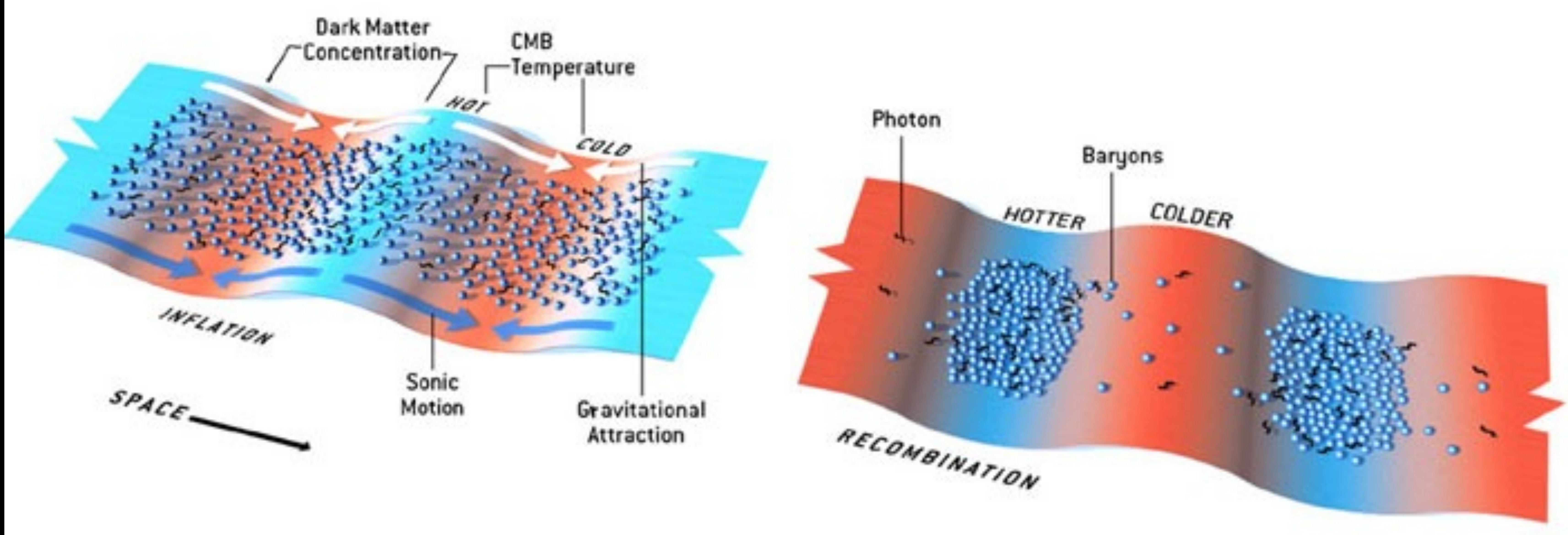
PLANCK, 2013



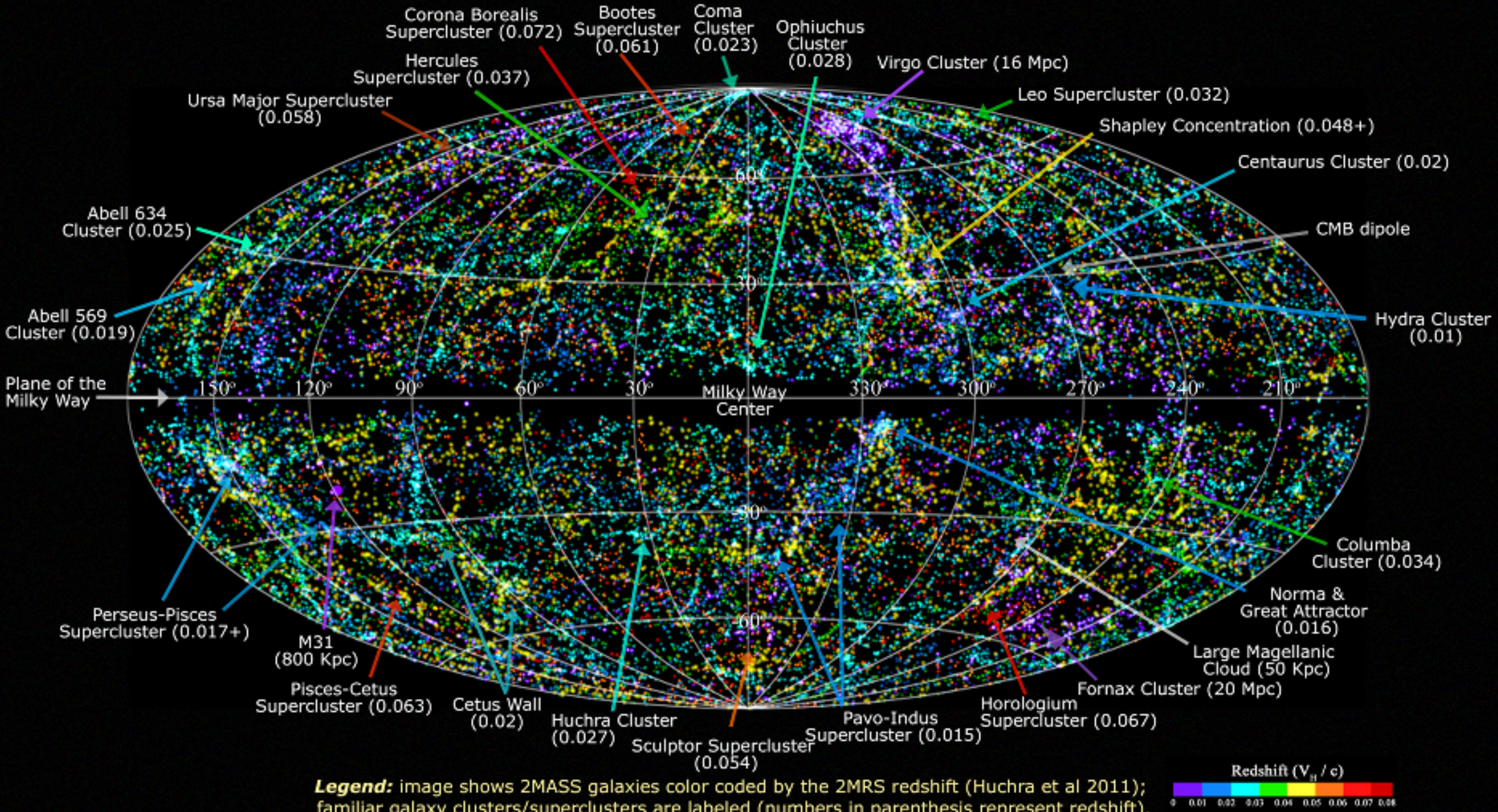


Quantum Fluctuations of space





2MASS Redshift Survey



Legend: image shows 2MASS galaxies color coded by the 2MRS redshift (Huchra et al 2011); familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift).

Graphic created by T. Jarrett (IPAC/Caltech)

