Introduction to Particle Detectors

with Particle Physics at the Large Hadron Collider at CERN

Dr Clara Nellist

@ParticleClara (she/her)

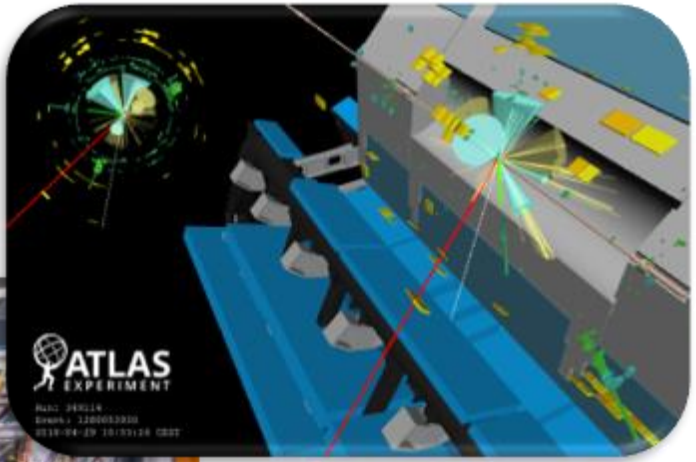
8th October 2024

CERN-Solvay Student Camp

Nikhef
ATLAS EXPERIMENT
Universiteit van Amsterdam

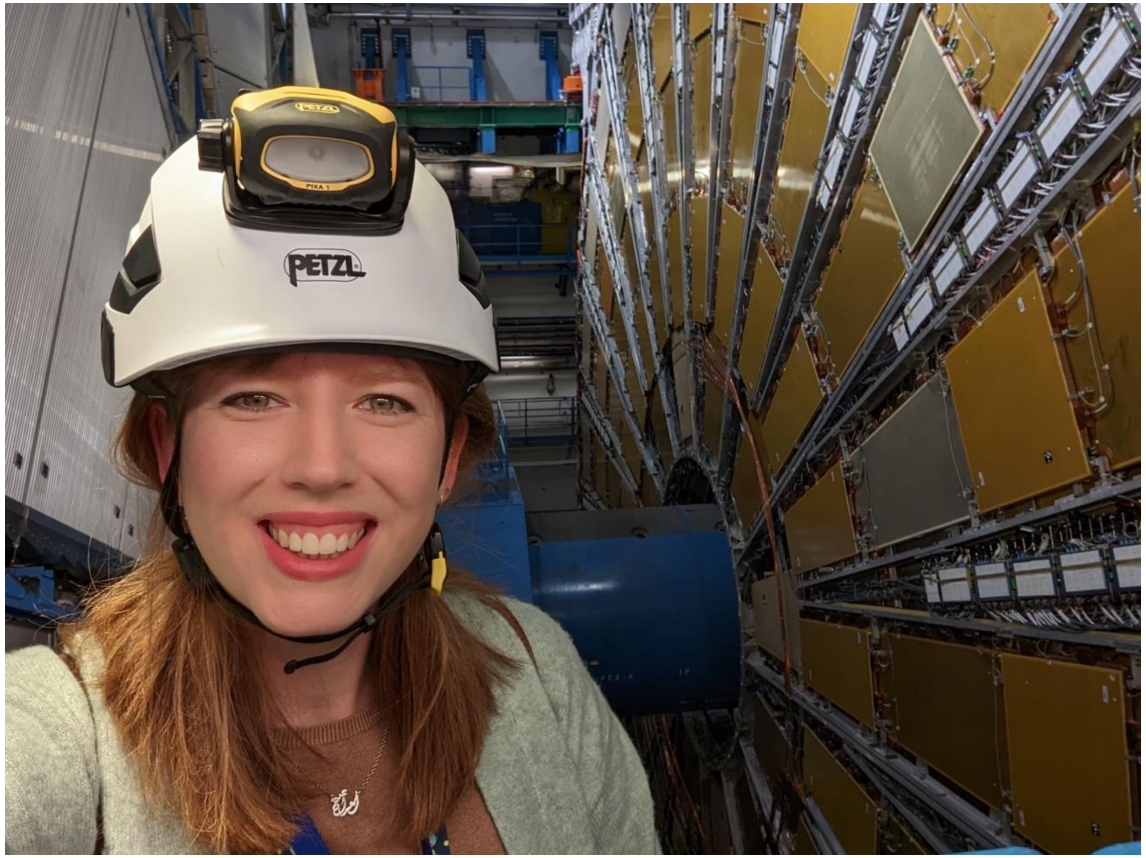
Introduction to me

Particle physicist working on the ATLAS experiment

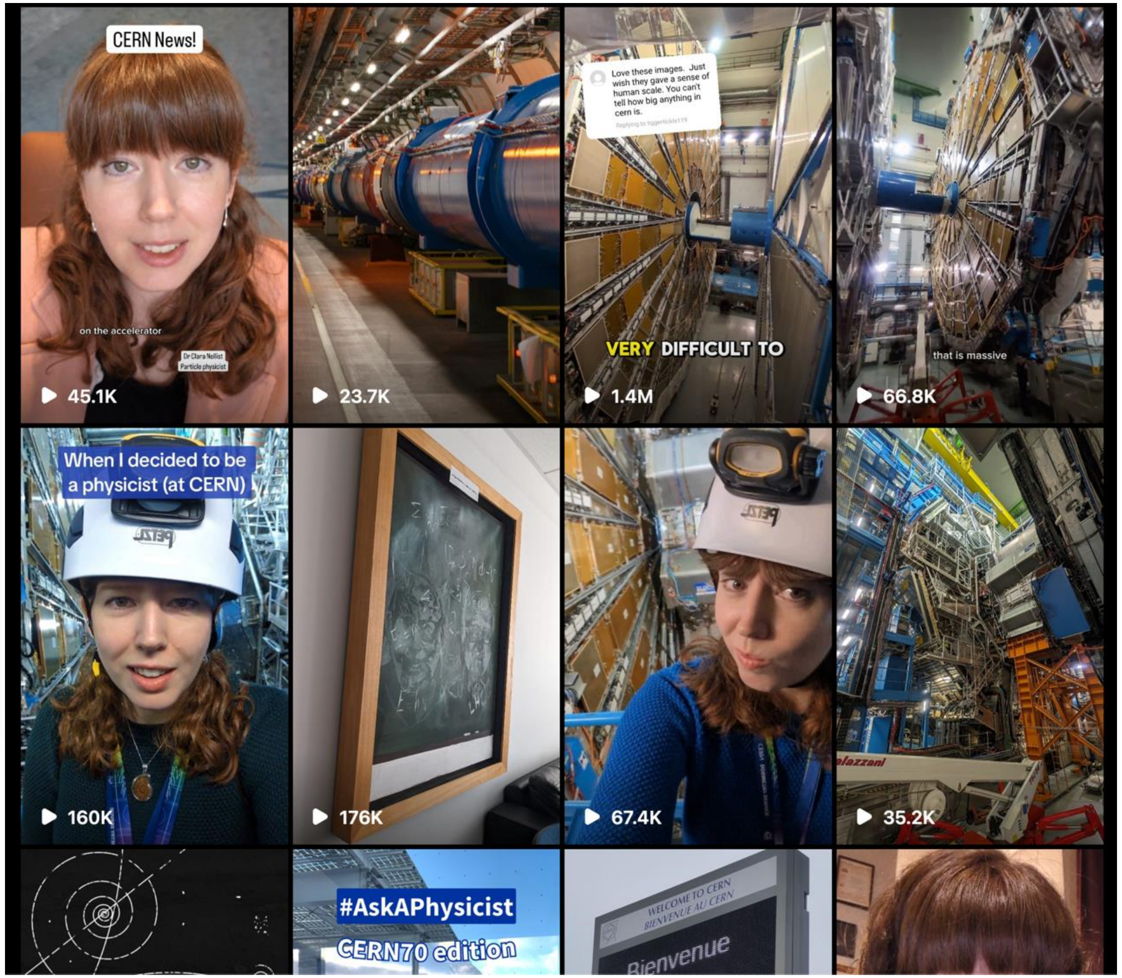


PhD in particle physics working on the ATLAS Experiment at CERN

Research on 3D silicon pixel detectors for the Insertable B-Layer upgrade of ATLAS



Science Communicator



@ParticleClara everywhere

Voyage into the world of atoms

https://videos.cern.ch/record/2307613


CERN

1
$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2}ig_s^2(\bar q^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar G^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar G^a G^b g^c_\mu$$

2
$$-\partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac12\partial_\nu Z^0_\mu\partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac12 \partial_\mu A_\nu \partial_\mu A_\nu - \frac12\partial_\mu H\partial_\mu H - \frac12 m_h^2 H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - M^2\phi^+\phi^- - \frac12\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h\left[\frac{2M^2}{g^2} + \frac{2M}{g}H + \frac12(H^2+\phi^0\phi^0+2\phi^+\phi^-)\right] + \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)] - \frac12 g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac12 g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2(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^-] - \frac18 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)^2H^2] - gMW^+_\mu W^-_\mu H - \frac12 g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac12 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)] + \frac12 g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] + \frac12 g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac14 g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \frac14 g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2-1)^2\phi^+\phi^-] - \frac12 g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \frac12 ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac12 g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \frac12 ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2-1)Z^0_\mu A_\mu\phi^+\phi^- - g^1 s_w^2 A_\mu A_\mu\phi^+\phi^-$$

3
$$-\bar e^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar\nu^\lambda\gamma\partial\nu^\lambda - \bar u^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j - \bar d^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_wA_\mu\left[-(\bar e^\lambda\gamma^\mu e^\lambda) + \frac23(\bar u^\lambda_j\gamma^\mu u^\lambda_j) - \frac13(\bar d^\lambda_j\gamma^\mu d^\lambda_j)\right] + \frac{ig}{4c_w}Z^0_\mu[(\bar\nu^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar e^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar u^\lambda_j\gamma^\mu(\tfrac43 s_w^2 - 1 - \gamma^5)u^\lambda_j) + (\bar d^\lambda_j\gamma^\mu(1 - \tfrac83 s_w^2 - \gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt2}W^+_\mu[(\bar\nu^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + (\bar u^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt2}W^-_\mu[(\bar e^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar d^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1+\gamma^5)u^\lambda_j)]$$

4
$$+\frac{ig}{2\sqrt2}\frac{m_e^\lambda}{M}[-\phi^+(\bar\nu^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar e^\lambda(1+\gamma^5)\nu^\lambda)] - \frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar e^\lambda e^\lambda) + i\phi^0(\bar e^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt2}\phi^+[-m_d^\kappa(\bar u^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m_u^\lambda(\bar u^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j)] + \frac{ig}{2M\sqrt2}\phi^-[m_d^\lambda(\bar d^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar d^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j)] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar u^\lambda_j u^\lambda_j) - \frac g2\frac{m_d^\lambda}{M}H(\bar d^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar u^\lambda_j\gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar d^\lambda_j\gamma^5 d^\lambda_j)$$

5
$$+\bar X^+(\partial^2 - M^2)X^+ + \bar X^-(\partial^2 - M^2)X^- + \bar X^0\left(\partial^2 - \frac{M^2}{c_w^2}\right)X^0 + \bar Y\partial^2 Y + igc_wW^+_\mu(\partial_\mu\bar X^0 X^- - \partial_\mu\bar X^+ X^0) + igs_wW^+_\mu(\partial_\mu\bar Y X^- - \partial_\mu\bar X^+ Y) + igc_wW^-_\mu(\partial_\mu\bar X^- X^0 - \partial_\mu\bar X^0 X^+) + igs_wW^-_\mu(\partial_\mu\bar X^- Y - \partial_\mu\bar Y X^+) + igc_wZ^0_\mu(\partial_\mu\bar X^+ X^+ - \partial_\mu\bar X^- X^-) + igs_wA_\mu(\partial_\mu\bar X^+ X^+ - \partial_\mu\bar X^- X^-) - \frac12 gM\left[\bar X^+ X^+ H + \bar X^- X^- H + \frac{1}{c_w^2}\bar X^0 X^0 H\right] + \frac{1-2c_w^2}{2c_w}igM[\bar X^+ X^0\phi^+ - \bar X^- X^0\phi^-] + \frac{1}{2c_w}igM[\bar X^0 X^-\phi^+ - \bar X^0 X^+\phi^-] + igMs_w[\bar X^0 X^-\phi^+ - \bar X^0 X^+\phi^-] + \frac12 igM[\bar X^+ X^+\phi^0 - \bar X^- X^-\phi^0]$$

But what are we looking for?

Studying nature's building blocks and the forces that govern them

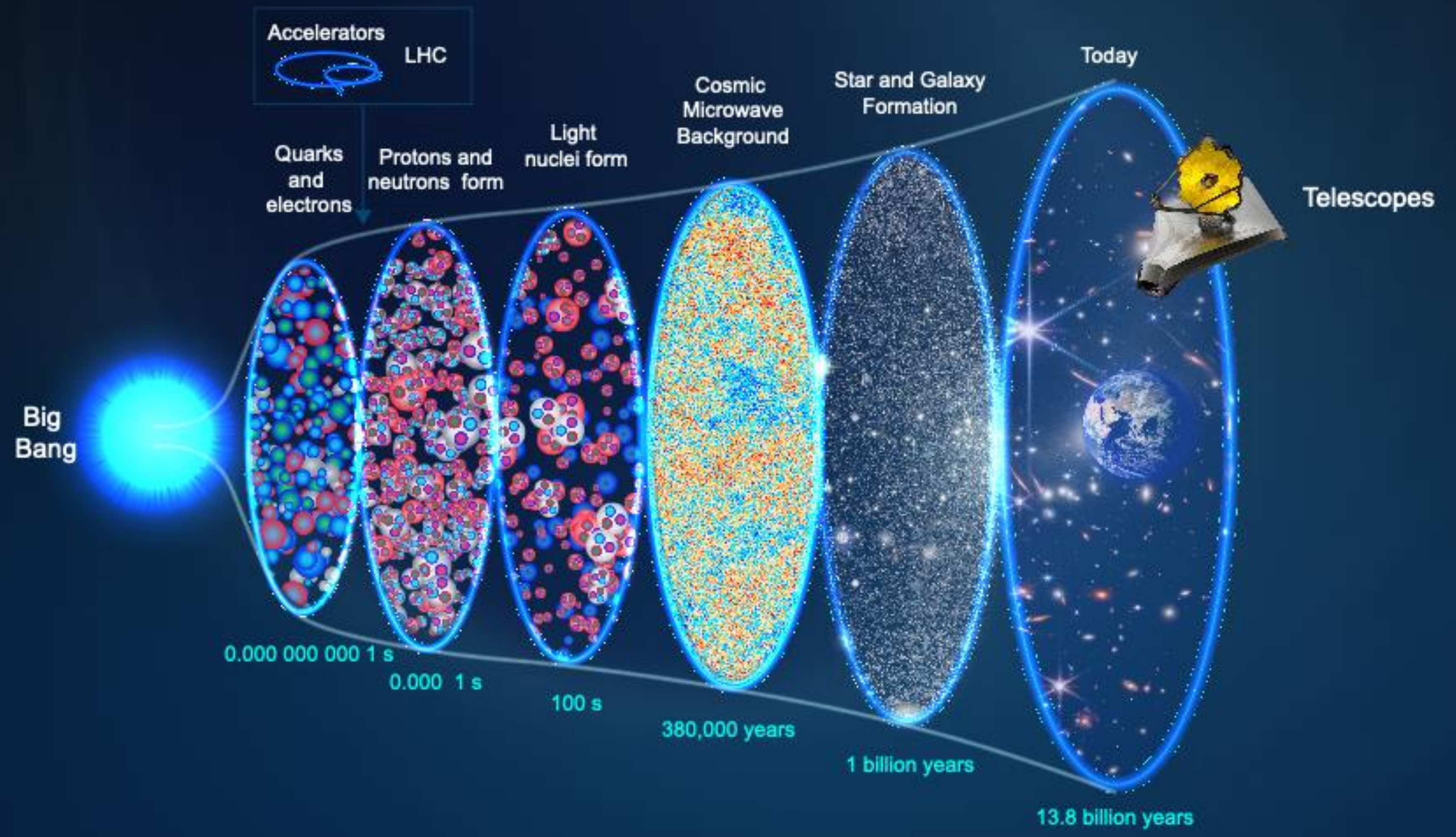
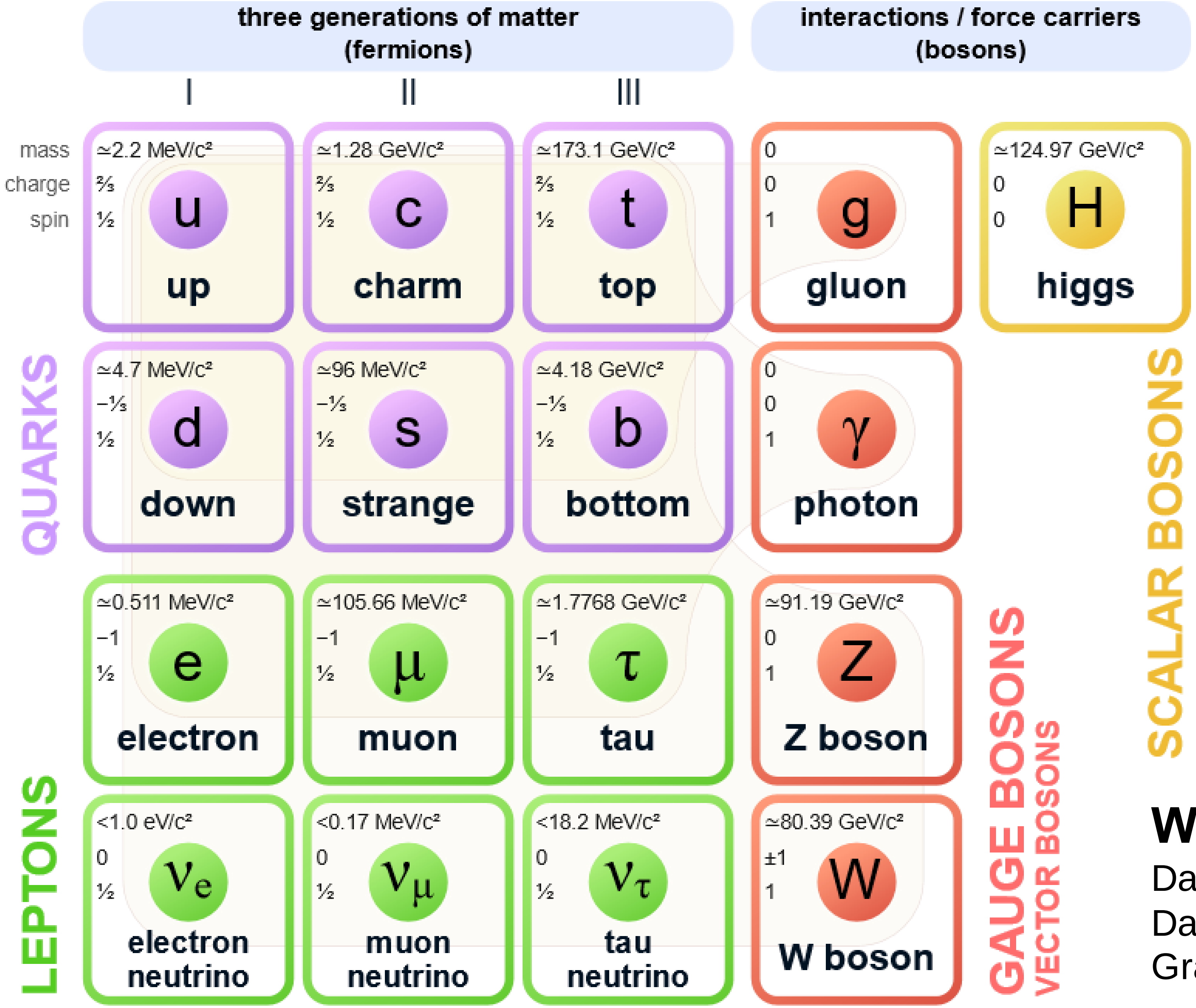


Image: CERN

The Standard Model



What's missing?

Dark matter
Dark energy
Gravity!

The Big Questions

Image: Jorge Cham / PhD Comics

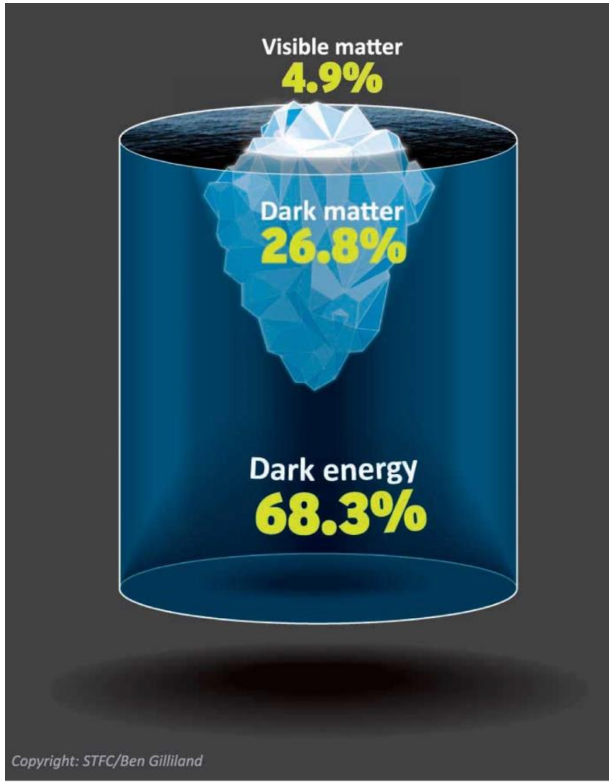


Illustration by Carolina Deluca / ATLAS © CERN

The search for the Higgs boson

Image: Jorge Cham / PhD Comics

But

WHY ?

The search for the Higgs boson

Fun fact! If this happened very quickly, it might have caused gravitational echos that with bigger and better graviational waves detectors, maybe we can ‘see’ this

Aim: to understand the origin of the mass of elementary particles.

