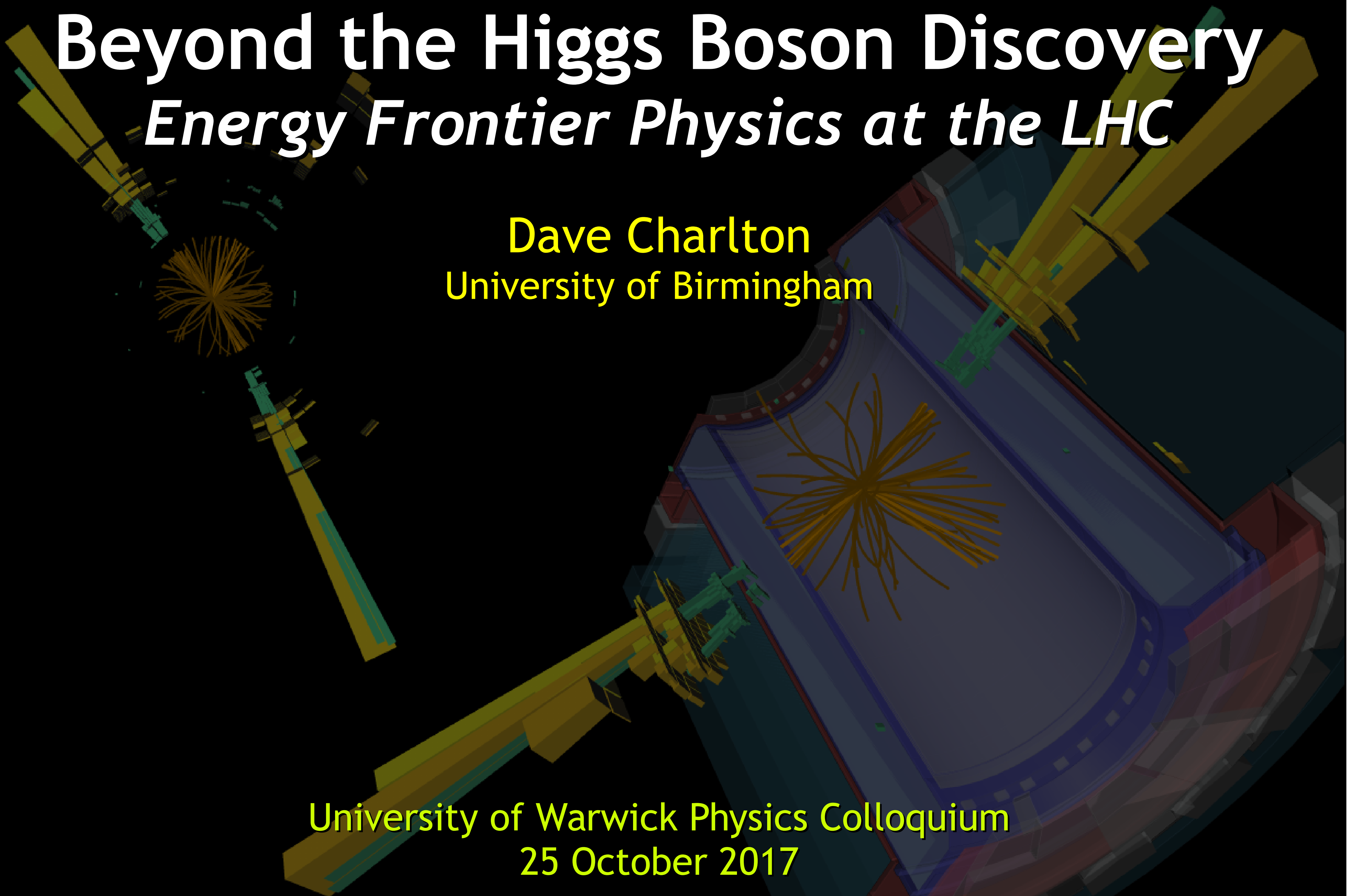
Beyond the Higgs Boson Discovery

Energy Frontier Physics at the LHC



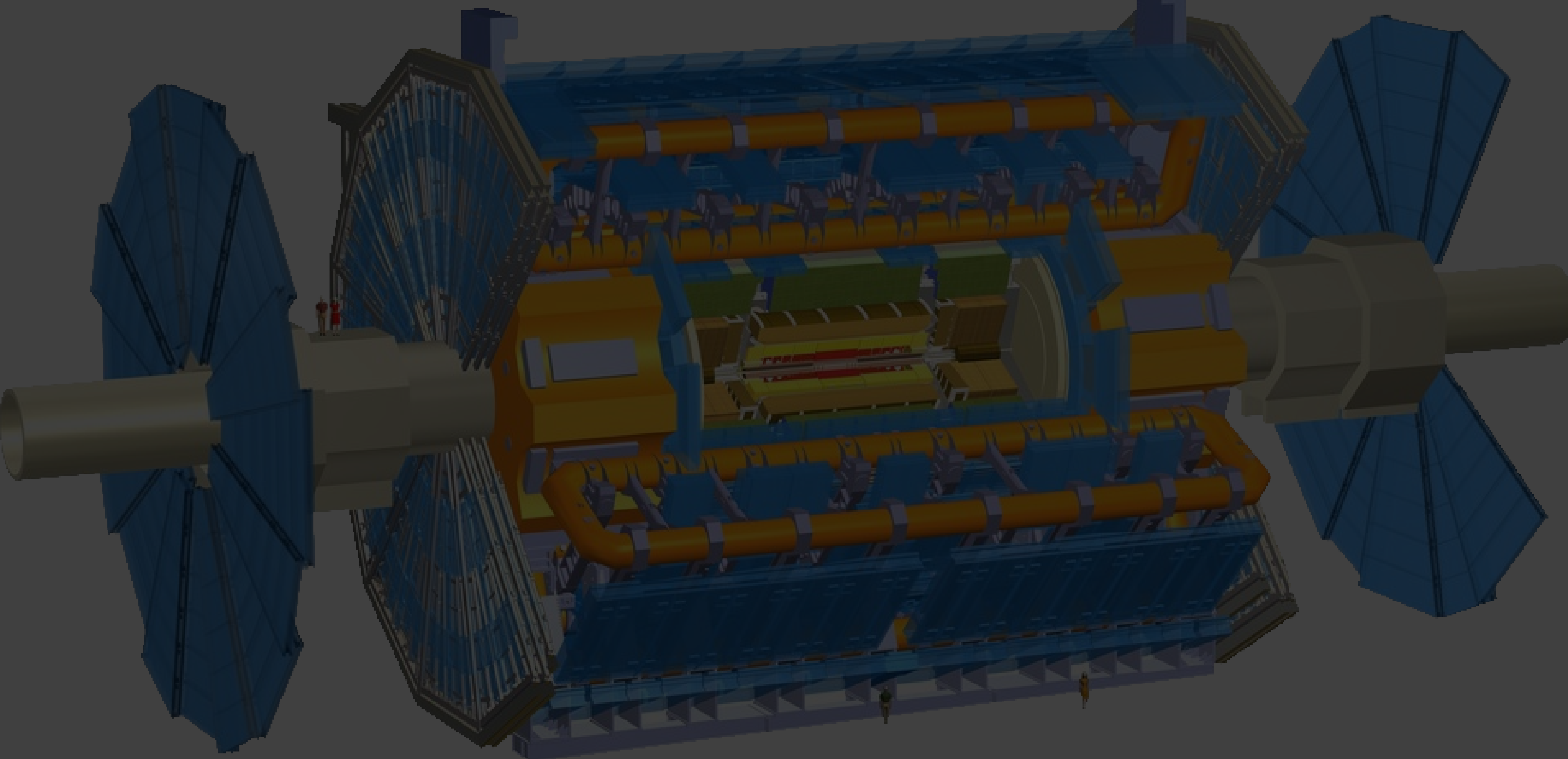
Dave Charlton

University of Birmingham

University of Warwick Physics Colloquium

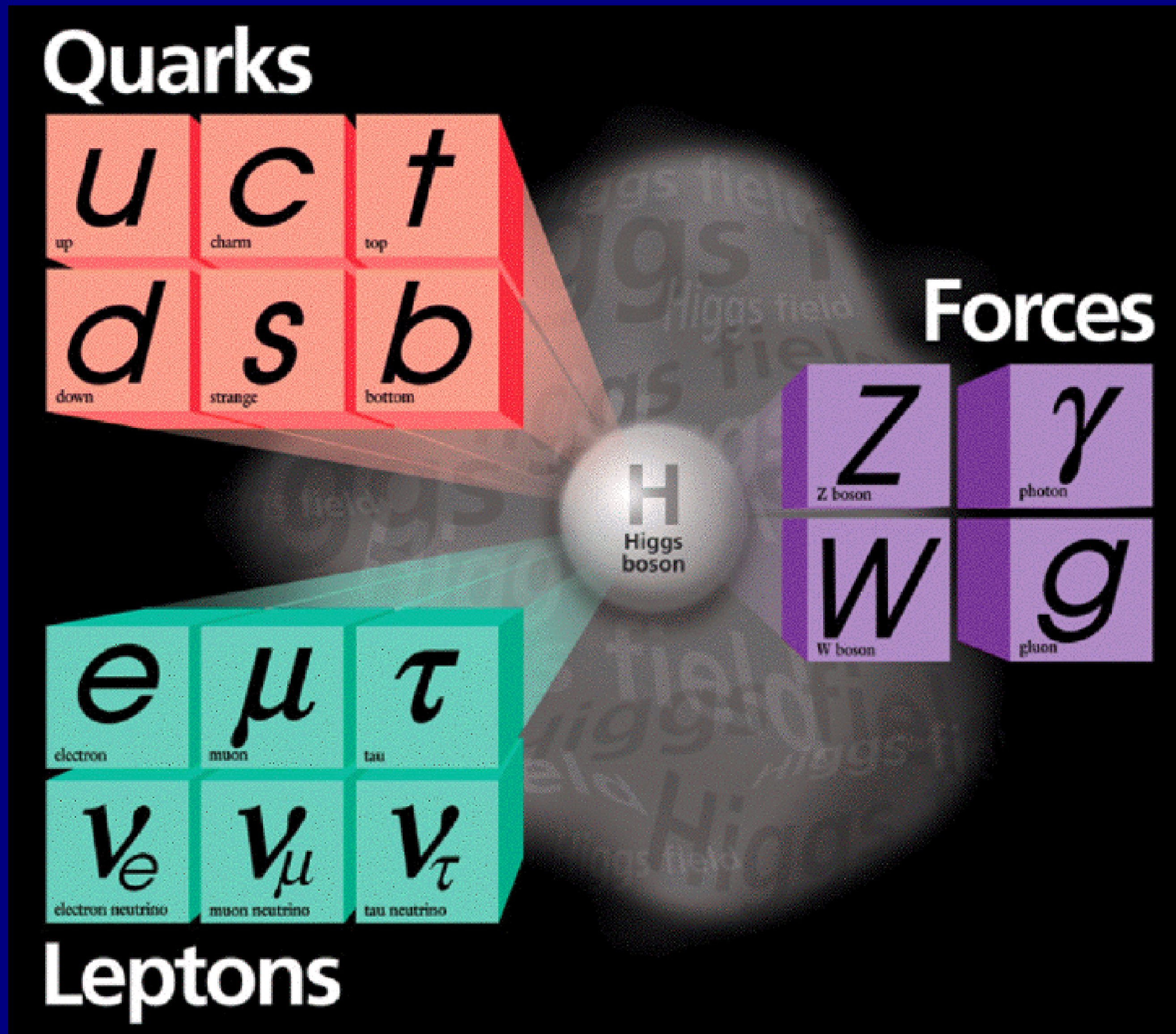
25 October 2017

Where we start:
the Standard Model



The Standard Model, SM

Matter Particles

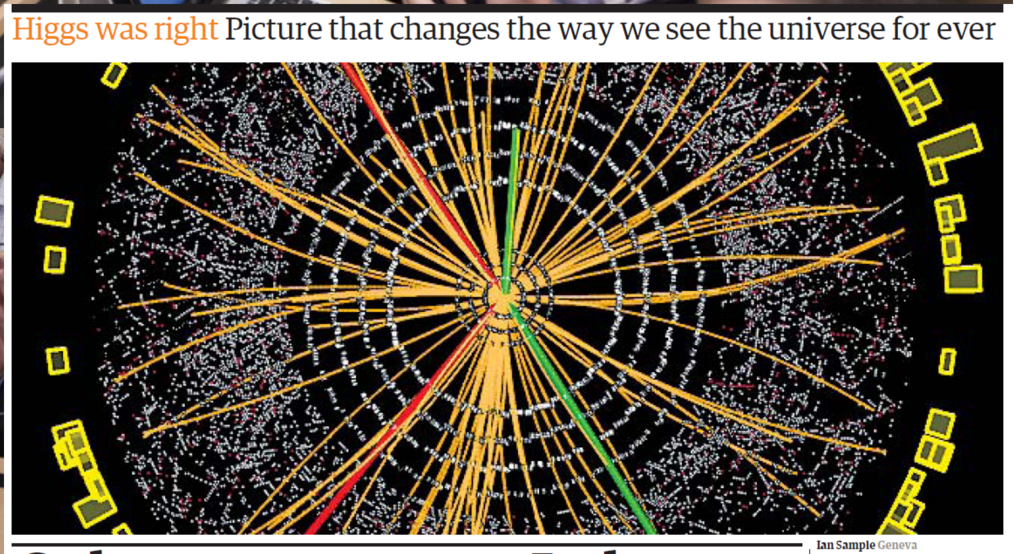


Force-carriers

Fermions Bosons

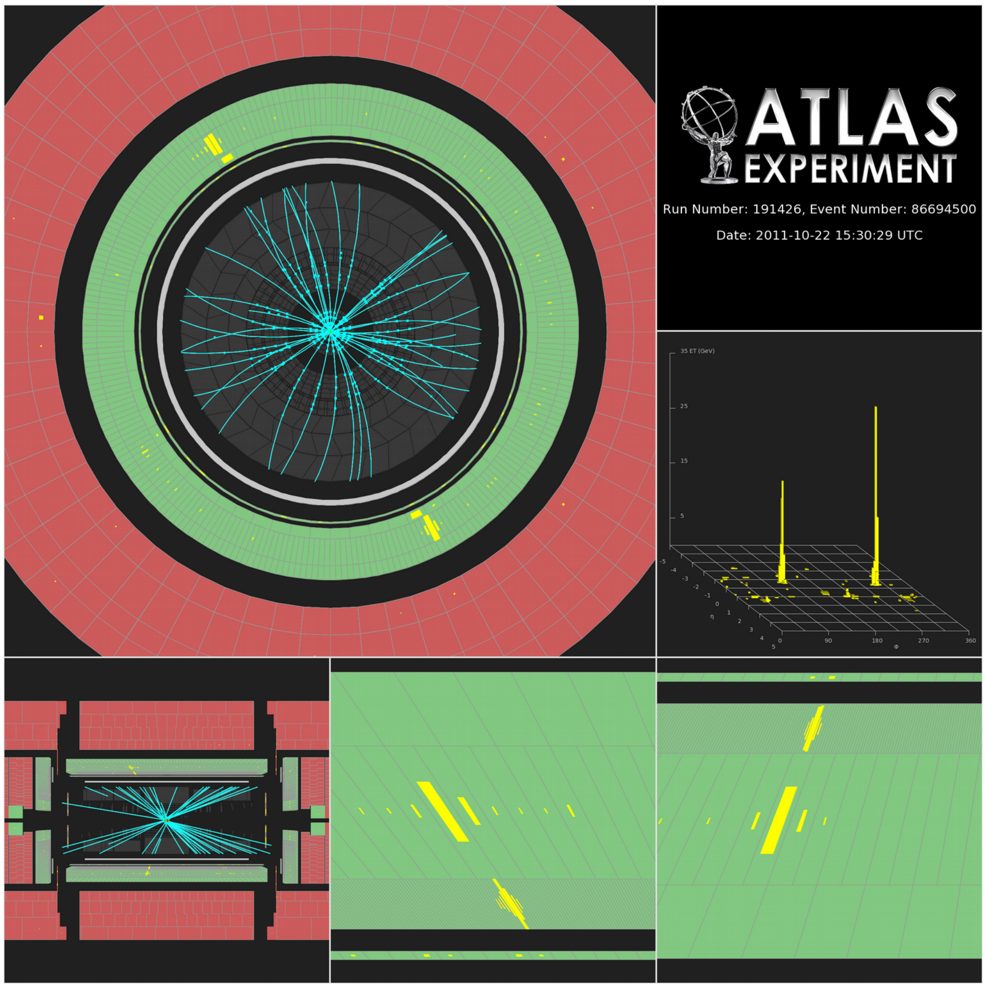
Higgs Discovery (ATLAS and CMS)

July 4th 2012 (CERN and Melbourne)

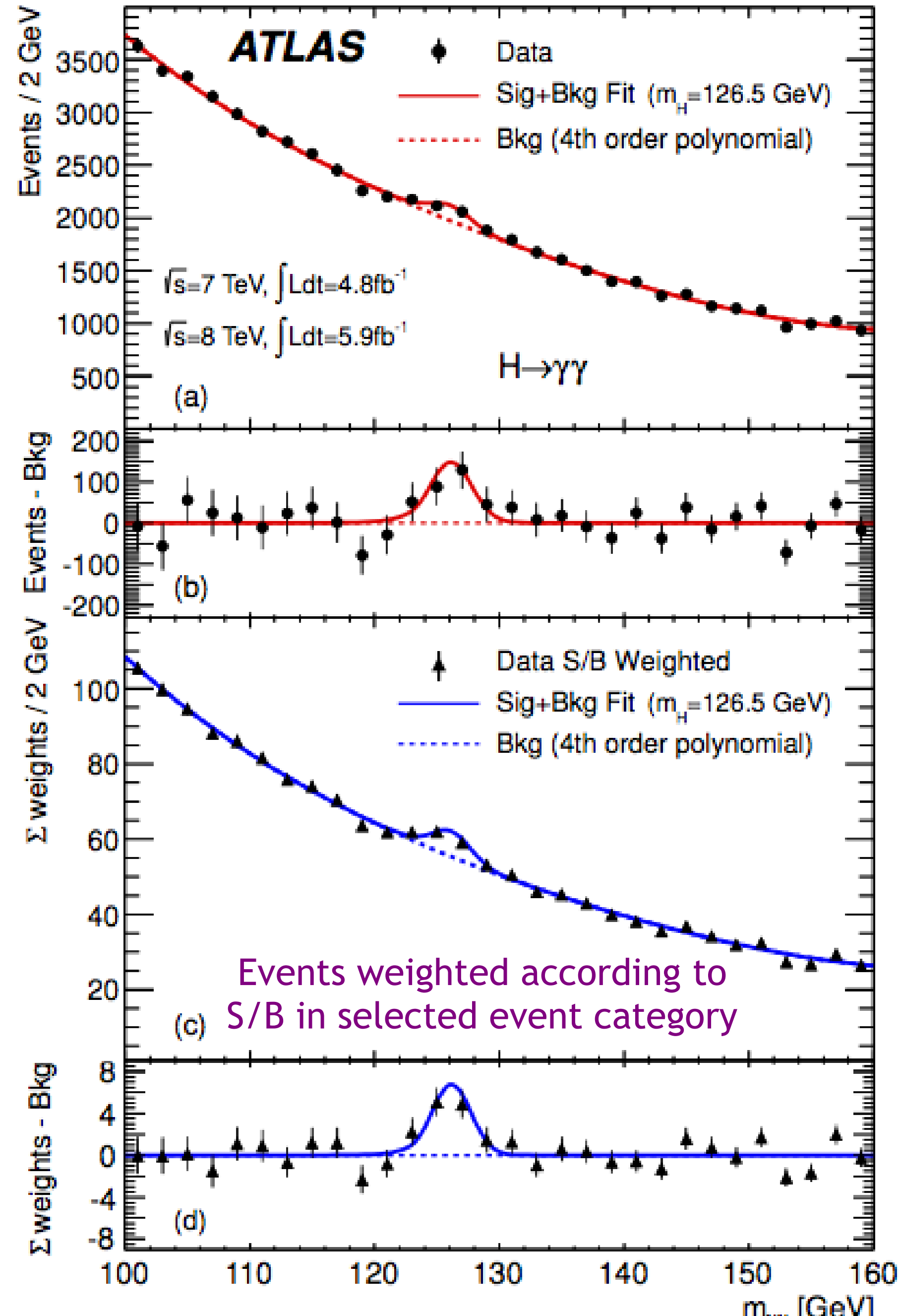


July 2012 - the new boson

Excellent γγ mass resolution crucial, as well as γ-ID to reject jet/π^0 background



Inclusive signal/background S/B ~3%



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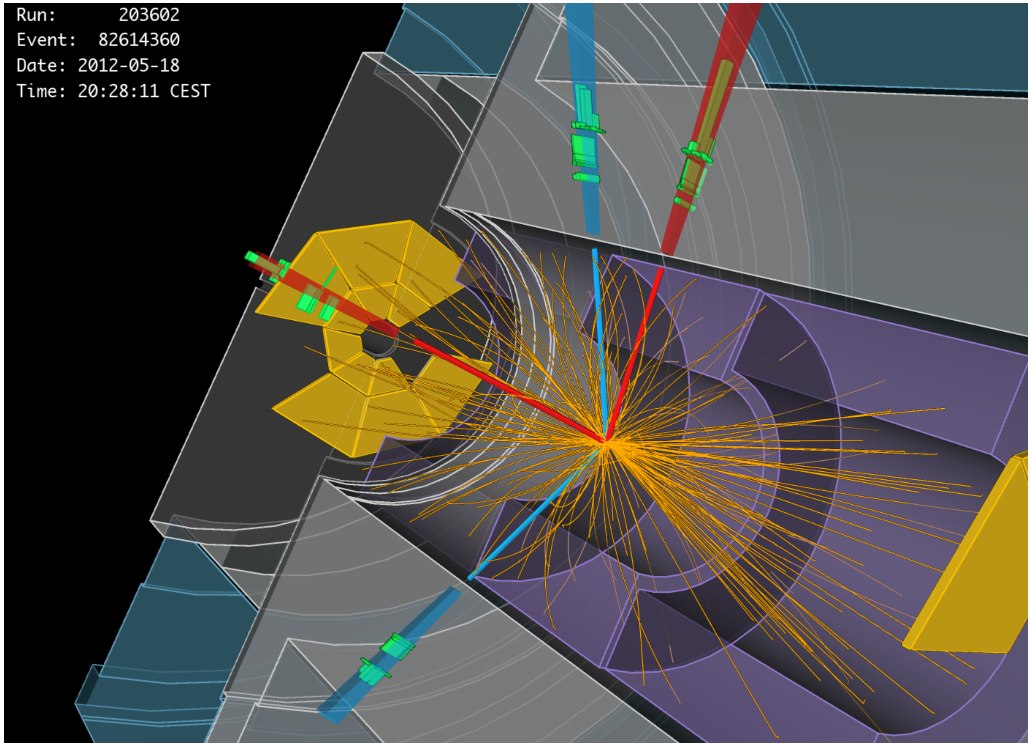
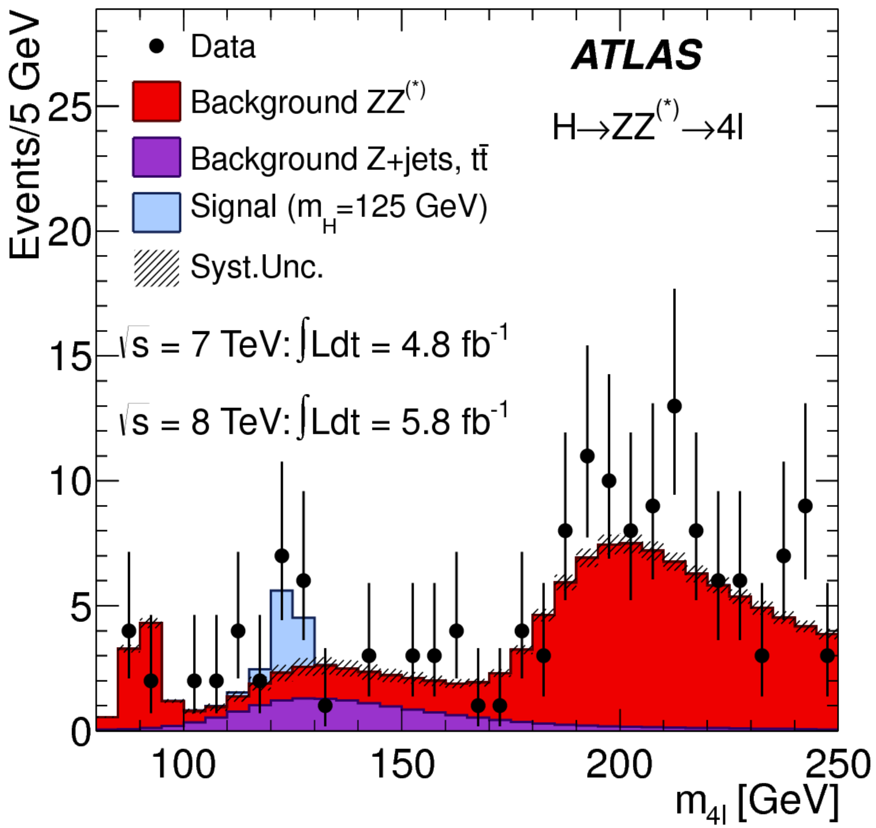
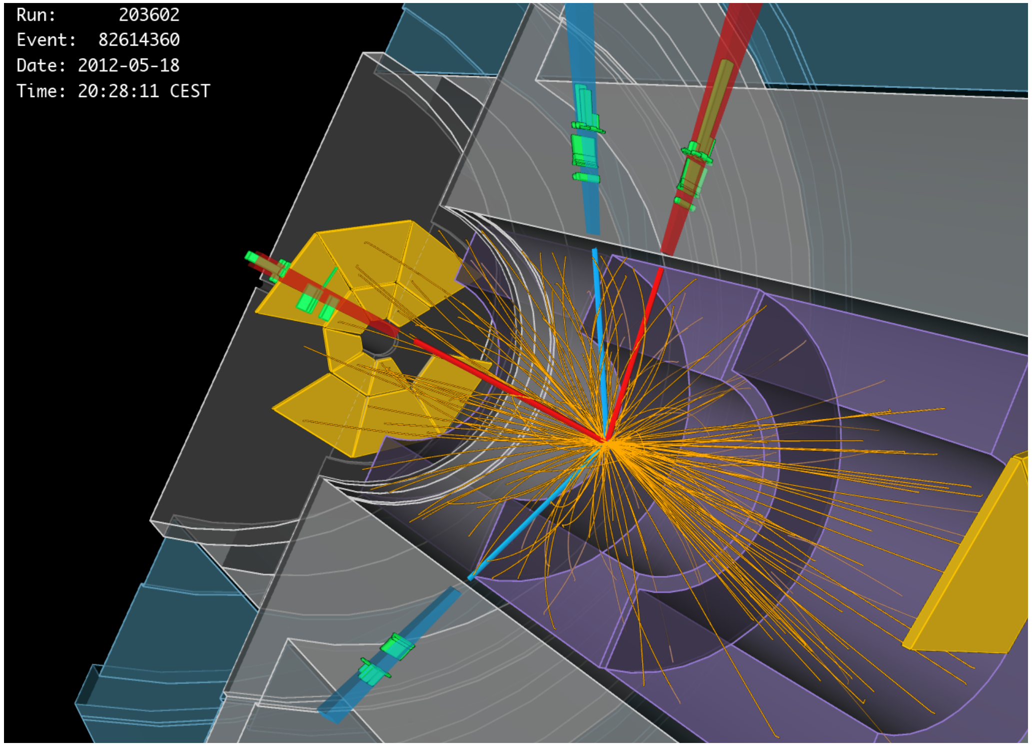


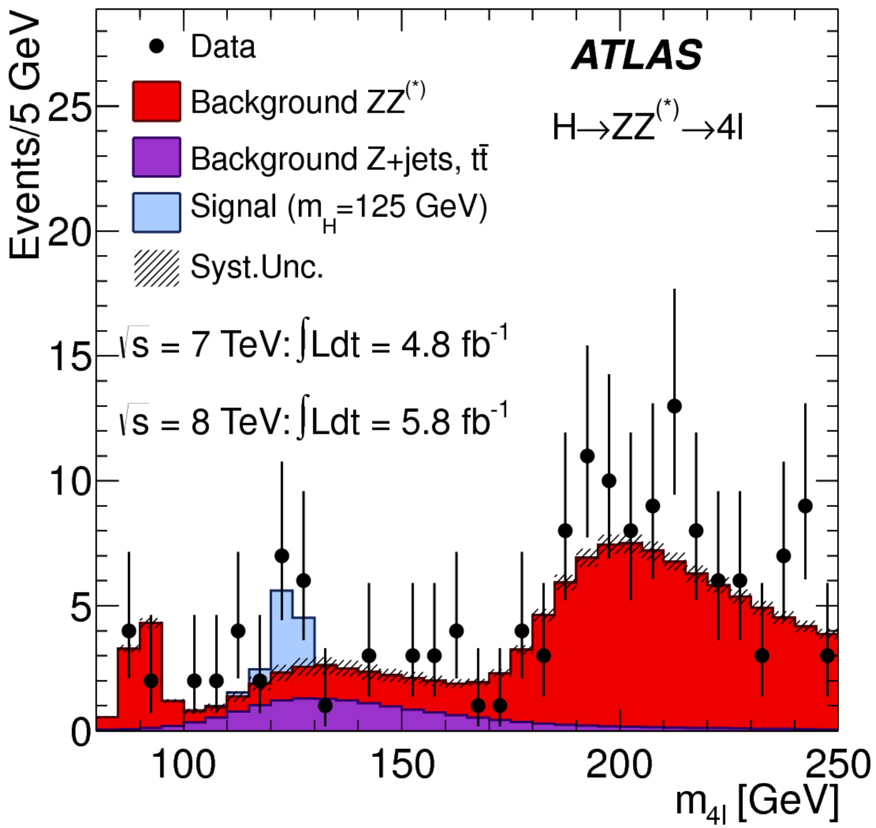


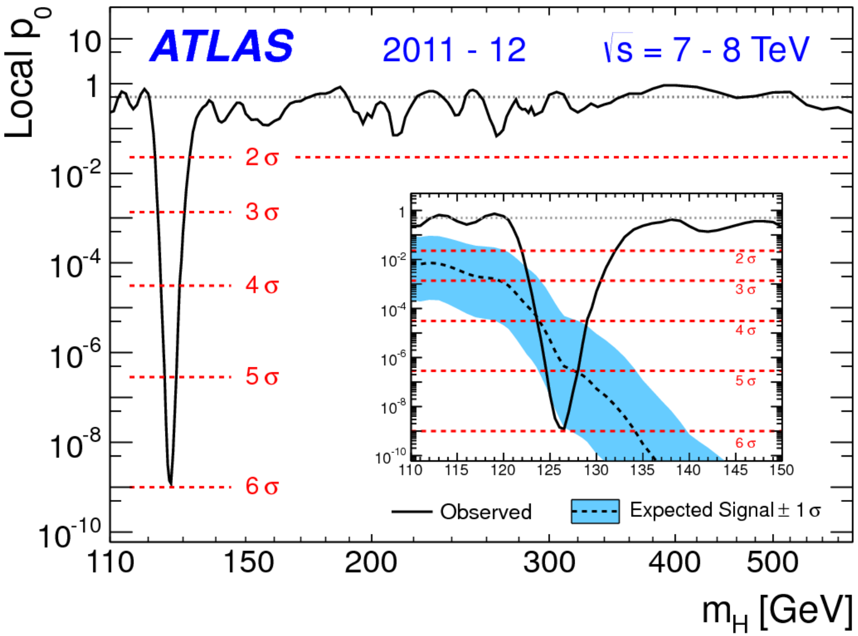
H → ZZ* → 4ℓ

“Golden channel” - excellent mass resolution and S/B~1

July 2012 - the new boson

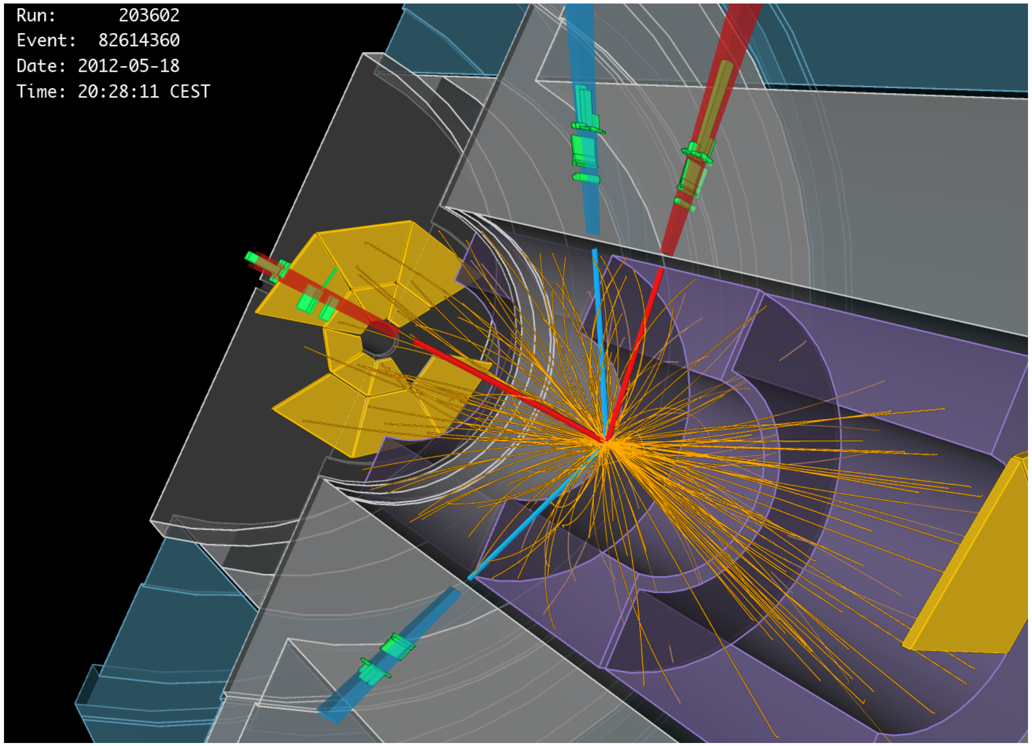


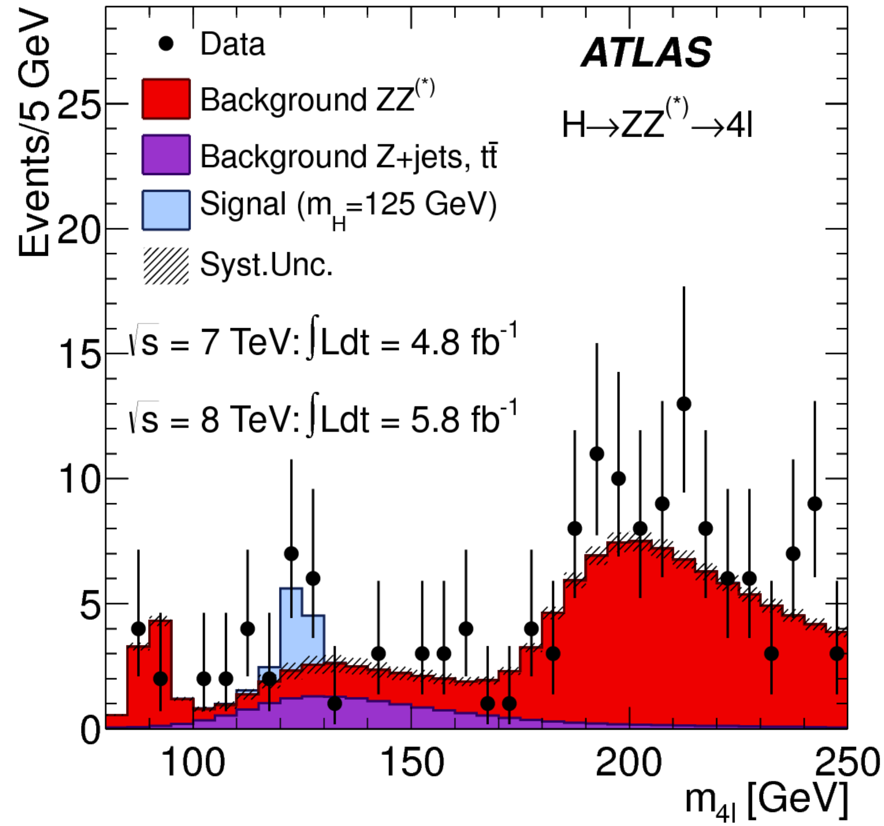


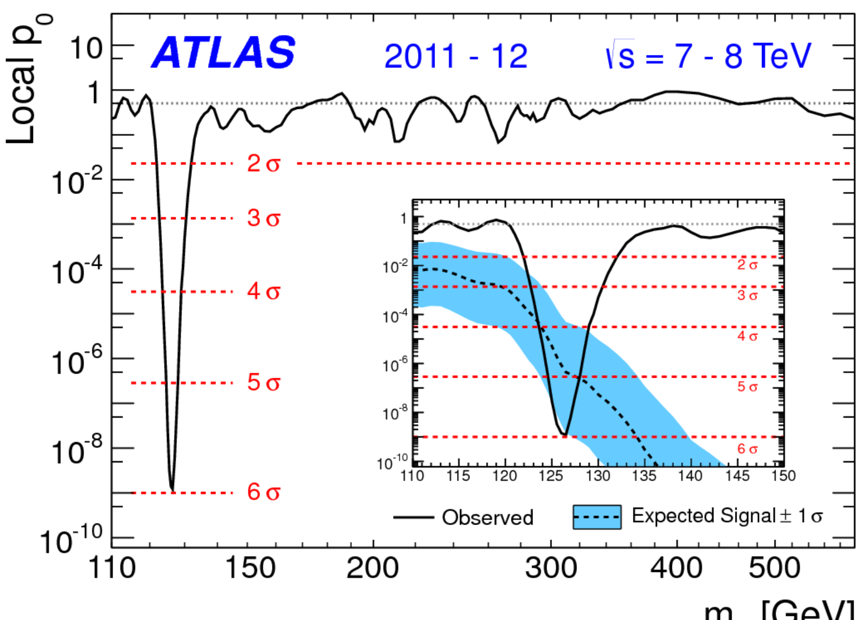


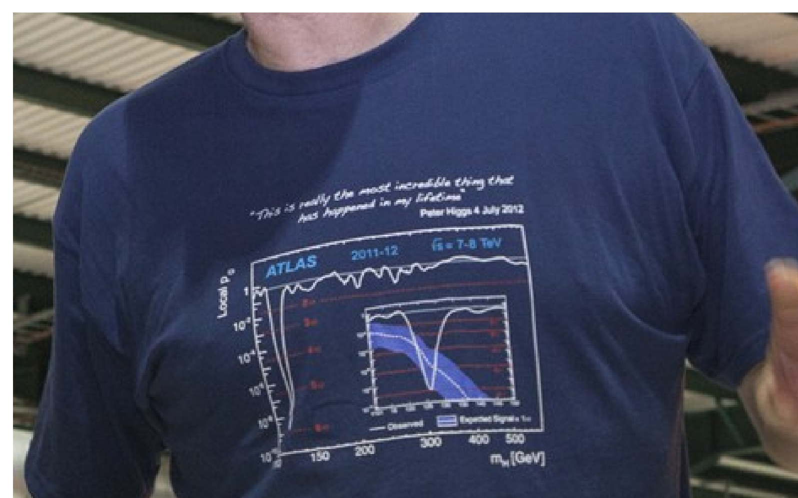
Combining γγ, 4ℓ and WW* channels
Overall significance (end July 2012) 5.9σ

July 2012 - the new boson









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Physics Letters B

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Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

>7700 citations!