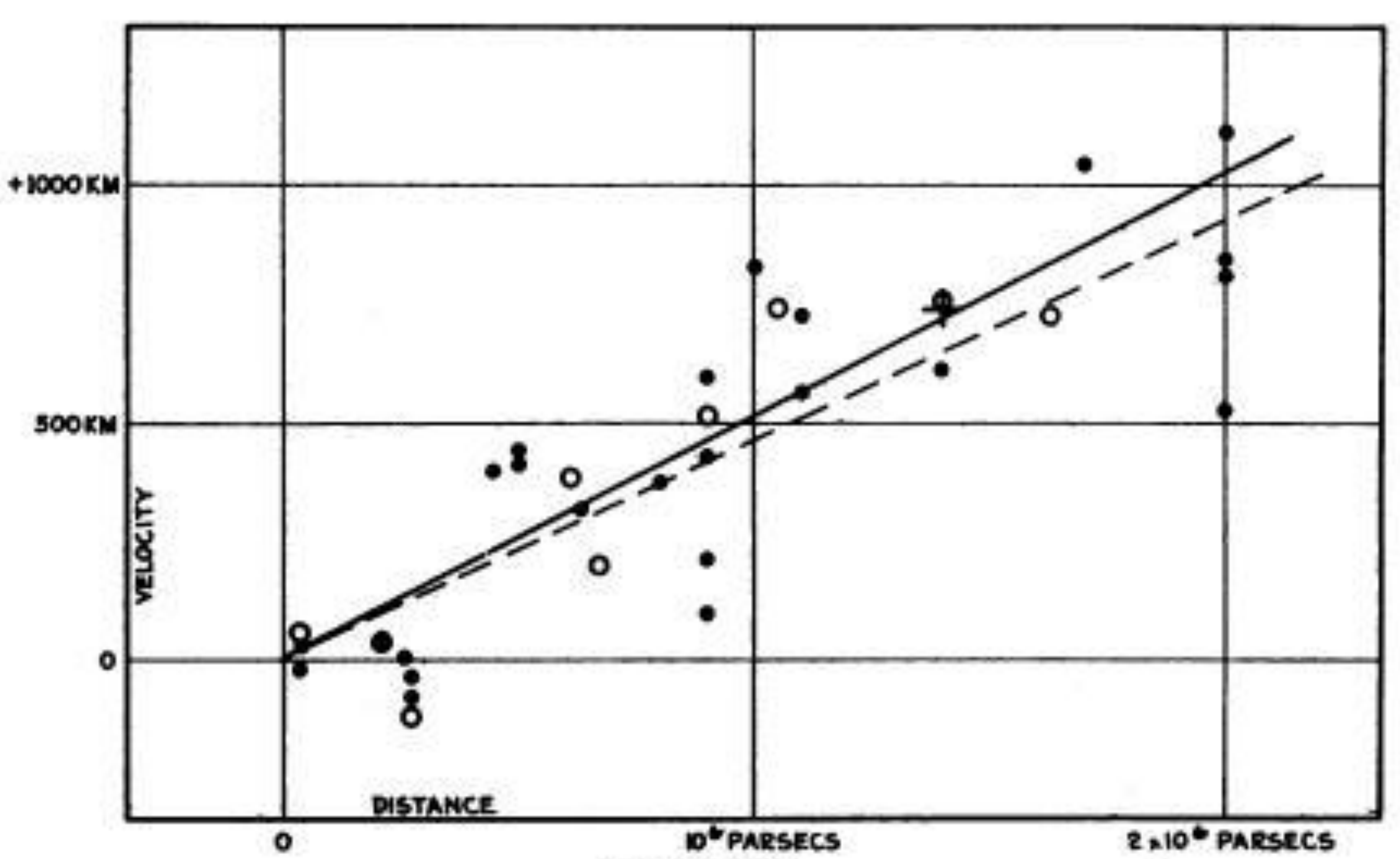