Image: Jorge Cham / PhD Comics

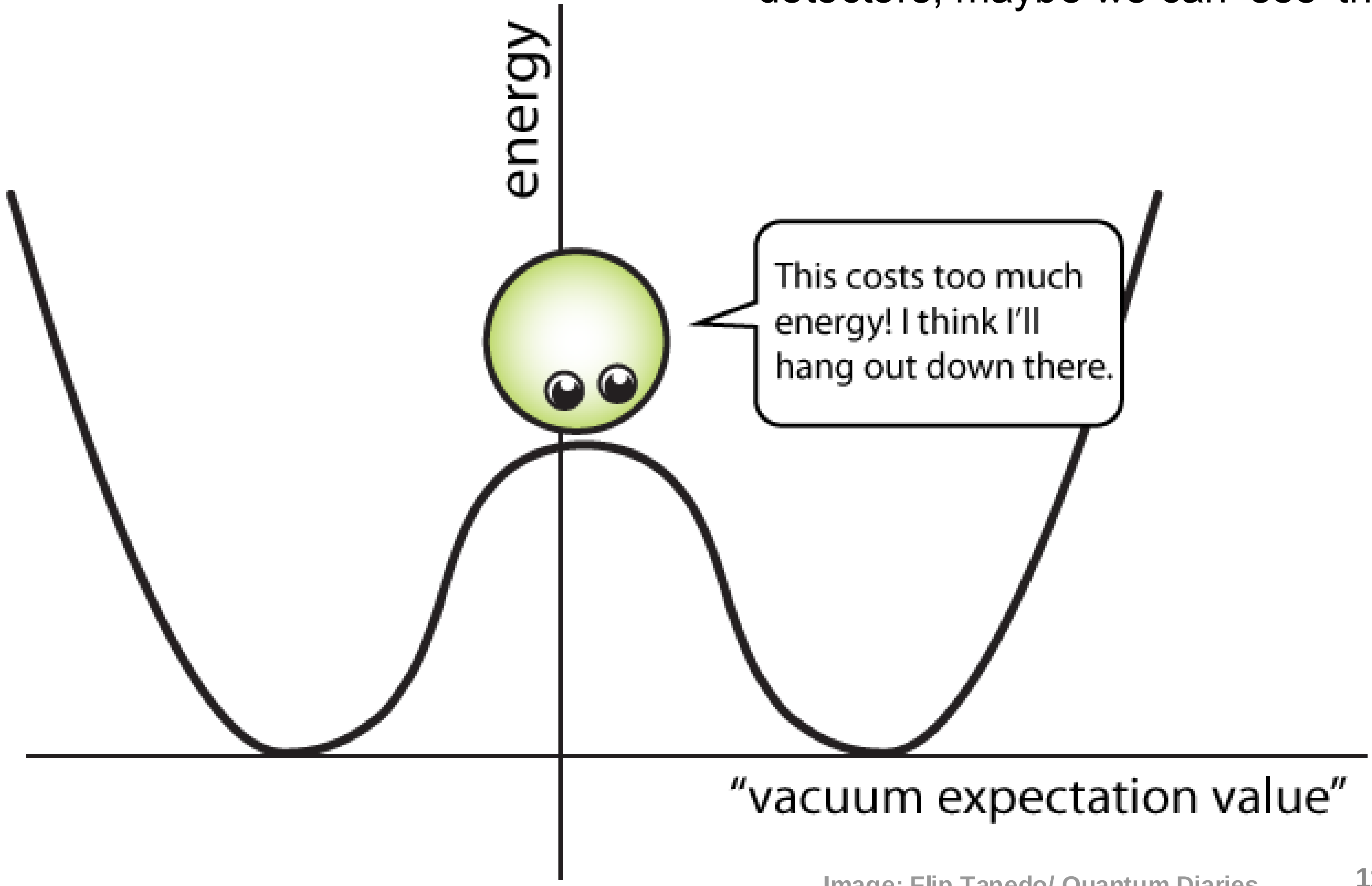


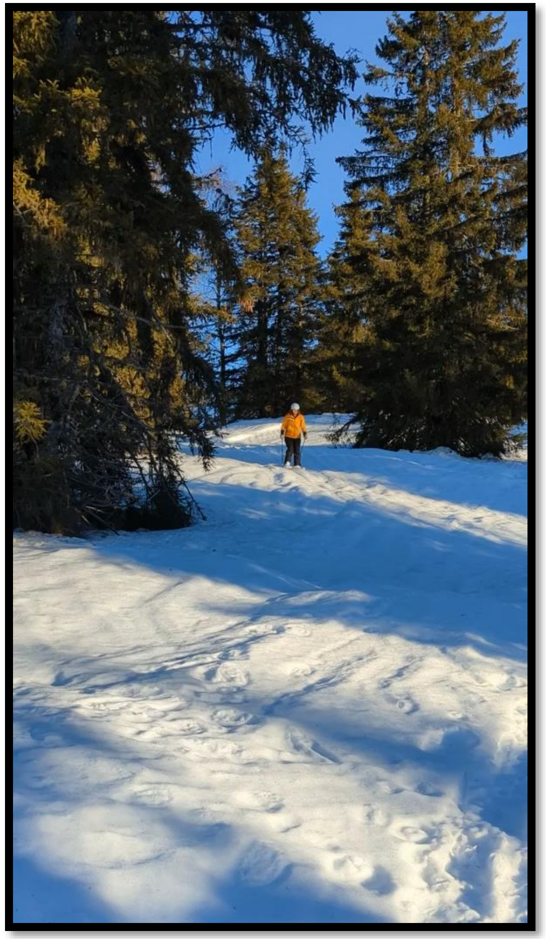
Image: Flip Tanedo/ Quantum Diaries

The Higgs boson

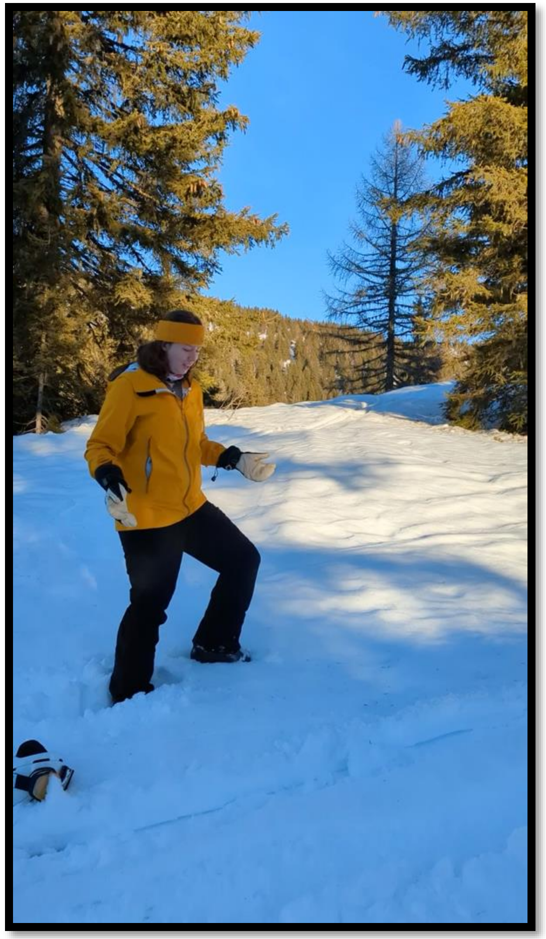
Image: Jorge Cham / PhD Comics

https://youtu.be/71alQCeCW6c

Light particle



Heavy particle



The Higgs boson

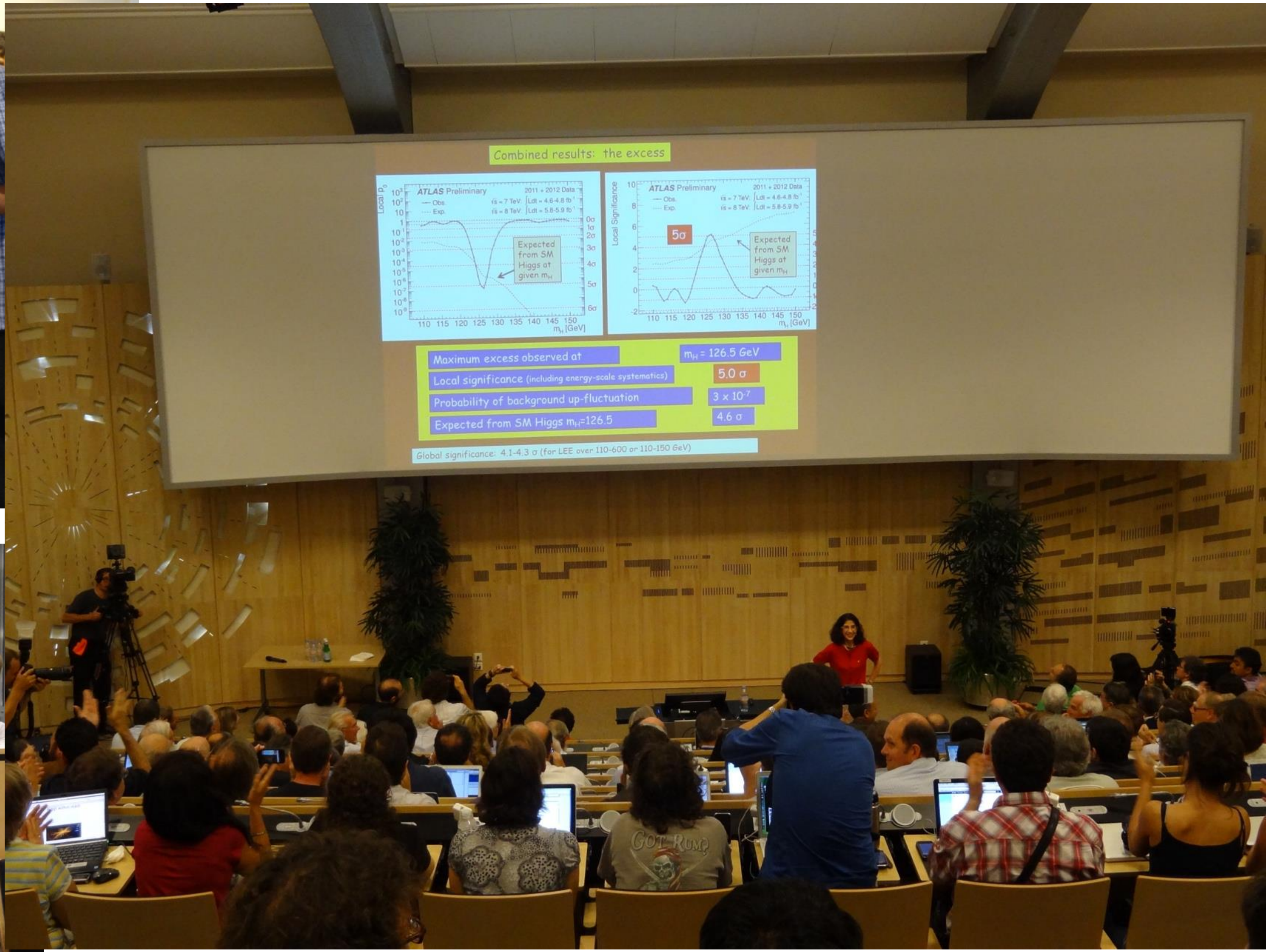
The discovery of a new boson!

The Higgs boson – a major success of the first LHC run.

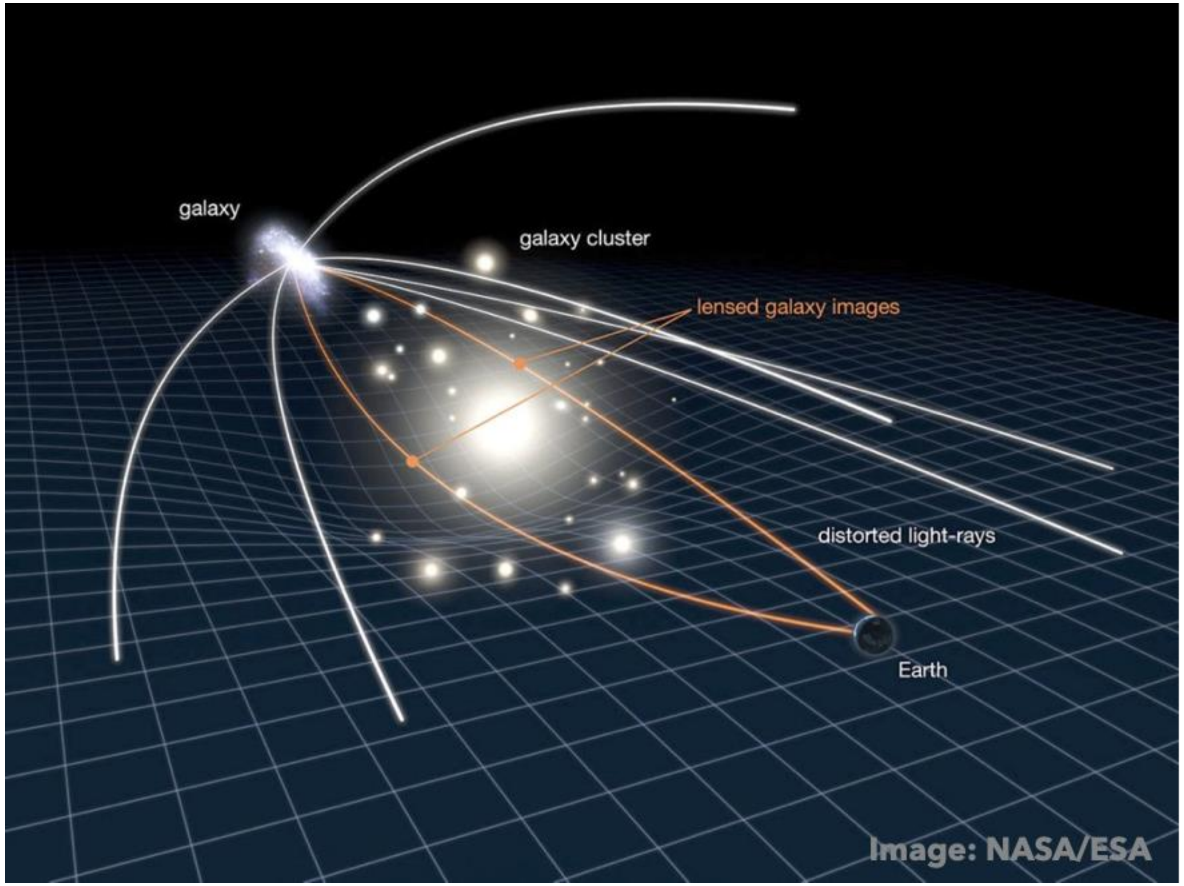
Physicists Find Elusive Particle Seen as Key to Universe

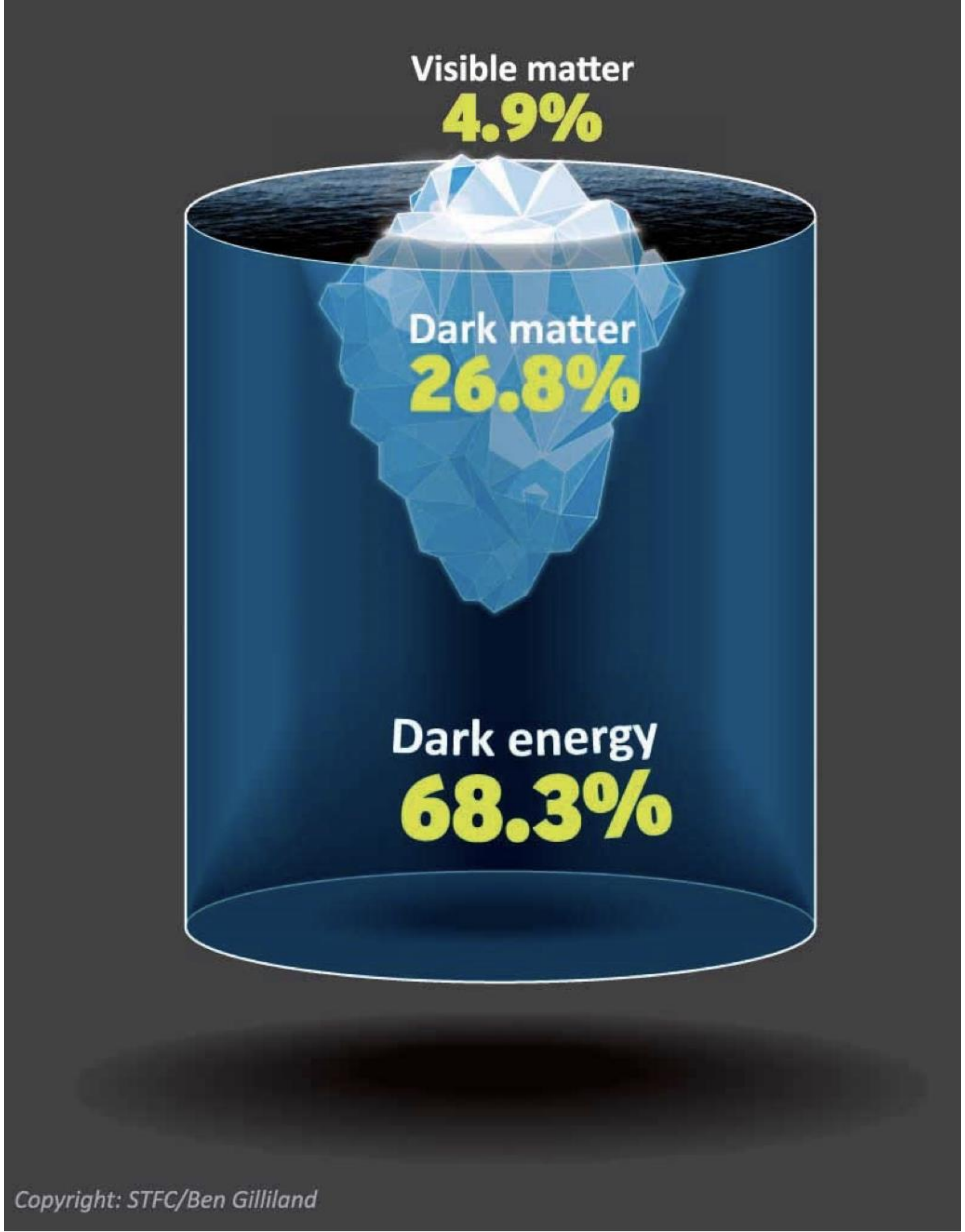
By **DENNIS OVERBYE** JULY 4, 2012

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson. Pool photo by Denis Balibouse


Combined results: the excess
ATLAS Preliminary
2011 + 2012 Data
Obs.
Exp.
Expected from SM Higgs at given m_H
Local Significance
5σ
Maximum excess observed at
m_H = 126.5 GeV
Local significance (including energy-scale systematics)
5.0 σ
Probability of background up-fluctuation
3×10^{-7}
Expected from SM Higgs m_H=126.5
4.6 σ
Global significance: 4.1-4.3 σ (for LEE over 110-600 or 110-150 GeV)

The search for new particles (dark matter?)





The search for

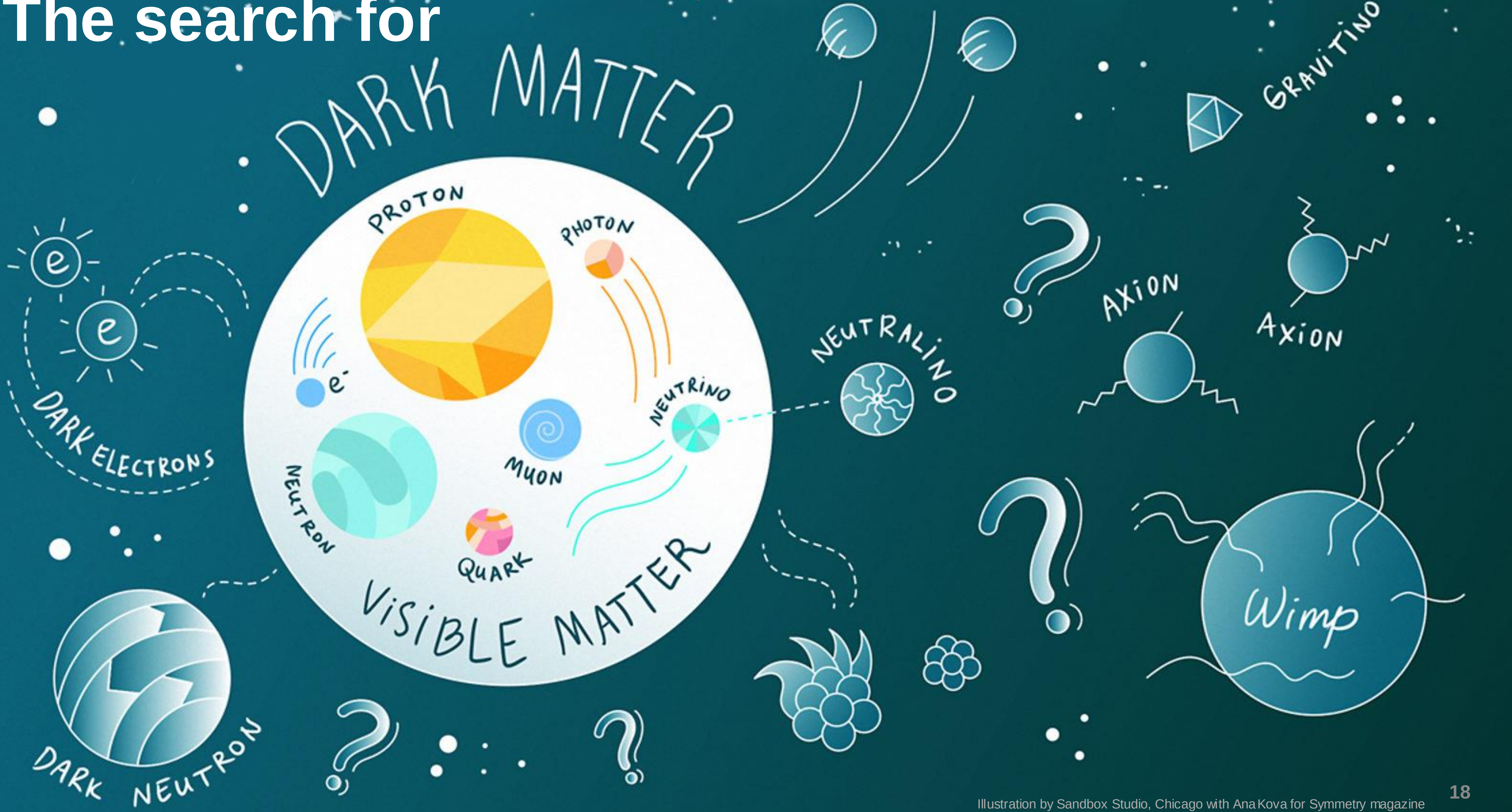
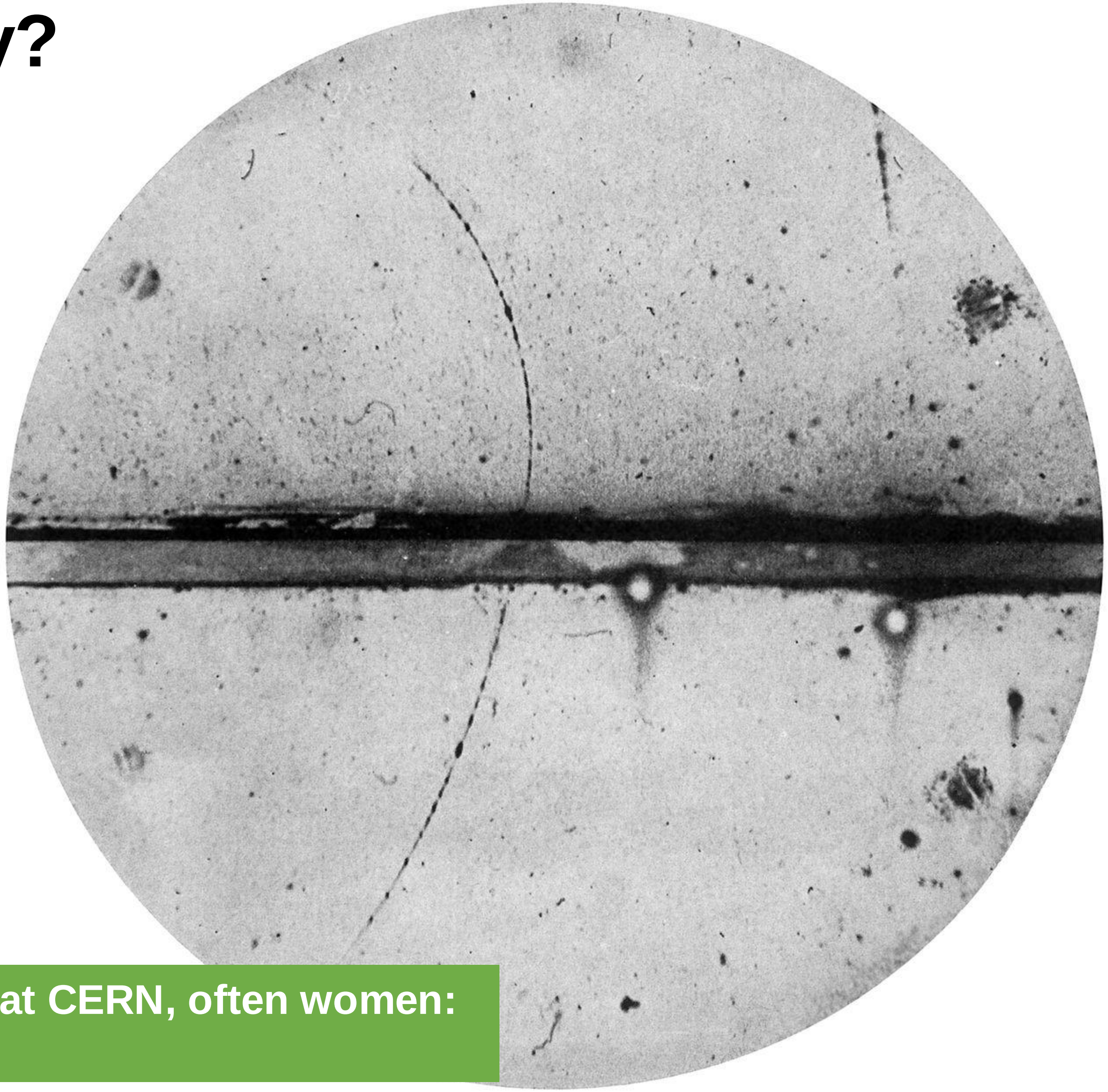


Illustration by Sandbox Studio, Chicago with Ana Kova for Symmetry magazine

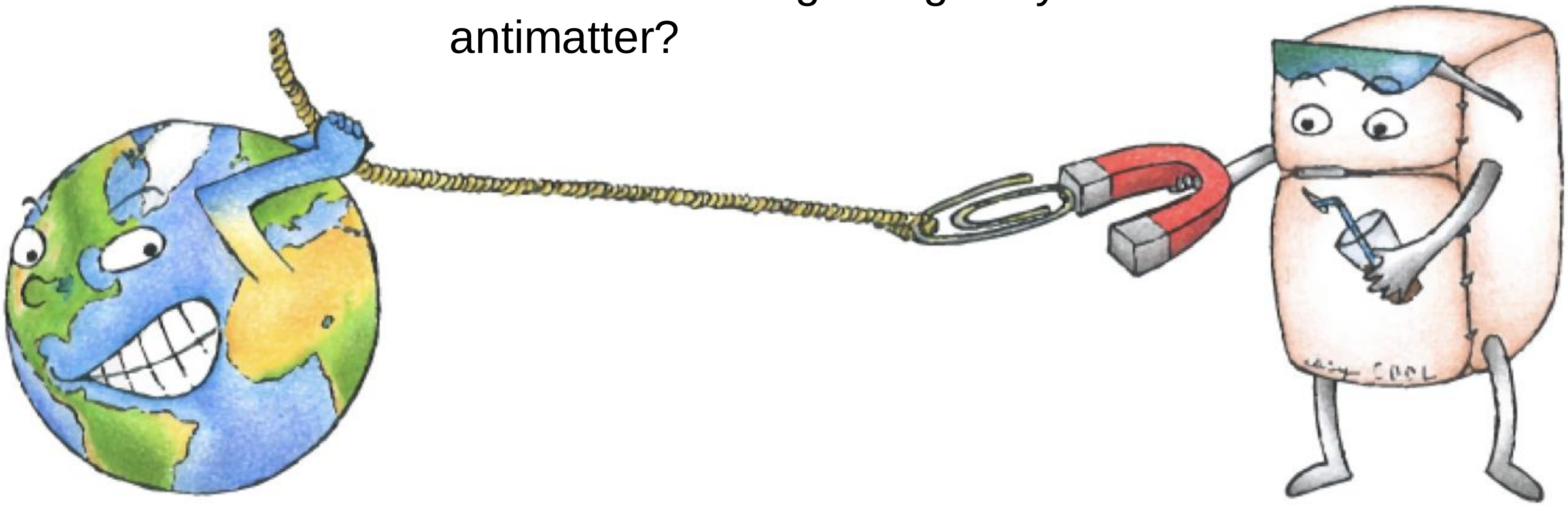
Matter-Antimatter asymmetry?



Note: originally detectors / scanners were people at CERN, often women:
https://videos.cern.ch/record/2299808

The Strength of Gravity?

- Is there a graviton?
- Are there extra dimensions that gravity is leaking into?
- What is the strength of gravity for antimatter?