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

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ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

1. Introduction

120–135 GeV; using the existing LHC constraints, the observed local significances for $m_H = 125$ GeV are 2.7σ for CDF [14], 1.1σ for

The end of physics?

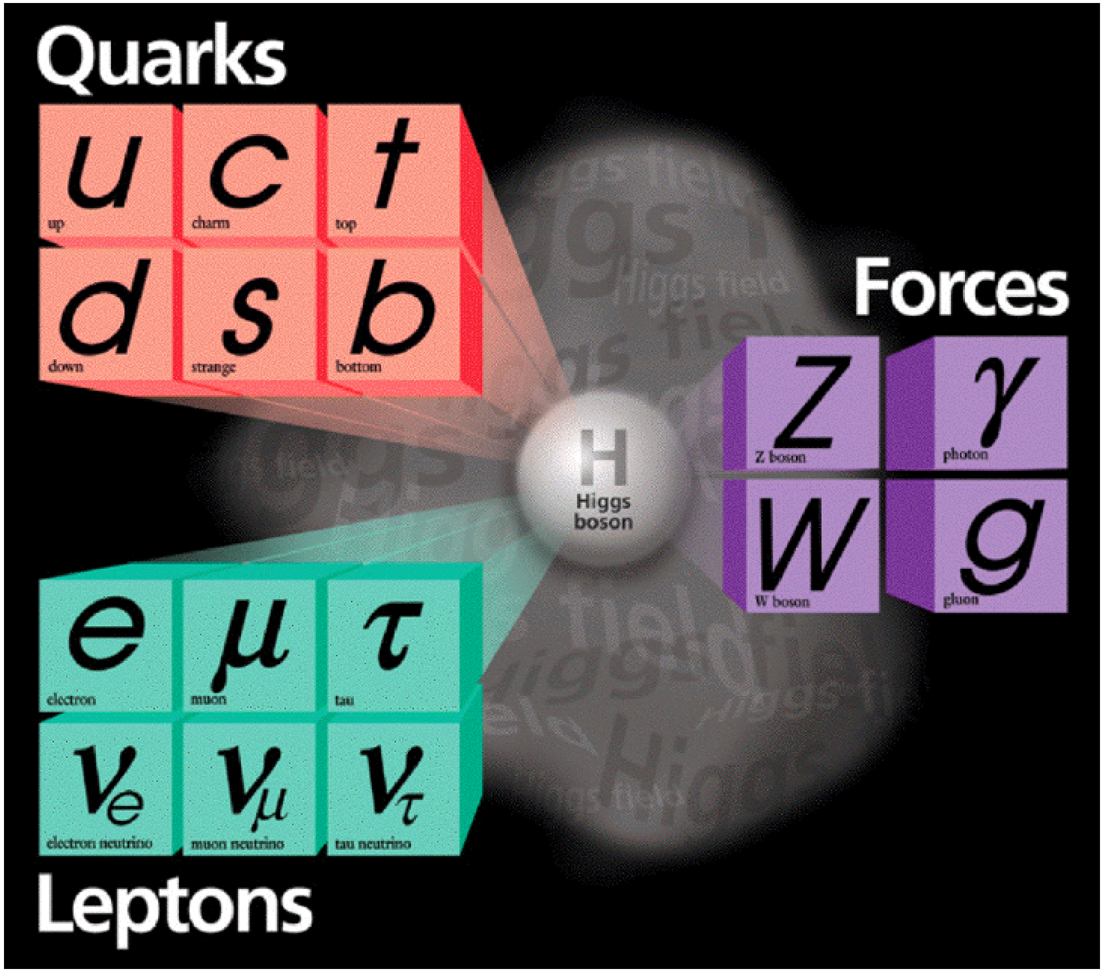
With the H discovery, we can identify all the particles in the SM with known states

But many questions are raised:

- Is it the *SM* Higgs boson?
- Is there *only one* scalar?
- Is the H(125) *solely* responsible for electroweak symmetry-breaking (EWSB)?
- Why is the H so light?

And we almost learned to stop asking the harder questions

- Why 3 generations of fermions?
- Why such *different* masses?
- Where is grand unification?
- What is dark matter & energy?
- Matter-antimatter asymmetry?
- Extra dimensions? Branes?



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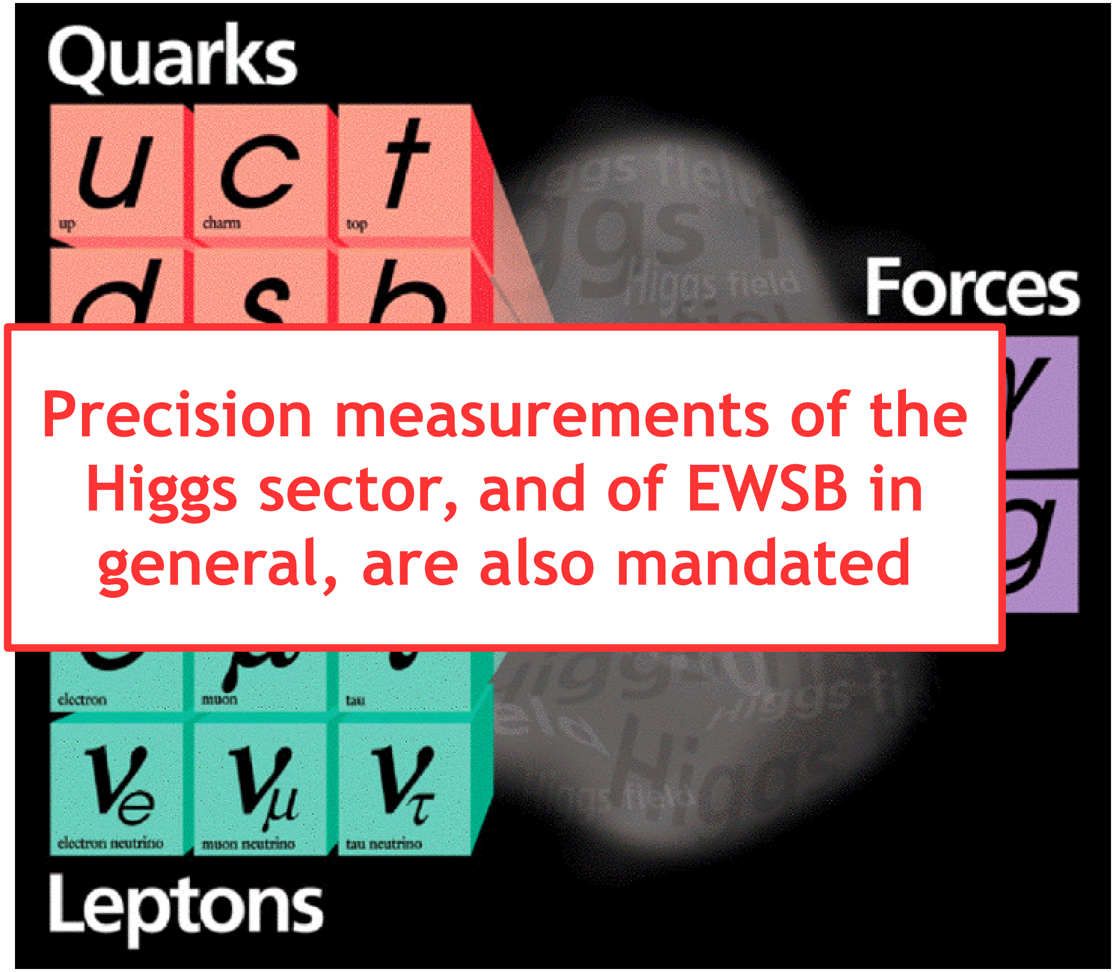

Precision measurements of the Higgs sector, and of EWSB in general, are also mandated

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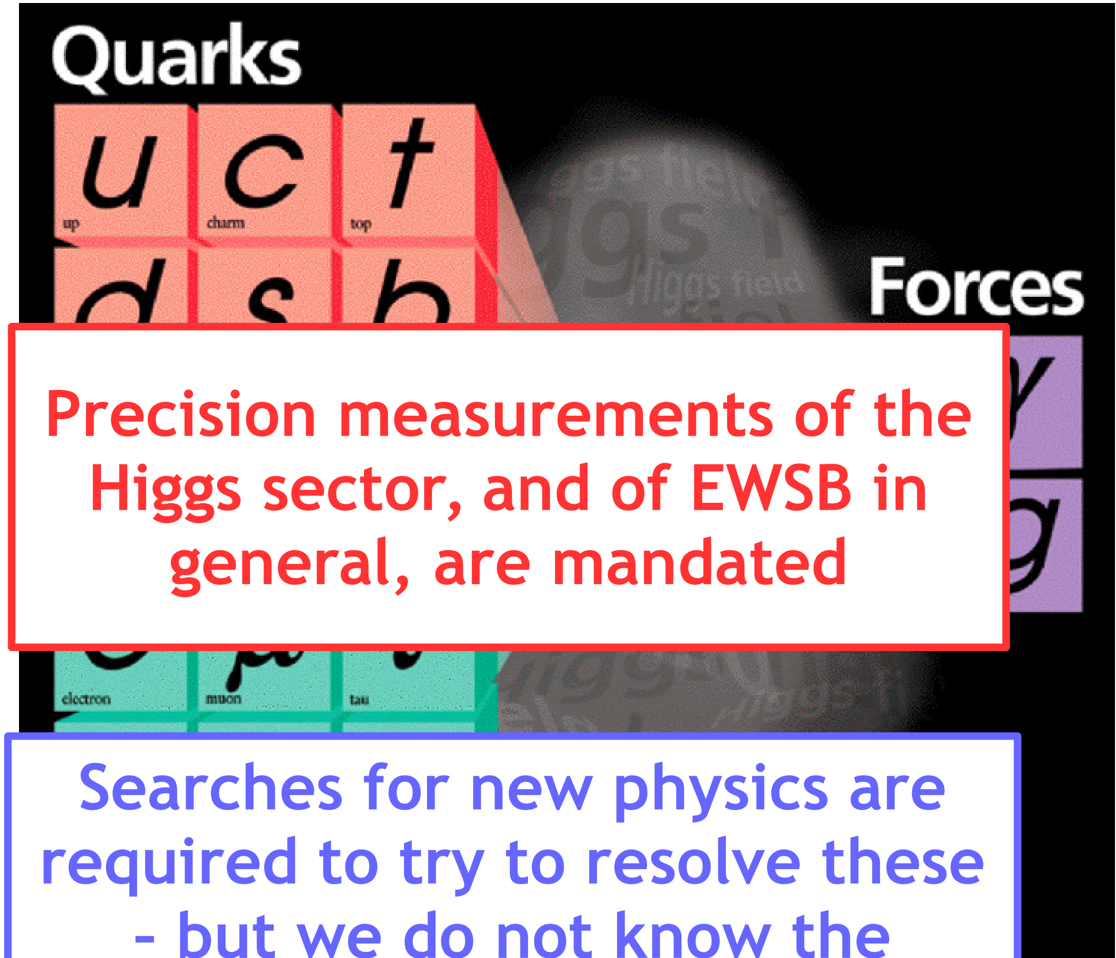
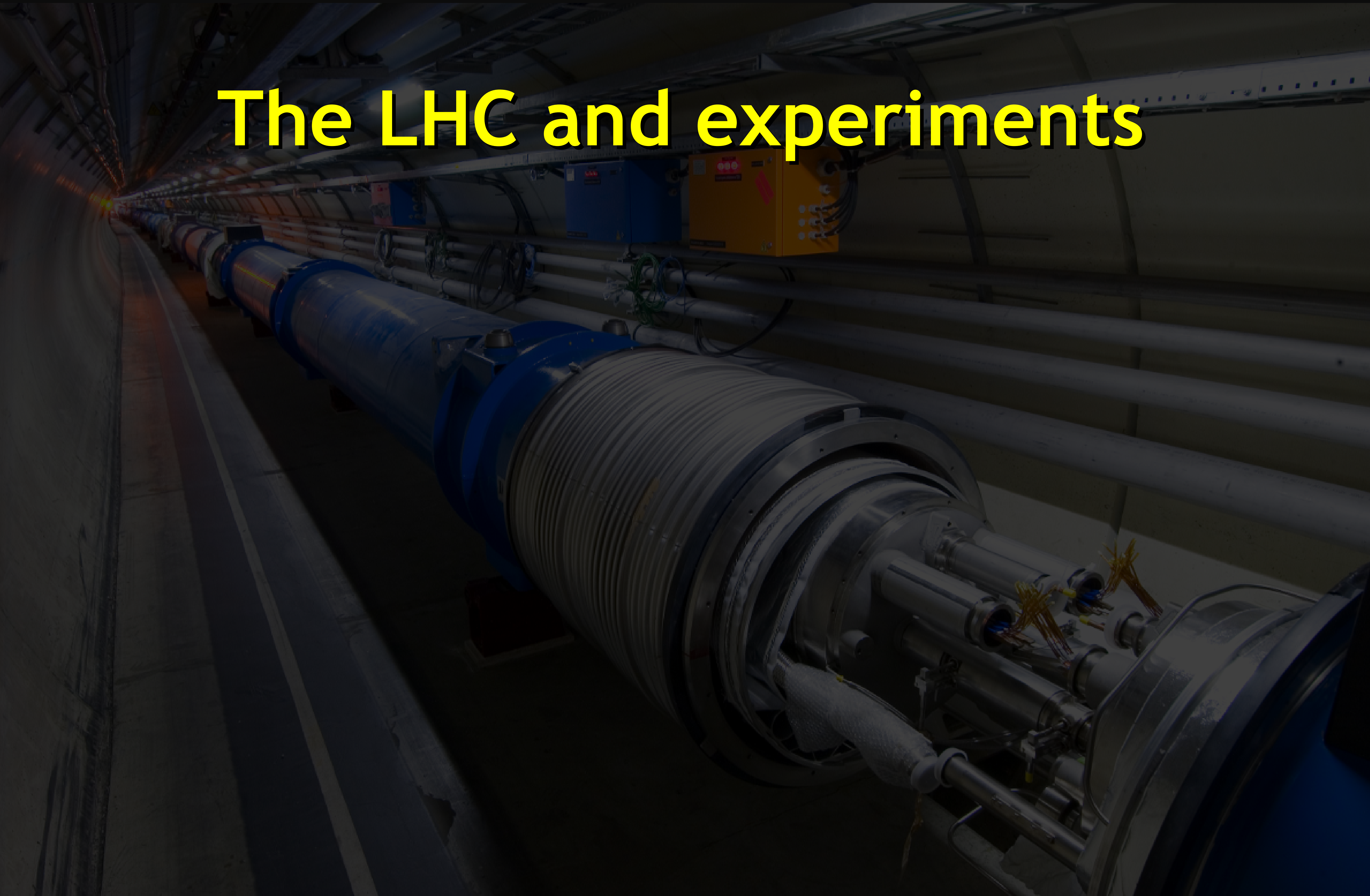


Precision measurements of the Higgs sector, and of EWSB in general, are mandated

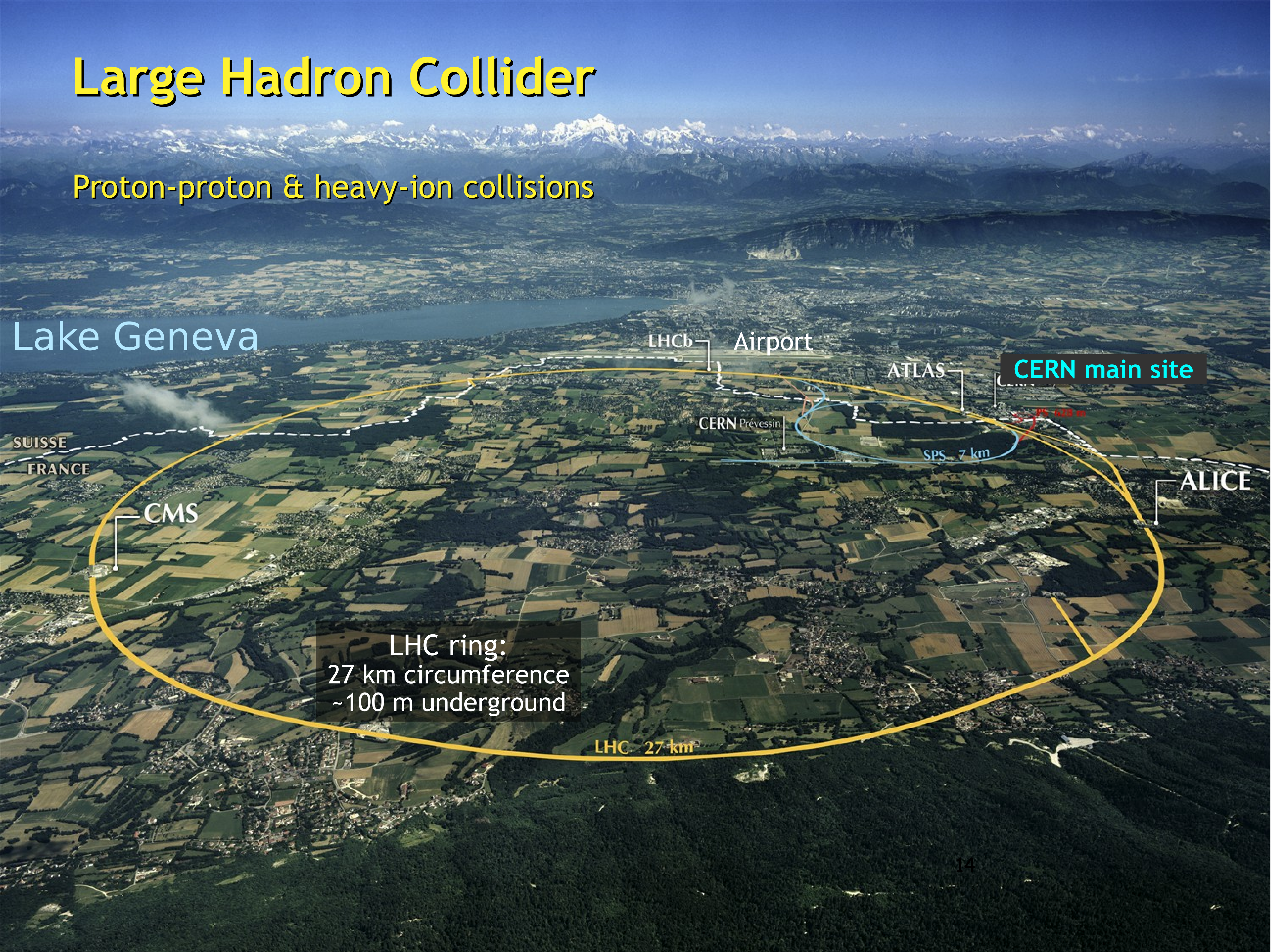
Searches for new physics are required to try to resolve these - but we do not know the energy scale of such beyond-SM physics, except for general indications that it should be in the TeV-scale range

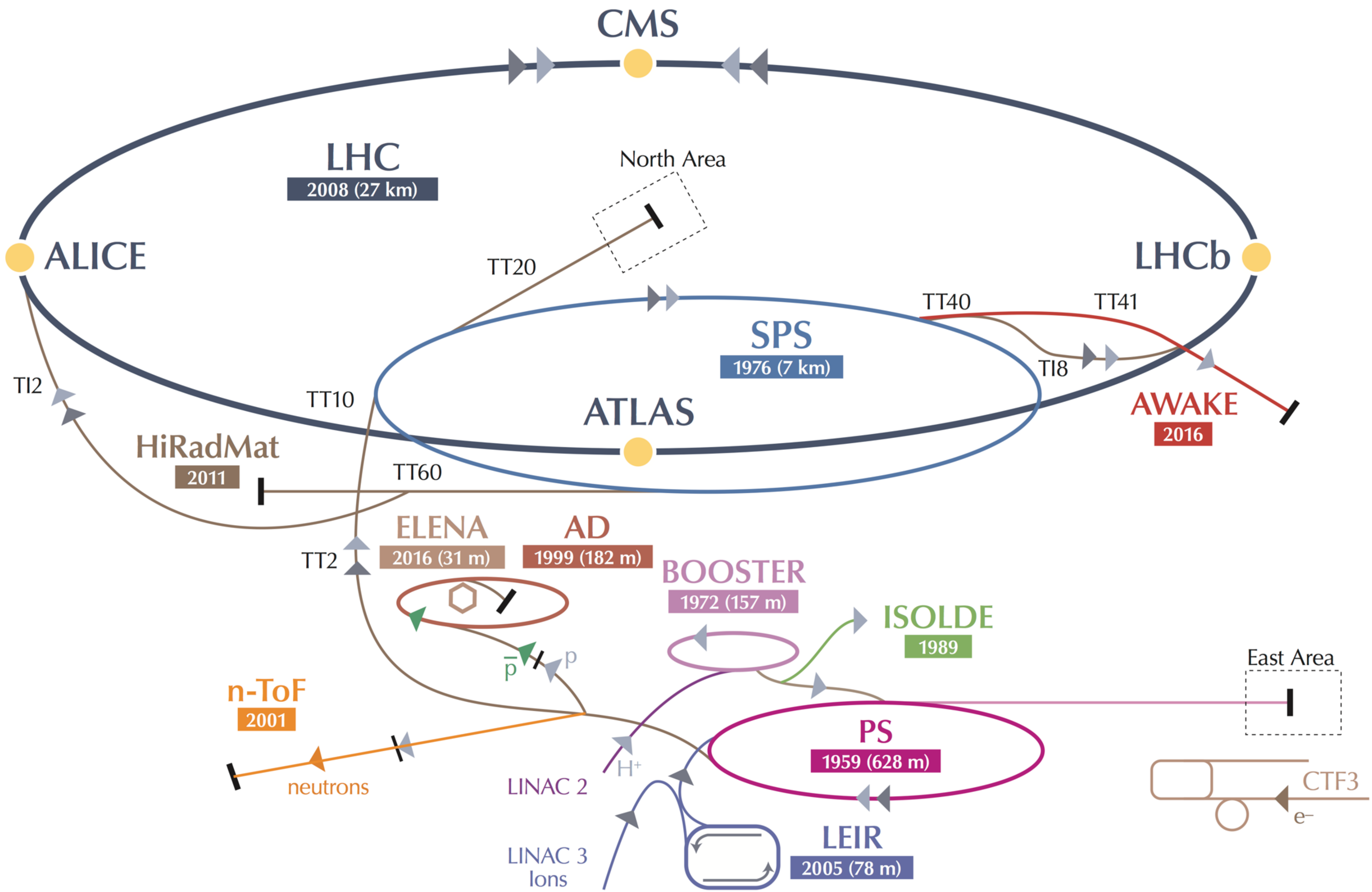
The LHC and experiments



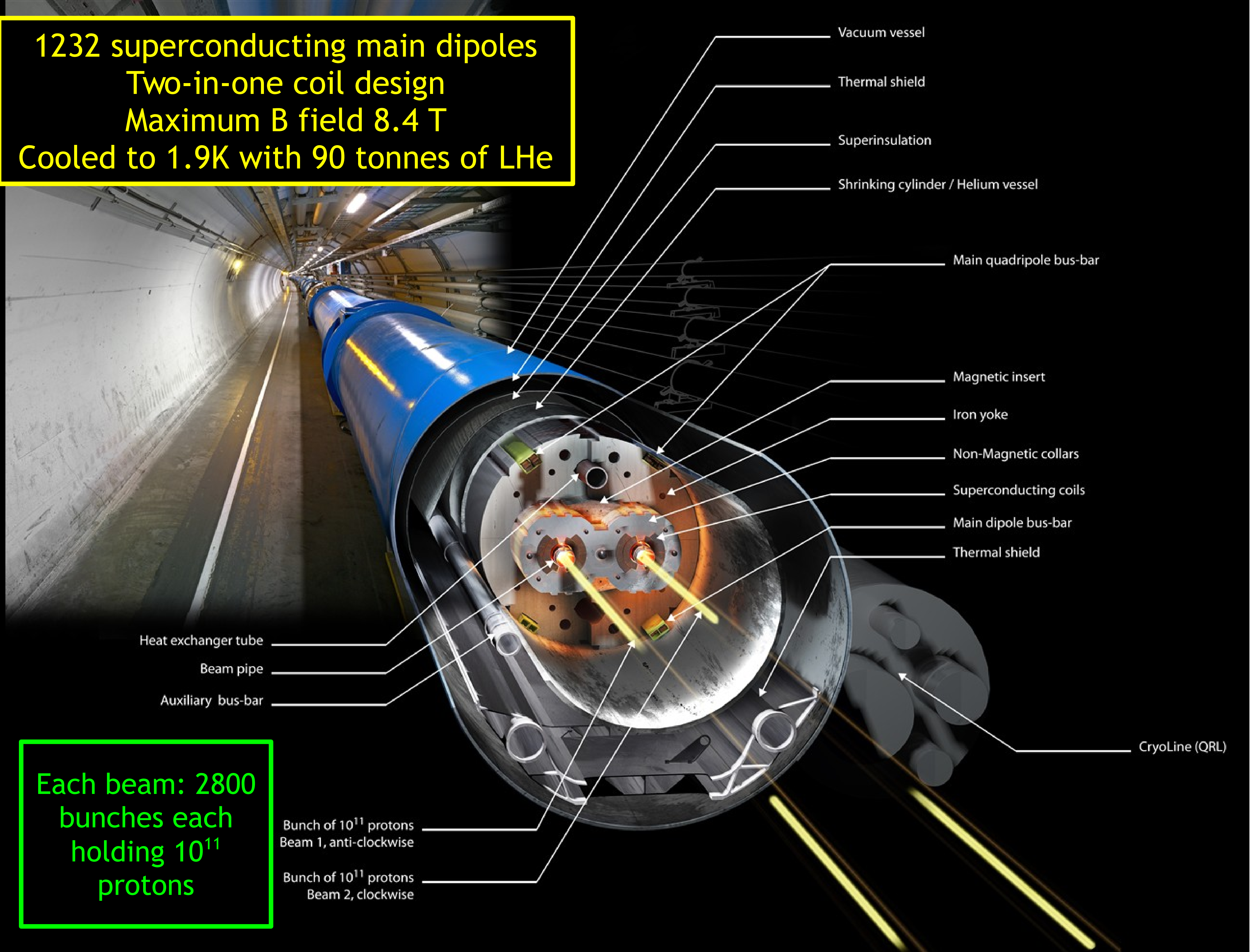
Large Hadron Collider

Proton-proton & heavy-ion collisions




CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
p̄
p
East Area
n-ToF
2001
PS
1959 (628 m)
neutrons
LINAC 2
H+
CTF3
e–
LEIR
2005 (78 m)
LINAC 3
Ions

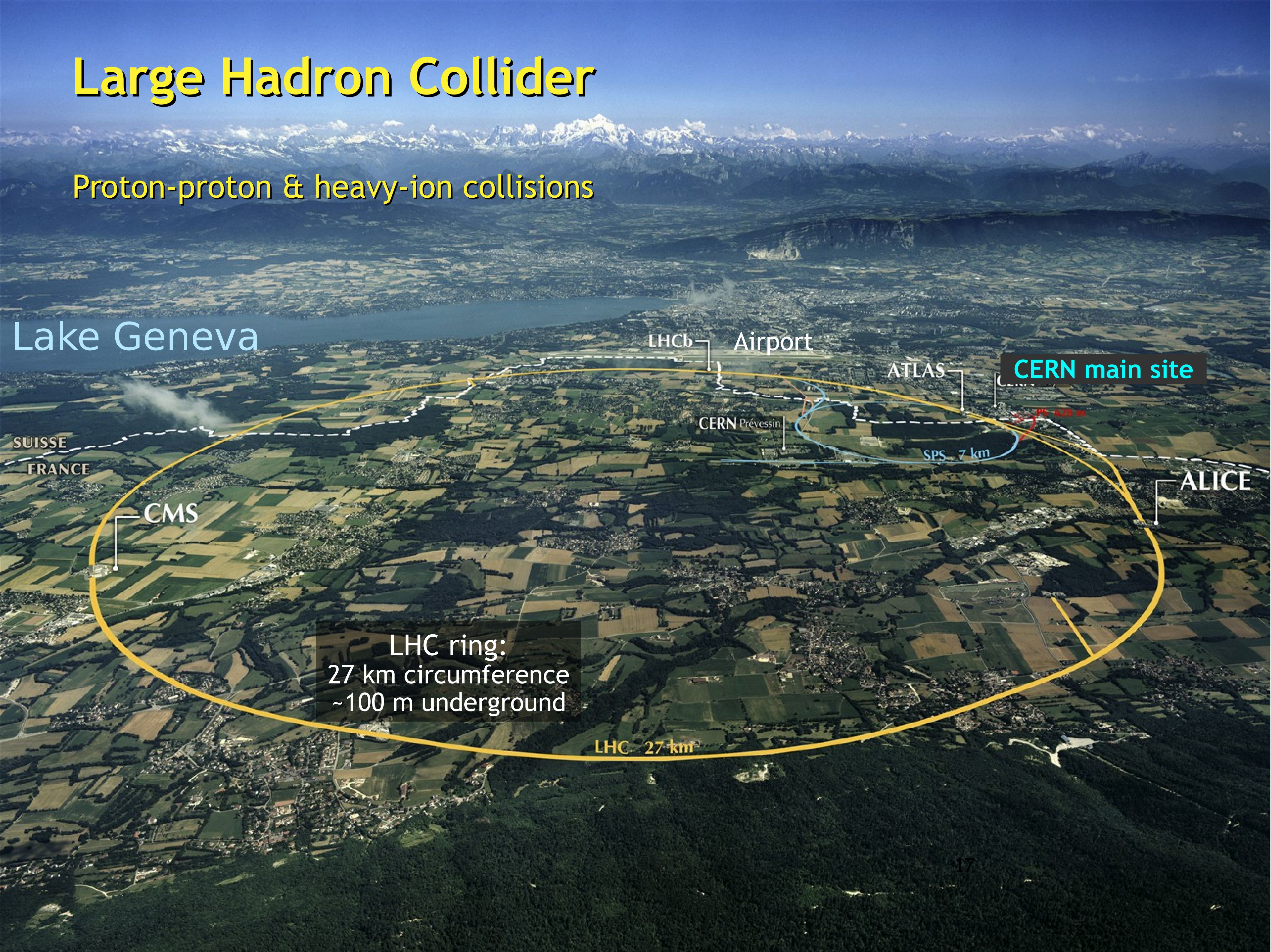
1232 superconducting main dipoles
Two-in-one coil design
Maximum B field 8.4 T
Cooled to 1.9K with 90 tonnes of LHe

