DAILY NEWS

World - Business - Finance - Lifestyle - Travel - Sport - Weather

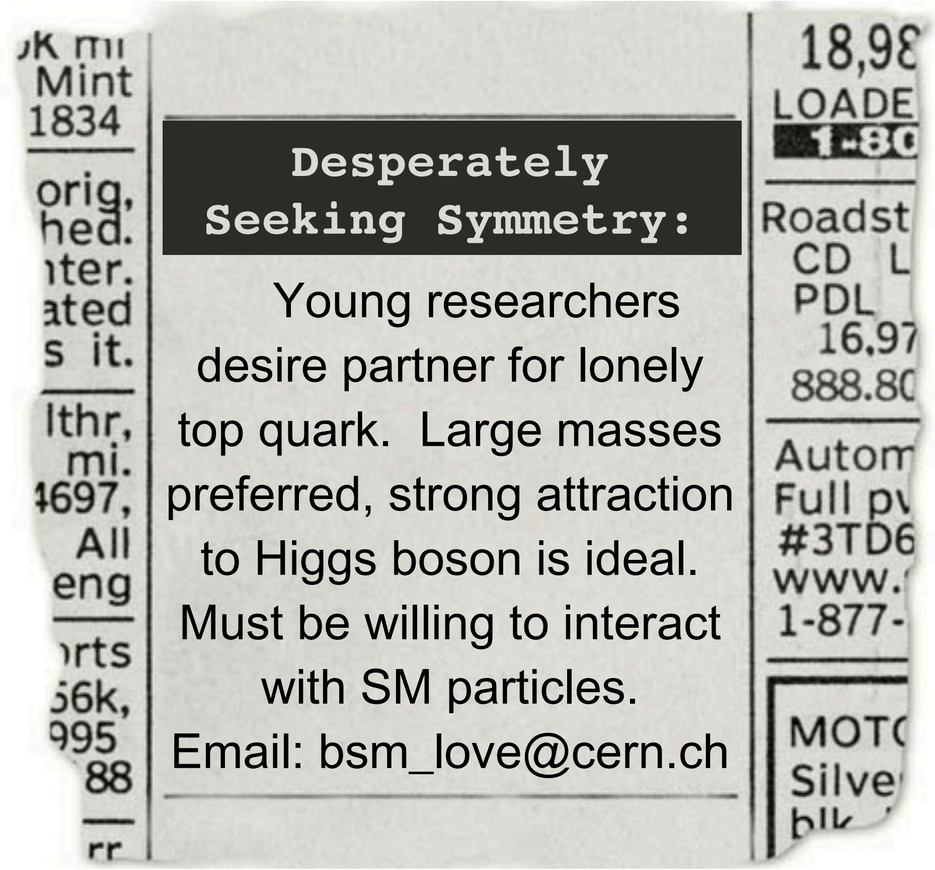
Issue: 240104 THE WORLDS BEST SELLING NATIONAL NEWSPAPER Est - 1965

First Edition Monday 5th June

Standard Model Scandal:

The Higgs boson is boring?

Miracle cure leaves researchers wanting more. CERN researchers continue their search for new physics while prominent theorists cite need for beyond Standard Model phenomenology. “Where’s the beef?,” asks John Ellis, “There has got to be more to this puzzle.”



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Desperately Seeking Symmetry:

Young researchers desire partner for lonely top quark. Large masses preferred, strong attraction to Higgs boson is ideal. Must be willing to interact with SM particles. Email: bsm_love@cern.ch

18,98

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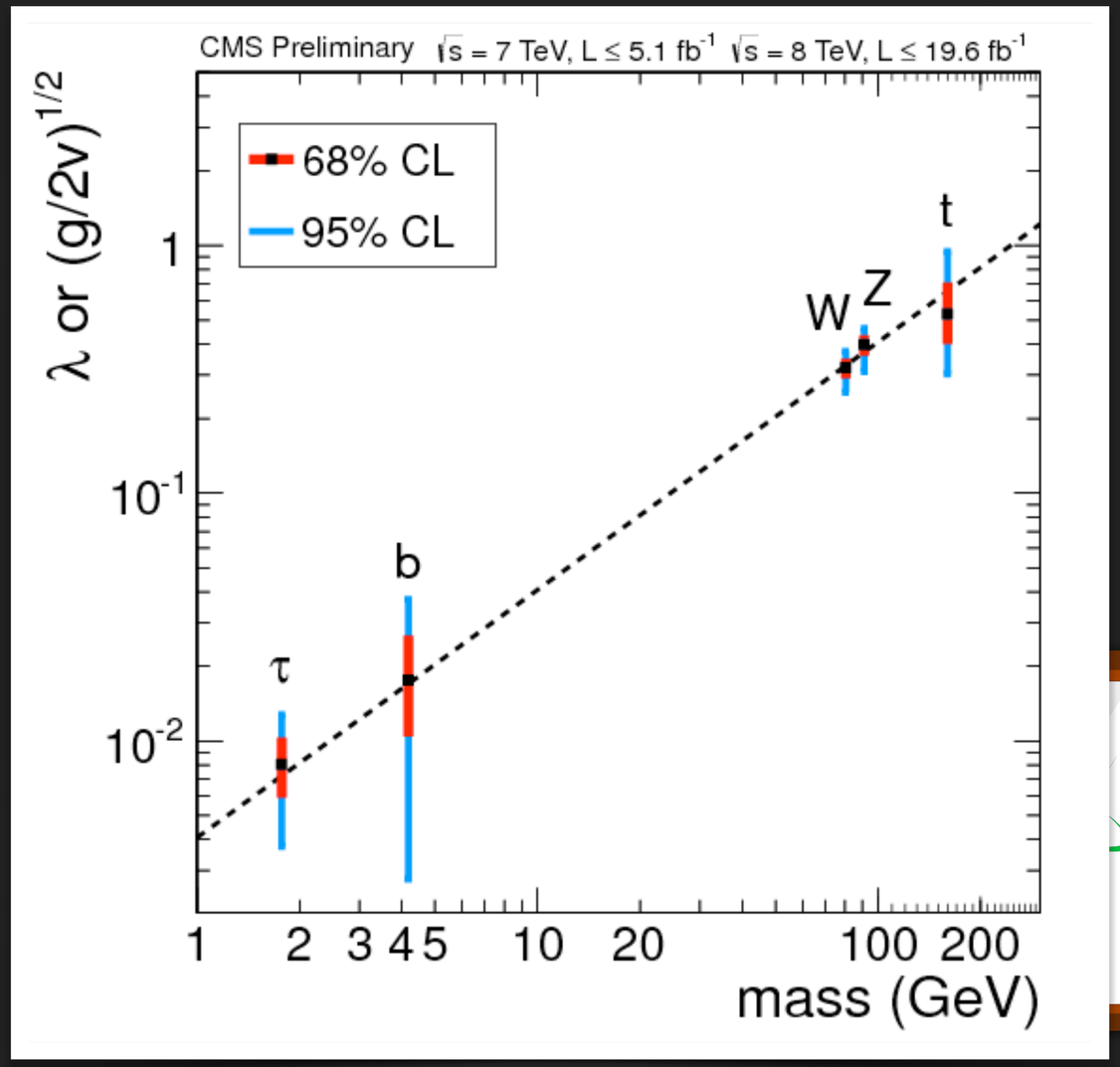
In the LHC News:

New paths to new physics & WAY more data ahead

July 4, 2012

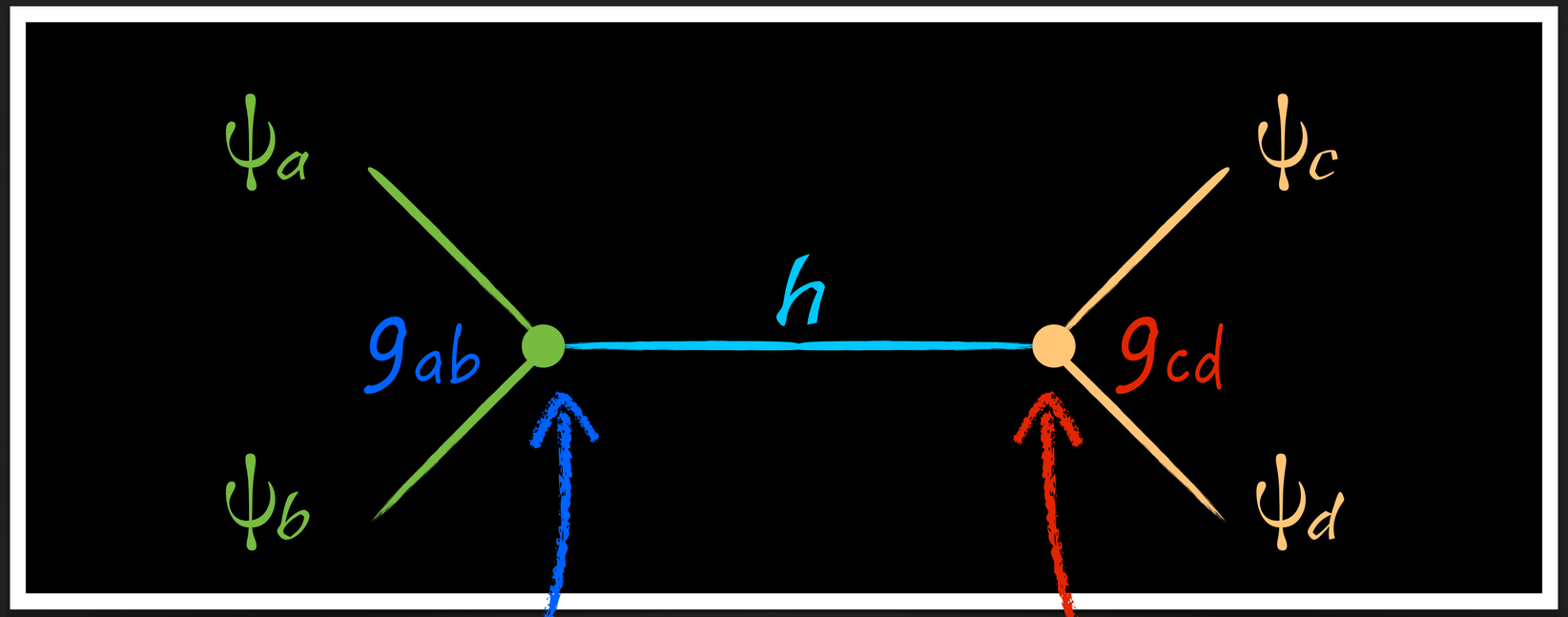

ATLAS today's main result (preliminary):
5.0 σ excess at m_H~126.5
These accomplishments are the results of more than 20 years of talented work and extreme dedication by the ATLAS Collaboration, with the continuous support of the Funding Agencies
More in general, they are the results of the ingenuity, vision and painstaking work of our community (accelerator, instrumentation, computing, physics)
Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
South Africa
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR
ICHEP
Melbourne
ATLAS
Collaboration
ATLAS Experiment

October, 2013



But is it a Higgs boson??

A Simplifying Illustration



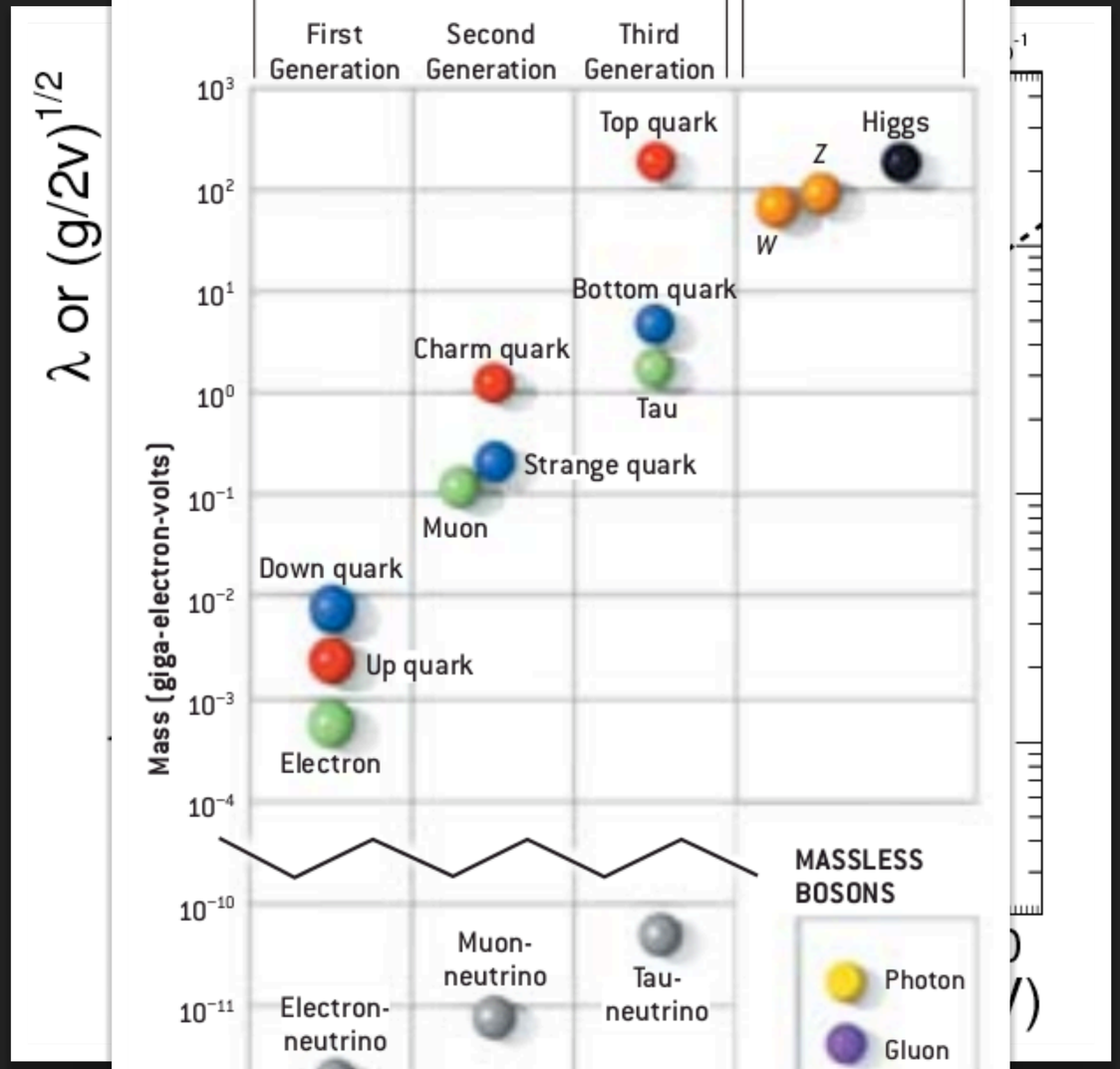
Production

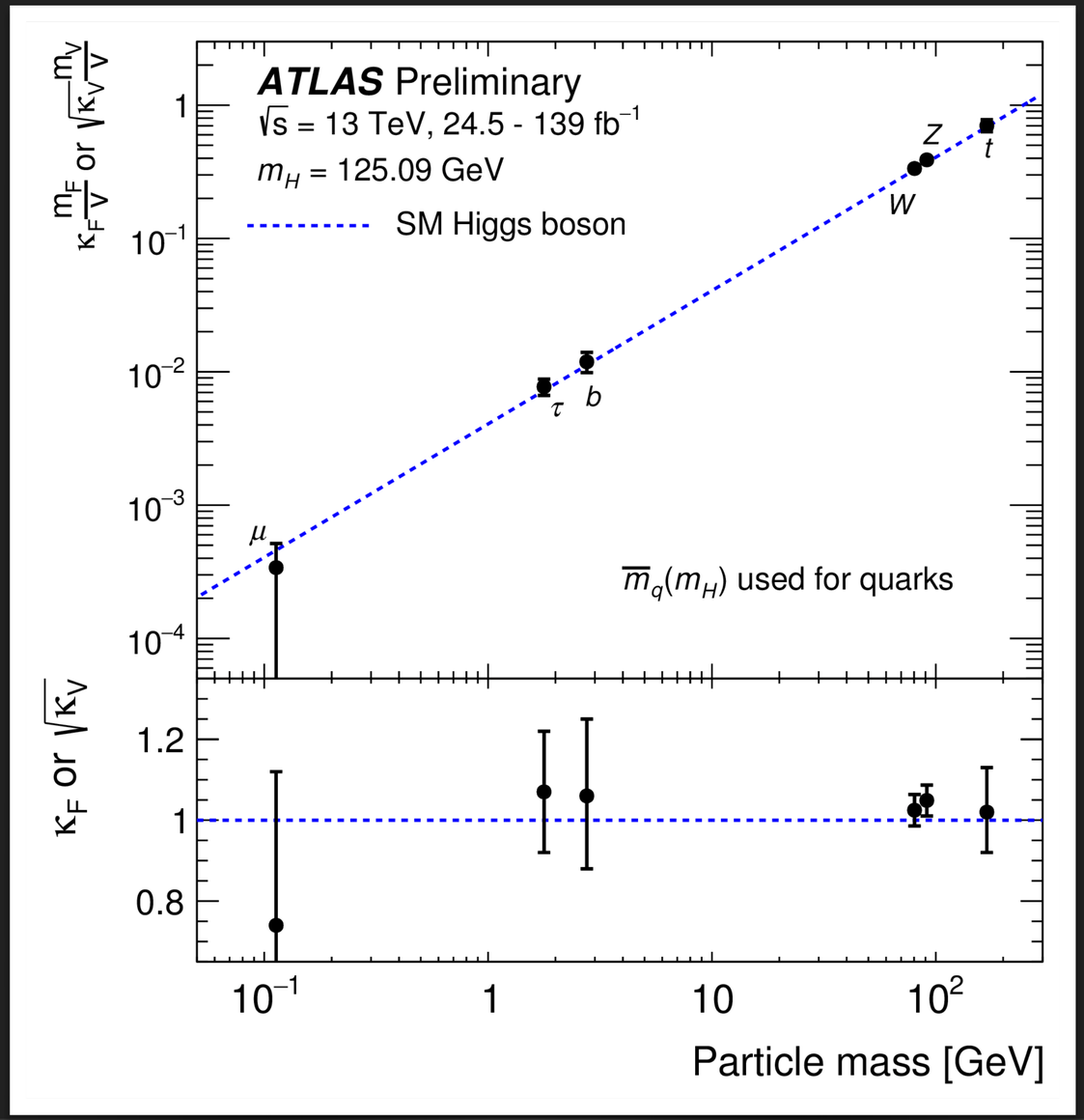
Decay

$$\sigma \propto g^2_{cd} \times g^2_{ab}$$

Higgs Couplings: 2013 vs 2022

Fast forward to today





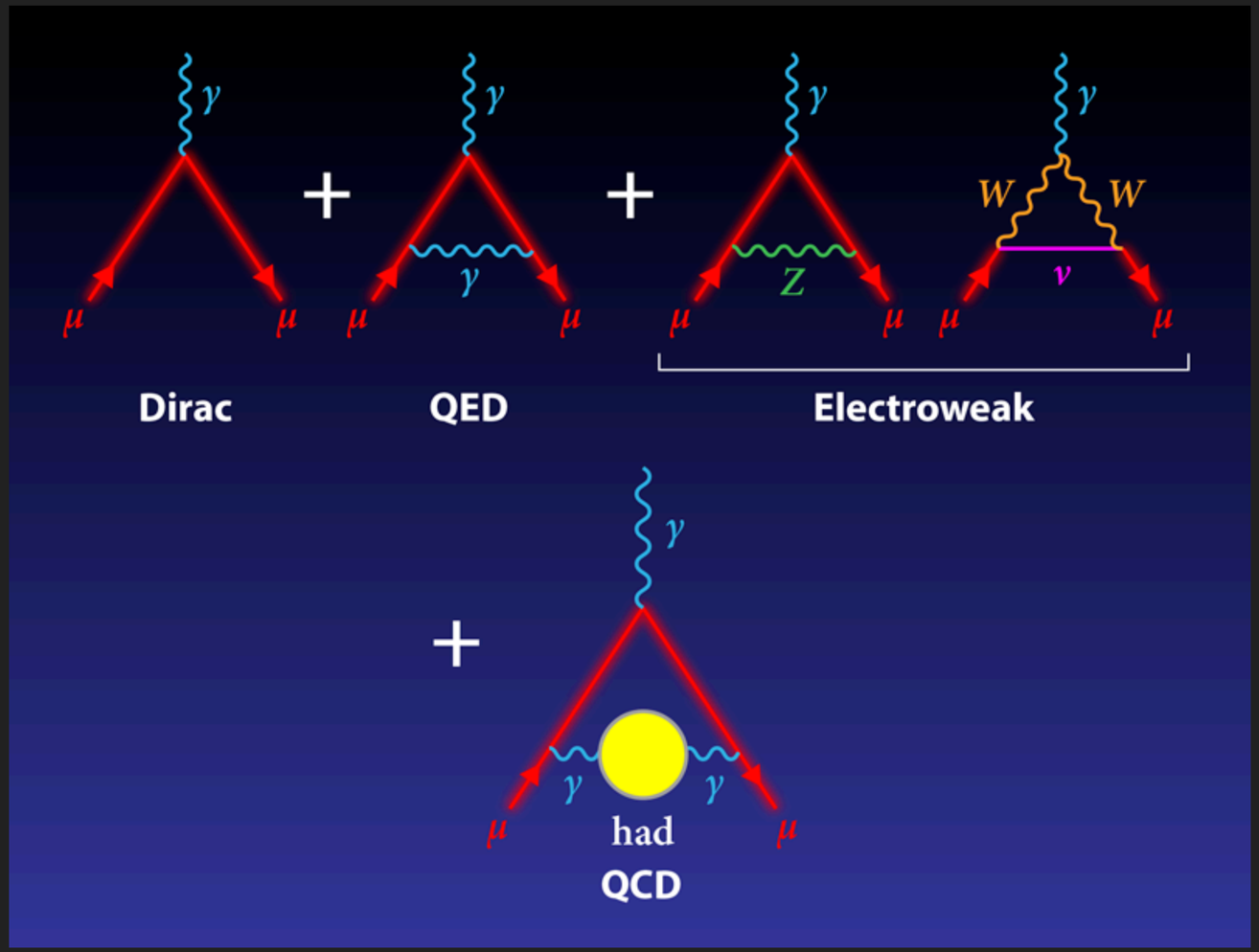
The Standard Model ~~Succeeds~~ Survives

Get your t-shirt!

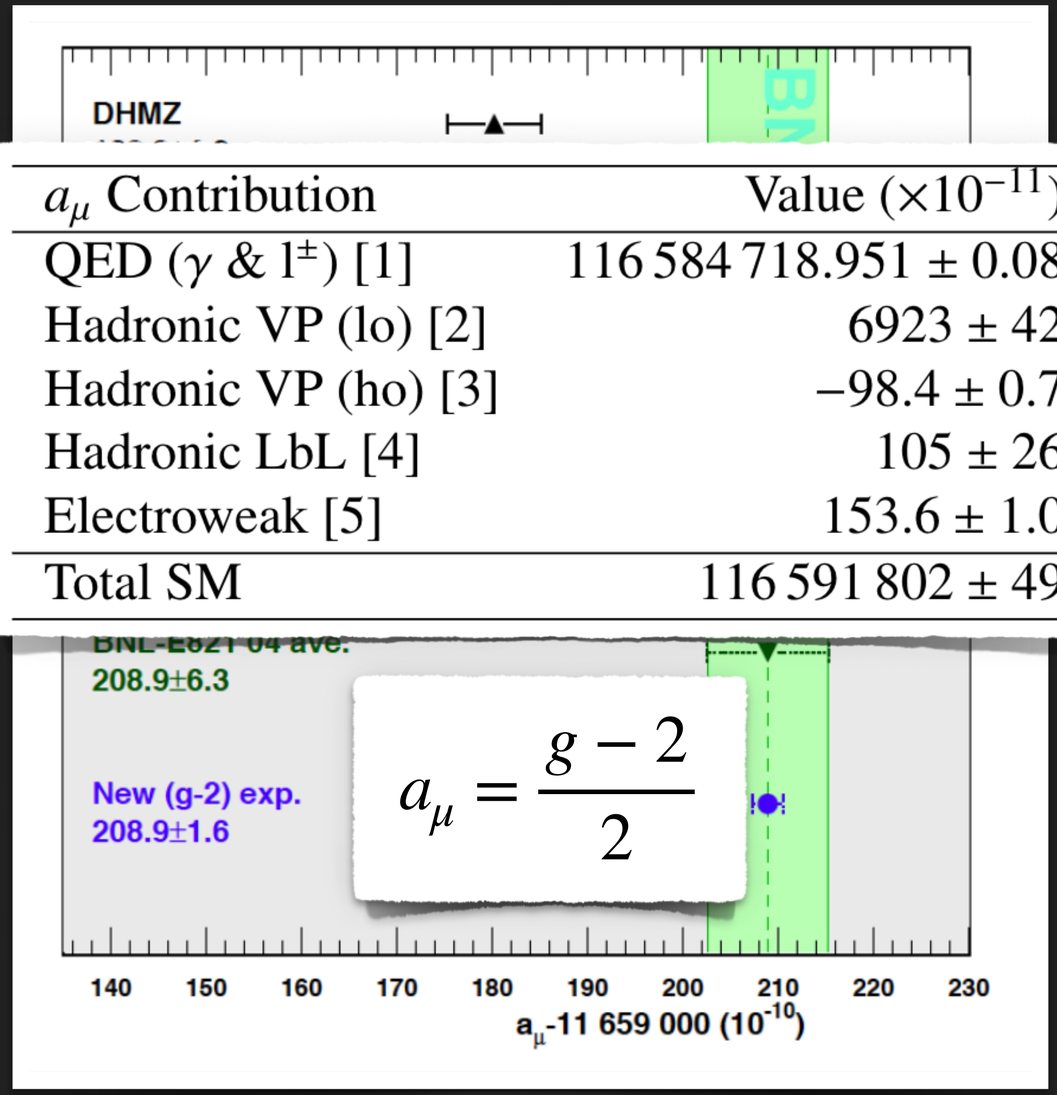
$$
\begin{aligned}
\mathcal{L} \quad = \quad & -\frac{1}{2}\mathrm{Tr}\, G_{\mu\nu}G^{\mu\nu} - \frac{1}{2}\mathrm{Tr}\, W_{\mu\nu}W^{\mu\nu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\
& + (D_\mu \phi)^\dagger D^\mu \phi + \mu^2 \phi^\dagger \phi - \frac{1}{2}\lambda \left(\phi^\dagger \phi\right)^2 \\
& + \sum_{f=1}^{3} \left(\bar{\ell}_L^f i \not{D} \ell_L^f + \bar{\ell}_R^f i \not{D} \ell_R^f + \bar{q}_L^f i \not{D} q_L^f + \bar{d}_R^f i \not{D} d_R^f + \bar{u}_R^f i \not{D} u_R^f \right) \\
& - \sum_{f=1}^{3} y_\ell^f \left(\bar{\ell}_L^f \phi \ell_R^f + \bar{\ell}_R^f \phi^\dagger \ell_L^f \right) \\
& - \sum_{f,g=1}^{3} \left(y_d^{fg} \bar{q}_L^f \phi d_R^g + (y_d^{fg})^* \bar{d}_R^g \phi^\dagger q_L^f + y_u^{fg} \bar{q}_L^f \tilde{\phi} u_R^g + (y_u^{fg})^* \bar{u}_R^g \tilde{\phi}^\dagger q_L^f \right),
\end{aligned}
$$

Muon Anomalous Magnetic Moment

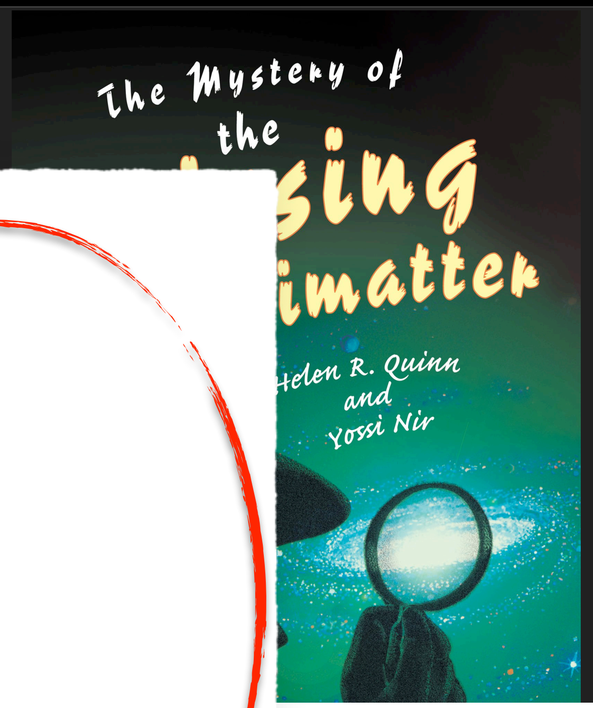
An exposition of precision

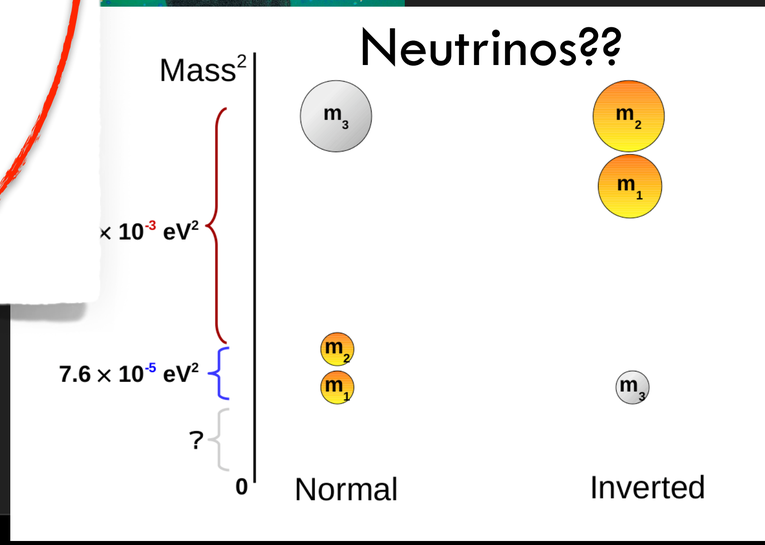


a_μ Contribution	Value ($\times 10^{-11}$)
QED (γ & $l^{\pm}$) [1]	116 584 718.951 ± 0.08
Hadronic VP (lo) [2]	6923 ± 42
Hadronic VP (ho) [3]	−98.4 ± 0.7
Hadronic LbL [4]	105 ± 26
Electroweak [5]	153.6 ± 1.0
Total SM	116 591 802 ± 49



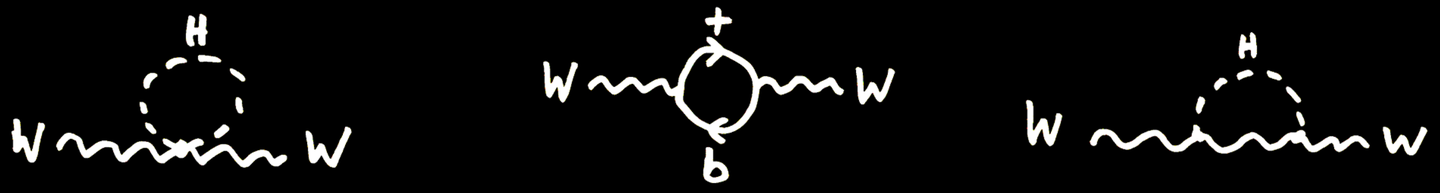
Puzzles in the Standard Model

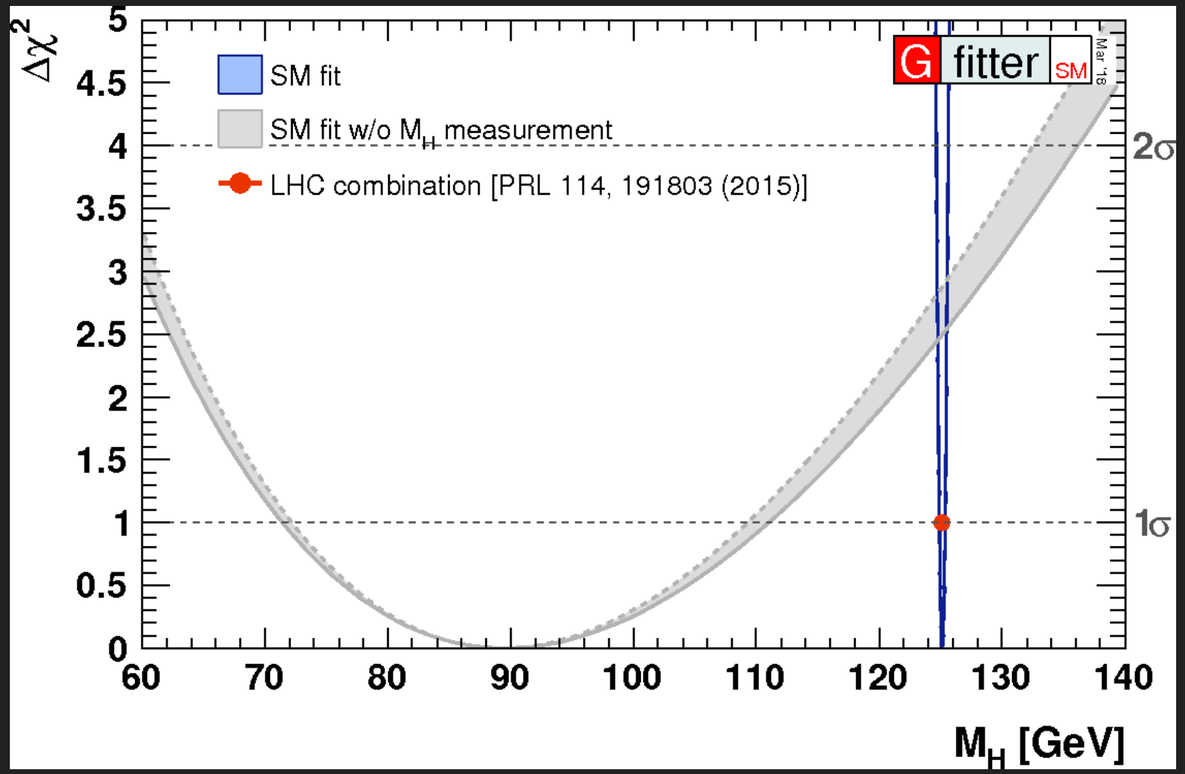




Higgs Mass Radiative Corrections

Getting loopy?