So, we keep searching

Searches

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2023

ATLAS Preliminary

$\int \mathcal{L}\,dt = (3.6 - 139)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Conditions	Reference
Extra dimen.	ADD $G_{KK} + g/q$	0 e, μ, τ, γ	1 – 4 j	Yes	139	M_D	11.2 TeV	$n = 2$	2102.10874
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S	8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	139	M_{th}	9.4 TeV	$n = 6$	1910.08447
	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	–	–	139	G_{KK} mass	4.5 TeV	$k/\overline{M}_{Pl} = 0.1$	2102.13405
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass	2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥1 b, ≥1J/2j	Yes	36.1	g_{KK} mass	3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥2 b, ≥3 j	Yes	36.1	KK mass	1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	139	Z' mass	5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass	2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass	2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	0 e, μ	≥1 b, ≥2 J	Yes	139	Z' mass	4.1 TeV	$\Gamma/m = 1.2\%$	2005.05138
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	139	W' mass	6.0 TeV		1906.05609
	SSM $W' \to \tau\nu$	1 τ	–	Yes	139	W' mass	5.0 TeV		ATLAS-CONF-2021-025
	SSM $W' \to tb$	–	≥1 b, ≥1 J	–	139	W' mass	4.4 TeV		ATLAS-CONF-2021-043
	HVT $W' \to WZ$ model B	0-2 e, μ	2 j / 1 J	Yes	139	W' mass	4.3 TeV	$g_V = 3$	2004.14636
	HVT $W' \to WZ \to \ell\nu\,\ell'\ell'$ model C	3 e, μ	2 j (VBF)	Yes	139	W' mass	340 GeV	$g_V c_H = 1$, $g_f = 0$	2207.03925
	HVT $Z' \to WW$ model B	1 e, μ	2 j / 1 J	Yes	139	Z' mass	3.9 TeV	$g_V = 3$	2004.14636
	LRSM $W_R \to \mu N_R$	2 μ	1 J	–	80	W_R mass	5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ	21.8 TeV	η_{LL}^-	1703.09127
	CI $\ell\ell qq$	2 e, μ	–	–	139	Λ	35.8 TeV	η_{LL}^-	2006.12946
	CI $eebs$	2 e	1 b	–	139	Λ	1.8 TeV	$g_* = 1$	2105.13847
	CI $\mu\mu bs$	2 μ	1 b	–	139	Λ	2.0 TeV	$g_* = 1$	2105.13847
	CI $tttt$	≥1 e,μ	≥1 b, ≥1 j	Yes	36.1	Λ	2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	1811.02305
DM	Axial-vector med. (Dirac DM)	–	2 j	–	139	m_{med}	3.8 TeV	g_q=0.25, g_χ=1, $m(\chi)$=10 TeV	ATL-PHYS-PUB-2022-036
	Pseudo-scalar med. (Dirac DM)	0 e, μ, τ, γ	1 – 4 j	Yes	139	m_{med}	376 GeV	g_q=1, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Vector med. Z'-2HDM (Dirac DM)	0 e, μ	2 b	Yes	139	$m_{Z'}$	3.0 TeV	$\tan\beta$=1, g_Z=0.8, $m(\chi)$=100 GeV	2108.13391
	Pseudo-scalar med. 2HDM+a	multi-channel			139	m_a	800 GeV	$\tan\beta$=1, g_χ=1, $m(\chi)$=10 GeV	ATLAS-CONF-2021-036
LQ	Scalar LQ 1st gen	2 e	≥2 j	Yes	139	LQ mass	1.8 TeV	$\beta = 1$	2006.05872
	Scalar LQ 2nd gen	2 μ	≥2 j	Yes	139	LQ mass	1.7 TeV	$\beta = 1$	2006.05872
	Scalar LQ 3rd gen	1 τ	2 b	Yes	139	LQ_3^u mass	1.49 TeV	$\mathcal{B}(LQ_3^u \to b\tau) = 1$	2303.01294
	Scalar LQ 3rd gen	0 e, μ	≥2 j, ≥2 b	Yes	139	LQ_3^u mass	1.24 TeV	$\mathcal{B}(LQ_3^u \to t\nu) = 1$	2004.14060
	Scalar LQ 3rd gen	≥2 e, μ, ≥1 τ	≥1 j, ≥1 b	–	139	LQ_3^d mass	1.43 TeV	$\mathcal{B}(LQ_3^d \to t\tau) = 1$	2101.11582
	Scalar LQ 3rd gen	0 e, μ, ≥1 τ	0 – 2 j, 2 b	Yes	139	LQ_3^d mass	1.26 TeV	$\mathcal{B}(LQ_3^d \to b\nu) = 1$	2101.12527
	Vector LQ mix gen	multi-channel	≥1 j, ≥1 b	Yes	139	LQ_3^V mass	2.0 TeV	$\mathcal{B}(\tilde{U}_1 \to t\mu) = 1$, Y-M coupl.	ATLAS-CONF-2022-052
	Vector LQ 3rd gen	2 e, μ, τ	≥1 b	Yes	139	LQ_3^V mass	1.96 TeV	$\mathcal{B}(LQ_3^V \to b\tau) = 1$, Y-M coupl.	2303.01294
Vector-like fermions	VLQ $TT \to Zt + X$	2e/2μ/≥3e,μ	≥1 b, ≥1 j	–	139	T mass	1.46 TeV	SU(2) doublet	2210.15413
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass	1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3}T_{5/3}\lvert T_{5/3} \to Wt + X$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	36.1	$T_{5/3}$ mass	1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3}Wt)$= 1	1807.11883
	VLQ $T \to Ht/Zt$	1 e, μ	≥1 b, ≥3 j	Yes	139	T mass	1.8 TeV	SU(2) singlet, κ_T= 0.5	ATLAS-CONF-2021-040
	VLQ $Y \to Wb$	1 e, μ	≥1 b, ≥1 j	Yes	36.1	Y mass	1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb$	0 e,μ	≥2b, ≥1j, ≥1J	–	139	B mass	2.0 TeV	SU(2) doublet, κ_B= 0.3	ATLAS-CONF-2021-018
	VLL $\tau' \to Z\tau/H\tau$	multi-channel	≥1 j	Yes	139	τ' mass	898 GeV	SU(2) doublet	2303.05441
Exctd ferm.	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass	6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1910.08447
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass	5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	139	b^* mass	3.2 TeV		1910.08447
	Excited lepton τ^*	2 τ	≥2 j	–	139	τ^* mass	4.6 TeV	$\Lambda = 4.6$ TeV	2303.09444
Other	Type III Seesaw	2,3,4 e, μ	≥2 j	Yes	139	N^0 mass	910 GeV		2202.02039
	LRSM Majorana ν	2 μ	2 j	–	36.1	N_R mass	3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to W^\pm W^\pm$	2,3,4 e, μ (SS)	various	Yes	139	$H^{\pm\pm}$ mass	350 GeV	DY production	2101.11961
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	139	$H^{\pm\pm}$ mass	1.08 TeV	DY production	2211.07505
	Multi-charged particles	–	–	–	139	multi-charged particle mass	1.59 TeV	DY production, $\lvert q\rvert = 5e$	ATLAS-CONF-2022-034
	Magnetic monopoles	–	–	–	34.4	monopole mass	2.37 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1905.10130

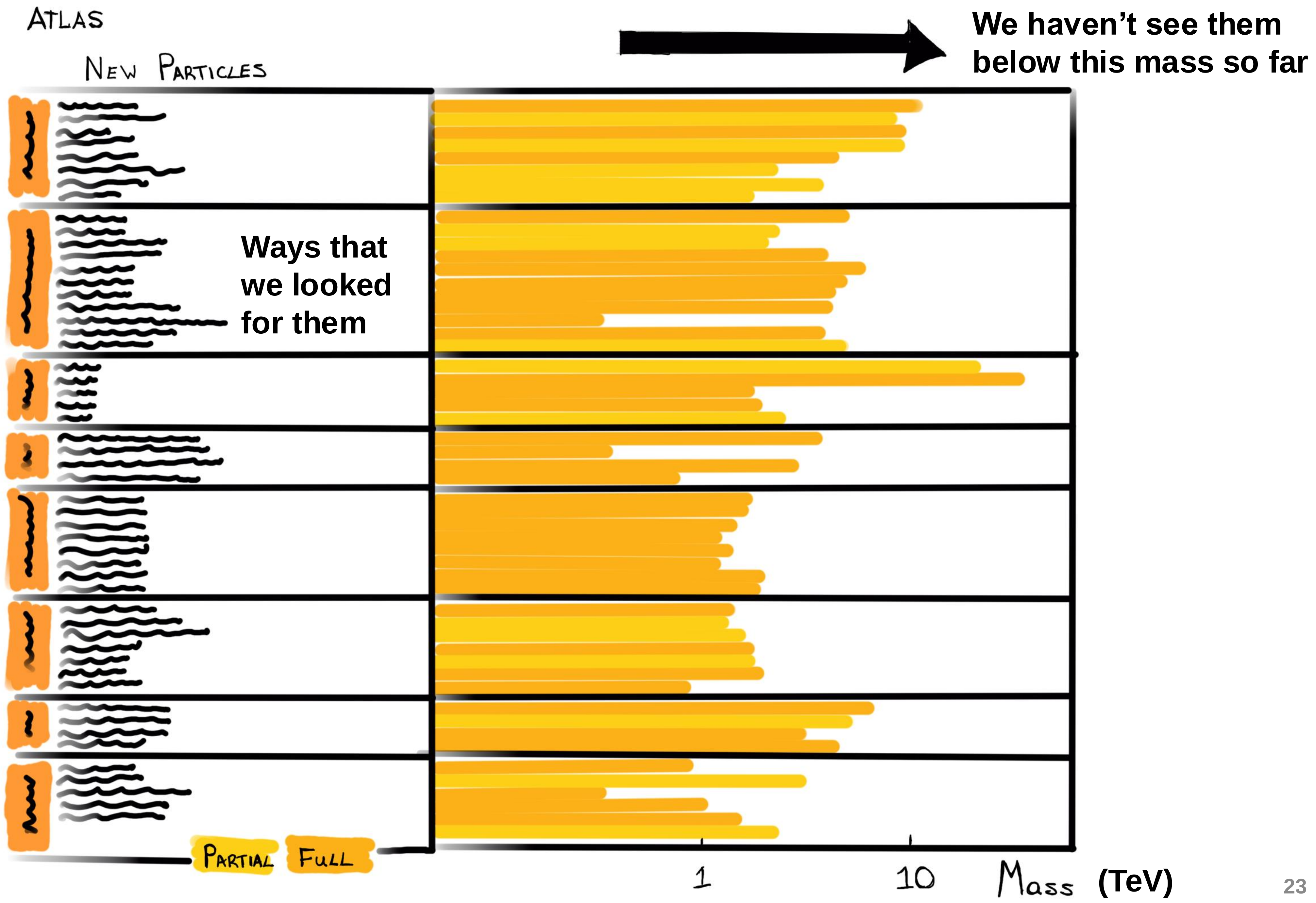
Legend: $\sqrt{s}$ = 13 TeV partial data; $\sqrt{s}$ = 13 TeV full data

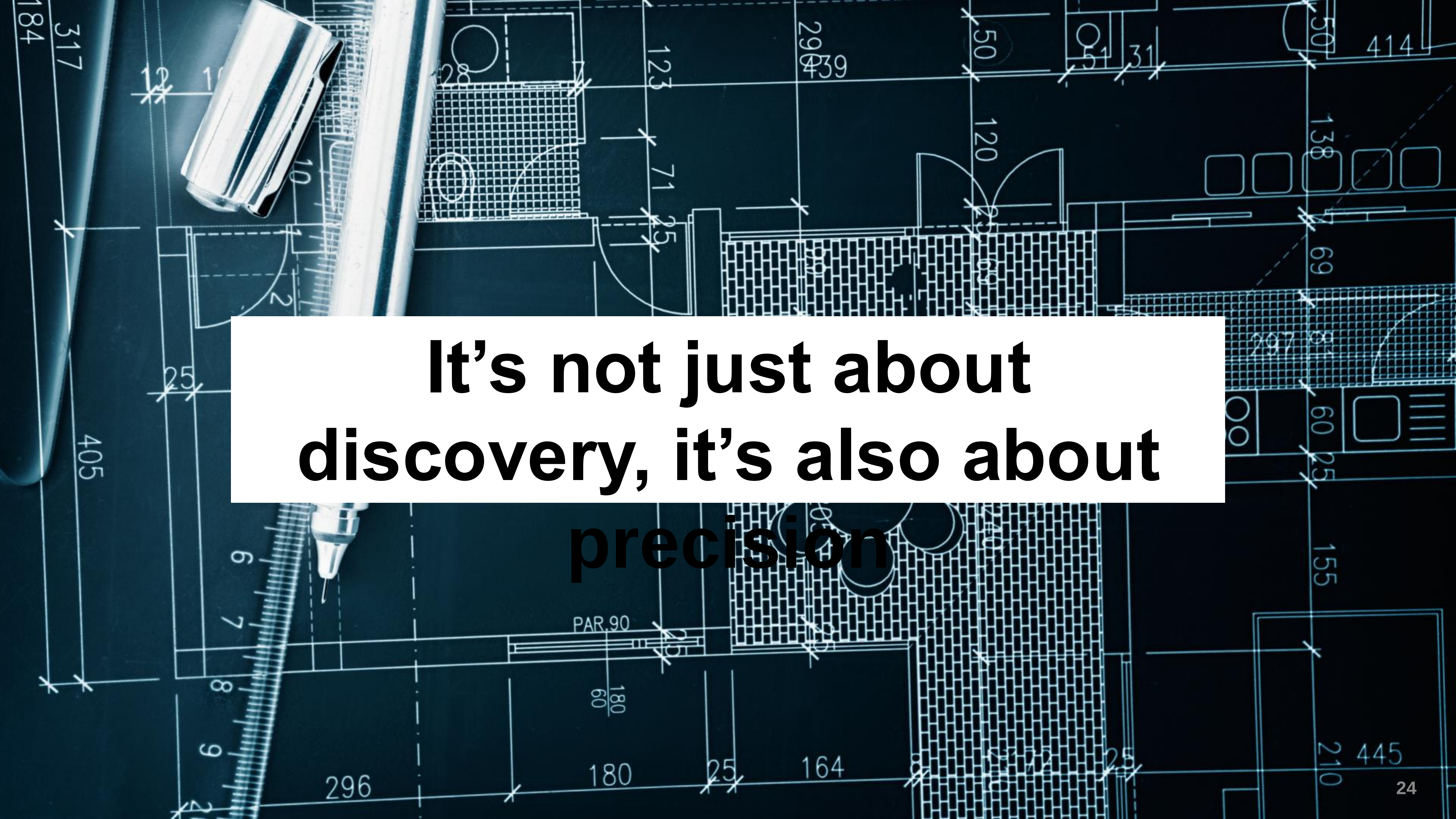
Axis: 10^{-1}, 1, 10 — Mass scale [TeV]

*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).

Searches


ATLAS
NEW PARTICLES
We haven't see them below this mass so far
Ways that we looked for them
PARTIAL
FULL
1
10
Mass
(TeV)

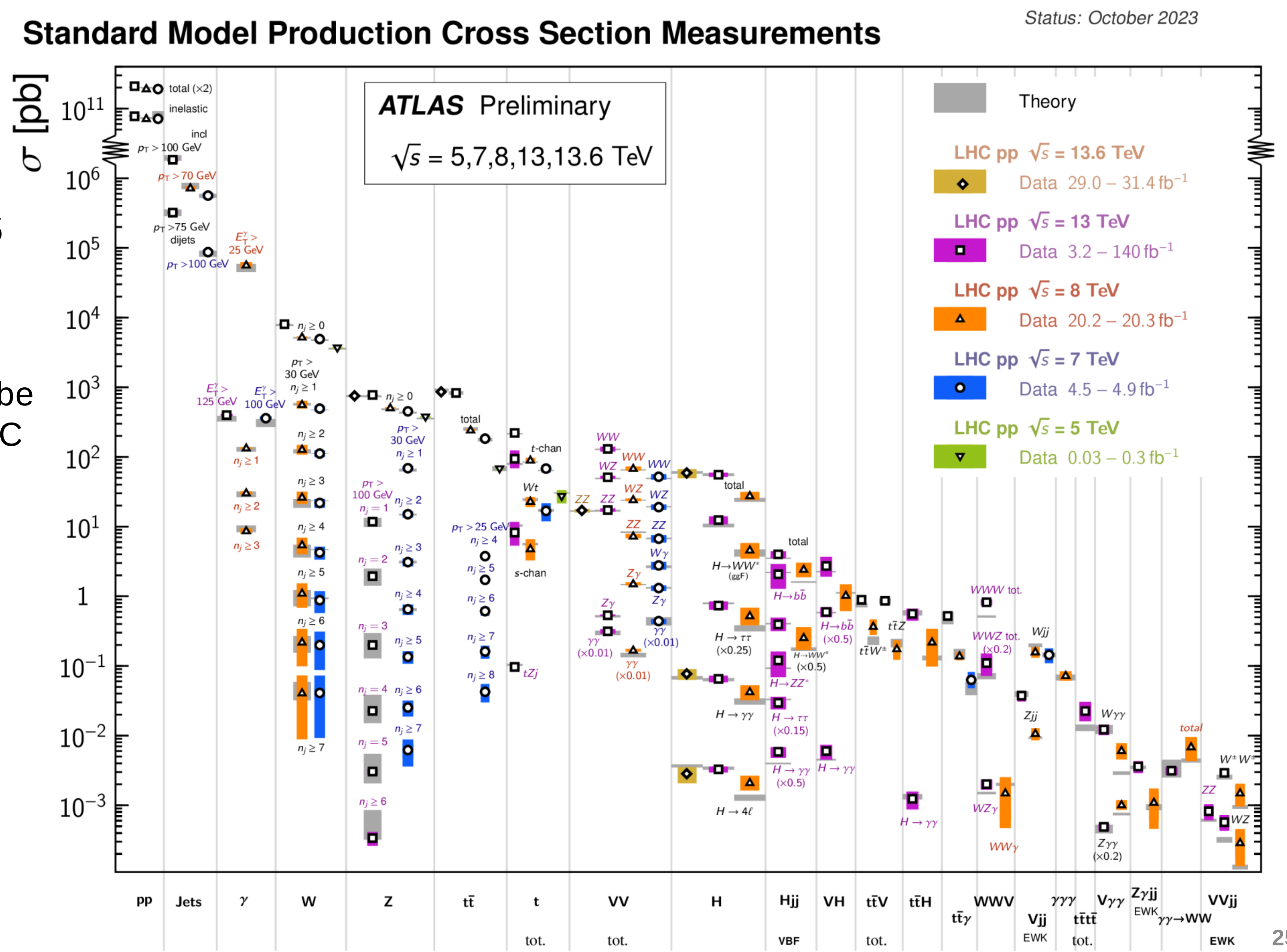


It’s not just about discovery, it’s also about precision

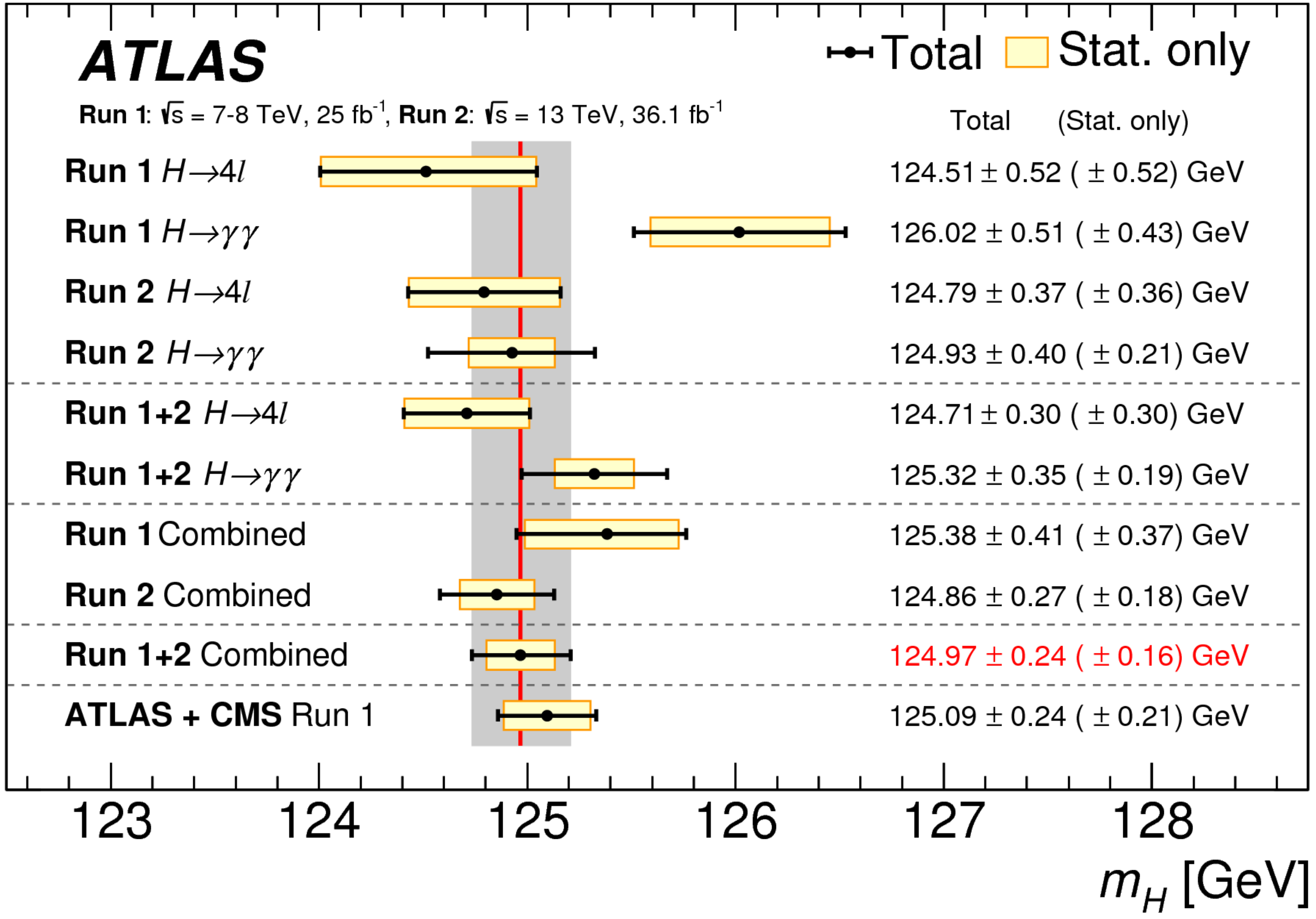
Precision measurements

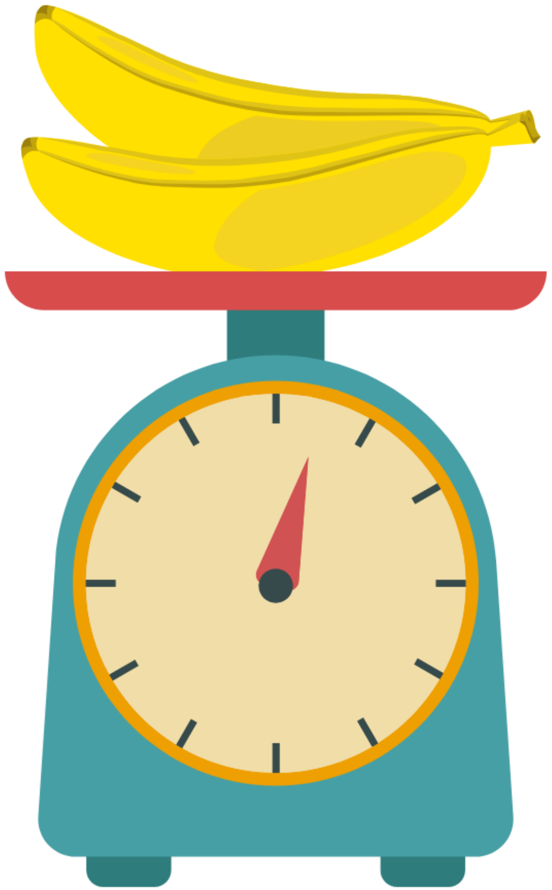
How likely a process is to be created in LHC collisions

A rarer process



Precision Higgs measurements

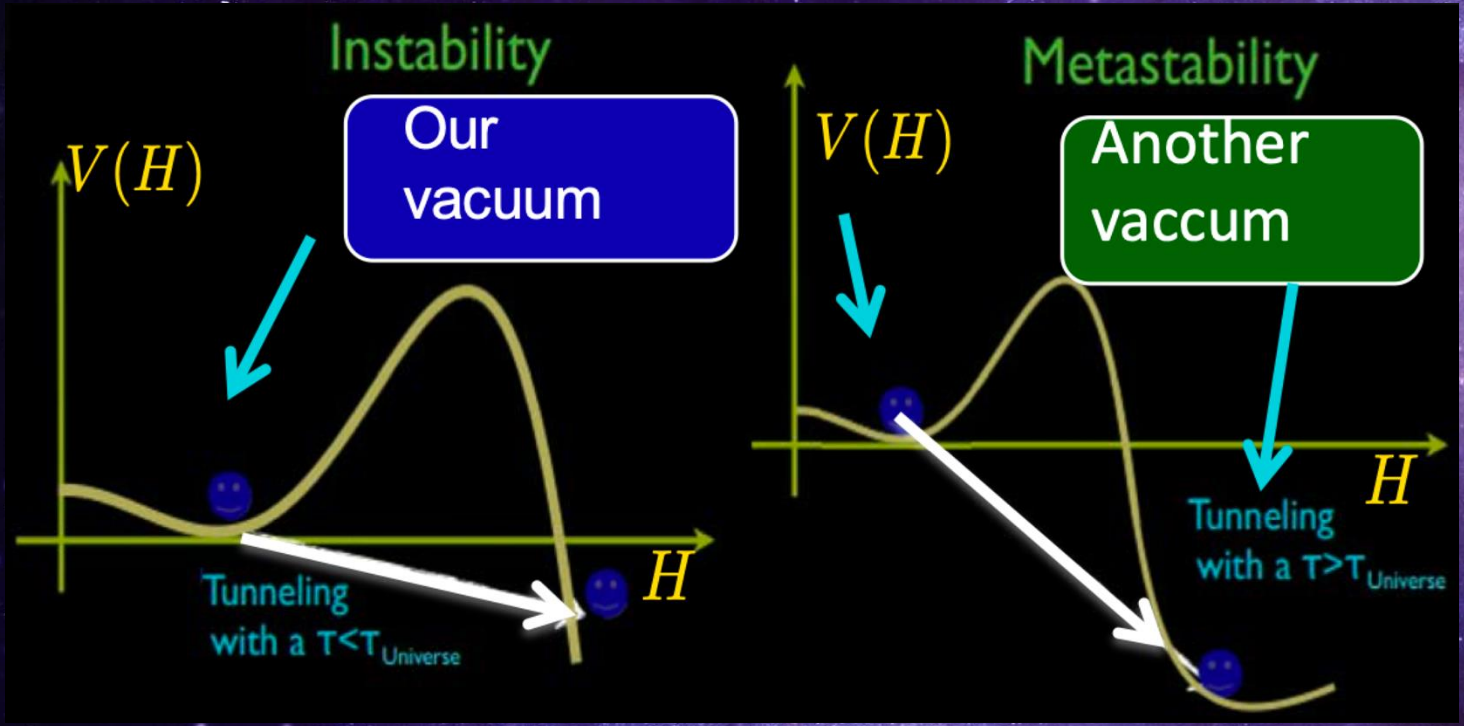


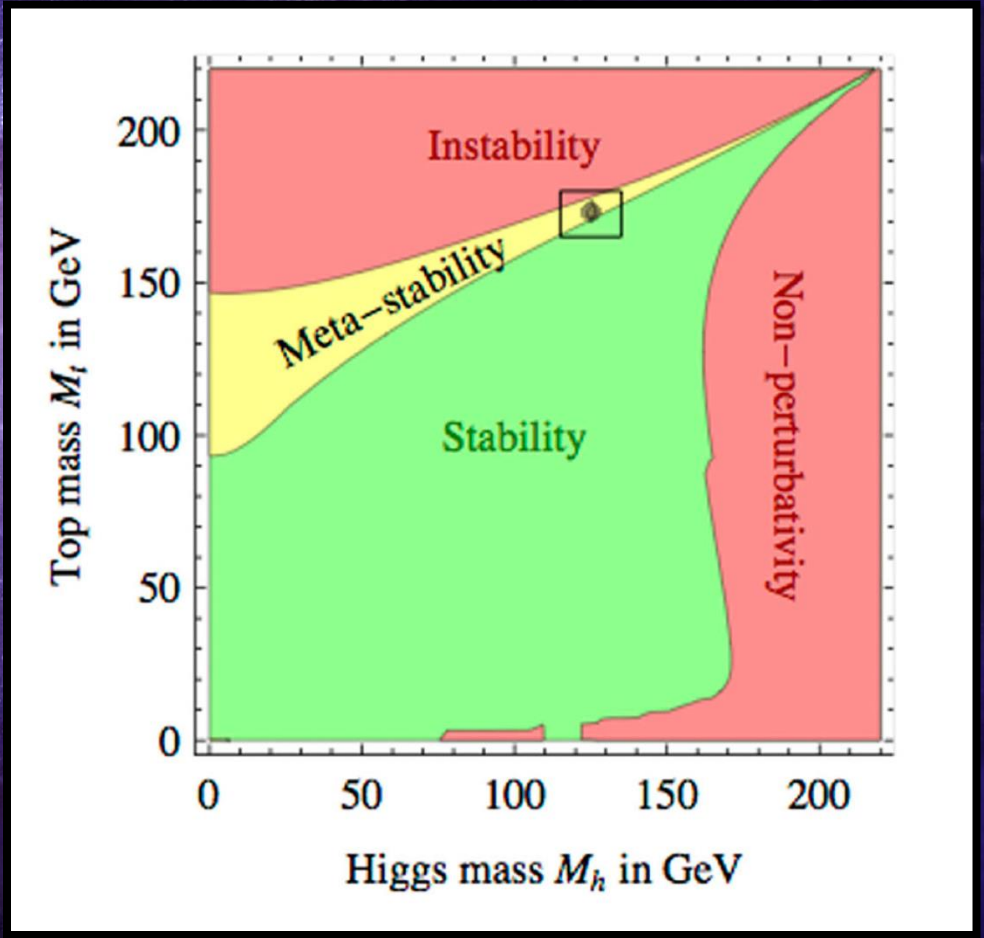


Mass measurements

The stability of the universe depends on it!