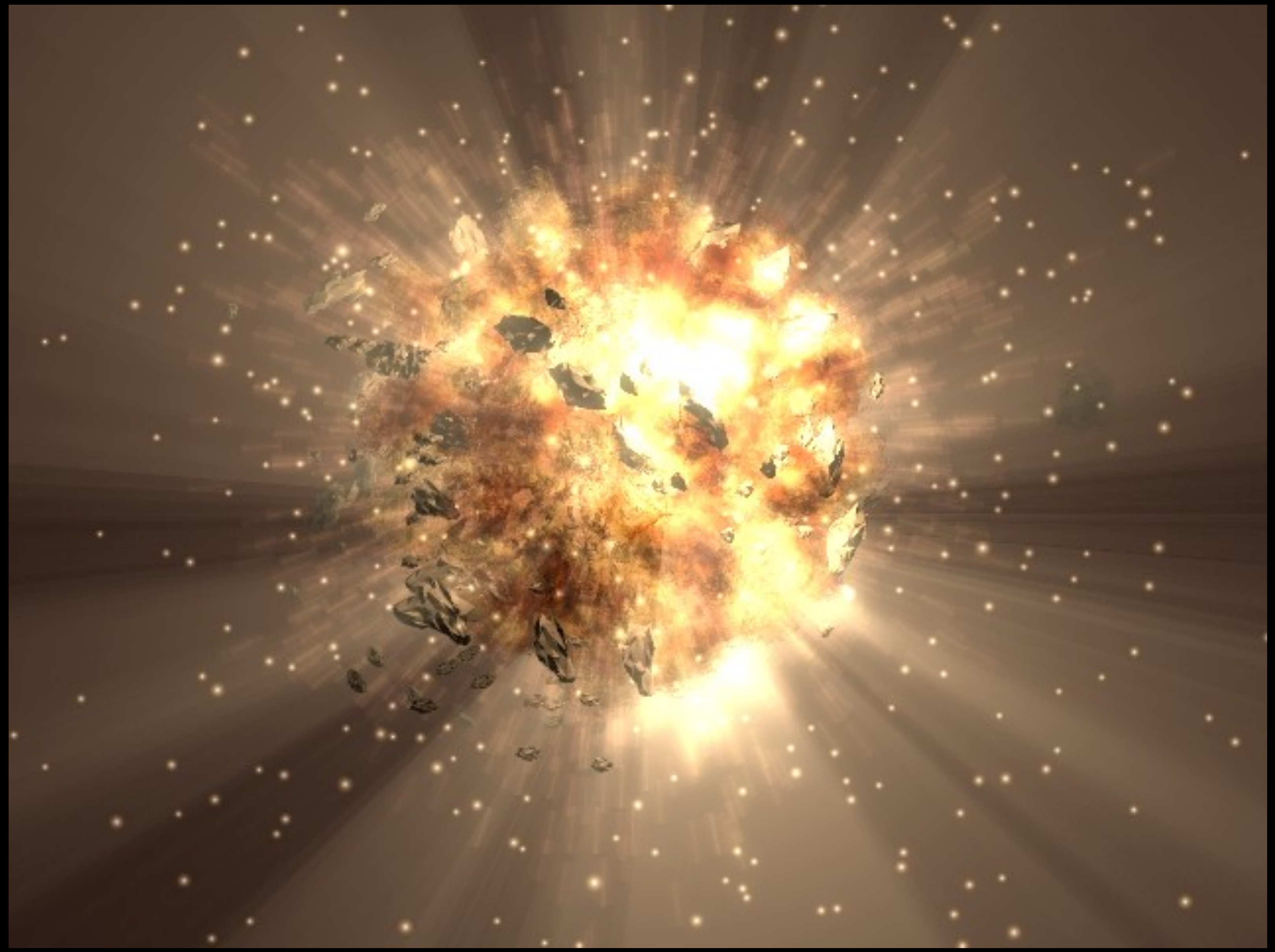