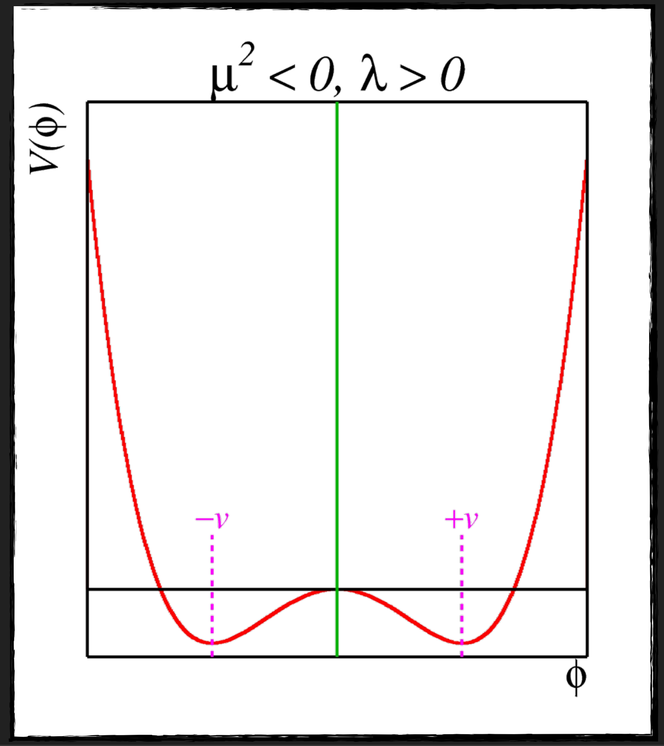
The Higgs Vacuum

Getting loopy?

$$V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

Higgs boson mass

Vacuum stability



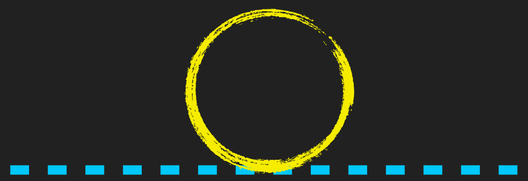
The Higgs Vacuum

Getting loopy?

$$V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

$$M_H^2 = M_{\text{Tree}}^2 + M_{\text{Loops}}^2$$

$$\lambda_H = \lambda_{\text{Tree}} + \lambda_{\text{Loops}}$$



The Higgs Vacuum

Getting loopy?

$$V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

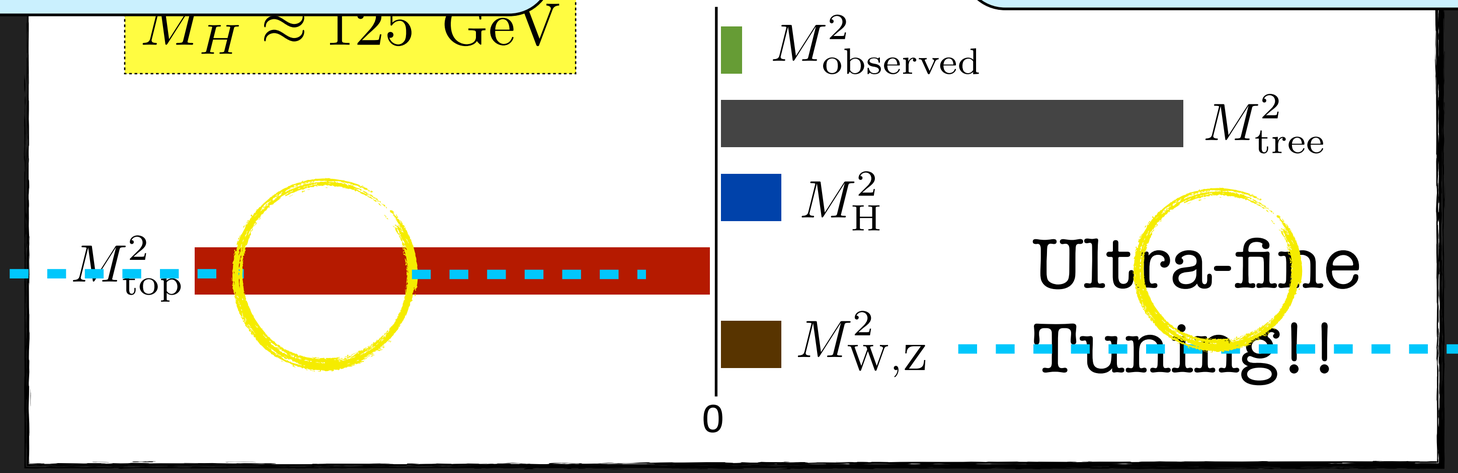
$$M_H^2 = M_{\text{tree}}^2$$

$$\delta M^2 \propto \frac{a}{16\pi^2} g^2 \Lambda^2$$

$$M_H^2 = M_{\text{Tree}}^2 + M_{\text{Loops}}^2$$

$$\lambda_H = \lambda_{\text{Tree}} + \lambda_{\text{Loops}}$$

$M_H \approx 125$ GeV



The Higgs Vacuum

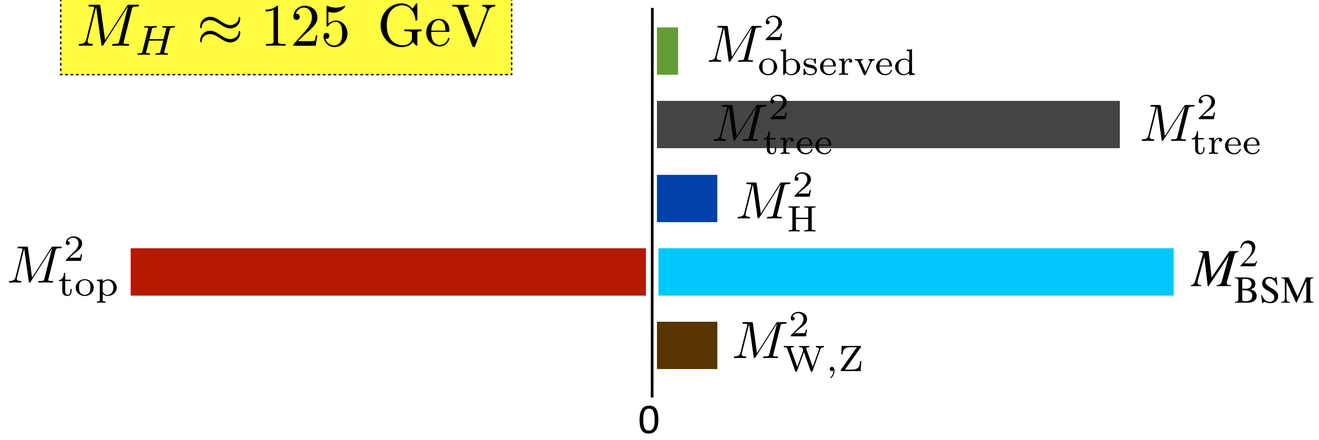
Getting loopy?

$$V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

$$M_H^2 = M_{\text{tree}}^2 + \left(\begin{array}{c}\text{H}\\ \text{H}\quad\quad\text{H}\end{array}\right) + \left(\begin{array}{c}\bar{t}\\ \text{H}\quad\quad\text{H}\\ t\end{array}\right) + \left(\begin{array}{c}W,Z\\ \text{H}\quad\quad\text{H}\end{array}\right)$$

$$\delta M^2 \propto \frac{a}{16\pi^2} g^2 \Lambda^2$$

$M_H \approx 125$ GeV



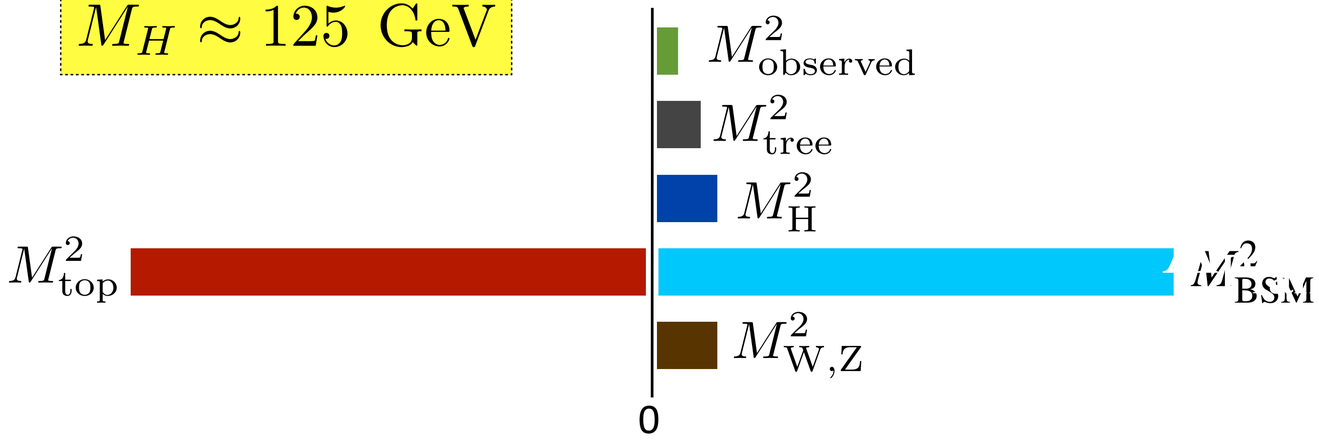
The Higgs Vacuum

Getting loopy?

$$V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

$$M_H^2 = M_{\text{tree}}^2 + \left(\begin{array}{c} H \\ \text{○} \\ H \quad\quad H \end{array}\right) + \left(\begin{array}{c} \bar{t} \\ \text{○} \\ H \quad\quad H \\ t \end{array}\right) + \left(\begin{array}{c} W,Z \\ \text{○} \\ H \quad\quad H \end{array}\right) + \left(H \text{ ---- } \boxed{BSM} \text{ ---- }\right)$$

$M_H \approx 125$ GeV



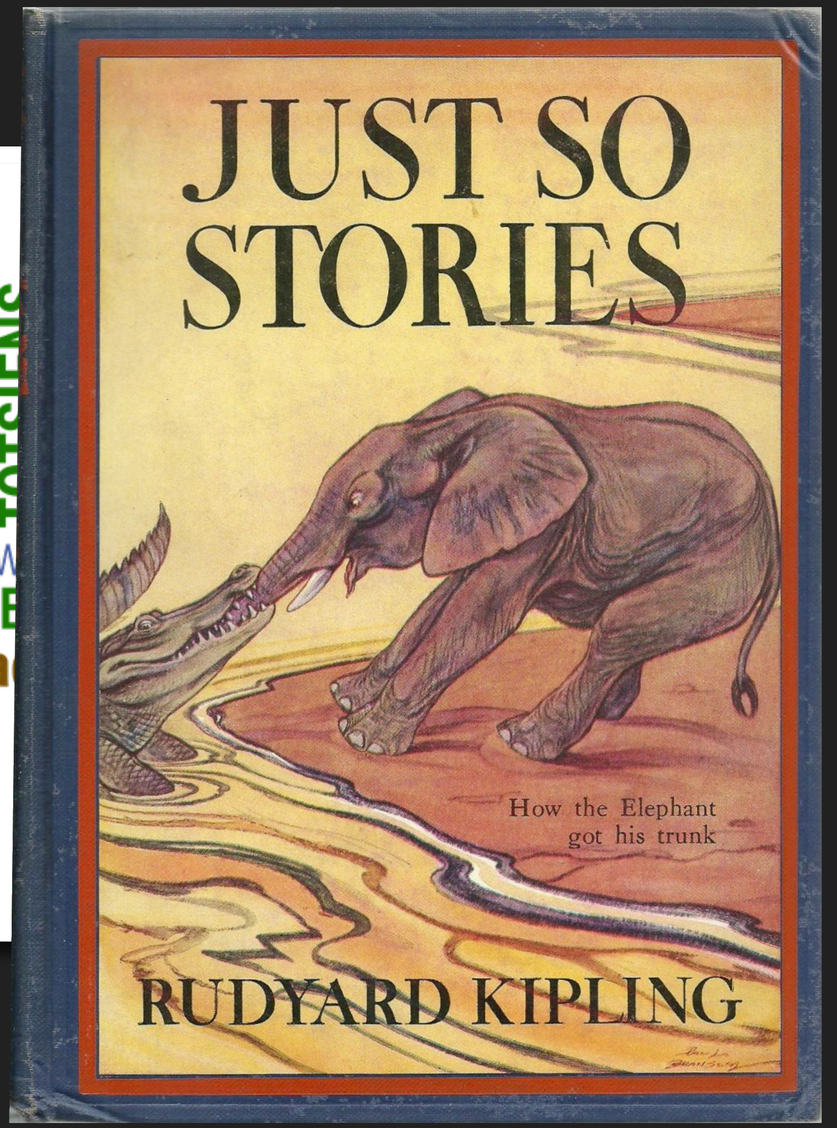
$$\propto \frac{a}{16\pi^2} g^2 \Lambda^2$$

$\sim 10^{19}$ GeV

The Language of the Standard Model

Is this the truth or just a convenient description?

$$
\begin{aligned}
\mathcal{L} \;=\; & -\frac{1}{2}\mathrm{Tr}\, G_{\mu\nu}G^{\mu\nu} - \frac{1}{2}\mathrm{Tr}\, W_{\mu\nu}W^{\mu\nu} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\
& + (D_\mu\phi)^\dagger D^\mu\phi + \mu^2\phi^\dagger\phi - \frac{1}{2}\lambda\left(\phi^\dagger\phi\right)^2 \\
& + \sum_{f=1}^{3}\left(\bar{\ell}_L^f i\not{D}\ell_L^f + \bar{\ell}_R^f i\not{D}\ell_R^f + \bar{q}_L^f i\not{D}q_L^f + \bar{d}_R^f i\not{D}d_R^f + \bar{u}_R^f i\not{D}u_R^f\right) \\
& - \sum_{f=1}^{3} y_\ell^f\left(\bar{\ell}_L^f\phi\ell_R^f + \bar{\ell}_R^f\phi^\dagger\ell_L^f\right) \\
& - \sum_{f,g=1}^{3}\left(y_d^{fg}\bar{q}_L^f\phi d_R^g + (y_d^{fg})^*\bar{d}_R^g\phi^\dagger q_L^f + y_u^{fg}\bar{q}_L^f\tilde{\phi}u_R^g + (y_u^{fg})^*\bar{u}_R^g\tilde{\phi}^\dagger q_L^f\right),
\end{aligned}
$$



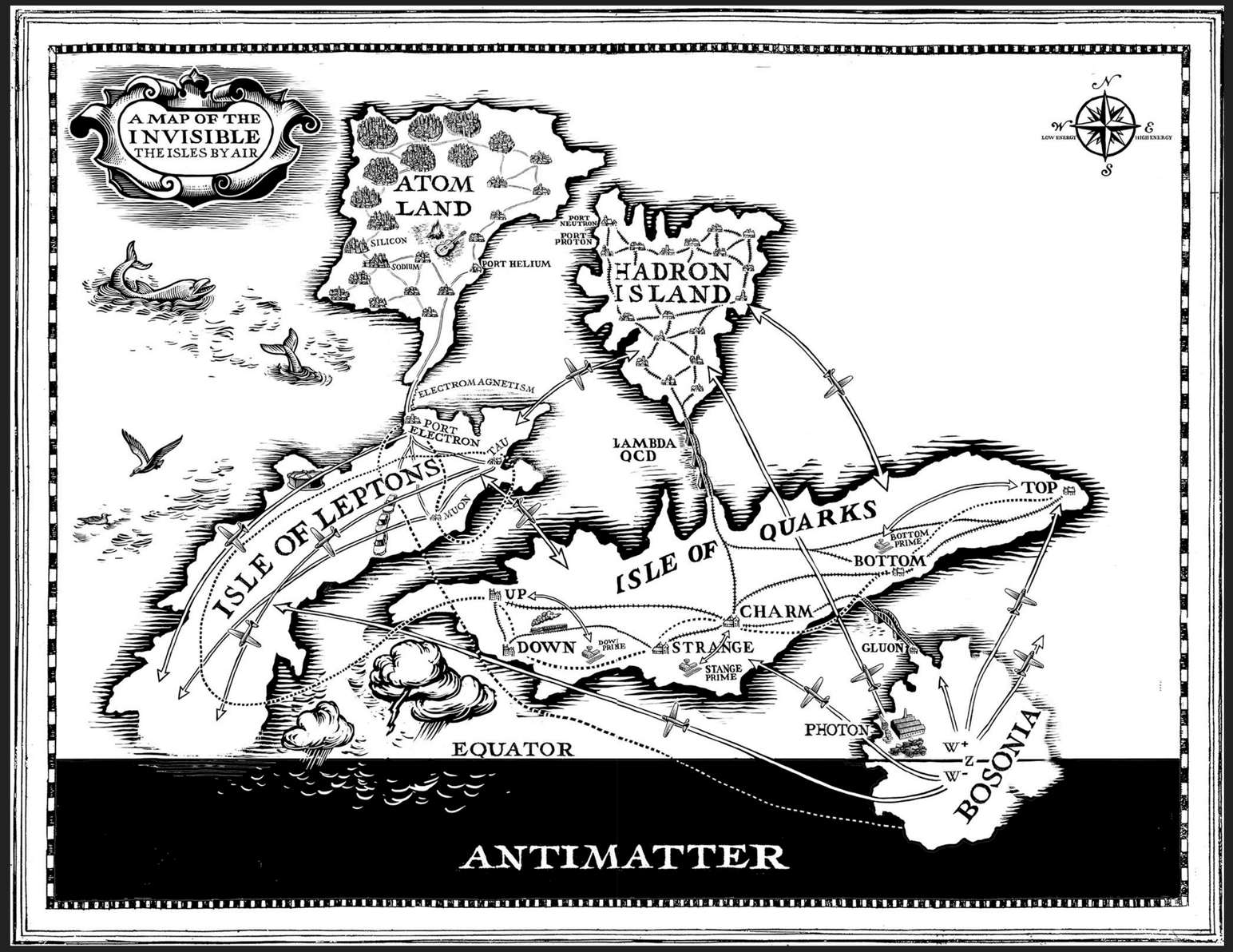
A historical perspective

Was it a right or a left turn at Lambda QCD??

Atom Land:
A Guided Tour Through the Strange (and Impossibly Small) World of Particle Physics

By Jon Butterworth
UC London

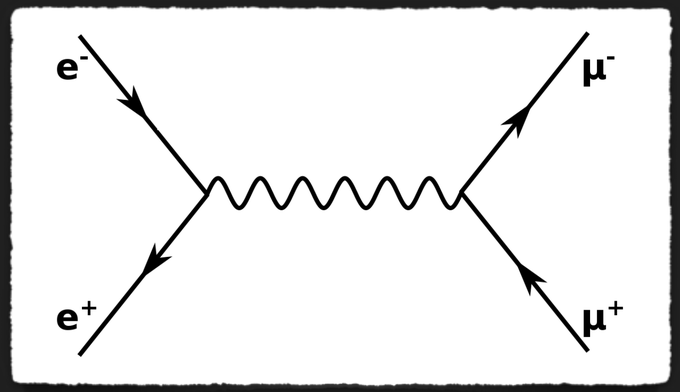
ISBN: 978-1615193738

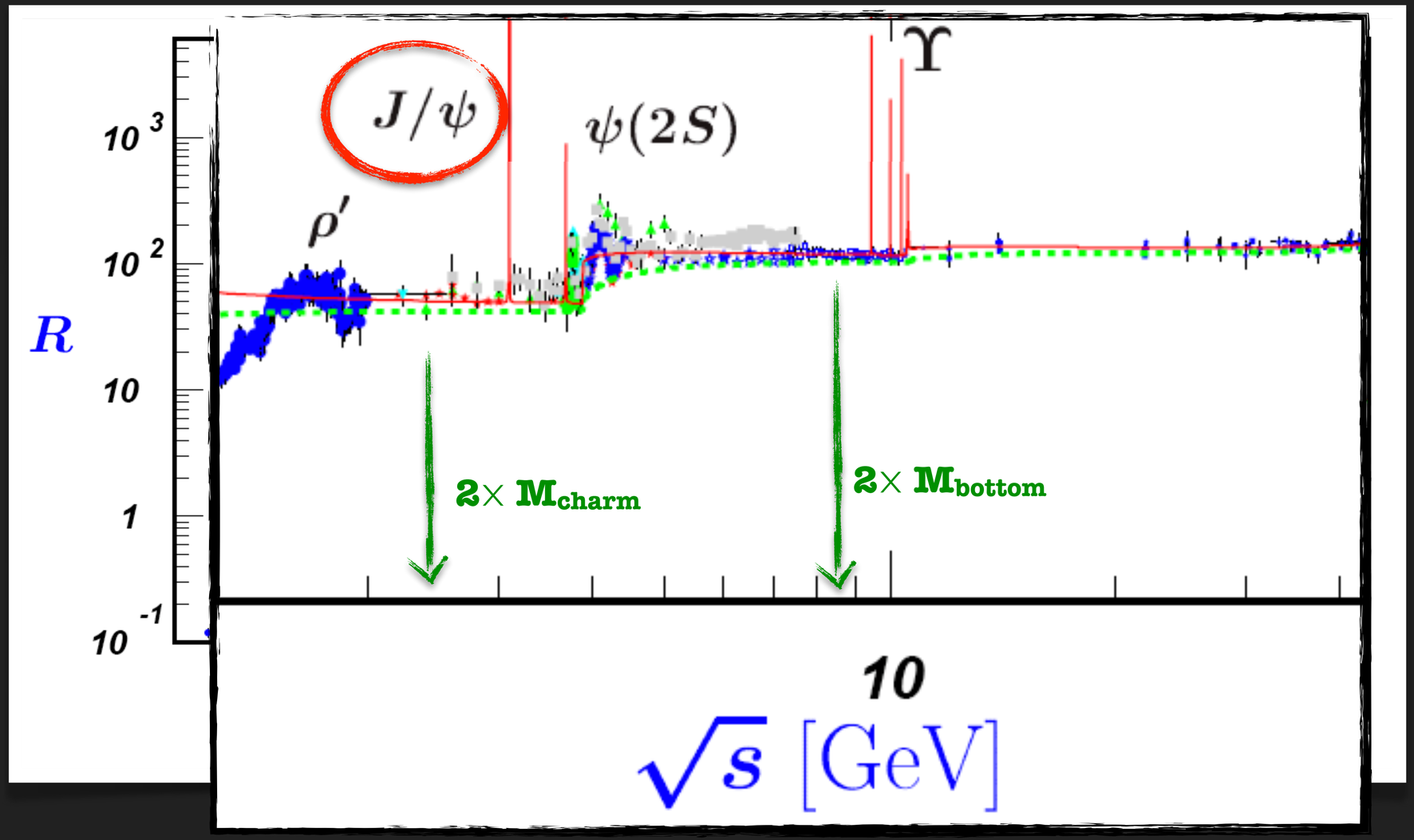


Mass Resonances

A historic guide to discovery

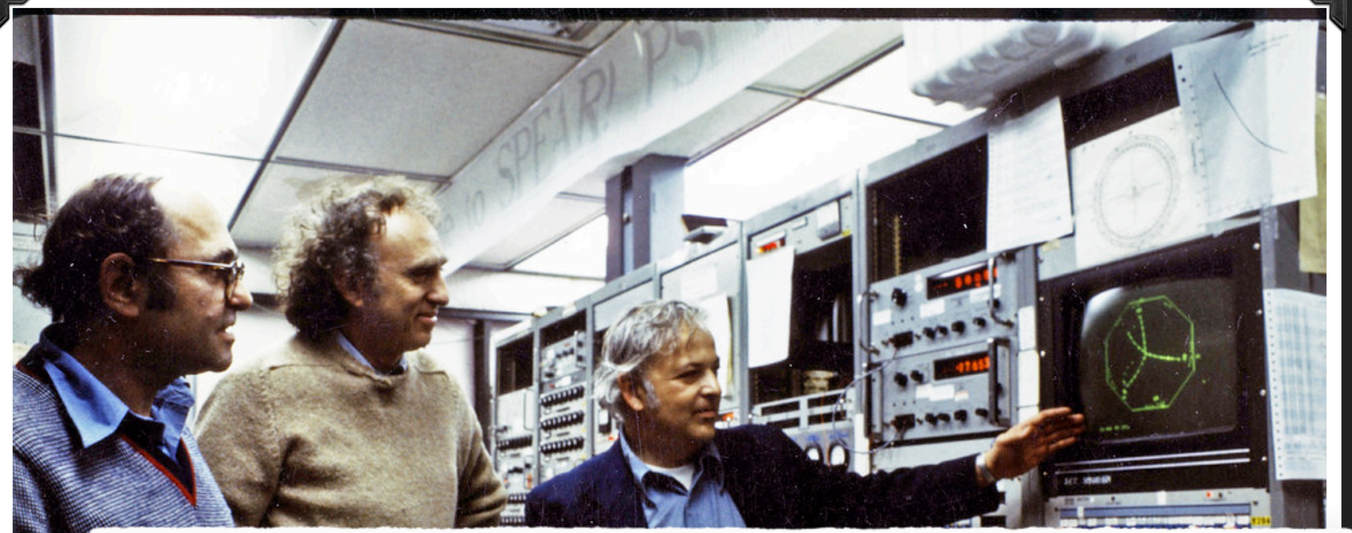
$$R = \frac{\sigma(e^+e^- \to q\bar{q})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$





The November Revolution

November 1974: Discovery of the Charmed Quark



VOLUME 33, NUMBER 23 PHYSICAL REVIEW LETTERS 2 DECEMBER 1974

Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

Y. Y. Lee
Brookhaven National Laboratory, Upton, New York 11973
(Received 12 November 1974)

We report the observation of a heavy particle J, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \mathrm{Be} \rightarrow e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

Discovery of a Narrow Resonance in $e^+ e^-$ Annihilation*

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci‡
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