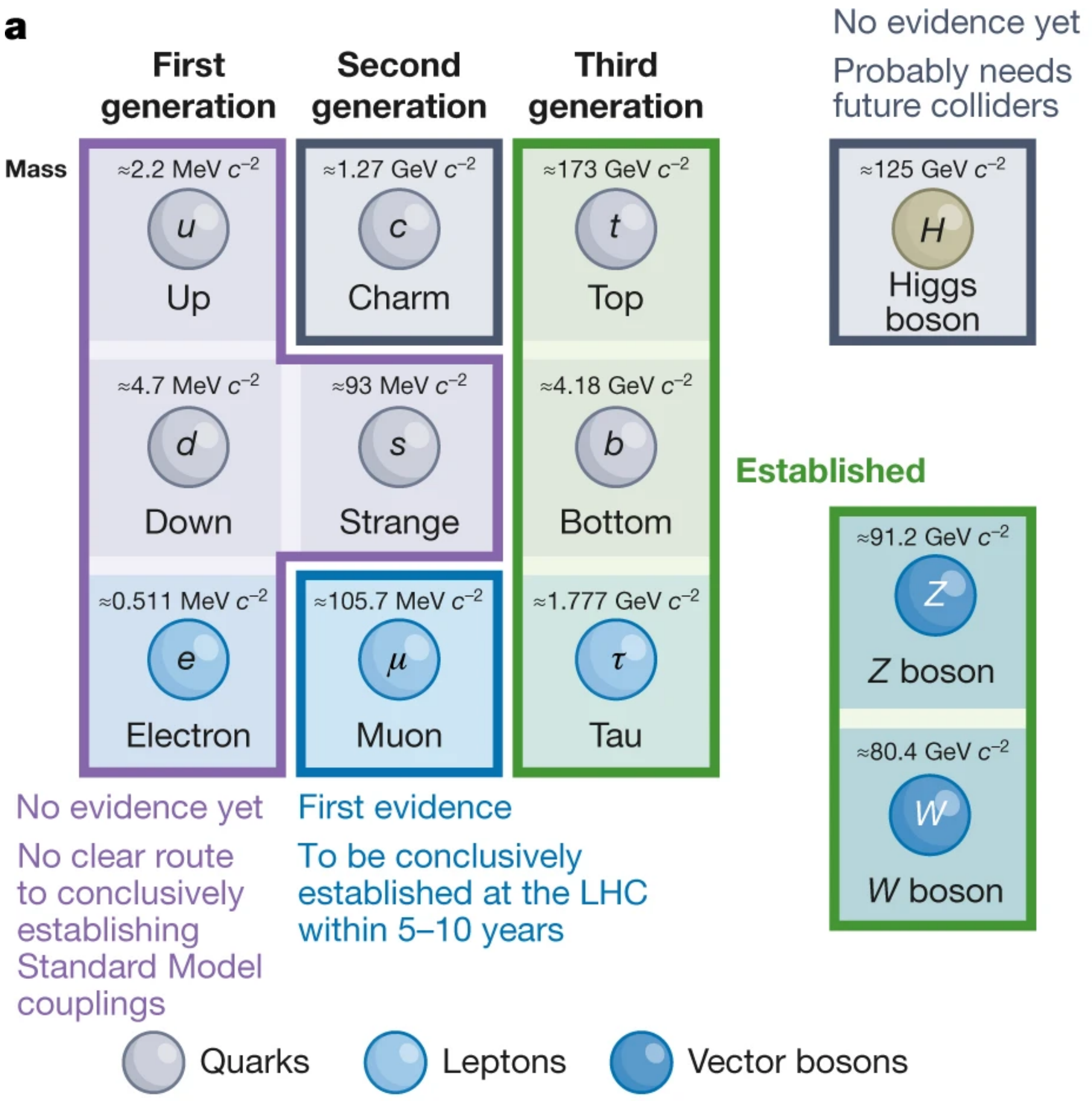
(Please note: measuring this doesn't affect the stability. We're a passive observer.)

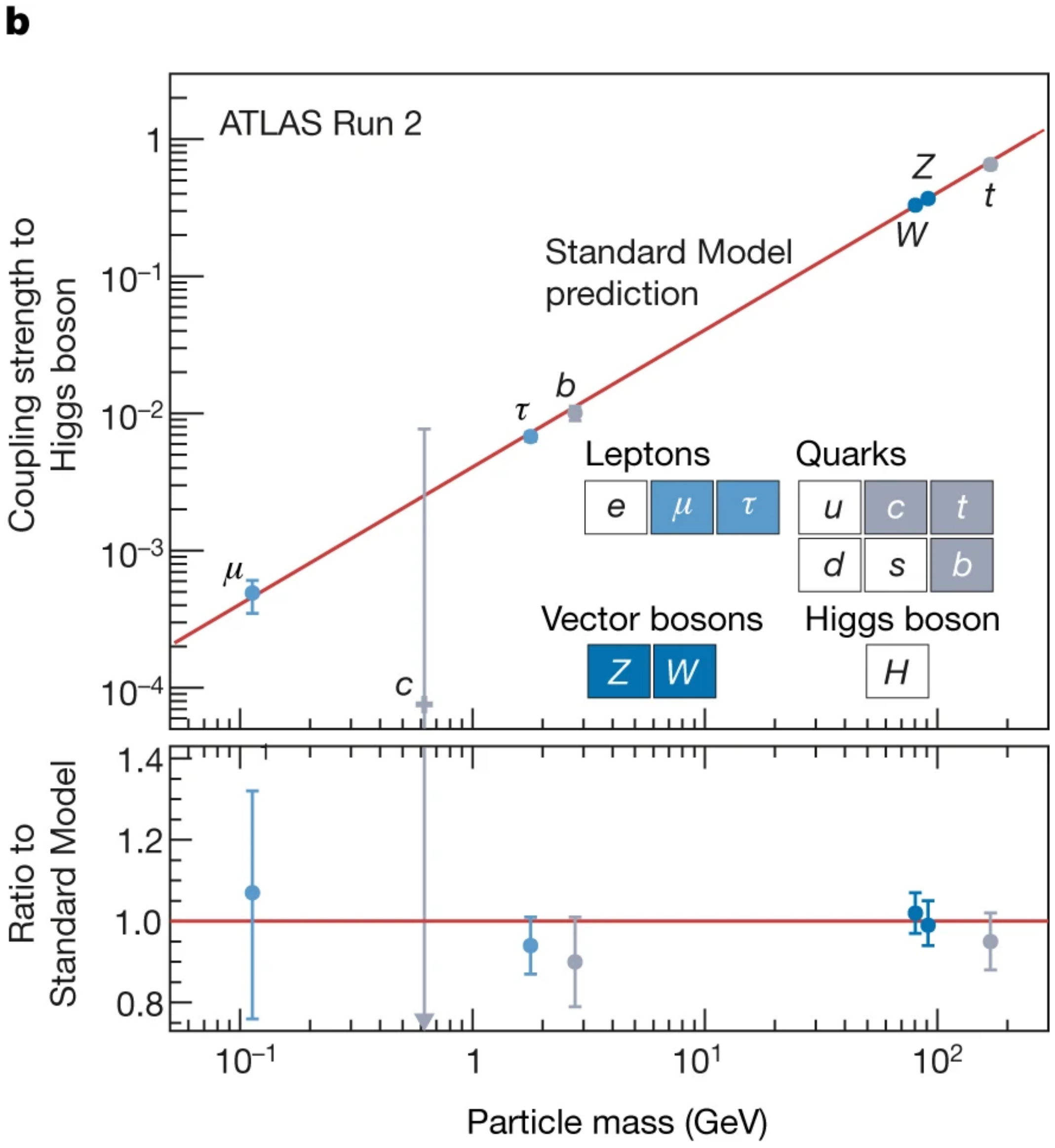




Precision Higgs measurements

Nature 607, p41-47 (2022), G. Salam et al.





Dark ? matter

Nature 607, p41-47 (2022), G. Salam et al.

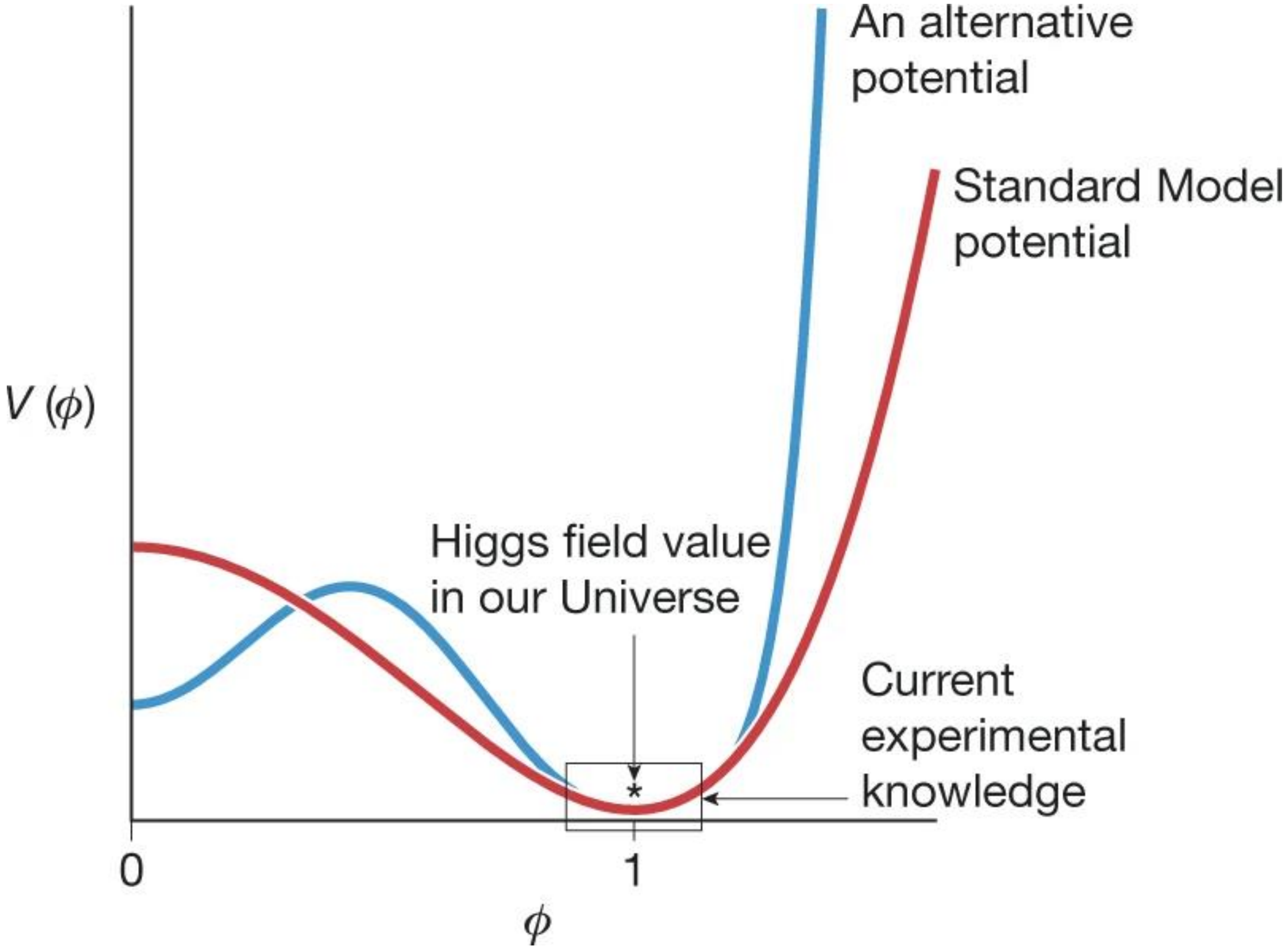
Next step: Higgs self-interaction

Hello there!

Image: Jorge Cham / PhD Comics

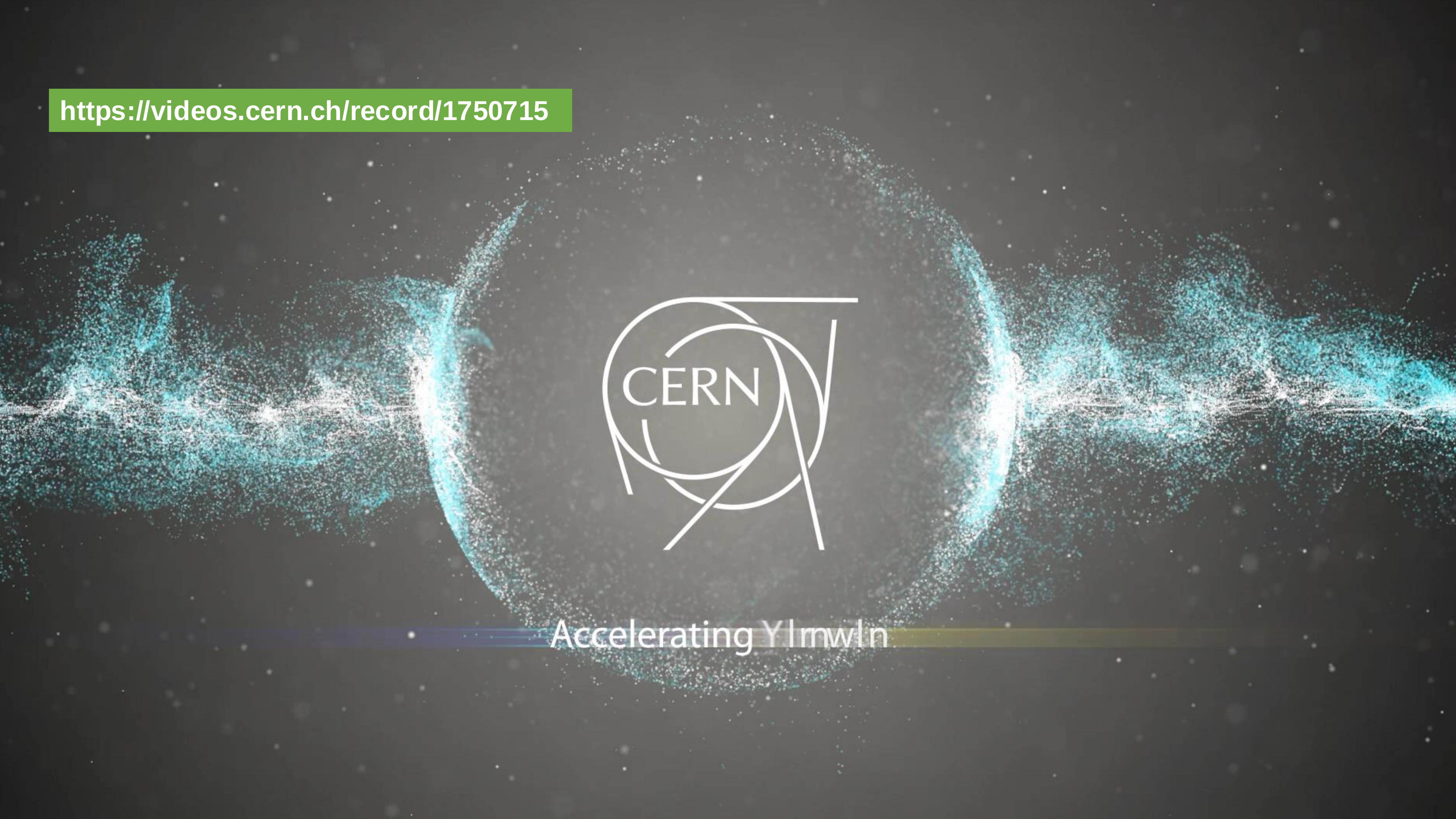
Nice to meet you!

Image: Jorge Cham / PhD Comics

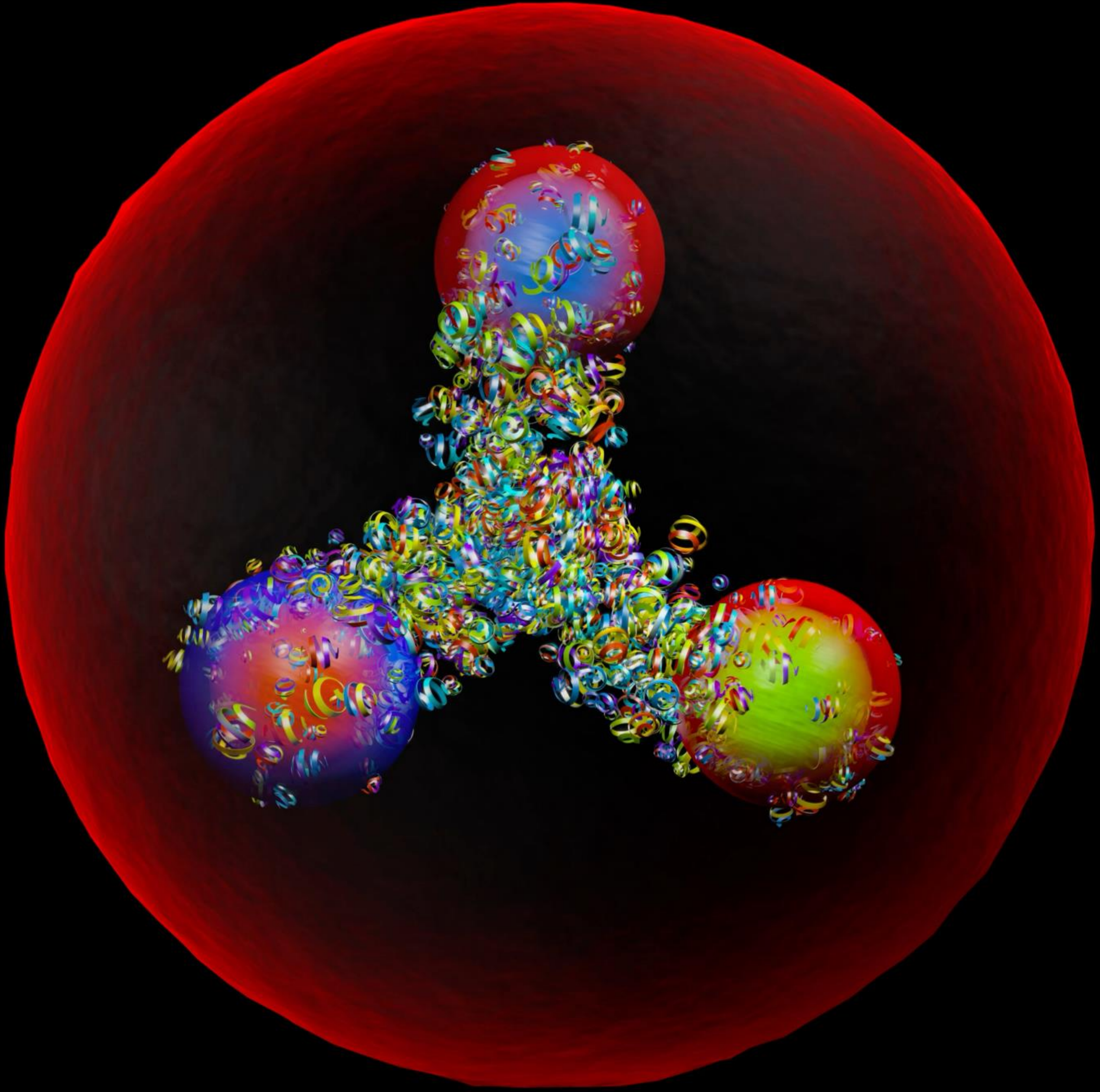


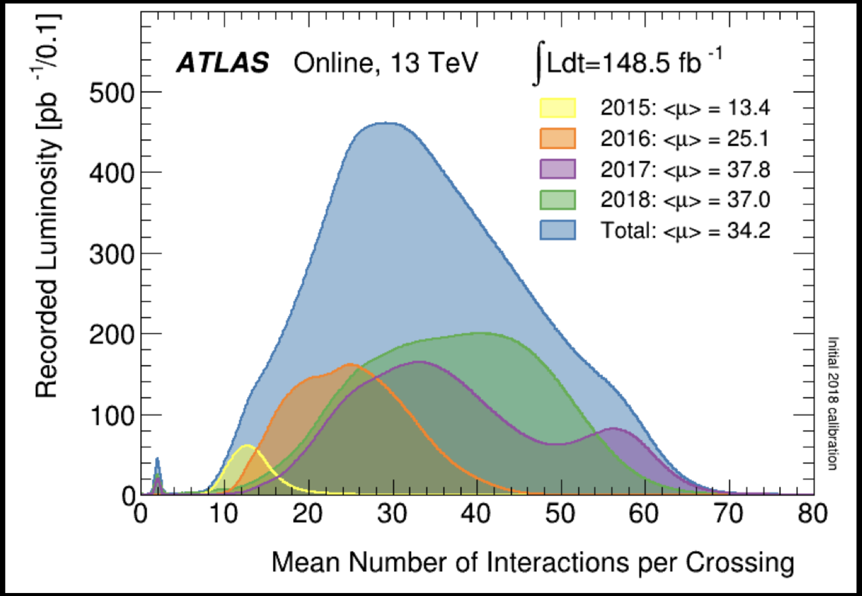
So how do we go about answering these questions?