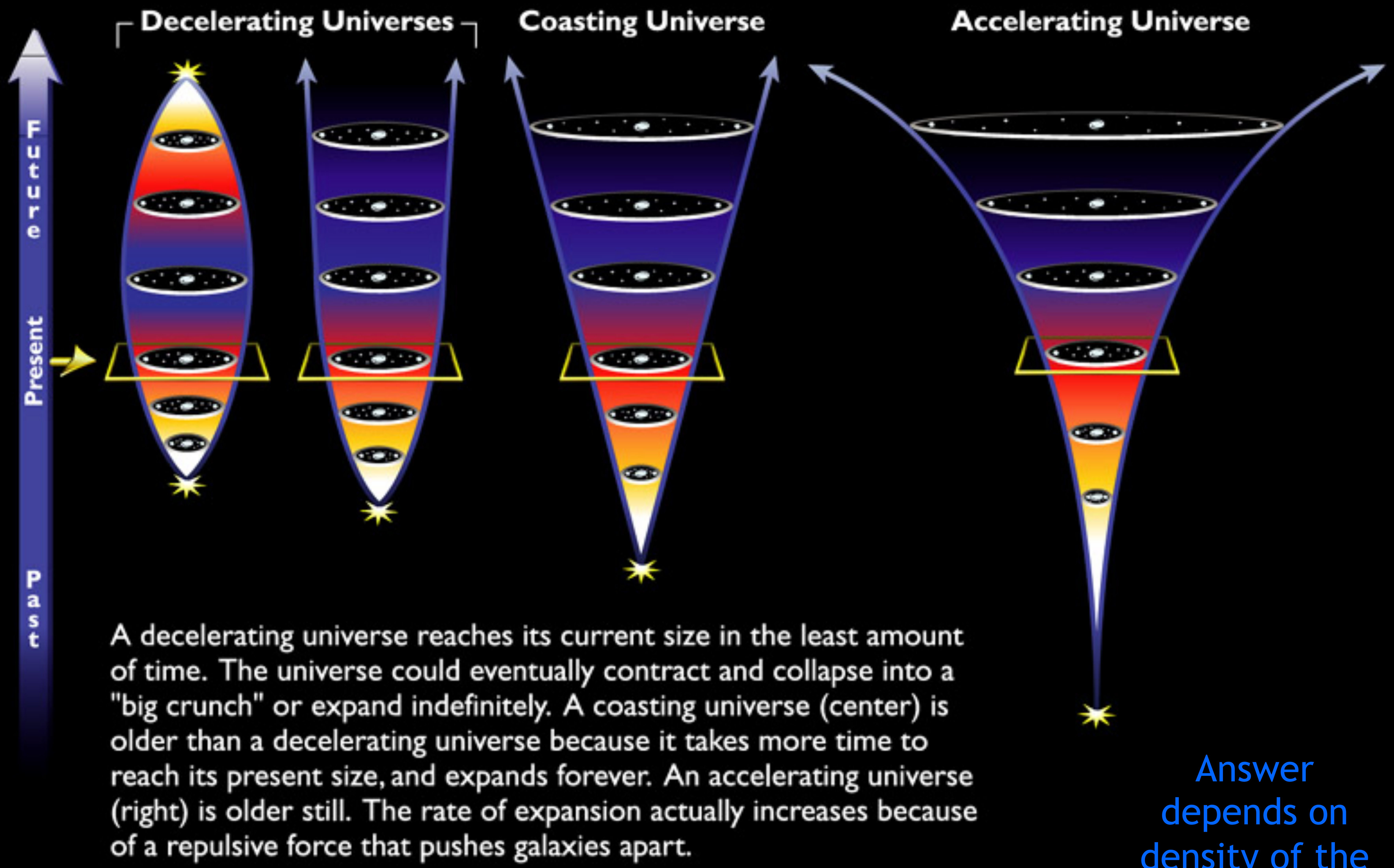
FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.