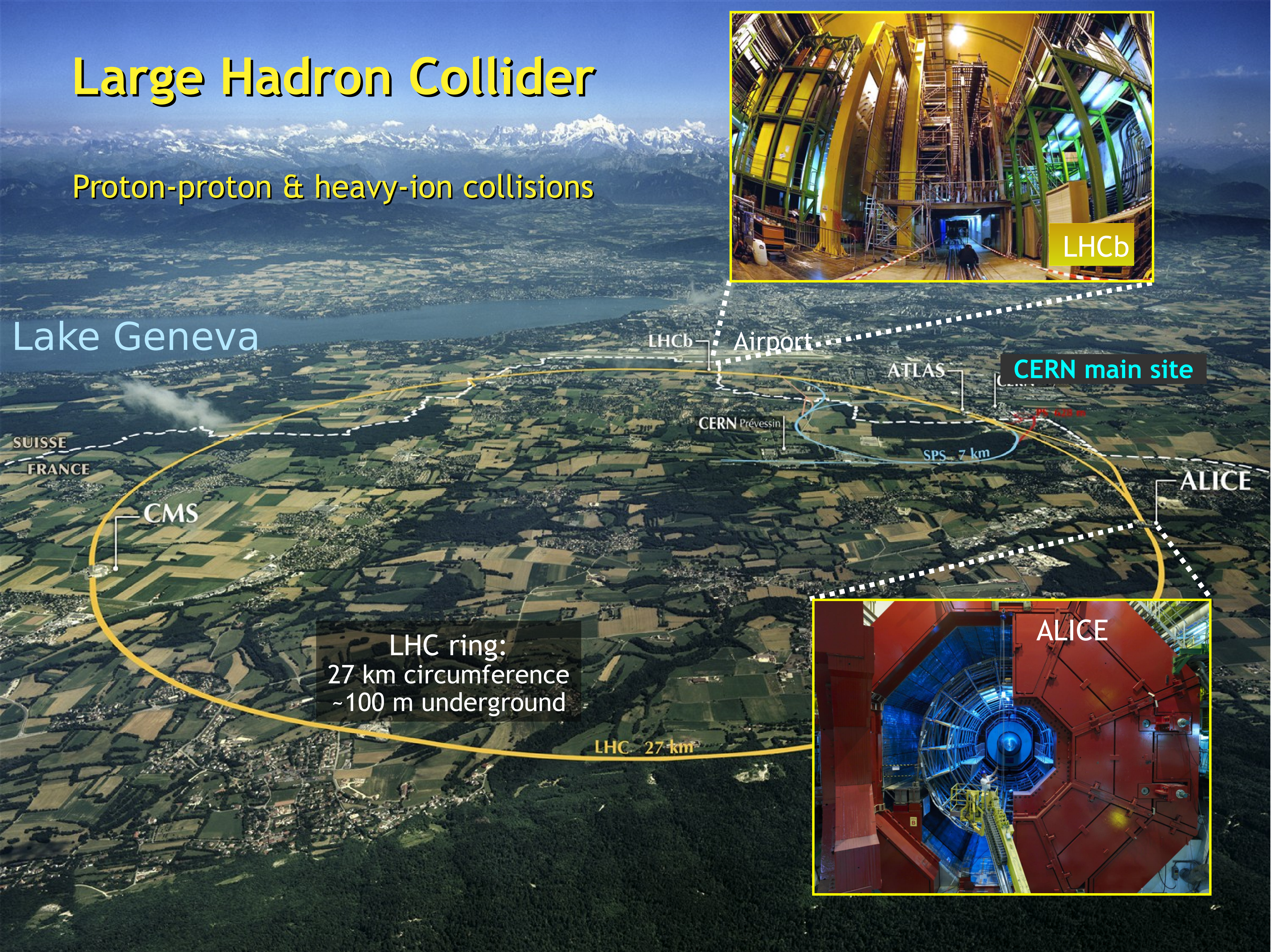


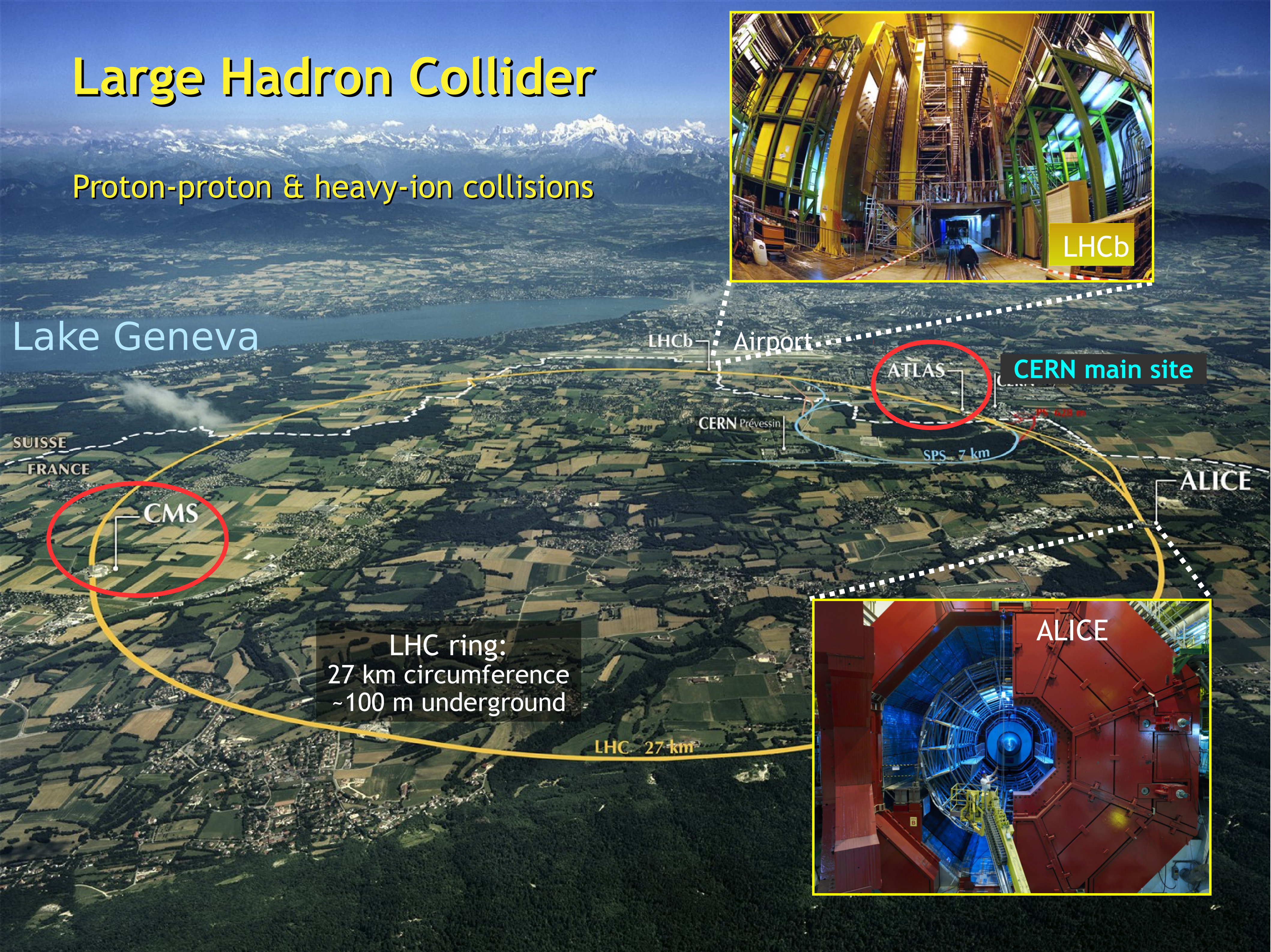
Each beam: 2800 bunches each holding 10^{11} protons

Large Hadron Collider

Proton-proton & heavy-ion collisions

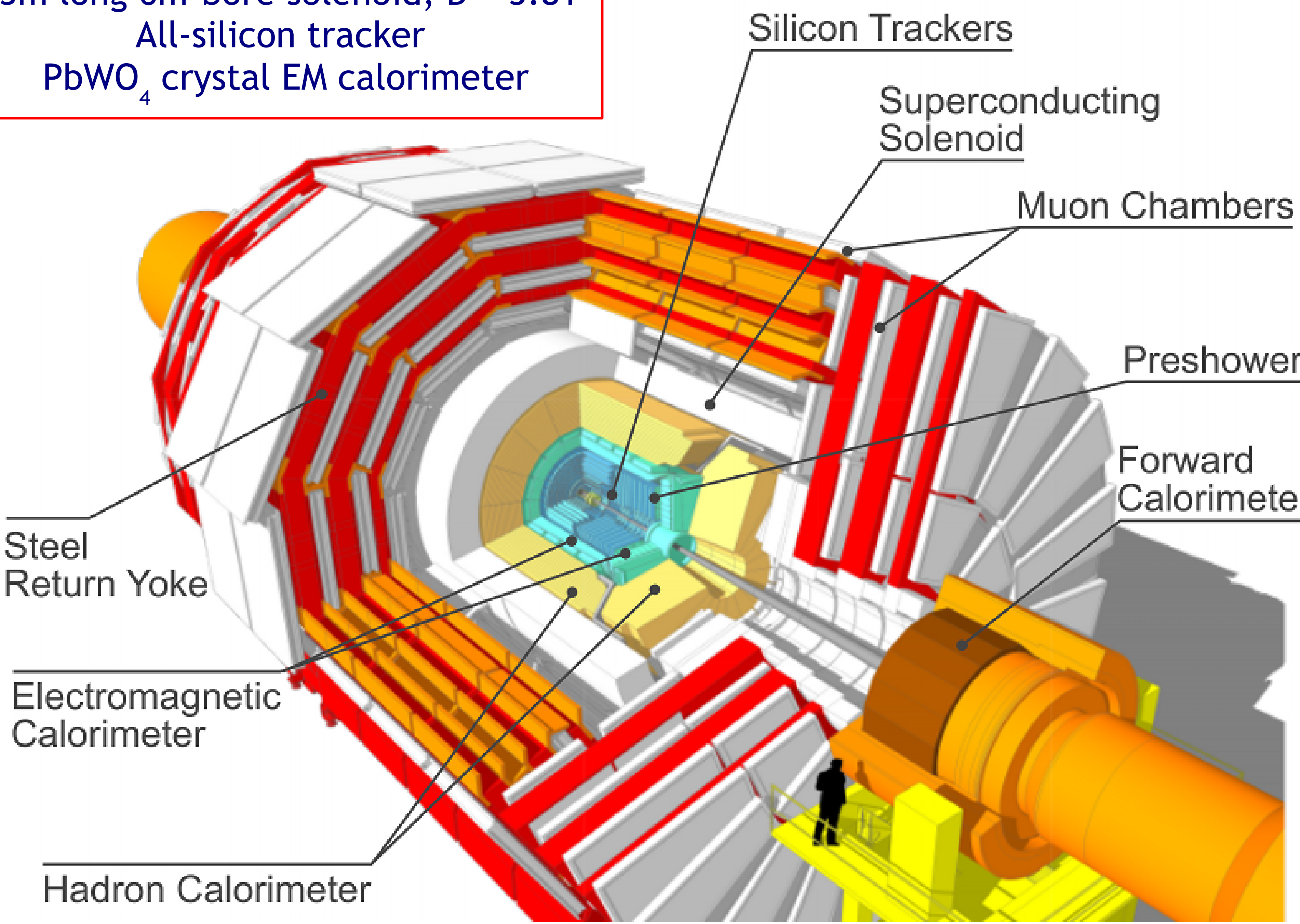



Large Hadron Collider
Proton-proton & heavy-ion collisions
Lake Geneva
LHCb
Airport
ATLAS
CERN main site
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC ring:
27 km circumference
~100 m underground
LHC 27 km
LHCb
ALICE

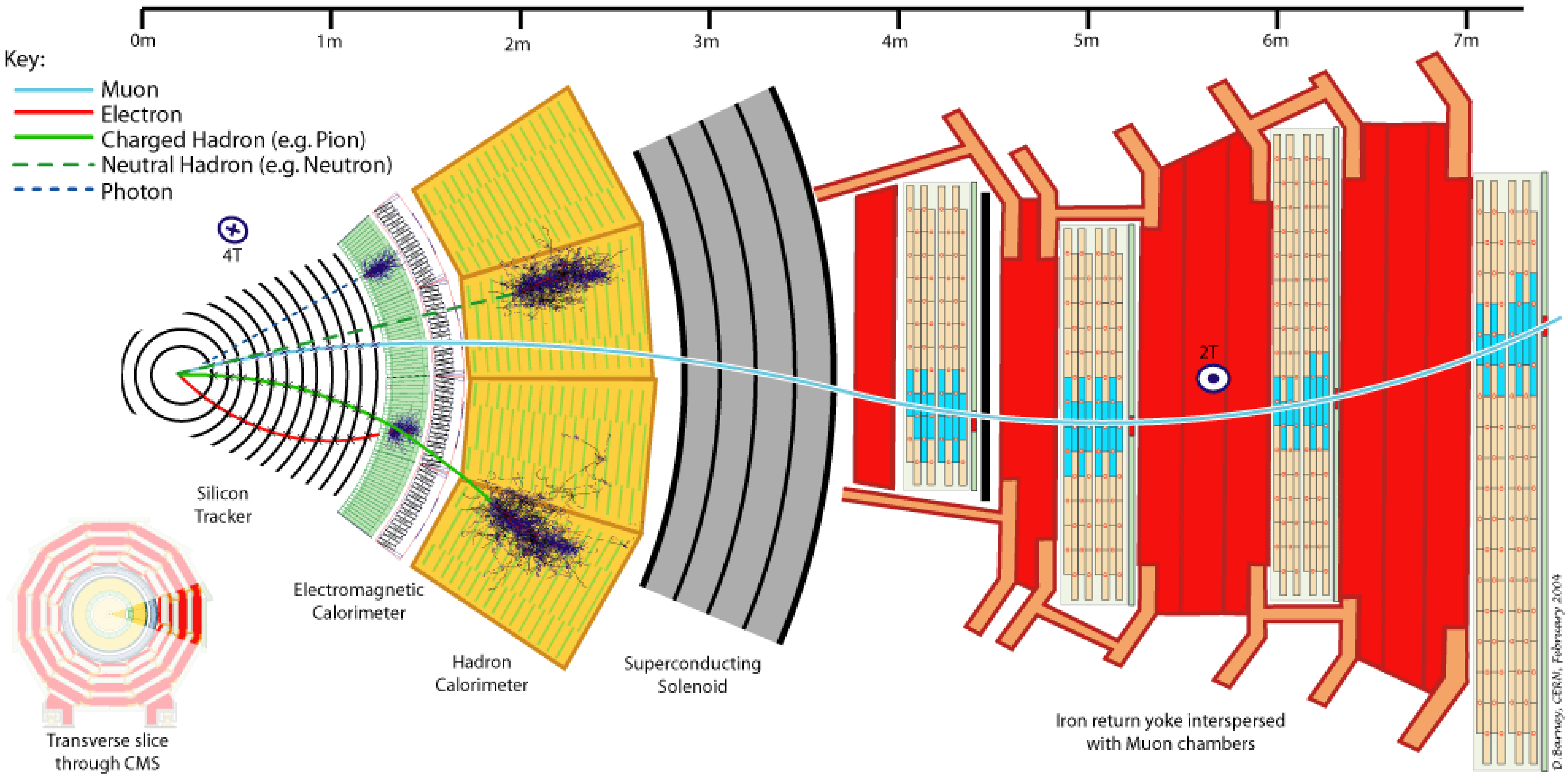

Large Hadron Collider
Proton-proton & heavy-ion collisions
LHCb
Lake Geneva
LHCb
Airport
ATLAS
CERN main site
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC ring:
27 km circumference
~100 m underground
LHC 27 km
ALICE

CMS Detector

14000t, 29m long x 15m diameter
13m long 6m-bore solenoid, B = 3.8T
All-silicon tracker
$PbWO_4$ crystal EM calorimeter



Detector principles

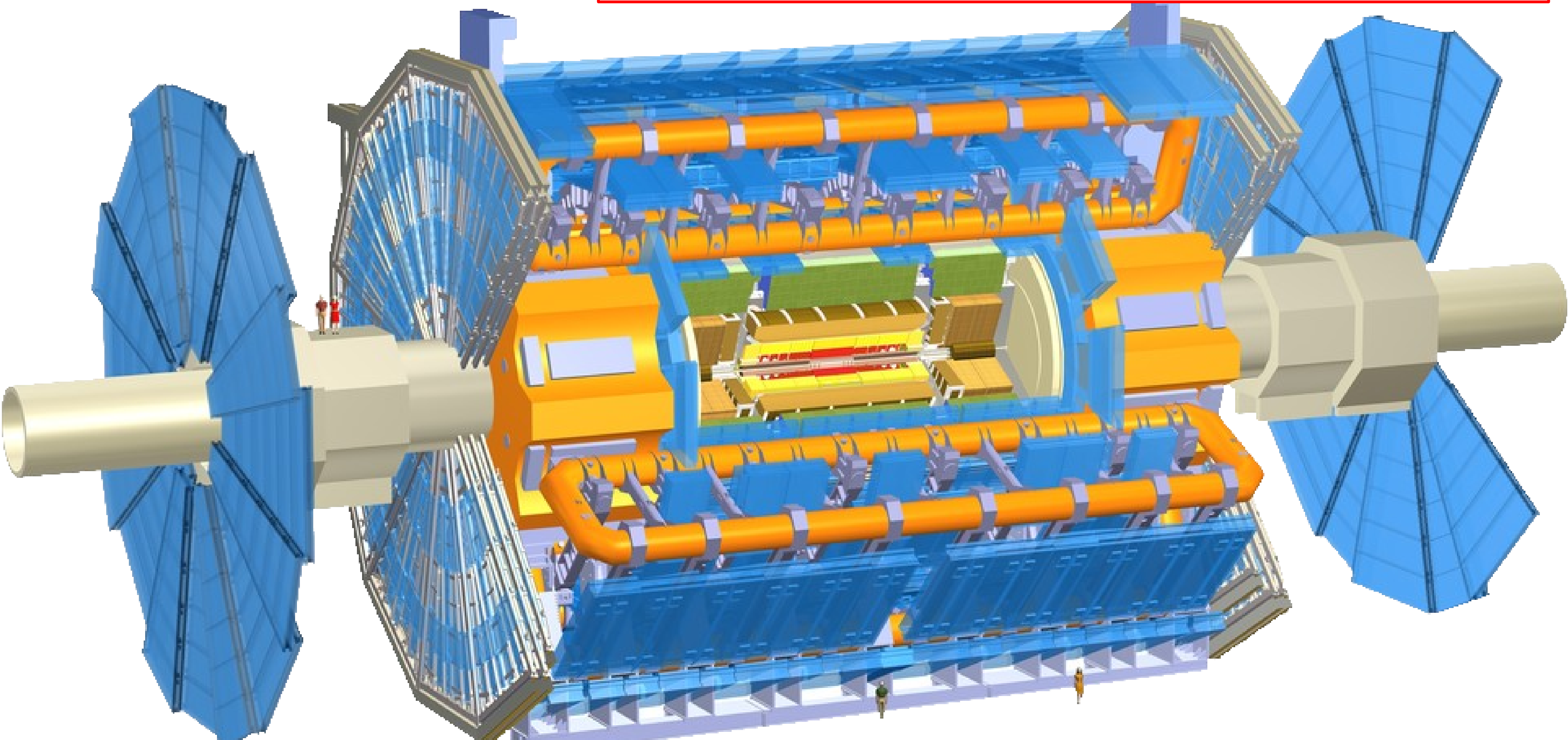


Multiple detector layers measure charged particle momenta (tracks), EM and hadronic energies (calorimetry), and provide particle identification from different signatures

Full event: missing transverse momentum balance can be used → sensitive to invisible particles (ν, new physics – dark matter?)

ATLAS Detector

7000t, 45m long x 25m diameter
Si+transition radiation tracker, 2T solenoid, LAr sampling calorimetry, large air-core muon system

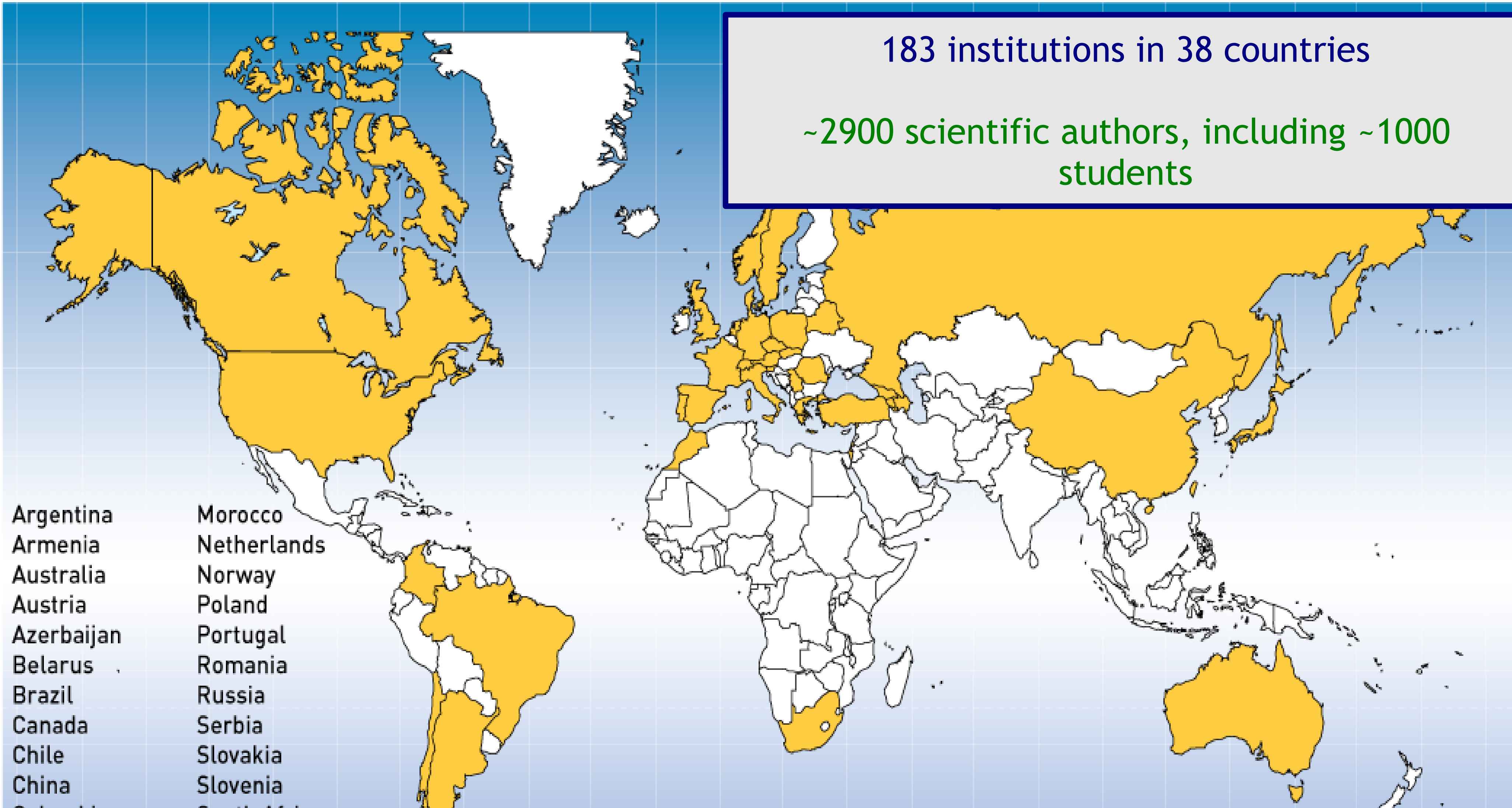


~110 M channels, with timing capable of separating particles from adjacent bunch-crossings (25ns)

Physical size allows precise momentum measurements and provides material depth to absorb TeV-energy jets of hadrons

183 institutions in 38 countries

~2900 scientific authors, including ~1000 students



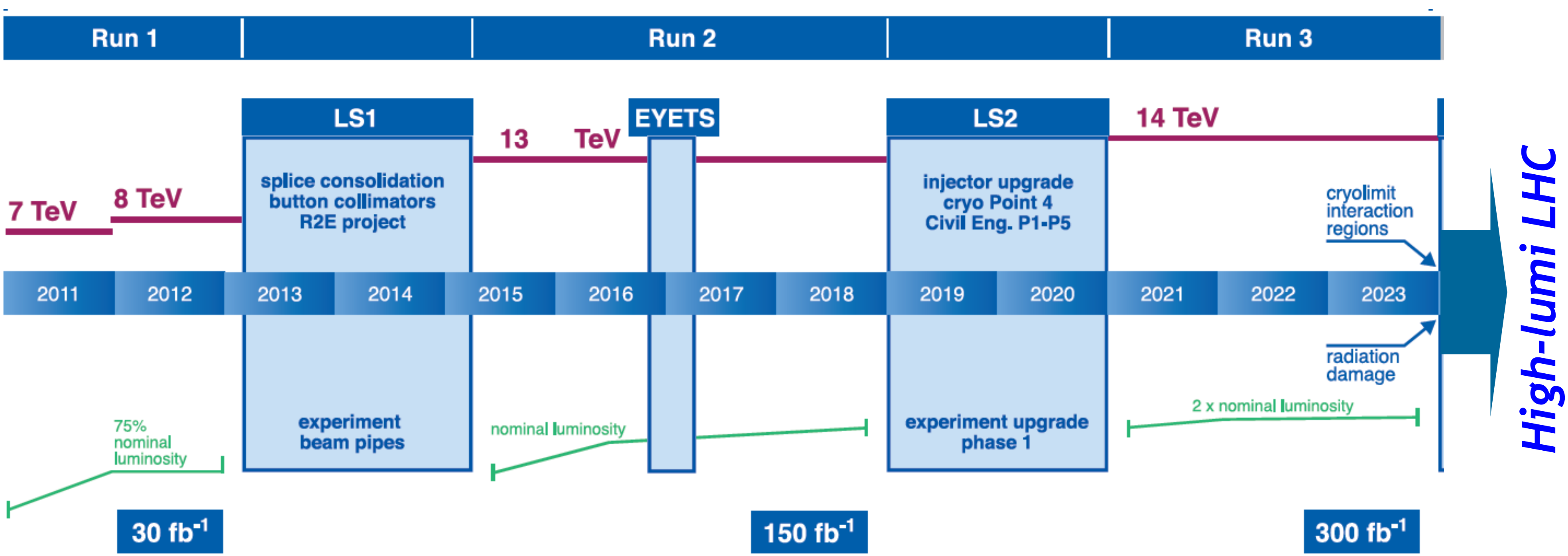
Adelaide, Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, UT Austin, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brazil Cluster, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, China IHEP-NJU-THU, China USTC-SDU-SJTU, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, Demokritos, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Harvard, Heidelberg, Hiroshima IT, Hong Kong, NTHU Hsinchu, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Kyushu, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QM London, RH London, UC London, Louisiana Tech, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, Northern Illinois University, Novosibirsk BINP-NSU, NPI Petersburg, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Rome I, Rome II, Rome III, RAL-STFC, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, South Africa Cluster, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Tomsk SU, Toronto, Trento, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBC Vancouver, Victoria, Warwick, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

The first decades of LHC operation

Run-1: little data and low energy!

Run-2: 13 TeV, much more data

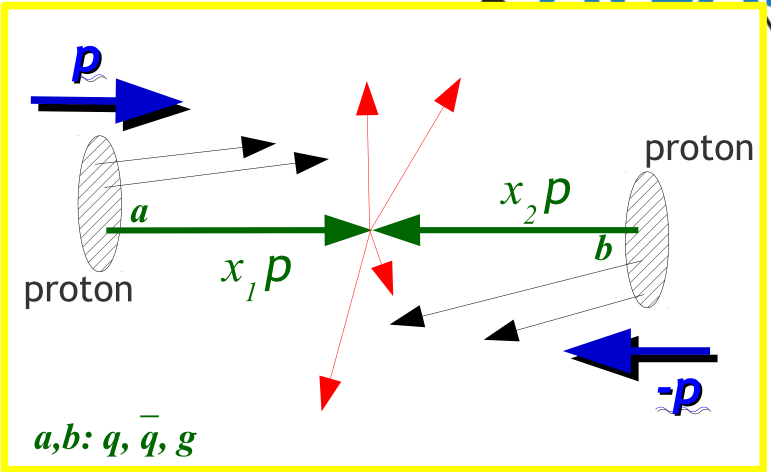
Run-3: 14 TeV, and doubling data again



Why we went to 13 TeV

"Interesting" processes come from hard scattering of partons

- Colliding *partons* carry a fraction of the proton momentum, x_i, according to a parton density function ("pdf")
- The partonic centre-of-mass energy is



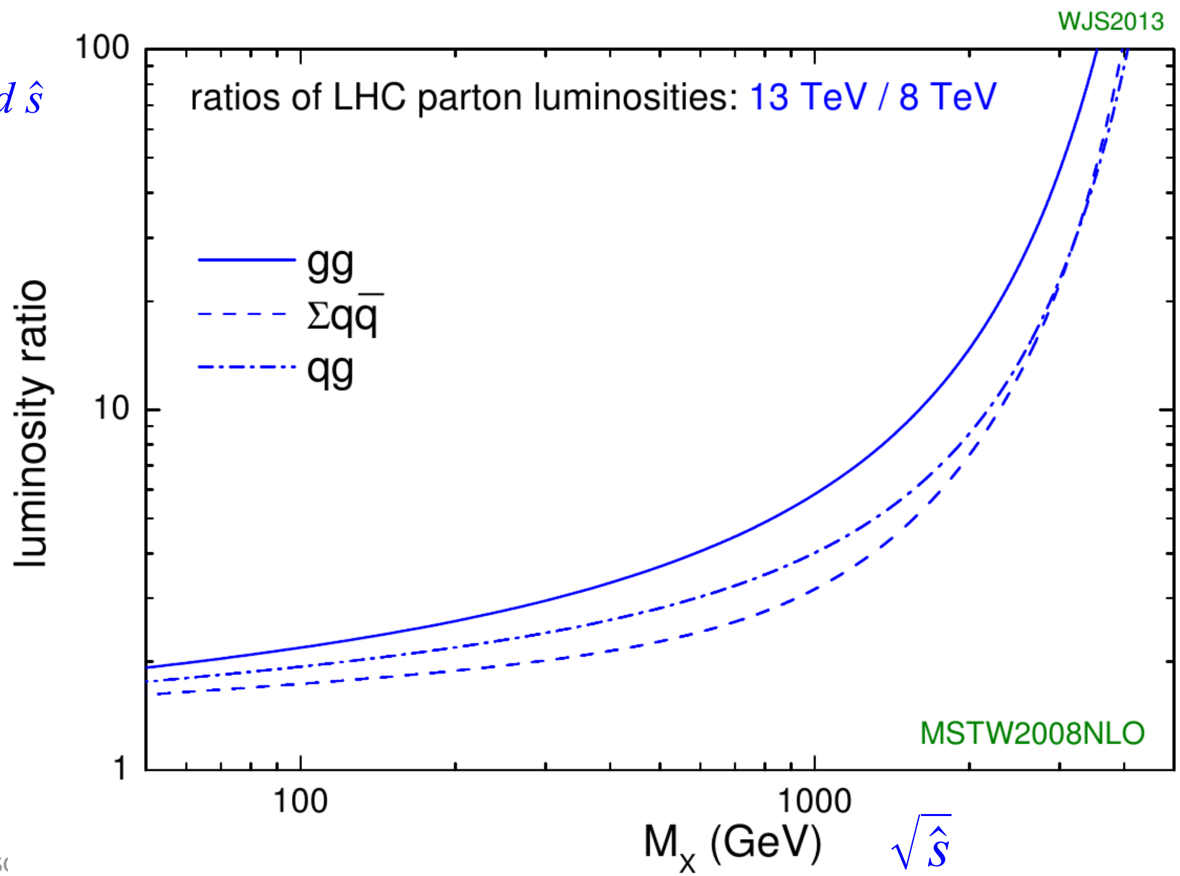
$$\sqrt{\hat{s}} = \sqrt{x_1 x_2 s} = M_X$$

$$\sigma = \sum_{\text{parton flavours } a,b} \int \hat{\sigma}(a,b) \left(\frac{dL(a,b)}{d\hat{s}} \right) d\hat{s}$$

- Parton-parton luminosity

$$\left(\frac{dL(a,b)}{d\hat{s}} \right)$$

Ratio of parton-parton luminosity for pp centre-of-mass energy (√s) 13 TeV / 8 TeV



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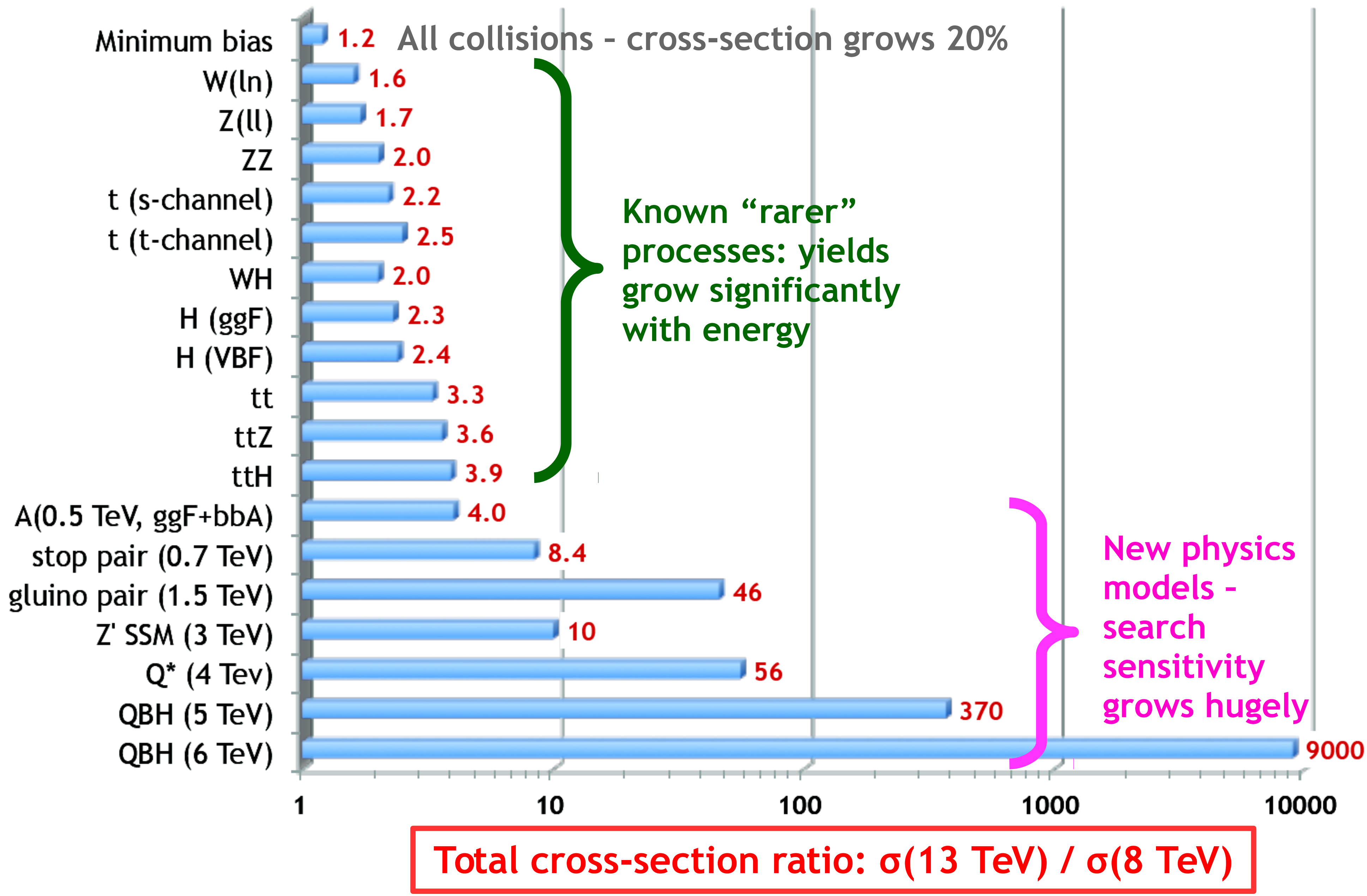