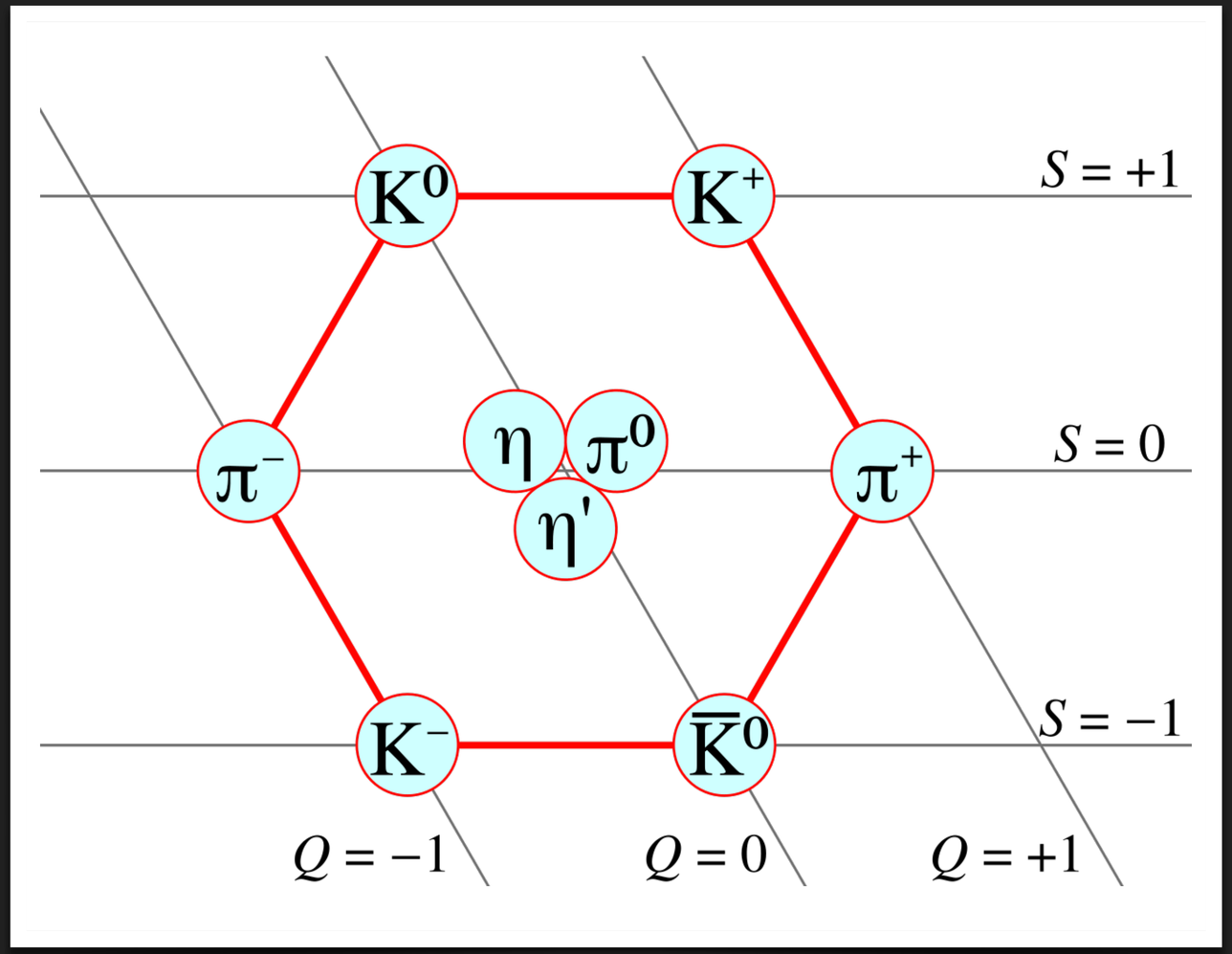
and

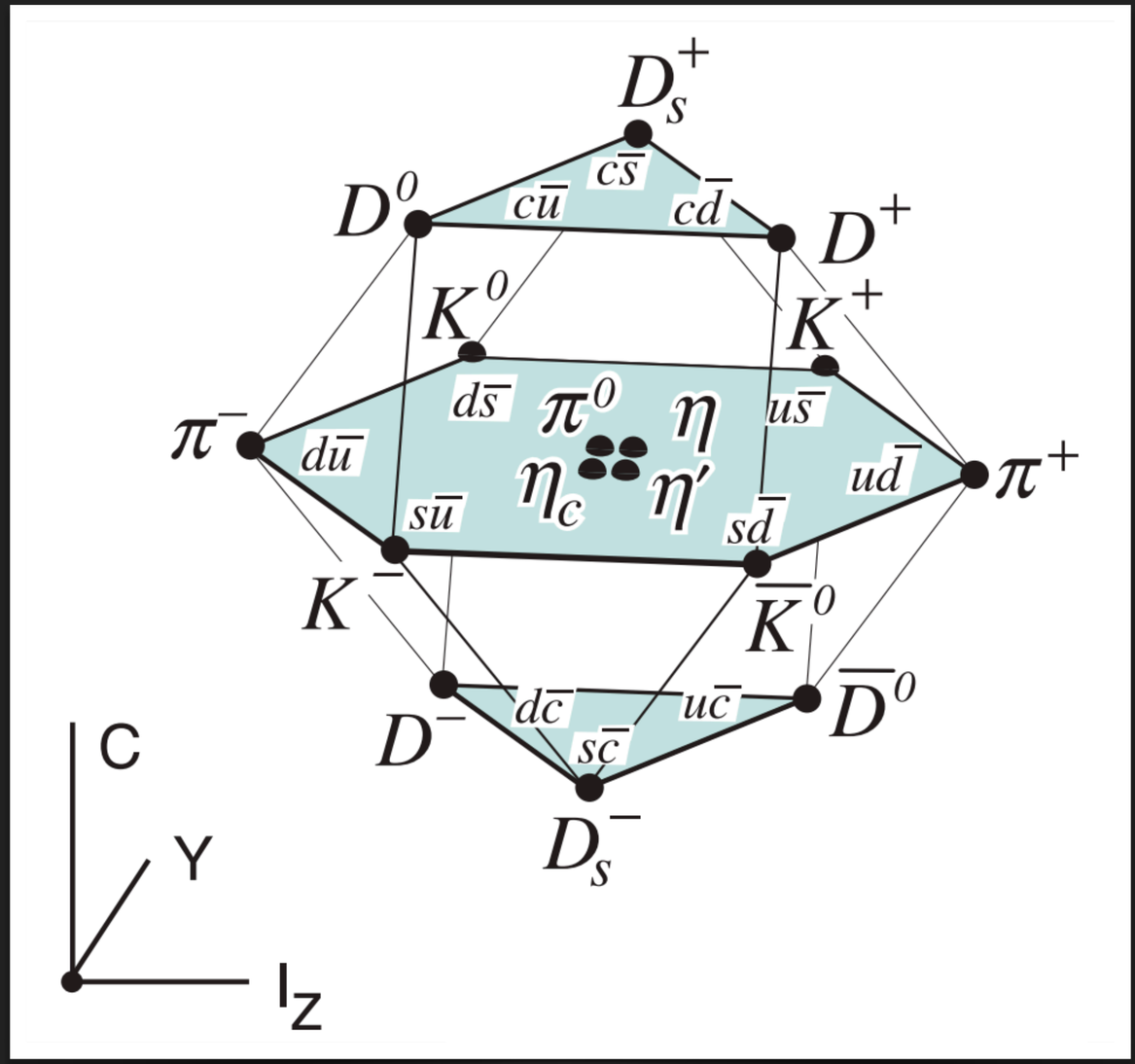
G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek, J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Whitaker, J. Wiss, and J. E. Zipse
Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720
(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^- \rightarrow$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

Emerging Landscape

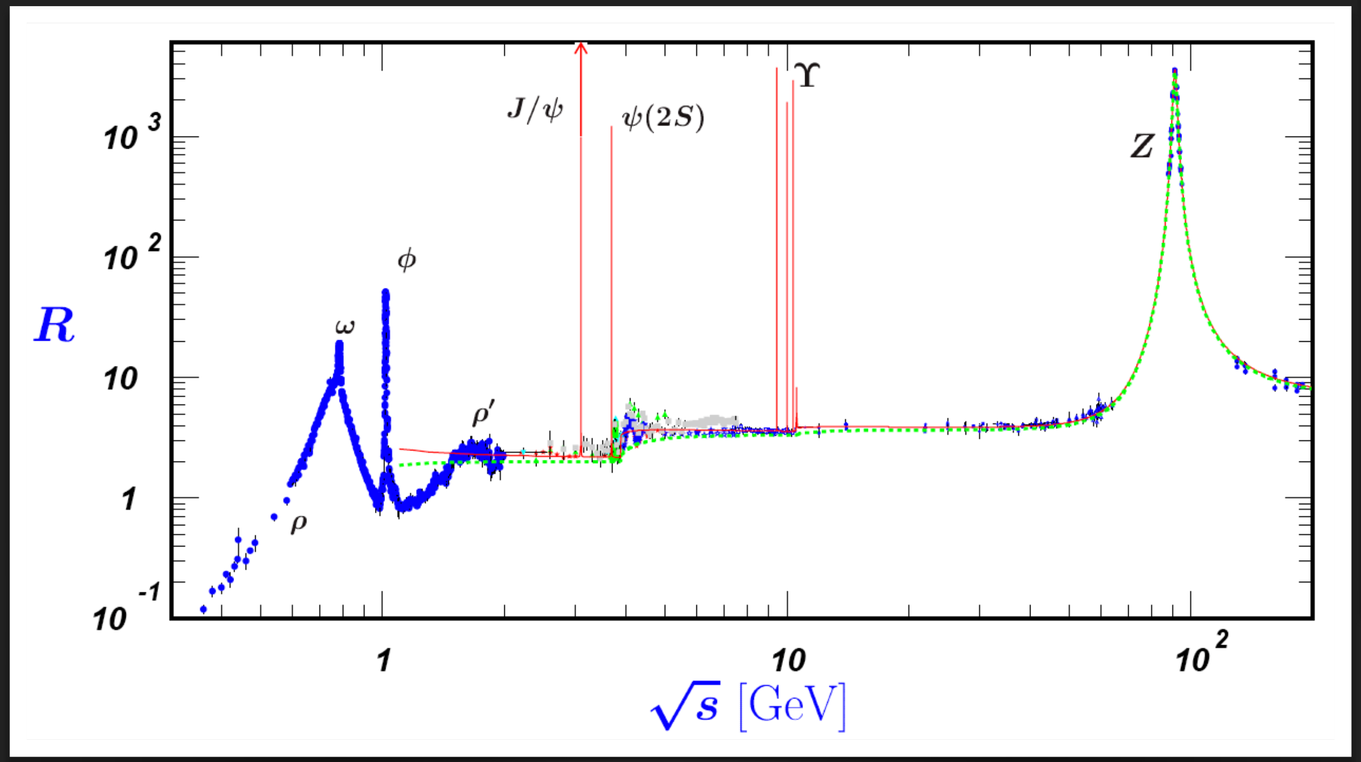
Charm is a game-changer!

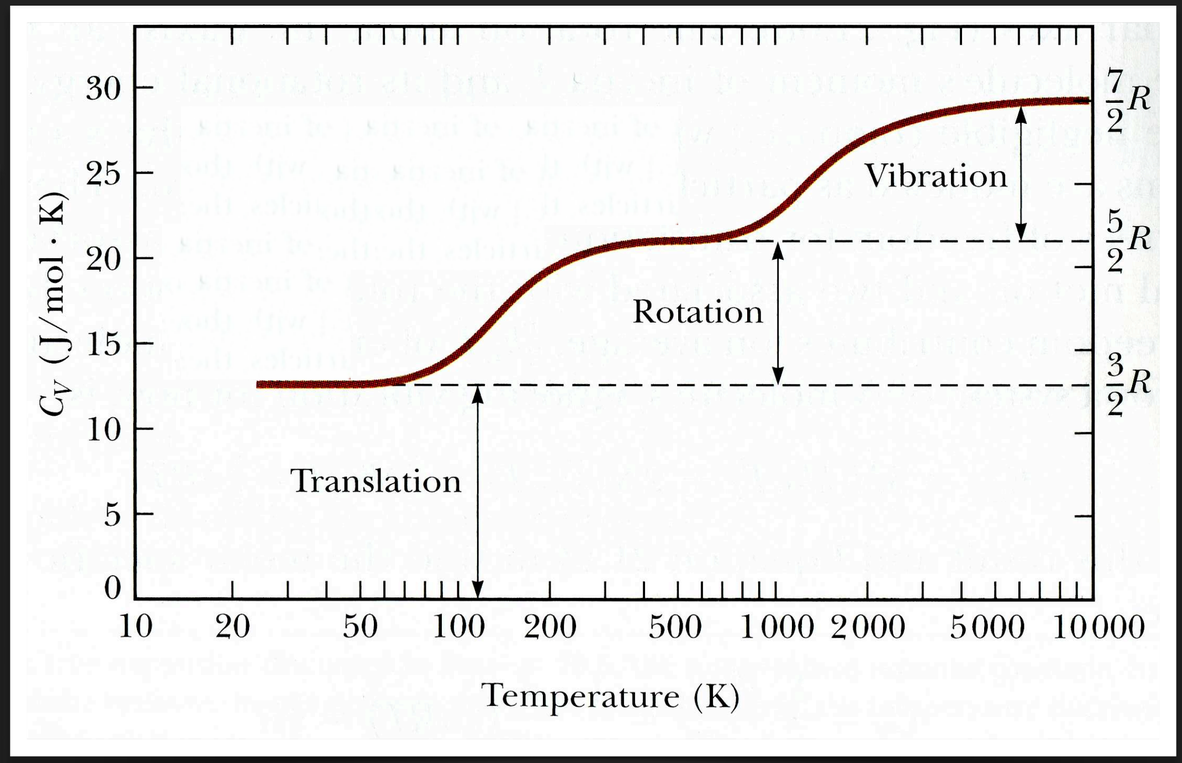


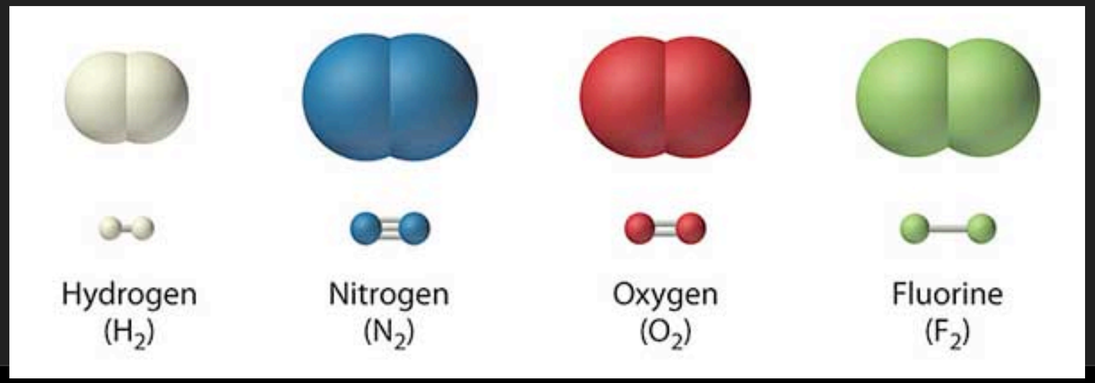


“New” phenomena?

Structure as a guide to the underlying theory.

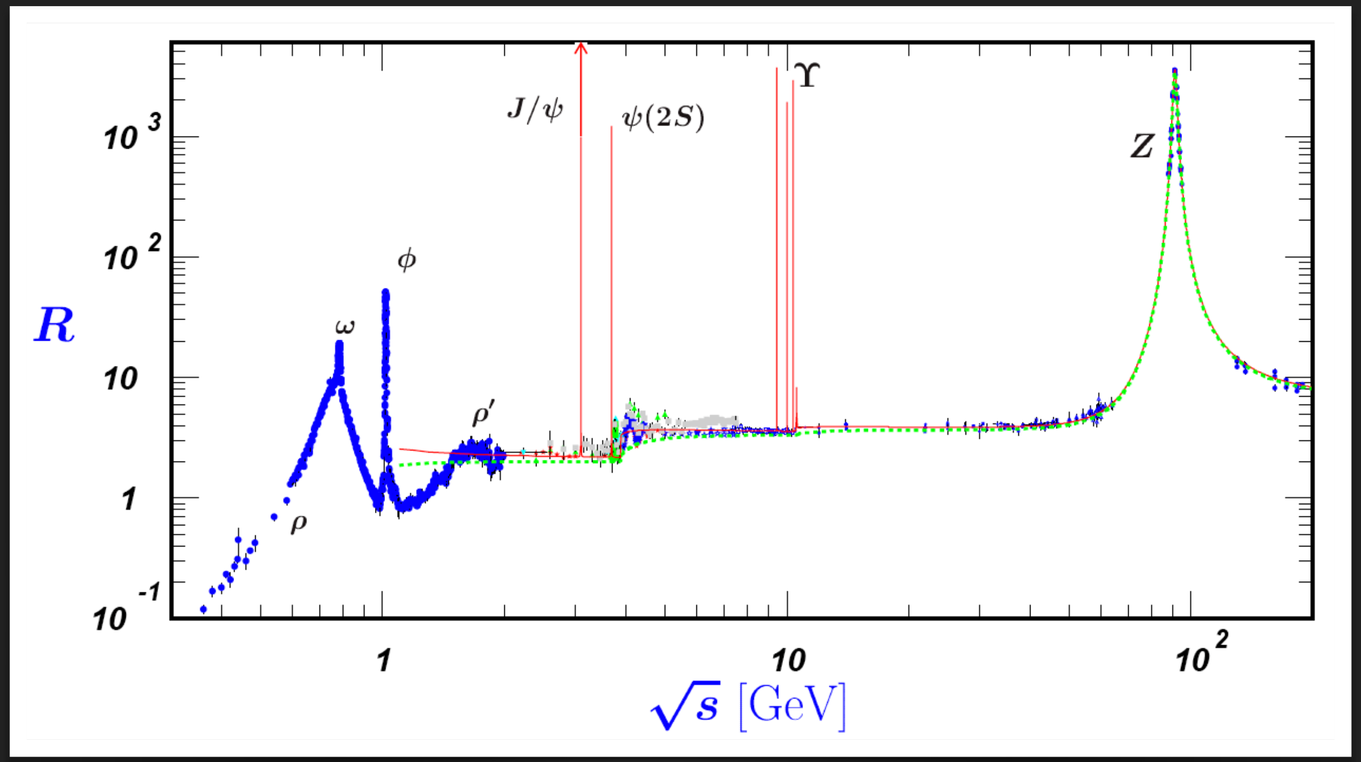


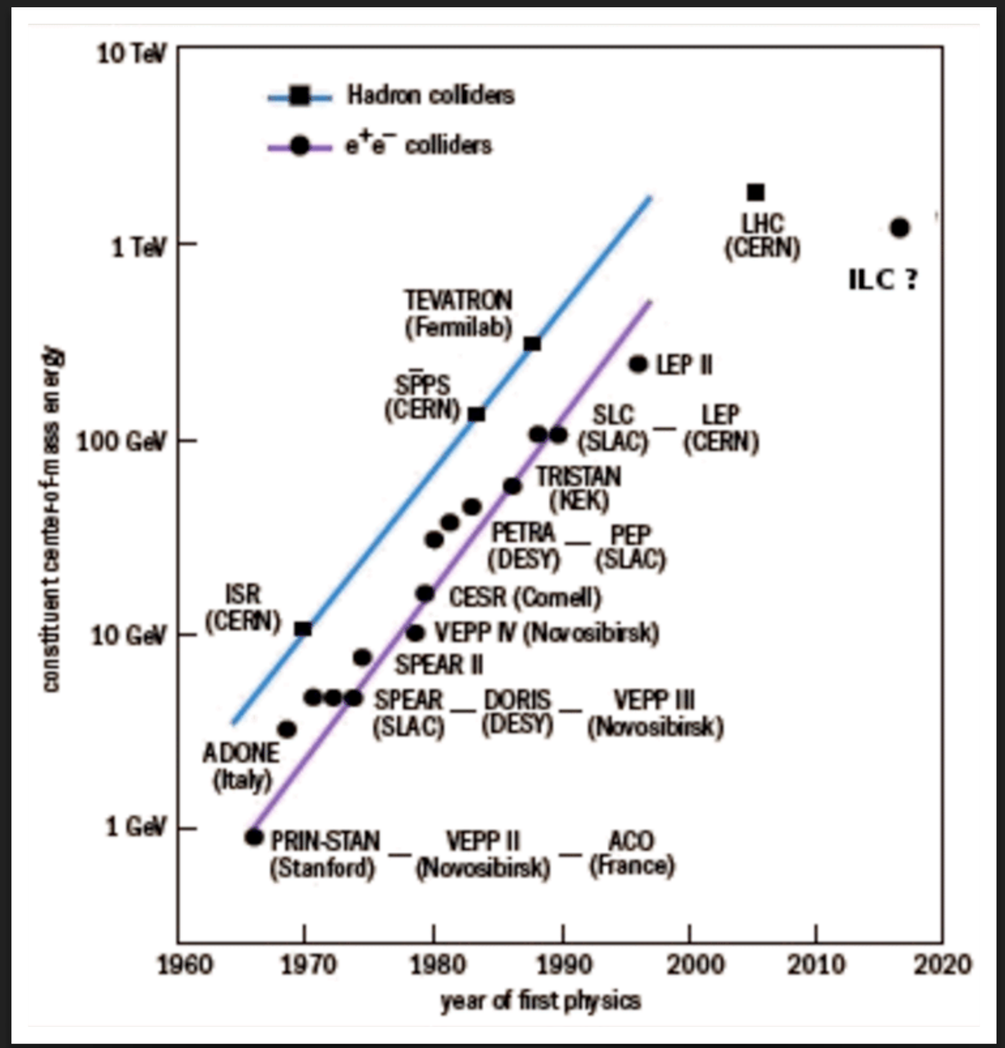




The Livingston Line

Particle colliders as engines of discovery

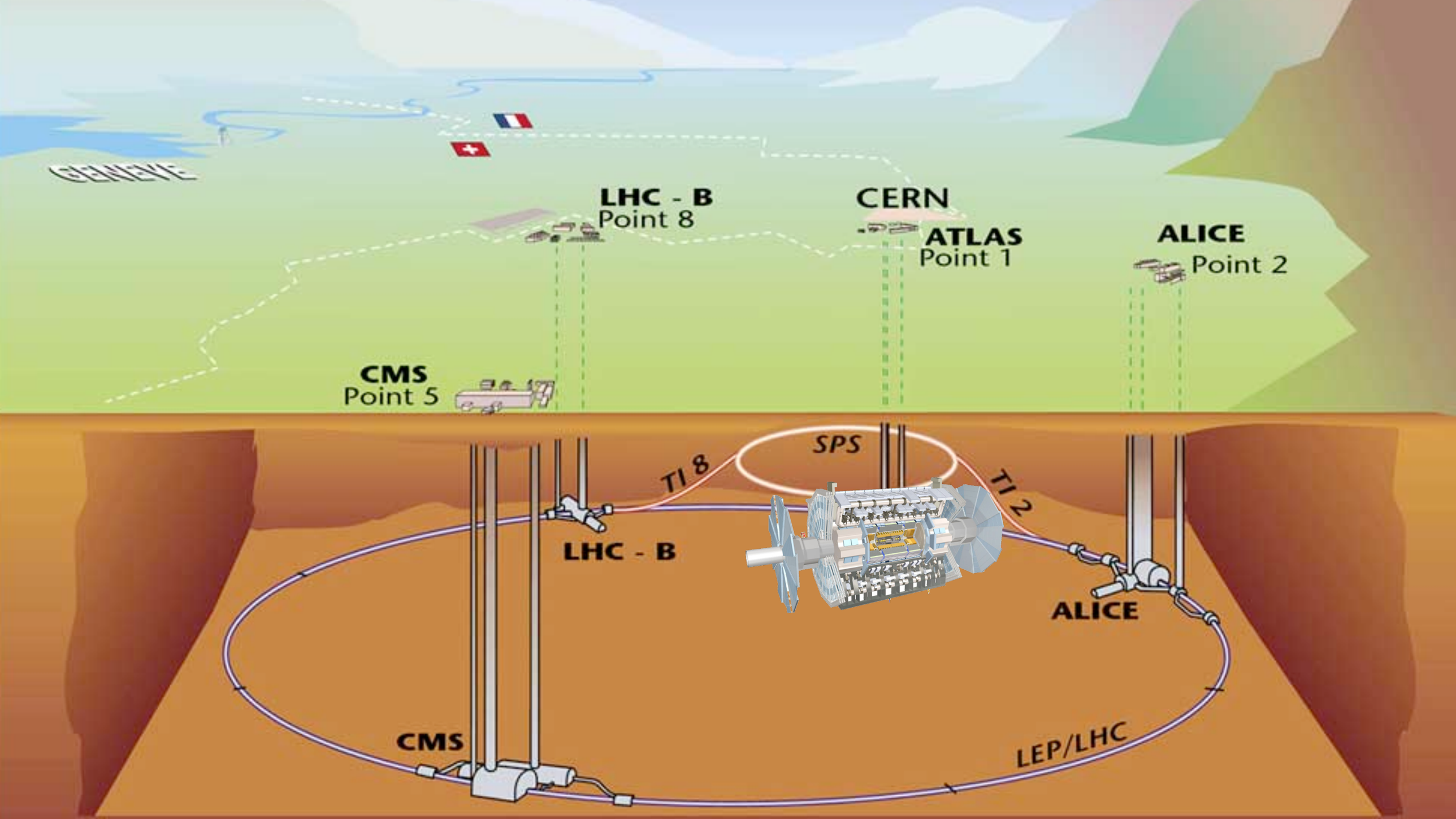


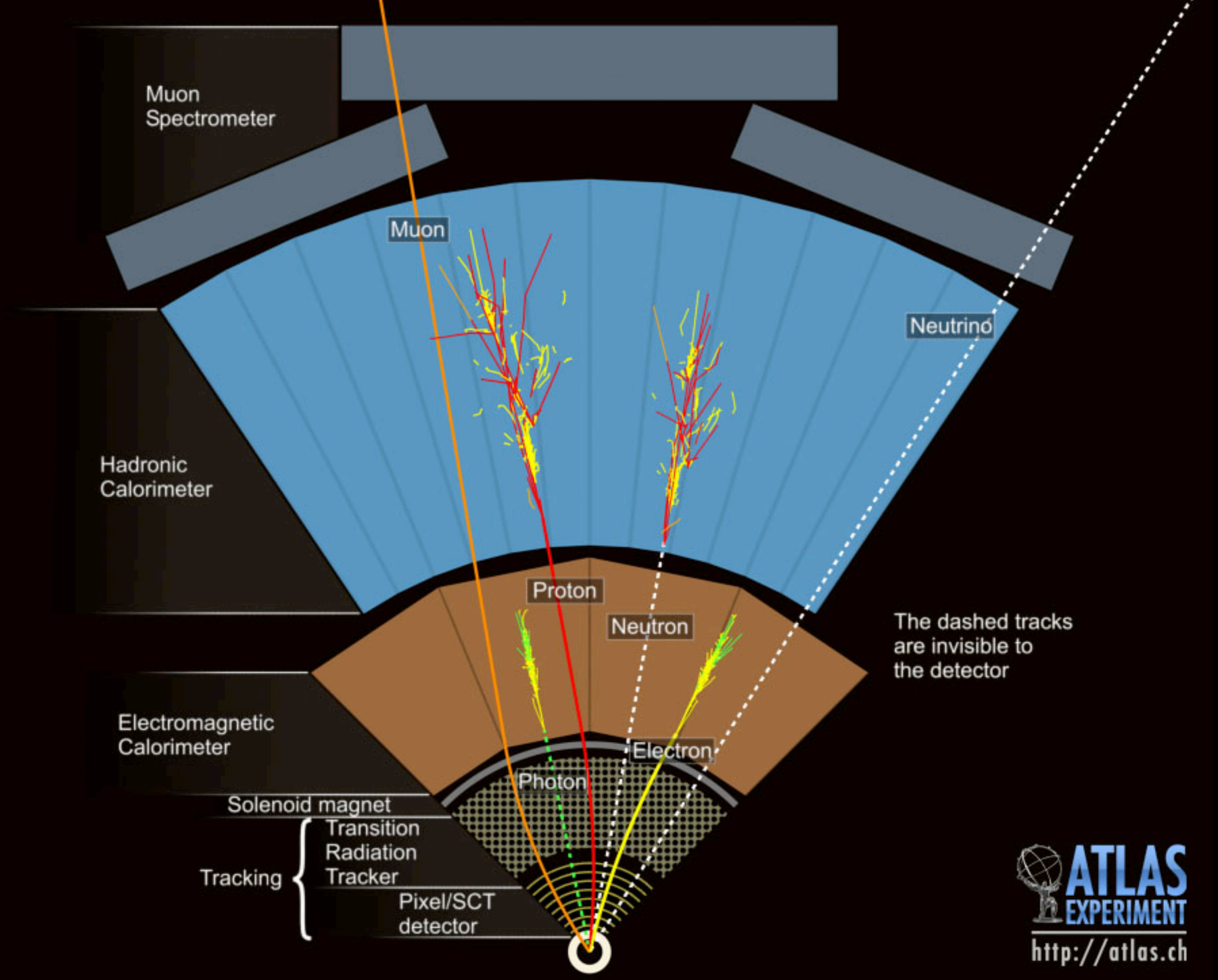


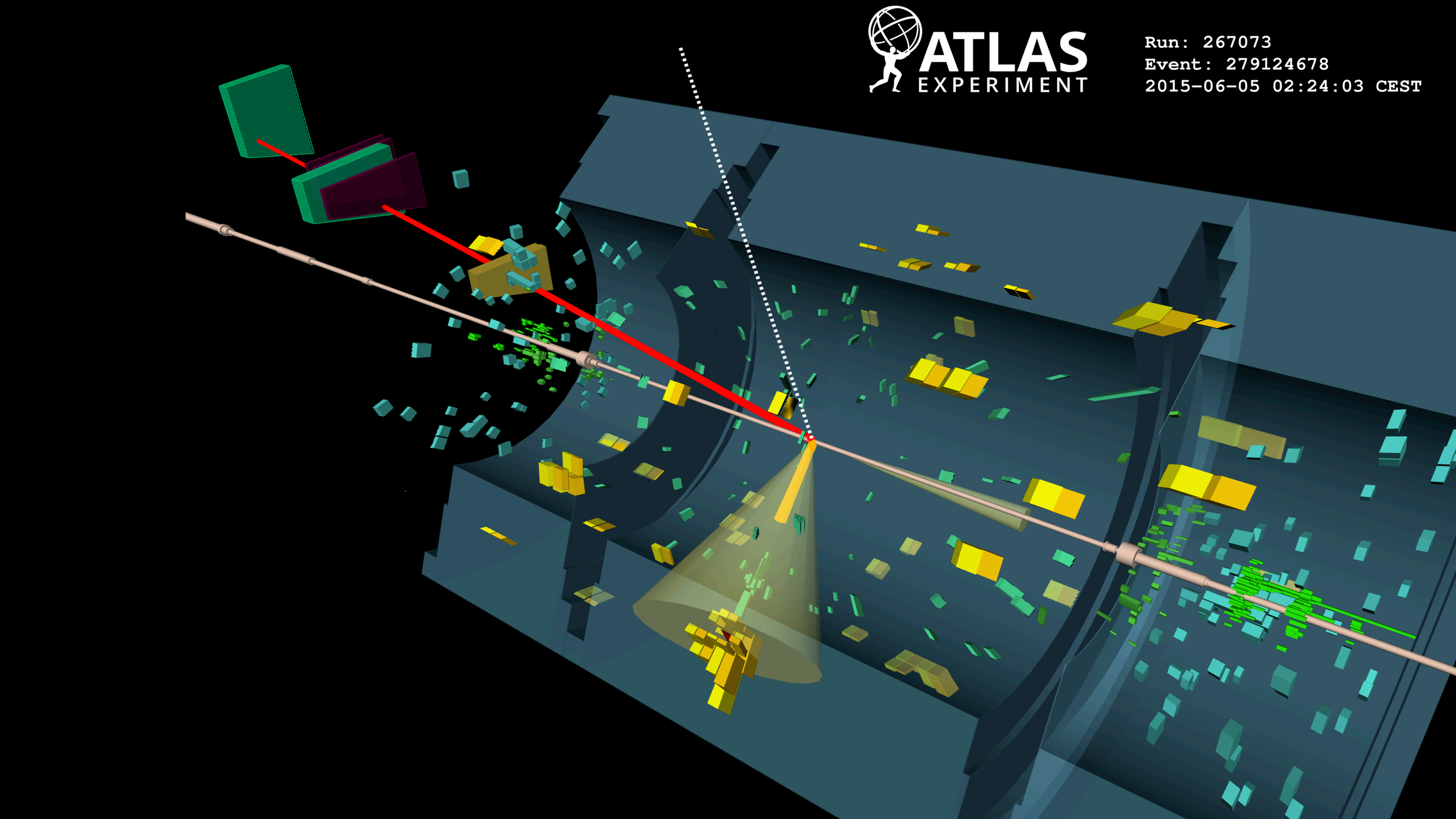
Large Hadron Collider
(2009 - Present)