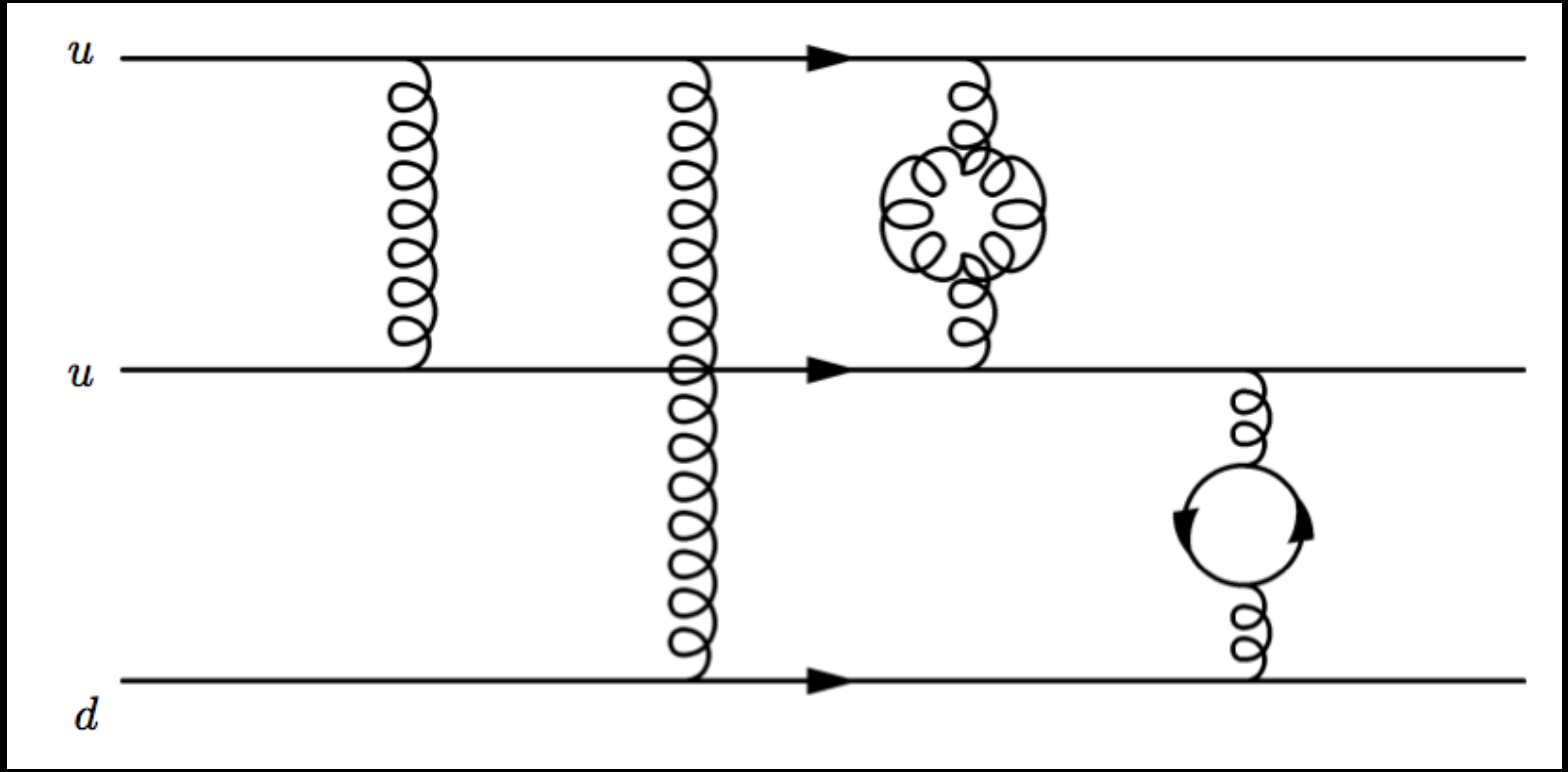
The Future of the Universe

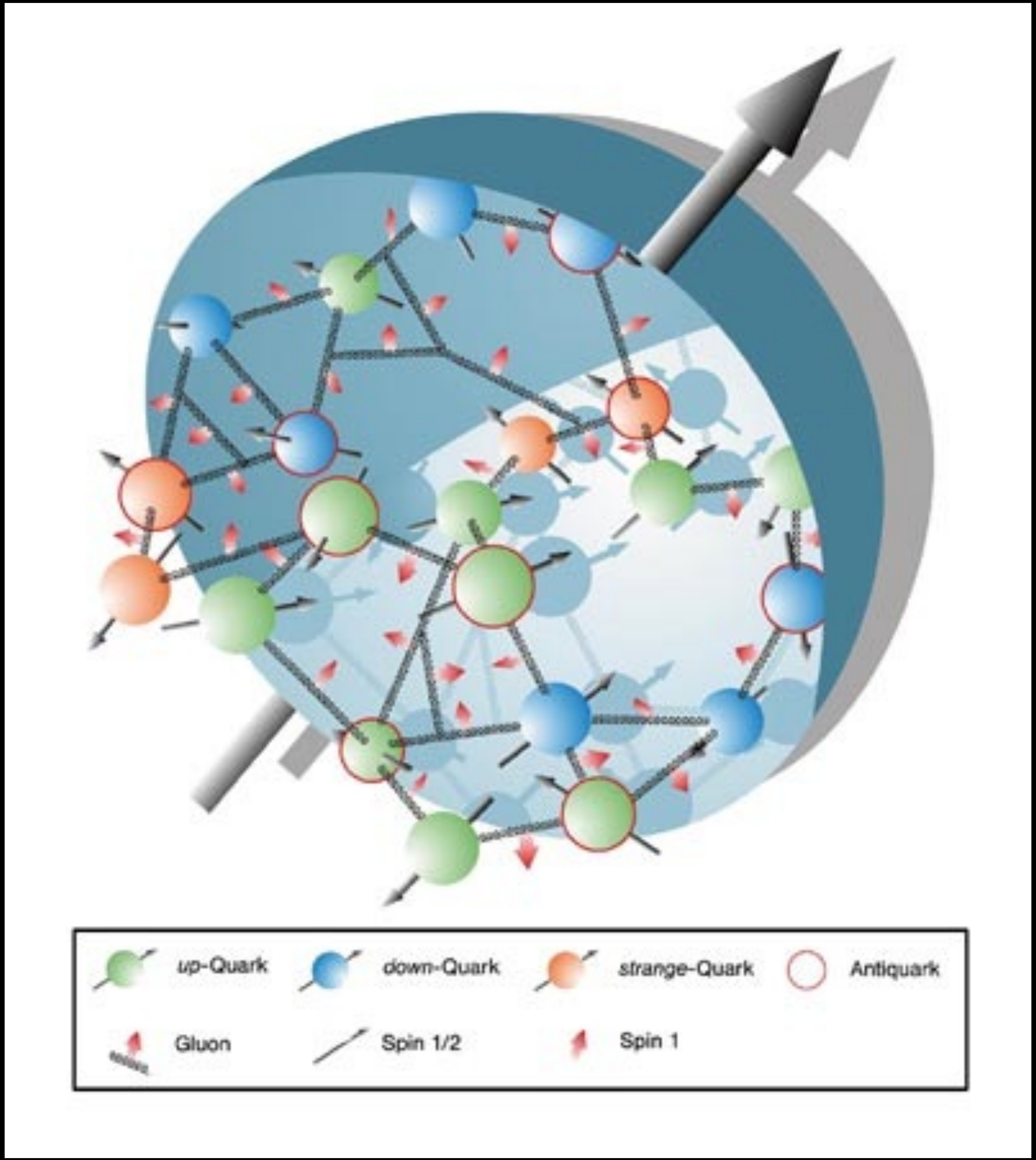
Big Freeze or Big Crunch?



A decelerating universe reaches its current size in the least amount of time. The universe could eventually contract and collapse into a "big crunch" or expand indefinitely. A coasting universe (center) is older than a decelerating universe because it takes more time to reach its present size, and expands forever. An accelerating universe (right) is older still. The rate of expansion actually increases because of a repulsive force that pushes galaxies apart.