The main 2013-14 LHC consolidations

1695 Openings and final reclosures of the interconnections

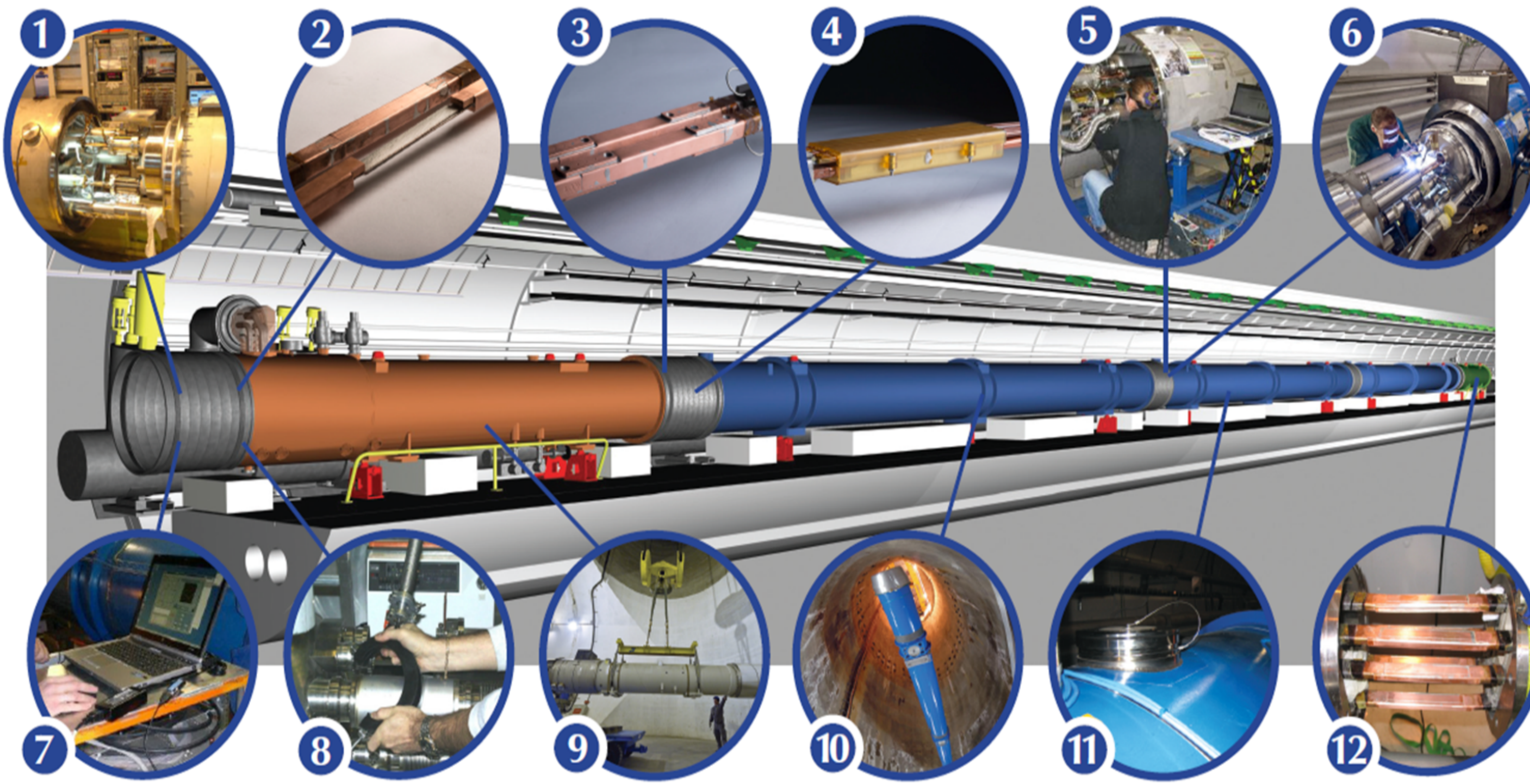
Complete reconstruction of 3000 of these splices

Consolidation of the 10170 13kA splices, installing 27 000 shunts

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

3 quadrupole magnets to be replaced

15 dipole magnets to be replaced

Installation of 612 pressure relief devices to bring the total to 1344

Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes

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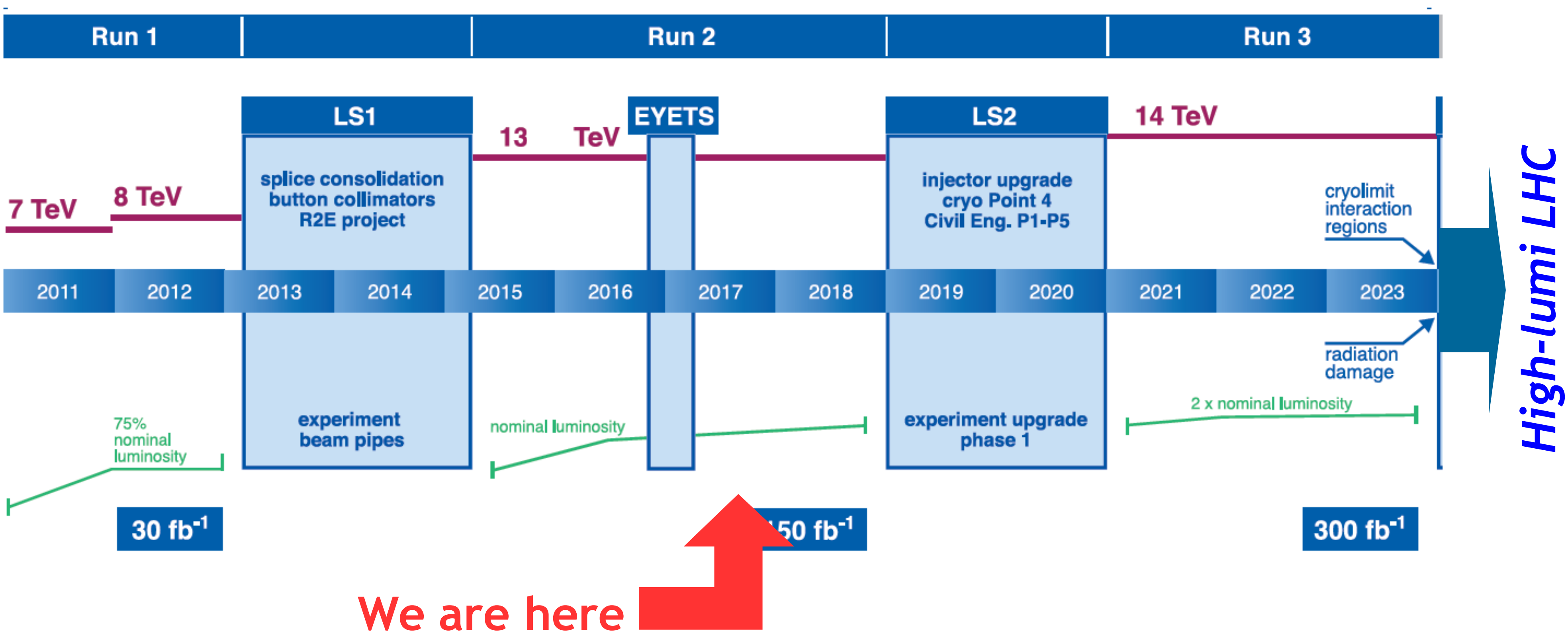

Half-way through the "standard lumi LHC" era in time,
~ a third of the way in terms of integrated luminosity

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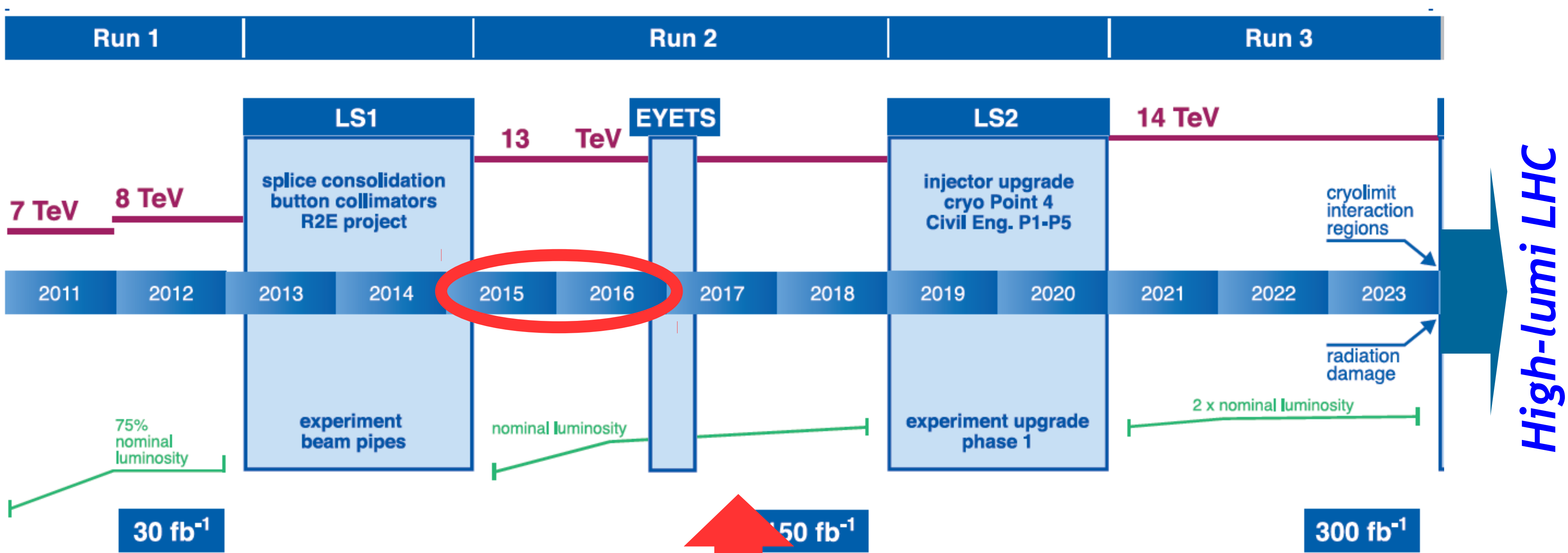


We are here

Half-way through the "standard lumi LHC" era in time,
~ a third of the way in terms of integrated luminosity

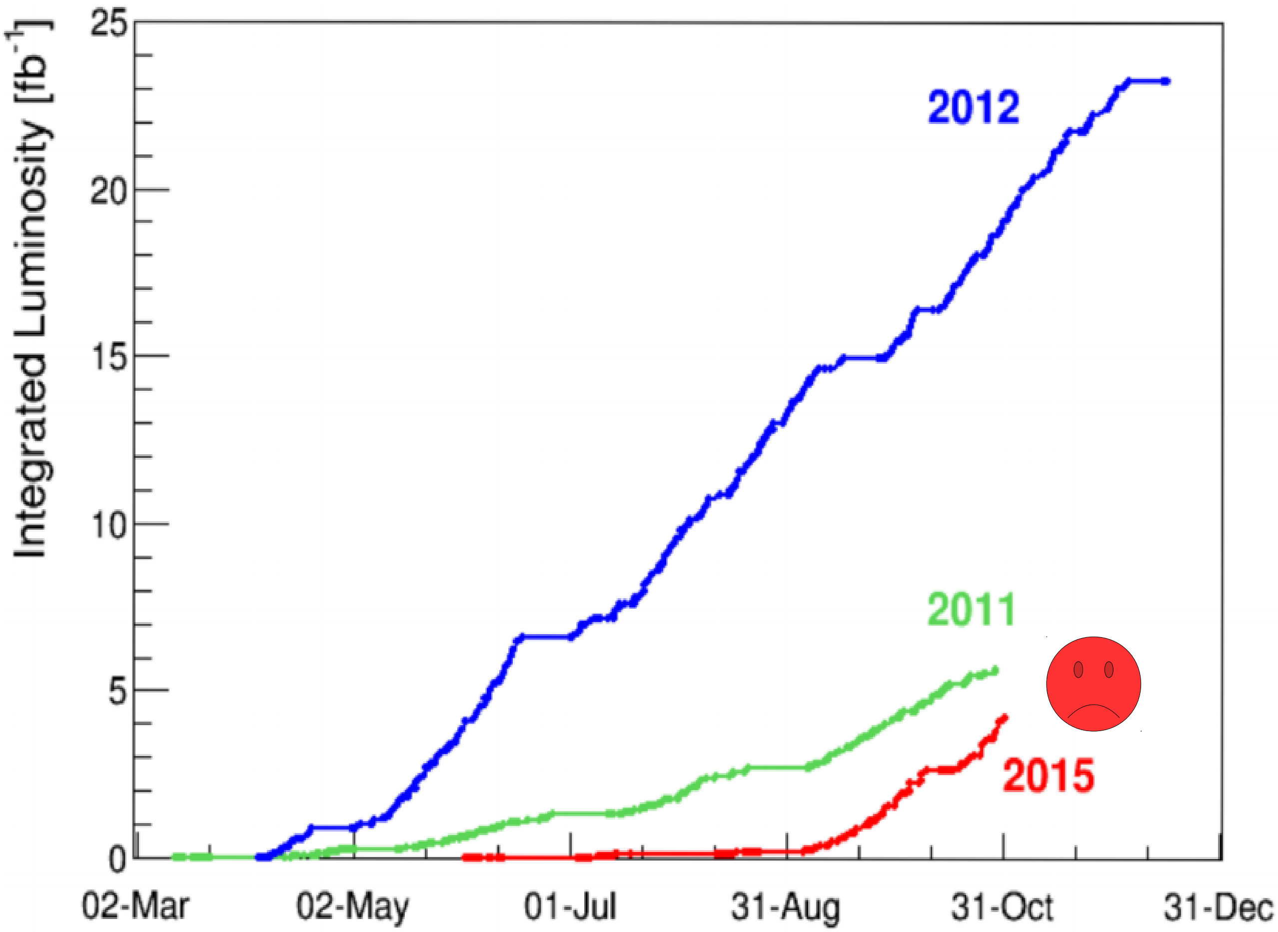
2015 - the restart at 13 TeV

Integrated luminosity $\int Ldt$ drives the signal event yield N_{obs}

$$N_{obs} = \sigma \, \varepsilon_{exp} \int Ldt$$

σ: cross-section $\sigma(\sqrt{s})$
ε_{exp}: *experimental efficiency*

Almost like starting a brand new accelerator: a late start in the year, and various problems after the two-year stop
A slow year...



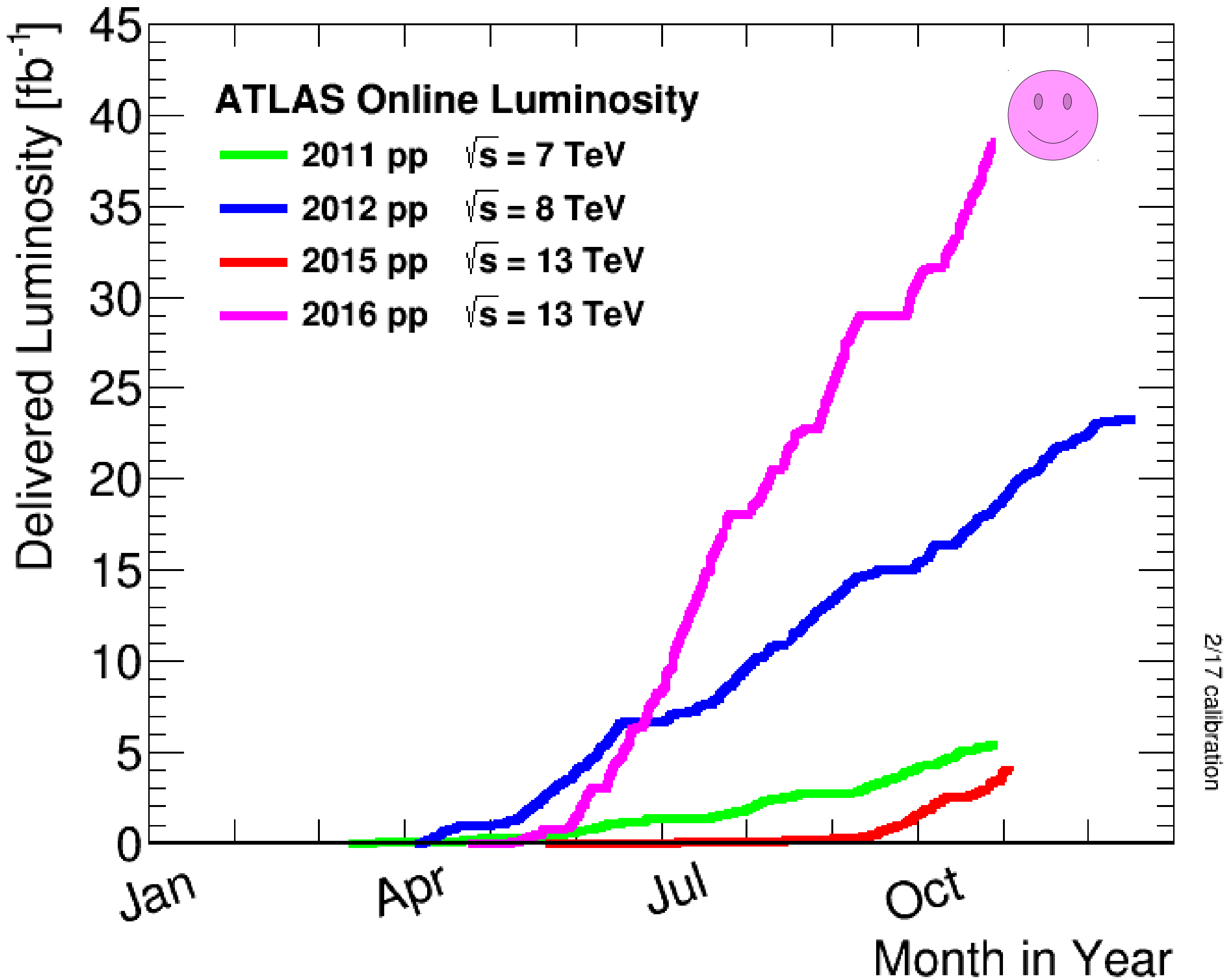
2016 - a great production year

Integrated luminosity $\int Ldt$ drives the signal event yield N_{obs}

$$\boxed{N_{obs} = \sigma\, \varepsilon_{exp} \int Ldt}$$

σ: cross-section $\sigma(\sqrt{s})$
ε_{exp}: *experimental efficiency*

More integrated luminosity in 2016 than in all previous years together!



2017 - another good year

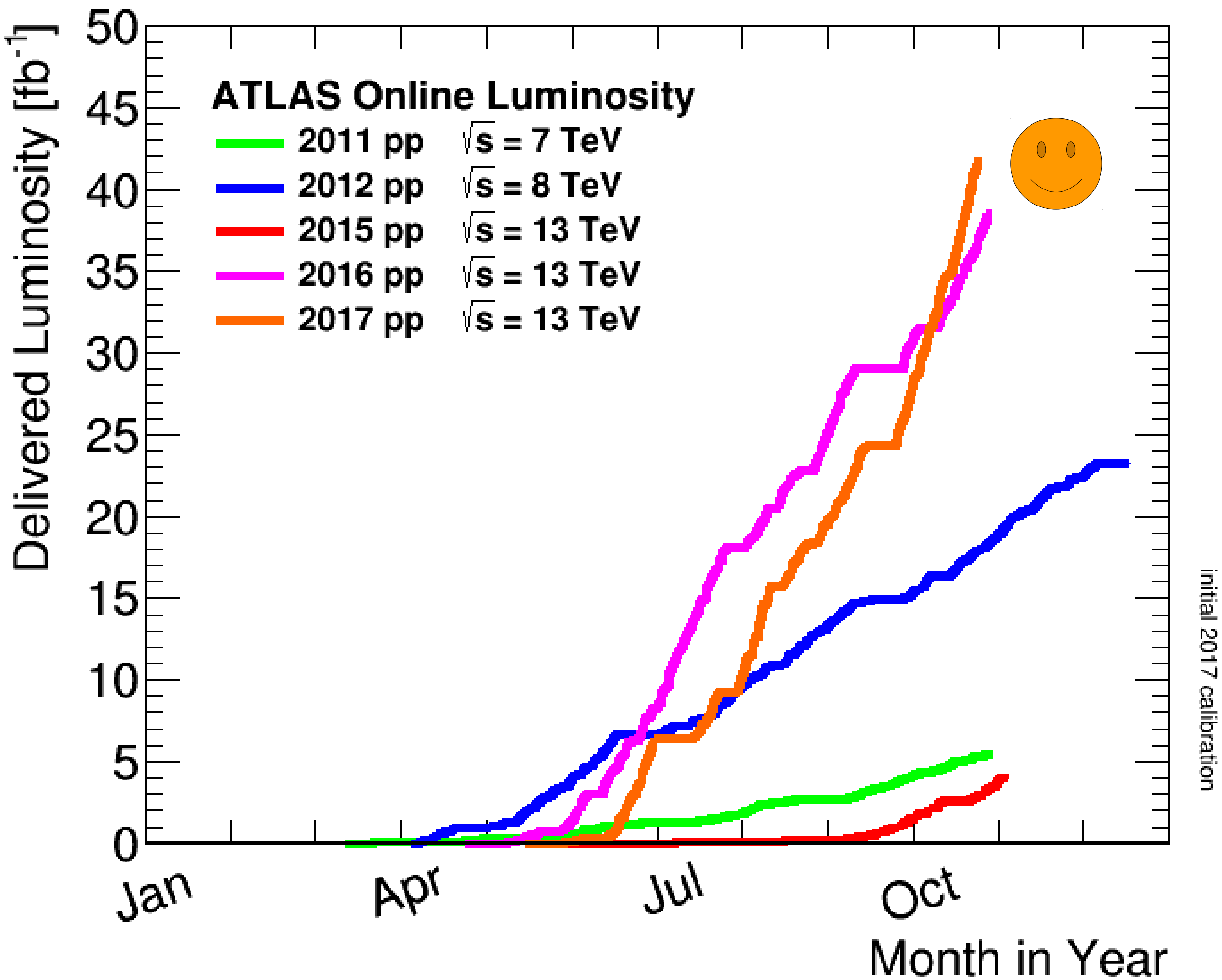
Integrated luminosity $\int Ldt$ drives the signal event yield N_{obs}

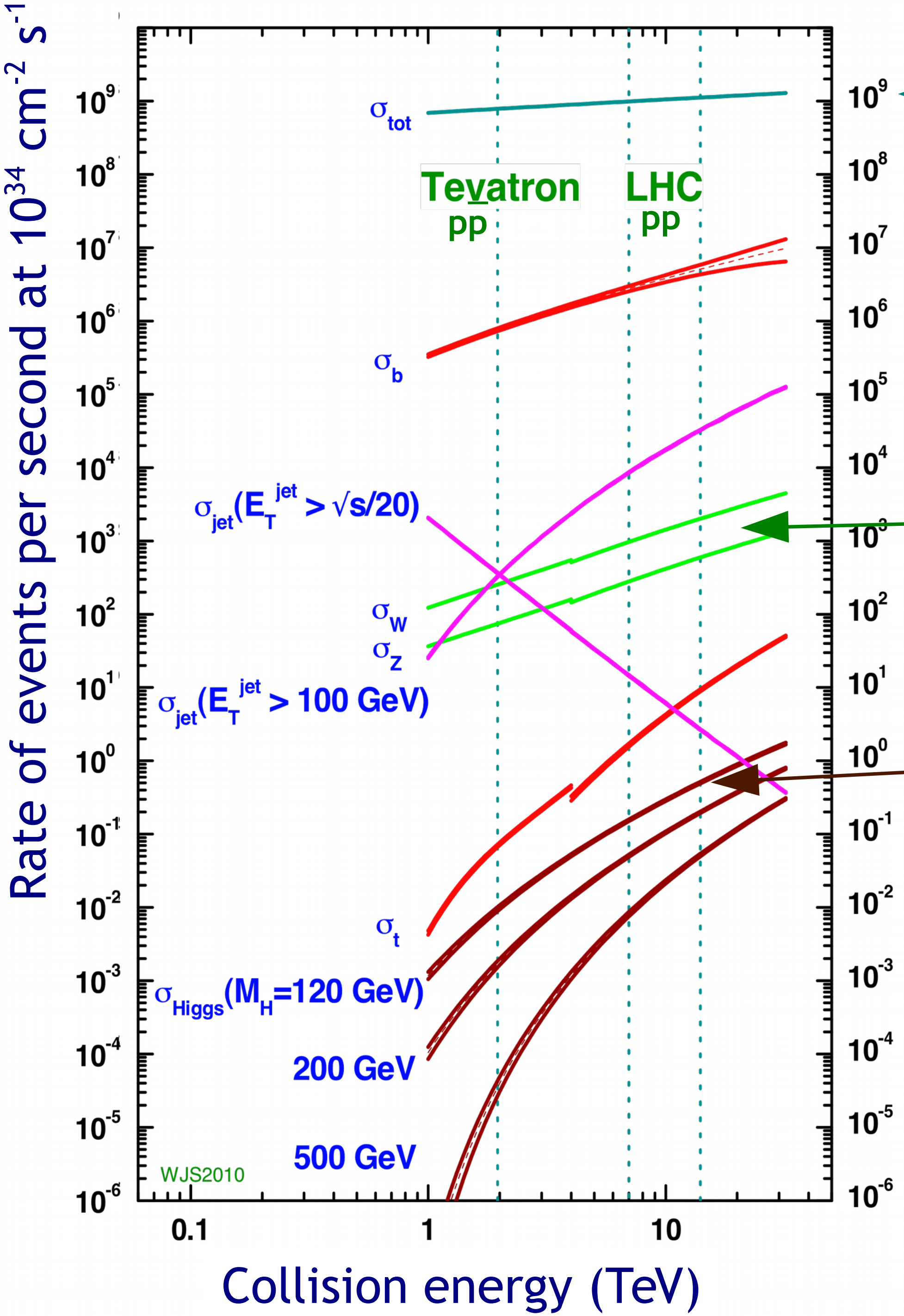
$$N_{obs} = \sigma\, \varepsilon_{exp} \int Ldt$$

σ: cross-section $\sigma(\sqrt{s})$

ε_{exp}: *experimental efficiency*

Higher peak luminosity than 2017, better LHC live-time, still taking data!





Total event rate ~ 1 billion / second

but only ~30 million bunch-crossings per second → pileup! (next)

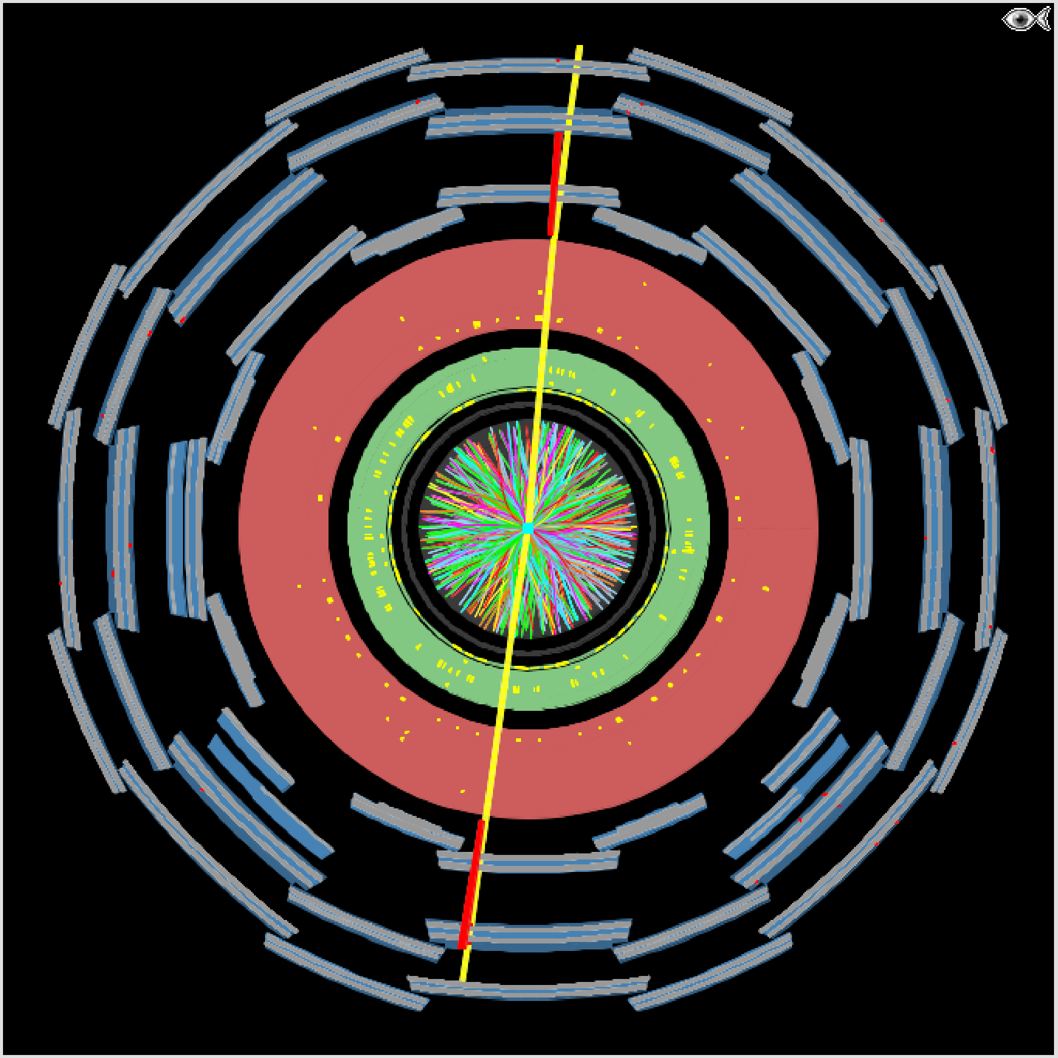
Rates are for LHC design luminosity of 10^{34} cm^{-2} s^{-1}

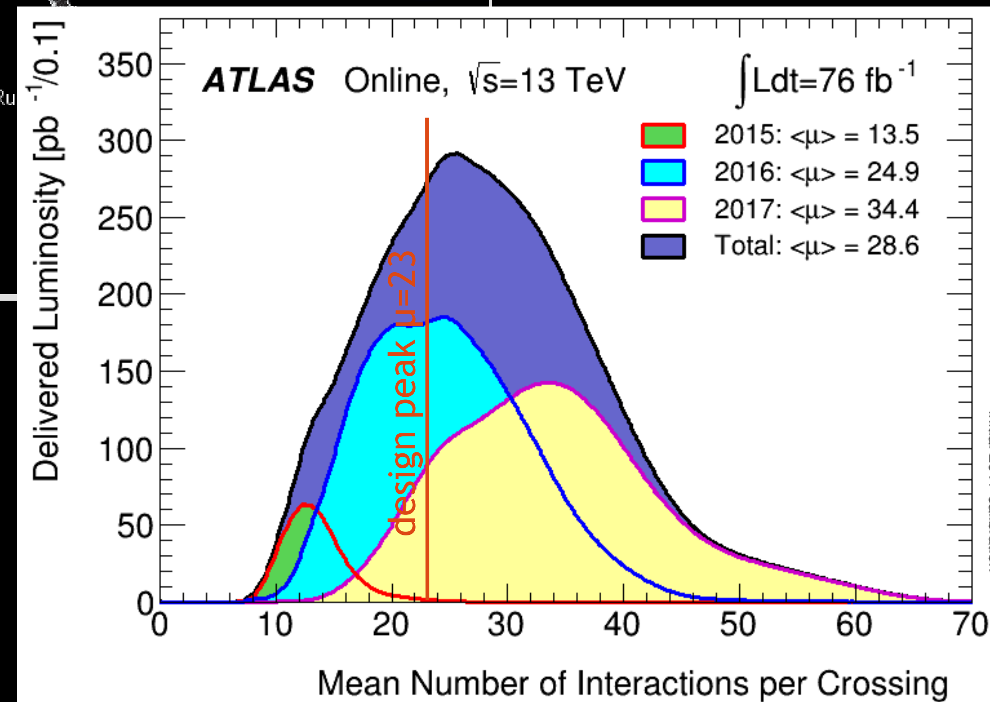
W and Z ~1 kHz

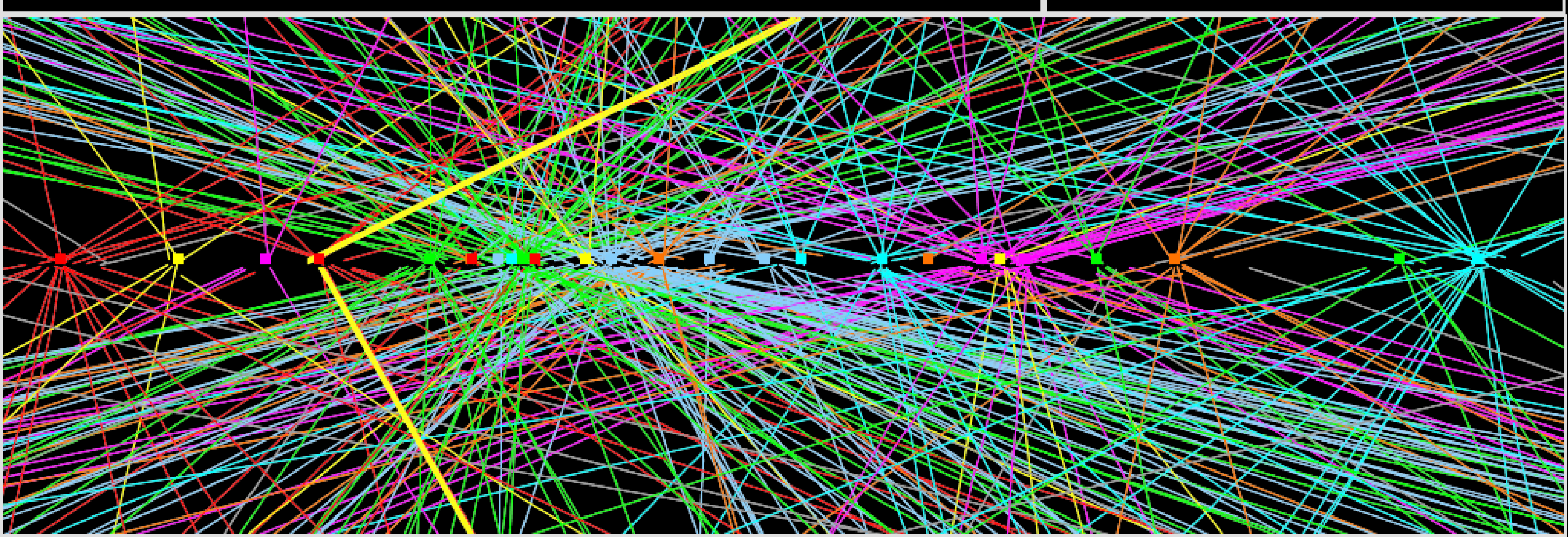
H ~ 0.5 Hz (produced!)