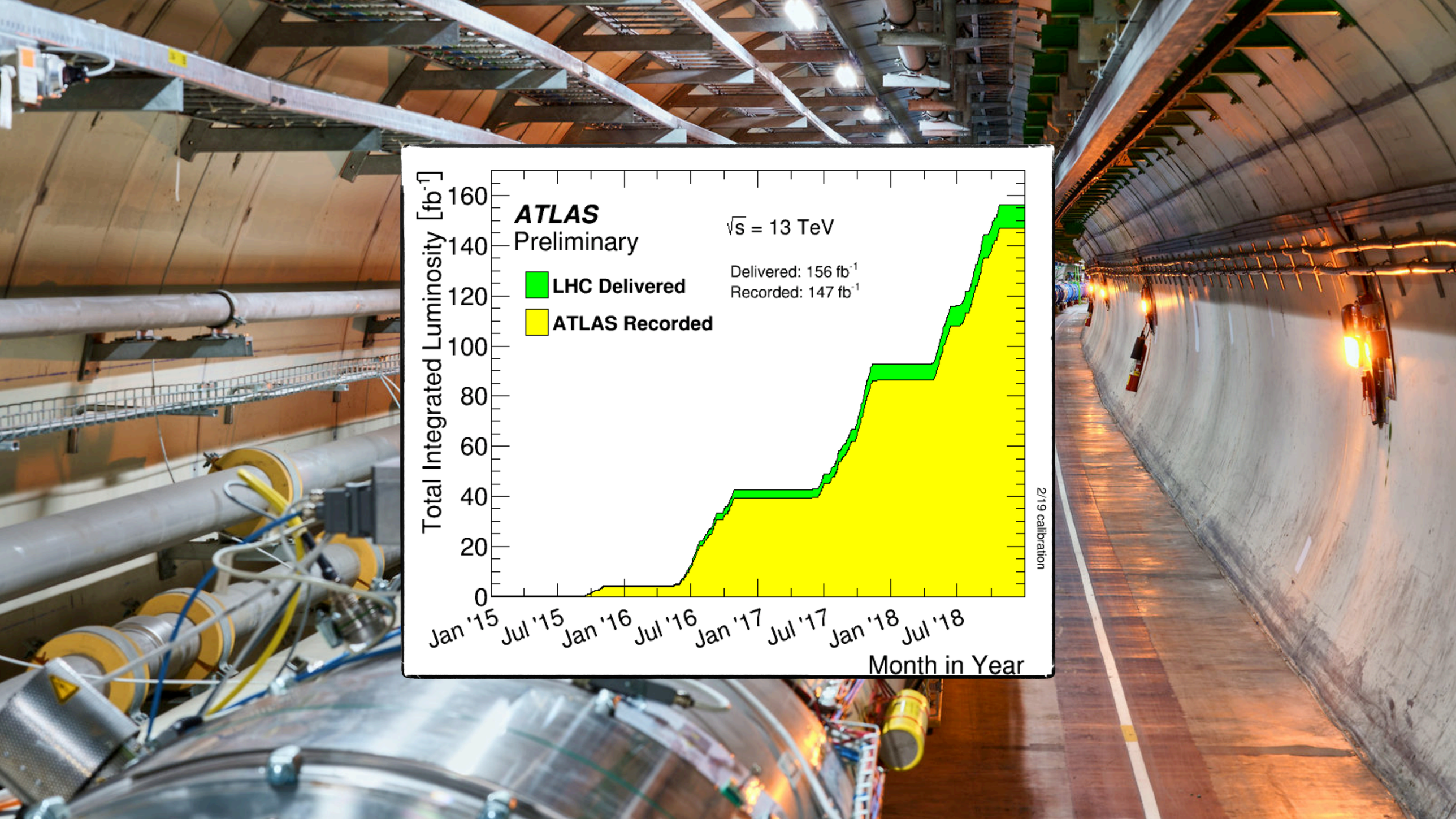
proton - proton &
heavy-ion collisions

collision energy:
7-14 TeV


GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ALICE
CMS
LEP/LHC


Muon
Spectrometer
Muon
Neutrino
Hadronic
Calorimeter
Proton
Neutron
The dashed tracks
are invisible to
the detector
Electromagnetic
Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition
Radiation
Tracker
Pixel/SCT
detector
ATLAS
EXPERIMENT
http://atlas.ch


ATLAS
EXPERIMENT
Run: 267073
Event: 279124678
2015-06-05 02:24:03 CEST


ATLAS
Preliminary
√s = 13 TeV
Delivered: 156 fb-1
Recorded: 147 fb-1
LHC Delivered
ATLAS Recorded
Total Integrated Luminosity [fb-1]
0
20
40
60
80
100
120
140
160
Jan '15
Jul '15
Jan '16
Jul '16
Jan '17
Jul '17
Jan '18
Jul '18
Month in Year
2/19 calibration

A Roadmap

Guide to enhancing discovery potential

Enhancements to search potential via targeted model tests

- Models with Heavy Resonances
- Combined searches

Upgrades to the ATLAS triggering capabilities & Jet Identification

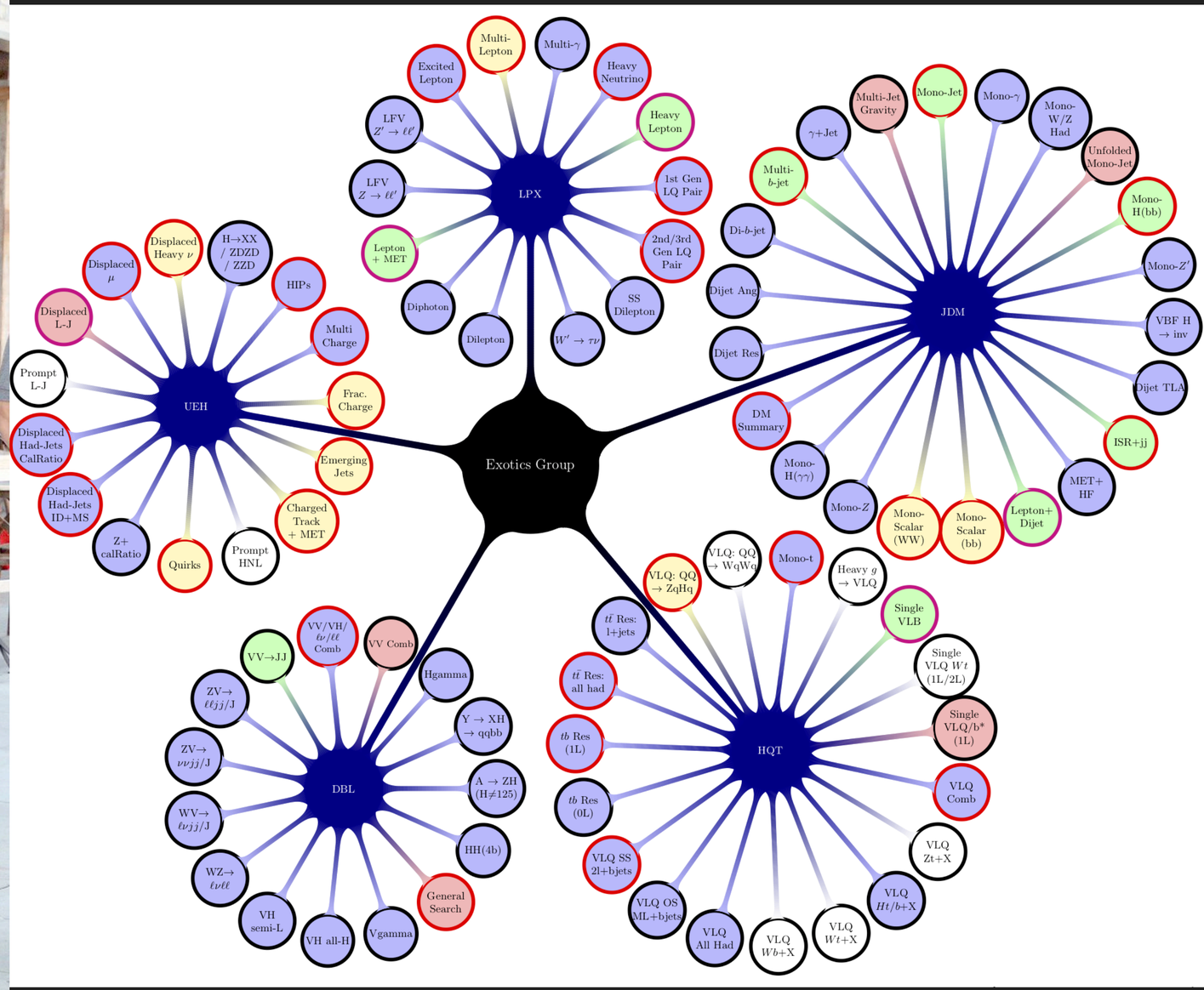
- Phase-1: 2019-2022
- HL-LHC: 2026-2028

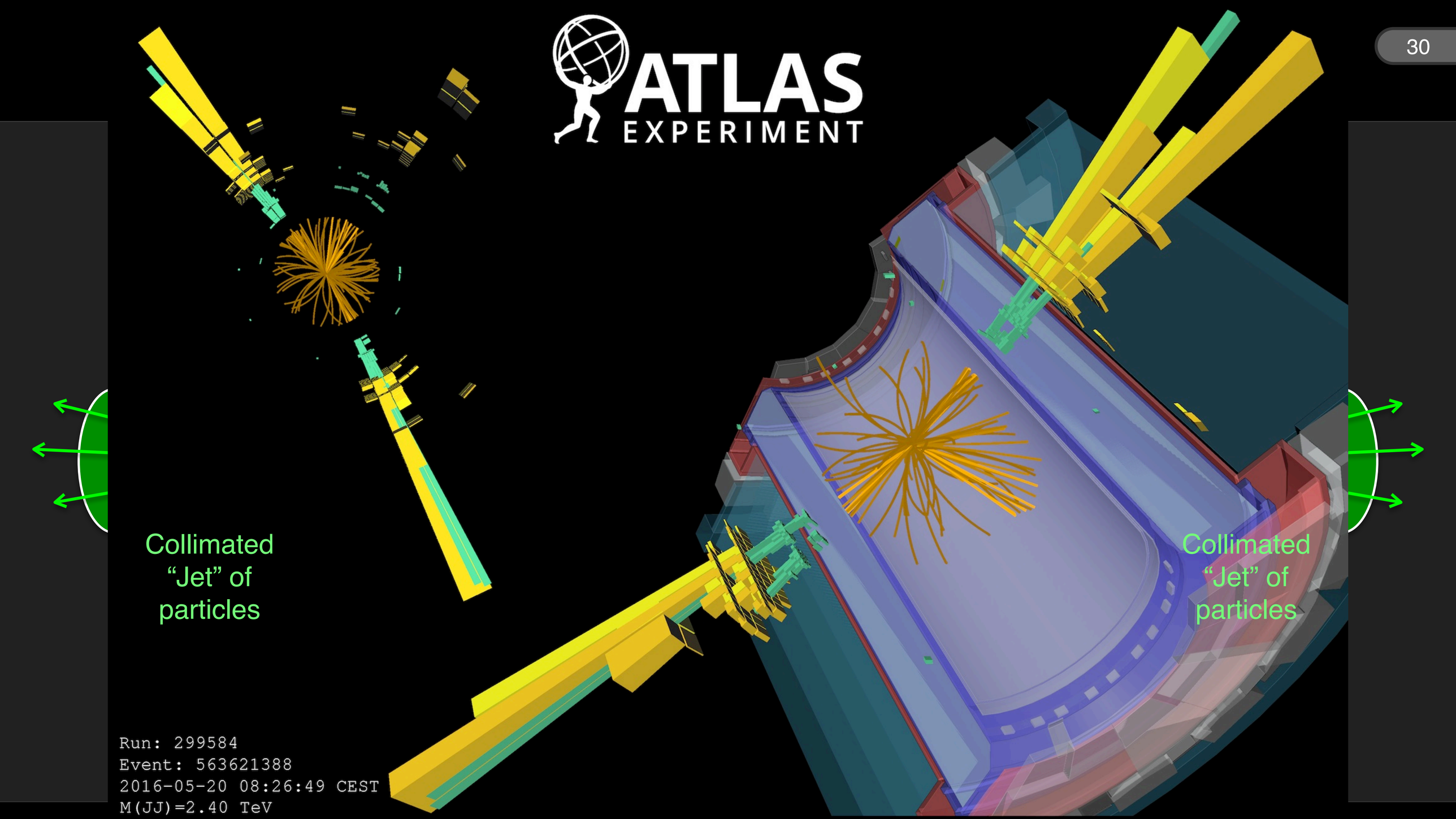
Programmatic foundation of searches for new physics at ATLAS

- Searches for heavy resonances

So where's the new physics hiding?

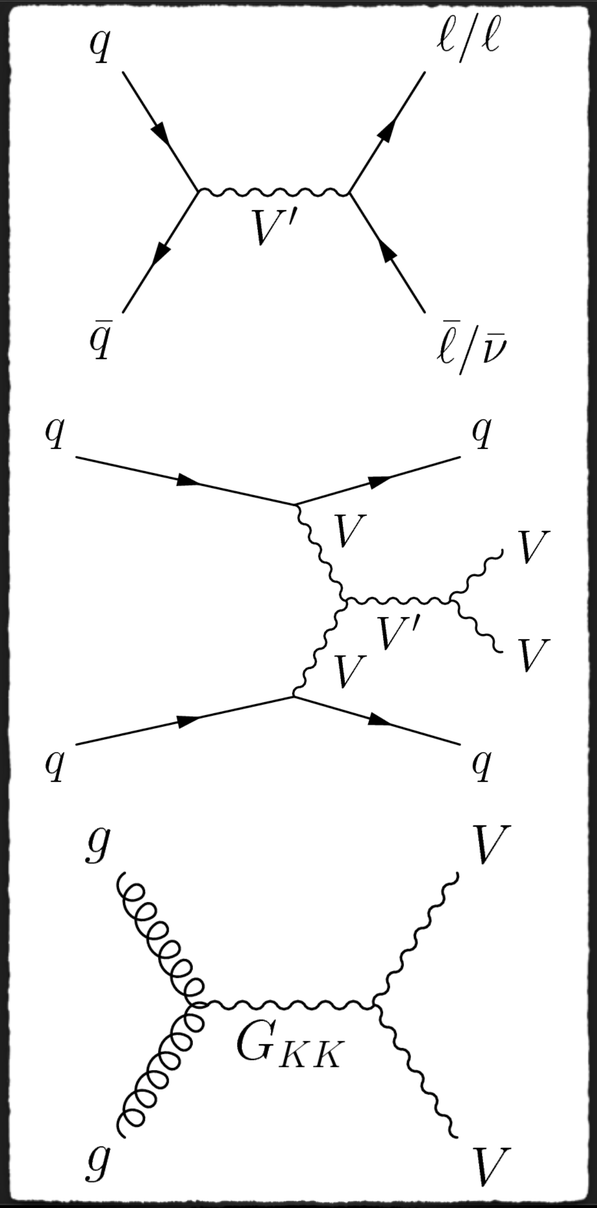
No, really, where is it?

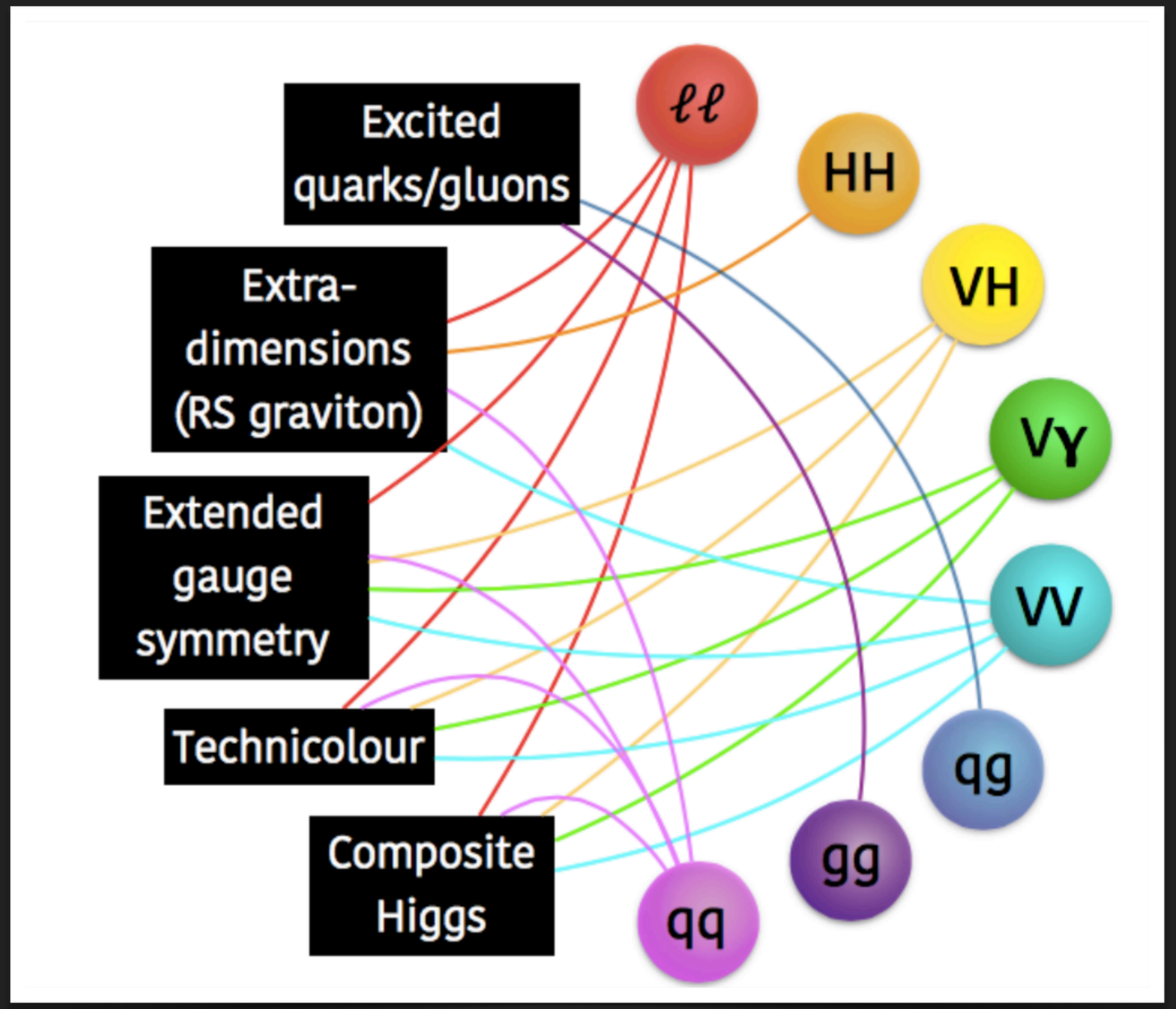



ATLAS
EXPERIMENT
Collimated
“Jet” of
particles
Collimated
“Jet” of
particles
Run: 299584
Event: 563621388
2016-05-20 08:26:49 CEST
M(JJ)=2.40 TeV

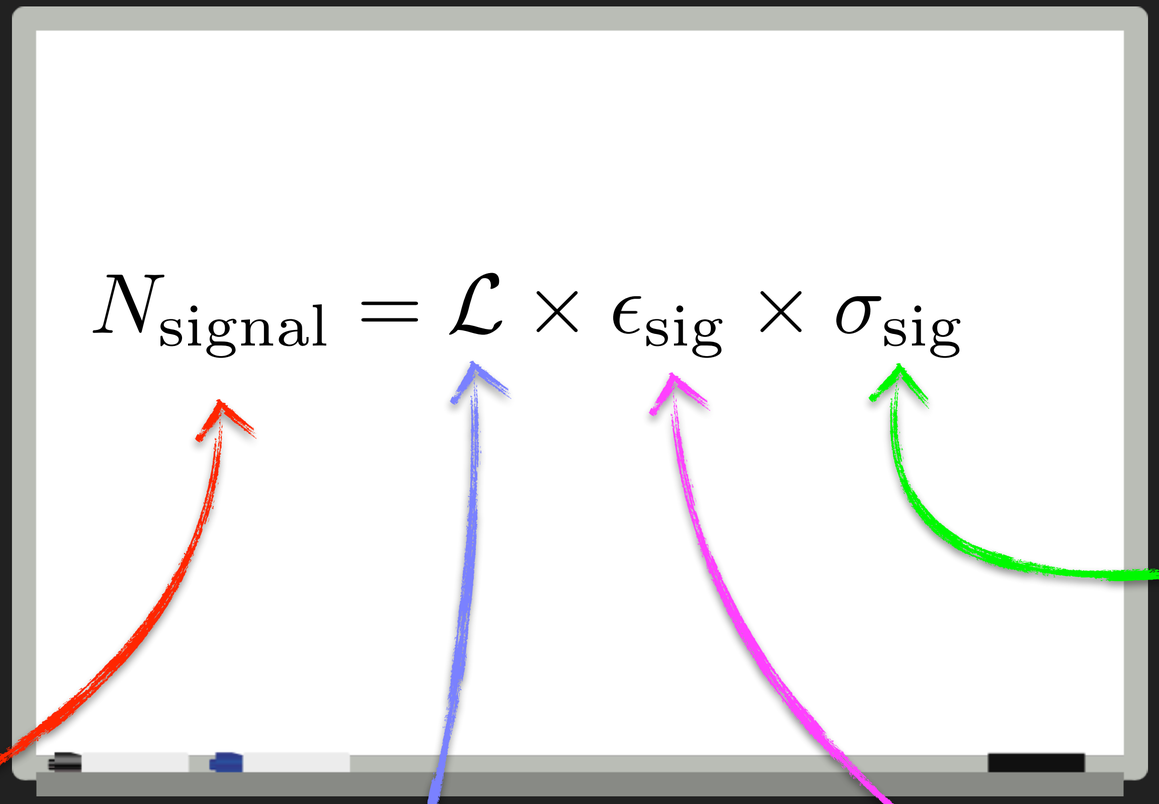
Heavy Resonances

A window to new physics





A "Simple" Relationship

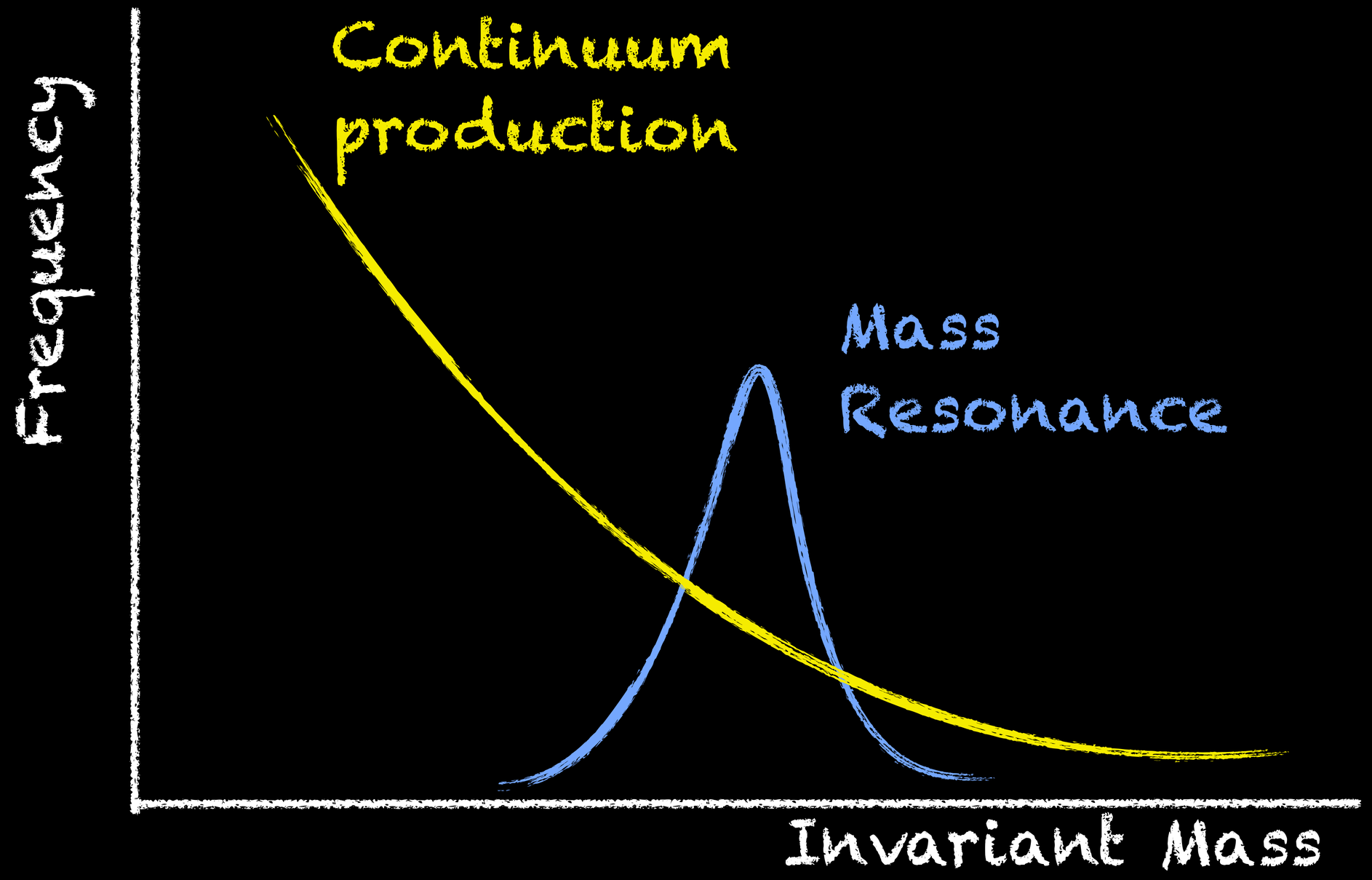


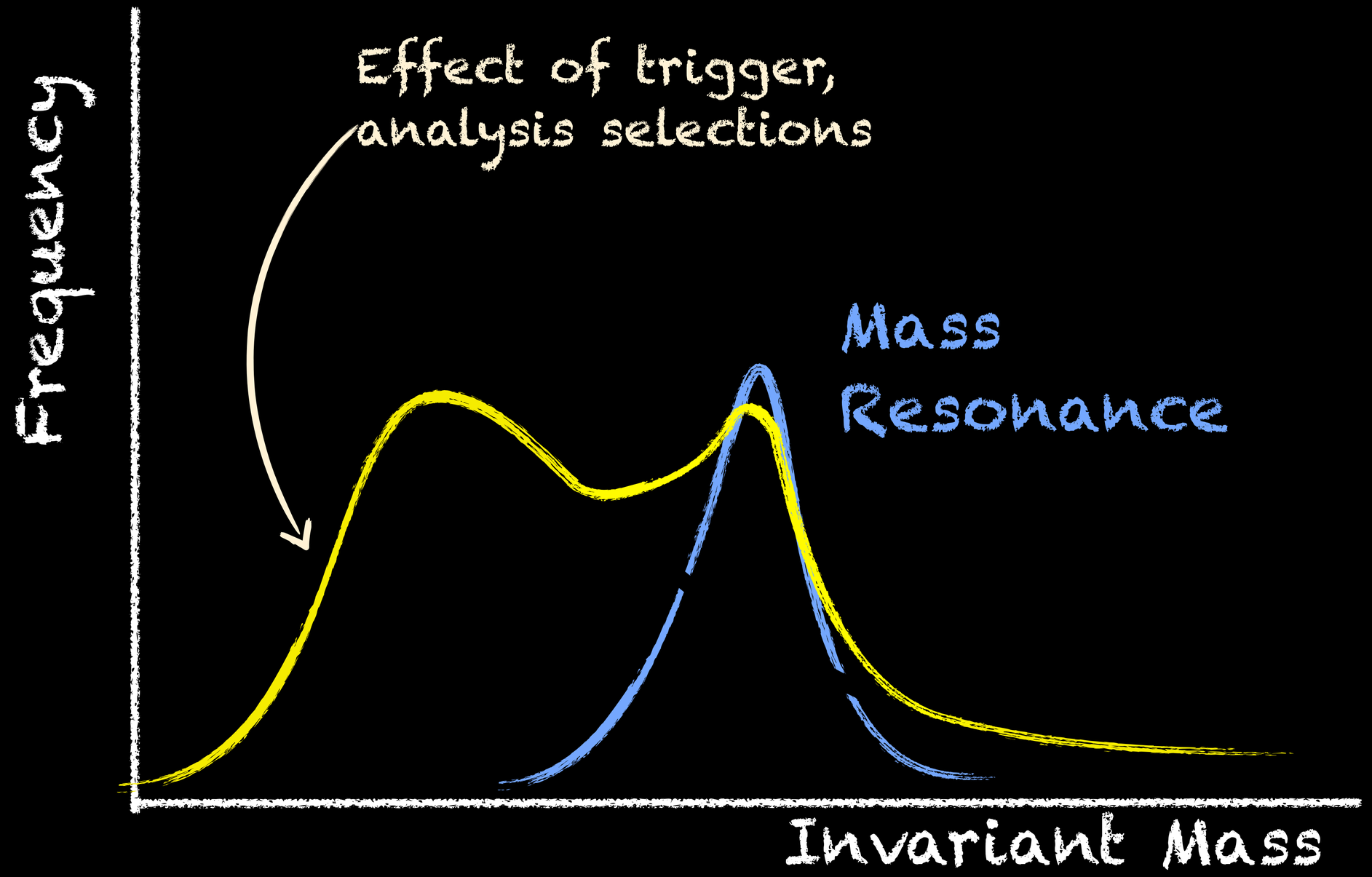
Cross Section:
QM probability to create this state. Set by QM, not optimizable for a given state.