https://videos.cern.ch/record/1750715



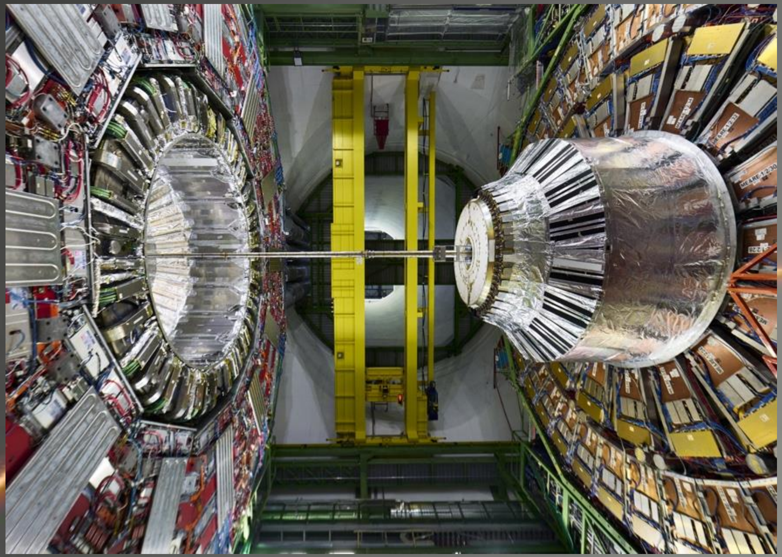
Colliding protons

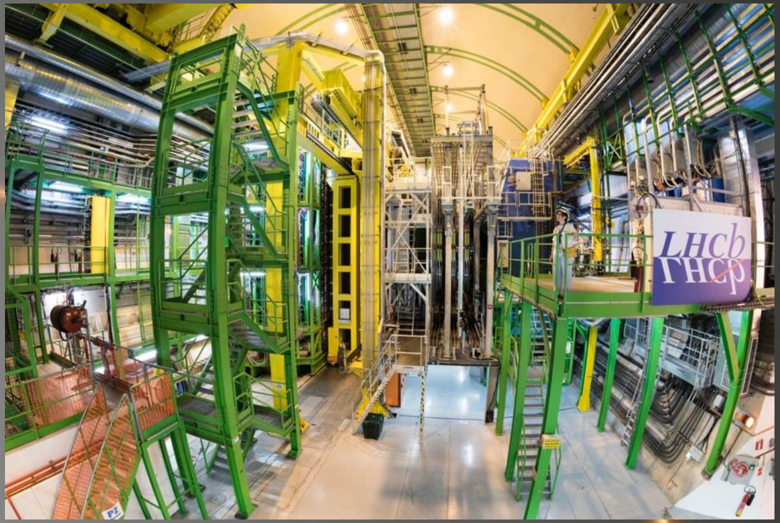




We wanted to explore a high range of masses: from 50 GeV to 1 TeV

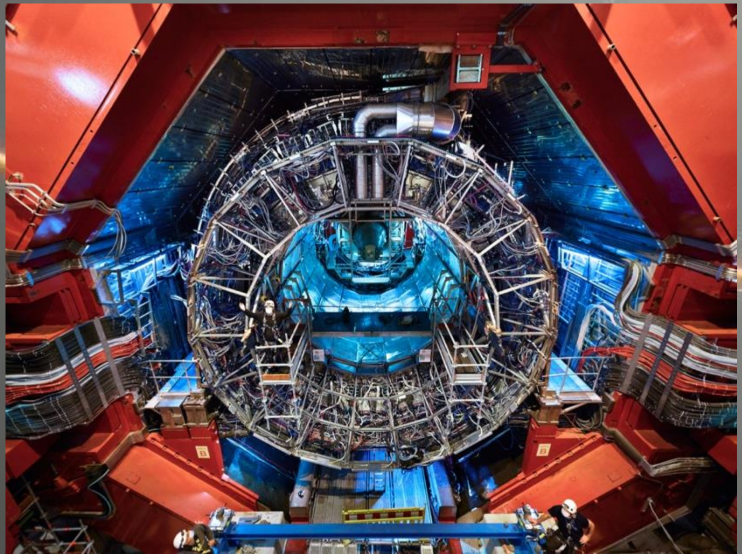
The LHC detectors

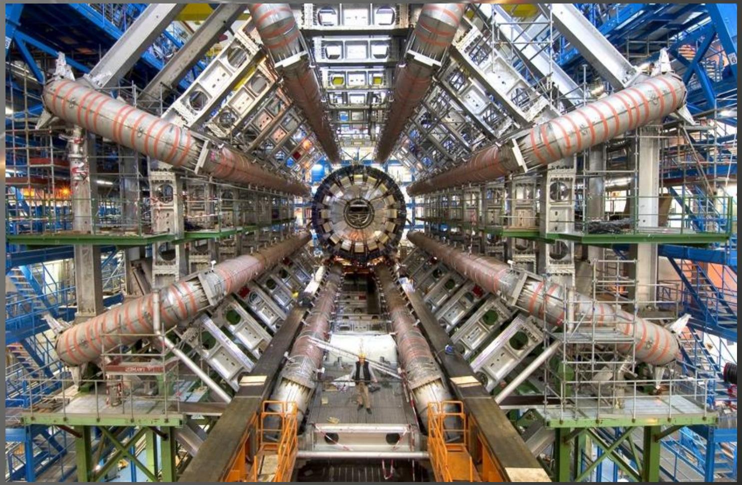




https://videos.cern.ch/record/1702939

CMS
LHCb
ALICE
ATLAS



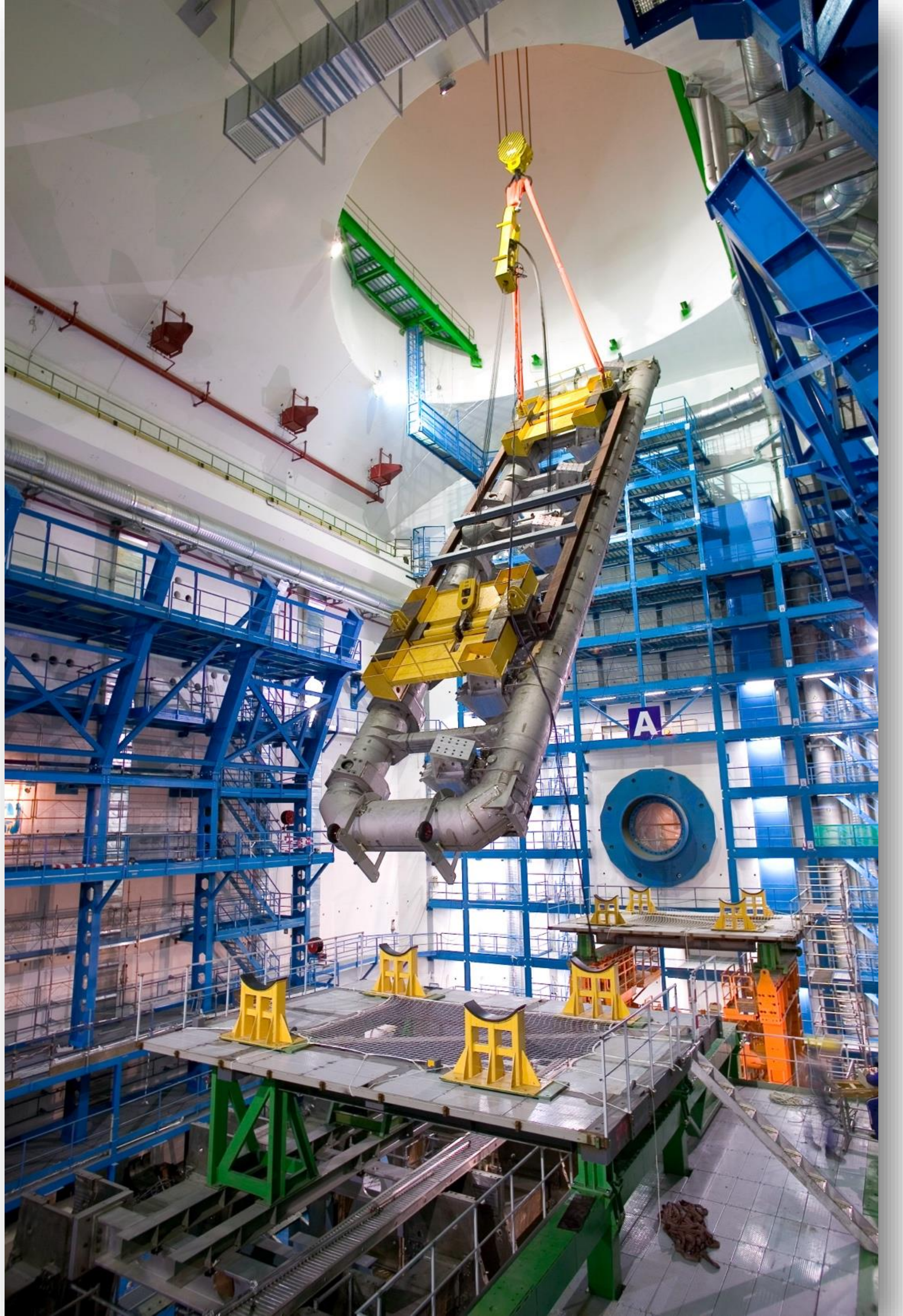


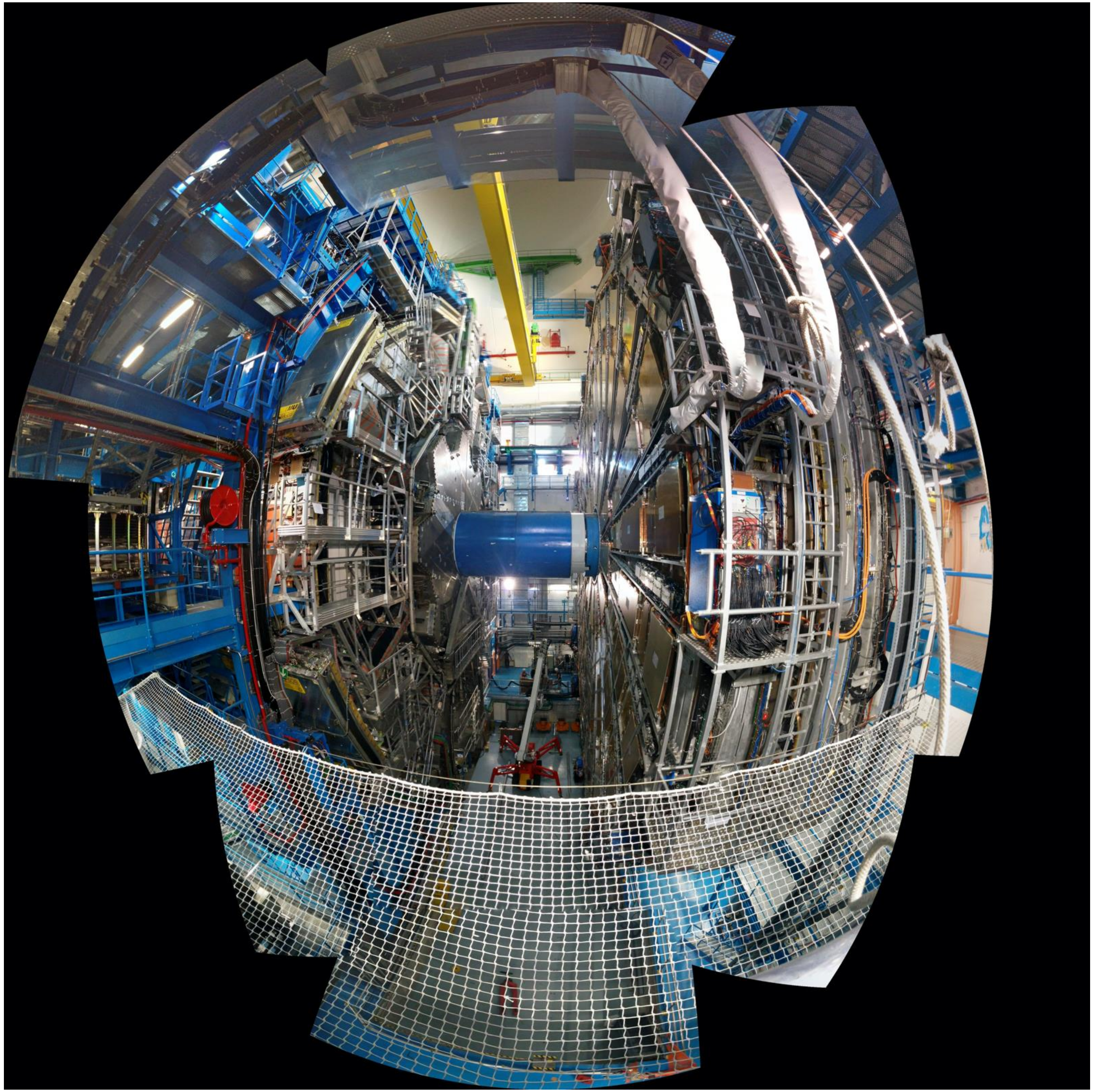
2002

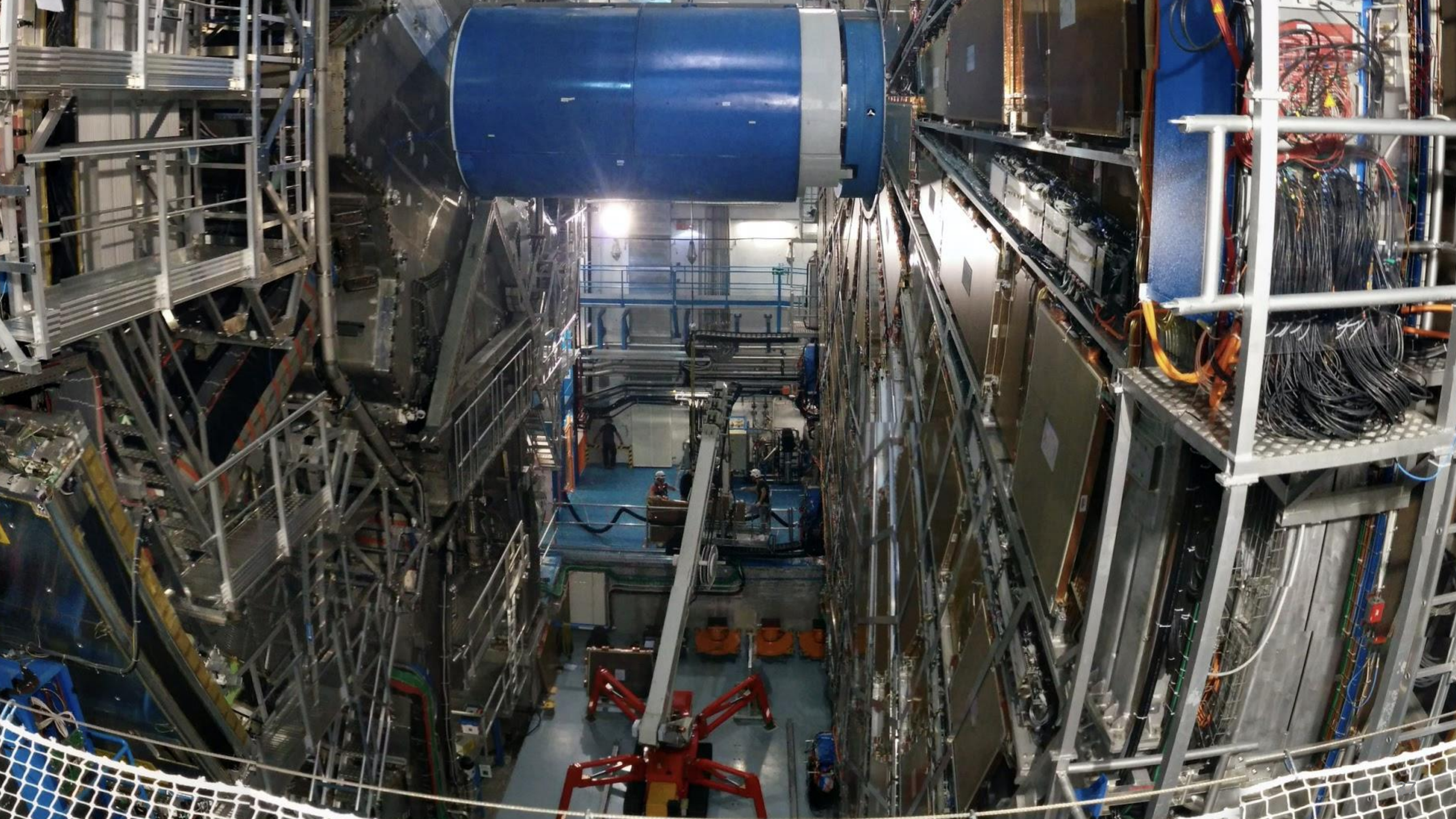
ATLAS Installation in the cavern

2004

ATLAS Installation in the cavern







Status: November 2018

Albania
Algeria
Argentina
Armenia
Australia
Austria
Azerbaijan
Bangladesh
Belarus
Belgium
Bosnia and Herzegovina
Botswana
Brazil
Bulgaria
Burundi
Canada
Chile
China
Colombia
Costa Rica
Croatia
Cuba
Cyprus
Czech Republic
Denmark
Ecuador
Egypt
Finland
France
Georgia
Germany
Ghana
Greece
Honduras
Hong Kong
Hungary
Iceland
India
Indonesia
Iran
Iraq
Ireland
Israel
Italy
Japan
Jordan
Kazakhstan
Kenya
Kyrgyzstan
Latvia
Lebanon
Lithuania
Luxembourg
Madagascar
Malaysia
Malta
Mauritius
Mexico
Mongolia
Montenegro
Morocco
Nepal
Netherlands
New Zealand
Niger
Nigeria
Norway
Pakistan
Palestine
Peru
Philippines
Poland
Portugal
Romania
Russia
Saudi Arabia
Senegal
Serbia
Slovakia
Slovenia
South Africa
South Korea
Spain
Sri Lanka
Sudan
Swaziland
Sweden
Switzerland
Syria
Taiwan
Thailand
Tunisia
Turkey
Ukraine
UAE
UK
USA
Uruguay
Uzbekistan
Venezuela
Vietnam
Zambia
Zimbabwe

ATLAS Collaboration member nationalities

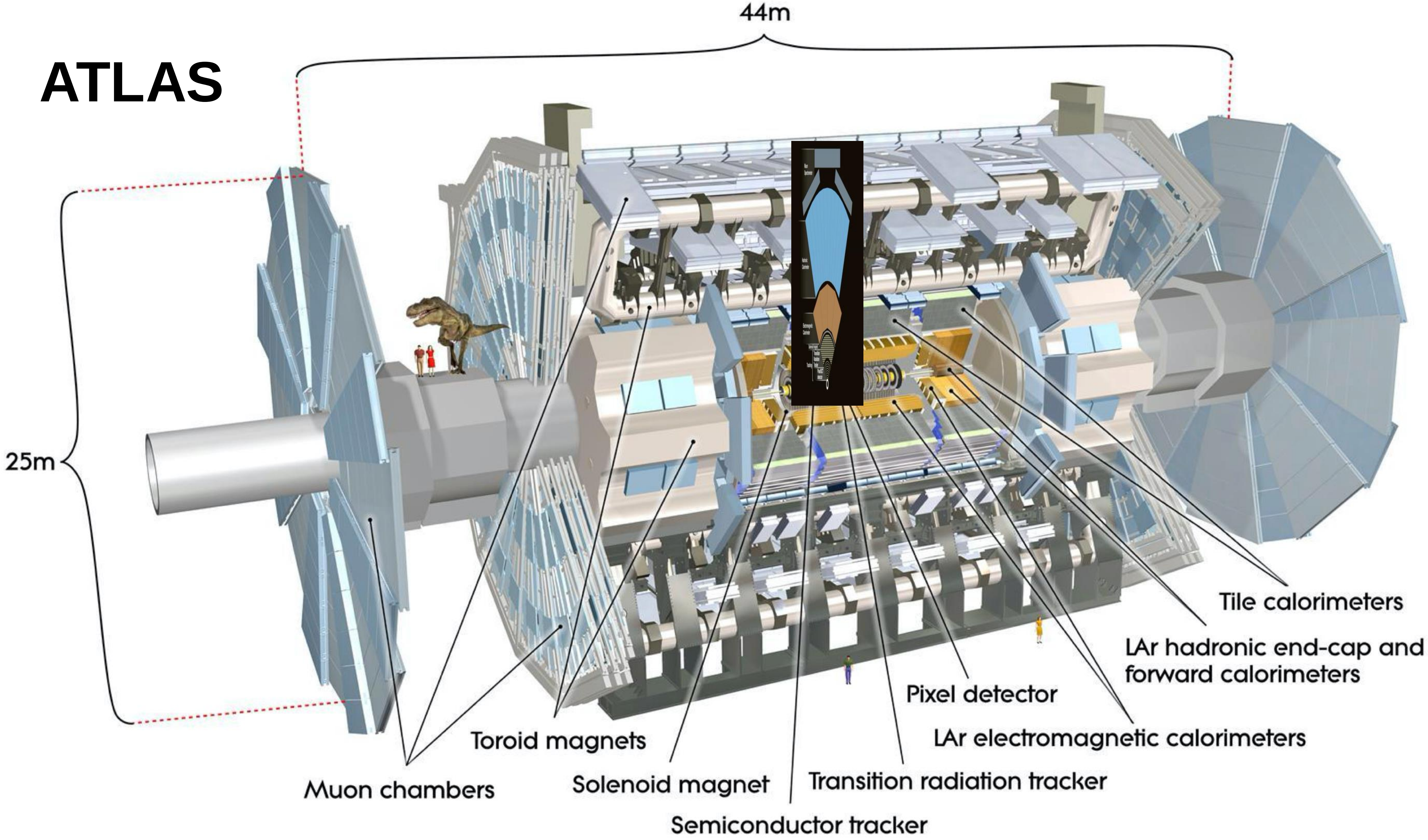
Over 5500 members of 103 nationalities

ATLAS EXPERIMENT


LHCb

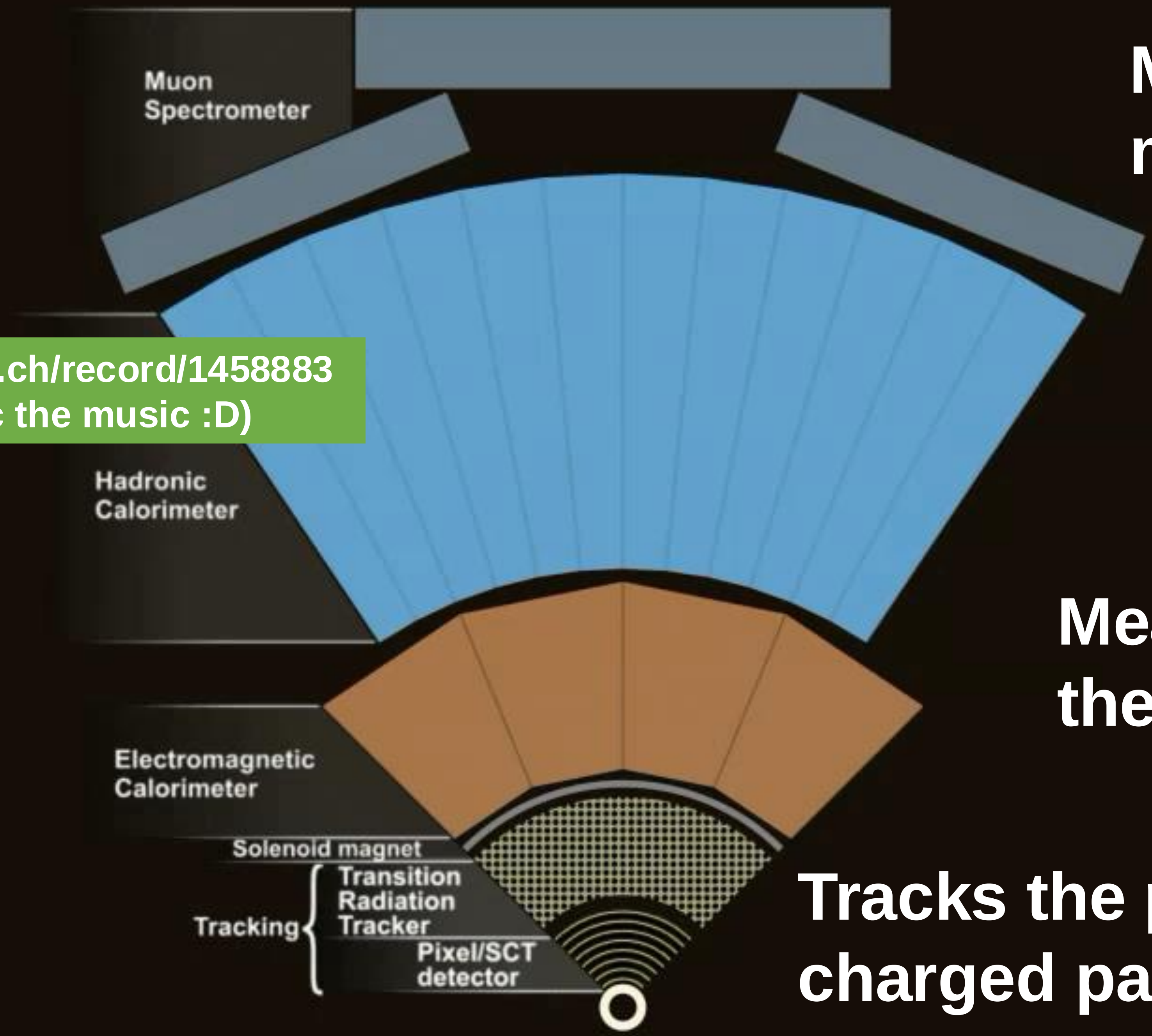

ATLAS
EXPERIMENT

ATLAS


44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Solenoid magnet
Transition radiation tracker
Muon chambers
Semiconductor tracker

Measures muons

https://videos.cern.ch/record/1458883
(with very dramatic the music :D)

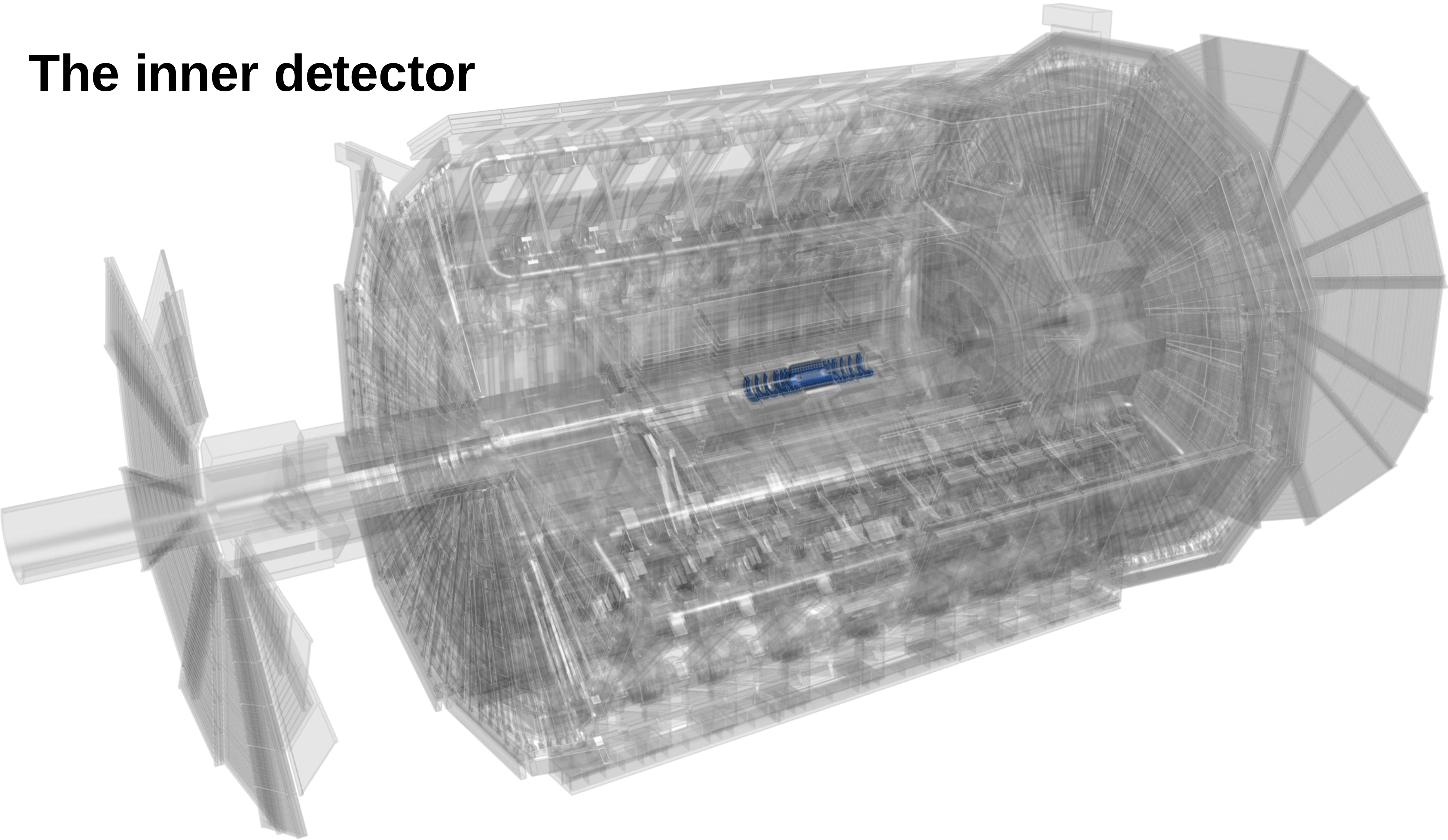


Measures the energy

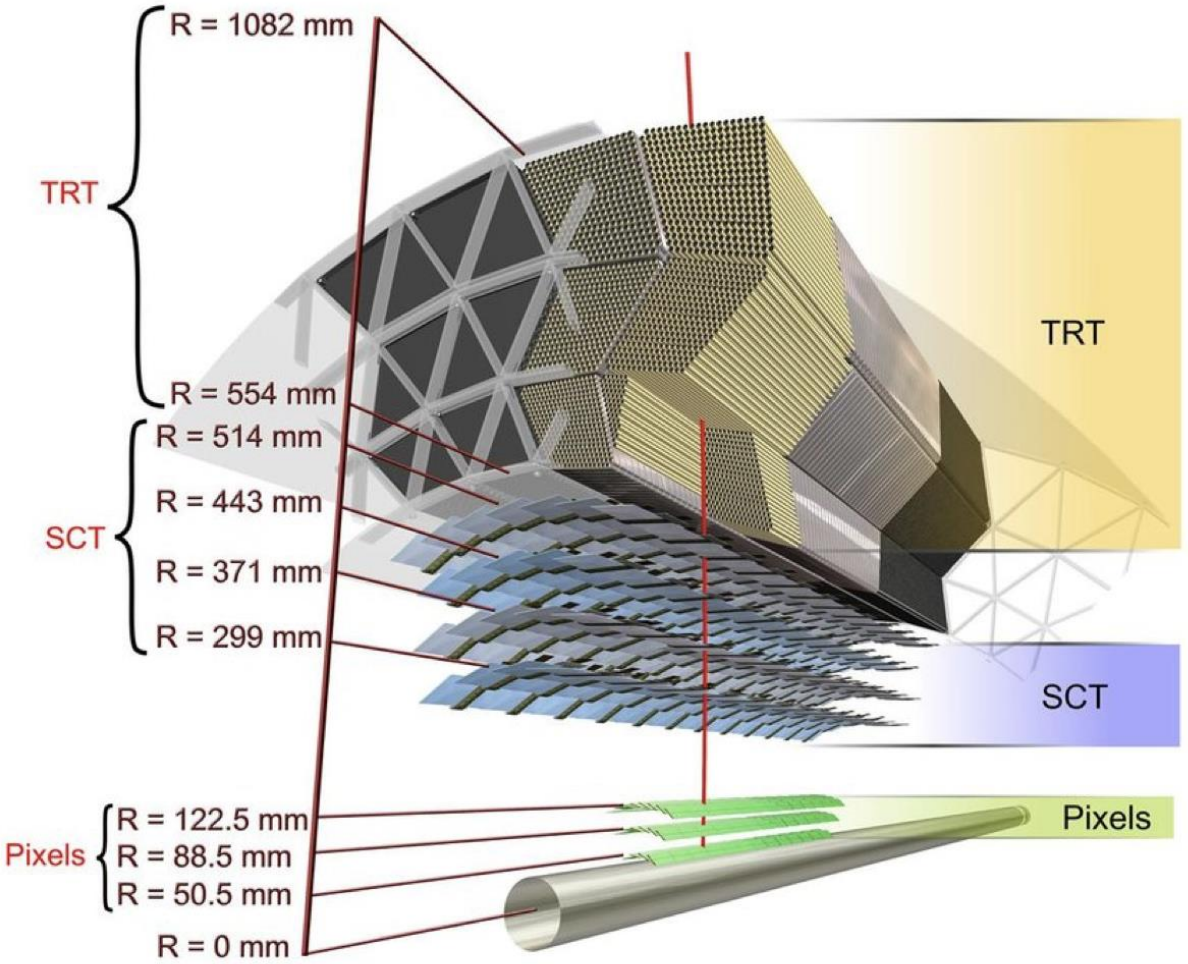
Tracks the path of charged particles

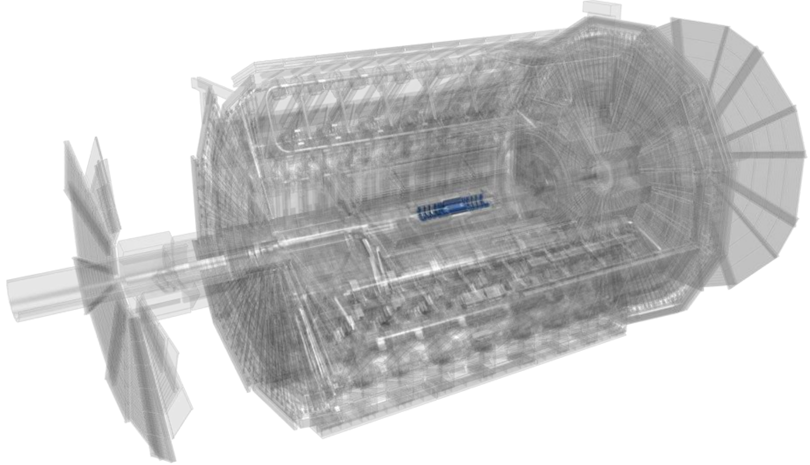
LHC beam pipe

The inner detector



The inner detector





THE INNER DETECTOR

The Inner Detector is the innermost part of ATLAS to see the decay products of the collisions, so it is very compact and highly sensitive. It consists of three different systems, measuring the direction, momentum and charge of electrically-charged particles produced in collisions.