Output rate to disk:
Run-1 ~ 400 Hz
Run-2 ~ 1 kHz

Online trigger crucial: factor few x 10^4 reduction
→ Billions of events, PB of data





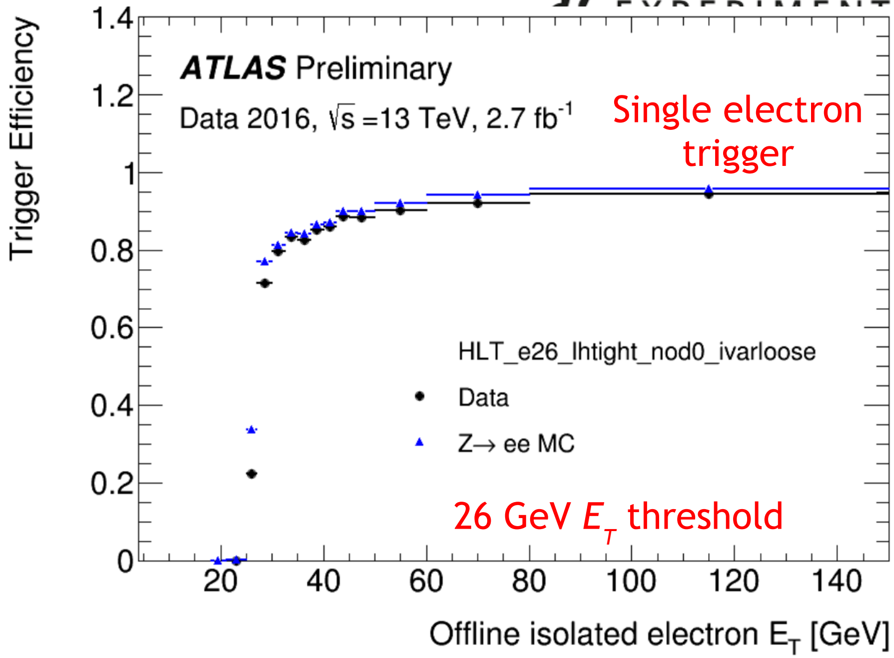


"Pileup" is a constant issue – but the detector copes very well, with ingenuity in its design, and in trigger and reconstruction

The trigger challenge

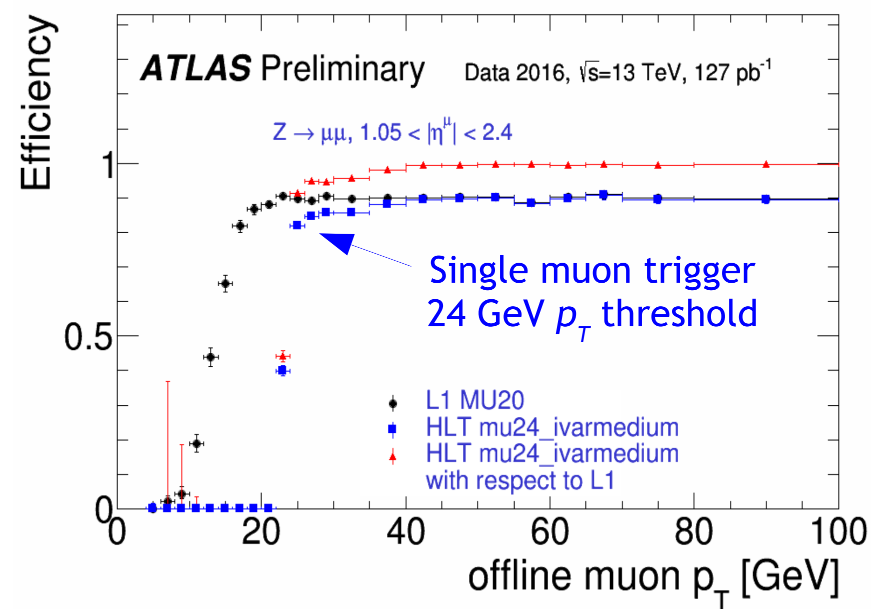
Complex trigger menu designed to meet varied physics, monitoring and performance requirements

- Typically ~2000 active menu items
- **Key is to keep stable, well understood, main primary triggers**
- **Use as low energy thresholds as possible to keep efficiencies as high as possible**
- ***Small and active community manages trigger menus to optimise physics output***

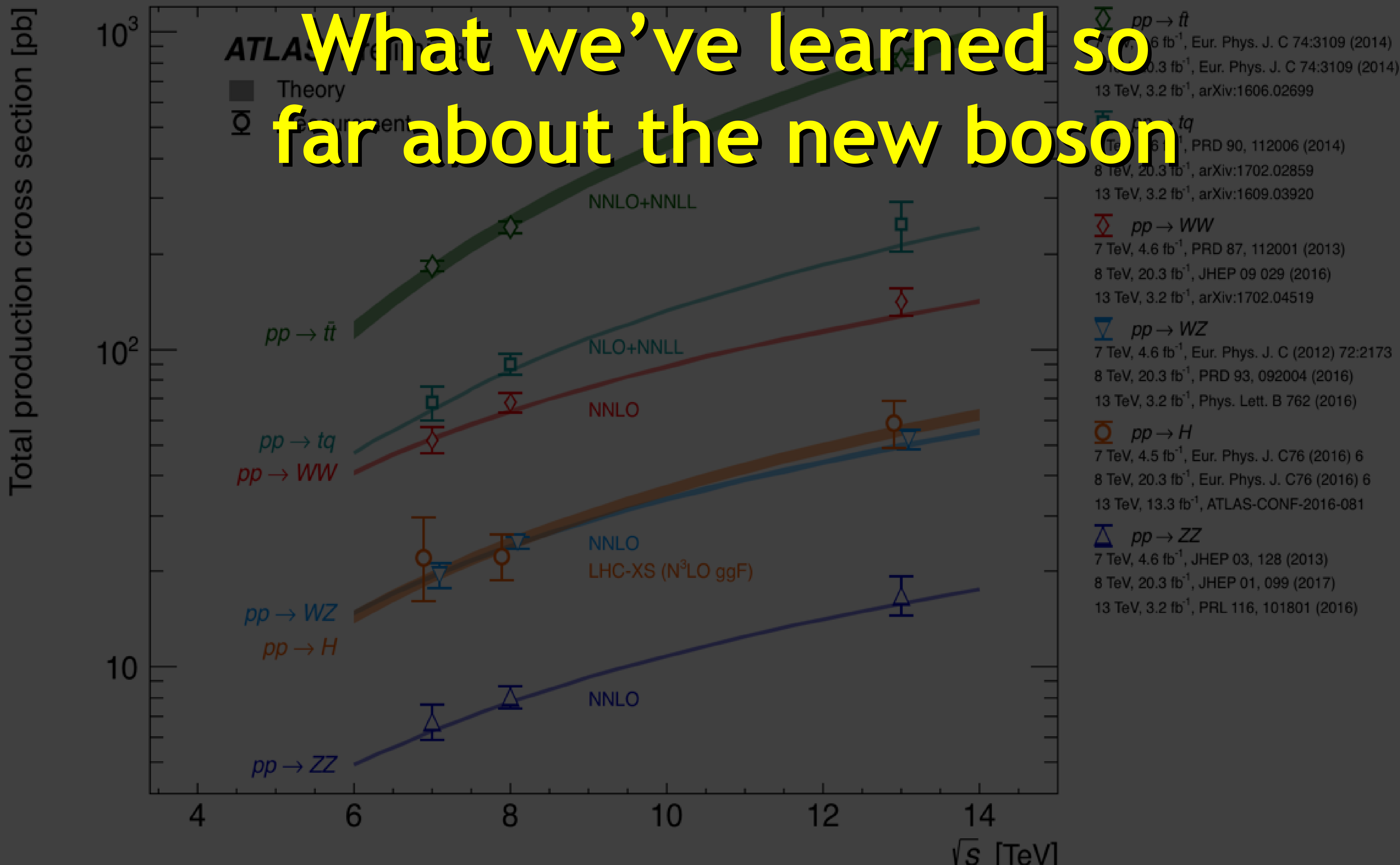


A few, example, trigger thresholds (GeV)

- E_T(e) > 24-26
- p_T(μ) > 24-26
- E_T^{miss} > 90-110
- E_T(jet) > 380
- E_T(γ) > 140
- p_T(μ1,μ2) > 6,6 + topo/mass selections
- E_T(γ1,γ2) > 35,25



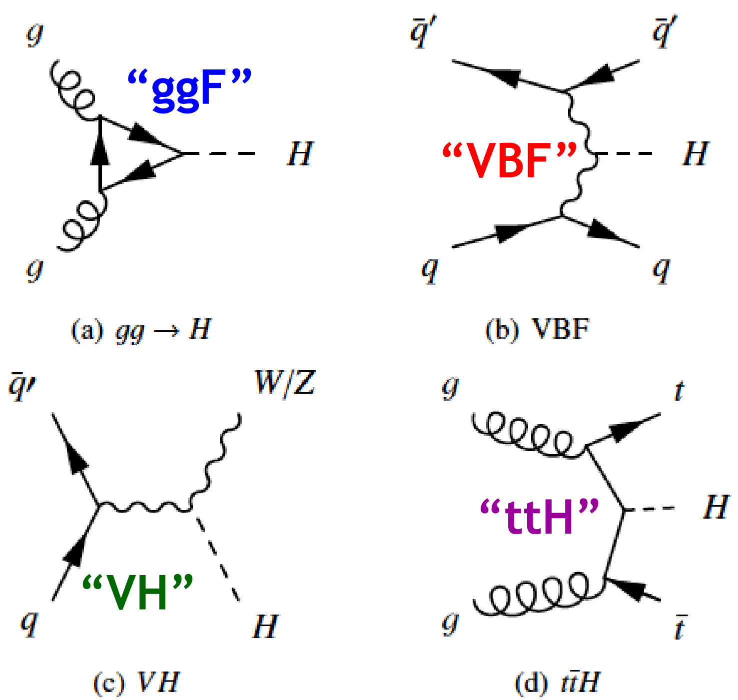
What we've learned so far about the new boson



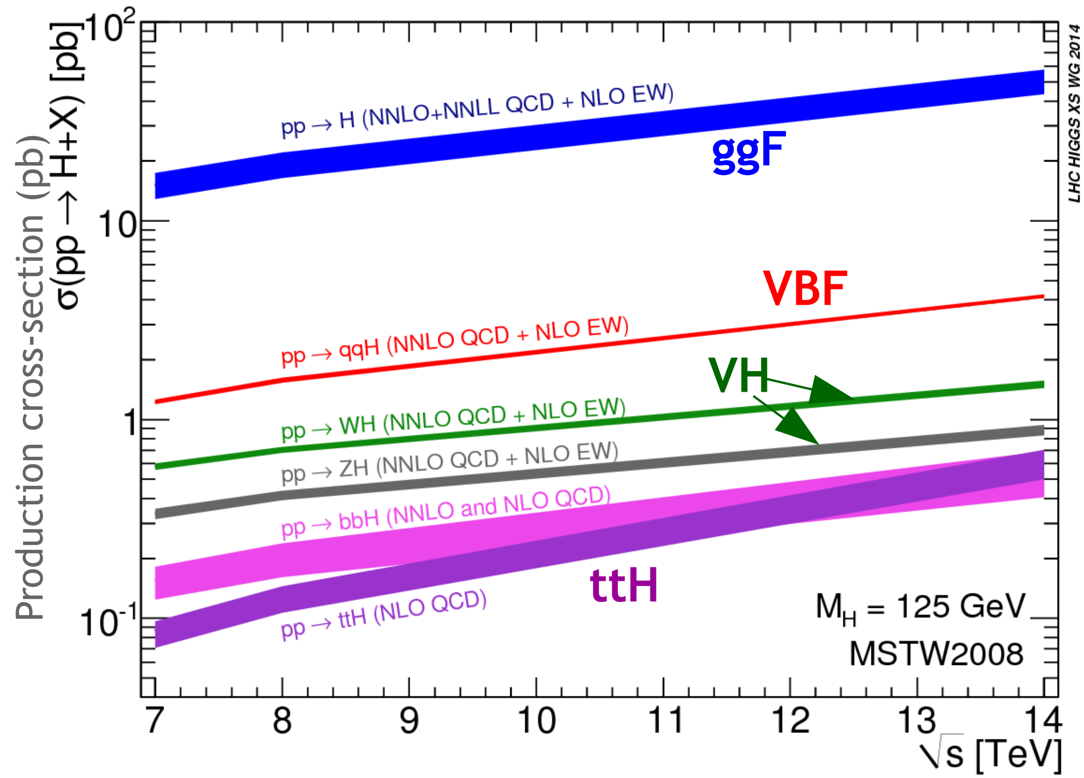
H(125) production & decay

A 125 GeV Higgs boson is a convenient object experimentally – many production and decay modes should be measurable

- Production and decay processes probe couplings of H to different particles
- *Is it the Standard Model Higgs or not?*



Main (single H) production diagrams



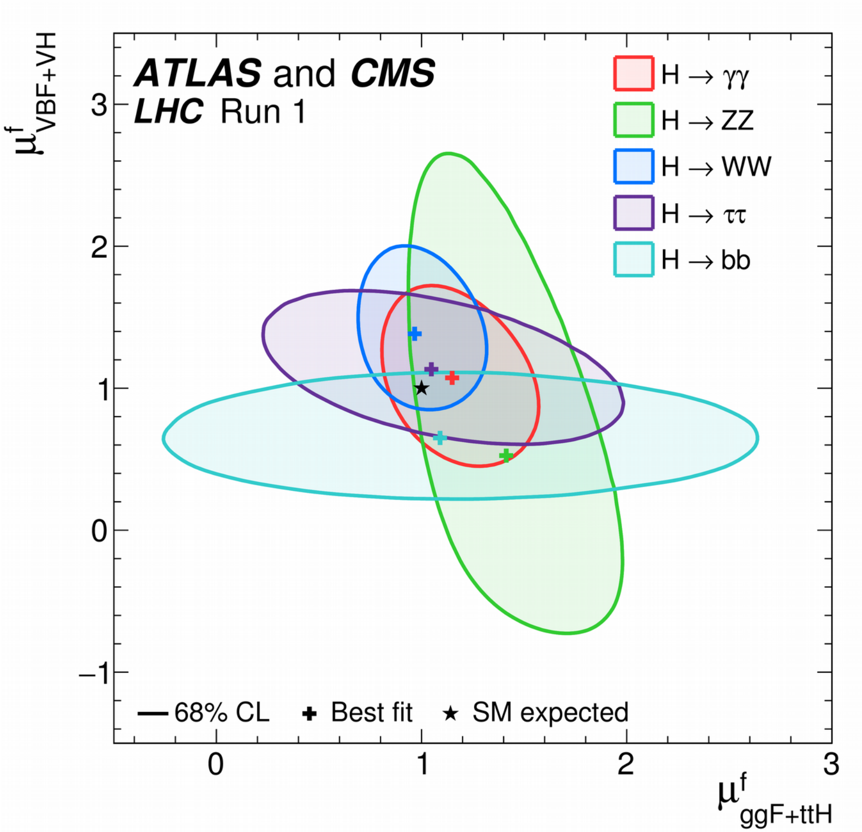
"ggF" dominates, but multiple SM processes accessible

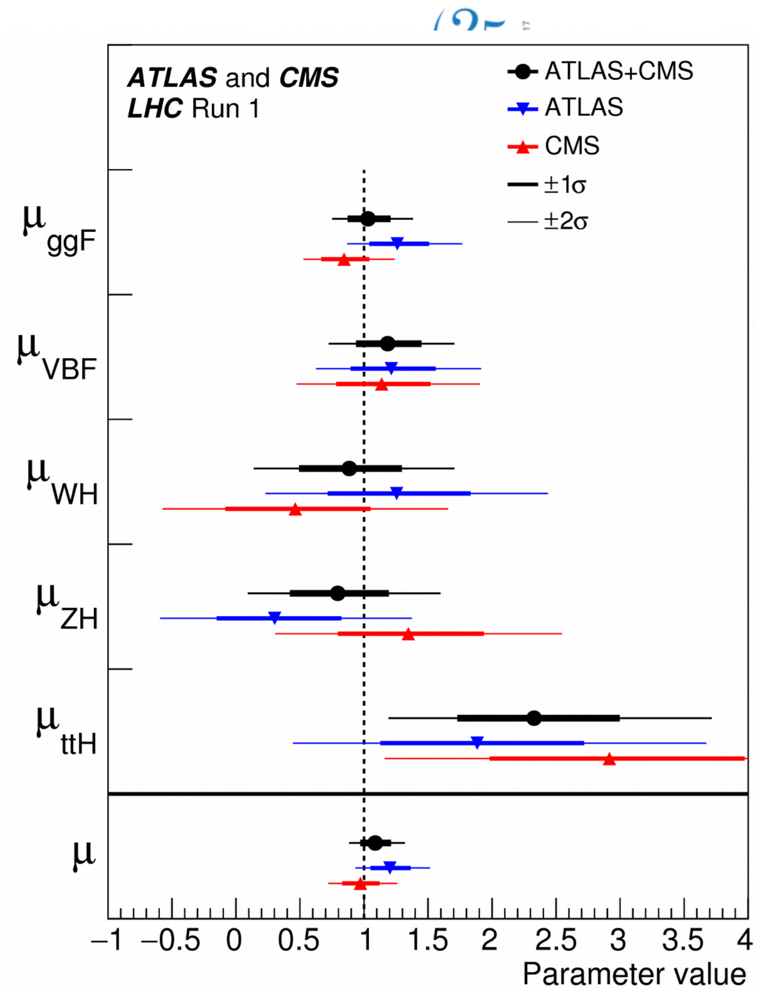
Are there non-SM production modes?

H(125) production modes

Combined analysis of Run-1 data:
H(125) production & decays

With assumptions about decays, we can probe the different production processes (normalised rates "μ" (=1 in SM))





- Able to separate statistically the ggF and VBF processes
- Not yet VH or ttH at 5σ
- Observing ttH production is a key Run-2 goal

These are not yet precision measurements – but few percent errors should be obtainable with the expected LHC samples

H(125) production & decay

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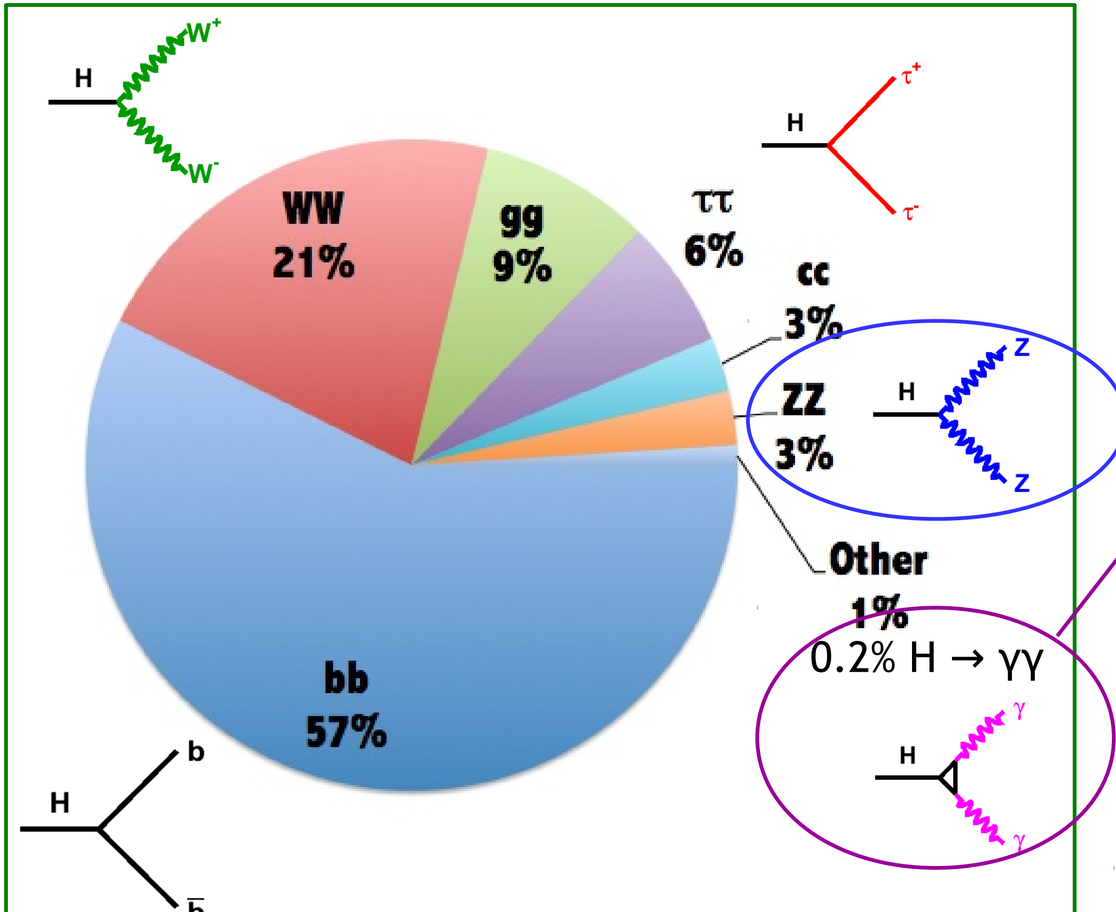

Main decay modes in SM

Discovery channels

Low branching fractions

BF($H \to ZZ^* \to 4(e/\mu)$) ~ 0.01%

BF($H \to \gamma\gamma$) ~ 0.2%

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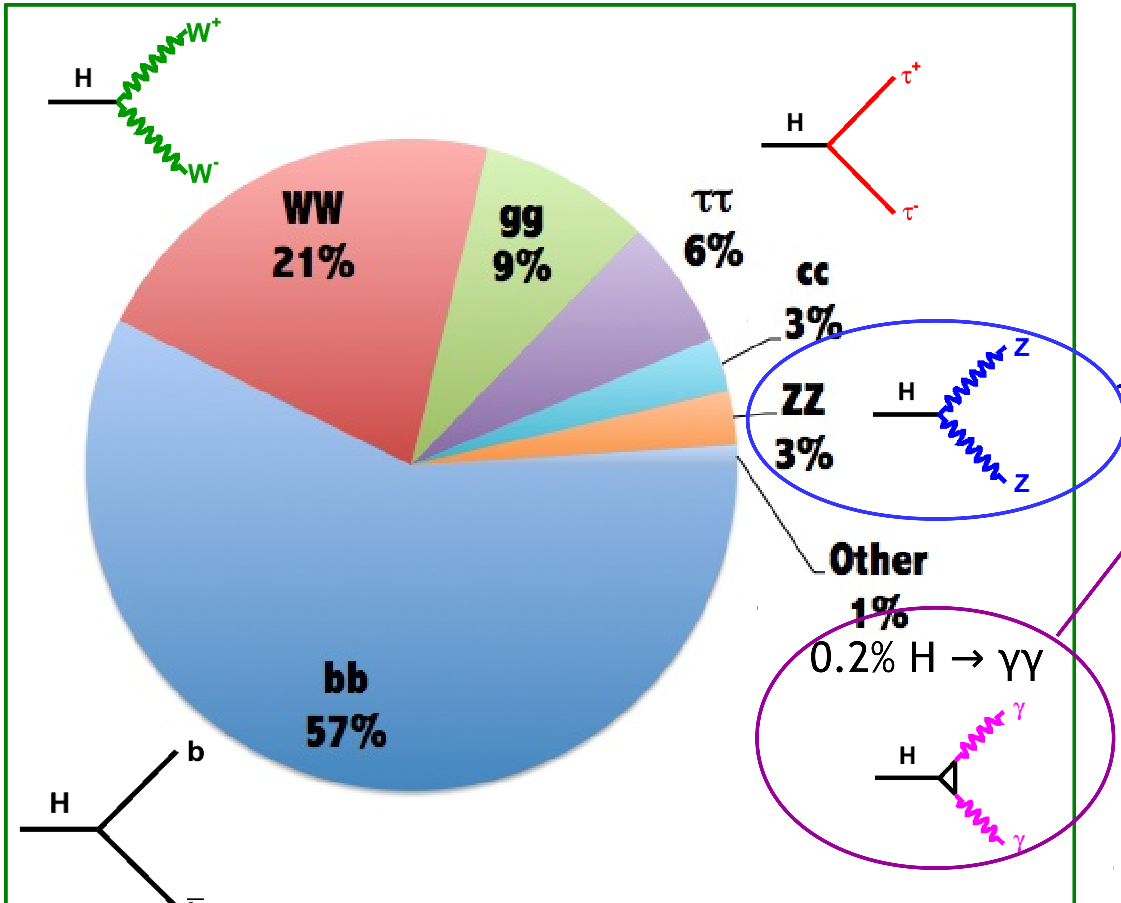

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Are there non-SM decay modes?

H(125) is a completely new type of particle coupling to mass – may be new "light" particles we have not yet seen

H(125) decay modes

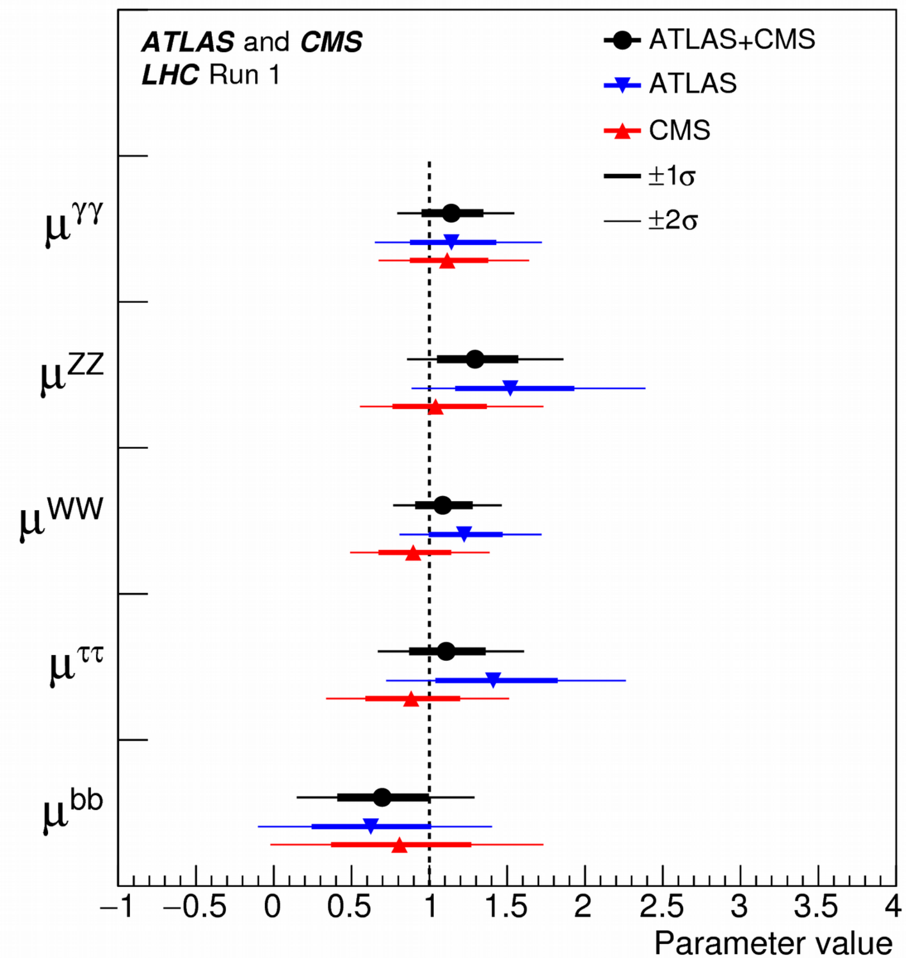
Combining ATLAS and CMS Run-1 data, observed (at >5σ significance)

- H→γγ
- H→ZZ(→4ℓ (ℓ=e,μ))
- H→WW
- H→ττ

Run-1 data not yet sensitive to the dominant H→bb, or rarer, decays, such as to second generation fermions μ, c, s

No direct evidence of Higgs coupling to (any) quarks from Run-1 data

Coupling to only one lepton species (τ) observed



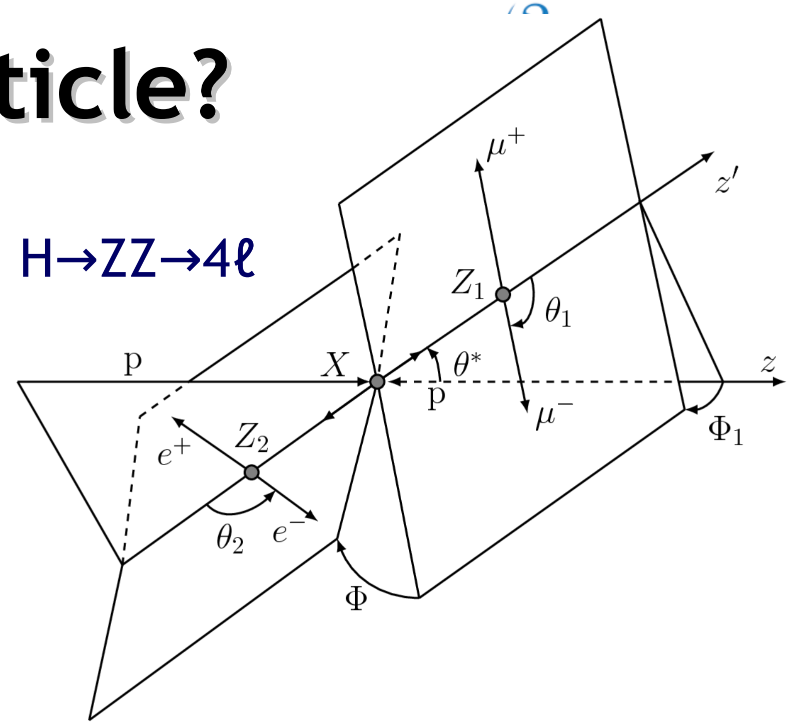
Decay signal strengths relative to Standard Model "μ" (=1 in SM)

H(125) - is it a scalar particle?

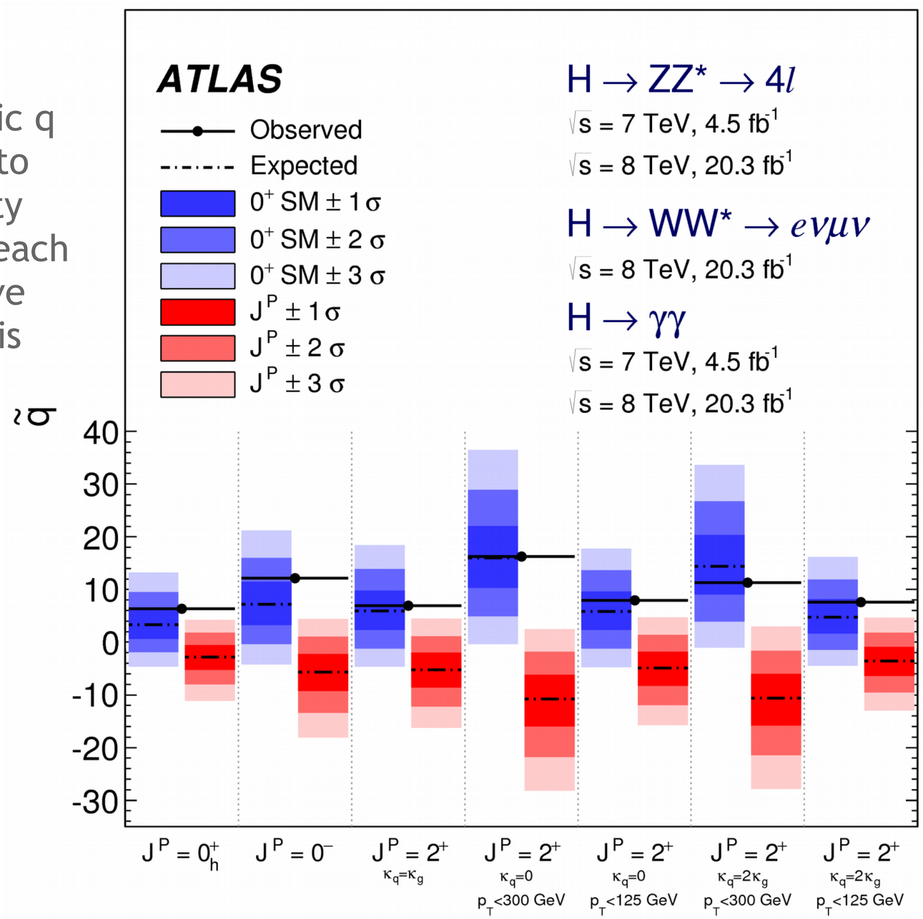
Spin-analysis of the decay product angular distributions

- Is this a spin-parity $J^P=0^+$ object?