Number of events expected to be observed

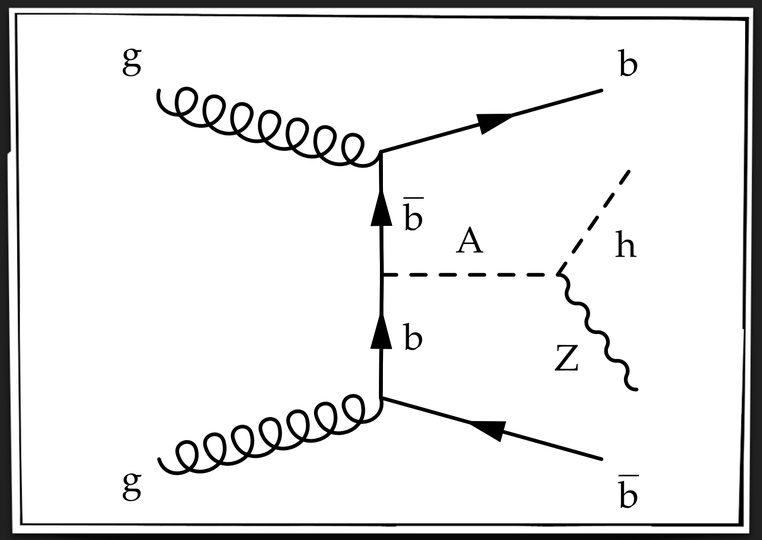
Luminosity:
How much data you've collected.

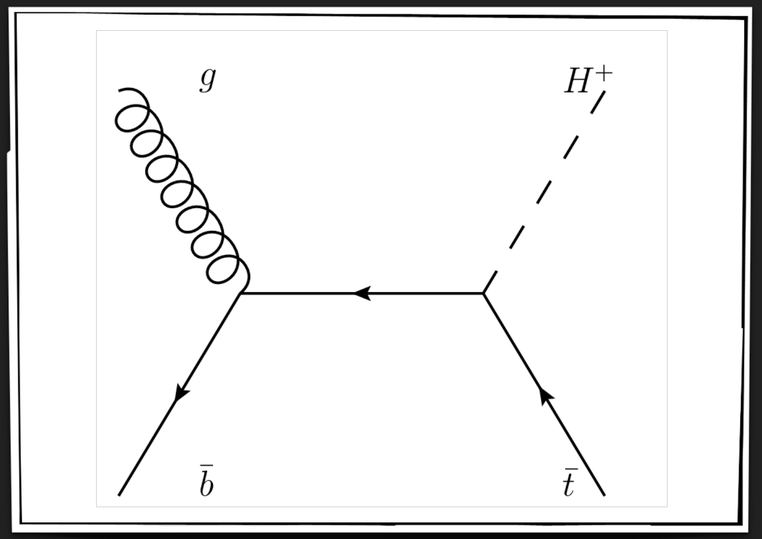
Acceptance:
How many events pass your selection criteria out of the total produced?


Continuum
production
Mass
Resonance
Frequency
Invariant Mass


Frequency
Effect of trigger, analysis selections
Mass Resonance
Invariant Mass

Example: Two-Higgs Doublet Models





Positives:

✓ Provides additional degrees of freedom in the Higgs sector
- 5 Higgs bosons!
- A, H, h, $H^{\pm}$

✓ Potential to ease naturalness problem

✓ Potentially allows flavor-changing neutral currents

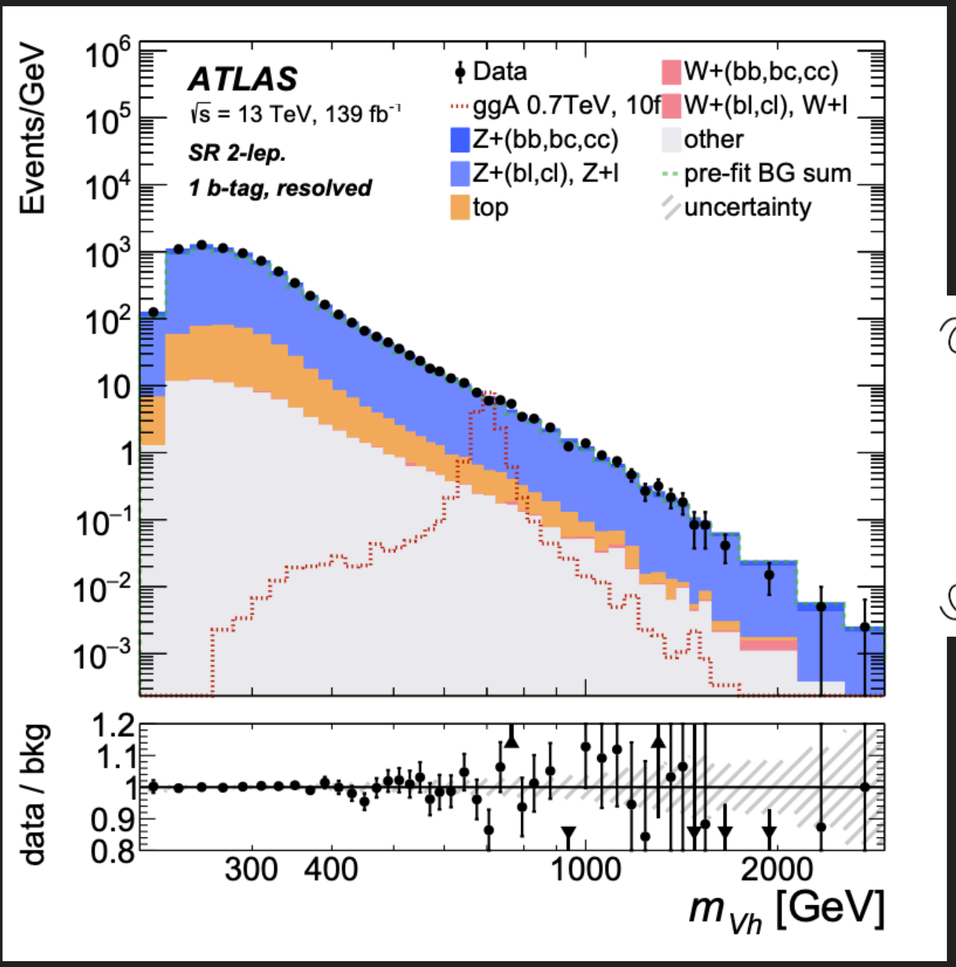
Negatives:

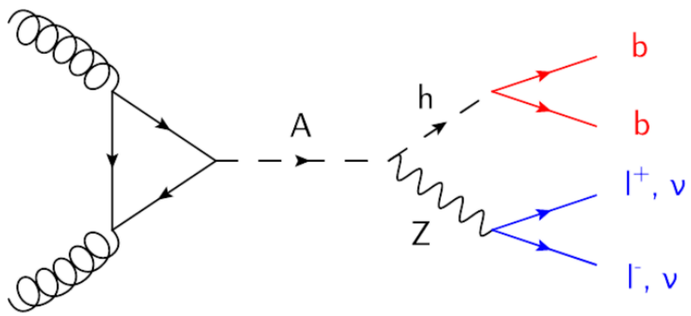
◉ Complicates Higgs boson physics

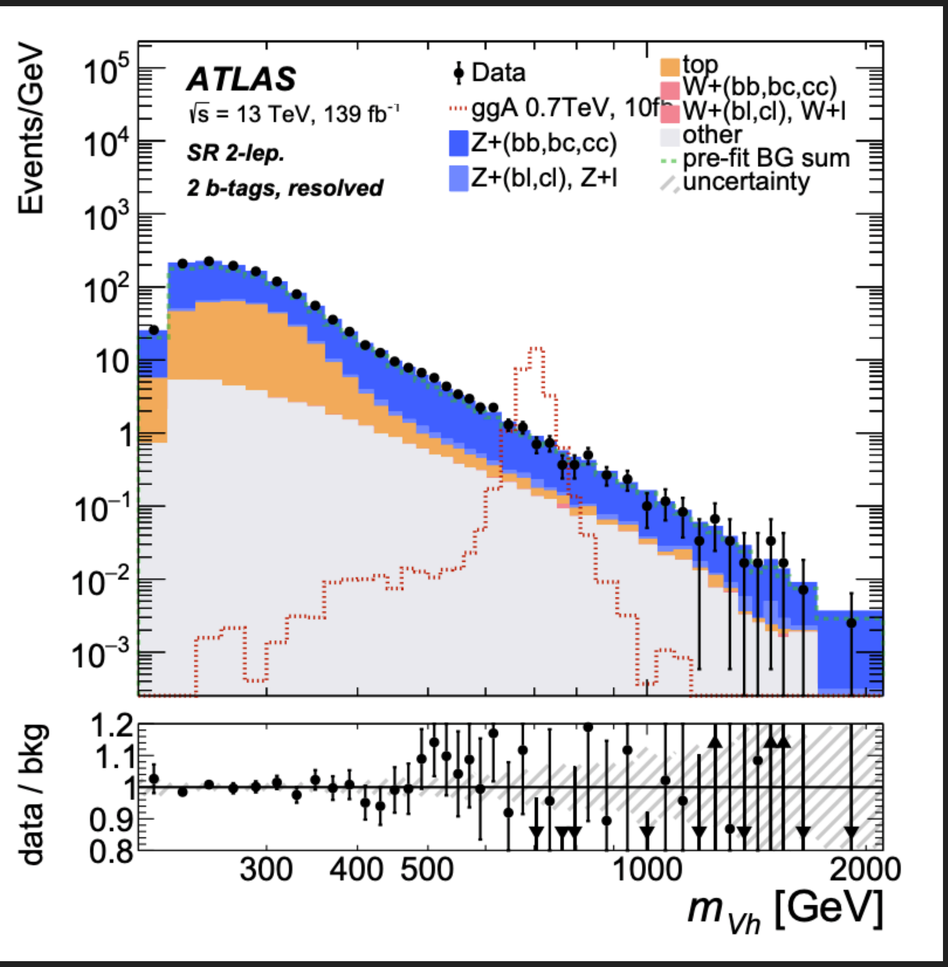
◉ Additional resonances haven't been found yet

◉ Likely doesn't explain some anomalies seen thus far

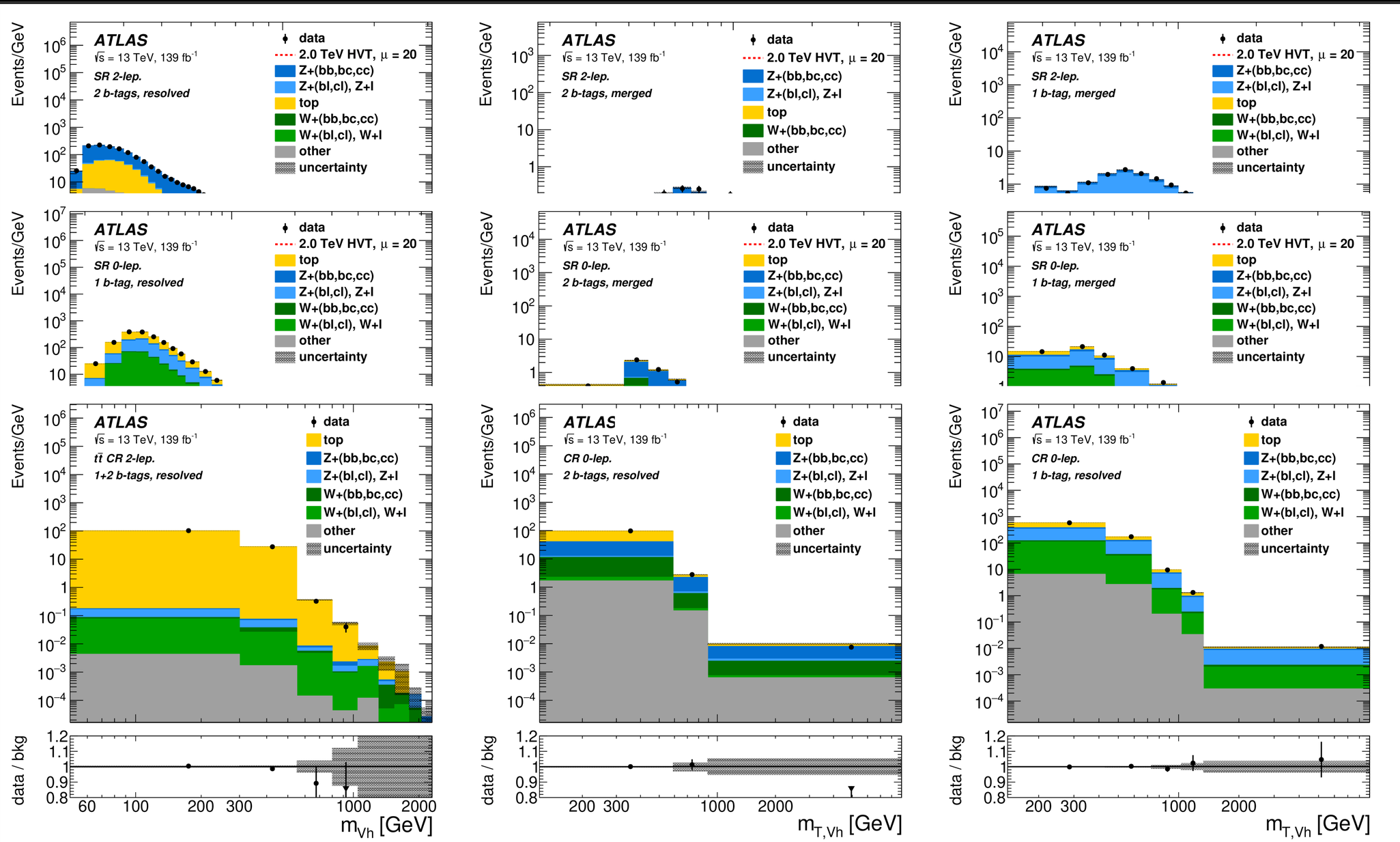
Di-Boson Resonances







Di-Boson Resonances



The Dev

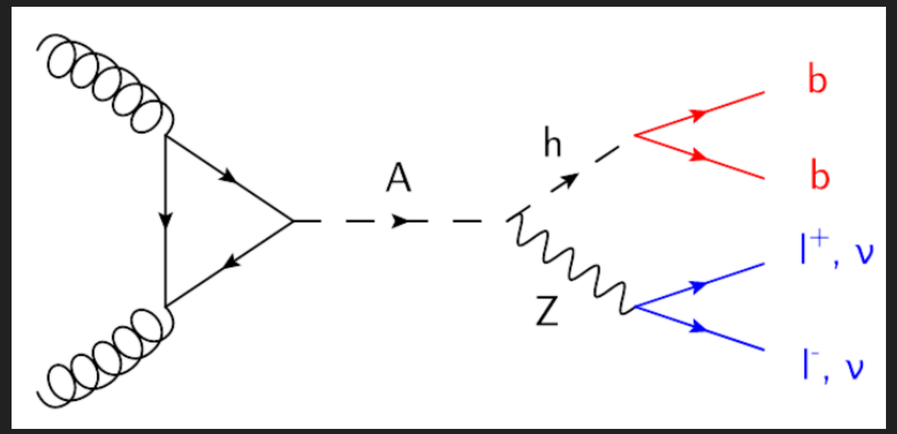
Sometimes

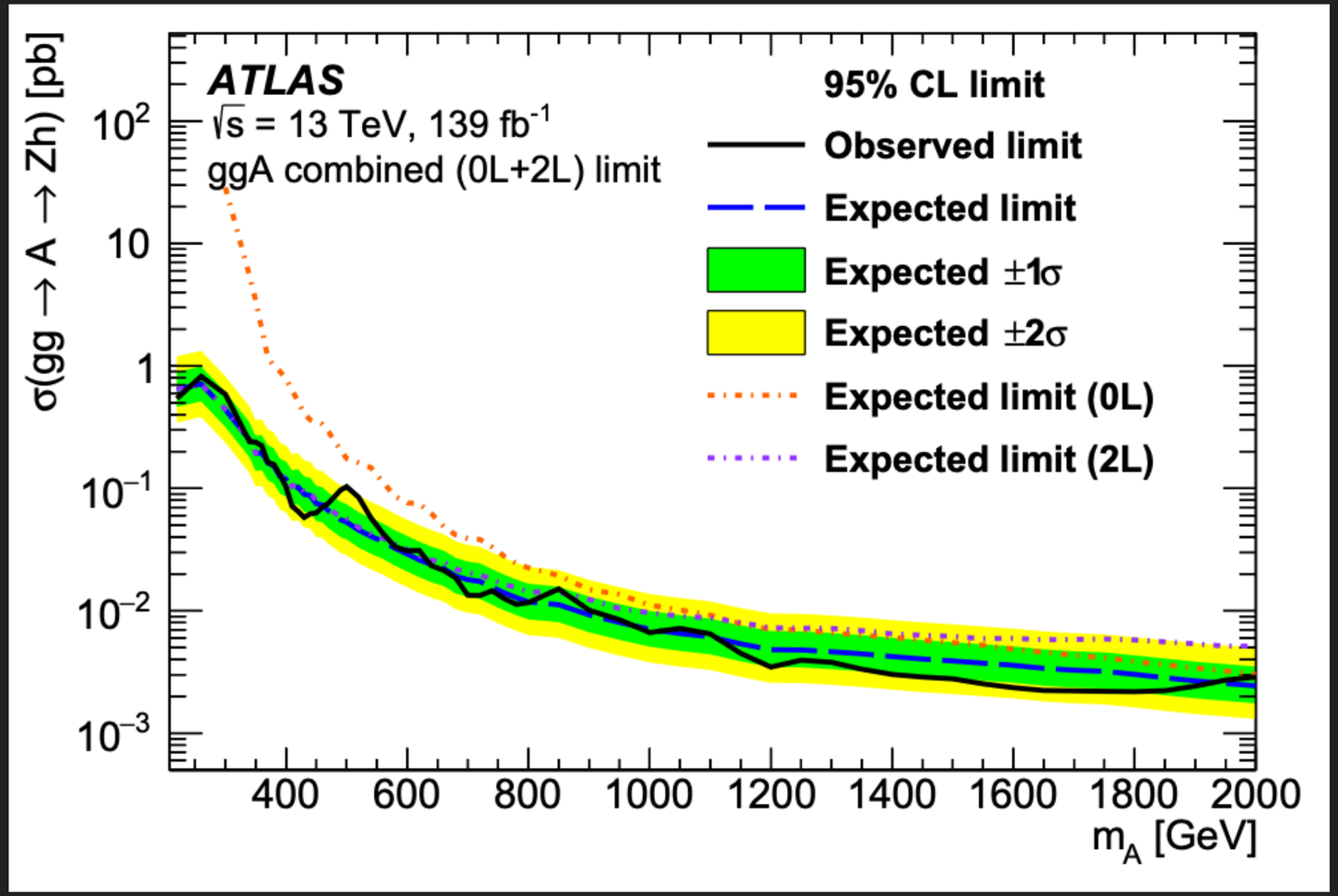
0-lepton	Resolved			Merged			
	1 b-tag	2 b-tag	3+ b-tag	1 b-tag	2 b-tag	1 b-tag add. b-tag	2 b-tag add. b-tag
$t\bar{t}$	22900 ± 890	6640 ± 180	1000 ± 34	1650 ± 160	68 ± 12	2110 ± 70	105 ± 11
Single top quark	2440 ± 330	552 ± 76	25.8 ± 5.6	217 ± 52	15.4 ± 4.1	136 ± 50	5.6 ± 2.4
Diboson	317 ± 41	41.2 ± 5.8	4.5 ± 1.1	188 ± 30	34.8 ± 4.8	12.9 ± 2.3	1.6 ± 0.4
Z+l	580 ± 210	1.3 ± 1.3	–	310 ± 130	0.38 ± 0.29	11.8 ± 8.2	0.1 ± 0.1
Z+(bl, cl)	8240 ± 840	50 ± 17	5.4 ± 1.8	910 ± 160	10.1 ± 3.7	118 ± 27	0.6 ± 0.4
Z+(bb, bc, cc)	1280 ± 170	1270 ± 150	41 ± 8	238 ± 45	101 ± 16	16.8 ± 4.2	8.6 ± 2.3
W+l	960 ± 300	3 ± 2	–	227 ± 95	1.0 ± 0.6	5.4 ± 3.9	0.02 ± 0.02
W+(bl, cl)	5960 ± 1100	56 ± 17	3.7 ± 2.3	770 ± 230	6.6 ± 3.2	65 ± 21	0.1 ± 0.1
W+(bb, bc, cc)	530 ± 150	470 ± 130	16.5 ± 4.7	112 ± 44	40 ± 16	10.2 ± 5.1	3 ± 2
SM Vh	55 ± 21	102 ± 39	1.04 ± 0.57	7.4 ± 2.9	4.7 ± 1.8	0.4 ± 0.2	0.06 ± 0.04
$t\bar{t}$ h	10.4 ± 5.3	7.8 ± 3.9	6 ± 3	1.4 ± 0.7	0.2 ± 0.1	4 ± 2	0.6 ± 0.3
$t\bar{t}$ V	102 ± 54	41 ± 22	8.7 ± 4.5	17.7 ± 9.5	1.4 ± 0.8	24 ± 12	1.8 ± 1.0
Total	43400 ± 200	9240 ± 95	1110 ± 30	4650 ± 79	282 ± 14	2510 ± 50	127 ± 11
Data	43387	9236	1125	4657	283	2516	127

1-lepton	1 b-tag	2 b-tag	1 b-tag	2 b-tag
$t\bar{t}$	16300 ± 600	3900 ± 120	8100 ± 300	400 ± 50
Single top quark	4100 ± 600	860 ± 130	1100 ± 300	120 ± 30
Diboson	110 ± 20	12 ± 2	220 ± 30	34 ± 5
Z+l	40 ± 10	0.09 ± 0.05	14 ± 6	0.2 ± 0.1
Z+(bl, cl)	170 ± 10	0.7 ± 0.5	38 ± 6	0.4 ± 0.2
Z+(bb, bc, cc)	27 ± 4	17 ± 2	11 ± 2	4.5 ± 0.6
W+l	550 ± 180	3 ± 3	590 ± 230	0.2 ± 0.2
W+(bl, cl)	5700 ± 440	24 ± 8	1800 ± 300	30 ± 10
W+(bb, bc, cc)	820 ± 140	420 ± 70	350 ± 80	180 ± 40
SM Vh	60 ± 20	90 ± 30	14 ± 6	11 ± 4
Multijet	200 ± 100	1.7 ± 0.9	–	–
Total	28100 ± 170	5320 ± 70	12200 ± 120	780 ± 30
Data	28073	5348	12224	775

2-lepton	1 b-tag	2 b-tag	3+ b-tag	1 b-tag	2 b-tag	1+2 b-tag add. b-tag
$t\bar{t}$	2570 ± 80	1940 ± 110	58 ± 9	5.3 ± 2.6	0.4 ± 0.2	11 ± 5
Single top quark	185 ± 25	58 ± 9	1.5 ± 0.4	0.7 ± 0.1	0.2 ± 0.2	0.5 ± 0.3
Diboson	570 ± 80	159 ± 24	5.2 ± 1.3	35 ± 5	8.5 ± 1.3	4.6 ± 0.8
Z+l	2210 ± 950	2 ± 3	–	85 ± 34	1.0 ± 0.5	6 ± 4
Z+(bl, cl)	37200 ± 1100	130 ± 50	12 ± 5	240 ± 40	2.3 ± 0.8	55 ± 11
Z+(bb, bc, cc)	7840 ± 690	6320 ± 170	150 ± 20	74 ± 12	34 ± 5	12 ± 3
W+l	1.9 ± 0.7	–	–	0.03 ± 0.01	–	0.01 ± 0.01
W+(bl, cl)	37 ± 9	0.9 ± 0.7	–	0.4 ± 0.1	–	0.01 ± 0.01
W+(bb, bc, cc)	5.4 ± 1.4	1.9 ± 0.3	0.03 ± 0.01	0.17 ± 0.06	0.02 ± 0.01	0.06 ± 0.05
SM Vh	105 ± 40	140 ± 60	1.3 ± 0.7	1.6 ± 0.6	0.8 ± 0.3	0.2 ± 0.1
$t\bar{t}$ h	0.9 ± 0.5	1.6 ± 0.8	1.1 ± 0.5	0.05 ± 0.02	0.01 ± 0.01	0.15 ± 0.07
$t\bar{t}$ V	140 ± 80	60 ± 30	6 ± 3	10 ± 5	0.6 ± 0.3	12 ± 6
Total	50900 ± 230	8810 ± 90	240 ± 20	450 ± 20	47 ± 5	101 ± 9
Data	50876	8798	235	439	50	101

Upper limits on pseudo-scalar production

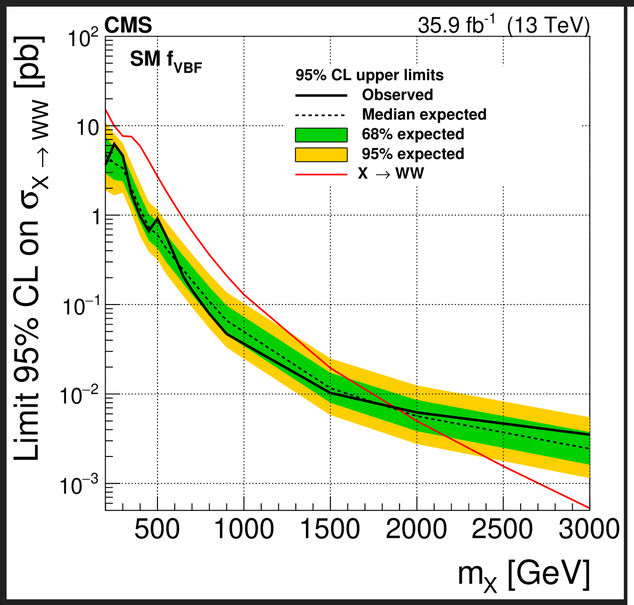




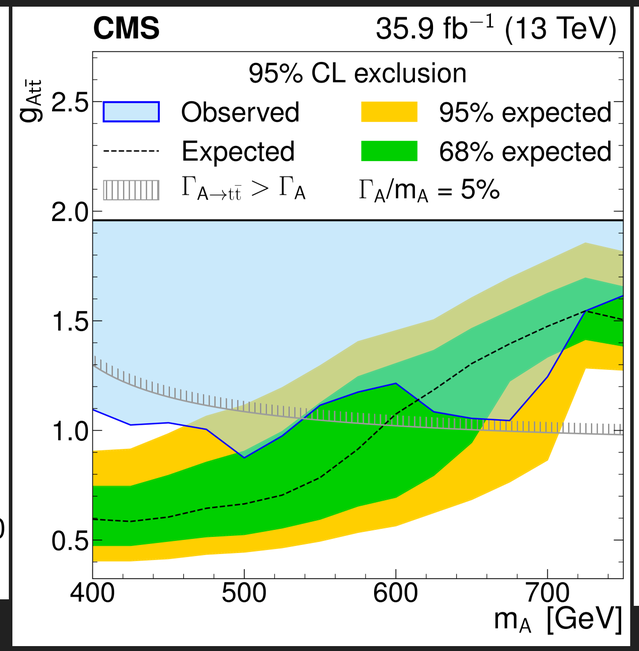
There's lots more!