PIXEL DETECTOR

Located just 3.3 cm from the LHC beam line, the Pixel Detector is the first point of detection in the ATLAS experiment. It is made up of four layers of silicon pixels, with **each pixel smaller than a grain of sand**. As charged particles burst out from the collision point, they leave behind small energy deposits in the Pixel Detector. These signals are measured with a precision of almost 10 μm to determine the origin and momentum of the particle. The Pixel Detector is incredibly compact, with over **92 million pixels and almost 2000 detector elements.**

SEMICONDUCTOR TRACKER

The Semiconductor Tracker surrounds the Pixel Detector and is used to detect and reconstruct the tracks of charged particles produced during collisions. It consists of over 4,000 modules of **6 million "micro-strips" of silicon sensors.** Its layout is optimised such that each particle crosses at least four layers of silicon. This allows scientists to **measure particle tracks with a precision of up to 25 μm** - that's less than half the width of a human hair!

TRANSITION RADIATION TRACKER

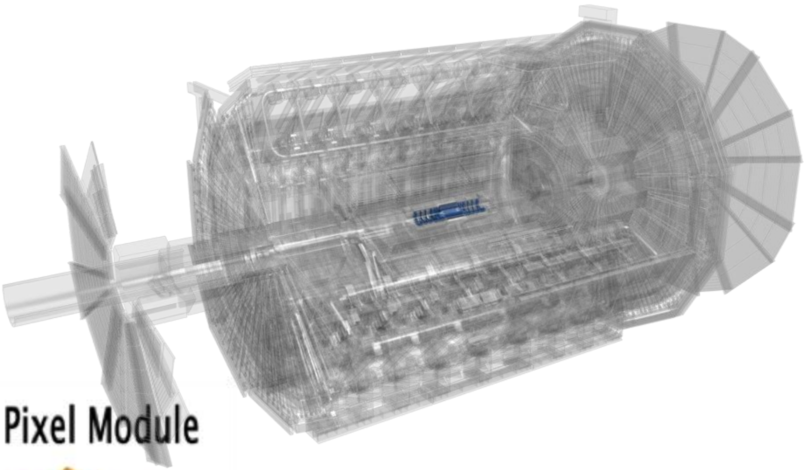
The third and final layer of the Inner Detector is the Transition Radiation Tracker (TRT). Unlike its neighbouring sub-detectors, the TRT is made up of **300,000 thin-walled drift tubes** (or "straws"). Each straw is just 4 mm in diameter, with a 30 μm gold-plated tungsten wire in its centre. The straws are filled with a gas mixture. As charged particles cross through the straws, they ionise the gas to create a detectable electric signal. This is used to reconstruct their tracks and, owing to the so-called transition radiation, **provides information on the particle type** that flew through the detector, i.e. if it is an electron or pion.

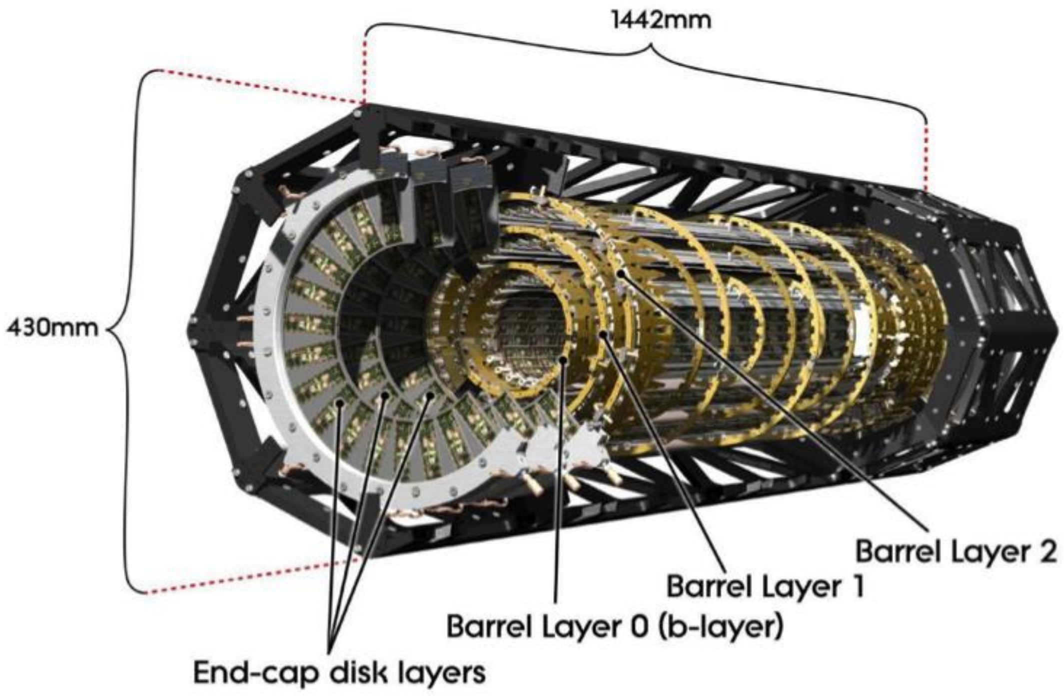
https://atlas.cern

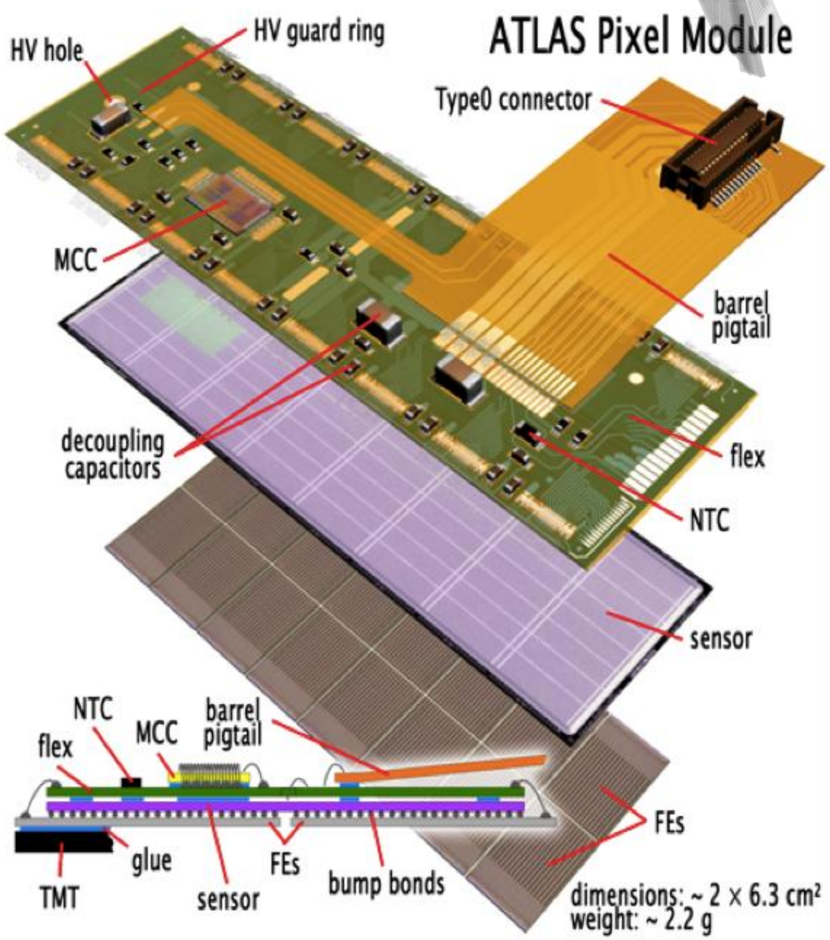
ATLAS EXPERIMENT

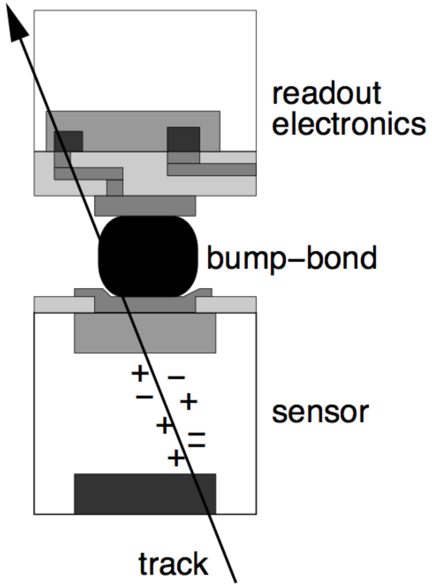
Information sheets:
https://atlas.cern/Resources/Fact-sheets

The pixel detector

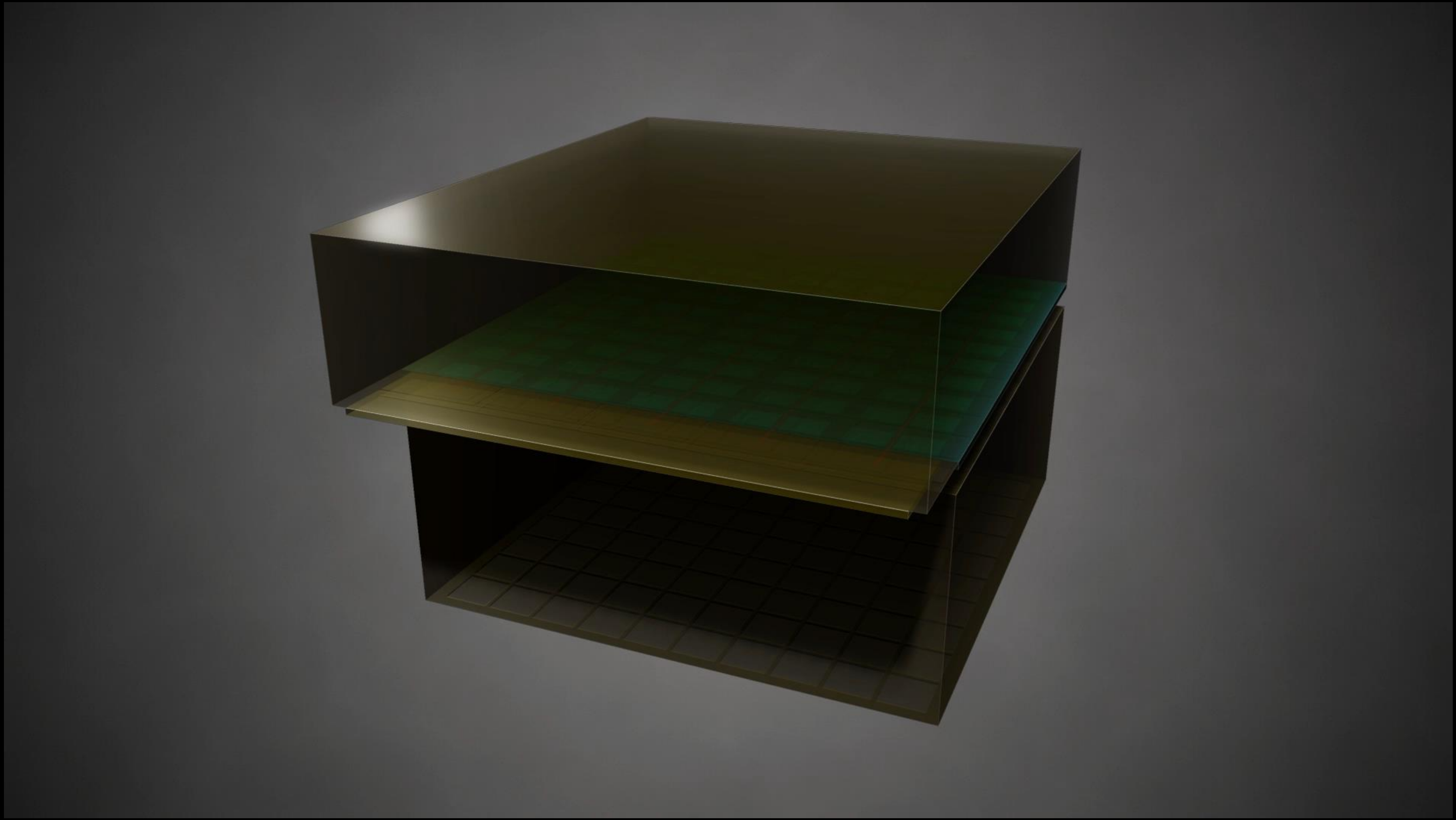




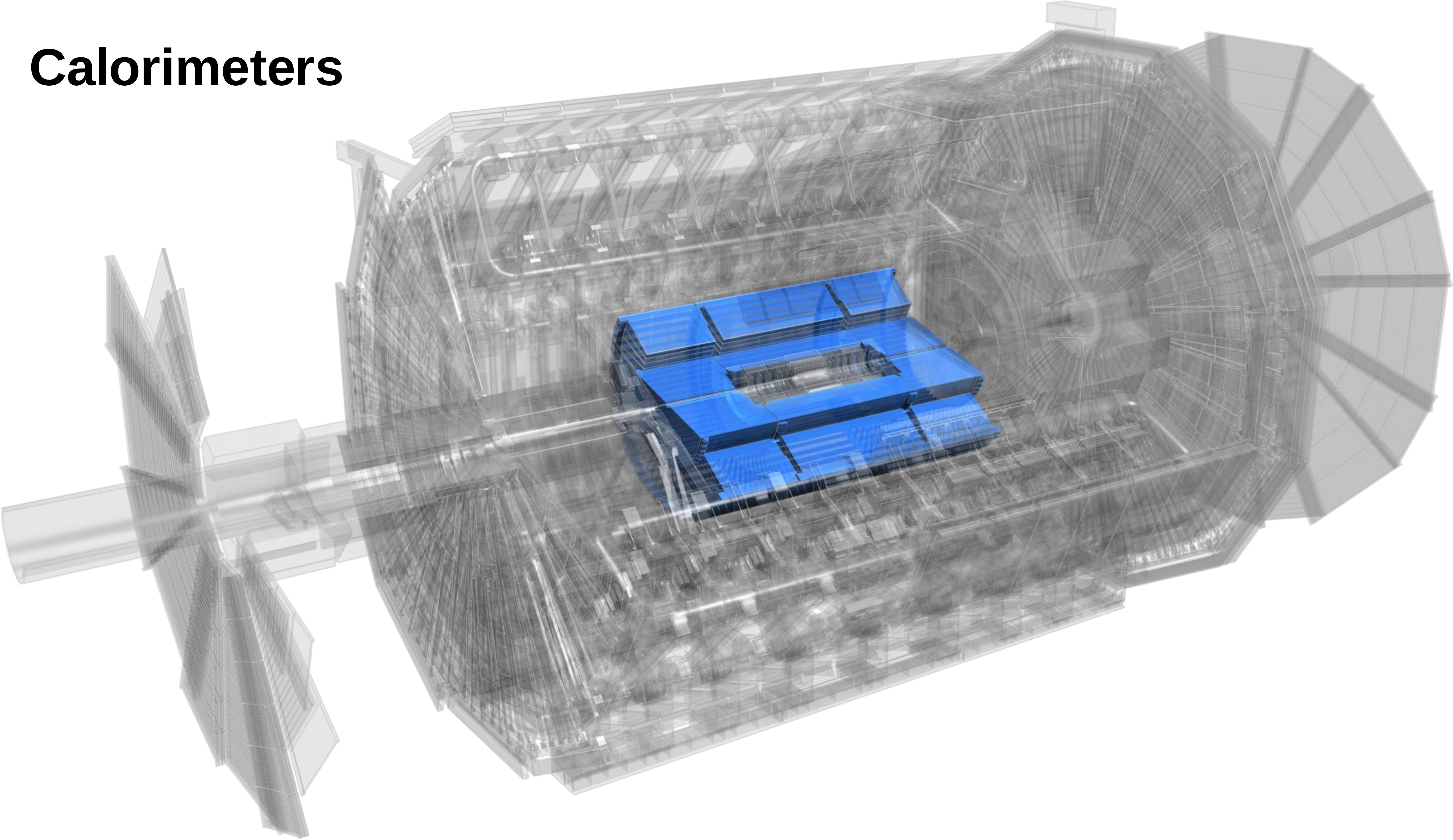




How a pixel detector works

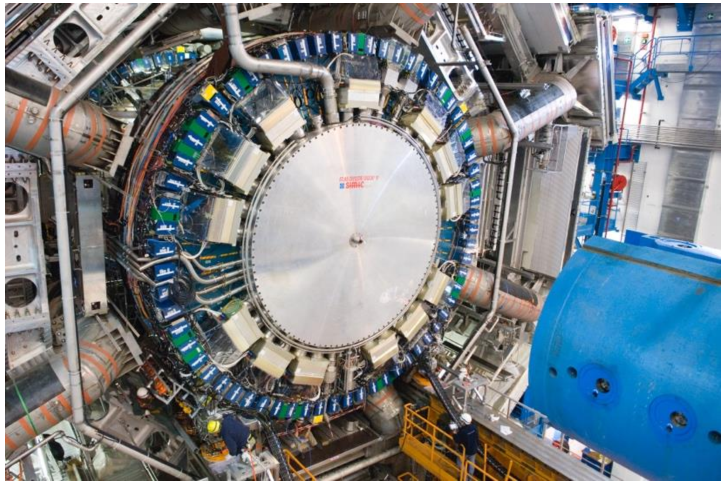


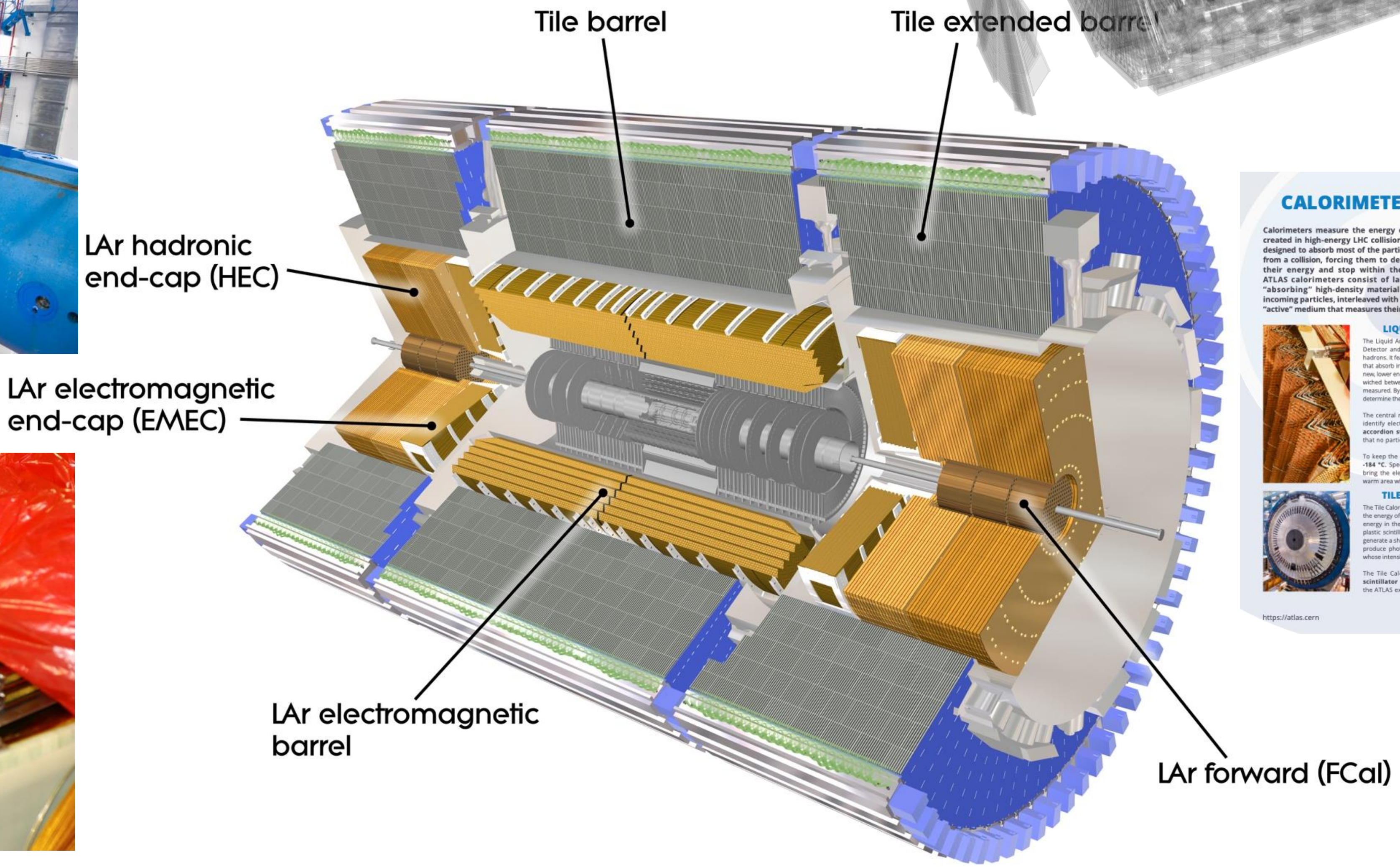
Calorimeters

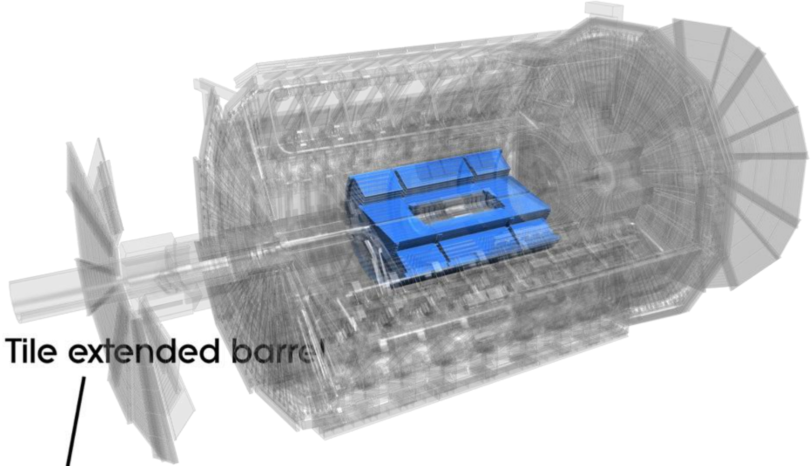


Calorimeters

Information sheets:
https://atlas.cern/Resources/Fact-sheets







CALORIMETERS

Calorimeters measure the energy of particles created in high-energy LHC collisions. They are designed to absorb most of the particles coming from a collision, forcing them to deposit all of their energy and stop within the detector. ATLAS calorimeters consist of layers of an "absorbing" high-density material that stops incoming particles, interleaved with layers of an "active" medium that measures their energy.

LIQUID ARGON CALORIMETER

The Liquid Argon (LAr) Calorimeter surrounds the ATLAS Inner Detector and measures the energy of electrons, photons and hadrons. It features layers of metal (either tungsten, copper or lead) that absorb incoming particles, converting them into a "shower" of new, lower energy particles. These particles ionise liquid argon sandwiched between the layers, producing an electric current that is measured. By combining all of the detected currents, physicists can determine the energy of the original particle that hit the detector.

The central region of the calorimeter is specially designed to identify electrons and photons. It features a **characteristic accordion structure**, with a honeycomb pattern, to ensure that no particle escapes unchallenged.

To keep the argon in liquid form, the **calorimeter is kept at -184 °C.** Specially-designed, vacuum-sealed cylinders of cables bring the electronic signals from the cold liquid argon to the warm area where the readout electronics are located.