$H \rightarrow ZZ \rightarrow 4\ell$



Test statistic q sensitive to spin-parity (differs for each alternative hypothesis tested)



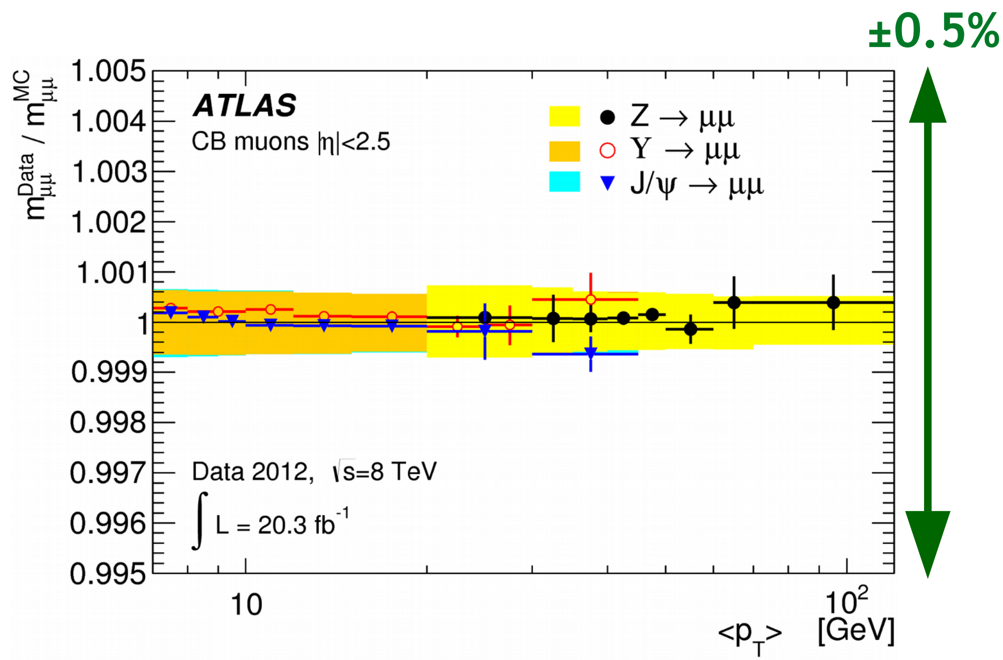
In all cases tested, strong preference for 0^+ assignment

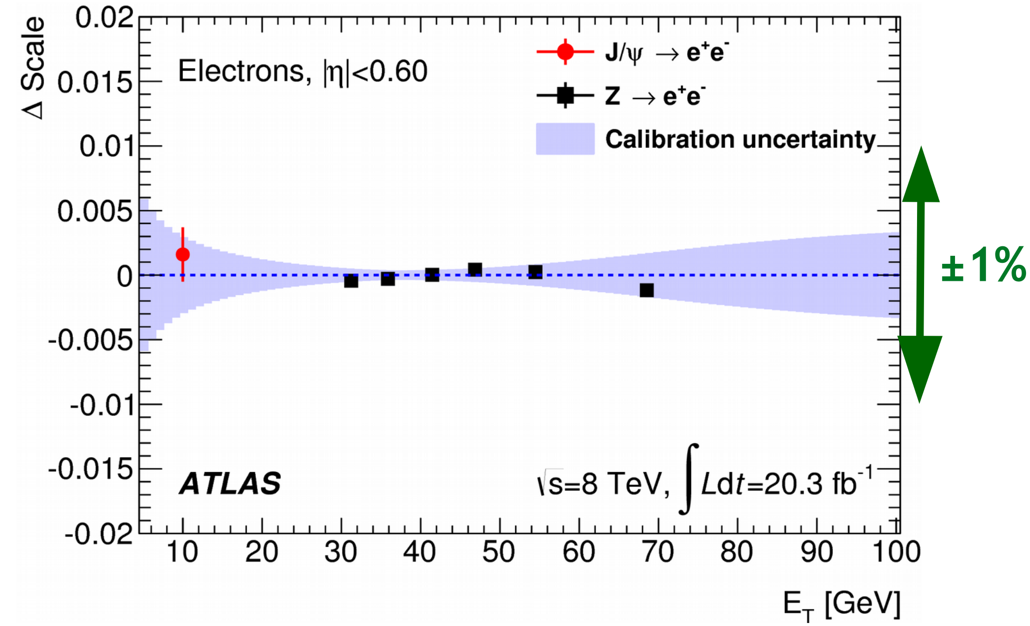
It is consistent with a 0^+ scalar particle, and not with any other model tested (at >>95% CL)

Mass of the H("125")

Recall that m_H is a free parameter in the Standard Model

- To measure m_H, we use γγ and 4ℓ decays, where we can reconstruct the mass event-by-event with high resolution
- Requires excellent understanding of energy scales for lepton/photons





Calibrate detector performance relative to simulations using very large and clean samples of decays of particles of known mass, here:

$J/\psi, \Upsilon, Z \rightarrow ee/\mu\mu$

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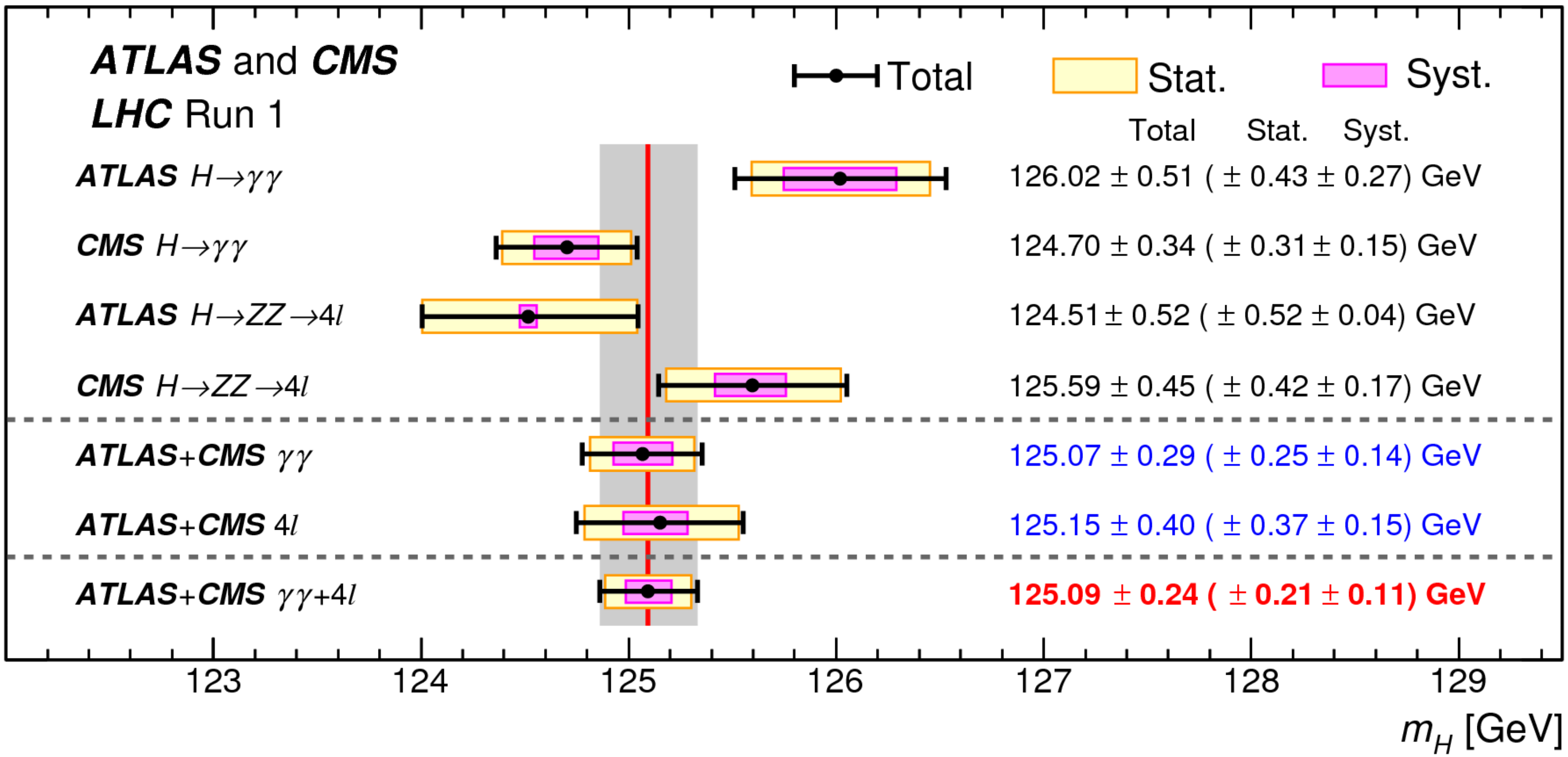
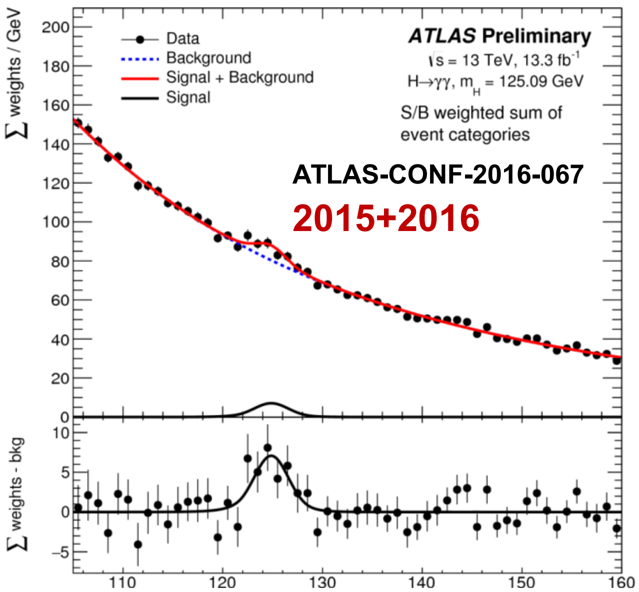
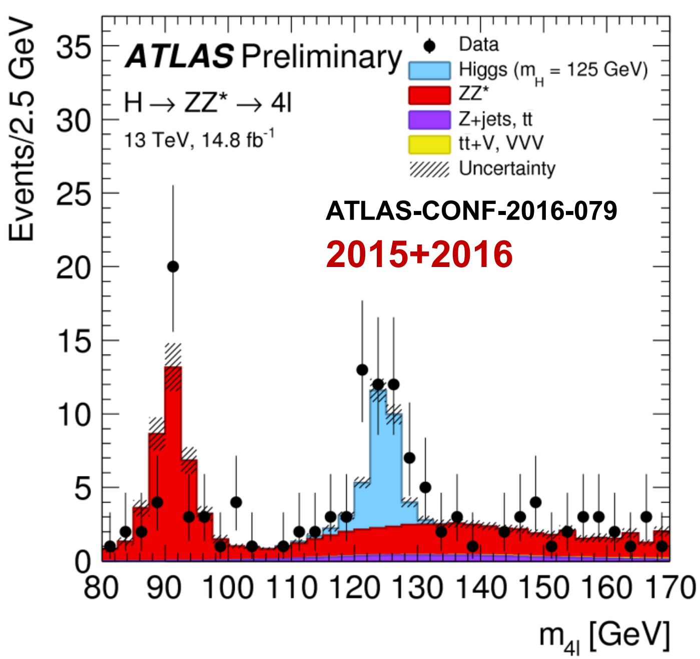


Already a precision measurement: 2 per-mille relative error – dominated by statistical not systematic uncertainties

Measuring H(125) at 13 TeV in Run-2

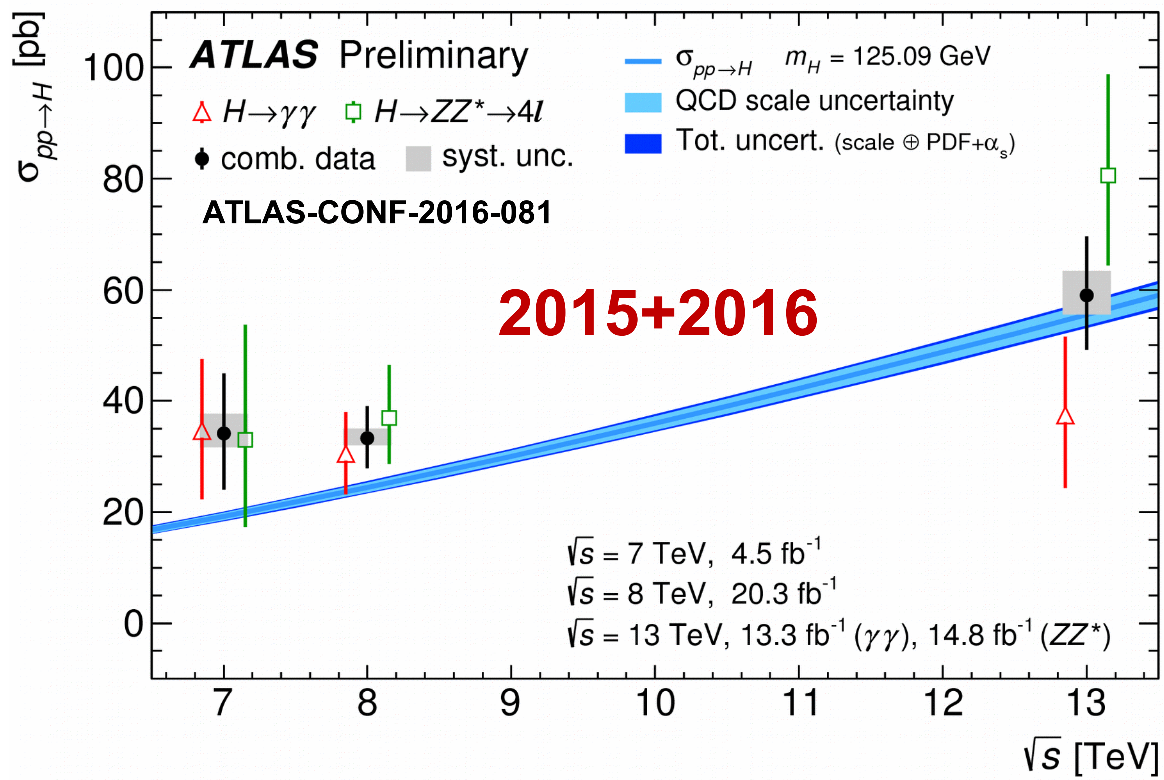




Clear signals in γγ and 4ℓ

→ combined σ(pp→H) at 13 TeV

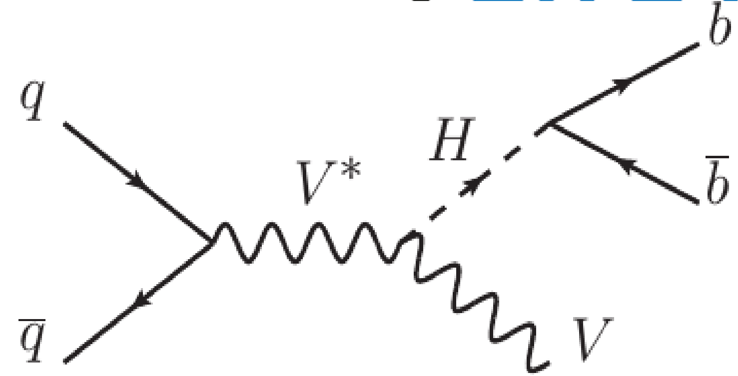
→ overall significance at 13 TeV ~10σ



$\sigma = 59.0\ ^{+9.7}_{-9.2}\,\text{(stat)}\ ^{+4.4}_{-3.5}\,\text{(syst) pb}$

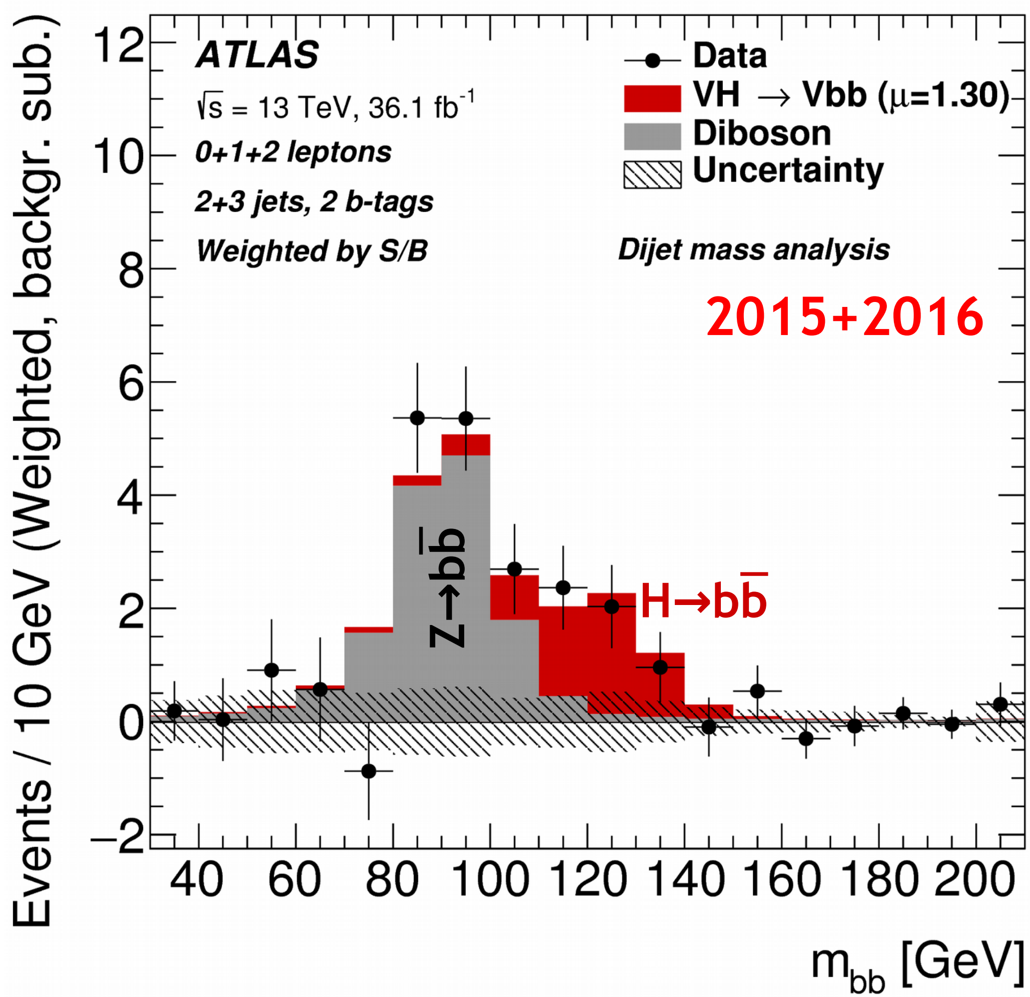
(SM: $55.5\ ^{+2.4}_{-3.4}$ pb)

First evidence for H→b$\bar{b}$



Hunt for H→b$\bar{b}$ decay, produced with a W or a Z boson

- H → bb dominant Higgs decay in SM: BR~58%



Signal strength relative to SM expected value:

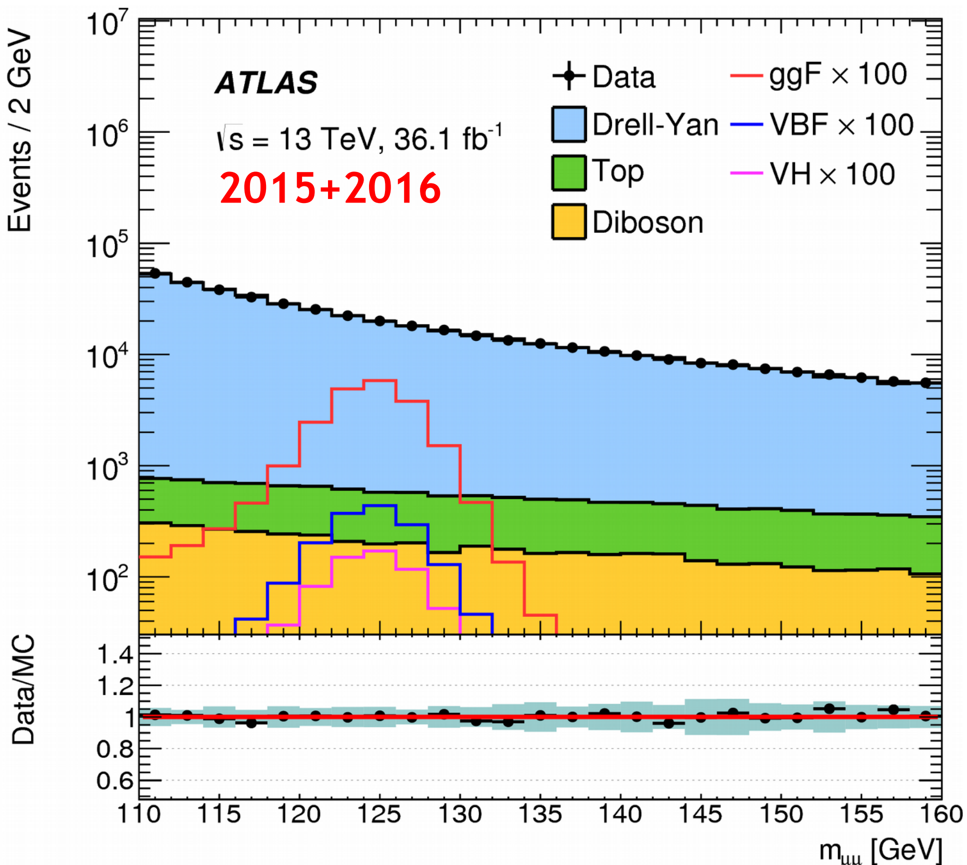
$$0.90 \pm 0.18(\text{stat.})^{+0.21}_{-0.19}(\text{syst.})$$

Significance 3.5σ (expected 3.0σ)

First evidence for H decay to quarks - observing this at 5σ remains a key goal for Run-2

H→μμ - rare decay: 2nd generation!

Inclusive distribution



PRL 119 (2017) 051802

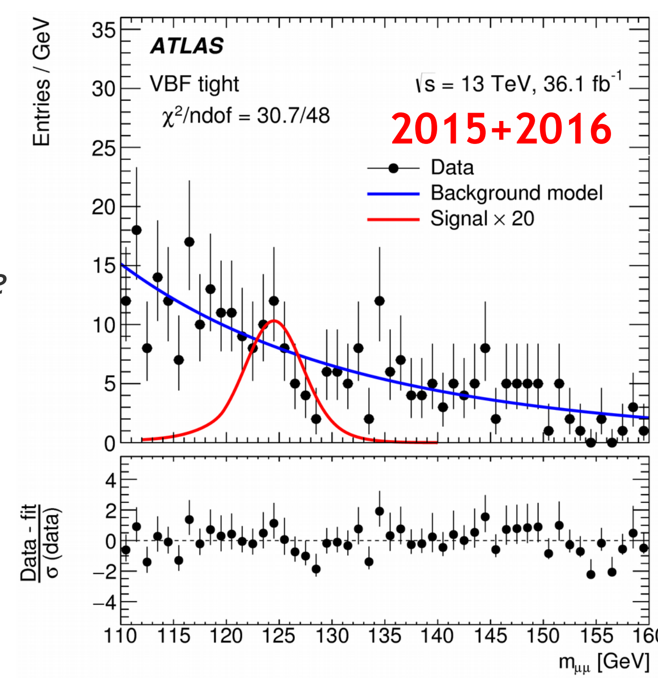
With full 2015+2016 data, look for a peak in dimuon mass spectrum

- Event categories improve sensitivity

No excess observed → place limits on signal strength μ_S relative to Standard Model, combine also with (weaker) Run-1 results:

μ_S < 2.8 at 95% CL (2.9 expected)

Distribution in one of the eight event categories



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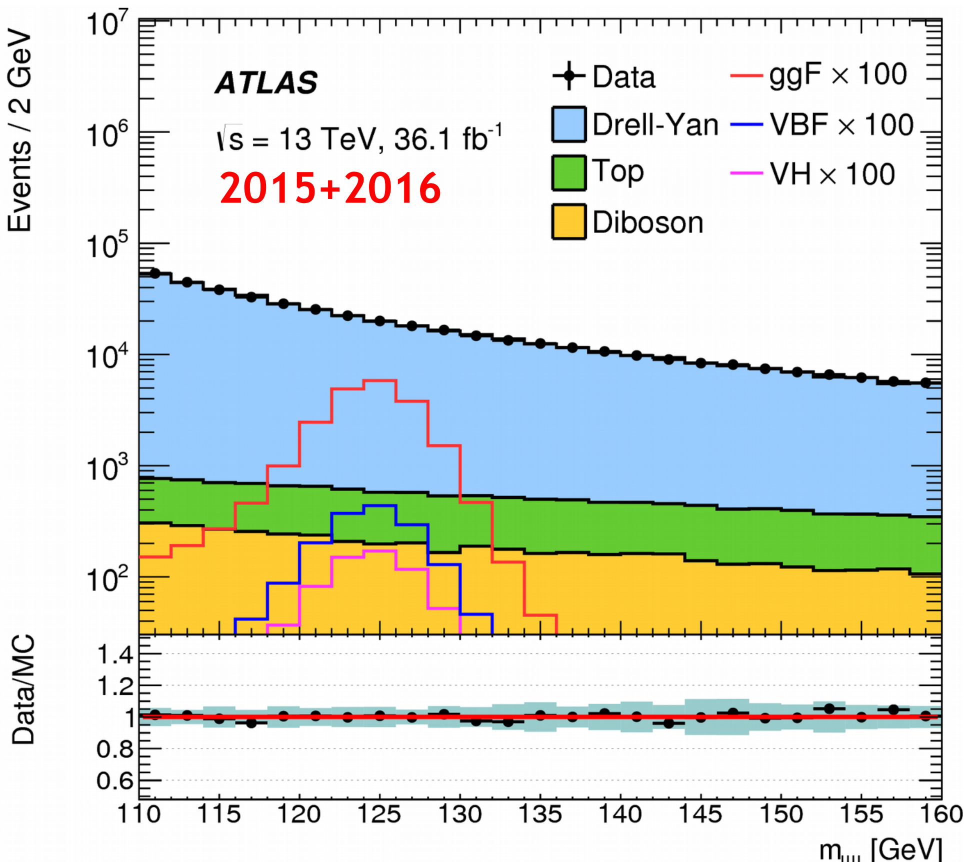

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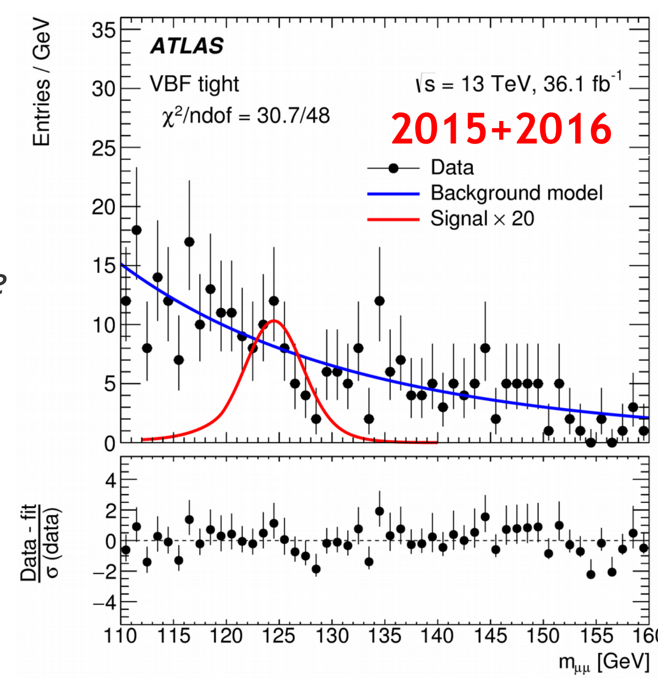
μ_s < 2.8 at 95% CL (2.9 expected)

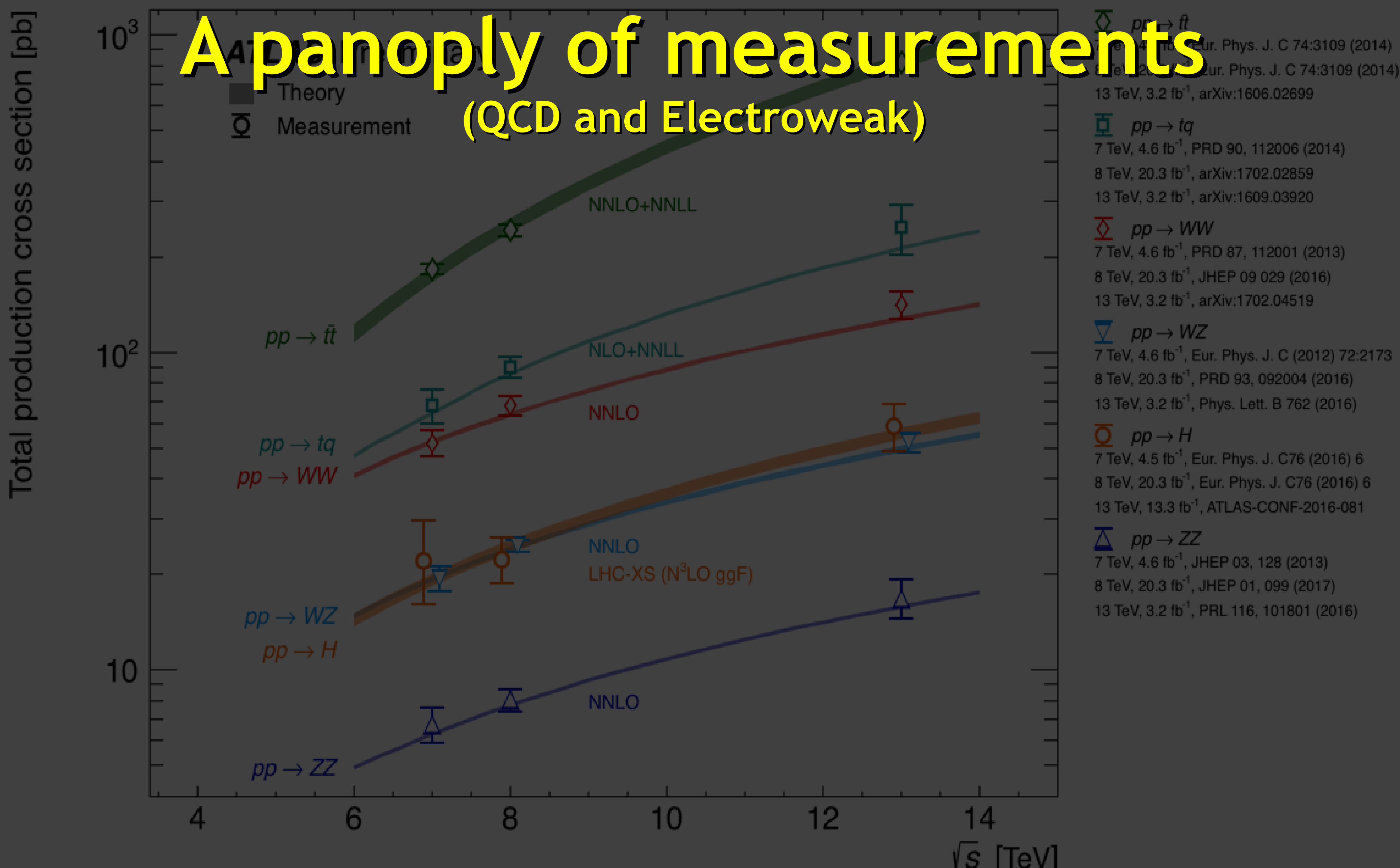
Still a way to go here – precise measurements of Higgs couplings to *any* second generation fermion will require much more data (→ HL-LHC)

Distribution in one of the eight event categories

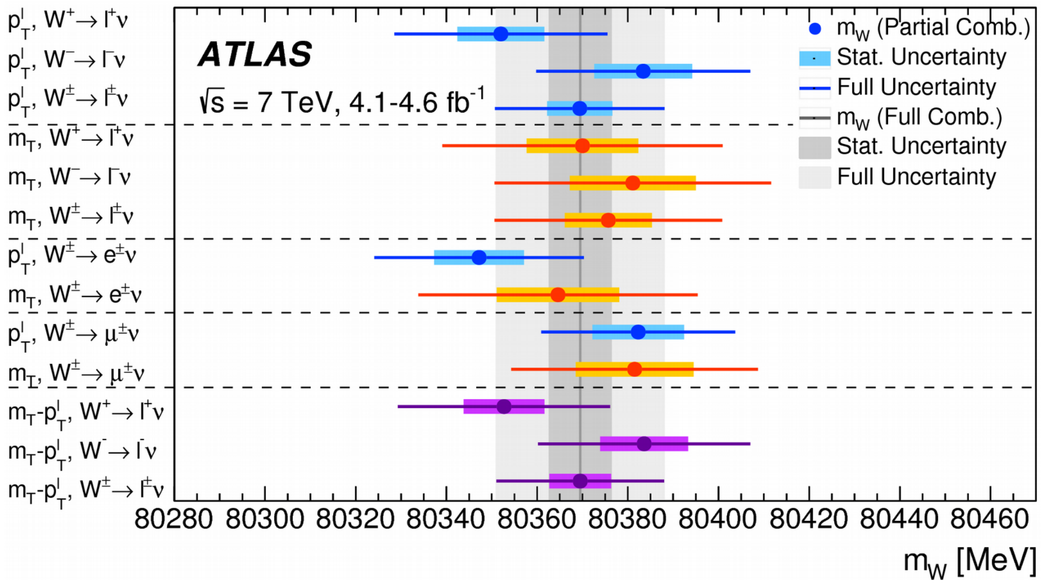


A panoply of measurements

(QCD and Electroweak)



W-boson mass



Consistency between results using

- $W \to e\nu$ or $W \to \mu\nu$ decay mode
- Different mass-sensitive variables $p_T(\ell)$ or m_T
- Different ℓ-charge signs

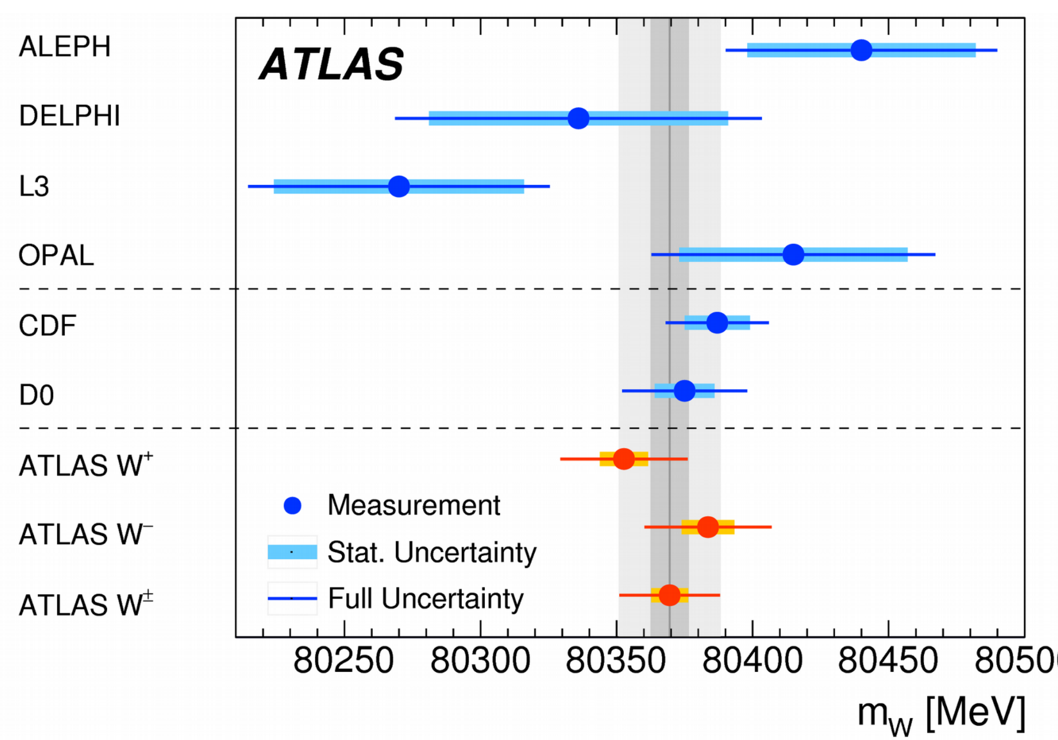
Combining the two channels, charges and methods, find overall:

$$m_W = 80370 \pm 19 \text{ MeV}$$

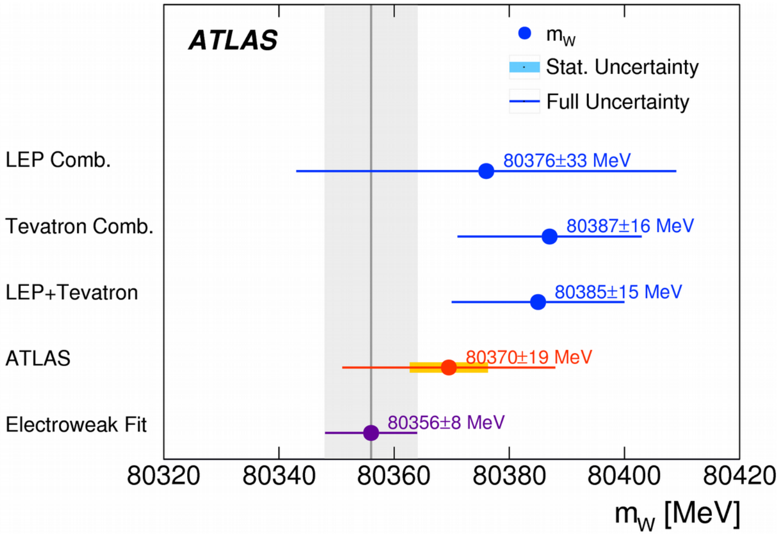
± 7 (stat.) ± 11 (exp. syst.) ± 14 (mod. syst.) MeV

Measurement precision of 19 MeV equals best previous measurement, from CDF at the Tevatron