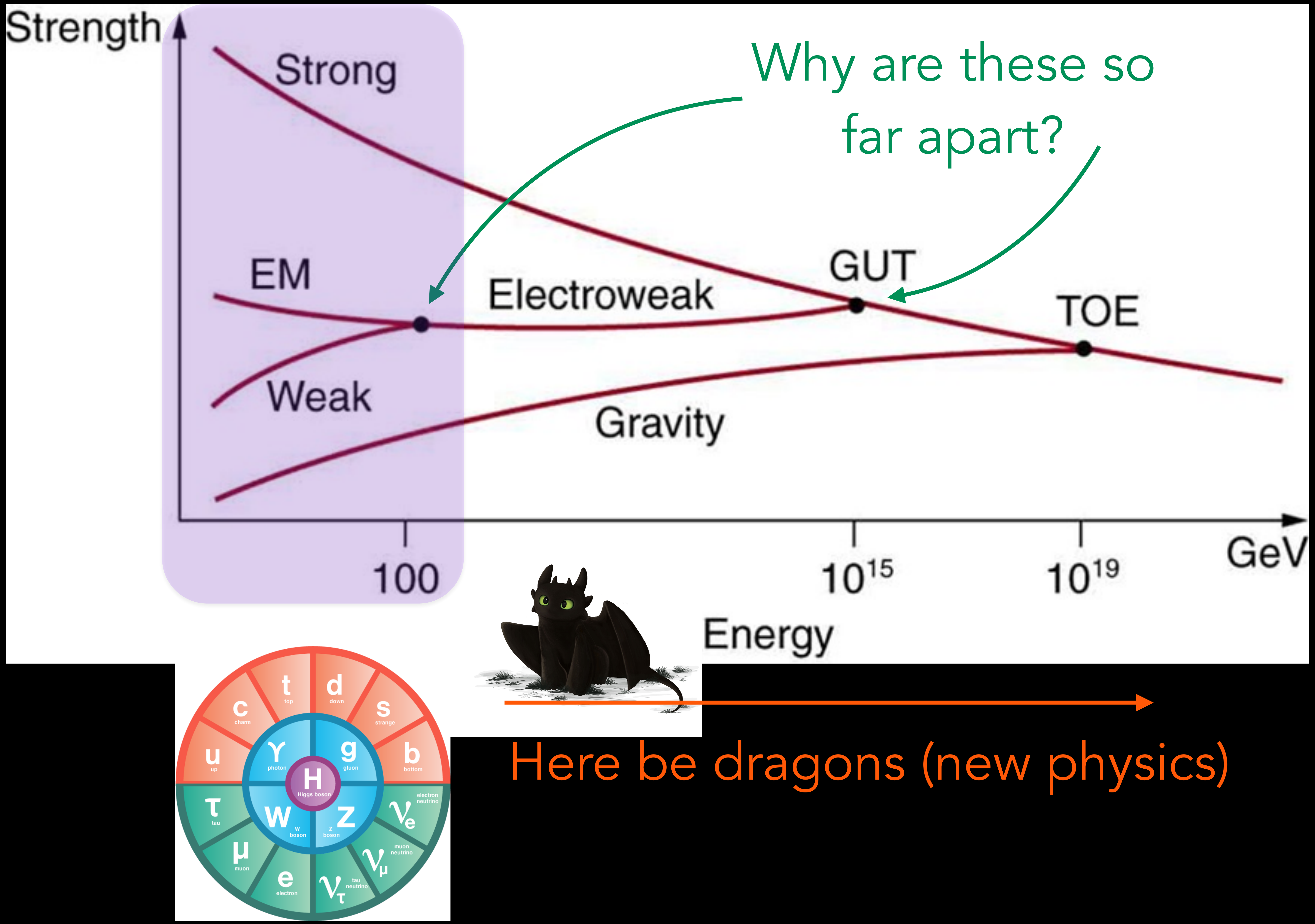
Answer depends on density of the universe


u
u
d


up-Quark
down-Quark
strange-Quark
Antiquark
Gluon
Spin 1/2
Spin 1

`

Kingdom of SM



Why are these so far apart?

Here be dragons (new physics)