TILE HADRONIC CALORIMETER

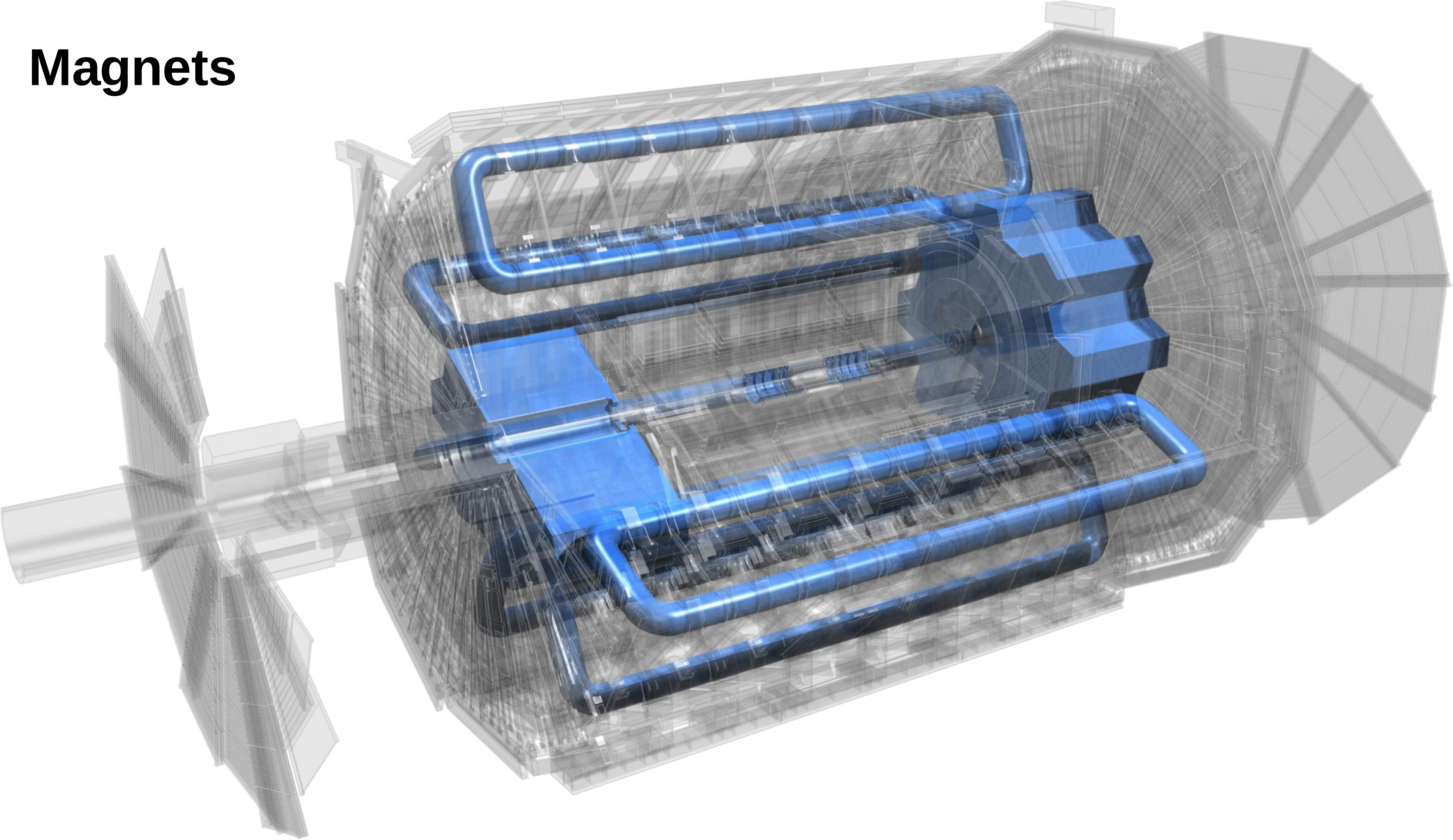
The Tile Calorimeter surrounds the LAr calorimeter and measures the energy of hadronic particles, which do not deposit all of their energy in the LAr Calorimeter. It is made of layers of steel and plastic scintillating tiles. As particles hit the layers of steel, they generate a shower of new particles. The plastic scintillators in turn produce photons, which are converted into an electric current whose intensity is proportional to the original particle's energy.

The Tile Calorimeter is made up of about **420,000 plastic scintillator tiles** working in sync. It is the heaviest part of the ATLAS experiment, weighing almost 2900 tons!

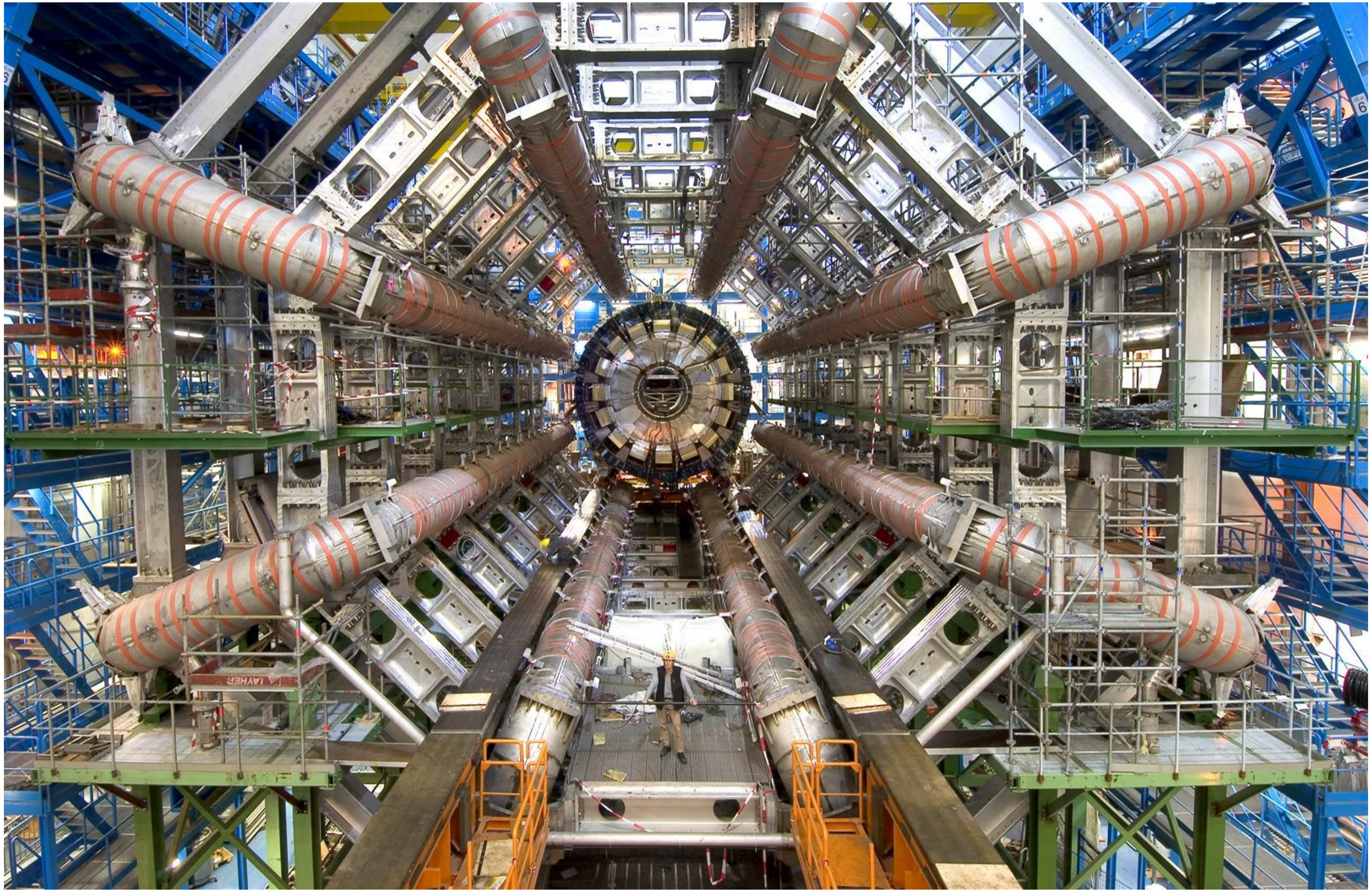
https://atlas.cern

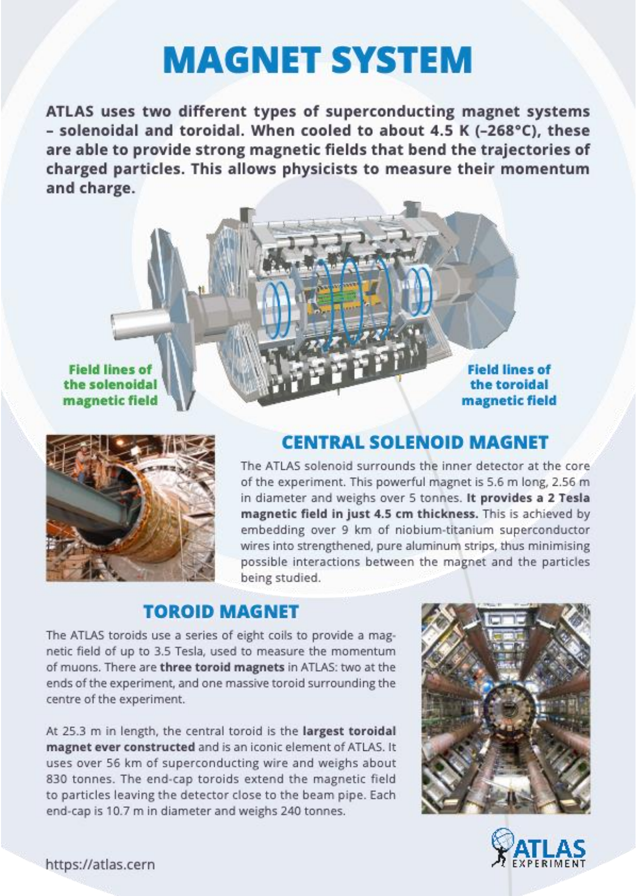
ATLAS EXPERIMENT

Magnets



Information sheets:
https://atlas.cern/Resources/Fact-sheets




MAGNET SYSTEM

ATLAS uses two different types of superconducting magnet systems – solenoidal and toroidal. When cooled to about 4.5 K (–268°C), these are able to provide strong magnetic fields that bend the trajectories of charged particles. This allows physicists to measure their momentum and charge.

Field lines of the solenoidal magnetic field

Field lines of the toroidal magnetic field

CENTRAL SOLENOID MAGNET

The ATLAS solenoid surrounds the inner detector at the core of the experiment. This powerful magnet is 5.6 m long, 2.56 m in diameter and weighs over 5 tonnes. **It provides a 2 Tesla magnetic field in just 4.5 cm thickness.** This is achieved by embedding over 9 km of niobium-titanium superconductor wires into strengthened, pure aluminum strips, thus minimising possible interactions between the magnet and the particles being studied.

TOROID MAGNET

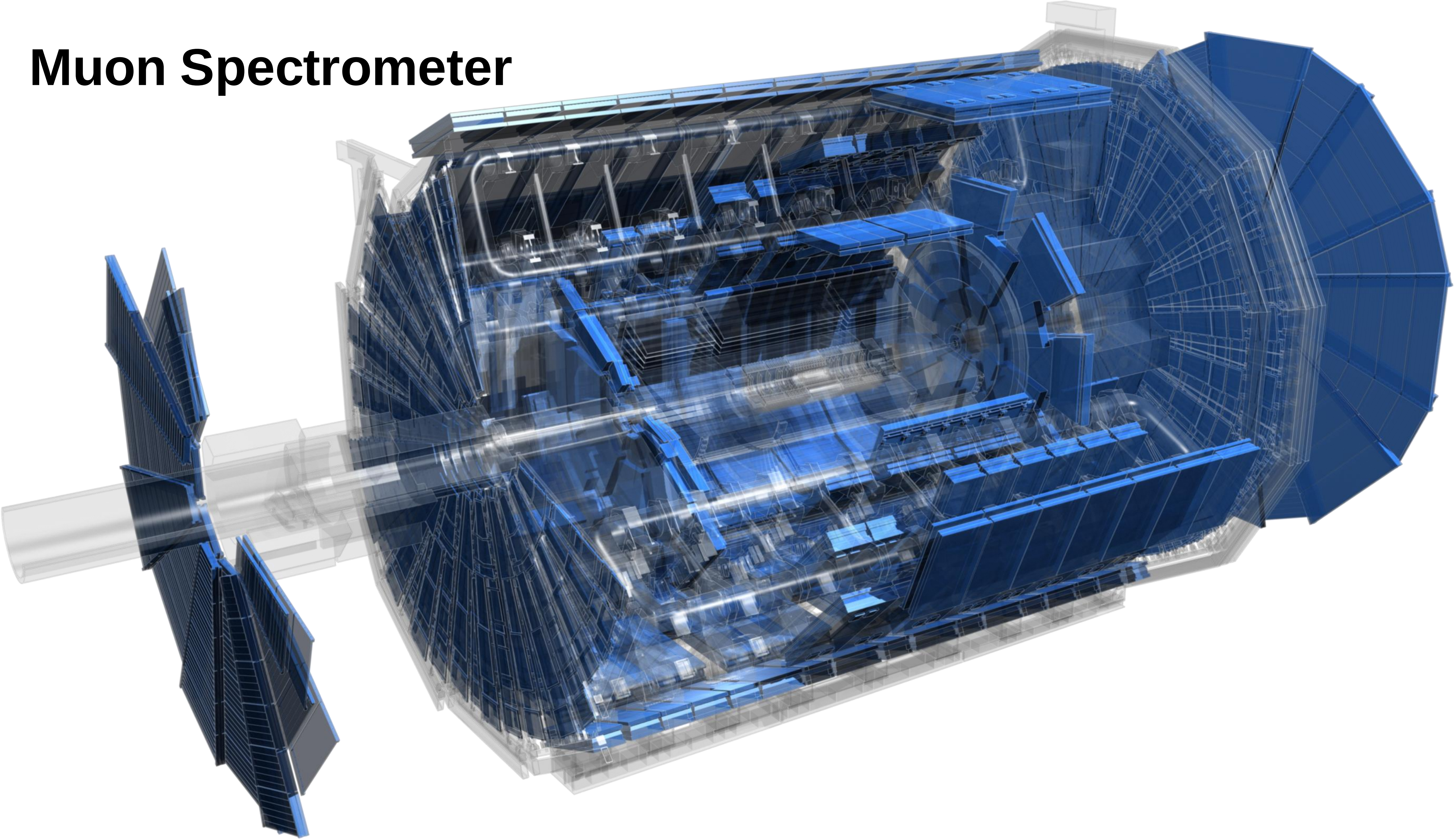
The ATLAS toroids use a series of eight coils to provide a magnetic field of up to 3.5 Tesla, used to measure the momentum of muons. There are **three toroid magnets** in ATLAS: two at the ends of the experiment, and one massive toroid surrounding the centre of the experiment.

At 25.3 m in length, the central toroid is the **largest toroidal magnet ever constructed** and is an iconic element of ATLAS. It uses over 56 km of superconducting wire and weighs about 830 tonnes. The end-cap toroids extend the magnetic field to particles leaving the detector close to the beam pipe. Each end-cap is 10.7 m in diameter and weighs 240 tonnes.

https://atlas.cern

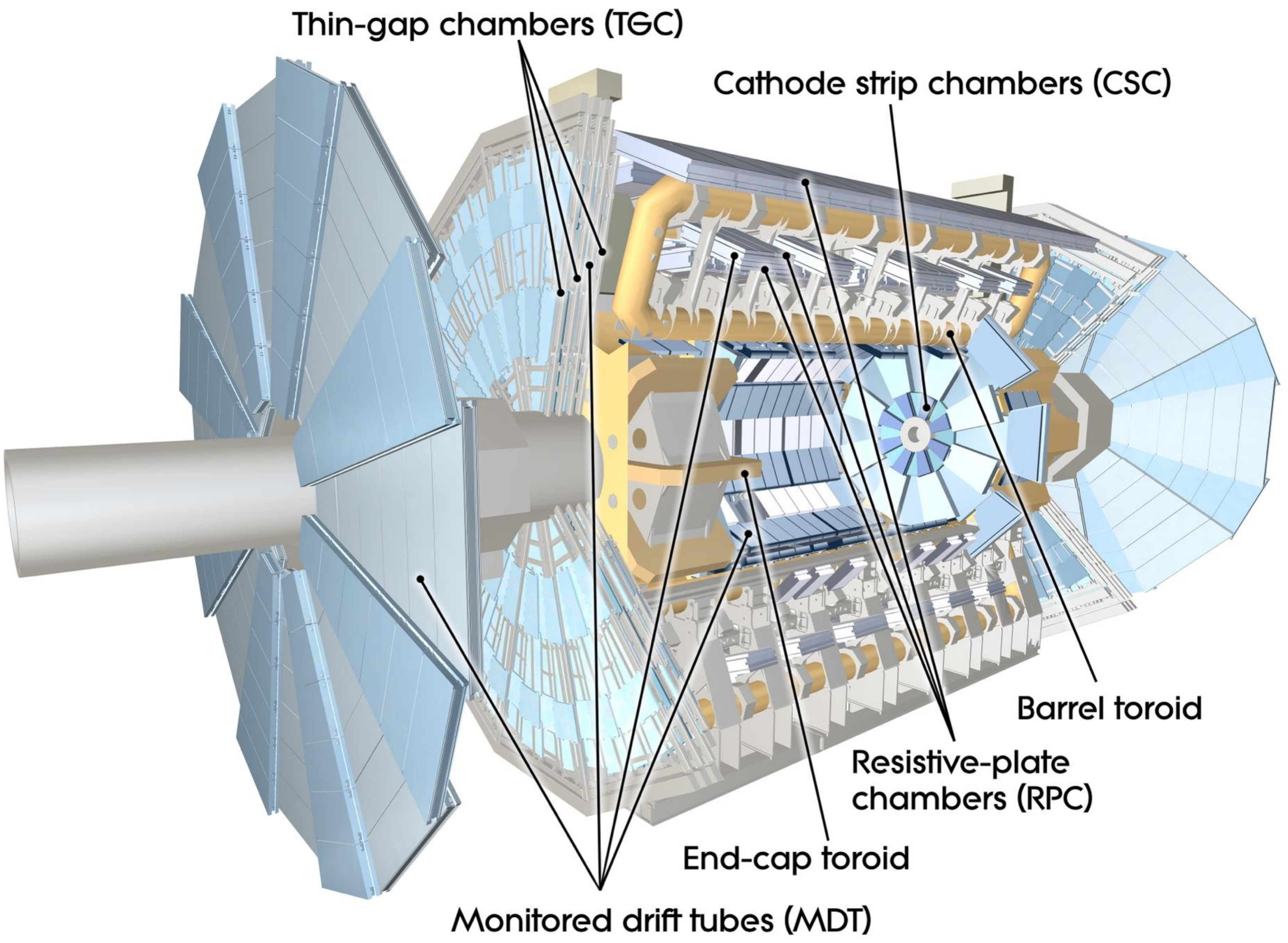
ATLAS EXPERIMENT

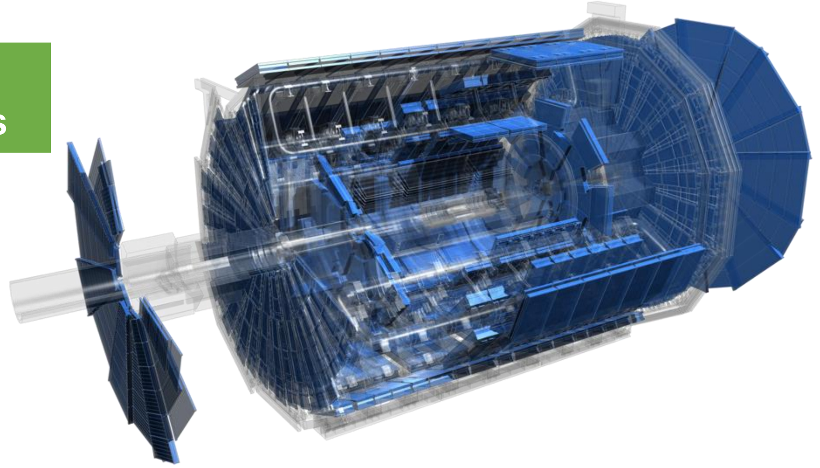
Muon Spectrometer

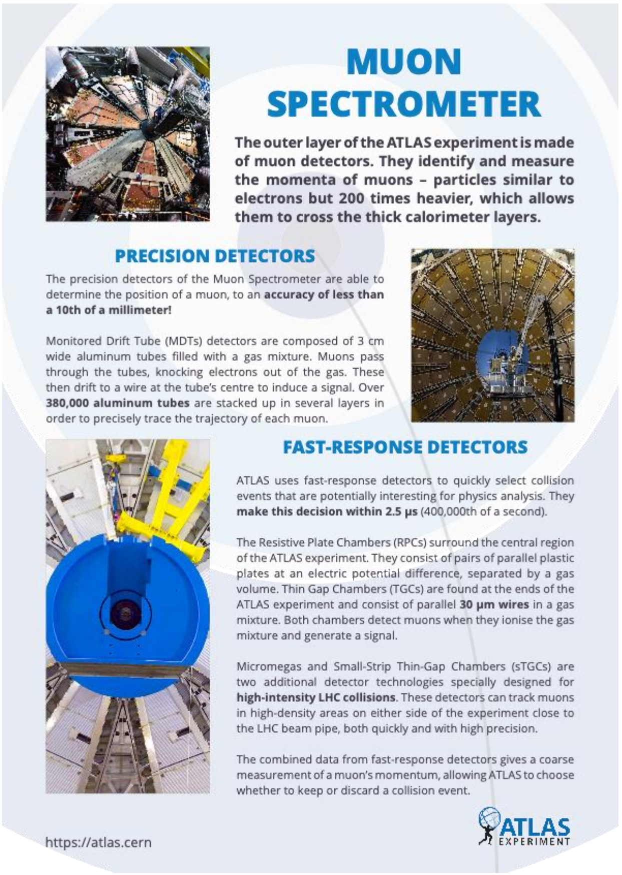


Muon Spectrometer

Information sheets:
https://atlas.cern/Resources/Fact-sheets







MUON SPECTROMETER

The outer layer of the ATLAS experiment is made of muon detectors. They identify and measure the momenta of muons – particles similar to electrons but 200 times heavier, which allows them to cross the thick calorimeter layers.

PRECISION DETECTORS

The precision detectors of the Muon Spectrometer are able to determine the position of a muon, to an **accuracy of less than a 10th of a millimeter!**

Monitored Drift Tube (MDTs) detectors are composed of 3 cm wide aluminum tubes filled with a gas mixture. Muons pass through the tubes, knocking electrons out of the gas. These then drift to a wire at the tube's centre to induce a signal. Over **380,000 aluminum tubes** are stacked up in several layers in order to precisely trace the trajectory of each muon.

FAST-RESPONSE DETECTORS

ATLAS uses fast-response detectors to quickly select collision events that are potentially interesting for physics analysis. They **make this decision within 2.5 μs** (400,000th of a second).

The Resistive Plate Chambers (RPCs) surround the central region of the ATLAS experiment. They consist of pairs of parallel plastic plates at an electric potential difference, separated by a gas volume. Thin Gap Chambers (TGCs) are found at the ends of the ATLAS experiment and consist of parallel **30 μm wires** in a gas mixture. Both chambers detect muons when they ionise the gas mixture and generate a signal.

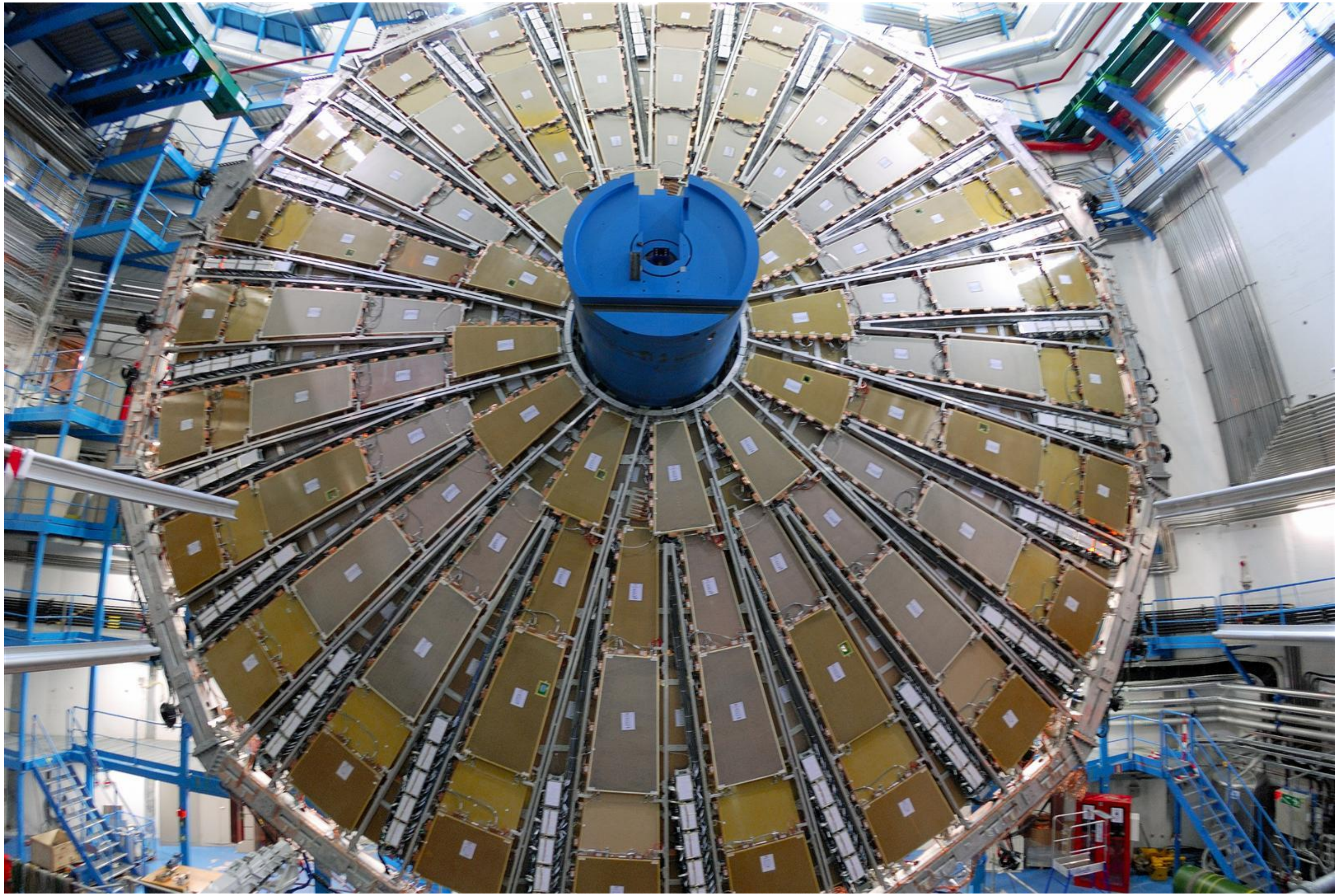
Micromegas and Small-Strip Thin-Gap Chambers (sTGCs) are two additional detector technologies specially designed for **high-intensity LHC collisions**. These detectors can track muons in high-density areas on either side of the experiment close to the LHC beam pipe, both quickly and with high precision.