This is just the start for m_W at LHC



Electroweak precision test



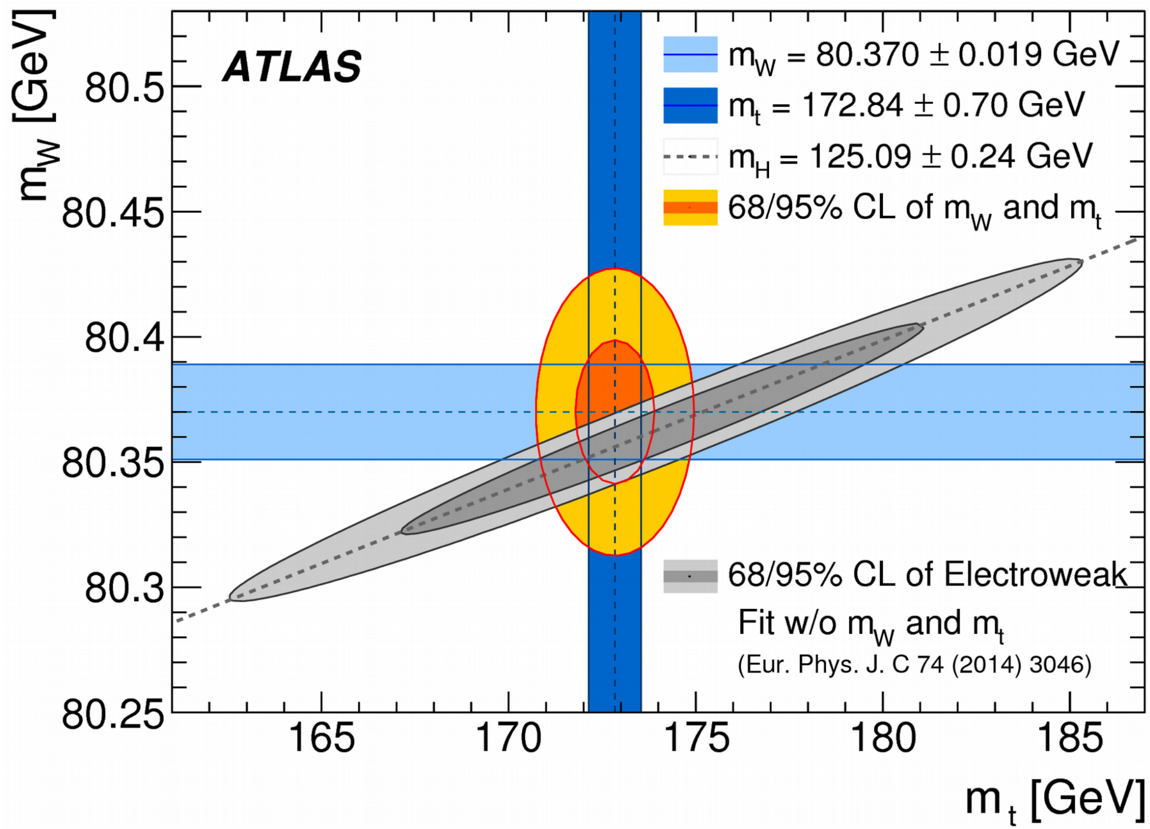
Within the SM framework, the precise value of m_W is related to other quantities via:

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r),$$

Where Δr includes radiative effects (loops), and so depends on (e.g.) m_H and m_{top}

Fits to precision electroweak data from LEP/SLD and others, plus the LHC m_H, provide an indirect prediction of m_W and m_{top} ("indirect measurement in the framework of the SM")

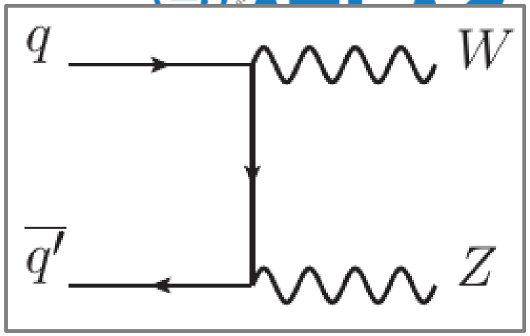
Compared here to ATLAS measurements of W and top masses



Massive diboson production

Run-1 puzzle to describe inclusive diboson cross-sections
- Measurements tended to lie above NLO calculations

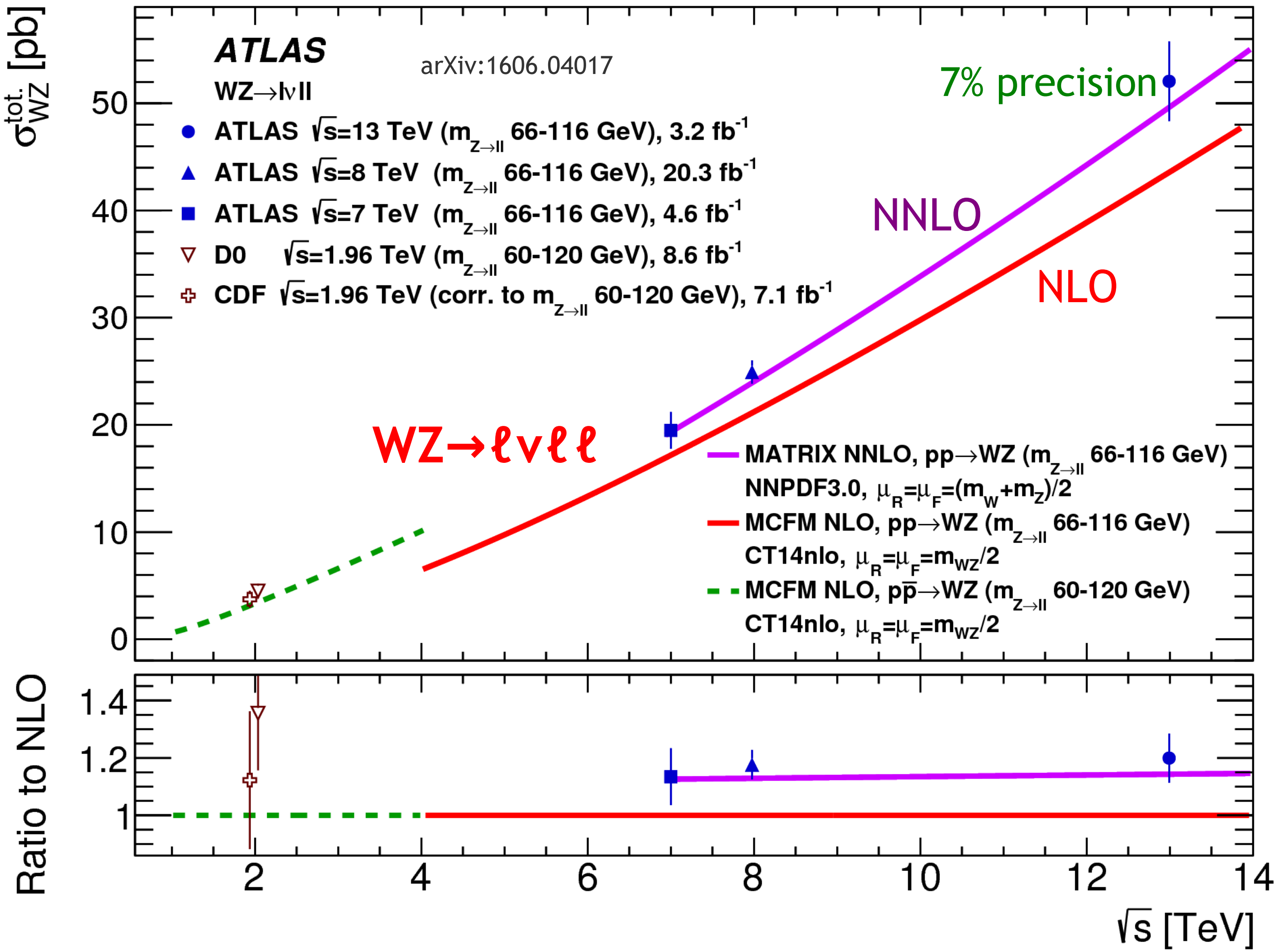
NNLO calculations → ~20% corrections and better agreement



NLO - *Next-to-leading order calculations - include first order of QCD corrections (additional gluons in diagrams)*
NNLO - *Next-to-next-to-leading order*

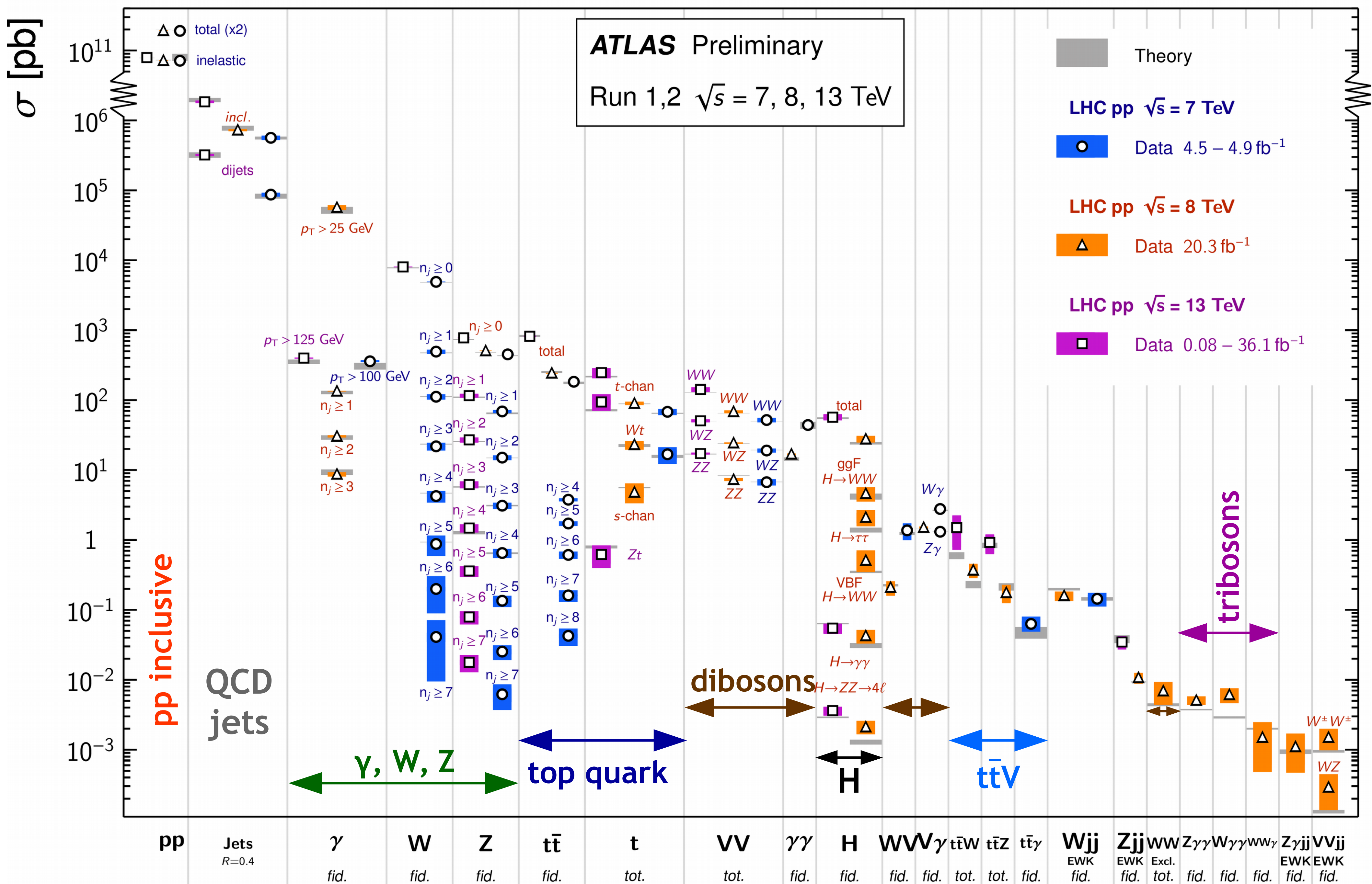
Example:
WZ leptonic decays
NNLO calculations describe data much better than NLO

This run-1 puzzle appears to be solved!

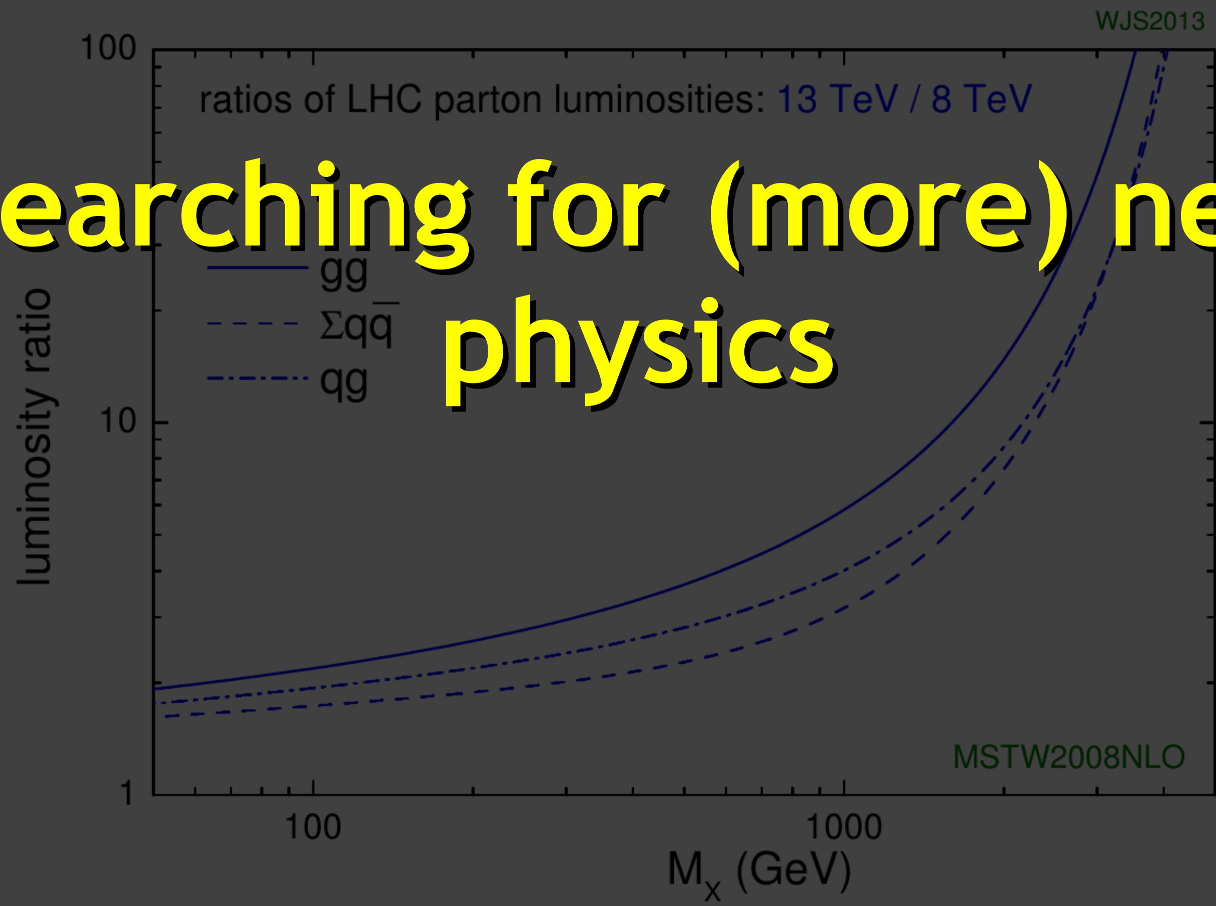


Standard Model Production Cross Section Measurements

Status: July 2017



Searching for (more) new physics



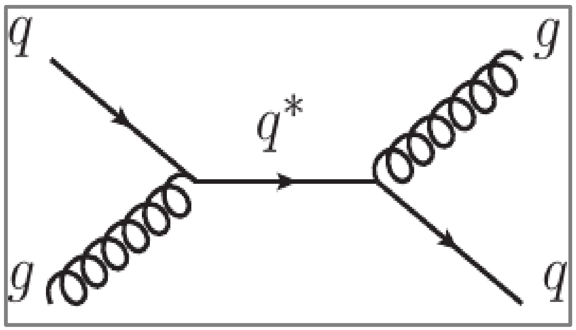
a.k.a. Beyond-the-SM, BSM, searches

There are far too many to describe (hundreds of results) – I pick just one of my favourites

Dijet resonance search

arxiv:1703.09127

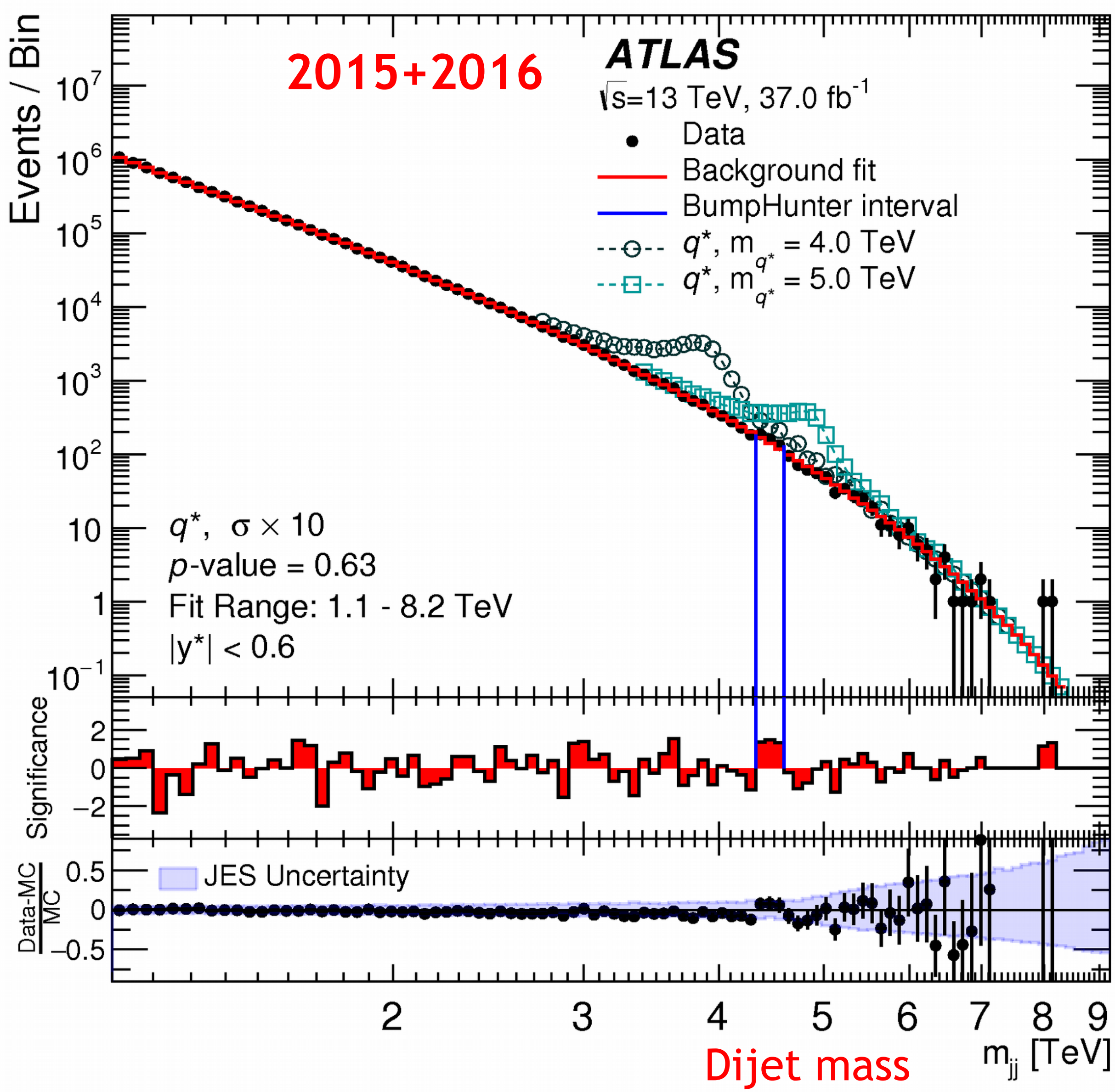
Search for new physics in dijet invariant mass spectrum



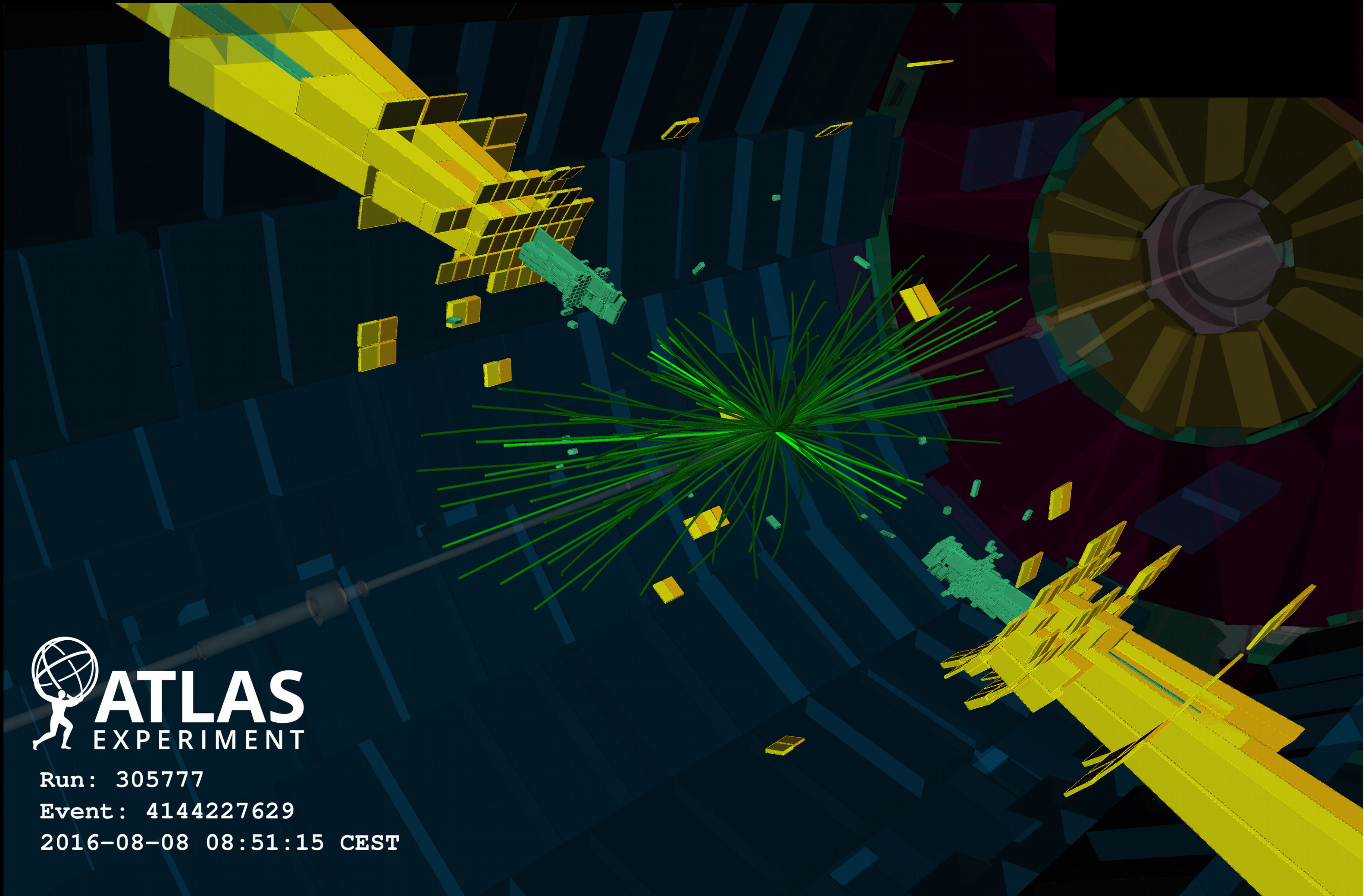
Examples (at 95% CL):

m(q*) > 6.0 TeV
(Cf Run-1: 4.1 TeV)

m(W*) > 3.4 TeV and not within 3.77-3.85 TeV



Highest-mass central dijet event (2016) - m(jj)=8.2 TeV



ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

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

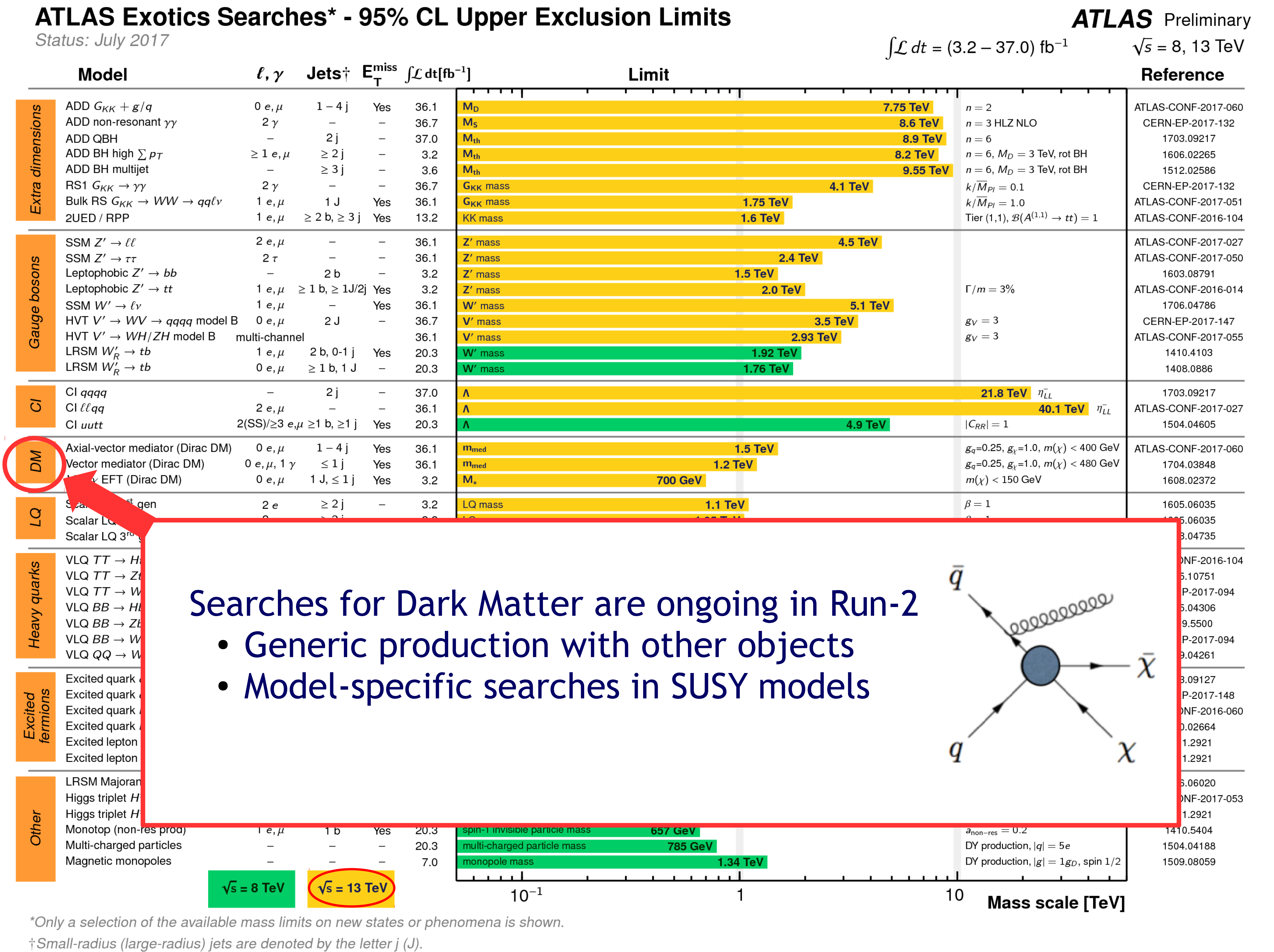
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	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)/$\geq$3 e,μ	$\geq$1 b, $\geq$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	$\geq$1 b, $\geq$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/$\geq$3 e, μ	$\geq$2/$\geq$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

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 for Dark Matter are ongoing in Run-2

- Generic production with other objects
- Model-specific searches in SUSY models

SUSY Searches

ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

ATLAS Preliminary

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

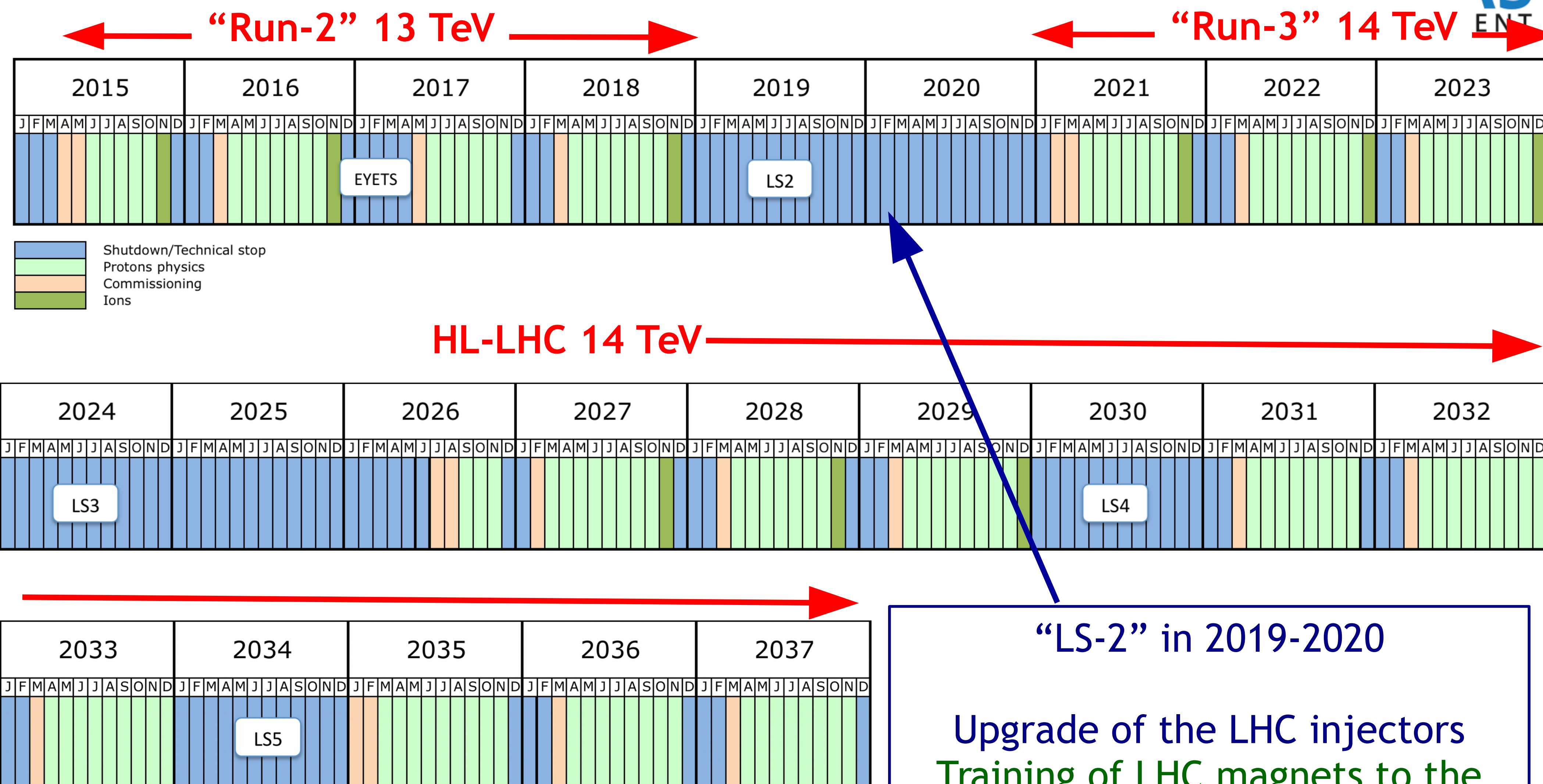
$\sqrt{s}$ = 7, 8 TeV | $\sqrt{s}$ = 13 TeV

	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
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	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
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (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
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 2.02 TeV	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	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
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	36.1	$\tilde{g}$ 1.825 TeV	m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2017-030
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	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.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	$\tilde{g}$ 1.92 TeV	m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	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
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	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	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$ 950 GeV	m($\tilde{\chi}_1^0$)<420 GeV	ATLAS-CONF-2017-038
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ 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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	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
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + Z$	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
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + h$	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	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	36.1	$\tilde{\ell}$ 90-440 GeV	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	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
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	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., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$ 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	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 $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, 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
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	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 $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	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 $pp\to\tilde{\nu}_\tau + X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	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
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}_1^{\pm}$ 1.14 TeV	m($\tilde{\chi}_1^0$)>400GeV, $\lambda_{12k}\neq 0$ (k = 1, 2)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{133}\neq 0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 1.55 TeV	m($\tilde{\chi}_1^0$)=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 2.1 TeV	m($\tilde{\chi}_1^0$)= 1 TeV, $\lambda_{112}\neq 0$	ATLAS-CONF-2017-013
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 1.65 TeV	m($\tilde{t}_1$)= 1 TeV, $\lambda_{323}\neq 0$	ATLAS-CONF-2017-013
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$ 410 GeV, 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	36.1	$\tilde{t}_1$ 0.4-1.45 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

10^{-1} | 1 | Mass scale [TeV]

*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.