Far too much for today, but…

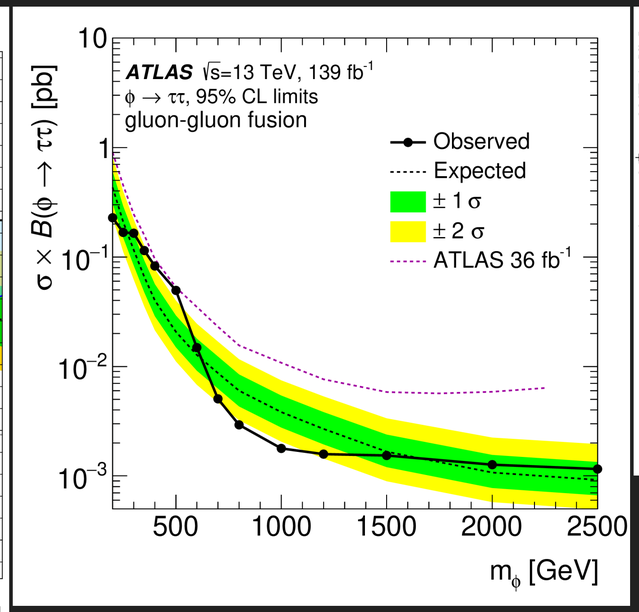
JHEP 03 (2020) 034



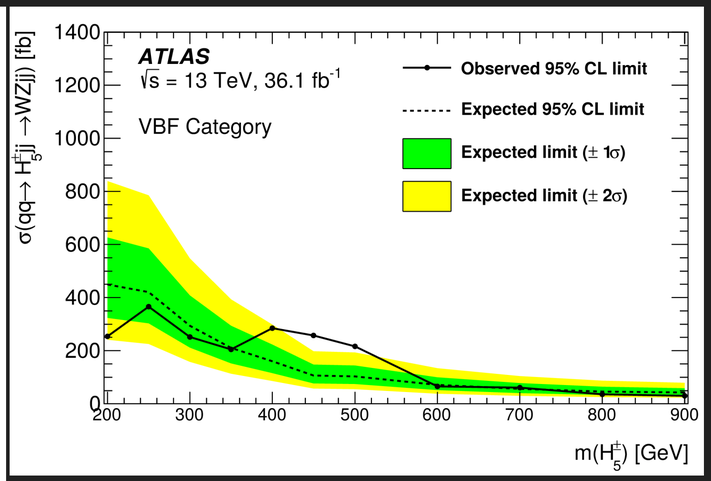
JHEP 04 (2020) 171

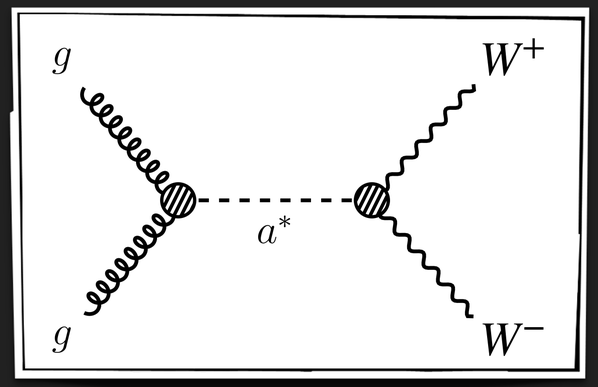


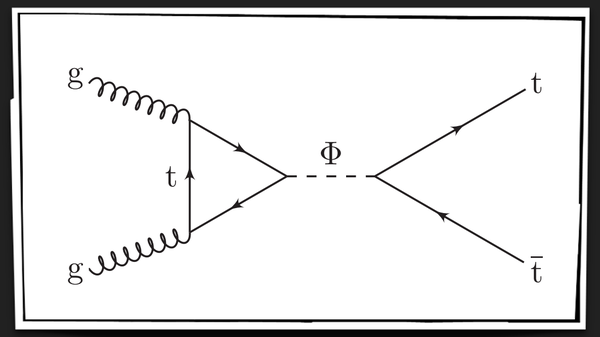
PRL 125 (2020) 051801

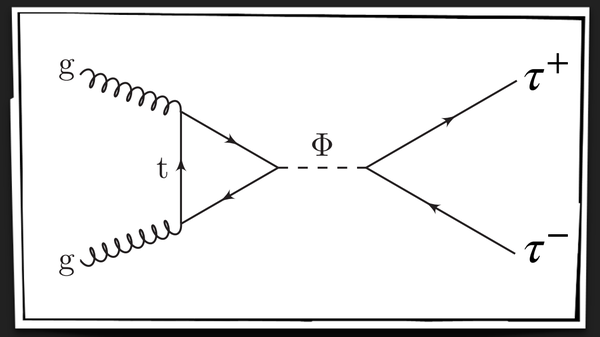


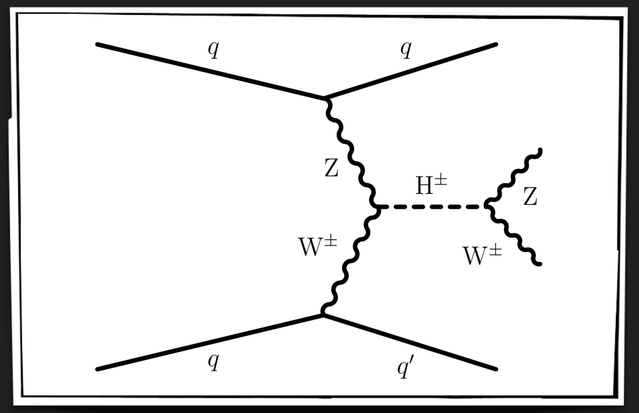
PLB 787 (2018) 68





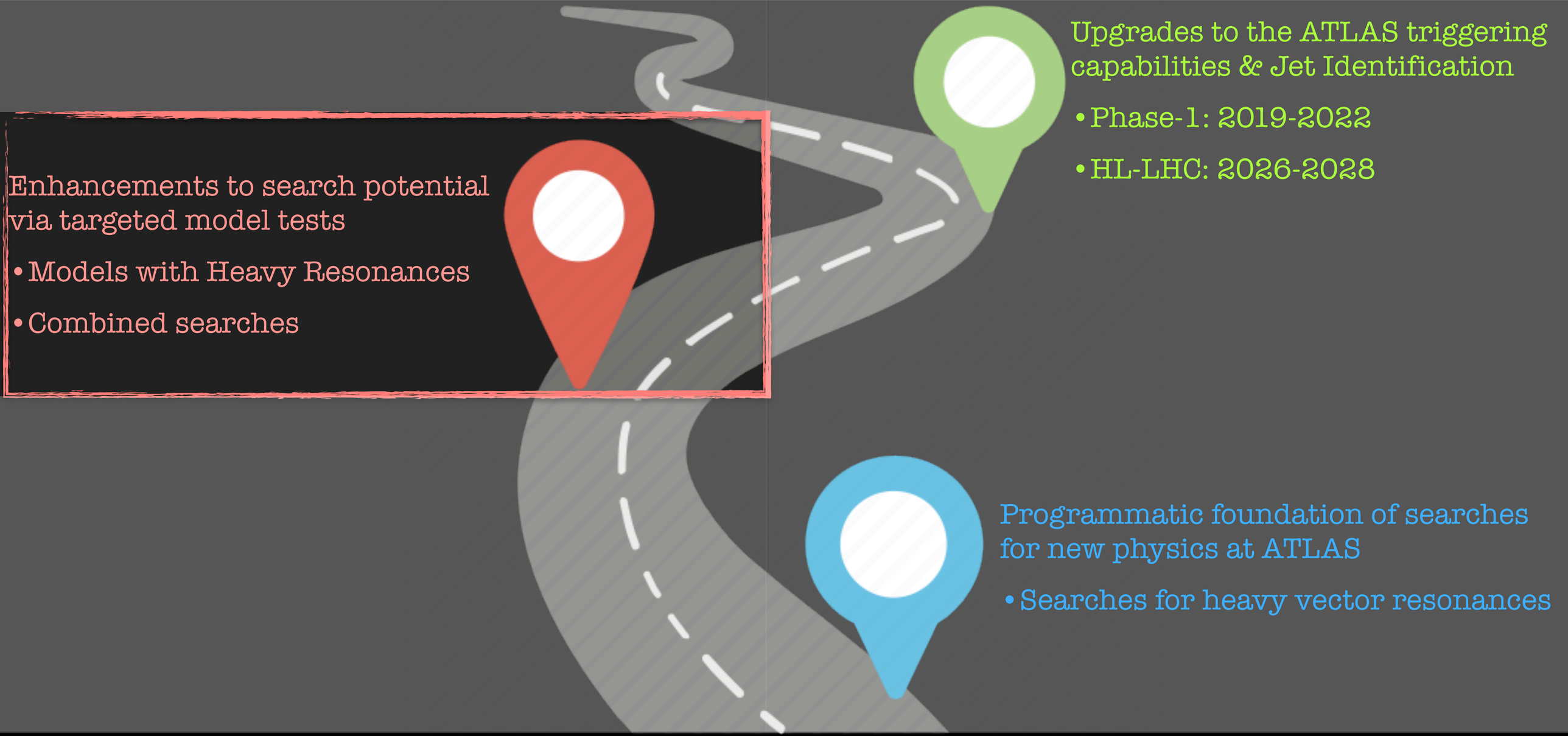






A Roadmap

Guide to enhancing discovery potential



Upgrades to the ATLAS triggering capabilities & Jet Identification

- Phase-1: 2019-2022
- HL-LHC: 2026-2028

Enhancements to search potential via targeted model tests

- Models with Heavy Resonances
- Combined searches

Programmatic foundation of searches for new physics at ATLAS

- Searches for heavy vector resonances

What would new physics look like?

Finding new physics in increasingly-rare places

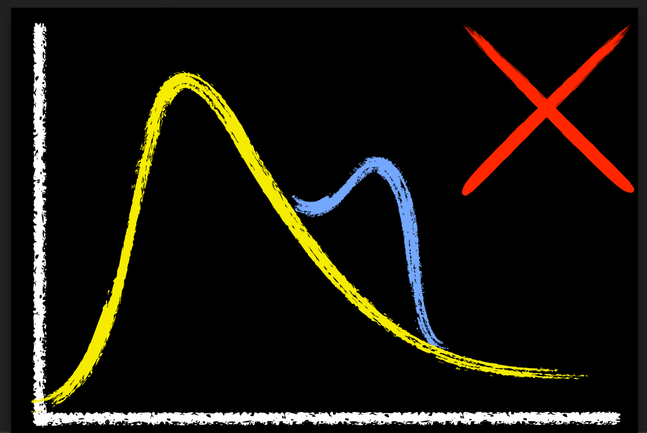
Facts:

1) We've looked in a lot of places, but not everywhere.
2) We haven't observed anything "obvious" just yet.

Inferences:

1) New physics couplings may be "too weak" to see yet.
2) Sm… …n our data.
3) We… …e corners.

graphicpanic.com



What would new physics look like?

Model-driven probe for new physics

Facts:

1) We've looked in a lot of places, but not everywhere.
2) We haven't observed anything "obvious" just yet.

Inferences:

1) New physics couplings may be "too weak" to see yet.
2) Smaller excesses may already be hiding in our data.
3) We have to be willing to look in very rare corners.

graphicpanic.com

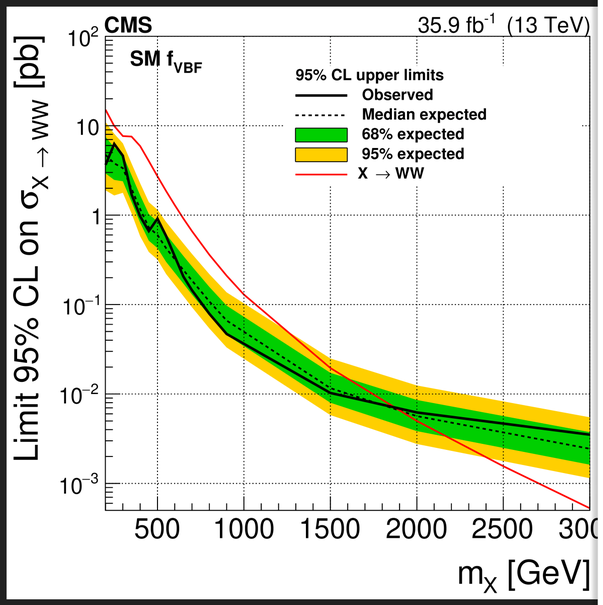
"Heavy Vector Triplet" Model

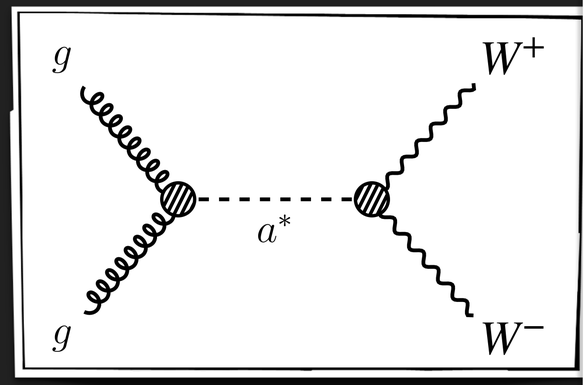
$$\begin{aligned}\mathcal{L}_V \;=\; & -\frac{1}{4} D_{[\mu} V^a_{\nu]} D^{[\mu} V^{\nu]\,a} + \frac{m_V^2}{2} V^a_\mu V^{\mu\,a} \\ & + i\, g_V c_H V^a_\mu H^\dagger \tau^a \overleftrightarrow{D}^\mu H + \frac{g^2}{g_V} c_F V^a_\mu J_F^{\mu\,a} \\ & + \frac{g_V}{2} c_{VVV}\, \epsilon_{abc} V^a_\mu V^b_\nu D^{[\mu} V^{\nu]\,c} + g_V^2 c_{VVHH} V^a_\mu V^{\mu\,a} H^\dagger H - \frac{g}{2} c_{VVW} \epsilon_{abc} W^{\mu\nu\,a} V^b_\mu V^c_\nu \,.\end{aligned}$$

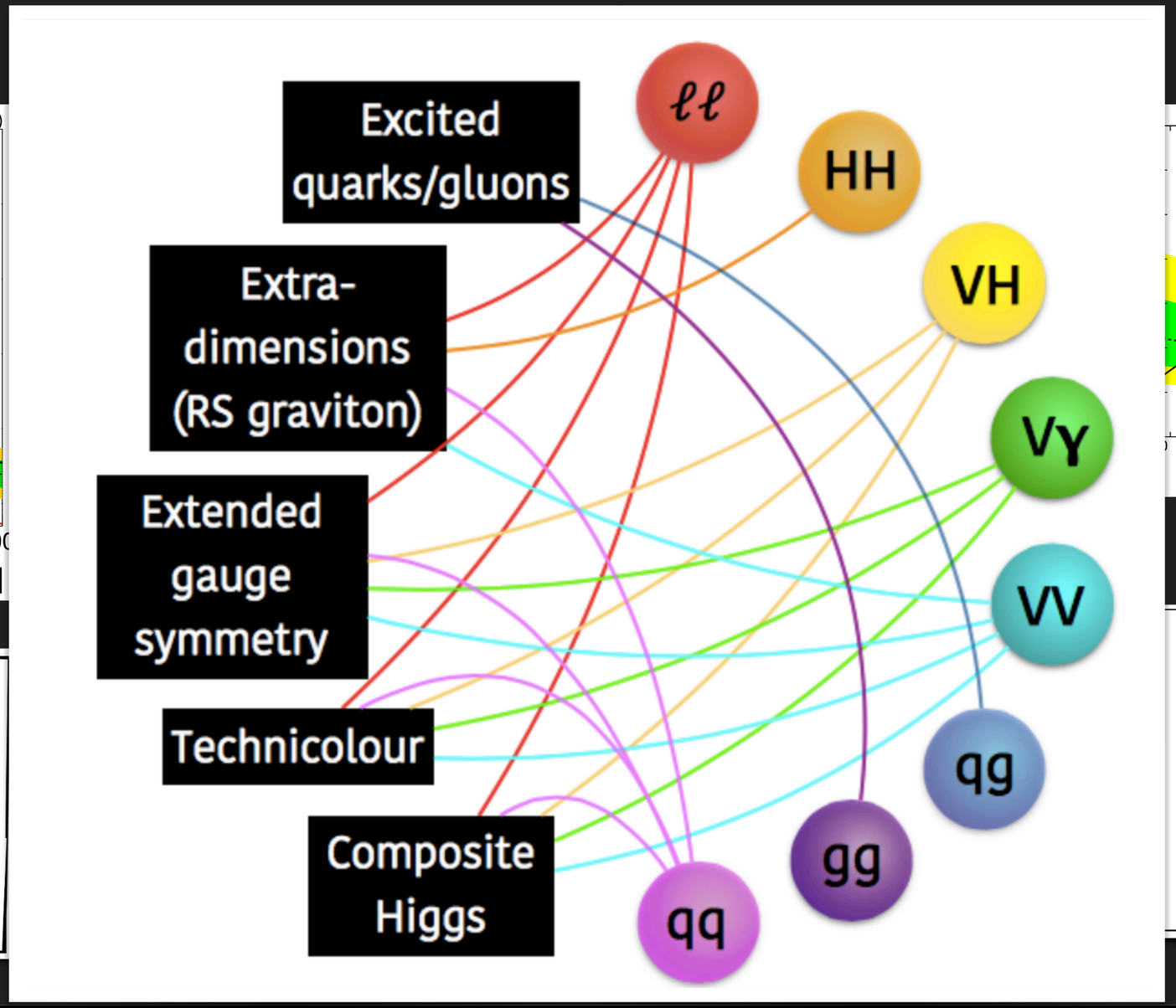
There's lots more!

Far too much for today, but…

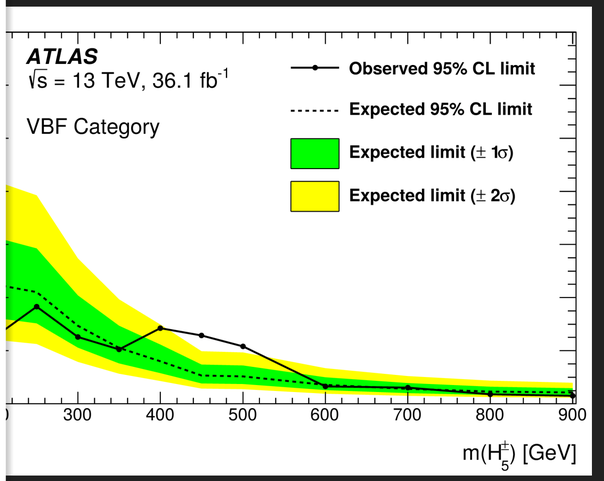
JHEP 03 (2020) 034

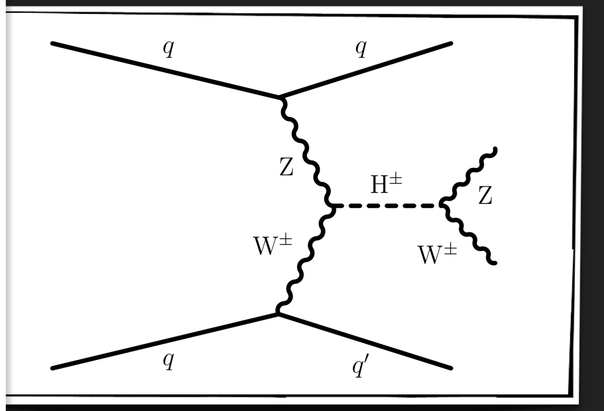




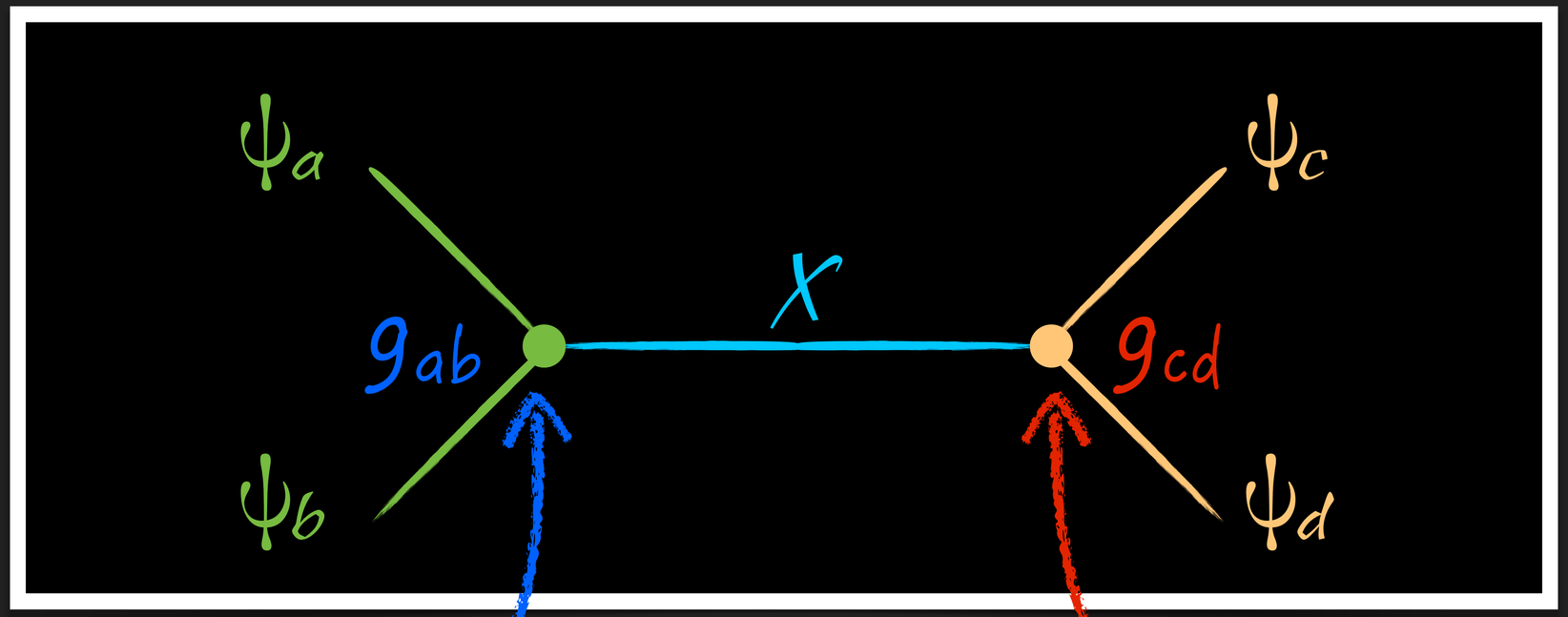


PLB 787 (2018) 68



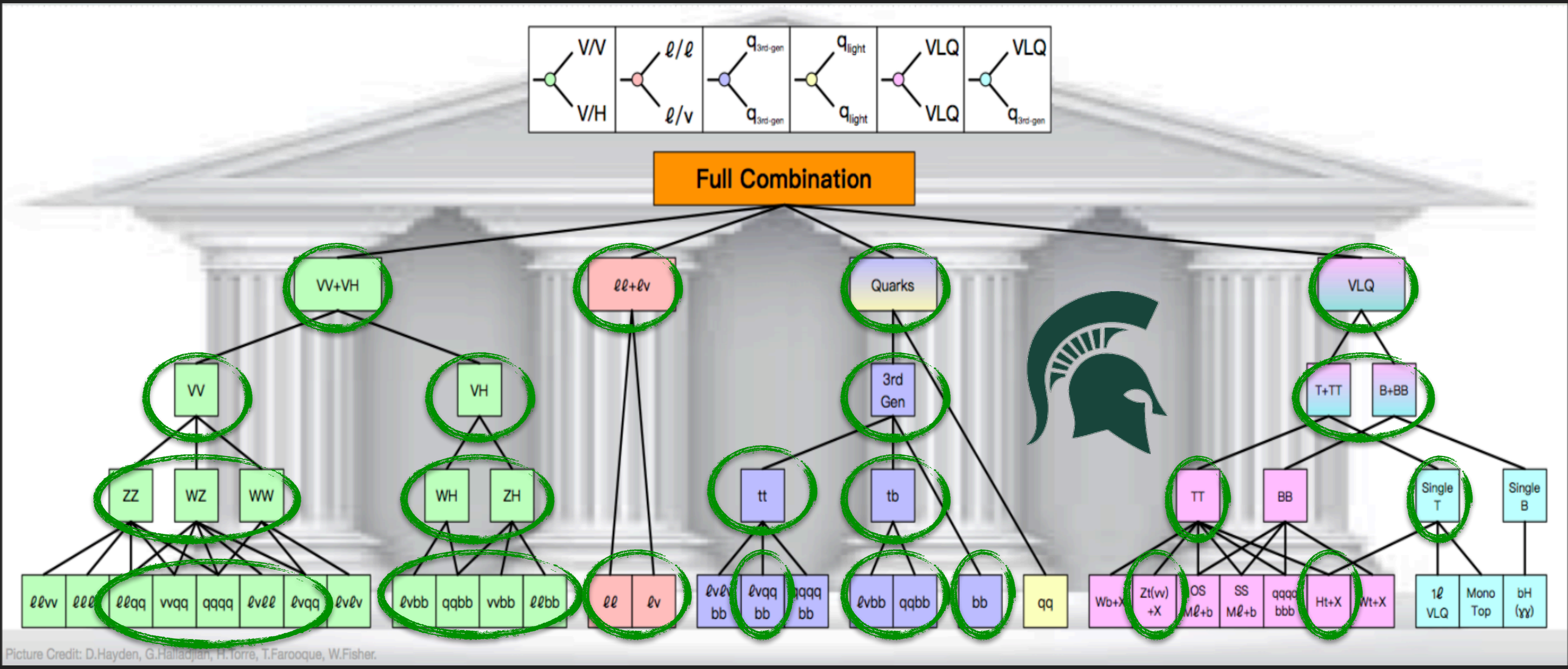


A reminder...


ψ_a
ψ_b
g_{ab}
X
g_{cd}
ψ_c
ψ_d
Production
Decay
$\sigma \propto g^2_{cd} \times g^2_{ab}$

Build & Test a Model

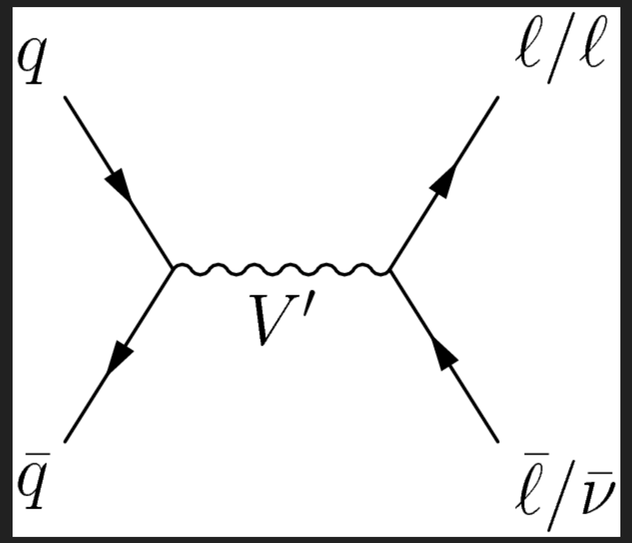
Model-driven probe for new physics

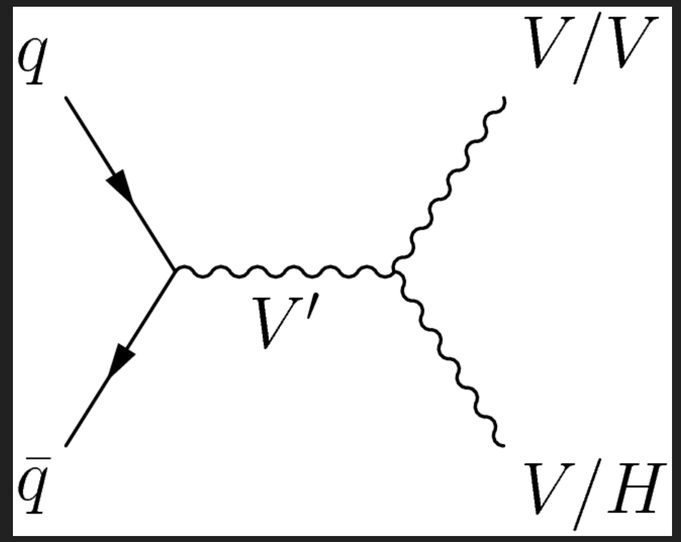


Picture Credit: D.Hayden, G.Halladjian, H.Torre, T.Farooque, W.Fisher.

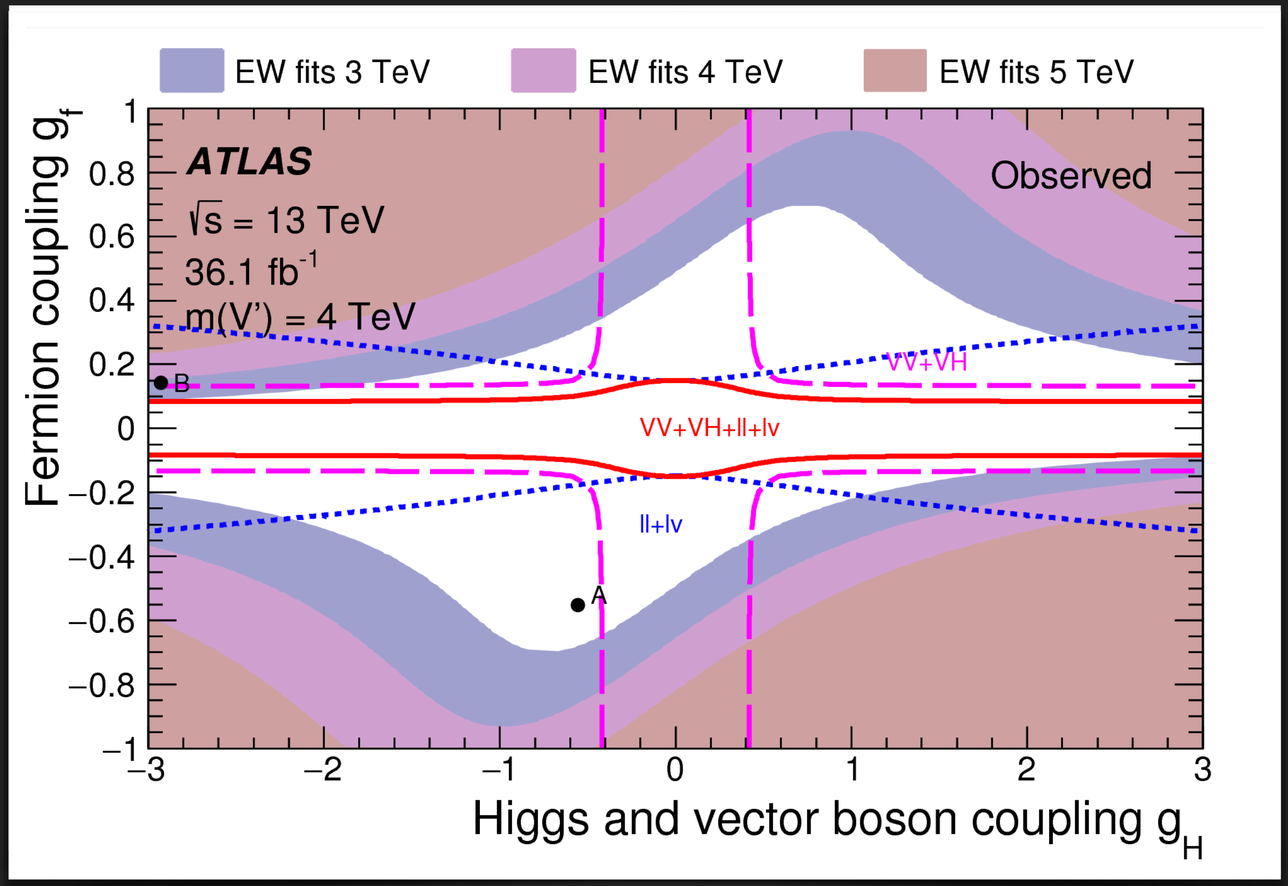
Heavy Vector Triplet Example

A model with W' and Z' bosons





JHEP 07 (2018) 089



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Upgrades to the ATLAS triggering capabilities & Jet Identification

- Phase-1: 2019-2022
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LHC Upgrade Program

Staged upgrades during operations pauses

LHC / HL-LHC Plan

HiLumi LARGE HADRON COLLIDER

We are here!

LHC HL-LHC

Run 1 | Run 2 | Run 3 | Run 4 - 5...