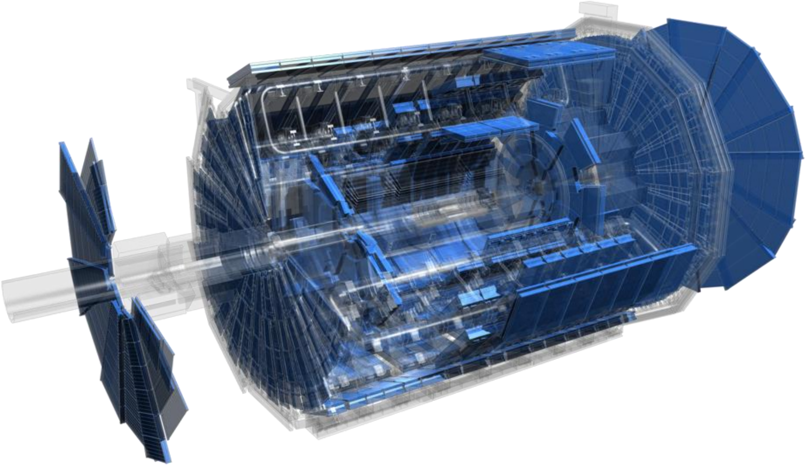
The combined data from fast-response detectors gives a coarse measurement of a muon's momentum, allowing ATLAS to choose whether to keep or discard a collision event.

https://atlas.cern

ATLAS EXPERIMENT

Muon Spectrometer

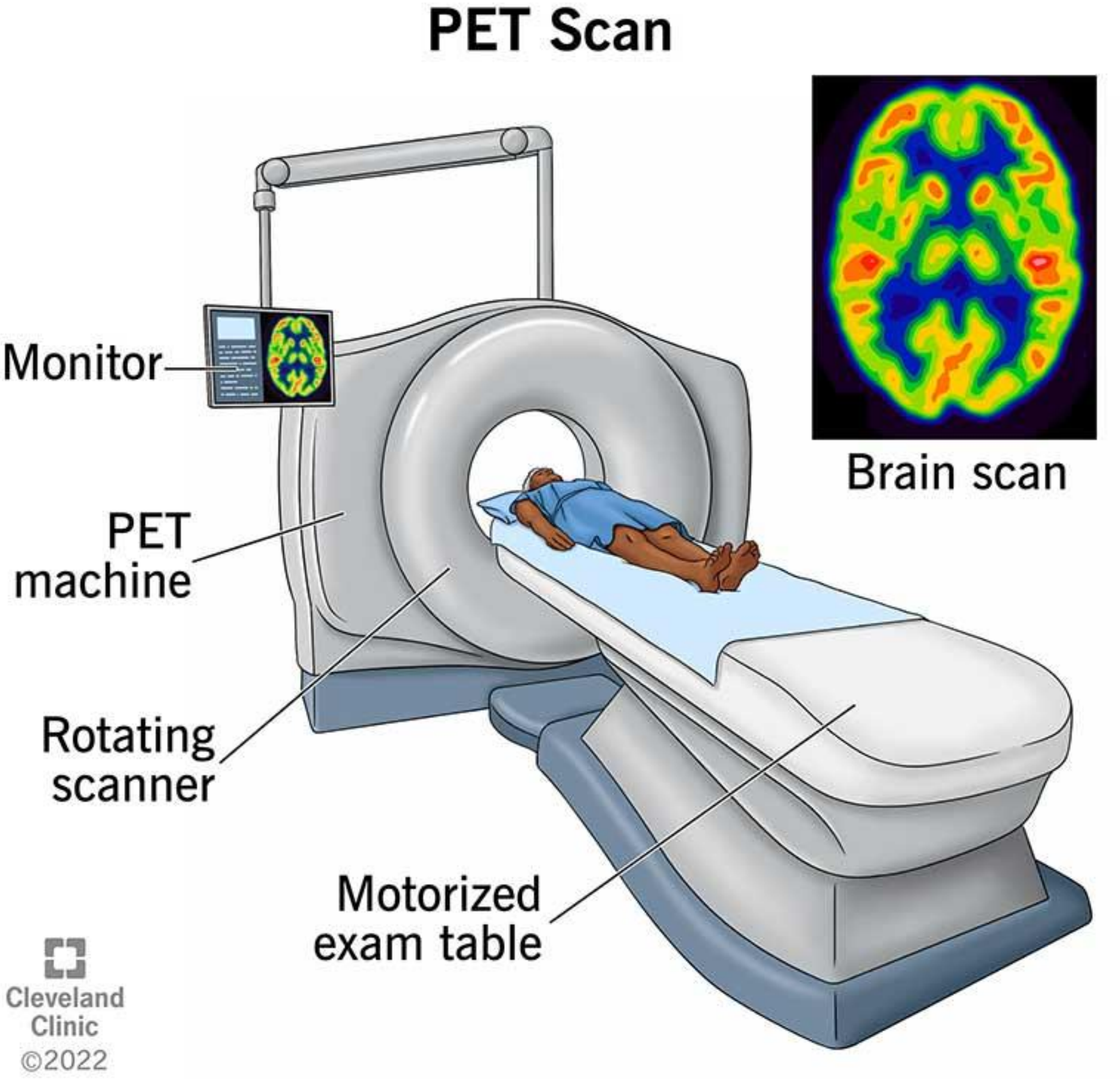




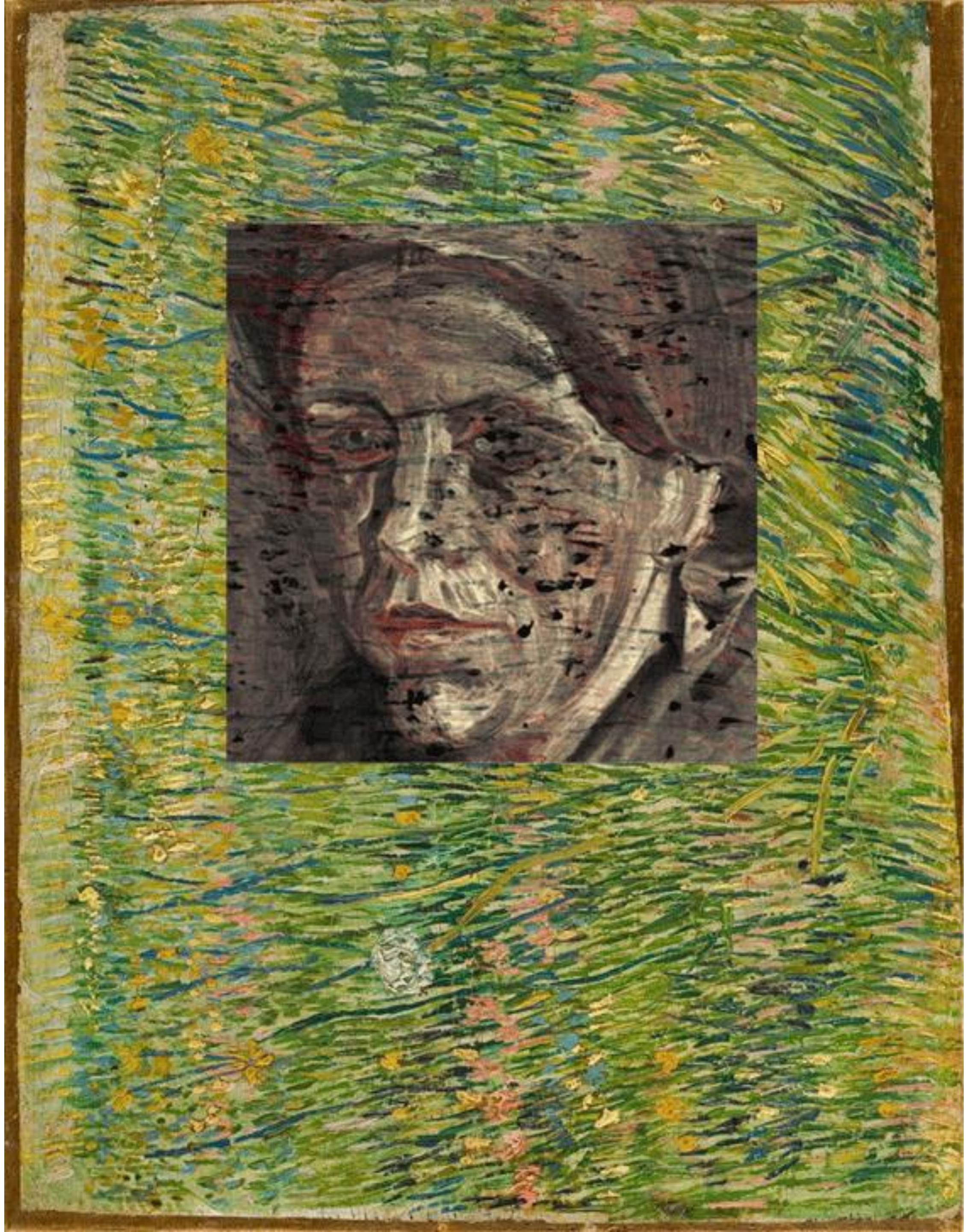
https://videos.cern.ch/record/1541893
(again, with energetic music :D)

Learning more about our universe is a fundamental human curiosity

Doing difficult things gives us better technology that improves our lives and tells us interesting things right now!



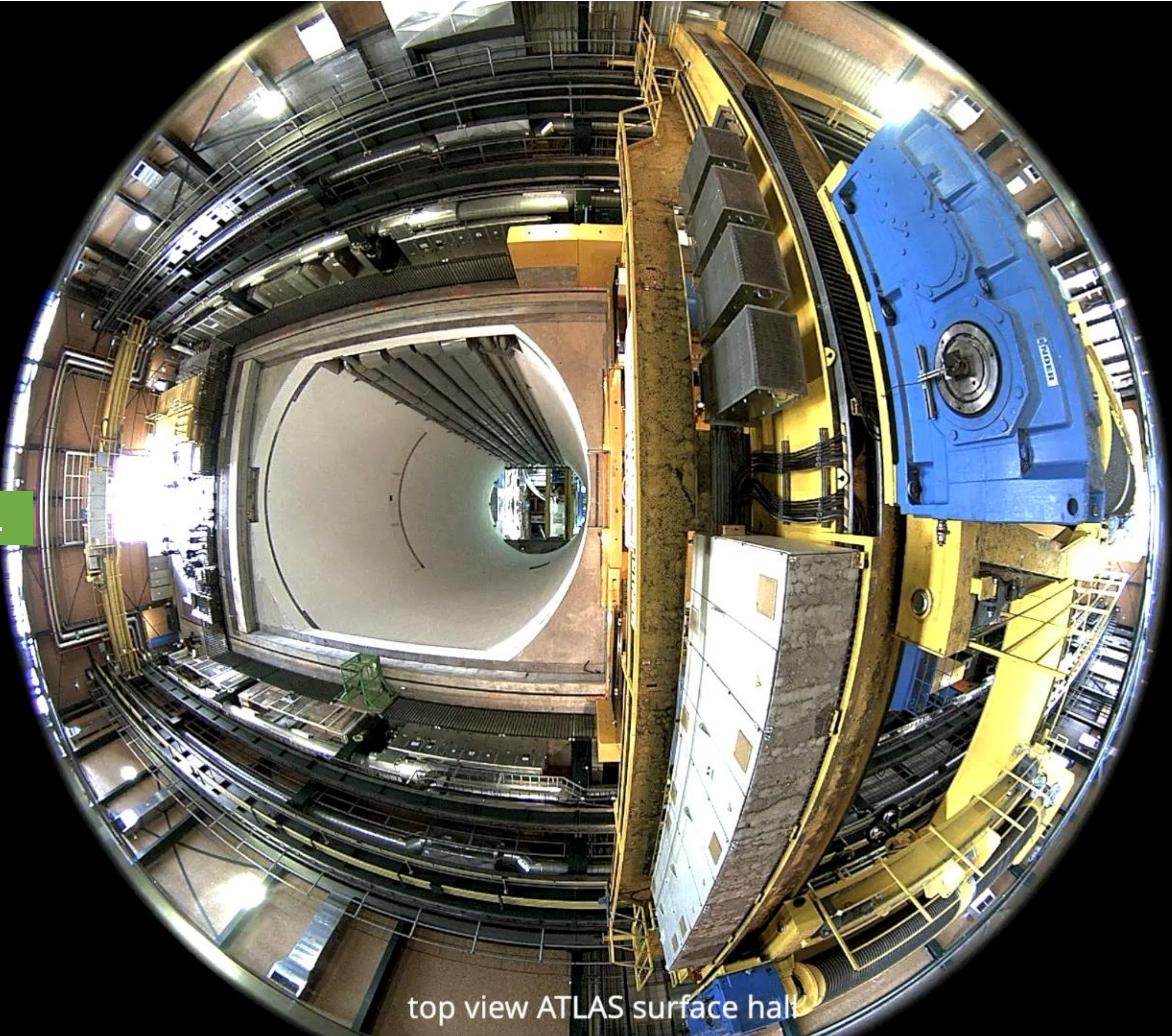
Synchrotron Radiation Based X-ray Fluorescence Elemental Mapping



Muon tomography for pyramids


FUTURE

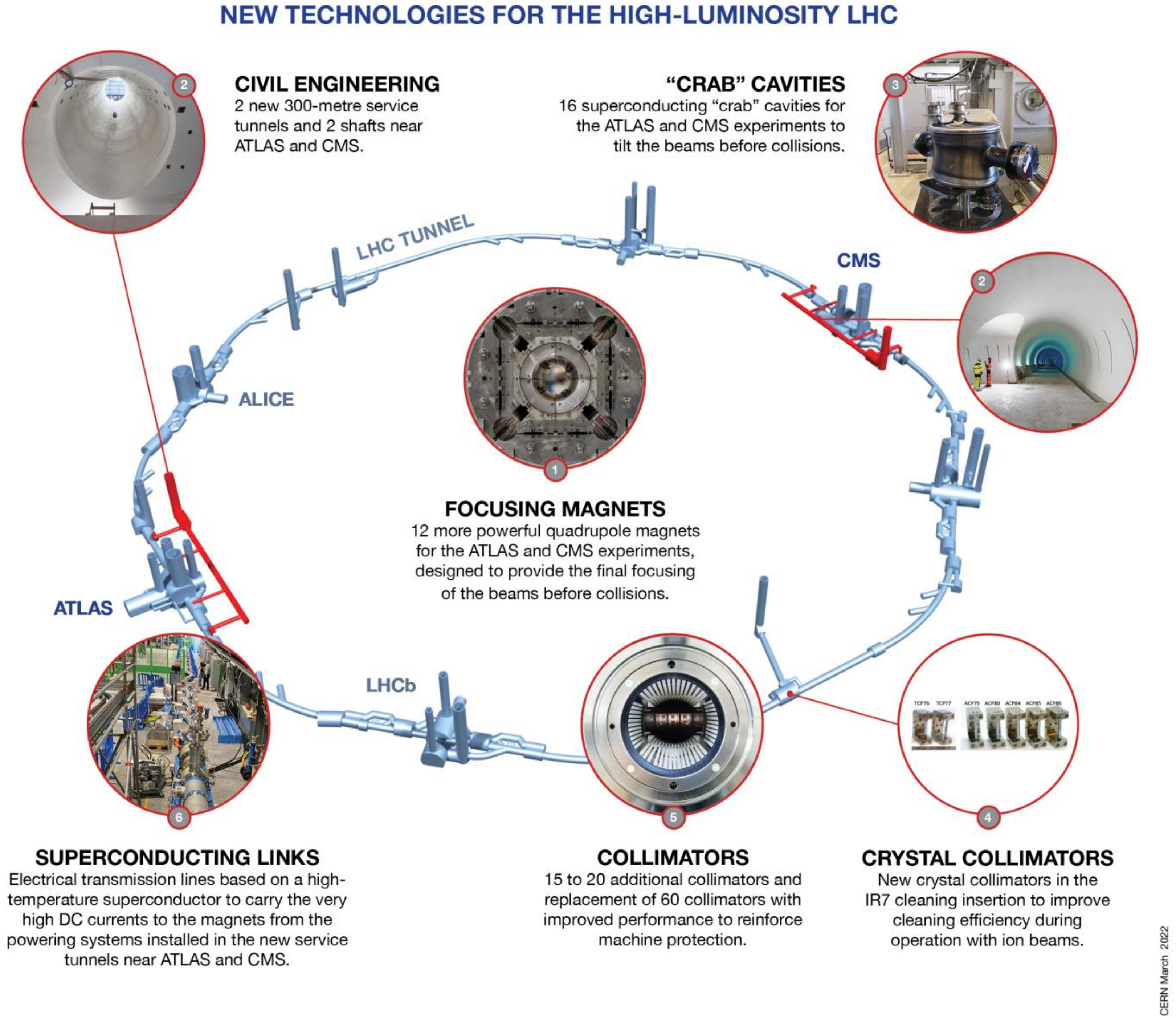
https://videos.cern.ch/record/2776371



Have only taken ~ 7% of planned data so far

2026

A new LHC
Towards high luminosity



2040 and after

The future

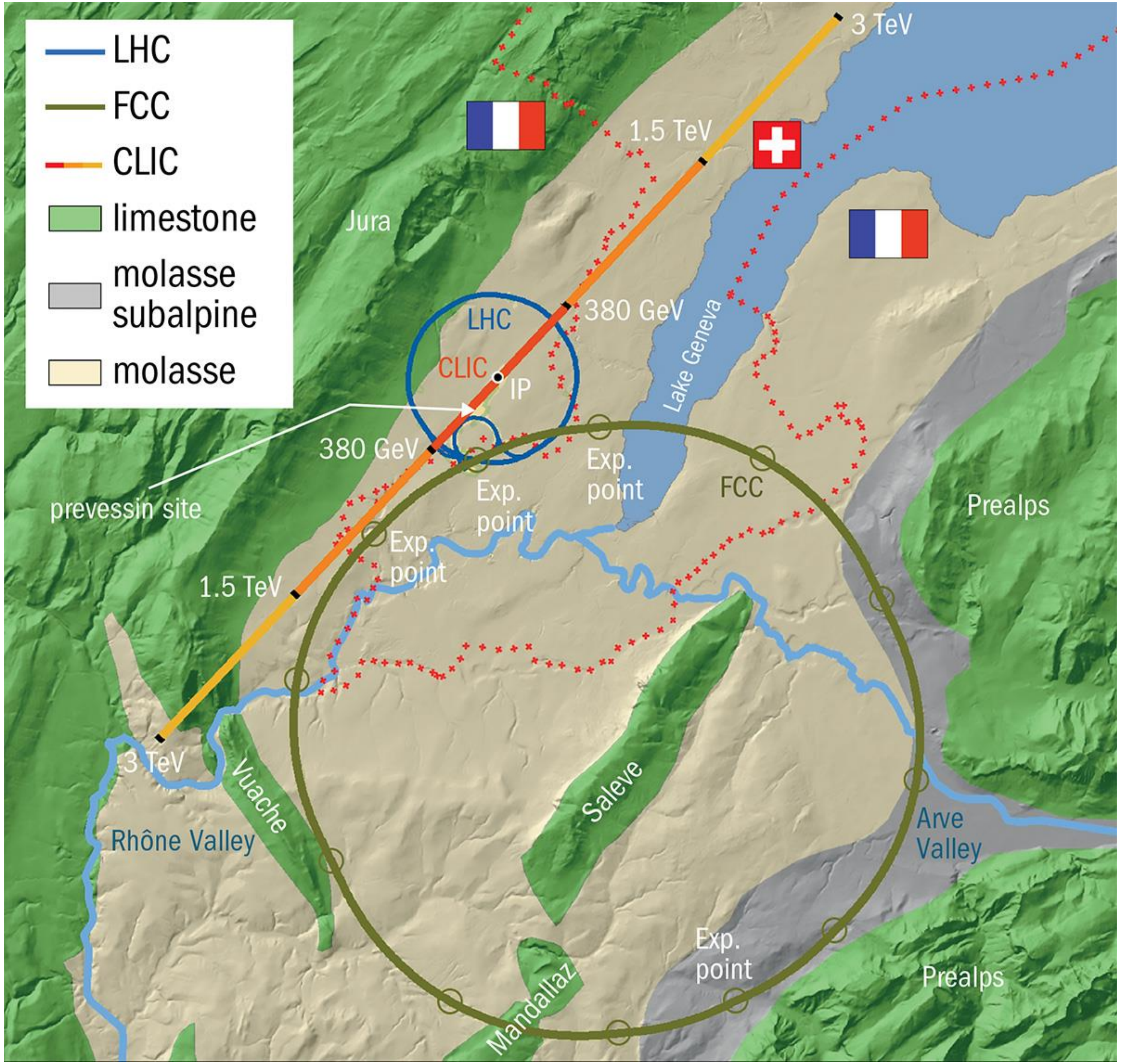
What's beyond the HL-LHC?

For the FCC we need magnets with strength of 16 T

- We don't have this yet
- Need R&D!

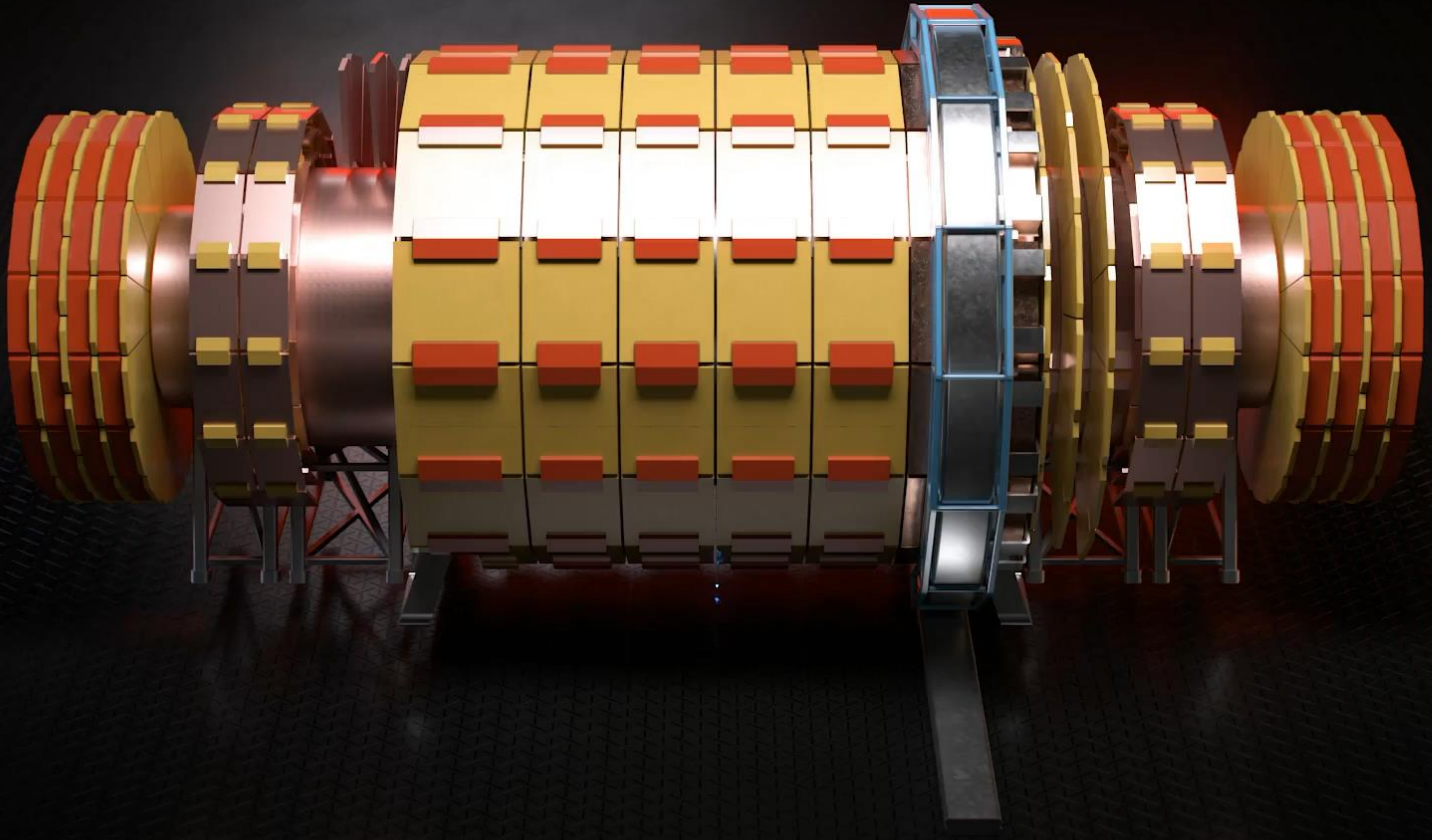
Also, muon colliders, plasma wakefield accelerators…

Linear collider?



Circular collider?

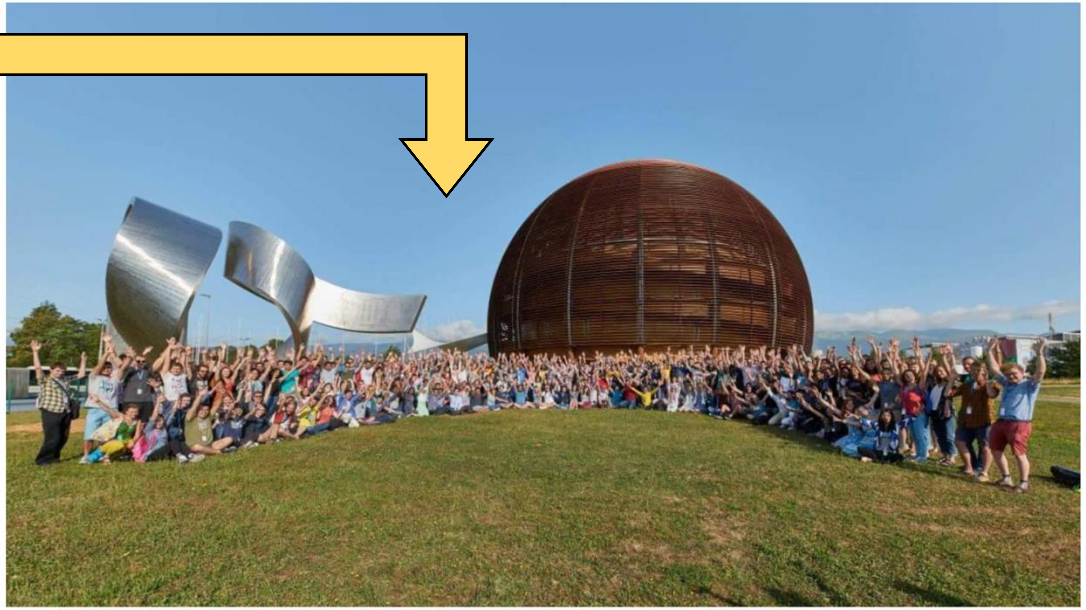
https://videos.cern.ch/record/2299641



Your future

There are a number of summer programmes and internships you can apply to throughout your undergraduate programme.

Apply to **EVERYTHING** you’re interested in.



“I don’t know if we were particularly lucky, but I really enjoyed every aspect of the summer student program: work, lectures and social life (a lot!).”

Summer programmes:

CERN Summer Student Programme
DESY Summer Student Programme
HASCO Summer School

Internships:

CERN Technical Student programme
ESA Student Internships

thank you!

Backup

Here’s one I prepared earlier