The future



"LS-2" in 2019-2020

Upgrade of the LHC injectors

Training of LHC magnets to the field needed for 14 TeV operation

Significant upgrades to the experiments - "Phase-I"

ATLAS Phase-I upgrades

LHC luminosity (collision rate) has exceeded LHC design already by 40%

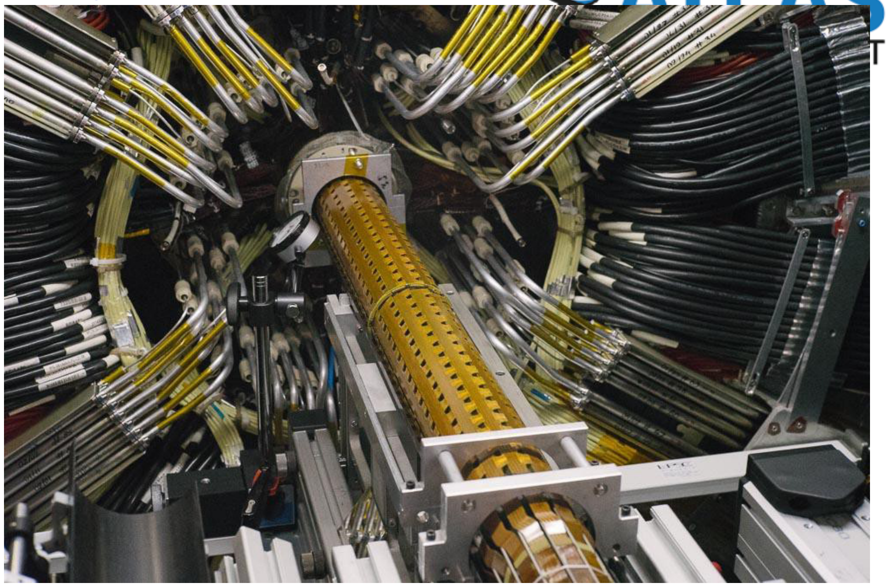
Could exceed design luminosity by a factor ~2.5 in “Run-3”

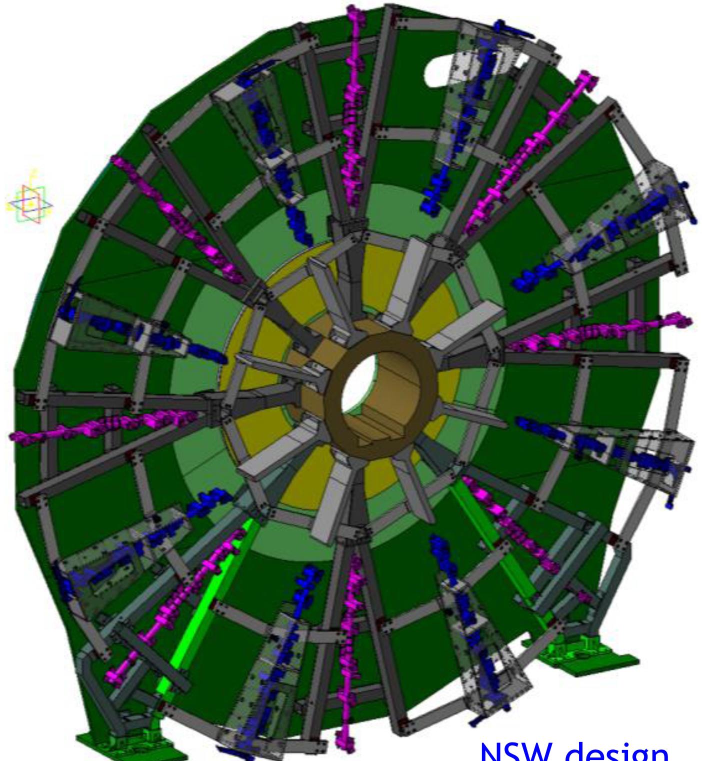
→ Phase-1 upgrades give us better first-level trigger performance (better selectivity in hardware within ~3 μs), and also to provide better tracking close to the interaction point

Main ATLAS Phase-I upgrades:

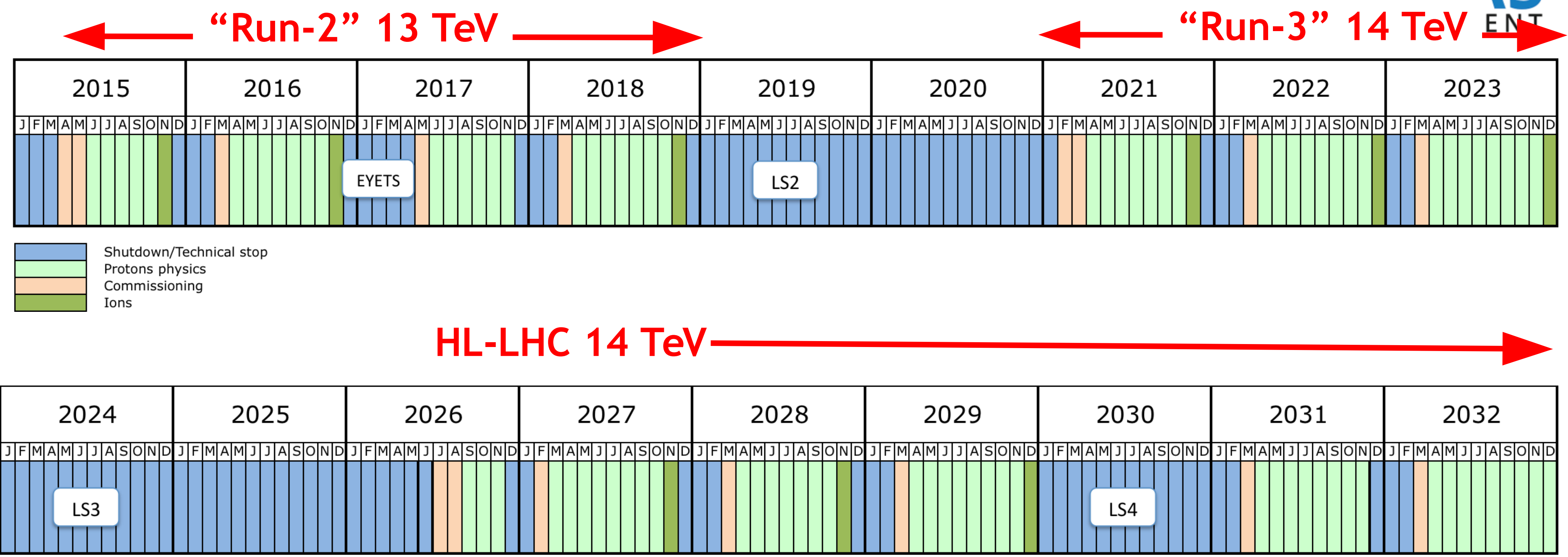
- New inner pixel layer installed already in 2014
  - *Having impact e.g. for H→bb analysis*
- New track & calorimeter trigger electronics
- New “small muon wheel” (9.3m diameter)

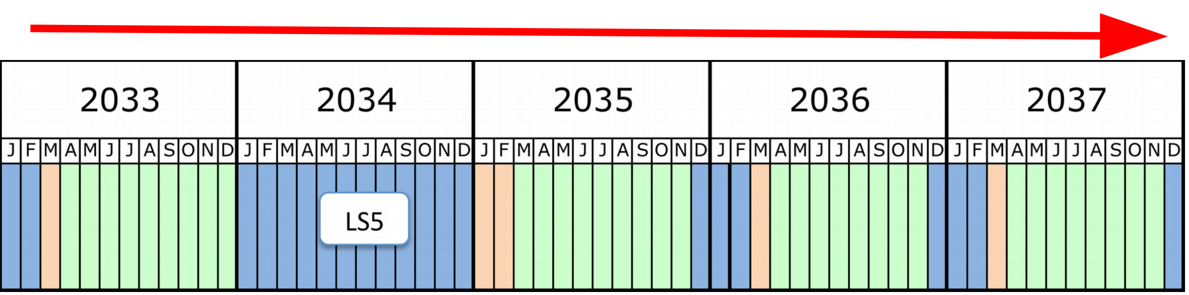
ATLAS IBL insertion





NSW design





HL-LHC: "levelled" luminosity 5-7 times the original design, until ~2035

Accumulate 10x more data than in Runs 1-3 combined - era of high precision

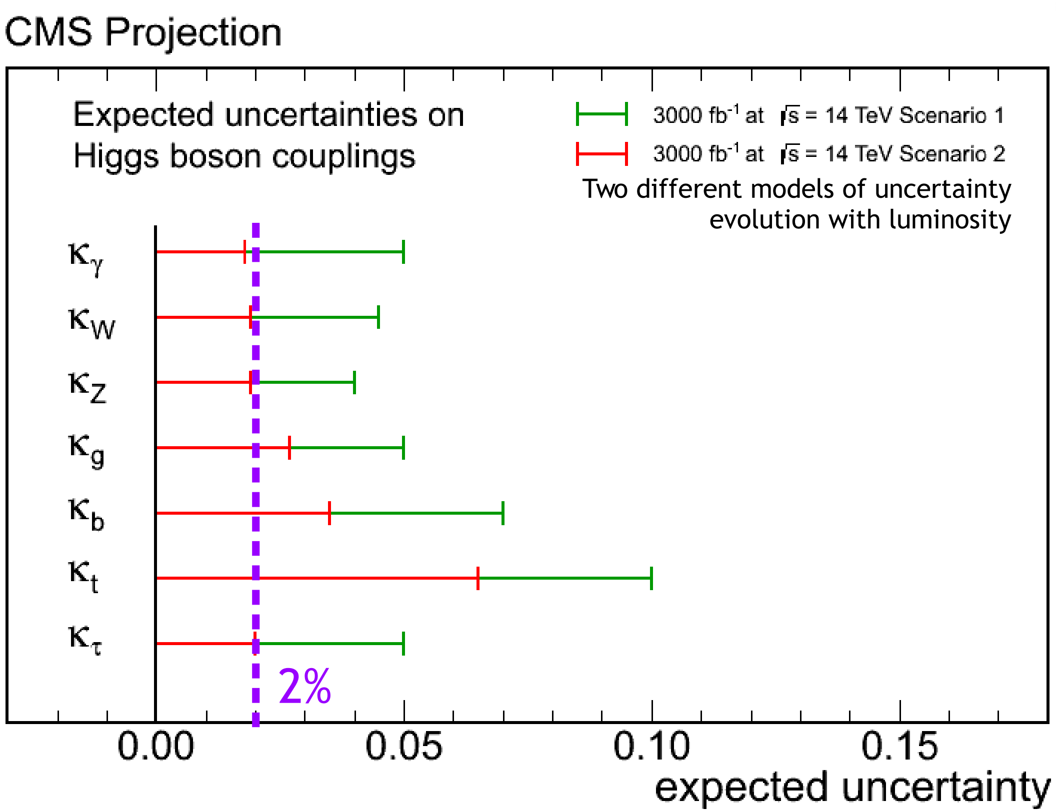
Must upgrade detectors!

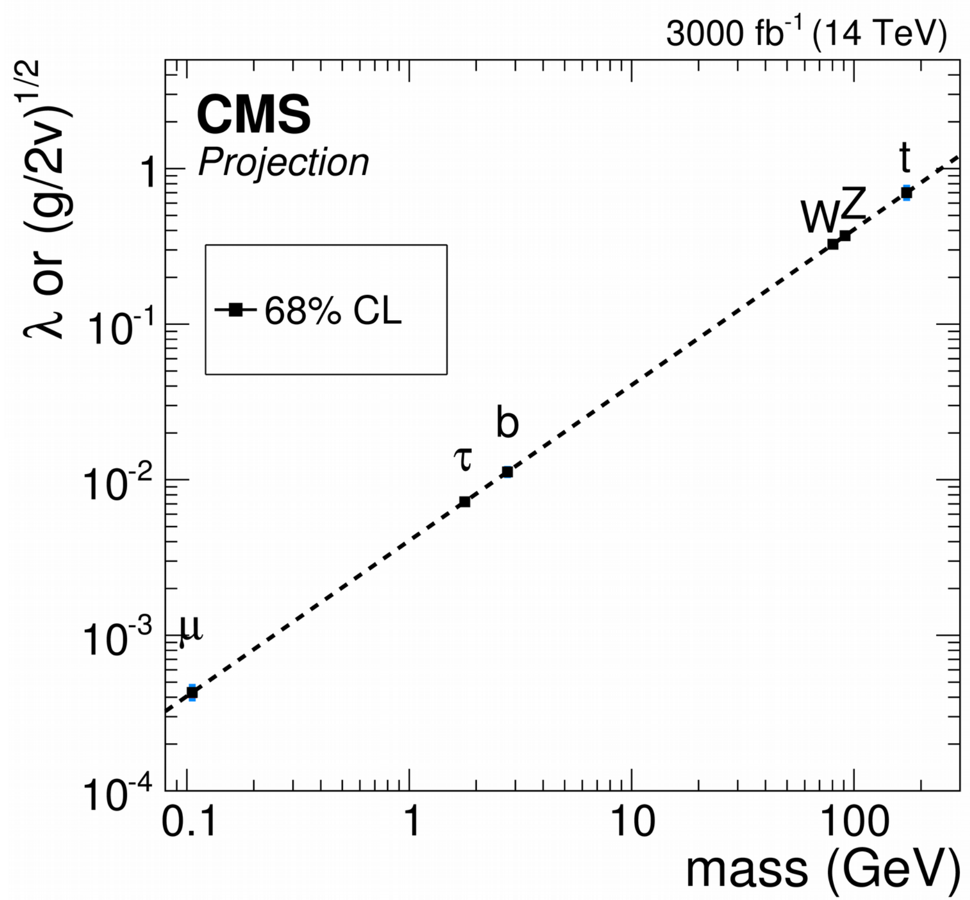
HL-LHC accelerator upgrade was approved by CERN Council in June 2016 (cost: 930M CHF)

HL-LHC: precision Higgs physics

All measurements in Higgs sector will benefit strongly from more statistics, right through HL-LHC programme

- Start measuring rarer decays (SM, BSM?)
- Higher precision measurements
  - Probe Higgs couplings at ~percent level to look for sign of new physics in loops
- Search for anomalous production etc etc



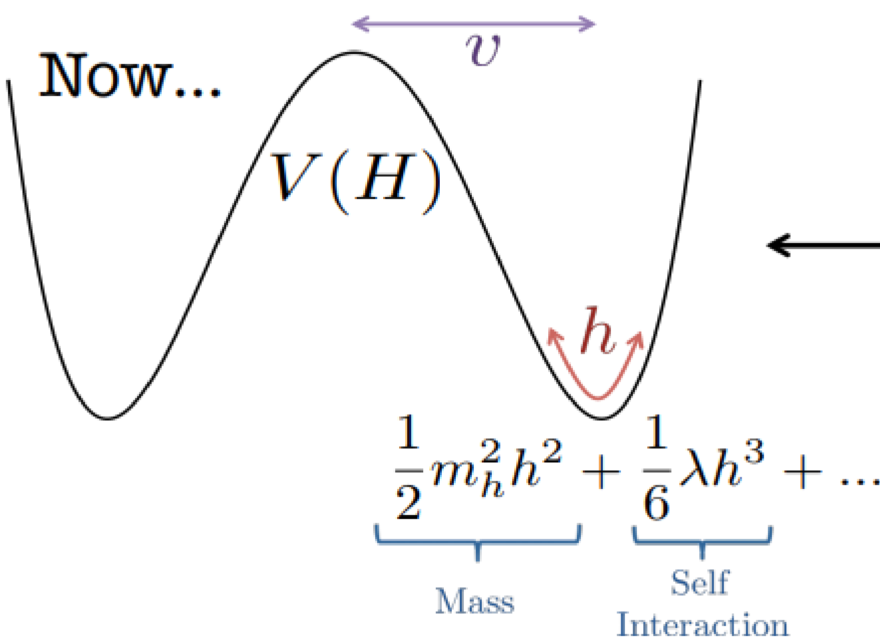


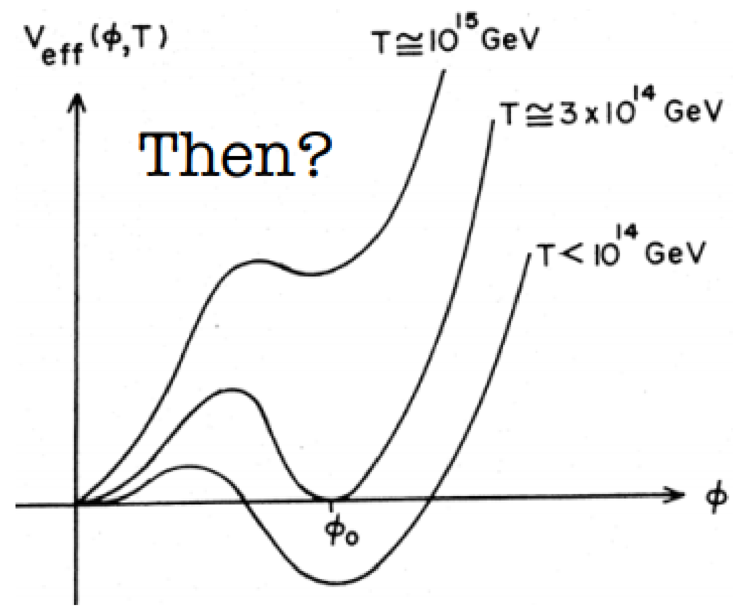
D

HL-LHC: di-Higgs production

The Higgs potential V is fundamental to the "Brout-Englert-Higgs mechanism"
→ non-zero scalar field *in vacuo*

Essential to explore shape of the potential – beyond quadratic term → m_H
→ also to throw light on electroweak phase-transition in early universe





Matthew McCollough

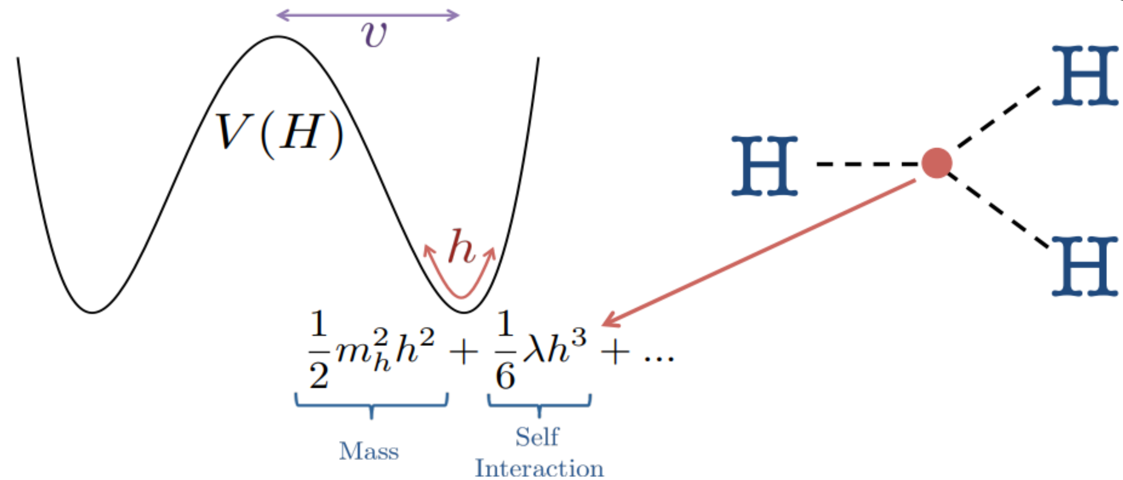
HL-LHC: di-Higgs production

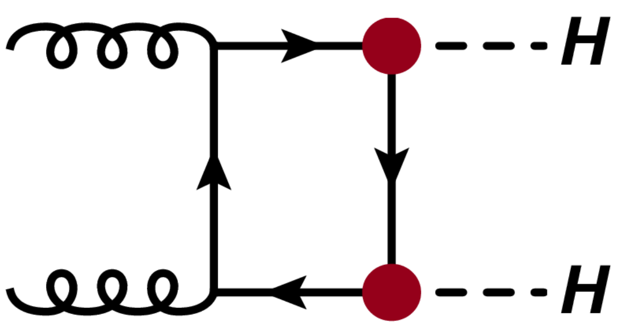
H pair production provides this sensitivity, in principle

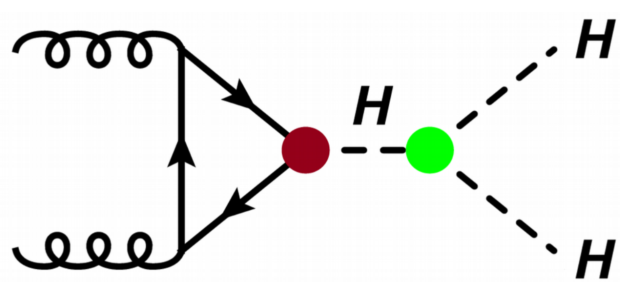
Range of studies going on to assess λ sensitivity

- Many channels
- High backgrounds – will need to be measured from the data

Matthew McCollough







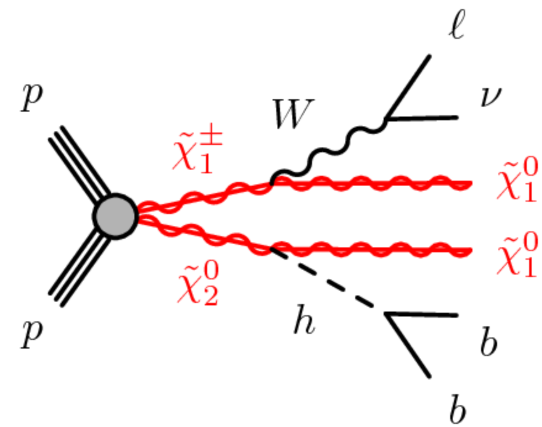
Indications we can measure HH rate at ~30-50% level with the full HL-LHC data sample – maybe better

→ sensitivity to anomalous large λ

Studies continue…

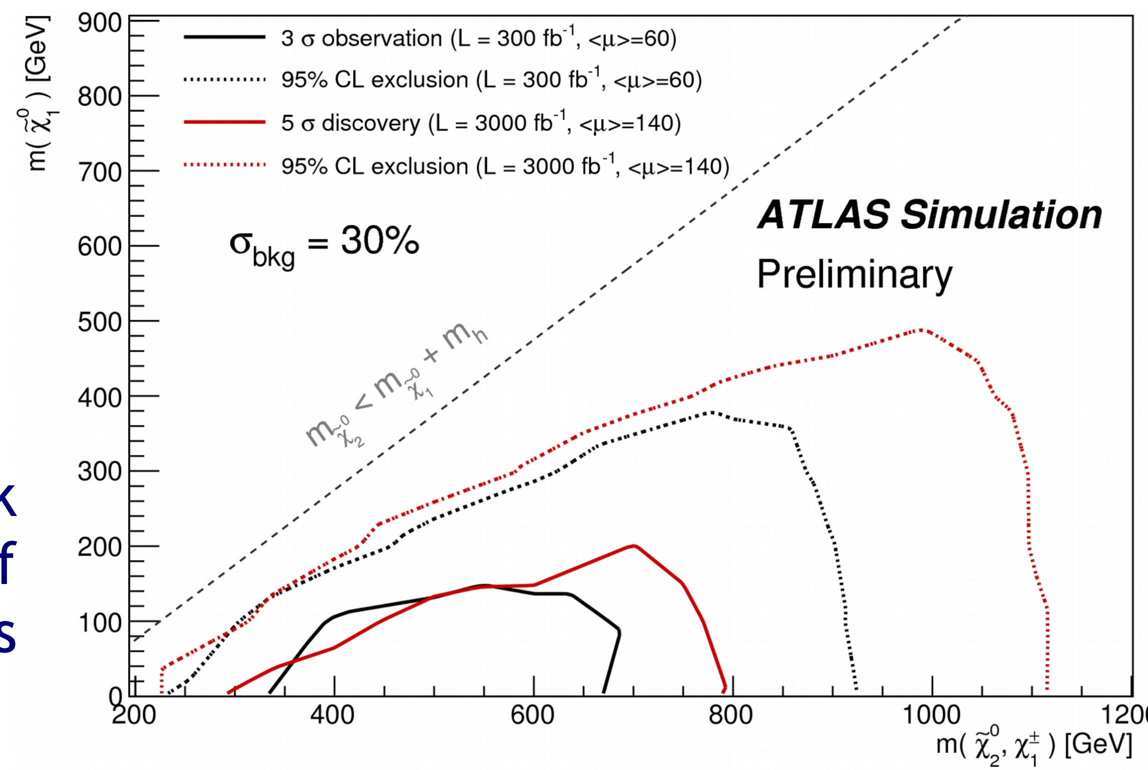
HL-LHC: extended search reach

With ten times the luminosity, mass reach for new particles increases by roughly 30% for many processes



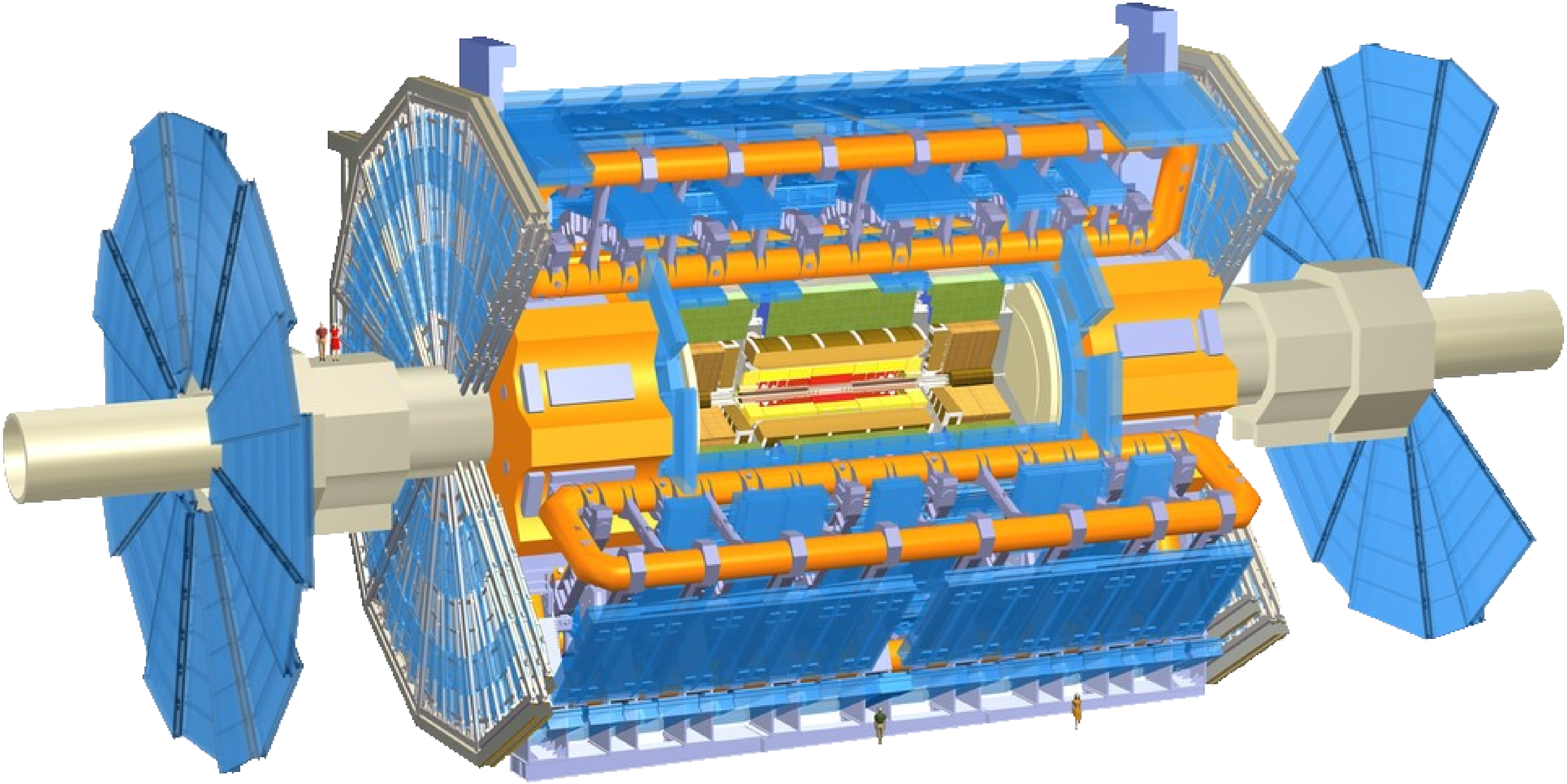
For new processes with lower cross-sections, the sensitivity gain can be much higher

- e.g. weakly-coupled dark matter models



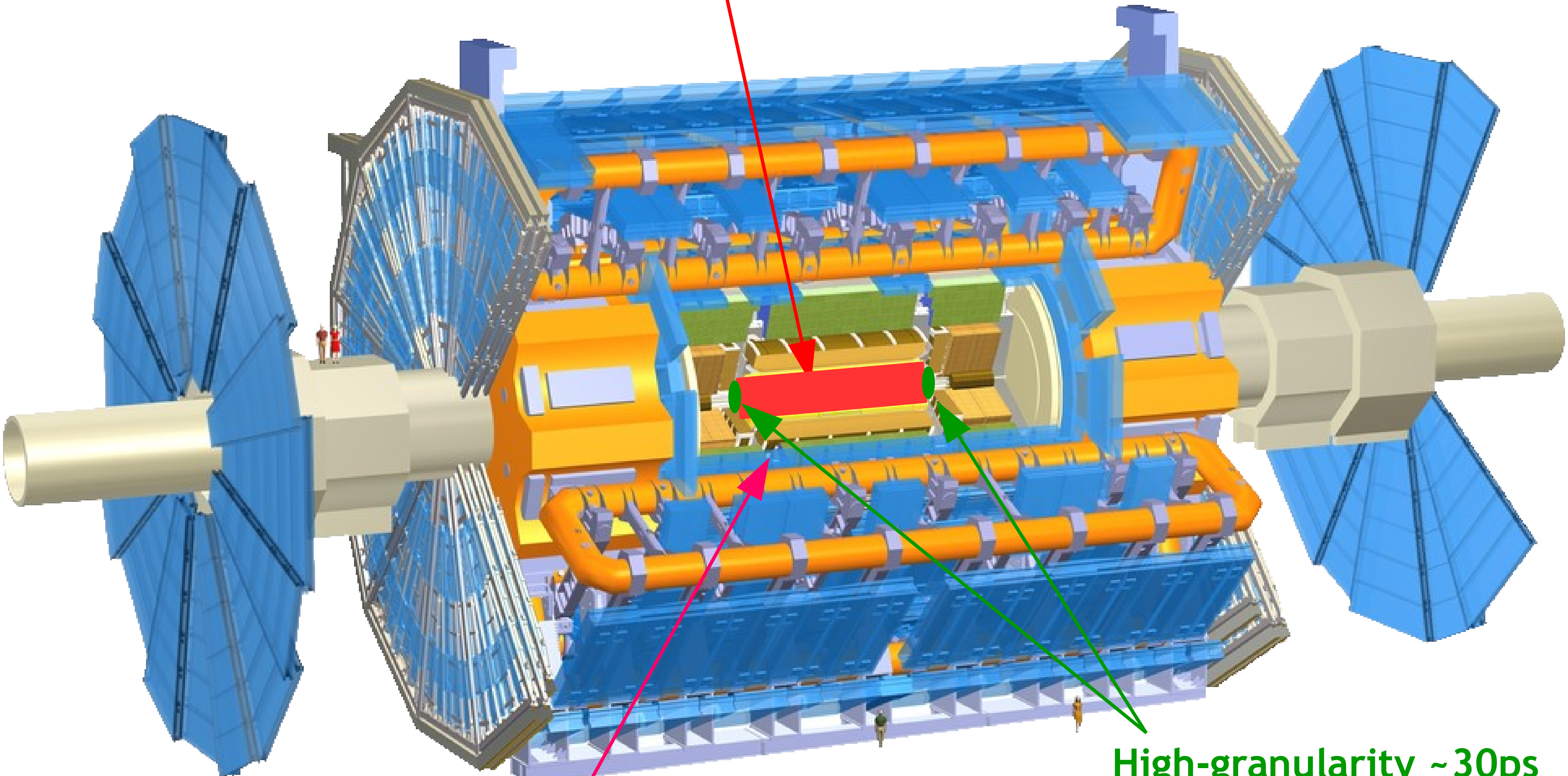
Example shown: Electroweak production of SUSY partners of electroweak bosons

Current ATLAS



Phase-II

New central tracker (ITk)

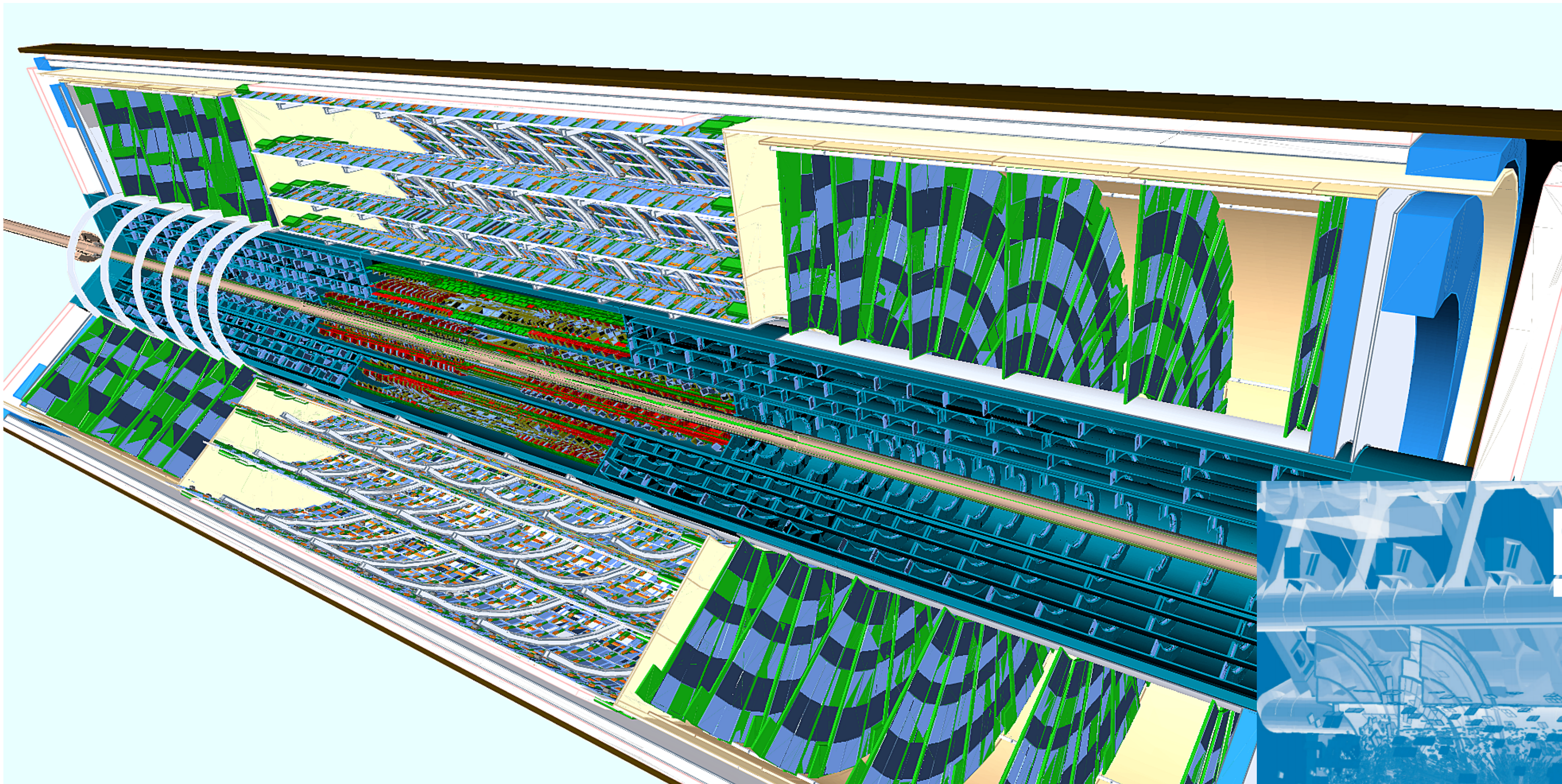


New muon chambers (e.g. BI RPC)

High-granularity ~30ps timing detector option, around beam directions

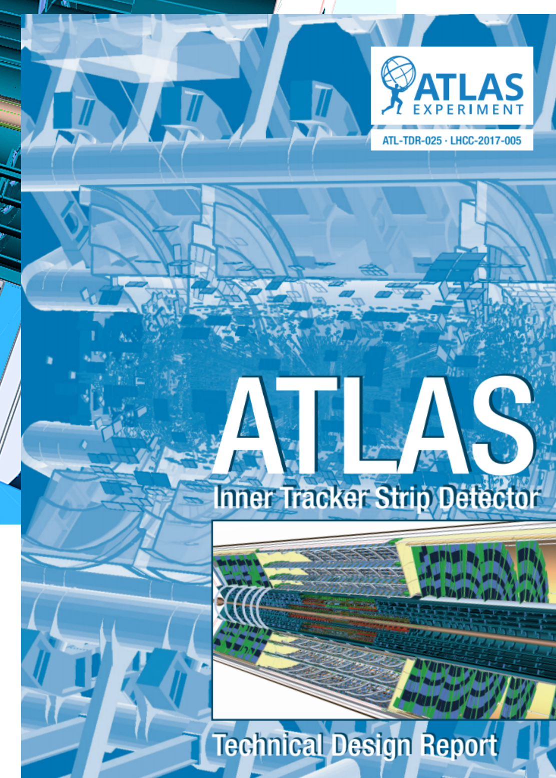
Massive readout electronics rework (LAr, Tile, Muons)
New trigger/readout architecture

Phase-II tracking detector: ITk



All silicon-sensor tracker:
- inner layers pixel sensors
- outer layers strip sensors

Sensor and systems R&D ongoing for some years



Closing

Run: 191426
Event: 86694500
2011-10-22 17:30:29 CEST

ATLAS EXPERIMENT
http://atlas.ch

The LHC is delivering well-beyond-design luminosity, at 13 TeV pp collision energy in Run-2

- Rich and diverse physics programme (also LHCb, ions … …)
- Many searches for new particles and interactions in progress
- Irrespective of new discoveries, there is a broad precision physics programme at ATLAS and CMS

The Higgs boson discovery was just the start of the programme of study of the scalar sector at the LHC

- We know now that it is a Higgs scalar, with broadly SM-like properties
- Huge scope for new physics in the scalar sector – we have just scratched the surface so far
- Only the LHC will address these questions for the next two decades

The LHC is, and will remain to the mid-2030’s, the world’s energy frontier particle collider