LS1 | EYETS | LS2 | EYETS | LS3

7 TeV | 8 TeV | 13 TeV | 13.8 TeV | 13.8 - 14 TeV energy

splice consolidation
button collimators
R2E project

cryolimit interaction regions

Diodes Consolidation
LIU Installation
Civil Eng. P1-P5

pilot beam

inner triplet radiation limit

HL-LHC installation

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2040

ATLAS - CMS
upgrade *phase 1*

ALICE - LHCb
upgrade

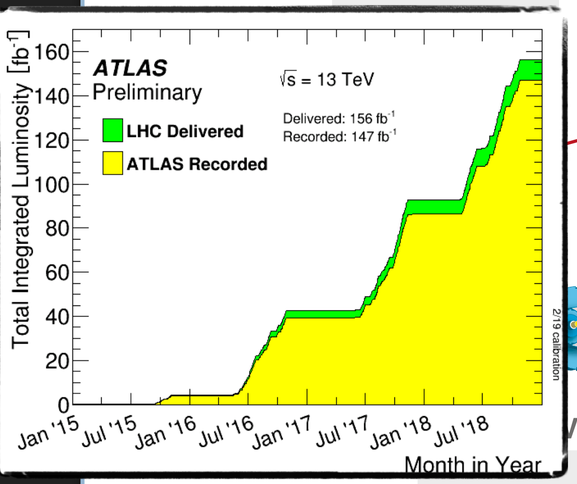
ATLAS - CMS
HL upgrade

nominal Lumi | 2 x nominal Lumi | 2 x nominal Lumi | 5 to 7.5 x nominal Lumi

190 fb^{-1} | 450 fb^{-1}

integrated luminosity 3000 fb^{-1} 4000 fb^{-1}

PROTOTYPES | CONSTRUCTION | INSTALLATION & COMM. | PHYSICS

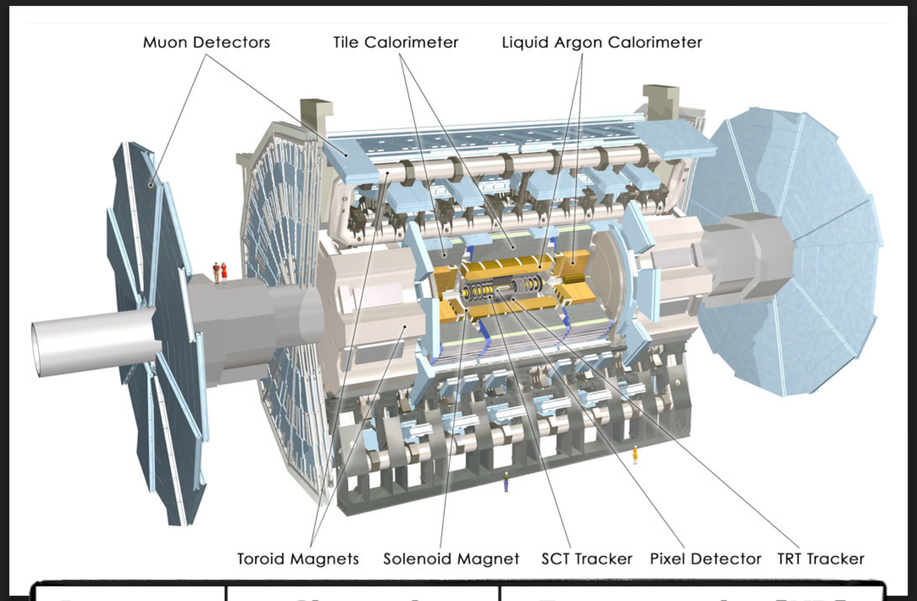


VIL ENGINEERING:

DEFINITION | EXCAVATION | BUILDINGS

Triggering in a Nutshell

Filtering down to the data we want to keep



Detector	Channels	Fragment size [KB]
Pixels	$1.4*10^8$	60
SCT	$6.2*10^6$	110
TRT	$3.7*10^5$	307
LAr	$1.8*10^5$	576
Tile	10^4	48
MDT	$3.7*10^5$	154
CSC	$6.7*10^4$	256
RPC	$3.5*10^5$	12
TGC	$4.4*10^5$	6
LVL1		28

Triggering 101

40 MHz proton collision rate

x Data from 150 million channels encoded in 1.5 MB per event

= 55 TB/sec

1500 MB/sec mass storage rate

1000 Hz event rate storage

Reject **99.9975%** of collisions in custom hardware

What gets dropped?

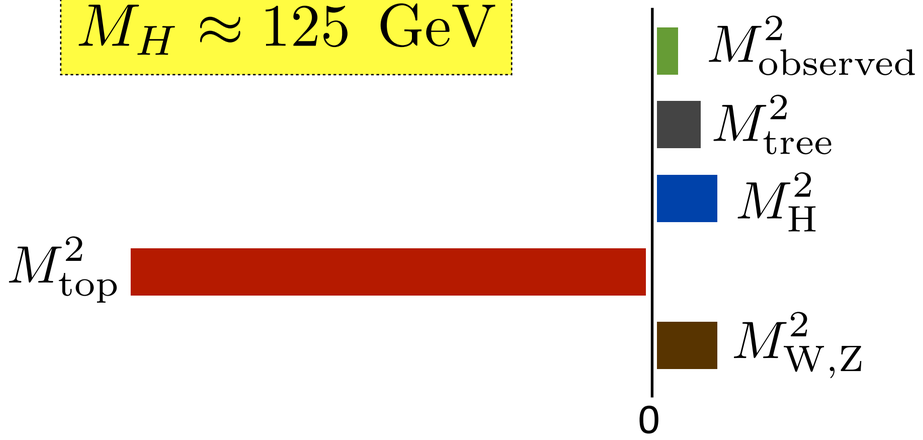
Ideally not top quarks

$$V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

$$M_H^2 = M_{\text{tree}}^2 + \left(\begin{array}{c} H \\ \text{○} \\ H \quad\quad H \end{array}\right) + \left(\begin{array}{c} \bar{t} \\ \text{○} \\ H \quad\quad H \\ t \end{array}\right) + \left(\begin{array}{c} W,Z \\ \text{○} \\ H \quad\quad H \end{array}\right)$$

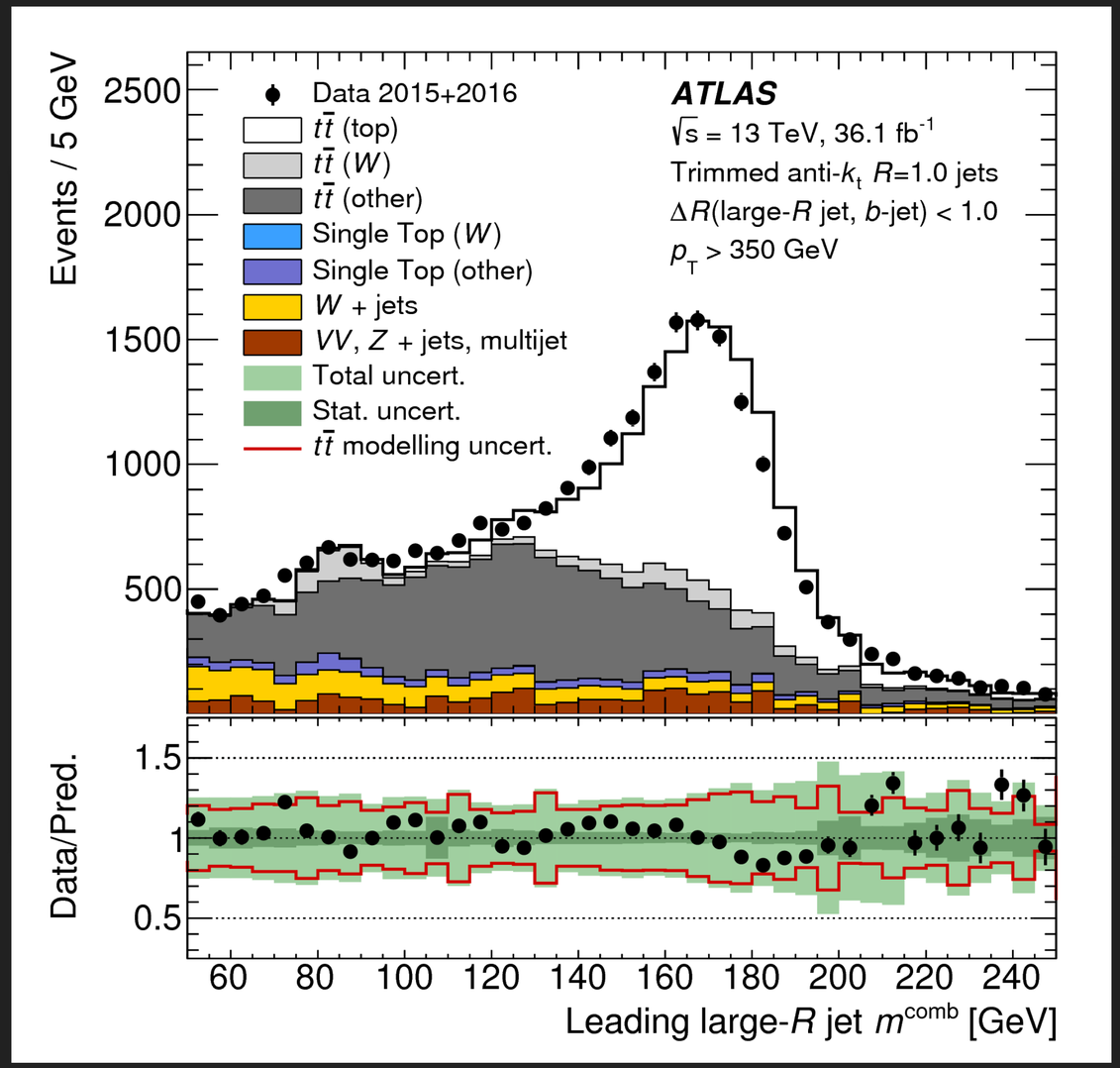
$$\delta M^2 \propto \frac{a}{16\pi^2} g^2 \Lambda^2$$

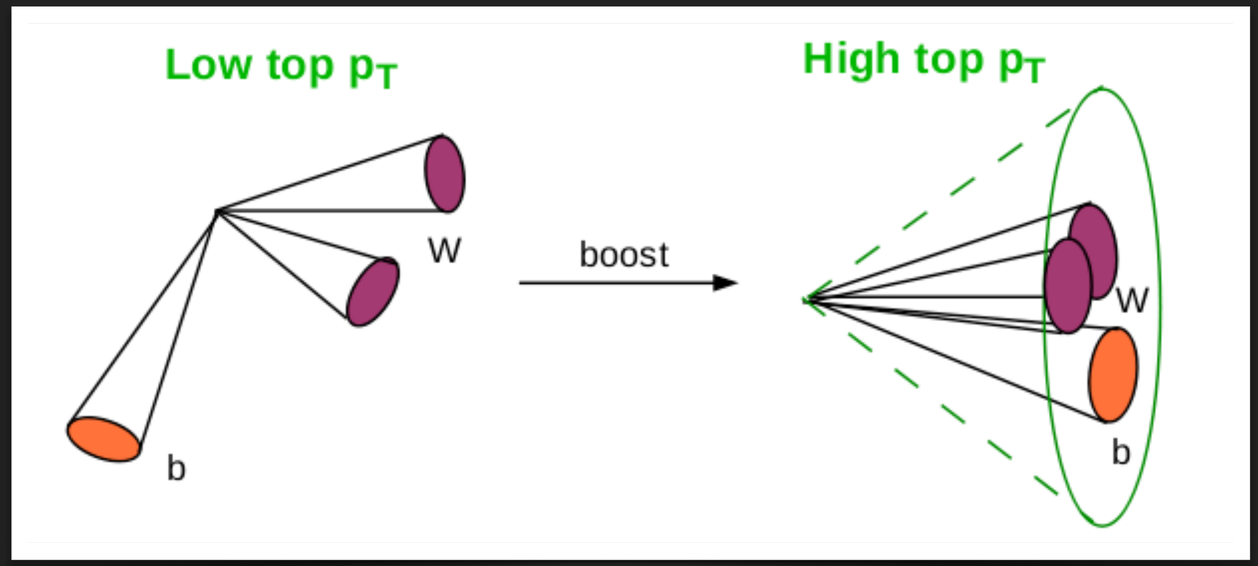
$M_H \approx 125$ GeV

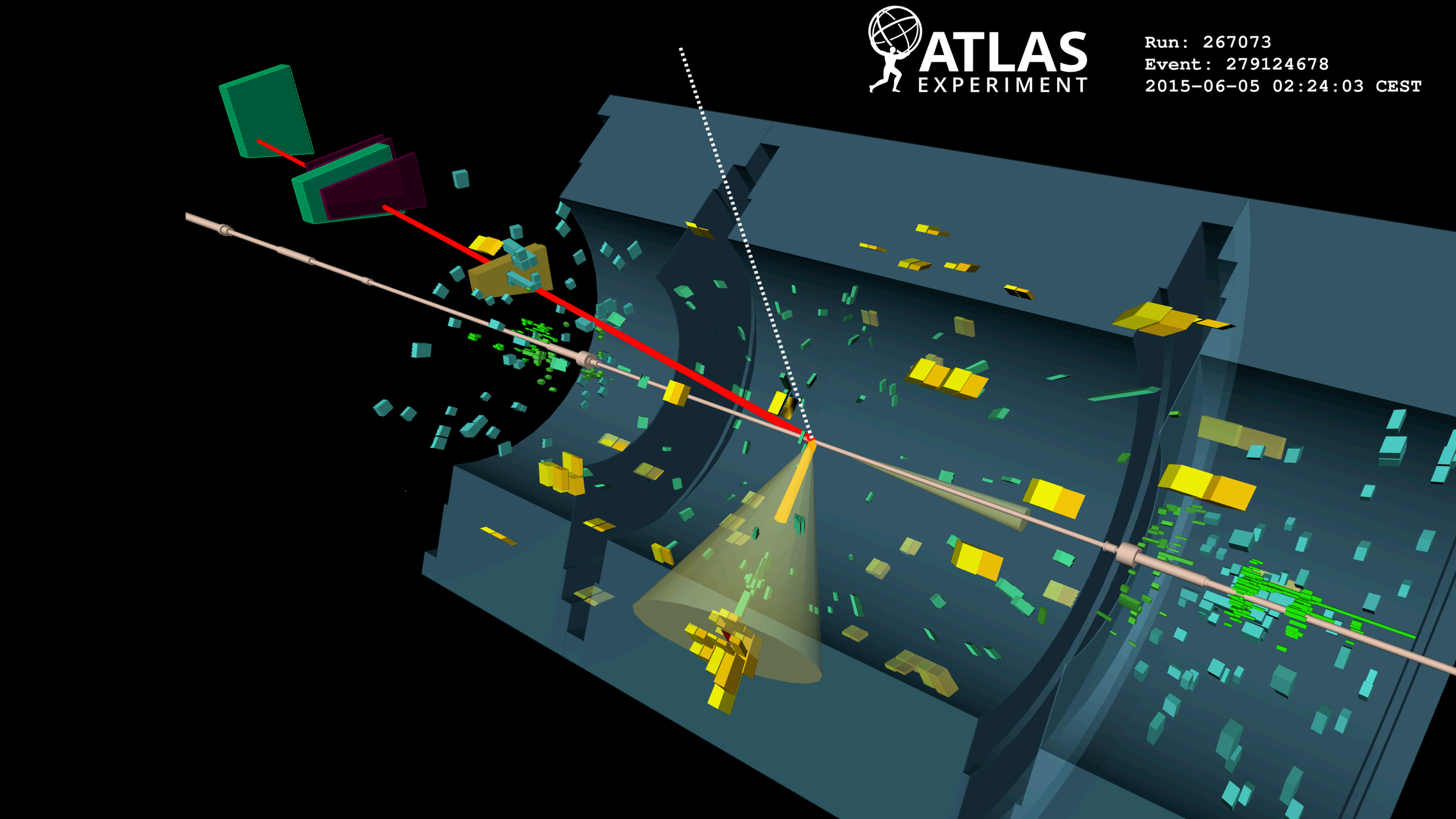


Purifying our top samples

Lemonade from lemons



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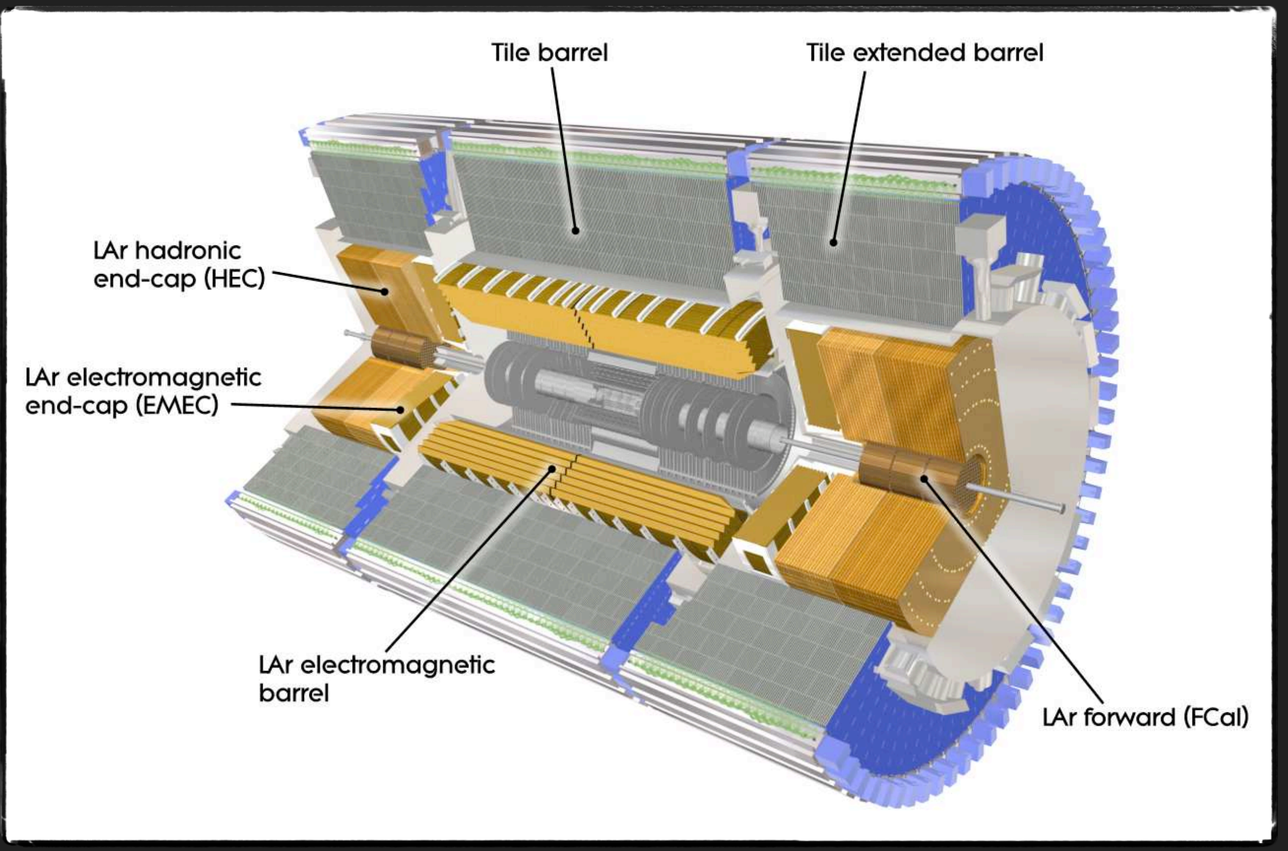
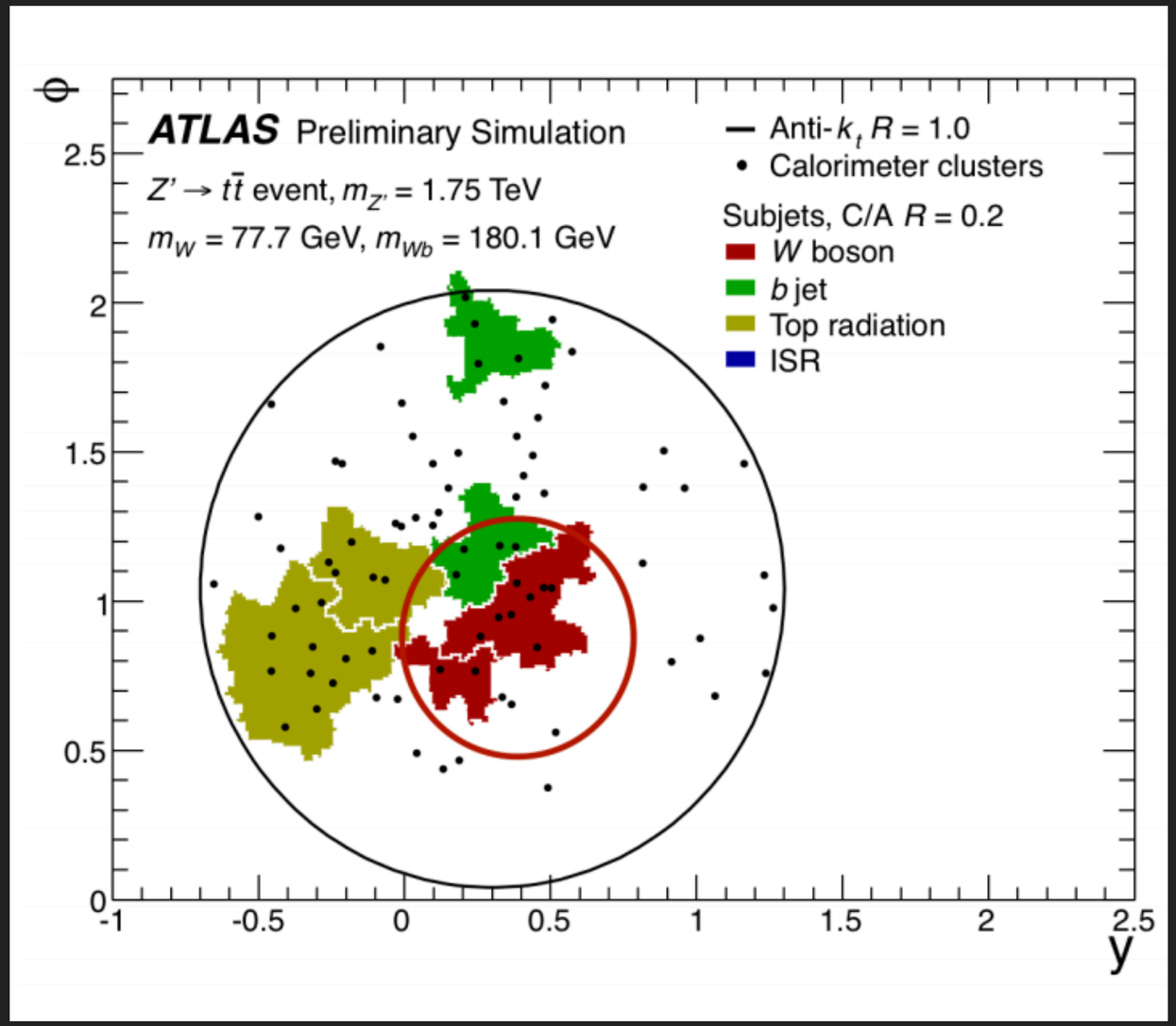
EXPERIMENT
Run: 267073
Event: 279124678
2015-06-05 02:24:03 CEST

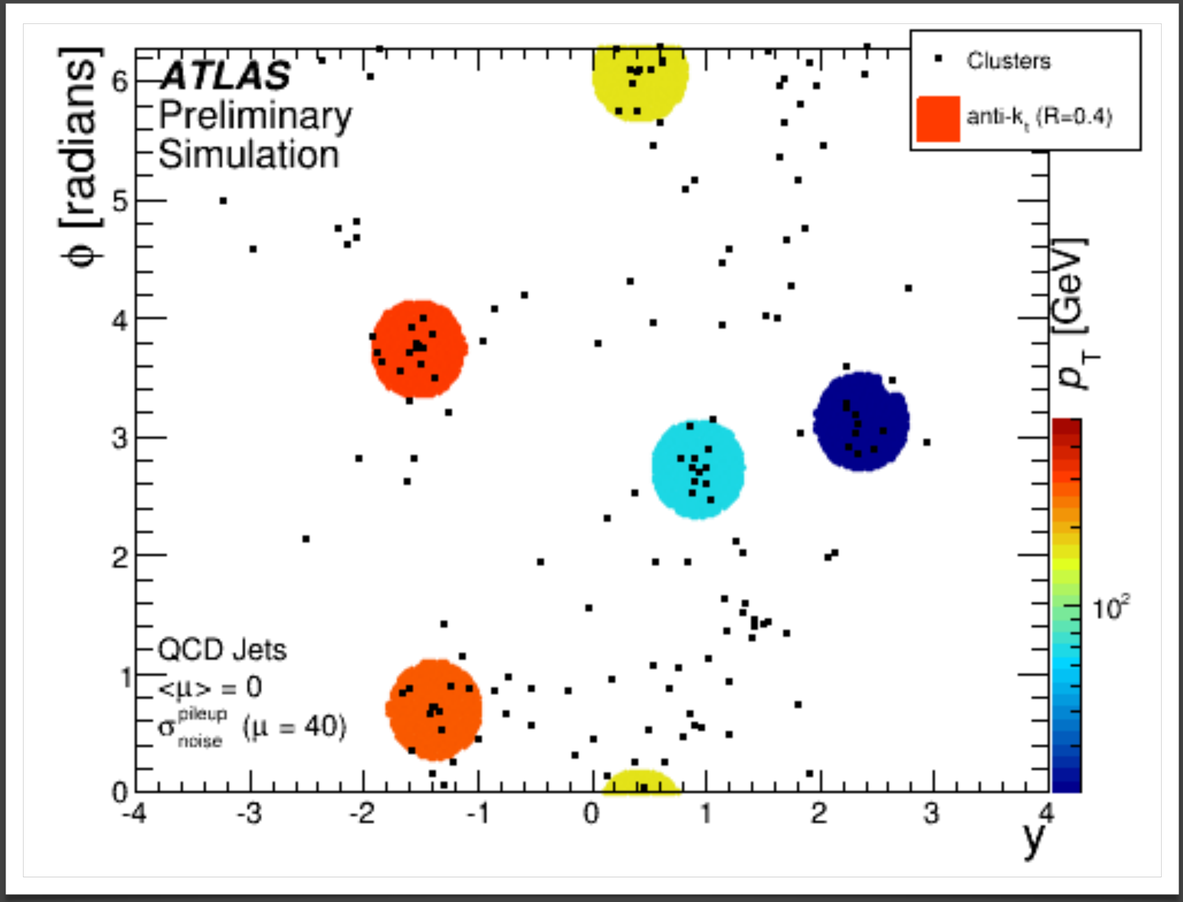
Purifying our top samples

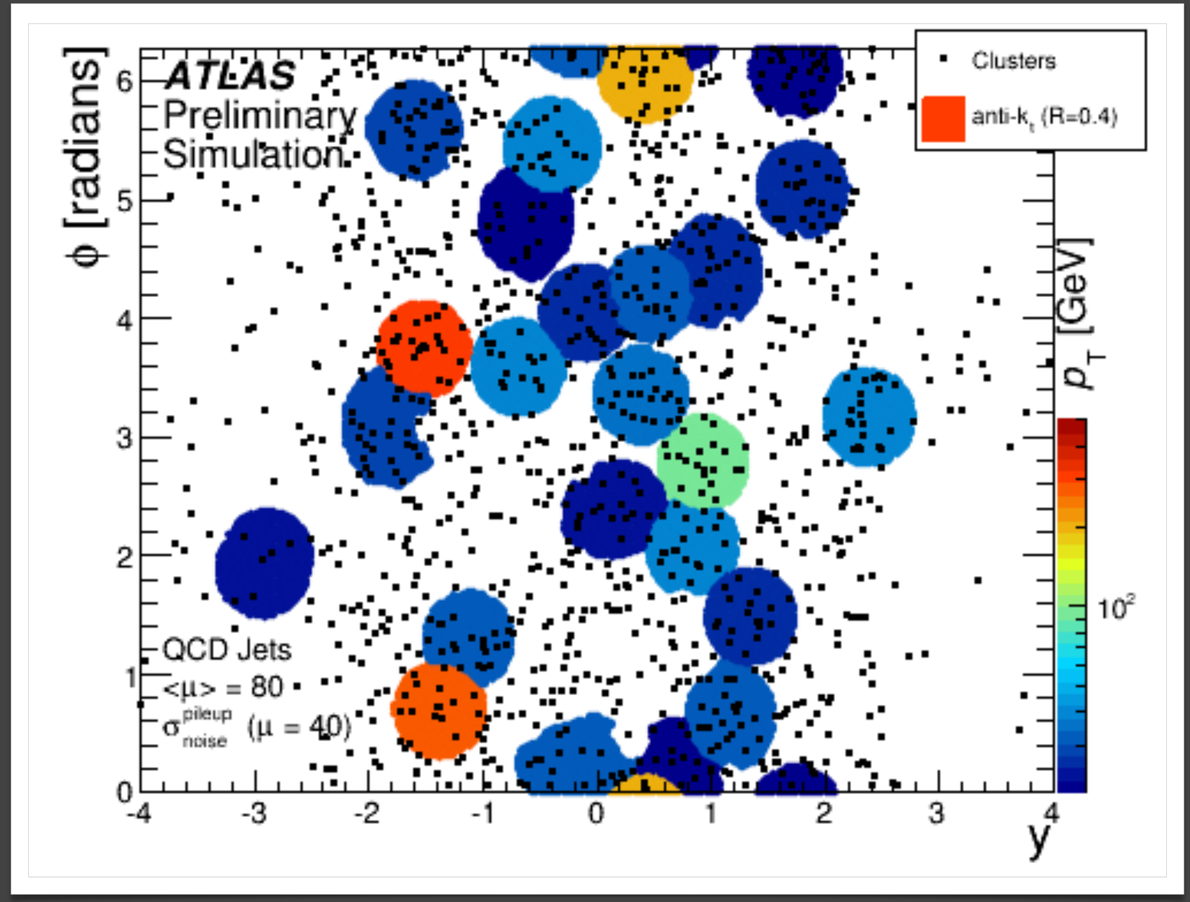
Lemonade from lemons





Increased Luminosity = Messier Events





ATLAS Phase-1 Upgrade

Focusing on the calorimeter for now

HIGH RES IMAGE 300dpi

LOW RES IMAGE 72dpi

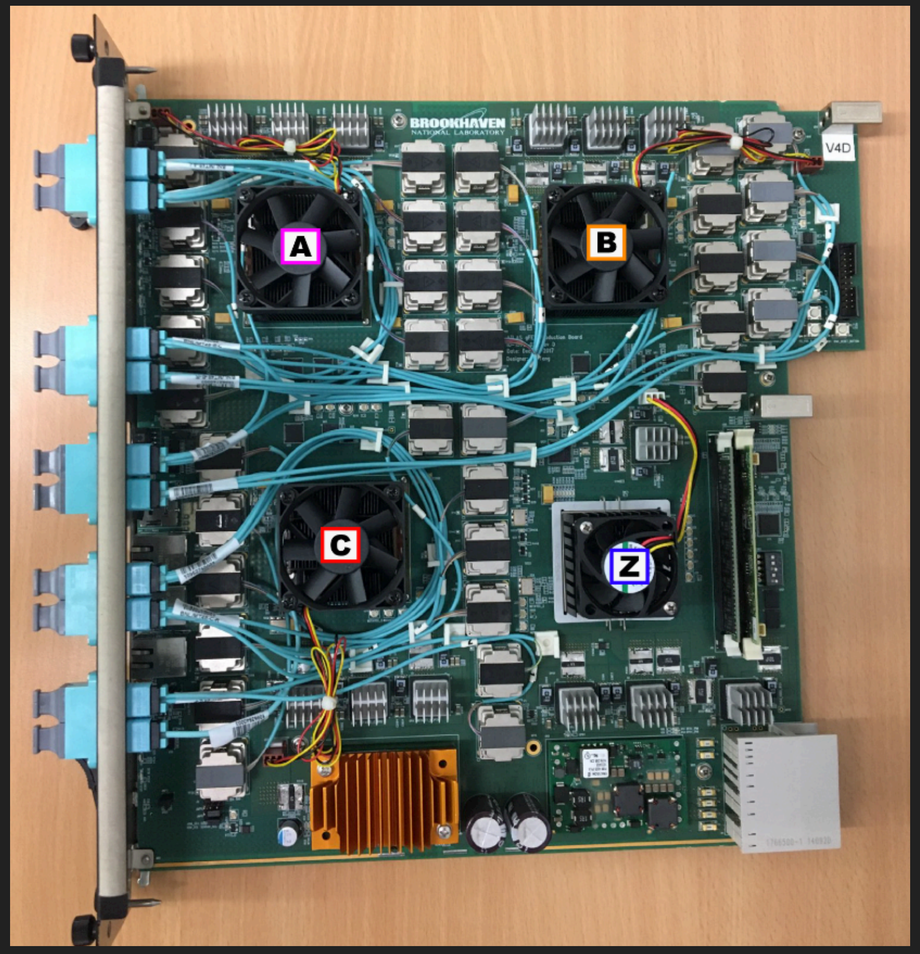
10x increase in image resolution
1,700 Towers → 17,000 Super-Cells

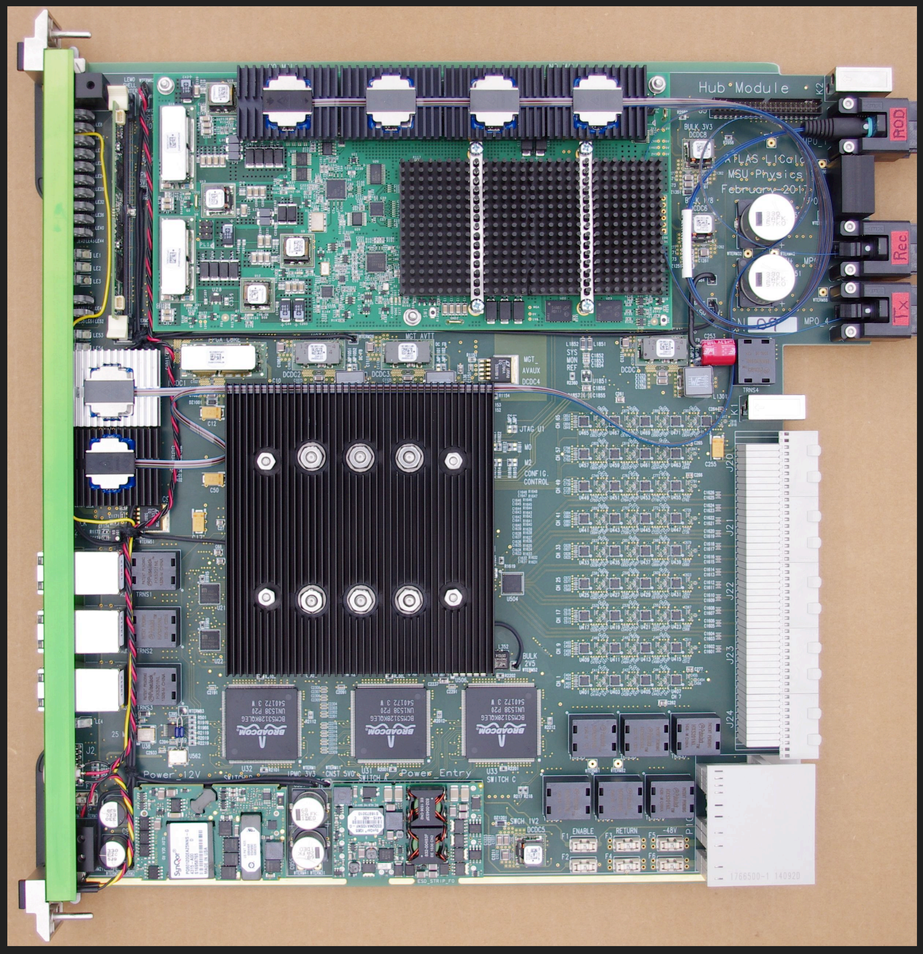
Level-1 Calorimeter Trigger

Super-cells!

Level-1 Calorimeter Trigger electronics.

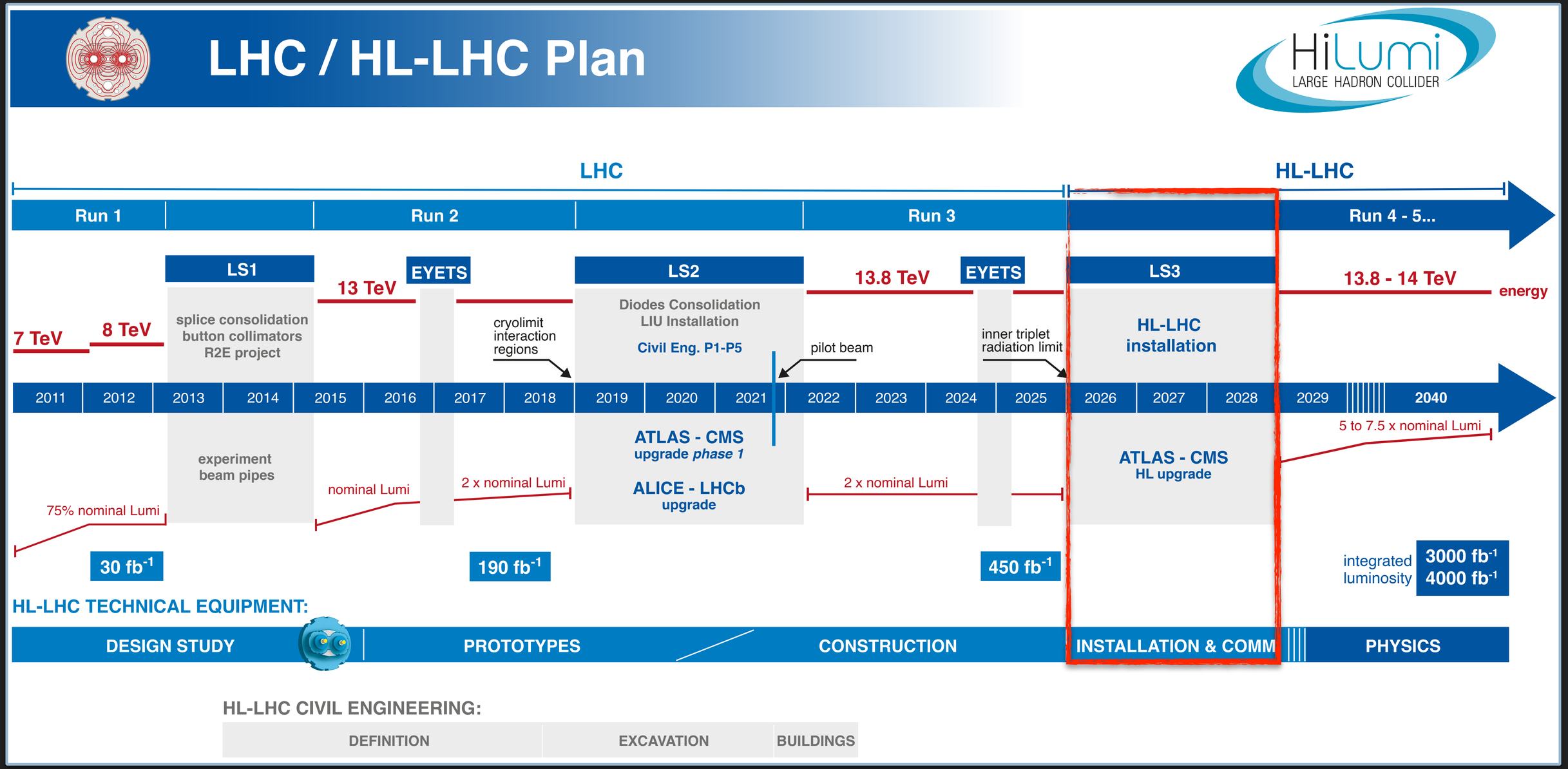
Being installed & commissioned NOW.





LHC Upgrade Program

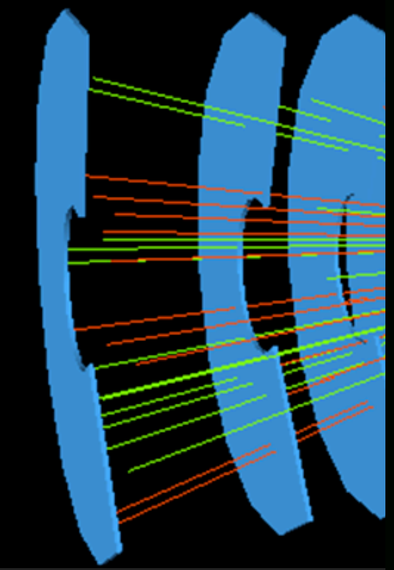
Staged upgrades during operations pauses

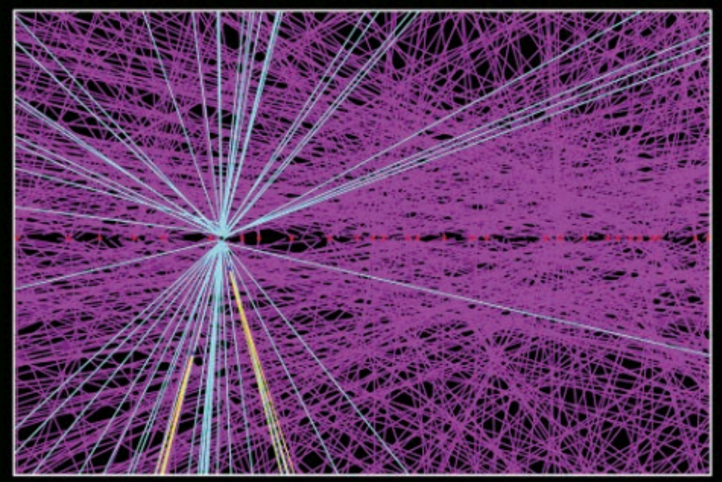


LHC Upgrade Program

Staged upgrades during operations pauses

Mean





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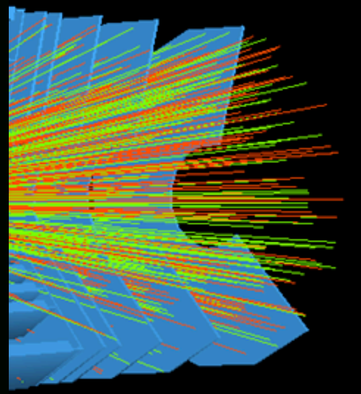
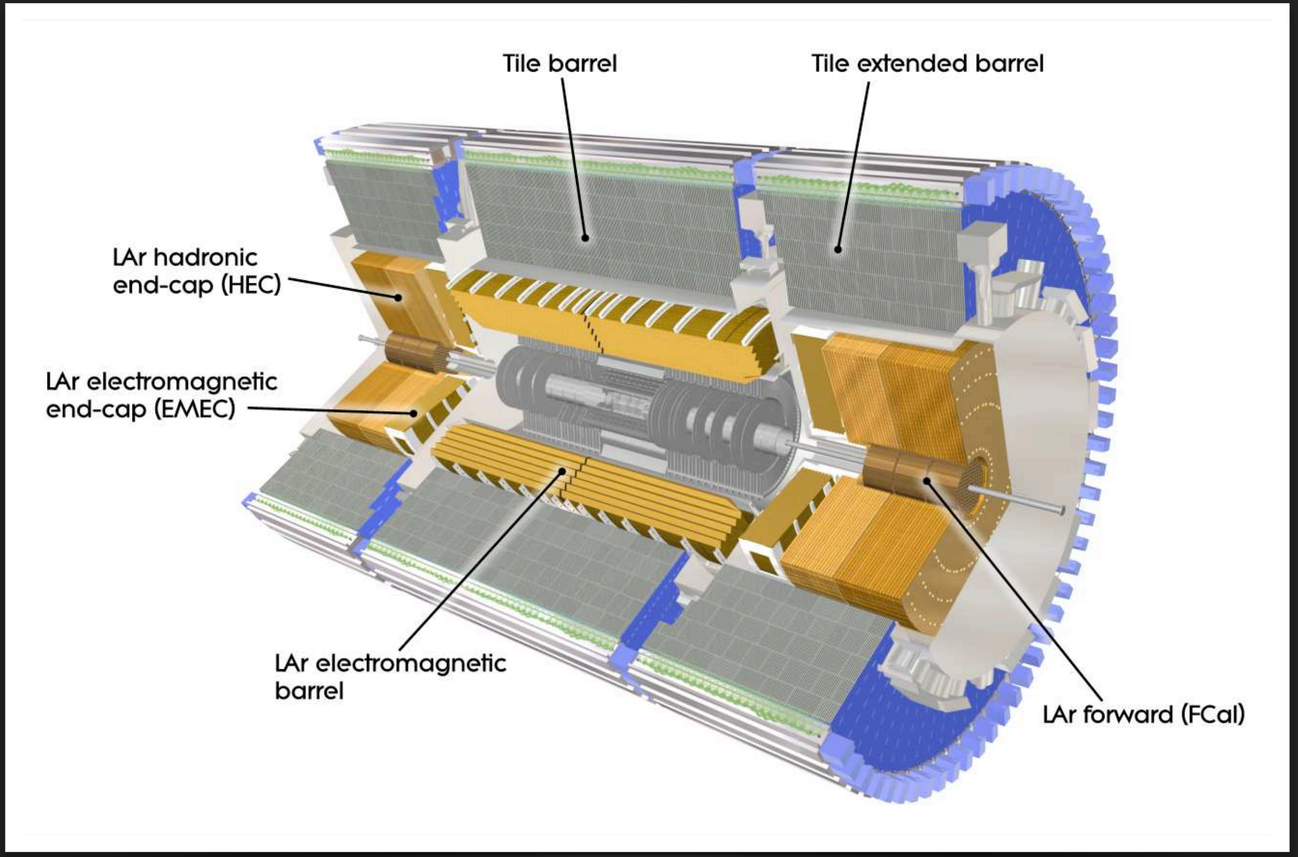
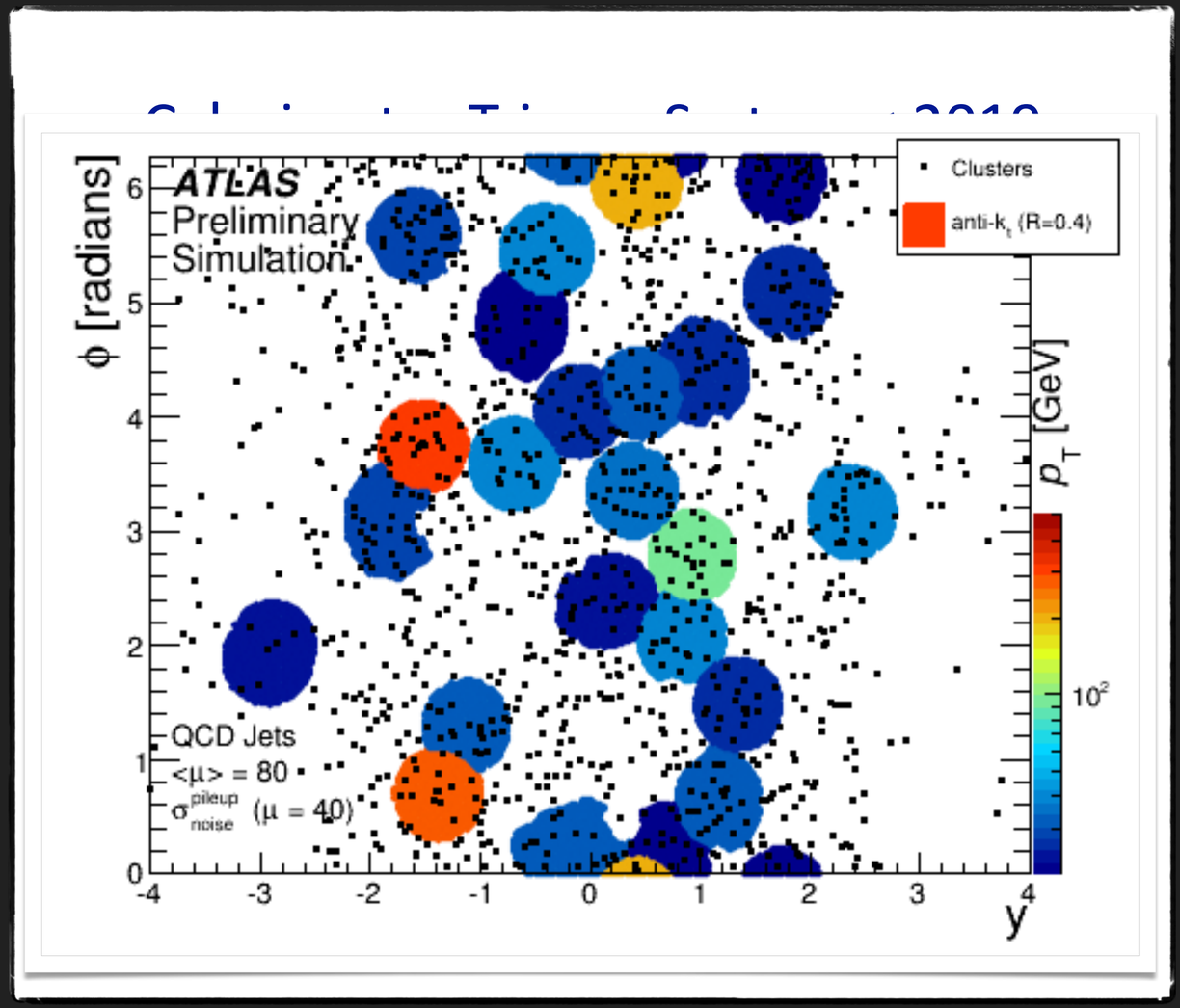


One more degree of complexity

process ALL the data!





Process the entire calorimeter every 25 ns!

5G to the rescue!

Bootstrapping modern telecom

- 28
- Pa

A

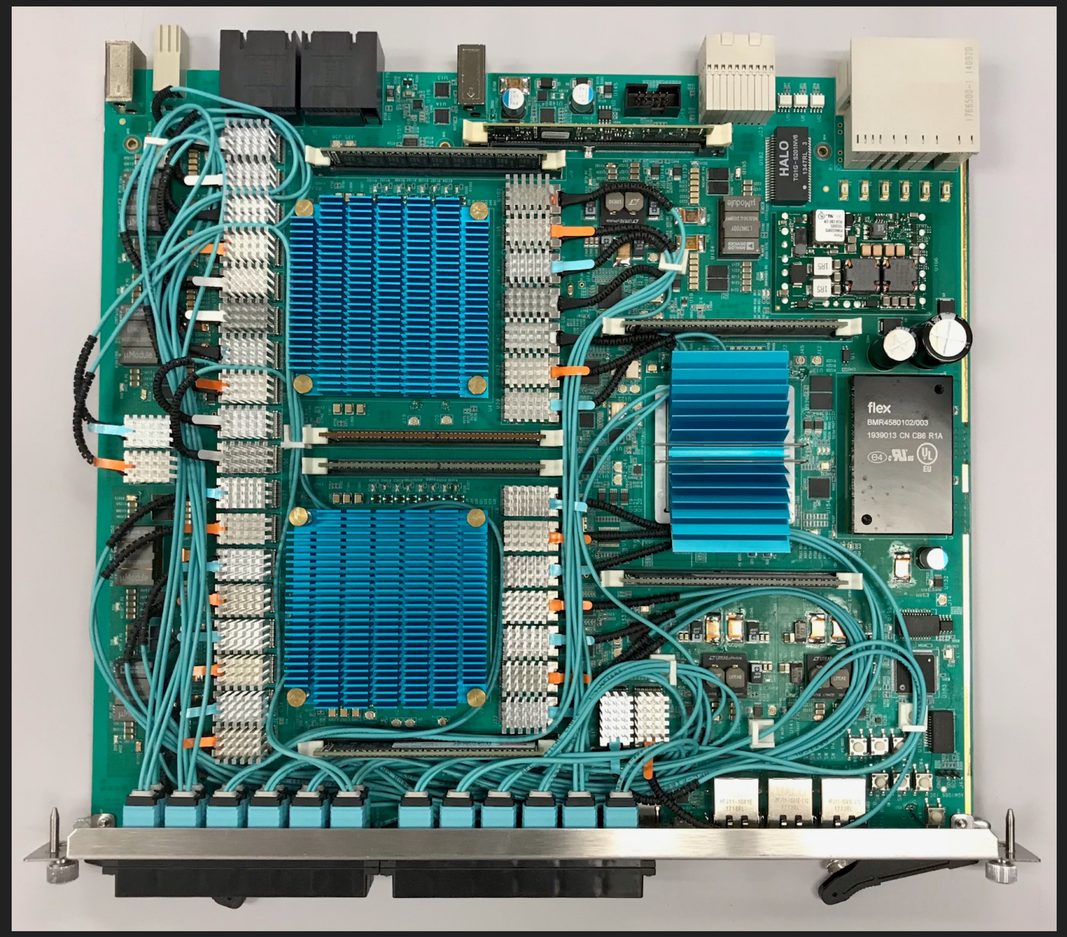
72+R5F)

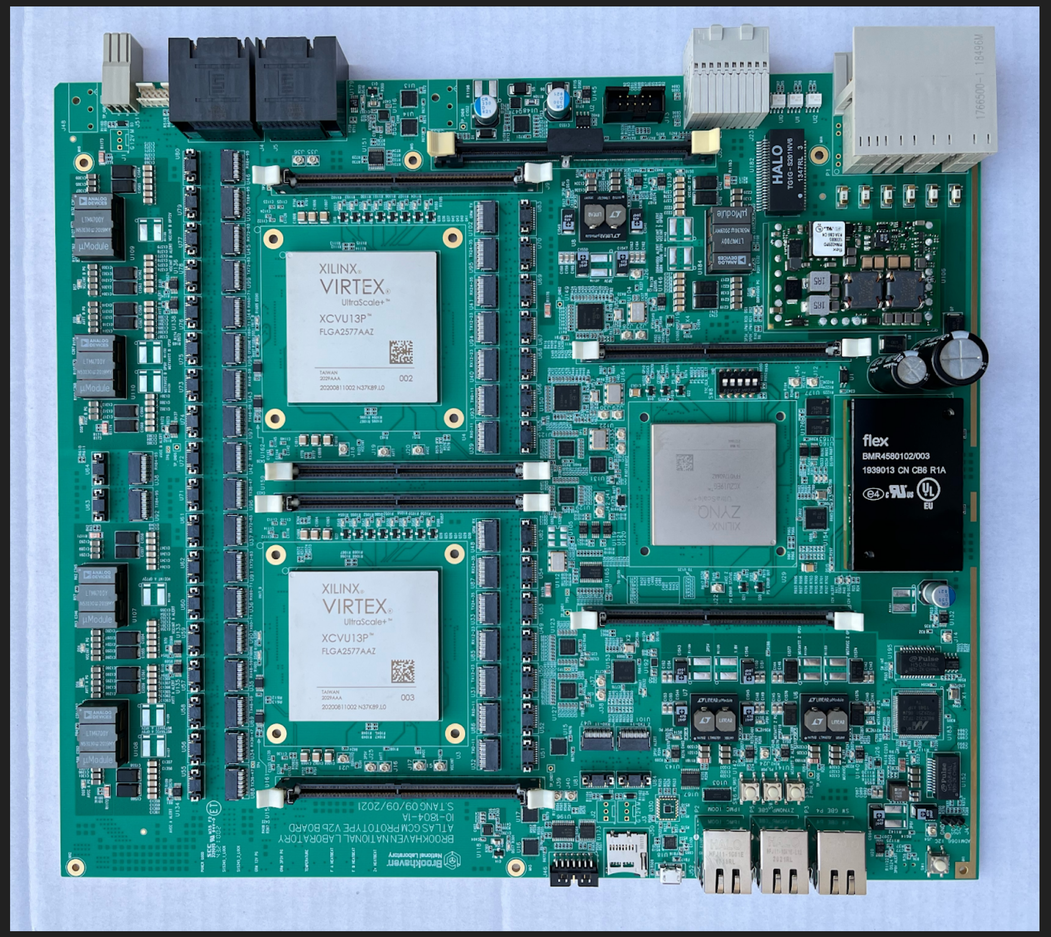
ATLAS Global Trigger

Bootstrapping modern telecom

HL-LHC Global Trigger hardware prototypes

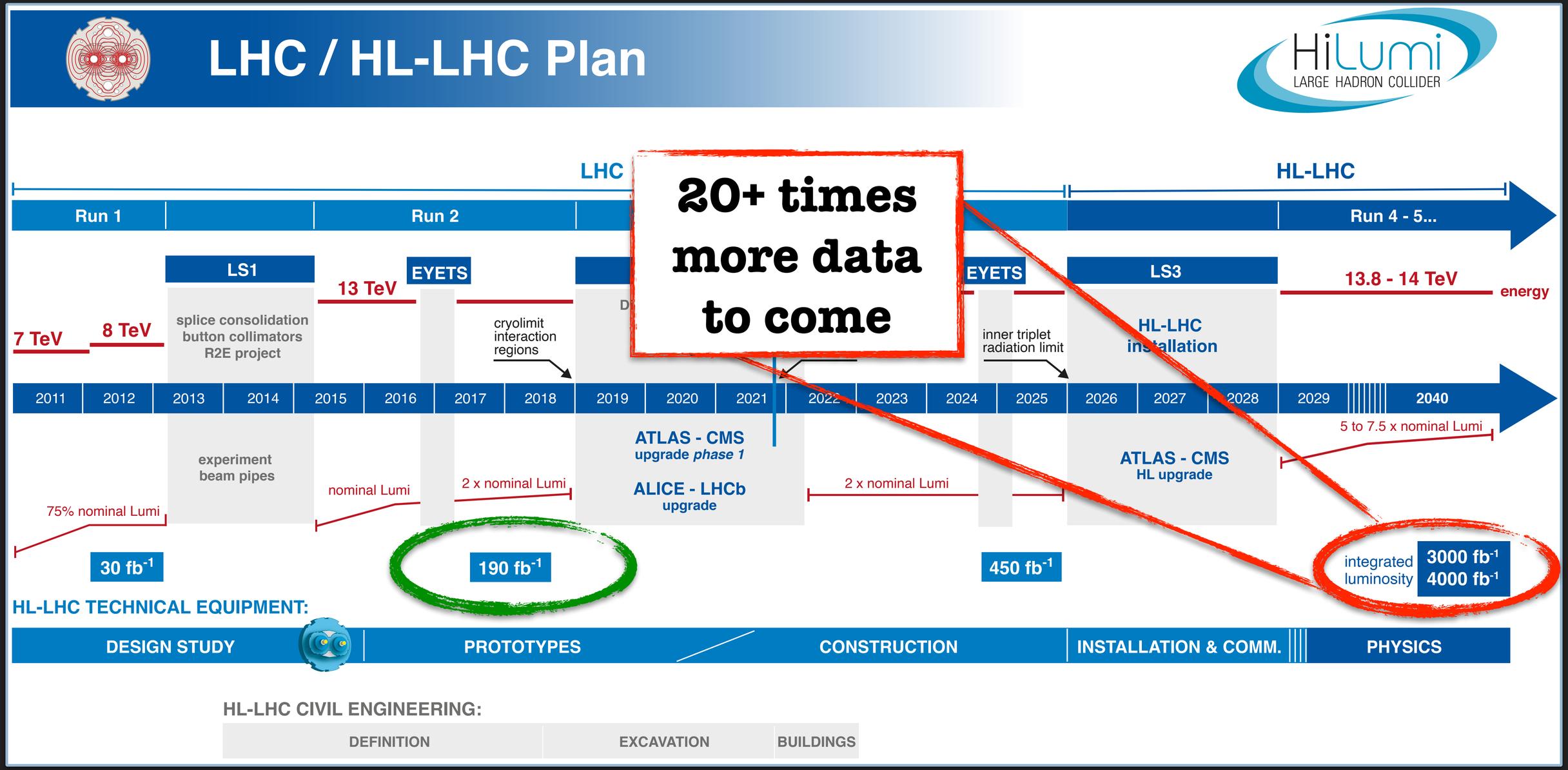
Ongoing area of R&D



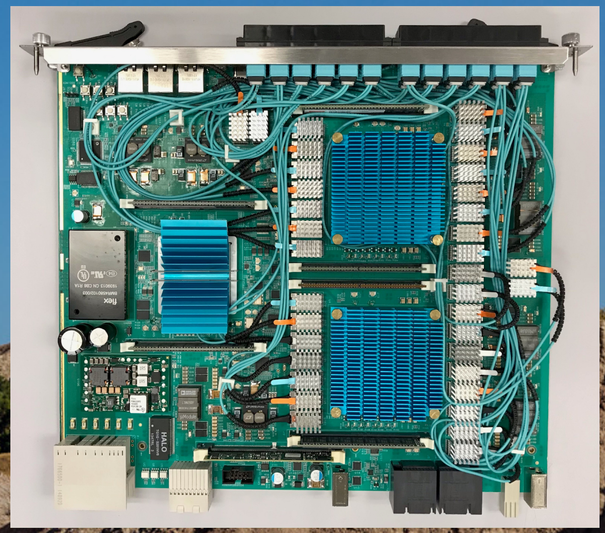


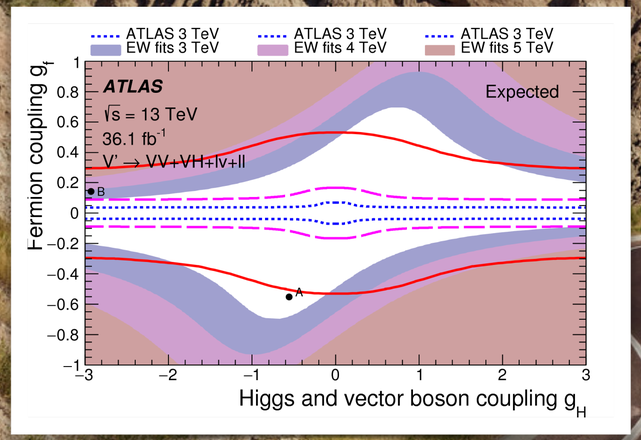
LHC Upgrade Program

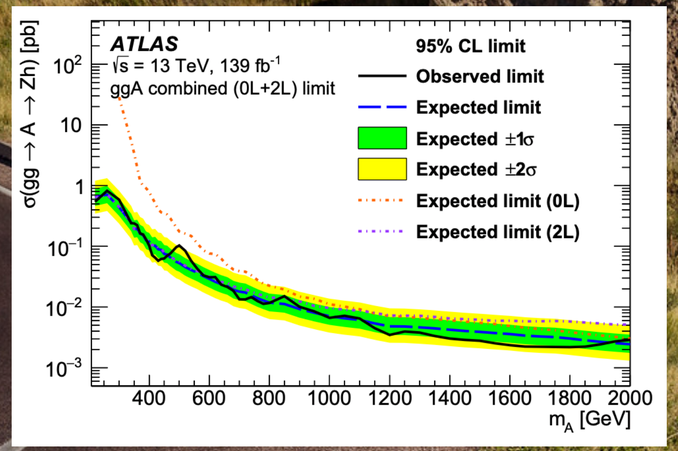
Staged upgrades during operations pauses



The unfinished road to discovery.







(Most of) The MSU Team

The ones that get the work done.